#3
'96 Oct. 15 11:00-11:35

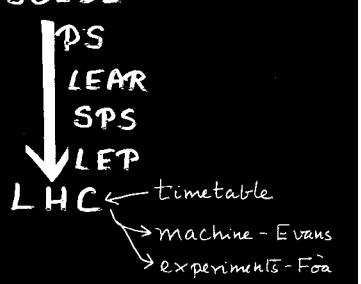
LAB Plans

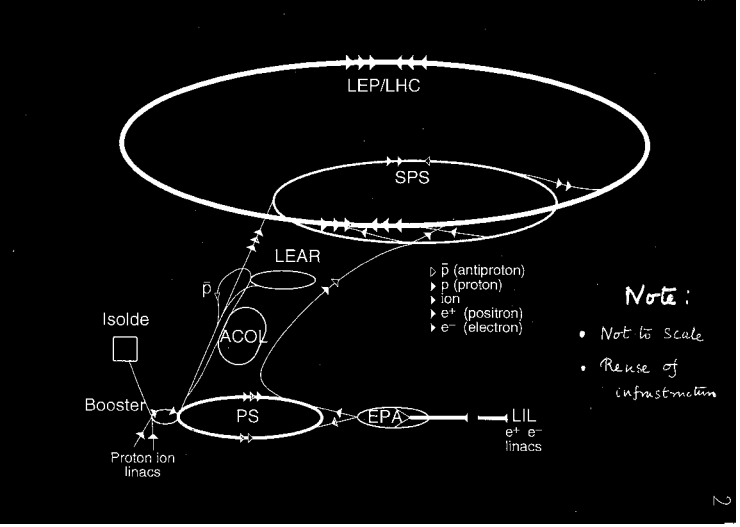
Title: CERN

Author: C.Llewellyn Smith

The Future CERN Programme

From ISOLDE

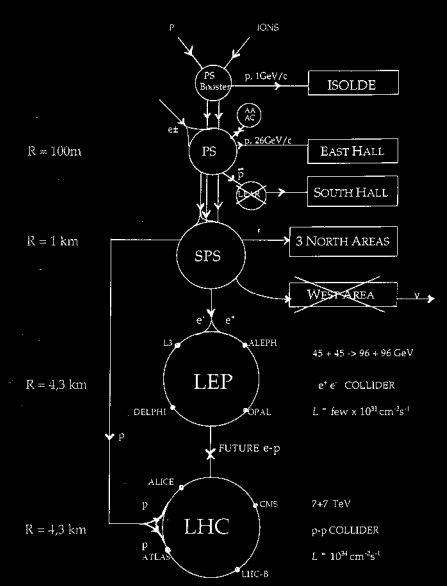


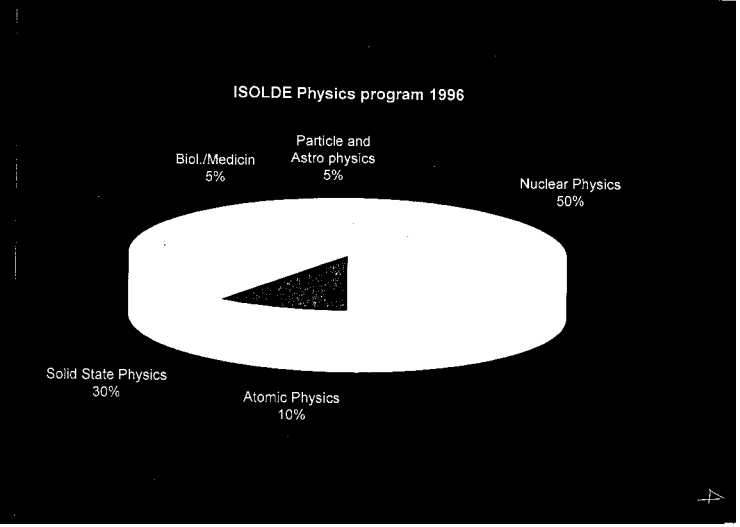


Note:

- Not to Scale
- Reuse of infrastructure

CERN ACCELERATORS




ISOLDE Physics program 1996
Biol./Medicin
5%
Particle and
Astro physics
5%
Nuclear Physics
50%
Solid State Physics
30%
Atomic Physics
10%

LEAR

Stops at end of 1996

- Spectroscopy Crystal Barrel, OBELIX } glueballs?
- CP Leav (completed)
- Traps (CPT...) PS196, PS200, PS205.....

Future?

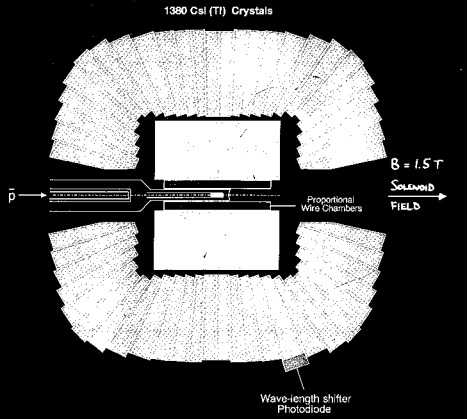
Antiproton **D**ecelerator

6

Crystal Barrel

Electromagnetic Calorimeter

1380 CsI (Tl) Crystals



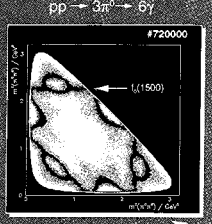
γ: $\sigma_E/E = 2.7\%$ [1 GeV]

$\pi^\pm/K^\pm$: $\sigma_p/p \approx 6\%$ [0.5 GeV]

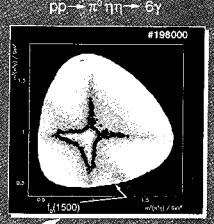
Crystal Barrel Dalitz Plots

Search for the scalar glueball

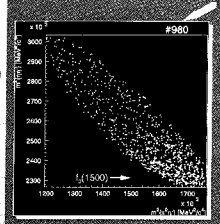
$p\bar{p} \to 3\pi^0 \to 6\gamma$



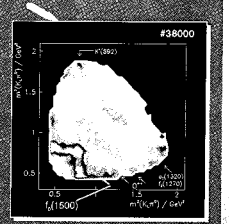
$p\bar{p} \to \pi^0\eta\eta \to 6\gamma$



$p\bar{p} \to f_0(1500)\,\pi^0$

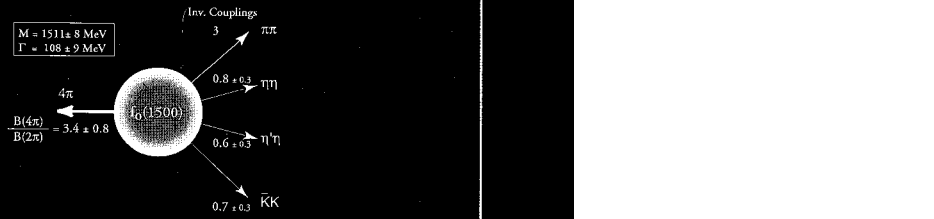


$p\bar{p} \to \pi^0\eta\eta' \to 6\gamma$



$pp \to K_S K_S \pi^0 \to 3\gamma$

$f_0(1500)$ Decay Properties



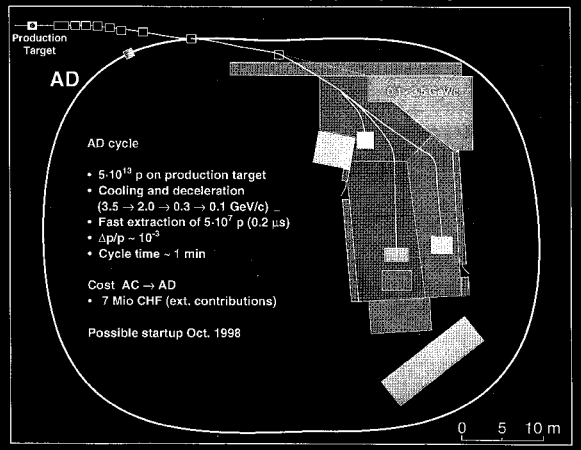
- 4π decay dominates ($\sigma\sigma$, $\pi\pi(1300)$)
- $\Gamma(f_0(1500) \to 4\pi, \pi\pi) \approx 100$ MeV, $\quad \Gamma(f_0(1500) \to \eta\eta, \eta\eta', K\bar{K}) \approx$ 15 MeV — LIGHT QUARK DECAY $\gg s\bar{s}$
- $\Gamma(f_0(1500) \to \pi\pi) \approx 20$ - 30 MeV ! Reminder: expect $\Gamma(f_0(n\bar{n}) \to \pi\pi) \sim$ 200 MeV
- Strong coupling to light quarks & Weak coupling to strange quarks
  (but: $\neq n\bar{n}$) ($\neq s\bar{s}$)

Which Scalar Resonance is the Glueball ?

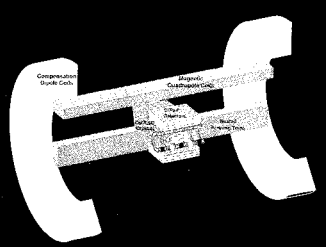
"n" = u,d

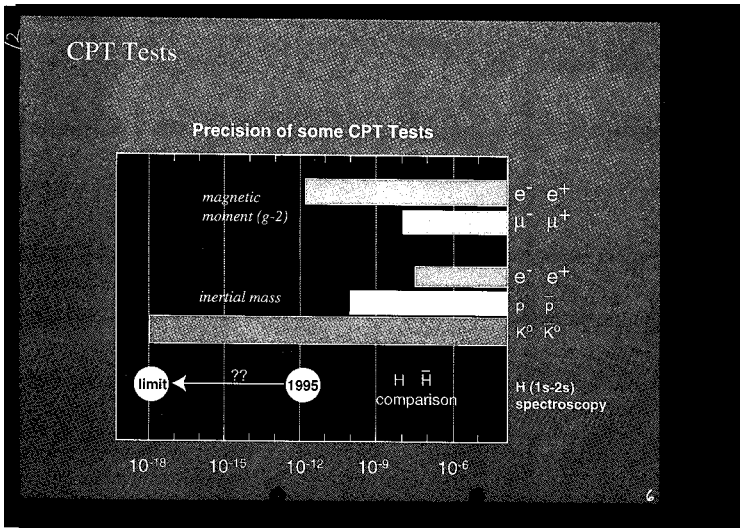
Resonance	Width [MeV]	Decay Modes	Seen in $J/\psi \to \gamma X$	Seen in $\bar{p}p$ ann.	Seen in Cent. Prod.	NOT seen in $\gamma\gamma$	Tentative Classific.
$f_0(980)$	~ 50	$K\bar{K}$, $\pi\pi$	☹	☑	☑	☹	$s\bar{s}$
$f_0(1000)$	~ 500	$\pi\pi$ dominant	☹	☑	?	☑	$n\bar{n}$
$f_0(1300)$	~ 200-300	$\pi\pi$, $K\bar{K}$, $\eta\eta$ (4π)	?	☑	☑	☹	$n\bar{n}$ (+ glue)
$f_0(1500)$	~ 110	4π, $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$	☑	☑	☑	☑	glue (+ $n\bar{n}$)
$f_0(1710)$	~ 180	4π, $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$	☑	?	☑	☑	glue (+ $s\bar{s}$)
$f_0(1780)$	~ 120	4π, $K\bar{K}$, $\pi\pi$	☑	?	?	☹	$s\bar{s}$

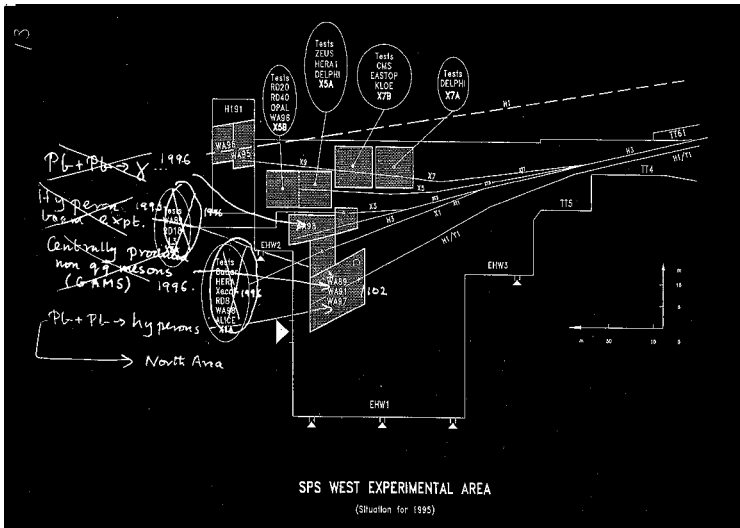
Antiproton Decelerator (AD) - Project Study



ATHENA - Antihydrogen Recombination Trap and Detector




CPT Tests
Precision of some CPT Tests
magnetic moment (g-2)
inertial mass
e⁻ e⁺
μ⁻ μ⁺
e⁻ e⁺
p p̄
K⁰ K̄⁰
limit
??
1995
H H̄ comparison
H (1s-2s) spectroscopy
10⁻¹⁸
10⁻¹⁵
10⁻¹²
10⁻⁹
10⁻⁶



SPS WEST EXPERIMENTAL AREA

(Situation for 1995)

Search for Neutrino Oscillations

- CHORUS & NOMAD
  - Search for $\nu_\mu \to \nu_\tau$ in very interesting region ($\delta m^2 \gtrsim 10\,eV^2$; $\theta_{\mu\tau} \sim \theta_{lep}$) →
  - Take data through 1997, results soon

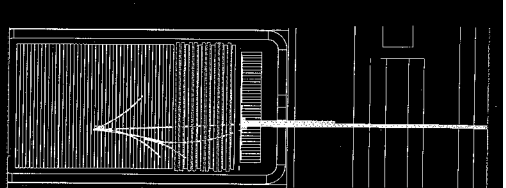
Future possibilities, being kept open:

- Further experiment(s) behind West Area
- Long baseline experiment:

  beam: SPS → nearby detector → Gran Sasso (730 km)

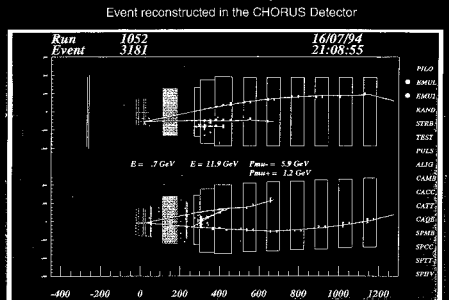
  ICARUS (TRICH, GENIUS, NOE ... ?)

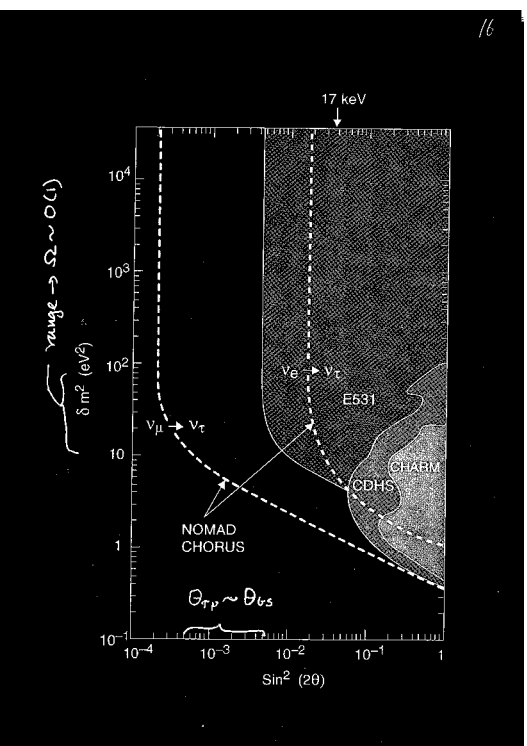
EVENEMENT RECONSTRUIT DANS "NOMAD"

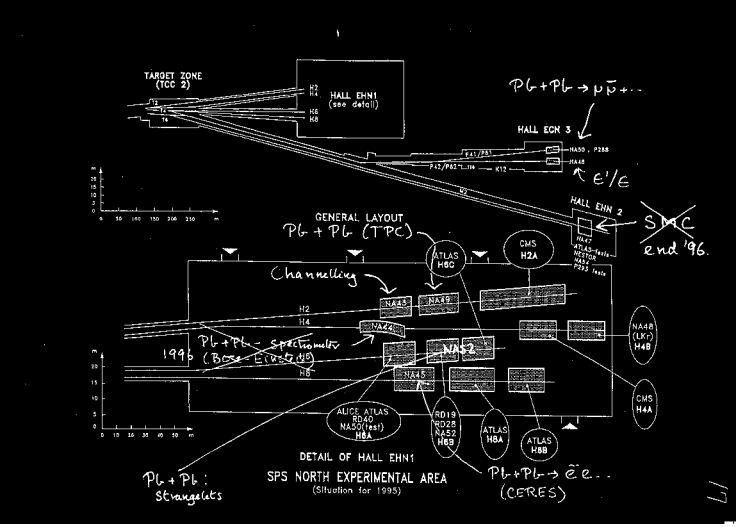


EVENEMENT RECONSTRUIT DANS "CHORUS"

Event reconstructed in the CHORUS Detector




17 keV
10^4
10^3
10^2
10
1
10^{-1}
δm^2 (eV^2)
$\nu_e \to \nu_\tau$
E531
$\nu_\mu \to \nu_\tau$
CHARM
CDHS
NOMAD
CHORUS
$\theta_{\tau\mu} \sim \theta_{Gs}$
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$\sin^2(2\theta)$


TARGET ZONE
(TCC 2)
HALL EHN1
(see detail)
Pb+Pb → μ μ̄ + ..
HALL ECN 3
NA50 , P288
NA48
ε'/ε
HALL EHN 2
SMC
end '96.
GENERAL LAYOUT
Pb + Pb (TPC)
ATLAS
H6C
CMS
H2A
Channelling
NA45
NA49
NA48
(LKr)
H4B
Pb+Pb - spectrometer
1996 (Bose-Einstein)
NA52
NA45
CMS
H4A
ALICE ATLAS
RD40
NA50(test)
H6A
RD19
RD28
NA52
H6B
ATLAS
H8A
ATLAS
H8B
DETAIL OF HALL EHN1
SPS NORTH EXPERIMENTAL AREA
(Situation for 1995)
Pb + Pb :
Strangelets
Pb+Pb → ē e ..
(CERES)

CP Violation (ϵ'/ϵ)

NA48 - K_L, K_S beams + spectrometer (π^+, π^-, γs)

- tests very successful

- Data taking starts 1997

hope $\rightarrow \frac{\epsilon'}{\epsilon} \sim 10^{-4}$

NA48

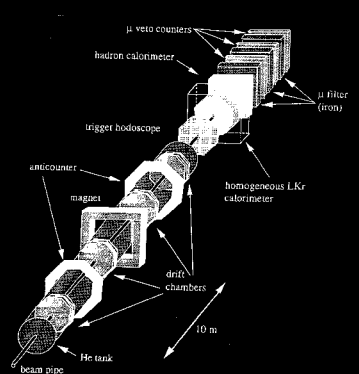


Figure 1: Perspective view of the NA48 detector

COMPASS proposal

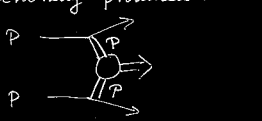
for a COmmon Muon and Proton Apparatus for Structure and Spectroscopy

detector ~ recovery of old equipment + funding from outside CERN

- gluon polarisation from $\vec{\mu} + \vec{P} \to \mu + C + \cdots$

$\Rightarrow \delta\left(\frac{\Delta G}{G}\right) \sim 0.1$

- Centrally produced mesons / glueballs

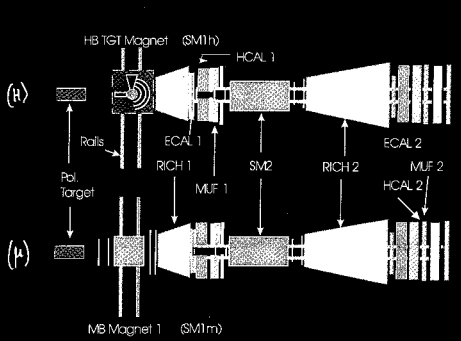


- Charm production

100 days run $\longrightarrow$ 5.5×10^5 reconstructed charm particles

$\to 100$ ($c\bar{c}q$)

HADRON PROGRAM CONFIGURATION

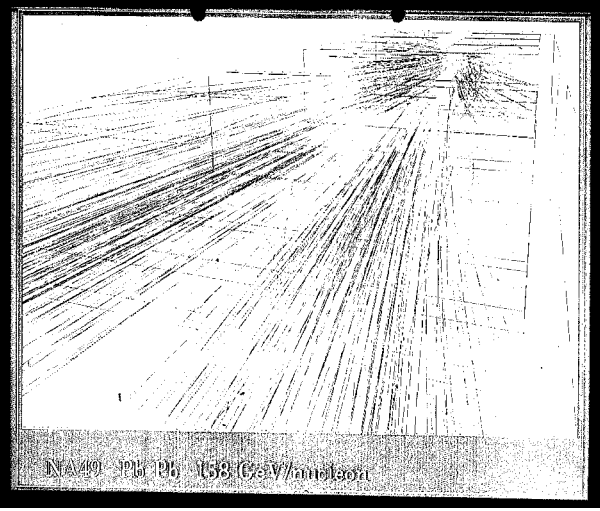


MUON PROGRAM CONFIGURATION

Heavy Ions

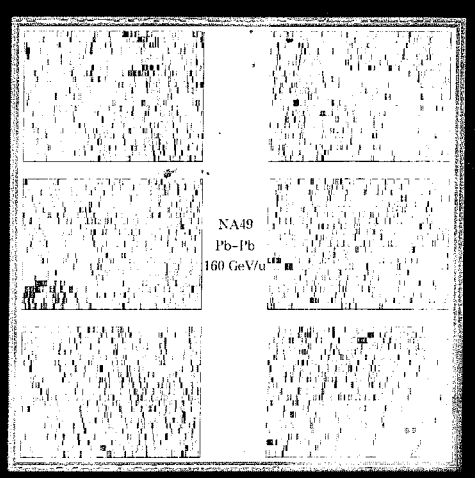
Results of first major Pb + Pb run, at 160 GeV/nucleon, in 1995:

- experiments working well — e.g. NA49 →
- exciting hints
  - $\bar{e}e$ spectrum (CERES) → ρ broadening / shift.
  - $\frac{\Omega + \bar{\Omega}}{\Xi + \bar{\Xi}}$ much bigger in Pb + Pb than in p + Pb (WA97)
  - J/ψ suppression much greater in Pb + Pb than S + U (NA50) →


NA49 Pb Pb 158 GeV/nucleon

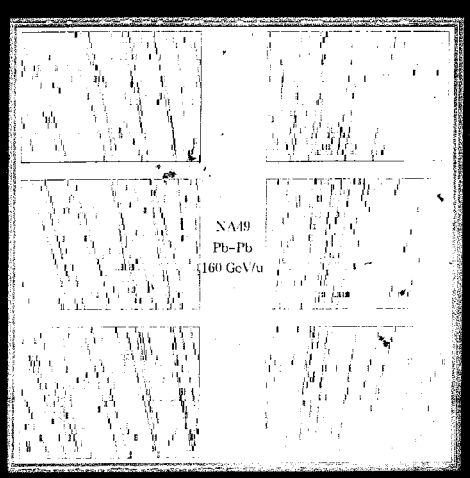
NA 49 TPC

~ 20cm slice



NA 49 TPC

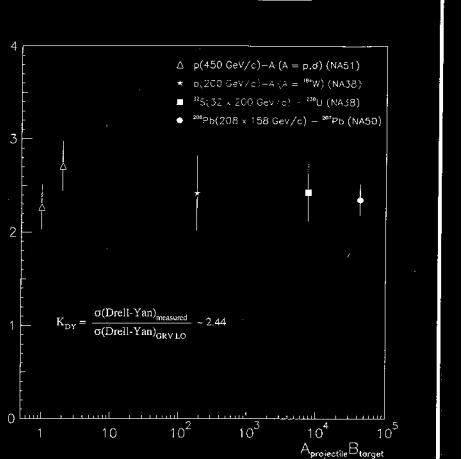
~ 5 cm slice

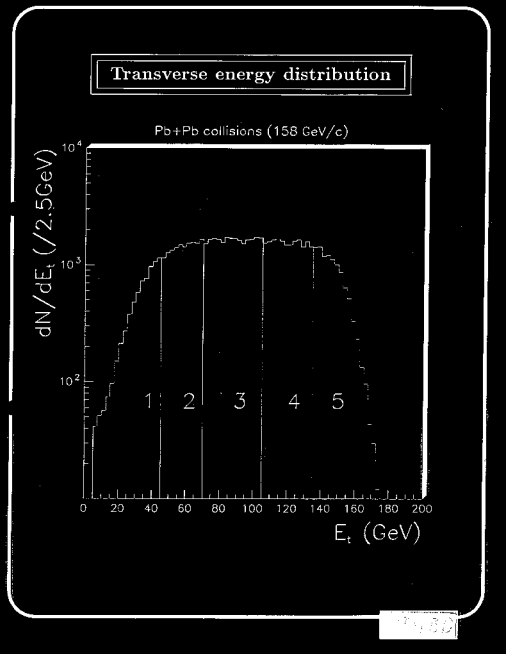


beam horoscope
active target
multiplicity
e-m calo
0m
4m
6m
12m
16m
magnet
R1
R2
R3
R4, R5
NA50

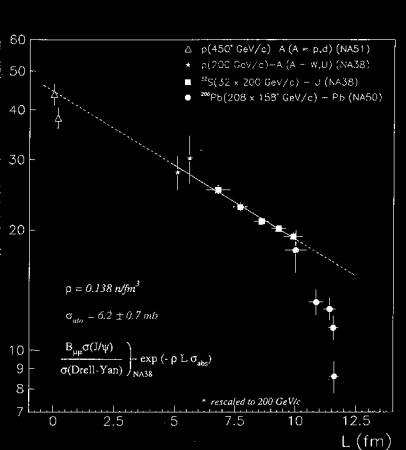
△ p(450 GeV/c)–A (A = p,d,C,Al,Cu,W) (NA51,NA38)
★ p(200 GeV/c)–A (A = Cu,W,U) (NA38)
▲ ¹⁶O(15 x 200 GeV/c) – Cu, U (NA38)
■ ³²S(32 x 200 GeV/c) – U (NA38)
● ²⁰⁸Pb(208 x 158 GeV/c) – Pb (NA50)
$B_{\mu\mu}\sigma(J/\psi)/(A_{projectile}B_{target})$ (nb/nucleon²)
$B_{\mu\mu}\sigma(J/\psi)_{NA38} \sim (A_{projectile}B_{target})^{0.91}$
* rescaled to 200 GeV/c
$A_{projectile}B_{target}$

Drell-Yan K factors




Transverse energy distribution
Pb+Pb collisions (158 GeV/c)
dN/dE$_t$ (/2.5GeV)
10^4
10^3
10^2
1
2
3
4
5
0
20
40
60
80
100
120
140
160
180
200
E$_t$ (GeV)

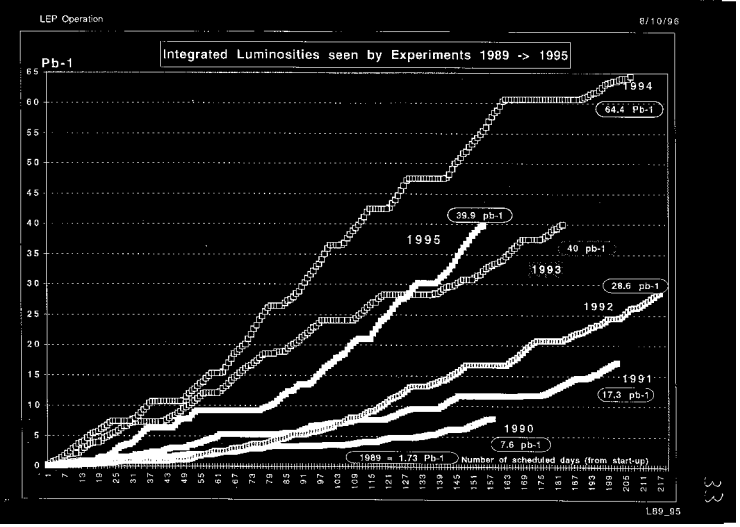
(J/ψ)/Drell-Yan ratios



LEP

Achieved integrated luminosity per interaction point

- at Z° sum over the years 1989 to 1996: $\int Ldt = 200\ pb^{-1}$
- at $\sqrt{s}$ = 130 to 140 GeV in Autumn 1995: $\int Ldt = 6.3\ pb^{-1}$
- at $\sqrt{s}$ = 161 GeV in Summer 1996: $\int Ldt = 12.1\ pb^{-1}$


LEP Operation
8/10/96
Integrated Luminosities seen by Experiments 1989 -> 1995
Pb-1
1994
64.4 Pb-1
39.9 pb-1
1995
40 pb-1
1993
28.6 pb-1
1992
1991
17.3 pb-1
1990
7.6 pb-1
1989 = 1.73 Pb-1
Number of scheduled days (from start-up)
LB9_95

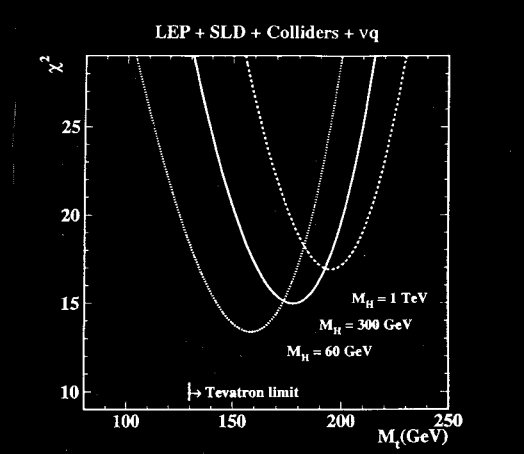
Precision tests of the Standard Model at LEP:

→ Born approximation predictions for $\Gamma_{Z \to F\bar{F}}$, forward / backward asymmetries

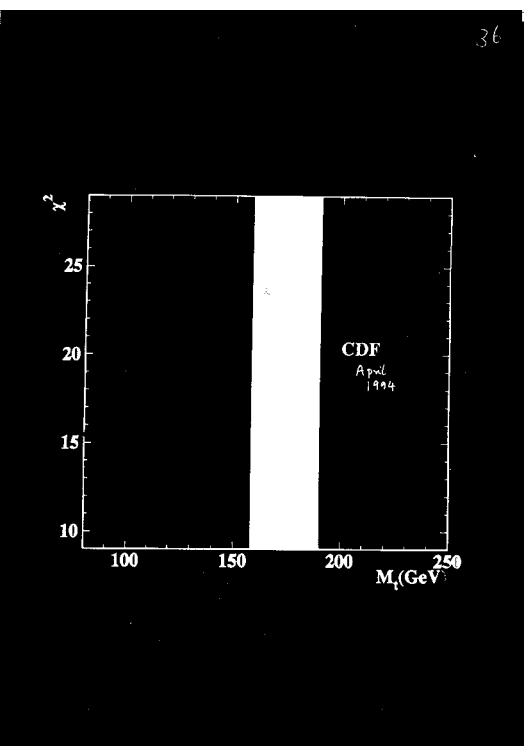
$O\left(\frac{\alpha_{weak}}{\pi}\right)$ corrections

→ sensitive to m_t, m_H

→ many consistency checks → "Lamb shift" of electroweak theory


LEP + SLD + Colliders + νq
χ²
25
20
15
10
100
150
200
250
M_t(GeV)
M_H = 1 TeV
M_H = 300 GeV
M_H = 60 GeV
Tevatron limit

March 1994

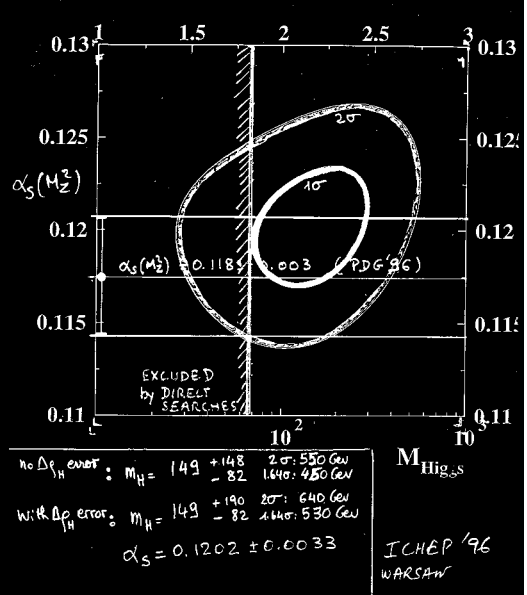

χ^2
25
20
15
10
CDF
April
1994
100
150
200
250
M_t(GeV

MSM fit all data

All data LEP/SLD/CDF/DØ/νN

except α_s and m_H PRELIMINARY

PDG AVERAGE, DOES NOT INCLUDE Z-pseudo data

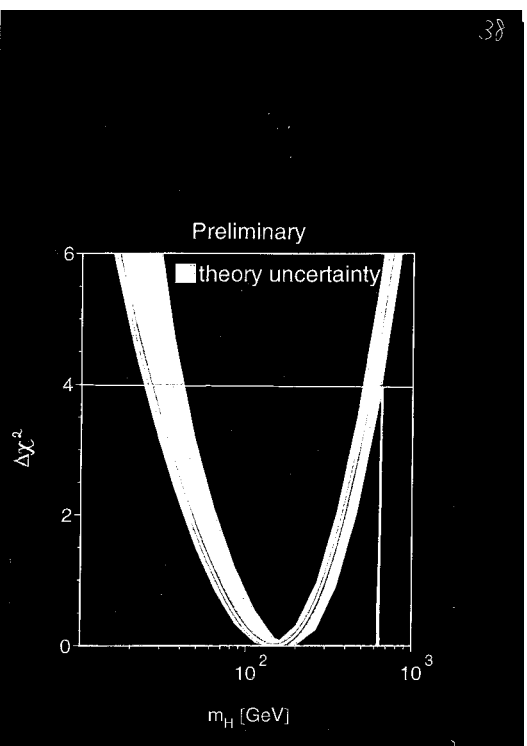


no $\Delta\rho_H$ error: $m_H = 149^{+148}_{-82}$ 2σ: 550 GeV, 1640: 450 GeV

With $\Delta\rho_H$ error: $m_H = 149^{+190}_{-82}$ 2σ: 640 GeV, 1640: 530 GeV

$\alpha_s = 0.1202 \pm 0.0033$

ICHEP '96
WARSAW


Preliminary
theory uncertainty
6
4
2
0
$\Delta\chi^2$
10^2
10^3
m_H [GeV]

Generally : M_H obtained from LEP data can be interpreted as cut-off scale (Λ) beyond which the physics responsible for $M_{W,Z} \neq 0$ cannot be ignored

Effective theory = (Std. model - Higgs) ← part that is tested
+ "elementary" masses for W and Z
valid for $E \lesssim \Lambda$
$\Longrightarrow$ Predictions $\approx$ Std model predictions with $\ln M_H \to \ln \Lambda$

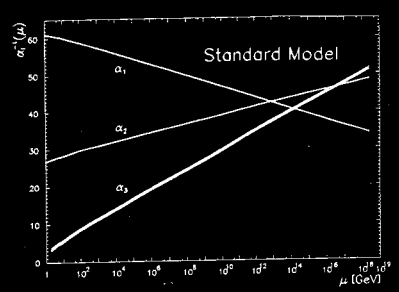


Figure 2. Evolution of the inverse of the three couplings in the minimal SM.

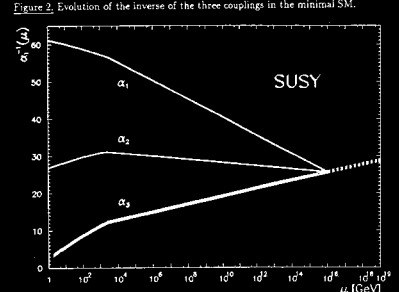


Figure 3. Evolution of the inverse of the three couplings in the MSSM. The line above M_{GUT} follows the prediction from the supersymmetric SU(5) model.

LEP2

Period	Ecm (GeV)	Int.L. per IP (pb-1)	Cavities SC	Cavities NC
Summer 1996	161	12.1	144	120
Autumn 1996	172	≥ 10 *)	176	120
1997	188	500 *)	240	86
1998	192		272	52
1999	192		272	52

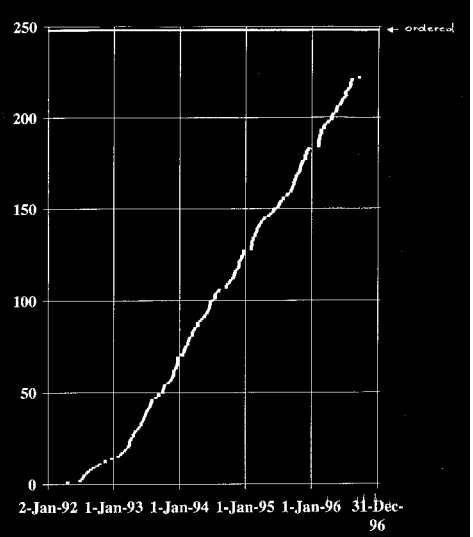
*) goal

RECEPTIO Chart 1

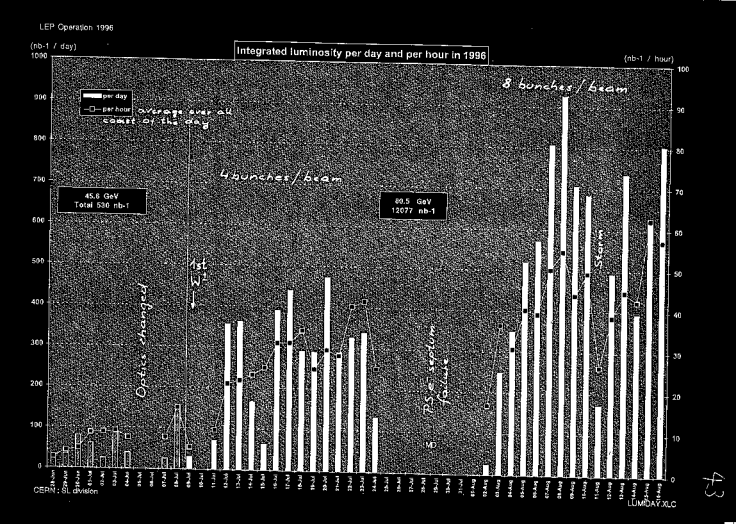
LEP 2

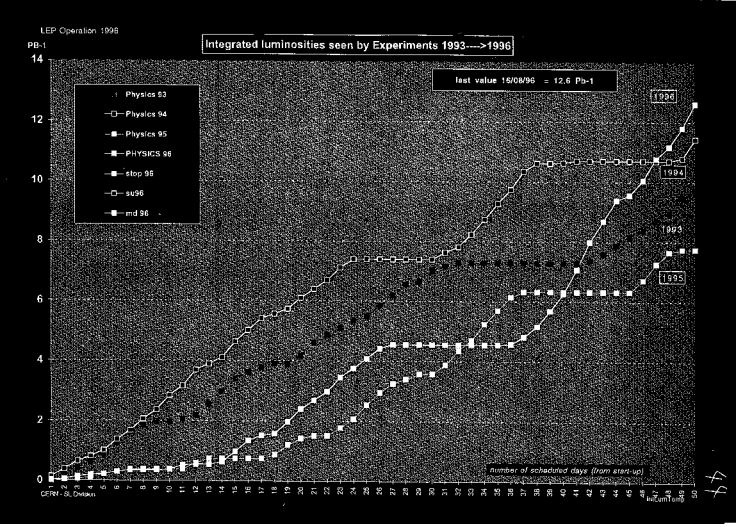
Total number of accepted cavities

Nb - film



1/10/96


LEP Operation 1996
Integrated luminosity per day and per hour in 1996
(nb-1 / day)
(nb-1 / hour)
per day
per hour
average over all coast of the day
8 bunches / beam
4 bunches / beam
45.6 GeV
Total 530 nb-1
60.5 GeV
12077 nb-1
1st W±
Optics changed
PS e- septum failure
Storm
CERN : SL division
LUMIDAY.XLC


LEP Operation 1996
PB-1
Integrated luminosities seen by Experiments 1993---->1996
last value 16/08/96 = 12.6 Pb-1
Physics 93
Physics 94
Physics 95
PHYSICS 96
stop 96
su96
md 96
1996
1994
1993
1995
number of scheduled days (from start-up)
CERN - SL Division

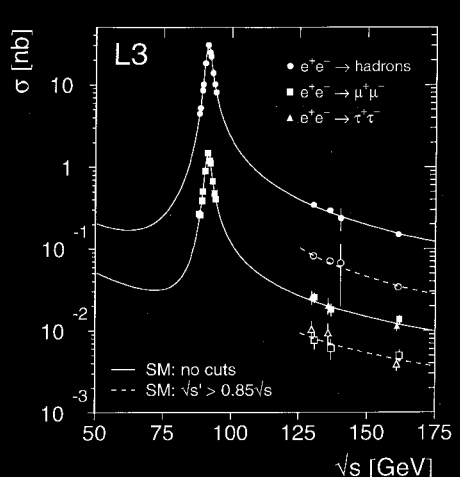
LEP2 Results

- Very clean experimental conditions
- Dominant processes is "return to the Z": $e^+e^- \to Z\gamma$
  - each experiment has > 1000 events with $Z \to$ hadrons

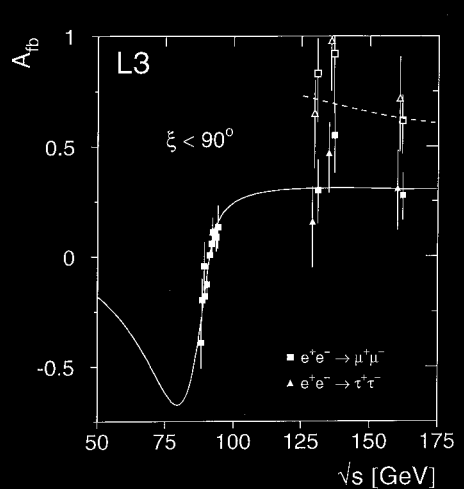
  Note: $e^+e^- \to Z\gamma^{*}/Z^{*} \to \ldots$
  $\hookrightarrow \nu\bar{\nu}$

  is important background for new particle searches
- Each experiment has ~ 300 e^+e^- direct hadron events and ~ 30 WW events

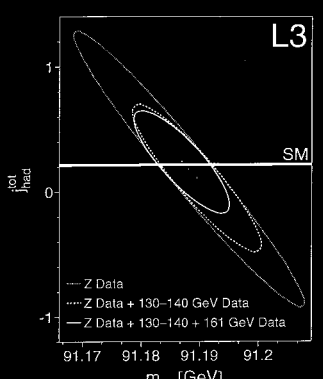
Fermion Pair Cross Sections



Fermion Pair Asymmetries

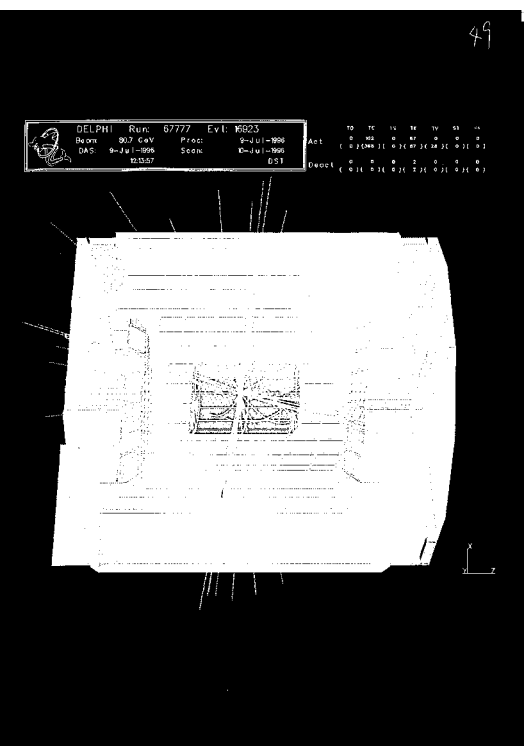


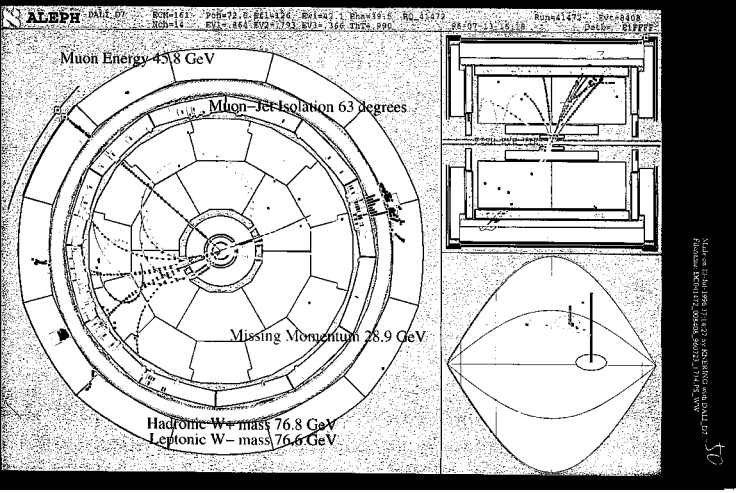
Hadronic Interference Term



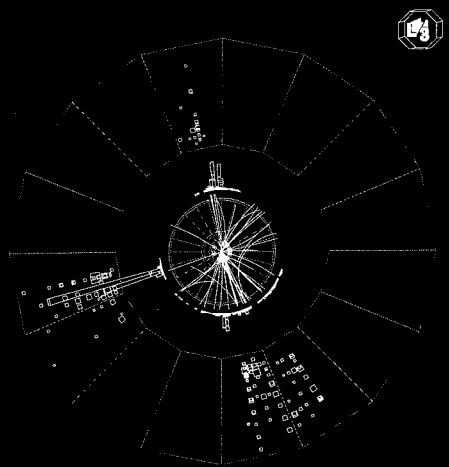
Data	j^{tot}_{had}	M_Z
LEP 1	0.18 ± 0.73	$91188. \pm 13.$
LEP 1 + 140	0.11 ± 0.39	91189.6 ± 7.3
LEP 1 + 140 + 160	0.24 ± 0.27	91187.0 ± 5.4

SM: 0.21


49
DELPHI Run: 67777 Evt: 16823
Beam: 80.7 GeV
DAS: 9-Jul-1996
12:13:57
Proc: 9-Jul-1996
Scan: 10-Jul-1996
DST
Act
Deact


ALEPH
Muon Energy 45.8 GeV
Muon–Jet Isolation 63 degrees
Missing Momentum 28.9 GeV
Hadronic W+ mass 76.8 GeV
Leptonic W– mass 76.6 GeV

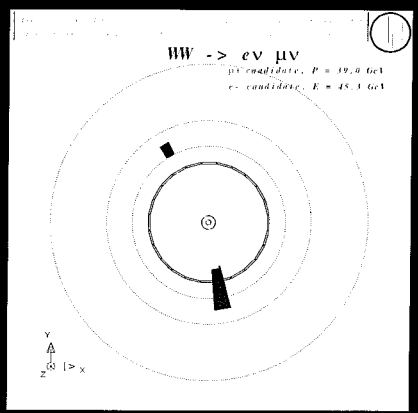
$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'\tau\nu$



Efficiency: 39.6%
Selected events: 1

Background: 259 fb

$W^+W^- \to \ell^- \bar{\nu}_\ell \ell'^+ \nu_{\ell'}$ Event Selection



2 acoplanar "jets", low multiplicity, missing momentum

- Kinematic cuts on $\sum p_T$, $E_{\rm jet}$...specific to final state (ee, $\mu\mu$, $\tau\tau$, $e\mu$, $e\tau$, $\mu\tau$)
- 2 charged, ≤ 1 neutral cone jets, allows $\ell^- \bar{\nu}_\ell \ell'^+ \nu_{\ell'}(\gamma)$
- veto forward $\mu^\pm$, net charge, ISR γ

Goals of LEP2 (I)

- Measure M_W

σ at threshold $\Delta M_W \sim 90 \sqrt{\frac{100\,pb^{-1}}{\int \mathcal{L}\,dt}}$ MeV

4 expts. → reconstruction $\Delta M_W \sim 50 \sqrt{\frac{100\,pb^{-1}}{\int \mathcal{L}\,dt}}$ MeV

- WWZ/γ vertex – nothing significant yet
- Higgs

Standard: LEP1 excluded: $0 < M_H < 65$ GV

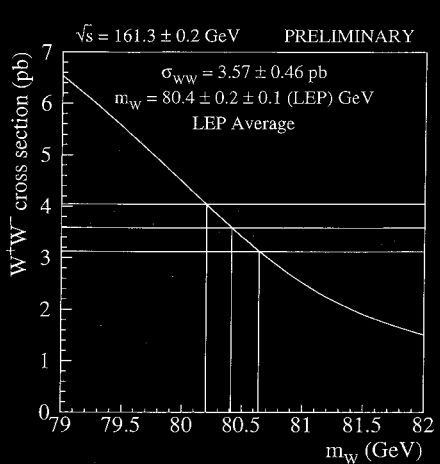
LEP2 will find to 95–98 GV

→ Limits not (yet) improved: candidates exist, but have other explanations →

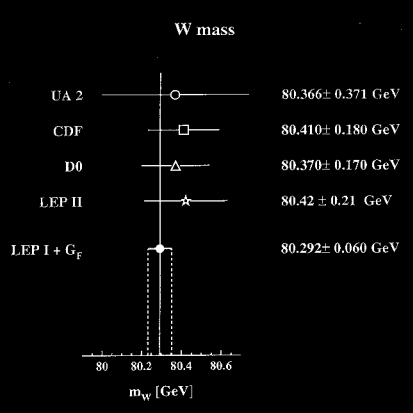
Minimal SUSY:

LEP1 excluded part of param. space

LEP2 would discover in large region

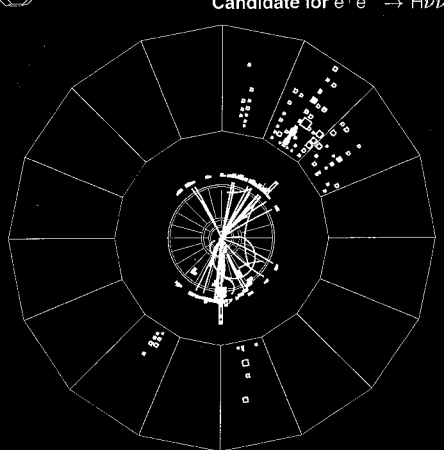


LEPC 8 Oct 96
LEP EW Working Group

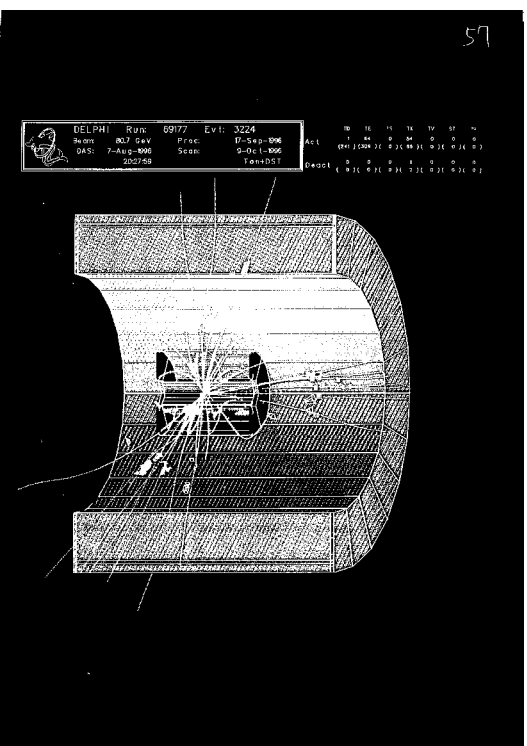

W mass
UA 2
CDF
D0
LEP II
LEP I + G_F
80.366± 0.371 GeV
80.410± 0.180 GeV
80.370± 0.170 GeV
80.42 ± 0.21 GeV
80.292± 0.060 GeV
80
80.2
80.4
80.6
m_W [GeV]

SM Higgs and Other Higgses

Candidate for $e^+e^- \to H\nu\nu$



$E_{vis} = 78.4$**GeV,** $M_{vis} = 73.2 \pm 8$**GeV,** $M_{mis} = 78.1$**GeV**
$D_{btag} = 0.232$, **very unlikely to be a** $b\bar{b}$


DELPHI Run: 69177 Evt: 3224
Beam: 80.7 GeV Proc: 17-Sep-1996
DAS: 7-Aug-1996 Scan: 9-Oct-1996
202759 Ten+DST

Goals of LE2 (II)

- Search for SUSY

$e^+e^- \to \tilde{\chi}^+\tilde{\chi}^-$
- $\to \tilde{\chi}_1^0 f\bar{f}'$
- $\to \tilde{l}\,\tilde{\nu}$ } if kinematically allowed
- $\to \tilde{\nu}\,\tilde{l}$ }

$\to \tilde{\chi}_1^0\,\tilde{\chi}_2^0$
- $\to \tilde{\chi}_1^0 f\bar{f}'$

$\to \tilde{e}^+\tilde{e}^-$
- $\to e\,\tilde{\chi}_1^0$
- $\to \tilde{G}\gamma$ { Possibility invoked to explain CDF $e^+e^-\gamma\gamma\not{E}_T$ event

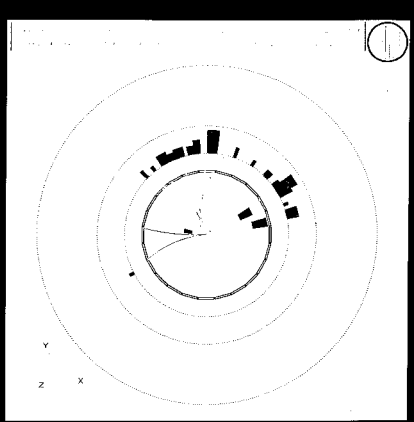
Candidates found, but have other explanations →

New limits in MSSM, e.g.

$M_{\tilde{\chi}^\pm} > 79$ GV ($m_{\tilde{\nu}} > 200$ GV)
> 60 GV ($m_{\tilde{\nu}} \sim 60$ GV)

$M_{\tilde{\chi}_0} > 20.4$ GV ($m_{\tilde{\nu}} = 200$ GV, but limit for all masses) →
$m_{\tilde{e}} > 71.8$ GV, ALEPH
$m_{\tilde{\mu}} > 52.0$ GV

$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$ Candidate

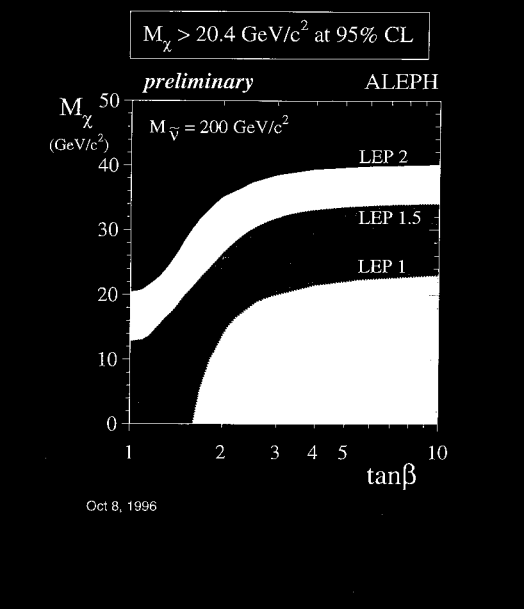


- Recoil mass = 99 GeV, visible energy = 55 GeV
- Missing transverse momentum = 39 GeV
- Also selected as: $\mathrm{L}^+\mathrm{L}^-, \tilde{t} \to \mathrm{b}\ell^+\tilde{\nu}, \ldots$

60
DELPHI Run: 68301 Evt: 1680
Beam 80.7 GeV Proc: 13-Aug-1996
DAS: 17-Jul-1996 Scan: 24-Sep-1996
194944 Tane4DST
Act
Deact

Made on 24-Sep-1996 17:56:53 by schmitm with DALI_D6.
Filename: DC041587_001866_960924_1756.PS

61


$M_\chi > 20.4$ GeV/c^2 at 95% CL
preliminary
ALEPH
M_χ (GeV/c^2)
$M_{\tilde{\nu}} = 200$ GeV/c^2
LEP 2
LEP 1.5
LEP 1
50
40
30
20
10
0
1
2
3
4
5
10
tanβ
Oct 8, 1996

LHC

- **Machine** – excellent progress → L Evans
- **Detectors** – excellent progress → L Foà
- **Timetable:**

The LHC was approved in Dec 1994 as a "missing money / magnet" machine
→ 2/3 Emax in 2004 → Emax in 2008
- not important for t_3, b_3 ions
- reach < 2/3 full reach for susy, W_3, Z', ...
- much worse for Higgs

- Obviously want → Emax directly

→ Seeking contributions from major Non-Member States that are involved in LHC experiments to speed up the Project

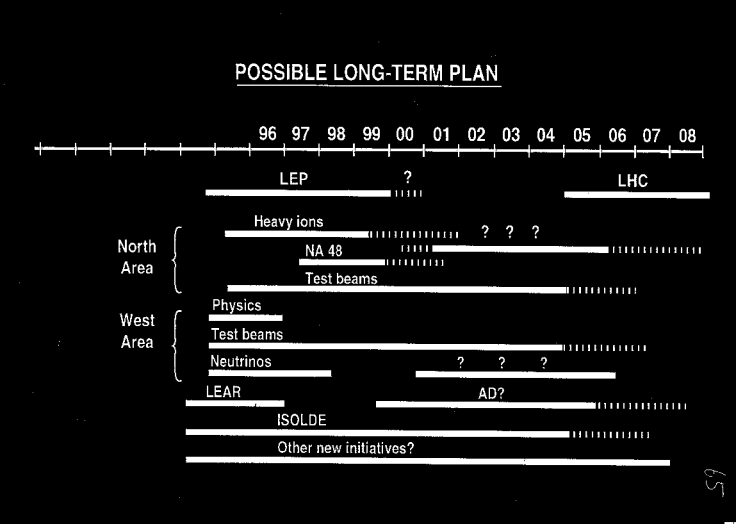
Optimistic that these contributions will reach 450 MCHF which with CERN Member State funding agreed in 1994 will allow the LHC to be completed in one step in 2005. However

Single stage (2005) construction of the LHC is not yet agreed, and additional uncertainty has been created by Germany's recent request to contribute less to CERN

The question of the German request, and its knock-on effects, has not yet been resolved, but following a first discussion on 26/9/96

"The CERN Member States reaffirmed their strong and unanimous support for the Large Hadron Collider Programme, and their wish to find a quick and stable solution to the budget problem which will allow the LHC to be completed in a single stage as early as possible"

Optimistic that this will happen


POSSIBLE LONG-TERM PLAN
96 97 98 99 00 01 02 03 04 05 06 07 08
LEP
?
LHC
North Area
Heavy ions
? ? ?
NA 48
Test beams
West Area
Physics
Test beams
Neutrinos
? ? ?
LEAR
AD?
ISOLDE
Other new initiatives?