ACTAR TPC
a new gas detector for nuclear physics

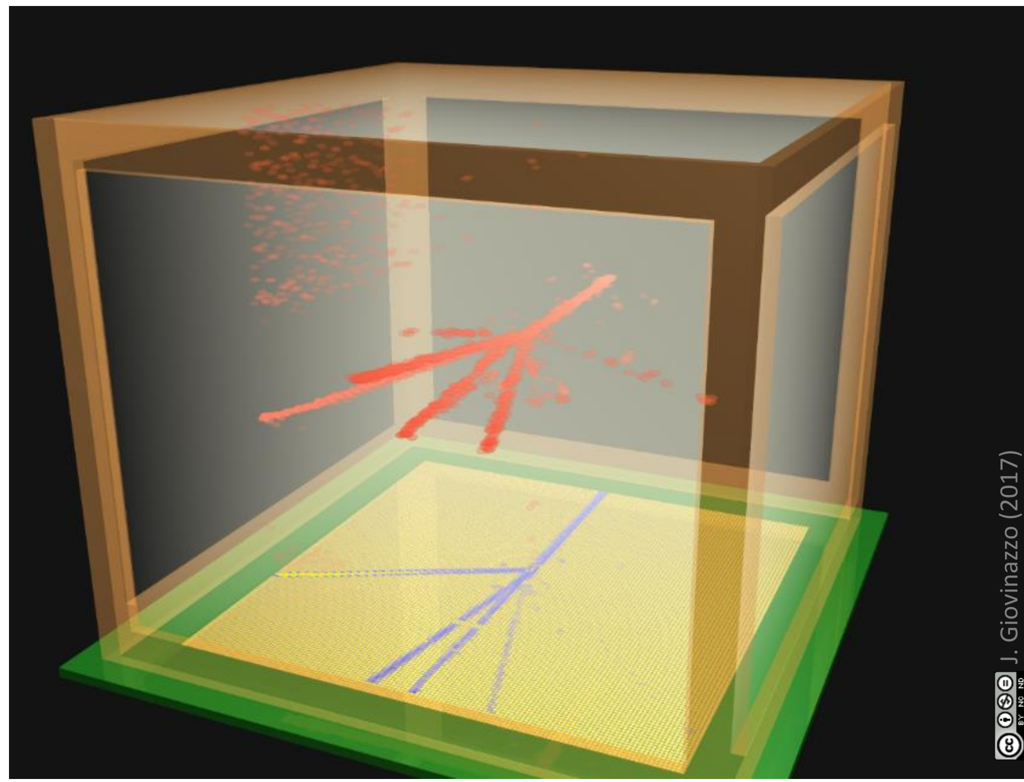
J. Giovinazzo - CENBG
and the ACTAR TPC collaboration

▷ what is ACTAR TPC
- global presentation
- physics program

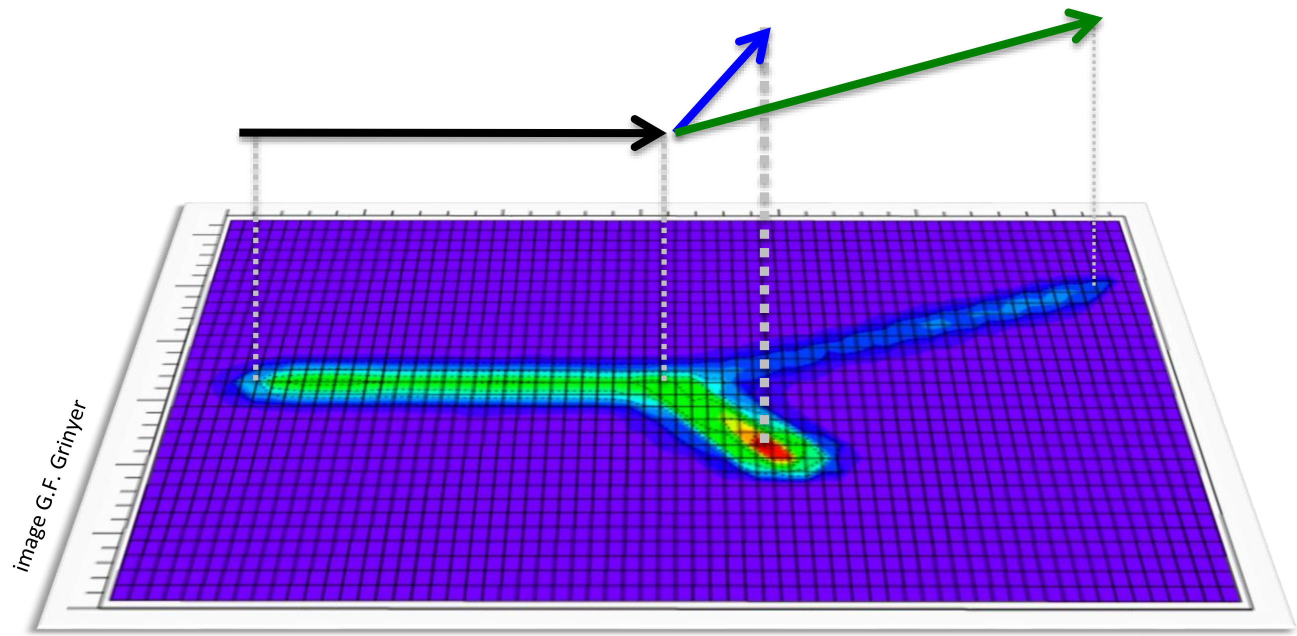
▷ detector development
- main elements
- electronics

▷ tests and analysis
- source characterization
- in-beam tests

▷ gas considerations
- decays & reactions

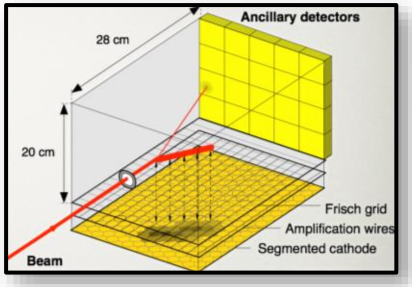


what is ACTAR TPC



birth of ACTAR TPC

time projection chambers for (fundamental) nuclear physics

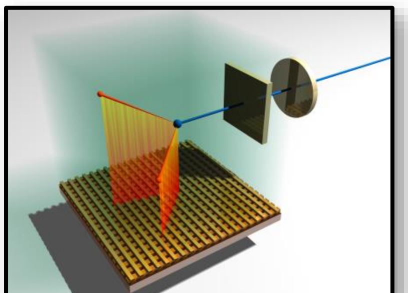


MAYA

(GANIL and coll.)

nuclear reactions

pads (hex): 2D proj.
wires: drift time



CENBG TPC

ions stopping and decay

X-Y strips
energy & time:
2x 1D proj.

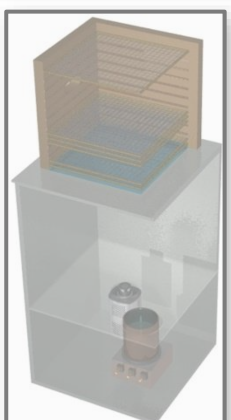


image Warsaw coll.

Optical TPC
(Warsaw)

ions stopping and decay

CCD cam.: 2D proj.
PM + sampling:
global time dist.

development of a new TPC
for a large (nuclear) physics case

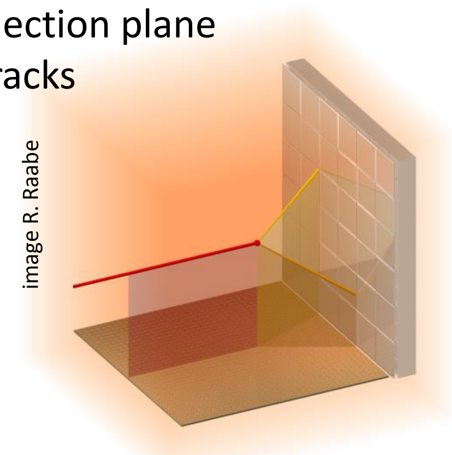
GANIL, CENBG, IPNO
Leuven, Santiago de C.

1 development, 2 detectors

“reaction” chamber

128x128 pads collection plane

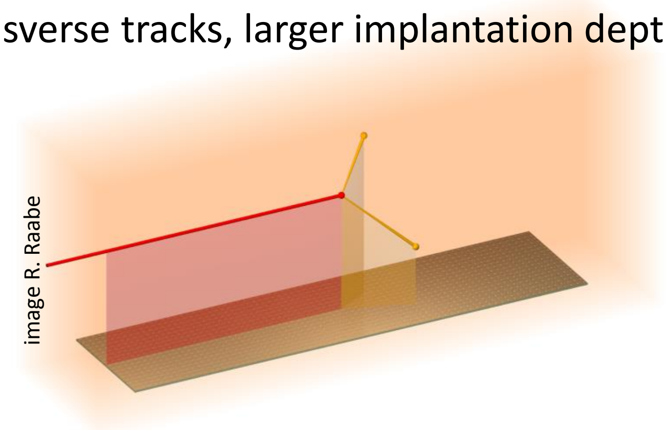
large transverse tracks



“decay” chamber

256x64 pads collection plane

short transverse tracks, larger implantation depth



shared design and technology

16384 pads, 2x2 mm^2

2 geometries

→ main funding: ERC (J.F. Grinyer, GANIL)

→ decay chamber: Region pad plane R&D (J. Giovinazzo, CENBG)

2014 – 2018/19

GET electronics

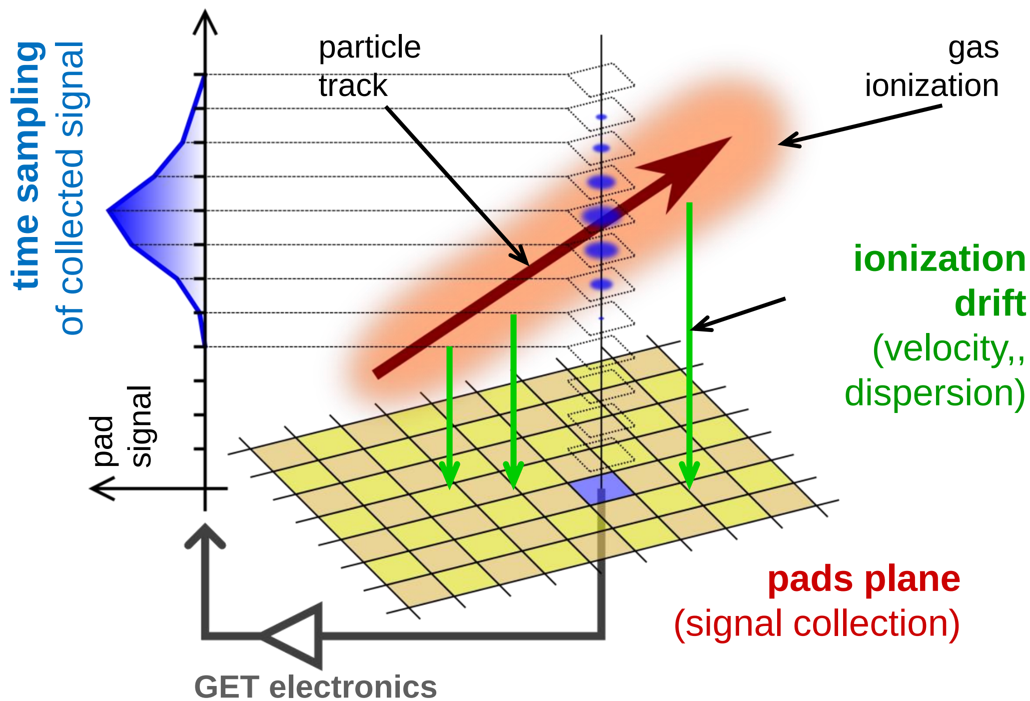
technical solution for channels readout

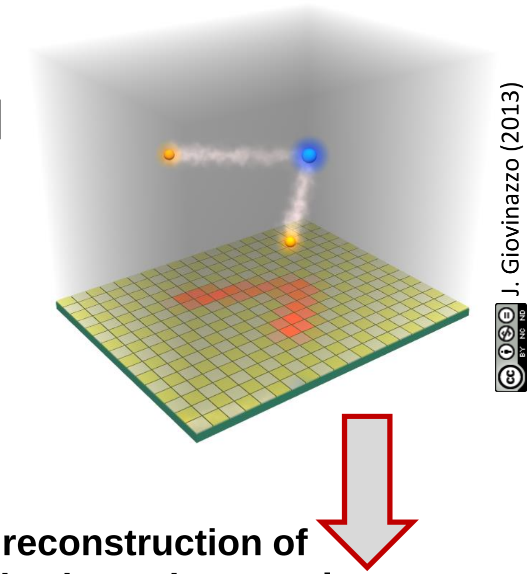
2011 – 2016/17

a 4D detector: tracking + energy

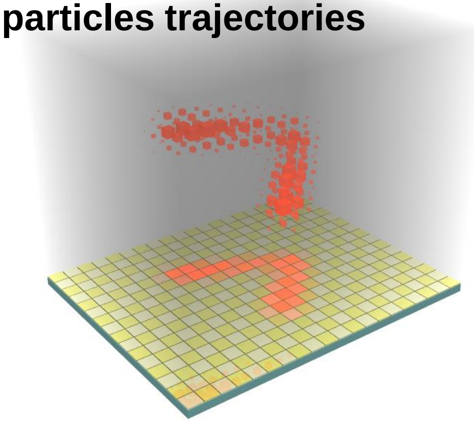
pads plane	**TPC principle**	**time sampling of signal**
(signal collection)		
2D digitization	$z \Leftrightarrow t$	3D digitization

$$\Delta E(x,y,z) \Longleftrightarrow \Delta E[x_i,y_j](z) \Longleftrightarrow \Delta E[x_i,y_j](t) \Longleftrightarrow \Delta E[x_i,y_j,t_k]$$



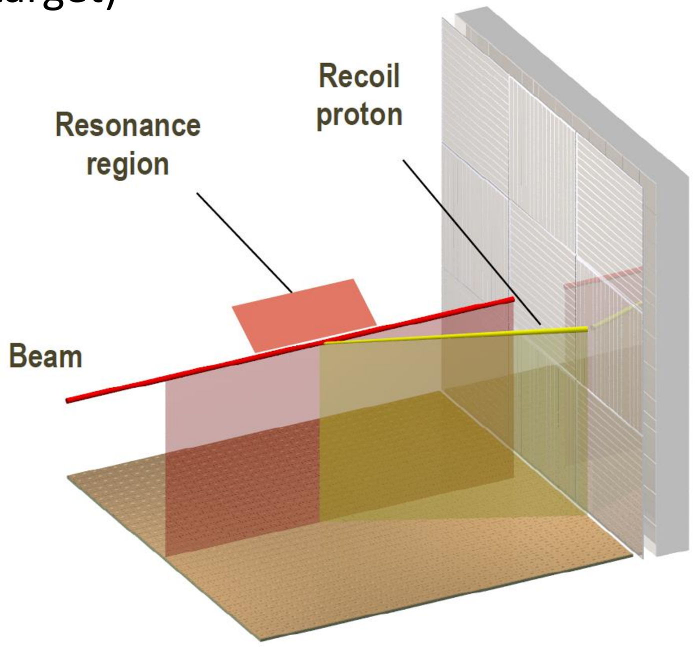


3D reconstruction of ionizations charges along the particles trajectories



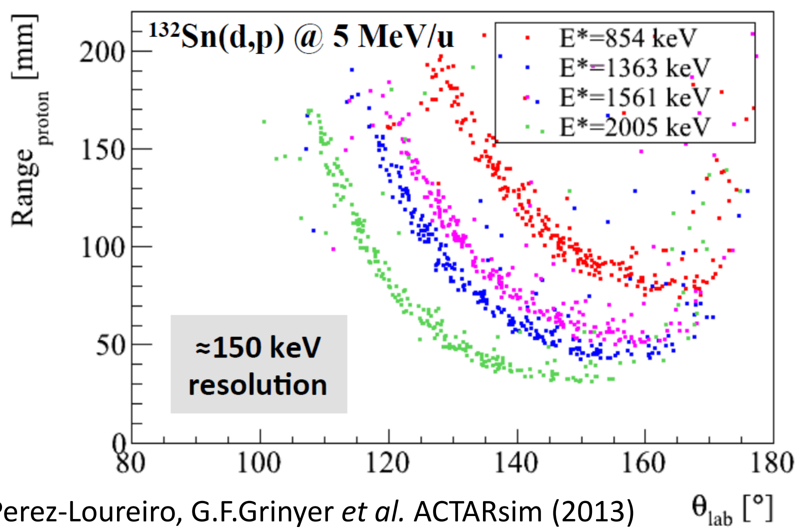
physics opportunities: Active Target

Active Target: excellent tool for inverse kinematics reactions studies
many advantages / traditional approaches (solid target)



unbound resonances, highly excited states

- thick target
- vertex measurement / particles tracking
- good energy resolution
- large angular acceptance
- low background (selected target gas)
- ...



D.Perez-Loureiro, G.F.Grinyer *et al.* ACTARsim (2013)

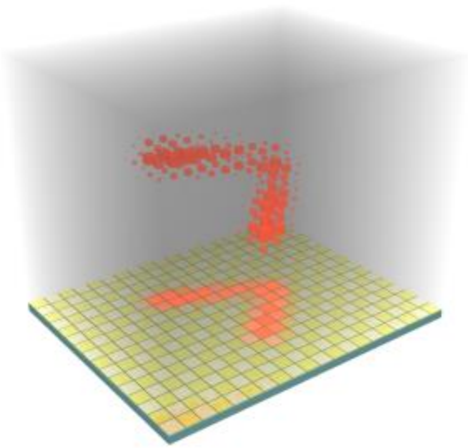
transfer and charge exchange reactions

- thick target, higher count rate
- detect low energy particles (protons)
- good energy resolution
- ...

physics opportunities: exotic decay modes

beta-delayed particles(s) emission

- detect low energy protons / no beta background (→ nuclear astrophysics)
- multi-particle decay (β-2p, β-3p)
- rare particles decay (^{6}He: β-αd, ^{9}C: β-p2α)

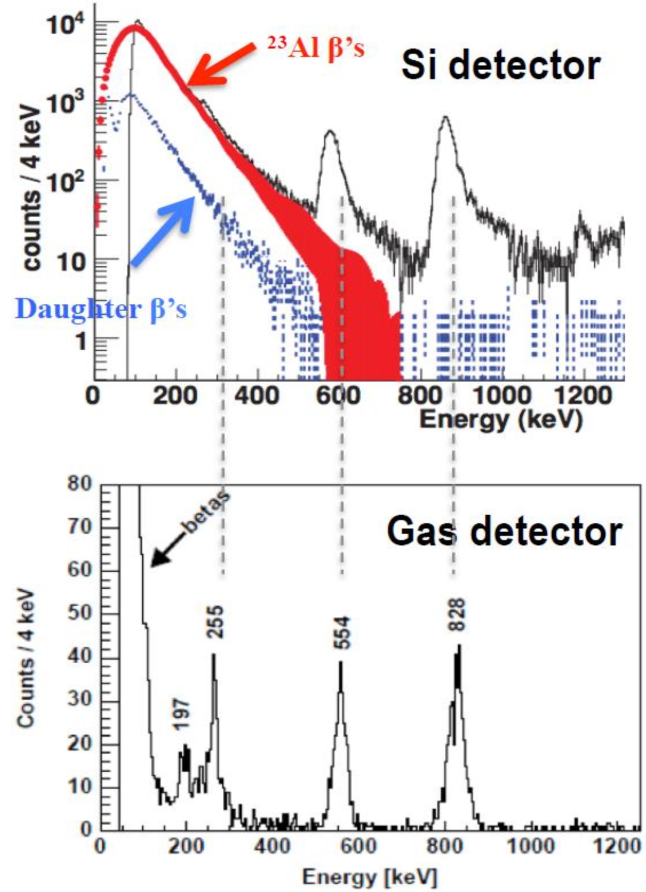


2-proton radioactivity

- tracking: angular and energy correlations
- only access to decay mechanism & structure

particle(s) decay of excited states

- decay channel selectivity
- i.e.: 12C* → 3$^{\alpha}$ (Hoyle state)



A. Saastamoinen *et al.* PRC 83, 045808 (2011)
E.C. Pollacco *et al.* NIM A 723, 102 (2013)

ACTAR TPC development

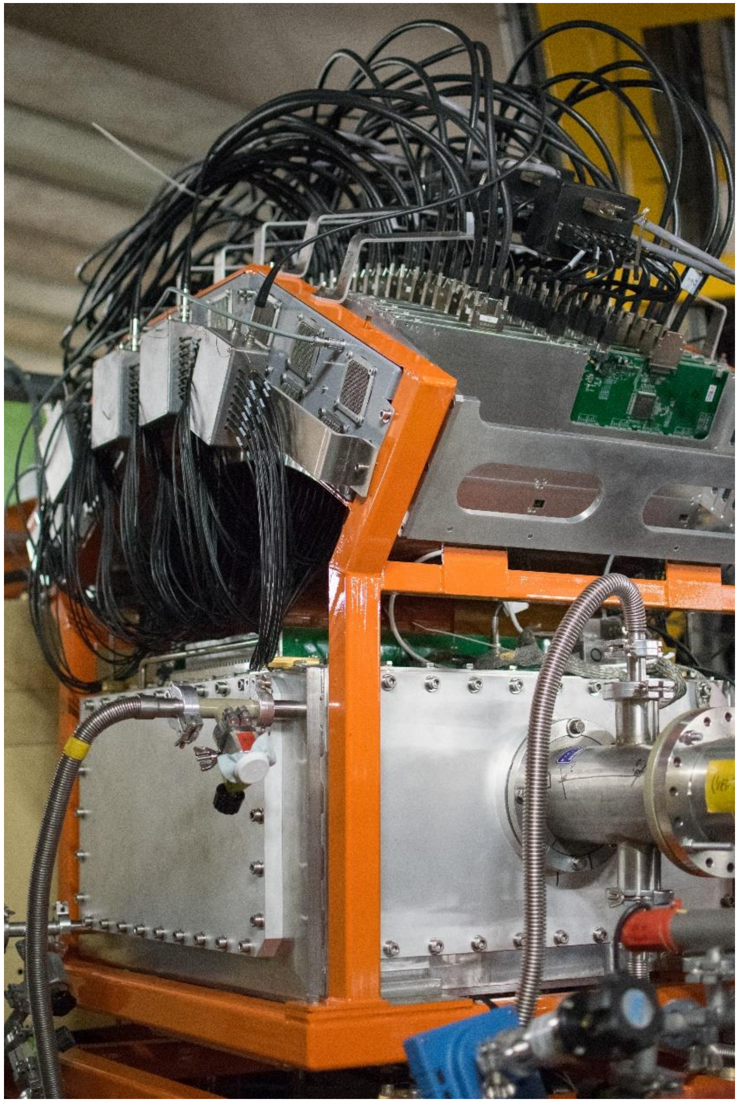


photo O. Poleshchuk (2017)

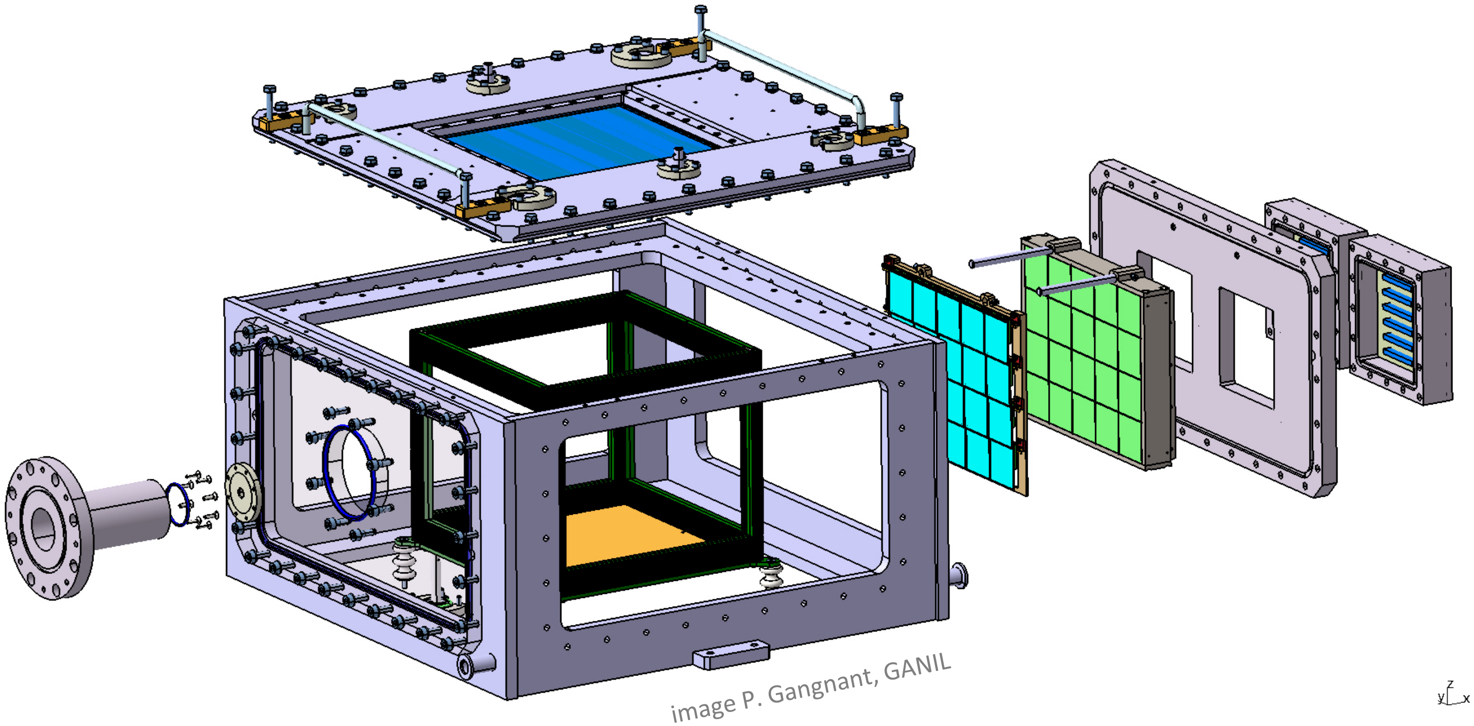
ACTAR TPC global design

- 2 demonstrators
  (32x64 pads: **2048 channels**)
  at GANIL & CENBG
- 2 final detector geometries
  (**16384 channels**)

  → **“reaction”** (GANIL) chamber (128x128 pads)

  → **“decay”** (CENBG) chamber (64x256 pads)

- **active volume (drift region)**
- **collection plane (pads) & amplification**
- **electronics**
- **additional detectors**



ACTAR TPC design: active volume & drift cage

electric field **uniformity**
transparent **to particles**

→ **double wires frames**
- 1 and 2 mm pitch (inside/outside)
- 98 % transparency

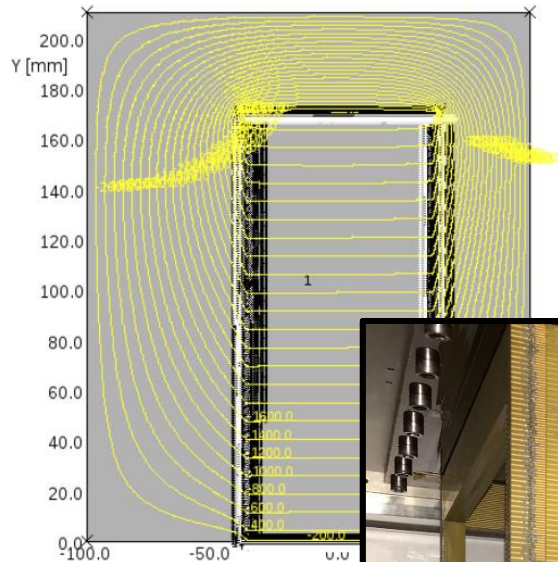
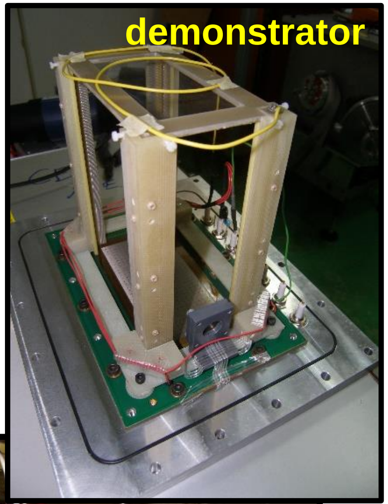


photo JG/CENBG (2016)



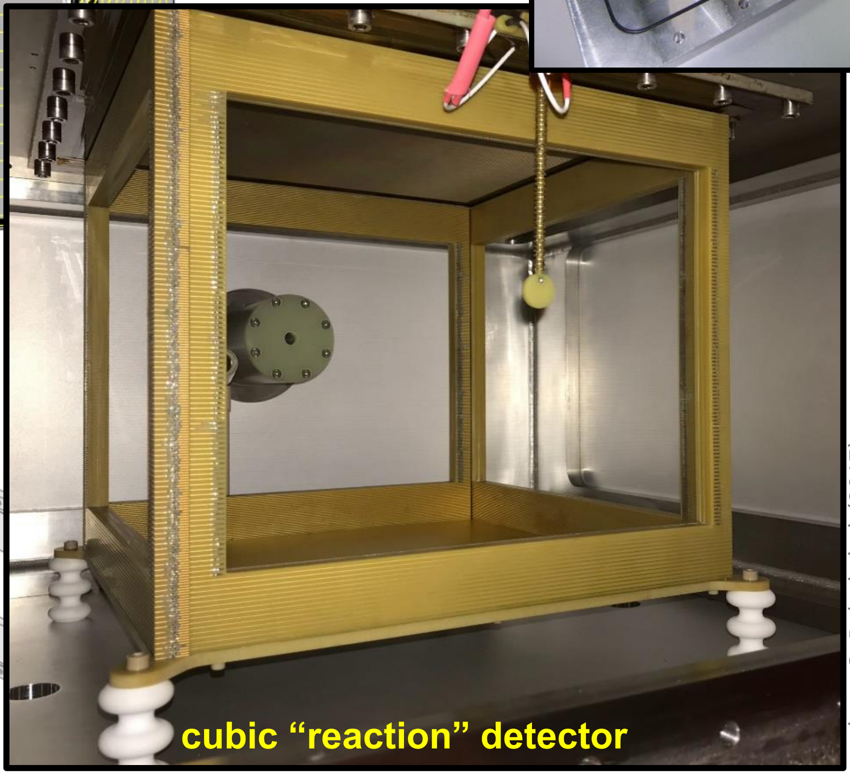
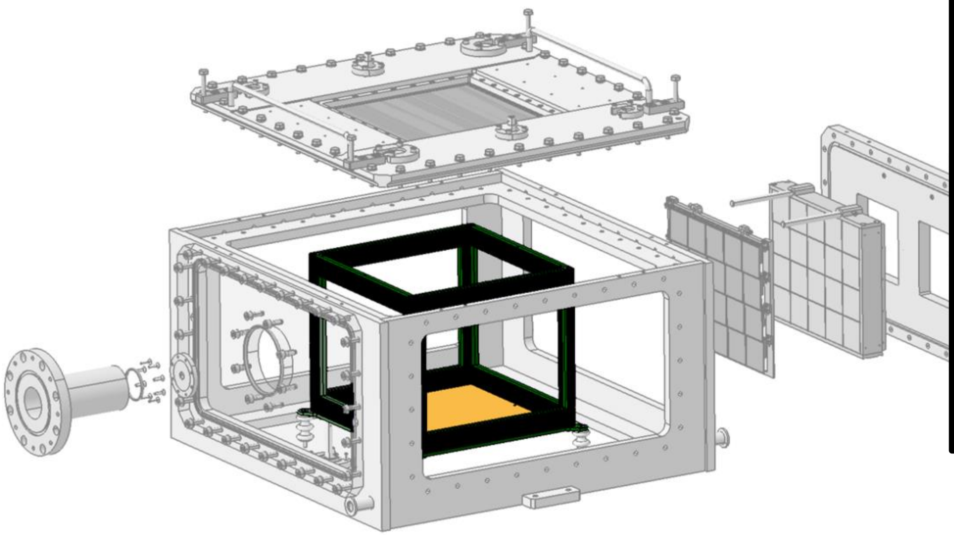


photo O. Poleshchuk (2017)



GANIL SPIRAL2 design

ACTAR TPC design: auxiliary detectors

TPC chambers designed to include additional (side) detectors

- **tracking of particles escaping the drift region (reaction studies and active target mode)**
- **events tagging / reactions selection**
- **additional position and energy information (used also for commissioning)**

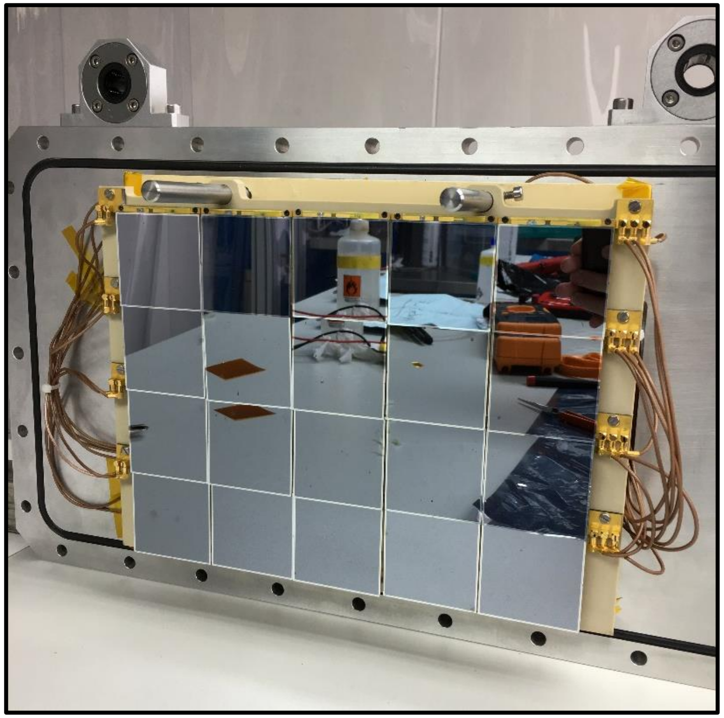
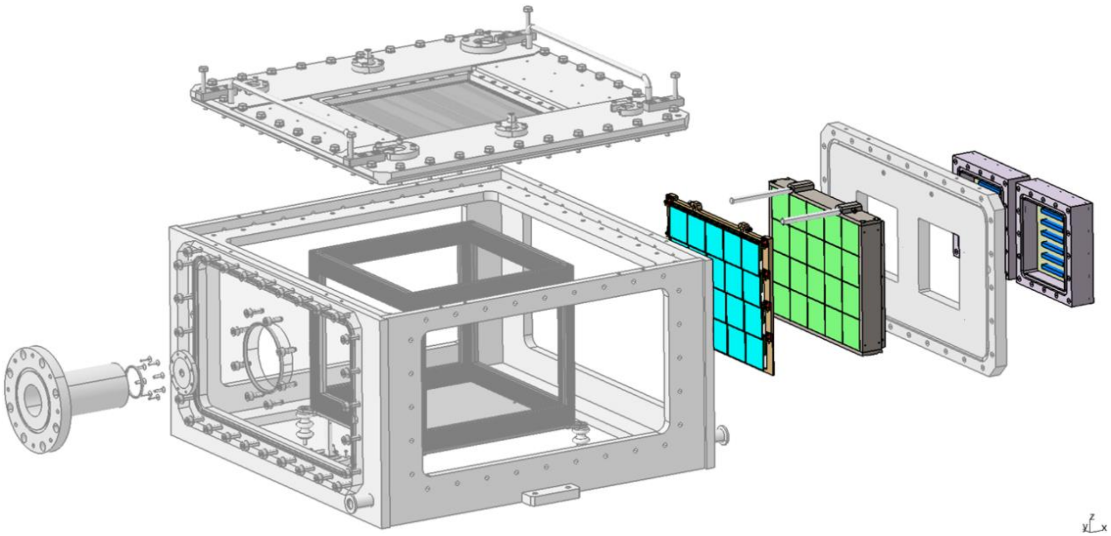


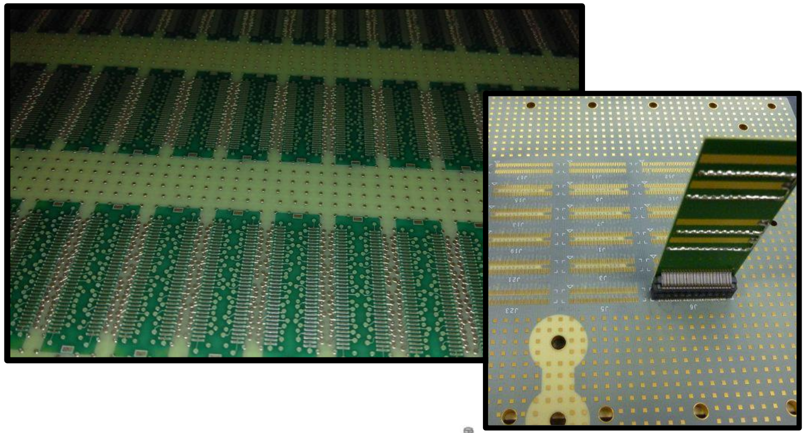
photo GANIL (2017)



ACTAR TPC design: collection (pads) plane

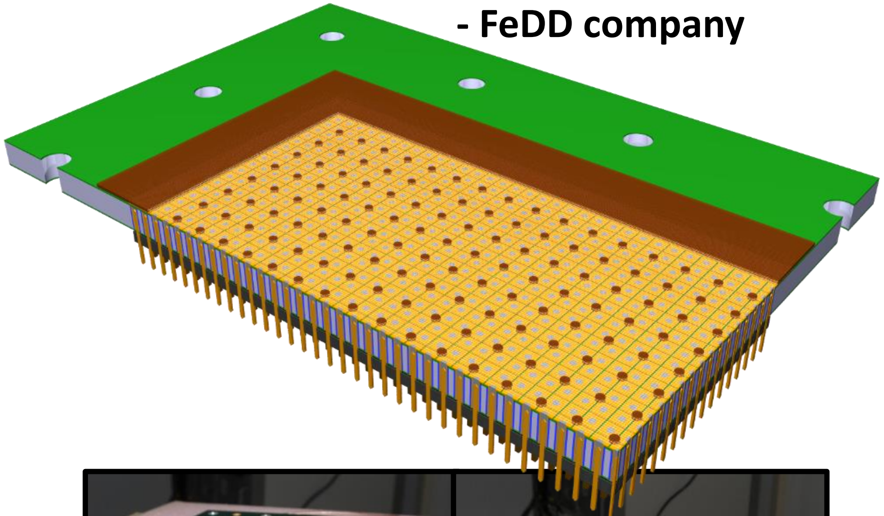
high density of pads
mechanical constraints

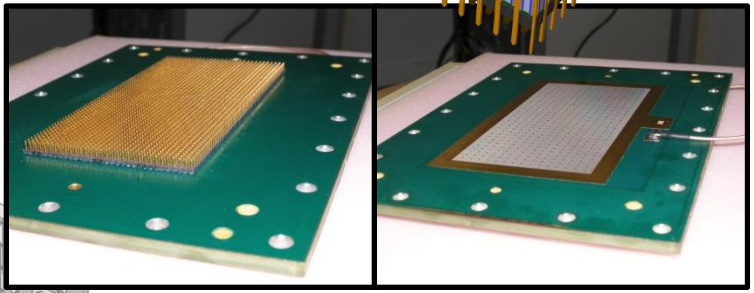
multi-layer PCB (GANIL version)

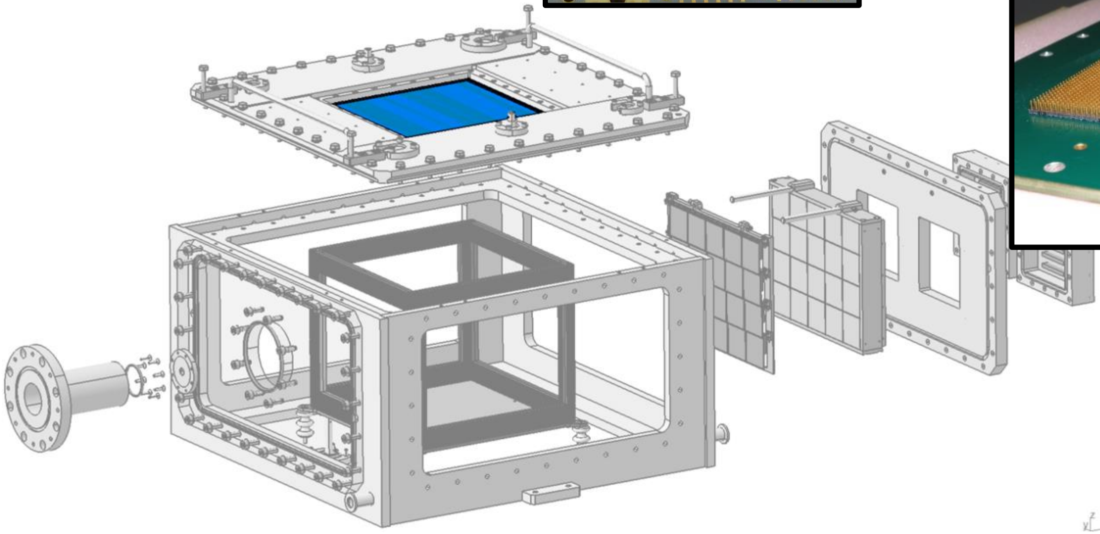


metal-core PCB (CENBG version)

developed with
- CERN PCB workshop
- FeDD company







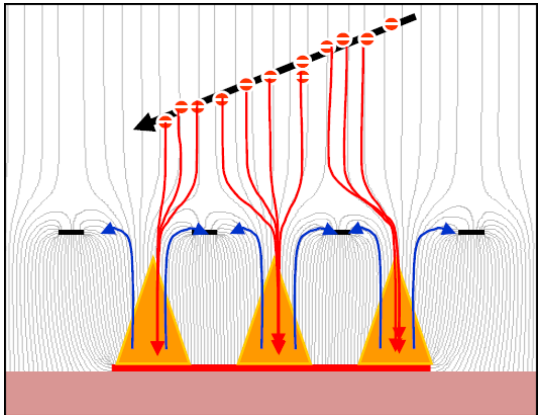
both tested on demonstrators

→ specific the connection to readout electronics

ACTAR TPC design: signal amplification

bulk micromegas
(CERN)

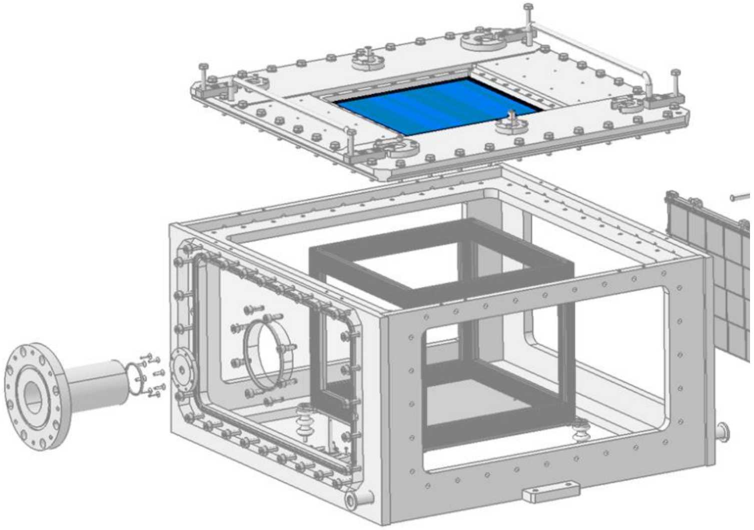
possible use of GEMs

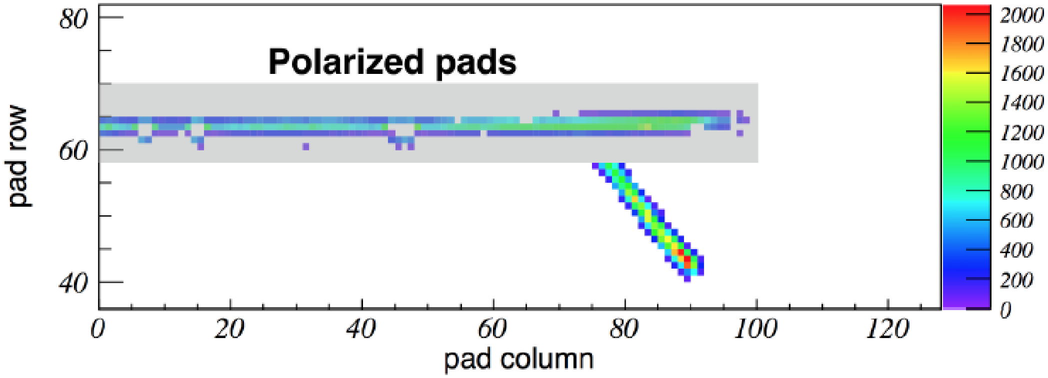


selected pads polarization

- **local reduction of the gain**
- **"active target" mode:**
  - **- high intensity beam**
  - **- few interactions**

→ avoid saturation





ZAP connectors: signal extraction and sparks protection

connectors for multi-layer PCB

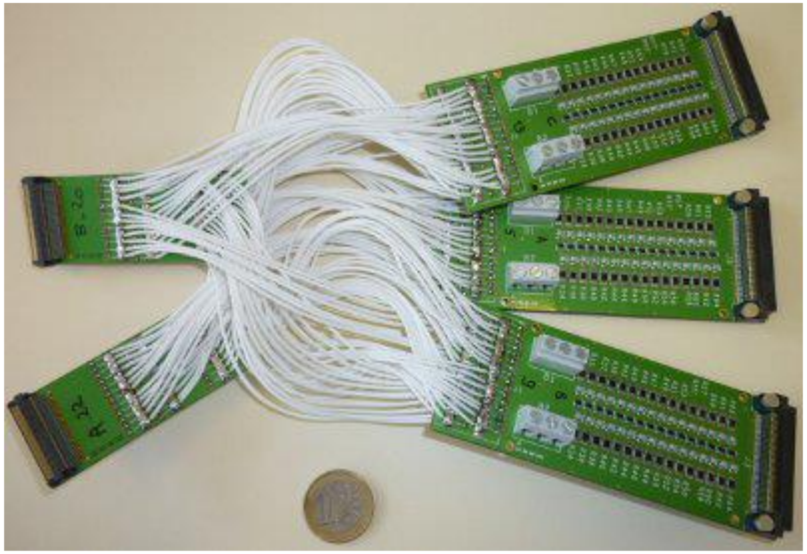


photo GANIL (2015)

with µ-coax cables
problem for 16384 pads…

connectors for metal-core PCB

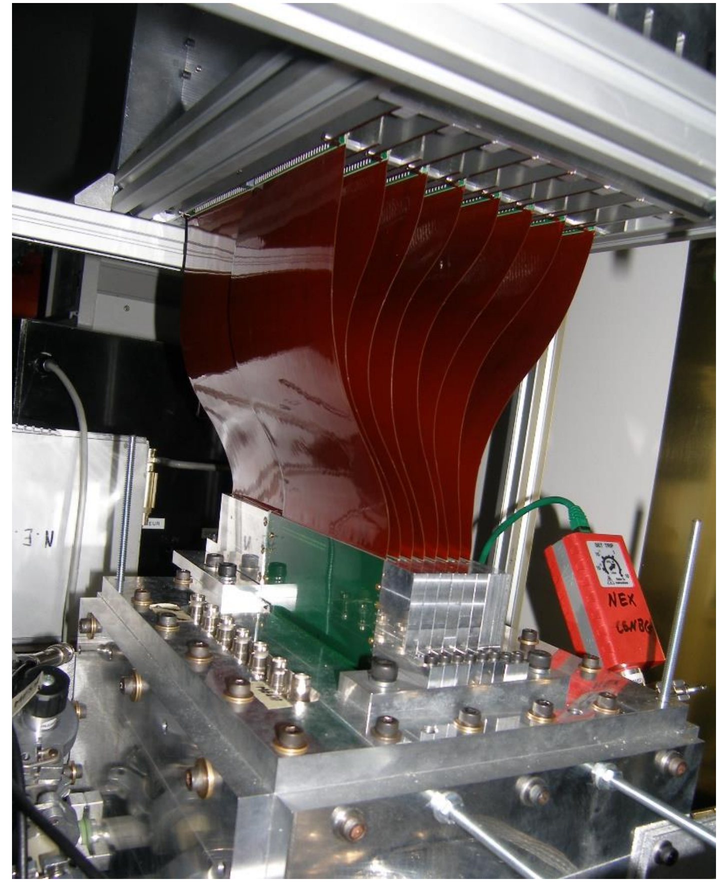


photo JG/CENBG (2016)

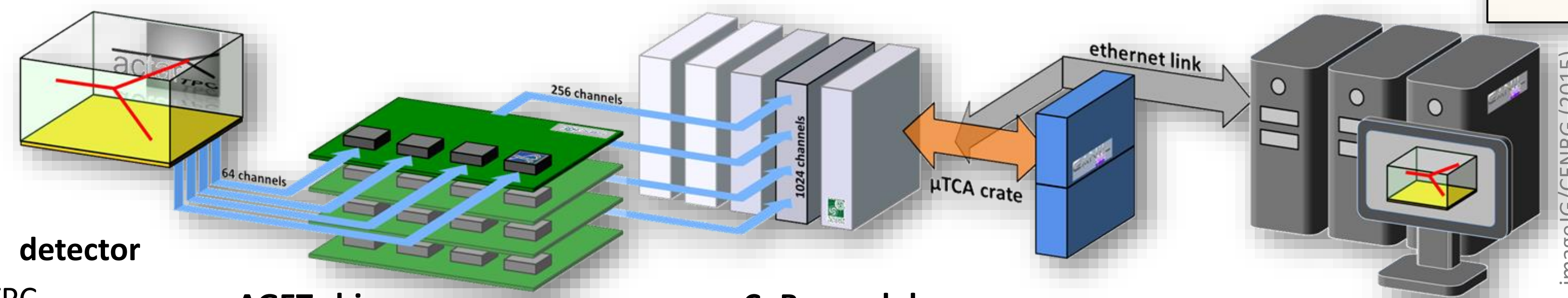
with flex (shielded) PCB

comparable noise (test measurements)

pads polarization for both geometries

readout electronics

IRFU, CENBG, GANIL, MSU
ANR 2011-2015



detector
TPC
16384 pads

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

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

CoBo module
4 AsAd boards
digital data
management

MuTAnT
clock distrib.,
trigger management
(3 levels)

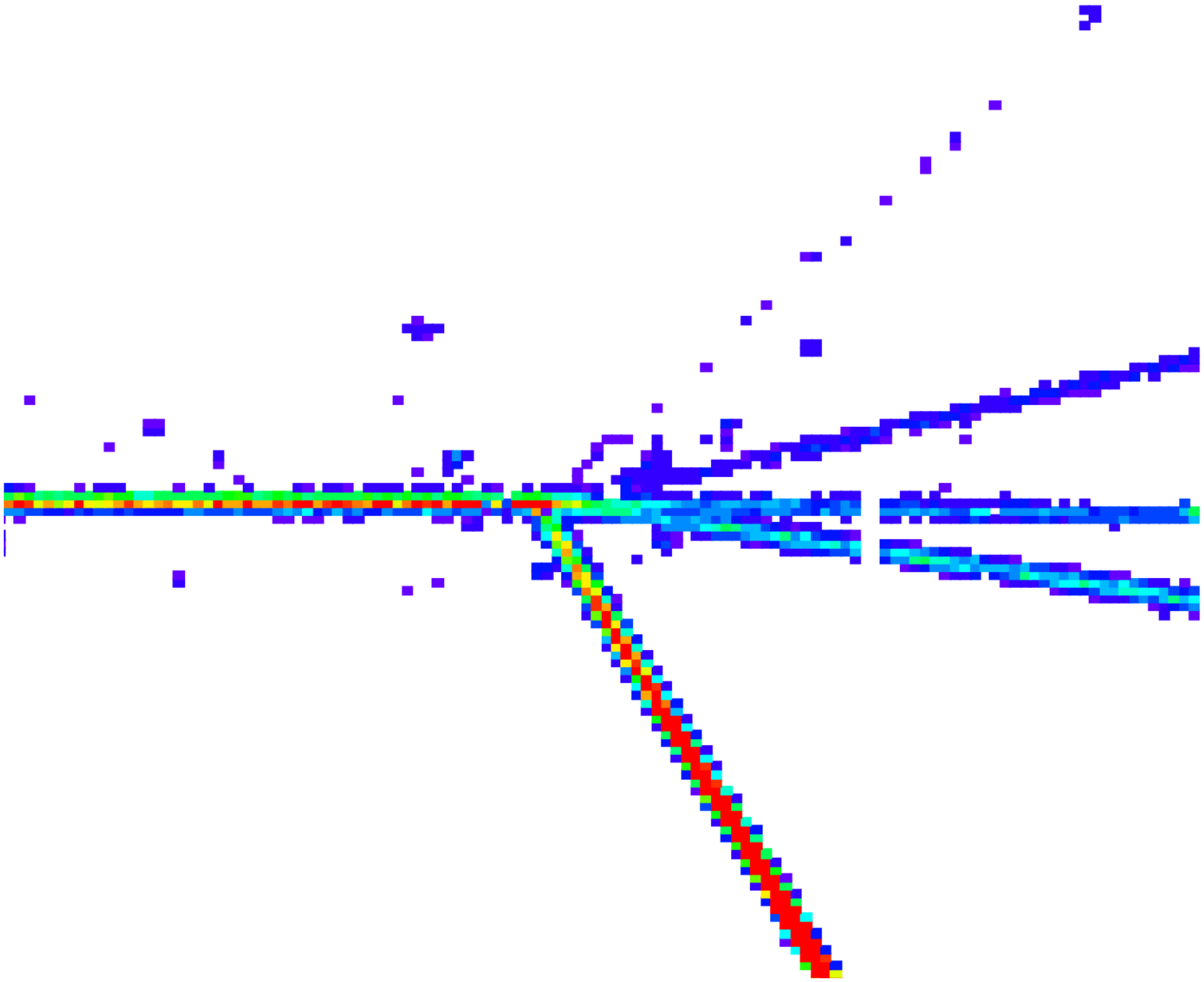
control / acquisition

for each channel:

time sampling (max. 512, freq. 1-100 *MHz*): analog mem. + ADC
discriminator → internal multiplicity trigger

designed to handle 1 *kHz* count rate for 10% of channels hit (~1600 channels)

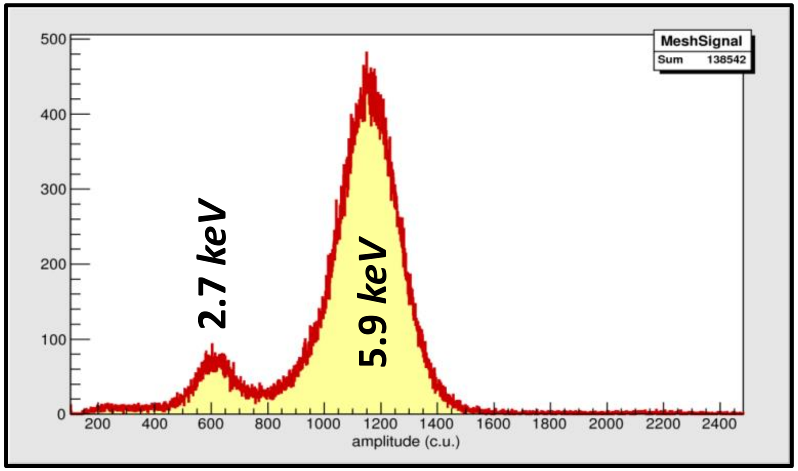
performances



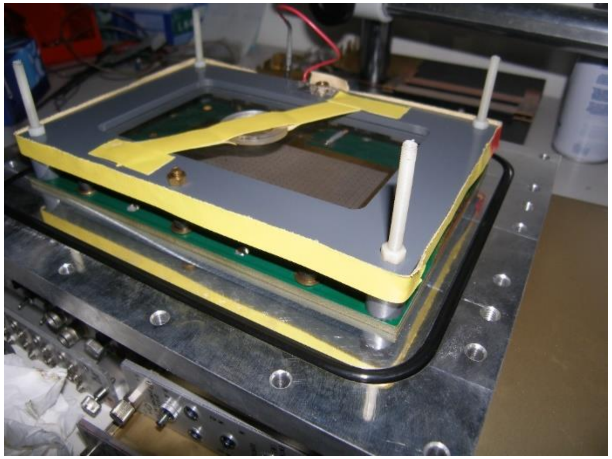
pad plane validation

^{55}*Fe* source X-rays

drift volume thickness: **2.5 *cm***
HV*mesh* = **–570** *V*
HV*drift* = **–1000** *V*

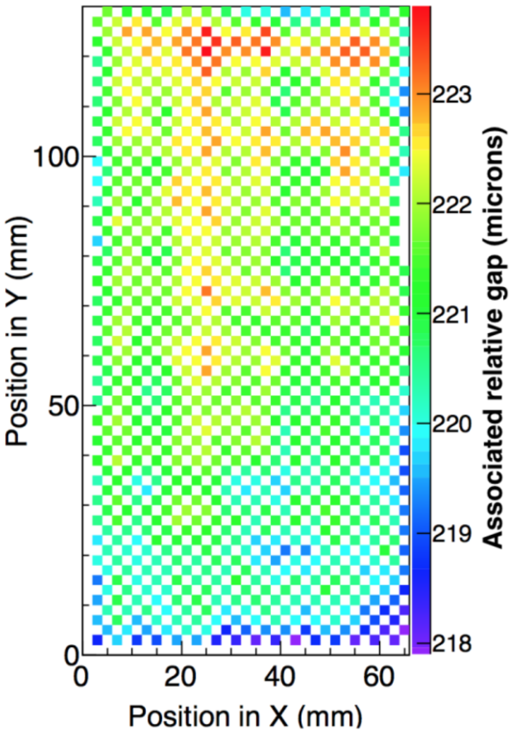


resolution (FWHM) @ **6** *keV*: ~**21 %**
mesh signal & **pads** signal



GANIL scanning table

- amplification gap homogeneity
- gain matching



B. Mauss, PhD thesis (GANIL)

demonstrator tests: energy resolution

3-alpha source

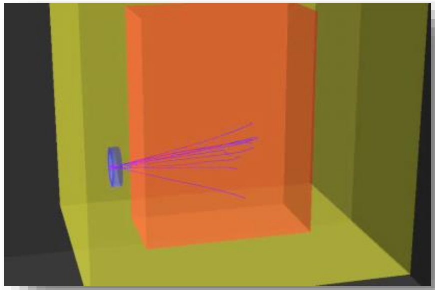
GANIL drift cage

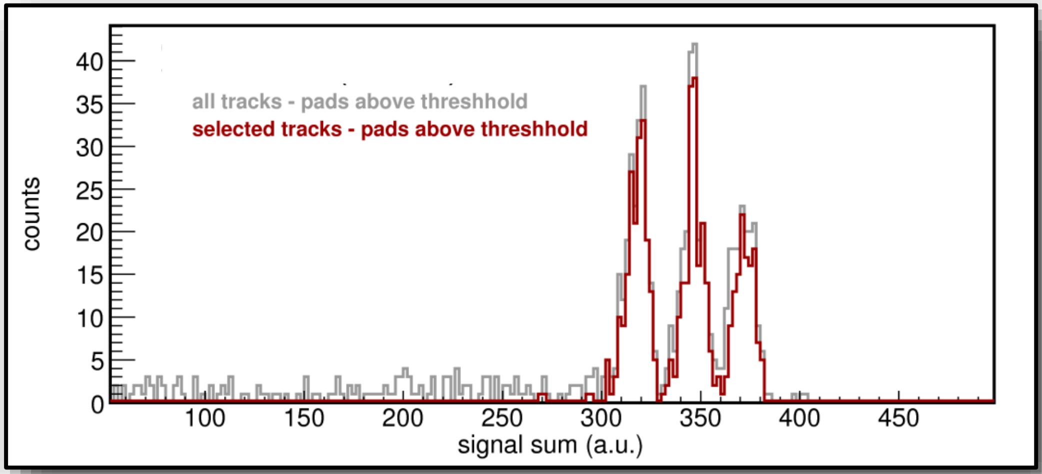
HV_{mesh} = **–350** *V*

HV_{drift} = **–2000** *V*

P10 gas (Ar-CH_4), 400 mbar

alpha energy correction
(Geant4 simulation)



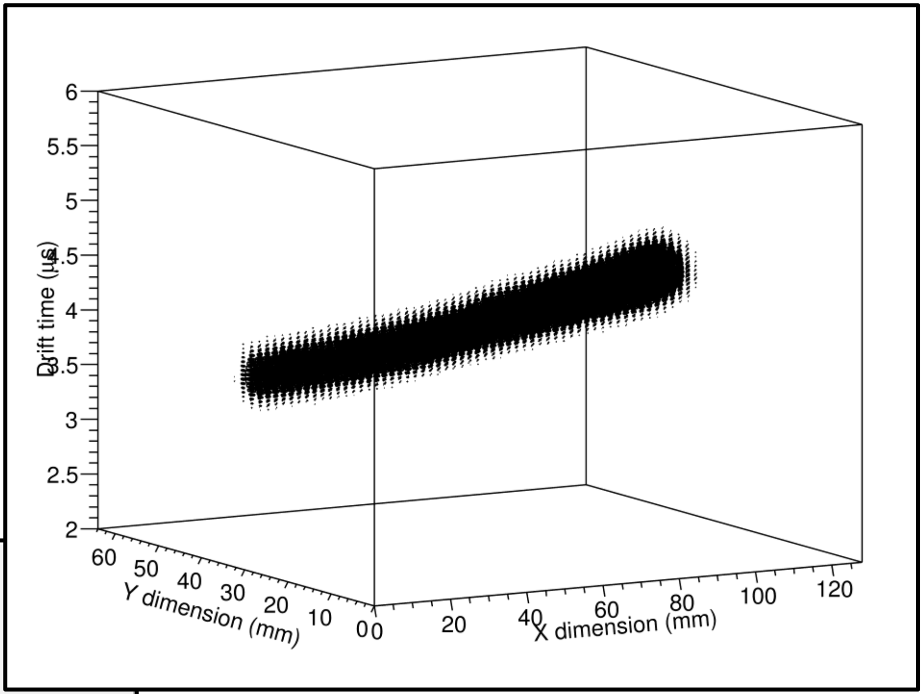


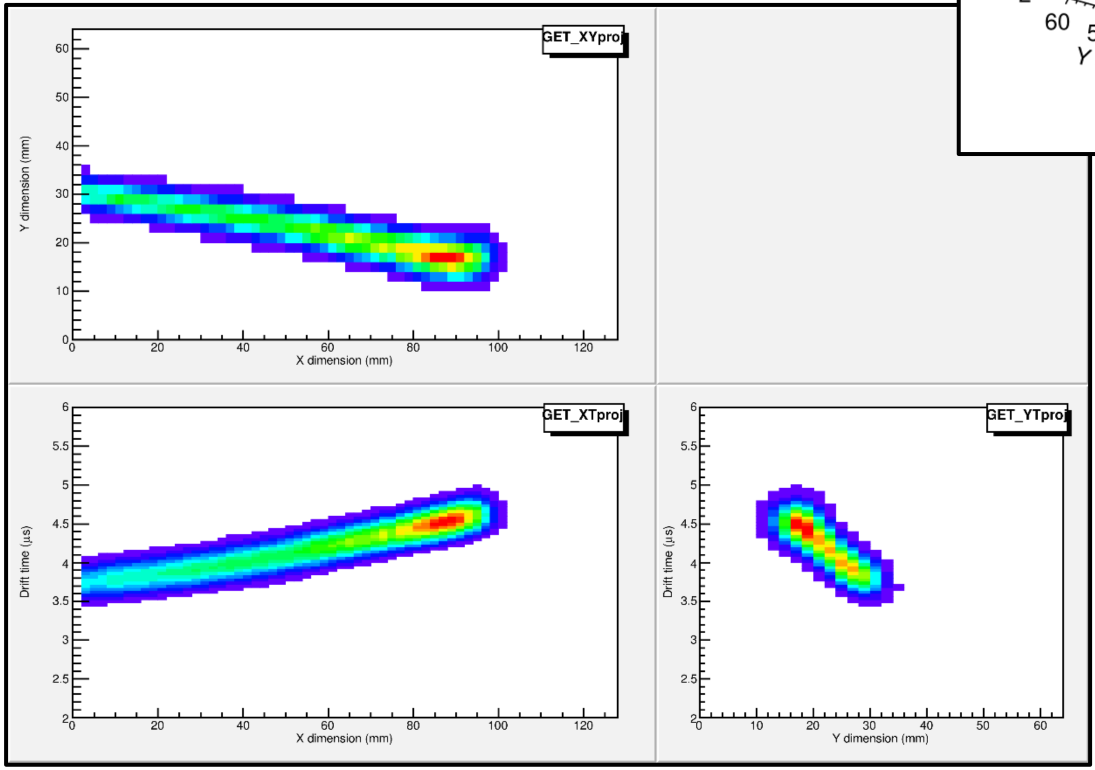
resolution (FWHM) @ **5** *MeV*: ~**100** *keV*

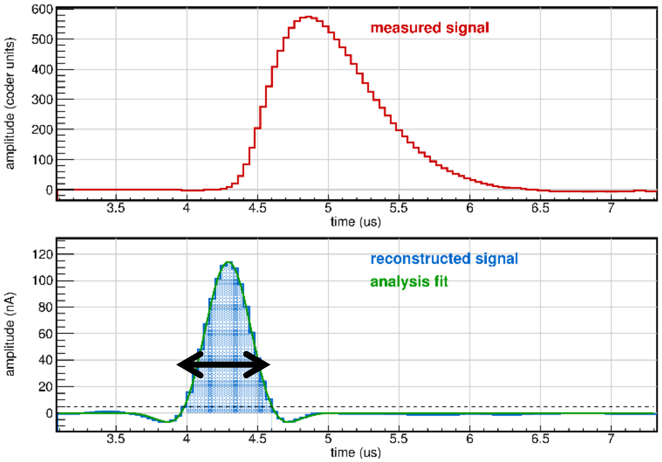
full 3D charge reconstruction

with response function de-convolution
→ effective Z charge distribution

energy resolution from rec. signal
equiv. to output signal



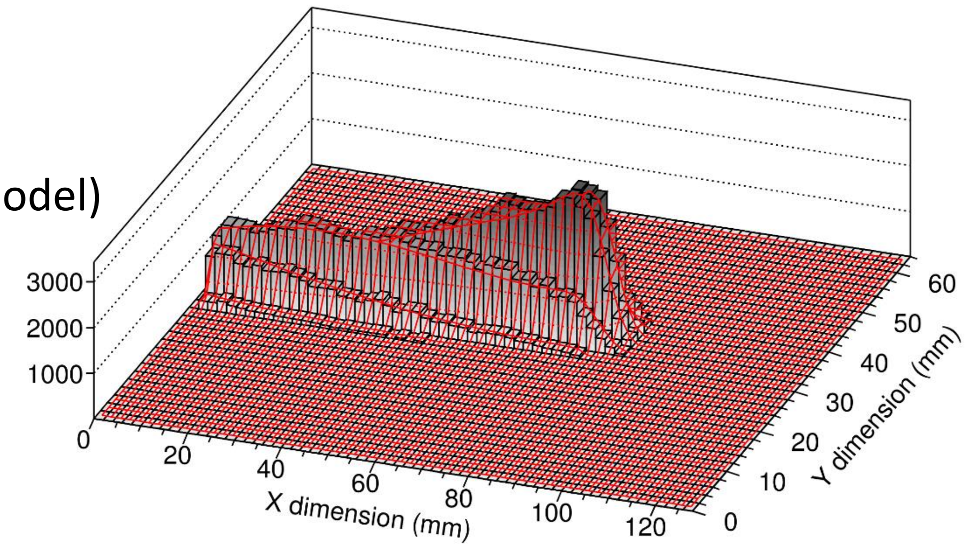


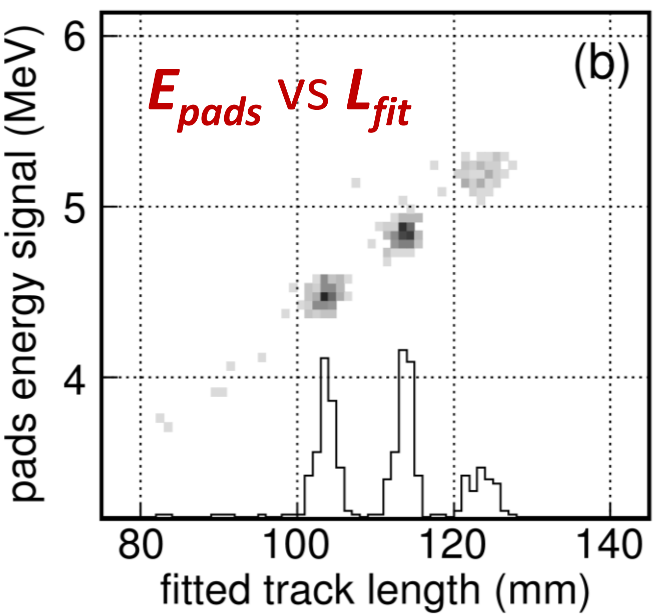


stopped tracks reconstruction

3-alpha source tests

2D projection of Bragg peak:
- energy deposit along track (Bragg peak model)
- X & Y dispersion
- no time (Z) distribution of signal





independent precision of
energy estimate (pads signal)
& **track length** (fit)

energy resolution: $\boldsymbol{\sigma_E^{pads}} \sim \mathbf{100}\ keV$

fitted length dispersion: $\boldsymbol{\sigma_L^{rec}} \sim \mathbf{3.2}\ mm$
(particles dispersion from simulation)

⇨ no improvement expected from correlation

in-beam commissioning

tests @ GANIL
(11/2017 & 04/2018)
Commissioning of the
128x128 pads
full detector

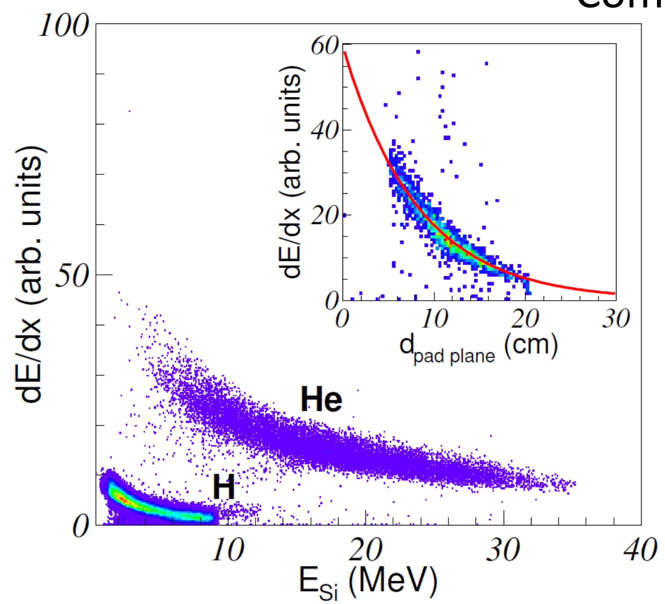
$^{18}O(p,p)$ and $^{18}O(p,\alpha)$ excitation functions

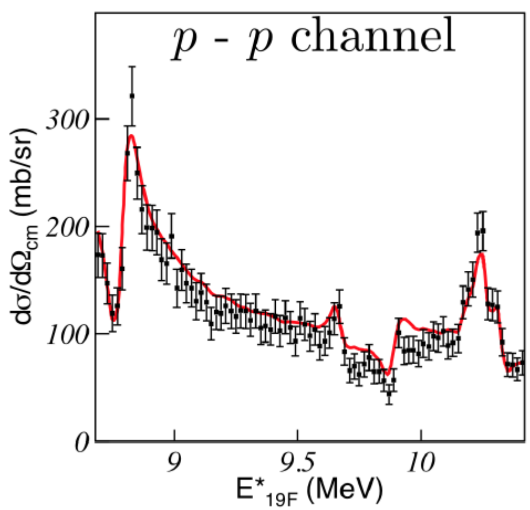
→ scattered particles identification
channel selection

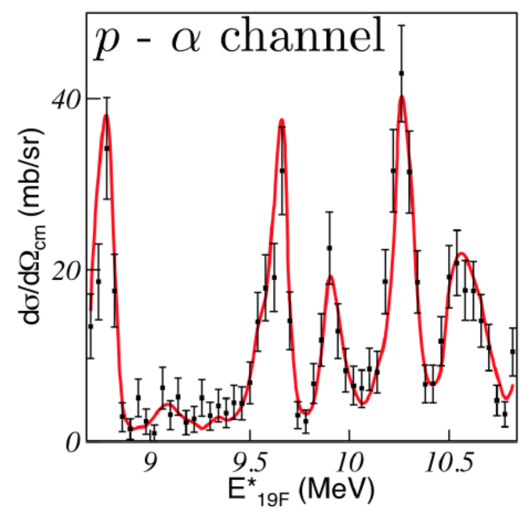
→ reaction kinematics
part. tracks & energy

→ absolute cross section

energy resolution 50~100 *keV*







B. Mauss, PhD thesis (GANIL)

gas considerations

By Macluskie - Own work, Public Domain
https://commons.wikimedia.org/w/index.php?curid=3109366

ACTAR TPC: a gas device

TPC detector for decay experiments

emitted particles energy
tracks (Bragg peak) analysis, 4π random direction

role of gas limited to signal creation and transport

- energy loss
- drift velocity
- signal dispersion

most tests performed with P10
(Ar 90% - CH_4 10%)
fast drift, large dispersion

active target mode

the gas needs to contain the **target nuclei** !

compromise between purity/contamination and signal quality
limitations in the use of pure gases such as H_2 (protons target)
or He (alpha target)

test with GANIL demonstrator at LNS Catania (dec. 2018)
various sets of beams and gases
see talk by T. Marchi

proton target

courtesy of T. Roger

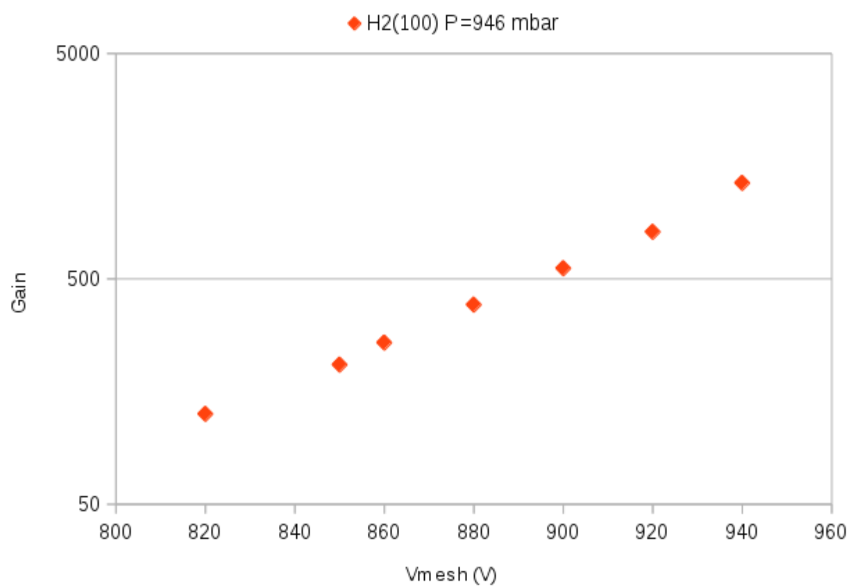
→ **proton target**: usually use isobutane (C_4H_{10}), at least 50 mm of thickness

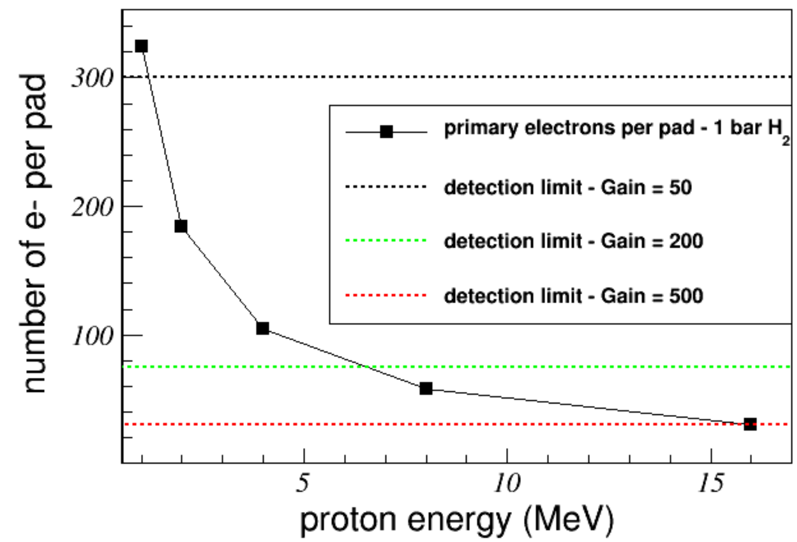
- at 76 mbar: 9.25×10^{19} protons/cm^2 (equivalent CH_2 solid target @ 1 mg/cm^2)
- proton purity: **71 %**

→ **pure H_2 gas**

- equivalent pressure for the **same dE/dx**: 1000 mbar → 2.47×10^{20} protons/cm^2
- proton purity: **100 %**
- but poor gain…

→ **increase mesh HV for detection at low dE/dx**





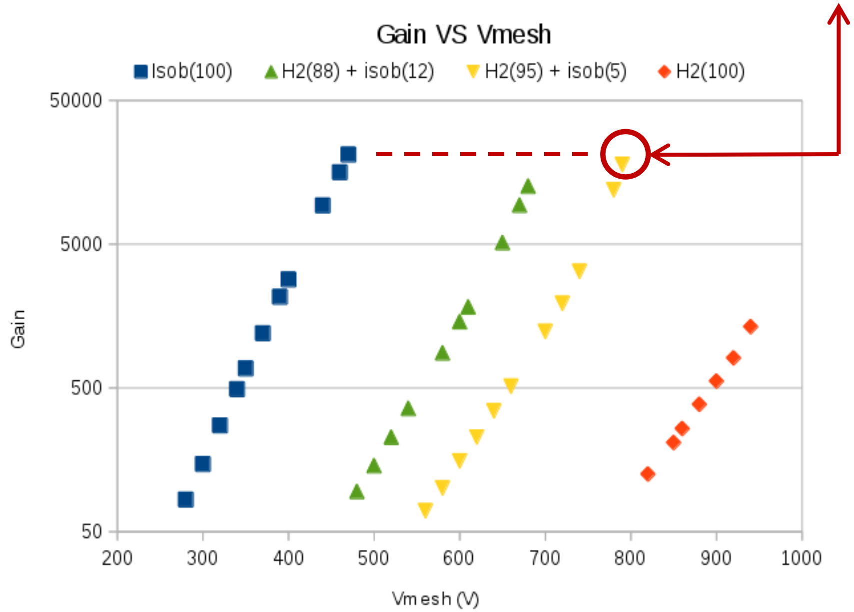
proton target

courtesy of T. Roger

→ **higher gain with hybrid solutions** (e.g. GEM + µmegas, micro-pix, ...)

→ **use of a quencher** (e.g. isobutane)

	H2 (100%)	**H2 + iC4H10 (2%)**	**H2 + iC4H10 (5%)**	**iC4H10**	**CH_2** (equiv. for 2 mm target thickness)
Pressure (**constant dE/dx**)	1000 mbar	813 mbar	626 mbar	76 mbar	40 µg/cm2
number of protons/cm2 2 mm thickness	9.88×10^{18}	8.58×10^{18}	7.29×10^{18}	3.70×10^{18}	3.42×10^{18}
Proton purity	**100%**	**96%**	**92%**	**71%**	**66%**



H_2 (95 %) + isobutane (5 %)

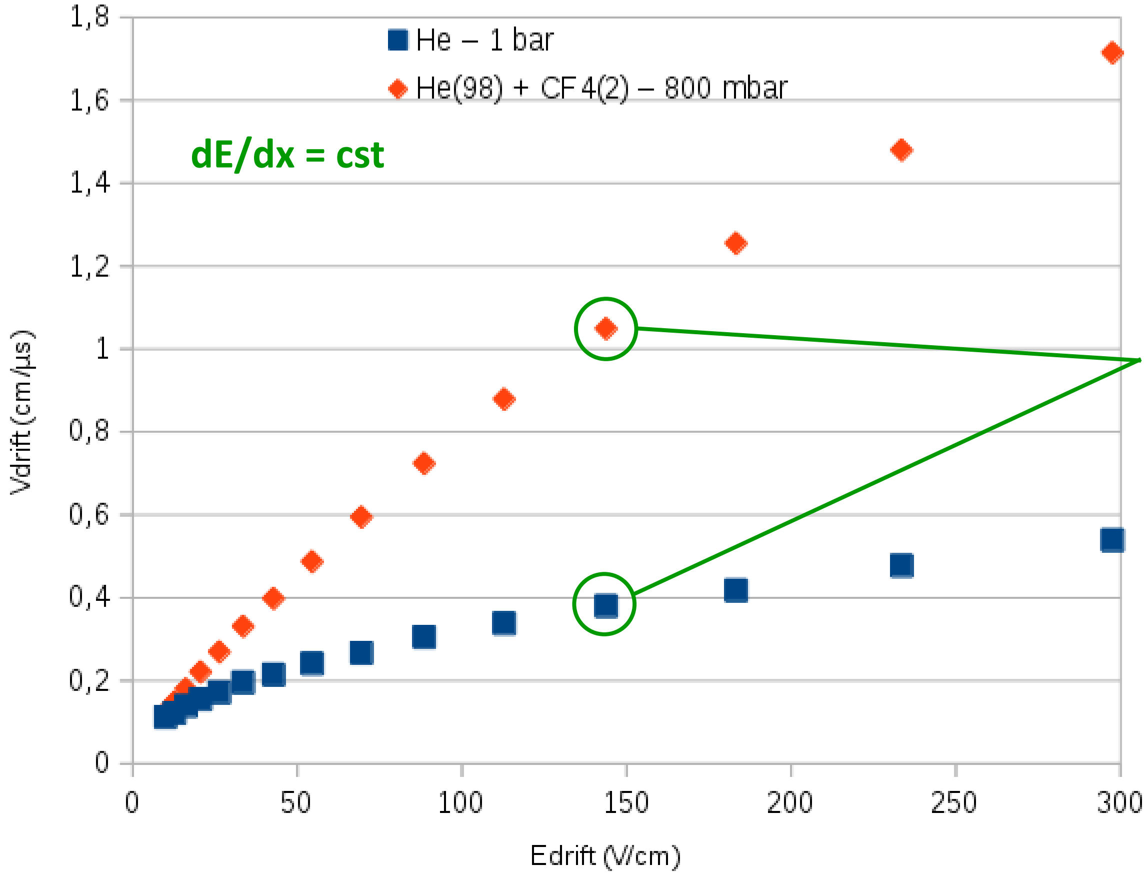
max gain as high as pure isobutane

helium target

pure He gas: same problem as pure H_2 gas

→ **hybrid solutions** (e.g. GEM + µmegas, micro-pix, ...)

→ **use of a quencher** (e.g. CF4 to avoid protons)



2% of **CF4** (with dE/dx constant) is raising the drift velocity by a factor more than 2 !

courtesy of T. Roger

conclusion…

ACTAR TPC: ready for experiments

spring 2019 @ GANIL (LISE)

→ "**active target**" exp. (S. Ceruti *et al.*)
giant resonances in exotic Ni isotopes: ^{68}Ni(α,α')

→ "**TPC detector**" (decay) exp. (D. Rudolph *et al.*)
proton emission from ^{54}Ni isomeric state

2020 ?...

→ 2P radioactivity of ^{48}Ni / ^{54}Zn (J. Giovinazzo *et al.*)

→ resonant proton elastic scattering on ^{17}F
and 2p emission from excited states in ^{18}Ne (G.F. Grinyer *et al.*)

→ ^{33}K unbound states with ^{32}Ar+p (B. Fernandez Dominguez *et al.*)

more experiments...

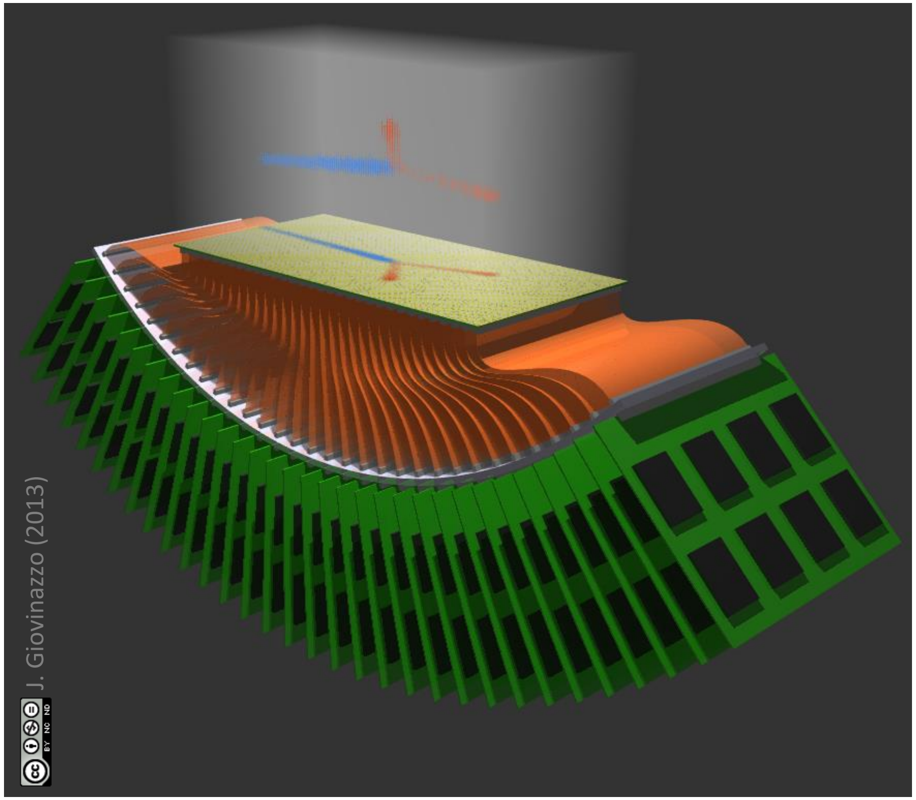
7 experiments accepted by PACs
9 more proposals
many letters of intent...

several facilities

- first exp. @ GANIL (France), RIKEN (Japan), ISOLDE (CERN / Switzerland)
- opportunities @ TRIUMF (Canada), GSI/FAIR (Germany)

ongoing work

end of "decay chamber" construction
data analysis procedures, tracking algorithms... simulations



from 2012 schematic view…

… to 2018 detector

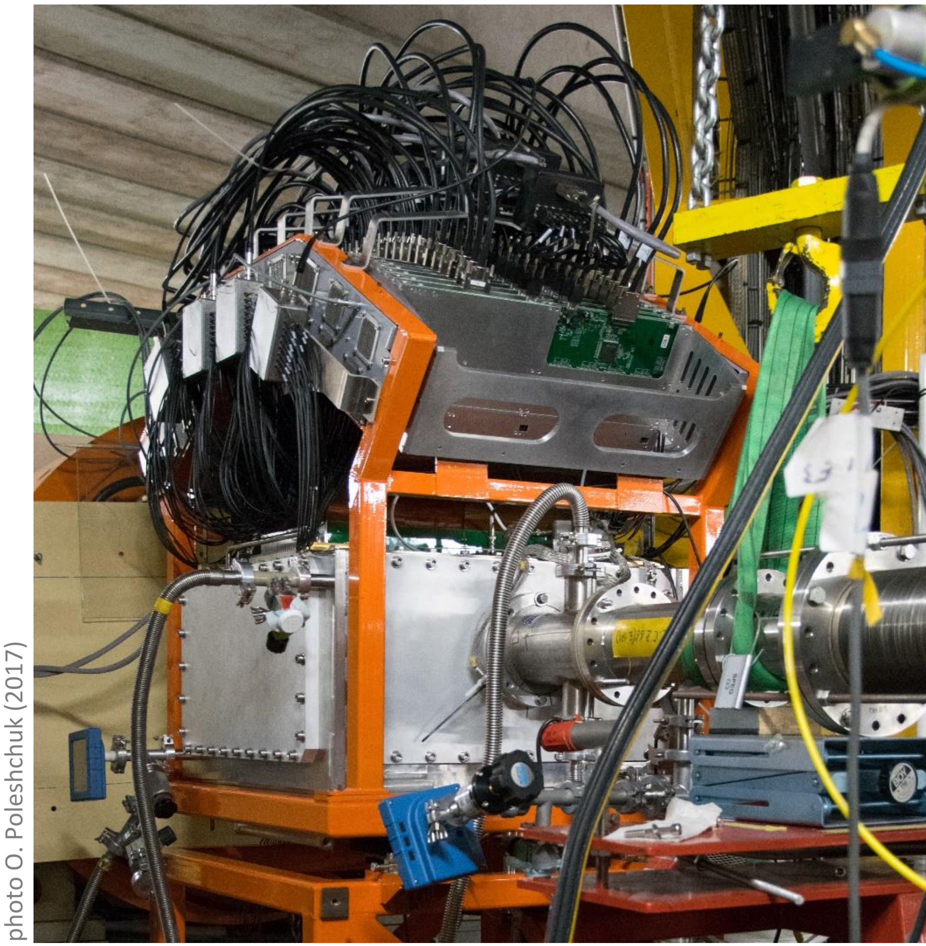


photo O. Poleshchuk (2017)