MEGII experiment at PSI: Positron Analysis

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Particle Physics Experiments at the Intensity Frontier

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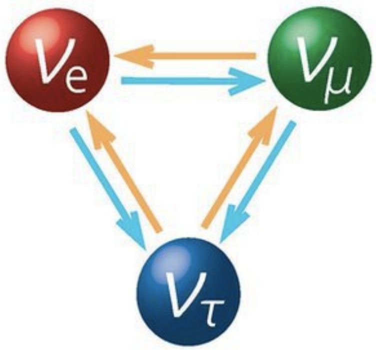
Outline

1) **The MEGII experiment**
   A. Lepton Flavour Violation
   B. The $\mu^+ \rightarrow e^+\gamma$ probe
   C. Signal and backgrounds
   D. Setup and detectors

2) **Positron analysis**
   A. Introduction
   B. Investigation of misalignment
   C. Michel edge fitting and extraction of momentum resolution

1) A. The Lepton Flavour violation



- Lepton flavour violation observed experimentally with neutral leptons —> neutrino oscillations
- Never observed with a charged lepton (cLFV)

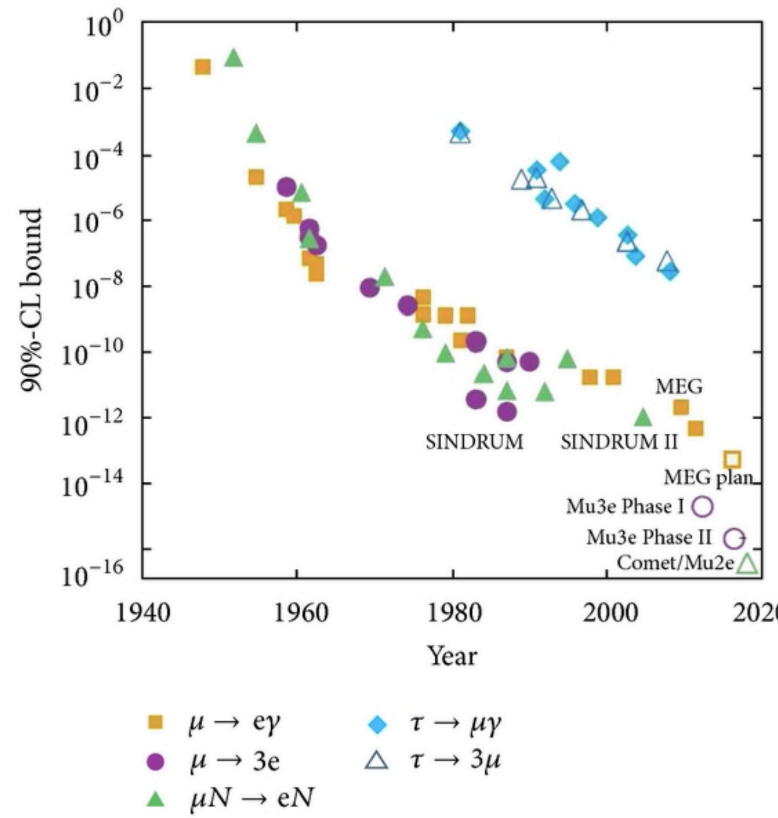
- Intense muon beams obtained by hitting light targets with low E protons

—> muon very good probe of cLFV processes

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

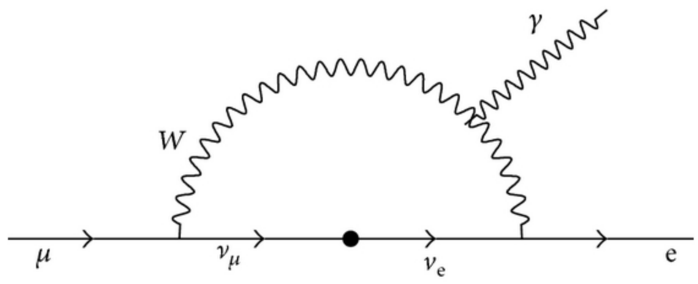
$$\mu^+ \rightarrow e^+e^-e^+$$

$$\tau^+ \rightarrow \mu^+\gamma$$



1) B.The $\mu^+ \to e^+\gamma$ probe

SM

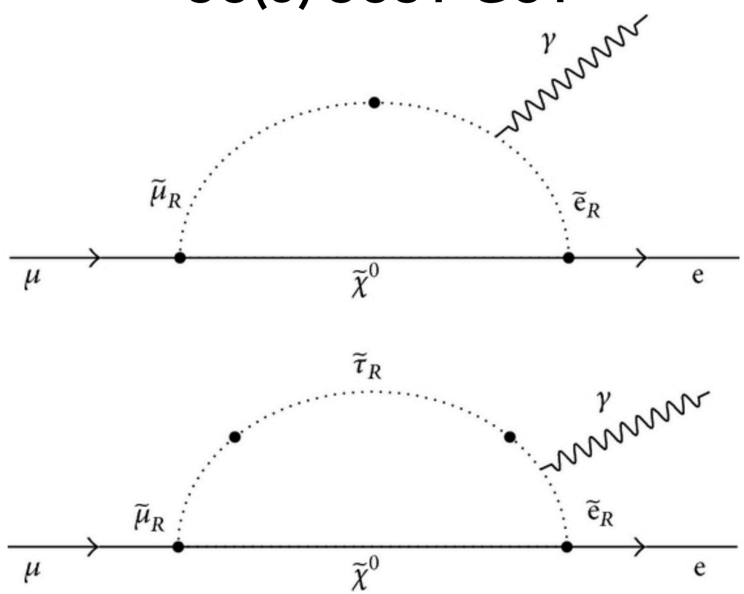


- Decay possible in the SM with massive neutrinos but

$$BR(\mu \longrightarrow e\gamma) \approx 10^{-54}$$

—> Unreachable experimentally

SU(5) SUSY GUT



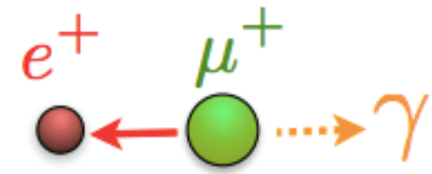
- BSM models allow experimentally attainable BRs

- MEG set the best 90% confidence upper limit: 4.2×10^{-13}

- MEG upgrade —> 6×10^{-14}

1) C. Signal and backgrounds

SIGNAL

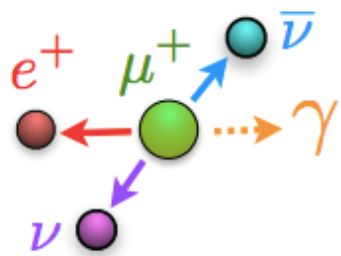


$E_\gamma = E_e = 52.8$ MeV
$\theta_{e\gamma} = 180°$
$t_{e\gamma} = 0$ s

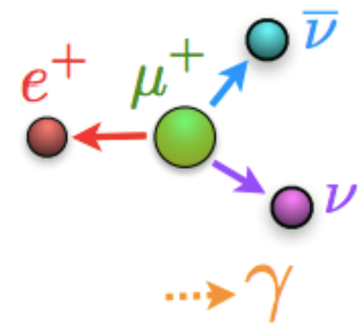
- 28 MeV/c μ continuous beam stopped on a 130 μm polyethylene slanted target (15°)
- Paul Scherrer Institut (Switzerland) has the most intense DC muon beam in the world: up to 10^8 μ/s
- 5 kinematic variables: $E_e, E_\gamma, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}$

BACKGROUNDS

$E_\gamma < 52.8$ MeV
$E_e < 52.8$ MeV
$\theta_{e\gamma} < 180°$
$t_{e\gamma} = 0$ s



- Radiative muon decay (RMD)



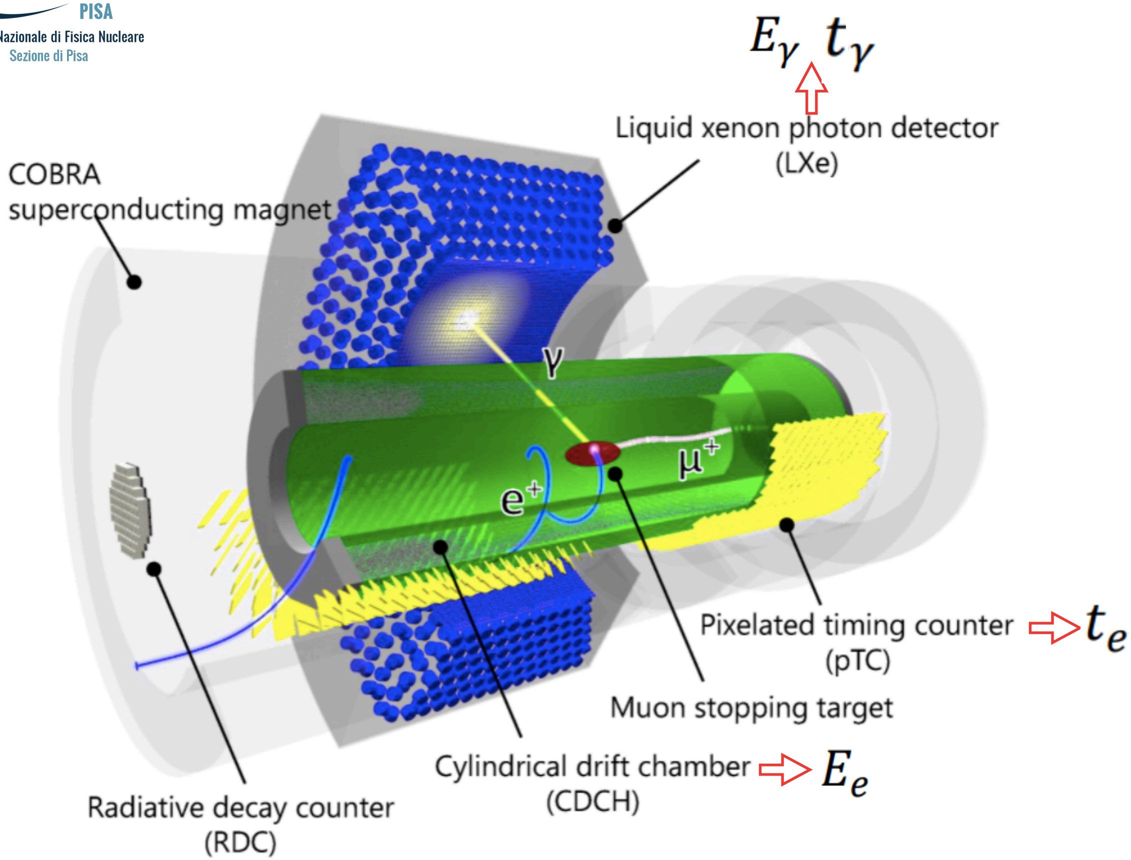
$E_\gamma < 52.8$ MeV
$E_e < 52.8$ MeV
$\theta_{e\gamma} < 180°$
$t_{e\gamma} =$ flat

- Accidental background
  —> Michel decay + Gamma from RMD, AIF or bremsstrahlung

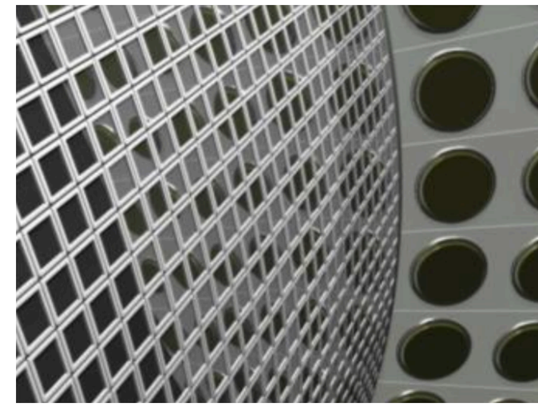
$$N_{\rm acc} \propto R_{\mu^+}^2 \times \Delta E_\gamma^2 \times \Delta p_{e^+} \times \Delta\Theta_{e^+\gamma}^2 \times \Delta t_{e^+\gamma} \times T$$

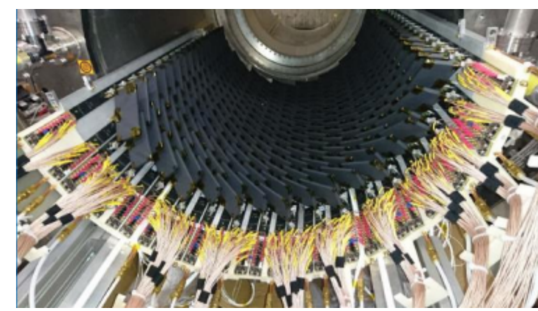
—> Accidental bkg dominant at high rates

1) D. Setup and detectors

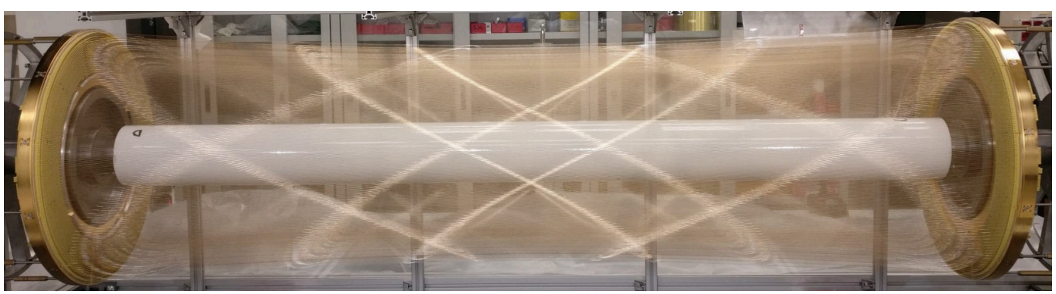


900L of LXe readout by 4092 SiPMs and 668 PMTs





pTC - 2 x 256 of scintillator plates readout by SiPMs



Low-mass single volume detector with high granularity
—> 9 concentric layers of 192 drift cells defined by 11904 wires

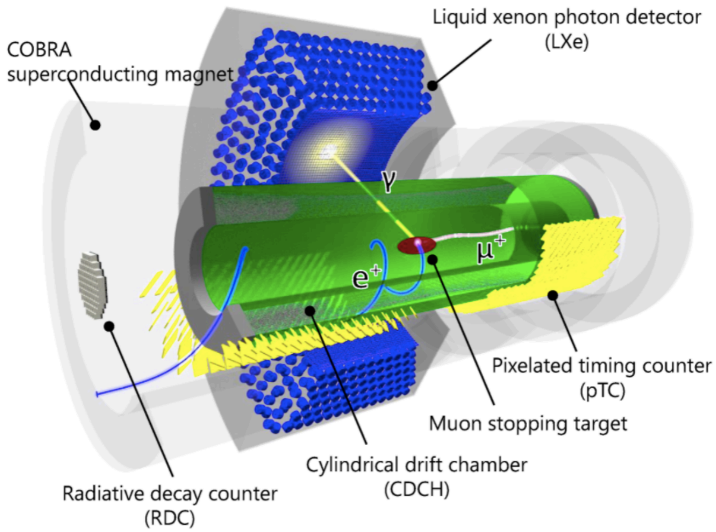
Resolutions	MEG	MEG II
p_e (keV)	306	130
ϑ_e(mrad)	9.4	5.3
φ_e(mrad)	8.7	4.8
e^+ efficiency (%)	40	88

x2 resolution compared to MEG

1) D. Setup and detectors: status

- 2021: for the first time, MEGII apparatus fully installed

- All detectors/electronics are working up to 5e7 muon/s



- After successful calibration and engineering runs, physics data taken between September and November. First data collected by MEGII for the muegamma search.

- Pion beam in December for the LXe calibration

My main objectives with MEGII

1. Perform the positron analysis for the $\mu^+ \rightarrow e^+\gamma$ search

2. Study other physics channels that can be exploited with MEGII focused on the positron analysis ($\mu^+ \rightarrow e^+$ X)

3. Develop new calibration methods for the MEGII experiments

More details

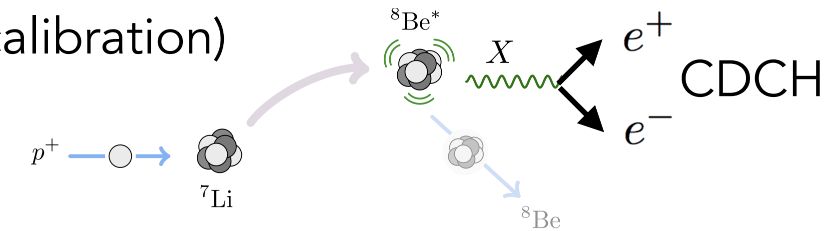
HANDS-ON WORK

- Shifts during beam time
- Preparation of the CEX reaction (LXe calibration)

—> LHe and LH2 circuit assembly

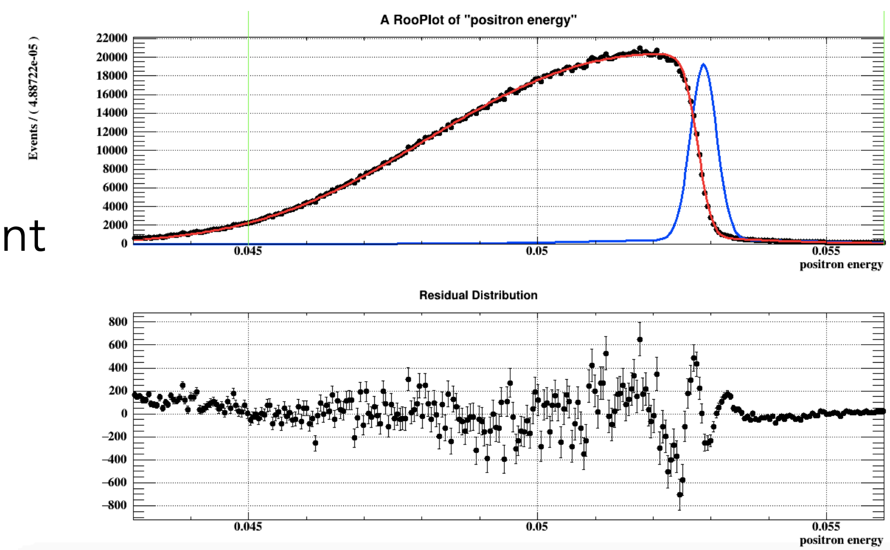
—> LH2 liquefaction

- Preparation of the X17 data taking



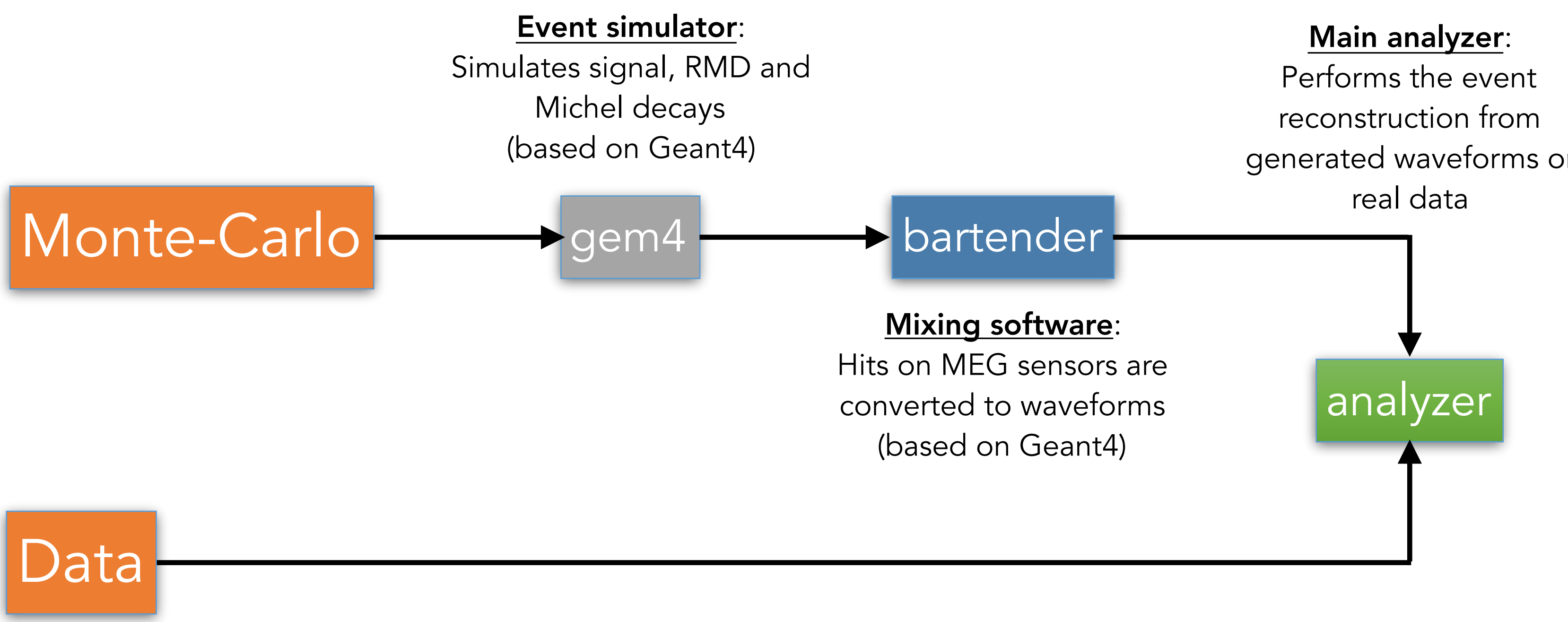
POSITRON ANALYSIS

- Investigation of CDCH misalignment
- Monte-Carlo simulations
- Positron momentum resolution



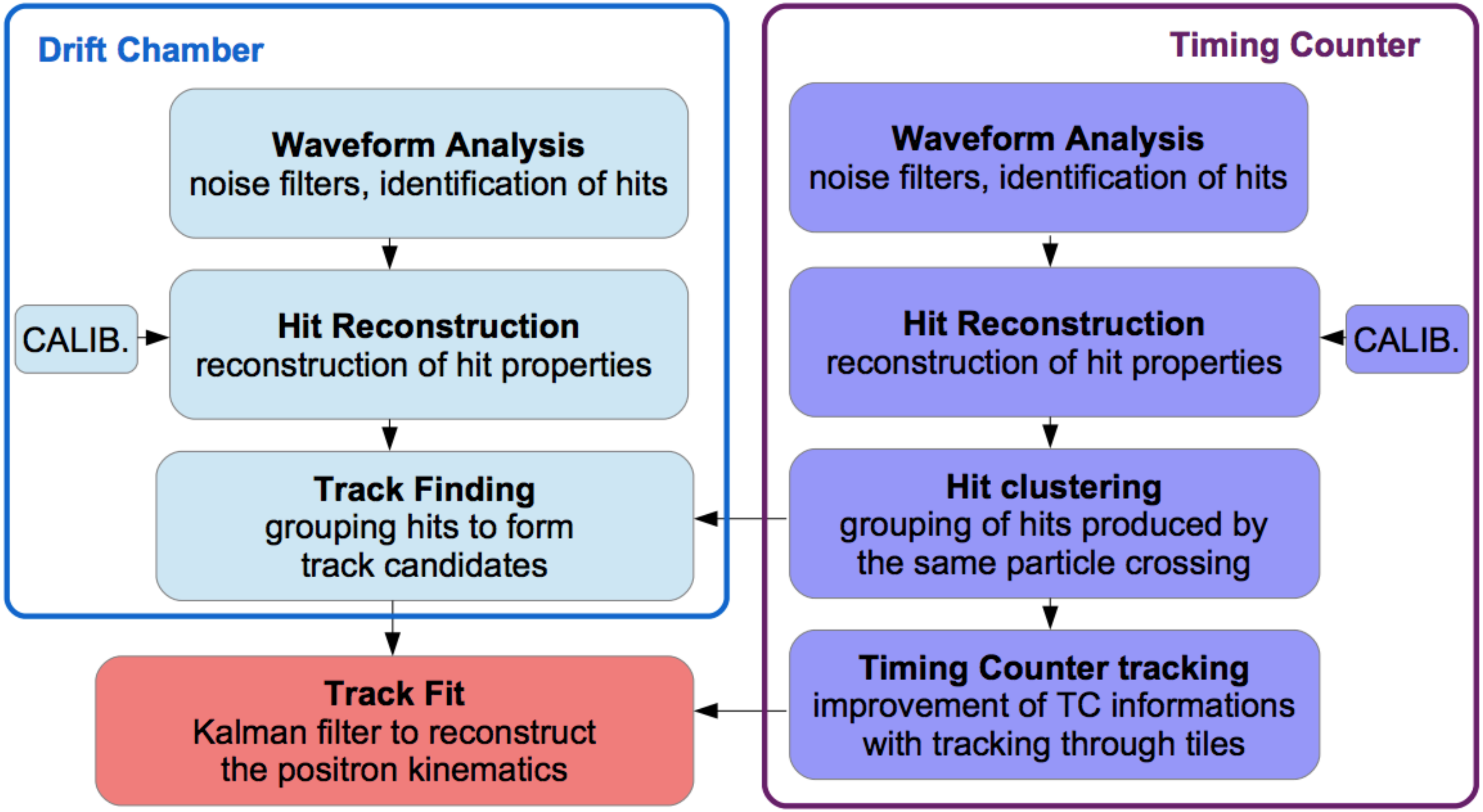
2) A. Software introduction

- MEGII software is organized around 3 complementary modules:
  —> gem4, bartender, analyzer

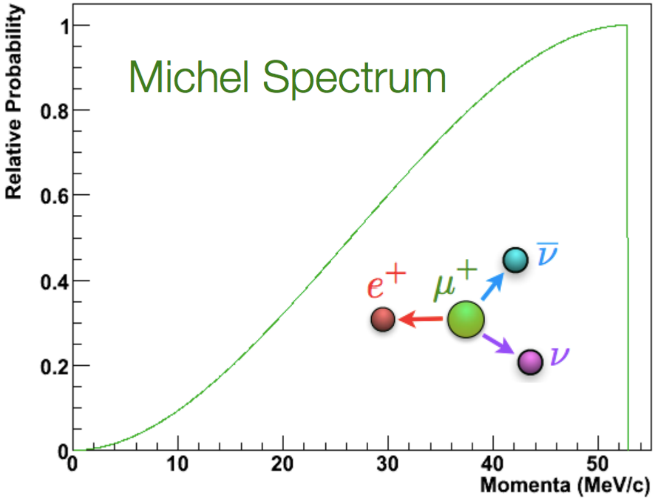


2) A. Positron Analysis introduction

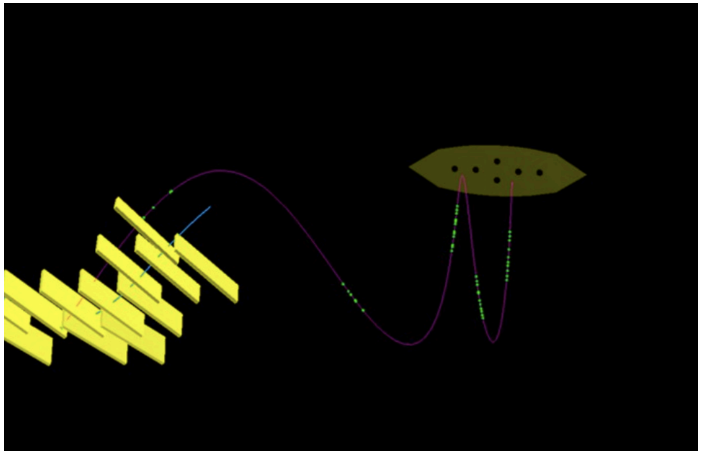
- How is the analysis of positron kinematics organized?



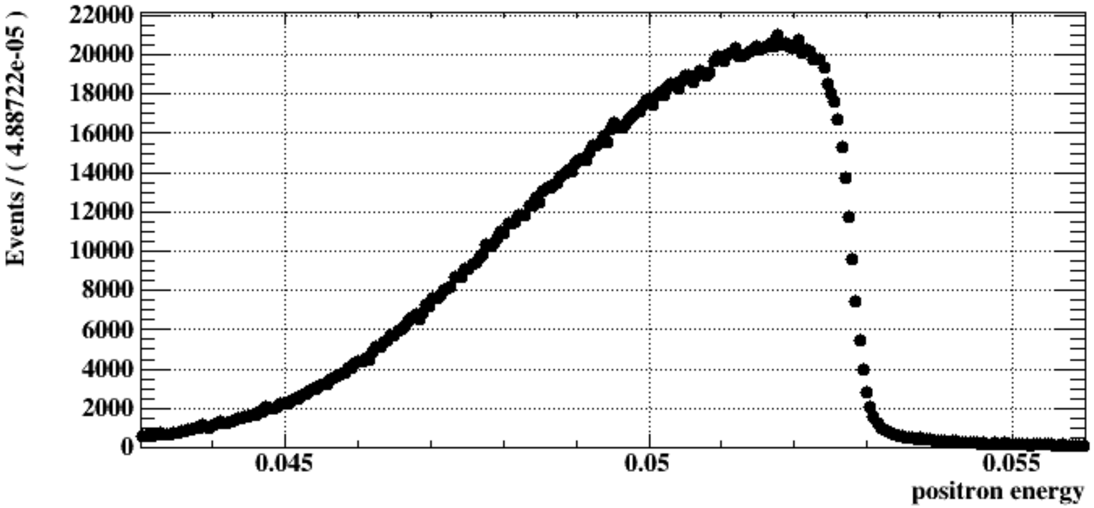
2) A. Positron Analysis introduction



Positron spectrum from muon Michel decay



Positron track is bent by COBRA field
Positron momentum is extracted from radius of track

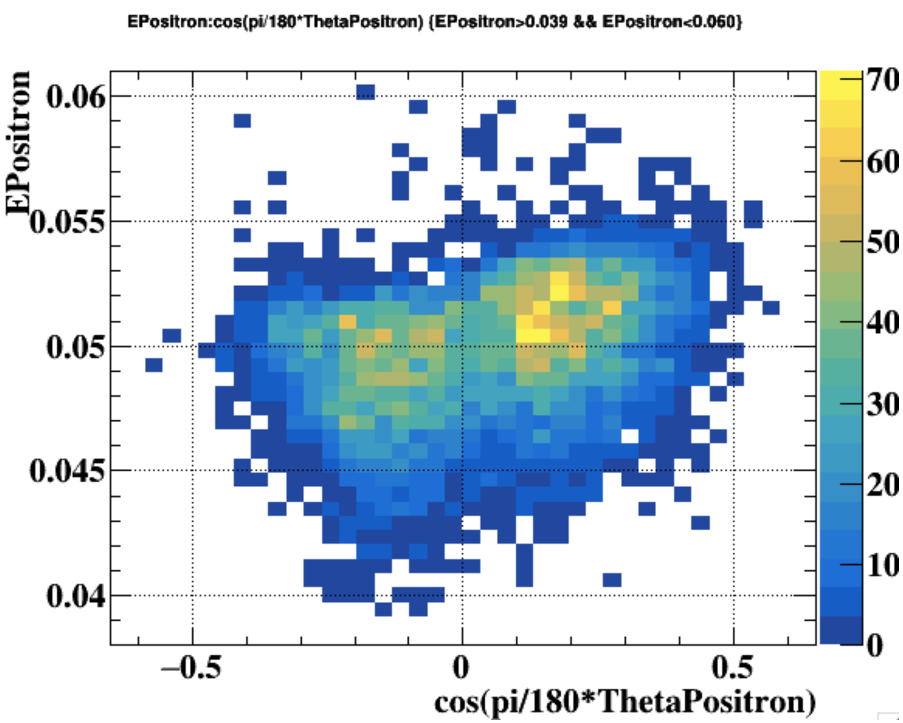


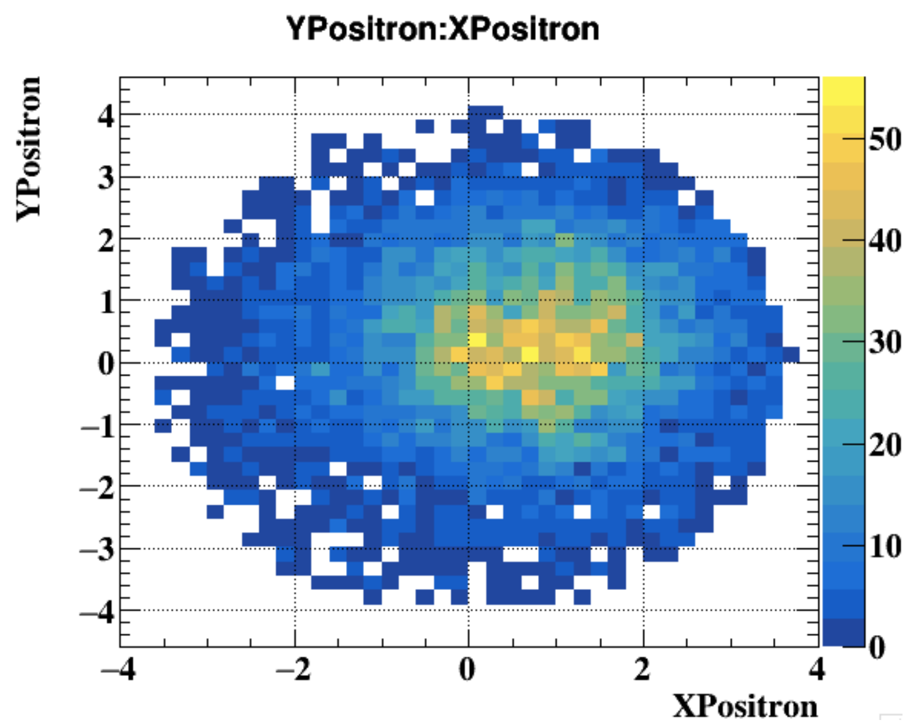
Obtained spectrum is distorted. Used to extract resolution of CDCH.

2) B. Investigation of misalignment

Analysis of MuEGamma trigger runs taken in 2021

—> analysed assuming NOMINAL wire positions



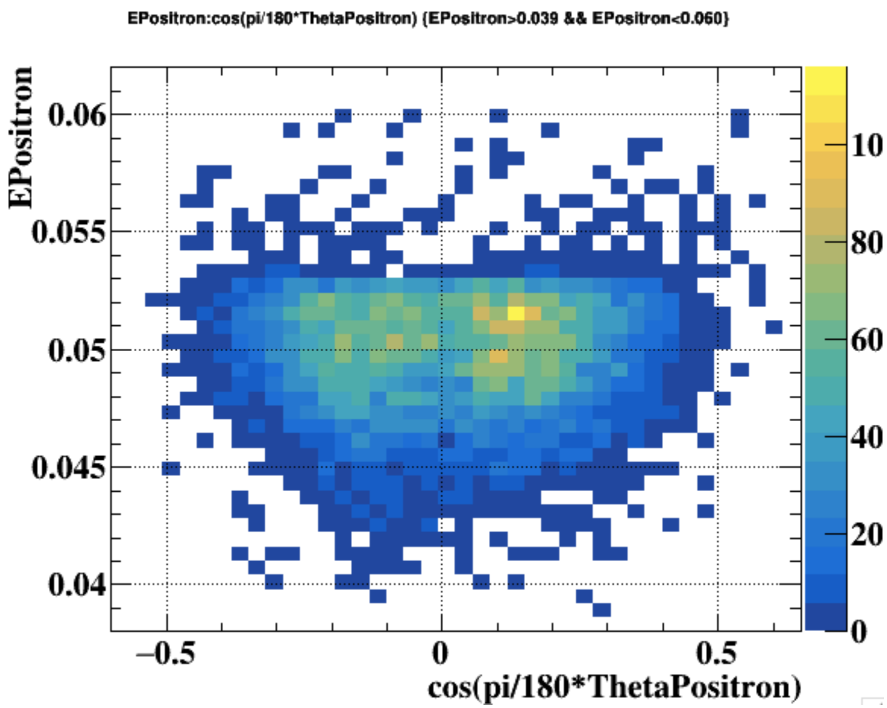


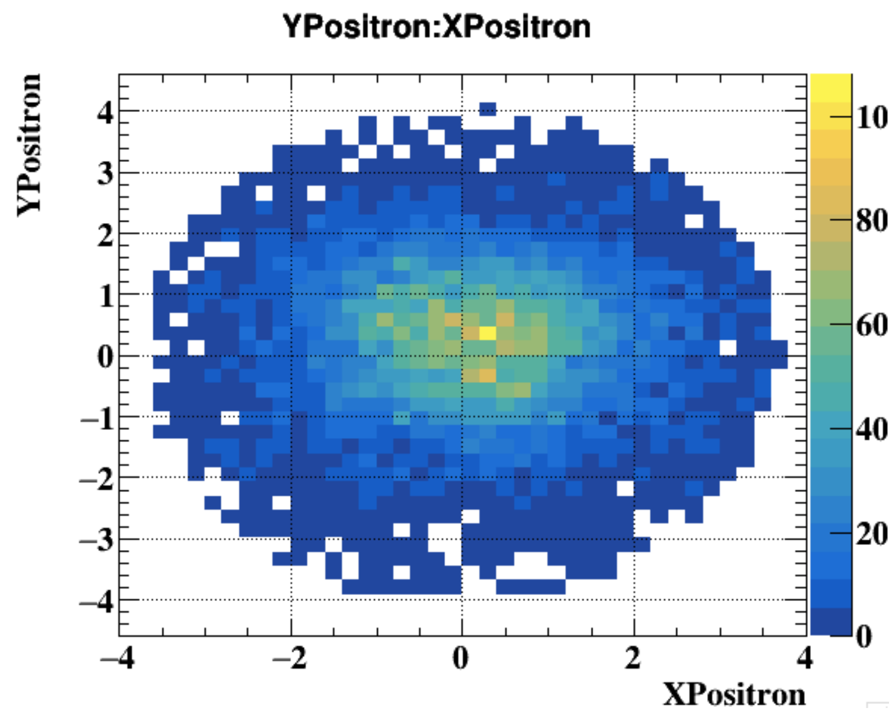
—> **asymmetry** of the momentum distribution
—> target: **distorted**, center **shifted**
—> due to a misalignment of the CDCH wires?

2) B. Investigation of misalignment

Analysis of MuEGamma trigger runs taken in 2021

—> analysed assuming NOMINAL wire positions with 15 MM SHIFT





—> momentum distribution is **flat**

—> target: shape seems correct and **center is closer** to the origin

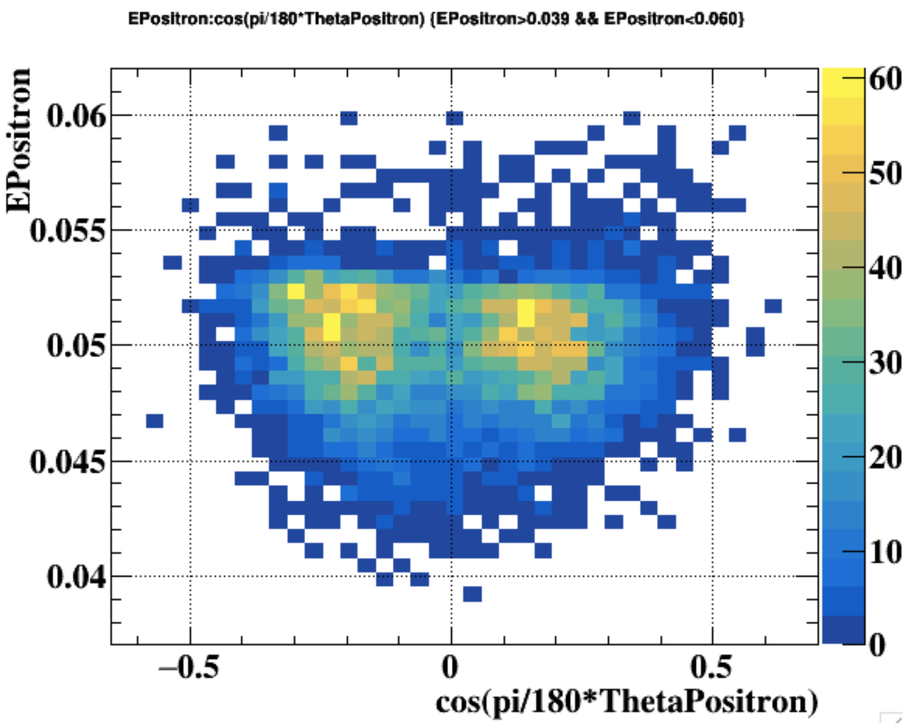
—> still a **slight shift** of the center

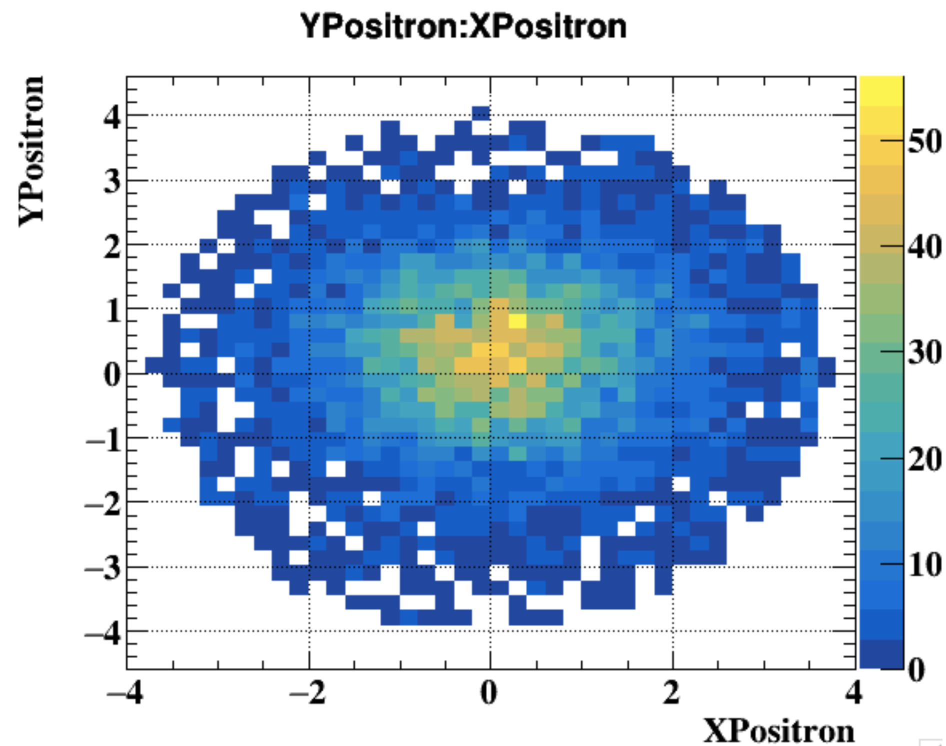
—> actual shift of 15 mm of the whole chamber?

2) B. Investigation of misalignment

Analysis of MuEGamma trigger runs taken in 2021

—> analysed assuming MEASURED wire positions

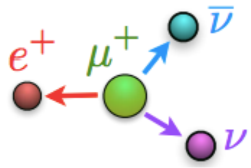




—> symmetry of momentum distribution **largely improved**
—> target: seems better centered than assuming a 15mm shift
—> the asymmetry was actually due to small angles of each wire compared to the nominal configuration

2) C. Michel edge fits

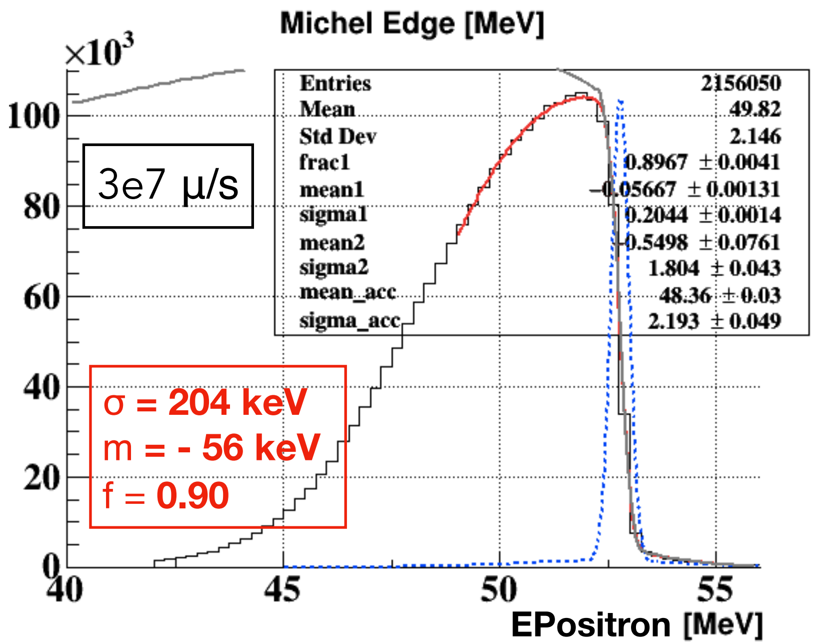
- Michel decay is the main (~100%) muon decay channel. The radius of the positron in the CDCH allows to extract its momentum. Michel spectra ca be built. Fits of the spectra allow to extract resolution of the chamber.

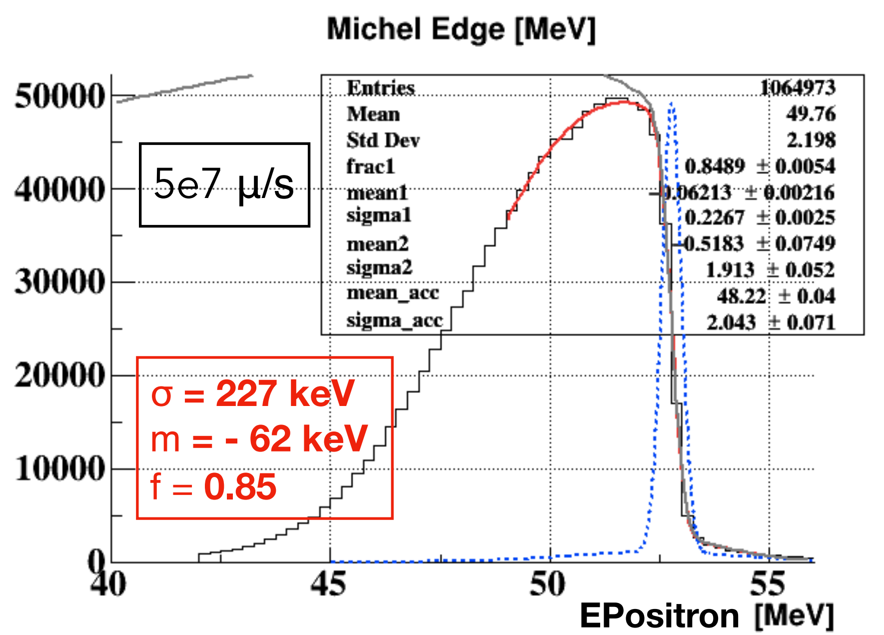


- Fits done with:

(Theoretical Michel spectrum x Acceptance) ⓧ Response

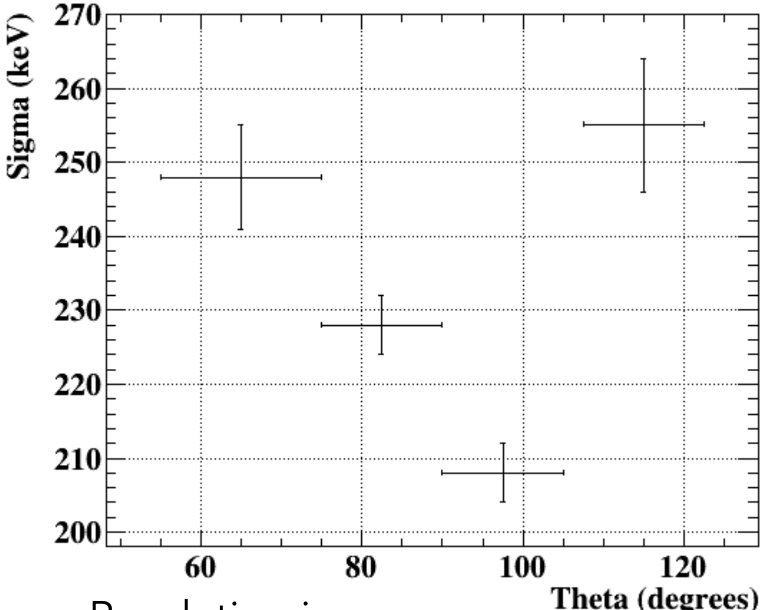
- Response is a **double gaussian** and data were analyzed with latest CDCH wire survey

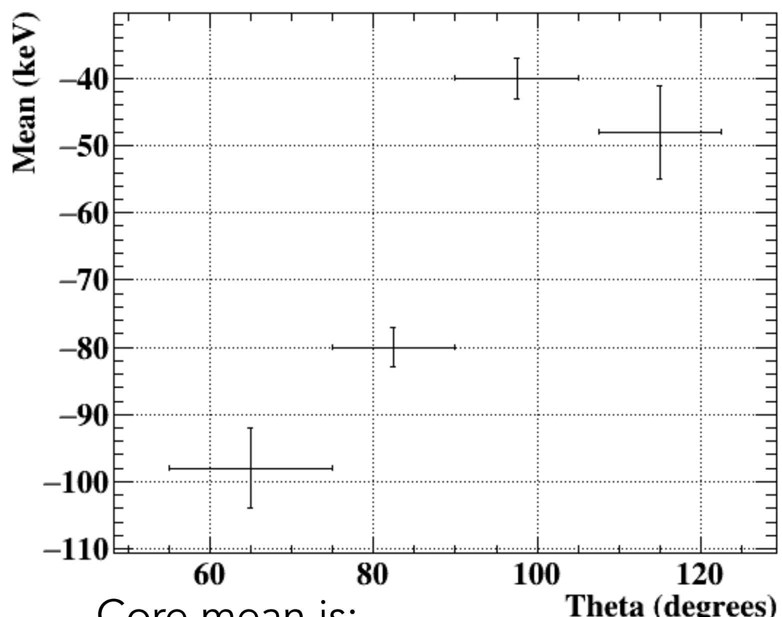




2) C. Michel edge fits: cuts on angles

5e7 μ/s	55°<θ<75°	75°<θ<90°	90°<θ<105°	105°<θ<125°
Sigma 1 Mean 1	σ = 248 keV m = - 98 keV	σ = 228 keV m = - 80 keV	σ = 208 keV m = - 40 keV	σ = 255 keV m = - 48 keV
Average over all angles	σ = 227 keV m = - 62 keV			





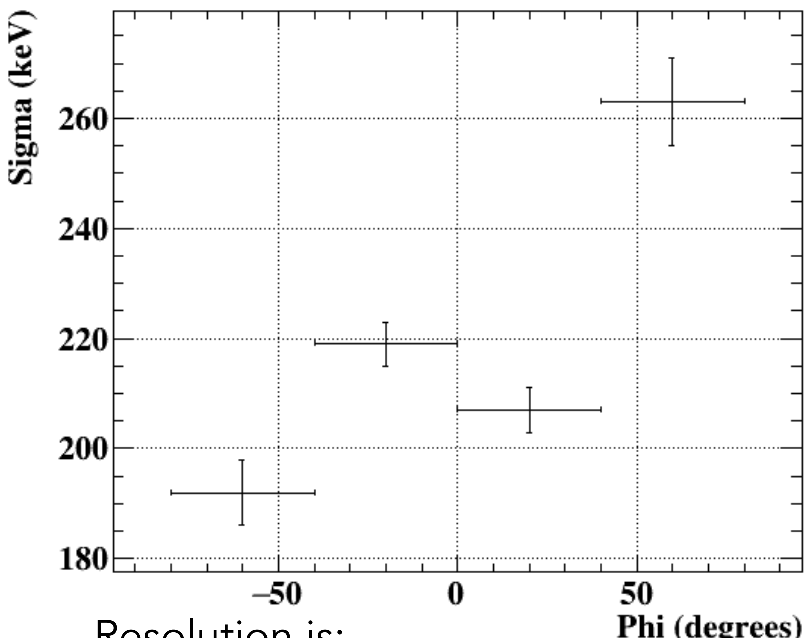
Resolution is:
—> better for θ~90°
—> gets worse for low and high θ

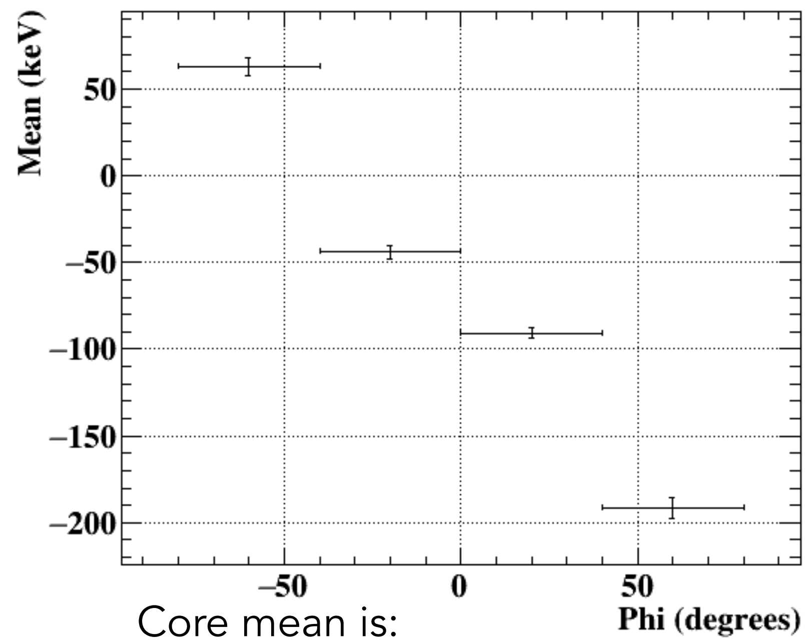
Core mean is:
—> always negative: underestimate of the momentum

—> sigma and mean seem to show opposite behaviours
—> systematics in the alignment and/or magnetic field

2) C. Michel edge fits: cuts on angles

5e7 μ/s	-80°<ϕ<-40°	-40°<ϕ<0°	0°<ϕ<40°	40°<ϕ<80°
Sigma 1 Mean 1	σ = 192 keV m = + 63 keV	σ = 219 keV m = - 44 keV	σ = 207 keV m = - 91 keV	σ = 263 keV m = - 192 keV
Average over all angles	σ = 227 keV m = - 62 keV			





Resolution is:

—> best for high ϕ<0

—> gets worse for high ϕ>0

Core mean is:

—> very large for high ϕ>0

—> positive for high ϕ<0

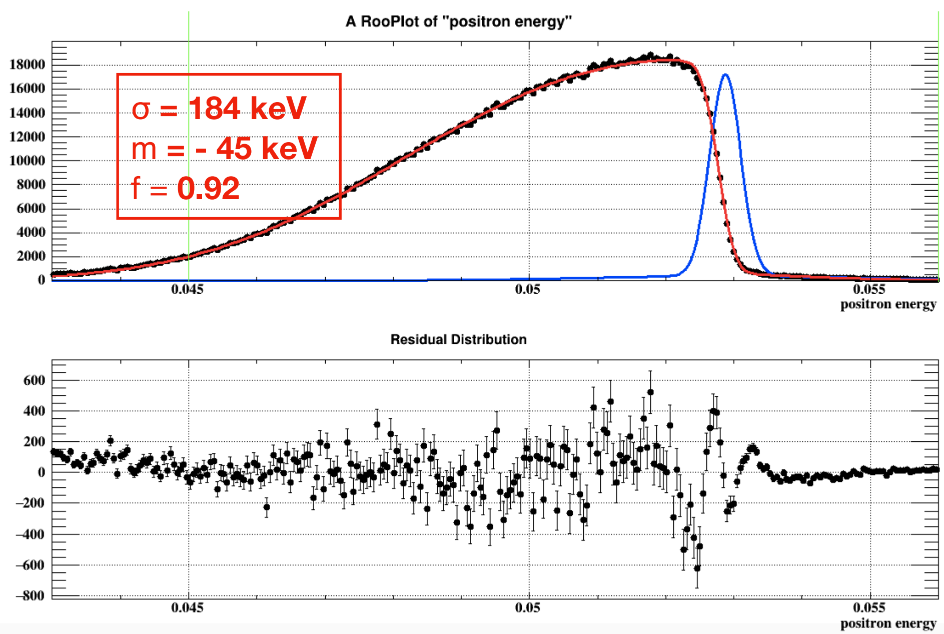
(overestimate of the momentum?)

—> Sigma and mean seem to show an opposite behaviour

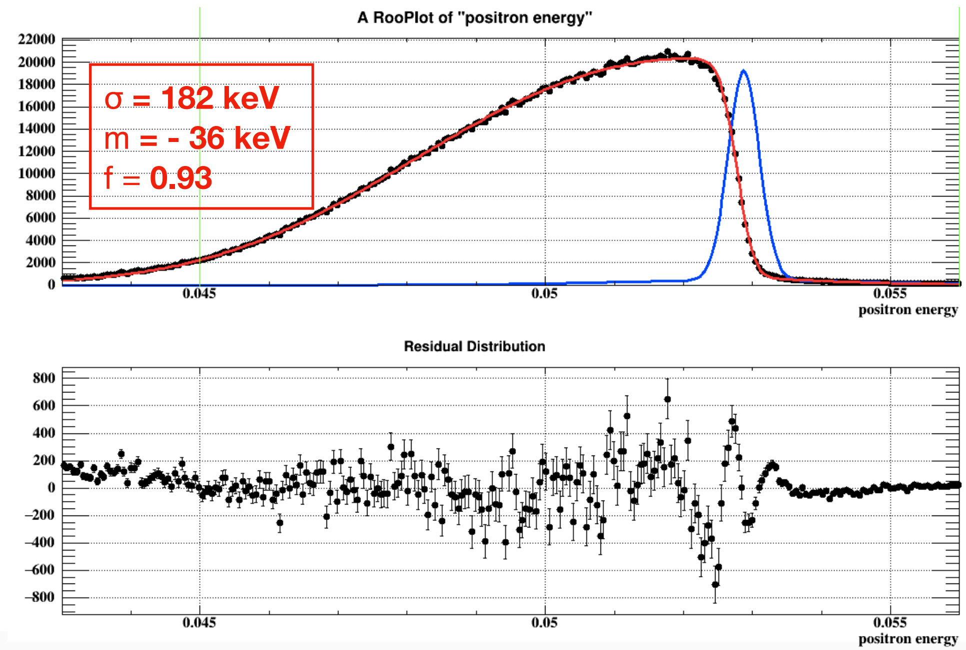
2) C. Michel edge fits: which model?

—> badly reconstructed events should be reconstructed in average not too far from the core ones

2-gaussian with 1 mean



2-gaussian with 2 means



- Investigation going on to extract the correct resolution: best model to implement, best way to take into account polarization, systematics with angles

Conclusion

- Both hands-on and data analysis work with MEGII

- Asymmetries in positron distribution were investigated

- First value for the CDCH resolution was extracted from the fits of the Michel Spectra

- Positron analysis next steps:

—> find the most accurate model for Michel fits
—> implement polarization correctly
—> compare results with Monte-Carlo simulations

- On the longer term:

—> New algorithm and methods for the CDCH calibrations
—> PDF extractions for the $\mu^+ \to e^+\gamma$ analysis
—> Sensitivity study for $\mu^+ \to e^+$X