The L3 PSF System

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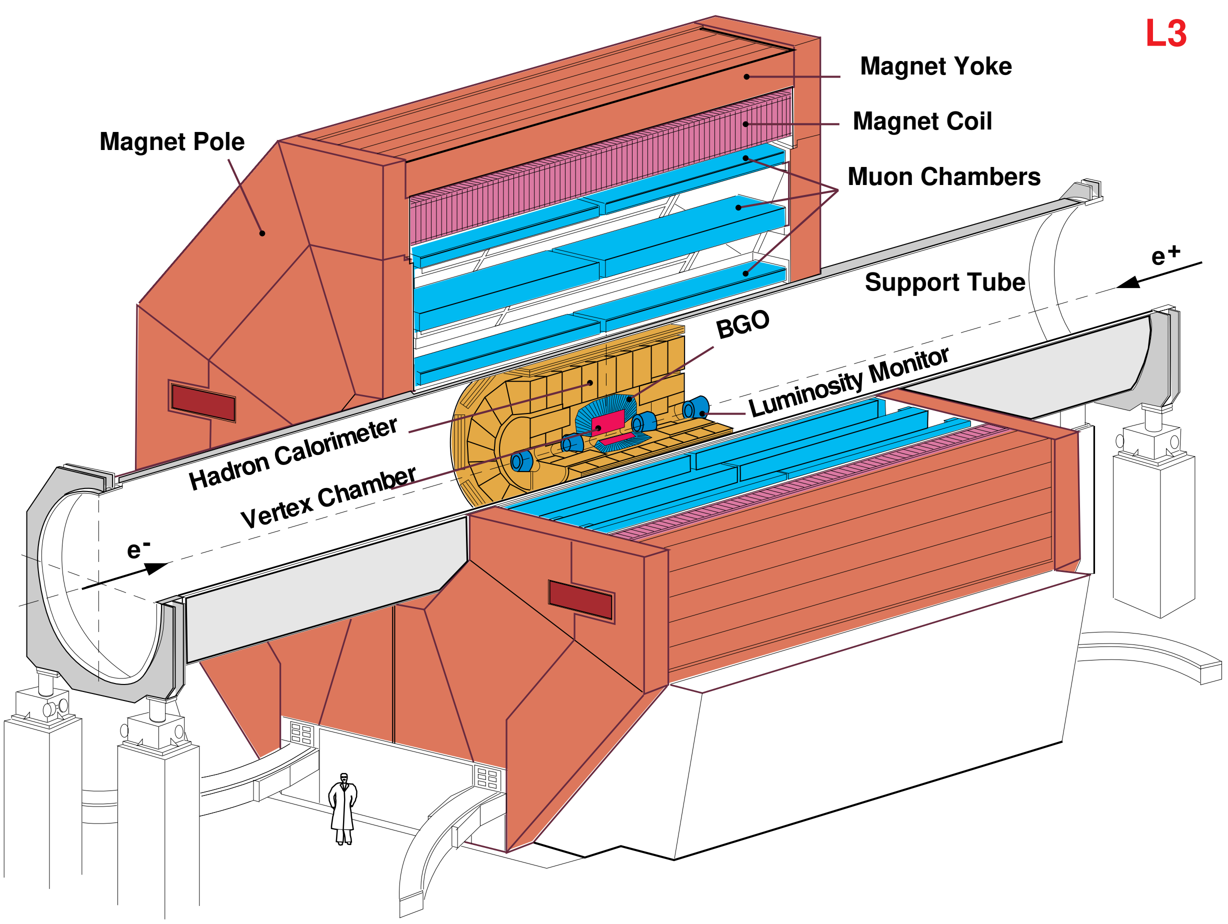
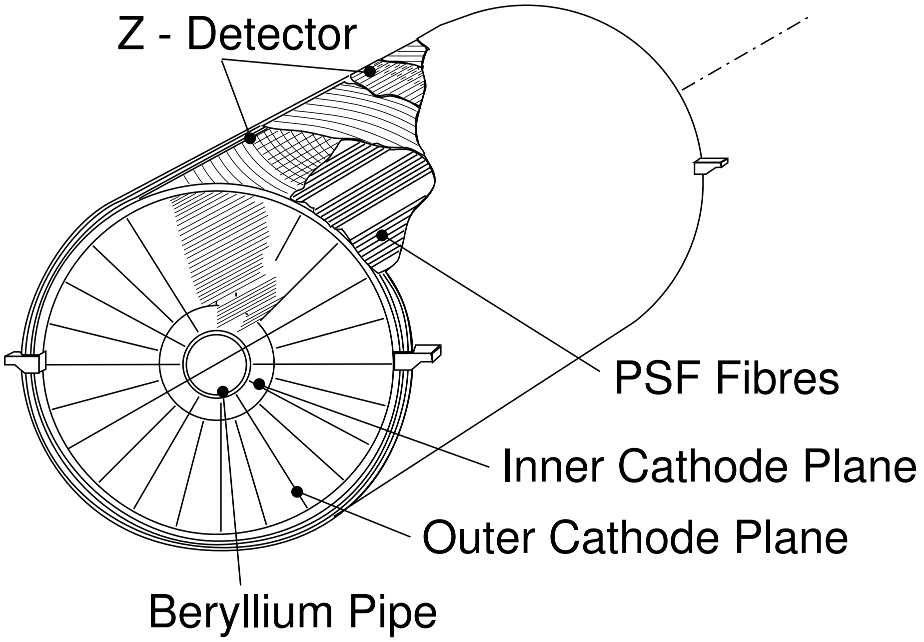
The L3 Detector





L3 Central Tracking

Time Expansion Chamber (TEC)

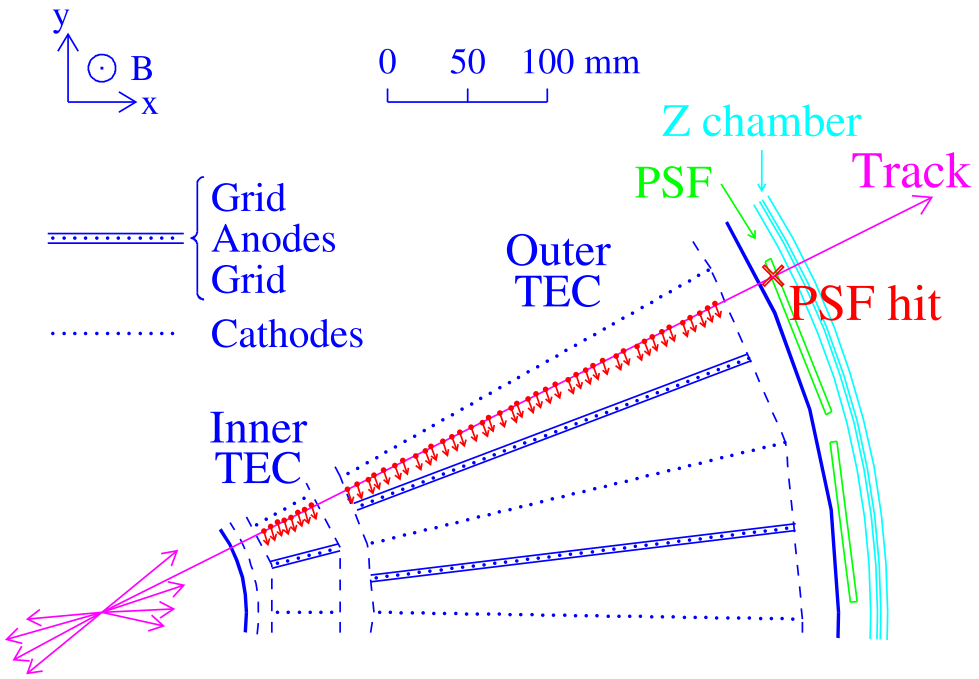
High precision drift chamber with:

12 Inner sectors:	**8 anodes/sector**
24 Outer sectors:	**54 anodes/sector**
Radial coverage:	**11cm – 43cm**

Plastic Scintillating Fibres (PSF)

For calibration of TEC drift velocity

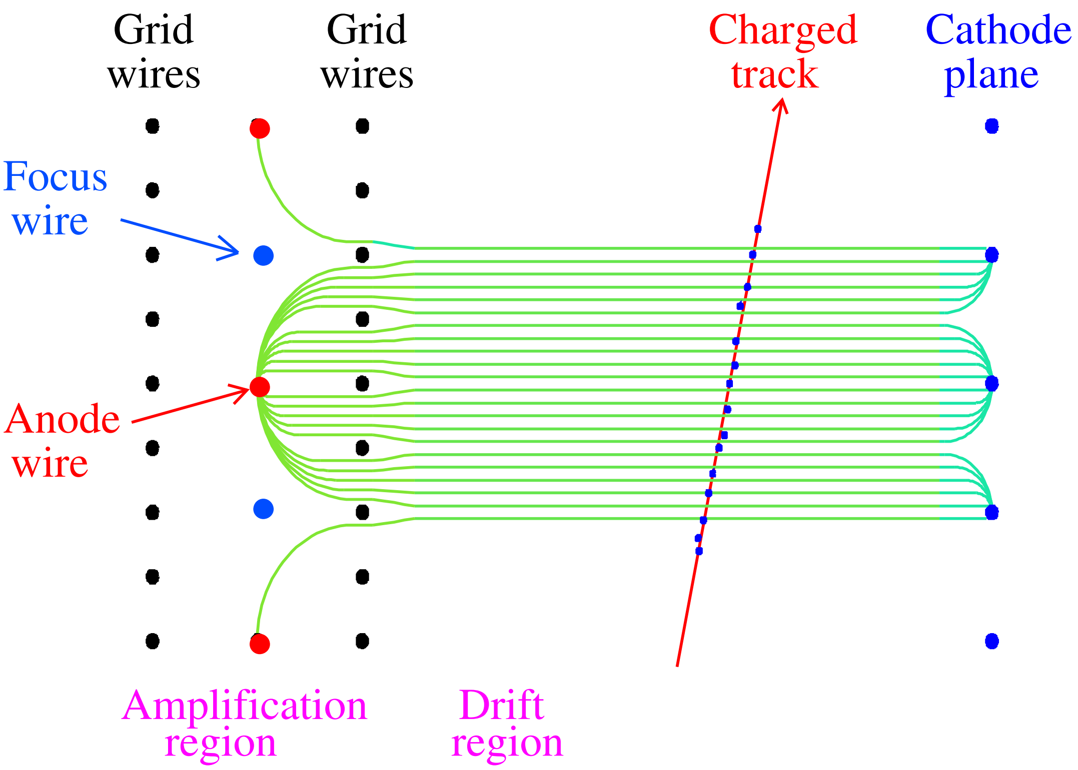
24 Ribbons:	**143 fibres/ribbon**
Fibre dimensions:	$\mathbf{1.3m \times 1mm \times 0.7mm}$



The TEC principle

Drift region:
- Saturated drift velocity
- Very slow ($v_{\mathrm{drift}} \simeq 6\mu$m/ns)
- $\Rightarrow$ high precision ($\sim 50\mu$m)

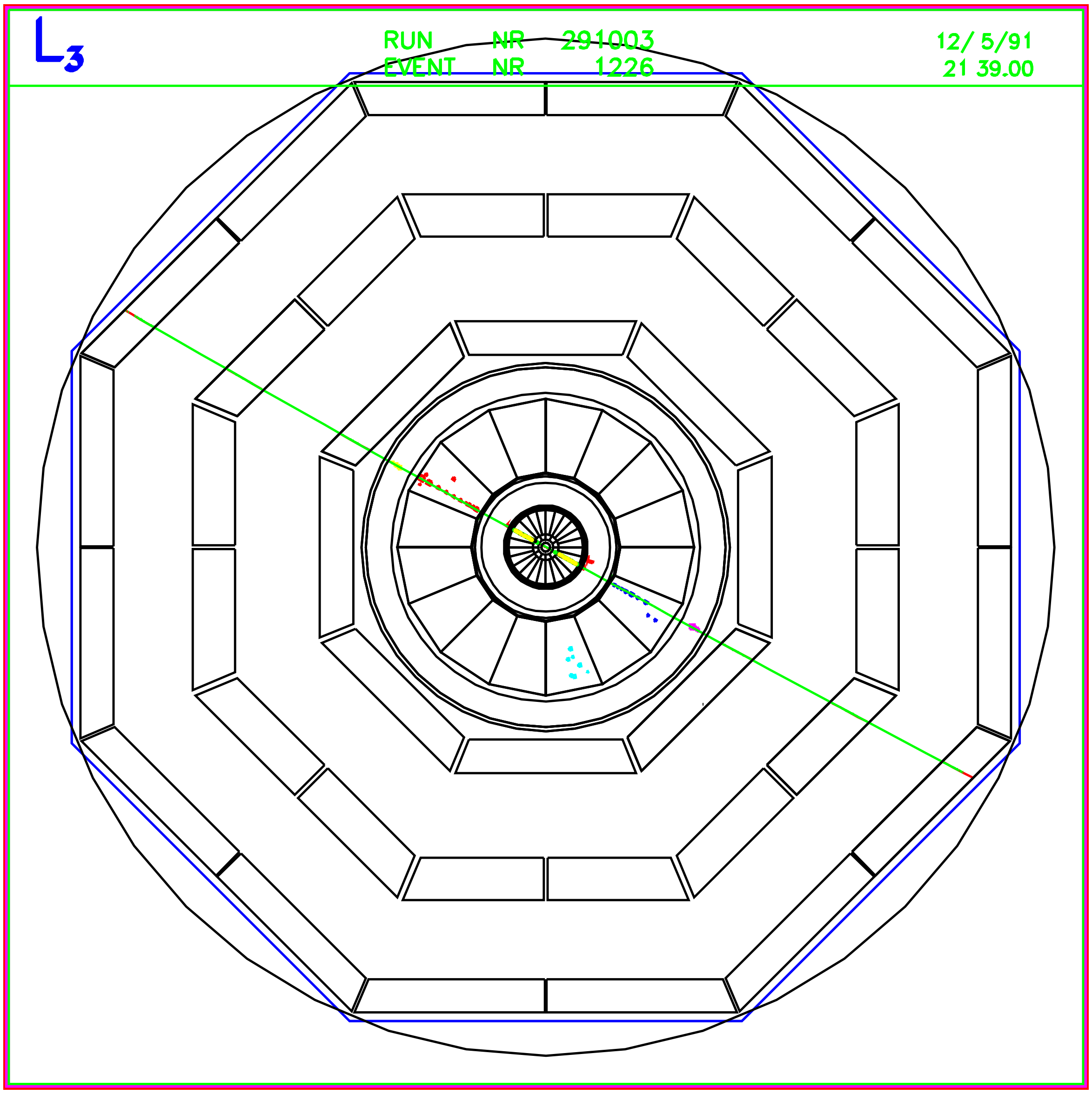
Amplification region:
- 3mm wide with high electric field
- Drift velocity, $v_{\mathrm{drift}} \simeq 50\mu$m/ns
- $\Rightarrow$ lower precision ($\sim 300\mu$m)



Calibration $\Rightarrow$ measurement of drift velocity throughout TEC to better than 1% accuracy

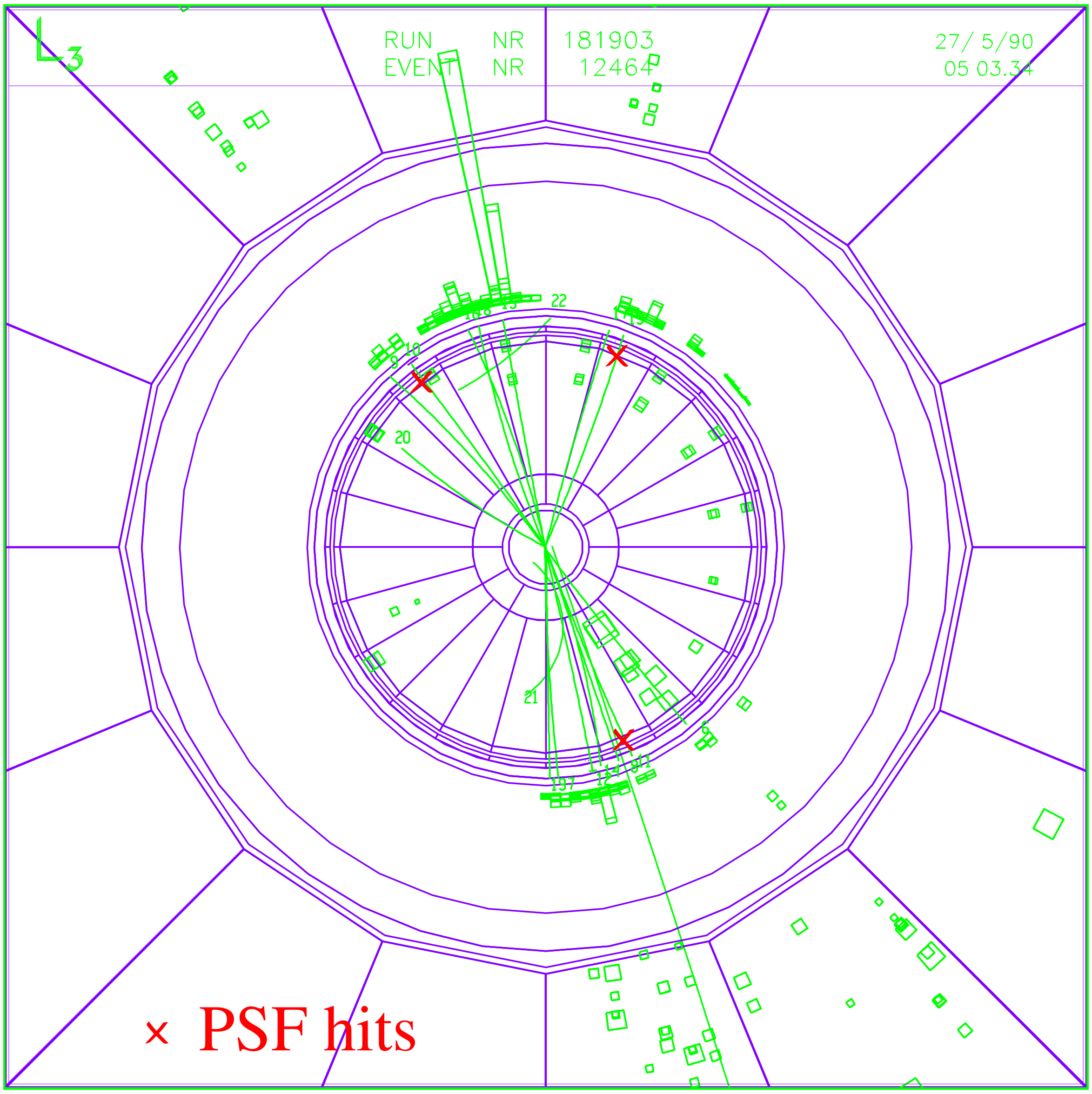
Dimuon Calibration of TEC

Use Z $\longrightarrow \mu^+\mu^-$ (momentum from muon spectrometer)



PSF Calibration of TEC

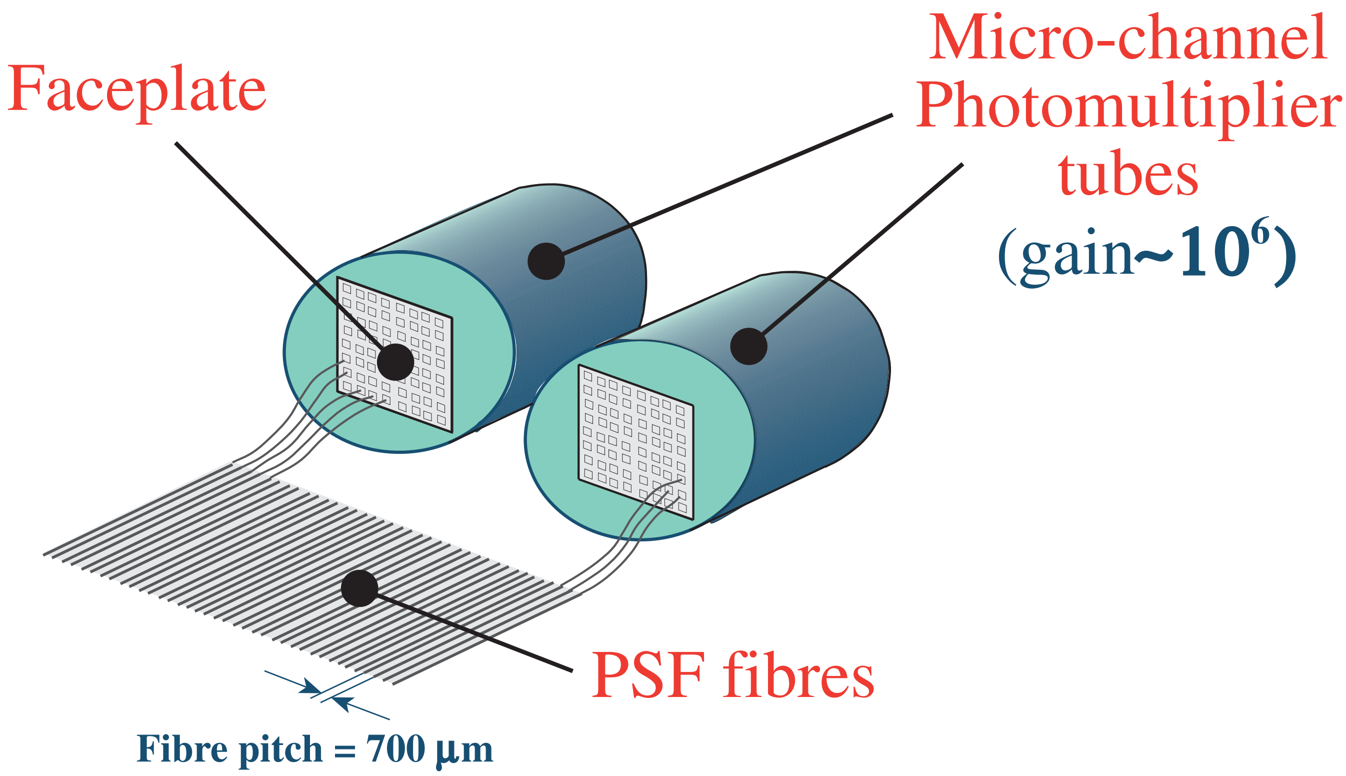
Constrain track positions using PSF hits



Comparison of calibration methods

Dimuon calibration	PSF calibration
Clean event topology	Multi-track environment
Known track momentum	Unknown track momentum
Full $r\phi$ acceptance	83% $r\phi$ acceptance
No external track position	Independent track position
Few 100 tracks/day	$\sim$50 000 tracks/day
Tracks almost straight	Curved tracks

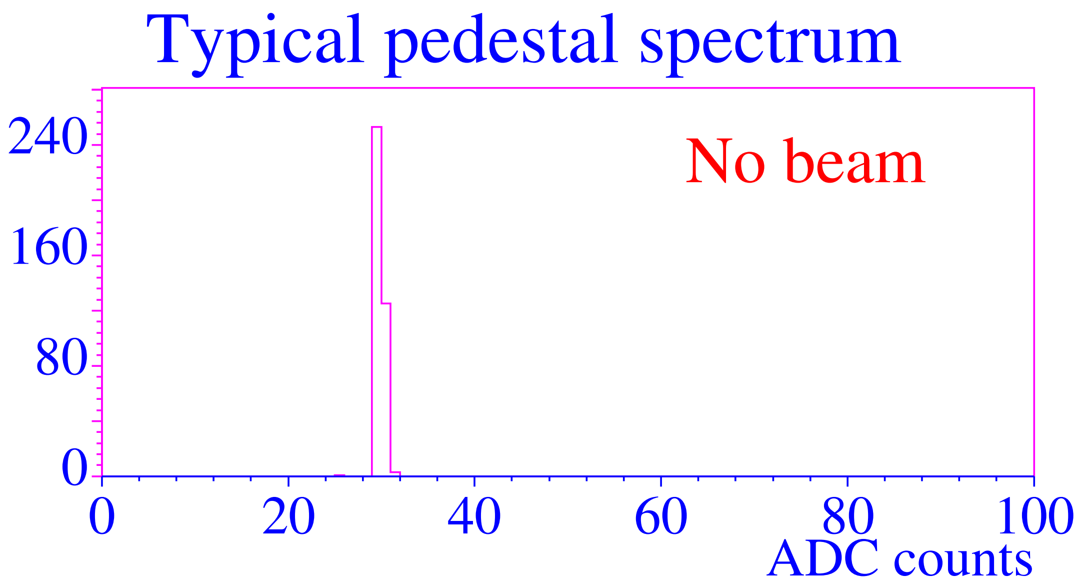
The PSF calibration system

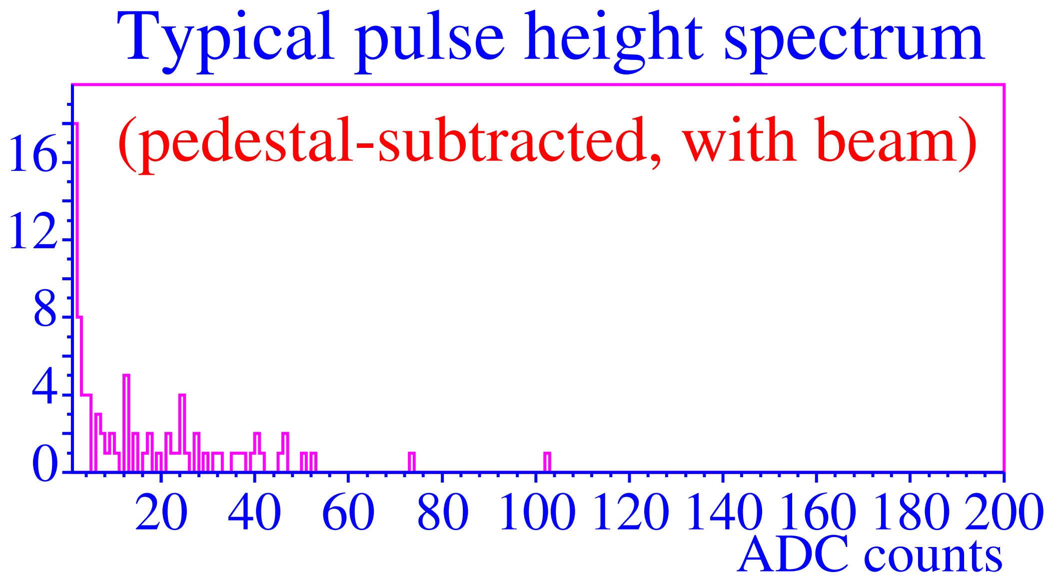


- **24 ribbons of 143 fibres each**
- **48 ITT Microchannel Phototubes**

- **48 MX4 multiplex chips, FADC's & discriminators**
- **3 Data Reduction Processors**
- **VME–based VAX cluster DAQ system**

PSF signals





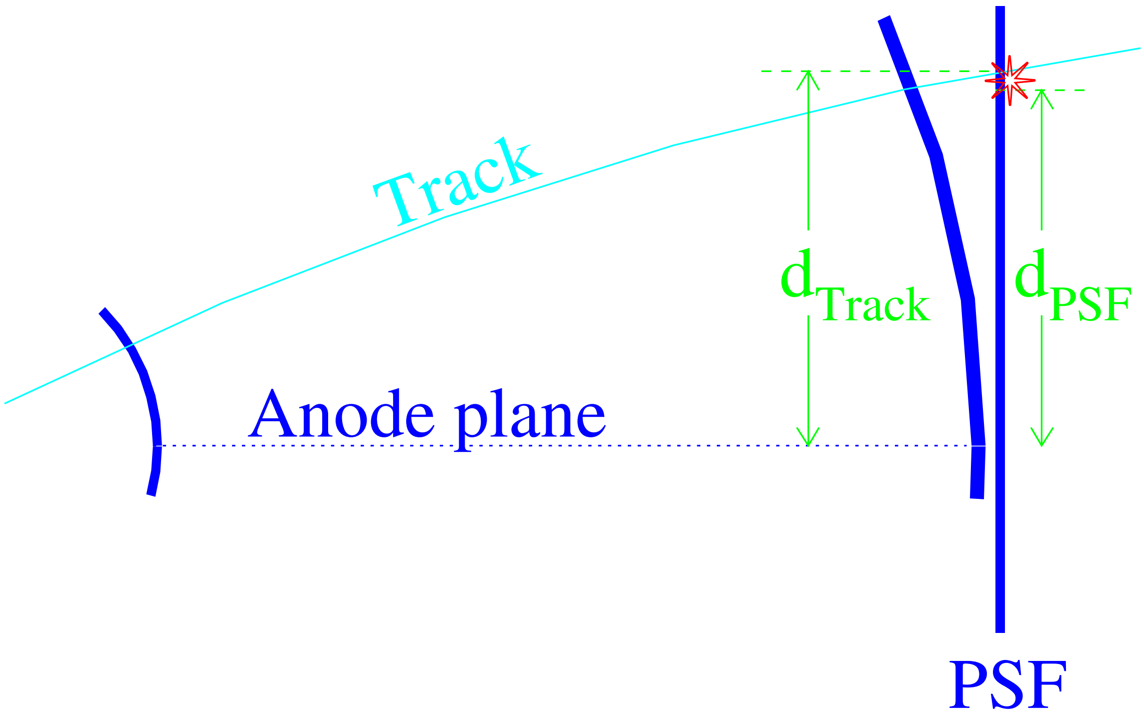
Set threshold of ∼1–4 ADC counts and run in digital mode

i.e. **record 1/0 if a fibre is/is not hit**

PSF resolution

Measure PSF resolution by comparing PSF hit positions and intersections of extrapolated track with PSF ribbon, allowing for the PSF alignment (see later. . .)

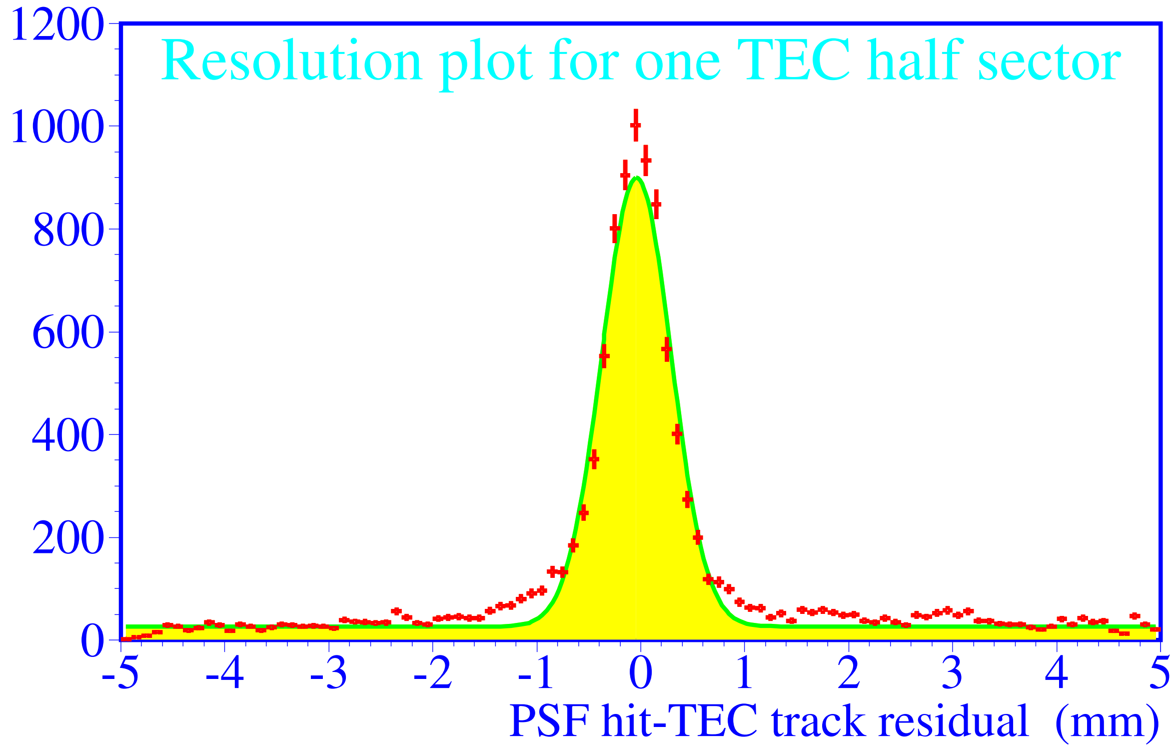
$$\textbf{Residual} = \mathbf{d_{PSF} - d_{Track}}$$



PSF resolution

Measured resolution is a convolution of:

– **Heaviside response function:** $(570/\sqrt{12} = 165)\mu\mathrm{m}$
– **(Unknown) efficiency profile of fibres**
– **(Unknown) variations of fibre position along axis**
– **TEC track position extrapolation error:** $\sim 50\mu\mathrm{m}$



Average PSF resolution : $\sigma_{\mathrm{PSF}} = 245\mu\mathrm{m}$

Signal to noise ratio is typically 20:1

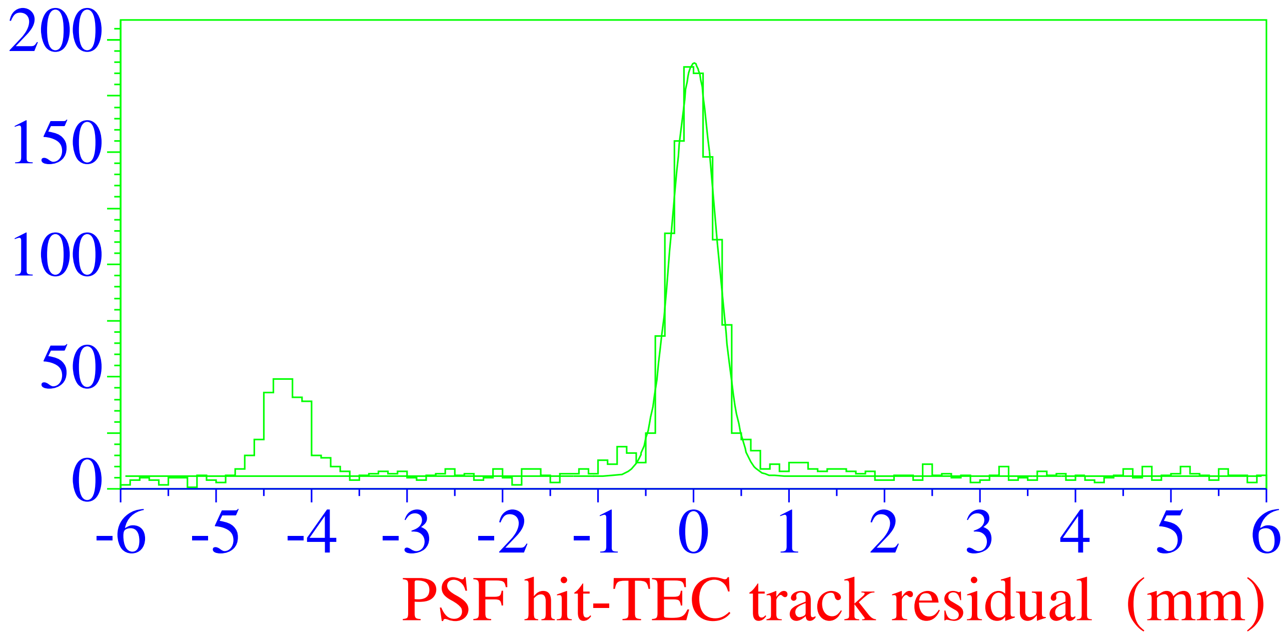
Cross-talk

There is a 5% probability for an extra hit in an adjacent fibre due to showering in the 4mm Al TEC cylinder. (light leakage between fibres is negligible)

No evidence for cross-talk on the MCP tube was found

One single pair of adjacent MX4 channels fired always

Some MCP tubes were slightly misaligned with the face-plate $\Rightarrow$ fibres could give signals on two anodes



Measured PSF efficiency

The Intrinsic PSF efficiency is the probability that a track, traversing the *active* part of a ribbon, produces a PSF hit.

Corrections have been applied for :

- **The 83% $r\phi$ geometrical acceptance of PSF *cf* TEC**
- **The 19% loss in opaque cladding between fibres**
- **Signal to noise ratio (on average 20:1)**
- **Broken fibres (less than 1% of total)**

$\boxed{\textbf{Mean efficiency of PSF = 25\%}}$

Maximum observed efficiency was 40%

There has been no observable efficiency drop in time

Losses of efficiency

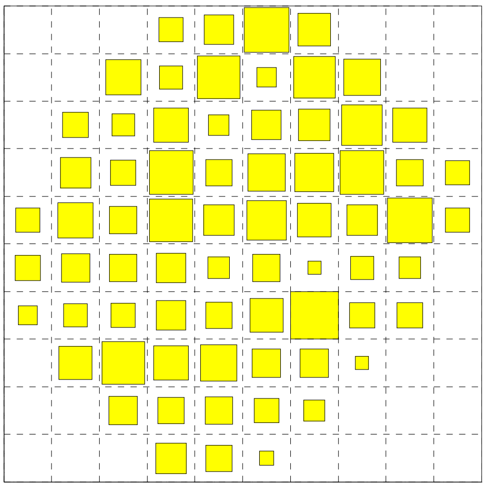
From measurements in the laboratory, expect:

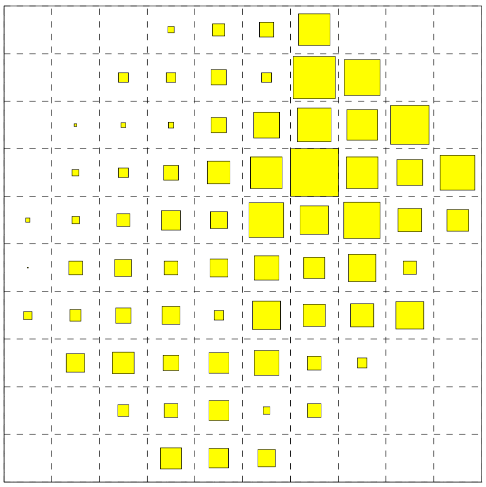
$$\langle \text{number of photoelectrons} \rangle \approx 1$$

Which corresponds to an expected efficiency of $\sim 60\%$

Causes of lower than expected efficiency:

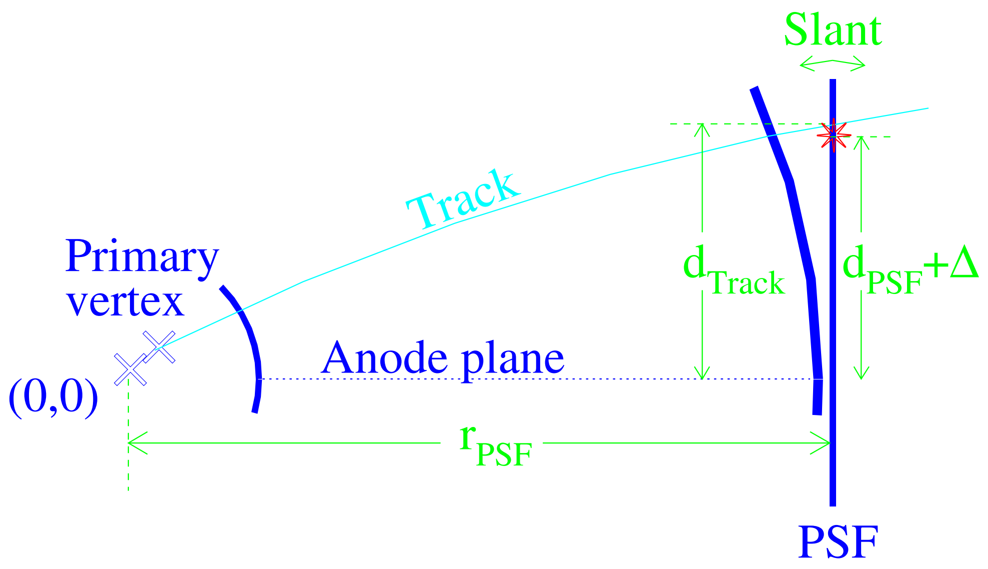
- **MX4 microplex chip "degradation" (pedestal variations and possible gain loss)**
- **Scintillator crazing and fibre damage**
- **Poor optical coupling at fibre–tube interface:**





PSF geometry & alignment

Align PSF using tracks from hadronic events (reduce correlations by using curved tracks)



Degree of freedom	Required precision	Measured precision
Radius, r_{PSF}	500μm	$\sim$100μm
Offset, Δ	Not critical	$\sim$10μm
Slant	10mrad	$\sim$1mrad

Results are almost independent of drift velocity

Temperature effects are negligible :

Δ(Radius of PSF ribbon) $\sim$ 10μm / °C
Δ(Width of PSF ribbon) $\sim$ 1μm / °C

PSF fibre pitch

Pitch is separation of equivalent points on adjacent fibres

$$\boxed{\textbf{Nominal pitch} = 700\mu\mathrm{m}}$$

Pitch is $\sim$100% correlated with drift velocity $\Rightarrow$

cannot be independently measured with tracks

Measure pitch directly on a precise milling machine:

$$\boxed{\langle \mathrm{pitch} \rangle = 697 \pm 1\mu\mathrm{m}}$$

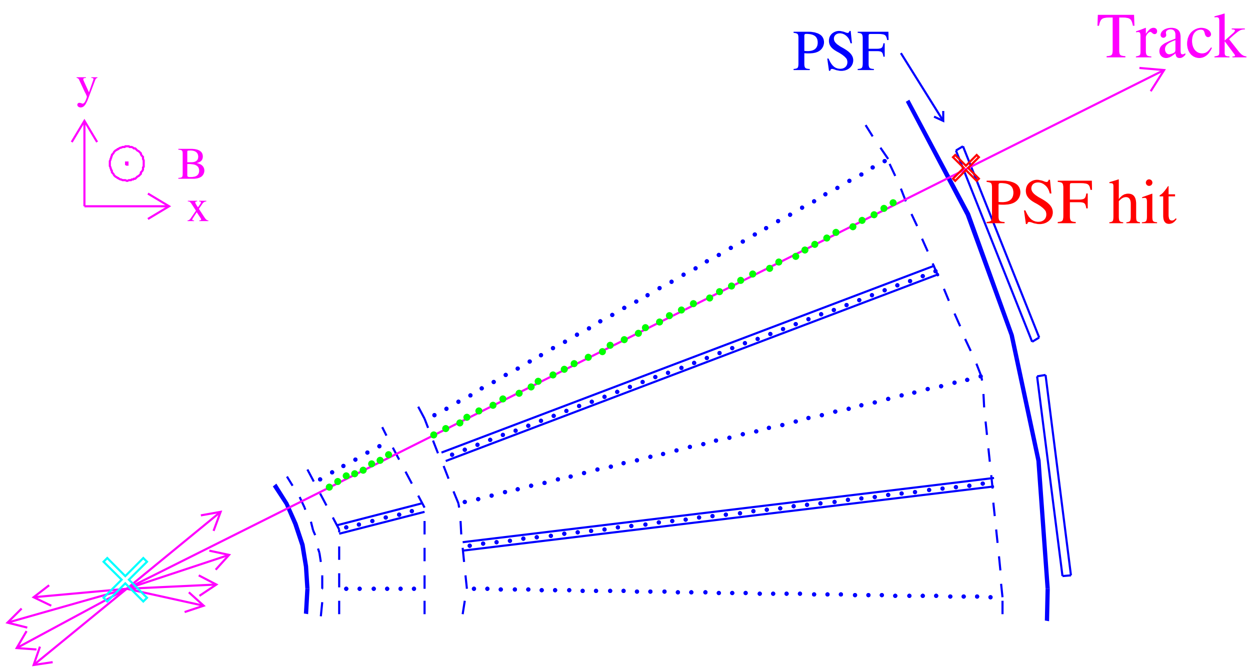
Measurement is inconsistent with expectation $\Rightarrow$
pitch uncertainty is $\mathcal{O}(3\mu\mathrm{m})$

The pitch error translates into an error in drift velocity

PSF calibration method

Calibration uses good tracks in hadronic events and exploits the following constraints:

1. TEC drift distance–time relation is linear
2. Tracks are circles
3. Tracks pass through the beam centroid
4. Continuity (average residuals zero for each anode as a function of drift time $\Rightarrow$ inner/outer TEC matching)
5. Residuals of PSF hits and tracks are zero



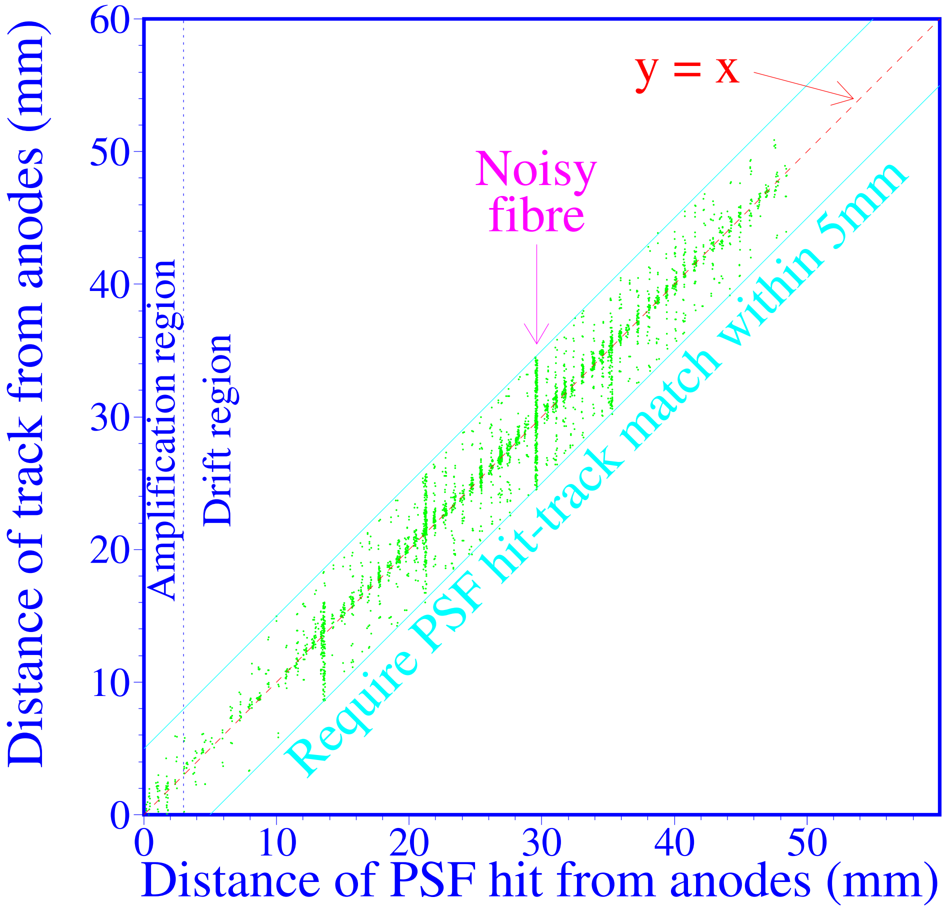
Linearity of TEC

TEC is run with saturated drift velocity ⇒

$$d_{\text{drift}} = c + v_{\text{drift}} t_{\text{drift}}$$

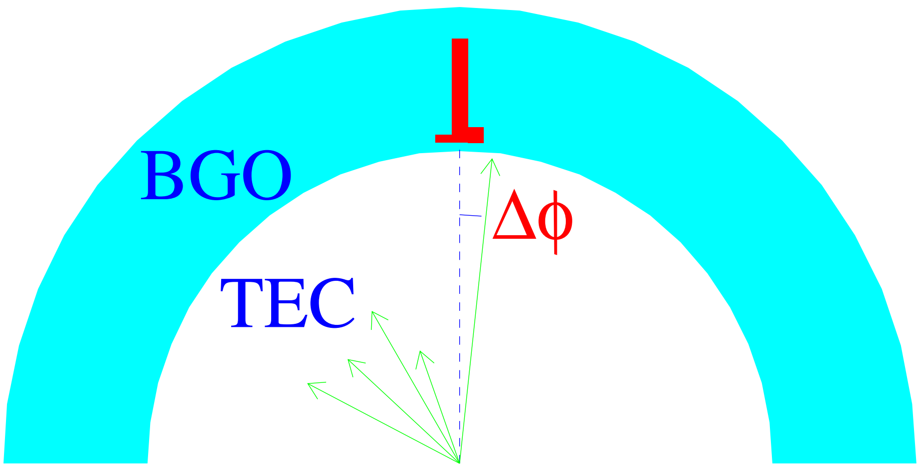
Must verify linearity of drift distance–time relation

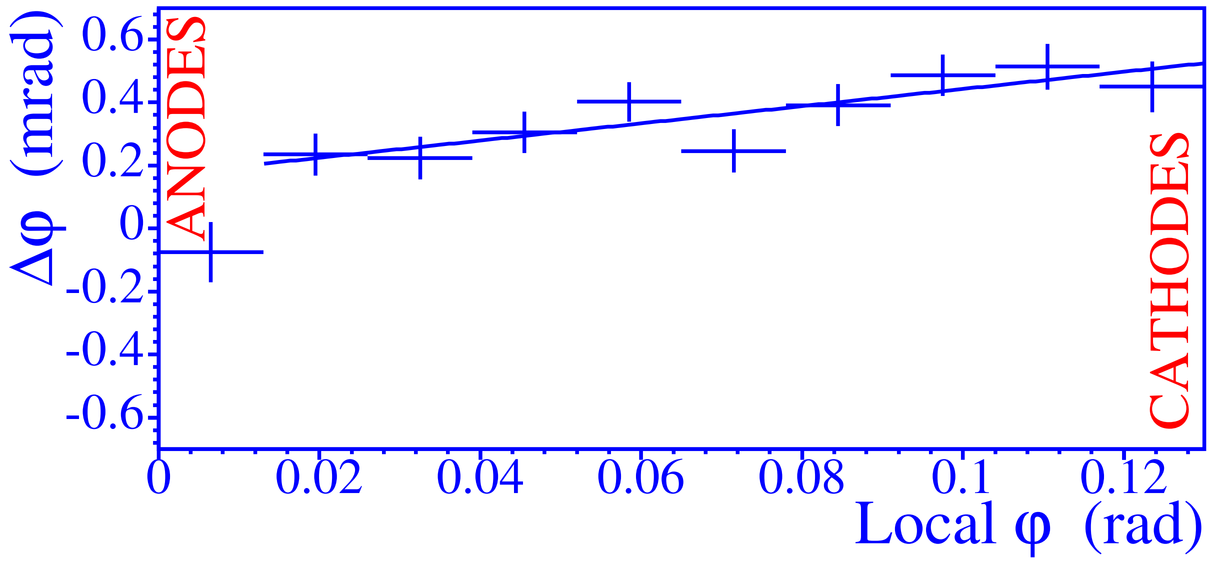
Compare perpendicular distance (from anode planes) of PSF hit and intersection of track with PSF ribbon



Linearity of TEC

Check track ϕ match with clusters in BGO electromagnetic calorimeter for 45GeV electrons in $Z \rightarrow e^+e^-$ events





$\Rightarrow$ TEC is linear to (a few)$\times$0.1%

PSF calibration method

STEP 1.

Fit hits on (circular) tracks assuming $d_{\rm drift} = c + v_{\rm drift} t_{\rm drift}$ allowing for the Lorentz angle of α ≈2.4°

STEP 2.

For <u>each anode</u> plot: $\langle \text{hit residual} \rangle$ *vs.* $t_{\rm drift}$

Fit plot with : $\langle \text{residual} \rangle = \Delta c + \Delta v_{\rm drift} \times t_{\rm drift}$

STEP 3.

Apply corrections, Δc & $\Delta v_{\rm drift}$ to constants c & $v_{\rm drift}$

STEP 4.

Look at SLOPE of residuals of track with PSF hits

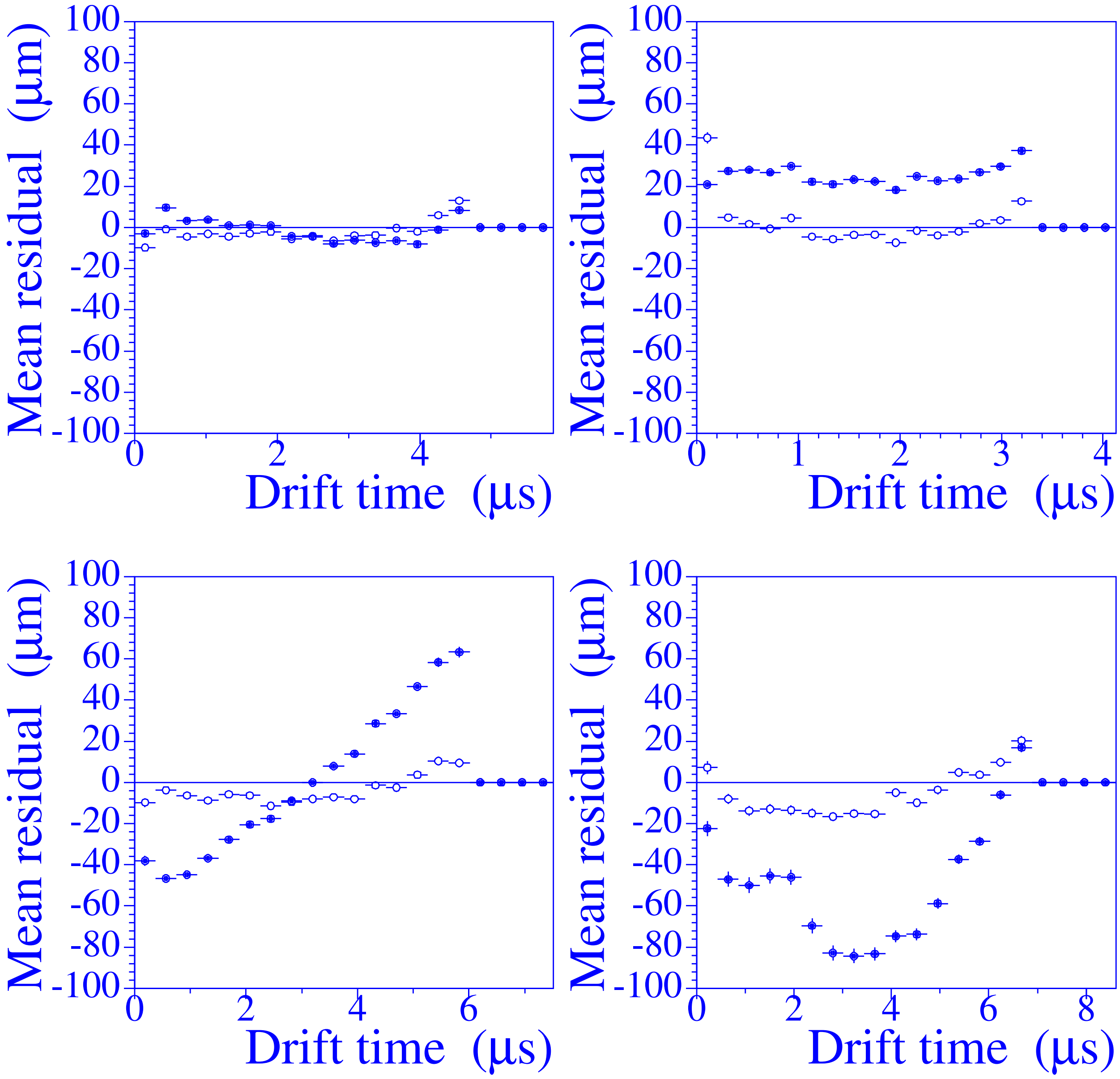
$\Rightarrow$ global $v_{\rm drift}$ correction for each half sector

STEP 5.

Repeat steps 1.-4. until all corrections $\longrightarrow$ 0 ($\sim$ 5 iterations)

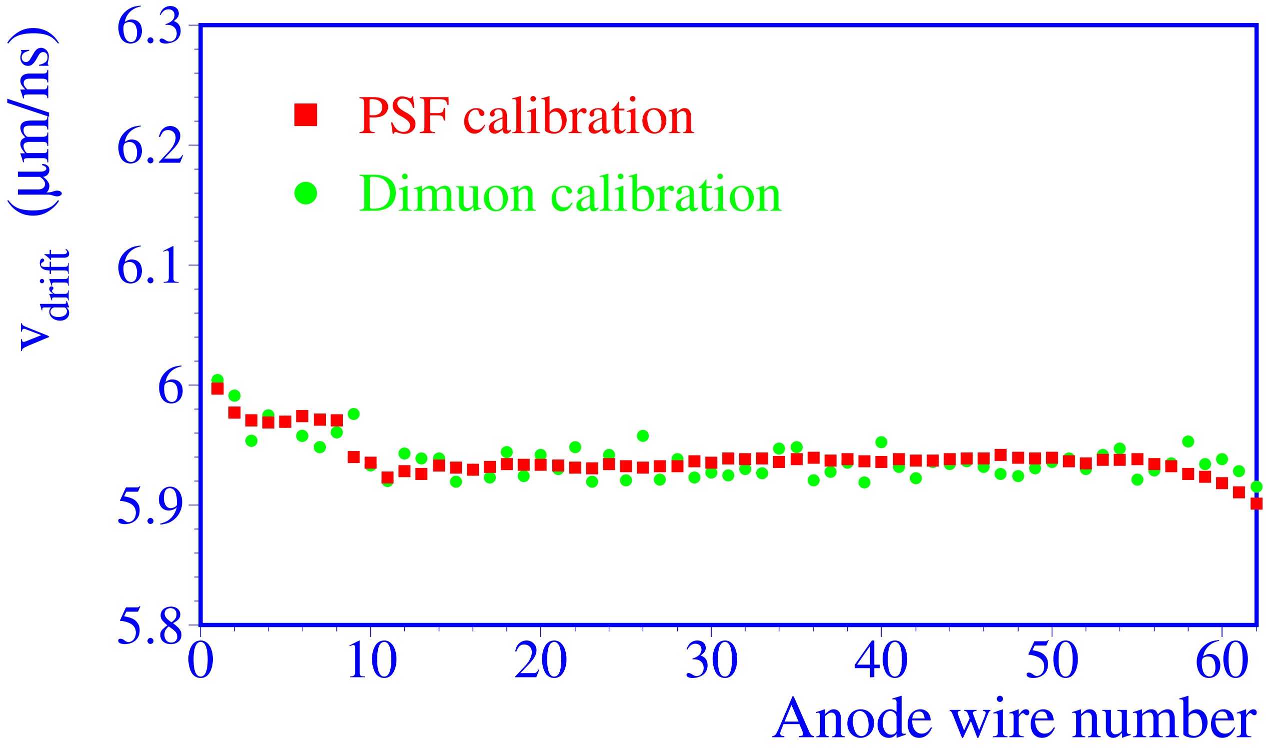
Single wire residuals *vs.* t_{drift}

- ○ **PSF calibration**
- ● **Dimuon calibration**



Drift velocities from PSF

All anodes of one half-sector (∼20 000 Z ⟶ q$\bar{q}$ events)

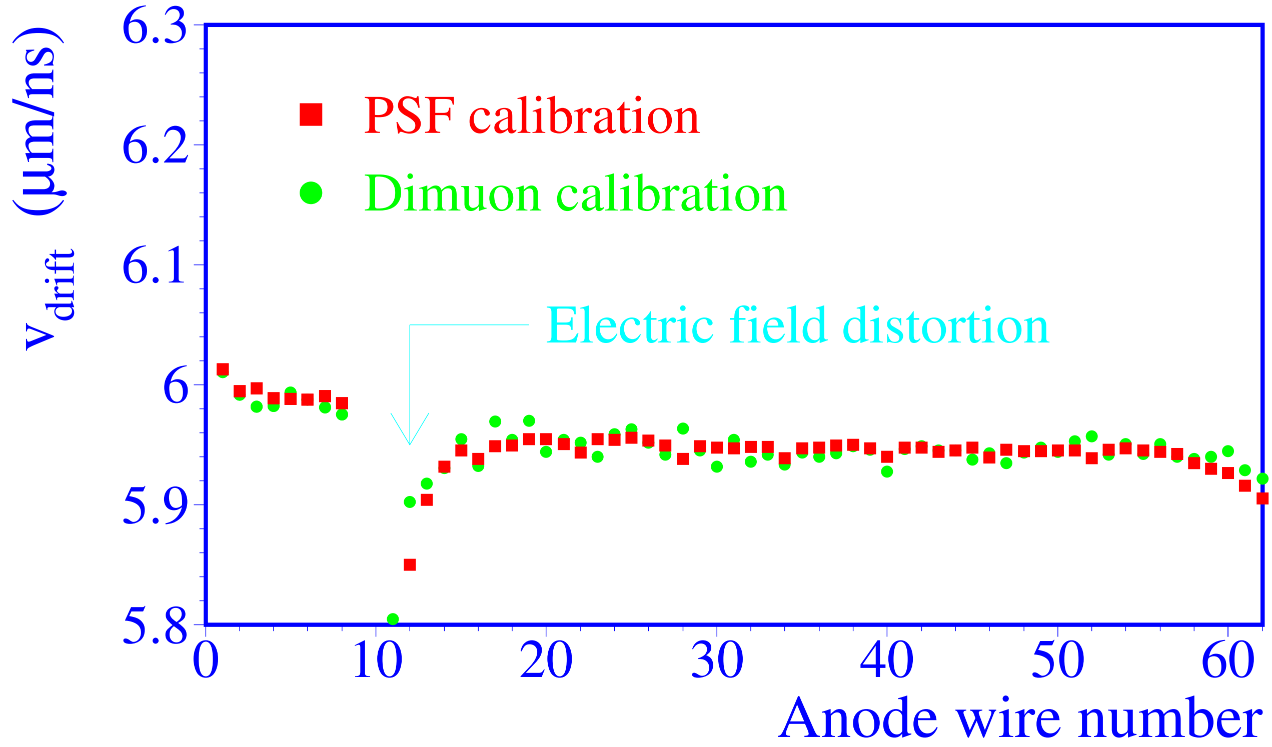


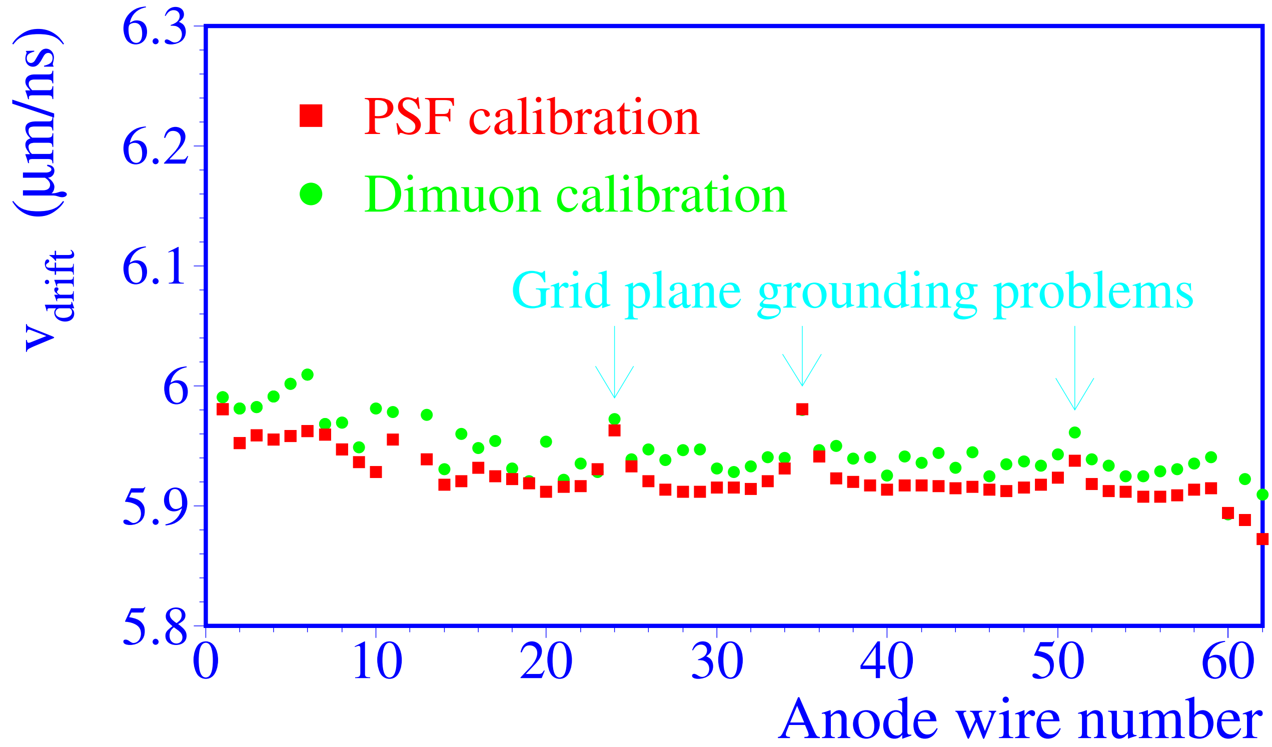
Two methods are compatible (PSF has smaller errors)

Statistical error: $\sigma(v_{\text{drift}}) \approx 0.1\,\%/\text{anode}$

Uncertainty in fibre pitch ⇒ $\dfrac{\Delta v_{\text{drift}}}{v_{\text{drift}}} \approx 0.5\%$

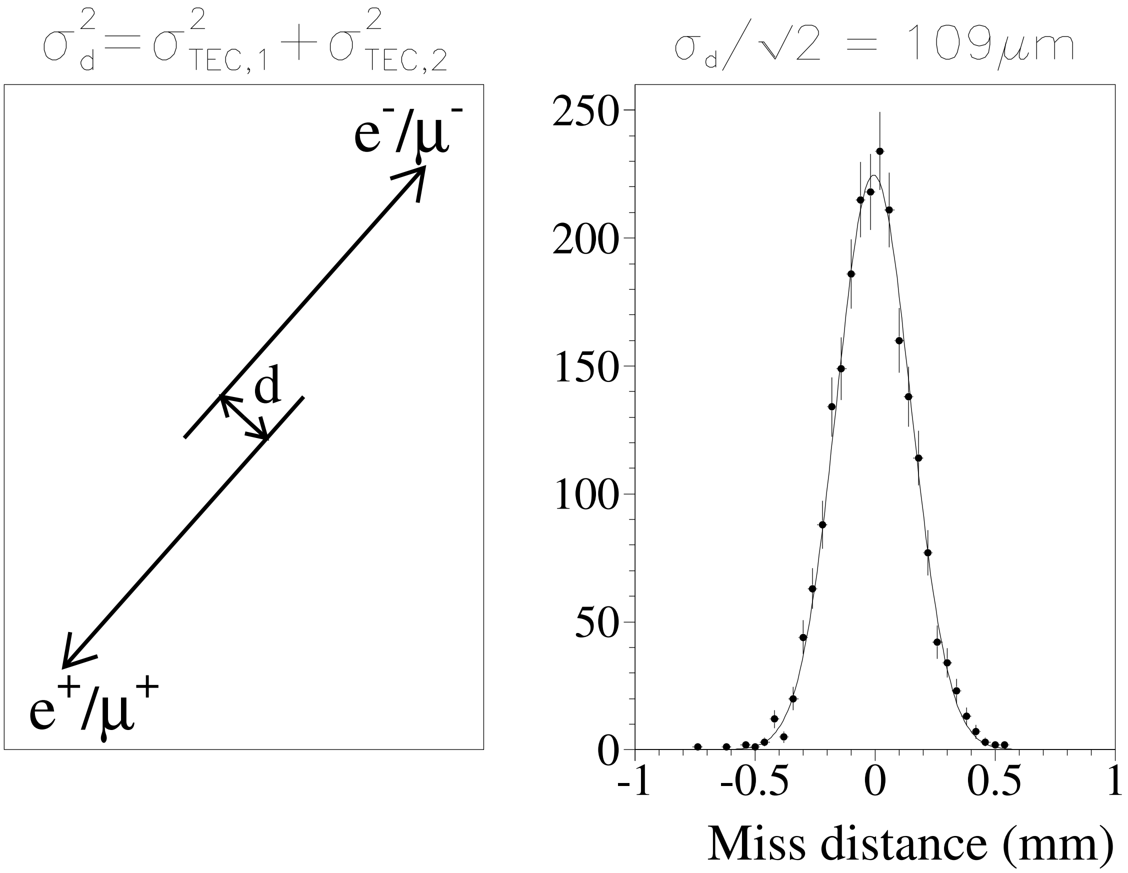
Drift velocities from PSF





Impact parameter resolution

In Bhabha and dimuon events, measure track separation at origin $\Rightarrow$ independent of beam position & size



$$\boxed{\sigma_\delta = 109\mu\mathrm{m}}$$

(Using dimuon calibration method: $\sigma_\delta = 142\mu\mathrm{m}$)

p_t resolution

To obtain the p_{T} resolution, compare muon tracks in TEC to measurement in the muon spectrometer for:

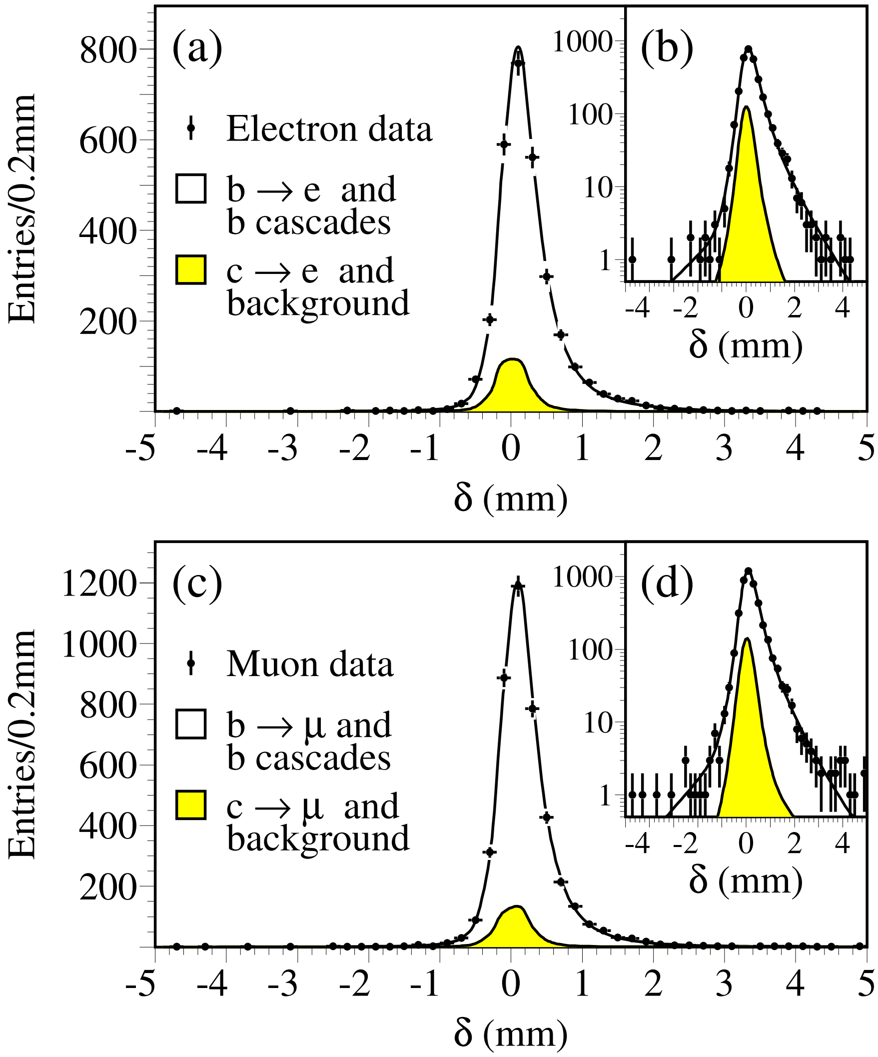
$$\mathrm{Z} \longrightarrow \mu^+\mu^-$$

$$\mathrm{Z} \longrightarrow \tau^+\tau^-; \quad \tau \longrightarrow \mu$$

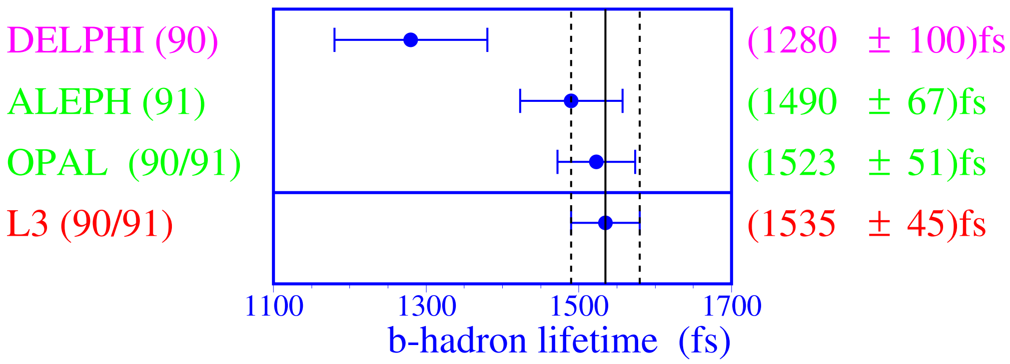
Comparison of Calibration methods

	Predicted	Dimuons	PSF
$\sigma(1/p_{\mathrm{T}})$ (GeV^{-1})	$\sim$0.017	$\sim$0.023	$\sim$0.026
Impact parameter resolution (μm)	$\sim$105	$\sim$142μm	$\sim$109μm

The average b-lifetime



Comparison of LEP experiments



Conclusions

The L3 PSF calibration system is working with:

- **excellent resolution (245μm)**
- **adequate efficiency ($\sim$25%)**
- **no problems from noise or cross-talk**

The resulting TEC resolutions are close to design:

- **impact parameter:** $\sigma_\delta = 109\mu m$
- **transverse momentum:** $\sigma(1/p_{\mathrm{T}}) = 0.026\,\mathrm{GeV}^{-1}$

A precise knowledge of the internal and external geometry of the L3 PSF fibre system was essential $\Rightarrow$

The data should be sufficient to align a fibre system