Application of Timepix cameras in optical TPCs for 3D track and events reconstruction in low-energy nuclear reactions

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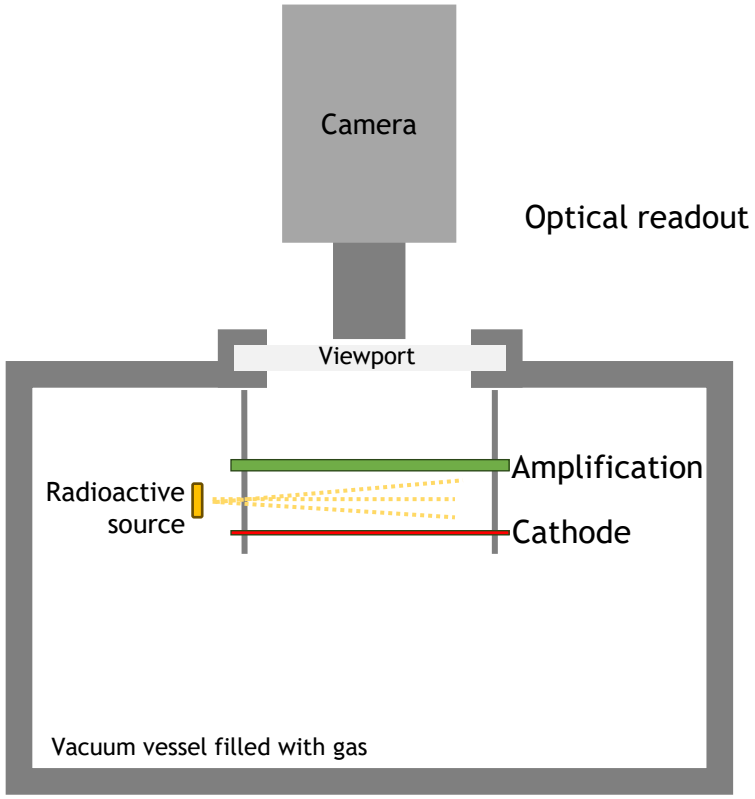
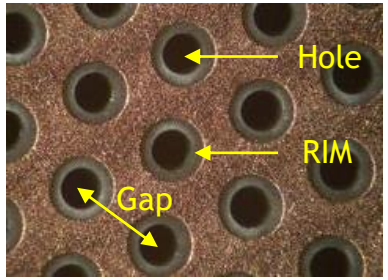
Optical Time Projection Chambers (oTPC)



- Charged particles passing through the gas ionizes it and creates electron-ion pairs.
- Electrons drift from Cathode to the Amplification structure.
- The electron avalanche produces photons in different wavelengths depending on the gas
- GEMs (Gaseous Electron Multiplier) structures multiply this effect.
- A camera is used as optical readout system.

GEM characteristic parameters:



Goals

- Investigate the ability to measure:
  - Neutron energies and P_n values using ^{16}C
  - Differentiate between emitted charged particles using ^{9}C
- Collect traces of recoiling nuclei and emitted charge particle to reconstruct the decay energy.
- Use of different gas mixtures (CF_4 and CS_2) and novel GEM detectors.

^{16}C beam

- P_n=99.30(12)%
- Measured multiple times in great agreement
- Only 3 neutron energies
- 53, 113 and 220 keV recoils should be observed
- Try to reproduce the branching ratios

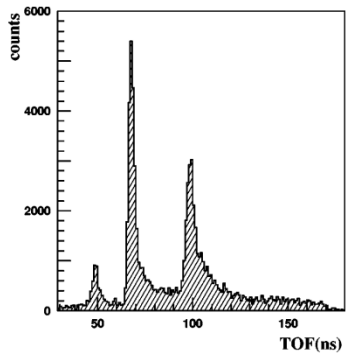
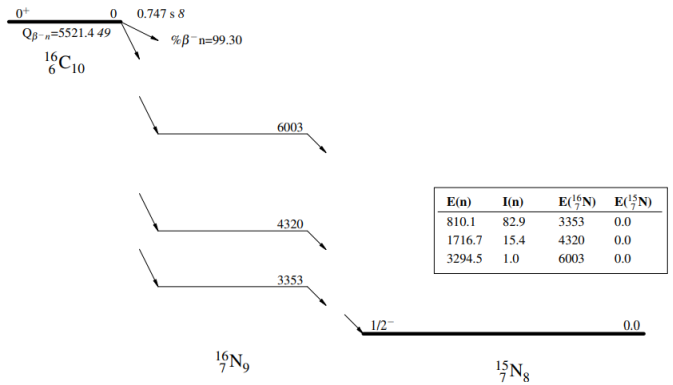


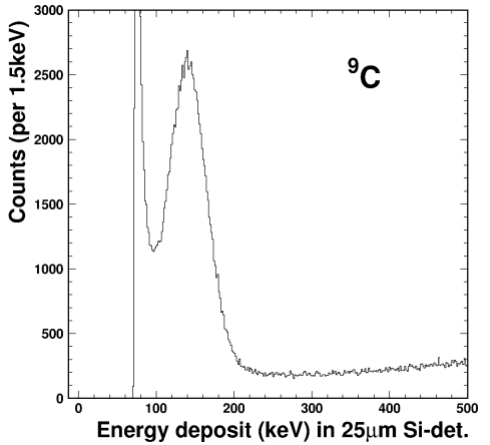
FIG. 3. β-delayed neutron TOF spectrum for the decay of ^{16}C.

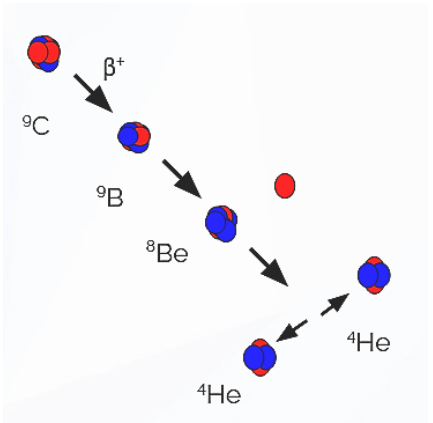


E(n)	I(n)	E($^{16}_{7}$N)	E($^{15}_{7}$N)
810.1	82.9	3353	0.0
1716.7	15.4	4320	0.0
3294.5	1.0	6003	0.0

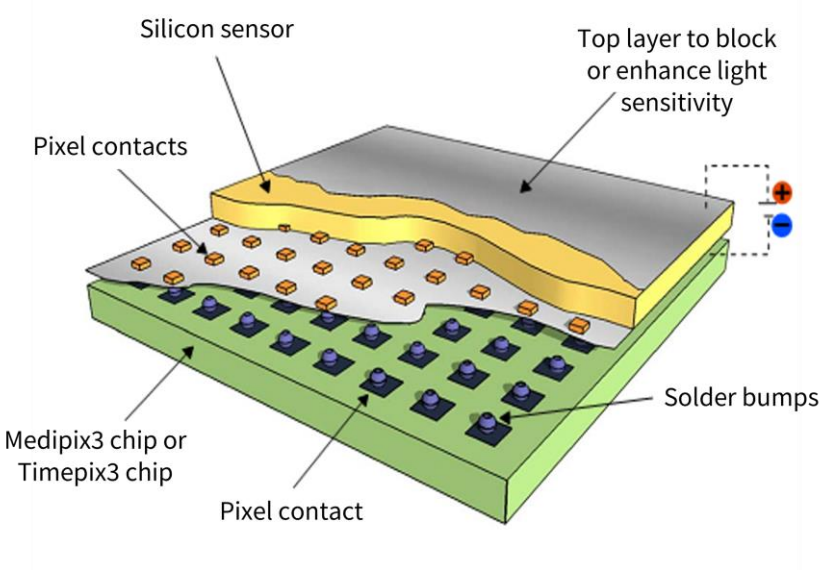
^{9}C beam

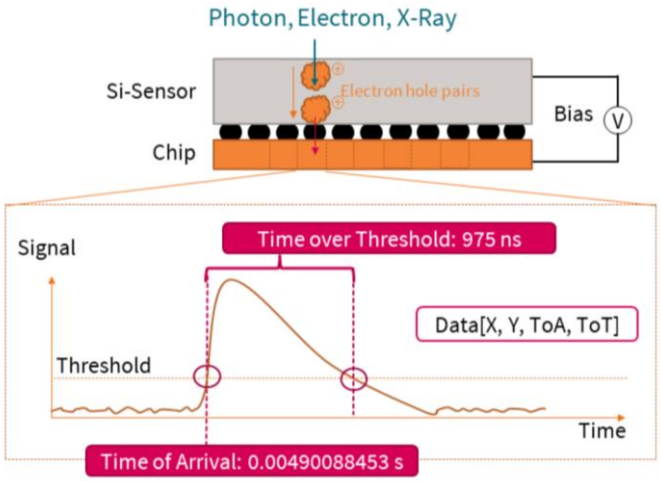
- Decays by β^+
- The result is a 165-keV p^+ and two 55-keV α
- Already measured at ISOLDE
- Large β^+ background (not us)
- α below threshold
- Great opportunity for particle ID and angular resolution





The Timepix 3 detector





Ultrafast and ultrasensitive particle detector developed at CERN

Timepix 3 detector:

- 256×256 pixel matrix (55 μmx55 μm each), 300 um silicon sensor
- Time resolution: 1.56 ns
- TDC resolution: 260 ps
- Detection wavelength range: 400-1000 nm
- Single photon detection (with image intensifier)
- Event-driven detection mode with up to 80 million hits per second
- Noise free

Output information:

- Simultaneous (x,y) coordinate of the hit
- Time of arrival (ToA) with 1.56 ns
- Time over Threshold (ToT) correlated to energy for each individual pixel

3D information (x,y and time)

Experimental setup: Overview

Amplification structure:

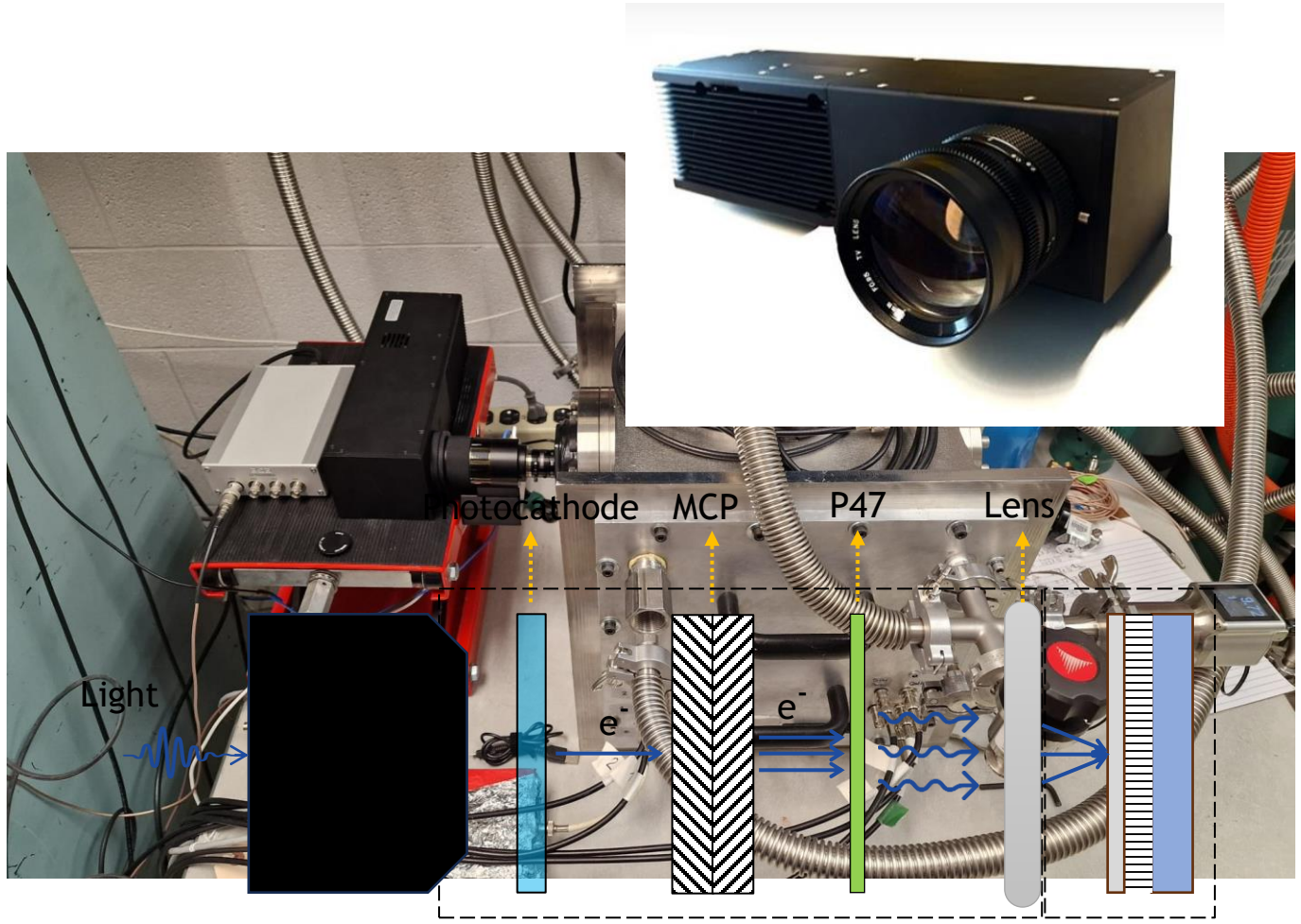
- 3-layer MTHGEM
- Thickness: 0,056 mm/layer
- 0.1 mm hole, 0.7 mm pitch, 0.0mm RIM

Drift region: 4 cm

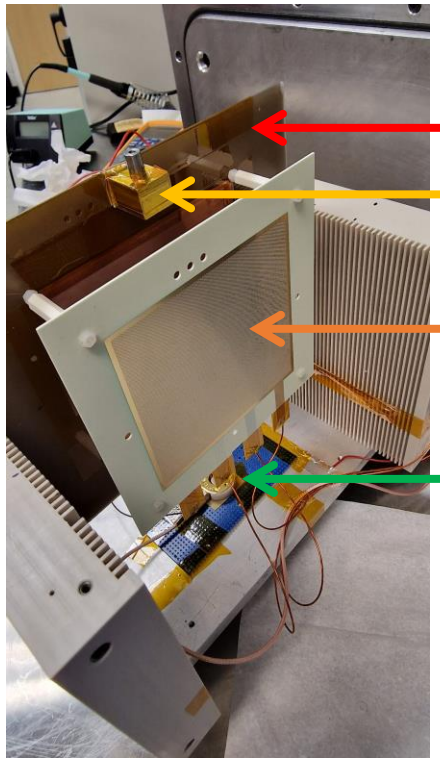
Gas: Ar, He, CF4 (flow)

Image intensifier:

- Photonis Cricket P47 (Gated Hi-QE green)
- Maximum QE wavelength: 400-475 nm
- No WLS



Experimental setup

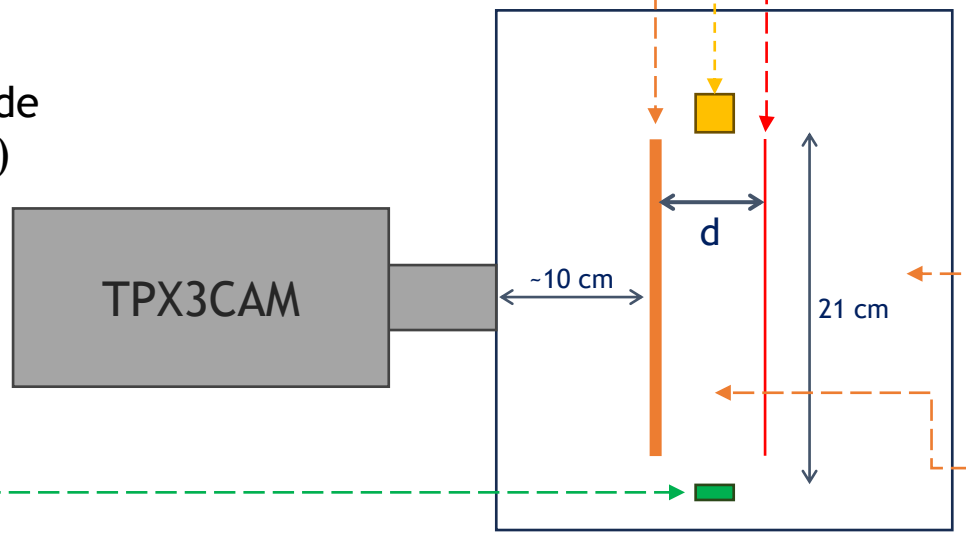


Cathode

228Th source

MTHGEM

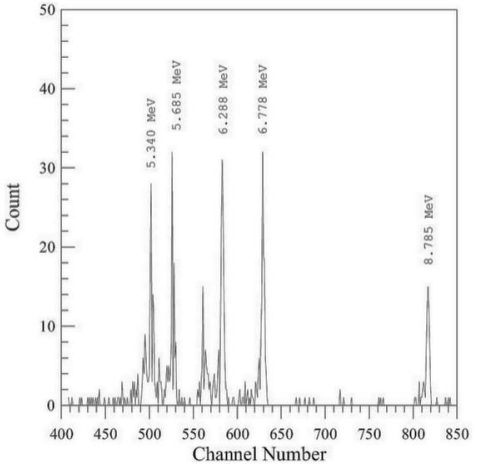
Silicon diode
(trigger)



d = 4.0 cm

Detector vessel filled with scintillating gas: Ar, He, CF4

Drift region



E.M. Awad “Alpha particle spectroscopy for CR-39 detector utilizing matrix of energy equations”

EL emission wavelength for different gases

Borosilicate viewport:
- Transmission over 85% in the visible region
- Cut in ~300 nm

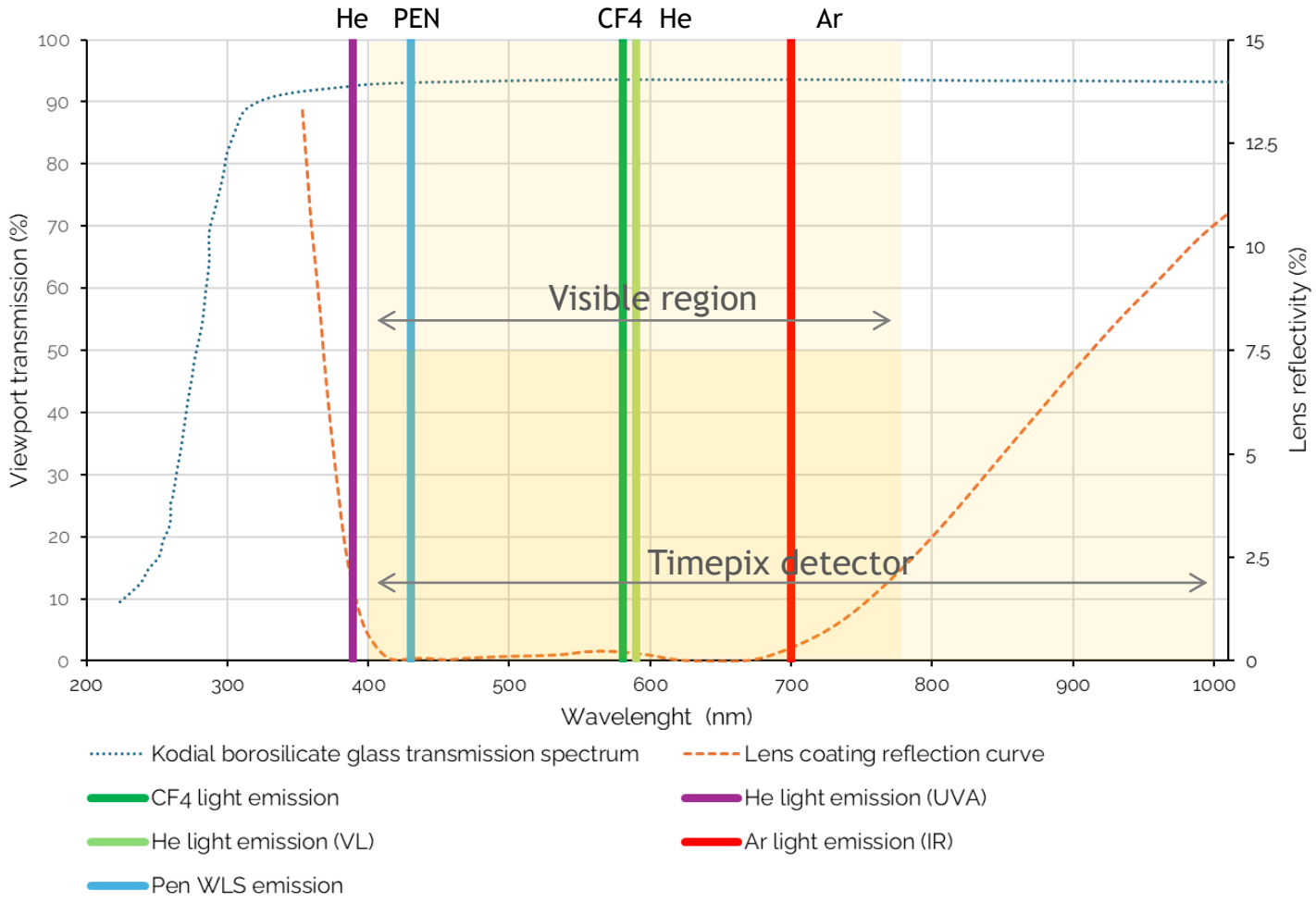
Camera lenses:
- Anti-Reflection (AR) in the visible region
- Range 425-675 nm

Argon EL emission:
- 128 nm VUV (Transition of Ar excimers)
- 170-300 nm UV (Third continuum)
- 700-850 nm IR (Atomic emission)
- Neutral Bremsstrahlung in the visible region[1]

CF4 emission:
- 581 nm

Helium main contributions in the visible region:
- 389 nm, 587 nm

PEN foil (WLS) emission:
- 430 nm



[1] Measurement of emission spectrum for gaseous argon electroluminescence in visible light region from 300 to 600 nm (Kazutaka Aoyama et al Nucl. Instrum. Methods. Phys. Res. A, V.1025, Feb. 2022)

Tracks reconstruction

Enhancement of optical Time Projection Chamber capabilities for data acquisition, clustering and events recognition:

- Time information
- 2D & 3D projection
- Energy information
- Scattering events information

Events reconstruction in pure CF4

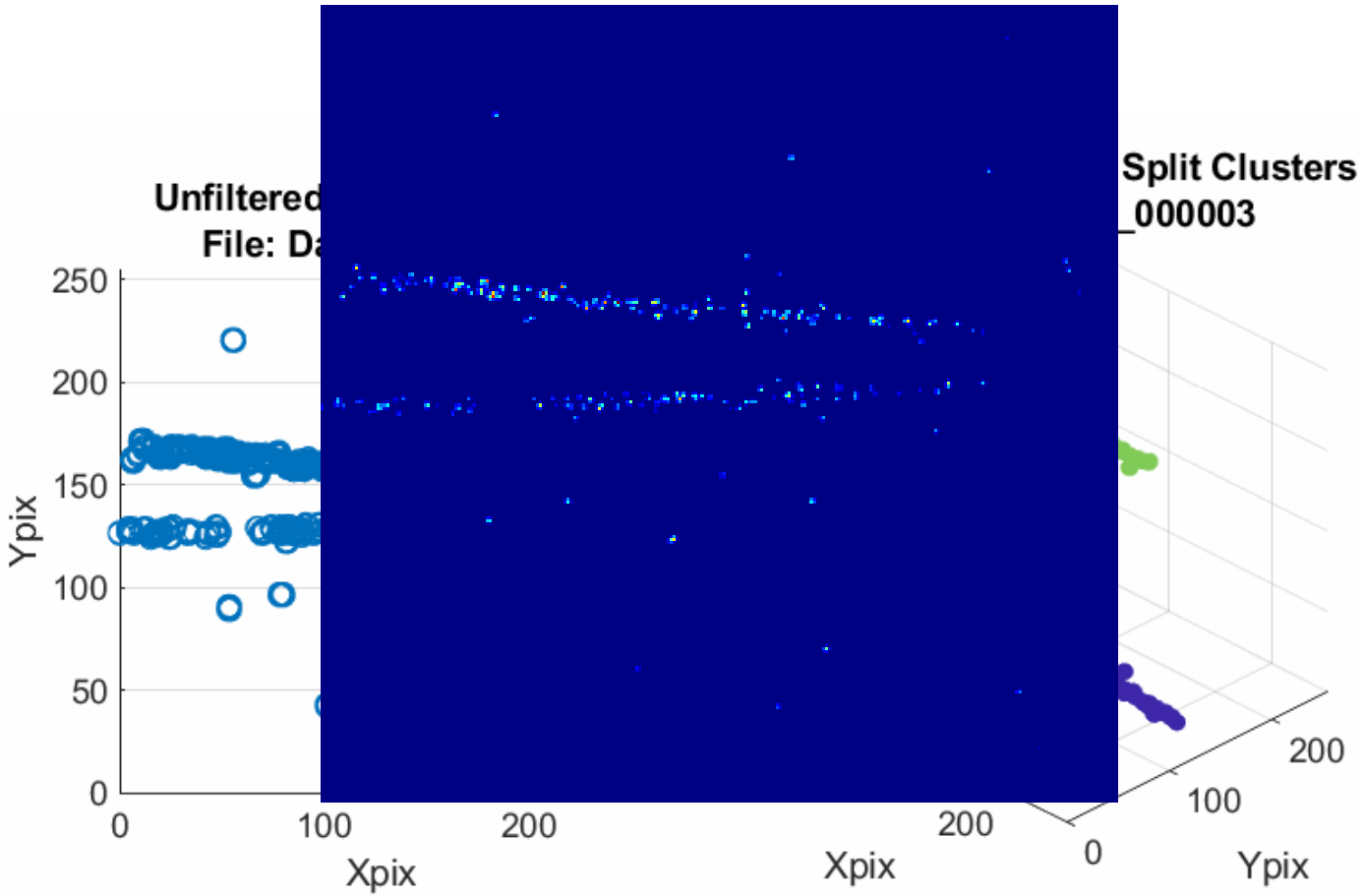
- Pressure: 98 Torr
- Drift: 700 V/cm/bar
- Amplification: 40 kV/cm/bar
- Cricket gain: 0.5 V

CF4 makes easy the tracks visualization

The image intensifier allows to increase the light collection intensity

Clustering allows unambiguous tracks identification

Cosmic rays and undesired data can be easily filtered



Argon data: Visible light and WLS

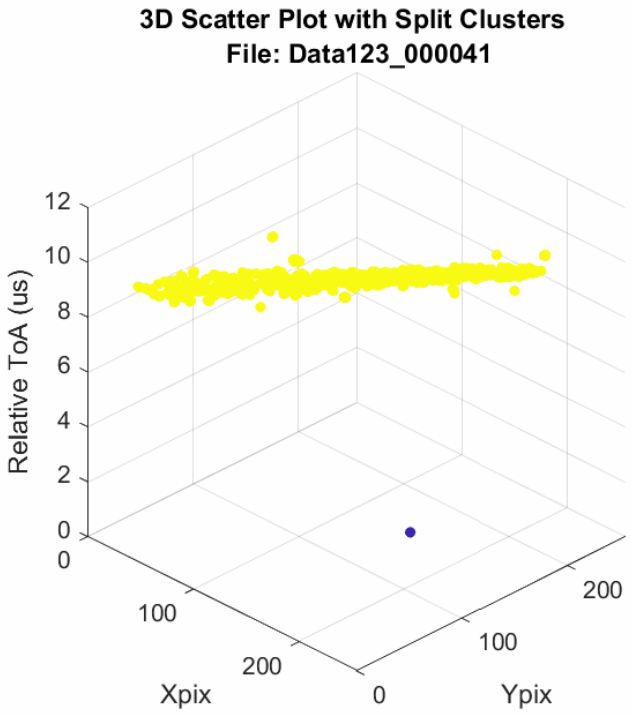
Argon EL emission sources (400-1000 nm):

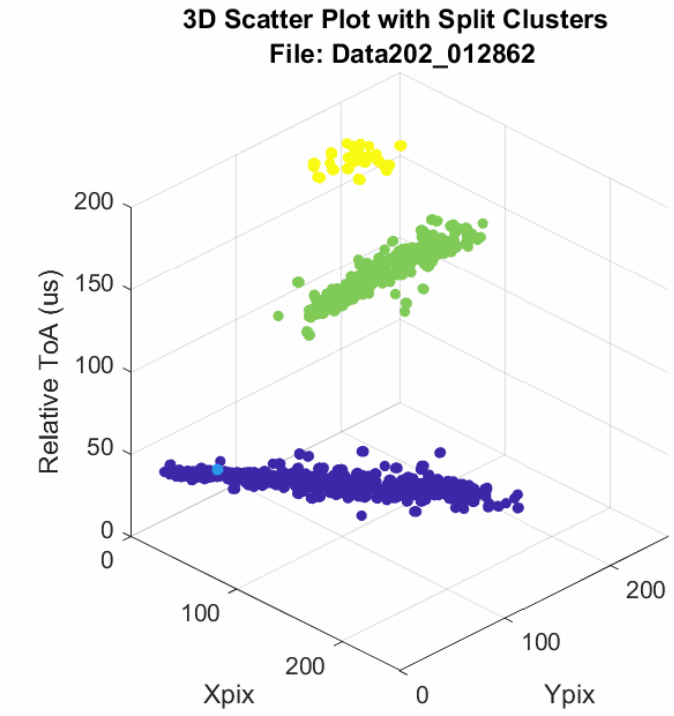
- 700-850 nm IR (Atomic emission)
- Neutral Bremsstrahlung in the visible region
- N2 contamination emission
- Additional 430 nm emission using PEN foil as wavelength shifter

Gas pressure: 400 Torr, continuous flow

No PEN foil

Visible light contribution only





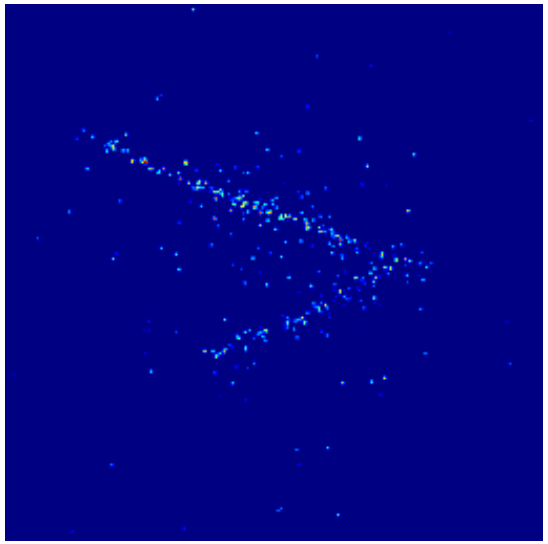
PEN foil

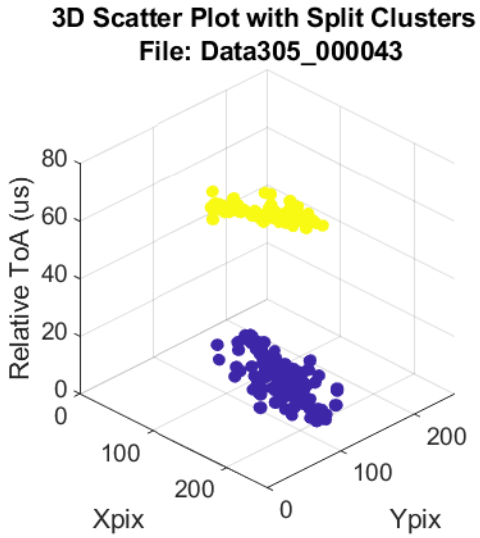
UV light shifted to 430 nm

Increase over 20% cluster/frame

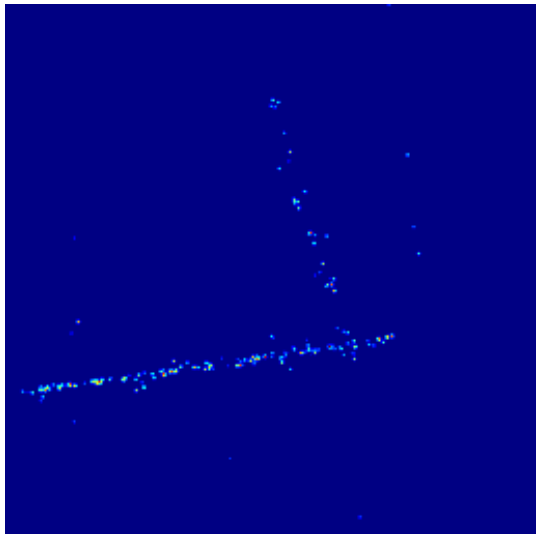
Scattering events identification

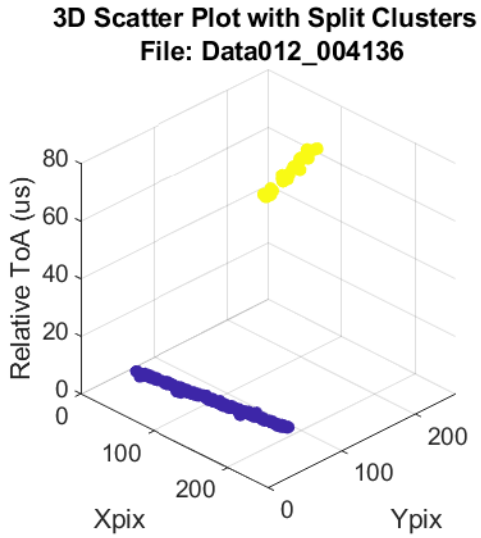
Time information allows us to uncertainly identify events that with a simple 2D projection may look like scattering.





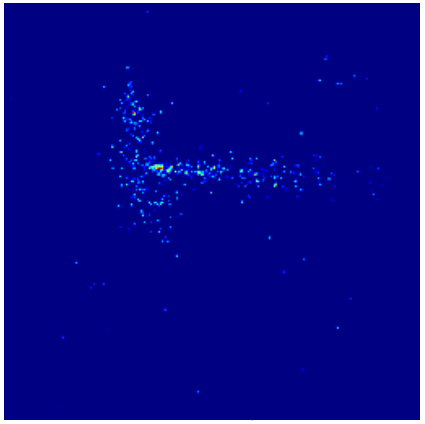
Pure He @ 500 Torr
Drift: 350 V/cm/bar
Amplification: 4.42 kV/cm/bar

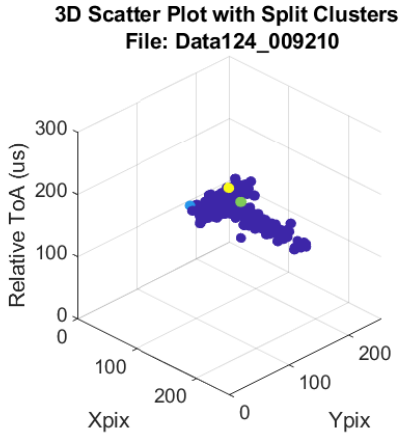




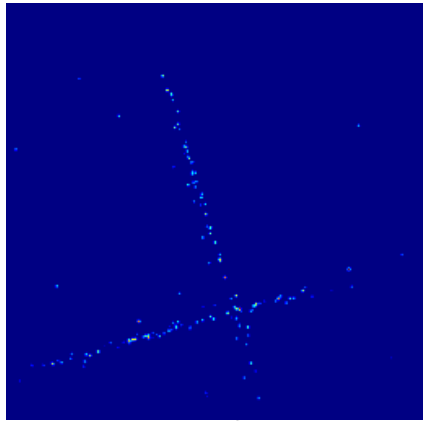
Pure CF4 @ 98 Torr
Drift: 700 V/cm/bar
Amplification: 40.0 kV/cm/bar

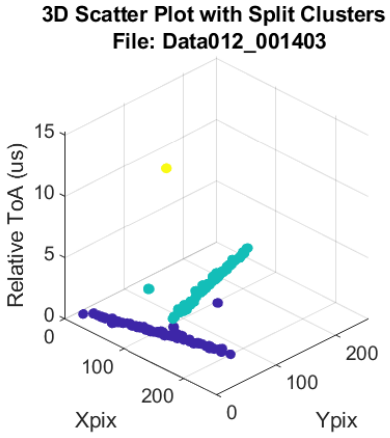
Scattering events identification



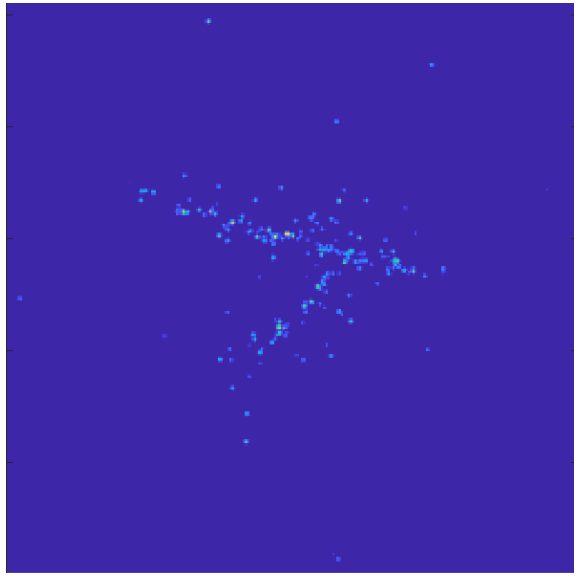


Pure Ar @ 400 Torr
Drift: 250 V/cm/bar
Amplification: 13.5 kV/cm/bar



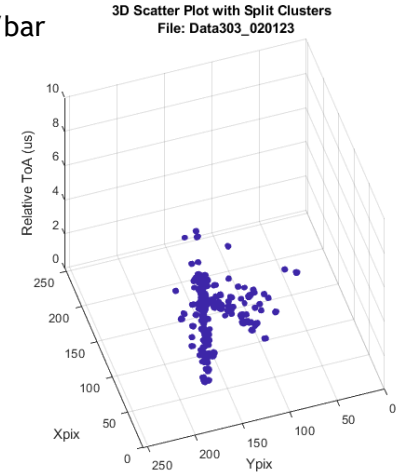


Pure CF4 @ 98 Torr
Drift: 700 V/cm/bar
Amplification: 40.0 kV/cm/bar



Pure He @ 300 Torr
Drift: 350 V/cm/bar
Amplification: 3.68 kV/cm/bar

Alpha elastic scattering



Argon data: Image intensifier

Argon EL emission sources (400-1000 nm):

- 700-850 nm IR (Atomic emission)
- Neutral Bremsstrahlung in the visible region
- N2 contamination emission
- Additional 430 nm emission with PEN foil WLS

Gas pressure: 400 Torr, continuous flow

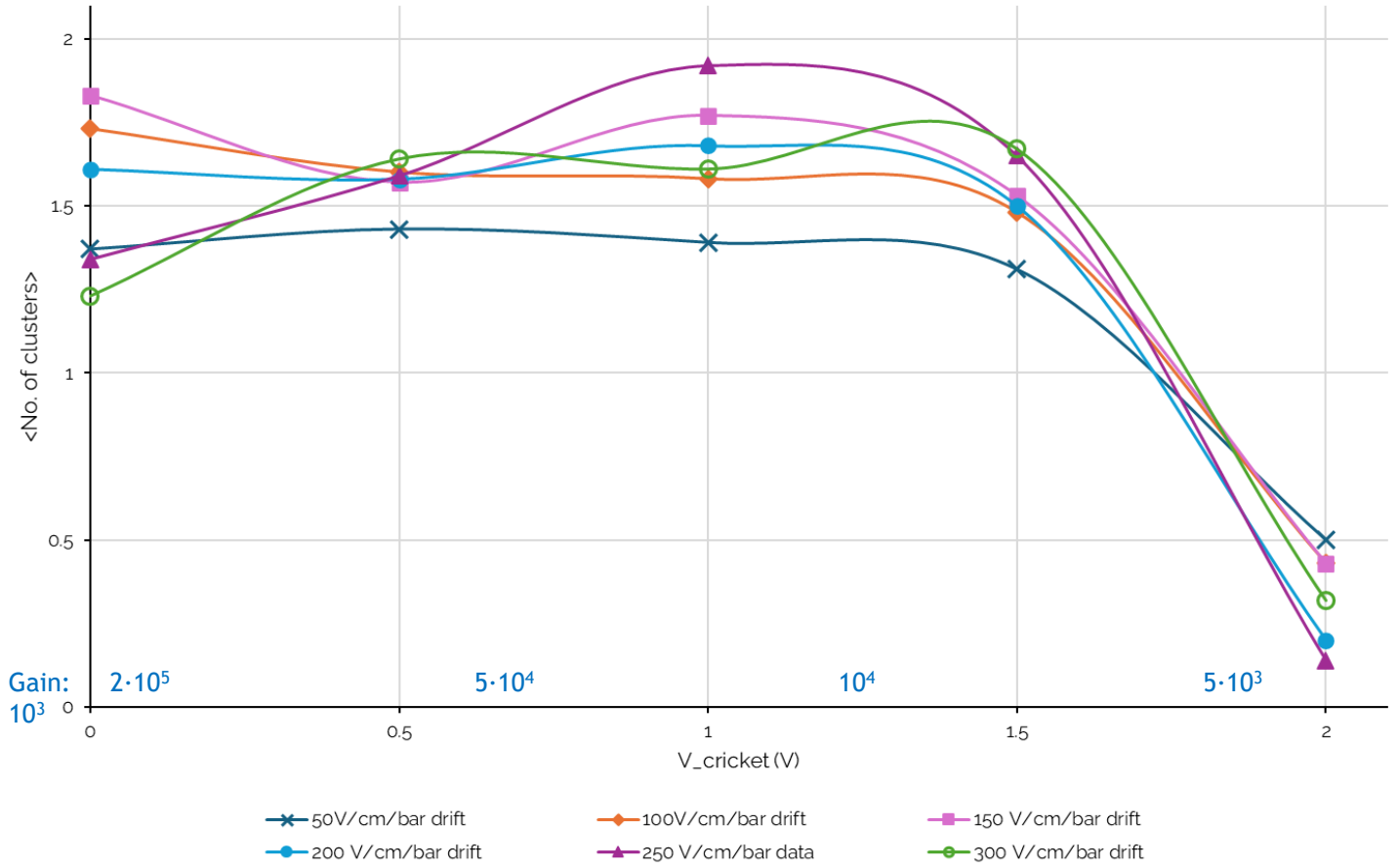
Image intensifier gain characterization

- Fixed MThGEM gain (13.5 kV/cm/bar)
- Variable drift velocity (50-300 V/cm/bar)

Saturation for maximum gain ($2 \cdot 10^5$ V)

Maximum cluster number at optimal drift field value (Magboltz)

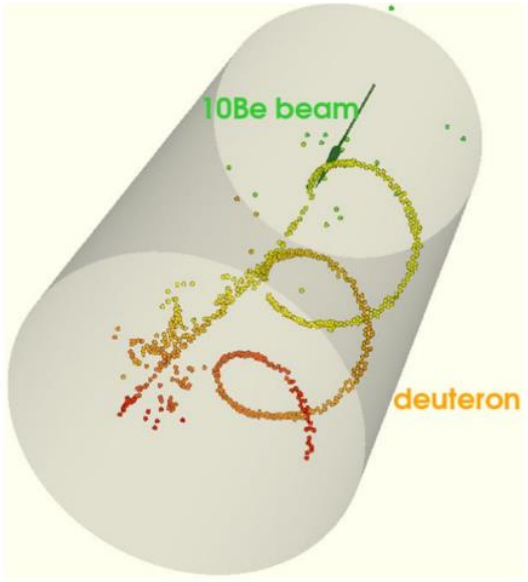
To do: User filters to identify scintillation wavelengths

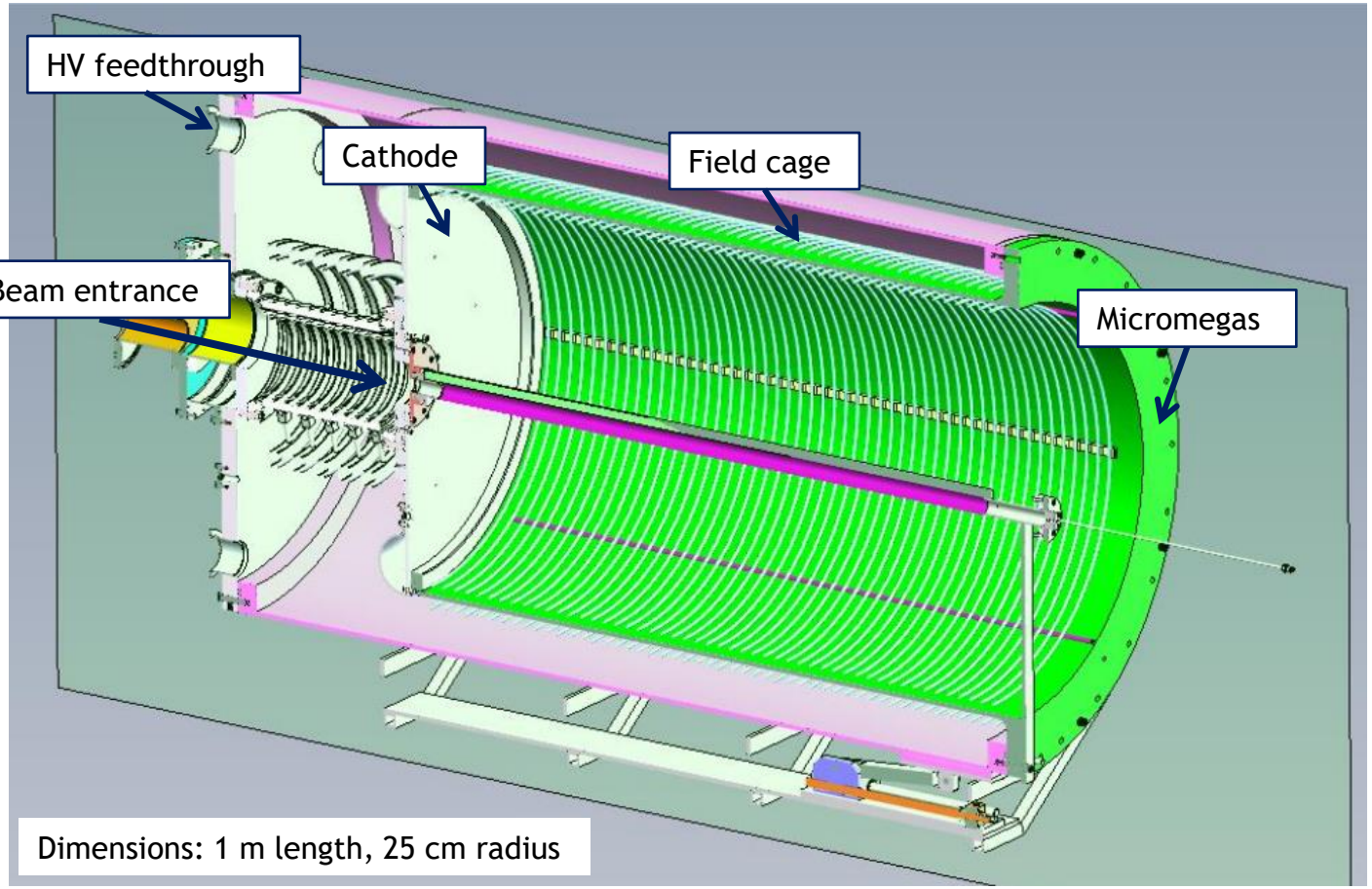


AT-TPC on-going activities: ^{3}He tube

Active Target Time Projection Chamber (AT-TPC)

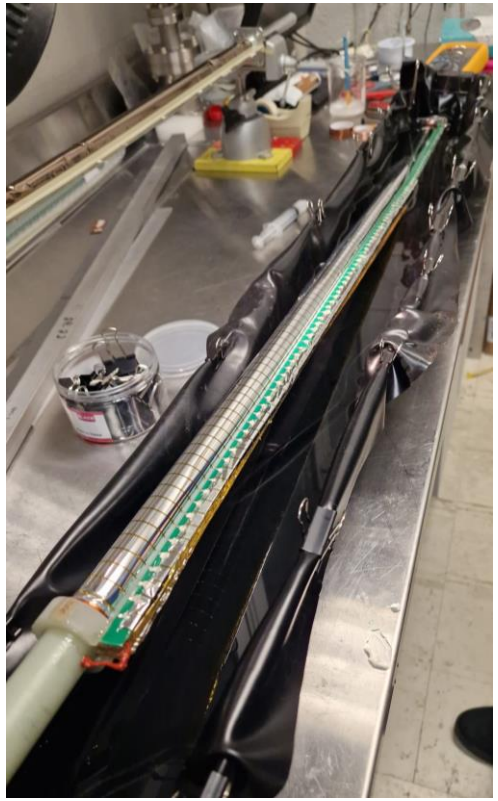
- Versatile setup for different type of reactions
- Magnetic field enables rigidity measurement
- Cylindrical configuration: large thickness with a moderate cost for electronics
- High resolution (in principle better than solid state detectors)
- High luminosity and large dynamic range
- Use with pure elemental gases





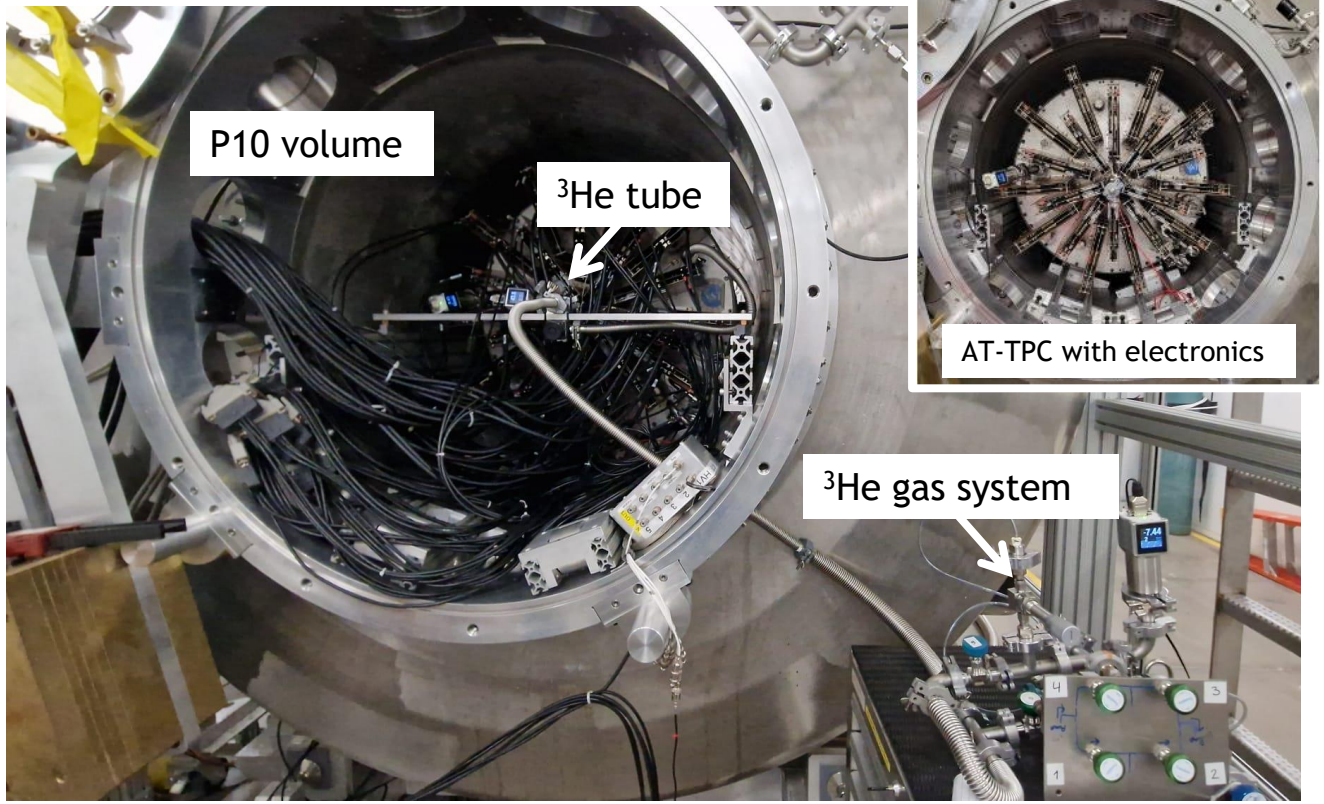
But… the kinematics reconstruction is not trivial

AT-TPC on-going activities: ^{3}He tube commissioning



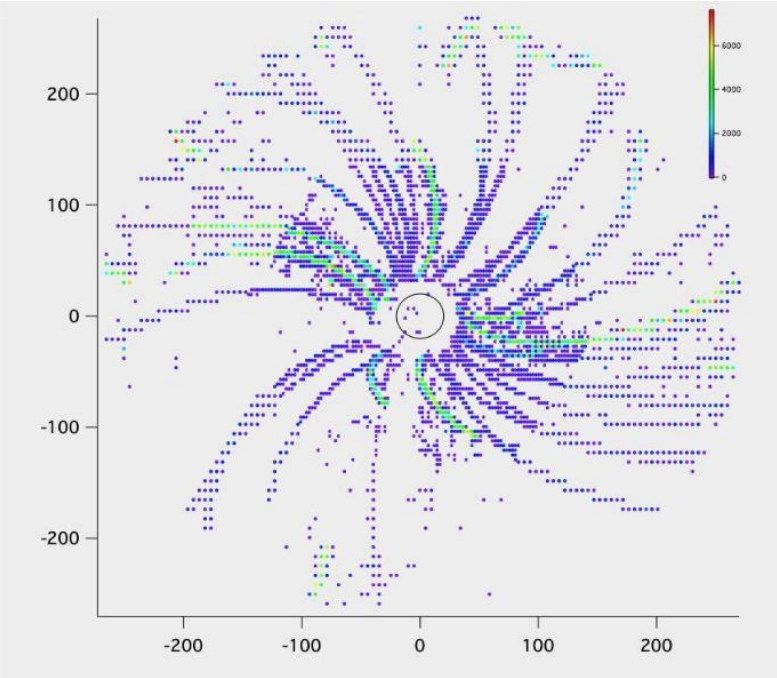
Tube construction

Assembly into AT-TPC



Commissioning with P10 @ 500 Torr

AT-TPC on-going activities: Entanglement



Commissioning data with ^{36}Ar beam

^{56}Ni beam (half-life 3 days, production at Los Alamos)

Selected beam:

- Out of stability valley
- N=Z to find entangled neutron-proton pairs with the quasi-deuterium spin inside the nucleus
- Few thousand of particles per second

Currently on-going experiment at FRIB (Facility for Rare Isotope Beams, Michigan State University, USA)

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Thanks for your attention

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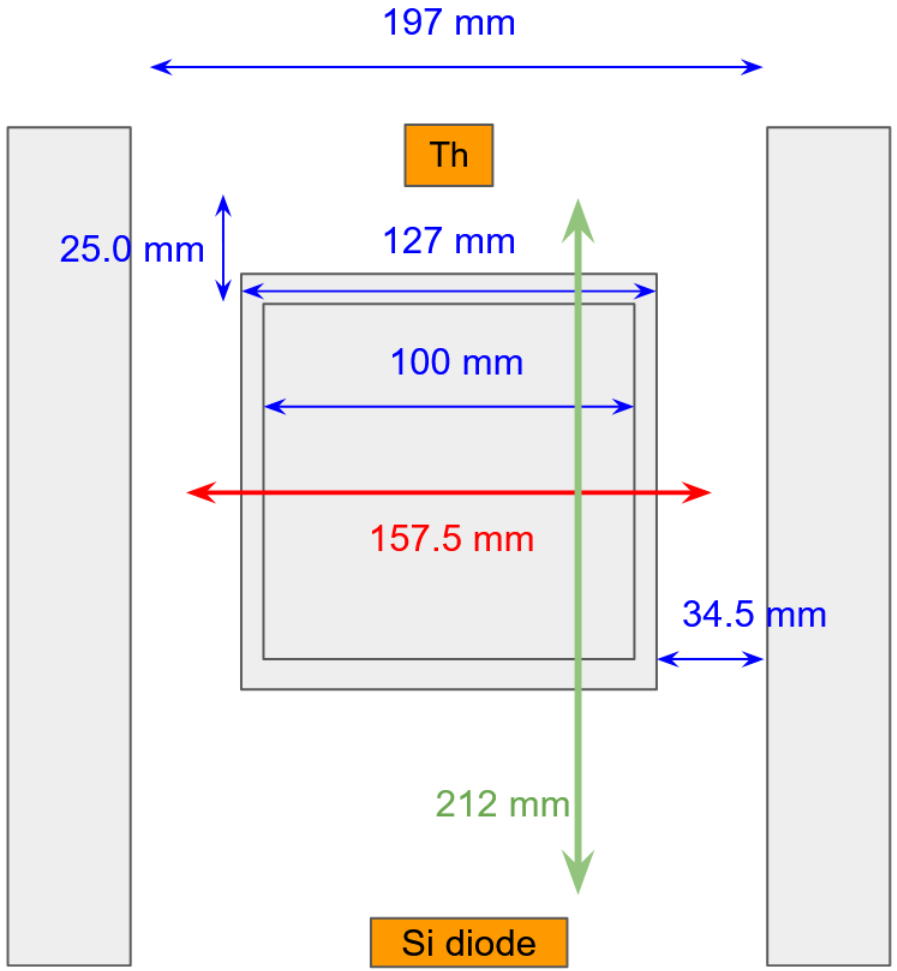
Dimensional drawings



Source: ^{228}Th

Alphas: 5.5 MeV, 6.8 MeV, 8.8 MeV

CF4 @ 98 Torr: 12.4 to 24.8 cm
Ar @ 400 Torr: 8.6 to 9.0 cm
He @ 300 Torr: 59 to 123 cm
He @ 500 Torr: 35 to 74 cm