Mu2e tracker momentum calibration using $\mu^- \longrightarrow e^- \overline{\nu}_e \nu_\mu$

Tommaso Radicioni

University of Pisa

Supervisor: P. Murat

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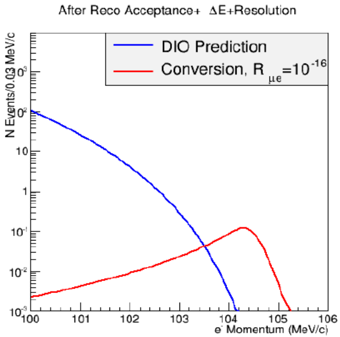
Outline

Mu2e experiment objective

The goal of Mu2e experiment is the search for the conversion of muons into electrons in the field of a nucleus of Al:

$$\mu^- + N \longrightarrow e^- + N \tag{1}$$

Decay-In-Orbit (DIO) electrons, namely electrons originated from muons which decay after being captured in Al meso-atoms, is the single most important background.

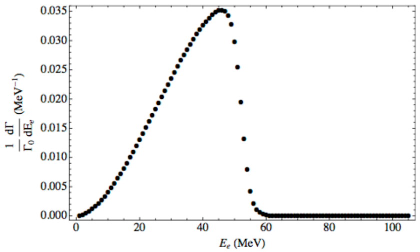


Momentum separation between Conversion Electrons (CE) and DIO electrons is fundamental for Mu2e experiment purpose

Tracker calibration with muon decay

Measurement of electron track momentum in the tracker reconstruction is the key measurement in Mu2e experiment$\longrightarrow$the success of the experiment depends critically on the tracker calibration and resolution:

- Simulated intrinsic momentum resolution is $\sigma \sim 120 \frac{keV}{c}$;
- A calibration with an accuracy of $\approx 0.1\%$ ($\approx 100 \frac{keV}{c}$) is required$\longrightarrow$a source of particles with a known momentum is needed, such as DIO electrons momentum spectrum which has a well-known value of the edge.



Analysis purpose

In order to use DIO electrons spectrum for calibration purposes, few questions are supposed to be answered first:

- How can we calibrate the tracker with DIO electrons?
- How much statistics is required to calibrate the tracker momentum response with required accuracy?

Reconstructed momentum parametrization

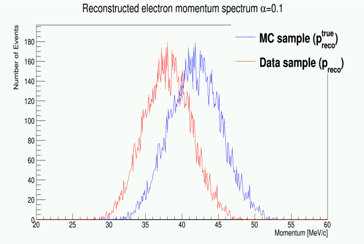
It's possible to express the reconstructed value of the curvature c_{reco} as a true curvature value c_{true} Taylor expansion:

$$c_{reco} = c_{true} + \alpha c_{true} + \beta + \cdots \tag{2}$$

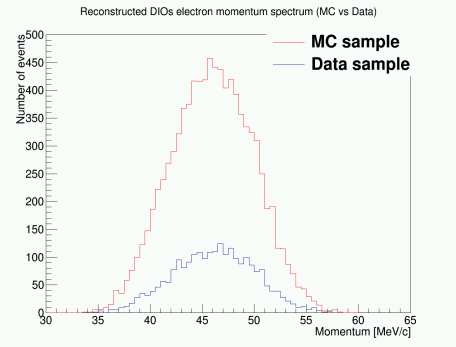
where β is the *false curvature* and α is the *absolute momentum scale*. Assuming that false curvature is negligible, the effect of a non-zero momentum scale is reported in the next picture supposing α=0.1:

Why α could it be non-zero?

Magnetic field inside the tracker could be slightly different from the expected one $B^{'} = (1-\alpha)B$



Simulation



Generation of two samples of DIO electrons:

- **MC sample** (10^6 events);
- **Simulated data sample** ($2.5 \cdot 10^5$ events).

Same generator code but:

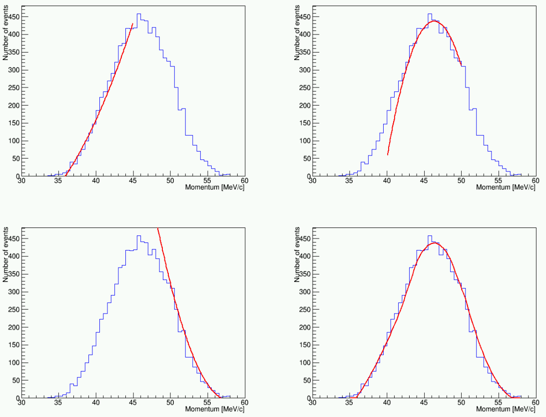
- difference in statistics of events so that statistical error is not a limitation factor;
- magnetic field 0.5% lower wrt MC samples (α=0.005).

In the picture on the right, DIO electrons reconstructed momentum is reported after a set of fit quality requirement for reconstructed tracks has been applied.

Parametrization of reconstructed DIO electrons spectrum

In order to fit the reconstructed momentum spectrum for DIO electrons, a piecewise function f(p) is defined in three different intervals of values:

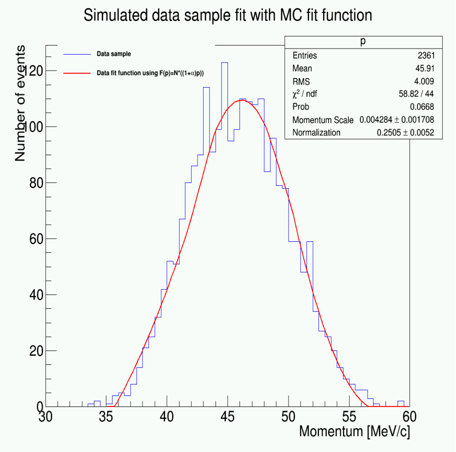
- a parabola with free parameters is plotted in each of them;
- smooth connection in next plot regions.



This technique is not sensitive to the statistical jitter

Comparisons between data and MC samples

Using a normalization factor N, the plot result is the following:



Value returned by the fit is α=0.004284$\pm$0.001708

This value is compatible within the statistical accuracy with the expected value, that is α=0.005

In order to reach the required accuracy is needed 4 times the number of simulated data events.

Strategy for the calibration run

In order to calibrate tracker using DIO electrons, other few questions are supposed to be answered first:

- How much time is it needed to collect that statistics?
- Which limitations could affect the calibration run?

Mu2e experiment requires a high intensity pulsed proton beam to produce an intense beam of low energy muons:

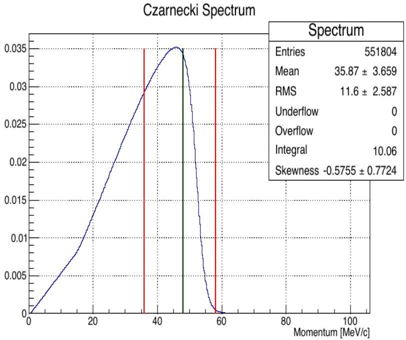
- a μ**Bunch** is a bunch of $\approx 10^7$ protons delivered to the production target;
- every $\approx$1.7μs a μBunch is injected into the beamline.

At nominal proton beam intensity, the expected number of the DIO electrons is $\approx 2 \cdot 10^4$ per μBunch. At 1 T, most of DIO electrons doesn't produce hits in the detector$\longrightarrow$ a reduction of magnetic field up to 0.5 T is needed to detect the spectrum edge.

Strategy for the calibration run

Proton beams reduction factor

$\approx 5 \cdot 10^3$ DIO electrons per μBunch is in the acceptance band of the tracker$\longrightarrow$DIO electrons hit multiple times inner straw tubes causing misreconstruction effects.



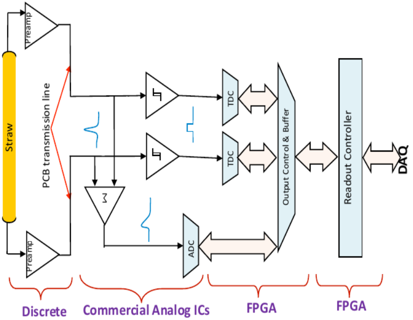
A reduction of DIO electrons per μBunch is needed in order to improve the momentum reconstruction

The number of protons per bunch could be reduced by a factor of about 10. An additional reduction of 10÷100 could be achieved by moving and defocusing the extracted proton beam before the production target. The final result is ≈ 5 DIO electrons per μBunch.

Strategy for the calibration run

Data acquisition timing

Assuming that no online triggering is needed and all events taken during the calibration run are written to disk, the bandwidth B required for a calibration run at 0.5 T is given by the following formula:



$$B = N(\frac{Bytes}{hits})\overline{N(\frac{hits}{\mu Bunch})}N(\frac{\mu Bunch}{s}) \quad (3)$$

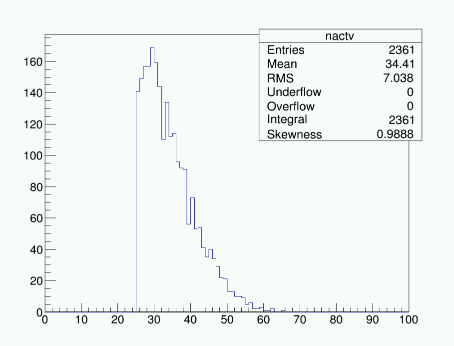
to be compared with the maximum data logger rate to read and write the disk array equal to B≈50$\frac{MBytes}{s}$.

Strategy for the calibration run

Data acquisition timing

Given that:

- DAQ system transfer data at 128 bits per hit format, that is $N(\frac{Bytes}{hits})=16\frac{Bytes}{hits}$;
- the mean number of hits per μBunch is $\approx$35;
- the number of μBunch per second is fixed and is $\approx 2 \cdot 10^5$.



B$\approx$100$\frac{MBytes}{s}$ is required per μBunch so $\approx$0.5 DIO electrons per μBunch allows us to efficiently transfer data

Summary and conclusions

To summarize:

- There's the possibility to use reconstructed DIO electrons spectrum to calibrate tracker⟶we can predict a non-zero momentum scale value;
- At half field, a reduced beam intensity is needed to prevent misreconstruction effects and DAQ system difficulties.

There are still unsolved questions such as:

- What if the false curvature is non-zero?
- Which is the maximal beam intensity for the dedicated run at 0.5 T?