



# GAMPix: Grid Activated Multi-scale Pixel Readout

**W**

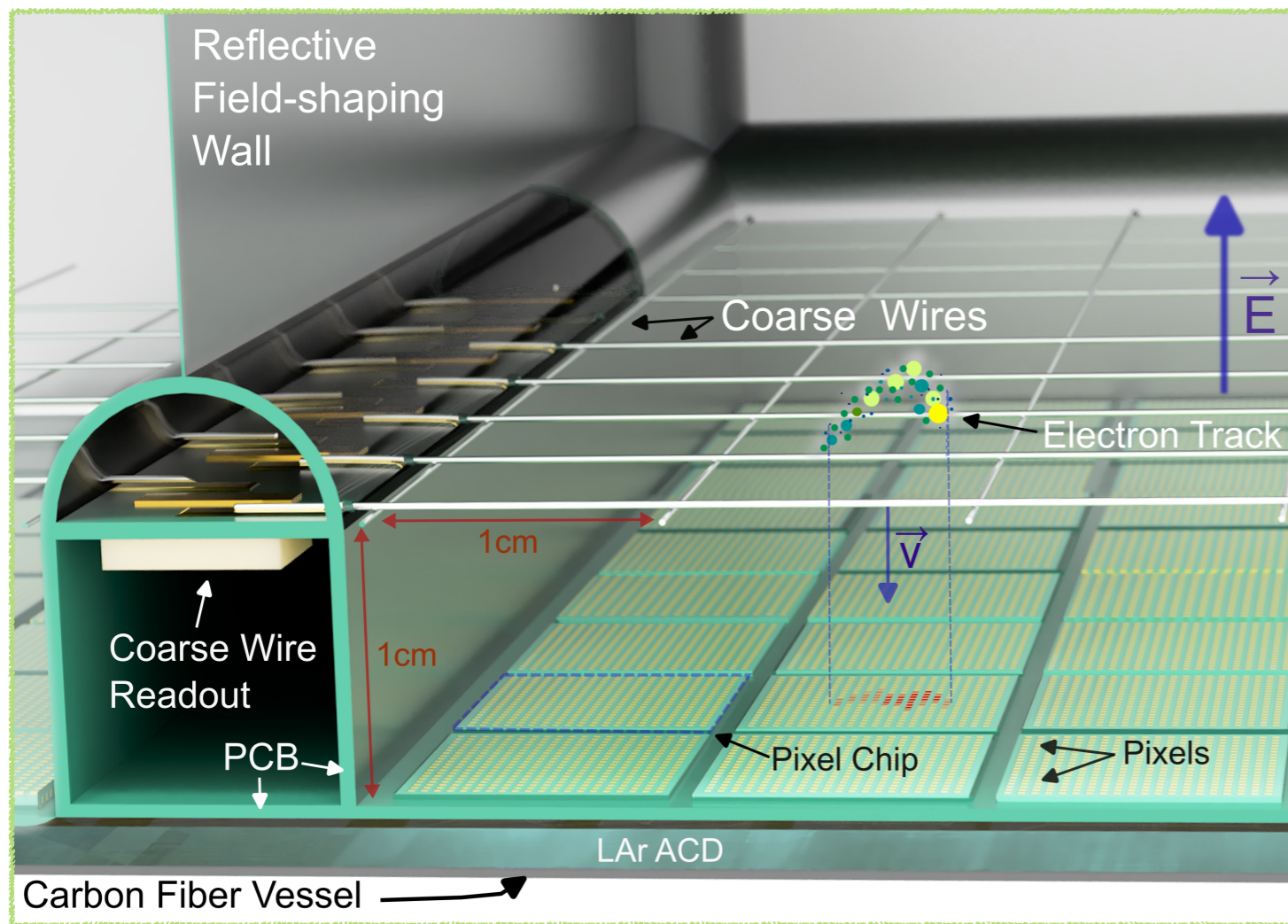
Shih-Chieh Hsu  
TIDC Annual Meeting  
January 7th 2026

Thanks for slides from Yun-Tse Tsai @SLAC

# GAMPix

## Grid Activated Multi-scale Pixel readout

[arXiv: 2402.00902](https://arxiv.org/abs/2402.00902)

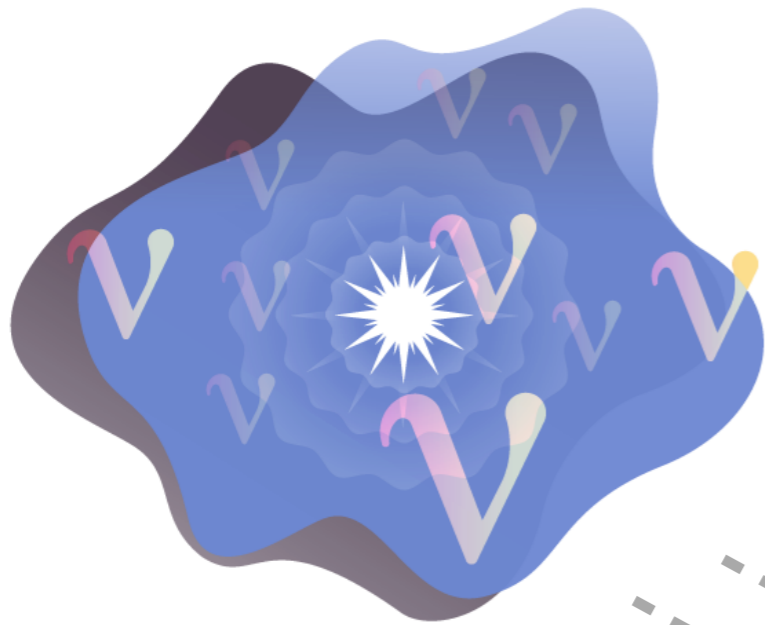


- Novel charge readout architecture for liquid argon time projection chambers
- Combines coarse induction grids with fine-pitch pixel arrays for 3D imaging
- Achieves diffusion-limited spatial resolution while preserving charge measurement
- Ultra-low power operation via power-cycled pixel chips triggered by coarse grids

GammaTPC

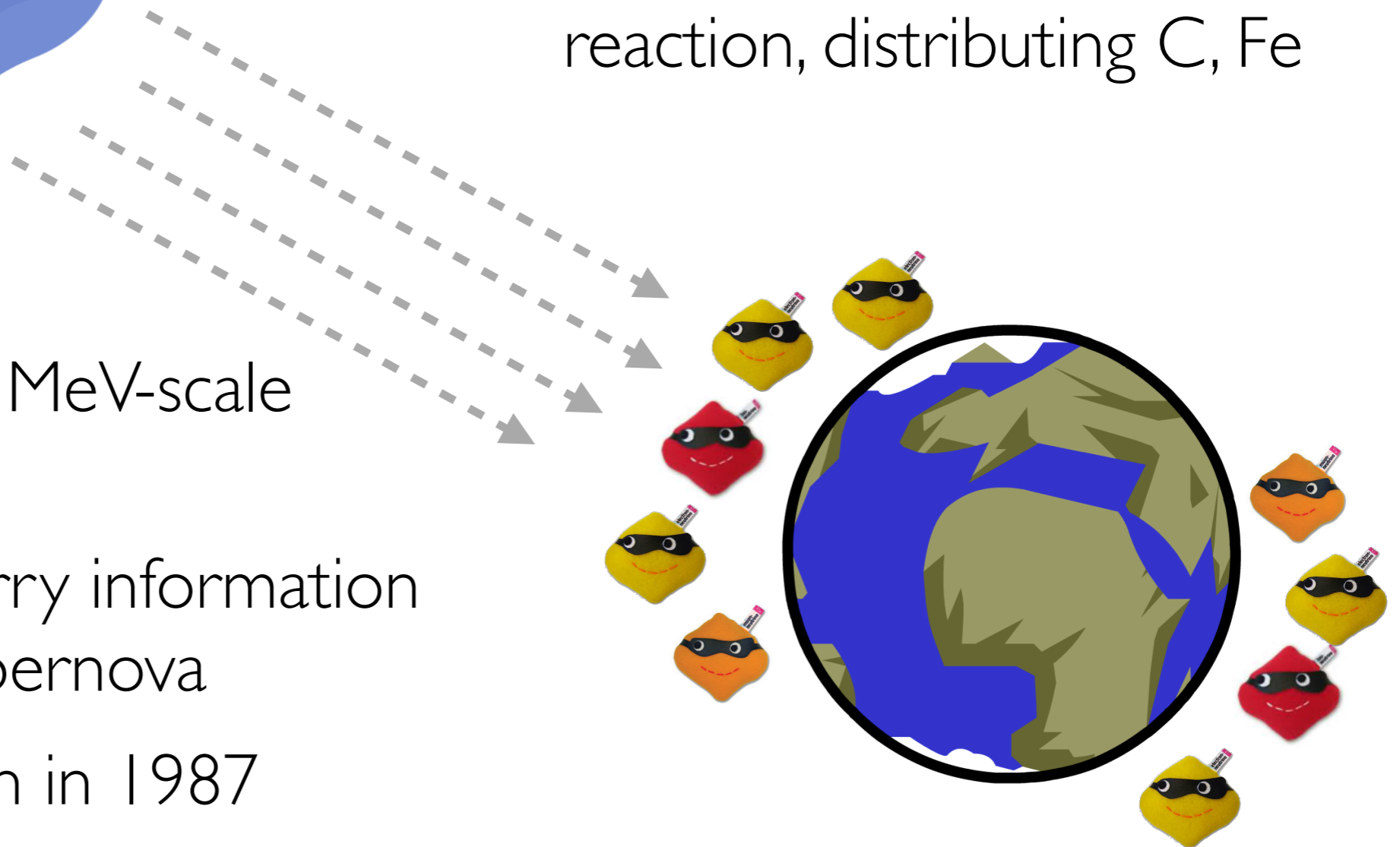


# Supernova Neutrinos

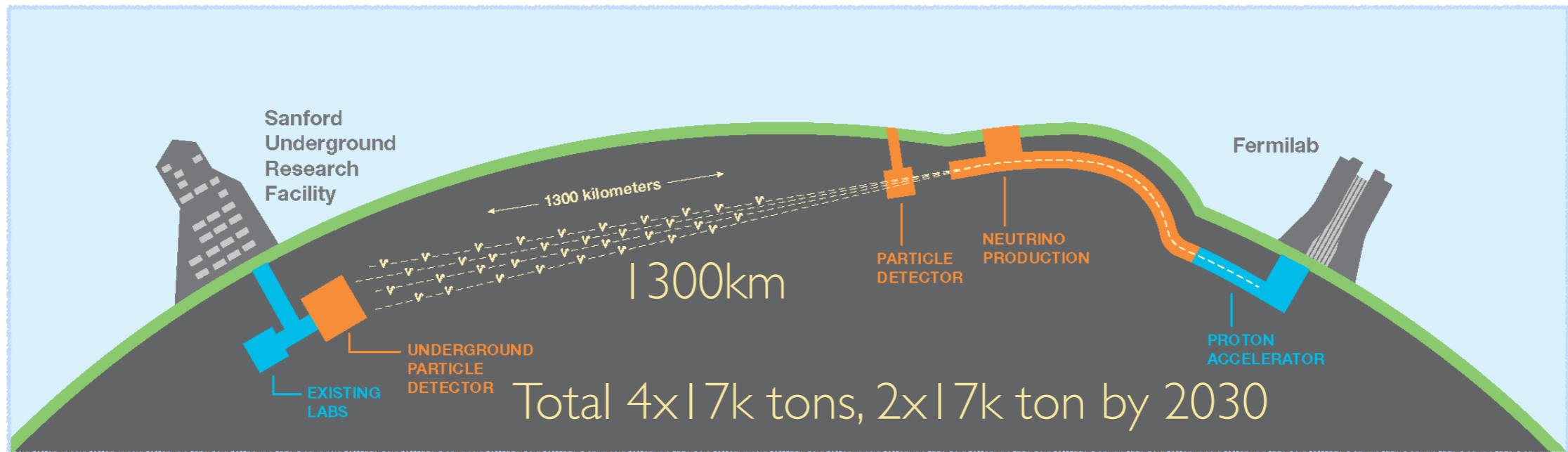


- Core-collapse supernovae: the end of the star's lives
- A hurricane of nuclear reaction, distributing C, Fe

- Create  $\sim 10^{58}$  MeV-scale neutrinos
- Neutrinos carry information about the supernova
- First detection in 1987



# DUNE

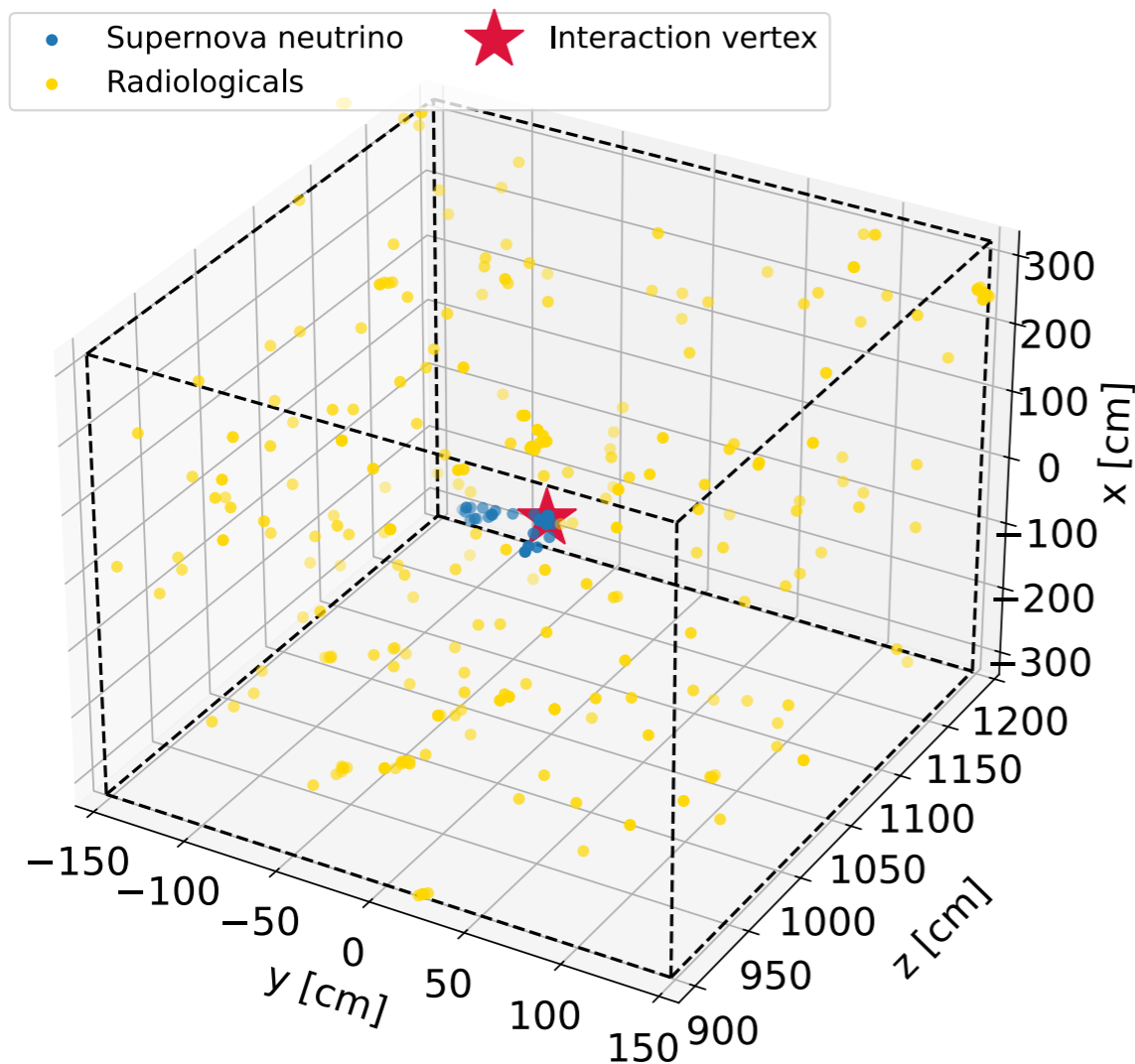


- Aim to measure:
  - CP violation in lepton sector,  $\nu$  mass ordering
  - neutrinos from supernovae, nucleon decays, etc.
- GeV-scale  $\nu_\mu$  from Fermilab accelerator
- Deep underground far detector based on Liquid Argon Time-Projection Chambers (LArTPCs)



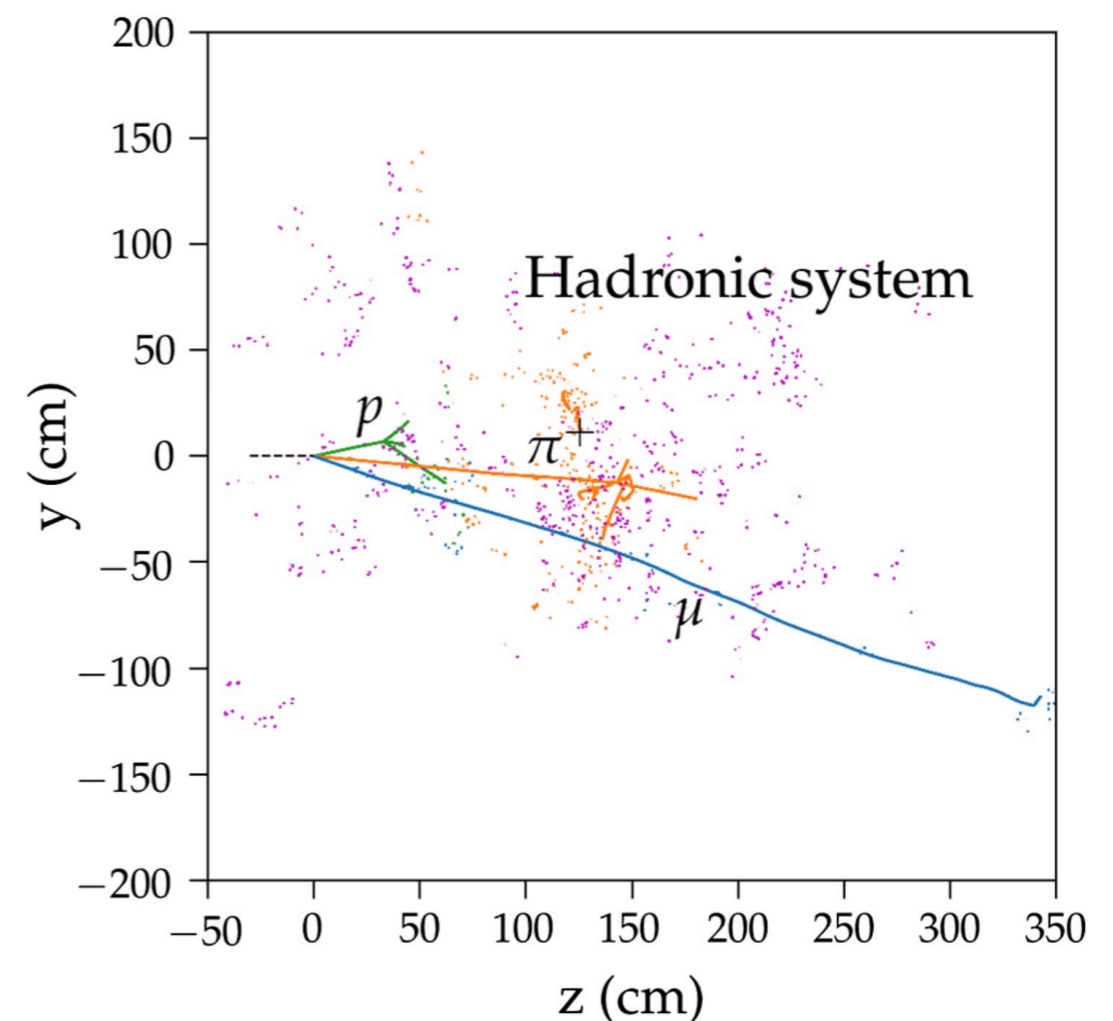
# MeV-scale Physics in DUNE

Astrophysical neutrinos: e.g.  
Supernova and solar neutrinos  
(MeV scales)



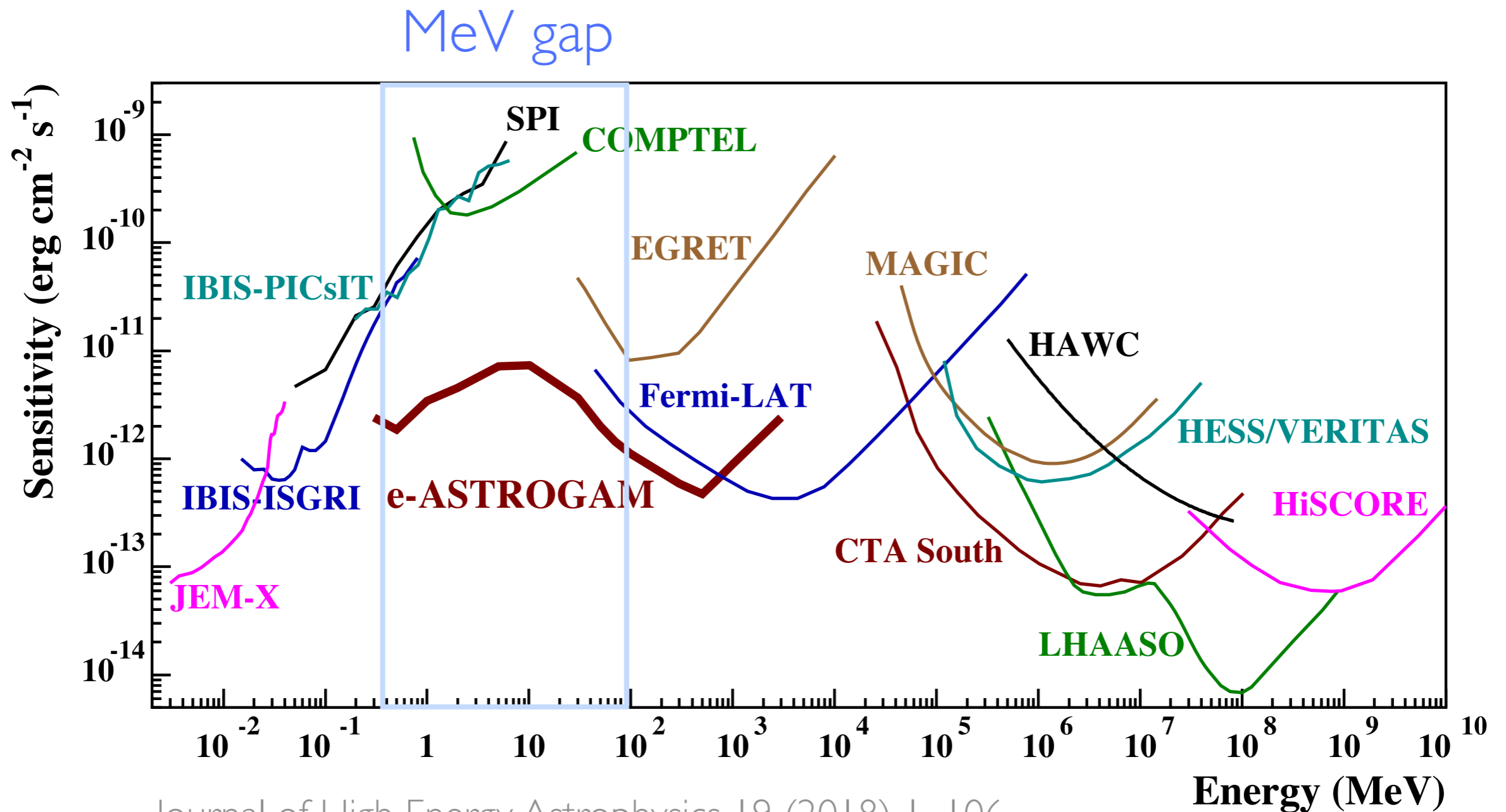
[arXiv: 2203.00740](https://arxiv.org/abs/2203.00740)

MeV  $\gamma$ s from neutron scattering and  
nuclear deexcitation in GeV- $\nu$   
oscillation experiments (e.g. DUNE)



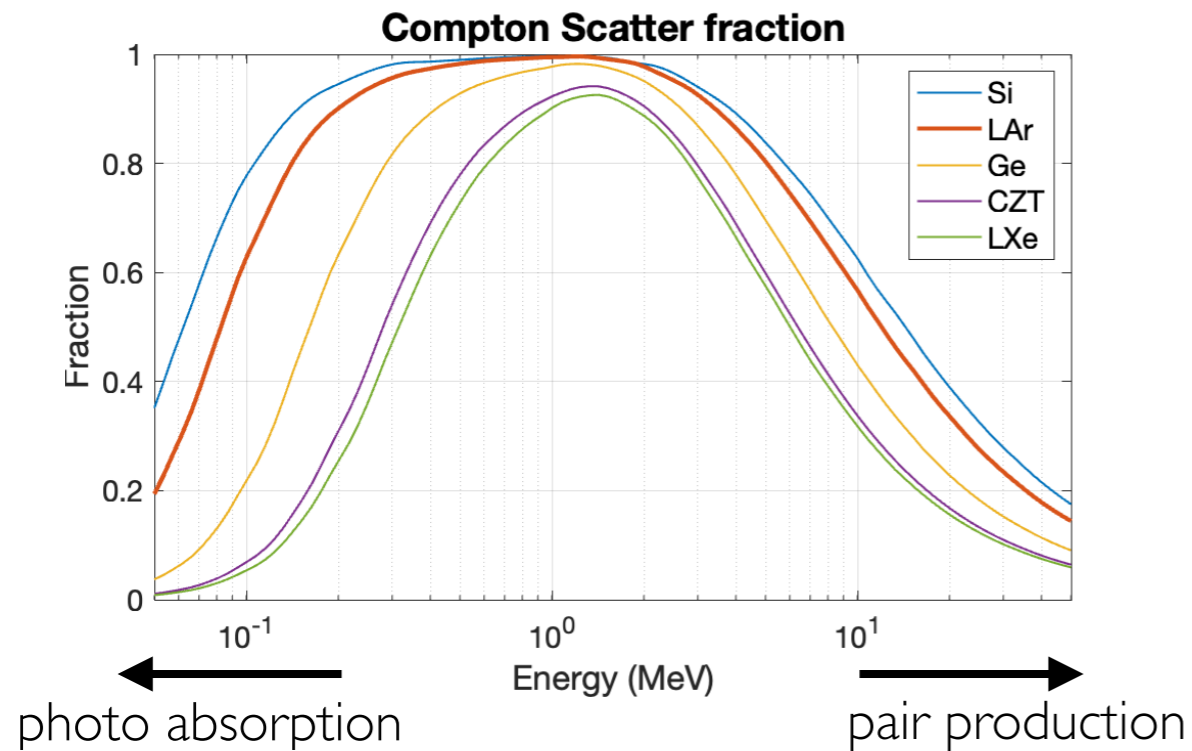
[PRD 99, 036009 \(2019\)](https://arxiv.org/abs/1903.03609)

# MeV-scale $\gamma$ Astronomy

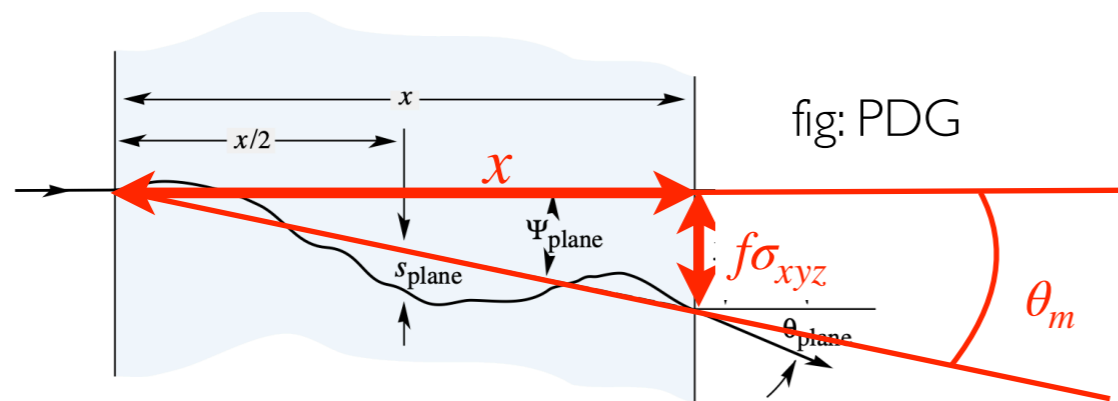


- Pulsars, Transients and multi-messengers, etc., Primordial black holes (arXiv: [2007.10722](https://arxiv.org/abs/2007.10722), [2010.04797](https://arxiv.org/abs/2010.04797))

# MeV $\gamma$ s in LAr



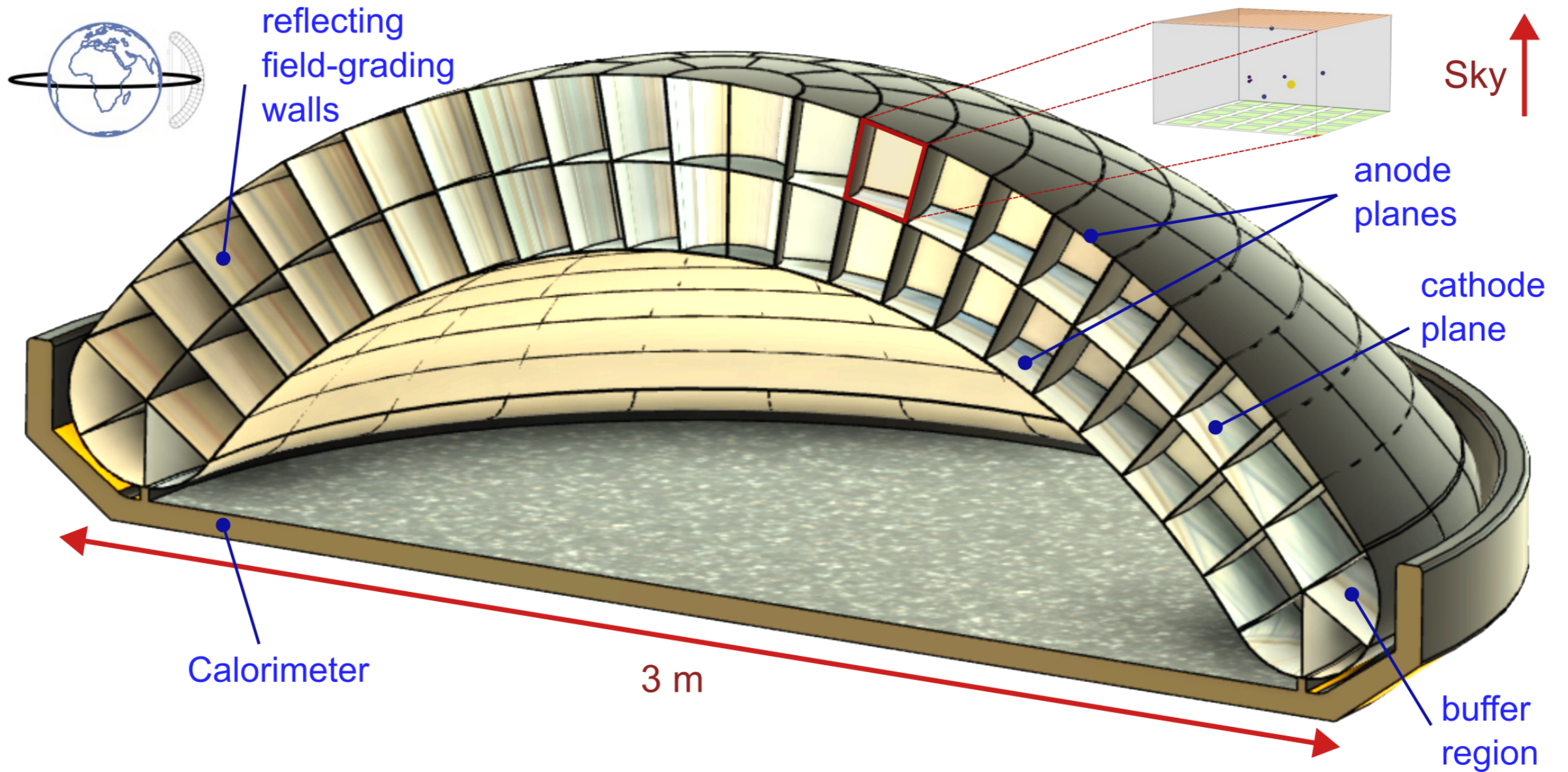
- Ar: relatively low  $Z$
- Maximize the Compton energy window
- Events spreading out
- Reduced Molière scattering



$$\Delta\theta \sim \left( \frac{f}{\beta^2 p^2} \frac{\sigma_{xyz}}{X_o} \right)^{1/3}$$

	$\lambda_\gamma(1 \text{ MeV})$ (cm)	$l_e(1 \text{ MeV})$ (mm)	$\chi_o$ (cm)
LAr (120 K)	14.9	5.1	16.8
LXe (165 K)	5.9	2.4	2.9
Si	6.7	2.3	9.4
Ge	3.3	1.2	2.3
W			0.35

# GammaTPC

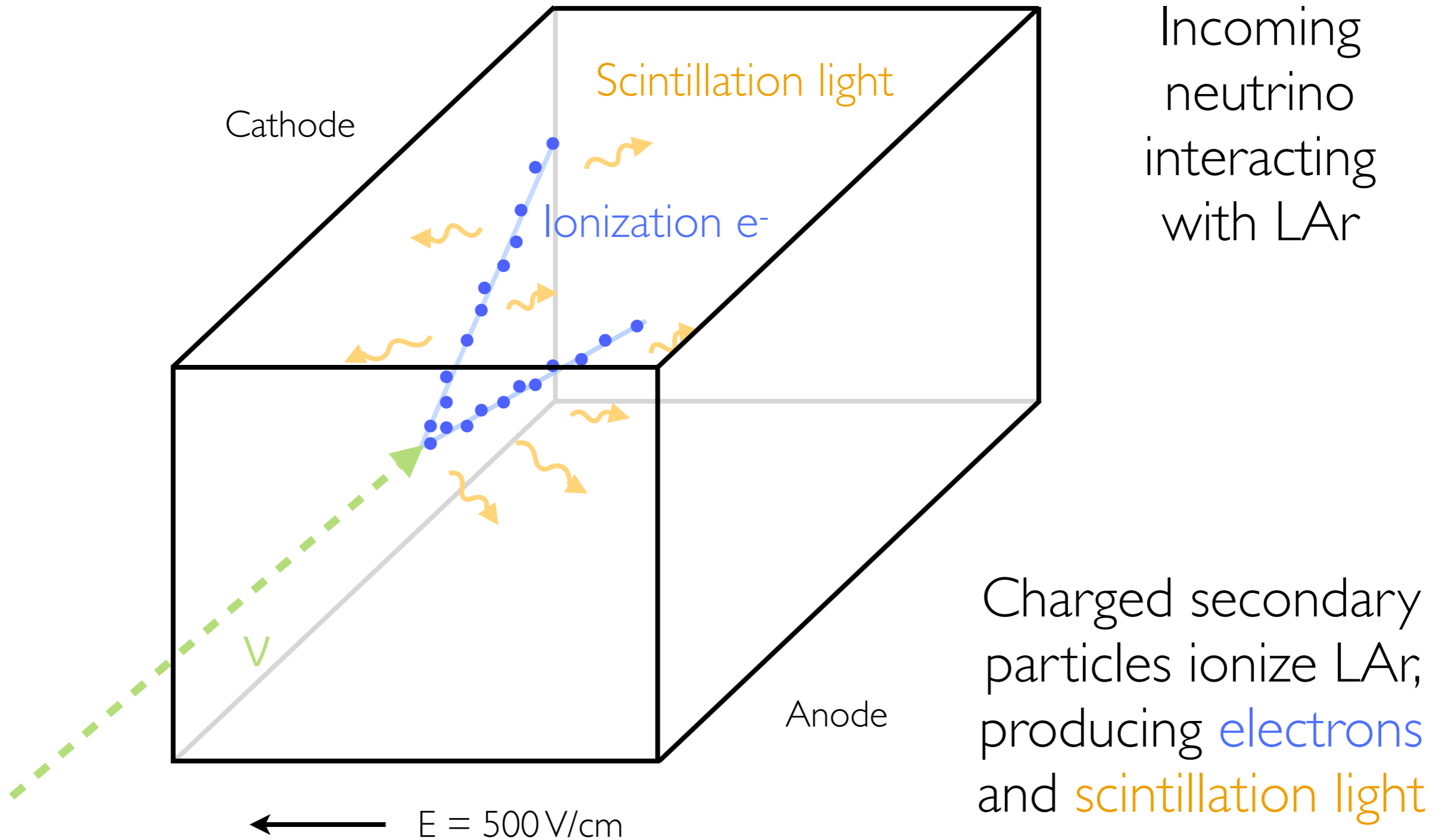


Modular LArTPC: 10 m<sup>2</sup>, 4 ton configuration

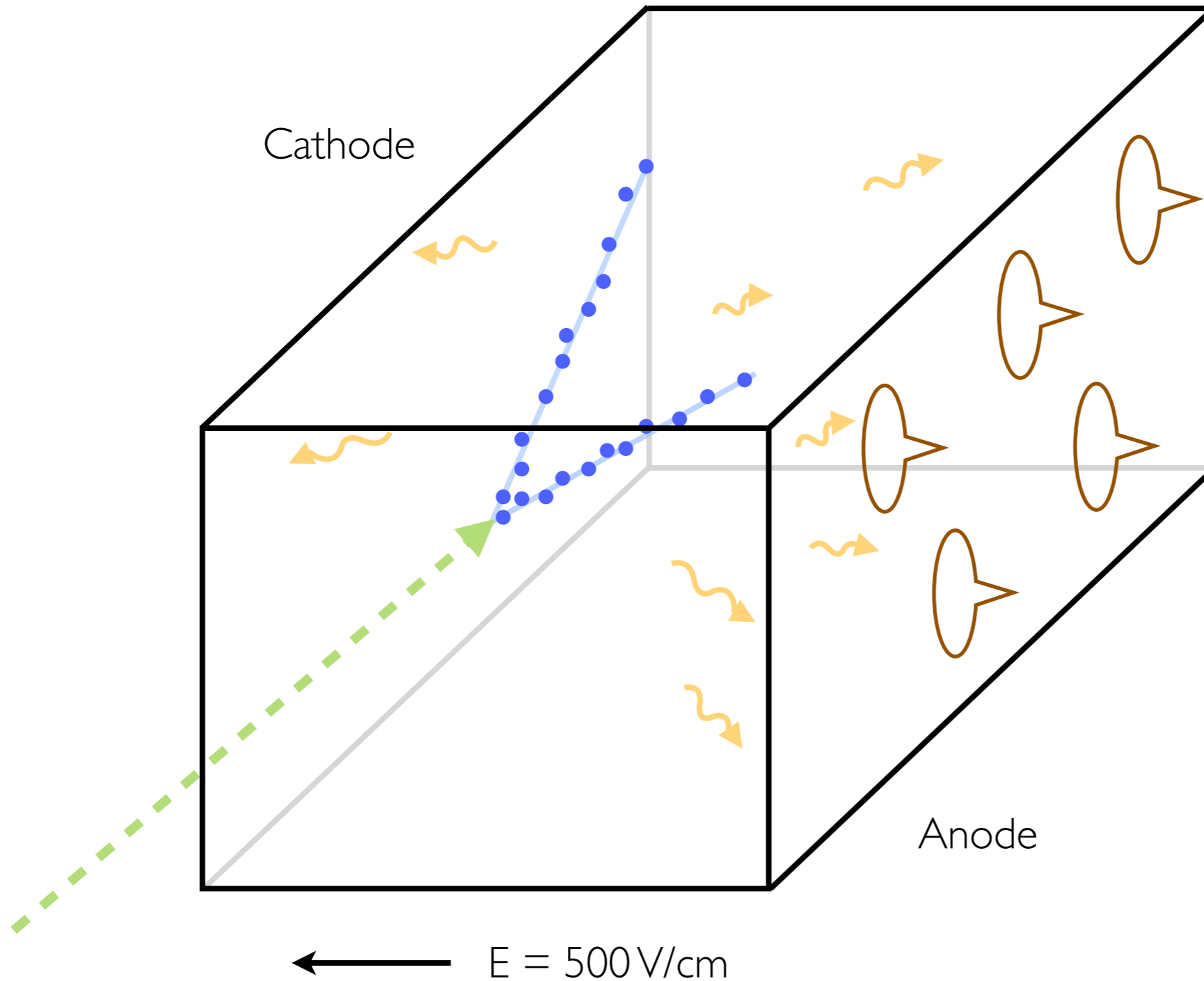
[arXiv: 2502.14841](https://arxiv.org/abs/2502.14841), founder: Tom Shutt



# LArTPC

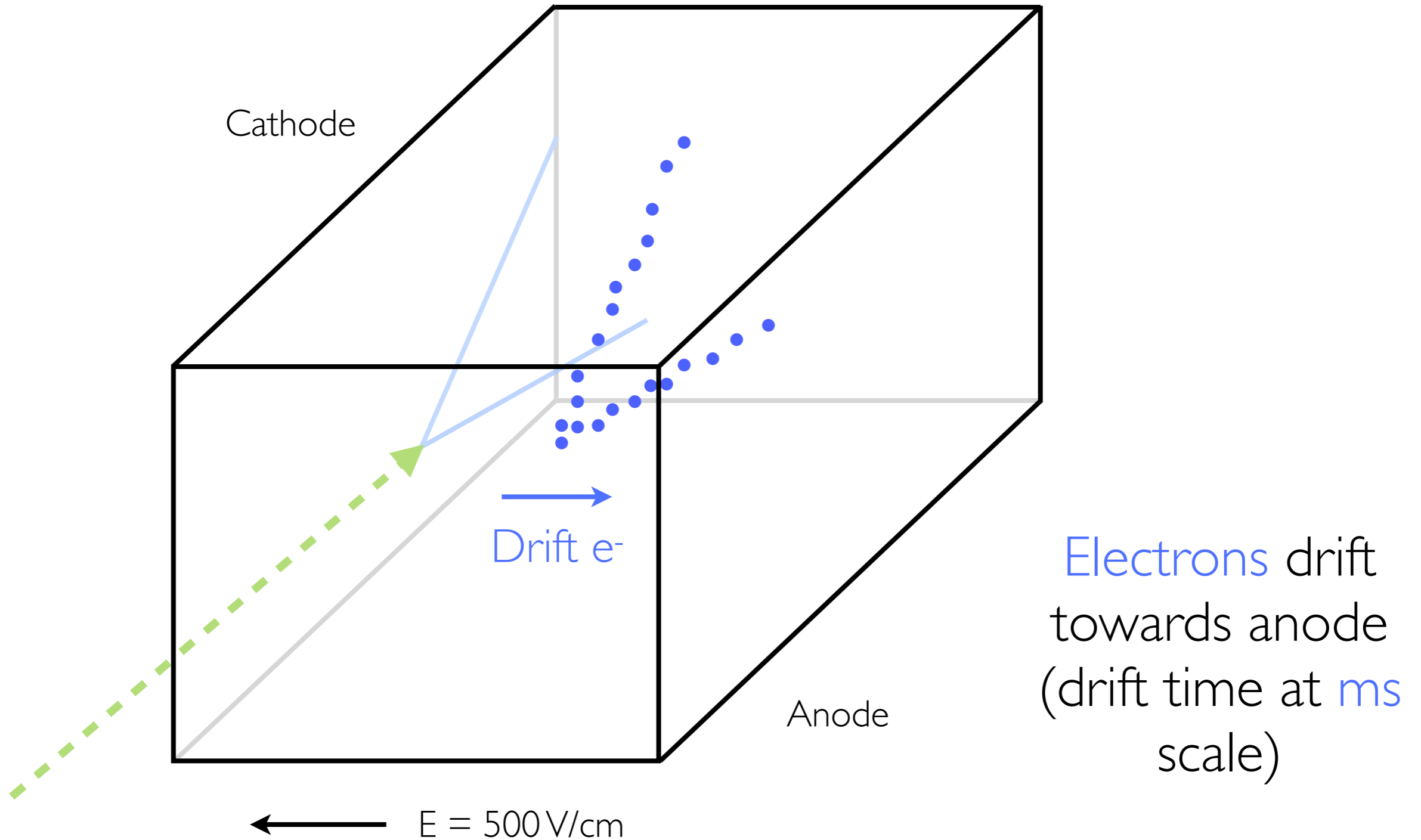


# LArTPC

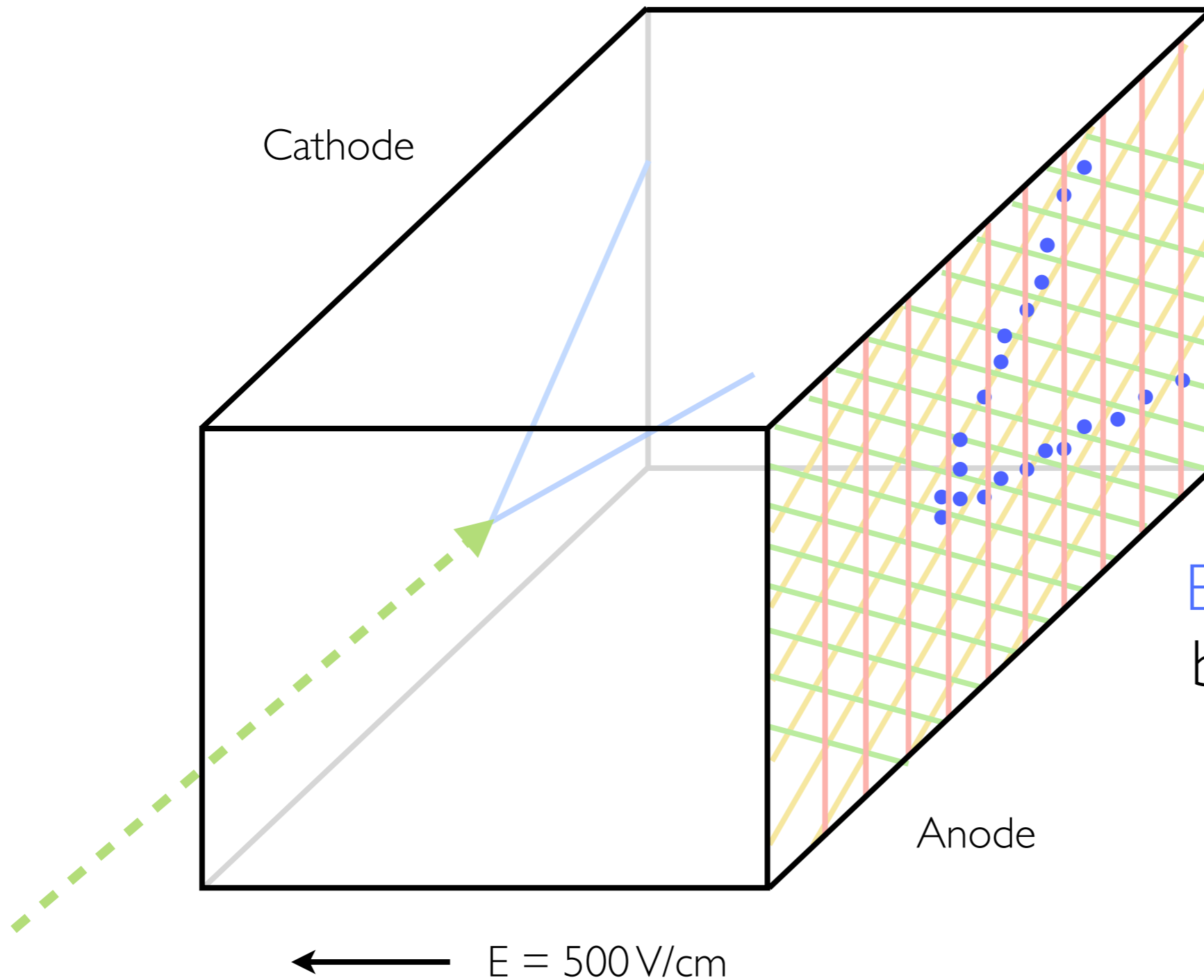


Light collected by  
photon detectors  
(10-100ns),  
determining  
event time  $t_0$

# LArTPC



# LArTPC

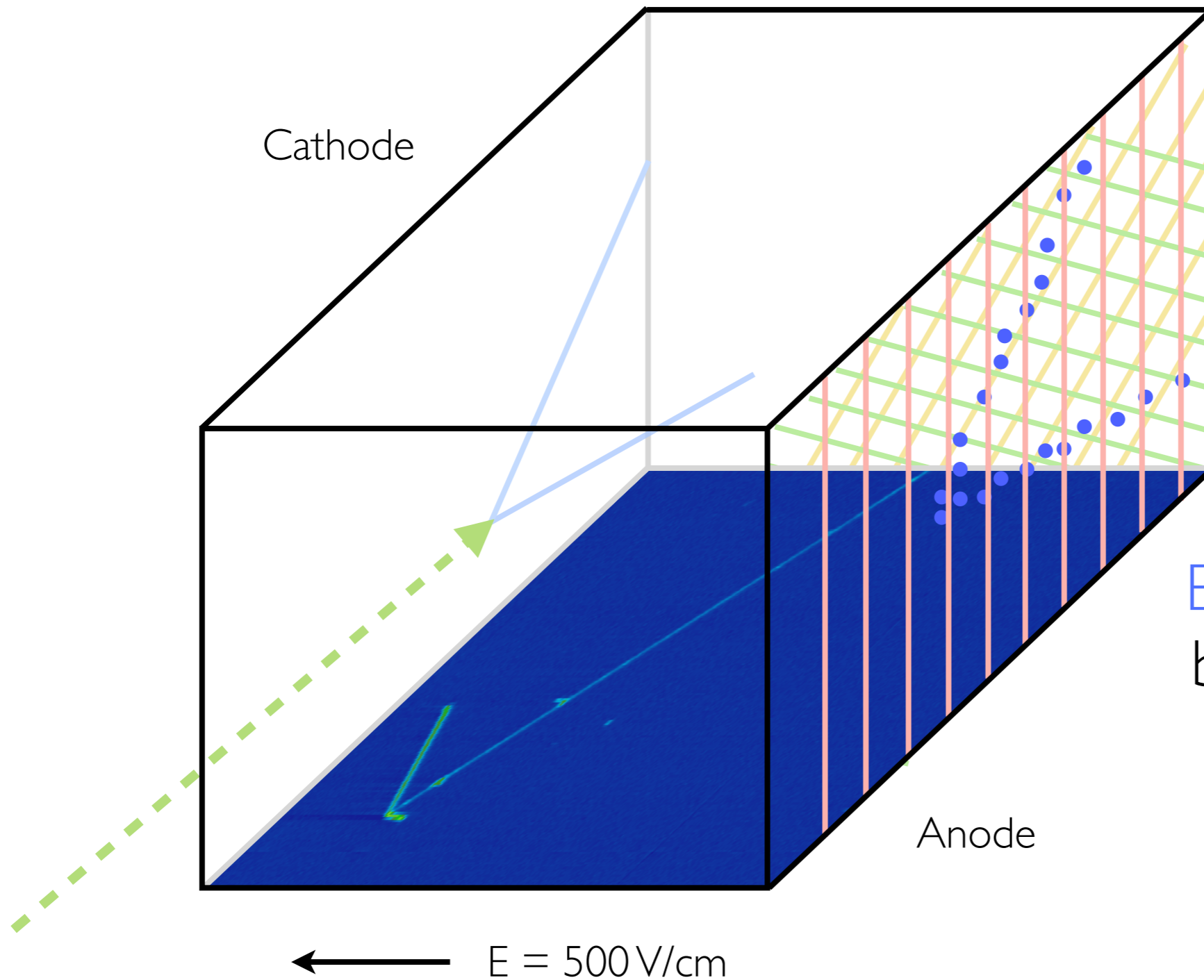


2 induction planes  
1 collection plane

Electrons detected  
by the wire planes  
at anode,  
providing the  
spatial, kinematic  
information.



# LArTPC



Electrons detected by the wire planes at anode, providing the spatial, kinematic information.

# $\mu$ BooNE

Color scale indicates amount of deposited charge

Neutrino direction  
-----▶

Time (-drift direction)

cosmic ray

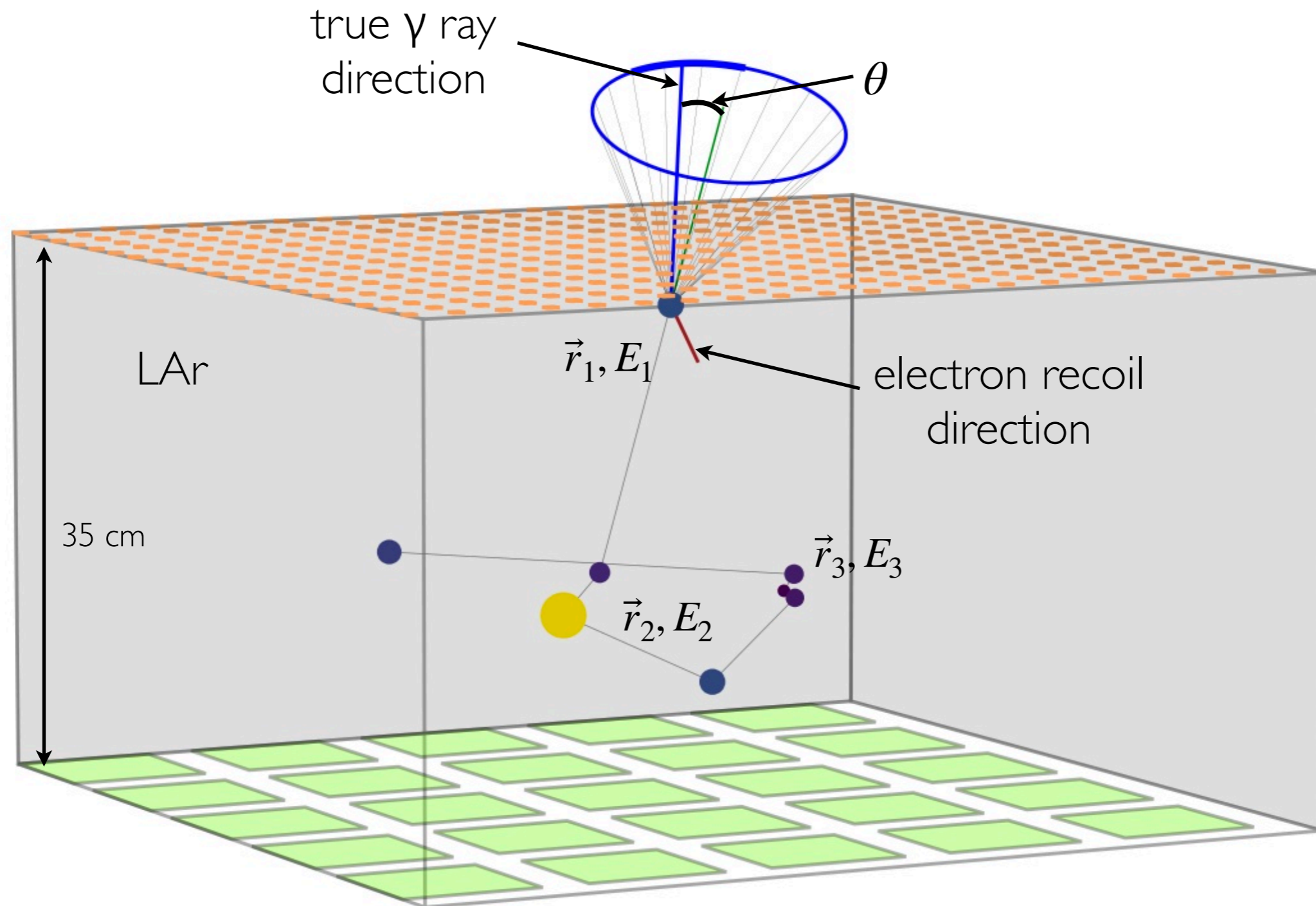
75 cm

Wire

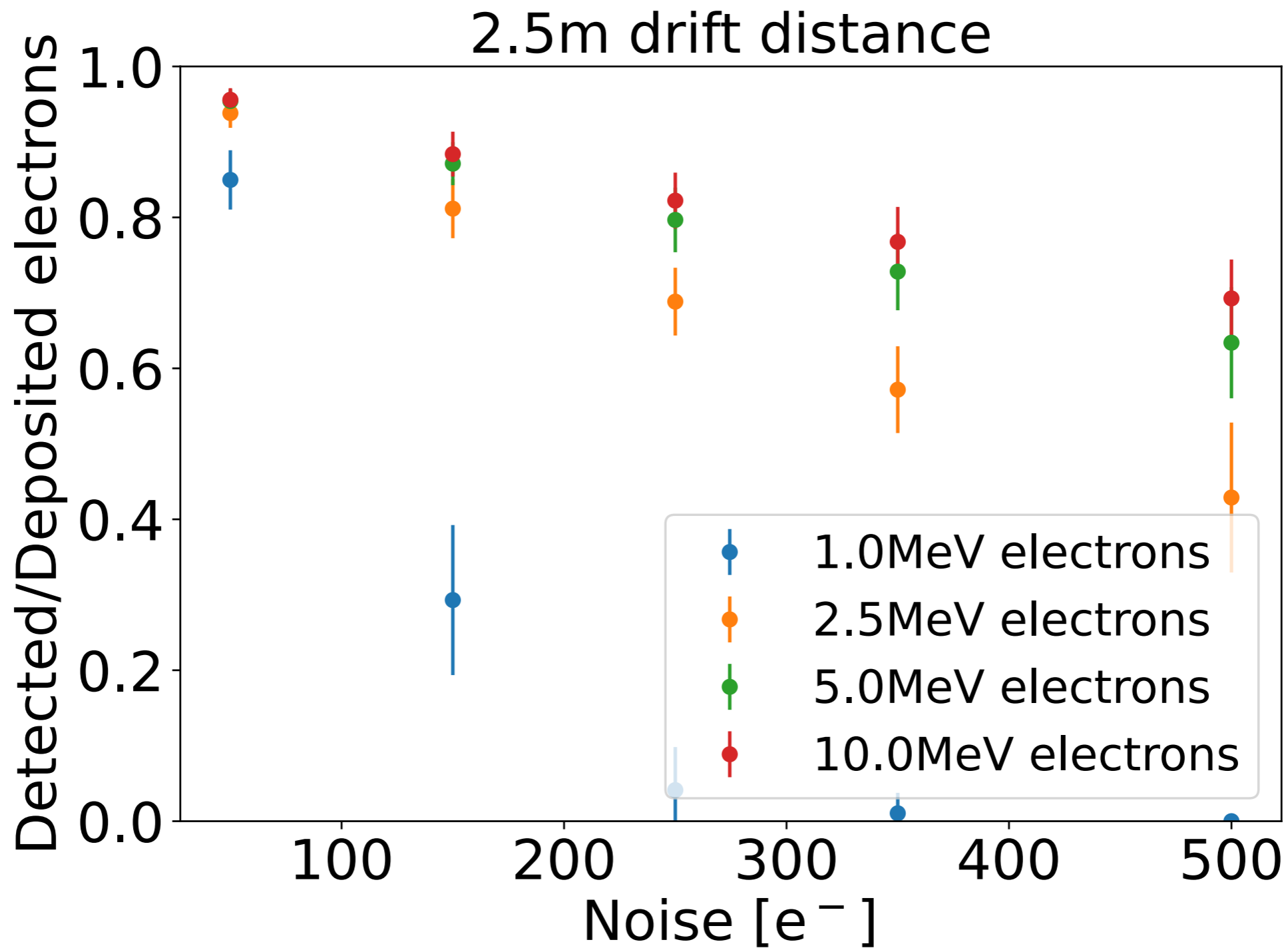
Run 3493 Event 41075, October 23<sup>rd</sup>, 2015



# MeV $\gamma$ Direction



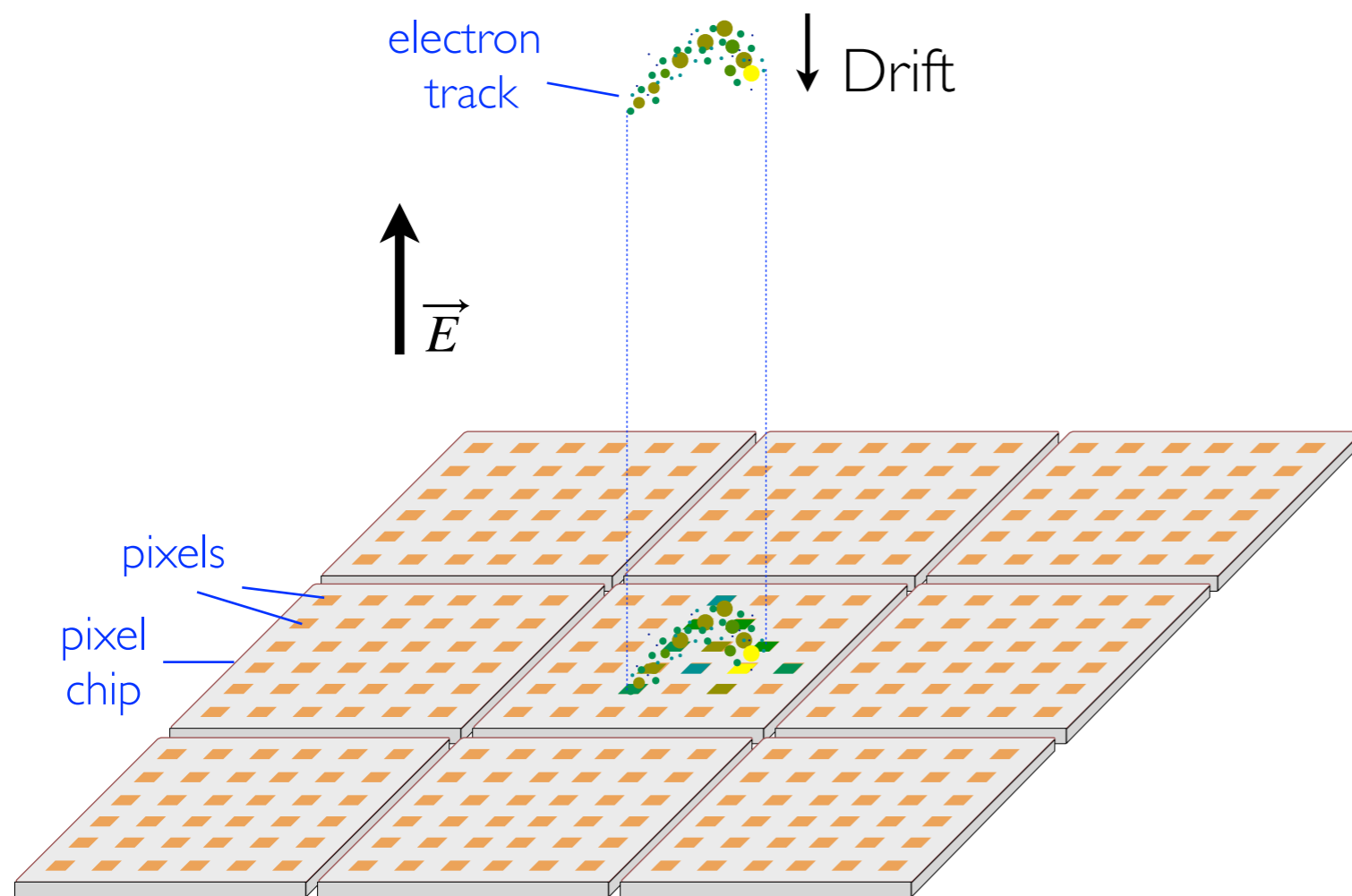
# MeV Particle Energy





# Pixelated Charge Readout

Detecting MeV-electrons from  $\nu_e$ -Ar CC interactions and Compton scatterings of MeV- $\gamma$ s

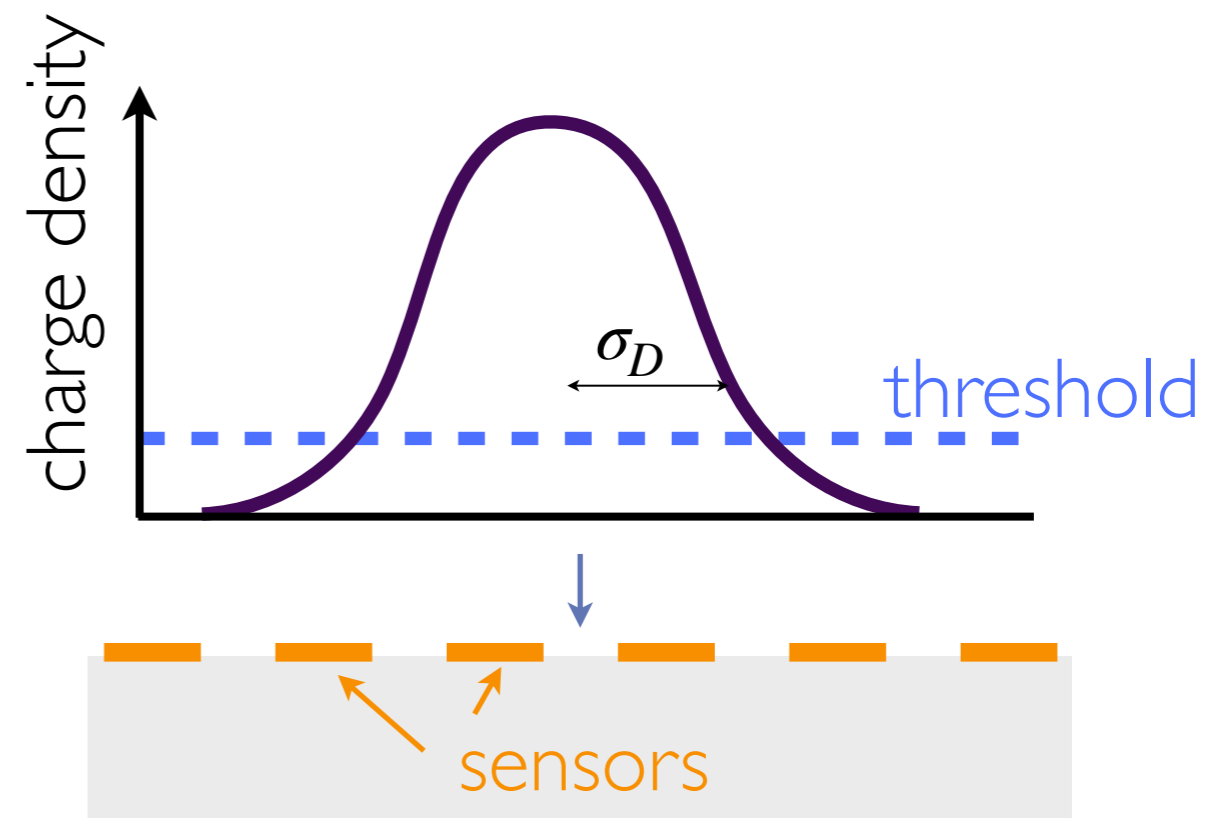
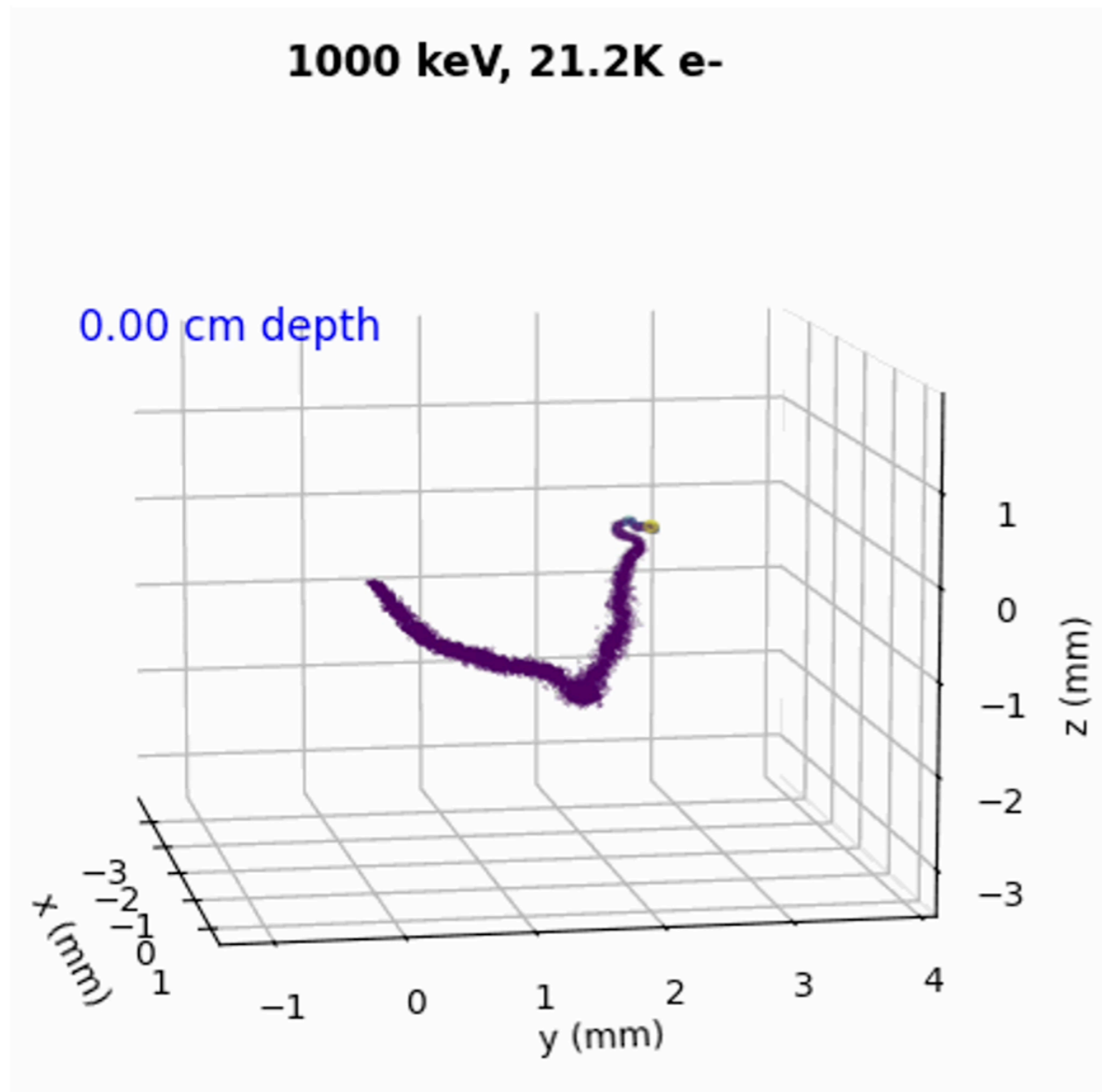


- True 3D charge distribution
- Challenges of pixels:
  - Naive power  $\sim$  kW/m<sup>2</sup>
  - $10^4$  ch/m<sup>2</sup>, data volume
- Specific requirements
  - 0.5-5mm granularity
  - Low noise level (high power needed)
- Issues of TPCs
  - Charge loss owing to diffusion

# Electron Cloud Diffusion

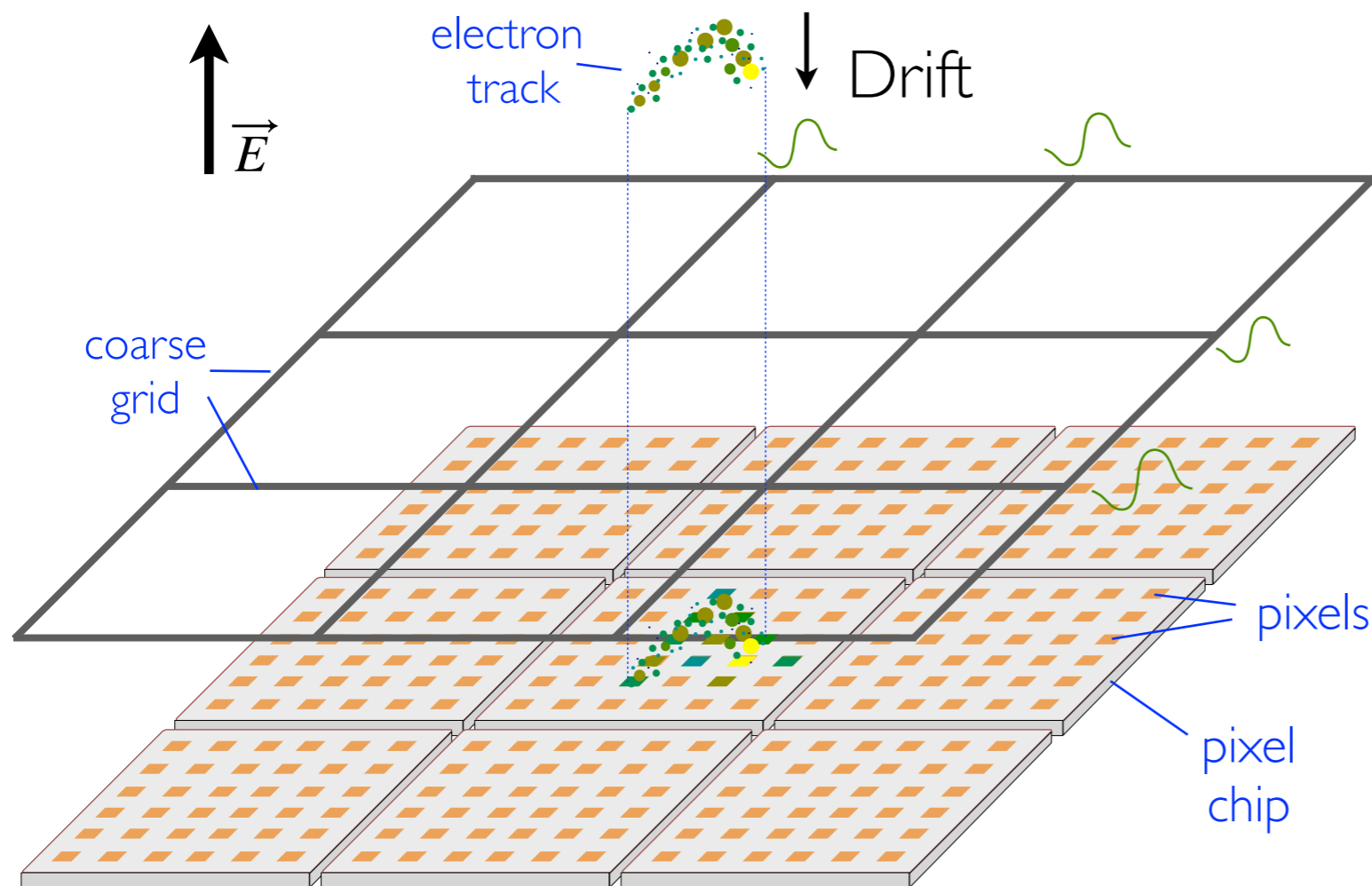
Electron clouds **diffuse** while drifting to anode.

**Charge loss** when the diffusion is on the scale of the sensors.



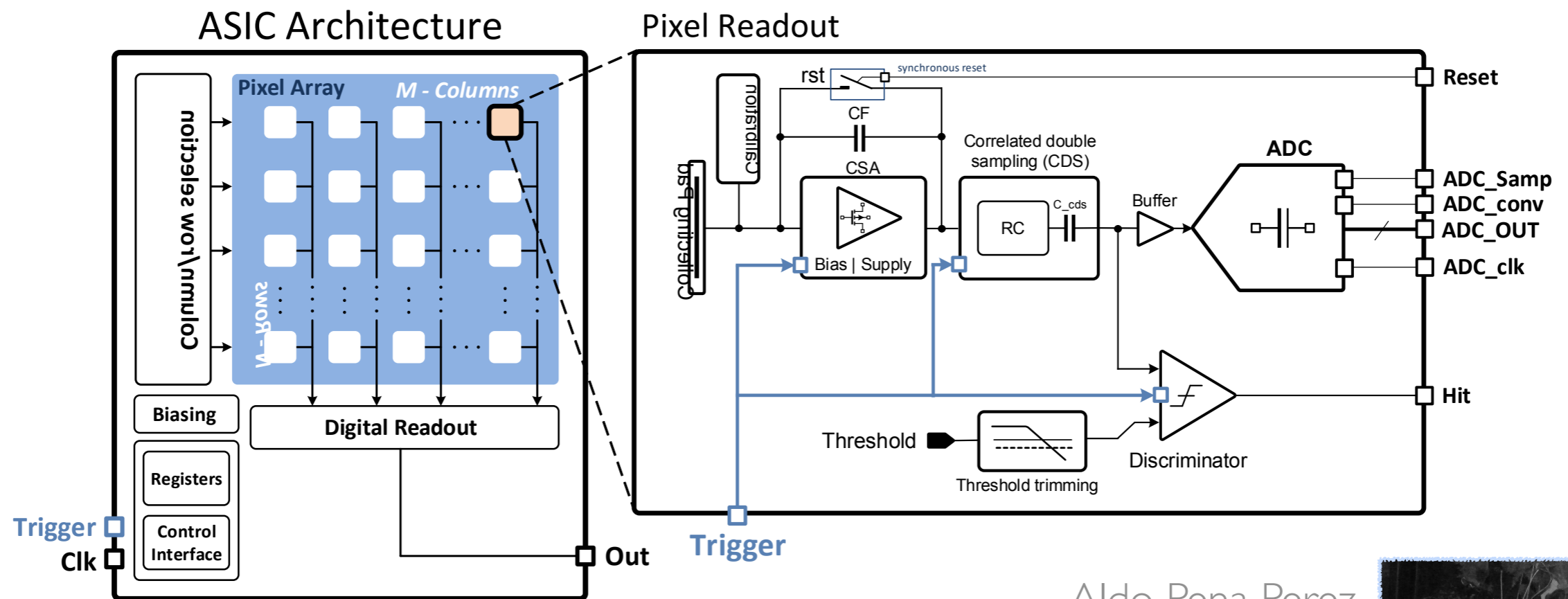
# GAMPix

Grid Activated Multi-scale Pixel readout  
[arXiv: 2402.00902](https://arxiv.org/abs/2402.00902)



- Coarse grid chips:
  - Triggers for pixels
  - Measure charge integral,  $\sigma_e \sim 15e^-$
- Pixel chips:
  - Power up in  $< 1 \mu s$  when triggered
  - Image tracks
- Solves both the issues of power consumption and charge diffusion
- Measures drift length

# Fast Power Switching ASIC



Aldo Pena Perez



- Being designed by SLAC TID-IC team
- Cryogenic system-on-chip ASIC development
- 130nm CMOS process (foundry+SLAC custom cryo models)
- Digital logics for timing, pixel configurations, and data readout

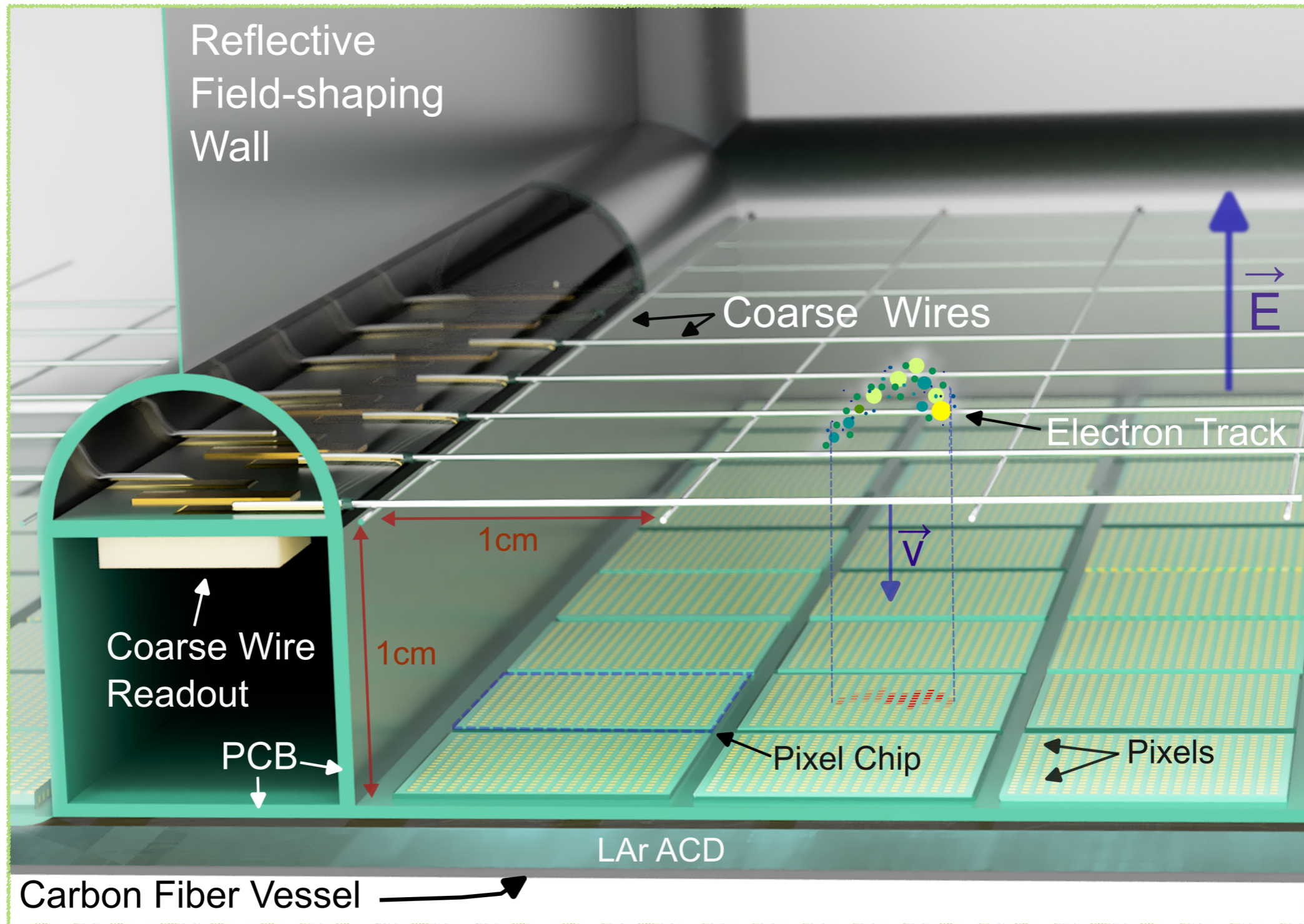


# Spec for GammaTPC

Param	Value
Temperature	LAr (87 K)
Technology	130 nm
Pixel size	500 $\mu\text{m}$ $\times$ 500 $\mu\text{m}$
Pad size	$\sim$ 200 $\mu\text{m}$
Pad capacitance	$\sim$ 500 fF
Noise requirement	$<$ 50 e $^-$
On-power	$<$ 0.250 mW/pixel
Off-power	$<$ 300 nW/pixel
Dynamic range	7000 e $^-$ ( $Q_{\text{in}} = \sim 1.12$ fC)
Settling time after trigger	$<$ 5 $\mu\text{s}$
Sampling rate	2.0 MS/s
Resolution	10 bit
RC filter	150ns – 600ns (programmable)

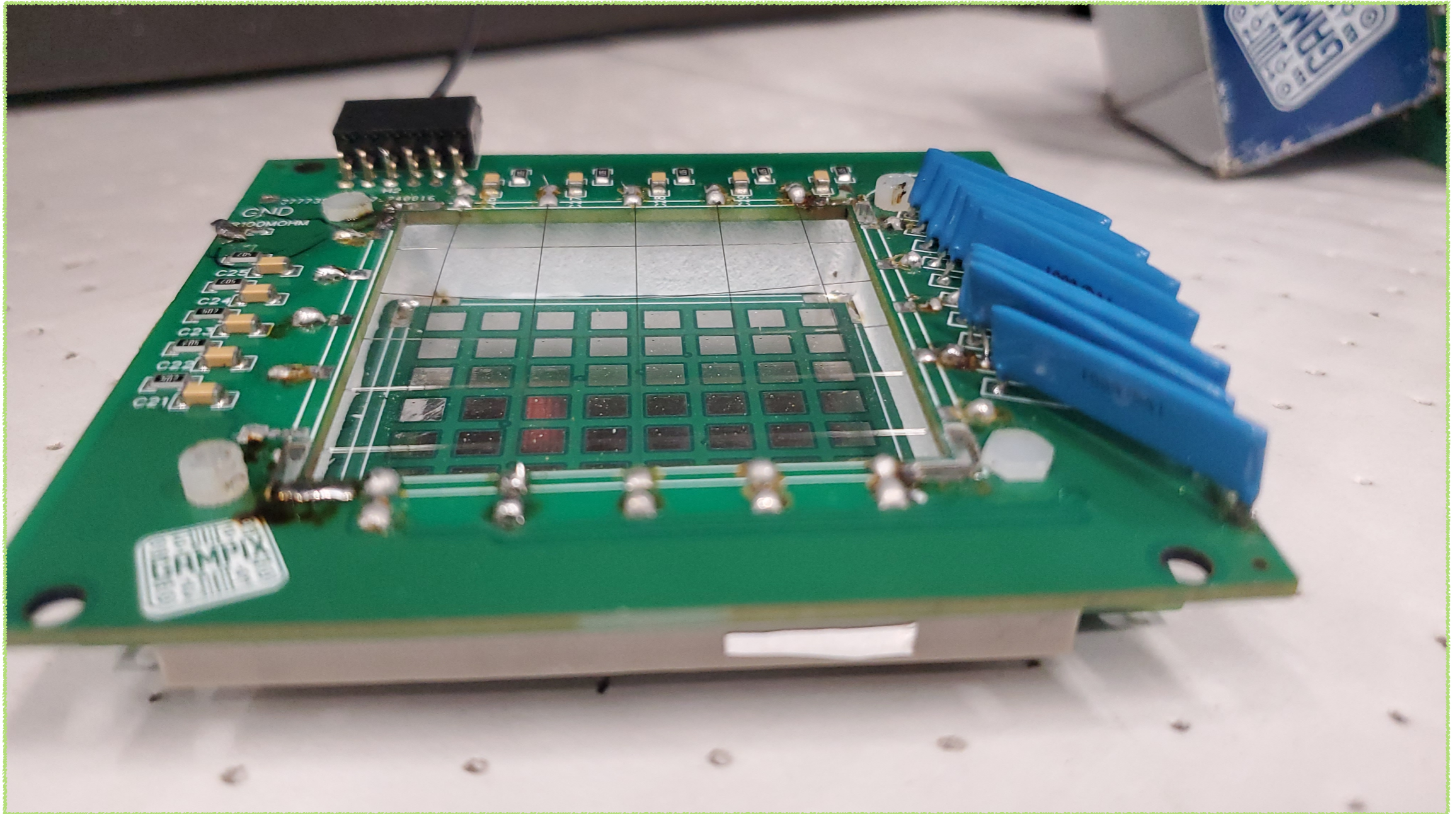
- Current estimate per pixel:
  - On-power:  $\sim 0.22$  mW
  - Off-power:  $\sim 280$  nW
  - Full pixel ENC:  $\sim 40$  e $^-$
  - 10-bit ADC
- Tape out on **Nov. 1st 2025!**
- Prototype:  $5 \times 5$  mm $^2$  (8 $\times$ 8 pixel array)
- DUNE spec study got started

# GAMPix Drawing





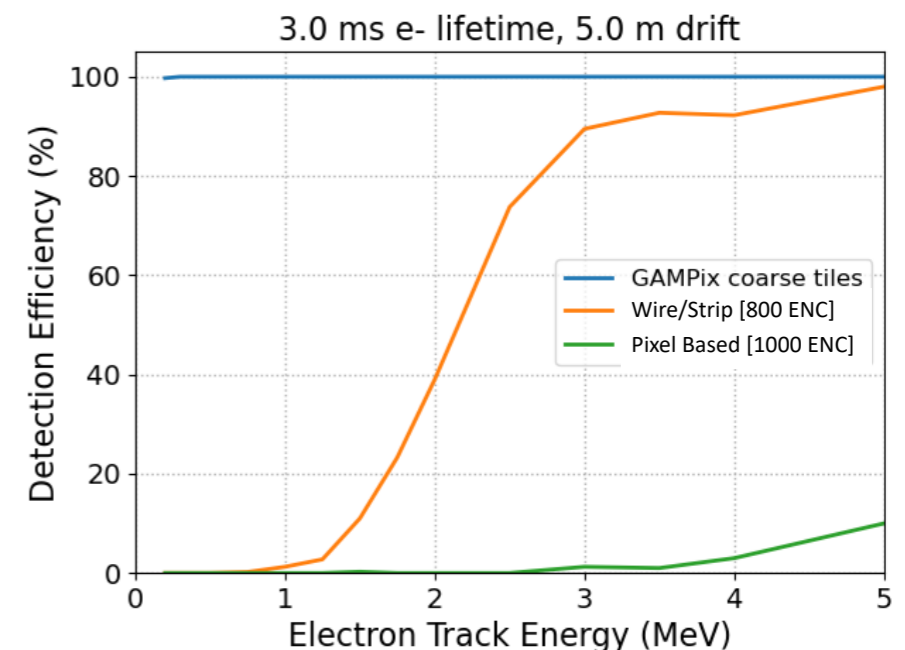
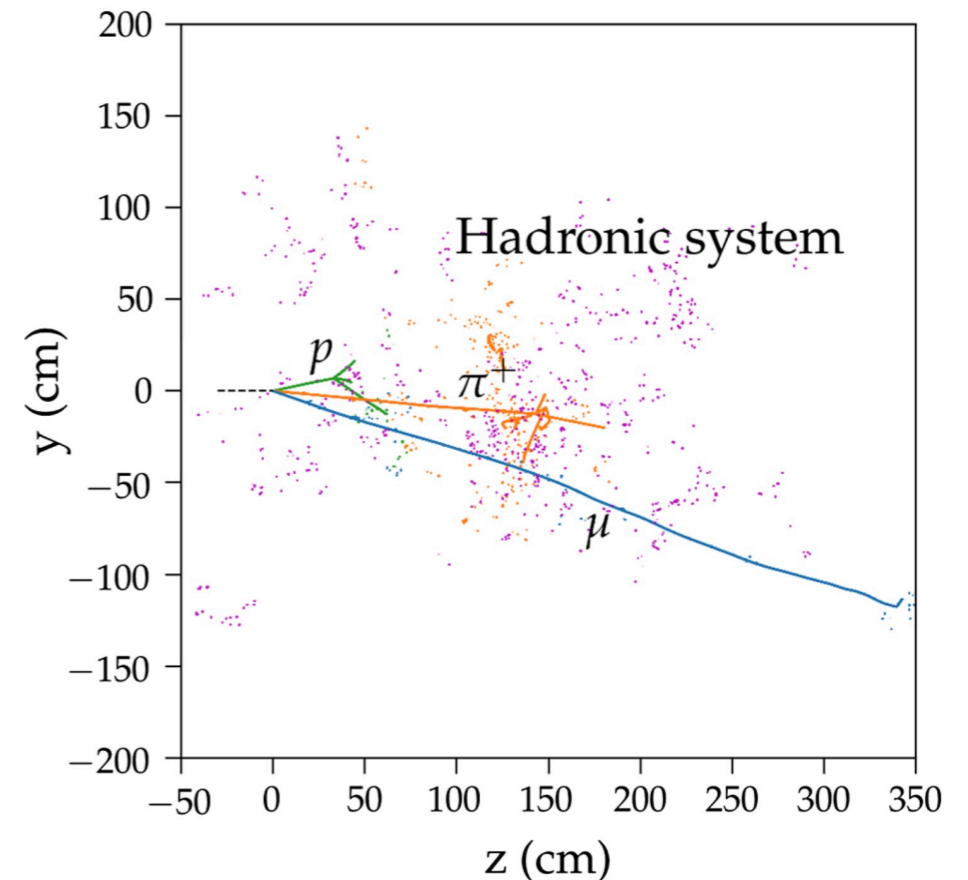
# GAMPix Prototype





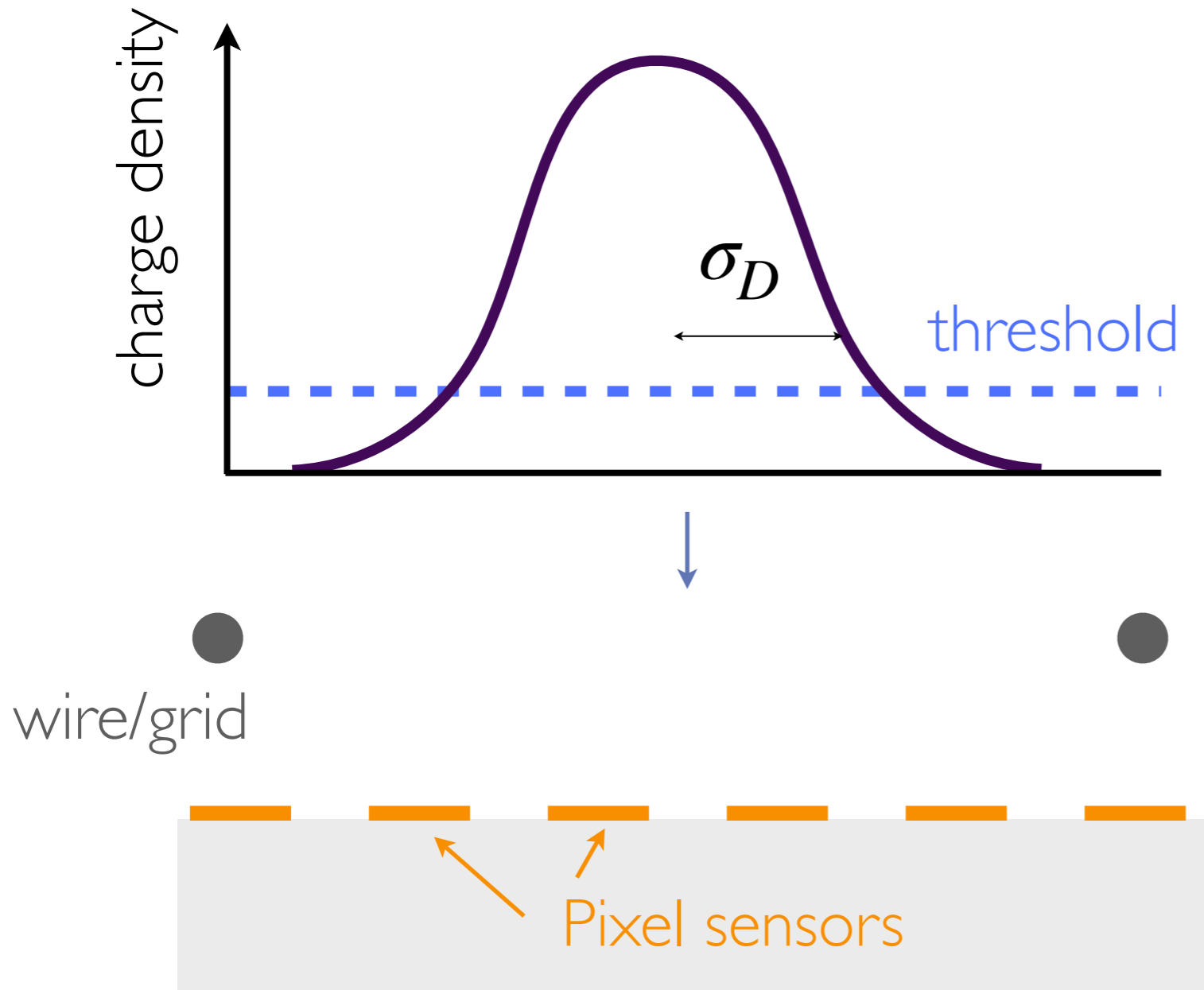
# Potential on DUNE

- 5mm-pixels, 10cm-wires/grids
- Small charge deposition (blips) retained
  - lower detection threshold (sub-MeV) and better energy resolution
- Drift length determined
  - improve background rejection
- Expect to improve the supernova neutrino measurements and the energy resolution in all the measurements





# Dual Readout

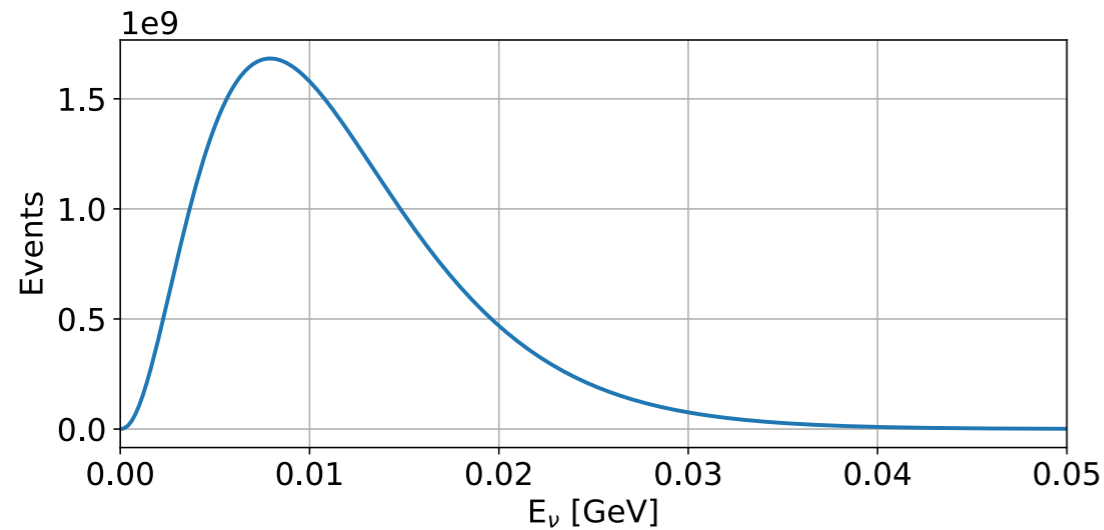


Compare the amount of charge detected by the coarse and the fine-pitch readout planes

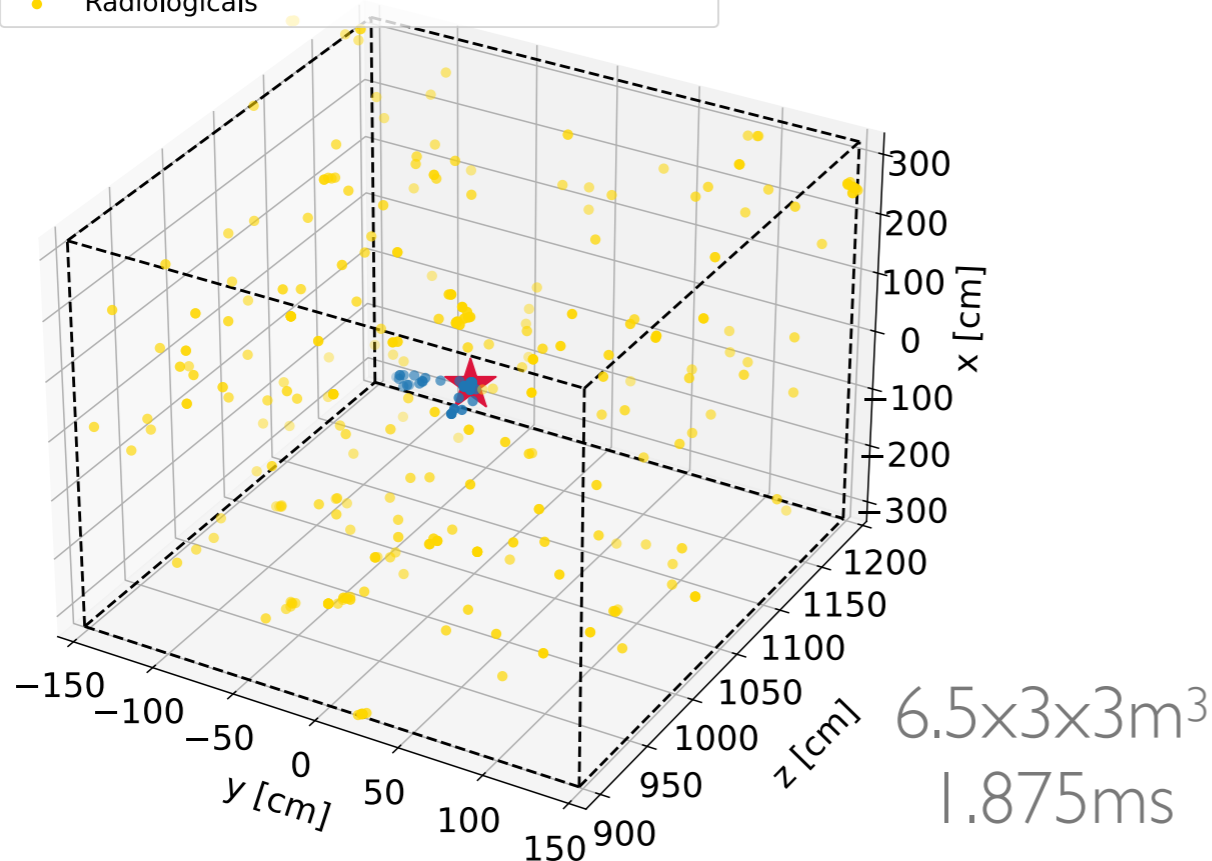
→ Measure the diffusion effects

→ Infer the drift lengths cluster-by-cluster

# Supernova $\nu$ + Radiologicals



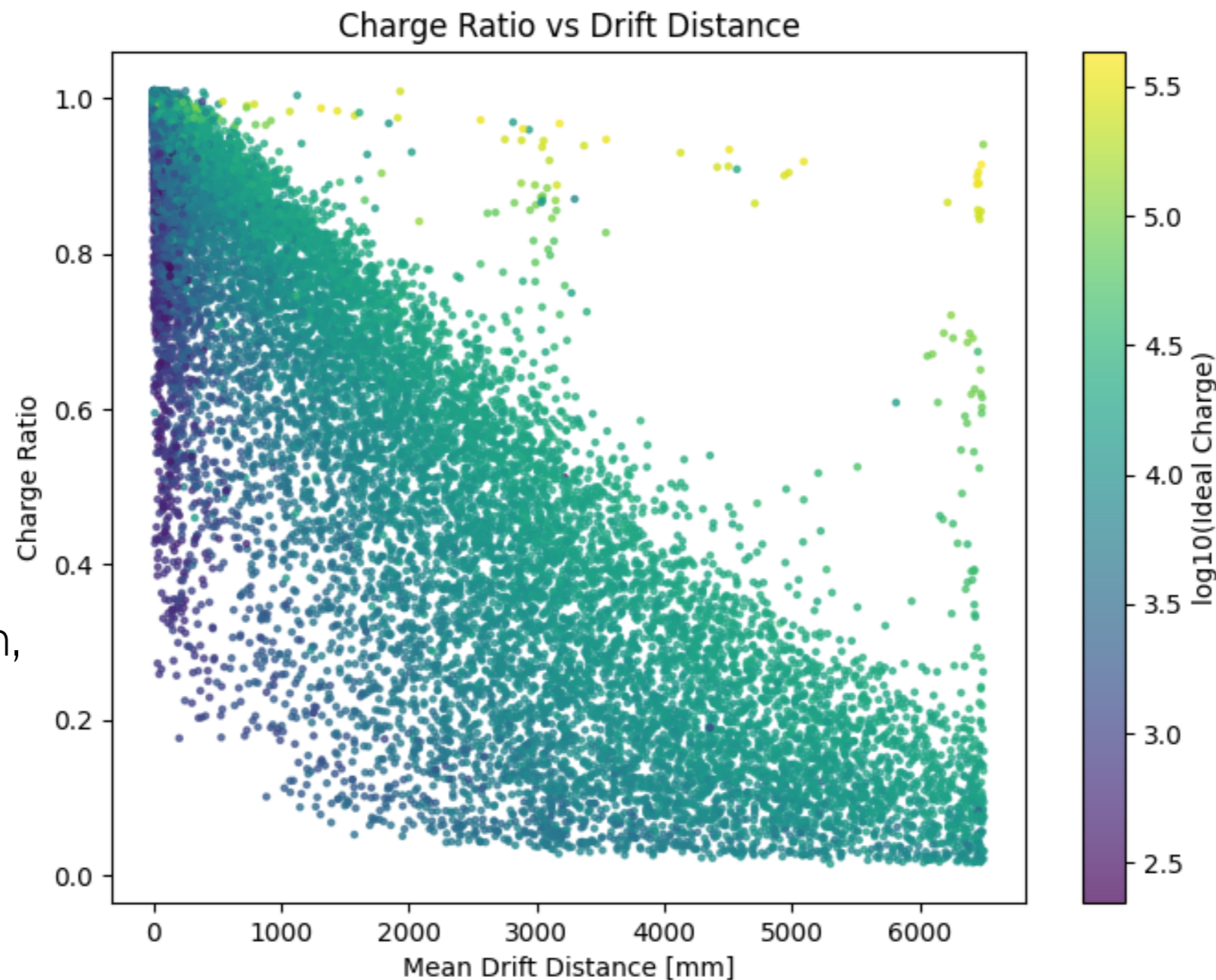
● Supernova neutrino  
● Radiologicals  
★ Interaction vertex



- Garching supernova neutrino  $\nu_e$  flux
  - Normal mass ordering
- DUNE official radiological sample for VD 1x8x14
  - Upper module, full drift distance, 6.5m
  - Include cavern  $\gamma, n$
  - 25cm LAr above upper charge readout plane (CRP)
  - Thanks to Juergen Reichenbacher & Gleb Sinev!!

# Charge on Pixel vs Grid

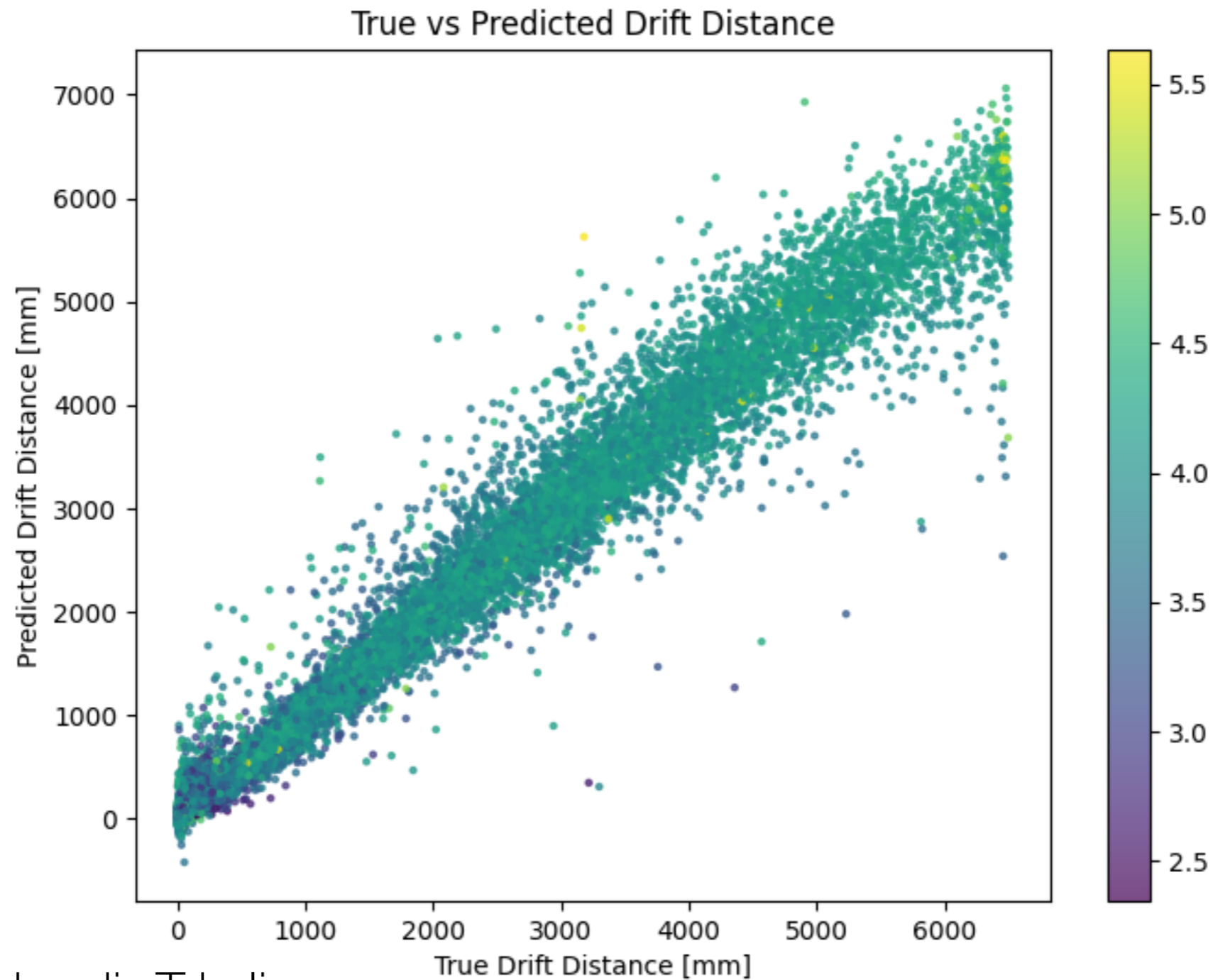
Charge Ratio = Charge(detected by pixel)/Charge(detected by grid)



Recombination,  
electron  
lifetime not  
considered  
here

Analysis by  
Bahrudin Trbalic

# Drift Length Analysis



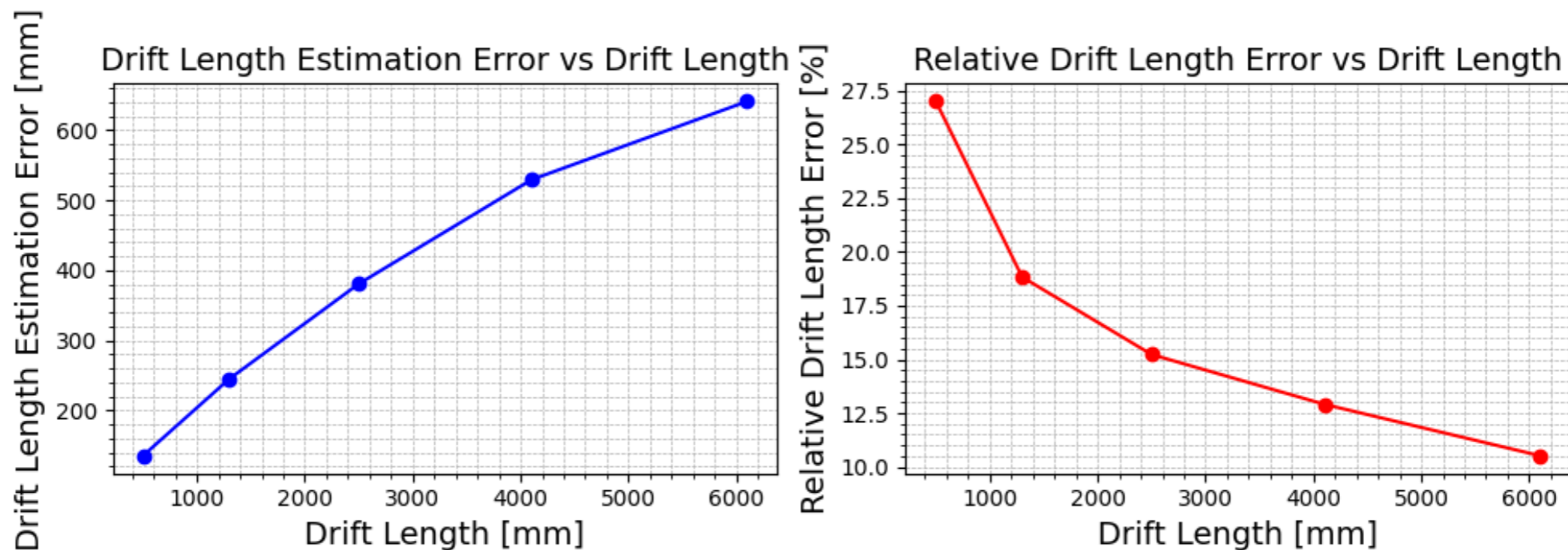
Analysis by Bahrudin Trbalic



# Estimated Error

- [Proof-of-concept](#) analysis by Bahrudin Trbalic
- No recombination and electron lifetime considered now
- DBSCAN to cluster charge deposits
- Neutral network to predict drift lengths by charge ratio
- Refine and improve the results underway

FWHM Analysis of Drift Length Estimation Error



# Current Progress

- More sophisticated detector simulation and machine-learning based analysis
- Optimizing the pixel pitches to physics performance
- Team: Yun-Tse Tsai (SLAC), Dan Douglas (SLAC), Boxun Yu (Peking U.), Sanjay Dev (U. of Washington), Shih-Chieh Hsu (U. of Washington)

# Summary

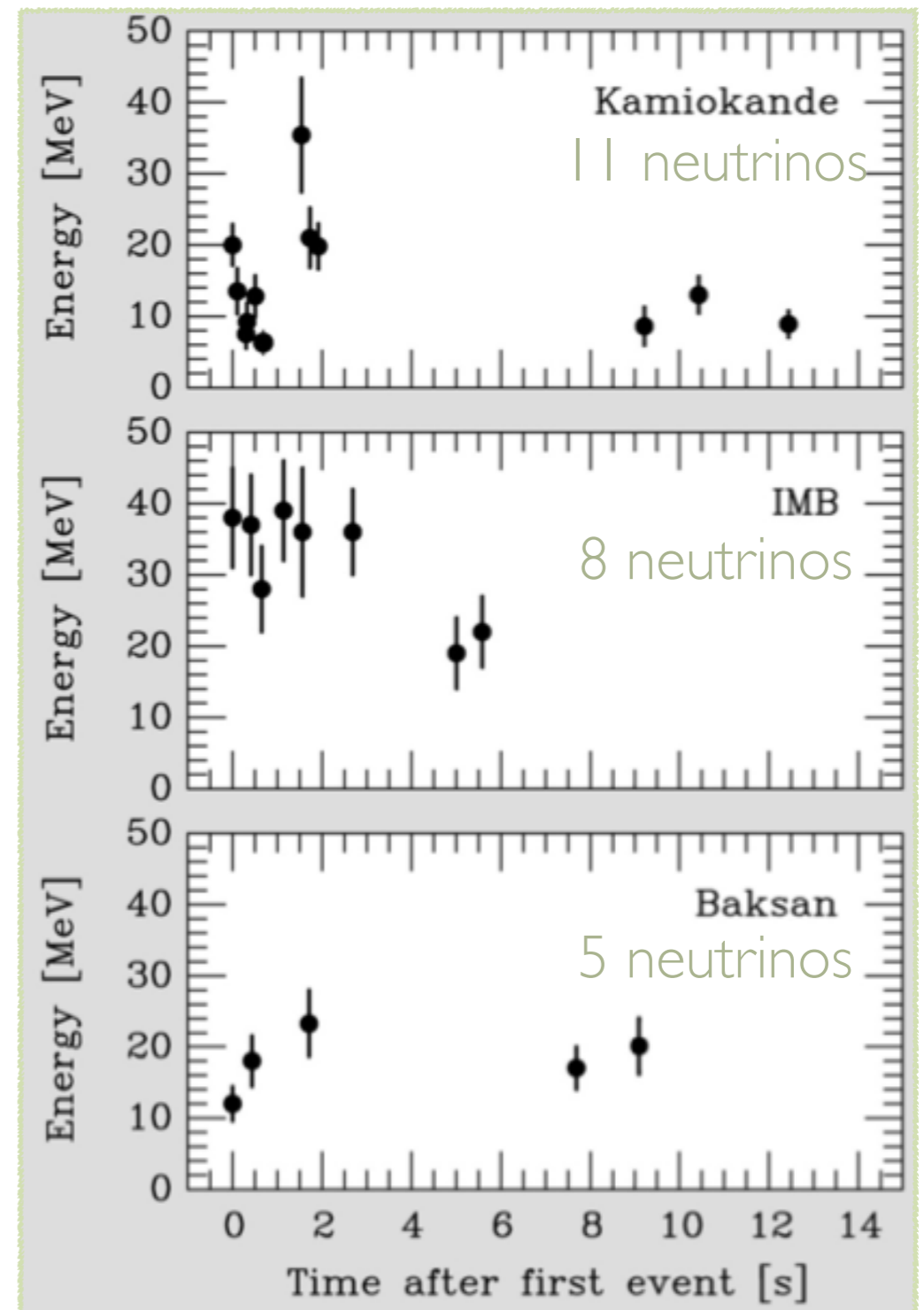
- MeV-scale physics in LArTPCs not largely explored. Unique opportunities, e.g.
  - Supernova  $\nu_e$  measurements in DUNE
  - $\gamma$ -rays in space (GammaTPC)
- Detector R&D underway optimized to MeV physics
  - GAMPiX R&D at SLAC
  - Looking for collaborators



# Backup

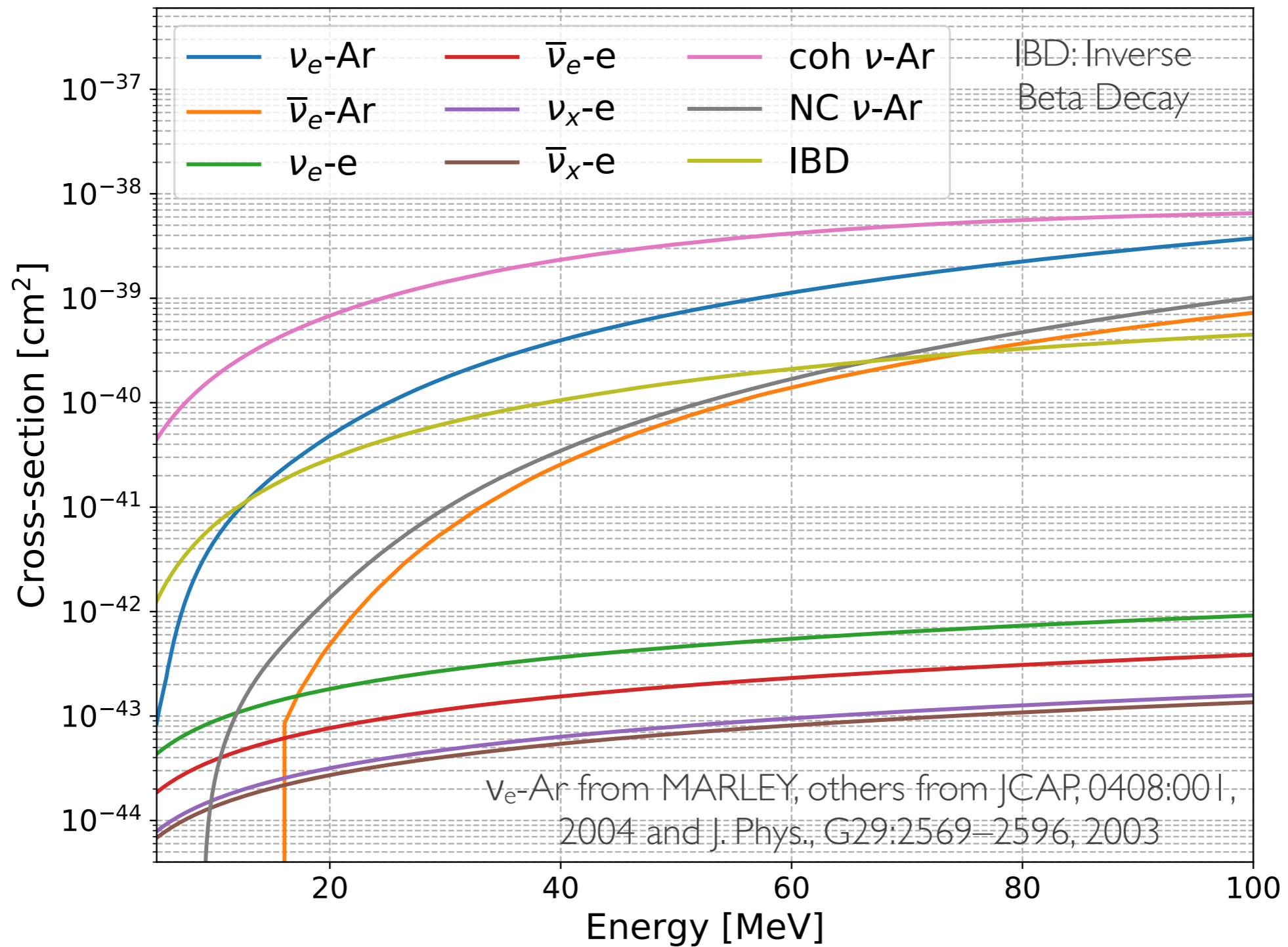
# What We Can Learn from SN $\nu$

- Test supernova models
- Search for new physics
- Neutrinos produced in extreme conditions
- Sensitivity to all the neutrino flavors is desirable
- Total 24 neutrinos detected in 1987, thousands of papers
- all the detectors were sensitive to  $\bar{\nu}_e$

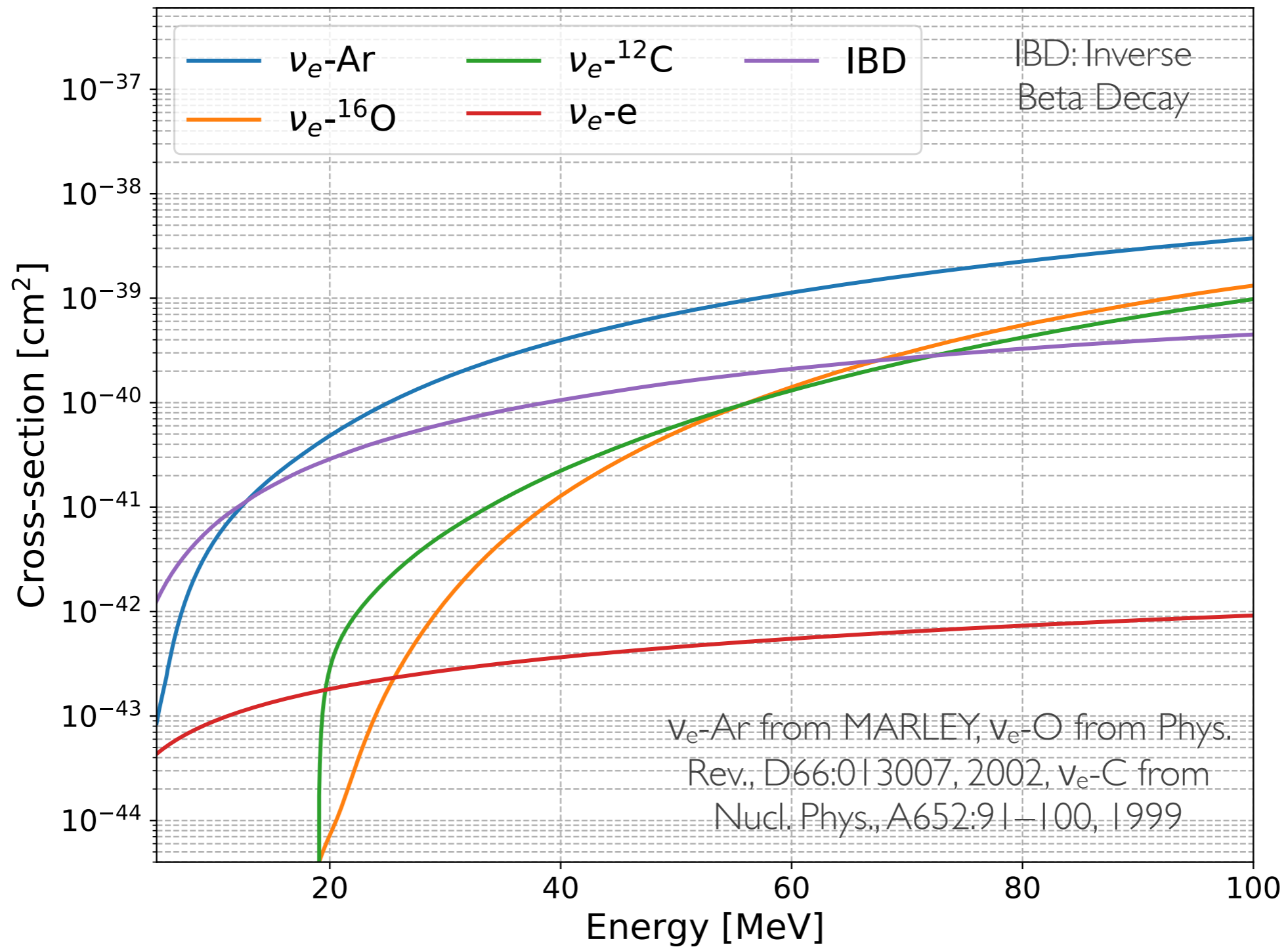




# $\nu_e$ -Ar Cross Sections

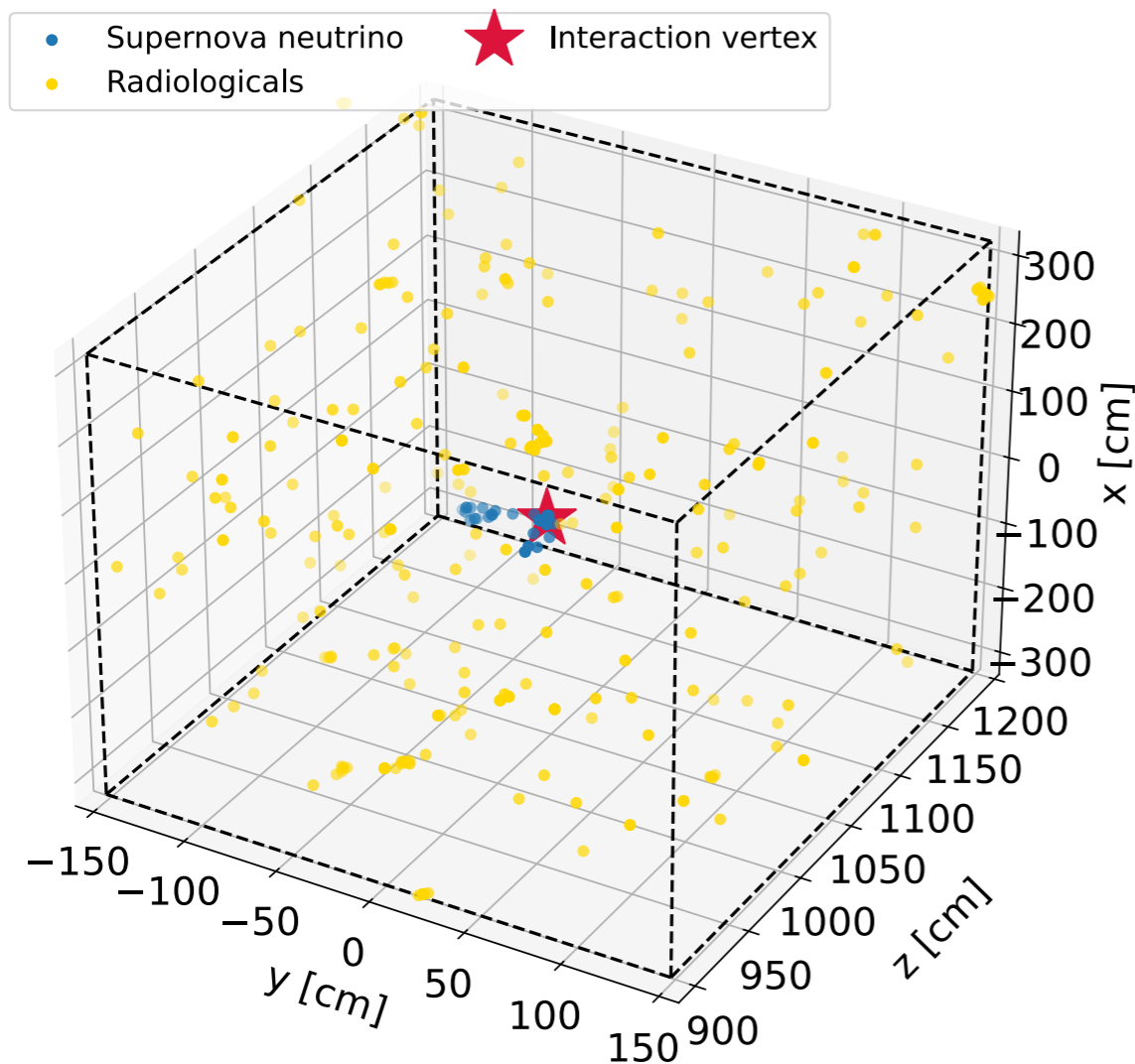


# $\nu_e$ Cross Sections



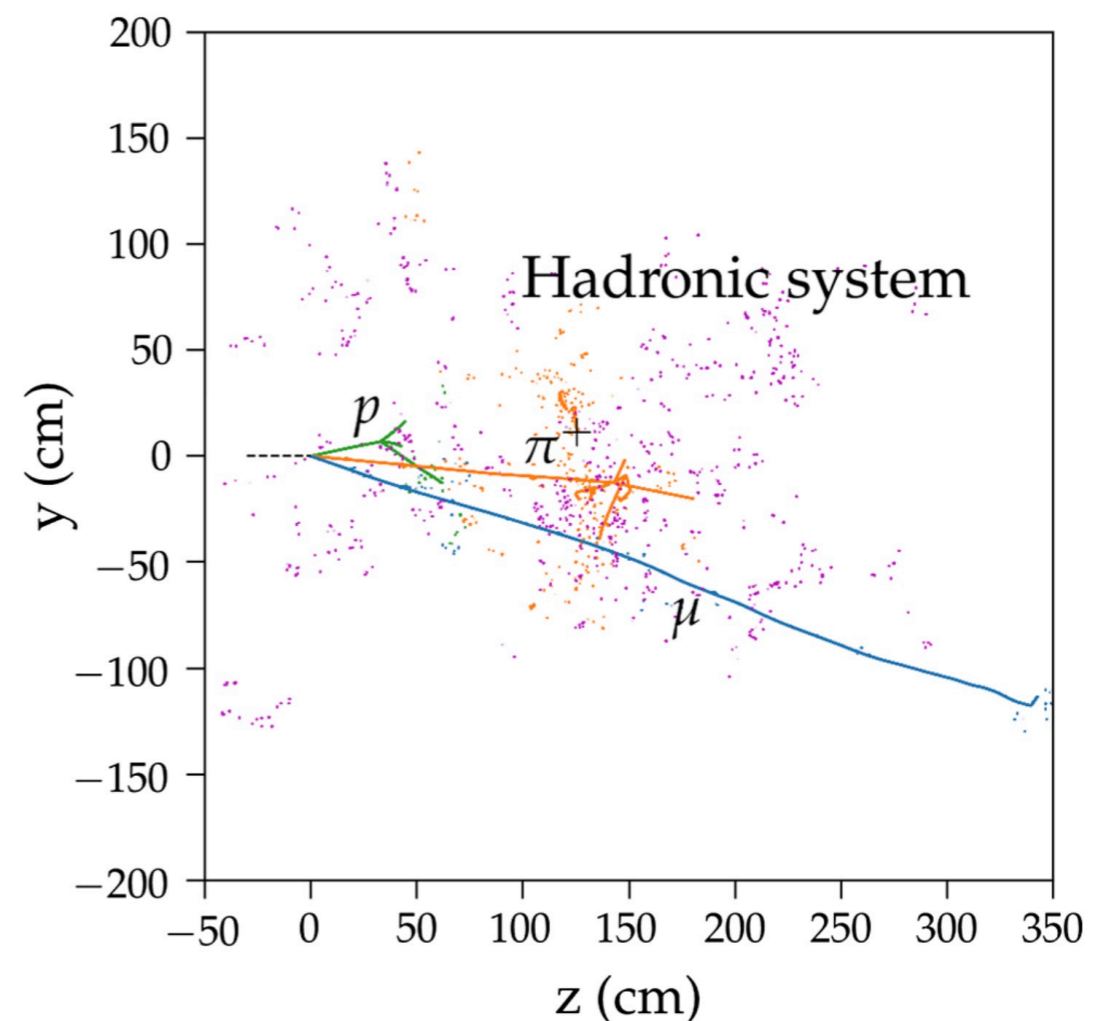
# MeV-scale Physics in DUNE

Astrophysical neutrinos: e.g.  
Supernova and solar neutrinos  
(MeV scales)



[arXiv: 2203.00740](https://arxiv.org/abs/2203.00740)

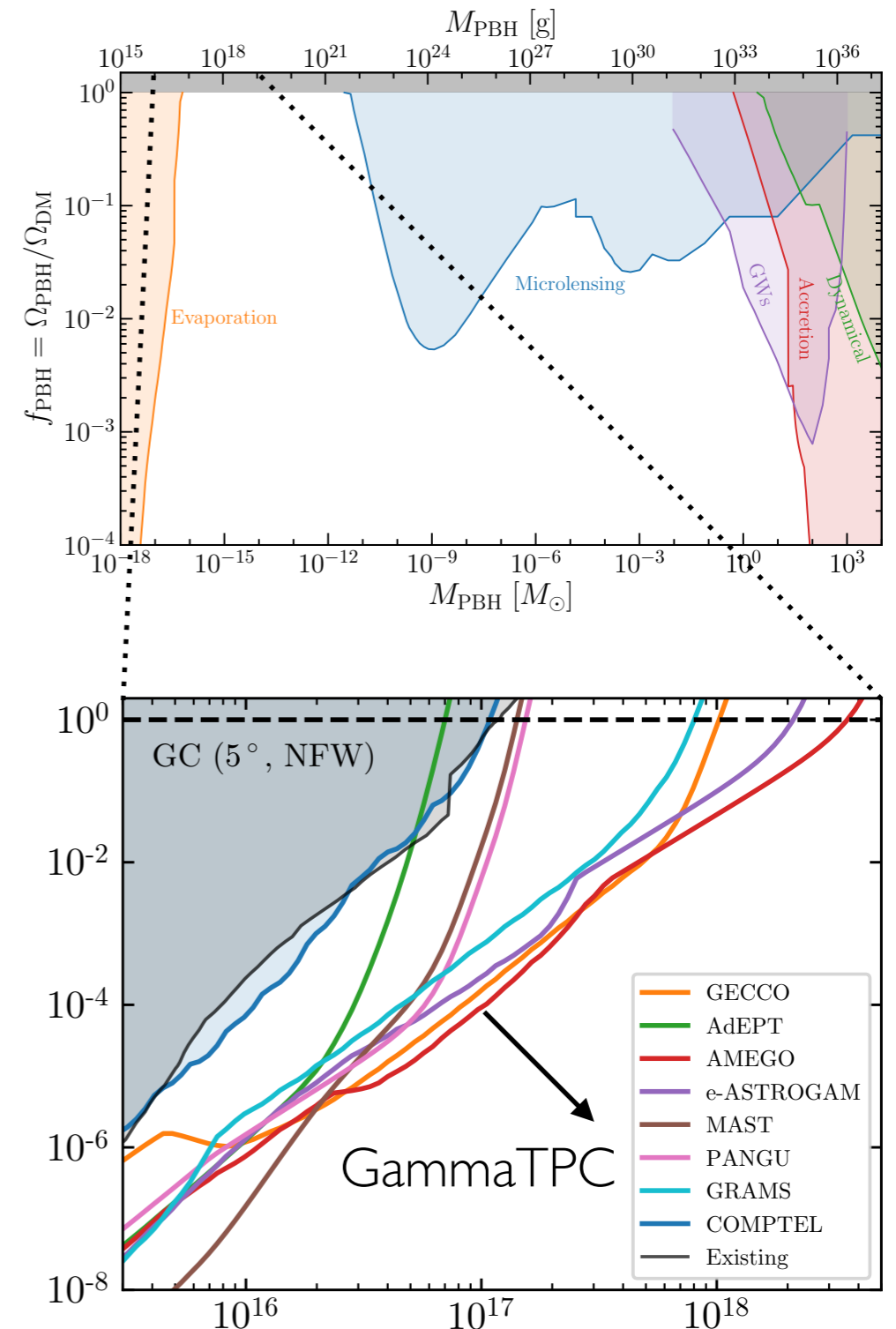
MeV  $\gamma$ s from neutron scattering and  
nuclear deexcitation in GeV- $\nu$   
oscillation experiments (e.g. DUNE)



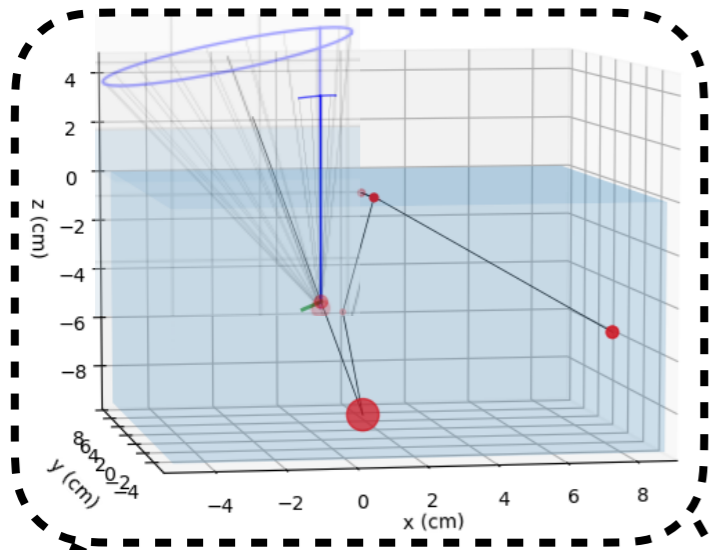
[PRD 99, 036009 \(2019\)](https://arxiv.org/abs/1903.03609)

# Astrophysics & Dark Matter

- Pulsars
- r-process
- Transients and multi-messengers, etc.
- Primordial black holes
  - $E_\gamma \sim 1/M_{BH}$
  - arXiv: [2007.10722](#), [2010.04797](#)
- Sub-GeV thermal relics
  - Decay through mesons to  $\gamma$ s
- Pulsars as axion factories?

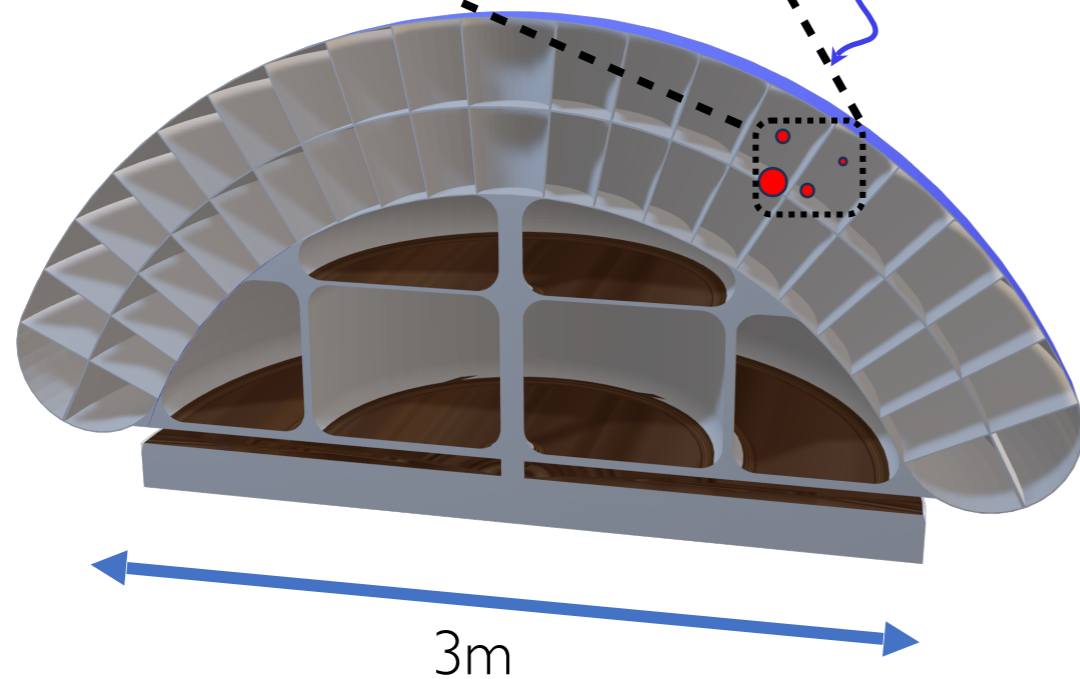


# MeV-scale $\gamma$ in LArTPCs

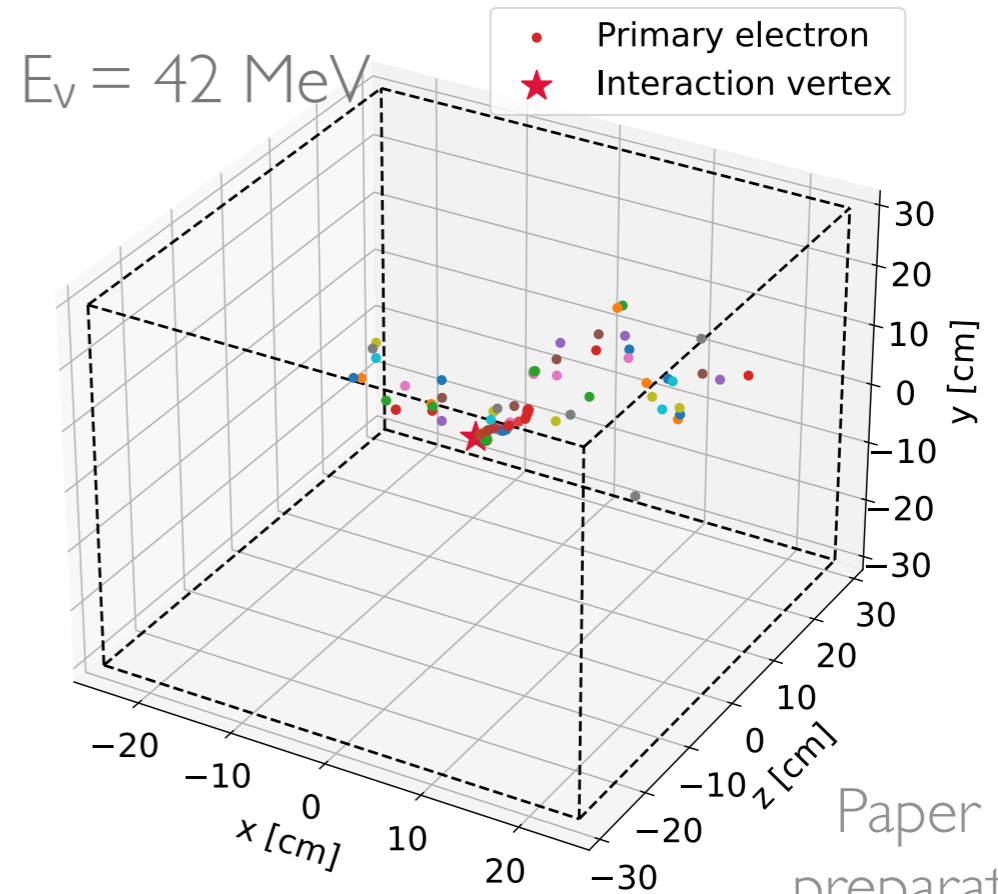


GammaTPC:  
LArTPC in  
space detecting  
MeV-scale  $\gamma$ s

$$E_\gamma \sim O(\text{MeV})$$



Measure  $\nu$ -Ar cross section  
with  $E_\nu \sim O(10 \text{ MeV})$  in  
LArTPCs for DUNE

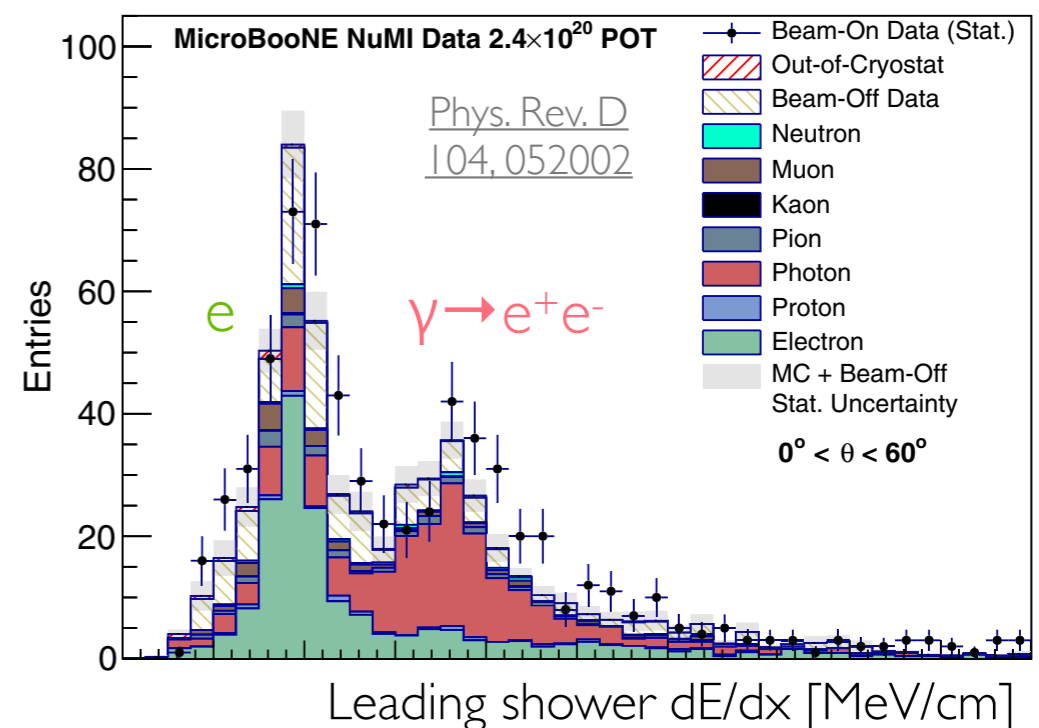


Paper in  
preparation

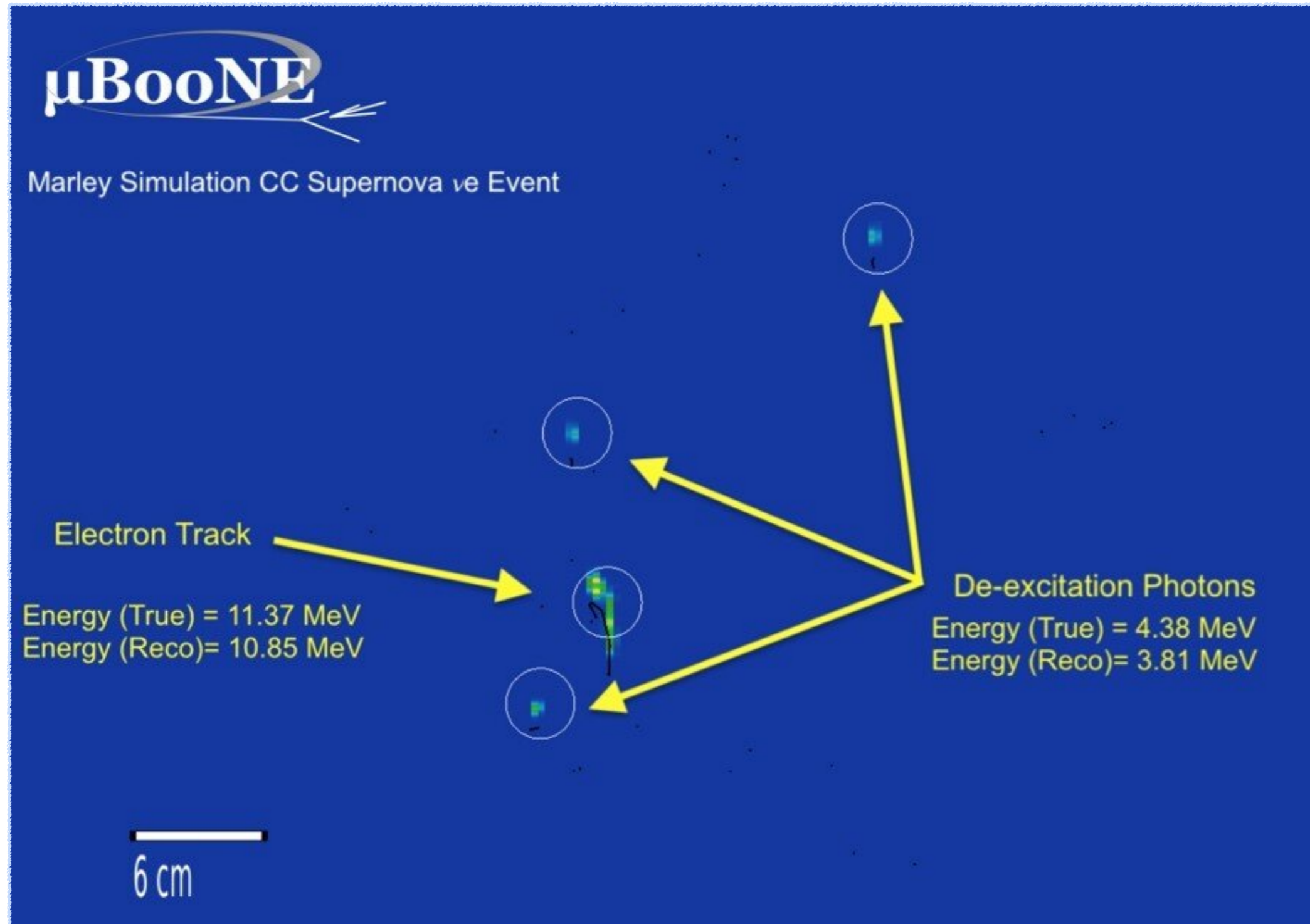


# Why LArTPC?

- LAr: large interaction rate
- Modular and scalable
- Nearly fully instrumented
  - 3D information from 1-2D instrumentation
- Millimeter resolution
- Calorimetric measurement
- Low detection threshold for protons
- Supernova  $\nu_e$  ( $E \sim 10$  MeV)



# Supernova $\nu_e$ Measurement





# GammaTPC

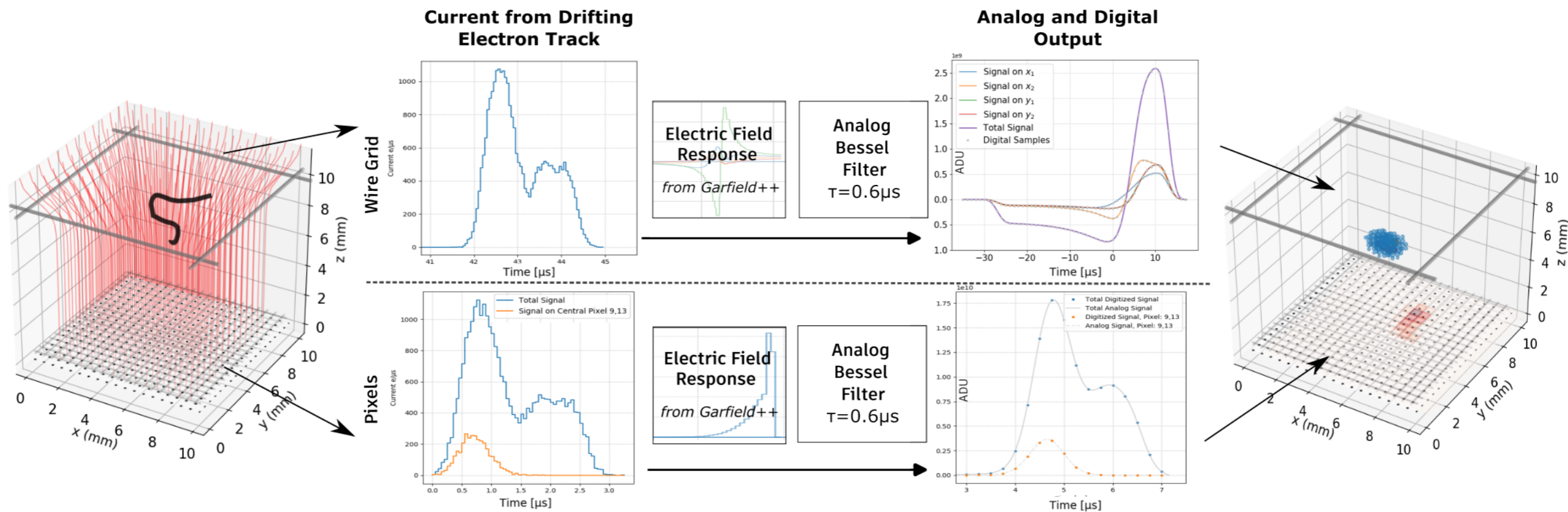


T. Shutt, B. Trbalic, M. Buuck, E. Charles, M.  
Convery, S. Jett, N. Di Lalla, A. Dragone,  
O. Hitchcock, R. Linehan, G. Madejski,  
A. Pena-Perez, S. Luitz, A. Mishra, Y.-T. Tsai  
[arXiv:2502.14841](https://arxiv.org/abs/2502.14841)



# Calorimetry

Total energy deposition on the coarse wires corrected by finer tracking from the pixels



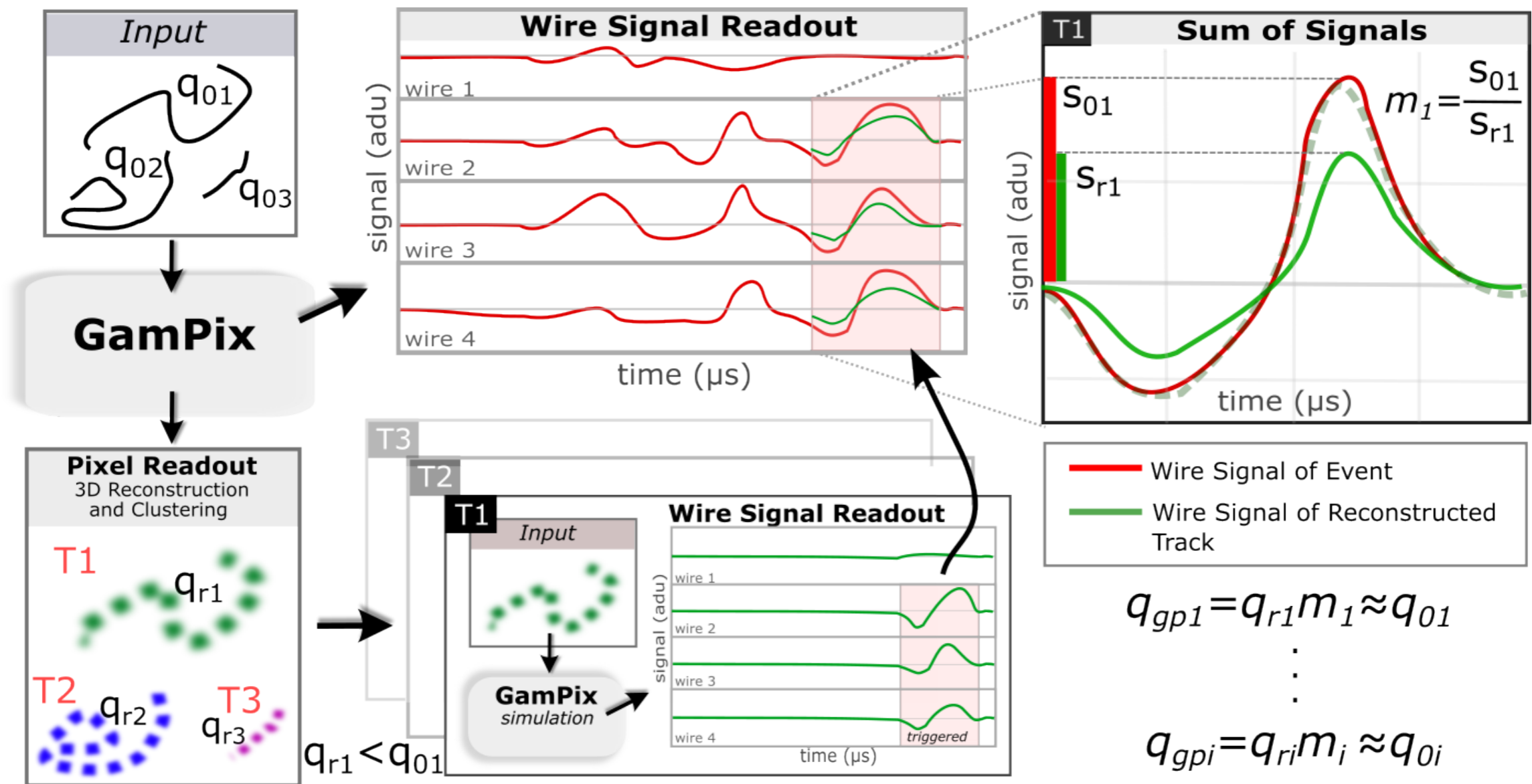
Studied by Bahrudin Trbalic (Stanford)





# GAMPix Simulation

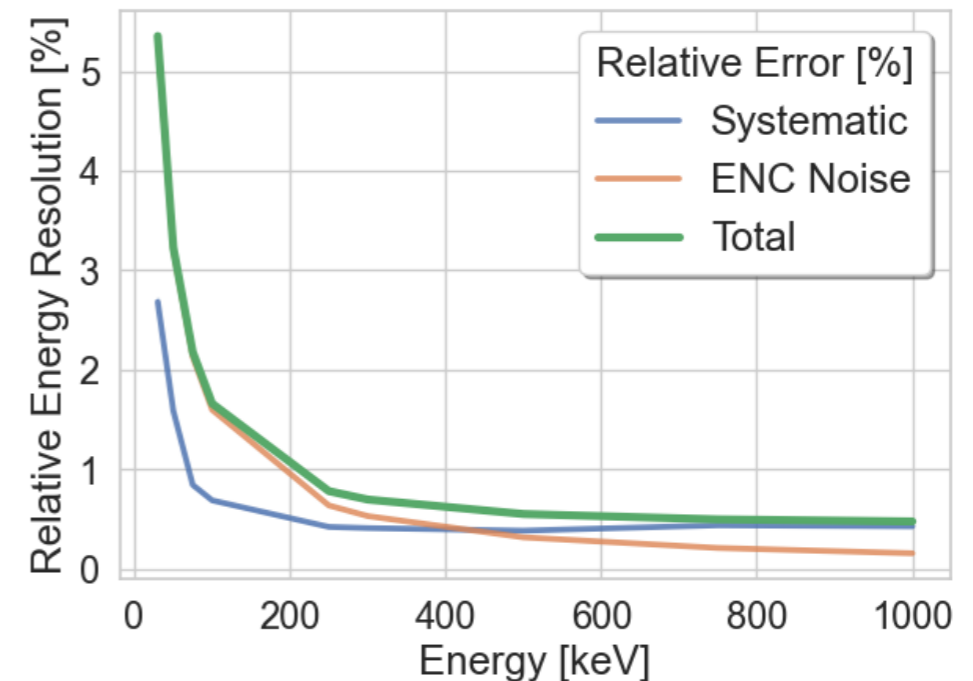
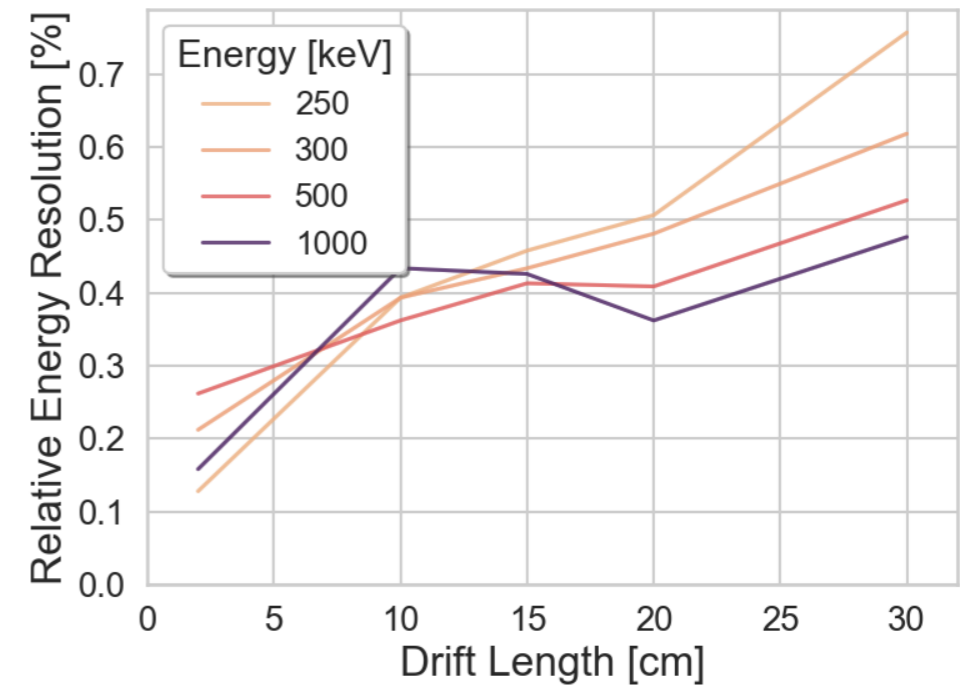
The field response on the wires depends on the location of the charge deposition with respect to the wire



Studied by Bahrudin Trbalic (Stanford)

# Performance on $\gamma$ TPC

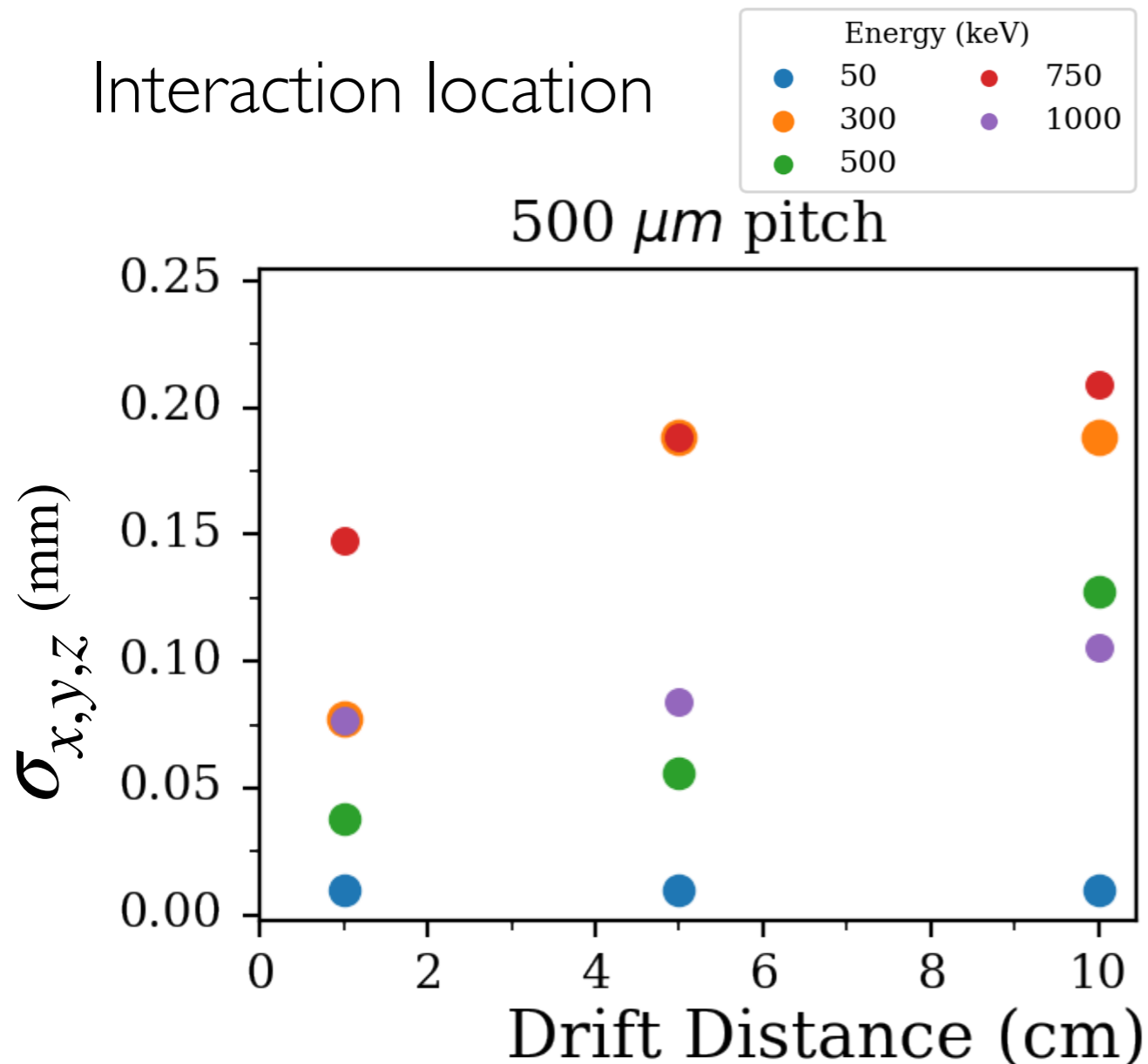
- 500 $\mu\text{m}$ -pixels, ENC 20e<sup>-</sup>
- 1cm-wires, ENC 30e<sup>-</sup>
- Track imaging resolution  $\sim 0.25\text{mm}$
- Energy resolution  $< 1\%$  for electron tracks  $> 100\text{keV}$  (2k e<sup>-</sup>)
- Power consumption  $\sim 1\text{W}/\text{m}^2$   
Saves by a factor of  $10^3$ - $10^4$
- Drift length measurements vis diffusion with  $\sim 5\%$  accuracy



# Directionality

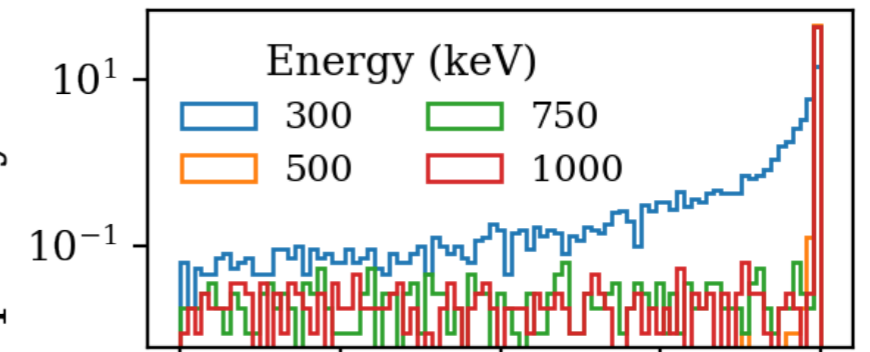
Use CNN to find interaction locations and directions

Interaction location

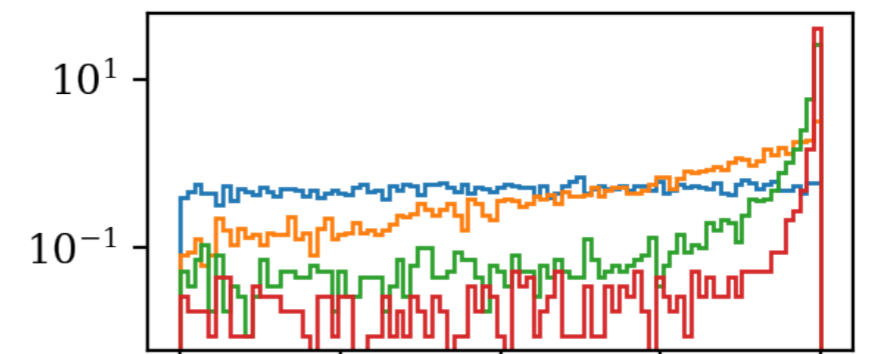


45

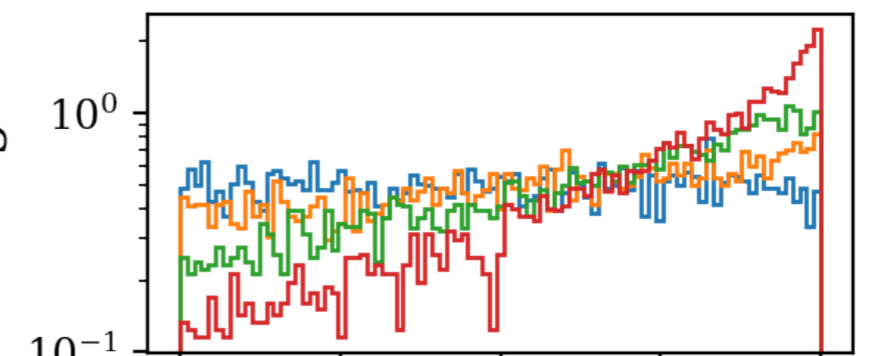
Initial direction  
1cm



5cm

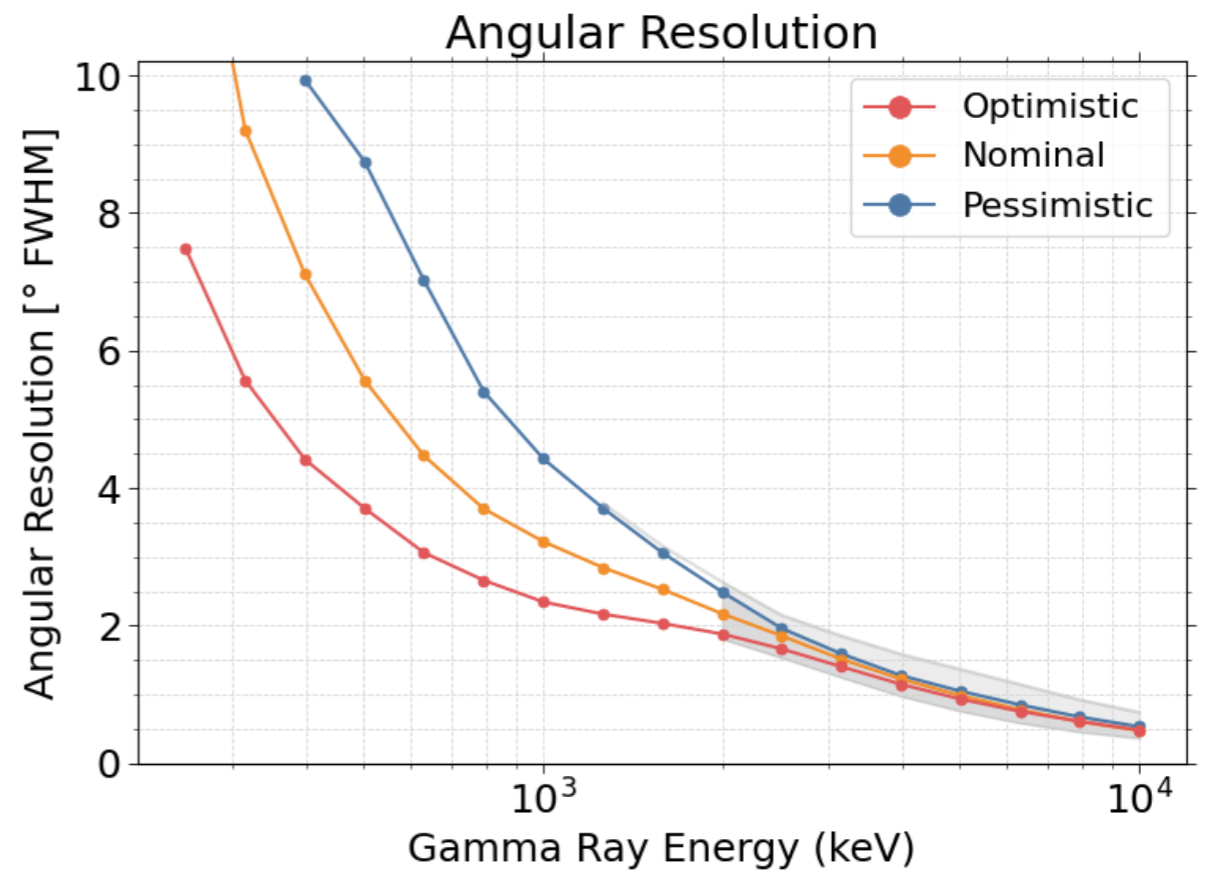
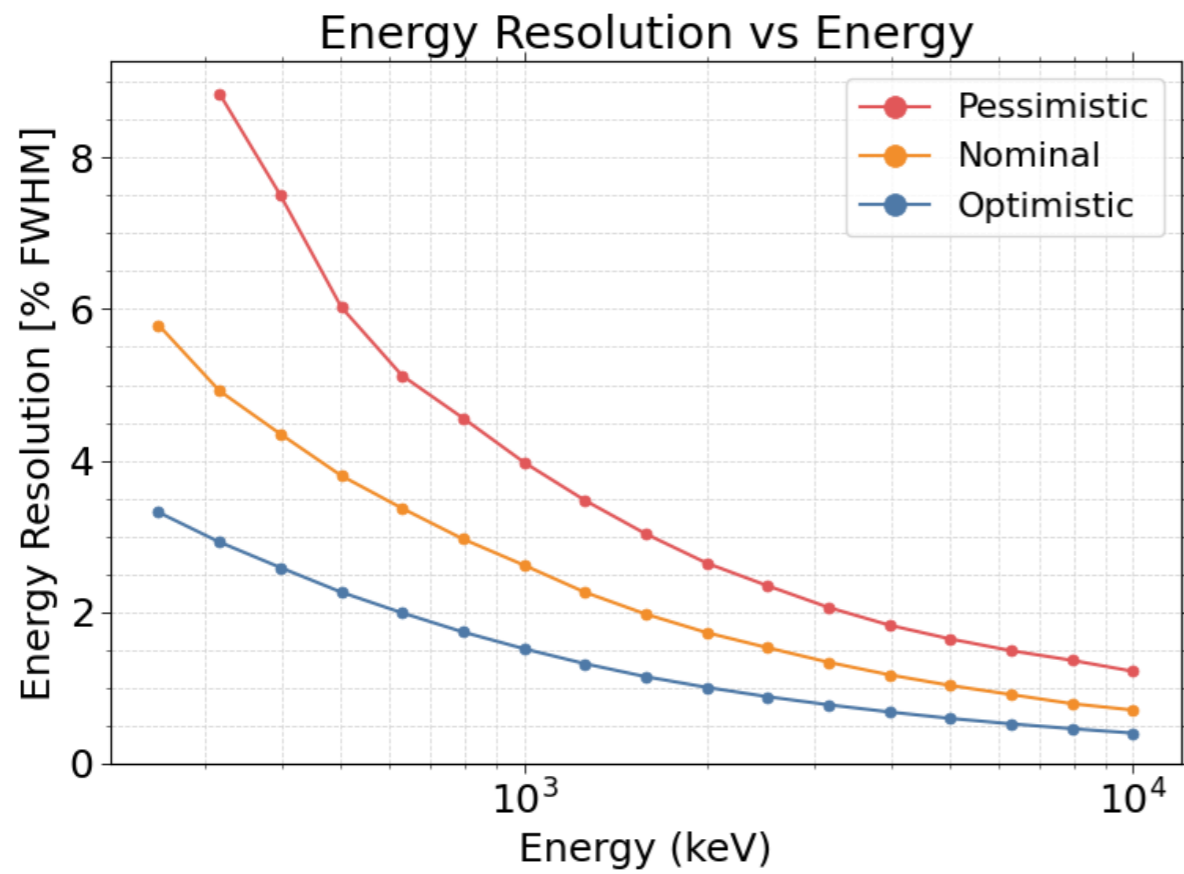


10cm



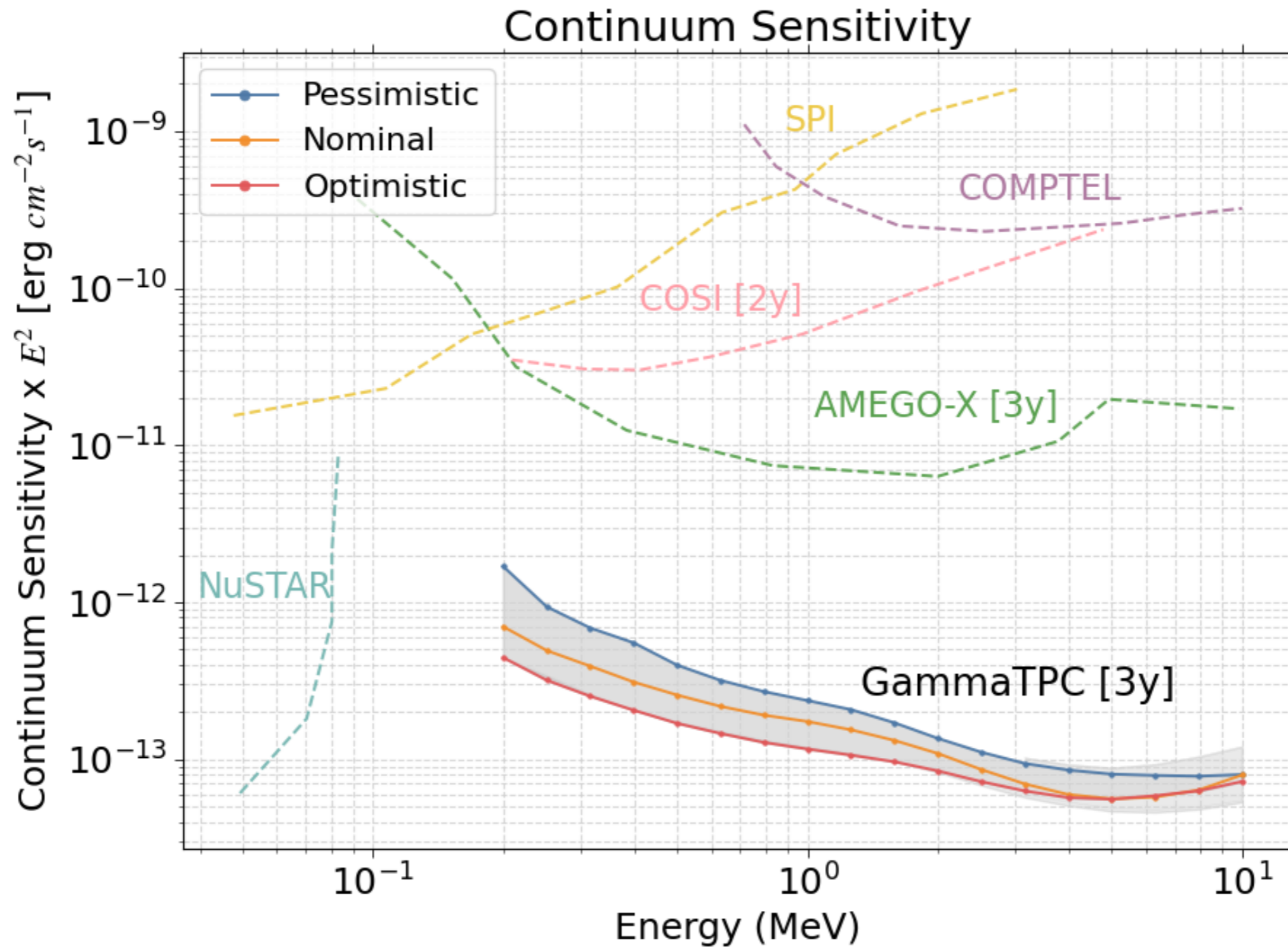
$\cos(\delta)$

# Resolution





# Sensitivity



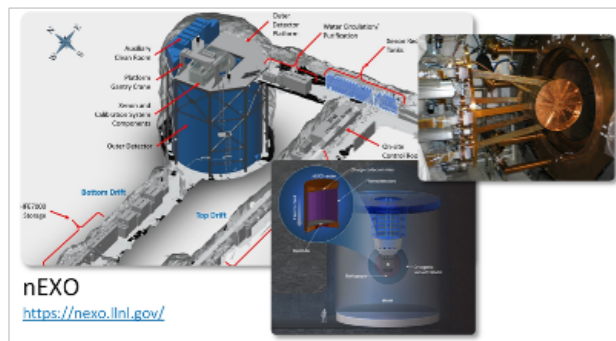
# Cryo-CMOS at SLAC

LXe | ~165K (nEXO)

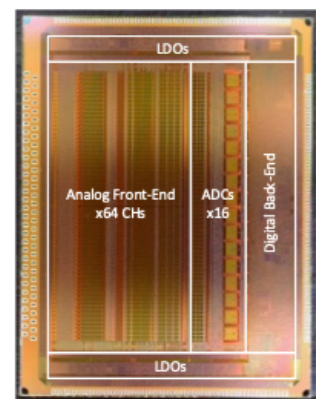
LAr | ~87K (DUNE and GammaTPC)

LHe | ~4K

## Next-generation liquid noble gas experiments: Neutrino science & $\gamma$ -ray detection

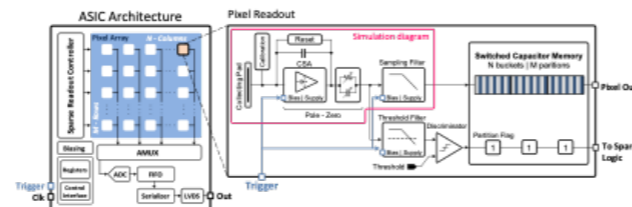
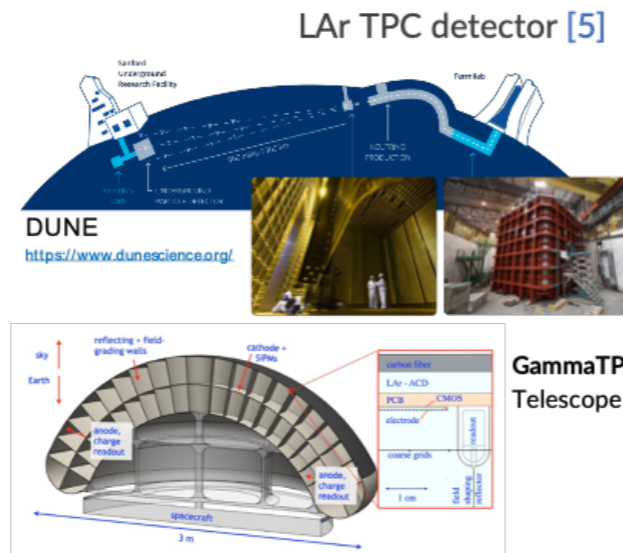


LXe TPC detector [2]



CRYO ASIC [3-4]

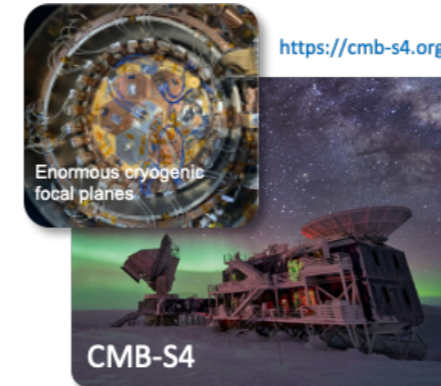
- SoC charge readout
- 130nm CMOS
- FE + ADC + Digital
- Small size: (7 x 9)mm



GAMPix ASIC (in progress, NASA proposal, [6])

- Low noise pixel-based charge readout ASIC
- 130nm CMOS

## NSF/DOE CMB survey experiment: CMB-S4 [7] & quantum computing applications



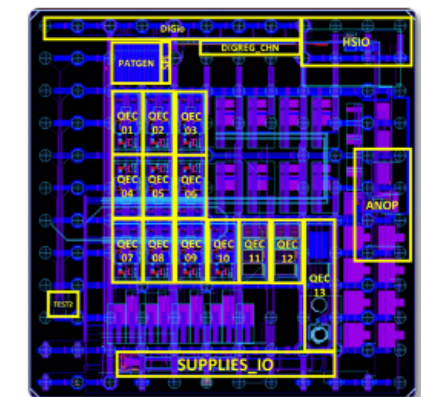
21 telescopes at Atacama Desert in Chile and the South Pole will be used to survey the sky



SLAC + equal1 [8]

### ~4K cryo-CMOS IC prototype

- 22nm FDSOI CMOS (more in next slides)
- Includes several circuits solutions
- Chip characterization on-going



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