Workshop On Active Target and Time Projection Chamber

17th of January 2018

The ACTAR TPC and its Physics Program

Pierre Morfouace
on behalf of the ACTAR TPC collaboration
GANIL
morfouace@ganil.fr

Outline

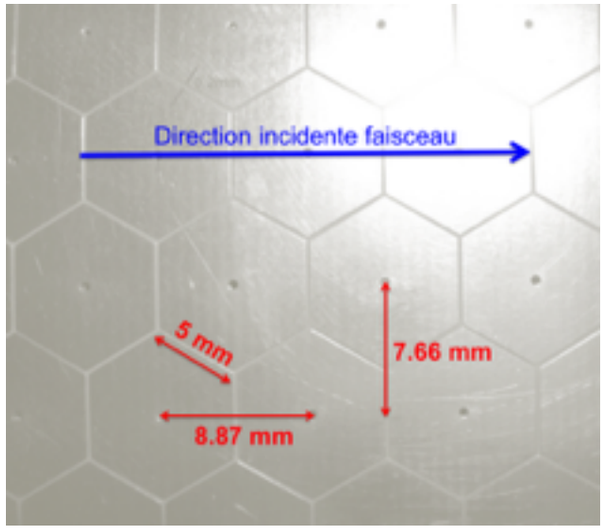
- Active target
- The ACTAR TPC
  - Mechanical design
  - Electronics
- The Physics cases
- Experiments approved at GANIL
  - Resonant elastic scattering
  - shell evolution
  - Exotic decay: two-proton decay

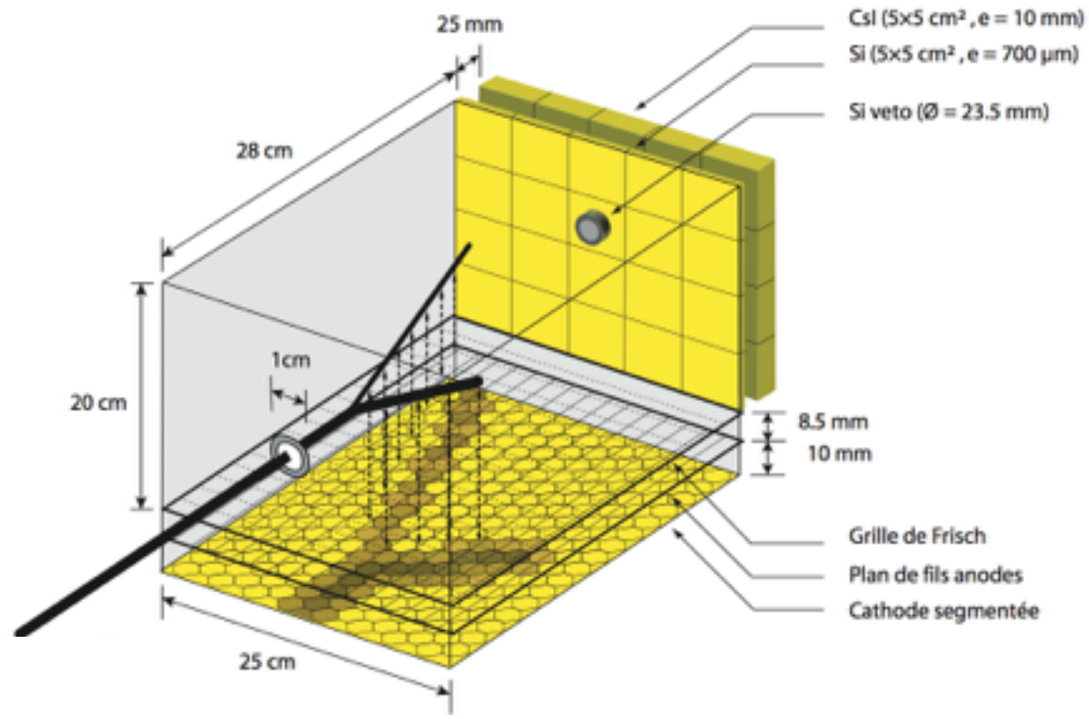
Goal of active target and time projection chamber

- Reaction with very negative Q-value in inverse kinematics
  - Recoil stops inside the target
  - Inelastic reaction for giant resonances or clustering…
- Study of excitation function
  - thick target, need to differentiate the reaction channels
  - Resonant scattering…
- Reaction with very low intensity beam (need of thick target)
  - toward the dripline, nuclei with short half life.
  - halo nuclei…
- Use of thick target without degradation of the resolution

Active target and GANIL

MAYA: a two dimensional charge - one dimensional time projection chamber



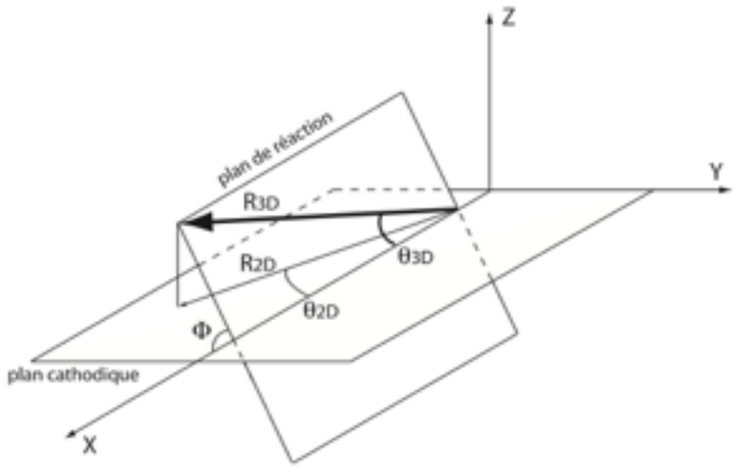


C.E. Demonchy *et al.* NIM **A583**, 341-349 (2007)

MAYA design:

- Cathode recorded charge
  - 2 dimension (32x32 pads)
- Wire recorded time
  - 3rd dimension (32 wires)

Binary reaction only!



Next generation: ACTAR TPC

What has to be improved

- Multi-particle detection
- Low energy threshold
- Spatial resolution (angular and range)
- Reconstruction efficiency
- New electronics (16k channels)
- Energy dynamics
  - pad polarization
  - electrostatic mask

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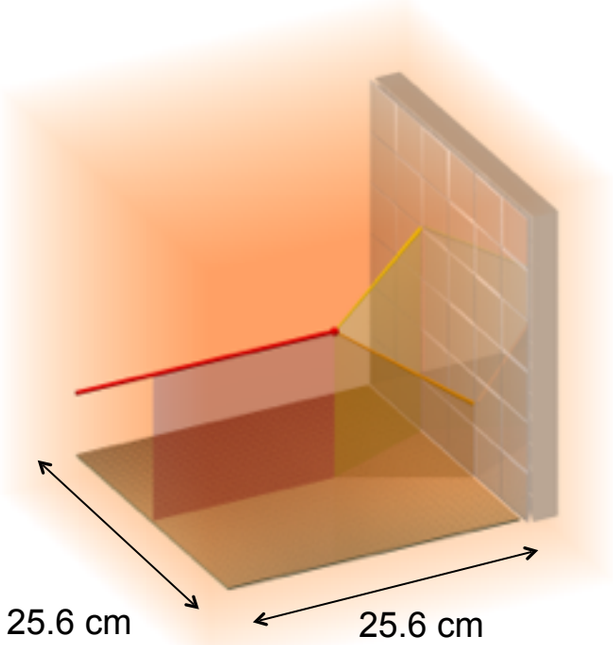
The ACTAR TPC

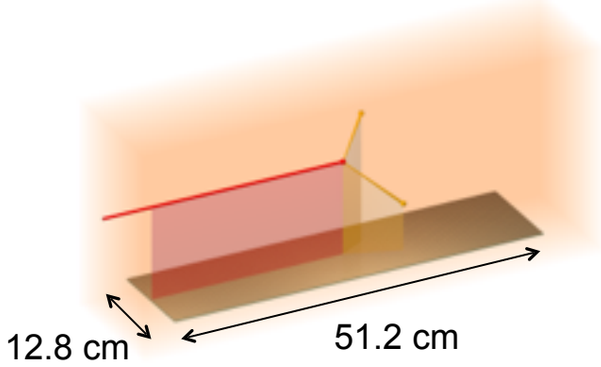
- Tracking considerations: transverse multiplicity > 3 pads
- Micromegas: multiplicity given by the lateral straggling of the e^- in the gas J. Pancin *et al.* NIM **A735**, 532-540 (2014).
- ACTAR: 2x2 mm^2 pads
  - Extending to many-body reactions
  - Technical challenge: connecting 2 mm side square pads the to electronics.
  - equipped with digital electronics (GET): 512 samples ADC readout depth + sparking protection circuit (ZAP)

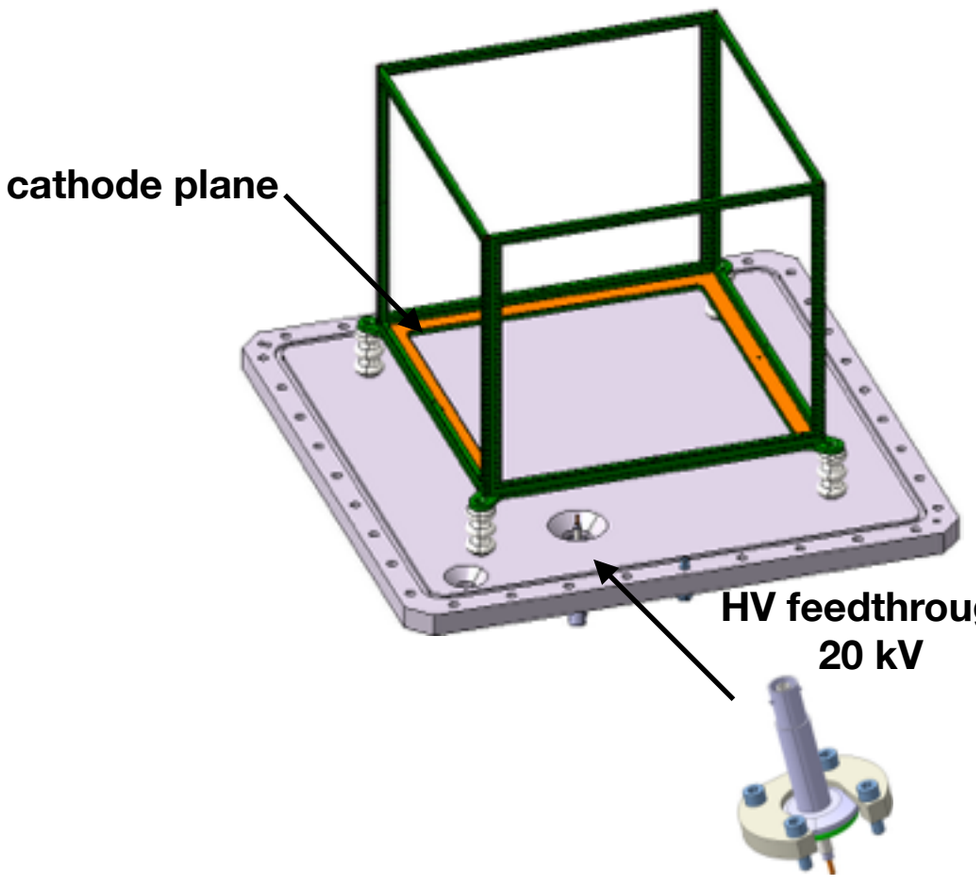
The ACtive TARget and Time Projection Chamber

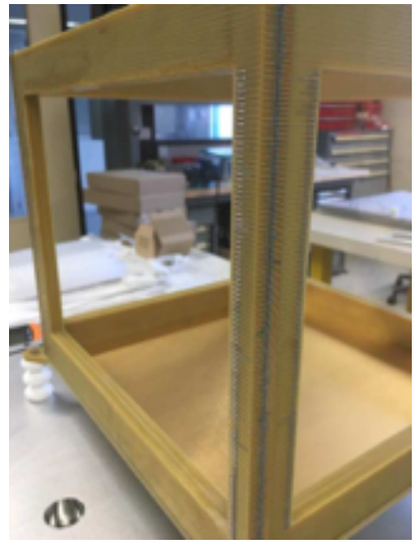
Cubic design



Decay geometry design is also planned

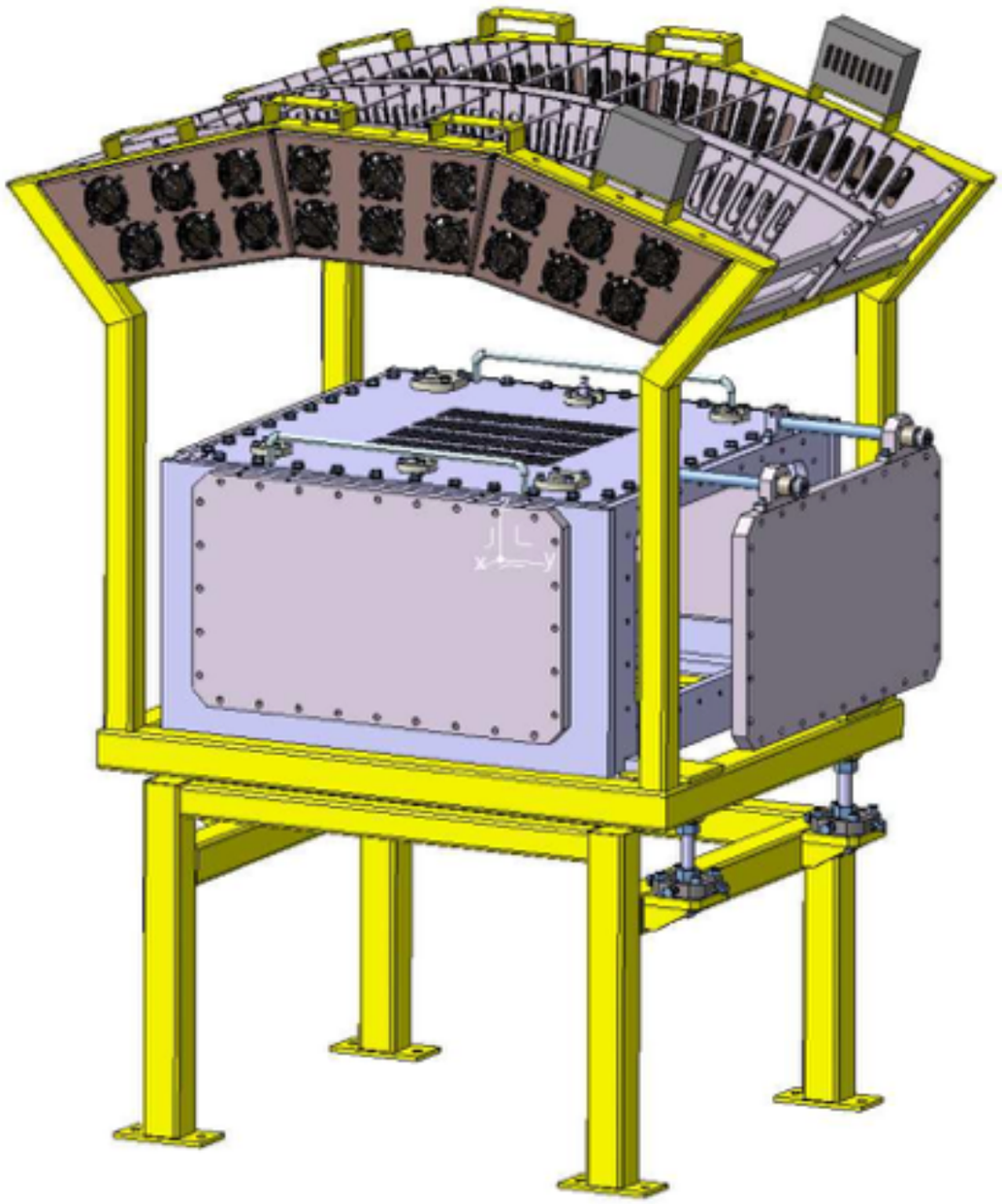




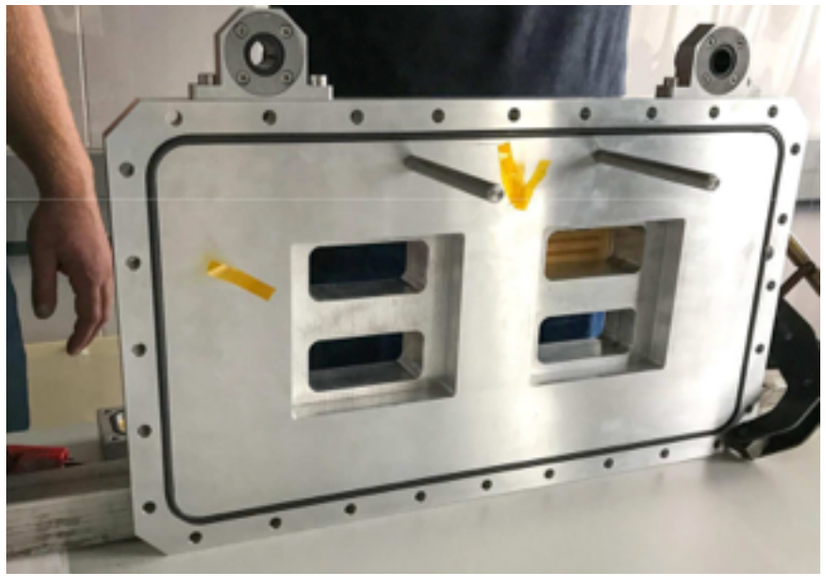


- Field cage: transparent to particles
- Double wire field cage
  - 2 mm pitch outside
  - 1 mm pitch inside
- Possibility to equip to 4 sides with ancillary detectors.

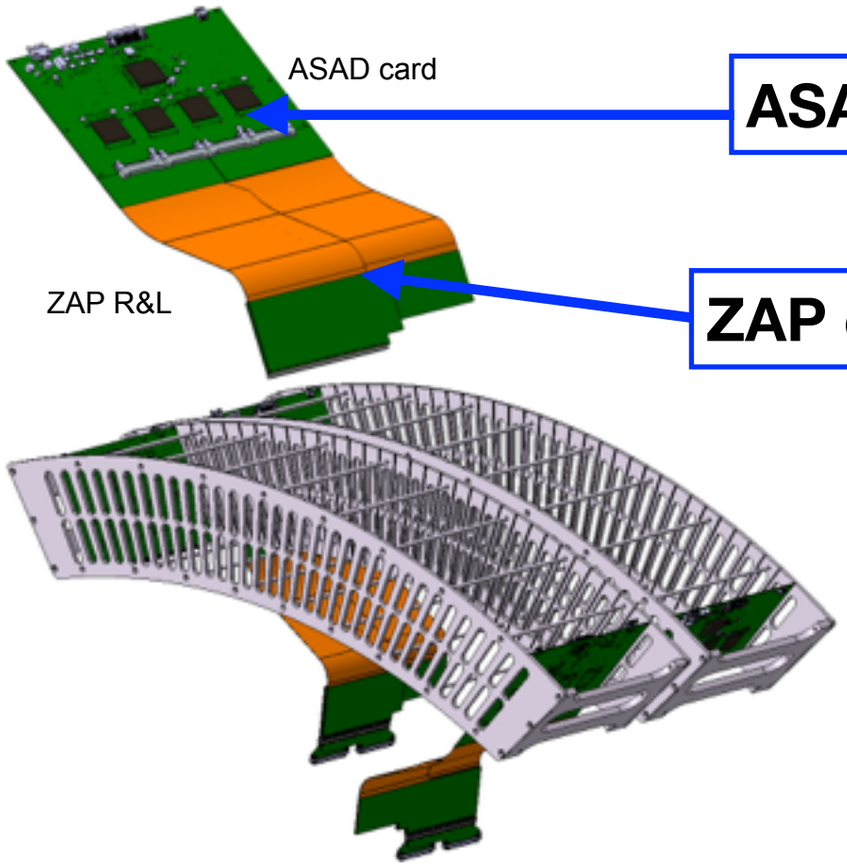
The ACtive TARget and Time Projection Chamber

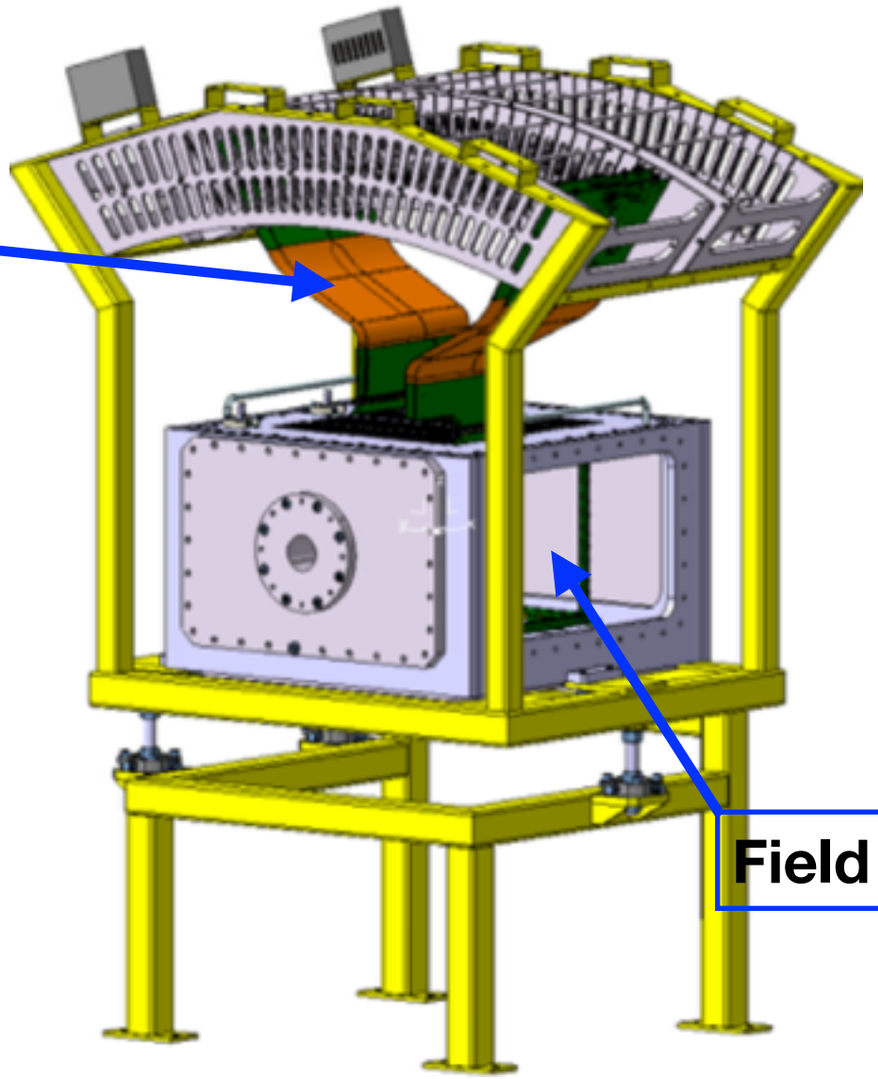


- Should be able to sustain 3 bars differential pressure
- Possibility to couple with different ancillary detectors
- Possibility 2π coverage



The ACtive TARget and Time Projection Chamber

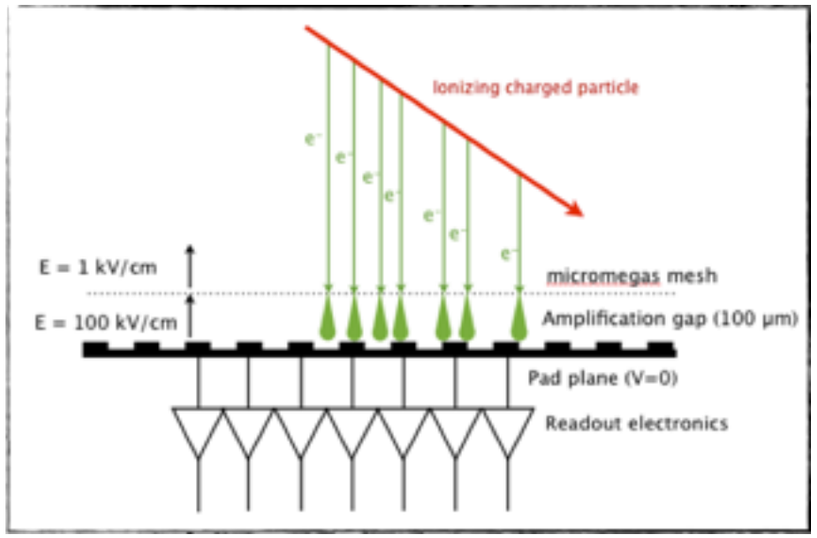




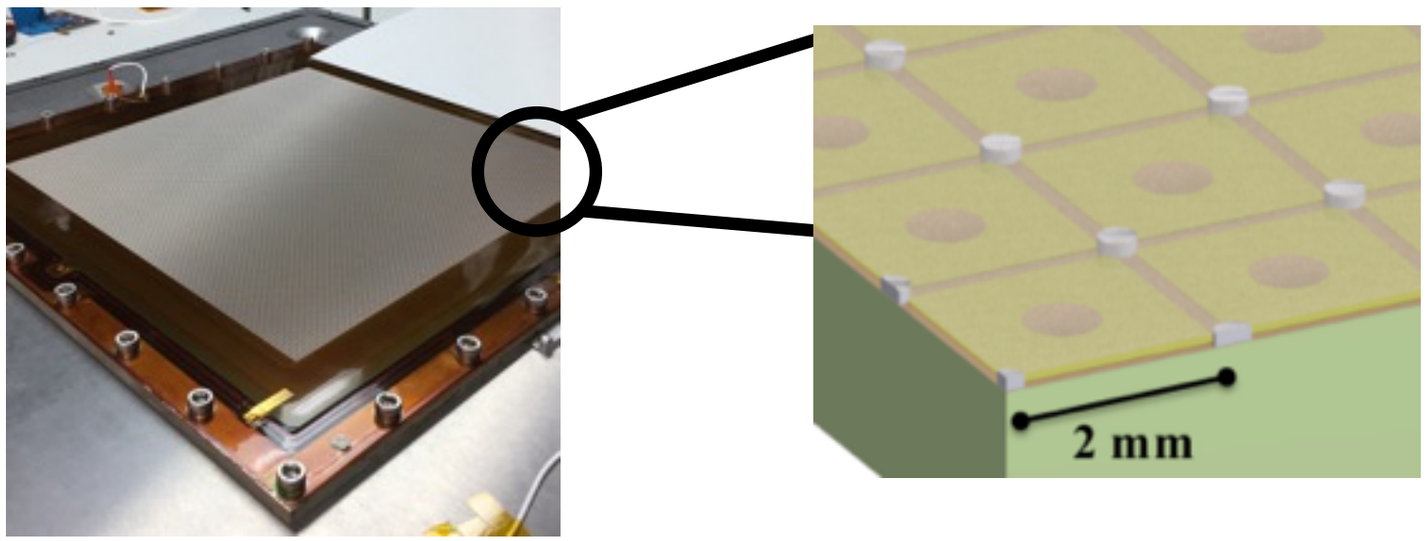
ASAD rack:

- 2x parallel raws of 32 ASAD cards
- ASAD cards are arranged in semi-circular shape to use the same ZAP length.

The ACtive TARget and Time Projection Chamber



- Cubic field cage: 25.6 cm^3.
- Highly segmented: pad plane with 16384 channels: 2x2 mm^2.
- Micromegas technology (≈220 µm gap).



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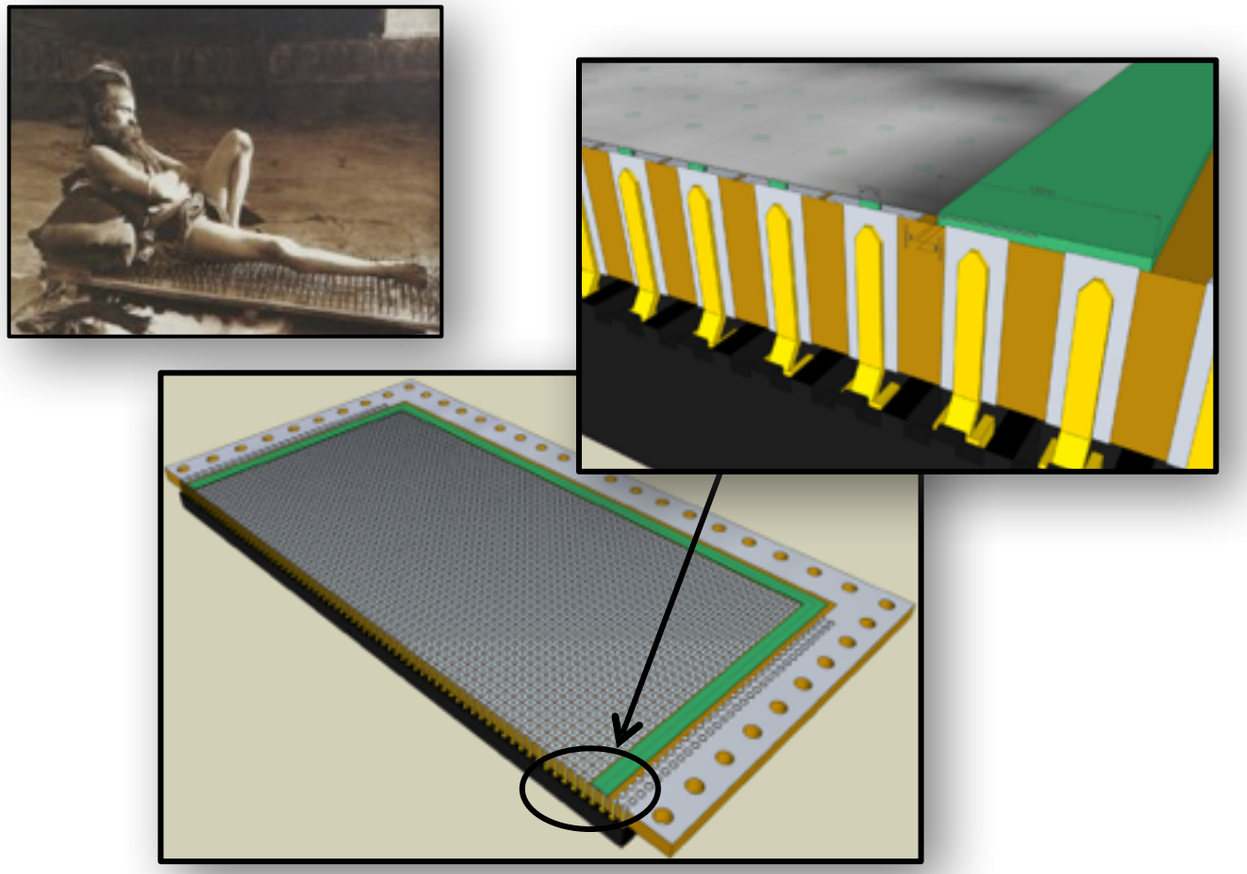
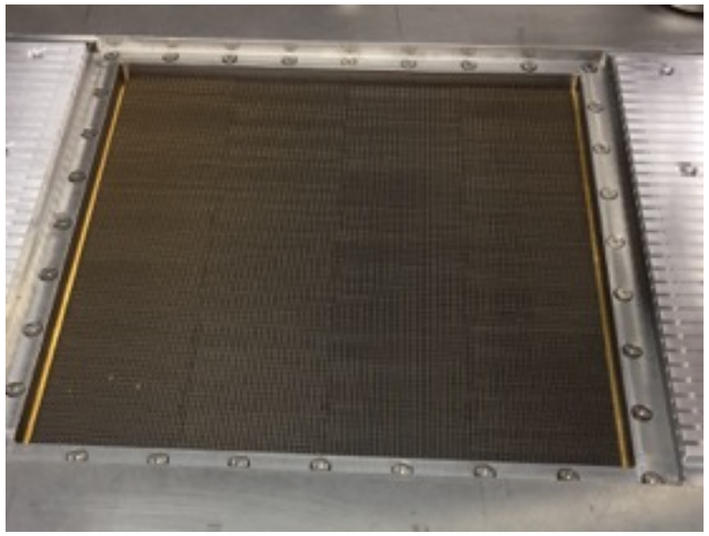
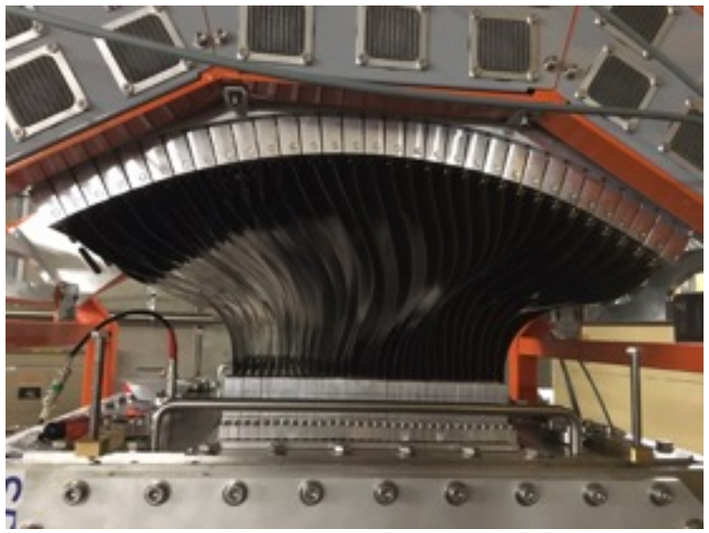




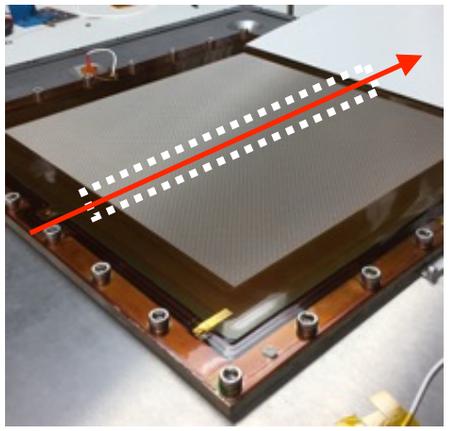


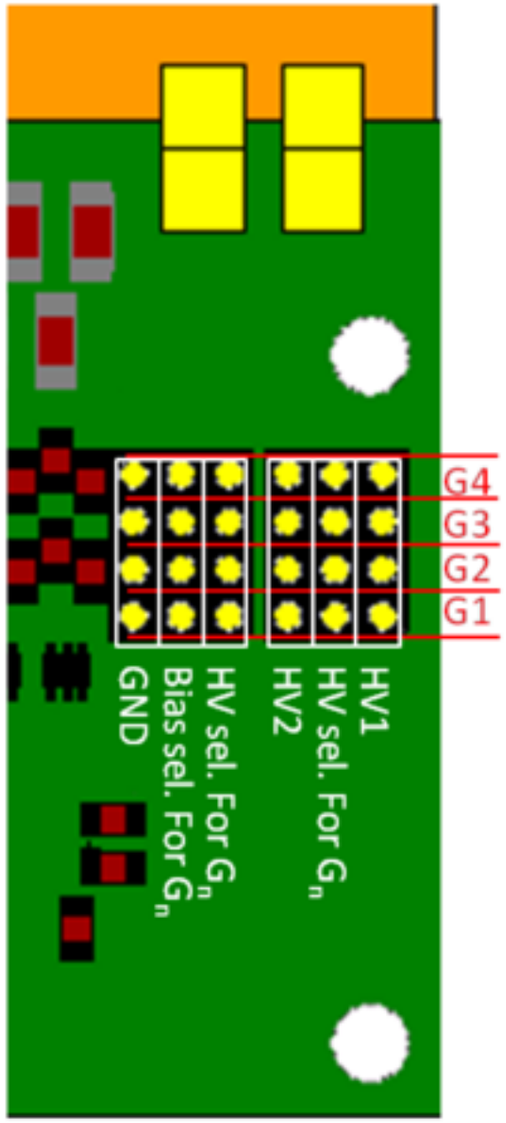
- Fakir geometry
- The ZAP cards are directly connected to the back of the pad plane.
- Original proposition: J. Pibernat.
- Collaboration with CERN and FED.

The ACtive TARget and Time Projection Chamber

Polarizing central pads

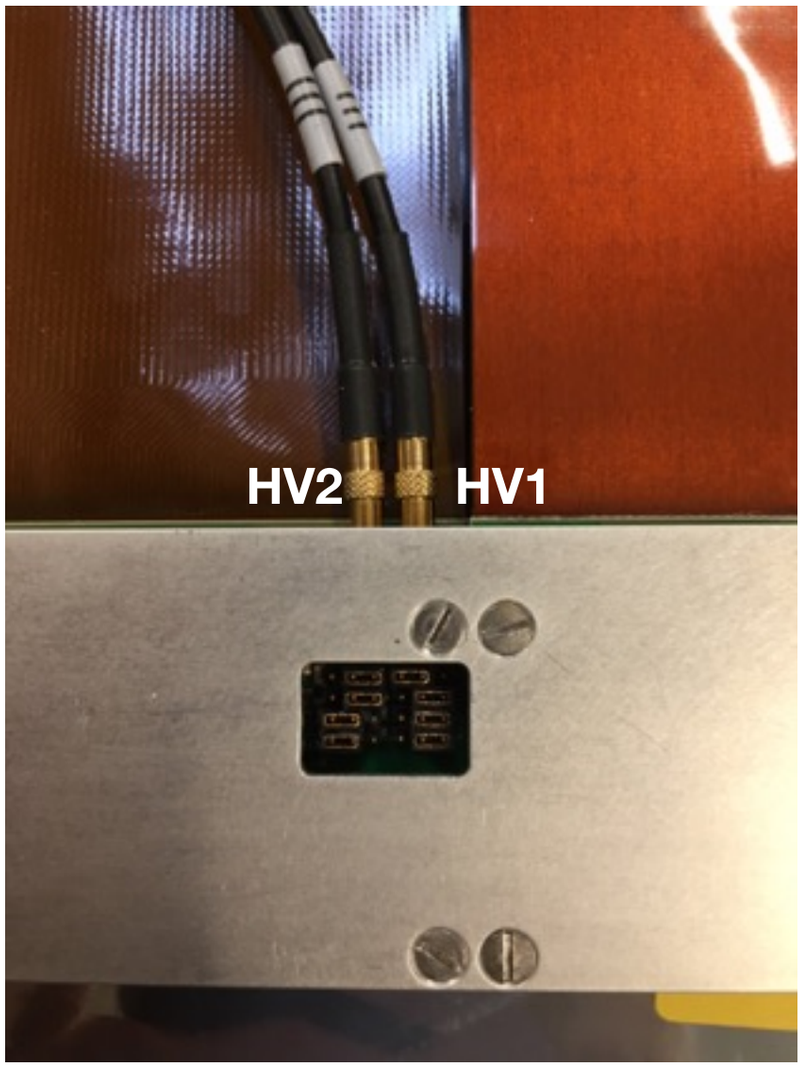
- Central pad below the beam can be set at a different voltage to reduce the gain.
- Avoid saturation problem due to high energy deposition of the beam.
- 6 or 12 central pads can be set.
- Done through jumpers on the ZAP card.



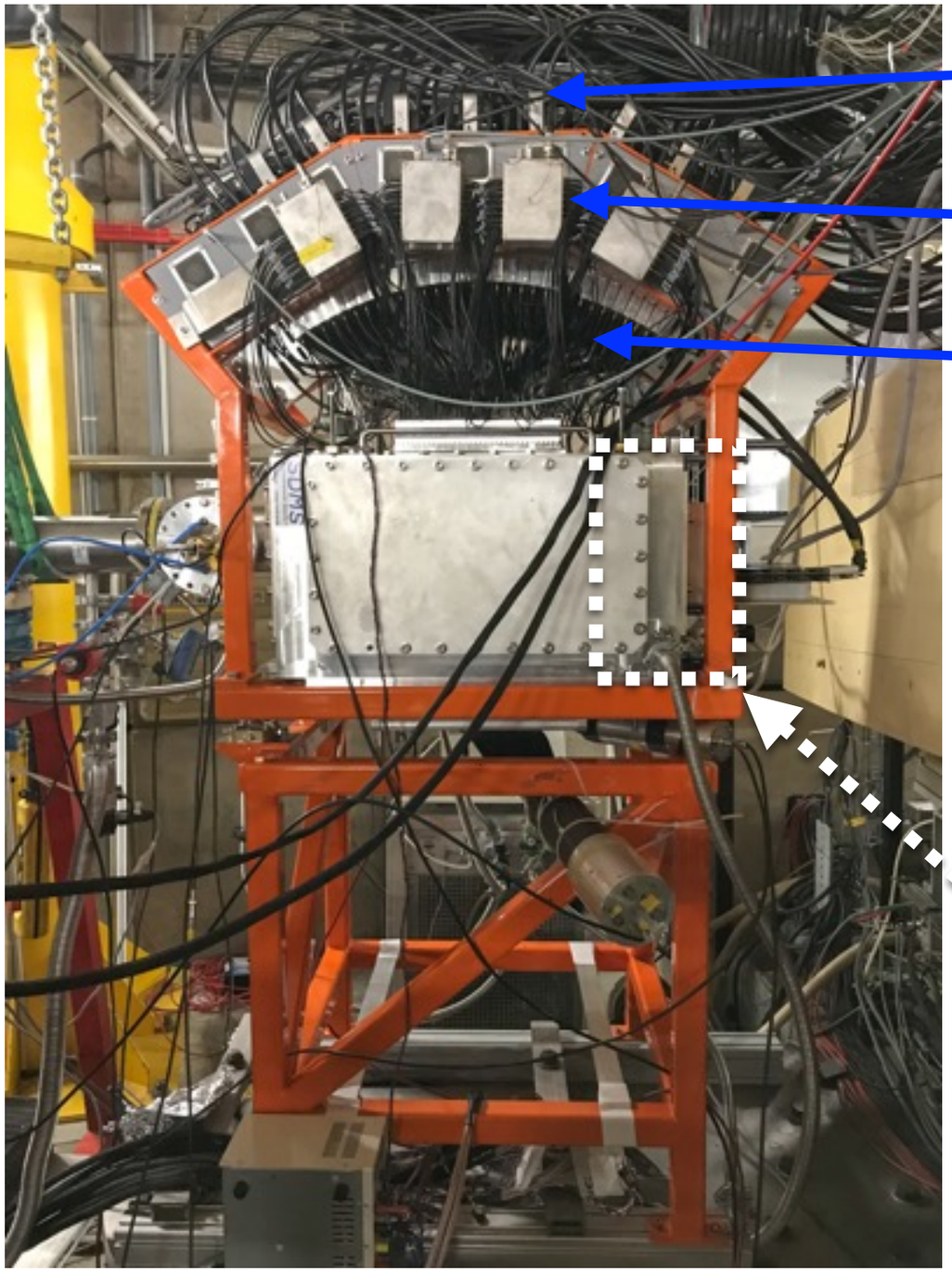


ZAP R

(AGET 0-1)



The ACtive TARget and Time Projection Chamber

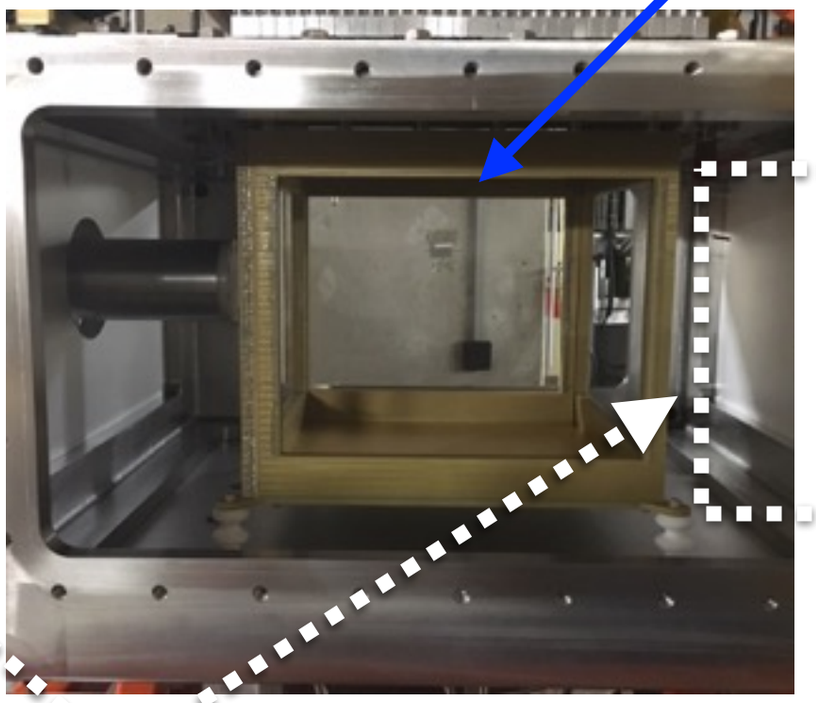


ASAD cards

HV distribution box

ZAP cards

Field cage



Ancillaries: Si and CsI

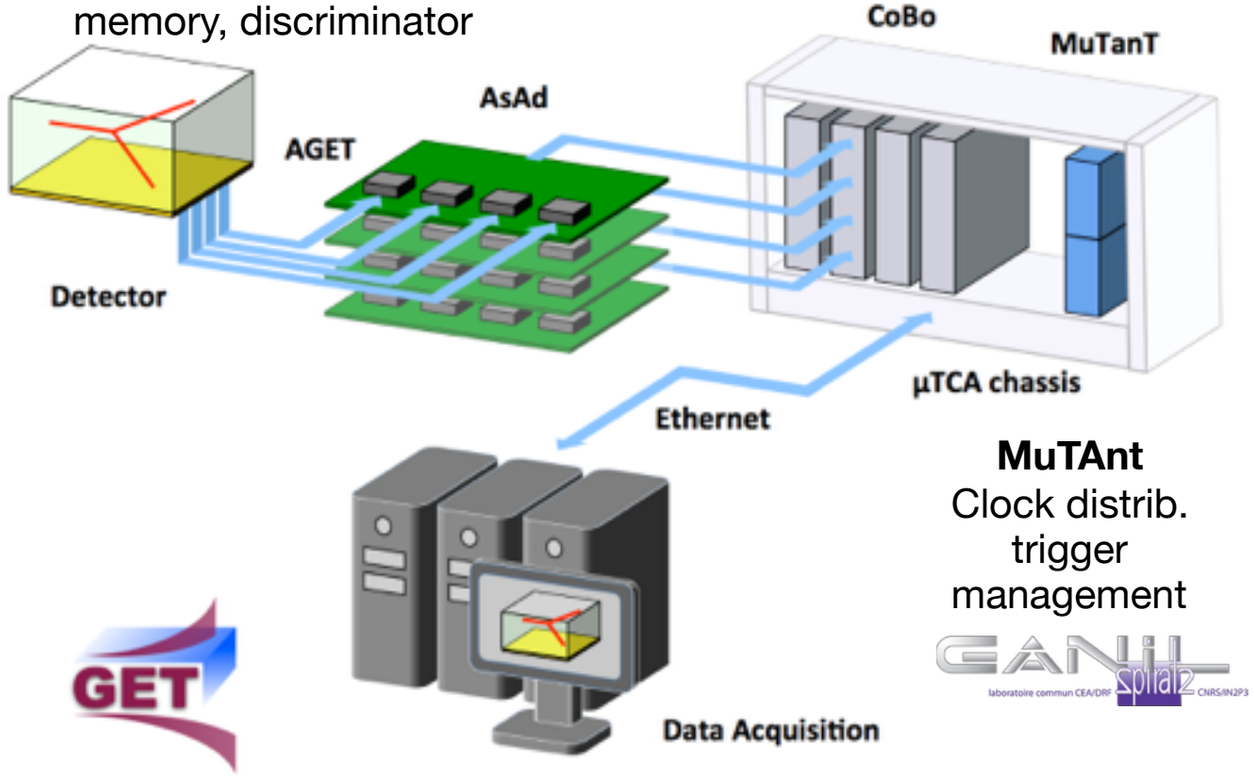
General Electronics for TPC (GET)

- Digital signals and adjustable sampling (up to 100 MHz).
- Input dynamical range from 120 fC up to 10 pC.
- 3-level triggers (L0 external, L1 internal and L2).
- Multiplicity Trigger and Time (MuTanT) module distributes master and clock and event number.
- Extended data readout bandwidth (10 Gb/s) and on-board data filtering.

AGET
64 channels signal processing (CSA +shaper), analog memory, discriminator

AsAd
4 chips (+config) signal & mult. coding (ADC)

COBO
4 AsAd boards digital data management

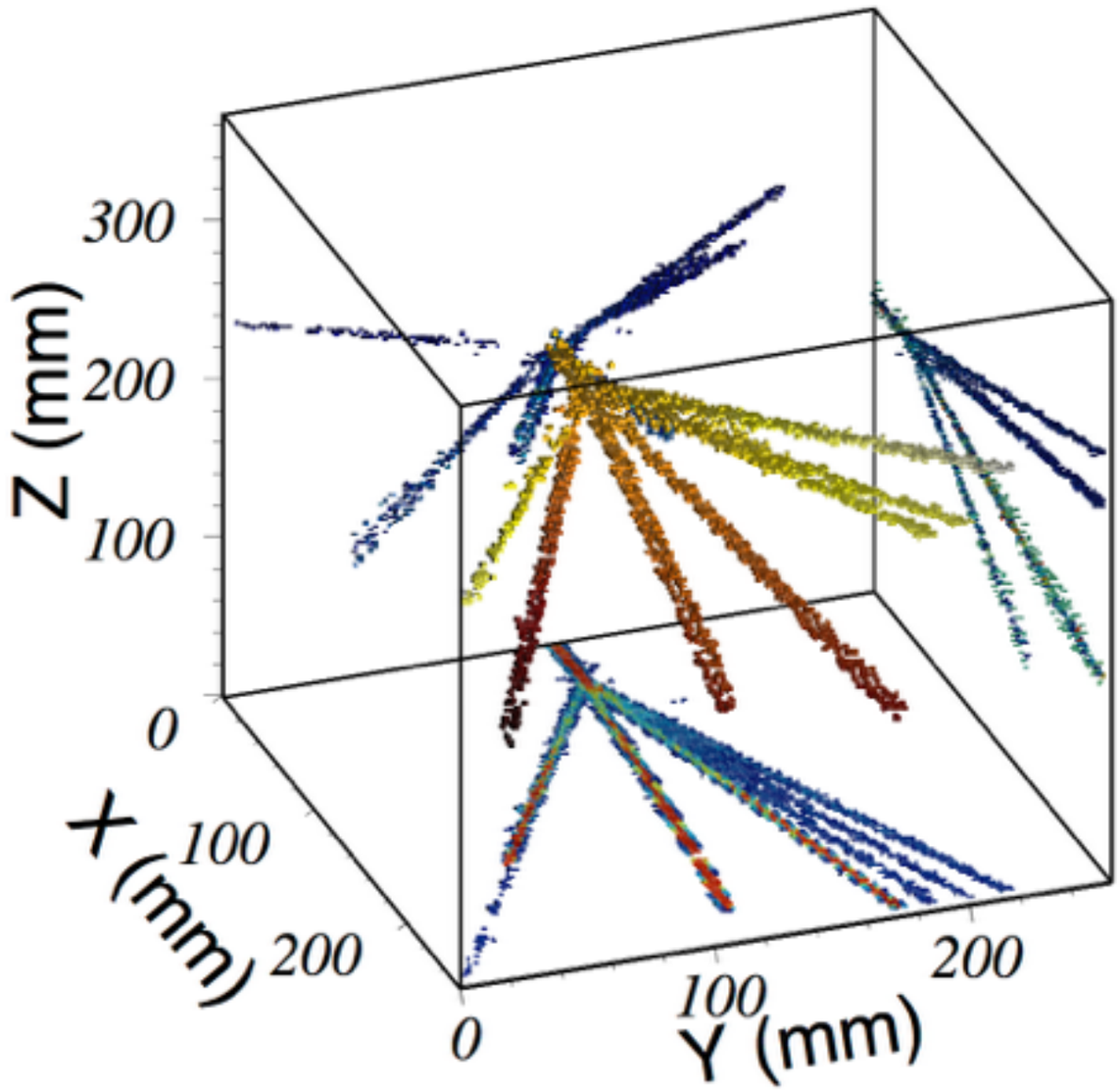


MuTAnt
Clock distrib. trigger management

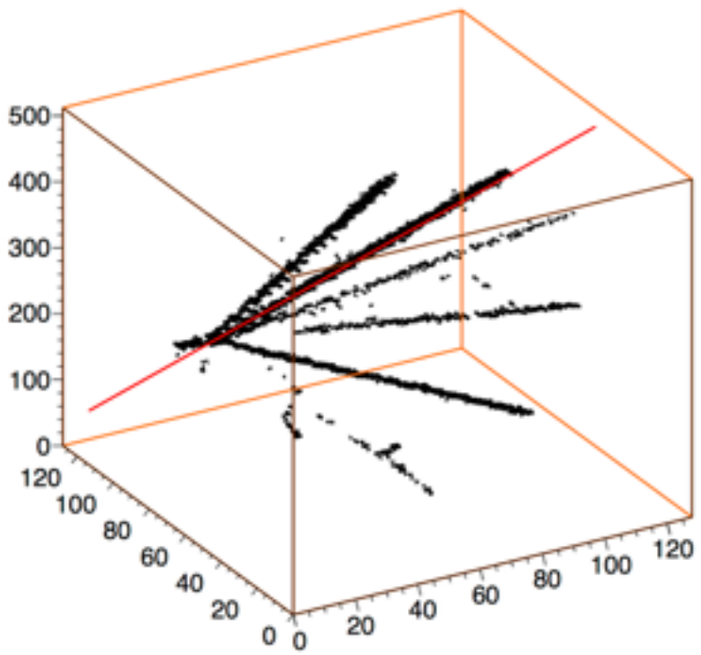
Commissioning

- The ACTAR TPC has been recently completed and commissioned: proton resonant elastic scattering of ^{18}O from 3.5 MeV/u (**see talk of Benoît Mauss**).
- This example: ^{18}O at 20 MeV/u
- Allow us to develop new tracking algorithms (Hough, Ransac, Neural network…) Y. Ayyad *et al.* NIM **A880**, 166-173 (2018)
- Ready to use for physics experiments.

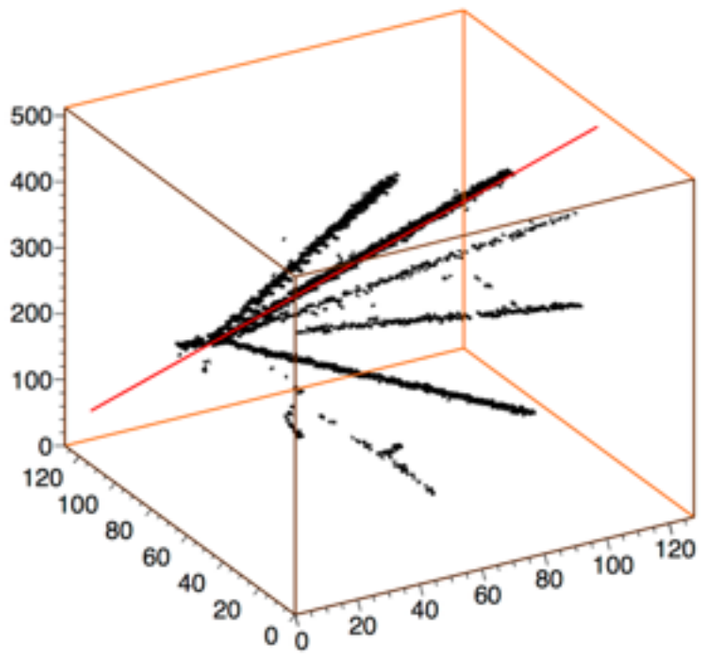
^{18}O+^{12}C at 20 MeV/u
Fragmentation event

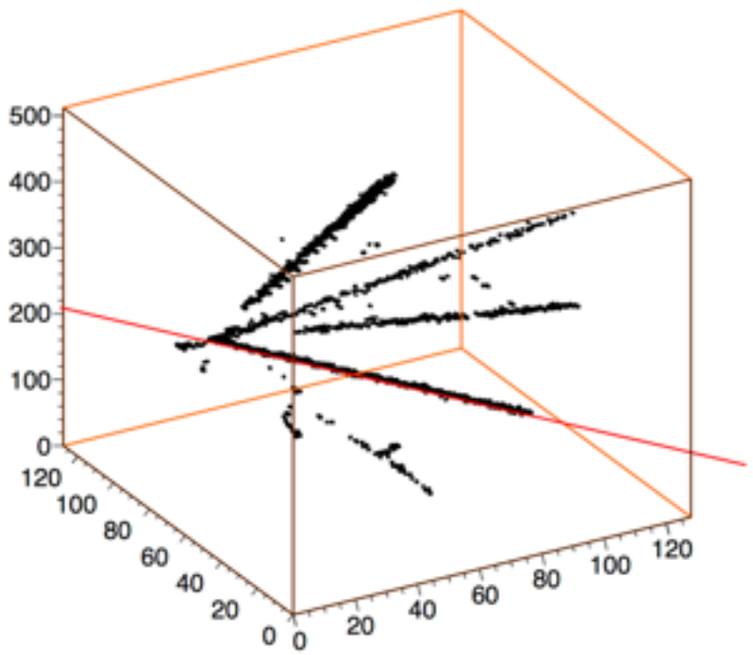


RANSAC tracking

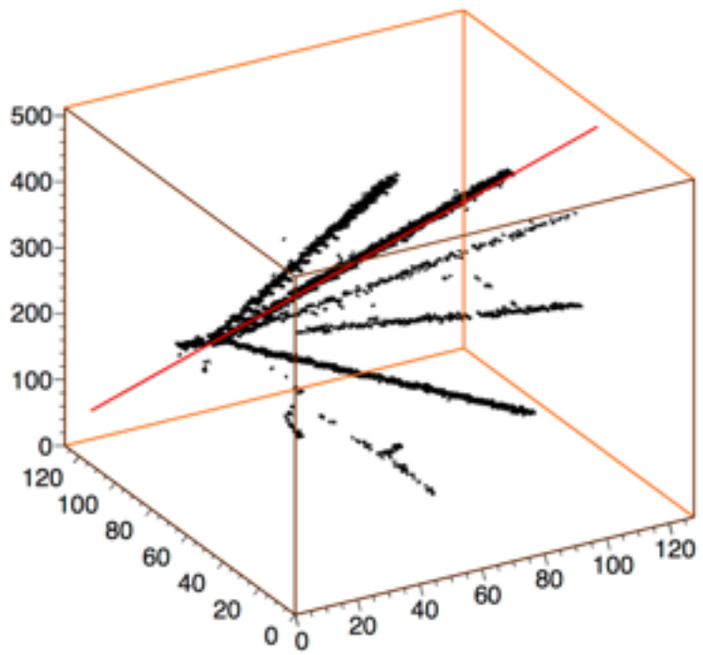


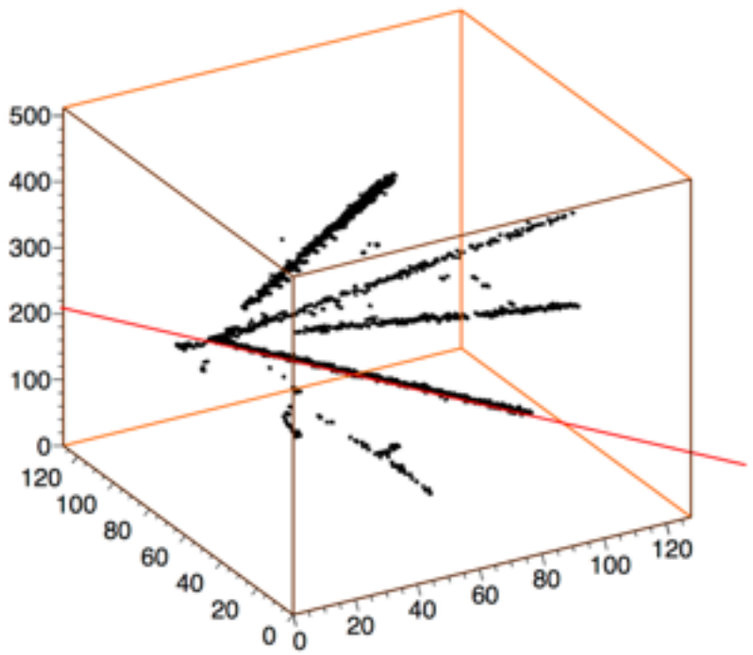
RANSAC tracking

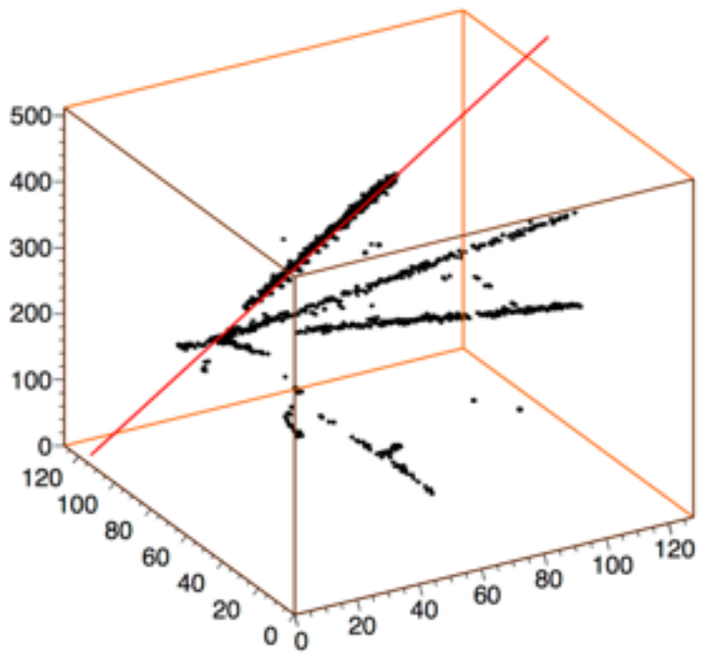




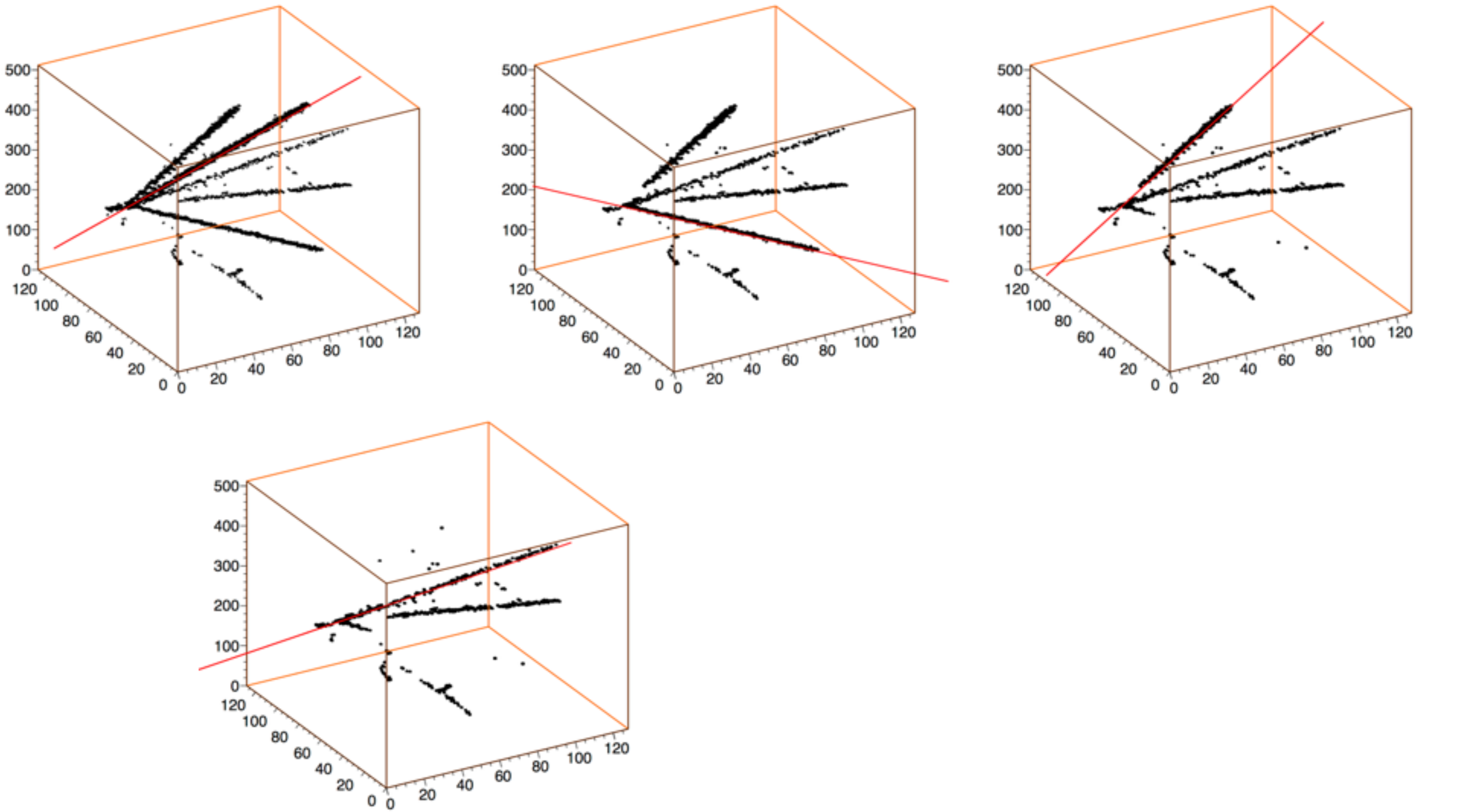
RANSAC tracking



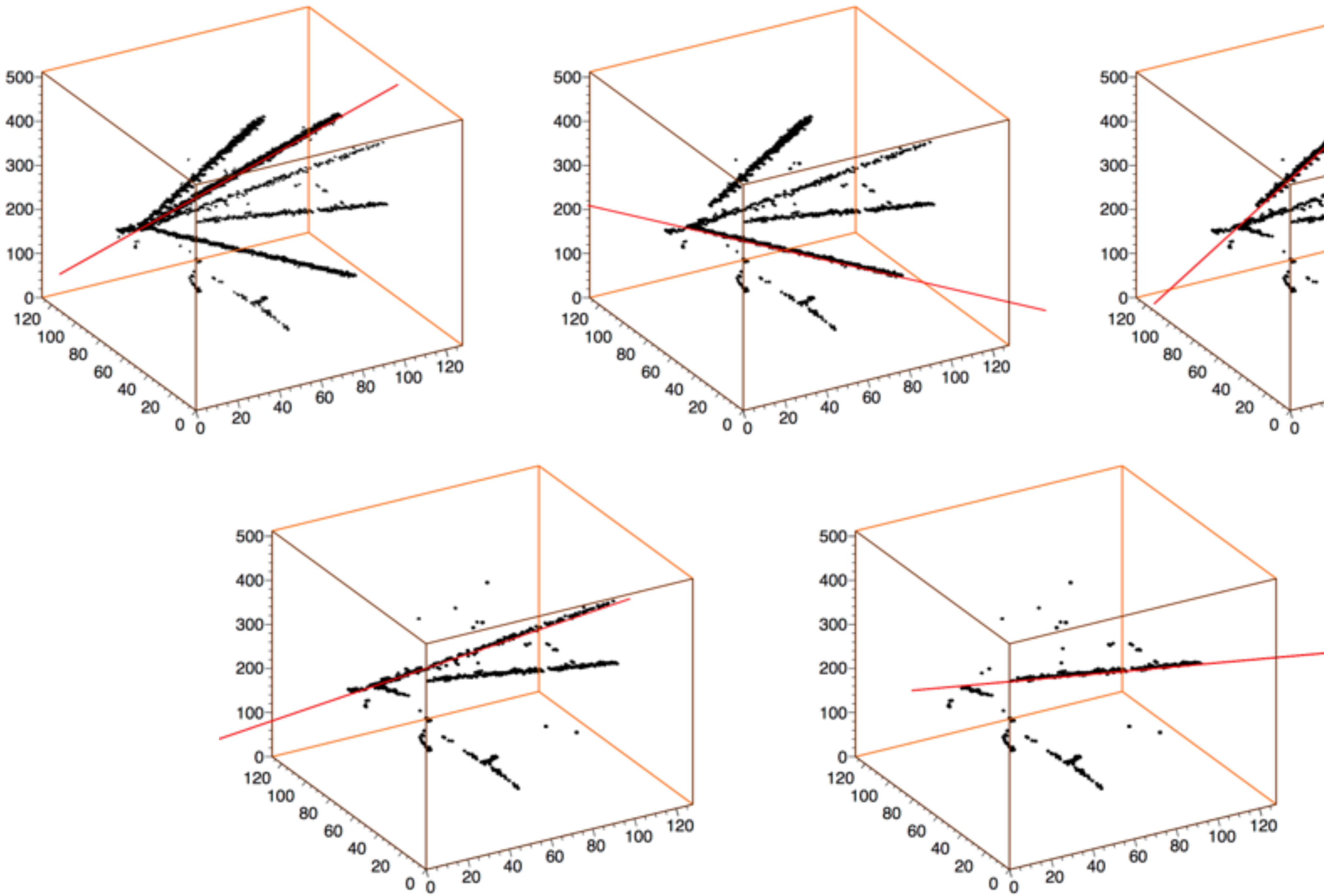




RANSAC tracking



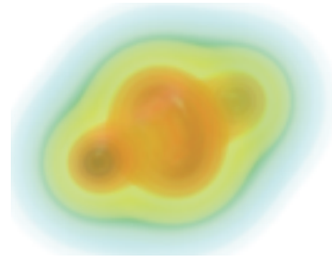
RANSAC tracking

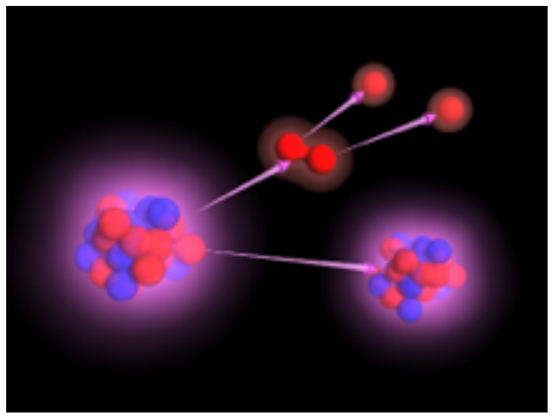


Physics opportunity with ACTAR TPC

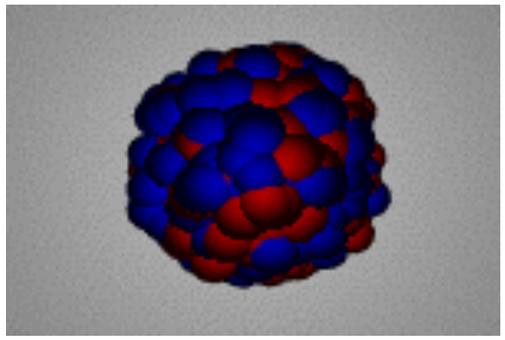
The ACTAR TPC will play an important role for:

- Resonant elastic scattering: Resonance states and unbound nuclei
- Astrophysical reactions: r-process and (α,p) reactions
- Inelastic scattering: Giant resonances and clusters
- Exotic decay mode: 2 proton radioactivity, β2p
- Transfer reactions

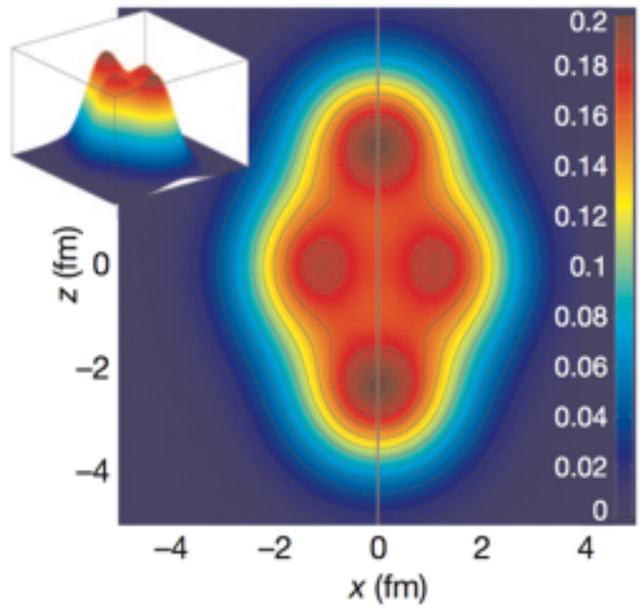




CENBG

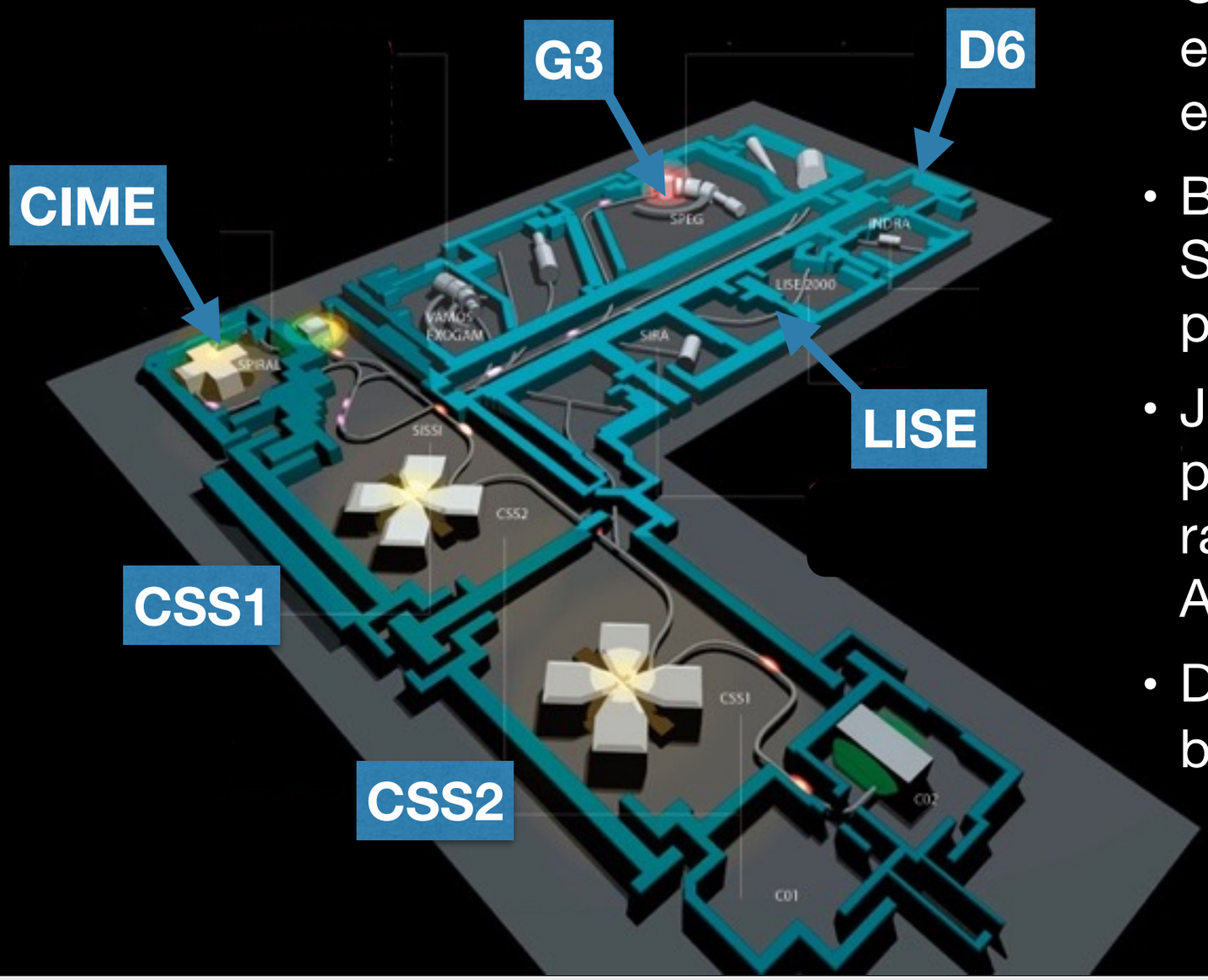


credit A. Krasznahorkay (ATOMKI)



J.P. Ebran et al. Nature **487**, 341 (2012)

Experiments approved at GANIL

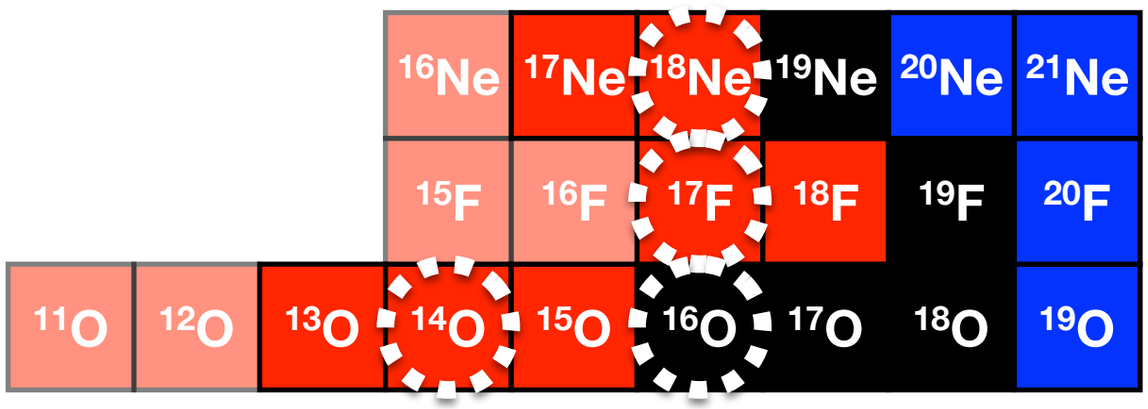


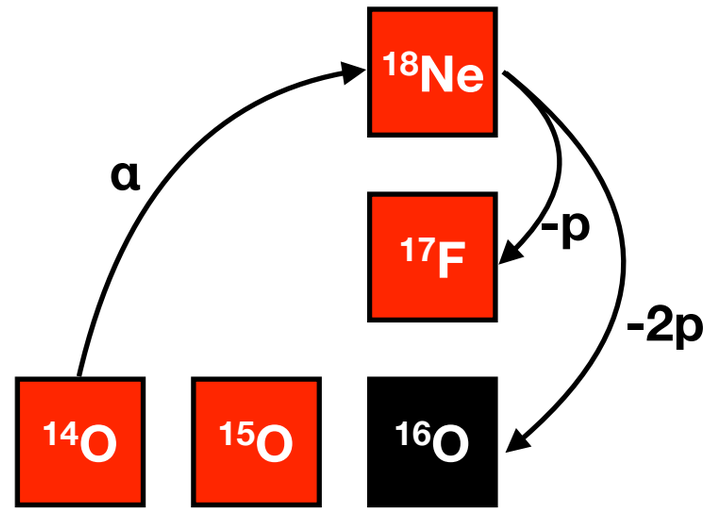
Four approved experiments at GANIL

- G.F. Grinyer **E750**: Resonant proton elastic scattering on ^{17}F and 2-proton emission from excited states in ^{18}Ne.
- B. Fernández-Domínguez **E751**: Spectroscopy of the unbound proton-rich nucleus ^{33}K.
- J. Giovinazzo **E743**: Study of proton-proton correlations in the two-proton radioactivity of ^{54}Zn or ^{48}Ni with ACTAR TPC.
- D. Rudolph **E690**: Proton-decay branches from the 10+ isomer in ^{54}Ni.

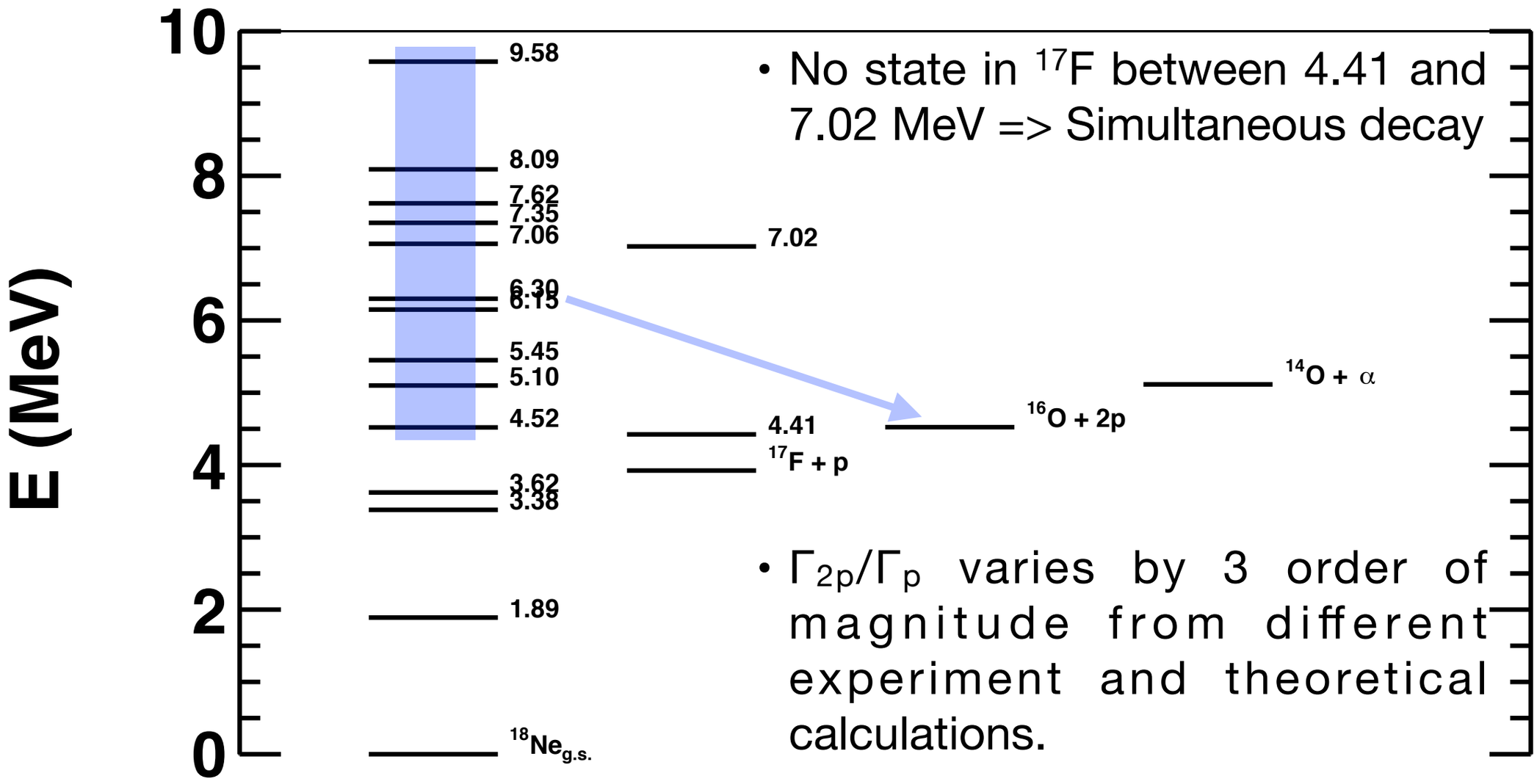
E750: 2*p* emission from excited states in ^{18}Ne

- Excited states in ^{18}Ne above proton decay threshold: key role in the ^{14}O(α,p)^{17}F reaction rate.
- For typical novae outburst temperatures (0.1 to 0.4 GK), the reaction is dominated by a single resonance at 6.15 MeV (1^-).
- Ay higher temperature (>2 GK), additional resonances at 7.35 and 8.10 MeV dominate.
- Not clear if these states decay by two-proton emission.
- A large 2p-decay branch would lead to a reduction of the ^{14}O(α,p)^{17}F astrophysical reduction rate by as much as 30%.



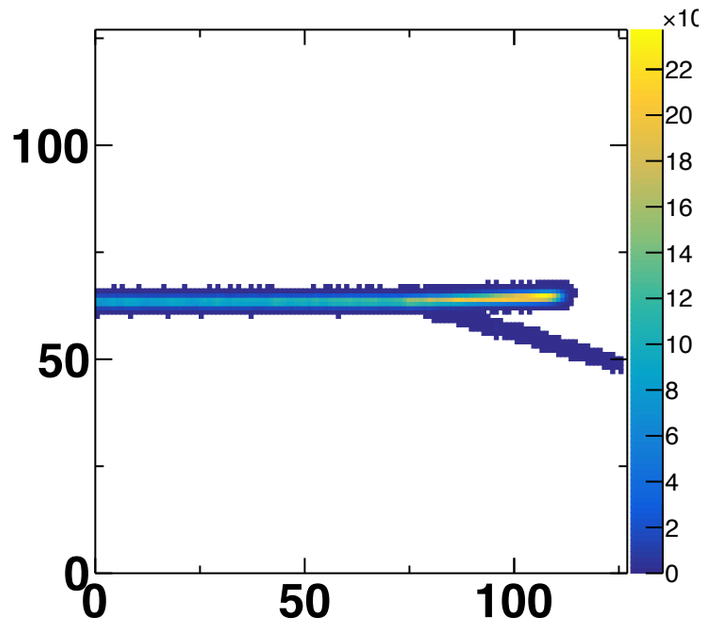


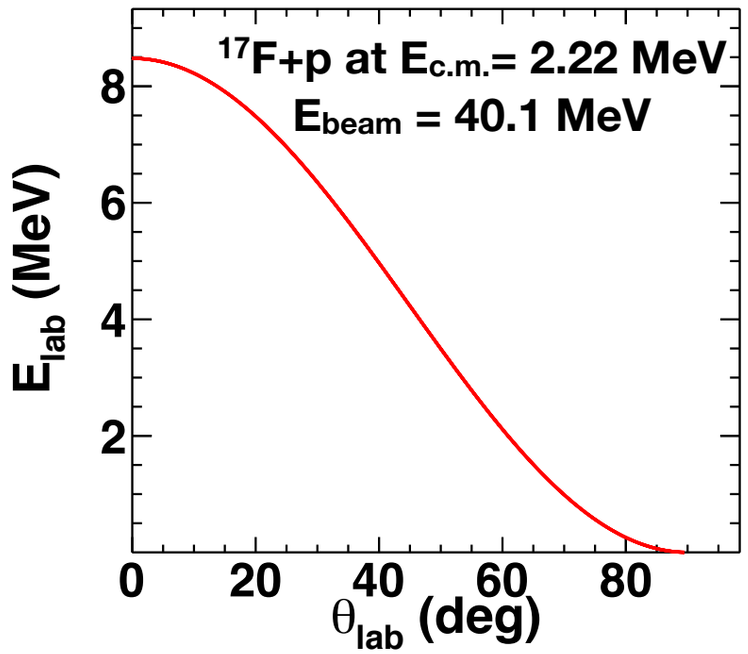
E750: 2*p* emission from excited states in ^{18}Ne

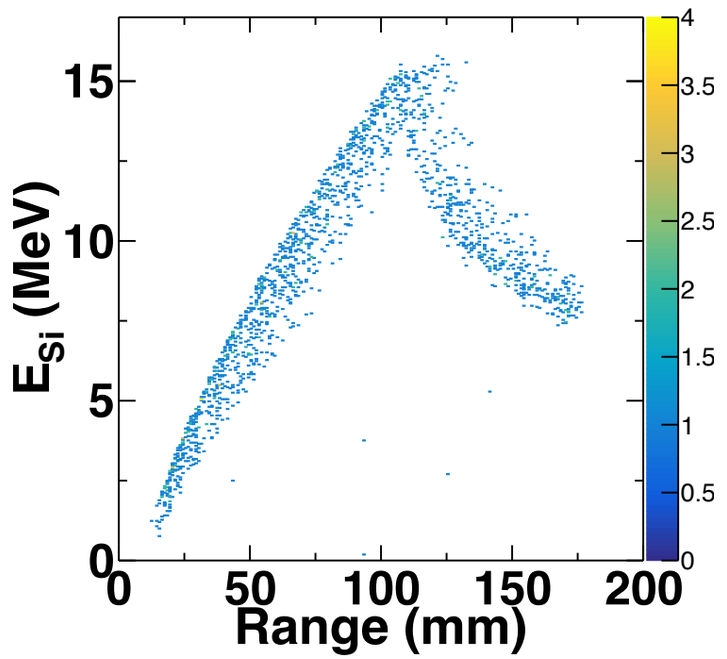


E750: 2*p* emission from excited states in ^{18}Ne

- ^{17}F(p,p) resonant elastic scattering.
- ^{17}F secondary beam at 7 MeV/u in CIME cyclotron and sent to G3.
- iC_4H_{10} at 200 mbar.
- Ancillaries: Silicon wall (DSSD).
- Complete kinematic measurement (angle, energy and vertex position).
- Proton-proton correlations studies provide insight into the nature of the 2-proton decay.



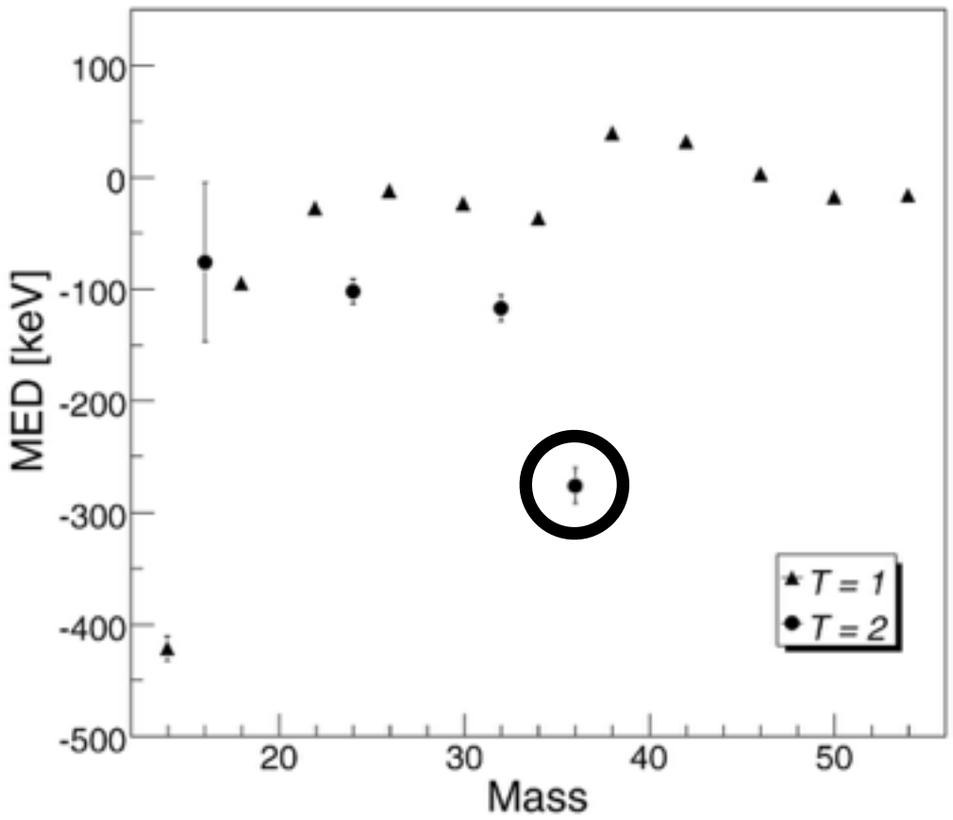




E751: Spectroscopy of the unbound proton-rich ^{33}K

Shell evolution

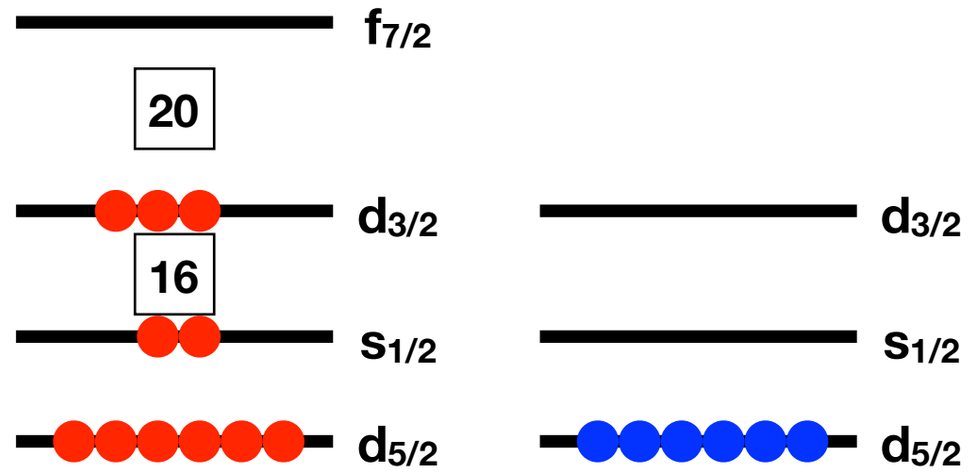
- The Mirror Energy Differences (MED) for the 2^+ states in the mirror pair ^{36}Ca/^{36}S were found to be exceptionally large (T=2).
- Systematic of the T=1 and T=2 MED lead to a reduction of the Z=14 gap in the N=8 isotones and the N=14 gap in the Z=20 isotopes.
- Another “island of inversion in ^{34}Ca”?
- The structure of ^{33}K (one proton away from ^{34}Ca) should manifest the predicted quenching.
- Other effects such as coupling to continuum and 3N as well.



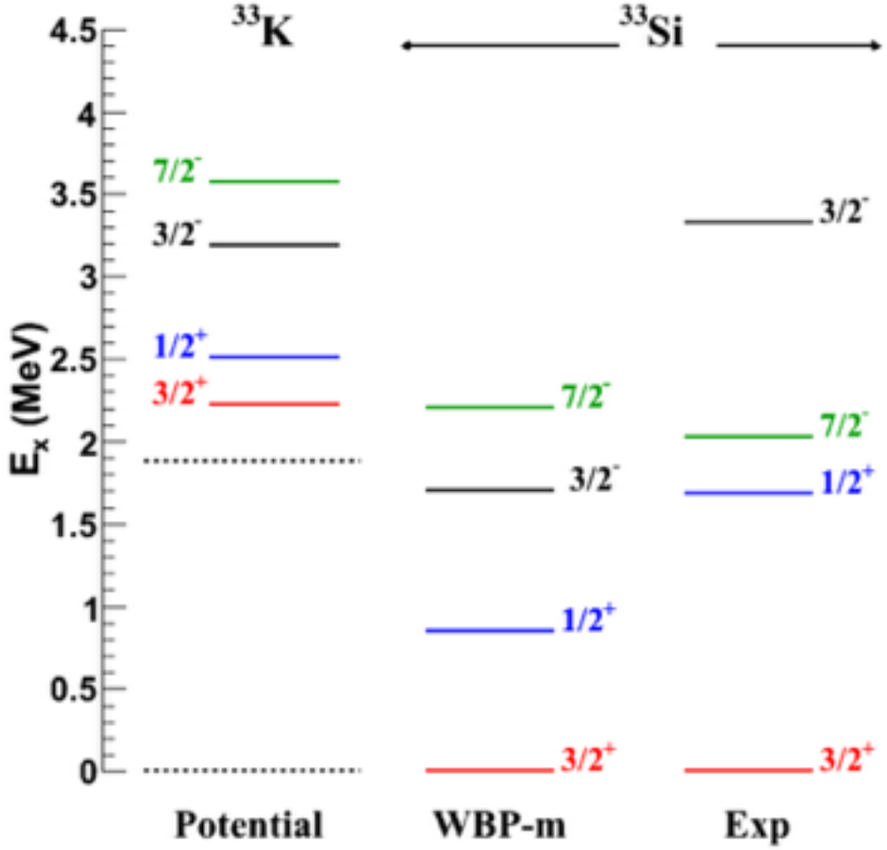
P. Doornenbal *et al.* PLB **647** 237-242 (2007)

E751: Spectroscopy of the unbound proton-rich ^{33}K

- Study of the proton-unbound ^{33}K nucleus
- Mirror or ^{33}Si.
- $T_{1/2}$< 25 ns
- Predicted unbound by S_p=-1.95 MeV

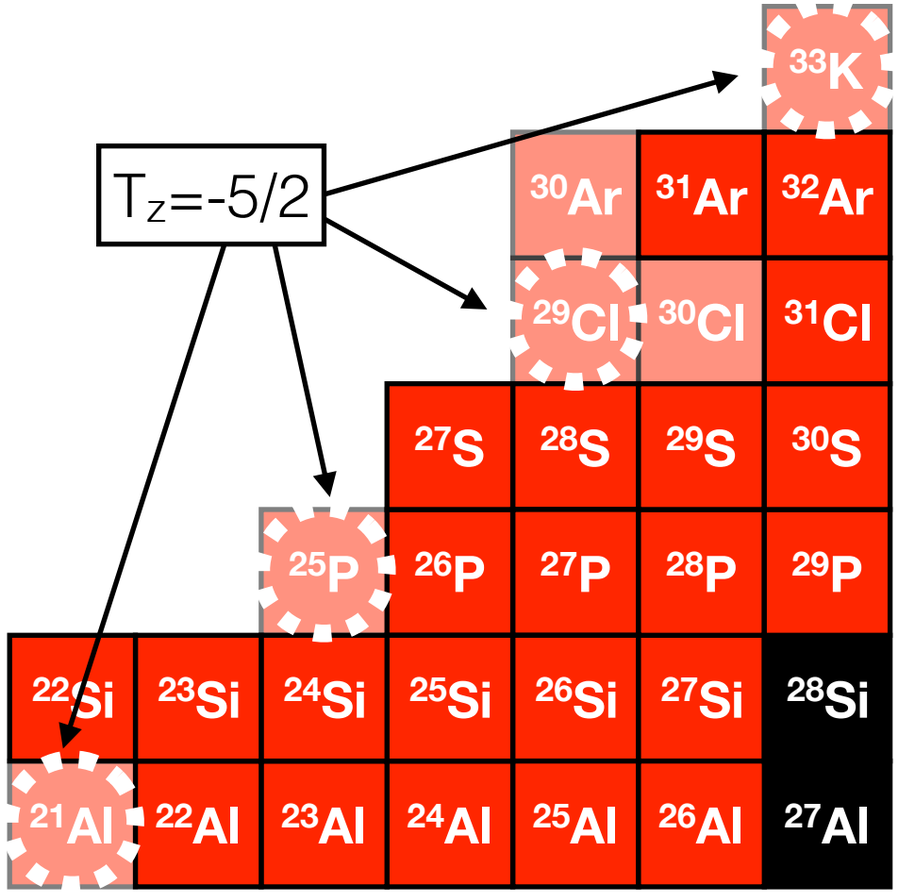


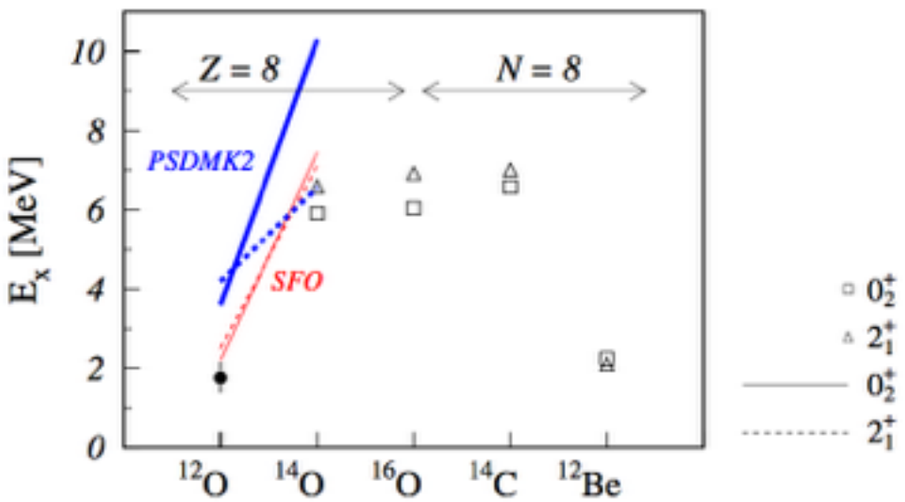
- Study of Z=16 and Z=20 proton shell gap at N=14.
- Prediction from shell-model: $3/2^+$ and $1/2^+$ only 300 keV appart => Z=16
- Energy between the $7/2^-$ and the $3/2^+$ will provide information on the Z=20 gap.



E751: Spectroscopy of the unbound proton-rich ^{33}K

- ^{33}K: T_z=-5/2
- None of the T_z=-5/2 nuclei are expected to be bound (^{13}F, ^{17}Na, ^{21}Al, ^{25}P and ^{29}Cl)
- Experimental studies on ^{29}Cl indicate a violation of isobaric symmetry due to a strong Thomas-Ehrmann shift. I. Mukha *et al.* PRL **115**, 202501 (2015)
- Systematics of the Thomas-Ehrmann shift in T=5/2 with increasing Coulomb.

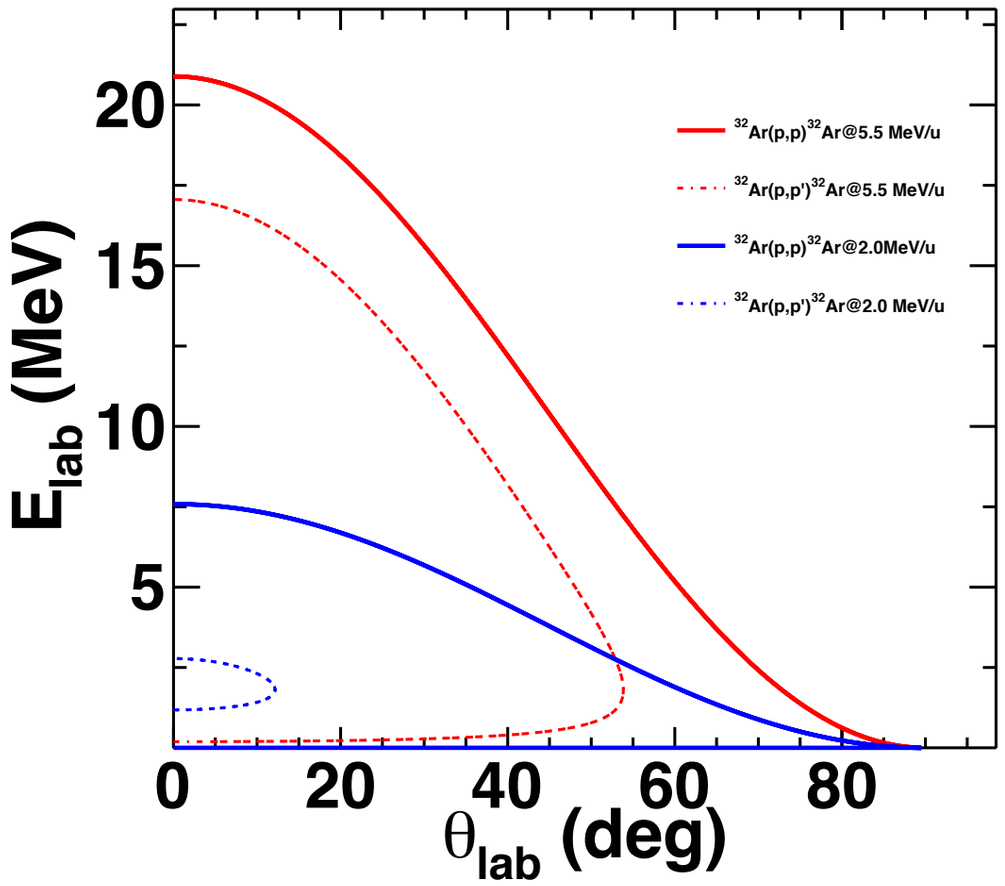


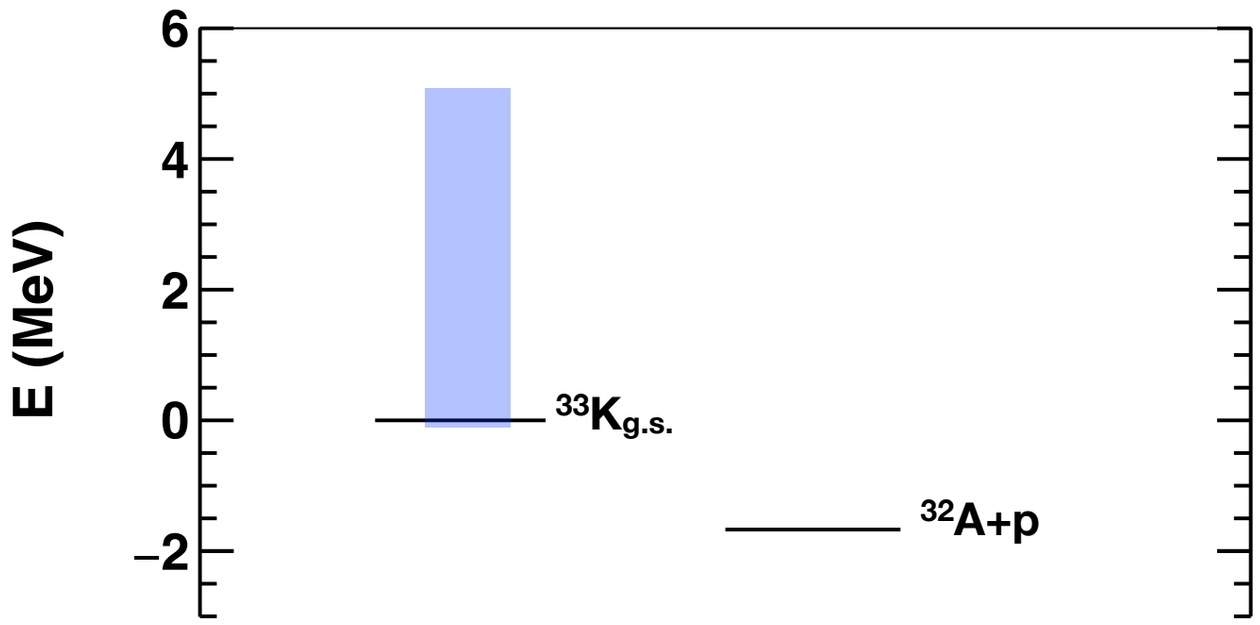


Thomas-Erhmann shift in ^{12}O

D. Suzuki *et al.* PRL **103**, 152503 (2009)

E751: Spectroscopy of the unbound proton-rich ^{33}K

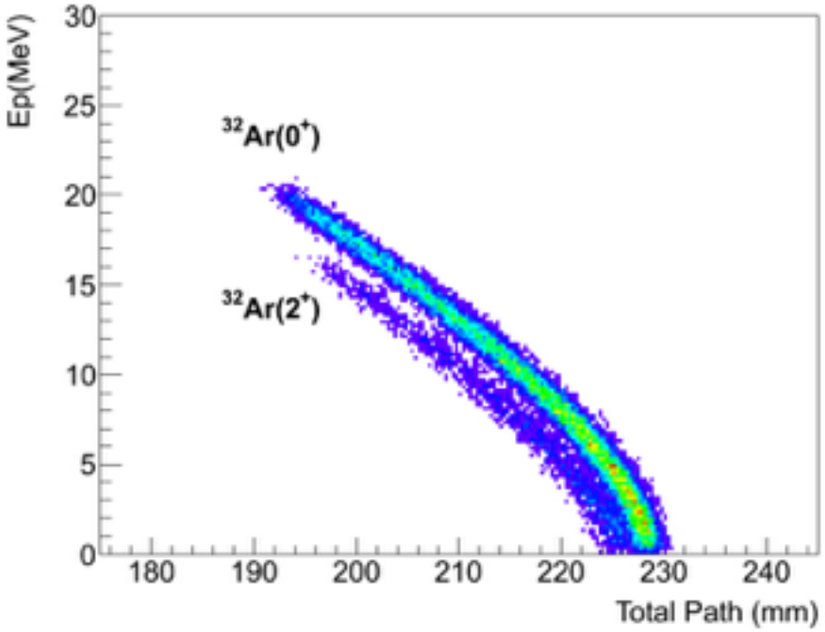


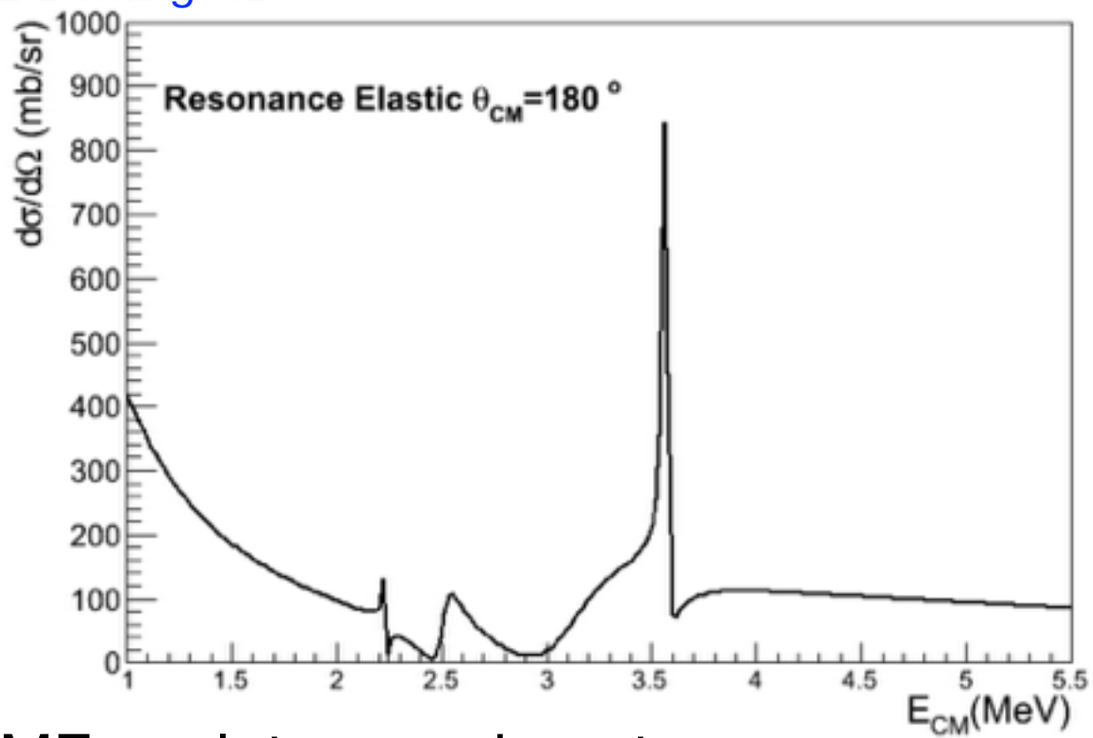


- Study of the proton-unbound ^{33}K nucleus
- Through proton resonant elastic scattering ^{32}Ar(p,p)@ 5.5 MeV/u.
- Populate from 5.5 MeV down to the ground state of ^{33}K.

E751: Spectroscopy of the unbound proton-rich ^{33}K

credit B. Fernández-Domínguez





- ^{32}Ar secondary beam at 5.5 MeV/u in CIME cyclotron and sent to G3.
- H_2 at 1.5 bar => Test needed.
- Ancillaries: Silicon wall (DSSD) at forward angles: ΔE 1mm thick + E 1.5 mm thick. Needed to determine the angle if gain issue to detect the proton in the TPC.
- Complete kinematic measurement (angle, energy and vertex position).

E743: Proton-proton correlation from 2p radioactivity in ^{54}Zn or ^{48}Ni

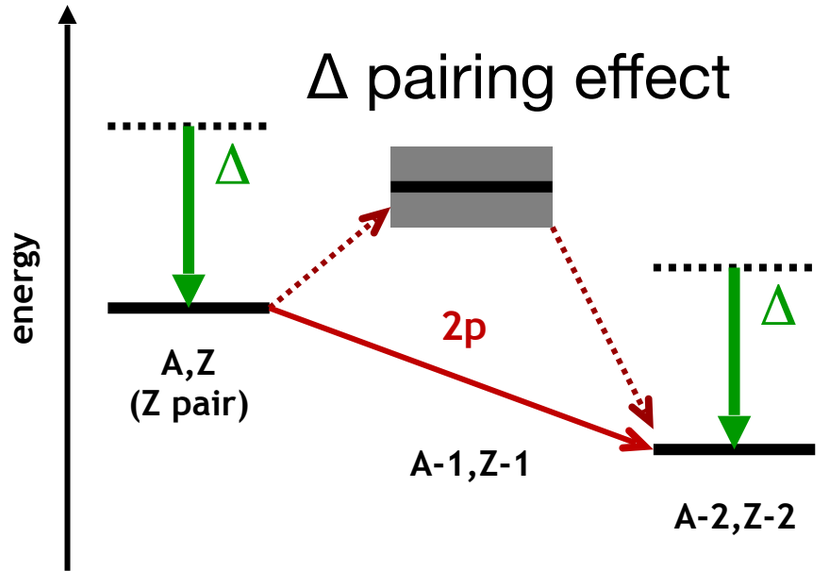
"Exotic" radioactive decays:

- 1-proton for odd-Z isotopes
- 2-protons for even-Z isotopes

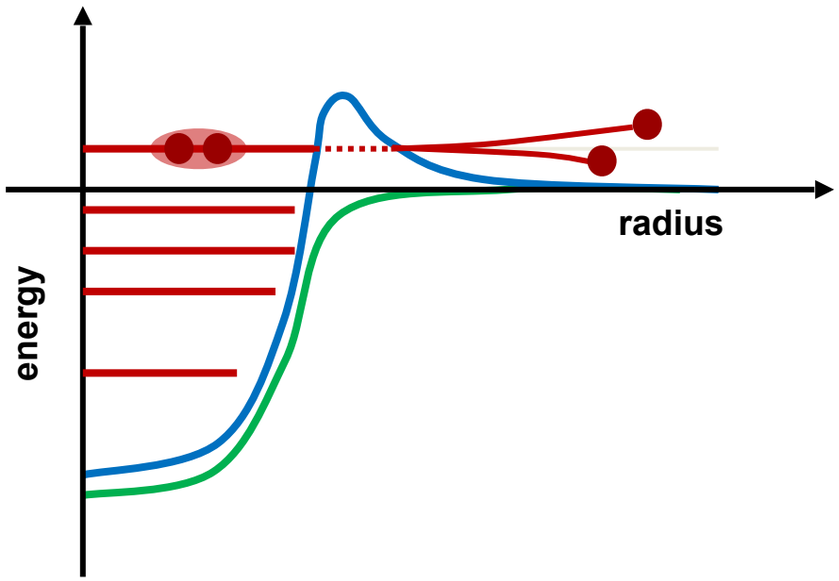
Physics motivation:

- drip-line and masses.
- nuclear structure effect beyond the drip line.
- pairing: energy and angular correlations of emitted protons.
- decay dynamics and tunnel effect

The 2-proton radioactivity mixes the structure (wave function) and the dynamics (decay).



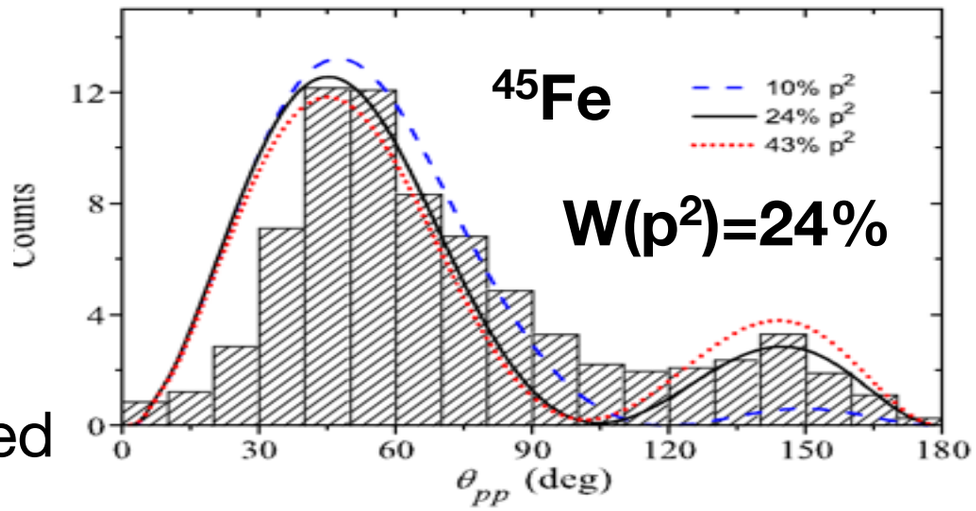
credit J. Giovinazzo



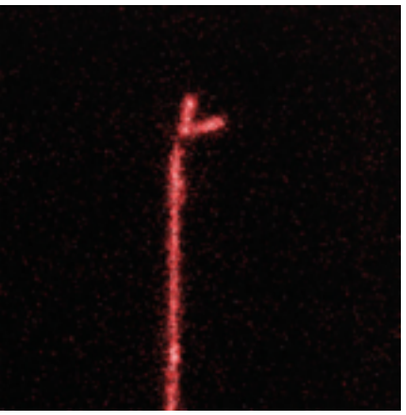
E743: Proton-proton correlation from 2p radioactivity in ^{54}Zn or ^{48}Ni

Four known ground state 2p emitters

- ^{45}Fe: first and most studied case
  - First direct observation (2006, TPC CENBG)
  - angular correlation (2007, OTPC Warsaw/MSU)
- ^{48}Ni: few counts only
- ^{54}Zn: low statistics, decay scheme well established
  - indirect observation (2004, GANIL)
  - limited angular distribution (2011, TPC CENBG)
- ^{67}Kr: last observed 2p emitter
  - indirect observation (2015, RIKEN)
  - no individual protons information

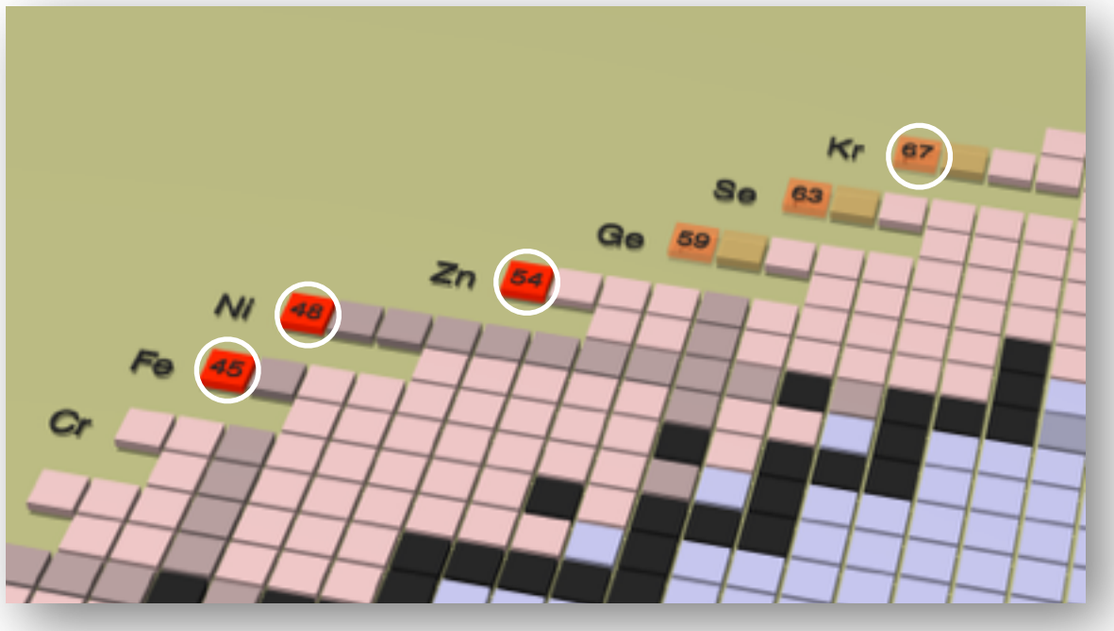


K. Miernik *et al.*

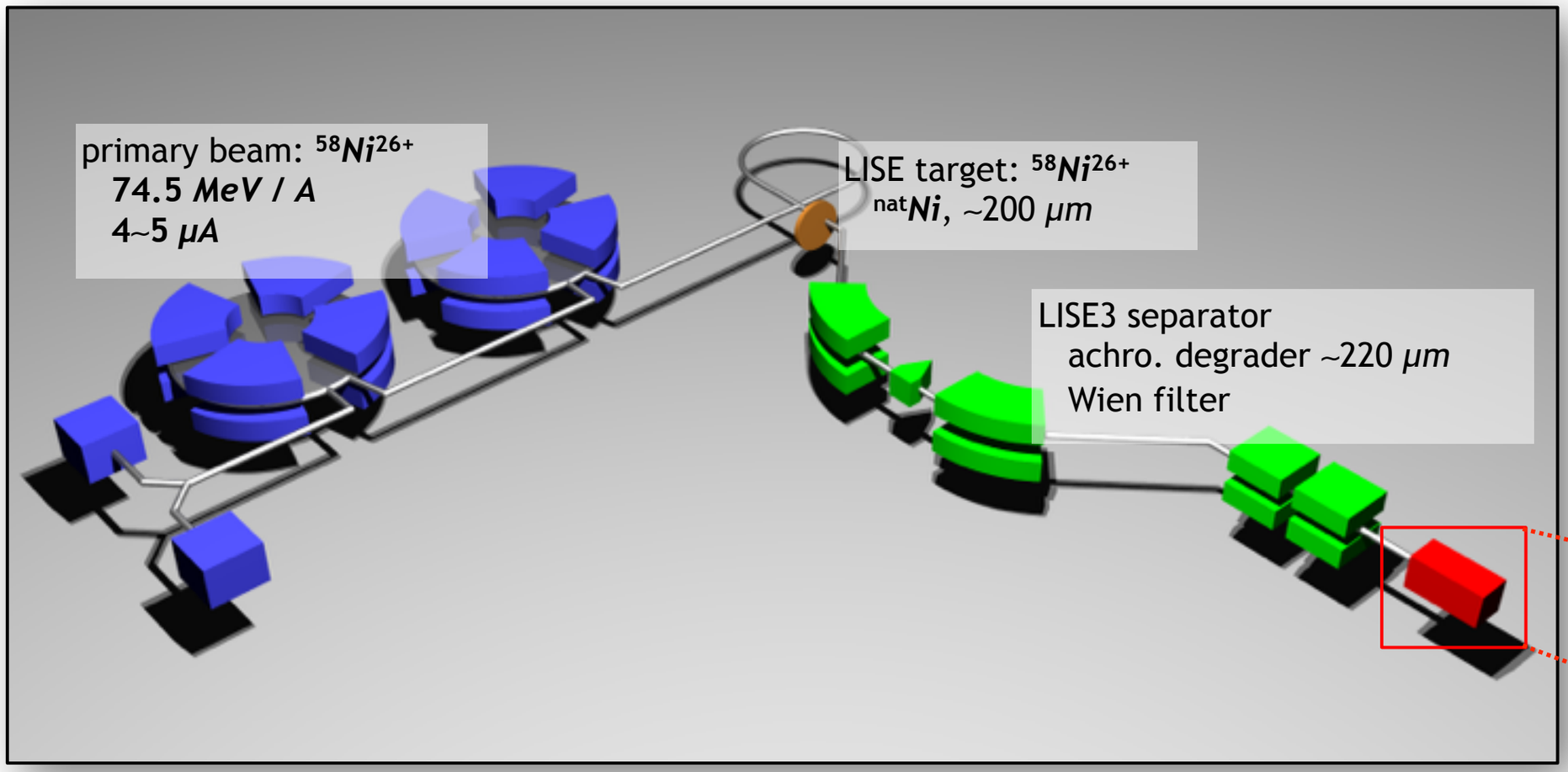


M. Pomorski *et al.*

Tracking experiments with TPC needed



E743: Proton-proton correlation from 2p radioactivity in ^{54}Zn or ^{48}Ni

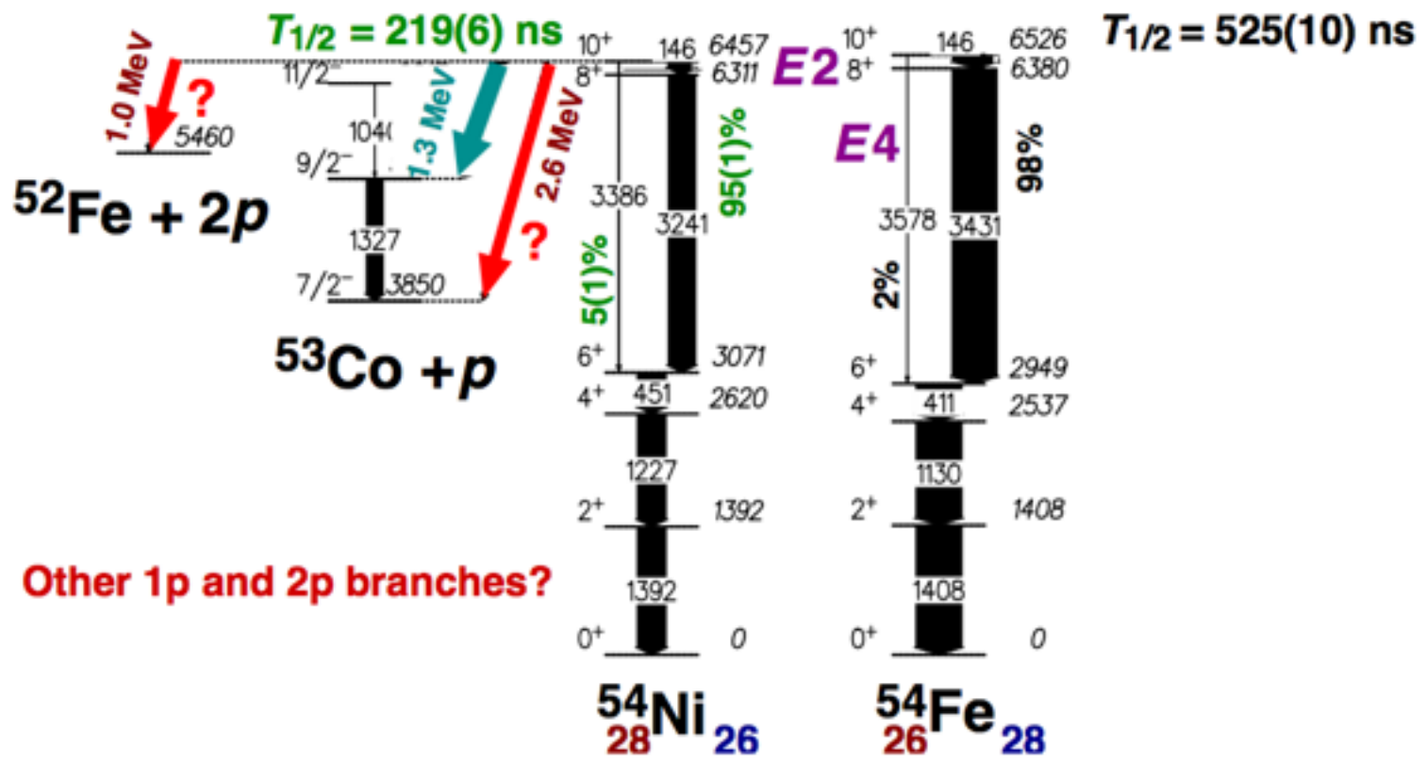


credit J. Giovinazzo

Decay experiments

- Implantation of the beam, then 2p decay.
  => Challenging for the dynamic range
- Specific 2p mode for the GET electronics.

E690: Proton-decay branches from the 10^+ isomer in ^{54}Ni



- Very similar γ-decay pattern between ^{54}Ni and its mirror nucleus ^{54}Fe.
- Very different half-life: $T_{1/2}(^{54}Ni) \approx 0.4 * T_{1/2}(^{54}Fe)$
- Experiments in GSI measured only γ from the implantation of ^{54}Ni
  - 1327 keV from ^{53}Co: proton-branch br_{p1}
  - No access to the branching-ratio to the ground state br_{p2}

Summary

The short term physics plan will cover

- Exotic decay with proton-proton correlations to probe the nature of the decay.
- Reaction relevant for astrophysical physics.
- Shell evolution in very exotic nuclei.

The ACTAR TPC will also be used for

- Giant resonances: GMR, GDR, GQR, Pygme…
- Cluster physics in light neutron-rich nuclei.

Summary

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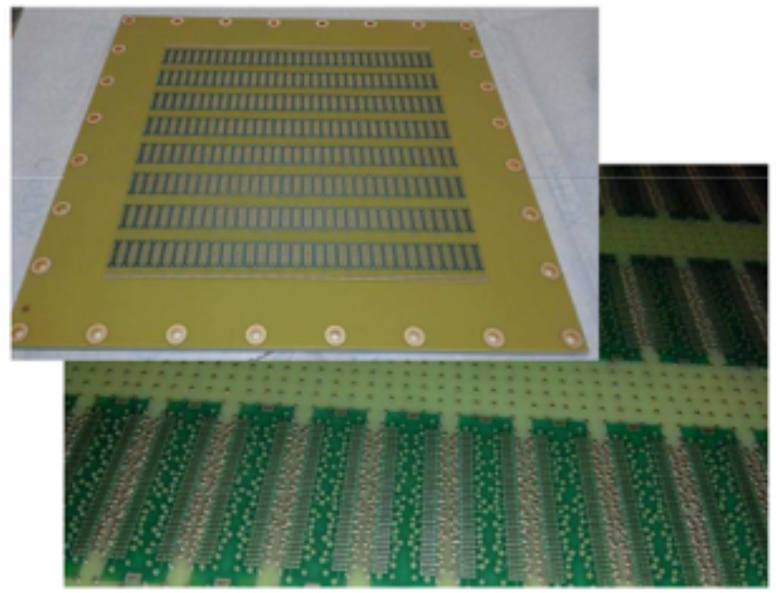
Detector development

- Finalizing current development
  - Micromegas scanning
  - GANIL solution for the pad plane
- Gain measurement (gas type and pressure)
- GEM, THGEM…

Software development

- Tracking algorithm comparison



Collaboration

GANIL
M. Blaizot
P. Bourgault
B. Duclos
G. Fremont
P. Gangnant
J. Goupil
G.F. Grinyer[1]
A.T. Laffoley[2]
L. Legeard
C. Maugeais
B. Mauss
M. Michel
P. Morfouace
J. Pancin
T. Roger
P. Senecal
C. Spitaels
K. Turzo

GANIL
G. Voltolini
V. Vandevoorde
G. Wittwer
F. Saillant

SACLAY
E.C. Pollacco
P. Sizun
M. Vandebrouck

K.U. Leuven
S. Ceruti
J. Daemen
T. Marchi
O. Poleshchuk
R. Raabe
R. Renzi
J.A. Swartz
C. Wouters
J.C. Yang

CENBG
B. Blank
J. Giovinazzo
T. Goigoux
J.L Pedroza
J. Pibernat

USC
H. Alvarez-Pol
M. Camaano
B. Fernández
P. Konczykowski

IPNO
M. Babo
F. Flavigny

RIKEN
D. Suzuki

Current affiliation:
[1]University of Regina, Canada
[2]University of Guelph, Canada

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For more information:
http://pro.ganil-spiral2.eu/laboratory/detectors/actartpc