A GASEOUS ARGON TPC FOR THE DUNE ND

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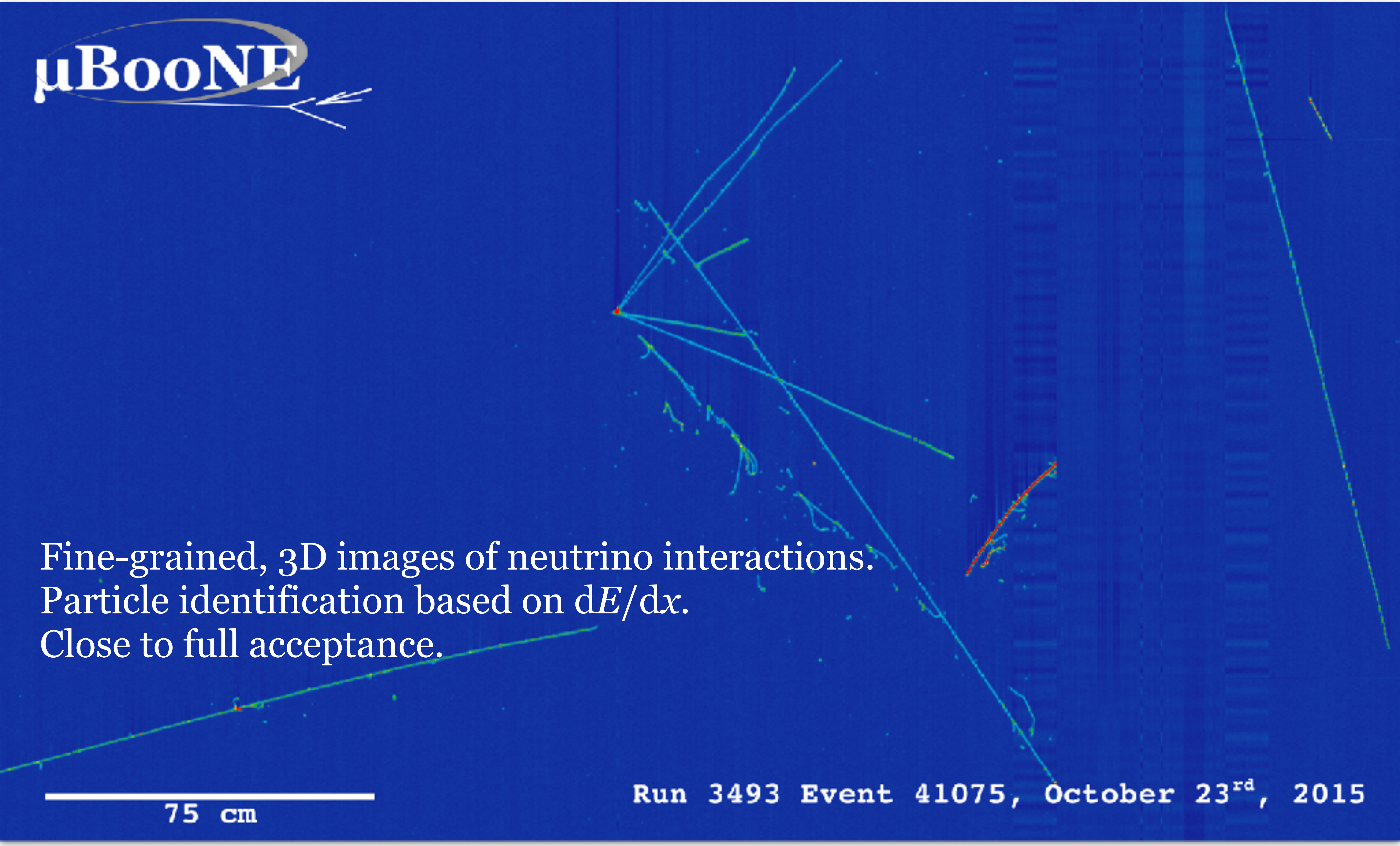
DUNE Near Detector Workshop — Fermilab, 27th March 2017

WHY AN ARGON TPC?

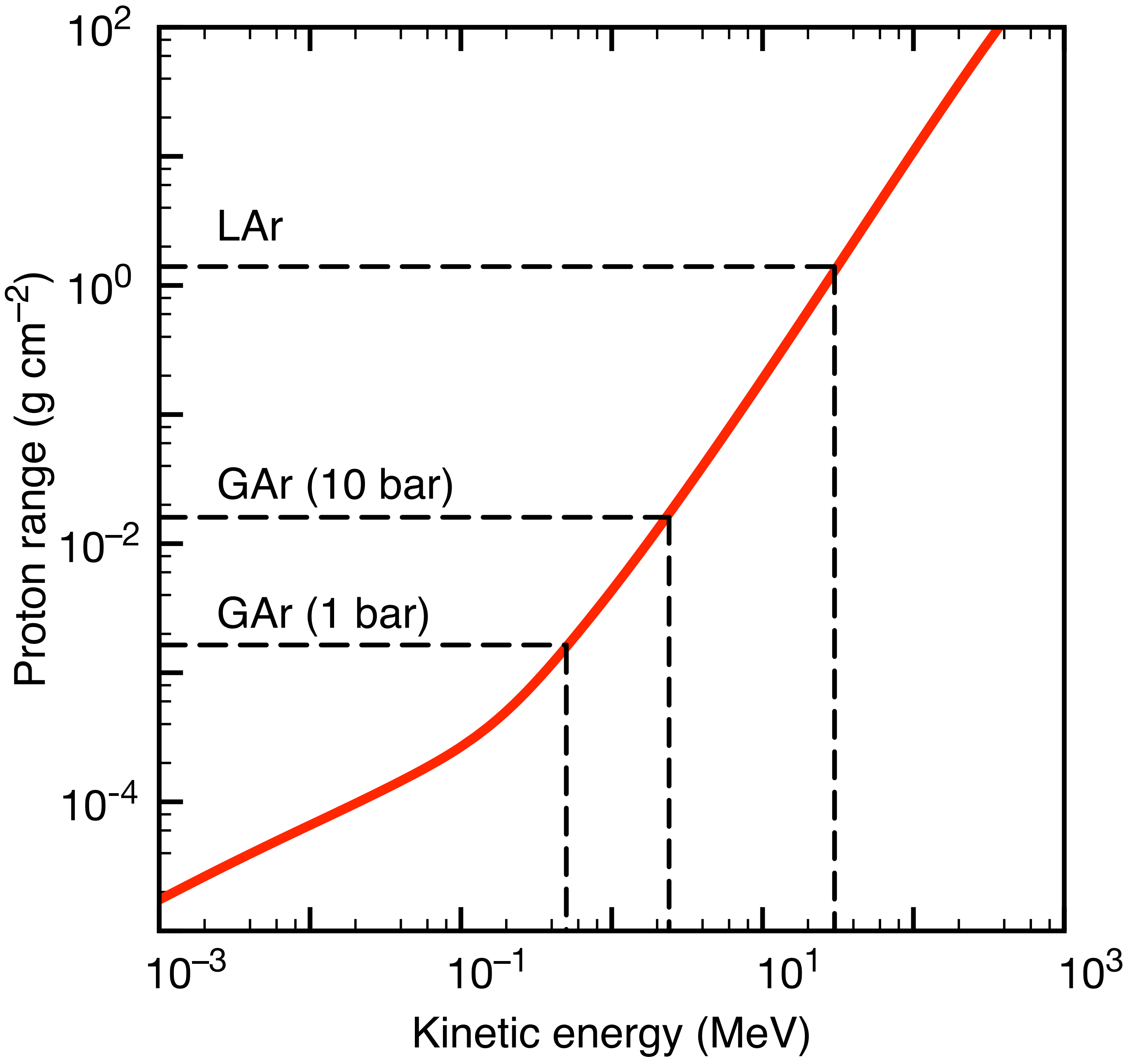


Fine-grained, 3D images of neutrino interactions.
Particle identification based on dE/dx.
Close to full acceptance.

WHY A GASEOUS ARGON TPC?

- The lower density of gaseous argon (85 times less dense, for 10 bar pressure) results in
  - less multiple scattering and hence better momentum resolution;
  - lower detection thresholds and thus higher sensitivity to *soft* hadrons produced in neutrino interactions.
- Might be the only feasible argon near detector if pile-up or magnetisation result too challenging for LAr.
  - See James's talk for details on how those issues are being addressed.

WHY A GASEOUS ARGON TPC?



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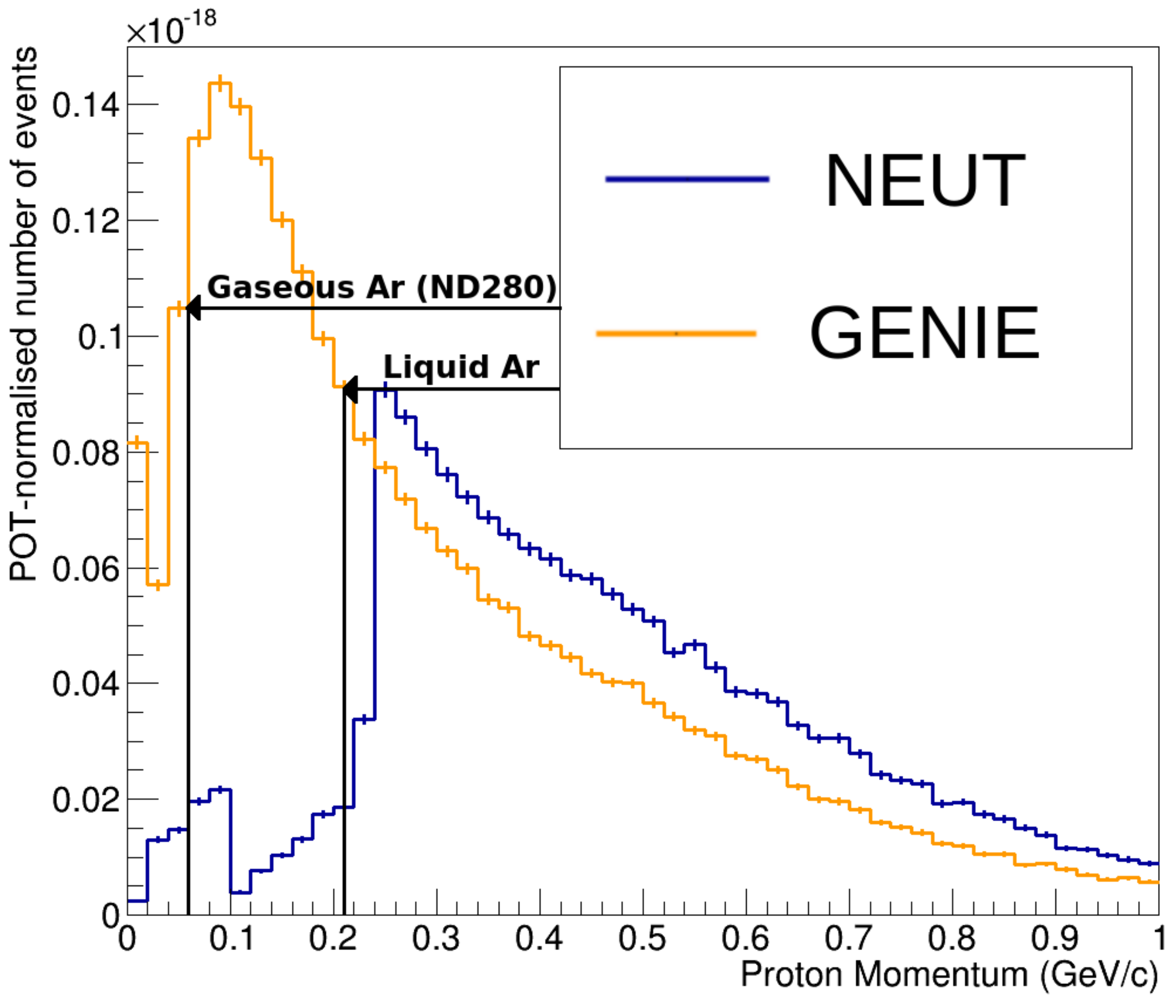
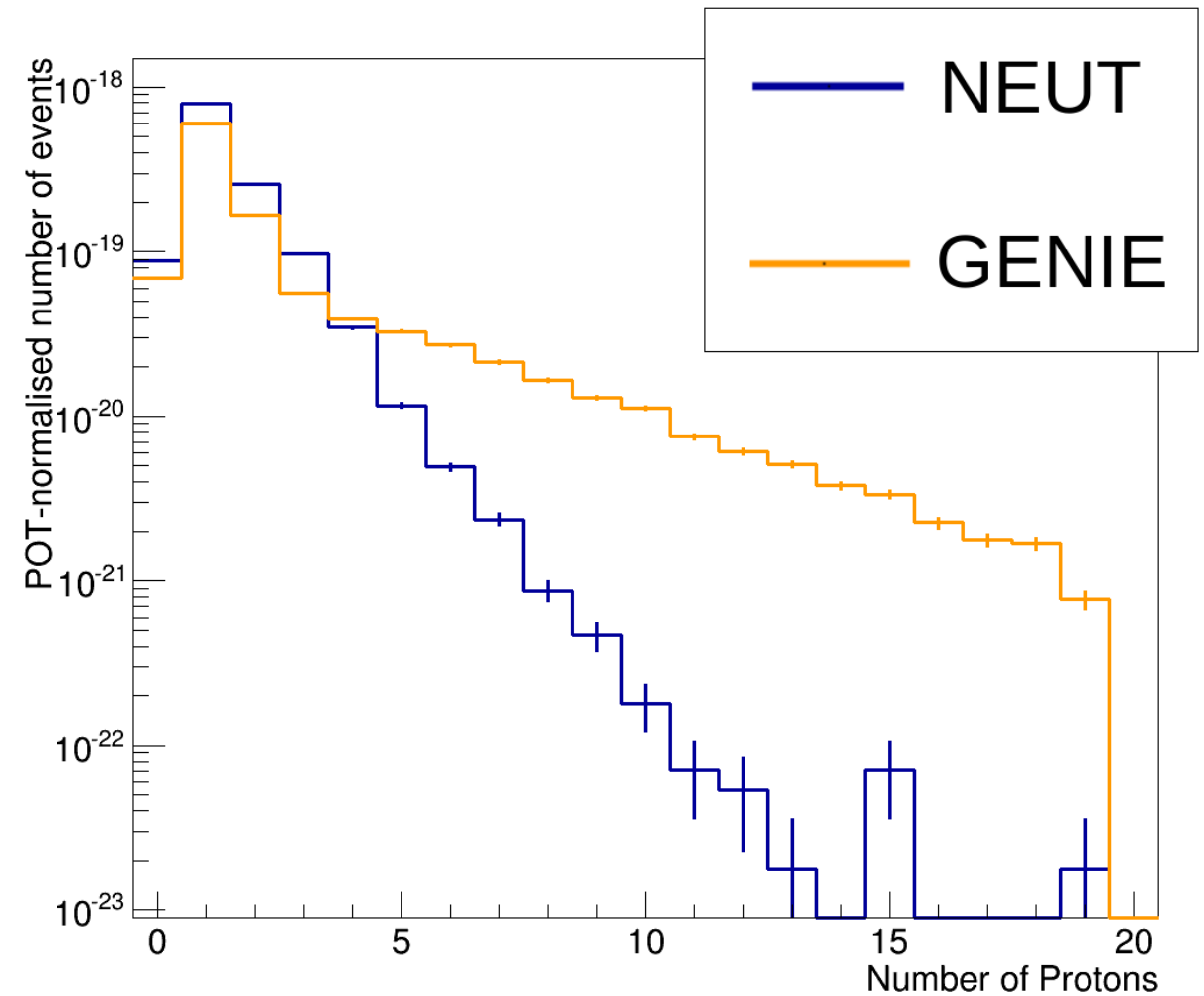




Pip Hamilton's PhD Thesis, *"A study of neutrino interactions in argon gas"*

WHY A GASEOUS ARGON TPC?

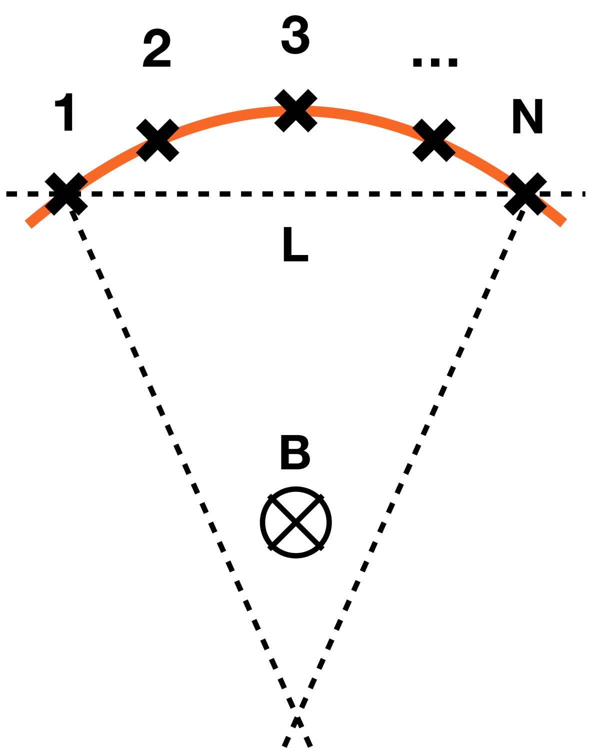
- Nuclear effects seen as largest uncertainty in cross sections:
  - ISI
  - FSI
  - 2p2h
  - Etc.
- Uncertainties in cross sections affect
  - neutrino energy reconstruction;
  - background estimations;
  - near-far acceptance corrections.

TPC PERFORMANCE

Parameter/Experiment	PEP4	TRIUMF	TOPAZ	AlEPH	DELPHI	STAR	ALICE[a]
Operation	1982/1984	1982/1983	1987	1989	1989	2000	2009
Inner/Outer radius (m)	0.2/1.0	∼ 0.15/0.50	0.38/1.1	0.35/1.8	0.35/1.4	0.5/2.0	0.85/2.5
Max. driftlength ($L/2$) (m)	1	0.34	1.1	2.2	1.34	2.1	2.5
Magnetic field (T)	0.4/1.325	0.9	1	1.5	1.23	0.25/0.5	0.5
Gas :	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	$Ne/CO_2/N_2$
Mixture	80/20	80/20	90/10	91/9	80/20	90/10	90/ 10/ 5
Pressure (atm)	8.5	1	3.5	1	1	1	1
Drift field (kV cm^{-1} atm^{-1})	0.088	0.25	0.1	0.11	0.15	0.14	0.4
Electron drift velocity (cm μs^{-1})	5	7	5.3	5	6.69	5.45	2.7
$\omega\tau$ (see section 2.2.1.3)	0.2/0.7	2	1.5	7	5	1.15/2.3	<1
Pads: Size $w \times L$ (mm × mm)	7.5 × 7.5	(5.3–6.4) × 19	(9–11) × 12	6.2 × 30	∼7 × 7	2.85 × 11.5 6.2 × 19.5	4 × 7.5 6 × 10/15
Max. no. 3D points	15—straight	12	10—linear	9 + 12—circular	16—circular	13 + 32—straight	63 + 64 + 32
dE/dx: Max. no. samples/track	183	12	175	148 + 196	192	13 + 32	63 + 64 + 32
Sample size (mm atm); w or p	4 × 8.5; wires	6.35; wires	4 × 3.5; wires	4; wires	4; wires	11.5 + 19.5; pads	7.5 + 10 + 15; pads
Gas amplification	1000	50 000		3000–5000	5000	3000/1100	20 000
Gap a–p; a–c; c–gate[b]	4; 4; 8	6	4; 4; 8	4; 4; 6	4; 4; 6	2; 2; 6/4; 4 ; 6	2; 2; 3/3; 3; 3
Pitch a–a; cathode; gate	4; 1; 1		4; 1; 1	4; 1; 2	4; 1; 1	4; 1; 1/ 4; 1; 1	2.5; 2.5; 1.5
Pulse sampling (MHz/no. samples)	10/455, CCD	only 1 digitiz., ADC	10/ 455, CCD	11/ 512, FADC	14/300, FADC	9.6/400	5–10/500–1000, ADC
Gating[c]	⩾1984 o.on tr.	⩾1983 o.on tr.	o. on tr.	synchr. cl.wo.tr	static	o.on tr.	o.on tr.
Pads, total number	15 000	7800	8200	41 000	20 000	137 000	560 000
Performance							
Δx_T (μm)-best/typ.	130–200	200/	185/230	170/200–450	180/190–280	300–600	spec:800–1100
Δx_L (μm)-best/typ.	160–260	3000	335/900	500–1700	900	500–1200	spec:1100–1250
Two-track separation (mm), T/L	20		25	15	15	8 - 13/30	
$\partial p/p^2$ $(GeV/c)^{-1}$: TPC alone; high p	0.0065		0.015	0.0012	0.005	0.006	spec:0.005
dE/dx (%) Single tracks/ in jets	2.7/4.0		4.4 /	4.4 /	5.7/7.4	7.4/7.6	spec:4.9/6.8
Comments		a in single PCs strong $E \times B$ effect	chevron pads	circular pad rows	circular pad rows	No field wires $>$3000 tracks	No field wires ⩽20 000 tracks

H. J. Hilke, *"Time projection chambers"*, Rep. Prog. Phys. **73** (2010) 116201

TPC PERFORMANCE: MOMENTUM RESOLUTION



$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma_T\, p_T}{0.3\, B\, L^2}\sqrt{\frac{720}{N+4}} + \frac{0.05}{B\, L}\sqrt{\frac{1.43\, L}{X_0}}$$

$$\sigma_\theta = \frac{\sigma_L}{L}\sqrt{\frac{12\,(N-1)}{N\,(N+1)}} + \frac{0.015}{\sqrt{3}\, p}\sqrt{\frac{L}{X_0}}$$

$$(p_T = p\,\sin\theta)$$

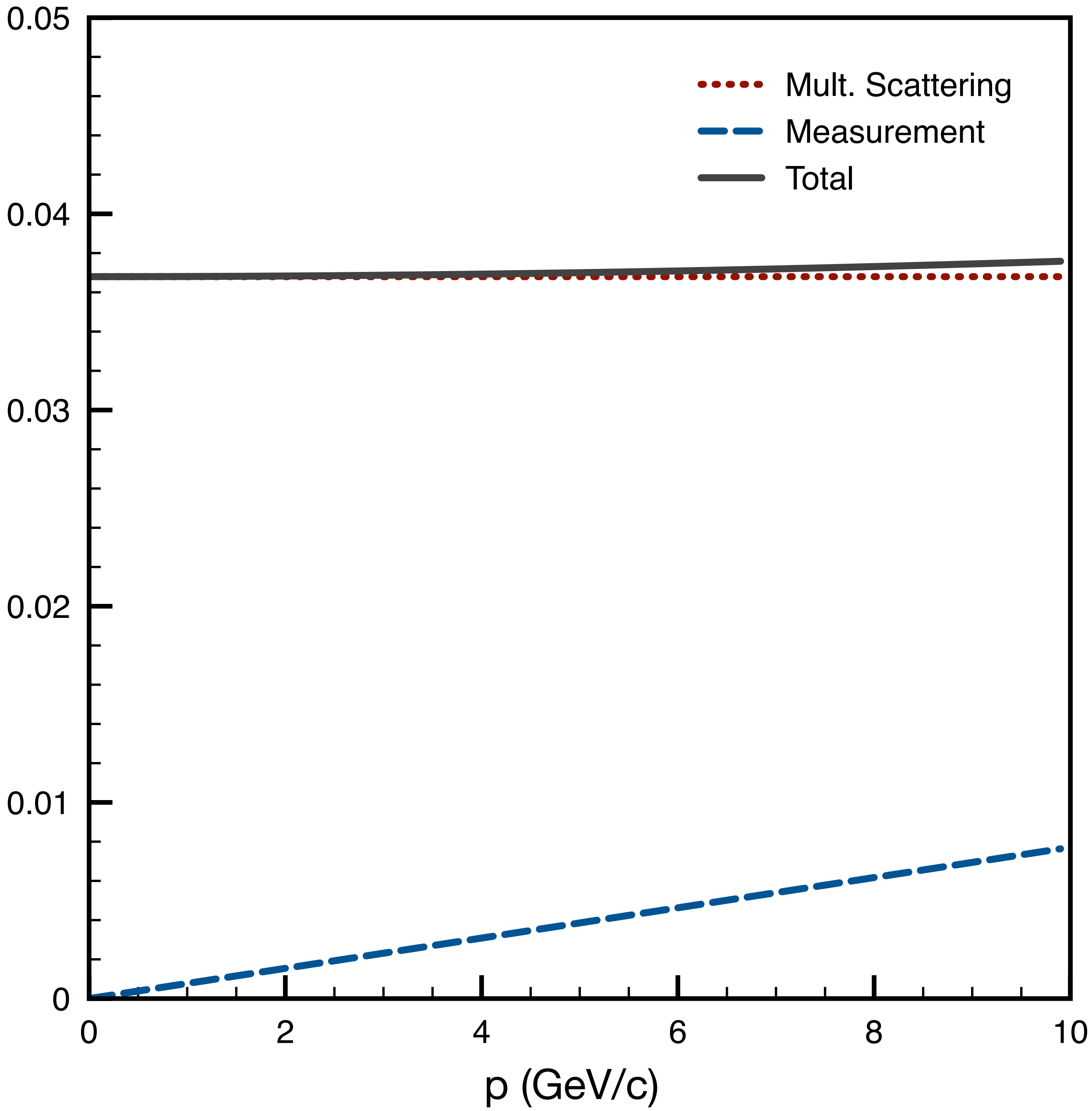
measurement terms

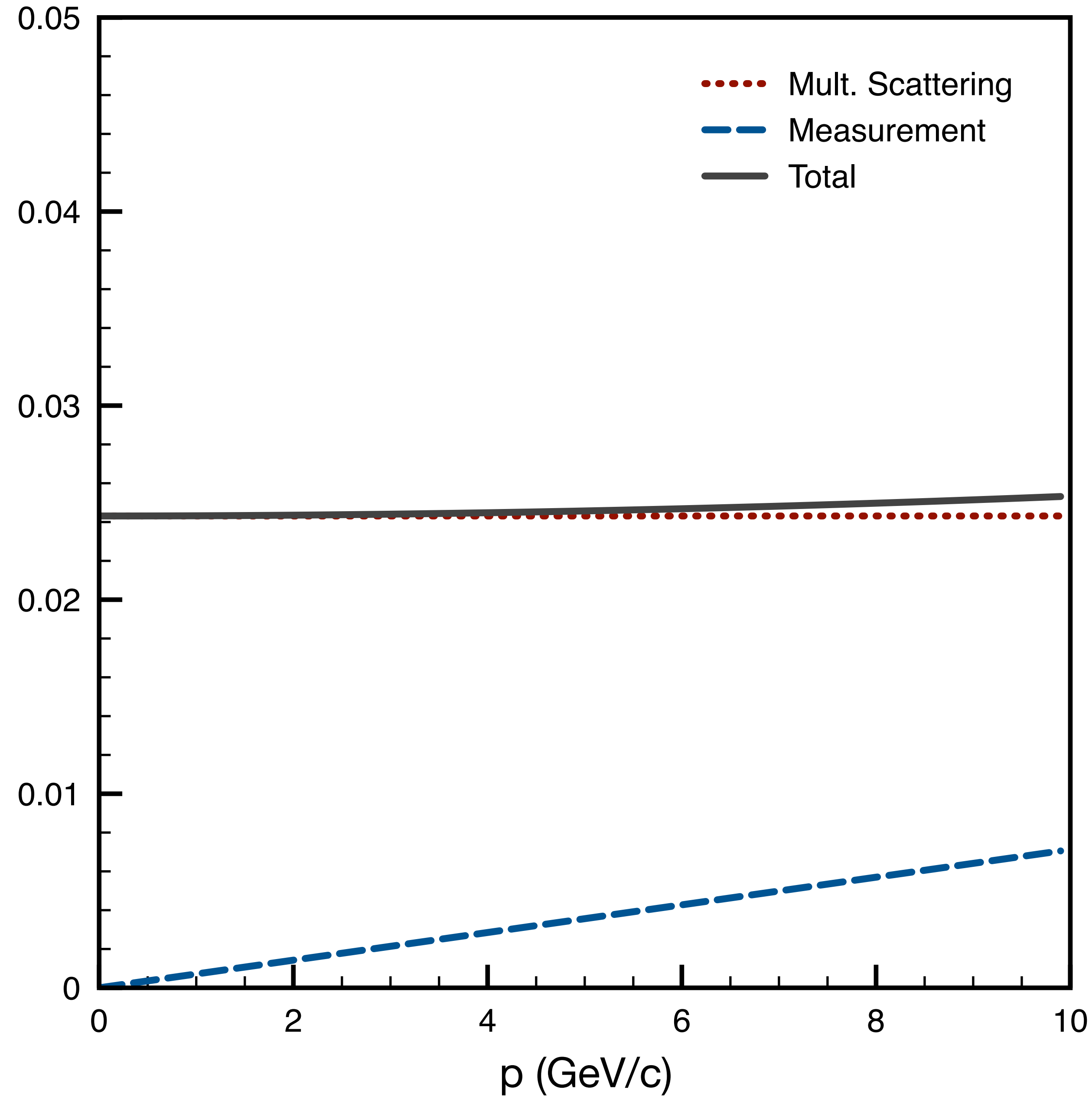
scattering terms

(σ: point resolution; p: momentum; B: magnetic field;
L: track length; N: no. of measurements; X_0: radiation length)

R.L. Gluckstern, NIM **24** (1963) 381

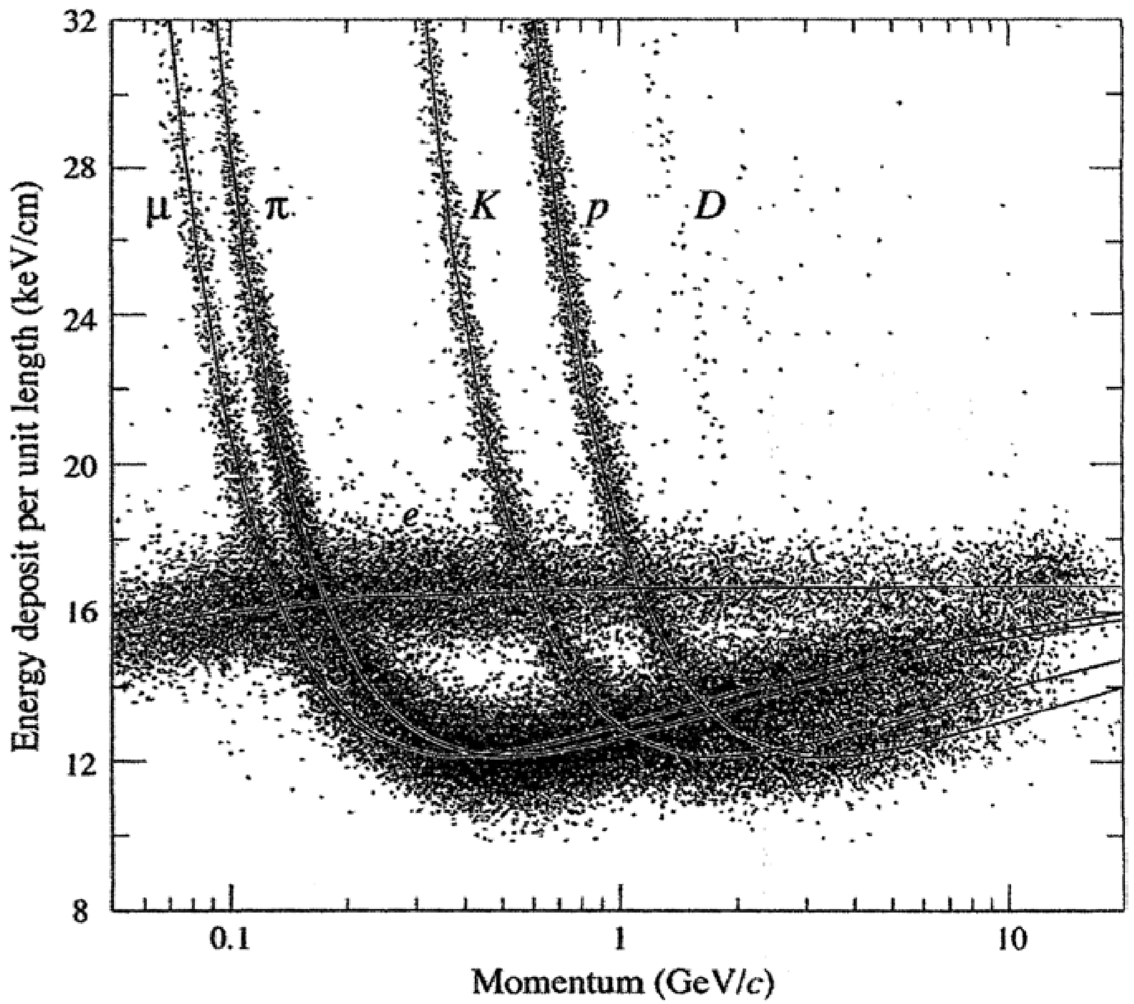
TPC PERFORMANCE: MOMENTUM RESOLUTION



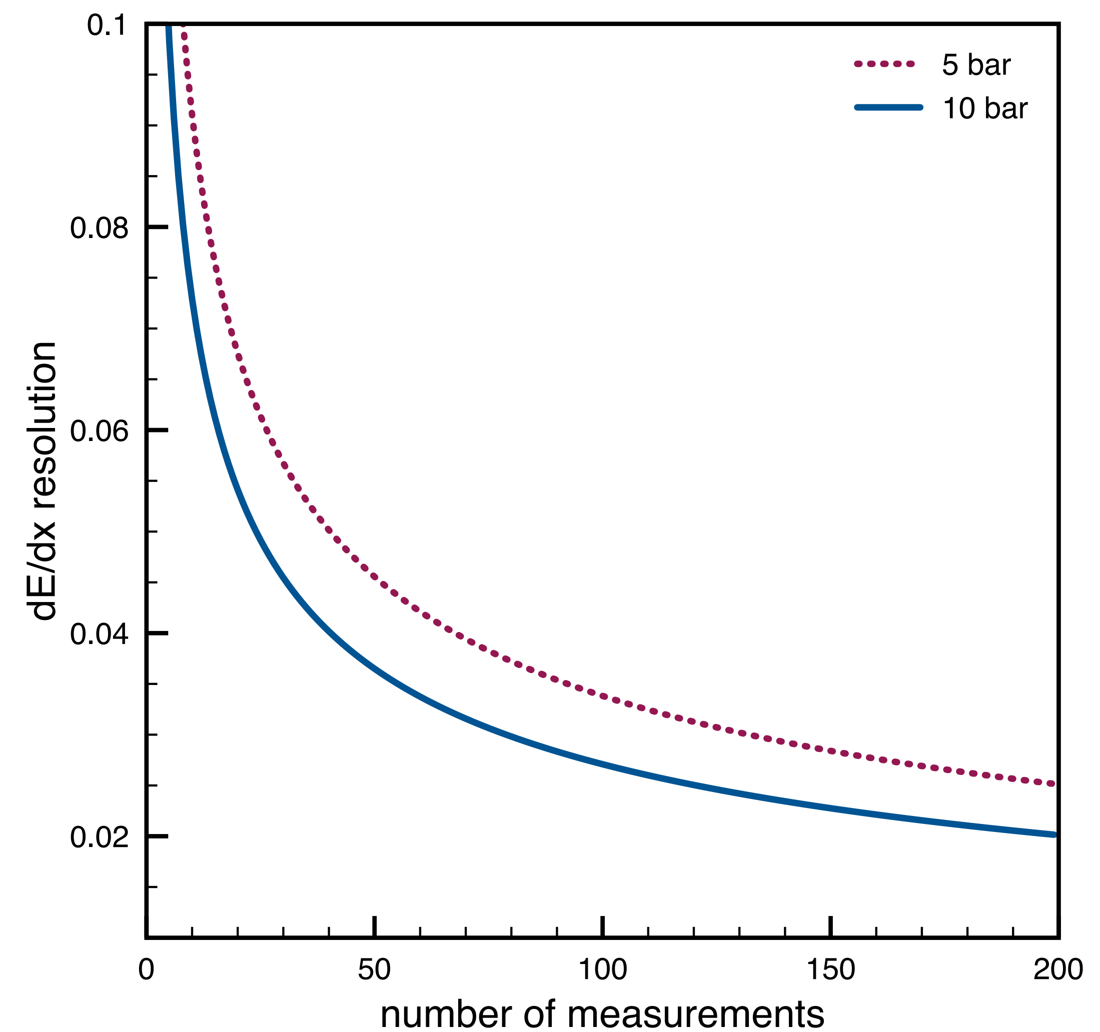


Predicted momentum resolution for forward-going, long tracks (3 m) in FGT and GArTPC.

TPC PERFORMANCE: PARTICLE ID



PEP-4 TPC (~3%)



$$\sigma(\mathrm{d}E/\mathrm{d}x) = 0.41\, N^{-0.43}\, (t\, P)^{-0.32}$$

Good separation of muons (pions), kaons and protons using dE/dx measurement in TPC.

PROS AND CONS

\+ Target = detector

\+ 3D track reconstruction

\+ High-resolution momentum measurement

\+ Excellent PID capabilities

\+ Low detection thresholds

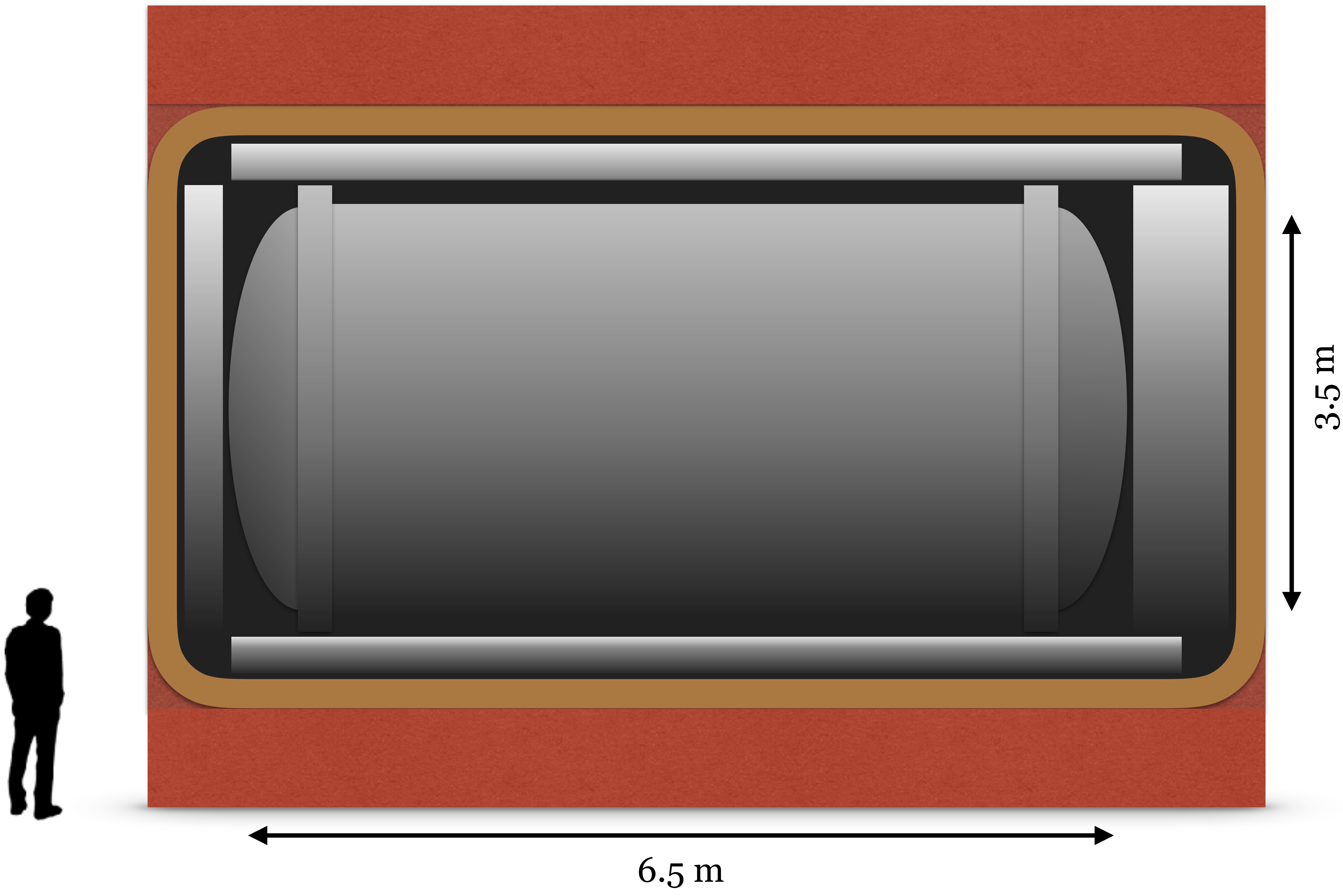
\+ Almost full acceptance

\+ Possibility to use different gases/targets

\- Low mass (requires high pressure and large volume)

\- Slow detector (all interactions in a spill integrated in a drift window)

TASK FORCE DETECTOR CONCEPT



TARGET MASS & GAS PRESSURE

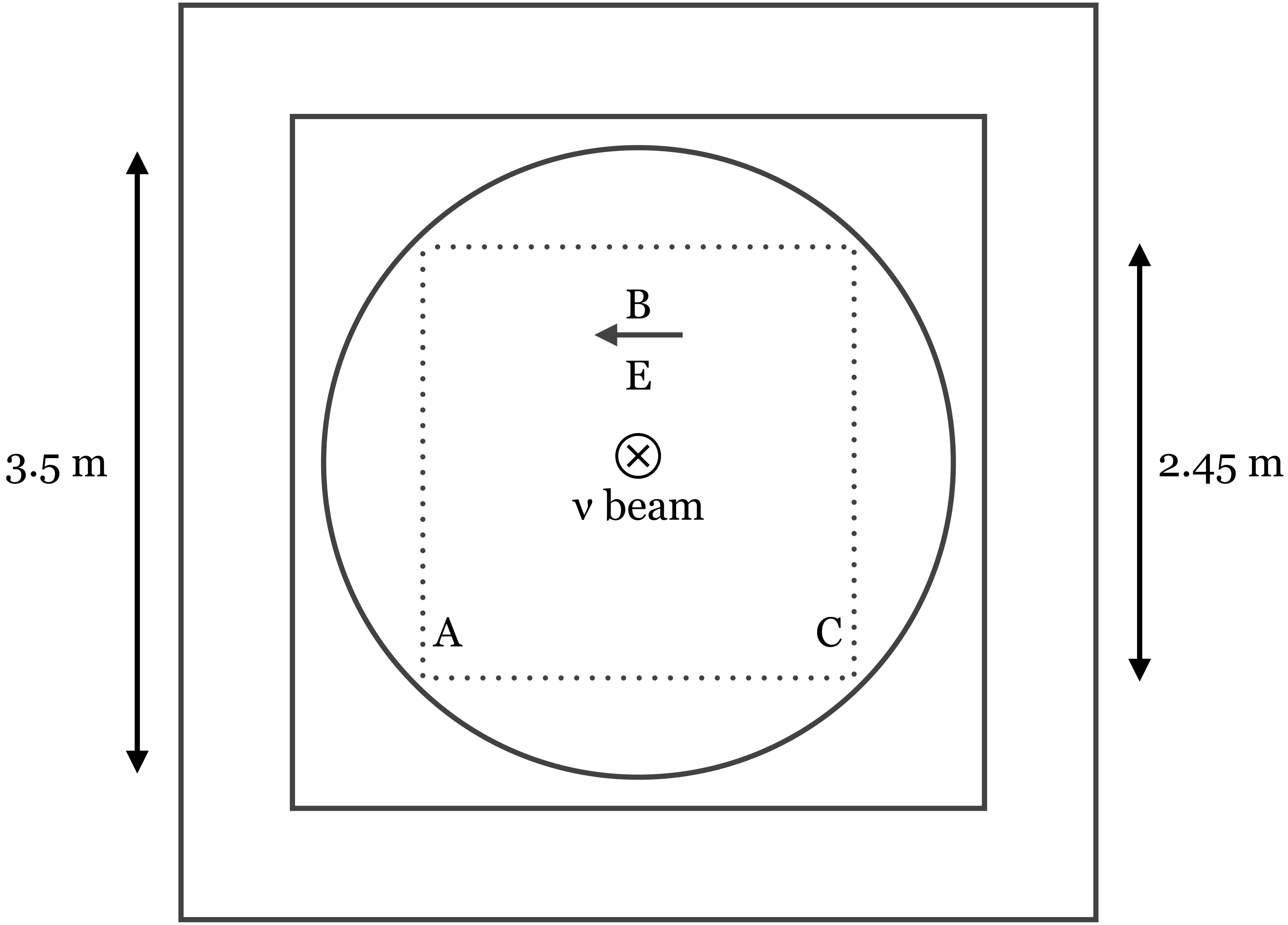
- FGT contains 112 kg of argon (passive targets) and 377 kg of calcium.
  - Expected statistics: O(1M) CC events in neutrino mode per year; O(0.3M) CC events in antineutrino mode.
- To provide similar statistics (assuming a ~50% passive/active volume ratio), 1 tonne of argon needed for GArTPC:
  - 5 bar, 300 K: 125 m^3
  - 10 bar, 300 K: 62 m^3
  - 15 bar, 300 K: 41 m^3
- Vessel dimensions for **10 bar** match approximately those of the FGT's straw-tube tracker, and that pressure seems also more manageable for charge readout.

PRESSURE VESSEL

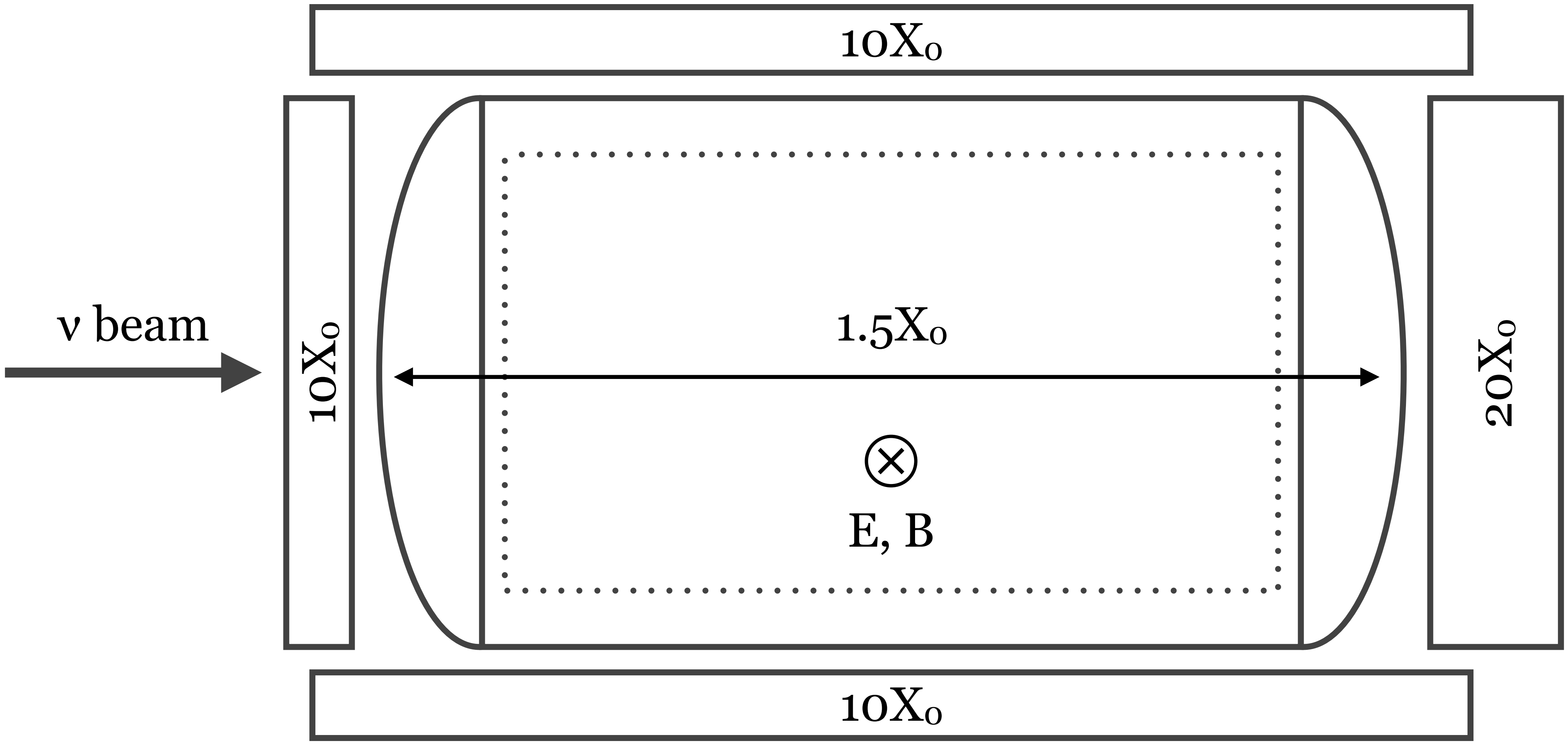
- Titanium alloy UNS-R56323
  - Wall thickness: barrel, 9 mm (0.25X0); endcaps, 17 mm (0.5X0).
  - Mass: ~13 tonnes. 5 bar, 300 K: 125 m^3
- Stainless steel 304L
  - Wall thickness: barrel, 15 mm (1X0); endcaps, 27 mm (2X0).
  - Mass: ~20 tonnes.

Calculations by S. Cárcel (IFIC, Valencia) following ASME code and assuming torispherical endcaps.

TASK FORCE DETECTOR CONCEPT



TASK FORCE DETECTOR CONCEPT

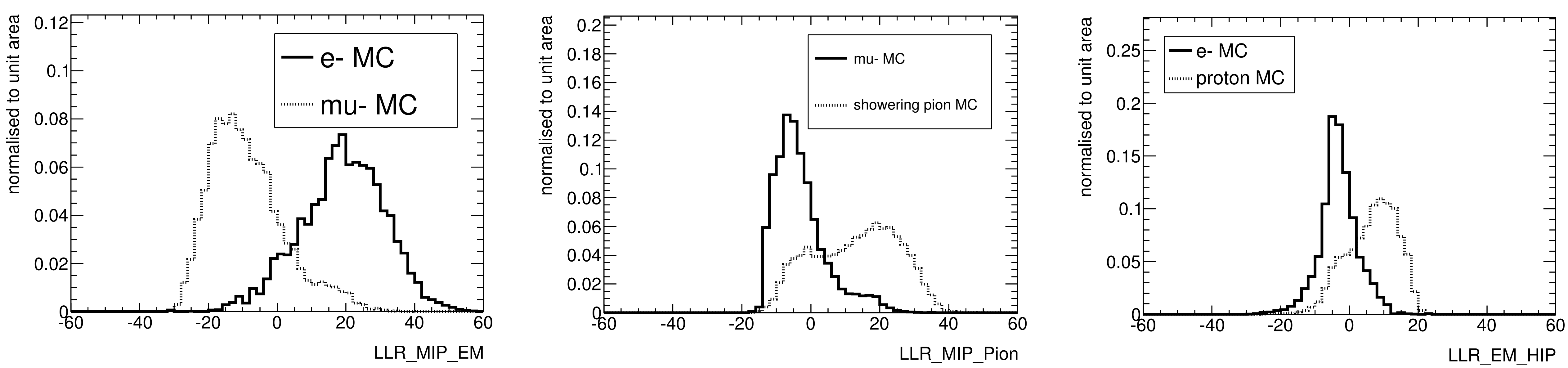


X_0 (Ar) = 19.55 g/cm^2 –> 6.3 m @ 10 bar (16.11 kg/m^3): ~0.5 X_0

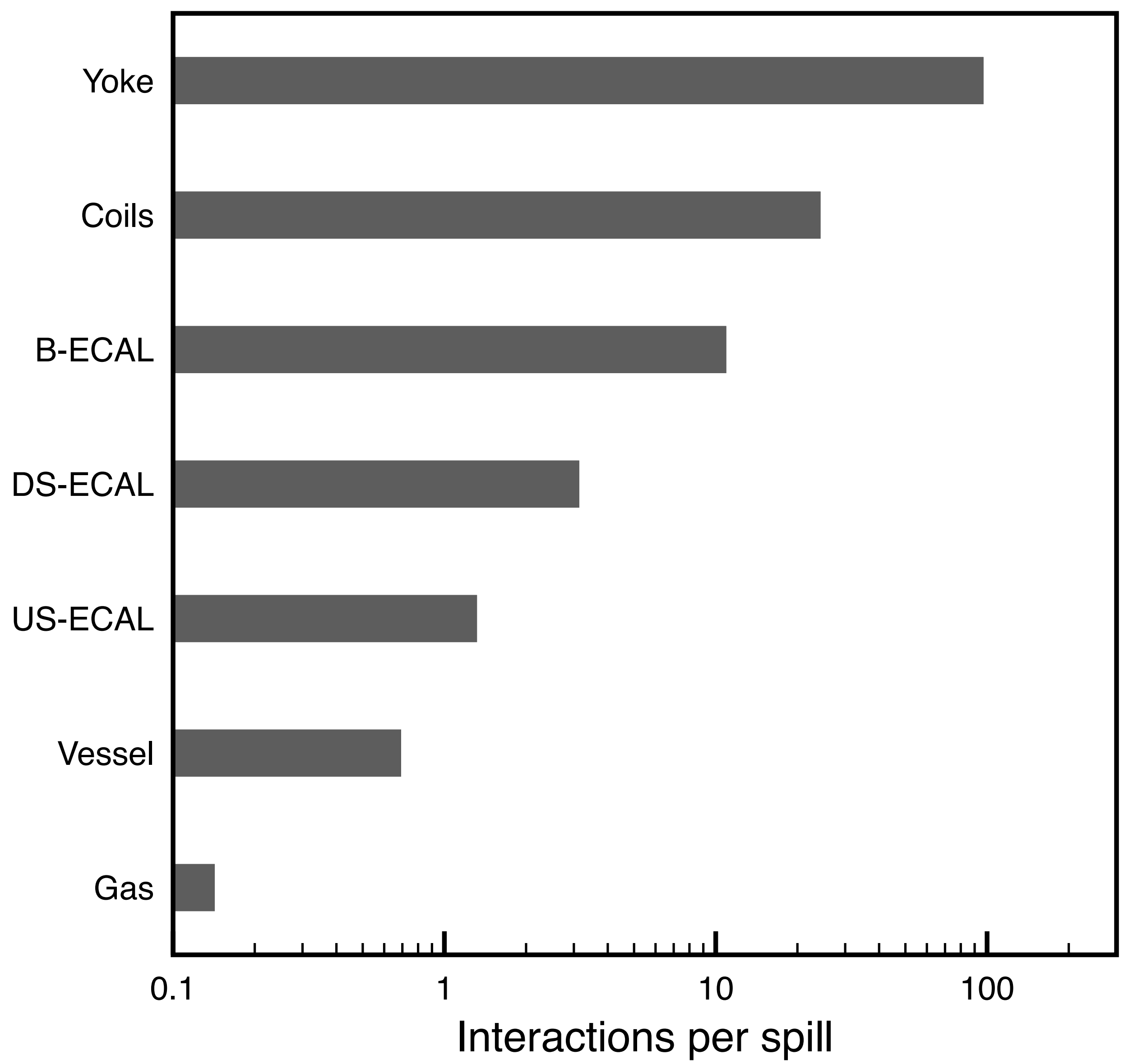
X_0 (Ti) = 3.6 cm –> 1.7 cm (x2) = ~0.5 X_0 (x2)

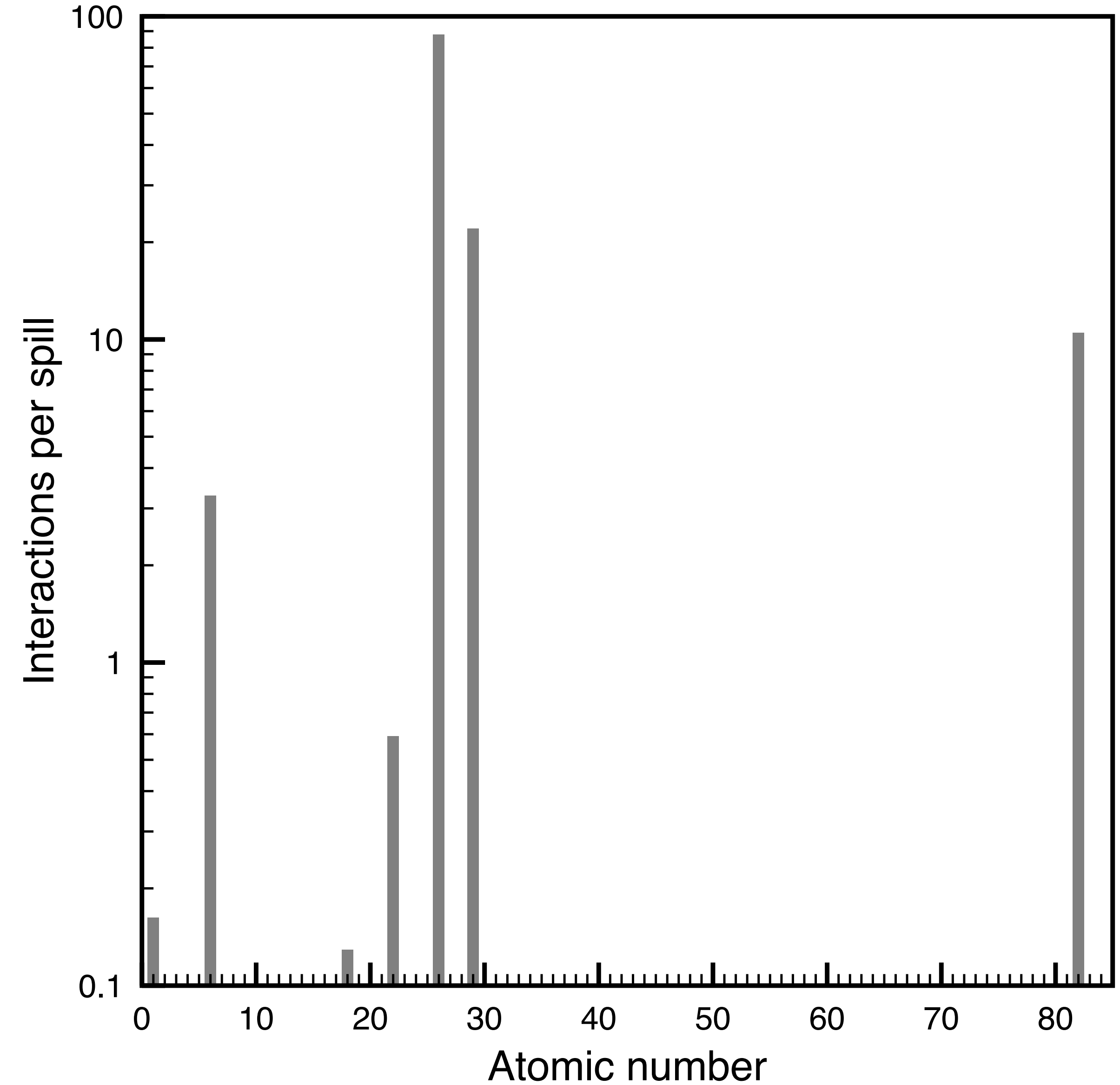
THE ELECTROMAGNETIC CALORIMETER

- The TF GArTPC-ND copies the ECAL design used by the FGT (Pb and plastic scintillator sampling calorimeter):
  - Downstream: 1.75 mm Pb, 1 cm scint., 60 layers.
  - Barrel, upstream: 3.5 mm Pb, 1 cm scint., 18 layers.
- ECAL is essential for detection of π^0's.
  - A 100 MeV gamma has an attenuation length of tens of meters in argon gas.
- ECAL also used for particle identification and track time-stamping.



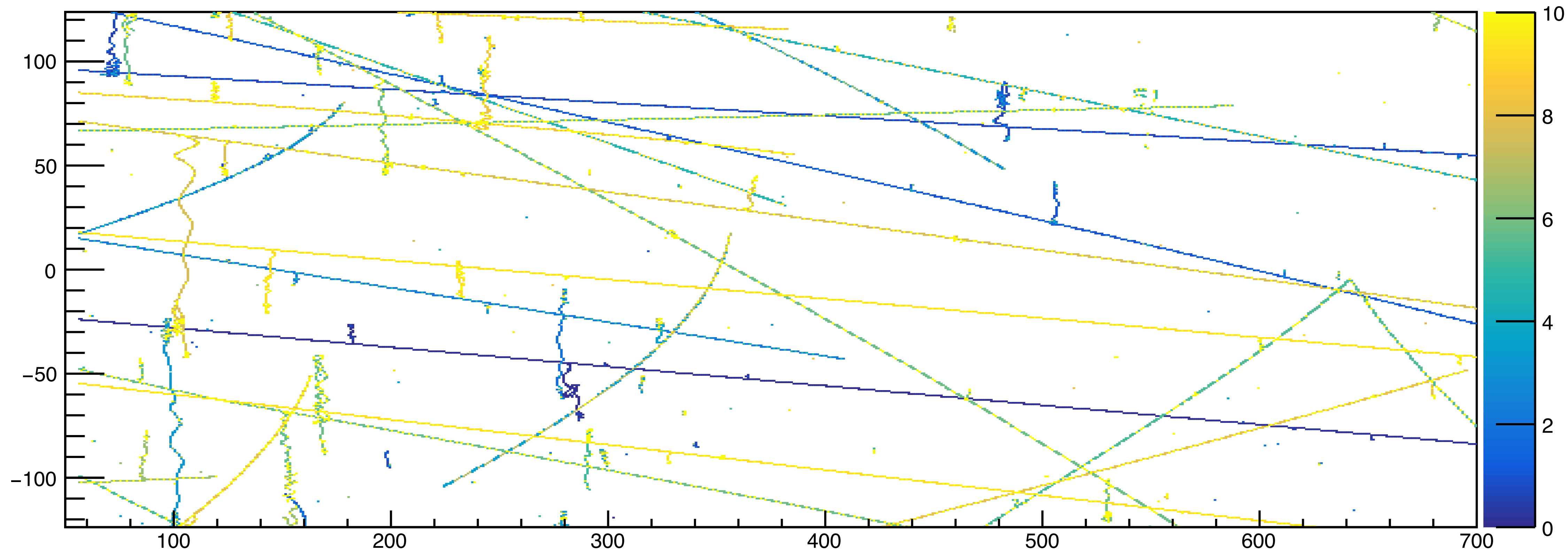
EVENT RATE

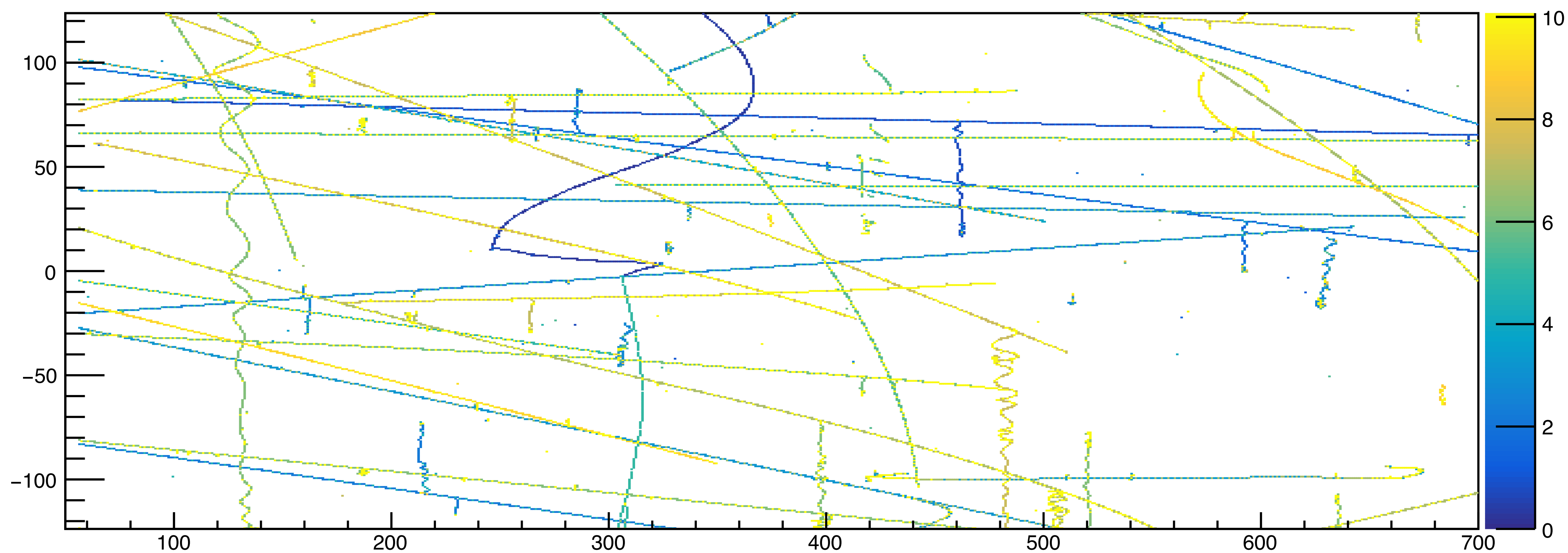




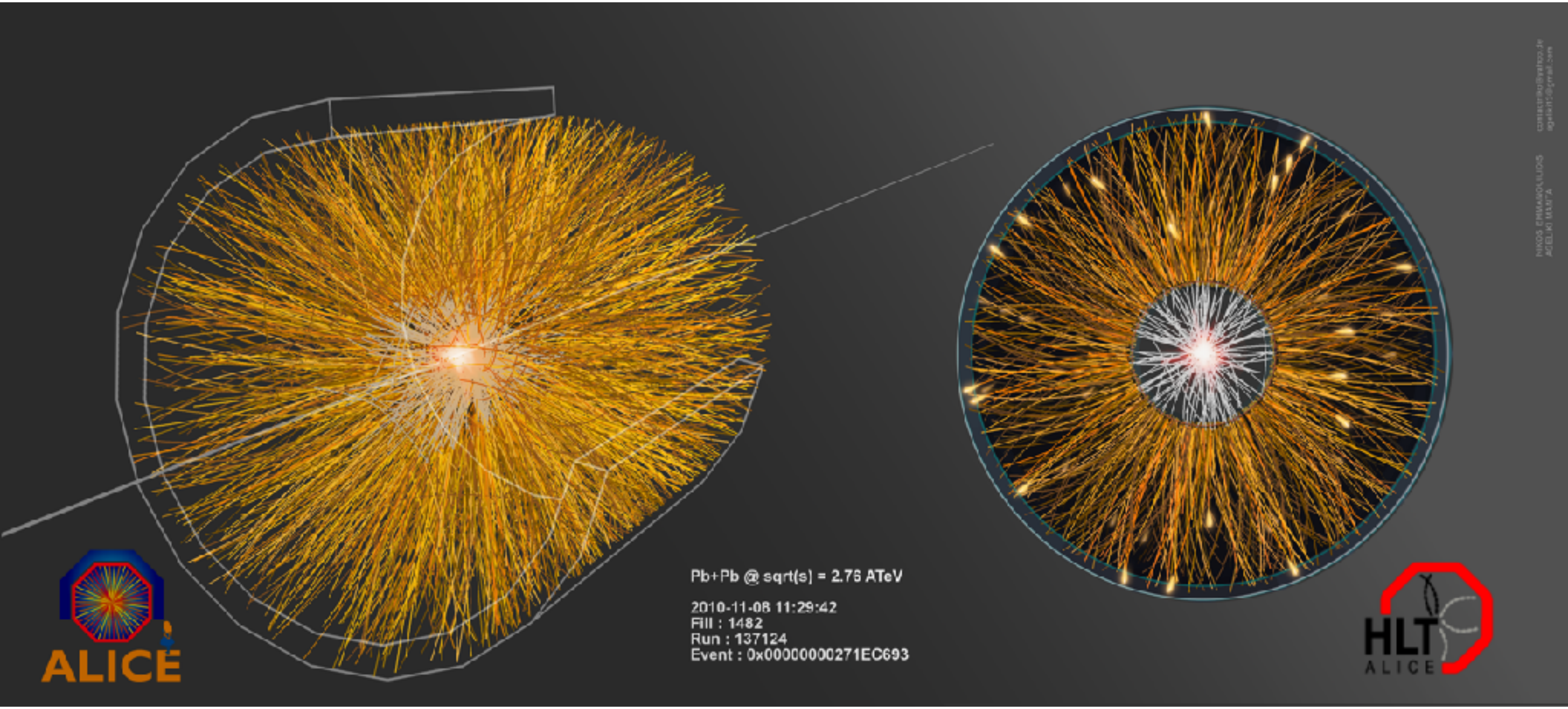
0.15 interactions per spill (7.5E13 POT) and tonne of argon;
3 orders of magnitude more interactions in other detector volumes.

BACKGROUND TRACKS



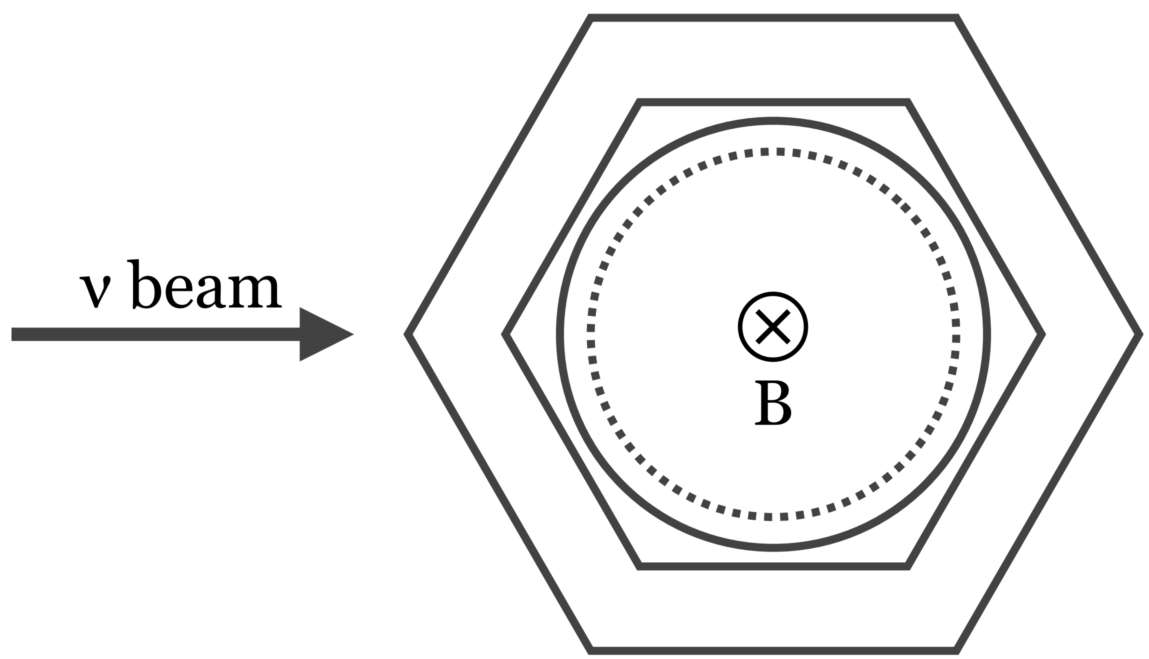


BACKGROUND TRACKS



BEYOND THE TF DESIGN

- Motivation for most design choices in TF GArTPC-ND was facilitating the comparison with FGT.
- Optimizations possible, but they will most likely depend on role of GArTPC in ND system.
    - For example, total detector mass could be smaller if the ND system has a LArTPC.
- Some obvious studies:
    - ECAL configuration (shape, integration with vessel, etc.).
    - Fiducial volume and magnetic field.



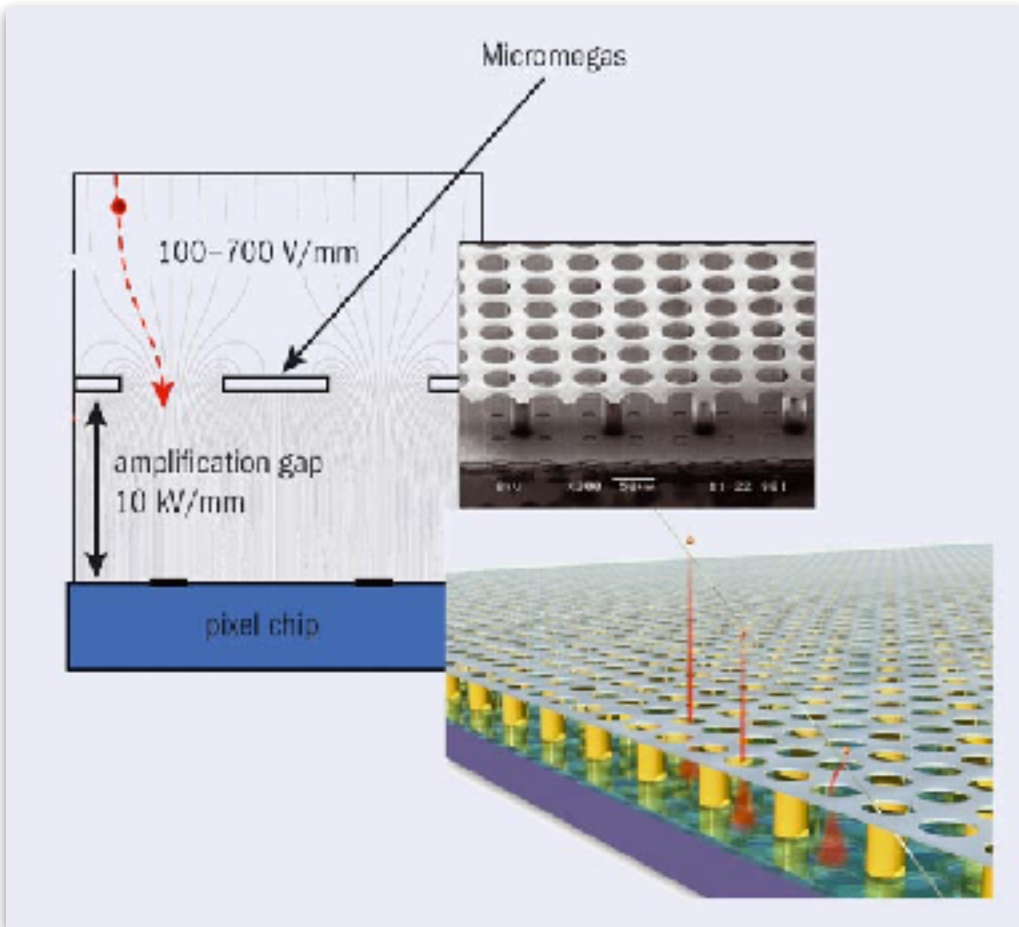
BEYOND THE TF DESIGN

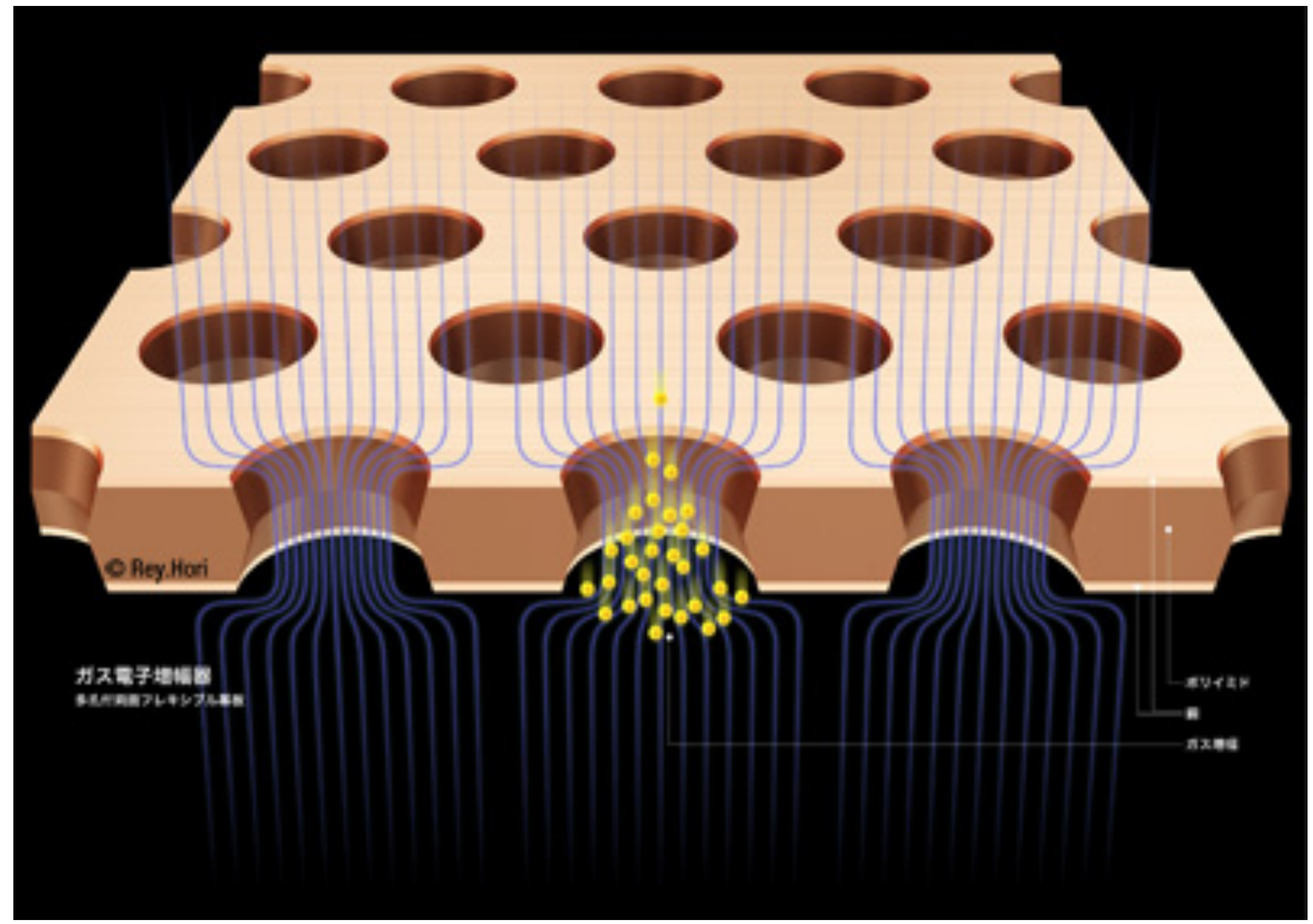
- Detector R&D efforts in Europe and USA will try to address open design questions:
  - readout technology;
  - gas mixture (if any);
  - gas pressure;
  - etc.
- UK prototype (~1 m3 TPC with optical and charge readout) will measure proton/pion response at CERN test beam next year.
  - See M. Wascko's talk tomorrow.
- Ongoing work on track reconstruction (TREx).
  - See J. Haigh's talk tomorrow.

CONCLUSIONS

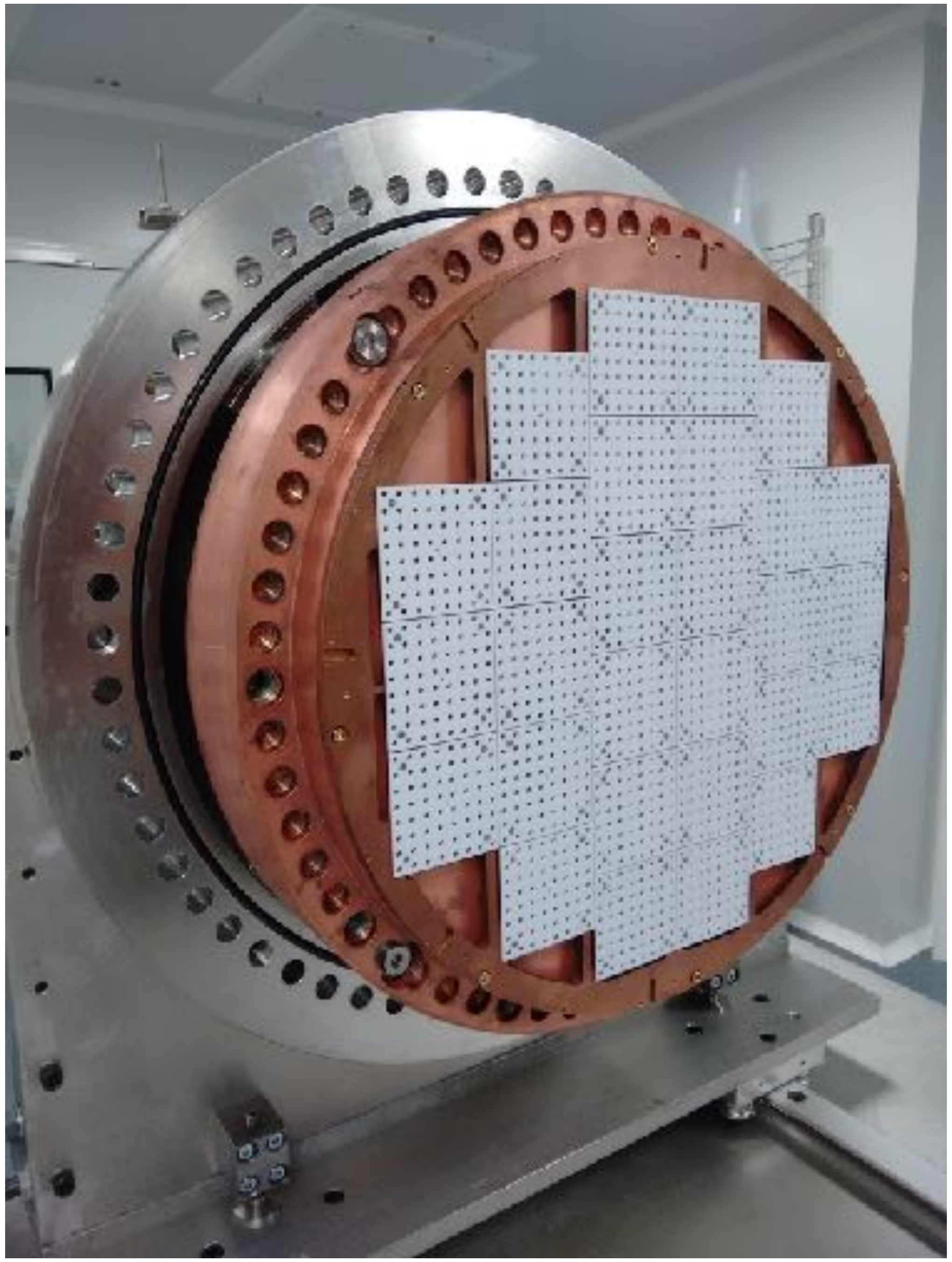
- A GAr TPC offers a continuos argon target with low detection thresholds, good momentum resolution and excellent particle identification capabilities.
- Might be the idea detector to measure nuclear effects in neutrino interactions.
- Ongoing hardware (two prototypes in different stages of development) and software (simulation and reconstruction) efforts within the DUNE GArTPC WG.

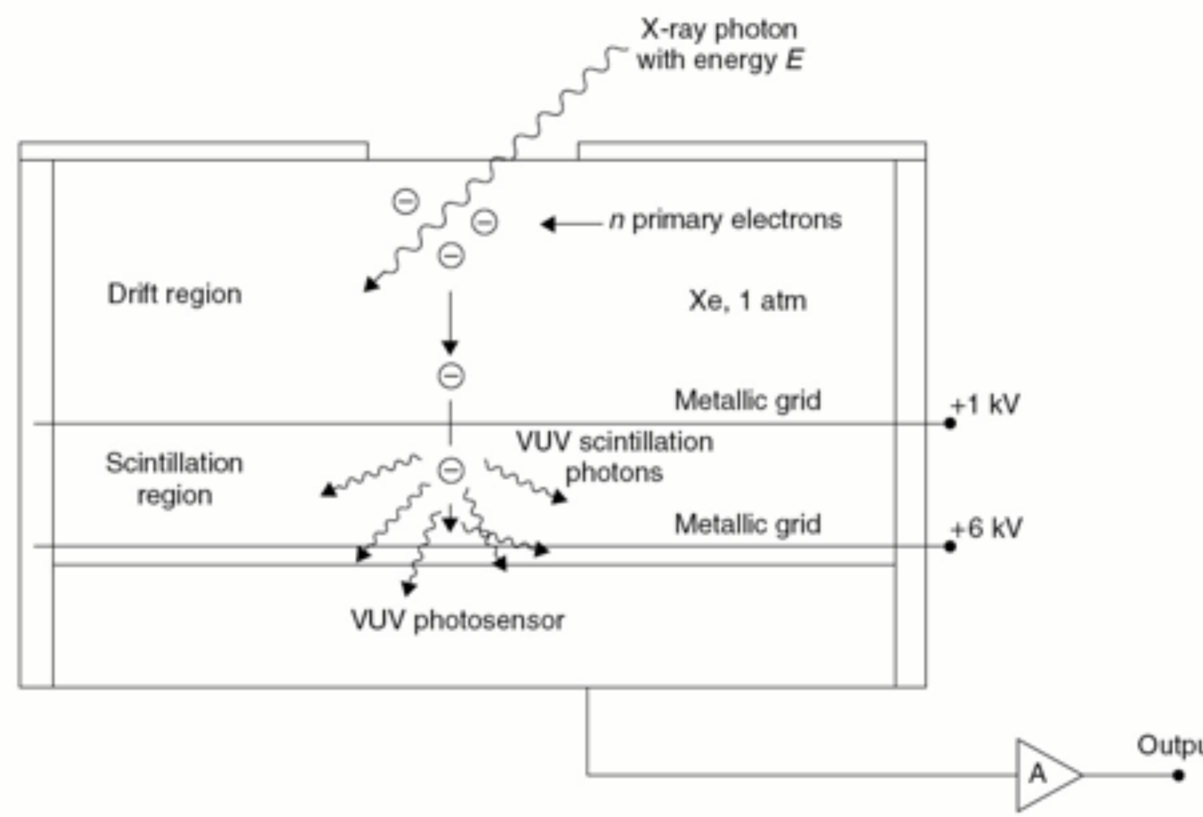
CHARGE AVALANCHE READOUT





ELECTROLUMINESCENCE READOUT





GAS MIXTURES