Discussion on ILC detector maintenance needs

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Some thoughts on

- Calibration
  - Z-peak @Lep 2 => ILC
  - B-map
- Push-pull frequency
- Detector maintenance examples
  - Aleph
  - (SLD, L3)
- Disaster/Upgrade scenarios
- What else?

Z-peak

- At Lep2 ,all experiments - except Opal - requested ~ 1-2 days running at the Z-peak during a year for calibration, usually because some incident (eg, beam-loss) had damaged some subdetector which had to be recalibrated.

- At Lep1 (and SLC) this wasn't necessary because we were running at the Z-peak and taking "calibration data" (incidentally, also used for real physics) all the time.

- Therefore only the Lep2 experience can give is a guess as to what to plan for at the ILC.

Email 2005 (at Daegu ACFA8) to Mark Thomson:

Thanks Mark,
So the conculsion is, taking the year 2000 as an example and rounding, for Z-peak calibration running:

at Lep2 we had:

=>per detector<= 3/pb at the beginning of a year, and
" one run of 0.5/pb during a year

For the ILC, we might then request

at ILC:

=>per detector<= 10/pb at the beginning of a year, and
" one run of 1/pb during a year

since the detector(s) will be more demanding. Does this sound reasonable?
Cheers,
Ron

Z-peak

- So a fundamental question for the ILC machine is: how easy/difficult will it be to run at the Z-peak, if e.g. data-taking is at 250 or 350 GeV (c.m.s.) that year?

B-map

Preparing LC Note…

LC-DET-2005-XXX
Draft 22 August 2005

On the Magnetic-field Requirements for a TPC at the Linear Collider[1]

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DRAFT 2005-08-22
Please do not distribute since the draft is still evolving

…based on experience with Aleph TPC

The systematic uncertainty

From the Aleph experience, systematic effects for the TPC were corrected to the 70μm level, as can be seen on p. 58 of [14]. Aleph was well understood in 1999, and the best possible tracking precision (calculated using the Aleph Monte Carlo) was $\delta(\frac{1}{p}) = 4.5 \cdot 10^{-4}(\mathrm{GeV/c})^{-1}$, whereas a value of $4.9 \cdot 10^{-4}(\mathrm{GeV/c})^{-1}$ is the average of the year-to-year resolution achievements. The difference in quadrature between these two numbers translates to a 70 μm effect[15] which increased the TPC point resolution and can be considered as a measure of the understanding of corrections for systematic effects.

Using this as a guide and the fact that the LC TPC will have a better σ_{point} and more measured points than Aleph and allowing at most a 5% increase in the momentum error means that the systematic error on the point resolution should be below about $\sigma_0 \simeq 30$ μm for the LC TPC (the symbol σ_0 will be used for the tolerance).

Note that the final systematic error will include all corrections (detector alignment, distortions related to background, B-map accuracy, etc.). We shall use 30 μm as an upper limit in the following for estimating accuracy of the B-field map.

The B-field

- Compute distortions from Langevin equation

$$\vec{v}=\frac{\mu}{1+(\omega\tau)^2}\left(\vec{E}+(\omega\tau)\frac{\vec{E}\times\vec{B}}{|\vec{B}|}+(\omega\tau)^2\frac{\vec{B}(\vec{E}\cdot\vec{B})}{\vec{B}^2}\right)$$

Corrections exact if B-field known exactly; so what must B accuracy be?

$$\Delta\widehat{r\varphi}_E=\frac{1}{1+(\omega\tau)^2}\int_z^{z_M}\left(\frac{E_\varphi}{E_z}-(\omega\tau)\,sign(B_z)\frac{E_r}{E_z}\right)dz\ ;\quad \Delta\hat{r}_E=\frac{1}{1+(\omega\tau)^2}\int_z^{z_M}\left(\frac{E_r}{E_z}-(\omega\tau)\,sign(B_z)\frac{E_\varphi}{E_z}\right)dz\ ;$$

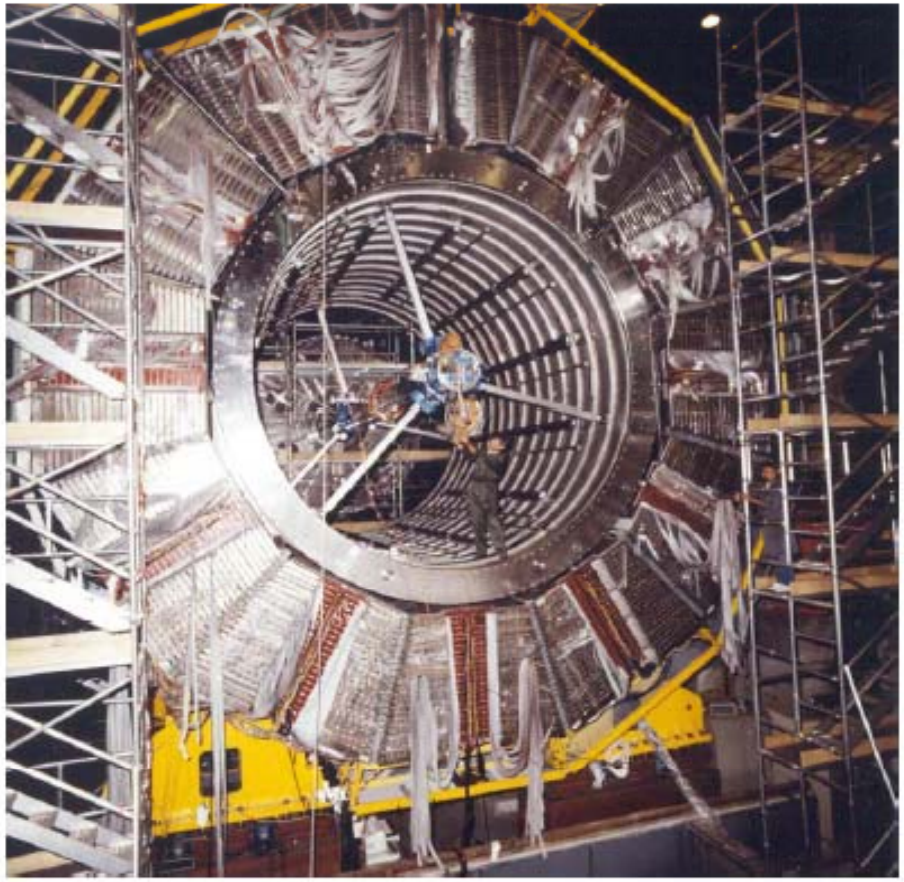
$$\Delta\widehat{r\varphi}_B=\frac{(\omega\tau)}{1+(\omega\tau)^2}\int_z^{z_M}\left((\omega\tau)\frac{B_\varphi}{B_z}-\frac{B_r}{|B_z|}\right)dz\ ;\quad \Delta\hat{r}_B=\frac{(\omega\tau)}{1+(\omega\tau)^2}\int_z^{z_M}\left((\omega\tau)\frac{B_r}{B_z}-\frac{B_\varphi}{|B_z|}\right)\ ;$$

The relevant equations for movement of drifting electrons in B-field

The Aleph B-map…

main reason for this is contained in a sentence from the article on "Tracking Alignment" by Alain Bonissent:

"The magnetic field measurements were made in a very short period during the first mounting of Aleph, and the experimental conditions were not ideal. After the complete assembly, such measurements could never be repeated, so that this will remain forever as an uncertainty."



Hall probe measuring devices being set up in the coil

From the LC Note…

4.1 The Aleph B-field Map

The goal of Aleph B-field map was to be internally self-consistent to an accuracy of $\frac{\delta B}{B} \simeq 1 \times 10^{-4}$, according to [3], for the magnet configuration (i.e., main-coil current $\leftrightarrow$ correction-coil currents) which was set during mapping. This map verified[3] that the '2mm condition' of Eq.1 was satisfied for all components of the Aleph B-field.

However 1×10^{-4} was not achieved. The standard deviation, σ_{map}, between measurements and the fit of a model derived from Maxwell's equations, for the Aleph B-map after corrections (see below) was 0.3 G for B_z and ~6 G for the B_r and B_φ[26], which corresponds to 5×10^{-4} or 0.5 permille. The residual uncertainty after integrating over the drift distances of the points for a track was $\frac{\sigma_{map}}{\sqrt{N_{map}}}$ where N_{map} was the number of fluctuations between measurements and map for the B-field. Typically N_{map} was about 60 for Aleph (Fig.8 in [26]) so that the residual error was < 1 G.

One problem with the Aleph B-field map was that the configuration used for

Problems: - Different coil configuration between mapping and running

- Hall plate drifts

- Temperature drifts

$\Rightarrow$ Aleph should have taken more time for the calibration of various effects and mapped with more configurations.

B-field Map for the LC TPC

Aleph map almost good enough for the LC TPC; profit from experience:

- Map to better than 0.5‰ internal consistency; lay out for 0.1‰ to achieve this.
- Construct main detector coil to adhere to '2mm condition' (before superimposing the antiDID). Map with the antiDID on and off.
- Establish tolerances with careful simulation:

  - The Hall plate calibration.
  - The number of Hall plates and NMR probes.
  - The position accuracy of the probes and mapping gear.
  - The number of positions per map.
  - The stability of power supplies, monitoring devices, etc.

- Do same for stray fields of MDI magnets.
- Mount matrix of Hall plates on LCTPC to monitor/check while running.
- Devise model including all material to compare with Hall-plate matrix.

Push-pull frequency

Now is maybe a good time to look briefly at the physics of the ILC. From my talk at the Arlington LC Workshop January 2003:

WHY LC?

TWO-PRONG ATTACK at LC on PHYSICS beyond the SM

→ INDIRECT

PRECISION MEASUREMENT

Higgs – Top – WW – $q\bar{q}$ – GZ – M_W

⇒ High statistics
⇒ Polarized beams

e.g., $M_{Z'} \sim 5$ TeV

→ DIRECT

DISCOVERY

Susy – Alternative Theories

e.g., 'Susy Forest'

→ **NECESSARY** COMPLEMENT to LHC

PHYSICS $\longrightarrow$ MACHINE

Executive Summary

HIGGS

DISCOVERY & PRECISION MEAS. of
PRODUCTION, COUPLINGS

10^5 Higgs few % 20%

$\rightarrow$ 500 fb^{-1} @ $\sqrt{s} \sim m_Z + m_W + 25$ GeV
$\sim$ 230 GeV acc. to EW fits

TOP

PRECISION MEASUREMENT
Mass $\delta m_t \sim 100$ Mev

Z charges $v_t = 1 - \frac{8}{3} \cdot s_W{}^2$, $a_t = +1$ $\sim 1\%$

Mag., El. dip. mom. $\sim 1\%$, $\sim 10^{-18}$
Yukawa Coupling $g^2_{ttH} \sim 5\%$
$\rightarrow$ 300 fb^{-1}, 1000 fb^{-1} @ 400 GeV, 700 GeV
polarized beams

WW

PRECISION MEAS.

Mag.dip., El.quad. mom.

$$\left.\begin{aligned} \mu_{\gamma,Z} &= -\frac{e}{M_W}[z + \delta\kappa_{\gamma,Z} + \lambda_{\gamma,Z}] \\ Q_{\gamma,Z} &= -\frac{e}{M_W^2}[1 + \delta\kappa_{\gamma,Z} + \lambda_{\gamma,Z}] \end{aligned}\right\} \quad \delta\kappa, \delta\lambda \sim 10^{-3}$$

→ few 100 fb^{-1} @ 500 GeV

polarized beams

SUSY

DISCOVERY & PRECISION MEAS.

Meas. all Susy parameters

→ many 100 fb^{-1} up to highest energy

polarized beams

BEYOND E–W

PRECISION MEAS. & DISCOVERY

Z', f^*, H^{ns}, LQ, TC, $n_D > 4 \ldots$

→ few 100 fb^{-1} up to highest energy

polarized beams

Z – PEAK

PRECISION MEAS.

$\delta \sin^2\theta_W \sim 10^{-5}, \delta M_W \sim 6$ MeV

→ 1 Giga Z

polarized beams

Example of Experimental Programme

- TESLA

$\sqrt{s} =$	91	500	800/1000	GeV
$\mathcal{L}$	$= 6 \times 10^{33}$	3×10^{34}	5×10^{34}	$cm^2 s^{-1}$

- PHYSICS

Year	Physics	$\sqrt{s}$ Gev	$\int \mathcal{L} dt$ fb^{-1}	Years Runnin
2018	Commissioning			1
2019	Higgs	250	200	2
2020	Top	350	200	1
2024	WW, HHH	500	500	2
+y	Susy			
2027	Yukawa ttH	750	1000	2
+y+SF	New Physics			
y	GZ	91	50	1
y	M_W	161	100	1

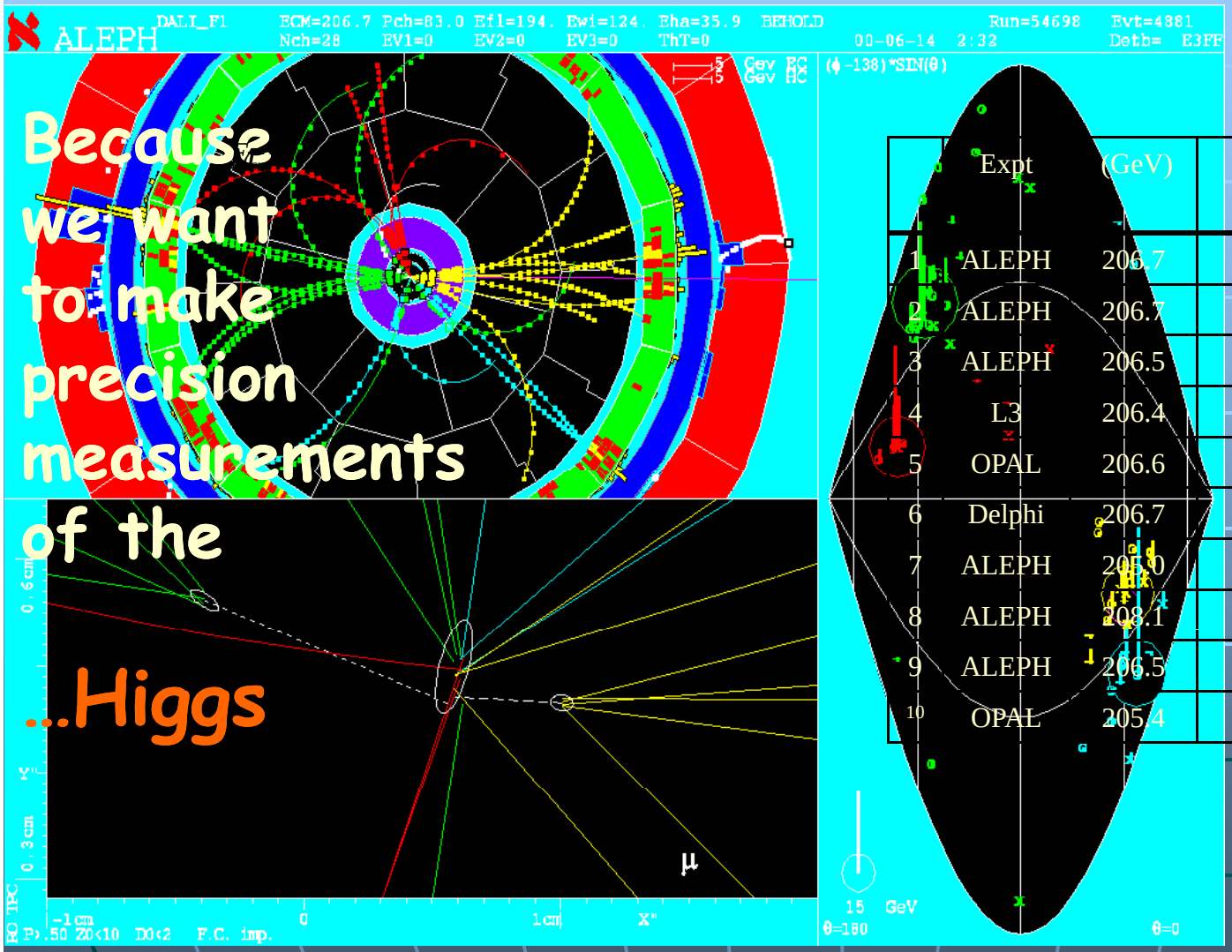
$\Sigma \sim 15$

Detector Goals

• vertexing e.g. $t\bar{t}$	$\delta(\mathrm{IP}_{\phi,z}) \lesssim 5\mu\mathrm{m} \bigoplus \frac{10\mu\mathrm{m}\mathrm{GeV}/c}{\mathrm{p}\sin^{3/2}\theta}$
• tracking e.g. Higgs	$\delta(1/\mathrm{p_t}) \lesssim 5 \times 10^5$ GeV/c^{-1}
• fwd. dirn e.g. lumi, t–ch.phys.	$\delta(1/\mathrm{p_t}) \lesssim 3 \times 10^4$GeV/c^{-1}, $\delta(\theta) \lesssim 2 \times 10^{-5}, \cos\theta \lesssim 0.99$
• jet energy from energy flow	$\delta(\mathrm{E/E}) \lesssim \frac{0.35\mathrm{GeV}^{1/2}}{\sqrt{\mathrm{E}}}$
• hermeticity for $\not{E}$ meas.	$\sim$ 5 – 10 mrad for beampipe, only hole
• backgrounds robustness	min. material inside Ecal, $\vec{\mathrm{B}} \gtrsim$ 3T, granularity

R & D, prototyping to shoot for these goals

Motivation…



Because we want to make precision measurements of the

…Higgs

	Expt	(GeV)	Decay Channel	(GeV/c^2)	ln(1+*s*/*b*) 115 GeV/c^2
1	ALEPH	206.7	4-jet	114.3	1.73
2	ALEPH	206.7	4-jet	112.9	1.21
3	ALEPH	206.5	4-jet	110.0	0.64
4	L3	206.4	E-miss	115.0	0.53
5	OPAL	206.6	4-jet	110.7	0.53
6	Delphi	206.7	4-jet	114.3	0.49
7	ALEPH	205.0	Lept	118.1	0.47
8	ALEPH	208.1	Tau	115.4	0.41
9	ALEPH	206.5	4-jet	114.5	0.40
10	OPAL	205.4	4-jet	112.6	0.40

To make progress in understanding, we have to distinguish two different phases:

(1) Running for precision measurements
(2) Running for discovery

DISCUSSION

(1) Precision measurements

-Here frequent change is not so important; once a year is enough unless a detector problem crops up.

-A well calibrated detector is essential. For this Z-peak running is one of the most valuable tools we have. At Acfa8, Mark Thompson and I made the following gestimate for ILC based on Lep2 experience:

-- 10/pb Z-peak at the beginning of a year (after detector maintenance, meaning it had been taken apart and put back together

-- 1/pb Z-peak later in case of incidents/accidents during a year.

-A similar procedure was followed at Lep2 every year and was valuable/necessary for all 4 detectors. (At Lep1 we were running on the Z-peak all the time and therefore were taking calibration data all the time.)

(2) Discovery

-Here a frequent change is important, and therefore the change should be as rapid as possible.

(For example, at Lep2 we did this, went through a "Higgs-discovery" mode, where—this is an example for the machine and not the detector--went through frequent cycles of filling to the highest possible energy, running for an hour or two, then refilling rapidly after a beam loss, in 1-2 hours typically.)

-But we have to remember that at the ILC good MDI teams and a lot of planning/training/experience will be needed to achieve the fastest possible "Formula-1-Pitstop"-type switch.

(Aleph) detector maintenance examples

- Coil failure
- TPC carbon-fiber saga

Coil failure story told by Pierre Lazyrus at http://alephwww.cern.ch, click on The Aleph 'Experience' for details (and other stories)

- At the beginning of January 1994, the coil was at room temperature and a last pressure test showed a very large leak.

- Tests indicated that the leak was close to the inlet, 10m or so from it.

- We first opened the valve box, to find that two of the three supports of the 500 l helium vessel were broken; fortunately one was still intact and the piping was keeping the vessel in place quite well, but unfortunately, no leak

- The cryogenics chimney connecting the valve box to the vacuum vessel was open and found perfectly tight, but at this moment it was possible to hear the leak when pressurizing the screen pipe.

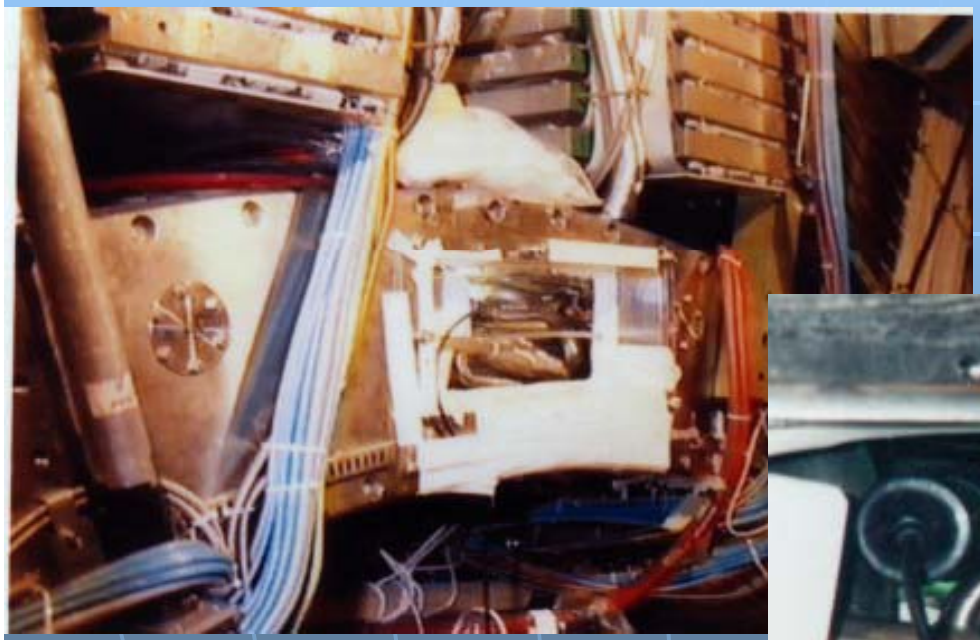
- With the aid of an endoscope and a mirror it was possible to see the leak just at a piece called bibraze, between the aluminium pipe on the screen and the stainless steel pipe coming from the manifold, about 30cm inside the vacuum vessel.

- It was decided to cut an aperture as large as possible through the flange, ≈ 90 mm thick, which closed the vacuum vessel

- For the drilling a framework was built, able to support a milling machine with enough stability versus the vibrations. This object was fixed on the magnet, on the barrel on one side and on the end-cap on the other side. The milling machine was installed on this framework.

- The drilling started on February 15, went smoothly, was finished by February 17, the superinsulation was opened and we could see exactly what had happened.

•For some unknown reason, during assembly, the stainless pipe had been blocked between two pipes; thus the flexible part supposed to take care of the contraction of the screen due to temperature could not play its role, and the result was an enormous tensile stress on the pipe, until it broke.



•Meanwhile, at Saclay, a piece was prepared and tested to replace the broken part.

•Finally on March 8th the new junction was put in place, glued on the screen pipe and then welded at the other end on the manifold. At 16.45 the repair work was over!!!

Conclusion

We were very lucky!, because the leak was reachable without doing really major work on Aleph. footnotes 1, 2

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footnote 1:
Had the leak been somewhere inside the coil cryostat, we would have had to completely dismantle Aleph; from inside out: beam pipe, SiCAL, LCAL, VDET, ITC, TPC, ECAL, COIL, the open the cryostat, fix the leak, and the reinstall everything in the reverse order. This would have taken at least a year, so that we would have missed all of 1994 data-taking!

footnote 2:
1994 was the year of acquiring the highest Z statistics for the SM precision measurements at Lep1…

TPC carbon-fiber saga (a.o.t.)

Distortion Corrections for the ALEPH TPC

Werner Wiedenmann

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Werner's talk contains many details, see
http://www.mppmu.mpg.de/~settles/tpc/Cern_LC.pdf

Overview of happenings

- LEP start-up: 1989-1990
  - Failure of magnet compensating power supplies in 1989 required development of field-corrections methods
    - derived from 2 special laser runs (B on/off)
    - correction methods described in NIM A306(1991)446
  - Later, high statistics Z->μμ events give main calibration sample
- LEP 1: 1991-1994
  - VDET 1 becomes operational in 1991
  - Development of common alignment procedures for all three tracking detectors
  - Incidents affect large portions of collected statistics and require correction methods based directly on data
    - 1991-1993, seven shorts on field cage affect 24% of data
    - 1994, disconnected gating grids on 2 sectors affect 20% of data
  - All data finally recuperated with data-based correction methods

- LEP 1/2: 1994-1996
  - Tracking-upgrade program (LEP 1 data reprocessed)
    - Improved coordinate determination requires better understanding of systematic effects
    - Combined calculations for field and alignment distortions, reevaluation of B-field map
  - All methods for distortion corrections now based directly on data
  - Development of "few"-parameter correction models to cope with drastically reduced calibration samples at LEP 2
- LEP 2: 1995-2000
  - New VDET with larger acceptance
  - Calibrations@Z at beginning of run periods have limited statistics
  - Frequent beam losses cause charge-up effects and new FC shorts
    - Superimposed distortions
    - Short-corrections with Z -> μμ;time-dep. effects tracked with hadrons
- LEP 1 & 2: Three times over the 10 years a sector was replaced by a spare.

Examples from Werner's slides…

Distortion Corrections for the TPC

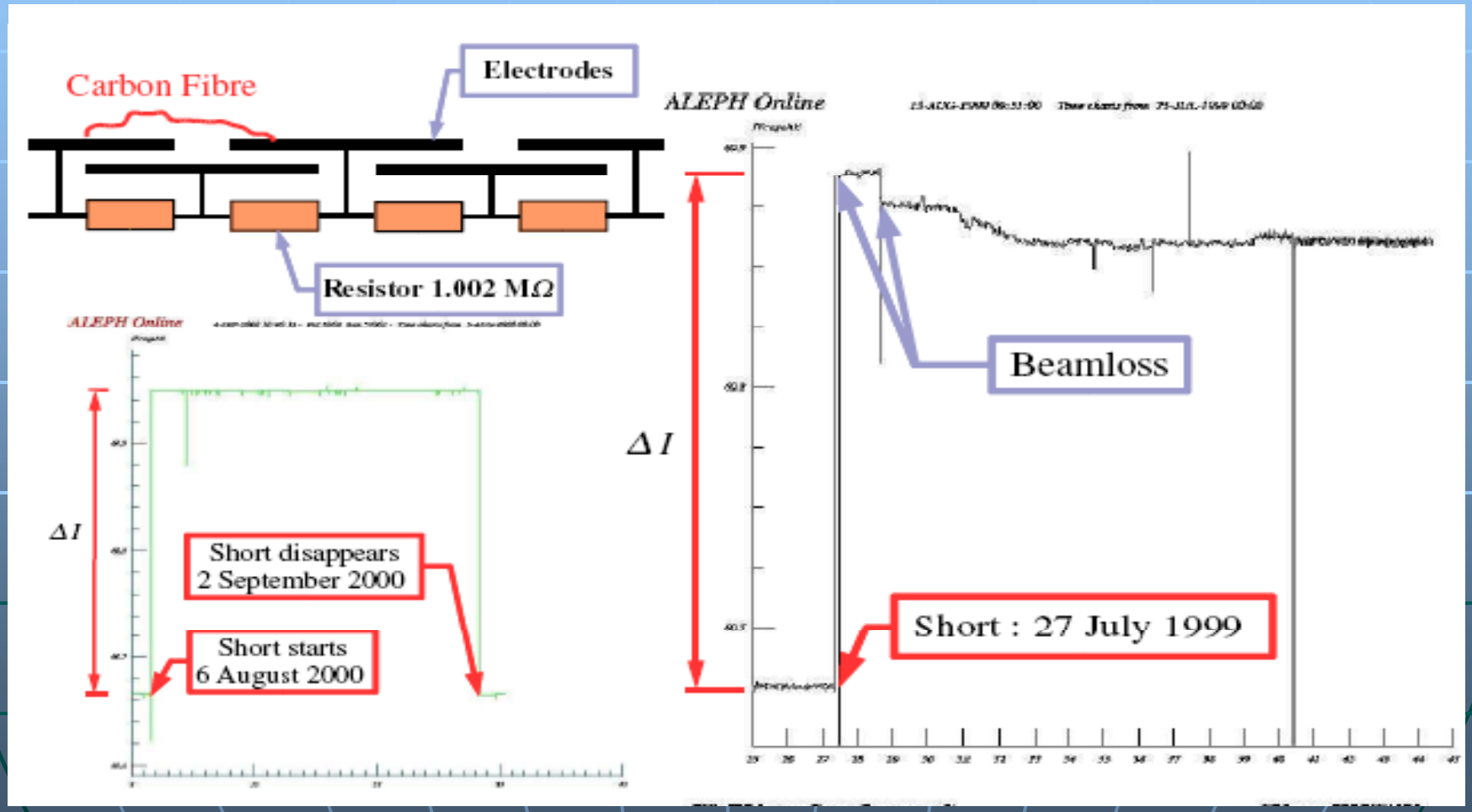
- Use real data : Muon pairs from Z–decays
- Prerequisite: preliminary calibration of inner tracking detectors exists already
  - Global alignment e.g. from survey measurements or from previous data alignments
  - Internal calibration for VDET and ITC (Can be done without TPC)
- Fit the 2 tracks of each muon pair with a common single helix
  - Momentum is constrained to beam energy
  - Helix parameters are determined with 4 hits from VDET and up to 16 hits from ITC. TPC is not in the track fit.

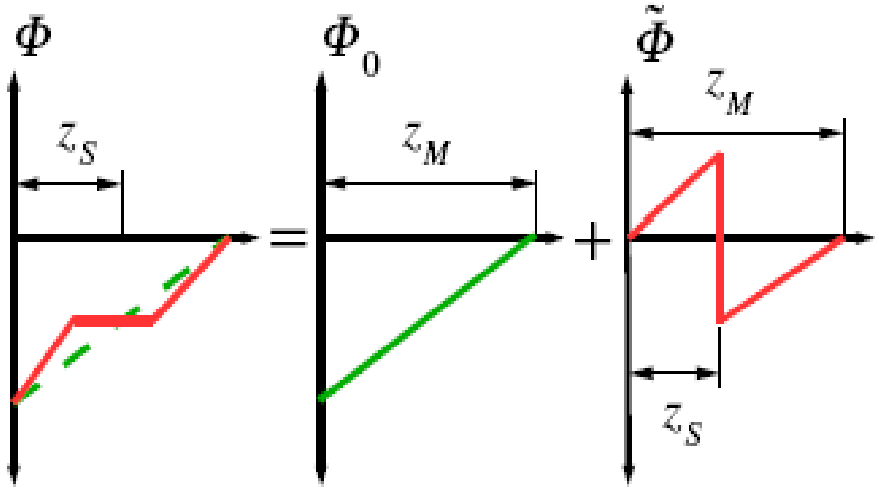
Werner Wiedenmann *Cern, December 2001* 10

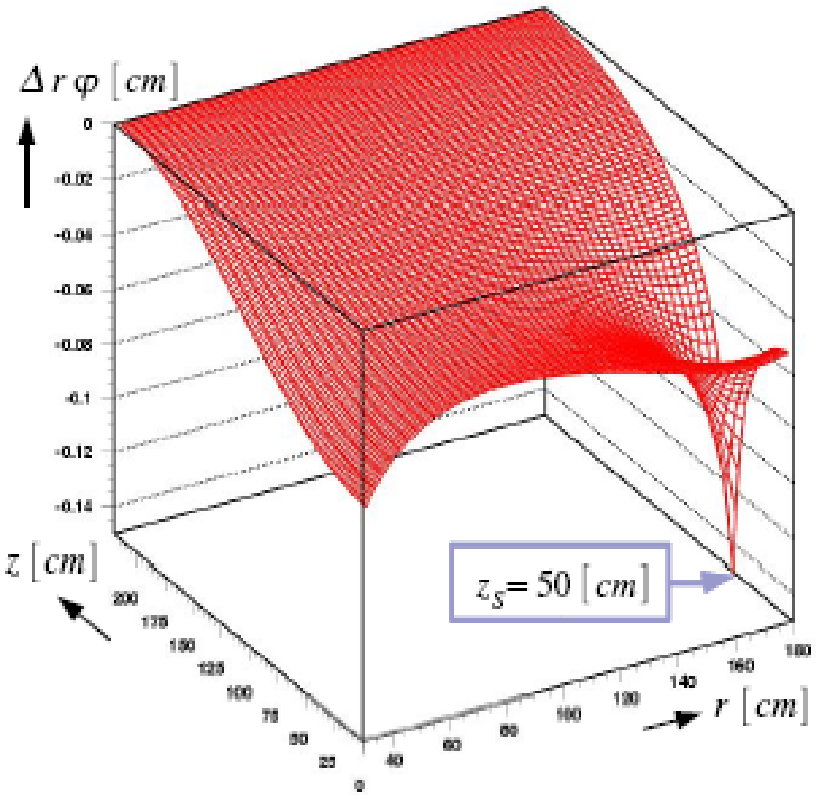
Tour through some problems and their correction

- Static problems (always there)
  - TPC tilt
  - Endplate bowing
  - Nonlinear potential on fieldcage
- Single incidents
  - Disconnected gating grids (space charge)
  - Shorts on field cage
- Time dependent effects
  - "Charge up" effects

e.g., field-cage shorts



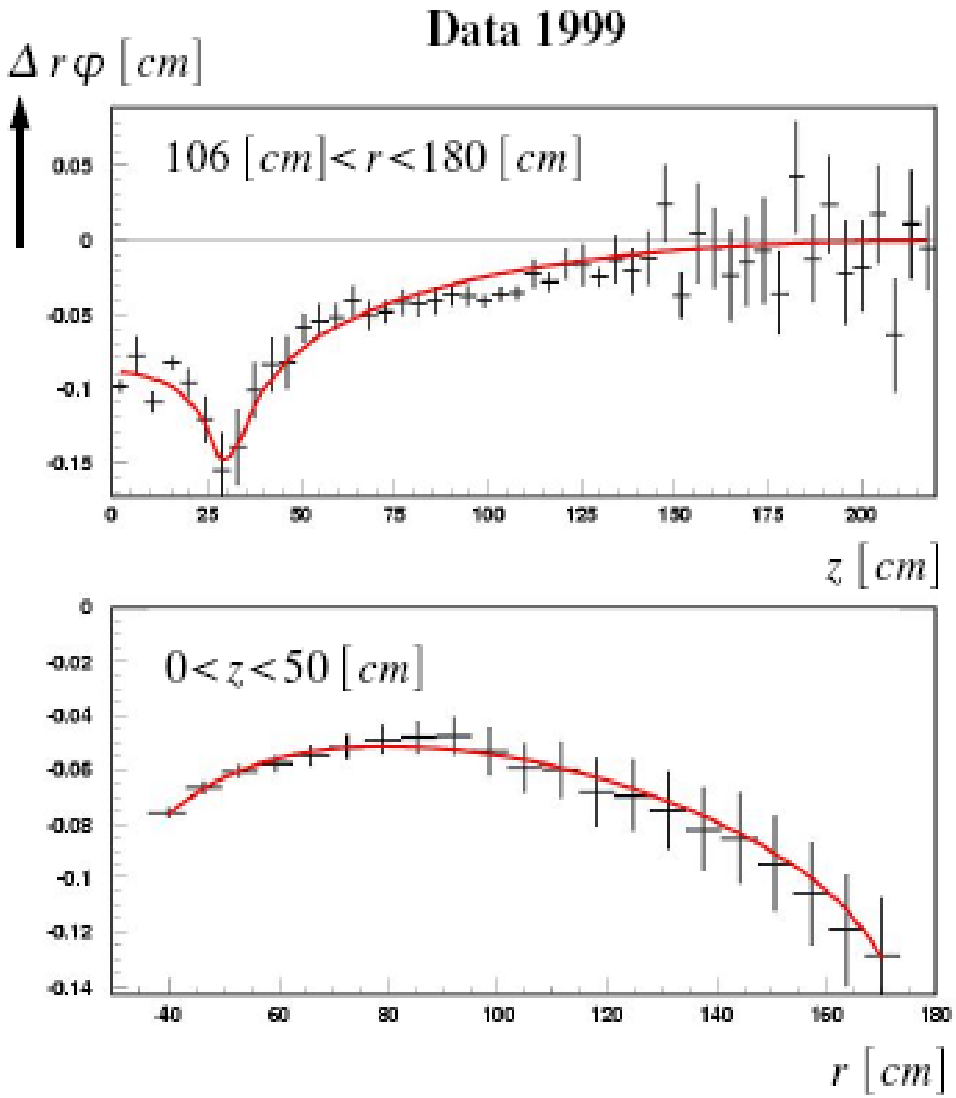


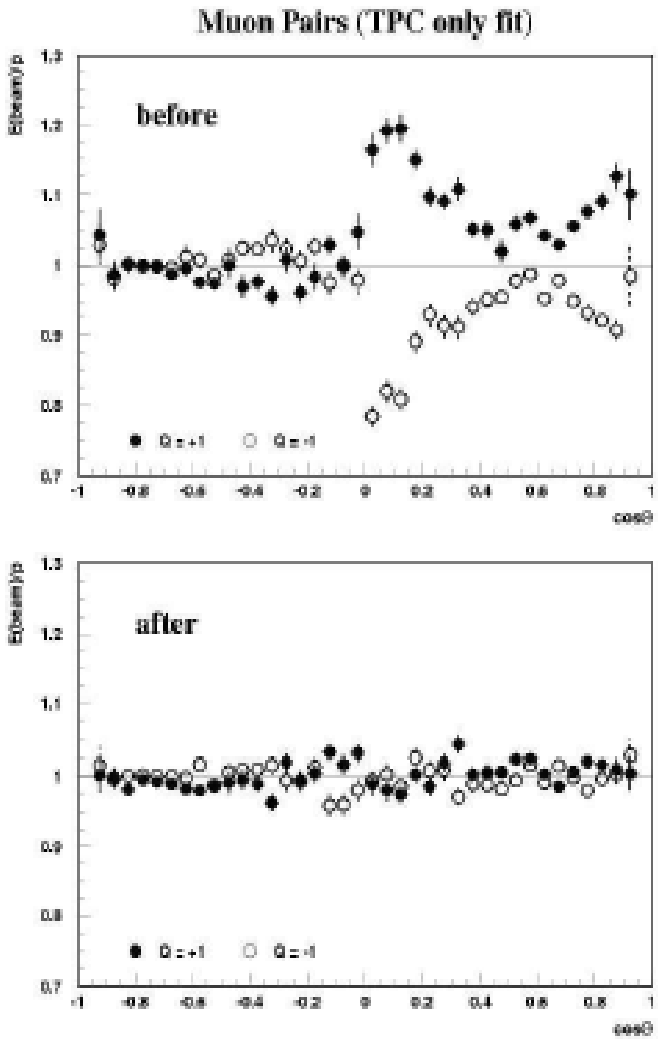


- Two parameter model
  - Shortposition
  - Voltage/current change

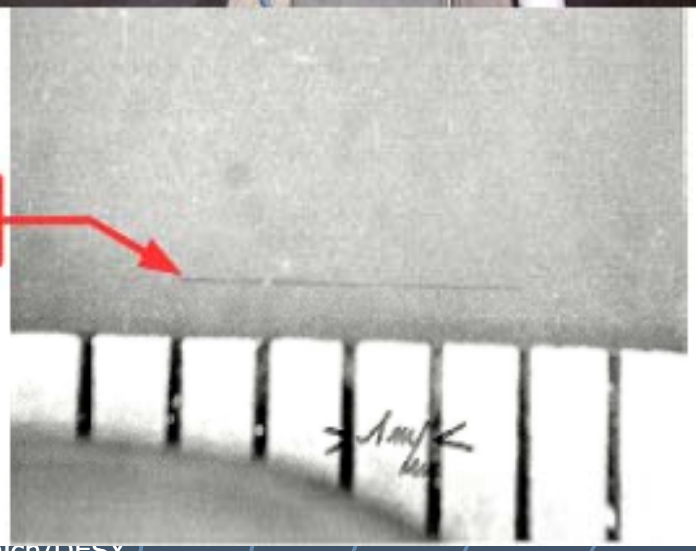
Distortionpotential

$$\tilde{\Phi}(r,\varphi,z) \simeq sign(z_S)\left(\frac{\Delta U_0}{U_0}\right)\sum_n \frac{\cos\left(\frac{n\pi}{z_M}z_S\right)}{n\pi}\sin\left(\frac{n\pi}{z_M}z\right)P_{0n,\,FCin/FCout}\left(\frac{n\pi}{z_M}r\right);$$


Data 1999
$\Delta r\varphi$ [cm]
106 [cm] < r < 180 [cm]
z [cm]
0 < z < 50 [cm]
r [cm]

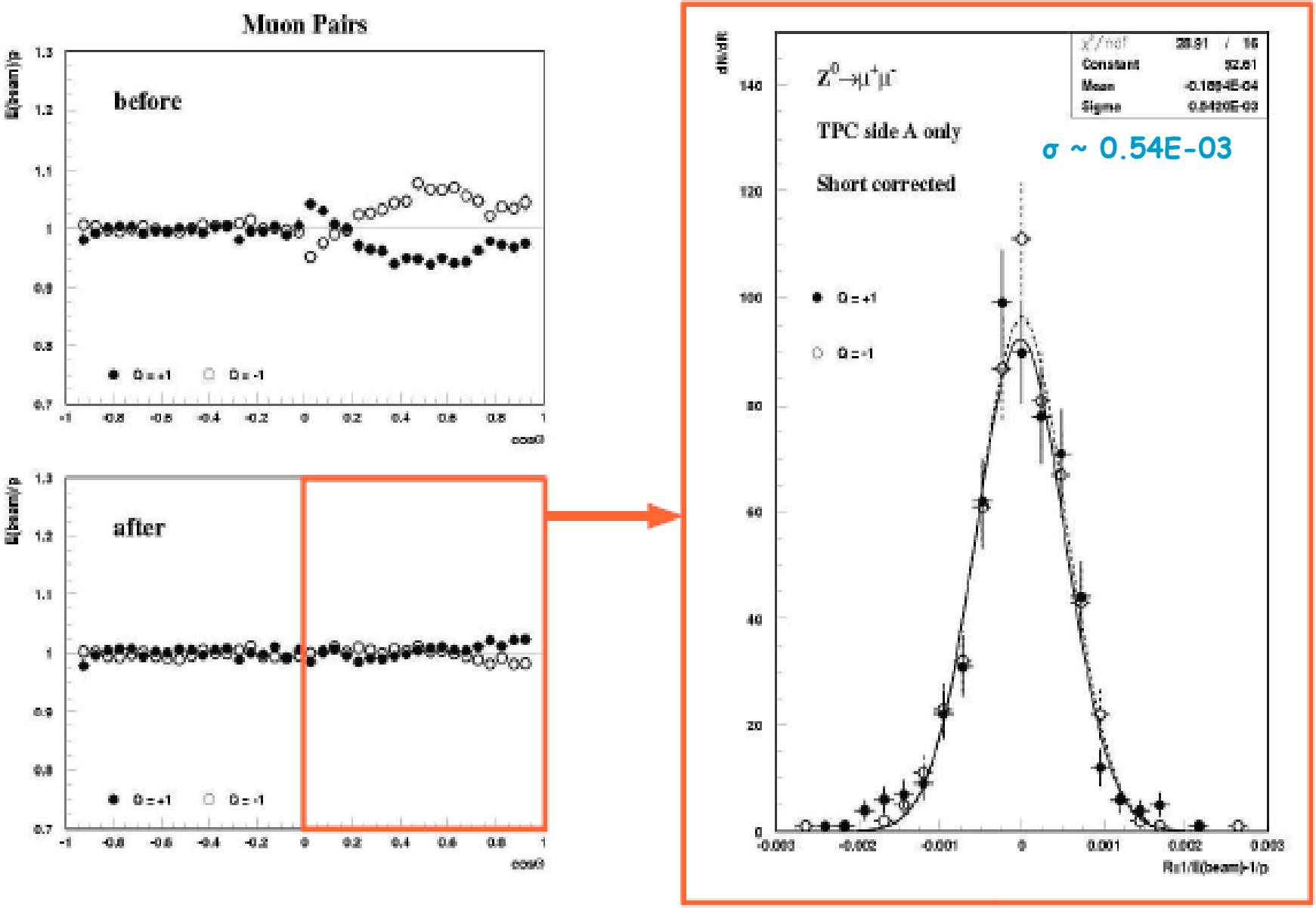

Muon Pairs (TPC only fit)
before
after
cosθ

(N.B., design your detector to be easily accessible…)



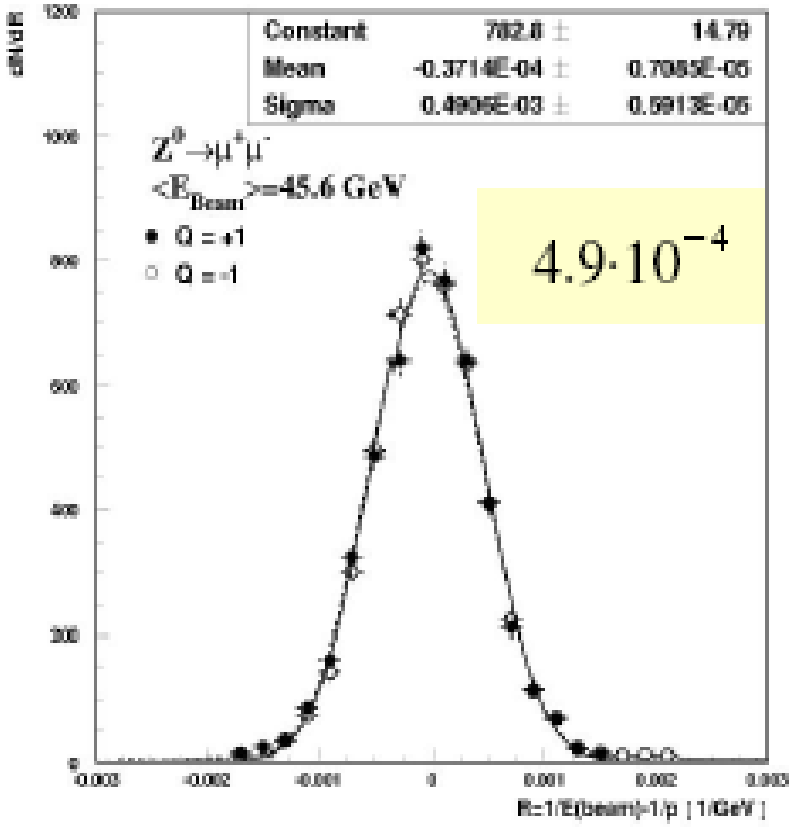
Intervention during 1999 shutdown

Short 1999 : Fit with all tracking detectors

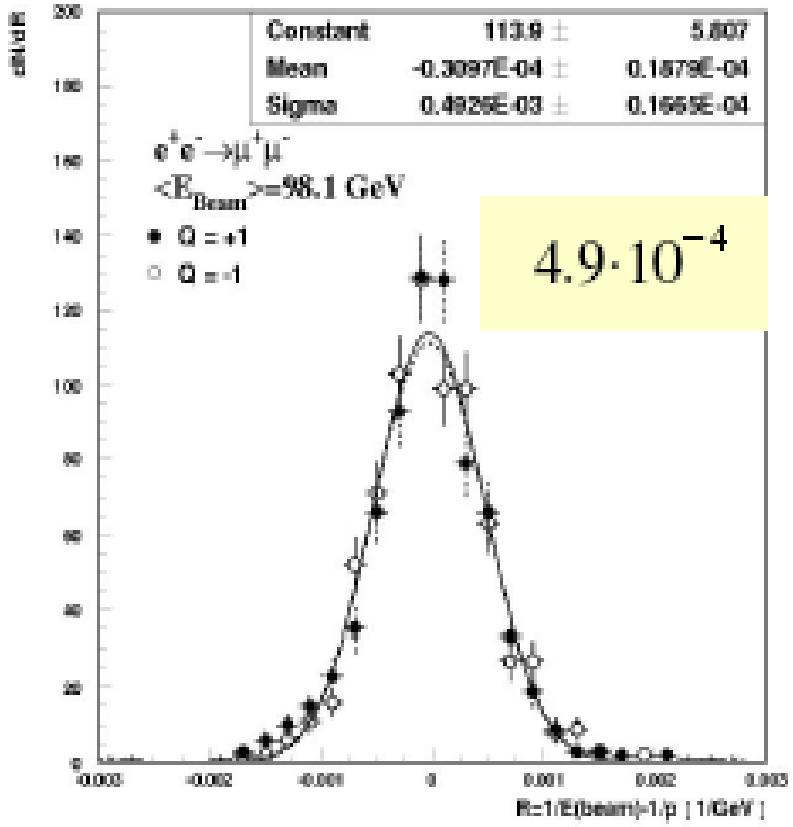


The bottom line (e.g., momentum resolution)

Calibration Data



High Energy Data



Disaster/Upgrade scenarios

1) Disaster: dismantle->repair->re-install
2)Upgrade: dismantle->upgrade->re-install

1) Can turn you off for a long time since you were caught by surprise…
2) Can prepare in parallel to normal running (but CDF and D0 took a long time to upgrade their detectors – although the machine was being upgraded at the same time)…

Conclusion

-Design your detector/subdetectors to be as accessible as possible so that you can get in and fix them

-What else?