

GammaTPC: a transformative MeV-GeV gamma ray instrument concept

Tom Shutt

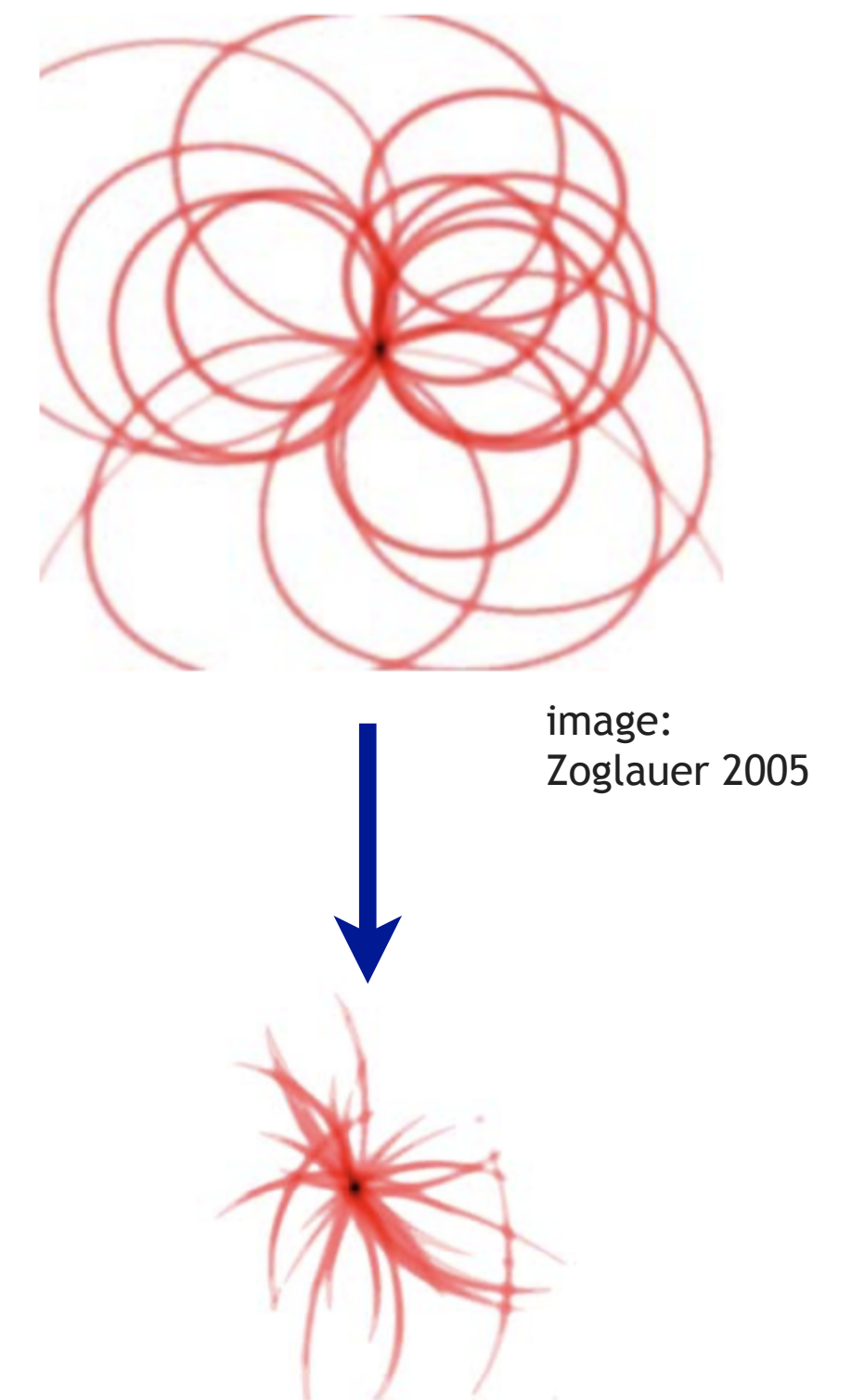
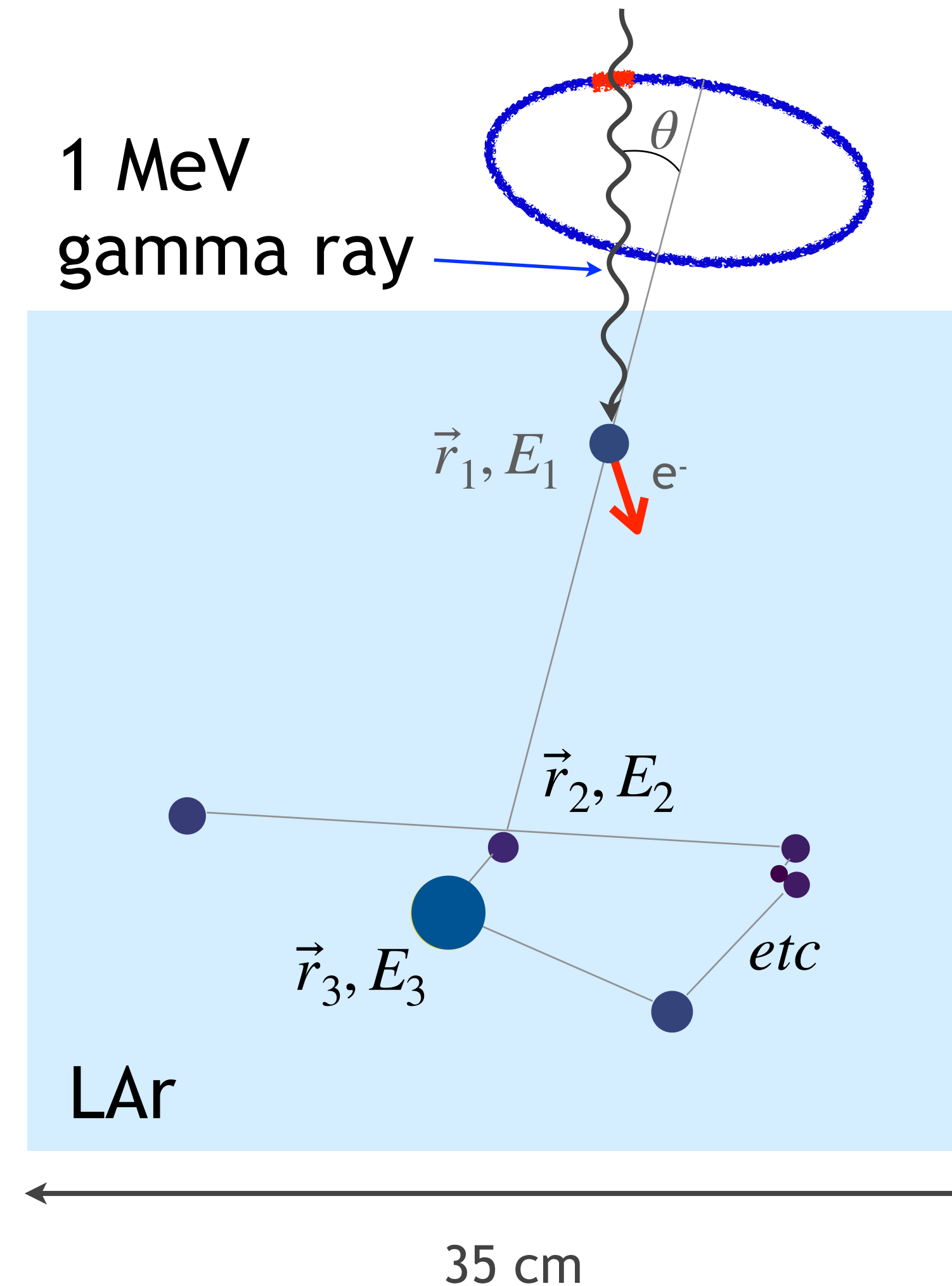
SLAC National Accelerator Laboratory

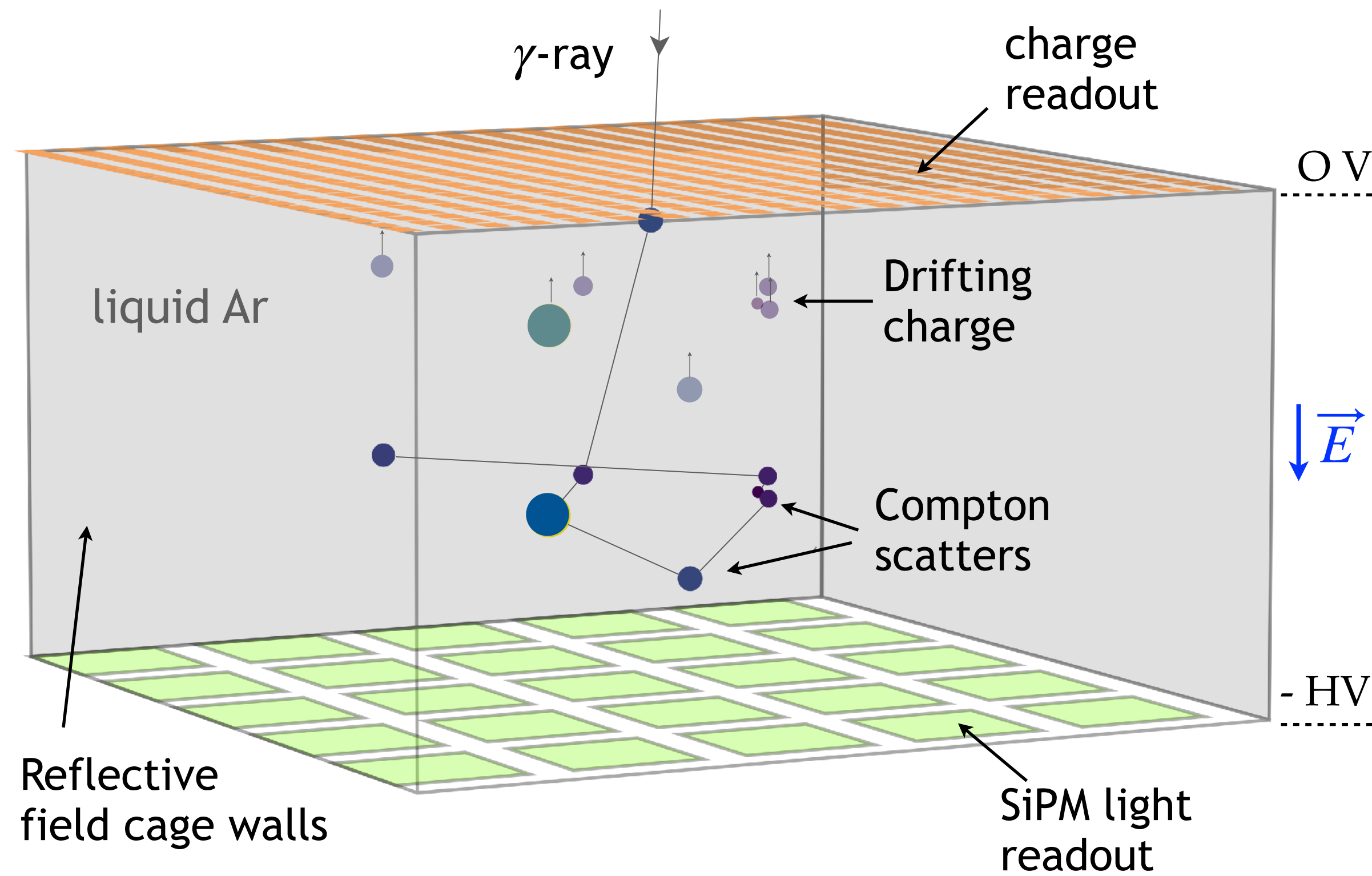
Stanford University

Need precise measurements over a large volume

- Kinematic tests find sequence; “*psf*” is a circle.
- Measurement of electron recoil direction will improve things considerably
- Requires:
 - Large detector volume + mass to contain events
 - Good energy measurement
 - Precise spatial imaging

Compton Telescope technique





Liquid noble time projection chamber (TPC) technology has delivered 20 years of world-leading dark matter searches

- 2D sensors read out 3D volume
 - Scalable at low cost and power
- LAr: ~zero cost detection medium
- Chosen technology for flagship 20 kton DUNE ν experiment

Dark Matter

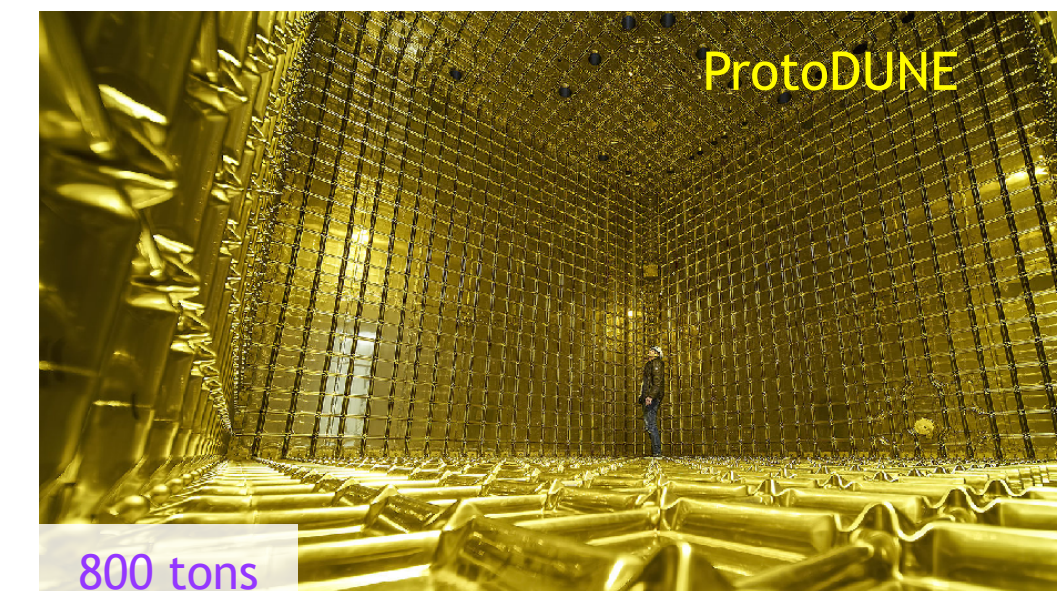


2006



2020

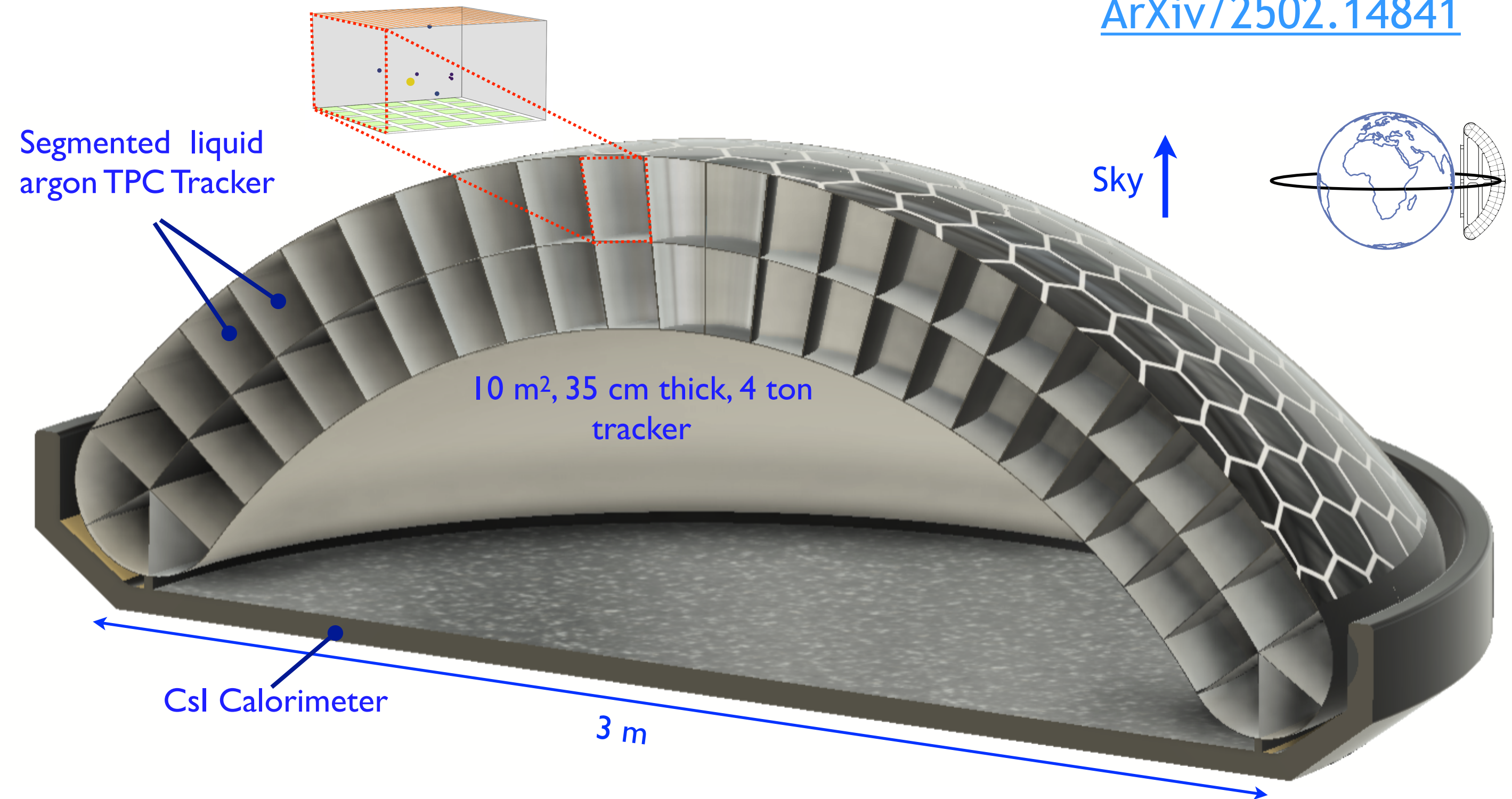
Neutrinos



GammaTPC: scalable, efficient and sensitive

[ArXiv/2502.14841](https://arxiv.org/abs/2502.14841)

- *Mass scale*: drives sensitivity for MeV γ -rays
- *Efficient*: thick tracker contains Compton events
- *Sensitive*: large area



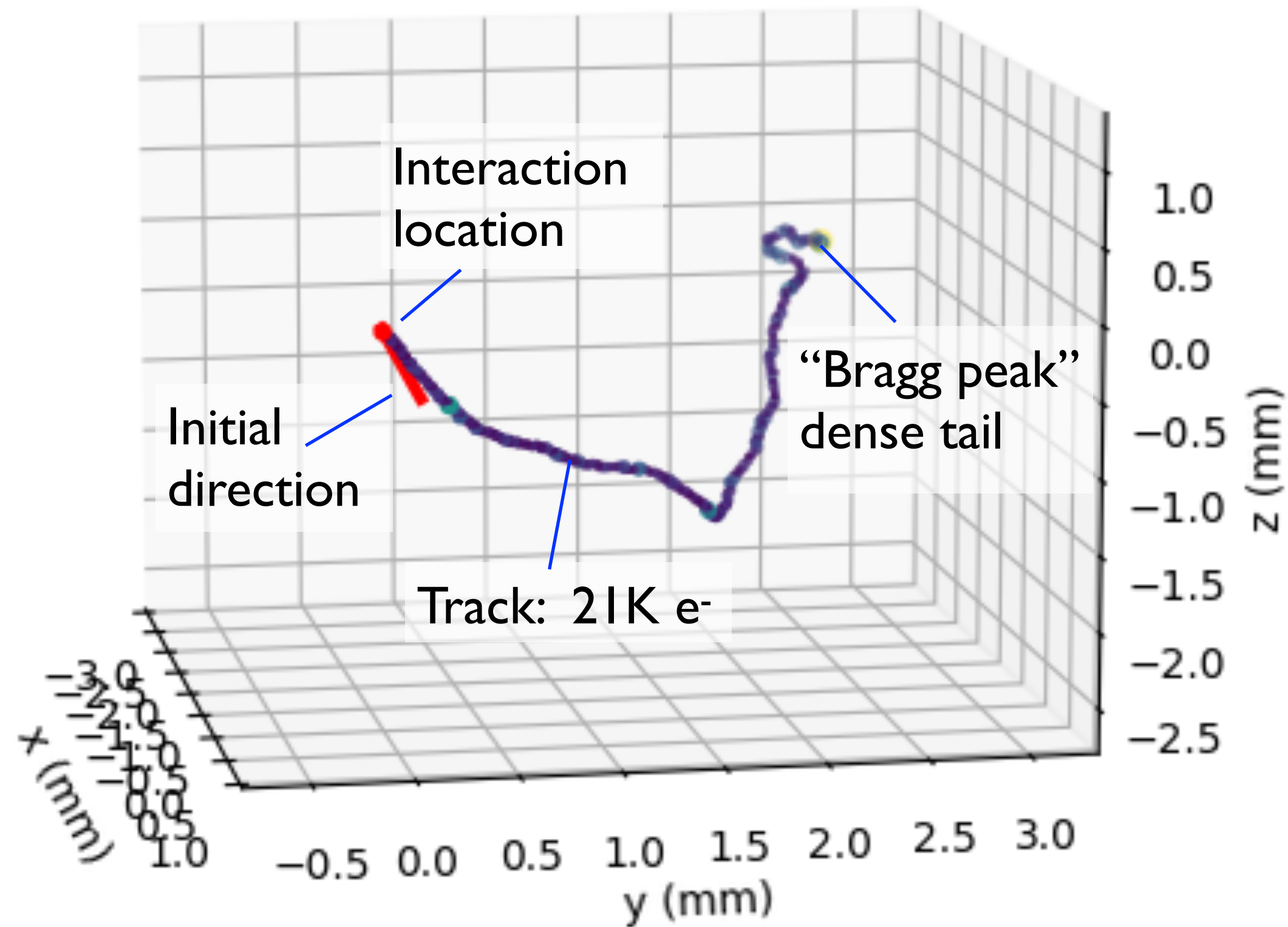
Tracker Comparison

- GammaTPC: 10.0 m², 4.1 g/cm²
- COSI (Ge): 0.026 m², 3.2 g/cm²
- AMEGO-X (Si): 0.58 m², 0.7 g/cm²

**Ideal match to low-cost
large-mass launch vehicles**

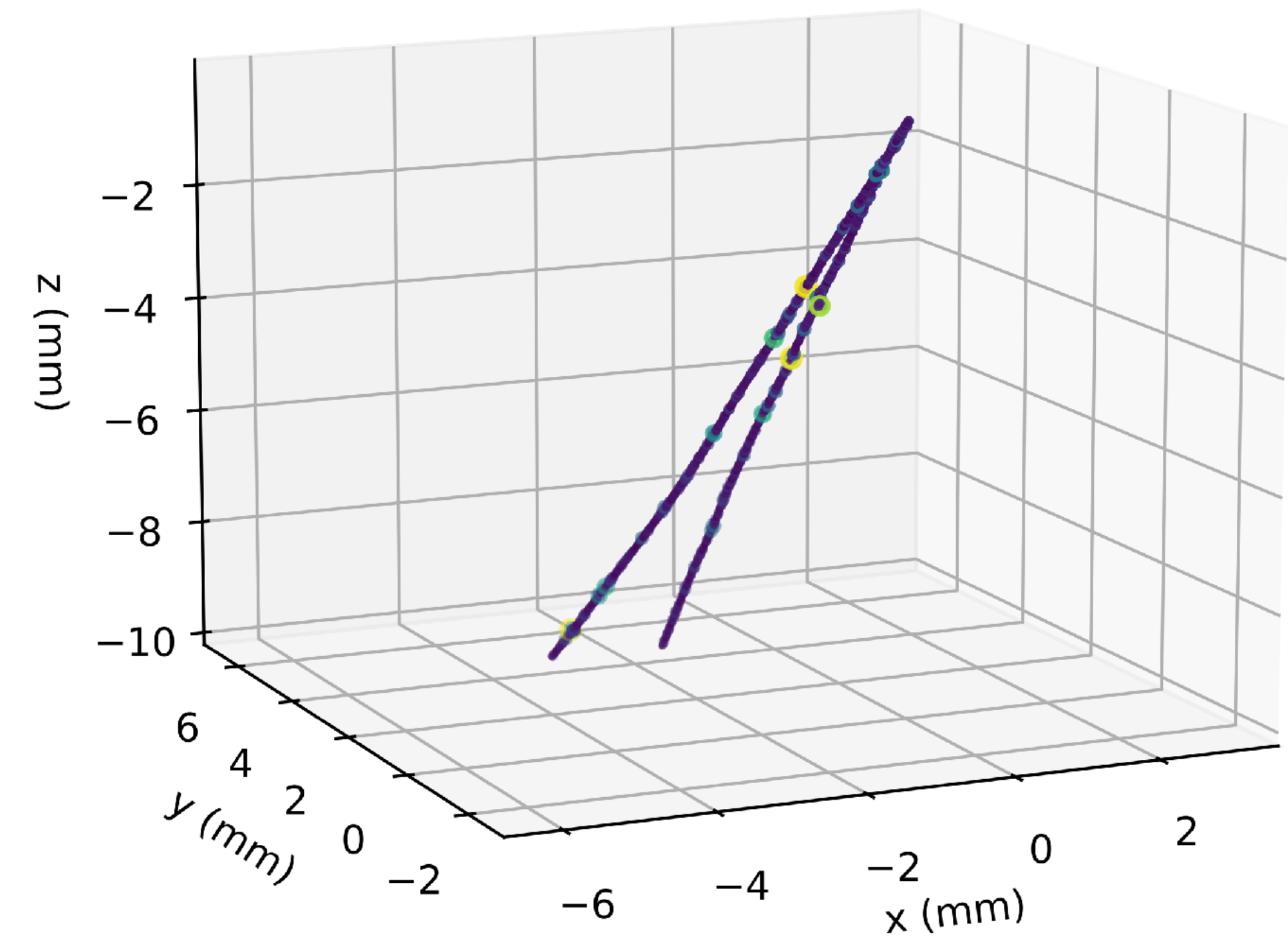
Sub-mm imaging needed

Compton regime



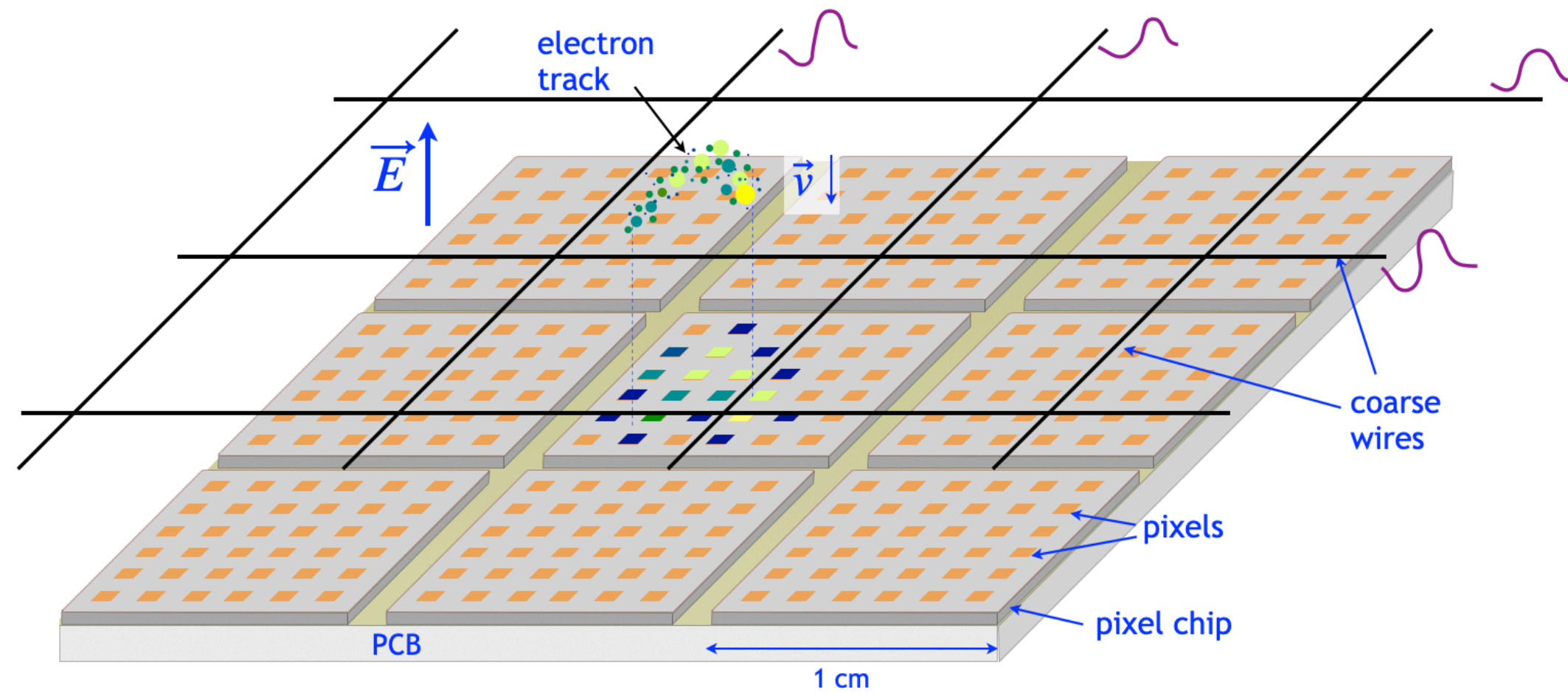
1 MeV electron track

Pair regime



100 MeV $e^\pm$ pair

GAMPix: Grid-activated multi-scale pixel readout

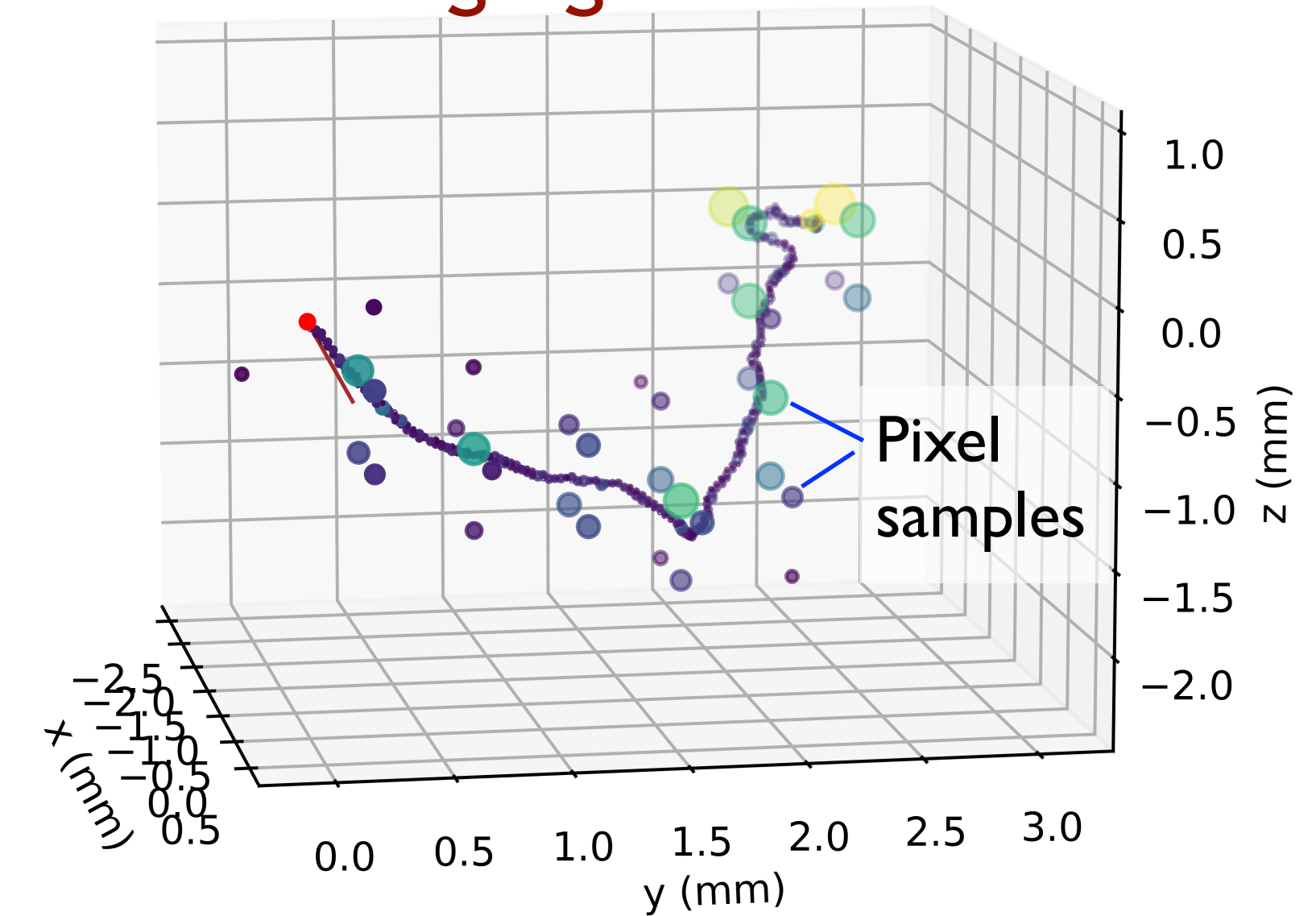


- **GAMPix Measure charge *twice*, solving two serious problems**

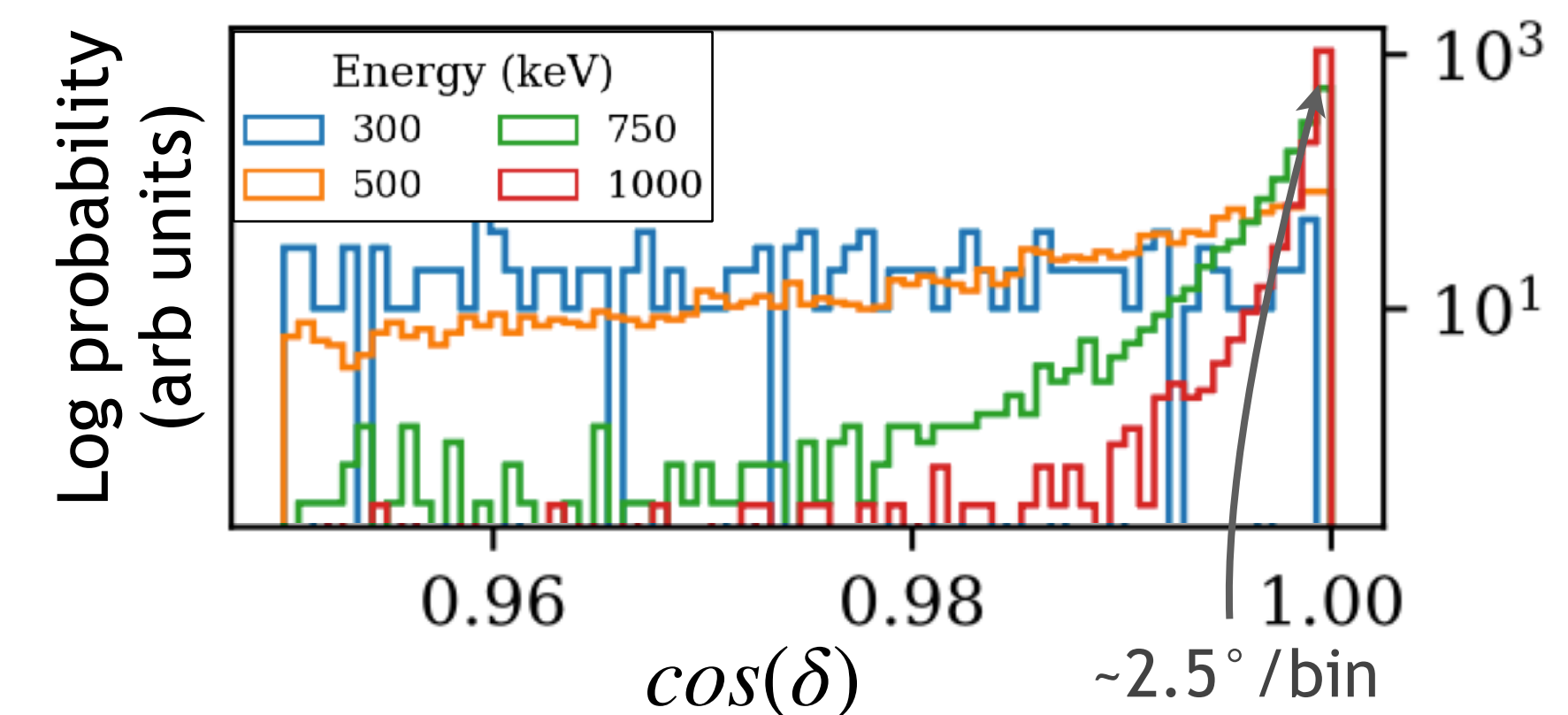
- Charge is missed when sensor pitch comparable to diffusion. Here, coarse-spaced wires provide diffusion-independent signal.
- Power too high, but coarse signal provides trigger for pixel chip power-up, reducing power by $10^3 - 10^4$, making

- **State-of-art imaging over full volume**

Pixel imaging of 1 MeV track



Initial track direction, 5 cm drift



First chip working well!



A. Peña-Perez

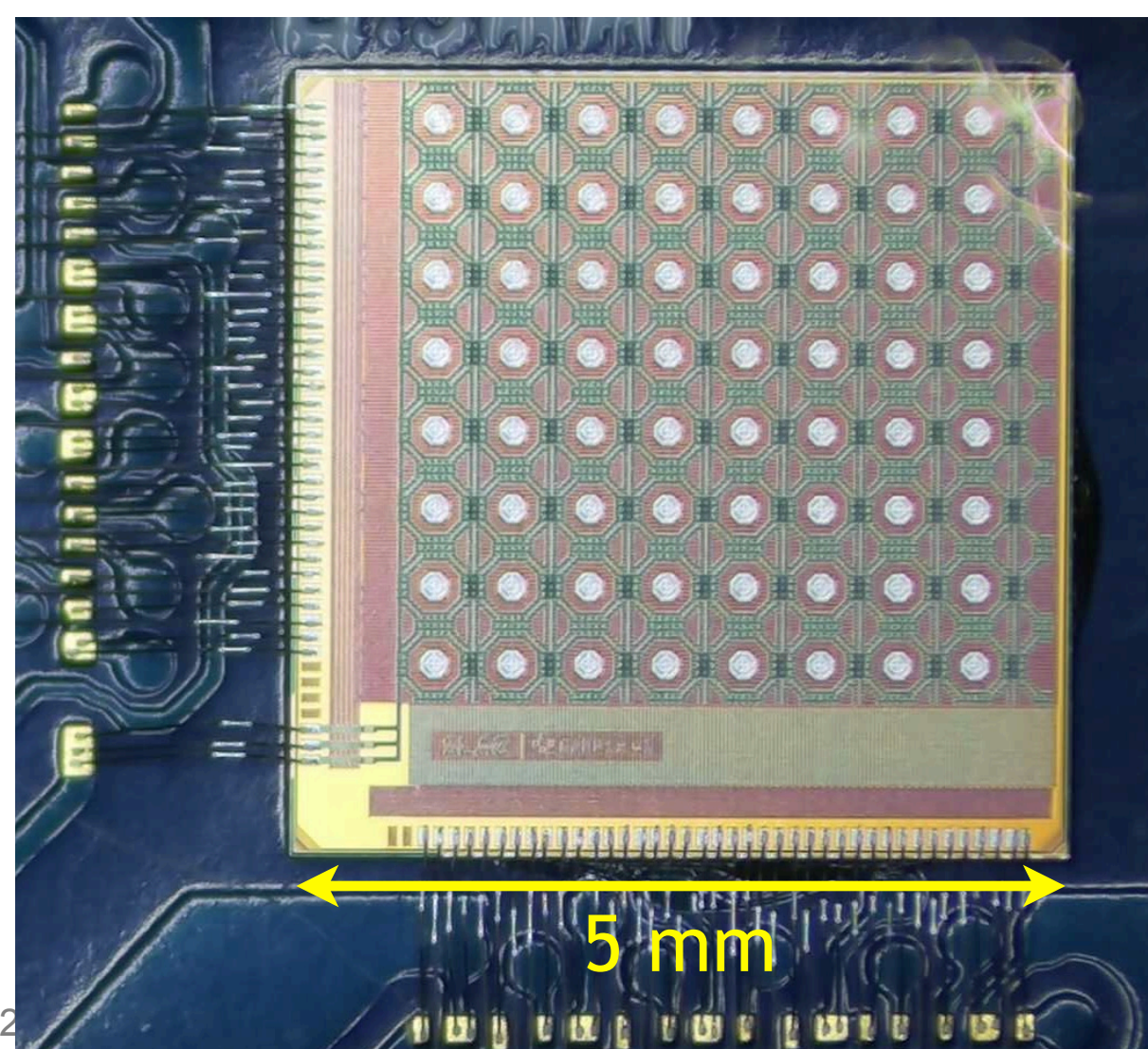


B. Trbalic

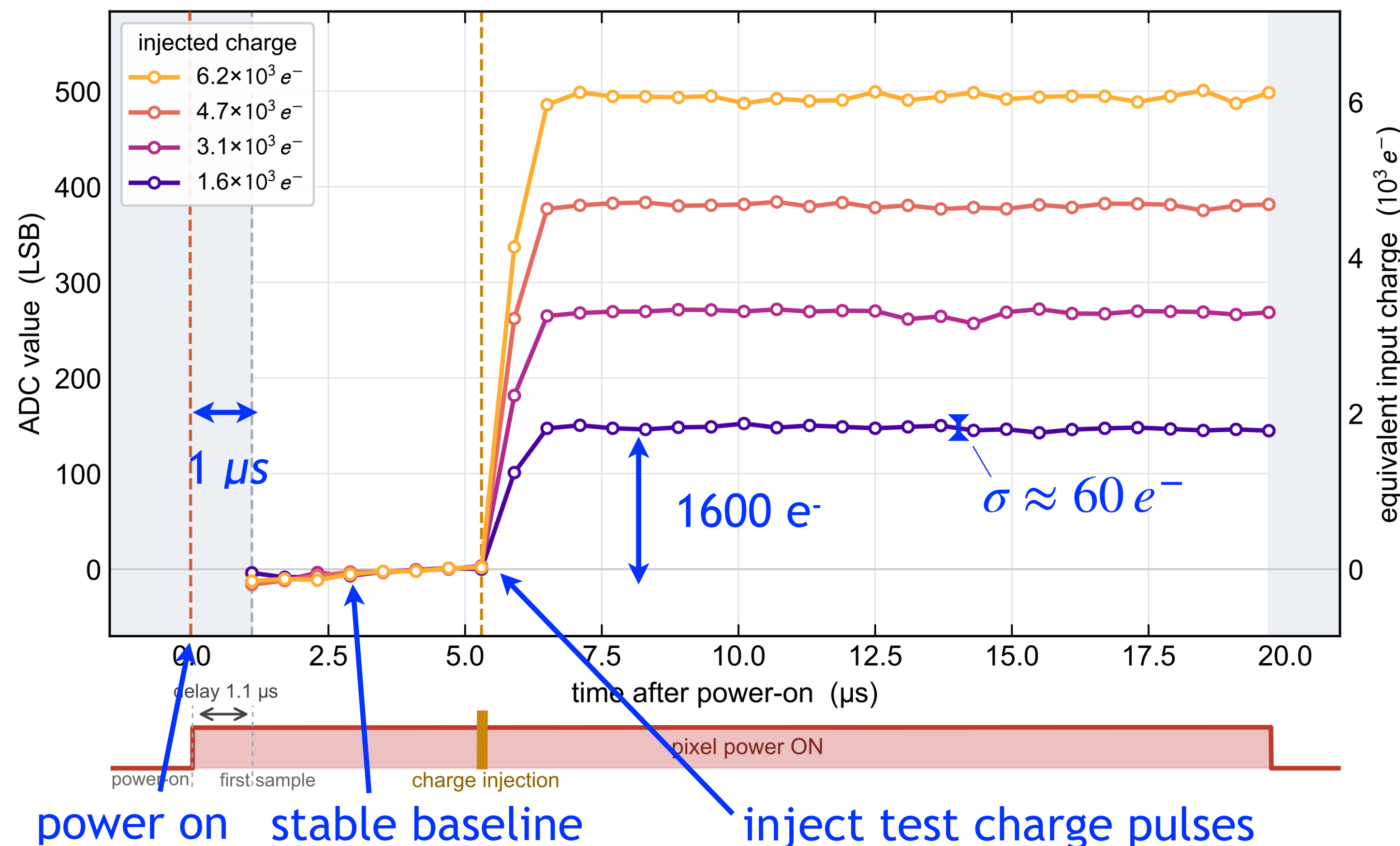
- Full front-end, with ADC per pixel, $P_{on} = 100 \mu W/\text{pixel}$
- Designed by SLAC ASIC team on shoe-string budget.

First look encouraging
on all key metrics.

500 μm pitch GAMPixPi_v1



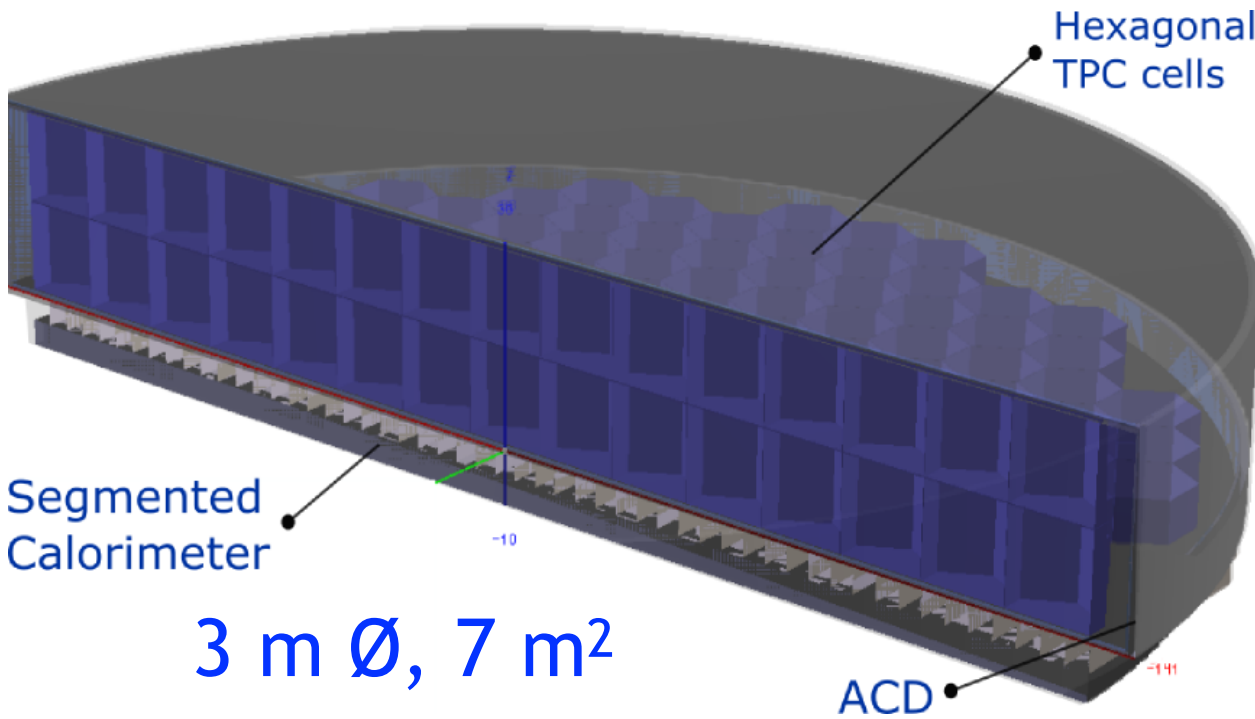
GAMPixPi_v1, immersed in LAr



Shown is response of a single pixel;
uniformity across pixels is excellent.

Detailed simulation

- Particle interactions: Geant4-based “industry standard” MEGALIB Cosima
- Custom reconstruction and classification pipeline: Gampy
 - Ar micro-physics
 - Parameterized charge, light collection and readout
- Pessimistic, Nominal and Optimistic scenarios
 - Geometry: % dead material
 - Readout: light collection, charge noise, spatial resolution



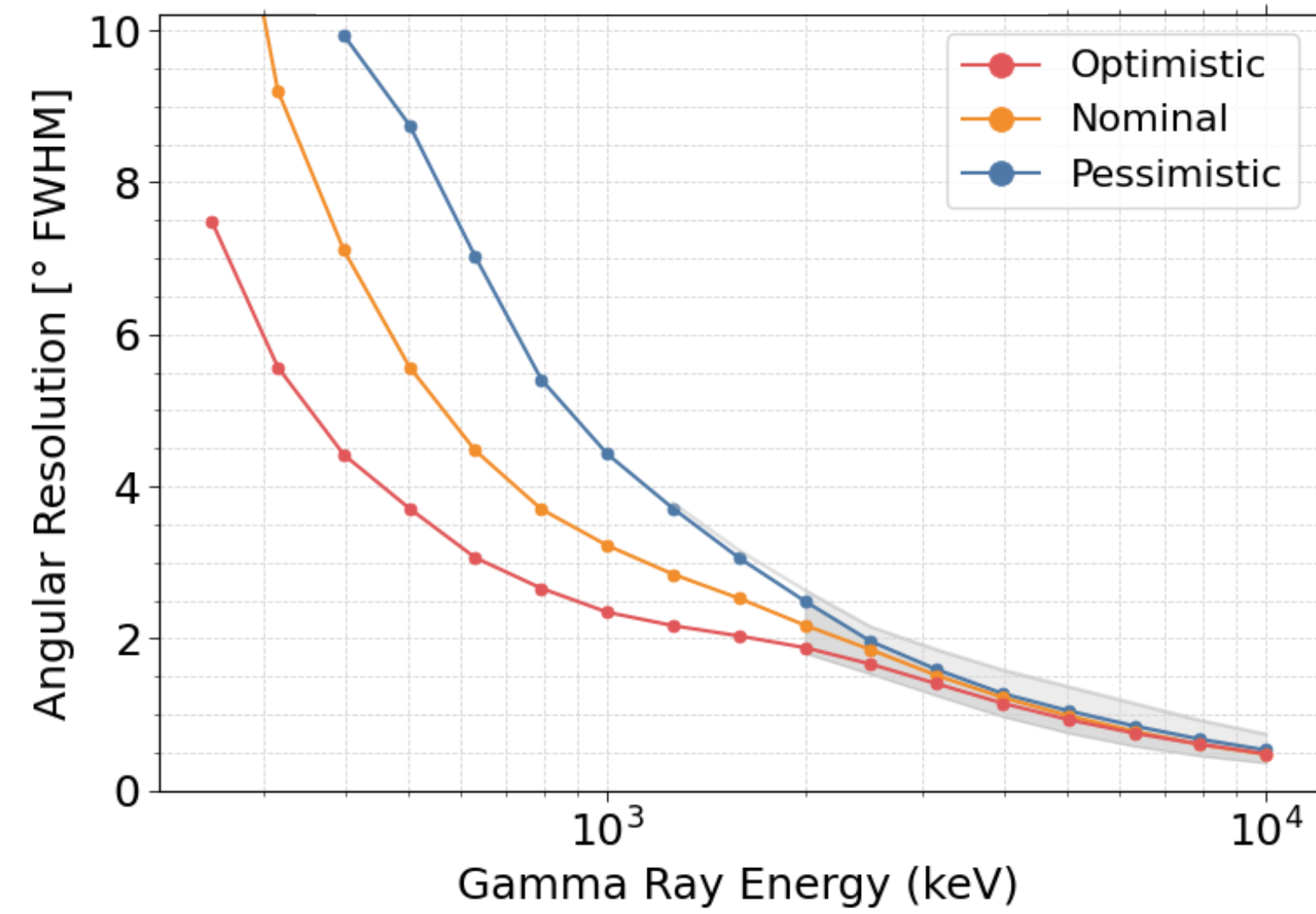
B. Trbalic

Table 2. Varied Instrument Geometry and Response Parameters for Different Scenarios.

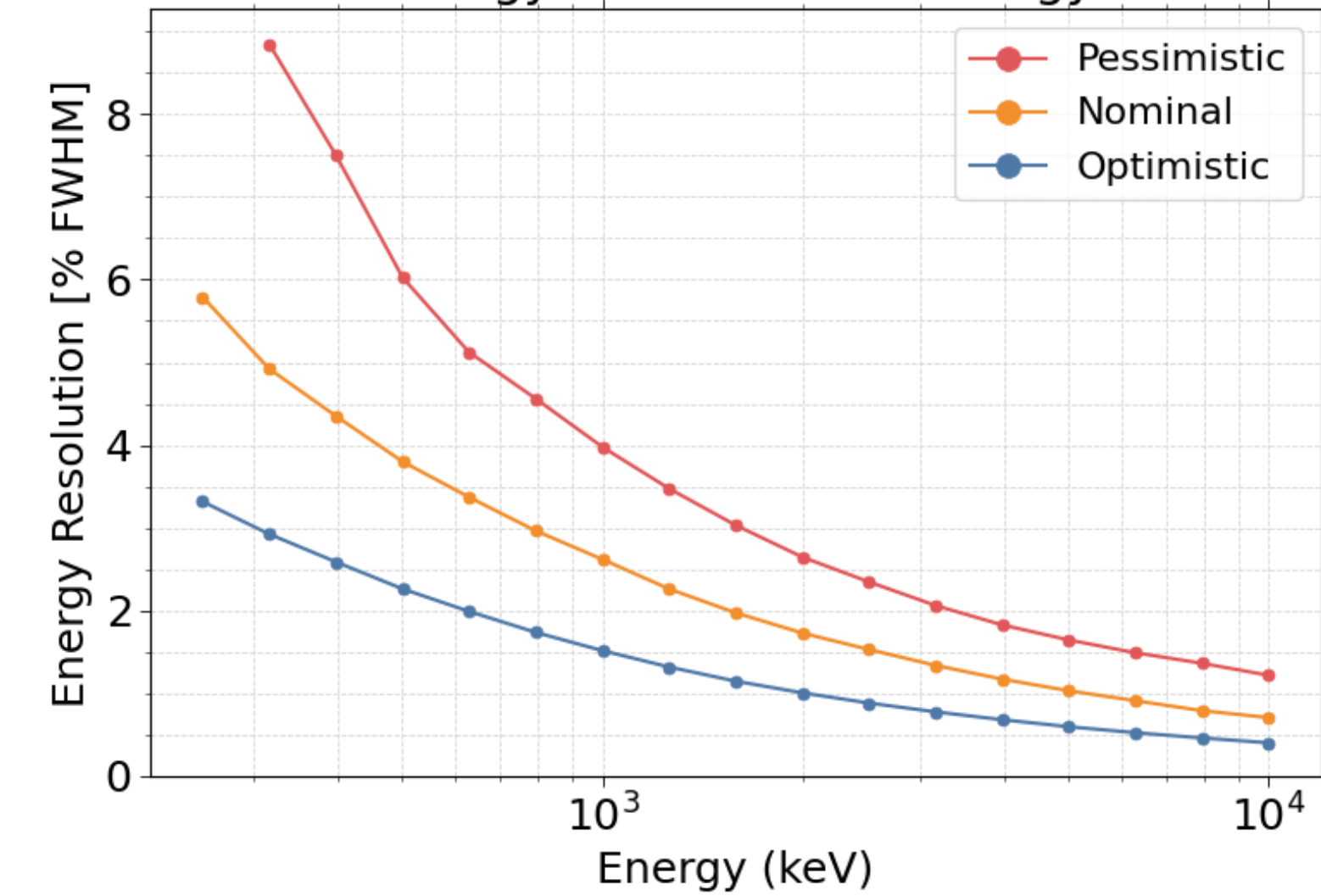
Simulation Parameters	Optimistic	Nominal	Pessimistic
Geometry			
Instrument diameter (m)	...	3	...
Tracker cell height and flat-to-flat width (cm)	...	17.5	...
Number of tracker cells	...	374	...
LAr mean ACD thickness (mm)	...	9.5	...
CsI calorimeter thickness (cm)	...	10.0	...
Anode and cathode plane thicknesses (mm)	0.7	1.2	2.0
Ribs + planes + walls mass fraction (%)	1.4	2.2	4.0
Total dead mass fraction (%)	2.5	5.6	9.7
Readout			
Spatial resolution multiplier	0.75	1.0	1.5
e ⁻ direction error multiplier	0.8	1.0	1.2
Light collection efficiency	0.3	0.1	0.05
Recombination fluctuations strength parameter	0.04	0.05	0.06
Coarse grids noise ENC (e ⁻)	10	20	40

Performance metrics

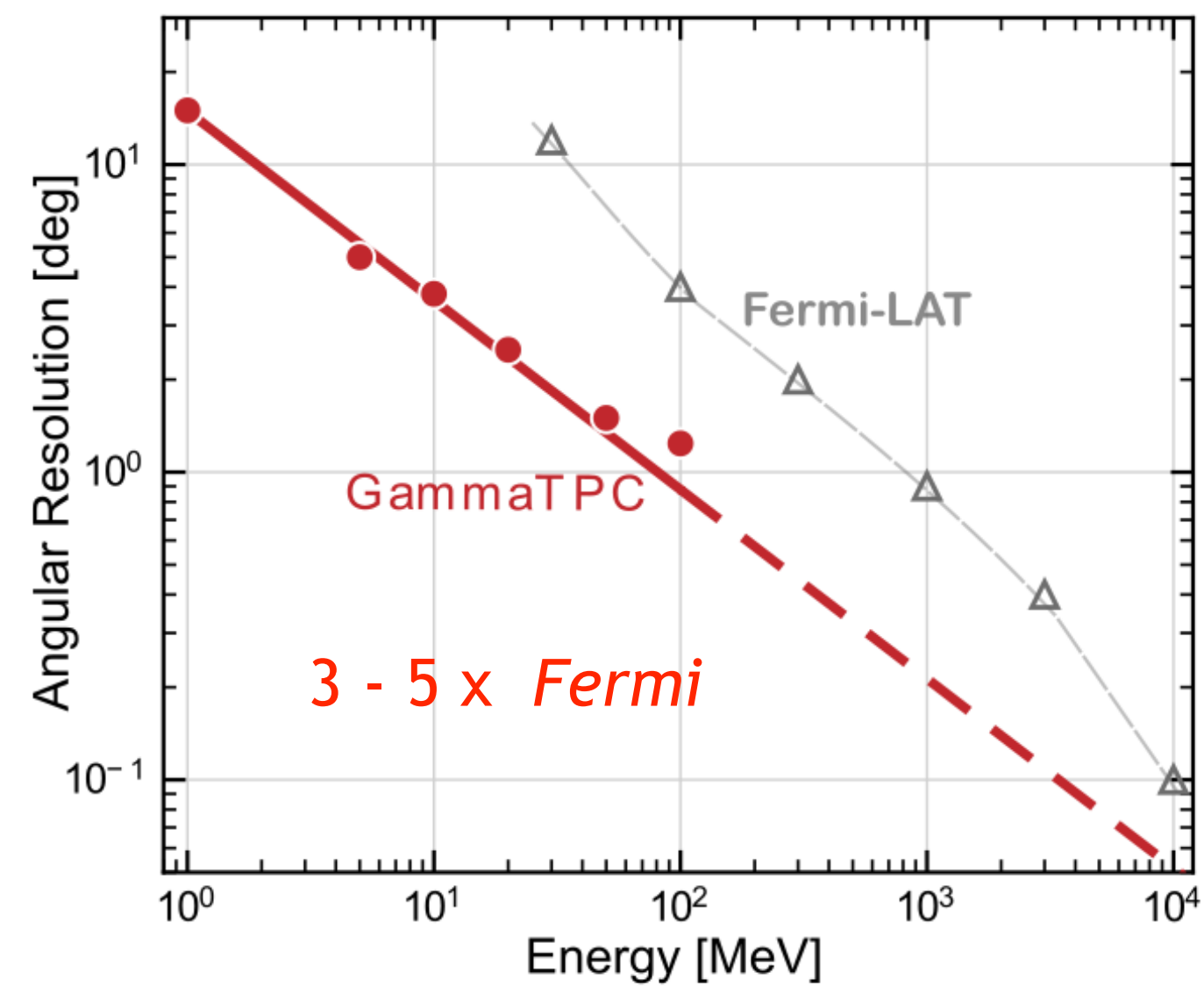
Compton regime



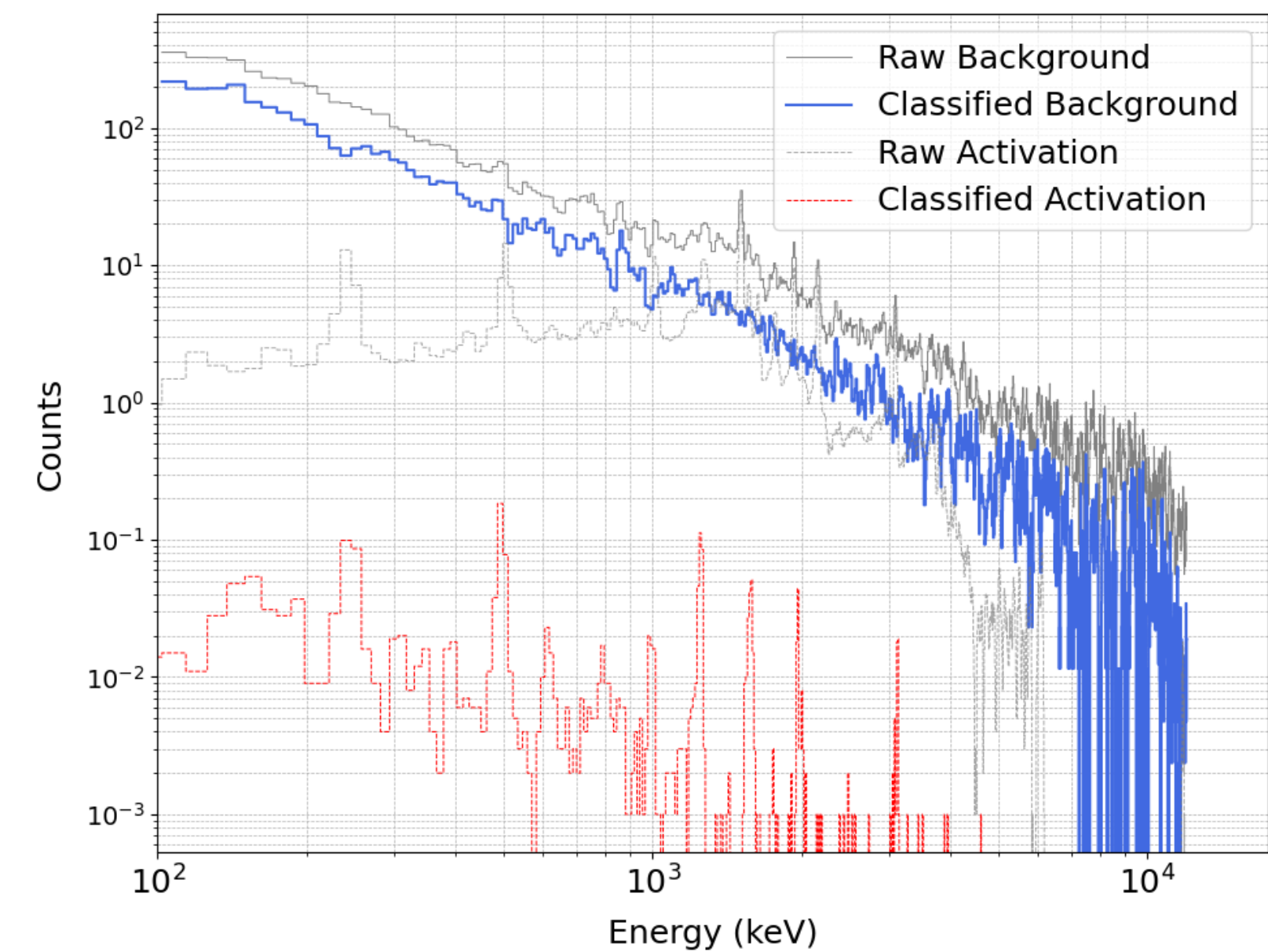
Energy Resolution vs Energy



Pair regime

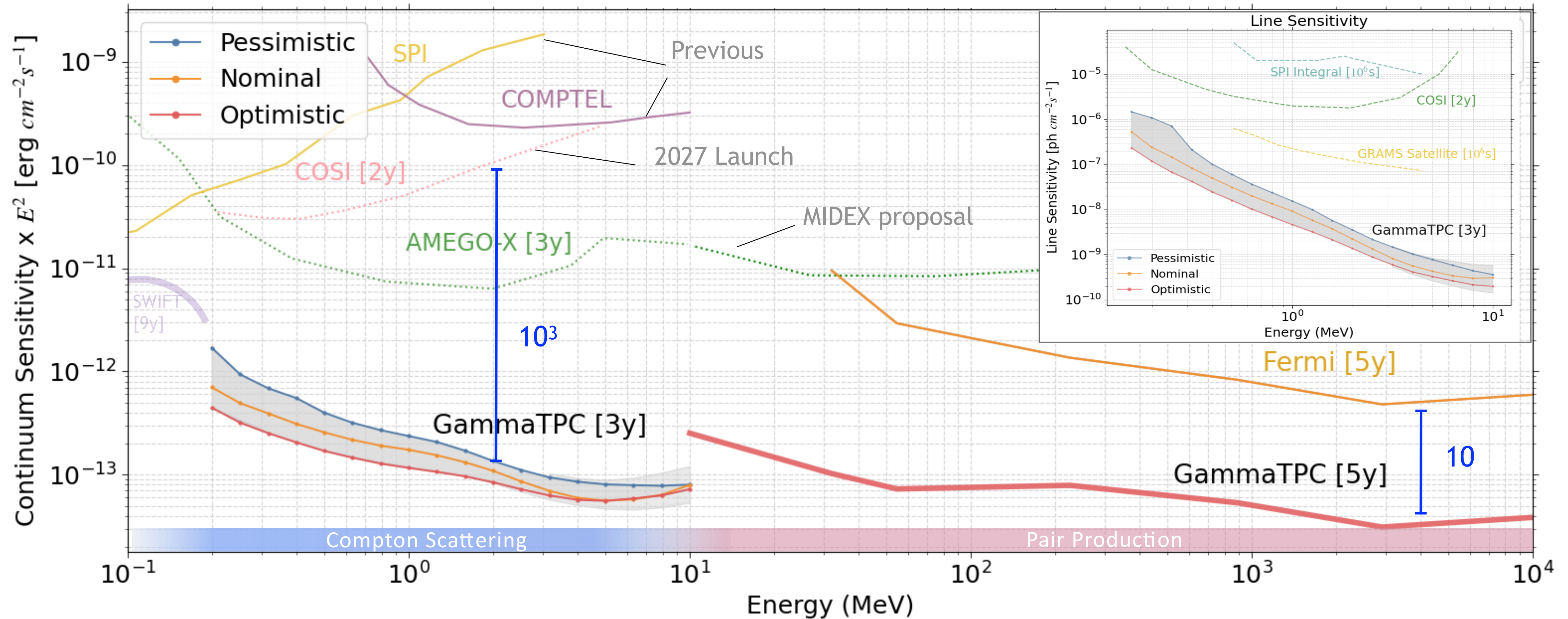


Background



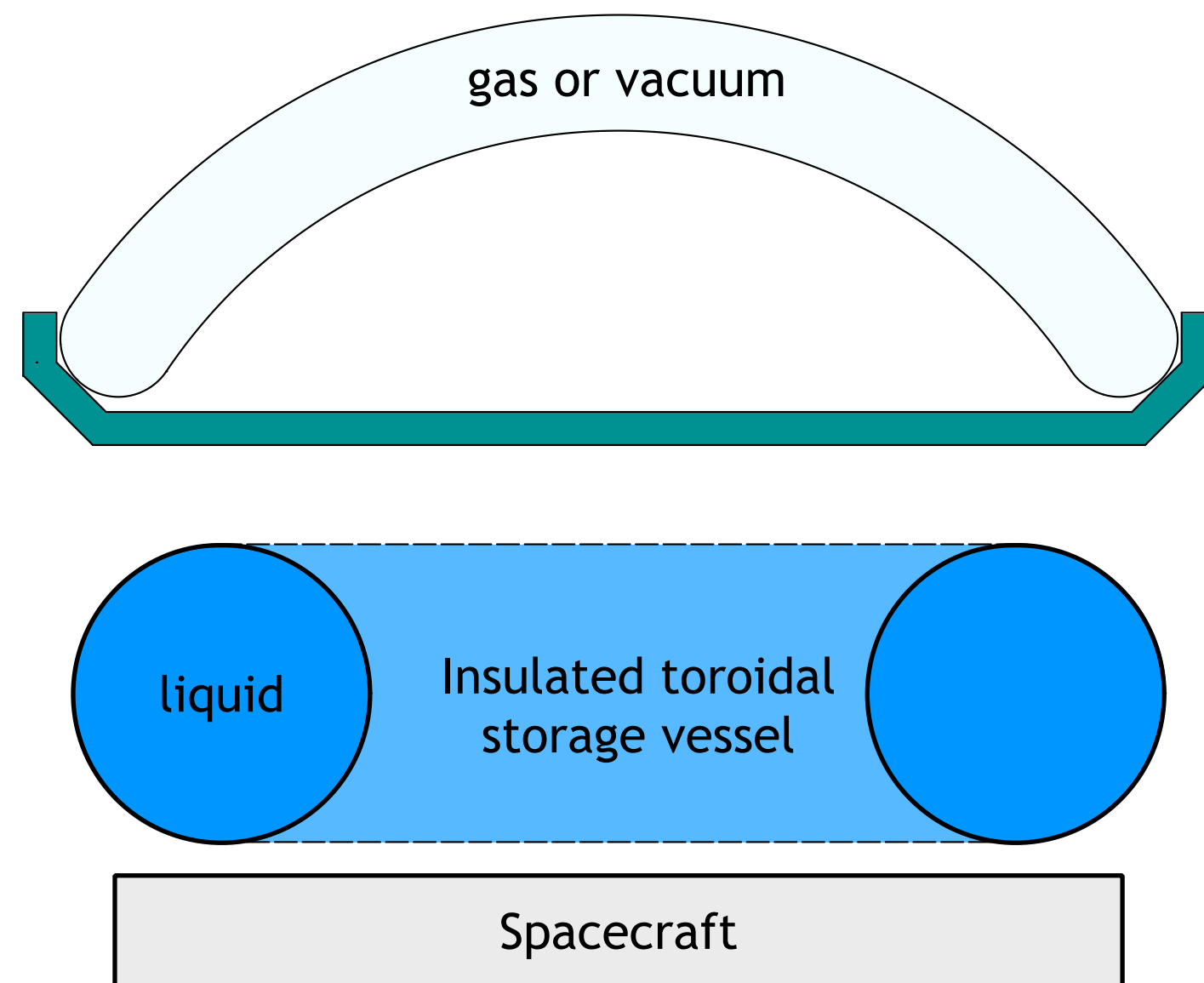
Transformative sensitivity over wide energy range

Continuum Sensitivity

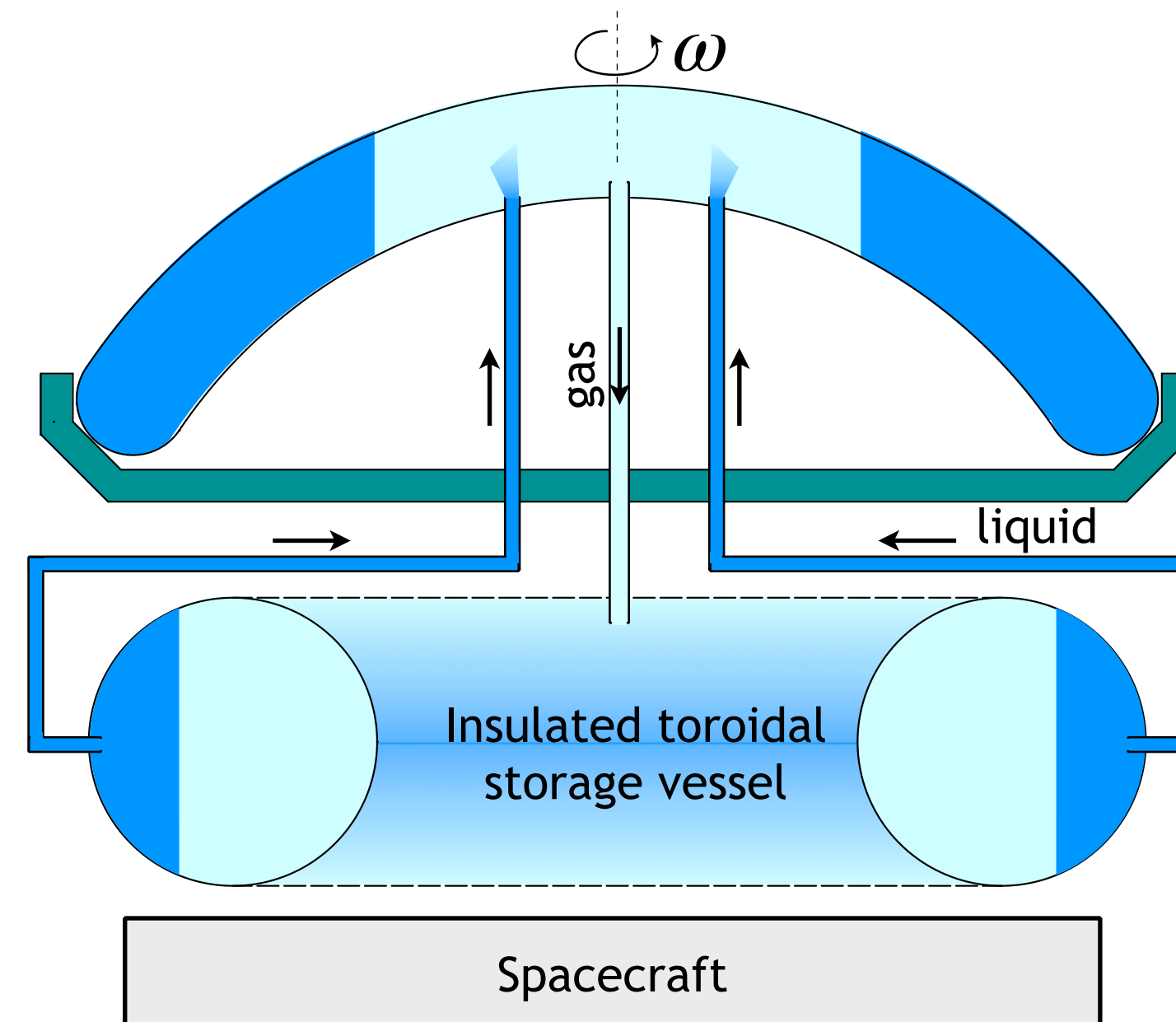


Handling liquid argon in zero-g

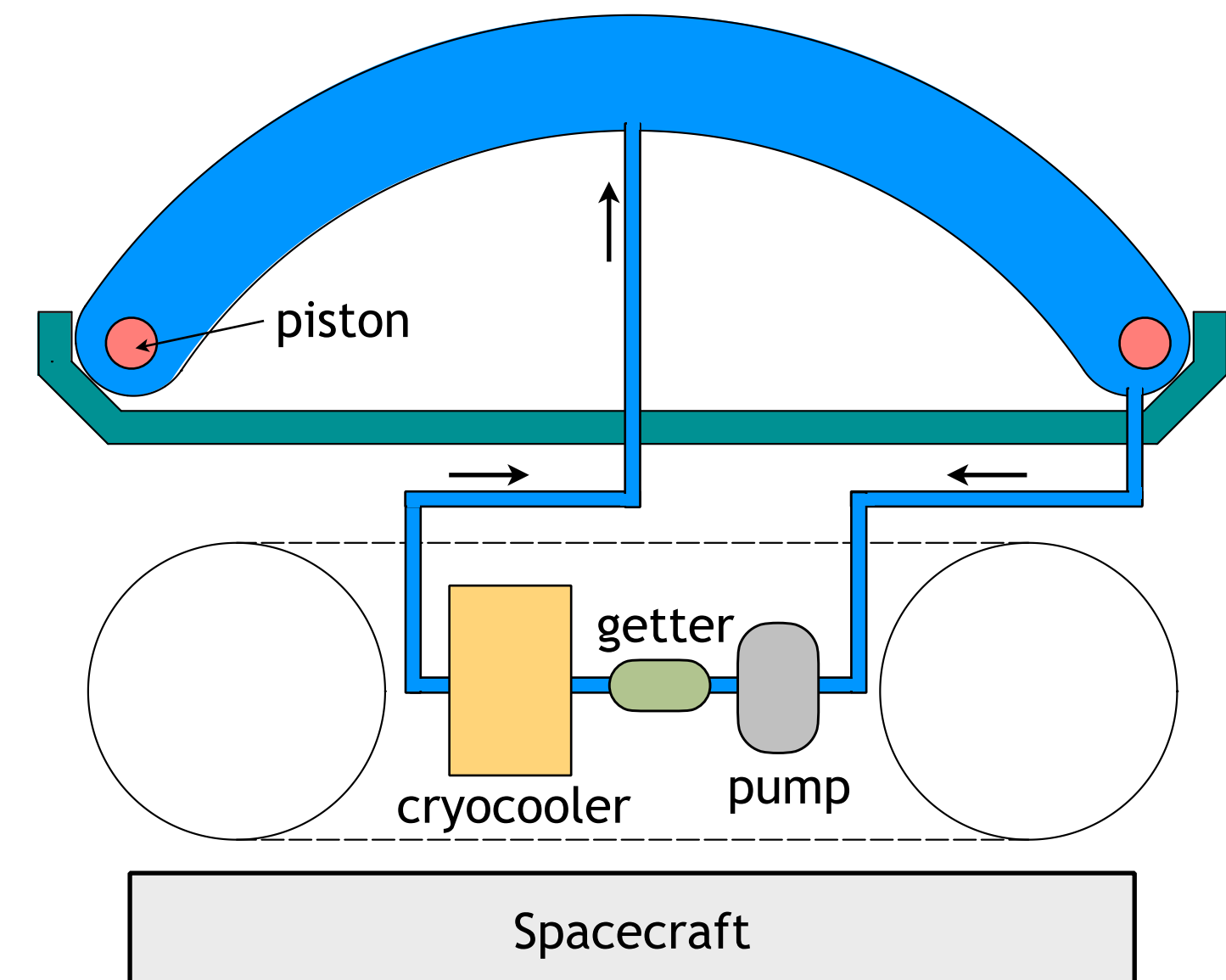
Launch



Fill



Operate



Probably requires dedicated small satellite launch(es)

Program notes

- Most technology in hand, developed for neutrinos and dark matter
 - Biggest TPC risk appears retired due to success of first GAMPix chip
- Key remaining issue of handling LAr in zero-g could be significant, given likely need for dedicated flights at scale of RocketLabs Electron
- Spacecraft demands, in first look, appear modest
- Strong argument for large instrument
 - Large upfront costs: demonstration of LAr in zero-g, development of 4-5 ASICs
 - After that, cost scales weakly with mass, taking advantage of low launch costs.

Summary

- GammaTPC excels in two factors that drive sensitivity
 - Scalability to very large area, stopping power
 - Fine grained track imaging
- Orders-of magnitude sensitivity improvements appear feasible.