Time Projection Chamber Correction Issues

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Topical meeting 20180706

I've shown these slides a couple of times at various meetings, so many of you have already seen them; I will be brief.

Slides from talk by Werner who led the correction efforts for the Aleph TPC…

Distortion Corrections for the ALEPH TPC

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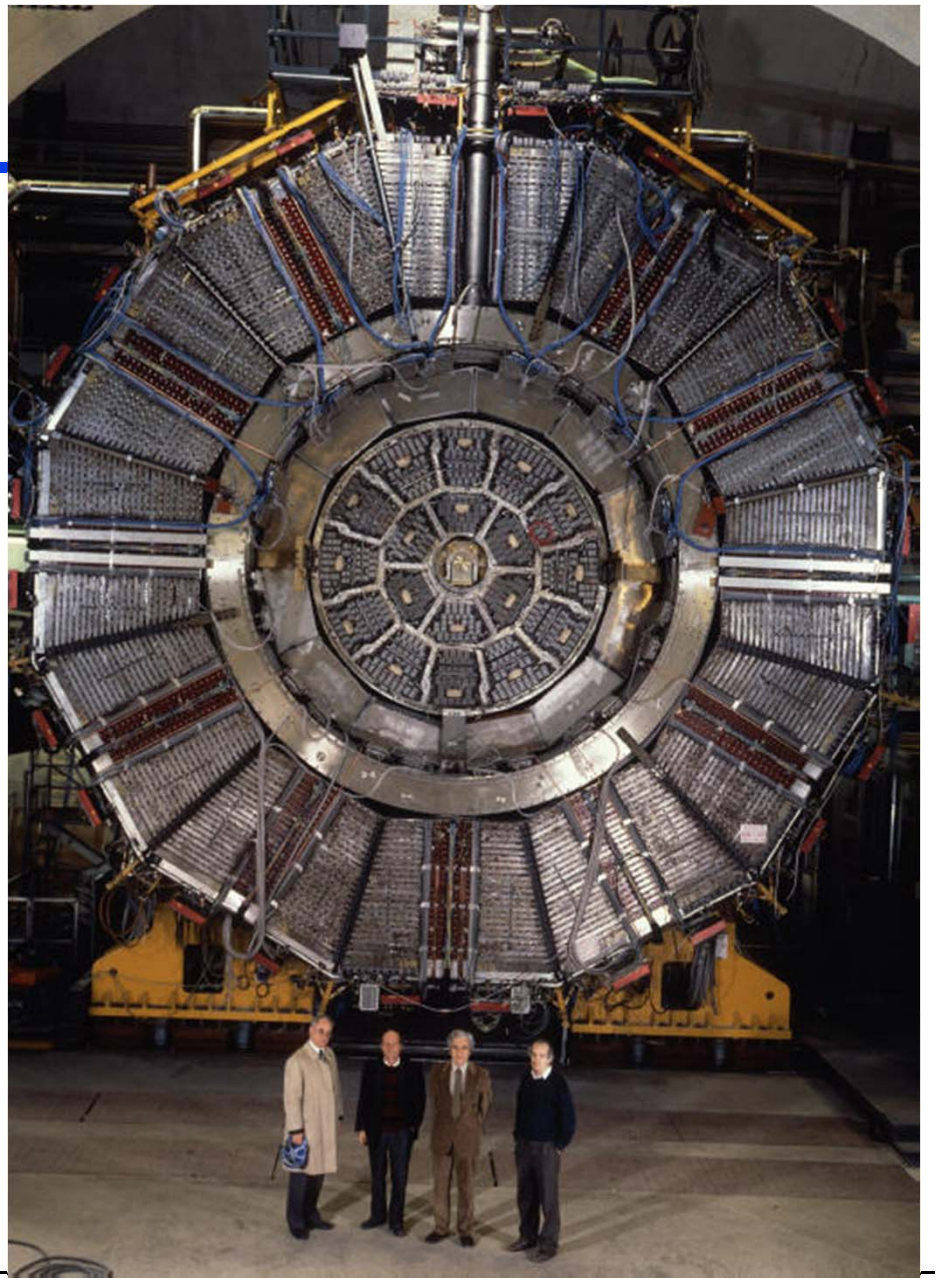
Werner's talk contains many details, see https://mpp.mpg.de/~settles → • here a few examples…

A Detector with TPC

Just to remind you that the magnet had ``compensating coils´´ to make the B-field more uniform...



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
  - 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** (slide 14) 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

Historical Development (2)

- LEP 1/2: 1994-1996
  - Tracking-upgrade program (LEP 1 data reprocessed, improved understanding of correction effects)
  - 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

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.

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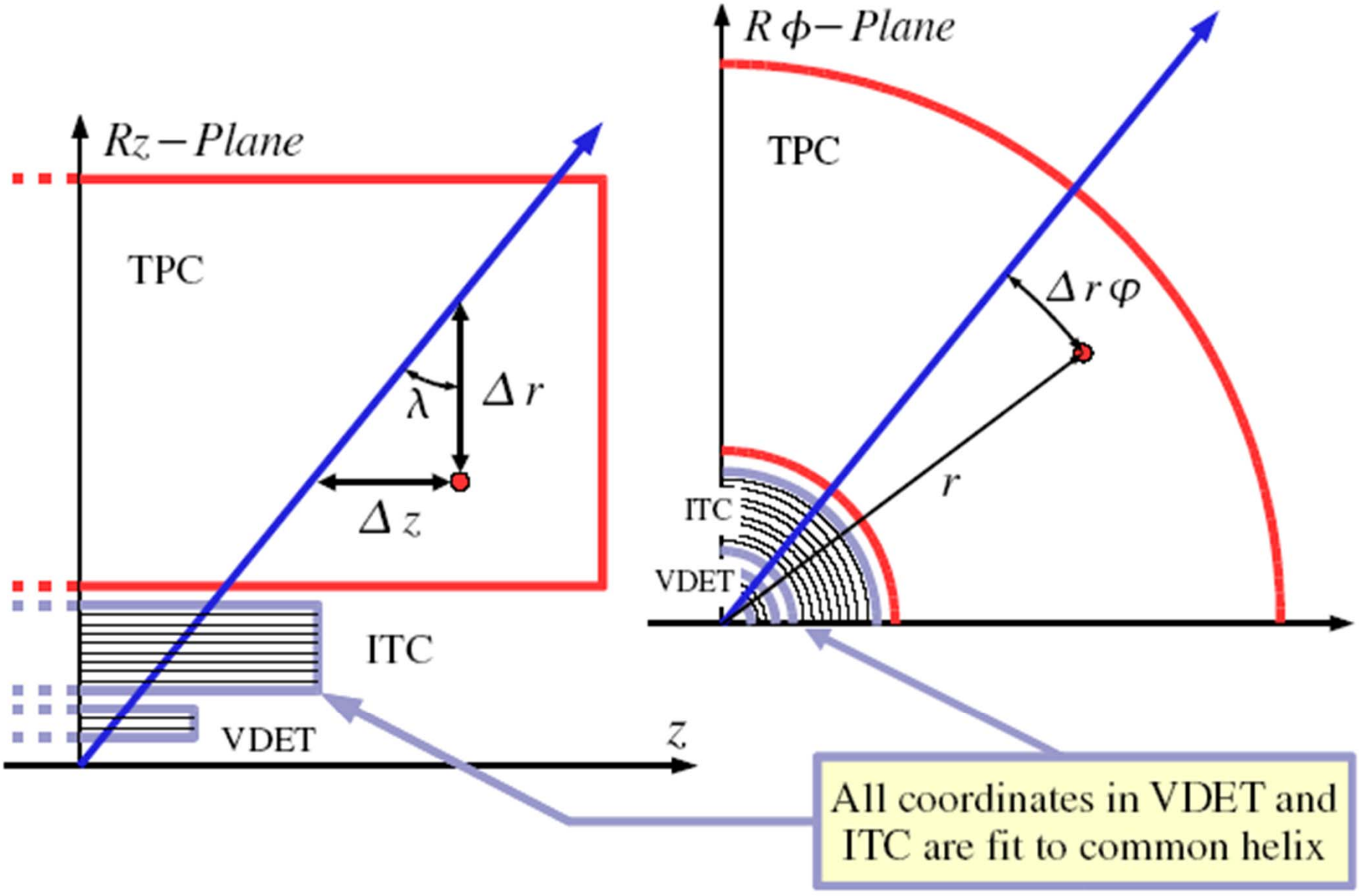
Rz – Plane
TPC
Δ r
λ
Δ z
ITC
VDET
z
R φ – Plane
TPC
Δ r φ
r
ITC
VDET
All coordinates in VDET and ITC are fit to common helix
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- Measure coordinate residuals in TPC respective to extrapolated single helix on 3 dimensional grid $(\Delta r\varphi, \Delta z)_{obs.}(r_n, \varphi_n, z_n)$

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

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

d_0 = Signed distance of closest approach to origin

- 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

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

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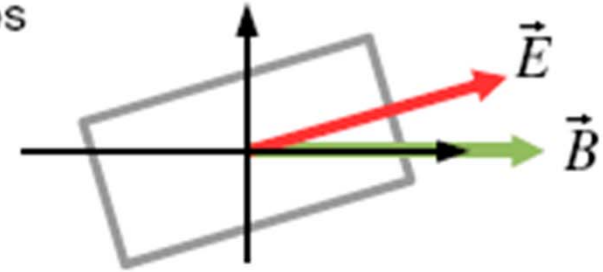
Tour through some problems and their correction

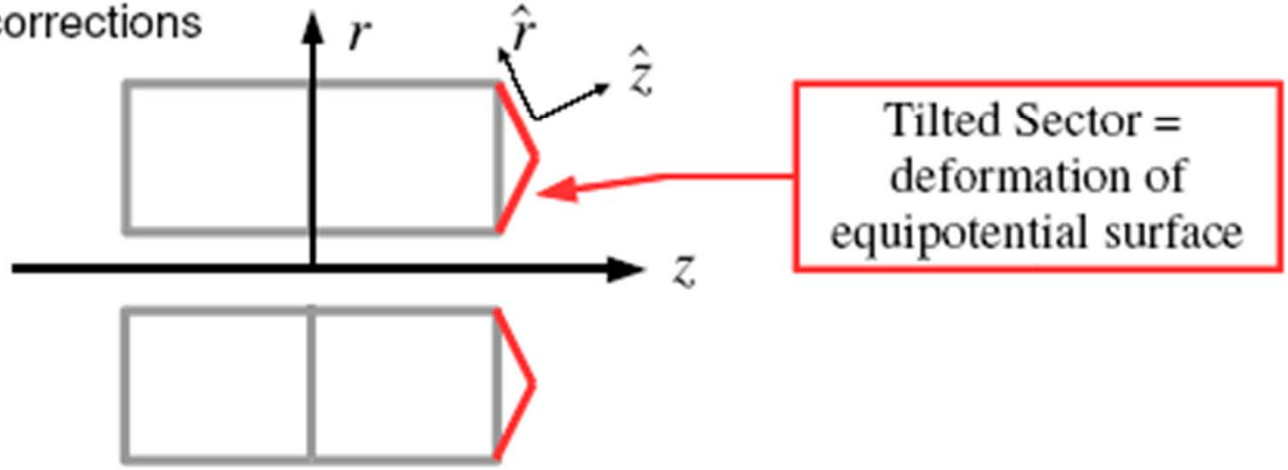
- Static problems (always there)
  - TPC tilt
  - Endplate bowing
  - Nonlinear potential on fieldcage
- Single incidents
  - Disconnected gating grids (space charge)
  - Shorts on field cage
- Time dependent effects
  - "Charge up" effects

e.g. ...

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

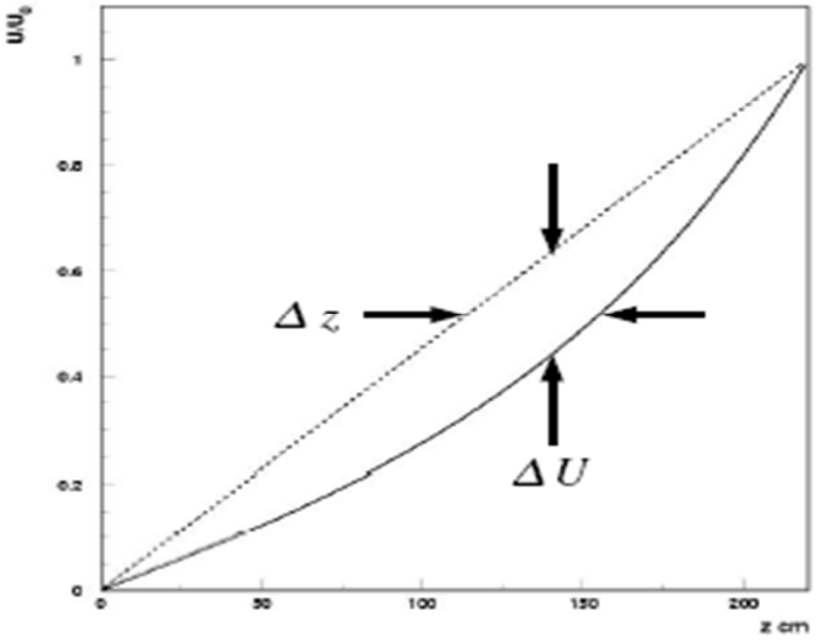


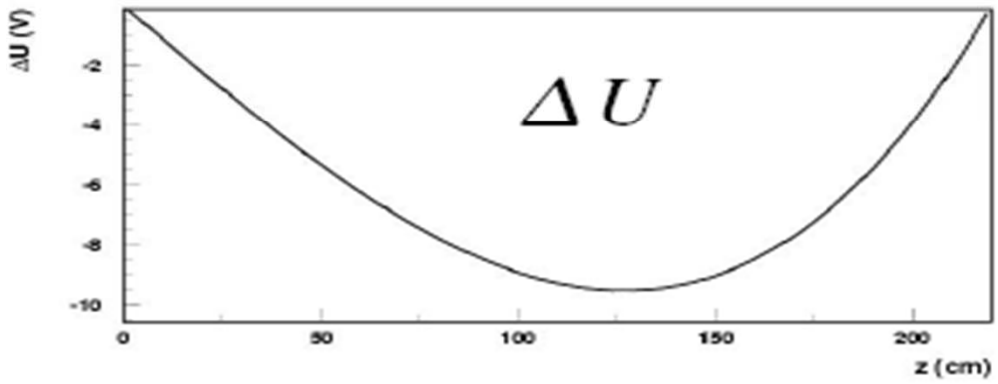
  - e.g bowing of the TPC endplate requires alignment and E–field corrections

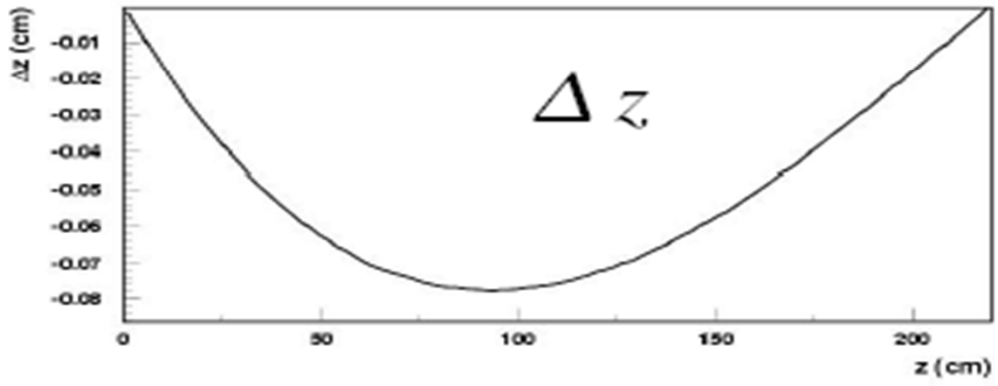


e.g., non-linear F.C. potential

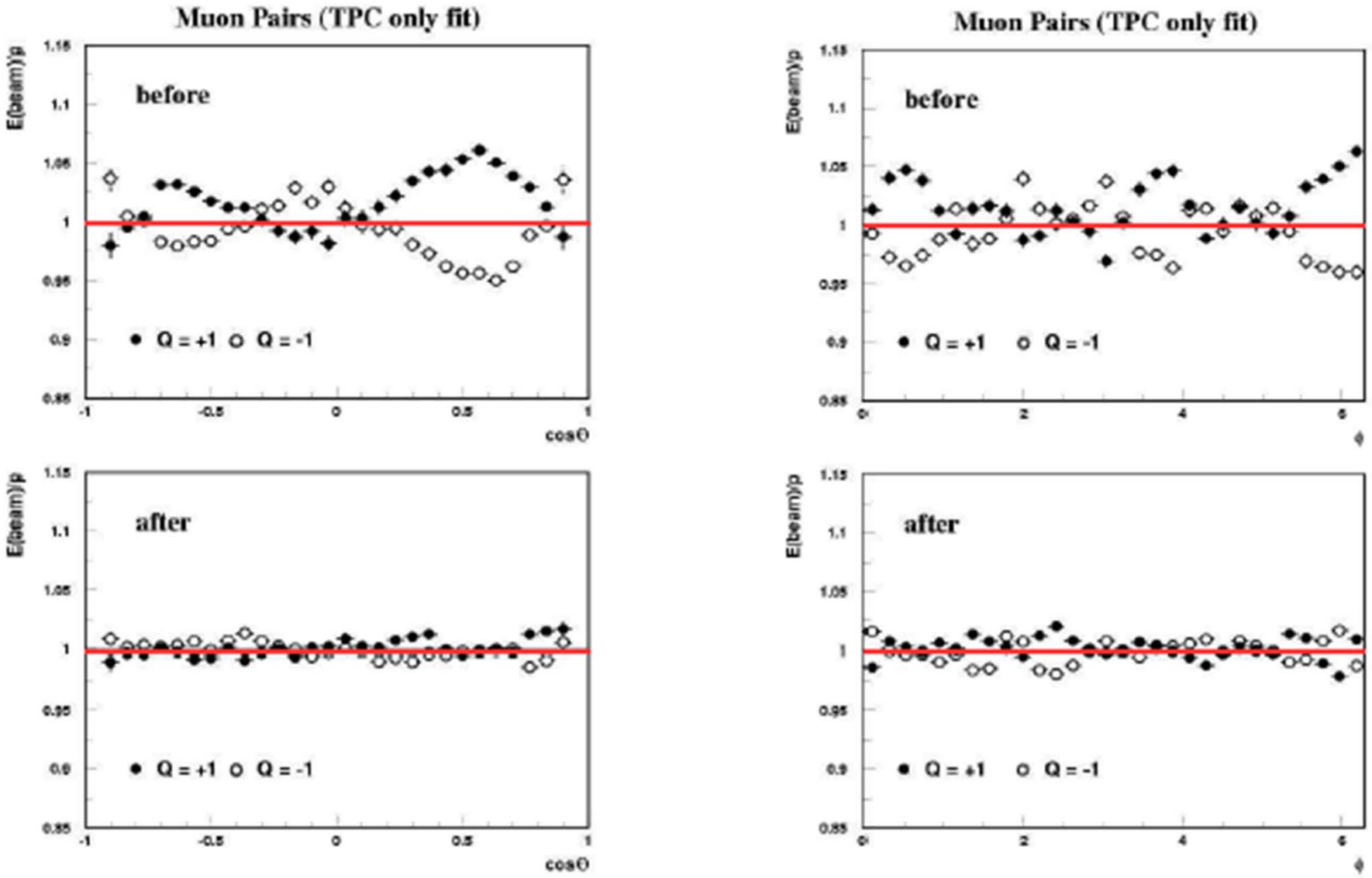
- Results from fit can be interpreted as potential deviation or axial shift of electrodes
- Fit prefers $\rho \simeq 10^{16}\,[\Omega\ cm]$



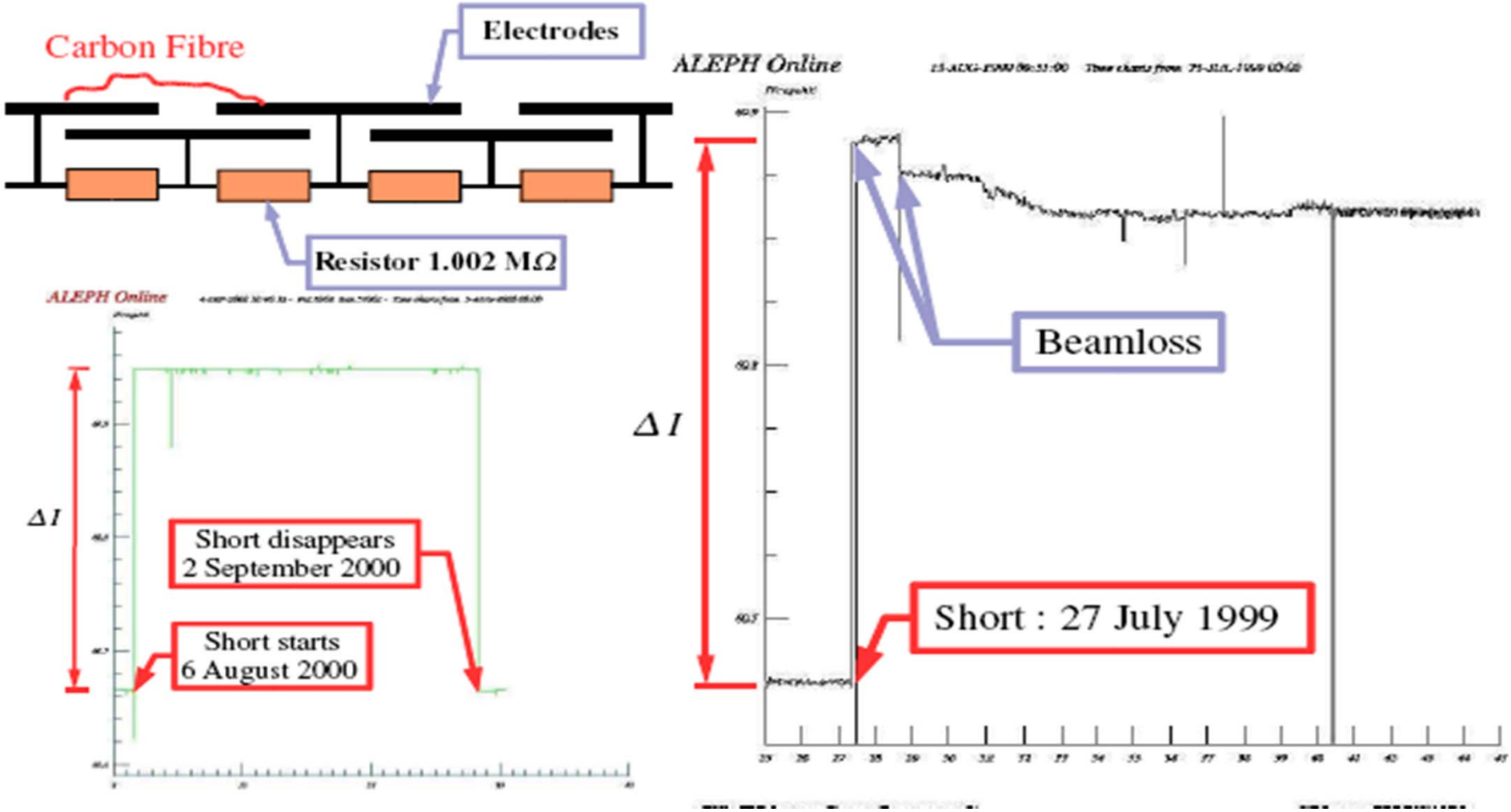


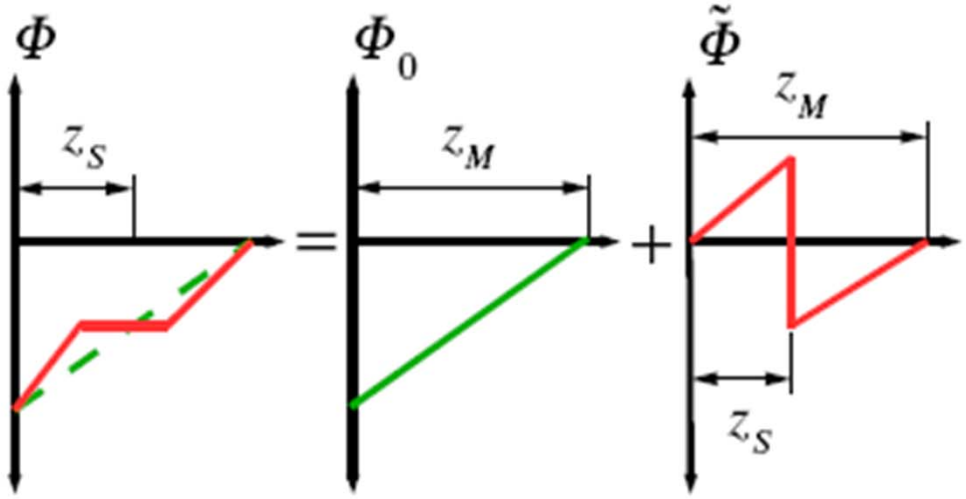


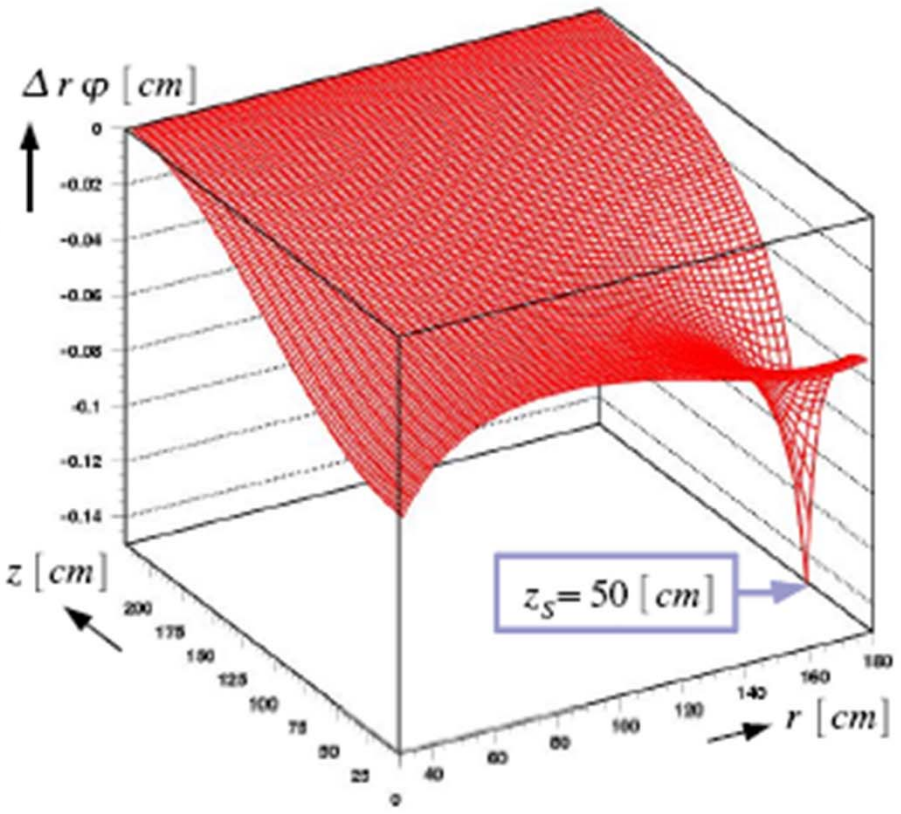
Correction for nonlinear potential + endplate bowing



e.g., field-cage shorts (a technical mistake led to the deposit of carbon fibres into the TPC field cage)





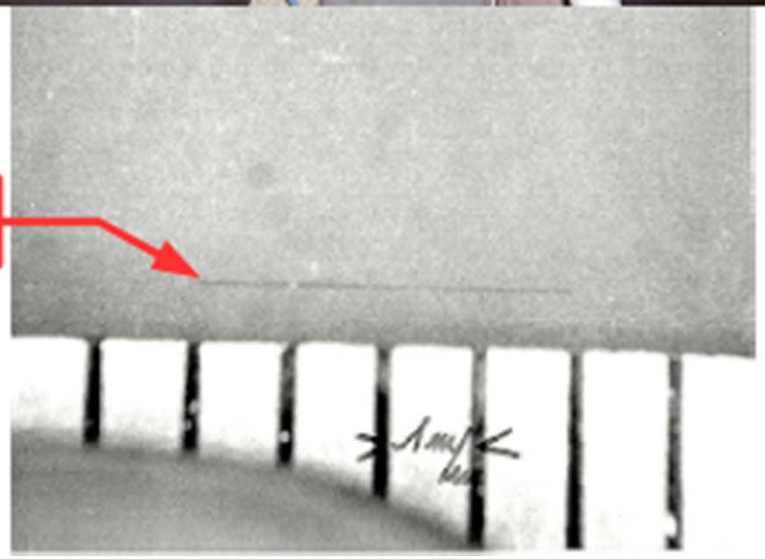


- Two parameter model
  - Shortposition
  - Voltage/current change

Distortionpotential

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

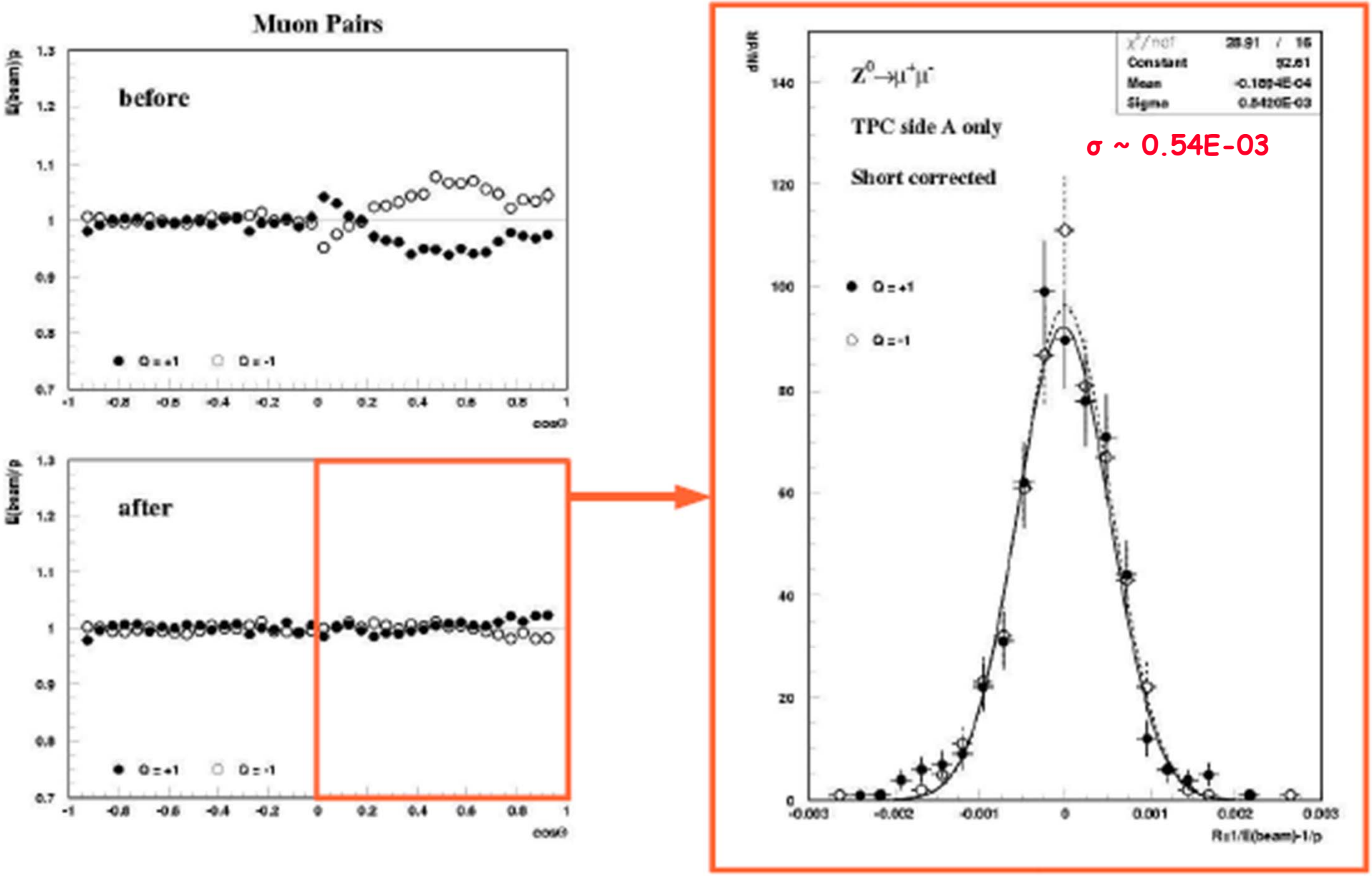
(N.B., design your detector to be easily accessible…)



Fibre found at z=36 cm

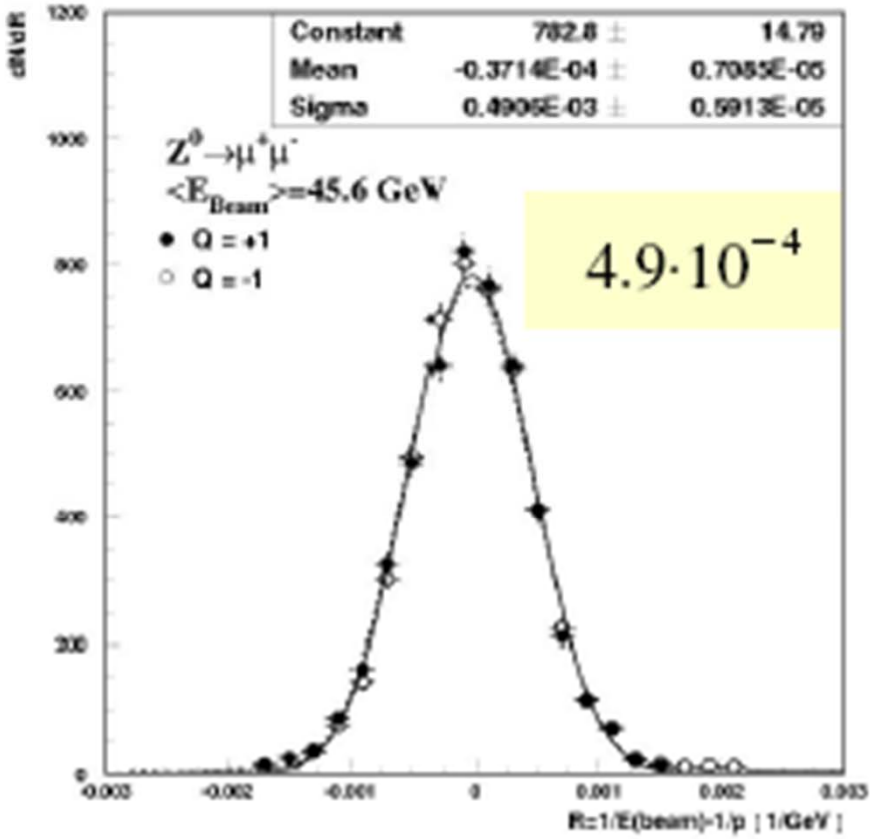
Intervention during 1999 shutdown

Short 1999 : Fit with all tracking detectors

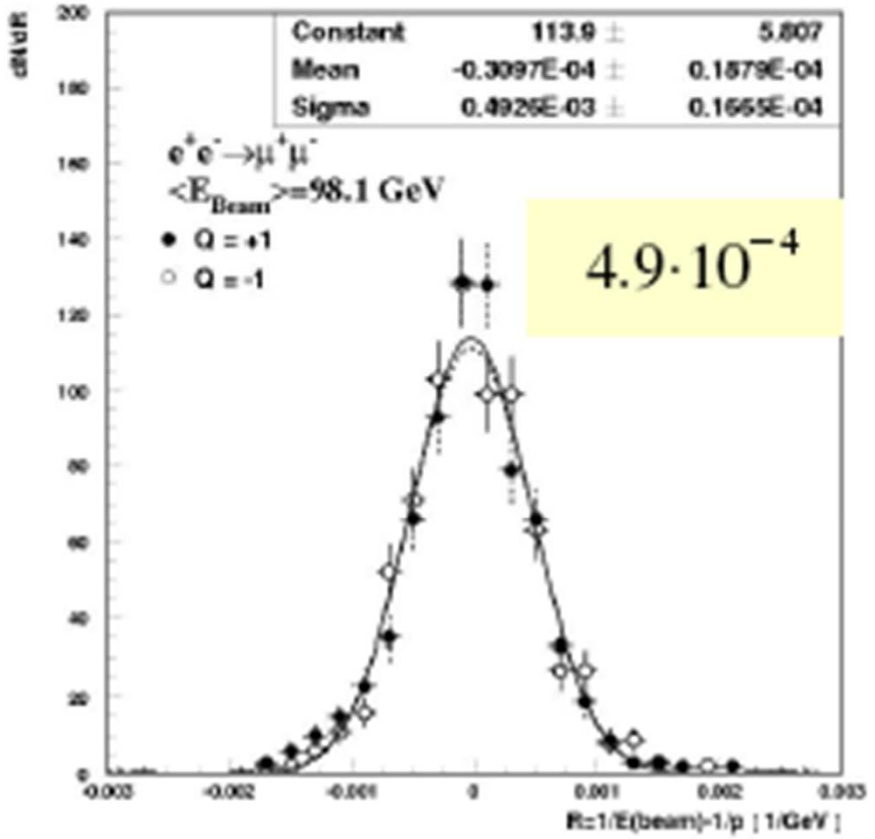


the bottom line (e.g., momentum resolution)

Calibration Data



High Energy Data



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…

Back up slides

Historical Development (2)

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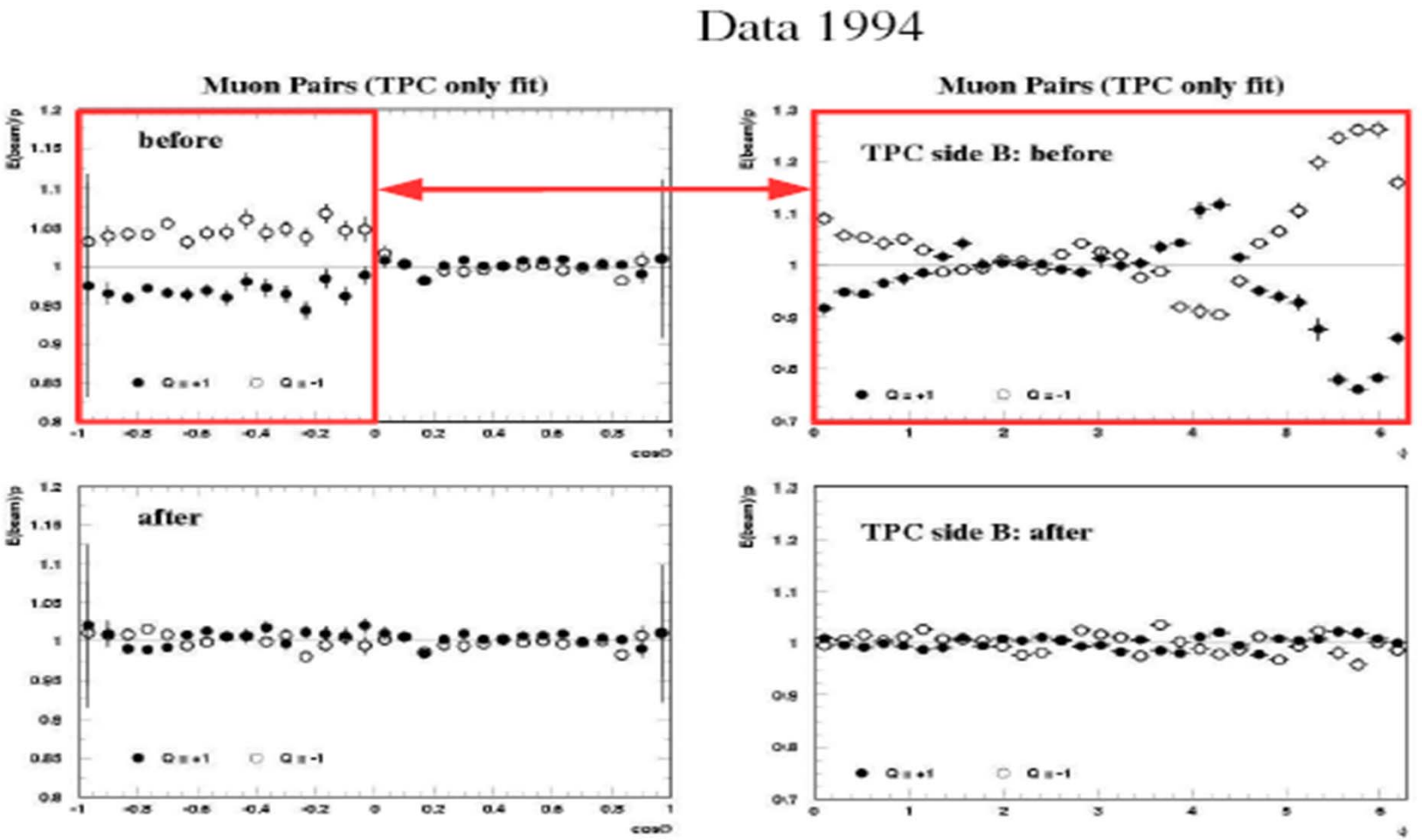
- Solve system of linear equations with *Singular Value Decomposition (SVD) (e.g. Numerical Recipes, Cambridge University Press)*
  - *SVD* can cope with linear dependencies in function matrix. Solution has from all possibilities the smallest length.

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

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

e.g., disconnected gating grids

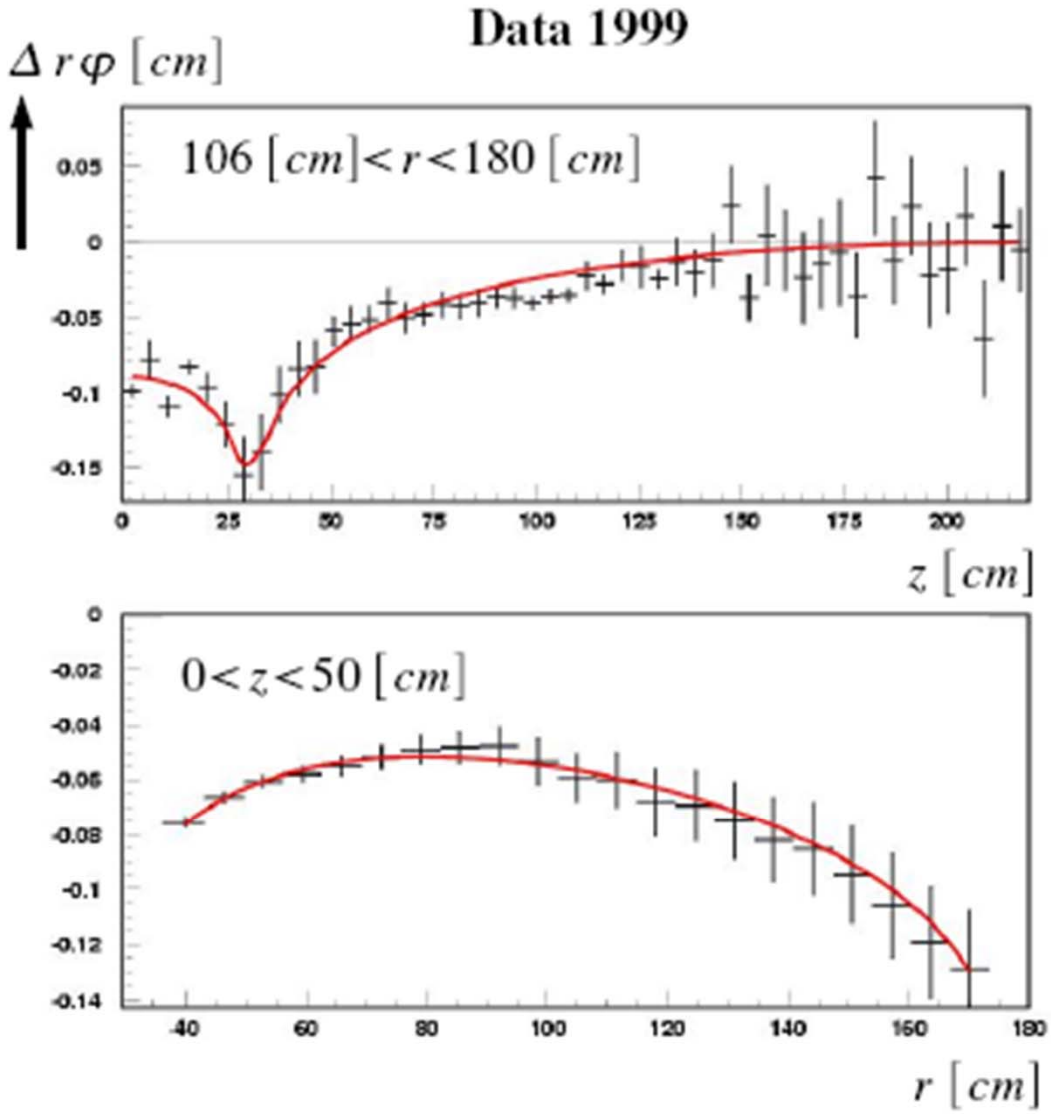


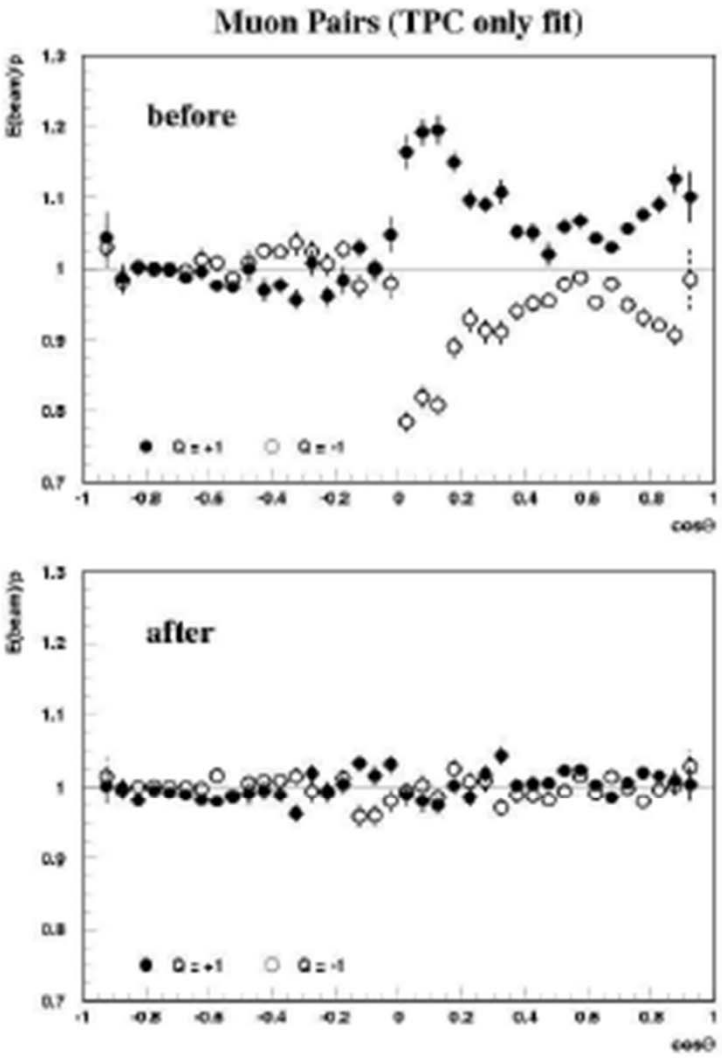
Parameters used:

$\varphi: 0 \le \nu \le 6$

$r: 1 \le m \le 5$

$z: 1 \le n \le 8$


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
E(beam)/p
cosΘ