INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

13 June - 29 July 1994

RECENT PRECISION ELECTROWEAK RESULTS FROM LEP

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and
CERN, Geneva

Please note: These are preliminary notes intended for internal distribution only.

RECENT PRECISION ELECTROWEAK RESULTS FROM LEP

TRIESTE, 7/7/94

M. KORATZINOS / UNIVERSITY OF OSLO

OUTLINE

- LEP
- PHYSICS ,MOTIVATION
- LEP ENERGY
- 1993 SCAN
- MAIN RESULTS
- S.M. FITS – m_{top} / m_{Higgs}
- CONCLUSIONS

LEP

LEP IS CERN's LARGE ELECTRON-POSITRON COLLIDER

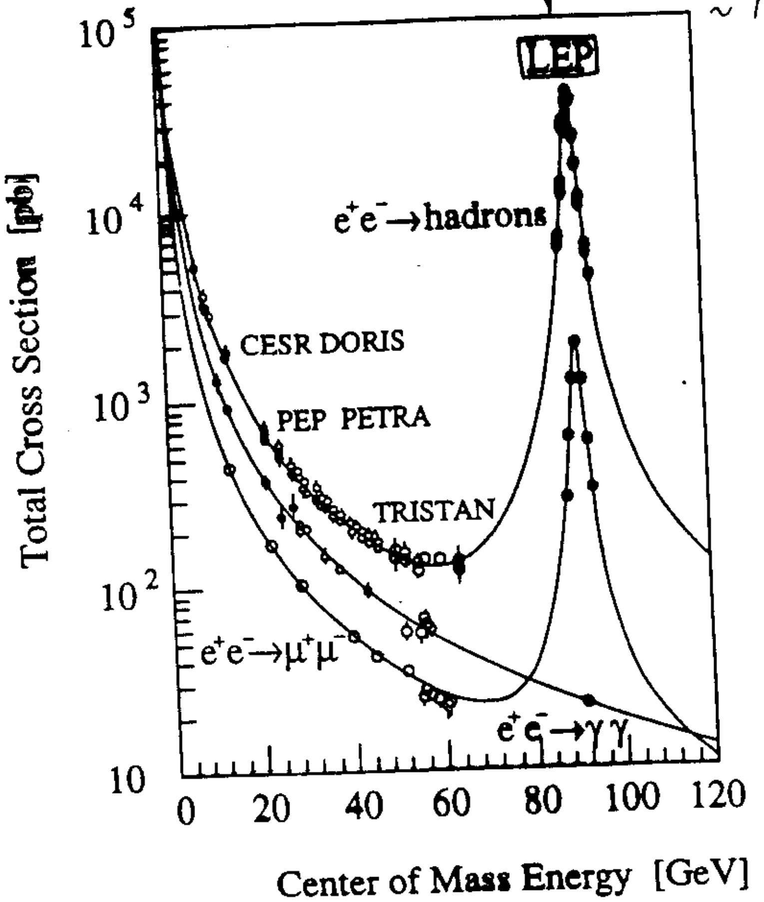
CIRCUMFERENCE : 27 kms

LEP I . ENERGY ≈ 90GeV (M_Z)

xSECTION ≈ 30nb (HADRONS)

- FOUR EXPERIMENTS ≣
- LEP I CAPABLE OF PRODUCING ~ 1M Z° / EXPERIMENT / YEAR

enhancement factor $\sim \left(\frac{M_Z}{\Gamma_Z}\right)^2 \sim 10^3$

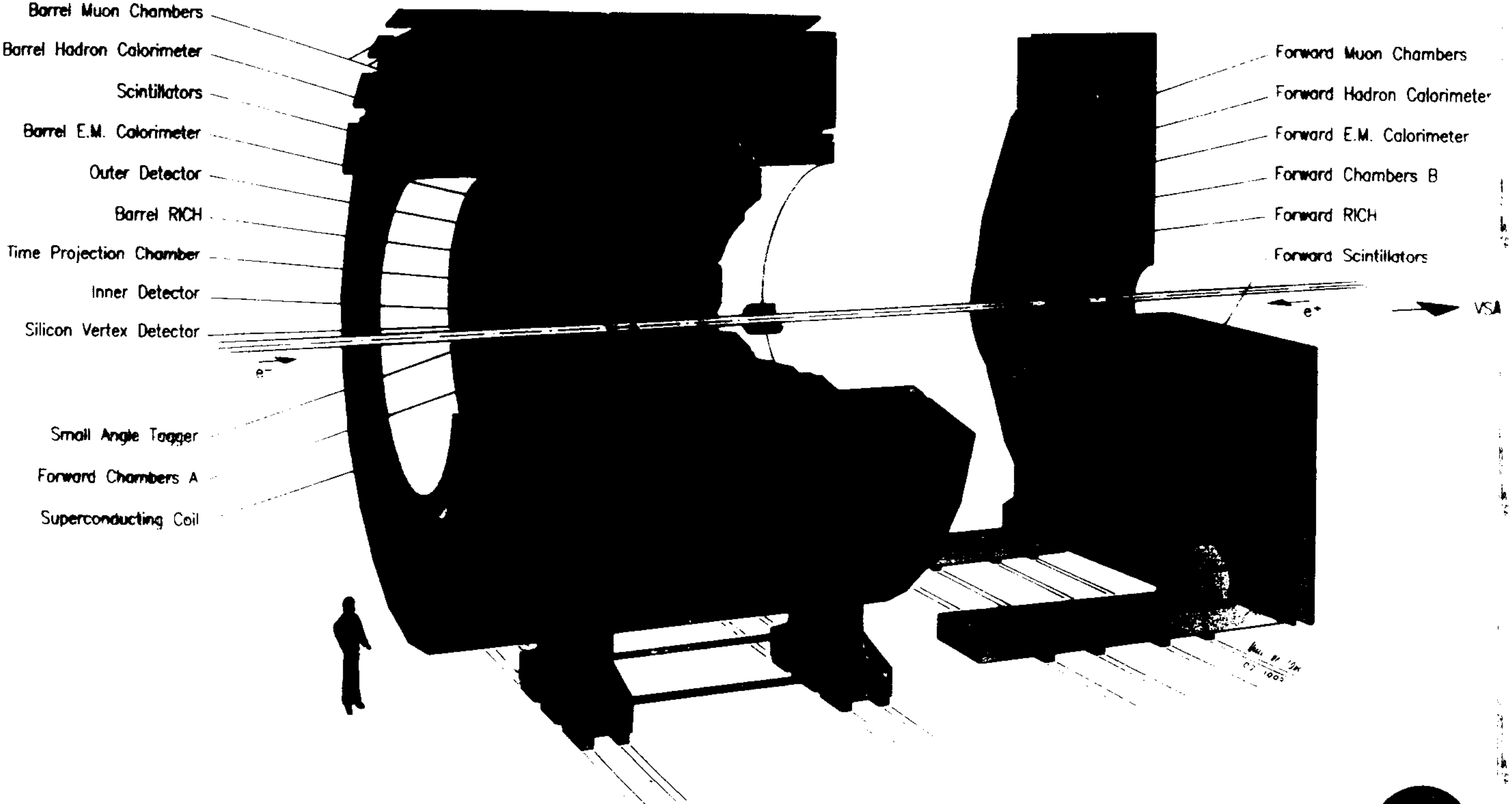


$$Br(Z \longrightarrow \text{hadrons}) = \frac{\Gamma_h}{\Gamma_Z} \simeq 70\% \quad \left(\Gamma_h = \sum_q \Gamma_q\right)$$

highest stat.

$$Br(Z \longrightarrow \ell^+\ell^-) = \frac{\Gamma_e + \Gamma_\mu + \Gamma_\tau}{\Gamma_Z} \simeq 10\%$$

$$Br(Z \longrightarrow \nu\bar{\nu}) = \frac{\Gamma_{\nu_e} + \Gamma_{\nu_\mu} + \Gamma_{\nu_\tau}}{\Gamma_Z} \simeq 20\%$$


Barrel Muon Chambers
Barrel Hadron Calorimeter
Scintillators
Barrel E.M. Calorimeter
Outer Detector
Barrel RICH
Time Projection Chamber
Inner Detector
Silicon Vertex Detector
e⁻
Small Angle Tagger
Forward Chambers A
Superconducting Coil
Forward Muon Chambers
Forward Hadron Calorimeter
Forward E.M. Calorimeter
Forward Chambers B
Forward RICH
Forward Scintillators
e⁺
VSAT

DELPHI

PHYSICS MOTIVATION

STANDARD MODEL: ASSUMPTIONS + SET OF INPUT PARAMETERS

⟹ DERIVE PREDICTIONS ON ALL OBSERVABLES

∴ A SET OF ACCURATE MEASUREMENS CAN PROBE S.M. ASSUMPTIONS AND/OR SET LIMITS TO (UNKNOWN) INPUT PARAMETERS TO THE S.M.

LEP CAN PROVIDE THIS SET OF ACCURATE MEASUREMENTS

WHAT CAN WE MEASURE?

(MINIMAL) STANDARD MODEL:

VERY SUCCESSFUL, ALTHOUGH INTUITIVELY UNCOMFORTABLE.

INPUTS: MSM INVOLVES:

known to

- 9 FERMION MASSES ---→ m_{top} ?
- 4 CKM MIXING MATRIX ELEMENTS
- 1 HIGGS ---→ m_H ?

--- PUT LIMITS

- 4 PARAMETERS TO DETERMINE ALL GAUGE BOSON MASSES AND COUPLINGS TO FERMIONS

α_{EM} $\sim 10^{-8}$ (e^- CHARGE)

G_F $\sim 10^{-5}$ (μ DECAY)

IMPROVE --→ M_Z $\sim 6\times 10^{-5}$ (LEP 93)

IMPROVE --→ α_s $\sim 5\%$ (LEP 93)

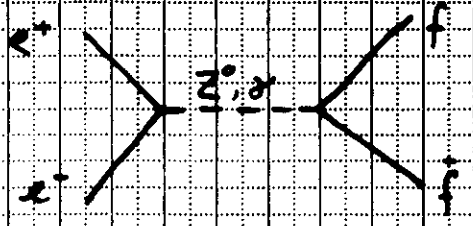
- N FAMILIES

CHECK --→ N_ν $= 3$ (LEP)

POSTULATES: UNIVERSALITY $\sim 1\%$ (LEP)

PREDICTIONS: ON ALL LEP OBSERVABLES!

FUNDAMENTAL PROCESS AT LEP



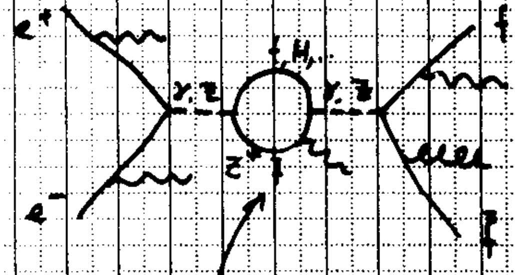
TO LOWEST ORDER:

Dominated at $\sqrt{s} \sim M_Z$

$$\sigma_f(s) \simeq \underbrace{\frac{4\pi\alpha^2 N_c^f e_f^2}{3s}}_{\gamma} + \underbrace{12\pi \frac{\Gamma_e \Gamma_f}{M_Z^2} \frac{s}{(s-M_Z^2)+M_Z^2\Gamma_Z^2}}_{Z^0} \Big[1+\epsilon$$

$+ \gamma Z$ interference

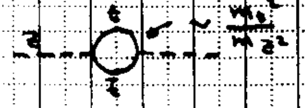
BUT IN REALITY:



RADIATIVE VIRTUAL CORRECTION

IT IS THROUGH THESE RADIATIVE CORR$^{\underline{ns}}$ THAT LEP OBSERVABLES ARE SENSITIVE TO PROCESSES WITH ENERGY SCALES > ECM$_{LEP}$

c.f.



$\sim \frac{m_t^2}{m_Z^2}$

$\sim \ln \frac{m_H}{m_W}$

Z LINESHAPE + ASYMMETRIES IN THE S.M.

$$\frac{d\sigma}{d(\cos\theta)} \propto 1 + \cos^2\theta + \frac{8}{3} A_{FB} \cos\theta$$

$$\left[A_{FB} = \frac{N_F - N_B}{N_F + N_B} \right]$$

$$\Gamma_f = \frac{G_F M_Z^2}{6\pi\sqrt{2}} \left[(g_A^f)^2 + (g_V^f)^2 \right]$$

$$A_{FB}^f = \frac{3}{4} A_e A_f \qquad \text{where} \quad A_f = \frac{2 g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}$$

g_V, g_A : VECTOR AND AXIAL VECTOR COUPLING CONSTANTS OF THE NEUTRAL CURRENT TO FERMIONS

CONVENIENT TO DEFINE:

$$\sin^2\theta_W^{eff} = \frac{1}{4}\left(1 - \frac{g_V}{g_A}\right)$$

ABSORB RADIATIVE CORRECTIONS

A WAY TO COMPARE DIFFERENT OBSERVABLES

LEP OBSERVABLES

LINESHAPE A SET WITH MINIMAL EXPERIMENTA
CORRELATIONS

5 OR 9 PARAM. → SET (UNIVERSALITY ASSUMED OR NOT)

M_Z
Γ_Z
σ^0 (N_ν, α_s)
$R_\ell \left(= \frac{\Gamma_h}{\Gamma_\ell}\right)$ (g_V, g_A)
A_{FB}^{ℓ} (g_V, g_A)

τ POLARIZATION $P_\tau(\cos\theta)$ $(A_e\, A_\tau)$

HEAVY FLAVOURS $R_b\left(= \frac{\Gamma_b}{\Gamma_h}\right)$ (m_{top})
R_c
A_{FB}^{b}
A_{FB}^{c}

CHARGE ASYMMETRY A_{FB}^{q}

LINESHAPE: EXPERIMENTALLY WHAT WE MEASURE IS CROSS SECTIONS

$\sigma_H(E_1)$, $\sigma_H(\boxed{E_2})$, …
$\sigma_e(E_1)$, …
$\sigma_\mu(E_1)$, …
$\sigma_\tau(E_1)$, …

E_{LEP} (SYST. ERROR

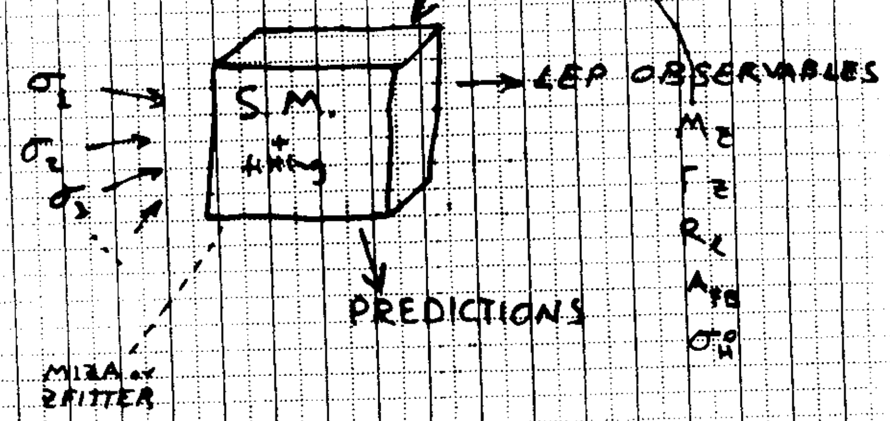
where $$\sigma_f(E) = \frac{\boxed{N_f} - \boxed{N_{bg}}}{\boxed{\varepsilon}\,\boxed{\mathcal{L}}}$$

NEED STATISTICS

KNOWN TO GOOD ACCURACY

LUMINOSITY = FROM 'REFERENCE' PROCESS (STAT. + SYST. ERR)
→ SMALL ANGLE BHABHA SCATT.

THEN:

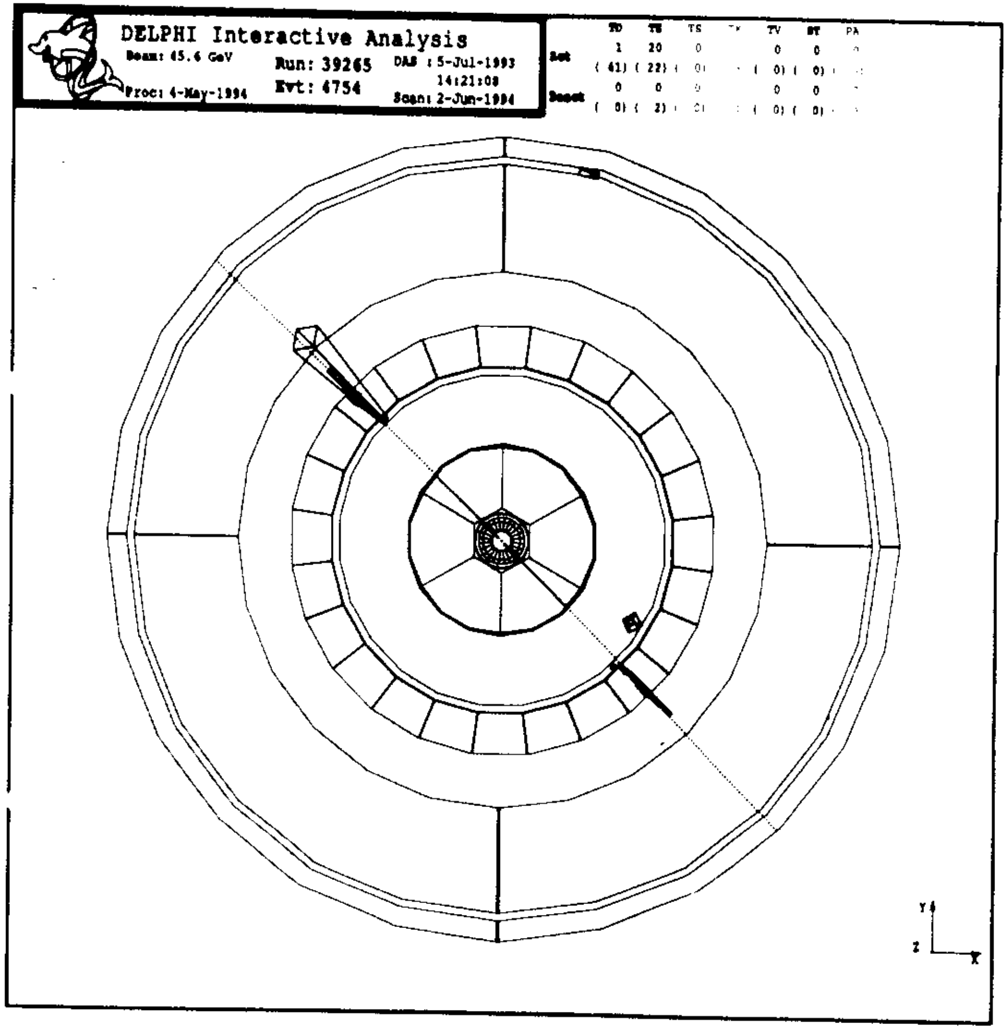


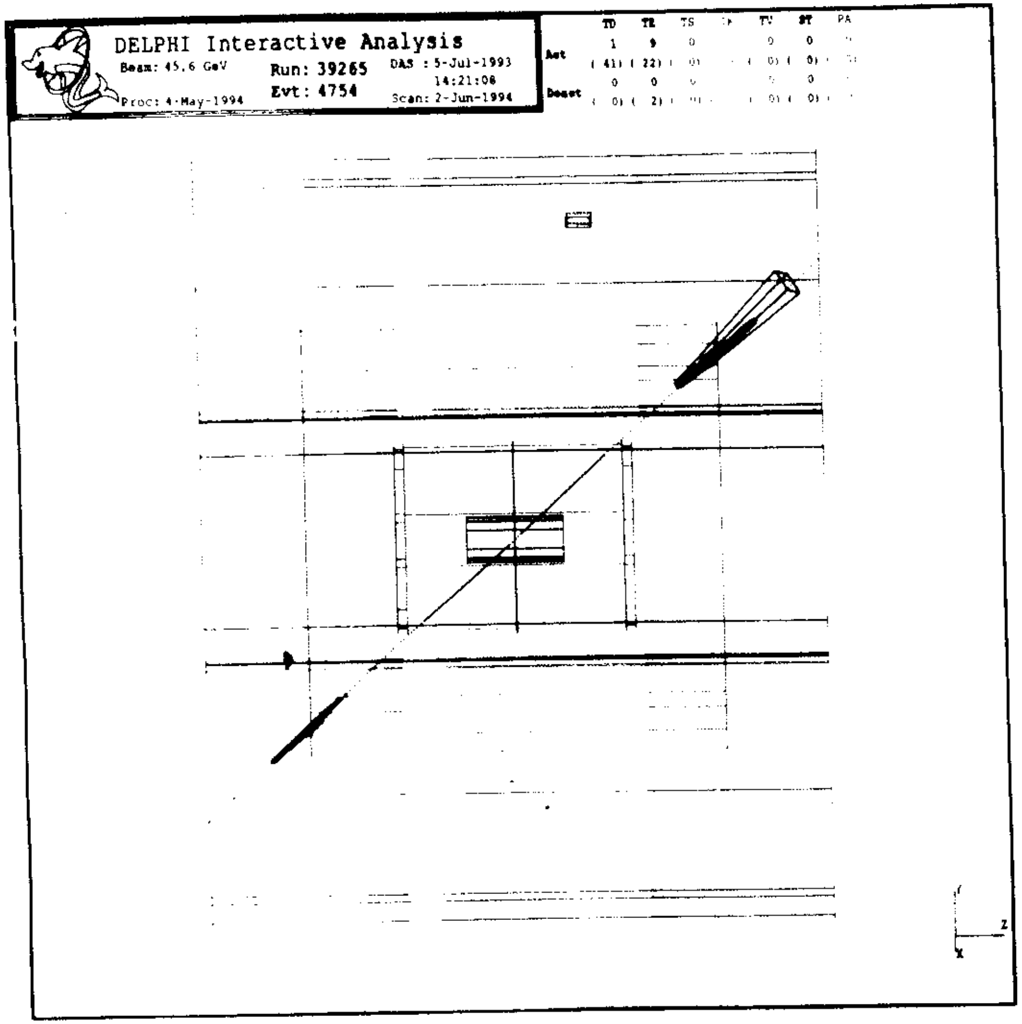
R0039265E0004754

$e^+e^- \to e^+e^-$, barrel

Clear Bhabha event where the electron and positron have associated showers in the HPC. Both tracks are measured in the VD, ID and TPC. The e^- (upward in x,y projection) is reconstructed with a momentum of 45.9 GeV/c and has an associated HPC shower of 48.1 GeV. The e^+ (downward in x,y projection) has 37.4 GeV/c momentum and an associated HPC shower of 44.0 GeV.

$e^+e^- \to e^+e^-$



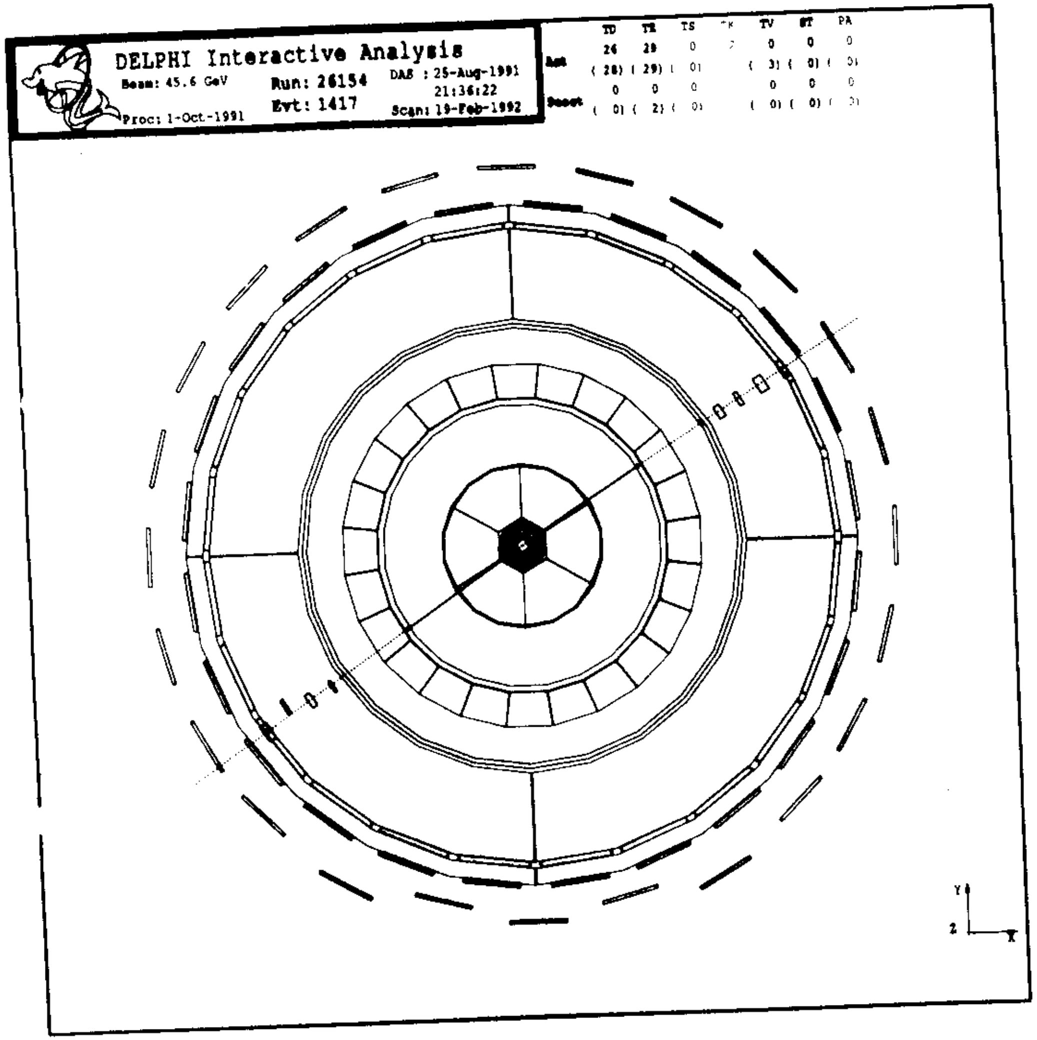


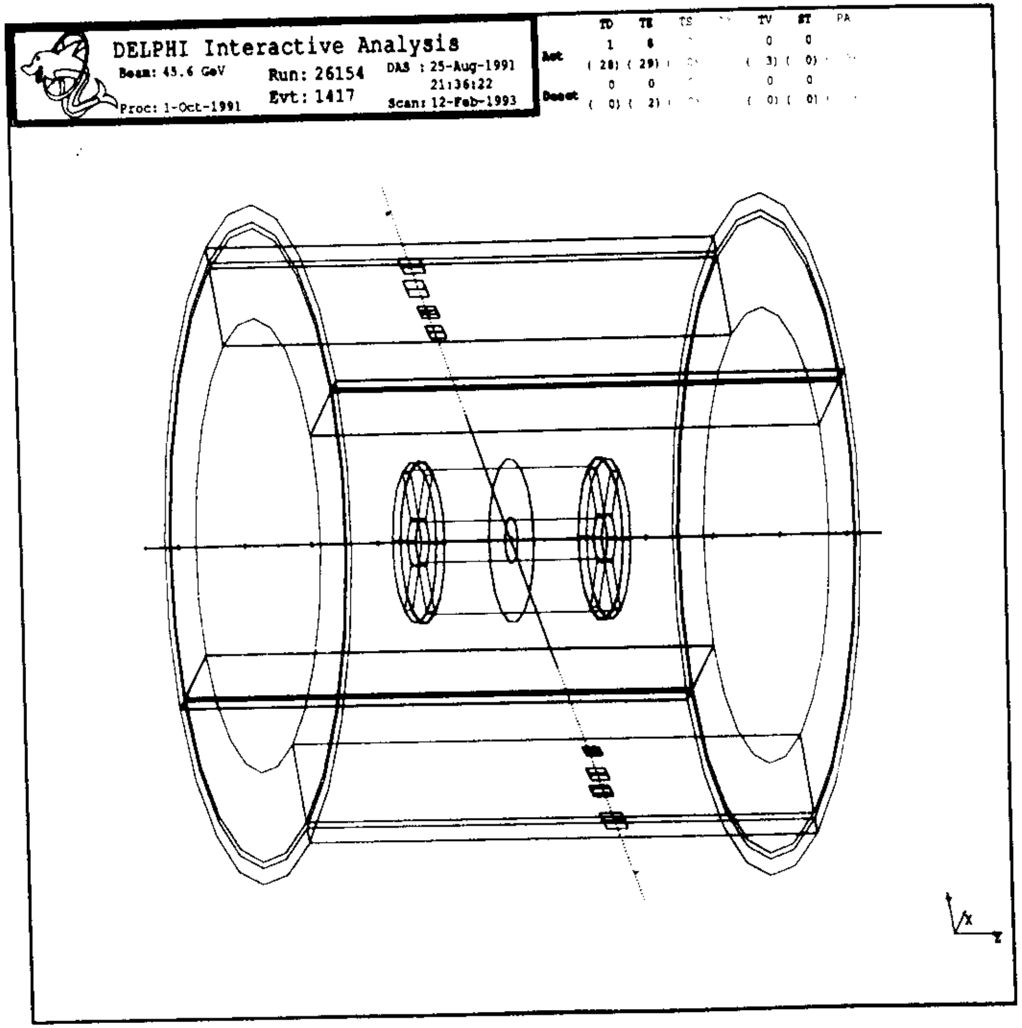
R0026154E0001417

$e^+e^- \to \mu^+\mu^-$, barrel

The two tracks do not deposit detectable energy in the HPC, are minimum ionizing in the HAB and produce hits in both planes of the MUB. Both tracks are reconstructed from information in the VD, ID, TPC and OD. The μ^+ (up-right in x,y) has a momentum of 47.8 GeV/c and the μ^- (down-left in x,y) has 43.8 GeV/c. Both are compatible with the beam momentum.

$e^+e^- \to \mu^+\mu^-$


DELPHI Interactive Analysis
Beam: 45.6 GeV
Run: 26154
Evt: 1417
DAS : 25-Aug-1991
21:36:22
Proc: 1-Oct-1991
Scan: 19-Feb-1992
TD TE TS TK TV ST PA
Act
26 29 0 0 0 0
(28) (29) (0) (3) (0) (0)
0 0 0 0 0 0
(0) (2) (0) (0) (0) (0)
Y
Z
X


DELPHI Interactive Analysis
Beam: 45.6 GeV
Run: 26154
Evt: 1417
DAS : 25-Aug-1991
21:36:22
Proc: 1-Oct-1991
Scan: 12-Feb-1993
TD TE TS TV ST PA
Act
1 6 0 0
(28) (29) (3) (0)
0 0 0 0
(0) (2) (0) (0)
X
Y
Z

R0023438E0000581

$$e^+e^- \to \tau^+\tau^-$$

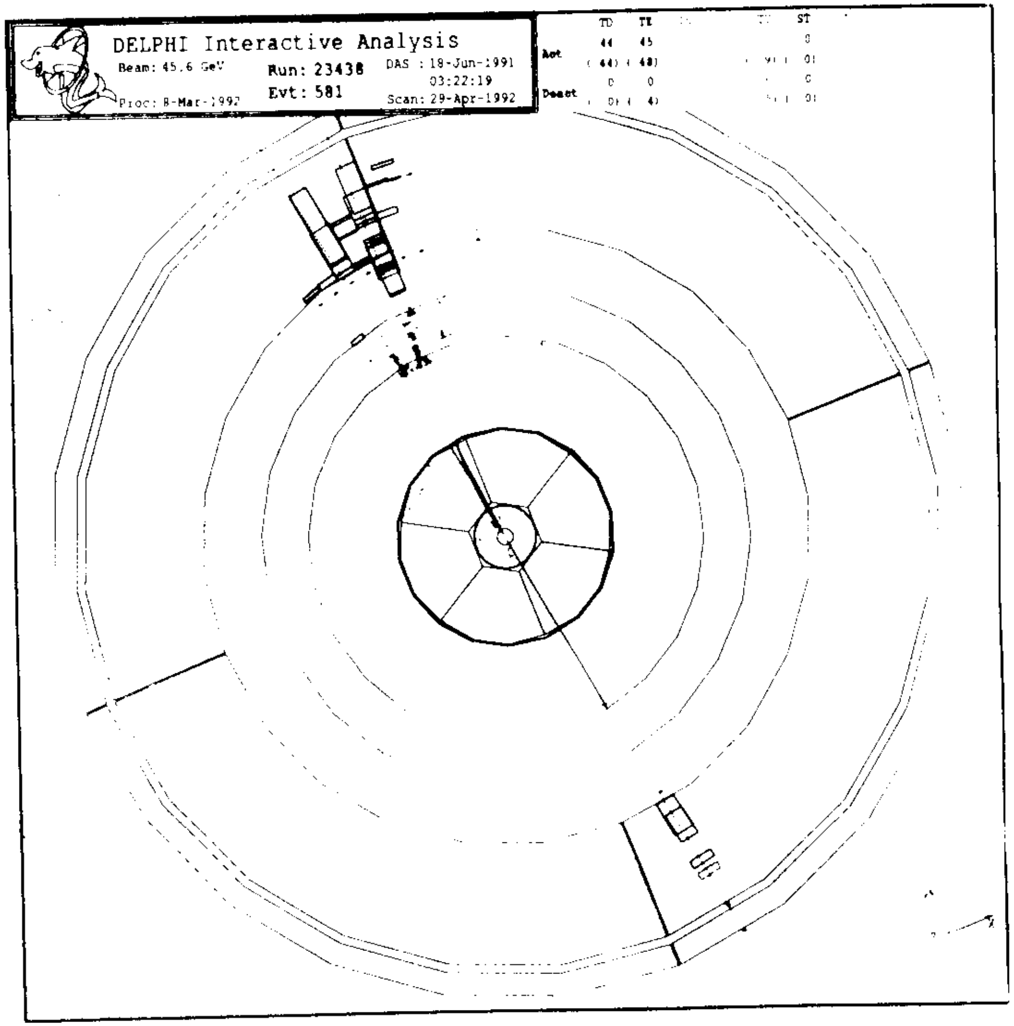
The Tau pair is cleanly identified by a 1 vs 3 topology.

The τ^- decays into a μ^-(42.0 GeV), identified by the barrel Muon chambers and 4.7 GeV in the barrel Hadron calorimeter.

The τ^+ decays into 3 very collimated particles, π^-(19.3 GeV), π^+(8.3 GeV), π^+(1.4 GeV), all three being minimum ionizing in the HPC and the two energetic ones depositing energy in the HAB. The 3-particle system has 29.0 GeV energy and 1.01 GeV mass, hence compatible with a Tau. They are accompanied by a 3 GeV energy deposition in the HPC, probably originating from a π^0. The three tracks are beautifully separated in the VD, IDjet, IDtrigger and TPC.

The interest of this event resides in the fact that the candidate muon is so energetic.

$e^+e^- \to \tau^+\tau^-$
$\hookrightarrow \mu^-\nu_\tau\bar{\nu}_\tau$
$\hookrightarrow \pi^-\pi^+\pi^+\nu_\tau$

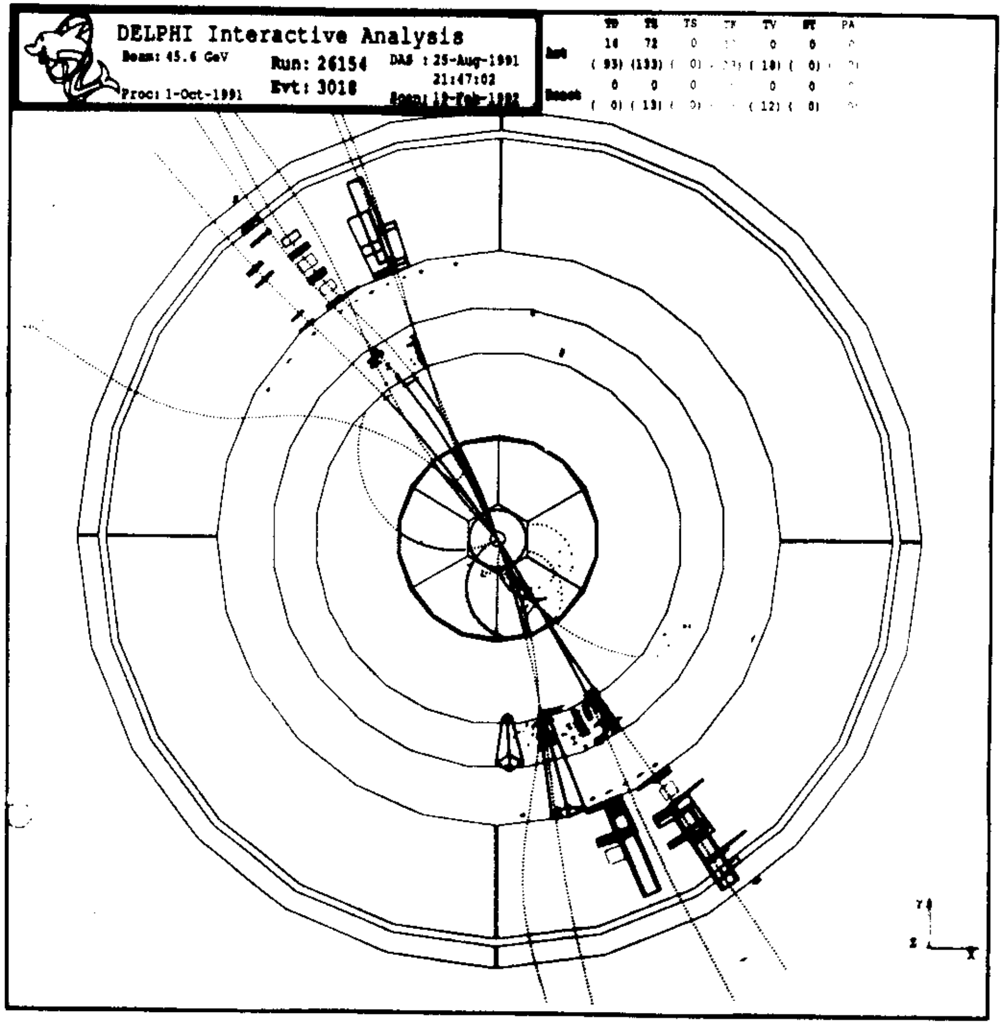


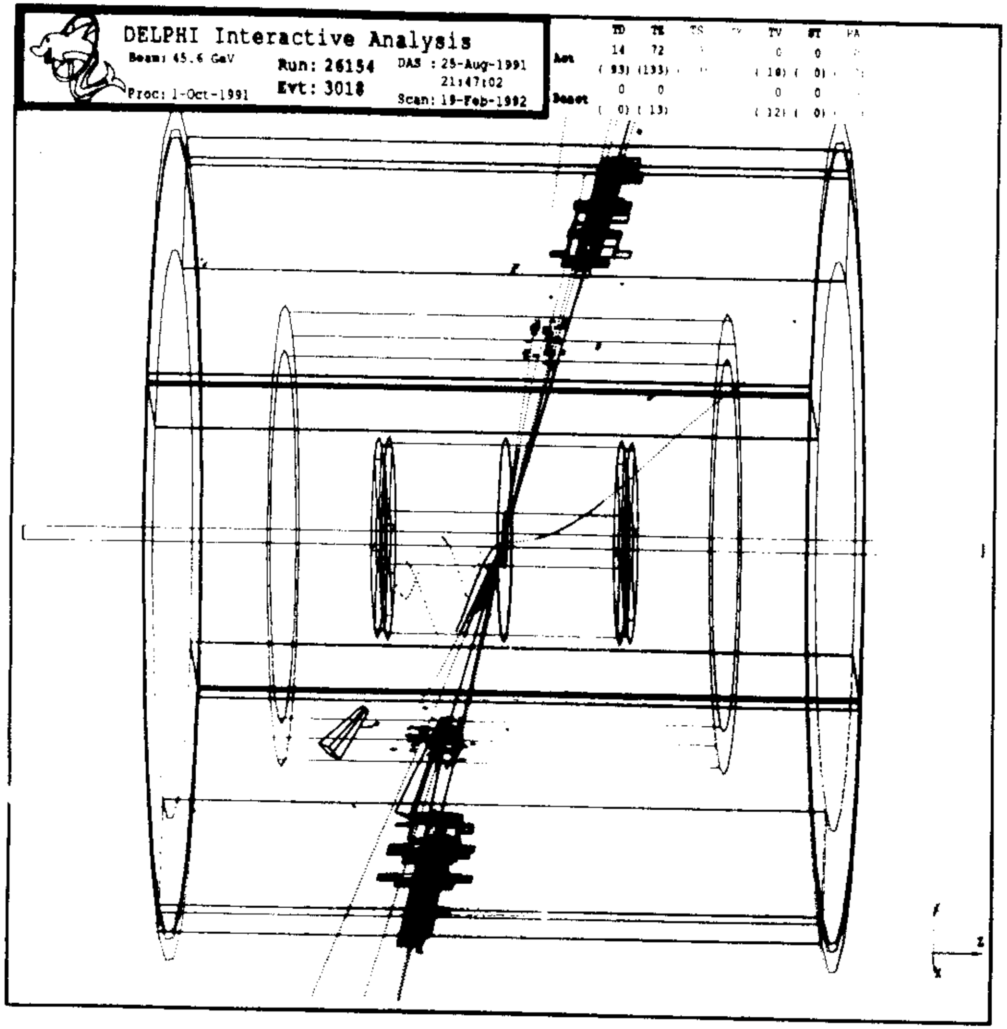
$e^+e^- \to q\bar{q}$

R0026154E0003018

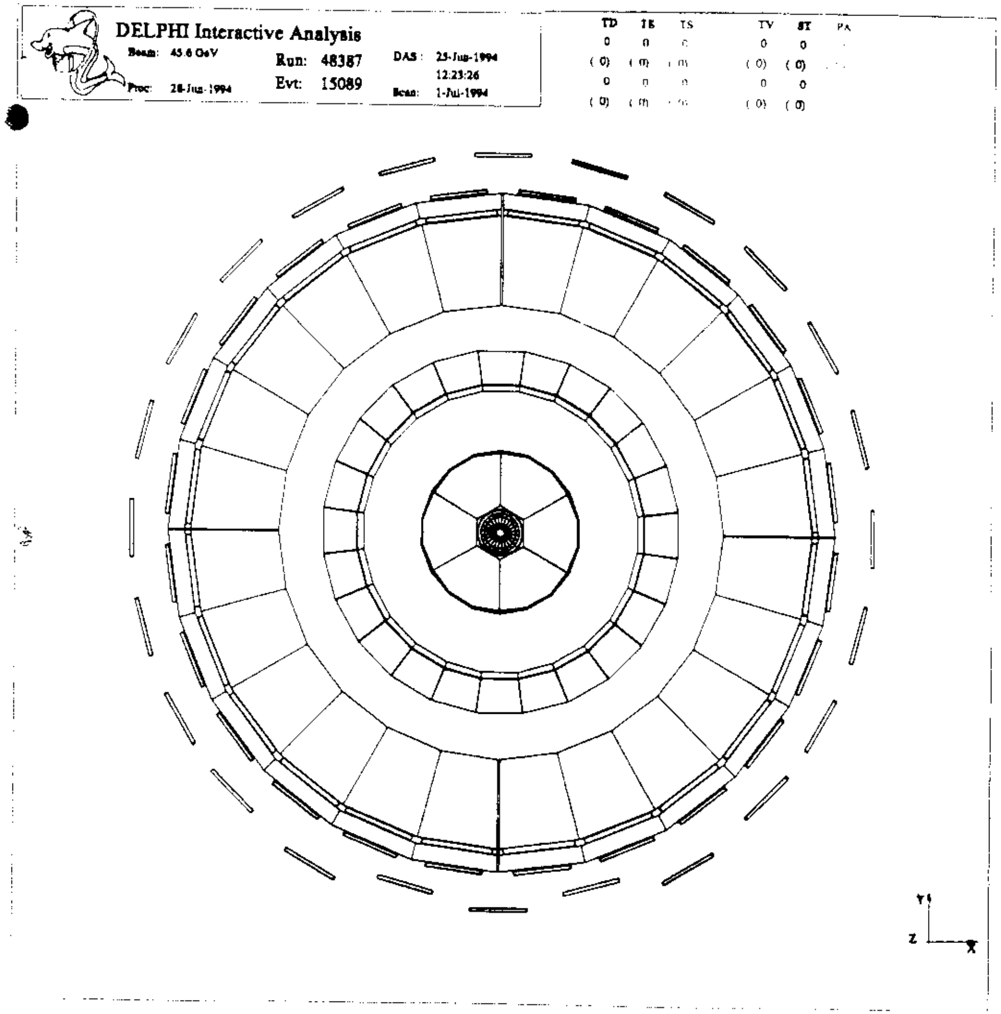
$e^+e^- \to q\bar{q}$, 2 jet

Hadronic event with two very narrow jets and a considerable amount of energy deposited in the Hadron Calorimeter.





$e^+e^- \rightarrow \nu\bar{\nu}$



LEP ENERGY MEASUREMENT

TOOL: RESONANT DEPOLARISATION METHOD

PRINCIPLE:

- ✱ "SPIN TUNE" [$\propto$ SPIN PRECESSION FREQ.] IS PROPORTIONAL TO ENERGY OF THE BEAM

$$E_{BEAM} = \underbrace{\frac{m_e c^2}{a_e}}_{\text{KNOWN TO } 10^{-7}} \nu_s$$

m_e : e^- mass

a_e : gyromagn. anomaly of e^-

ν_s : spin tune

$$E_{Beam}\,(GeV) = 0.4406486\left(N_s + \frac{f^{res}_{dep}}{f_{rev}}\right)$$

$$\Delta E_b < 1\,MeV\,!$$

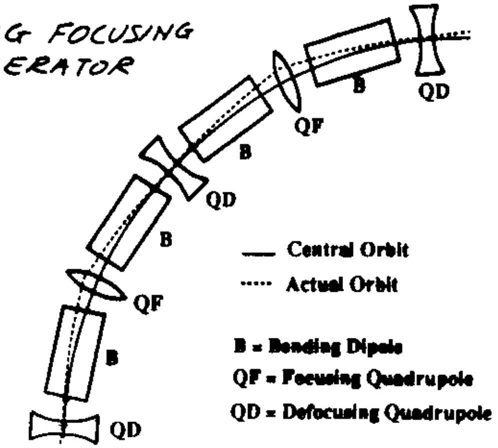
$$N_s = 103$$

∴ TO MEASURE E_{LEP}, WE NEED

- DECENT TRANSVERSE POLARIZATION LEVELS ($\gtrsim$10
- RF "KICKER" MAGNET
- POLARIMETER (LASER, COMPTON SCATTERING)

ORBIT ENERGY RELATIONSHIP

LEP: STRONG FOCUSING ACCELERATOR



$$\frac{\Delta E}{E} = -\frac{1}{\alpha}\frac{\Delta C}{C_c}$$ — CIRCUMFERENCE

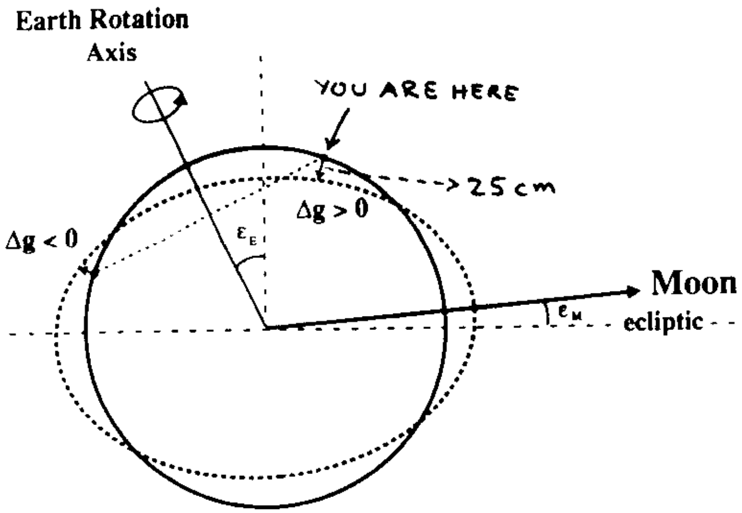
α : MOMENTUM COMPACTION FACTOR

for LEP: $\alpha = 1.86 \times 10^{-4}$

⟹ CHANGES IN CIRCUMFERENCE ARE AMPLIFIED BY 10^4 !

LENGTH OF ORBIT OF ELECTRONS IS FIXED BY f_{RF}, BUT THE LENGTH OF THE LEP RING IS NOT...

EFFECT OF TIDES TO LEP ENERGY



TIDES: ELASTIC DEFORMATION OF EARTH'S CRUST DUE TO MOON AND SUN (45% WEAKER EFFECT)

$$\left.\frac{\Delta L}{L}\right|_{TIDES} = \sim 3 \times 10^{-8} \quad \left[\text{LEP: 0.8mm IN CIRCUMFERENCE}\right]$$

$$\therefore \quad \frac{\Delta E}{E} = -\frac{1}{\alpha}\frac{\Delta L}{L} = \sim 1.6 \times 10^{-4}$$

at 91 GeV : ~ 15 MeV

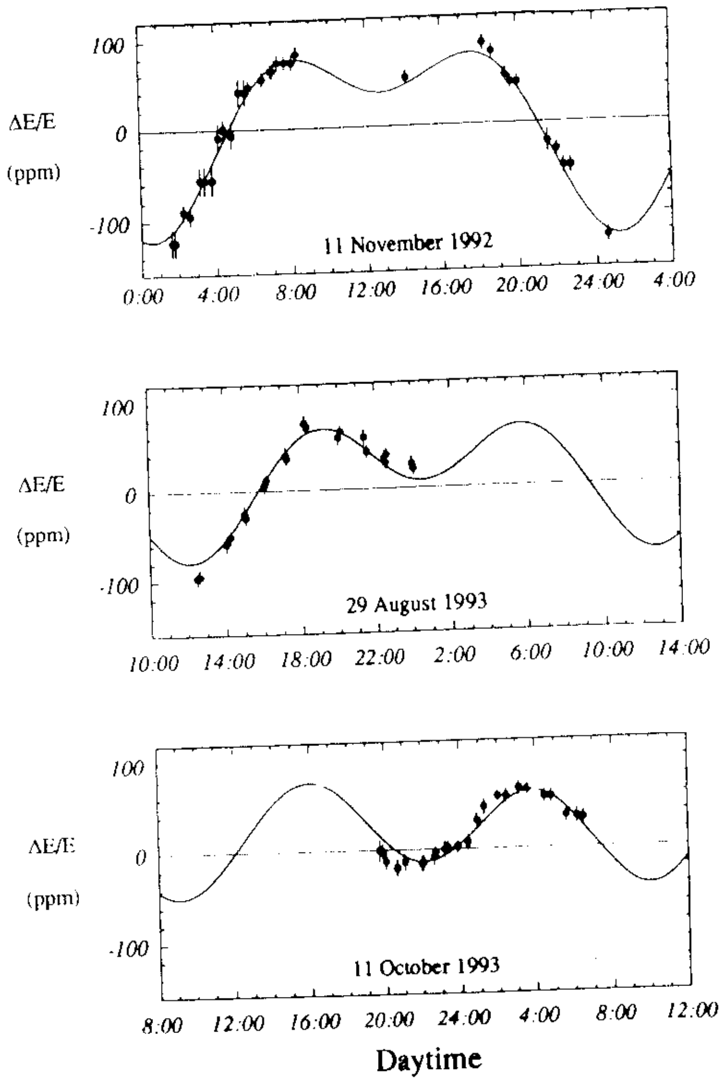


Figure 3: The evolution of the relative beam energy variation due to tides is shown as a function of time for three periods with stable beam conditions. The solid line is calculated using the CTE tide model with the average coefficient from equation 4. The top picture corresponds to full-moon, the bottom picture to a time close to half-moon. Relative beam energy variations of up to 220 ppm are observed on November 11th 1992.

LEP 1993 SCAN

SUMMER 93: USING 90-91+92 DATA
WE HAD:

$\Delta M_Z = 7 \text{MeV}$
$\Delta \Gamma_Z = 7 \text{MeV}$

SET TO IMPROVE ABOVE NUMBERS.

TWO MAJOR FEATURES IN 93:

① STATISTICS

② LEP ENERGY KNOWLEDGE

---

① STATISTICS:

- LEP HAS DELIVERED $40 pb^{-1}$ IN 1993
  $20 pb^{-1}$ ON PEAK, $20 pb^{-1}$ OFF PEAK
  ROUTINELY ACHIEVING LUMINOSITIES EXCEEDING LEP's DESIGN VALUE ($= 1.3 \times 10^{31}$)

- OPTIMIZED* SCAN STRATEGY

3 SCAN POINTS

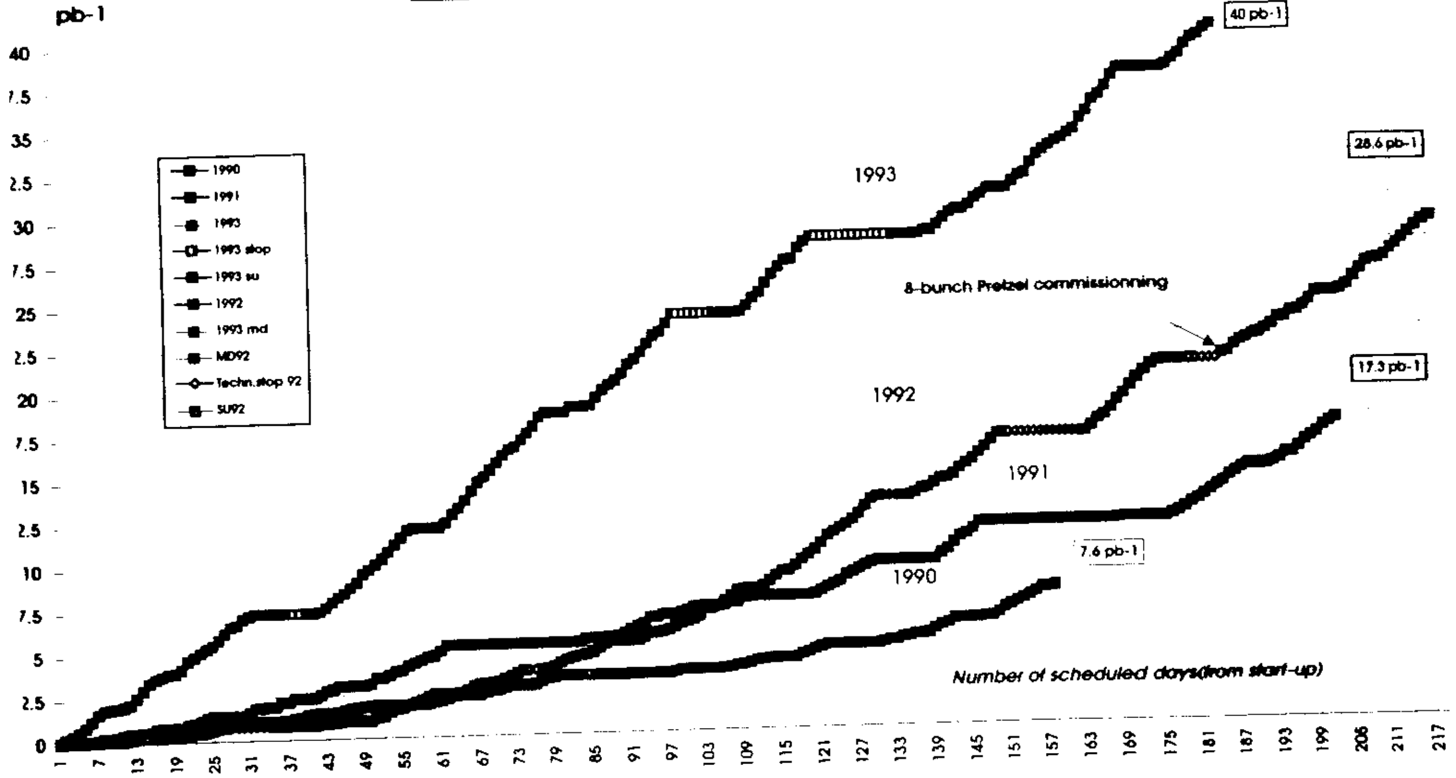
	P-2	P	P+2
ENERGY	89.4 GeV	91.2 GeV	93.0 GeV
$\int L$	$10 pb^{-1}$	$20 pb^{-1}$	$10 pb^{-1}$

* TO GIVE SMALLEST ERRORS ON M_Z, Γ_Z WHILE SACRIFISING THE SMALLEST AMOUNT OF STATISTICS FOR THE REST OF THE LEP PHYSICS PROGRAMME.

LEP OPERATIONS

2/06/94

Integrated luminosities seen by experiments 1990 -> 1993

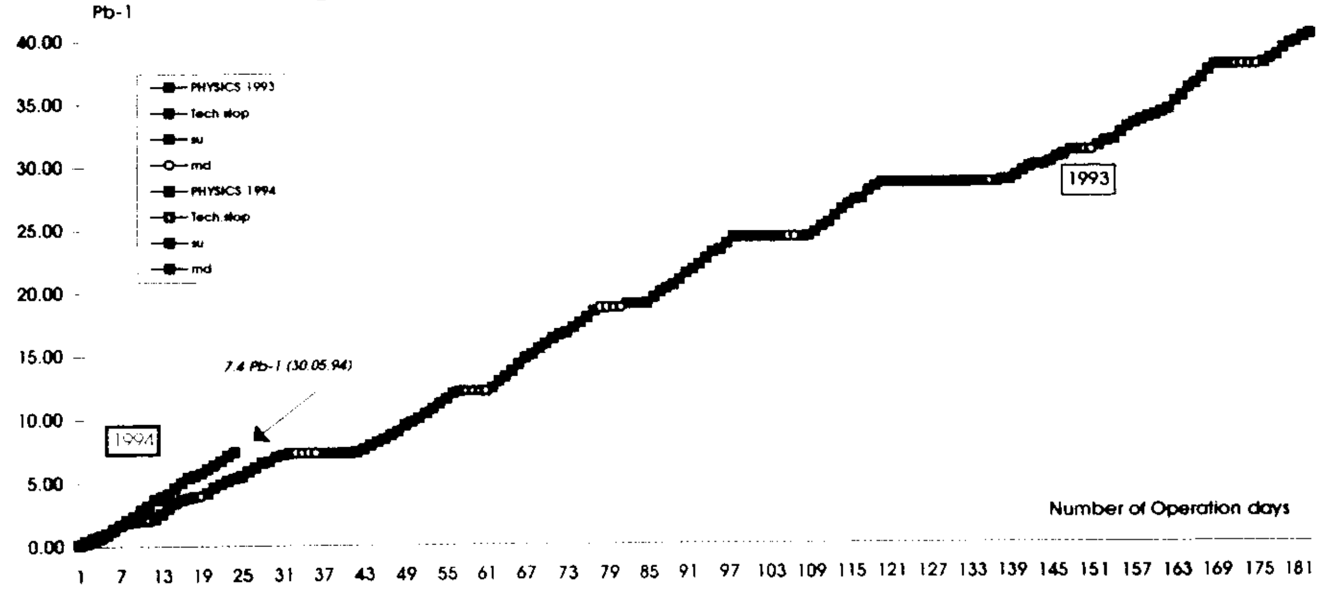


L90_93.XLC

LEP OPERATION 1994

2/06/94

Integrated luminosities seen by experiments 1993-1994



L93_94.XLC

② LEP ENERGY DETERMINATION

* LIMITING FACTOR FOR M_Z, Γ_Z IN 1993

$$1993: \begin{cases} \Delta M_Z = 1.8\,\text{MeV} \oplus \text{LEP ERROR} \\ \Delta \Gamma_Z = 2.5\,\text{MeV} \oplus \text{LEP ERROR} \end{cases}$$

$$\text{LEP ERROR IN 1991 SCAN: } \begin{cases} 6\,\text{MeV in } M_Z \\ 4.5\,\text{MeV in } \Gamma_Z \end{cases}$$

➡ TOOL: RESONANT DEPOLARIZATION

- MEASURES THE INSTANTANEOUS MEAN ENERGY OF LEP TO WITHIN < 1MeV

NEW IN 93 → PLUS
- P-2, P+2, (P) CAN BE CALIBRATED
- CALIBRATION DONE AT PHYSICS CONDITIONS

BUT: COSTLY
- NO DATA TAKING DURING MEASUREMENT
- A MEASUREMENT TAKES ~4 HOURS

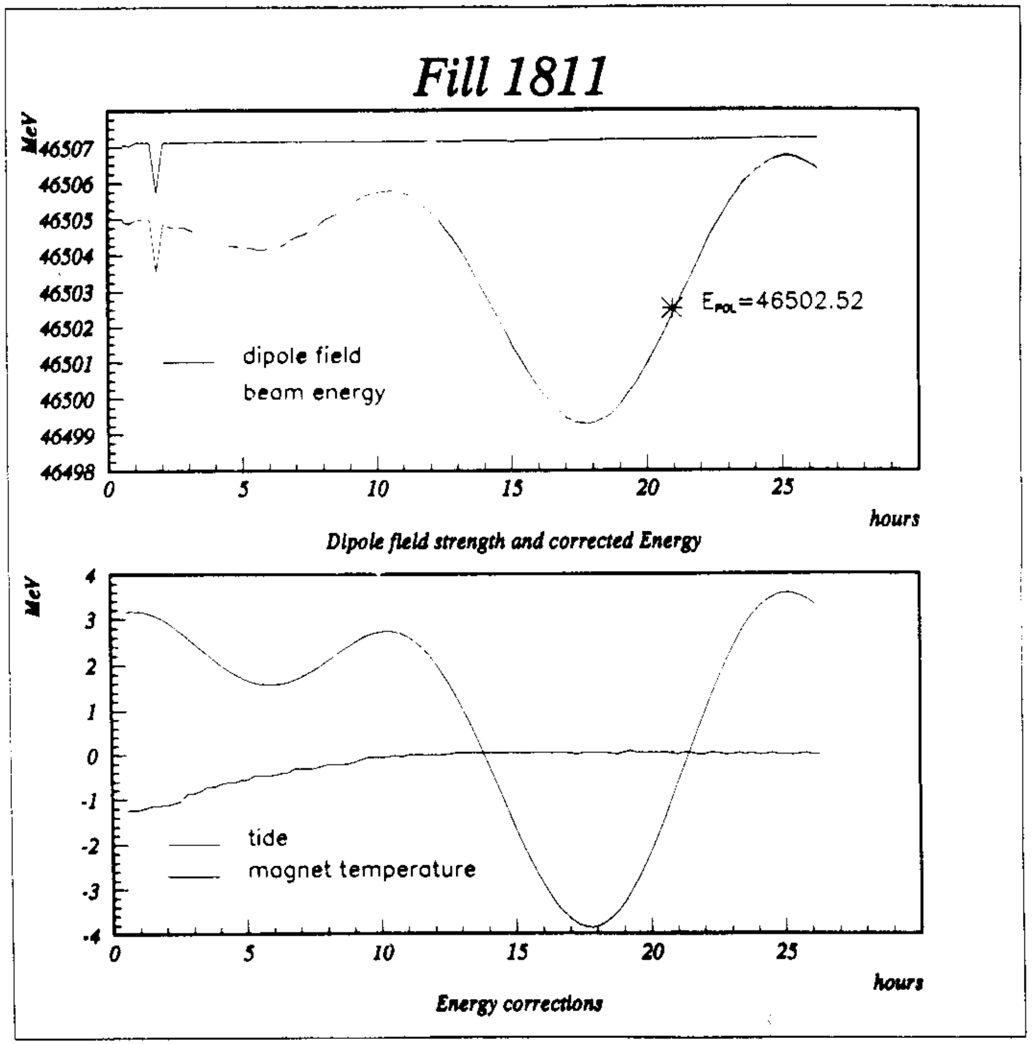
∴ STRATEGY: PERFORM EPOL

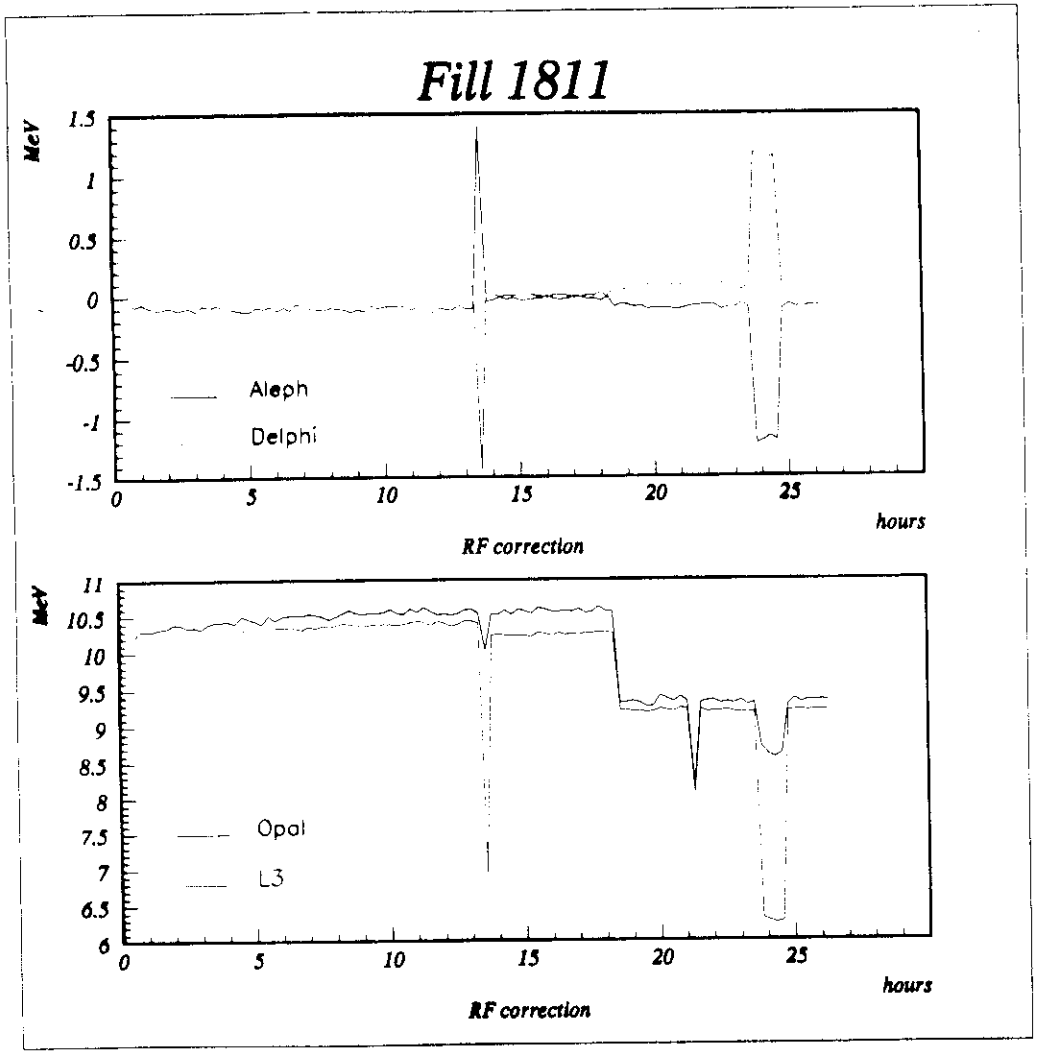
~2 × WEEK

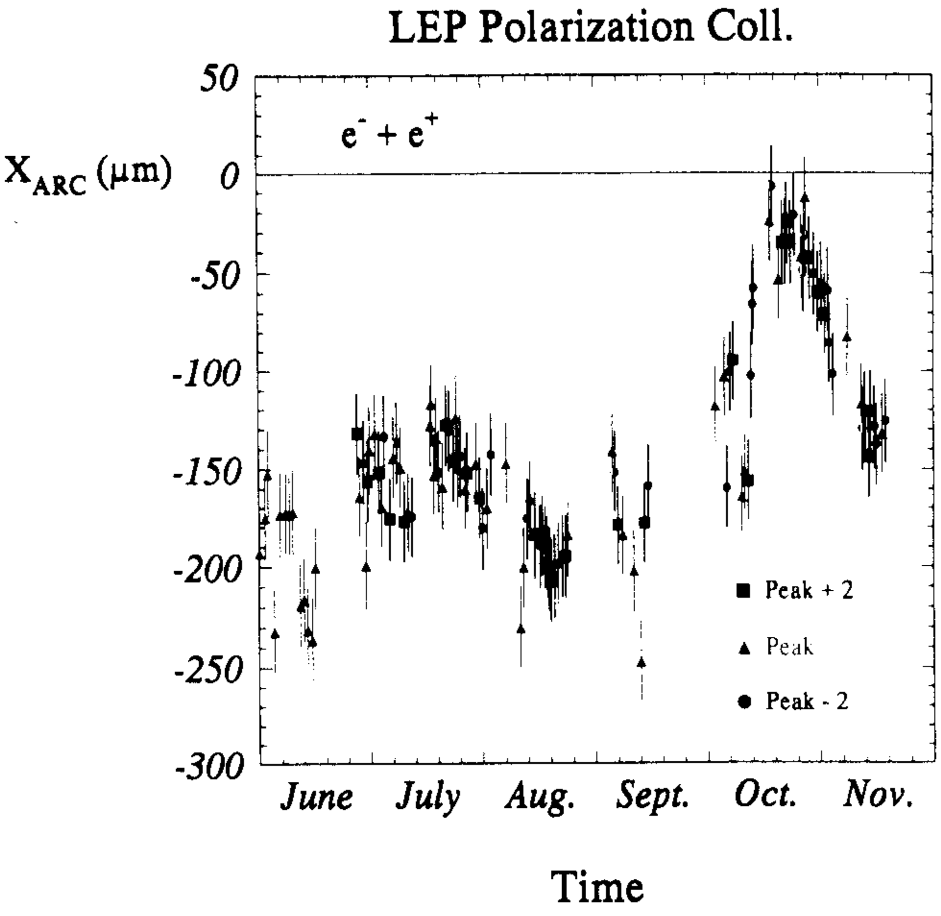
⟹ FOLLOW LONG TERM STABILITY

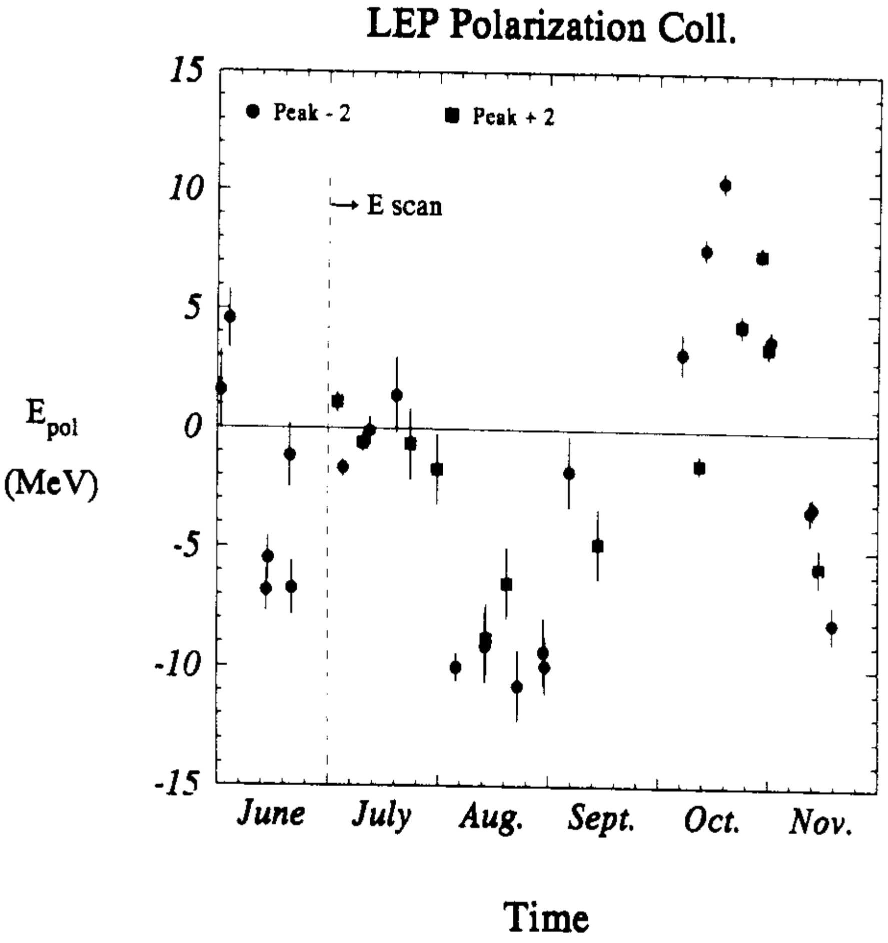
SHORT TERM STABILITY: MONITORING (TEMPS, CURRENTS, TIDES, ...
(WITHIN A FILL)

MEDIUM + LONG TERM STABILITY: LEP BEAM ORBIT
(FILL TO FILL)




Fill 1811
MeV
1.5
1
0.5
0
-0.5
-1
-1.5
Aleph
Delphi
0
5
10
15
20
25
hours
RF correction
MeV
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
Opal
L3
0
5
10
15
20
25
hours
RF correction


LEP Polarization Coll.
X_{ARC} (μm)
50
0
-50
-100
-150
-200
-250
-300
$e^- + e^+$
■ Peak + 2
▲ Peak
● Peak - 2
June
July
Aug.
Sept.
Oct.
Nov.
Time



LEP ERROR

WINTER '94 CONFERENCES:

ERROR CONSERVATIVELY ESTIMATED AS:

$\sigma_{syst\ LEP}$*: M_Z : 4 MeV
Γ_Z : 3 MeV

*ESTIMATED AS IF NO UNDERLYING TREND FOR THE EVOLUTION OF E_{LEP} WITH TIME EXISTS. WE NOW KNOW THAT THERE IS AN UNDERLYING TREND.

[NOTE THAT THE ERRORS ASSOCIATED TO VARIOUS CORRECTIONS (i.e. TEMP, RF, TIDES) AMOUNT TO 0.3 MeV for M_Z, Γ_Z]

NOW: ERRORS (PRELIMINARY) σ_{M_Z} = 3.3 MeV
σ_{Γ_Z} = 2.2 MeV

FUTURE: ERRORS WILL BE ~2 MeV

The LEP statistics in units 10^3

		ALEPH	DELPHI	L3	OPAL
$q\bar{q}$	'90-'91	451	356	416	454
	'92	680	697	678	733
	'93 prel.	653	677	671	656
	total	1784	1730	1765	1843
$\ell^+\ell^-$	'90-'91	55	37	39	58
	'92	82	69	59	88
	'93 prel.	79	67	–	83
	total	216	173	98	229

The experimental systematic errors for the analysis of the Z^0 line shape

	ALEPH		DELPHI		L3		OPAL	
	'92	'93 prel.	'92	'93 prel.	'92	'93 prel.	'92	'93 prel.
σ_{had}	0.14%	0.14%	0.13%	0.13%	0.15%	0.25%	0.20%	0.24%
σ_e	0.4 %	0.4%	0.59%	–	0.3 %	–	0.22%	0.35%
σ_μ	0.5 %	0.5%	0.37%	0.5%	0.5%	–	0.19%	0.22%
σ_τ	0.3%	0.3%	0.63%	–	0.7 %	–	0.44%	0.51%

M_Z : MAINLY FROM 1993 DATA

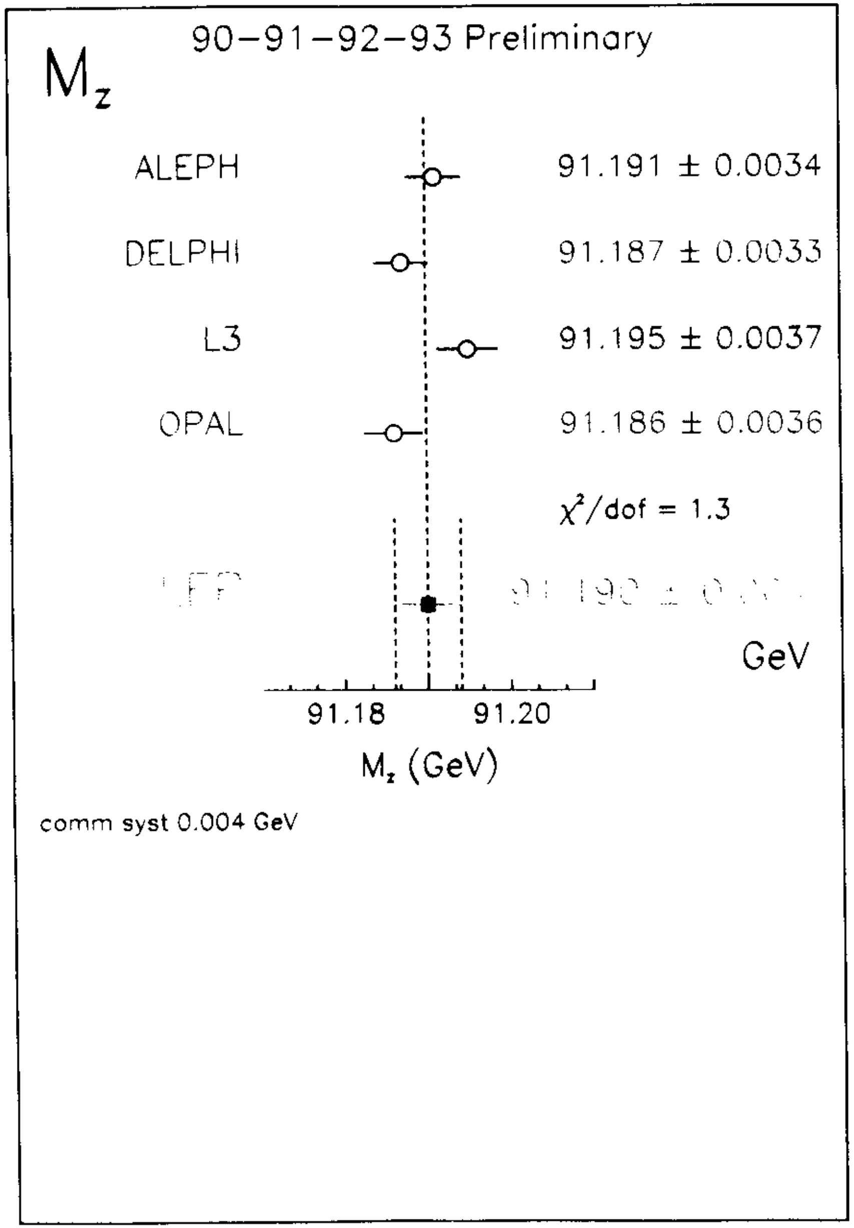
$$M_Z = 91{\cdot}1899 \pm 0.0018 \pm 0.004 \text{ (LEP)}$$

SUMMER '93 : $M_Z = 91{\cdot}187 \pm 0.004 \pm 0.005$ (LEP)

⇒ IMPROVEMENT BY ALMOST A FACTOR OF 2.

- INPUT TO S.M. (NO PREDICTION)
- ONLY RELATIVE (POINT TO POINT) LUMINOSITY NEEDED

⇒ LEP ERROR DOMINATES



Γ_Z:

$$\Gamma_Z = 2.497 \pm 0.0026 \pm 0.003 \text{ (LEP)}$$

(SUMMER '93 - Γ_Z = 2.499 ± 0.005 ± 0.0045)

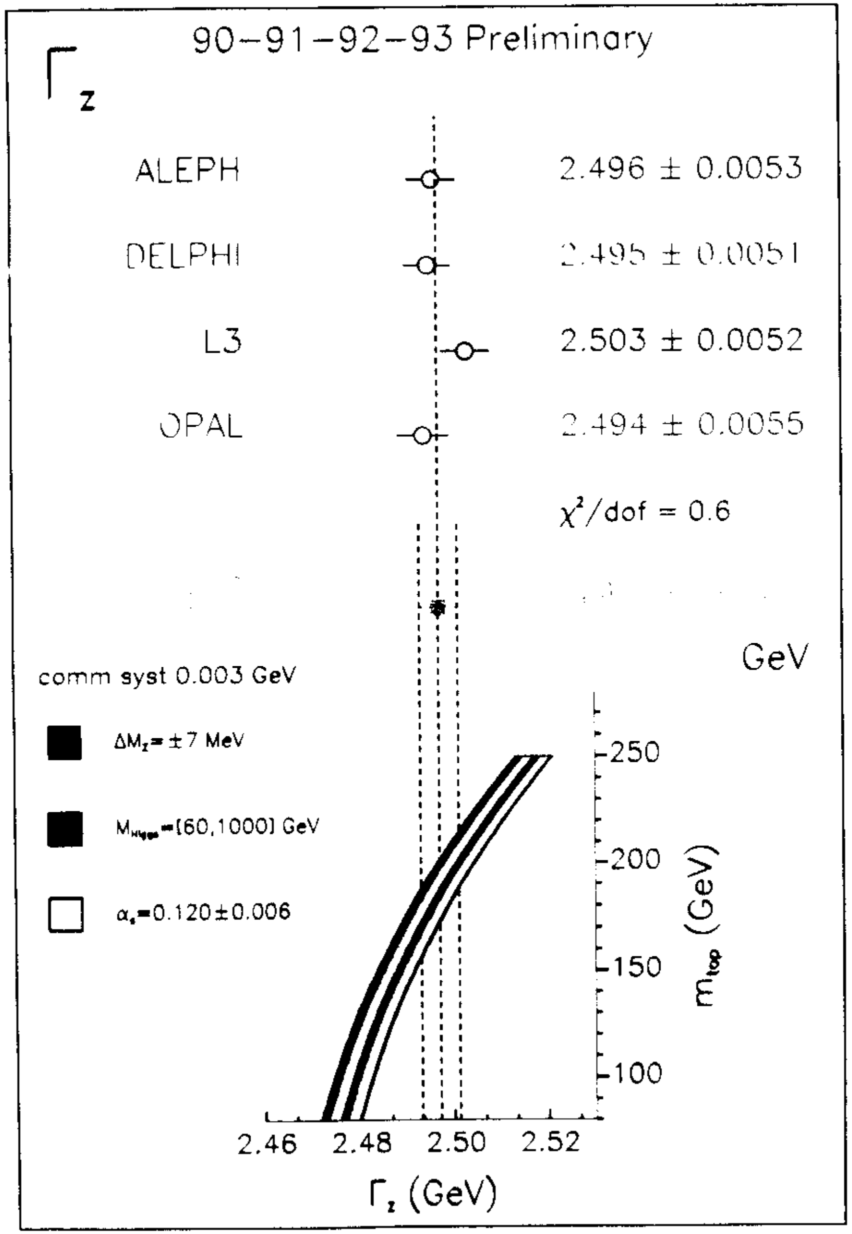
LEP ERROR DOMINATES, AS FOR M_Z

- NEXT SYSTEMATIC γγ background – non-reson
  (~ 0.5 MeV effect [DELPHI])

DELPHI: RELATIVE LUMINOSITY CALORIMETER WITH VERY HIGH RATE ($\sigma_{vis} \simeq$ 500nb compared to ~85nb (ALEPH))

⟹ VIRTUALLY ZERO STATISTICAL UNCERTAIN FROM LUMINOSITY MEASUREMENT

⟹ REDUCES DELPHI ERROR BY ~15%.



σ^0_{had}

- '93 RESULTS FROM ALEPH AND DELPHI ONLY

$\frac{\Delta\mathcal{L}}{\mathcal{L}}\Big|_{SYST, EXP}$ = 0·09% (ALEPH)
0·28% (DELPHI) ⟶ 0·18% (SUMMER

ALEPH: STATE OF THE ART Si-W CALORIMETER –
– $\frac{\Delta R}{R}\Big|_{INNER}$ = 18μ ($\Rightarrow \sigma$ = 0·06%)

DELPHI: OLD CALORIMETER + MASK TECHNIQUE
$\frac{\Delta R}{R}\Big|_{INNER}$ = 6μ BUT Z_{beam} SENSITIVITY

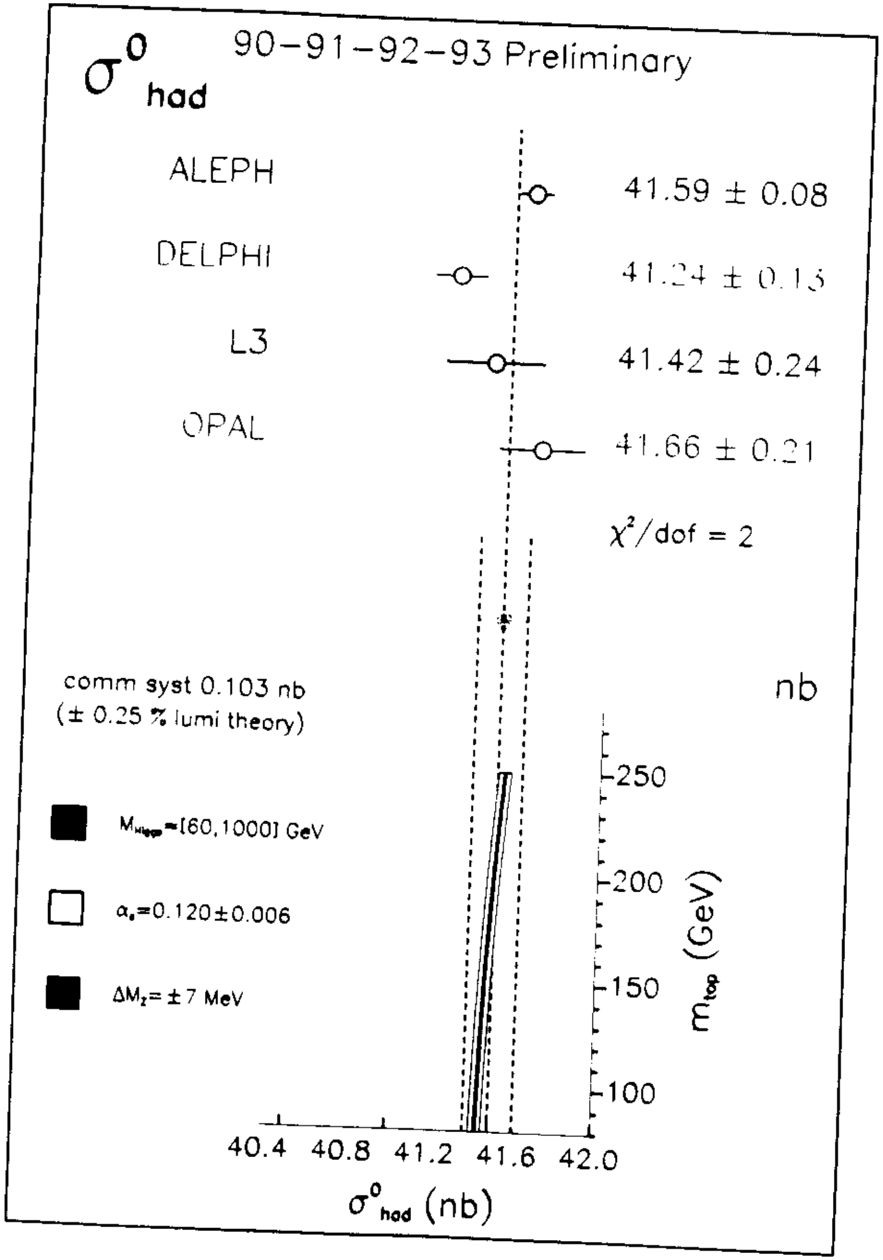
- IMPRESSIVE PROGRESS IN THIS FRONT:

FOR EXAMPLE. <u>DELPHI</u>

	$\sigma_{SYST, EXP}$
TECHNICAL PROPOSAL	2%
'90	1·2%
'91	0·6%
'92	0·4%
'93 (PRELIM.)	0·28%
'93 (FINAL)	0·18% ??
'94 (NEW DETECTOR)	<0·1%

BUT σ_{THEORY} = 0·25% ← LIMITING SYSTEMATIC

HOPE TO ACHIEVE $\sigma_{TH} \simeq$ 0·1% IN NEAR FUTURE



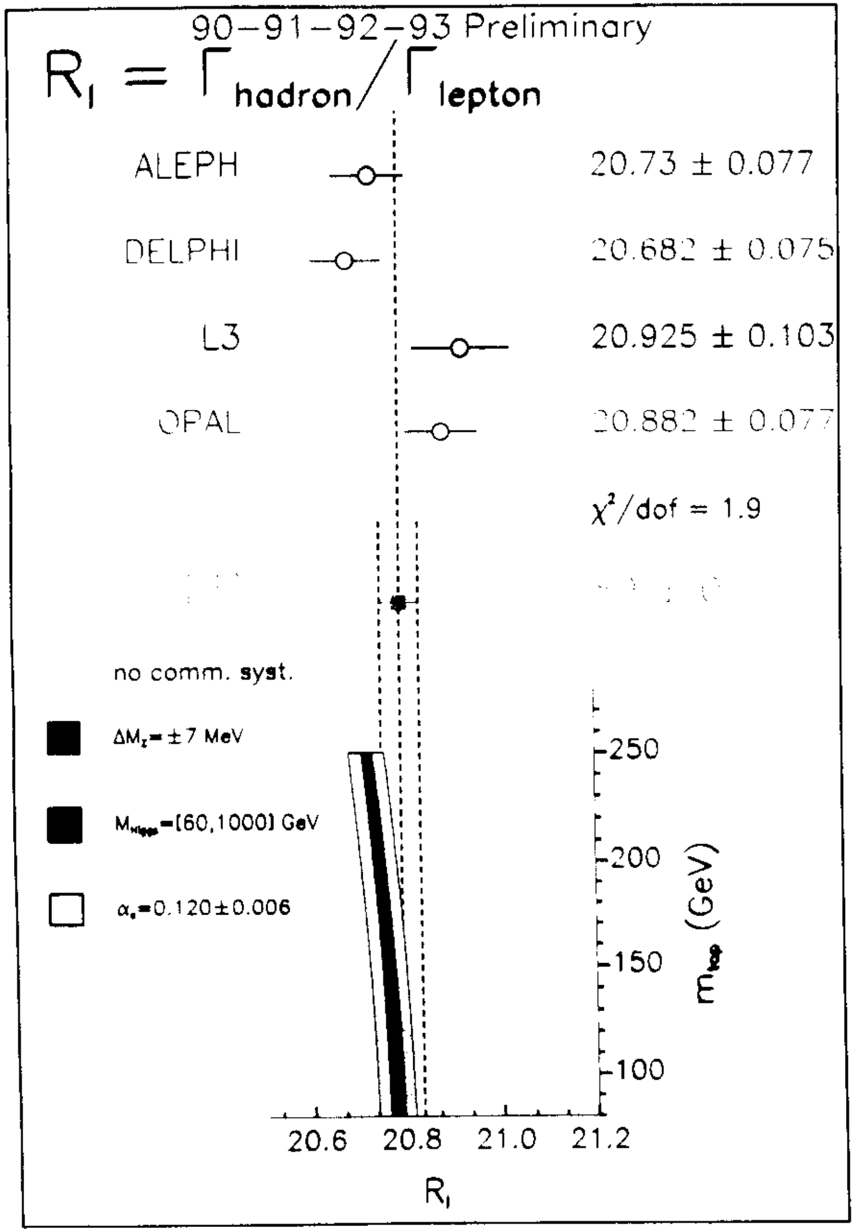
R_ℓ

→ INDEPENDENT OF LUMINOSITY

SYSTEMATICS : e^+e^- : t-channel (0.2%)
$\tau^+\tau^-$: $\gamma\gamma$ background, acceptance (0.7%)

- R_τ CORRECTED TO $m_\tau = 0$ (0.23%)

[NO '93 DATA FROM L3
NO μ, τ '93 DATA FROM DELPHI]

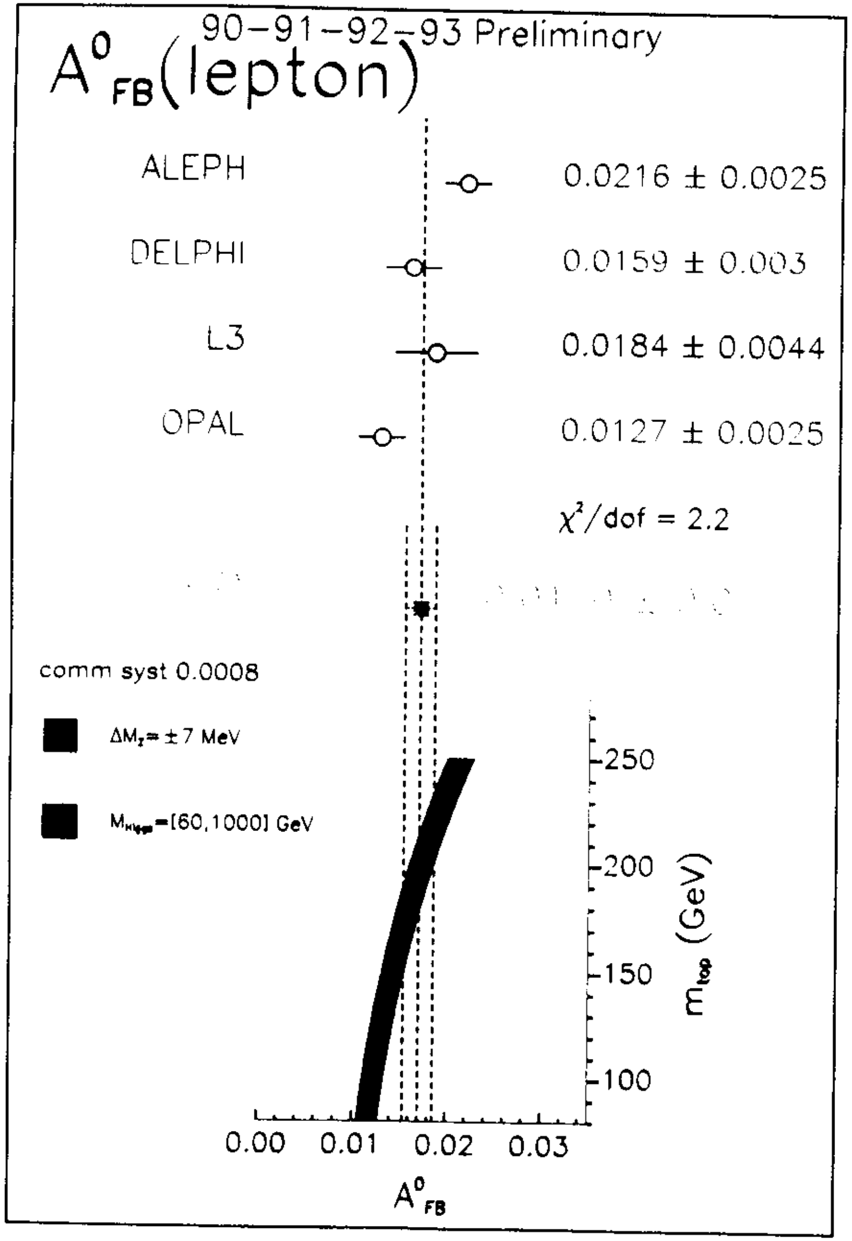


$\underline{A^0_{FB}}$ LEPTON ASYMMETRIES

DERIVED FROM A FIT TO $\cos\theta$ DISTRIBUTION

- CORRECT FOR INITIAL STATE RADIATION
  + QED EFFECTS
- SUBTRACT t-CHANNEL FROM e^+e^-

CAN THEN USE: $\left.\begin{matrix} A^{0\,\ell}_{FB} \\ \Gamma_\ell \end{matrix}\right\} \Rightarrow g_A, g_V \Rightarrow \sin^2\theta^\ell_{eff}$



$\underline{\underline{\tau_{POL}}}$: THE TAU POLARIZATION CONVEYE
INFORMATION ON BOTH A_τ $\underline{\underline{\text{AND}}}$
[LIKE A_{LR}]

THE HELICITY OF THE τ CAN BE MEASURED THROUGH A FIT TO THE MOMENTUM DISTRIBUTIONS OF THE τ DECAY PRODUCTS

5 CHANNELS USED, BUT HIGHEST SENSITIVITY:

$\tau \rightarrow \pi \nu$
$\tau \rightarrow \rho \nu$

[LEPTONIC CHANNELS HAVE HIGHER BR.FR. BUT ALSO TWO NEUTRINOS...]

The τ Polarization

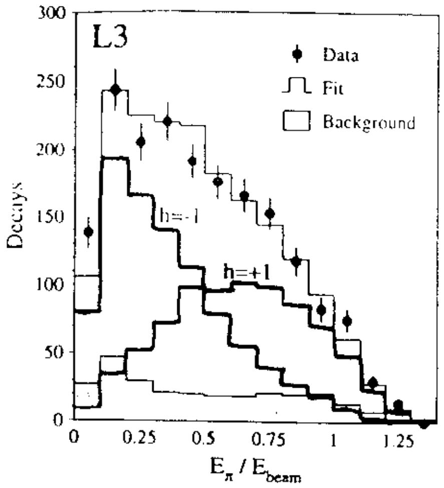
$$\mathcal{P}_\tau = \frac{\sigma_R-\sigma_L}{\sigma_R+\sigma_L}$$

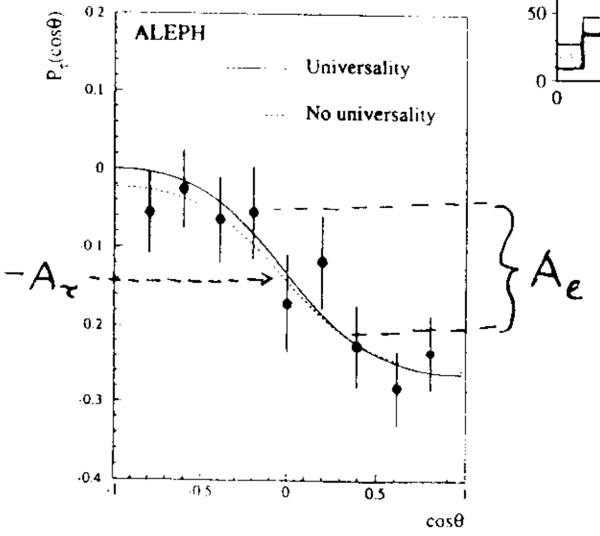
$$\mathcal{A}_\ell = \frac{2g_{V_\ell}g_{A_\ell}}{g_{V_\ell}^2+g_{A_\ell}^2}\ .$$

$$\mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau+\mathcal{A}_e\frac{2\cos\theta}{1+\cos^2\theta}}{1+\mathcal{A}_\tau\mathcal{A}_e\frac{2\cos\theta}{1+\cos^2\theta}}\ ,$$

τ decay products are used to determine the helicity state:

- **electron**
- **muon**
- **pion**
- **rho**
- **a_1**

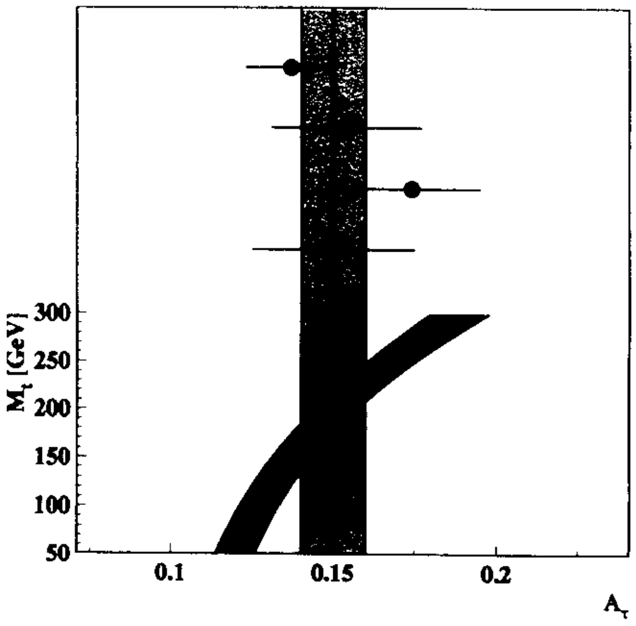




$\mathcal{A}_\tau$ measurement

ALEPH	**0.137**	±	**0.014**
DELPHI	**0.154**	±	**0.023**
L3	**0.174**	±	**0.021**
OPAL	**0.150**	±	**0.025**
LEP	**0.150**	±	**0.010**
	$\chi^2/d.o.f.$	=	**0.7**

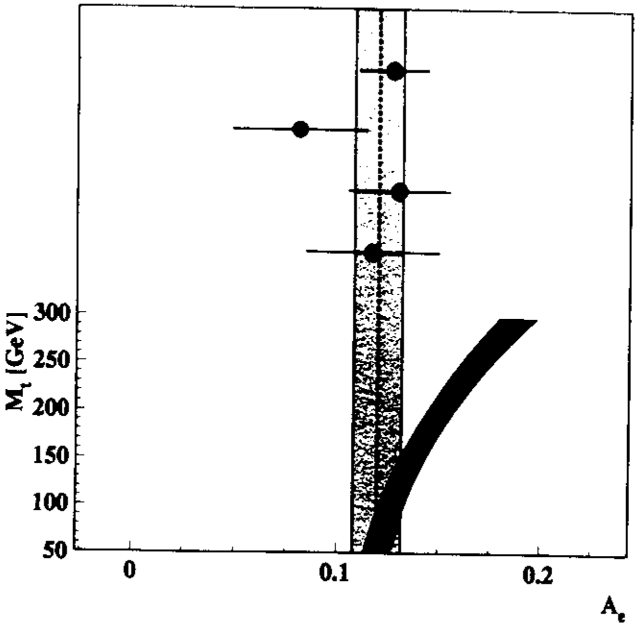
No common syst.



$\mathcal{A}_e$ measurement

ALEPH	0.127	±	0.017
DELPHI	0.081	±	0.033
L3	0.130	±	0.025
OPAL	0.117	±	0.033
LEP	0.120	±	0.012
	$\chi^2/d.o.f.$	=	0.6

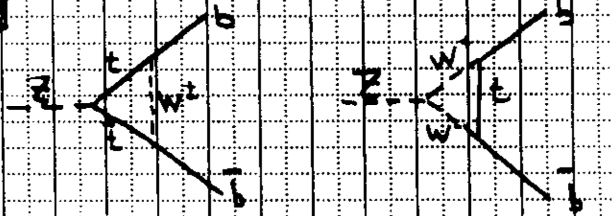
No common syst.



HEAVY FLAVOUR EW RESULTS

- $R_b = \frac{\Gamma_{b\bar{b}}}{\Gamma_{had}}$ → HAS A SPECIAL FEATURE: DEPENDS ON m_{top} (AND IT IS INSENSITIVE TO m_H)
- A_{FB}^b

[• R_c, A_{FB}^c]



[this info also contained in R_c & less significant]

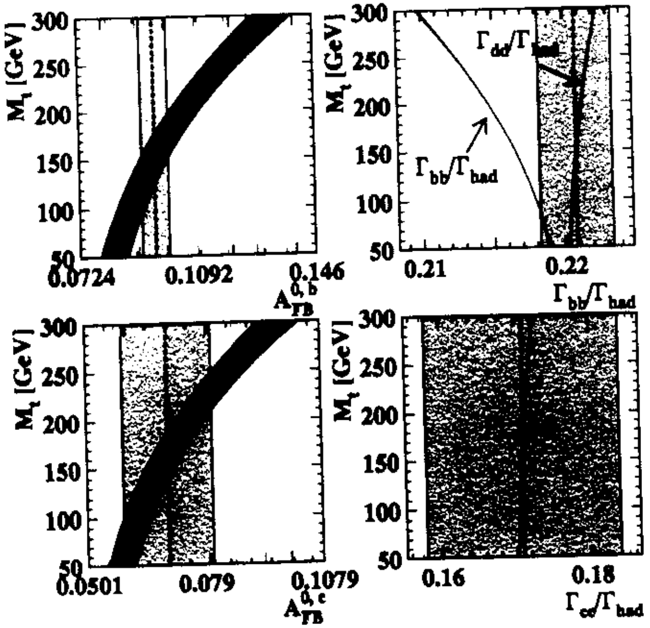
HEAVY FLAVOUR TAGGING

- LEPTON TAG lepton from semileptonic B decay has large p and p_T
- LIFETIME TAG $\tau_B \doteq 1.5 ps$ ($\tau_D \simeq 1 ps$)
- EVENT SHAPE TAG thrust/sphericity/aplanarity/... ⇒ NEURAL NETWORKS ← NEED GOOD MC
- ADDITIONAL HELP: DOUBLE TAGGING
- CALIBRATION: BY MONTE CARLO / USING DATA
- COMPLICATED AVERAGING PROCEDURE

Electroweak results with heavy quarks

Hadr. Charge Asym

$$
\begin{aligned}
R_b &= 0.2208 \pm 0.0013 \pm 0.0020\\
R_c &= 0.1697 \pm 0.0035 \pm 0.0134\\
A^b_{FB} &= 0.0960 \pm 0.0038 \pm 0.0021\\
A^c_{FB} &= 0.0700 \pm 0.0080 \pm 0.0072
\end{aligned}
$$

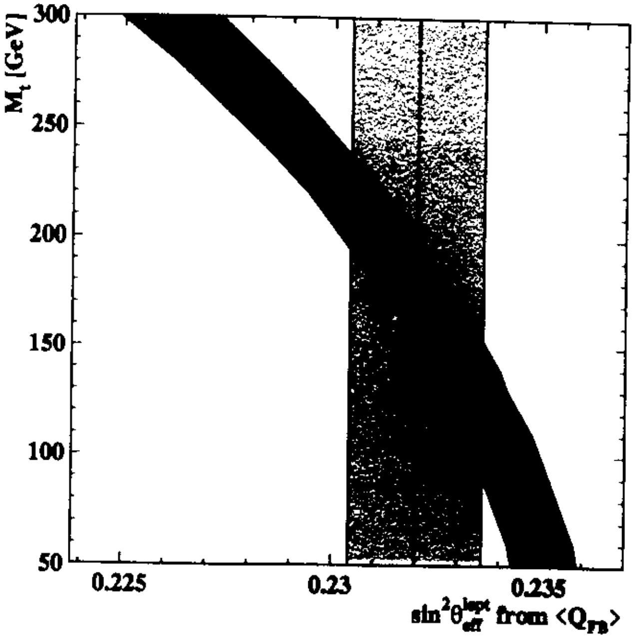


The Hadronic Charge Asymmetry

$$Q_{\overline{FB}} = \left(\frac{\sum q p^k}{\sum p^k}\right)_F - \left(\frac{\sum q p^k}{\sum p^k}\right)_B = c\mathcal{A}_e \sum_q \delta_q \mathcal{A}_q \frac{\Gamma_q}{\Gamma_h}$$

$$sin^2\Theta_{eff}^{lept}$$

ALEPH	0.2317	±	0.0013	±	0.0011
DELPHI	0.2345	±	0.0030	±	0.0027
OPAL	0.2321	±	0.0017	±	0.0028
Average	0.2320	±	0.0011	±	0.0011

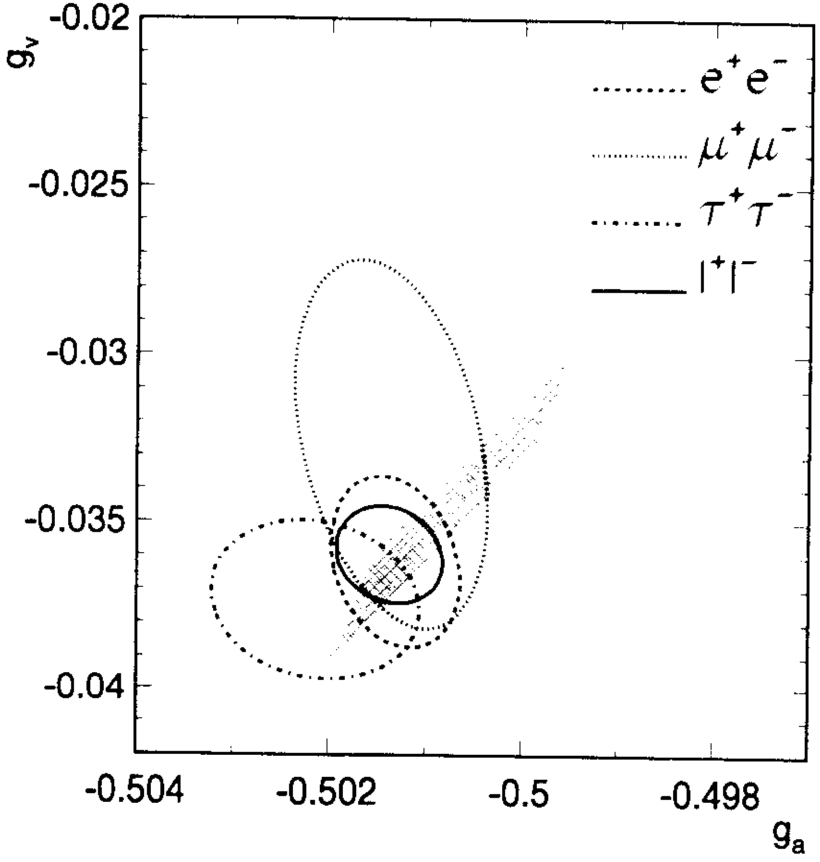


... THIS CONCLUDES THE PRESENTATION OF LEP OBSERVABLES. WHAT CAN WE NOW SAY ABOUT THE STANDARD MODEL ?

⟹ CHECK UNIVERSALITY

⟹ ARE WE REALLY SEING THE EW PART OF THE S.M. OR IS QED ENOUGH TO EXPLAIN EVERYTHING AT THIS LEVEL OF EXP. PRECISION ? YES, FOR THE FIRST TIME.

⟹ SINCE THE AGREEMENT IS GOOD, WHAT CONSTRAINS CAN WE DERIVE FOR THE TWO UNKNOWNS, M_{top} and M_H ?



▨ : SM PREDICTION

- PURE EW CORRECTIONS SEEN FOR THE FIRST TIME!

$(\epsilon_1, \epsilon_3) \Rightarrow (g_A, g_V)$

MODEL INDEP. WAY OF PRESENTING THE LEP RESULTS

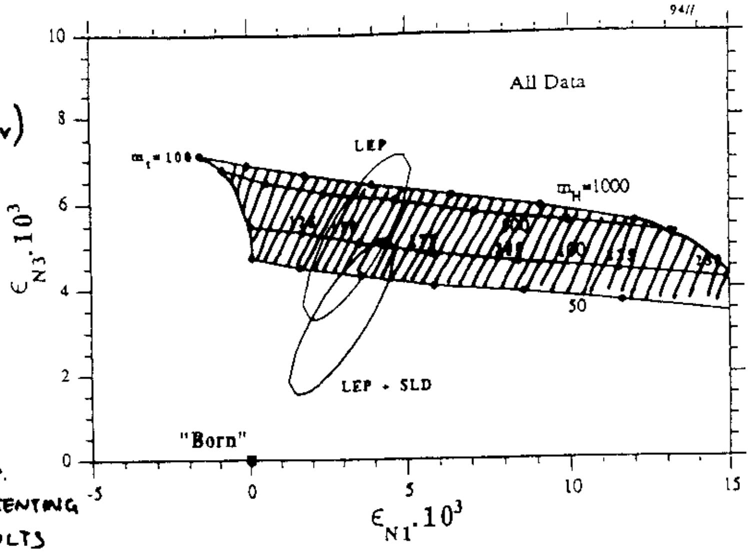


Figure 2 Plot of ϵ_3 versus ϵ_1 from the fit of the data, with (LEP+SLD) or withou inclusion of the SLD result (LEP). The projections of the ellipsis on the axe correspond to the 1 σ errors displayed in Table 3

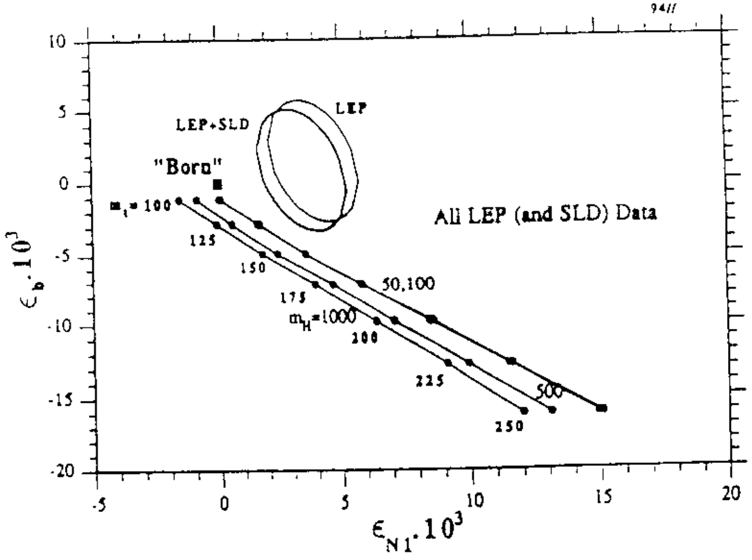
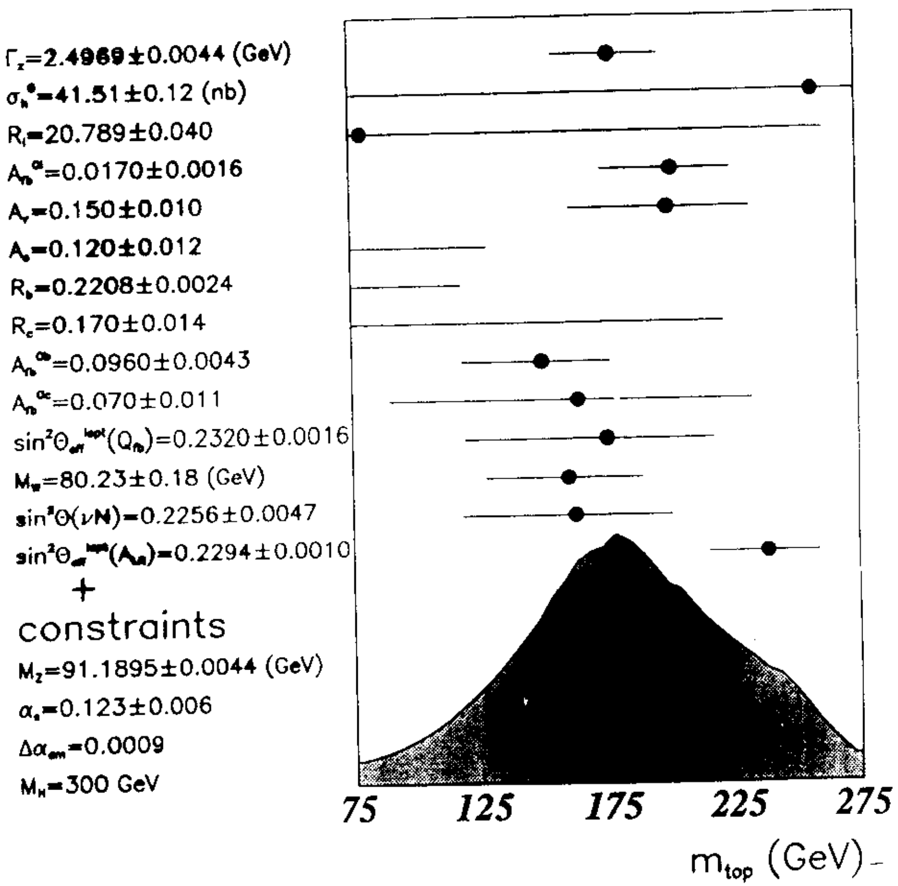


Figure 3 Plot of ϵ_b versus ϵ_1 as in figure 2

Summary of measurements for the Standard Model analysis

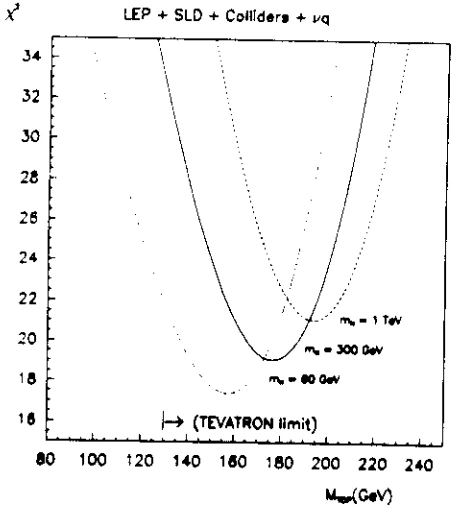
	measurement	Standard Model fit	pull
a) <u>LEP</u>			
line-shape and lepton asymmetries:			
M_Z **[GeV]**	91.1895 ± 0.0044	91.192	0.6
Γ_Z **[GeV]**	2.4969 ± 0.0038	2.4967	0.1
σ_h^0 **[nb]**	41.51 ± 0.12	41.44	0.6
R_ℓ	20.789 ± 0.040	20.781	0.2
$A_{FB}^{0,\ell}$	0.0170 ± 0.0016	0.0152	1.1
+ correlation matrix			
τ **polarization:**			
$\mathcal{A}_\tau$	0.150 ± 0.010	0.142	0.8
$\mathcal{A}_e$	0.120 ± 0.012	0.142	1.8
b and c quark results:			
$R_b = \Gamma_{b\bar{b}}/\Gamma_{had}$	0.2208 ± 0.0024	0.2158	2.0
$R_c = \Gamma_{c\bar{c}}/\Gamma_{had}$	0.170 ± 0.014	0.172	0.1
$A_{FB}^{0,b}$	0.0960 ± 0.0043	0.0997	0.8
$A_{FB}^{0,c}$	0.070 ± 0.011	0.071	0.1
+ correlation matrix			
$q\bar{q}$ **charge asymmetry:**			
$\sin^2\theta_{eff}^{lept}$ **from** $\langle Q_{FB} \rangle$	0.2320 ± 0.0016	0.2321	0.1
b) $p\bar{p}$ and νN			
M_W **[GeV] (CDF, CDF prel., D0 prel., UA2;**	80.23 ± 0.18	80.31	0.4
$1 - M_W^2/M_Z^2(\nu N)$	0.2256 ± 0.0047	0.2246	0.2
c) <u>SLC</u>			
$\sin^2\theta_{eff}^{lept}$ **from** $\mathcal{A}_e$	0.2294 ± 0.0010	0.2321	2.7

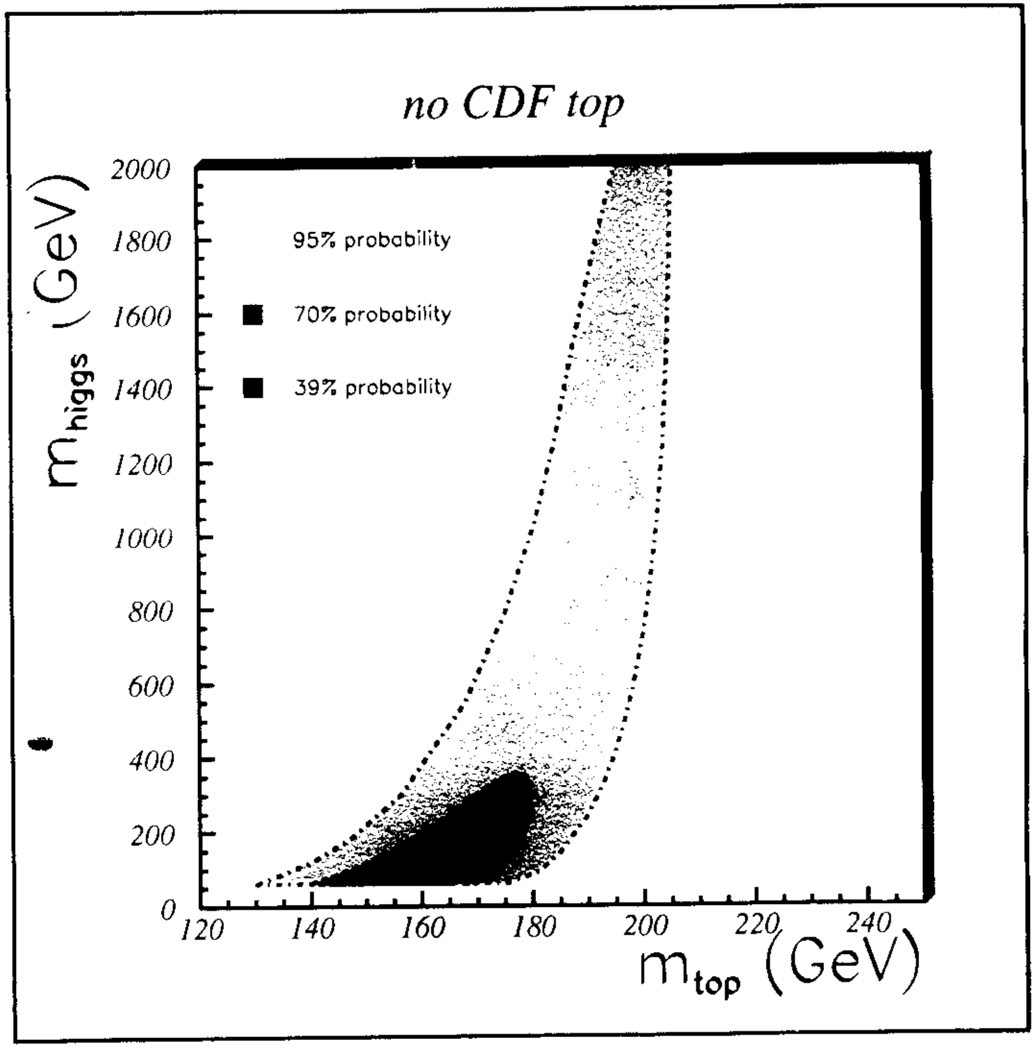
Individual m_top determinations



Results of SM fits to LEP and other data

	LEP	LEP + Collider and ν data	LEP + Collider and ν data + A_{LR} from SLC
M_t (GeV)	$172^{+13\ +18}_{-14\ -20}$	$170^{+12\ +18}_{-12\ -19}$	$177^{+11\ +18}_{-11\ -19}$
$\alpha_s(M_Z^2)$	$0.125 \pm 0.005\ \pm 0.002$	$0.125 \pm 0.005\ \pm 0.002$	$0.124 \pm 0.005\ \pm 0.002$
$\chi^2/(d.o.f.)$	**11.4/9**	**11.5/11**	**19.1/12**
$\sin^2\theta_{eff}^{lept}$	$0.2323 \pm 0.0002\ ^{+0.0001}_{-0.0002}$	$0.2324 \pm 0.0002\ ^{+0.0001}_{-0.0002}$	$0.2320 \pm 0.0003\ ^{+0.0001}_{-0.0002}$
$1 - M_W^2/M_Z^2$	$0.2251 \pm 0.0015\ ^{+0.0003}_{-0.0003}$	$0.2253 \pm 0.0013\ ^{+0.0003}_{-0.0002}$	$0.2243 \pm 0.0012\ ^{+0.0003}_{-0.0002}$
M_W (GeV)	$80.28 \pm 0.08\ ^{+0.01}_{-0.02}$	$80.26 \pm 0.07\ ^{+0.01}_{-0.01}$	$80.31 \pm 0.06\ ^{+0.01}_{-0.01}$





⇒ IMPRESSIVE LIMITS FOR M_{top}

JUST STARTING TO HAVE SOME SENSITIVITY TO M_H, BUT A LONG WAY TO GO...

CAN WE DO BETTER FOR M_H ???

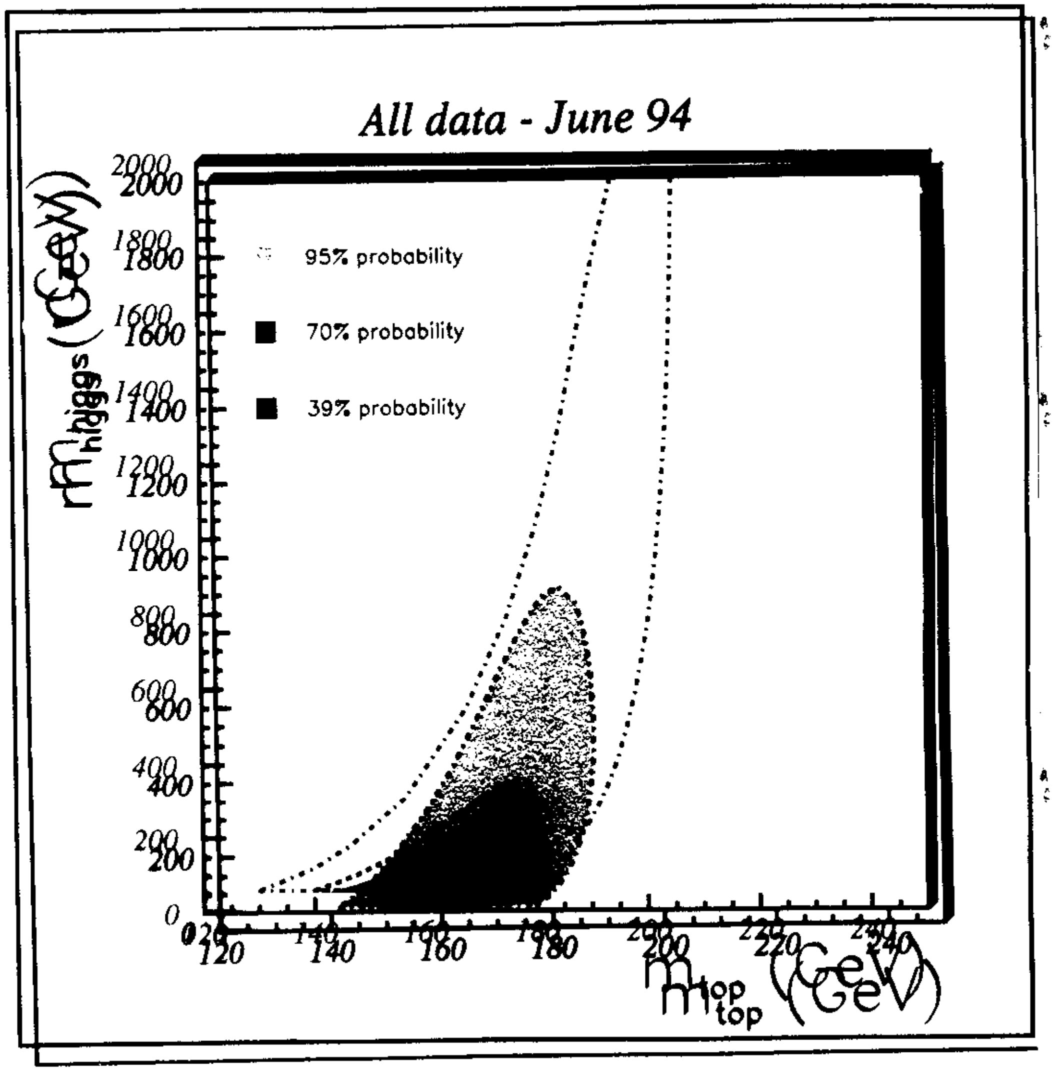
YES, IF TOP IS SEEN, CONFIRMED AND M_{top} MEASURED WITH A DECENT ERROR

⇒ ASSUME THAT 'EVIDENCE FOR...' OF CDF IS TRUE

⇒ COMBINE DIRECT M_{top} MEASUREMENT WITH CROSSSECTION (ELLIS et al CERN-TH 7261/94)

$$m_{top} = 167 \pm 12 \text{ GeV}$$

$$\Rightarrow m_H = 45^{+95}_{-28} \quad !$$



CONCLUSIONS

- LEP IS A HIGH PRECISION TESTING GROUND / FUNDAMENTAL VARIABLE MEASURING TOOL FOR THE STANDARD MODEL
- 1993 HAS BEEN A TOUR DE FORCE OF LEP THAT PROVIDED MUCH REDUCED UNCERTAINTIES TO MOST MEASURED VARIABLES.
- CONFIRMATION OF M_{top} FROM DIRECT SEARCHES WILL START CONSTRAINING m_H...
- S.M. STILL GOING STRONG BUT RUNNING OUT OF PARAMETER SPACE TO HIDE ITS DEFECTS...