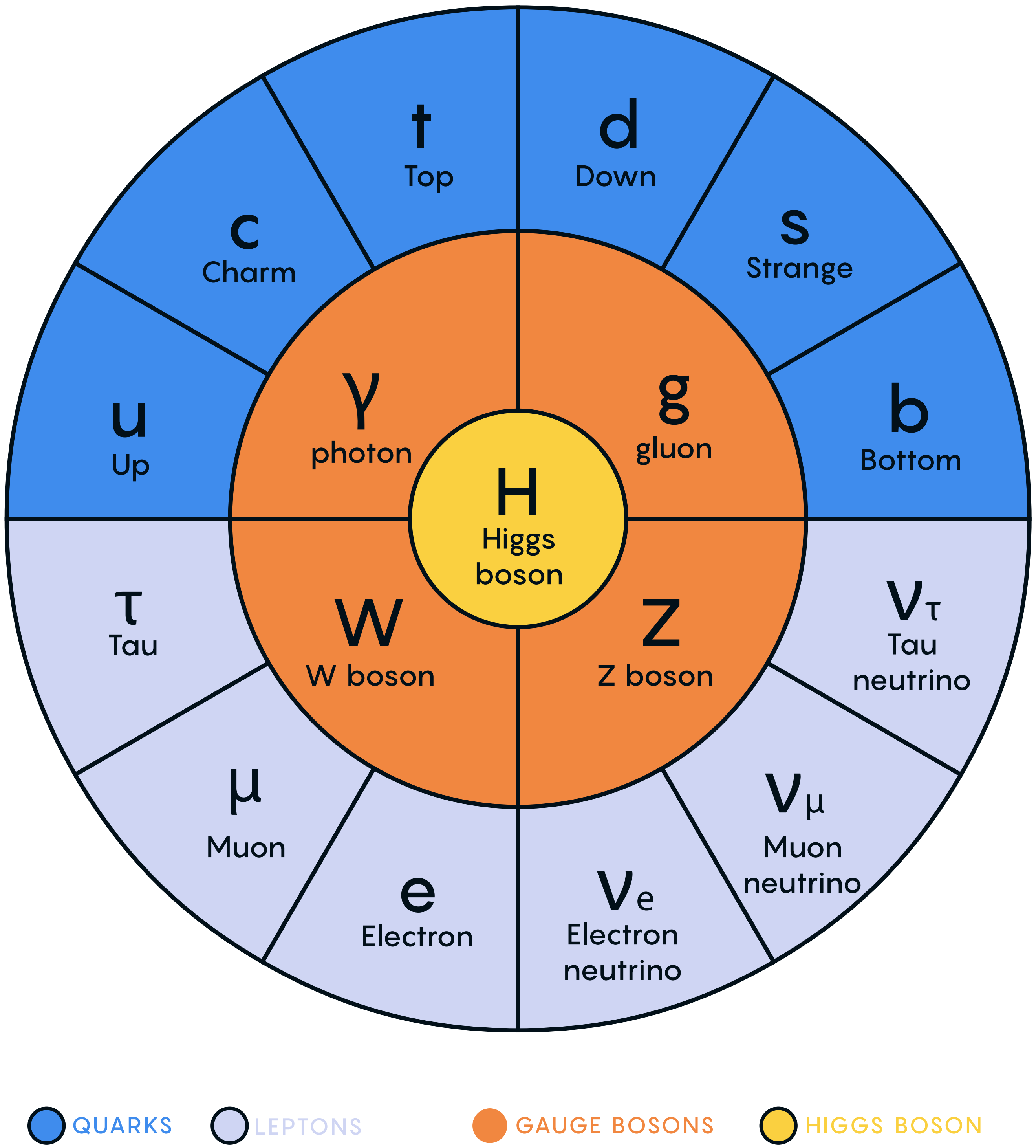
PIONEER

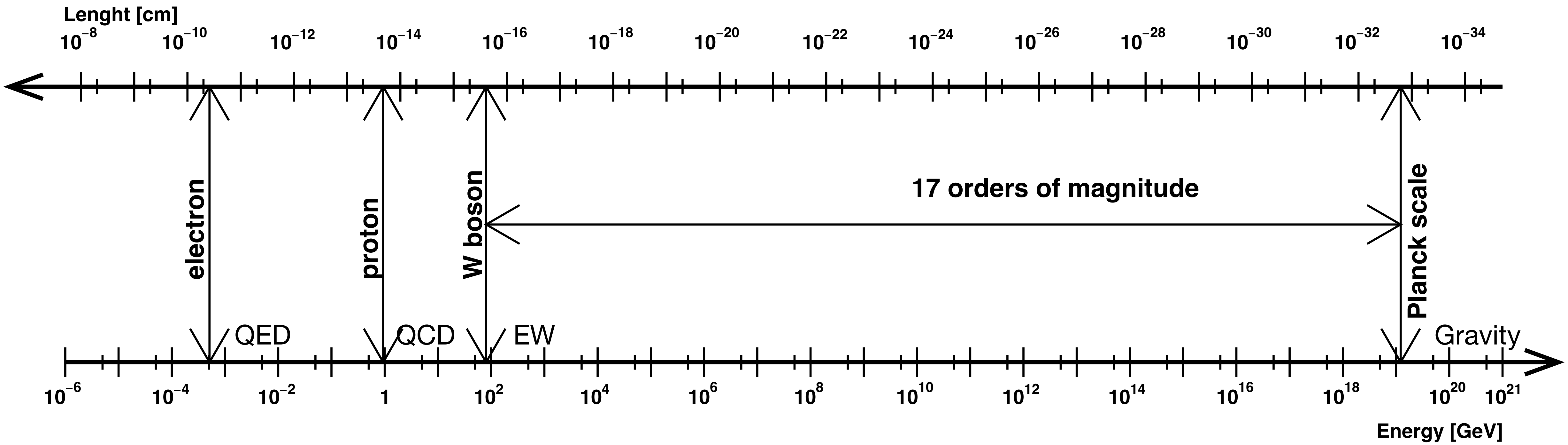
A next generation rare pion decay experiment

Quentin Buat (University of Washington) — April 21, 2026

The SM of Particle Physics



Fundamental interactions



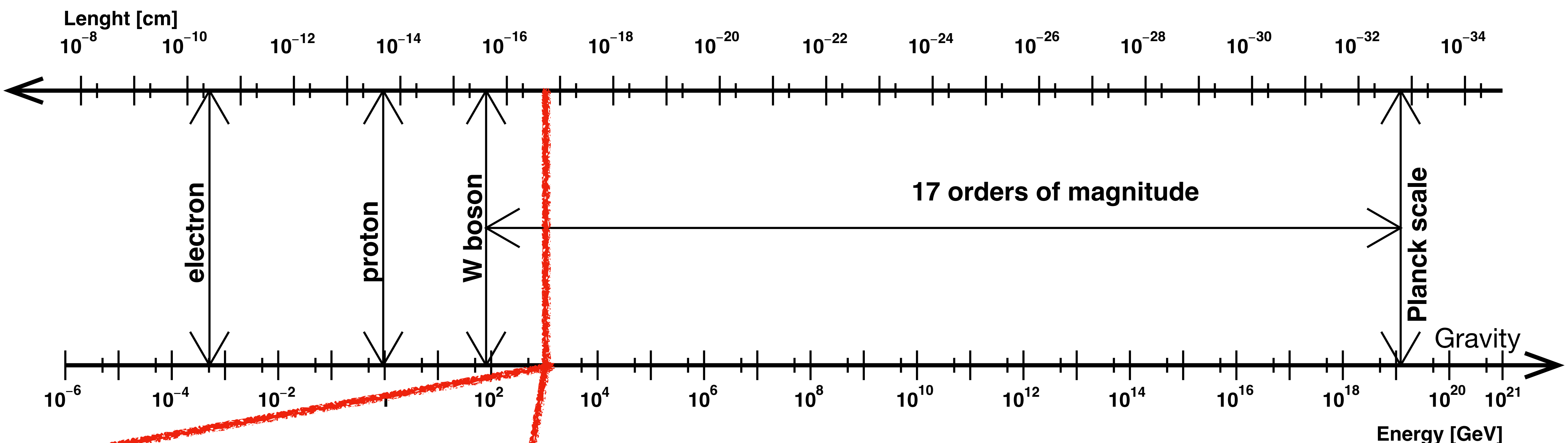
Known forces in Nature and their associated energy scale

Explore the gap between EW and Gravity scales

Look for feeble interactions below the EW scale

The direct approach

Collide particles at the highest possible energy

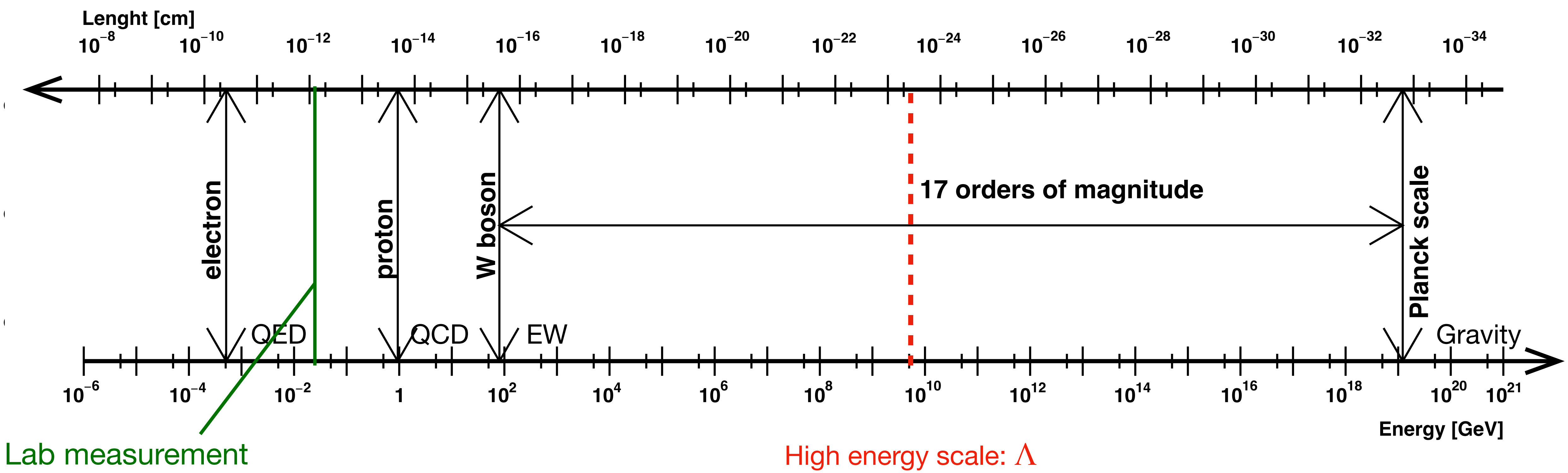


Discovered the Higgs boson and deploy a comprehensive measurement program to understand the EWSB mechanism

However, no sign of deviations from the SM and no large collision energy increase foreseen anytime soon

The indirect approach

Consider "well-defined" SM quantities and measure them very precisely



The **lab measurement** can be impacted by
high energy scale physics through quantum effects

Precision measurements require large datasets:
opportunity to discover feeble interactions

This is PIONEER's approach

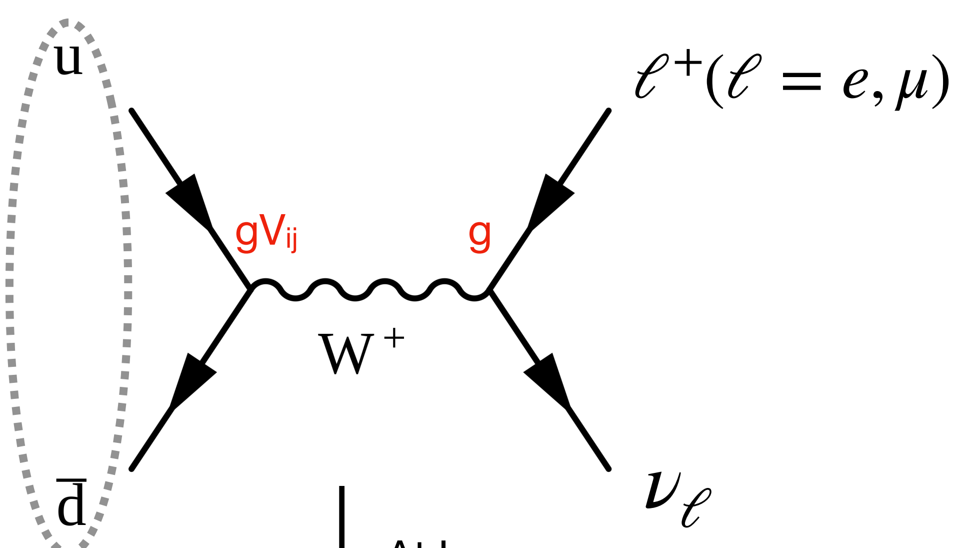
PIONEER

Tests of the weak interaction in rare pion decays

Charged currents in the SM are mediated by the exchange of a W boson between **left-handed fermions** and **right-handed anti-fermions**

The coupling (g) is the same for all fermions

Charged pion (quark model)



At low energy

$$G_F^{(\beta)} \sim \frac{\mathrm{g}^2}{\mathrm{M}_\mathrm{W}^2} \times V_{ij}$$

Lepton Flavour Universality

$$\left[G_F^{(\beta)}\right]_e / \left[G_F^{(\beta)}\right]_\mu = 1$$

Cabbibo Universality

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

PIONEER will test both!

Weak (β) Decay

PIONEER

Tests of the weak interaction in rare pion decays

Outline

Part I: Lepton Flavor Universality Test

Part II: Detector Prototyping

Part III: Quark-mixing measurement and exotic decays

Lepton Flavour Universality

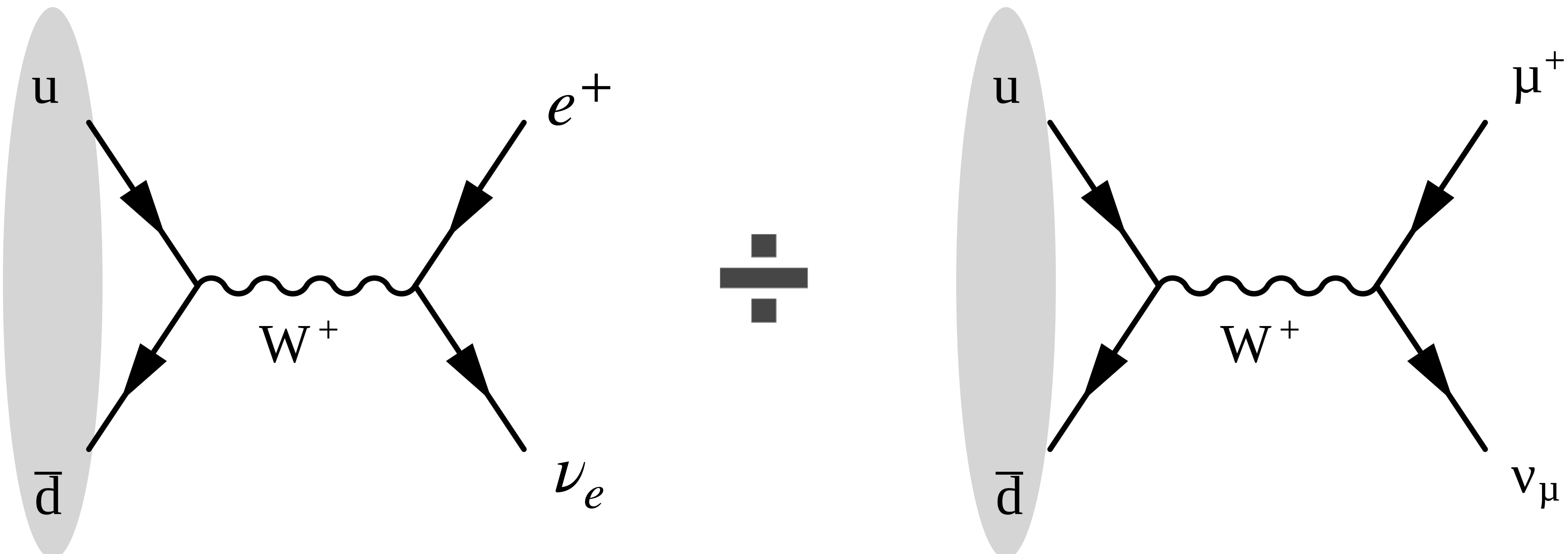
$$\left[G_F^{(\beta)}\right]_e / \left[G_F^{(\beta)}\right]_\mu = 1$$

Cabbibo Universality

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Rare Pion Decays

Lepton Flavour Universality



$$R_{e/\mu} = \Gamma(\pi \to e\nu(\gamma)) \div \Gamma(\pi \to \mu\nu(\gamma))$$

$$R_{e/\mu} = \frac{m_e^2}{m_\mu^2} \times \left(\frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2}\right)^2 \times \left[1 + \text{EW corrections}\right] = 1.23524(015) \times 10^{-4}$$

'Helicity suppression' term: ~2.3 x10^{-5}

Phase space term: ~ 5.5

Fully computed at NLO
O(10^{-4}) uncertainties at NNLO

Rare Pion Decays

History

$$R_{e/\mu} = \Gamma(\pi \to e\nu(\gamma)) \div \Gamma(\pi \to \mu\nu(\gamma))$$

Current prediction of the Standard Model: $R_{e/\mu} = 1.23524(015) \times 10^{-4}$

Lokanathan and Steinberger Experiment (1955):
Range telescope at Columbia Nevis cyclotron: $R_{e/\mu} < 1.2 \times 10^{-4}$ (90% CL)

Anderson and Lattes Experiment (1957):
Magnetic spectrometer at Chicago cyclotron: $R_{e/\mu} < 1.3 \times 10^{-5}$ (90% CL)

The $\pi \to e\nu$ branching ratio is so small that for a while the process was excluded

~1 out of every 10^4 pions decay to an electron

Rare Pion Decays

History

Causing a lot of confusion…

Theory of the Fermi Interaction

R. P. Feynman and M. Gell-Mann
California Institute of Technology, Pasadena, California
(Received September 16, 1957)

PR 109, 193 (1958)

In any event one would expect a decay into $e+\bar{\nu}$ also. The ratio of the rates of the two processes can be calculated without knowledge of the character of the closed loops. It is $(m_e/m_\mu)^2(1-m_\mu{}^2/m_\pi{}^2)^{-2}=13.6\times10^{-5}$. Experimentally[16] no $\pi\rightarrow e+\nu$ have been found, indicating that the ratio is less than 10^{-5}. This is a very serious discrepancy. The authors have no idea on how it can be resolved.

$$R_{e/\mu} = \frac{m_e^2}{m_\mu^2} \times \left(\frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2}\right)^2 \times \left[1 + \text{EW corrections}\right] = 1.23524(015) \times 10^{-4}$$

Rare Pion Decays

History

$$R_{e/\mu} = \frac{\Gamma(\pi \rightarrow e\nu(\gamma))}{\Gamma(\pi \rightarrow \mu\nu(\gamma))}$$

DISCOVERY!

At a small lab that opened 4 years prior on the outskirts of Geneva, Switzerland

CERN circa 1958

ELECTRON DECAY OF THE PION

T. Fazzini, G. Fidecaro, A. W. Merrison, H. Paul, and A. V. Tollestrup*
CERN, Geneva, Switzerland
(Received September 12, 1958)

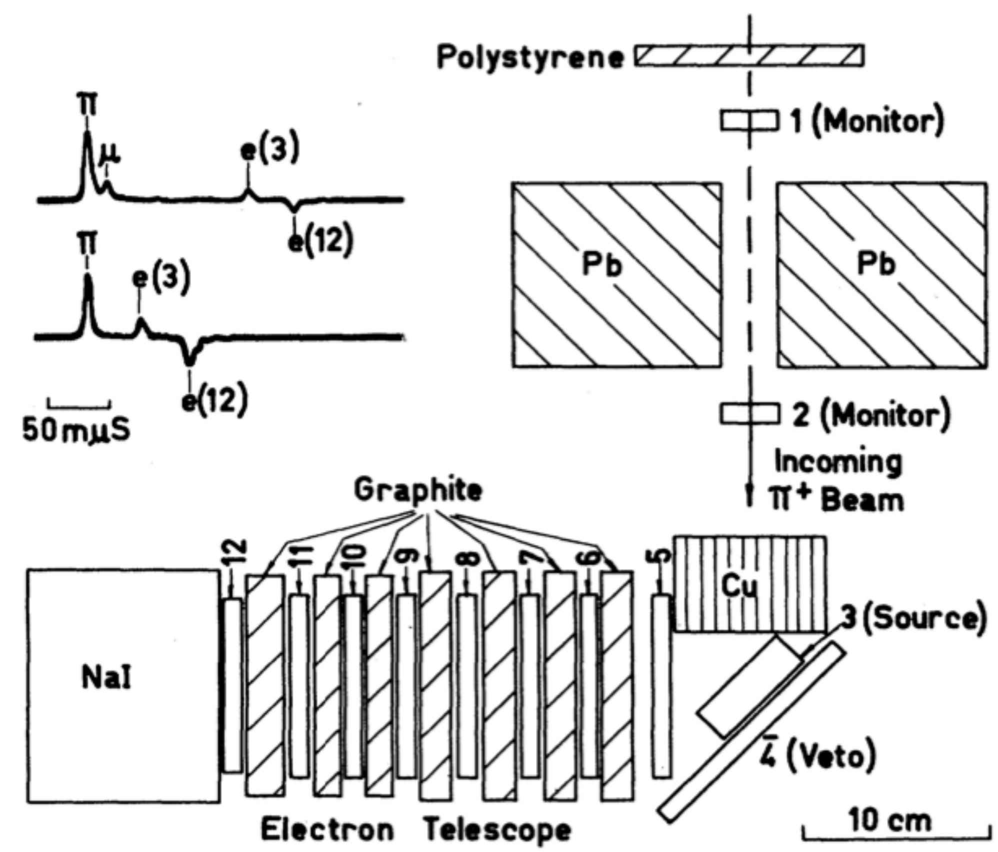
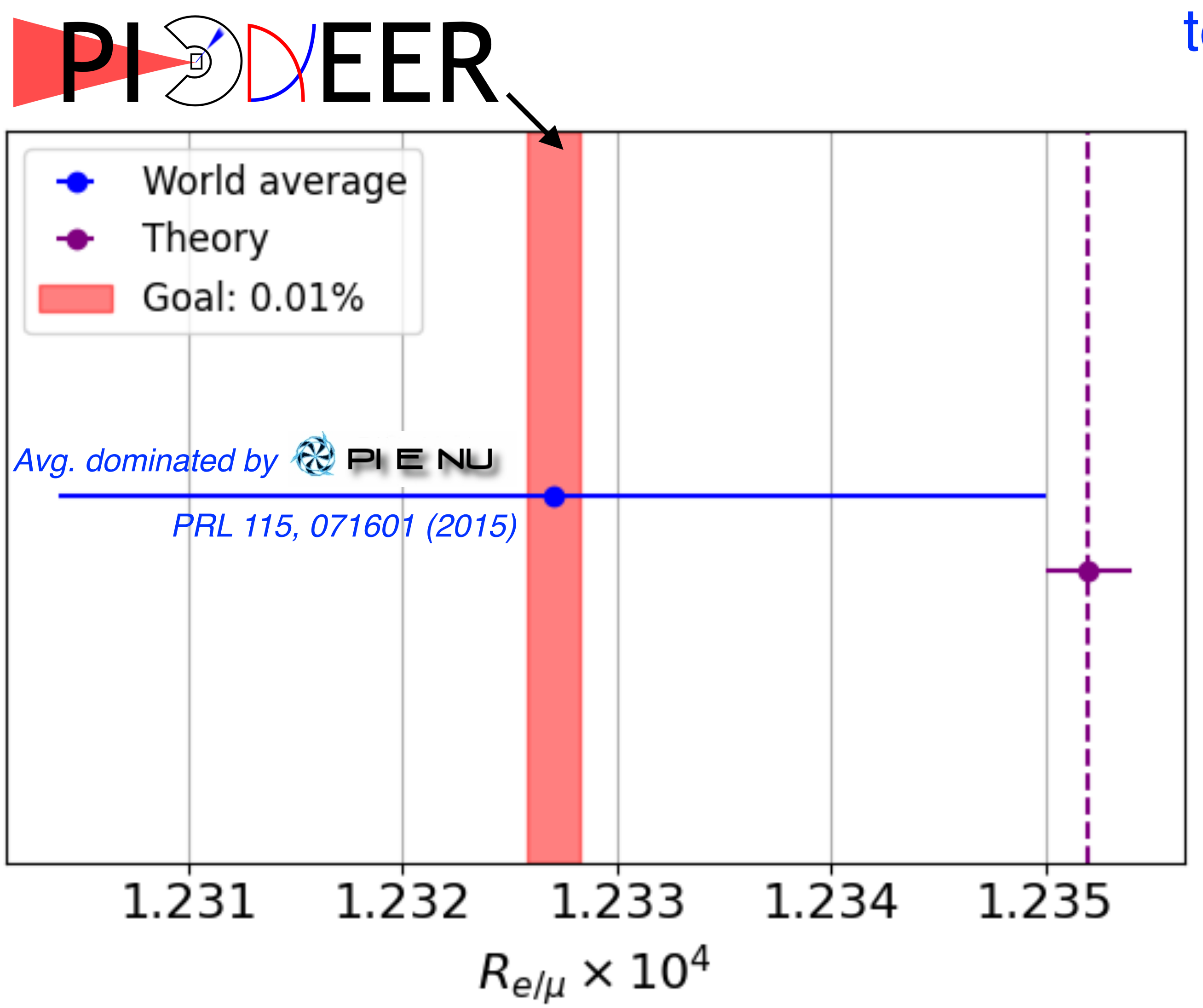


FIG. 1. Experimental layout, and (inset) typical π-μ-e and π-e pulse.

~ 40 $\pi \rightarrow e\nu$ events

Rare Pion Decays

Current state of the art



Best measurement from PIENU at TRIUMF tested Lepton Flavour Universality at $O\left(10^{-3}\right)$

$$R_{e/\mu}[\text{Exp.}] = 1.23270(230) \times 10^{-4}$$
$$R_{e/\mu}[\text{SM}] = 1.23524(015) \times 10^{-4}$$

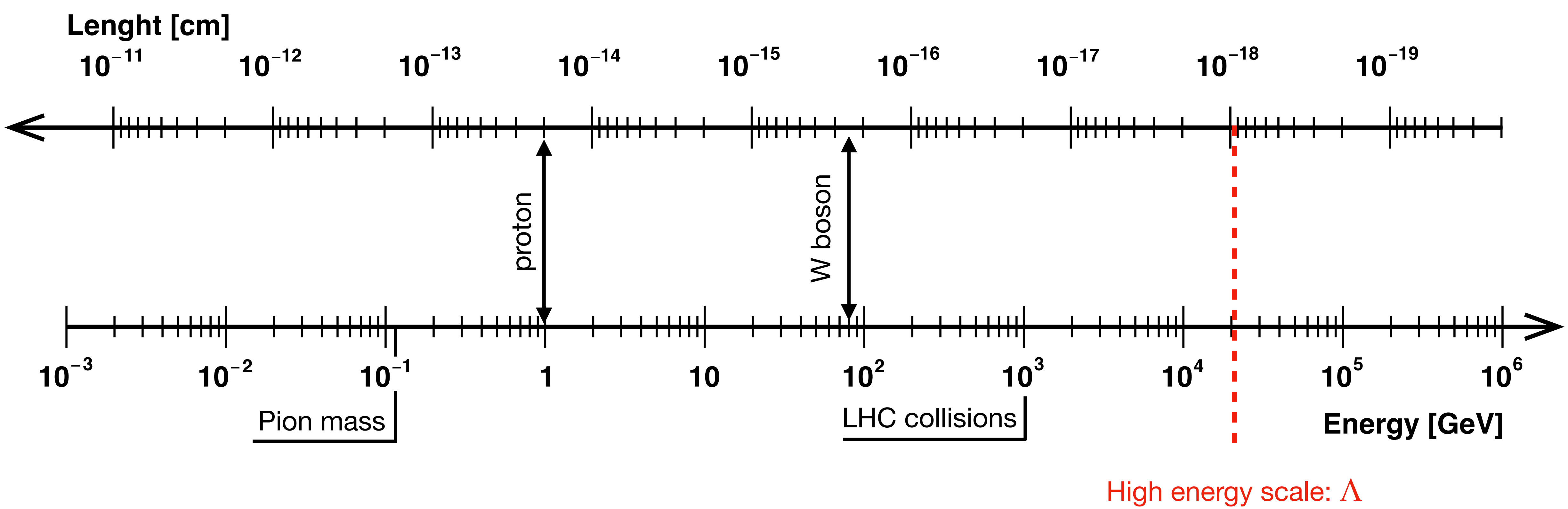
To match the precision of the SM prediction:

- ➡ PIONEER aims to measure $R_{e/\mu}$ to 0.01% precision
- ➡ 15-fold improvement over the current world best

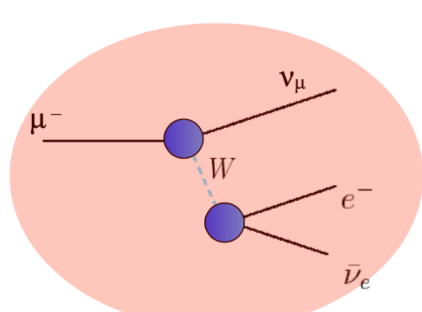
What is the point of measuring this so precisely?

Quantum corrections

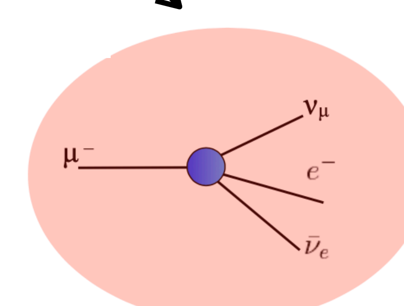
SM Effective Field Theory (SMEFT)



Extend the Standard Model with high-order operators
which modify the $W\ell\nu$ vertex and add 4-fermion contact interactions



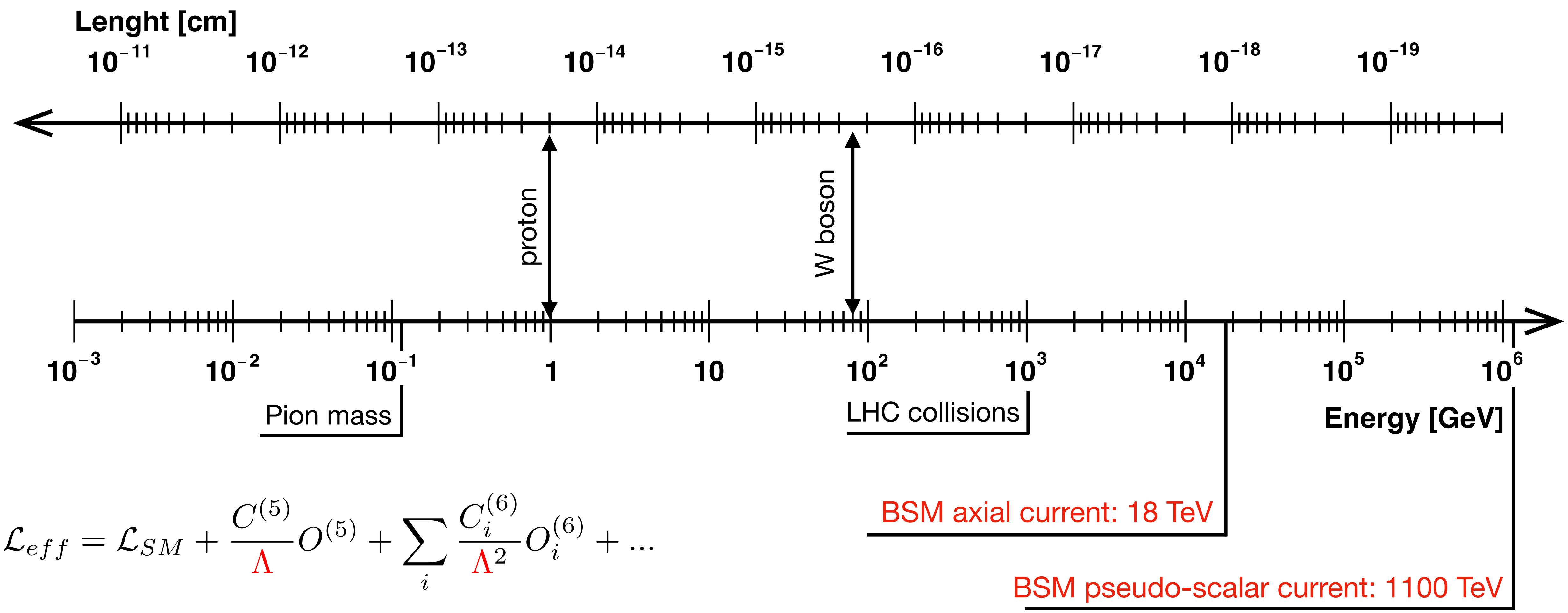
Vertex corrections



4-fermion contact interaction

Quantum corrections

SM Effective Field Theory (SMEFT)



$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda} O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \ldots$$

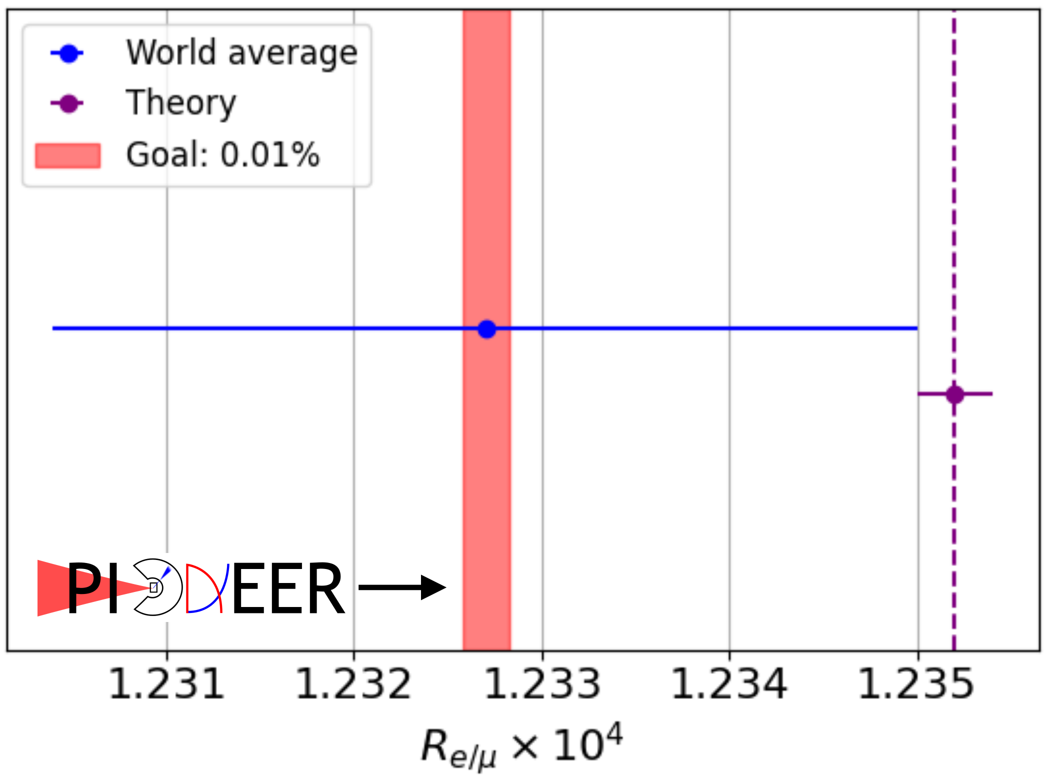
Systematic analysis of all possible operators

1210.4553, JHEP
0908.1754, NPB

Sensitivity up to the ~ PeV scale!

Rare pion decays are the most powerful probe for BSM effects modifying the $W\ell\nu$ vertex

Tests of the weak interaction in rare pion decays



Pristine probe of the Standard Model

Challenge: measure this $O(10^{-4})$ value with a precision of 10^{-4}

How do we plan to do this?

Outline

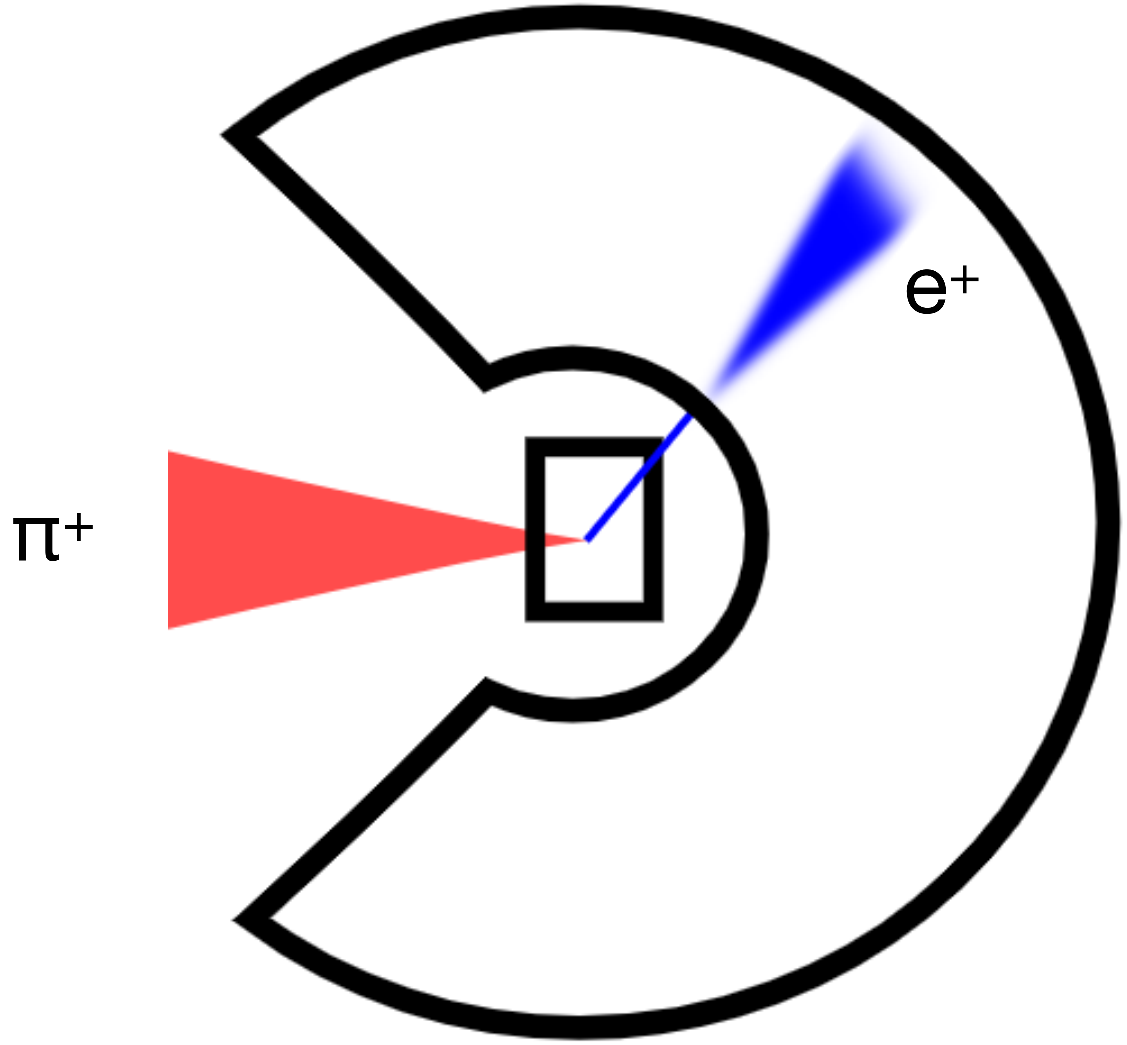
Part I: Lepton Flavor Universality Test

Part II: Detector prototyping

Part III: Quark mixing measurement and exotics decays

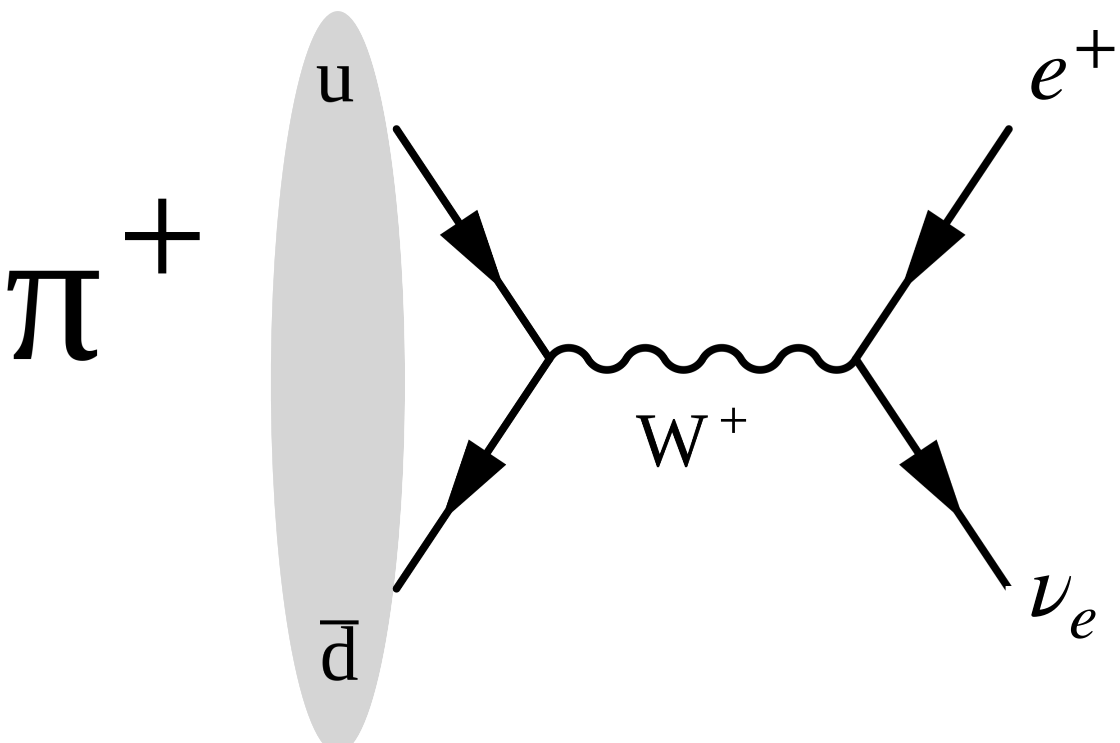
Introducing PIONEER

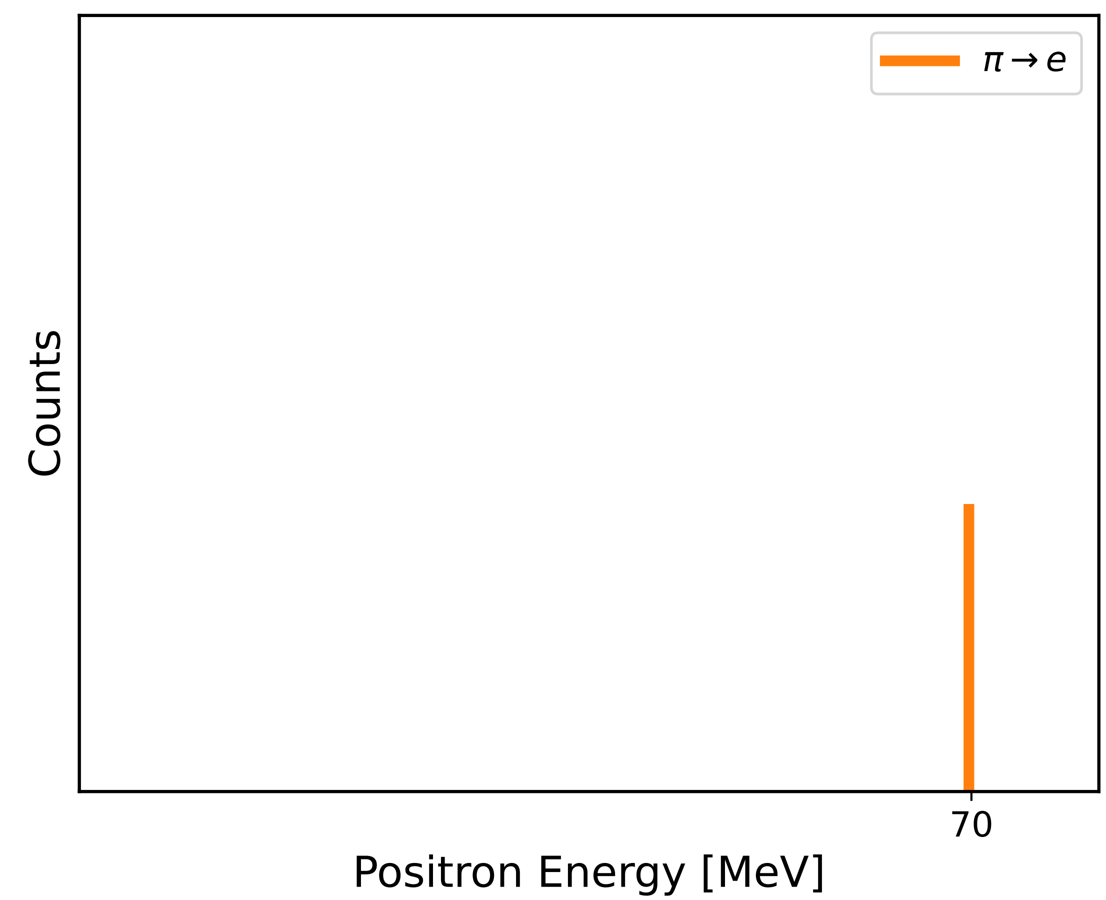
$$R_{e/\mu} = \Gamma(\pi \to e\nu(\gamma)) \div \Gamma(\pi \to \mu\nu(\gamma))$$



Introducing PIONEER

$R_{e/\mu}$ measurement strategy



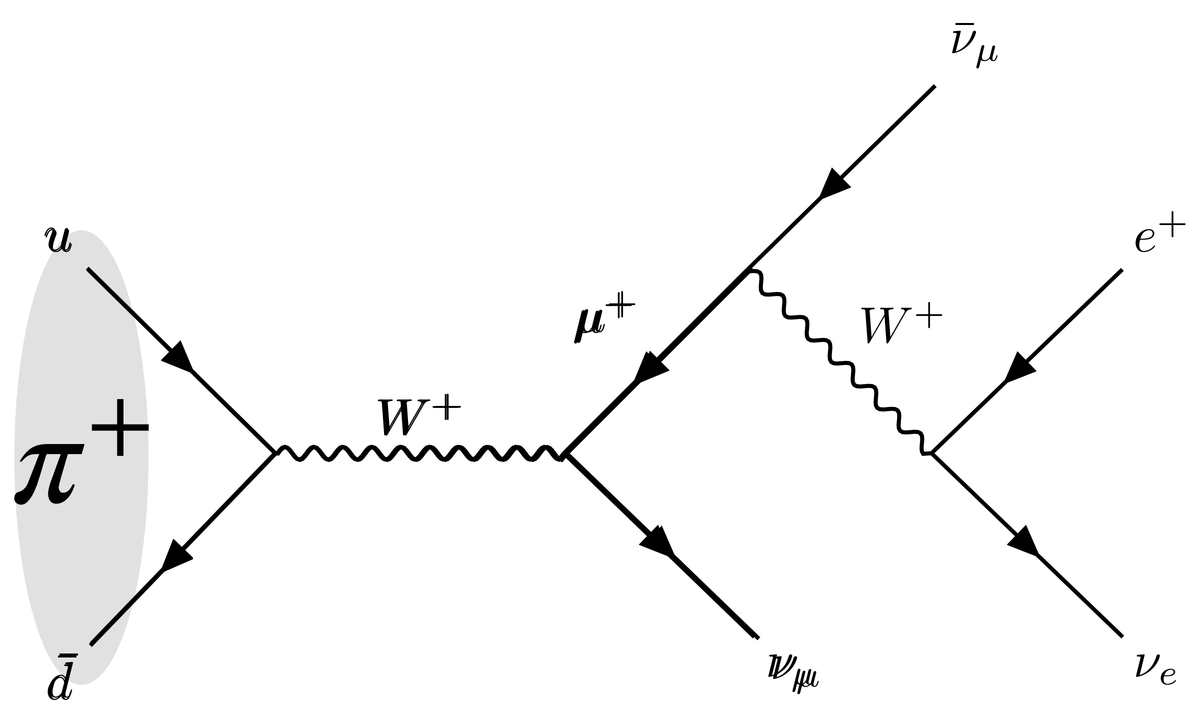


$$m_{\pi^+} = 139.6\,\text{MeV}$$
$$\tau_{\pi^+} \approx 26\,\text{ns}$$

The pion stops in the target and decays

Introducing PIONEER

$R_{e/\mu}$ measurement strategy



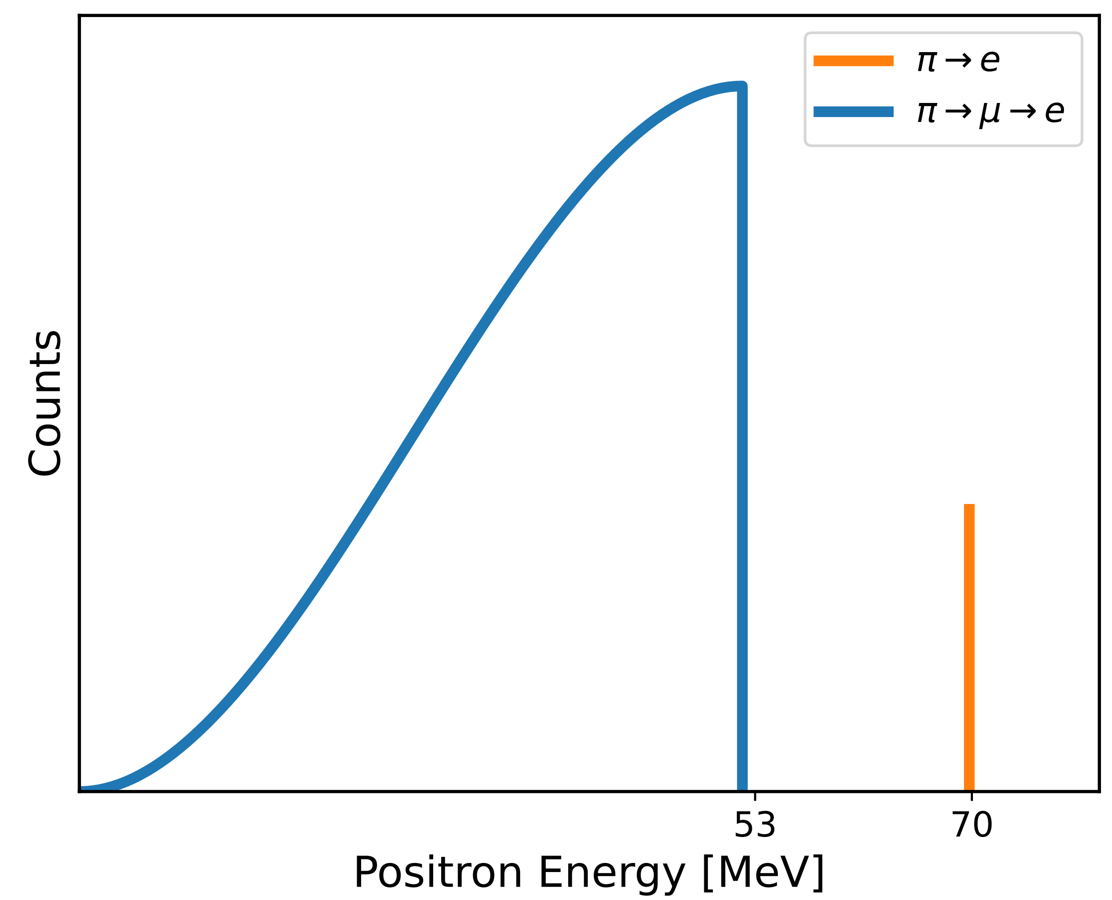
$m_{\pi^+} = 139.6\,\text{MeV}$

$m_{\mu^+} = 105.7\,\text{MeV}$

$\tau_{\mu^+} \approx 2.2\,\mu\text{s}$

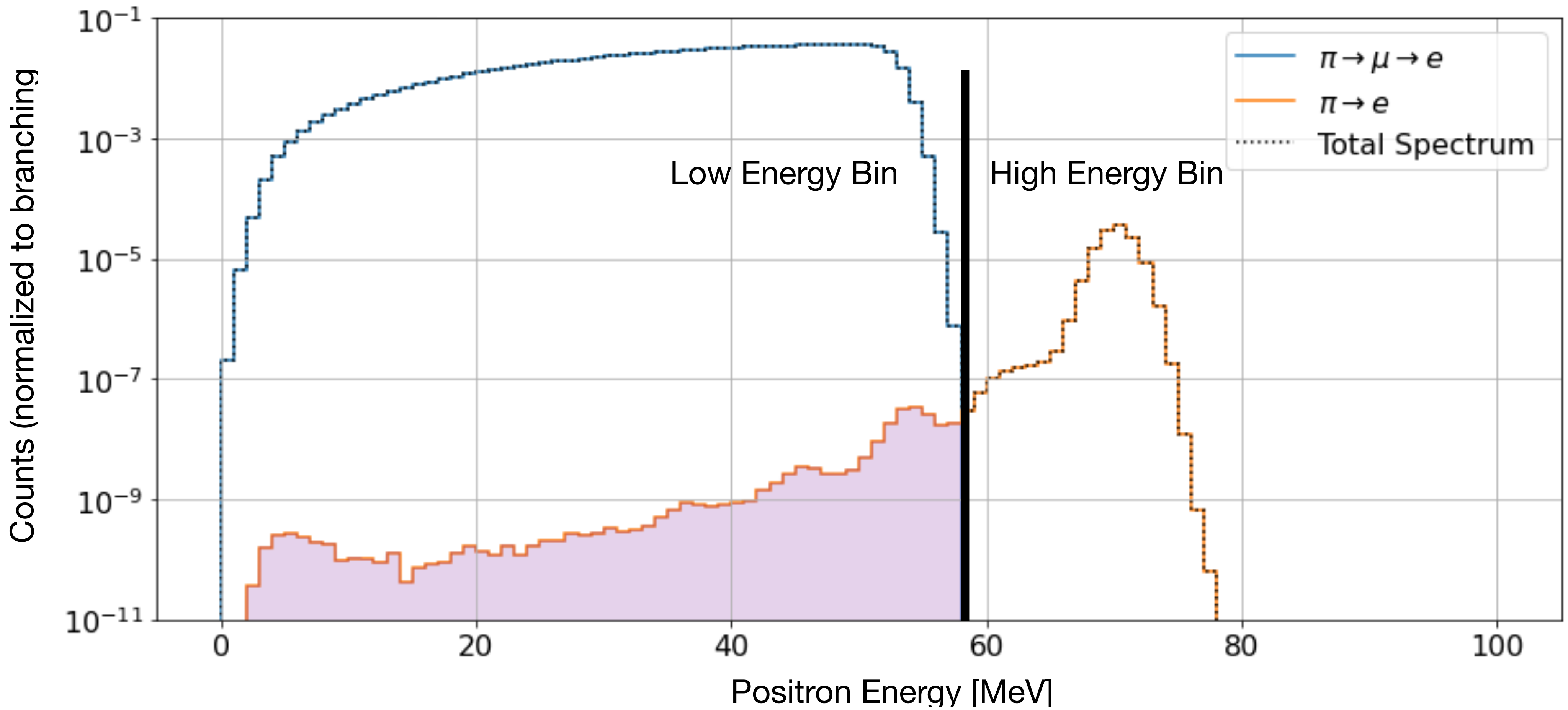
The pion stops in the target and decays

Then the muon stops in the target and decays



Introducing PIONEER

Facing experimental reality



Master formula

$$R_{e/\mu} = \frac{N^{HE}_{\pi-e}}{N^{LE}_{\pi-\mu-e}} \times [1 + C_{tail}] \times R_\epsilon$$

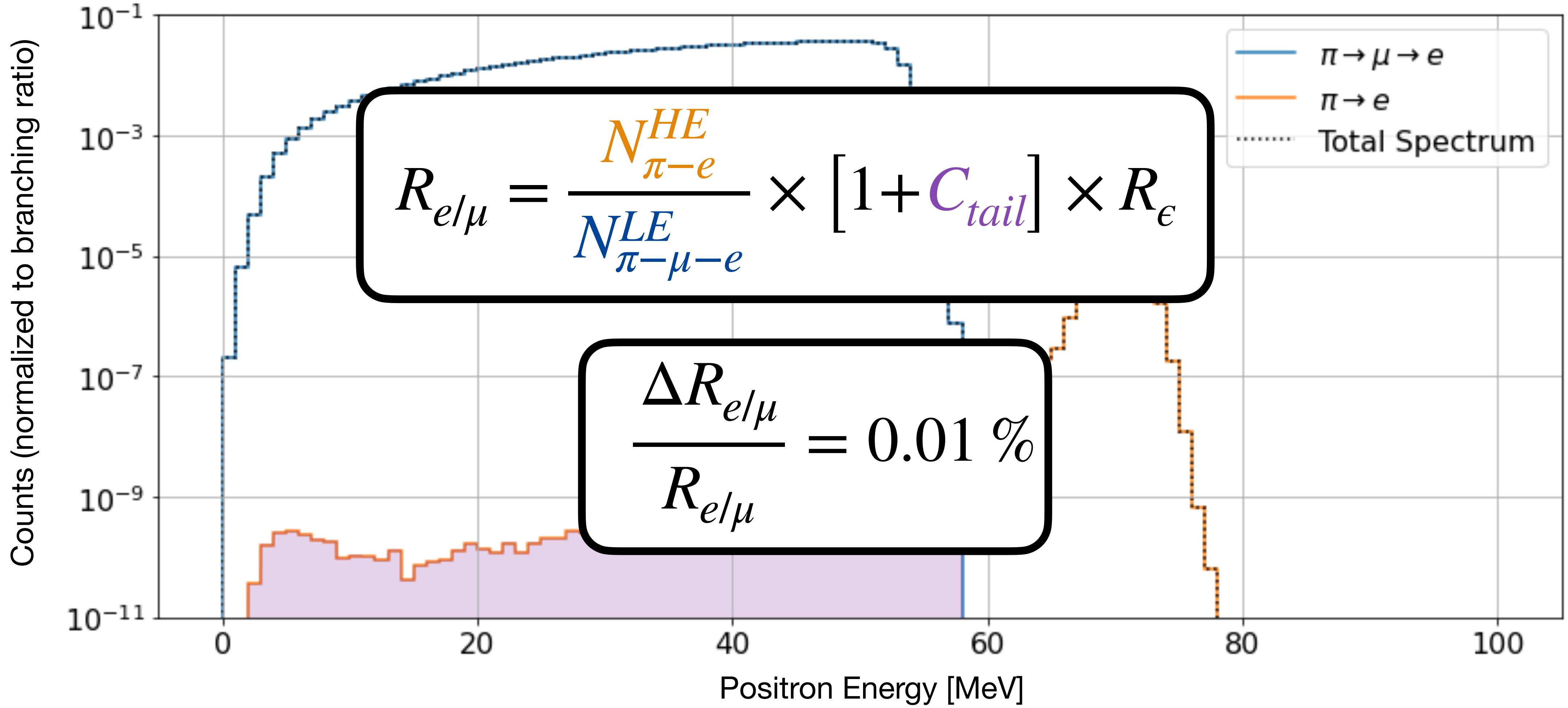
$N^{HE}_{\pi-e}$: number of $\pi \to e\nu$ events in the High Energy Bin

$N^{LE}_{\pi-\mu-e}$: number of $\pi \to \mu(\to e\nu\nu)\nu$ events in the Low Energy Bin

C_{tail}: fraction of $\pi \to e\nu$ events in the LE bin

R_ϵ: relative acceptance of $\pi \to e\nu$ and $\pi \to \mu(\to e\nu\nu)\nu$ events

Introducing PIONEER



$$R_{e/\mu} = \frac{N^{HE}_{\pi-e}}{N^{LE}_{\pi-\mu-e}} \times \left[1 + C_{tail}\right] \times R_{\epsilon}$$

$$\frac{\Delta R_{e/\mu}}{R_{e/\mu}} = 0.01\ \%$$

Guiding principles to the design of the experiment:

1. Collect very large datasets of rare pion decays (2e8 $\pi^+ \rightarrow e^+ \nu_e$ during Phase I)
2. Tail must be less than 1% of total signal
3. Tail must be measured with a precision of 1%
4. Acceptance must be understood with a precision of 0.01%

PAUL SCHERRER INSTITUT

Located near Zurich, Switzerland
World most intense low-energy pion beamline

Beam configuration
Phase I: 3e5 π+/s, 65 MeV/c, $\Delta p/p$ = 1%

Guiding principles to the design of the experiment:

1. **Collect very large datasets of rare pion decays** ✓
2. Tail must be less than 1% of total signal
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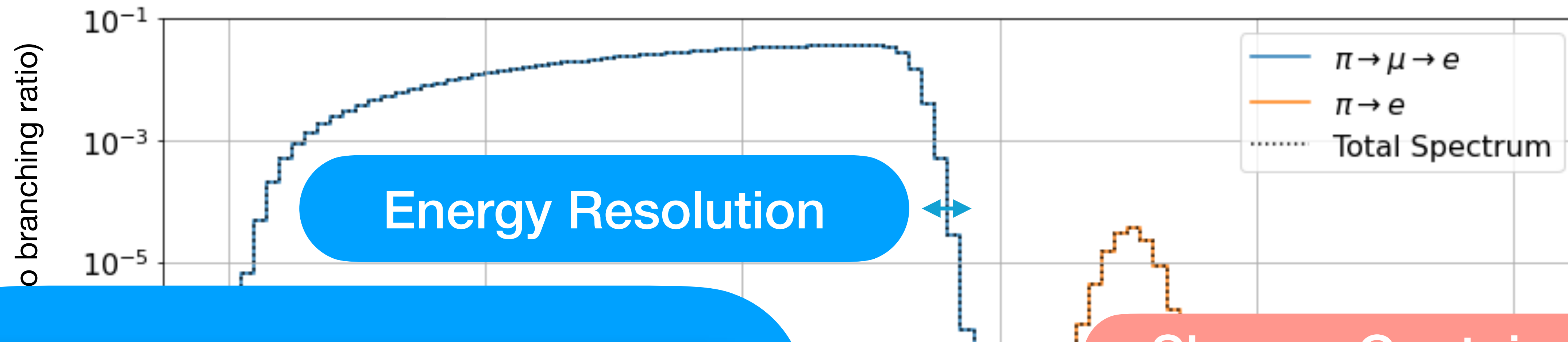
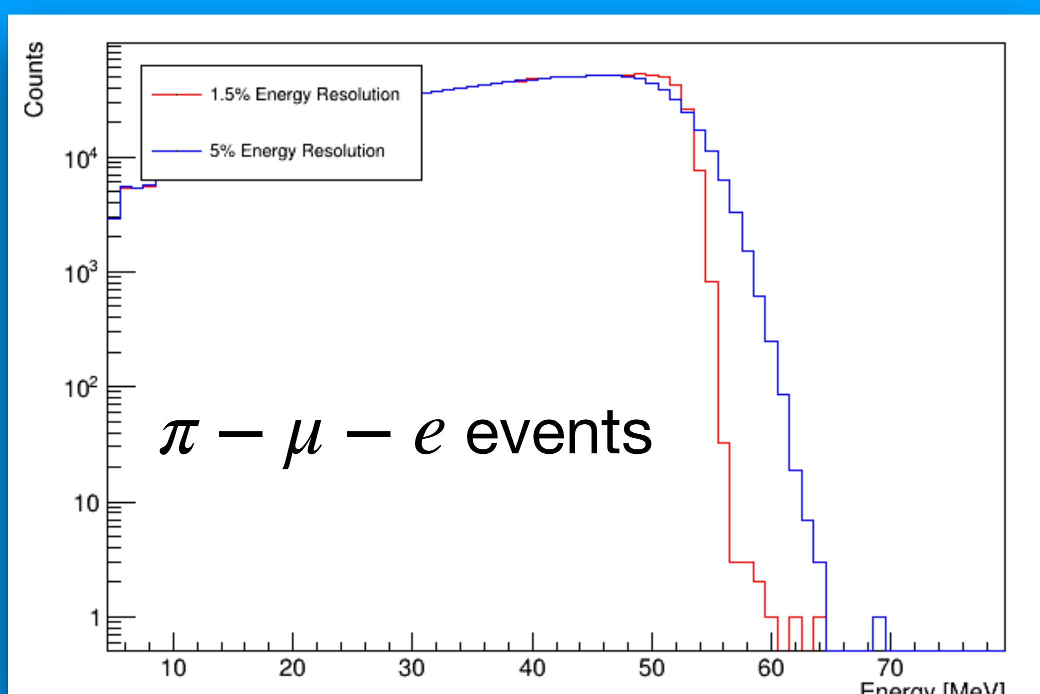
Calorimeter design

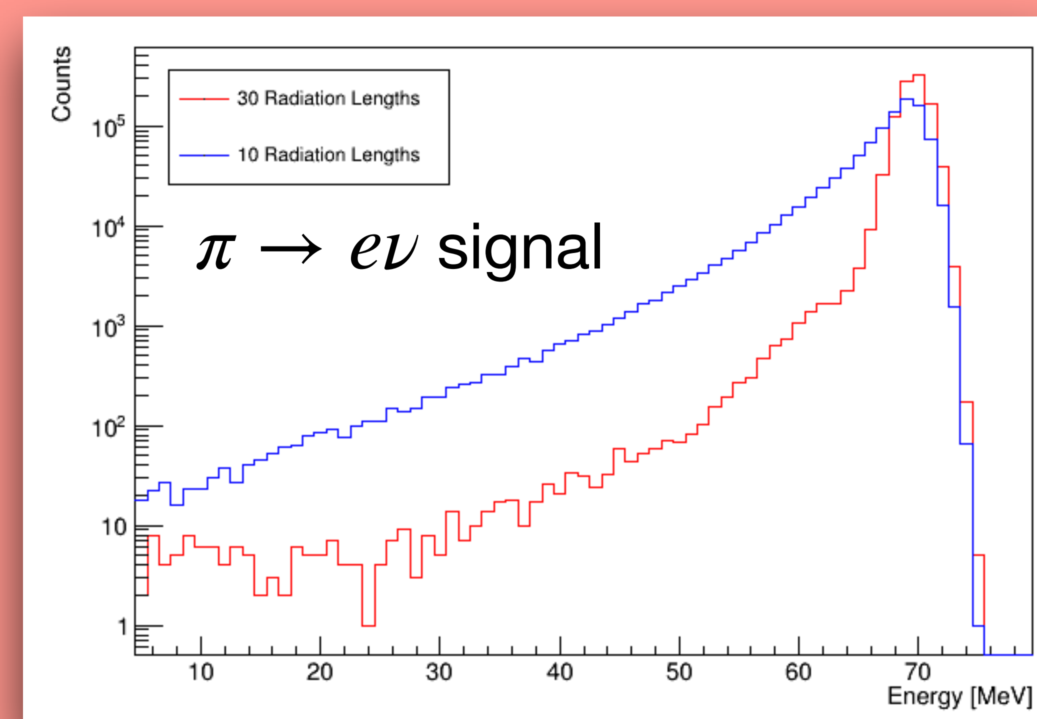


Energy Resolution

Shower Containment



At least 2% for positrons
with 70 MeV/c momentum



At least 19 radiation length (X_0),
Large solid angle (~3π steradians)

Gui … **m**

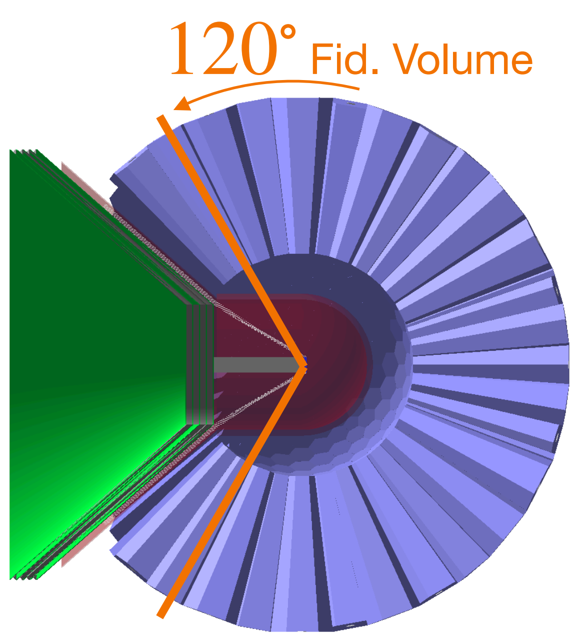
1. … ay
2. …
3. Tail must be measured with a precision of 1%
4. Acceptance must be understood with a precisio

Calorimeter design

Baseline choice

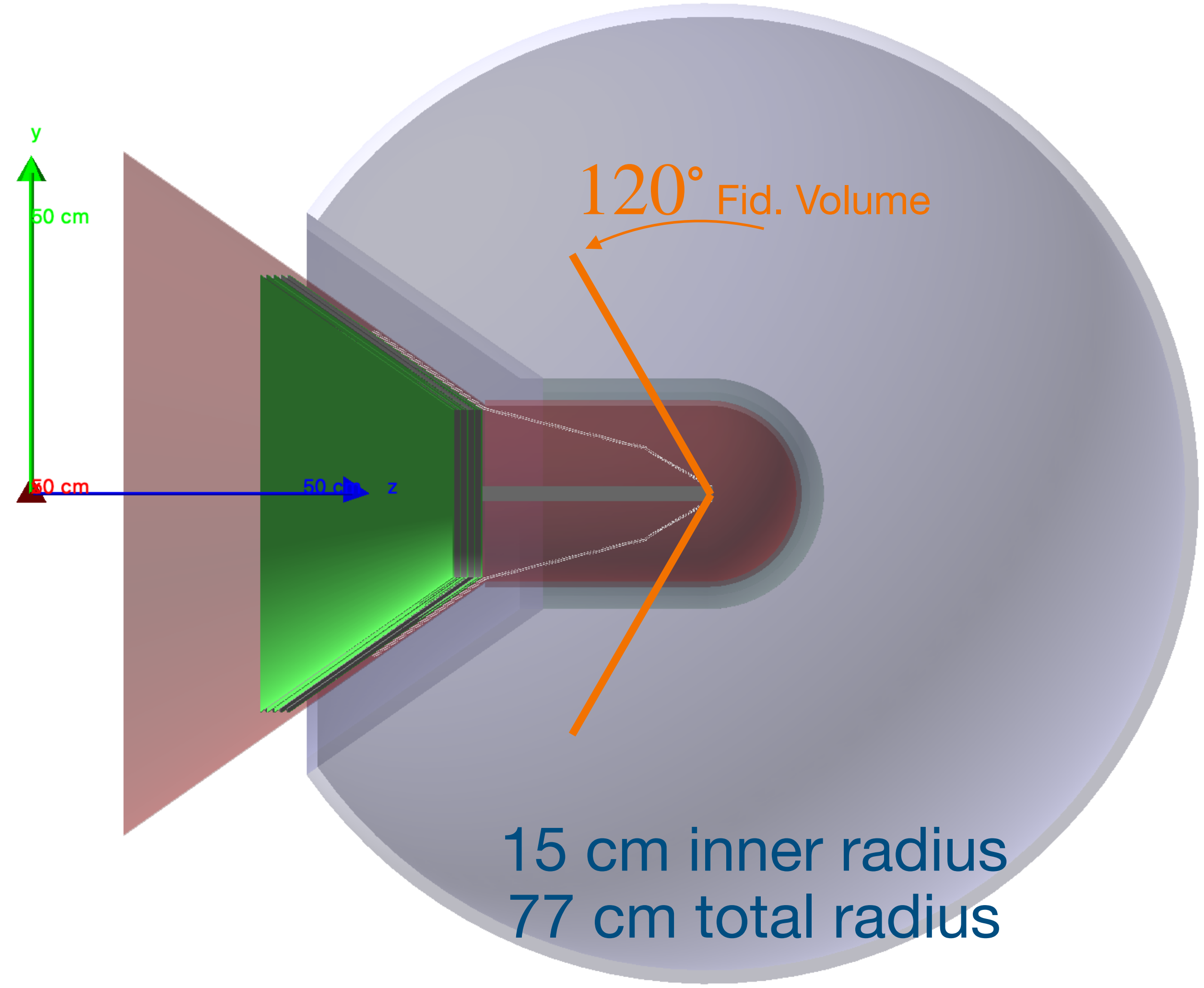
LYSO Crystals

Lutetium-yttrium oxyorthosilicate, $Lu_{2(1-x)}Y_{2x}SiO_5$



15 cm inner radius
42 cm total radius

Liquid Xenon



With a high-rate π^+ beam, fast (~50ns) light collection is critical

LYSO Calorimeter R&D Program

LYSO is a fast, bright, and dense crystal scintillator that is typically used in small (~1cm^2) sizes for triggering in HEP

The PIONEER calorimeter will be composed of the 311 largest LYSO crystals ever grown (21.3 cm / 19X_0)

2023 Test Beam

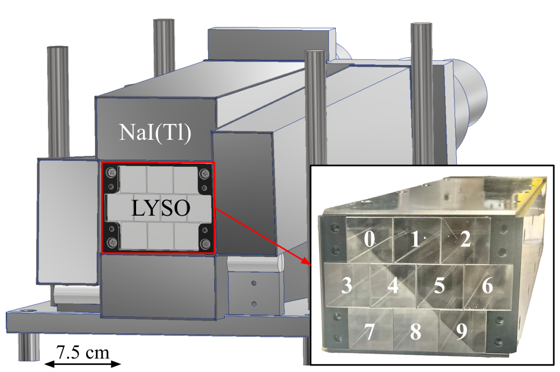
Characterized an array of 10 rectilinear LYSO crystals (2.5 x 2.5 x 18 cm^3)

Main findings

1) 1.52% energy resolution for 70 MeV e^+. ~3x better than previous LYSO arrays at this energy

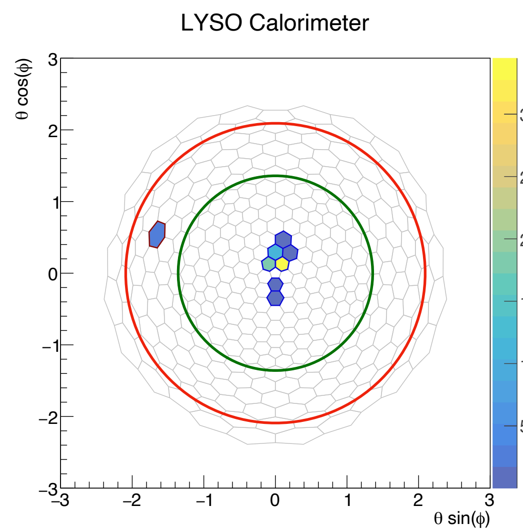
2) 100 ps time resolution for pulses larger than 30 MeV

3) 6 mm spatial resolution at 70 MeV



Beesley, et al,
NIM A 1075 (2025) 170320

Simulation efforts



Using 2023 test beam data, a **realistic detector response** was integrated into the the PIONEER simulation framework.

Developed clustering algorithms capable of **order of magnitude improvements** in pileup suppression in the presence of intrinsic radioactivity.

2025 Test Beam

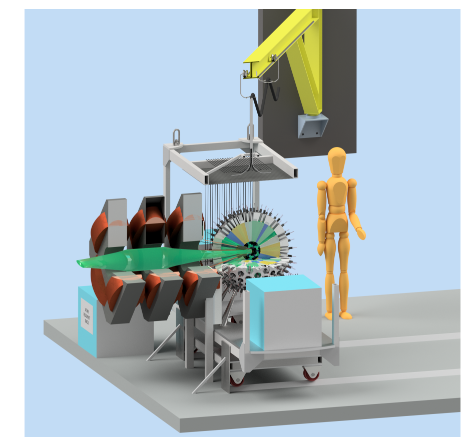
small array of six LYSO crystals in the exact sizes/ shapes of the final calorimeter design

Main findings
LYSO meets PIONEER specifications

1) 2% energy resolution for 70 MeV e^+ despite significant lateral leakage due to the small size of the array
2) 100 ps time resolution for pulses larger than 30 MeV
3) Successful test of rear-mounted supports

Paper in preparation

Next steps



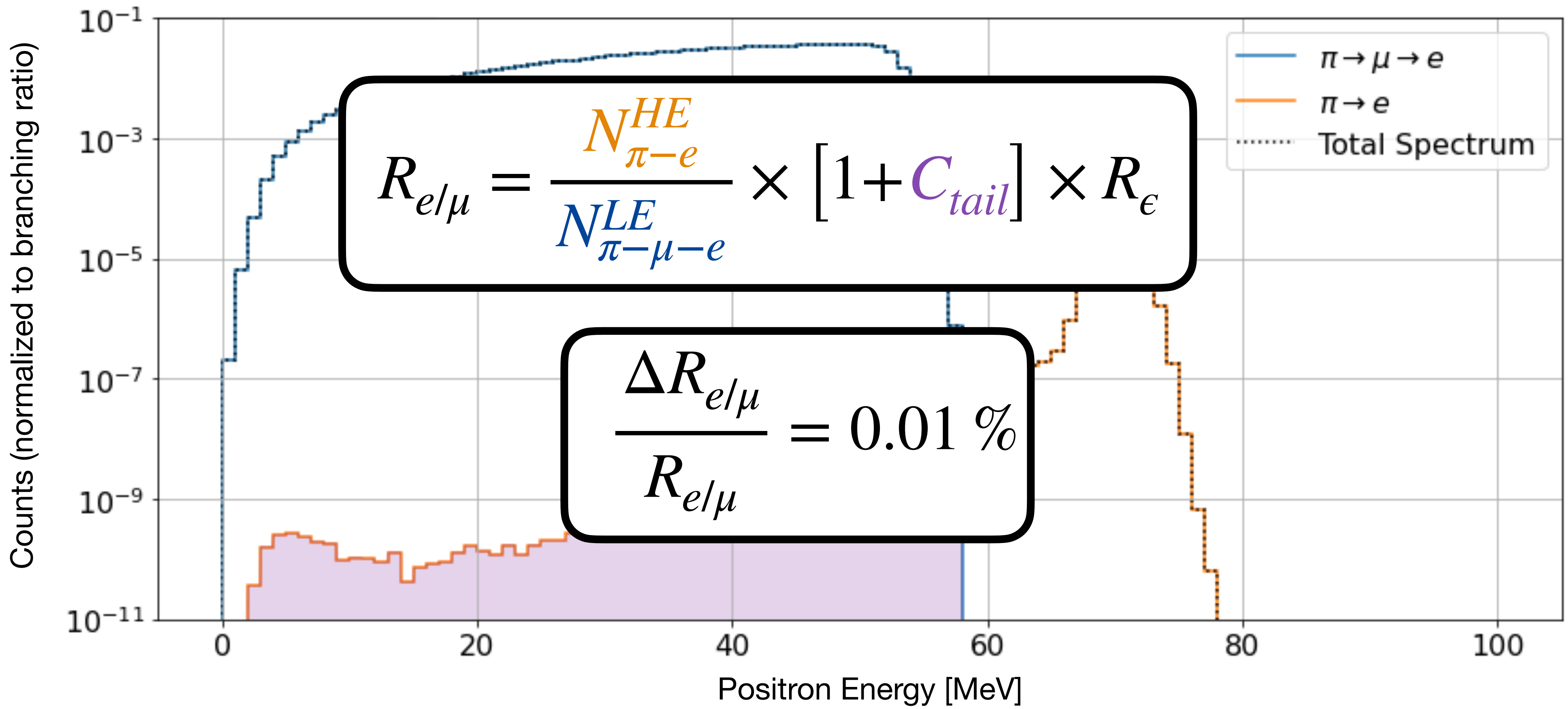
Remaining work is focused on:

1) Optimization of crystal surface roughening for maximal longitudinal response uniformity.

2) Optimization of PMT voltage dividers for fast rise times, high linearity, and constant pulse shape across 0.1 – 100 MeV range.

3) Integration of calorimeter information within our current AI ATAR reconstruction to create a global PIONEER AI reconstruction.

Back to the guiding principles



$$R_{e/\mu} = \frac{N^{HE}_{\pi-e}}{N^{LE}_{\pi-\mu-e}} \times \left[1 + C_{tail}\right] \times R_{\epsilon}$$

$$\frac{\Delta R_{e/\mu}}{R_{e/\mu}} = 0.01\ \%$$

Guiding principles to the design of the experiment:

1. Collect very large datasets of rare pion decays ✓
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3. **Tail must be measured with a precision of 1%**
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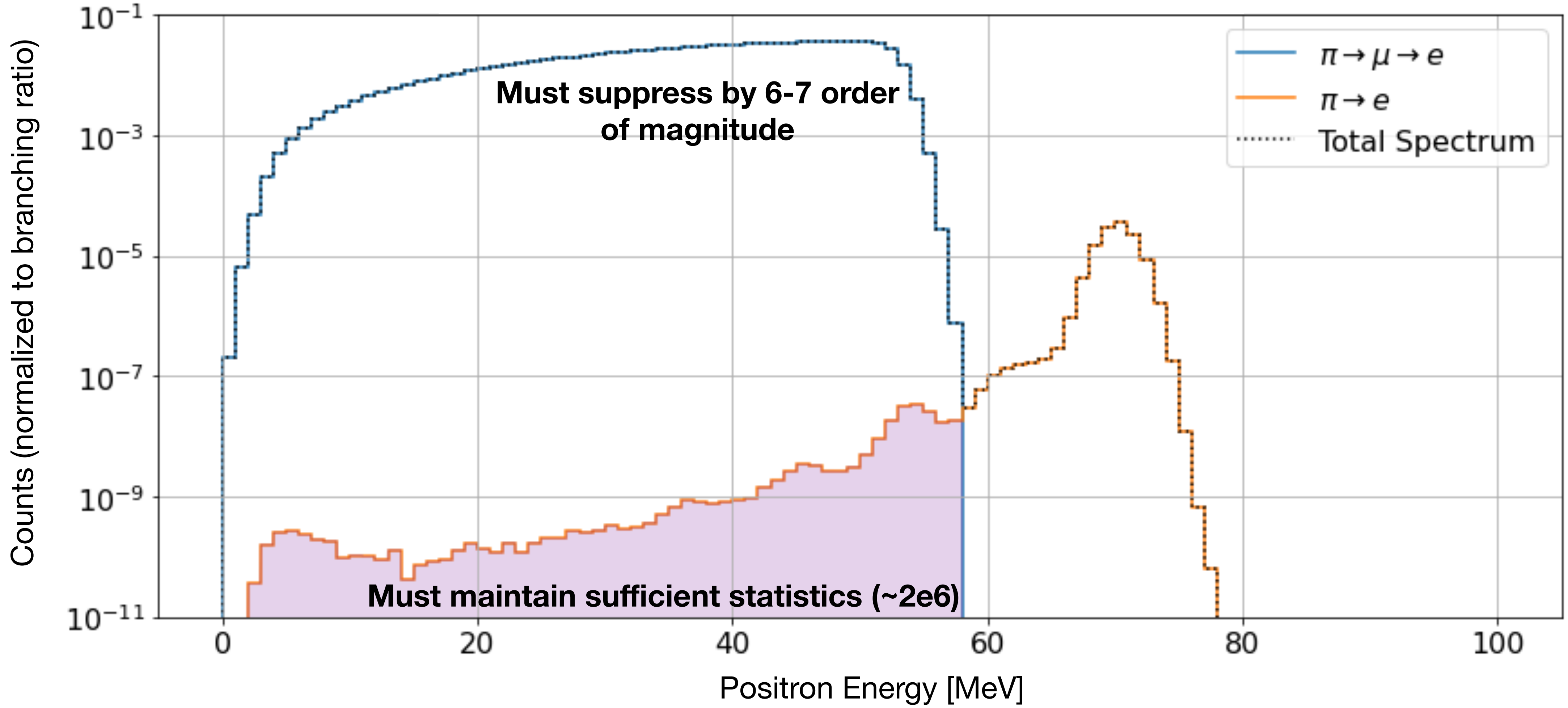
Insitu C_{tail} measurement



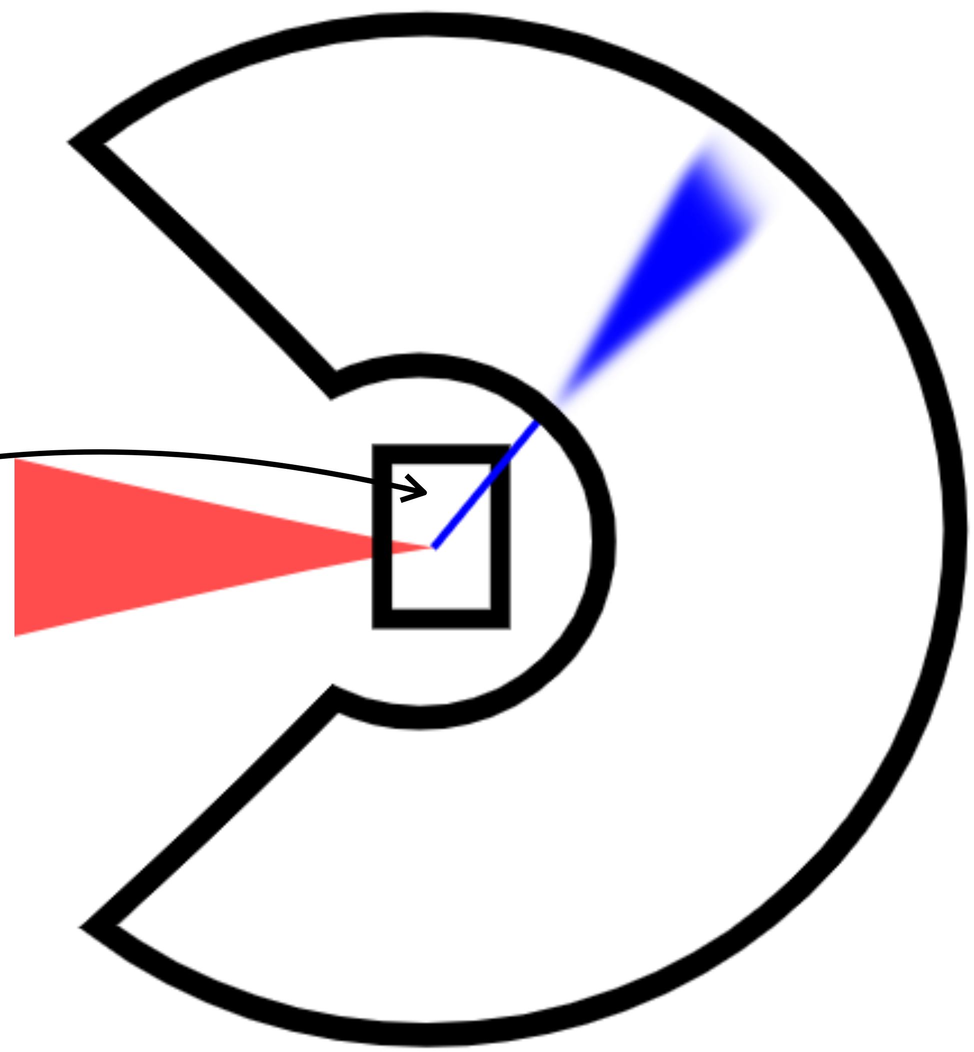
With $C_{tail} \sim 1\,\%$, we expect the $\pi \to \mu \to e$ process to occur at a rate **10^6 larger** than the $\pi \to e$ process in the low energy region

How can we reliably slice through the data to reveal the tail?

The approach

PIONEER is a **fixed target** experiment

Can we instrument the target
to our advantage?

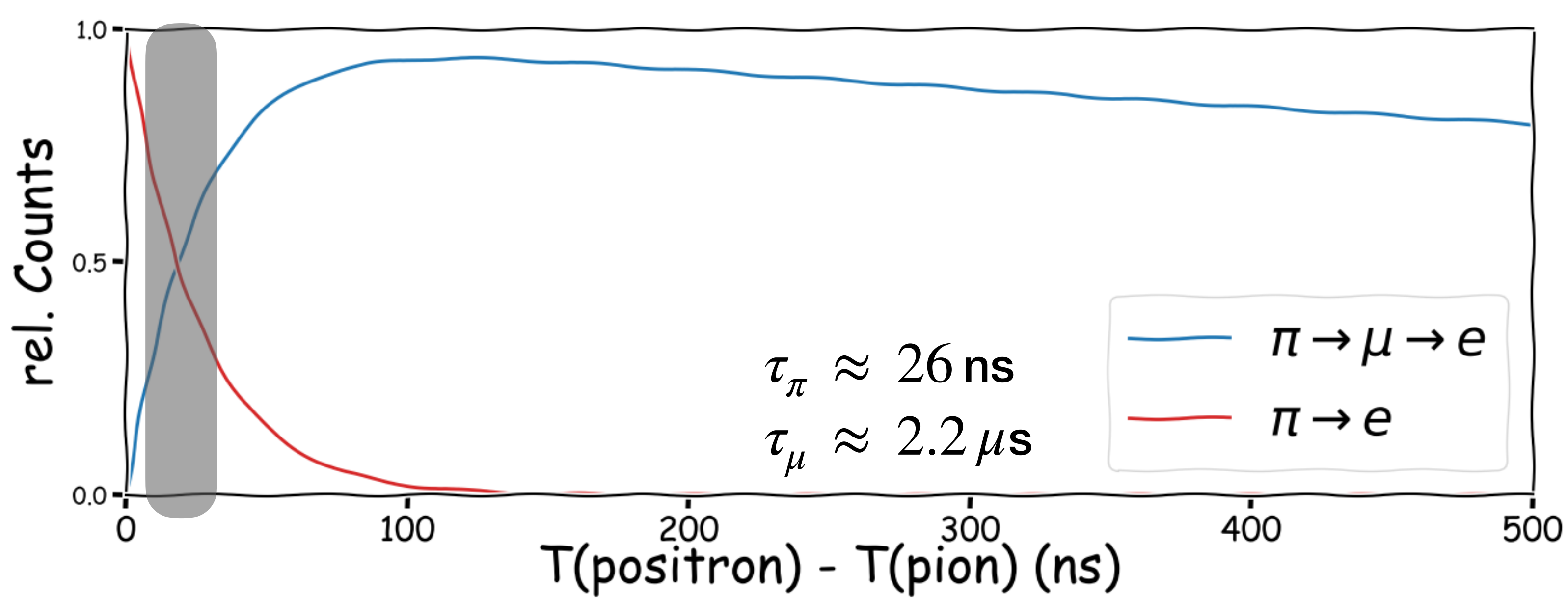


The approach

Timing

$\pi \to e$ selection efficiency ~60%
$\pi \to \mu \to e$ rejection rate ~150

~nanosecond timing measurement



Fraction of events in [2, 32]ns

$\pi \to e : 63\,\%$

$\pi \to \mu \to e : 0.6\,\%$

Rejection rate of ~ 150

The approach

Timing

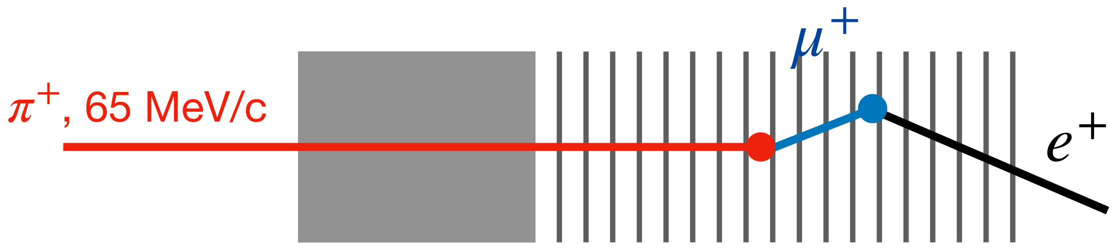
$\pi \rightarrow e$ **selection efficiency ~60%**

$\pi \rightarrow \mu \rightarrow e$ **rejection rate ~150**

Energy

$\pi \rightarrow e$ **selection efficiency ~85%**

$\pi \rightarrow \mu \rightarrow e$ **rejection rate ~10^3**



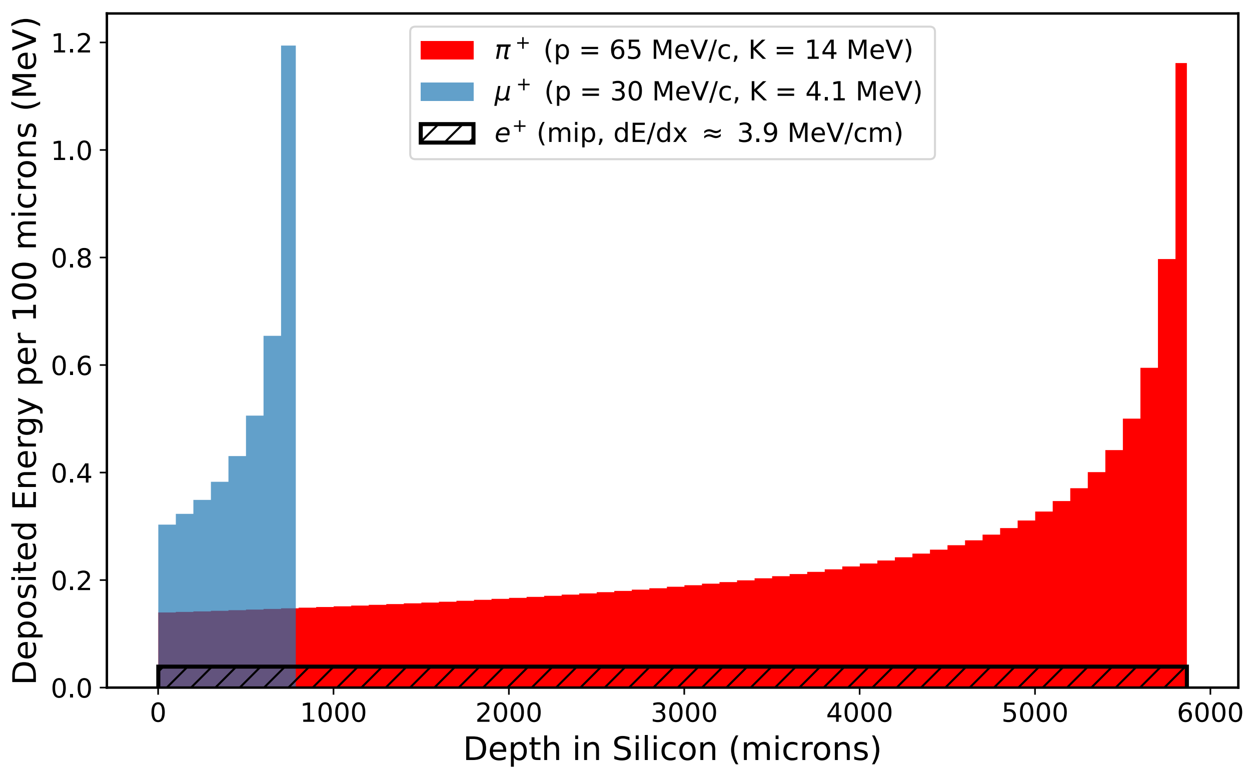
65 MeV/c pion “dE/dx”

Integrated: ~14 MeV

30 MeV/c muon “dE/dx”

Integrated: 4.1 MeV

In this regime, the positron is a Minimum Ionising Particle (MIP) energy for 120µm of silicon: ~50 keV



The approach

Timing

$\pi \rightarrow e$ selection efficiency ~60%

$\pi \rightarrow \mu \rightarrow e$ rejection rate ~150

Energy

$\pi \rightarrow e$ selection efficiency ~85%

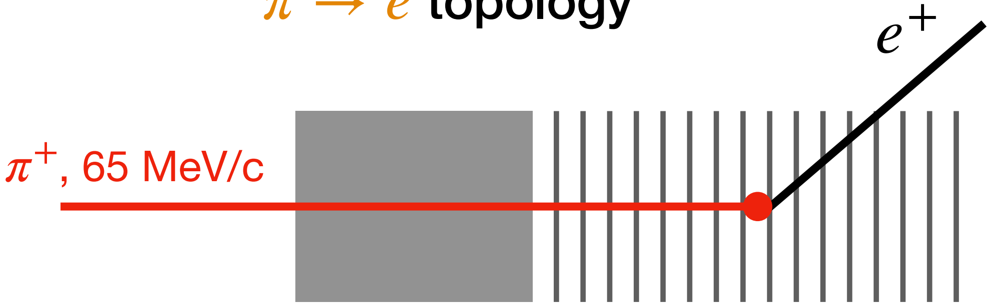
$\pi \rightarrow \mu \rightarrow e$ rejection rate ~10^3

Topology

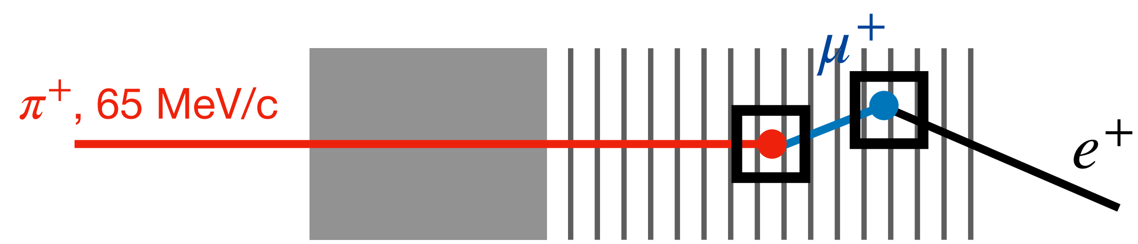
$\pi \rightarrow e$ selection efficiency ~50%

$\pi \rightarrow \mu \rightarrow e$ rejection rate ~500

$\pi \rightarrow e$ topology



$\pi \rightarrow \mu \rightarrow e$ topology



Pion and muon can decay in flight

Need for a segmented device to reconstruct trajectory of charged particles

Timing, Energy and Topology: all needed to reach the desired precision

PIONEER’s Active TARget (ATAR)

A 5D tracking device

Timing

$\tau_\pi \approx 26$ ns
$\tau_\mu \approx 2.2\,\mu$s

Nanosecond precision, micro-second length signal

Energy

Positrons are MIPs
Muons / pions are ~100 MIPS

Large dynamic range (1000) to see all particles

Topology

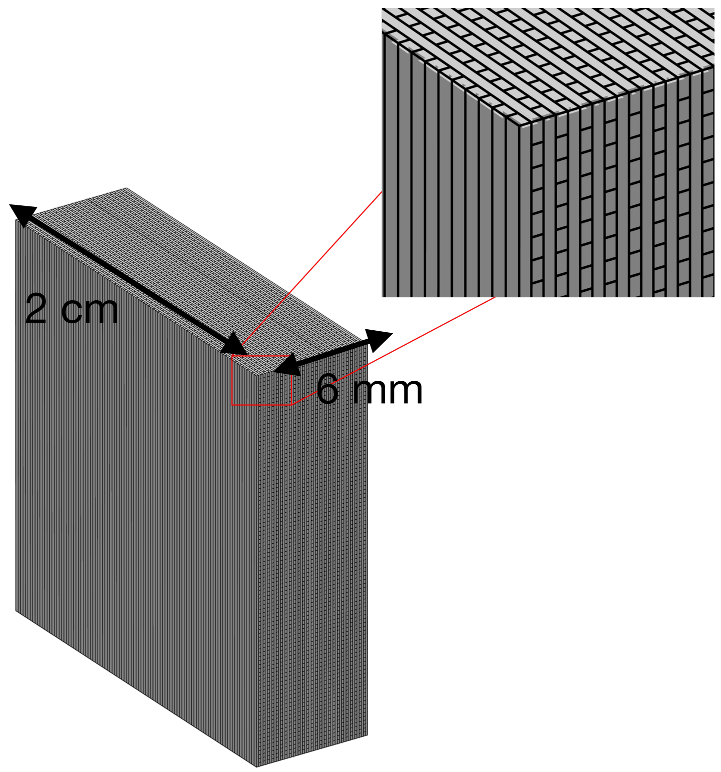
Muon from stopped pion

E_{kin} = 4.1 MeV
Travel in Silicon ~ 0.8 mm

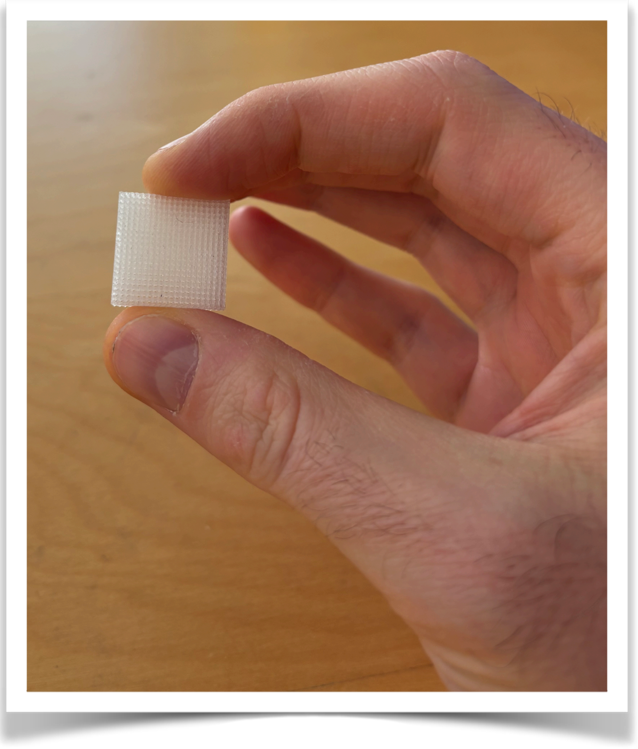
Sub-millimeter position resolution

PIONEER's Active TARget (ATAR)

The heart of the experiment



3D printed model to scale



Silicon sensors

6mm thick (48 layers of 120um)

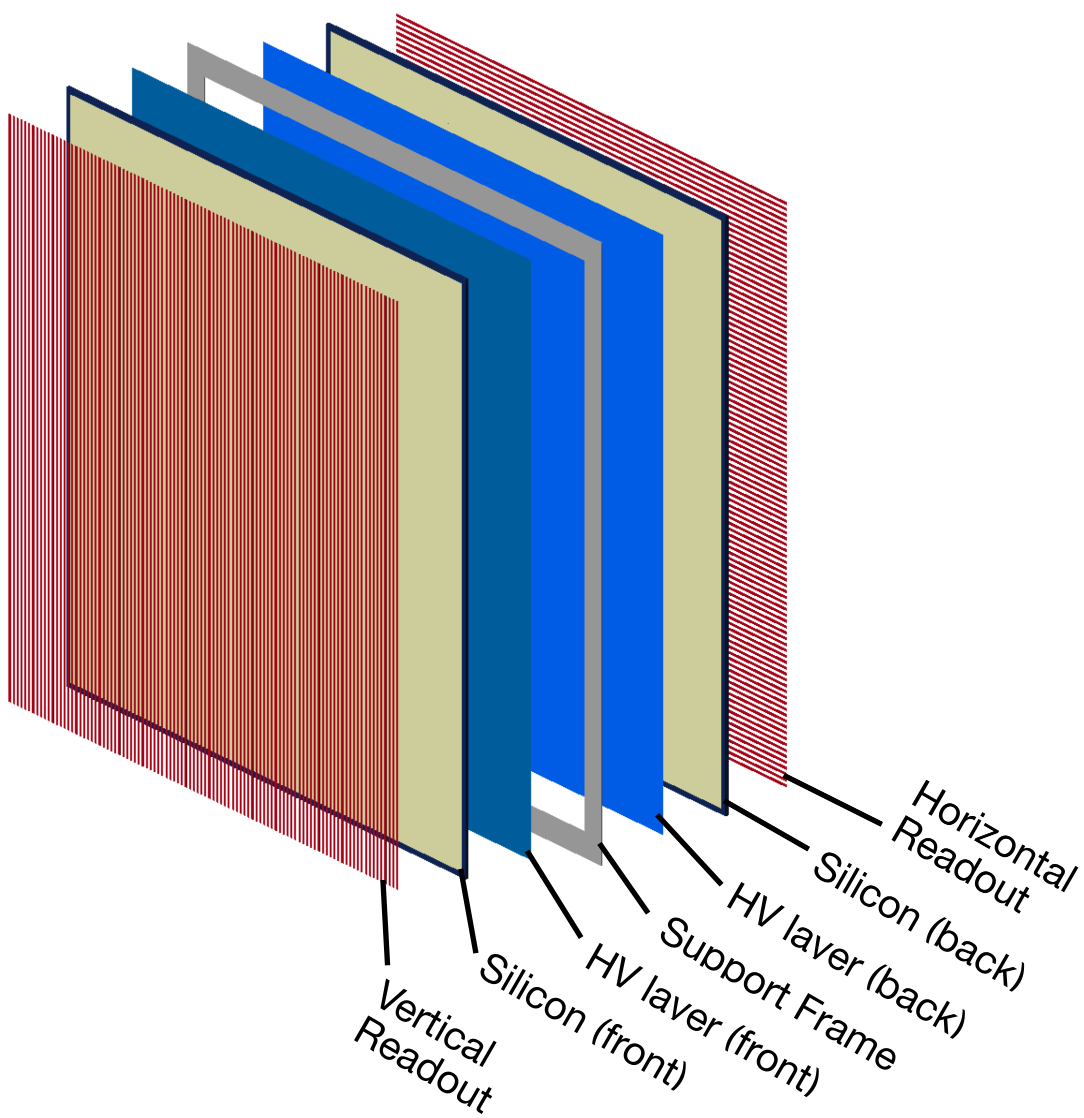
100 strips per layer covering 2x2 cm^2 area

5000 readout channels

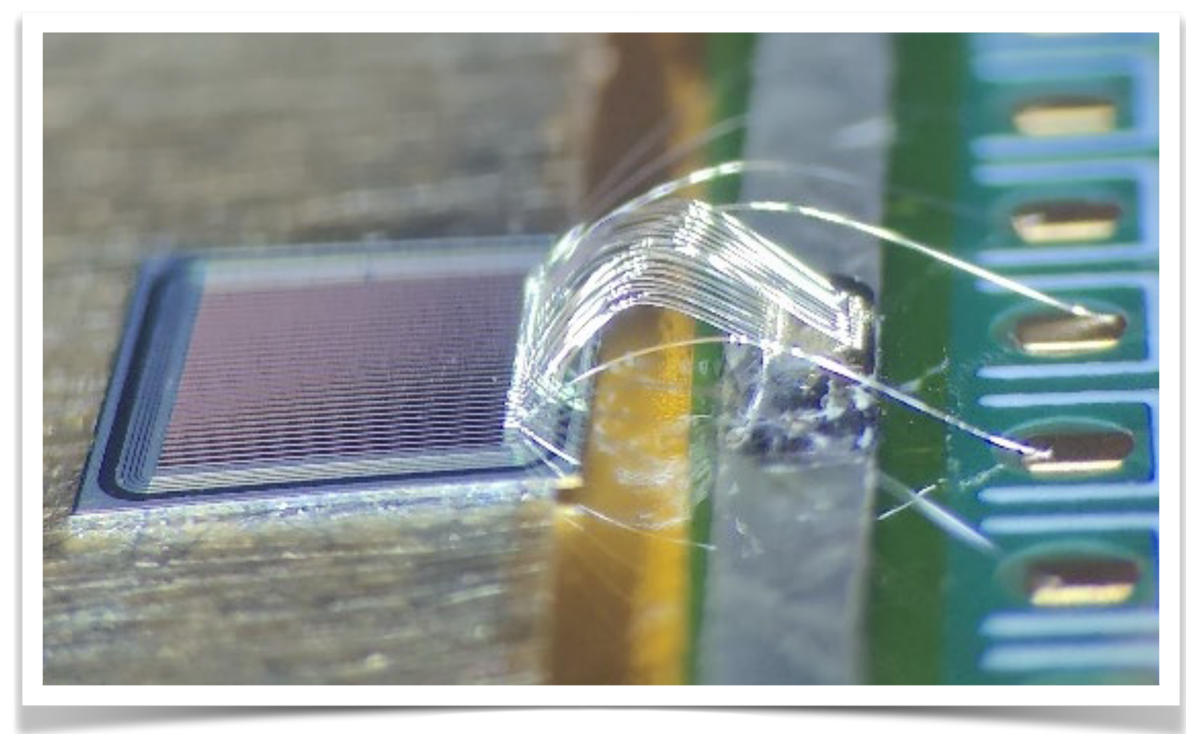
PIONEER's Active TARget (ATAR)

The heart of the experiment

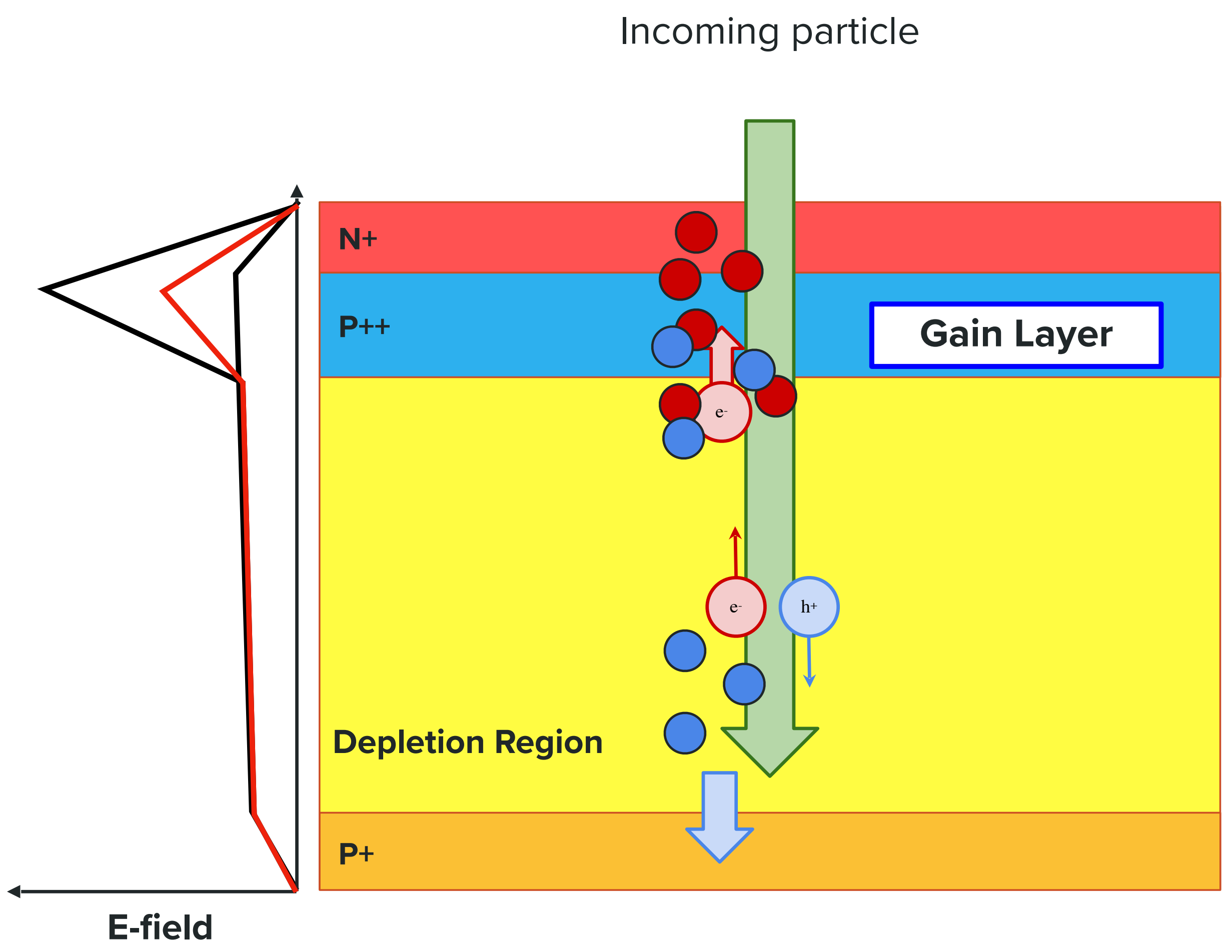
Schematic of one layer



Test sensor from FBK



Low Gain Avalanche Diodes



Silicon Diodes:
p-n junction separated by
an intrinsic layer (undoped)

LGADs:
additional highly doped layer
generates a very high electric field
→ avalanche effect

The signal amplification allows for thin sensors and very good timing resolution

The gain mechanism saturates for **large energy deposit** and introduces an angle dependency

Sensor characterisation

CENPA
Center for Experimental Nuclear Physics and Astrophysics

Test beam campaigns in 2023—2025 at the **University of Washington** using the CENPA tandem Van De Graaf Accelerator

Goal: gain measurement with highly ionising particles

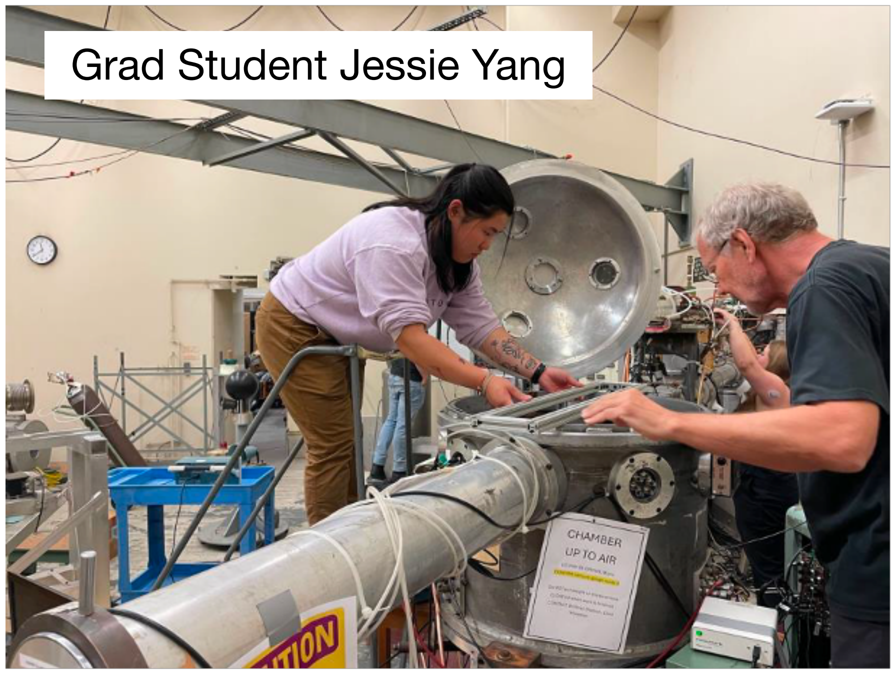
Critical for PIONEER to understand precisely the energy response saturation for π^+ and μ^+

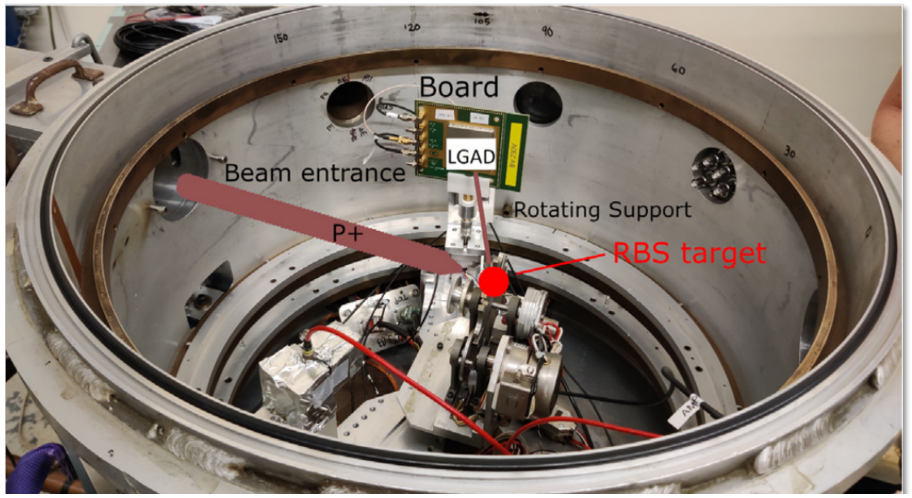
Sensor characterisation

Main objectives

Optimize LGAD doping configuration

Parameterize and infer saturation for pions and muons





We use protons and the Rutherford Back-Scattering (RBS) technique

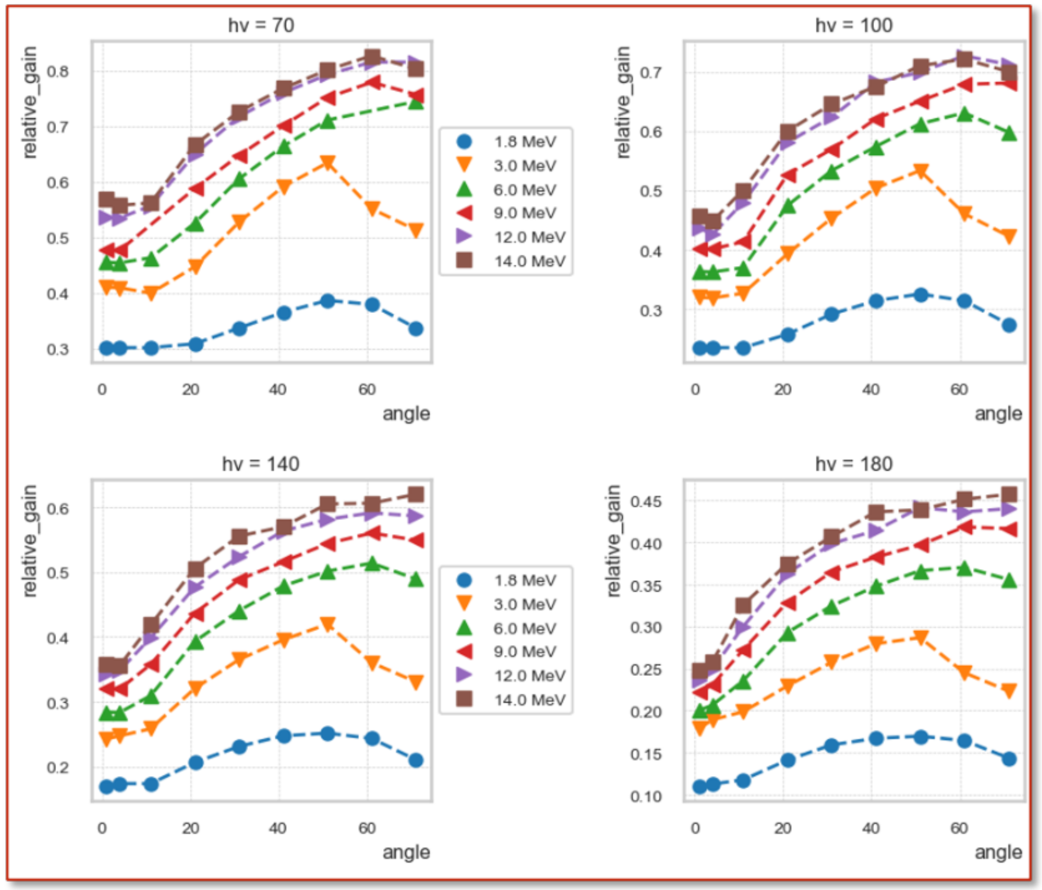
Sensor tested

Sensor	Thickness	Doping Depth	Year Tested
FBK W9	50 um	Shallow	2025
FBK W18	50 um	Deep	2025
FBK W16	50 um	Deep	2025
FBK W1	50 um	Shallow	2024
FBK W8	100 um	Shallow	2024
FBK W11	150 um	Shallow	2024
HPK 3.1	50 um	Deep	2023
HPK 3.2	50 um	Deep	2023

HPK: Hamamatsu electronics
FBK: Fondazione Bruno Kessler

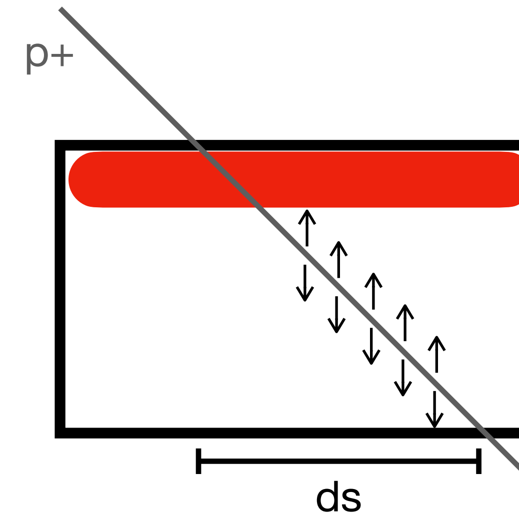
Sensor characterisation — main results

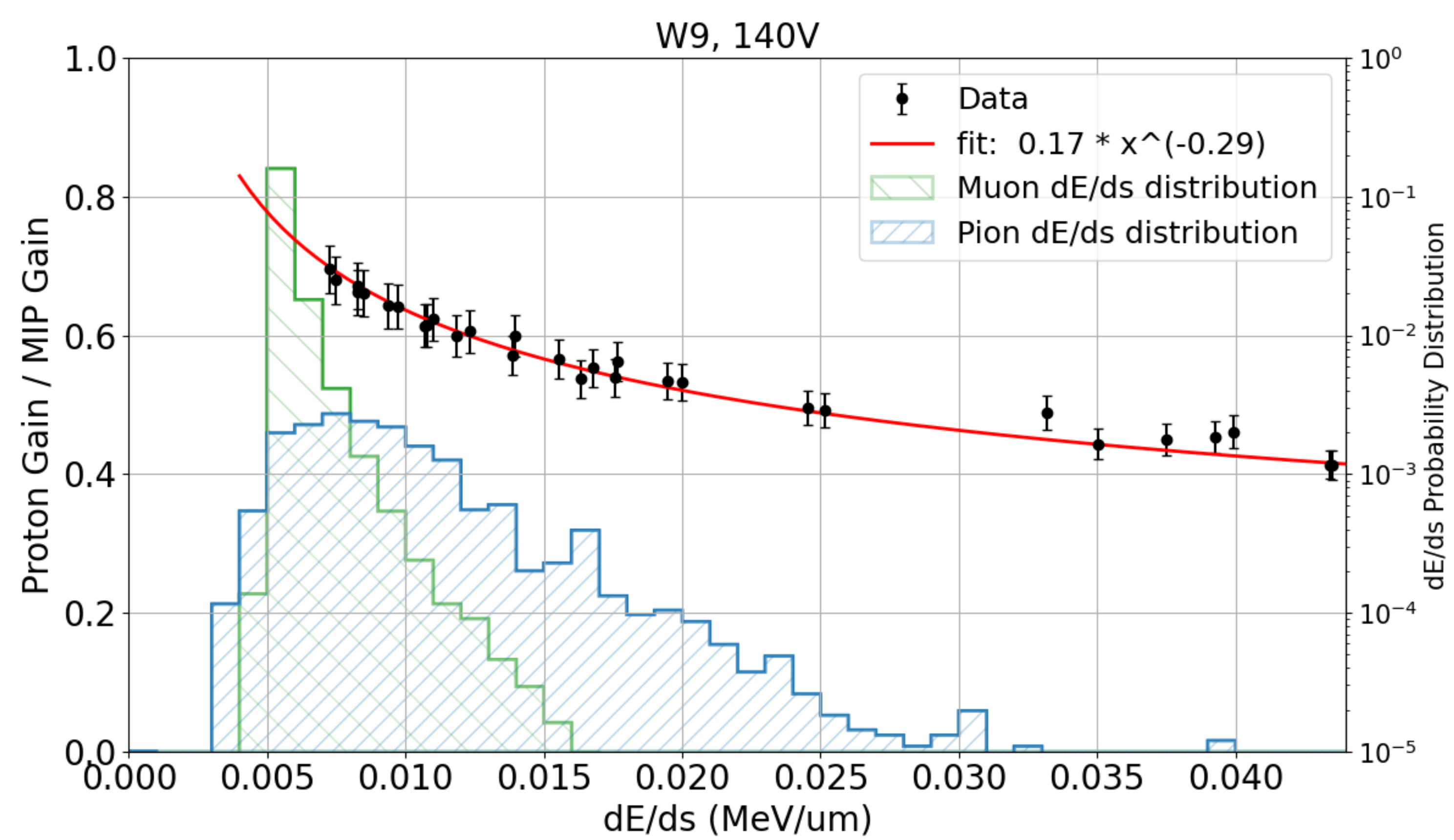
Example data



Relative gain = proton gain / MIP gain

We used protons and scanned over bias voltage, incident angle (0-75 degrees) and proton energy 1.8-14MeV



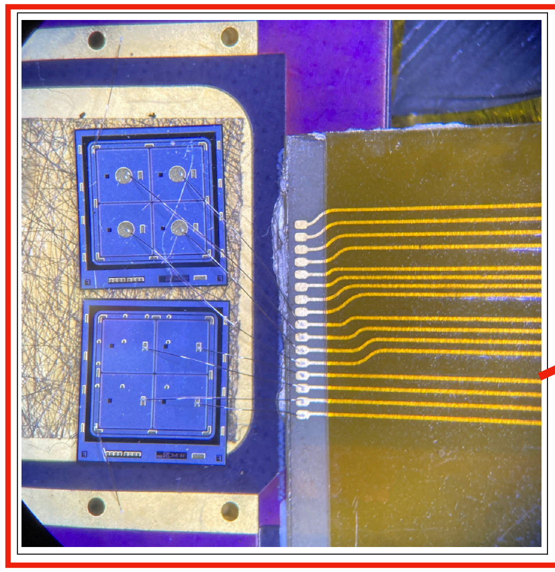


Parameterized gain saturation established

Relative gain ∝ $(dE/ds)^{\alpha}$

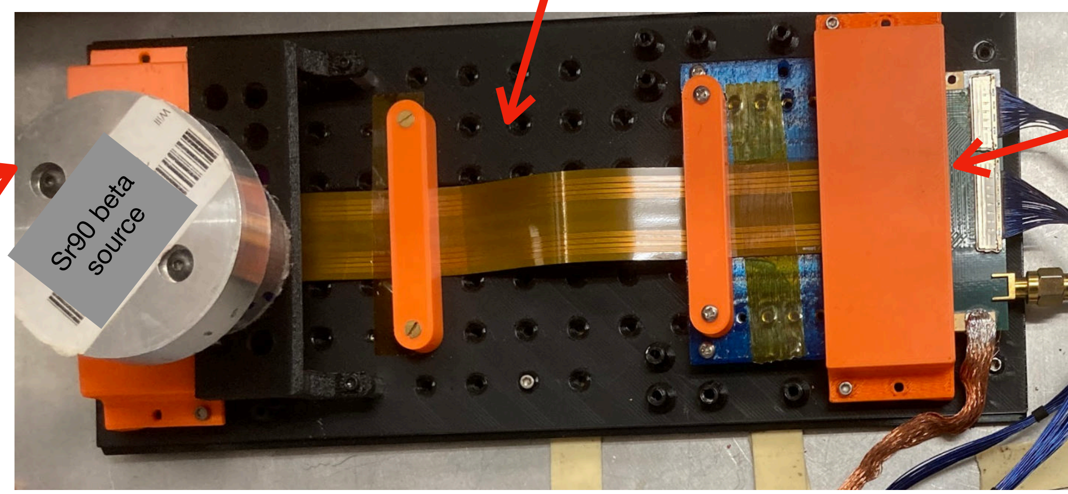
The ATAR — Toward first prototype

Full assembly of ATAR readout chain in the lab - Jan 2026

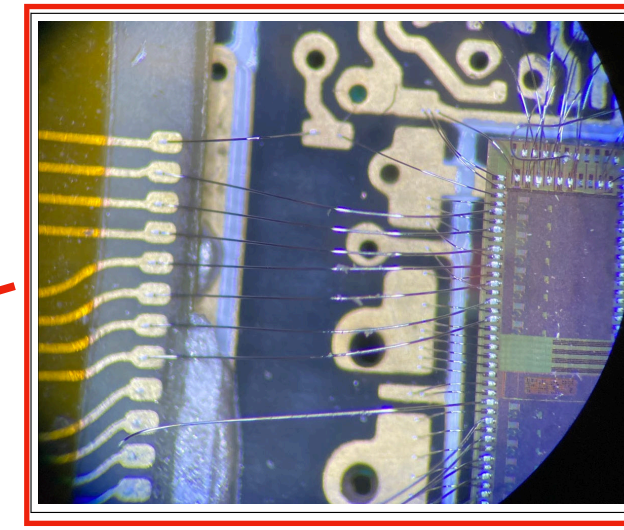


LGAD test sensors wire bonded to flex

Long flex before 1st stage amplifier to reduce material in PIONEER fiducial region

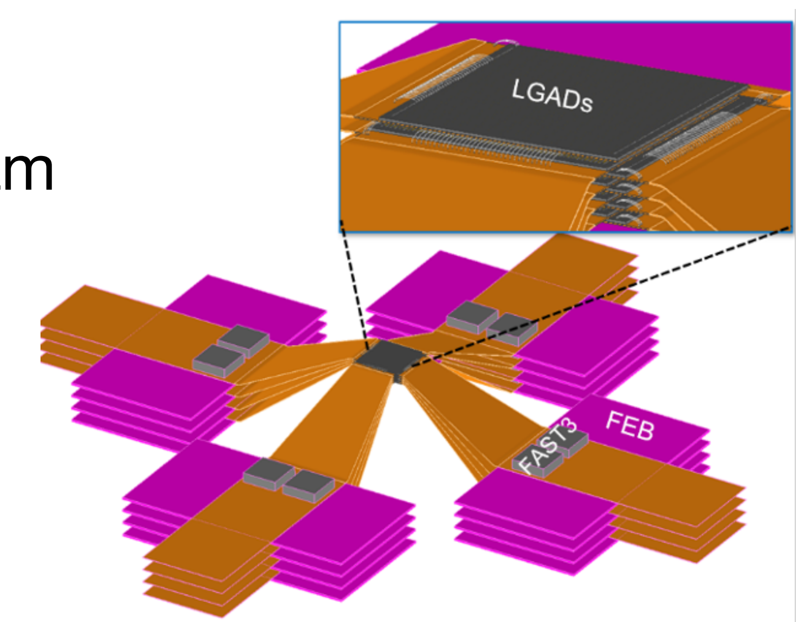


Flex to FAST3 TIA amplifier wire bonds



Fall 2026: Build and operate first prototype in PSI piM1 beam

Prototype scope: 8 layers, 32 channels per layers
(full system has 48 layers with 100 channels per layer)



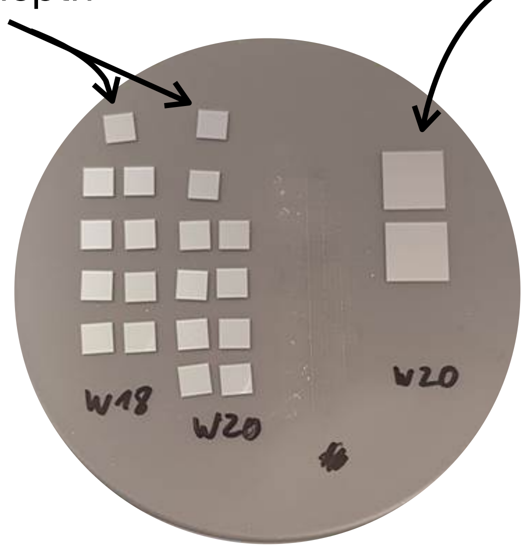
ATAR8 Prototype

The ATAR — Toward first prototype

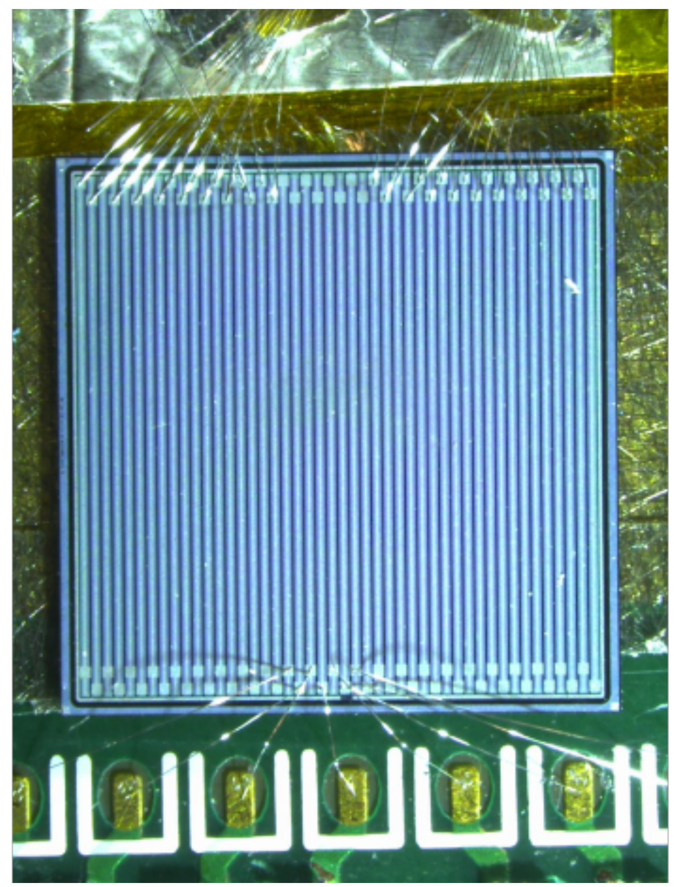
Ti-LGAD sensors for demonstrator run

1x1 cm^2
200 µm pitch
110 µm depth

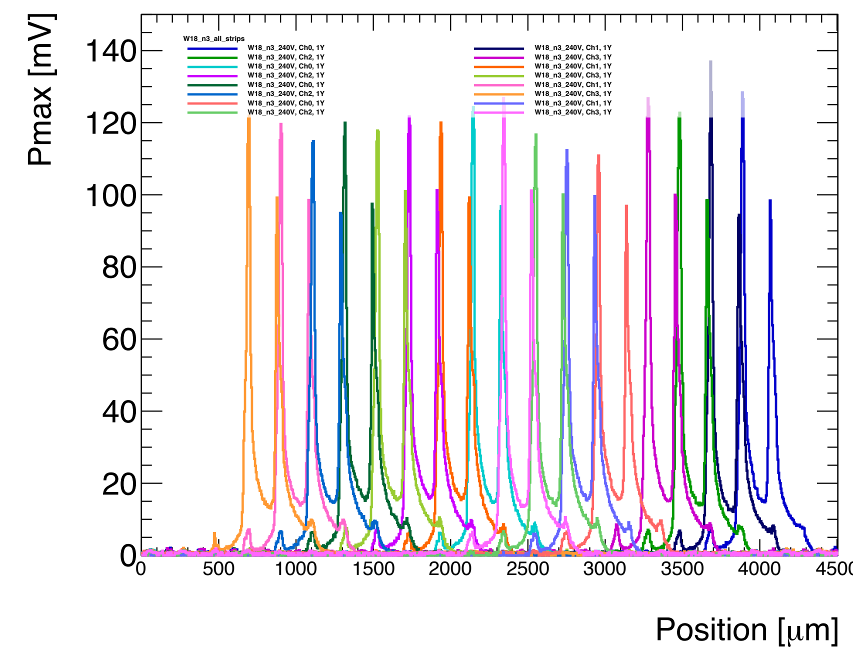
2x2 cm^2
100 µm pitch
110 µm depth



Ti-LGAD sensors from FBK (joint production with GSI)



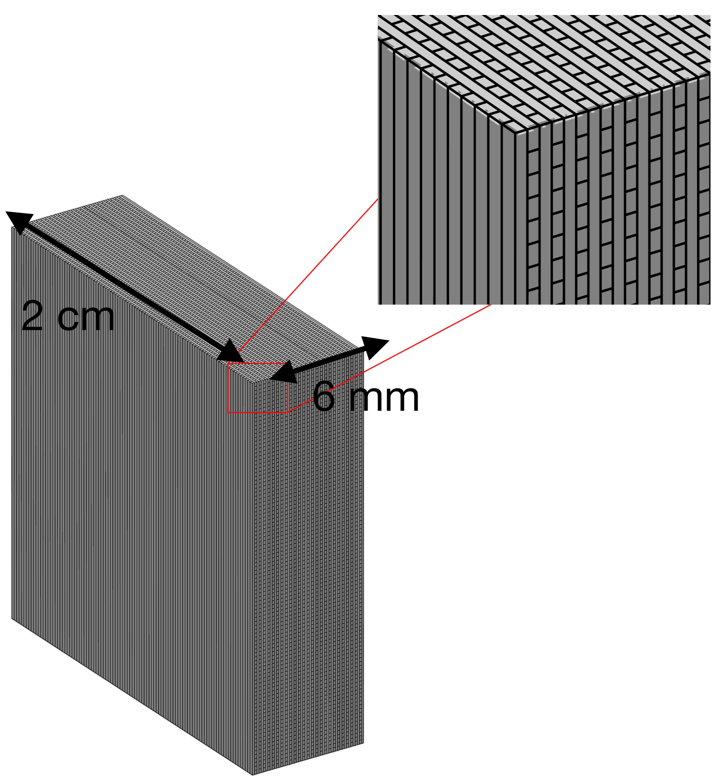
Wirebounded sensors for x-ray testing at UCSC

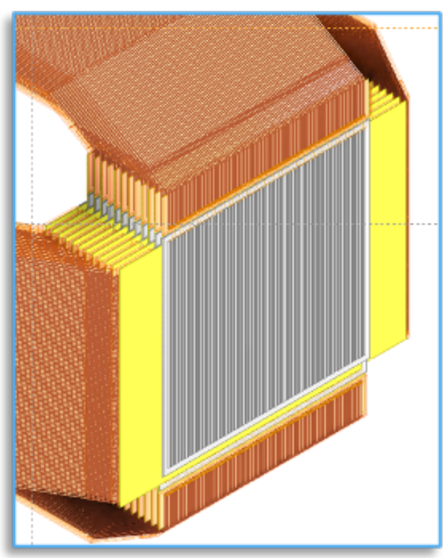


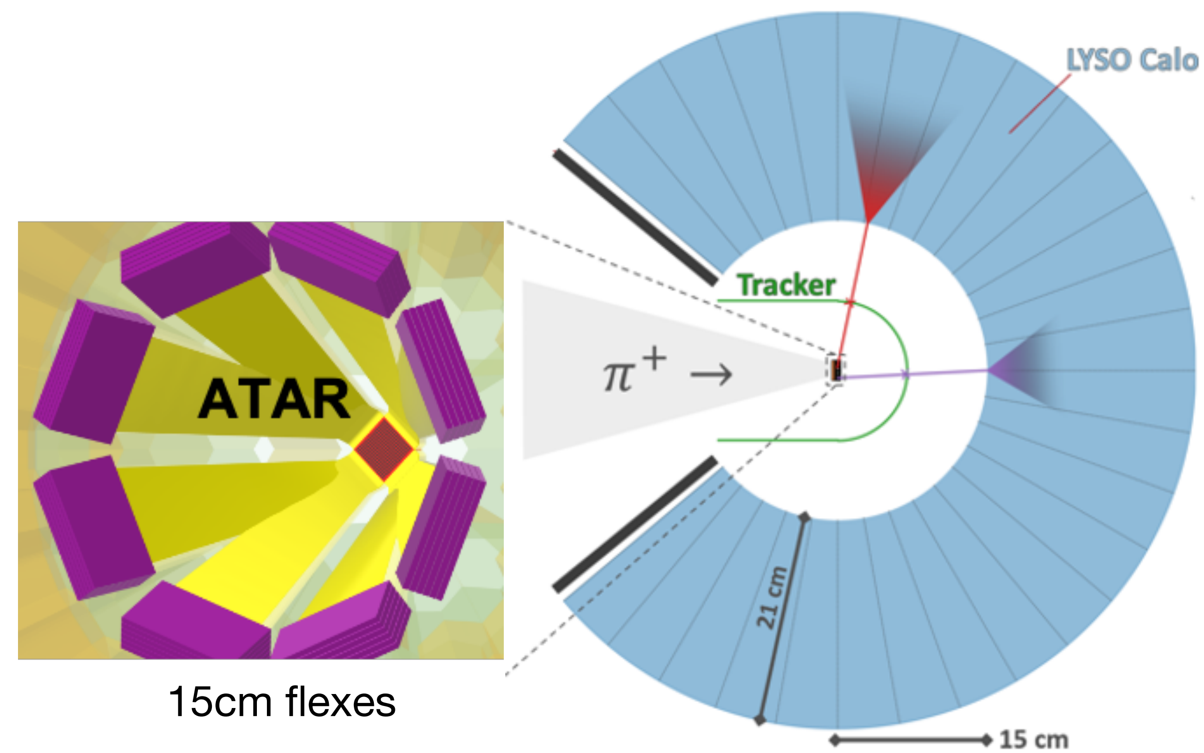
~Few %-level cross-talk on the neighbouring strip observed

PIONEER's Active TARget (ATAR)

From sensors to system







15cm flexes

Fast (~ns rise time) multichannel amplifier chips with large dynamic range

Very high sampling frequency digitizer (2GS/s)

Back to the guiding principles

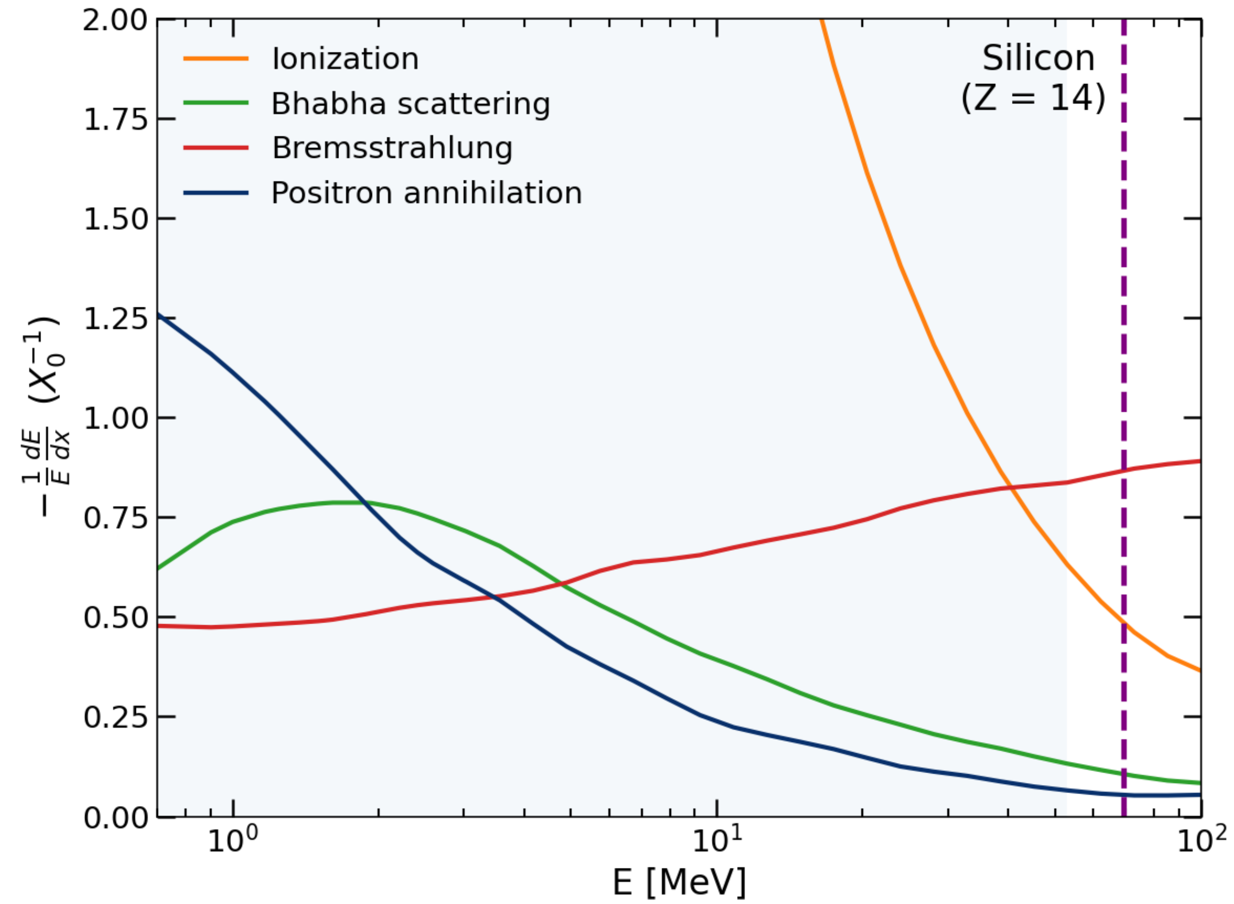
Reconstruction challenge

Master formula

$$R_{e/\mu} = \frac{N^{HE}_{\pi-e}}{N^{LE}_{\pi-\mu-e}} \times \left[1 + C_{tail}\right] \times R_{\epsilon}$$

R_{ϵ}: relative acceptance of $\pi \rightarrow e\nu$ and $\pi \rightarrow \mu(\rightarrow e\nu\nu)\nu$ events

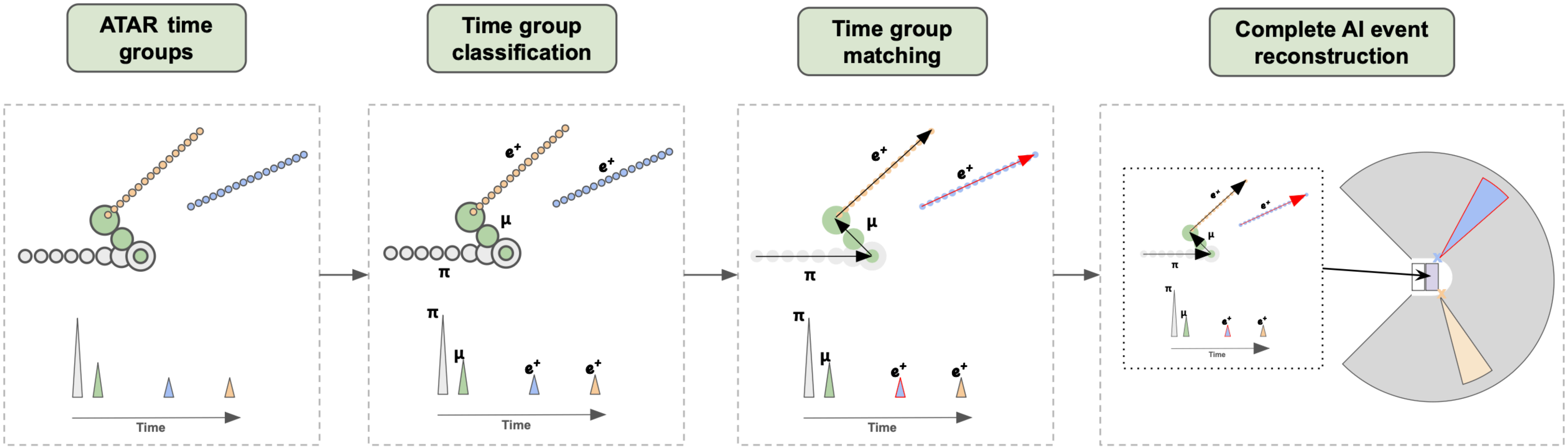
Tracking/Reconstruction challenge



Guiding principles to the design of the experiment:

1. Collect very large datasets of rare pion decays
2. Tail must be less than 1% of total signal
3. Tail must be measured with a precision of 1%
4. **Acceptance must be understood with a precision of 0.01%**

PIONEER Event Reconstruction Pipeline(s)



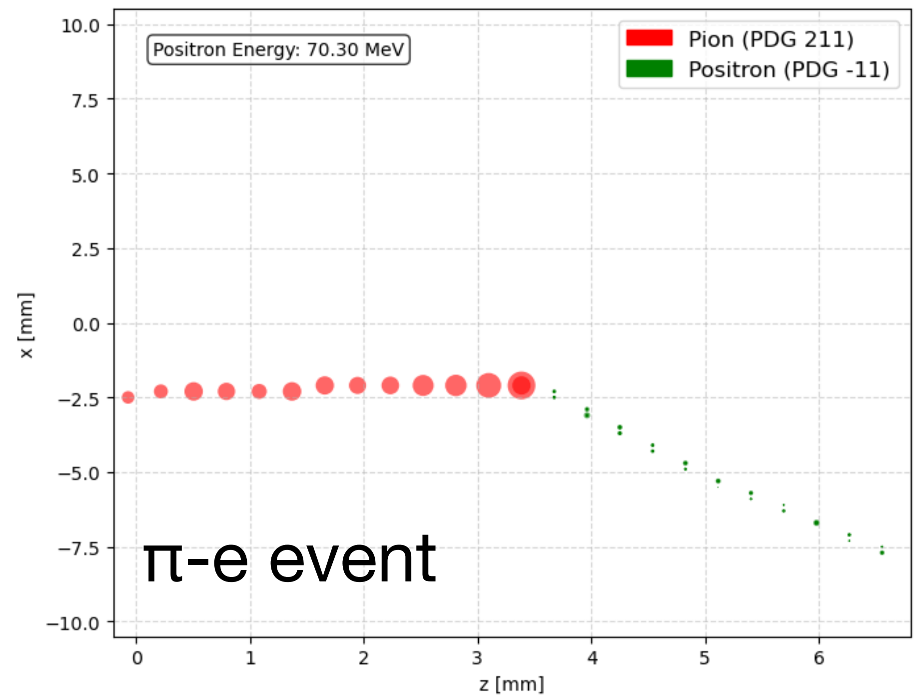
Two reconstruction pipeline in development
AI/ML employing Transformers
Traditional algorithmic "rule-based"

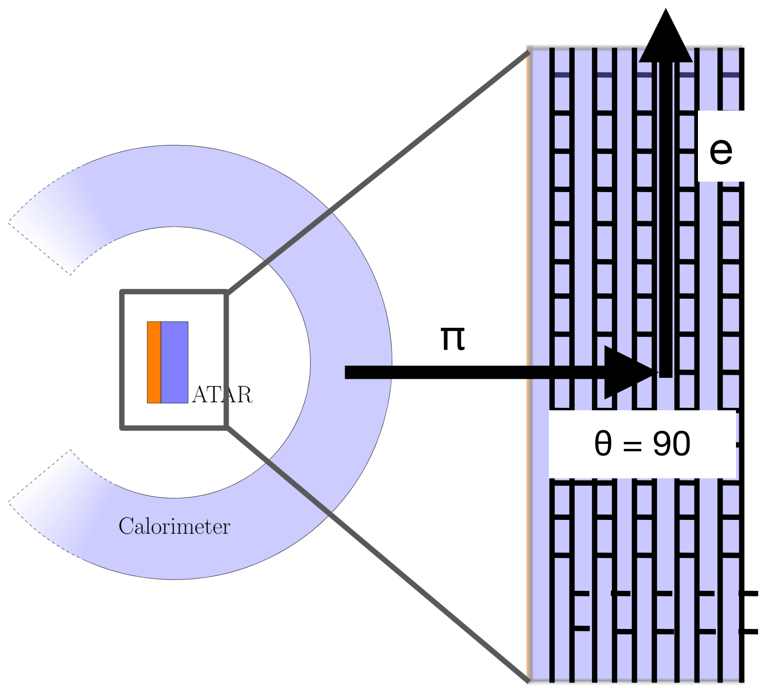
AI pipeline developed by UW Grad student Omar Beesley

See P. Schwendimann slides at ACTS4NP and the public material of PIONEER first reconstruction workshop

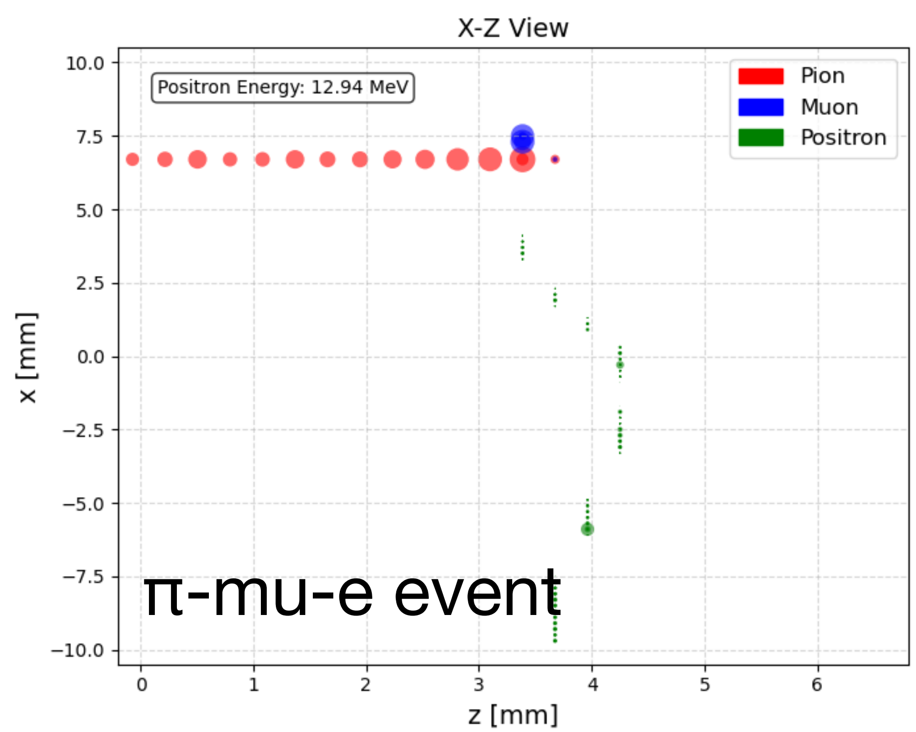
Nascent effort critical to support sensitivity estimates and test beam data reconstruction

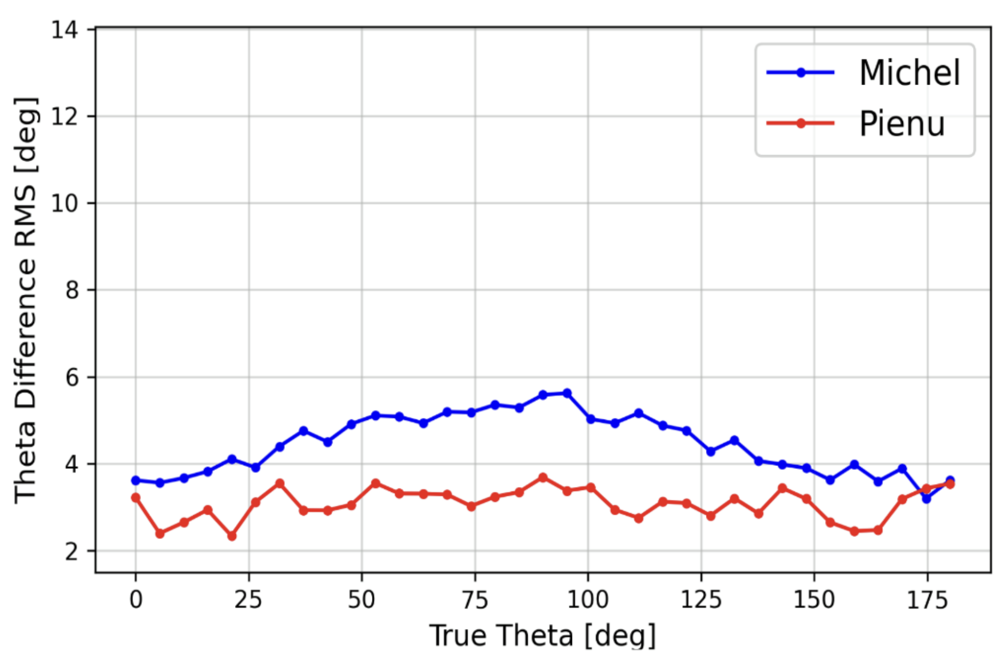
ATAR Event Reconstruction





AI (transformer) reconstruction

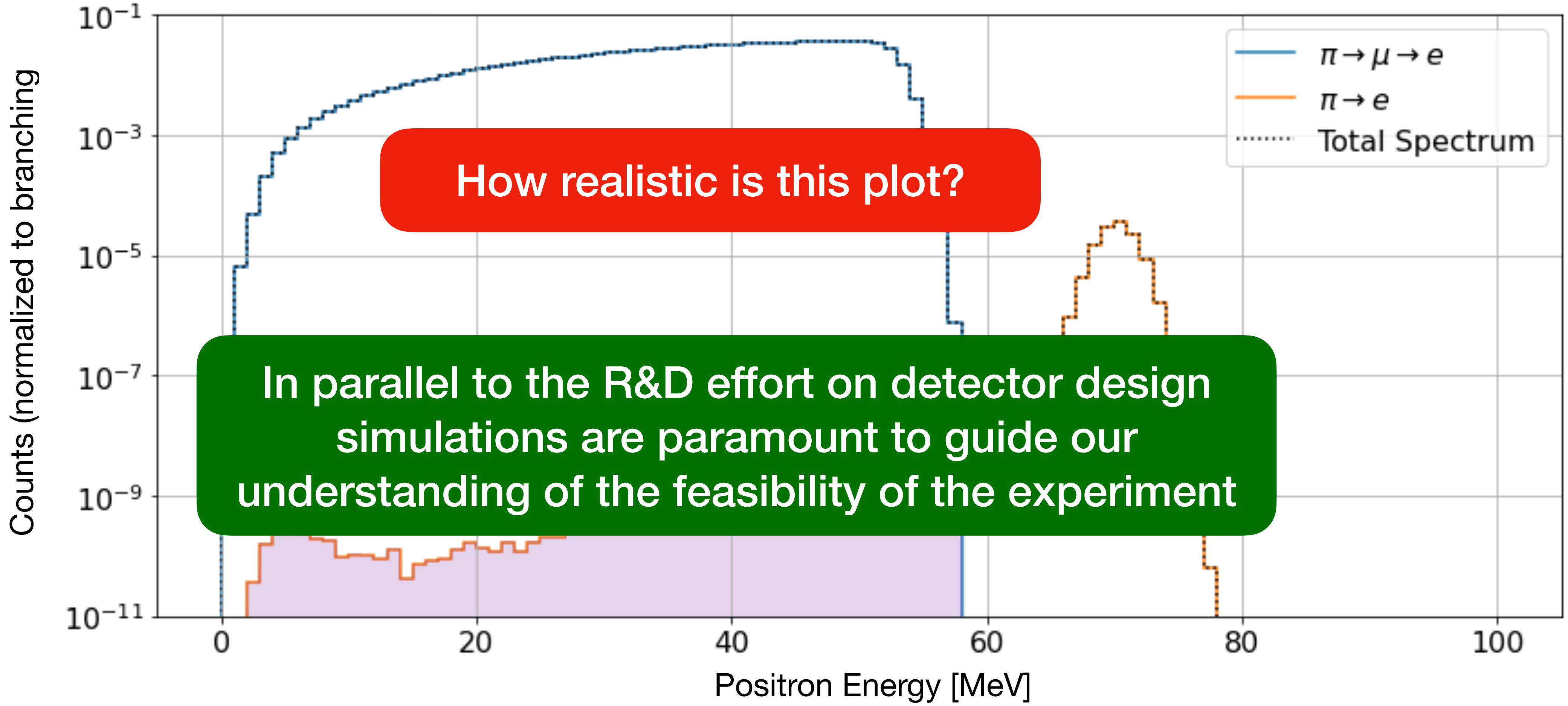




Achieving very good angular resolution even for theta~90deg

Back to the guiding principles

Simulating the experiment

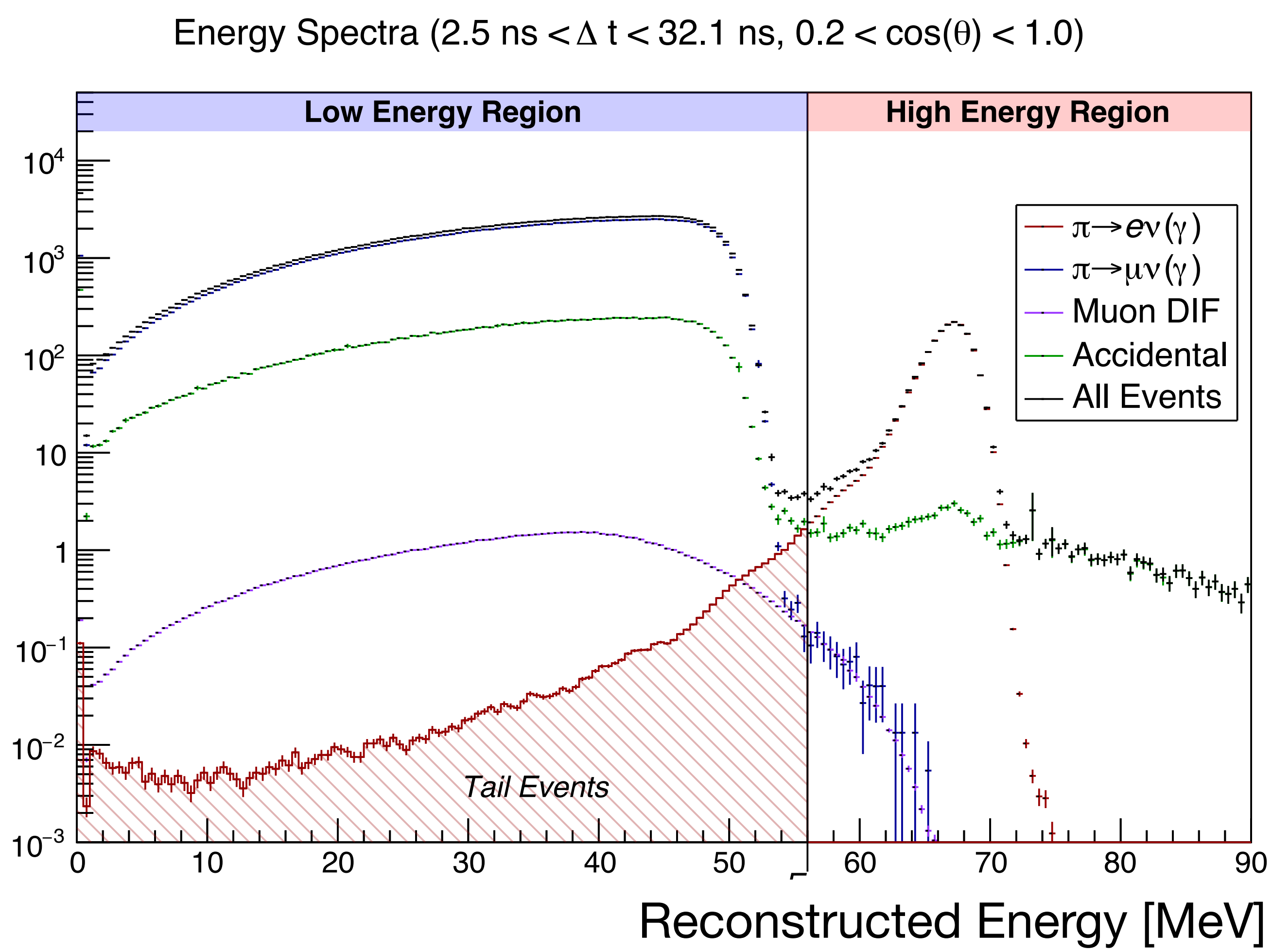


Guiding principles to the design of the experiment:

1. Collect very large datasets of rare pion decays
2. Tail must be less than 1% of total signal
3. Tail must be measured with a precision of 1%
4. Acceptance must be understood with a precision of 0.01%

Back to the guiding principles

Simulating the experiment



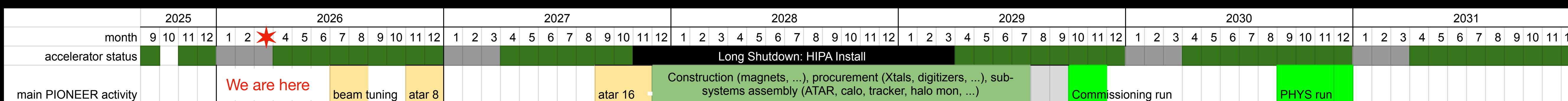
Using simulation, we validate each term of the master formula and its required precision

So far, everything indicates we can reach our targeted precision!

Timeline of the project

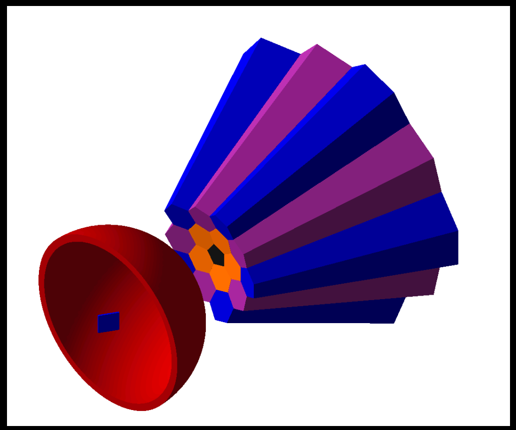
Very active R&D effort supported by simulations aiming for data-taking circa ~2030

Three test beam campaigns planned in 2026 at PSI



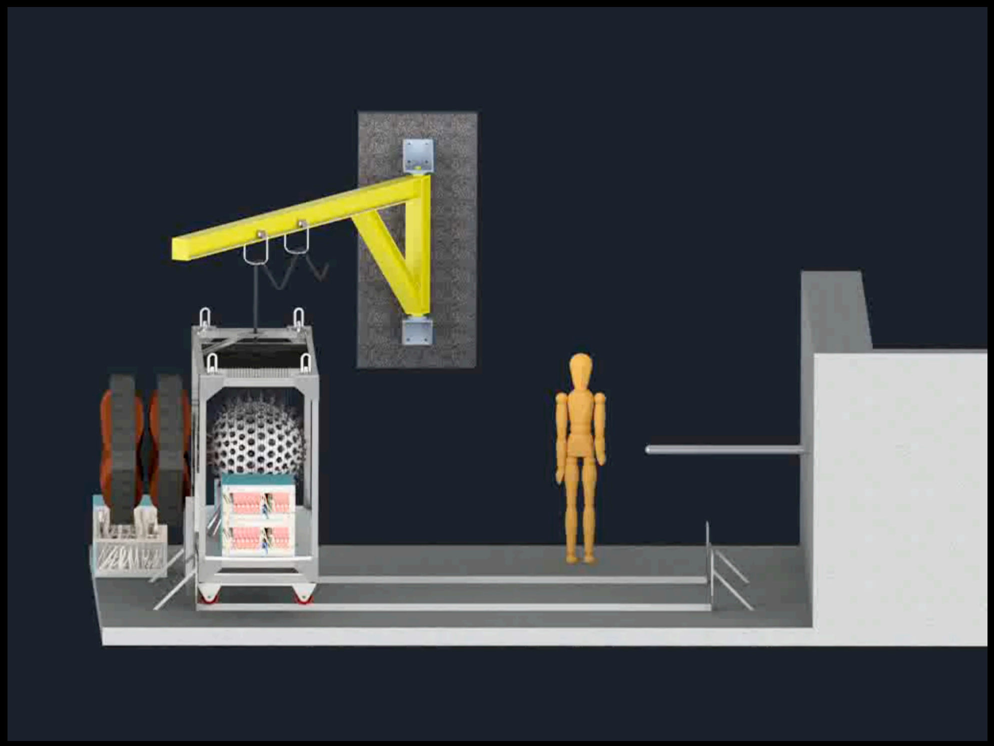
Fall 2026: ATAR 8

Fall 2027: demonstrator



16 layers ATAR
16 LYSO array
Tracker?

Assembly
Commissioning



$R_{e/\mu}$ measurement

PIONEER

Tests of the weak interaction in rare pion decays

Outline

Are we building this entire detector for a single number?

What else can we measure and search for?

Part I: Lepton Flavour Universality Test

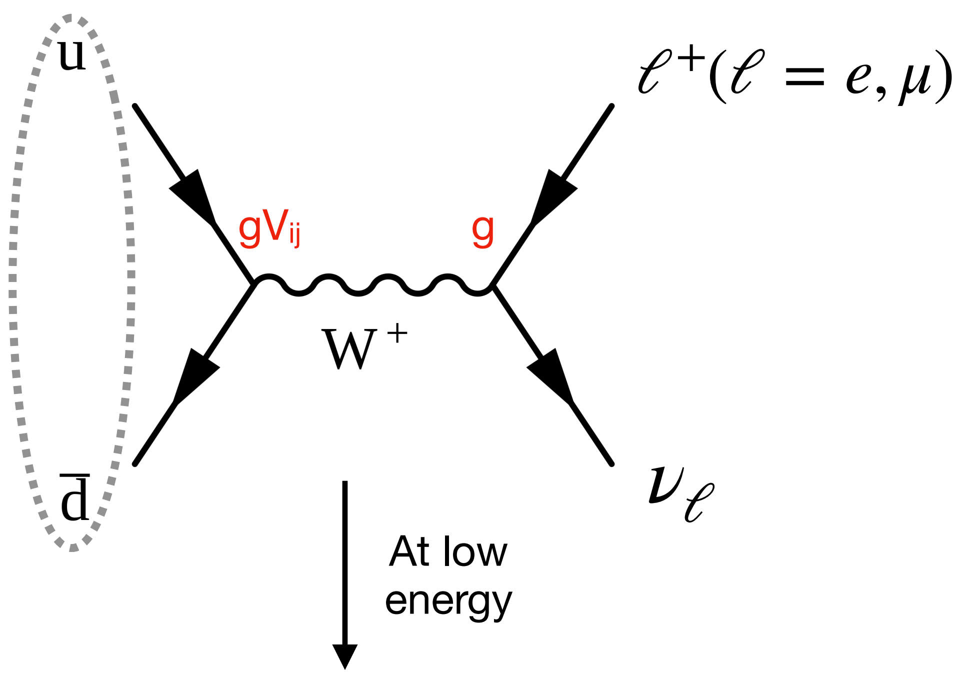
Part II: Detector prototyping

Part III: Quark-mixing measurement and exotic decays

PIONEER

Tests of the weak interaction in rare pion decays

Charged pion
(quark model)



$$G_F^{(\beta)} \sim \frac{g^2}{M_W^2} \times V_{ij}$$

Weak (β) Decay

Lepton Flavour Universality

$$\left[G_F^{(\beta)}\right]_e / \left[G_F^{(\beta)}\right]_\mu = 1$$

Cabbibo Universality

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Rare Pion Decays

Quark-mixing measurement

Cabbibo Universality

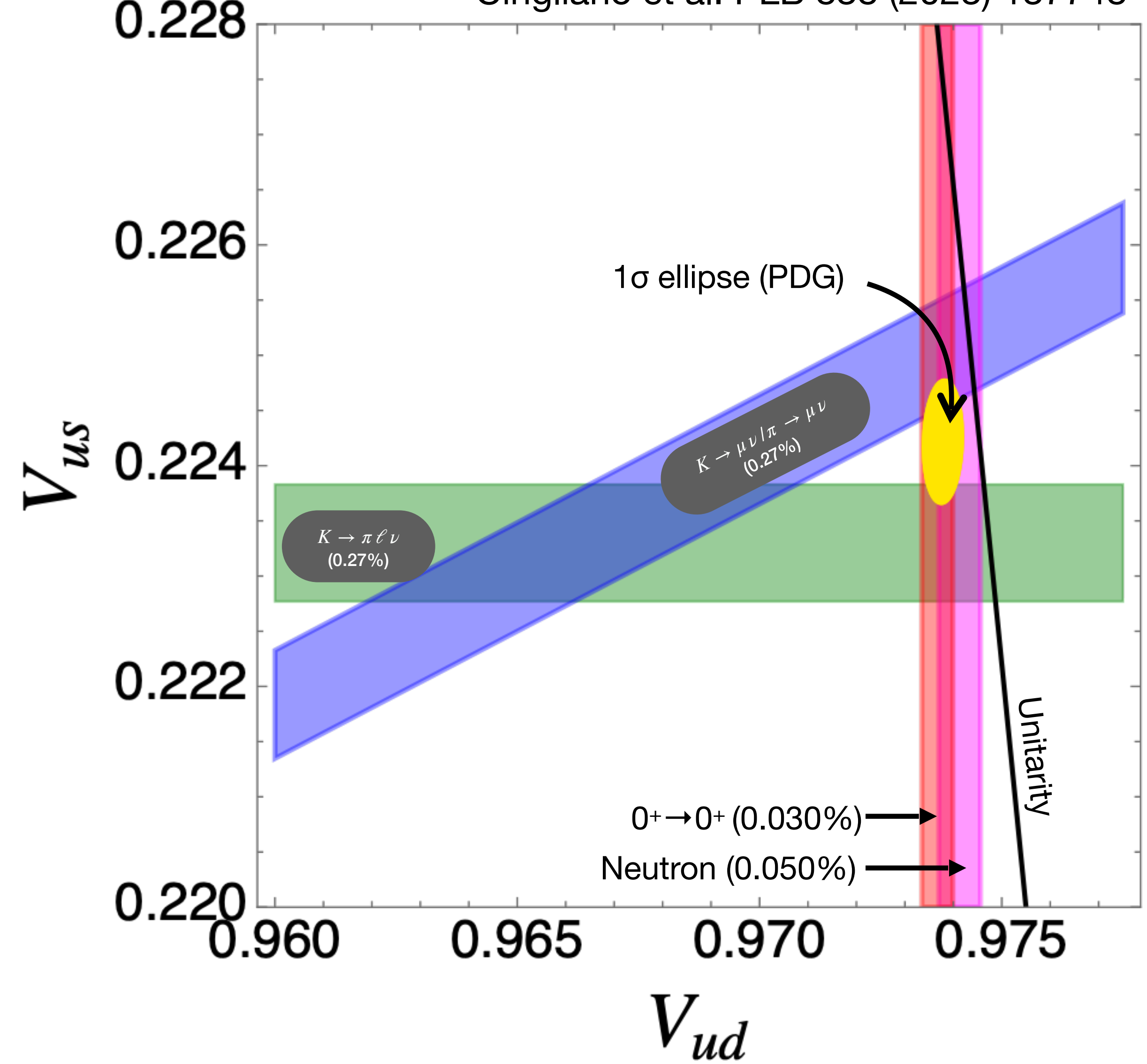
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Since $|V_{ub}| \ll |V_{us}|$, the third term can be neglected and the first row of the CKM matrix can be studied in a 2D plane: V_{us} vs V_{ud}

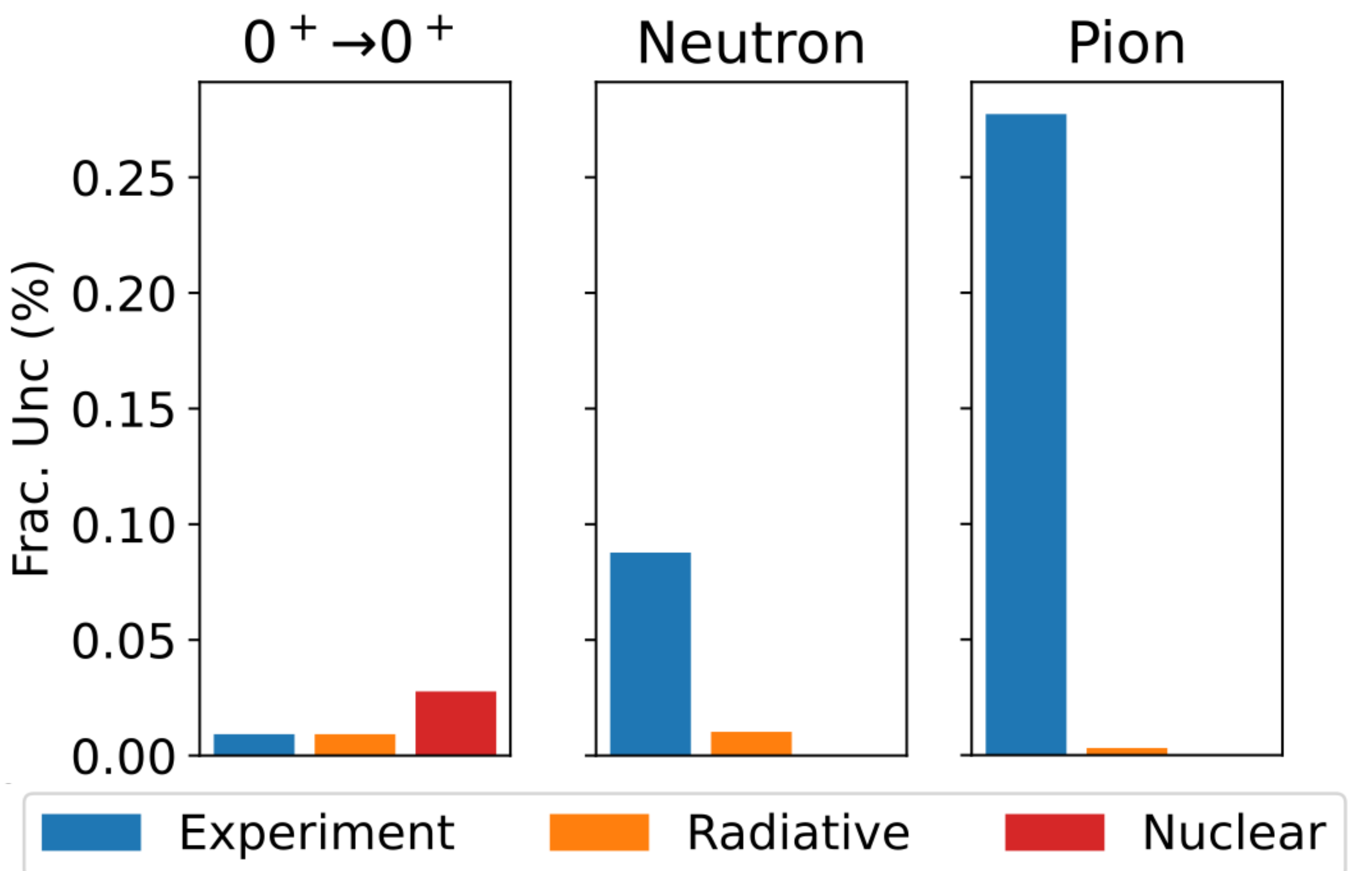
Tension between V_{us} measurements

Tensions between V_{ud} measurement and unitarity condition

Cirigliano et al. PLB 838 (2023) 137748



Landscape of V_{ud} measurements



Brodeur et al, arXiv:2301.03975

$$V_{ud}^{0^+\to 0^+} = 0.97367(11)\text{exp}(13)_{\Delta_V^R}(27)_{NS}[32]\text{total}$$

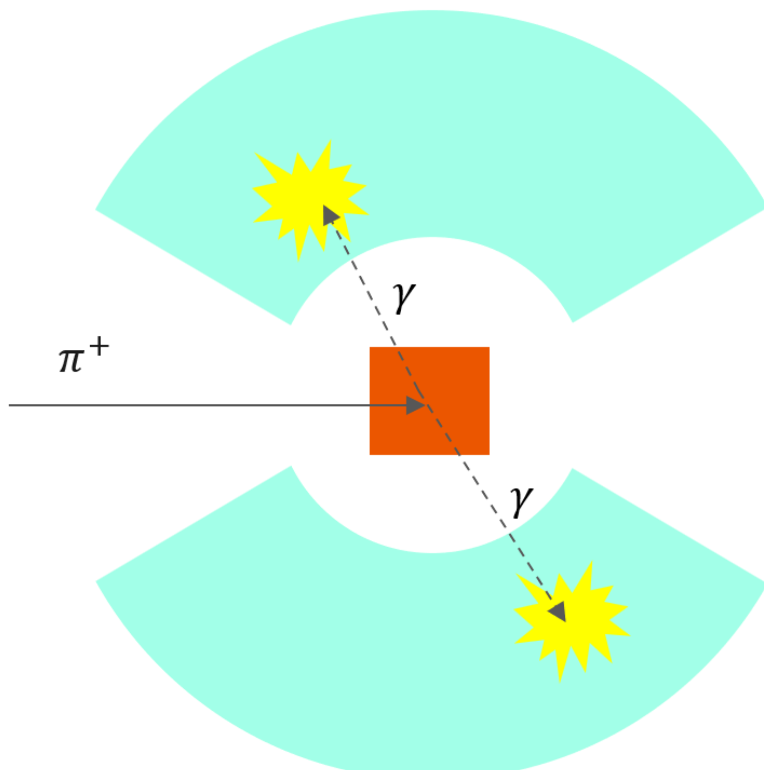
$$V_{ud}^{n,\text{PDG}} = 0.97430(2)_{\Delta_f}(13)_{\Delta_R}(82)_{\lambda}(28)_{\tau_n}[88]\text{total}$$

$$V_{ud}^{\pi} = 0.97386\underline{(281)\text{BR}}(9)_{\tau_\pi}(5)_{\Delta_R^\pi}(27)_{\Delta_f}[283]\text{total}$$

PIONEER can address this!

V_{ud} extraction from pion decays

$\pi^+ \to \pi^0 e^+ \nu_e$ measurement

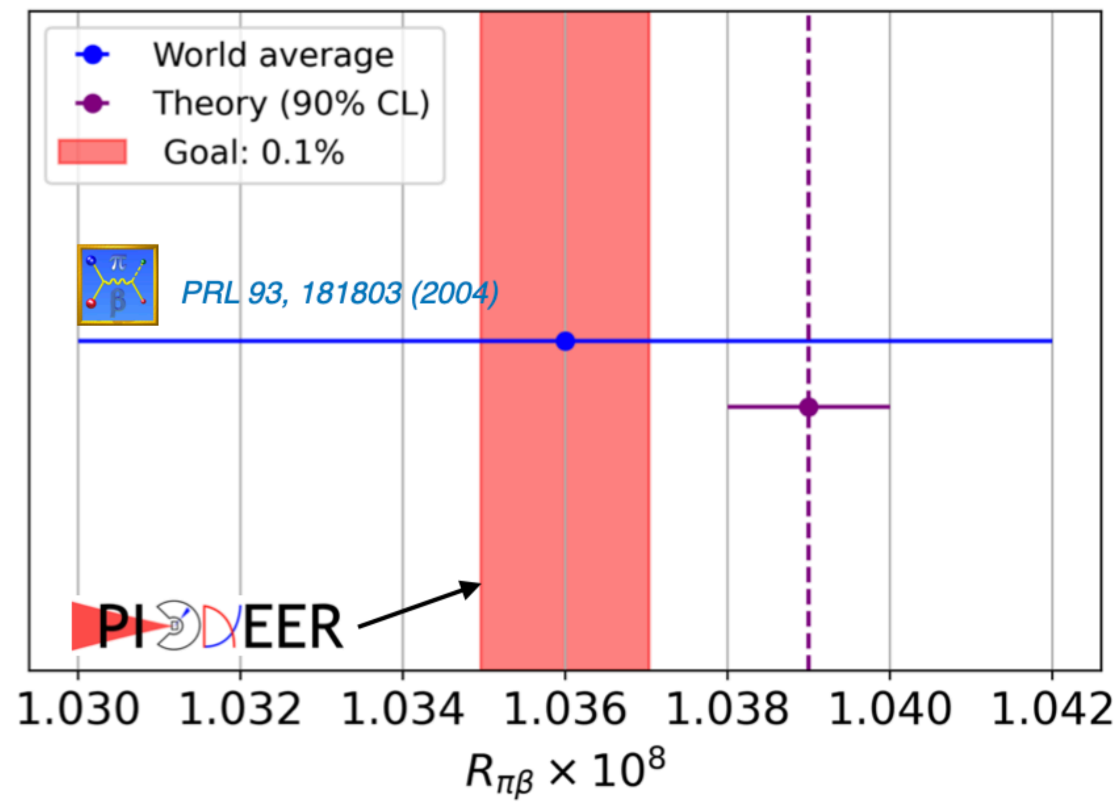


$$m_{\pi^+} = 139.6\text{MeV}$$
$$m_{\pi^0} = 135.0\text{MeV}$$
$$\tau_{\pi^0} = 0.084\text{fs}$$

Two back-to-back photons

Very low energy positron

$$R_{\pi\beta} = \frac{\Gamma(\pi^+ \to \pi^0 e^+ \nu_e)}{\Gamma(\pi^+ \to \text{all})}$$



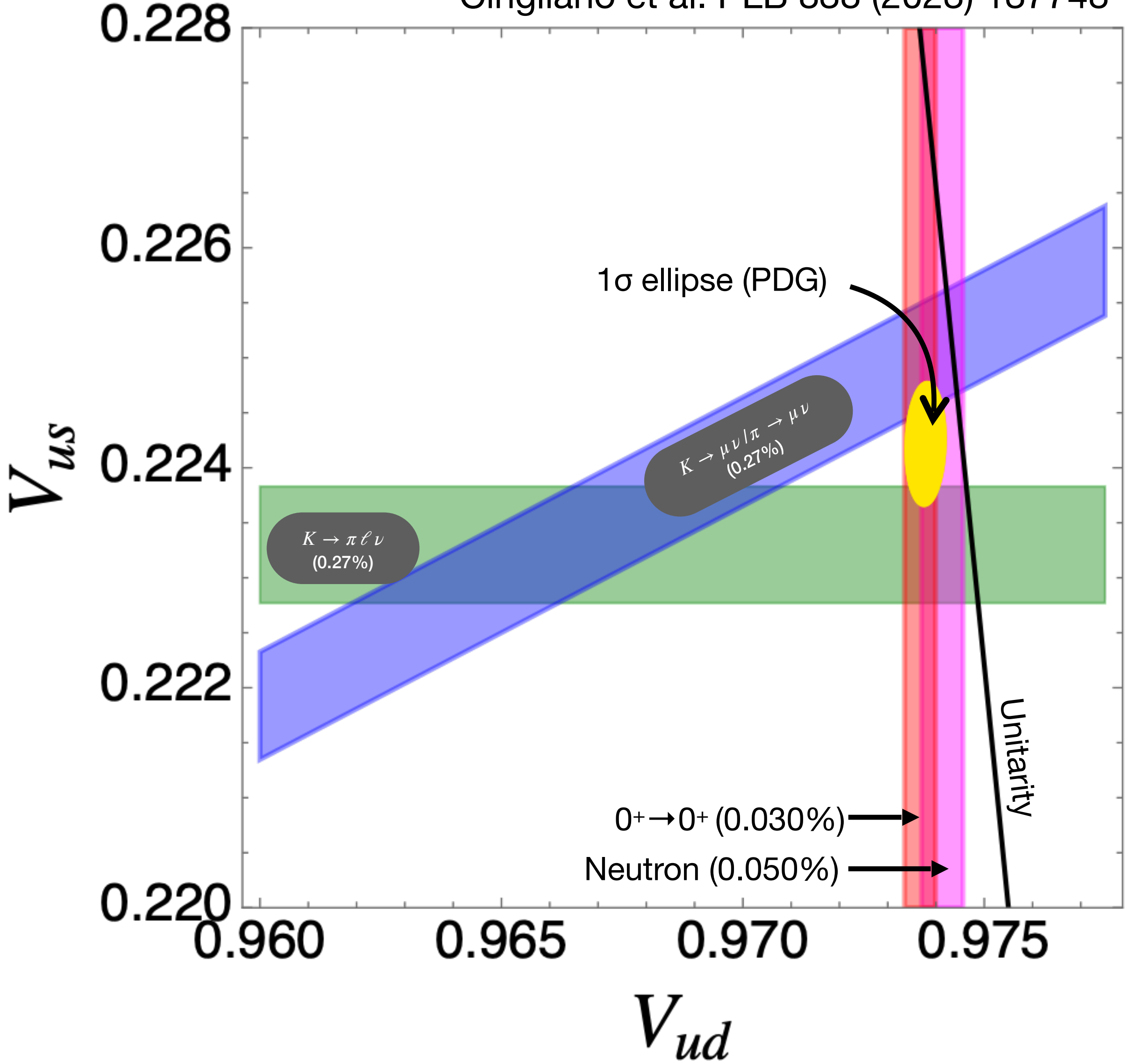
$$R_{\pi\beta}[\text{Exp.}] = 1.036(0.006) \times 10^{-8}$$

$$V_{ud}^{\pi} = 0.97386(283)$$

V_{ud} extraction from pion decays

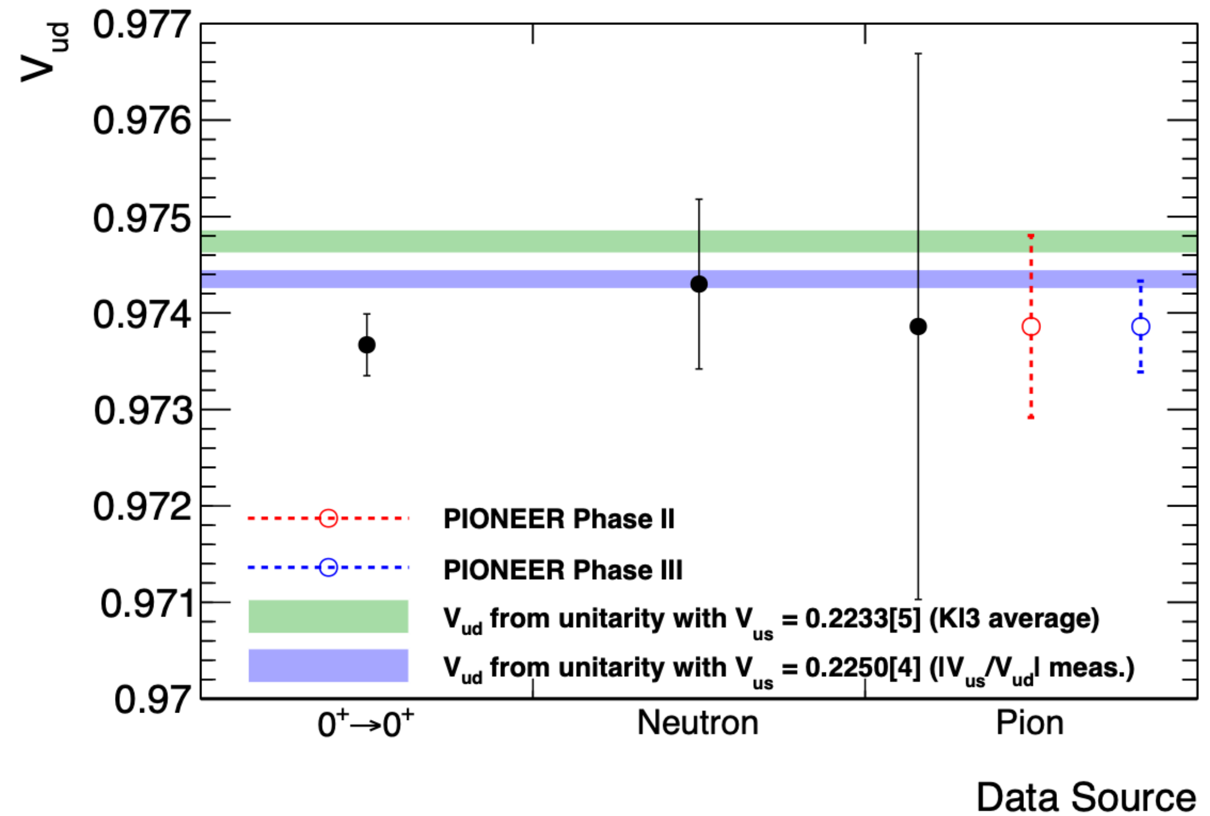
PIONEER vs other probes

Cirigliano et al. PLB 838 (2023) 137748



1D projection

PIONEER vs neutron/nuclei



Competitive probe with a completely different error budget

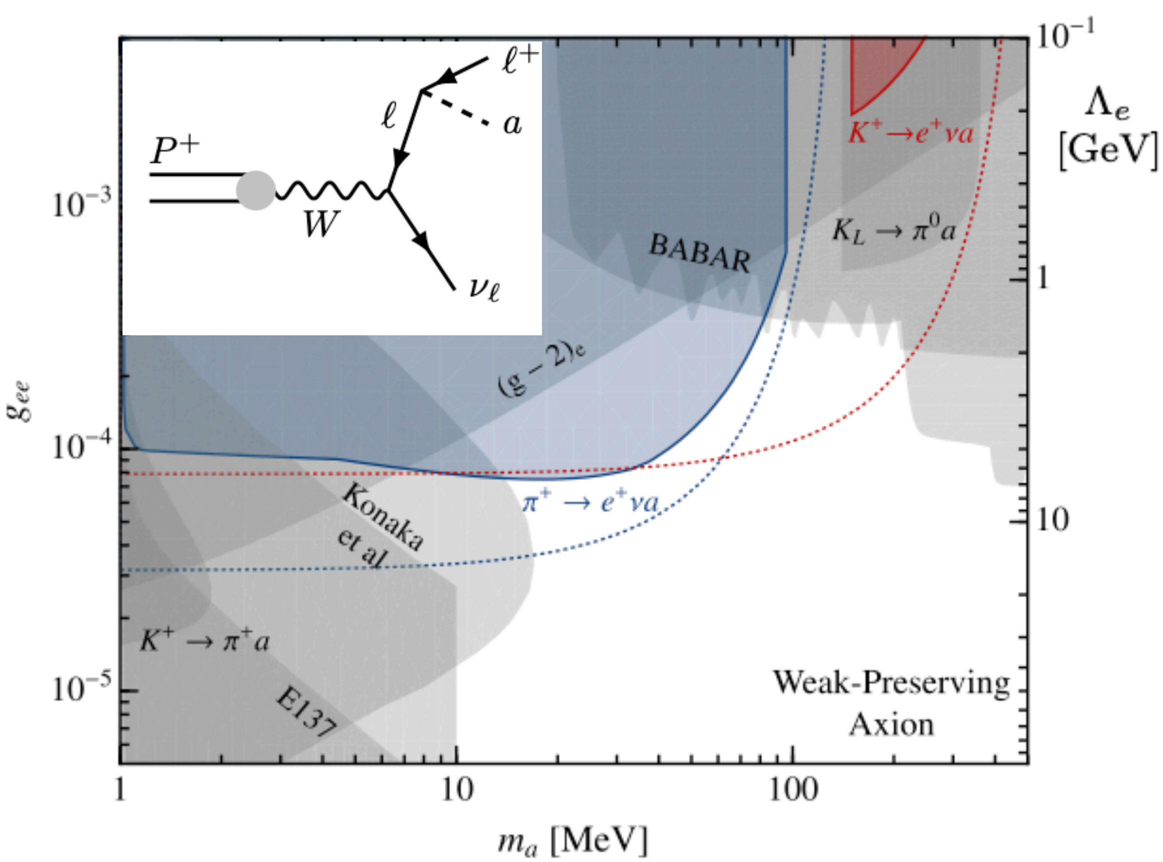
Great potential to verify the observed discrepancy!

Exotic decays of the charged pion

Goal of PIONEER
Increase reach of the global search program for feeble interactions
(ie ALPs, heavy neutrinos, …) in the 10—100 MeV range

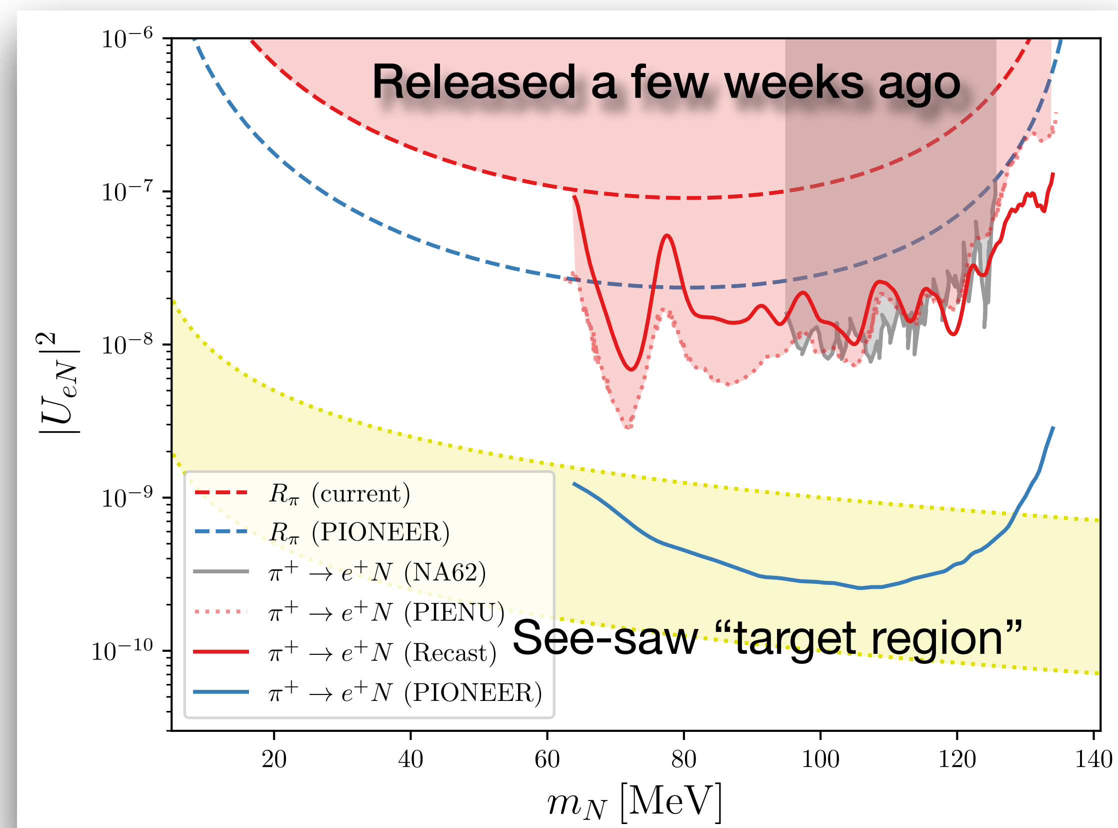
Searches profit from the very large datasets
needed for $R_{e/\mu}$ measurement

Lepto-philic axion



W. Altmannshofer, J. Dror, and S. Gori
Phys. Rev. Lett. **130**, 241801

Sterile neutrinos



W. Altmannshofer, J. Dror, et al.
arXiv:2601.06254

Conclusion

PIONEER

A next generation rare pion decay experiment

Turning a false alarm from the early days of the field…

Theory of the Fermi Interaction

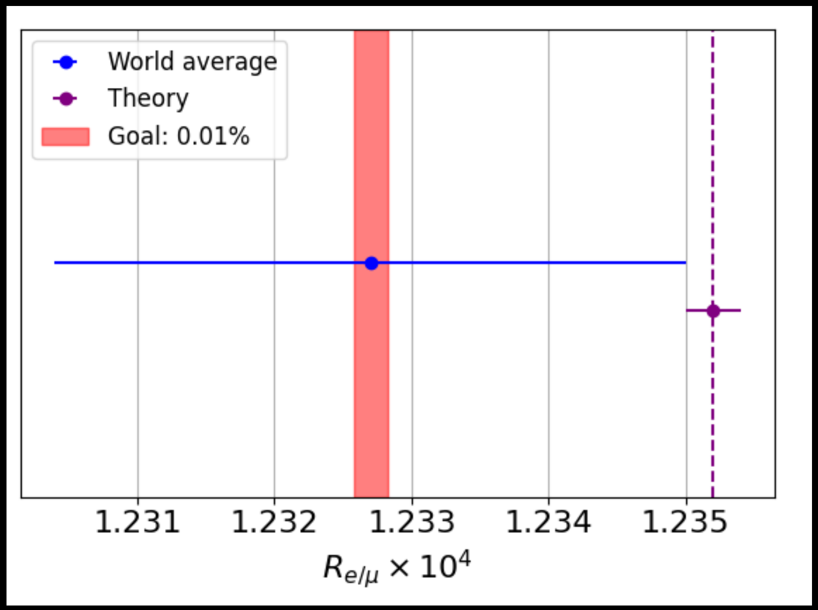
R. P. Feynman and M. Gell-Mann
California Institute of Technology, Pasadena, California
(Received September 16, 1957)

In any event one would expect a decay into $e+\bar{\nu}$ also. The ratio of the rates of the two processes can be calculated without knowledge of the character of the closed loops. It is $(m_e/m_\mu)^2(1-m_\mu{}^2/m_\pi{}^2)^{-2}=13.6\times10^{-5}$. Experimentally[16] no $\pi\rightarrow e+\nu$ have been found, indicating that the ratio is less than 10^{-5}. This is a very serious discrepancy. The authors have no idea on how it can be resolved.

PR 109, 193 (1958)

…To a pristine test of the Standard Model up to the PeV scale

By leveraging emerging technology in tracking and calorimetry



PIONEER

A next generation rare pion decay experiment

Thank you!

PIONEER Collaboration

Collaboration Meeting — Vancouver, Canada — Oct 2025