A Tracker for PIONEER

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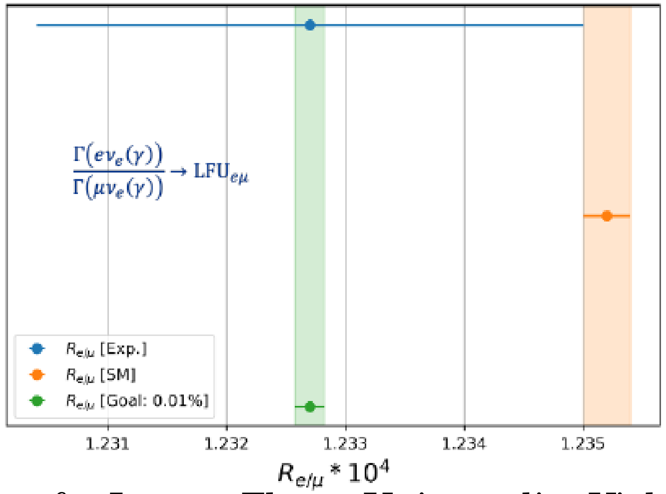
PIONEER Collaboration

Center for Frontiers in Nuclear Science

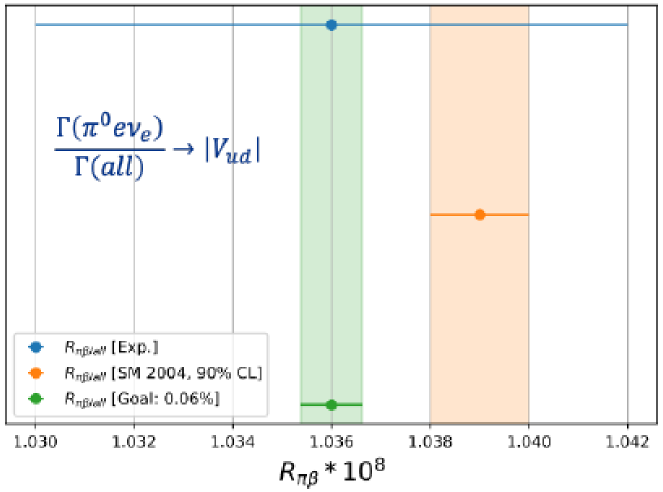
Stony Brook University

Motivation and goals of PIONEER

- PIONEER is a rare pion decay experiment to be built in Paul Scherrer Institute in Switzerland
- Existing accelerators will be used to generate intense π^+ beam with momentum of 55 ~ 70 MeV/c
- Studies π^+ decay channels for BSM phenomena.



Test for Lepton Flavor Universality Violation (LFUV)



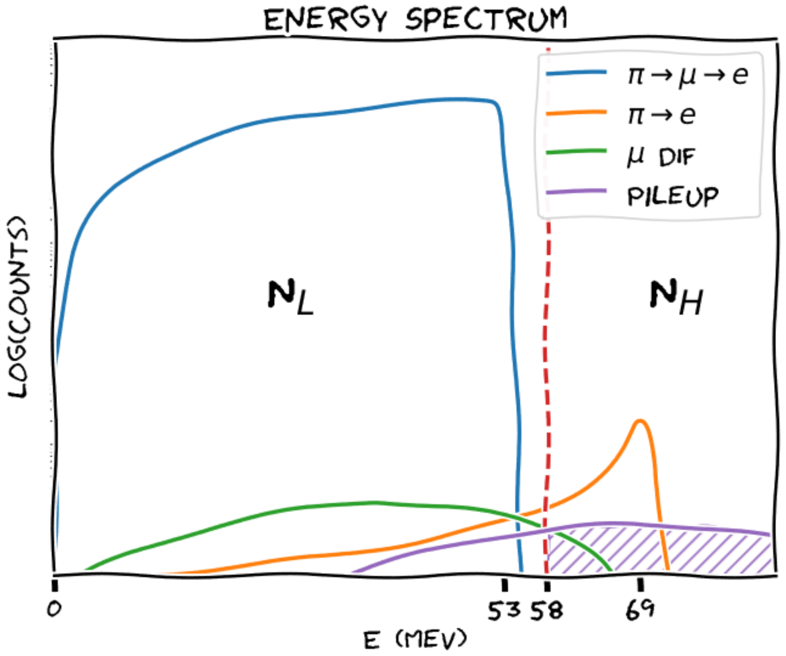
CKM Unitarity test

- Measure $R_{e/\mu} = \dfrac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$: $O(\pm 0.01\%)$
- Measure $R_{\pi\beta} = \dfrac{\Gamma(\pi^+ \to \pi^0 e^+ \nu)}{\Gamma(\pi^+ \to all)}$: $O(\pm 0.05\%)$

Ref: PIONEER proposal, arXiv: 2203.01981

Experimental requirements

- The experiment targets for 0.01% uncertainty in $R_{e/\mu}$ measurement and 0.05% uncertainty in pion beta decay measurement, which asks for very precise counting of the events.
- Though the positrons from $\pi^+ \rightarrow e^+$ and $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ have very distinct energy, still due to loss of energy in various processes, the e^+ spectra from π^+ gets distorted and mixed up with the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ spectra



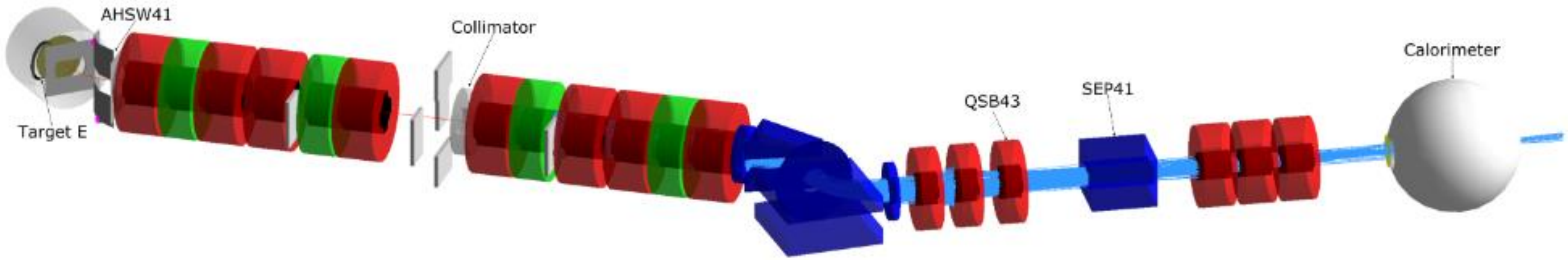
$$R_{e/\mu} = \frac{N_H}{N_L} \frac{1 + c_T}{1 + c_{DIF} + c_{PU}}$$

To Reach our Sensitivity Goal

	Value	Precision
$R_{e/\mu}$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-8})$
N_L	$\mathcal{O}(1)$	$\mathcal{O}(10^{-4})$
N_H	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-8})$
c_T	$\mathcal{O}(10^{-2})$	$\mathcal{O}(10^{-4})$
c_{DIF}	???	$\mathcal{O}(10^{-4})$
c_{PU}	???	$\mathcal{O}(10^{-4})$

Ref: Talk given by P. Schwendimann in Rare Pion Decay Workshop, 2022

The experiment

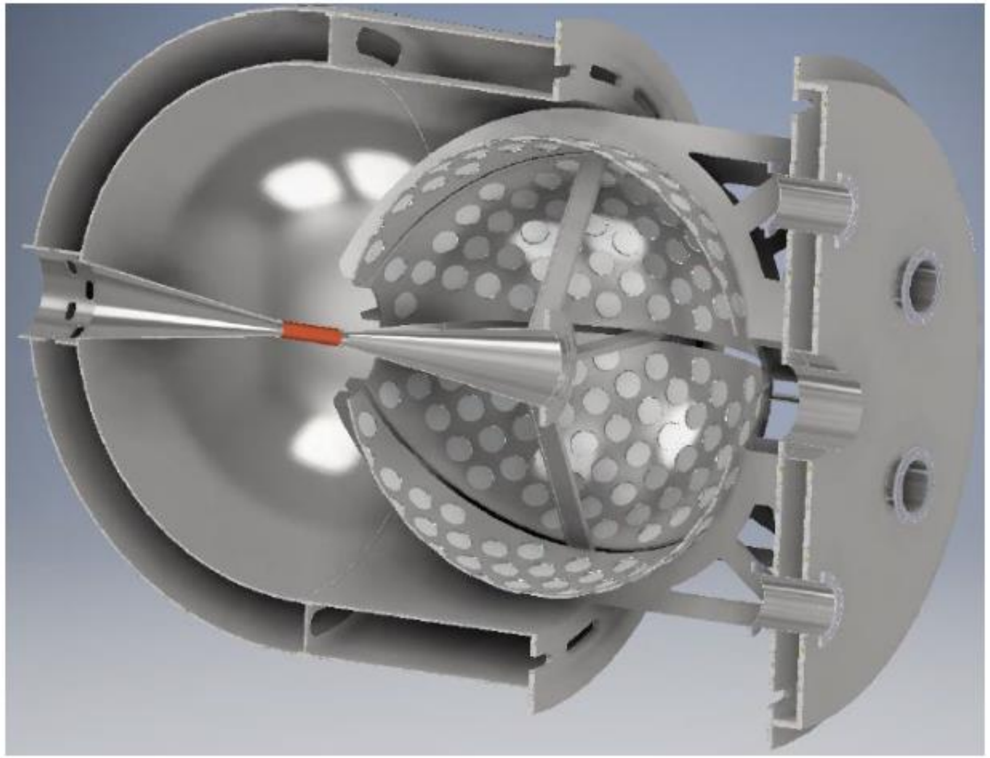


G4 beamline model of the πE5 beam line with Calorimeter

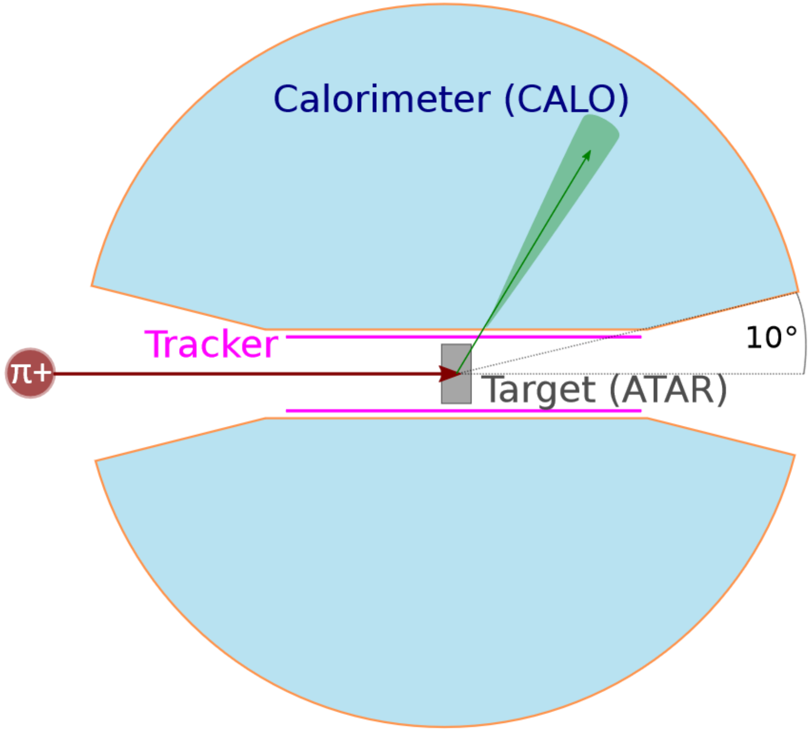
Phase	p (MeV/c)	Δp/p (%)	ΔZ (mm)	ΔX x ΔY (mm^2)	ΔX',ΔY'	R_π (10^6/s)
I	55-70	2	1	10x10	$\pm 10°$	0.3
II,III	≈ 85	≤ 5	3	15x15	$\pm 10°$	20

Required beam properties

Working principal

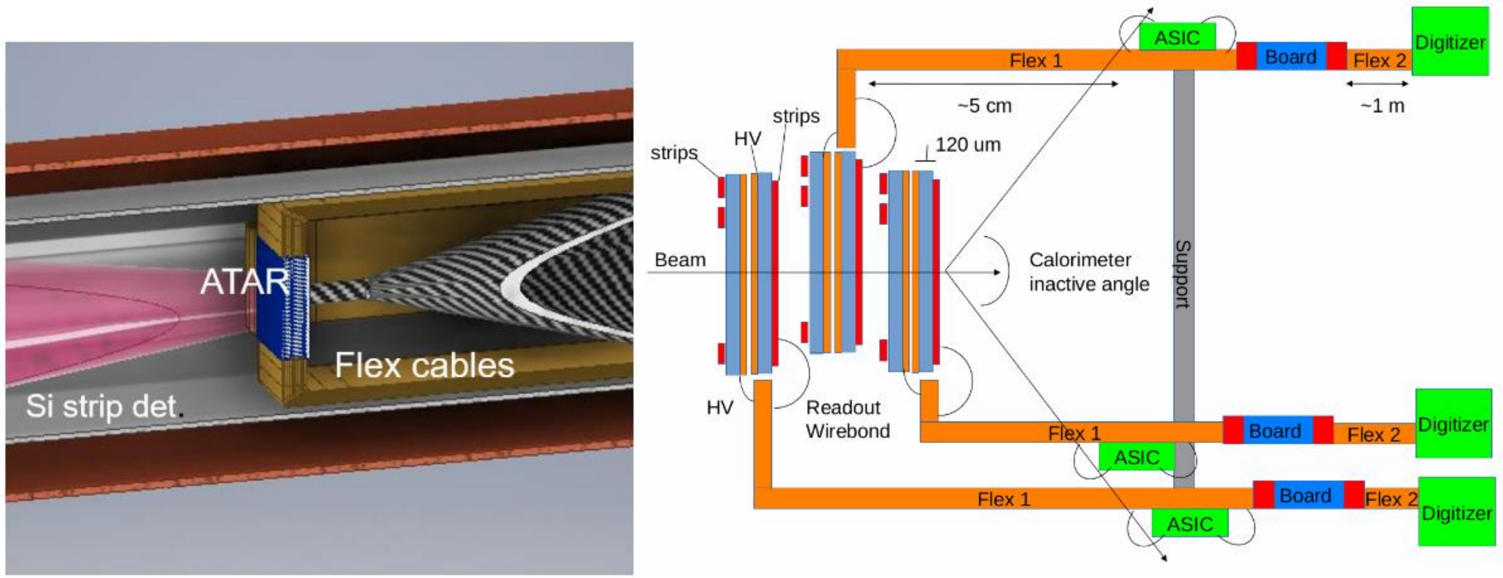


Conceptual design for the PIONEER experiment.
Ref: arXiv:2111.05375



Simple schematic of the PIONEER experiment, with Liquid Xenon (LXe) calorimeter, Low Gain Avalanche Detector (LGAD) as Active TARget (ATAR) and cylindrical Tracker. (Ref: arXiv:2203.01981)

Active TARget

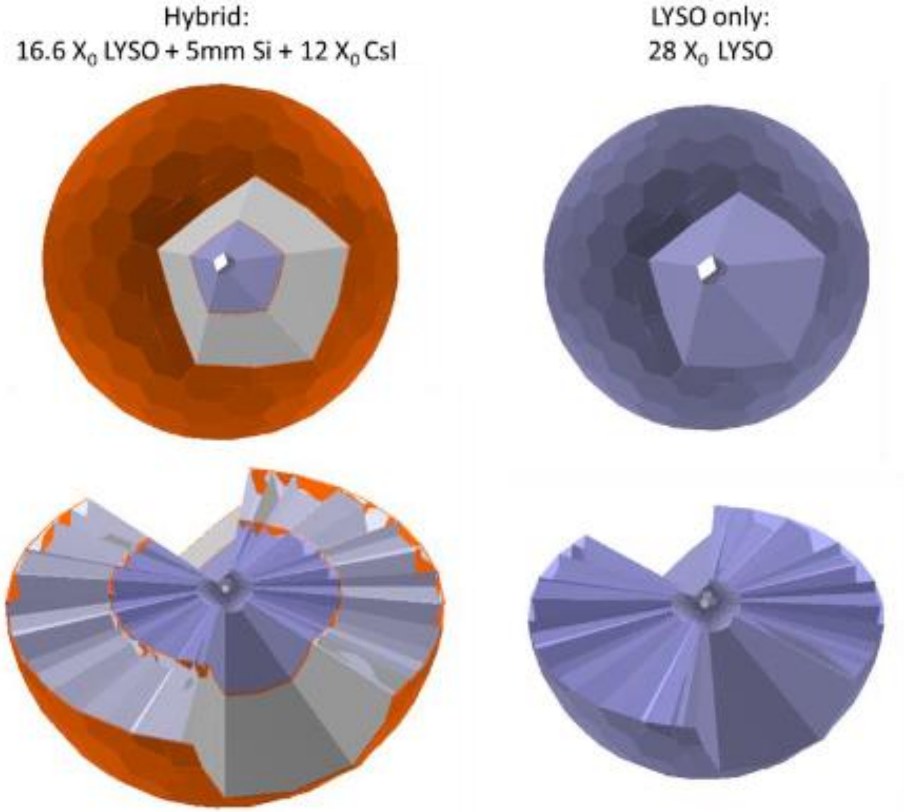


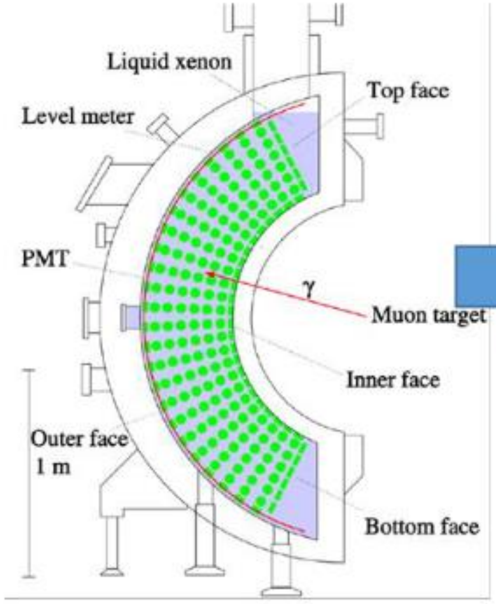
ATAR schematic and proposed electronics

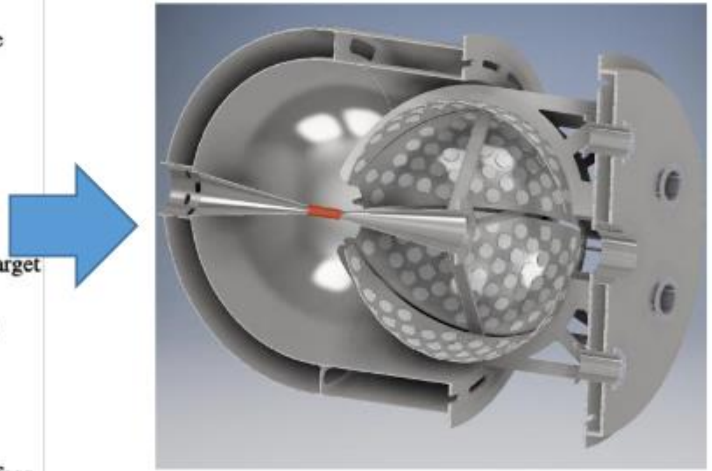
- Low Gain Avalanche Detector based detector used as Active TARget (ATAR).
- Dimensions: 2 cm x 2 cm transverse to beam, 6 mm in beam direction, each strip 120 μm thick
- 50 layers of silicon strip detectors, placed in orthogonal direction in consecutive layers
- 200 μm pitch for strips, ~ 5000 channel to read

Ref: PIONEER proposal, arXiv: 2203.01981

Calorimeter



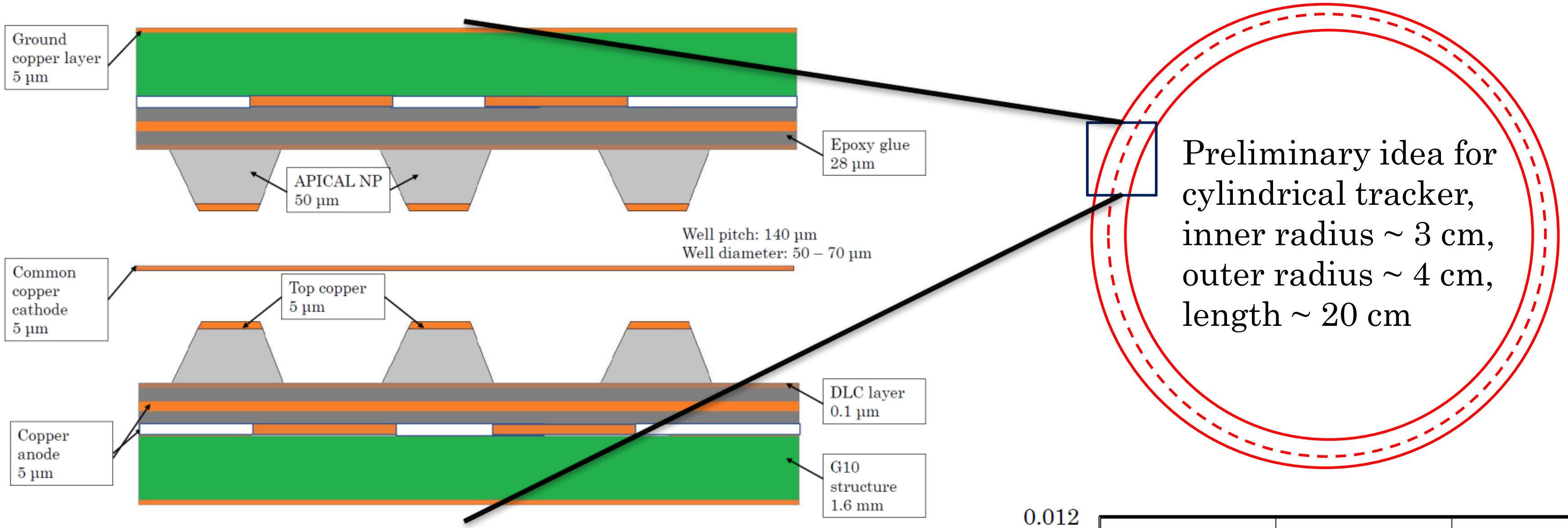




Ref: Talk given by D. Hertzog at TAU 2021

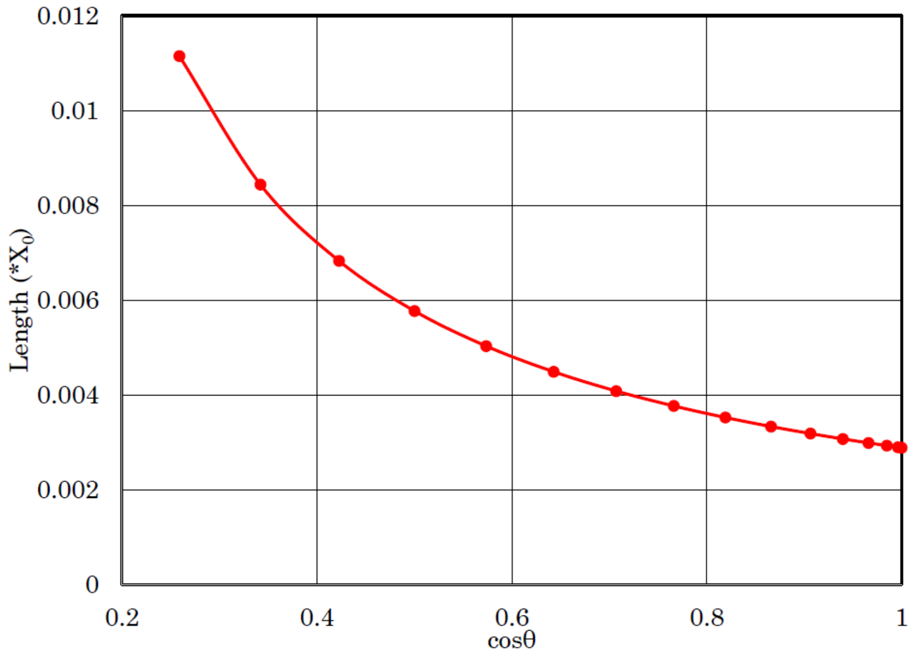
- PIONEER goal requires complete energy deposition in the calorimeter
- Fast response, high resolution and symmetric
- 2 options for calorimeter, LXe scintillator or LYSO based calorimeter

µ-RWell for tracker



Detailed view of µ-RWell (not according to scale)

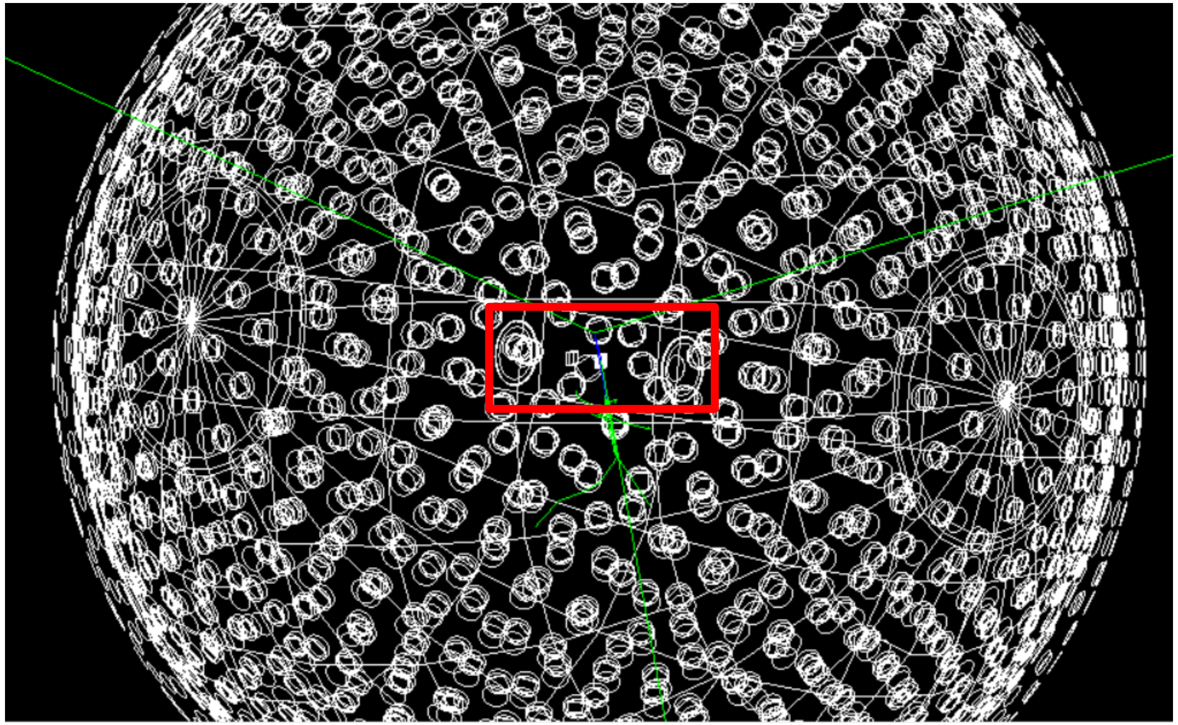
- High gain (~ 10^4)
- Good spatial resolution (<100 µm)
- Good time resolution (~ 5.7 ns)
- High rate capability (~ 1 MHz/cm^2)
- Ease of deployment



Material budget for proposed tracker

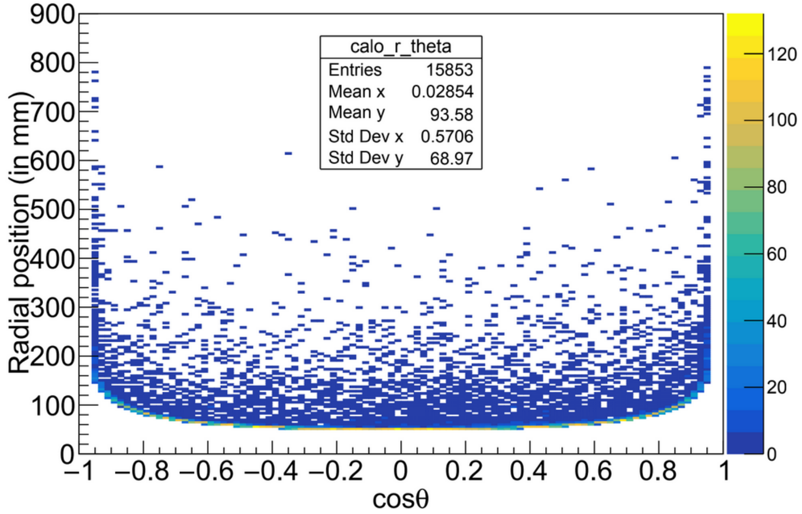
Simulation conditions

- For precise measurement, simulation of the tracker is being carried out assuming a simple geometry for tracker
- A solid cylindrical shell of length 15 cm and average density of 1.47 gm/cc is implemented as tracker
- It has been assumed that stopped π^+ are decaying at the center of the ATAR, and can decay in any channel.
- $\pi^+ \rightarrow e^+$ event rate has been taken to be of 10^{-2} order w.r.t. $\pi^+ \rightarrow \mu^+$ events
- Effect of one or more layer of tracker has also been studied.

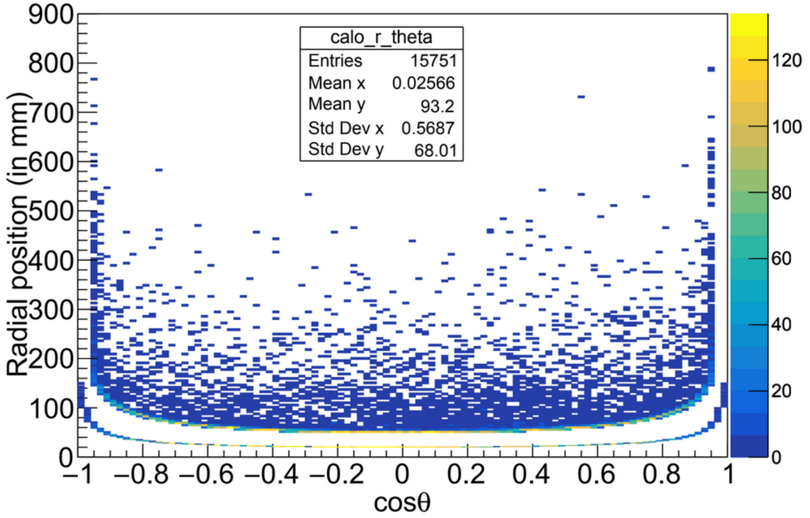


PIONEER detector simulation

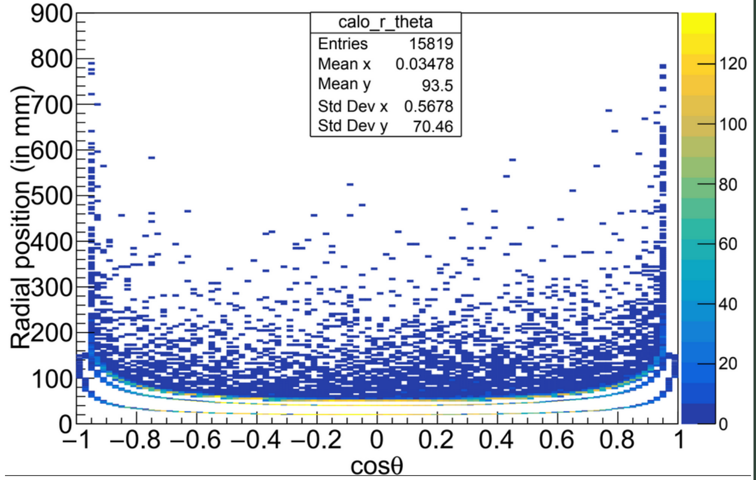
Energy deposition in detector



Energy deposition pattern
without any tracker



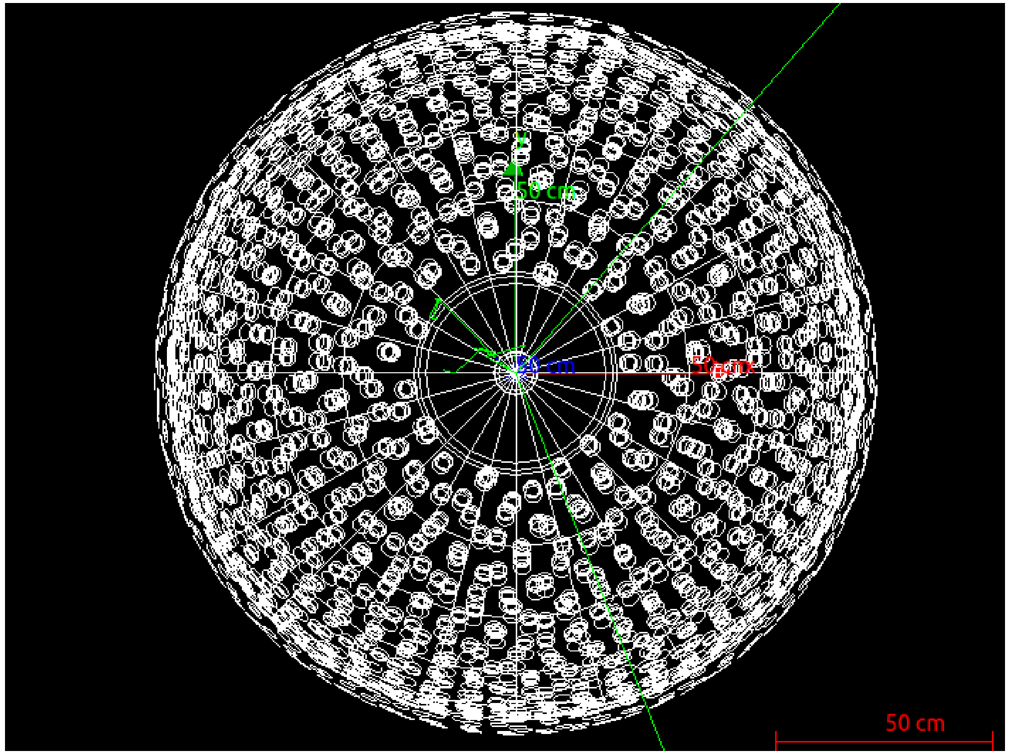
Energy deposition pattern
with one layer tracker



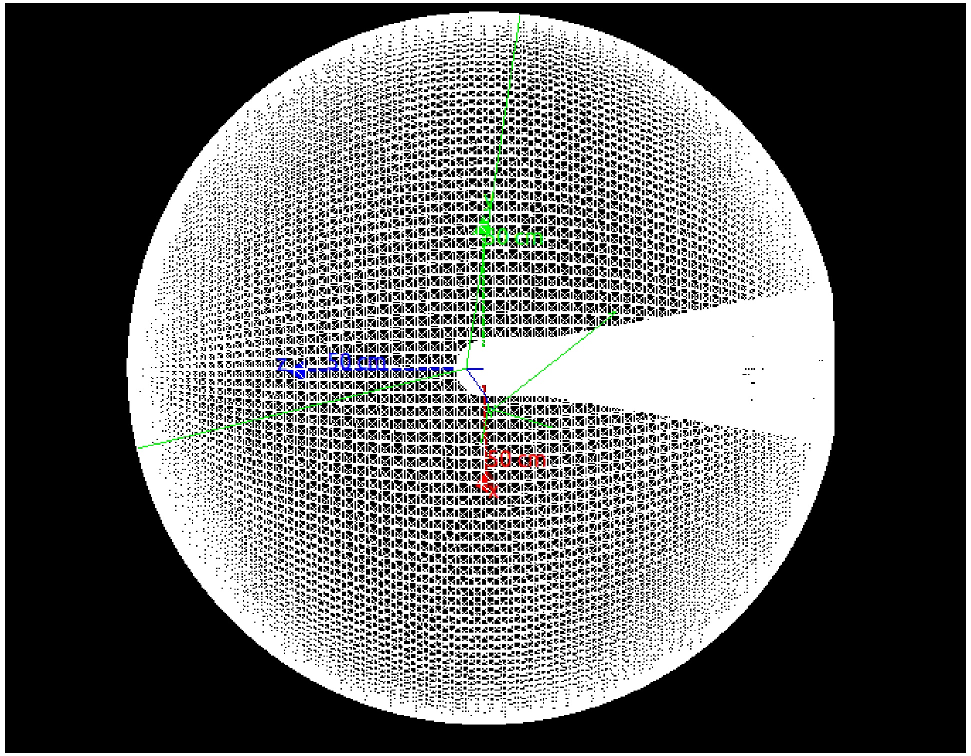
Energy deposition pattern
with two layers tracker

- The three panels show the energy deposition pattern in the detector in cases of no tracker, one layer of tracker and two layers of tracker.
- Calorimeter does not cover the whole range of theta.
- Presence of tracker improves particle detection and energy reconstruction

Modified calorimeter

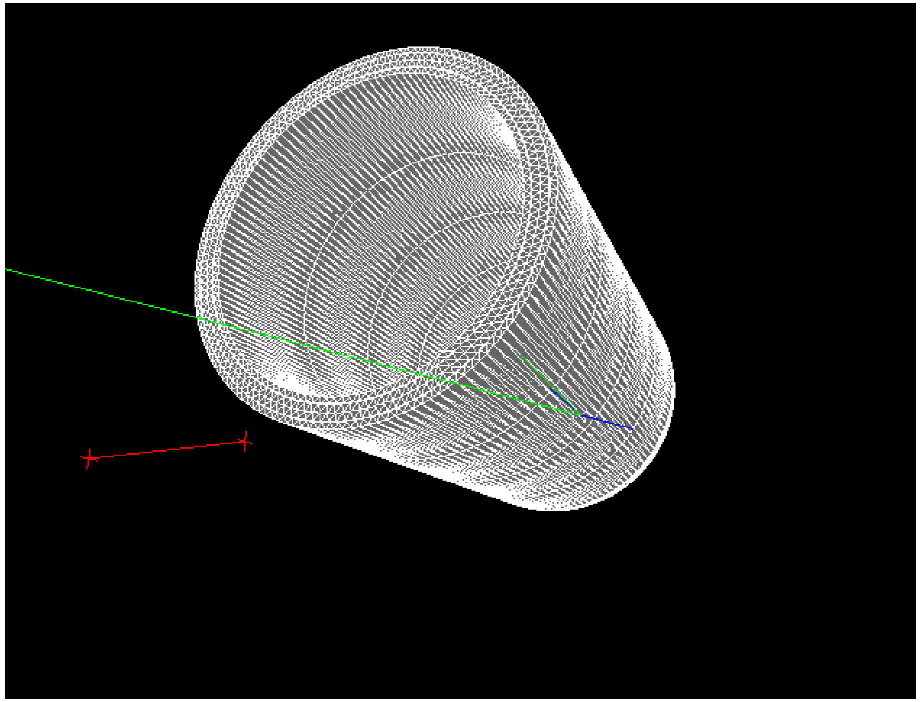


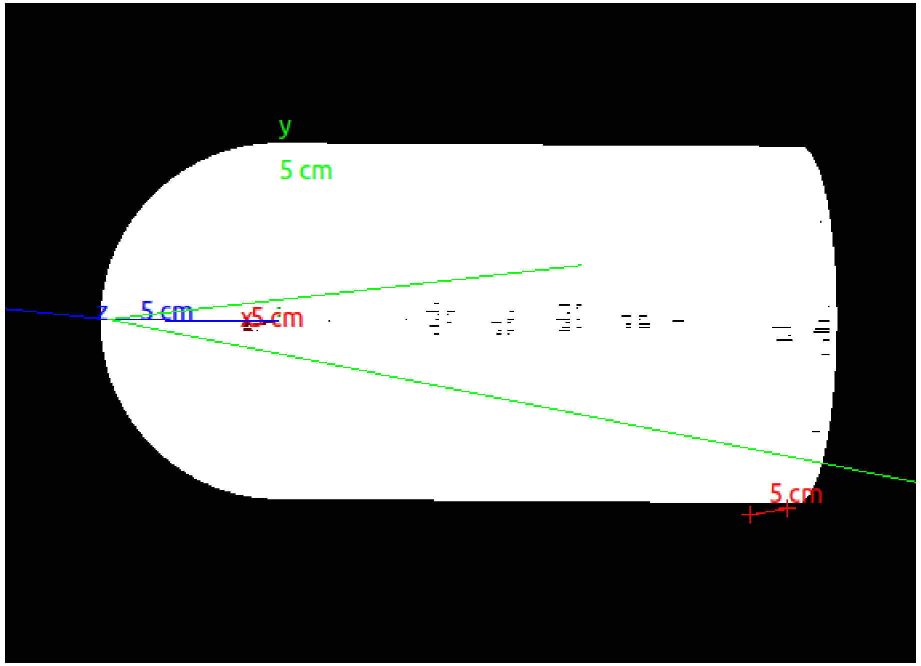
This geometry suffers from less acceptance



To avoid, the calorimeter is closed in forward direction

Modified tracker





- For the forward going particles one can build a separate tracker, but that will add more dead materials
- To avoid that, a bullet shaped tracker has been conceptualized
- Single volume, but a little more tricky to make

Future plans

- Detector design of the tracker and calorimeter is in process
- Simulations are being carried out to optimize the calorimeter geometry
- Tracker development is under process

Acknowledgement

- We would like to thank CFNS and Stony Brook University for their help
- We are thankful to the PIONEER collaboration for their helpful discussions

Thank you