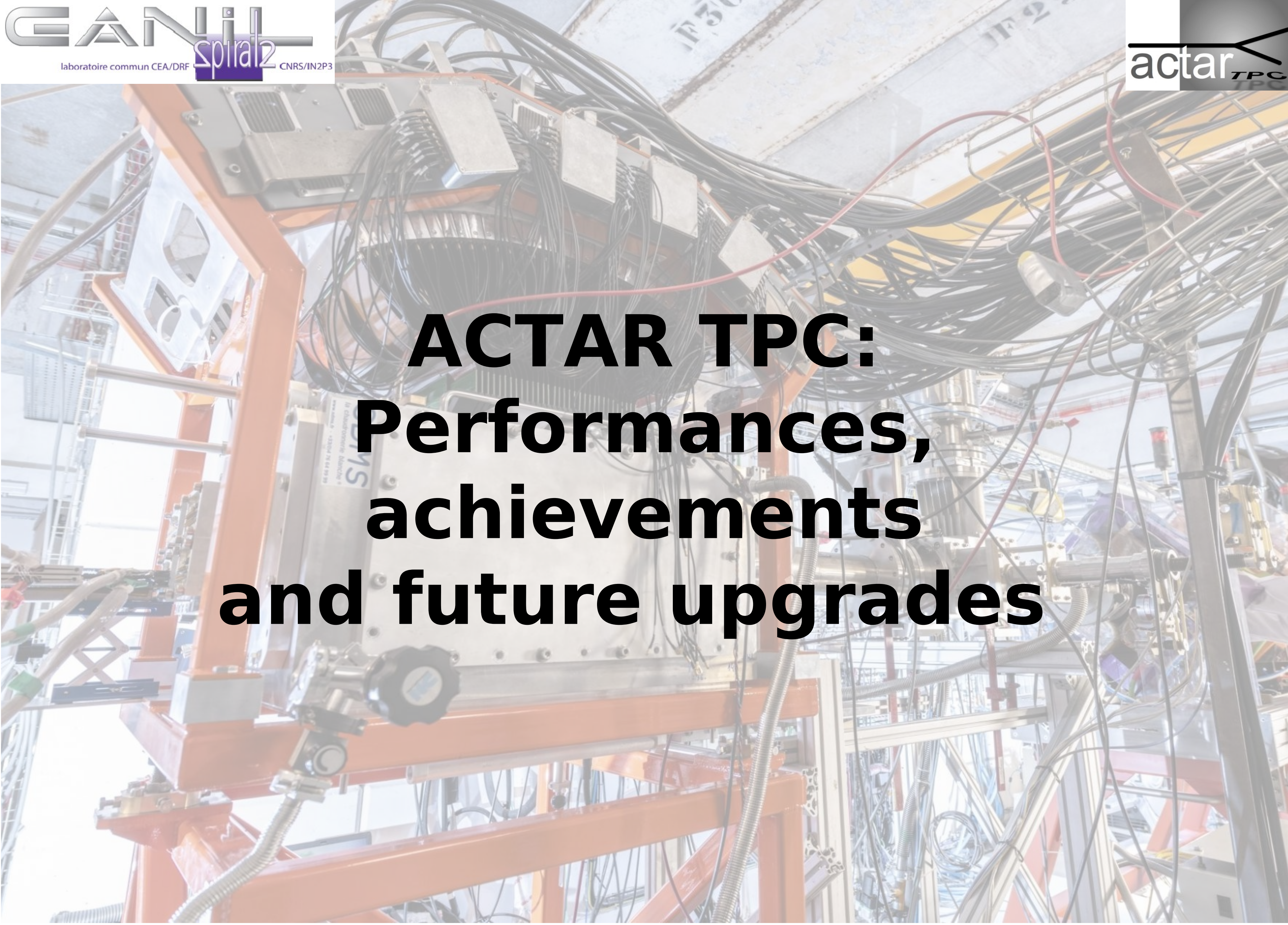
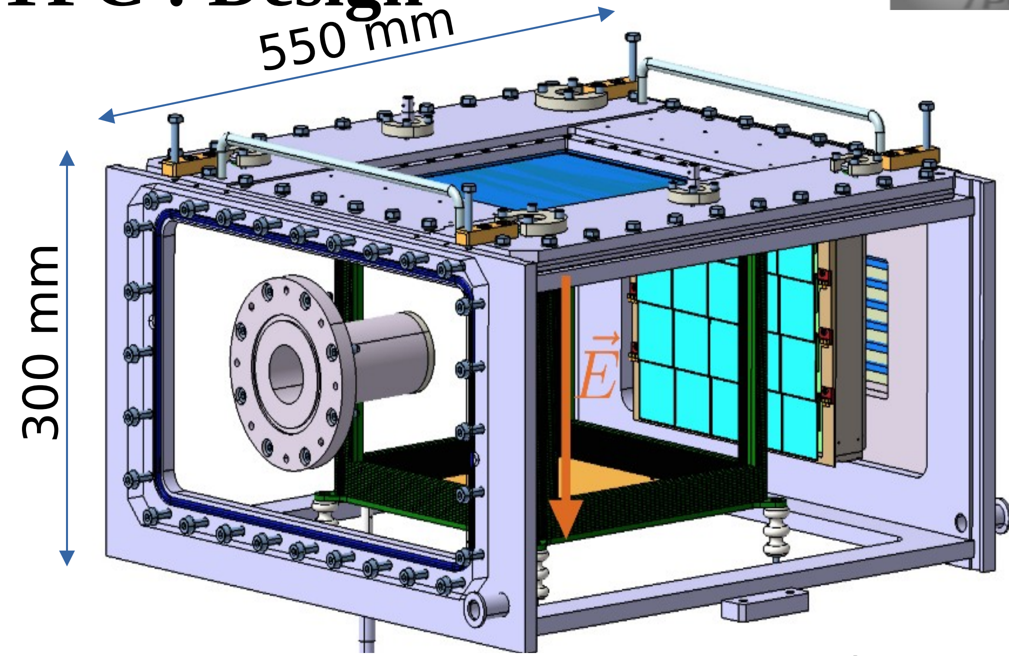


ACTAR TPC: Performances, achievements and future upgrades

ACTAR TPC : Design

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

→ Wire field cage

- Homogeneous vertical drift electric field

→ Double wire field cage: 2 mm/1 mm pitch

✓ 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!

→ Two solutions investigated

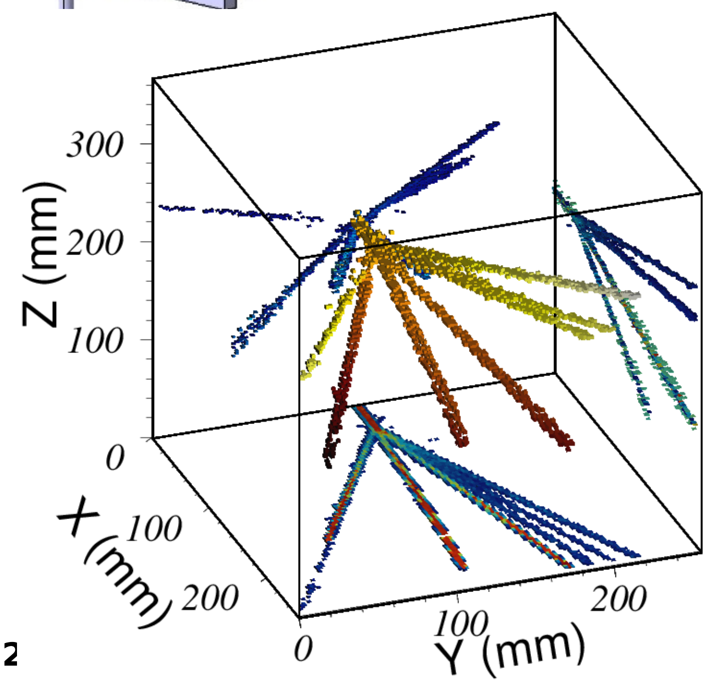
✓ Electronics: GET

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:

- Study of excitation functions (resonant scattering, etc...)
  → thick target, need to differentiate the reactions channels
- Reactions with very negative Q-value in inverse kinematics
  → recoil stops inside the target
- Reactions with (very) low intensity beams
  → thick target, possibly no ^{12}C contamination
- Time Projection Chamber mode
  → Ideal for implantation/decay studies

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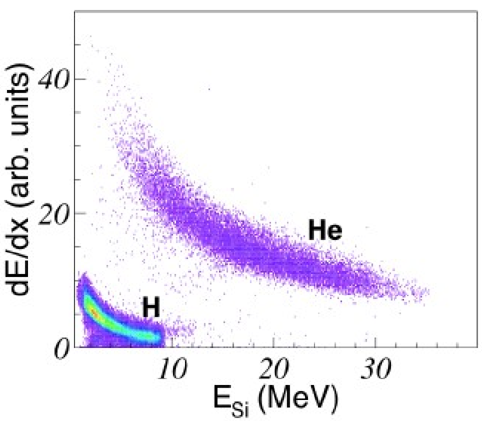
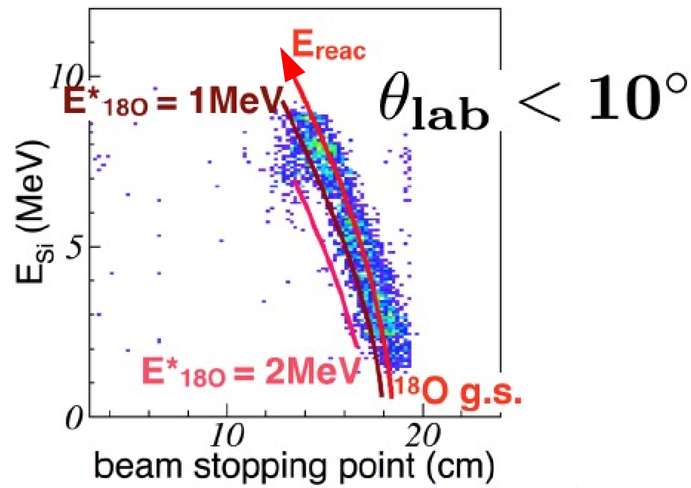
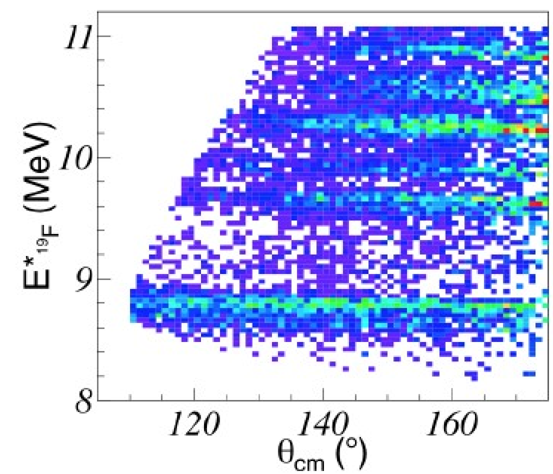
Resonant scattering : principle

- "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)







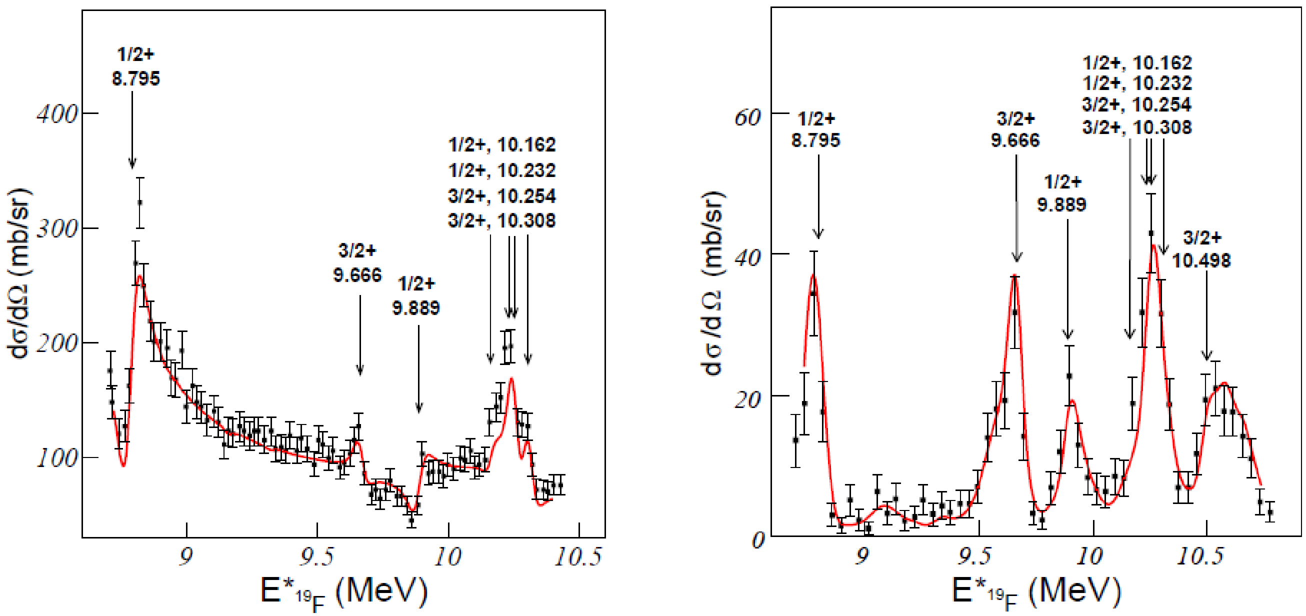
Particle identification → Tracking algorithm → Channel selection → Reaction kinematics + energy loss tables → Double differential cross section

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

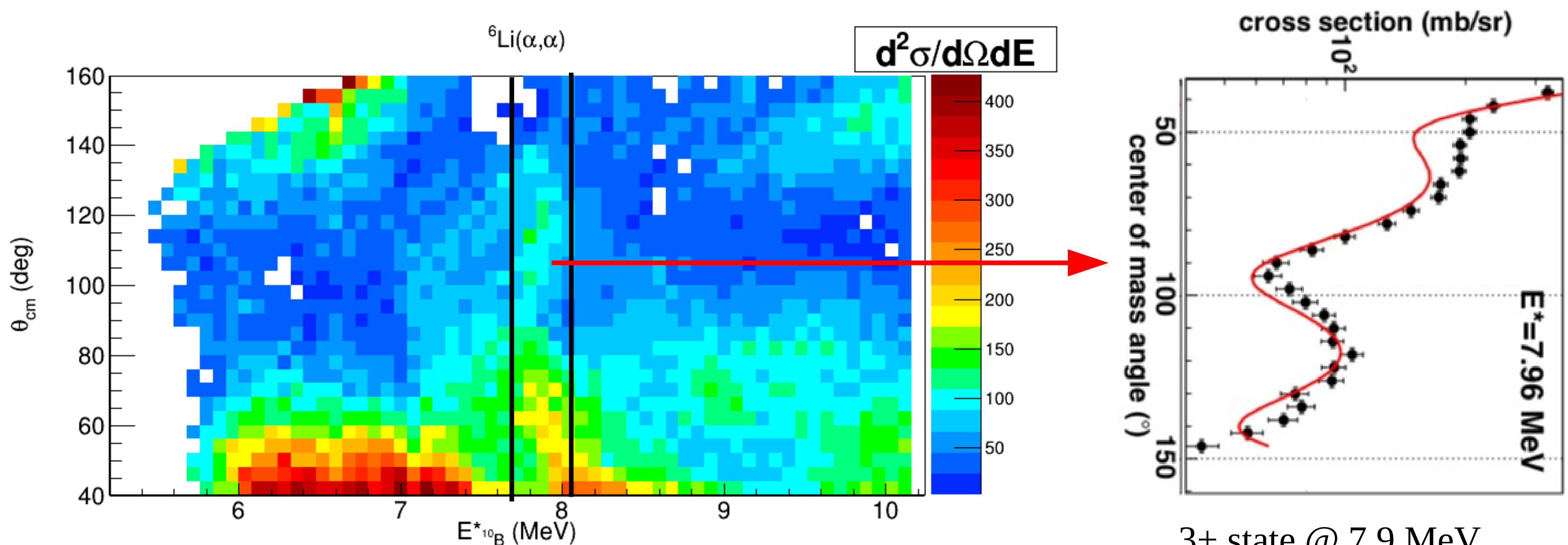
	iC_4H_{10}	H_2	CH_2
Pressure for stopping the beam	206 mbar	2.87 bar	165 µm
dN_{proton}/dE @ 3*A* MeV (protons/MeV)	$2.4.10^{20}$	$7.2.10^{20}$	$2.2.10^{20}$
Angular straggling for 5 MeV proton on 10 cm gas	11 mrad	6.5 mrad	12.6 mrad

→ 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)

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



3+ state @ 7.9 MeV,
large alpha decay width

Preliminary work, B. Mauss

Resonant scattering : 1st physics result

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

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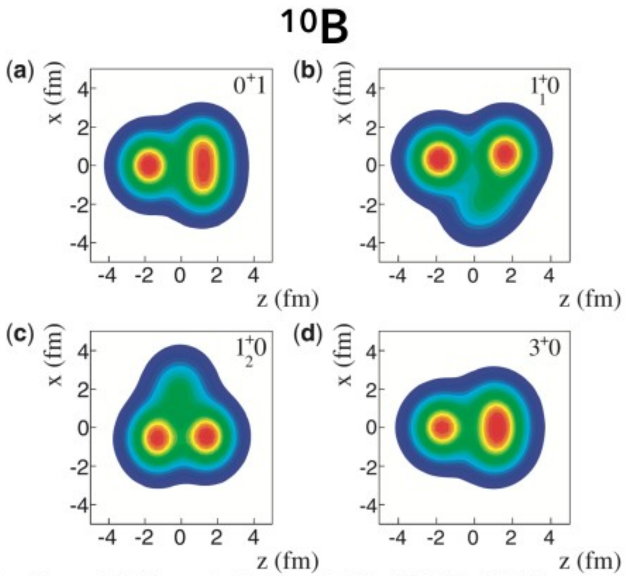
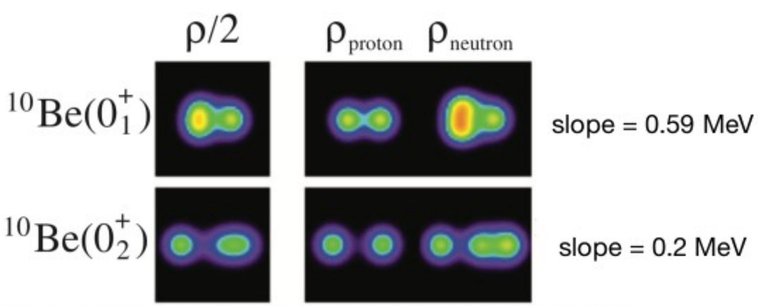
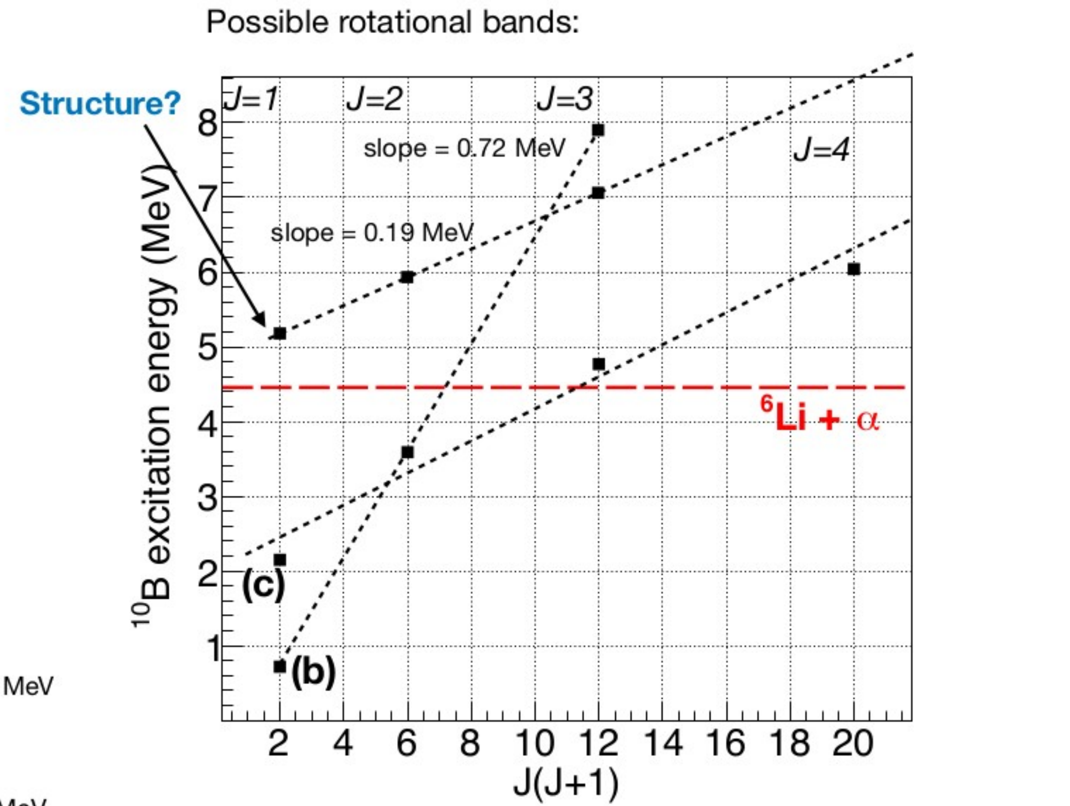


H. Morita and Y. Kanada-En'yo, PTEP 103D02 (2016)



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



→ Large similarities with ^{10}Be rotational bands

Interpretation ongoing...

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

Physics cases addressed:

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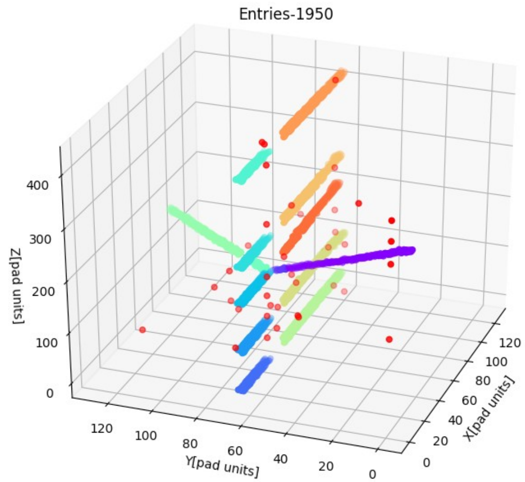
Time Projection Chamber mode

→ Ideal for implantation/decay studies

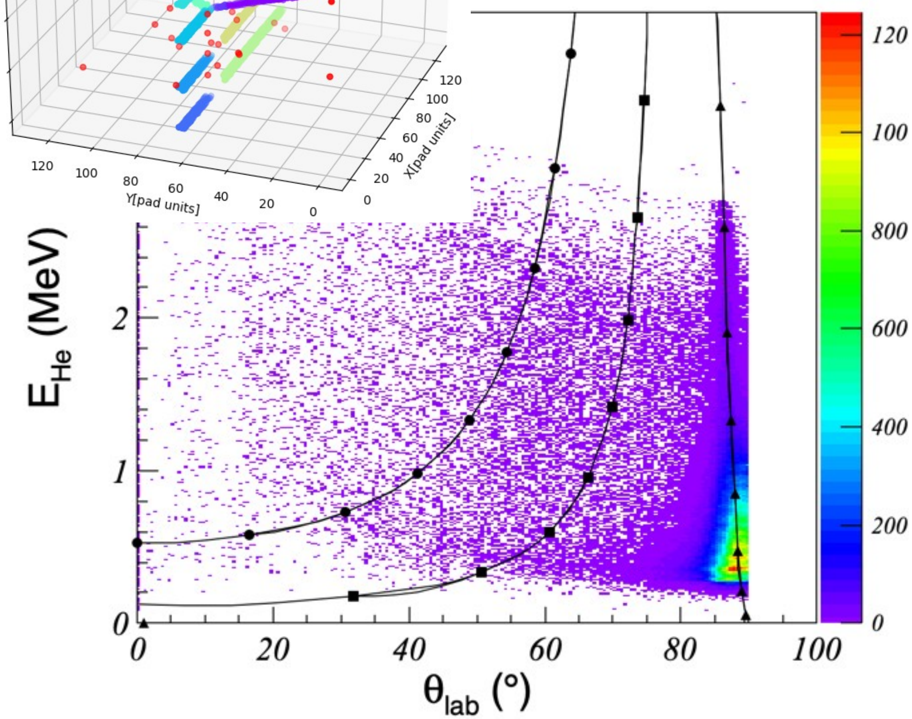
Inelastic scattering : performances

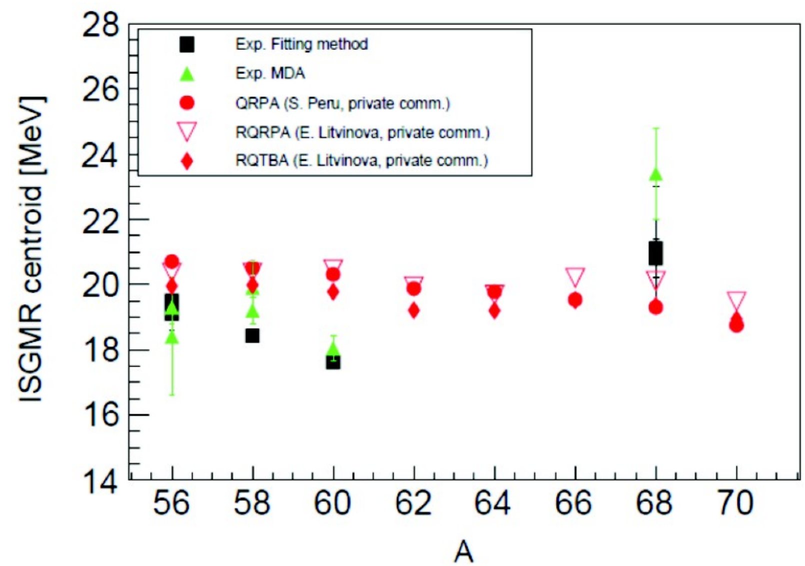
✓ Study of the Giant Monopole Resonance in the Ni chain (April 2019)

^{58,68}Ni(α,α') : → 49*A* MeV ^{58,68}Ni beams in 400 mbar He(98%) + CF_4(2%)



PhD thesis A. Arokia Raj (K.U. Leuven)
→ work in progress





Courtesy B. Mauss & M. Vandebrouck

- ✓ **Helium gas, 2.10^{20} α/cm^{-2}**
- ✓ **50 kHz beam (limit)**
- ✓ **Observation of 200 keV α**
  ➔ θ_{CM} > 1.5°

Inelastic scattering : performances

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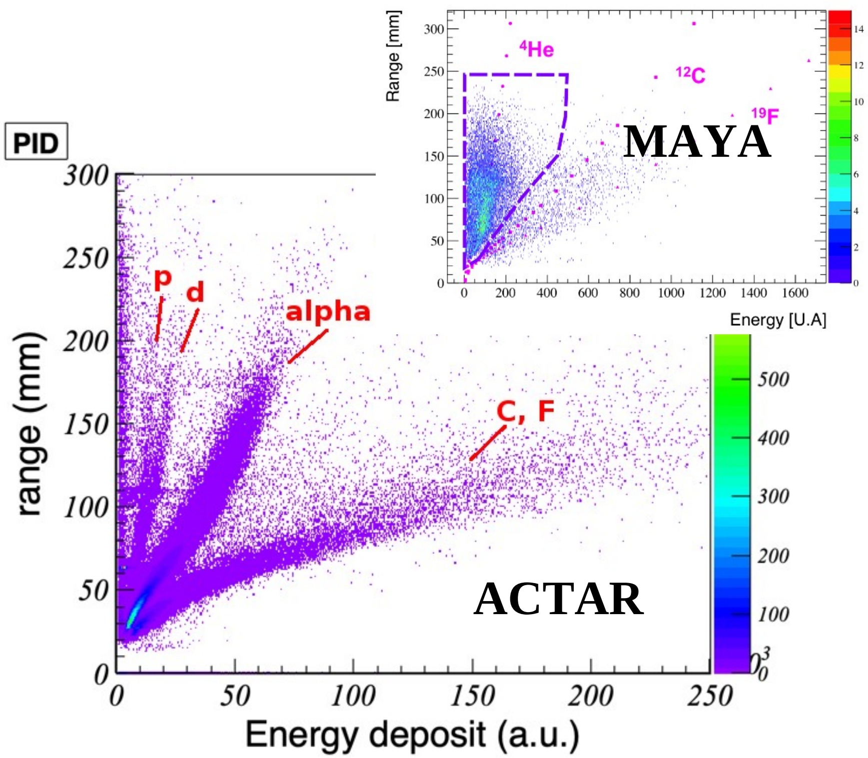

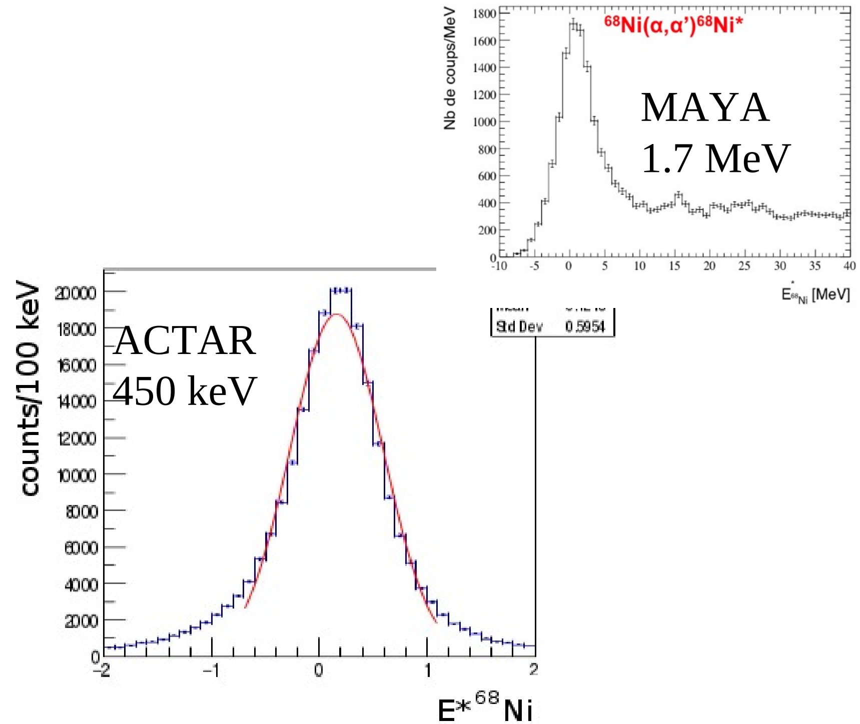

→ Elastic peak resolution for θ_{cm}<10°
Dominated by straggling (range) in the gas.

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

Physics cases addressed:

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

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Time Projection Chamber mode

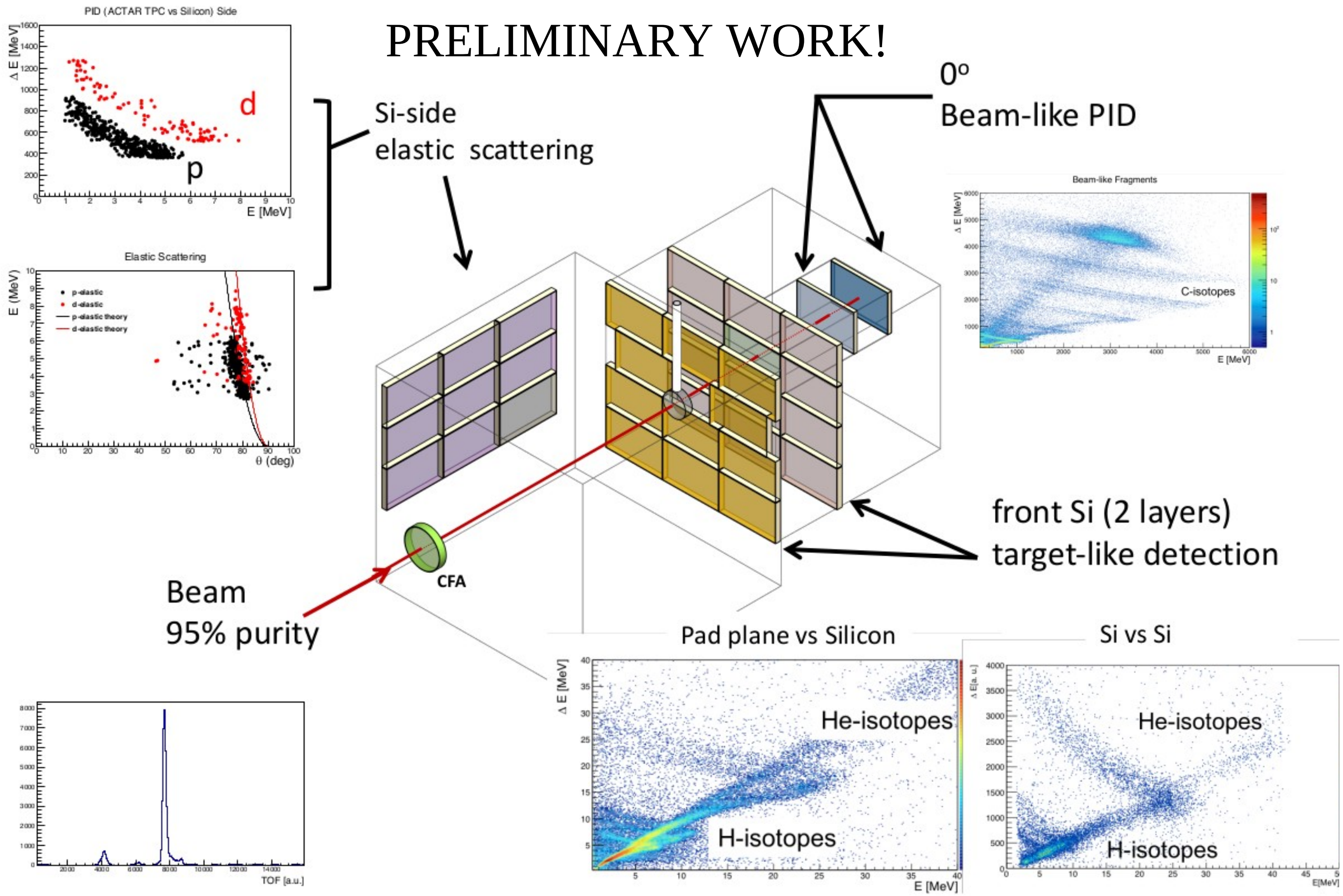
→ Ideal for implantation/decay studies

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/cm²** CD_2 target

J. Lois-Fuentes PhD thesis (U. Santiago de Compostella)



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

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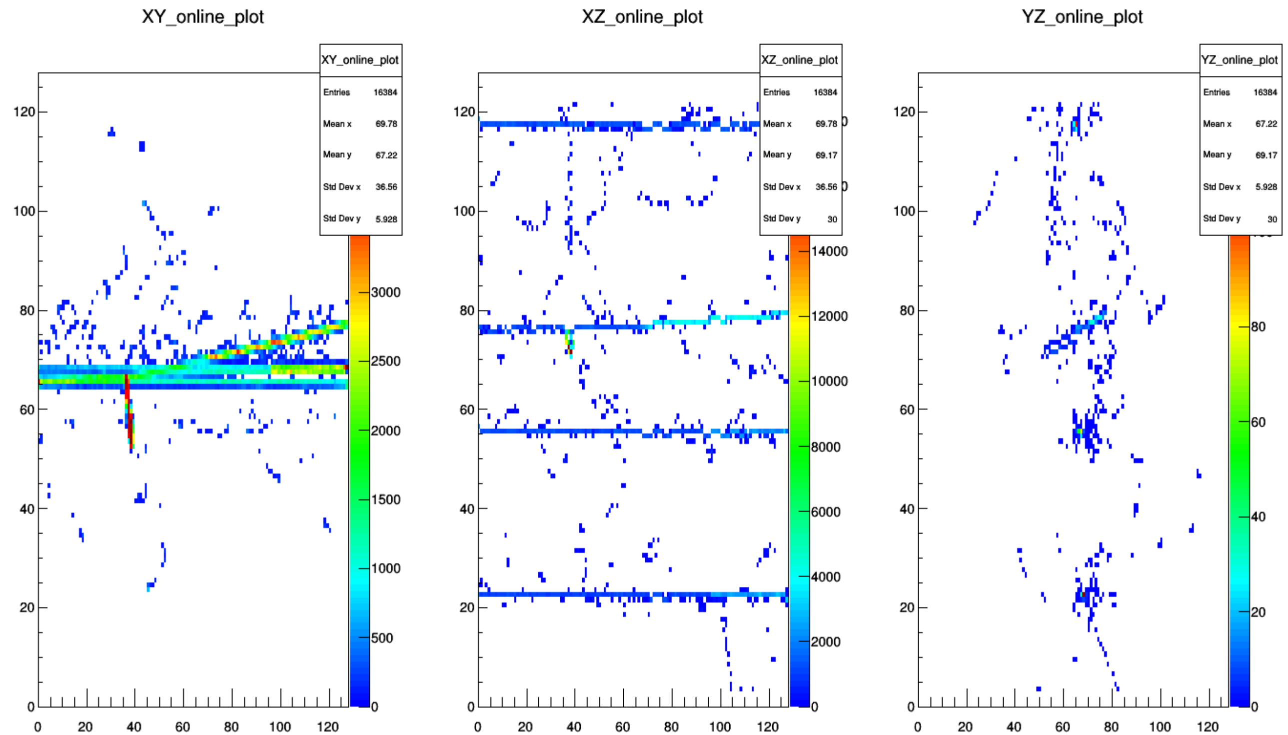


Thick target, E* resolution limited by the Silicon energy resolution…

BUT: Delta Electrons mess up things (pad multiplicity trigger not possible)

→ Visible with high energy beam & high gain (i.e. high energy light recoils)

Transfer reactions

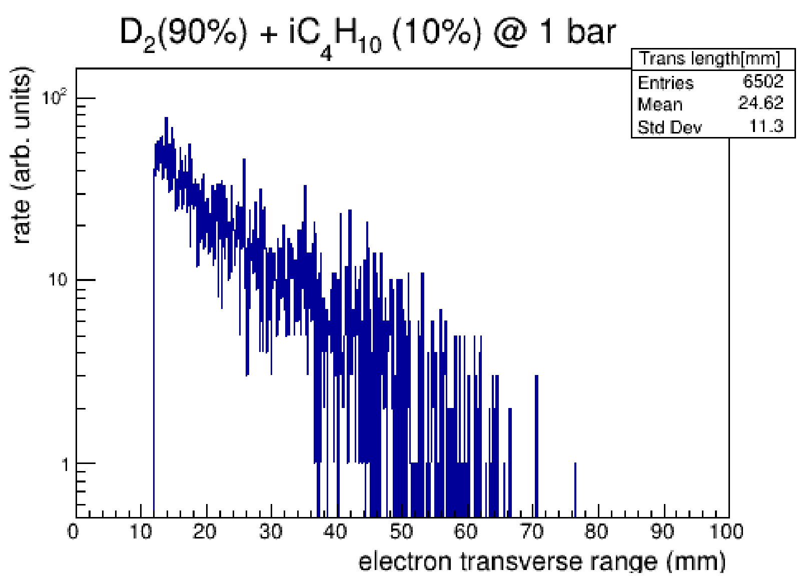
✓ Study of the ^{19}N(d,^{3}He) reaction (2020-2021)

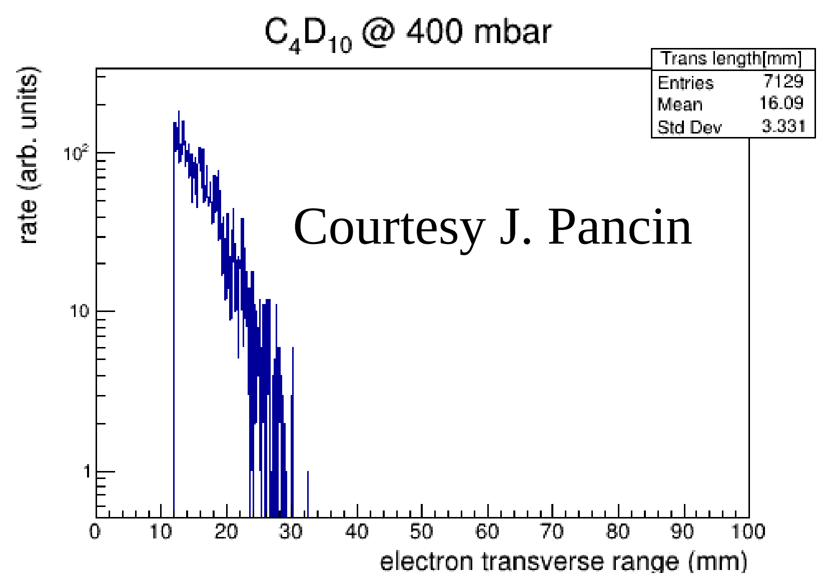
^{19}N at 30A MeV in 1 bar D_2(90%) + iC_4H_{10} (10%) → Equivalent **11 mg/cm²** CD_2 target

Problem of delta electrons: target with more stopping power

→ Ok for "high energy" recoils → losing (very) forward c.m. angles

→ e.g. C_4D_{10} @ 400 mbar → Equivalent **26 mg/cm²** CD_2 target





→ expensive gas! Requires Recirculation/Purification system (ongoing)

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

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- Time Projection Chamber mode

→ Ideal for implantation/decay studies

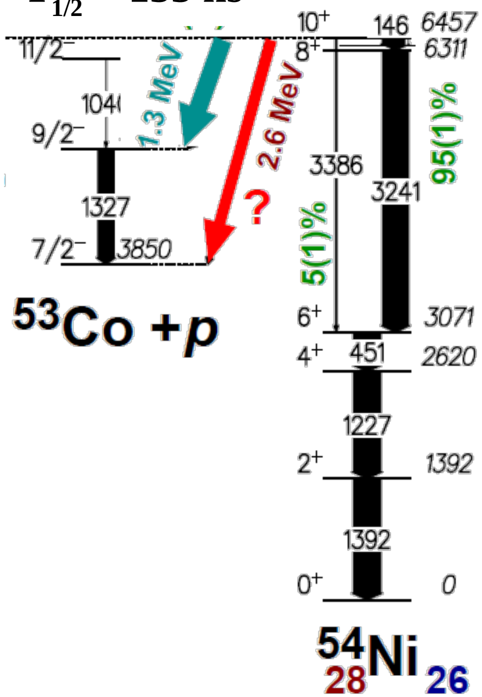
Implantation/Decay

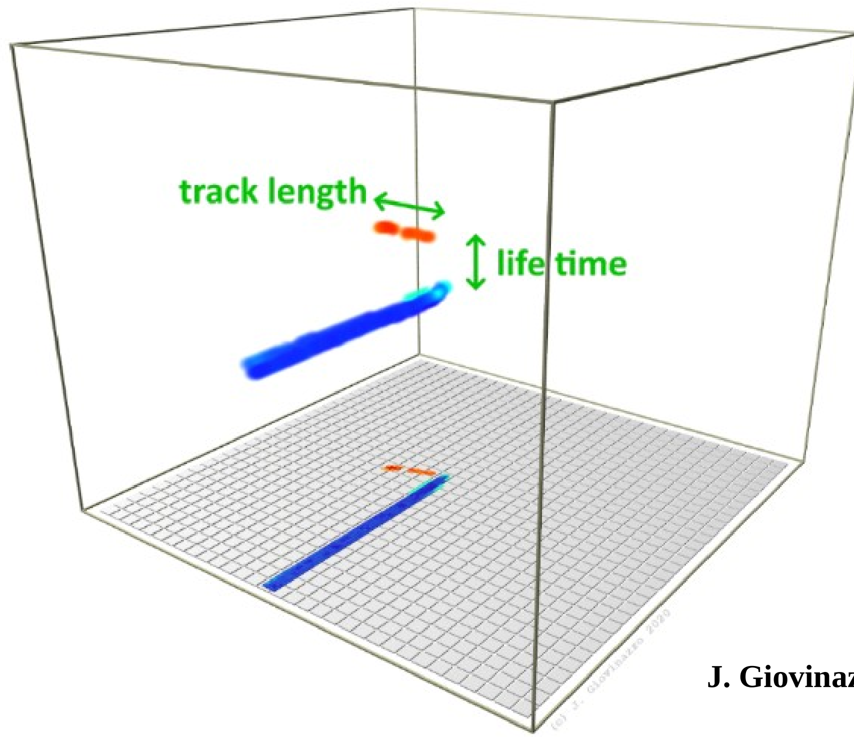
✓ Proton-decay branches from the 10^+ isomer in ^{54}Ni (May 2019)

^{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!**

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%)

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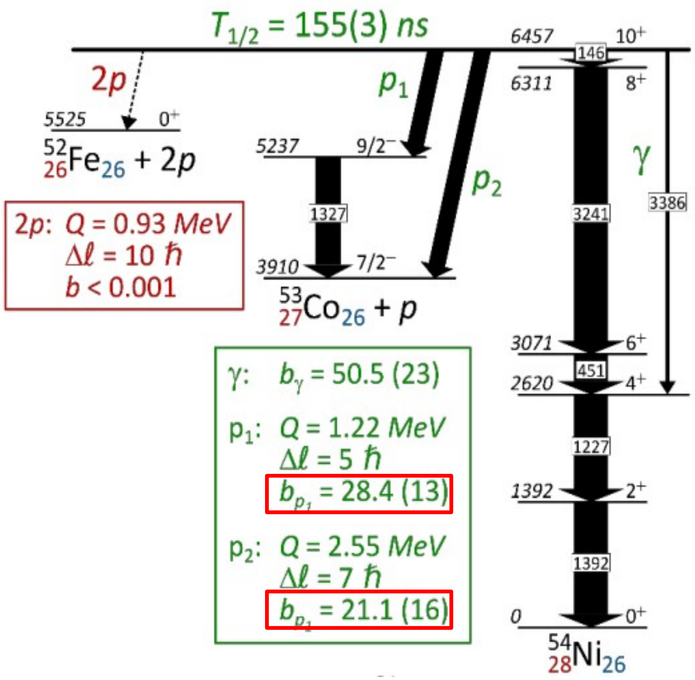
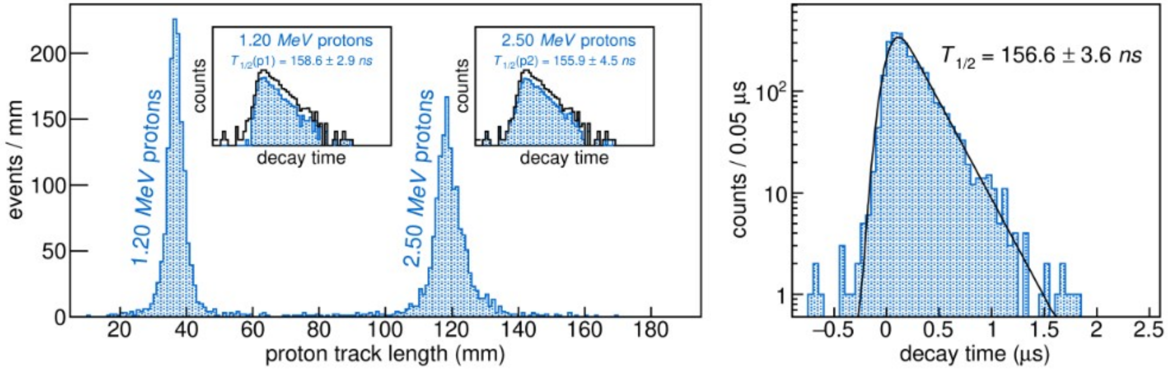




- Proton decay branches carry unusually high angular momentum

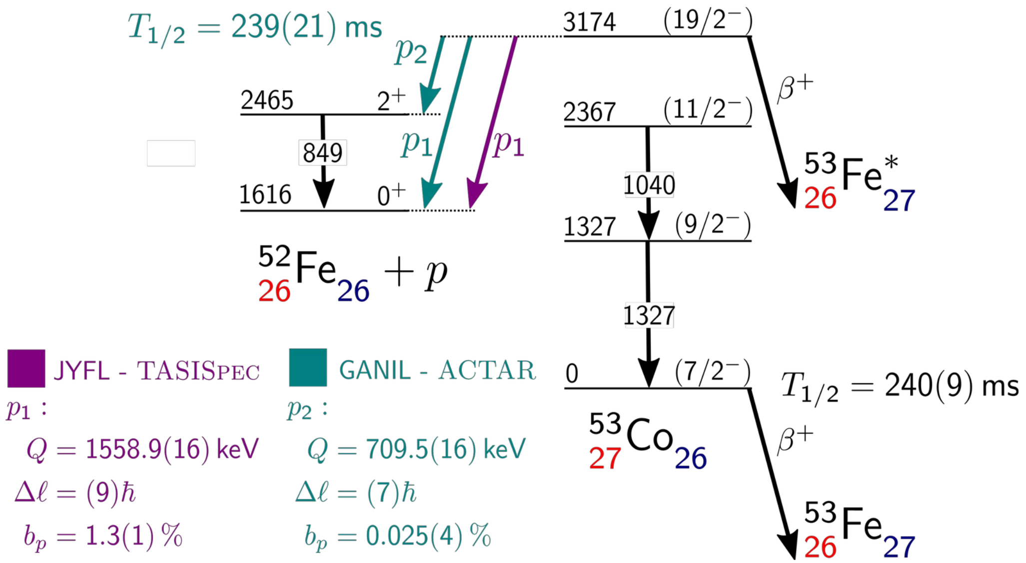
- Branching ratio approximated theoretically with potential model for barrier penetration & Shell Model calculation for the initial and final WF overlap
  → C^2S of the order of 10^{-6}

- 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

Implantation/Decay

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

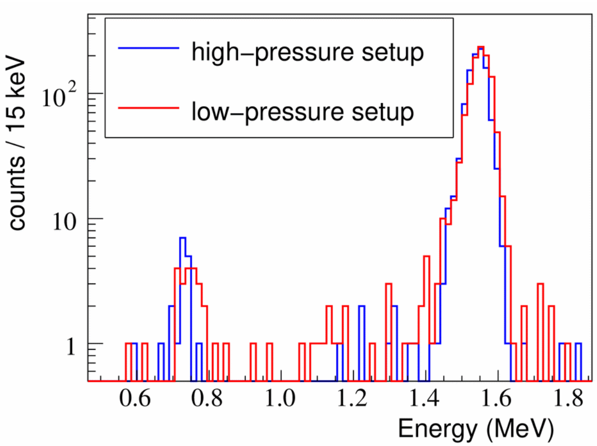
^{53}Co implantation – proton decay: → 10*A* MeV ^{53}Co beam in 400 mbar Ar(95%) + CF_4(5%)

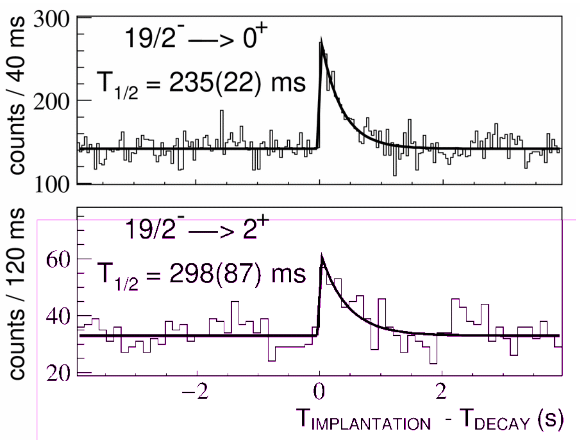


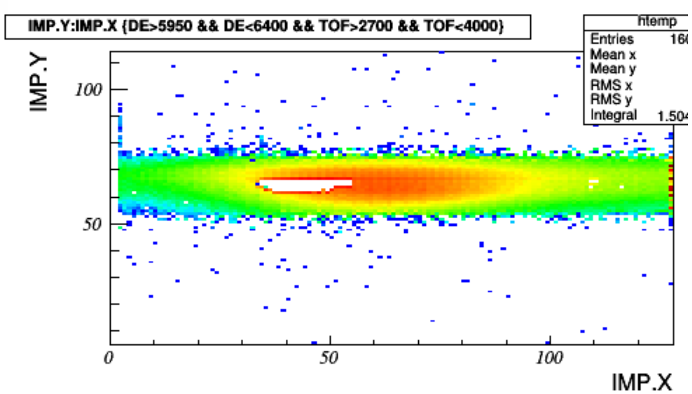
- ✓ **Decay of $T_{1/2}$ = 239 ms isomer : OK**
- ✓ **Measurement of 0.025 % BR : OK**
- ✓ **BUT : implantation profile larger than the TPC length**

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

L. Sarmiento et al.: to be published







Implantation/Decay

✓Two-Proton decay of ^{48}Ni (May 2021)

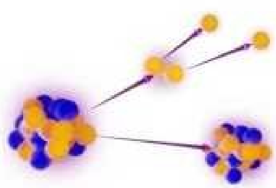
Two proton decay of ^{48}Ni with ACTAR TPC.

Aurora Ortega Moral

CENBG (CENTRE D'ETUDES NUCLEAIRES BORDEAUX-GRADIGNAN)

Colloque GANIL - September 2021

implantation profile larger than the TPC length



- Introduction
- Proton radioactivity
- ACTAR TPC
- Preliminary results
- Further results

CENBG

Aurora Ortega Moral | CENBG | Colloque GANIL 09/21

Two proton decay of ^{48}Ni with ACTAR TPC. | 1 / 15

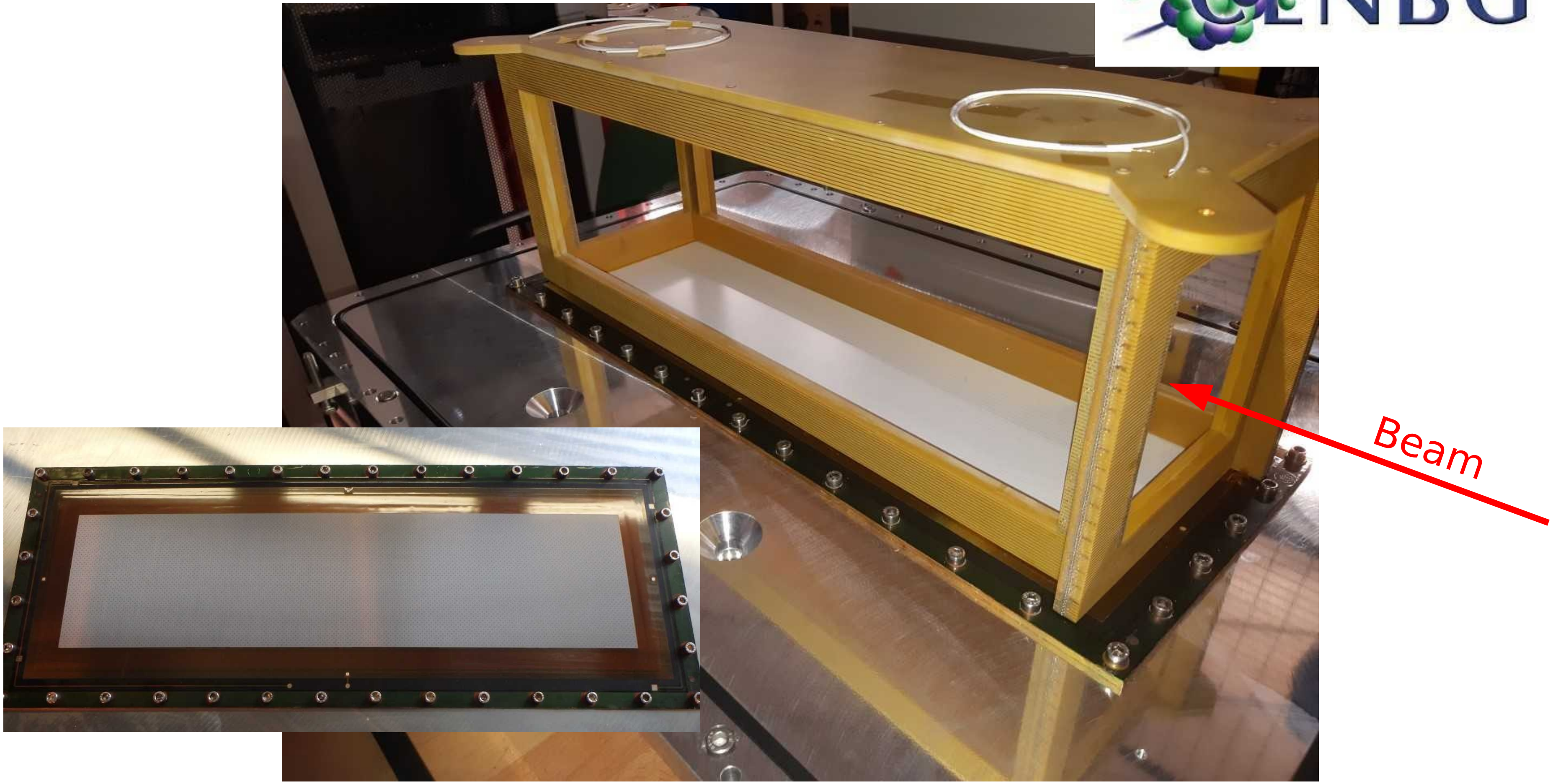
Implantation/Decay

Implantation profile larger than the TPC length : inherent to “high energy” fragmentation beams: straggling

→ Use a longer TPC !

→ L-ACTAR : 256 x 64 pads (512 mm x 128 mm)

CENBG



Summary

✓ Resonant scattering : Ecm resolution dominated by the angular straggling in the gas
→ Optimized with pure H_2 gas (proton scattering)

✓ Inelastic scattering : access to (very) forward cm angles. Resolution in E^* dominated by the range straggling in the gas
→ No real amelioration possible

✓ Implantation / decay : no detection dynamics problem, OK for lifetimes > ~ 100 ns. Possible problem due to the large implantation profile inherent to fragmentation beams
→ Built a twice longer detector

✓ Transfer reactions : possibly very efficient for low energy beams (no delta rays) Not ideal for high energy reactions → Better use « classic » method (MUGAST/GRIT) when possible

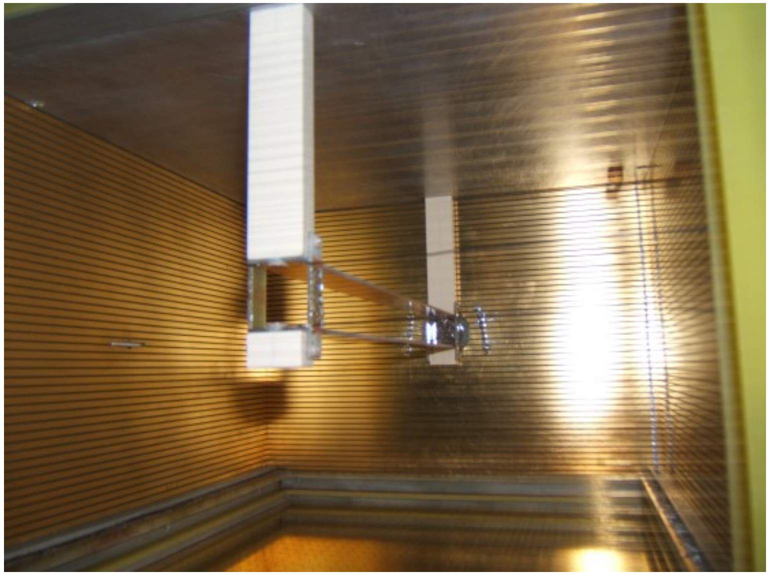
Future developments

✓ LoI (C. Borcea et al.): use ACTAR TPC for SHE synthesis via two body reactions producing high energy α particles at 0° using $^{132/134}Xe$ gas for target

1. Requires to send high intensity / heavy beam in ACTAR

→ Beam region must be screened to prevent distortions of the drift electric field

→ Construction of an electrostatic beam mask (ongoing)

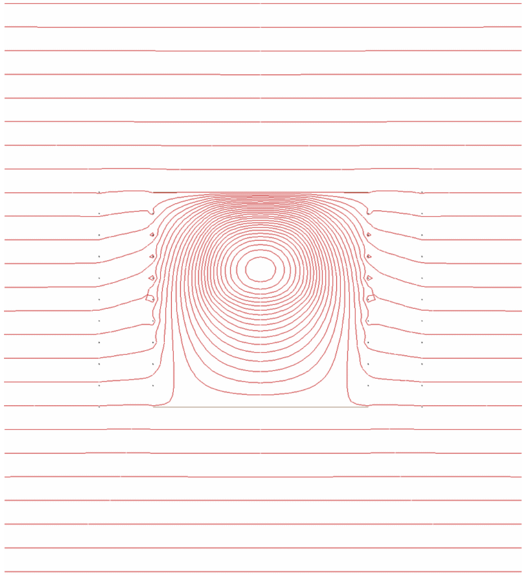


*C. Rodriguez et al., NIM A**768**, 179 (2014)*

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)

Future developments

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1. Requires to send high intensity / heavy beam in ACTAR
   → Beam region must be screened to prevent distortions of the drift electric field
   → Construction of an electrostatic beam mask (ongoing)

2. Requires to recirculate (and purify) the gas

→ Project financed by Région Normandie

→ **Postdoc position opened for 2 years at GANIL**

ACTAR TPC Collaboration