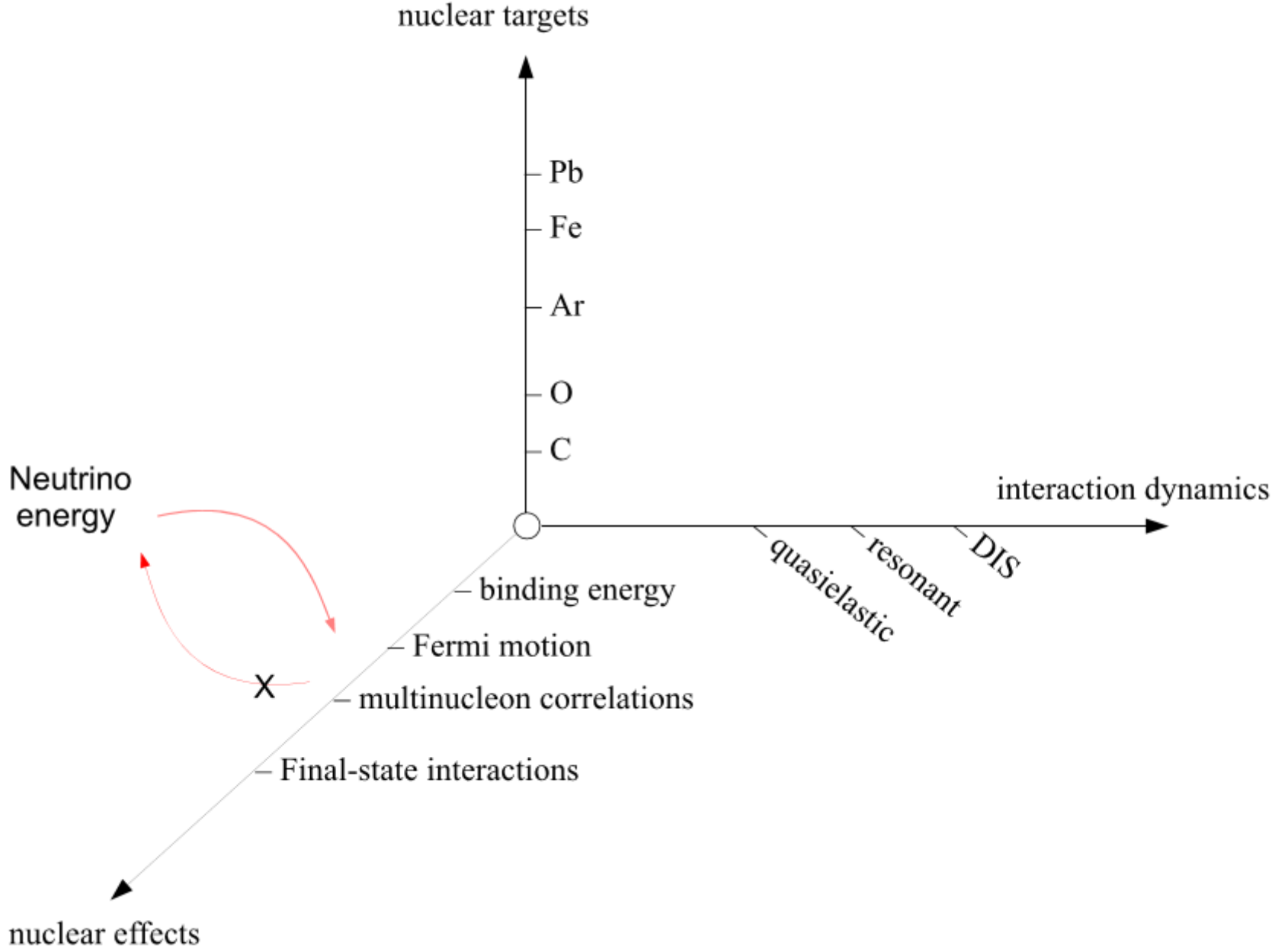
UNIVERSITY OF WARWICK

WarTPC: Let There Be Light

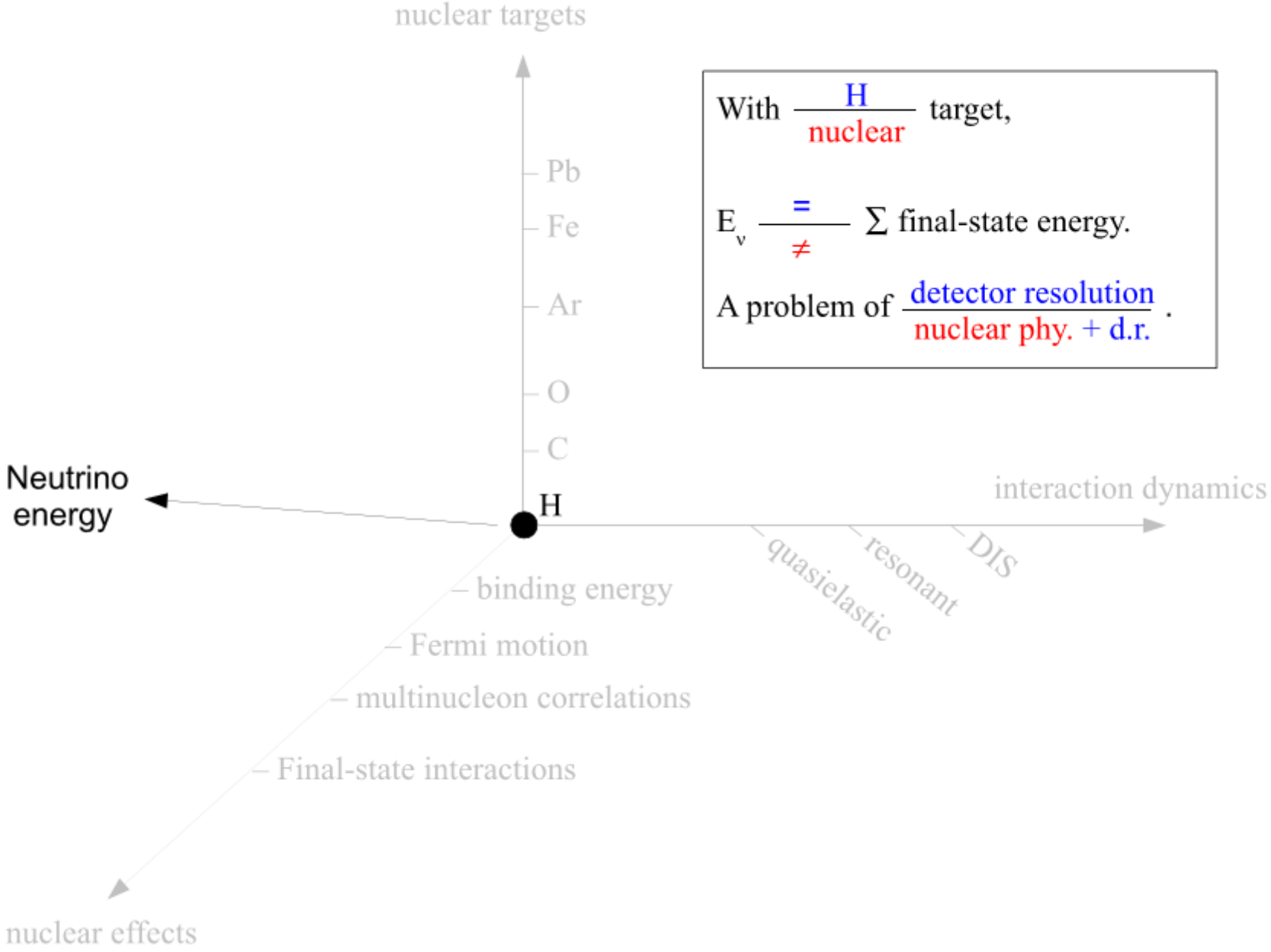
Radical solution for neutrino interactions

XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)



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XL, et al., Phys.Rev.D 92, 051302 (2015)
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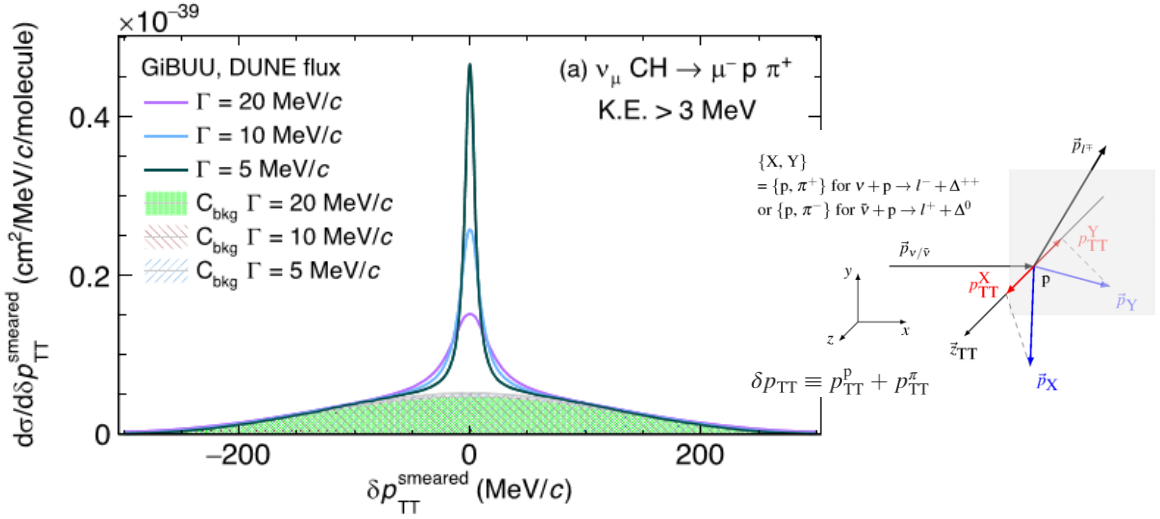
With $\frac{H}{\text{nuclear}}$ target,

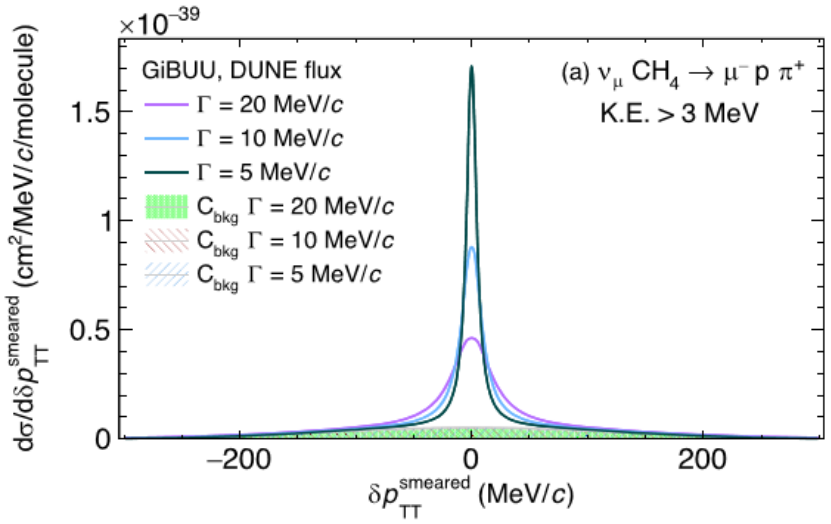
$E_\nu \ \frac{=}{\neq} \ \sum$ final-state energy.

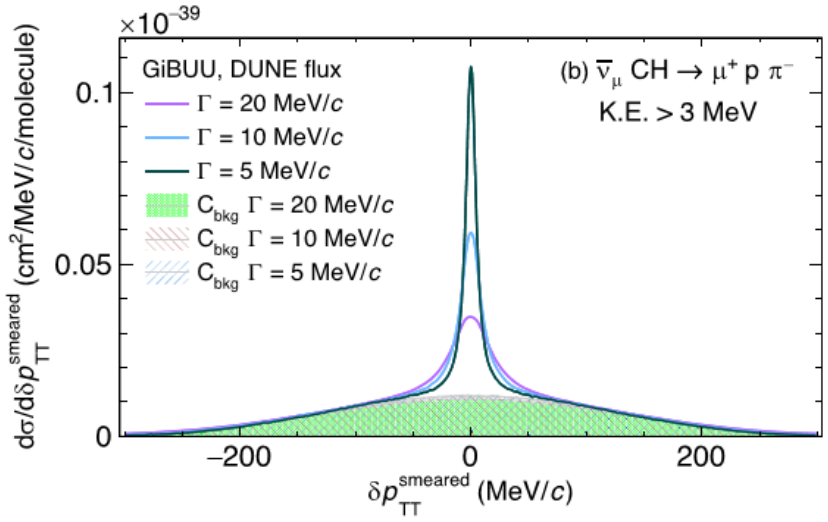
A problem of $\frac{\text{detector resolution}}{\text{nuclear phy. + d.r.}}$.

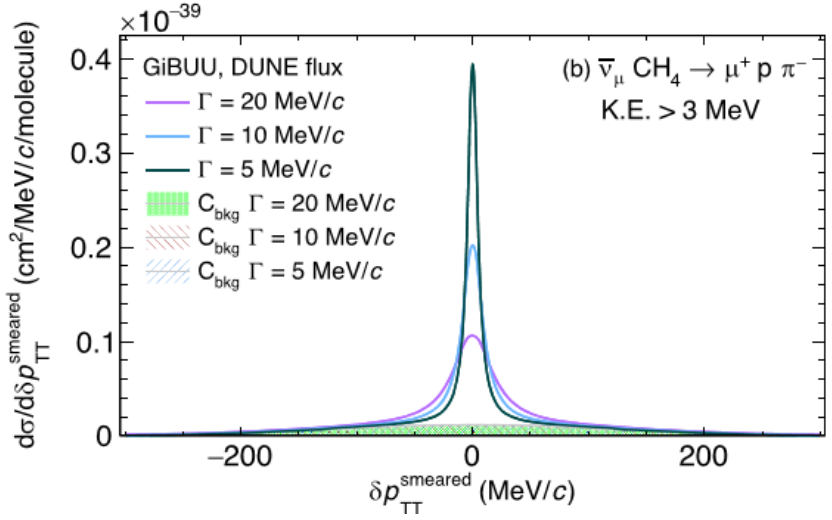
Radical solution for neutrino interactions

XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)









- Event-by-event selection of neutrino/antineutrino-hydrogen interactions!

Radical solution for neutrino interactions

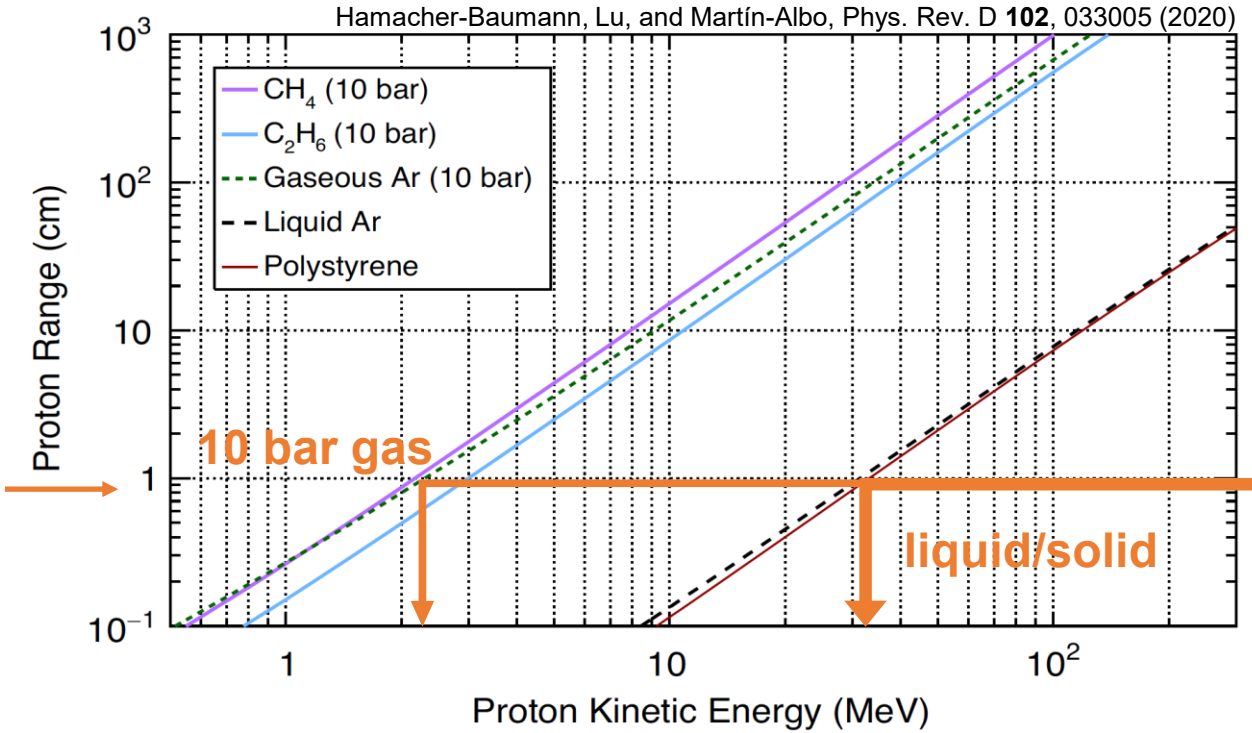
Proton Range $\sim (\text{kinetic energy})^2/(\text{material density})$

(Range: how far a particle can travel in a medium)

vs

Kinetic Energy

Hamacher-Baumann, Lu, and Martín-Albo, Phys. Rev. D **102**, 033005 (2020)



Sensor granularity
~ mm-cm

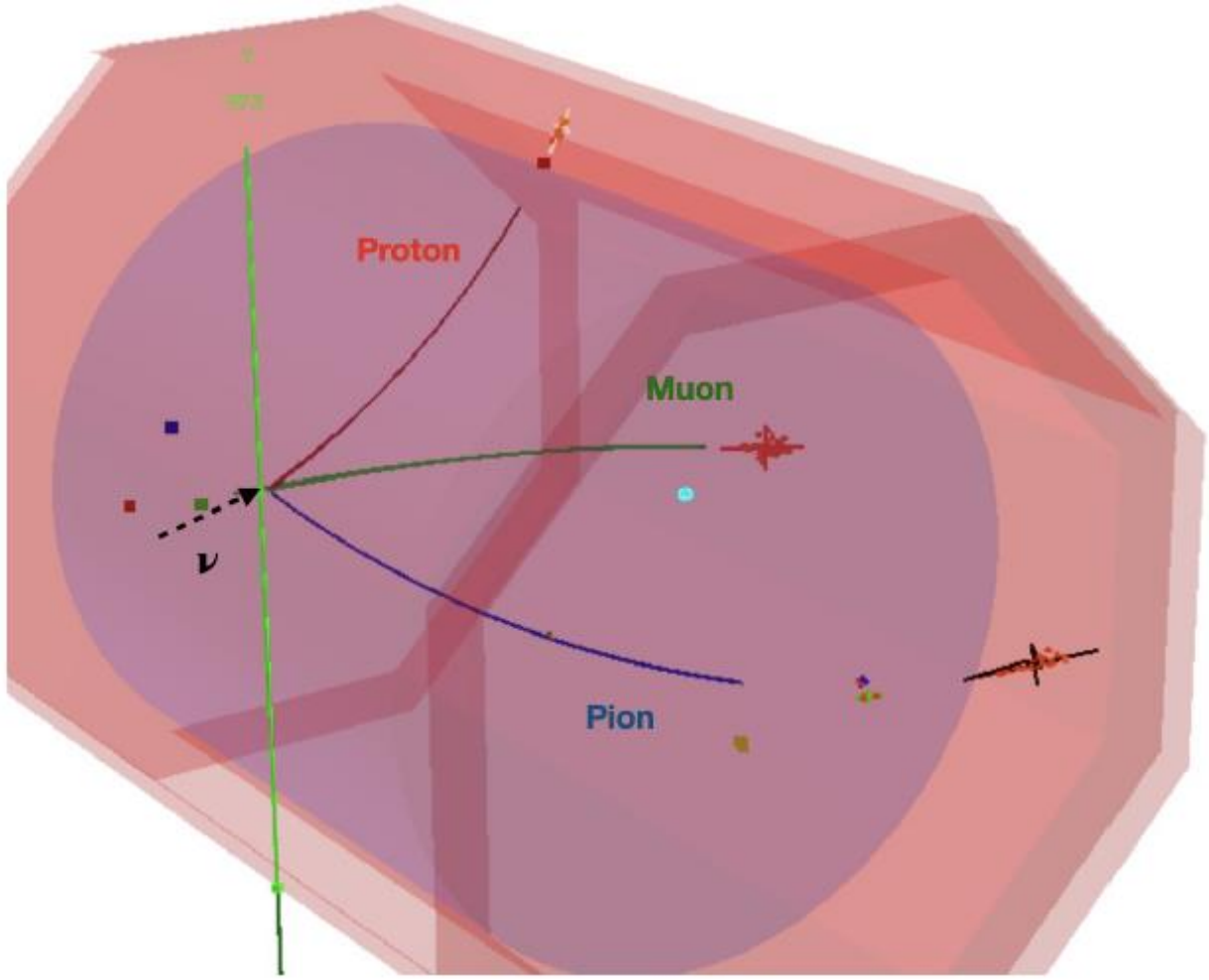
Tracking threshold
(no momentum measurement possible below it)
~ few MeV for 10 bar gas
~ 10s MeV for liquid/solid

Radical solution for neutrino interactions

XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)

Hydrogen-rich high-pressure TPC

- **Why hydrogen? Why gas TPC? Why high pressure?**
  - No nuclear effects
  - Acceptance, tracking threshold
  - Target mass



Raaf, TPC Mini Workshop

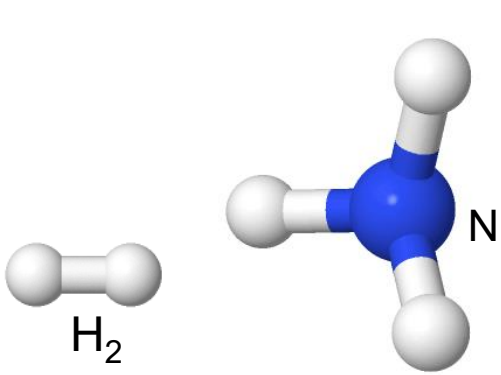
Radical solution for neutrino interactions

XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)

Hydrogen-rich high-pressure TPC

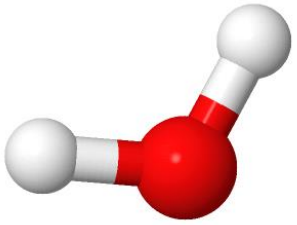
- **Why hydrogen? Why gas TPC? Why high pressure?**
  - No nuclear effects
  - Acceptance, tracking threshold
  - Target mass
- Why not pure hydrogen TPC
  - Bubble chamber: worse tracking
  - H_2 gas: not hydrogen-rich enough
- **How rich is rich?**
  - Element carrying as much hydrogen as possible: Carbon base C_xH_y
    - Saturated, acyclic: Alkane C_nH_{2n+2}
      - ✓ CH_4 most efficient H-carrier, but not the largest one
  - Maximal partial pressure limited by vapor pressure
    - Theoretically hydrogen-richest mix at 10 bar: $C_{3.93}H_{9.86}$

    = 17% $C(CH_3)_4$ (neopentane) + 35% iC_4H_{10} (isobutane) + 24% C_4H_{10} (butane) + 24% C_3H_8 (propane)

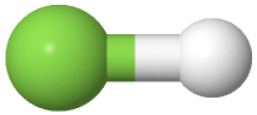


H_2

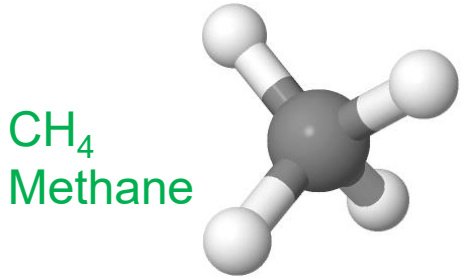
NH_3
Ammonia



H_2O
Water

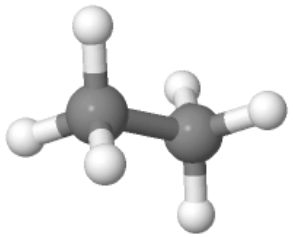


HF
Hydrogen fluoride

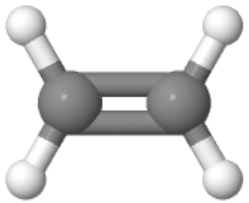


CH_4
Methane

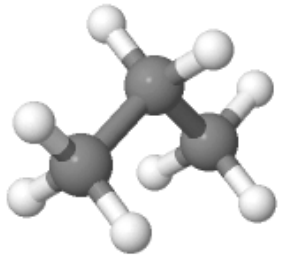
					2 He
5 B	6 C	7 N	8 O	9 F	10 Ne
13 Al	14 Si	15 P	16 S	17 Cl	18 Ar



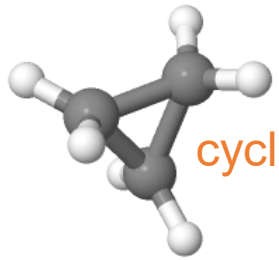
C_2H_6
Ethane



unsaturated
C_2H_4
Ethene



C_3H_8
Propane



cyclic
C_3H_6
Cyclopropane

http://www.jmol.org/

Radical solution for neutrino interactions

XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)

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- **Why hydrogen? Why gas TPC? Why high pressure?**
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  - Target mass

Warwick TPC Platform (WarTPC)

- Unique high-pressure gas TPC flatform in the UK
- Generic R&D with potential application for the DUNE
- Neutrino-hydrogen measurements?!



August, 2022

Radical solution for neutrino interactions

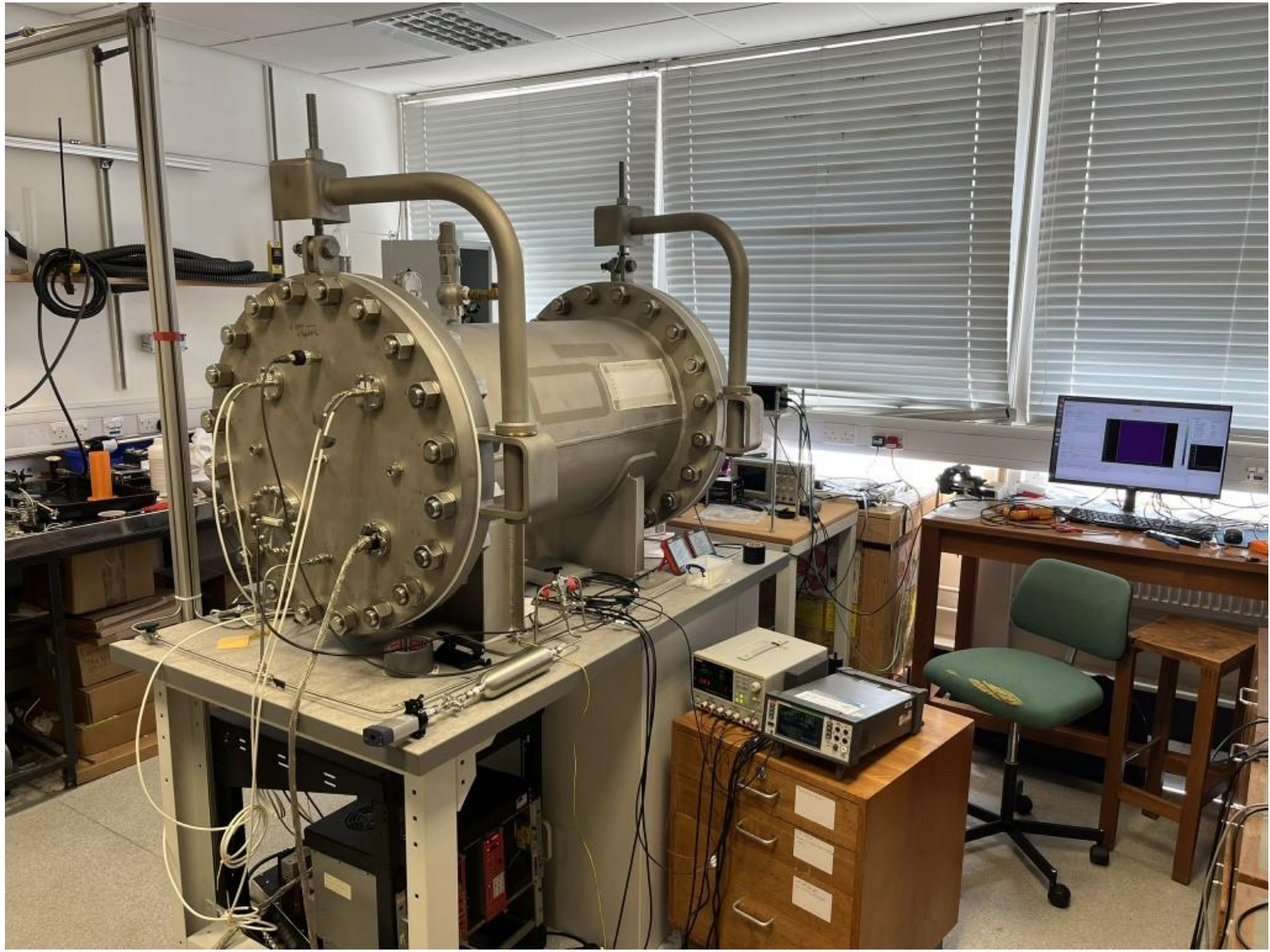
XL, et al., Phys.Rev.D 92, 051302 (2015)
Hamacher-Baumann, XL, Martín-Albo, Phys.Rev.D 102, 033005 (2020)

Hydrogen-rich high-pressure TPC

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Warwick TPC Platform (WarTPC)

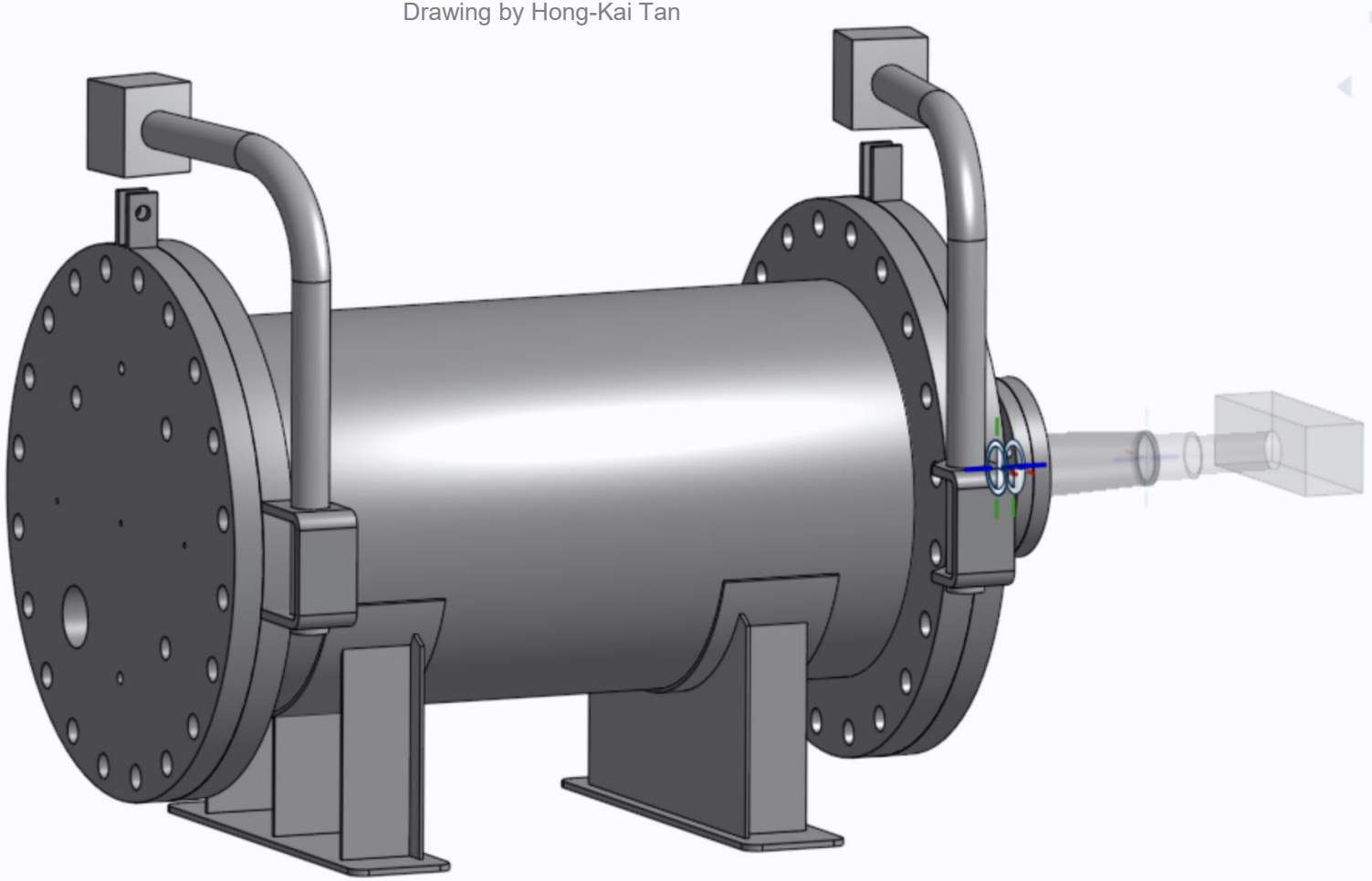
- Unique high-pressure gas TPC flatform in the UK
- Generic R&D with potential application for the DUNE
- Neutrino-hydrogen measurements?!



WarTPC

Stainless steel vessel
Capacity: 195 L
Maximum pressure: 16 bar
Working pressure: Up to 10 bar
Tracking gases: Ar, CH_4, CF_4

Drawing by Hong-Kai Tan

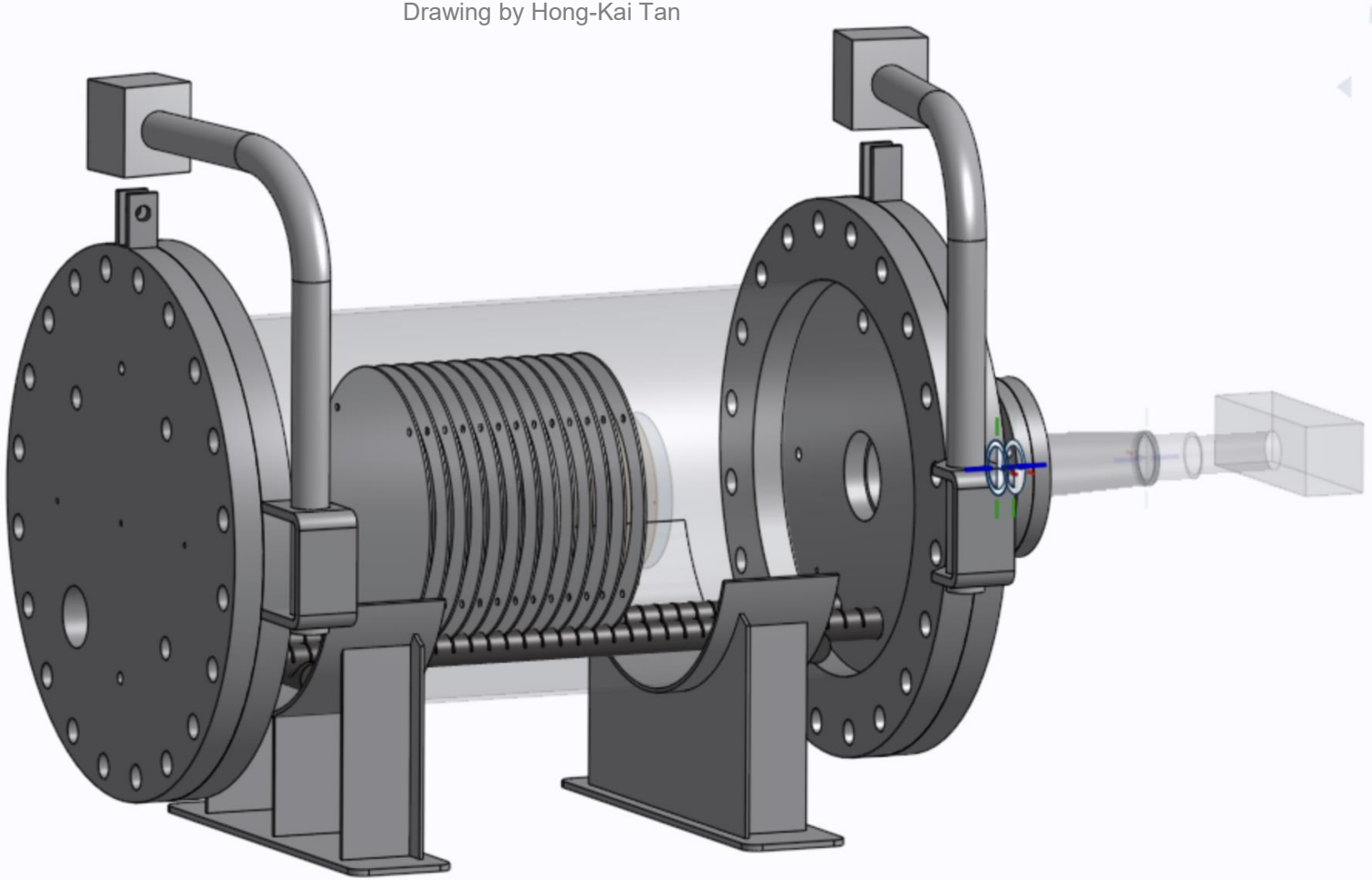


WarTPC

Stainless steel vessel
Capacity: 195 L
Maximum pressure: 16 bar
Working pressure: Up to 10 bar
Tracking gases: Ar, CH_4, CF_4

Field cage
Drift length: 26.2 cm
Field cage Ø: 28 cm
Maximum voltage: 15 kV
Max. configured drift field: 404 V /cm

Drawing by Hong-Kai Tan



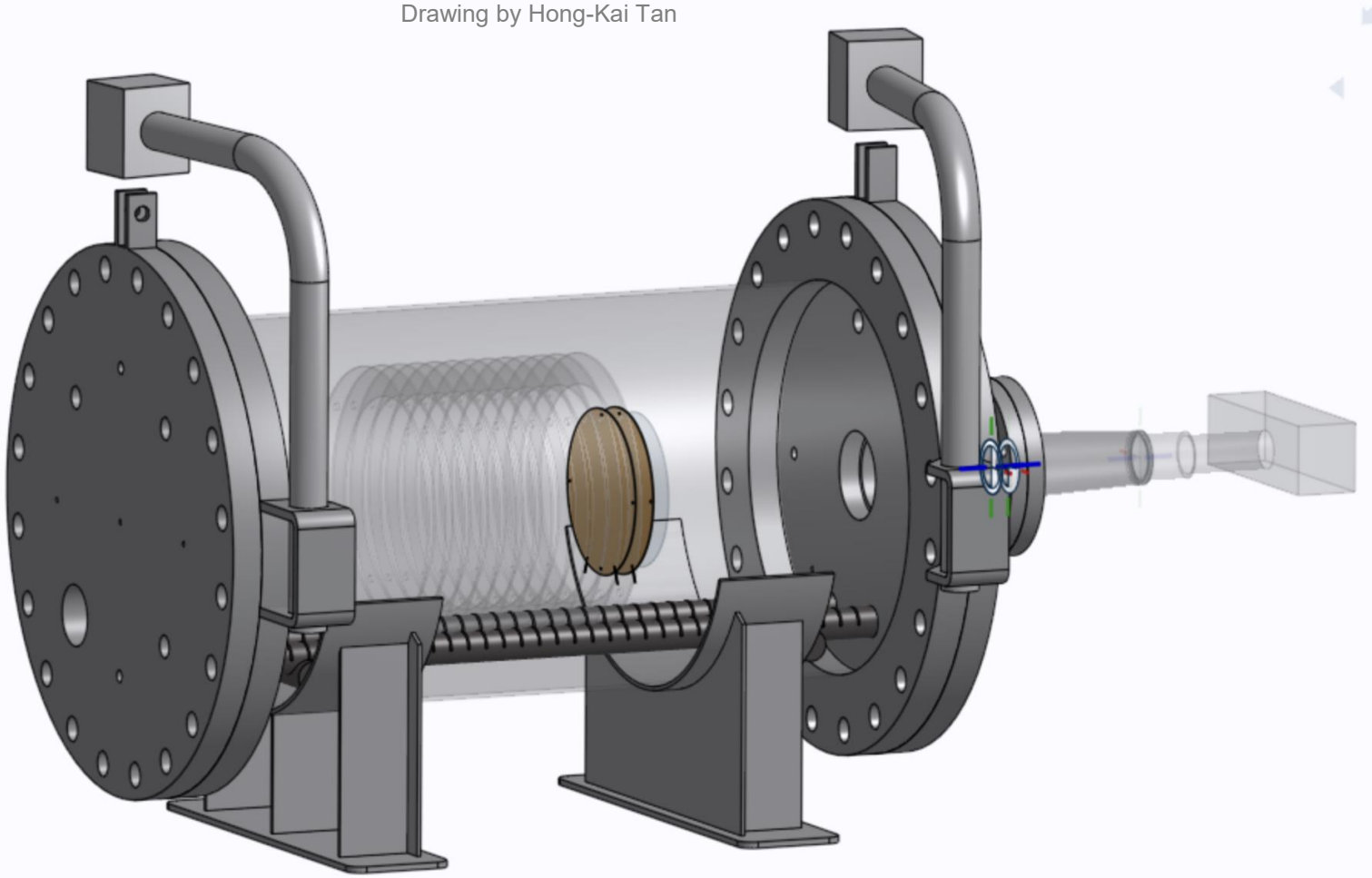
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2 THGEMs
Hole size: 0.5 mm
Hole pitch: 0.8 mm
Maximum voltage: 5.5 kV/channel
Transfer gap: 3.5 mm

Drawing by Hong-Kai Tan



WarTPC

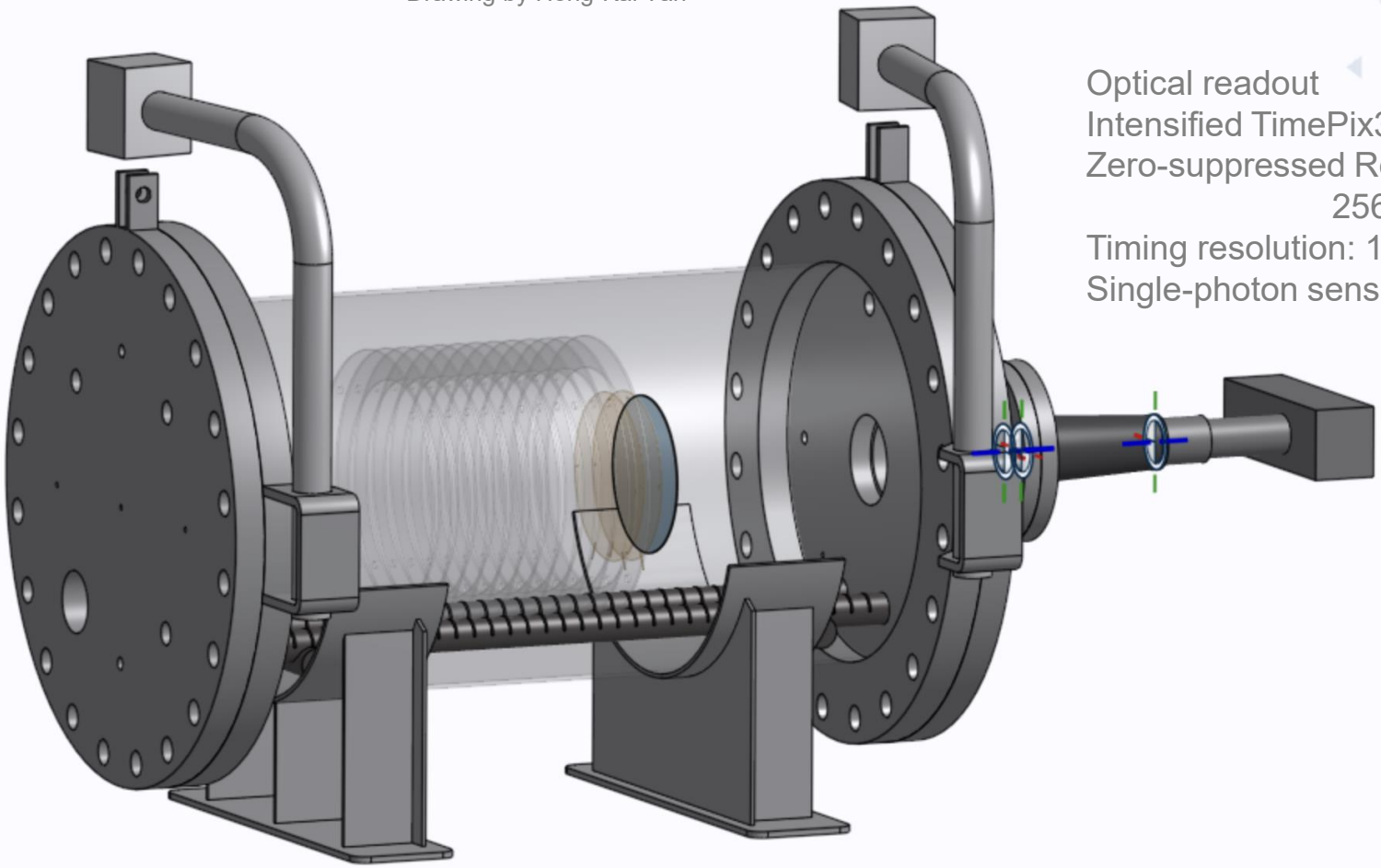
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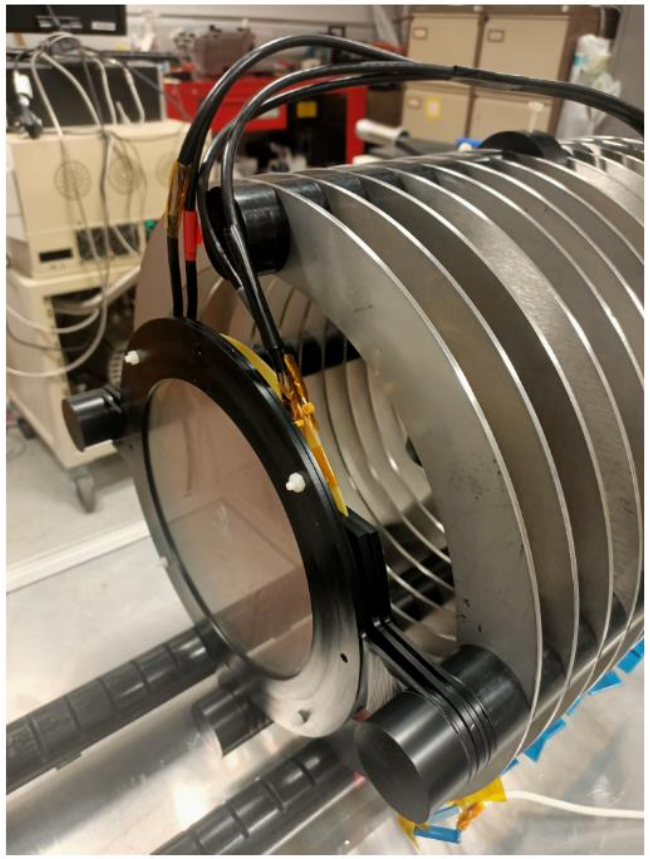
2 THGEMs
Hole size: 0.5 mm
Hole pitch: 0.8 mm
Maximum voltage: 5.5 kV/channel
Transfer gap: 3.5 mm

Wavelength Shifter
Polyethylene Napthalate (PEN)
Thickness: 25 um

Drawing by Hong-Kai Tan



Optical readout
Intensified TimePix3 CMOS
Zero-suppressed Resolution:
256 x 256 pixels
Timing resolution: 1.56 ns
Single-photon sensitive

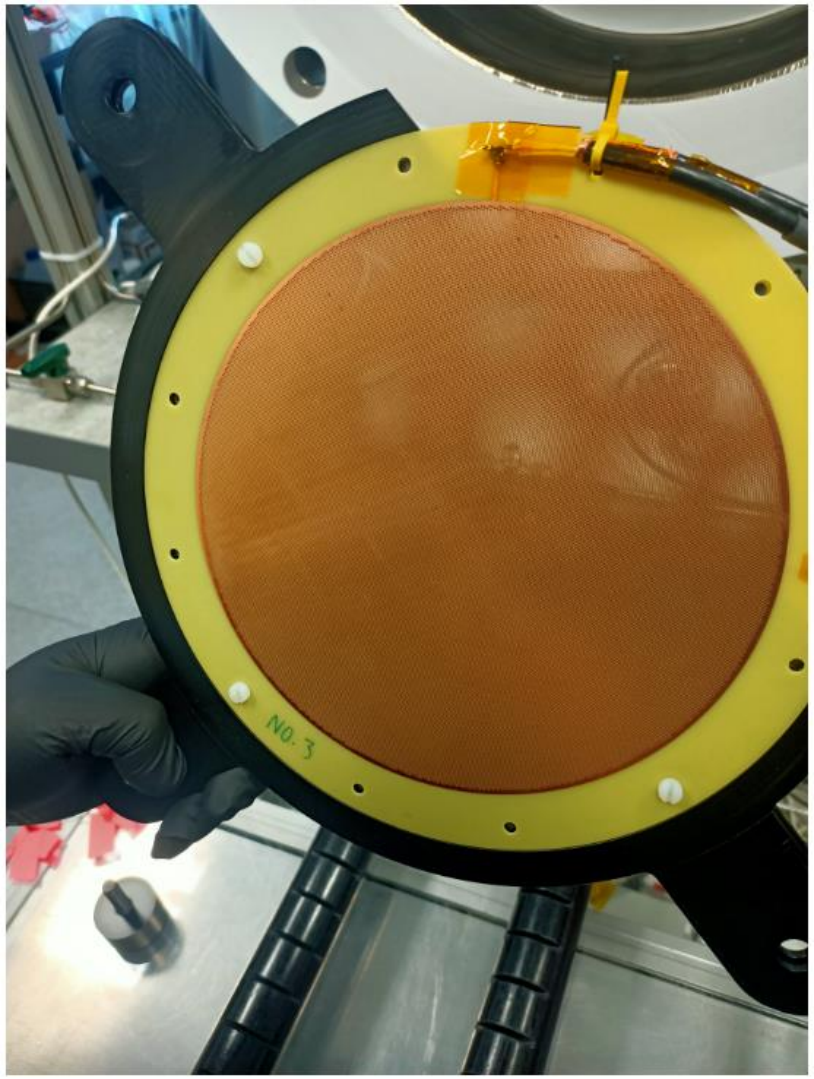


(a) The THGEMs and WLS mounted at the end of the field cage (Taken: 09/03/2026).



Figure 4.32: The full assembly of the field cage with the cathode side on the right. The THGEMs and WLS are mounted on the left, and the source holder is mounted in the middle of the field cage. The field cage holder can be seen underneath, and the Delrin spacers can be seen in between each field cage ring (Taken: 09/03/2023).

Photos by Matthew Snape



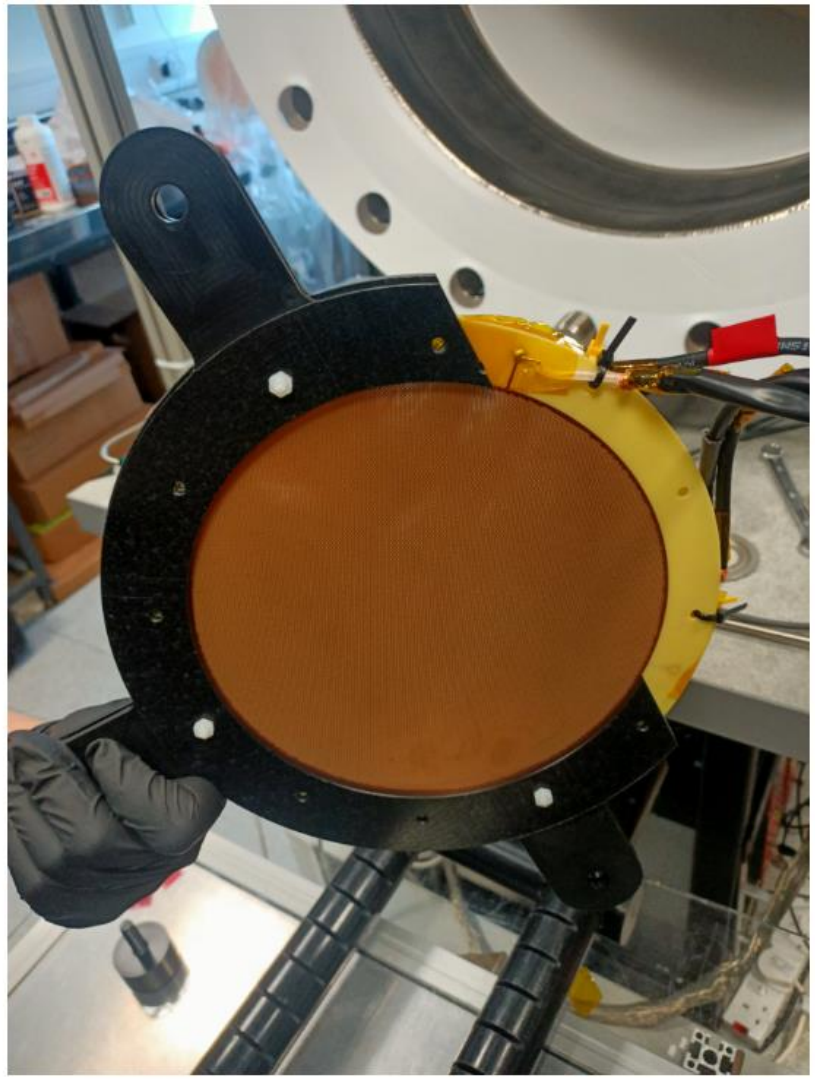


Figure 4.37: The full assembly of the double-THGEM stack. The three M4 nylon bolts can be seen all the way through both holders, which ensures that the holders are attached together (Both taken: 08/06/2026).

Photos by Matthew Snape

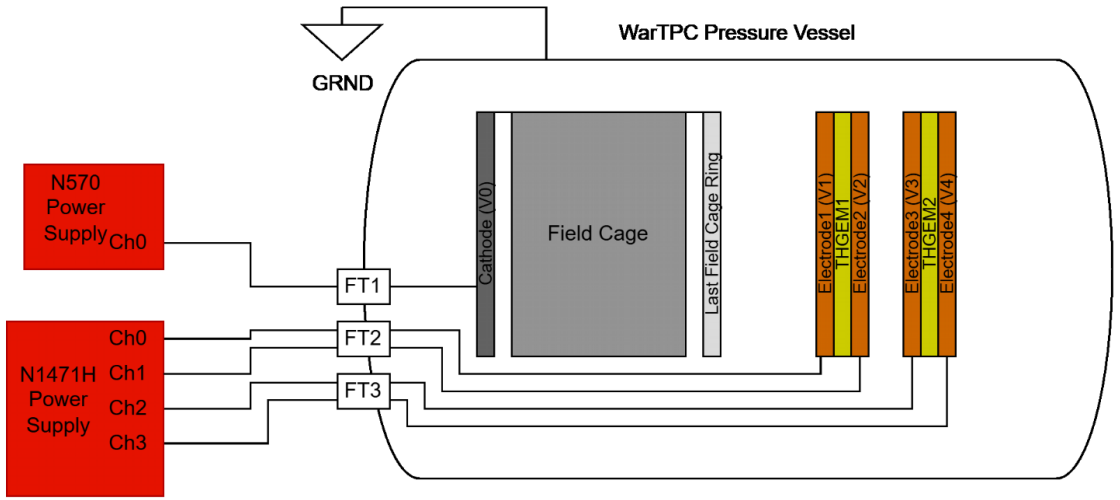


Figure 4.51: A diagram of the power supply setup. FT1 is the field cage feedthrough, FT2 and FT3 are two-pin SHV feedthroughs (23/09/2026).

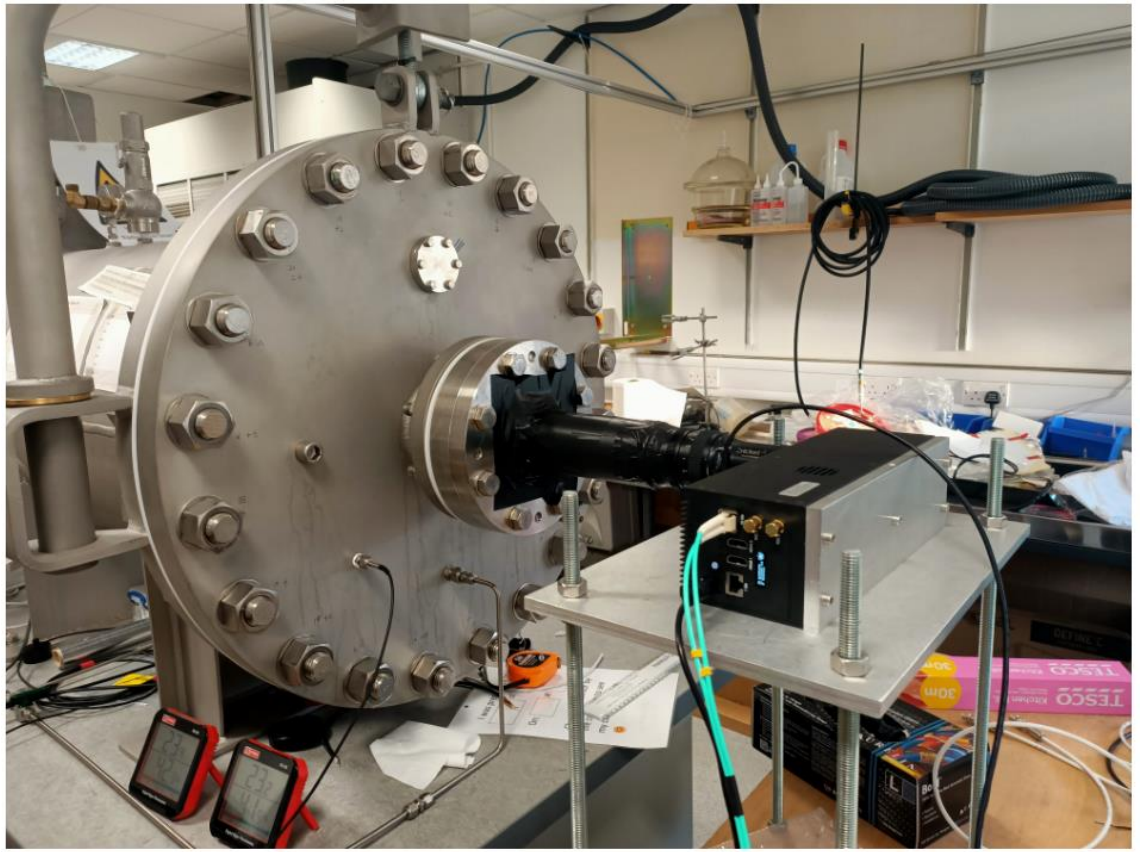
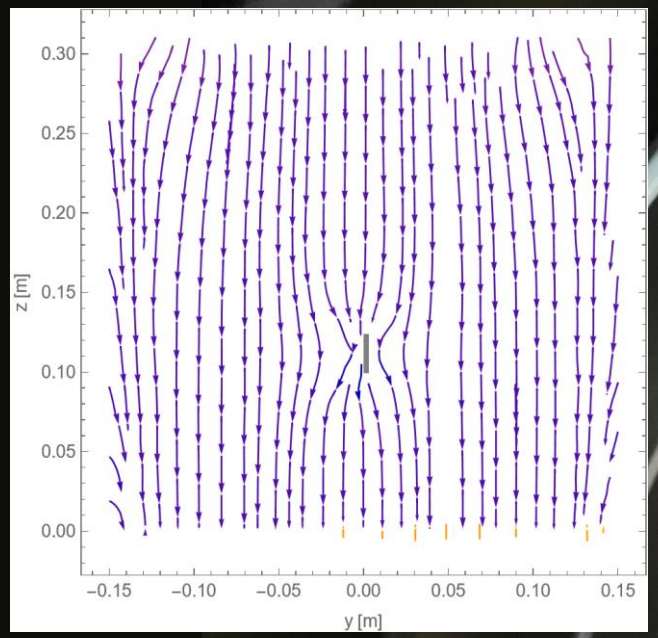


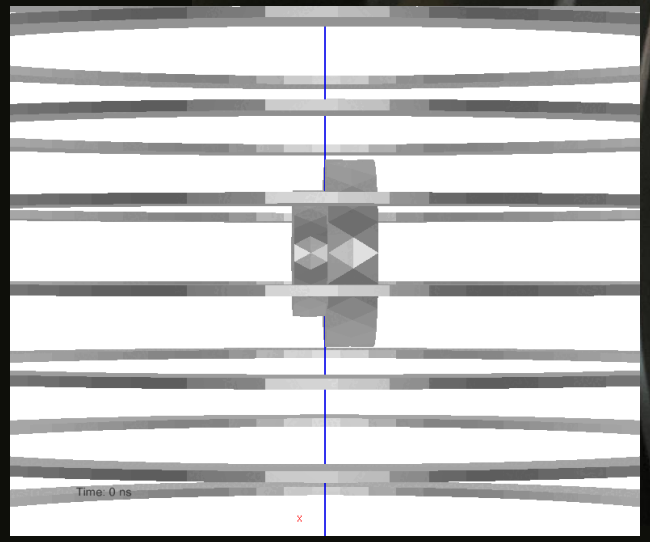
Figure 4.69: The TPX3 camera mounted onto the camera stand. The intensifier and lens are attached to it. Electrical tape was used to attach the light shield to the viewport and to form a light-tight seal. The camera is connected to the TPX3 computer (Taken: 12/12/2025).

Drawing and photo by Matthew Snape

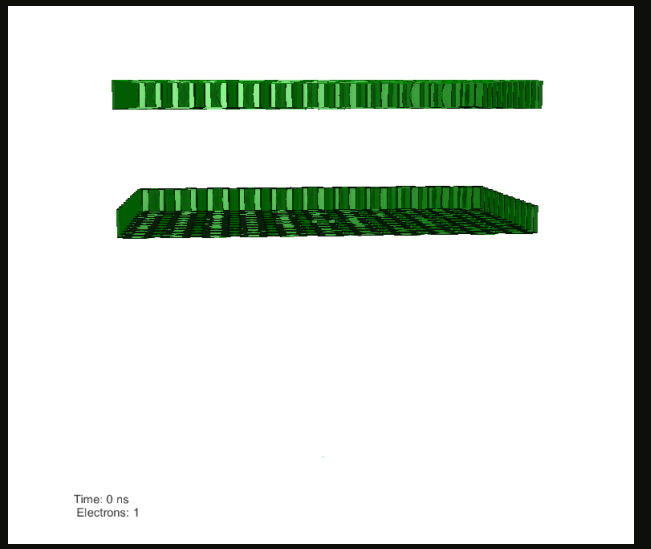
WarTPC

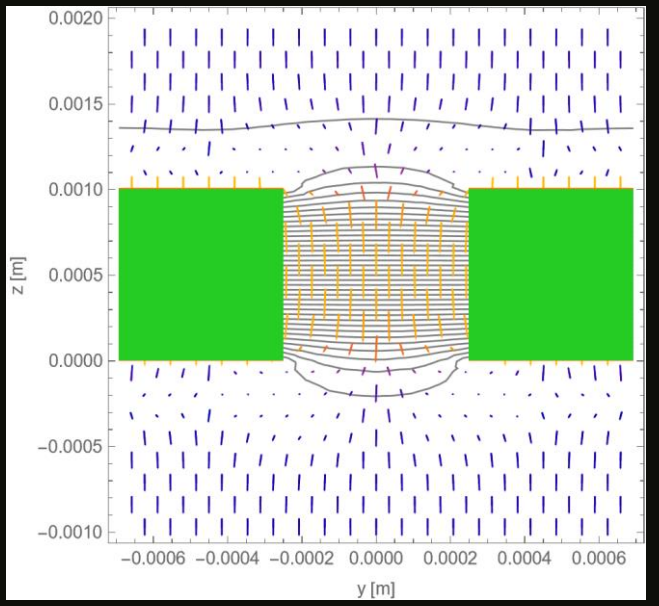
Photo by Alexander Deisting
Simulation and animation by Hong-Kai Tan











Bressler et al., Prog.Part.Nucl.Phys. 130,104029 (2023)

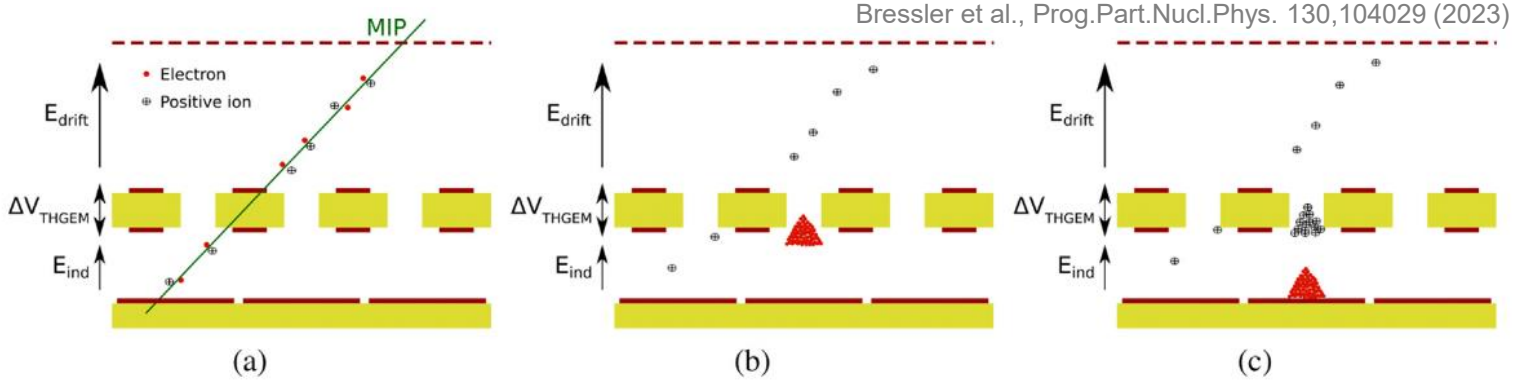


Fig. 2. The principle of operation of a THGEM: (a) electron–ion pairs created by incoming radiation, (b) electron avalanche in the THGEM holes, (c) drift of the avalanche electrons and ions to the anode and THGEM-top, respectively.

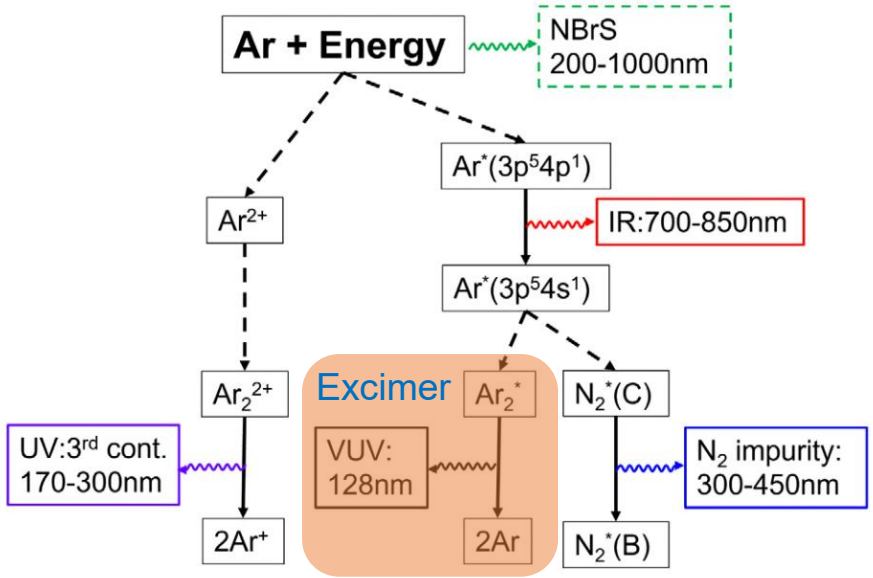


Fig. 1. Simplified diagram of the electroluminescence (EL) mechanism of the Ar-N mixture gas.

Aoyama et al., Nucl.Instrum.Meth.A 1025, 166107 (2022)

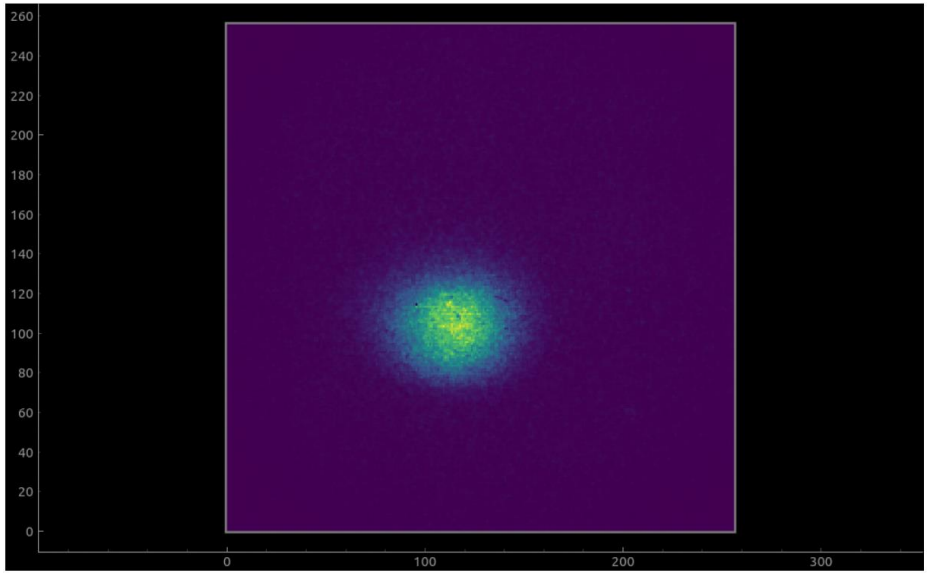
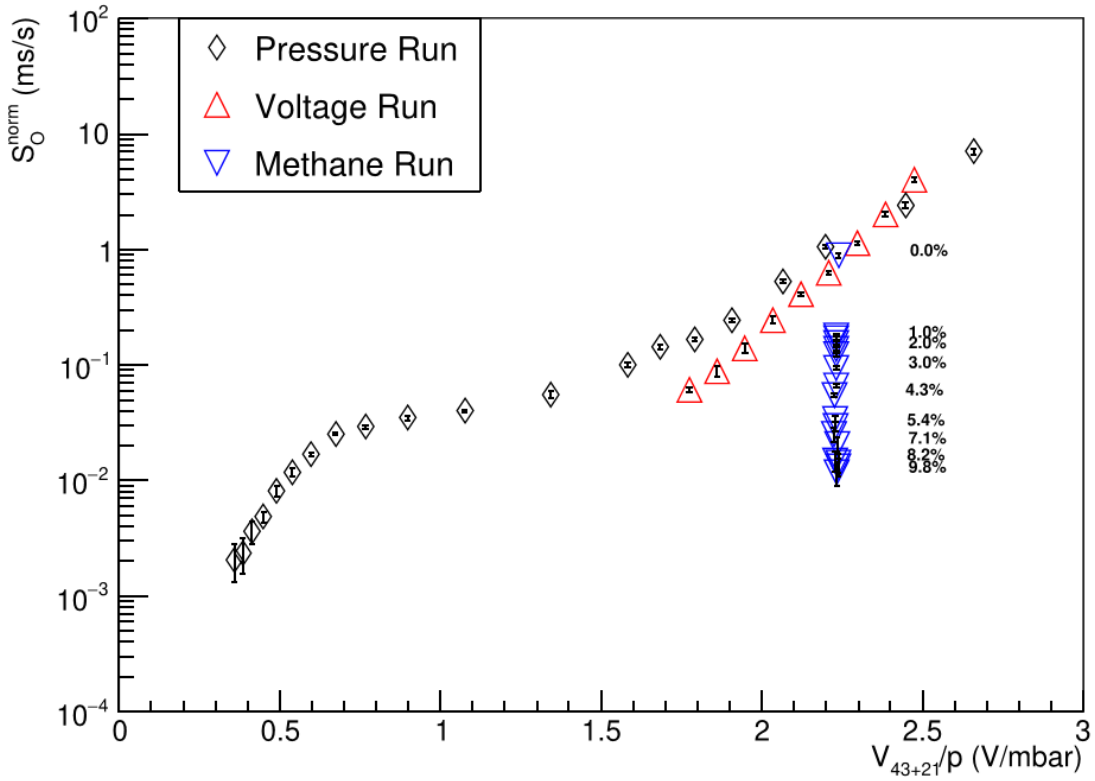
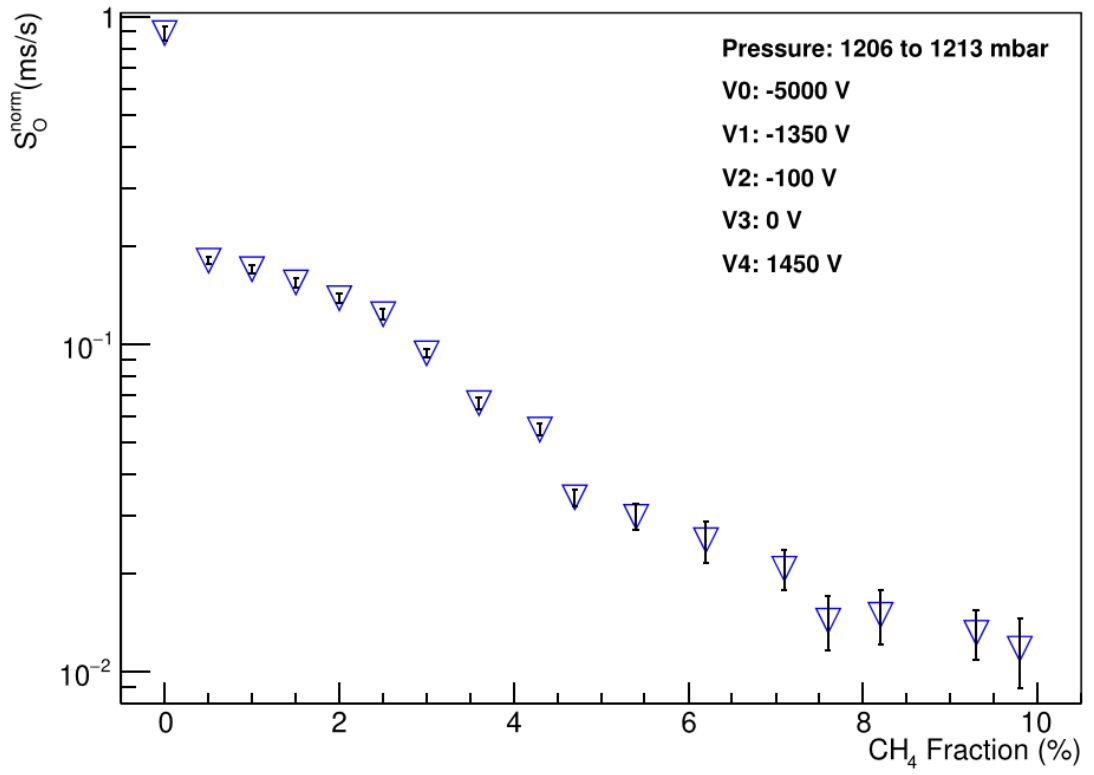


Figure 4.71: The integrated image taken in the first integration test. For this test, the cathode was set at -8000 V, electrode 1 was set at 250 V, electrode 2 was set at 1200 V, electrode 3 was set at 2200 V, and electrode 4 was set at 3000 V. The signal region is quite large due to the image being unfocused. For all remaining images presented, the light shield was used to focus the image (Taken: 22/04/2024).

Matthew Snape, PhD Thesis, U. Warwick, 2026

^{214}Am data

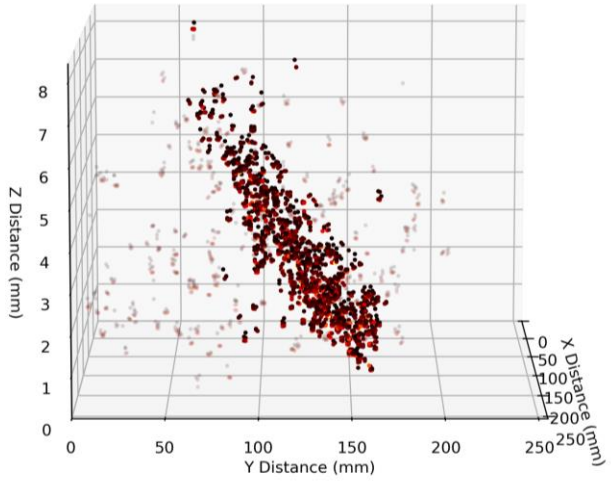




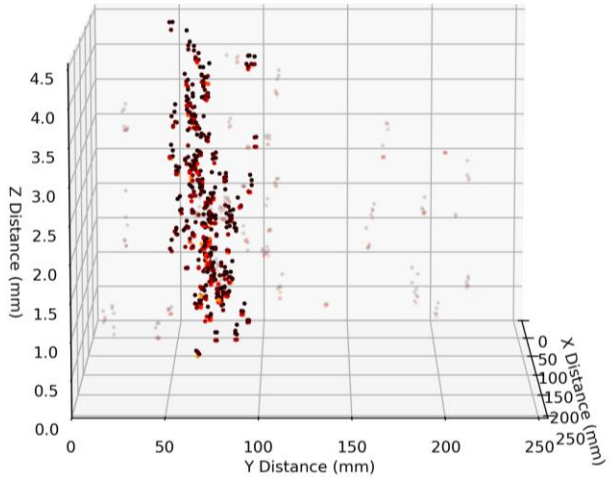
Matthew Snape, PhD Thesis, U. Warwick, 2026

- EL production breaks *E*/*p* (non collisional), or gas conditions differ…
- CH_4 introduces light absorption and quenching

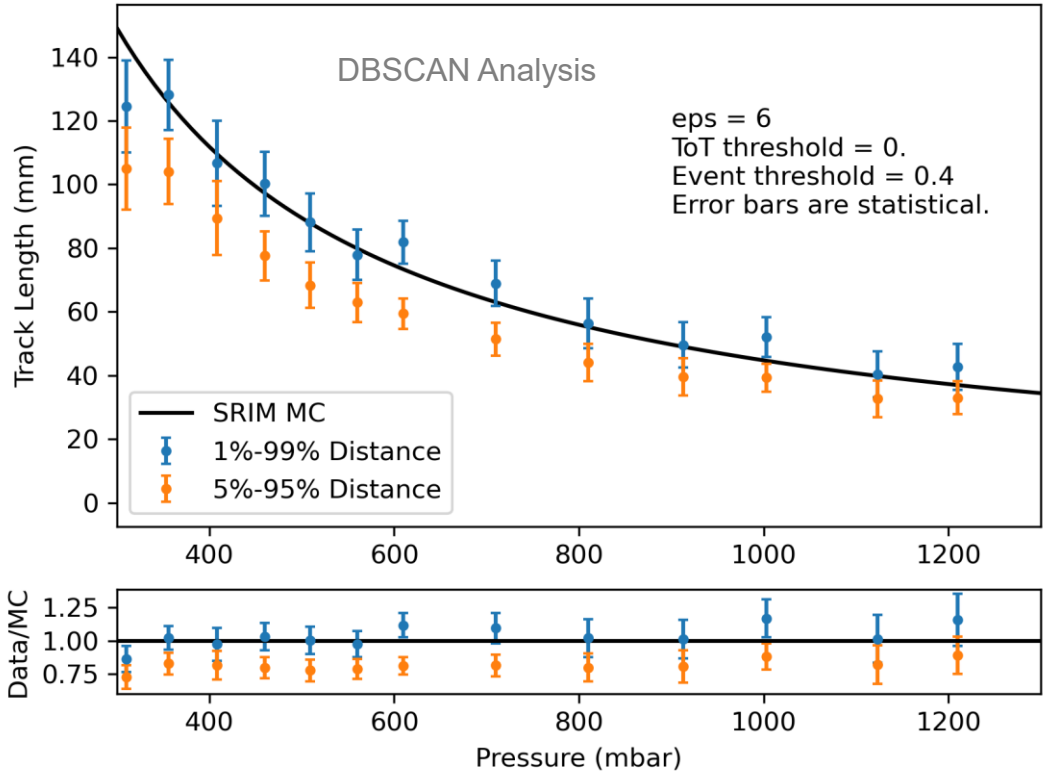
^{214}Am data: pure argon



α track at 0.31 bar

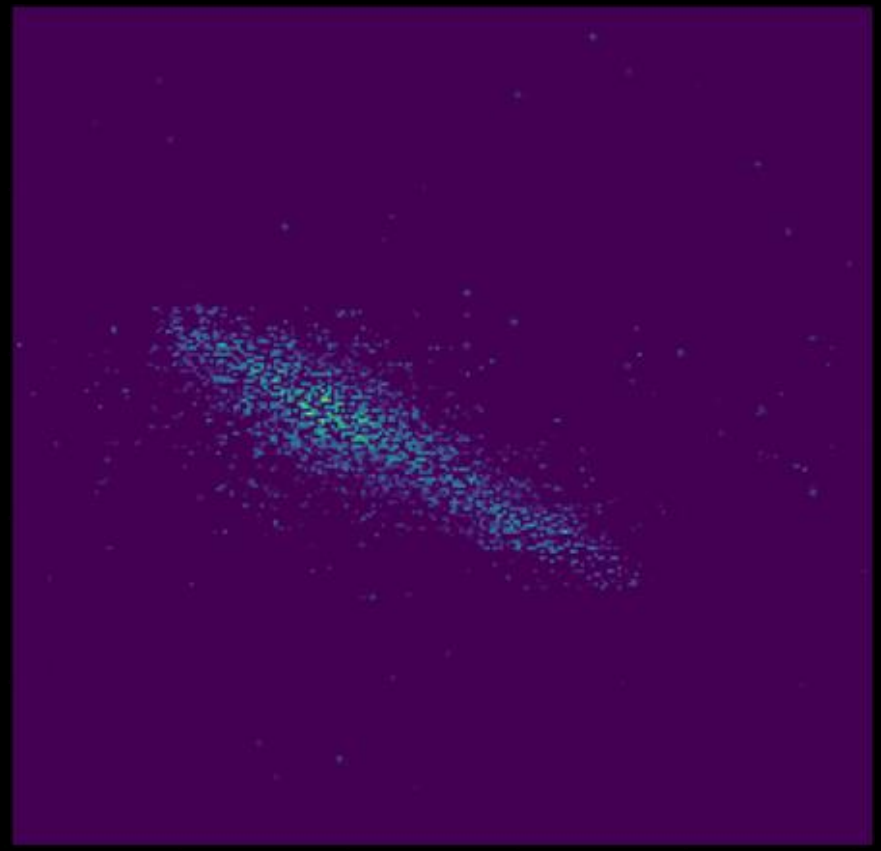


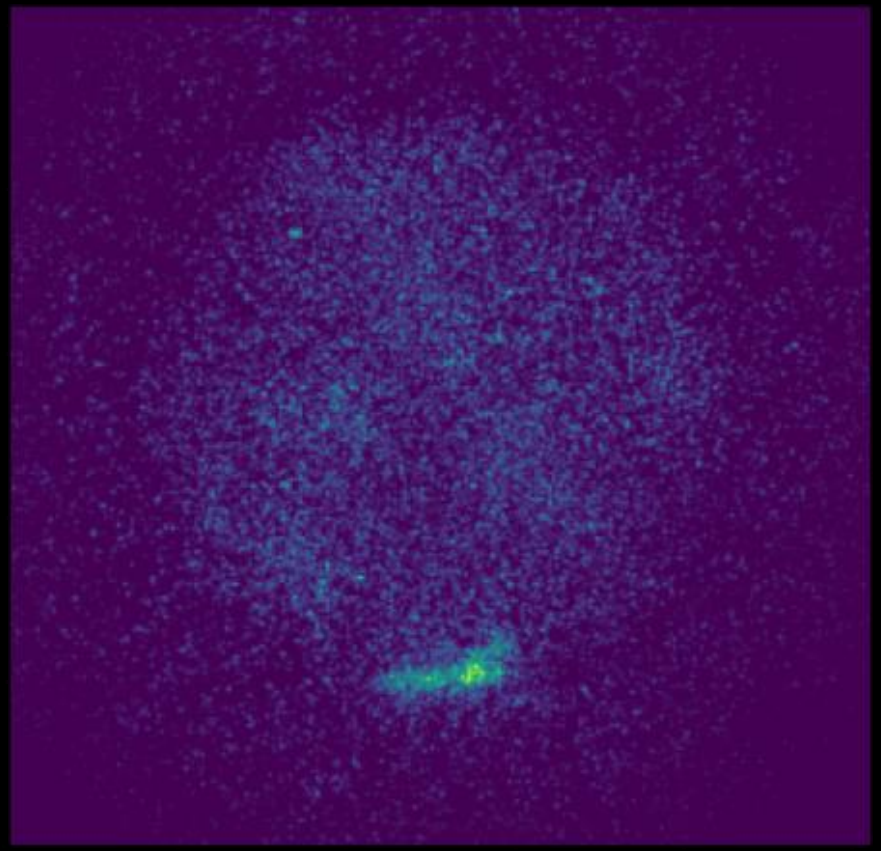
α track at 0.91 bar



Reconstruction and analysis by Hong-Kai Tan

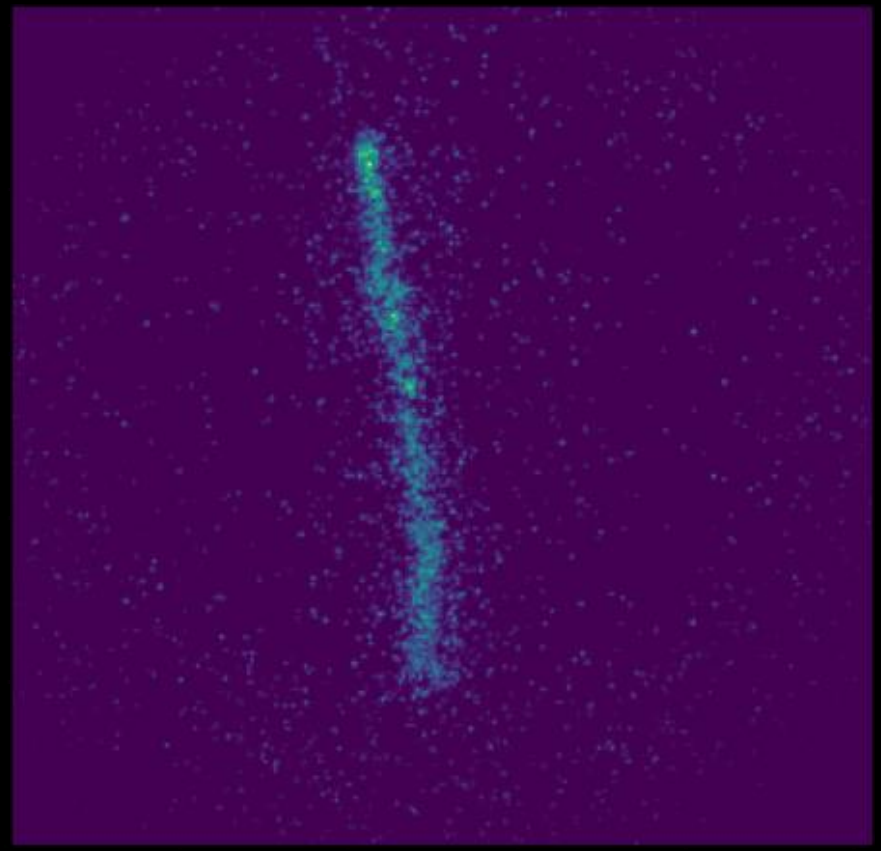
Cosmic data: 4.7% CF_4 + Ar (~100 mbar)

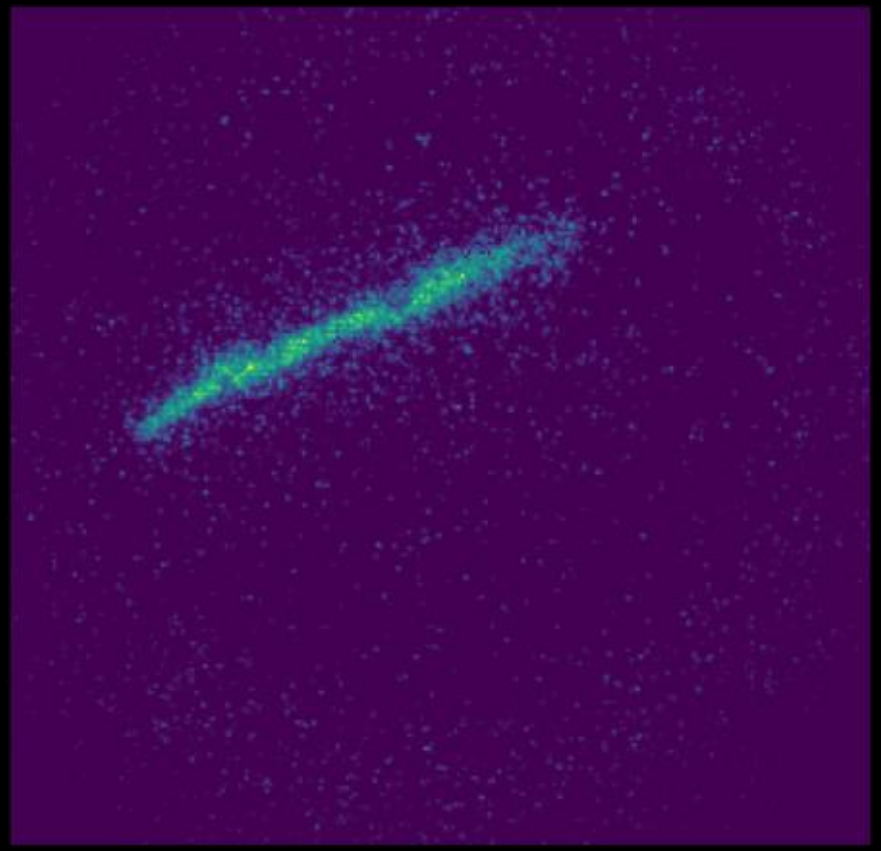




Alexnader Deisting, Matthew Snape, Hong-Kai Tan, Oct. 8, 2026

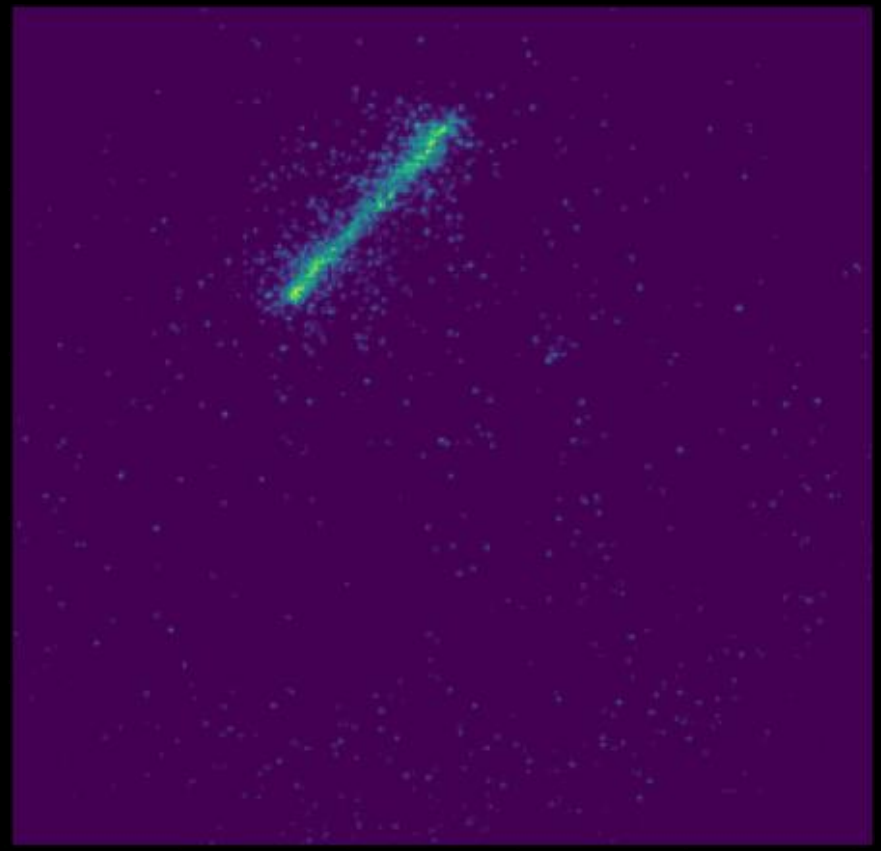
Cosmic data: 9.9% CF_4 + Ar (~100 mbar)

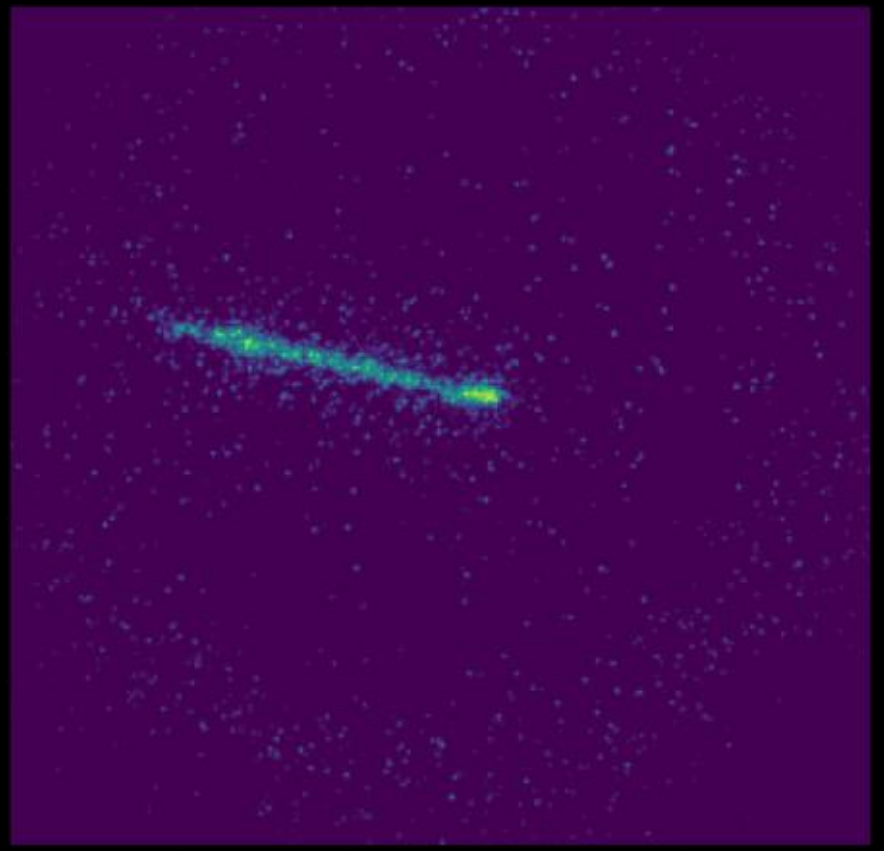




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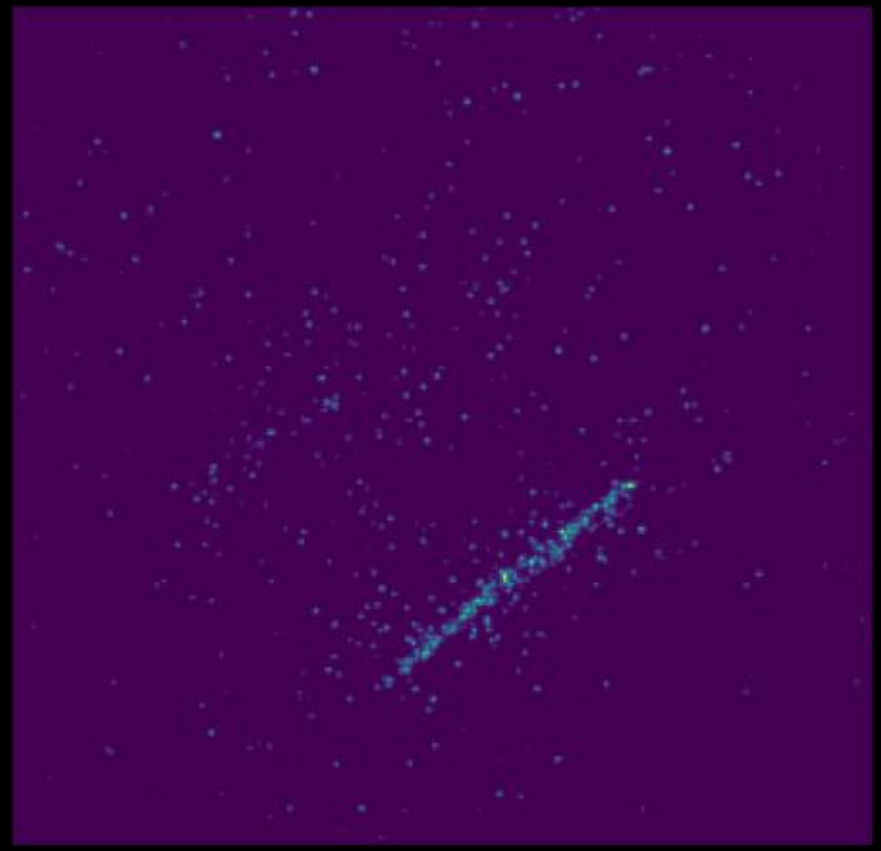
Cosmic data: 15% CF_4 + Ar (~100 mbar)

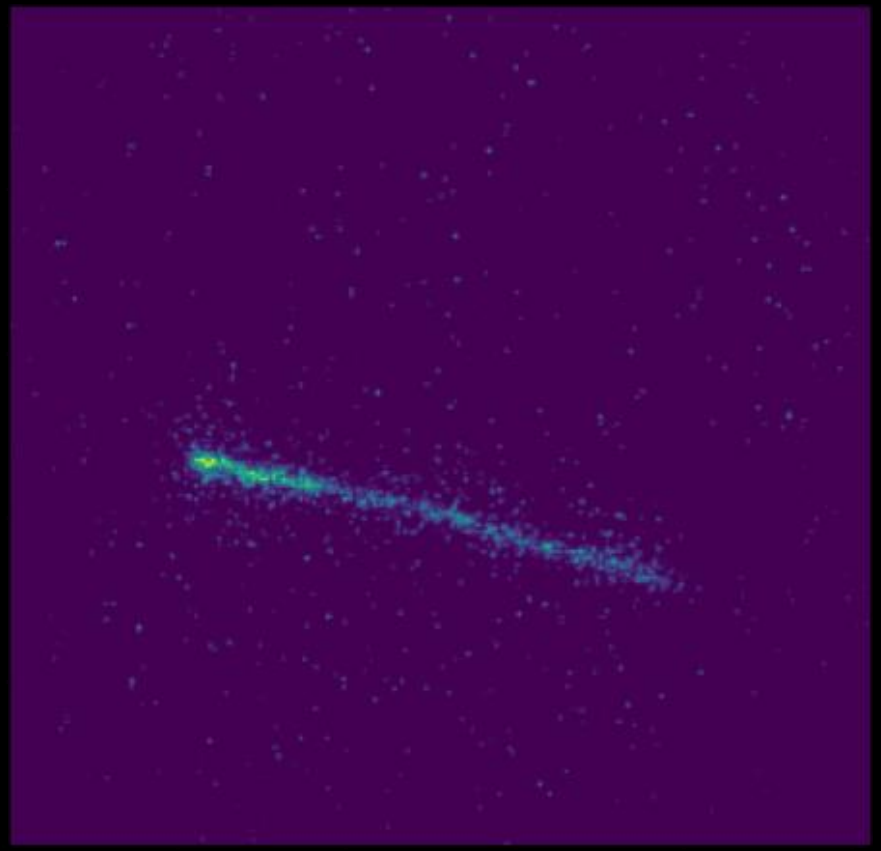




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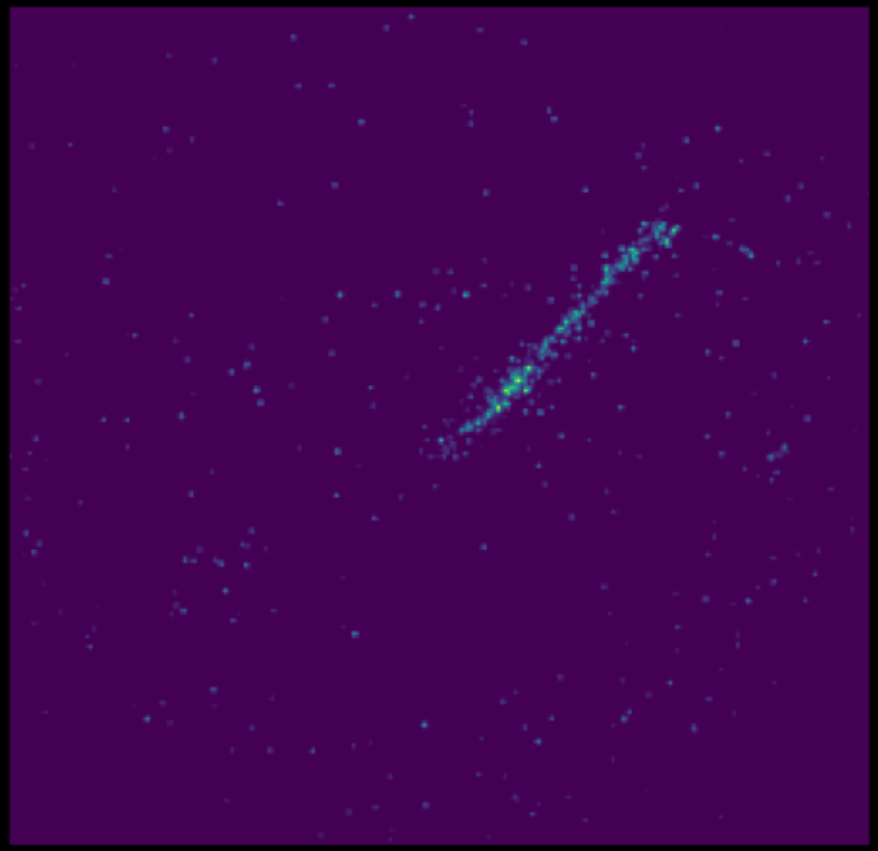
Cosmic data: 20% CF_4 + Ar (~100 mbar)

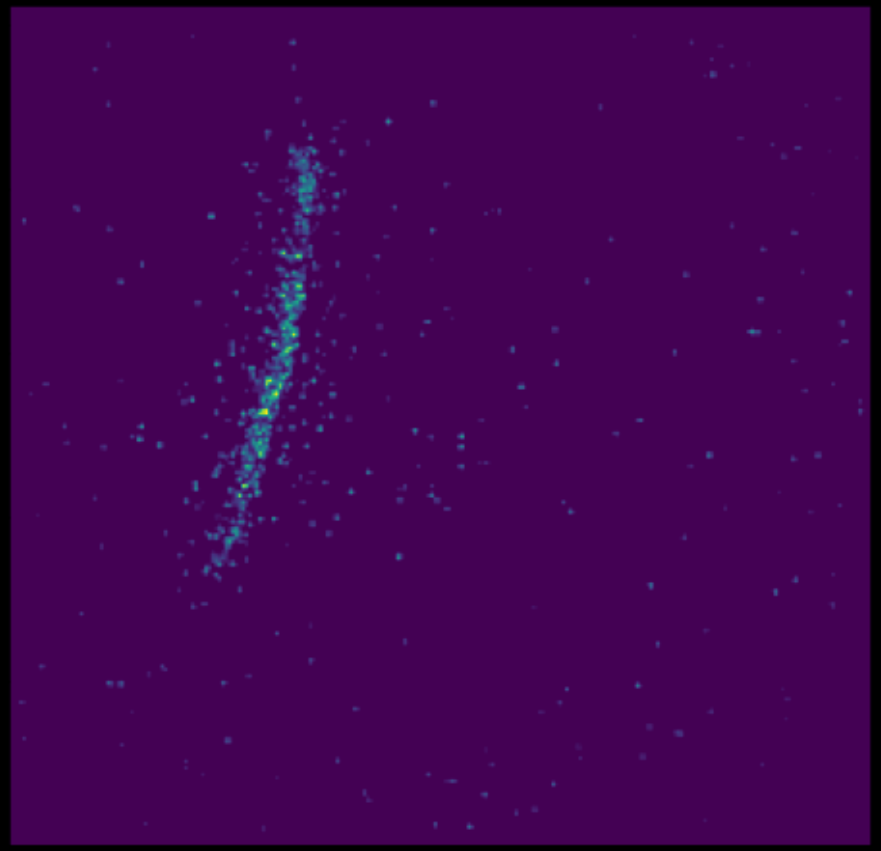




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Cosmic data: 25% CF_4 + Ar (~100 mbar)

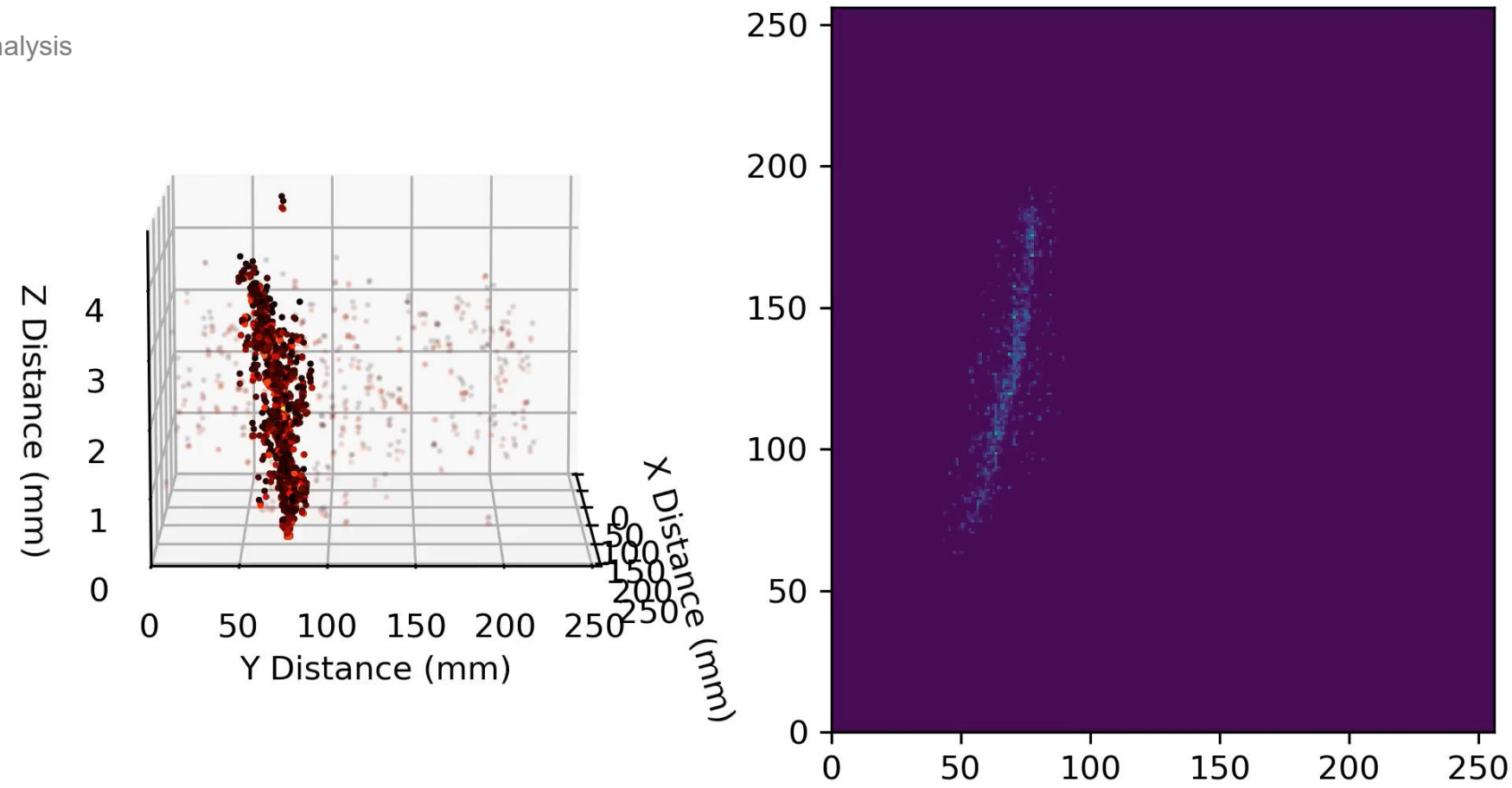




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Cosmic data: 25% CF_4 + Ar (~100 mbar)

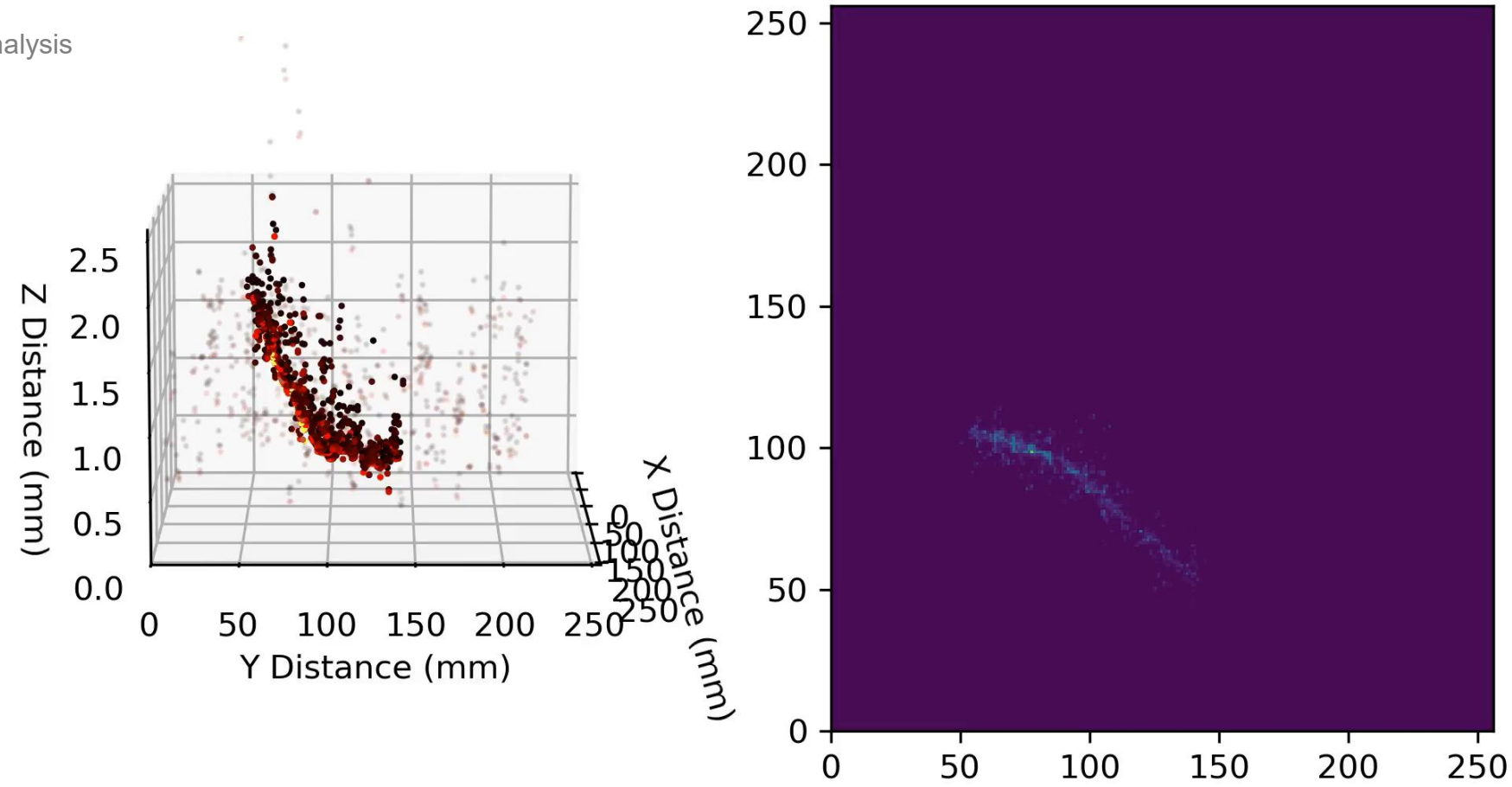
DBSCAN Analysis



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Cosmic data: 25% CF_4 + Ar (~100 mbar)

DBSCAN Analysis



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