Target monitor performance

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Mu2e Extinction Technical Design Review
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Outline

- Define signal and backgrounds
- Spectrometer simulation and reconstruction
- Signal reconstruction efficiency and linearity
- Expected background rates
- Off-target interactions

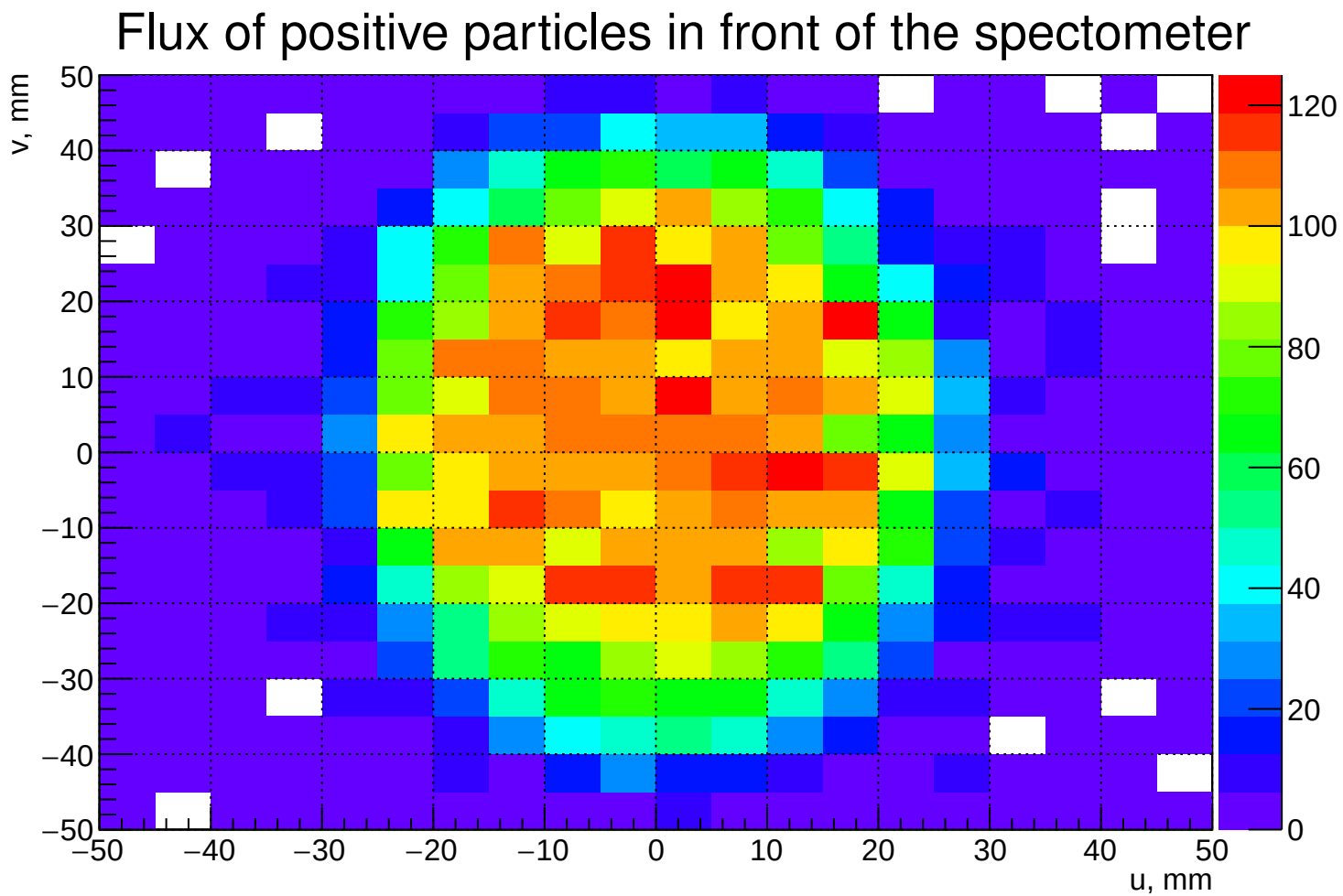
Signal and backgrounds

- Signal: 4.2 GeV/c secondaries from the production target
  - In-time: normalization
  - Out-of-time: measurement of non-extinct protons
- Backgrounds: out-of-time reconstructed tracks at 4.2 GeV/c for perfect true extinction
- Another potential issue: secondaries from out-of-time protons interacting outside the target
  - The tracker is designed to be efficient for the signal and minimize backgrounds
  - The proton beamline and ExtMon collimation system are designed to minimize out of target tracks

Spectrometer simulation

- GEANT4 model of spectrometer is a part of Mu2e Offline
- Detailed silicon pixel digitization
  - Sensor response: Fano factor, charge drift and diffusion
  - Electronic response: time over threshold circuit model, timewalk
  - Fluctuations in non-hit pixels: random noise
  - “Detector like” output does not contain any MC truth info
- Reconstruction runs on the “detector like” data
  - Pixel cluster formation
  - Track finding
  - χ^2 fit of track parameters
  - Elimination of duplicates

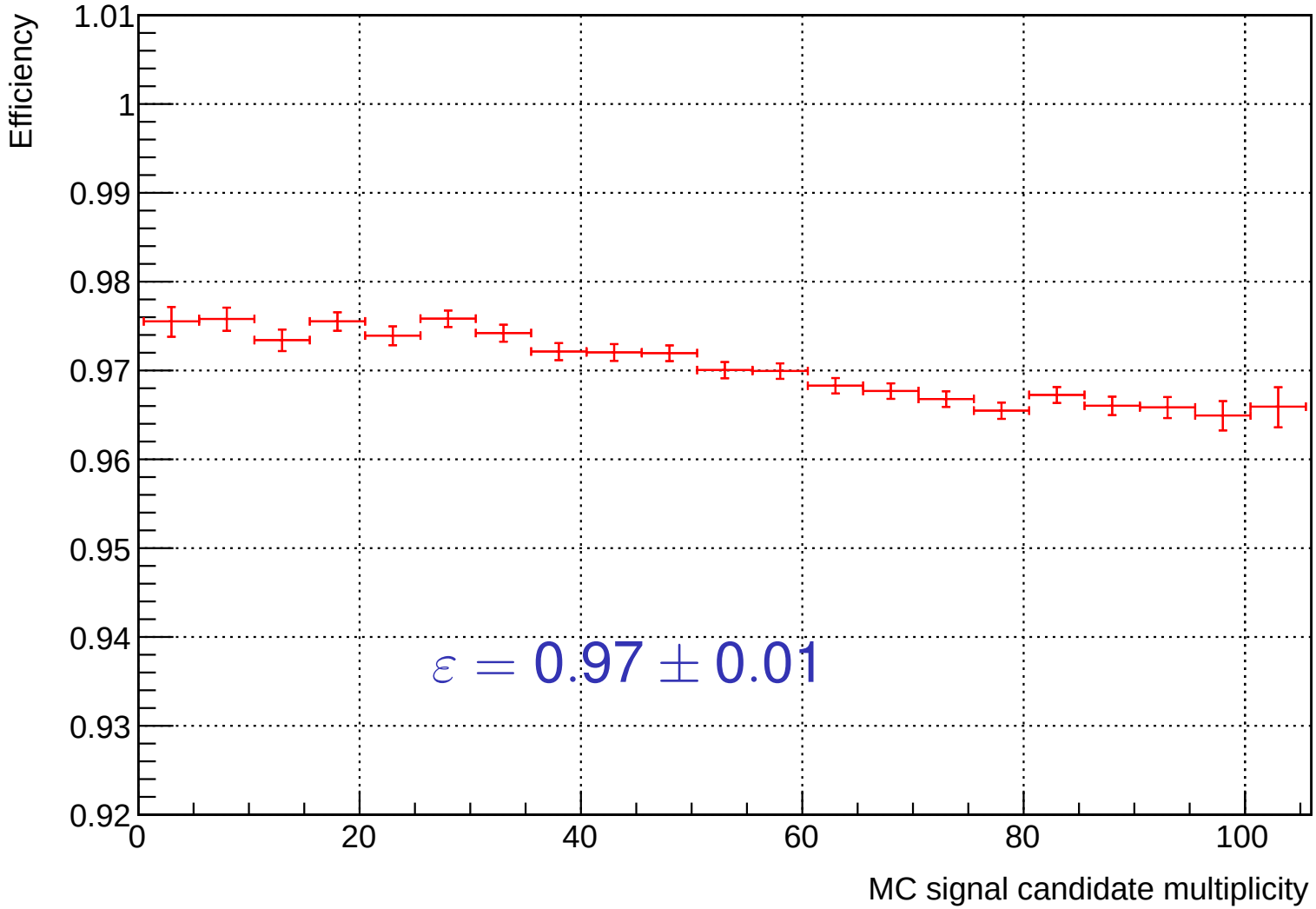
Filter+spectrometer signal performance



Reconstructed 4528 tracks$/5.1 \times 10^{9}$ POT $= 0.89 \times 10^{-6}$ yield

Spectrometer linearity

Test: simulate “microbunches” of 1 to 100 tracks through the spectrometer

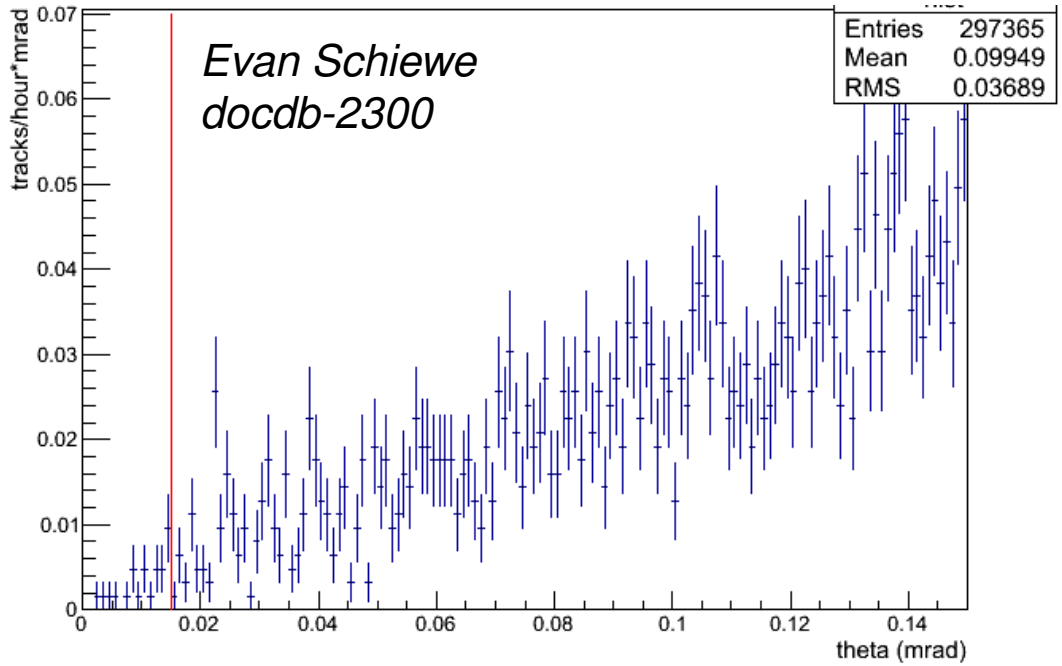


Potential background sources

- Cosmic rays
- Delayed tracks from interactions of primary in-time protons
- Fake tracks: random combinations of detector hits from any sources that look like 4 GeV/c tracks

Backgrounds: cosmic rays

- Passed 3.6×10^9 cosmic rays through GEANT4
- Recorded hits on a 1 m^2 "detector" plane, scaled to 4×4 cm^2
- Background candidates:
  - $\theta < 15$ mrad w.r.t detector axis
  - Did not use momentum discrimination



0.030 ± 0.07 events/hour

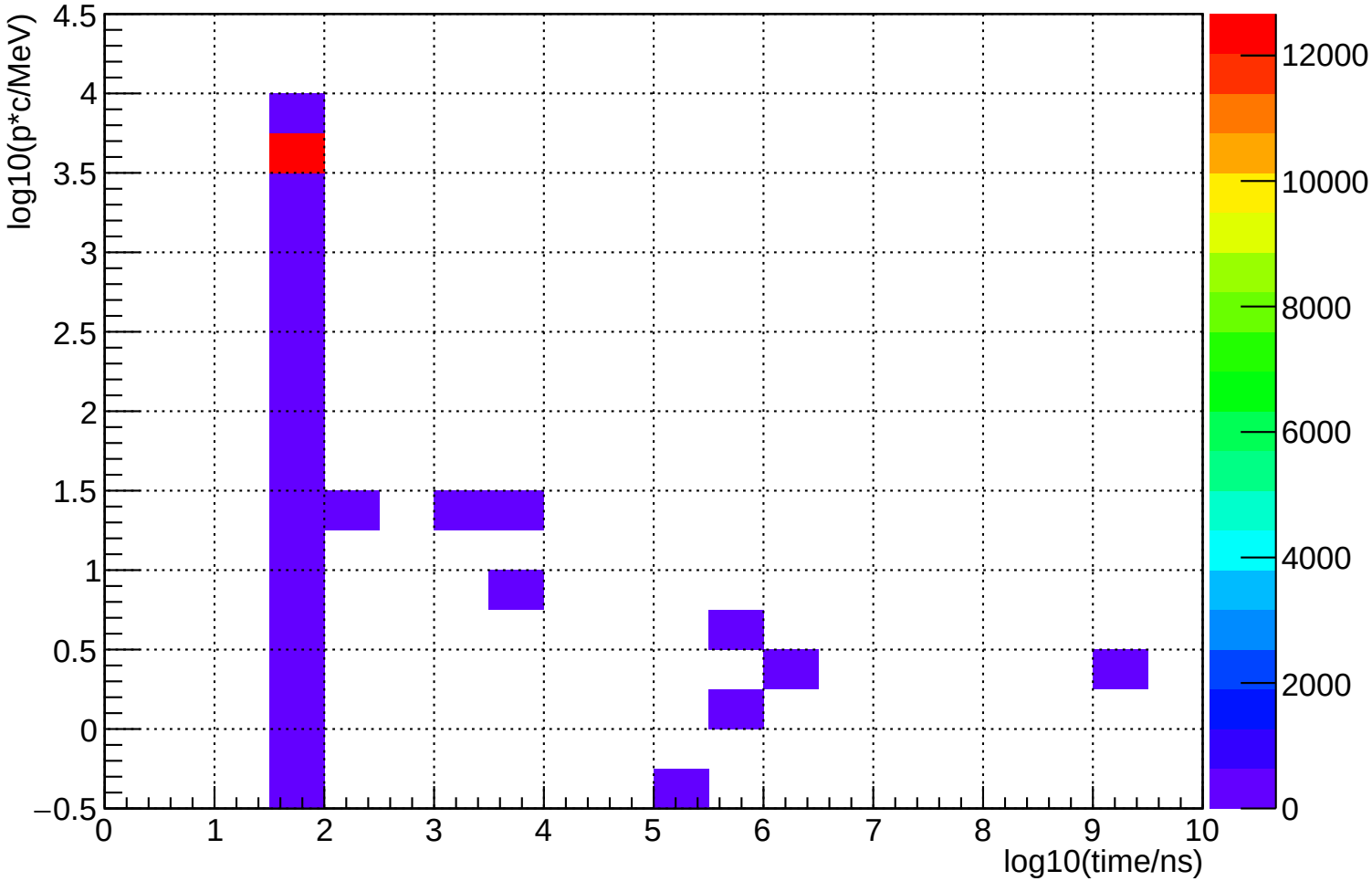
Can be measured in the detector with beam off

Backgrounds: delayed particles

- For proton $p > 1\ \mathrm{GeV/c} \quad \Longrightarrow \quad \beta > 0.7$
  - Time spread for signal $\Delta t < (L/c)(1/0.7 - 1/1) \approx 70$ ns
- Decays of stopped or slow particles?
- Pion, kaon: short lived and $p < 1\ \mathrm{GeV/c}$
- Muon: long lived, but $p < 0.1\ \mathrm{GeV/c}$
- Nuclear: low energy

No feasible sources of delayed tracks above 1 GeV

Backgrounds: delayed particles



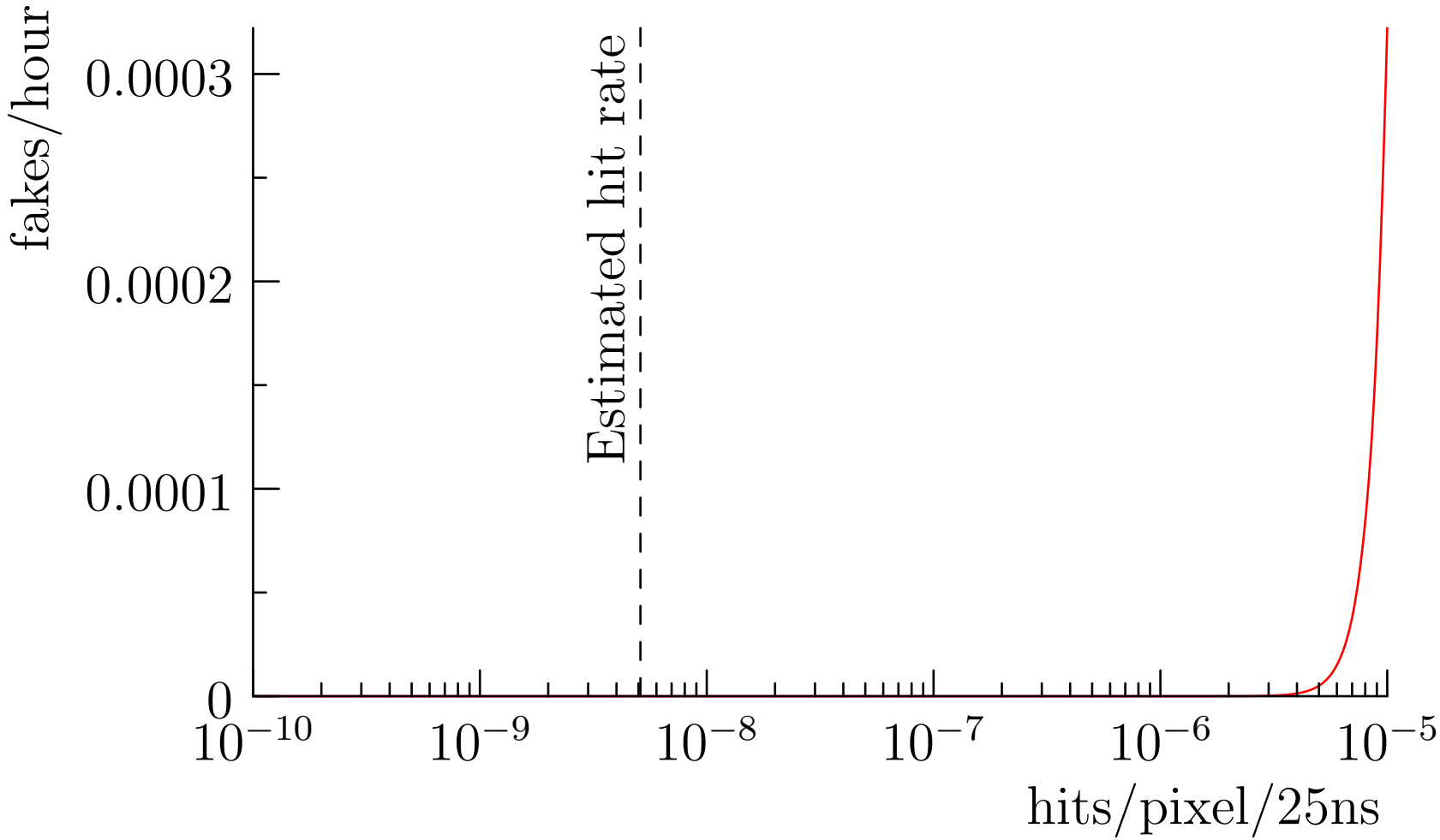
Positive particles crossing a 20×20 cm^2 area in front of the pixel spectrometer for 5.1×10^9 primary protons in GEANT4

Backgrounds: fake tracks

- Analytic estimate of fake rate: docdb-1845
- $N_{fakes} \propto p^{\text{nplanes}}$ where p is expected number of hits in a pixel per 25 ns
- We have 8 planes, but allow up to 2 have dead time during beam pulse. Same tracking cuts for out-of-time, thus use nplanes $= 6$:
- Out of time hit rates (docdb-2481)
  - Beam related 4.5×10^{-9}
  - Material activation (MARS) 5×10^{-10}
  - Pixel noise 1×10^{-10}
  - Cosmic *hits* 10^{-13}

  $\Longrightarrow$ total: 5.1×10^{-9} hits/pixel/25 ns

Backgrounds: fake tracks



Safe by more than 3 orders of magnitude

Backgrounds: direct test of fake tracks (docdb-2481)

- Multi-stage simulation of out-of-time hits with resampling
- Two stages in MARS, then two stages in GEANT4
- Achieved equivalent statistics of 2×10^{16} primary protons (about 15 minutes of beam)
- Out of time hits digitized and passed through track reconstruction
- No complete tracks found
- From half-detector straight line "tracklets" get limit
  $N_{\text{fakes}} < 7.4 \times 10^{-4}$ per hour, or
  $N_{\text{fakes}} < 1.2 \times 10^{-20}$ per POT

Off-target interactions

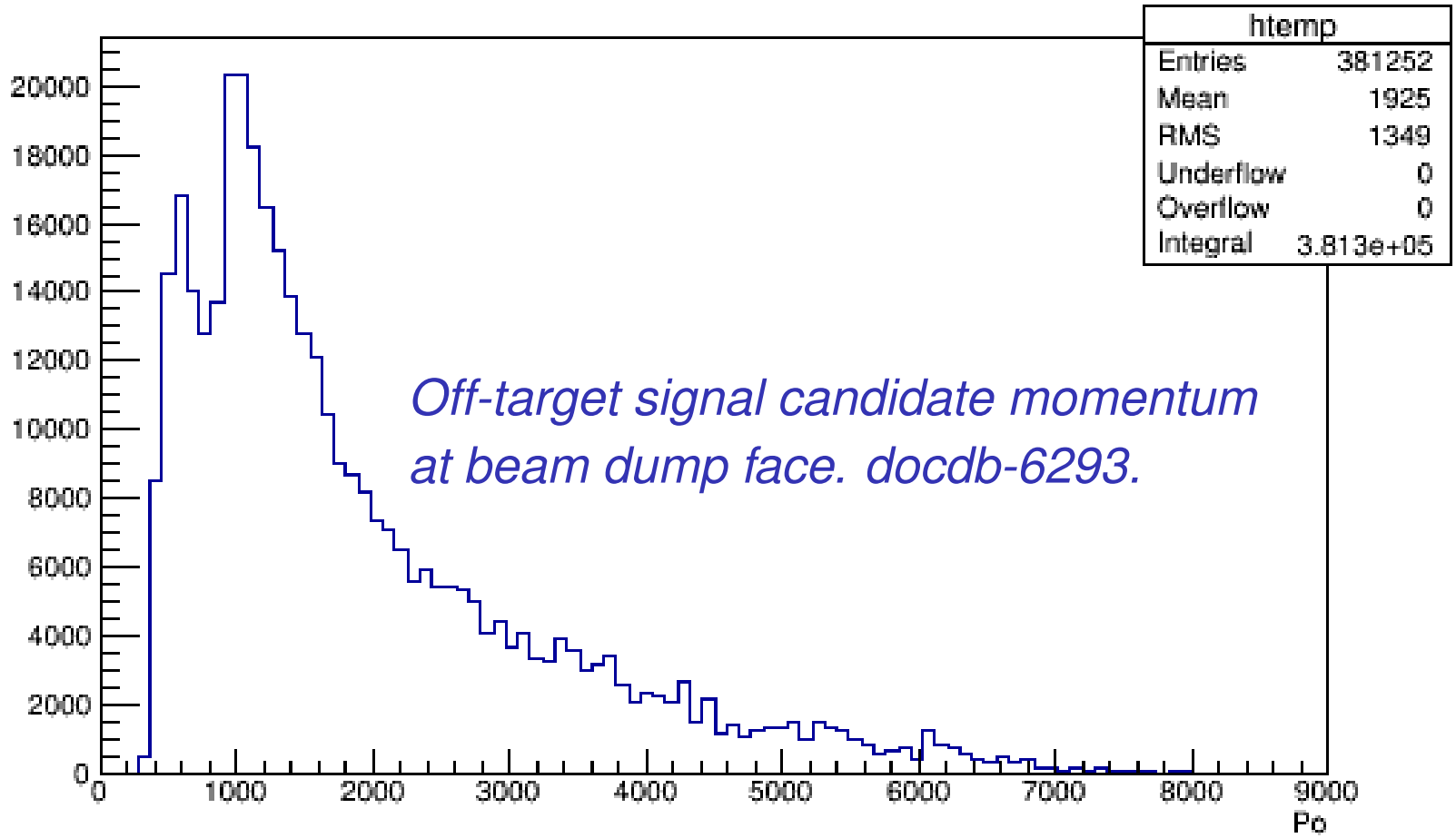
- This can only be an issue if we have a high rate of non-extinct protons
- If there are out-of-time protons but they miss the production target
  - Such protons do not create Mu2e backgrounds (at least not at the same rate as on-target protons)
  - We should still be able to take Mu2e physics data
  - Would like ExtMon to not veto such runs
- Secondaries from off-target interactions may differ from the signal just in their production point
- ExtMon spectrometer does not discriminate between on-target and off-target secondaries
- Instead, the beamline and ExtMon collimation system are designed to minimize acceptance for off-target interactions

Off-target interactions

Peter Kasper, docdb-6293

- Obtained out-of-time distribution at the final focus of M4:
  - Input particle from simulations of Delivery Ring extraction
  - AC dipole bend set to the worst case value
- Resampled the distribution in 5 dimensions
- Propagated protons through the rest of the setup up to the beam dump face
- Signal candidates
  - Particles hitting dump face within 100 mm of collimator entrance
  - With $p > 500\ \mathrm{MeV/c}$
- Normalization: protons hitting the target

Off-target interactions



Further cut on signal candidates: produced upstream of the PS endcap (to be in the acceptance of the filter)

$\Longrightarrow$ 1% off-target/on-target ratio for out of time beam

Summary

- Spectrometer reconstruction efficiency 97%
  - Linear to better than 1%
- Filter+spectrometer signal yield: 0.89×10^{-6}/pot
- Backgrounds
  - Random hits from all sources: $< 1.2 \times 10^{-20}$/pot
  - Cosmic: 0.030 ± 0.07/hour, or $(0.36 \pm 0.8) \times 10^{-18}$/pot
- Maximum off-target contamination for out of time tracks: 1%