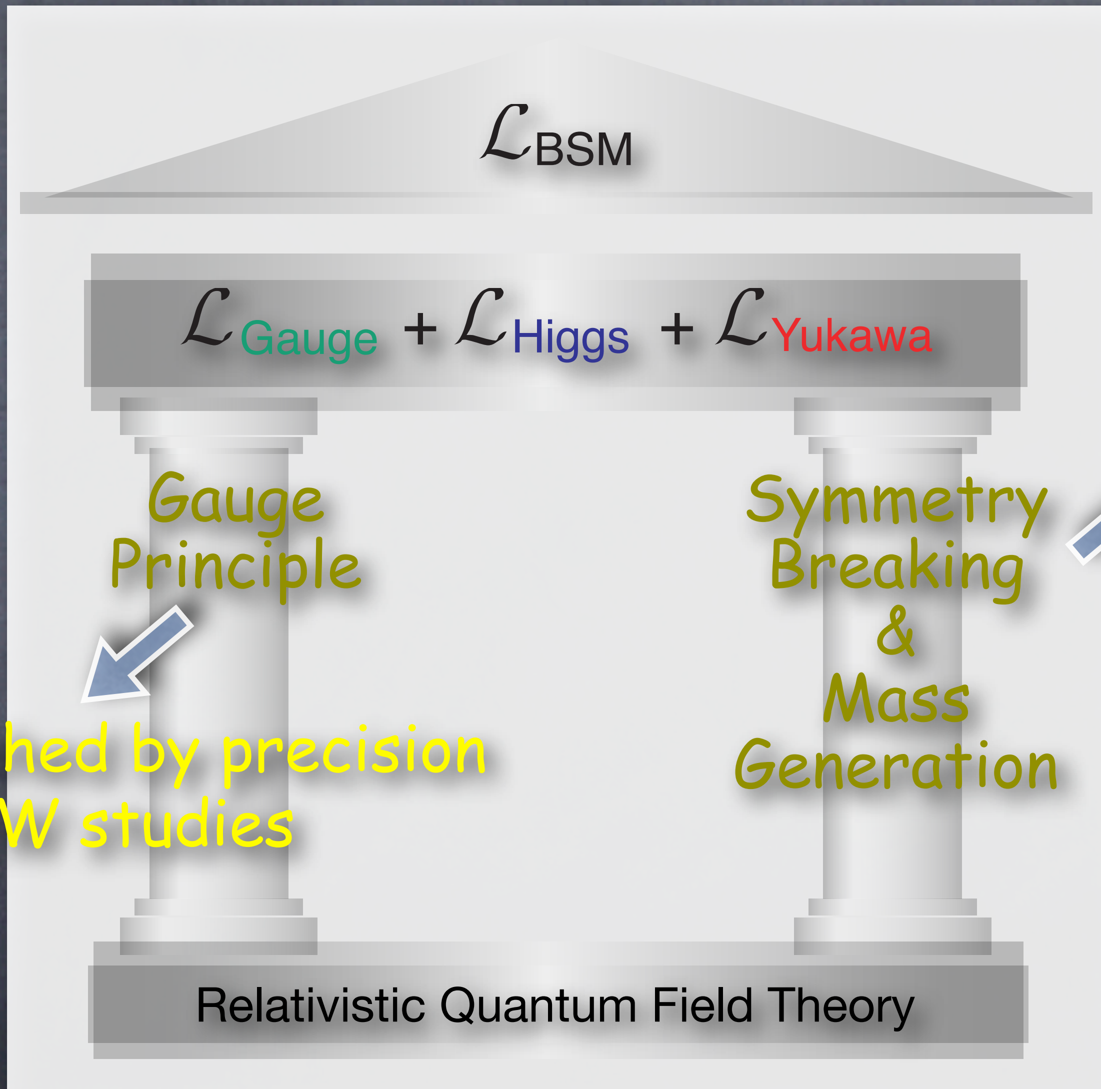
Why are we doing what we are doing ?

-- Detector R&D for the ILC TPC --

Keisuke Fujii on behalf of the D-R&D 2 Team
FJPPL, '08
CNRS HQ: 17 May, 2008

Two Main Pillars of SM



Established by precision EW studies

This pillar is not yet tested!

We don't know how firm it is!

We have to check it!

We are not yet ready to put the BSM roof!

We have LHC to test the 2nd pillar.
Then why do we need a LC?

What kind of extra tests of the 2nd pillar can the LC make?

What Breaks EWS?

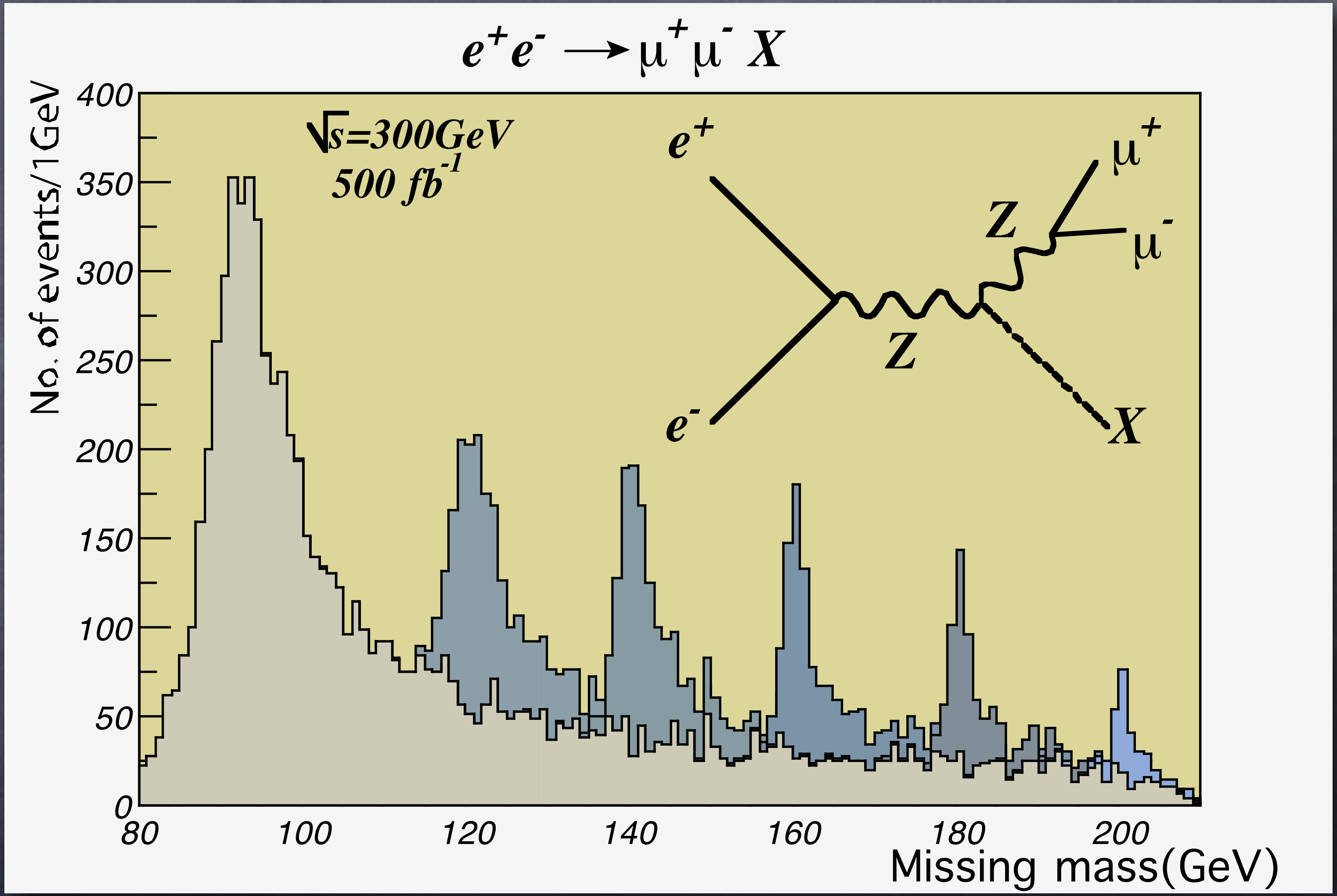
Once a Higgs-like particle is found at LHC,
LC can make precision measurements of its basic properties

- For a 120 GeV Higgs boson, LC can measure, with 500 fb-1,
  - the Higgs mass to 40 MeV
  - the Higgs width to 6%
- and confirm that it is indeed spinless

Then we can say we find a Higgs-like spinless boson

Recoil Mass Measurement

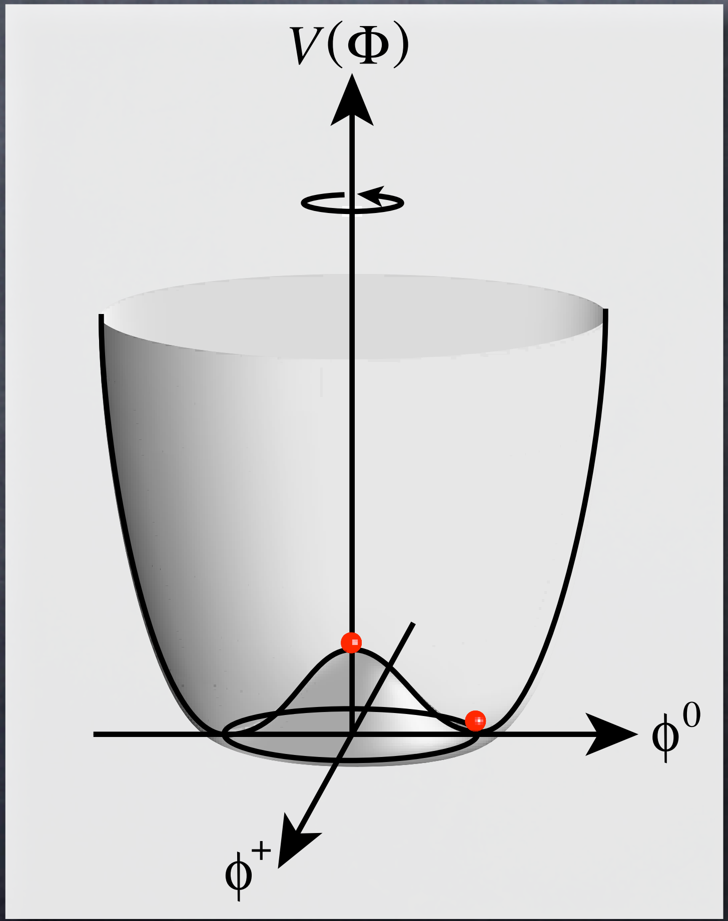
We can measure H even if it decays totally invisibly



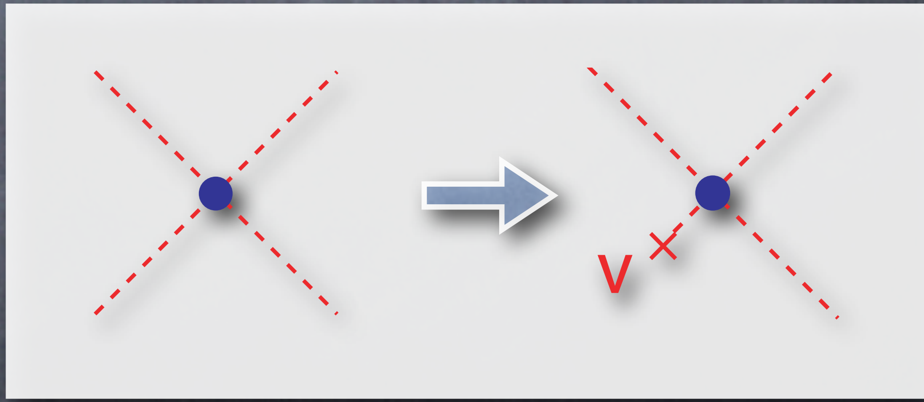
$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

What is the dynamics behind it?

- The Discovery of a Higgs-like boson is not enough! We need to observe the force that makes the Higgs boson condense in the vacuum



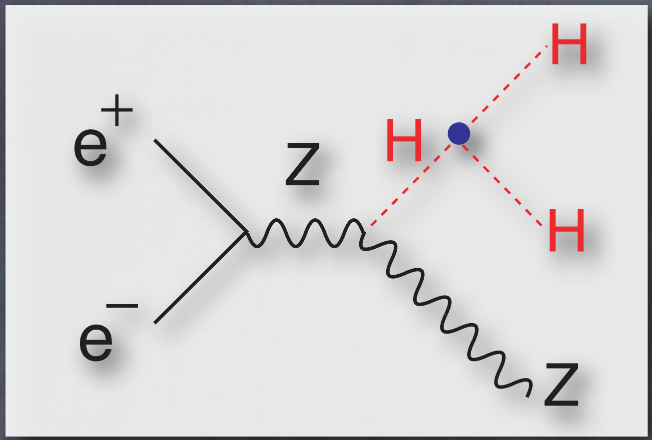
We need to measure the Higgs self coupling!

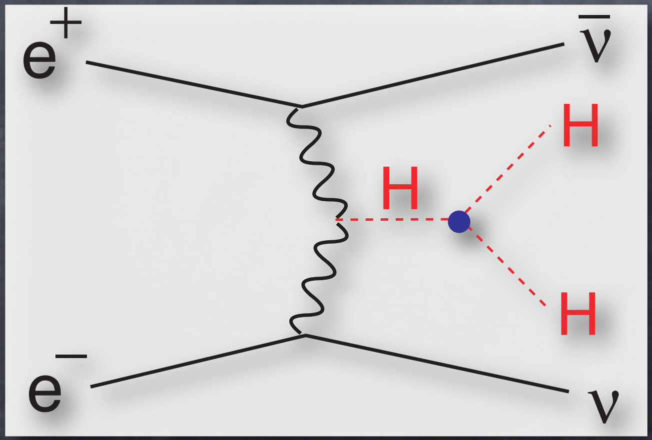


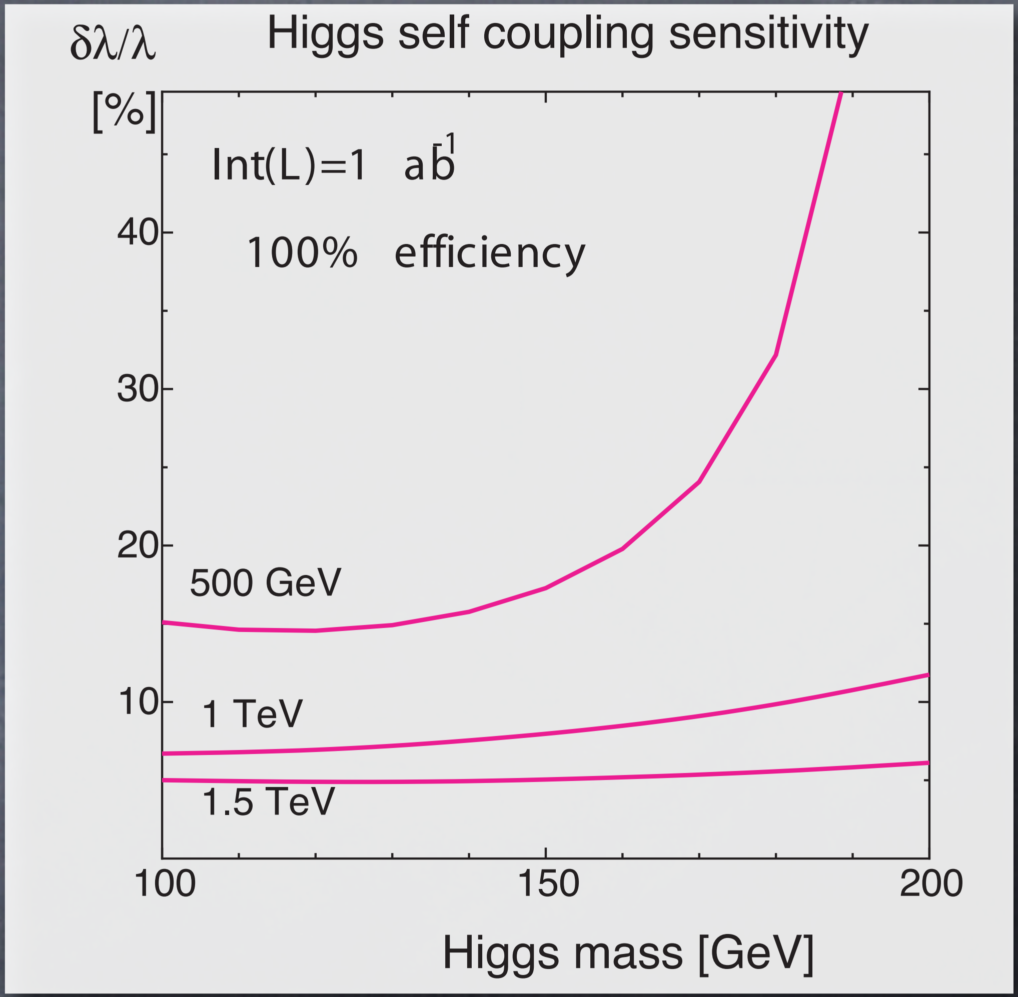
We need to measure the shape of the Higgs pot.

Then How?

Standard Ways







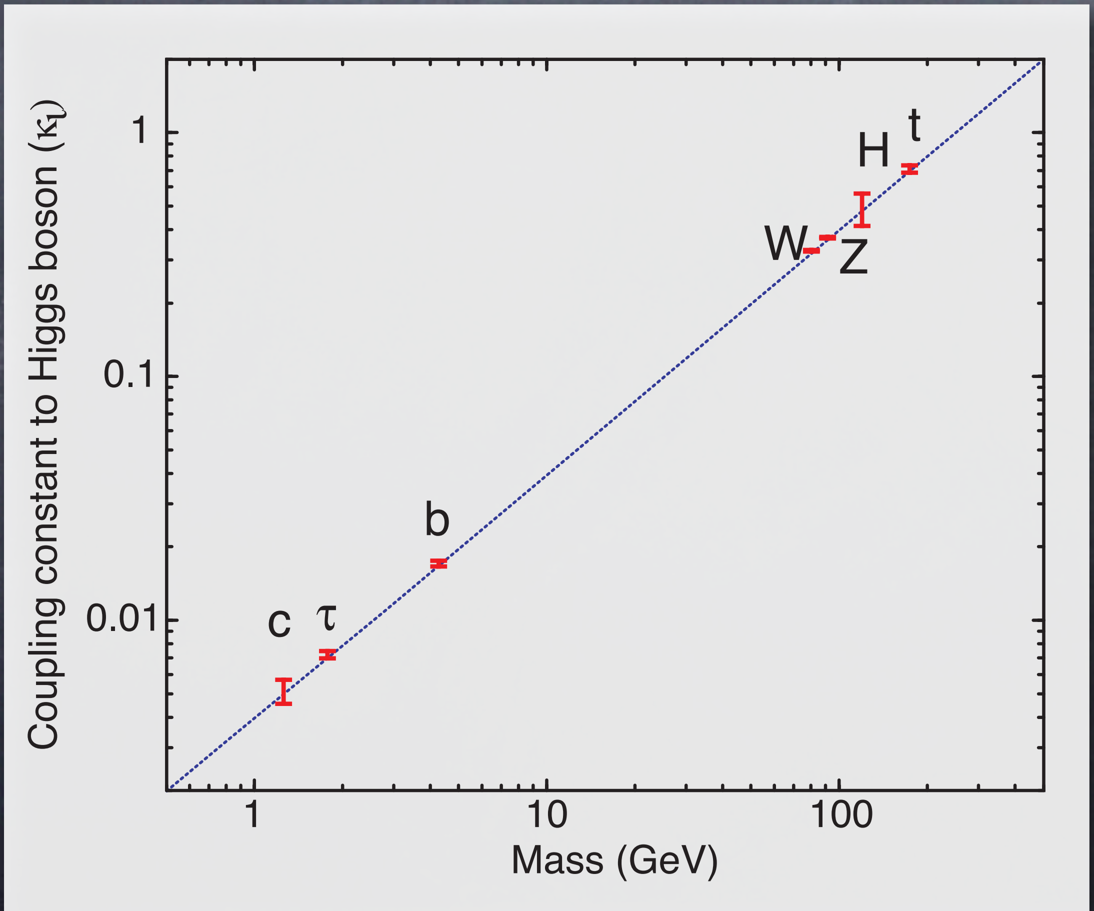
The self coupling can be measured to O(10%)

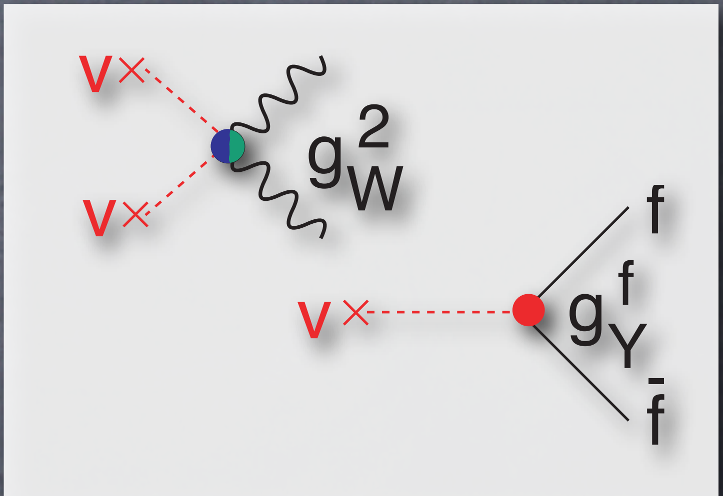
Another Way

We might be able to do better with a photon collider at the HH threshold (Belusevic & Jikia)

Origin of Mass

- If the Higgs boson is the one to give masses to all the SM particles, we need to observe proportionality between mass and coupling





Might see two or more lines if the Higgs sector is non-minimal!

Then we will be ready to go beyond the Standard Model

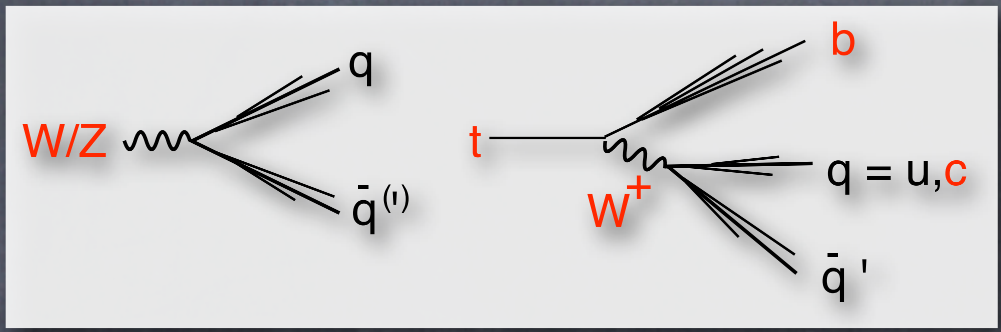
To what extent the LC will be able to explore the BSM depends on its scale and thus luck

But, in any case, the detector should make full use of the collider's potential

Then how ?

Concept of LC Experiment

- Reconstruct final states in terms of partons (q,l,gb)



2ndary & 3tiary vertex ID

Jet invariant mass --> W/Z/t ID --> p^μ
--> angular analysis --> s^μ

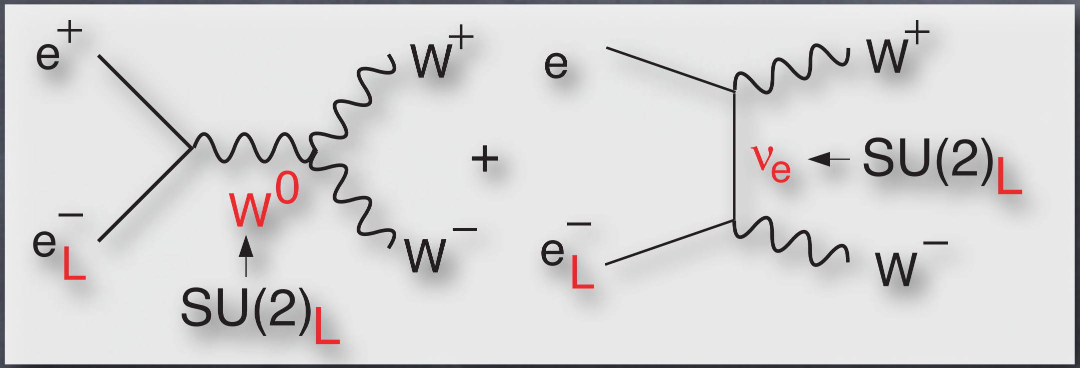
Energy Flow

Missing momentum --> neutrinos

Hermeticity

Visualize events as viewing Feynman diagrams!

- Select Feynman diagrams with beam polarization



In the symmetry limit

$$\sigma_{WW} \to 0$$

for R-handed e- beam

Study events as looking at S-matrix elements!

This requires a state-of-the-art detector!

2ndary & 3tiary vertex ID

Thin and high resolution vertexing

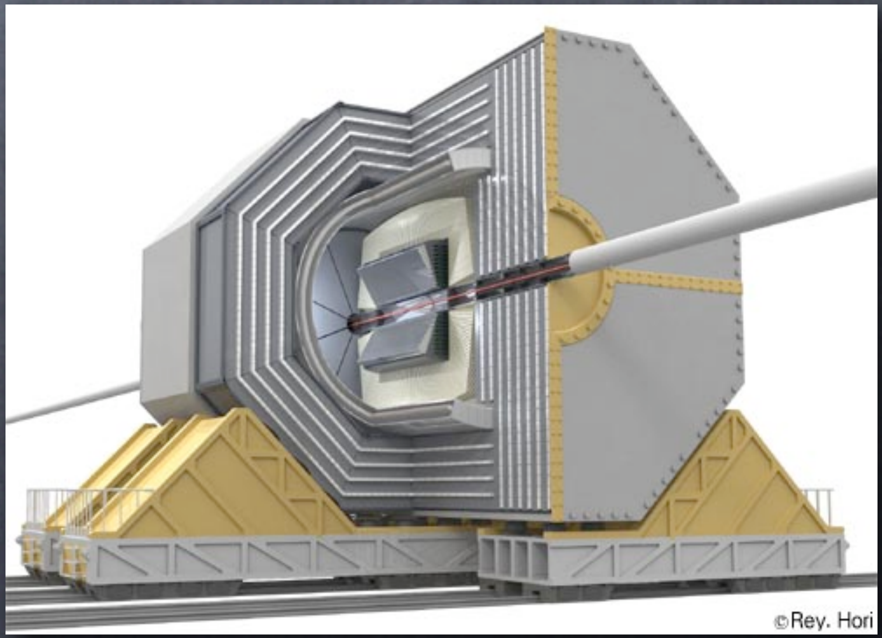
Energy Flow (PFA)

High resolution tracking

High granularity calorimetry

Hermeticity

down to O(10mrad) or better



Performance Goals

for the LC-TPC

- >200 sampling points along a track with a spatial resolution better than ~100 microns in the XY plane over the full drift length of >200 cm

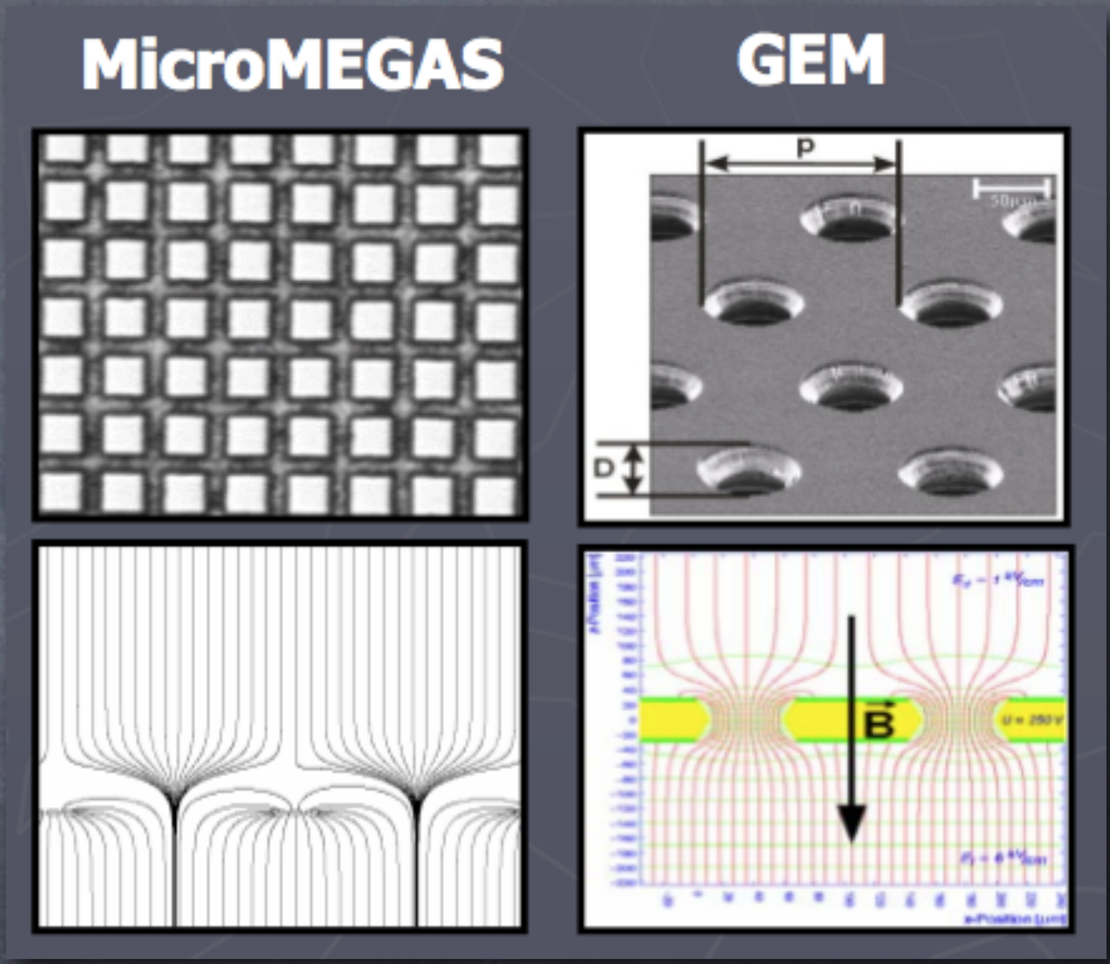
- 2-track separation better than ~2mm to assure essentially 100% tracking efficiency for jetty events

- High tracking efficiency also requires minimization of dead spaces near the boundaries of readout modules

Why MPGD readout ?

Why not conventional MWPC readout ?

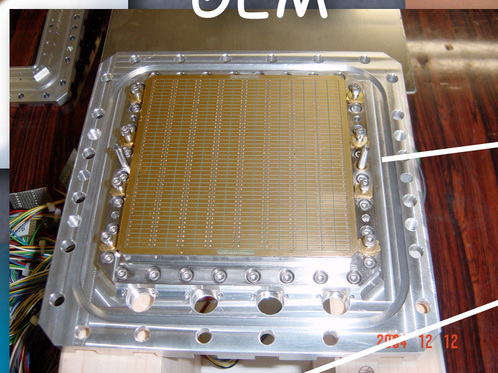
- We need high (>3 T) B field to confine e+e- pair BG from beam-beam interactions, then ExB too big for conventional MWPC readout
- 2mm 2-track separation is difficult with MWPC readout
- Thick frames are unavoidable for MWPC readout

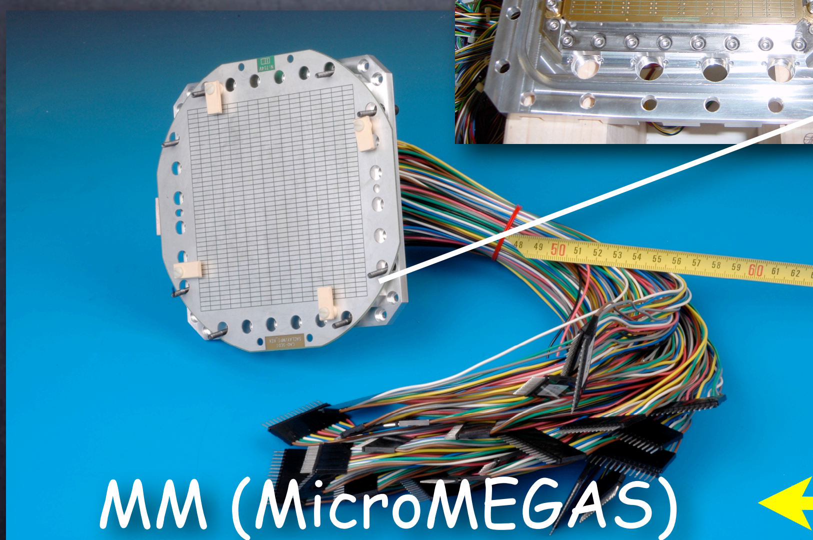


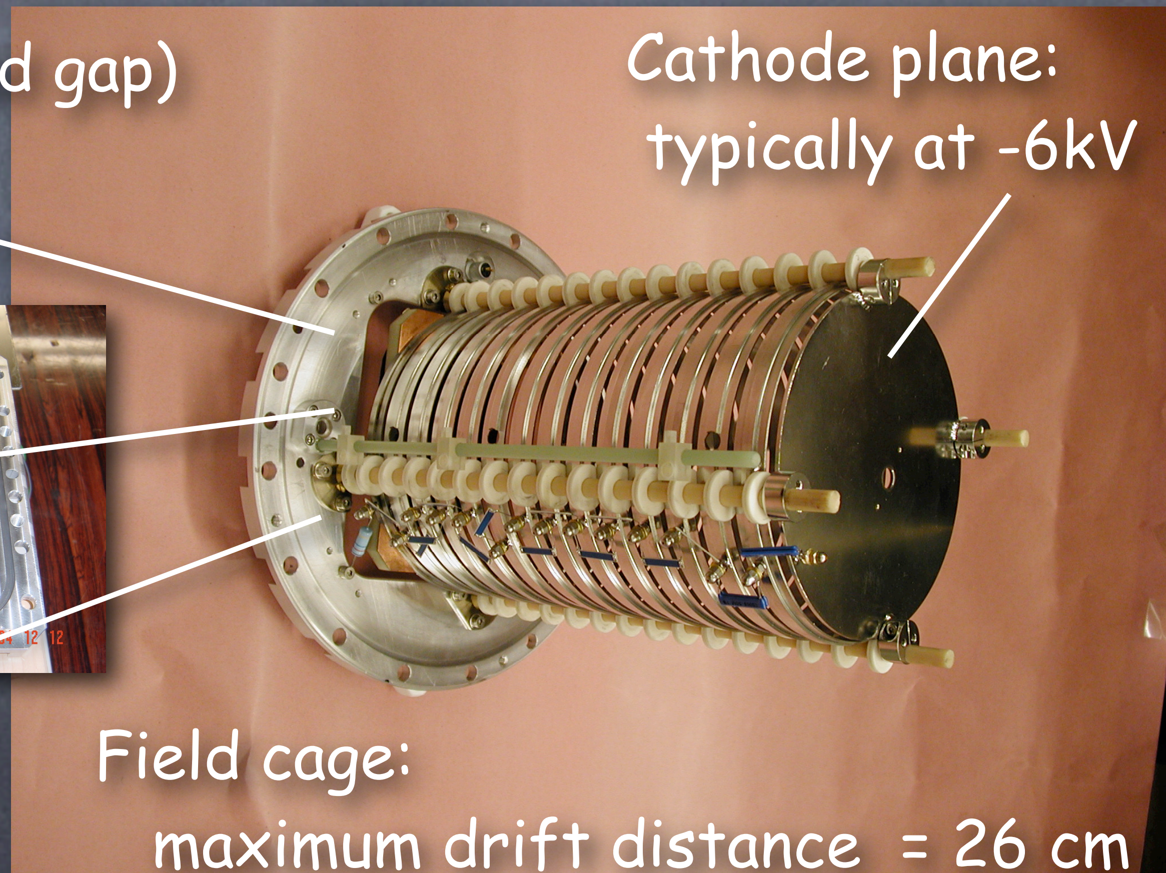
→ Micro-Pattern Gas Detectors

The F-J Collaboration on the LC-TPC R&D Started with KEK Beam Tests

Using the same small prototype (MP-TPC) as a test bench to compare different readout planes:







French contribution

Effort to Understand the KEK Beam Test Data Yielded the Analytic Formula

$$\sigma_{\bar{x}}^2 \equiv \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \int d\bar{x}\, P(\bar{x};\tilde{x})\,(\bar{x}-\tilde{x})^2 = \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left[[A] + \frac{1}{N_{eff}}[B]\right] + [C]$$

$$N_{\rm eff} := \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}}\right)^2 \right\rangle\right]^{-1} < \langle N \rangle$$

- Purely geometric term

$$[A] = \left(\sum_j (jw)\ \langle f_j(\tilde{x}+\Delta x)\rangle - \tilde{x}\right)^2$$

- Diffusion, gas gain fluctuation & finite pad pitch term

$$[B] = \sum_{j,k} jkw^2\ \langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle - \left(\sum_j jw\,\langle f_j(\tilde{x}+\Delta x)\rangle\right)^2$$

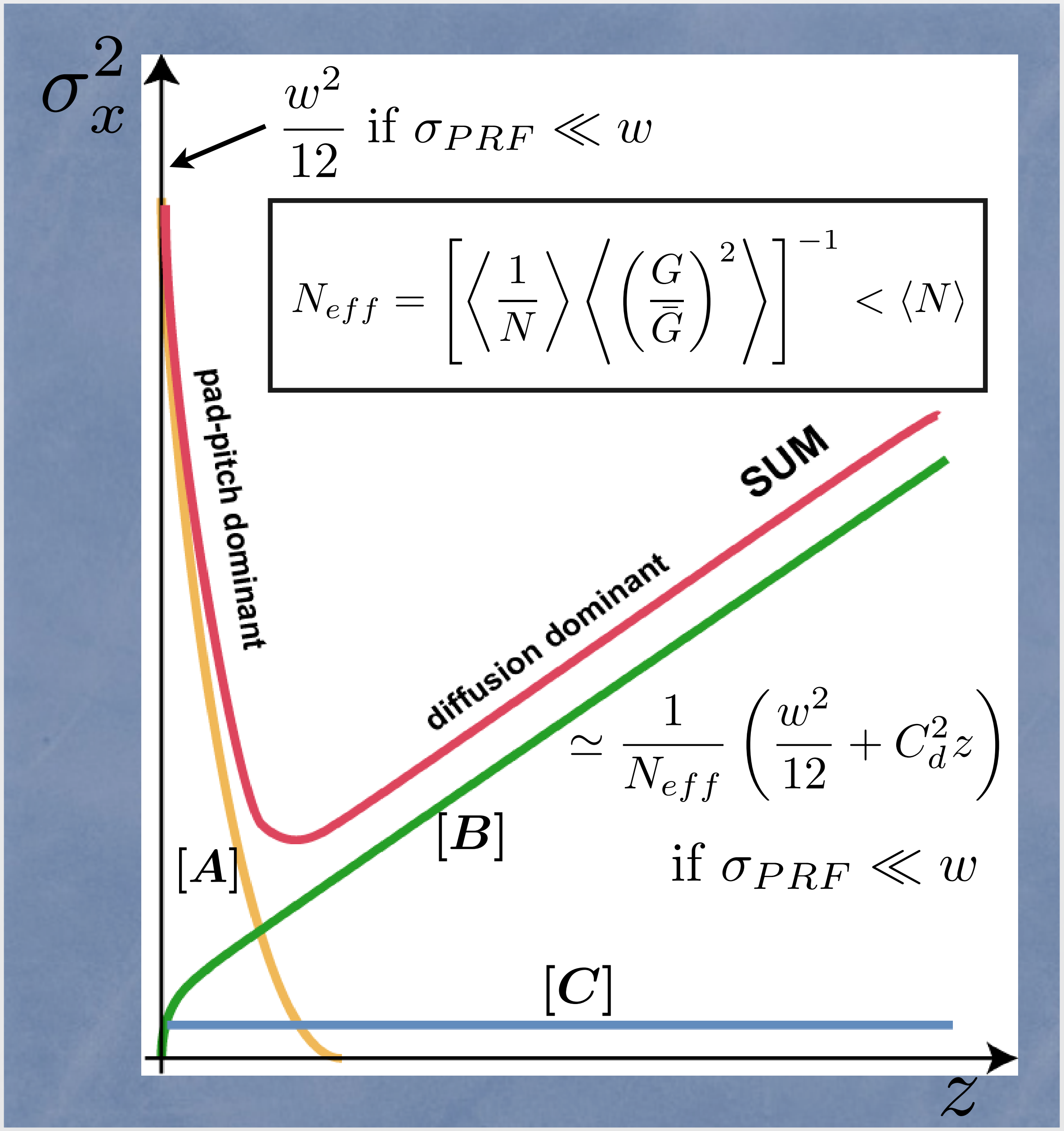
$$\langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)\, f_k(\tilde{x}+\Delta x)$$

$$\langle f_j(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)$$

- Electronic noise term

$$[C] = \left(\frac{\sigma_E}{\bar{G}}\right)^2 \left\langle \frac{1}{N^2} \right\rangle \sum_j (jw)^2$$

Interpretation



[A] Purely geometric term (S-shape systematics from finite pad pitch): rapidly disappears as Z increases

[B] Diffusion, gas gain fluctuation & finite pad pitch term: scales as $1/N_{eff}$, for delta-fun like PRF asymptotically:

$$\sigma_{\bar{x}}^2 \simeq \frac{1}{N_{eff}} \left(\frac{w^2}{12} + C_d^2 z\right)$$

[C] Electronic noise term: Z-independent, scales as $\langle 1/N^2 \rangle$

Importance of the Analytic Formula

- We now understand why Neff is significantly smaller than <N> where the gas gain fluctuation was found to be one of the major reasons.

- We can now analytically estimate the spatial resolution

drift distance

$$\sigma_x = \sigma_x(z; w, C_d, N_{eff}, [f_j])$$

pad pitch

pad response function

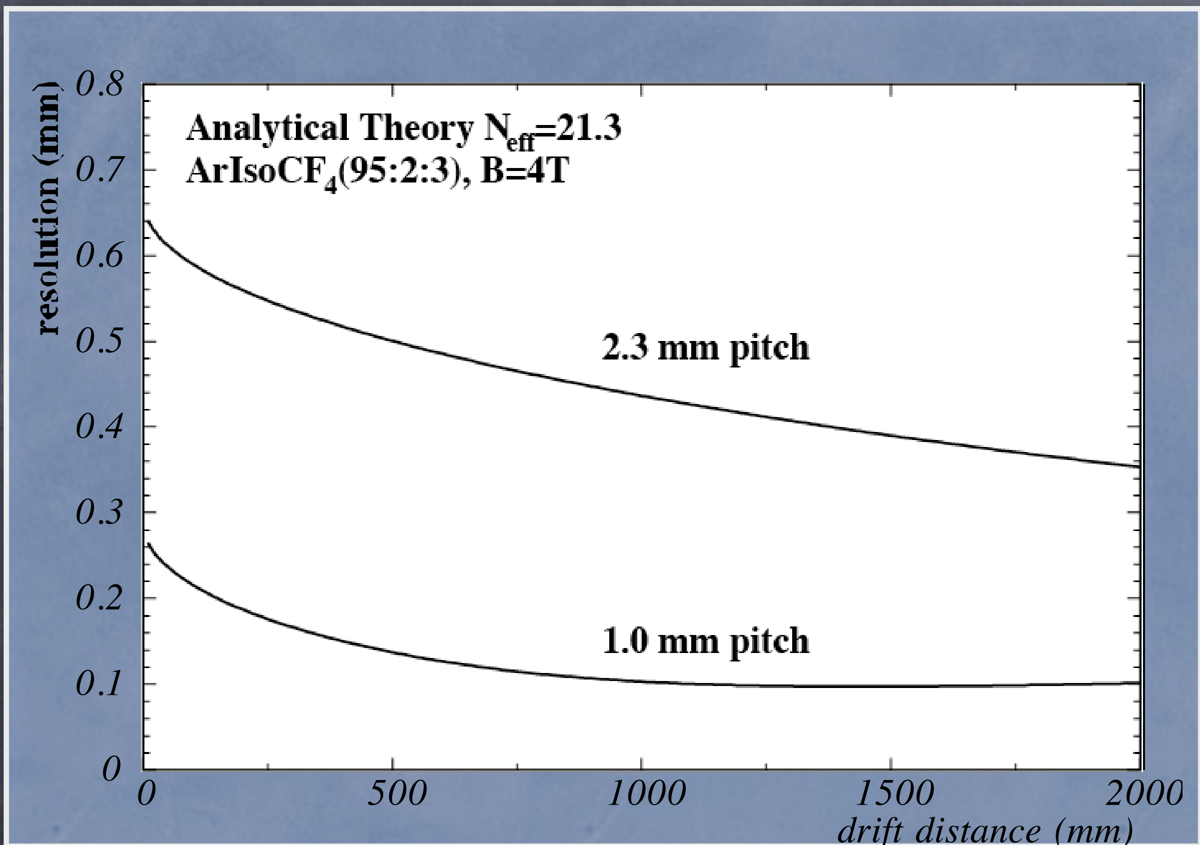
diffusion const.

Effective No. track electrons

Theoretical basis for how to improve the spatial resolution!

Possible improvement of theory: angle effects

Extrapolation to LC TPC



- Need to reduce pad size relative to Pad Response Func.
  - MM + resistive anode
  - MM + digital pixel readout, ideal to avoid effect of gain fluctuation, if feasible
  - GEM with defocusing + narrow (~1mm) pads

The 3 Solutions

The three solutions have been tested with small prototypes.

--> demonstration phase

We now need to test them with a larger prototype.

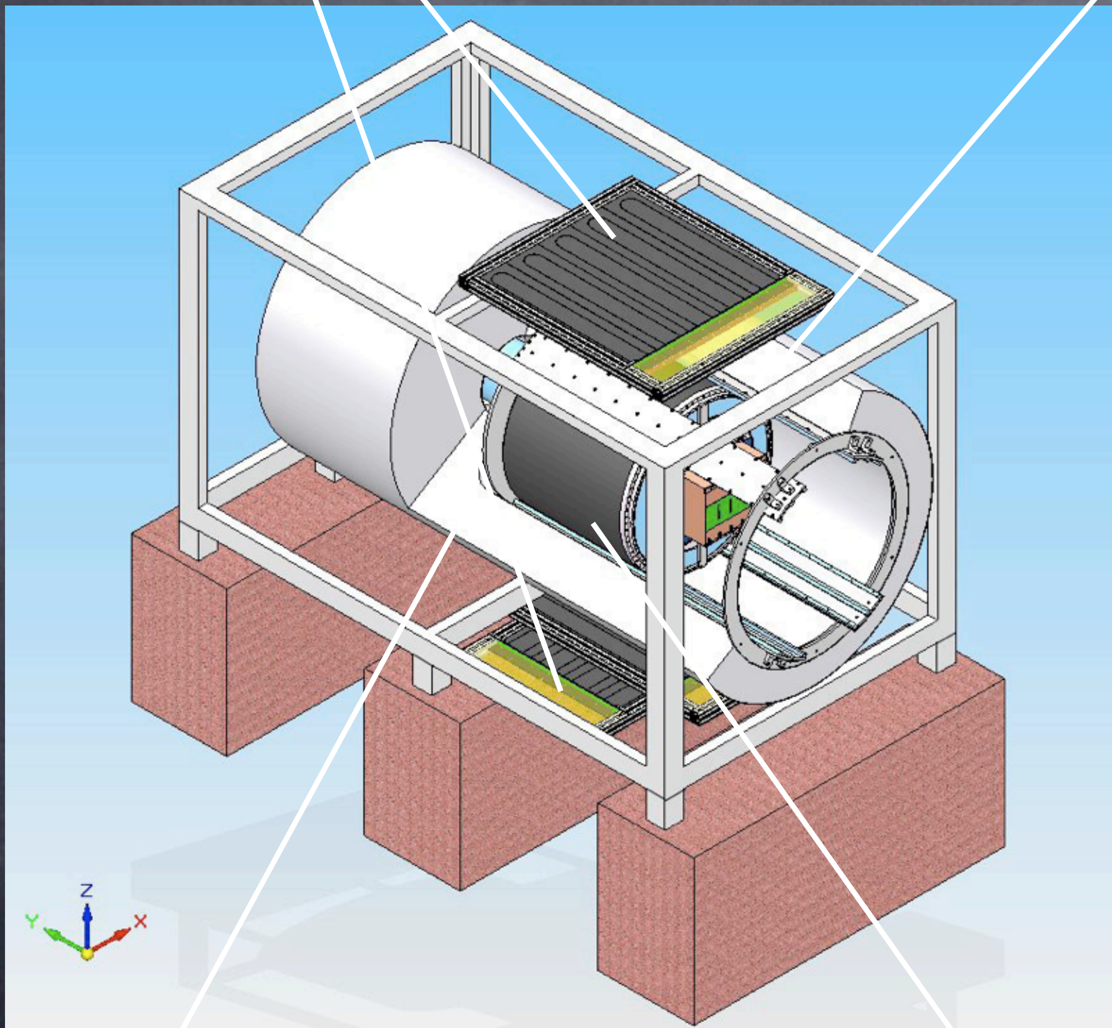
--> consolidation phase

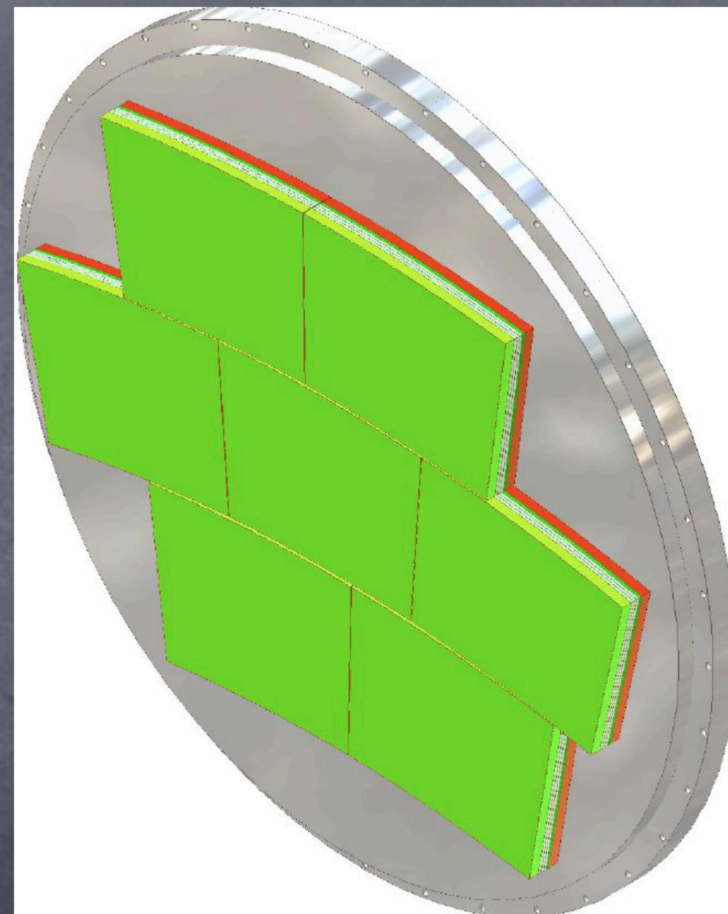
The Main Stream of
the Current LC-TPC R&D
is hence the Tests of
the Three Solutions
with a Large Prototype

Cosmic ray trigger counters
with MPPC readout system

Endplate to house
7 Interchangeable readout modules

GEM+1mm pads, MM+RA, MM+TimePix





Field cage : 75 cm phi & 61 cm long

Thin (0.2X0) superconducting magnet (PCMAG from KEK) : B_max=1.25 T

Consolidation Phase

TPC Large Prototype Beam Test at DESY

Pixel beam telescope (EUDET)

Si strip detector (EUDET/SiLC)

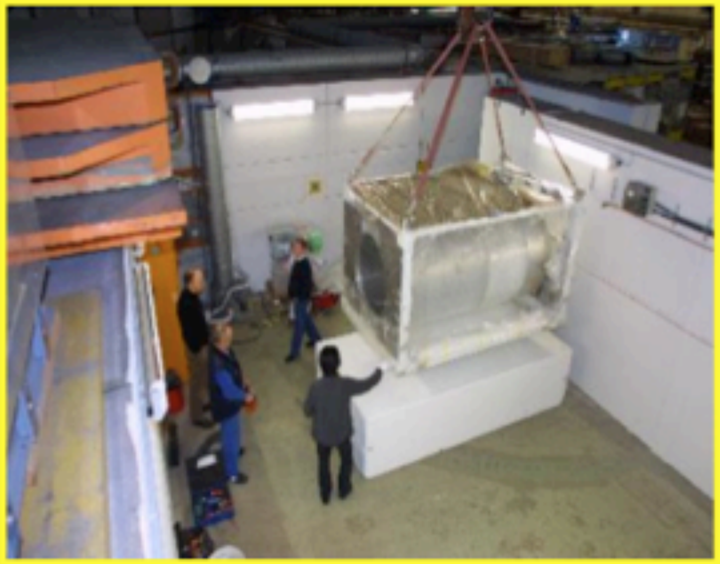
Magnet: PCMAG (LC TPC/EUDET)

Field cage & All Mechanics (EUDET)

Endplate (LC TPC)

MPGD Detector Modules (LC TPC)

Gas system (EUDET)



Test beam (DESY)

Cosmic trigger (LC TPC)

DAQ & Monitoring (EUDET)

Readout electronics (EUDET & LC TPC)

Software development (EUDET & LC TPC)

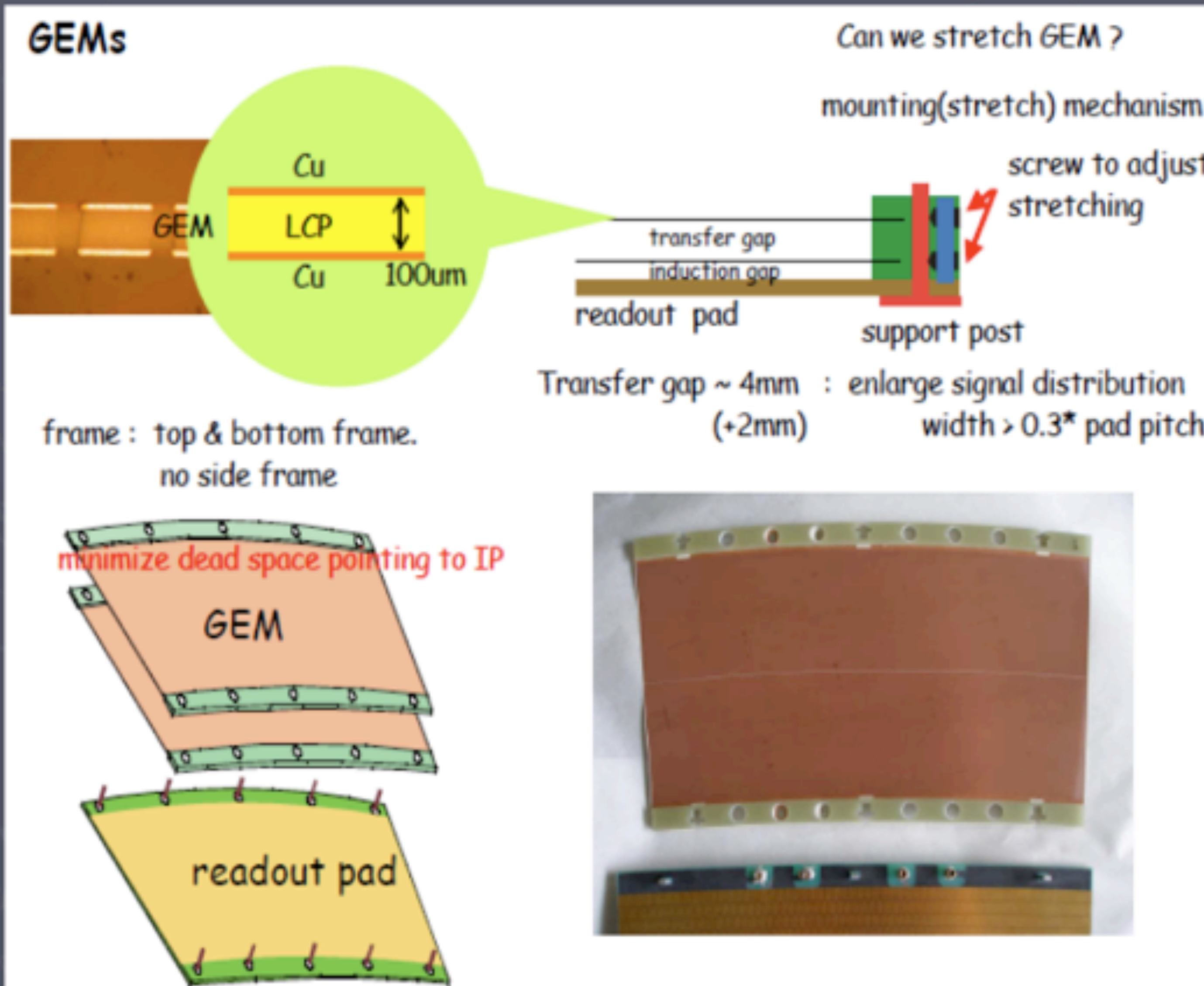
Time

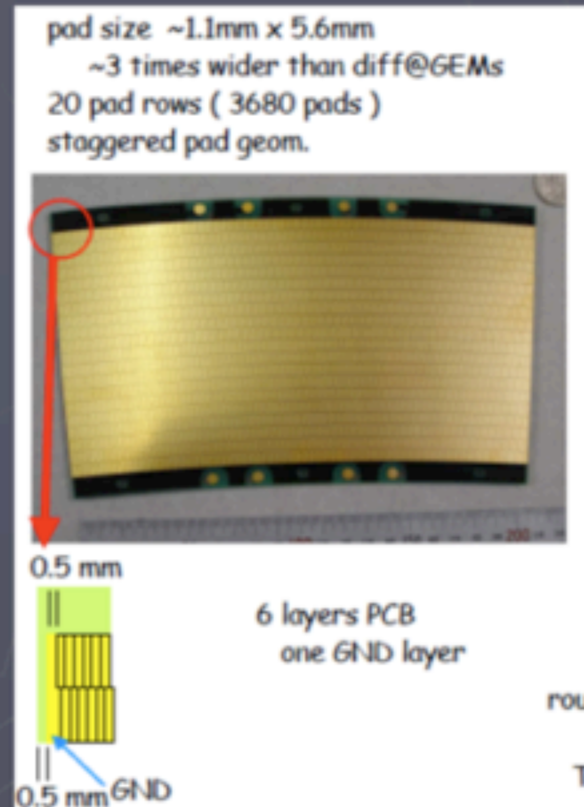
Detector Module: Double GEM with a gating GEM

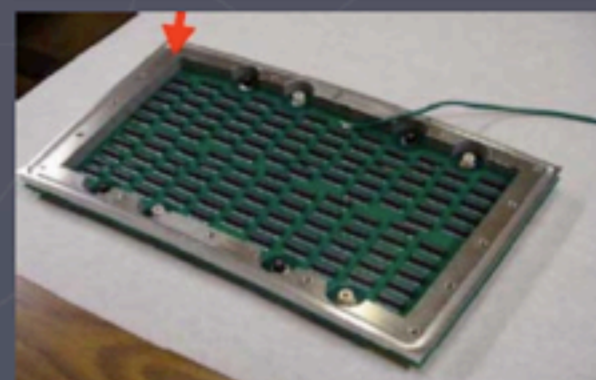
Saga, Tsinghua

(1) Double thick (100 μm) GEM with a (thin) gating GEM:

(Gating GEM is not drawn)



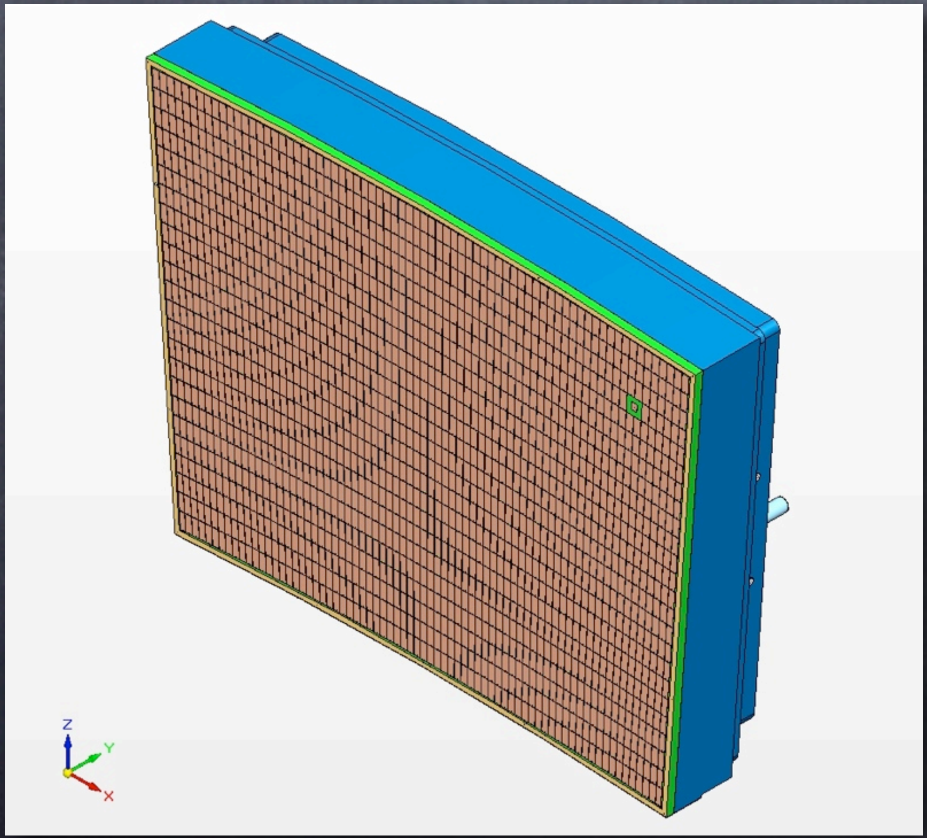


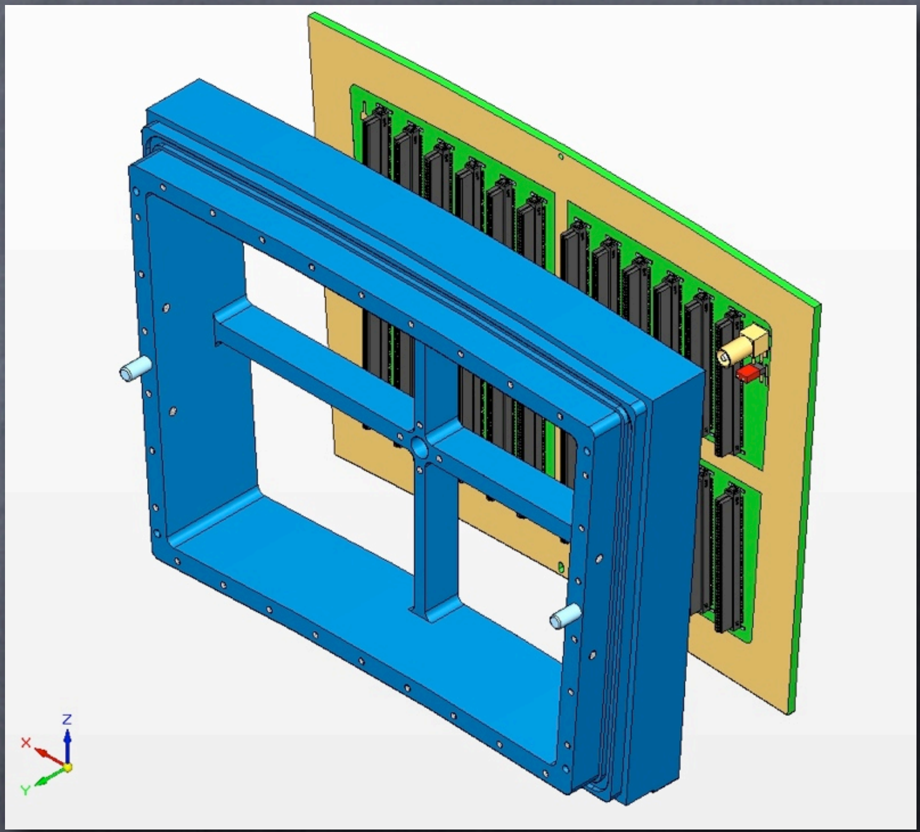


Micromegas with R.A.

LP1 detector module

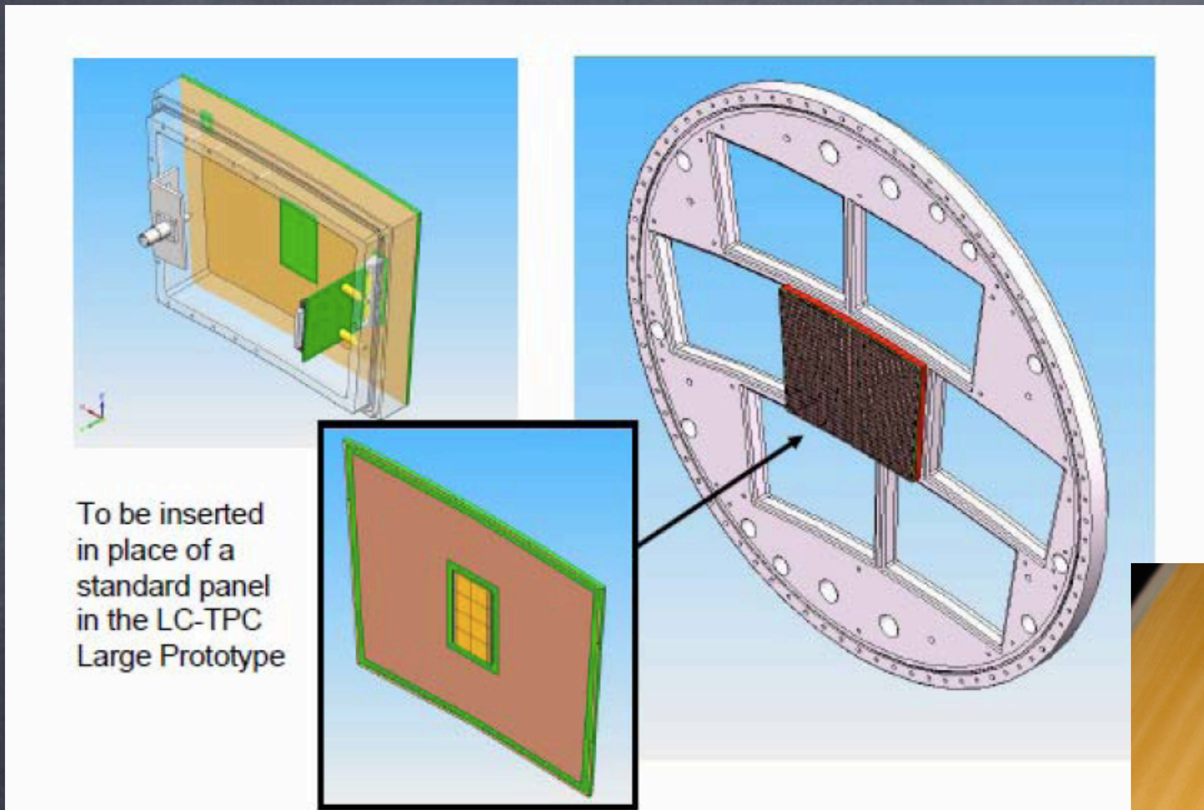
- 24 rows x 72 pads
  Av. pad size ~ 3.2x7 mm^2

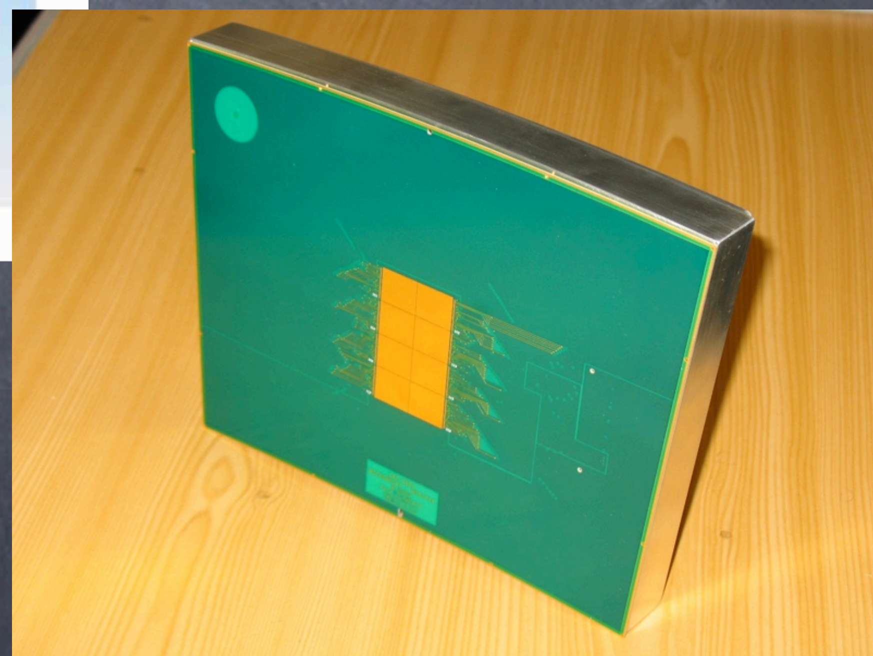




Micromegas with TimePix

Saclay/NIKHEF





EUDET

Summary

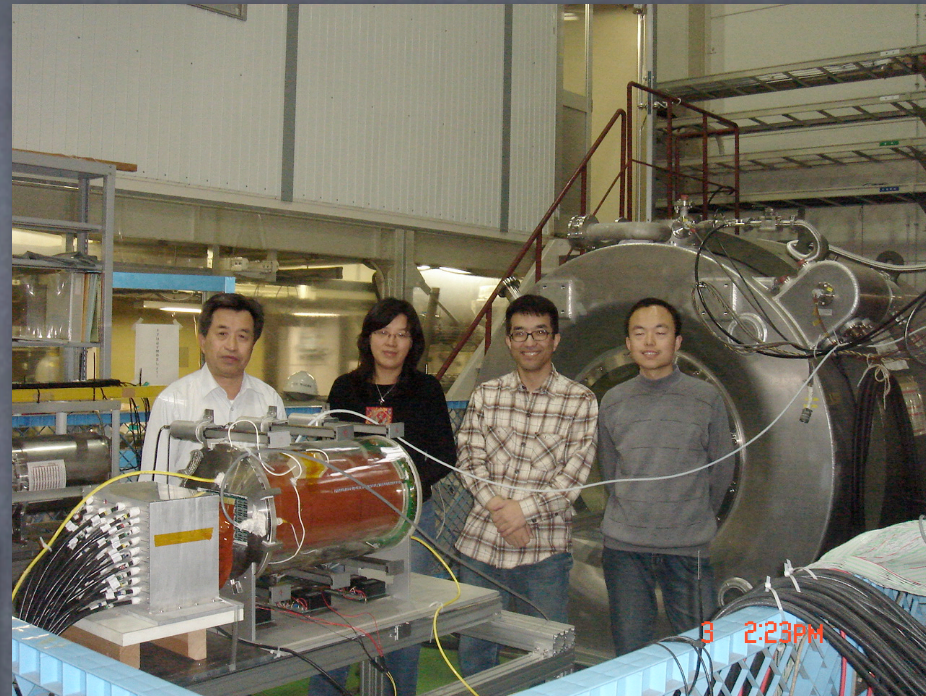
- The test of the 2nd pillar of the SM (symmetry breaking and mass generation mechanism) is the most important and urgent task to do.
- The sub-TeV LC will be crucial to carry out this mission and hence we need it, regardless of the BSM scenarios or equivalently the LHC outcomes.
- To what extent the LC will be able to explore the BSM depends on its scale and thus luck.
- In any case we need a state-of-the-art detector system to make full use of the LC's potential.

Summary (continued)

- We are busy preparing for the large prototype (LP1) beam test at DESY starting late this year.
- The LP1 data will be invaluable to prepare ourselves for the design phase.
- Hope we can show some LP1 data at the next FJPPL WS.
- We continue small prototype tests for
  - understanding of gas multiplication processes
  - optimization of gas mixtures
  - gating, ... etc.
- We continue more R&D for MM+TimePix since it is theoretically the best choice.

Tsinghua TPC School
Jan. 2008 in Beijing

2 French, 5 Japanese, and >40 Chinese



TU-TPC Test at KEK Cryo-center with a PC-Mag Dec. 2007

We are now becoming the F-J-C team !