A data-driven method to estimate the $\bar{p}$ background in Mu2e

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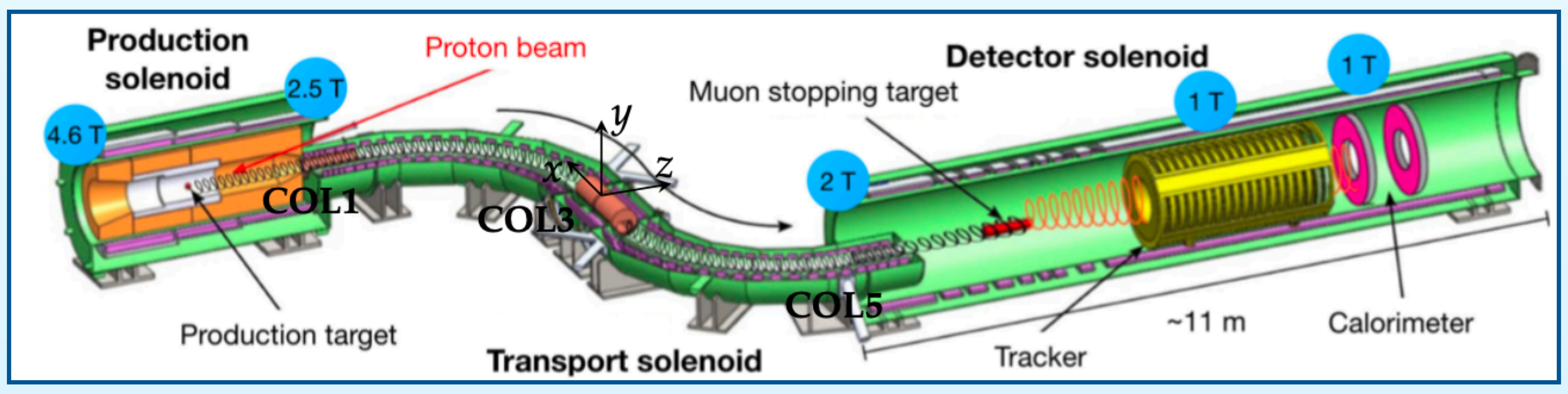
Mu2e: An Overview

Search for neutrinoless, coherent conversion $\mu^- N \rightarrow e^- N$ in the field of an Al nucleus by measuring,

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(Z,A) \rightarrow e^- + N(Z,A))}{\Gamma(\mu^- + N(Z,A) \rightarrow \nu_\mu + N(Z-1,A))}$$

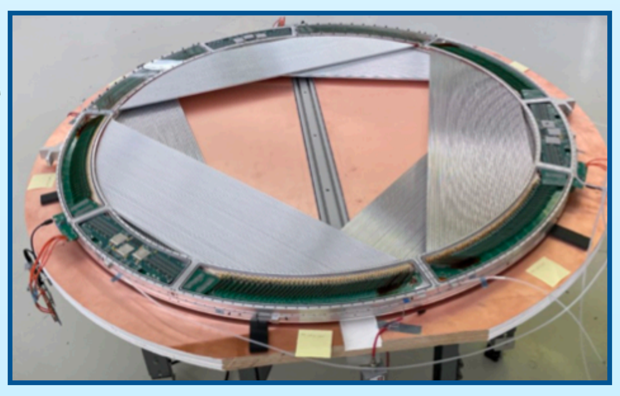
Signal: Monochromatic, 104.97 MeV/c e^-.

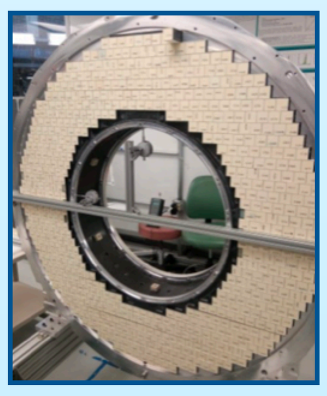


PS	TS	DS
8 GeV pulsed proton beam interacts with the Tungsten target. Mostly produces pions.	Selects muons with p < 100MeV/c. Rotating collimator COL3 selects μ^- or μ^+ beam.	Muons stop in the Al stopping target (ST). Annular tracker and calorimeter to detect the conversion e^- (CE).

The tracker consists of 18 stations with 1152 straws per station. The straws are filled with 80%:20% $Ar : CO_2$ mixture.

The calorimeter has 2 disks covering radii 37 cm-66 cm. Each disk has 674 pure CsI crystals.





The expected Run I 5σ discovery sensitivity is $R_{\mu e} = 1.2 \times 10^{-15}$. If no signal, the expected upper limit is $R_{\mu e} < 6.2 \times 10^{-16}$ at 90% CL.

The estimated $\bar{p}$ background for Run 1 is $0.01 \pm 0.003(stat) \pm 0.010(syst)$*. The systematic error is dominated by the uncertainty on the $\bar{p}$ production cross section.

$\bar{p}$ background in Mu2e

$\bar{p}$s are produced in the pW interactions in the PS.

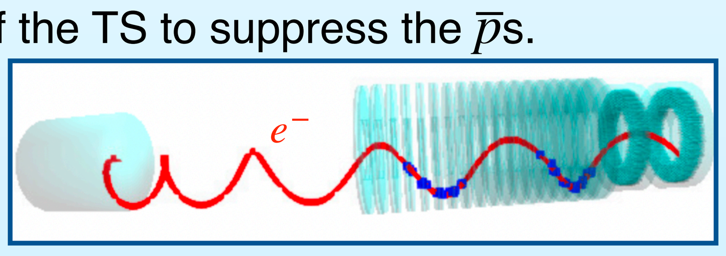
$p\bar{p}$ annihilation at ST can produce e^-s by $\pi^0 \rightarrow \gamma\gamma$ decays followed by γ conversions and $\pi^- \rightarrow \mu^-\bar{\nu}$ decays followed by the μ^-decays.

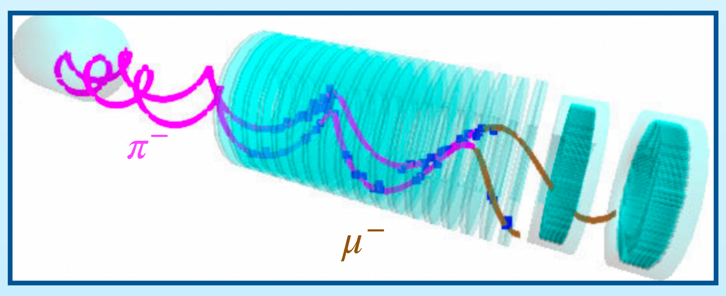
It cannot be suppressed by the time window cut because $\bar{p}$s are much slower than other beam particles.

Absorber elements placed at entrance and centre of the TS to suppress the $\bar{p}$s.

$p\bar{p}$ annihilation at ST can give multi- tracks final state with p ~ 100 MeV/c for each track at much higher rate than signal-like e^-. From GEANT4 simulations,

$$\frac{N_{e^- perMeV}(110 > p > 90 MeV/c)}{N_{multi-track}(p \geq 80 MeV/c)} \approx \frac{1}{500}$$





Goal: Identify and reconstruct the multi-track final state events and get an estimate of the CE like events by rescaling the ratio of the two final states.

Mu2e event reconstruction

Mu2e event reconstruction is optimised for single e^- track events.

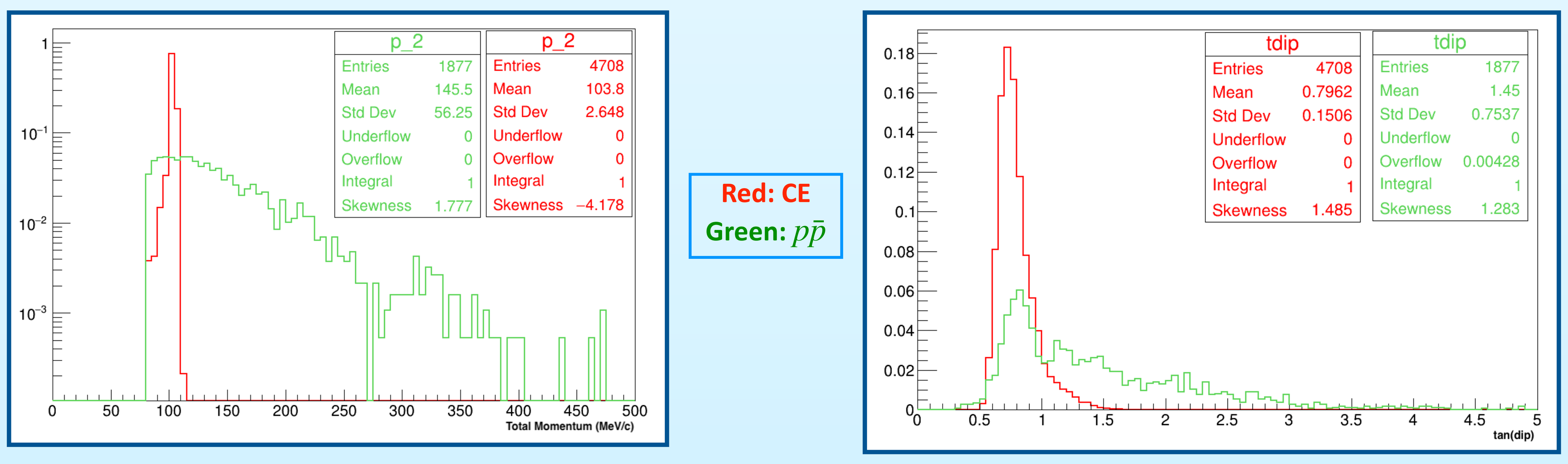
From MC studies, 90% of hits in an event are from low energy e^-, e^+, p.

They are flagged background prior to reconstruction.

Assuming hits by same particle have close reconstructed times, they are time clustered.

TimeClusters are input for pattern recognition which search for 3-D *Helices*.

Finally, the reconstructed track parameters are determined by the Kalman fit.



The default algorithms to flag background hits and form *TimeClusters* use an ANN trained for efficient CE search, which removes a large fraction of pion and muon hits.

This reduces the efficiency of reconstructing tracks from $p\bar{p}$ annihilation significantly.

We developed new algorithms, without any ANN, highly efficient for a wide spectrum of particle topologies.

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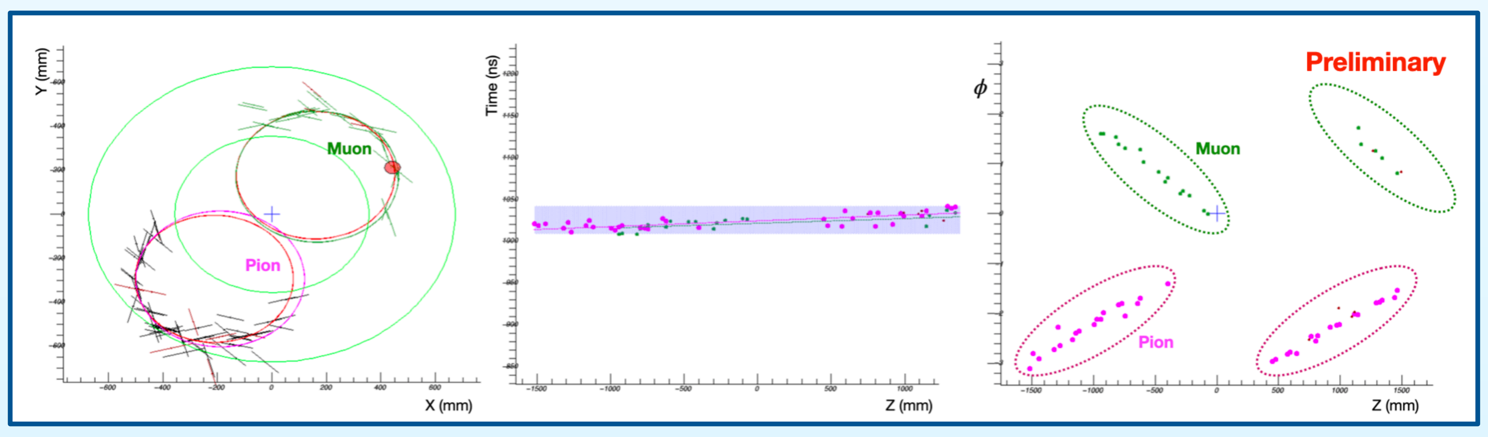
Simple time clustering alone is insufficient for $\bar{p}$ annihilation events as the tracks are mostly simultaneous in time.

However, hits from different particles could be well separated in $\phi = tan^{-1}(y/x)$.

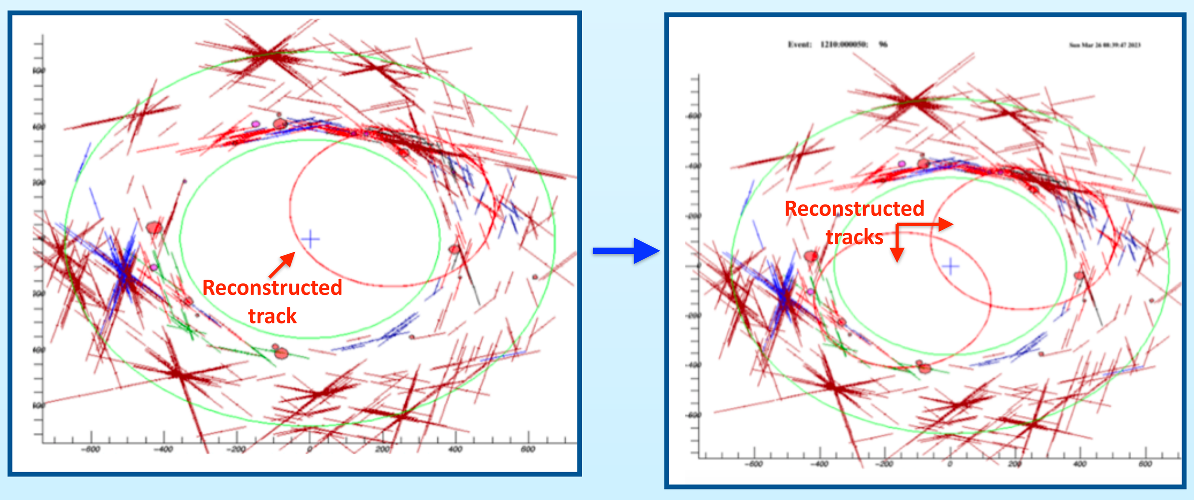


y vs x, *time* v/s z and ϕ v/s z views for an example $p\bar{p}$ annihilation at the ST event.

Mu2e Run I will operate in low intensity mode: 1.6×10^7 $protons/pulse$, ~ 2.5×10^4 $\mu^-/pulse$ in ST.

For high intensity mode, the corresponding numbers are × 2.5higher.

We tested the reconstruction procedure with datasets containing $p\bar{p}$ annihilation events mixed with low and high intensity backgrounds as well.



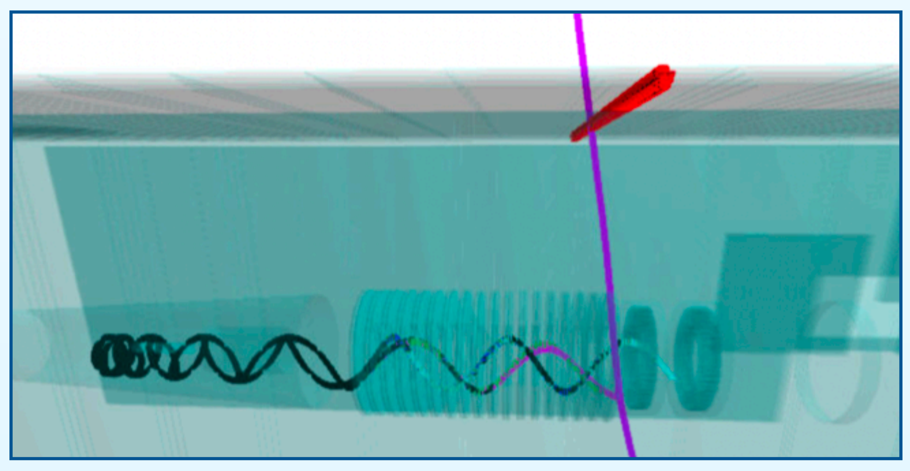
Default Reconstruction | New Reconstruction

Contribution of cosmic rays to multi-track events

A cosmic ray veto (CRV) system built from scintillator counters surrounds the DS to identify the cosmic rays.

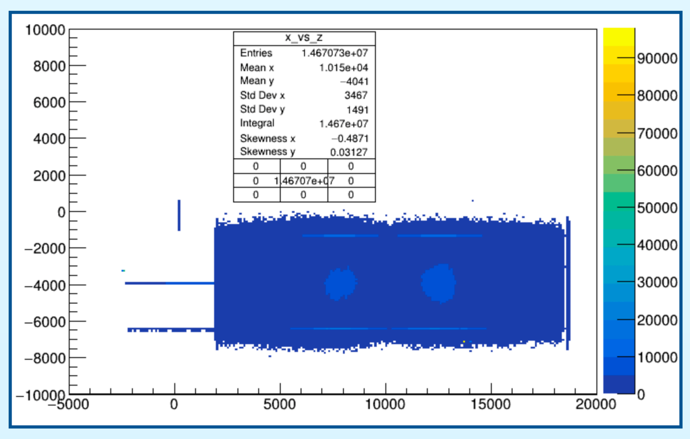
The multi-track events from cosmic rays are:

1) Muons trapped in the magnetic bottle structure of the DS or interacting with calorimeter producing e^-/e^+, which then travel up towards the ST and back to the calorimeter end.
2) Muons interacting with ST producing e^-/e^+.

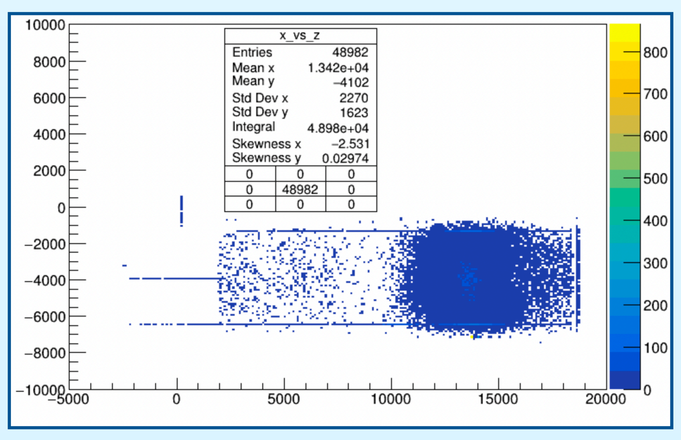


Cosmic μ^- hits the CRV scintillation bars (shown in red), performs helical motion in the DS back and forth.

Thus, most cosmic multi-track events are made of an upstream and downstream moving leg of the same particle while $\bar{p}$ annihilation at the ST gives multiple particle tracks moving downstream from the ST.

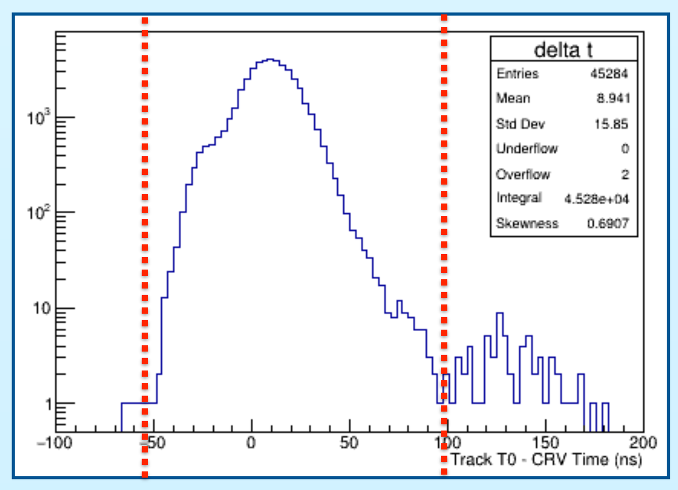


x v/s z view for all cosmic ray events

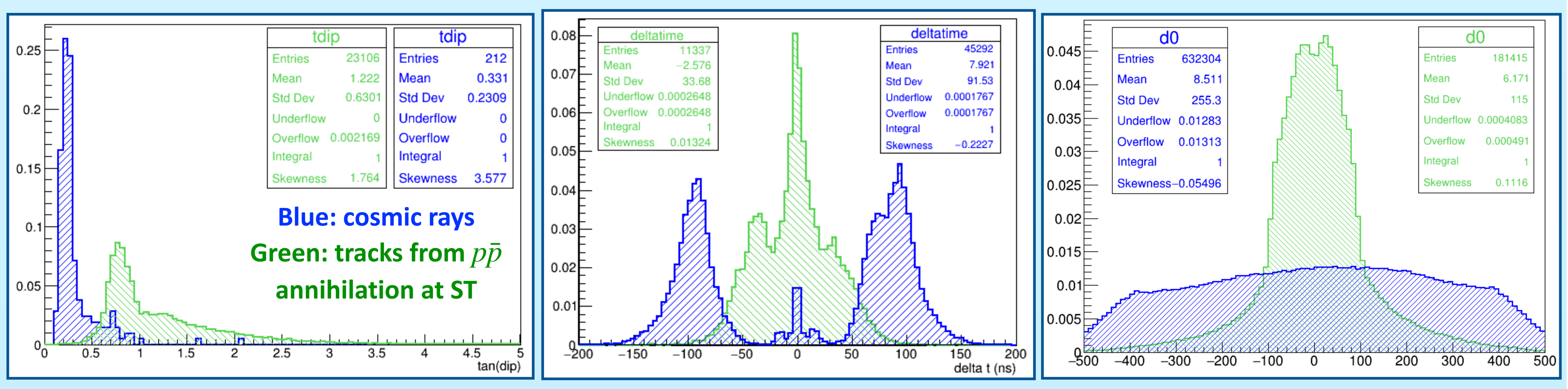


x v/s z view for multi-track cosmic ray events

About 99.98% of these multi-track events can be vetoed using the signal from the CRV. Cosmic event candidates are identified by the timing window $-50 < \Delta T_{CRV} < 100ns$ where $\Delta T_{CRV} = T_0 - T_{CRV}$.



For events with no matched CRV signal, we have identified track parameters: pitch($tan(\lambda)$), impact parameter ($D0$) that can be used to distinguish tracks from cosmic muons from $\bar{p}$ background events.



$tan(\lambda)$ | $\Delta T_{trk}(ns)$ | D0 (mm)

Conclusion

We developed a novel data-driven approach to constrain the $\bar{p}$ background in Mu2e.

Tested the reconstruction with pure $p\bar{p}$ annihilation events and with $p\bar{p}$ annihilation events mixed with low and high intensity backgrounds.

We reconstruct about 42% of the multi-track events from $p\bar{p}$ annihilation at the ST where each track has a total momentum > 80 MeV/c and makes at least 20 hits in the tracker.

Compared to the default reconstruction, the number of multi-track events increased by × 2.1 times.

Currently, we are working on improving the reconstruction further and getting a final estimate on the $\bar{p}$ background.