PAUL SCHERRER INSTITUT

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Mott Scattering
A Dedicated Calibration Method for the MEG I & MEG II Positron Spectrometer

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Paul Scherrer Institut Villigen & ETH Zürich

on behalf of the MEG Collaboration

SPS Meeting Fribourg

02.07.14

A very brief introduction to MEG

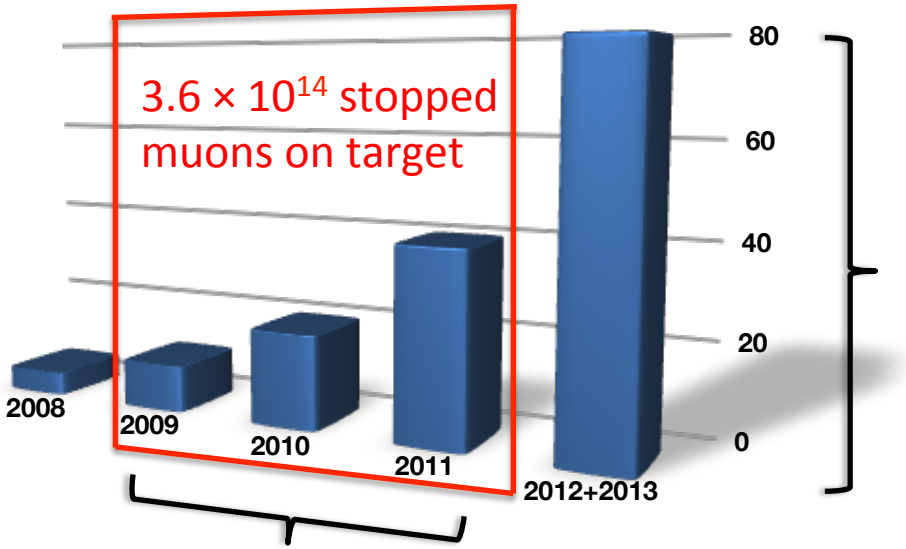
Search for the charged lepton flavour violating decay

$$\mu^+ \rightarrow e^+ + \gamma$$

with a sensitivity of few × 10^{-13} using one of the world's most intense continuous surface muon beams O(10^8 μ/sec) at the Paul Scherrer Institut, Switzerland

Standard model (with massive neutrinos) $BR(\mu \rightarrow e + \gamma) \approx O(10^{-54})$	Beyond the SM physics $BR(\mu \rightarrow e + \gamma) \approx O(10^{-13})\text{-}O(10^{-14})$

MEG's current status



analysis of 2012 and 2013 sample currently underway

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

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

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

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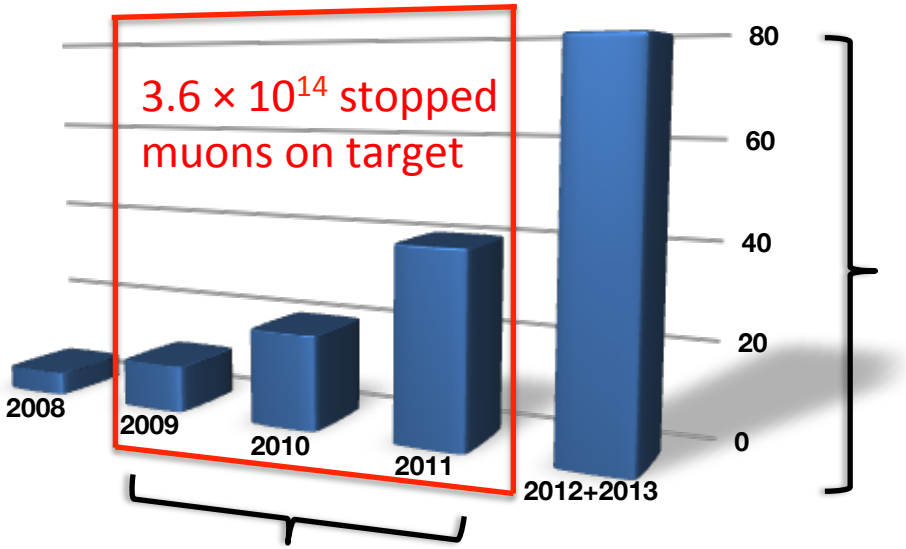

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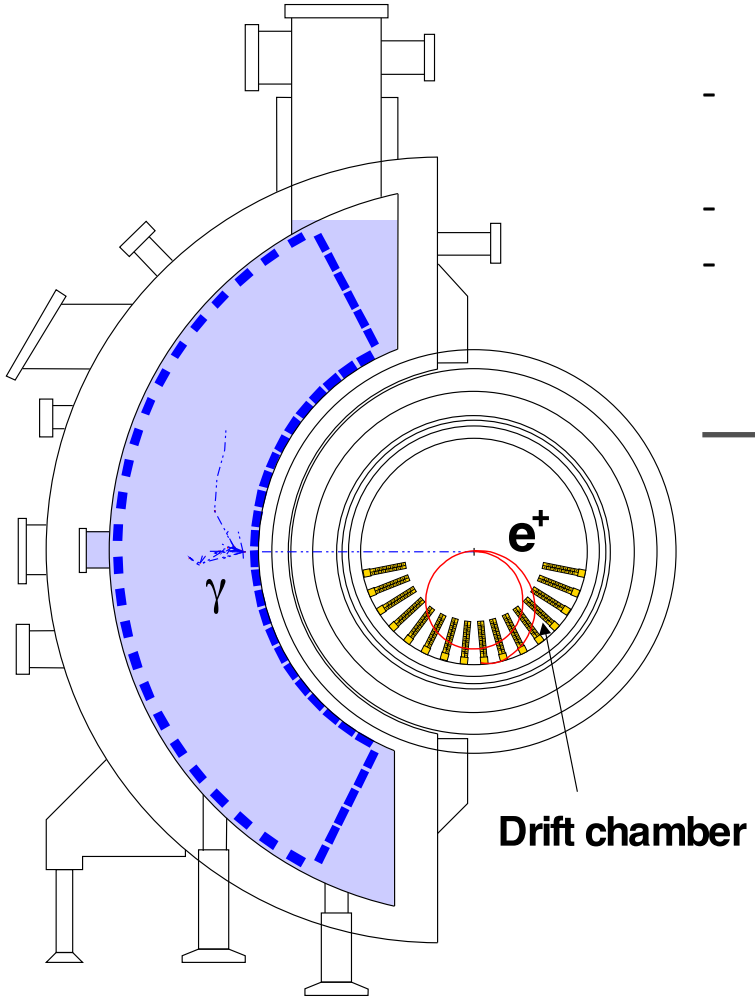
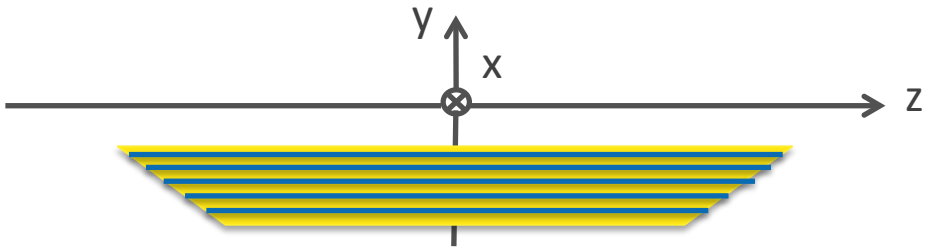
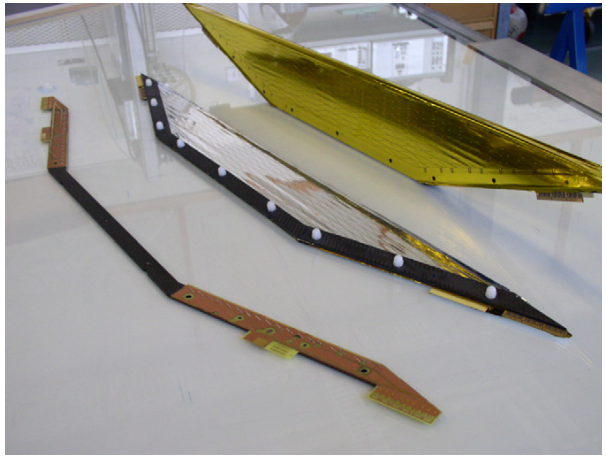
... **Mott scattering of positrons**

MEG Positron Spectrometer



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

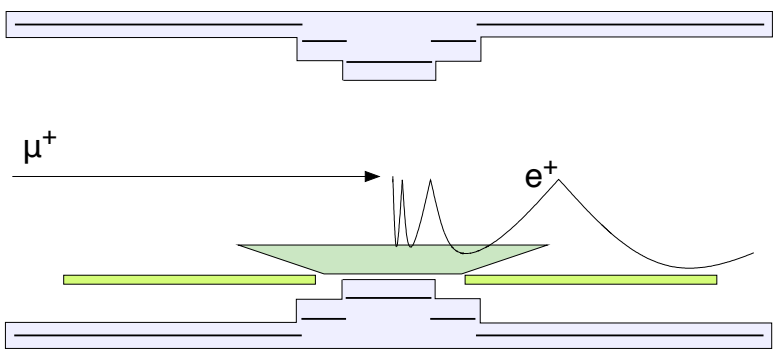




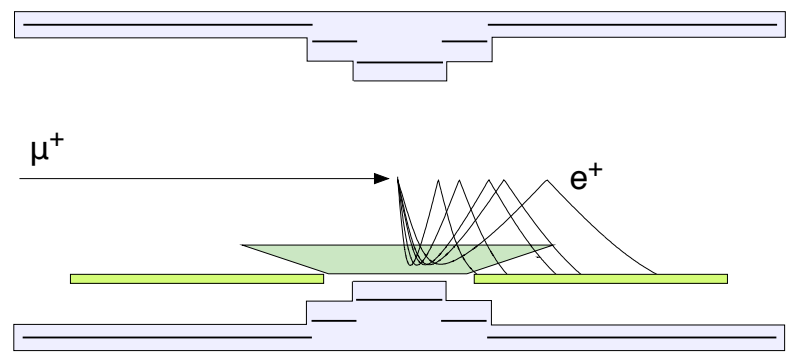
MEG Magnetic Field

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

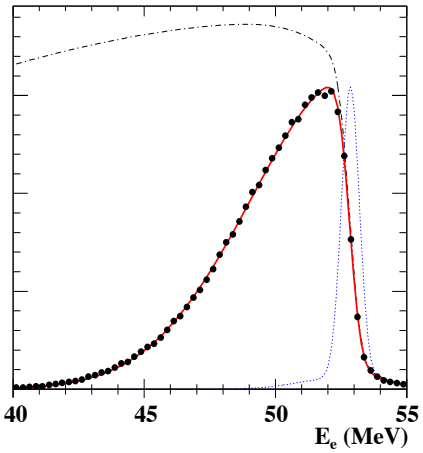
quickly sweep away particles emitted at polar angles θ ≈ 90°



projected bending radius independent of polar angle θ



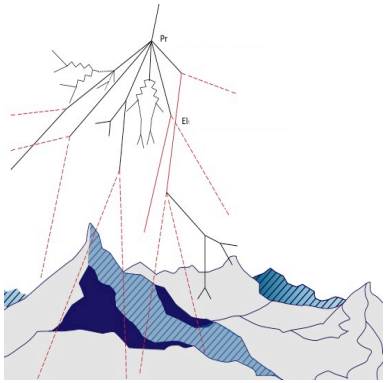
MEG e^+ Spectrometer's Calibration Methods



Michel Decay

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

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

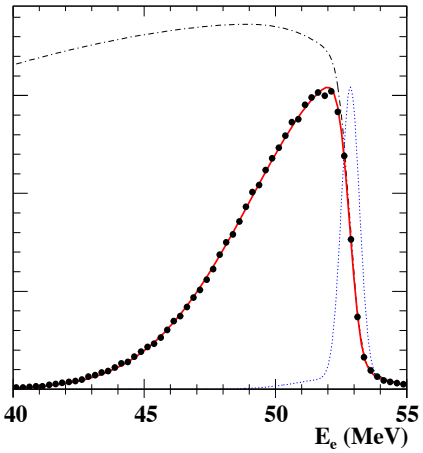


Cosmic Rays

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

picture from http://www.weltderphysik.de

MEG e^+ Spectrometer's Calibration Methods



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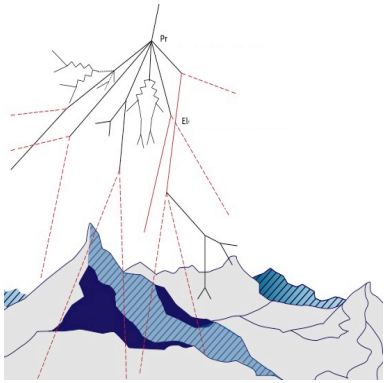

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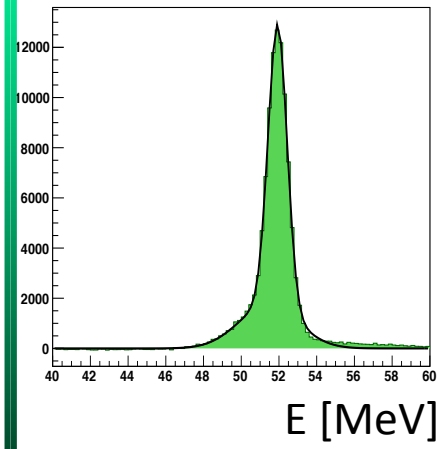
NEW



Monochromatic e^+ Beam

"line" instead of an "edge"

↓

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

How the 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

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

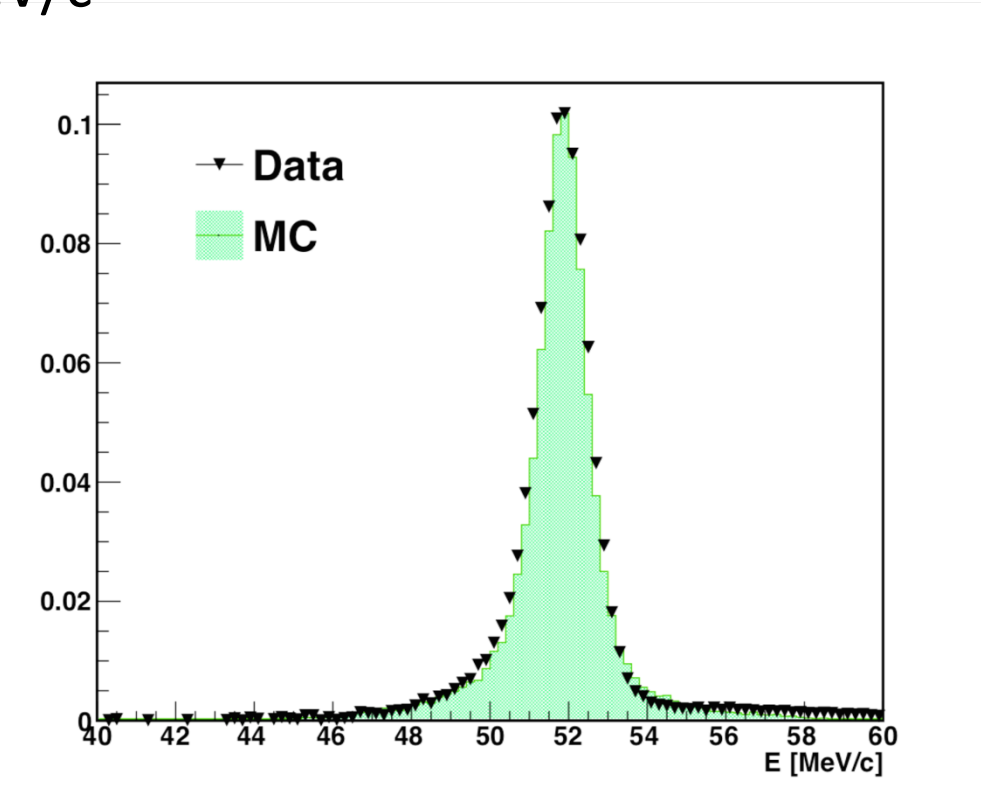
$\sigma_{tot} \approx 500 \pm 20$ keV/c

from MC simulation

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

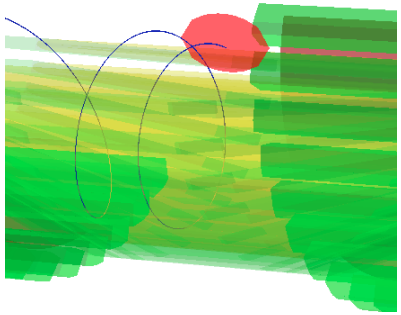
consistent with

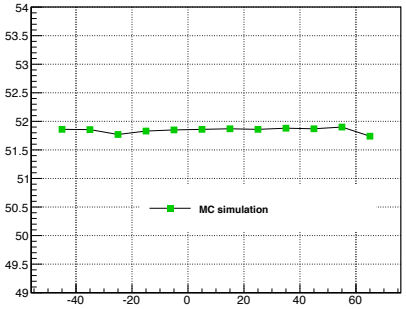
$\sigma_{Mott} \approx 350$ keV/c



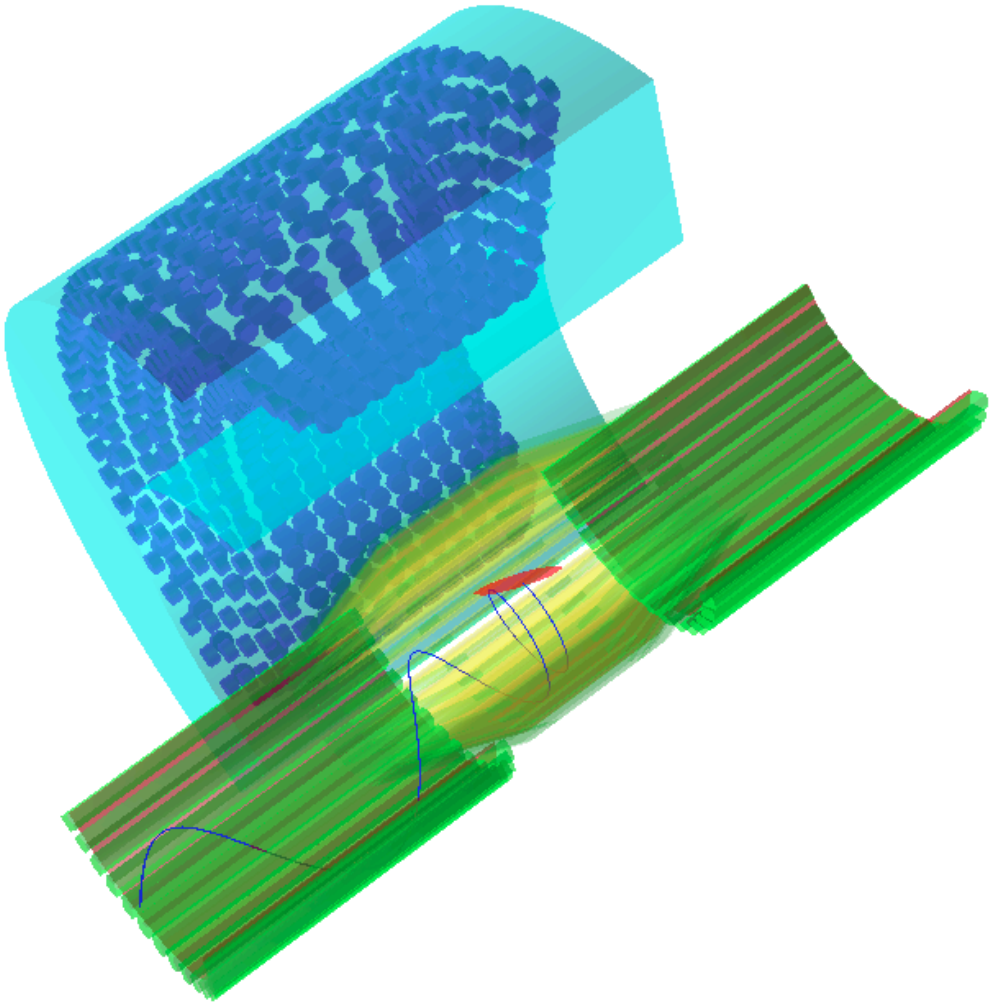
What can we do with Mott Data?

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

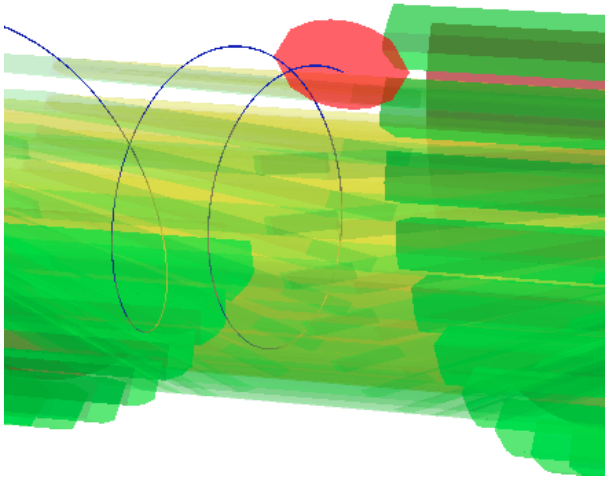




Double Turn Tracks

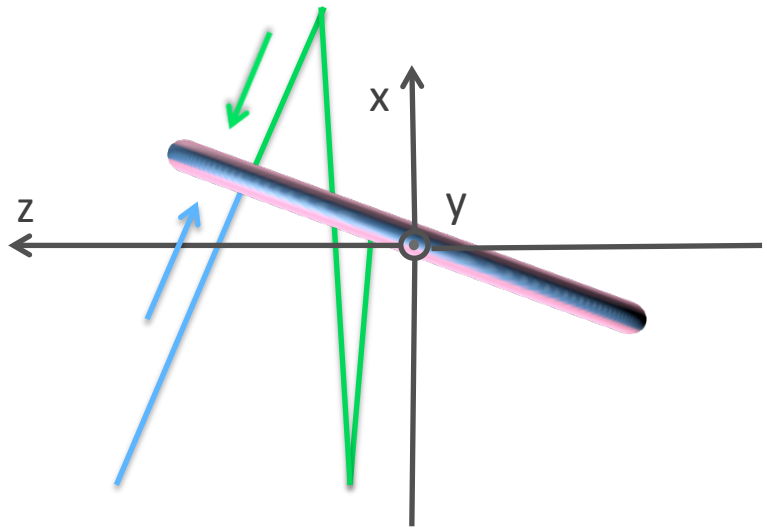


Consider tracks which make two turns in the drift chamber region before hitting the timing counter



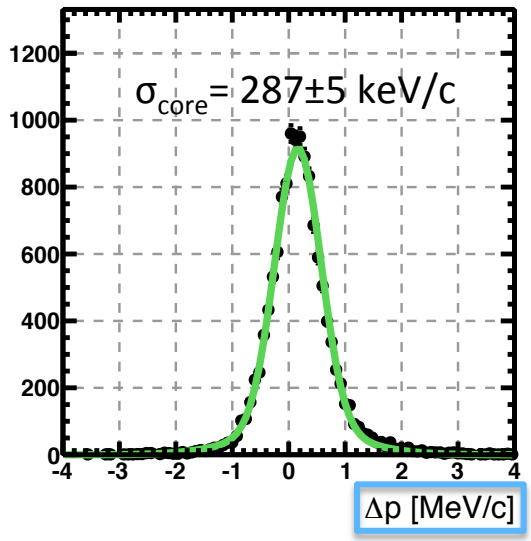
Positron Variables Resolutions from Double Turn Tracks

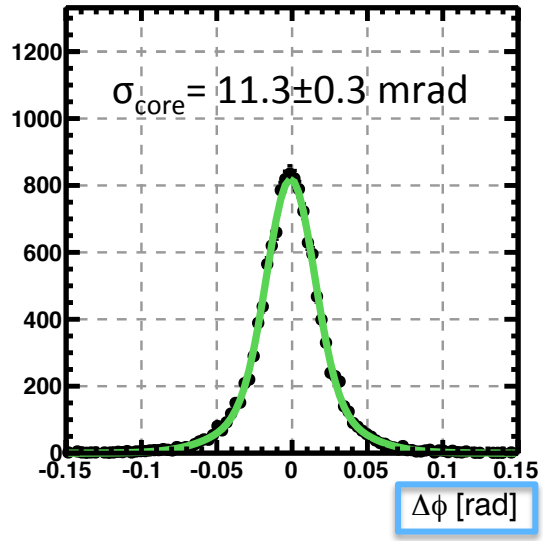
How to extract them?

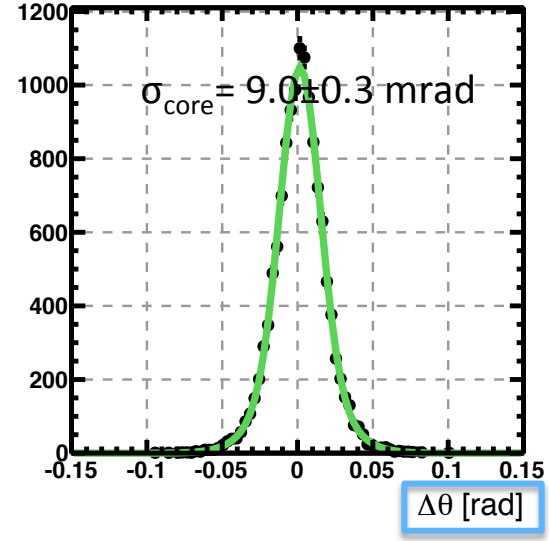


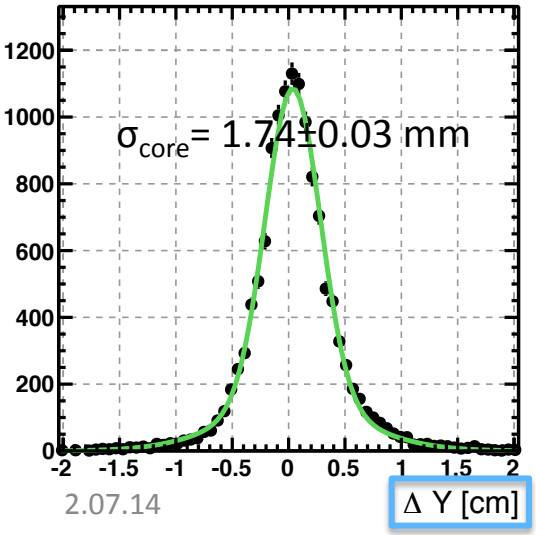
- treat the two turns independently
- propagate turn 1 and turn 2 to the target
- compute the difference ($A_{turn\ 1} - A_{turn\ 2}$) for A= p, ϕ, θ, y,z

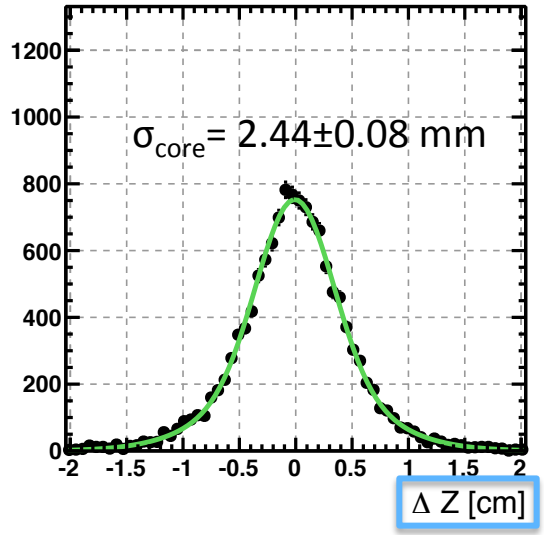
Positron Variables Resolutions from Double Turn Tracks











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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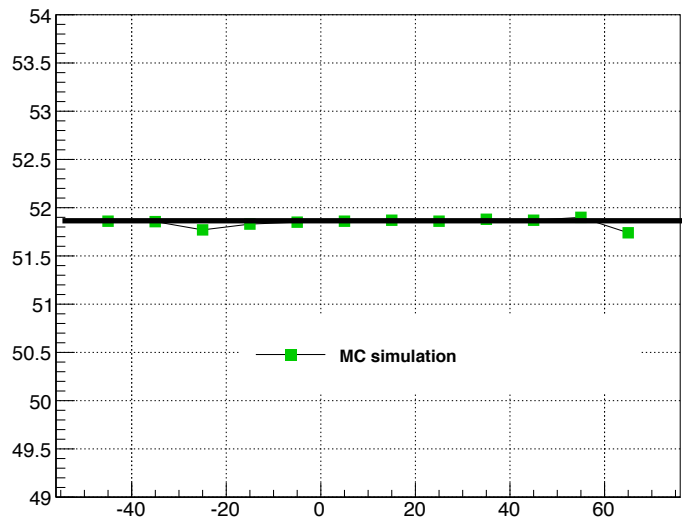
p [MeV/c]



Monte Carlo simulation without misalignment

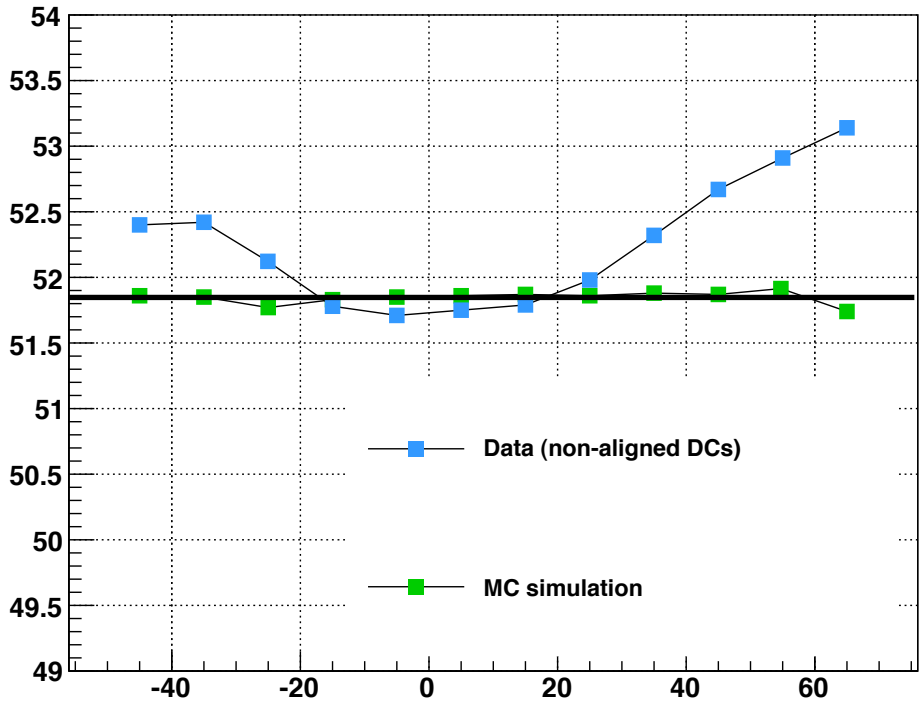
stat. error bars not visible in this scale

Φ [deg]

Check of Drift Chamber Alignment

Example of non-aligned drift chambers

p [MeV/c]



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Φ [deg]

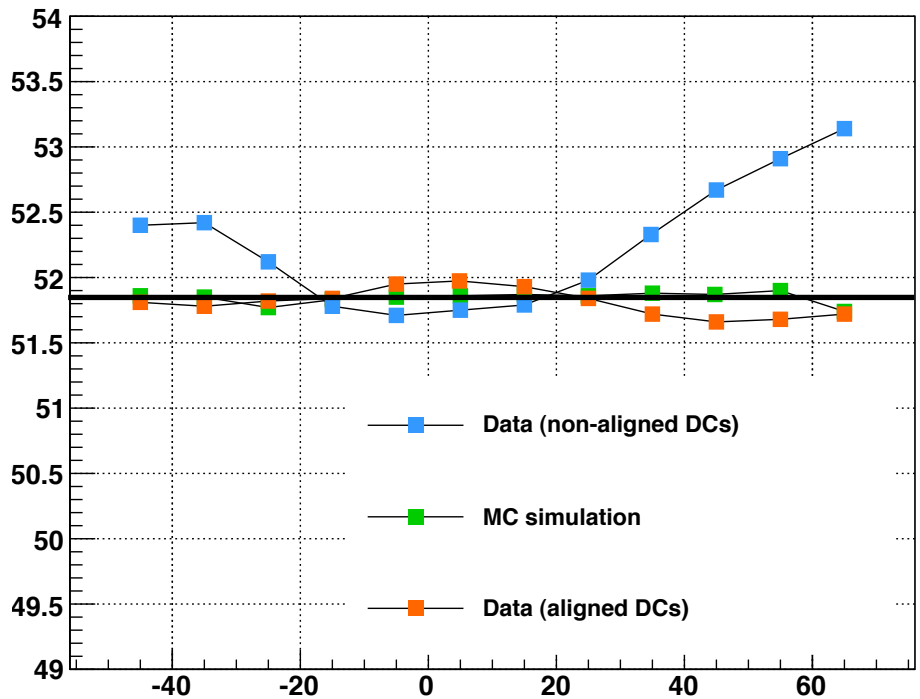
Data with non-aligned DCs

Monte Carlo simulation without misalignment

Check of Drift Chamber Alignment

Example of aligned drift chambers

p [MeV/c]



stat. error bars not visible in this scale

Φ [deg]

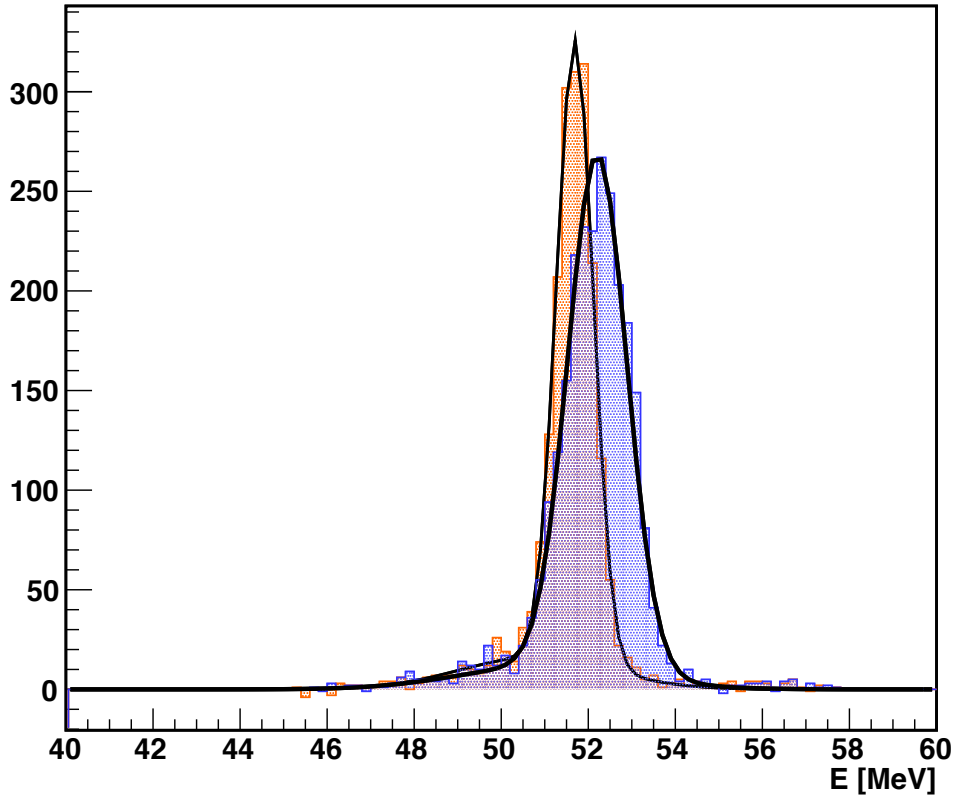
Data with non-aligned DCs

Data with aligned DCs

Monte Carlo simulation without misalignment

Check of Drift Chamber Alignment

Comparison Mott line for non- and aligned DCs



$\sigma_{nonaligned} \approx 675$ keV/c

↓

$\sigma_{aligned} \approx 420$ keV/c

$\mu_{nonaligned} \approx 52.2$ MeV/c

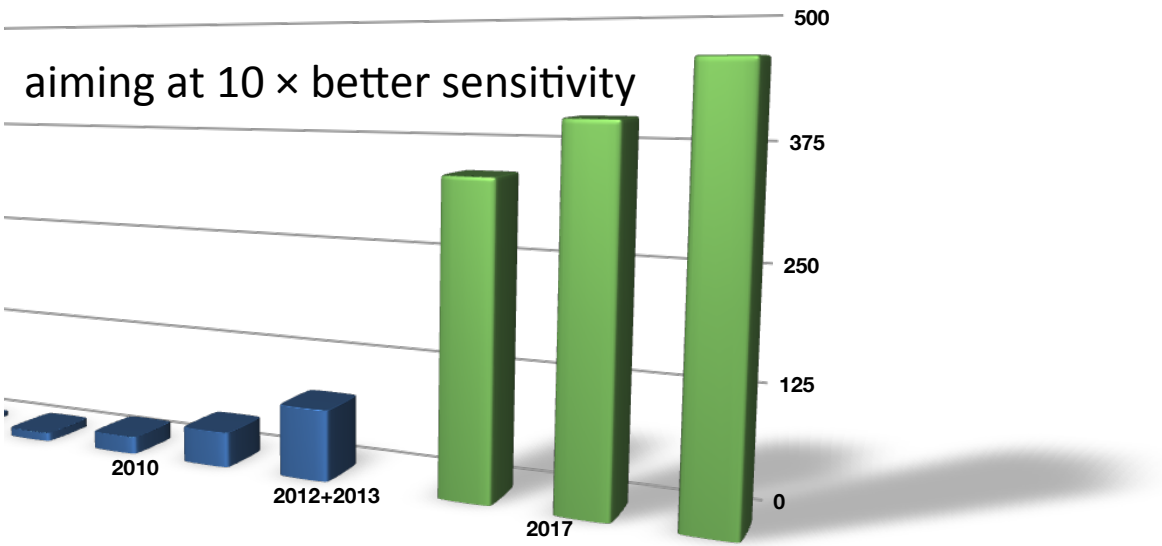
↓

$\mu_{aligned} \approx 51.9$ keV/c

Conclusions

- 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 methods since based on completely independent method!

MEG II – The Upgrade



Upgrade will include newly designed spectrometer - Mott calibration method will be very important!