Mu2e-II/III:
DIO Studies for Titanium Stopping Target

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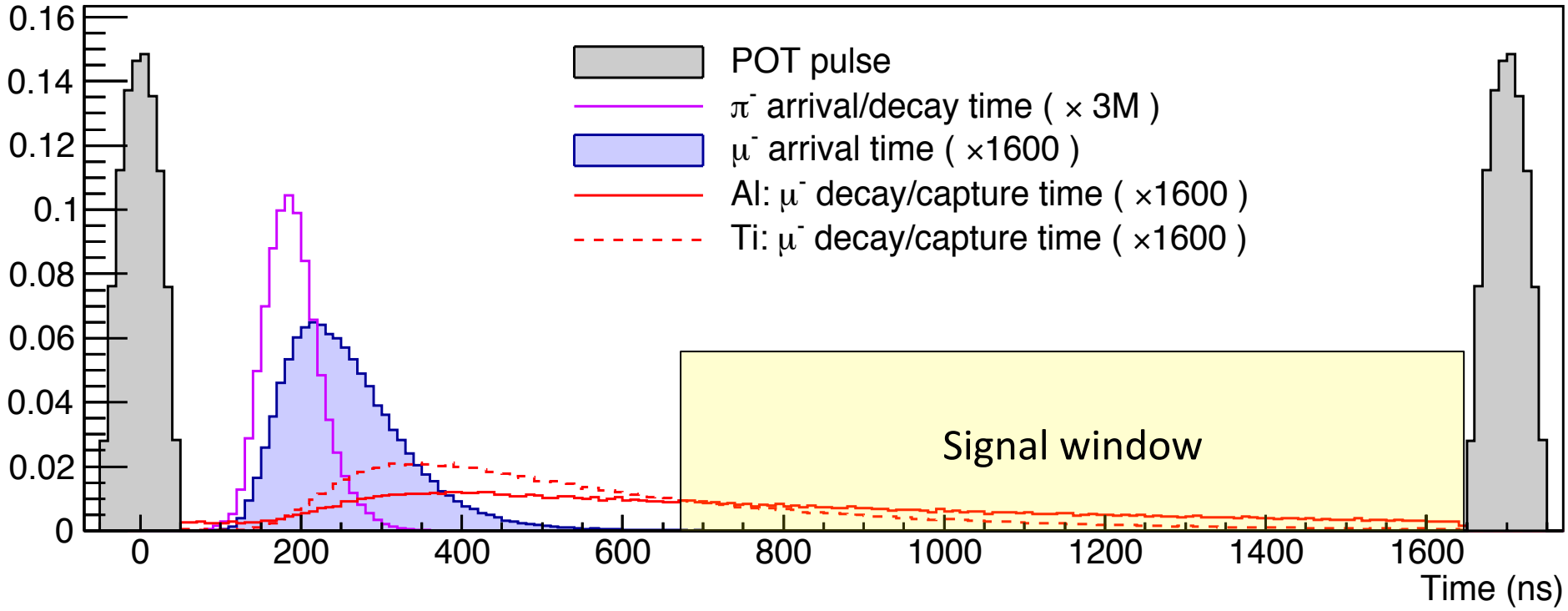
Prerequisites



	Aluminum	Titanium
% muons that decay	**39%**	**15%**
% of decays in timing window	**50%**	**30%**
Time constant for muon decay	**864 ns**	**329 ns**

Context

- In the Mu2e experiment, dominant irreducible background originates from SM muon decays:
  - Decays in orbit (DIOs)

$$\mu^- + N \rightarrow e^- \overline{\nu}_e \nu_\mu + N$$

- Energy distribution of electron from muon decay given by (modified) Michel spectrum:
  - Normal Michel spectrum endpoint: 52.8 MeV
  - Mu2e signal at E > 100 MeV, so how can this be a background?

Context

- In the Mu2e experiment, dominant irreducible background originates from SM muon decays:
  - Decays in orbit (DIOs)

$$\mu^- + N \rightarrow e^- \overline{\nu}_e \nu_\mu + N$$

- Presence of atomic nucleus → momentum transfer

  Kinematic endpoint (Al): E_e = 104.973 MeV
  Kinematic endpoint (Ti): E_e = 104.272 MeV

  - Mu2e signal at E > 100 MeV, so how can this be a background?

Previous DIO assumptions

- In the feasibility study (arXiv:1307.1168), we did not have the expected DIO spectrum implemented in the Mu2e computing framework.
- The DIO background was computed by scaling the background:

$$\frac{1 - C_{\mathrm{Ti}}}{1 - C_{\mathrm{Al}}} \times \frac{\epsilon(t_0, \mathrm{Ti})}{\epsilon(t_0, \mathrm{Al})} \approx 0.24$$

Difference in capture fractions **Difference in decay-time distribution**

- Naively, DIO background for Ti looks to be **¼** that of Al.
- Did *not* include differences in the electron energy spectrum (*i.e.* differential decay rate).

Those differences now taken into account – today's topic.

Implementing the *Czarnecki, et al* DIO spectrum

PHYSICAL REVIEW D **84**, 013006 (2011)

Muon decay in orbit: Spectrum of high-energy electrons

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(Received 11 May 2011; published 14 July 2011)

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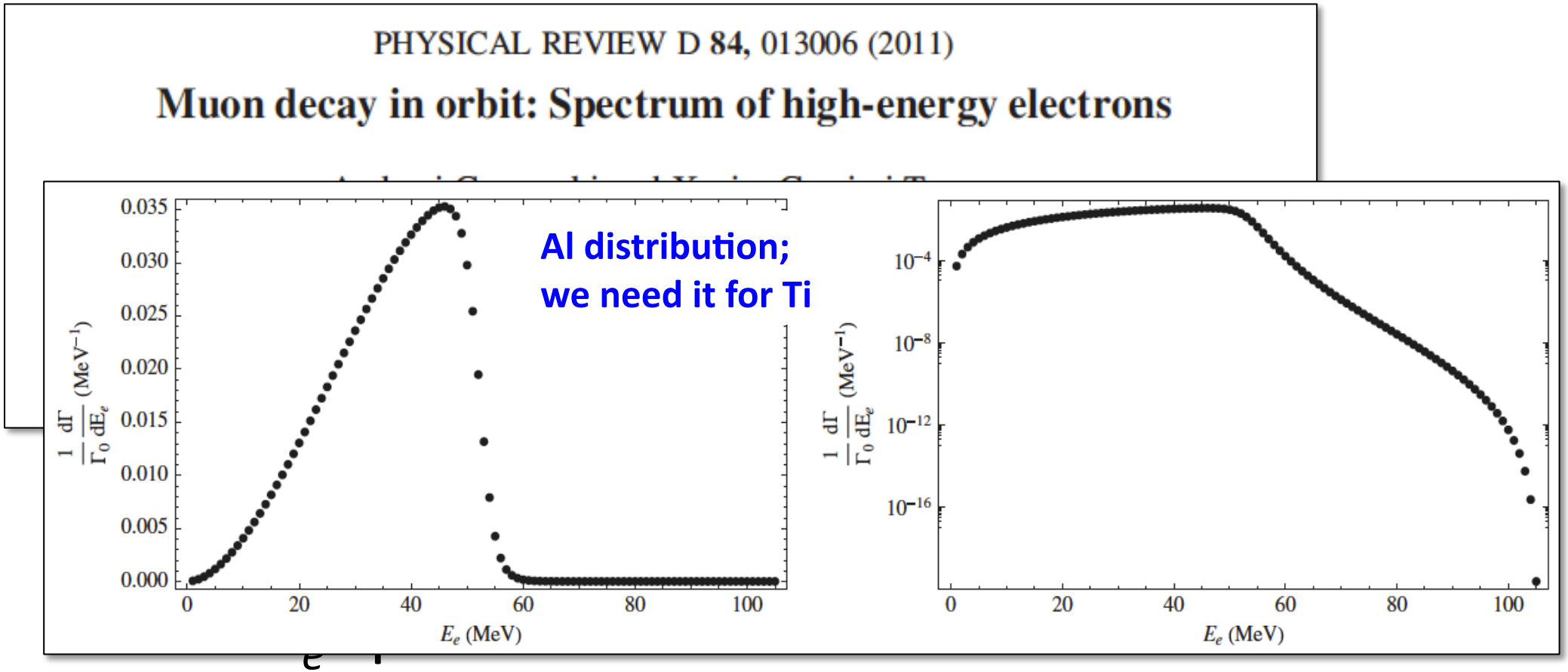
- Very readable approach to calculating the E_e spectrum.
- No closed form solution for the full spectrum
- But there are some simple approximations

Implementing the *Czarnecki, et al* DIO spectrum



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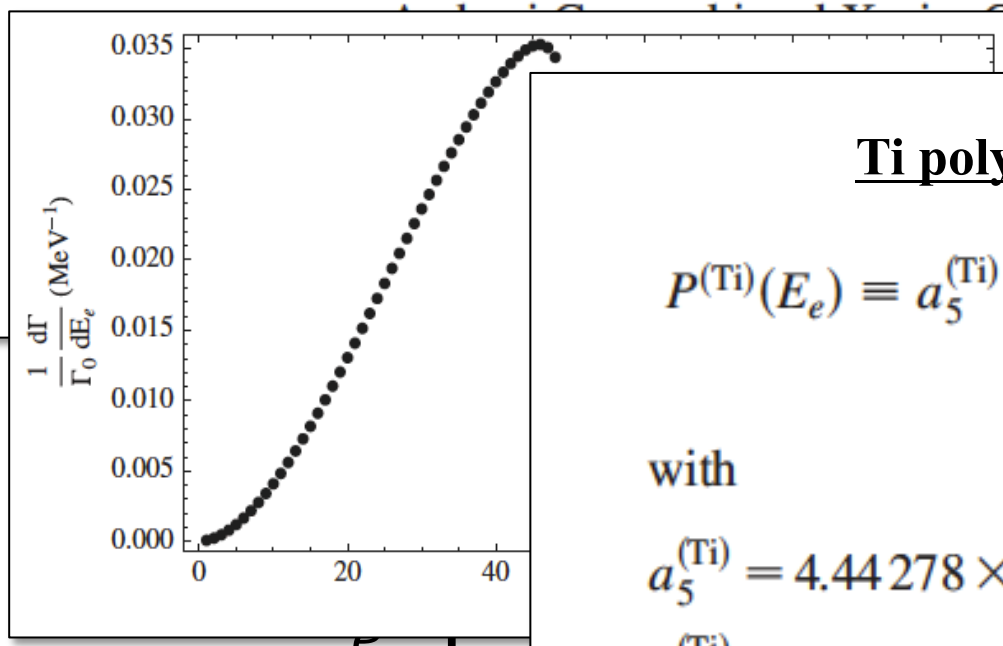


Ti polynomial approx. for E > 85 MeV

$$P^{(\mathrm{Ti})}(E_e) \equiv a_5^{(\mathrm{Ti})}\delta_{(\mathrm{Ti})}^5 + a_6^{(\mathrm{Ti})}\delta_{(\mathrm{Ti})}^6 + a_7^{(\mathrm{Ti})}\delta_{(\mathrm{Ti})}^7 + a_8^{(\mathrm{Ti})}\delta_{(\mathrm{Ti})}^8, \tag{29}$$

with

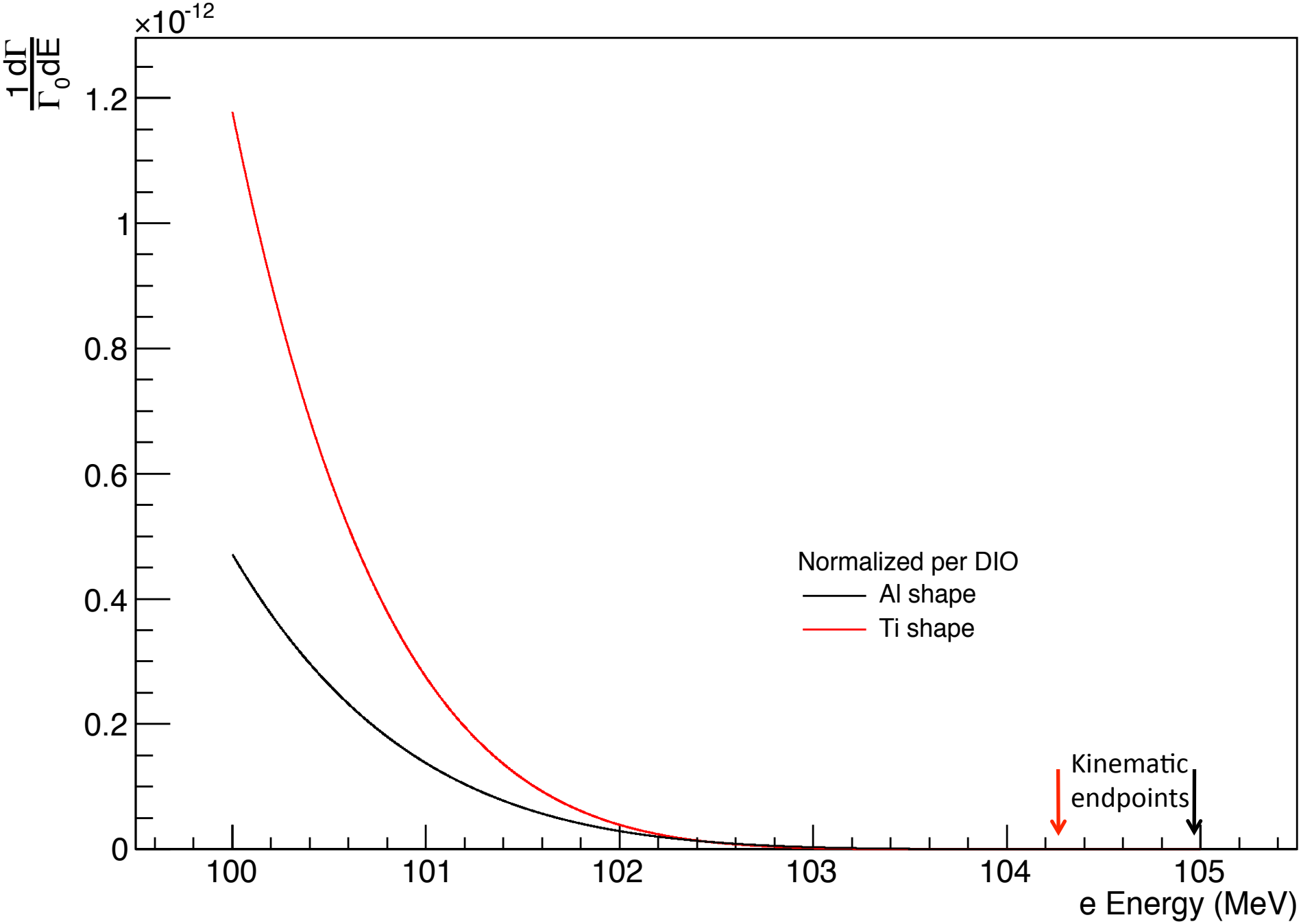
$$a_5^{(\mathrm{Ti})} = 4.44278\times10^{-16}, \quad a_6^{(\mathrm{Ti})} = 9.06648\times10^{-17}, \quad a_7^{(\mathrm{Ti})} = -4.26245\times10^{-18}, \quad a_8^{(\mathrm{Ti})} = 8.193\times10^{-19}, \tag{30}$$

the energies expressed in MeV,

$$\delta_{(\mathrm{Ti})} = E_\mu - E_e - \frac{E_e^2}{2m_{\mathrm{Ti}}}, \tag{31}$$

- No closed
- But there

Comparing Al-Ti DIO spectra (1)



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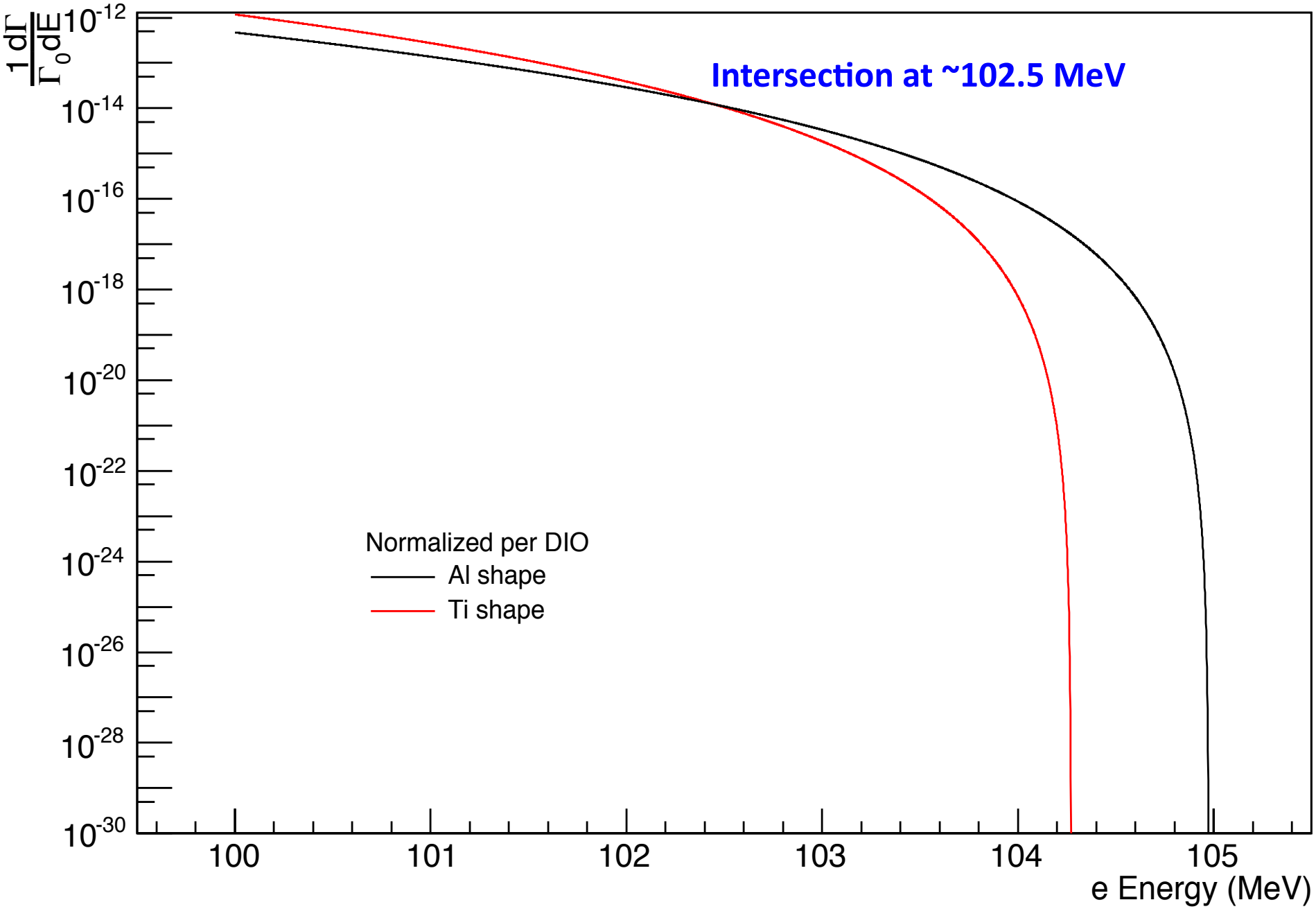
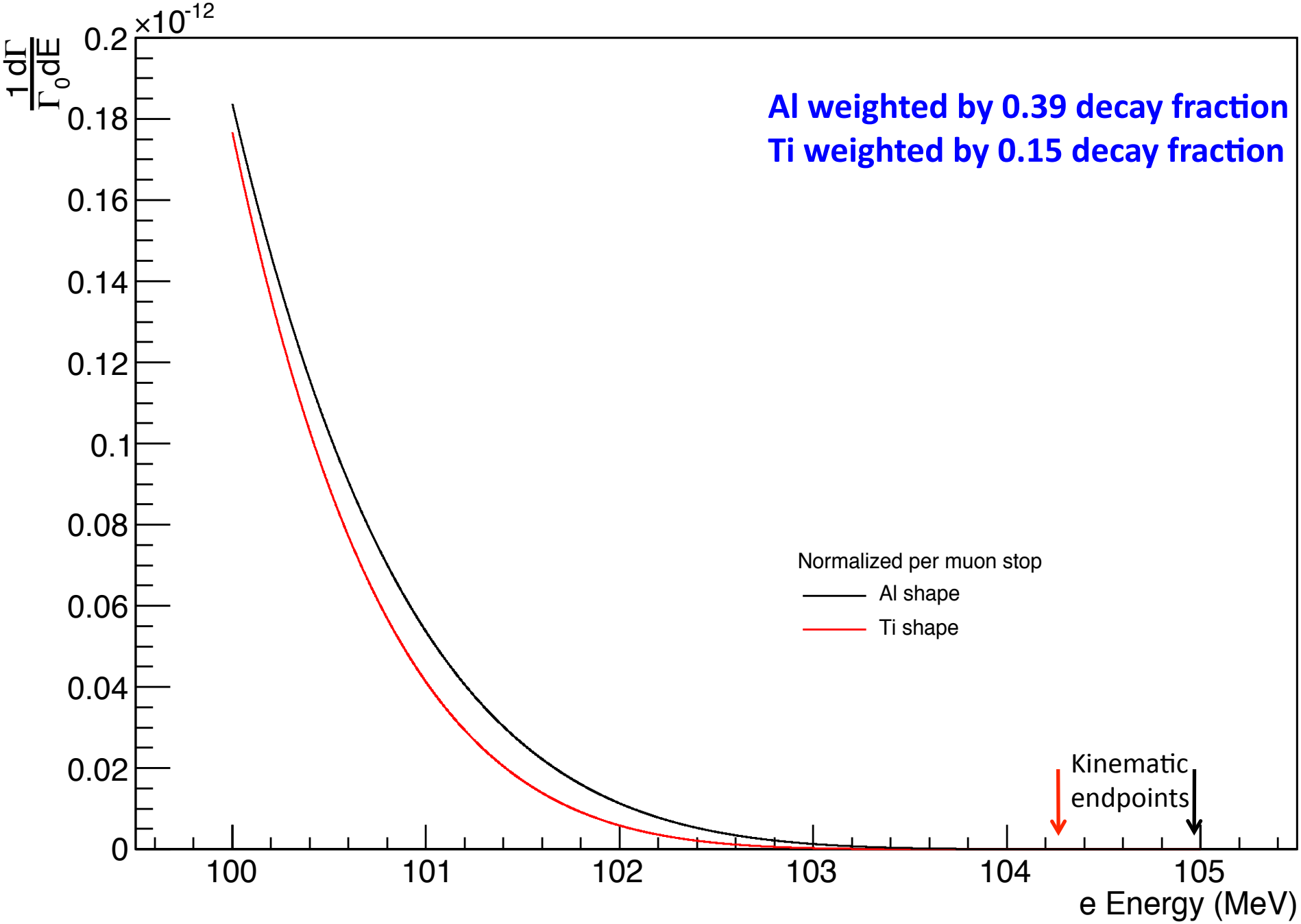


Comparing Al-Ti DIO spectra (2)



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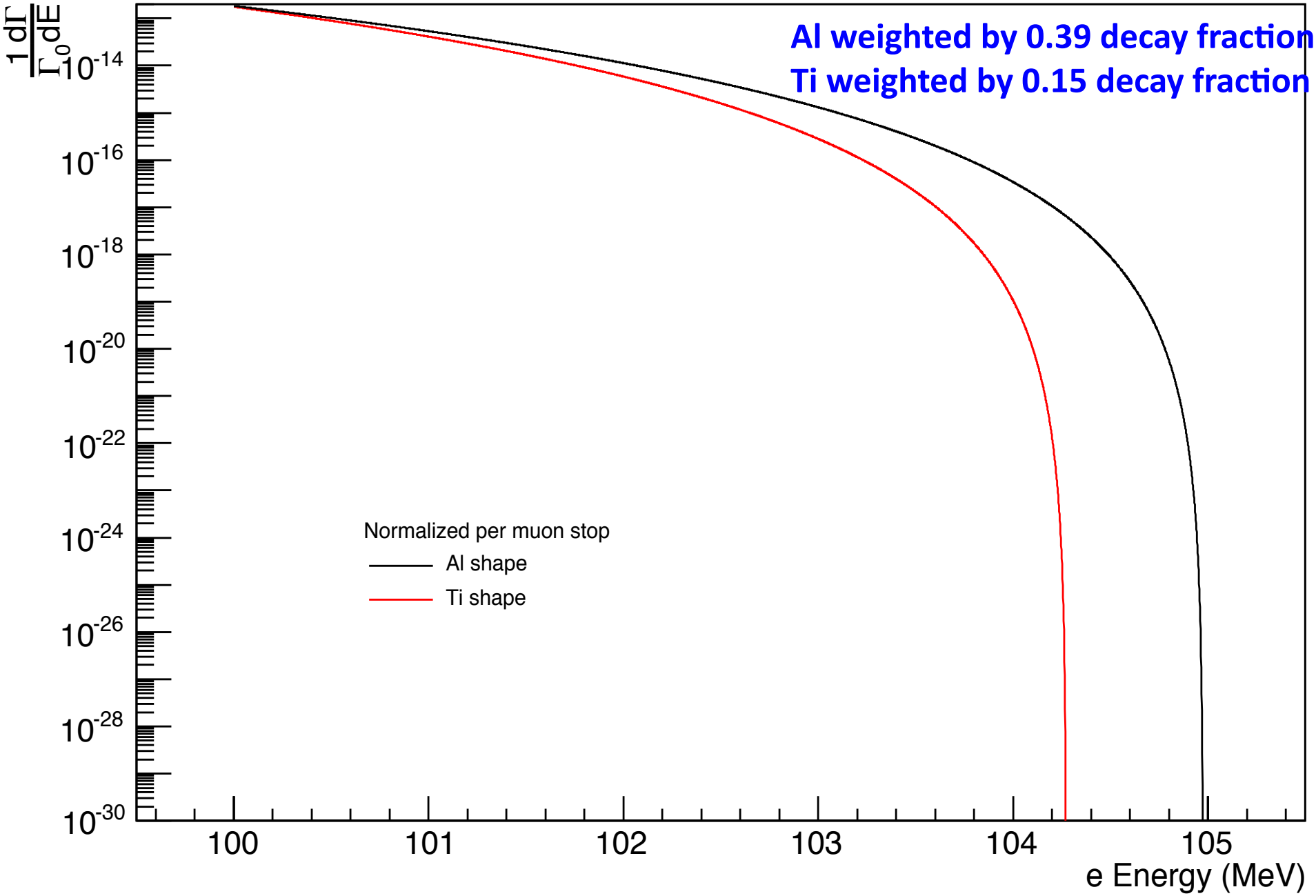
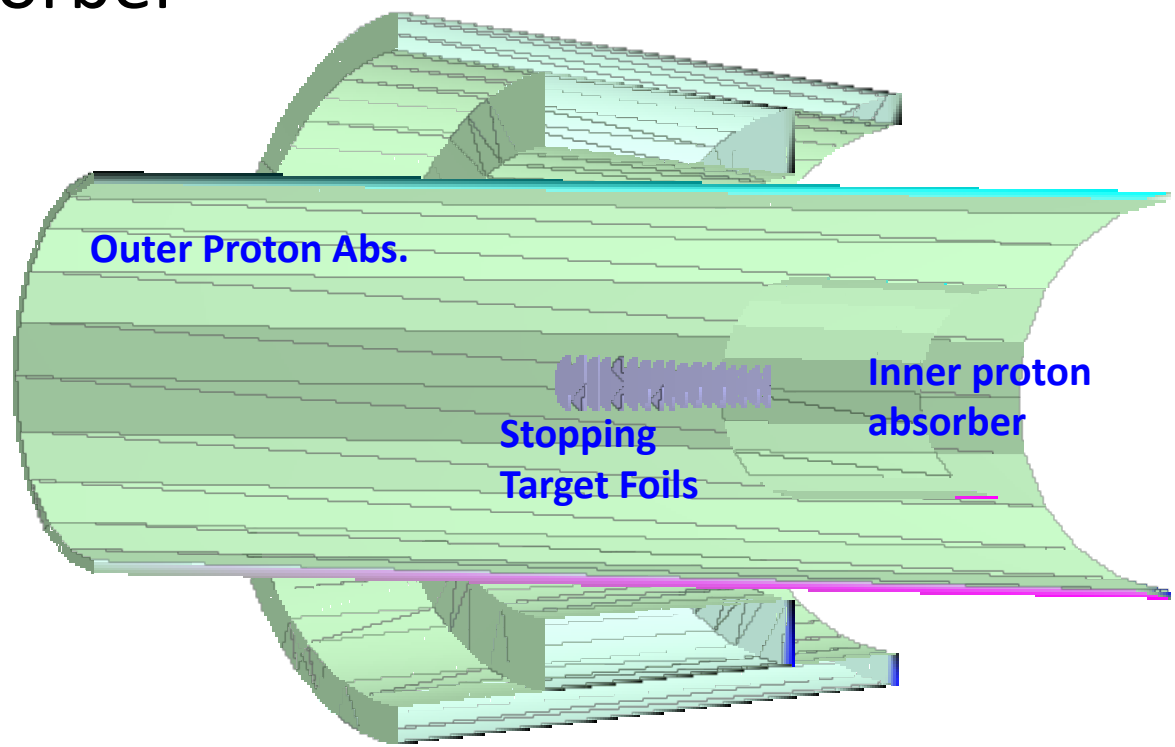


Simulated DIO studies

- Offline Mu2e geometry (G4) is being finalized.
- Geometry used includes:
  - Half-length inner proton absorber
  - Outer proton absorber



Simulated DIO studies

- Offline Mu2e geometry (G4) is being finalized.
- Geometry used includes:
  - Half-length inner proton absorber
  - Outer proton absorber
- Four situations considered:

  [0] Al w/baseline mu2e (validation)

  [1] Ti w/baseline mu2e

  [2] Ti w/narrower stopping target foils
    - Same stopping target mass as in Al case

  [3] Ti case (2) with smaller tracker straw walls
    - 8 μm thick vs. 15 μm thick (baseline)

Simulated DIO studies – Assumptions

- The number of stopped muons is assumed to be 7.56×10^{17}.

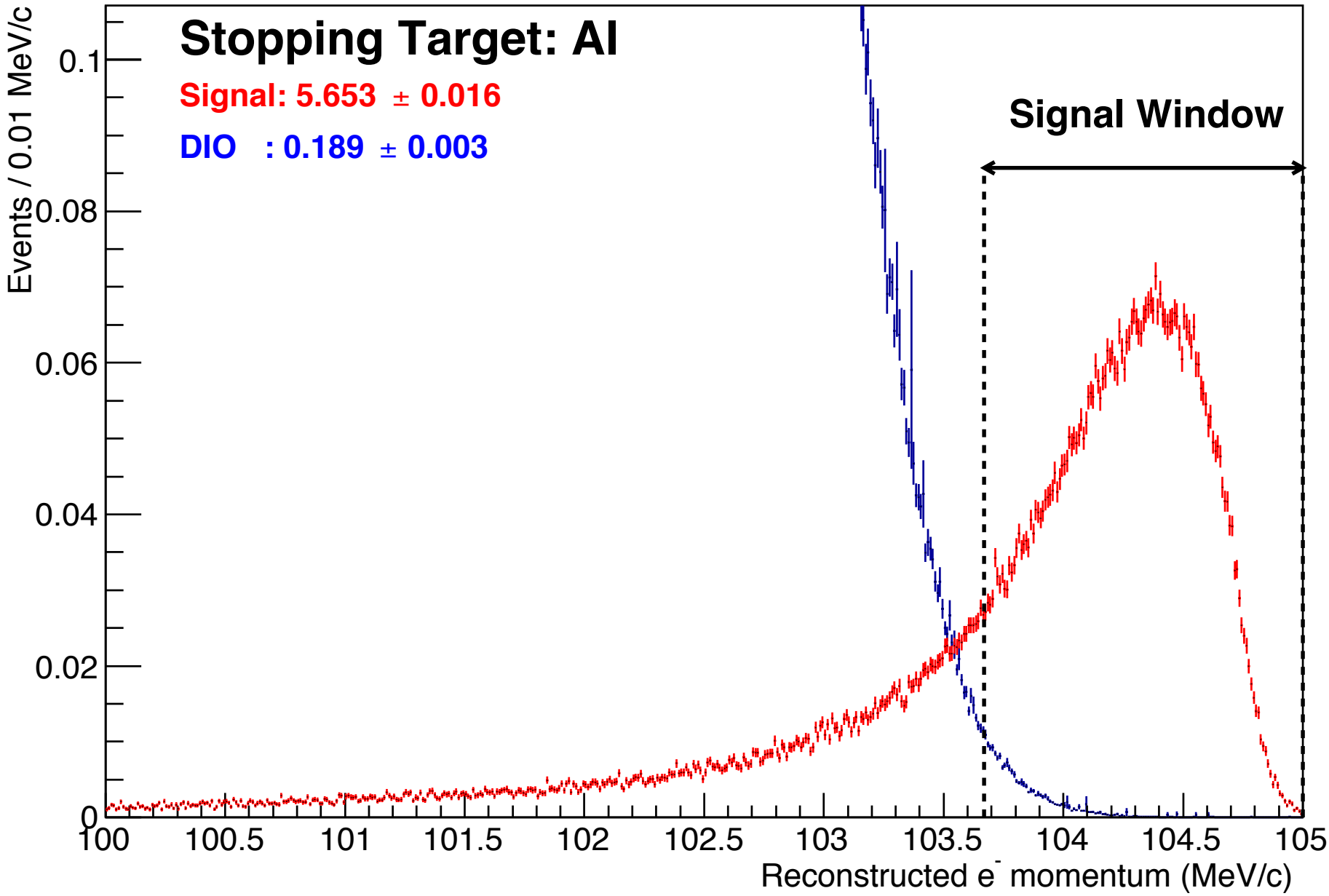
- The assumed value of $R_{\mu e}$ is 10^{-16}.

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

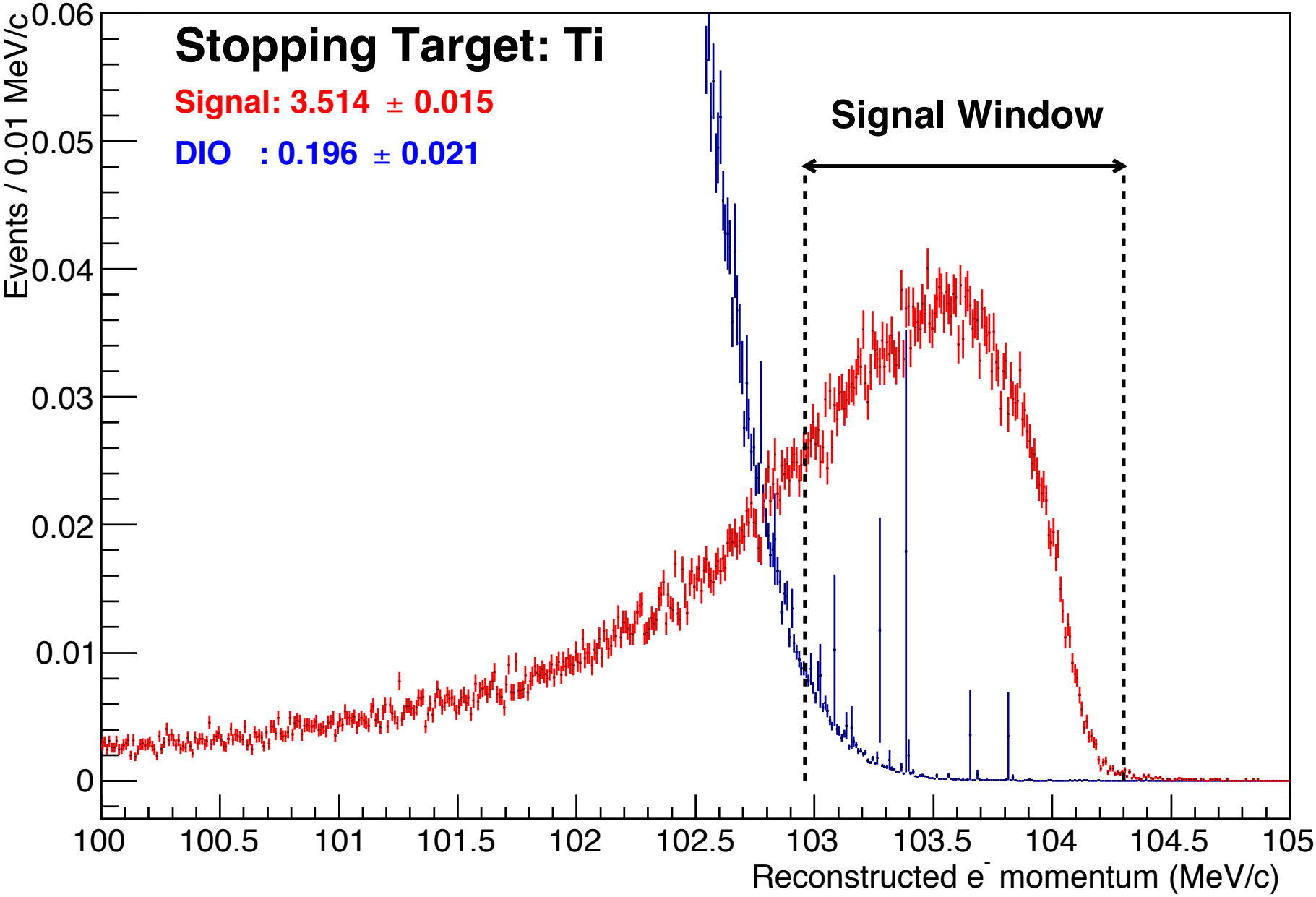
Coherent μ→e conversion

Muon capture

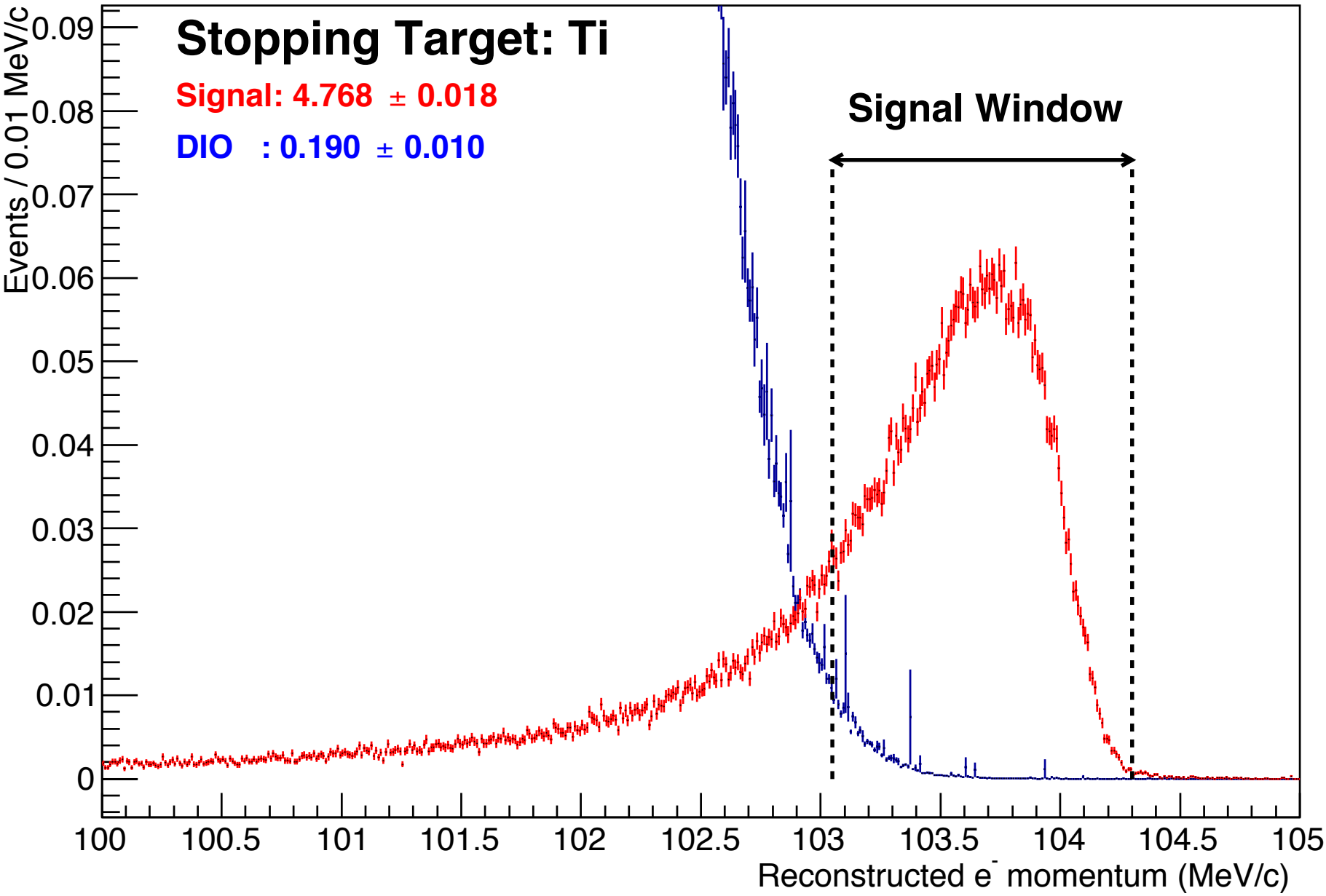
Case 0: Al baseline validation



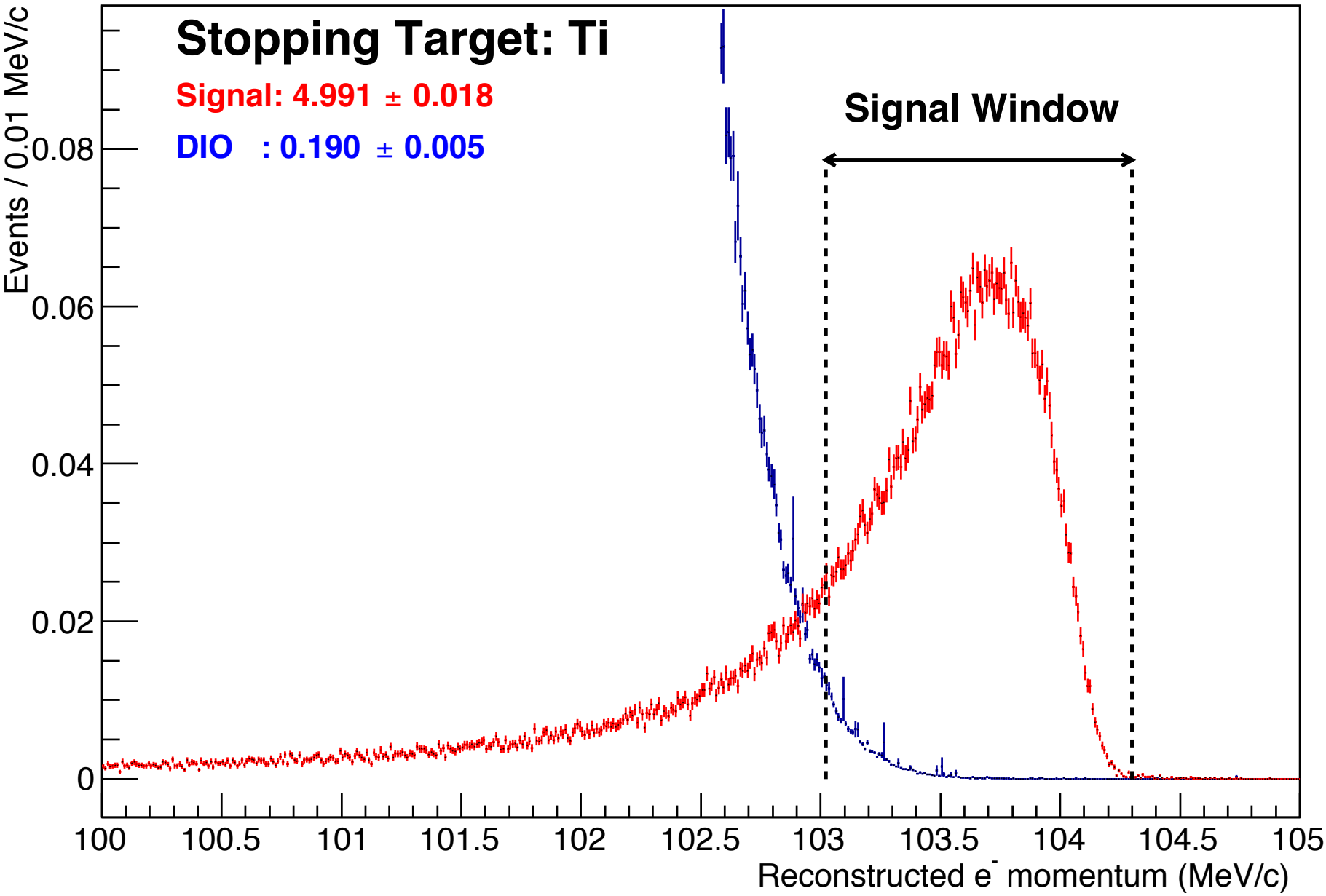
Case 1: Ti baseline detector design



Case 2: Ti with thinner target foils



Case 3: Ti case 2 + thinner straw walls



Conclusions

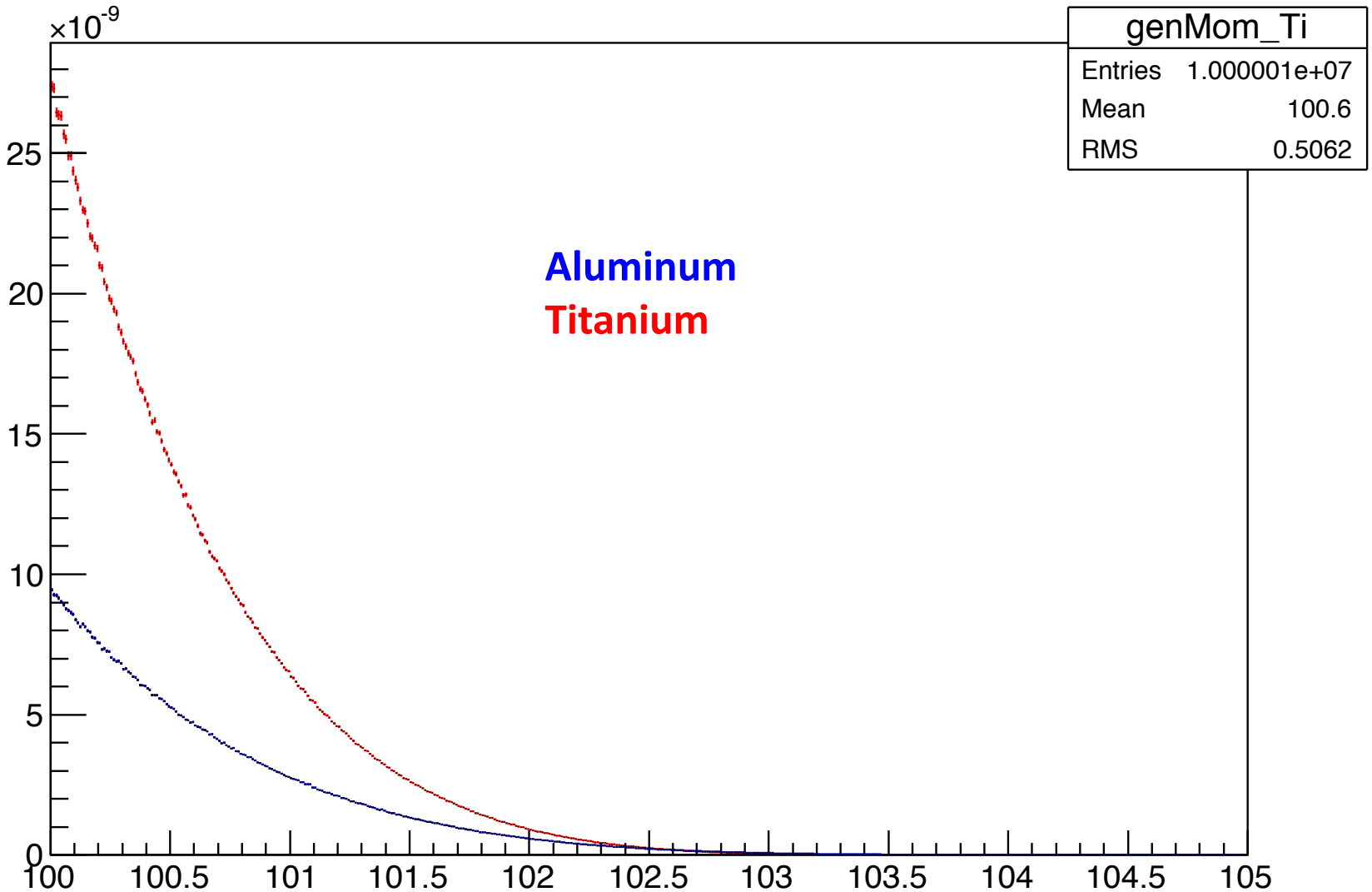
- Ti DIO spectrum (*a la* Czarnecki *et al*) now fully implemented in Mu2e Offline computing framework

- For the same number of stopped muons (7.56×10^{17}) and the same $R_{\mu e}$ (10^{-16}), and modest changes to the geometry:
  - Reasonable separation between DIO and signal distributions for Titanium,
  - Roughly 5 signal events for 0.2 DIO events
  - Comparable to Al case

- Can further optimize the window for < 1 DIO event for 10 × the number of stopped muons.

Back-up Slides

Generated distributions



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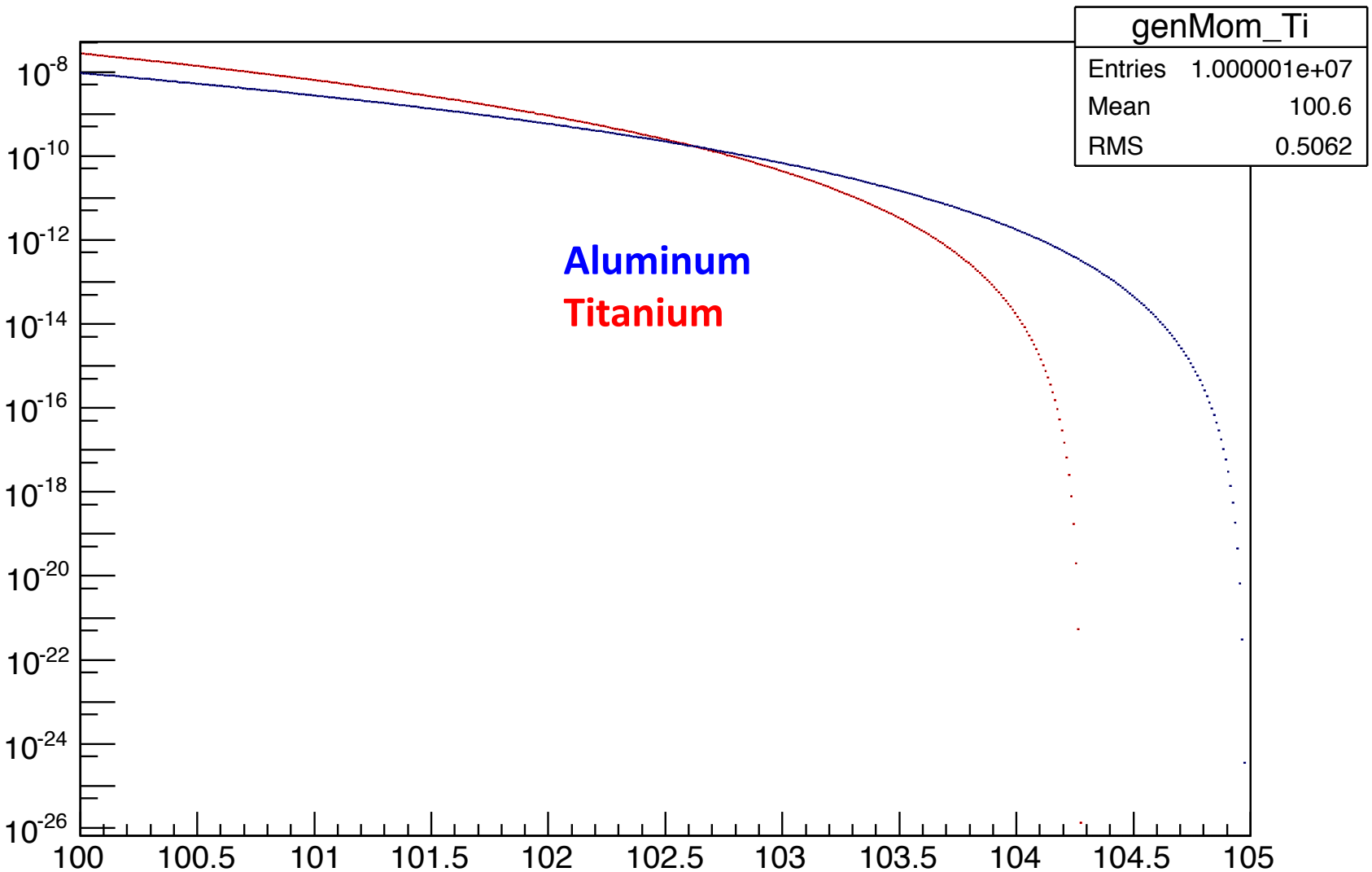
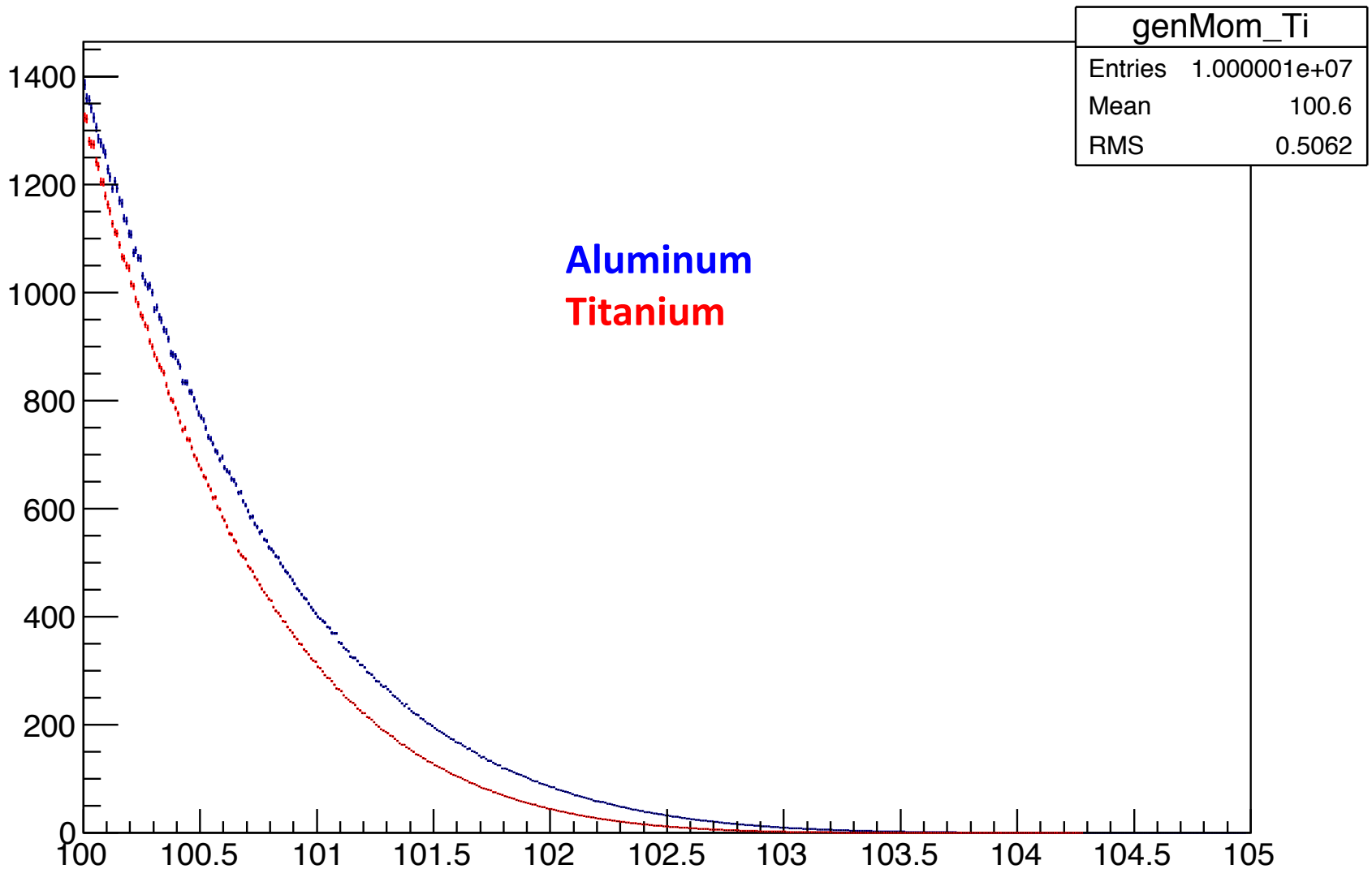


Generated distributions with weighting & reco cuts



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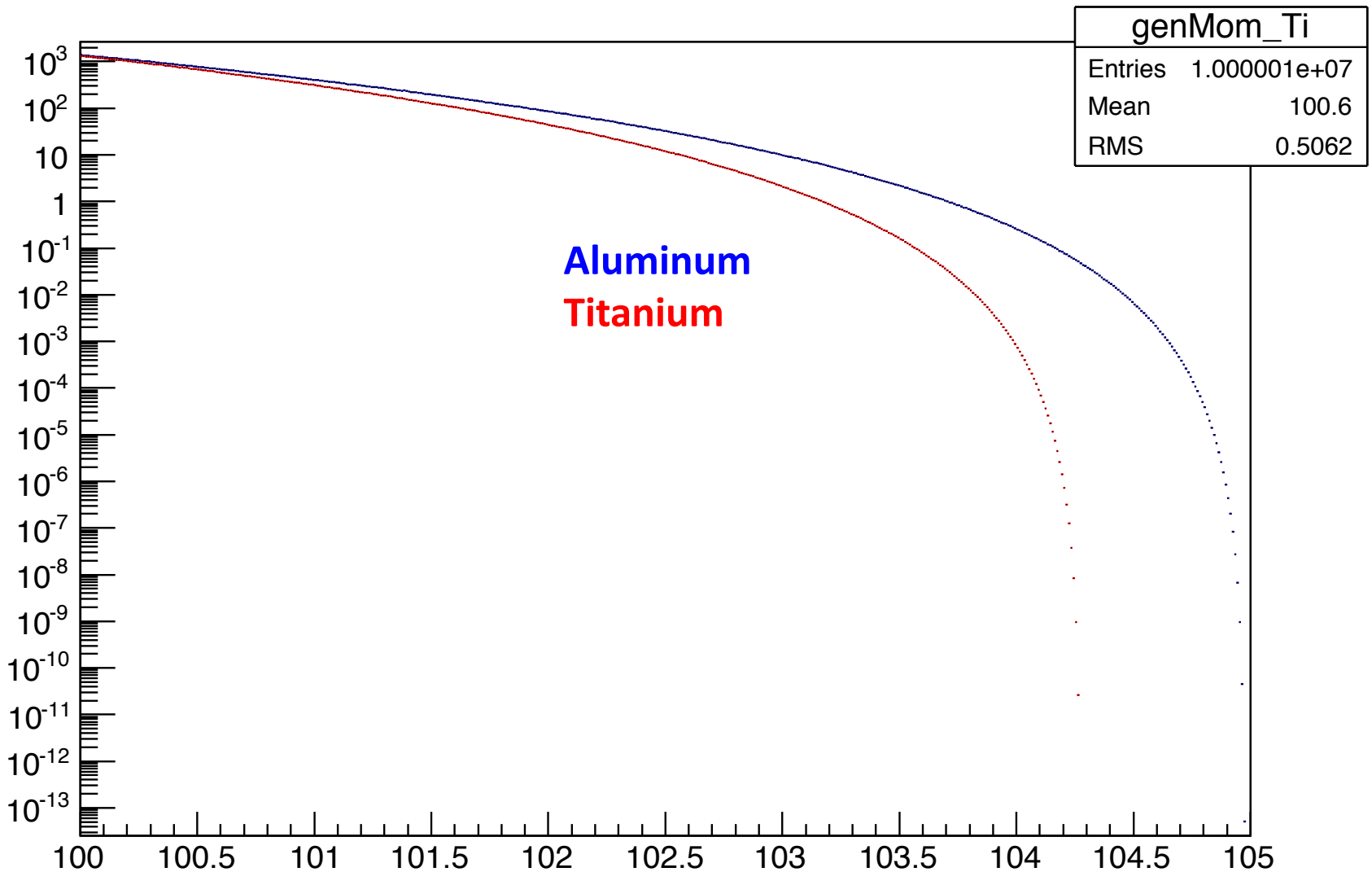
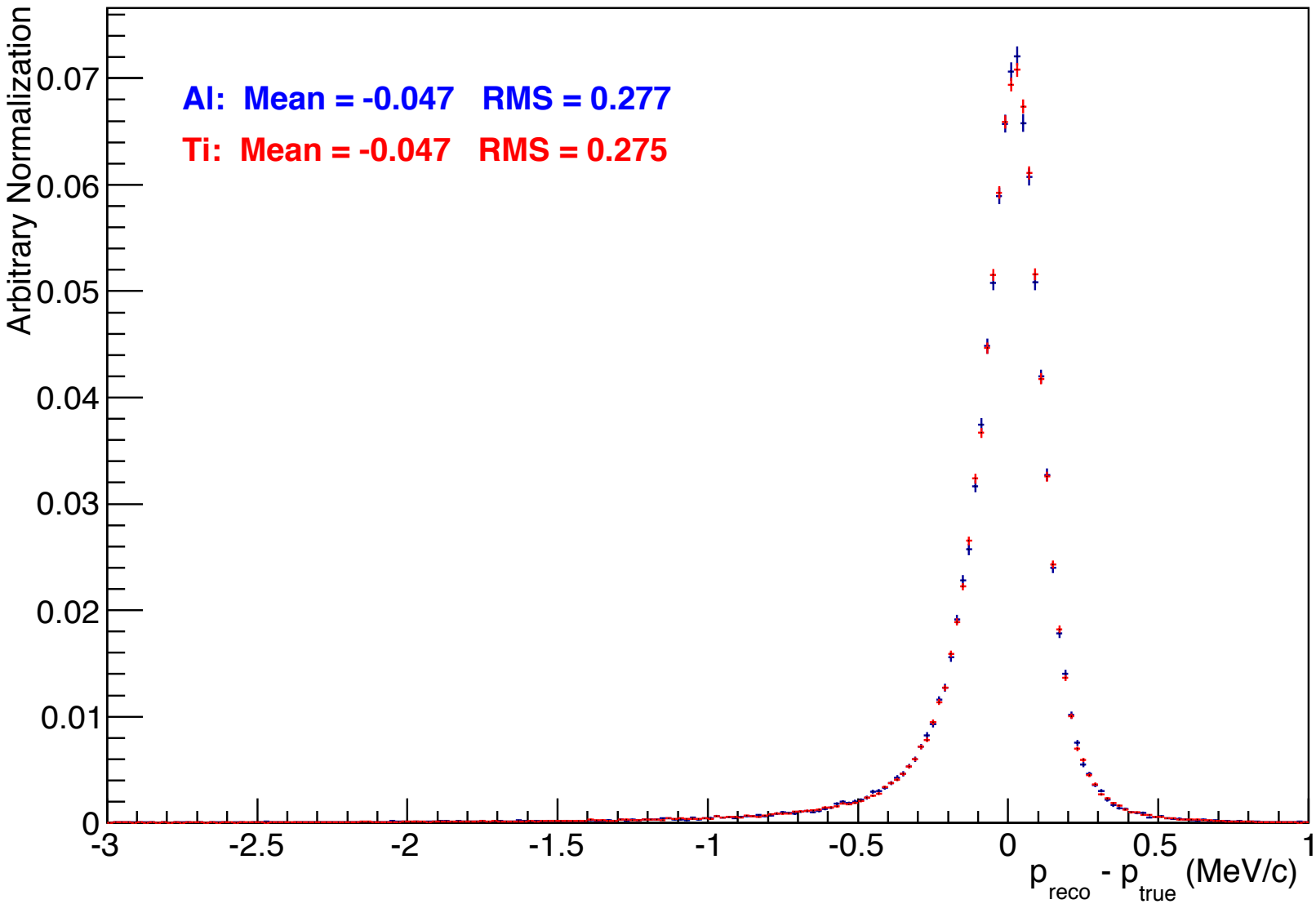


Testing Momentum Resolution between Ti and Al

Generate electrons with p_{true} = 100 MeV/c



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