Distortion Corrections for the ALEPH TPC

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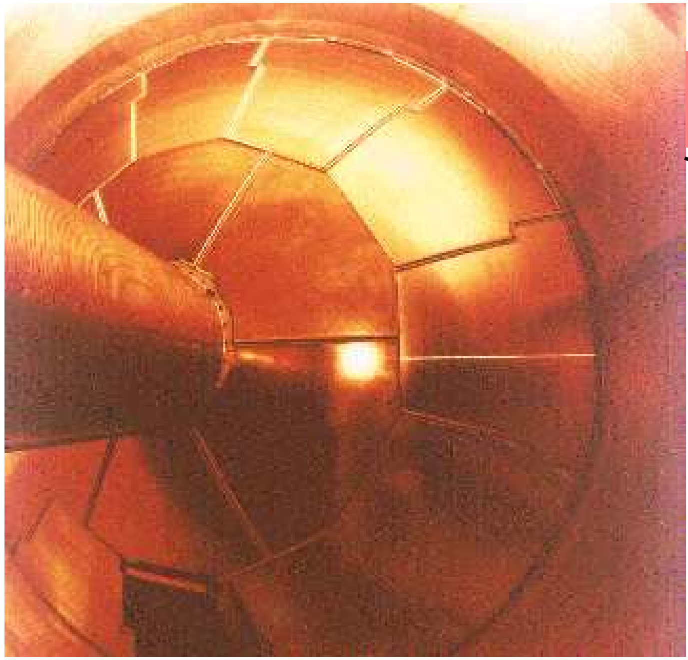
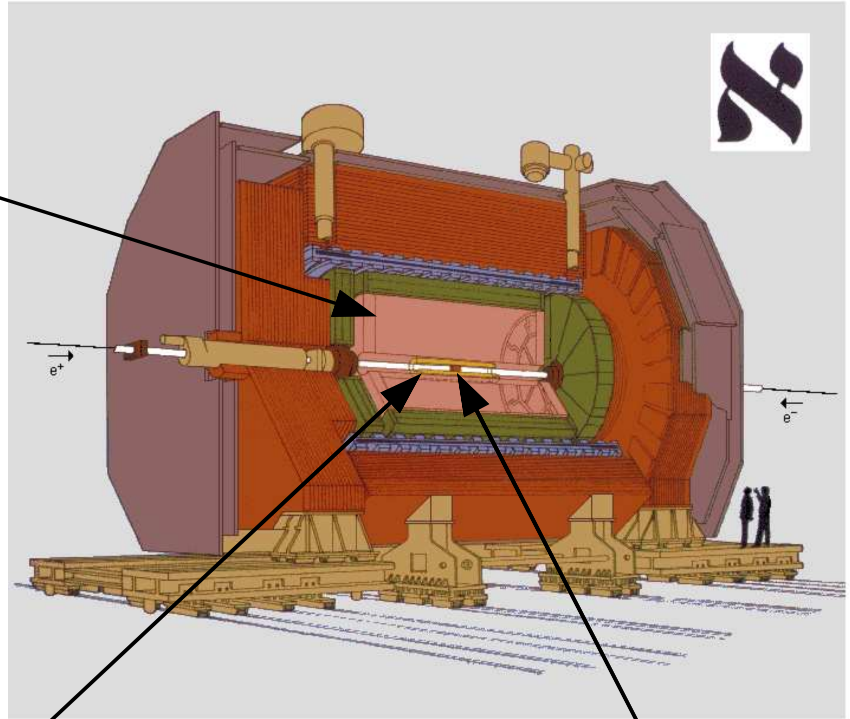
Overview

- Brief overview of the detector
- Historical development
- Distortion corrections for the TPC
- Tour through some problems and their correction
- Detector performances
- Summary

The ALEPH Detector



TPC



Vertex Detector

Inner Tracking Chamber

Time Projection Chamber

Electromagnetic Calorimeter

Superconducting Magnet Coil

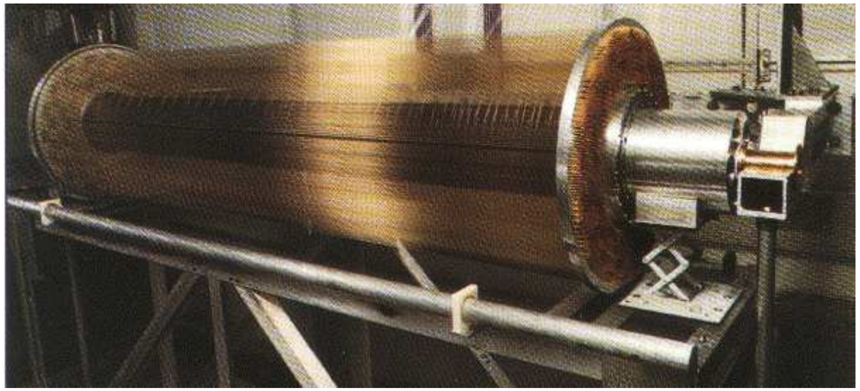
Hadron Calorimeter

Muon Chambers

Luminosity Monitors

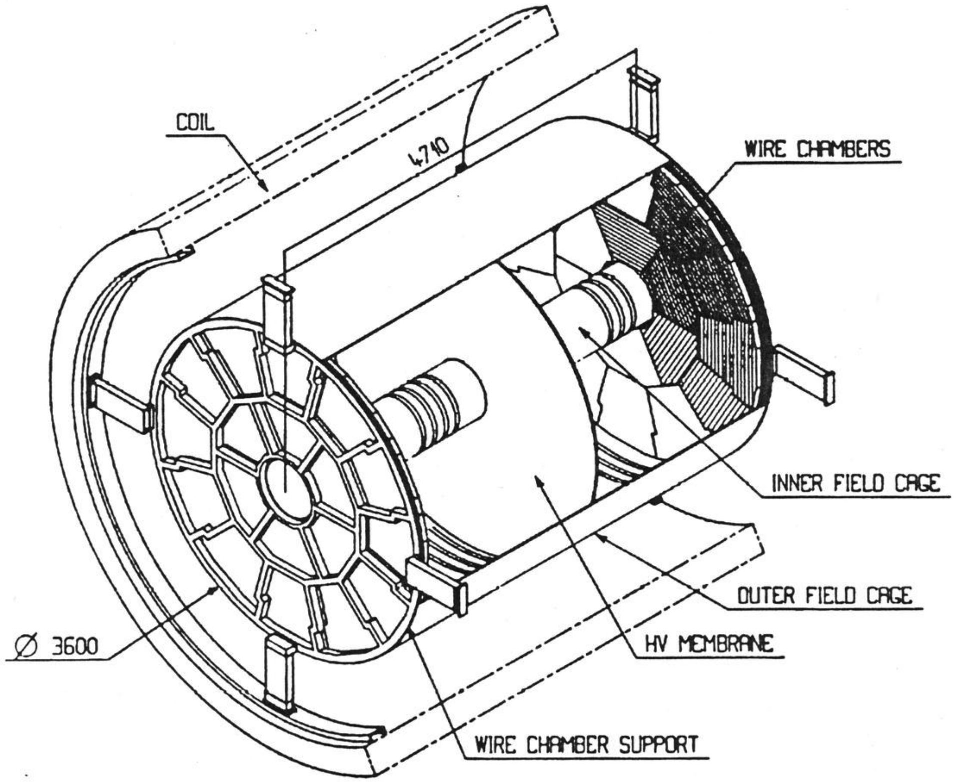
The ALEPH Detector

ITC



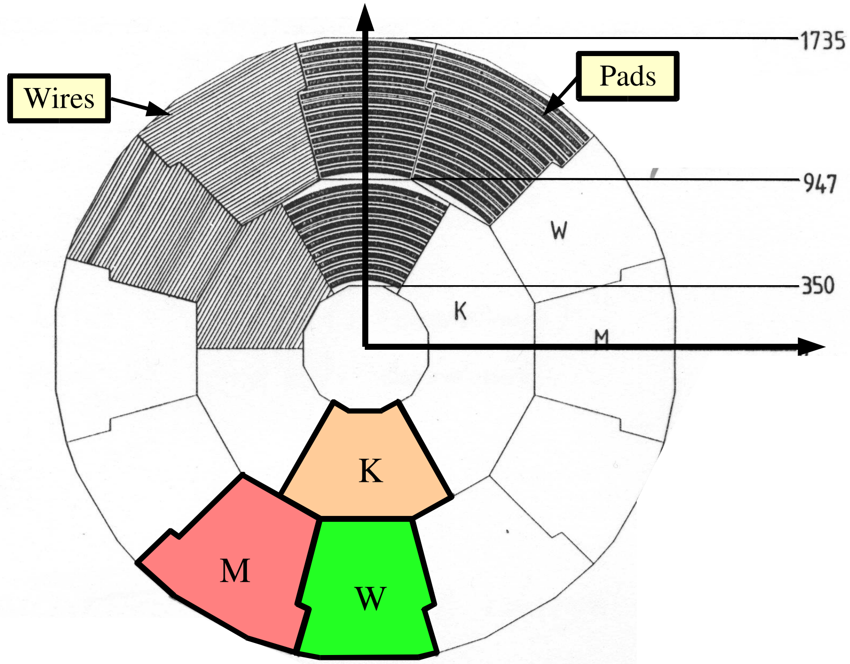
VDET

TPC



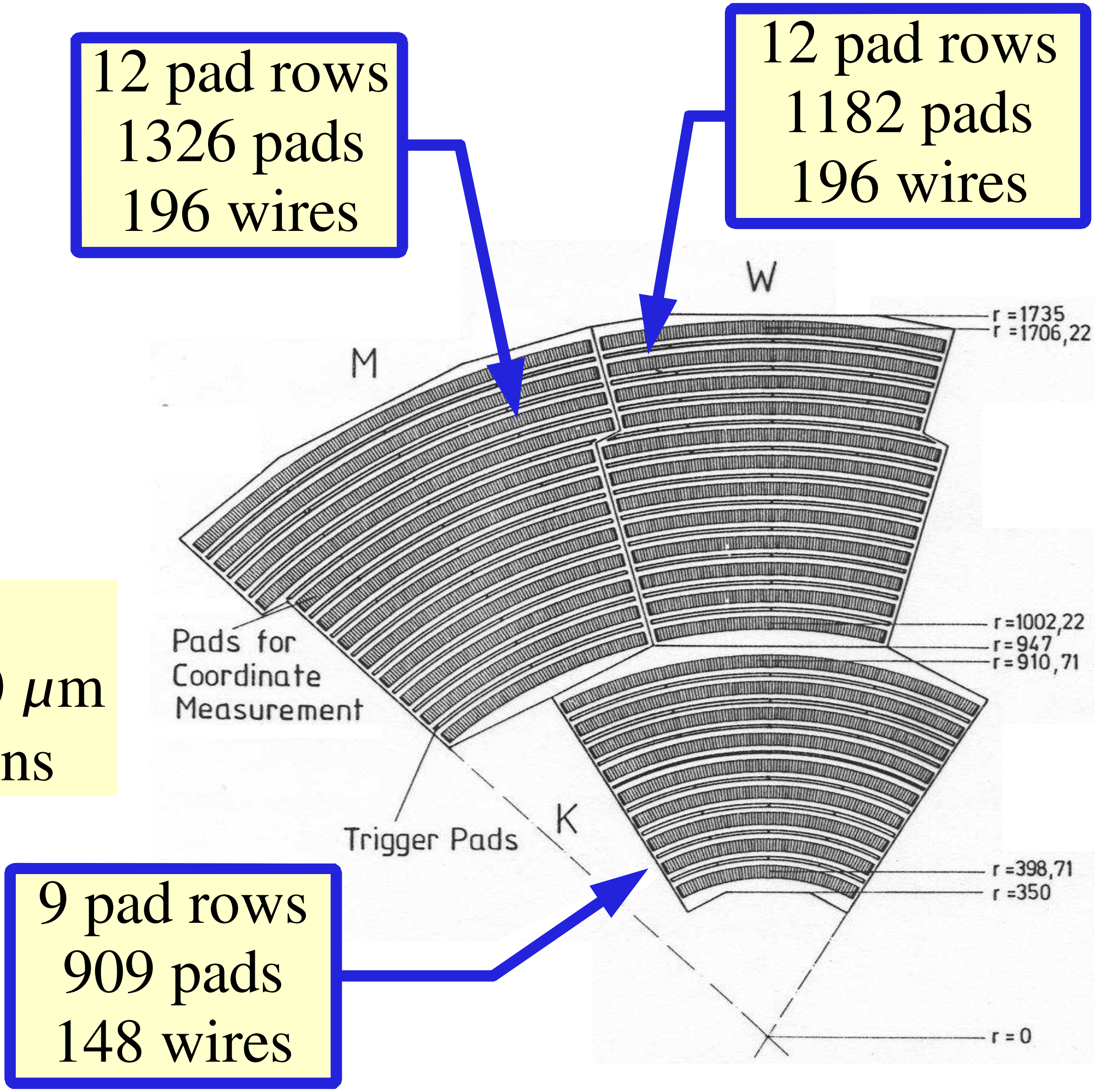
- rφ from pad position
- z from drift time (pads + wires)
- dE/dx from wires and pads

- 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 $|\cos\Theta| \leq 0.97$



Pad size: $\delta r\varphi \times \delta r = 6.2\,[mm] \times 30\,[mm]$

- rφ-resolution : 180 μm
- z–resolution (pads + wires) : 500 μm
- dE/dx : 4.5 % for Bhabha electrons



Historical Development

LEP startup 1989 –1990

- Failure of magnet compensating power supplies in 1989 requires development of field correction methods
  - Derived from 2 special Laser runs (B on/off)
  - Correction methods described in NIM A306(1991)446
- High statics Muon pairs from Z–decay is main calibration sample

1991–1994 (LEP 1)

- Silicon Vertex Detector 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 7 shorts on field cage affect 24% of collected data. 1994 disconnected gating grids make 20% of data unusable
  - All data finally recuperated with data–based correction models

1994–1996 (LEP 1/2)

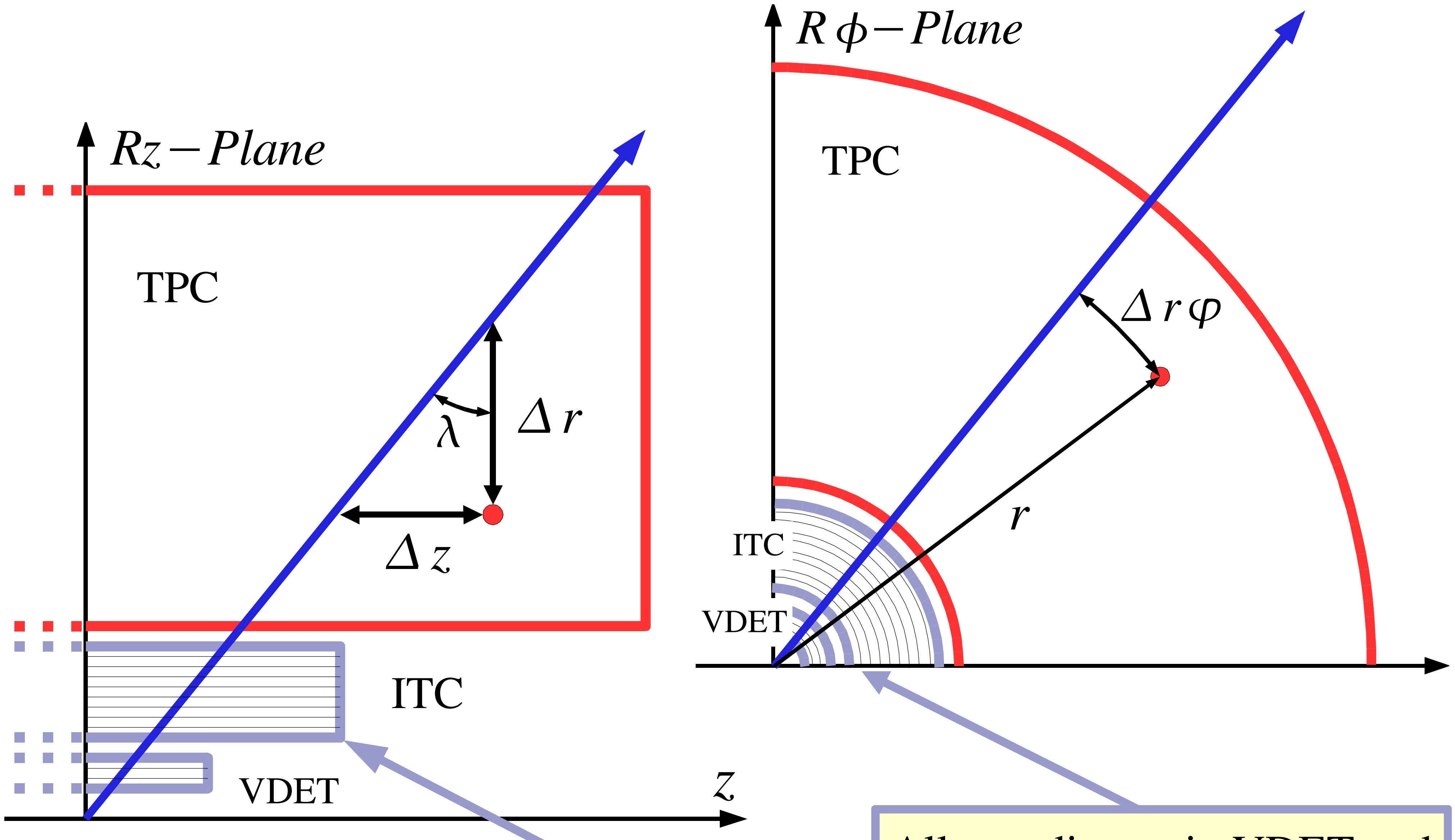
- Aleph Tracking Upgrade Program (Reprocessing of LEP 1 data)
  - Improved coordinate determination requires better understanding of systematic effects.
  - Combined calculations for field and alignment distortions in TPC. Reevaluation of B–field map.
  - All methods for distortion corrections are based now directly on data
  - Development of "few" parameter correction models to cope with drastically reduced calibration samples at LEP 2.
  - Use high statistics LEP 1 muon pairs to make improved maps also for LEP 2

1995–2000 (LEP 2)

- New VDET 2 with larger acceptance (end 1995)
- Z pairs are only available in special calibration runs at begin of running period and on request from experiments after incidents. Very limited statistics compared to LEP 1.
- More frequent beam losses cause time dependent "charge up" effects in the TPC and new shorts. Both distortions are superimposed.
  - For short corrections LEP delivers small amount of Z pairs (~700 muon pairs) on experiment's request.
  - Time dependent effects are usually present throughout the year and have to be tracked with hadrons.

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.



All coordinates in VDET and ITC are fit to common helix

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

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

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

d_0 = Signed distance of closest approach to origin

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

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

Computed from first principles

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

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

- Solve system of linear equations with *Singular Value Decomposition (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.

$$\left\| \vec{A} \right\| = \boldsymbol{Min}$$

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

Ansatz for $\boxed{(\Delta \widehat{r\varphi}, \Delta \hat{r}, \Delta \hat{z})_{Fields}}$

- Start with Potential

$$\Phi_E = U_0 \left(1 - \frac{|z|}{z_M} \right) - U_0 \tilde{\Phi}_E(r,\varphi,z) \; ; \; U_0 \simeq -27\,kV \; ; \; \left|\tilde{\Phi}_E(r,\varphi,z)\right| \ll 1 \; ; \qquad E-Field$$

$$\Phi_B = -B_z^0 z - B_z^0 z_M \tilde{\Phi}_B(r,\varphi,z) \; ; \; B_z^0 \simeq 15\,kG \; ; \; \left|\tilde{\Phi}_B(r,\varphi,z)\right| \ll 1 \; ; \qquad B-Field$$

- Calculate solutions for Laplace equation for double cylinder

$$\Delta \Phi = 0 \; ; \; \rightarrow \; \Phi = \sum_{ij} a_{ij} \Phi_{ij}(r,\varphi,z) \; ;$$

- Compute

$$\vec{E} = -\nabla \Phi_E \; ; \; \vec{B} = -\nabla \Phi_B$$

- Compute distortions from Langevin equation

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

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

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

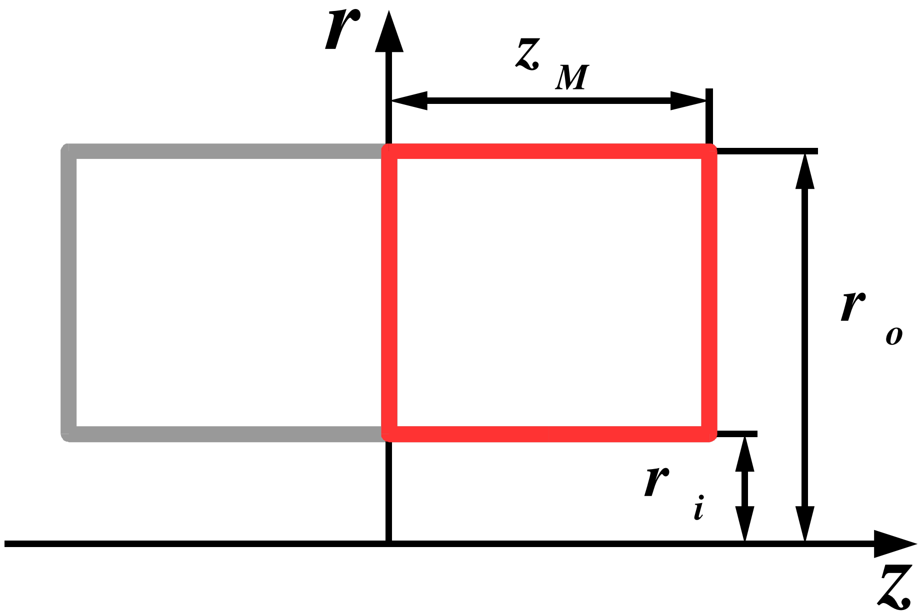
Approximations:

$$r(z)\simeq r+\frac{\partial r}{\partial z}\delta z\ ;\quad \varphi(z)\simeq\varphi+\frac{\partial\varphi}{\partial z}\delta z\ ;\quad \left|\frac{\partial r}{\partial z}\right|,\left|\frac{\partial\varphi}{\partial z}\right|\ll 1$$

$$E_z(r,\varphi,z)\simeq E_z^0=\pm\frac{U_0}{z_M}\ ;\quad B_z(r,\varphi,z)\simeq B_z^0\ ;$$

Characteristics of Solutions

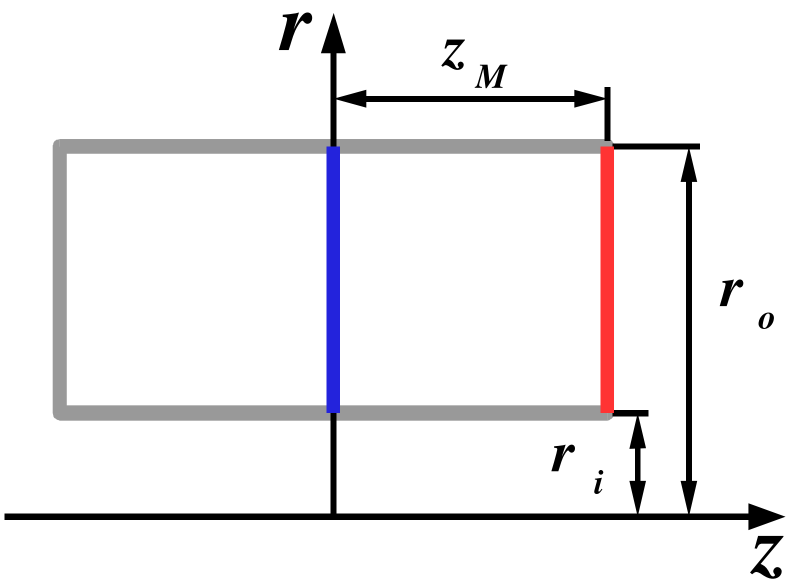
- Solution by separation of variables. 3 classes of solutions corresponding to choice of separation variable k^2
- $k^2 = 0$



$$\tilde{\Phi}_0 = \ln\left(\frac{r}{r_o}\right)\left(A_0\left(\frac{z}{z_M}\right) + B_0\right) ;$$

$$\tilde{\Phi}_\nu = \left(\frac{r}{r_o}\right)^\nu \sin(\nu\varphi)\left(A_\nu\left(\frac{z}{z_M}\right) + B_\nu\right) + \left(\frac{r}{r_o}\right)^\nu \cos(\nu\varphi)\left(C_\nu\left(\frac{z}{z_M}\right) + D_\nu\right) ; \quad \nu = \pm 1 \ldots \pm\infty ;$$

- $k^2 > 0$

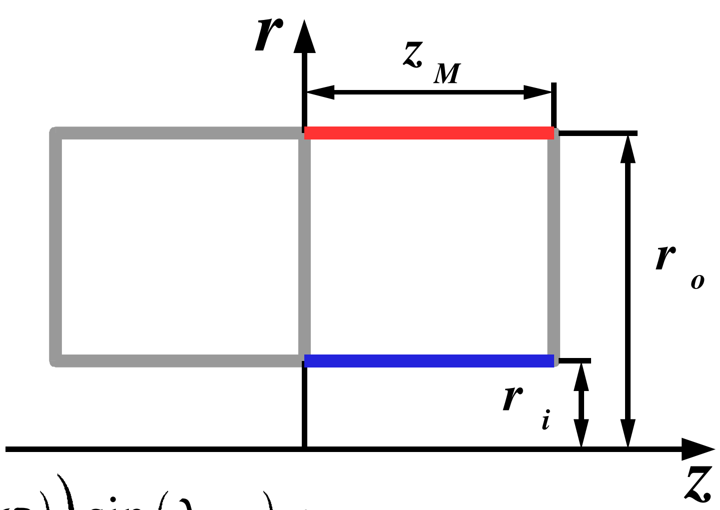


$$\tilde{\Phi}_{\nu m} = \Psi_{\nu m}(\lambda_{\nu m} r)\left(A_{\nu m}\sin(\nu\varphi) + B_{\nu m}\cos(\nu\varphi)\right)\begin{pmatrix} \dfrac{\sinh(\lambda_{\nu m}|z|)}{\sinh(\lambda_{\nu m} z_M)} \\ \\ \dfrac{\sinh(\lambda_{\nu m}(z_M - |z|))}{\sinh(\lambda_{\nu m} z_M)} \end{pmatrix};$$

$$\Psi_{\nu m}(\lambda_{\nu m} r) = \begin{vmatrix} J_\nu(\lambda_{\nu m} r_i) & N_\nu(\lambda_{\nu m} r_i) \\ J_\nu(\lambda_{\nu m} r) & N_\nu(\lambda_{\nu m} r) \end{vmatrix}; \quad \Psi_{\nu m}(\lambda_{\nu m} r_i) = \Psi_{\nu m}(\lambda_{\nu m} r_o) = 0 ;$$

$$\nu = 0 \ldots \infty \;; m = 1 \ldots \infty \;;$$

- $k^2 < 0$



$$\tilde{\Phi}_{\nu m} = \left(\frac{P_{\nu m,\ FCout}(\lambda_m r)}{P_{\nu m,\ FCin}(\lambda_m r)} \right) \left(A_{\nu m} \sin(\nu\varphi) + B_{\nu m} \cos(\nu\varphi) \right) \sin(\lambda_m z)\ ;$$

$$P_{\nu m,\ FCout}(\lambda_m r) = \frac{\begin{vmatrix} I_\nu(\lambda_m r) & I_\nu(\lambda_m r_i) \\ K_\nu(\lambda_m r) & K_\nu(\lambda_m r_i) \end{vmatrix}}{\begin{vmatrix} I_\nu(\lambda_m r_o) & I_\nu(\lambda_m r_i) \\ K_\nu(\lambda_m r_o) & K_\nu(\lambda_m r_i) \end{vmatrix}}\ ;\ P_{\nu m,\ FCin}(\lambda_m r) = \frac{\begin{vmatrix} I_\nu(\lambda_m r) & I_\nu(\lambda_m r_o) \\ K_\nu(\lambda_m r) & K_\nu(\lambda_m r_o) \end{vmatrix}}{\begin{vmatrix} I_\nu(\lambda_m r_i) & I_\nu(\lambda_m r_o) \\ K_\nu(\lambda_m r_i) & K_\nu(\lambda_m r_o) \end{vmatrix}}\ ;$$

$$\lambda_m = \frac{m\pi}{z_M}\ ;\quad \nu = 0 \ldots \infty\ ; m = 1 \ldots \infty\ ;$$

Greensfunction

$$\Delta_{\vec{x}} G(\vec{x},\hat{\vec{x}}) = -4\pi\,\delta(\vec{x}-\hat{\vec{x}})\ ;\quad G(\vec{x},\hat{\vec{x}})=0\ ;\quad \vec{x},\hat{\vec{x}}\in \boldsymbol{Boundary}$$

Solution with Ansatz : $G(\vec{x},\hat{\vec{x}}) = \sum_{\Lambda} a_{\Lambda}(\hat{\vec{x}})\,U_{\Lambda}(\vec{x})\ ;$

$$\Rightarrow \quad \boxed{G(\vec{x},\hat{\vec{x}}) = 4\pi \sum_{\Lambda} \frac{1}{\Lambda^2} U_{\Lambda}(\hat{\vec{x}})\,U_{\Lambda}(\vec{x})\ ;}$$

U fulfills Helmholtz equation :

$$\Delta U_{\Lambda} + \Lambda^2 U_{\Lambda} = 0\ ;\quad U_{\Lambda}(\vec{x})=0\ ;\quad \vec{x}\in \boldsymbol{Boundary}$$

$$U_{\Lambda_{\nu mn}}(r,\varphi,z) = \frac{1}{N_{\nu mn}}\Psi_{\nu m}(\lambda_{\nu m} r)\begin{pmatrix}\sin(\nu\varphi)\\ \cos(\nu\varphi)\end{pmatrix}\sin\left(\frac{n\pi}{z_M}z\right)\ ;\quad \Lambda^2_{\nu mn} = \lambda^2_{\nu m} + \left(\frac{n\pi}{z_M}\right)^2\ ;$$

Ansatz for $\boxed{(\Delta\widehat{r\varphi}, \Delta\hat{r}, \Delta\hat{z})_{Alignment}}$

- Transformation from measured TPC coordinate to global ALEPH coordinate

$$\vec{x}_{\aleph} = A_3(A_2(A_1\vec{x}_{TPC}+\vec{t}_1)+\vec{t}_2)+\vec{t}_3\ ;$$

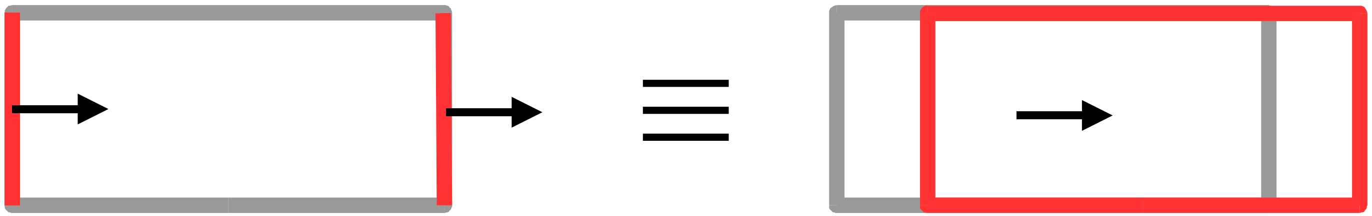
1. *TPC sector frame → TPC endplate frame*
2. *TPC endplate frame → TPC frame*
3. *TPC frame → Aleph global coordinate system*

- Compute $\Delta\vec{x}_{\aleph}$ as function of small variations of $(A_i, \vec{t}_i)$

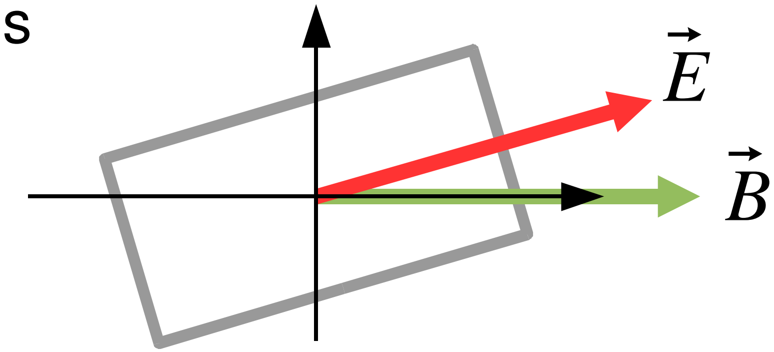
$$e.g.\quad A_2 = R_x R_y R_z\ ;\ \Rightarrow\ \Delta A_2 = \vartheta T_x R_x R_y R_z + \delta R_x T_y R_y R_z + \phi R_x R_y T_z R_z\ ;$$

$$R_{x,y,z} = Rotations\ of\ SO(3),\quad T_{x,y,z} = Generators\ of\ Lie\ Algebra\ of\ SO(3)$$

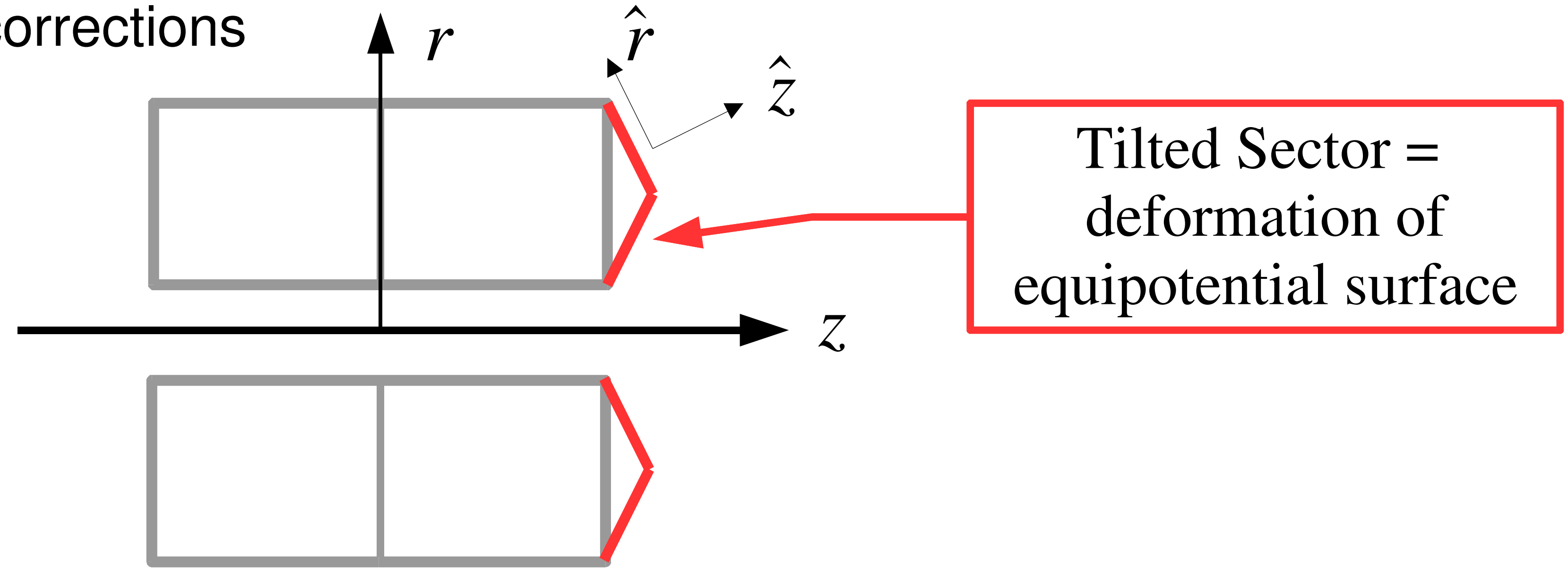
- Apply boundary conditions to alignment parameters, e.g endplate alignment should not move complete TPC



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

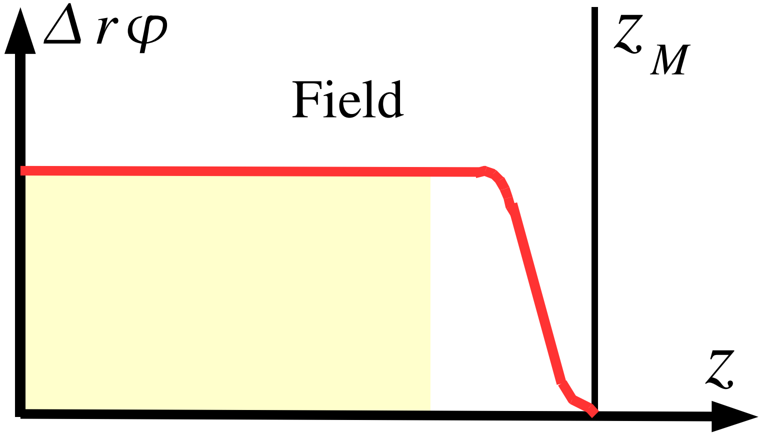


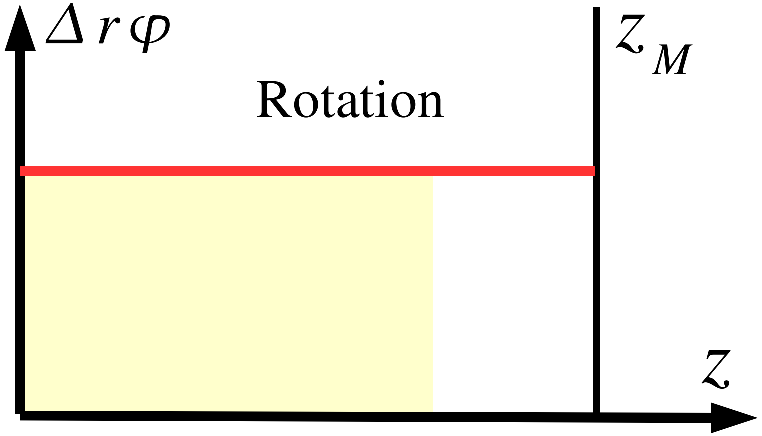
  - e.g bowing of the TPC endplate requires alignment and E–field corrections



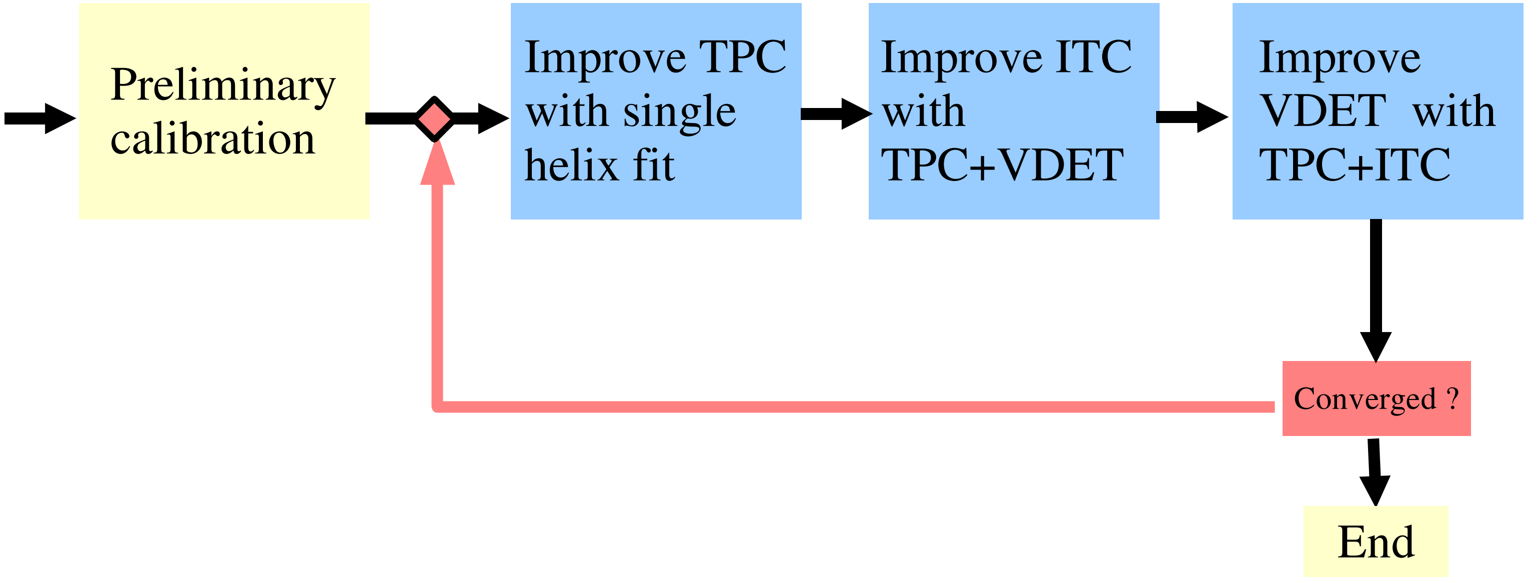
Remarks

- There are other corrections (e.g. timing shifts in hardware) which may interfere with the above corrections.
- With the single helix fit residuals can only be measured in a limited acceptance region, i.e.
  - Field and alignment corrections can not always be distinguished. The solution may be not unique.
  - Fit matrix can be therefore almost degenerate ($\rightarrow$ SVD).
  - "External" information helps in guiding the fit.



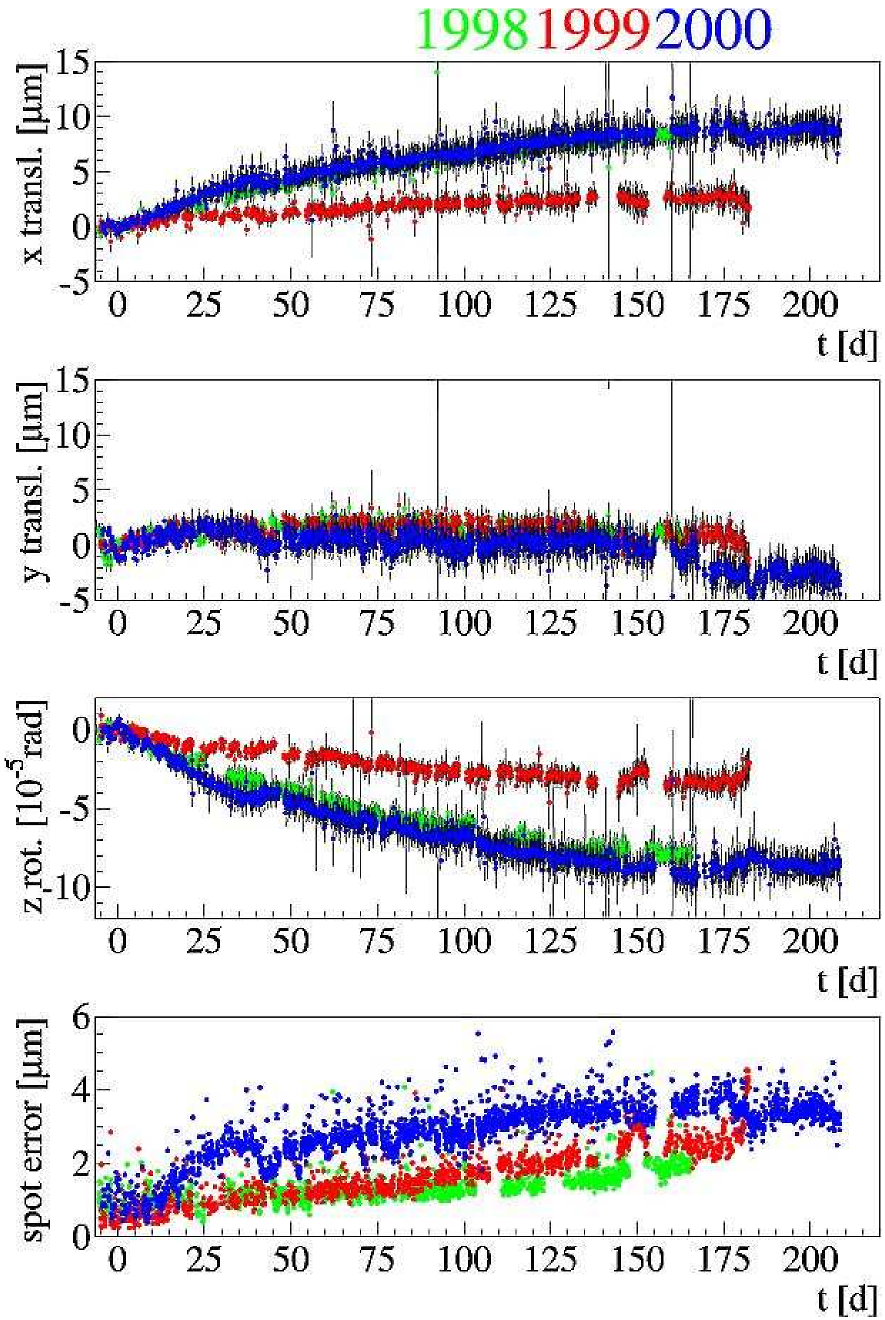


- Direct fitting of Fourierseries for field distortions is avoided
  - Slow convergence = many coefficients needed
  - Practical problems for numerical solutions
  - Does not allow to identify the contributing distortions
  - Normally a simple parameterised potential on the boundary is constructed and transformed via the Greensfunction in a parameterised distortion map (see examples later)
- The calibration is done iteratively (typically 2 iterations)

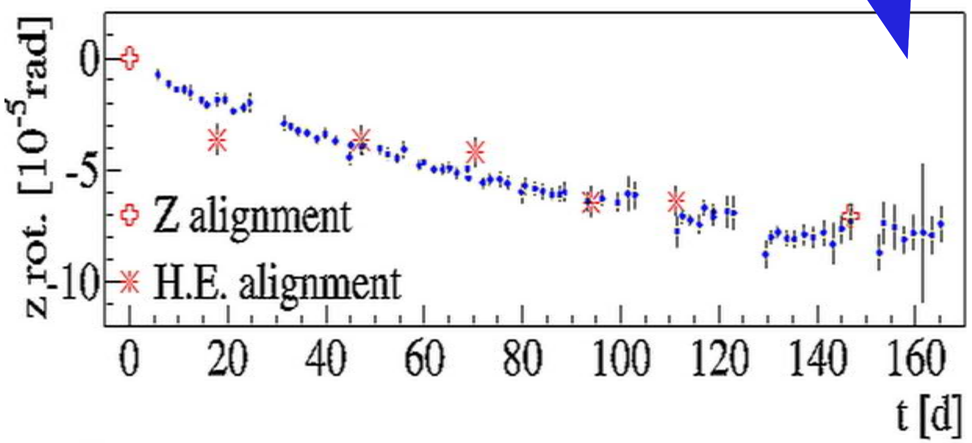


- Inner detector movements over time are monitored externally and are corrected for the final calibration

VDET movements recorded by the VDET laser system for the years 1998 to 2000



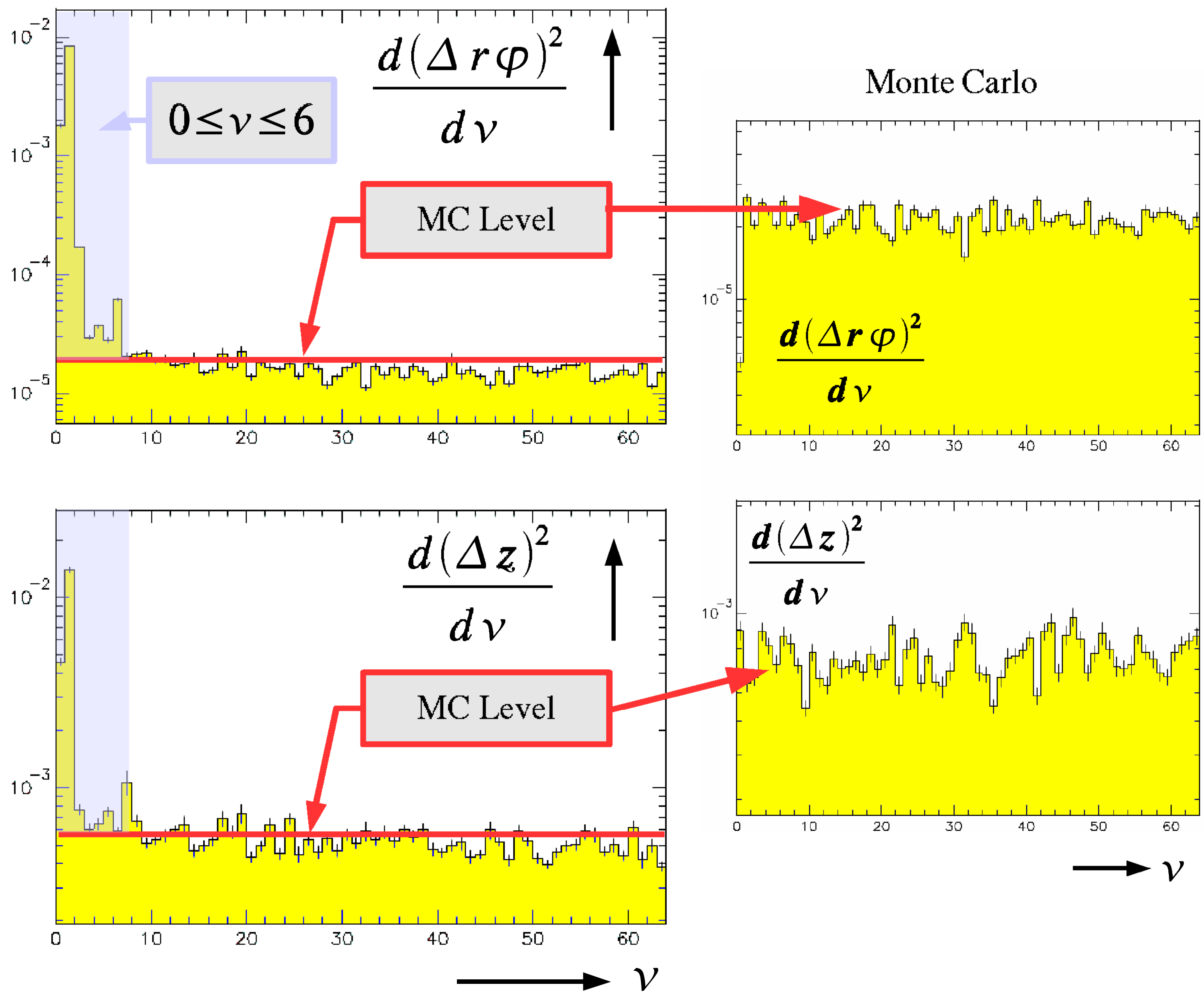
Comparison VDET laser system and real data alignment for 1998



Fourieranalysis

- Powerspectrum from measured residuals
- No corrections applied to data
- ν=0 : fields (E– and B–map needed)
- ν=1 : mainly global alignment
- ν > 1 : mainly internal alignment (e.g. sector alignment)

Data without corrections



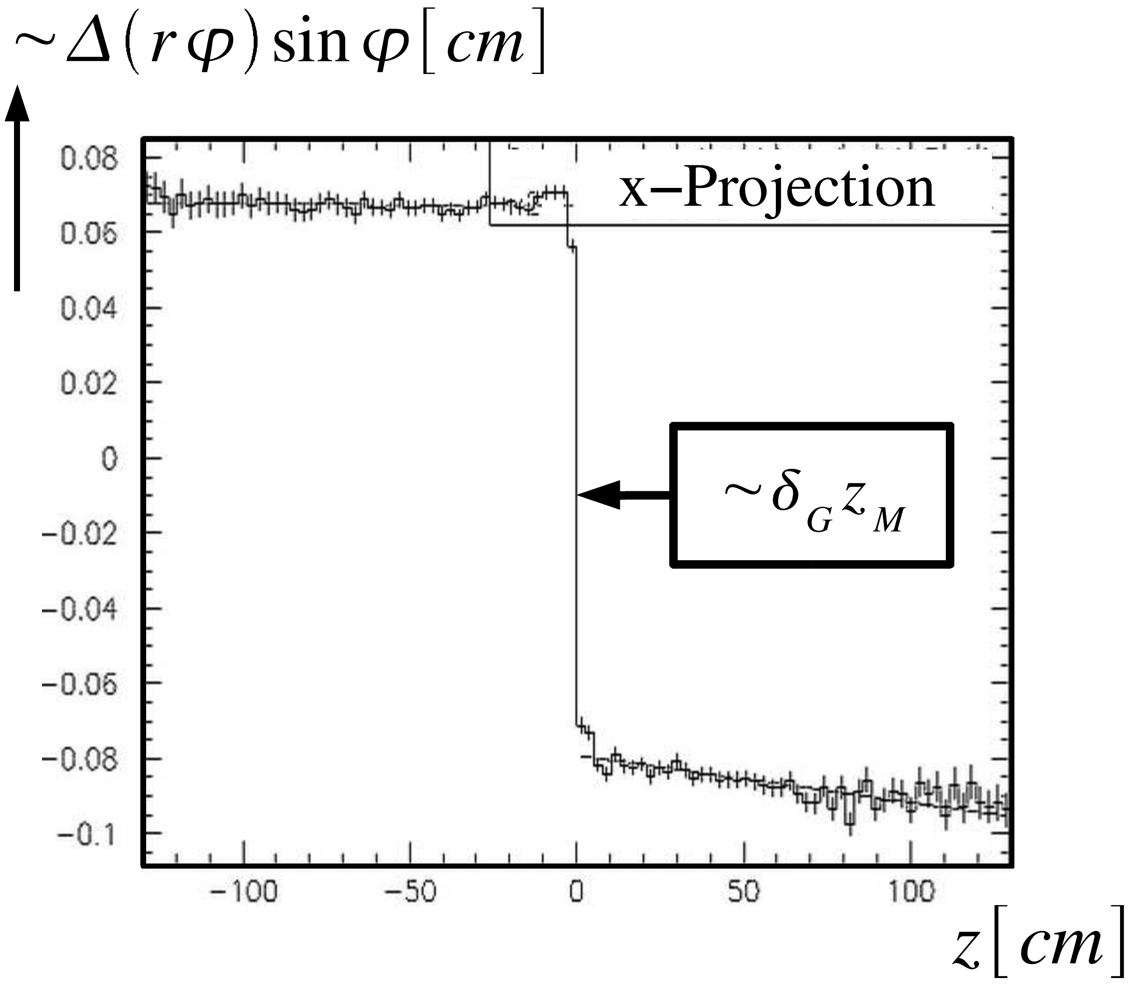
Tour through some problems and their correction

- 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

Tilt of TPC

$$\Delta r\varphi(r,\varphi,z) = r\phi_G - (\delta x)_G \sin\varphi + (\delta y)_G \cos\varphi - sign(z)\, z_M (\delta_G \sin\varphi + \vartheta_G \cos\varphi)$$

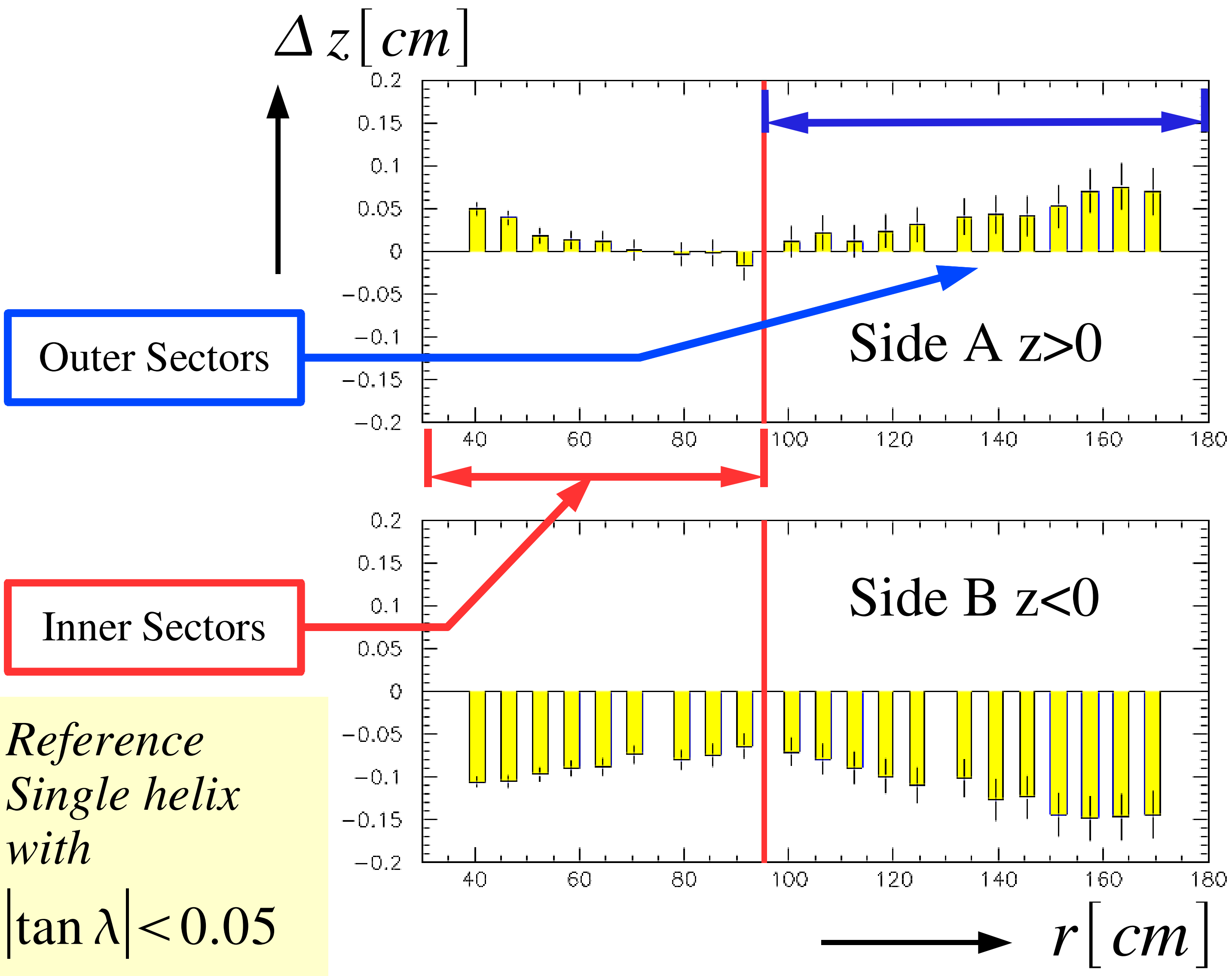
- Example for coupling of field and alignment corrections
- Tilt already seen in survey measurements
- Confirmed with cosmic run (low statistics)
- Data were used to improve the previous measurements and to monitor time dependence



Bowing of TPC endpaltes

$$\Delta z_{obs} = \Delta z_{Alignment} - (\Delta r_{Field} + \Delta r_{Alignment}) \tan\lambda$$

- Discovered after installation of VDET 1
- Endplate bows outward (TPC has slight overpressure)
- Main effect ~ 1mm bowing
- Small variation with time
- Coupling of alignment and field corrections (phi dependence from sectors)



Alignment

$$\Delta z(r,\varphi)=\sum_{S}\left(\vartheta_S r\sin(\varphi-\bar{\Phi}_S)+\delta_S(R_S-r\cos(\varphi-\bar{\Phi}_S))+(\delta z)_S\right);$$

Endplate is equipotential surface

$$\Phi(r,\varphi,z_M+\Delta z(r,\varphi))=0\ ;\quad\Rightarrow\quad\tilde{\Phi}(r,\varphi,z_M)\simeq-\frac{\Delta z(r,\varphi)}{z_M}\ ;$$

Distortionpotential

$$\tilde{\Phi}(r,\varphi,z)=-\sum_{\nu m}\frac{1}{2N_{\nu m}^2}(A_{\nu m}\sin\nu\varphi+B_{\nu m}\cos\nu\varphi)\Psi_{\nu m}(\lambda_{\nu m}r)\frac{\sinh(\lambda_{\nu m}z)}{\sinh(\lambda_{\nu m}z_M)}\ ;$$

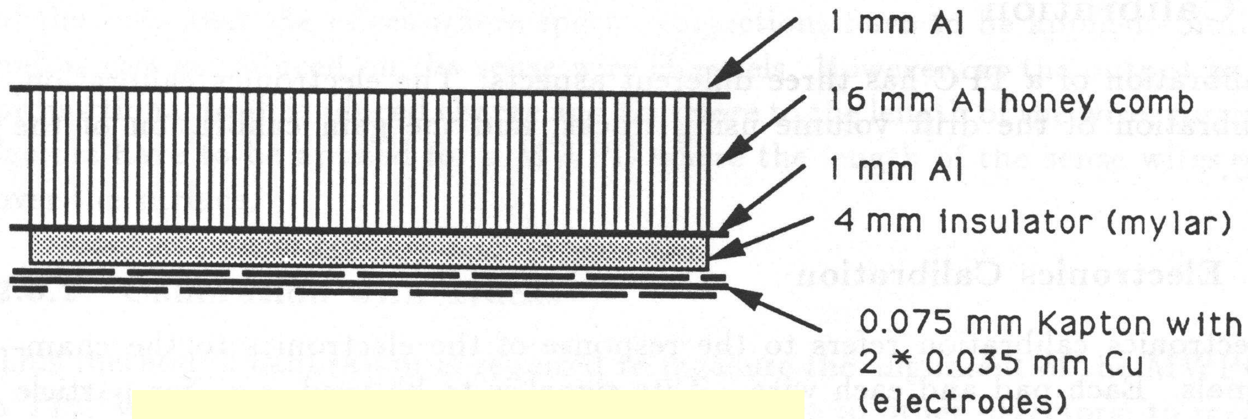
$$\begin{pmatrix}A_{\nu m}\\ B_{\nu m}\end{pmatrix}=\int_{r_i}^{r_o}\int_{0}^{2\pi}\Delta z(r,\varphi)\Psi_{\nu m}(\lambda_{\nu m}r)\begin{pmatrix}\sin\nu\varphi\\ \cos\nu\varphi\end{pmatrix}r\,dr\,d\varphi\ ;$$

Nonlinear Potential on Field Cage

Possible sources

- Manufacturing errors on electrodes
- Nonlinear resistor chain
- Finite resistivity of FC insulator

ALEPH Field Cage



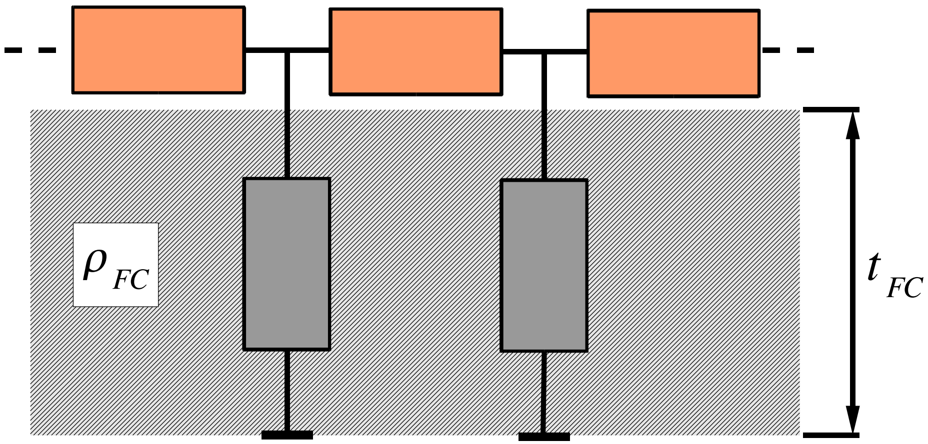
Insulator

- Helically wound Mylar 75 μm thick
- 100 mm pitch inner FC, 200 mm pitch outer FC
- Foils glued with Hexel 6103 (20 μm thick)

Resistivity

- Mylar $10^{18}\ [\Omega \cdot cm]$
- Hexel $10^{13}\ [\Omega \cdot cm]$

Finite Field Cage Resistivity



Potential on Field Cage Surface

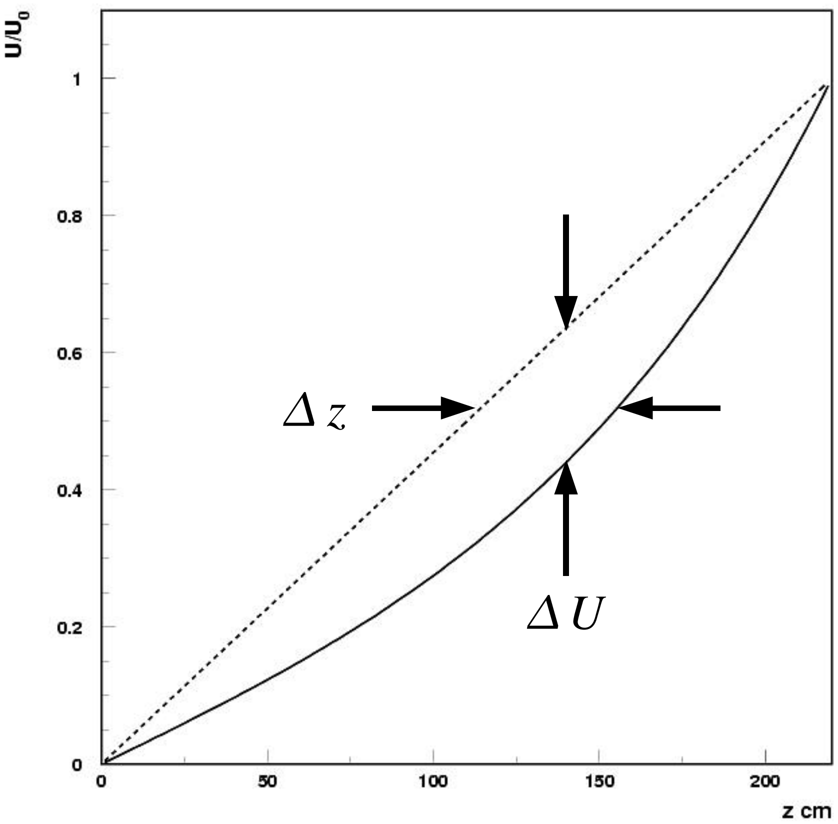
$$\Phi(r_{FC},\varphi,z)=U_0\frac{\sinh\left(\sqrt{\frac{R_{tot}}{R_B}}\left(1-\frac{|z|}{z_M}\right)\right)}{\sinh\left(\sqrt{\frac{R_{tot}}{R_B}}\right)}\;;\qquad R_B=\frac{\rho_{FC}\,t_{FC}}{2\pi\, r_{FC}\, z_M}\;;$$

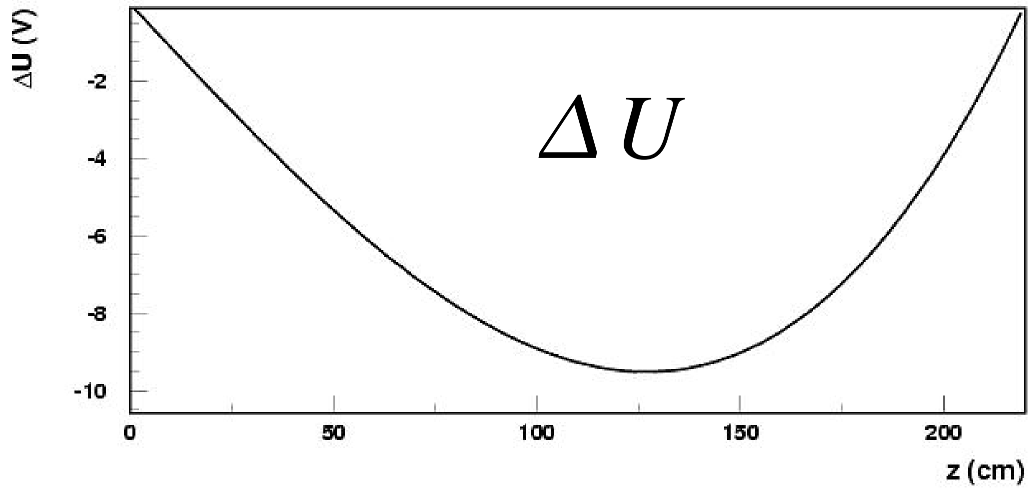
Distortionpotential

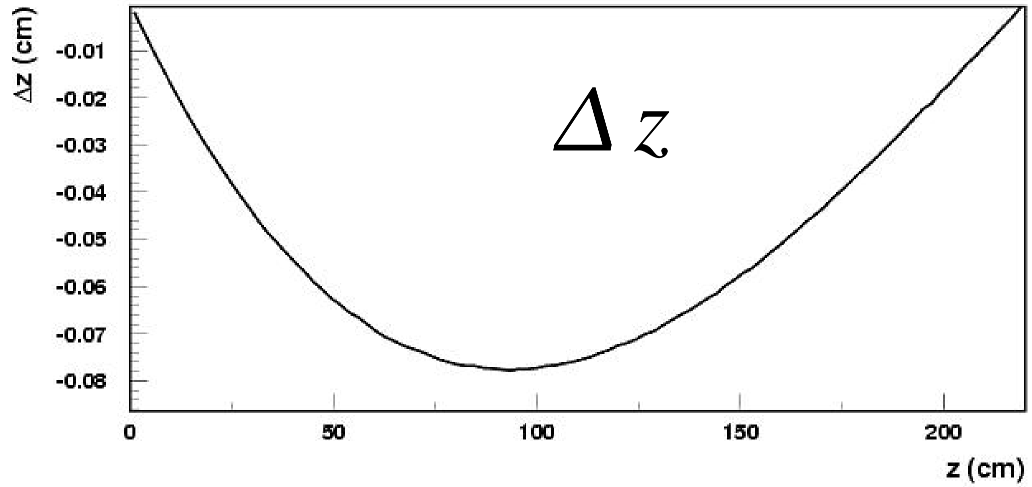
$$\tilde{\Phi}(r_{FC},\varphi,z)=\left(1-\frac{|z|}{z_M}\right)-\frac{\sinh\left(\sqrt{\frac{R_{tot}}{R_B}}\left(1-\frac{|z|}{z_M}\right)\right)}{\sinh\left(\sqrt{\frac{R_{tot}}{R_B}}\right)}\;;$$

$$\tilde{\Phi}(r,\varphi,z)\simeq-\boldsymbol{sign}(z)\frac{R_{Tot}}{R_B}\sum_n\frac{1}{(n\pi)^3}\sin\left(\frac{n\pi}{z_M}z\right)P_{0,(FCout,,FCin)}\left(\frac{n\pi}{z_M}r\right)\;;$$

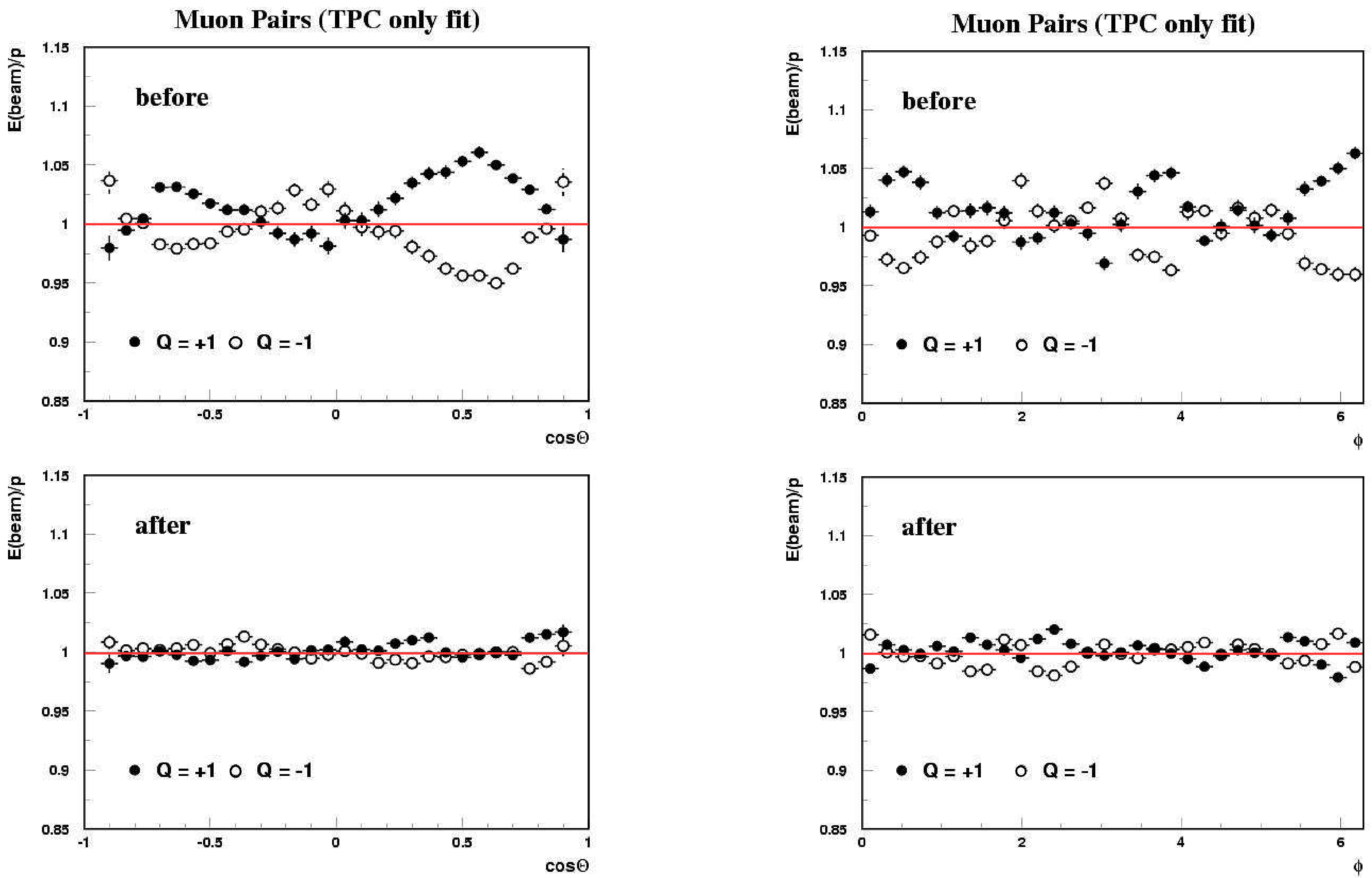
- Results from fit can be interpreted as potential deviation or axial shift of electrodes
- Fit prefers $\rho \simeq 10^{16}\,[\Omega\ cm]$





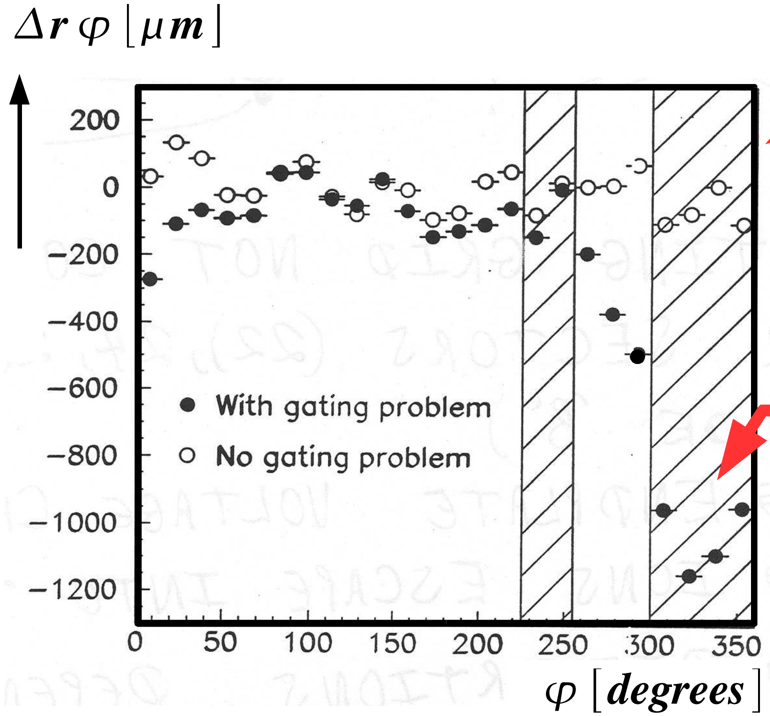


Correction for nonlinear potential + endplate bowing

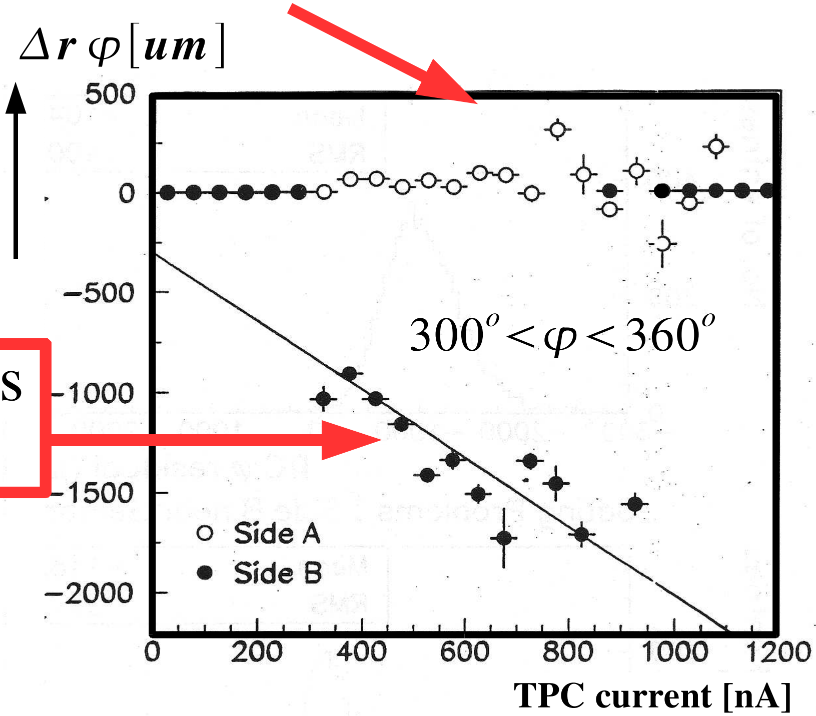


Disconnected Gating Grids

- In 1994 the gating grids of 2 sectors got disconnected
  - ~10% of collected statistics affected
  - Endplate potential changes
  - Ions escape into TPC volume (spacecharge)
  - Distortions depend on <u>azimuthal angle</u> and on <u>current</u>



Rφ –Residuals in ITC



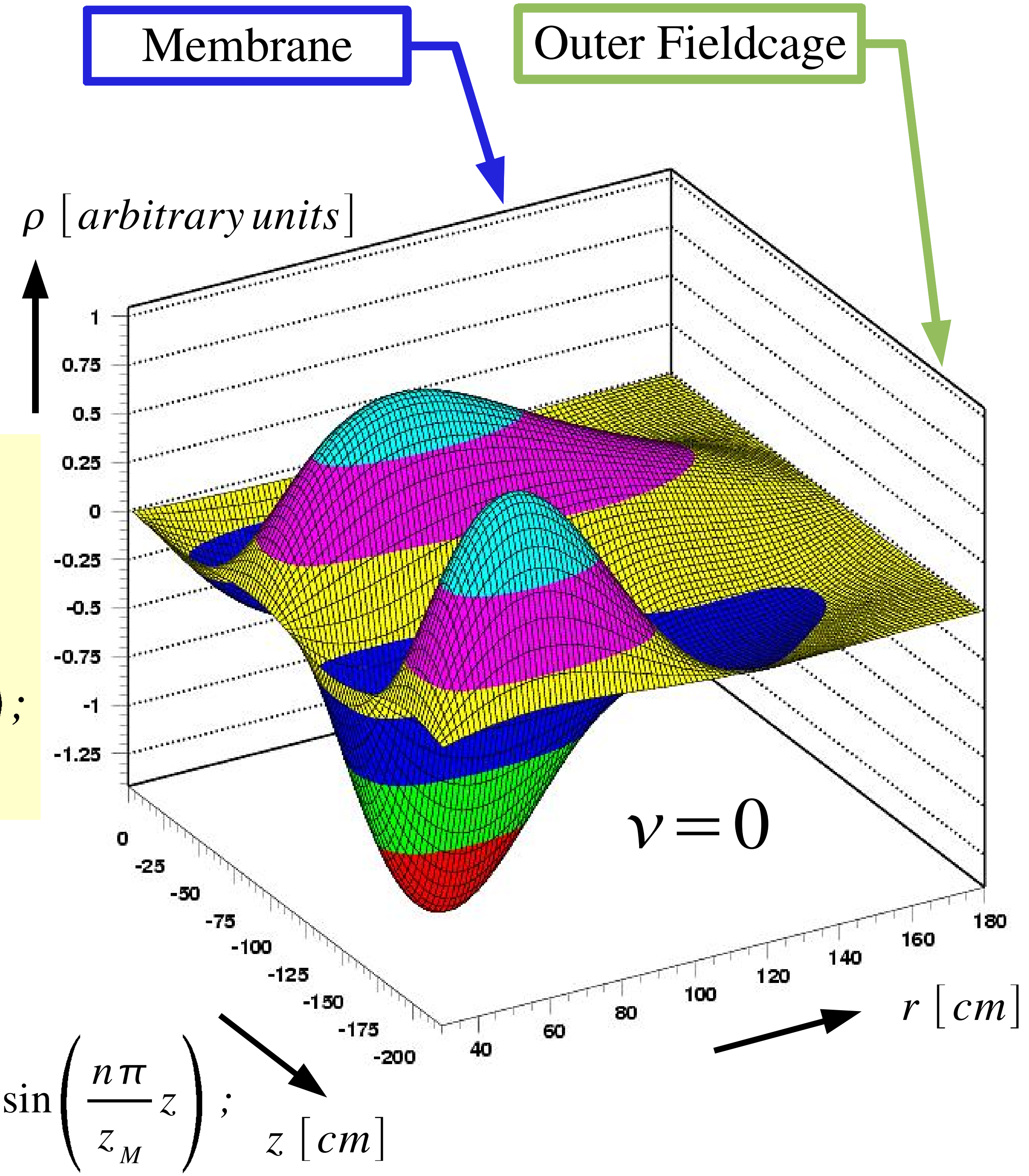
<u>Correction</u> : Fit directly Fourier expansion of Poisson equation :

$$\Delta\tilde{\Phi} = -\frac{4\pi}{U_0}\rho\,;$$

Ansatz

$$\tilde{\Phi}(r,\varphi,z) = \sum_{\Lambda} a_{\Lambda} U_{\Lambda}(r,\varphi,z)\,;$$

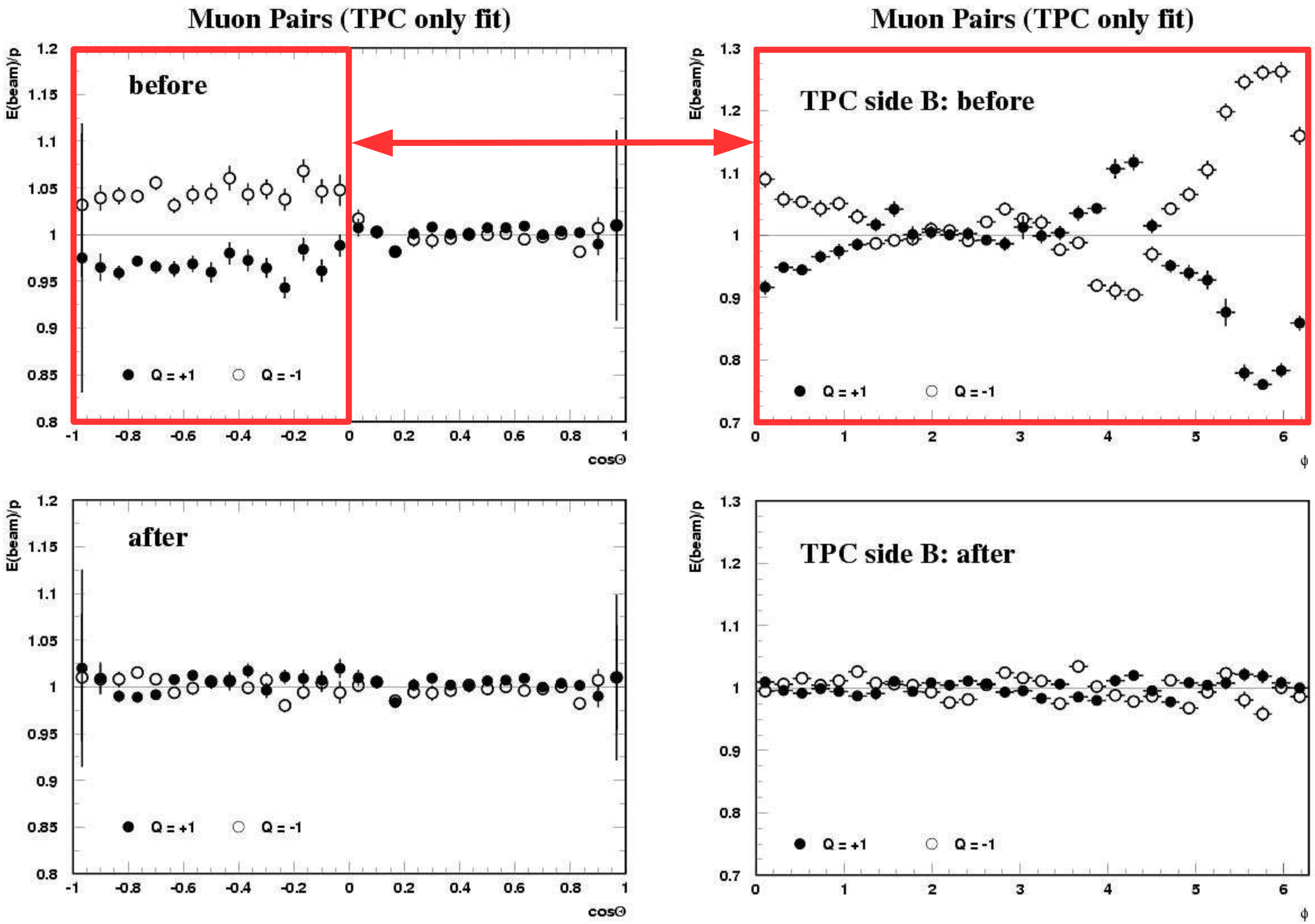
$$\rho(r,\varphi,z) = \frac{U_0}{4\pi}\sum_{\Lambda} a_{\Lambda}\Lambda^2 U_{\Lambda}(r,\varphi,z)\,;$$



$$\Lambda^2_{\nu mn} = \lambda^2_{\nu m} + \left(\frac{n\pi}{z_M}\right)^2;$$

$$U_{\Lambda_{\nu mn}}(r,\varphi,z) = \frac{1}{N_{\nu mn}}\Psi_{\nu m}(\lambda_{\nu m} r)\begin{pmatrix}\sin(\nu\varphi)\\ \cos(\nu\varphi)\end{pmatrix}\sin\left(\frac{n\pi}{z_M}z\right);$$

Data 1994



Parameters used:

$\varphi: \ 0 \leq v \leq 6$

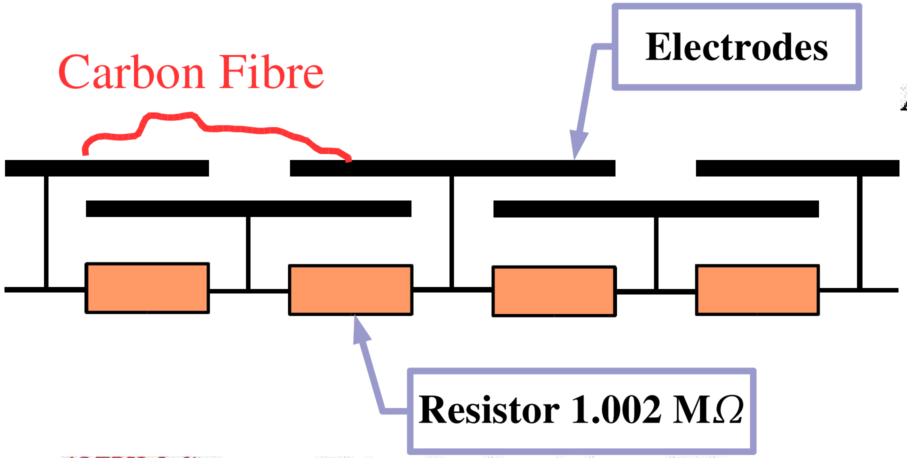
$r: \ 1 \leq m \leq 5$

$z: \ 1 \leq n \leq 8$

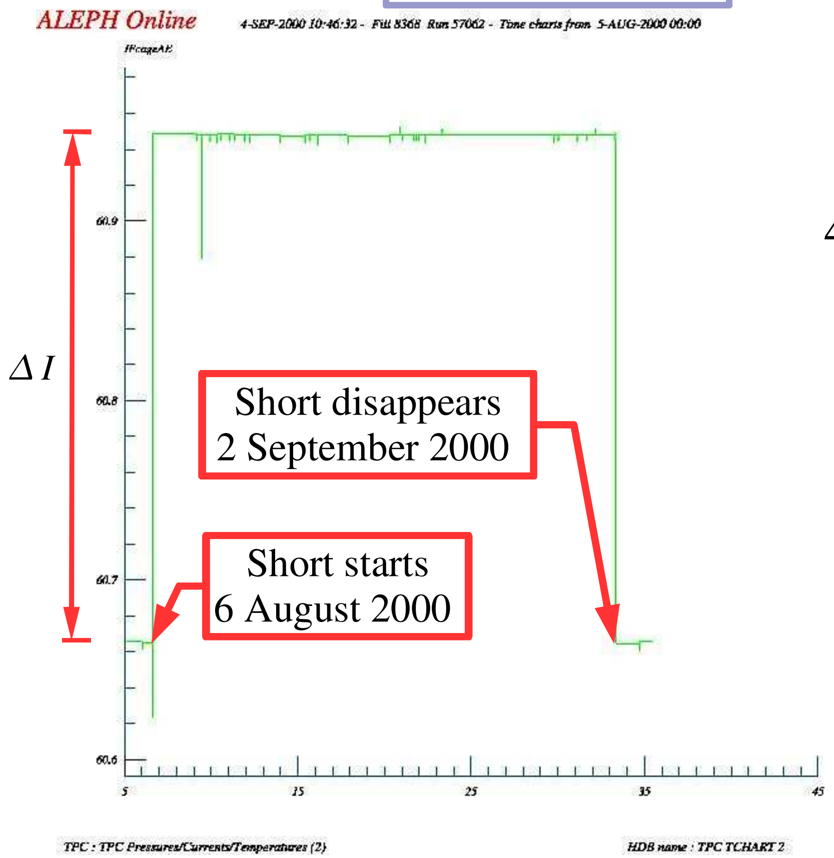
Short on Field Cage

- History
  - First one end of 1991 (~13% of collected data affected)
    - Sharp edge on electrode damaged FC insulator
    - During repair carbon fibres were introduced in the TPC volume
  - 1992: series of 5 shorts (~41% of collected data affected)
  - 1993: 1 short (~10% of collected data affected)
  - July 1999: short after beam loss (~58% of collected data affected)
    - Appears just before LEP ramps CM energy to 200 GeV
  - August–September 2000: short appears after beam loss and disappears after a second one (~15% of collected data affected)
    - Higgshunt

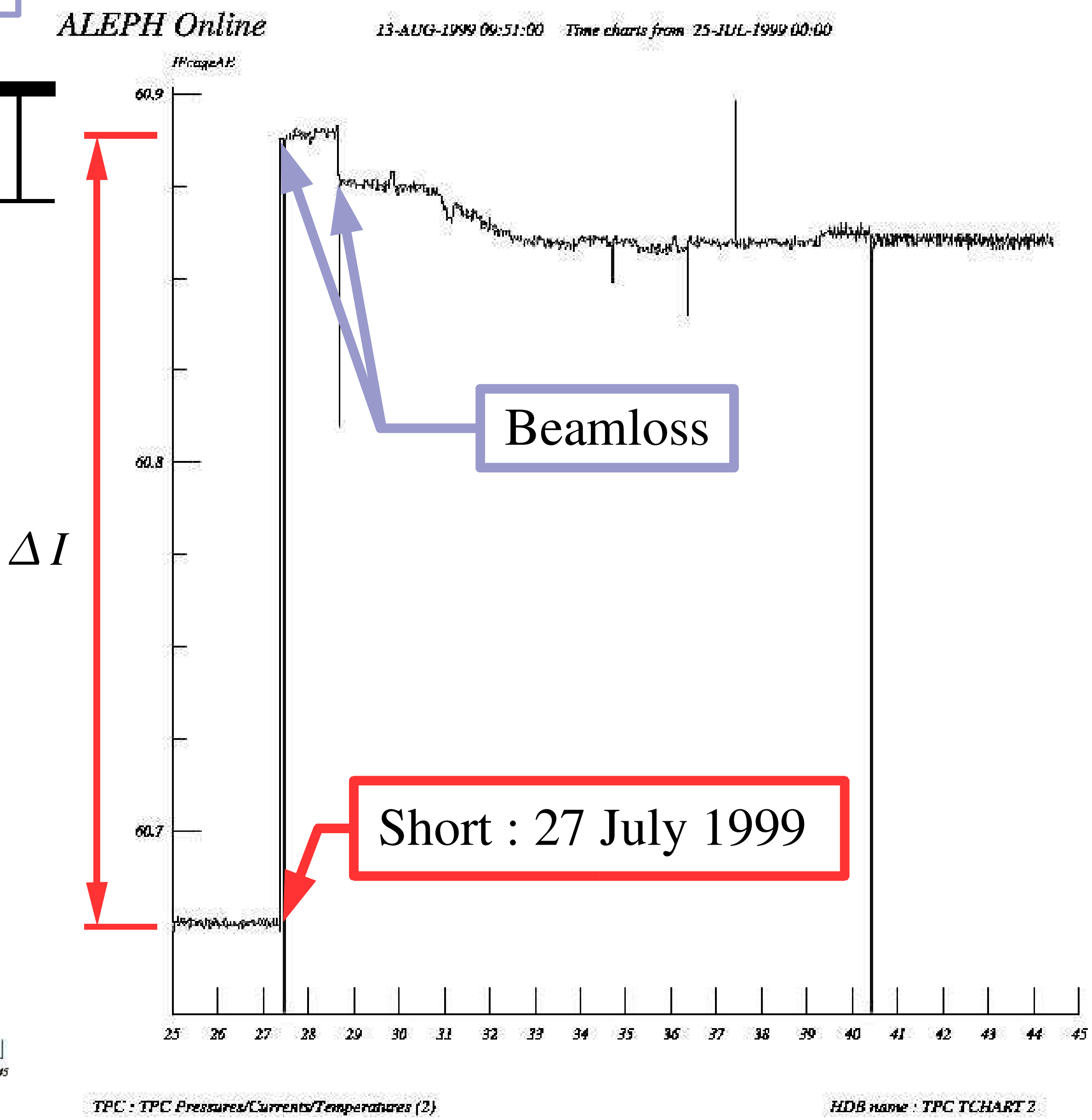
- Characteristics
  - Appear typically after beam loss
  - Rφ- residuals in TPC ~ 1 [mm] ⇒ severe impact on tracking
  - Except for the 1991 short all shorts are due to introduced carbon fibres
    - Short may disappear again (1992, 2000)
    - Position of fibre may change after a new beam loss (e.g. 1992)
    - Fibre may be not found or at a different place during a TPC opening = short position not necessarily known from intervention
      ⇒ corrections from data are essential
  - At LEP2 shorts were always accompanied by time dependent "charge up effects" on inner FC
    ⇒ need for parameterised model to disentangle both effects in data



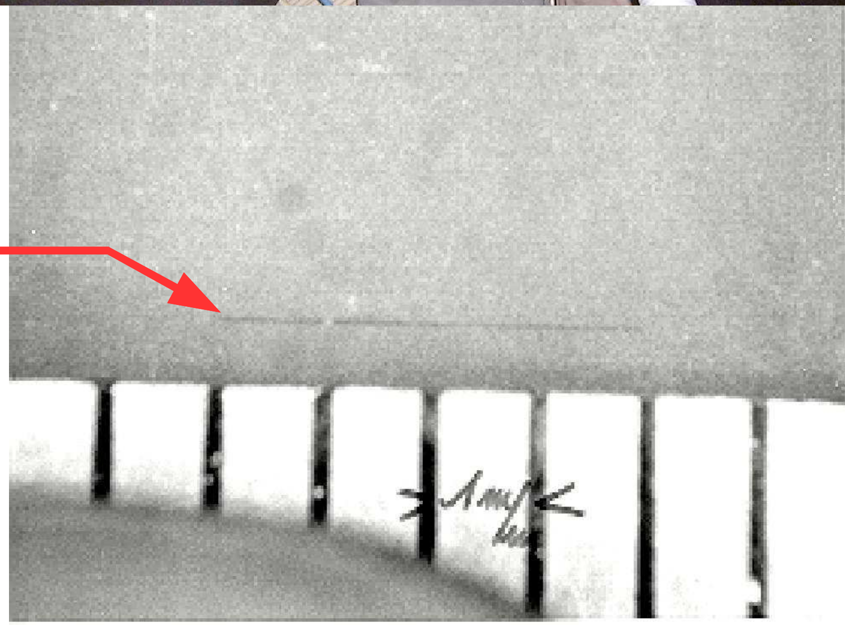
Carbon Fibre
Electrodes
Resistor 1.002 MΩ



ALEPH Online
4-SEP-2000 10:46:32 - Fill 8368 Run 57062 - Time charts from 5-AUG-2000 00:00
ΔI
Short disappears
2 September 2000
Short starts
6 August 2000
60.9
60.8
60.7
60.6
5
15
25
35
45
TPC : TPC Pressures/Currents/Temperatures (2)
HDB name : TPC TCHART 2

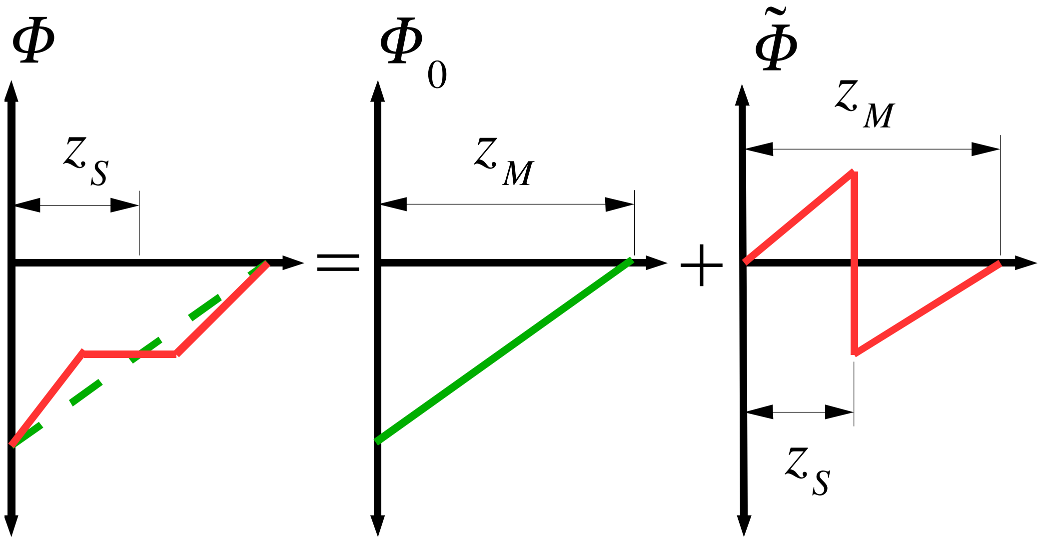


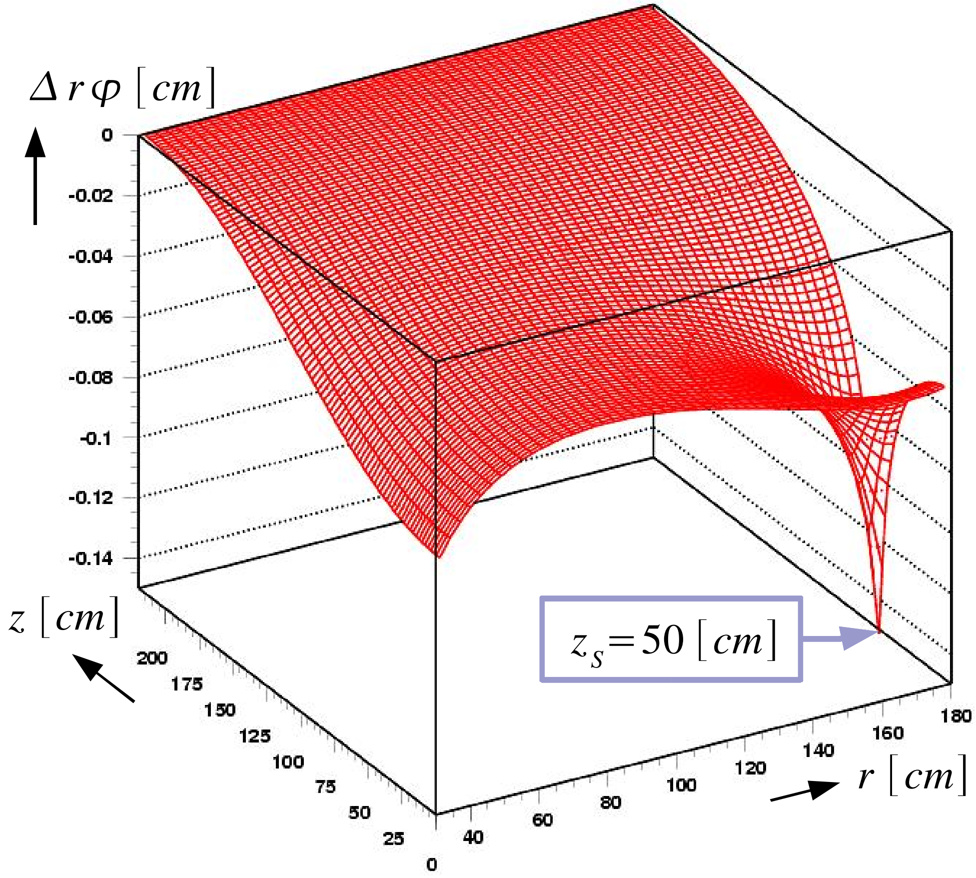
ALEPH Online
13-AUG-1999 09:51:00 Time charts from 25-JUL-1999 00:00
ΔI
Beamloss
Short : 27 July 1999
60.9
60.8
60.7
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
TPC : TPC Pressures/Currents/Temperatures (2)
HDB name : TPC TCHART 2



Fibre found at z=36 cm

Intervention during 1999 shutdown



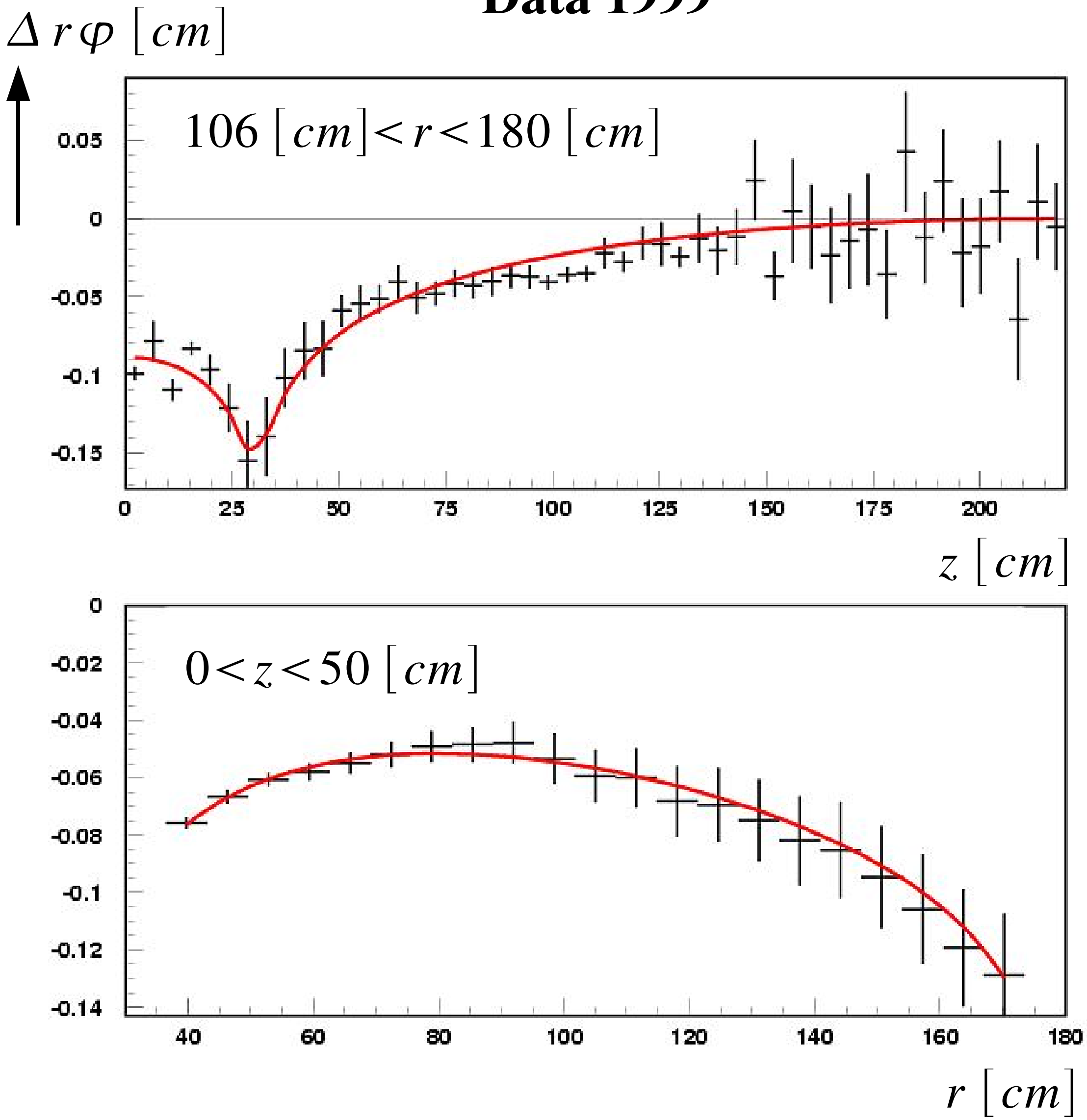


- Two parameter model
  - Shortposition
  - Voltage/current change

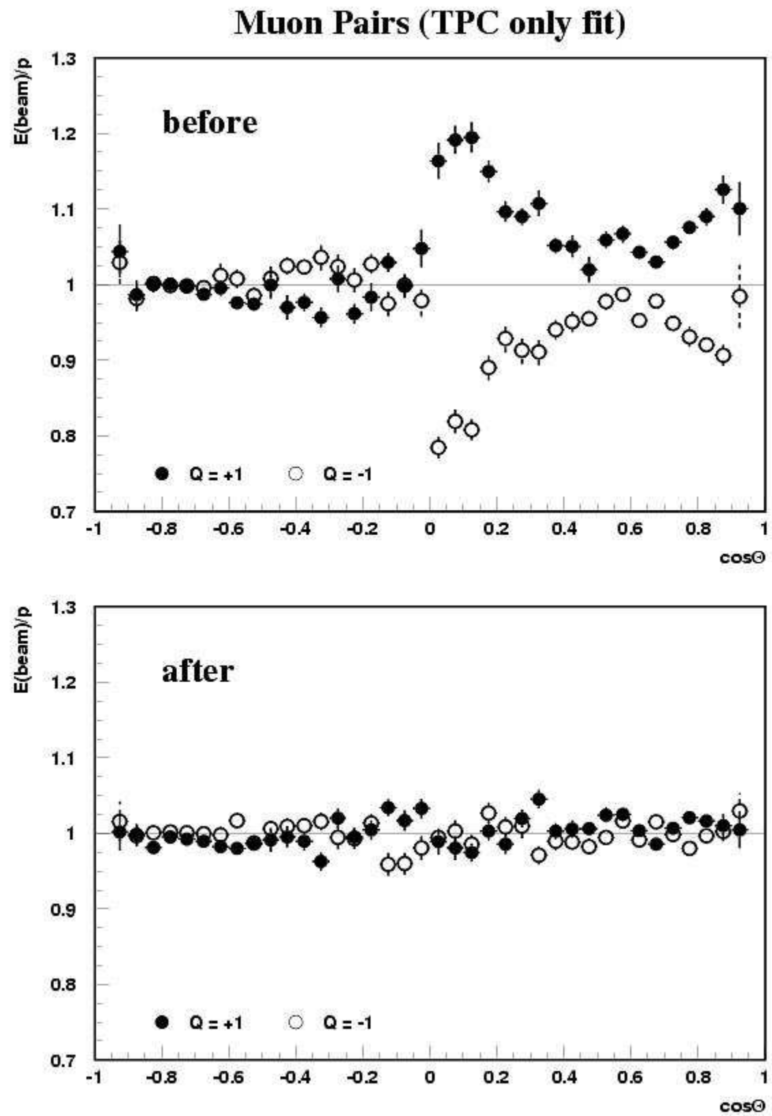
Distortionpotential

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

Data 1999

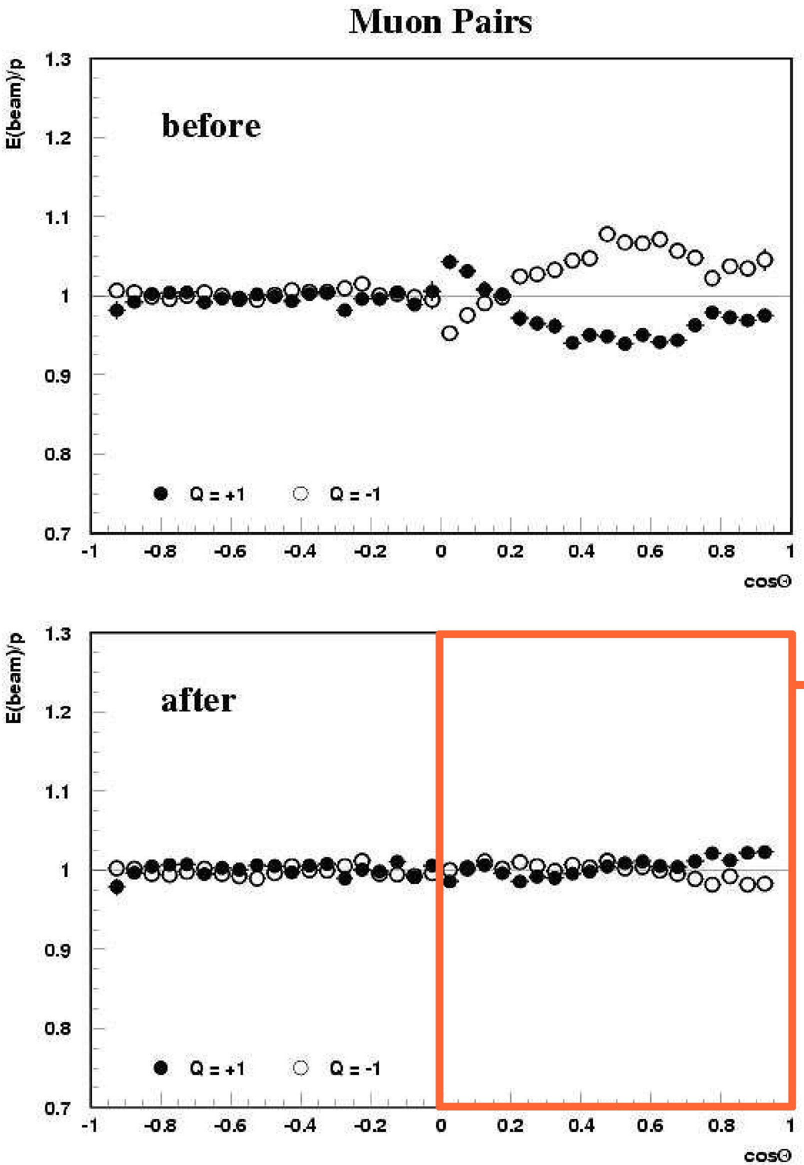


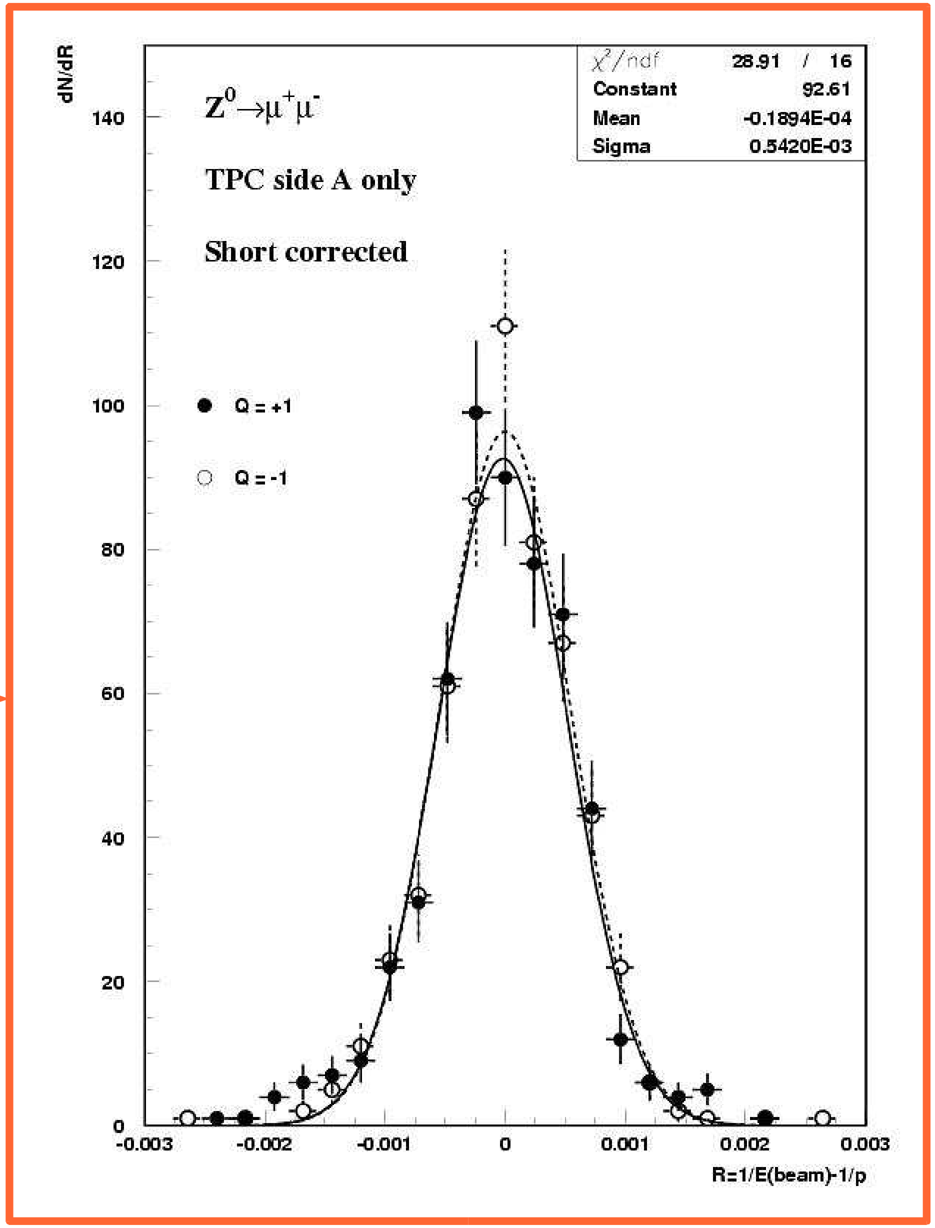
$\Delta r\varphi\ [cm]$
$106\ [cm] < r < 180\ [cm]$
$z\ [cm]$
$0 < z < 50\ [cm]$
$r\ [cm]$



Muon Pairs (TPC only fit)
E(beam)/p
before
after
Q = +1
Q = -1
cosΘ

Short 1999 : Fit with all tracking detectors

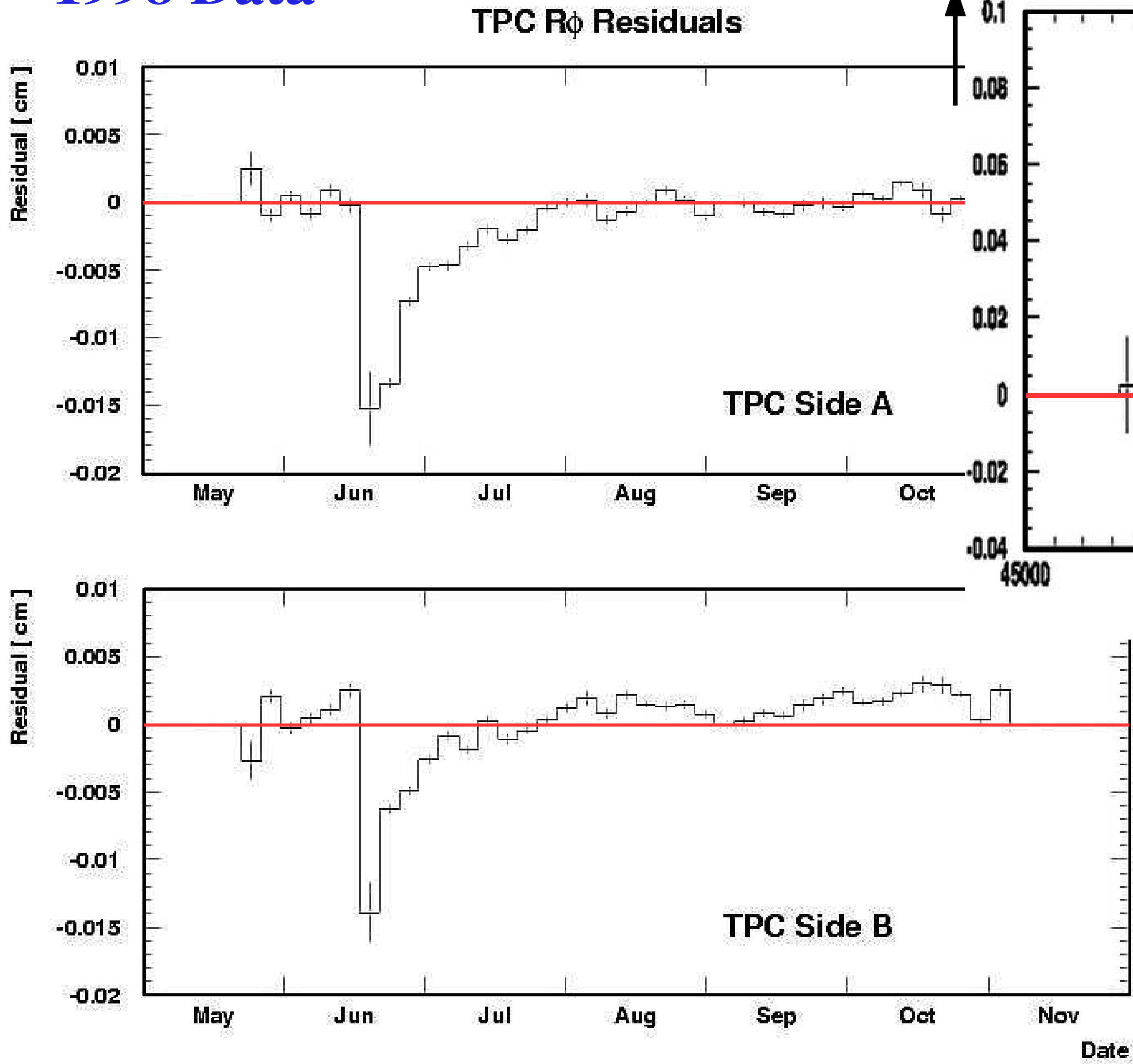




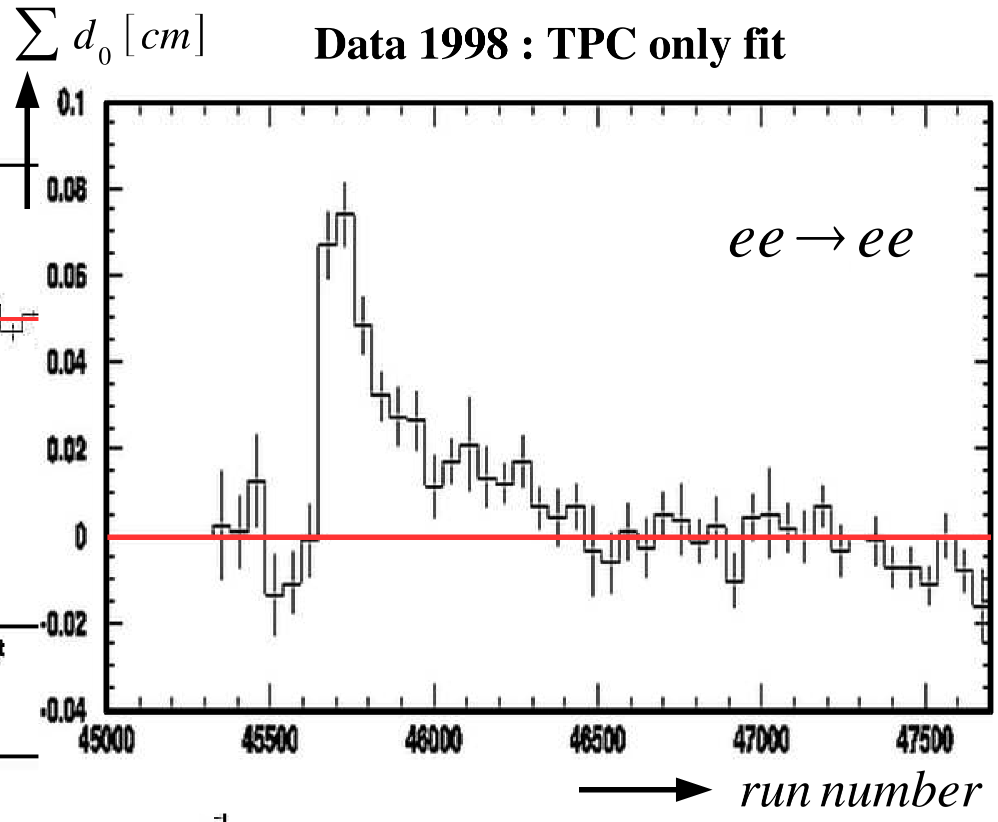
"Charge up" effects on Field Cage

- History
  - First observed 1992 after a beamloss which caused also a short
  - At LEP2 observed every year (beam losses were more frequent)
- Characteristics
  - Effect on inner FC, near interaction point , $\Delta r\varphi$ ~ 200 [μm] at inner padrows
  - Residuals depend on time, decaytime ~ month
  - No convincing azimuthal dependence observed
  - Impact on physics: mainly bias on impact parameter
  - Source: unknown
- Corrections can not be done with μ–pairs at LEP2 $\rightarrow$ not enough statistics to follow time evolution

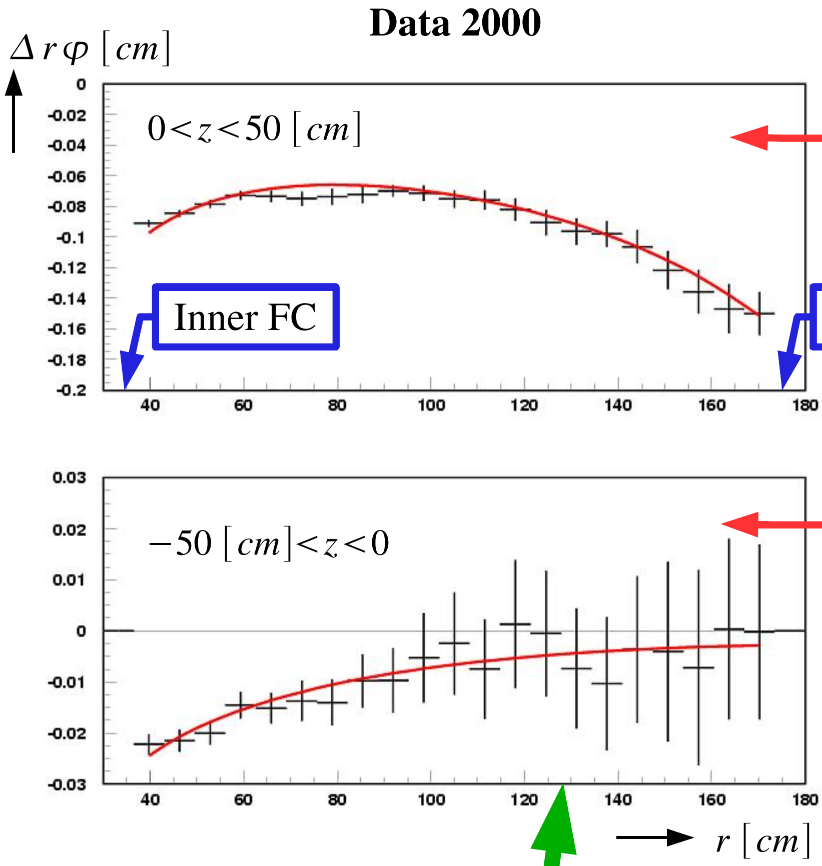
1998 Data

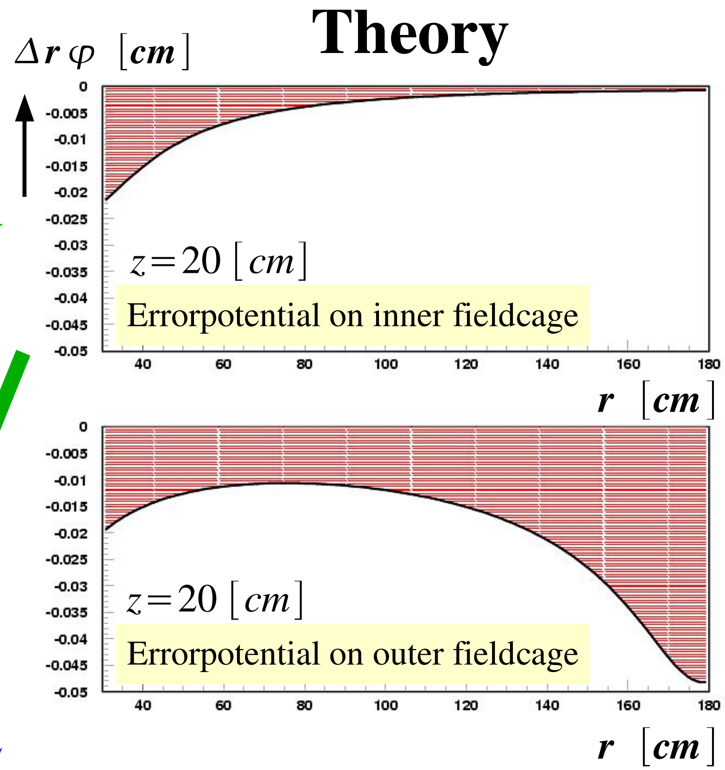


TPC Rϕ Residuals
Residual [cm]
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
May
Jun
Jul
Aug
Sep
Oct
TPC Side A
Residual [cm]
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
May
Jun
Jul
Aug
Sep
Oct
Nov
Date
TPC Side B



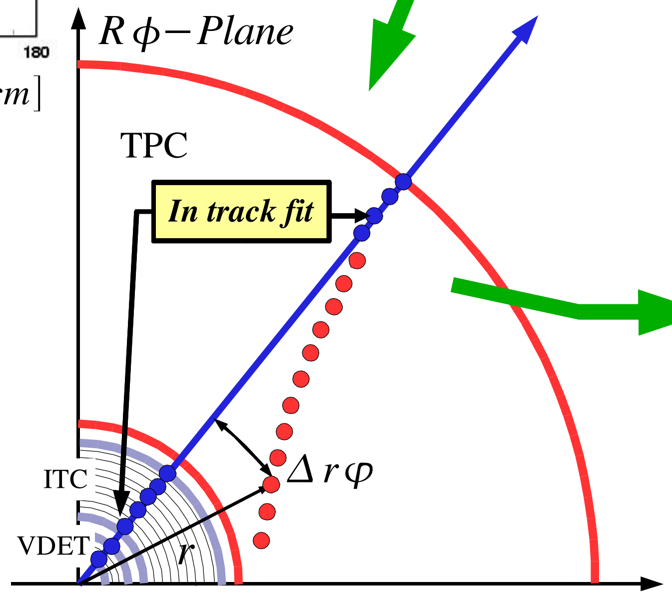
$\sum d_0\,[cm]$
Data 1998 : TPC only fit
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
45000
45500
46000
46500
47000
47500
$ee \rightarrow ee$
run number



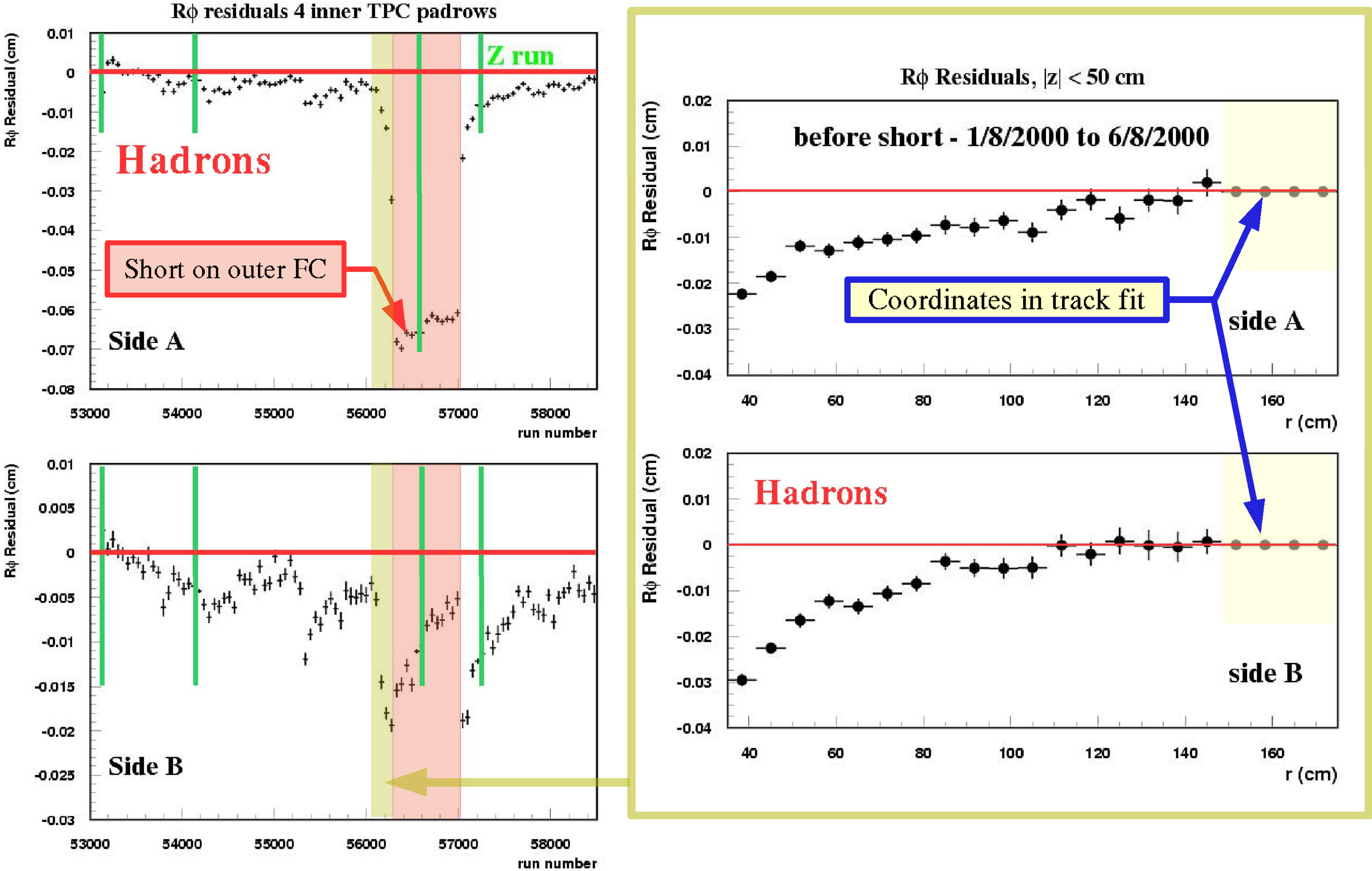


Single Helix Fit

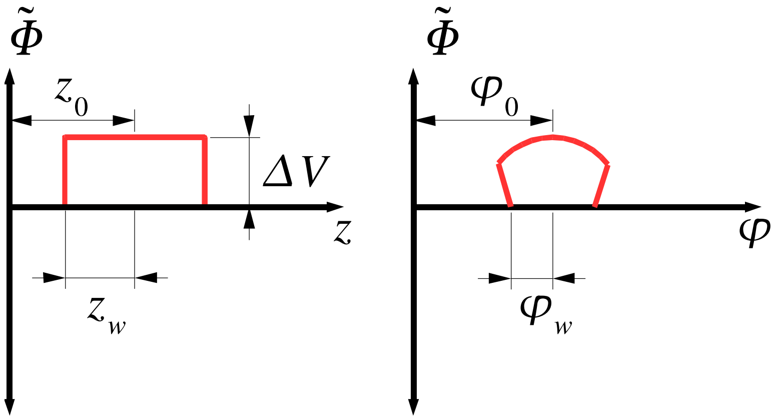
$Z^0 \rightarrow \mu\mu$

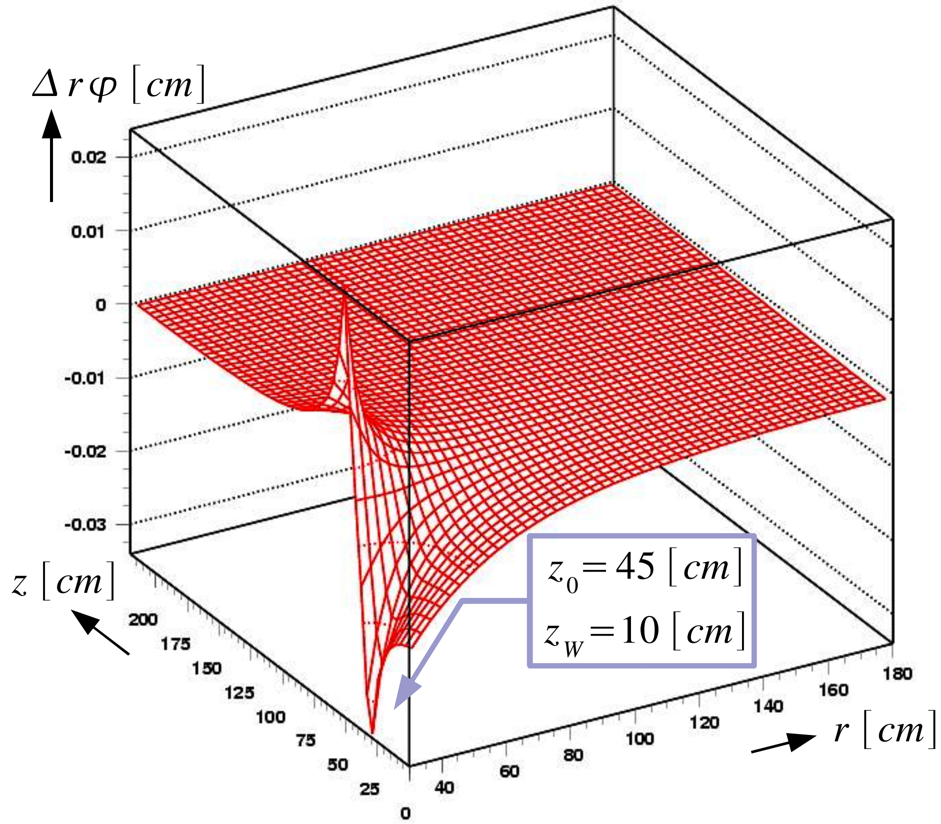


- Measure residuals with hadronic events using a special track fit
- Only coordinates in VDET, ITC and the 4 outermost padrows of the TPC are used in fit



Rφ residuals 4 inner TPC padrows
Z run
Hadrons
Short on outer FC
Side A
Side B
Rφ Residual (cm)
run number
Rφ Residuals, |z| < 50 cm
before short - 1/8/2000 to 6/8/2000
Coordinates in track fit
side A
Hadrons
side B
r (cm)



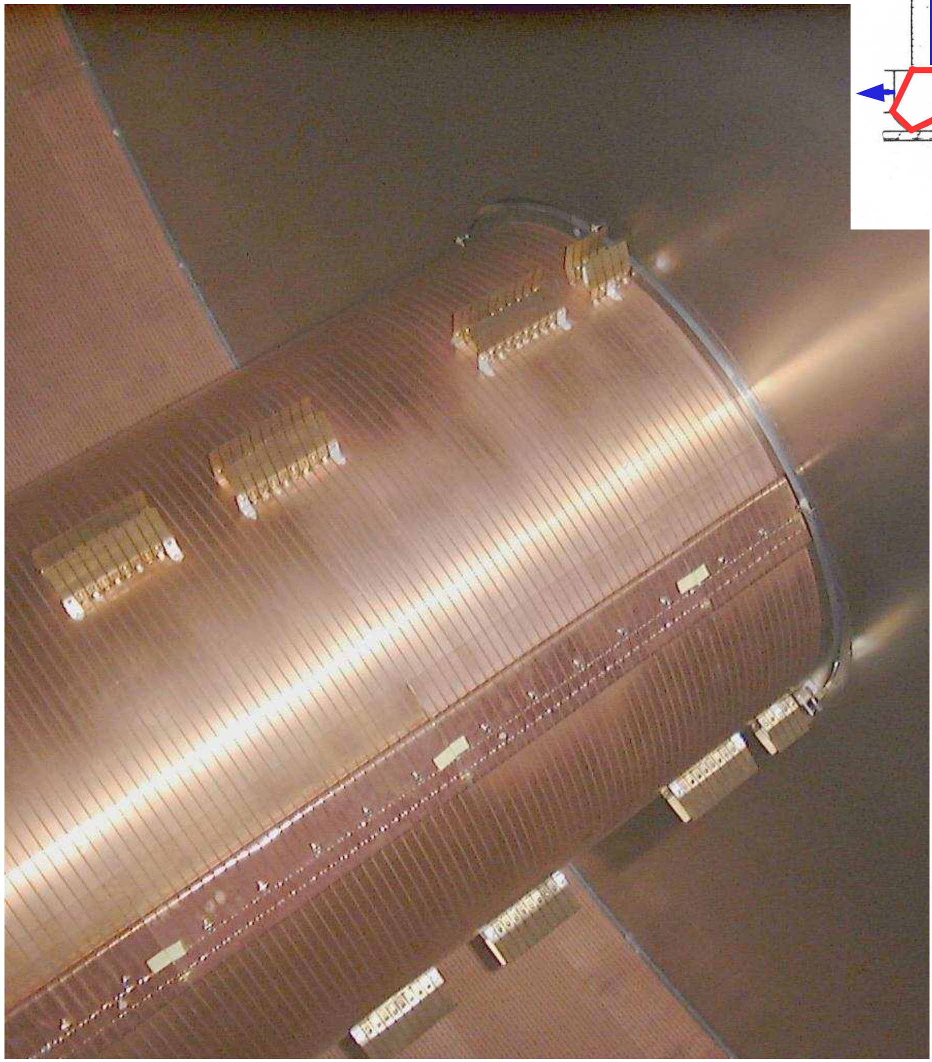


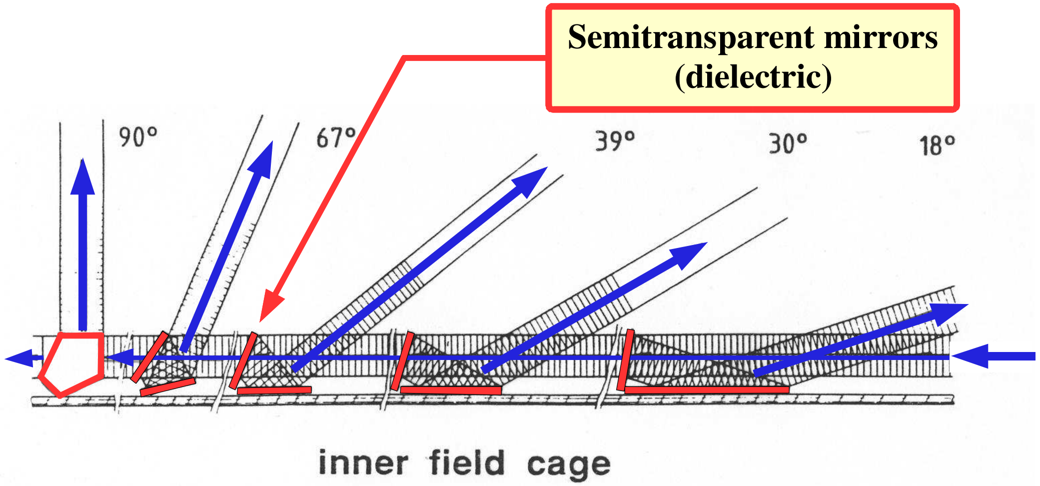
- Model parameters
  - Position $z_{0,}(\varphi_0)$
  - Width $z_{w,}(\varphi_w)$
  - ΔV
- Data are binned in time intervals and fitted with model

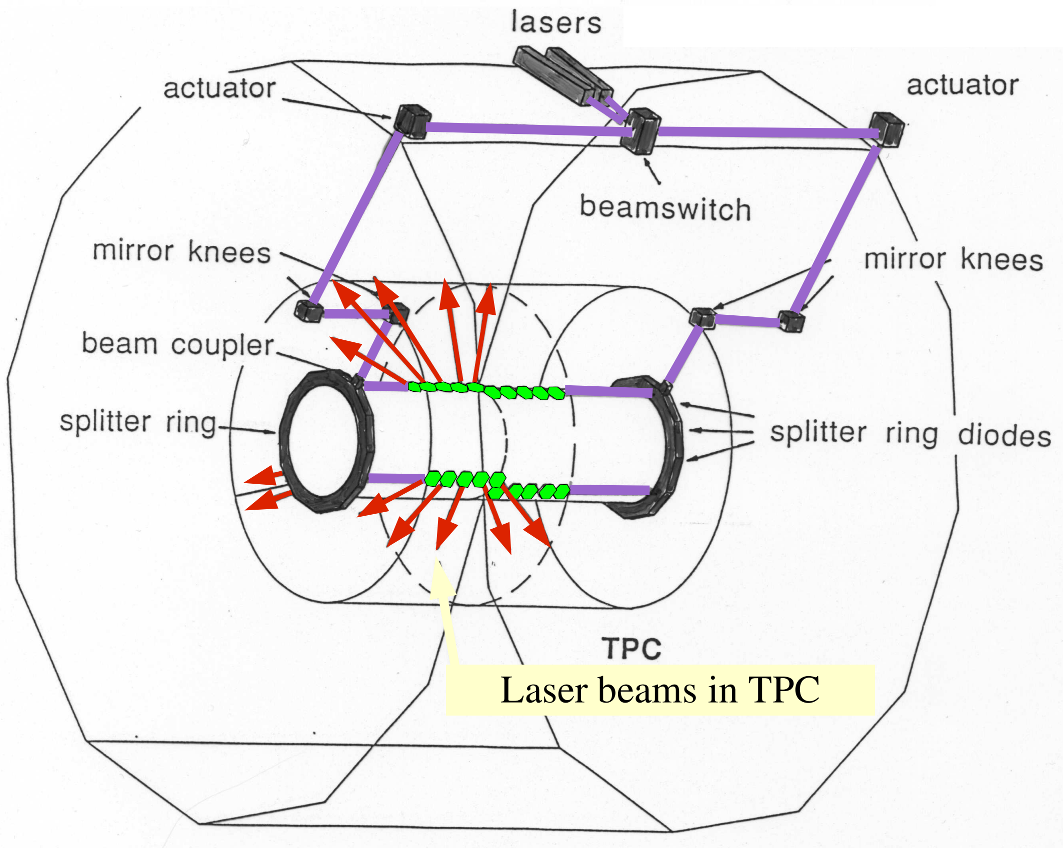
Distortionpotential (independent of φ)

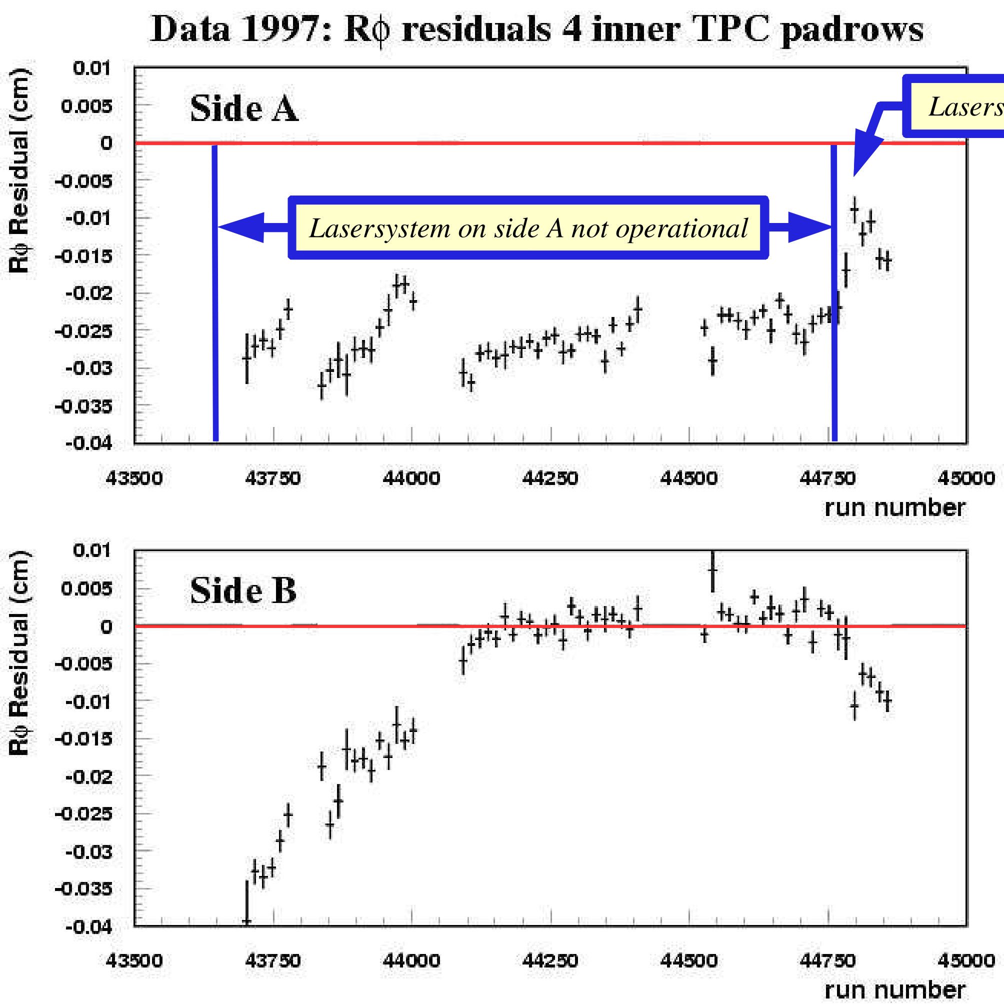
$$\tilde{\Phi}(r,\varphi,z) \simeq \sum_{i,n} \left(\frac{\Delta V_i}{U_0}\right) \frac{-2\sin\left(\frac{n\pi}{z_M} z_{0,i}\right)\sin\left(\frac{n\pi}{z_M} z_{w,i}\right)}{n\pi} \sin\left(\frac{n\pi}{z_M} z\right) P_{0n,\ FCin}\left(\frac{n\pi}{z_M} r\right) ;$$

TPC Lasersystem

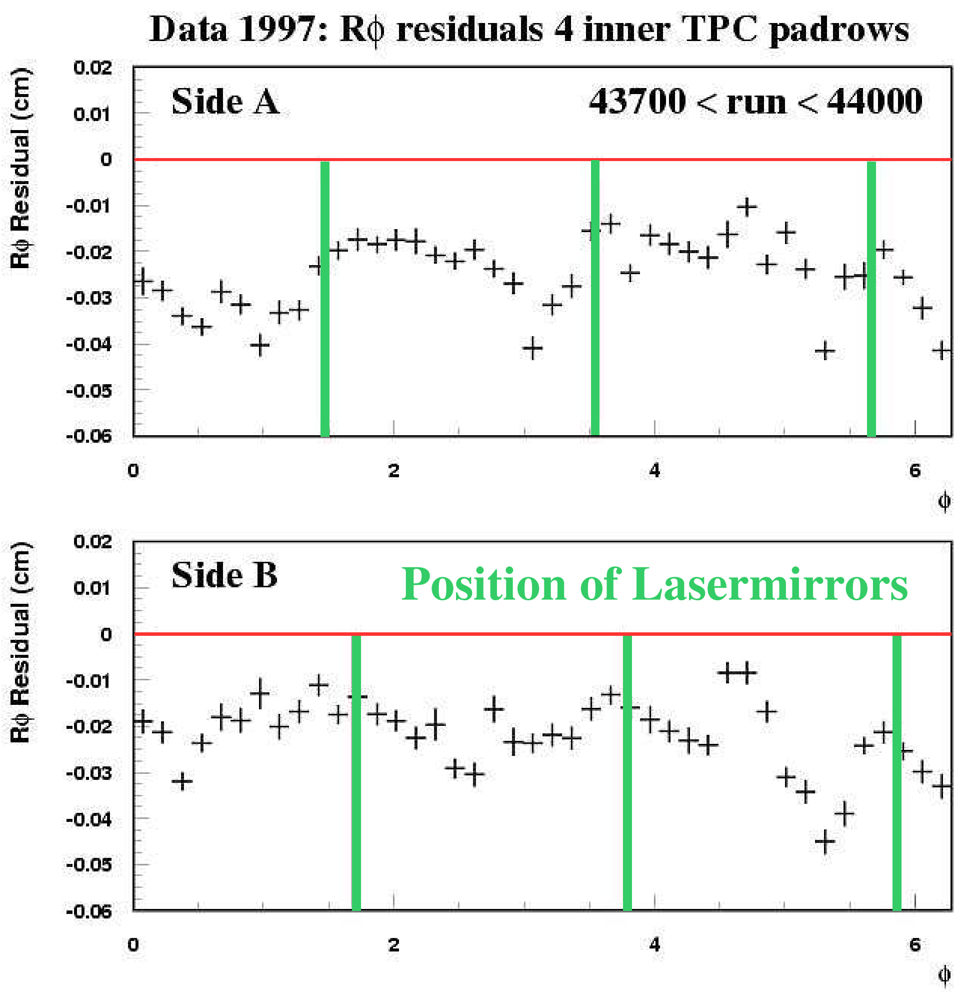




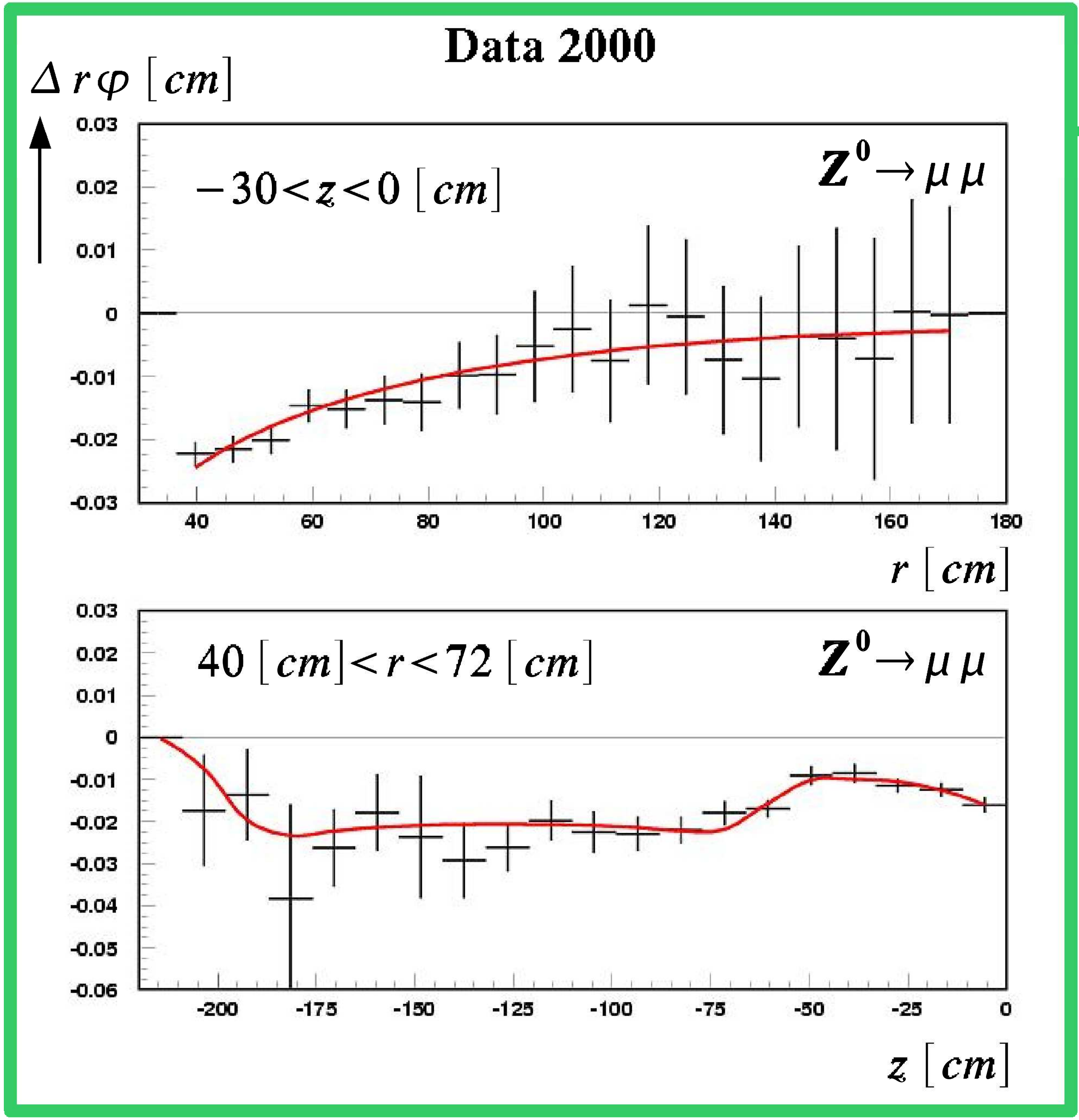


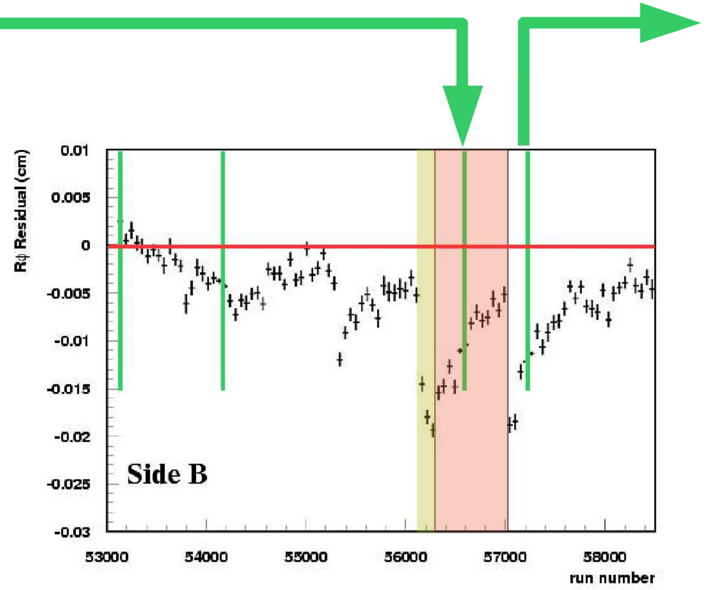


Data 1997: Rφ residuals 4 inner TPC padrows
Side A
Lasersystem on side A ok
Lasersystem on side A not operational
Side B
Rφ Residual (cm)
run number

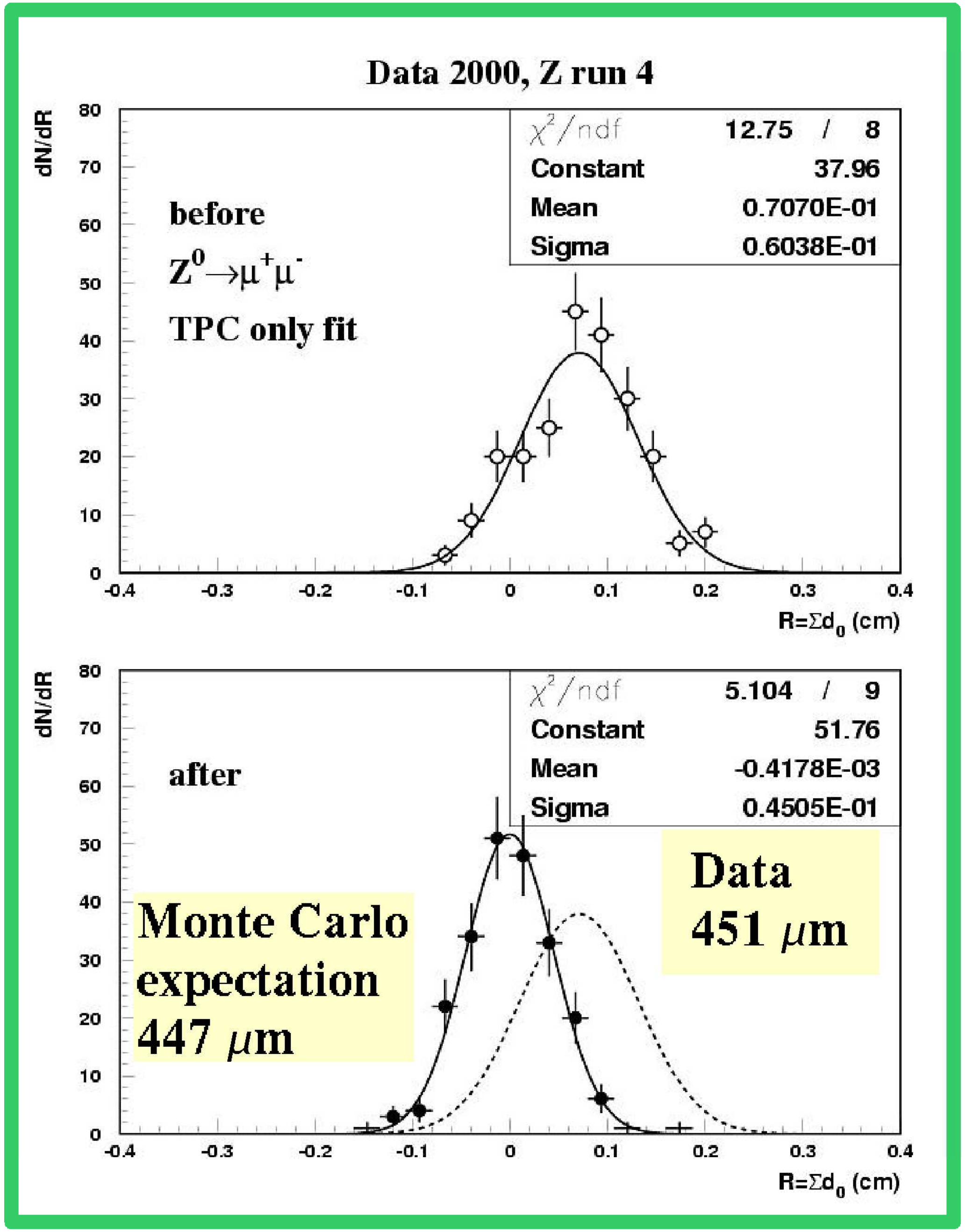


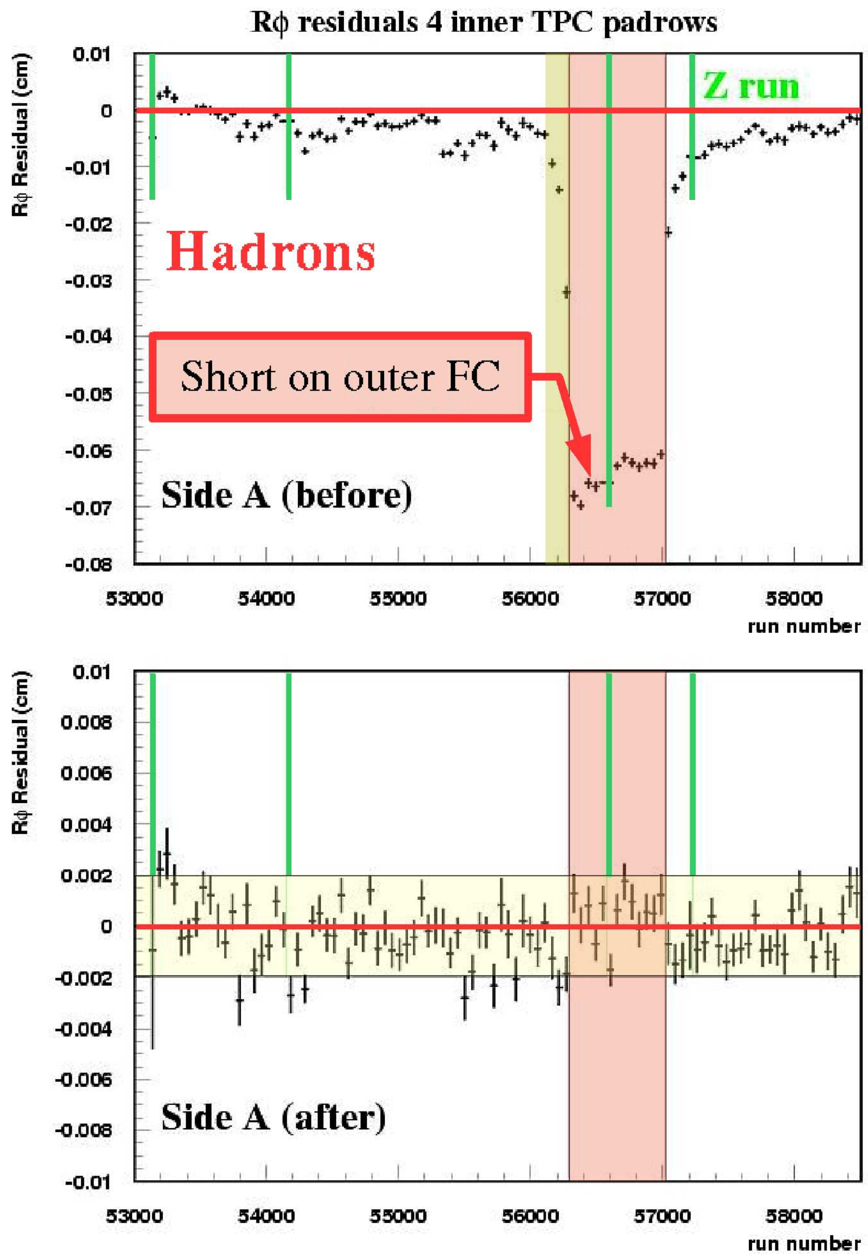
Data 1997: Rφ residuals 4 inner TPC padrows
Side A
43700 < run < 44000
Side B
Position of Lasermirrors
Rφ Residual (cm)
φ





- Corrections fitted with Hadrons in time slices
- Result tested with muon pairs


Data 2000, Z run 4
dN/dR
before
$Z^0 \rightarrow \mu^+\mu^-$
TPC only fit
χ^2/ndf 12.75 / 8
Constant 37.96
Mean 0.7070E-01
Sigma 0.6038E-01
R=Σd0 (cm)
after
χ^2/ndf 5.104 / 9
Constant 51.76
Mean -0.4178E-03
Sigma 0.4505E-01
Monte Carlo expectation 447 μm
Data 451 μm


Rφ residuals 4 inner TPC padrows
Rφ Residual (cm)
Z run
Hadrons
Short on outer FC
Side A (before)
run number
Side A (after)

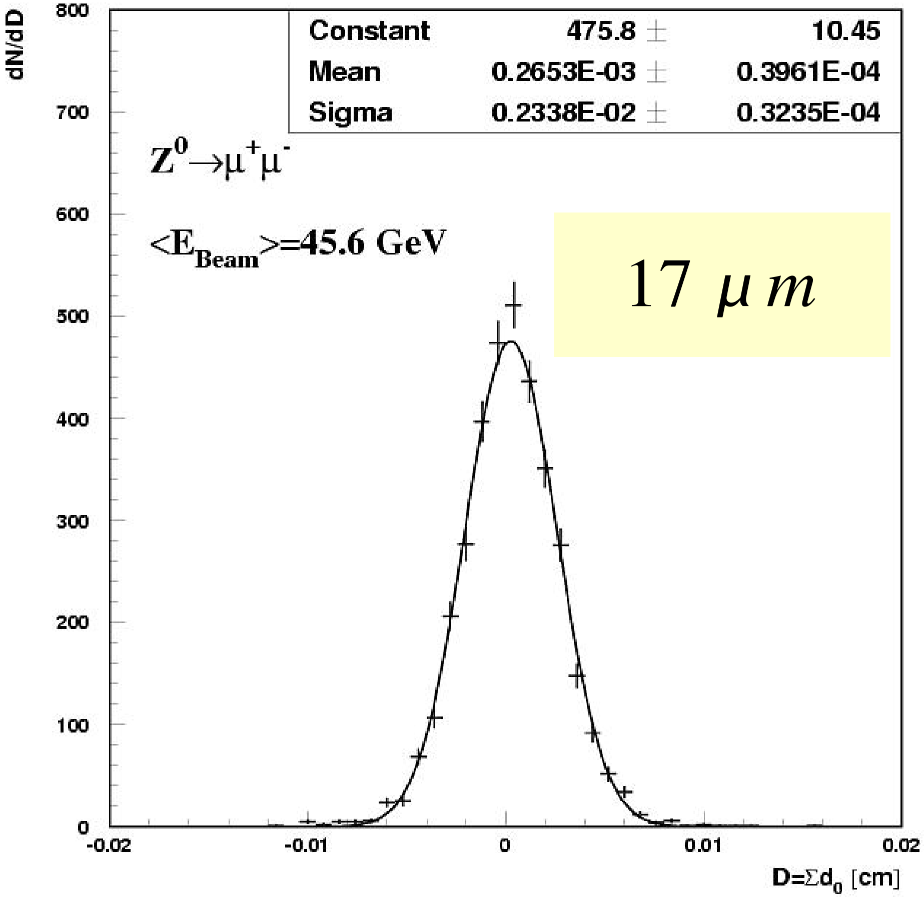
Tracking Spectrometer Resolutions

- All data are from 1997 to 2000
- Calibration data
  - Muon pairs taken at Z with no known detector problem
  - High statistics
  - Represent optimal resolutions
  - Calibration data for corrections of TPC problems are shown separately
- High energy muon pairs
  - Include also all periods with detector problems (e.g. shorts)
  - Low statistics
  - Test corrections obtained at Z or with Hadrons

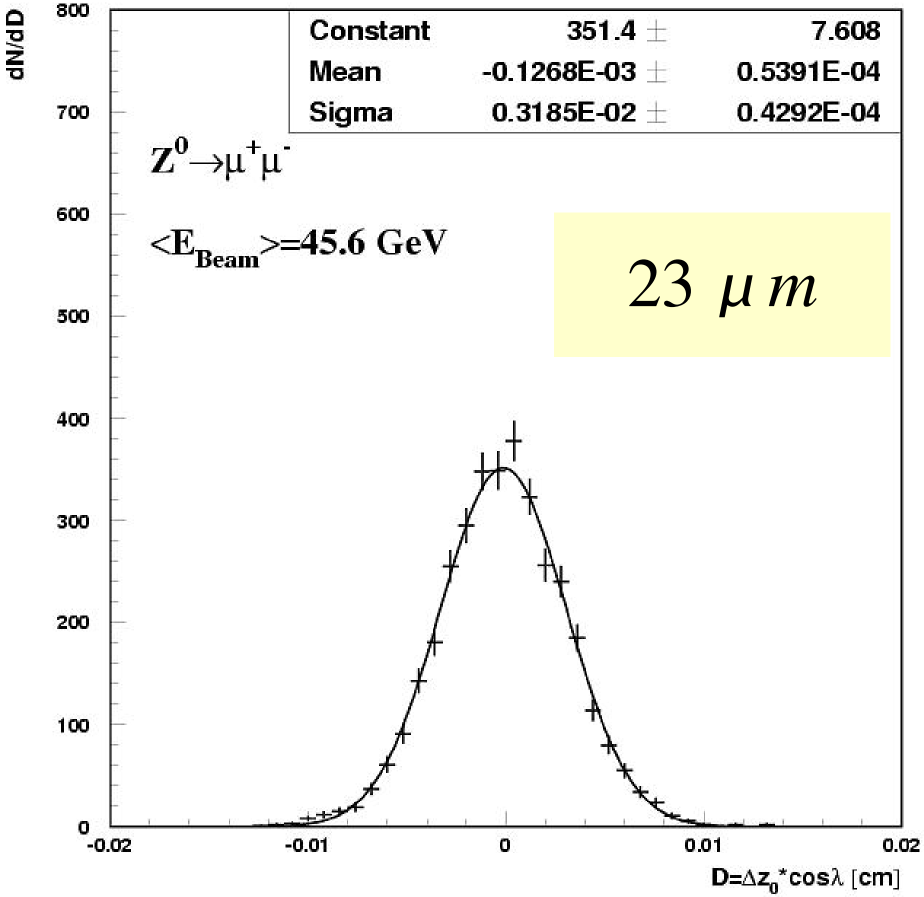
Impact Parameter Resolution

Calibration Data

$R\varphi$



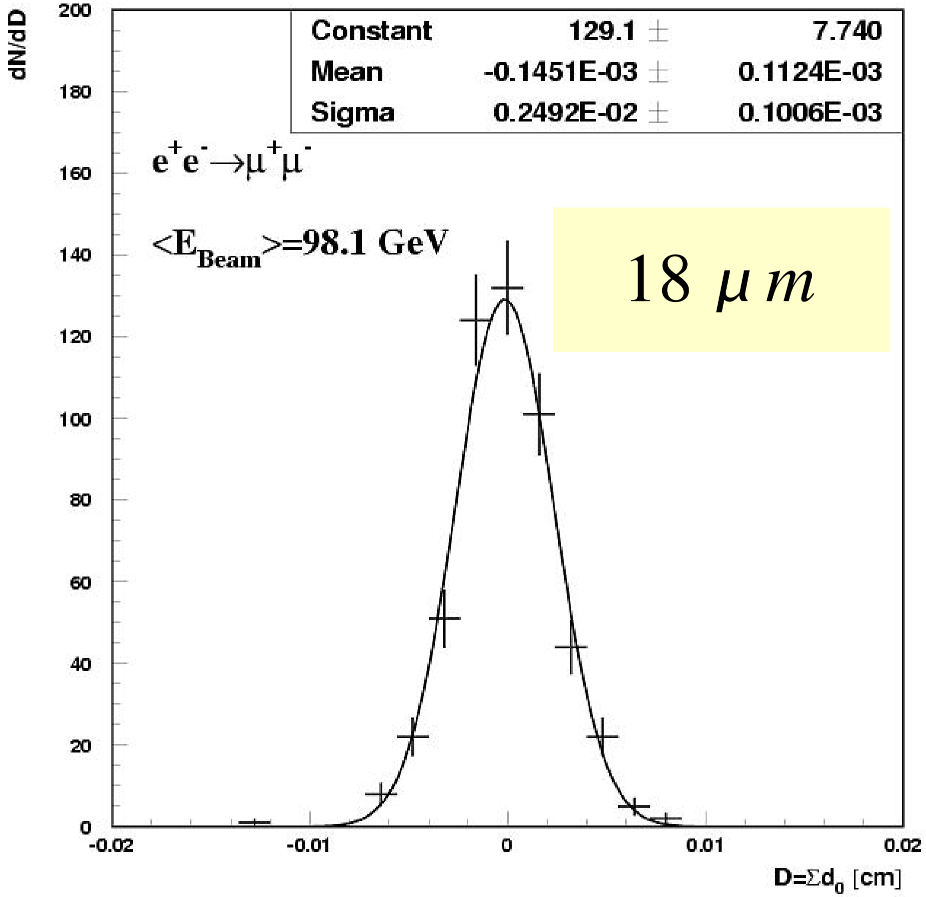
Rz



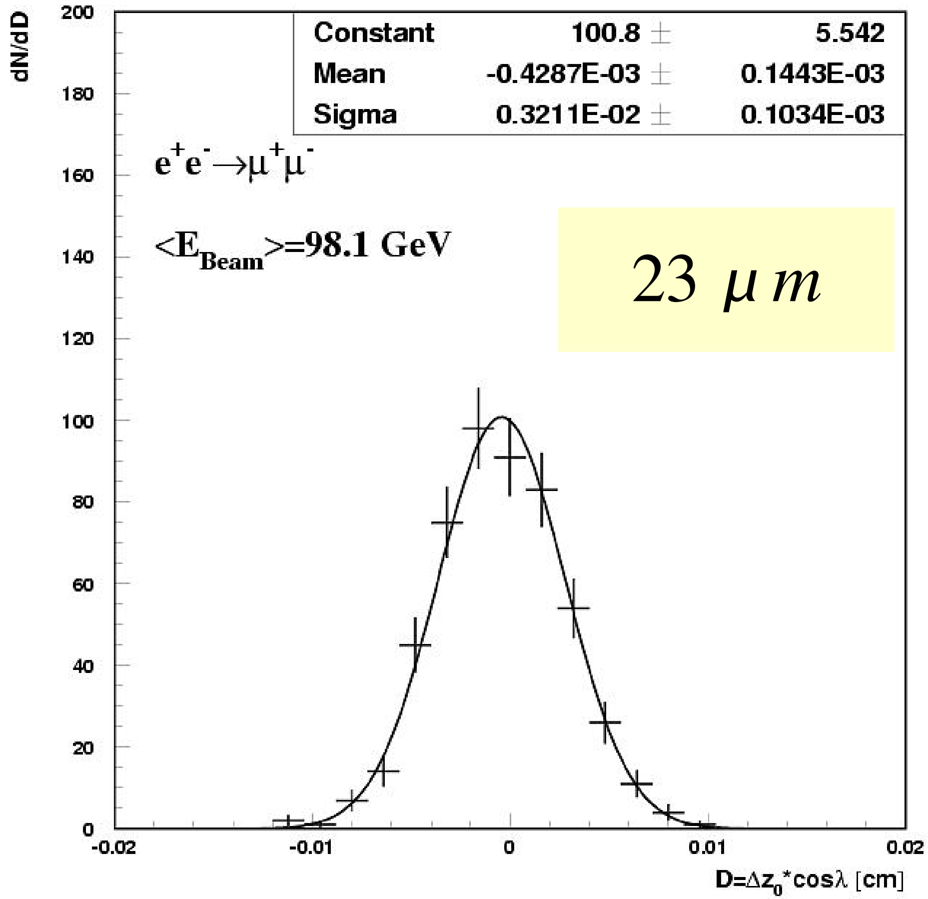
Impact Parameter Resolution

High Energy Data

R φ

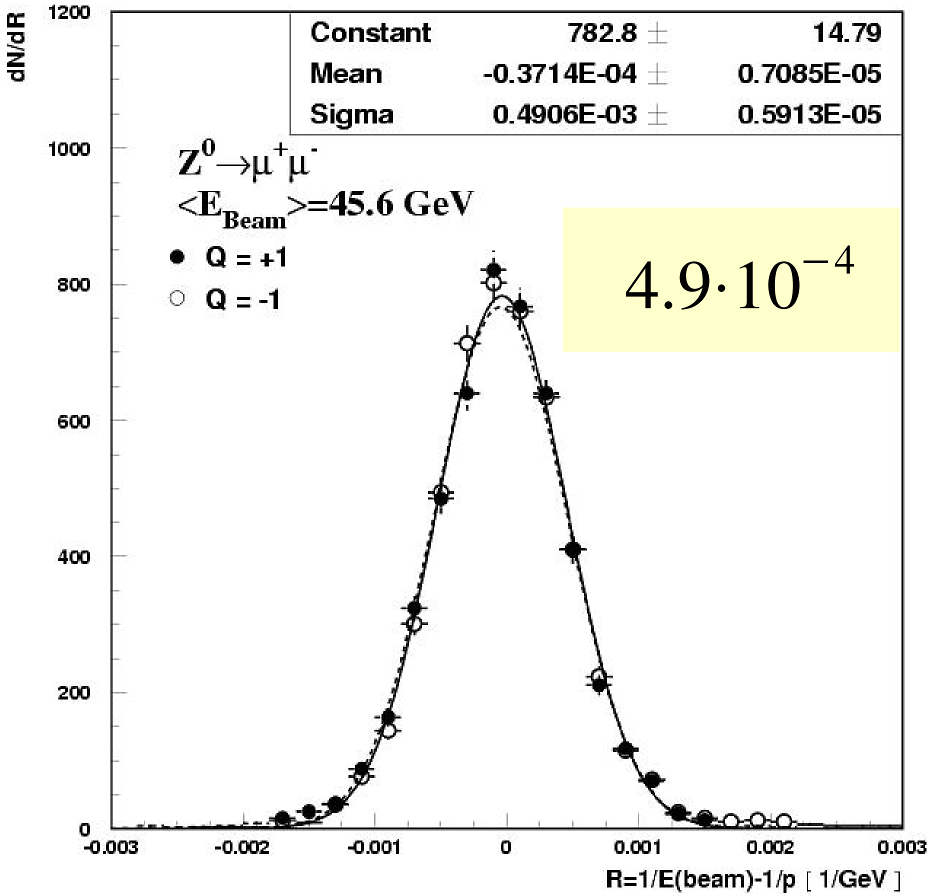


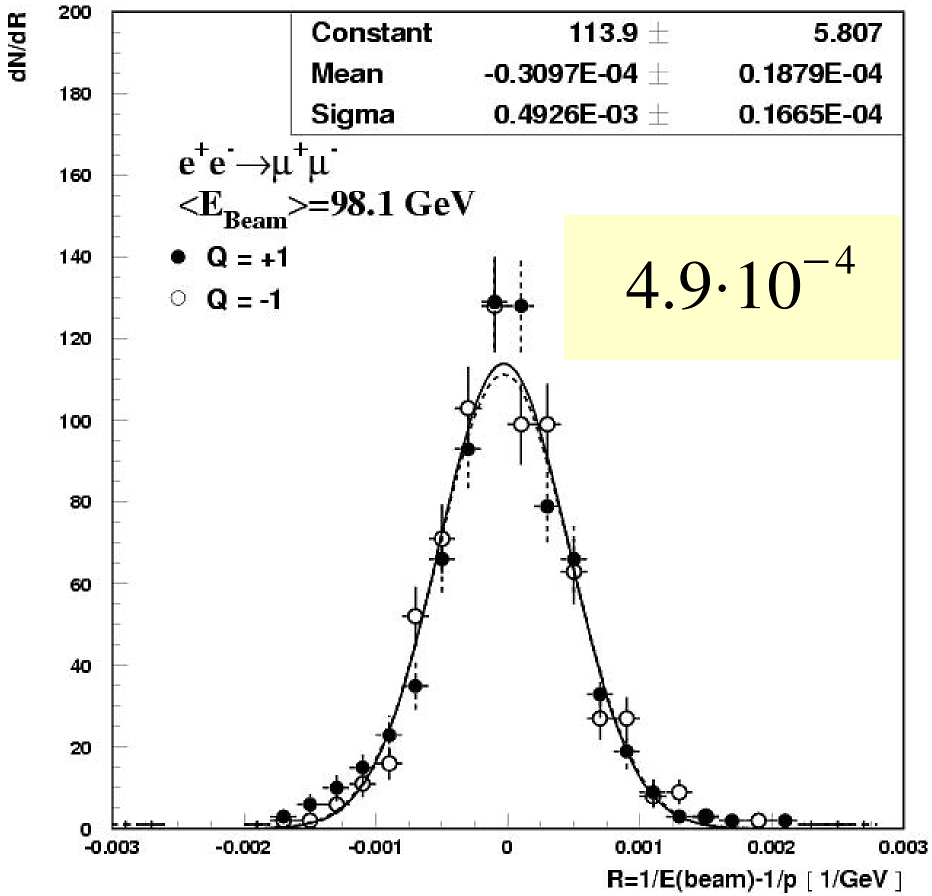
Rz



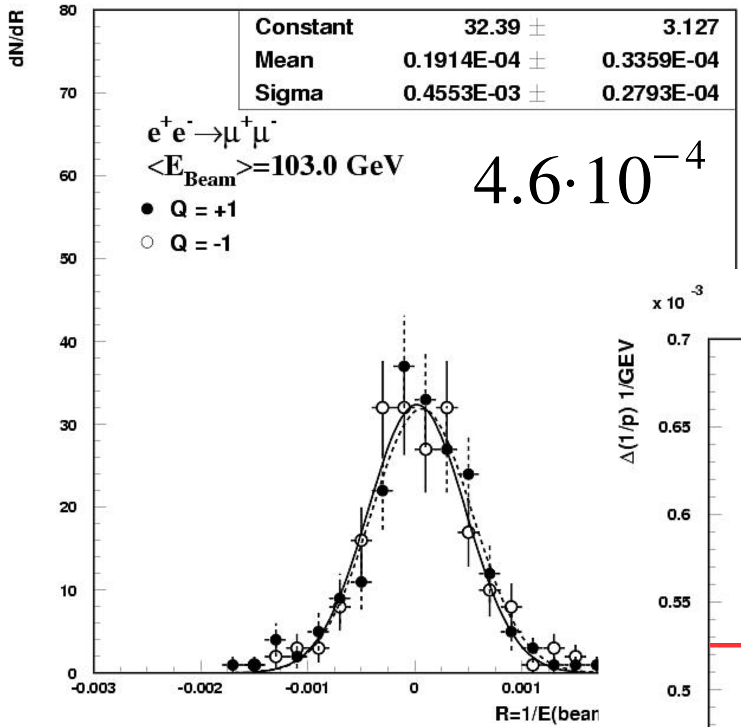
Momentum Resolution

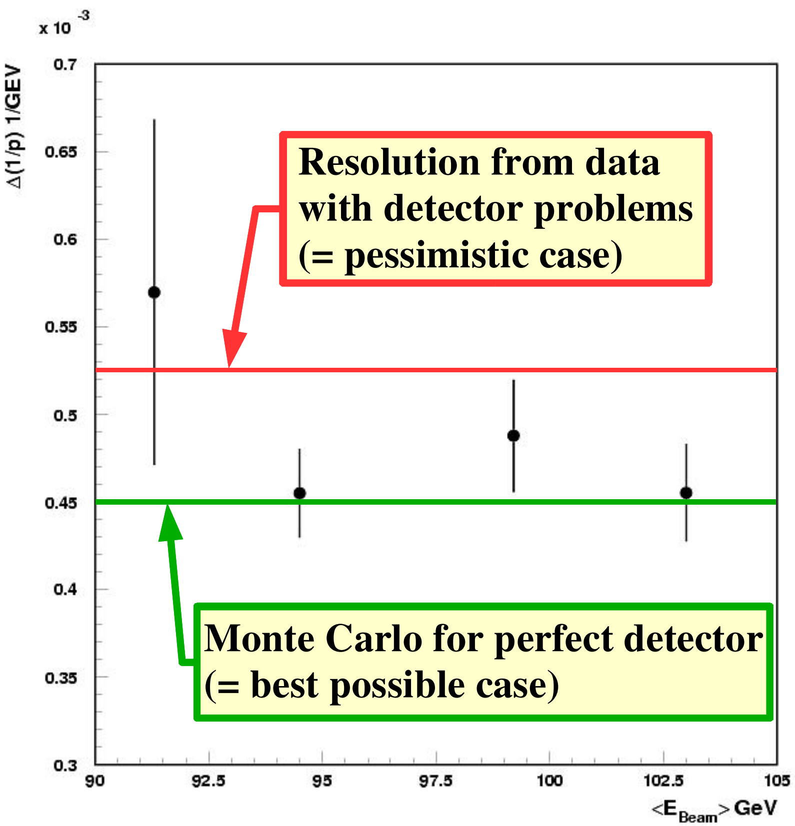
Calibration Data	High Energy Data

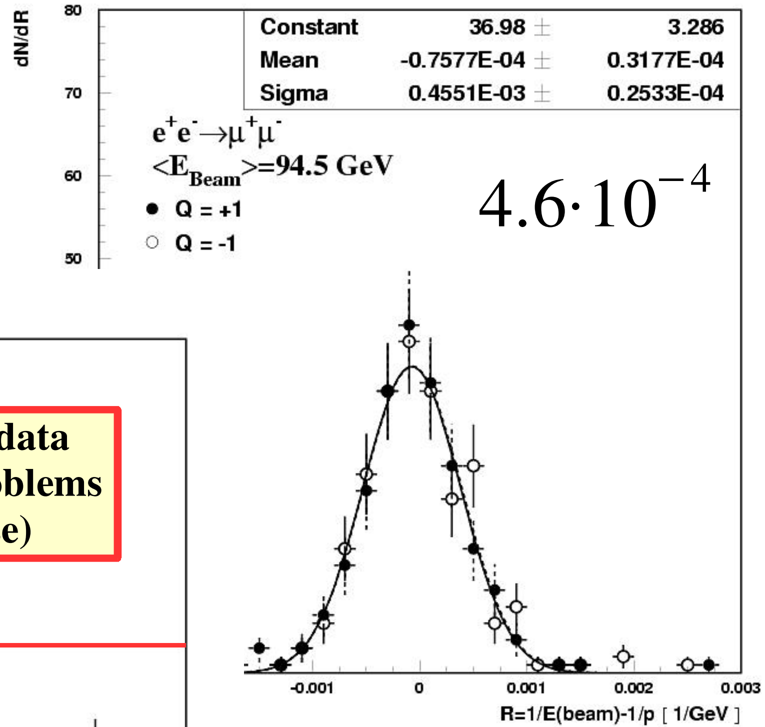




Momentum Resolution



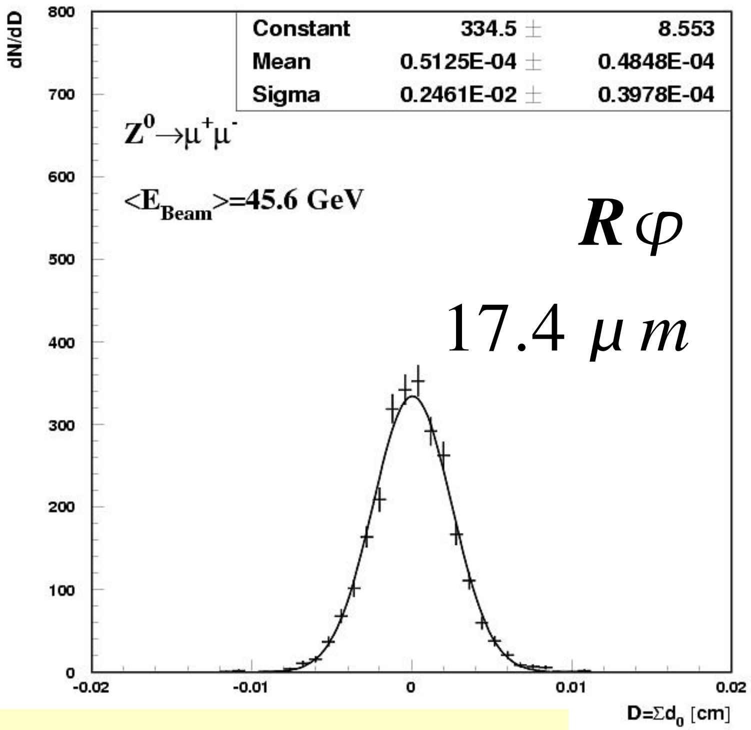


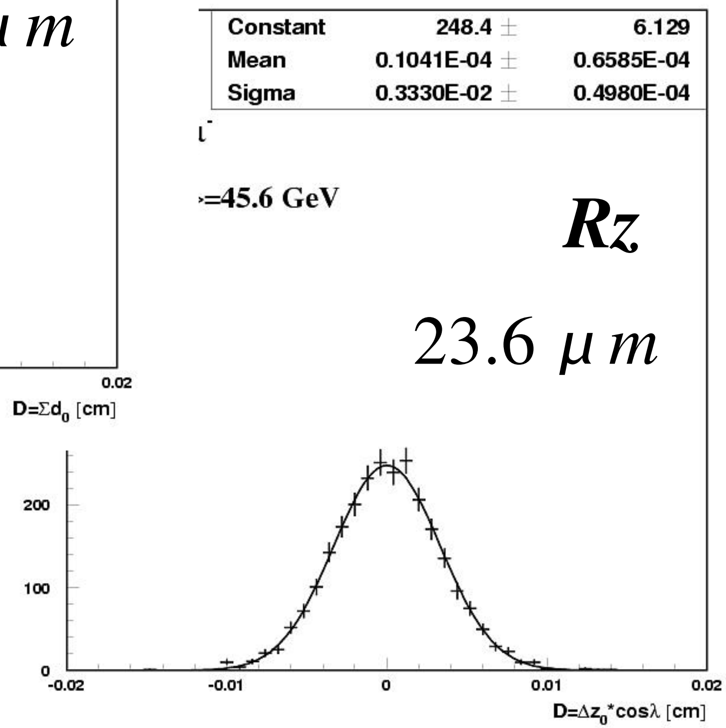


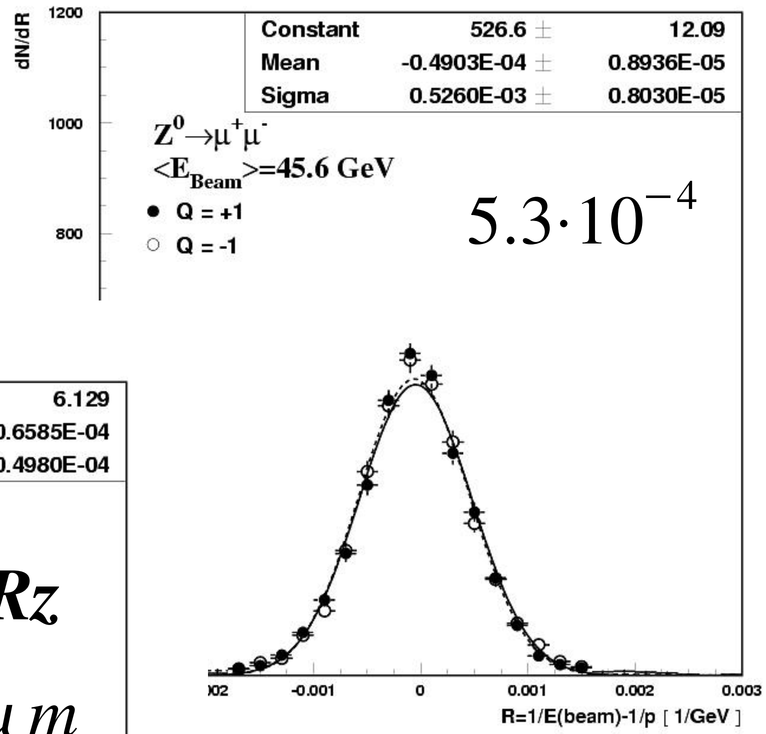
Resolutions for different beam energies (high energy data)

Calibration Data for TPC Problems

Impact Parameter







Momentum

Calibration data for TPC problems after correction = most pessimistic case

Summary

- Mathematical distortion correction models with only a <u>small number of free parameters</u> and mainly <u>data driven correction methods</u> allowed
  - to understand the different distortion contributions
  - to cope with limited calibration samples (e.g. at LEP 2)
  - to recuperate large portions of data which were affected by incidents
  - to follow time dependent effects
  - to maintain the spectrometer resolutions throughout the running periods

- Muon pairs from Z decays with its kinematic constraints provided a unique reaction to measure residual distributions in the TPC directly with data
  - no a priori assumptions about TPC distortions (>< "Hadron fit")
  - limits the application of some of the correction methods in other environments besides unbiased residual distributions can be obtained with other methods