A data-driven method for antiproton background measurement in Mu2e

N. Chithirasreemadam on behalf of the Mu2e Collaboration
INFN, Pisa and University of Pisa

Mu2e : A quick overview

Search for CLFV neutrinoless, coherent conversion $\mu^- N \rightarrow e^- N$ on an Al target.

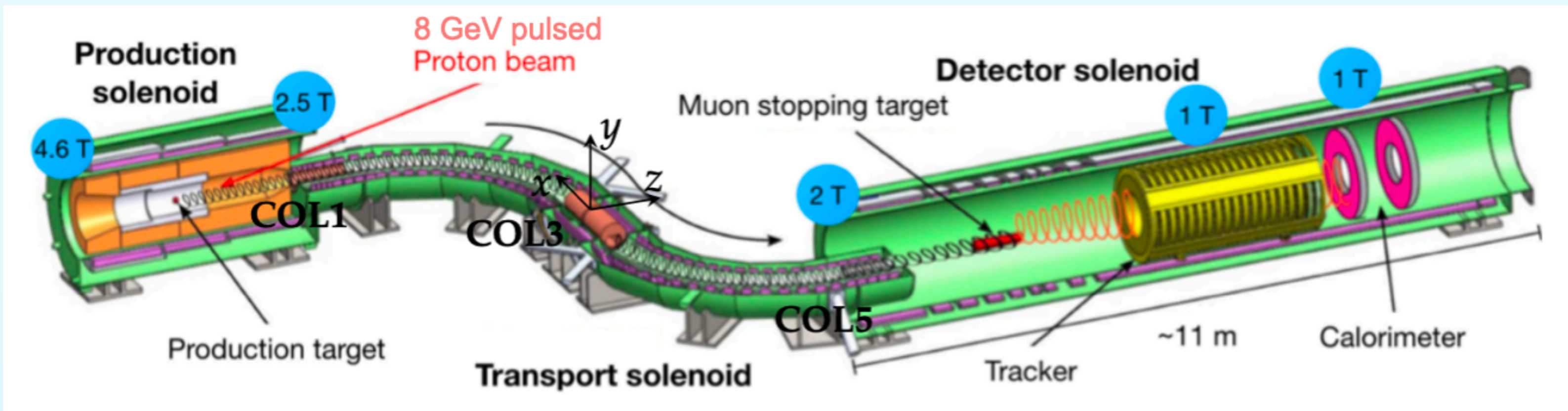
Present experimental limit set by SINDRUM II experiment [1]

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(Z,A) \rightarrow e^- + N(Z,A))}{\Gamma(\mu^- + N(Z,A) \rightarrow \nu_\mu + N(Z-1,A))} < 7 \times 10^{-13}(90\,\%\,CL)$$

SM + massive neutrinos: CLFV allowed but highly suppressed ($< 10^{-50}$ BR).

$\mu^- N \rightarrow e^- N$ would be clear proof for New Physics.

Signal : Monochromatic conversion electron $E_{CE} = 104.97$ MeV for an Al nucleus.



8 GeV proton beam interacts with Tungsten target and mostly produces pions. Pions decay into muons which spiral through the S-shaped Transport Solenoid. The μ^- beam will stop in the stopping target (ST) in the Detector Solenoid, where the conversion process to e^-may occur.

Background processes in Mu2e

The expected Run I 5σ discovery sensitivity is $R_{\mu e} = 1.2 \times 10^{-15}$.

Estimated $\bar{p}$ background for Run 1: $0.01 \pm 0.003(stat) \pm 0.010(syst)$, the systematic error is dominated by the uncertainty on the production cross-section at 8 GeV/c proton momentum.

Channel	Mu2e Run I
SES	2.4×10^{-16}
Cosmics	0.046 ± 0.010 (stat) ± 0.009 (syst)
DIO	0.038 ± 0.002 (stat) $^{+0.025}_{-0.015}$ (syst)
Antiprotons	0.010 ± 0.003 (stat) ± 0.010 (syst)
RPC in-time	0.010 ± 0.002 (stat) $^{+0.001}_{-0.003}$ (syst)
RPC out-of-time ($\zeta = 10^{-10}$)	$(1.2 \pm 0.1$ (stat) $^{+0.1}_{-0.3}$ (syst)) $\times 10^{-3}$
RMC	$< 2.4 \times 10^{-3}$
Decays in flight	$< 2 \times 10^{-3}$
Beam electrons	$< 1 \times 10^{-3}$
Total	0.105 ± 0.032

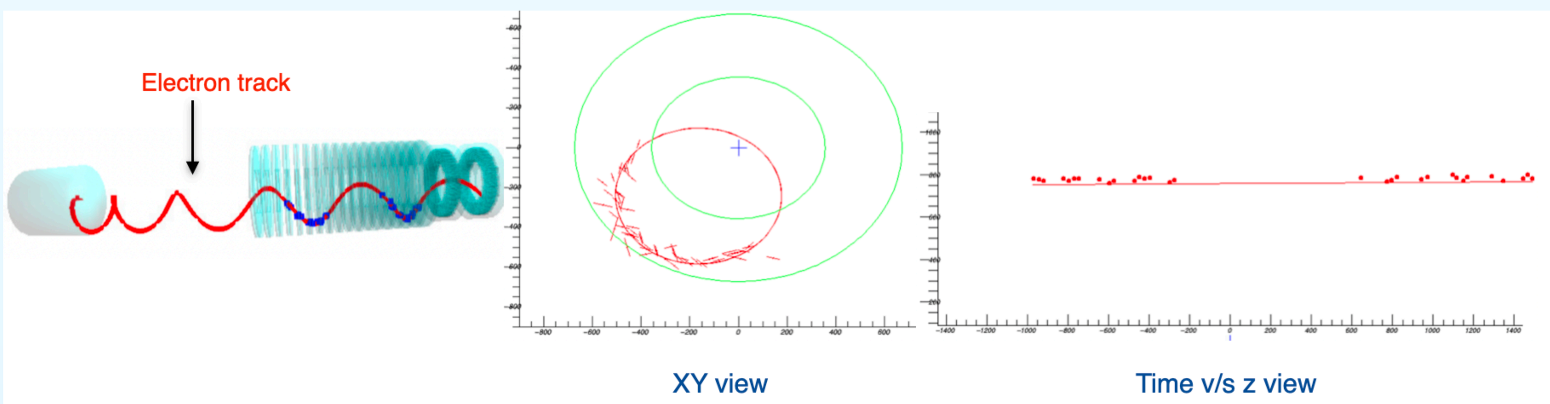
Background summary using the optimised signal momentum and time window
103.6<p<104.90 MeV/c and 640< T0<1650 ns[2]

Antiproton background

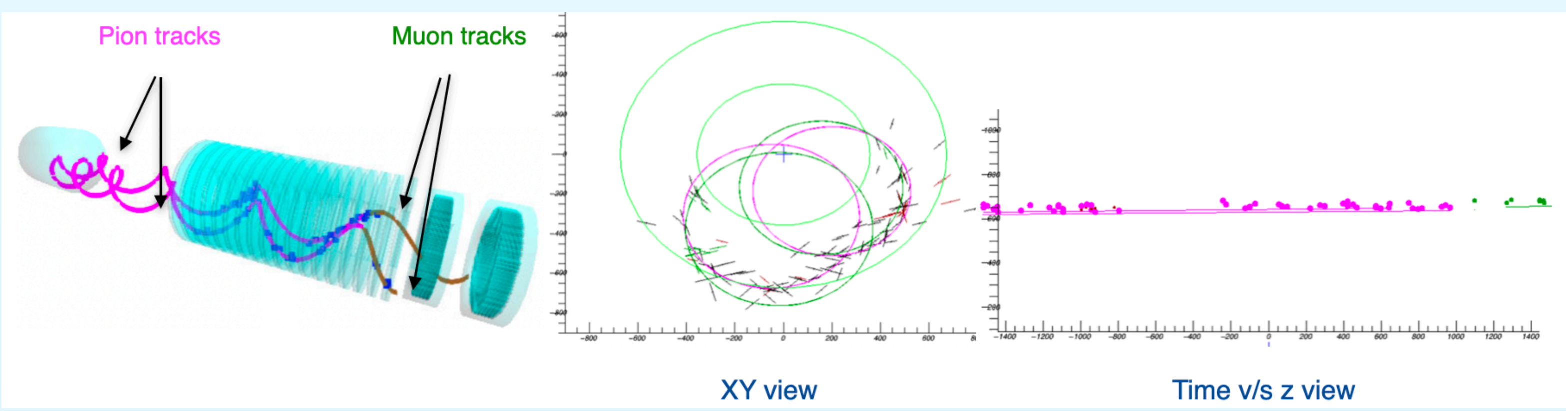
$\bar{p}$ produced by the pW interactions in the Production Solenoid can annihilate in the ST producing signal-like e^-s.

$\bar{p}$ background cannot be suppressed by the time window cut used to reduce prompt background because $\bar{p}$s are much slower than other beam particles.

Absorber elements at entrance and centre of the Transport Solenoid to suppress the $\bar{p}$ background.



Events from $p\bar{p}$ annihilation in the ST. Red = electron, Green = Muon, Pink = Pion



$p\bar{p}$ annihilation at rest in the ST can produce events with more than one track with p $\sim$ 100 MeV/c.

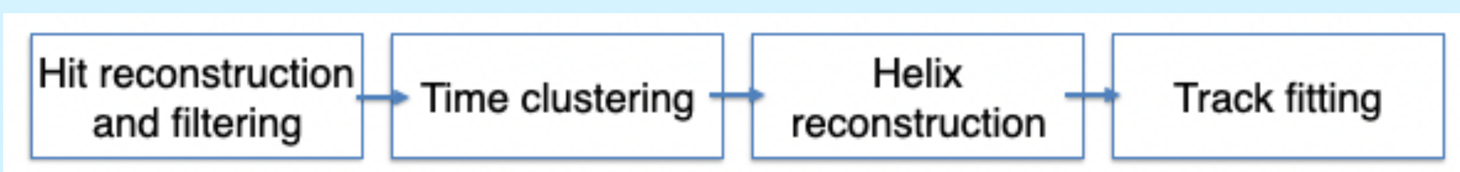
The rate of such multi-track events $\sim$ 500 times higher than the rate of events with 1 signal like electron.

Our idea is to identify and potentially reconstruct these two particle final state events and estimate the antiproton background by comparison.

Mu2e event reconstruction

Mu2e event reconstruction is optimised to reconstruct 1-track events with tracks coming from the ST.

Reconstruction sequence:

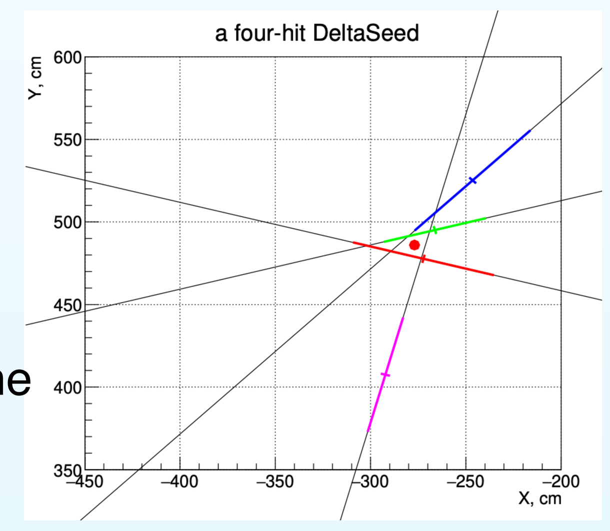


This work was supported by the EU Horizon 2020 Research and Innovation Program under the Marie Sklodowska-Curie Grant Agreement Nos. 734303, 822185, 858199, 101003460.

Low-momentum e^-/e^+ background identification

The current algorithm to remove low energy e^- hits removes significant fraction of pion and muon hits as well.

Developed a new low-momentum e^- identification algorithm which builds δe^- candidates out of "seeds": stereo intersections of hit wires, close in time, within one station.



With the new algorithm the rejection factor of pions and muons has been significantly reduced.

Early Stage Time-Z Clustering

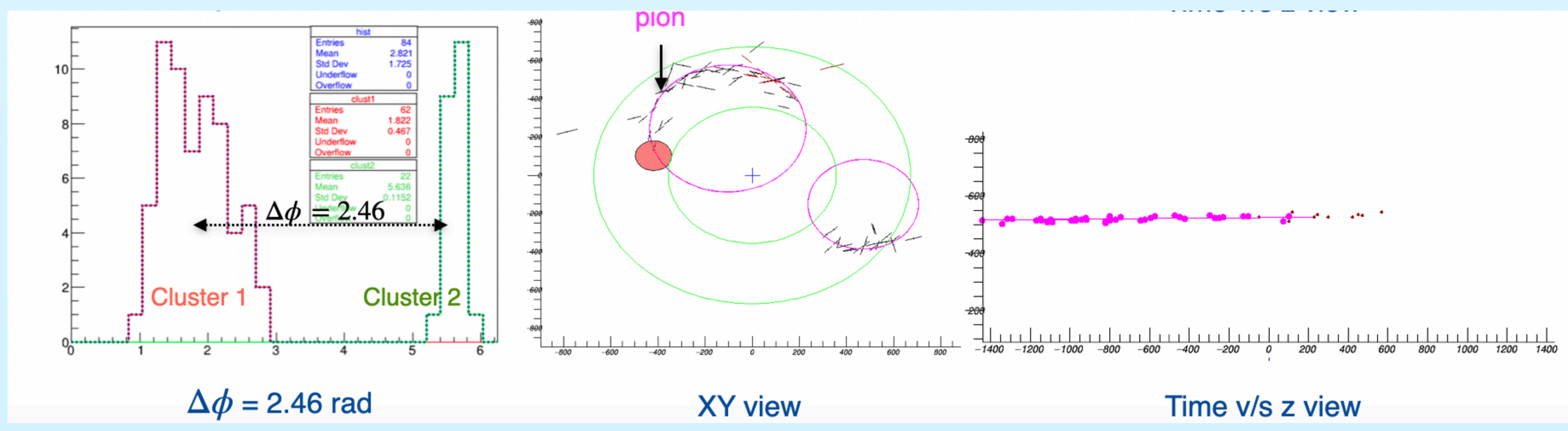
The current algorithm is based on ANN hit selection. It is highly tuned for Conversion Electron search.

We developed a more agnostic algorithm 'TZClusterFinder', highly efficient for a wide spectrum of topologies.

The 'TZClusterFinder' searches for hits that fit along a linear line in time vs. z space.

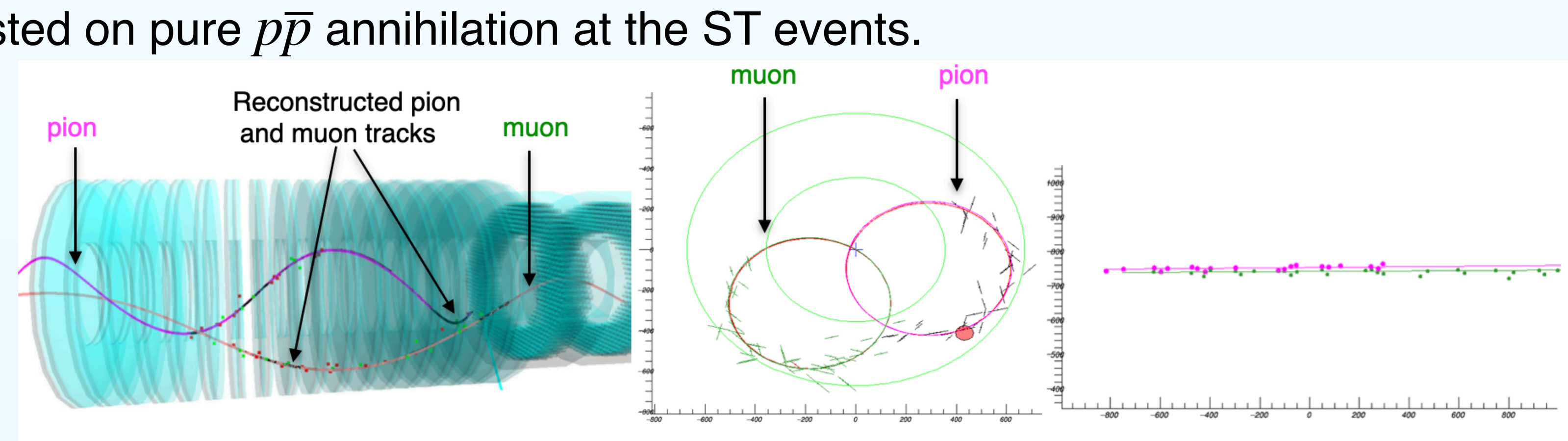
Early Stage Hit Phi Clustering

Hits from different particle tracks in the same time window could be well separated in ϕ.

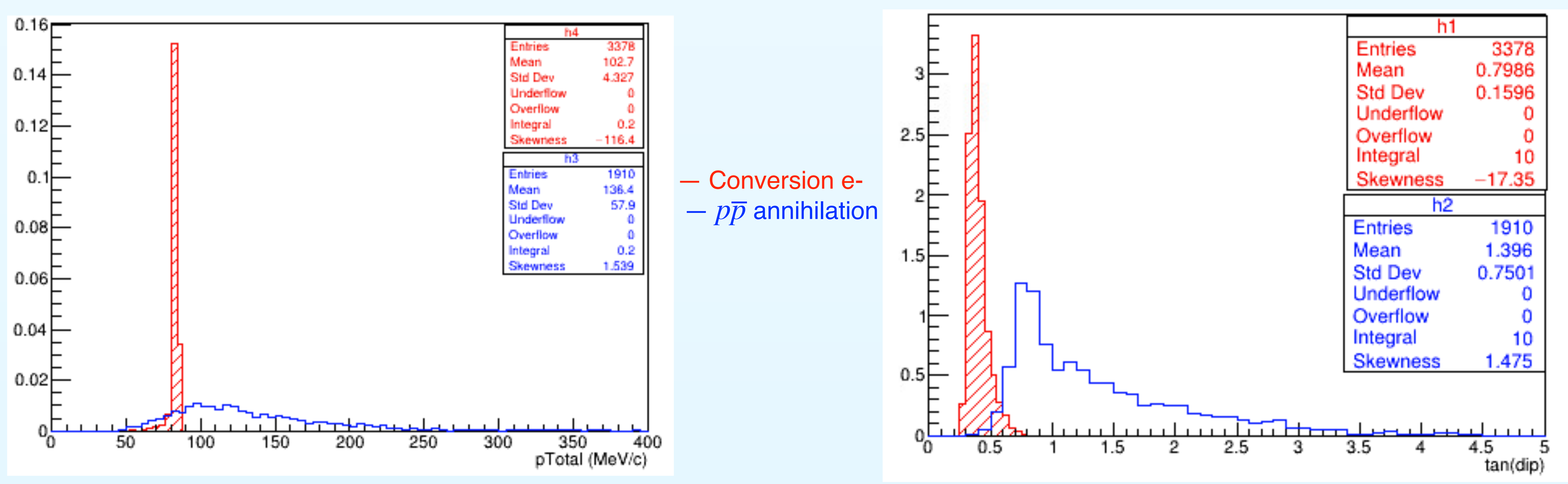


Preliminary results

Tested on pure $p\bar{p}$ annihilation at the ST events.



Green = Muon, Pink = Pion, Black = Reconstructed track in 3-D view, Red = Reconstructed track in 2-D views

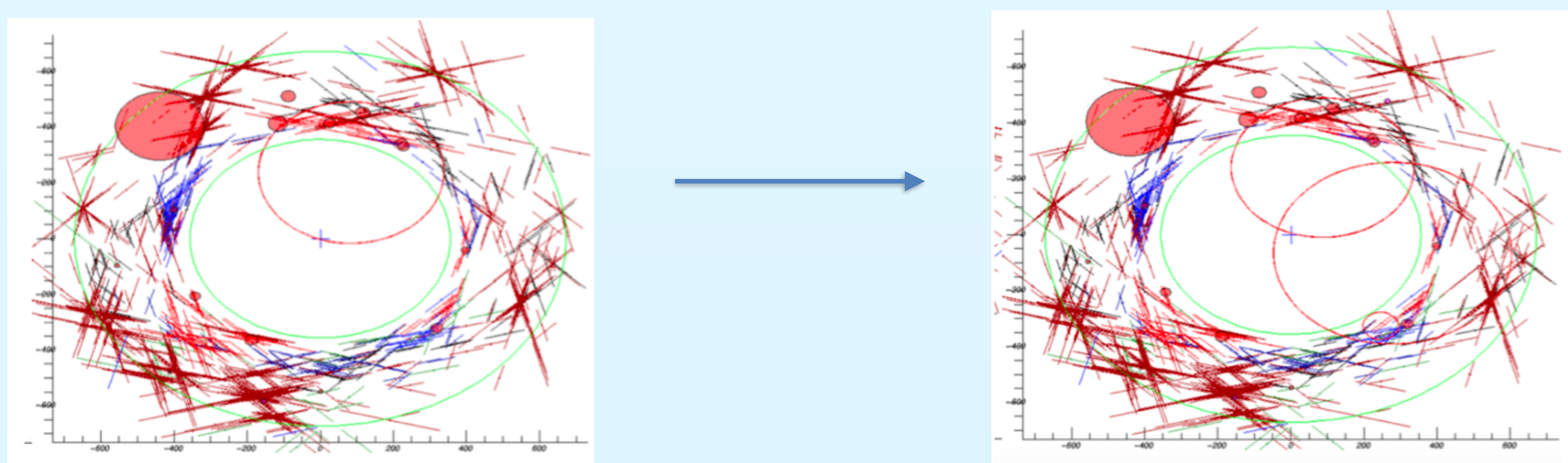


Total momentum **tan(λ)**

Comparing the default v/s new reconstruction chain:

Number of events with at least one track increased by **40%**;

Number of events with ≥ 2 tracks increased by **x2.8** times.



Mu2e standard reconstruction New reconstruction

Transverse view of $p\bar{p}$ annihilation + high intensity pile-up data event. The red circle is the transverse view of the reconstructed track. The segments are the "hit" tracker straws.

Summary

We are developing new algorithms to reconstruct events with more than one track.

Using the new reconstruction chain, the two-track reconstruction improved significantly.

We are studying the performance of this data-driven method using data samples with pile-up now.

The expected $\bar{p}$ background is small $\sim 10^{-2}$, so the expectation is that we will end up with an upper bound on the $\bar{p}$ background.

References

[1] A Search for muon to electron conversion in muonic gold SINDRUM II Collaboration 2006
[2] Mu2e Run I Sensitivity Projections Mu2e Collaboration Universe 2023