

Search for three body Pion Decays $\pi^+ \rightarrow l^+ \nu X$ in the PIENU Experiment

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For PIENU Collaboration

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Outline

- Pion decay.
- Experimental technique.
- The PIENU detector.
- Strategy.
- Results.
- Summary.



$\pi^+ \rightarrow e^+ \nu$ Branching Ratio

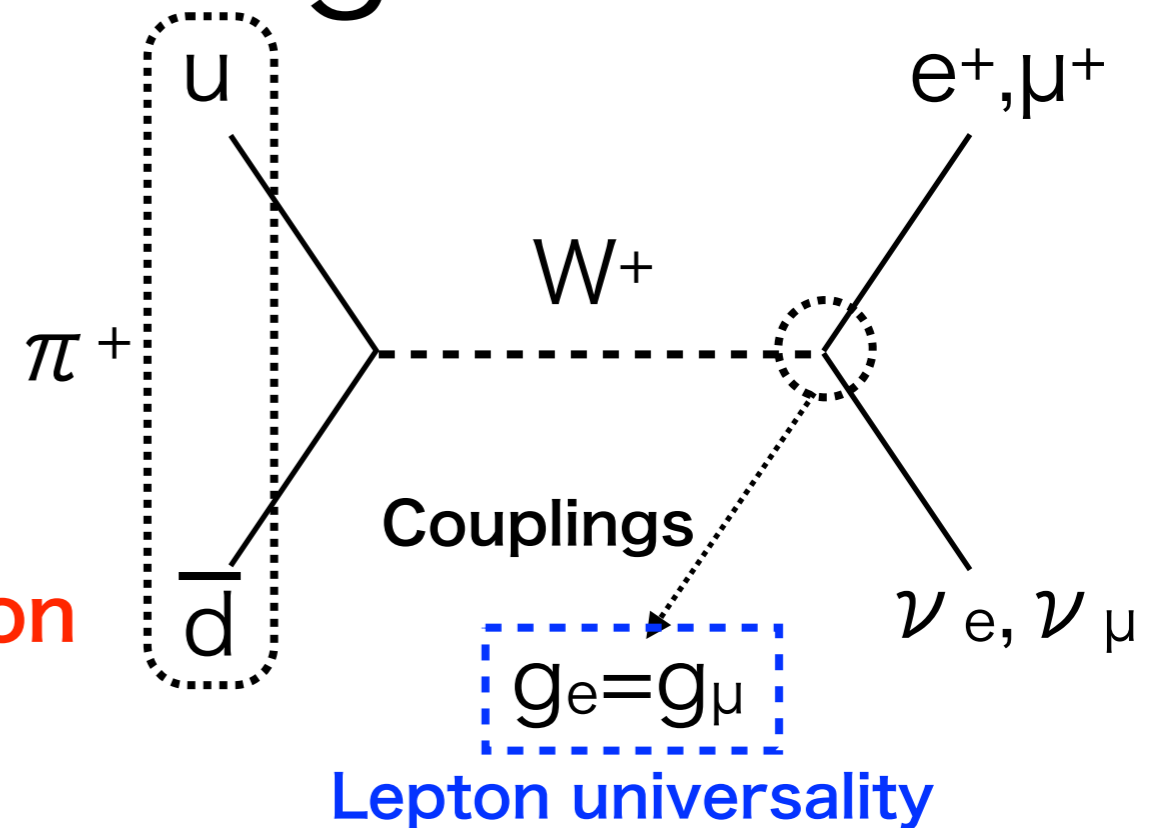
- $\pi^+ \rightarrow e^+ \nu$ branching ratio in SM

$$R_{SM}^\pi = \frac{\Gamma[\pi^+ \rightarrow e^+ \nu(\gamma)]}{\Gamma[\pi^+ \rightarrow \mu^+ \nu(\gamma)]}$$

$$= (1.2352 \pm 0.0002) \times 10^{-4}$$

$\pi^+ \rightarrow e^+ \nu$ decay: **helicity suppression**

V.Cirigliano, I.Rosell, PRL 99 231801 (2007)



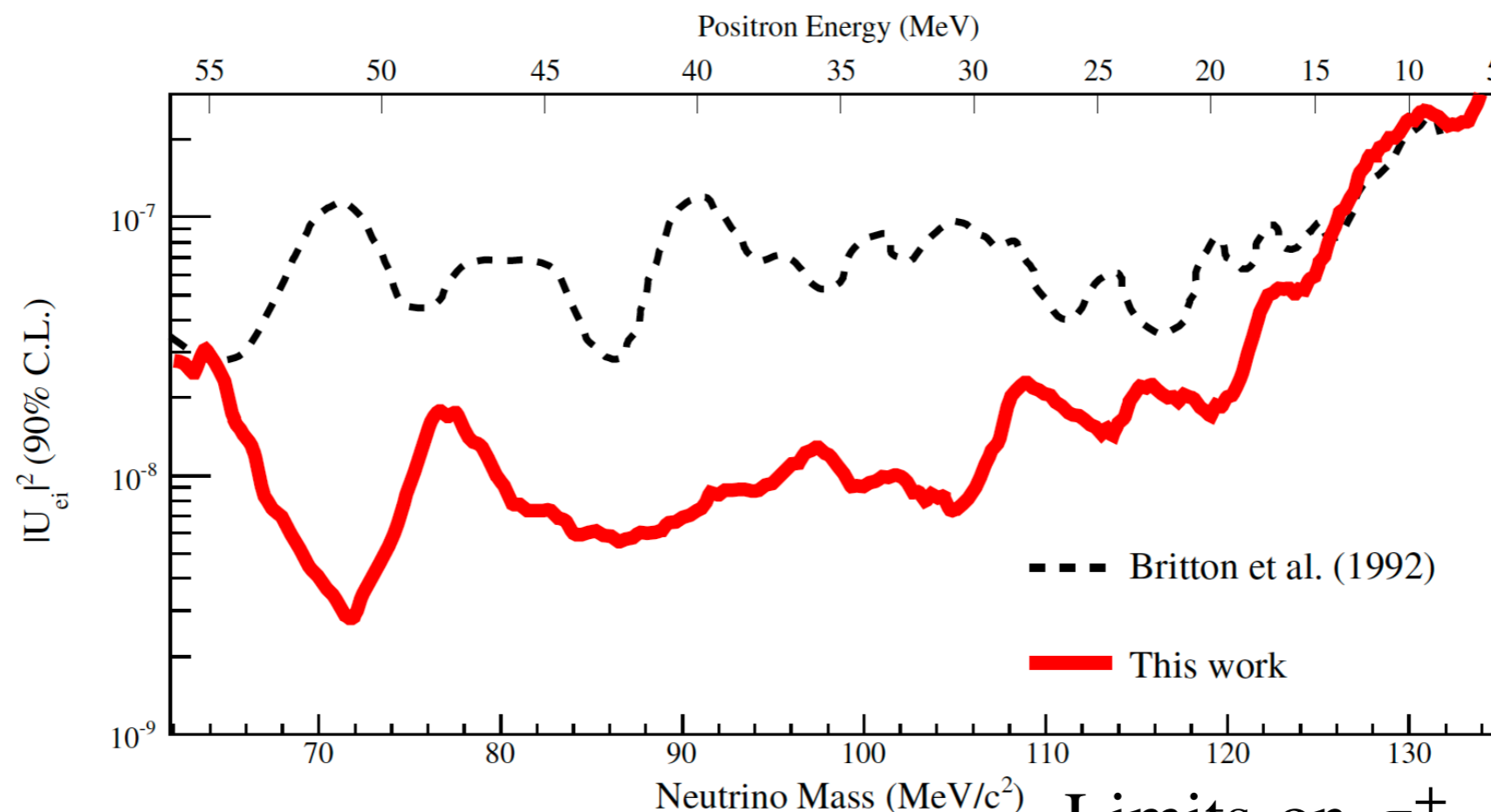
- **Lepton universality test:** R-parity violating SUSY, charged Higgs, Leptoquarks, heavy neutrino couplings.
- The PIENU experiment at TRIUMF was performed to measure the pion branching ratio R^π with precision of $<0.1\%$.
- Initial PIENU result (0.24% precision)

$$R_{\text{exp}}^\pi = [1.2344 \pm 0.0023(\text{stat}) \pm 0.0019(\text{syst})] \times 10^{-4}$$

Phys. Rev. Lett. 115 071801, (2015)

Exotic Decay Searches in PIENU

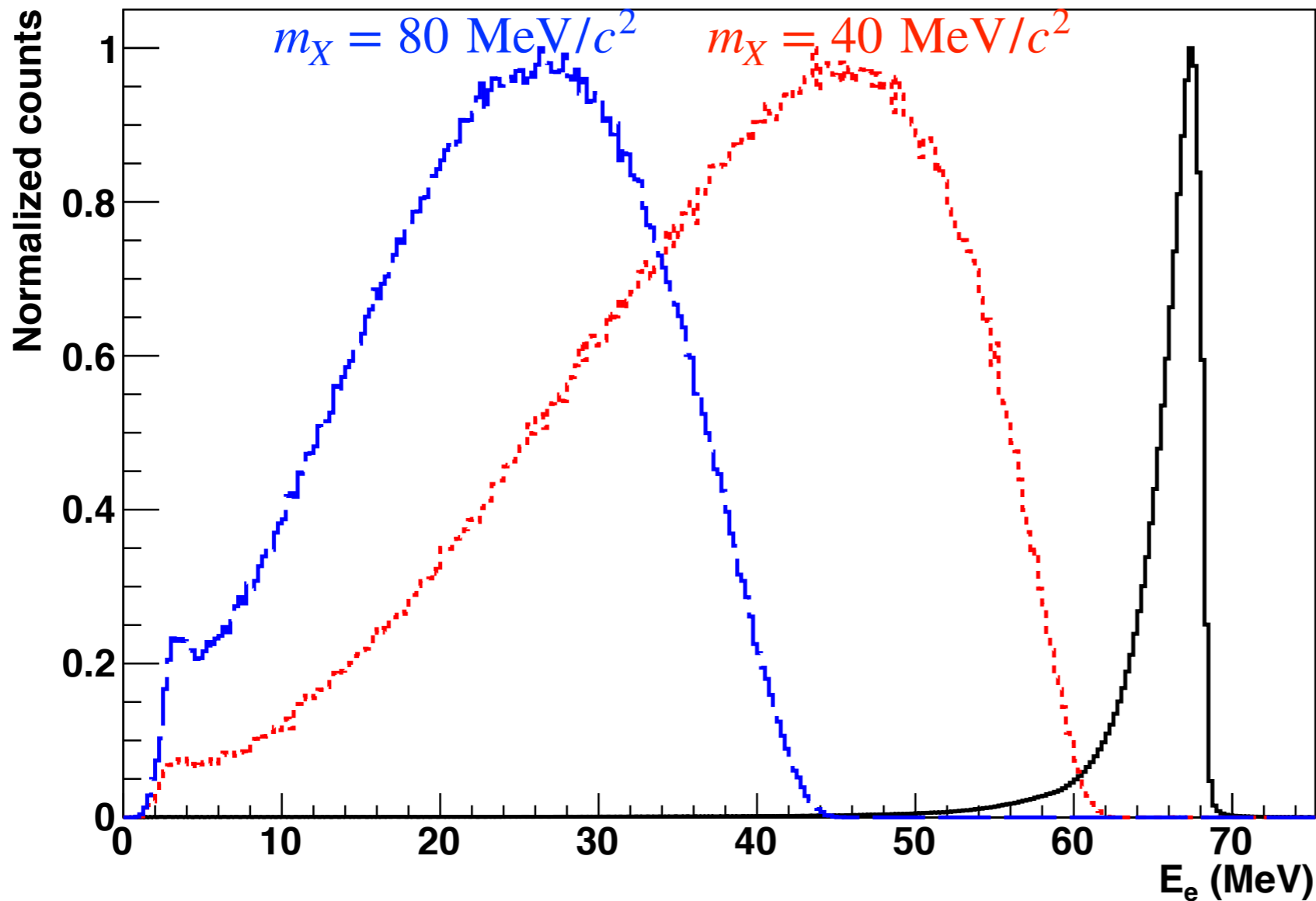
- Analysis of decay lepton (e, μ) energy spectrum is sensitive to search for exotic rare decays.
 - Massive neutrinos: [Phys. Rev. D 97 072012 \(2018\)](#)
 $\pi^+ \rightarrow e^+/\mu^+ \nu_H$ [Phys. Lett. B 798 \(2019\) 134980](#)
 - $\mu^+ \rightarrow e^+ X$ decay: [Phys. Rev. D 101 052014 \(2020\)](#)
 - $\pi^+ \rightarrow e^+/\mu^+ 3\nu$ decay: [Phys. Rev. D 102 012001 \(2020\)](#)
- ➔ [Details presented by Saul Cuen-Rochin.](#)



Limits on $\pi^+ \rightarrow e^+ \nu_H$ decay

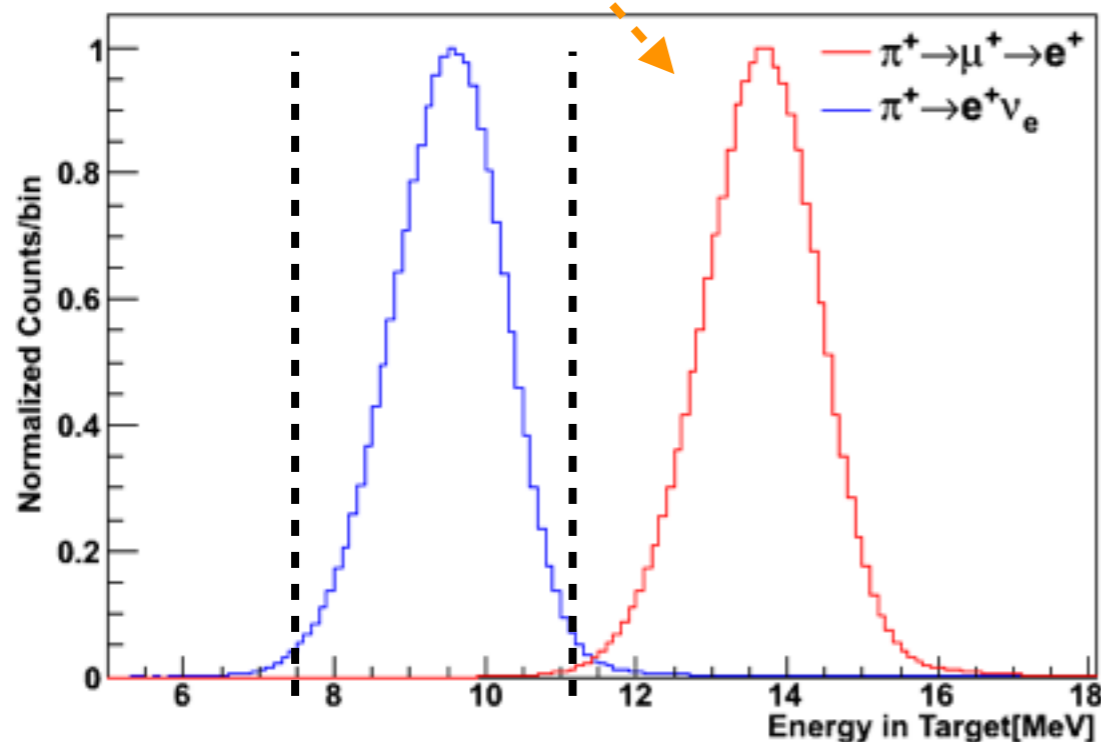
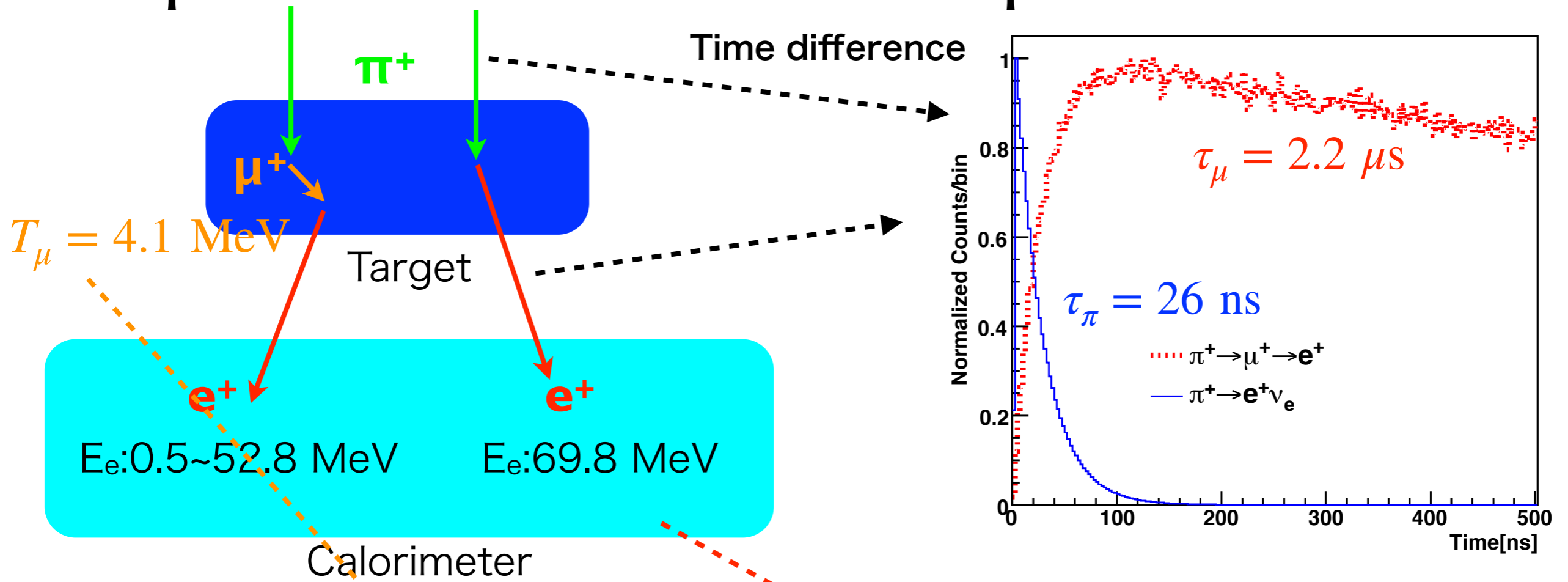
Search for three body pion decay in PIENU

- Another exotic pion decay: $\pi^+ \rightarrow e^+ \nu X$ where X is
 - Axion like particles (Phys. Rev. D 101 075002 (2020))
 - Majoron (Phys. Lett. 99B 411 (1981))
 - Sterile neutrinos (Phys. Rev. D. 97 075016 (2018))

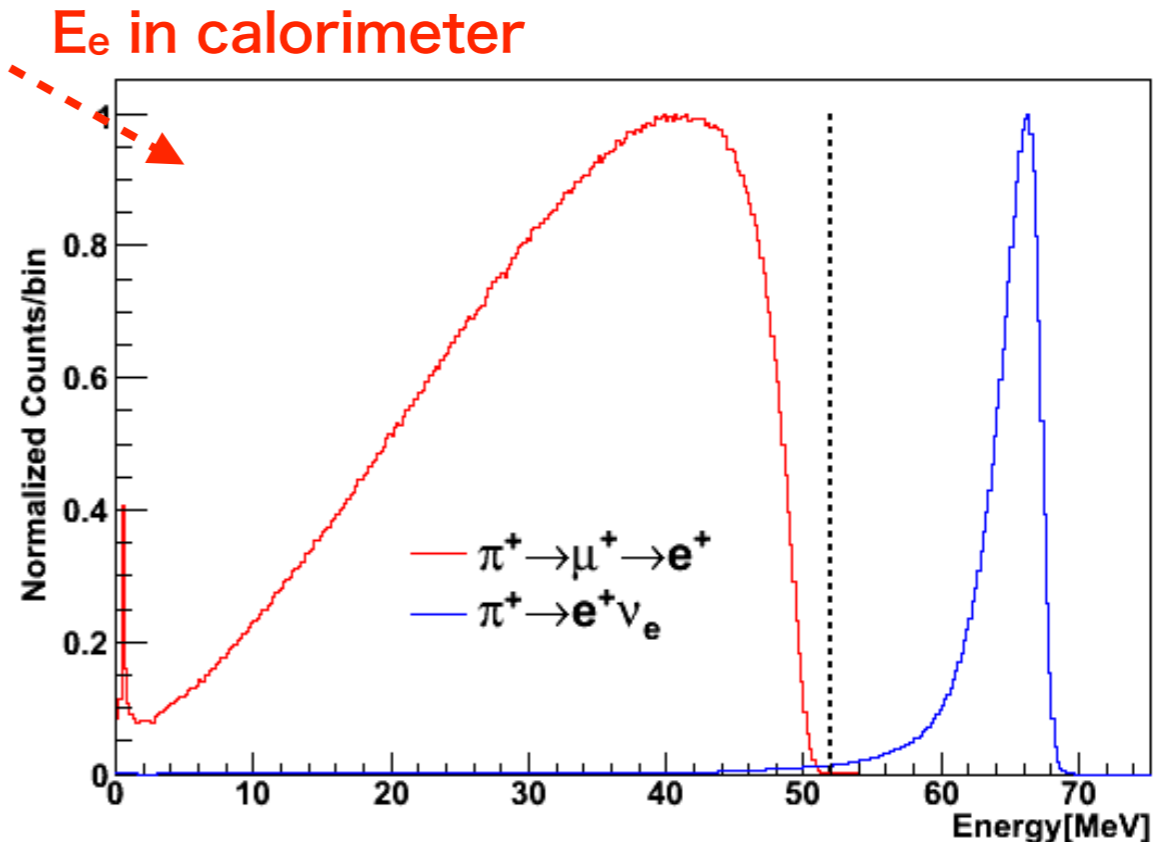


Normal $\pi^+ \rightarrow e^+ \nu$
(Mono-energetic peak,
including detector response)

Experimental Technique in PIENU



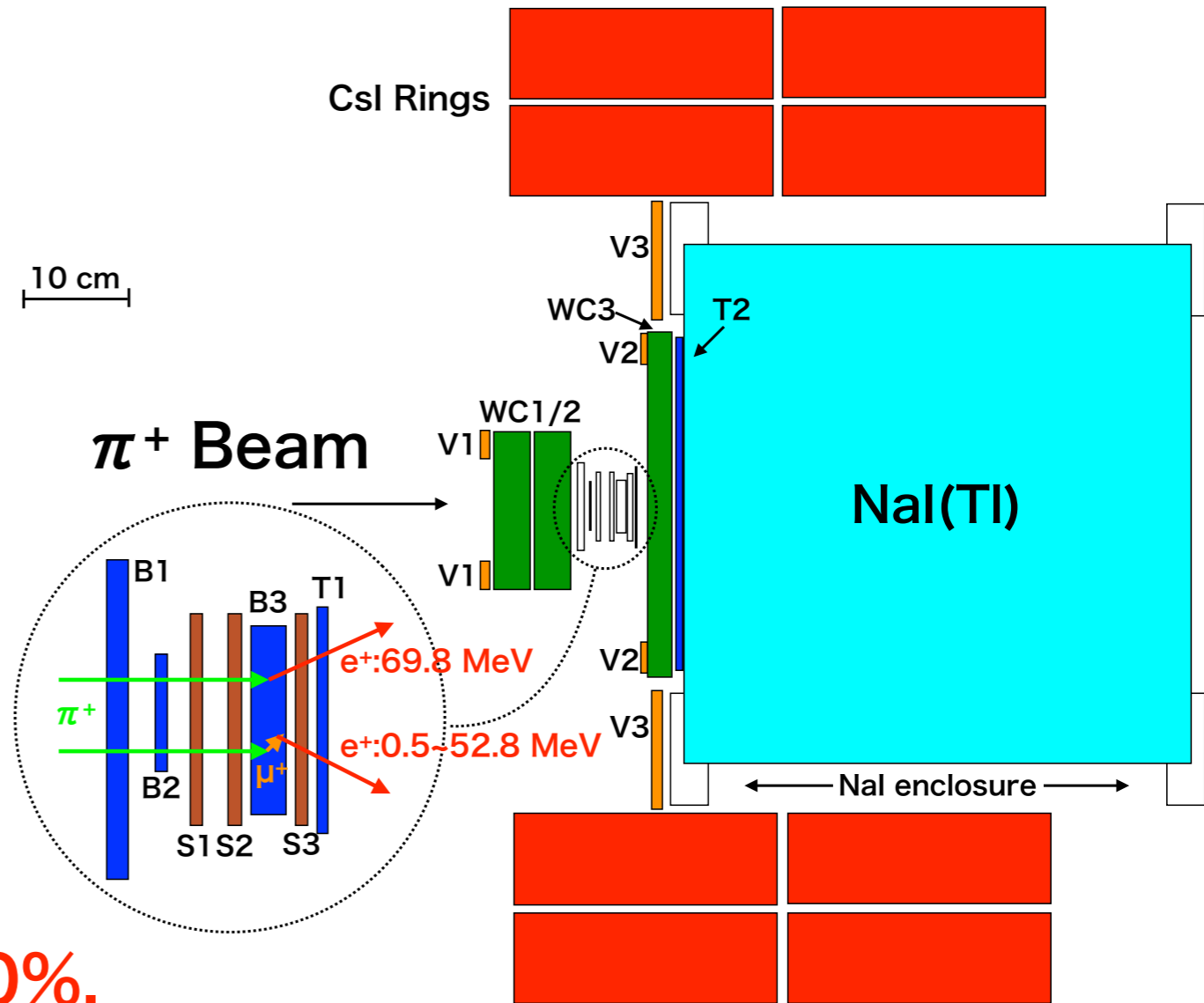
Energy in the target (MC)



Decay positron energy (MC)

The PIENU Detector

- The PIENU detector
 - NaI(Tl): 48 cm × 48 cm
 - CsI rings
 - WC: Wire chamber
 - S: Silicon strip
 - B1, B2, B3, T1, T2: Plastic scintillator

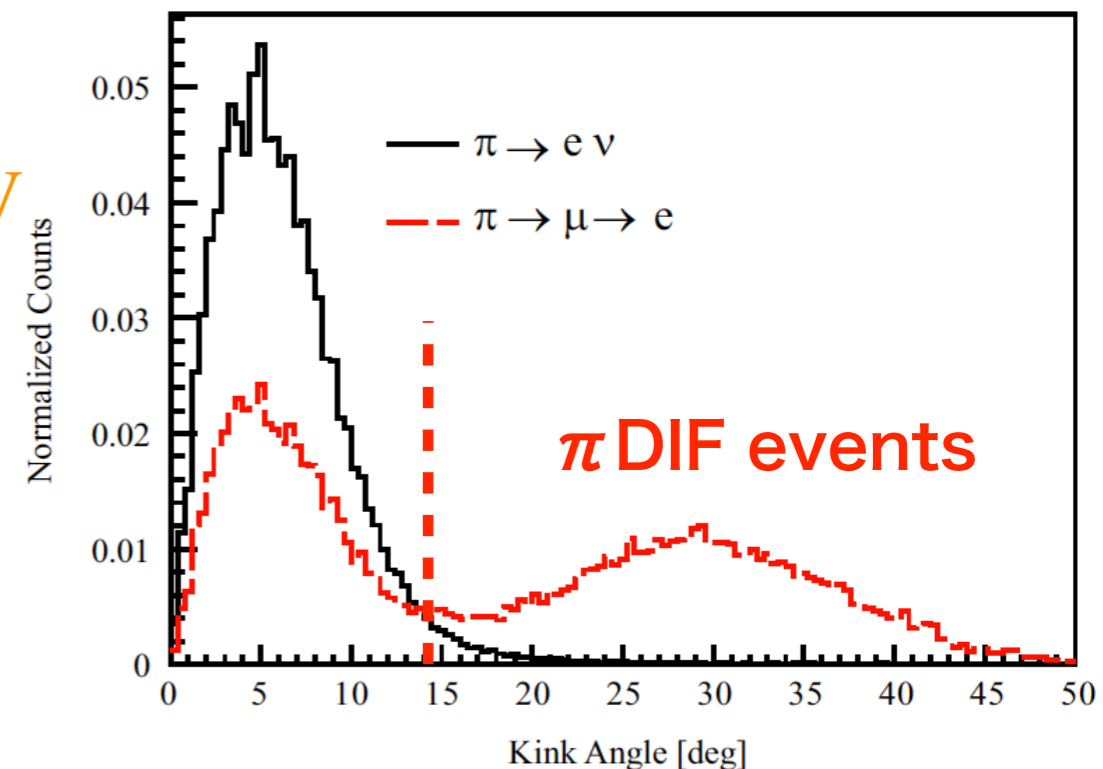
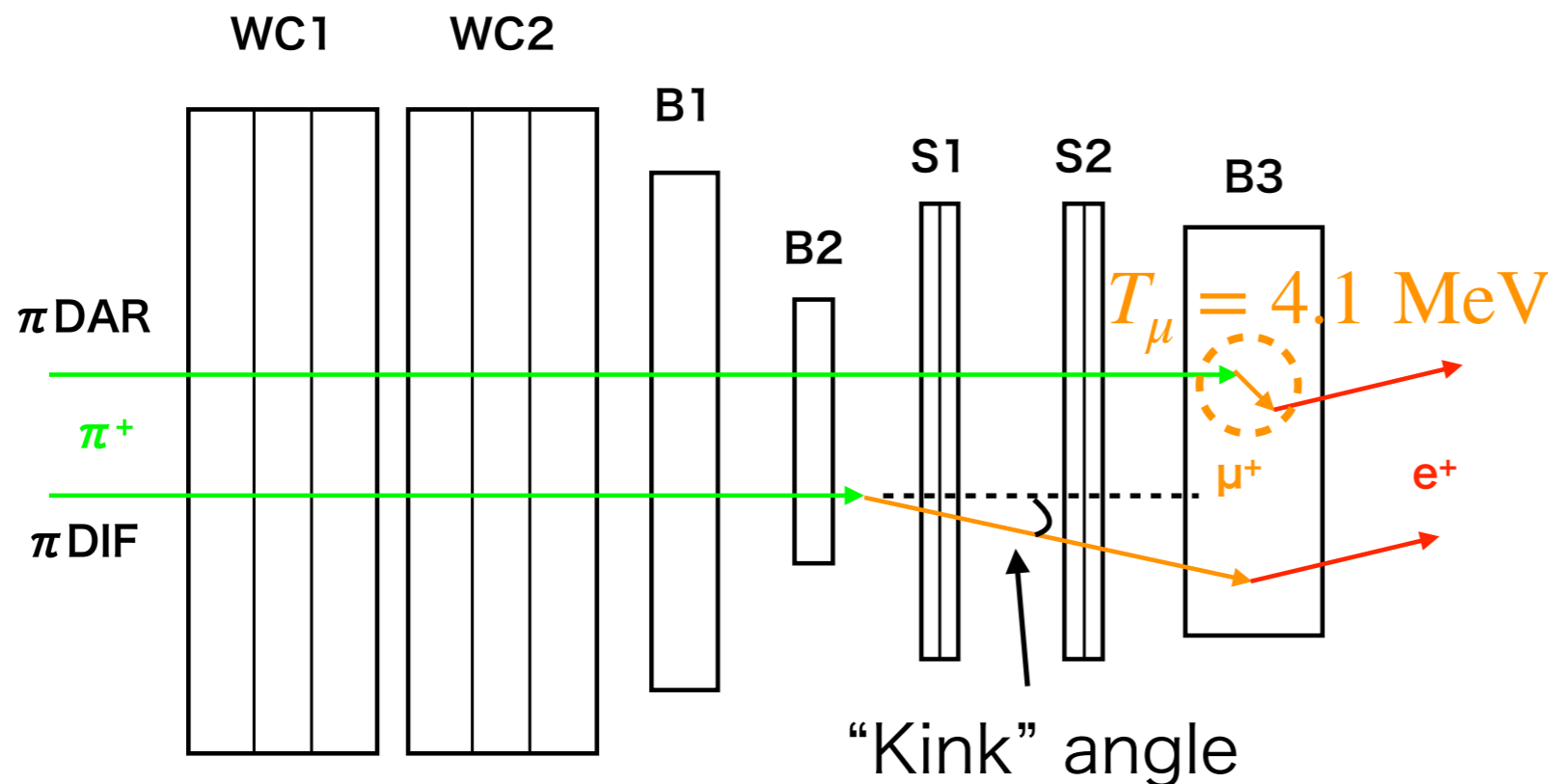


- ✓ Larger detector acceptance, **~20%**.
- ✓ NaI(Tl): high energy resolution.
 - ➔ **2.3%** at 70 MeV (FWHM).
- ✓ CsI rings: **shower leakage detection**.
- ✓ S1~S3, WC1~3: pion & positron tracking.

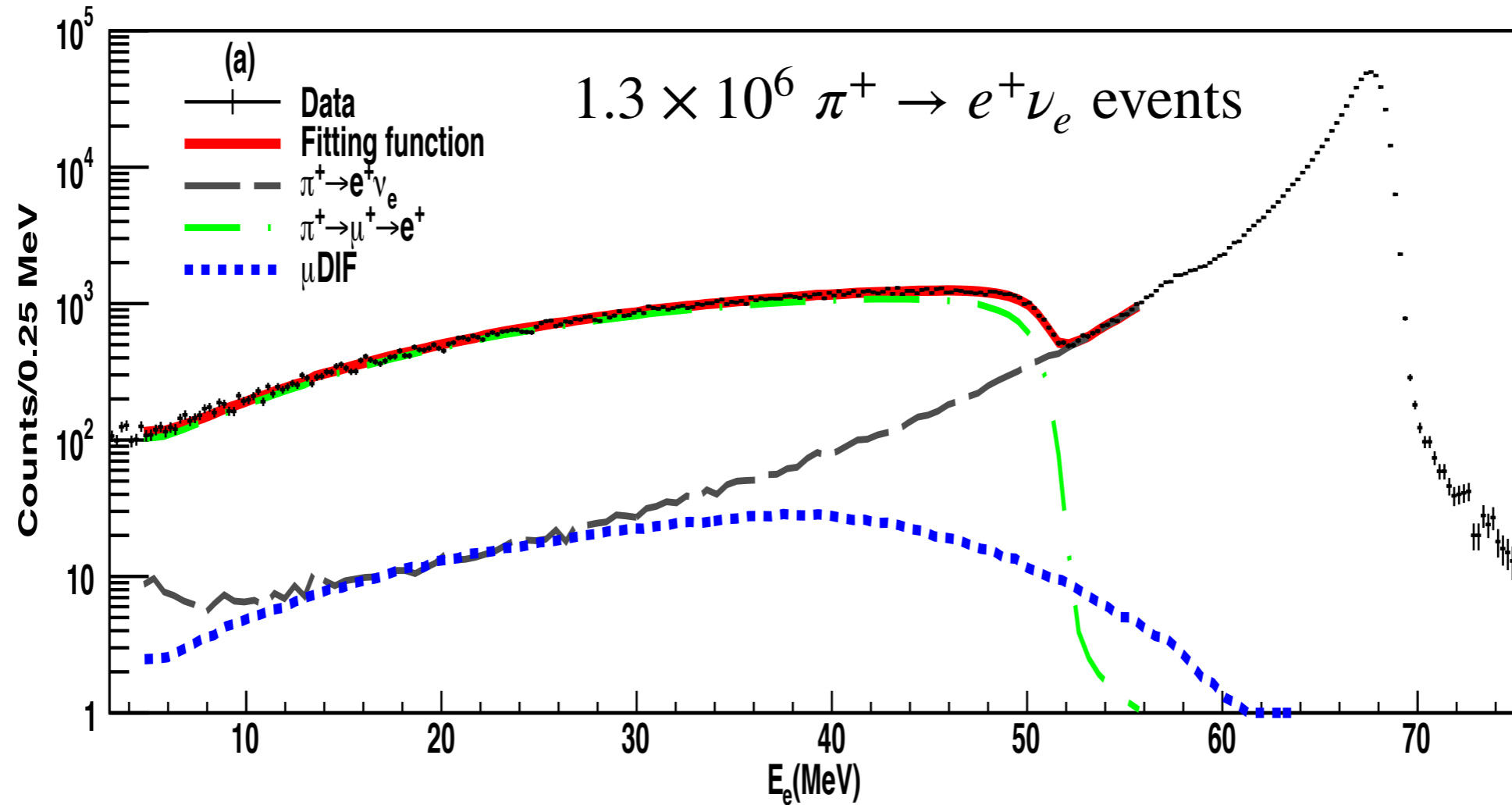
NIMA 791 38-46 (2015)

$\pi^+ \rightarrow \mu^+ \rightarrow e^+$ Suppression Techniques

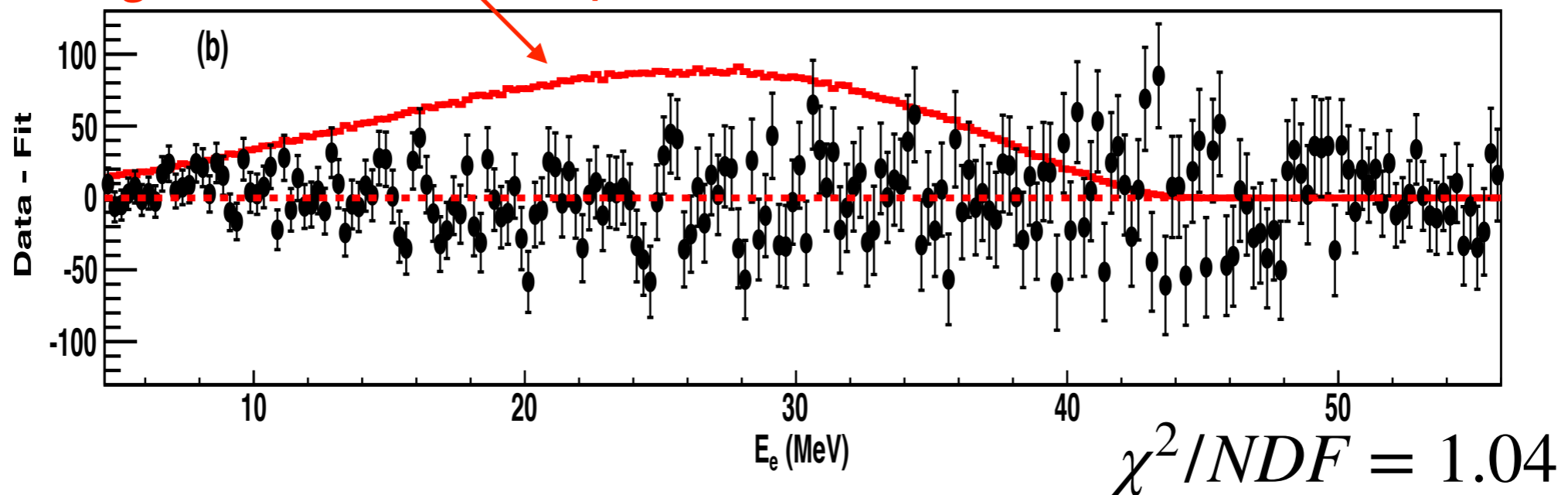
- To search for $\pi^+ \rightarrow e^+ \nu X$ decay, dominant $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ background should be suppressed by
 - exploiting shorter pion lifetime ($\tau_\pi \sim 26$ ns) than muon ($\tau_\mu \sim 2.2$ μ s)
 - target energy cut due to the presence of muon ($T_\mu = 4.1$ MeV)
 - “kink” angle cut to reject π -decay-in-flight (π DIF)
- $\rightarrow \pi^+ \rightarrow \mu^+ \rightarrow e^+$ suppression factor $\sim 10^5$.



Background Suppressed Energy Spectrum



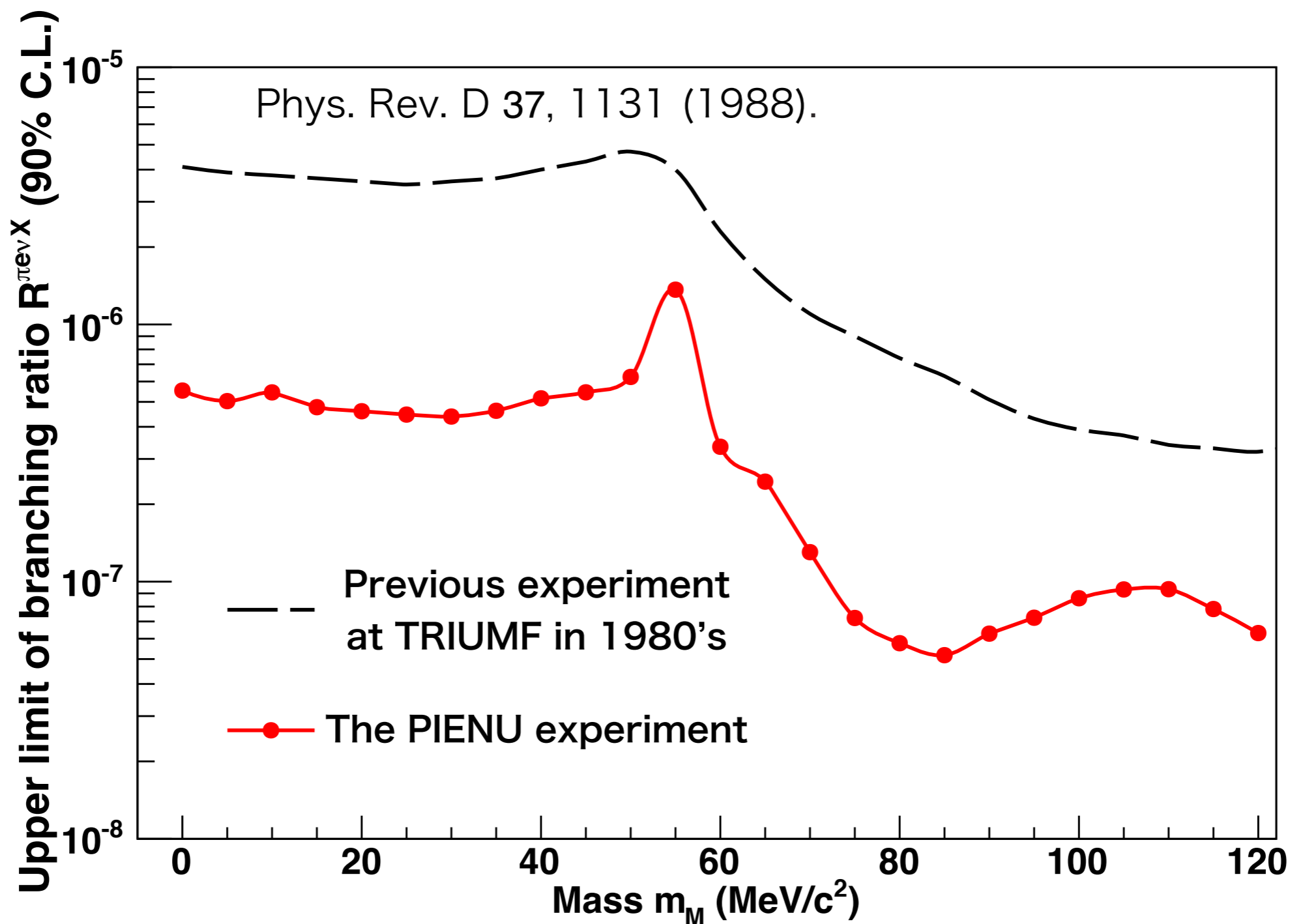
Hypothetical signal with $m_x = 80 \text{ MeV}/c^2$ and $\text{BR} = 2 \times 10^{-6}$.



Results of $\pi^+ \rightarrow e^+ \nu X$

- No signal was observed in $0 < m_X < 120 \text{ MeV}/c^2$.

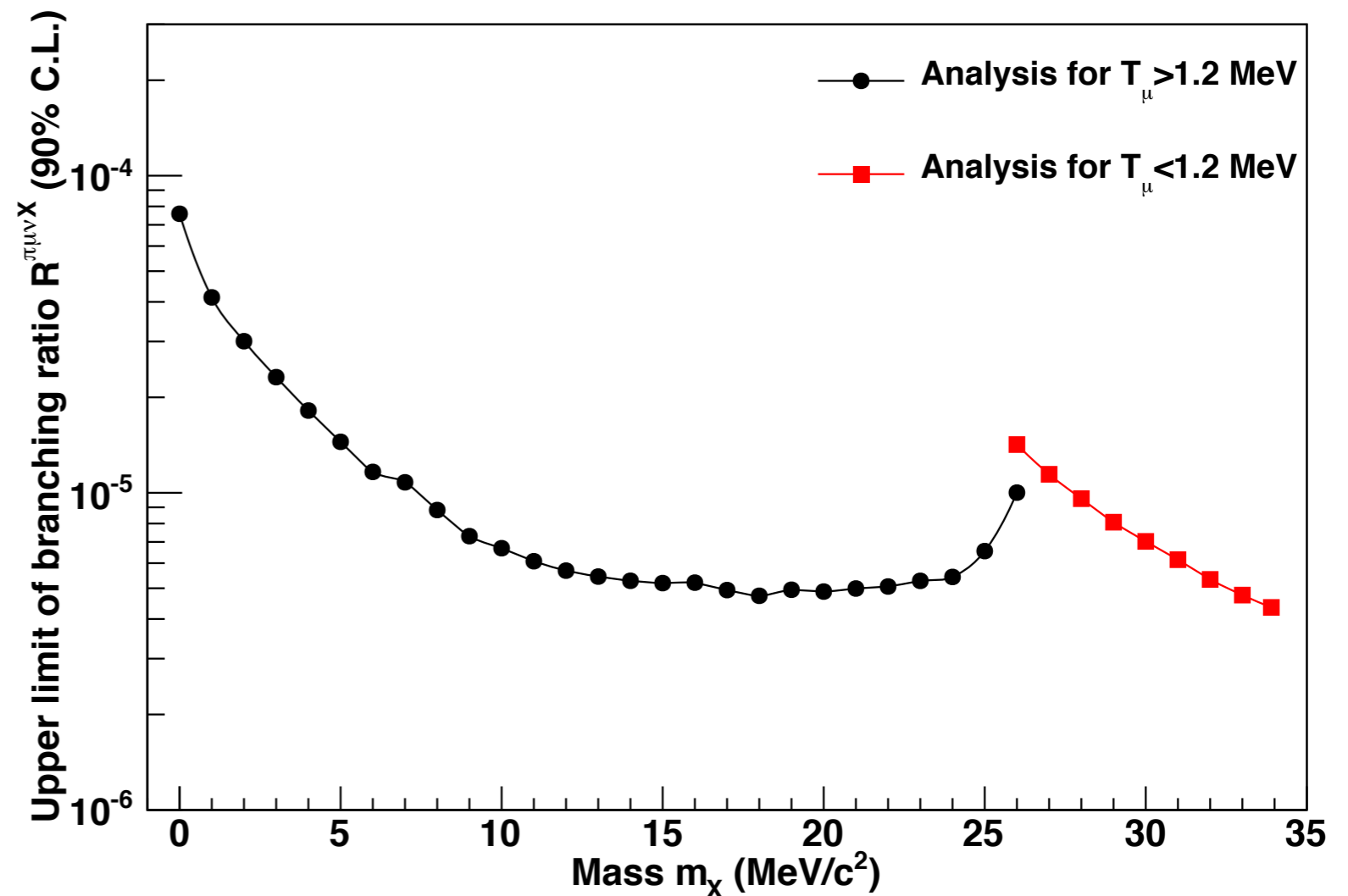
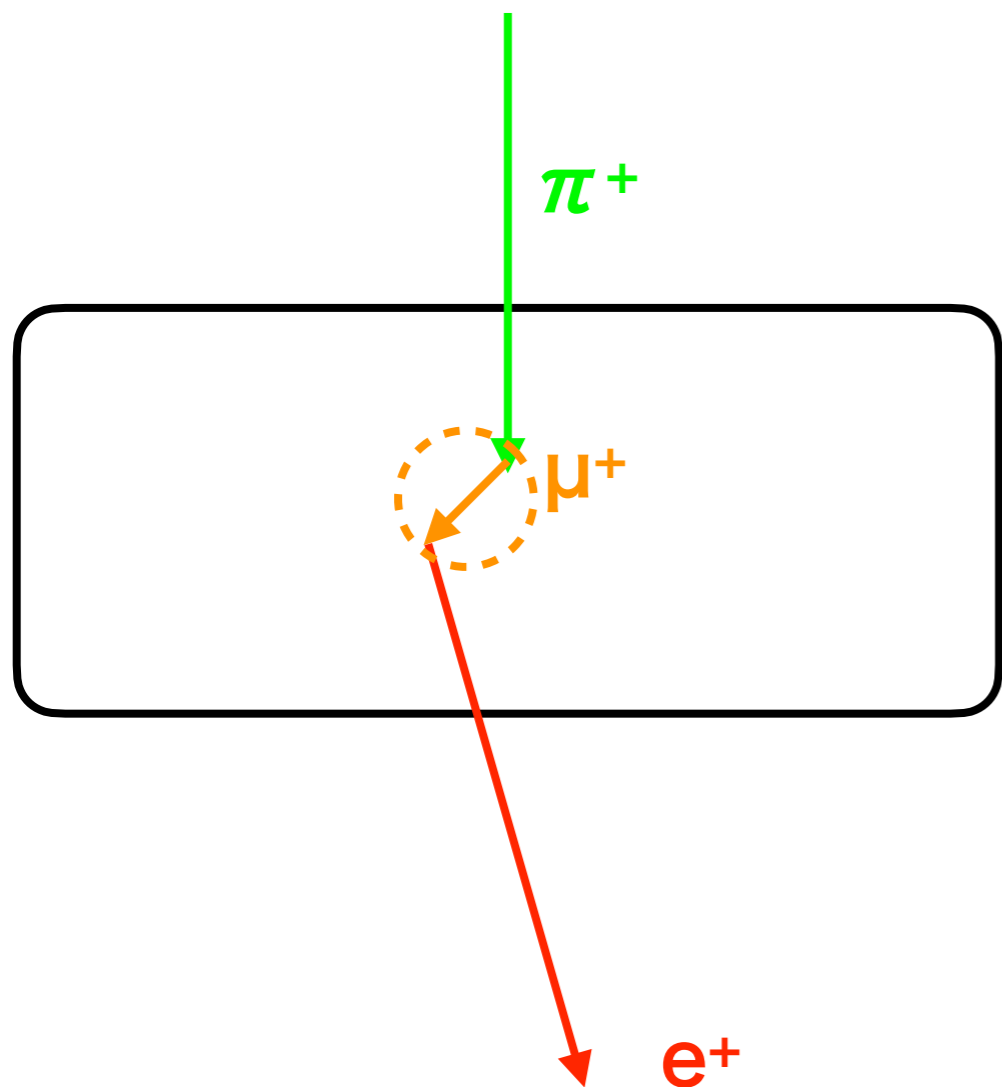
→ Improved by an order of magnitude.



Another Search $\pi^+ \rightarrow \mu^+ \nu X$

- $\pi^+ \rightarrow \mu^+ \nu X$ was also searched for using the energy information in the target.
- Set limits in $0 < m_X < 33.9 \text{ MeV}/c^2 \rightarrow$ **First available results.**

Accepted in Phys. Rev. D [arXiv: 2101.07381](https://arxiv.org/abs/2101.07381)



Summary

- The PIENU experiment was performed at TRIUMF to measure $\pi^+ \rightarrow e^+ \nu$ branching ratio $< 0.1\%$.
- The PIENU data is very sensitive to exotic decays.
- Three body pion decays $\pi^+ \rightarrow l^+ \nu X$ in PIENU
 - An order of magnitude of improvement: $\pi^+ \rightarrow e^+ \nu X$
 - First available results: $\pi^+ \rightarrow \mu^+ \nu X$
- Analysis of $\pi^+ \rightarrow e^+ \nu$ branching ratio with full statistics is ongoing and result is coming soon.



PIENU

Thank you for your attention!!