ACTAR TPC:
a tool for nuclear structure and astrophysics

ACTAR TPC Design : Field cage

Active target: (Gaseous) detector in which the atoms of the gas are used as a target

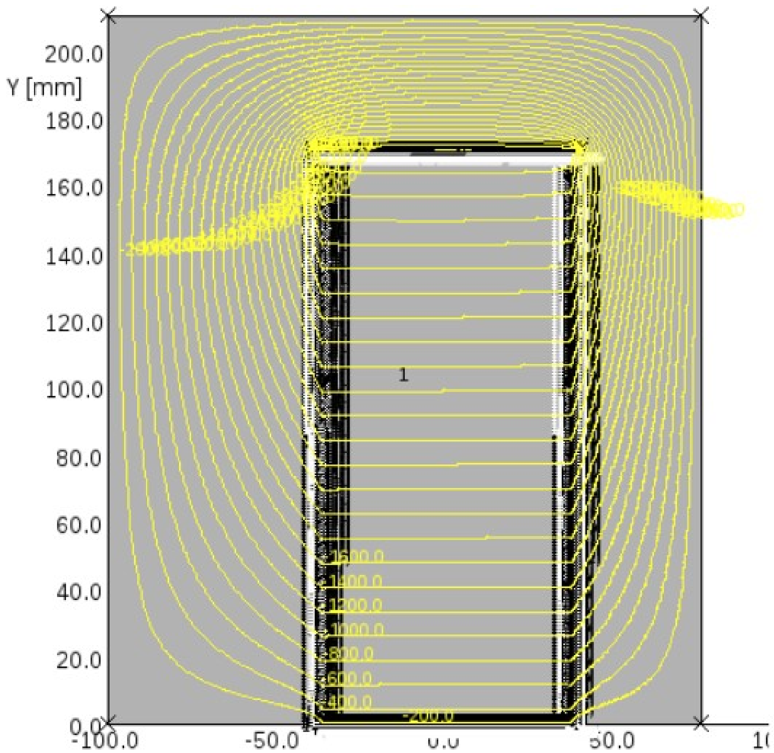
✓ Drift region: principle

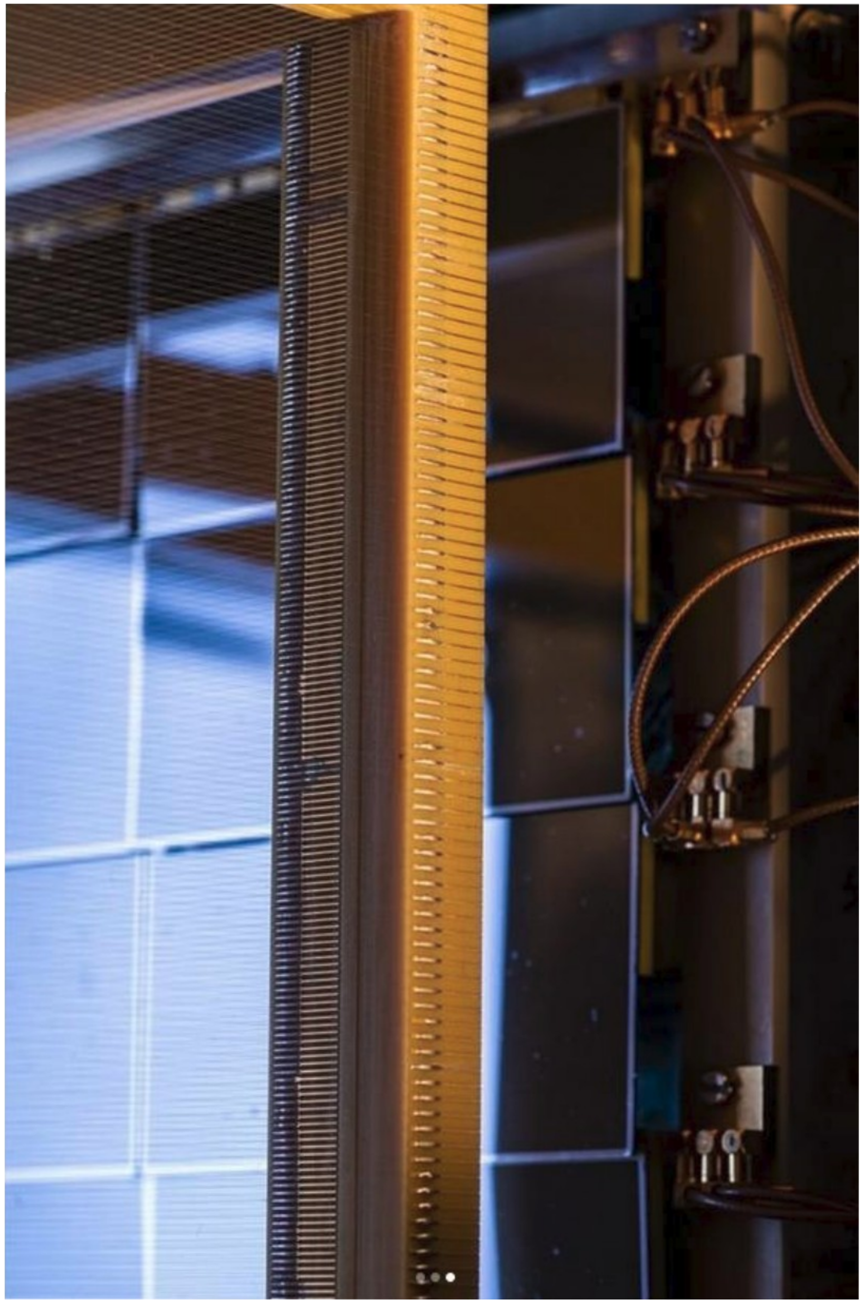
- Transparent to particles on 4 sides (for auxiliary detectors)

→ Wire field cage

- **Homogeneous** vertical drift electric field

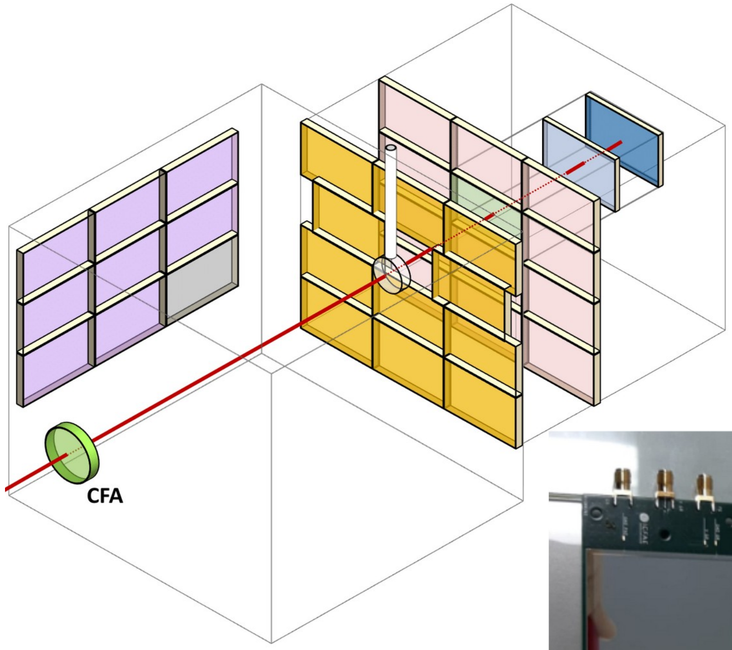
→ Double wire field cage: 2 mm/1 mm pitch (97% transparency)
(screens the inside from the FC → Chamber E field)



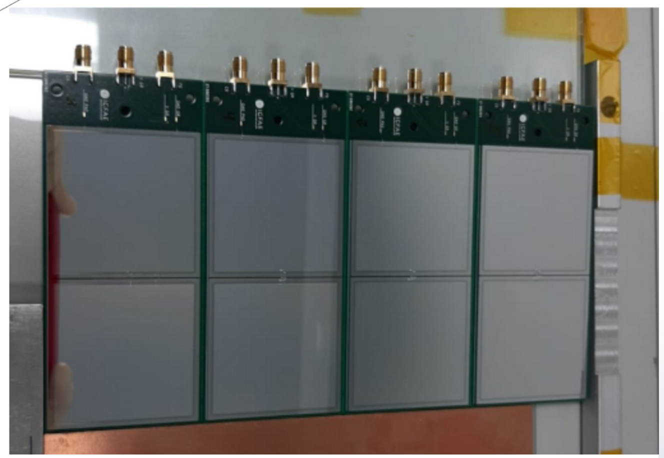


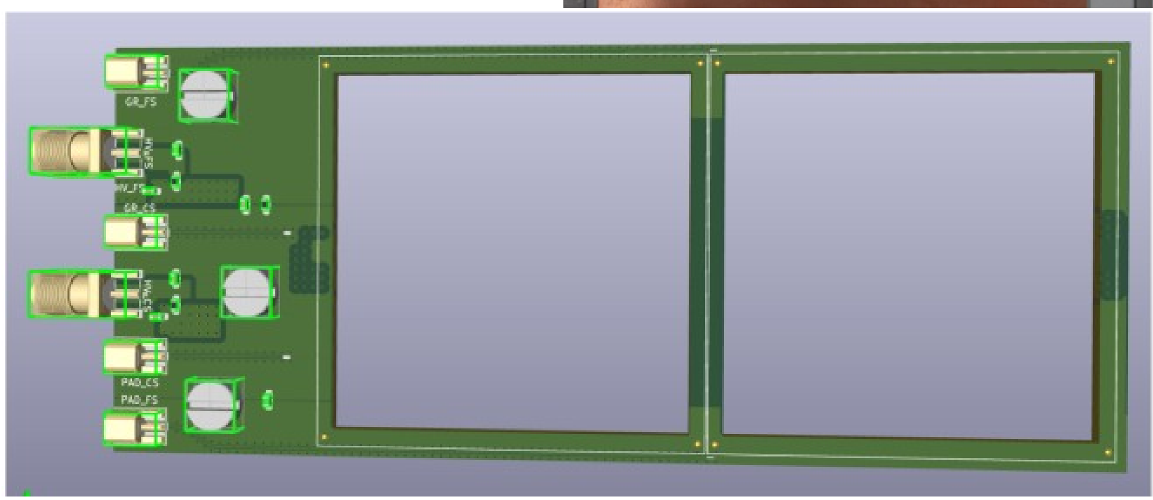
ACTAR TPC Design : Auxiliary detectors

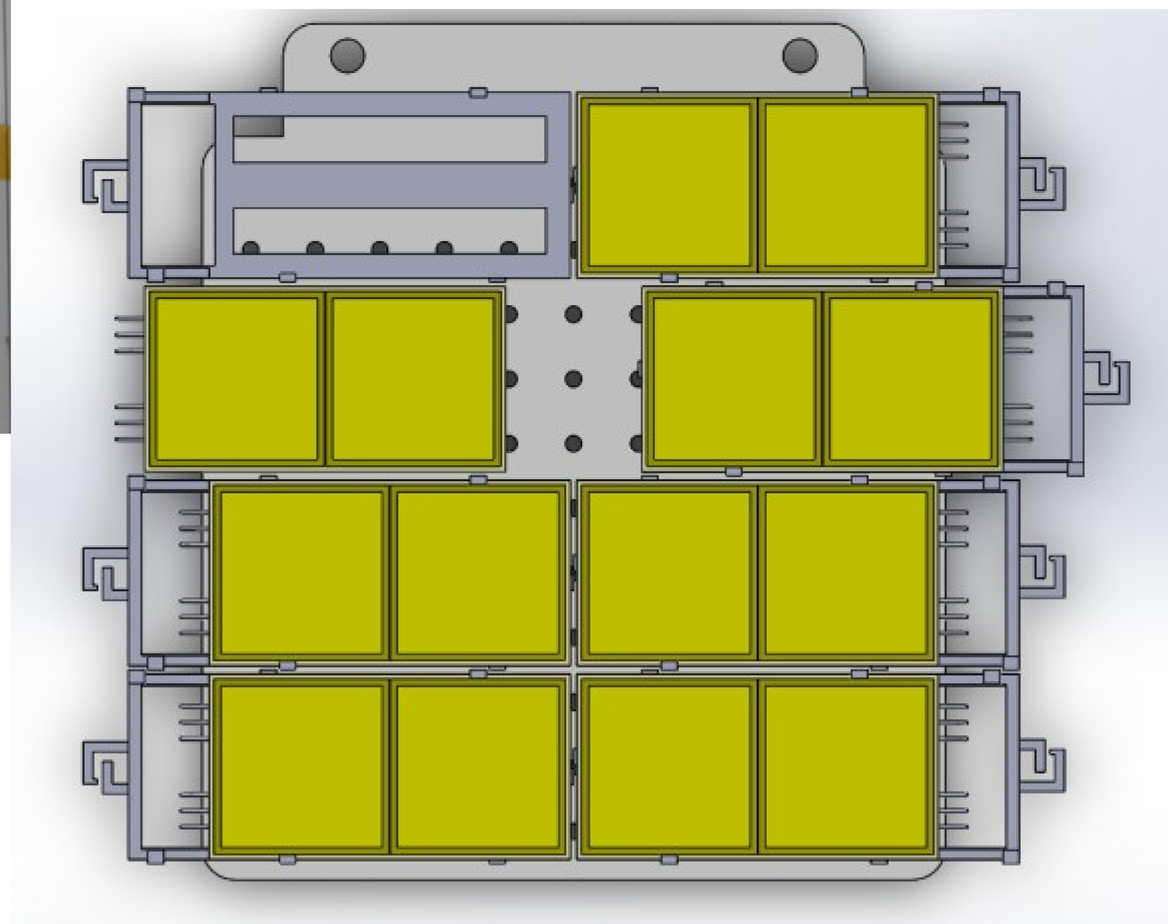
IGFAE
Instituto Galego de Física de Altas Enerxías



Today: 8x5 cm2, 0.5 mm thick Si detectors, 3 walls operational
Upgrade: 5x5 cm2, 1.5 mm thick (Micron), Modular holder design (C. Cabo – IGFAE)
3(+1) full walls foreseen (midterm upgrade)







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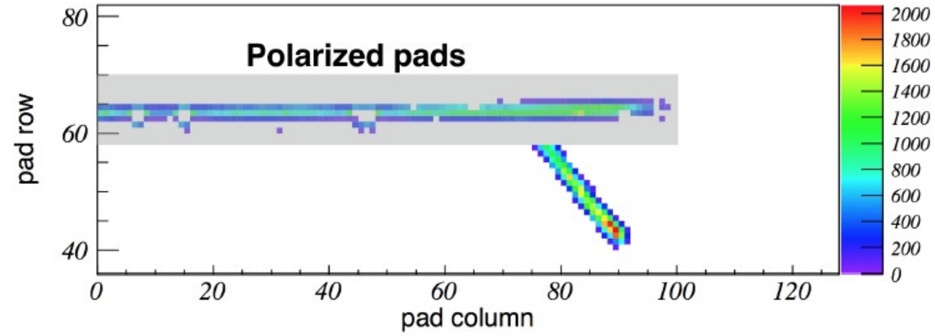
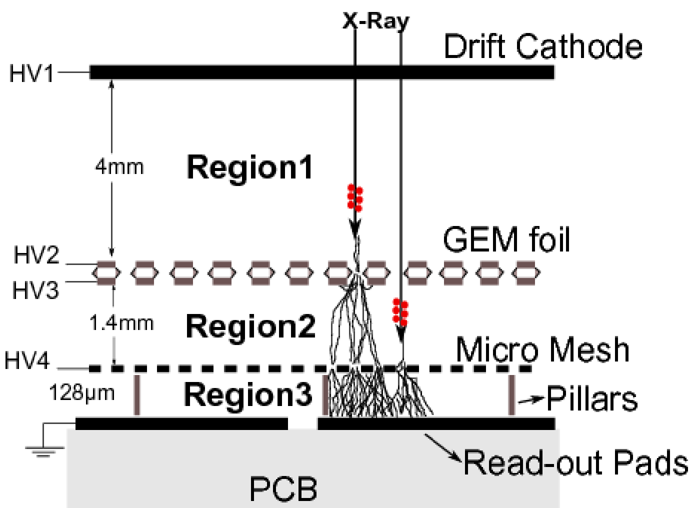
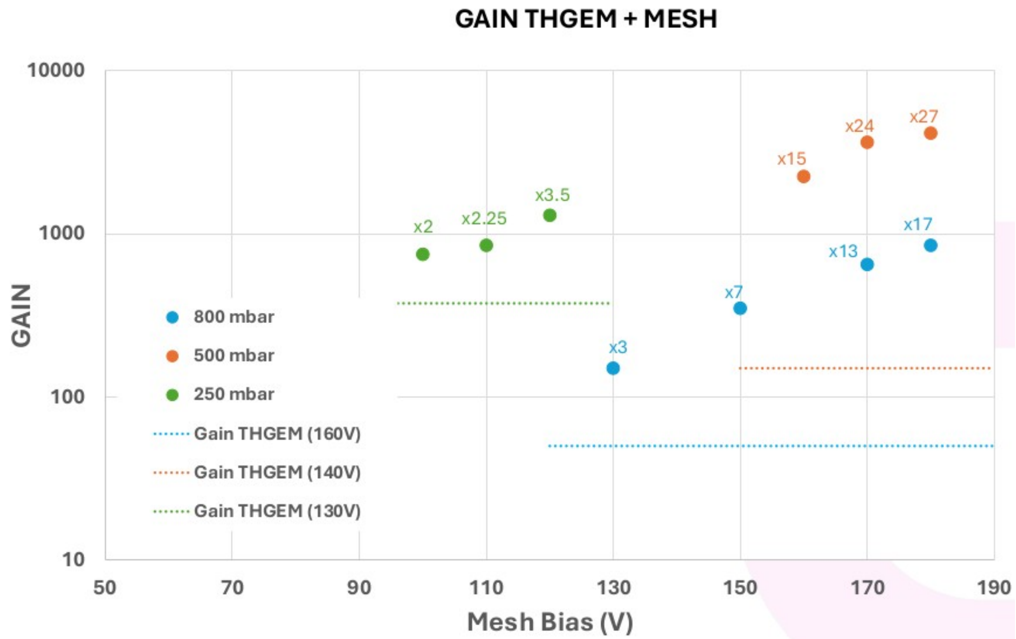
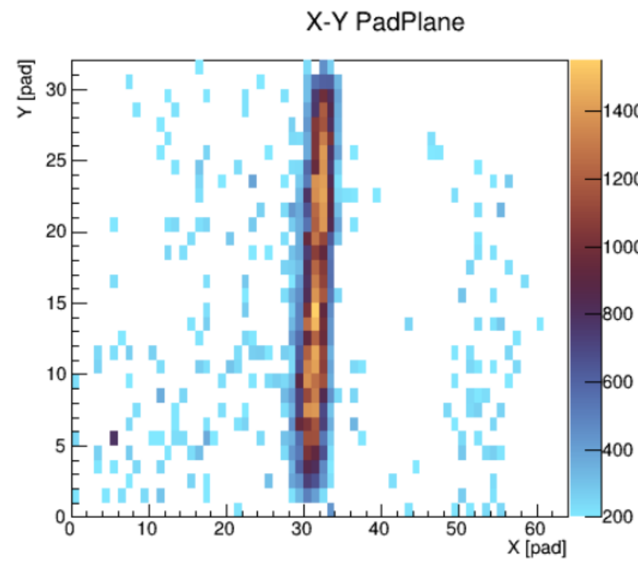


✓ Amplification region: principle

- Bulk Micromegas (CERN PCB workshop)
- Local gain reduction via pad polarization
- Working with pure monoatomic gases: add a ThGEM (M. Fisichella - GANIL)







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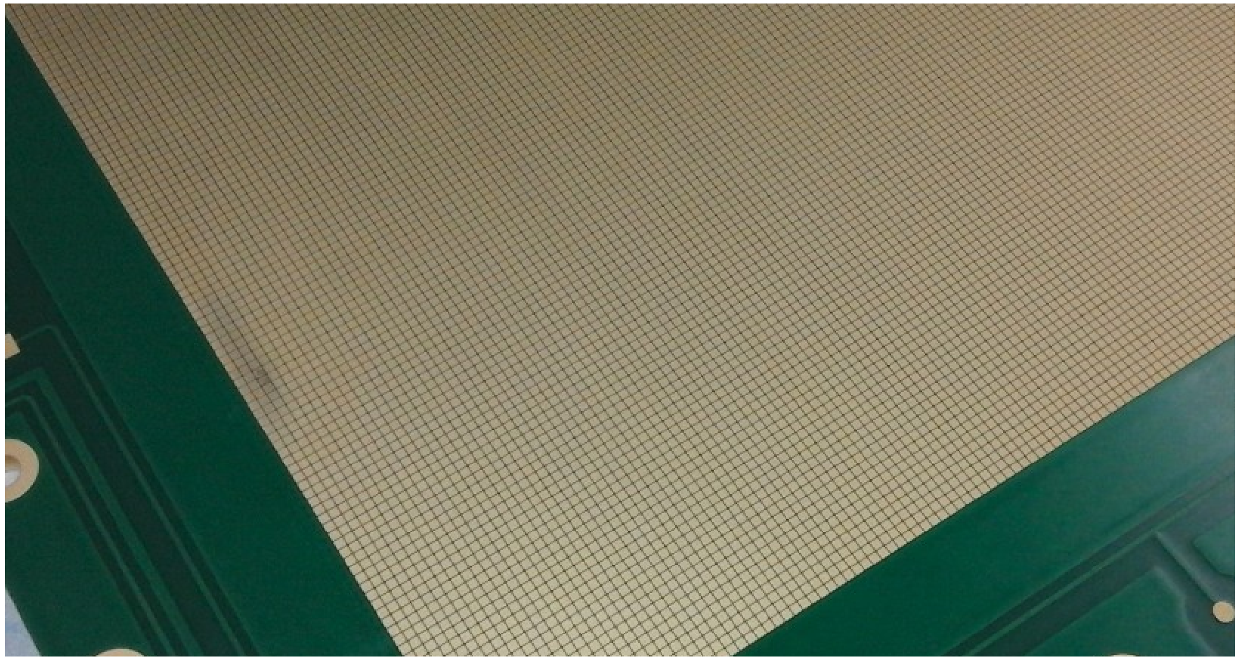


✓ Amplification region: principle

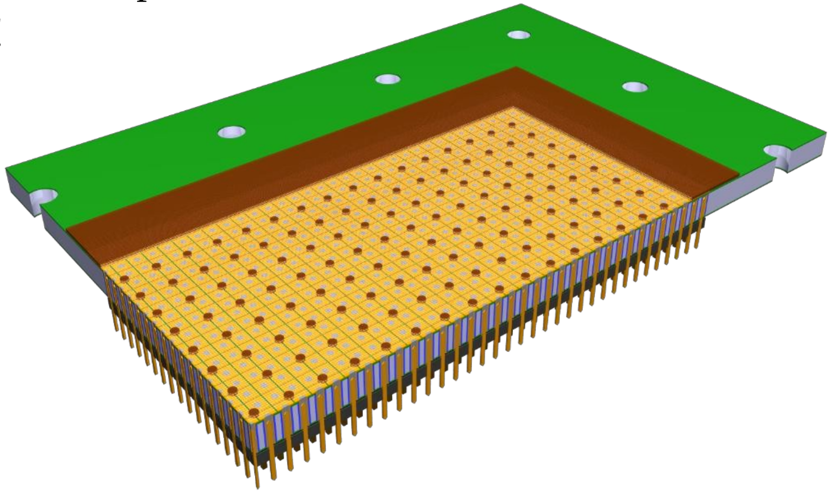
- Bulk Micromegas (CERN PCB workshop)
- Local gain reduction via pad polarization

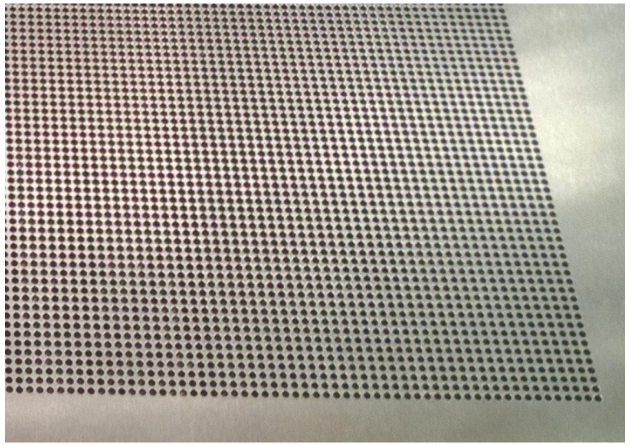
✓ Segmented pad plane

- Micromegas

→ transverse multiplicity ≈ electron straggling: 2x2 mm^2 pads

- 16384 pads with very high density: challenge!





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→ transverse multiplicity ≈ electron straggling: 2x2 mm^2 pads

- 16384 pads with very high density: challenge!

→ Two solutions investigated

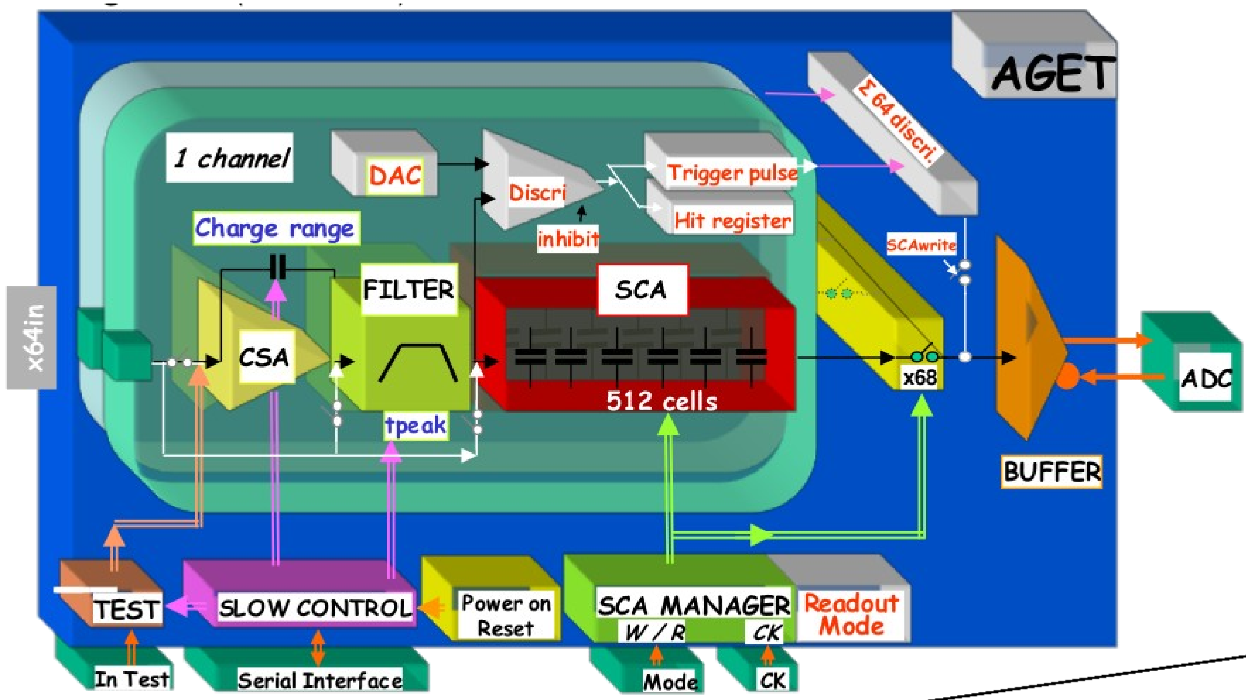
✓ Electronics: GET

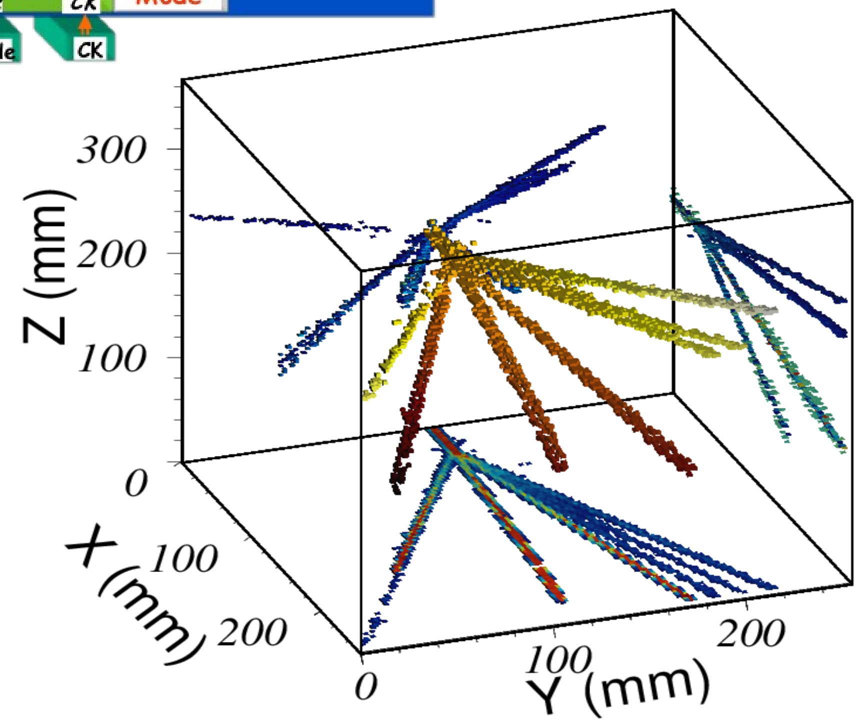
GET electronics:

- 512 samples ADC readout depth x 16384 pads

→ volume sampling in 8 Mega voxel

- adjustable gain, peaking time, individual trigger: pad per pad





Active target: (Gaseous) detector in which the atoms of the gas are used as a target

Physics cases addressed:

- Time Projection Chamber mode
  → Ideal for implantation/decay studies: proton(s) radioactivity, beta-delayed charged particle emission, ...
- Study of excitation functions (resonant scattering, etc...)
  → thick target, need to differentiate the reactions channels
- Reactions with (very) low intensity beams
  → thick target, mixed target, possibly no ^{12}C contamination

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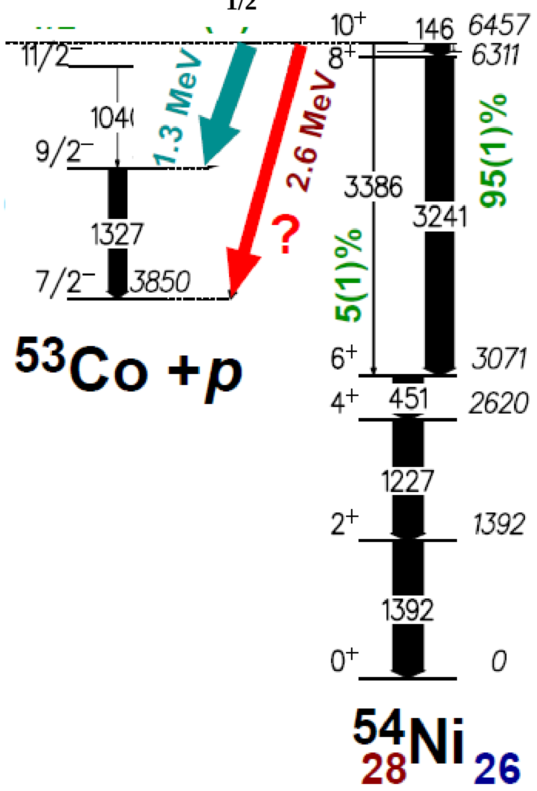
TPC mode : Implantation/Decay

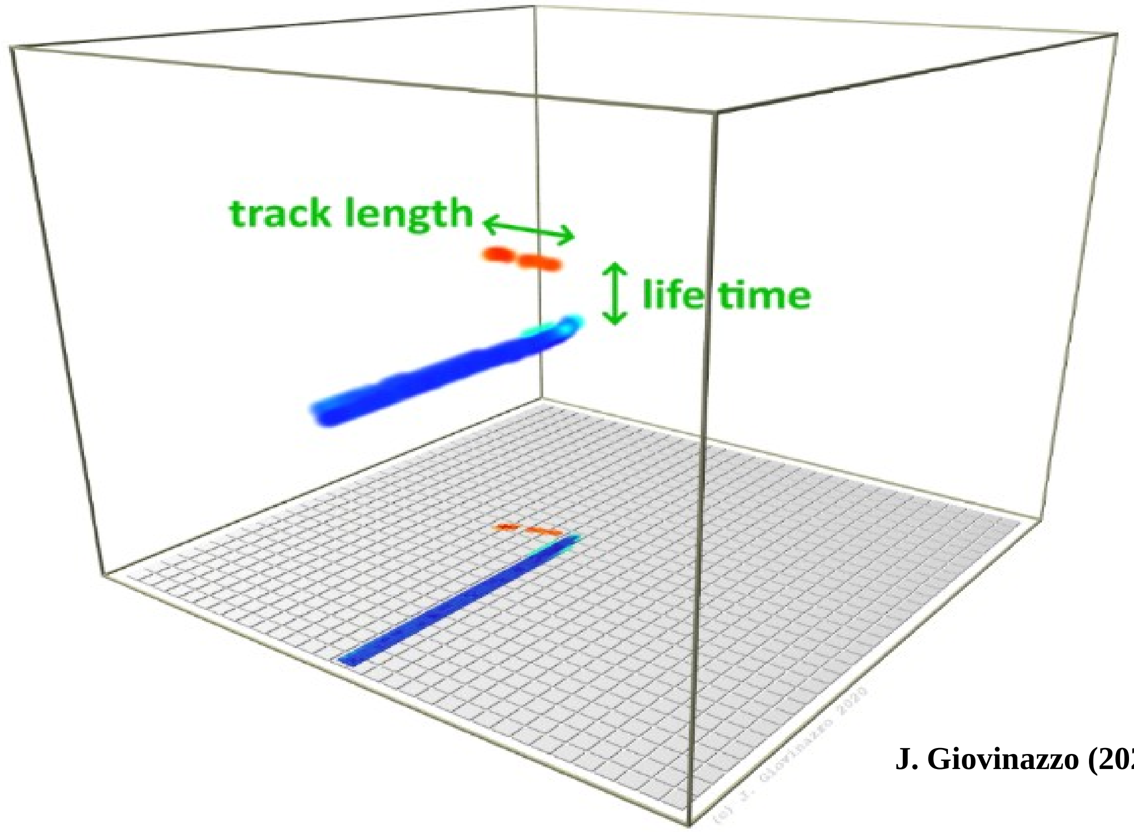
✓ Proton-decay branches from the 10^{+} isomer in ^{54}Ni (May 2019)

^{54}Ni implantation – proton decay: → 10*A* MeV ^{54}Ni beam in 900 mbar Ar(95%) + CF_4(5%)

J. Giovinazzo et al. "4D imaging of proton radioactivity" Nature communications 2021

$T_{1/2}$ = 155 ns





J. Giovinazzo (2020)

✓ **Simultaneous observation of Ni track (6 MeV/pad) and proton tracks (60 keV/pad)**

✓ **Decay of $T_{1/2}$ = 155 ns isomer : OK!**

TPC mode : Implantation/Decay

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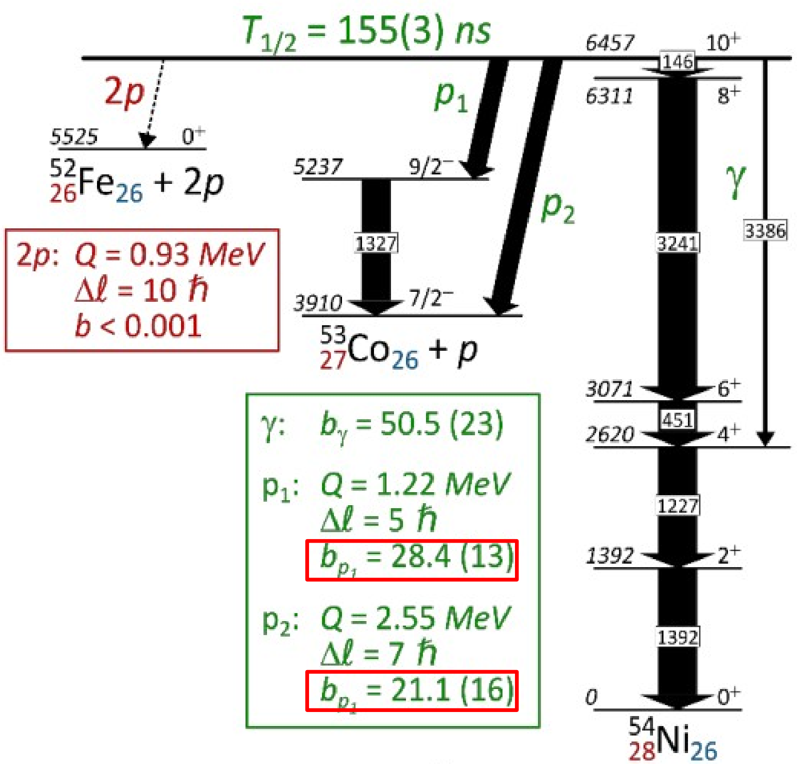
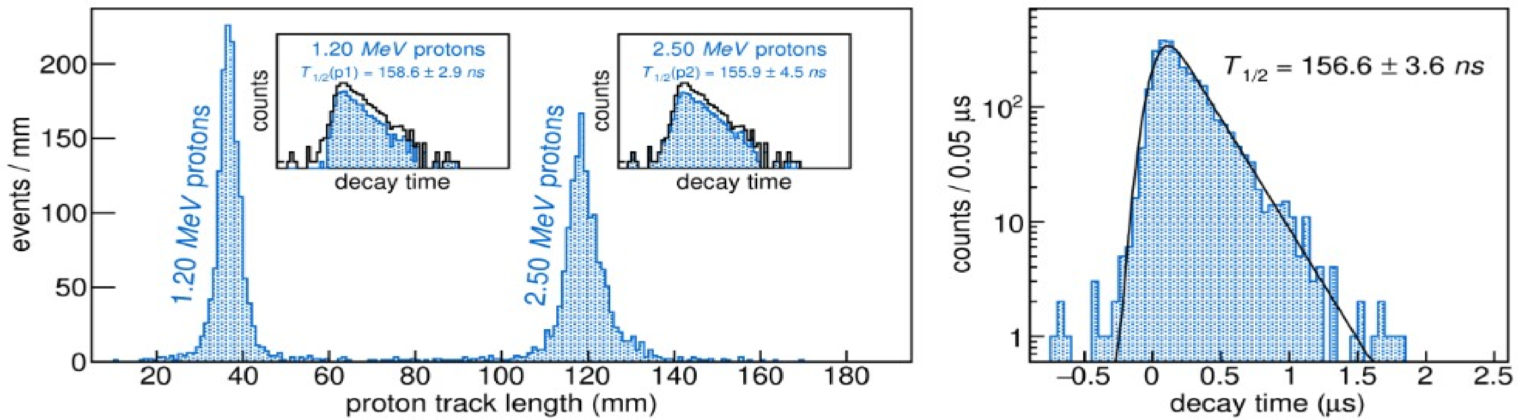


J. Giovinazzo (2020)



- Proton decay branches carry unusually high angular momentum

- Branching ratio approximated theoretically with potential model for barrier penetration & Shell Model calculation for the initial and final WF overlap

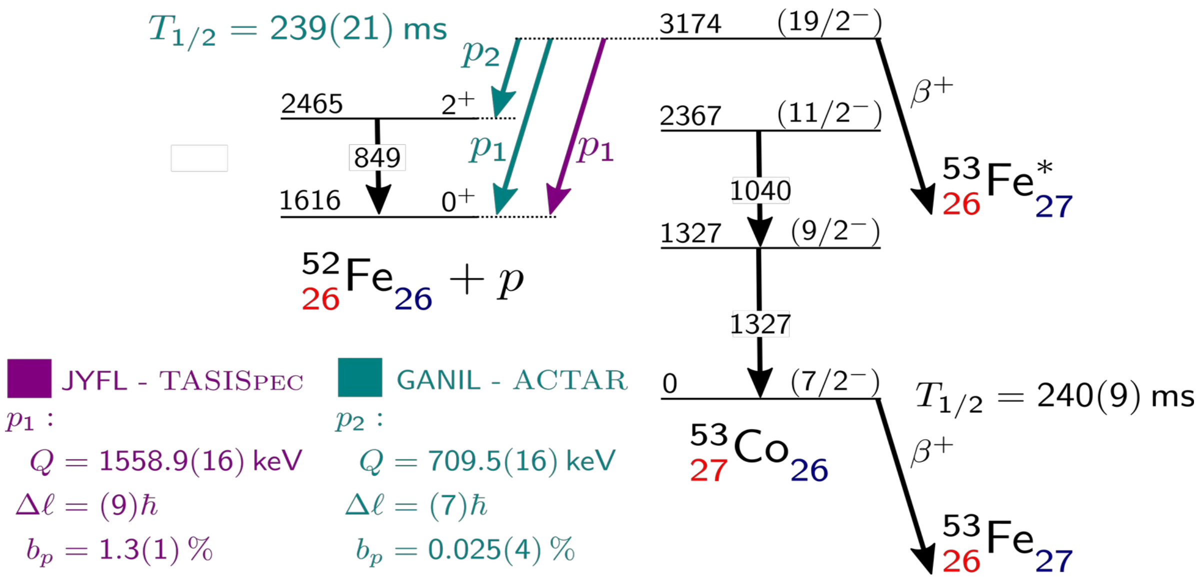
  → C^2S of the order of 10^{-6}

- the "high l" orbitals that mediate proton radioactivity in this region are also active in super-heavy nuclei and responsible for magic numbers in these nuclei

TPC mode : Implantation/Decay

✓ Proton-decay branches from the 19/2⁻ isomer in ^{53}Co (May 2019)

^{53}Co implantation – proton decay: → 10*A* MeV ^{53}Co beam in 400 mbar Ar(95%) + CF_4(5%)



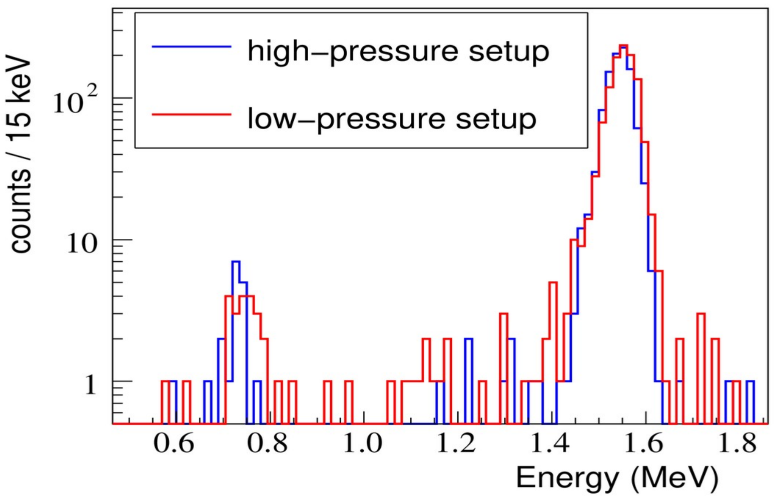
✓ **Decay of $T_{1/2}$ = 239 ms isomer : OK**

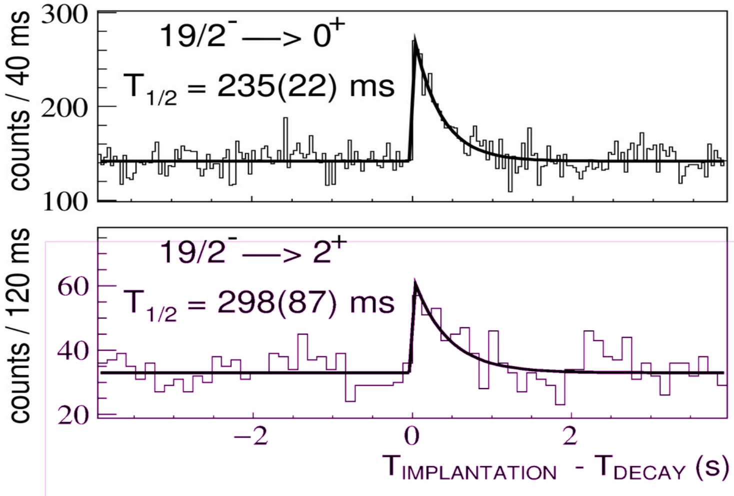
✓ **Measurement of 0.025 % BR : OK**

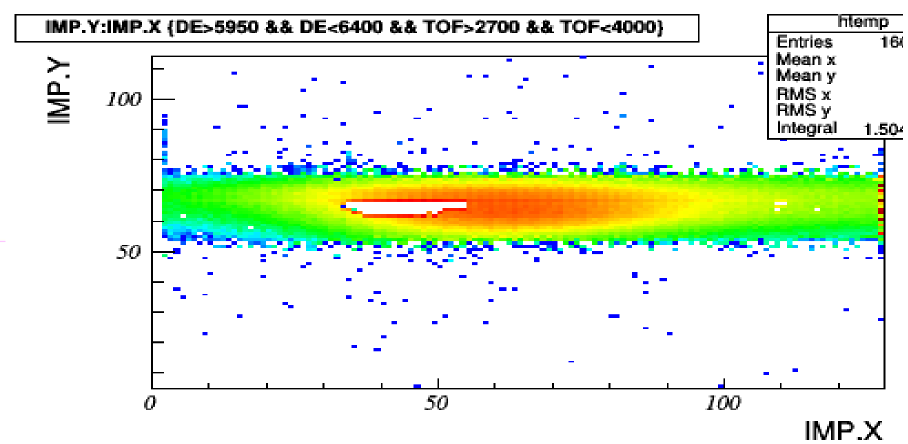
(not affected by β background)

50 years after the discovery of proton radioactivity (^{53m}Co), we reach a complete comprehension of this state

L. Sarmiento et al.: Nature Communications (2023)

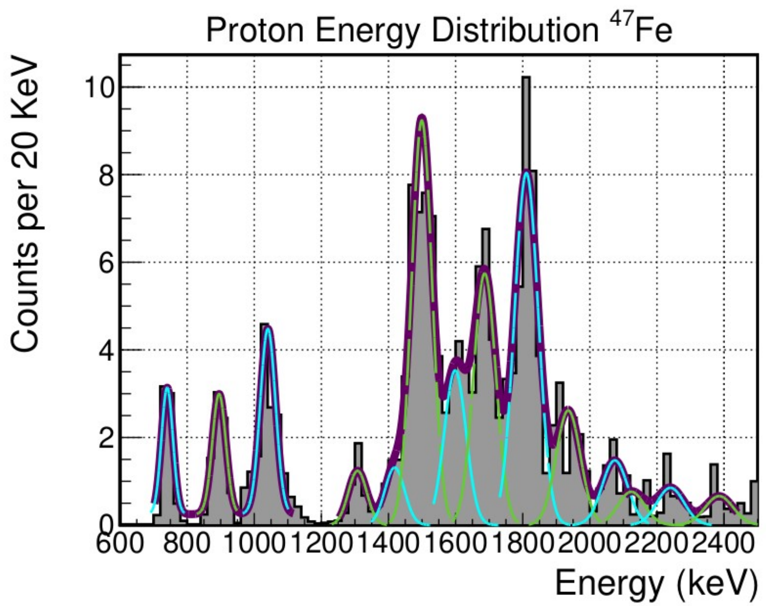


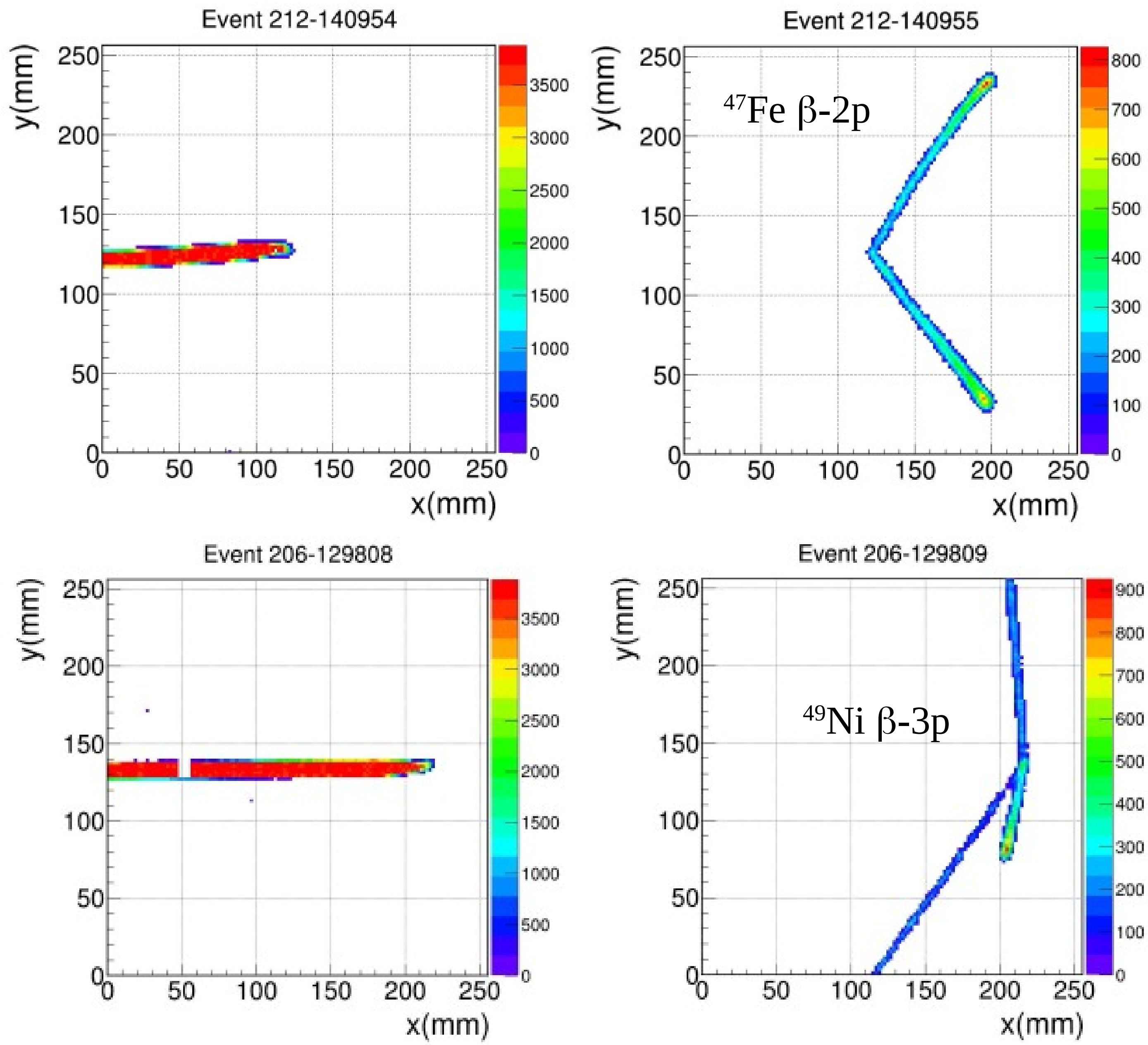




TPC mode : Implantation/Decay

✓ Exotic decays in the region of ^{48}Ni (May 2021): **PhD thesis** A. Ortega Moral **(LP2IB)**





→ tracking of low energy protons
→ multiple particle tracking in 3D, half-life, ...

Active target: (Gaseous) detector in which the atoms of the gas are used as a target

Physics cases addressed:

Time Projection Chamber mode

→ Ideal for implantation/decay studies: proton(s) radioactivity, beta-delayed charged particle emission, ...

- Study of excitation functions (resonant scattering, etc...)

→ thick target, need to differentiate the reactions channels

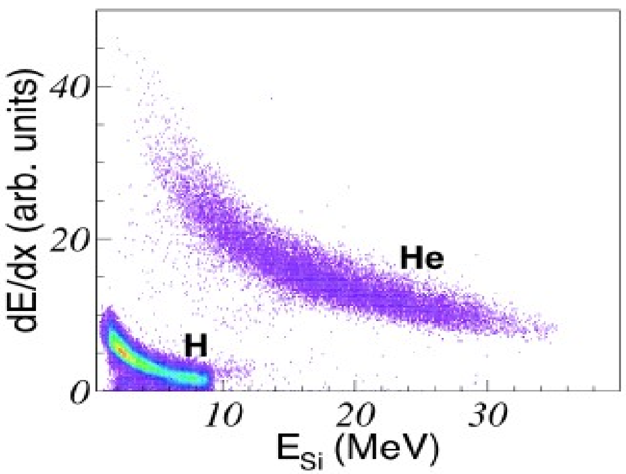
Reactions with (very) low intensity beams

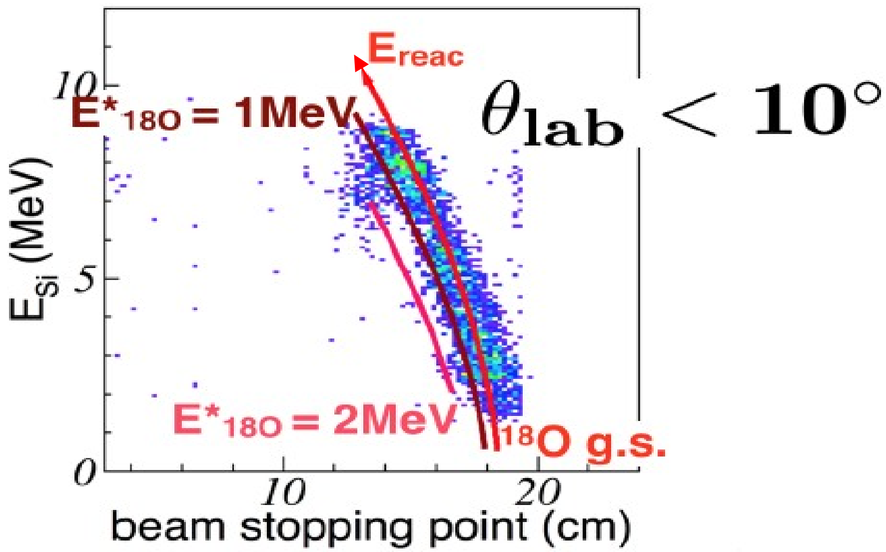
→ thick target, mixed target, possibly no ^{12}C contamination

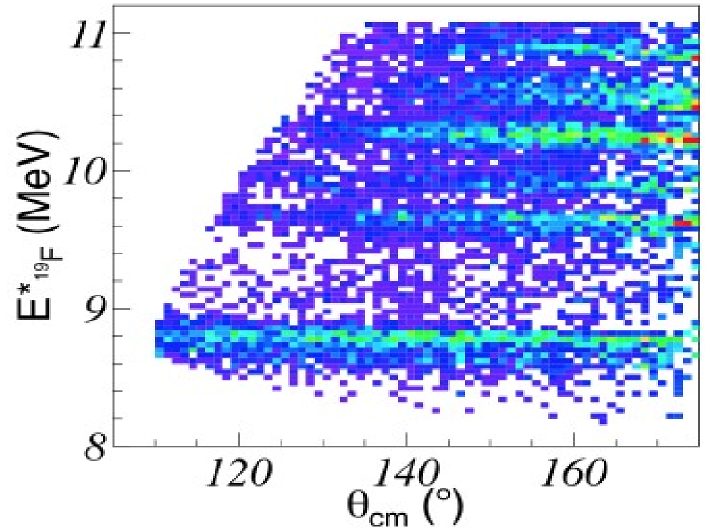
Resonant scattering : principle

- ✓ "Classic" TTIK method (thick solid target, beam stopped inside):
  - – 3 unknown: E_{CM}, θ_{CM}, E^* but only 2 observables (θ_{light}, E_{light})
  - → unable to disentangle elastic and inelastic channels (no info on E^*)
- ✓ Active Target: one more kinematic parameter (stopping point of the beam-like particle)
  - → full identification of the reaction
  - + reconstruction of double differential cross section ($d^2\sigma/d\Omega dE$)

B. Mauss, PhD thesis (GANIL)







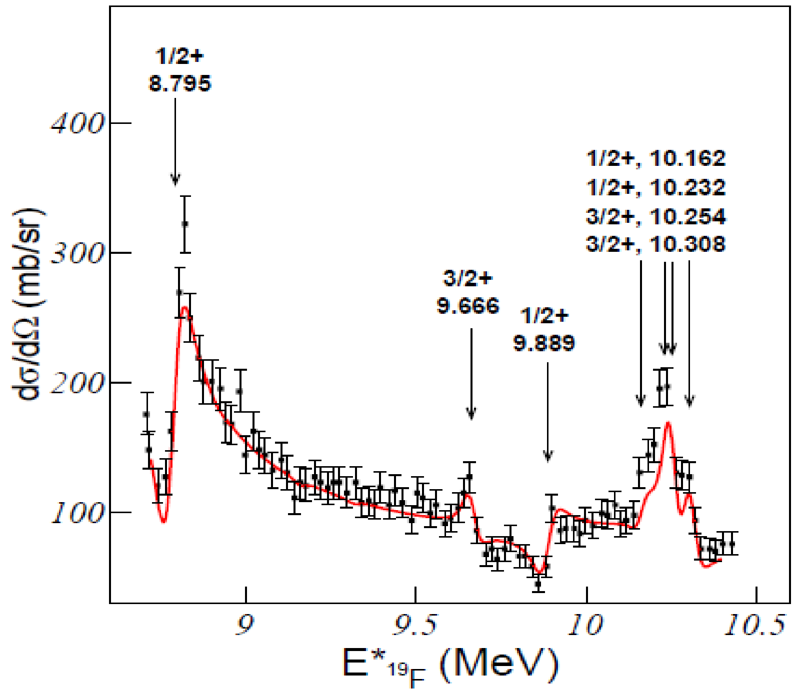
Particle identification → Tracking algorithm → Channel selection → Reaction kinematics + energy loss tables → Double differential cross section

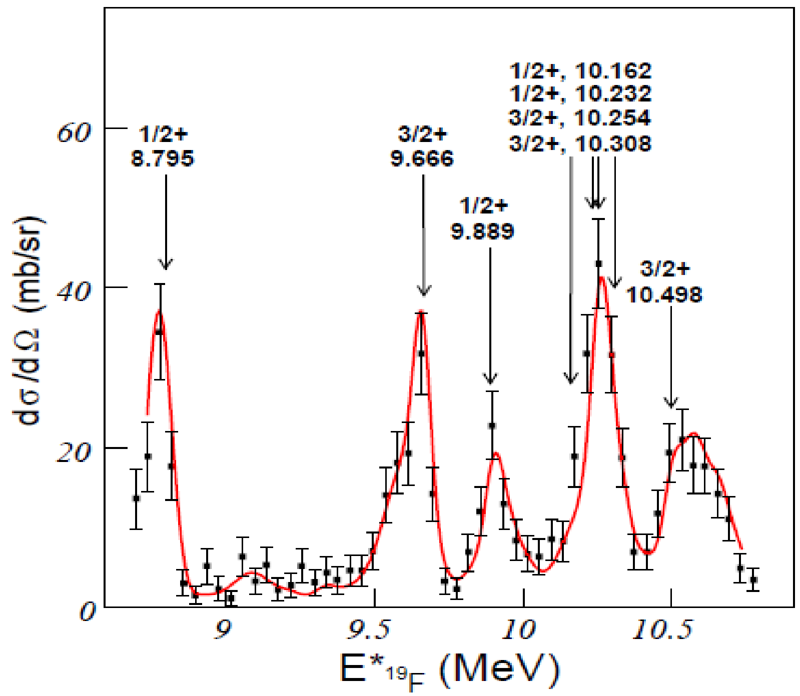
Resonant scattering : performances

✓ Commissioning of the 128x128 pad full detector

^{18}O(p,p) and ^{18}O(p,α) excitation functions: → 3.2*A* MeV ^{18}O beam in 100 mbar iC_4H_{10}

B. Mauss, et al., NIM A 940, 498 (2019)





✓ Absolute cross section measurement

✓ ^{18}O(p,p): c.m. energy resolution: 38(3) keV FWHM

✓ ^{18}O(p,α): c.m. energy resolution: 54(9) keV FWHM

→ Resolution limited by the angular straggling of the ions in the gas

Resonant scattering : possible upgrade

✓ Resonant scattering : Ecm resolution dominated by the angular straggling in the gas

→ Use pure H_2 gas instead of isobutane :

example with ^{20}O+p excitation function, initial energy = 5*A* MeV

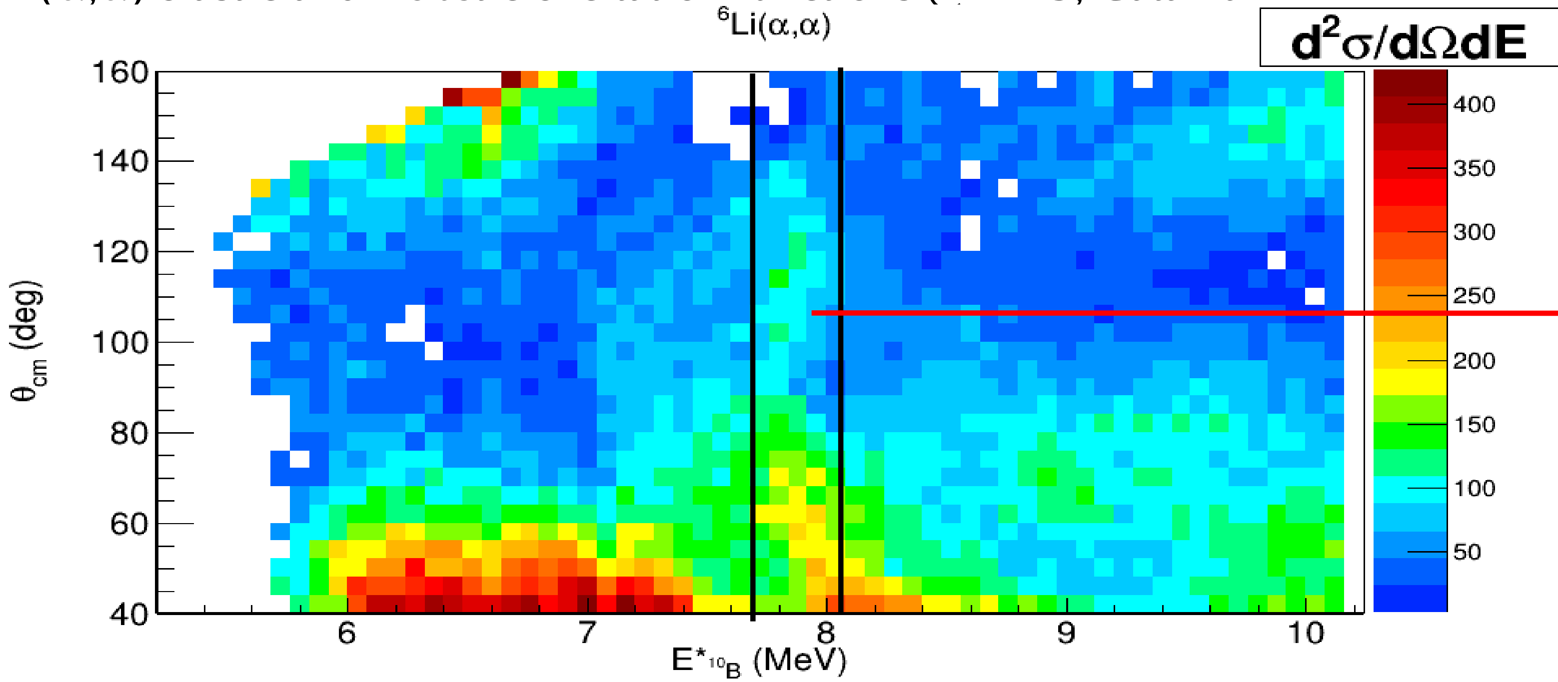
	iC_4H_{10}	H_2	CH_2
Pressure for stopping the beam	206 mbar	2.87 bar	165 µm
dN_{proton}/dE @ 3*A* MeV (protons/MeV)	$2.4.10^{20}$	$7.2.10^{20}$	$2.2.10^{20}$
Angular straggling for 5 MeV proton on 10 cm gas	11 mrad	6.5 mrad	12.6 mrad

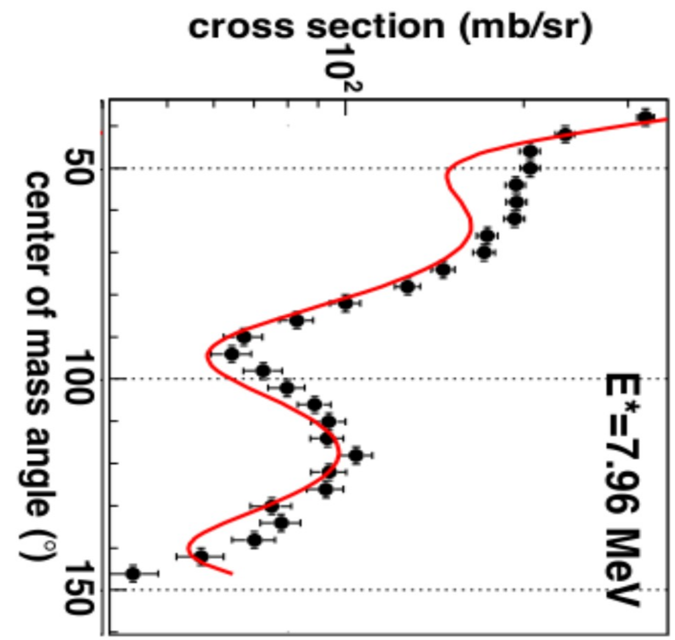
→ requires high pressure (partially accomplished)
→ requires amplification system for pure mono/diatomic gas (GEM): ongoing

Resonant scattering : 1st physics result

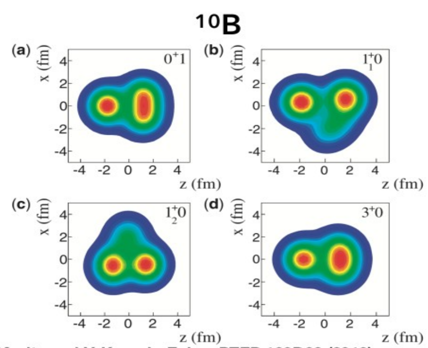
✓ Search for α-cluster states in ^{10}B (B. Mauss, PhD thesis – to be published)

^{6}Li(α,α) elastic and inelastic excitation functions @ LNS, Catania

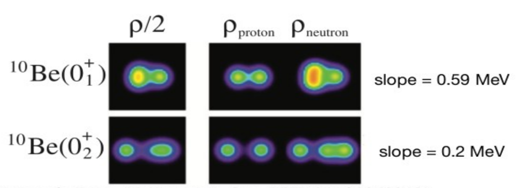




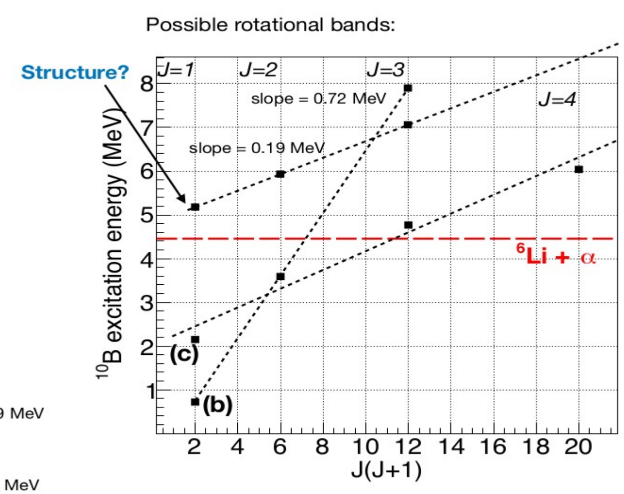
3+ state @ 7.9 MeV,
large alpha decay width



H. Morita and Y. Kanada-En'yo, PTEP 103D02 (2016)



Y. Kanada-En'yo, M. Kimura, A. Ono, PTEP, 01A202 (2012)

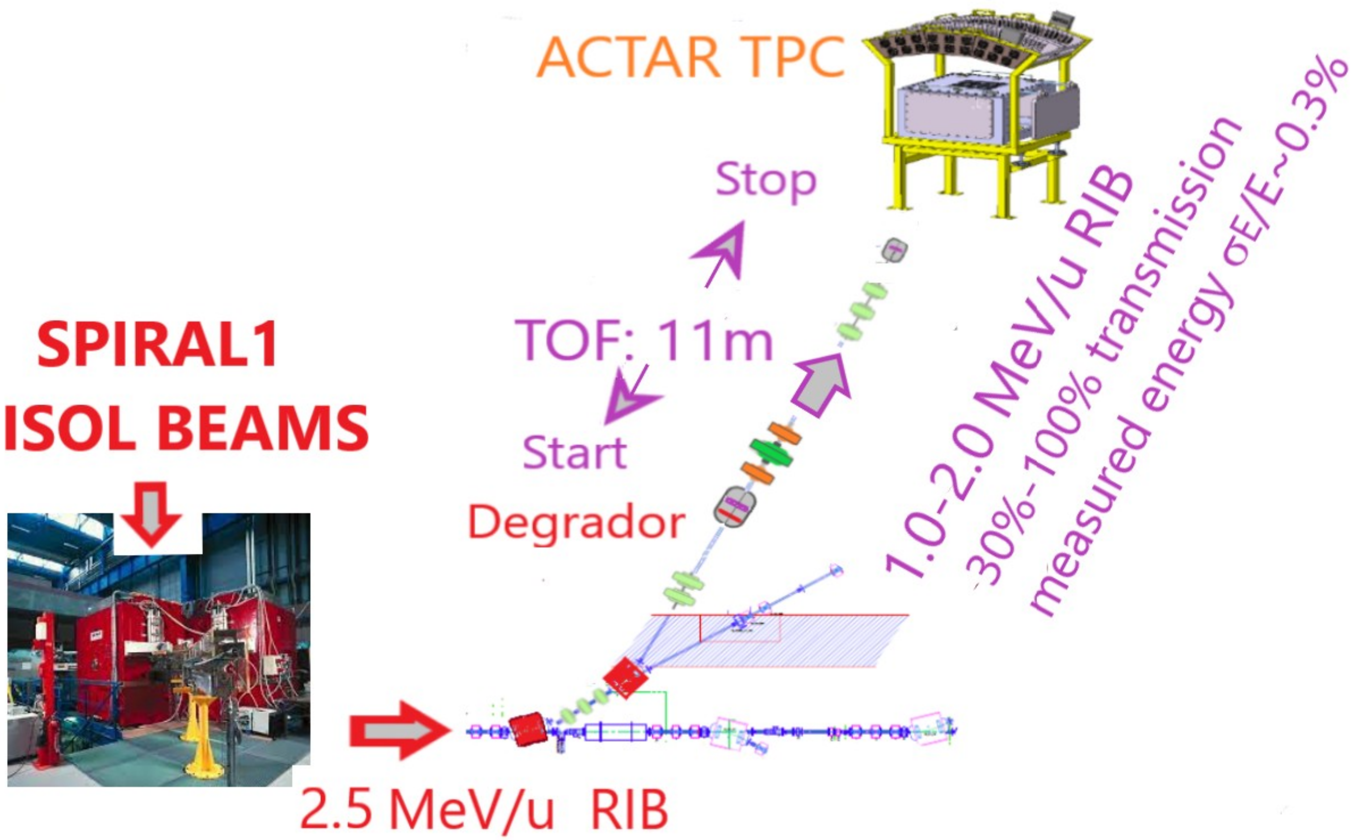


Preliminary work, B. Mauss

Reactions for astrophysics

✓ Beam line modifications required for ^{8}Li(α,n) reaction @ 1.2*A* MeV (Expt. M.G. Pellegriti – 2024)

→ CIME cyclotron has (very) low transport efficiency below 2*A* MeV
→ Energy degradation in the physics room (G2)
  → Large acceptance Qpoles to reach 100% transmission (for 1 charge state)
  → Energy dispersion due to straggling & degrader inhomogeneities: reconstruction of the incident beam energy with ToF (event by event): 0.3% resolution possible up to 10^5 pps



Reactions for astrophysics

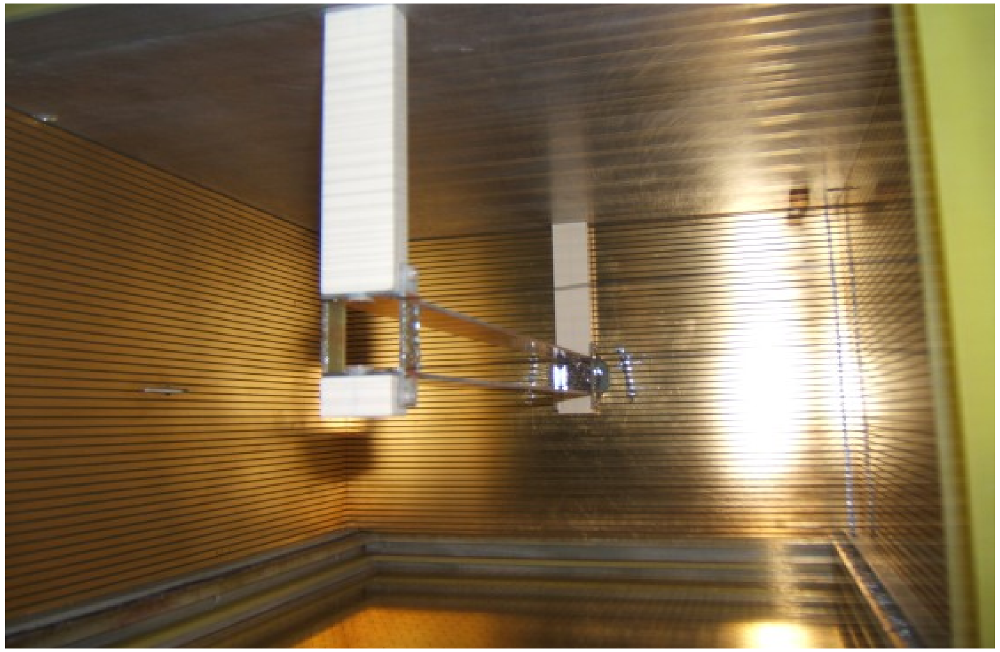
✓ New development for high intensity / heavy beams: electrostatic beam mask

High intensity / heavy beams will create important space charge in ACTAR

→ Space charge will distort the drift electric field and create deformed tracks

→ Beam region must be screened to minimize the distortions

→ Construction of an electrostatic beam mask (ongoing)

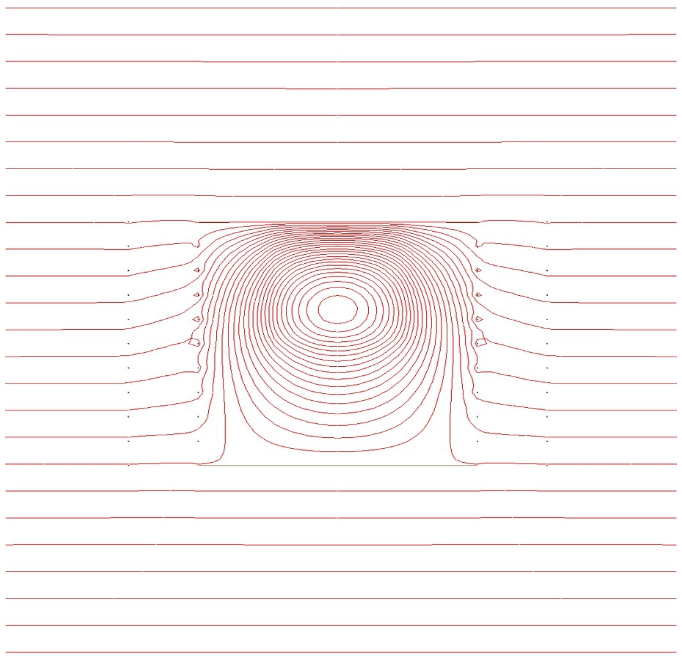


*C. Rodriguez et al., NIM A**768**, 179 (2014)*

mask with double wire planes

space charge density 140 pC/cm3

→ Equivalent: 10^6 Hz of ^{136}Xe @ 7A MeV in 100 mbar iC_4H_{10}



Simulations: R. Revenko (GANIL)

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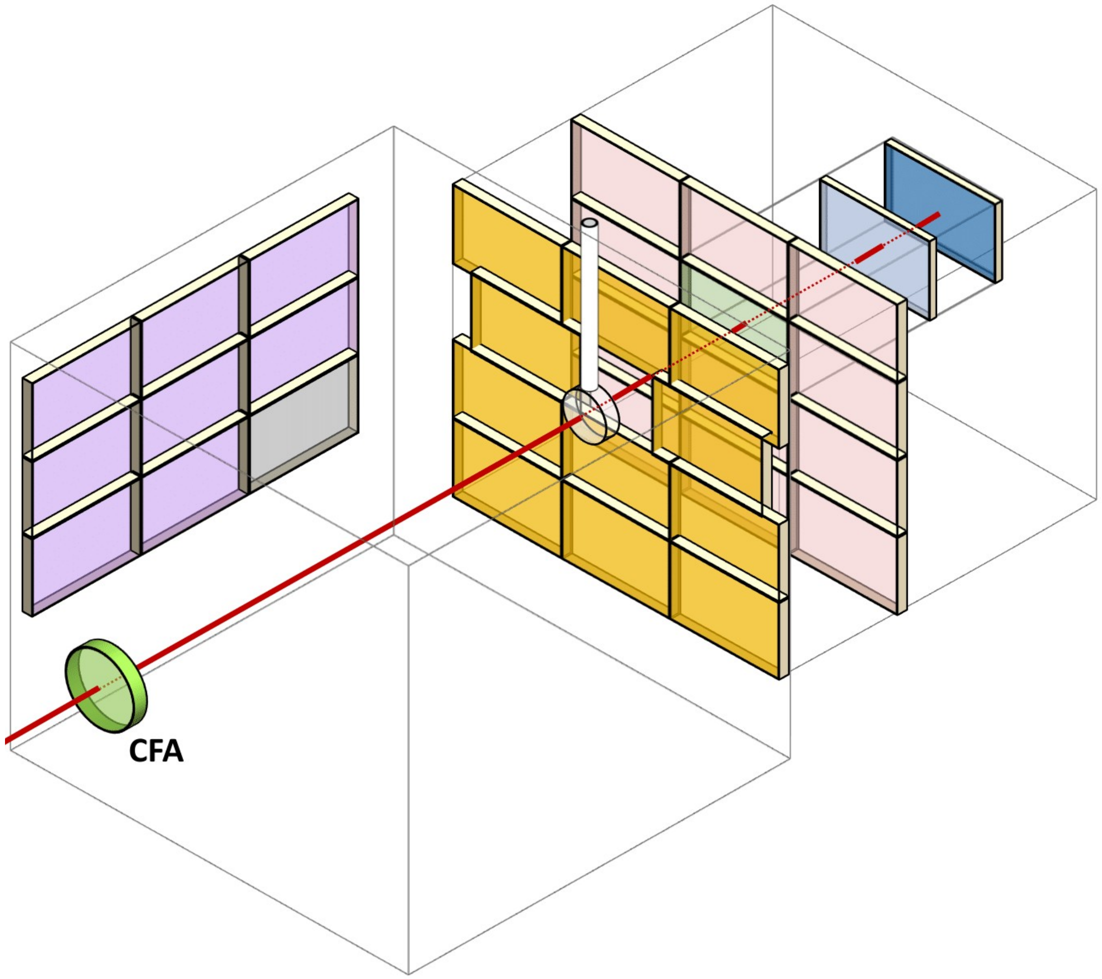
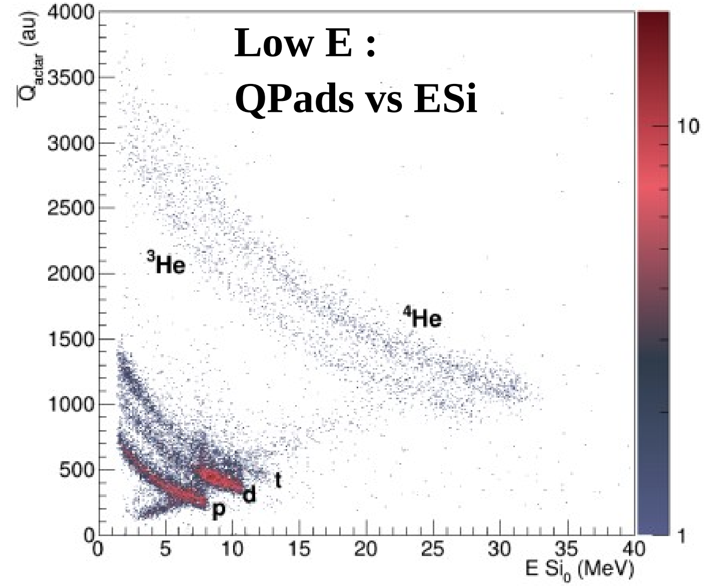
Transfer reactions

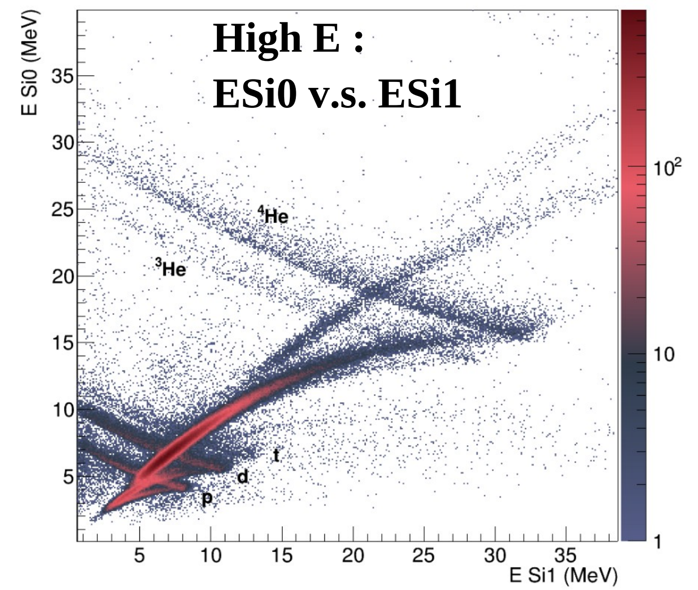
✓ Study of the ^{19}N(d,^{3}He) reaction (2020-2021-2022)

^{19}N at 30A MeV in 1 bar D_2(90%) + iC_4H_{10} (10%) → Equivalent **11 mg/cm^2** CD_2 target + **5.4 mg/cm^2** CH_2 target

J. Lois-Fuentes PhD thesis (IGFAE – USC - 2023)







Solid state detectors can be placed on 4 sides (according to the reaction kinematics)

PID can be performed for a wide range of energy

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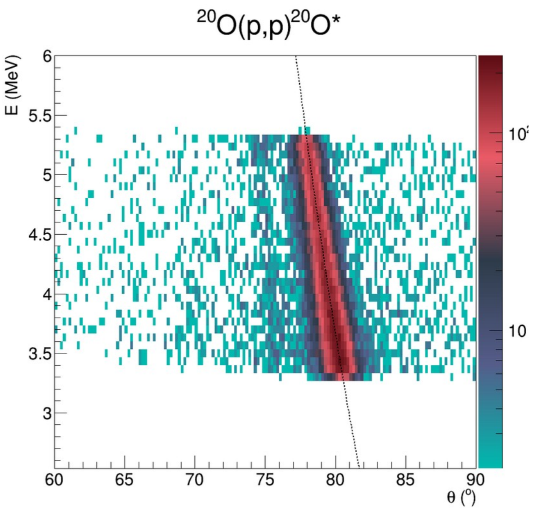
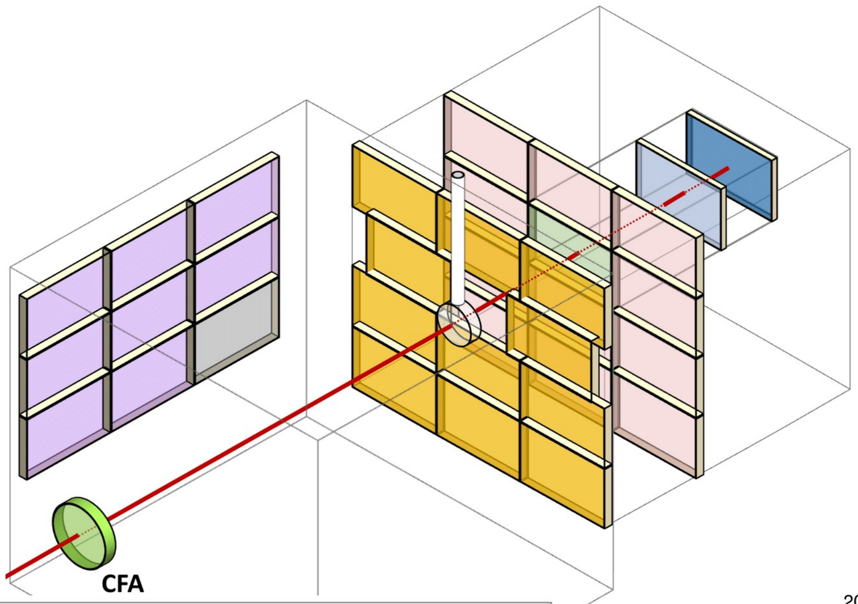
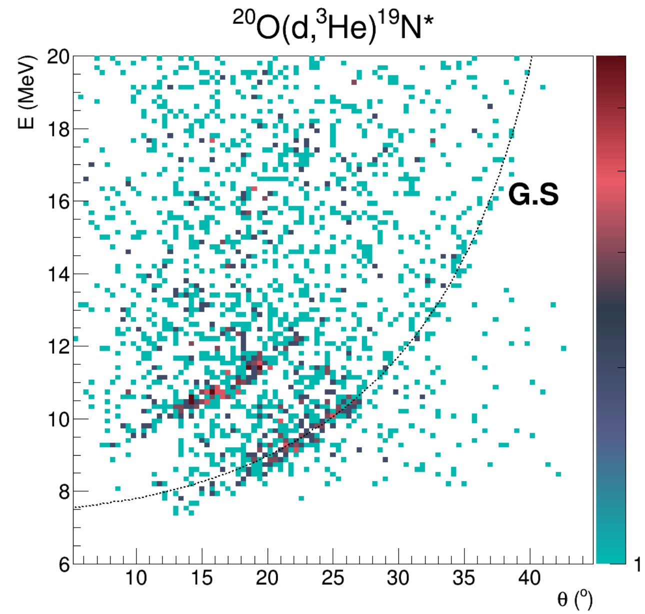
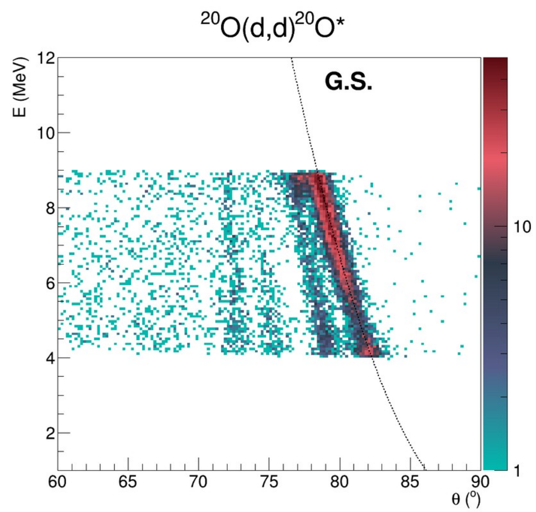
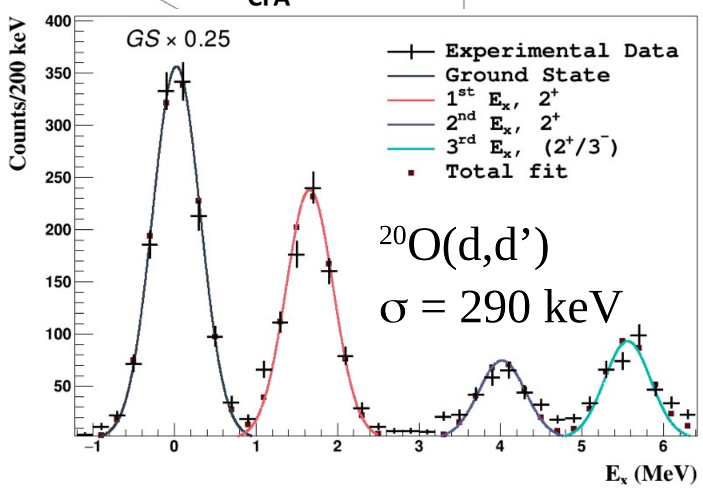
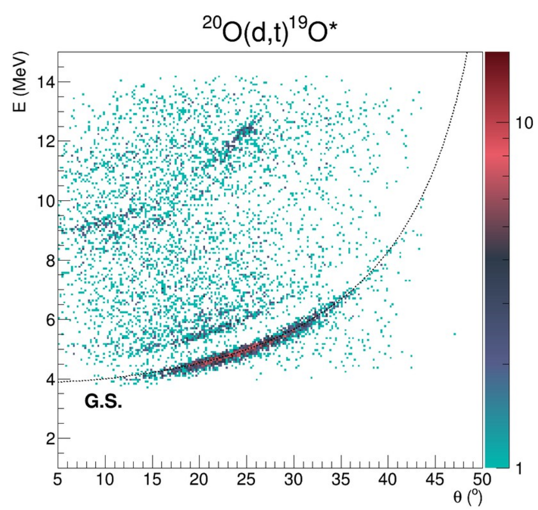


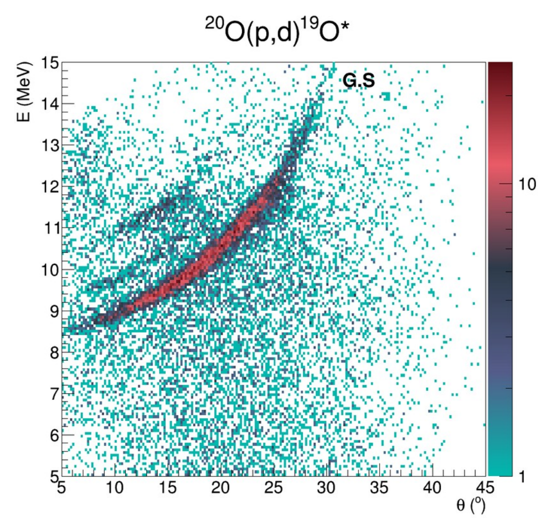












Thick target, E* resolution limited by the Silicon energy resolution…

Transfer reactions

✓ Future upgrade: pure ^{3}He target

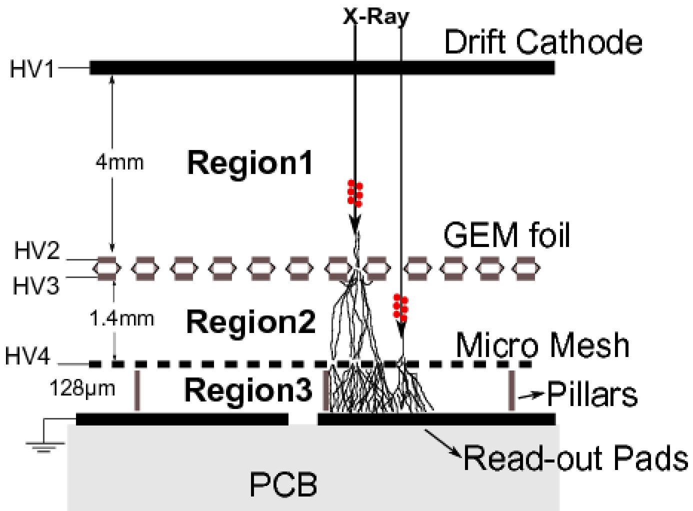
Scientific motivations:

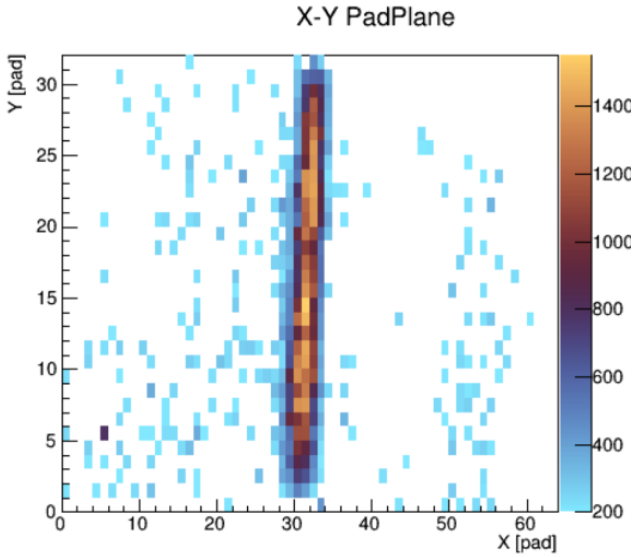
- (^{3}He,d) one proton transfer reaction for determining the resonances parameters (E*, J$^\pi$, Γ, …) in reactions involved in Type I X-ray burst events (F. Hammache, N. de Séréville – IJCLab)
- (^{3}He,d) and (d,^{3}He) reactions as mirrors of (d,p) and (p,d) reactions to study proton shell evolution (O. Sorlin, T. Roger - GANIL)
- (^{3}He,d) to study proton unbound nuclei (B. Fernandez Dominguez - IGFAE)

Technical developments: - working with pure monoatomic gases (Micromegas+ThGEM)
- gas purification/recirculation: K. Rojeeta Devi et al., NIM A1069, 169866 (2024)

Project financed by:

- Région Normandie (gas purification and recirculation part)
- ANR (Joint project IJCLab / GANIL for ^{3}He cryogenic and active targets)





Summary

✓ Resonant scattering : Ecm resolution dominated by the angular straggling in the gas
→ Optimized with pure H_2 gas (proton scattering)
→ New setup for “low energy” beams ongoing
→ Technical development for high intensity/heavy beams

✓ Implantation / decay : Tested for 3 different experiments:
→ OK for lifetimes > ~ 100 ns.
→ OK for small branching ratio (no beta background)
→ OK for multiparticle tracking

✓ Transfer reactions : thick target with resolution of thin target
possibilities with mixed targets (^{1}H+^{2}H)
^{3}He target coming soon (2027-2028)

Future plans for ACTAR TPC

✓ 2025: Campaign in TRIUMF

✓ 2026: Back to GANIL, on LISE (before QD6)?
→ Proposal to be submitted to the 2025 GANIL PAC
→ Contact the collaboration in advance (pre-PAC will be organized mid-2025)

ACTAR TPC Collaboration

GANIL

LP2i Bordeaux

IGFAE
Instituto Galego de Física de Altas Enerxías

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University of Regina

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