PAUL SCHERRER INSTITUT

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Mott Scattering
A Dedicated Calibration Method for the MEG Positron Spectrometer

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on behalf of the MEG Collaboration

PhD Seminar 2014

A very brief introduction to MEG

Search for the **charged lepton flavour violating** decay

$$\boldsymbol{\mu^+ \rightarrow e^+ + \gamma}$$

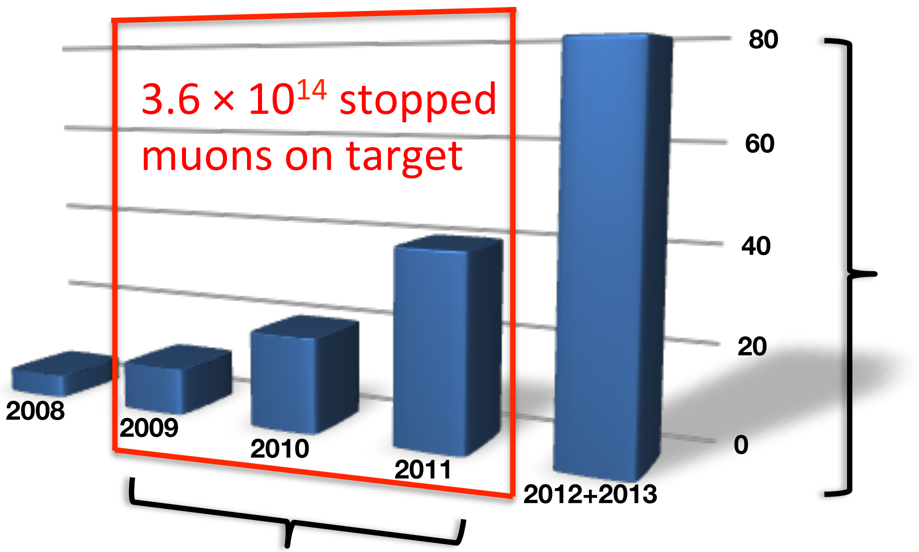
with a sensitivity of few × 10^{-13}

Standard Model (with massive neutrinos) $BR(\mu \rightarrow e + \gamma) \approx O(10^{-54})$	Beyond the SM physics $BR(\mu \rightarrow e + \gamma) \approx O(10^{-11})\text{-}O(10^{-14})$

Observation would be clear evidence for BSM physics!

Null result provides constraints on BSM models

MEGs current status



analysis of 2012 and 2013 sample currently underway

upper limit on BR($\mu \rightarrow e + \gamma$)
5.7×10^{-13} @ 90% CL

Phys. Rev. Lett. 110, 201801, published 13 May 2013

a new calibration method for the MEG spectrometer enters the stage...

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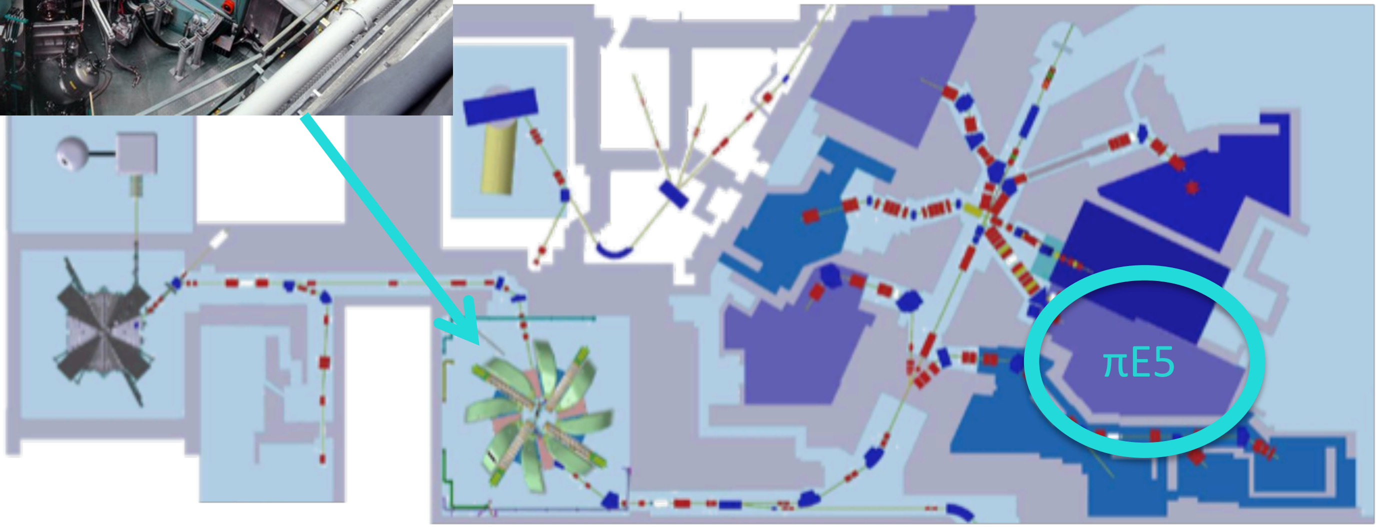
a new calibration method for the MEG spectrometer enters the stage...

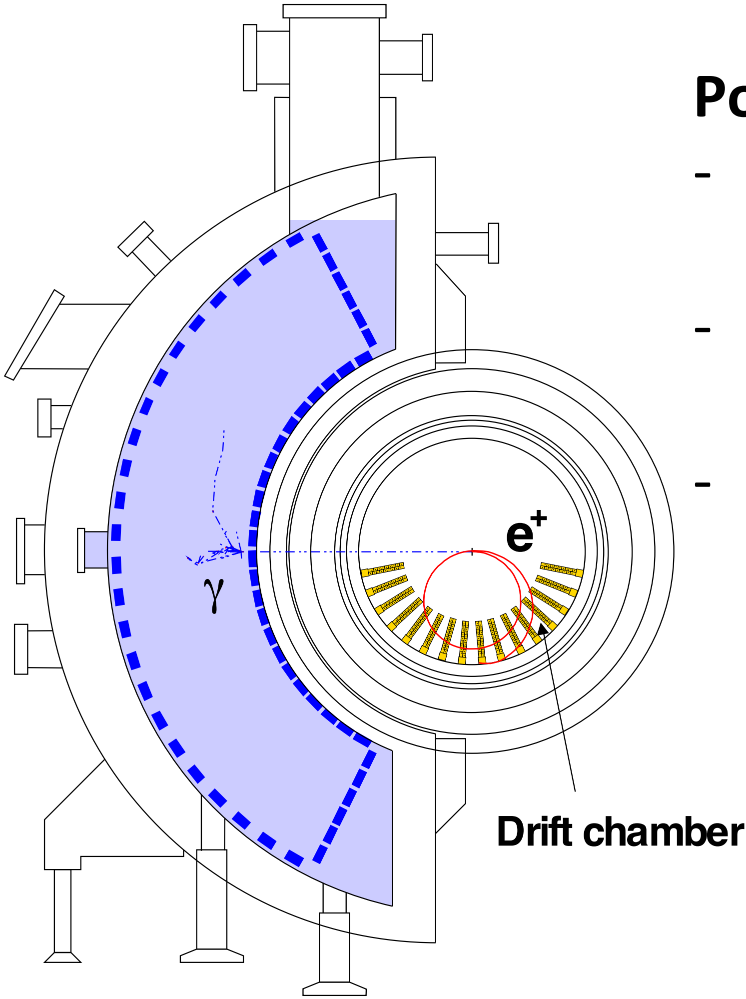
... **Mott scattering of positrons**

MEG's location

Using one of the world's most intense continuous positive surface muon beams O(10^8 μ/sec) at the Paul Scherrer Institut, Switzerland



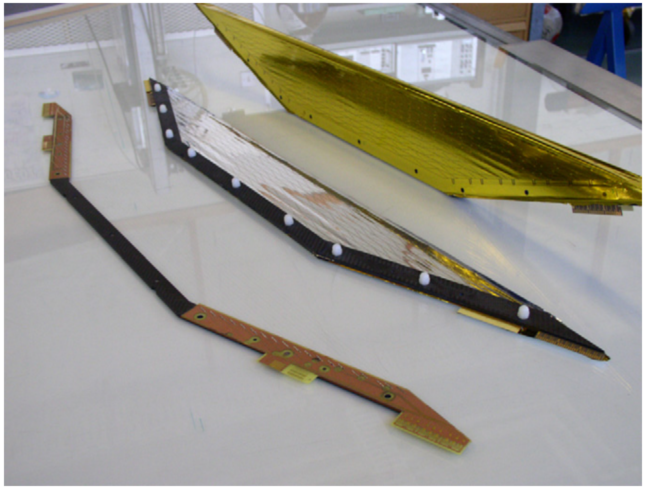
MEG experimental apparatus



Eur. Phys. J. C, 73 (2013) 2365

Positron Spectrometer

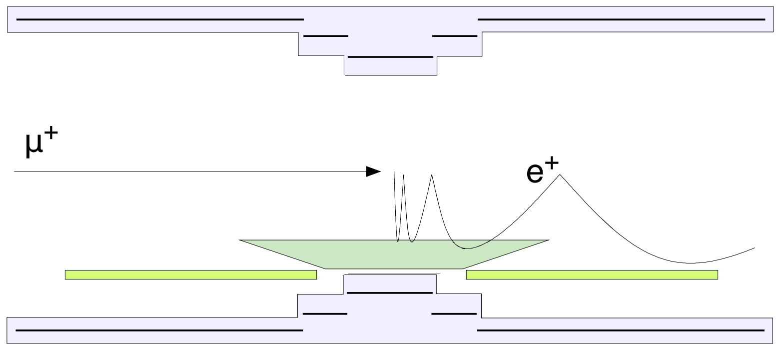
- Low mass Drift Chamber system for e^+ kinematic measurement
- COBRA gradient magnetic field (~ 1.3 T @ center)
- Scintillating bars for e^+ timing



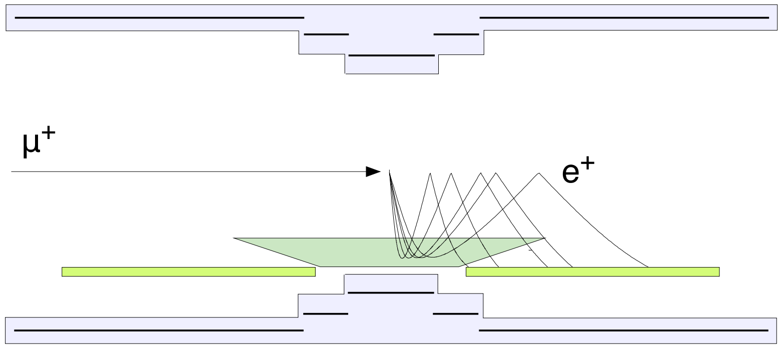
MEG experimental apparatus

COBRA = **CO**nstant **B**ending **Ra**dius
gradient magnetic field

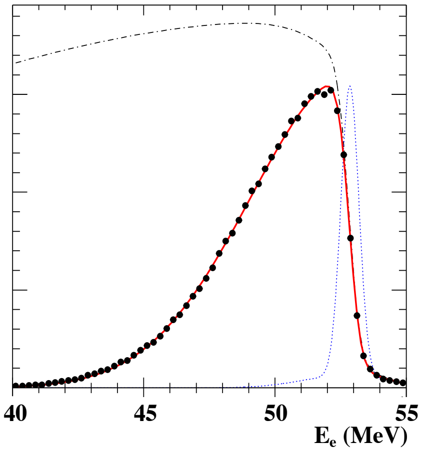
quickly sweep away particles emitted at polar angles θ ≈ 90°



projected bending radius independent of polar angle θ



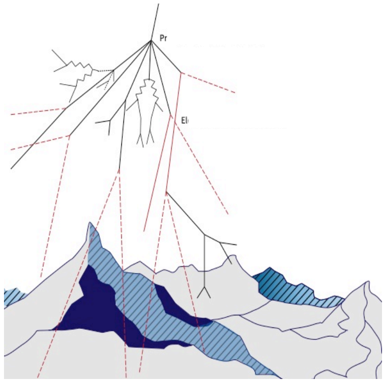
Calibration of the e^+ spectrometer



Michel Decay

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

- DC alignment
- extraction of e^+ variables‘ resolutions
- target alignment
- ....

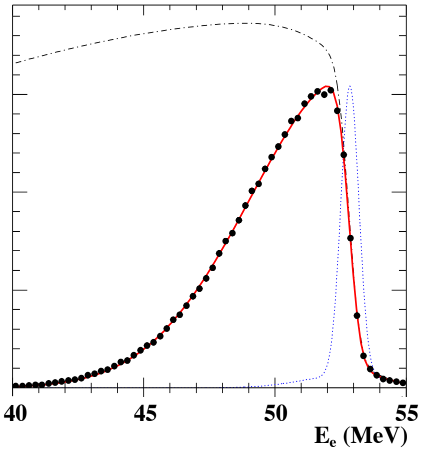


Cosmic Rays

- DC alignment
- Relative alignment of subdetectors
- TC calibration
- ....

picture from http://www.weltderphysik.de

Calibration of the e^+ spectrometer



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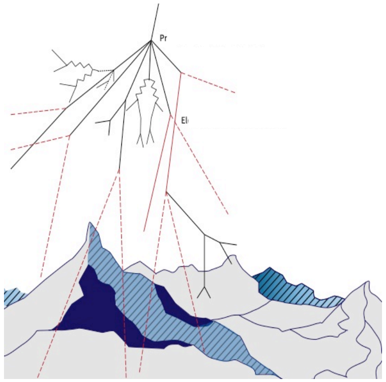

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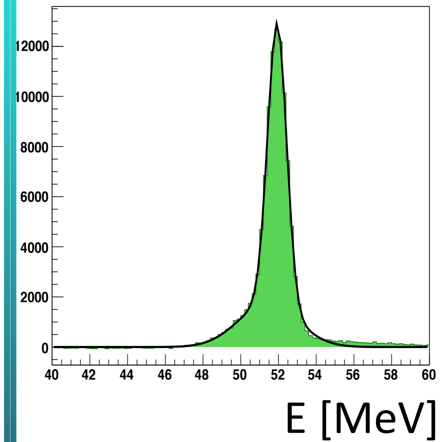
NEW



Monochromatic e^+ Beam

"line" instead of an "edge"

↓

perform some of the above-mentioned tasks in a **totally independent way**

How the Mott method works

- Make use of a **monochromatic, momentum-tunable positron beam** at p ≈ 53 MeV/c **close to the MEG signal 52.8 MeV/c** with an intrinsic beam spread of ≈ 250 - 350 keV/c
- Allow positrons to **Mott scatter** off the MEG target (= light nuclei, 205 μm thickness)
- Mott cross section well-known

$$\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2 Z^2}{Q^4}\left(1 - \frac{Q^2}{4p_0^2}\right)\left|F(Q^2)\right|^2$$

with $F(Q^2)$ nuclear form factor, Z nuclear charge

momentum transfer Q

$$Q^2 = 4pp_0 \sin^2\frac{\theta}{2}$$

$$p = \frac{p_0}{1 + \frac{p_0}{M}(1 - \cos\theta)}$$

with p_0, p = initial, final momentum
M nuclear mass

Mott data sample 2012

First high statistics data sample (ca. 5 days of DAQ), described well by Monte Carlo simulation with positron beam energy at 52 MeV/c and a beam spread of 350 keV/c

$\sigma_{tot}^2 = \sigma_{Mott}^2 + \sigma_{beam}^2$

measured

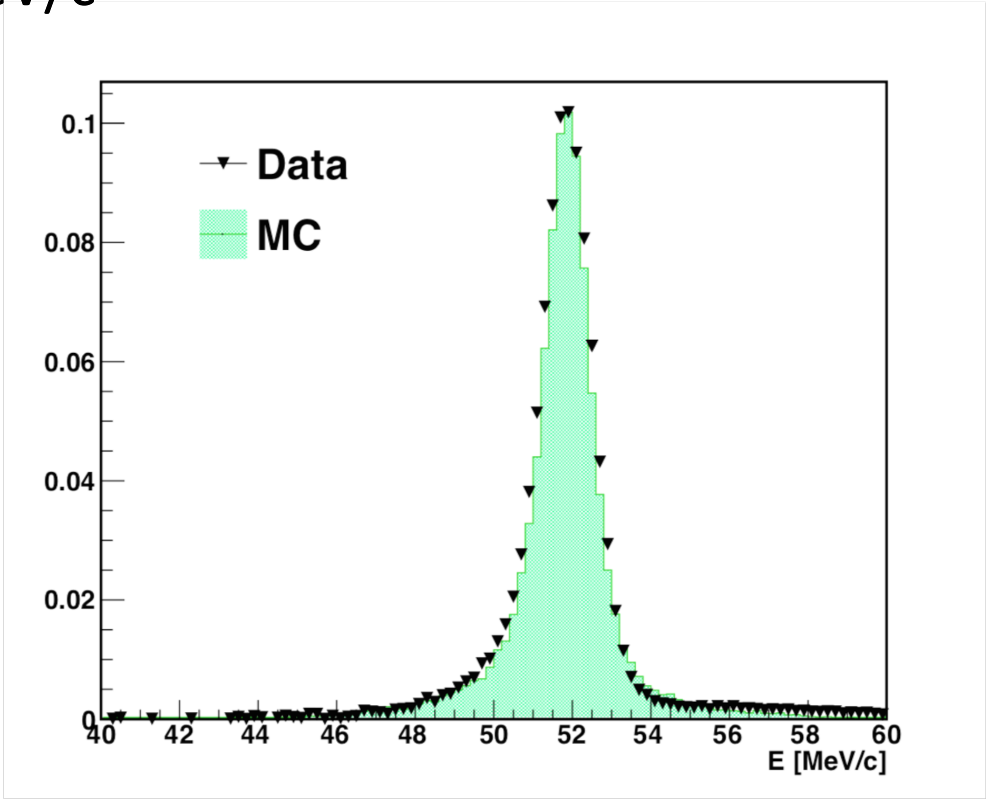
$\sigma_{tot} \approx 500 \pm 20$ keV/c

from MC simulation

$\sigma_{beam} \approx 350$ keV/c

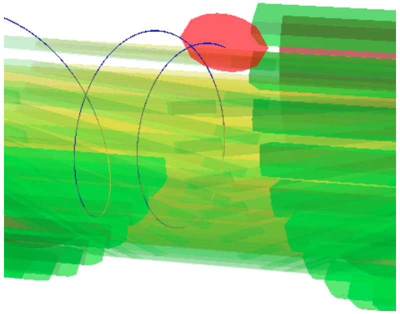
consistent with

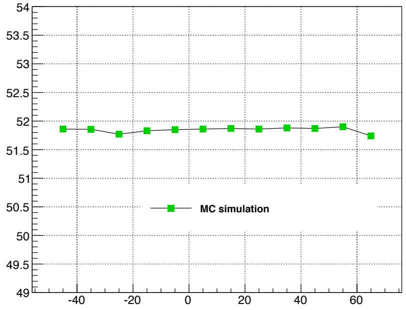
$\sigma_{Mott} \approx 350$ keV/c



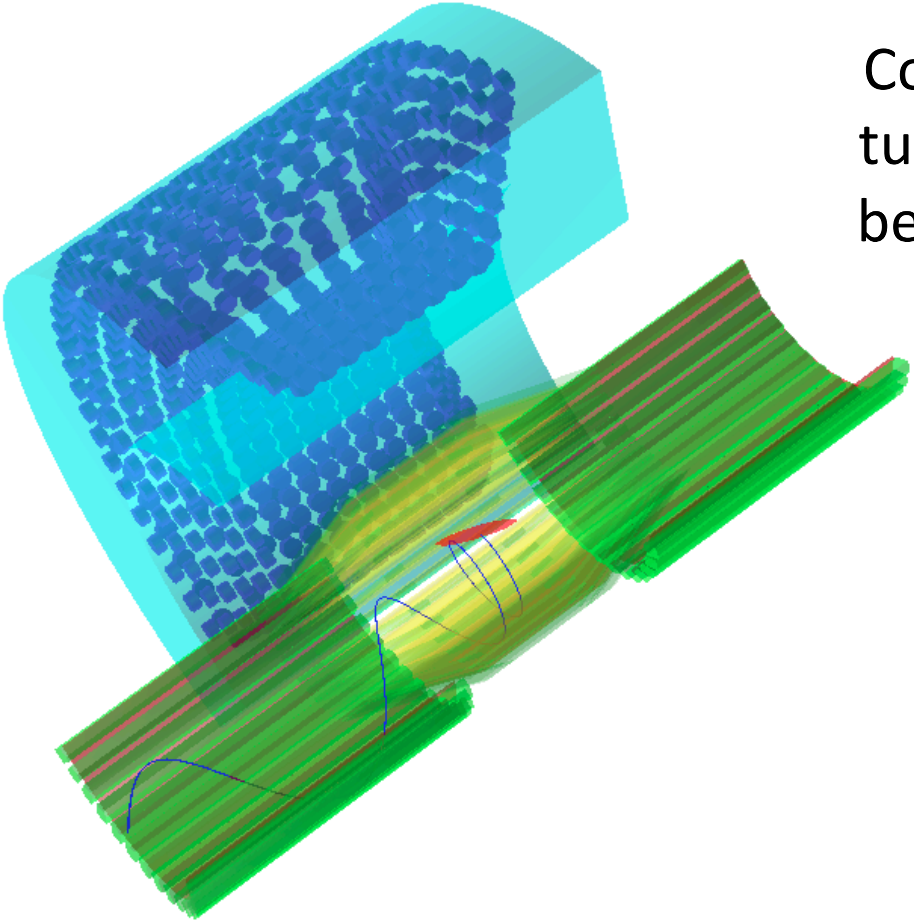
What can we do with Mott data?

- **Positron momentum and angular resolutions from double turn tracks ("double turn resolutions")**
- **Drift chamber alignment**
- Detector efficiency and acceptance to extract muon beam polarization
- Track reconstruction validation
- Hints on faulty detector behavior



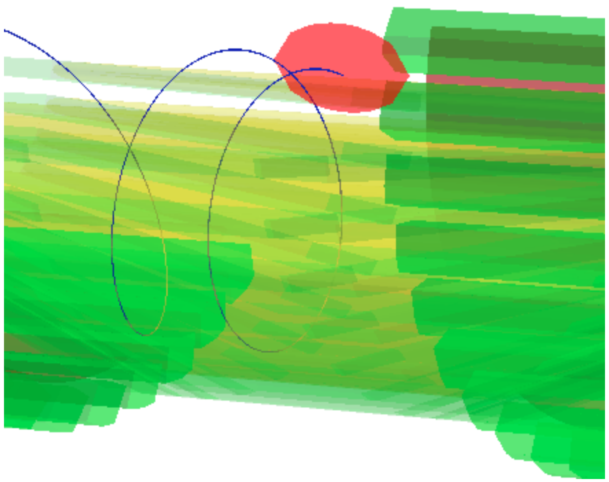


e^+ momentum & angular resolutions



Double Turn Tracks

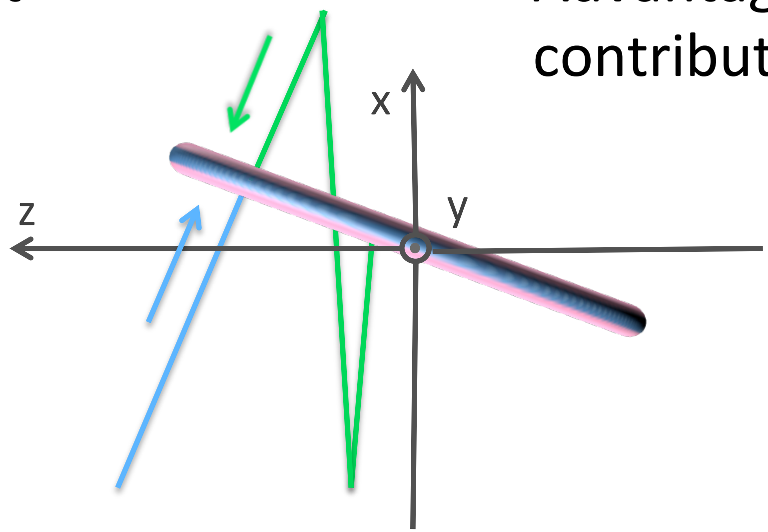
Consider tracks which make two turns in the drift chamber region before hitting the timing counter



e^+ momentum & angular resolutions

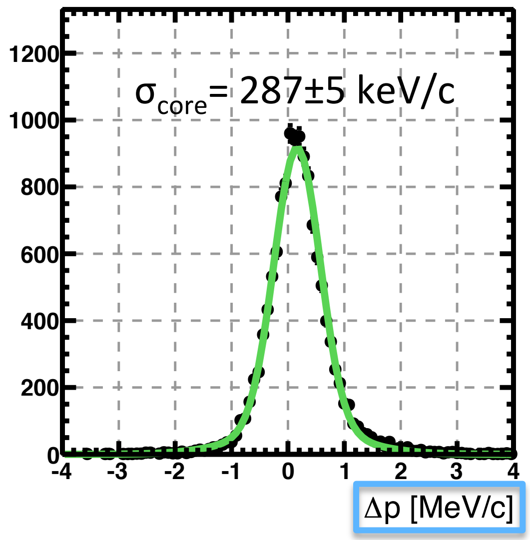
How to extract them?

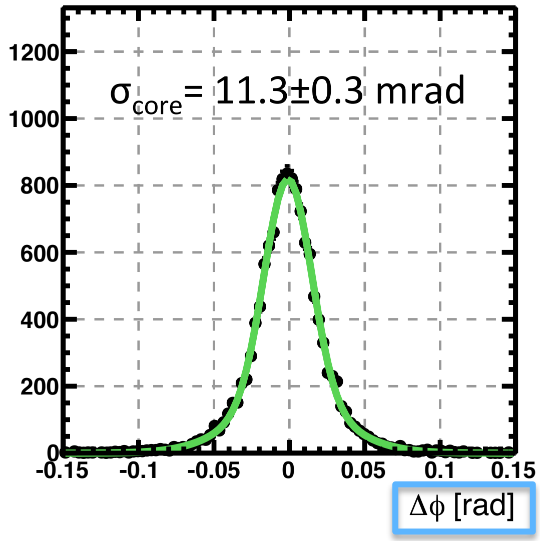
Advantage: Removes contribution of beam spread

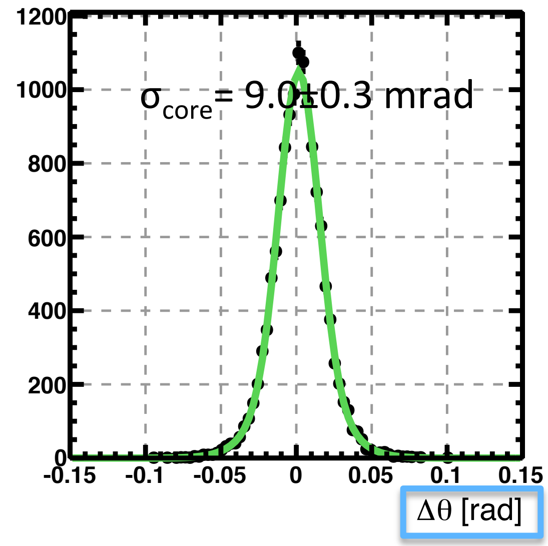


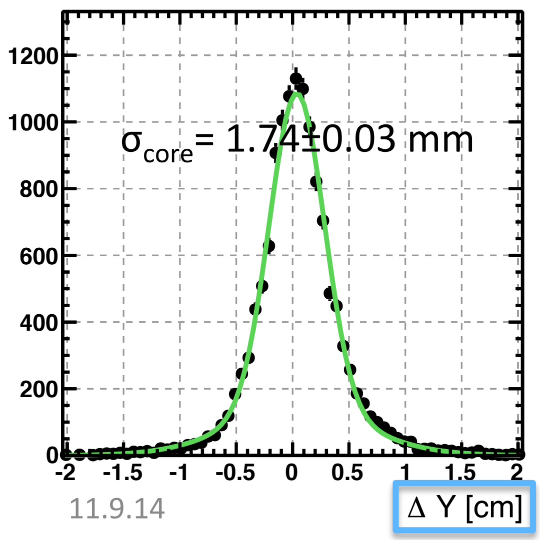
- treat the two turns independently
- propagate turn 1 and turn 2 to the target
- compute the difference ($A_{turn\ 1} - A_{turn\ 2}$) for A= p, ϕ, θ, y,z

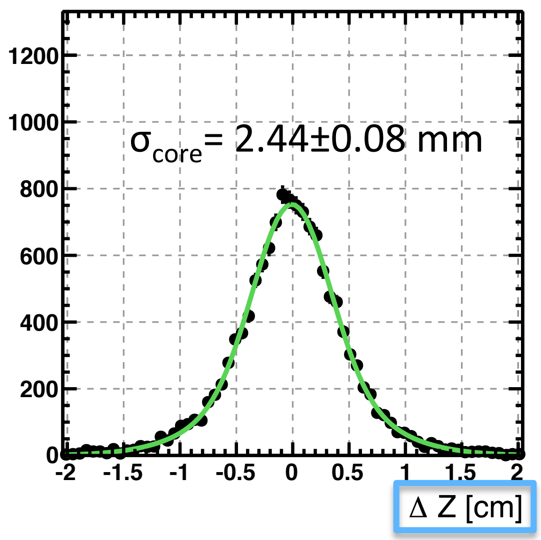
e^+ momentum & angular resolutions











observables

A= p, ϕ, θ, y, z

Mott DT resolutions consistent with DT resolutions obtained from Michel decay data

Check of Drift Chamber alignment

- Different methods to align the drift chamber exist
- An independent way to compare different alignment methods: use Mott data!

Idea: Mott scattering has no ϕ-dependence ➔ peak position of the Mott line as a function of ϕ should be constant

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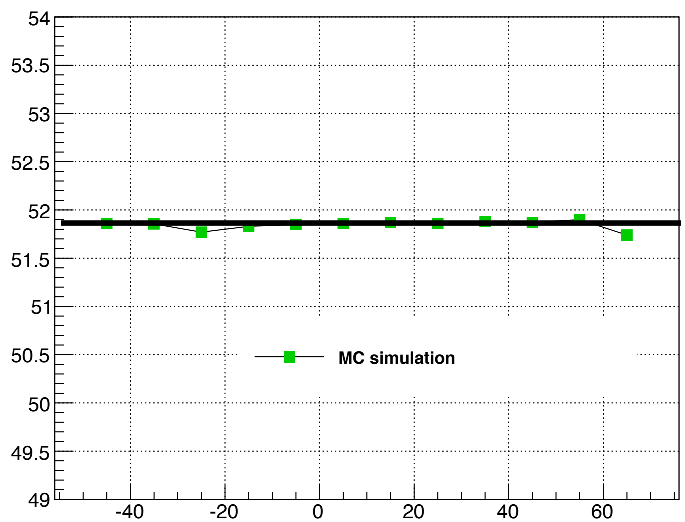
p [MeV/c]



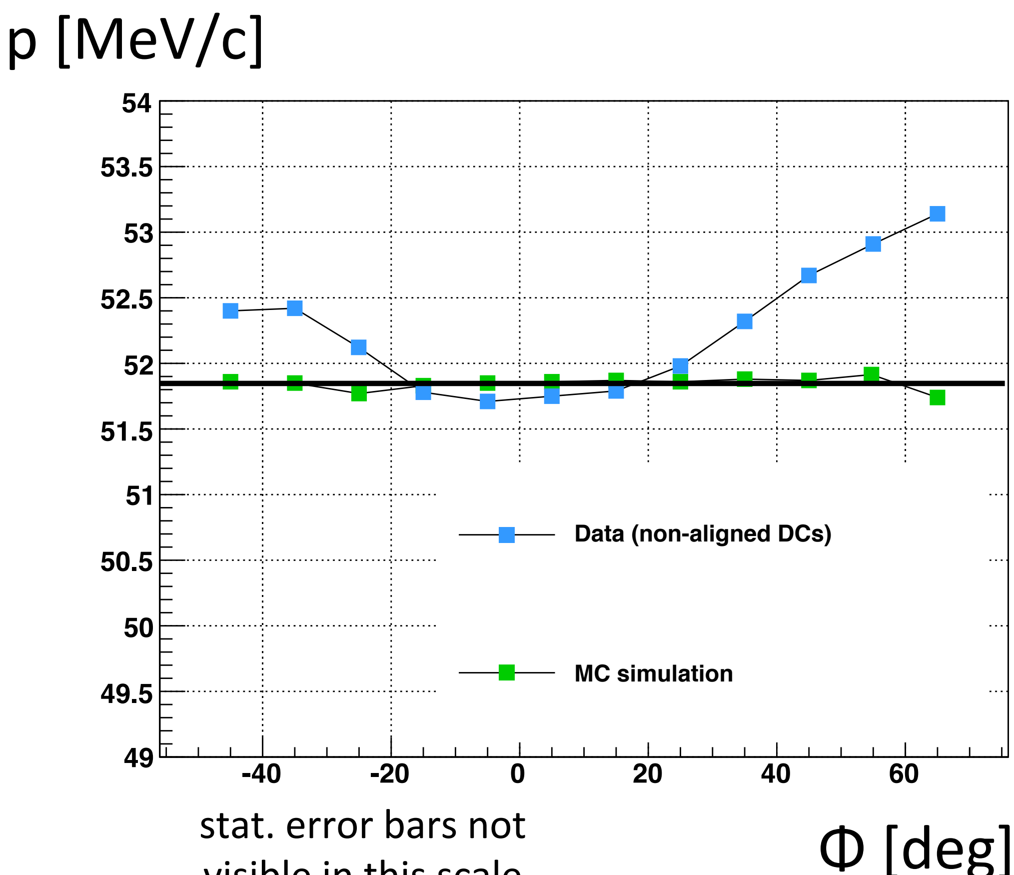
Monte Carlo simulation

stat. error bars not visible in this scale

Φ [deg]

Check of Drift Chamber alignment

Example of non-aligned drift chambers



stat. error bars not visible in this scale

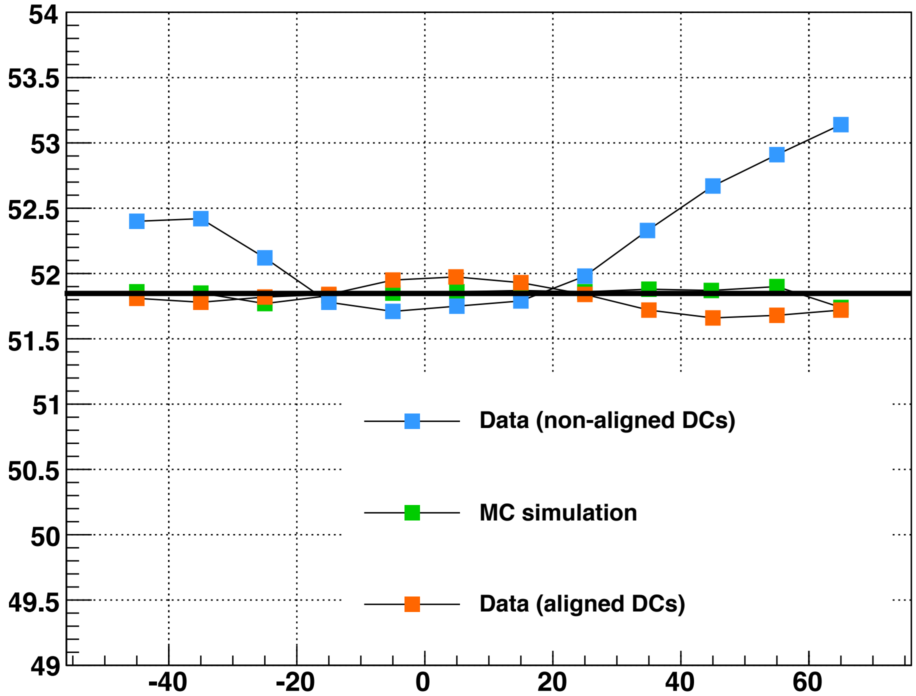
Data with non-aligned DCs

Monte Carlo simulation

Check of Drift Chamber alignment

Example of aligned drift chambers

p [MeV/c]



stat. error bars not visible in this scale

Φ [deg]

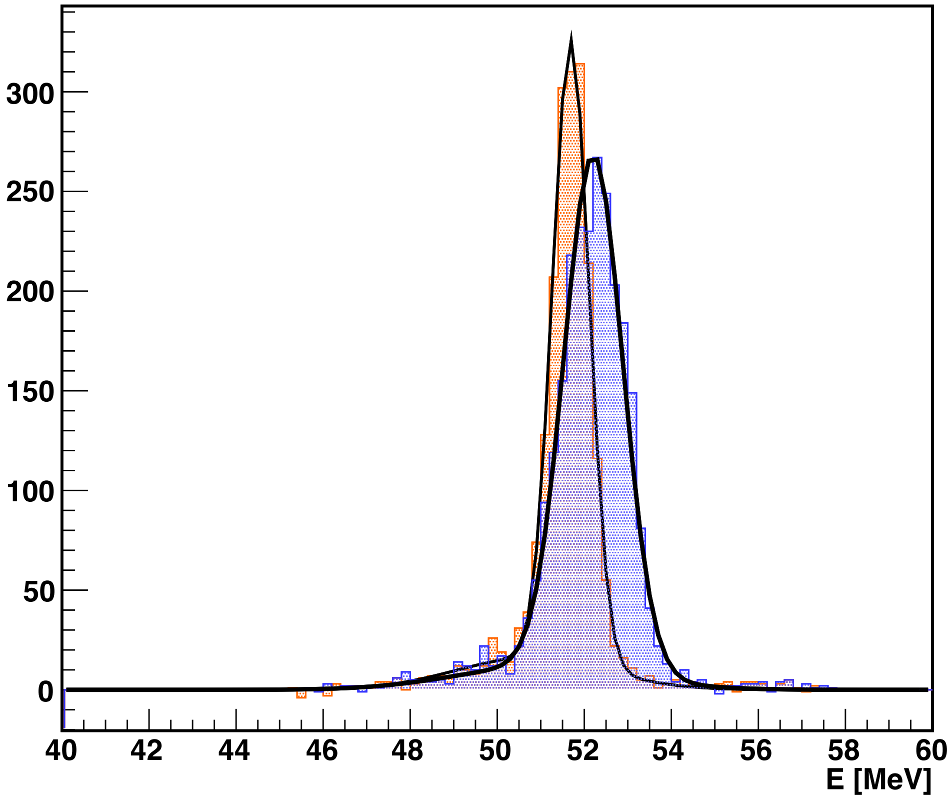
Data with non-aligned DCs

Data with aligned DCs

Monte Carlo simulation

Check of Drift Chamber alignment

Comparison Mott line for non- and aligned DCs



$\sigma_{nonaligned}$ ≈ 675 keV/c

↓

$\sigma_{aligned}$ ≈ 420 keV/c

$\mu_{nonaligned}$ ≈ 52.2 MeV/c

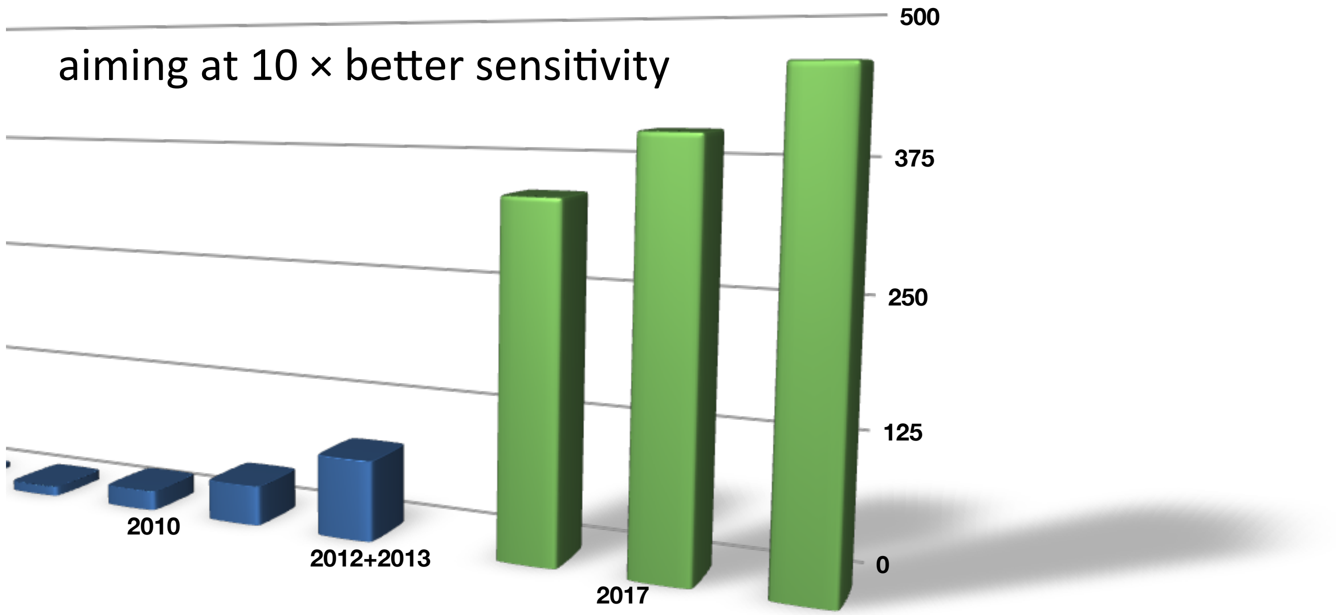
↓

$\mu_{aligned}$ ≈ 51.9 keV/c

Conclusion

- Mott scattering of positrons as calibration tool
  - Extraction of positron momentum and angular resolutions from double turn tracks
  - Check of Drift Chamber alignment
- Results are consistent with what is obtained from other kind of data
  - Gives confidence in the results and analysis techniques since based on completely independent method!

MEG II



Upgrade will include newly designed spectrometer with increased complexity – Mott calibration method will be a valuable tool!

Backup slides

DC alignment with Mott data

- What about aligning the DC with Mott data itself (as is being also done with Michel data)?
- "Software alignment": Iterative procedure

Process a set of raw data. For every chamber (treated as rigid body)...

1) ... histogram the residuals in r and z between the reconstructed tracks and their DC hits. Extract the **average residual in r and z**.

2) ... **subtract** from that particular DC's average residual **the average residual over all chambers** (such that mean residual of all chambers in both r and z equal to zero by construction)

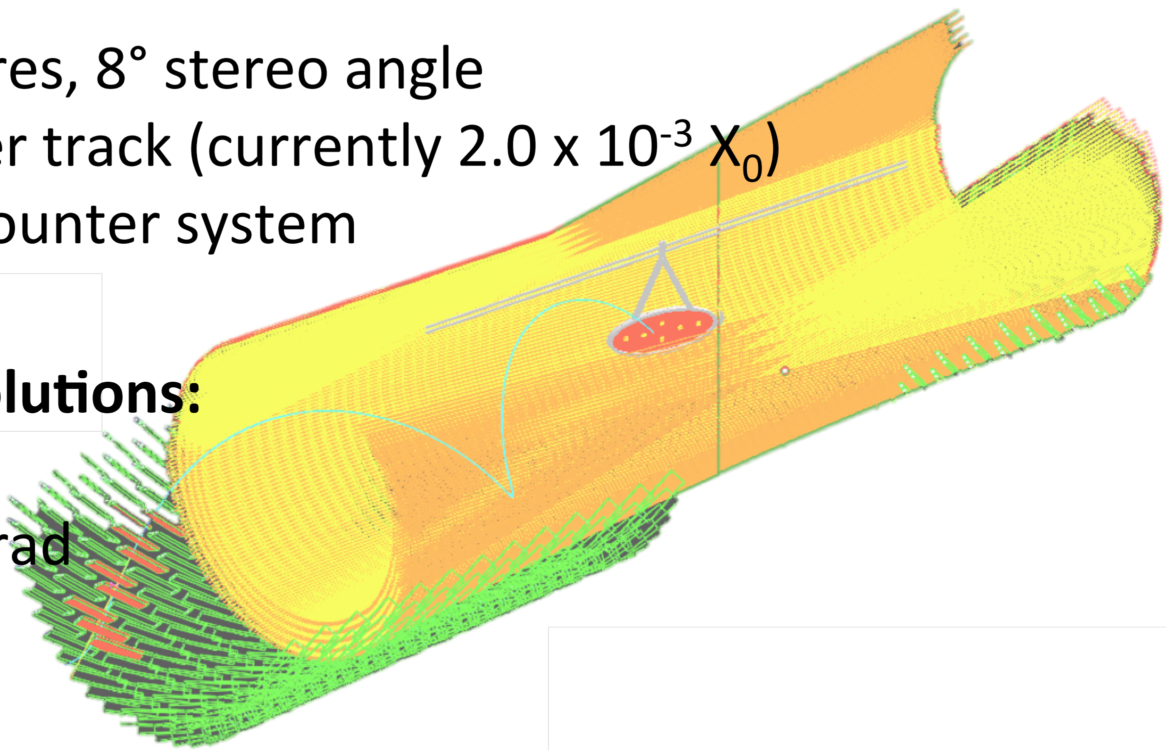
3) ... **correct** the corresponding **DC wire positions** by the amount obtained in 2) and hand them over to the data base

reanalyze the runs with the new DC wire positions

MEG II

Newly designed positron spectrometer:

- cylindrical low mass stereo-wire drift chamber system
  - 1200 sense wires, 8° stereo angle
  - $1.7 \times 10^{-3}\ X_0$ per track (currently $2.0 \times 10^{-3}\ X_0$)
- pixelated timing counter system



Aimed (current) resolutions:

$\sigma(E_e)$ ~ 150 (325) keV

$\sigma(\theta_e,\phi_e)$ ~ 5 (7-11) mrad

$\sigma(t_e)$ ~ 30 (70) ps