EPPSU

2020

Goals of the Symposium, Halina Abramowicz

European Particle Physics Strategy Update 2020

Organisation of the Update Process

- Decision making body – CERN Council
- Drafting of the Strategy Update document – responsibility of the European Strategy Group (ESG)
- Scientific Input to the Strategy Update – responsibility of the Physics Preparatory Group (PPG)
- Coordinating body – the Strategy Update Secretariat (SUS)

EPPSU 2020

Strategy Secretariat

- H. Abramowicz (Chairperson)
- J. D'Hondt (ECFA Chairperson, *ECFA: European Committee for Future Accelerators*)
- K. Ellis (SPC Chairperson, *SPC: Science Policy Committee @ CERN*)
- L. Rivkin (European LDG Chairperson, *LDG: Lab Directors Group*)

Contact: EPPSU-Strategy-Secretariat@cern.ch

5/13 Plenary Session
9:00 Welcom address and inauguration of the Symposium
9:29 Goals of the Symposium, Halina Abramowicz
CERN council, sub-groups time line
160 submissions of EU documents
Open simposium with parallel sessions , plenty of discussions

9:37 Implementation of the 2013 European Strategy Update, Fabiola
LDG Laboratory director group
results for the 2013 updates
to make priority by this ESU
HL-LHC LS2 2019-2020 LS3 2024-2026
11T Nb3Sn magnets 5.5m long x2 with collimator 11m long in total
CLIC and FCC R&Ds
AWAKE as prasma acceleration by proton drive beam
1,701 young people educated in 2018
CERN's scientific Gateway will start in 2020 complete in 2022

10:04 Outstanding Questions in Particle Physics, Pilar Hernandez
there is not no-lose theorem for future colliders
Majot issue is the shape of scalar potential - vacuum instability

11:10 State of the art and challenges in accelerator technology - Past and present, A.Yamamoto
Now, 16T magnet costs more than an order of magnitude the current LHC 9T ones. It is difficult to accelerate the R&D by moneys and manpowers. Technological break through is needed.
But it require 20 years R&D which is matched to the FCChh plan.

SM + high scale BSM = SMEFT

What if there is new physics (ie. new fields with mass Λ >> v)?

E

$$\mathcal{L}_{\rm SM}[\phi] + \mathcal{L}_{\rm BSM}[\phi, \Phi]$$

$$(g_3, g_2, g_1, y_q, y_l, \lambda, \mu^2, \ldots)$$

Λ

$$\mathcal{L}'_{\rm SM}[\phi] + \mathcal{L}_{\rm SMEFT}[\phi]$$

$$(g'_3, g'_2, g'_1, y'_q, y'_l, \lambda', \mu'^2, \ldots)$$

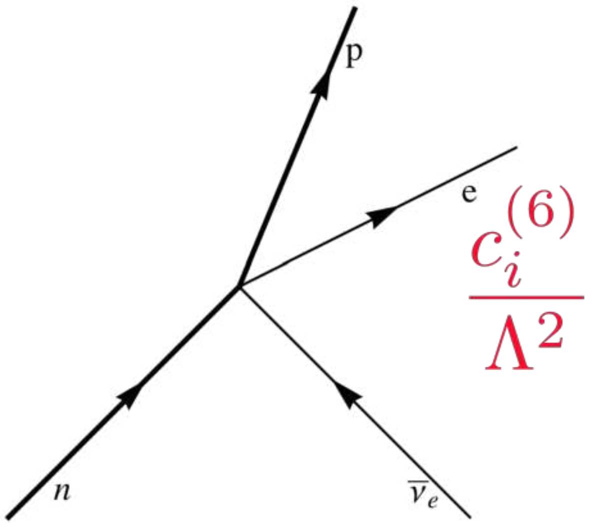
$$\mathcal{L}_{\rm SMEFT} = \sum_i \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \ldots$$

Hierarchy problem !

Violation of unitarity !

SMEFT predicting its own destruction ?

NP can induce similar non-renormalizable interactions



$$\sigma \propto \left(\frac{c_i^{(6)}}{\Lambda^2}\right)^2 s$$

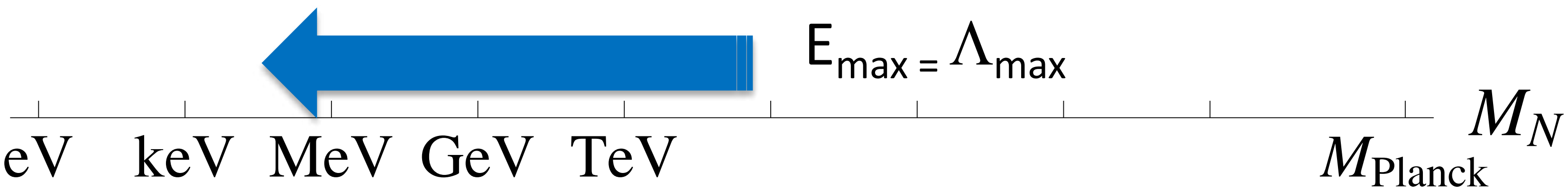
New physics must show up before unitarity is violated

$$E_{\max} \sim \frac{\Lambda}{\sqrt{c_i^{(6)}}}$$

SMEFT "No Lose Theorem" modification to SM couplings or a new type of interaction implies NP must show up before E_{max}

Observation: E_{max} depends on $\frac{c_i^{(d)}}{\Lambda^{d-4}}$ -> degeneracy between c and Λ

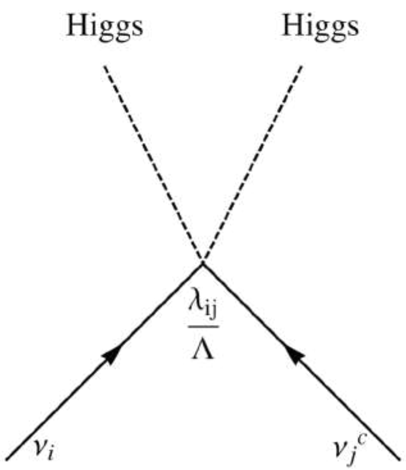
$$c_i^{(d)} \propto (\text{couplings})^{\#}$$



SMEFT @ d=5

$$\mathcal{L}_{\rm SMEFT} = \underbrace{\sum_i \frac{c_i^{(5)}}{\Lambda}\mathcal{O}_i^{(5)}}_{\text{1 operator}} + \underbrace{\sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)}}_{\text{2499 operators(59 B,L,FC)}} + \ldots$$

$\Delta L = 2$



$$\mathcal{O}^{(5)} = \frac{c_{ij}^{(5)}}{\Lambda}\bar{L}_i H (H L_j)^c + h.c. \rightarrow \overline{\nu}_L \frac{m_\nu}{2} \nu_L^c + h.c.$$

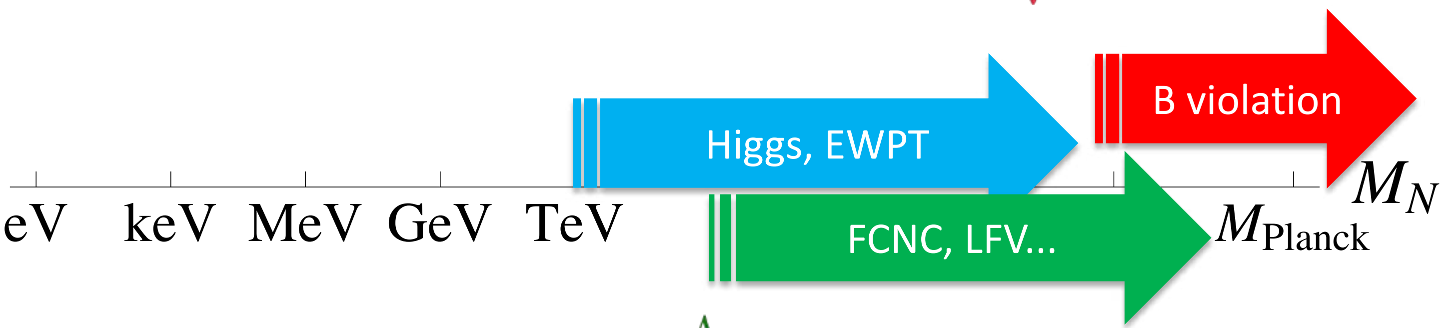
$$\frac{c^{(5)}}{\Lambda} = \frac{m_\nu}{v^2} \sim \mathcal{O}\left(\frac{1}{10^{15}\ \text{GeV}}\right)$$

SMEFT vs Flavour

BSM flavour puzzle: SM accidental symmetries must be there up to higher scales

$$\mathcal{L}_{\rm SMEFT} \supset \underbrace{\frac{c^q_{ij}}{\Lambda^2}(\bar{Q}_i\gamma_\mu P_L Q_j)^2}_{\Delta m_K,\Delta m_D,\Delta m_B,\ldots} + \ldots + \underbrace{\frac{c^l_{ij}}{\Lambda^2}\bar{L}_i\sigma_{\mu\nu}\Phi l_j F^{\mu\nu}}_{\mu\to e\gamma,\text{EDMs}\ldots} + \ldots + \underbrace{\frac{c^b_{ijkl}}{\Lambda_B^2}\epsilon_{\alpha\beta\gamma}Q_i^\alpha Q_j^\beta Q_k^\gamma L_l}_{\text{p-decay}}$$

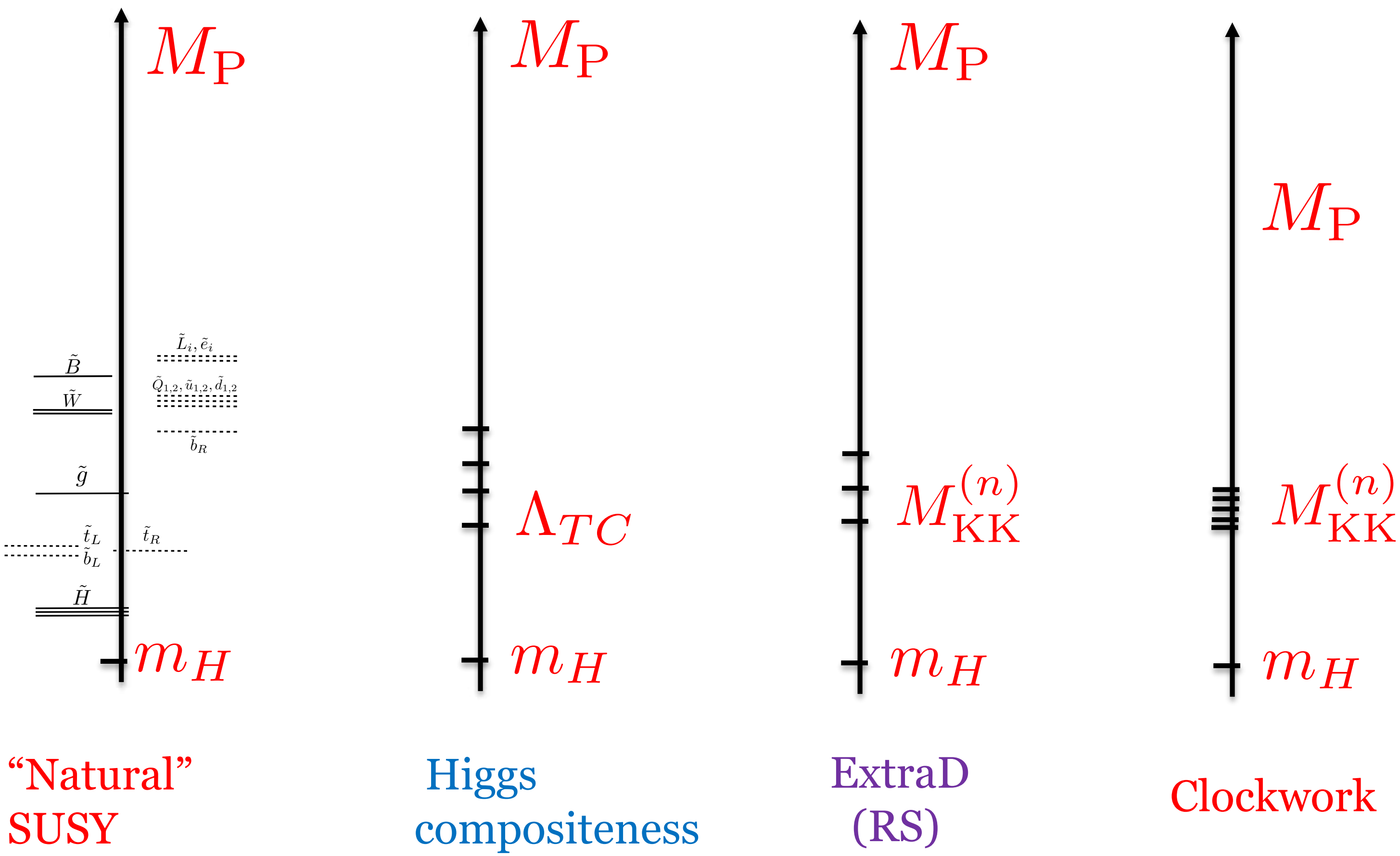
$$\frac{\Lambda_B}{\sqrt{c}} \geq [10^{12} - 10^{13}]\ \text{TeV}$$



$$\frac{\Lambda}{\sqrt{c}} \geq [10^2 - 10^5]\ \text{TeV}$$

EW Hierarchy problem ?

An enormous brain effort has been devoted to solving this problem, ie. understanding the separation between M_{Higgs} and M_{Planck}



New states at TeV, top quark special

EW Hierarchy Problem ?

LHC has found no smoking gun for a solution to the big hierarchy problema and enhanced the "Little hierarchy problem":

O(10-100)TeV still an interesting scale to explore!

The "to-be-or-not-to-be" question: energy vs precision

If $E_{\rm max} < \Lambda$ how can be better detect effects of NP ?

Non-trivial interplay: experimental precision, rare or adds up to SM process (with or wo interference),...

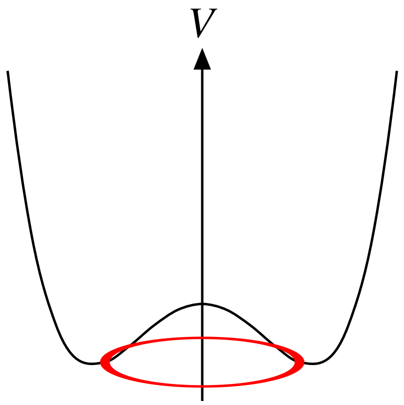
Required precision to detect NP depends on energy

$$\frac{\rm NP}{\rm SM} \propto c_i^{(d)} \underbrace{\left(\frac{\sqrt{s}}{\Lambda}\right)^{d-4}}_{\text{increases with energy}}$$

Other parametrizations of NP might hide this important point!

SMEFT and unitarity

Modifications to higgs self-couplings (higgs potential) still unconstrained

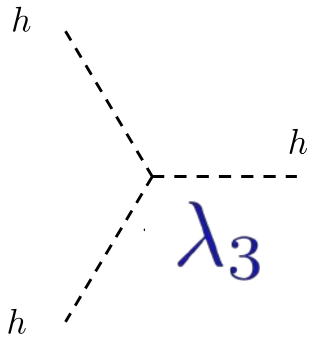


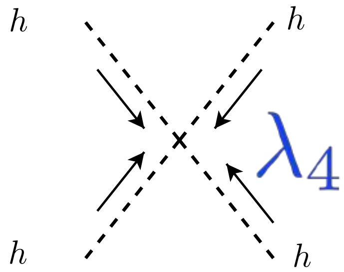
The shape of this potential is essential to understand EW phase transition and fate of this theory in the Cosmological context

δ_3, δ_4 must be measured at a Higgs factory in order to know the next energy scale (T.Tauchi)

$$\delta_i = \frac{\lambda_i - \lambda_i^{\rm SM}}{\lambda_i^{\rm SM}}$$

Process	Unitarity Violating Scale
$h^2 Z_L \leftrightarrow h Z_L$	$66.7\ \text{TeV}/\lvert\delta_3 - \frac{1}{3}\delta_4\rvert$
$h Z_L^2 \leftrightarrow Z_L^2$	$94.2\ \text{TeV}/\lvert\delta_3\rvert$
$h W_L Z_L \leftrightarrow W_L Z_L$	$141\ \text{TeV}/\lvert\delta_3\rvert$
$h Z_L^2 \leftrightarrow h Z_L^2$	$9.1\ \text{TeV}/\sqrt{\lvert\delta_3 - \frac{1}{5}\delta_4\rvert}$
$h W_L Z_L \leftrightarrow h W_L Z_L$	$11.1\ \text{TeV}/\sqrt{\lvert\delta_3 - \frac{1}{5}\delta_4\rvert}$
$Z_L^3 \leftrightarrow Z_L^3$	$15.7\ \text{TeV}/\sqrt{\lvert\delta_3\rvert}$
$Z_L^2 W_L \leftrightarrow Z_L^2 W_L$	$20.4\ \text{TeV}/\sqrt{\lvert\delta_3\rvert}$
$h Z_L^3 \leftrightarrow Z_L^3$	$6.8\ \text{TeV}/\lvert\delta_3 - \frac{1}{6}\delta_4\rvert^{\frac{1}{3}}$
$h Z_L^2 W_L \leftrightarrow Z_L^2 W_L$	$8.0\ \text{TeV}/\lvert\delta_3 - \frac{1}{6}\delta_4\rvert^{\frac{1}{3}}$
$Z_L^4 \leftrightarrow Z_L^4$	$6.1\ \text{TeV}/\lvert\delta_3 - \frac{1}{6}\delta_4\rvert^{\frac{1}{4}}$





Chang, Luty '19

11:50 Future – Path to very high energies, V.Shiltsev

plasma acceleration after 20-30 years R&D, we may say when this technique is available for colliders, some 1000 TeV colliders by end of this century. But only muons are accelerated.
matrices of colliders v.s. readiness/feasibility, power, cost

12:20 Technological challenges of particle physics experiments, Francesco Forti

70 - 20 - 10 Google model for now, next and horizon R&Ds

12:59 Computing challenges of the future, Simone Campana

HSF HEP Software Foundation
WLCG worldwide LHC Computing Grid
needs a strategy of the radical computing (industry standard?), e.g. using the GPUs
since C-language and root data base are old
quantum computing ? still far away from our computing
, where the problem is the stability,
10% investigation is needed for future.

Accelerator Sceince and Technology Session :
15:00 LHC future, Lucio Rossi

new type collimator, 11T dipole/Q for future accelerators
30 11T magnets are needed by 2024
Q/A cost of 16T magnet is assumed to be double of the present LHC for HE-LHC, FCChh

15:33 Future Circular Colliders , Michael Benedikt

the AC power comsumption < 2TWh/year, which is the most important parameter
Q/A budget ? the cost of FCCee is comparable to LHC

Questions in the Accelerator Sceince and Technology Session

- What is the best implementation for a Higgs factory? Choice and challenges for accelerator technology: linear vs. circular?

- Path towards the highest energies: how to achieve the ultimate performance (including new acceleration techniques)?

- How to achieve proper complementarity for the high intensity frontier vs. the high-energy frontier?

- Energy management in the age of high-power accelerators?

Finding *Common Denominators* * – Three Factors

** to be further discussed in the Symposium's accelerator sessions*

- ***F1*** **"Technology Readiness"** :

Green	- TDR
Yellow	- CDR
Red	- R&D

- ***F2*** **"Energy Efficiency"**

Green	: 100-200 MW
Yellow	: 200-400 MW
Red	: > 400 MW

- ***F3*** **"Cost"** :

Green	: < LHC
Yellow	: 1-2 x LHC
Red	: > 2x LHC

Higgs Factories	Readiness	Power-Eff.	Cost
ee Linear *250 GeV*			
ee Rings *240GeV/tt*			
μμ Collider *125 GeV*			*
Highest Energy			
ee Linear *1-3TeV*			
pp Rings *HE-LHC*			
FCC-hh/SppC			
μμ Coll. *3-14 TeV*			*

7-10 YEARS FROM NOW

WITH PROPOSED ACTIONS / R&D DONE / TECHNICALLY LIMITED

- ***ILC:***
  - Some change in cost (~6-10%)
  - All agreements by 2024, then
  - **Construction** (2024-2033)
- ***CLIC:***
  - TDR & preconstr. ~2020-26
  - **Construction** (2026-2032)
  - 2 yrs of commissioning
- ***CepC:***
  - Some change in cost & power
  - TDR and R&D (2018-2022)
  - **Construction** (2022-2030)
- ***FCC-ee:***
  - Some change in cost & power
  - **Preparations** 2020-2029
  - Construction 2029-2039
- ***HE-LHC:***
  - **R&D and prepar'ns** 2020-2035
  - Construction 2036-2042
- ***FCC-hh*** (w/o FCC-ee stage)***:***
  - **16T magnet prototype** 2027
  - Construction 2029-2043
- ***μ^+-μ^- Collider :***
  - **CDR completed** 2027, cost known
  - Test facility constructed 2024-27
  - Tests and TDR 2028-2035

Fermilab

16:04 Future LC, Steinar

overviews of ILC and CLIC, staging, schedule, cost etc.

assume novel accelerator technologies (NAT) for future upgrades

see slides for the upgrades and the LC in an overall strategy

C : ILC250 10Hz operation is only possible after the ILC500

17:20 Technical Overview and Challenges of Proposed Higgs Factories, D.Schulte

C : Z, W factories by FCCee physics values

FCCee 4 BCHF machines + 7 BCHF for CFS common for FCChh

transeverse polarization is important for the precise energy measurement at Z pole in FCCee

C : LHC-ep collision the same yields of Higgs but different mechanism

Q : feasibilities are slightly diffferent from the matrices presented at the plenary session

A : the operational effort can compensate some issues in the circular machines

A : the differences can be represented by existence of TDR or CDR,

, that is TDR at ILC, no TDR at FCCee, CEPC

17:57 Higgs precision measurements at future colliders, Maria Cepeda

Comparison tables of various kinds of kappa parameters, rare decays, invisible width, Higgs width, Higgs CP, Higgs mass

Future LC, Steinar

Upgrades and improvements

- ILC-250: double #bunches foreseen in baseline schedule, double frequency (to 10 Hz) considered?
  - The bunch number increase will add ~20-30 MW, cost at 8% level
- CLIC-380: double frequency (to 100 Hz)?, "margins" in emittance budget to be further studied
  - The frequency increases will add ~50 MW to power estimates, and cost at 5% level

- Energy staging foreseen in current programme shown in earlier slides

- One can consider further energy upgrades by improving the current RF technologies, or phasing in Novel Acceleration Technologies (plasma, di-electric)

C : ILC250 10Hz operation is only possible after the ILC500

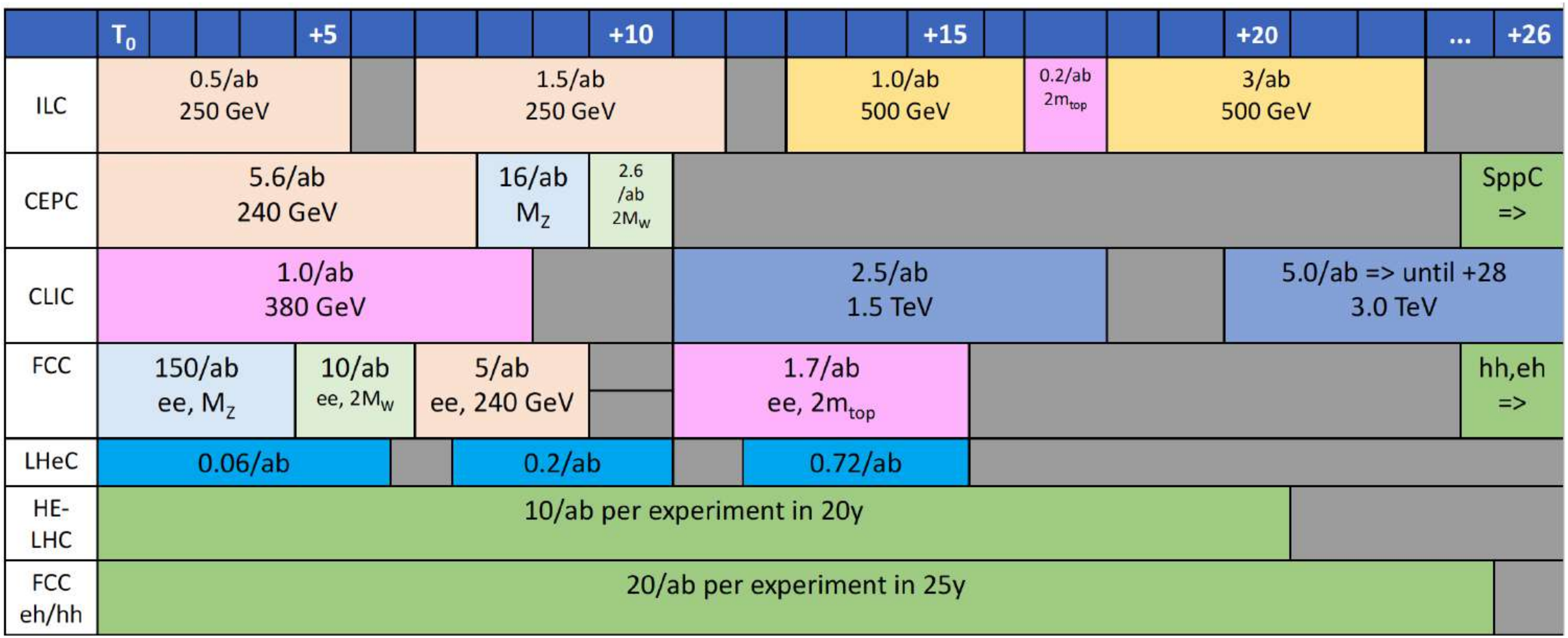
A linear collider as part of an overall strategy

2020 to ~2045	~2040-45 →
2020 - 2038 LHC/HL-LHC	
2020 - ~2035 const. and 2035-2045 operation • CLIC or ILC	Around 2040-45: Possible to move to higher e+e- stages with existing, improved or new LC technologies (as NAT below) – physics guidance from HiLumi, LC initial running and PBC
Develop hadron and muon machines towards construction readiness in 2030-2040 range	Around 2040-50: Possible to put proton and/or muon machines into operation, incl. HL-LHC and e+e- physics guidance, as well as from PBC projects
Develop NAT technologies for LC colliders	Around 2040-50: Introduce these technologies – if available - in LC facility
"Physics Beyond Collider" (PBC) projects	Continue ?
Other projects – CEPC among them	…

Main "features":

- Aim for "continuous" availability of e+e- and hadron/muon machines in next decades (using distinct facilities)
- Fast availability of e+e- accelerator, upgradable
- Affordable and mature proposals
- Flexible plan for hadron/muon accelerators at interesting timescale, encouraging rapid R&D developments

Schedule



Project	Start construction	Start Physics (higgs)
CEPC	2022	2030
ILC	2024	2033
CLIC	2026	2035
FCC-ee	2029	2039 (2044)
LHeC		

Proposed dates from projects

Would expect that technically required time to start construction is O(5-10 years) for prototyping etc.

Comparisons

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.8 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	7	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

Conclusion

- Four main proposals for higgs factories exist
  - ILC, CLIC, FCC-ee and CEPC
  - FCC-hh and HE-LHC need time for technology development
  - LHeC would also produce some higgs
  - No clear proposal for options like LEP3 or low field magnets in FCC-tunnel
  - Muon and plasma-based colliders will need more time to become realistic alternatives

- No feasibility issue is known for any of the proposed higgs factories CLIC, ILC, FCC-ee and CEPC
  - More work has to be done for each of them to ensure performance goal is met
  - Should review in detail them before commitment is made
  - In all cases need several years before construction could start
  - Currently, technology can not help with the choice of the next project

- Cost are high in all
  - 5.9 GCHF for 380 GeV CLIC, 5.3 GILCU for ILC, 11.6 GCHF for FCC-ee, 5 G$ for CEPC

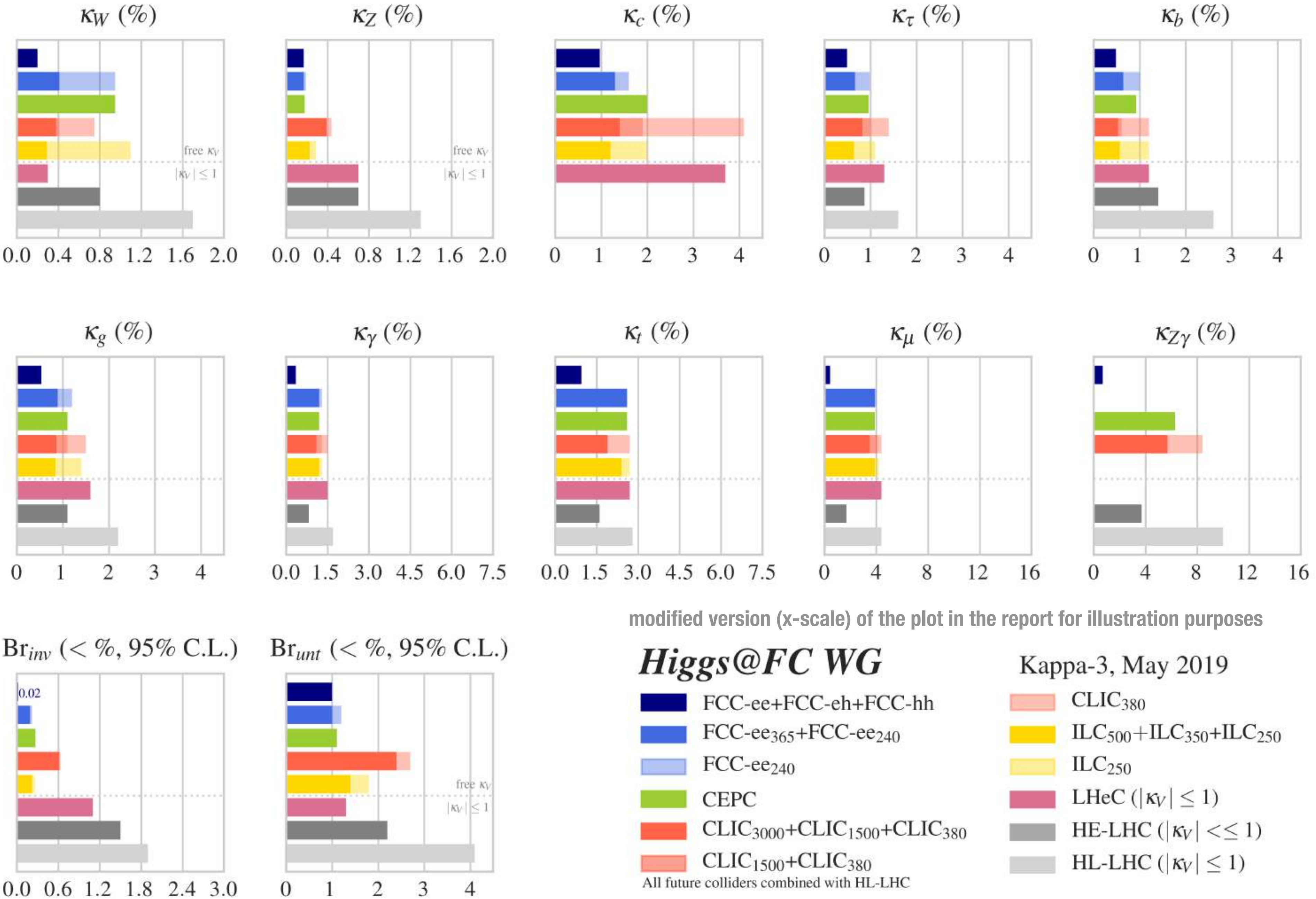
- Physics potential and strategy should be the governing principles

Future Colliders in a chart

Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] $[e^-/e^+]$	N(Det.)	$\mathscr{L}_{\text{inst}}$ $[10^{34}]\ \text{cm}^{-2}\text{s}^{-1}$	$\mathscr{L}$ $[\text{ab}^{-1}]$	Time [years]	Refs.	Abbreviation
HL-LHC	pp	14 TeV	-	2	5	6.0	12	[10]	HL-LHC
HE-LHC	pp	27 TeV	-	2	16	15.0	20	[10]	HE-LHC
FCC-hh	pp	100 TeV	-	2	30	30.0	25	[1]	FCC-hh
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[1]	
		$2M_W$	0/0	2	25	10	1-2		
		240 GeV	0/0	2	7	5	3		FCC-ee_{240}
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5		FCC-ee_{365}
							(+1)		(1y SD before $2m_{top}$ run)
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[3, 11]	ILC_{250}
		350 GeV	±80/±30	1	1.6	0.2	1		ILC_{350}
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5		ILC_{500}
							(+1)		(1y SD after 250 GeV run)
CEPC	ee	M_Z	0/0	2	17/32	16	2	[2]	CEPC
		$2M_W$	0/0	2	10	2.6	1		
		240 GeV	0/0	2	3	5.6	7		
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[12]	CLIC_{380}
		1.5 TeV	±80/0	1	3.7	2.5	7		CLIC_{1500}
		3.0 TeV	±80/0	1	6.0	5.0	8		CLIC_{3000}
							(+4)		(2y SDs between energy stages)
LHeC	ep	1.3 TeV	-	1	0.8	1.0	15	[9]	LHeC
HE-LHeC	ep	1.8 TeV	-	1	1.5	2.0	20	[1]	HE-LHeC
FCC-eh	ep	3.5 TeV	-	1	1.5	2.0	25	[1]	FCC-eh

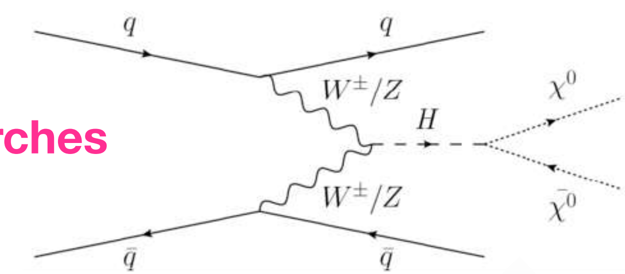
- The values for $\sqrt{s}$ are approximate: when a scan is proposed: included in the closest value
- When the entire programme is discussed, the highest energy value label is used inclusively

Kappa-3: +HL-LHC

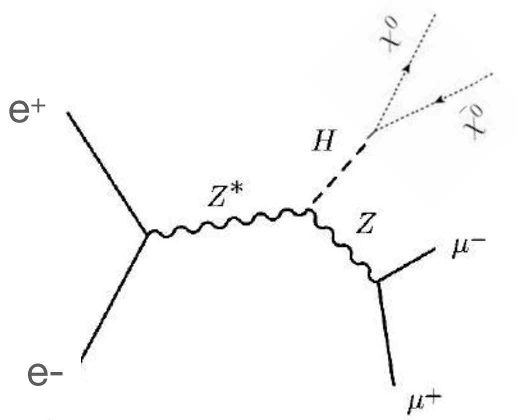


modified version (x-scale) of the plot in the report for illustration purposes

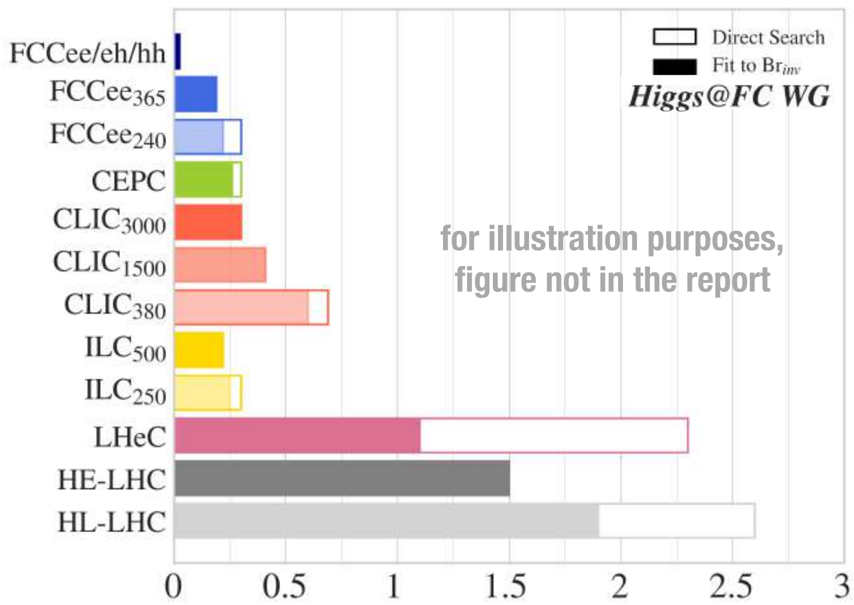
Invisible Width



- **Connection between the Higgs boson and dark matter searches**
- In the SM, BR_{SM}, inv = BR(H->4ν) = 0.11%
- Current LHC limits ~ 15-20% @ 95%CL
- Direct searches for Invisible width: fundamentally different in a hadron collider (MET uncertainties) and a lepton collider (Z recoil)
  - **Lepton colliders would improve upon HL-LHC limits by an order of magnitude**
  - **FCC-hh : another order of magnitude: values below the SM**



Collider	95% CL upper bound on BR_{inv} [%]		
	Direct searches	kappa-3 fit	Fit to BR_{inv} only
HL-LHC	2.6	1.9	1.9
HL-LHC & HE-LHC		1.5	1.5
FCC-hh	0.025	0.024	0.024
HL-LHC & LHeC	2.3	1.1	1.1
CEPC	0.3	0.27	0.26
$FCC\text{-}ee_{240}$	0.3	0.22	0.22
$FCC\text{-}ee_{365}$		0.19	0.19
ILC_{250}	0.3	0.26	0.25
ILC_{500}		0.22	0.22
$CLIC_{380}$	0.69	0.63	0.60
$CLIC_{1500}$		0.62	0.41
$CLIC_{3000}$		0.61	0.30



Higgs Width

- Three avenues explored for HL:
  - Diphoton interference studies can only provide constraints ~ 8-22xSM.
  - Fits in the kappa framework: subjected to theoretical constraints (eg: $|K_V|<1$ and $B_{unt}=0$).
  - HZZ on-shell and off-shell: 20% precision, but very model dependent
- **Measurements in Lepton colliders:**
  - mass recoil: measure the inclusive cross-section of the ZH without assumption on the Higgs BR's
  - mild model dependence

$$\frac{\sigma(e^+e^- \to ZH)}{\mathrm{BR}(H \to ZZ^*)} = \frac{\sigma(e^+e^- \to ZH)}{\Gamma(H \to ZZ^*)/\Gamma_H} \simeq \left[\frac{\sigma(e^+e^- \to ZH)}{\Gamma(H \to ZZ^*)}\right]_{\mathrm{SM}} \times \Gamma_H$$

Collider	$\delta\Gamma_H$ (%) from Ref.	Extraction technique standalone result	$\delta\Gamma_H$ (%) kappa-3 fit
ILC_{250}	2.4	EFT fit [3]	2.4
ILC_{500}	1.6	EFT fit [3, 11]	1.1
CLIC_{350}	4.7	κ-framework [80]	2.6
CLIC_{1500}	2.6	κ-framework [80]	1.7
CLIC_{3000}	2.5	κ-framework [80]	1.6
CEPC	3.1	$\sigma(ZH, \nu\bar{\nu}H)$, $\mathrm{BR}(H \to Z, b\bar{b}, WW)$ [85]	1.8
$\mathrm{FCC\text{-}ee}_{240}$	2.7	κ-framework [1]	1.9
$\mathrm{FCC\text{-}ee}_{365}$	1.3	κ-framework [1]	1.2

Higgs CP

$$\delta \mathcal{L}^{hVV}_{\rm CPV} = \frac{h}{v}\Big[\tilde{c}_{gg}\frac{g_s^2}{4}G^a_{\mu\nu}\tilde{G}^a_{\mu\nu} + \tilde{c}_{aa}\frac{e^2}{4}A_{\mu\nu}\tilde{A}_{\mu\nu} + \tilde{c}_{za}\frac{e\sqrt{g^2+g'^2}}{2}Z_{\mu\nu}\tilde{A}_{\mu\nu} + \tilde{c}_{zz}\frac{g^2+g'^2}{4}Z_{\mu\nu}\tilde{Z}_{\mu\nu} + \tilde{c}_{ww}\frac{g^2}{2}W^+_{\mu\nu}\tilde{W}^-_{\mu\nu}\Big]$$

$$\mathcal{L}^{hff}_{\rm CPV} = -\bar{\kappa}_f m_f \frac{h}{v}\bar{\psi}_f(\cos\alpha + i\gamma_5 \sin\alpha)\psi_f$$

- **Sensitivity to the CP-odd hVV weak operators:** studies have been performed both at the level of rates/distributions and via CP-sensitive observables

- **CP violation in fermionic Higgs decays:** ττ decay channel -> measurement of the linear polarisations of both taus and the azimuthal angle between them

Name	α_τ	$\tilde{c}_{zz}$	Ref.
HL-LHC	8°	0.45 (0.13)	[10]
HE-LHC	–	0.18	[10]
CEPC	–	0.11	[2]
FCC-ee$_{240}$	10°	–	[1]
ILC$_{250}$	4°	0.014	[3]

- **CP violation in the top quark interactions:** ttH and tH (rates and distributions):
  - HL-LHC: CP-odd Higgs excluded with 200fb^{-1}. CLIC 1.5 TeV : α_t (ttH) better than 15°. LHeC: Higgs interacting with the top quarks with CP-odd coupling excluded at 3 sigmas with 3 ab^{-1}. FCC-eh: precision of 1.9% on α_t.
  - Current indirect limits from EDM bounds are stronger than direct (though comparable for tau)

Higgs Mass

- **Current experimental precision ~0.1% (160 MeV)**
- Impact of the m_H uncertainty on the HZZ decay width: **In lepton colliders, m_H needs be improved to around 10 MeV to avoid any limitation on ZZ/WW couplings**
  - HL-LHC reach dependent on muon pt momentum calibration with high statistics: 10-20 MeV plausible (not a formal study)
  - ZH recoil at lepton colliders: statistically limited.

Collider Scenario	Strategy	δm_H (MeV)	Ref.	$\delta(\Gamma_{ZZ^*})$ (%)
LHC Run-2	$m(ZZ), m(\gamma\gamma)$	160	[83]	1.9
HL-LHC	$m(ZZ)$	10-20	[10]	0.12-0.24
ILC_{250}	ZH recoil	14	[3]	0.17
$CLIC_{380}$	ZH recoil	78	[85]	1.3
$CLIC_{1500}$	$m(bb)$ in $H\nu\nu$	30[15]	[85]	0.56
$CLIC_{3000}$	$m(bb)$ in $H\nu\nu$	23	[85]	0.53
FCC-ee	ZH recoil	11	[86]	0.13
CEPC	ZH recoil	5.9	[2]	0.07

Summary

- **Whatever the style of the future HEP collider, exploring the Higgs sector will be one of the primary objectives of the field**
- We provide a framework as homogeneous as possible for comparison to aid the discussion in this Symposium
- An overview of the methodology and the reach in terms of kappas, width, mass, rare decays and CP properties of the Higgs was presented in this talk, to be followed with detailed reports on EFT and HH tomorrow
- Going beyond the HL-LHC era, the future collider proposed will improve our knowledge of the Higgs boson with precise measurements of Higgs **couplings (large gain in κ_W, κ_Z, κ_b, access to κ_c)**, **invisible decays** and **CP properties**, and the opportunity to measure the **Higgs width**
- Full report in **arXiv:1905.03764**

5/14 BSM session

9:00 EWSB dynamics and resonances: what we can expect from experiments, Juan Alcaraz Maestre

Higgs composite overall factor C_H as a scale factor

Q/A Higgs is the longitudinal component, so W and Z are also composite

This talk is constrainted in FCChh for direct resonances. But there is no guarantee, The most demanding measurements are precise measurement of Higgs couplings.

9:37 EWSB dynamics and resonances: implications for theory, Andrea Wulzer

new gauge force Z'

massive U(1), fully equivalent to a heavy dark photon

coupling is a free parameter

10:25 Supersymmetry: what we can expect from experiments, Monica D'Onofrio

SUSY search, needs determinations of quantum numbers e.g. spin , where lepton colliders are needed.

11:30 Supersymmetry: implications for theory, Andreas Weiler

naturalness with tuning parameter of Δ

conclusions : Post HL-LHC: e+e- colliders (ILC,CLIC, FCCee) will provide some limited improvement in direct coverage and A high-energy pp machine would bring significant improvement in direct coverage

Q/A 100TeV collider ? Is there any reason ?

A : we do not know the energy scale.

C : linear colliders are needed for the compressed SUSY region

C/Q : Kappa_g has effect of stop mixing and their masses

12:15 Extended Higgs sectors and High-energy flavor dynamics: what we can expect from experiments, Philipp Roloff

conclusions : Substantial improvement with respect to HL-LHC possible for all discussed physics topics

・Large amount of complementarity:

- Direct and indirect sensitivity

(e.g. SM + heavy singlet, heavy MSSM Higgs bosons)

- Hadron and lepton collisions (e.g. doubly charged Higgs)

- Different energy stages of a lepton collider (e.g. top-quark FCNC effects)

12:45 Extended Higgs sectors and High-energy flavor dynamics: implications for theory, Veronica Sanz Gonzalez

C_H is proportional to $\sin^2 \gamma$ mixing parameter Higgs doublet

top FCNC decays

Flavor anomalies new vector LQ, U1

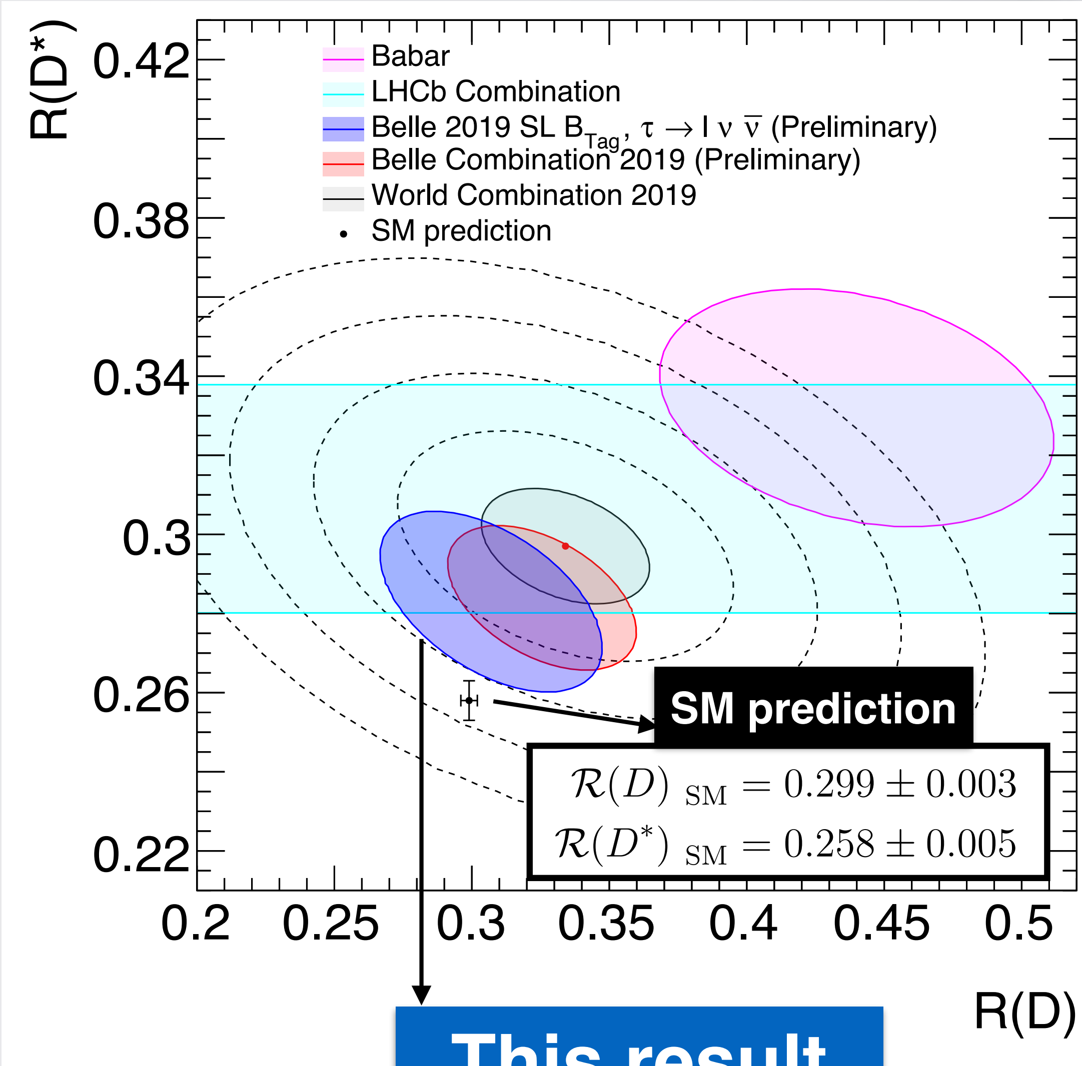
R_{D^*} - R_D

R_K

Outlook : If not minimal, could the EW phase transition be strong 1st order? Scalars need to be light (< TeV) and typically modify the properties of the Higgs. Colliders have an excellent coverage to these scenarios. Exceptional opportunity to connect with GWs and theoretical approaches to fluid dynamics

Conclusion / Preliminary $R(D^{(*)})$ averages

- **Most precise measurement** of R(D) and R(D*) to date
- First **R(D)** measurement performed with a **semileptonic tag**
- Results **compatible with SM** expectation within **1.2σ**
- **R(D) - R(D*) Belle average** is now within **2σ** of the SM prediction
- **R(D) - R(D*) exp. world average** tension with SM expectation **decreases from 3.8σ to 3.1σ**



This result

$$\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$$
$$\mathcal{R}(D^*) = 0.283 \pm 0.018 \pm 0.014$$

$R_{D^{(*)}}$

- Tests of lepton flavor universality:
  - $R_{D^{(*)}} = \frac{BR(B\to D^{(*)}\tau\nu)}{BR(B\to D^{(*)}\ell\nu)}, \quad (\ell = e,\mu)$
- SM:
  - $R_D = 0.299 \pm 0.003, \quad R_{D^*} = 0.258 \pm 0.005$
- 2019 measurement (Belle, 1904.08794):
  - $R_D = 0.307 \pm 0.037 \pm 0.016, \quad R_{D^*} = 0.283 \pm 0.018 \pm 0.014$
- 2018 world average [HFLAV]:
  - $R_D = 0.407 \pm 0.039 \pm 0.024, \quad R_{D^*} = 0.306 \pm 0.013 \pm 0.007$

- Future prospects:
  - LHCb [1812.07638]:

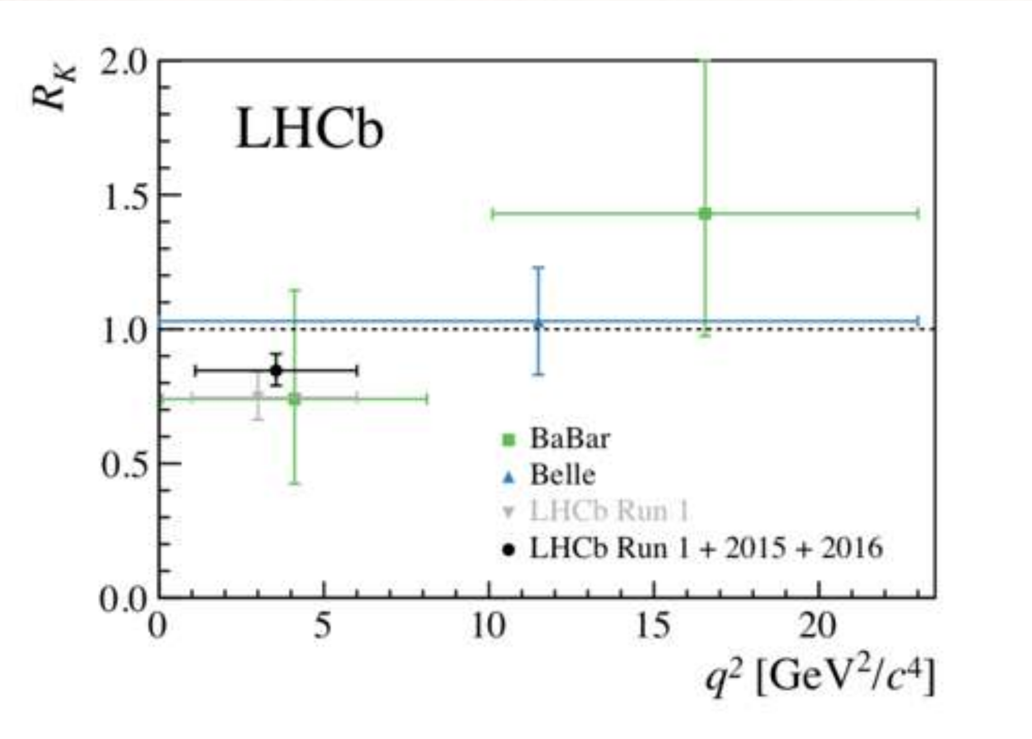
R_X precision	3 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}
R_{D^*}	0.03	0.01	0.007	0.003
R_{ψ}	0.25	0.08	0.05	0.02

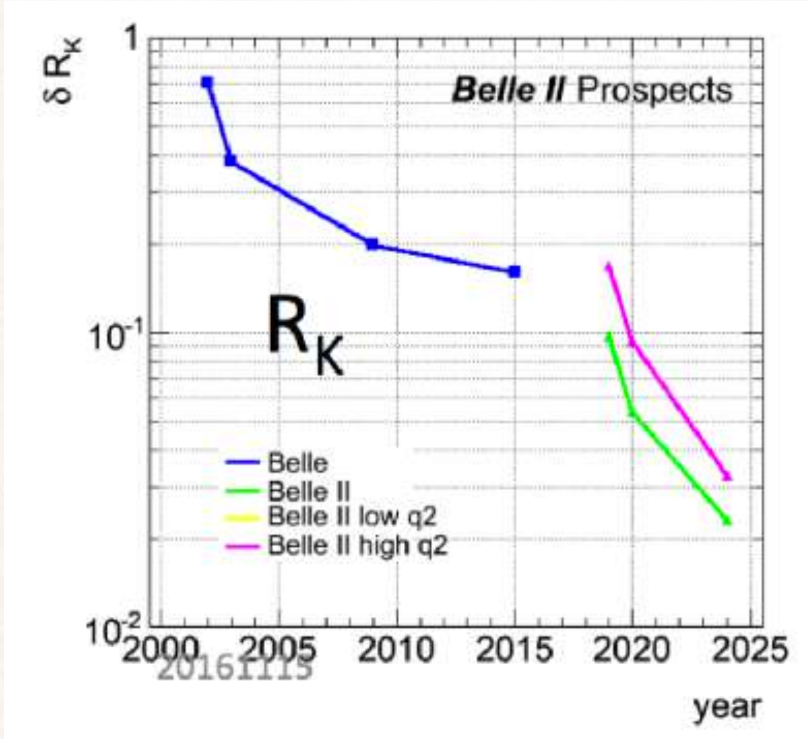
  - Belle II [1808.10567]:

$\delta R_X/R_X$	5 ab^{-1}	50 ab^{-1}
R_D	$\pm 0.060 \pm 0.039$	$\pm 0.020 \pm 0.025$
R_{D^*}	$\pm 0.030 \pm 0.025$	$\pm 0.010 \pm 0.020$

Flavour anomalies: current status

Moriond 2019, no paradigm shift
Data yet to be analysed and to be made public





One of the preferred explanations to this and other flavour anomalies is the existence of new LQs, particularly U1

$R_{K^{(*)}}$

- Tests of lepton flavor universality:
  - $R_{K^{(*)},[a,b]} = \frac{\int_a^b dq^2[d\Gamma(B\to K^{(*)}\mu^+\mu^-)/dq^2]}{\int_a^b dq^2[d\Gamma(B\to K^{(*)}e^+e^-)/dq^2]}$
- 2019 measurement:
  - $R_{K,[1.1,6.0]\mathrm{GeV}} = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$ (LHCb, 1903.09252)
- 2017 measurement:
  - $R_{K^*,[1.1,6.0]\mathrm{GeV}} = 0.69^{+0.11}_{-0.07} \pm 0.05$ (LHCb, 1705.05802)
- Future prospects:
  - LHCb [1812.07638]:

R_X precision	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}
R_K	0.043	0.025	0.017	0.007
R_{K^*}	0.052	0.031	0.020	0.008

  - Belle II [1808.10567]:

R_X precision	0.71 ab^{-1}	5 ab^{-1}	50 ab^{-1}
R_K	0.28	0.11	0.036
R_{K^*}	0.26	0.10	0.032

15:00 muon collider, Daniel Schulte

Not ready to draft a CDR

muon source by positron beam annihilating into muon pairs, which require no DR.

15:30 Accelerator-based Neutrino beams, Vladimir Shiltsev

Femilab proton complex , JPARC and new proposals (Protvino/ORKA, ESSνSB, ENUBET, νSTORM)

16:00 Energy efficiency of HEP infrastructures, Erk Jensen

Sustainability, energy and heat recovery, figure of merit as luminosity per power consumption

17:00 Current plasma acceleration projects, Edda Gschwendtner

FACET at SLAC, USA - positron acceleration

BELA, Berkeley, lab, USA

AWAKE at CERN

SPARCLAB, Frascati, Italy

Laser-Driven Plasma Acceleration Facilities

Beam-Driven Plasma Acceleration Facilities

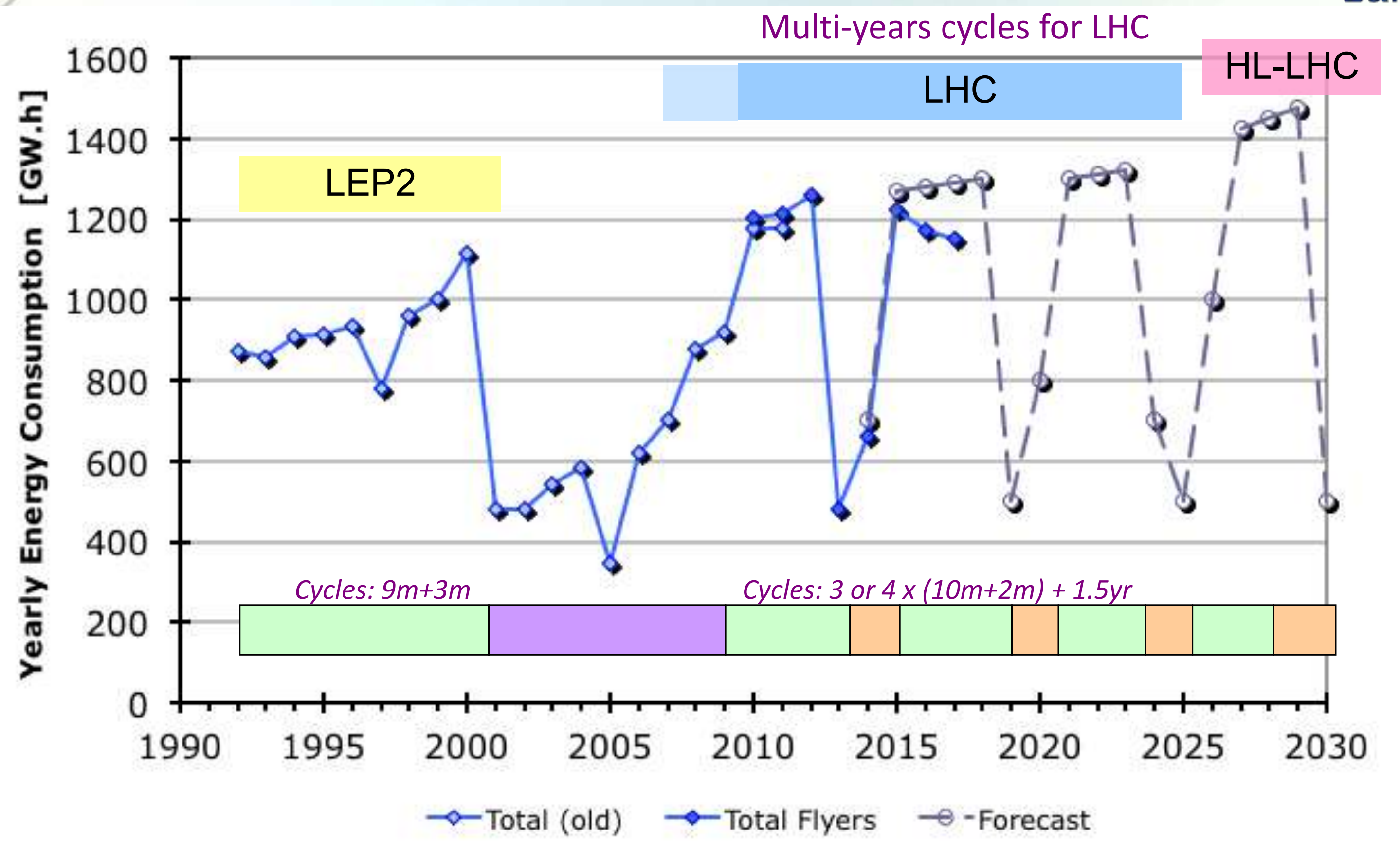
17:30 Challenges of plasma acceleration, Wim Leemans

18:00 Beyond colliders, Mike Lamont

fixed target experiments and facilities

Energy efficiency of HEP infrastructures, Erk Jensen

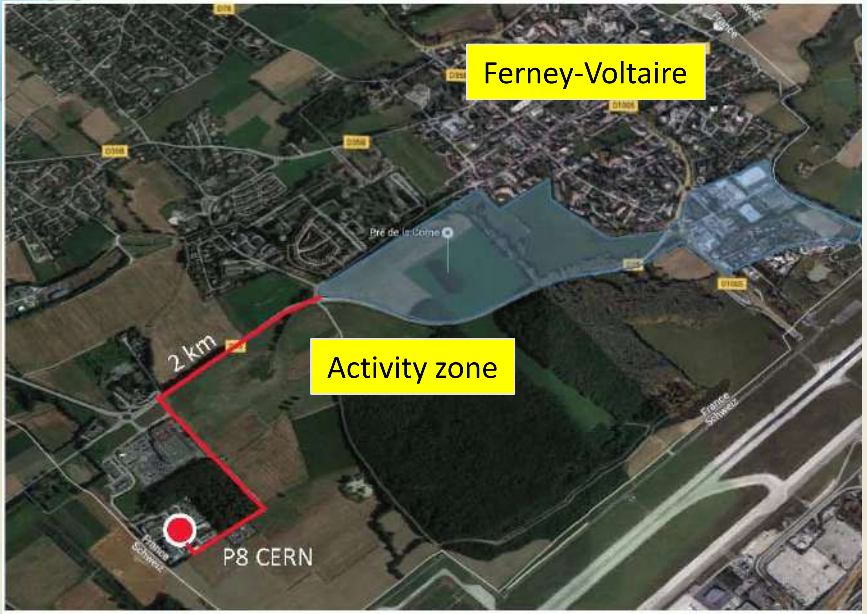
Energy Management - example CERN: consumption

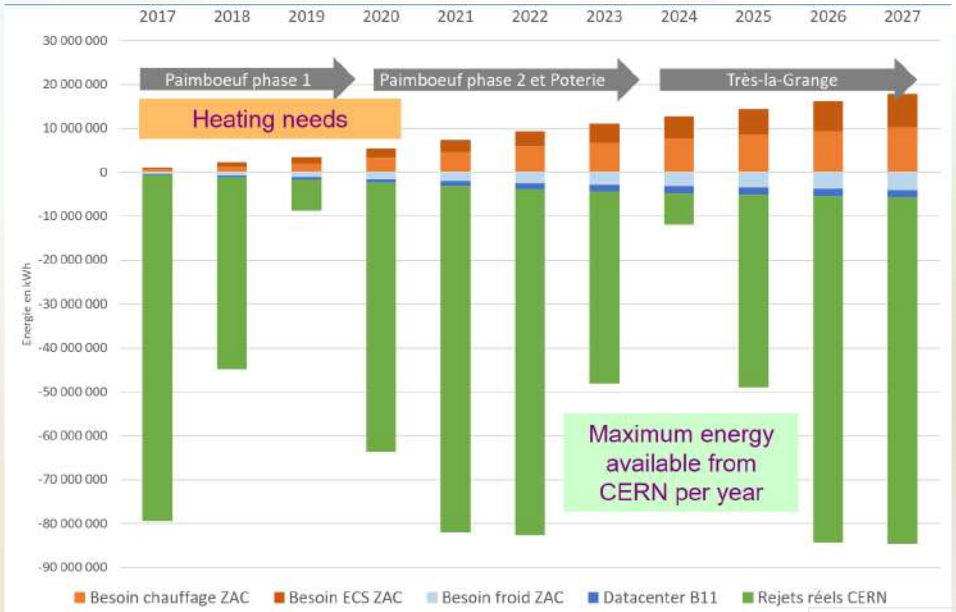


V. Mertens/CERN

Waste heat recovery

- Example from CERN: Thermal energy from LHC P8 to be injected in a local "anergie" loop in neighbouring Ferney-Voltaire:





S. Claudet/CERN

Applications of beam energy recovery

European Strategy Update

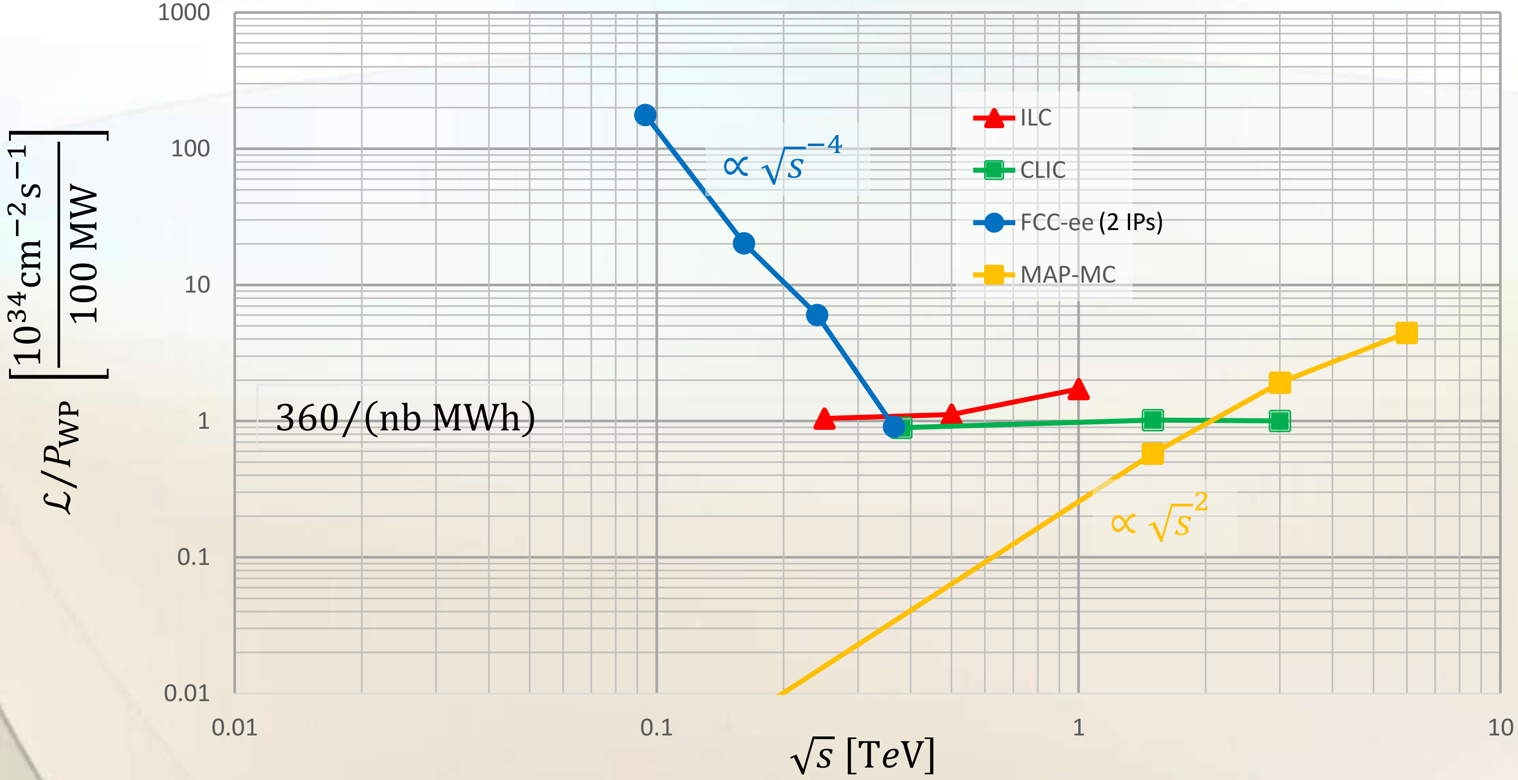
- In the CLIC two-beam-scheme, 90% of the drive beam energy is recovered (to power the main beam).
- In the LHeC and FCC-he proposals, e.g., an Energy Recovery Linac (ERL) is proposed to accelerate the 15 mA electron beam to 60 GeV (virtual beam power $15\ \mathrm{mA} \times 60\ \mathrm{GV} = 900\ \mathrm{MW!}$) and decelerates it – after the interaction with the hadron beam – to about 0.5 GeV, using $< 100\ \mathrm{MW}$ of power!

Figure of merit for proposed lepton colliders

European Strategy Update

Disclaimers:

1. This is not the only possible figure of merit
2. The presented numbers have different levels of confidence/optimism; they are still subject to optimisations



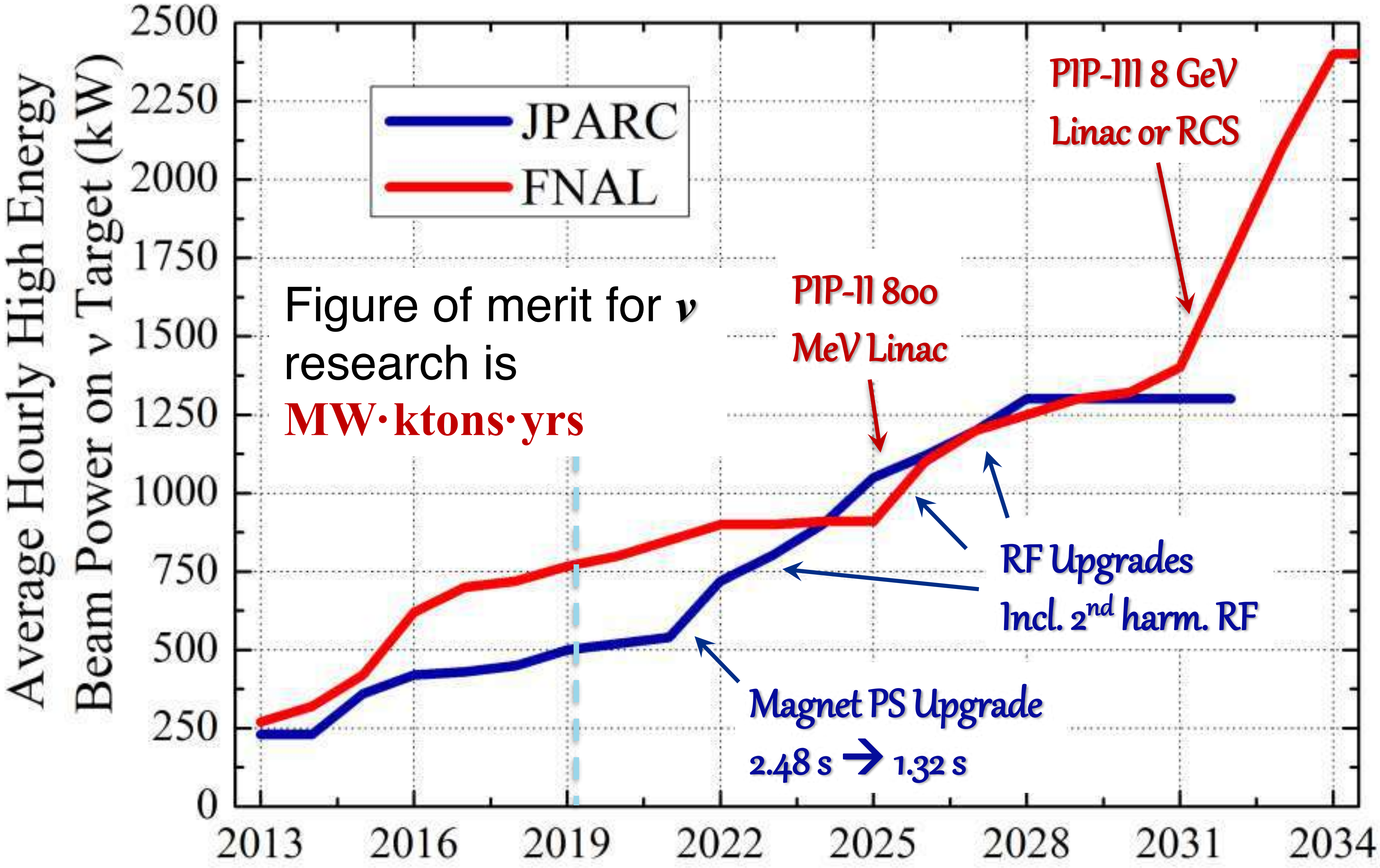
note : MAP(Muon Accelerator Program@FNAL)-MC = Muon collider, https://map.fnal.gov
Higgs factory by muon collider (C. Rubia, Aug.16 2013)

Content:

1. **Super-Beam Facilities and Upgrades** - how to achieve the ultimate energy and performance, R&D required :
   - Fermilab — Input #167 — Input #150
   - J-PARC — Input #76 — Input #158

2. **New Proposals** – opportunities and synergies :
   - Protvino/ORKA — L=2590km, E_ν ~5 GeV — Input #124
   - ESSνSB — ESS Neutrino Super Beams — Input #98
   - ENUBET — SPS-based Short base-line ν's — Input #57
   - νSTORM — ν from $\mu^\pm$ beams 1 GeV/c - 6 GeV/c at SPS — Input #154

Fermilab and J-PARC Power Upgrades



Current plasma acceleration projects, Edda Gschwendtner

Status of Today and Goals for Collider Application

	Current	Goal
Charge (nC)	0.1	1
Energy (GeV)	9	10
Energy spread (%)	2	0.1
Emittance (um)	>50-100 (PWFA), 0.1 (LFWA)	$<10^{-1}$
Staging	single, two	multiple
Efficiency (%)	20	40
Rep Rate (Hz)	1-10	10^{3-4}
Acc. Distance (m)/stage	1	1-5
Positron acceleration	acceleration	emittance preservation
Proton drivers	SSM, acceleration	Emittance control
Plasma cell (p-driver)	10 m	100s m
Simulations	days	Improvements by 10^7

Table 1: Facilities for accelerator R&D in the multi-GeV range relevant for ALIC and with emphasis on specific challenges

Facility	Readiness	ANA technique	Specific Goal
kBELLA	Design study	LWFA	e-, 10 GeV, KHz rep rate
EuPRAXIA	Design study	LWFA or PWFA	e-, 5 GeV, reliability
AWAKE	Operating	PWFA	e^-/p^+ collider
FACET II	Start 2019	PWFA	e^-, 10 GeV boost, beam quality, e^+ acceleration
Flash FWD	Operating	PWFA	e-, 1.5 GeV, beam quality

Summary

- European Strategy 2013 called for a '**vigorous accelerator R&D program**, including high-field magnets and **high-gradient accelerating structures**…' . This recommendation was directed to support the development of plasma-based technology.

- Since then many projects have evolved and **lots of progress** has been achieved in the plasma wakefield acceleration technology development
    - **Main advantage: large accelerating gradients:** 1 GV/m average, > 50-100 GV/m peak
    - **Challenges: collider beam quality** (see Wim Leeman's talk).
- Many of the challenges important for a collider design have been **demonstrated, but not necessarily at the same time.**

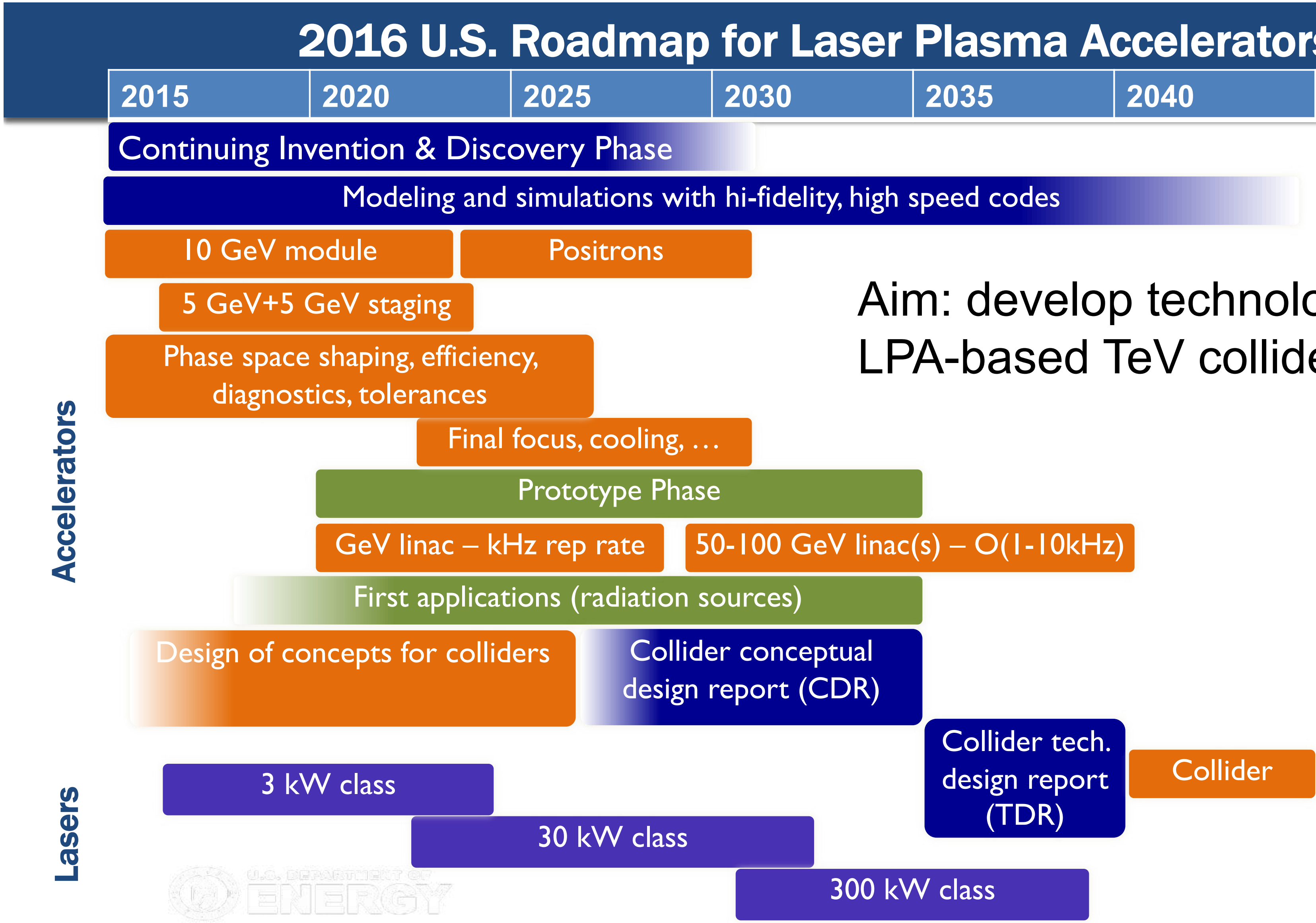
- Current and planned facilities (Europe, America, Asia) explore **different advanced and novel accelerator concepts and proof-of-principle experiments** and address beam quality challenges and staging of two plasmas.

- **Coordinated R&D program for dedicated international facilities t**owards addressing HEP challenges are needed over the next 5 to 10 years.
- Initiatives in Europe:
    - **EuPRAXIA**: design study towards superior beam quality.
    - **ALEGRO**: energize advanced accelerators community, includes HEP community towards an advanced collider: ALIC
    - **AWAKE**: plasma wakefield acceleration experiment dedicated to HEP collider applications.

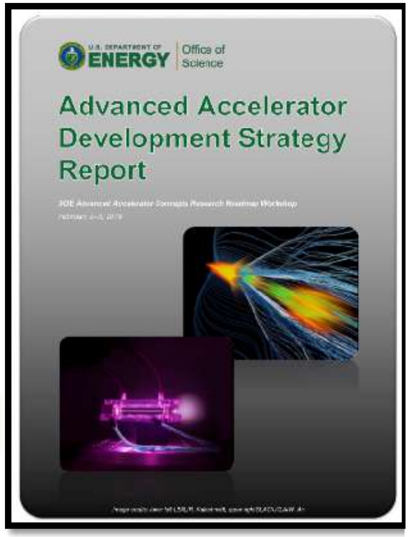
- **Near-term goals**: the laser/electron-based plasma wakefield acceleration could provide **near term solutions for FELs, medical applications, etc.**
- **Mid-term goal**: the **AWAKE technology** could provide **particle physics applications**.
- **Long-term goal**: design of a high energy electron/positron/gamma **linear collider** based on plasma wakefield acceleration.

- **Leading roles from accelerator laboratories** (CERN, DESY,…) is ESSENTIAL to reach collider parameters and technology demonstration.

Challenges of plasma acceleration, Wim Leemans



Aim: develop technology for LPA-based TeV collider by 2040



EuPRAXIA: High Quality Beam – Distributed Work

Modelled after highly successful concept of HEP detector construction, installation, operation

CERN
X Band RF Technology (Compact Driver)

Industry
European laser and accelerator Industry

Italy
Construction beam-driven plasma accelerator

Germany
Construction laser-driven plasma accelerator

France
Excellence Center FEL Quality Beam

Portugal
Excellence Center for Theory & Plasma Simulation

UK
Excellence Center for Application Beamline

ELI
Incubator for Applications Users Laser Science, Laser tests

POSSIBLE SHARE – PRELIMINARY – UNDER DISCUSSION

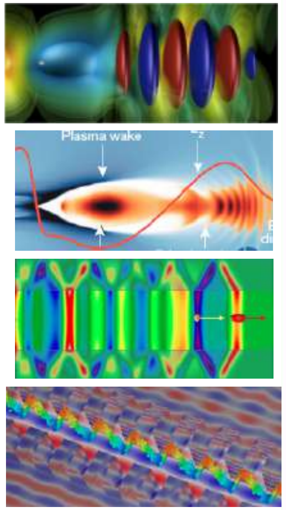
EuPRAXIA will form an **inter-disciplinary environment** of Nobel-prize winning laser science, advanced RF technology, research universities, industry and big science user labs in Europe.

EuPRAXIA forms a **close partnership with selected institutes in US, China and Japan**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Scientific roadmap for a collider up to design report delivery

ANAR2017 workshop and report http://www.lpgp.u-psud.fr/icfaana/ **Courtesy B. Cros, LPGP, Paris, France**



2017 - 2022	2022 - 2027	2027 - 2032	2032-2037
e- sources: optimization **e+ sources:** Concept devt **Driver development** **Accelerating structures** **Beam transport and coupling**	**e- acceleration :** Optimization of all parameters **e+ acceleration:** demonstration		
5 Ys **Injector, Accelerator stages with controlled parameters**	**10 Ys** **x10 Improved beam quality at higher energy**	**15 Ys** **Reliable staged accelaration, 10 GeV module**	**20 Ys** **Advanced Linear Collider CDR and TDR**

Address specific challenges :

- Staging →
- Reliability →
- Polarization →
- Efficiency →
- Beam Delivery System →

5/15

9:00 Feebly interacting particles: theory landscape (FIP theory), Gilad Perez

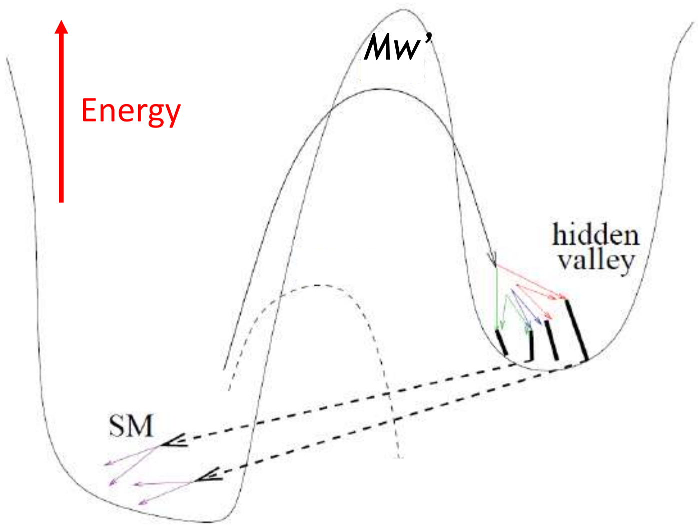
9:40 Feebly interacting particles: what we can expect from experiments, Gaia Lanfranchi

10:20 Global discussion on DM and FIPs

Generic motivation, the feeble-front

- The standard model (SM) consists of weakly interacting & long-lived particles.
- Many SM extensions => ultra weakly (feebly) interacting particles (FIPs).

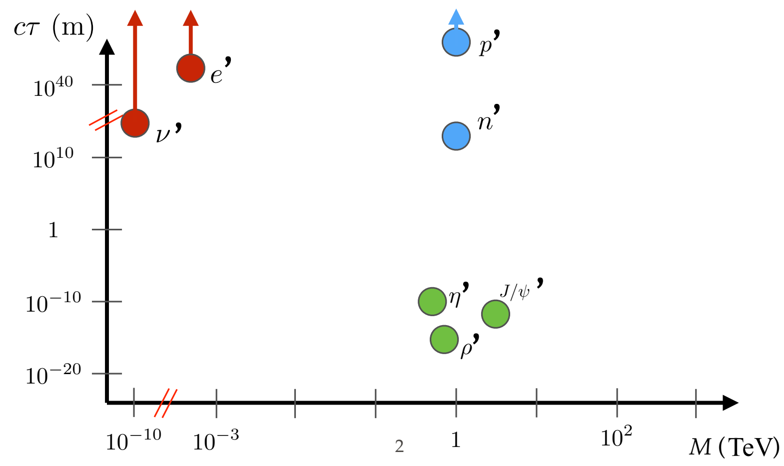
For reviews see e.g.: 1311.0029; 1205.2671; 1608.08632



Strassler, Zurek (06)

New strong sector spectrum

- LLP = "long lived particle"
- Travels a macroscopic distance before decaying ($\gtrsim 0.01$ mm)



Generic motivation, the feeble-front

- Heavy FIPs are hard to observe, possibly in energy frontier.
- Light FIPs can be copiously produced & probed across frontiers, relevant to this study: energy, luminosity, precision => *our mandate - focus on this case*.
- Are such light particles motivated by basic principles? Absolutely:

  pseudo-scalars (Goldstones, axion-like=ALP),

  scalars (SUSY, dilatons, Goldstones+CP violation),

  fermions (axial sym'),

  vectors (gauge sym') …

Naturalness @ 21st century => FIPS & new crisis

- Not common for naturalness-based models; the anchor for energy frontier which conventionally satisfies the equation:

Naturalness <=> TeV new physics (NP)

Talks by: Rattazzi, Weiler, Wulzer …

- New ideas cast doubt on this "equation".

  eg: "Cosmic attractors", "dynamical relaxation", "N-naturalness", "relating the weak-scale to the CC" & "inflating the Weak scale".

- New scalar-FIPs common to all of above: consider for ex. the relaxion.

  Graham, Kaplan & Rajendran (15)

- Relaxion models can be described via a scalar that mixes with the Higgs:

  Flacke, Frugiuele, Fuchs, Gupta & GP; Choi & Im (16)

Case (*iii*): Penetrating the relaxion physical region

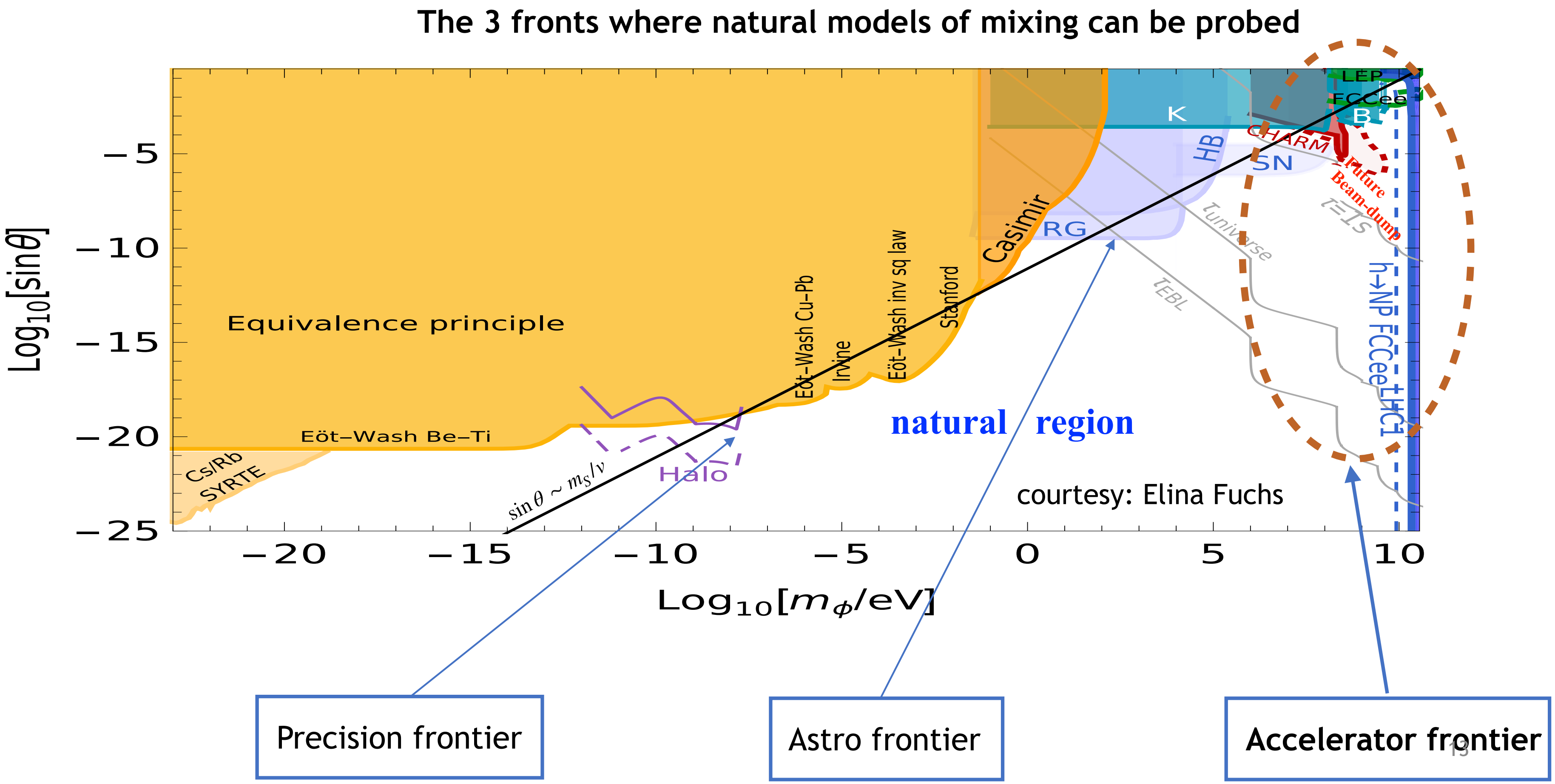
- As effective relaxion models can be described via a Higgs portal they suffer from their own naturalness problem which can be summarised as follows:

$$L_S \in m_S^2 SS + \mu S H^\dagger H + \lambda S^2 H^\dagger H\,, \quad \text{with } S = \text{light scalar \& } H = \text{SM Higgs}\,.$$

$$\text{Naturalness implies:} \quad \sin\theta \simeq \mu/\langle H\rangle \lesssim \frac{m_S}{\langle H\rangle} \;\;\&\;\; \lambda \lesssim \frac{m_S^2}{\langle H\rangle^2}\,.$$

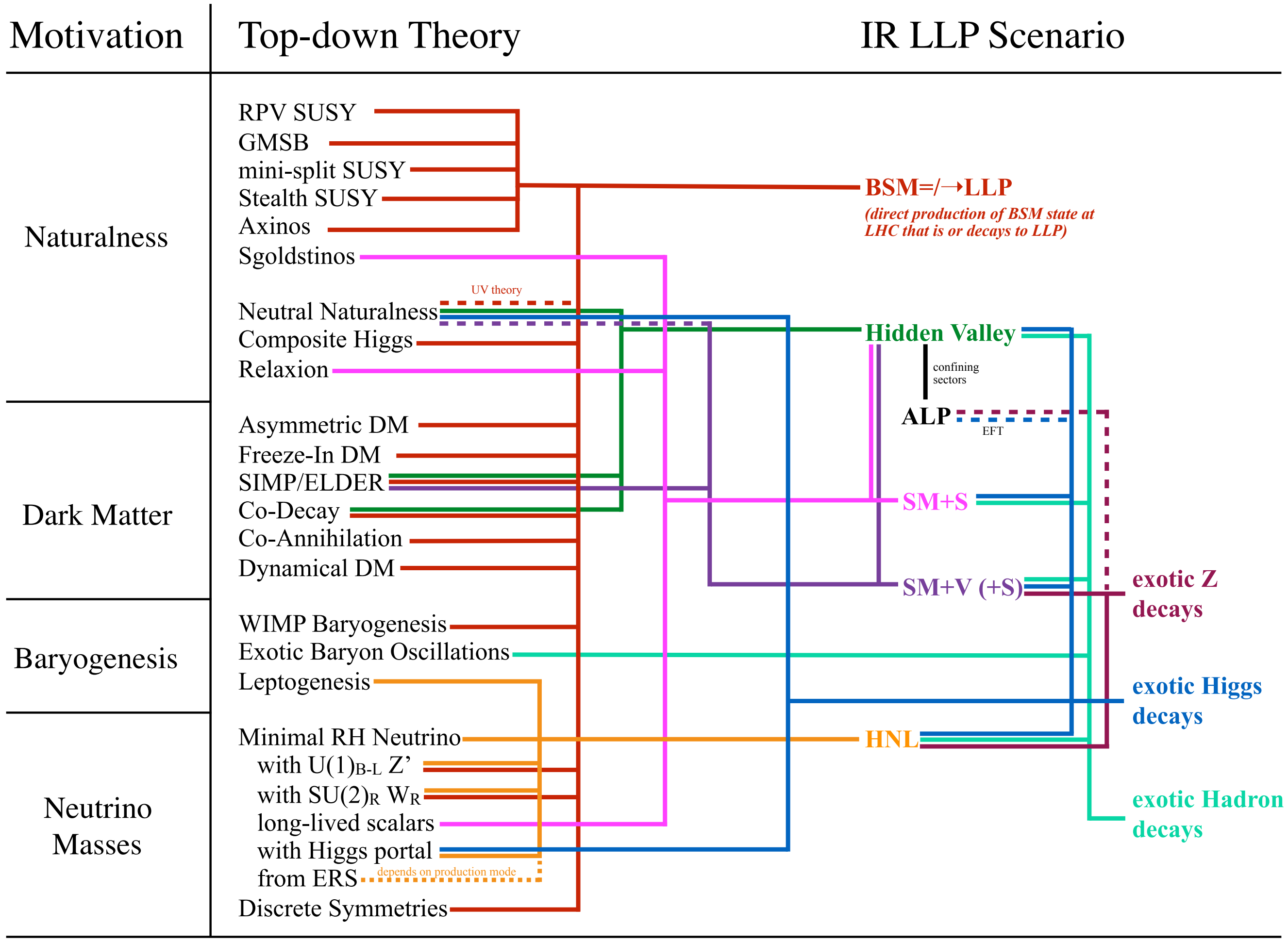
- As you see in following plot it is very hard to probe the natural region:

Accelerators: 1 among only 3 probes of physical models



Zoo of microscopic models giving FIPs+ long lived particles (LLPs)

1806.07396



European Strategy Update

Simplified (simplest?) models: the four portals

HNLs, LDM & Light mediators, ALPs must be SM singlets, hence options limited by SM gauge invariance:
According to generic quantum field theory, the lowest dimension canonical operators are the most important:

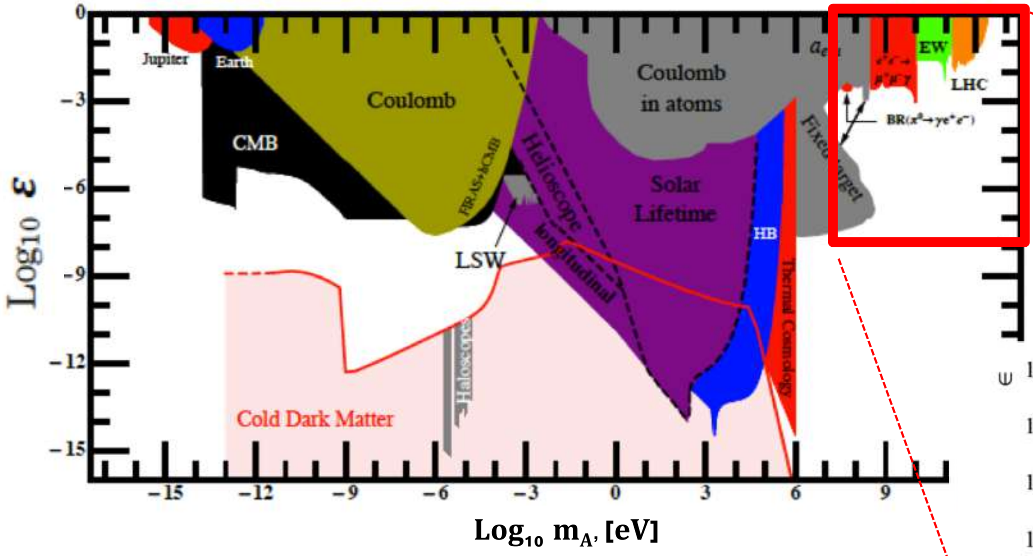
	Portal	Coupling
Vector portal	Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Scalar portal (dark scalar/relaxion)	Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$
Pseudo-scalar portal	Axion, a	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a} \overline{\psi} \gamma^\mu \gamma^5 \psi$
Fermion portal	Sterile Neutrino, N	$y_N L H N$

See also Murayama's (DM session) and Ceccucci's (Flavor session) talks.

From portals we can identify benchmark cases to evaluate the experimental sensitivities.
A common ground to compare the proposals against each other and put them in worldwide context.

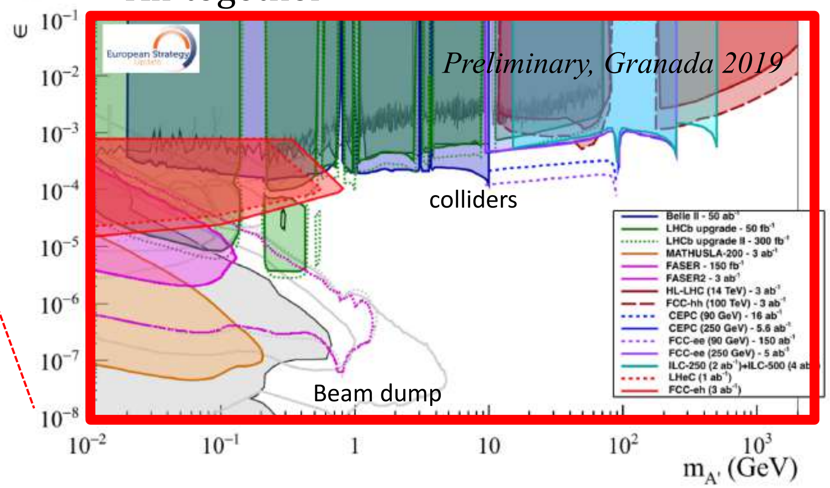
Four "lampposts" in the darkness of the orders of magnitude.
A starting point.

Vector portal: current limits in the ε versus Dark Photon mass plane



MeV-TeV range accelerators' domain (range compatible with the hypothesis of DM as thermal relic)

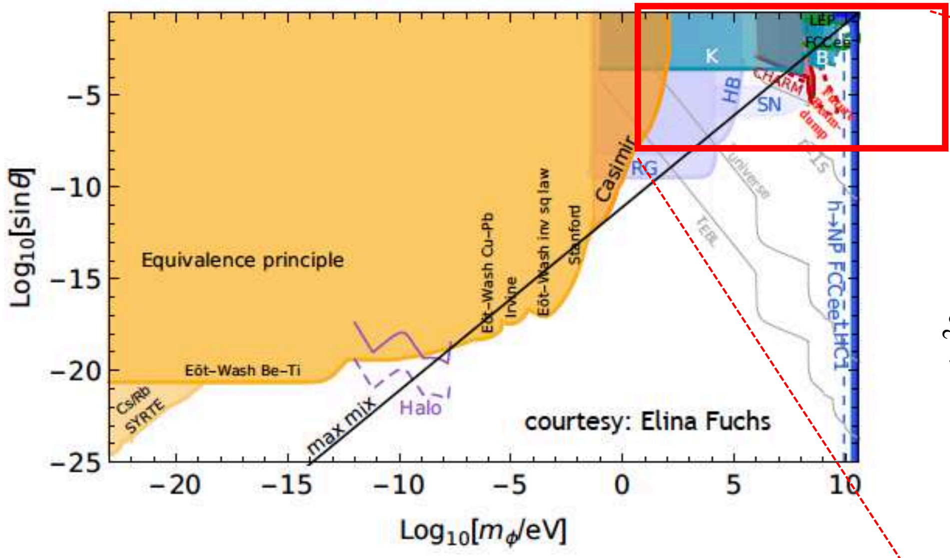
All together



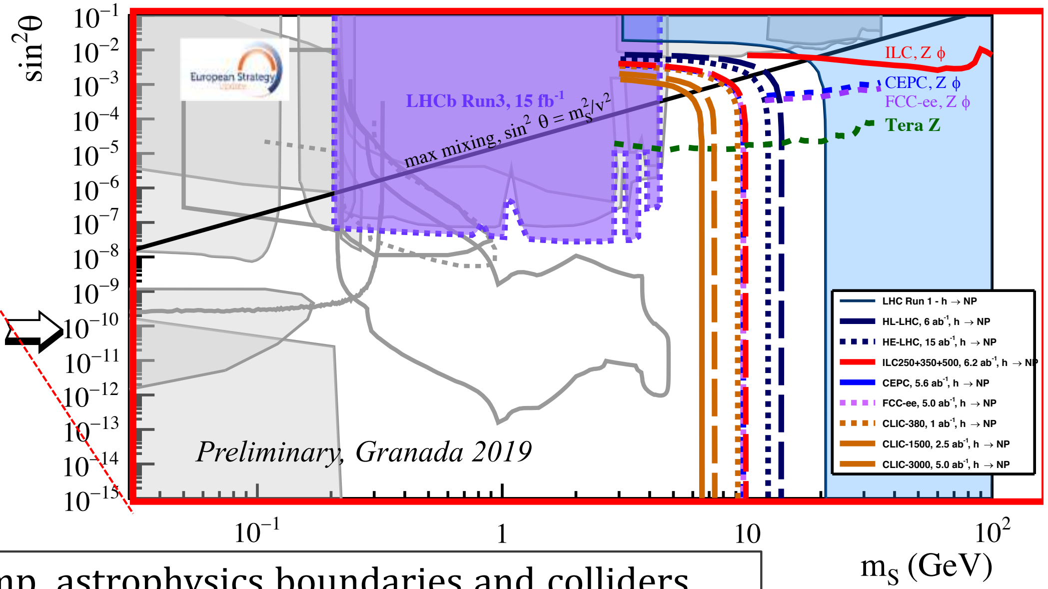
Improvements by several orders of magnitude both in low-mass low-coupling regime (beam-dump) and in high-mass large-coupling regime (colliders).

Nice complementarity between beam-dump and colliders' experiments

Hunting a “heavy” relaxion/scalar-portal



MeV-100 GeV range
is accessible at accelerators' based experiments

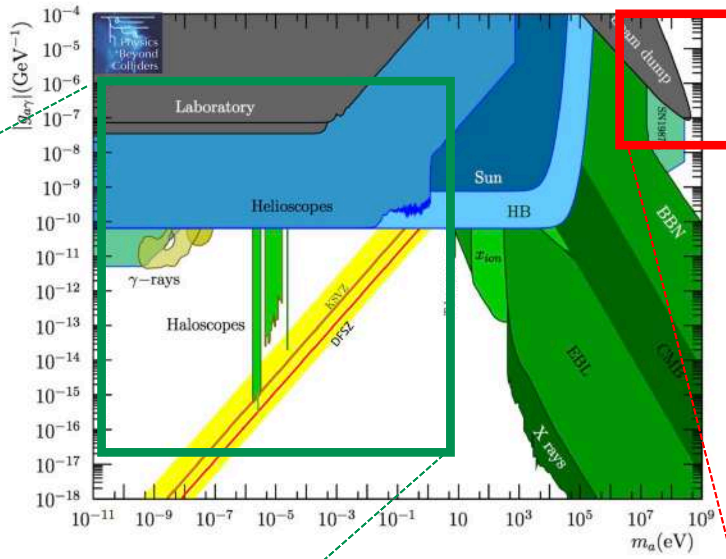


High-mass range can be excluded by the knowledge of the Higgs couplings; Improvements by several orders of magnitude possible in low-mass low-coupling regime using direct searches.

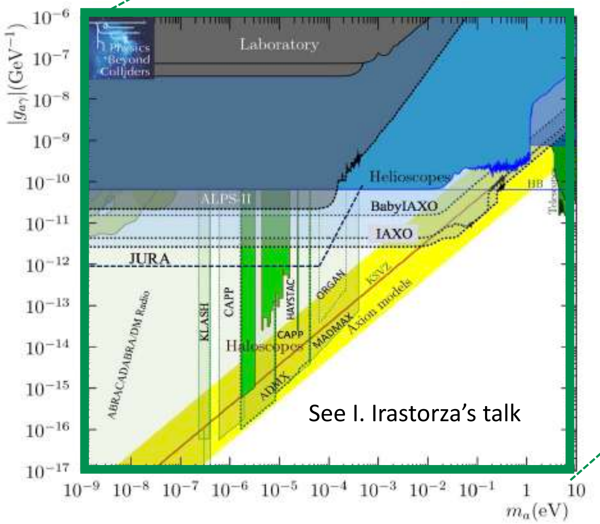
Nice complementarity between beam-dump, astrophysics boundaries and colliders. Together they can explore a large fraction of the “natural” relaxion region.

Pseudo-Scalar portal: ALPs with photon coupling

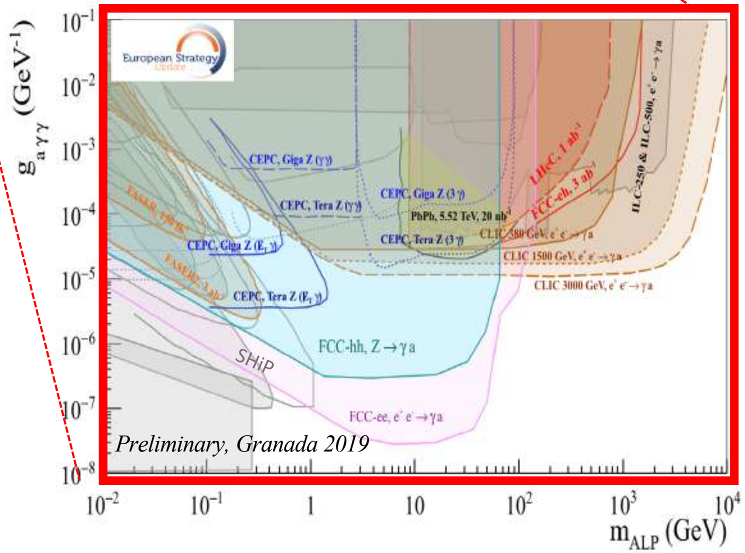
sub-eV range accessible at helioscopes and haloscopes



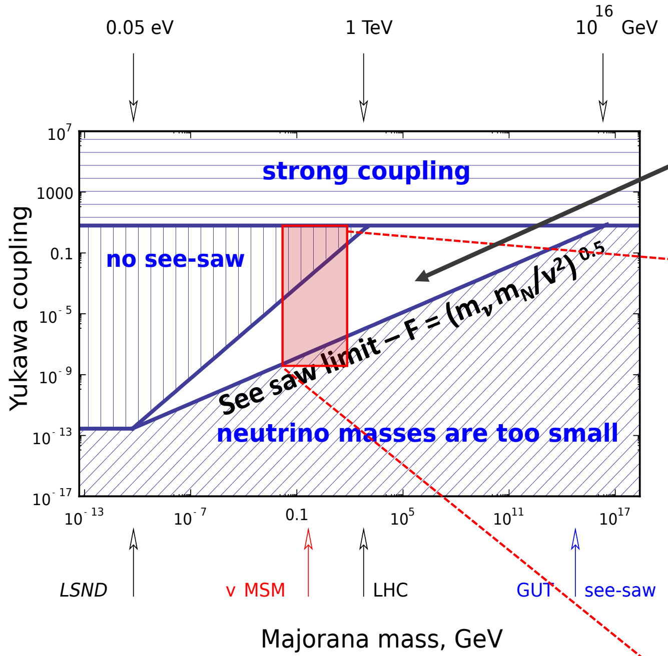
MeV-10 GeV range accessible at accelerators' based experiments



Nice complementarity of accelerator-based experiments, experiments in the sub-eV range, and cosmological bounds

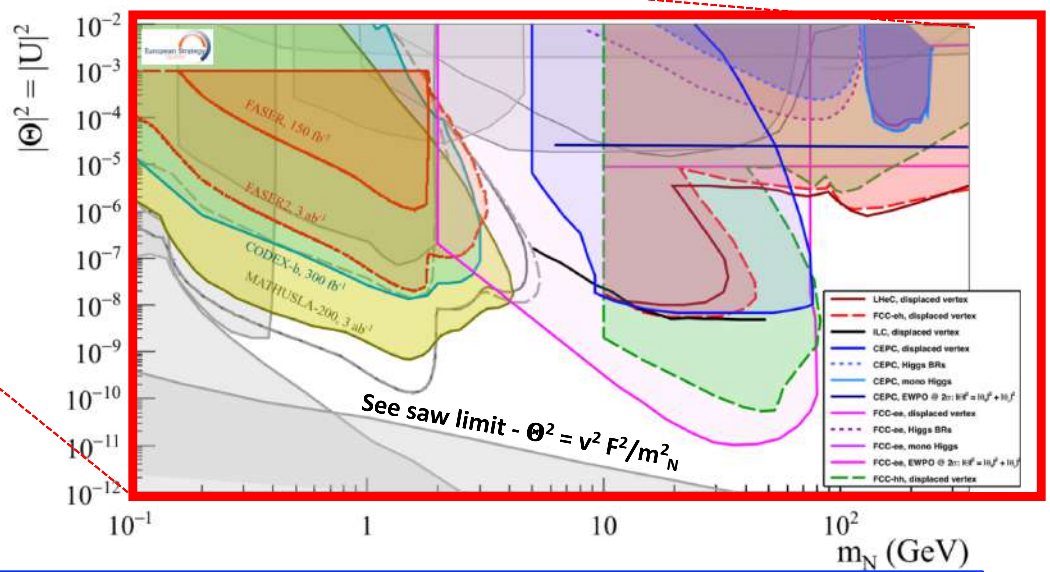


Fermion Portal: possible physics motivation
Origin of the neutrino masses and oscillations



Back to the initial plot:

SU(2)xU(1)$_L$ singlet Right Handed Neutrinos responsible of the neutrinos' mass generation can have any coupling/mass in the white area, assuming an approximate U(1)$_L$ global symmetry.



With beam dump and future colliders's experiments we can explore (light) RHN in the mass range 0.1-90 GeV almost down to the see-saw limit.

Conclusions

- ✓ Feebly interacting particles are generically motivated in a broad class of models:
  ⟶ they nicely complement the quest for New Physics in the high energy and flavor frontiers.

- ✓ No scale associated within this paradigm:
  ⟶ preferred mass/coupling regions are model-dependent.

- ✓ Four (vector, scalar, pseudo-scalar, fermion) portals provide a few, simple, gauge-invariant, (as much as possible) model-independent benchmarks cases to compare sensitivity across experiments over many orders of magnitudes:
  ⟶ a starting point.

- ✓ In the accelerator domain, collider based experiments nicely complement the physics reach at beam-dump experiments. But the field is much broader:
  ⟶ connection with neutrino-physics, cLFV, axion searches at helioscopes/haloscopes, DM direct detection searches, table-top experiments, astrophysical observations, etc., etc.

The “feeble paradigm” is an important physics case for the future: to explore it we need a multi-scale (multi-experiment) approach

11:30 Global discussion on EWSB, resonances, SUSY, extended scalars and HE flavor

EWSB dynamics and resonances

1st point : Which is the best way to find new interactions/particles around or above the electroweak scale using high-energy probes? (direct or indirect ?)

HE-LHC vs circular colliders (FCCee , CEPC) , FCChh vs linear colliders in M(TeV) v.s. g_Z'

C : definitely need e^-e^+ collider for the precise measurements of Higgs couplings

C : ILC results will be put on the final slide

C : luminosity and polarization are needed

2nd point : How can we tell whether the Higgs is composite (or not)?

FCChh vs CLIC m* and g*

C_ϕ, C_W C_{2W} by CLIC

Expected $O_H=O_\phi$: $\frac{c_\phi}{\Lambda^2} = \frac{g_*^2}{m_*^2}$

Expected O_W: $\frac{c_W}{\Lambda^2} = \frac{1}{m_*^2}$

Expected O_{2W}: $\frac{c_{2W}}{\Lambda^2} = \frac{1}{g_*^2 m_*^2}$

C : muon collider as very hig energy lepton collider

tuning parameter Δ = 200 @VHEL14 and 1200@VHEL30

New Gauge force : Y-Universal Z', 2σ

SUSY mass values? unification of couplings ? dark matter ? naturalness ?

gluino 17TeV@FCChh

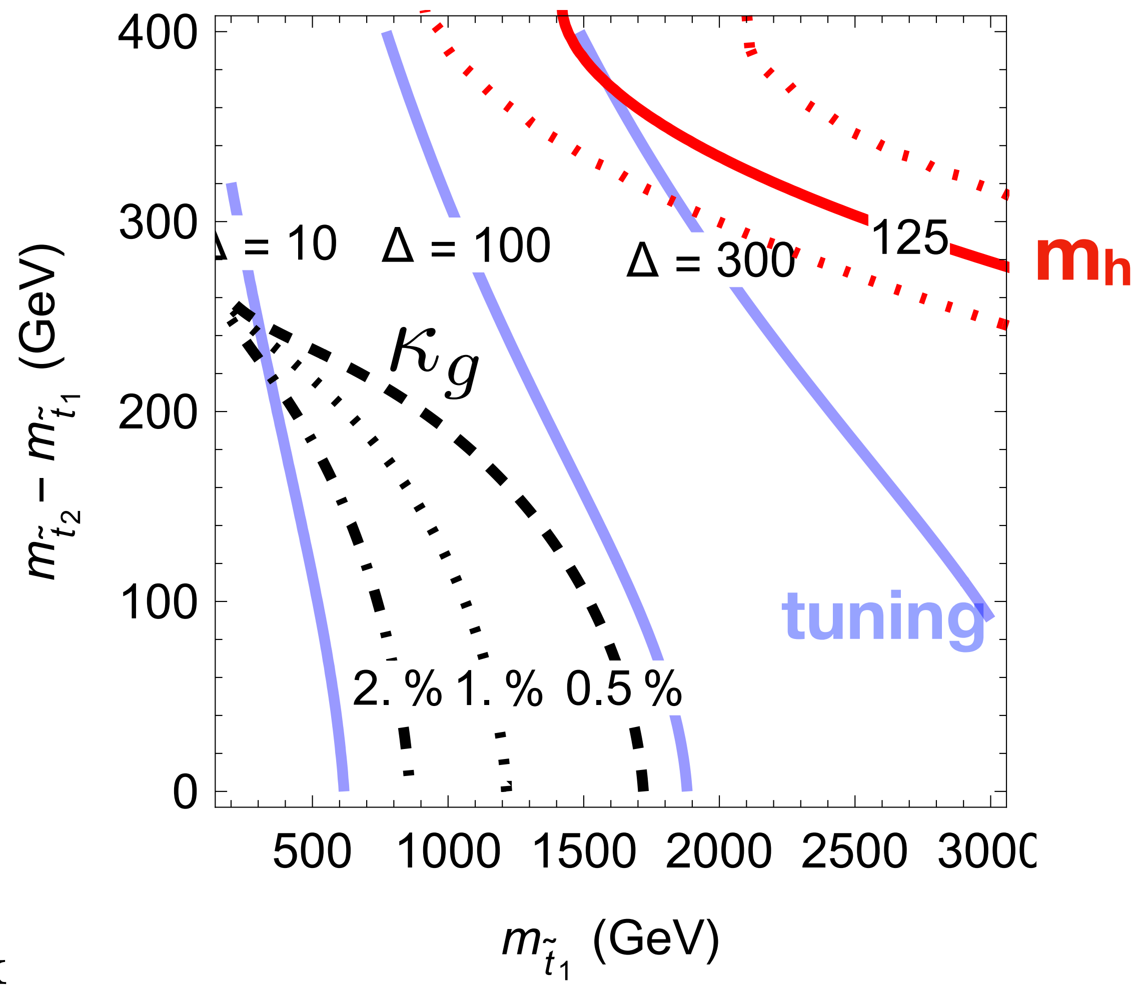
stop

wino-like LSP for the higher mass limit of 2.9 TeV...

complementarity : lepton and hadron colliders

e.g. compressed case , however mono jet + specific particle analysis can be applied at LHC

Indirect: Higgs precision



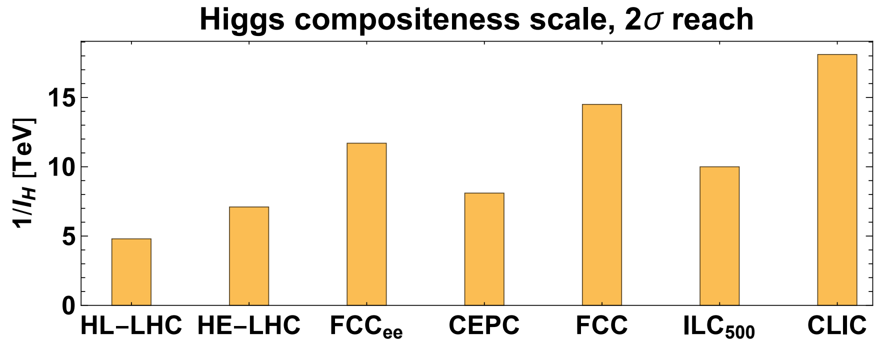
$$X_t = X_t^{\max}$$

Conclusions

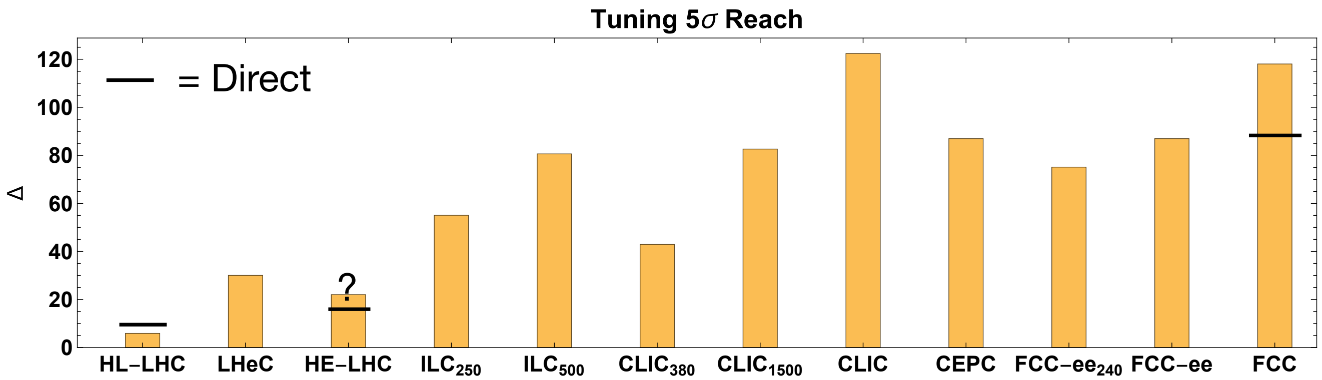
New Gauge Force:

CLIC is the only lepton collider that competes with hadron ones

Higgs Compositeness:



Natural Higgs Compositeness:



BSM summary

Higgs exists and No indications for new phenomena
precise measurements a clear priority
How can it be done best/most efficienly/realistically ?

the Higgs naturalness puzzle much shaper
scientific priority
LHC to FCC probe by a factor 30-50

unexplored experimental avenues e.g. FIPs, DM

after LHC Higgsino-like from Bino like and to TeV scale from 50GeV scale

FIPs small couplings, small masses as unexplored particles

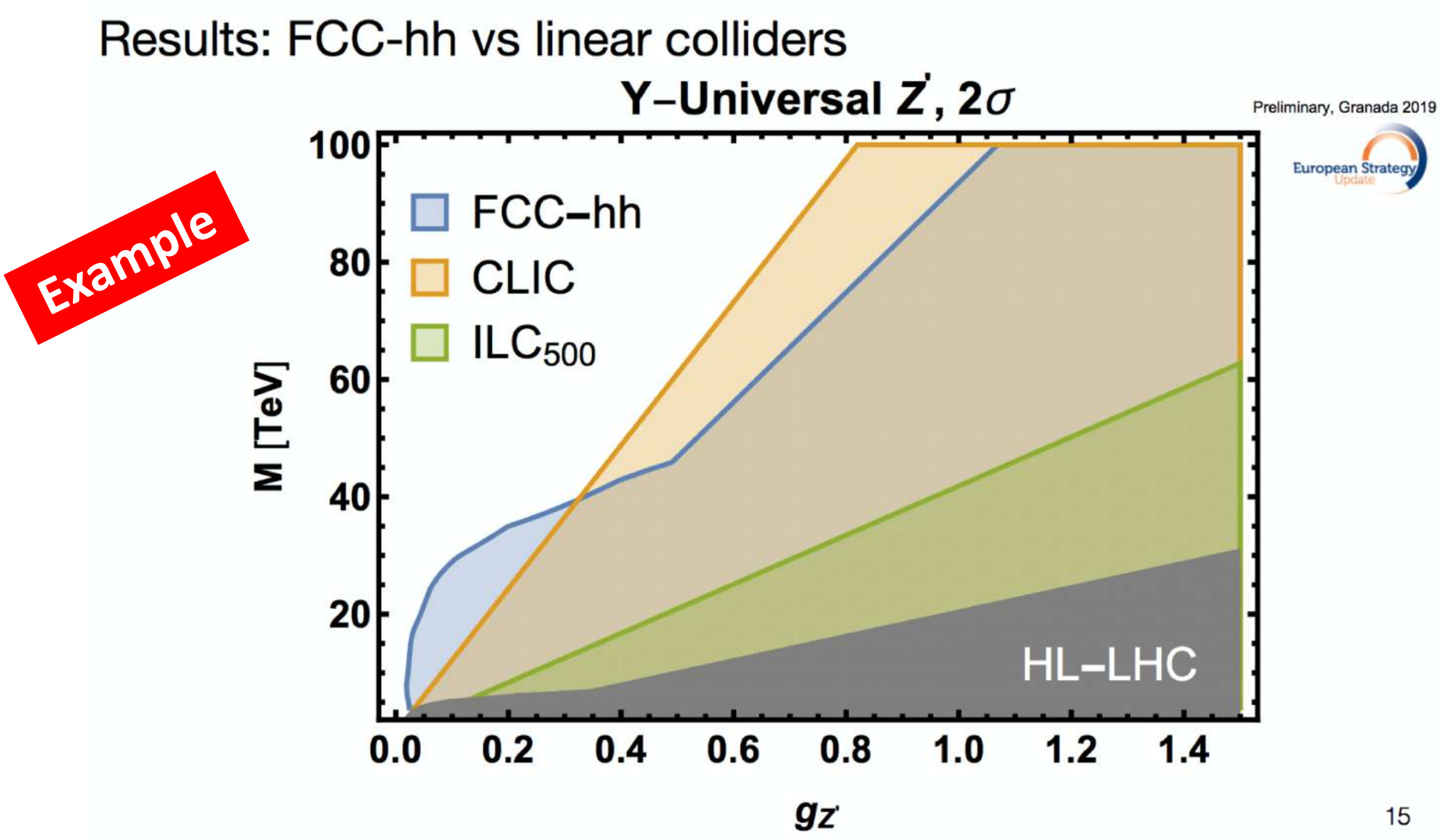
Naturalness a robust guidance

Questions
Should CERN take any role in being a hub for technology/experiment/theory/computing towards DM searches?
e.g. novel rare liguid gas detector etc.

Is the example of a universal Z' really representative? Does it miss important information about flavour?

SUSY benchmarks simplified models

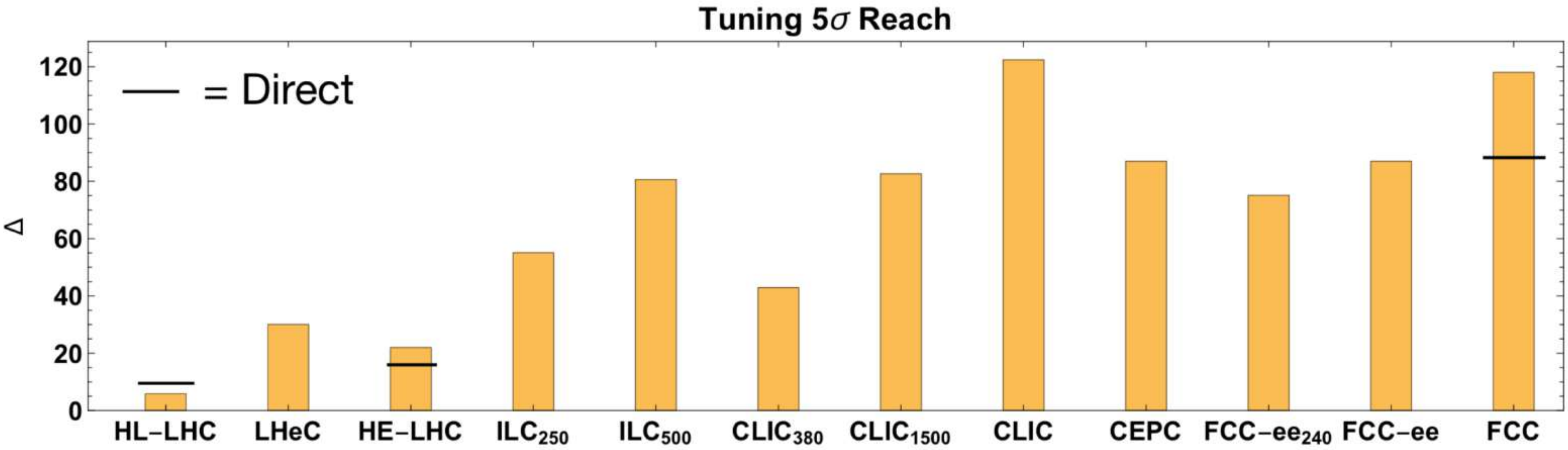
BSM summary discussion

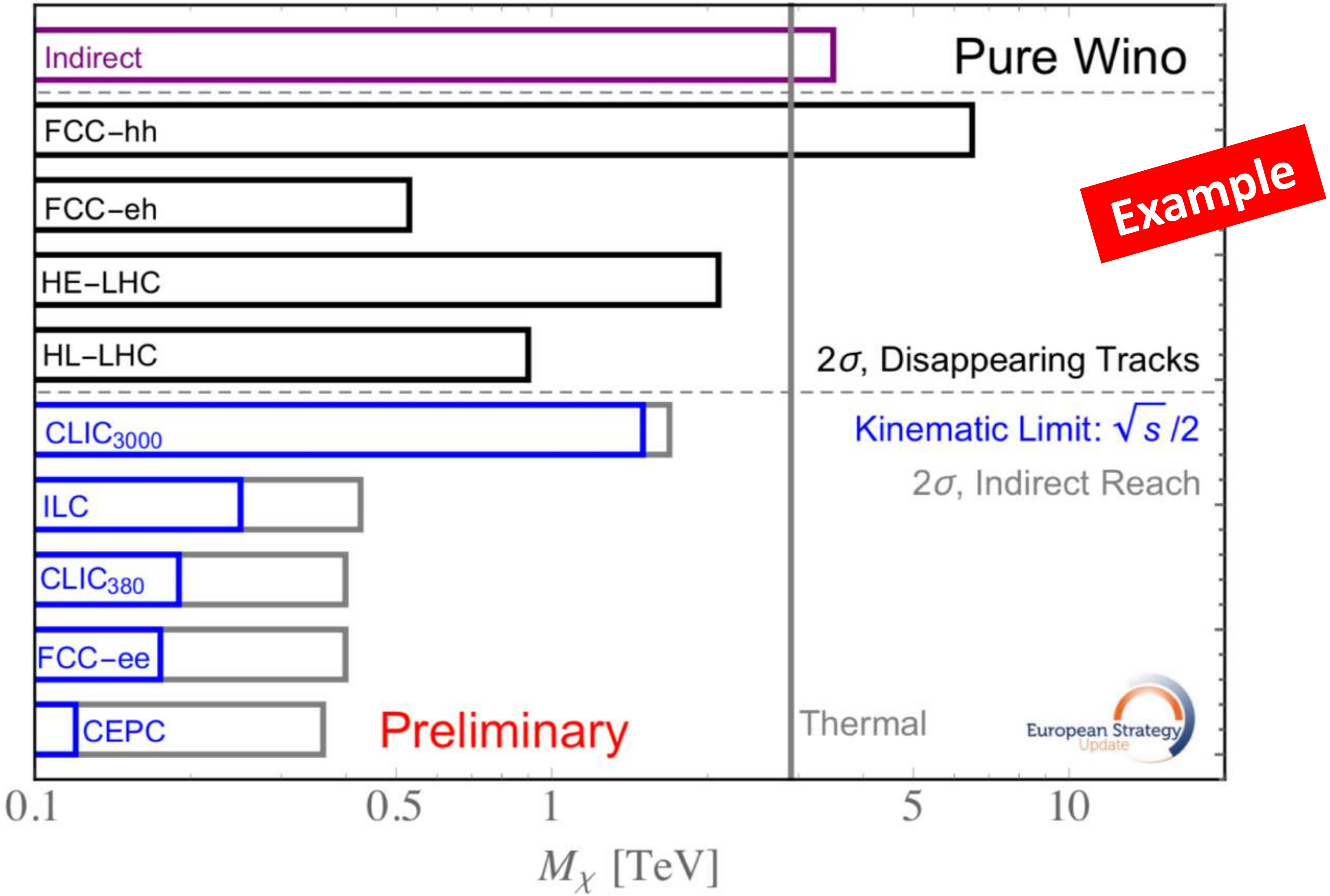


Composite Higgs Naturalness Formula:

Example

$$\Delta > \left(\frac{M_{\mathrm{T.P.}}}{500\,\mathrm{GeV}} \right)^2 > \frac{1}{\xi}$$




Indirect
Pure Wino
FCC−hh
FCC−eh
HE−LHC
HL−LHC
2σ, Disappearing Tracks
CLIC3000
Kinematic Limit: √s /2
ILC
2σ, Indirect Reach
CLIC380
FCC−ee
CEPC
Preliminary
Thermal
European Strategy Update
Example
0.1
0.5
1
5
10
Mχ [TeV]

14:50 Perspective on the European Strategy from the Americas (US,Canada, Laten America), Young-Kee Kim

C : FCCee Higgs/EW factory,

15:15 Perspective on the European Strategy from Asia, Geoffrey Taylor

Q : MEXT recognizes the energy upgrade plan ?

Q : 8 Billion dollars, 1/2 by Japan ?

A : it includes 2 detectors, (also salary (manpower) for the construction)

17:09 Programs of Large European and National Labs (LENL), Pierluigi Campana

17:50 Overview of National Inputs to the Strategy Update, Siegfried Bethke

slide -6 highest score in ILC ! 13.67/15 for 15 MS(member states)

C ; it is a snap shot, before December 2018

FCCee CDR is available, which was published in January 2019.

C : it is difficult to put scores in the table by Itarian

C : France is not properly scored.

C : Finland LC and also FCC

C : more work is needed so the table is not proper to put in the briefling report

C : Germany we must have important information as previously prepared as the national interests.

C : UK does not have priority ee and hh , it must be cautious , focus on CERN

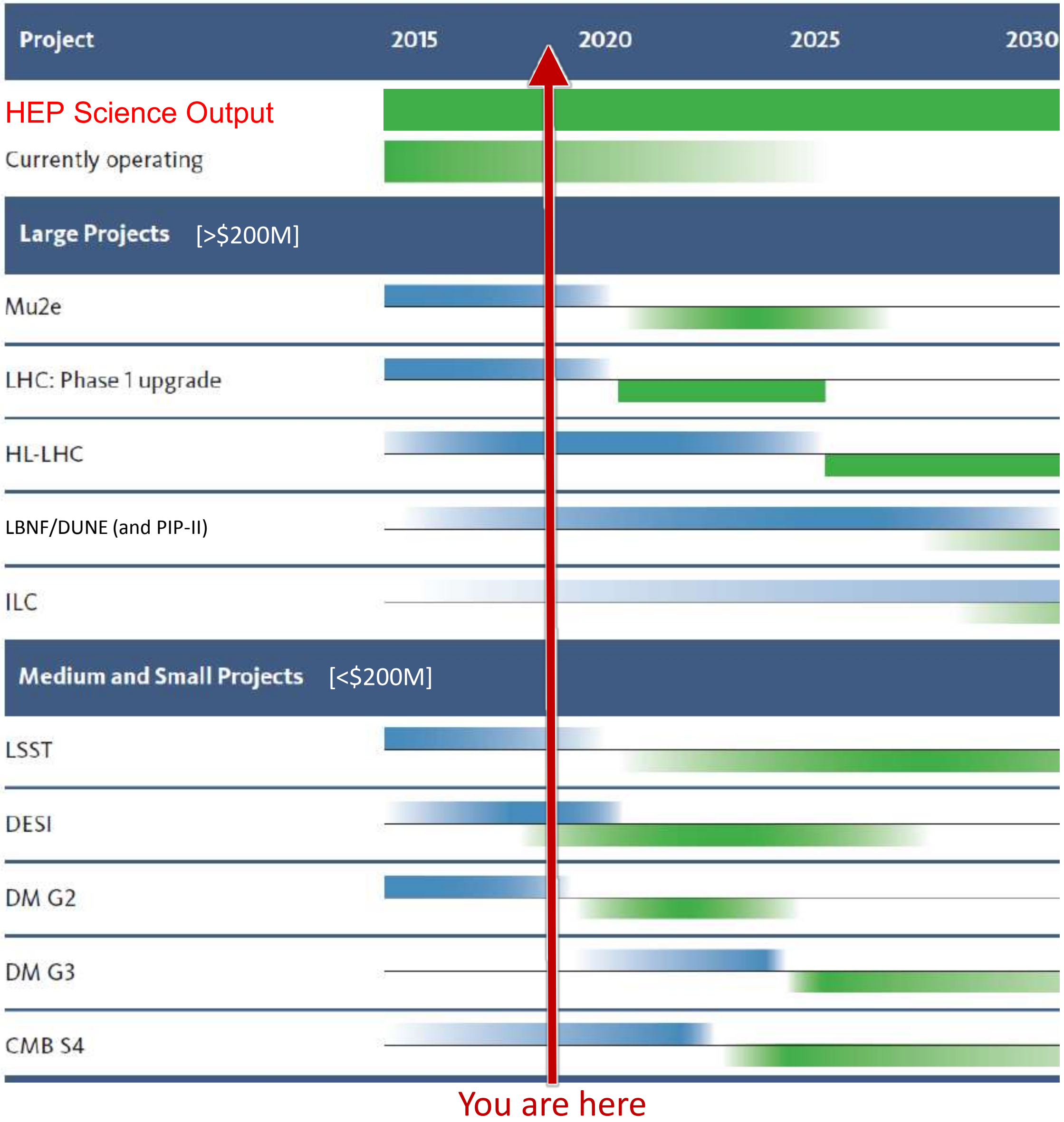
C : Germany support the table since they held many workshops to prepare the inputs.

18:23 education, communication and outreach, Perrine Royole-Degieux

Perspective on the European Strategy from the Americas (US,Canada, Laten America), Young-Kee Kim

U.S.: P5 Implementation Status – FY 2019

Legend:
- *Approximate Construction*
- *Expected Physics*



All projects on budget & schedule

- Projects fully funded in FY19
  - Muon g-2: 1st beam 2017
  - Mu2e : 1st data in ~2020
  - LHC detector upgrades (ATLAS, CMS, LHCb): on track for 2019/20 installation
  - LSST: full science operations 2023
  - DESI: 1st light on April 1, 2019
  - DM-G2(SuperCDMS,LZ,ADMX) 1stdata ~2020
- HL-LHC accelerator and detector upgrades started on schedule
- LBNF/DUNE & PIP-II schedules advanced due to strong support by Admin & Congress
- ILC: cost reduction R&D while waiting for decision from Japan
- DM-G3: R&D limited while fabricating G2
- CMB S4: developing technically-driven schedule to inform agencies, NAS Astro 2020 Decadal Survey
- Broad portfolio of small projects running

Next Collider Options

ILC

Statement by American Linear Collider Committee (US+Canada)

ALCC stance vis-a-vis discussions concerning the International Linear Collider in the context of the European Strategy for Particle Physics (2020)

ALCC, March 27, 2019

The Americas Linear Collider Committee supports the ICFA position confirming the international consensus that *"the highest priority for the next global machine is a 'Higgs Factory' capable of precision studies of the Higgs boson."* We remain convinced that the ILC best meets all of the requirements needed to probe detailed properties of the Higgs boson. The ILC has the potential for a future upgrade in energy, can sustain beam polarizations that increase its ability to do precision measurements, and is the most technically mature proposal for an electron-positron collider now available.

The recent statement by MEXT in Japan stated that further consideration by the Science Council of Japan and intergovernmental discussions are necessary before Japan would be in a position to make a bid to host the ILC. Unfortunately, this does not fit naturally into the timetable for finalizing the European Strategy recommendation. On the other hand, it appears that high-level interactions between the U.S. DOE and the Japanese principals, government and DIET, continue to be positive. We understand that the DOE remains interested in discussing with senior Japanese officials about ILC and the possibility of hosting it in Japan.

The ALCC is supportive of any electron-positron project that can distinguish the Standard Model from new physics models through precision measurements of the Higgs production and decay couplings. However, given the strengths of the ILC noted above and the recent progress in obtaining support for it within Japan, we urge that the European Strategy group support the completion of the process underway in Japan to decide on a bid to host the ILC.

CLIC

- CLIC and normal conducting high-gradient activities
- O(200) signatories for CDR
- Detector design and R&D
- Ongoing studies on physics potential

FCC-ee, ep, pp

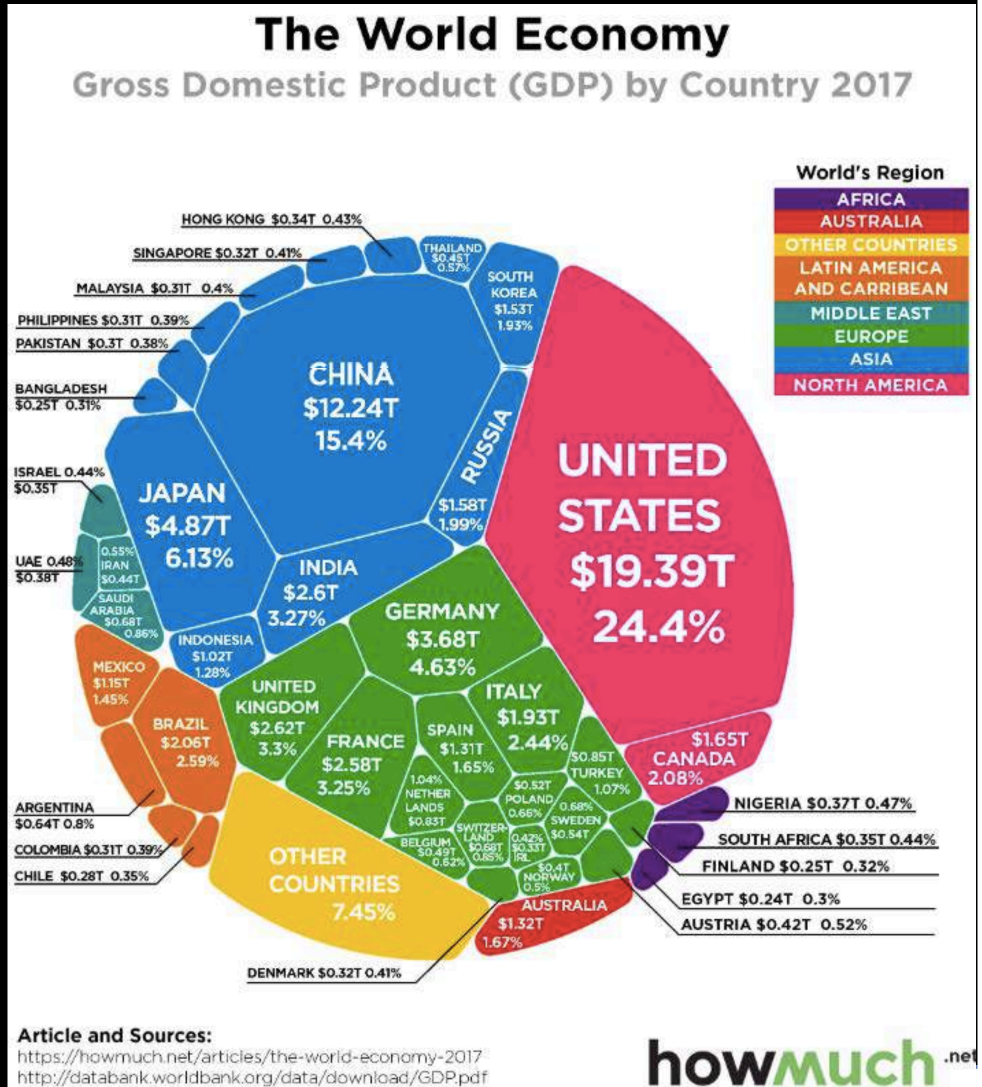
- Deep expertise in accelerator technologies including high field magnets and SCRF
- O(500) engaged; O(100) co-authored European Strategy Documents
- Ongoing studies on physics potential and detector design
- Long and productive cooperation on joint projects in US and at CERN

CEPC

- Pre-CDR & CDR on arXiv with international contributions
- O(100) participated
- Detector design and R&D

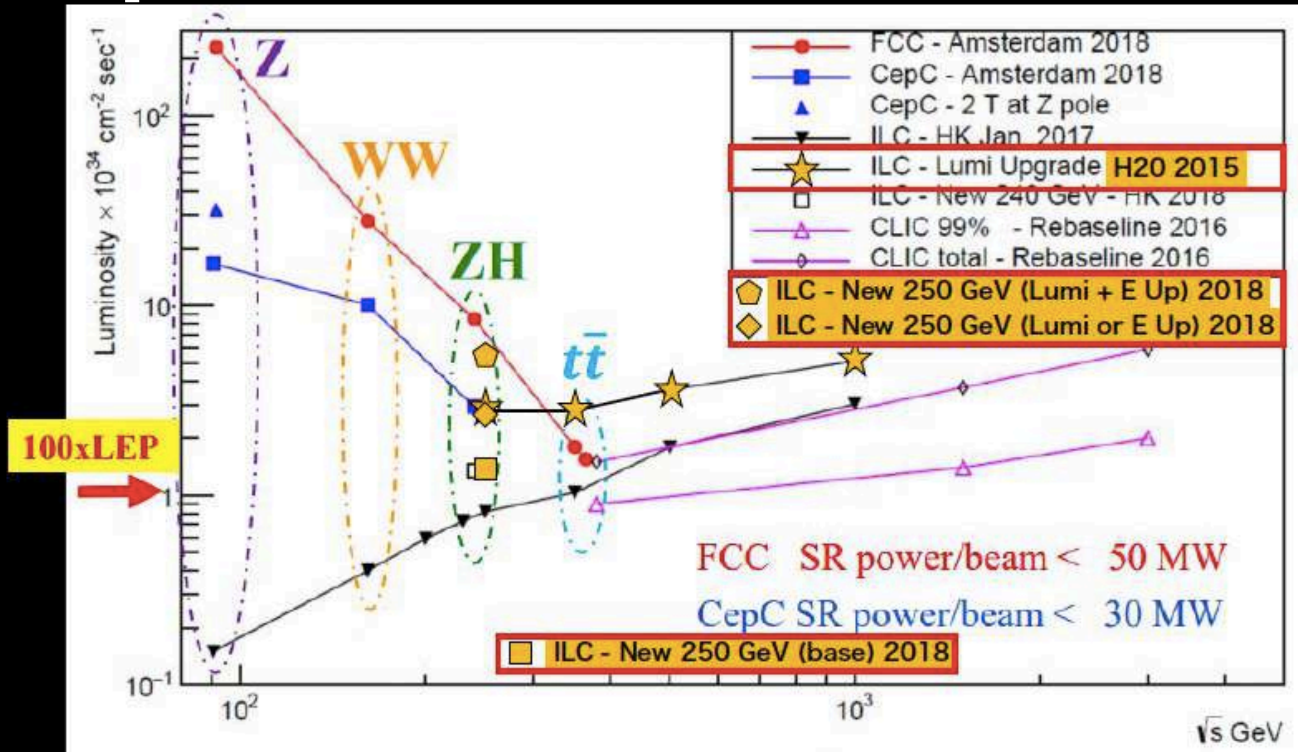
How can Asian projects/ facilities impact upon Europe's particle physics future?

- Desire
- Resources
- People
- Technology



e+e- Lumi Comparison

- Apparently significant difference at the overlap region (~250GeV) quite a range of luminosities
- See D Schulte's talk: differences should not be taken too seriously at this stage!



- Original Plot, F. Bedeschi , CEPC Workshop, Rome, May 2018
- Updates Private communication, Keisuke Fujii, IPNS, KEK

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

European Strategy Update

CepC Path to Funding

- **"Chinese Initiated International Large Scientific Plan and Large Scientific Project" :**
  - ***3-5 Projects will be selected for further development***
  - ***By 2020 select 1~2 projects for construction***
  - ***Should be complementary to other large national or multinational scientific projects.***
  - ***Be seen to be important to international scientific organizations' and laboratory scientific projects and activities.***
  - ***Process has commenced***

Yifang Wang, Jie Gao

ILC/CepC Advantage for Europe

- **Allows concentration on proton, high energy future**
  - ***CERN essential for the energy frontier.***
  - ***Proton and high-field magnet expertise***
  - ***The ONLY laboratory capable of attempting very difficult projects, thus should be setting a "high bar"***
- **CERN infrastructure in protons beams outlays the fear of a second 100km tunnel.**
  - ***Possible to see a new proton collider at CERN by mid-2040s (not mid 2060s, but also not 100TeV)***

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

European Strategy Update

Ultra-high magnetic fields for future machines

After the academic/industrial coordinated effort to build NbTi based SC LHC magnets, a new breakthrough is needed to satisfy the requests for future O(100 TeV) hadron colliders (FCC & SPPC)

Research focus concentrated on Nb_3Sn and HTS conductors. Nb_3Sn wire already needed for ITER and HL-LHC (modest quantities)
Large coordinated efforts at CERN and elsewhere (Europe, US, J, Kr, Ru), while industrial involvement is mandatory

Collaboration based on H2020 EuroCirCol design study and on agreements:
- WP5 on-going R&D at CERN, TUT, CEA, INFN, UT, CIEMAT, KEK, UNIGE
- specific programs in place with CEA, CIEMAT (Prismac), CH (Chart), INFN, and more to come

An Open Lab for the development of superconductors has been proposed as a specific ESPP 2020 input (to be located somewhere in Europe)

The same collaboration with LENL holds for a large series of common activities on FCC (integration, vacuum, cryogenics, diagnostics, cavities, …)

High and Ultra High gradients/high power beams for future machines

Technological challenge to overcome current limitations in accelerating capabilities of present Linacs. Two main R&D lines:
- higher RF gradients (100-200 MV/m), CLIC-based studies on X-band
- plasma wake fields (1-10 GV/m), generated by laser or charged beams (e, p)

Several facilities operating in US (Facet, Bella), CERN (Awake) and elsewhere

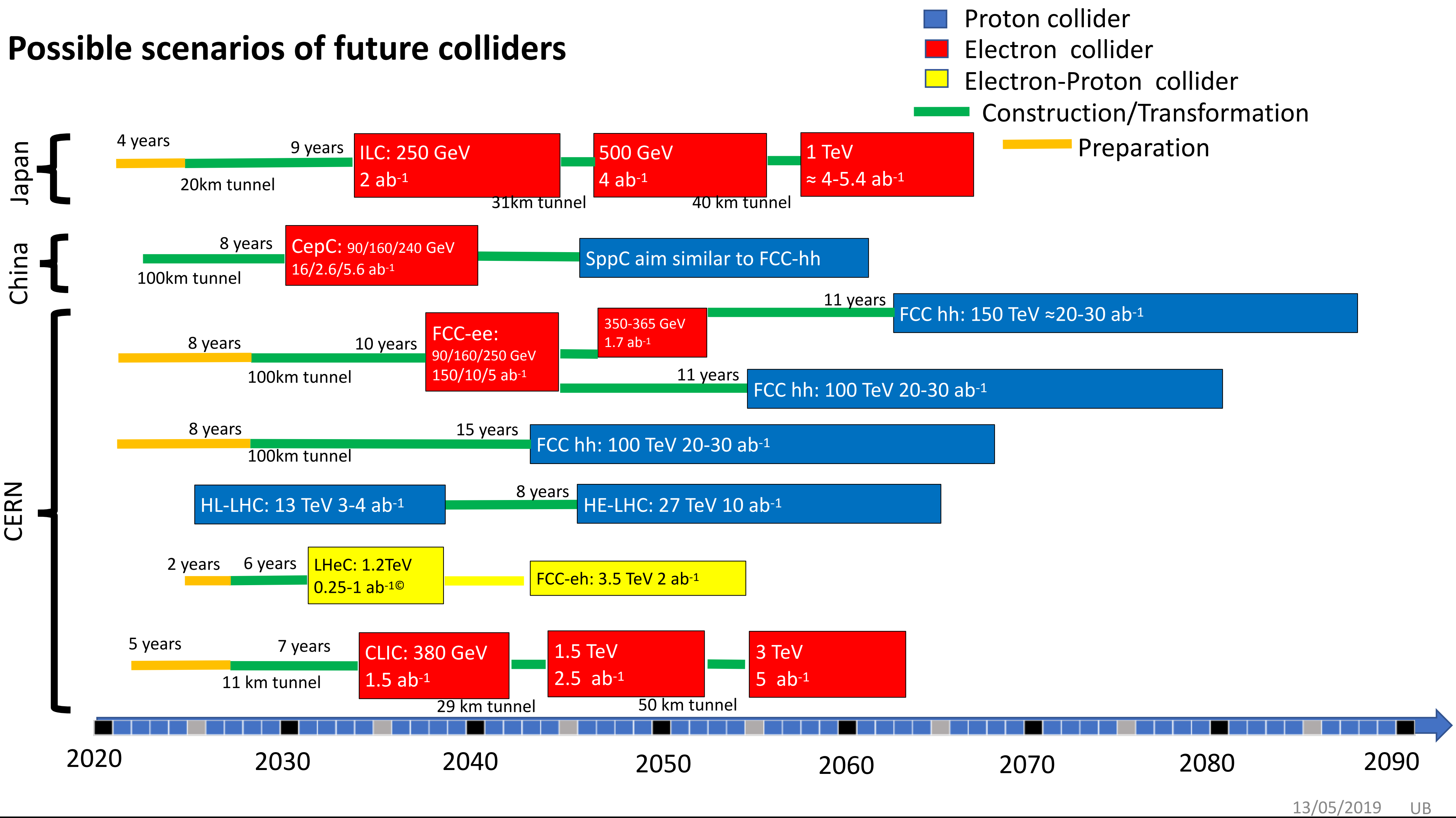
LENL (and CERN) are fully involved in H2020 design studies:
- Compact XLS, to design a e^- Linac facility based on X-band technology
- EuPRAXIA, to design a FEL operated by a plasma accelerating cell

and in ALEGRO, a study group towards Advanced HEP Linear Colliders

LENL and other Labs participate in this sector with existing facilities (including large laser infrastructures), or with planned future investments:
DESY (Sinbad, FlashFF) & the Helmholtz-ATHENA network, LNF (Sparc_Lab), STFC (VELA/CLARA, Central Laser Facility), CEA/CNRS (CILEX), SOLEIL, ELETTRA, PSI, ALBA, KARA, and a long list of collaborating Universities

A coordinated and large international effort in getting CW SCRF beams (e.g. at DESY-CMTB cryo-test stand), increasing Q factors & gradients.
Relevant to developments for LHeC and FCC-ee

Overview of National Inputs to the Strategy Update, Siegfried Bethke



summary of national priorities and interests:

country	item #	e+e- e-w,H,.. (ILC, ...)	e+e- incl. ttbar (FCC-ee)	e+e- incl. HH (ILC+,CLIC)	hh beyond LHC	hh he-LHC	hh FCC	eh	accel. R&D	R&D magnets FCC,he-LHC	R&D novel PWA,μ+μ-	non- accelerator (DM,ndbd)	neutrino physics	intensity frontier	nuclear (FAIR,EIC...)	astro- particle
A	108	**1**			**3**				**2**			√			√	√
B	122	**1**														
CH	142	**1**	1		**3**		3		**2**	2	3		√	√	√	√
CZ	88	**3**		3	**2**	2	2		**1**	1	1		√		4	
D	33	**1**		1	**3**	3	3		**2**	2	2	4	√	√	√	√
DK	61	**3**	3		**3**		3		**2**	2	2	1	√	√	√	√
E	31	**1**	3	1	**3**	3	3		**2**	2	4		√		√	√
F	15,116,155	**1**	√	√	**3**		3	√	**2**	2	√	√	√	√	√	√
FIN	55	**1**		1									√		√	√
I	26,138	**1**	1		**3**		3		**2**	2	2	√	√	√		√
IL	34	**√**			**√**							√	√	√		
N	43	**1**		1					**3**		3	√			√	√
NL	166	**1**	3	2	**3**		3		**2**	2	3	√	√	√		√
PL	125	**1**	√	√					**2**							
RO	73												√	√		
S	127	**1**		1					**2**	2	√	√	√	3		√
SLO	78															
UK	134,144	**1**		1	**2**		2	2	**3**	3	√	√	√		√	
total score:																

1...4: priority 1 to priority 4;
√: mentioned without (clear) assignment of priority

summary of NMS inputs:

Non Member States

country	item #	**e+e- e-w,H,.. (ILC, ...)**	e+e- incl. ttbar (FCC-ee)	e+e- incl. HH (ILC+,CLIC)	**hh beyond LHC**	hh he-LHC	hh FCC	eh	**accel. R&D**	R&D magnets FCC,he-LHC	R&D novel PWA,μ+μ-	**non-accelerator (DM,ndbd)**	**neutrino physics**	**intensity frontier**	**nuclear (FAIR,EIC,...)**	**astro-particle**
CDN	157	**√**	√	√	**√**	√	√					√	√			
J	63	**1**							**4**			3	2			
RUS	40								**√**			√	√	√	√	√
USA	149;150	**√**	√	√	**√**	√	√		**√**	√	√	√	√	√		√
total score:																

- 18 MS and 4 NMS submitted national inputs on HEP
- 3 MS and 3 NMS provided no explicit priorisation
- –> "total scoring" based on 15 MS
- total score defined as Σ(1/priority)

summary:

- clear preference for an e^+e^- collider as the next h.e. collider:
  - as H-factory and for precision e.w. measurements (ILC, CEPC, FCC-ee, CLIC)
  - significant demands for upgradeability to access $t\bar{t}$ (ILC, CEPC, FCC-ee, CLIC) and also HH and ttH final states (ILC+; CLIC)

- second priority: R&D for future h.e. collider: h.f. s.c. magnets for hadron colliders, and also novel accelerator techniques (PWA, μ-collider)

- third priority: future hadron collider beyond LHC (FCC-hh; fewer demands for he-LHC and eh-collider)

- large diversity of other, "smaller" projects (PBC, neutrino, DM searches, precision/intensity frontier, astro-particle, …

PBC = Physics Beyond Collider such as fixed target experiments

18:40 Summary : Accelerator Science and Technology, Caterina Biscari and Lenny Rivkin

C : Alan synergy FCCee to FCChh , where 7 BCHS is a common

C : Lyn FCCee to FCChh dismantle all magnets and install 16T magnets for 20 -25 years is expected from the LHC experiences (LEP to LHC)., 2 times the LHC while tunnel length is 4 times.

C : Benno build LC now to investigate the next energy for hadron machine (energy frontier, new particle discovery) including plasma acceleration.

C : CLIC 600MW@3TeV the plasma acceleration needs the same power at least. So 6000MW for 30TeV

C : gradient in the plasma acc. must be higher by an order of magnitude than the CLIC.

C : Alan to reply Lyn's comment, we learned from the LHC ones, e.g. large cross section of the tunnel for the expensive cost
FCCee not only Higgs but also EW factory

Q/A : technology for far future collider plasma?

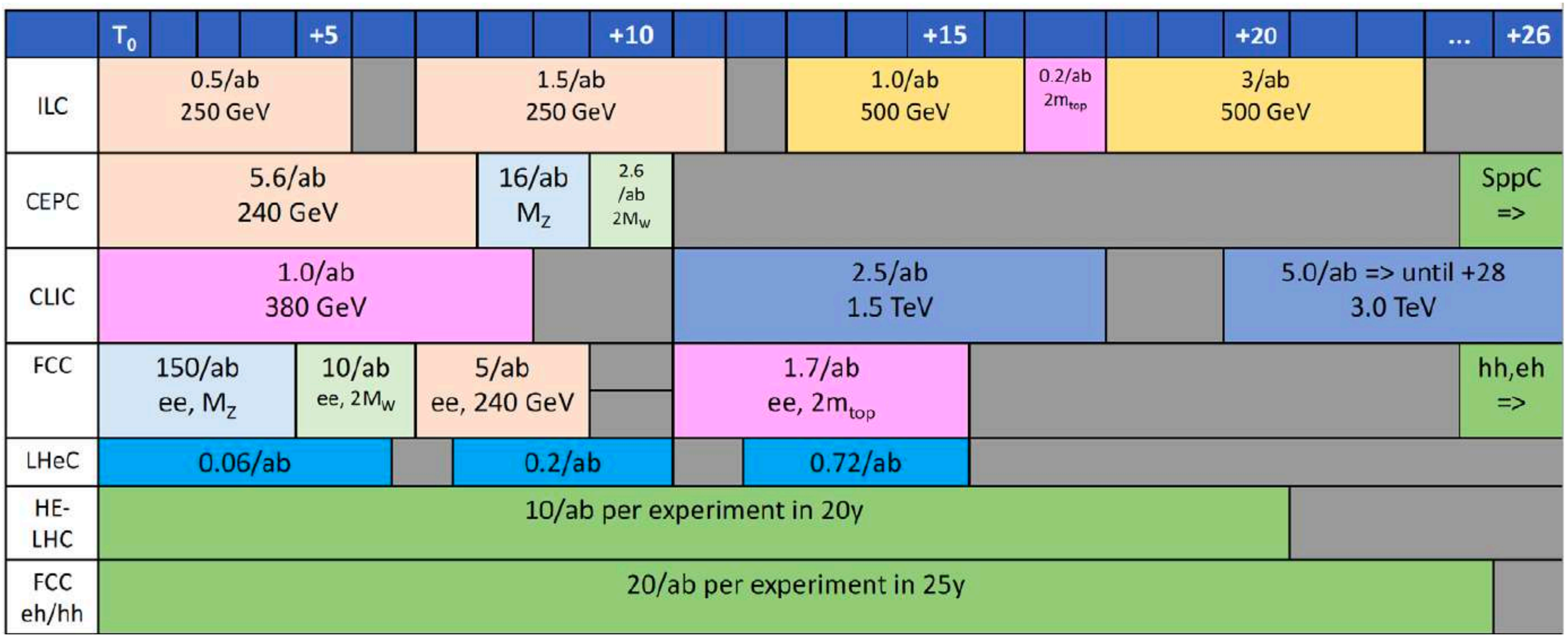
C : plasma is important better keep manpowers for the collider application
investigation to the technology, 100 people, 10million euro

C : high field magnet R&D must be executed at CERN
C : it benihits also for other fields

Comparisons

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

Proposed Schedules and Evolution



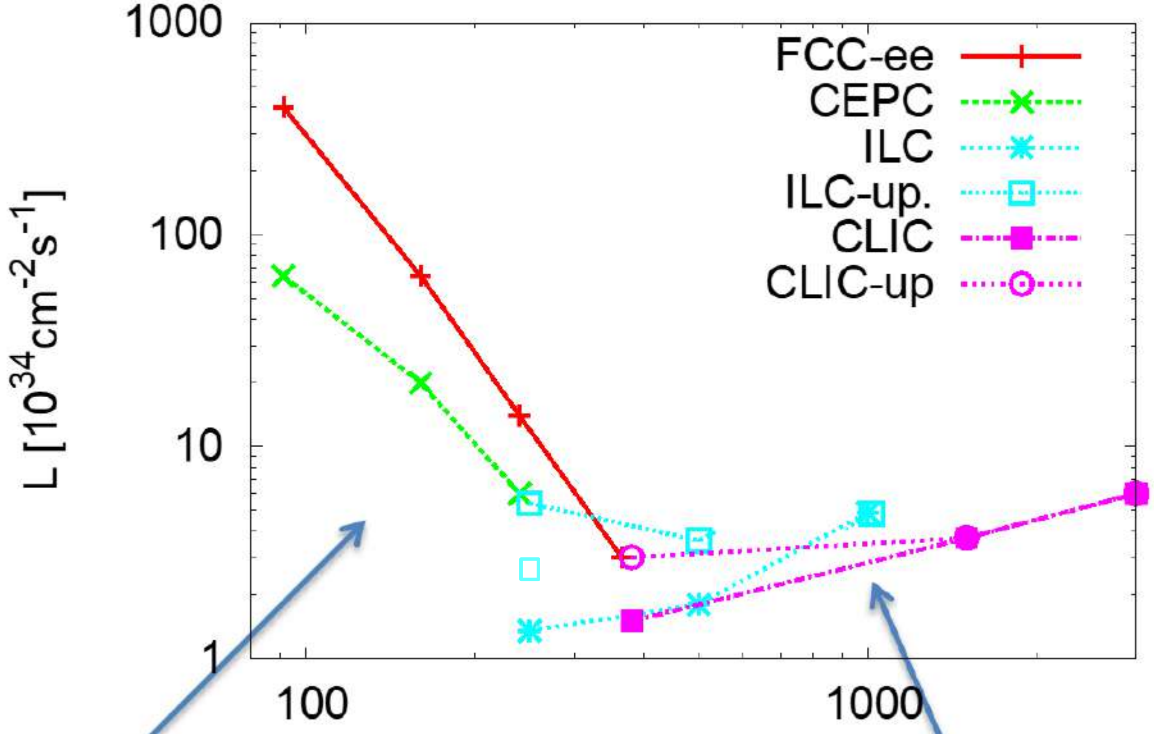
Project	Start construction	Start Physics (higgs)
CEPC	2022	2030
ILC	2024	2033
CLIC	2026	2035
FCC-ee	2029	2039 (2044)
LHeC	2023	2031

Proposed dates from projects

Would expect that technically required time to start construction is O(5-10 years) for prototyping etc.

Ours is a very dynamic field!
(Luminosity upgrades for ILC, CLIC)

Luminosity per facility



$L \propto P_{synrad} E_{cm}^{-3.5}$

$L \propto P_{RF} E_{cm}$

Maturity

- CEPC and FCC-ee, LHeC
  - Do not see a feasibility issue with technologies or overall design
  - But more hardware development and studies essential to ensure that the performance goal can be fully met
    - E.g. high power klystrons, strong-strong beam-beam studies with lattice with field errors, …

- ILC and CLIC
  - Do not see a feasibility issue with technology or overall design
  - Cutting edge technologies developed for linear colliders
    - ILC technology already used at large scale
    - CLIC technology in the process of industrialisation
  - More hardware development and studies required to ensure that the performance goal can be full met
    - e.g. undulator-based positron source, BDS tuning, …

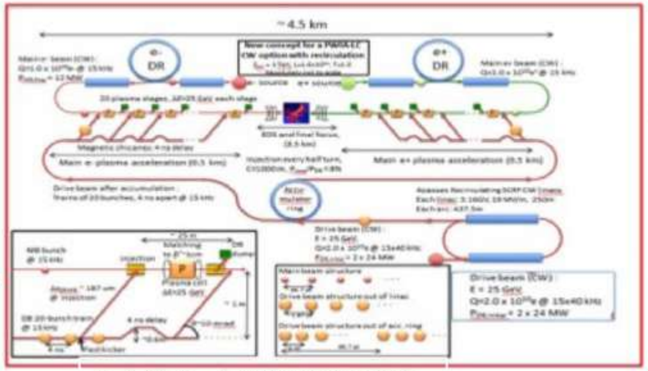
- Do not anticipate obstacle to commit to either CEPC, FCC-ee, ILC or CLIC
  - But a review is required of the chosen candidate(s)
  - More effort required before any of the projects can start construction

- Guidance on project choice is necessary
  - Physics potential
  - Strategic considerations

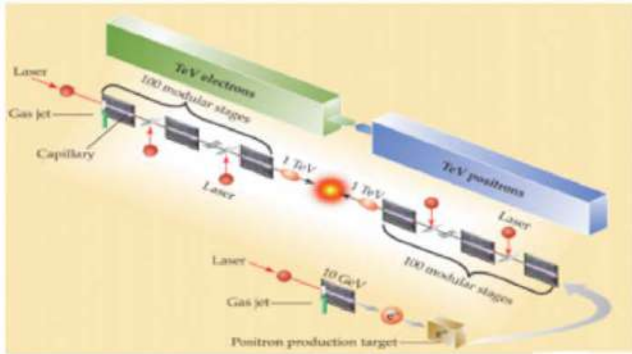
Plasma acceleration based colliders

Drive beams
Lasers: ~40 J/pulse
Electrons: 30 J/bunch
Protons: SPS 19kJ/pulse, LHC 300kJ/bunch

Witness beams
Electrons: 1010 particles @ 1 TeV ~few kJ



E. Adli et. al.,arXiv:1308.1145



Leemans & Esarey, Phys. Today 63 #3 (2009)

Key achievements in last 15 years in plasma based acceleration using lasers, electron and proton drivers

- Focus is now **on high brightness beams, tunability, reproducibility, reliability, and high average power**

The road to colliders passes through **applications** that need compact accelerators (Early HEP applications, FELs, Thomson scattering sources, medical applications, injection into next generation storage rings …)

Many key challenges remain as detailed in community developed, consensus based roadmaps (ALEGRO, AWAKE, Eupraxia, US roadmap,…)

Strategic investments are needed:

- **Personnel** – advanced accelerators attract large numbers of students and postdocs
- Existing **facilities** (with upgrades) and a few new ones (High average power, high repetition rate operation studies; fully dedicated to addressing the challenges towards a TDR for a plasma based collider)
- **High performance computing** methods and tools

HE-LHC 27 TeV

- Needs some 1700 large magnets in Nb_3Sn (1200 dipole 15 m long) operating at **16 T**. (same as FCC-hh)
- It needs a new generation of Nb_3Sn, beyond HiLumi (like FCC-hh): the 23 y timeline presented is realistic (21 for the magnets) but t_0 is probably 2025 or more because of SC development.
- **The set up of a SC Open Lab for fostering development of superconductors (F. Bordry and L. Bottura proposal) is critical for HEP HC progress.**
- A further upgrade to 42 TeV in HTS at 25 T possible to envisage for longer time. 24 T dipole is the long term goal also of the Chinese SppC.
  (Recently an HTS 32 T special solenoid and a commercial HTS 26 T NMR solenoid have been announced!)

HiLumi HL-LHC PROJECT

s.c. magnet technology

- Nb_3Sn superconducting magnet technology for hadron colliders, still requires **step-by-step** development to reach **14, 15, and 16 T**.
- It would require the following **time-line** (in my personal view):
  - **Nb_3Sn, 12~14 T:** 5~10 years for short-model R&D, and the following 5~10 years for prototype/pre-series with industry. It will result in **10 – 20 yrs** for the construction to start,
  - **Nb_3Sn, 14~16 T:** 10-15 years for short-model R&D, and the following 10 ~ 15 years for protype/pre-series with industry. It will result in **20 – 30 yrs** for the construction to start, (consistently to the FCC-integral time line).
  - **NbTi , 8~9 T:** proven by LHC and **Nb_3Sn, 10 ~ 11 T** being demonstrated. It may be feasible for the construction to begin in > ~ 5 years.
- **Continuing R&D effort** for high-field magnet, present to future, should be critically **important**, to realize highest energy frontier hadron accelerators in future.

A. Yamamoto, 190512b

Intensify HTS accelerator magnet development

Technical Challenges in Energy-Frontier Colliders proposed

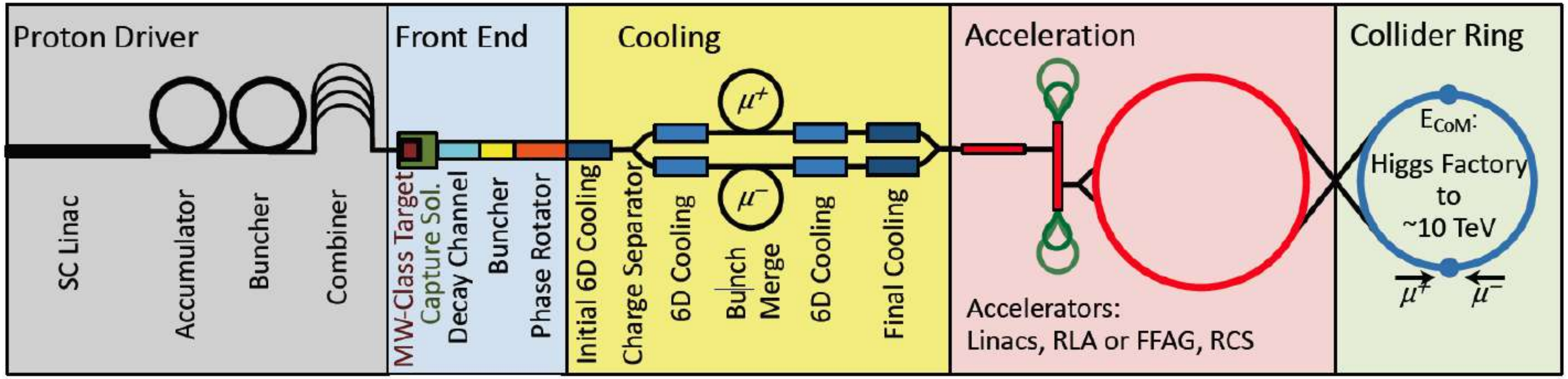
		Ref.	E (CM) [TeV]	Luminosity [1E34]	AC-Power [MW]	Cost-estimate Value* [Billion]	B [T]	E: [MV/m] (GHz)	Major Challenges in Technology
CC hh	FCC-hh	CDR	~ 100	< 30	580	24 or +17 (aft. ee) [BCHF]	~ 16		High-field SC magnet (SCM) - Nb3Sn: Jc and Mechanical stress Energy management
	SPPC	(to be filled)	75 – 120	TBD	TBD	TBD	12 - 24		High-field SCM - IBS: Jcc and mech. stress Energy management
CC ee	FCC-ee	CDR	0.18 - 0.37	460 – 31	260 – 350	10.5 +1.1 [BCHF]		10 – 20 (0.4 - 0.8)	**High-Q SRF** cavity at < GHz, Nb Thin-film Coating Synchrotron Radiation constraint Energy efficiency (RF efficiency)
	CEPC	CDR	0.046 - 0.24 (0.37)	32~ 5	150 – 270	5 [B$]		20 – (40) (0.65)	High-Q SRF cavity at < GHz, LG Nb-bulk/Thin-film Synchrotron Radiation constraint High-precision Low-field magnet
LC ee	ILC	TDR update	0.25 (-1)	1.35 (– 4.9)	129 (– 300)	4.8- 5.3 (for 0.25 TeV) [BILCU]		31.5 – (45) (1.3)	High-G and high-Q SRF cavity at GHz, Nb-bulk Higher-G for future upgrade Nano-beam stability, e+ source, beam dump
	CLIC	CDR	0.38 (- 3)	1.5 (- 6)	160 (- 580)	5.9 (for 0.38 TeV) [BCHF]		72 – 100 (12)	Large-scale production of Acc. Structure Two-beam acceleration in a prototype scale Precise alignment and stabilization. timing

A. Yamamoto, 190513b

*Cost estimates are commonly for "**Value**" (material) only.

Proton-driven Muon Collider Concept

Muon-based technology represents a unique opportunity for the future of high energy physics research: the multi-TeV energy domain exploration.



Short, intense proton bunches to produce hadronic showers

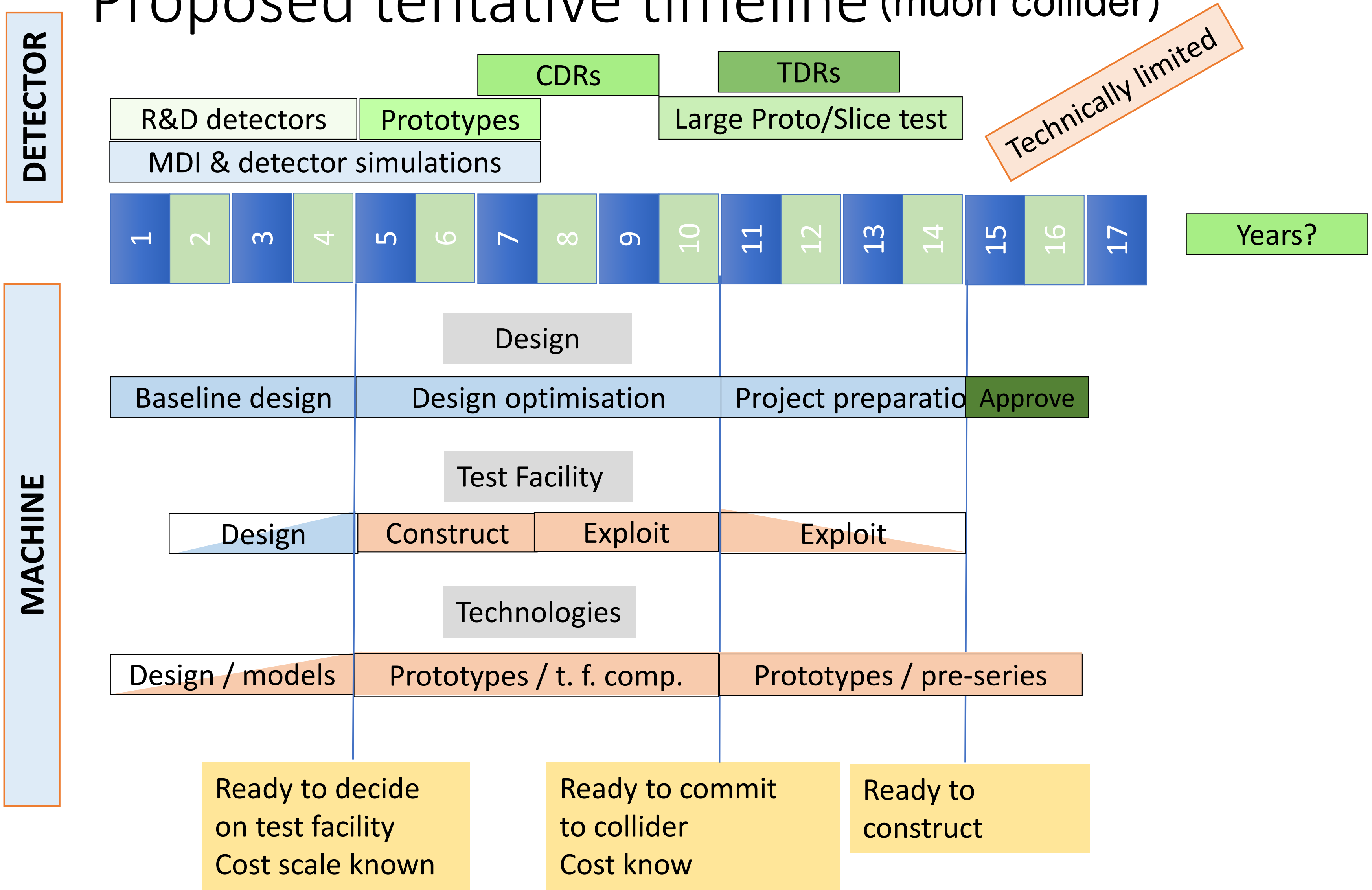
Pions decay into muons that can be captured

Muon are captured, bunched and then cooled

Acceleration to collision energy

Collision

Proposed tentative timeline (muon collider)



D. Schulte

5/16 8:30 Neutrino Physics (accelerator and non-accelerator), Marco Zito and Stan Bentvelsen

mass by Majorana term , and new neutral fermions window to new physics

Dirac or Majorana

mixing, CP violation, mass ordering

Q : CP violation joint analysis ?

A : yes, global fit, but a new facility is needed

Q/C : precision of nuclear interaction at percent level for collabolation with theorists

Q: Dirac or Majorana , plan ?

A : count rate is very low, 1/year background detector R&D

Q : "Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan" should be removed

A : we like to focus on the current programs, maybe next to next generation

9:10 Flavour Physics and CP violation (quarks, charged leptons and rare processes), Antonio Zoccoli and Belen Gavela

EDMs 2 loop by SM, 1loop by BSM

to 10^{-31}

B anomalies $R_{K(*)}$, $R_{D(*)}$

C : tau charm factory

C : new scale, anomaly for BSM

C : theoretical effort to continue

Q : Tera Z vs Giga Z w and w/o polarization

10:00 Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Marcela Silvia Carena Lopez and Shoji Asai

Long-Lived Particle (LLP) by SHIP and FASER of the SPS and LHC beam dump experiments, respectively

C : Dark sector, other than DM, which can solve other thing, e.g. heavy neutral leptons for neutrino mass, leptogenesis -- CP-violation for EDM

11:00 Beyond the Standard Model at colliders (present and future), Gian Giudice and Paris Sphicas

Deviations ~1% in Higgs couplings for mass/coupling ~2 TeV

C : holes in SUSY, small but theoretical weights are large

C : Higgsino is difficult for hadron colliders

11:45 Strong Interactions (perturbative and non-perturbative QCD, DIS, heavy ions), Jorgen D'Hondt and Krzysztof Redlich

α_s precision 0.1% is needed,

QGP, the proton radius, spin, muon g-2 (low energy hadronic int.) , precision lattice QCD

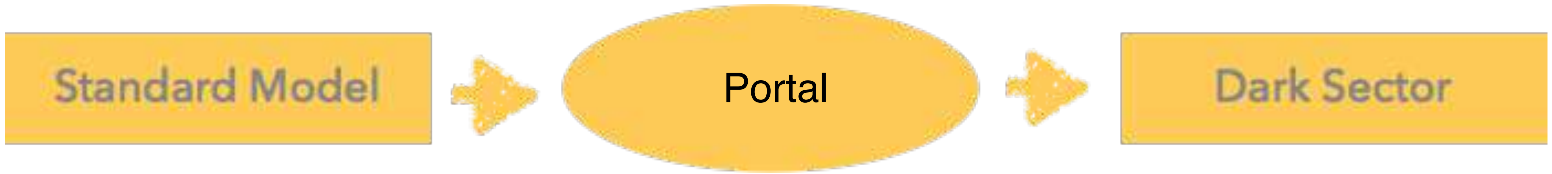
12:25 Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED), Beate Heinemann and Richard Keith Ellis

C :

14:30 Instrumentation and Computing, Brigitte Vachon and Xinchou Lou

Dark Sectors

What is meant by a dark sector ?
A Hidden sector, with Dark matter, that talks to us through a Portal



Portal can be the Higgs boson itself or New Messenger/s

Dark sector has dynamics which is not fixed by Standard Model dynamics

→ New Forces and New Symmetries

→ Multiple new states in the dark sector, including Dark Matter candidates

Interesting, distinctive phenomenology

Long-Lived Particles

Feebly interacting particles (FIP’s)

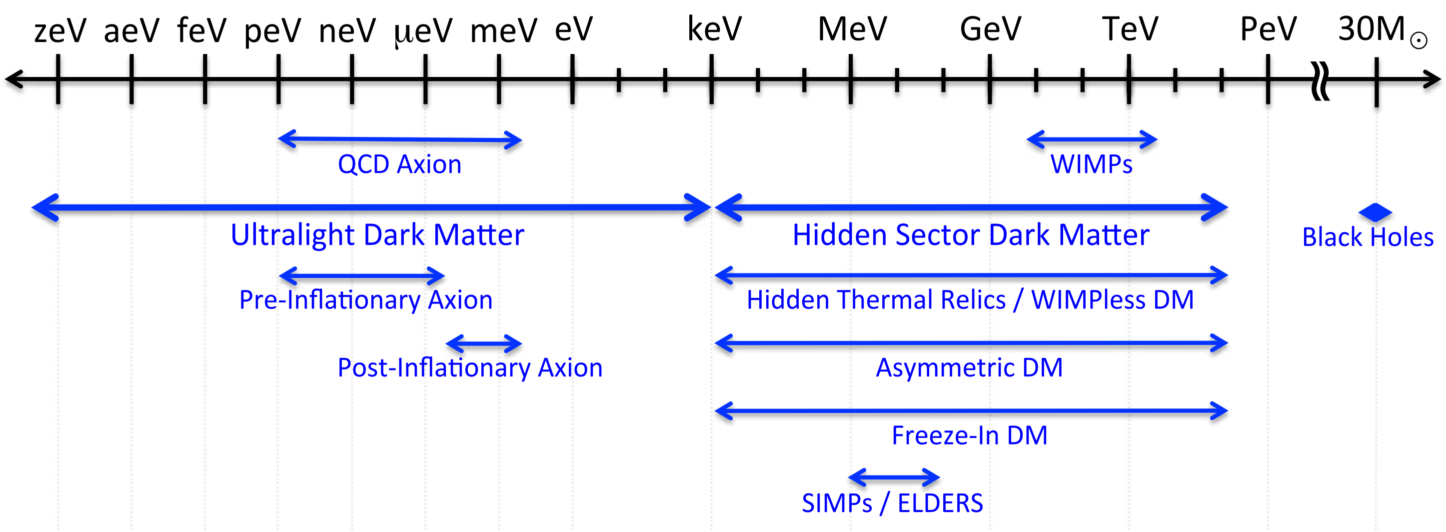
Marcela Silvia Carena Lopez and Shoji Asai, Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Open Symposium on the Update of European Strategy for Particle Physics, Grenada, Spain, May 13-16, 2019

Summary of Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Marcela Silvia Carena Lopez and Shoji Asai

European Strategy Update

Dark Matter Candidates: Very little clue on mass scales

Too small mass ⇒ won't "fit" in a galaxy!



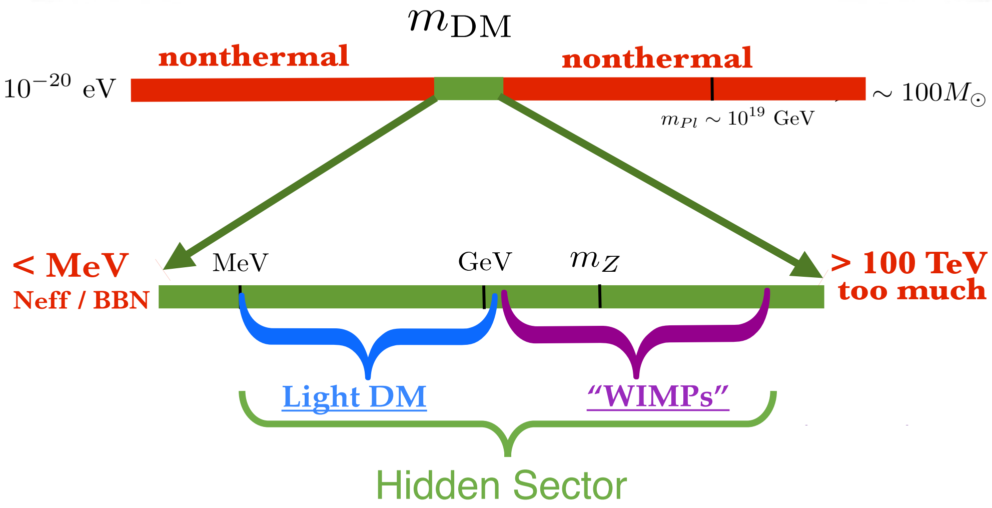
From MACHOs searches

Marcela Silvia Carena Lopez and Shoji Asai, Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Open Symposium on the Update of European Strategy for Particle Physics, Grenada, Spain, May 13-16, 2019

Dark Matter Candidates: Very little clue on mass scales

Folding in assumptions about early universe cosmology we can motivate more specific mass scales

Thermal Equilibrium in early Universe narrows the viable mass range



Explorable at accelerator based DM searches: collider and fixed target/beam dump experiments

Phenomenology of low mass region [MeV-GeV] thermal DM is quite different from Standard WIMP

==> Demands light mediator/s that in themselves are a search target

Marcela Silvia Carena Lopez and Shoji Asai, Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Open Symposium on the Update of European Strategy for Particle Physics, Grenada, Spain, May 13-16, 2019

WIMP Standard Candles

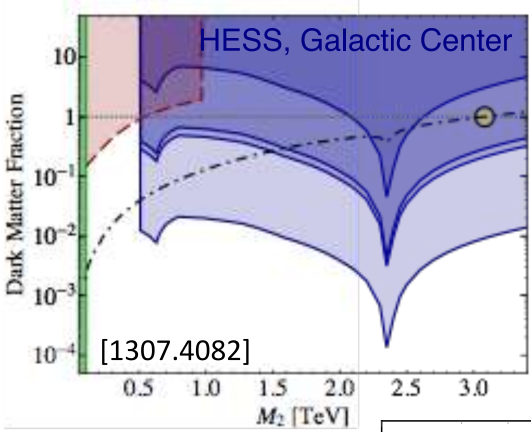
- Still a viable solution for Thermal DM (e.g. in many SUSY extensions/regions)
- Being broadly probed by Direct and Indirect detection as well as Collider experiments

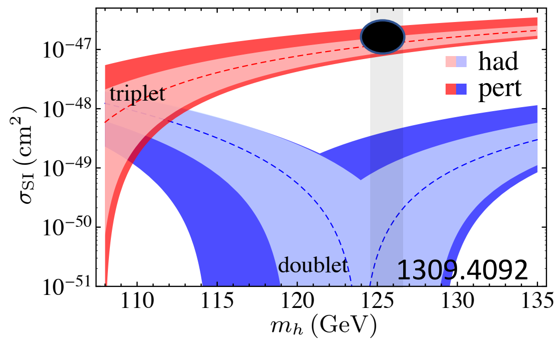
Pure Wino DM

- Thermal abundance requires Wino mass of about 2.9 TeV

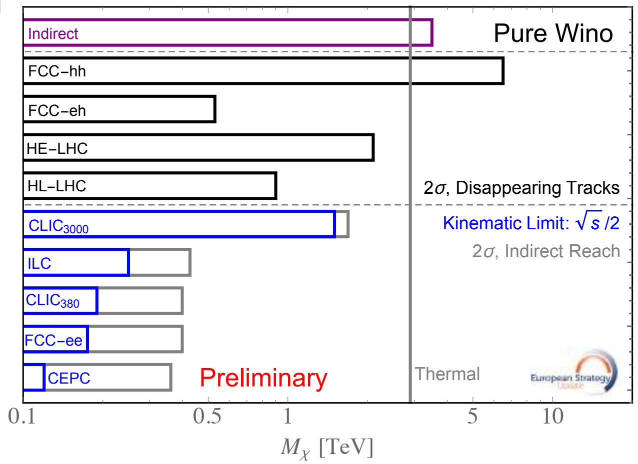
- DD: just above the neutrino floor.
  Ballpark of DarkSide 20k-200t-yr,
  DARWIN 200t-yr and Argo 3000t—yr.

- ID: Wino only constitutes all the DM for density profiles not generically produced in simulations of Milky Way-like galaxies





- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus precision measurements extended reach



See more details on Colliders in P. Sphicas' talk

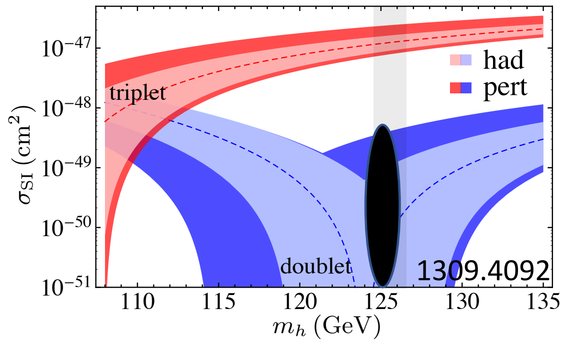
Talks by Lisanti, Monroe and McCullough

WIMP Standard Candles

- Still a viable solution for Thermal DM (e.g. in many SUSY extensions/regions)
- Being broadly probed by Direct and Indirect detection as well as Collider experiments

Pure Higgsino DM

- Thermal abundance requires Higgsino mass of about 1.1 TeV
- DD: Suppressed. Deep in neutrino floor region
- ID: Bounds strongly dependent on halo morphology.

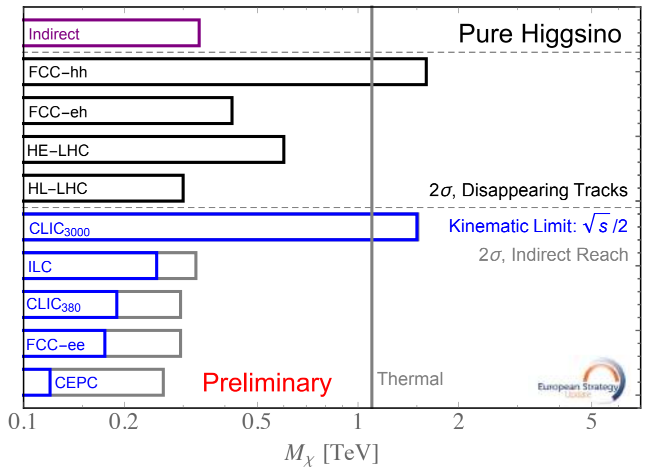


- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus precision measurements extended reach

See more details on Colliders in P. Sphicas' talk

Talks by Lisanti, Monroe and McCullough

Departures from pure Higgsino (mixings with bino/singlino) can lead to rich phenomenology.



Marcela Silvia Carena Lopez and Shoji Asai, Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions), Open Symposium on the Update of European Strategy for Particle Physics, Grenada, Spain, May 13-16, 2019

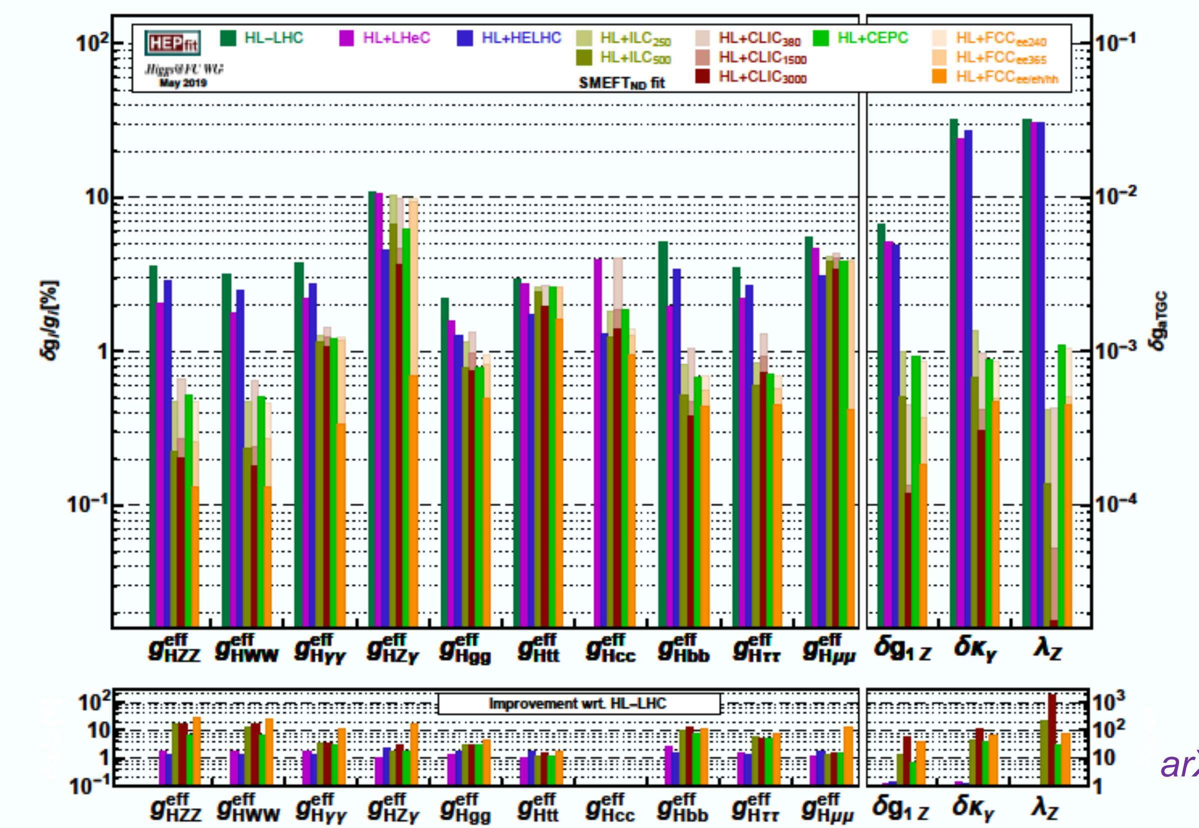
Summary of Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED), Beate Heinemann and Richard Keith Ellis

Comments on Higgs@FC Analysis

- Different simulation/analysis program for each proposal, **varying from full simulation to parametric modelling** (GUINEAPIG, CLICdet, WHIZARD, DELPHES)
- Lepton colliders: profit from the **recoil mass method** to obtain a precise ZH cross section measurement in a model independent way, regardless of the decay
- High energy hadron colliders: **probing the Higgs boson at high p_T** enhances the sensitivity to new physics (not captured in the analyses presented in this report)
- Circular colliders: **precision EWK program at MZ and MW**
- Linear colliders: **polarized beams and potential to go to higher energies**
- Generally assumed progress in systematic uncertainties over the next decades (experimental and theoretical)
- **We should not over-interpret 20% differences between projected sensitivities. In many cases, these are likely not significant.**

M. Cepeda

Comparison of Colliders: EFT



Effective Higgs couplings

- Constraints approach 0.1% precision for gauge bosons
- Major improvement w.r.t. HL-LHC for many colliders for fermions

Trilinear gauge couplings

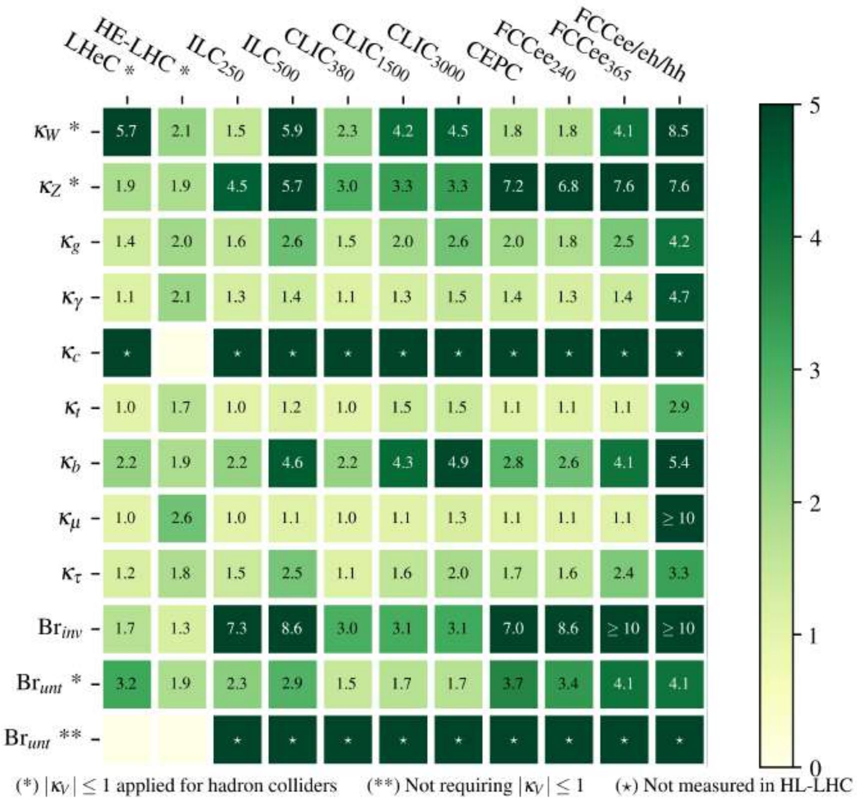
- Will achieve precision 10^{-3}-10^{-4}
- About 2-3 orders of magnitude better than LEP

arXiv:1905.03764

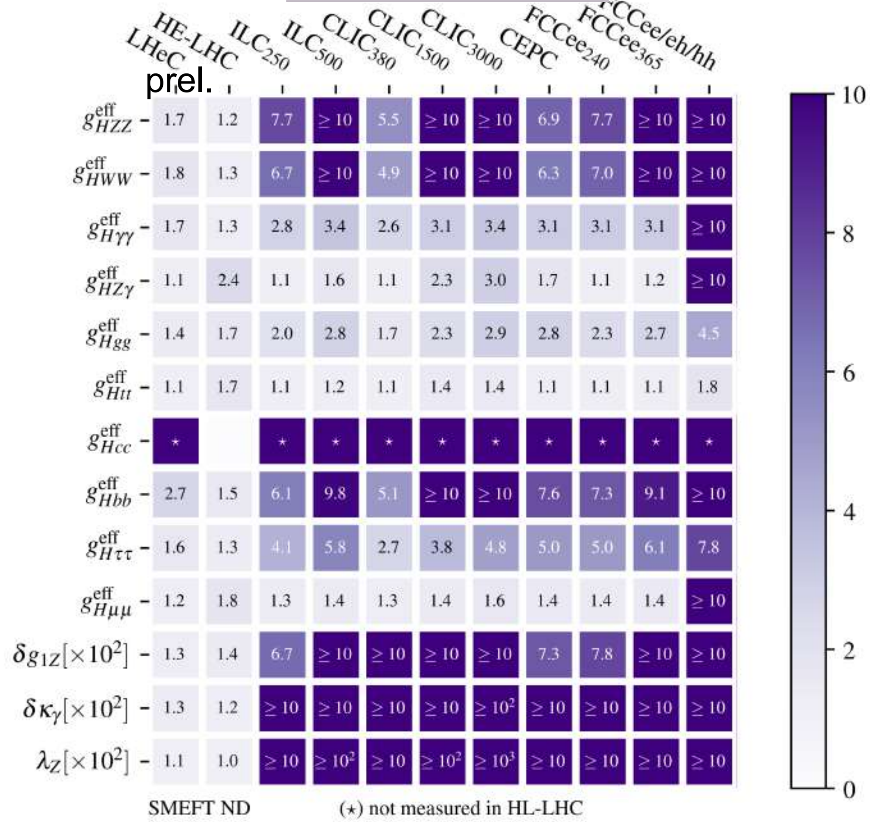
Improvements w.r.t. HL-LHC

M. Cepeda

Kappa-framework



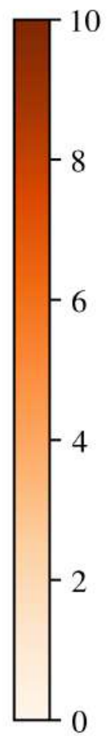
EFT-framework



Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED), Beate Heinemann and Richard Keith Ellis

EWK observables in EFT: improvement factor

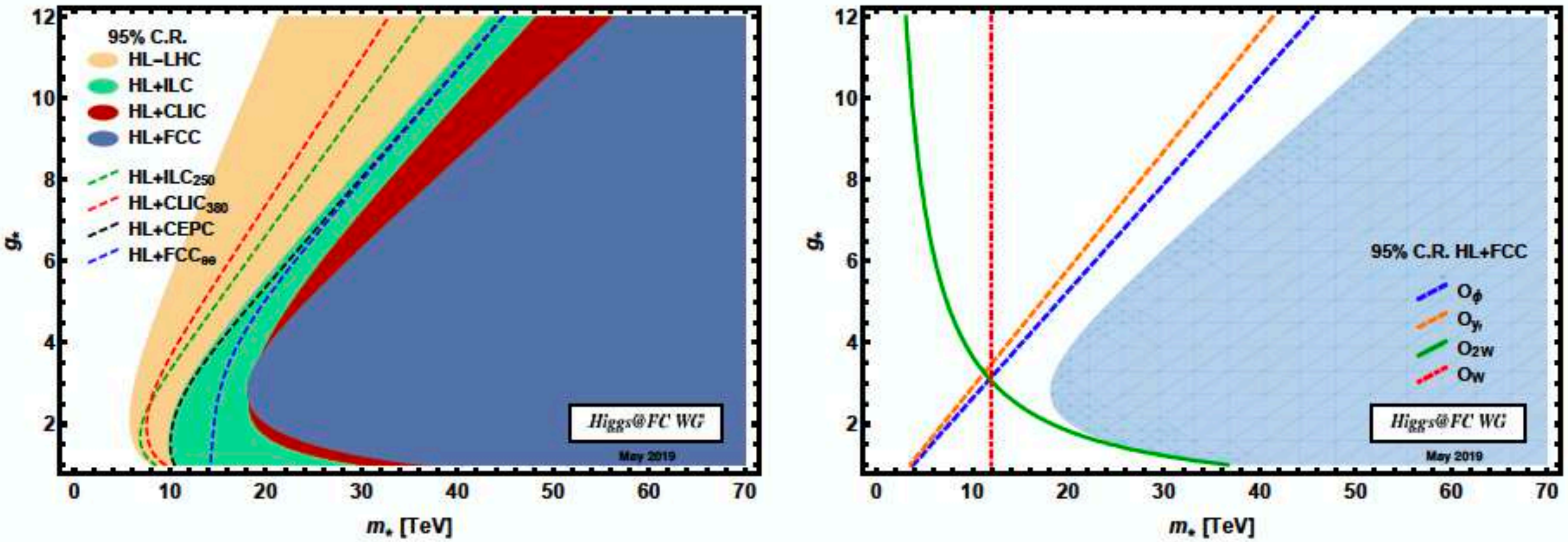
	gZveveL	gZvmuvmuL	gZvtavtaL	gZeeL	gZeeR	gZmumuL	gZmumuR	gZtataL	gZtataR	gZuuL	gZuuR	gZccL	gZccR	gZttL	gZttR	gZddL	gZddR	gZssL	gZssR	gZbbL	gZbbR
ILC_{250}	≥ 10	1.2	1.5	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.0	1.1	1.0	1.0		1.2	1.5	1.2	1.5	1.0	1.0
ILC_{500}	≥ 10	1.2	1.6	1.3	1.8	1.0	1.0	1.0	1.0	1.1	1.0	1.1	1.0	≥ 10	⋆	1.2	1.5	1.2	1.5	1.0	1.0
$CLIC_{380}$	≥ 10	5.1	9.6	1.7	1.4	1.1	1.1	1.0	1.0	1.1	1.0	1.1	1.0	1.0		1.2	1.6	1.2	1.6	1.0	1.0
$CLIC_{1500}$	≥ 10	5.3	≥ 10	2.7	1.9	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	≥ 10	⋆	1.3	1.6	1.3	1.6	1.0	1.0
$CLIC_{3000}$	$\geq 10^2$	5.4	≥ 10	3.1	2.4	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	≥ 10	⋆	1.3	1.6	1.3	1.6	1.0	1.0
CEPC	1.0	1.0	1.0	1.8	2.0	≥ 10	≥ 10	1.1	1.0	1.1	1.0	1.1	1.0	1.0		1.2	1.5	1.2	1.5	≥ 10	≥ 10
$FCCee_{240}$	≥ 10	≥ 10	≥ 10	7.9	9.2	≥ 10	≥ 10	≥ 10	≥ 10	4.2	2.9	4.2	2.9	1.0		4.6	4.4	4.6	4.4	4.6	4.4
$FCCee_{365}$	≥ 10	≥ 10	≥ 10	9.9	10.0	≥ 10	≥ 10	≥ 10	≥ 10	4.2	2.9	4.2	2.9	7.5	⋆	4.6	4.4	4.6	4.4	4.6	4.4
FCCee/eh/hh	≥ 10	≥ 10	≥ 10	9.9	≥ 10	≥ 10	≥ 10	≥ 10	≥ 10	≥ 10	≥ 10	≥ 10	≥ 10	9.1	⋆	≥ 10	≥ 10	≥ 10	≥ 10	4.6	4.4



Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED), Beate Heinemann and Richard Keith Ellis

Indirect constraints on Composite Higgs

Indirect constraints in CH models



Simplified CH benchmark: 1 coupling (g*) - 1 scale (m*)

$$\frac{c_{\phi,6,y_f}}{\Lambda^2} = \frac{g_\star^2}{m_\star^2}, \qquad \frac{c_{W,B}}{\Lambda^2} = \frac{1}{m_\star^2}, \qquad \frac{c_{2W,2B,2G}}{\Lambda^2} = \frac{1}{g_\star^2}\frac{1}{m_\star^2},$$

$$\frac{c_T}{\Lambda^2} = \frac{y_t^4}{16\pi^2}\frac{1}{m_\star^2}, \qquad \frac{c_{\gamma,g}}{\Lambda^2} = \frac{y_t^2}{16\pi^2}\frac{1}{m_\star^2}, \qquad \frac{c_{\phi W,\phi B}}{\Lambda^2} = \frac{g_\star^2}{16\pi^2}\frac{1}{m_\star^2}, \qquad \frac{c_{3W,3G}}{\Lambda^2} = \frac{1}{16\pi^2}\frac{1}{m_\star^2}$$

J. de Blas

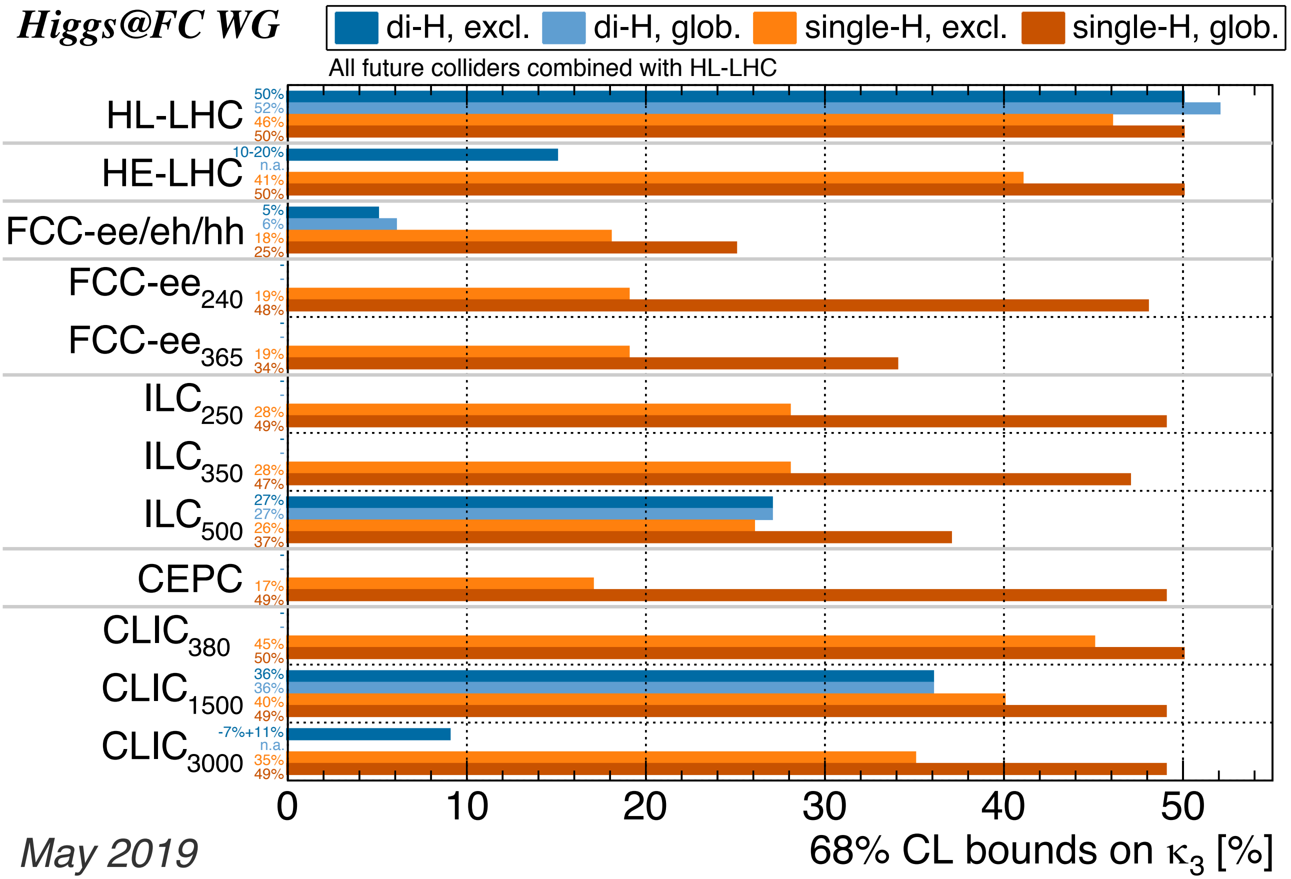
Sensitivity to λ: via single-H and di-H production

Di-Higgs:

- HL-LHC: ~50% or better?
- Improved by HE-LHC (~15%), ILC_{500} (~27%), $CLIC_{1500}$ (~36%)
- Precisely by $CLIC_{3000}$ (~9%), FCC-hh (~5%),
- Robust w.r.t other operators

Single-Higgs:

- **Global** analysis: FCC-ee365 and ILC500 sensitive to ~35% when combined with HL-LHC
  - ~21% if FCC-ee has 4 detectors
- **Exclusive** analysis: too sensitive to other new physics to draw conclusion

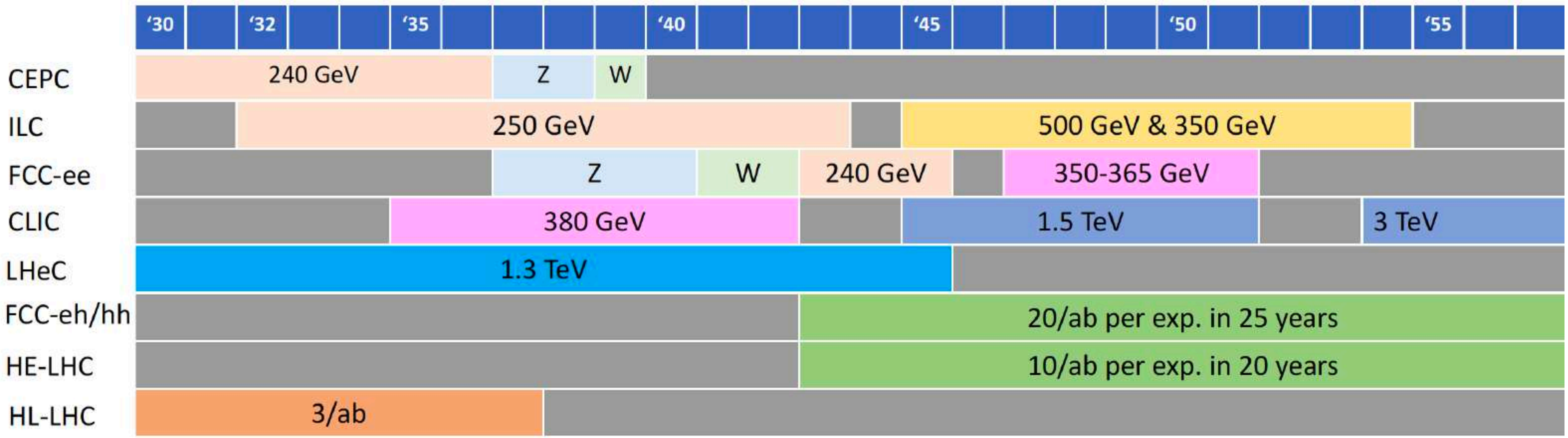


Accelerators relevant to Higgs physics

Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] $[e^-/e^+]$	N(Det.)	$\mathscr{L}_{inst}$ $[10^{34}]$ $cm^{-2}s^{-1}$	$\mathscr{L}$ $[ab^{-1}]$	Time [years]	Refs.	Abbreviation	
HL-LHC	pp	14 TeV	-	2	5	6.0	12	[10]	HL-LHC	pp
HE-LHC	pp	27 TeV	-	2	16	15.0	20	[10]	HE-LHC	
FCC-hh	pp	100 TeV	-	2	30	30.0	25	[1]	FCC-hh	
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[1]		ee
		$2M_W$	0/0	2	25	10	1-2			
		240 GeV	0/0	2	7	5	3		FCC-ee$_{240}$	
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5		FCC-ee$_{365}$	
							(+1)	(1y SD before $2m_{top}$ run)		
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[3, 11]	ILC$_{250}$	
		350 GeV	±80/±30	1	1.6	0.2	1		ILC$_{350}$	
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5		ILC$_{500}$	
							(+1)	(1y SD after 250 GeV run)		
CEPC	ee	M_Z	0/0	2	17/32	16	2	[2]	CEPC	
		$2M_W$	0/0	2	10	2.6	1			
		240 GeV	0/0	2	3	5.6	7			
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[12]	CLIC$_{380}$	
		1.5 TeV	±80/0	1	3.7	2.5	7		CLIC$_{1500}$	
		3.0 TeV	±80/0	1	6.0	5.0	8		CLIC$_{3000}$	
							(+4)	(2y SDs between energy stages)		
LHeC	ep	1.3 TeV	-	1	0.8	1.0	15	[9]	LHeC	ep
HE-LHeC	ep	1.8 TeV	-	1	1.5	2.0	20	[1]	HE-LHeC	
FCC-eh	ep	3.5 TeV	-	1	1.5	2.0	25	[1]	FCC-eh	

M. Cepeda

Schedules: by calendar year



14:55 Discussion and Closeout

C : Spiro Next CERN collider must be large circular collider

C : LC in Asia, pp circular collider FCChh at CERN , LHC type magnets can be installed in a 100km tunnel.

C : LC in Japan, CEPC in China,

C : proceed to prepare the TDR of CLIC

C : find money for 100km tunnel to continue the energy frontier machine
,but CLIC has no future as such machine

C : physics requires e^+e^- collider , next hadron collider should not be the gangatic machine

C : Steinar, CLIC should be next and also open novel technology, after the LC, hadron machine could be constructed.

C : involving other countries, CERN contributes to LC and FCChh.

C : Claude, global strategy is needed

C : For physics of FIP, ... FCCee, FCCeh, FCChh are the best machine

C : huge budget for FCCee, FCChh limits novel idea , It is dangelous to investigate

C : Higgs and top physics, Higgs self coupling, support Steinar's opinion

C : Murayama, worldwide thinking, Higgs factory, FCChh

C : Next is e^+e^- collider so support CLIC which has potentail to increase luminosity

C : DESY next is a e^+e^- collider, FCCee to FCChh is not good idea

C : For future hadron collider, tunnel is important

差出人: **T. Tauchi** toshiaki.tauchi@kek.jp
件名: Opinion at the Open Symposium, EPPSU2020
日付: 2019年5月20日 12:21
宛先: halina@tauex.tau.ac.il
CC: EPPSU-Strategy-Secretariat@cern.ch
Bcc: keisuke fujii keisuke.fujii@kek.jp

Dear Prof. Halina Abramowicz, Chairperson of the Strategy Secretariat

I am Toshiaki Tauchi, a participant in the Open Symposium from KEK, Japan.

Fist of all, I congratulate you the very successful symposium clarifying all the issues in the elementary particle physics democratically. They were concisely presented at the summary session.

At the last discussion session, I was very impressed by young lady physicists appealing from the hearts, that is, their strong desire to execute the precision measurement experiments of Higgs and Top physics by CLIC as the most affordable collider at CERN. I applauded involuntarily and I lost my words.

Coming back to Japan and spent for a few days, I remember my words.
Could you listen me ?

We greatly appreciate European contributions in the high energy physics by providing the large scientific infrastructures, CERN, especially opportunity of participation in the experiments to non-European countries for many years. In return, we would like to contribute by hosting such a large infrastructure, International Linear Collider (ILC), in Japan. The ILC has been prepared by the world effort under the ICFA leadership since the Global Design Effort (GDE) establishment in 2005. We must respect such world effort to realize the large infrastructures for requirements of large budget and human resources anywhere in the world. The ILC can achieve the young physicists' will, too.

In the European Particle Physics Strategy Updates (EPPSU2020), we would like to ask you for expression of your prospect of Japanese hosting ILC with your enthusiasm about the precision experiments operating concurrently with the HL-LHC in order to determine the next energy scale for future hadron collider. It is essential since Japanese government "officially" expressed the interest of hosting ILC and is carefully watching the ILC status in the EPPSU2020 for the final decision.

Most sincerely,
Toshiaki Tauchi

差出人: **Halina Abramowicz** halina@tauex.tau.ac.il
件名: Re: Opinion at the Open Symposium, EPPSU2020
日付: 2019年5月21日 3:57
宛先: T. Tauchi toshiaki.tauchi@kek.jp

HA

Dear Prof. Tauchi,

Thank you very much for your kind words. Many of us were disappointed by the "no-news" from Japan. It would have made the whole strategy update process so much easier.

The previous Strategy statement about the ILC was very strong. I am afraid it will be very difficult to reiterate it again. I hope that the strong message from the community about the necessity to build a Higgs factory as the next big investment in particle physics, if we get it through in the final document, will be sufficient for the Japanese Government to understand how important the ILC project could become.

Best regards, HA

Prof. Halina Abramowicz, Tel Aviv University
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Dear Halina,

Thank you very much for your attentive reply.

We hope that Japanese government will show the green sign soon after the EPPSU2020 and the SCJ (Science Council of Japan) master plan 2020 in February 2020. The ILC is expected to be selected in the important large research projects of the SCJ master plan. Then, the government's decision will be made on the international and domestic circumstances.

Also, we hope that the conclusions in the EPPSU document will be available concurrently with the SCJ master plan 2020 at least.

Best regards,

Toshiaki