PIONEER

Next Generation Rare Pion Decay Experiment

Douglas Bryman

University of British Columbia &TRIUMF

References

PIONEER Collaboration, **2203.01981** [hep-ex]

D.B., A. Crivillen, V. Cirigliano, and G. Inguglia, *Ann.Rev.Nucl.Part.Sci.* 72 (2022) 69-91.

Lepton Flavor

Electron *Thomson, Townsand, Wilson 1896*

Muon *Nedermeyer, Anderson 1937*

Tau *Perl et al. 1975*

±40 yrs

Lepton Flavor Universality ***Pontecorvo*** *1946*

Conserved Lepton Number ***Konopinski, Mahmoud*** *1953*

Separate lepton "numbers (flavors)" ***Pontecorvo*** *1959*

Neutrino oscillations: (***Pontecorvo*** *1957 → Davis, Kamioka, SNO, OPERA, MINOS… 1960-2001*)

Lepton flavor is not conserved. Neutrinos have (small) mass and mix.

Flavor is an enigma!

SM Flavor Tensions

Several high precision measurements of accurately predicted SM processes show indications of violating Lepton Flavor Universality and CKM unitarity.

- Muon g-2 (->5 σ ?)
- B Decays (2-4 σ)

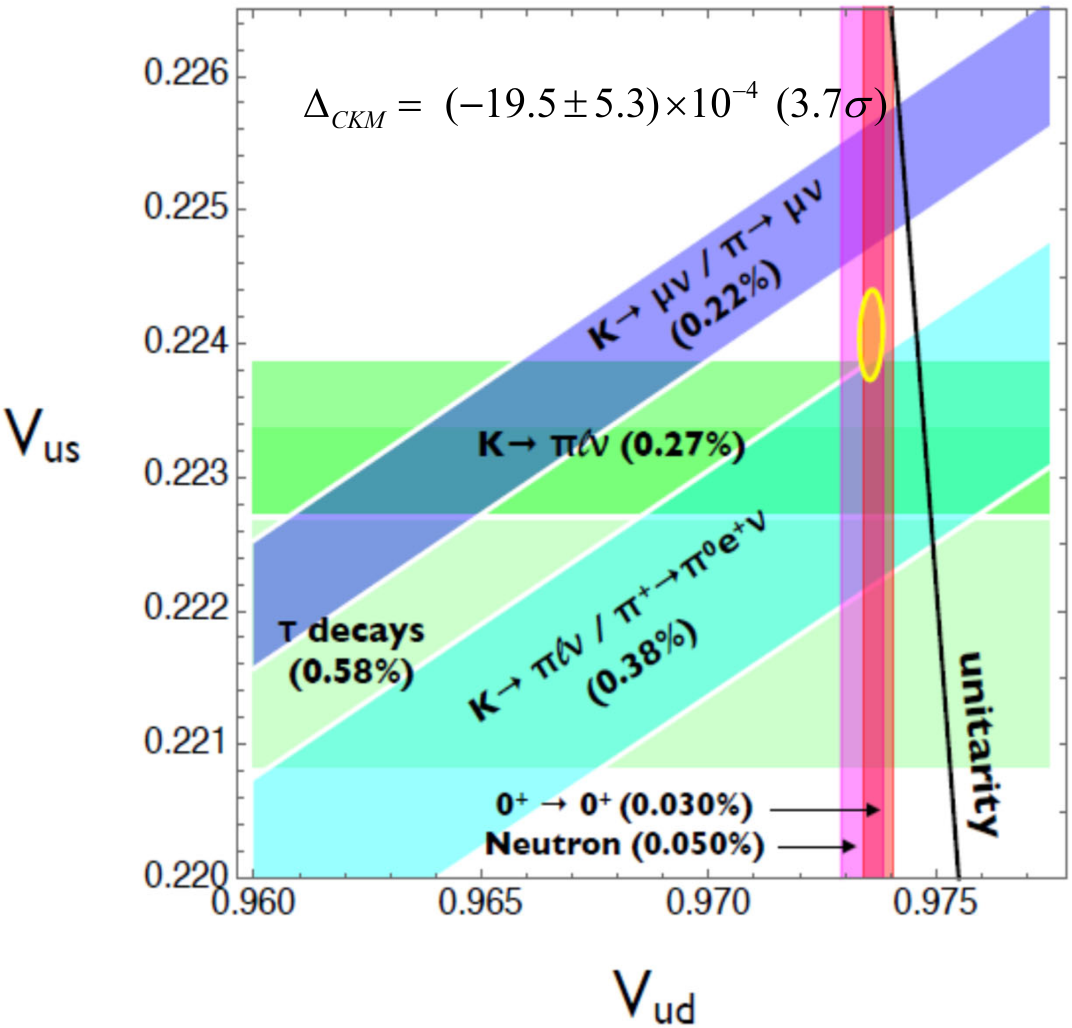
  $B \to D^{(*)}\tau\nu / B \to D^{(*)}\mu\nu$; charged currents

  O(10%) deviations from universality.

  Both heavy quarks and leptons involved!
- CKM Unitarity (3 σ)

• CKM Unitarity (~3σ)

$$SM: \; V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$



D.B., A. Crivellin, V. Cirigliano, and G. Inguglia, 2111.05338

Connection to LFU?

V_{ud} from β-decay & n-decay

G_F^{μ} Fermi const. from μ decay used to extract V_{ud}

V_{us} from K_{l3} and τ decay

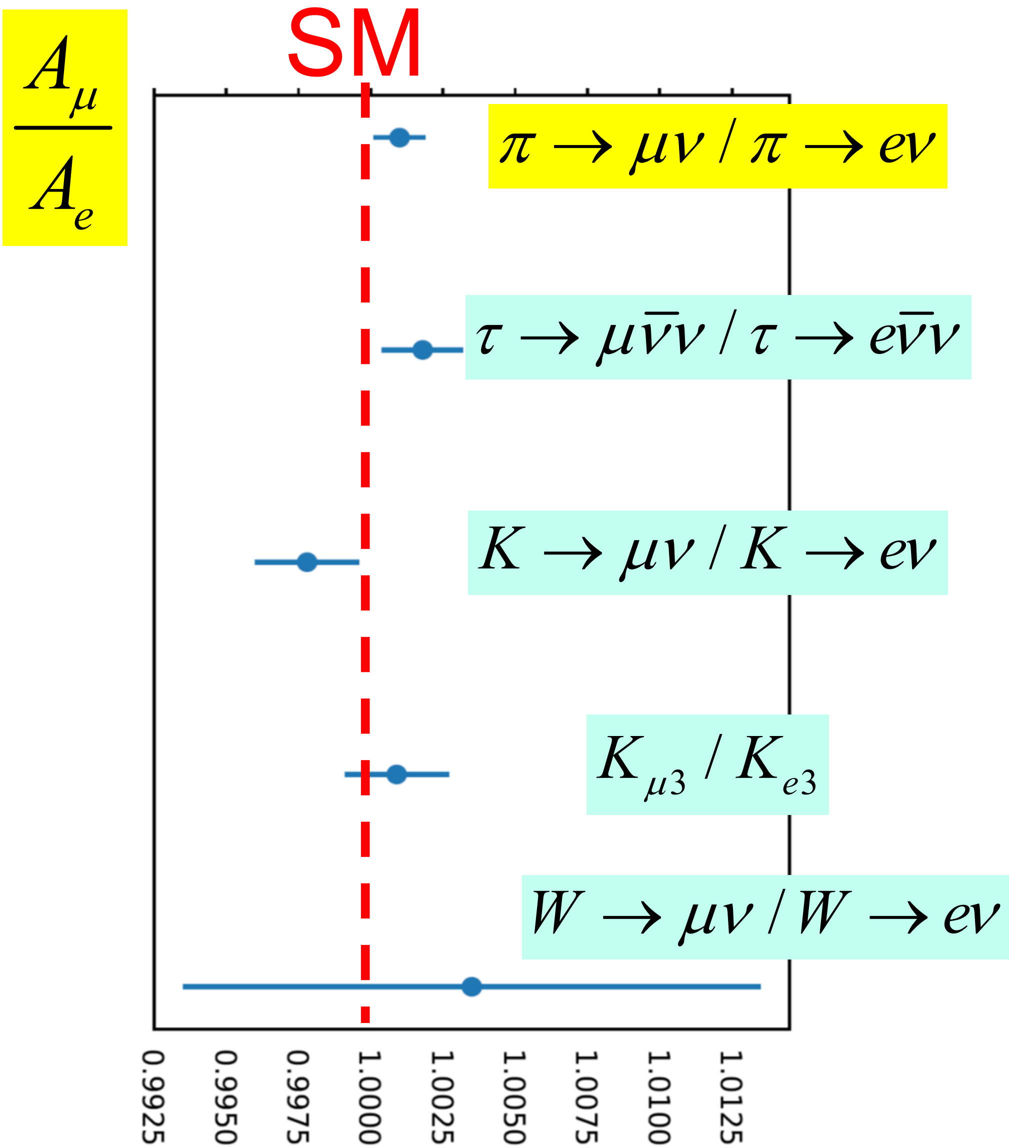
$\frac{V_{us}}{V_{ud}}$ from $\frac{K_{\mu 2}}{\pi_{\mu 2}}$; also $\frac{K_{l3}}{\pi_{l3}}$

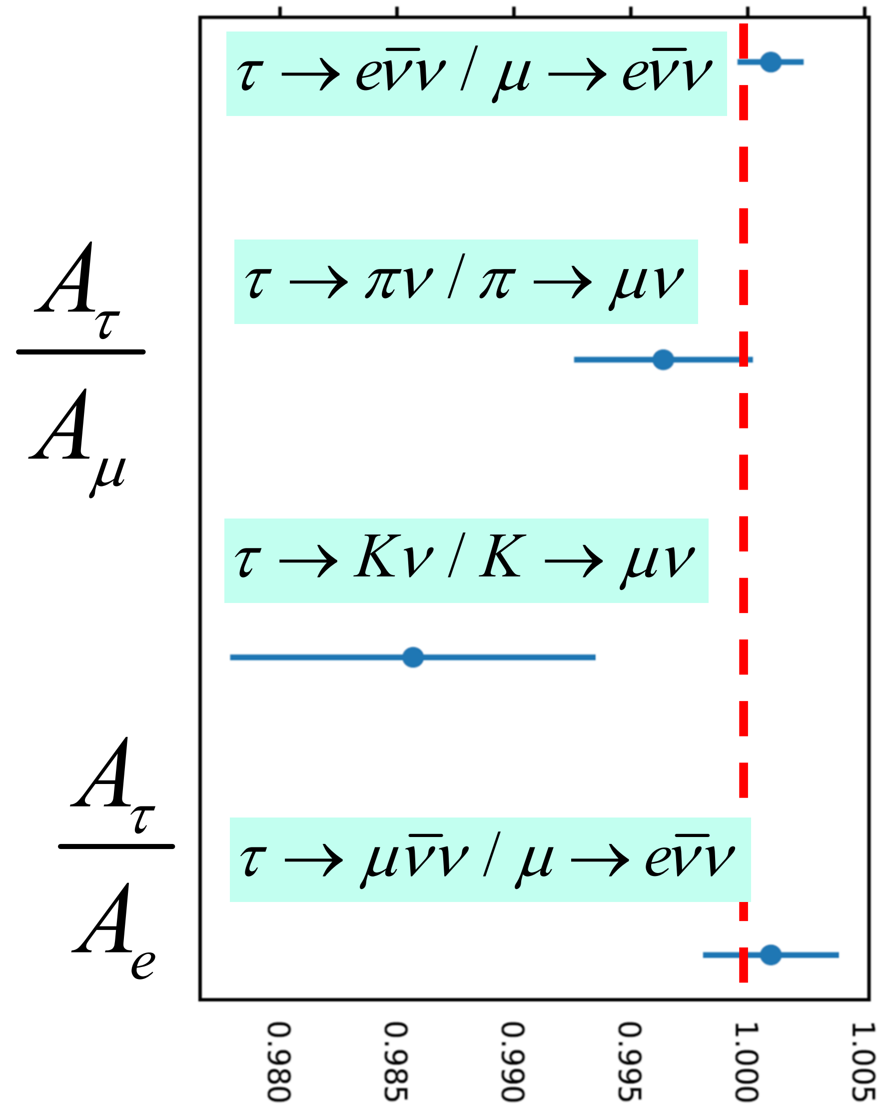
Agreement is poor; uncertainties from experiment and theory.

Deviations could be explained by small corrections ε_{ij} to W-l-ν couplings*

*Crivellin, Hoferichter, PRL 125, 111801 (2020)

μ-e Universality tested at $O(10^{-3})$
τ-μ/e Flavor Universality tested at $O(10^{-3})$





Charged Lepton Flavor Universality in π Decay

$$R_{e/\mu}^{theory} = \frac{\Gamma(\pi \to e\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))} = (1.23524 \pm 0.00015)x10^{-4}$$ (±0.012%)

Marciano/Sirlin → Cirigliano

Possibly the most accurately calculated decay process involving hadrons.

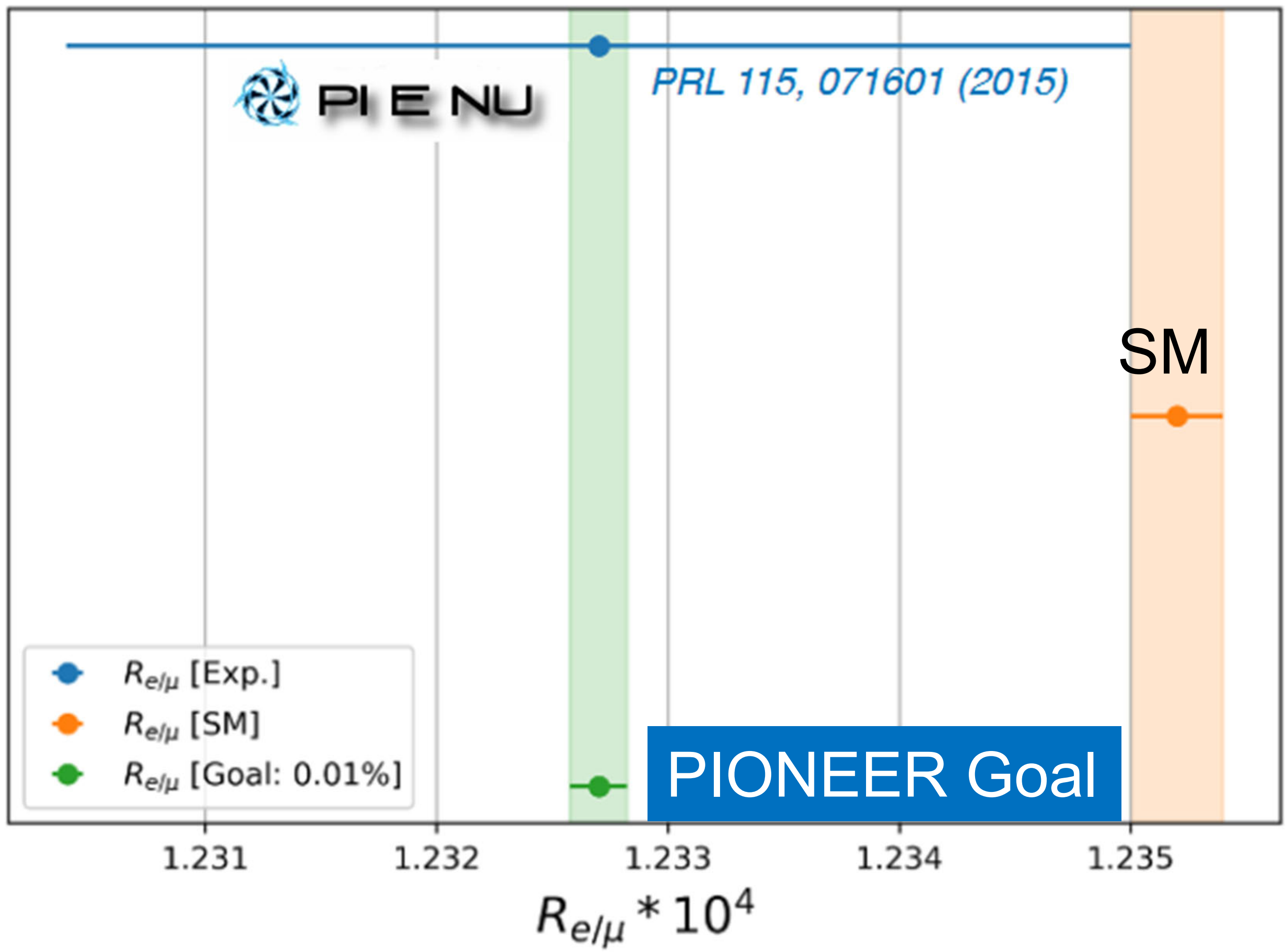
Current Result (PDG): $R_{e/\mu}^{\exp} = 1.2327 \pm 0.0023x10^{-4}$ (±0.19%)

PI E NU

Best test of LFU: $\frac{A_\mu}{A_e} = 1.0010 \pm 0.0009$ (±0.09%)

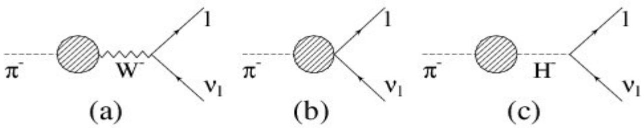
GOALS: PEN, PIENU ($R_{e/\mu}^{\exp} \leq \pm 0.1\%$); PIONEER ($\pm 0.01\%$)

Experiments: an order of magnitude less precise than theory.


PRL 115, 071601 (2015)
PI E NU
SM
$R_{e/\mu}$ [Exp.]
$R_{e/\mu}$ [SM]
$R_{e/\mu}$ [Goal: 0.01%]
PIONEER Goal
1.231
1.232
1.233
1.234
1.235
$R_{e/\mu} * 10^4$

$\pi^+ \to e^+\nu$ *LFU* Tests: Sensitivity to High Mass Scales

Pseudoscalar interactions



Charged Higgs (non-SM coupling)

$$1 - \frac{R^{New}_{e/\mu}}{R^{SM}_{e/\mu}} \sim \mp \frac{\sqrt{2}\pi}{G_\mu} \frac{1}{\Lambda^2_{eP}} \frac{m^2_\pi}{m_e(m_d + m_u)} \sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3$$

Marciano…

Phase I PIONEER Goal: 0.01 % measurement→Λ~3000 TeV

Many others:

- **Leptoquarks**
- **Excited gauge bosons**
- **Compositeness**
- **SU(2)xSU(2)xSU(2)xU(1)**
- **Hidden sector ….**

Induced Scalar Currents

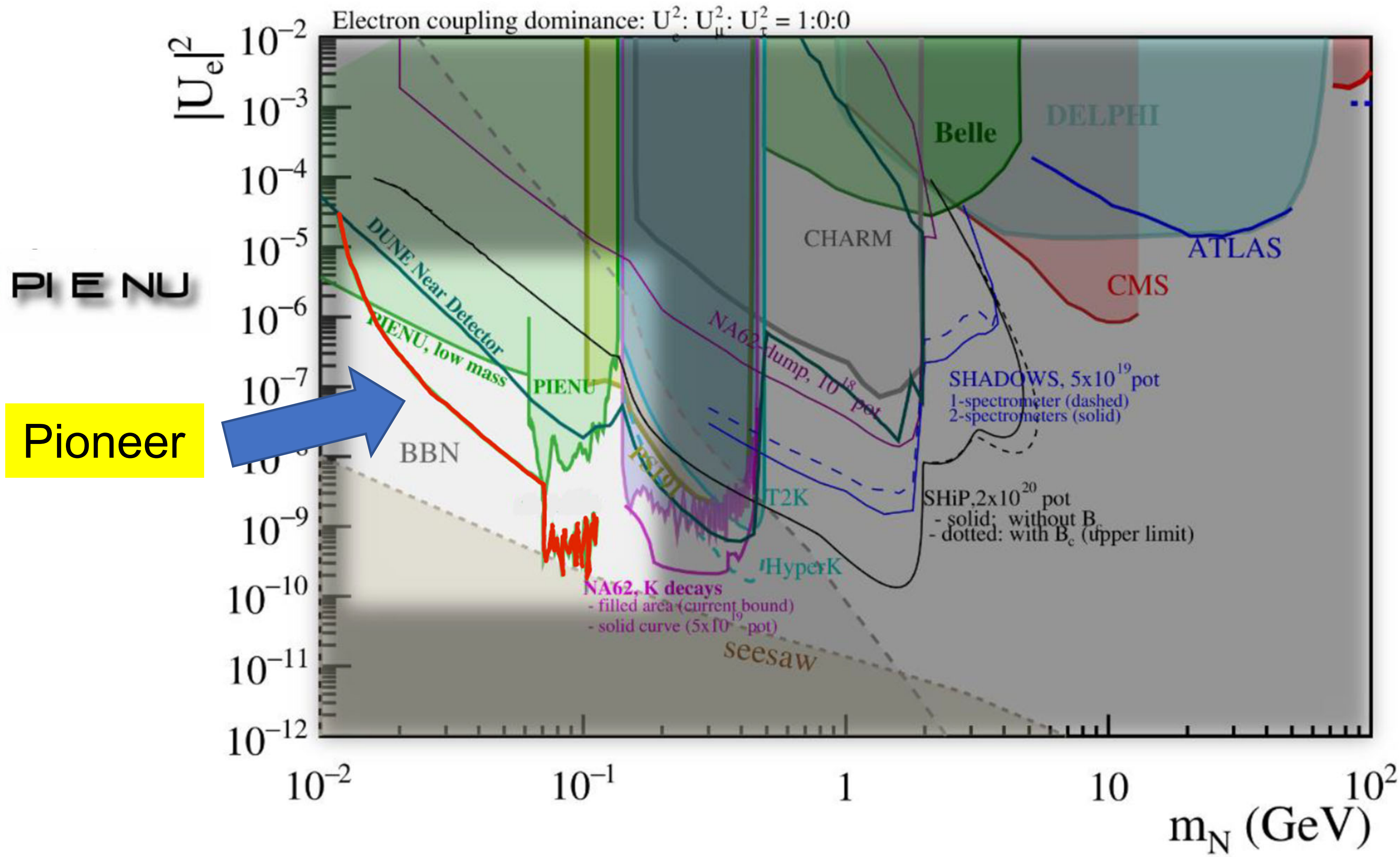
Campbell and Maybury (2005), Marciano

$R_{e/\mu}(0.01\%):\quad \Lambda_S > 180\,TeV\,(!)$

Apparent LFUV via massive sterile neutrinos (e.g. in $\pi^+ \to l^+\nu_H$) ;see DB and R. Shrock, PRD 100, 073011 (2019); Implications for leptogenesis (Elahi et al. **PRD 105, 055024 (2022)**); or other exotic processes like $\pi^+ \to l^+\nu a$ (Altmannshoffer et al. PRL 130, 241801 2023)).

Heavy Neutral Leptons Coupling to 1st Generation

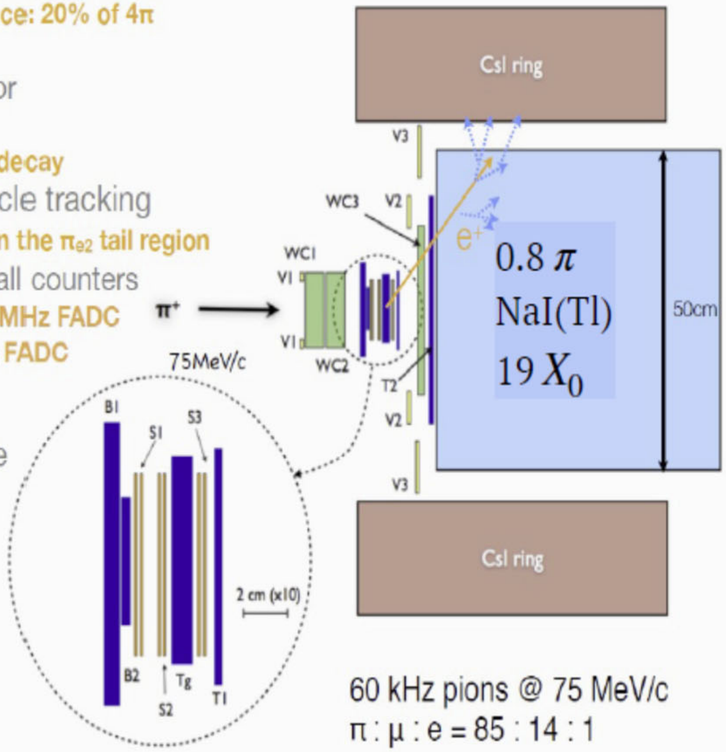
2203.08039 [hep-ph]



PIONEER builds on previous experience:

PIENU @ TRIUMF

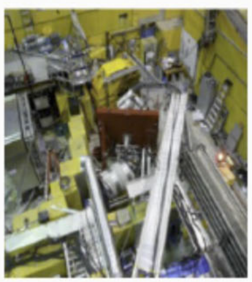
- Single crystal NaI(Tl) right behind the target
  - Geometrical Acceptance: 20% of 4π
  - ΔE = 2.2%(FWHM)
- CsI ring shower collector
  - π_{e2} tail suppression
  - gamma from radiative decay
- SSD and WC for particle tracking
  - Identify π-DIF events in the π_{e2} tail region
- Flash-ADC readout for all counters
  - Plastic Scintillator: 500MHz FADC
  - NaI(Tl) and CsI: 60MHz FADC
  - Pile-up tagging



60 kHz pions @ 75 MeV/c

π : μ : e = 85 : 14 : 1

- TRIUMF M13 beamline



NaI slow but excellent resolution (1% σ at 70 MeV)

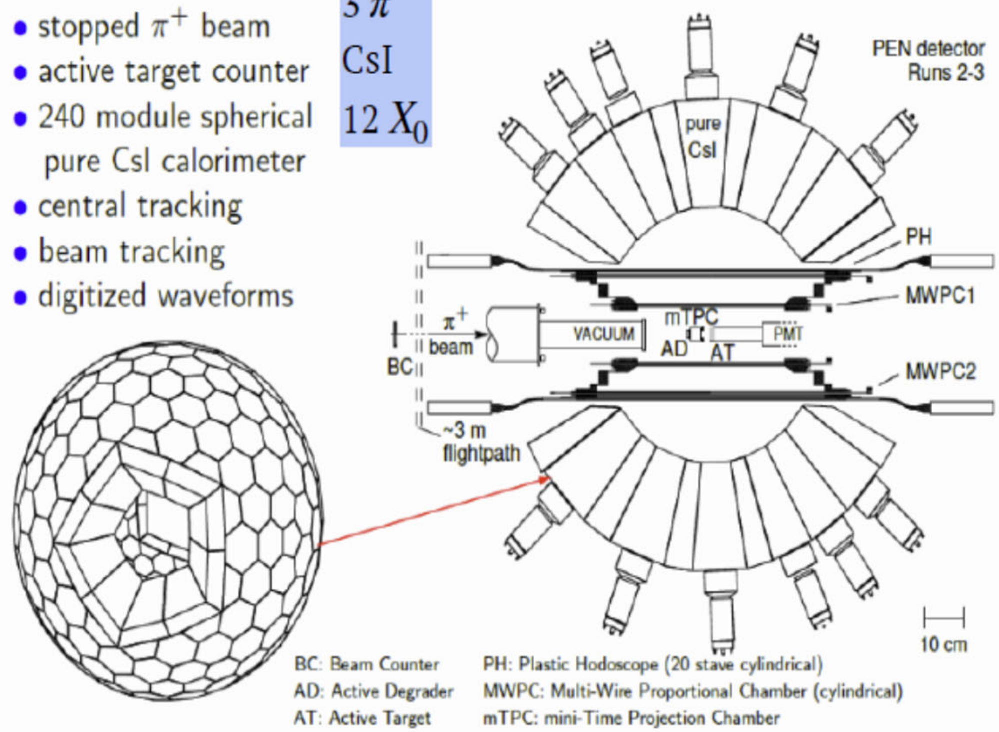
non uniformity, small solid angle

PEN @ PSI

The PEN/PIBETA apparatus

- πE1 beamline at PSI
- stopped π^+ beam
- active target counter
- 240 module spherical pure CsI calorimeter
- central tracking
- beam tracking
- digitized waveforms

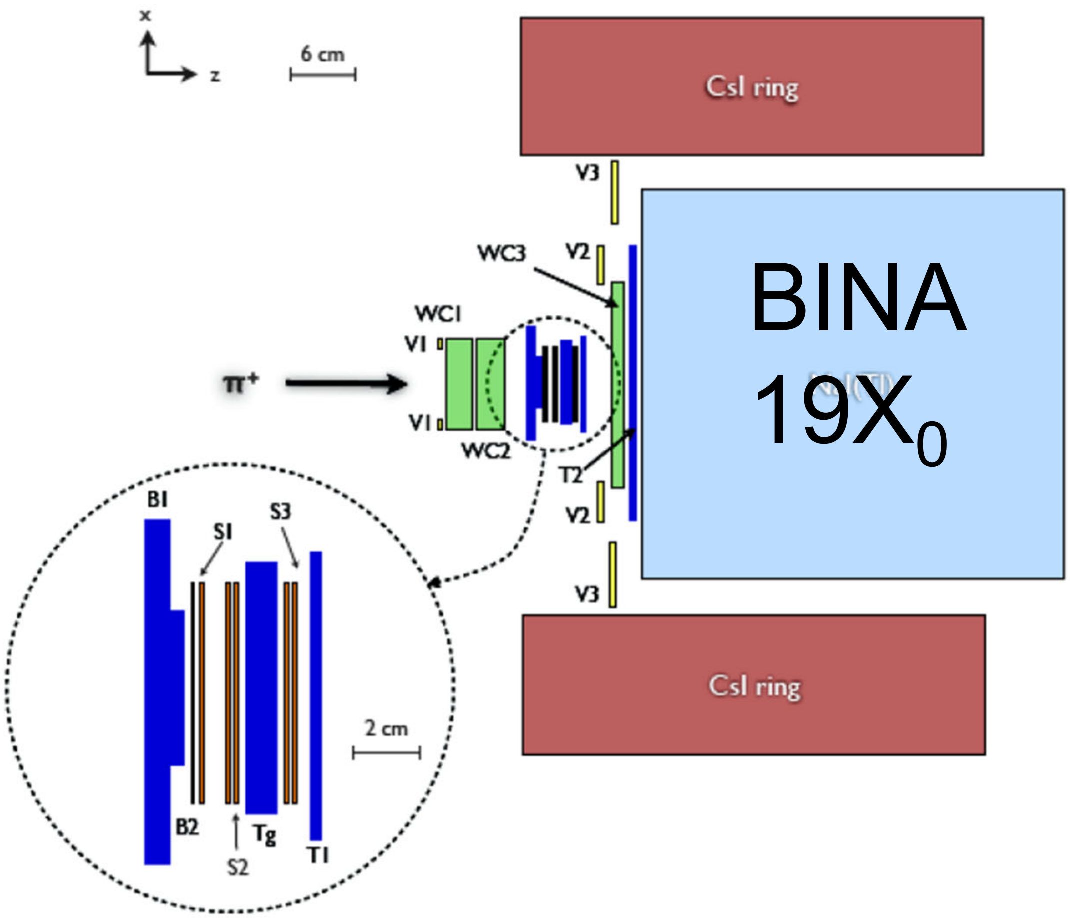
3 π
CsI
12 X_0

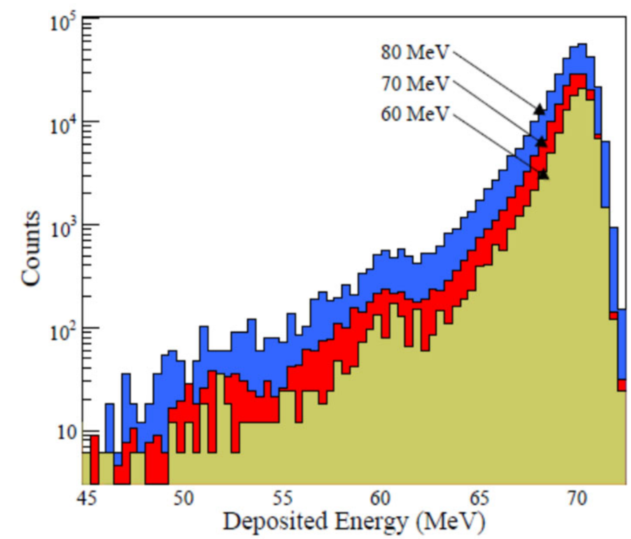


Good geometry but calorimeter depth too small

TRIUMF

PI E NU



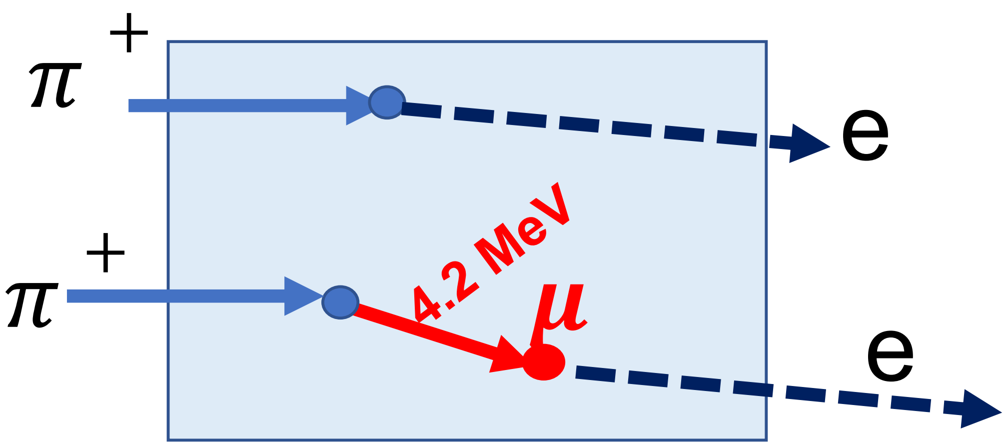


Photonuclear peaks revealed in direct lineshape measurement.

$$R_{e/\mu}^{\exp} = (1.2344 \pm 0.0023 \pm 0.0019) x 10^{-4}$$

$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))}$: Experimental Method

Simple experiment: count e^+ from π decay

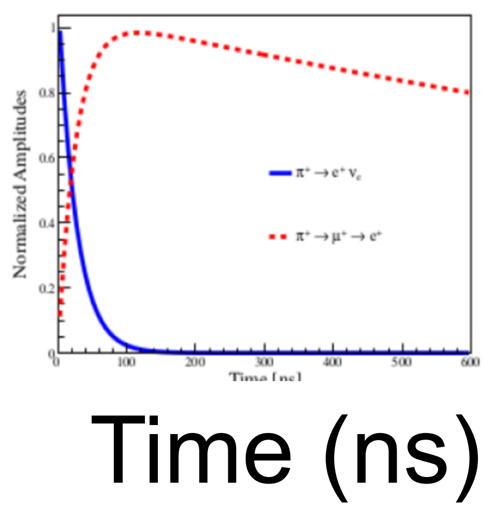


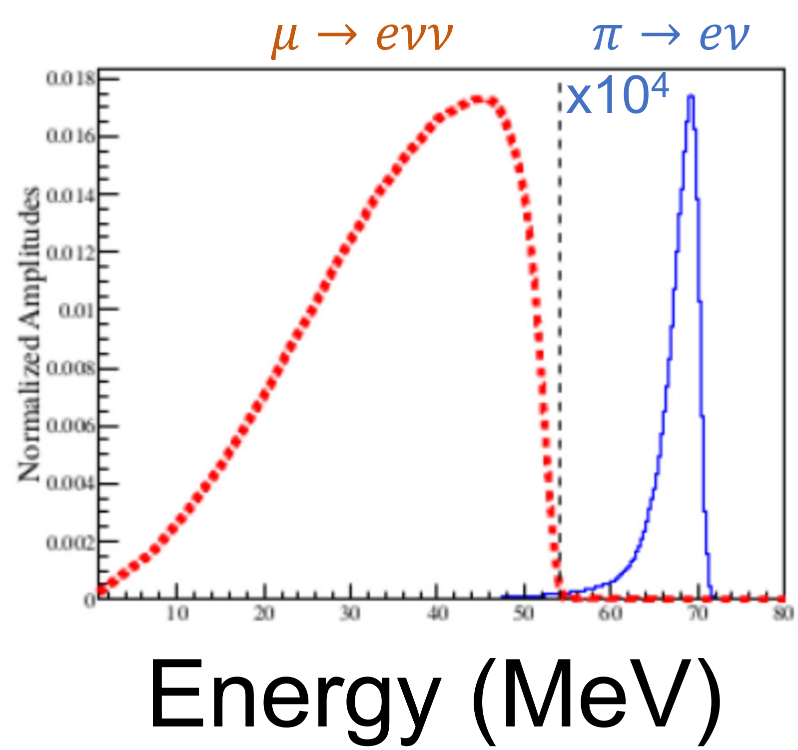
$$\frac{N(\pi \to e\nu)}{N(\pi \to \mu\nu)} \to \frac{N(\pi \to e\nu)}{N(\pi \to \mu \to e\nu\nu)}$$

Lifetimes

$\tau_\pi = 26ns$

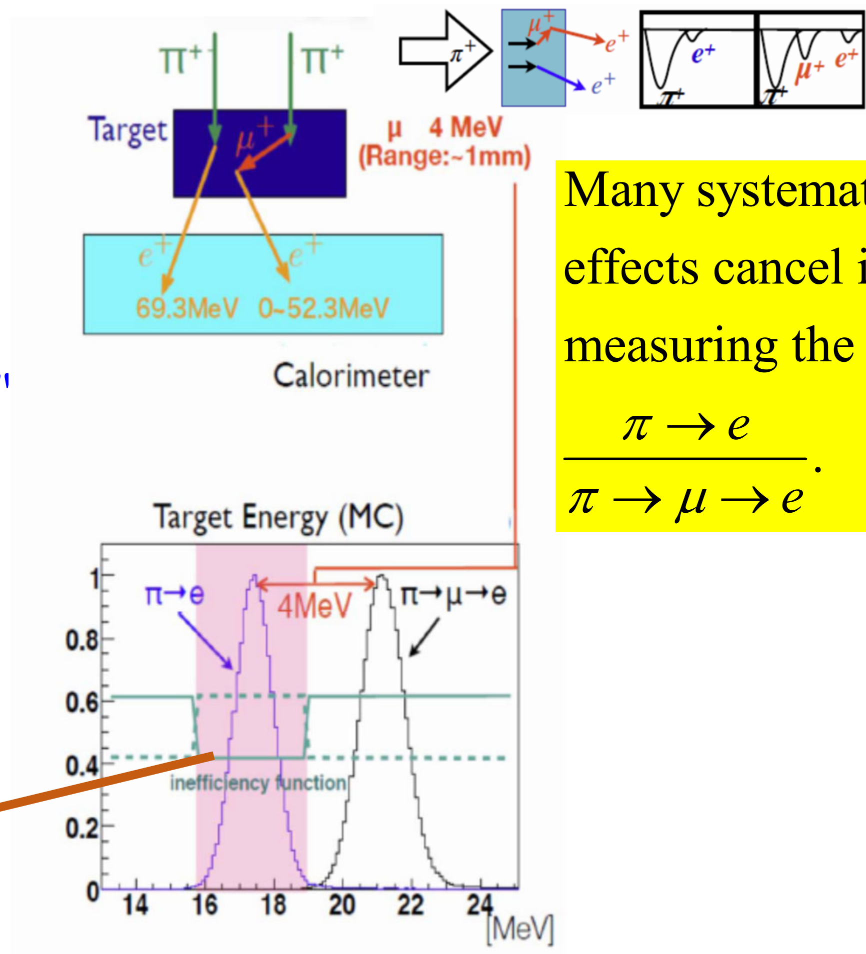
$\tau_\mu = 2.2\mu s$





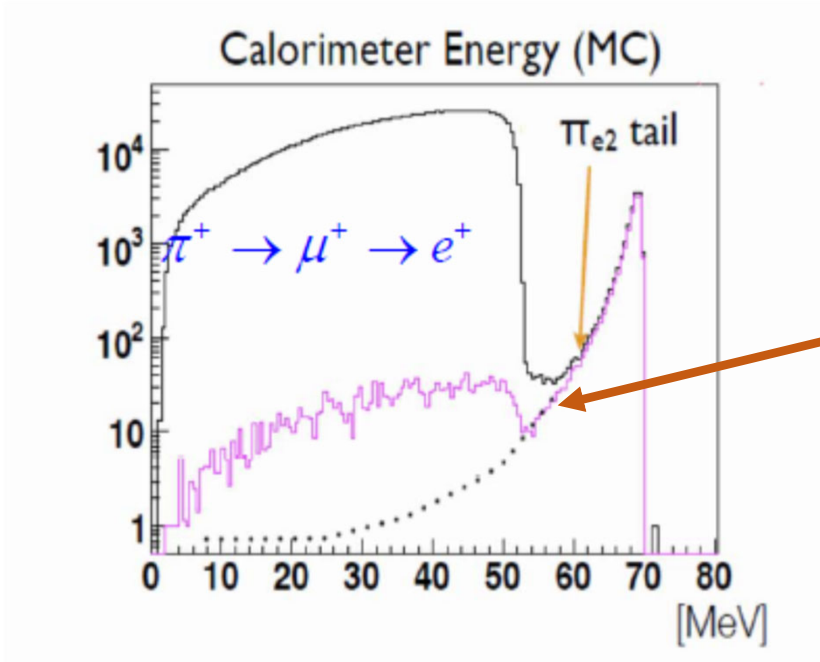
$\pi \to e\nu$: Experimental Method

- Pions stopped in an active target
- Positrons tracked; energy measured in a calorimeter
- Decays tagged in target by energy and time
- Principal sytematic uncertainty: Low energy "tail" of $\pi \to e\nu$ events under $\mu \to e\nu\nu$ "background".



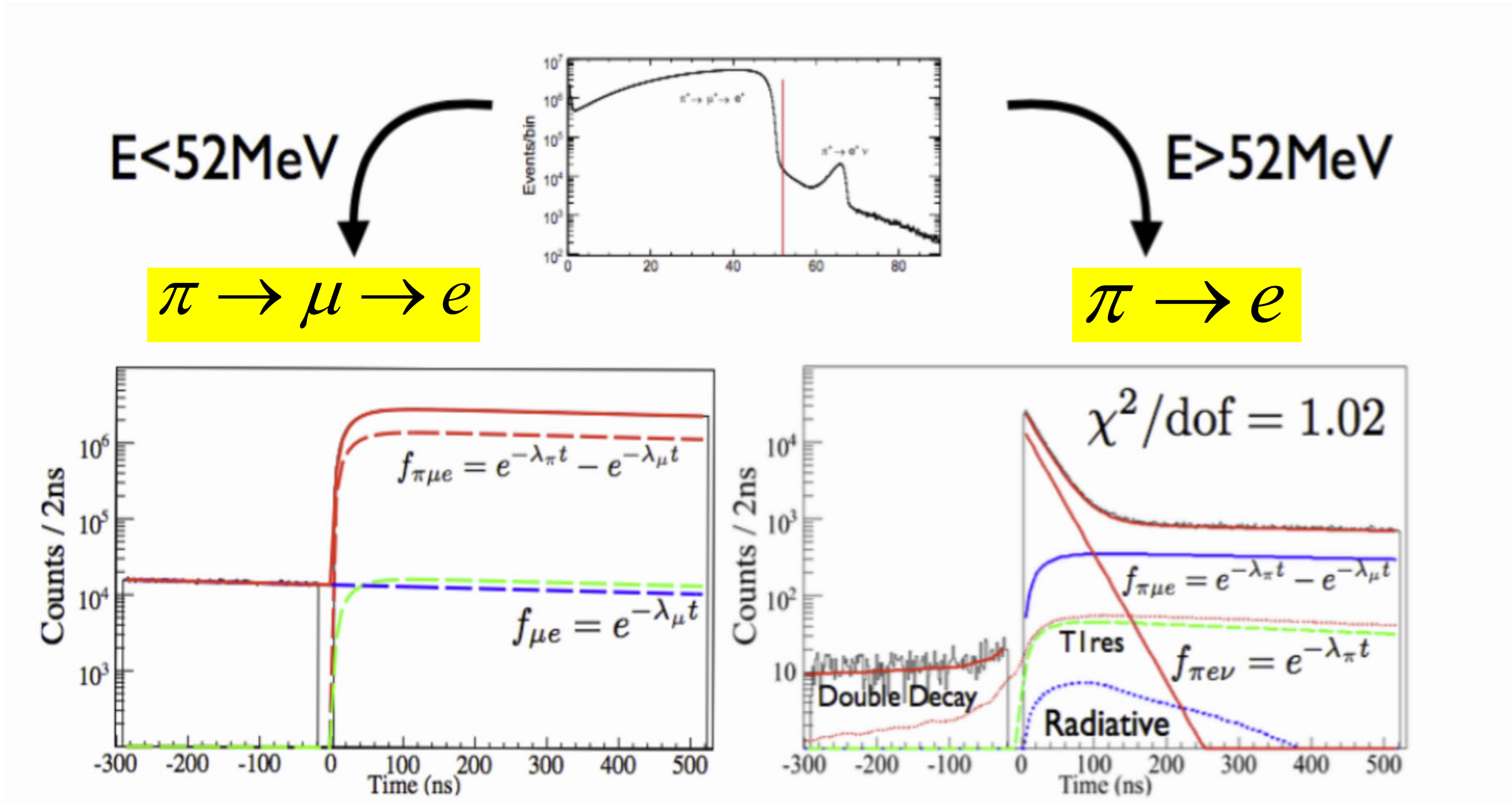
Many systematic effects cancel in measuring the ratio

$$\frac{\pi \to e}{\pi \to \mu \to e}.$$



Background suppression insufficient to determine "tail" for E<52 MeV.

Timing Analysis done for two Energy Regions



Correction for tail (E_e<52 MeV) obtained from direct measurement of line shape; other corrections also applied.

PIONEER
Next Generation Rare Pion Decay Experiment

PIONEER Goal: Improve precision by order of magnitude.

- Phase I:

  * Measure $R_{e/\mu} = \dfrac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$: $O(\pm 0.01\%)$

  * Improve exotic decay search sensitivities by an order of magnitude

    e.g. $\pi \to e\nu_H; \pi \to \mu\nu_H; \pi \to e/\mu\nu\nu\bar{\nu}; \pi \to e/\mu\nu X$

- Phase II $\to$ III:

  * Measure $R_{\pi\beta} = \dfrac{\Gamma(\pi^+ \to \pi^0 e^+ \nu)}{\Gamma(\pi^+ \to all)}$: $O(\pm 0.2\% \to \pm 0.05\%)$

PIONEER Proposal: $\pi^+ \rightarrow e^+\nu$

Approved at PSI 2022 – beam tests 2022,23

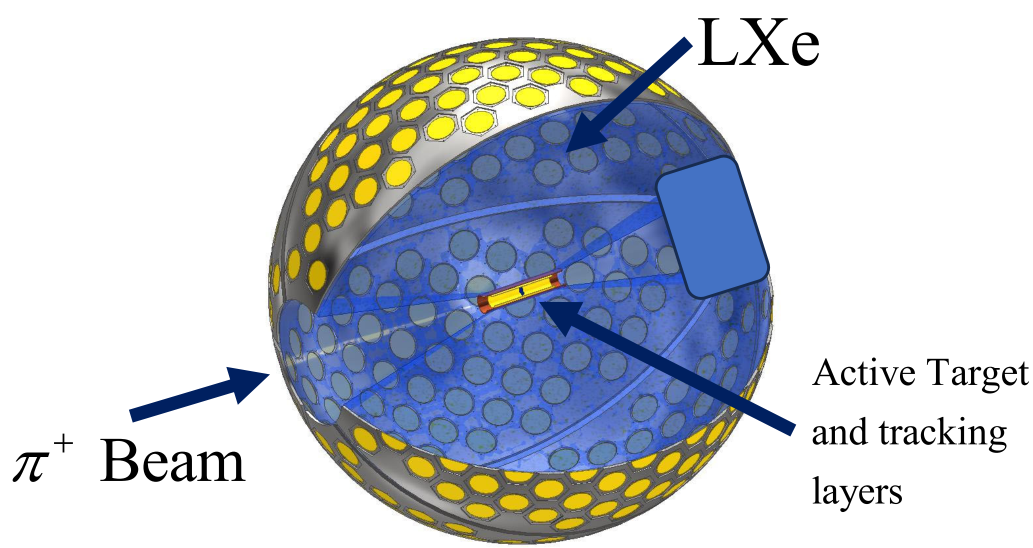
(→ Improvements Compared to PIENU)

- PSI cyclotron, πE5 beamline $\rightarrow 6x$ rate
- 25 X_0, 3π sr LXe scintillation calorimeter

  $\rightarrow$ Reduce Tail correction (5 x); $\rightarrow$ Improve uniformity (5 x)

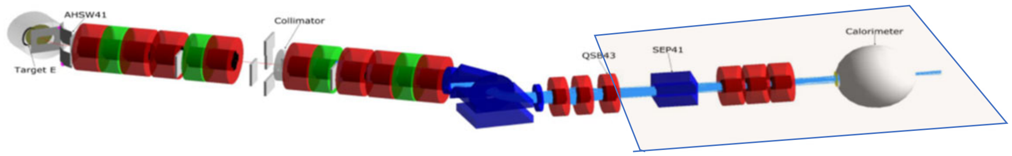
  Fast scintillation response (LXe) (10 x)
- Active Tracking Target $\rightarrow$ Reduce Tail correction uncertainty (10 x)

  Fast pulse shape $\rightarrow$ allow $\pi \rightarrow \mu \rightarrow$ e decay chain observation
- Fast electronics and pipeline DAQ $\rightarrow$ Improve efficiency

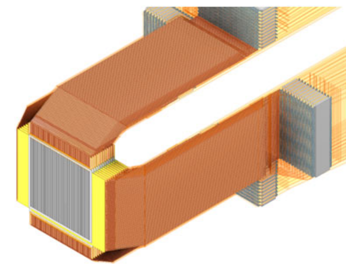


PIONEER Technologies for $\pi^+ \rightarrow e^+\nu$

Most intense low energy pion beam: PiE5 at PSI

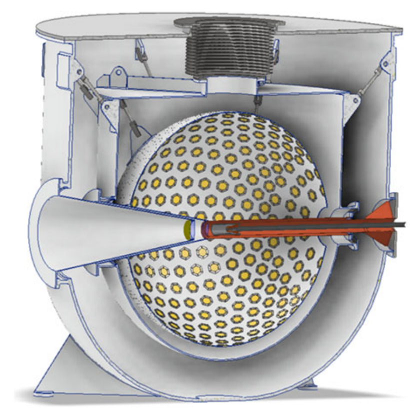


Active segmented LGAD 5D target



LXe Scintillation Calorimeter

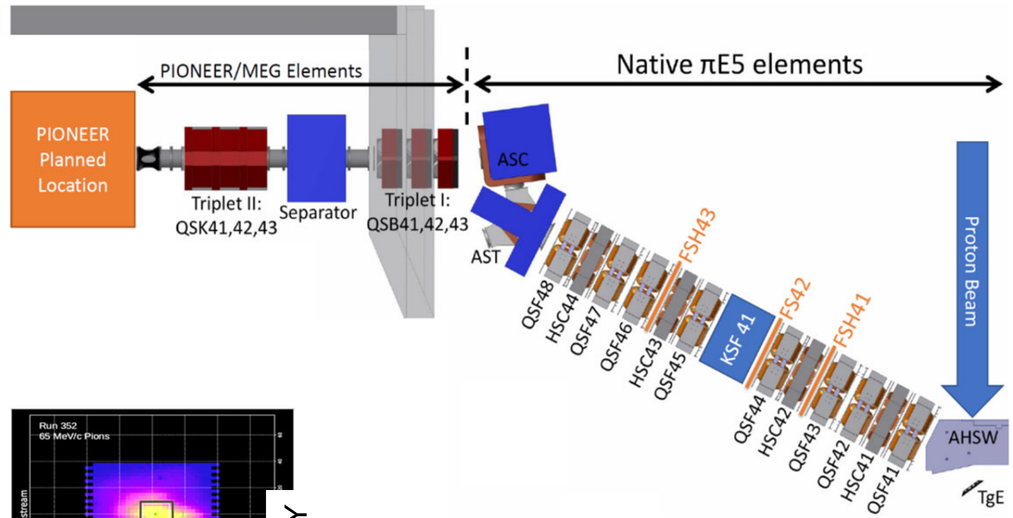
$$25\ X_0 \quad \Delta t{\sim}100\ \text{ps} \quad \frac{\sigma_E}{E}{\sim}1.5\%$$



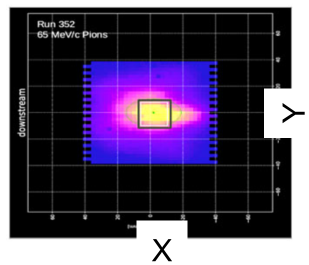
Fast DAQ, high speed digitization, etc.

Beam

- **piE5 @ PSI - World's Brightest Stopped Pion Bear**
  – Fundamental muon physics: MEG, Mu3e

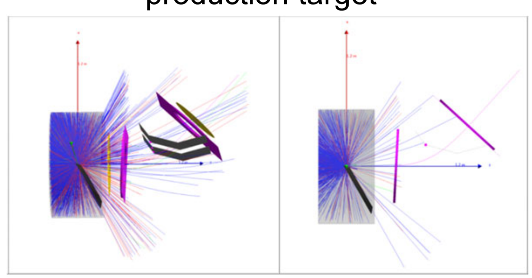


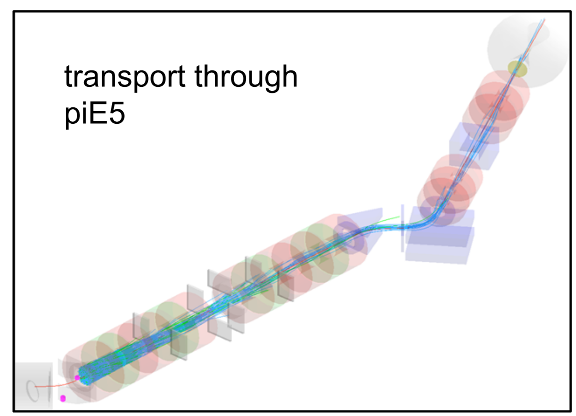
- **PIONEER requirements and test beam 2022 result**
  – **Rate: 300k π/s stopped in ATAR: ok at 65 MeV/c**
  – Momentum bite: $\Delta p/p < 2\%$: marginal
  – Spot size: <2 cm FWHM: not achieved
  – μ,e less than 10% π: needs second focus extension



- **Simulation effort and beam design**
  – non-linear effects due to large phase space
  – beam design with TRANSPORT, G4BL
  – novel promising machine learning approach

production target

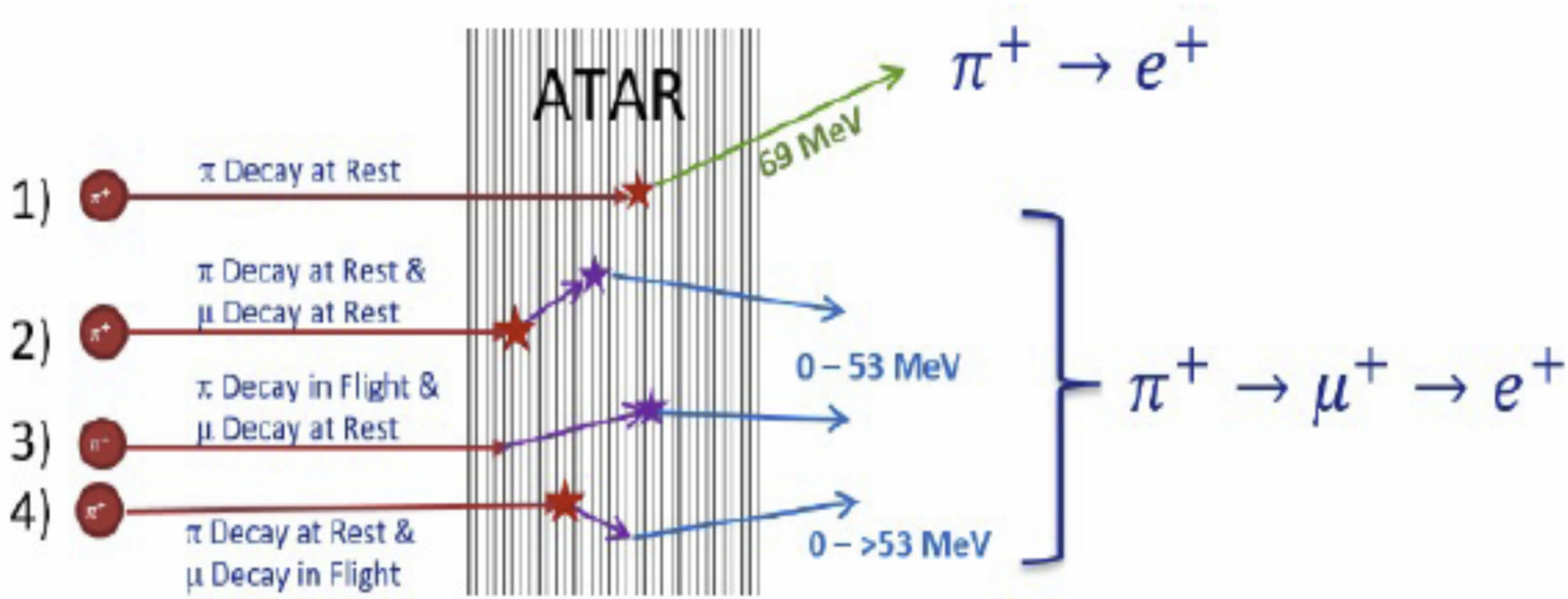




Peter Kammel

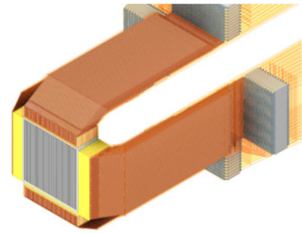
PIONEER Target (ATAR) for $\pi^+ \to e^+\nu$

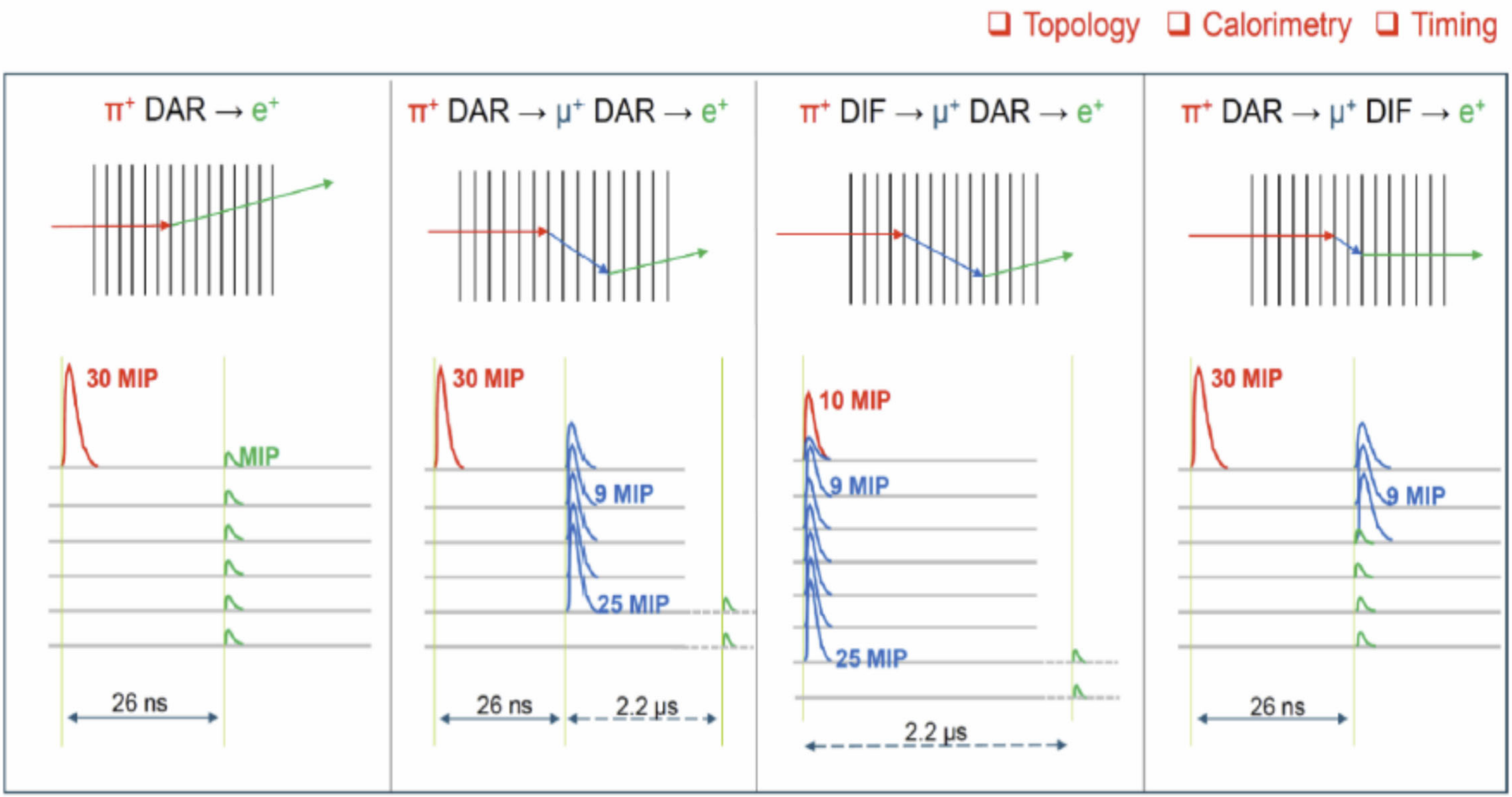
Event Topologies



4 MeV Mu stop time
Δt<12ps

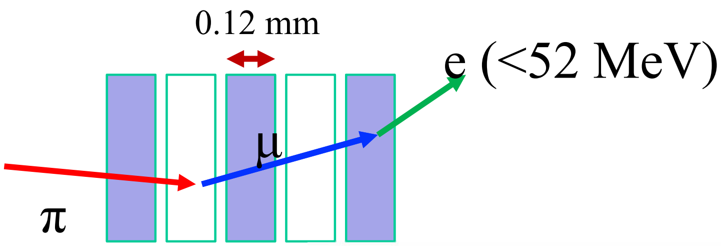
Active segmented LGAD 5D target



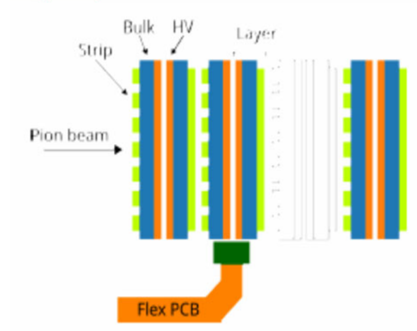


LGAD Si Strip Target

"5D" Detector (Space (3), Time, Energy)



- **Design: 48 layer Si strip target; stop pions**
  - Compact 2x2x0.6 cm block full of silicon strips
  - See all $\pi \to \mu$ decays;
  - Track $\pi \to e$ and $\pi \to \mu \to e$
- **Requirements**
  - **Longitudinal segmentation**:
    Track, stop, localize pions; *detect decays in flight*
  - **Compact, efficient**: minimal dead material
  - **Fast collection time**: separate pulses that are close in time from $\pi \to \mu \to e$ and $\pi \to e$ decays
  - **Large Dynamic range (1000)**: measure energy depositions from positrons and slow pions/muons

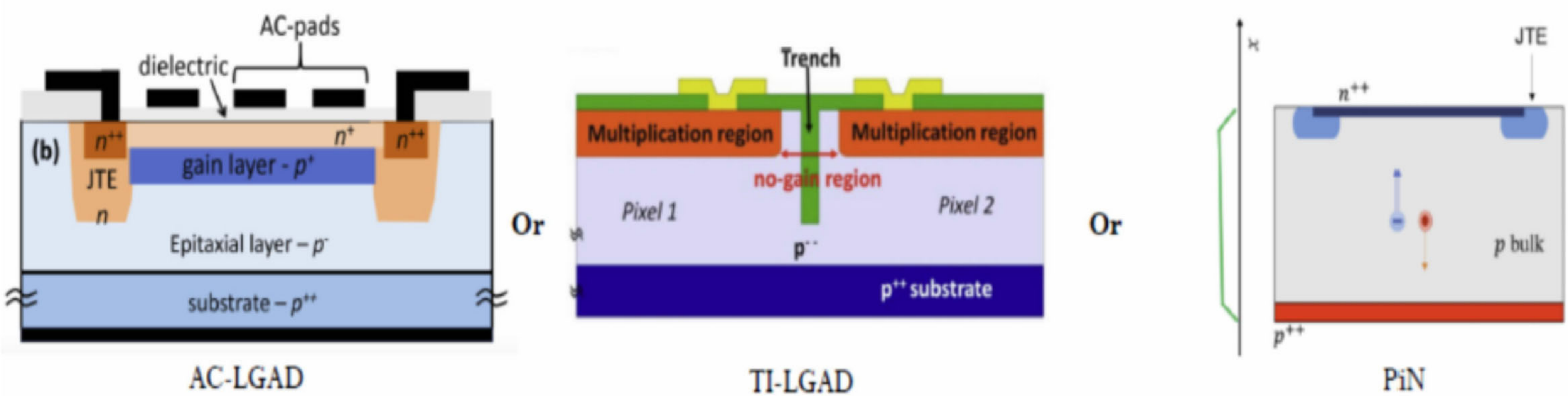


R&D in progress

ATAR Si Strip Designs and Challenges

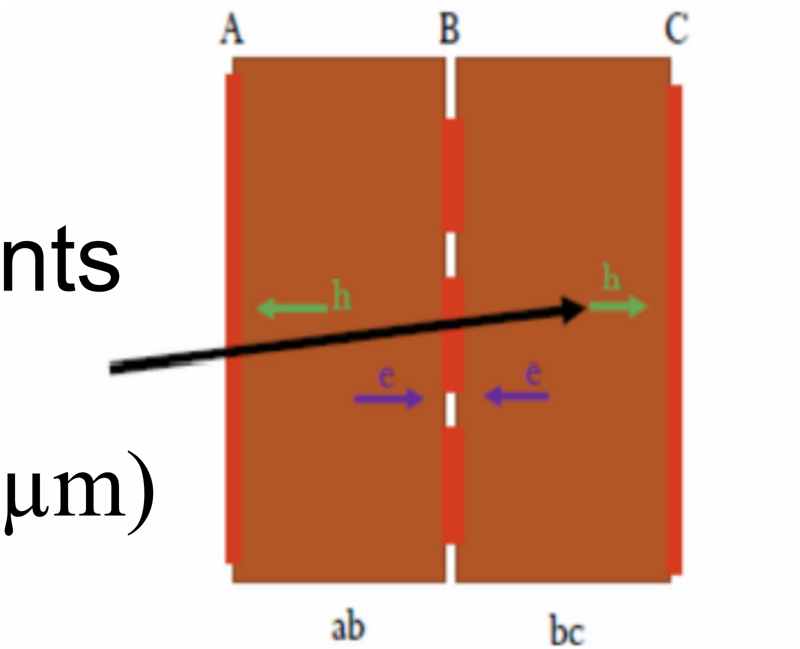
Specs: 48 layers; 120μm thick; 200μm pitch; 1000 dynamic range

- **AC LGAD**: High time resolution; minimum dead material; increased occupancy; complicated pattern recognition for π→μ→e; energy deposit saturation
- **TI LGAD:** Simple pattern recognition for π→μ→e; additional dead material; energy deposit saturation
- **PiN:** Excellent energy linearity; long time constants needed for good S/N; modest time resolution



Alternative ATAR design: Double sided strips

- LGAD or PiN type sensors
- Correlated x-y measurements
- Minimize dead material
- Minimize air gap (25μm→5μm)



BNL prototype being evaluated at UCSC (SCIPP)

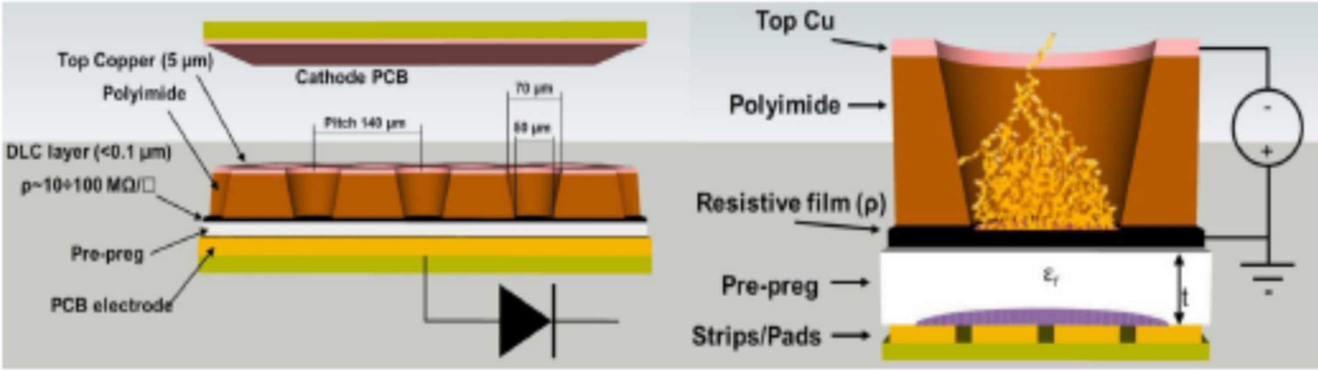
PIONEER Positron Tracker

Tracker installed between the active target and the calorimeter
→ connect the EM-shower to the pion stopping position.

- Low mass not to degrade the positron energy,
- Position resolution $\mathcal{O}(1\,\mathrm{mm})$,
- Time resolution $\mathcal{O}(1\,\mathrm{ns})$.

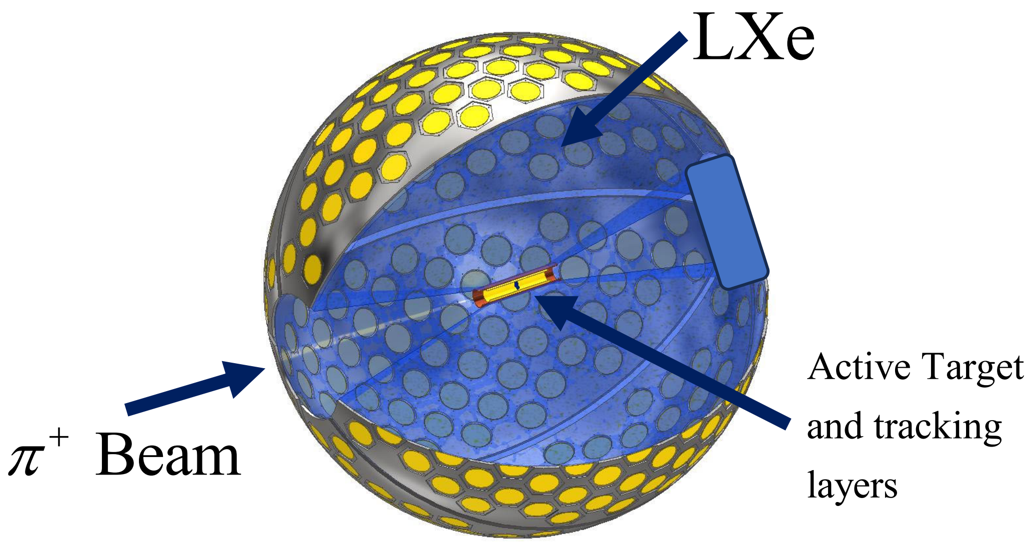
Possible options:

- μ-RWELL (a type of micro-pattern gas detector),
- HV-MAPS (High Voltage Monolithic Active Pixel Sensors),
- Silicon strips.



μ-RWELL – JINST 14 (2019) P05014

Liquid Xenon Scintillating Calorimetry



Liquid Xenon is:

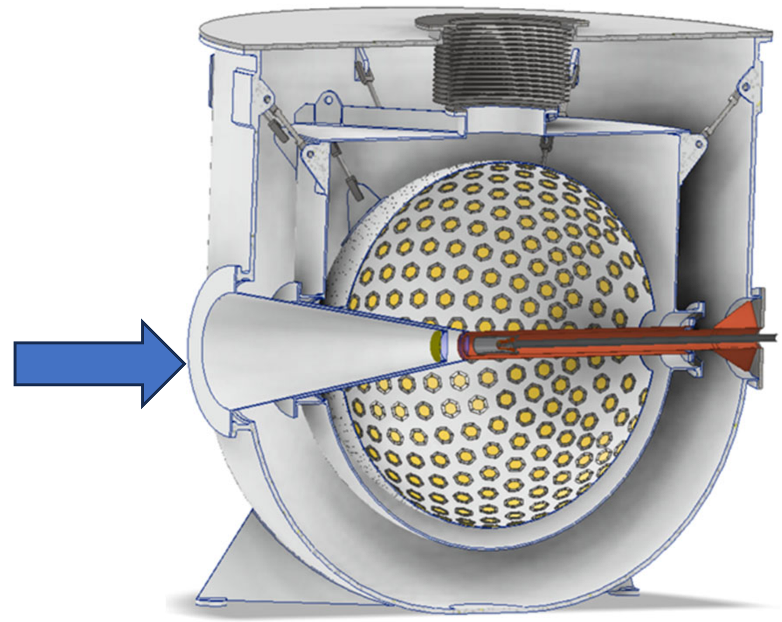
- **Bright (~60k photons/MeV) 178 nm**
- **Fast (~45 ns decay time)**
- **Dense (3.1 g/cc)**
- **Homogeneous**
- **Low intrinsic backgrounds**
- Expensive!

Goals Based on MEG at PSI :

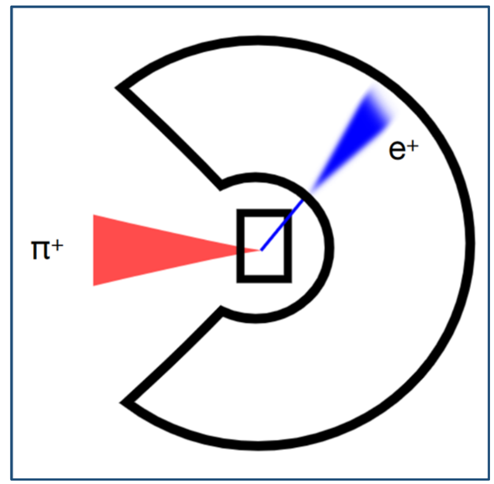
$$\Delta t \sim 100 \text{ ps} \; ; \quad \frac{\sigma_E}{E} \leq 1.5\% \, (70 \text{ MeV})$$

PIONEER LXe Calorimeter Version 0 Concept

- 7 t Fiducial LXe volume
- 1000 PMTs
- Thin inner region windows



Current concept: Forward acceptance geometry. Better acceptance; allows direct positron beam line shape measurements.



PIONEER is considering both PMTs and SiPMs

MEG II replaced entrance window PMTs with SiPMs

S. Ogawa / Nuclear Instruments and Methods in Physics Research A 845 (2017) 528–532 529

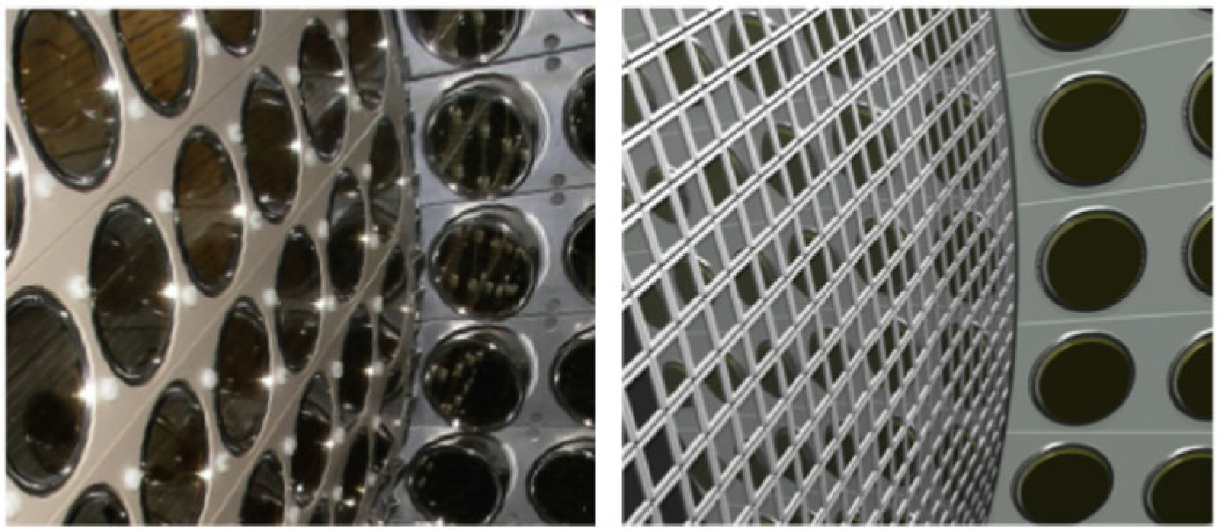


Fig. 1. γ-Ray entrance face of LXe detector. (Left) MEG experiment. (Right) MEG II experiment (CG). The uniformity and the granularity of the readout will improve with this replacement.

SiPM degradation problem in LXe.

PIONEER LXe Photosensor Possibilities

VUV light collection in LXe

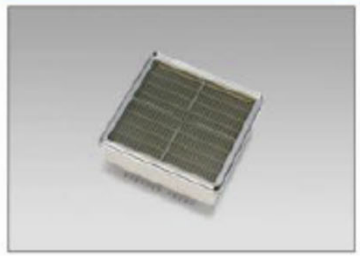
- VUV sensitive SiPMs
- Cryogenic PMTs with fused silica windows
- Other options:
  - WLS (TPB others) deposited on PMT/SiPM
  - WLS coated on reflective detector wall
  - other (light guide etc)

HAMAMATSU
PHOTON IS OUR BUSINESS

FLAT PANEL TYPE
MULTIANODE PHOTOMULTIPLIER TUBE
R12699-406-M4

FEATURES
- For low temperature operation down to -110 °C
- Large effective area: 48.5 mm x 48.5 mm
- 2 × 2 multianode, pixel size: 24.25 mm × 24.25 mm / anode
- High UV sensitivity
- Low profile
- Low radioactivity

APPLICATIONS
- Academic research (Dark matter detection)
- Nuclear medicine equipment (PET)



https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/etd/R12699-406-M4_TPMH1368E.pdf

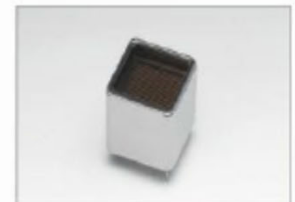
Developed for PandaX : fast, QE=33%
$k8/tube!

HAMAMATSU
PHOTON IS OUR BUSINESS

PHOTOMULTIPLIER TUBE
R8520-406/R8520-506

FEATURES
- For low temperature operation
  down to -110 °C: R8520-406
  down to -186 °C: R8520-506
- Low radioactivity 26 mm (1 inch) square
- High UV sensitivity by synthetic silica window

APPLICATIONS
- High energy physics
- Astrophysics
- Academic research

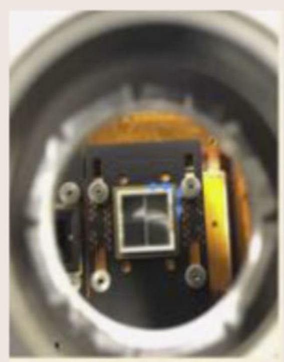


https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/etd/R8520-406_TPMH1342E.pdf

1 inch, fast, QE=30%

VuV SiPM : HPK / FBK

HPK VUV4-Q-50
Quad device
50um pitch

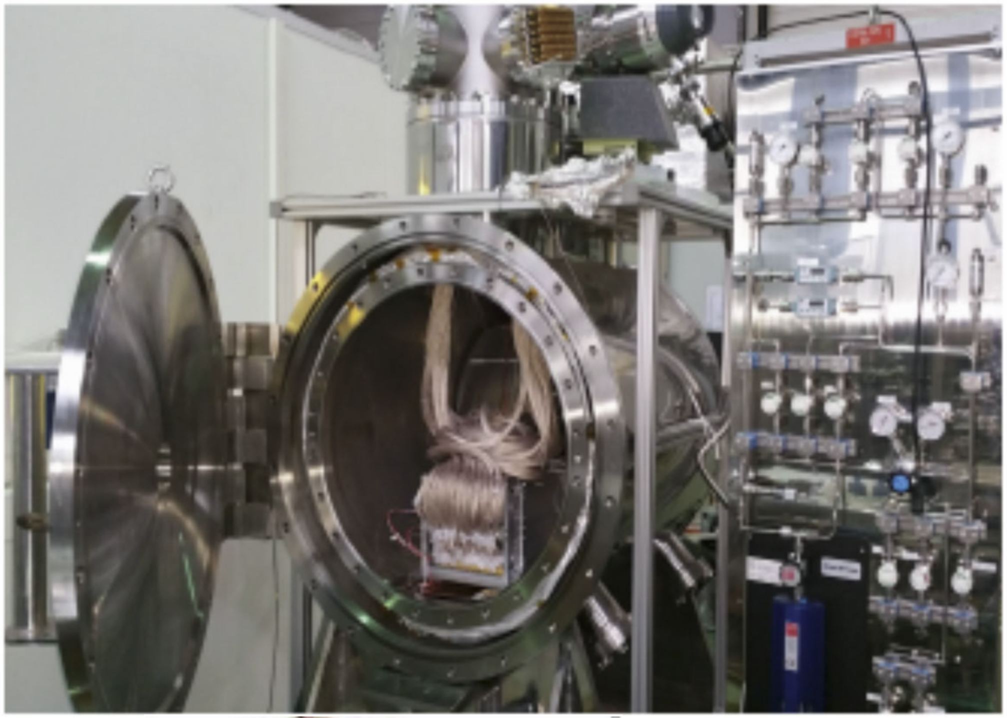


FBK VUVHD3

BEING CONCOMITANTLY TESTED in LOLX

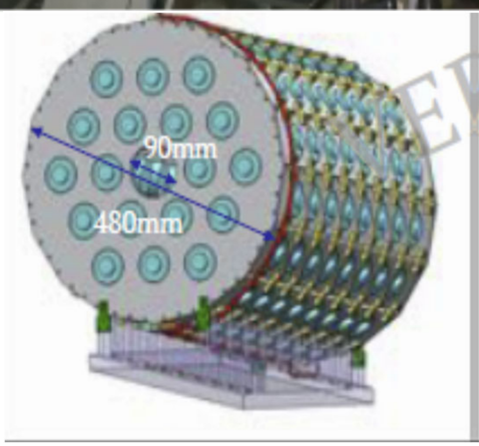
C. Malbrunot

100 L LXe Prototype (25 X0) under development

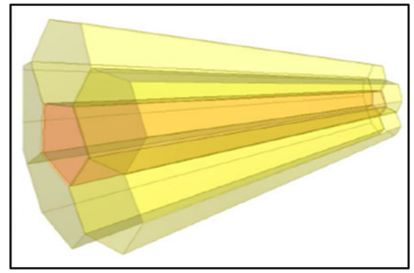


Objectives:

- Validate simulations
- Positron response at 70 MeV/c
- Measure lineshape
- Test thin windows
- Test optical coatings
- Investigate Cerenkov radiation
- Do some physics?



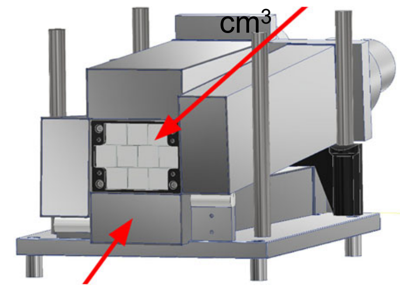
CALO R&D: LYSO option being investigated vigorously.



- LXe vs. LYSO Crystal

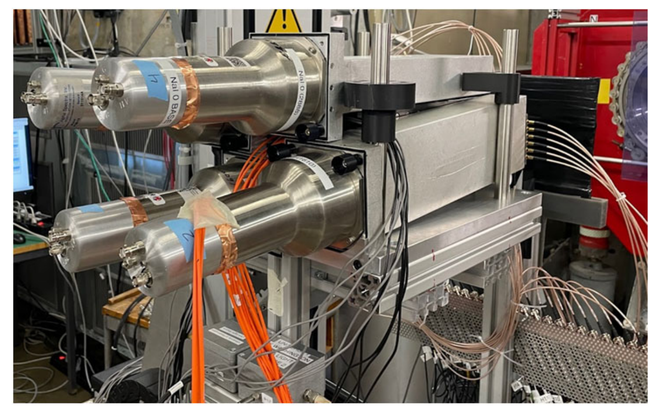
Detector	Density g/cm^3	dE/dx MeV/cm	X_0 cm	R_M cm	Decay time ns	λ_{max} nm	Light output %
LXe	2.953	3.707	2.872	5.224	3, 27, 45	178	100
LSO(Ce)	7.40	9.6	1.14	2.07	40	402	85

- LYSO R&D (New SICCAS Crystals)
  - scan 10 crystal array with e-beam
  - demonstrate resolution
  - measure backscattering albedo



Property	LXe	LYSO
Resolution	1.5%	4% !
Segmentation	R&D	natural
Photosensors	VUV	standard
Experience	MEG	mainly small Xtal for PET

- Recent Test run at PSI gives promising results.



Some experience with Mu2E/COMET LYSO arrays (not good enough for PIONEER).

Peter Kammel

Special Minneapolis Diversion:

Possible New Physics Search with the PIONEER Calorimeter Prototype

New physics in multi-electron muon decays

Matheus Hostert,[a,b,c] Tony Menzo,[d] Maxim Pospelov,[b,c] Jure Zupan,[d]

Muon decay to on-shell dark Higgs h_d

$$\mu^+ \to e^+ h_d ; h_d \to \gamma_d \gamma_d \to 2(e^+ e^-)$$

$$\mu^+ \to e^+ e^+ e^- e^+ e^-$$

$$\mathrm{Br}(\mu \to 5e) \sim 10^{-12} \Longleftrightarrow \text{Mass scale } \Lambda \sim 10^{15}\,GeV$$

$$\text{Current limit: } \mathrm{Br}(\mu \to 5e) < 4\mathrm{x}10^{-6}$$

Hostert,et al. arXiv:2306.15631v1 [hep-ph] 27 Jun 2023

Muon decay: total EM energy Measurement

Poutissou et al., Nuclear Physics B80 (1974) 221

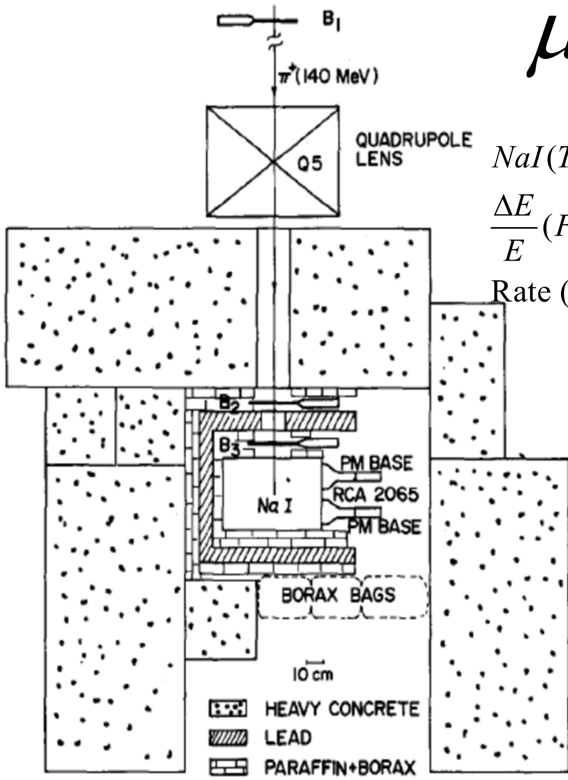


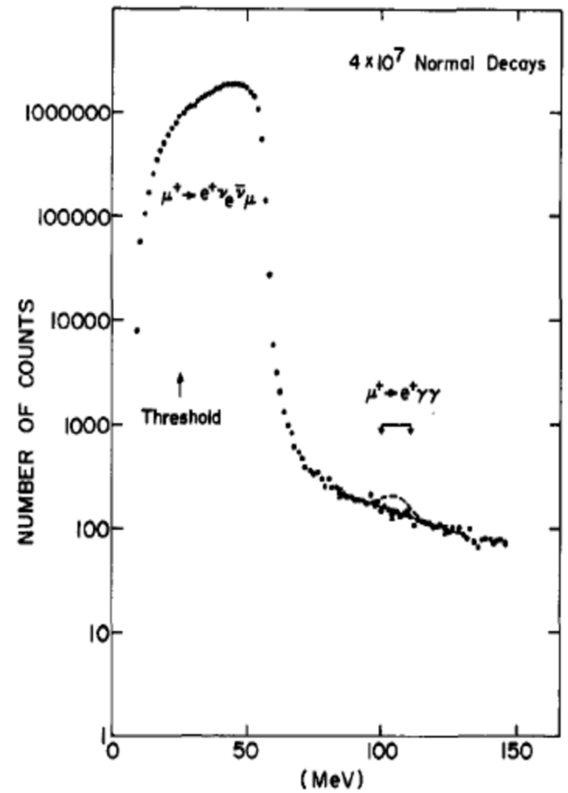
Fig. 1. Experimental set-up.

$\mu \to e\gamma\gamma$

$NaI(Tl)$ 40.6 cm dia. x 61 cm long

$\frac{\Delta E}{E}(FWHM) \sim 5\% \Rightarrow 10\%$

Rate (inst.) ~(1700/s)/0.3~5KHz



$4x10^7$ μ; $20\,hrs.$ (30% efficiency)

Current limit: Br($\mu \to$ 5e)<$4x10^{-6}$

Adrian Signer (PSI) private comm. To DB Sept. 14, 2023

New Calculation of the intrinsic background: $<10^{-12}$ to 10^{-11}

Integrated $B_{10}(\mu \rightarrow e\nu\nu\gamma)$ vs. E_{miss} for $E_\gamma < 10 MeV$.

$$E_{miss} = m_\mu - E_e - E_\gamma$$

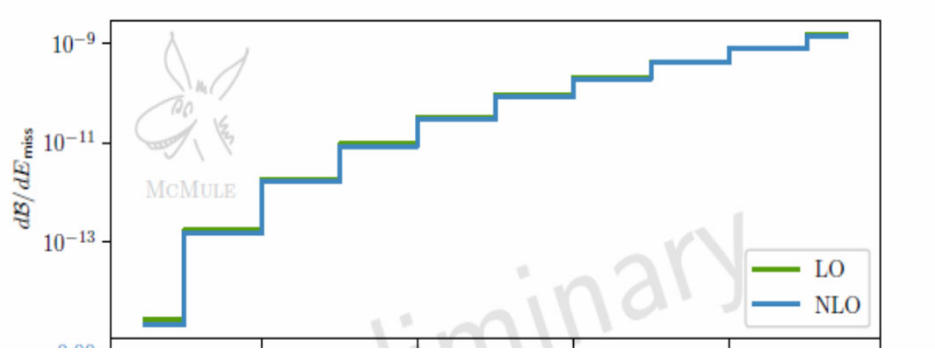


Figure 2: Differential branching ratio w.r.t. E_{miss} up to 10 MeV.

$\mathcal{B}_{10}^{\text{incl}}(E_{\text{miss}} < E_{\text{max}})$ integrated up to E_{max}

E_{max}	$\mathcal{B}_{10}^{\text{incl}}\vert_{\text{LO}}$	$\mathcal{B}_{10}^{\text{incl}}\vert_{\text{NLO}}$
1 MeV	$2.72(2) \cdot 10^{-15}$	$2.23(3) \cdot 10^{-15}$
2 MeV	$1.76(1) \cdot 10^{-13}$	$1.54(3) \cdot 10^{-13}$
3 MeV	$2.03(1) \cdot 10^{-12}$	$1.83(2) \cdot 10^{-12}$
4 MeV	$1.160 \cdot 10^{-11}$	$1.06(1) \cdot 10^{-11}$
5 MeV	$4.488 \cdot 10^{-11}$	$4.12(1) \cdot 10^{-11}$
6 MeV	$1.360 \cdot 10^{-10}$	$1.26(1) \cdot 10^{-10}$
7 MeV	$3.484 \cdot 10^{-10}$	$3.23(1) \cdot 10^{-10}$
8 MeV	$7.888 \cdot 10^{-10}$	$7.35(1) \cdot 10^{-10}$
9 MeV	$1.626 \cdot 10^{-9}$	$1.52(1) \cdot 10^{-9}$
10 MeV	$3.111 \cdot 10^{-9}$	$2.91(1) \cdot 10^{-9}$

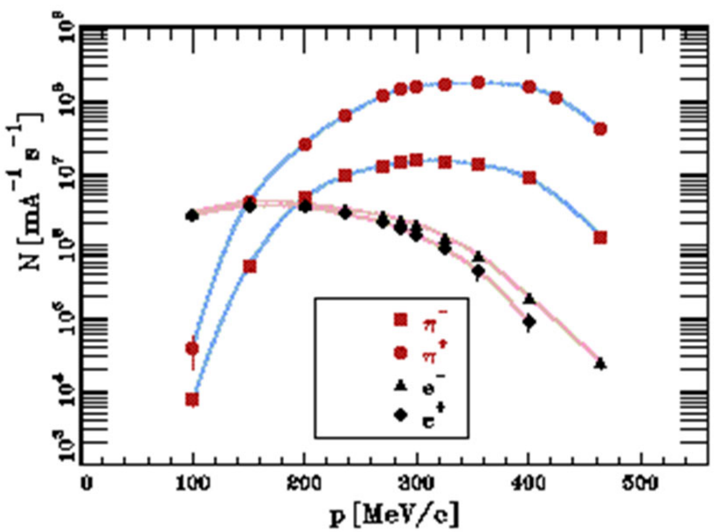
Experiment more likely to be limited by random pile-up effects.

PIONEER LXe Calo Prototype for $\mu \rightarrow 5e$?

Rough Estimate:

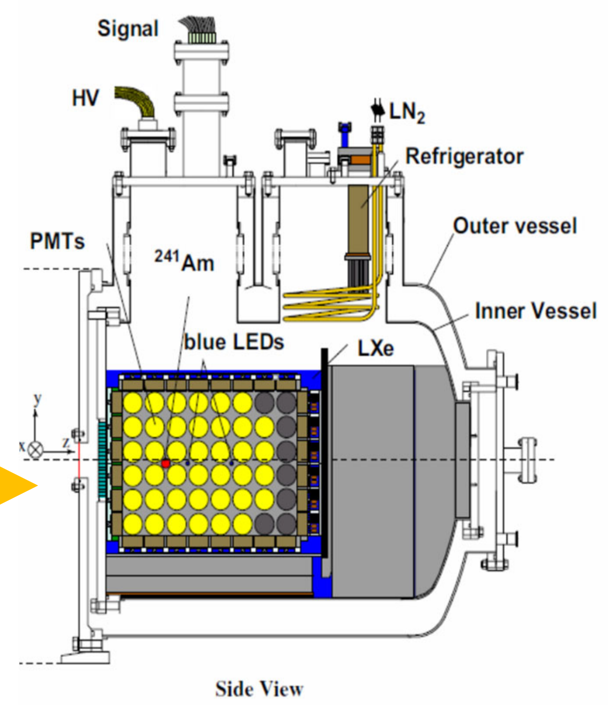
The PIONEER LXe prototype might be able to reach $\sim O(10^{-10})$ in a 10 day run at PSI πM1 beam.

$\pi M1$ Fluxes



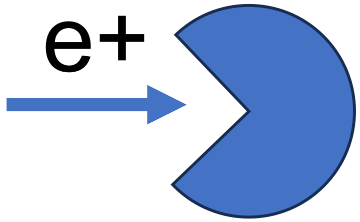
$\pi M1$: 300 MeV/c μ^+

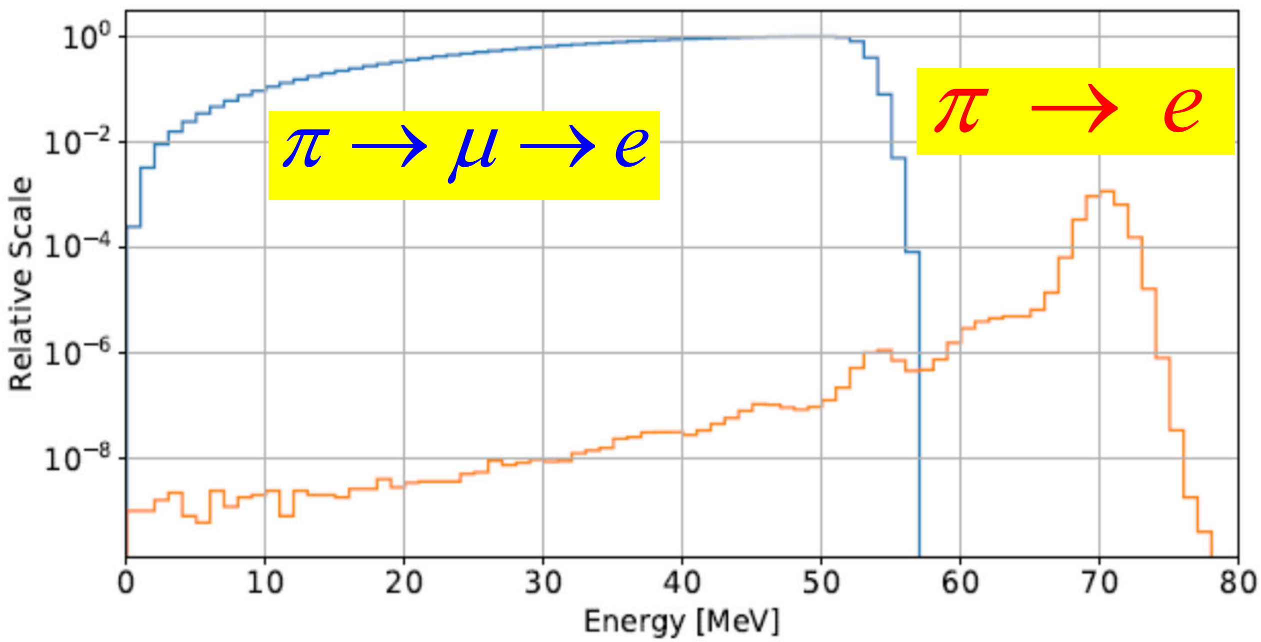
$50 kHz$



PIONEER Energy Spectra & $\pi \to e\nu$ Lineshape

PIONEER will make direct measurements of the calorimeter lineshape and "tail" with e+ beams; then use simulations to obtain $\pi \to e\nu(\gamma)$ response.





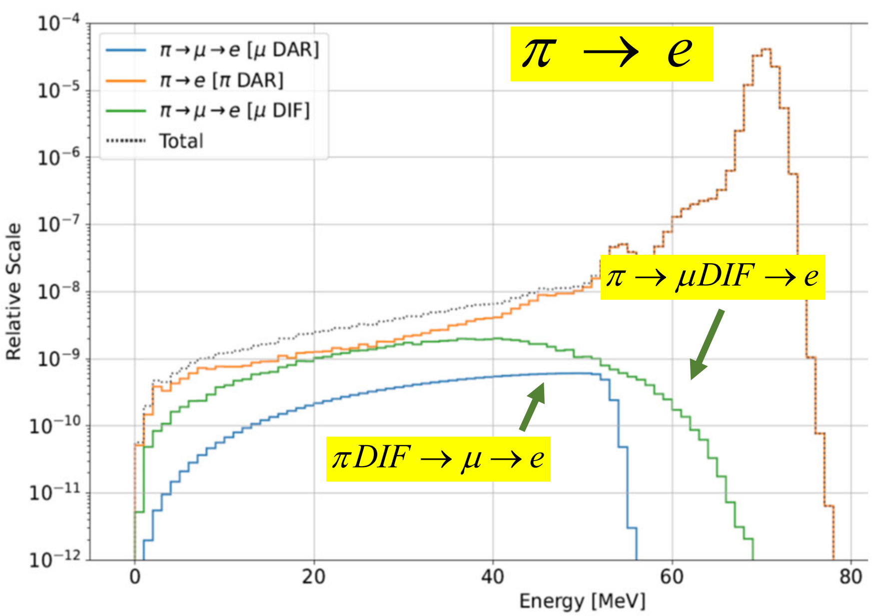
The $\pi \to e\nu$ lineshape and low energy tail correction will also be measured in situ using ATAR suppression of backgrounds:

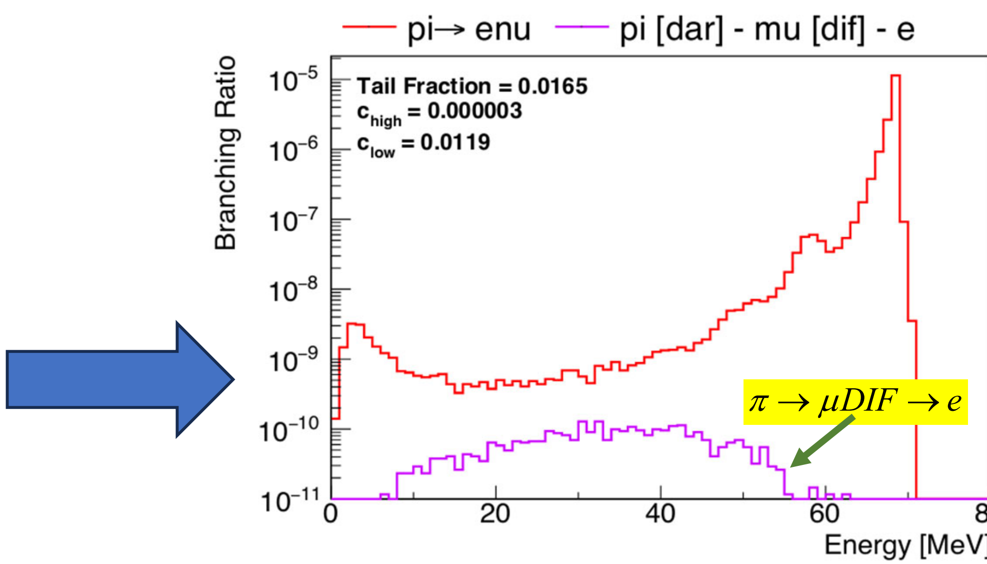
1) $\pi \to \mu$ decay at rest (πDAR),

2) $\pi \to \mu$ decay in flight (μDIF)

3) $\pi_{DAR} \to \mu_{DIF} \to$ e.

Initial simulations:





- ΔE in first μ strip
- π z-position with dE/dx

$\pi \rightarrow e\nu$: Estimated Uncertainties

To be verified by simulations and prototype measurements.

Error budget goals: $\sigma_{stat} = \sigma_{sys} = 0.7 \times 10^{-4}$

$2\text{x}10^8$ $\pi \rightarrow e\nu$ events (3 years)

Error Source	PIENU 2015 %	PIONEER Estimate %	
Statistics	0.19	0.007	
Tail Correction	0.12	<0.01	(Calorimeter/ATAR)
t_0 Correction	0.05	<0.01	*(ATAR timing/dE/dx)*
Muon DIF	0.05	0.005	*(ATAR)*
Parameter Fitting	0.05	<0.01	(Calorimeter/ATAR)
Selection Cuts	0.04	<0.01	(Calorimeter/ATAR)
Acceptance Correction	0.03	0.003	(Calorimeter)
Total Uncertainty*	**0.24**	$\leq$ **0.01**	

* Pion lifetime uncertainty not included

$\pi^+ \rightarrow \pi^0 e^+ \nu$: Estimated Uncertainties

	PiBeta	**PIONEER (Phase II;III)**
Statistics	0.4%	0.1%, 0.03%%
Systematics	0.4%	<0.1% (ATAR (β), MC, Photonuclear, π→ev)
Total	0.64%	**0.2%, 0.05%**

Conclusions: Testing Lepton Flavor Universality with Pions

- **Rare π, μ and K decays have unique and important roles to play in the search for new physics involving exotic effects like *Flavor Universality and Lepton Flavor Violation* --- especially sensitivity to very high mass scales.**

- **π/K/B results expected from PIENU, PEN, NA62, and LHCb, BESSIII, BELLE-II…. Important connections with searches for sterile neutrinos/dark sector particles , high mass scale physics, and L(F/N)V tests.**

- **Next generation pion decay experiment PIONEER aims at order of magnitude improvements in high precision for measurements of π →eν and pion beta decay to provide unique new information on Lepton Flavor Universality and CKM unitarity.**

PIONEER Collaboration

[1] University of California Santa Cruz
[2] University of Washington
[3] University of Chicago
[4] University of British Columbia
[5] TRIUMF
[6] Paul Scherrer Institute
[7] Tsinghua University, China
[8] Inst. for Nucl. Theory, University of Washington
[9] Argonne National Laboratory
[10] University of Zurich
[11] CERN
[12] Tec de Monterrey, Mexico
[13]. BNL
[14] University of Mainz
[15] Fermilab
[16] Cornell University
[17] University of Virginia
[18] ETH Zurich
[19] University of Kentucky
[20] University of Bern
[21] KEK
[22] University of Tokyo
[24] Stony Brook University
[25] University of Vitoria