Time Projection Chamber Corrections

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Time Projection Chamber Corrections

Some slides from my talk on the ALEPH TPC at the October 2003 TPC Symposium@LBNL, dedicated to Dave Nygren. You all know how a TPC works (Markus Ball yesterday), so I will skip through these quickly, be adding a few pictures from the STAR TPC, and then talk about corrections…

Summary

- TPC is a 3-D imaging chamber
  - Large volume, small amount of material.
  - Slow device (~30-50 μs)
  - 3-D 'continuous' tracking ($\sigma_{xy} \approx 170\ \mu m$, $\sigma_z \approx 600\ \mu m$ for Aleph)
- History
  - First proposed in 1976 (PEP4-TPC)
  - Used in many experiments
  - Aleph as an example here, along with Star…
  - Now a well-established detection technique that is still in the process of evolution (e.g. MPGDs = Micro-Pattern Gas Detectors, GEMs and MicroMegas…)

Some TPC examples

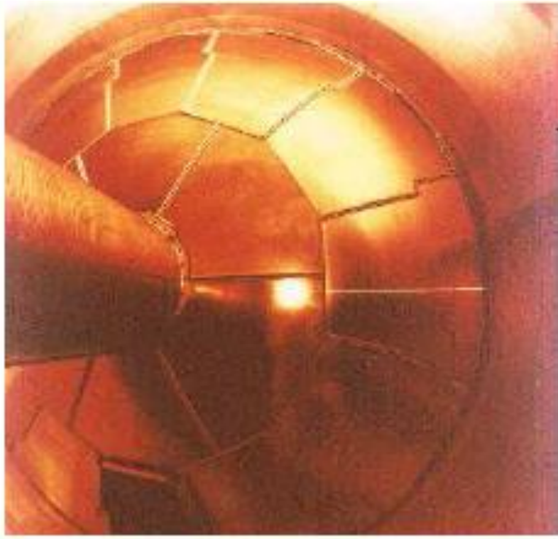
TPC	Reference
PEP4	PEP-PROPOSAL-004, Dec 1976
TOPAZ	Nucl. Instr. and Meth. A252 (1986) 423
ALEPH	Nucl. Instr. and Meth. A294 (1990) 121
DELPHI	Nucl. Instr. and Meth. A323 (1992) 209-212
NA49	Nucl. Instr. and Meth. A430 (1999) 210
STAR	IEEE Trans. on Nucl. Sci. Vol. 44, No. 3 (1997)

ALICE, LCTPC... ...

Grand-daddy/mama of all TPCs

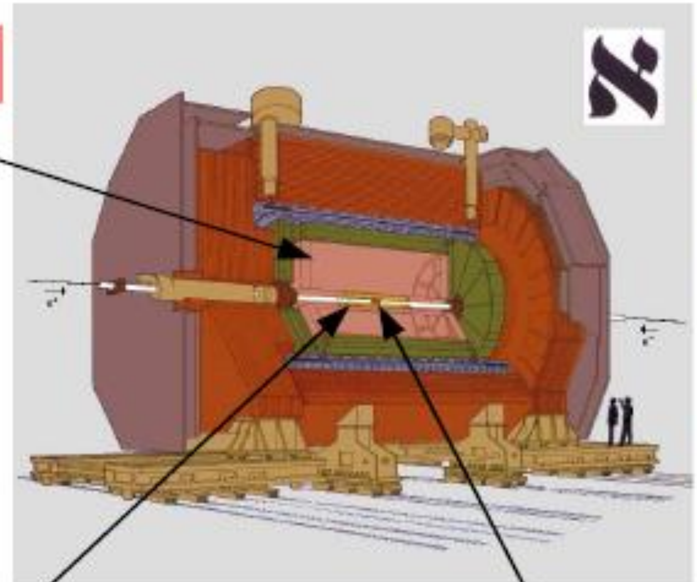
Which detector?

(...starting point for me...)



TPC

ITC



The ALEPH Detector

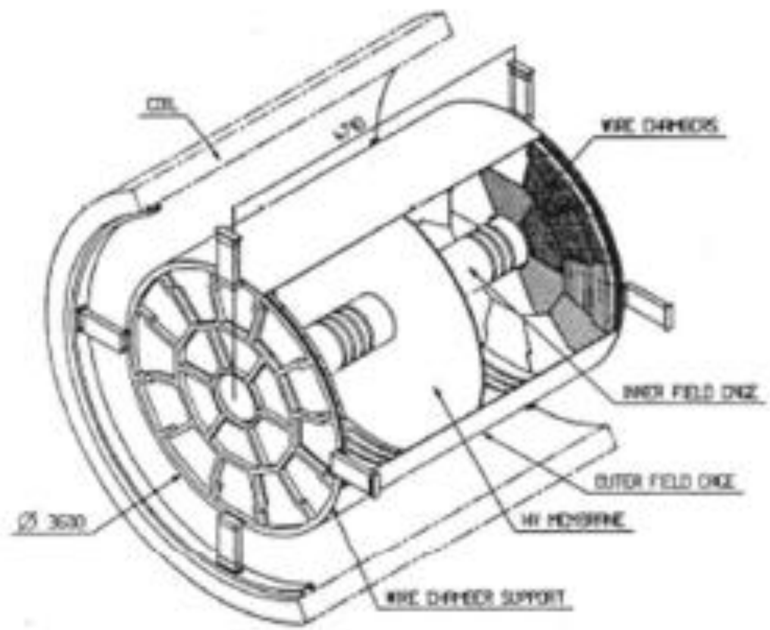
VDET

Outline

- TPC principles of operation
  - Drift velocity, Coordinates, dE/dx
- TPC hardware ingredients
  - Field cage, gas system, wire chambers, gating, laser calibration system, ~~electronics~~
- Some examples from Aleph and Star
- Performance
- Some 'features'
- Conclusion

Aleph TPC in one slide

TPC



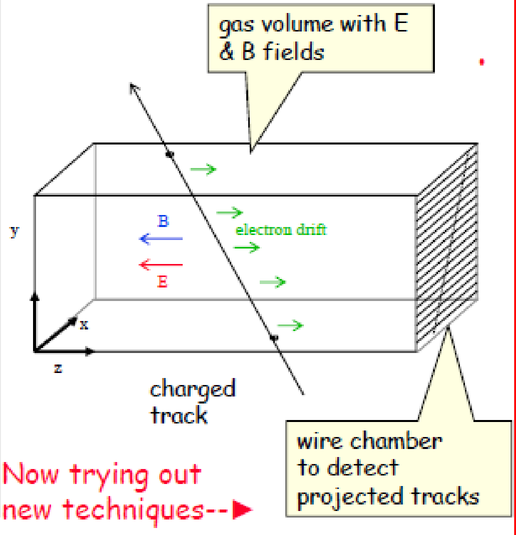
- $r\varphi$ from pad position
- z from drift time (pads + wires)
- dE/dx from wires and pads

- Length = 4.7 m
- Outer radius = 1.8 m
- Total weight = 3.6 t
- Drift length 2×2.2m
- Up to 21 space points / track
- 18 wire chambers / endplate
- 47340 channels in total
- B = 15 kG
- HV (Membrane) = −27.5 kV
- Gas
  - Volume $43\,m^3$
  - Argon/Methan (91:9) at atmospheric pressure
- Angular coverage
  - 2π in φ
  - 21 pad rows hit for $|\cos\Theta| \leq 0.8$
  - At least 3 pad rows for $|\cos\Theta| \leq 0.97$

TPC principles of operation

A TPC contains:

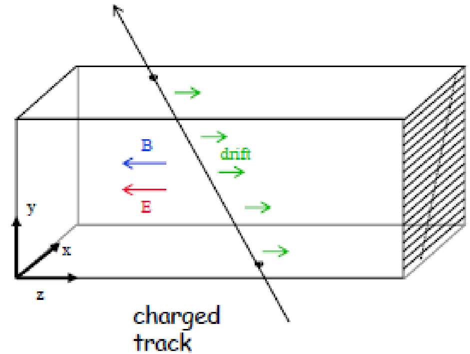
- Gas
  - E.g.: Ar + 10-20 % CH_4
- E-field
  - **E** ~ few x 100 V/cm
- B-field
  - as large as possible to measure momentum,
  - to limit electron diffusion
- Wire chamber (those days)
  - to detect projected tracks



Now trying out new techniques--▶

TPC Characteristics

- Only gas in active volume, small amount of material
- Long drift (> 2 m) therefore
  - slow detector (~50 µs)
  - want no impurities in gas
  - uniform E-field
  - strong & uniform B-field
  - $\vec{E} \times \vec{B} = 0$
- **Track points recorded in 3-D (x, y, z)**
- **Particle Identification by dE/dx**
- **Large track densities possible**



Drift velocity

Drift of electrons in E- and B-fields (Langevin)

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

τ mean drift time between collisions

$\mu = \frac{e\tau}{m}$ particle mobility

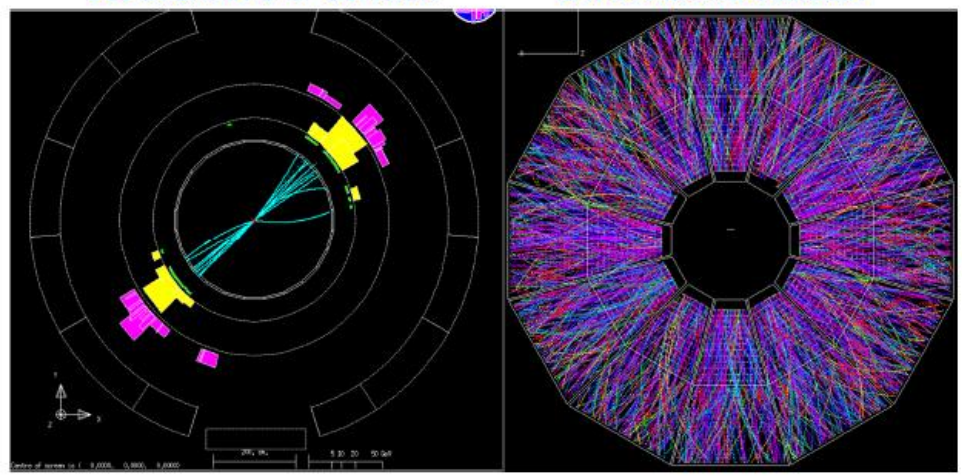
$\omega = \frac{eB}{mc}$ cyclotron frequency

$(\omega\tau) << 1$ V_d along E-field lines

$(\omega\tau) >> 1$ V_d along B-field lines

Typically ~5 cm/µs for gases like Ar(90%) + CH_4(10%)
Electrons tend to follow the magnetic field lines $(\varpi\tau) >> 1$

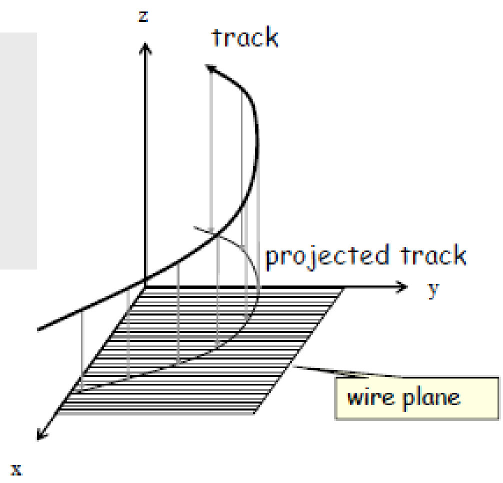
Jet event in e^+e^- collision STAR Au+Au collision



Jim Thomas, October 2003 TPC Symposium@LBNL

3-D coordinates

- Z coordinate from drift time
- X coordinate from wire number
- Y coordinate?
  - » along wire direction
  - » need **cathode pads**



Coordinate from cathode Pads

Amplitude on ith pad

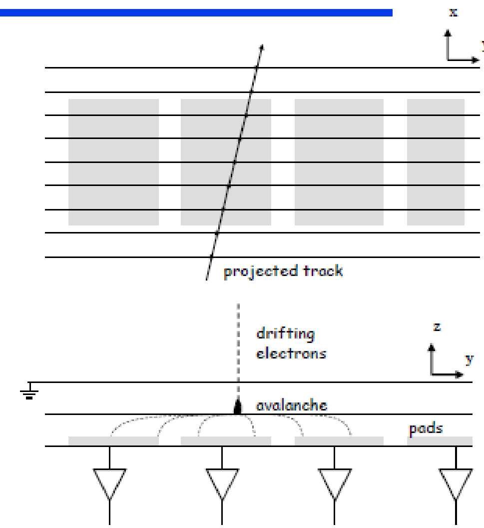
$$A_i = Ae^{(-(y-y_i)^2/2\sigma_{prw}{}^2)}$$

y avalanche position

y_i position of center of ith pad

σ_{prw} pad response width

- Measure A_i
- Invert equation to get y



TPC coordinate resolution

Same effects as for PRW are expected but statistics of drifting electrons must be considered

$\sigma^2_{r\phi}(\beta,\alpha,z) = \sigma^2_0$	electronics, calibration
$+\sigma^2_\beta \tan^2\beta$	angular pad effect (dominant for small momentum tracks)
$+\sigma^2_\alpha(\tan\alpha - \tan\psi)^2\cos^2\alpha$	angular wire effect (...disappears with new technologies...)
$+\sigma^2_D(z)\cdot z$	"diffusion" term

$$\sigma^2_Z = \sigma^2_z(dip\_angle)$$

forward tracks -> longer pulses -> degrades resolution

Particle Identification by dE/dx

Energy loss (Bethe-Bloch)

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\ln\frac{2mv^2}{J(1-\beta^2)} - \beta^2 - \frac{\delta}{2}\right]$$

m mass of electron

z, v charge and velocity of incident particle

J mean ionization energy

δ density effect term

- Energy loss (dE/dx) depends on the particle velocity.
- The mass of the particle can be identified by measuring simultaneously momentum and dE/dx (ion pairs produced)
- Particle identification possible in the non-relativistic region (large ionization differences)
- Major problem is the large Landau fluctuations on a single dE/dx sample.
  - » 60% for 4 cm track
  - » 120% for 4 mm track

Gating

Problem: Build-up of space charge in the drift region by ions.

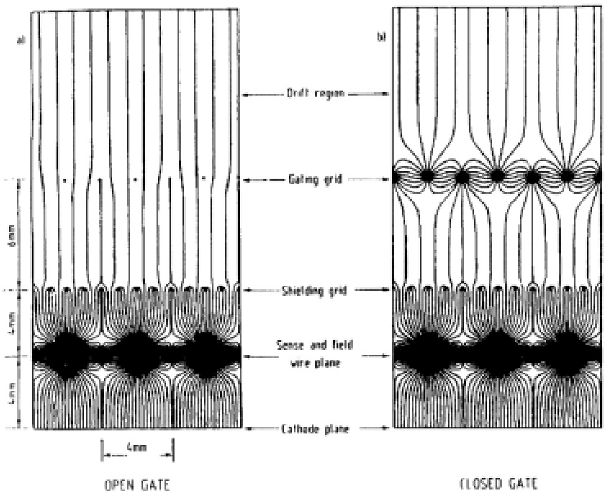
- Grid of wires to prevent positive ions from entering the drift region

"Gating grid" is either in the open or closed state

- Dipole fields render the gate opaque

Operating modes:

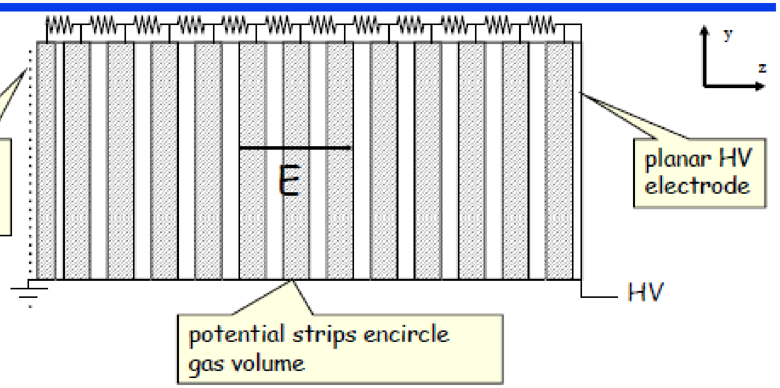
- Switching mode (Aleph)
- Diode mode



Cooling, Mechanics

- Terribly mundane but terribly important (**everything** is important)
- Cooling:
  - Combined air and water cooling to completely insulate the gas volume
- Mechanics:
  - 25% X_0 for sectors, preamps, cooling (but before cables)

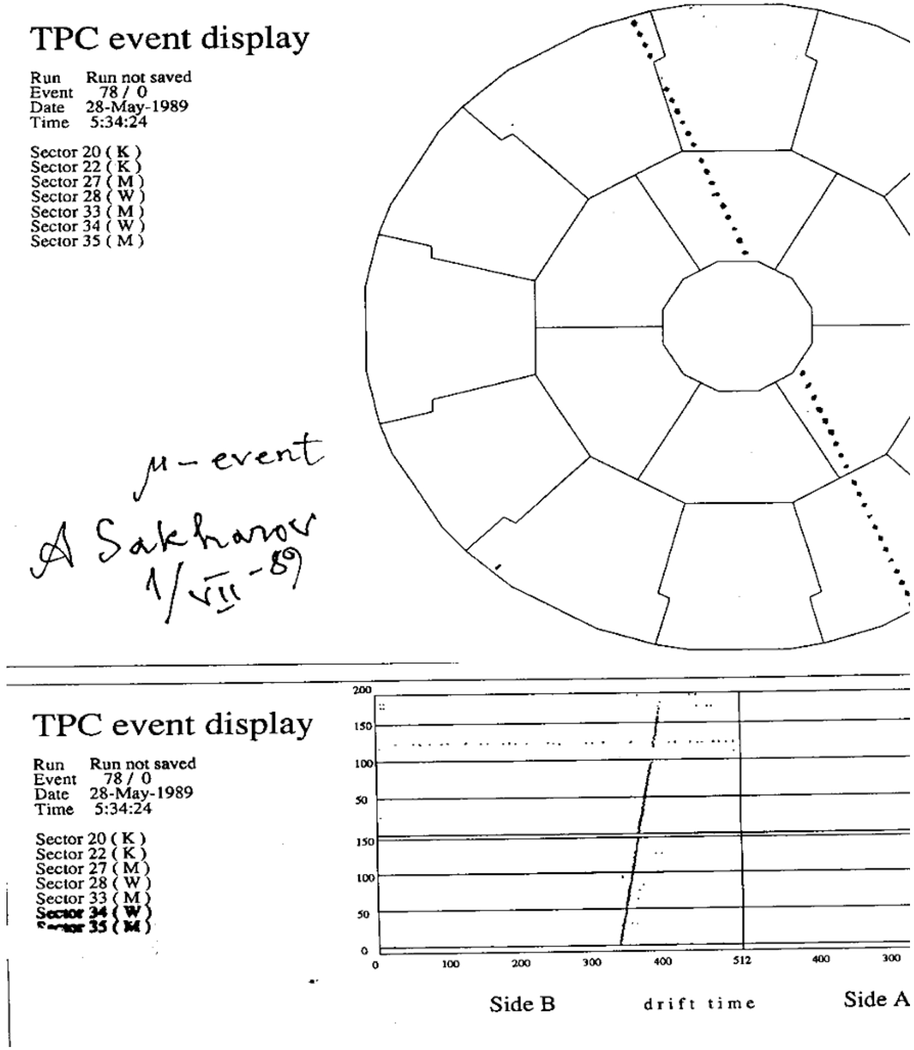
E-field produced by a Field Cage



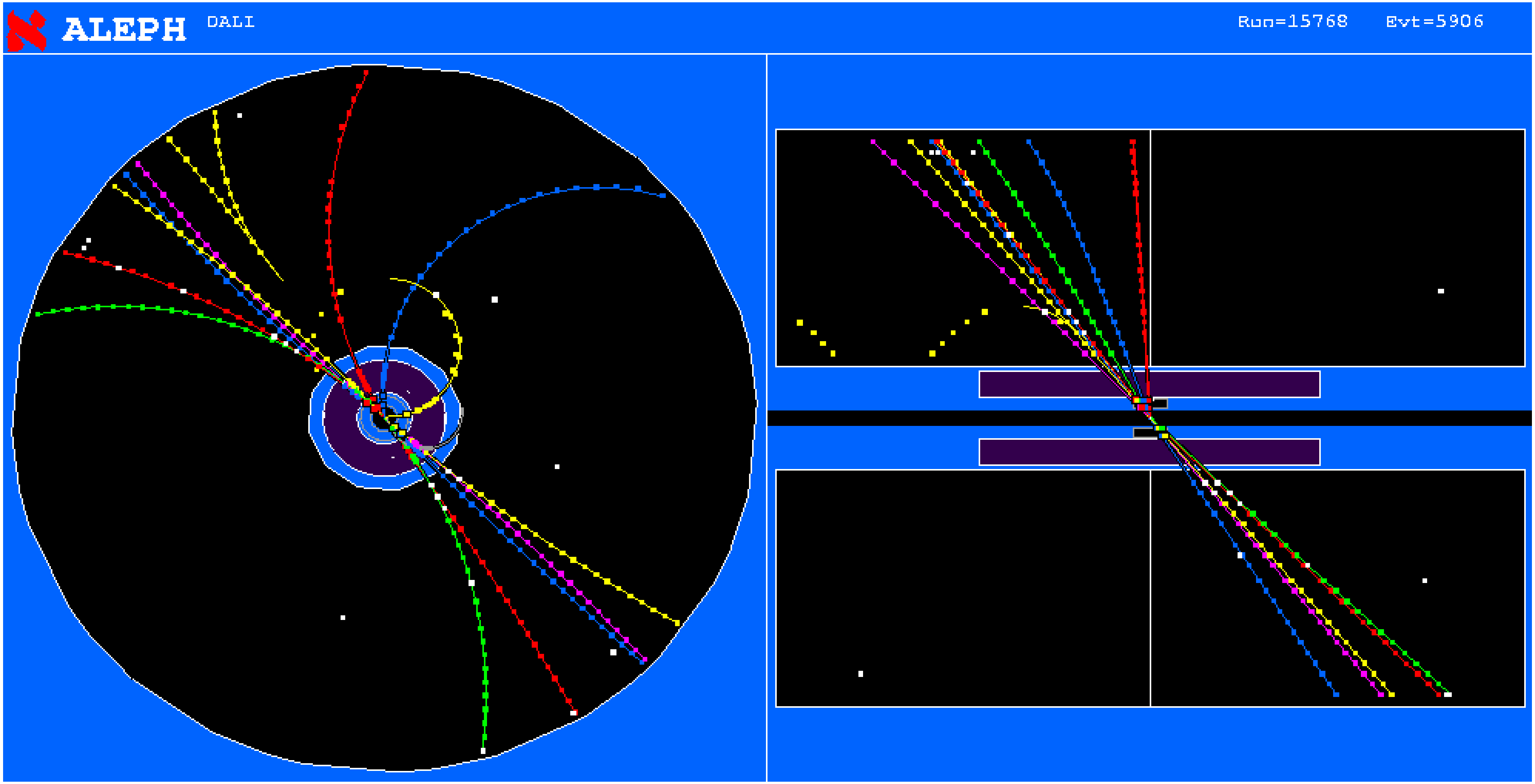
- chain of precision resistors with small current flowing provides uniform voltage drop in z direction
- non uniformity due to finite spacing of strips falls exponentially into active volume

STAR and ALEPH examples

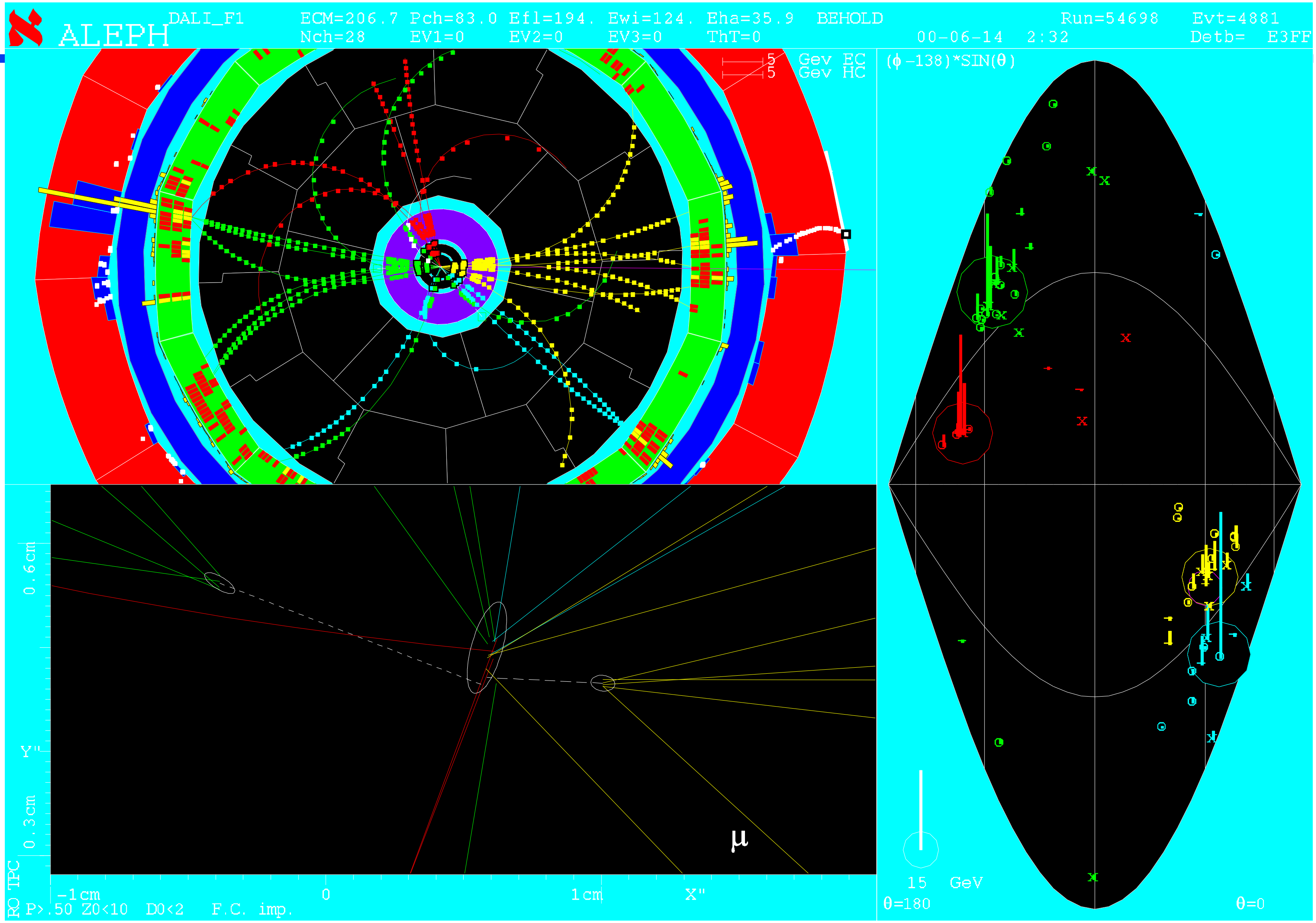
After 3 man-centuries of work, Aleph TPC finally started in 1989...



ALEPH Event, early days…



And towards the end...what is it?



There were 'FEATURES'...

Distortion Corrections for the ALEPH TPC

Werner Wiedenmann

Werner.Wiedenmann@cern.ch

Werner's slides (http://wisconsin.cern.ch/~wiedenma/TPC/Distortions/Cern_LC.pdf) contain many details, excerpts will be shown here

Historical Development (1)

- 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
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  - All data finally **recuperated** with data-based correction methods

Historical Development (1)

Laser used for these things

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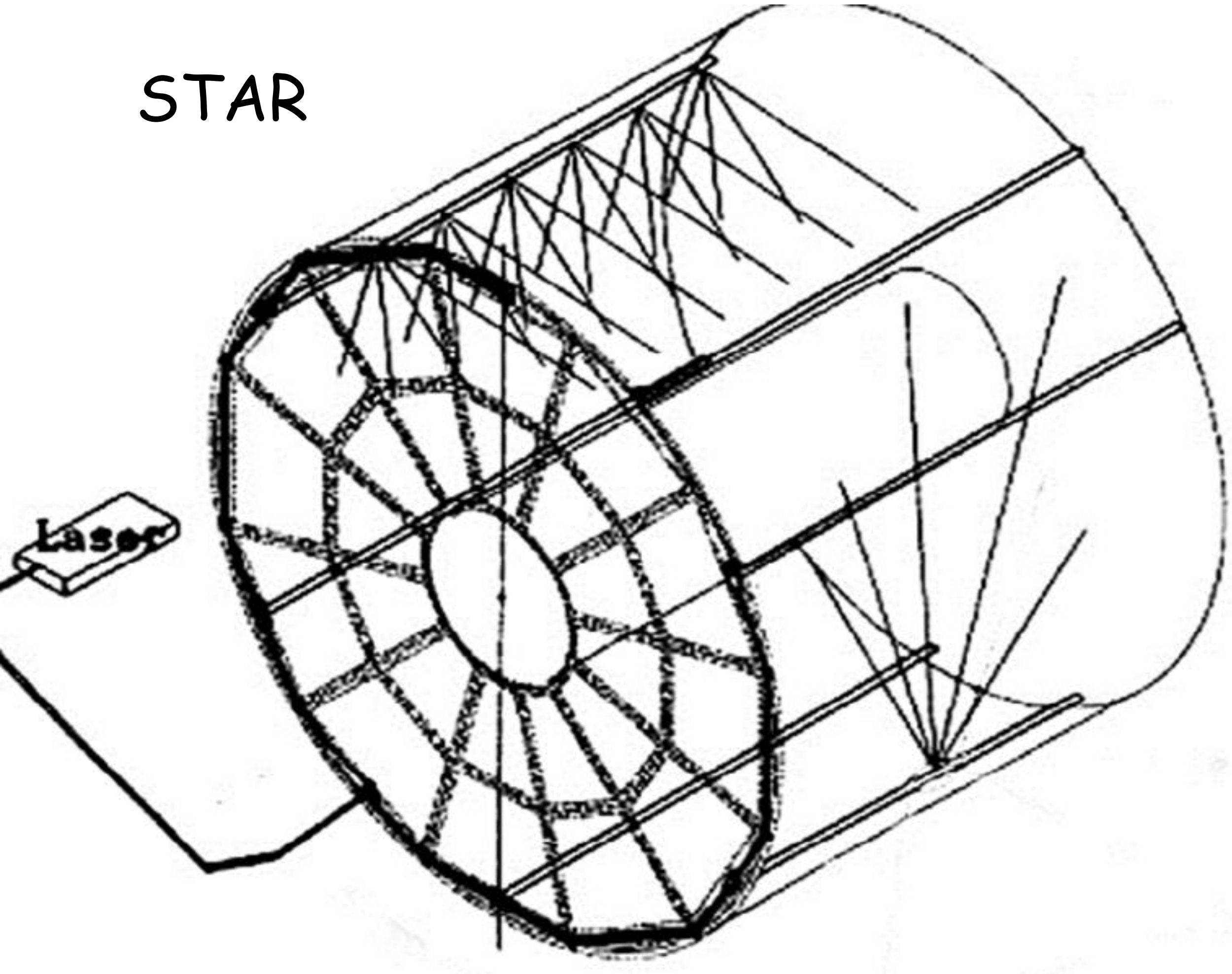
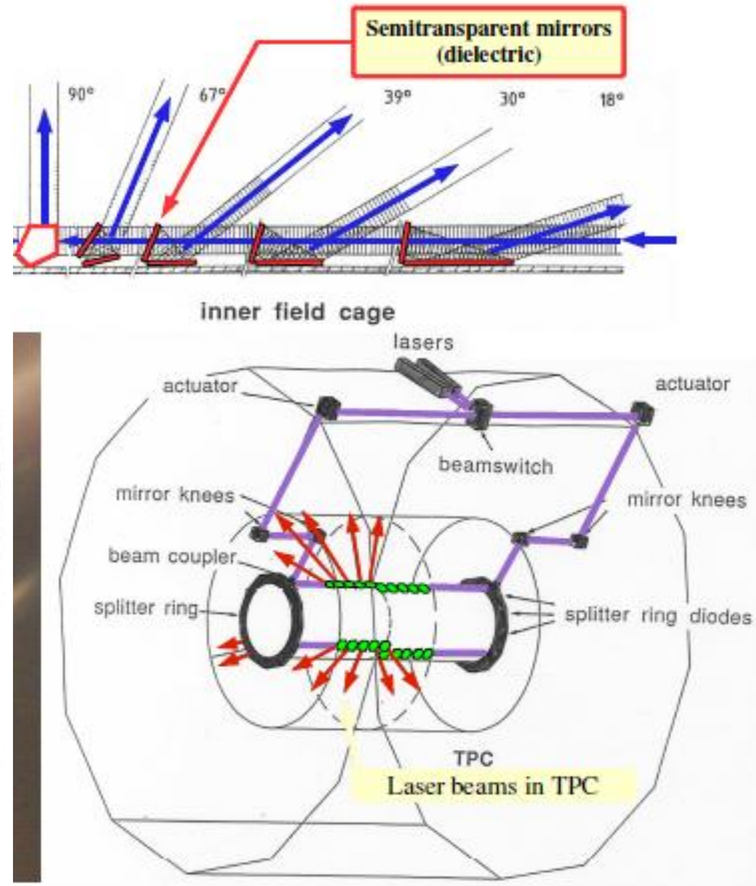
Laser Calibration System

STAR





ALEPH

...from the Aleph Handbook (ISBN 92-9083-072-7, Published by CERN 1995)

coordinates in high multiplicity jets. Both extremes are therefore due to compromises in the coordinate error parametrization. Nevertheless, the overall distribution is flat enough to allow track quality cuts based on the χ^2 of the fit.

11.3 Laser calibration

The quality of the track reconstruction depends critically on the precise knowledge of systematic distortions of the tracks during their drift towards the end-plates. The laser calibration system is used to measure and correct residual inhomogeneities of the electric and magnetic fields, which produce systematic displacements of reconstructed coordinates, and it is also used to measure the modulus of the drift velocity of electrons in the TPC gas.

The drift velocity of electrons in the gas as derived from the Langevin equation can be written as

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…from the Aleph Handbook (ISBN 92-9083-072-7, Published by CERN 1995)

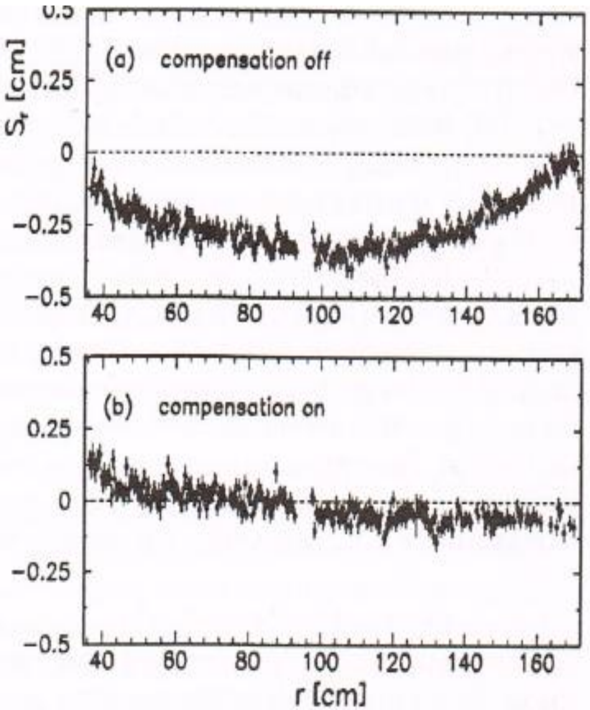
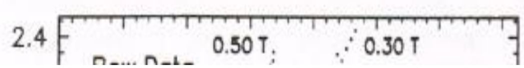


Fig. V.62 Radial coordinate displacements between full and zero magnetic field.



eliminate these systematic effects even in the case of compensation off (see Fig. V.63a).

11.3.2 The measurement of ωτ

For the measurement of ωτ (see also [AME 85c]), a scan over the magnetic field is performed, ranging from −1.5 T to +1.5 T, and the r and $r\varphi$ coordinates from the laser tracks are compared for fields of opposite polarity. In analogy to Subsection 11.3.1, one can derive the quantities $S_r(B)$ and $\Delta_{r\varphi}(B)$ from these measurements:

$$\Delta_{r\varphi}(B) \equiv \frac{1}{2}\left[r\varphi(+B) - r\varphi(-B)\right] = \frac{\omega\tau}{1+(\omega\tau)^2}\int\left(\frac{B_r}{B_z} - \frac{E_r}{E_z}\right)dz \quad ,$$

$$S_r(B) \equiv \frac{1}{2}\left[r(+B) - r(-B)\right] - r(0) = \omega\tau\,\Delta_{r\varphi}(B) \quad ,$$

These relations follow from the drift velocity equation without any assumptions on the azimuthal field components.

The limiting systematic effect in this measurement is again the reproducibility of the optical laser steering which changes slightly with varying magnetic field. This is demonstrated in Fig. V.63 where S_r is plotted versus $\Delta_{r\varphi}$ for all measured coordinates and several examples of magnetic fields. The linear

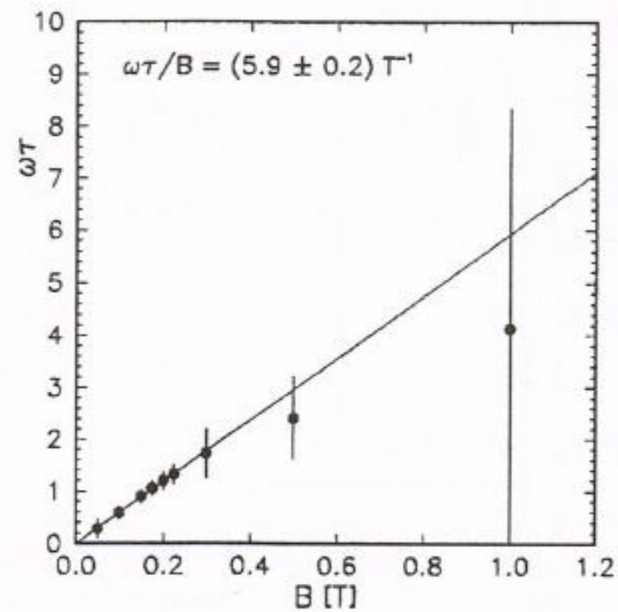


Fig. V.64 Results of the fits for ωτ as a function of B.

The results of the fits for ωτ as a function of B are shown in Fig. V.64. The error bars are almost entirely systematic…

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...from the Aleph Handbook (ISBN 92-9083-072-7, Published by CERN 1995)

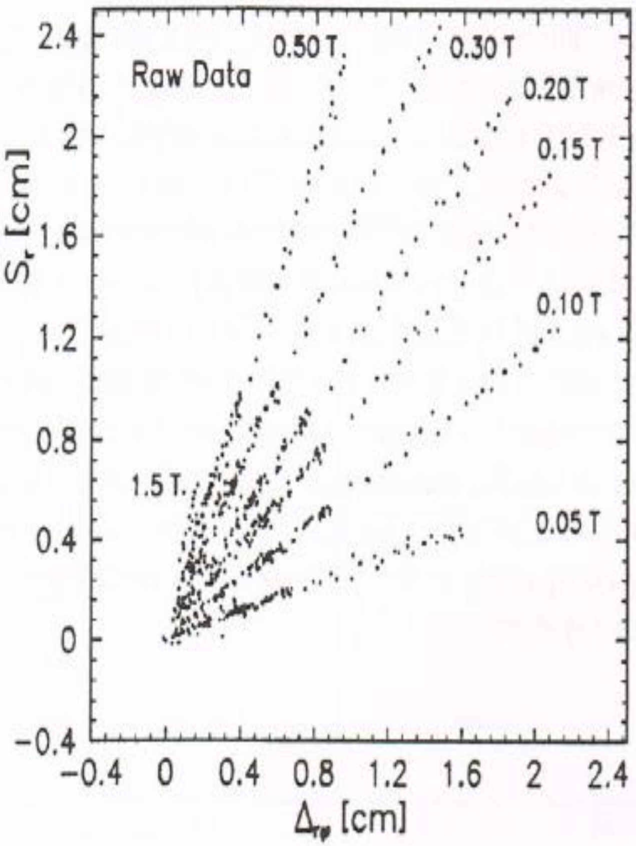

Fig. V.63 Uncorrected measurements for $\Delta_{r\varphi}$ and S_r.

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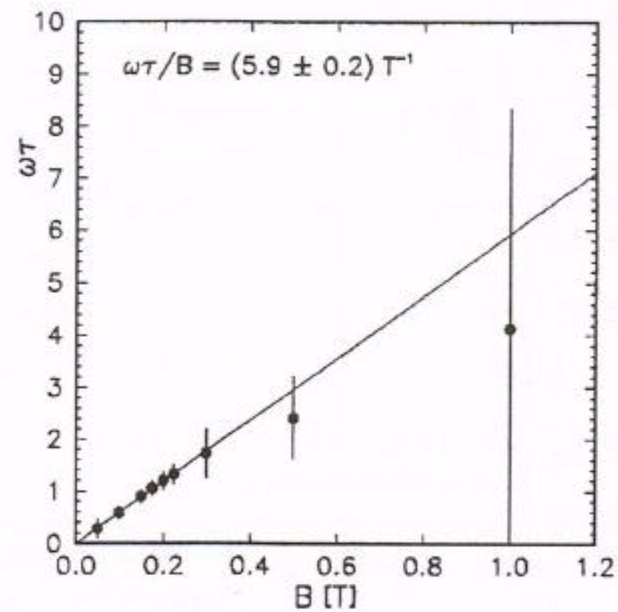

Fig. V.64 Results of the fits for ωτ as a function of B.

The results of the fits for ωτ as a function of B are shown in Fig. V.64. The error bars are almost entirely systematic...

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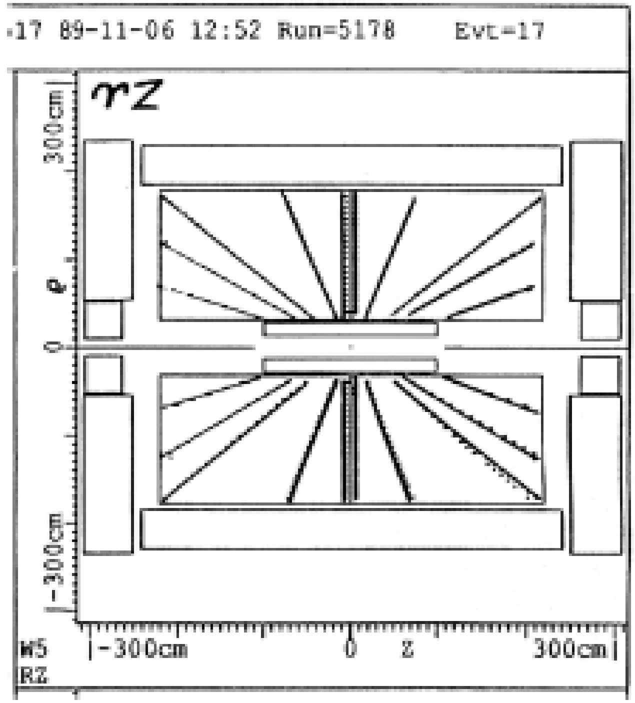
Conclusion Laser…

- **Purpose**
  - Measurement of drift velocity
  - Determination of E- and B-field distortions

- **Drift velocity**
  - Laser system → ∂(v_drift) ~ 1‰
  - Hookup tracks to Vdet → ∂(v_drift)~a few times 0.01‰ …used after Vdet installation

- **ExB Distortions**
  - Laser used only in early days to get first corrections. After, tracks (mostly μ pairs from Z decays) used exclusively (read on…)



Laser tracks in the ALEPH TPC

But there were many other corrections

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Correction Method

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 t 16 hits from ITC. TPC is not in the track fit.

- Compute for fields and alignment $(\Delta r\varphi, \Delta r, \Delta z)_{Fields,\ Alignment}$ from
  - Potential for fields
  - Coordinate transformation equations for alignment

$$\Rightarrow \Delta r\varphi_{Fields,Alignment}(r,\varphi,z) = \sum_i \Delta \widehat{r\varphi}_i(r,\varphi,z)\cdot A_i$$

Computed from first principles

- Solve (overdetermined) system of linear equations for unknown parameters A_i

$$\left\| \begin{pmatrix} \Delta r\varphi_{obs}(r_1,\varphi_1,z_1) \\ \Delta z_{obs}(r_1,\varphi_1,z_1) \\ \vdots \\ \Delta r\varphi_{obs}(r_N,\varphi_N,z_N) \\ \Delta z_{obs}(r_N,\varphi_N,z_N) \end{pmatrix} - \begin{pmatrix} \Delta\widehat{r\varphi}_1(r_1,\varphi_1,z_1) & \cdots & \Delta\widehat{r\varphi}_M(r_1,\varphi_1,z_1) \\ \Delta\hat{z}_1(r_1,\varphi_1,z_1) & \cdots & \Delta\hat{z}_M(r_1,\varphi_1,z_1) \\ \vdots & & \vdots \\ \Delta\widehat{r\varphi}_1(r_N,\varphi_N,z_N) & \cdots & \Delta\widehat{r\varphi}_M(r_N,\varphi_N,z_N) \\ \Delta\hat{z}_1(r_N,\varphi_N,z_N) & \cdots & \Delta\hat{z}_M(r_N,\varphi_N,z_N) \end{pmatrix} \cdot \begin{pmatrix} A_1 \\ \vdots \\ A_M \end{pmatrix} \right\| = Min$$

- Measure coordinate residuals in TPC respective to extrapolated single helix on 3 dimensional grid $(\Delta r\varphi, \Delta z)_{obs.}(r_n,\varphi_n,z_n)$

$$\Delta r\varphi_{observed} = \Delta r\varphi_{Fields,\ Alignment} - \frac{d_0}{\sqrt{r^2-d_0^2}}\Delta r_{Fields,\ Alignment};$$

$$\Delta z_{observed} = \Delta z_{Fields,\ Alignment} - \frac{r}{\sqrt{r^2-d_0^2}}\tan\lambda\,\Delta r_{Fields,\ Alignment};$$

d_0 = Signed distance of closest approach to origin

- Solve system of linear equations with <u>*Singular Value Decomposition*</u> *(SVD) (e.g. Numerical Recipes, Cambridge University Press)*
  - *SVD* can cope with linear dependencies in function matrix. Solution has from all possibilities the smallest length.

$$\|\vec{A}\| = Min$$

  - *SVD* provides for each parameter a weight which allows to identify insignificant parameters to the problem (i.e. remove all parameters with weight < threshold)

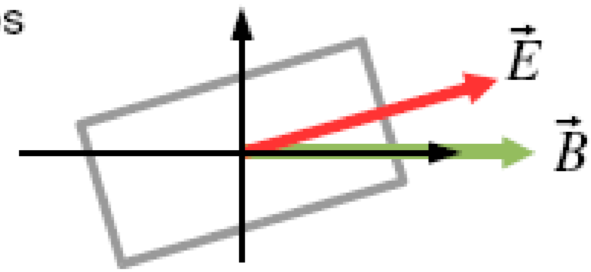
...continues several slides...

Tour through some problems and their correction

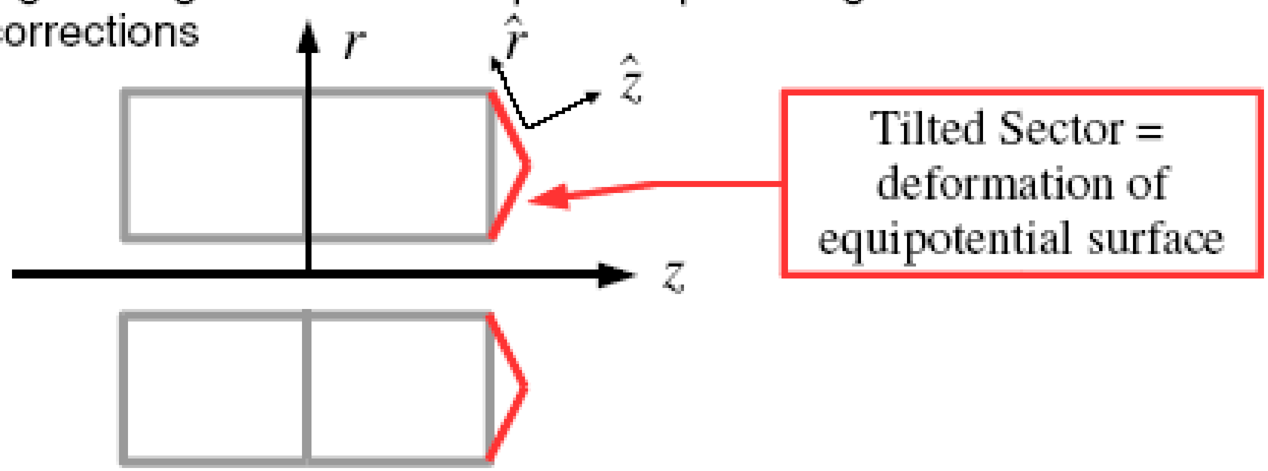
- Static problems (always there)
  - TPC tilt
  - Endplate bowing
  - Nonlinear potential on fieldcage
- Single incidents
  - Disconnected gating grids (space charge)
  - Shorts on field cage
- Time dependent effects
  - "Charge up" effects

e.g. (see Werner's slides…)

- Alignment and field corrections are not independent
  - e.g tilt of "perfect TPC" relative to B–field axis causes transverse drift velocities

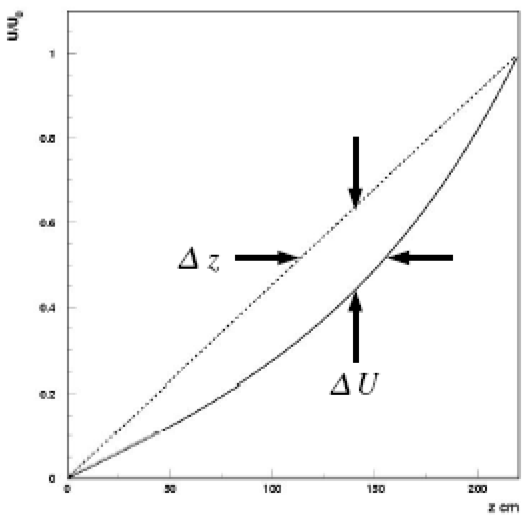


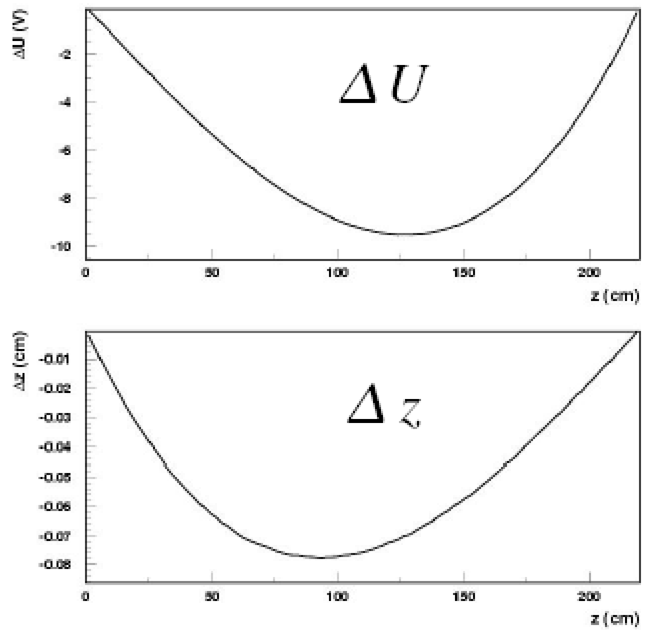
  - e.g bowing of the TPC endplate requires alignment and E–field corrections



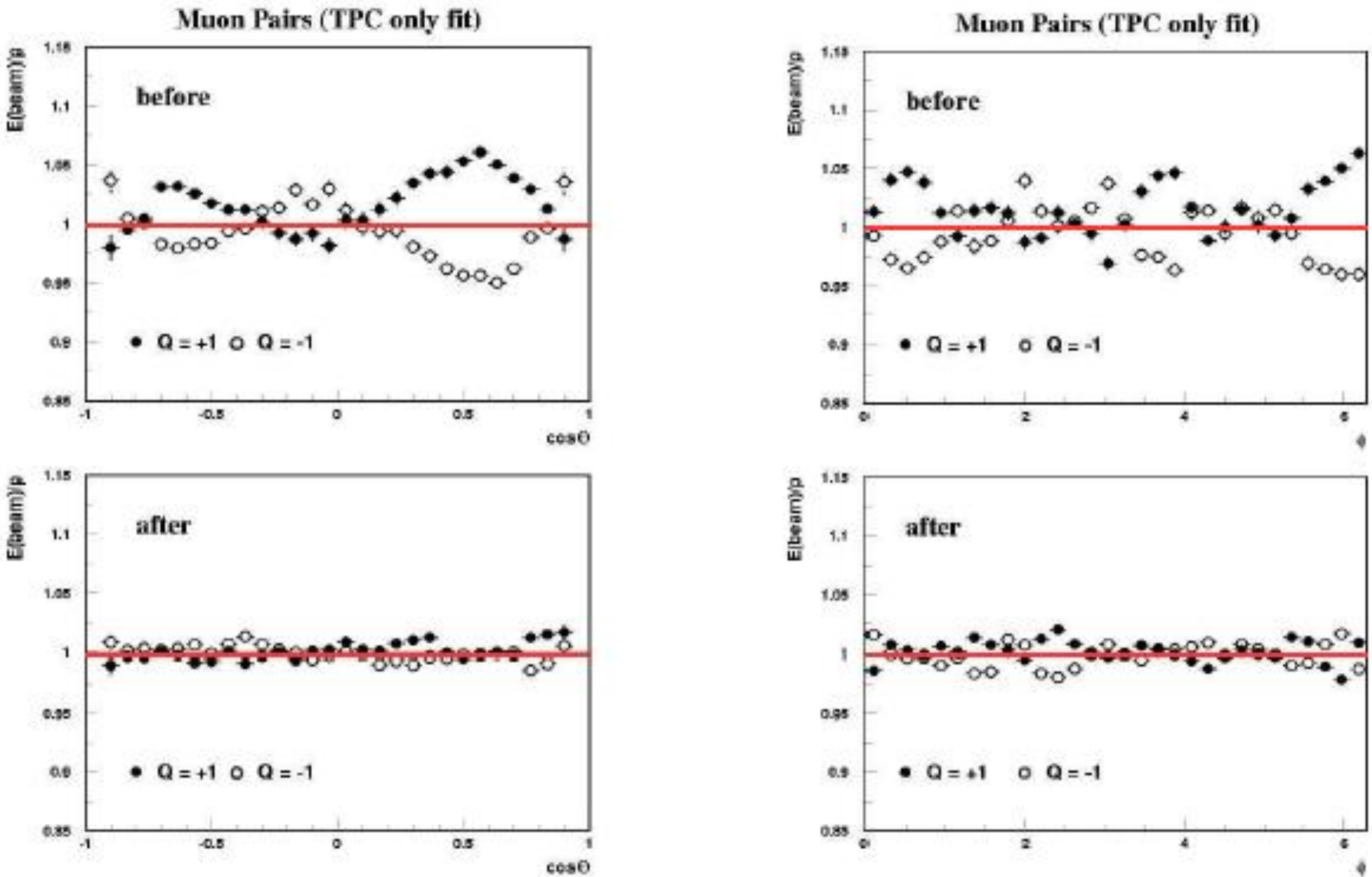
e.g., non-linear F.C. potential

- Results from fit can be interpreted as potential deviation or axial shift of electrodes
- Fit prefers $\rho \simeq 10^{16}\ [\Omega\ cm]$

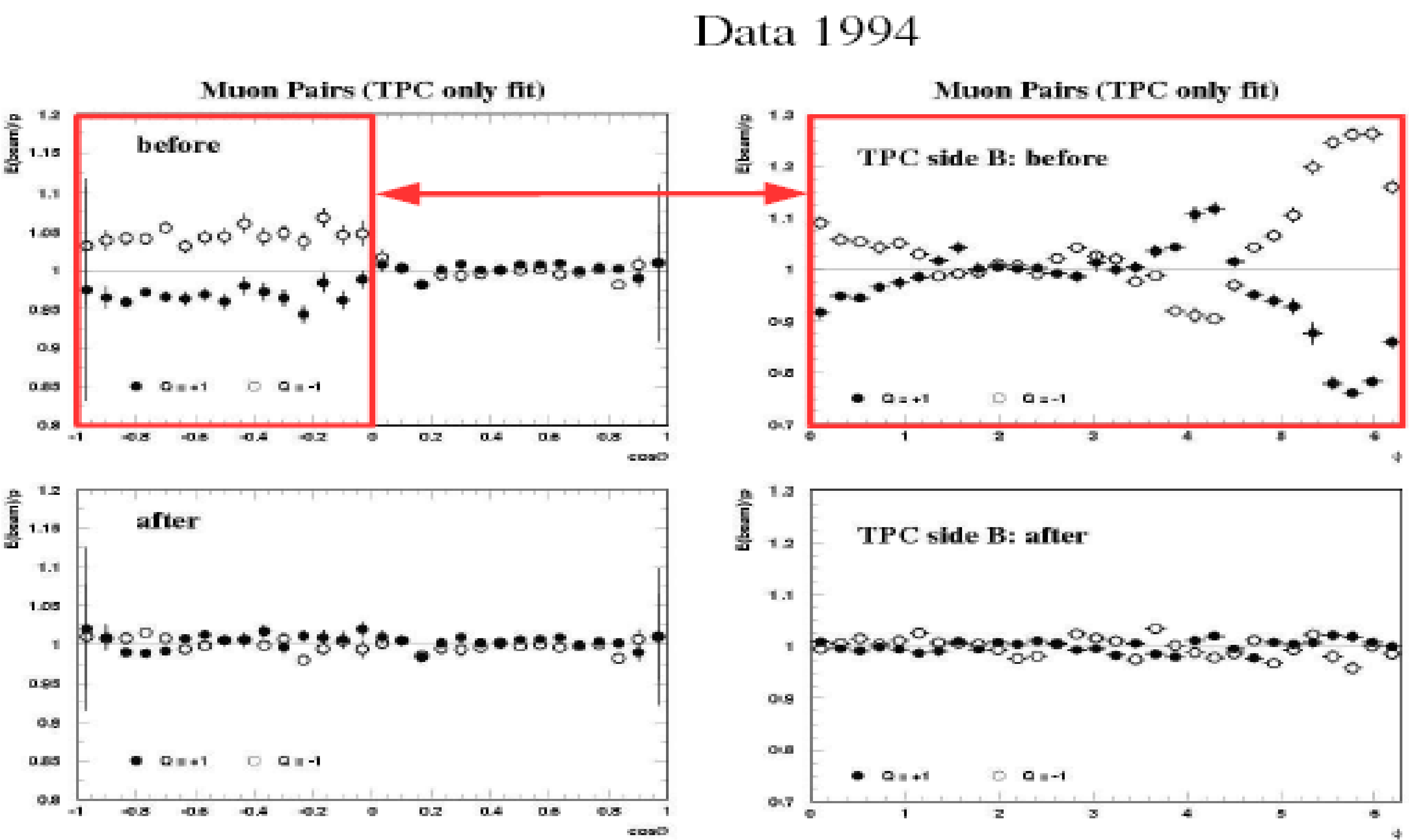




Correction for nonlinear potential + endplate bowing



e.g., disconnected gating grids



Parameters used:

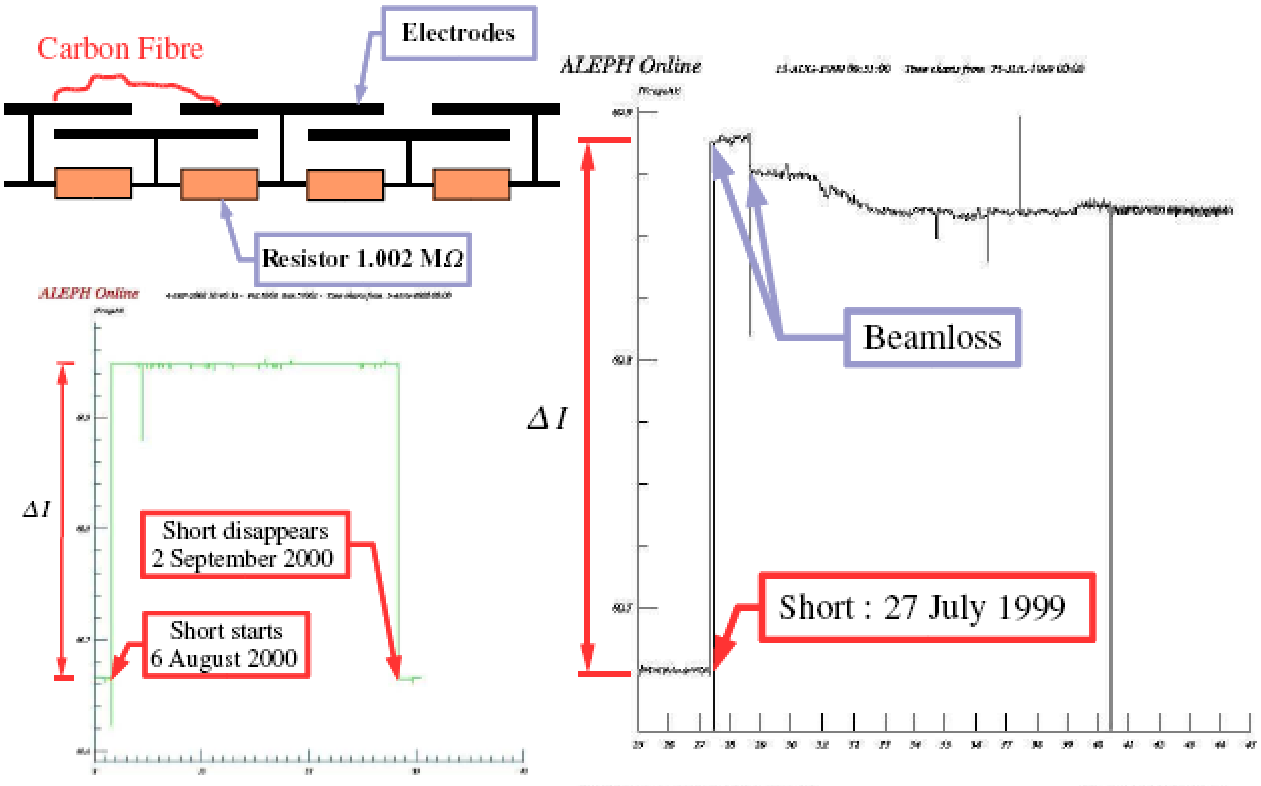
$\varphi: 0 \leq \nu \leq 6$

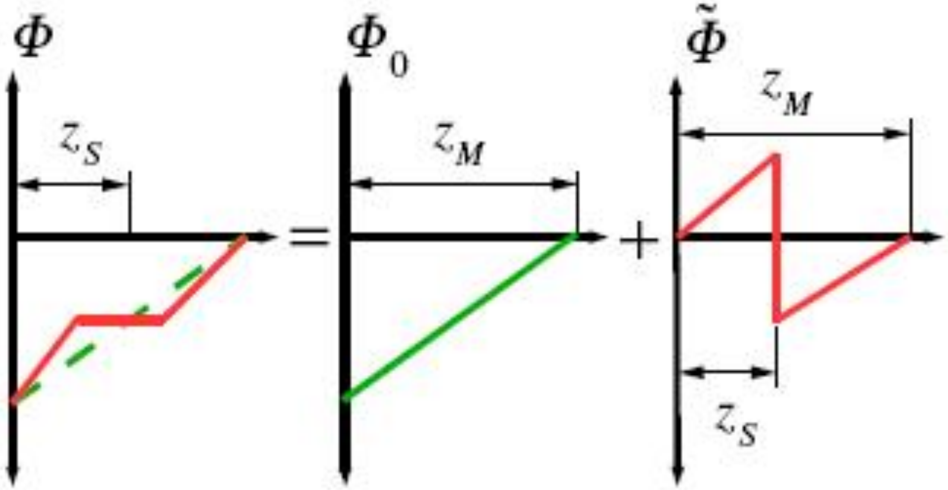
$r: 1 \leq m \leq 5$

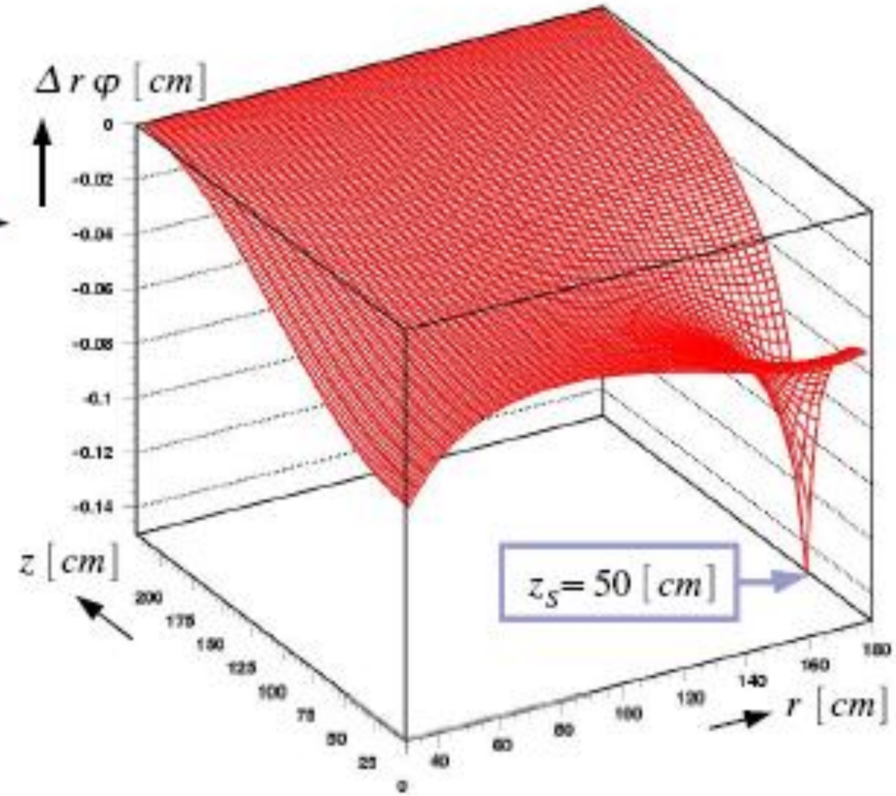
$z: 1 \leq n \leq 8$

Werner Wiedenmann *Cern, December 2001* 37

e.g., field-cage shorts



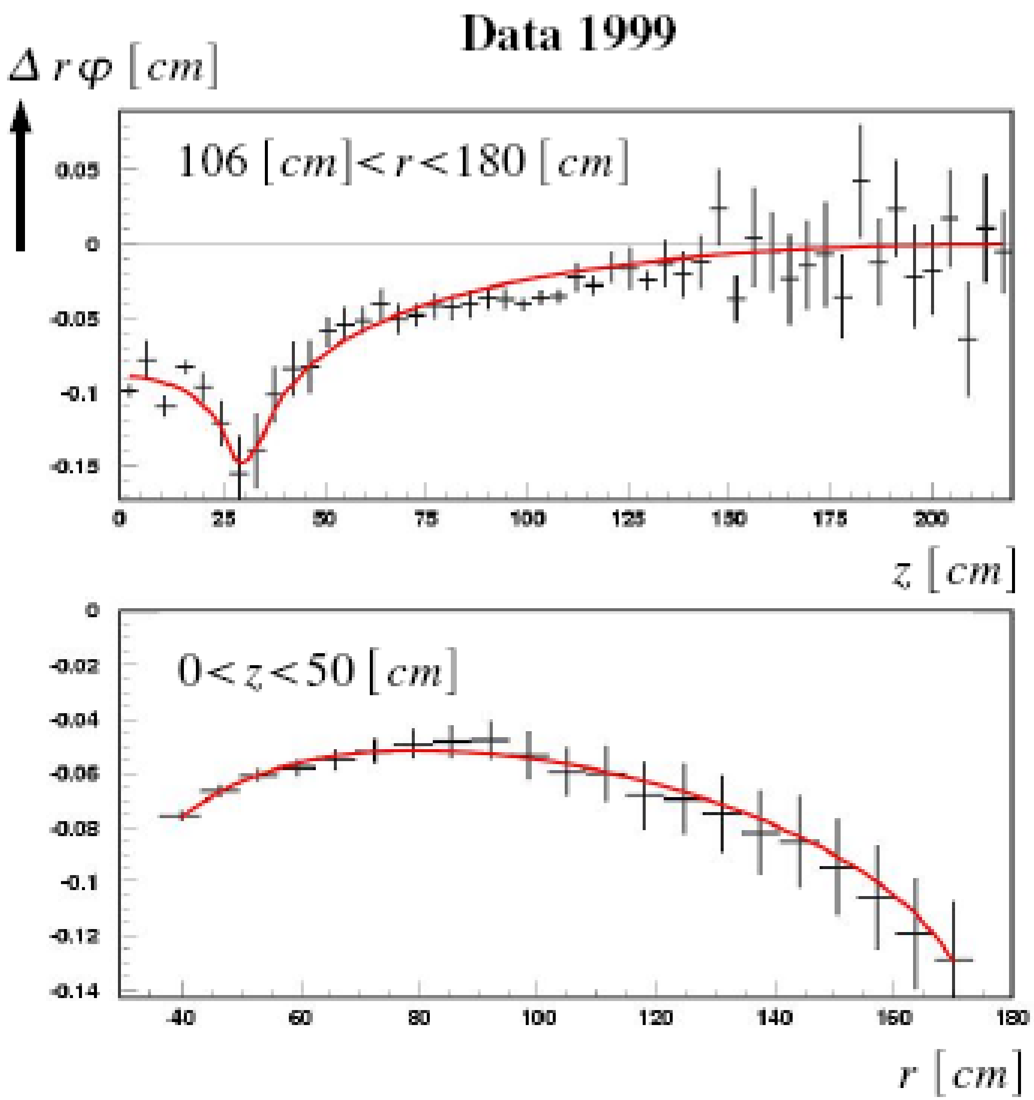


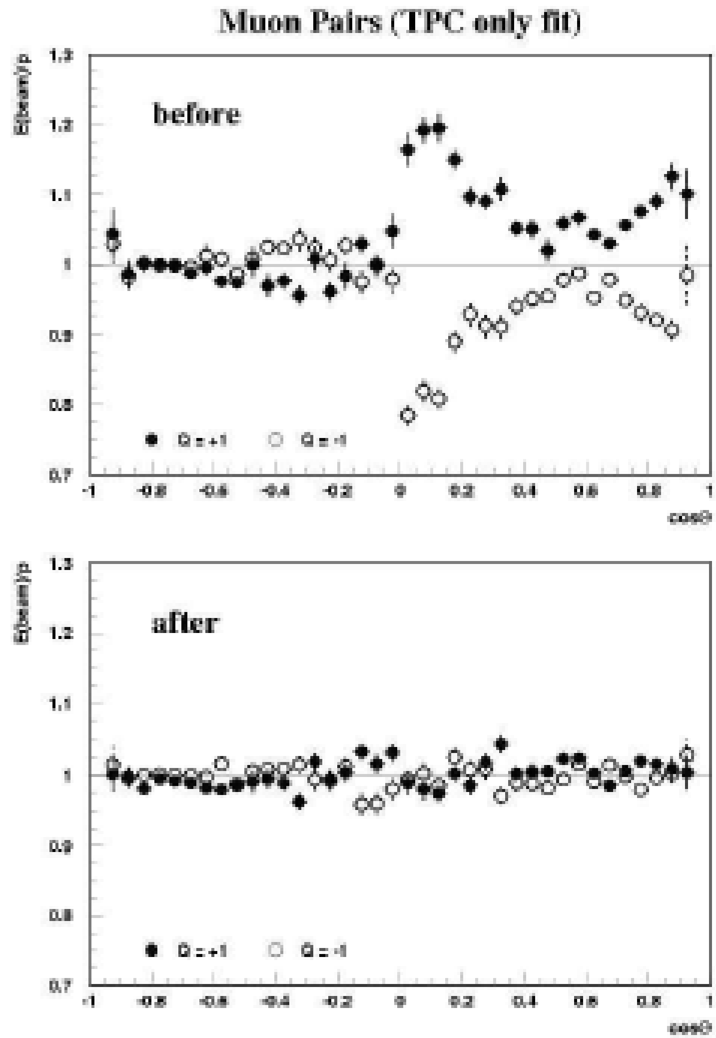


- Two parameter model
  - Shortposition
  - Voltage/current change

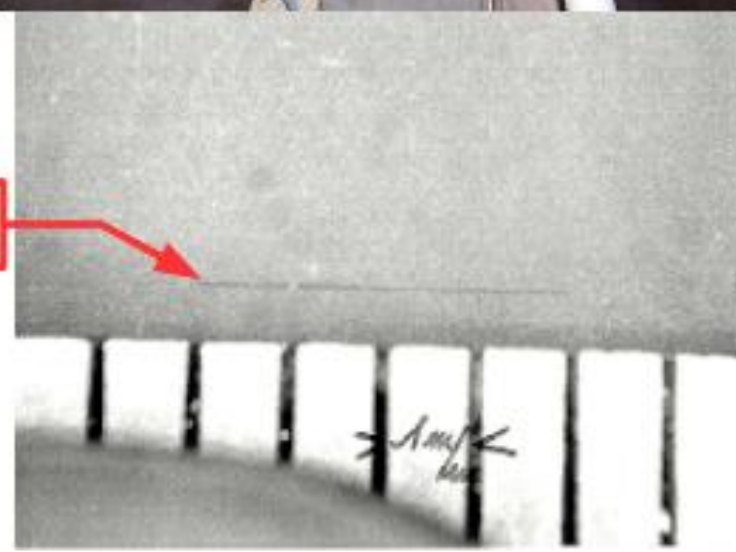
Distortionpotential

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


Data 1999
Δ r φ [cm]
106 [cm] < r < 180 [cm]
z [cm]
0 < z < 50 [cm]
r [cm]


Muon Pairs (TPC only fit)
before
after
E(beam)/p
cosΘ

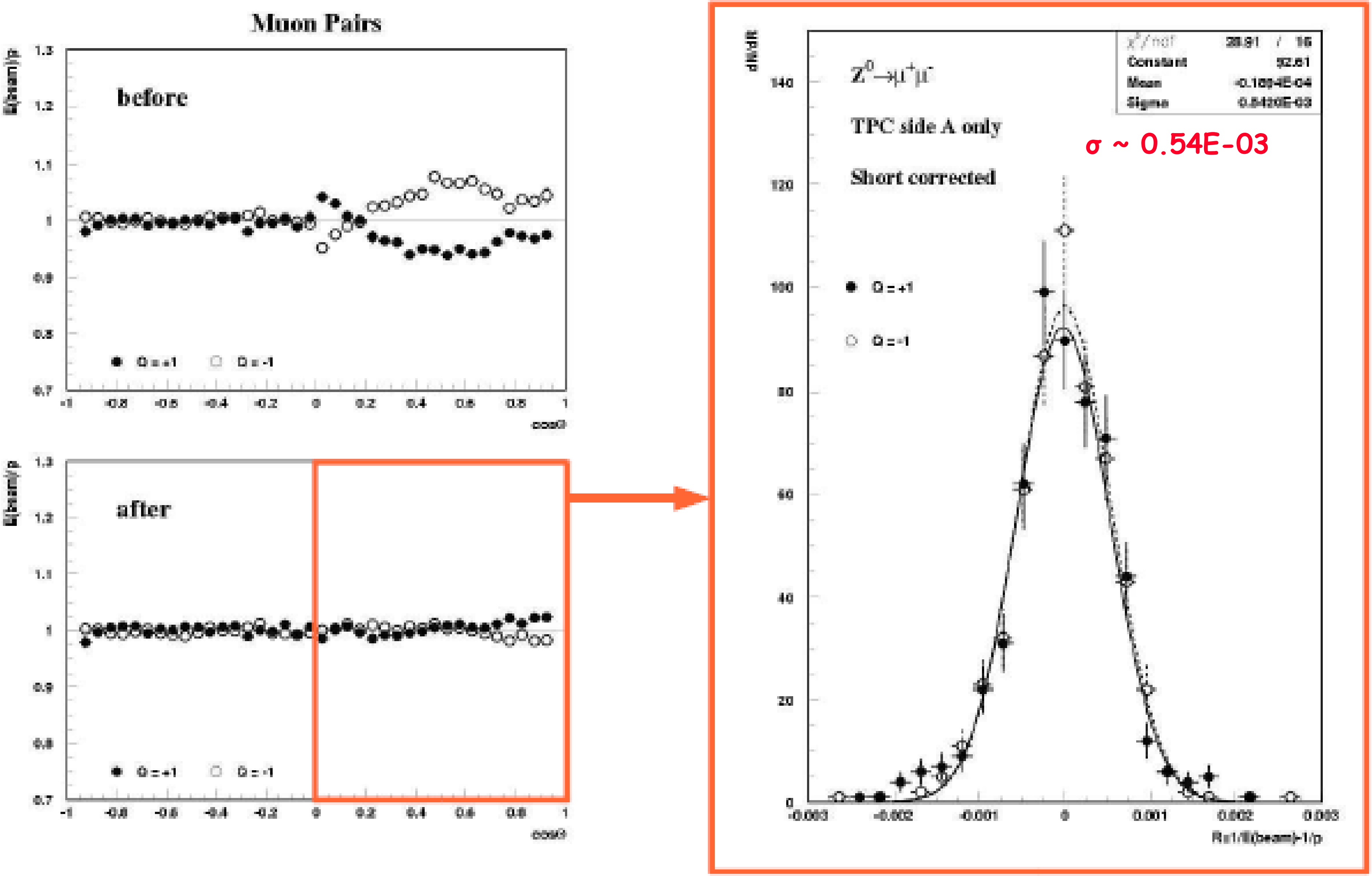
(N.B., design your detector to be easily accessible…)



Fibre found at z=36 cm

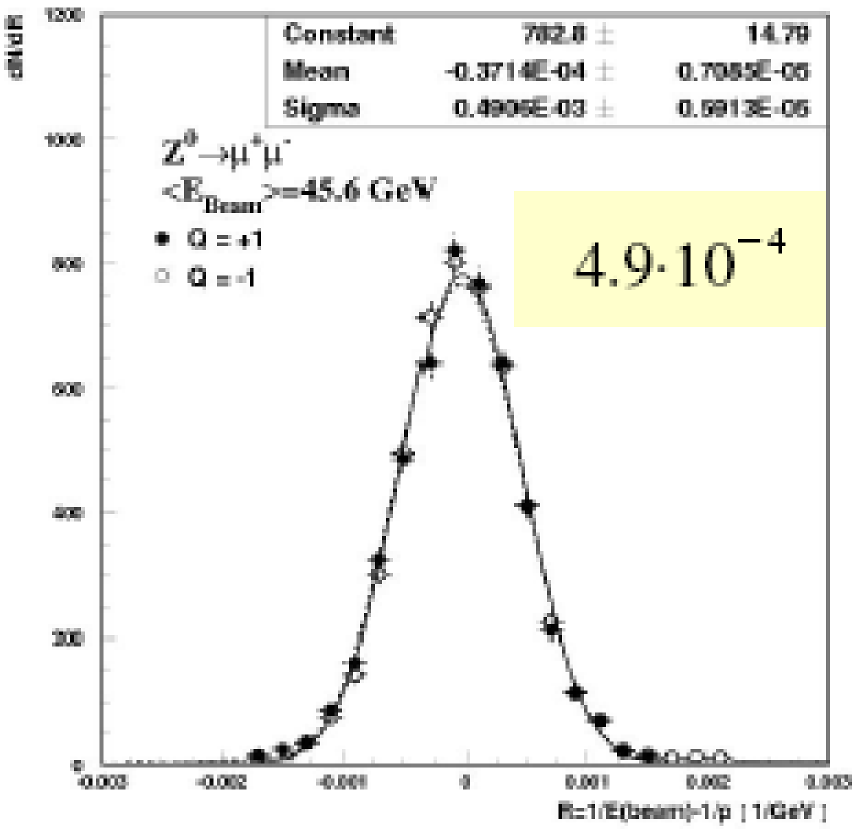
Intervention during 1999 shutdown

Short 1999 : Fit with all tracking detectors

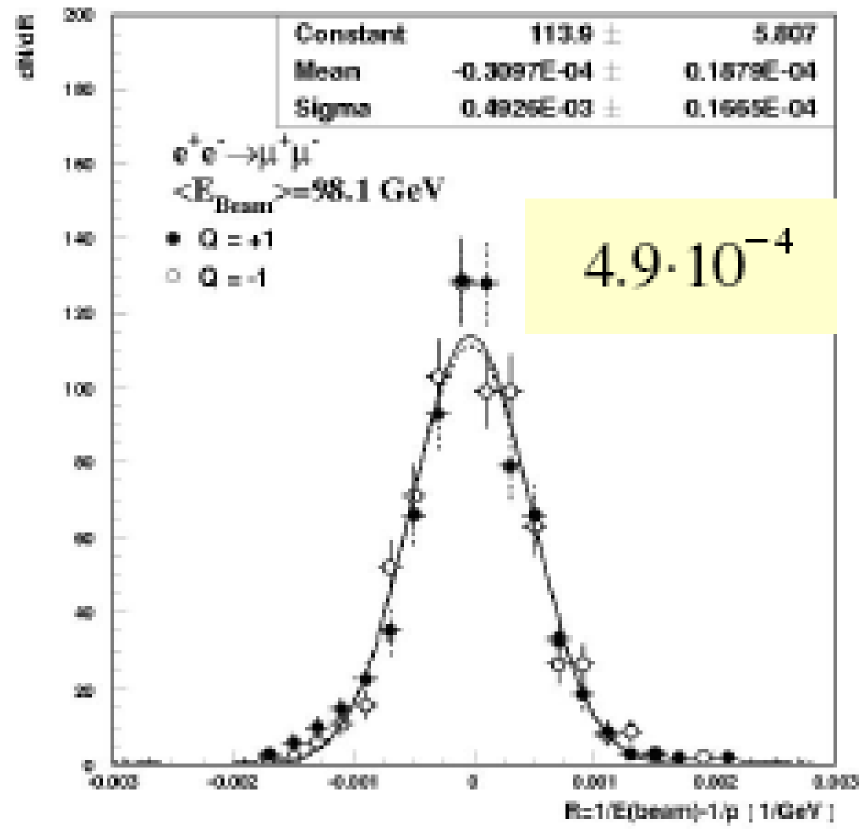


the bottom line (e.g., momentum resolution)

Calibration Data



High Energy Data



What about the B-field?

B-field

correction coils were originally foreseen, as in Aleph

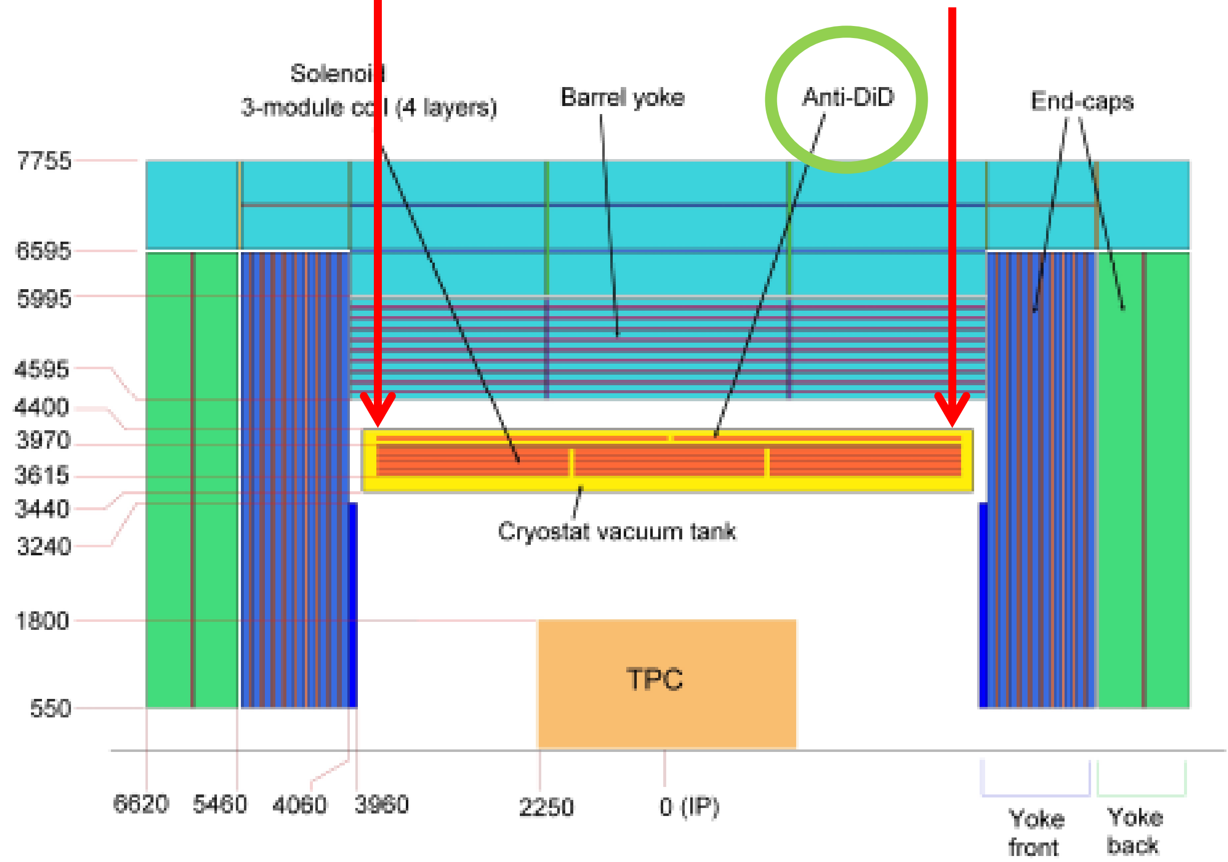


Figure 2.6.1: ILD magnet cross section, dimensions are in mm (half upper part, cylindrical symmetry)

B-field

Background reduction due to the antiDID

IR OPTIMIZATION, DID AND ANTI-DID*

Andrei Seryi, Takashi Maruyama, SLAC, Stanford, CA, USA
Brett Parker, BNL, Upton, NY 11973, USA.

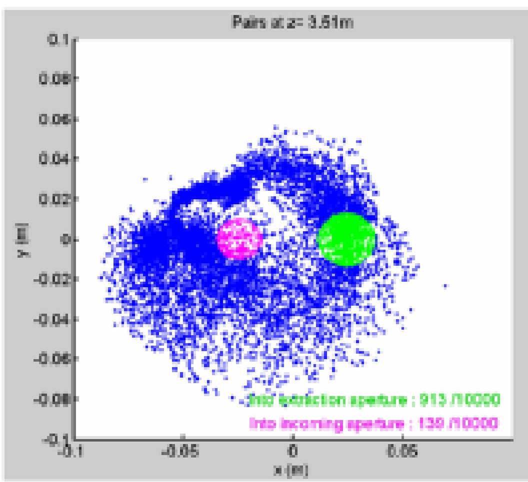


Figure 2: Distribution of pairs at 3.5m from IP in SiD detector when DID is used to compensate the vertical IP angle of the incoming beam. The incoming and outgoing apertures are shown by magenta and green colors.

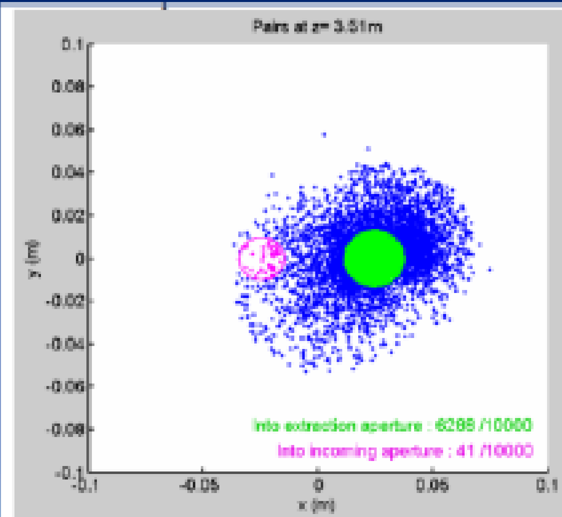


Figure 6: Distribution of pairs at 3.5m from IP in SiD detector when anti-DID is adjusted to direct pairs to the extraction hole. The incoming and outgoing apertures are shown by magenta and green colors.

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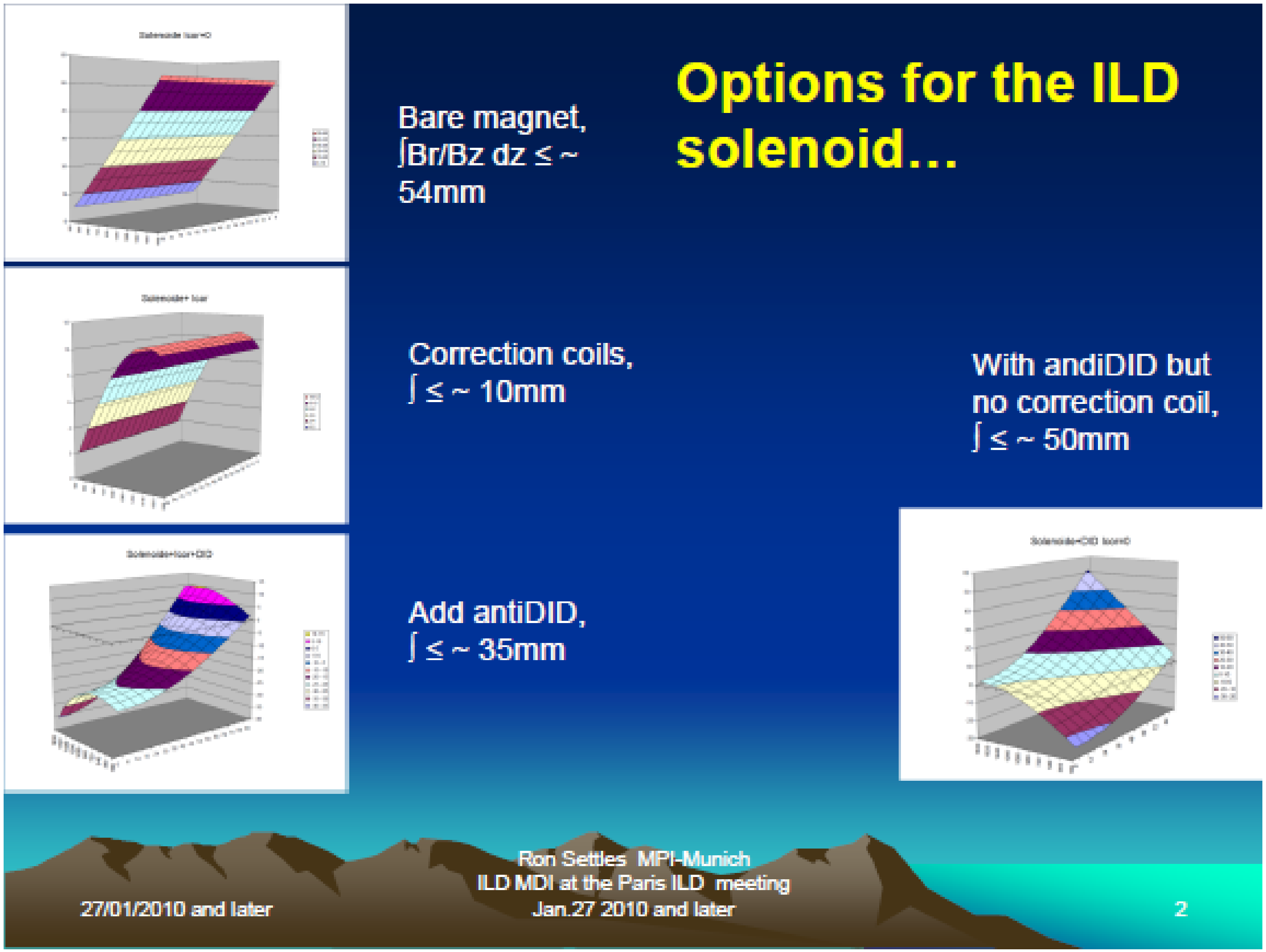
B-field


Options for the ILD solenoid…
Bare magnet,
∫Br/Bz dz ≤ ~ 54mm
Correction coils,
∫ ≤ ~ 10mm
Add antiDID,
∫ ≤ ~ 35mm
With andiDID but no correction coil,
∫ ≤ ~ 50mm
27/01/2010 and later
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B-field

Since 35mm (with) and 50mm (without) is not a big difference, thus the 'BIG' question: "Do we need the corrector windings?" The history of this issue…

- Henri Deports, Francois Kircher, and team corrected the solenoid for Aleph to $\int Br/Bz \, dz \leq \sim 2$mm, based on two notes by John Rander.
- The idea from John's notes was that the B field had to be homogeneous to ~ 2mm for the above integral so that displacement of electron drift remains small.
- John mentioned that "the events themselves may be used to measure [certain effects like] tilted E and B axes." This was done later by Werner Wiedenmann, see http://wisconsin.cern.ch/~wiedenma/TPC/Distortions/Cern_LC.pdf

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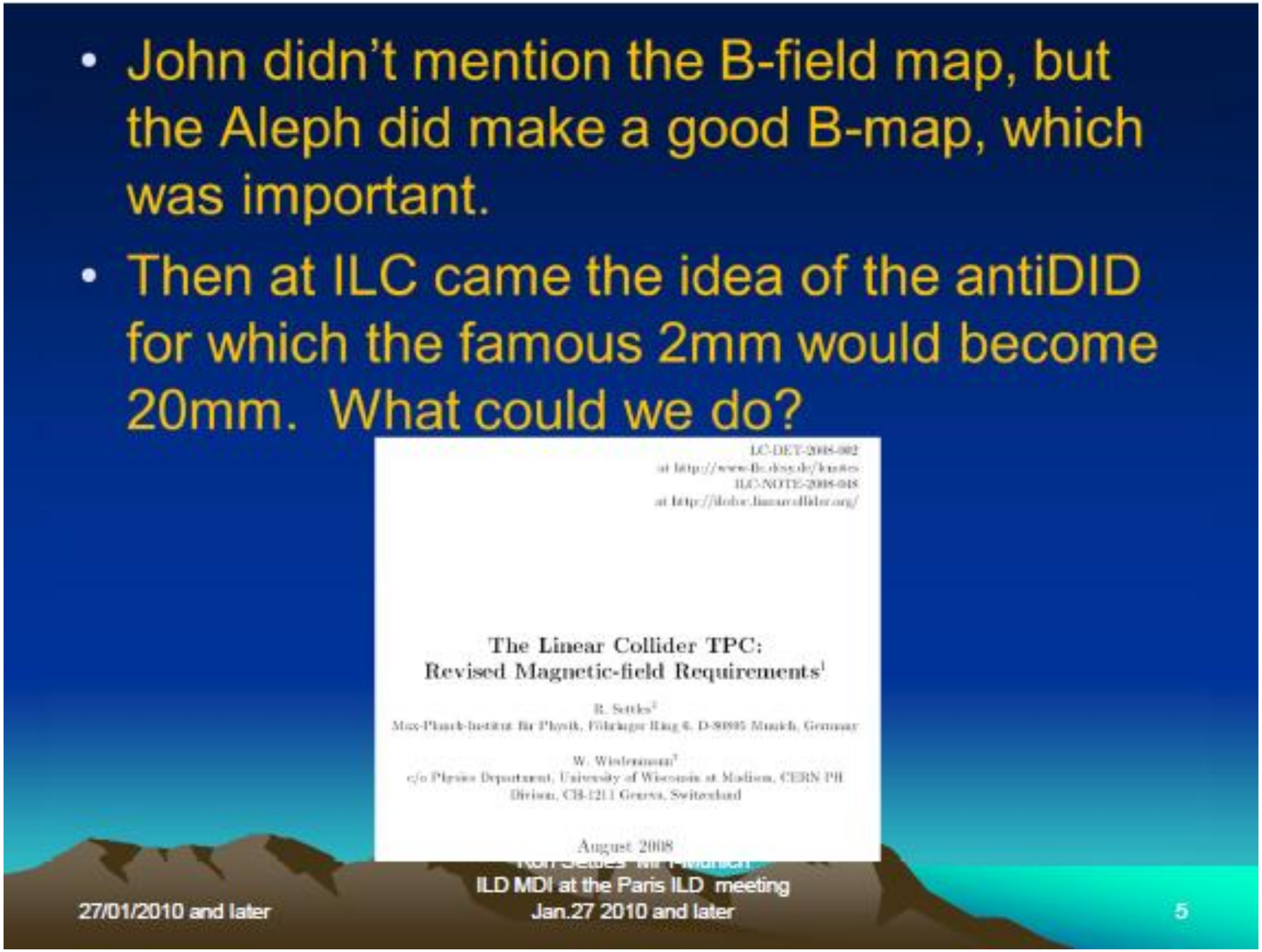
B-field



John didn't mention the B-field map, but the Aleph did make a good B-map, which was important.
Then at ILC came the idea of the antiDID for which the famous 2mm would become 20mm. What could we do?
LC-DET-2008-002
ILC-NOTE-2008-048
The Linear Collider TPC:
Revised Magnetic-field Requirements
R. Settles
W. Wiedenmann
August 2008
ILD MDI at the Paris ILD meeting
27/01/2010 and later
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B-field

- The basic idea: any B-inhomogeniety can be corrected if the B-field is known exactly, i.e., mapped well enough. We just have to invest sufficient effort in measuring it

3.2 Electron drift

The motion of drifting electrons in electric and magnetic fields is governed by the Langevin equation

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

where μ $(= e\tau/m)$ is the electron mobility, ω $(= eB/m)$ is the cyclotron frequency and τ is the mean drift time between two collisions with gas molecules.

The equations for the movement of drifting electrons due to the magnetic field $\vec{B}$ can be derived from Eq. 1 (see p.16 of [7]) and are the following:

$$\Delta r\varphi = \frac{\omega\tau}{1+(\omega\tau)^2}\int_z^{z_{max}}\left(\omega\tau\frac{B_\varphi}{B_z} + \frac{B_r}{|B_z|}\right)dz \qquad (2)$$

As stated earlier, the momentum resolution for the stiff tracks is directly affected by the $r\varphi$ movement from B-field gradients, Eq. 2. Thus the main requirement proposed here is that the uncertainty on this correction is smaller than σ_0:

$$\delta(\Delta r\varphi) = \frac{(\omega\tau)^2}{1+(\omega\tau)^2}\,\delta\left(\int_z^{z_{max}}\left(\frac{B_\varphi}{B_z} + \frac{1}{\omega\tau}\frac{B_r}{B_z}\right)dz\right) < \sigma_0. \qquad (5)$$

In other words, the accuracy of the B-field map must be good enough so that the integral of the field components over the drift paths is known to σ_0 or better. The Δr movement will be described in Sec. 3.5.4.

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B-field

- The recipe: increase the number of measuring points if you need more accuracy…

$$\sigma_{\Delta r\varphi_i} = \frac{1}{\sqrt{N_i}} \frac{\sigma_{B_\varphi}}{B_z} z_i \quad (6)$$

where each of the uncertainites $\delta B_{\varphi j}$ is sampled from the same Gaussian distribution of width σ_{B_φ}.

- And a.o.t. the Bphi component is more important than Br…

$$\sigma_{\Delta r\varphi_i} = \frac{1}{\sqrt{N_i}} \frac{z_i}{B_z} \sqrt{\sigma^2_{B_\varphi} + \frac{1}{\omega^2\tau^2}\sigma^2_{B_r}}.$$

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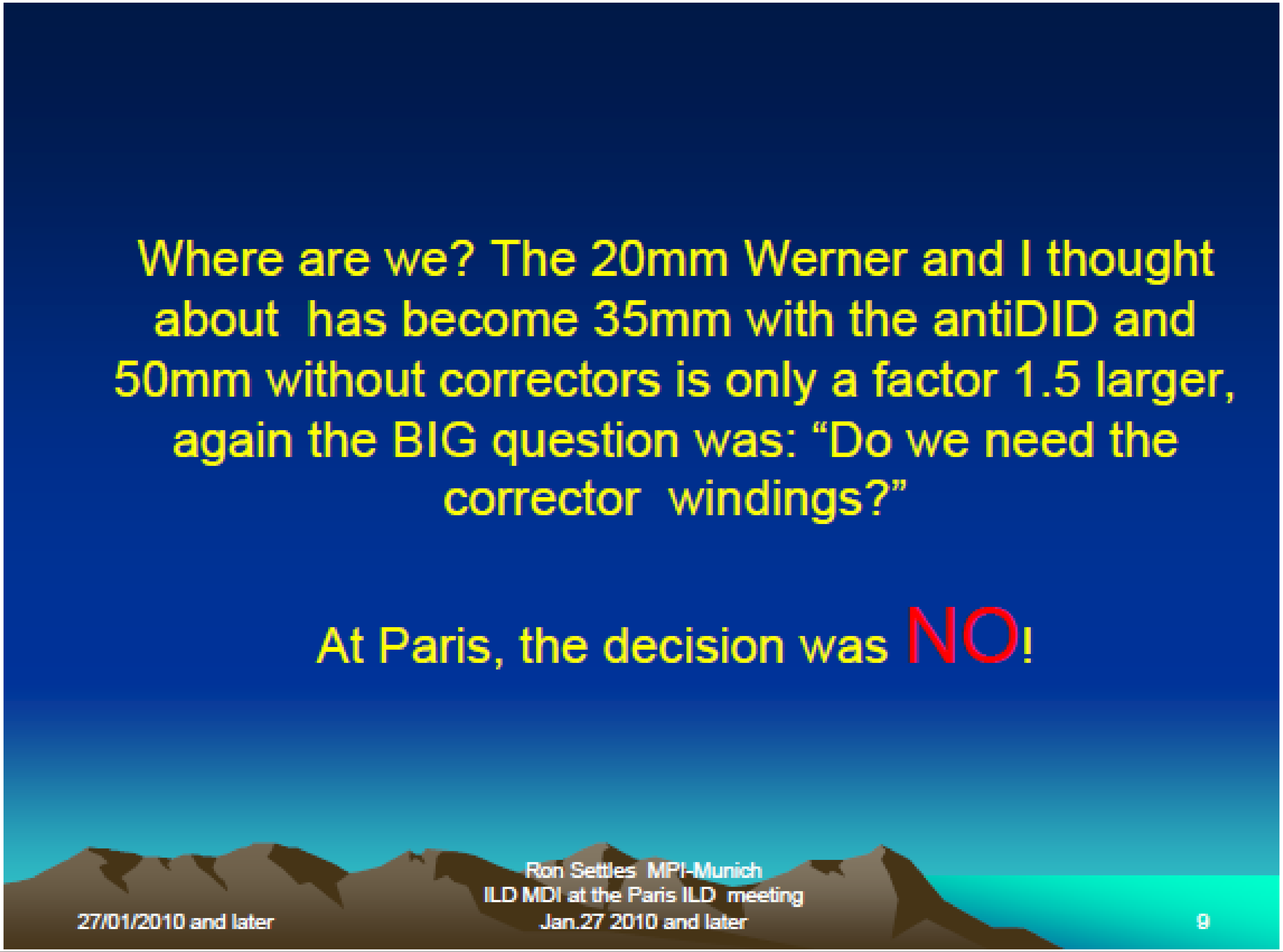
B-field

- …we just have to invest sufficient effort in measuring it: Aleph did invest a lot of effort, but several problems remained which we must avoid (read the note for details).

B-field


Where are we? The 20mm Werner and I thought about has become 35mm with the antiDID and 50mm without correctors is only a factor 1.5 larger, again the BIG question was: "Do we need the corrector windings?"
At Paris, the decision was NO!
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B-field

This decision was documented (a year later) in another LCNOTE:

final version 20111212
LC-DET-2011-002
http://www-flc.desy.de/lcnotes
ILC-NOTE-2011-061
http://ilcdoc.linearcollider.org
LCD-NOTE-2011-039
http://lcd.web.cern.ch/LCD/Documents/Documents.html

LCTPC and the Magnetic Field for ILD: Update 2010

R. Settles[1]
Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

Abstract

This note is a further development of the ideas presented in Refs. [1][2][3][4]. The recent issue is that the LCTPC [5] collaboration in conjunction with the ILD [6] has decided not to specify a limit on the uniformity of the magnetic field. The reason is that large gradients will result from the anti-DID (Detector Integrated Dipole)[7][8], which will be implemented to reduce backgrounds in the detector. Since now a uniformity-limit will not be defined, the corrector windings in the solenoid can be eliminated. This decision had not been published as LCNote in 2010 and will be documented here.[2] The TPC for CLIC is also addressed.

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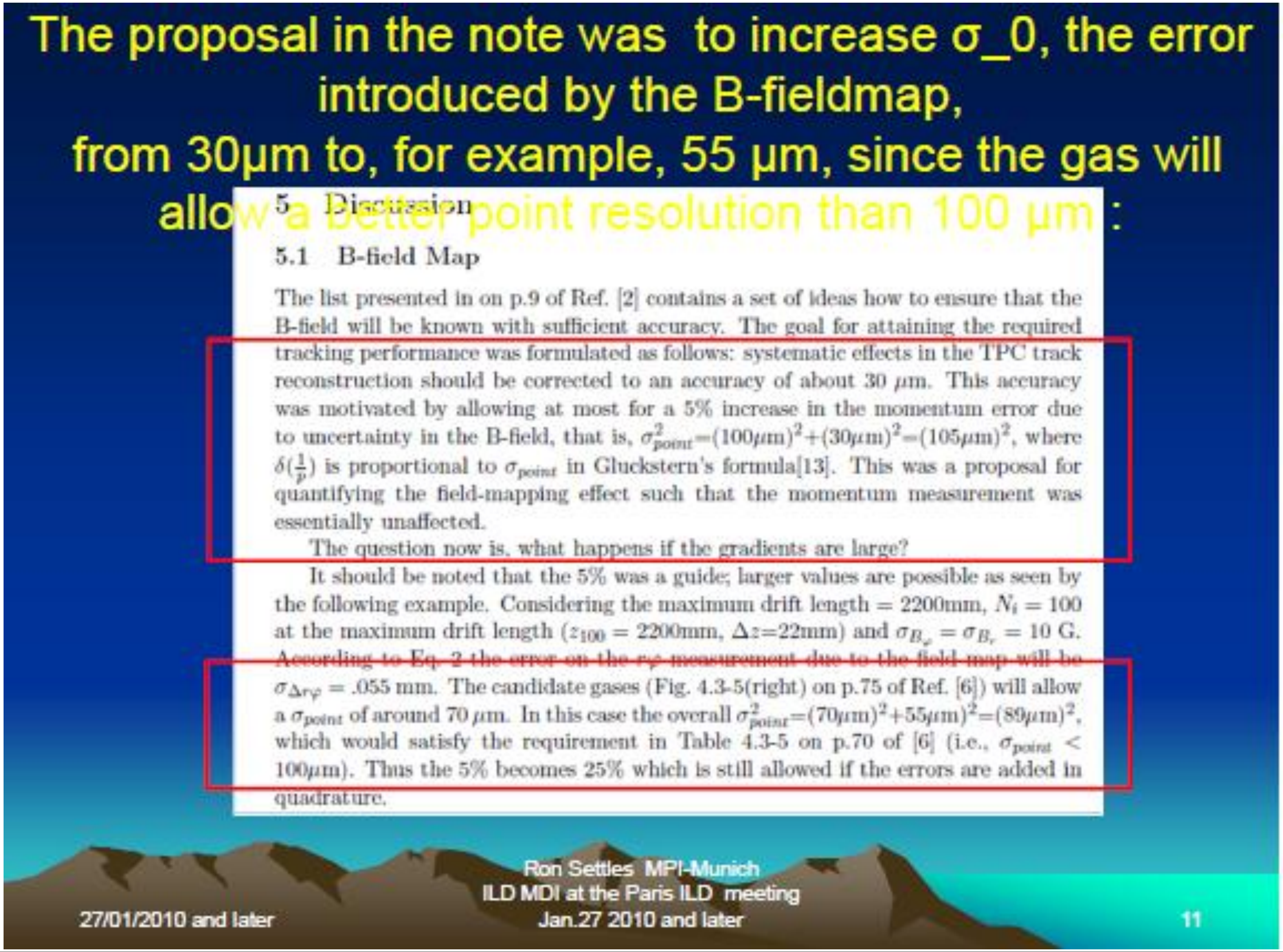
B-field



5 Discussion

5.1 B-field Map

The list presented in on p.9 of Ref. [2] contains a set of ideas how to ensure that the B-field will be known with sufficient accuracy. The goal for attaining the required tracking performance was formulated as follows: systematic effects in the TPC track reconstruction should be corrected to an accuracy of about 30 μm. This accuracy was motivated by allowing at most for a 5% increase in the momentum error due to uncertainty in the B-field, that is, σ^2_{point}=$(100\mu m)^2+(30\mu m)^2$=$(105\mu m)^2$, where $\delta(\frac{1}{p})$ is proportional to σ_{point} in Gluckstern's formula[13]. This was a proposal for quantifying the field-mapping effect such that the momentum measurement was essentially unaffected.

The question now is, what happens if the gradients are large?

It should be noted that the 5% was a guide; larger values are possible as seen by the following example. Considering the maximum drift length = 2200mm, $N_i = 100$ at the maximum drift length (z_{100} = 2200mm, Δz=22mm) and $\sigma_{B_\varphi} = \sigma_{B_r}$ = 10 G. According to Eq. 2 the error on the $r\varphi$ measurement due to the field map will be $\sigma_{\Delta r\varphi}$ = .055 mm. The candidate gases (Fig. 4.3-5(right) on p.75 of Ref. [6]) will allow a σ_{point} of around 70 μm. In this case the overall σ^2_{point}=$(70\mu m)^2+55\mu m)^2$=$(89\mu m)^2$, which would satisfy the requirement in Table 4.3-5 on p.70 of [6] (i.e., σ_{point} < 100μm). Thus the 5% becomes 25% which is still allowed if the errors are added in quadrature.

B-field


Start planning!!!
Hall probe measuring devices being set up in the coil.
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ILD MDI at the Paris ILD meeting
Jan.27 2010 and later
27/01/2010 and later
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Conclusion

- We'd better learn from these past lessons so that the new TPC will evolve to a much better main tracker for the future LC → its performance will then improve by an order of magnitude relative to that at Lep…