Developing a Photon Conversion Reconstruction Algorithm for Background measurements in Mu2e

Francesco Mattia Carone

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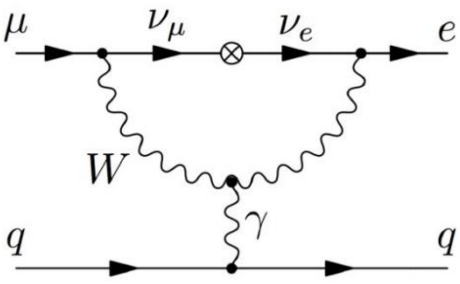
Mu2e Experiment purpose

The **main goal** of Mu2e is to look for the CLFV process: $\boldsymbol{\mu^- + \mathrm{N}(A, Z) \rightarrow e^- + \mathrm{N}(A, Z)}$.

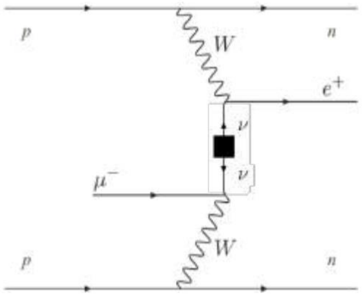
If no process is observed, Mu2e would improve the the current measure of the upper limit of the process's BR by 4 orders of magnitude and reach a Single Event Sensitivity (SES) of 3×10^{-17} with a 90% Confidence Level (CL) of 8×10^{-17}.



The process is monoenergetic: $\mathbf{E_{e^-} \sim 104.97}$ **Mev**

A **secondary goal** is the search for the CLFV and LNV process: $\boldsymbol{\mu^- + \mathrm{N}(A, Z) \rightarrow e^+ + \mathrm{N}(A, Z-2)}$.

The conversion can be mediated through either Giant Dipole Resonance or Ground State transition; in the latter case, the process is monoenergetic: $\boldsymbol{E_{e^+} \sim 92.3}$ **Mev**. In the former case, the search is overwhelmed by background processes, **RMC** (Radiative Muon Captures).



Complementary process to the double beta decay.

Backgrounds to the $\mu^- - e^+$ process

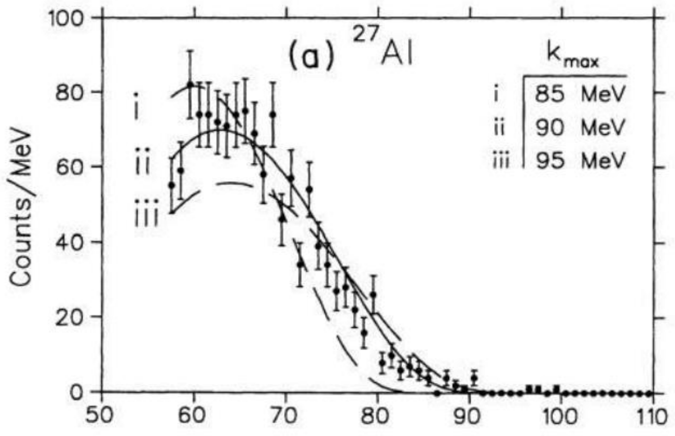
As for the $\mu^- - e^+$ process, the background processes are:

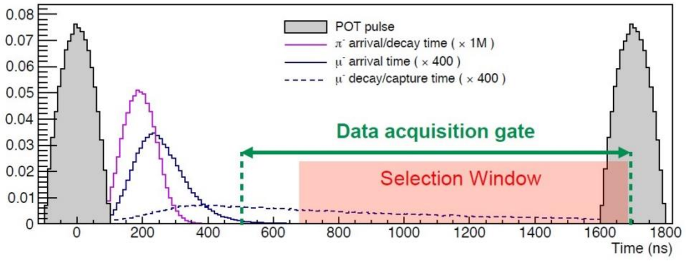
- **Radiative Muon Capture** (RMC)
  The photon produced can convert yielding a positron.
  The kinematic limit of the photon is $\mathbf{E}_\gamma^{\mathbf{lim}} \sim \mathbf{101.85}$ **MeV.**

- **Positrons and Muons from Cosmic Rays**
- **Antiprotons**

- **Radiative Pion Capture** (RPC)

Pions that survive the delayed live gate can reach the stopping target and produce a photon with spectrum endpoint at $\mathbf{E}_\gamma^{\mathbf{lim}} \sim \mathbf{135}$ Mev. This background is suppressed.





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Purpose of the Project

The **goal** is to develop an algorithm that is able to efficiently reconstruct double track events corresponding to **conversions of primary photons into electron/positron couples**.

A photon is said to be primary if it has not been produced starting by other photons. The efficiency of the algorithm should be higher for positrons in the CP momentum range, so that the algorithm can be adopted to reconstruct conversion events that are background to the $\mu^- - e^+$ process.

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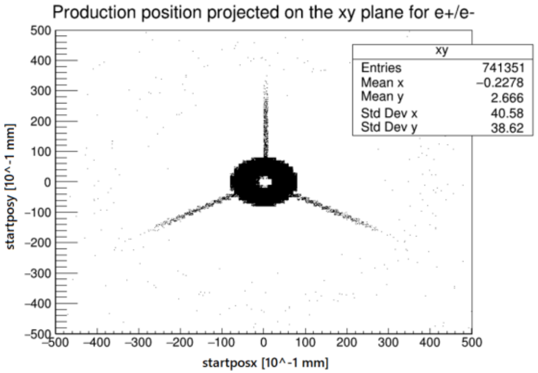
Software and Monte Carlo simulations

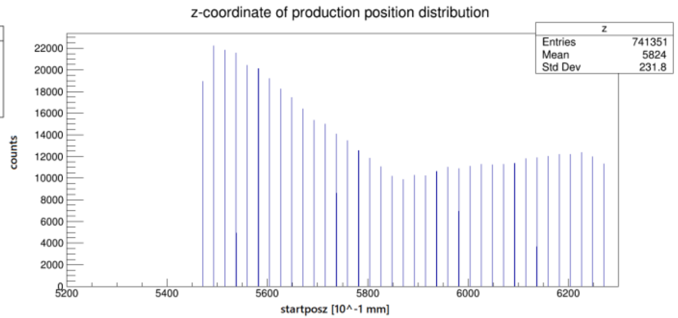
Monte Carlo simulated events are used in order to measure and optimize the efficiency of a developed track reconstruction algorithm.

Most of the code and of the scripts that are currently used for analysis of both simulation and reconstruction are kept in the Mu2e Offline GitHub repository at the link:

https://github.com/Mu2e/Offline.

Example: Monte Carlo sample of $\sim 10^8$ simulated photon conversion events, with photon energy randomly extracted from a flat distribution in the $70/102$ Mev interval (close to CP momentum). Such sample is typically called a «flat photons» sample.



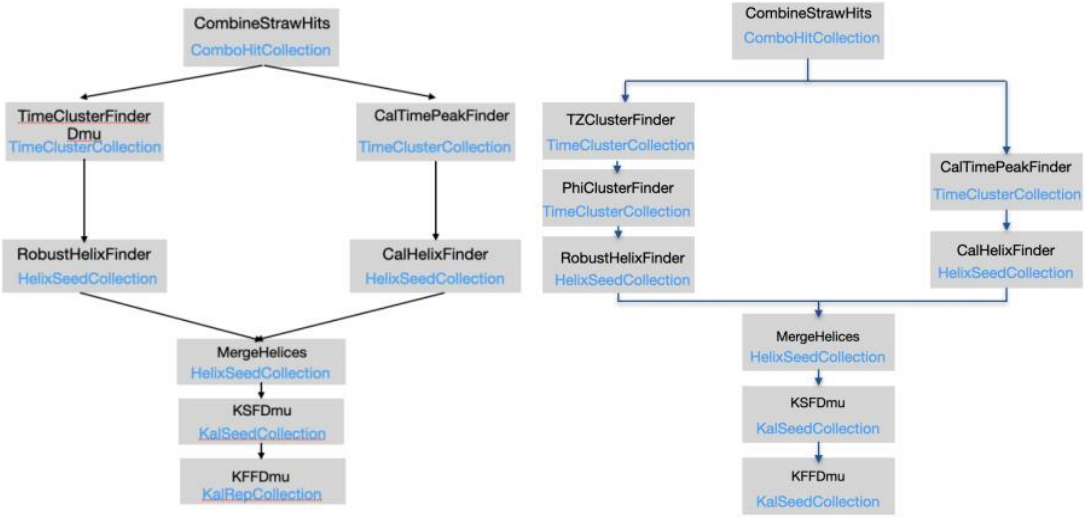


We can plot and visualize the most interesting physical properties of the photons from the sample, such as starting position (plots above).

Track reconstruction sequences

Reconstruction algorithms that have been already developed and tested were mostly written in order to reconstruct single track events for electrons with an energy range close to CE. Instead, we need a new algorithm that can efficiently reconstruct primary photon conversion double-track events.

We can start from already existing double track events reconstruction algorithms, not specialized in photon conversion events, to develop a new one that is useful for our purpose. Below, a double track reconstruction algorithm sequence, specialized in $p\bar{p}$, is compared with the default sequence.



(a) Default Reconstruction sequence. (b) New Reconstruction sequence.

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Analysis (part 1)

The double track reconstruction sequence showed in the previous slide was re-adapted to reconstruct double track electron/positron conversion events.

Starting from a sample of $\sim\mathbf{10^9}$ **Monte Carlo flat photons** events, the new reconstruction sequence was applied to the data gathered from the simulated detector. Then, the reconstruction results were compared to the known properties of the Monte Carlo events (Monte Carlo truth).

The **efficiency** of the sequence can be evaluated through the following analysis. First construct 6 separate sets of Monte Carlo truth conversion events, distinguished on the basis of the type of their final particles. Respectively, they are requested to exhibit, as final particles:

1. an electron/positron pair from same primary photon
2. an electron/positron pair from same photon
3. an electron/positron pair
4. at least an electron and a positron
5. a pair of any conversion particles
6. at least one conversion particle

Then, for each set, compute the ratio of the number of correspondencies between the set's events and the reconstructed events (numerator) and the number of events in the set (denominator).

As for «conversion particle», we refer either to an electron or a positron that converted from a photon.

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Analysis (parte 2)

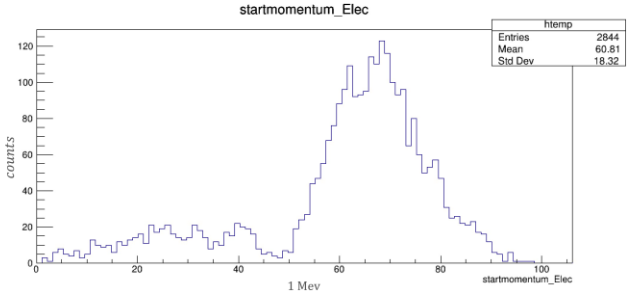
The **ratio corresponding to the first set** can be interpreted as the actual **efficiency of the sequence**. The other ratios provide information about the **false positives** appearing in the reconstructed events set.

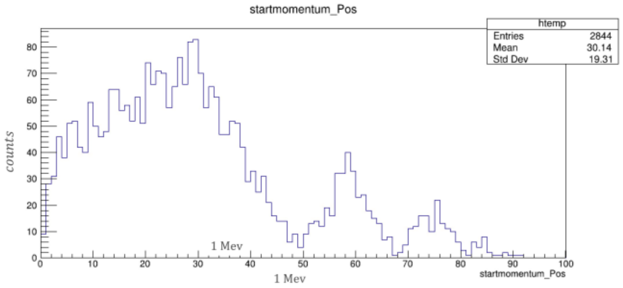
Set	Number of reconstructed events	Number of Monte Carlo truth events	Number of correspondecies	Ratio
e^-/e^+ from same primary photon	55	2844	2	7.0×10^{-4}
e^-/e^+ from same photon	55	5773	2	3.5×10^{-4}
e^-/e^+ pair	55	102822	5	4.9×10^{-5}
At least e^-/e^+	55	172862	12	6.9×10^{-5}
Just 2 conversion particles	55	186808	9	4.8×10^{-5}
At least 1 conversion particle	55	680687	49	7.2×10^{-5}

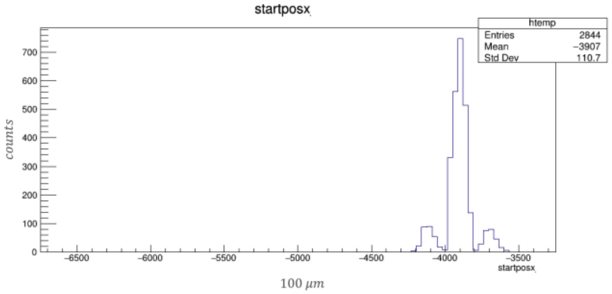
It was therefore measured an **efficiency** of $\sim\mathbf{0.07}\%$ and a **false positive ratio** of $\sim\mathbf{96}\%$.

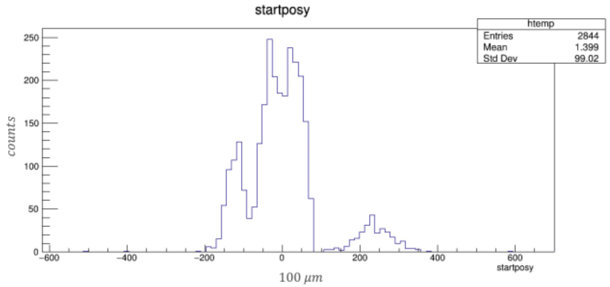
Analysis (part 3)

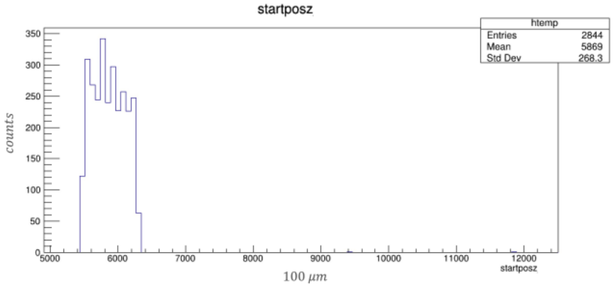
As for the Monte Carlo Truth conversion events corresponding to a primary photon converting into an electron/positron pair, it is interesting to observe the **conversion position distribution,** the electron and positron **starting momentum distributions** and **starting momentum along photon direction distributions**.



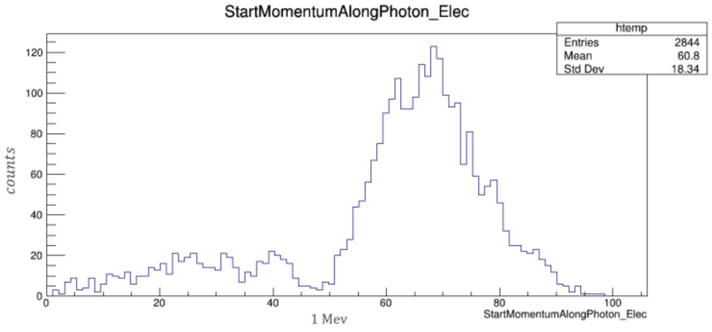


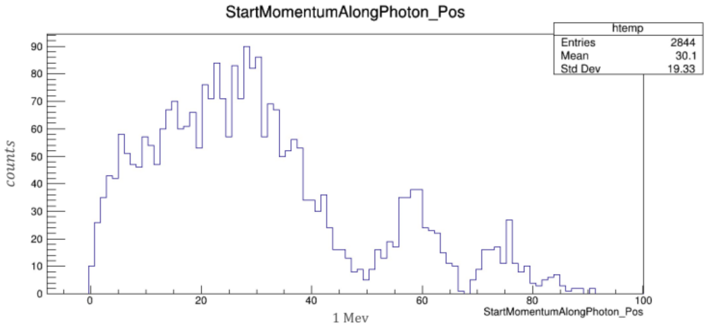




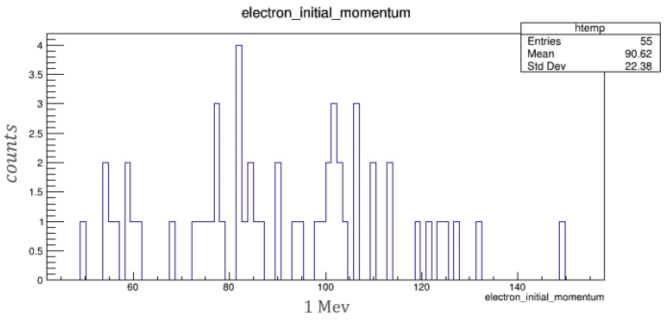


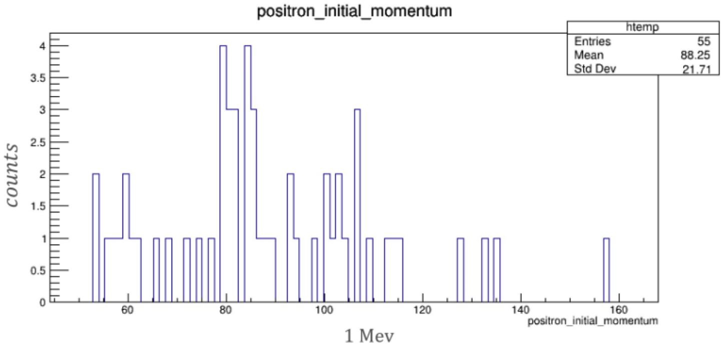
Analysis (part 4)





Analogously, for the reconstructed events set, the **starting momentum distributions** of the electron and the positron can be observed.





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Future developments for the reconstruction algorithm

Despite the low reconstruction efficiency reached with the current version of the algorithm, it is auspicable that the algorithm itself will be made more efficient in the future. The analysis conducted nevertheless proves that reconstruction for the class of events of interest is possibile.

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Side Projects

Together with the main project regarding the development of a photon conversion reconstruction algorithm for background measurements, I have also participated, during my stay at Fermilab, in:

1. Setup of the Mu2e DAQ system
2. Out-gassing of the Mu2e Calorimeter Redout Units

DAQ setup

Components of the DAQ set-up are now being chosen and tested. In particular, the insertion loss of the whole system is requested to be low enough to assure efficient data distribution.

By now, the long run cables and the vacuum cables have been tested and have given the positive expected results. It is now needed to test the whole system together at once.

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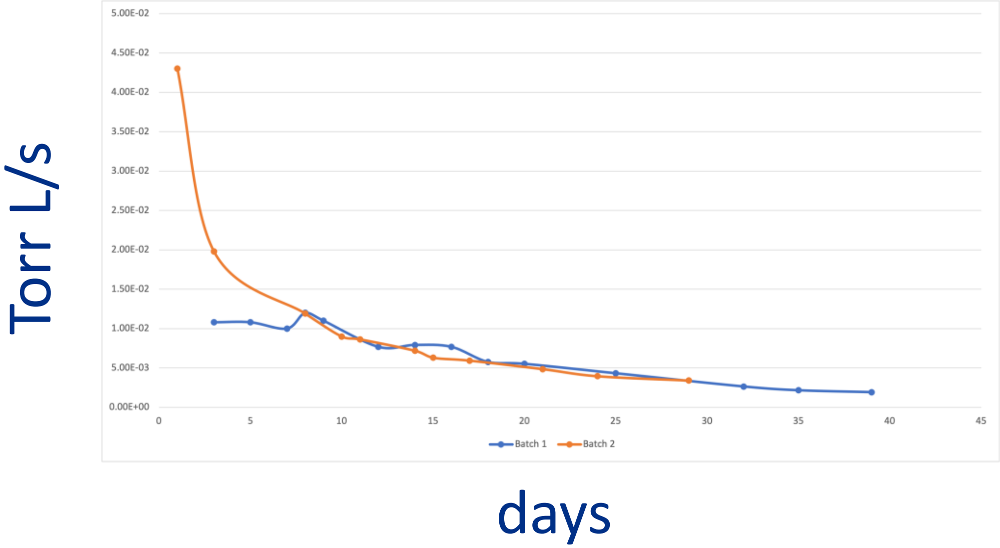
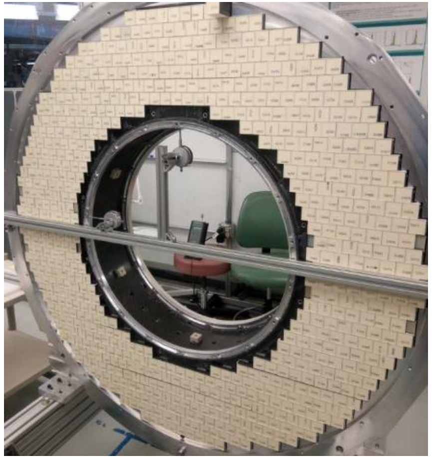
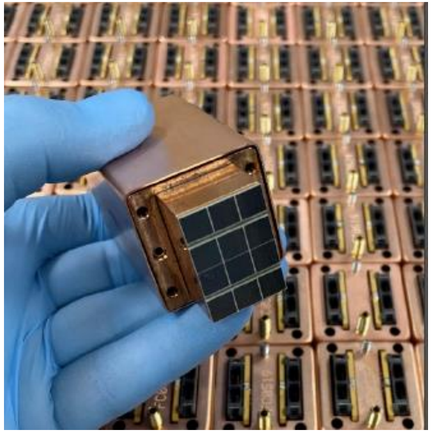
Outgassing of the calorimeter Readout units

Some of the readout units of the calorimeter have still to be put in place on the second calorimeter wheel.
Before doing that, in order to assure their well functioning in the vacuum, it is needed to outgas them.
The calorimeter will be completed by the end of the year.







Thank you for your attention!