Study of resonant states of astrophysical interest with an active target time projection chamber in FRIB

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Universidade da Coruña (UDC)

- Science at the Facility for Rare Isotope Beams (FRIB)
- Solenoidal spectrometers in Active Target mode (AT-TPC)
- Track reconstruction in Active Targets: Hit pattern, clustering, fitting.
- Experimental program.
- Outlook and conclusions.

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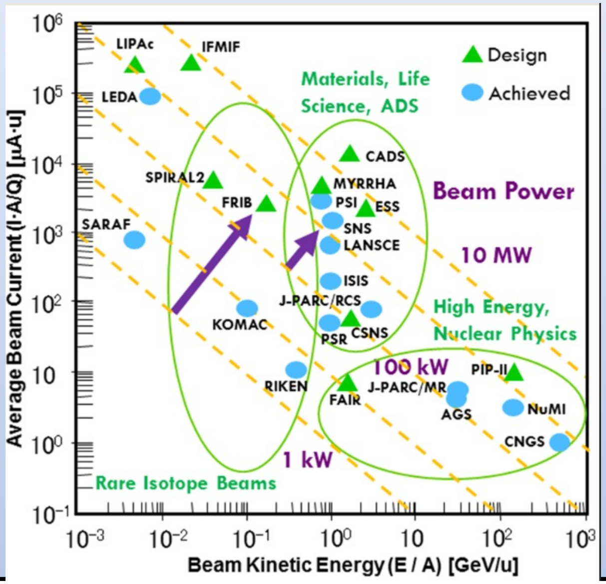
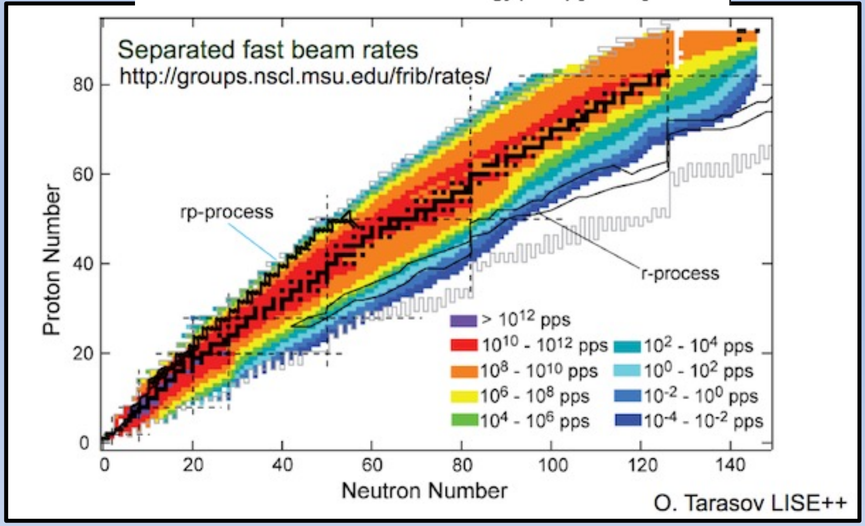
Available beams at the Facility for Rare Isotope Beams (FRIB)





- Key feature is 400 kW beam power for all ions (8pμA or 5x10^{13} 238 U/s).
- Separation of isotopes in-flight provides:
  - Fast development timefor any isotope
  - Beams of all elements and short half-lives
  - Fast, stopped, andreaccelerated beams
- FRIB will provide more beam power by two-to-three orders of magnitude over existing heavy-ion facilities.

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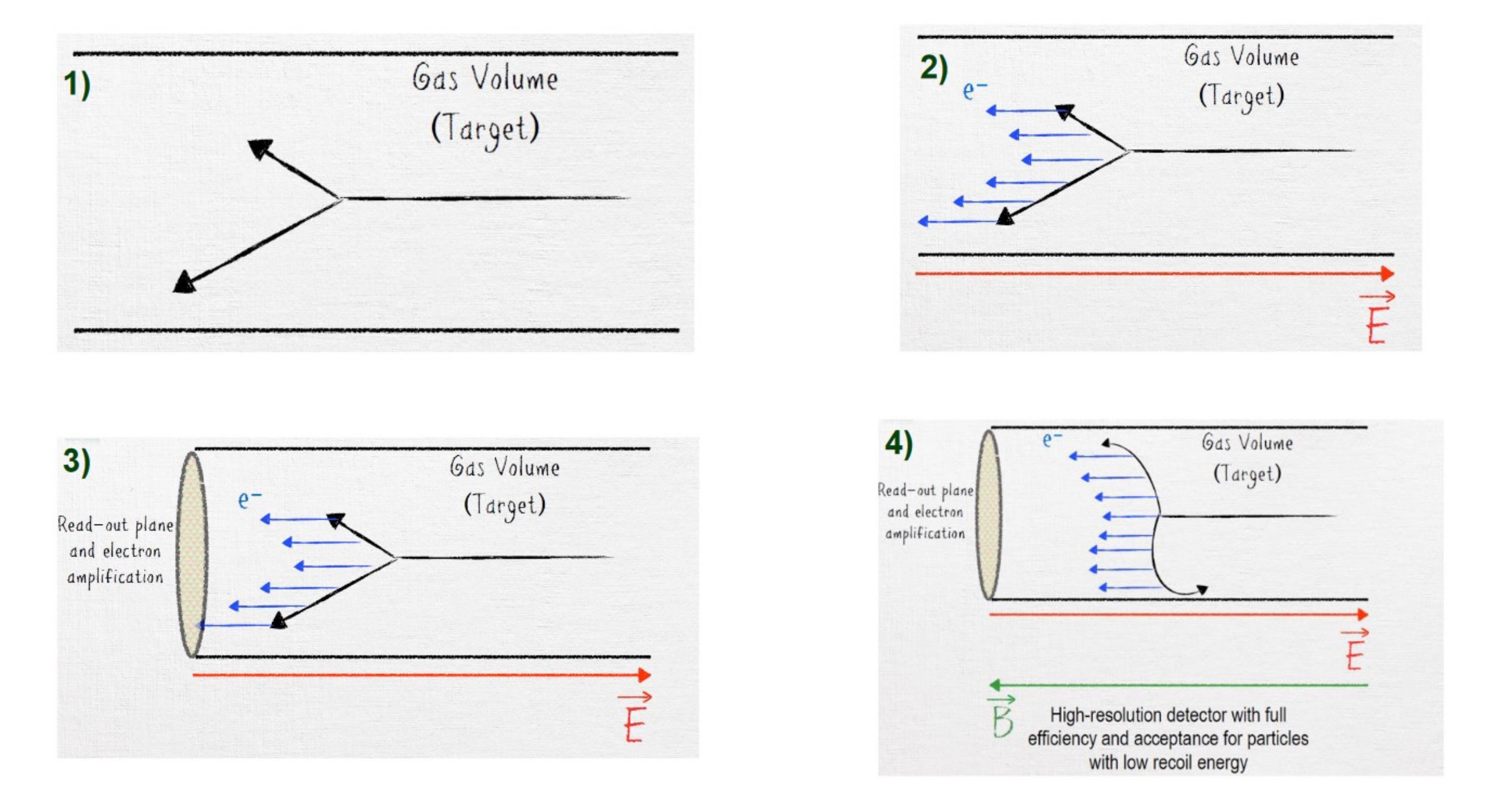
Active Target Time Projection Chambers (AT-TPC)



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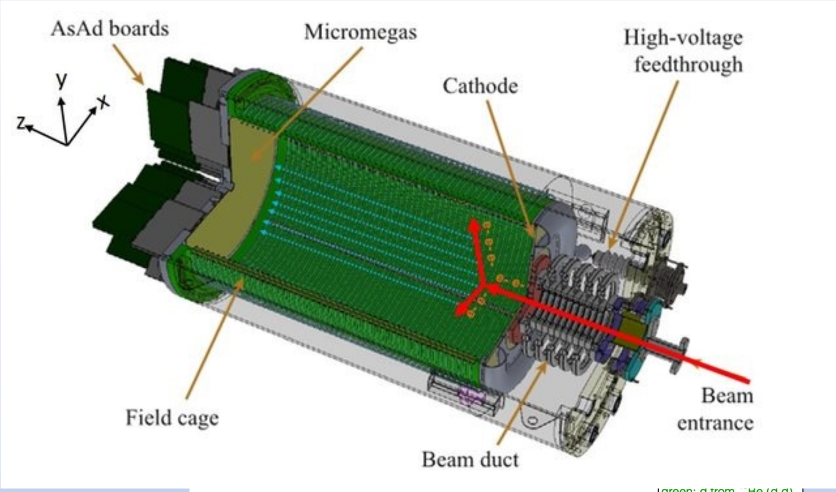
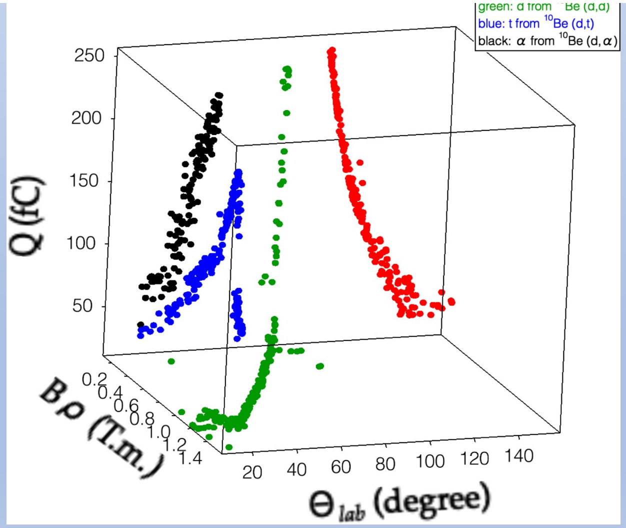
Active Target Time Projection Chambers (AT-TPC)

- High luminosity and large dynamic range.
- High resolution (in principle better than solid state detectors).
- Pure elemental gases.
- Cylindrical configuration: large thickness with moderate cost for electronics.
- Versatile setup for different type of reactions.
- Magnetic field enables rigidity measurement.
- Kinematics reconstruction not trivial...





Progress in Particle and Nuclear Physics Volume 114, September 2020, 103790

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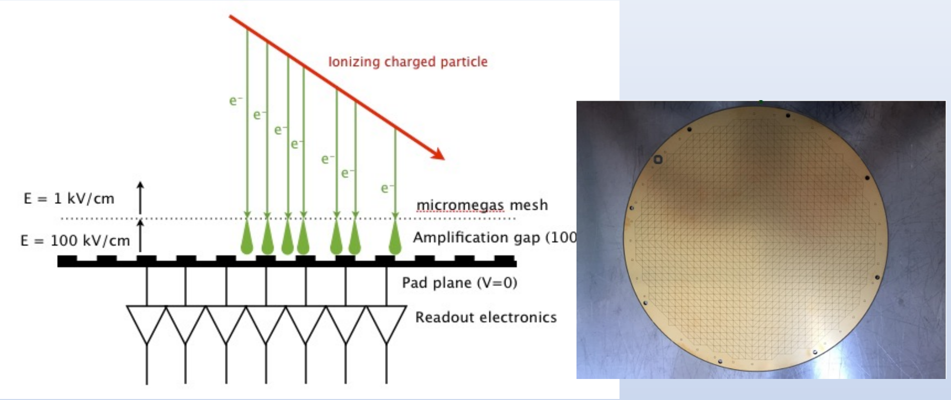
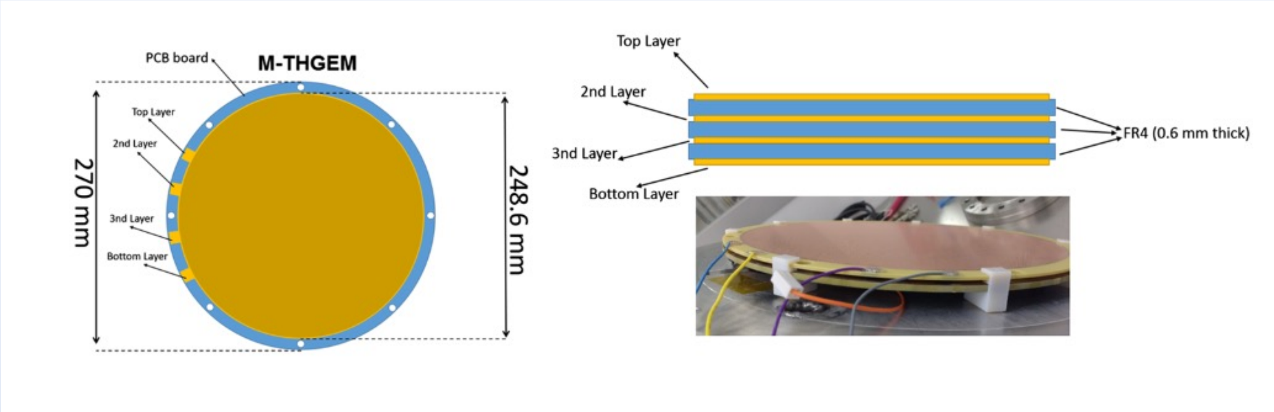
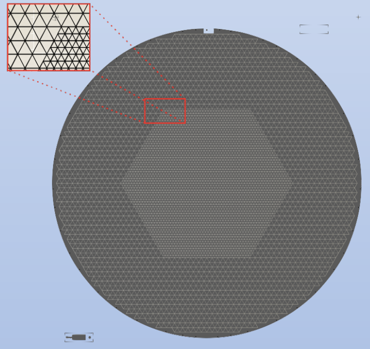
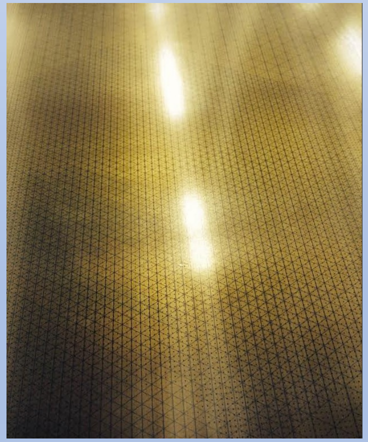
Novel Micropattern Gas Detectors (MPGD)

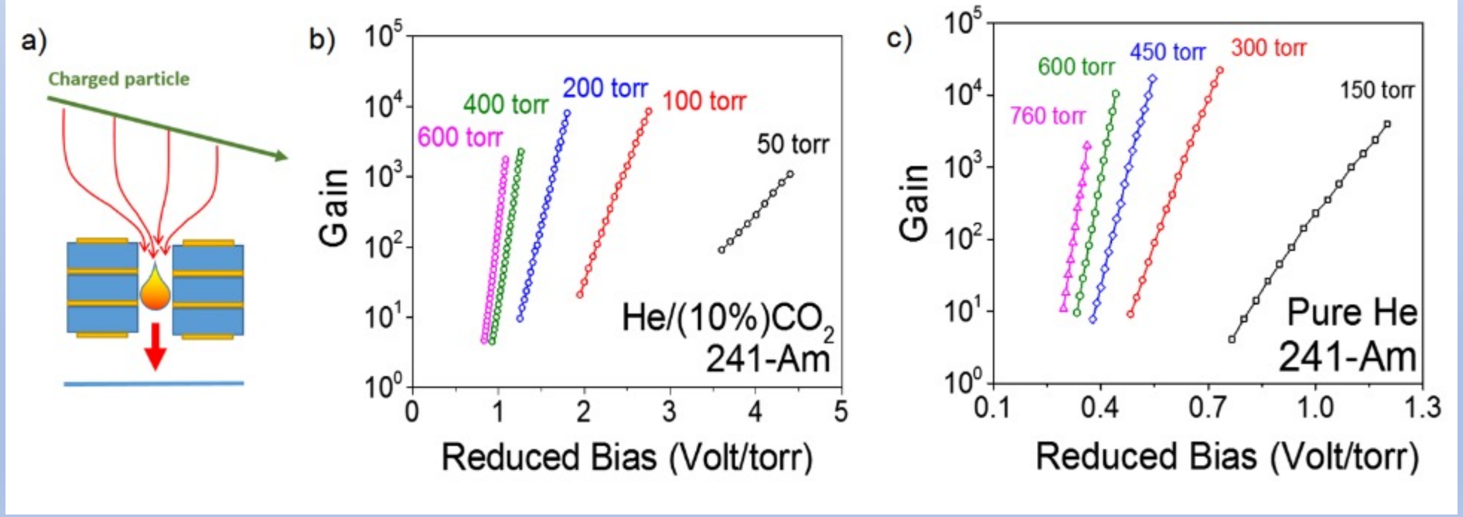








Pure targets!



Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)

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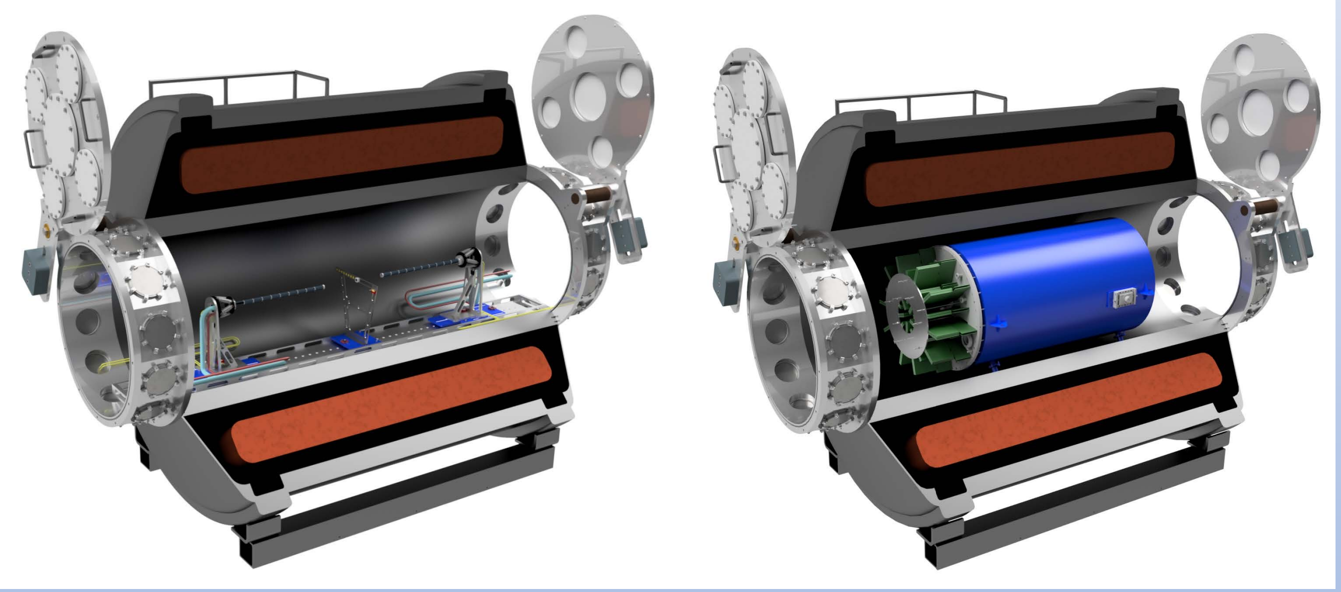

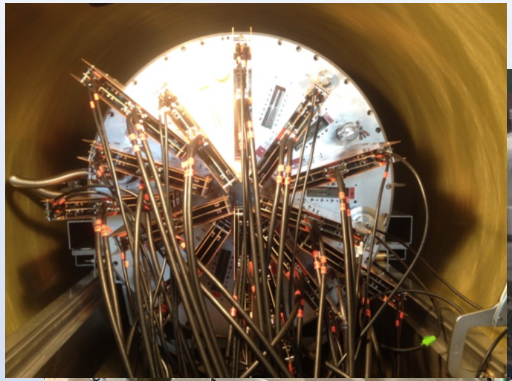

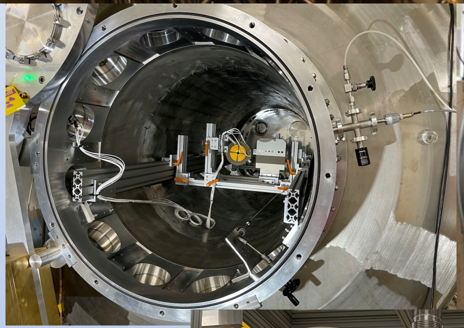

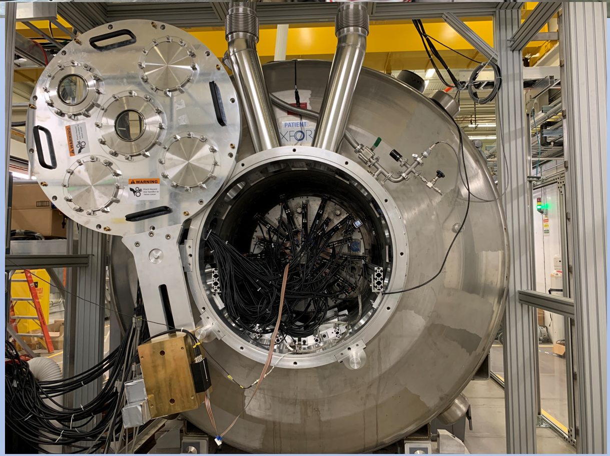

Facility for Rare Isotope Beams
at Michigan State University

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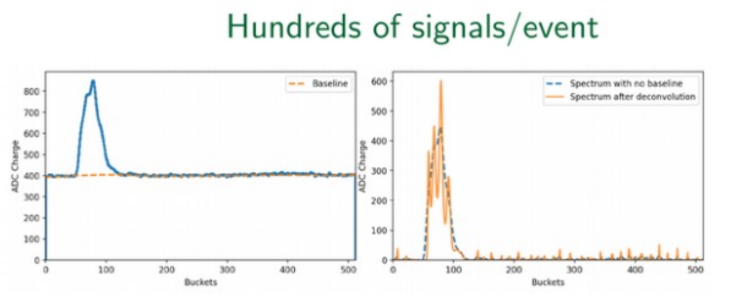
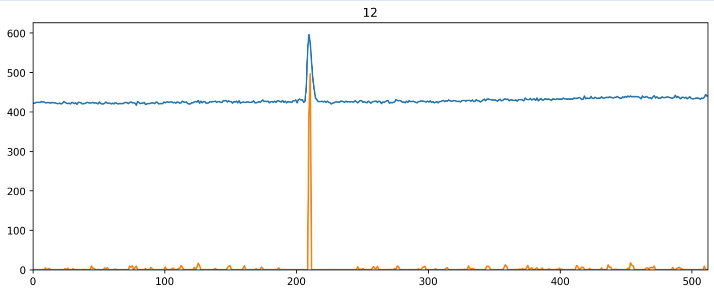
Track reconstruction I: Hit pattern

Pulse Shape Analysis with CNN





Courtesy of J.C. Zamora and G. Fortino.
U Sao Paulo

Select the proper pulse shape analysis algorithm: centroid or fit.

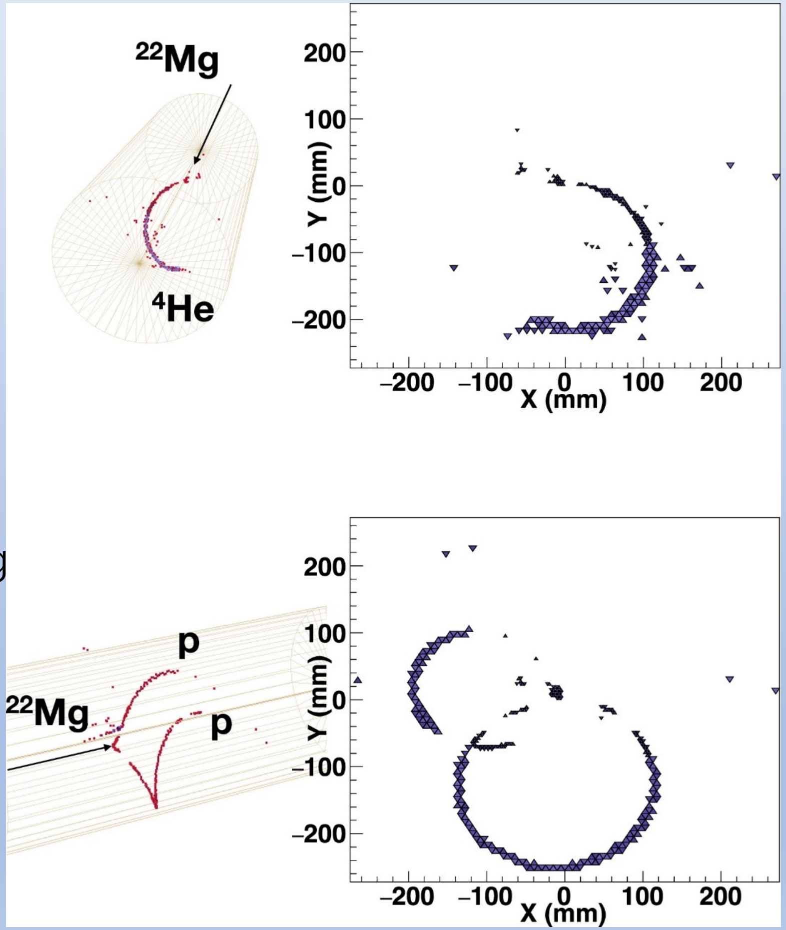
Multiparticle emission requires efficient peak finding algorithms.

Regions of the pad plane need different treatment: beam vs “scattered”.

This also causes a difficult threshold adjustment for noise reduction (i.e. using Fourer transform).

Charge clustering along the particle trajectory is needed for the fitting stage.

$^{22}Mg+^{4}He$ at 5A MeV



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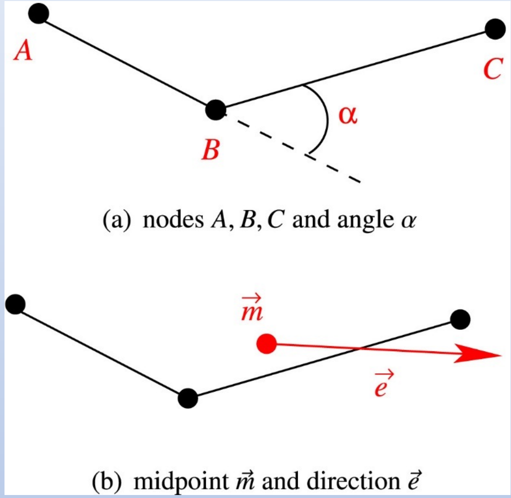
Track reconstruction II: Clustering



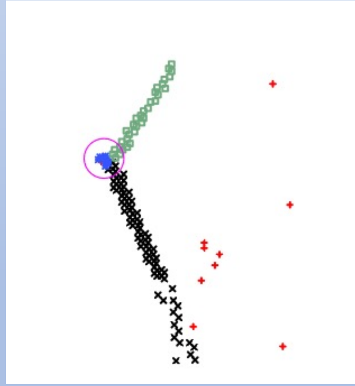
(a) nodes A, B, C and angle α

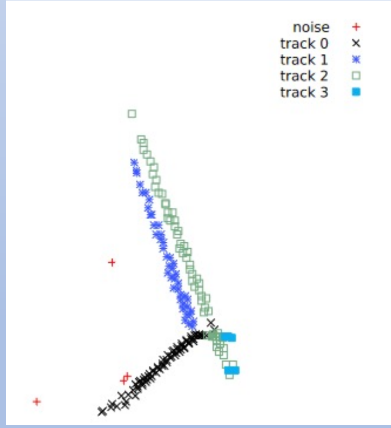
(b) midpoint $\vec{m}$ and direction $\vec{e}$

$$\cos(\alpha) = \frac{\langle \overline{AB}, \overline{BC} \rangle}{\|\overline{AB}\| \cdot \|\overline{BC}\|} = \frac{\langle \vec{q}_j - \vec{q}_i, \vec{q}_k - \vec{q}_j \rangle}{\|\vec{q}_j - \vec{q}_i\| \cdot \|\vec{q}_k - \vec{q}_j\|}$$

$$\vec{m} = \frac{1}{3}\left(\vec{q}_i + \vec{q}_j + \vec{q}_k\right) \quad \text{and} \quad \vec{e} = \frac{\vec{q}_k - \vec{q}_i}{\|\vec{q}_k - \vec{q}_i\|}$$

(a) noise classified as track segment (b) missed track segment





Computer Physics Communications 235 (2019) 159-168

Track reconstruction III: Fitting

Parameters from pattern recognition are used as initial fitting parameters.

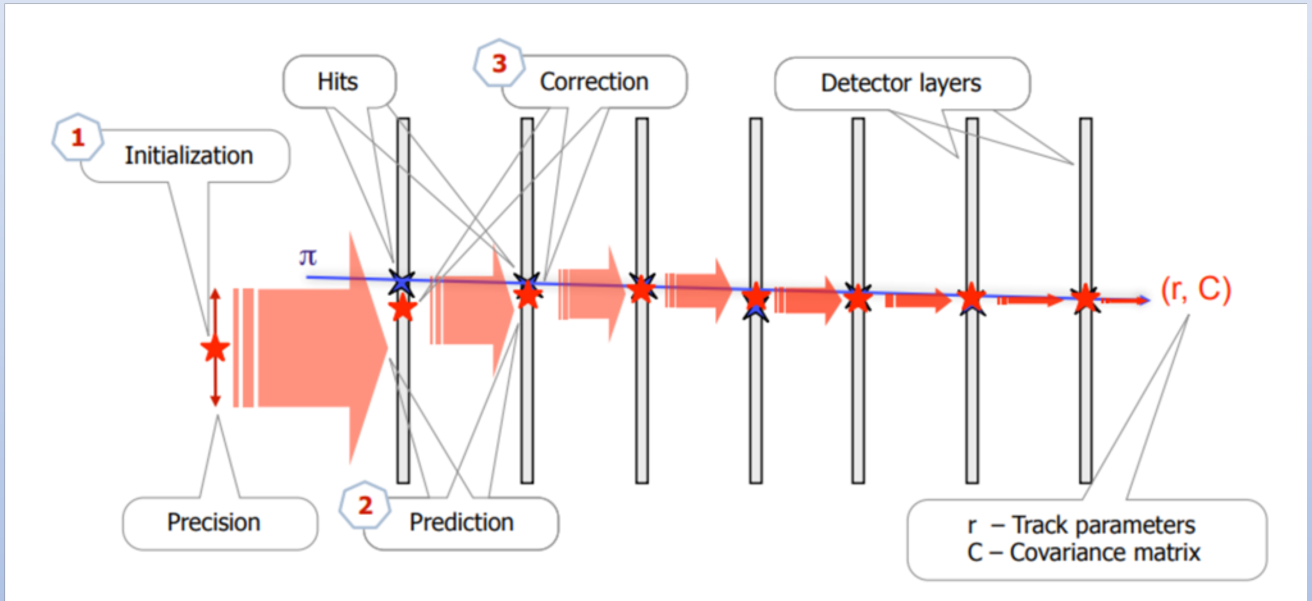
Using a Kalman Filter adapted to the AT-TPC. Widely used in HEP. Very fast!

Provides estimates of some unknown variables given the measurements observed over time.

Linear dynamical systems: Motion of charged particle in a magnetic field (4th order Runge-Kutta).

In the case of particle detectors, the trajectory is described by a state vector and a covariant matrix.

For the AT-TPC: detailed treatment of energy loss (low energy) and straggling effects are needed.



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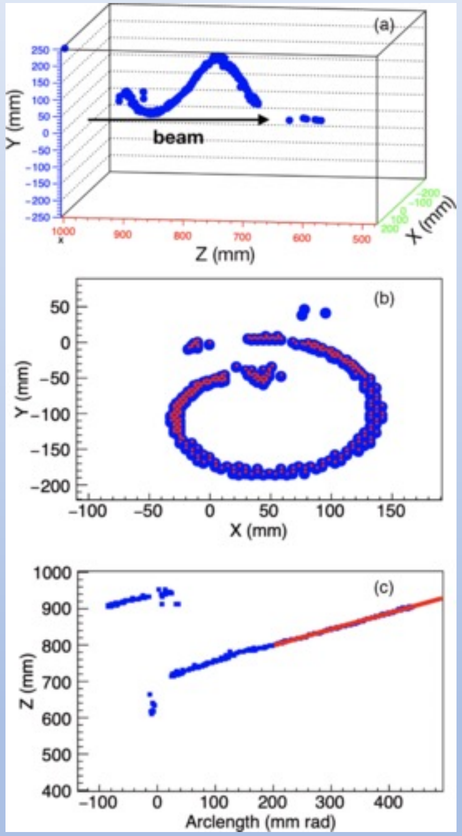
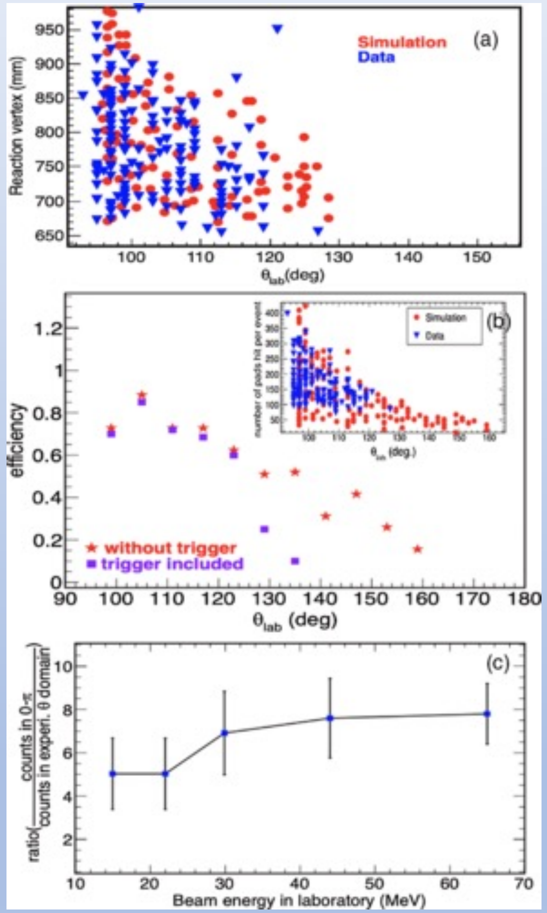
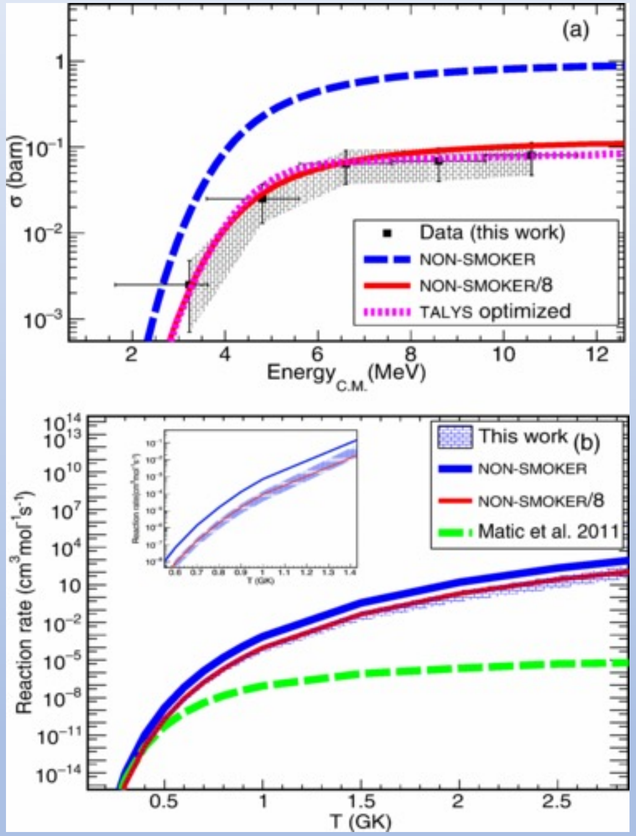
First Direct Measurement of ^{22}Mg(α,p)^{25}Al near the Gamow Window (2018)

J. S. Randhawa et al. Phys. Rev. Lett. 125 (2020)







- ^{22}Mg at 5A MeV 900 pps! (ReA3).
- Target: He+CO_2 600 torr.
- Continuous measurement of the excitation function with a single beam energy (just counted protons)
- Study of many reactions channels simultaneously.
- Large constraint to X Ray Burst Models and neutron stars compactness.

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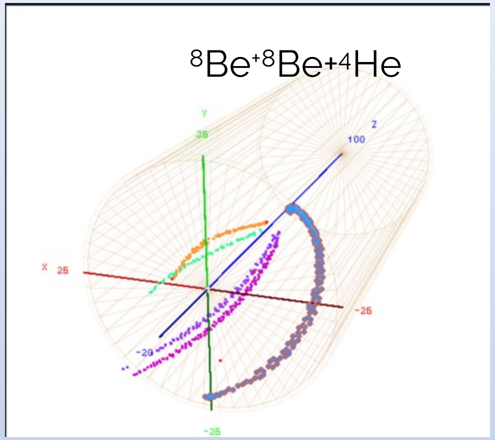
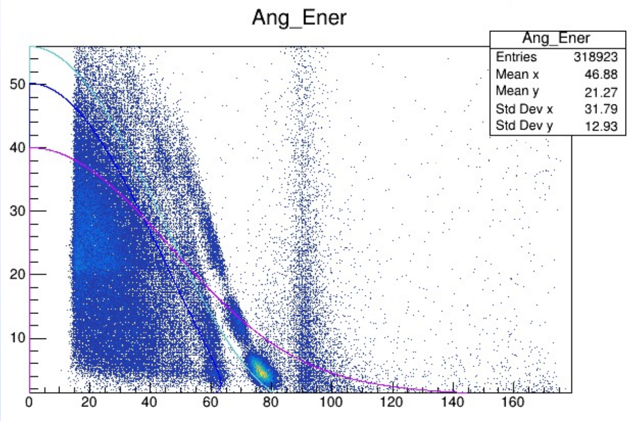
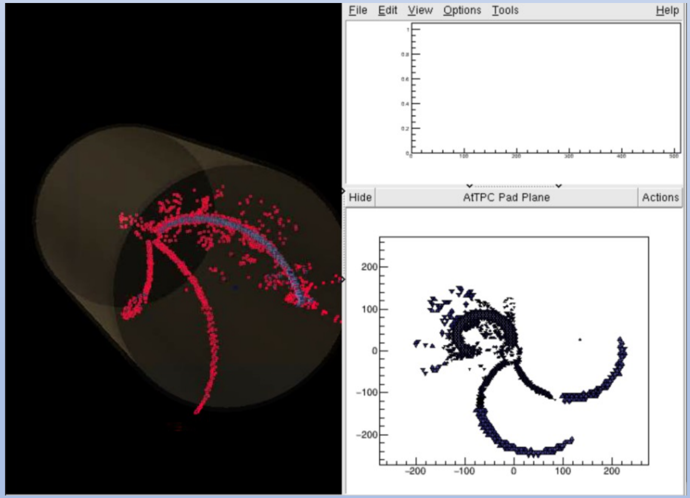
A plethora or reaction channels!

SOLARIS commissioning $^{16}O+^{4}He$ ReA6 (2021)

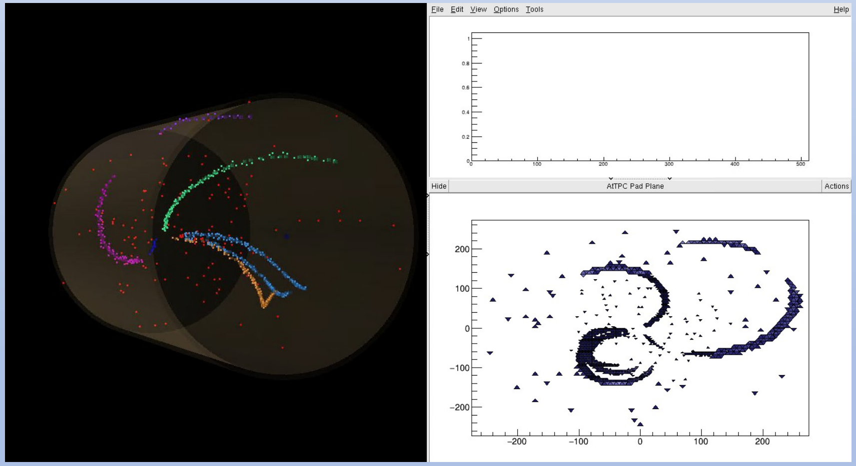
- Search for alpha-condensate states in ^{16}O
- A Bose-Einstein condensate in nuclei near alpha-emisión threshold.



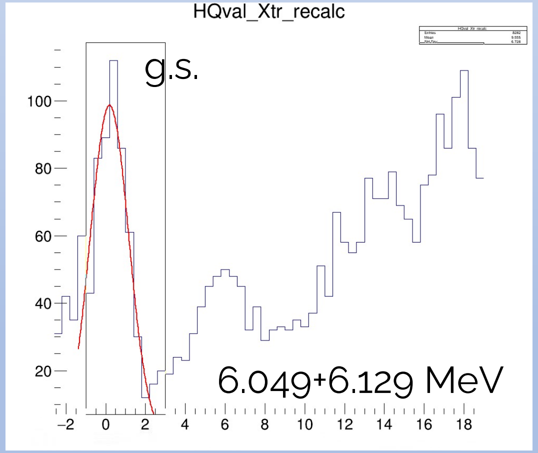




$^{12}C+^{4}He+^{4}He$



$^{12}C^{*}$ (Hoyle-state)$+^{4}He+^{4}He$



Accesible by Multiple Decomposition Analysis

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Conclusions and outlook

- Solenoidal spectrometers in Active Target mode are powerful and unique devices for exotic nuclei spectroscopy.
- Experiment with very low intensity beams (1000 pps) and pure targets are only possible with such devices.
- These detectors are ideal to probe direct reaction at astrophysical energies.

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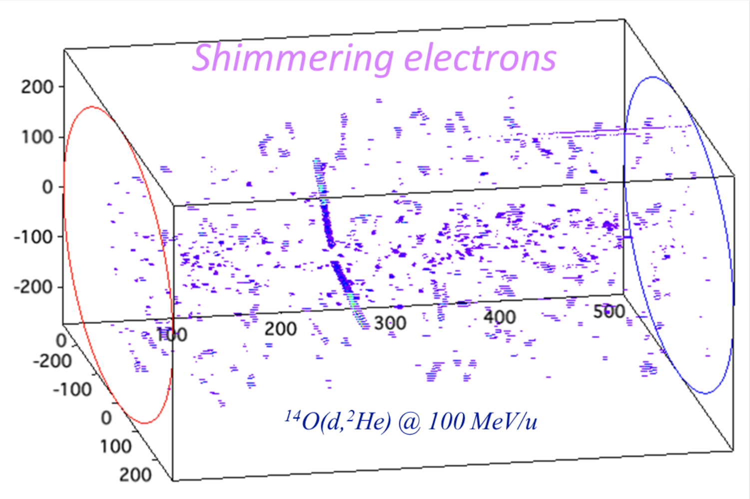

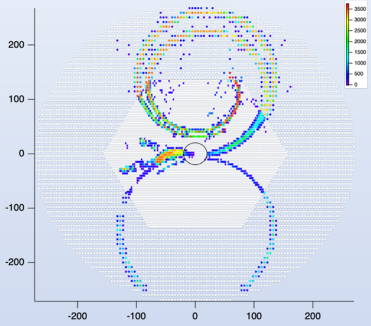

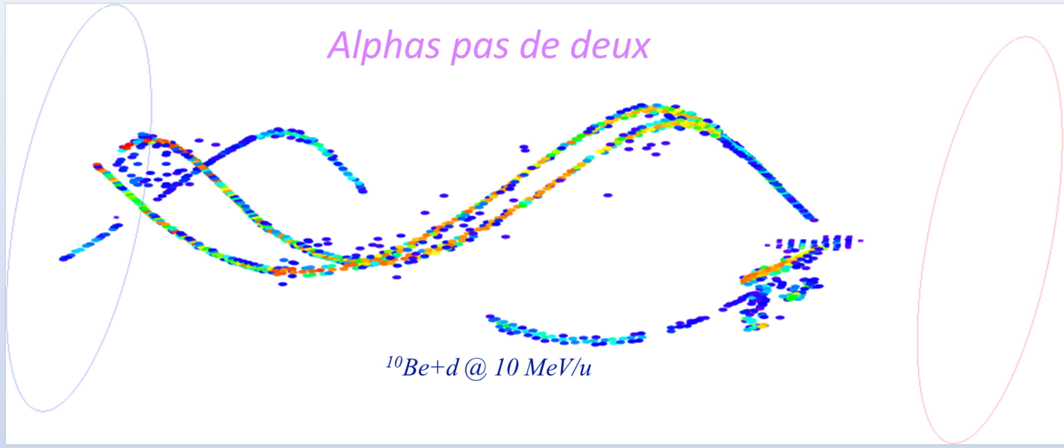

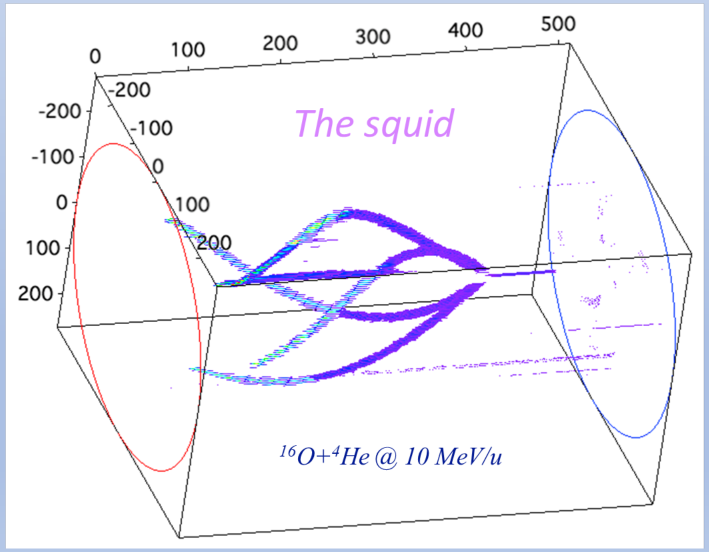

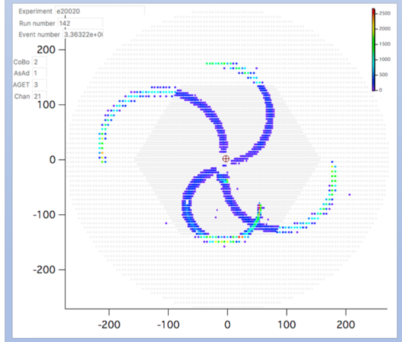

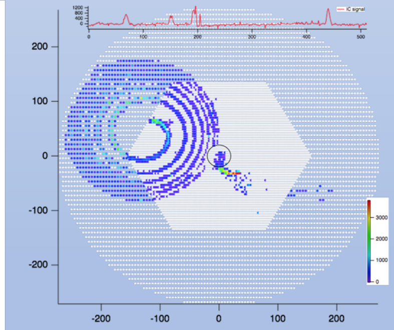

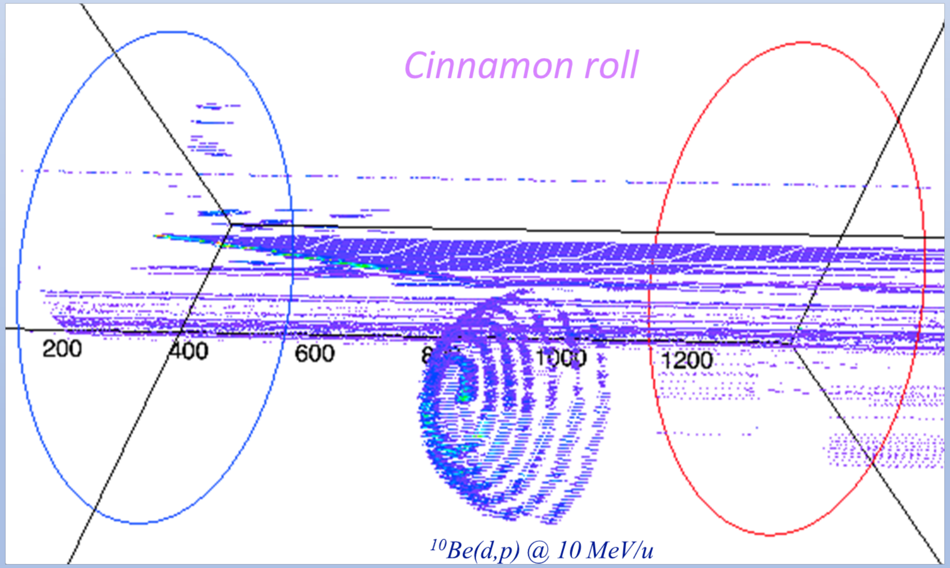

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AT-TPC Collaboration

(The ^{10}Be sample was provided by the Paul Scherrer Institute)