Workshop on Active Targets and Time Projection Chambers for High-intensity and Heavy-ion beams in Nuclear Physics

Second GDS Topical Meeting

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

IGFAE

EXCELENCIA MARÍA DE MAEZTU

ENSAR2

A personal overview

Héctor Alvarez Pol

GENP, Univ. de Santiago de Compostela
IGFAE, Santiago de Compostela

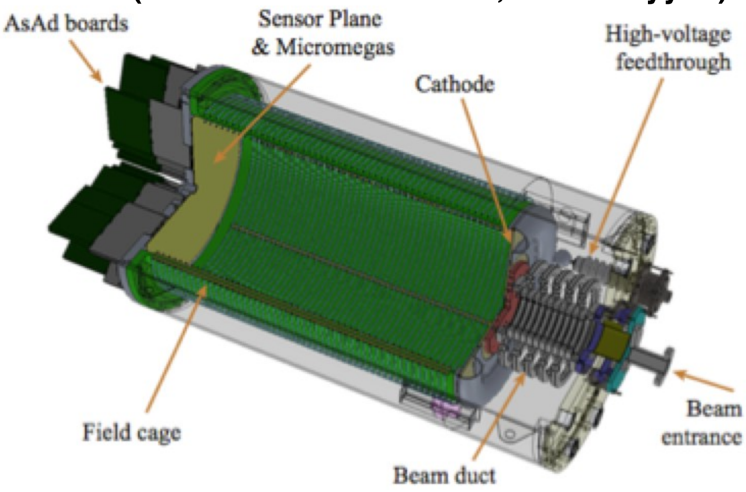
Santiago de Compostela, 19th January 2018

Main topics

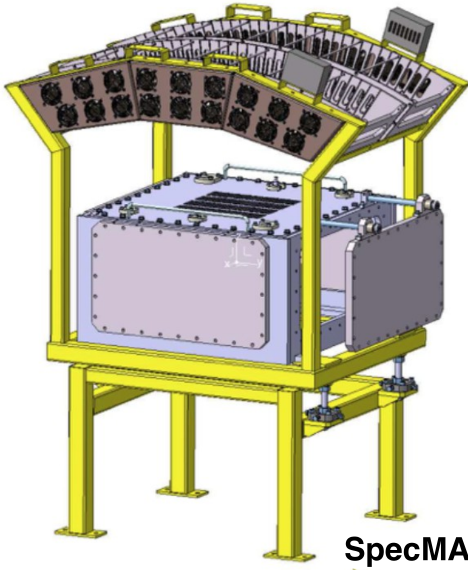
- Review of Active Targets and TPC’s in nuclear physics:
  - Design diversitity, specific solutions.
  - Reconstruction, analysis and simulation.
  - Wide physics program.
- High intensity, heavy ion beam effects:
  - Effects observed
  - Solutions?
- End of meeting, back to work...

Active Targets: diversity and commonality

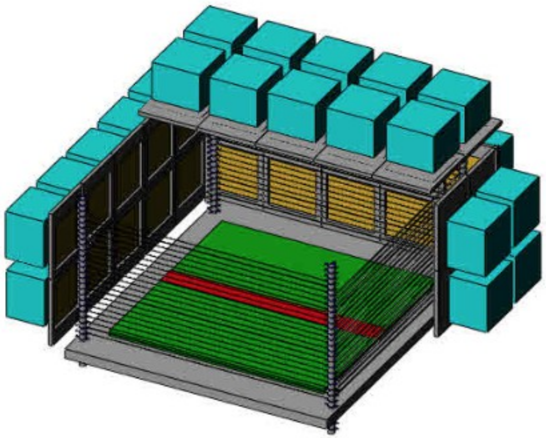
ATTPC (Clementine Santamaria, Yassid Ayyad)



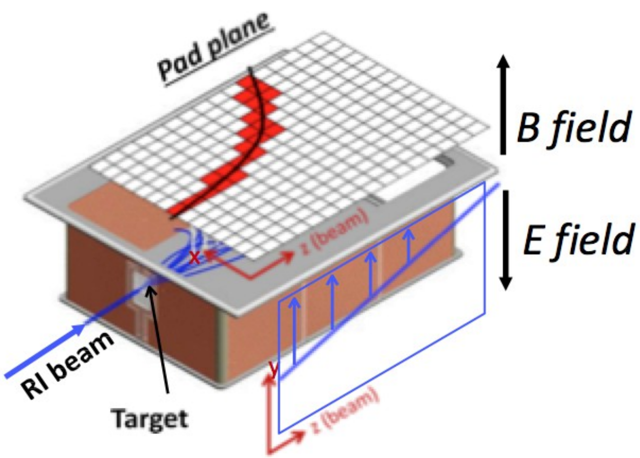
ACTARTPC
(Pierre Morfouace, Benoît Mauss)



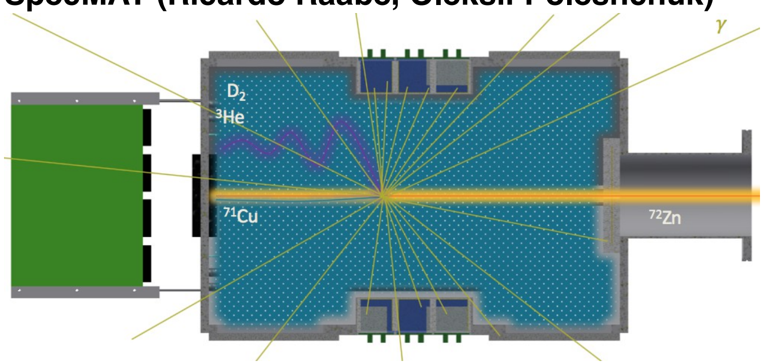
TexAT (Grigory Rogachev)



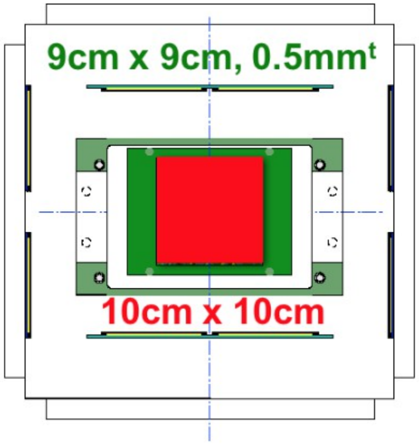
SPiRIT-TPC (Tadaake Isoke, B. Tsang)

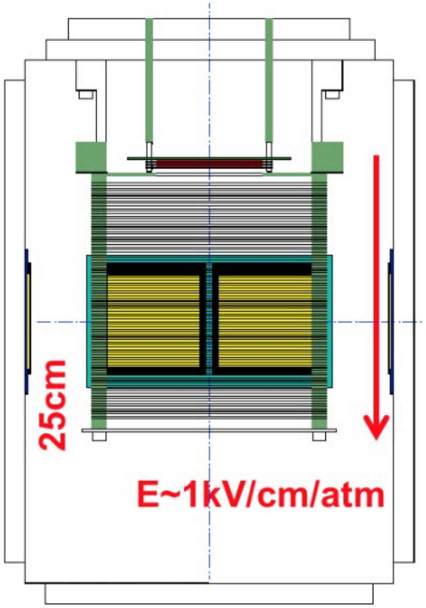


SpecMAT (Ricardo Raabe, Oleksii Poleshchuk)



CAT-S, CAT-M (Shinsuke Ota)





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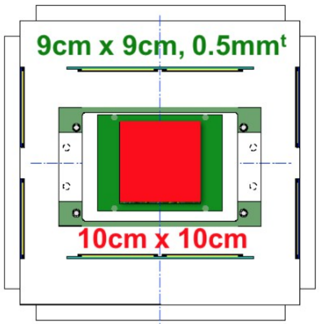
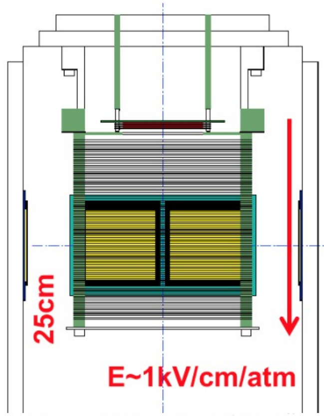
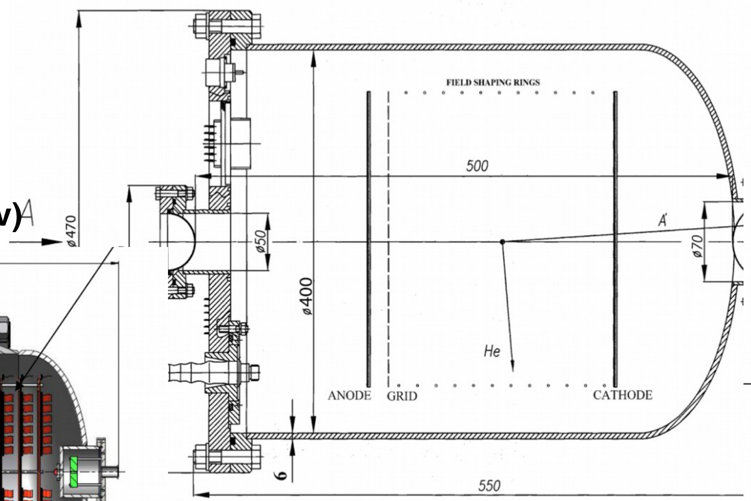
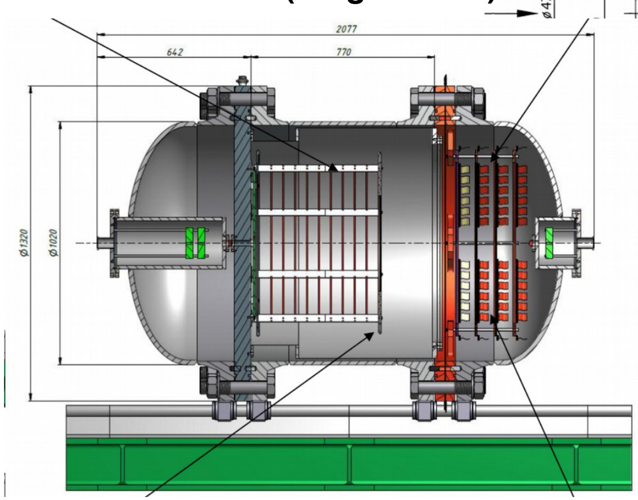
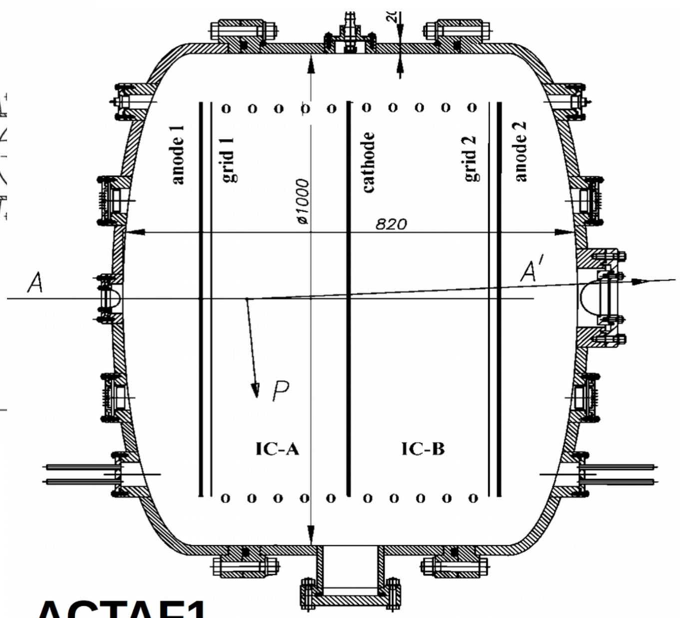




ACTAF1/2 + ATeT (Oleg Kiselev)







ACTAF1

Active Targets: diversity and commonality

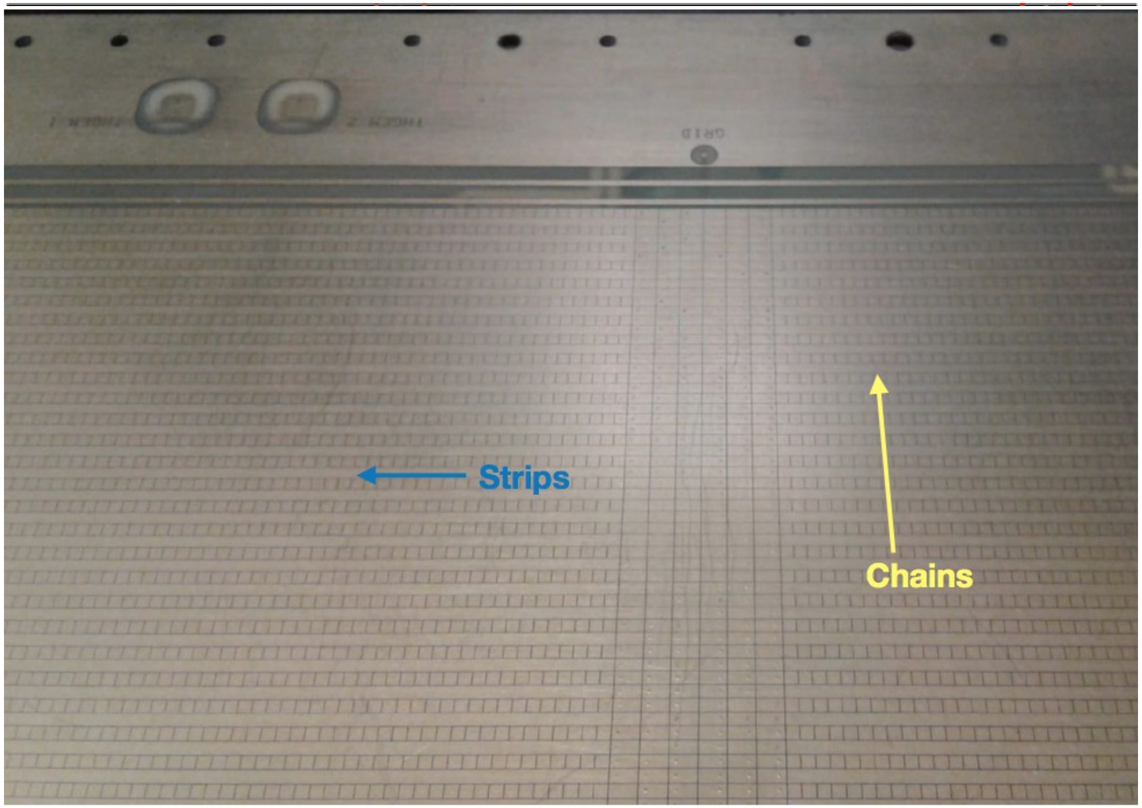
TexAT (Grigory Rogachev)

64 y-chains
64 1.75x1.75 mm^2 pads are connected
the pads are between the strips

128x6=768 pads
1.75x3.5 mm^2

64 y-chains
64 1.75x1.75 mm^2 pads are connected
the pads are between the strips

64 x-strips spaced
by 1.75 mm
1.75x101.5 mm^2



64 x-strips spaced
by 1.75 mm
1.75x101.5 mm^2

Active Targets: diversity and commonality

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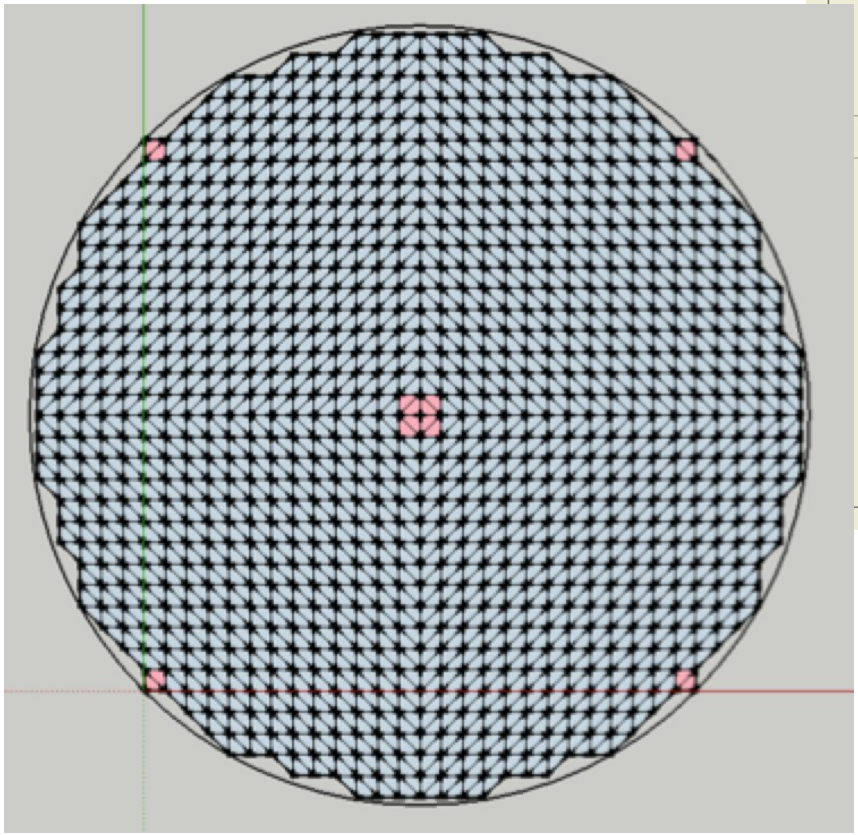
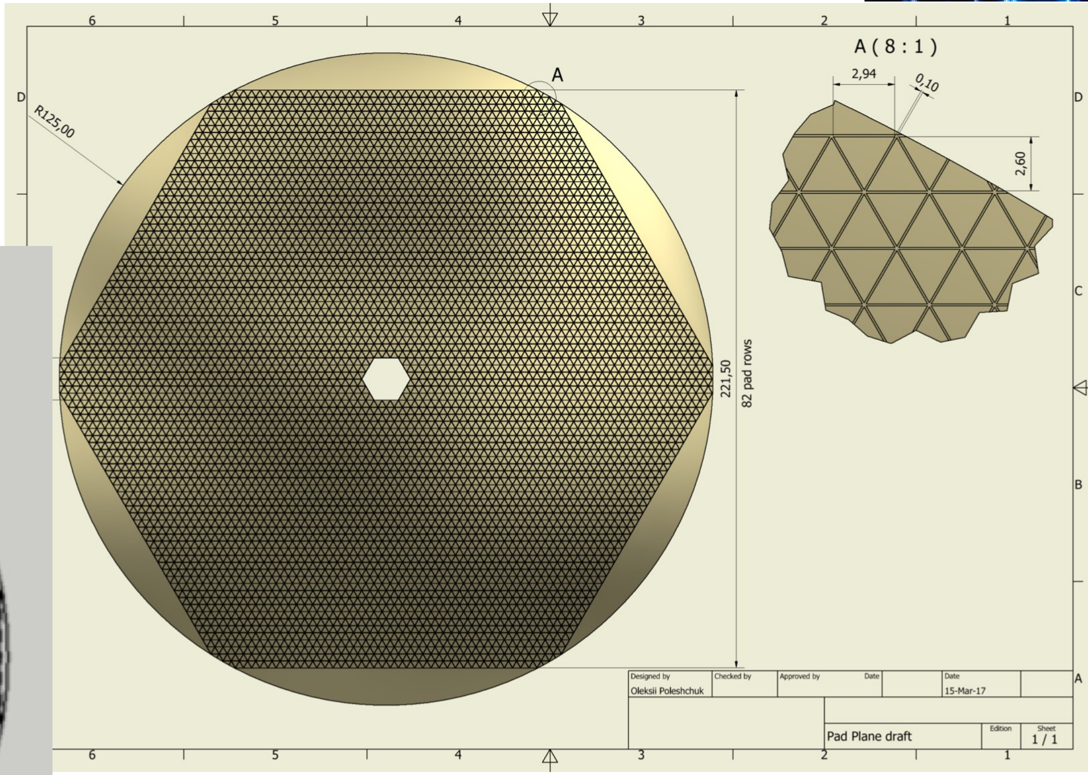
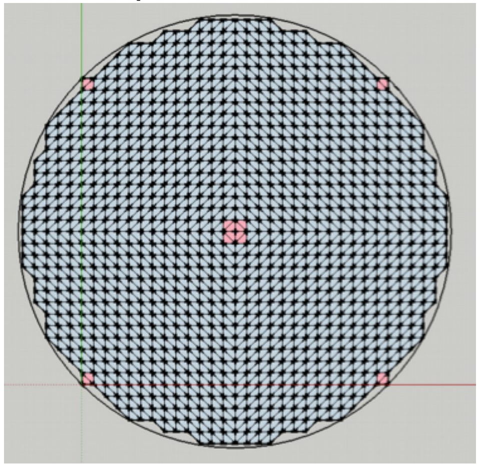




SpecMAT (Ricardo Raabe, Oleksii Poleshchuk)

Active Targets: diversity and commonality

ATTPC (Clementine Santamaria, Yassid Ayyad)



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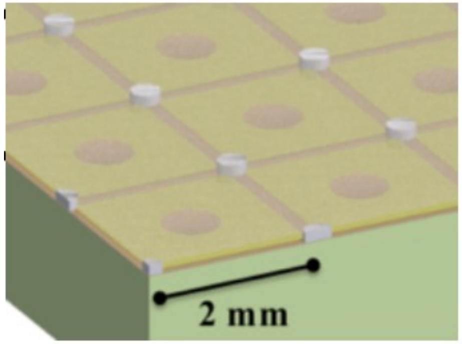

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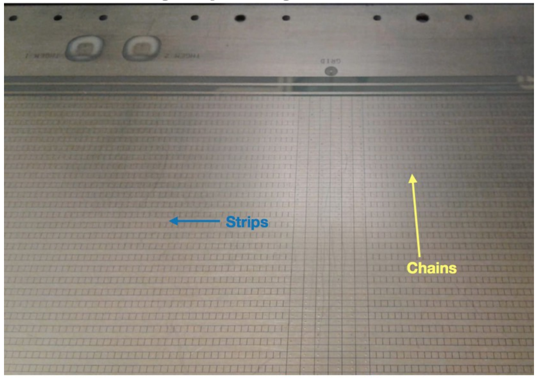
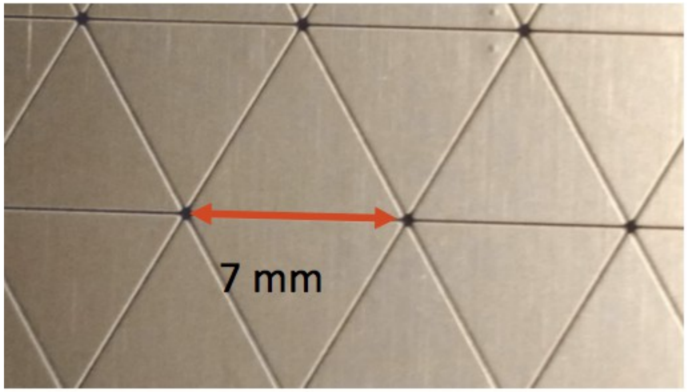


CAT-M (Shinsuke Ota)



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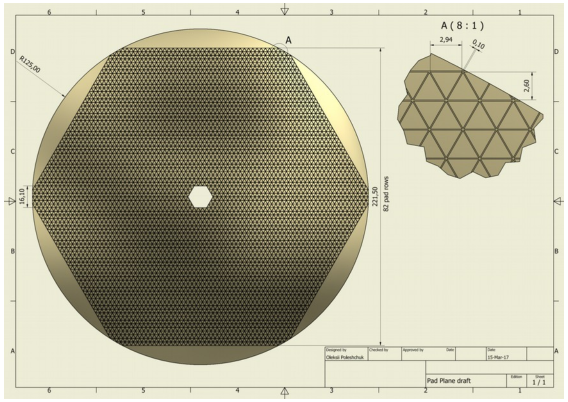

Active Targets: diversity and commonality

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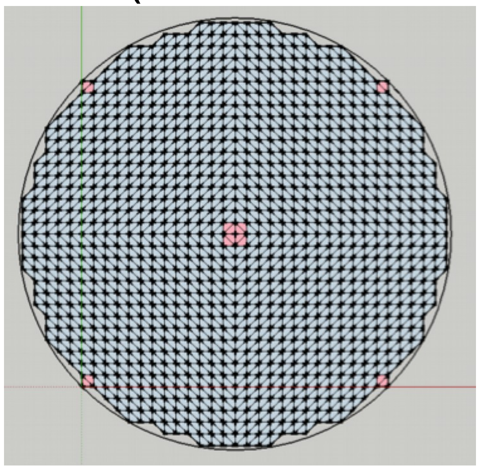

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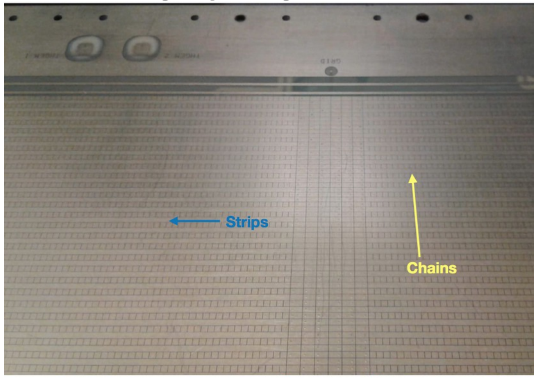

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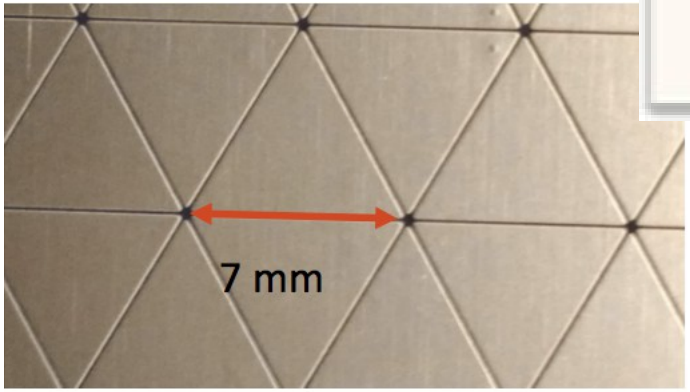
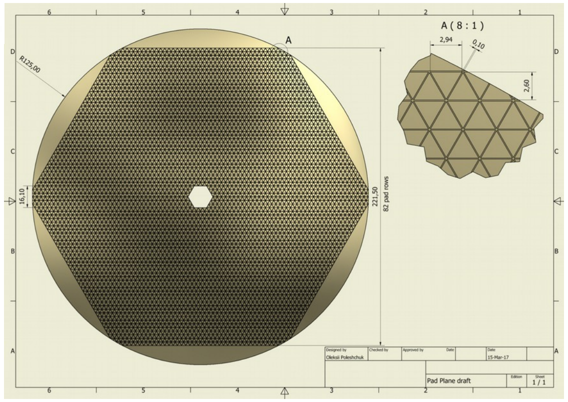
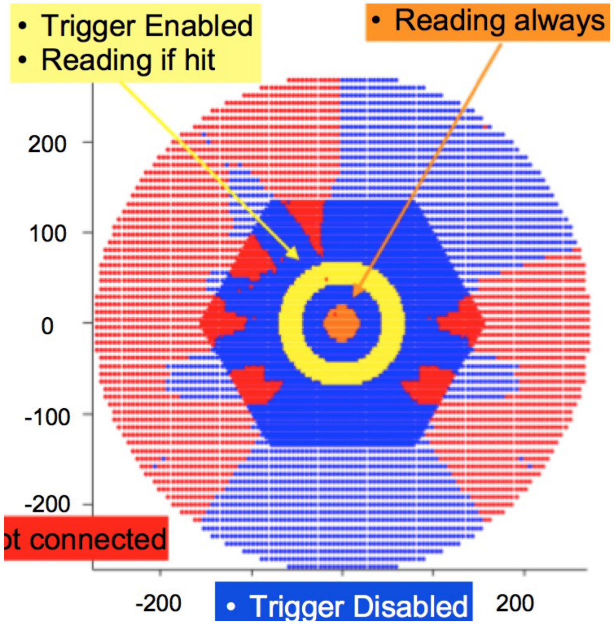


MAT (Ricardo Raabe, Oleksii Poleshchuk)

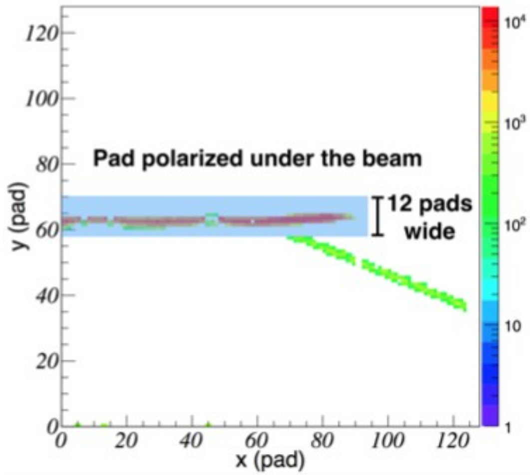


Active Target: GET trigger flexibility

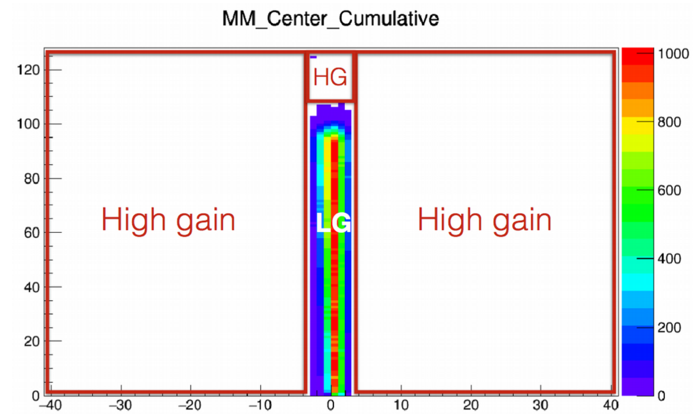
ATTPC (Clementine Santamaria)



ACTARTPC (Benoît Mauss)



TexAT (Grigory Rogachev)



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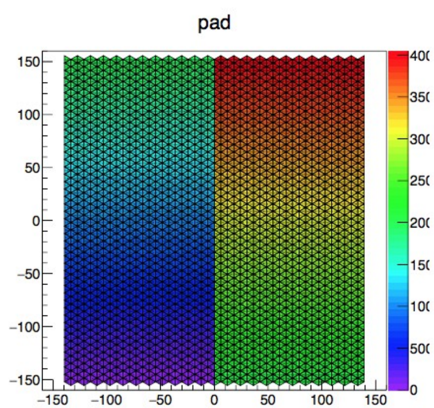
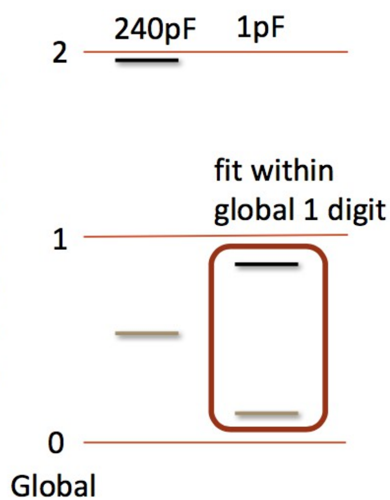


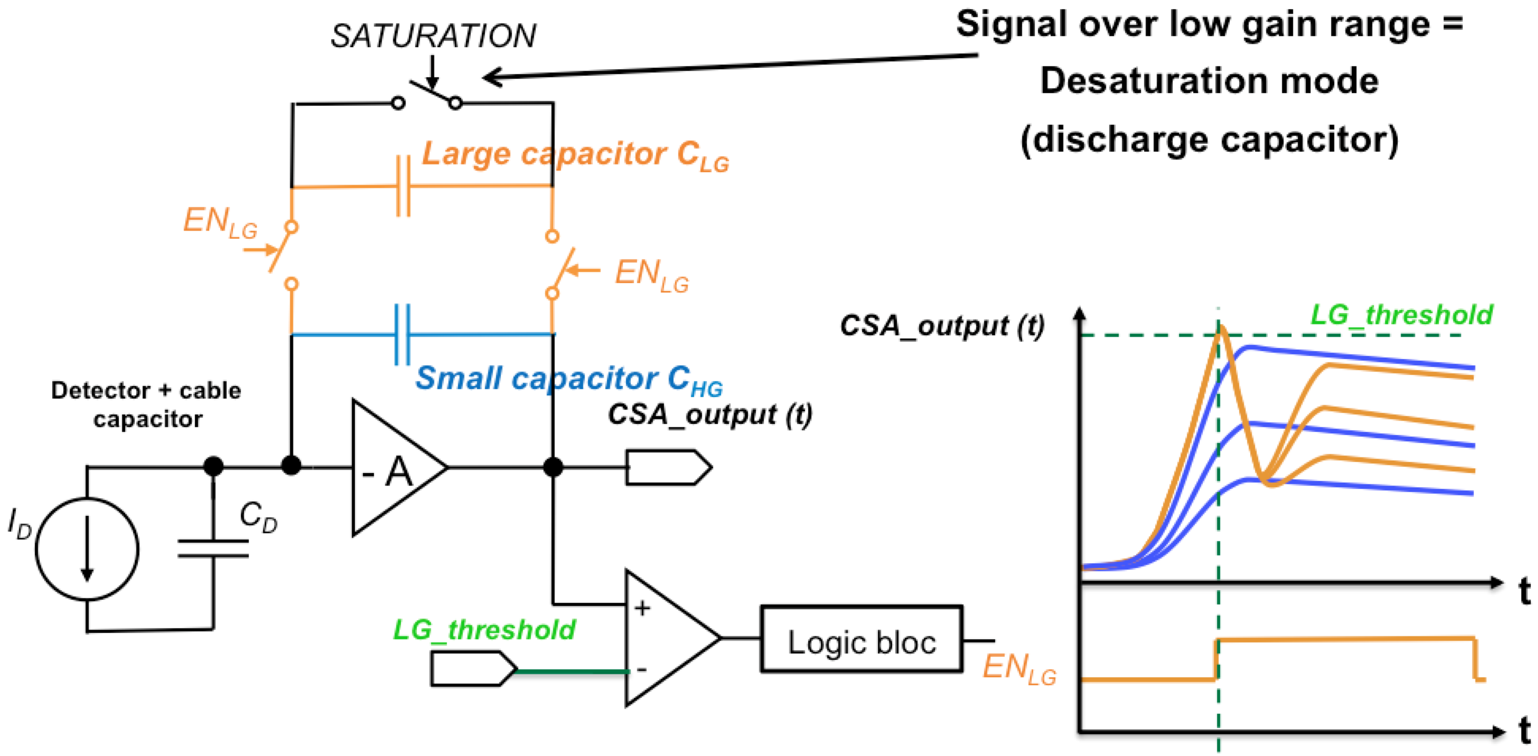


Self trigger for TPC and Silicon

- Energy deposition of recoil particle stopping in TPC active area is larger than delta ray
- Energy deposition of recoil particle reaching at Silicon detector is smaller than delta ray
- Each AGET includes beam and recoil region
- Global threshold is common for AGET
- => Threshold is tunable within 4 bits (Global threshold should be 1)

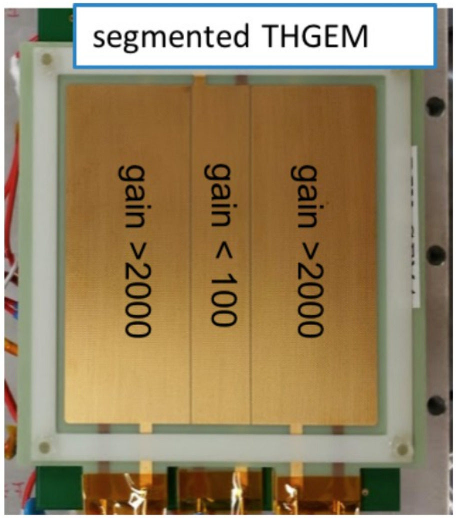
Active Target: preamplification improvements

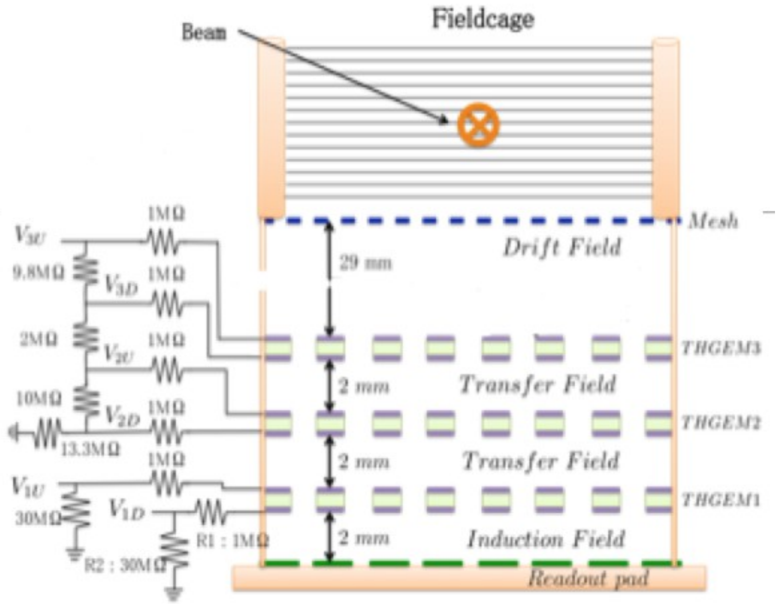
FEANICS (Florent Bouyjou)



With this method we can get a very large dynamic

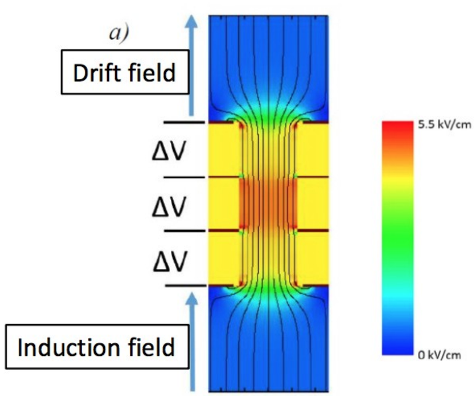
CAT-S (Shinsuke Ota)

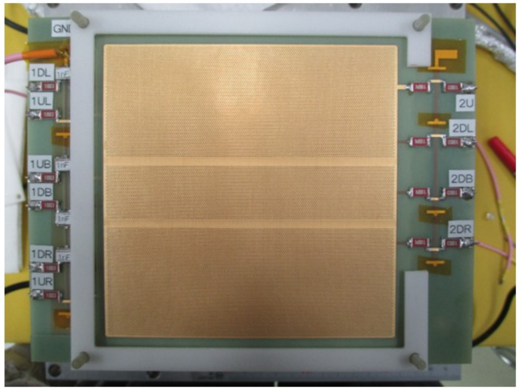




CAT-M (Shinsuke Ota)

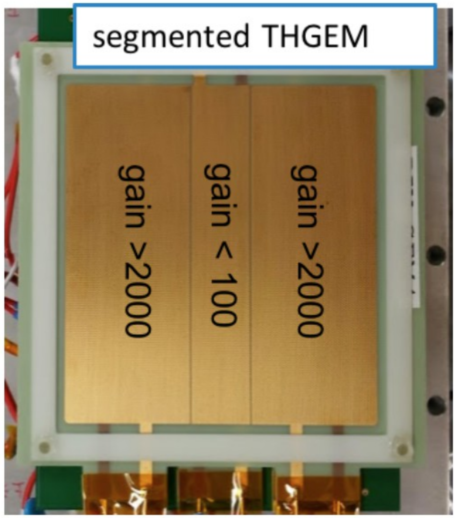
Dual gain multi-layer THGEM



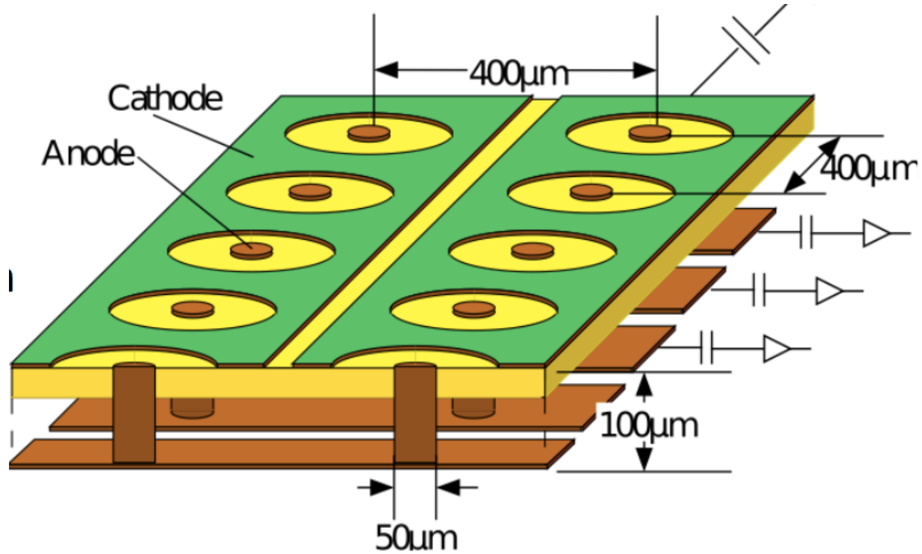


Active Target: micromegas and ...

CAT-S (Shinsuke Ota)



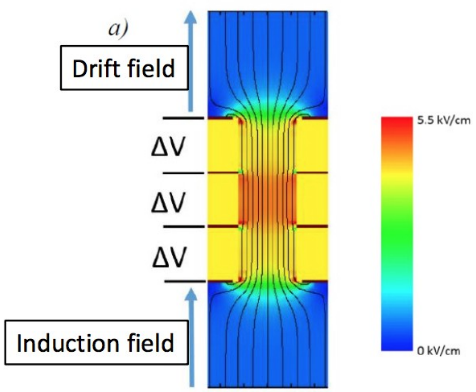
MAIKo (Tatsuya Furuno)

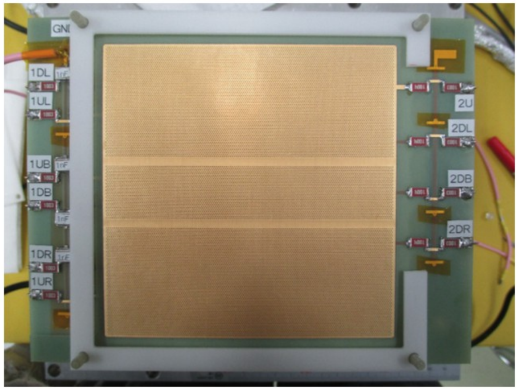


Micro-Pixel Chamber (µ-PIC)
A. Ochi, *et. al.* NIM A **478**, 196 (2002).

CAT-M (Shinsuke Ota)

Dual gain multi-layer THGEM

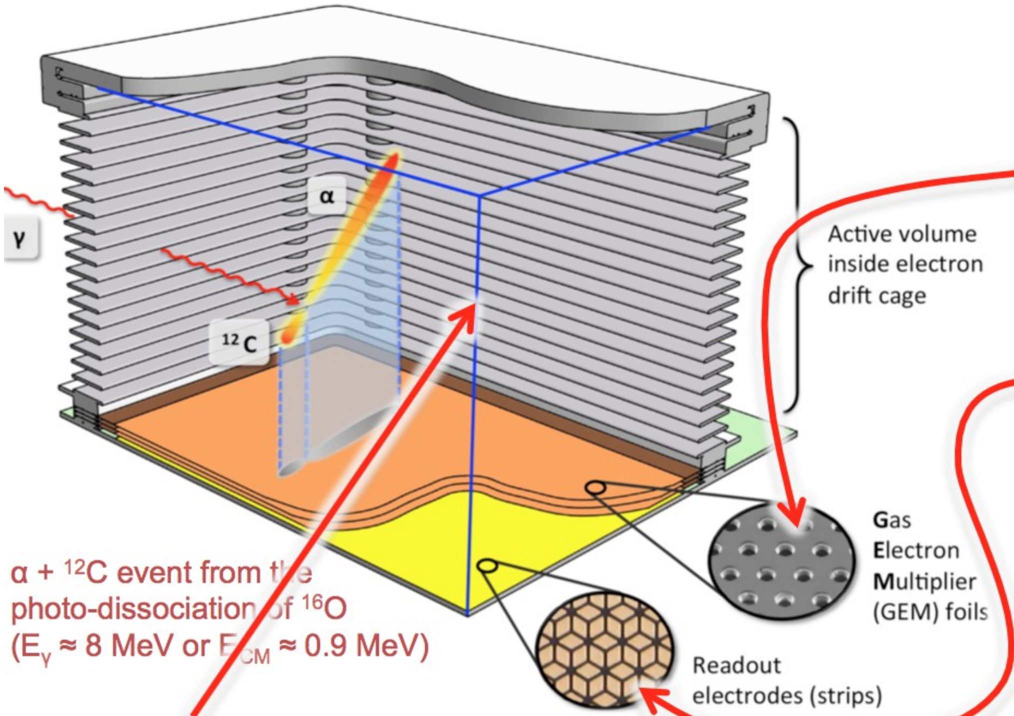




Active Target: micromegas and ...

ELI TPC (Mikołaj Ćwiok)

study (α,γ) and (p,γ) reactions of current astrophysical interest



Charge amplification:

- *Gas Electron Multiplier* (GEM) structures

Readout:

- Planar, 3-coordinate, redundant strip arrays
- about 1000 channels
- *GET* electronics for signal amplification & digitization
- external trigger (100 Hz)

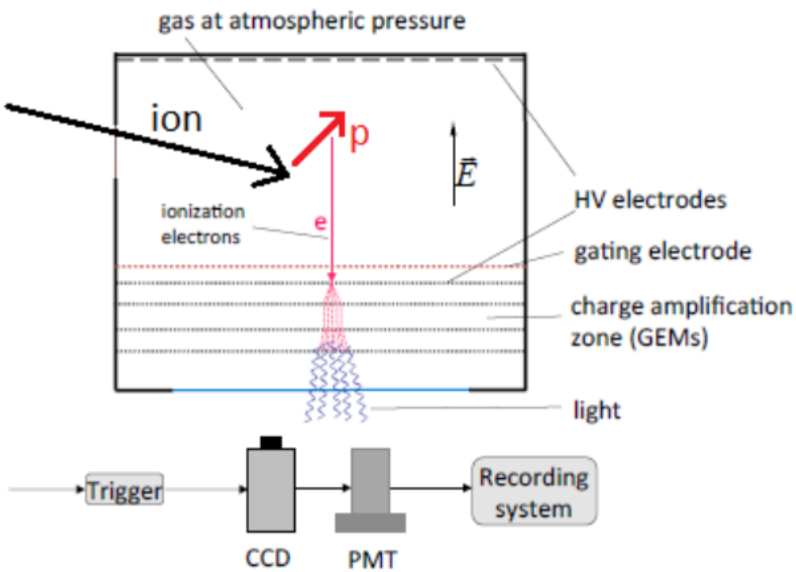
Active volume:

- 33 x 20 cm^2 (readout) x 20 cm (drift)
- gas pressure ~100 mbar ⇒ increase track lengths

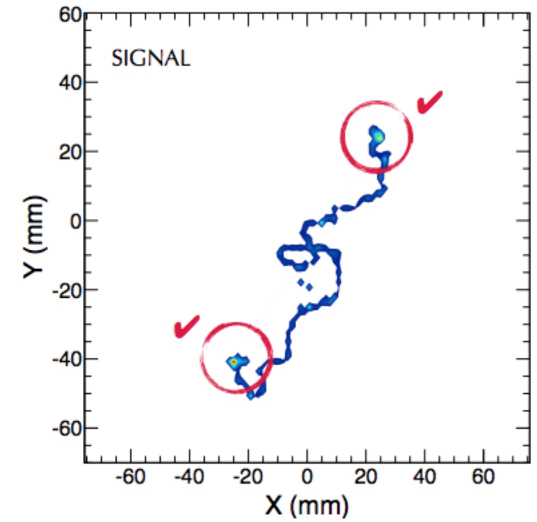
O.Tesileanu et al., Romanian Rep. in Phys. 68, Supplement (2016) S699

Active Target: micromegas and ...

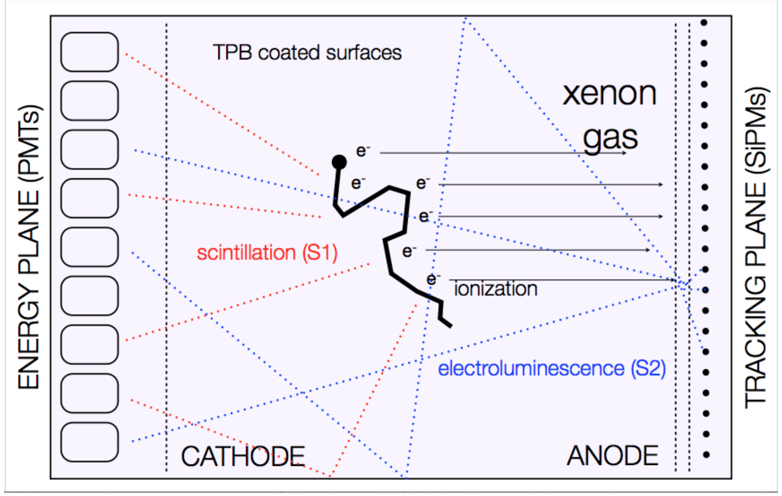
Warsaw Optical Time Projection Chamber (Natalia Sokołowska)

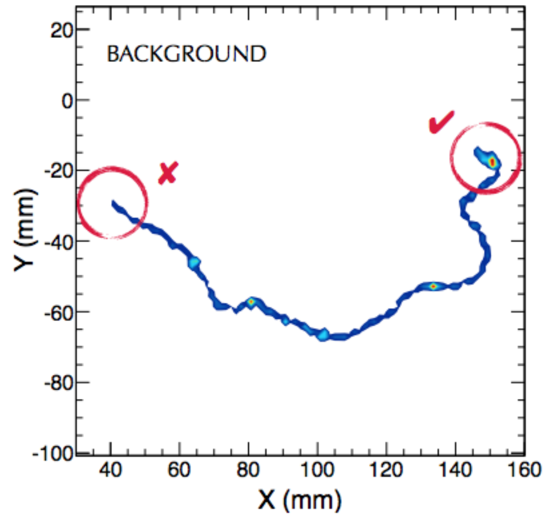


- atmospheric pressure
- different gas mixtures
- GEM foils provide charge amplification



NEXT (Jose Angel Hernando, Francesc Monrabal)

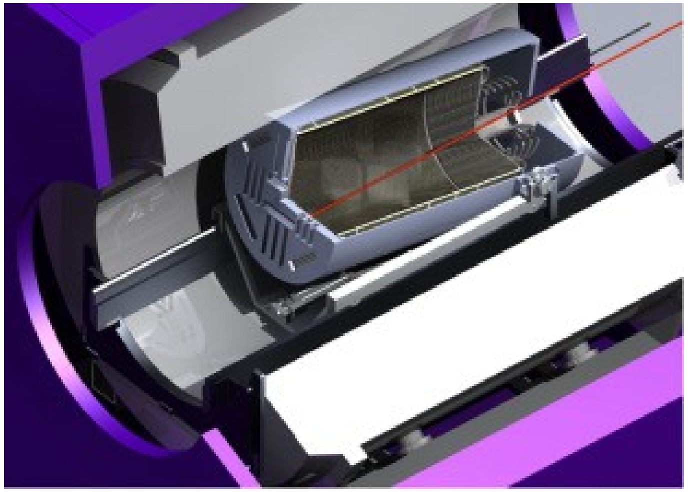




Active Targets: tracking in magnetic fields

SPiRIT-TPC (Tadaake Isoke, B. Tsang)

ATTPC (Yassid Ayyad)



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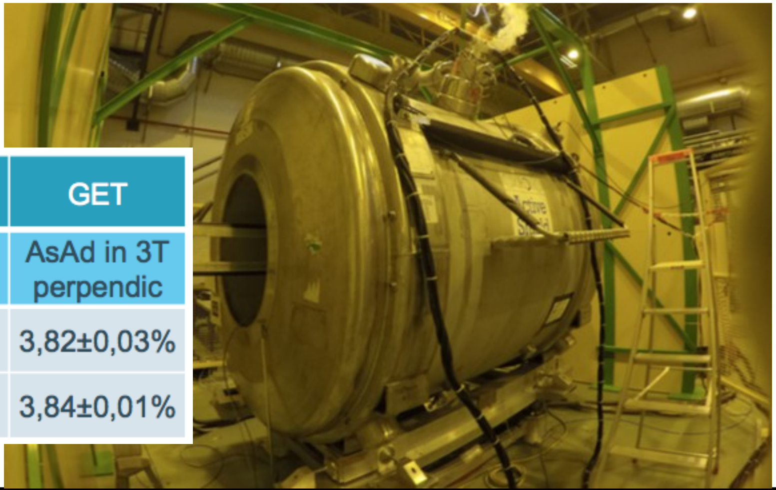
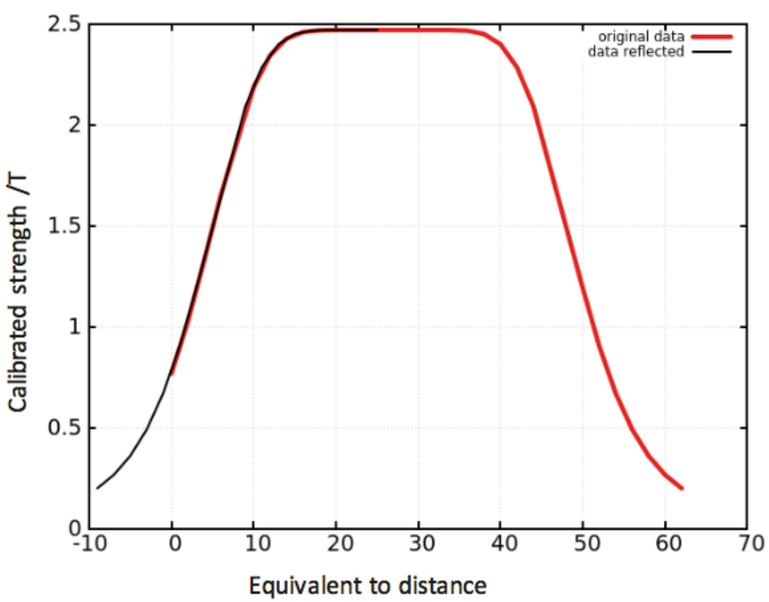


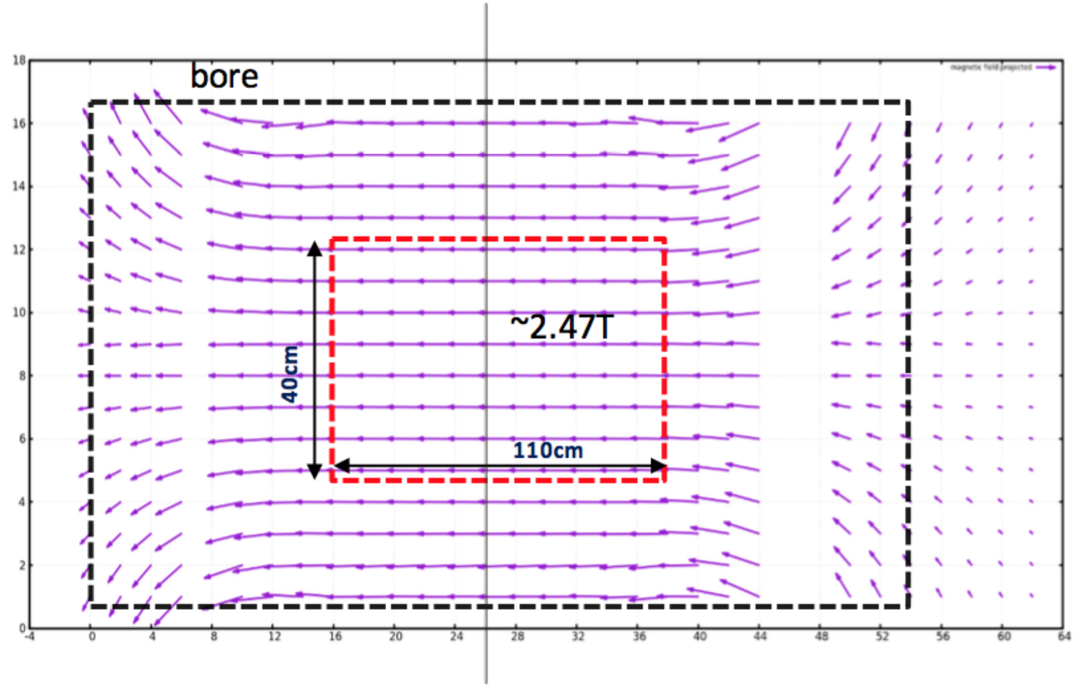
	DAQ	Analogue	CAEN	GET	GET	GET
Detector	B-field	No field	No field	No field	AsAd in 3T parallel	AsAd in 3T perpendic
$LaBr_3$+SiPM	No field	2,94±0,01%	3,22±0,01%	3,85±0,03%	3,85±0,03%	3,82±0,03%
$LaBr_3$+SiPM	3T	2,97±0,01%	3,24±0,01%	3,88±0,01%	3,85±0,01%	3,84±0,01%

Active Targets: tracking in magnetic fields

SpecMAT (Ricardo Raabe, Oleksii Poleshchuk)

Magnetic field strength
at 0 degree (horizontal)

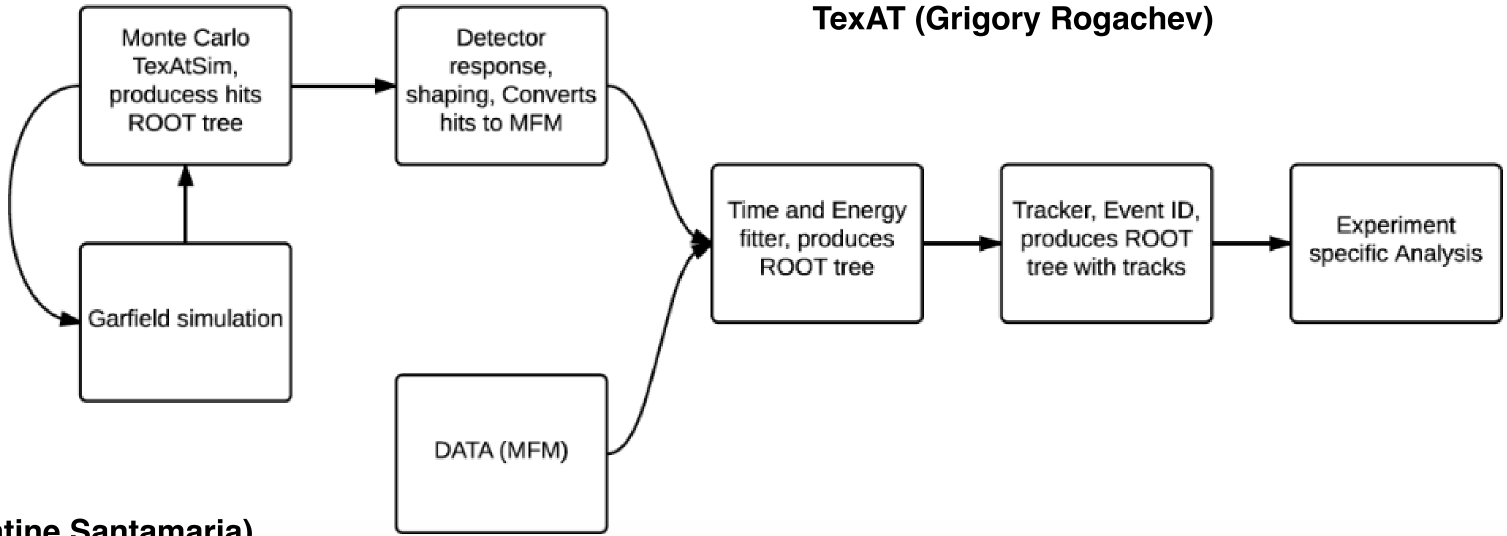




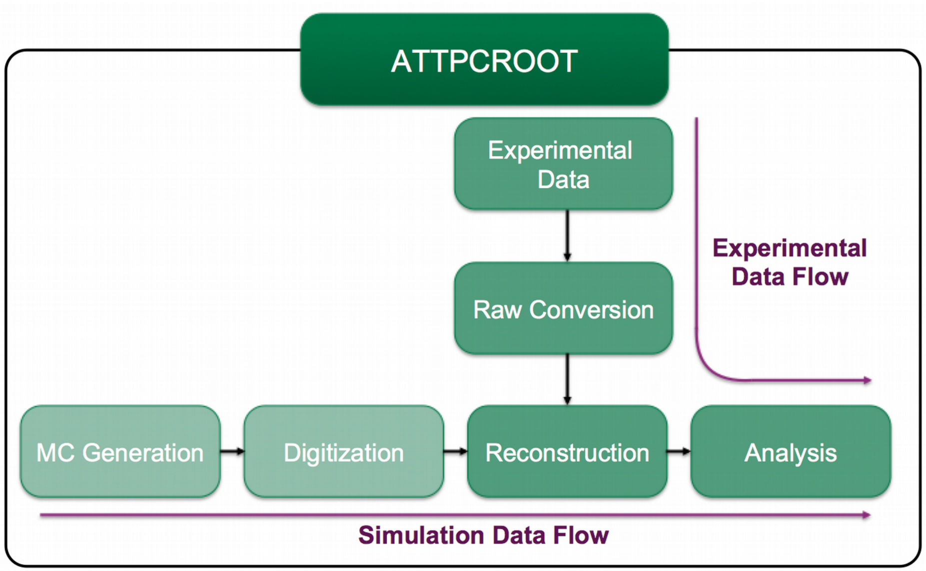
Magnetic field vector projection on x-y plane

Active Targets: track reconstruction and analysis

TexAT (Grigory Rogachev)



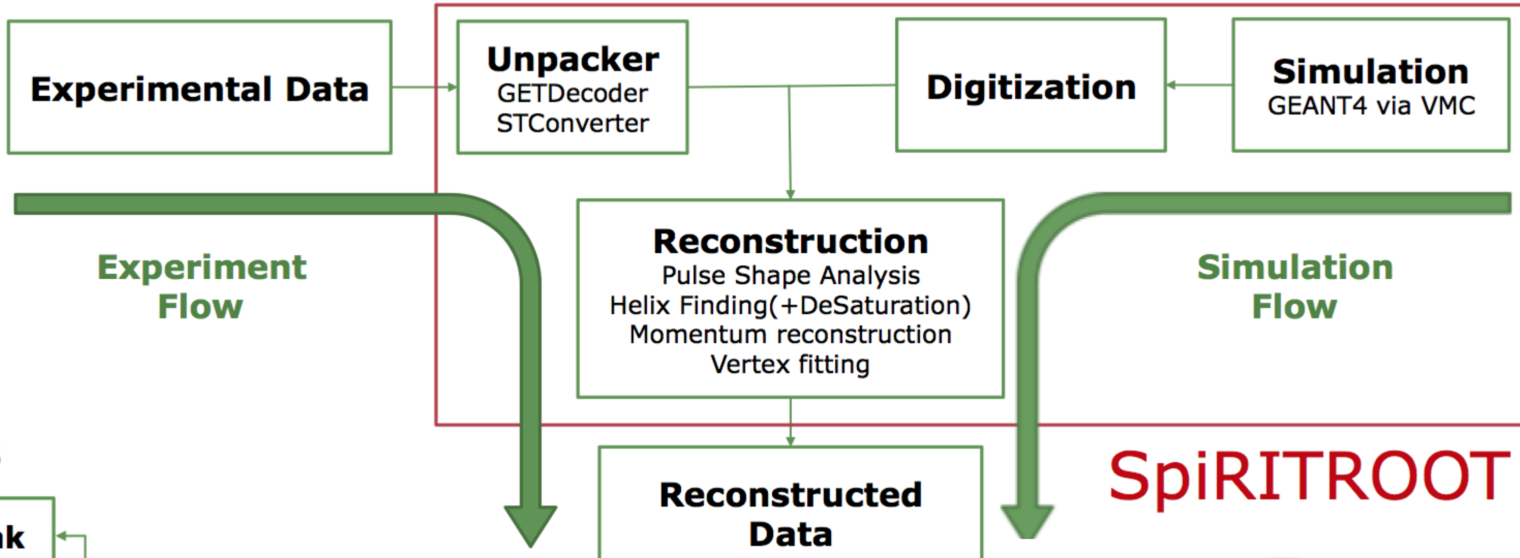
ATTPCROOT, pyTPC
(Yassid Ayyad, Clementine Santamaria)



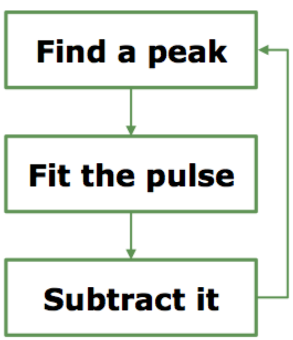
Active Targets: track reconstruction and analysis

SPIRIT (Genie Jhang)

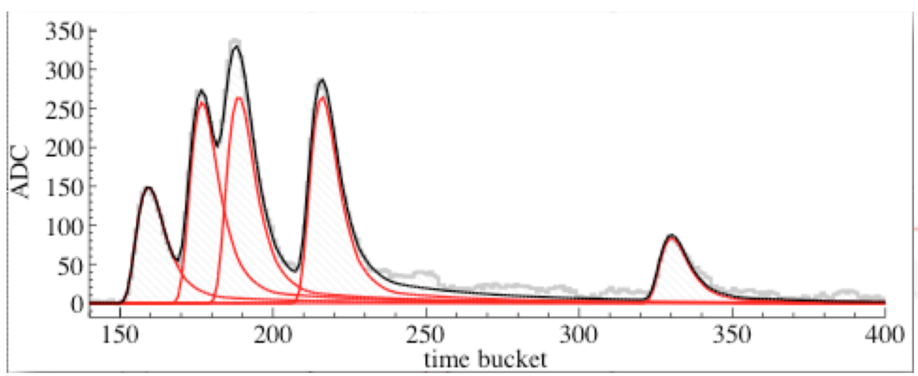
- SpiRITROOT is an analysis framework package dedicated for SπRIT TPC.

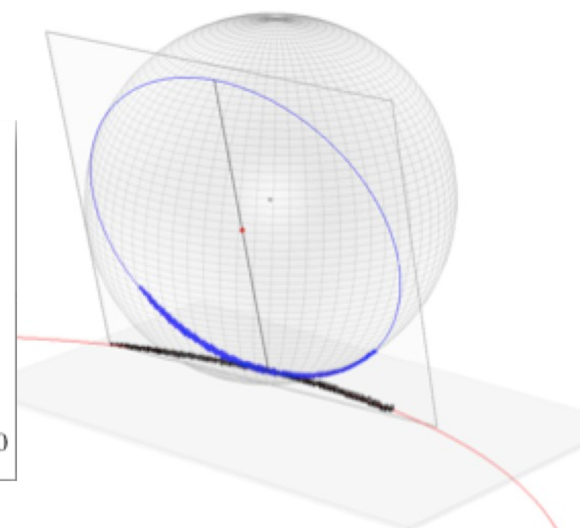


- PSA process



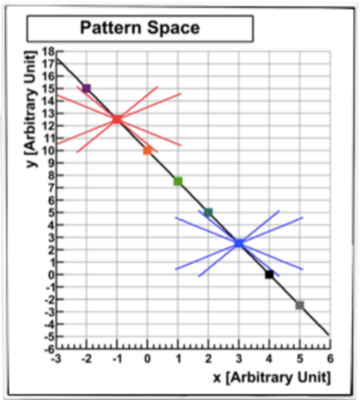
- Each fit pulse is recorded as a hit.

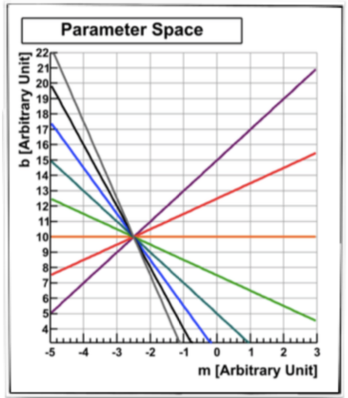




Hough transformation

Lines



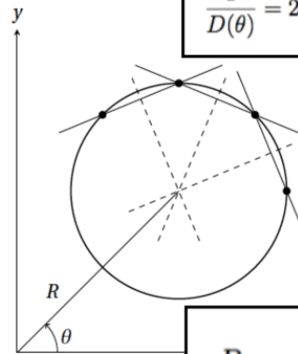


$$y(x) = mx + b$$

$$b(m) = y - mx.$$

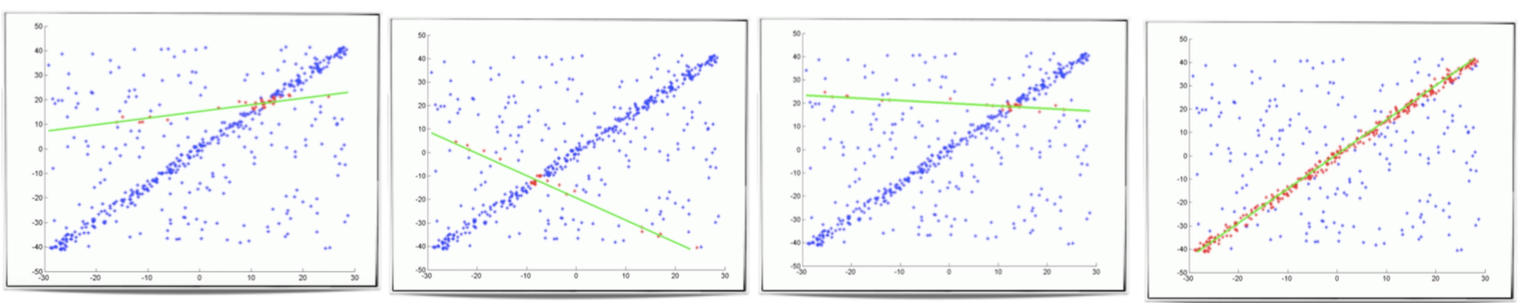
Circles

$$\frac{1}{D(\theta)} = 2 \cdot \frac{(y_1 - y_2)\sin\theta + (x_1 - x_2)\cos\theta}{(y_1^2 - y_2^2) + (x_1^2 - x_2^2)}$$

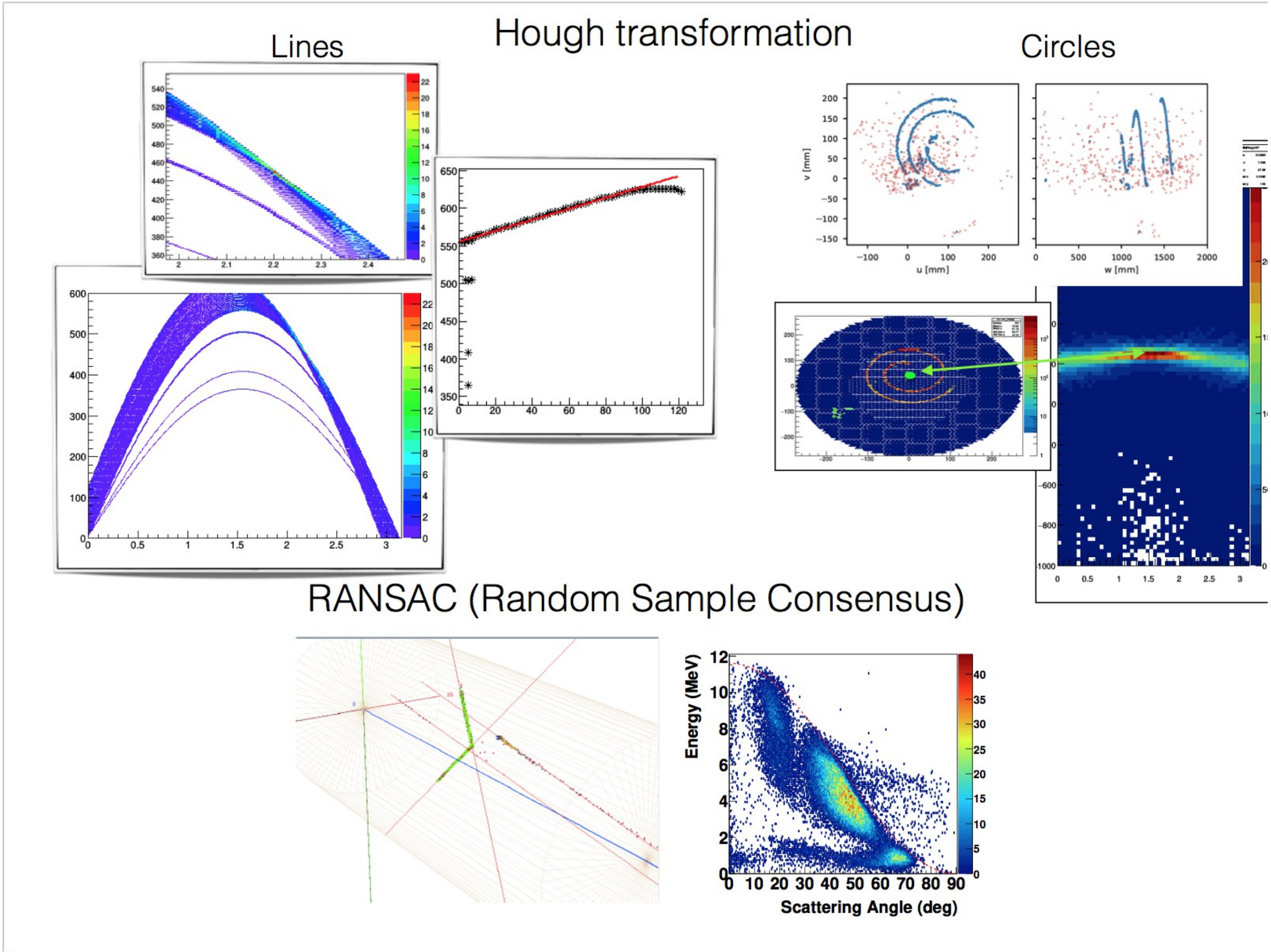


$$R = \sqrt{(a - x_{\mathrm{hit}})^2 + (b - y_{\mathrm{hit}})^2}.$$

RANSAC (Random Sample Consensus)



Active Targets: track reconstruction and analysis

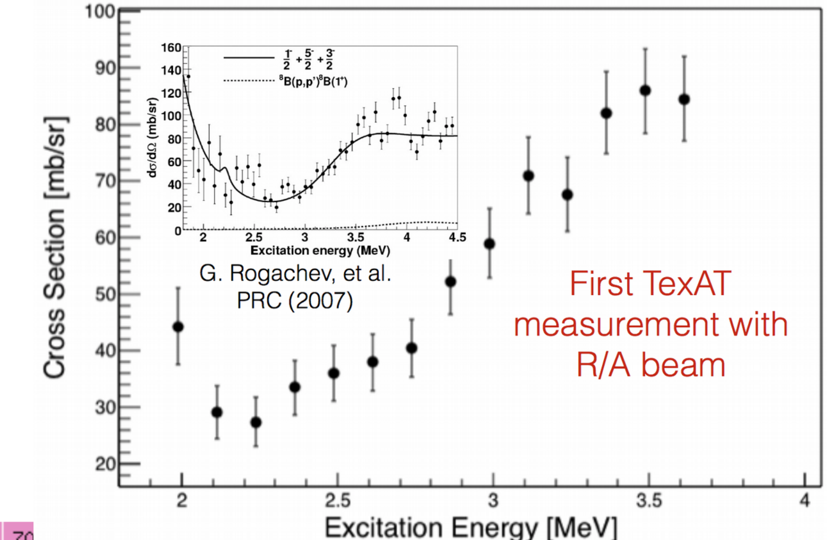


Active Targets: physics programs

TexAT (Grigory Rogachev)

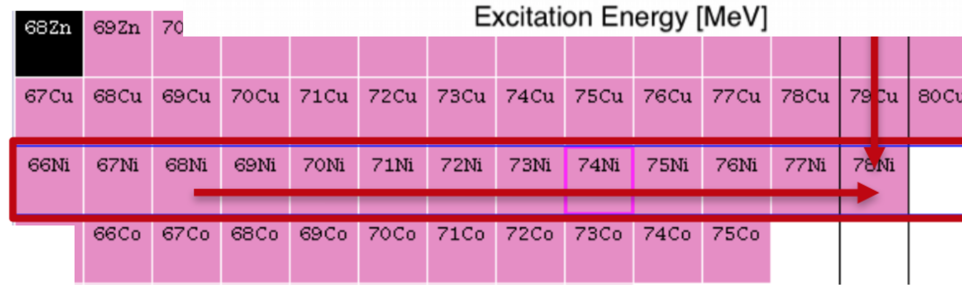
Structure of exotic nuclei.
Clustering phenomena.
Nuclear astrophysics.
by measuring:
Proton and α elastic and inelastic scattering excitation function direct (α,p) and (p,α) β-delayed charged particle decays Transfer reactions: (d,p), (p,d), (p,t), (d,^{3}He), etc.

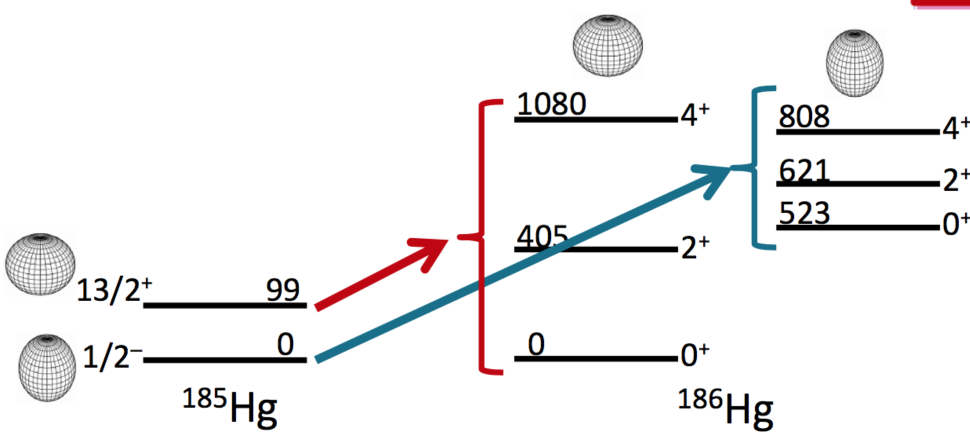
Excitation function for ^{8}B+p



SpecMAT (Riccardo Raabe)

Migration of $\pi f_{7/2}$, $\pi f_{5/2}$ as $\nu g_{9/2}$ is filled (tensor interaction)

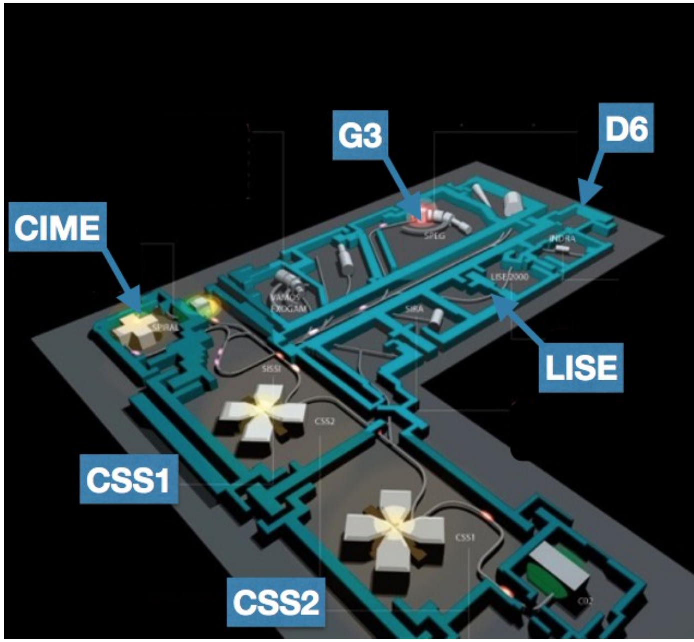




Evaluation shape coexistence using 1-n transfer on Hg in the neutron deficient lead region.

Active Targets: physics programs

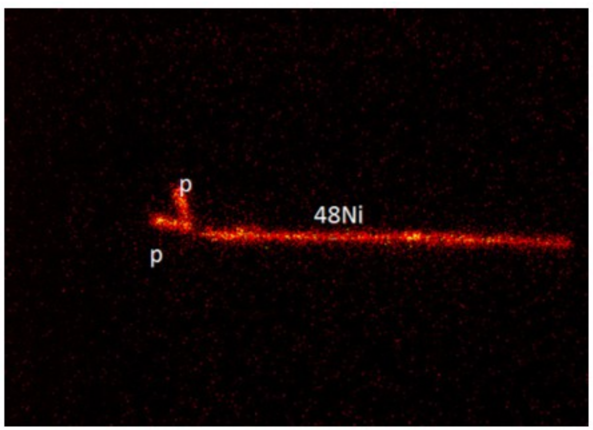
ACTAR TPC (Pierre Morfouace)



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.

Warsaw Optical Time Projection Chamber (Natalia Sokołowska)

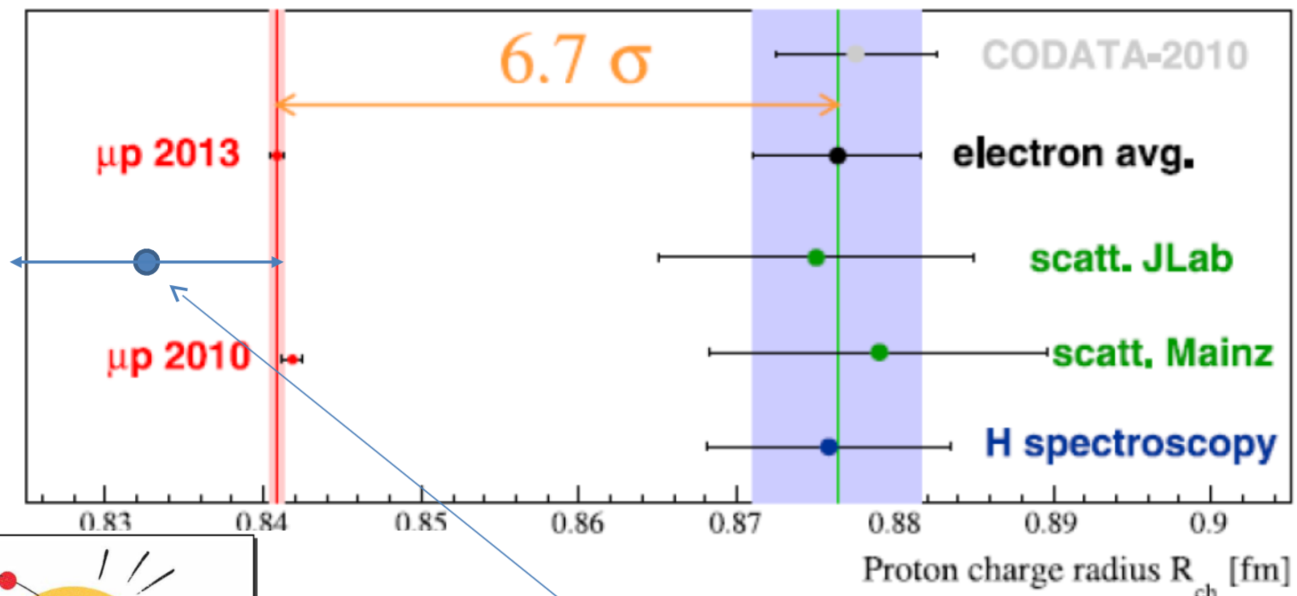


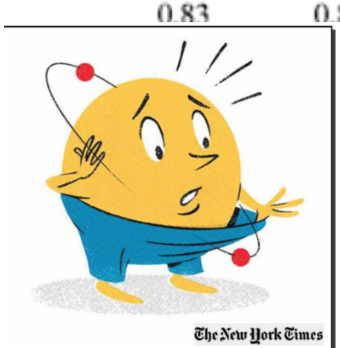
Two proton emission:

- rare events
- convincing evidence from a single event
- providing angular correlations
- providing energy distribution and decay mechanism

AT + electronTracker (Oleg Kiselev) @ MAMI

Proton charge radius
status 2016



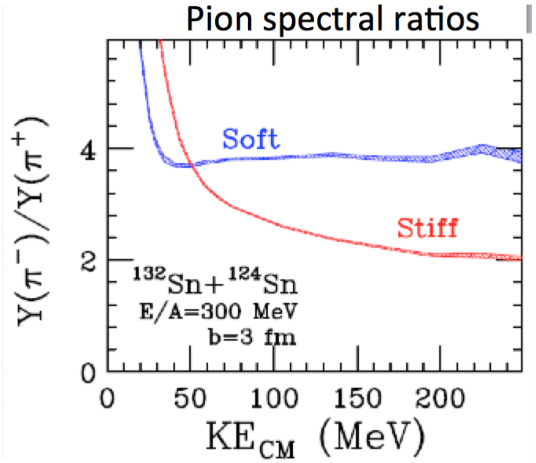


Rp = 0.877 fm
or
Rp =0.841 fm
???

H spectroscopy (2S – 4P),
A. Beyer et al., Science 358 (2017)

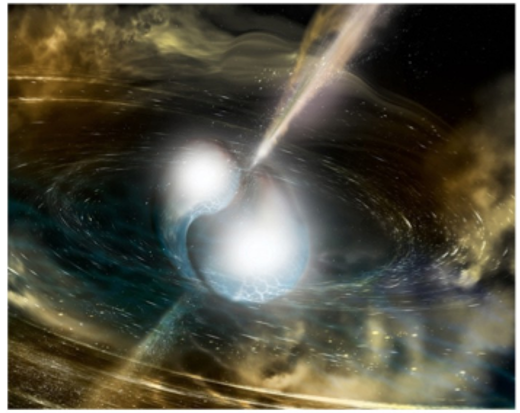
Active Targets: physics programs

SPIRIT (Betty Tsang)

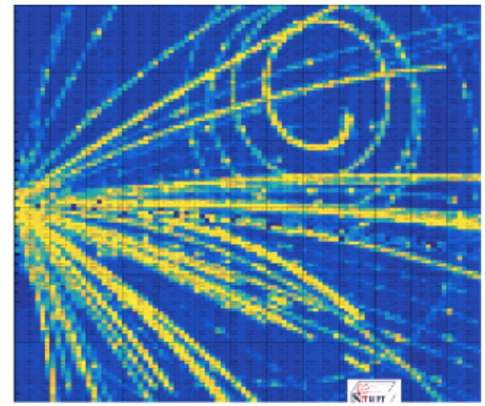


Highlights of SπRIT TPC – designed to investigate physics from neutron-star merger to nucleus-nucleus collisions

LIGO Detects a Neutron Star Merger



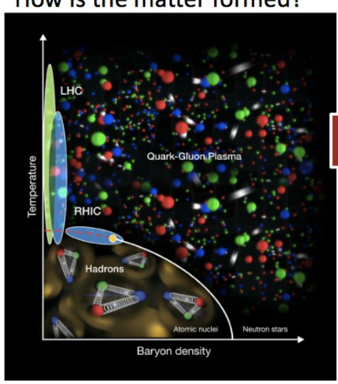
^{132}Sn+^{124}Sn @ E/A=270 MeV



CAT-S, CAT-M (Shinsuke Ota)

Nuclei, Neutron Stars, and Mergers

How is the matter formed?

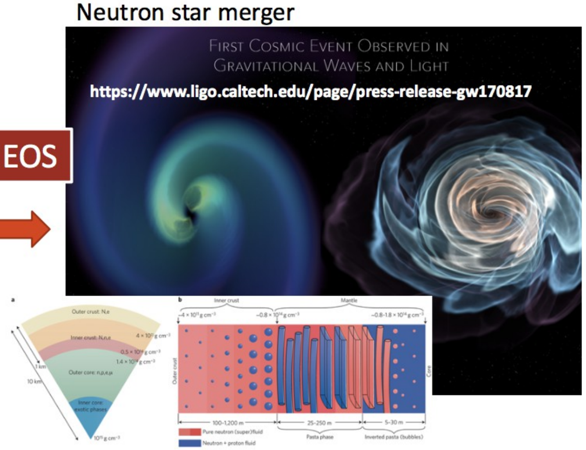


https://phys.org/news/2013-10-supercomputing-transition-ordinary-extraordinary.html

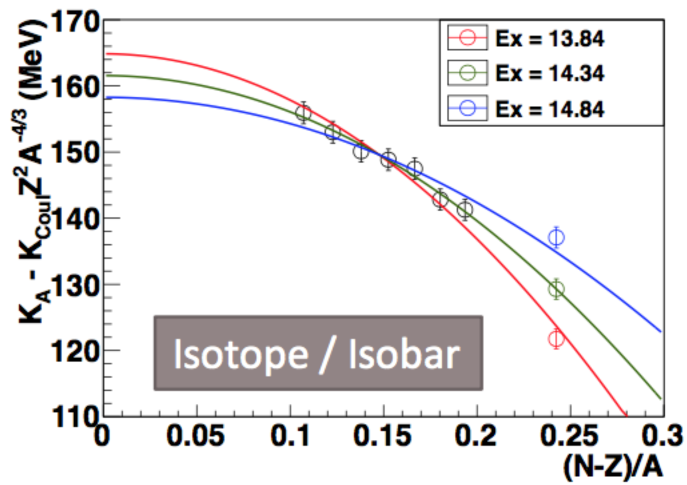
Nuclear-Matter EOS

⟷ E(ρ,α) ⟷

Neutron star merger



Nature Physics 9, 396–397 (2013)



SPiRIT-TPC (Tadaake Isoke, B. Tsang)

Dayone Heavy RI Collision experiment

- Systematic measurements of multiple observables in heavy RI collisions in same *Z* (Z=50) but different *N* system were realized with heavy RI beam.

CAT-S, CAT-M (Shinsuke Ota)

Aiming at

- **Determination of isospin dependence of equation of state of nuclear matter**
- Determination of electron capture rate for supernova nucleosynthesis

Missing mass spectroscopy in inverse kinematics via **forward angle**

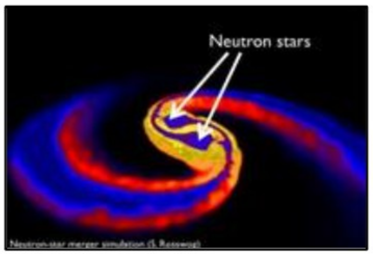
- **Inelastic scattering of p, d, α**
- (n,p) type charge exchange reactions

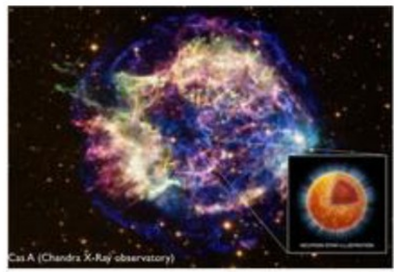
p, d, (α) scattering
(d,2p)

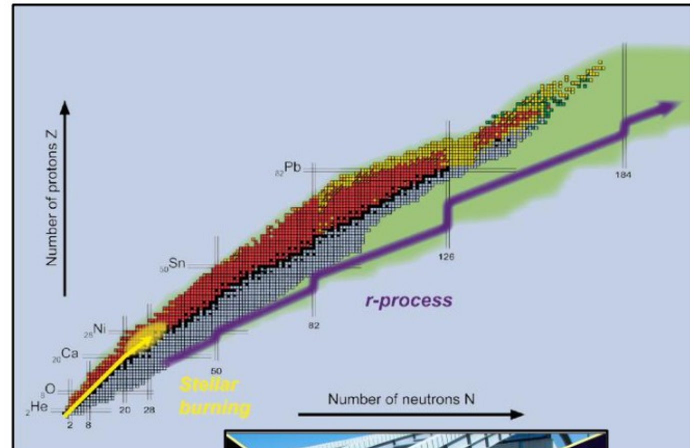
Active Targets: physics programs

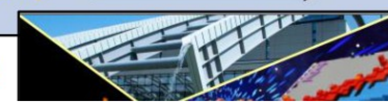
ACTAR-TPC@ISOLDE (Jozef Klimo)

- Fission is expected to play a key role in the description of r-process in nucleosynthesis n-rich nuclei in two neutron star merger

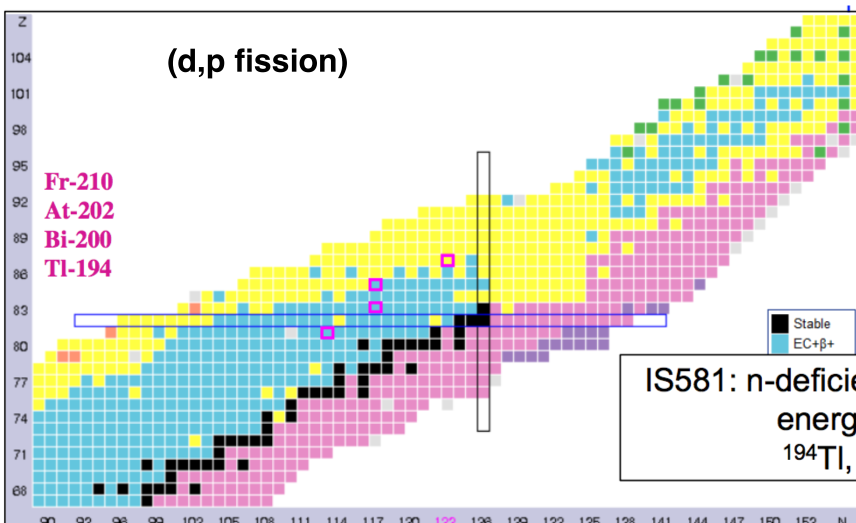


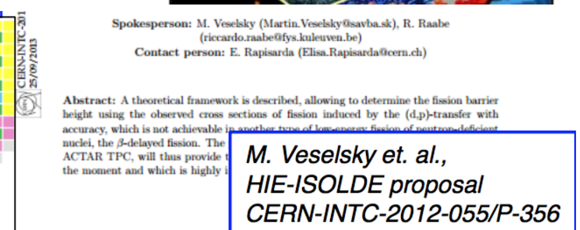






Fission barrier height is the parameter determining fission rate





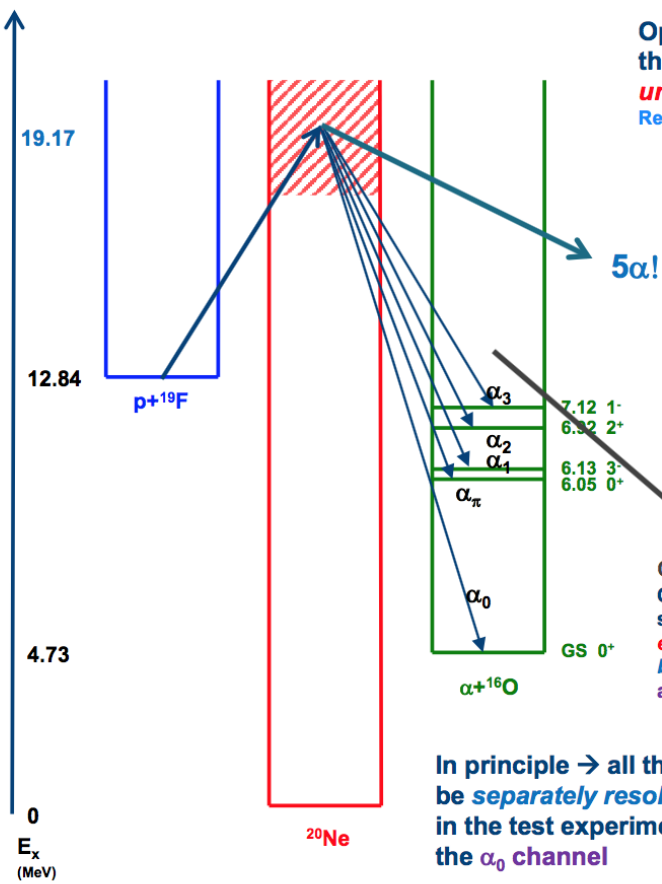
M. Veselsky et. al.,
HIE-ISOLDE proposal
CERN-INTC-2012-055/P-356

IS581: n-deficient nuclei with zero pairing energy @ saddle point
^{194}Tl, ^{200}Bi, ^{202}At, ^{210}Fr

Active Targets: physics programs

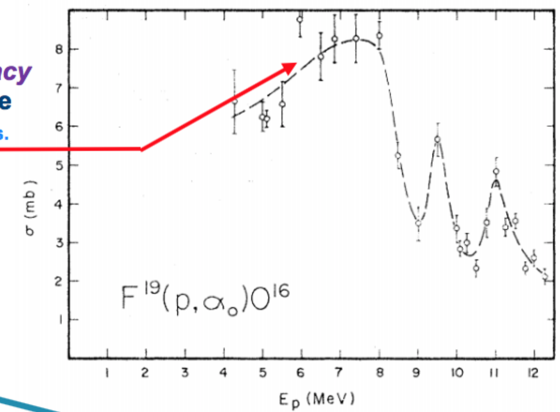
ACTAR TPC Demonstrator (Tommaso Marchi) @ LNS /SPES

Test case 1: $^{19}F(p,a)$ reaction at E_p=5-7 MeV (TANDEM)

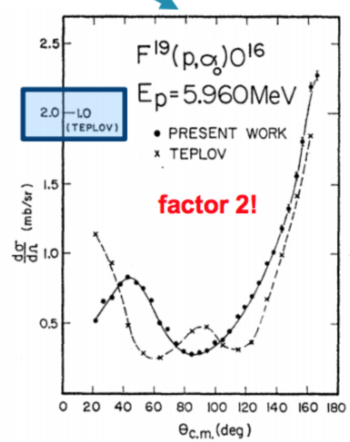


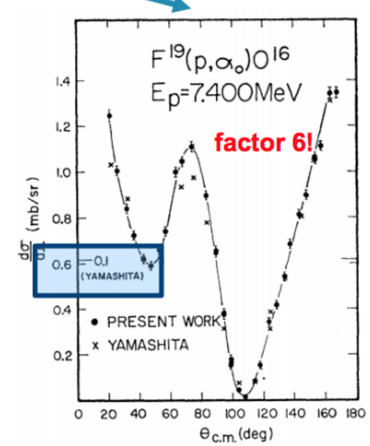
Opportunity to measure with *good accuracy* the angle-integrated *cross section* → large *uncertainties* at E_p=5-7 MeV (Warsh et al, Phys. Rev. 131 (1963) 1690)

Ambiguities in *shapes* and in the absolute *x-section scale* of angular distributions (Warsh et al, Phys. Rev. 131 (1963) 1690)



α feeding:
Opportunity of studying *multi-track events* with *low background* and no ambiguities





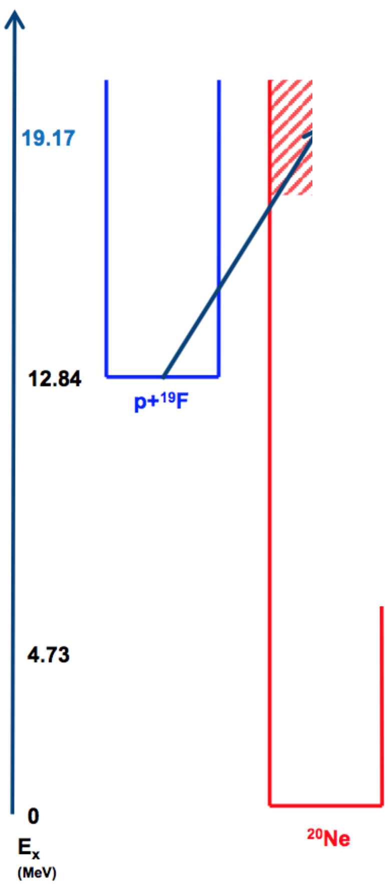
In principle → all the α_i channels can be *separately resolved* (to be verified in the test experiment) → surely for the α_0 channel

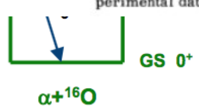
Active Targets: physics programs

ACTAR TPC Demonstrator (Tommaso Marchi) @ LNS /SPES

Test case 1: ^{19}F(p,a) reaction at E_p=5-7 MeV (TANDEM)

Test case 2: ^{120}Sn(d,p) reaction at E_{Sn}= 15 AMeV (CS)





Schneid et al, Phys Rev 156 (1967) 4

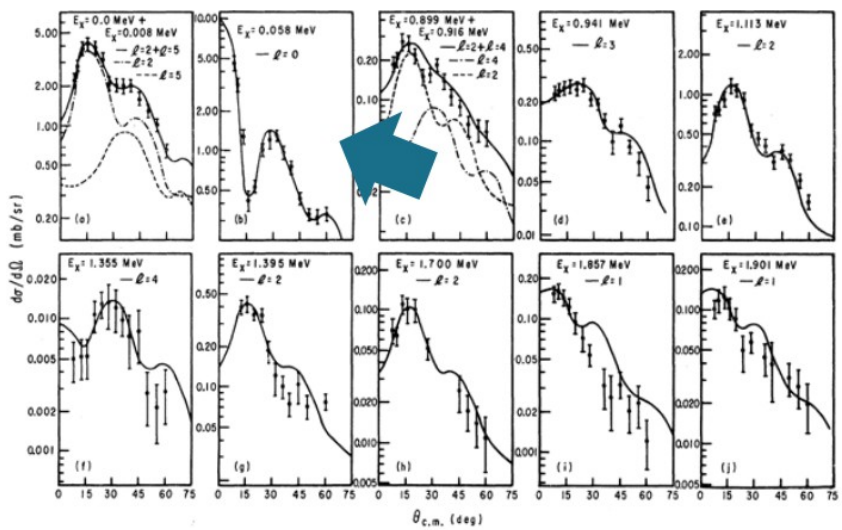
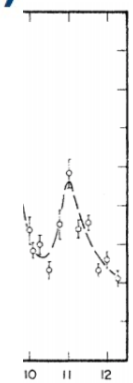
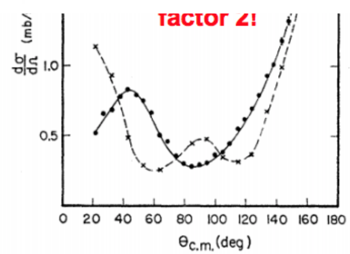
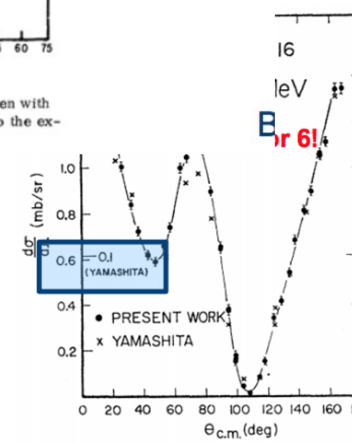


FIG. 2. Angular distributions of transitions in the ^{120}Sn(d,p)^{121}Sn reaction. The experimental points are given with error bars corresponding to statistics and background subtraction. The solid lines are DWBA curves fitted to the experimental data.



studying *multi-track events* with *low background* and no ambiguities





In principle → all the α_i channels can be *separately resolved* (to be verified in the test experiment) → surely for the α_0 channel

Active Targets: physics programs

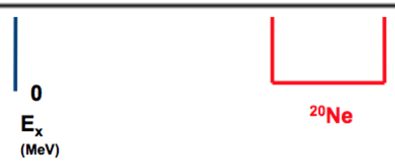
ACTAR TPC Demonstrator (Tommaso Marchi) @ LNS /SPES

Test case 1: $^{19}F(p,a)$ reaction at E_p=5-7 MeV (TANDEM)

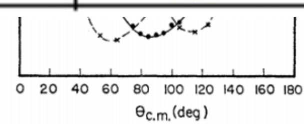
Test case 2: $^{120}Sn(d,p)$ reaction at E_{Sn}= 15 AMeV (CS)

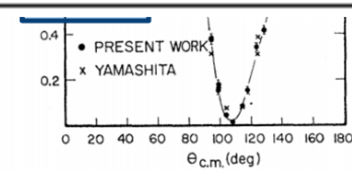
Table 1. List of the proposed projectile for the energy loss profile measurements. As an example, the pressure needed to stop the gas on the pad plane is given for the iC_4H_{10} case.

Ion	Beam Energy (MeV/u)	Gases to be measured	BTU requested	*iC4H10 pressure (mbar) typical case example*
^{7}Li	1.0 - 4.5	H_2, D_2, CH_4, iC_4H_{10}, CF_4, CO_2, He	4.5	*500*
^{9}Be	1.5 - 4.5		4.5	*500*
^{10}B	1.8 - 4.5		4.5	*500*
^{12}C	2.0 - 4.5		4.5	*250*
^{15}N	2.0 - 4.5		4.5	*250*
^{16}O	2.0 - 4.5		4.5	*250*
^{19}F	2.0 - 4.5		4.5	*250*
^{24}Mg	2.0 - 4.5		4.5	*250*
^{40}Ca	2.0 - 3.8		4.5	*250*
^{120}Sn	1.5 - 1.7		4.5	*125*
Total			45	



In principle → all the α_i channels can be *separately resolved* (to be verified in the test experiment) → surely for the α_0 channel

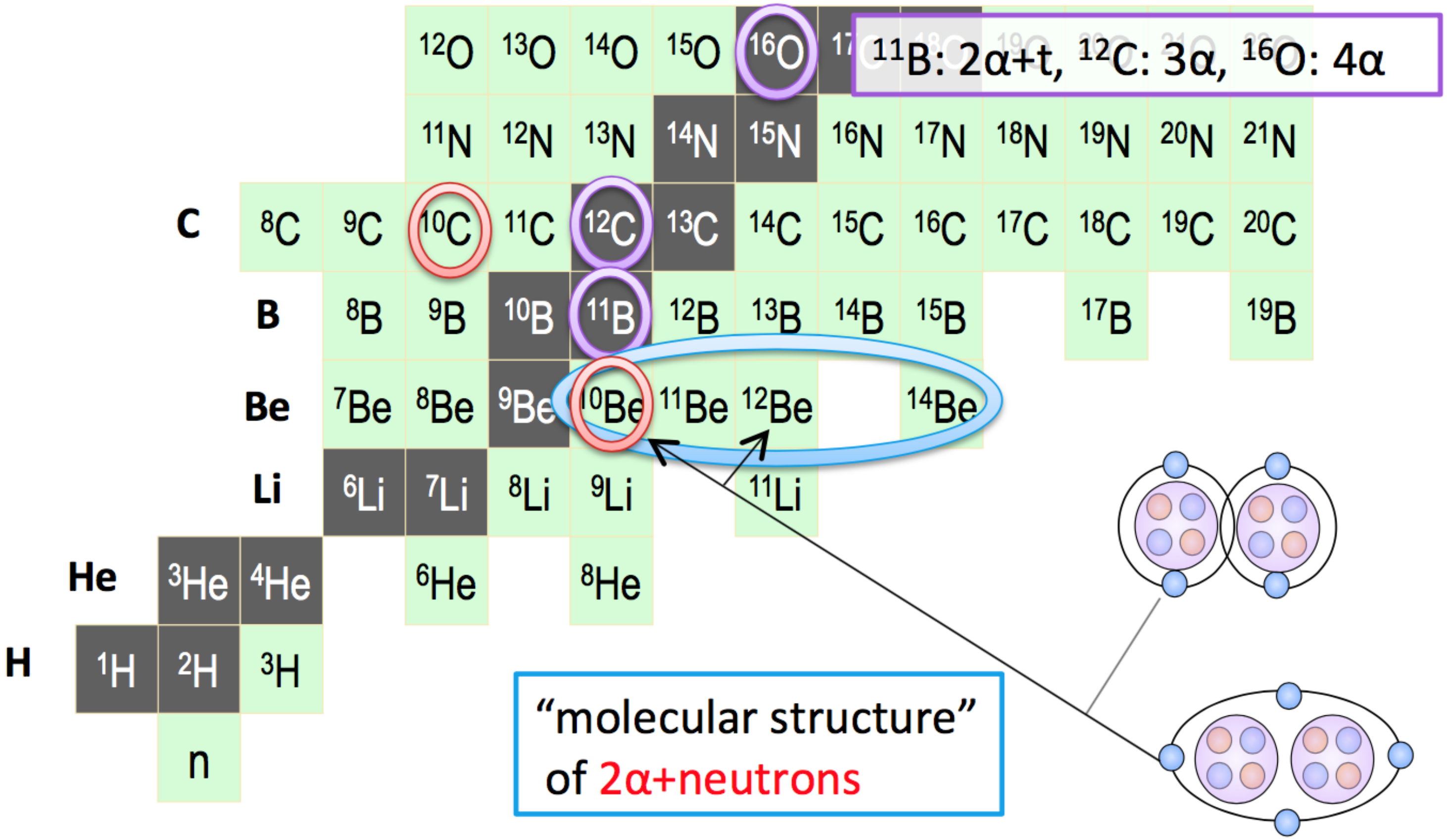




Active Targets: physics programs

MAIKo (Tatsuya Furuno)

α clustering is an important aspect of atomic nuclei.

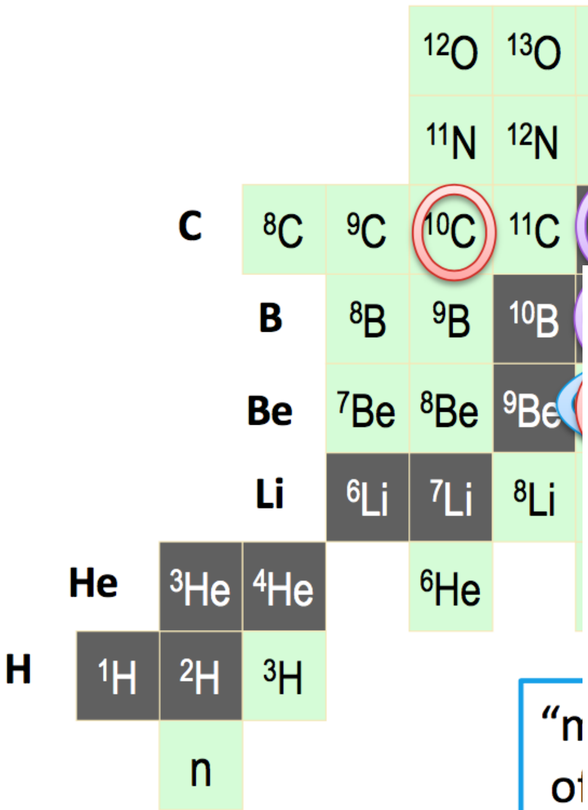


Can proton-rich nuclei also form α molecular structures?

Active Targets: physics programs

MAIKo (Tatsuya Furuno)

α clustering is an important aspect of atomic nuclei.



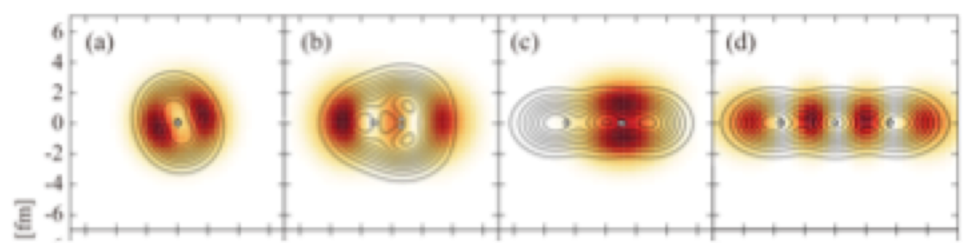
^{11}B: 2α+t, ^{12}C: 3α, ^{16}O: 4α

“n
of

Can proton-rich nuclei a

ATTPC (Tan Ahn)

- ^{10}C + α scattering experiment to search for large alpha widths in ^{14}O
- Investigated techniques for robust analysis of track images
  - Hough transform
  - Minimum enclosing triangle
- Radioactive beam experiments with 500 pps beam rates
- Alpha clustering on the proton-rich side of stability?



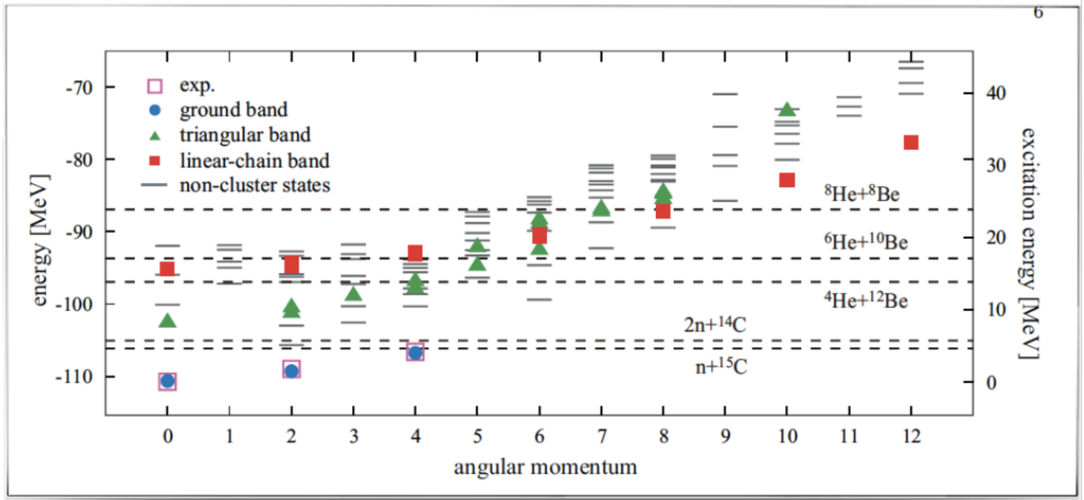
Active Targets: physics programs

ATTPC (Yassid Ayyad)

$^{16}C(J=0+)$	Triangular	Linear-Chain
E_x [MeV]	8.35	16.81
$\gamma\ [^{12}Be(0+)\otimes l=0]$	0.063	0.103
$\gamma\ [^{12}Be(2+)\otimes l=2]$	0.044	0.181

$^{16}C(J=2+)$	Triangular	Linear-Chain
E_x [MeV]	9.65	17.36
$\gamma\ [^{12}Be(0+)\otimes l=2]$	0.030	0.095
$\gamma\ [^{12}Be(2+)\otimes l=0]$	0.026	0.083
$\gamma\ [^{12}Be(2+)\otimes l=2]$	0.061	0.088
$\gamma\ [^{12}Be(2+)\otimes l=4]$	0.015	0.105

$^{16}C(J=4+)$	Triangular	Linear-Chain
E_x [MeV]	12.89	18.99
$\gamma\ [^{12}Be(0+)\otimes l=4]$	0.009	0.097
$\gamma\ [^{12}Be(2+)\otimes l=2]$	0.057	0.117
$\gamma\ [^{12}Be(2+)\otimes l=4]$	0.026	0.083
$\gamma\ [^{12}Be(2+)\otimes l=6]$	0.002	0.083



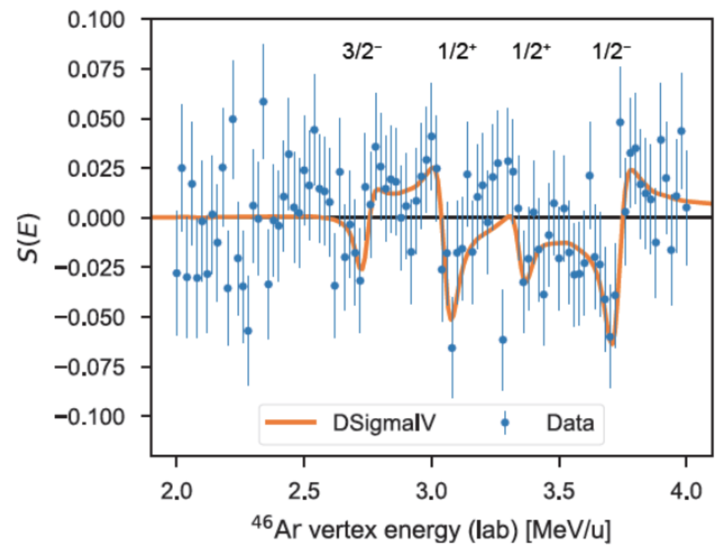
Resonant alpha scattering $^{12}Be+^{4}He$

T. Baba, Y. Chiba, and M. Kimura, Phys.

$^{46}Ar+p$ resonant scattering

Evolution of the N= 28 shell closure

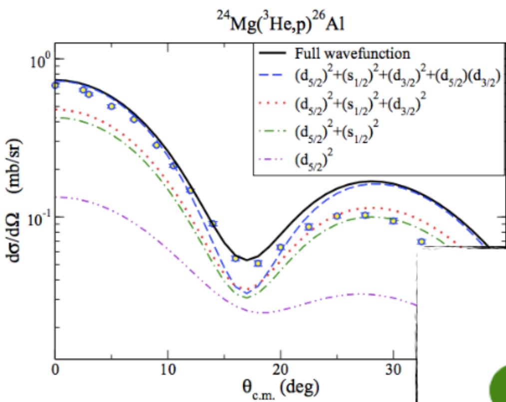
Resonances in ^{47}Ar

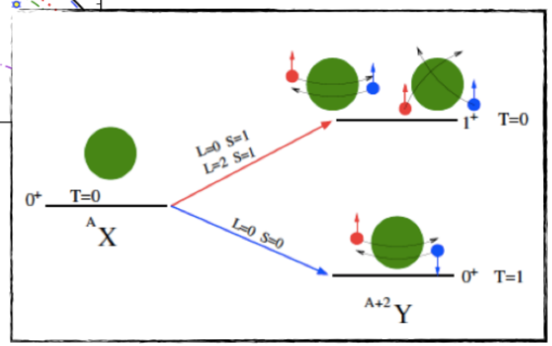


Active Targets: physics programs

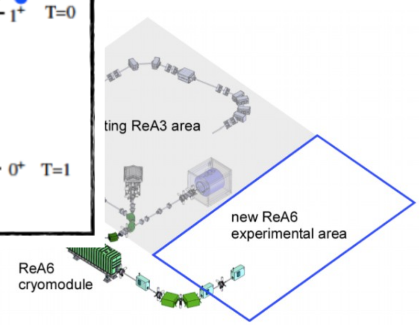
ATTPC (Yassid Ayyad)

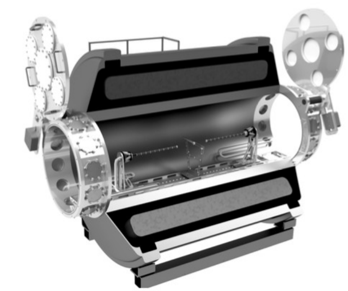
Isoscalar neutron-proton pairing

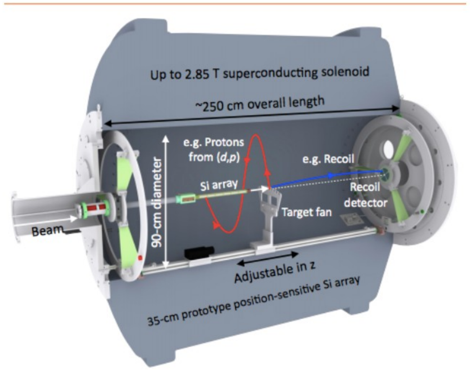


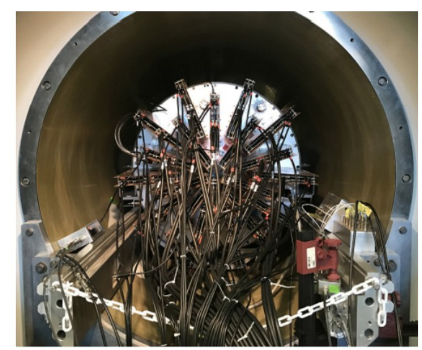


HELIOS + AT-TPC







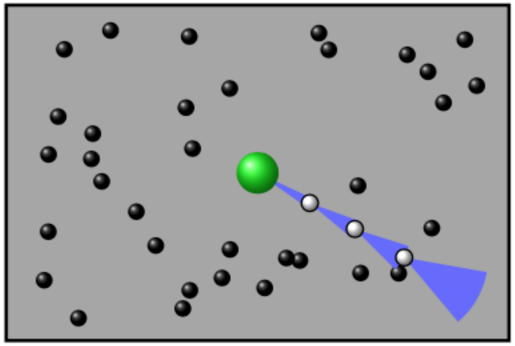


Active Targets: an challenging suggestions...

Jean-Marc Sparenberg

Project: deterministic quantum statistical detector model

- Inspired by [Mott 1929]'s original question: why no multiple tracks?
  - because of state-space structure
  - in "unaided" wave mechanics
- New question: why a particular track?
  - hypothesis: because of detector microscopic state [JMS et al. 2013] (fixed atom positions in simplest case)
  - deterministic statistical mechanics

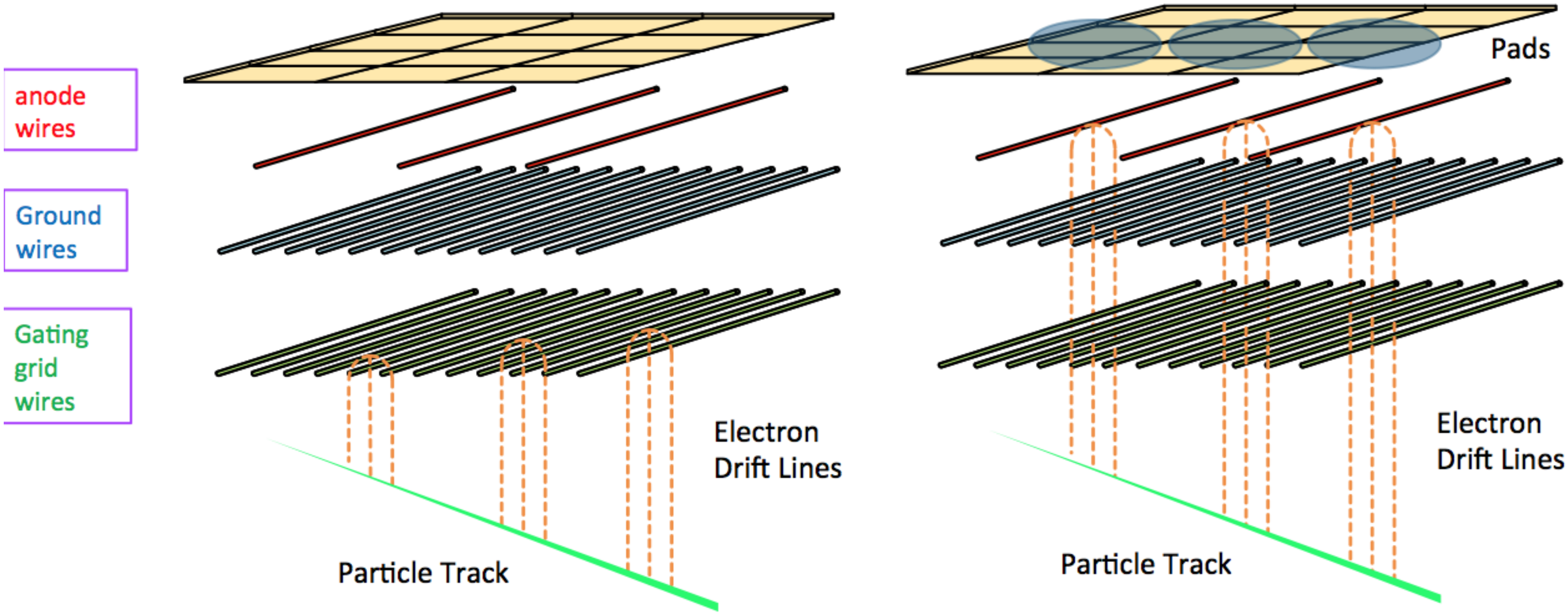


- α-particle source
- Unexcited atom
- Hit/excited/ionized atom

- Directly related to slowing-down (stopping power) through
  - (in)elastic scattering
  - ionization

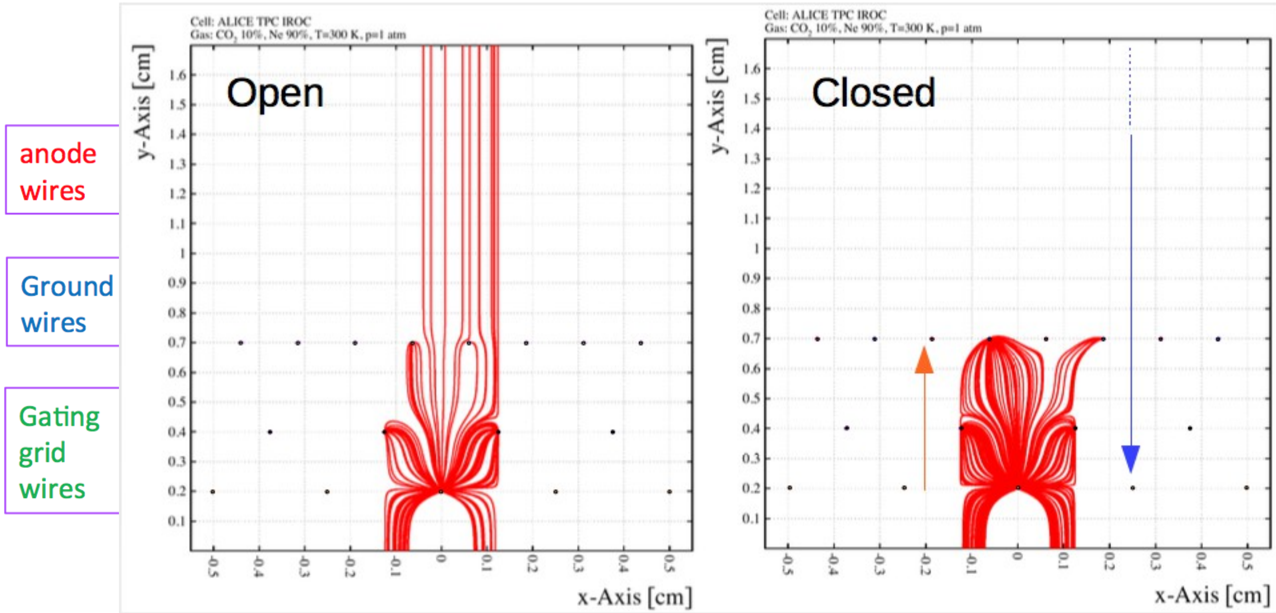
High intensity and heavy ion effects

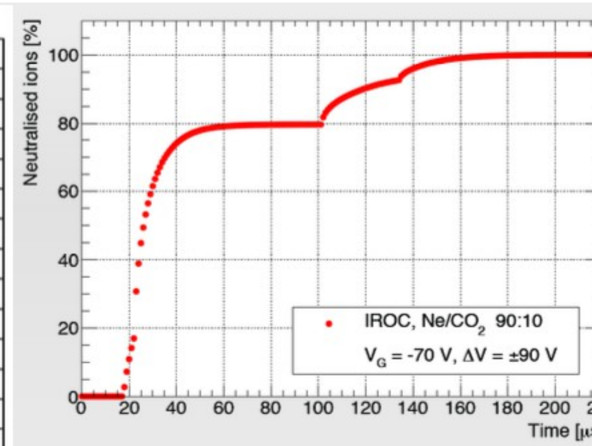
SPIRIT (Betty Tsang)



High intensity and heavy ion effects

ALICE (Jens Wiechula)

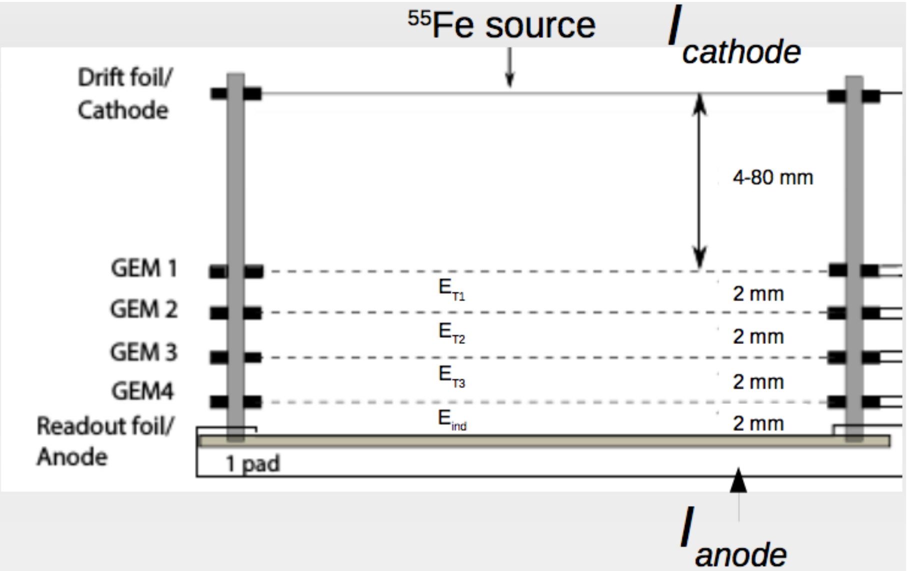




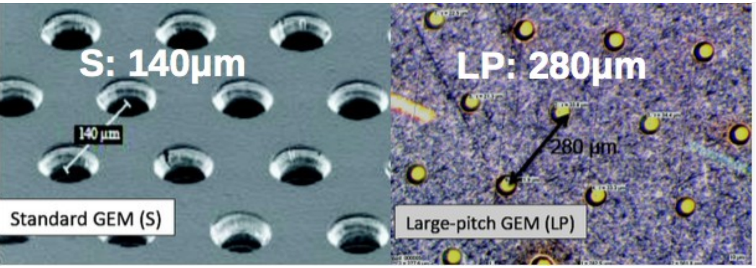
- Very good ion suppression (ion back flow – *IB* ~10^{-4} - 10^{-5})
- Limited rate capability
  - Readout cycle: $t_{readout} = t^{e-}_{drift,max} + t^{ion}_{drift}$
  - 100μs + 200μs → ~3.5kHz

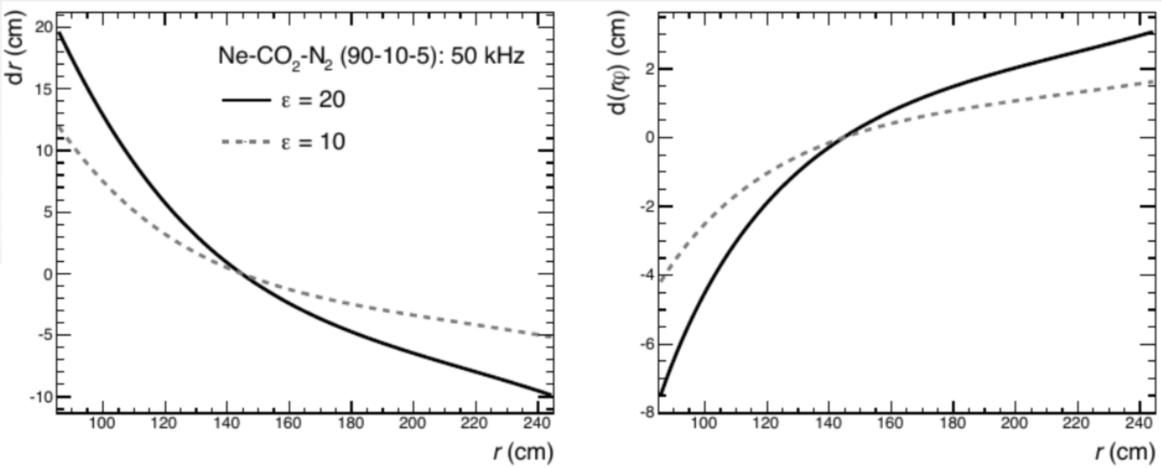
High intensity and heavy ion effects

ALICE (Jens Wiechula)



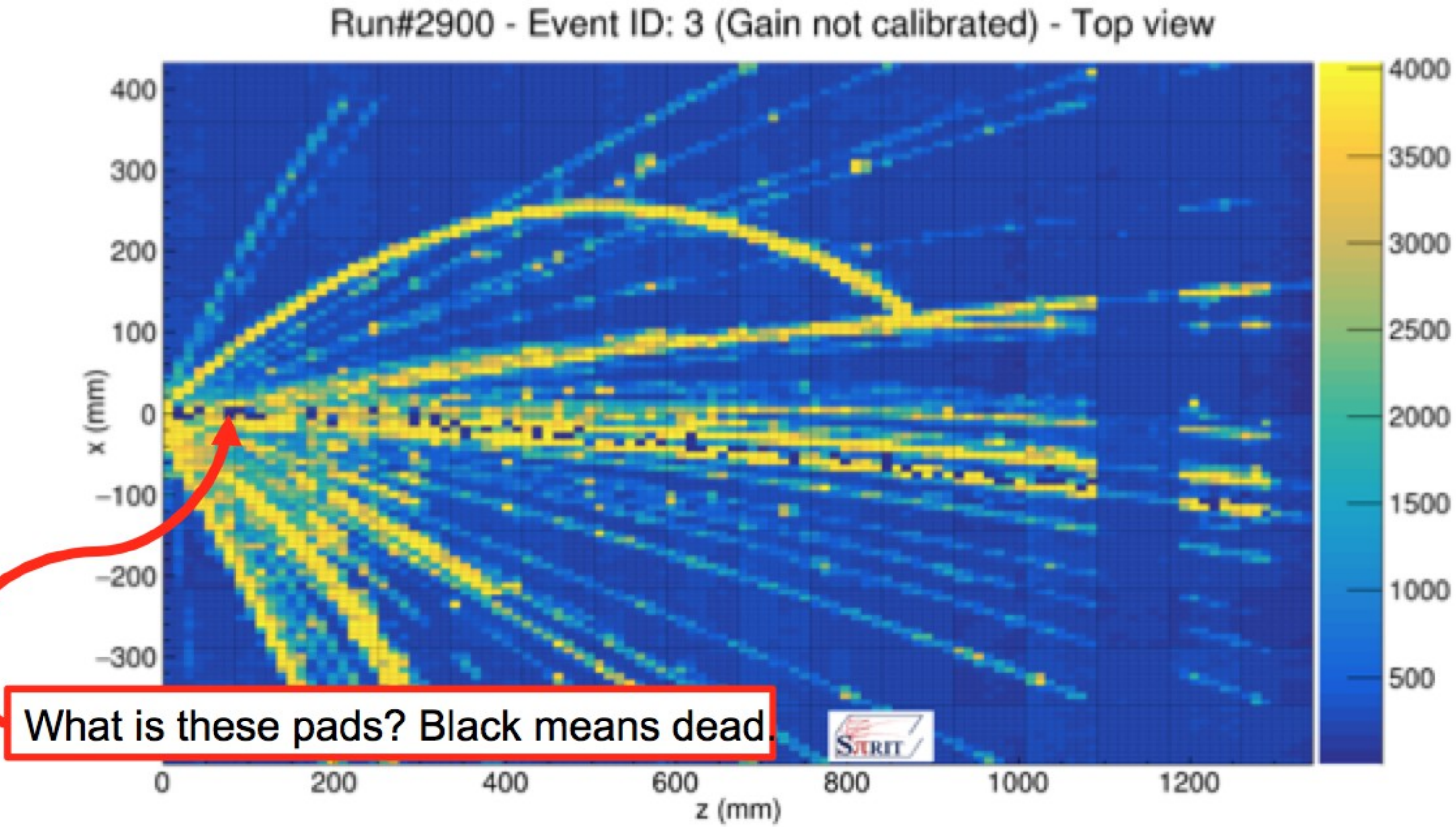
- Base line solution: 4-GEM stack (S-LP-LP-S)
  - σ_E/E < 12% for ^{55}Fe
  - *IB* < 1% @ gain 2000
  - Low discharge rate (5 trips per GEM stack per Pb–Pb running year)
- Large distortions (up to O(10cm)) expected
  - Calibration scheme developed to correct down to the intrinsic resolution (O(100µm))





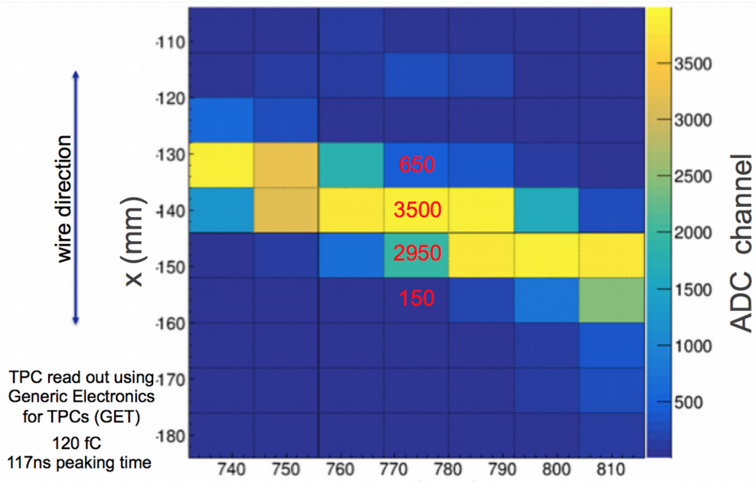
SPIRIT (Tadaaki Isobe)

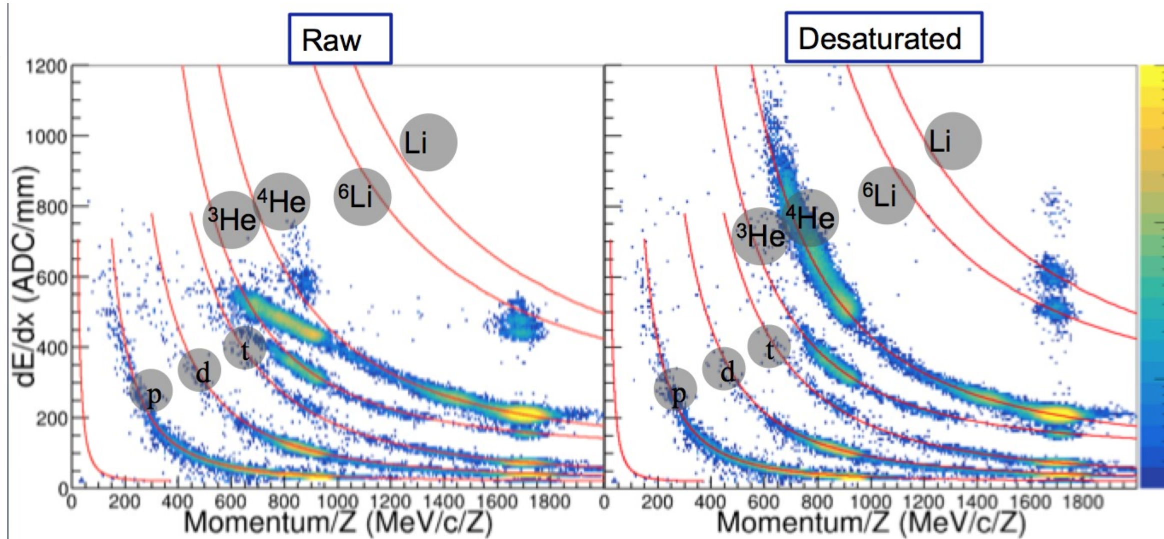
Dead channels along beam trajectory

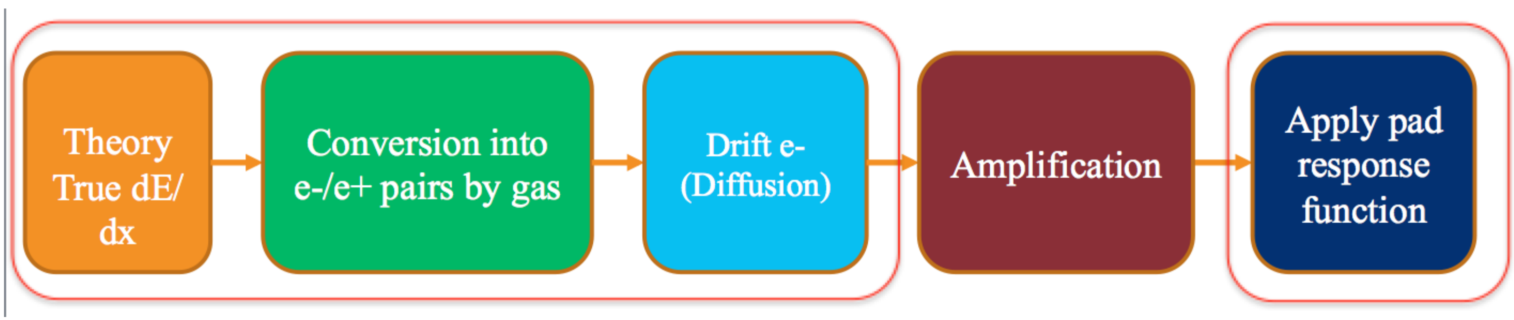


High intensity and heavy ion effects

SPIRIT (Justin Estee)

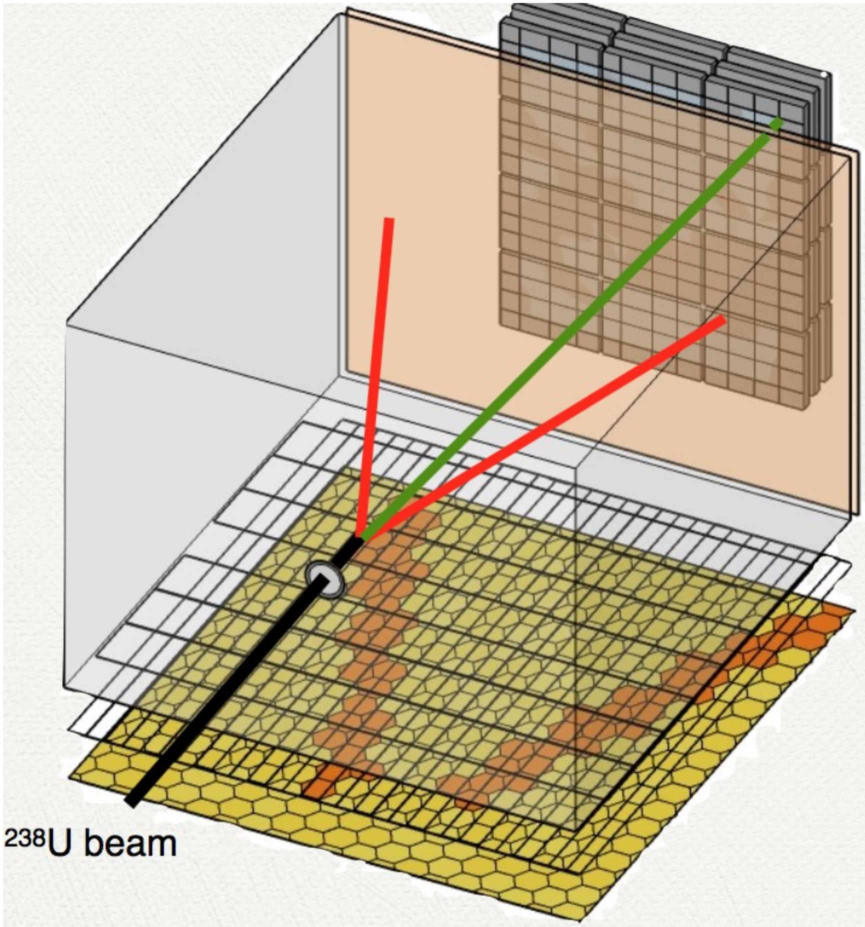






High intensity and heavy ion effects

Fission in MAYA (Carmen Rodríguez)



A challenging scenario:

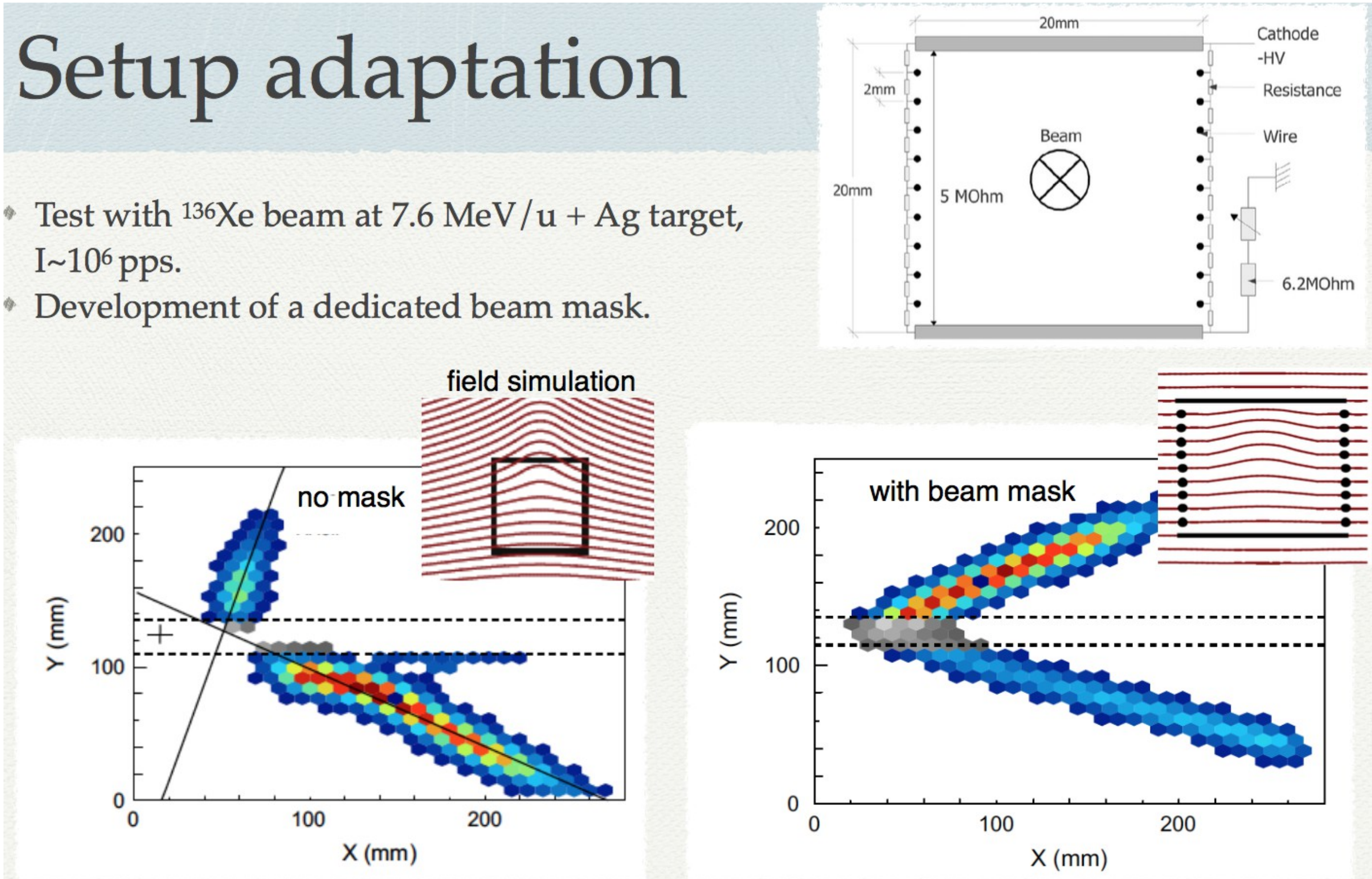
- ^{238}U beam at ~6 MeV/u, I~10^6pps.
- ΔE_{beam}~ 1 GeV.
- ~10^{13} electron-ion pairs/s created.

And therefore,

- Risk of sparks.
- Deformation of electric drift field.
- Delta e-, beam-induced signals.
- Pile-up.
- Simultaneous detection of light and heavy nuclei.

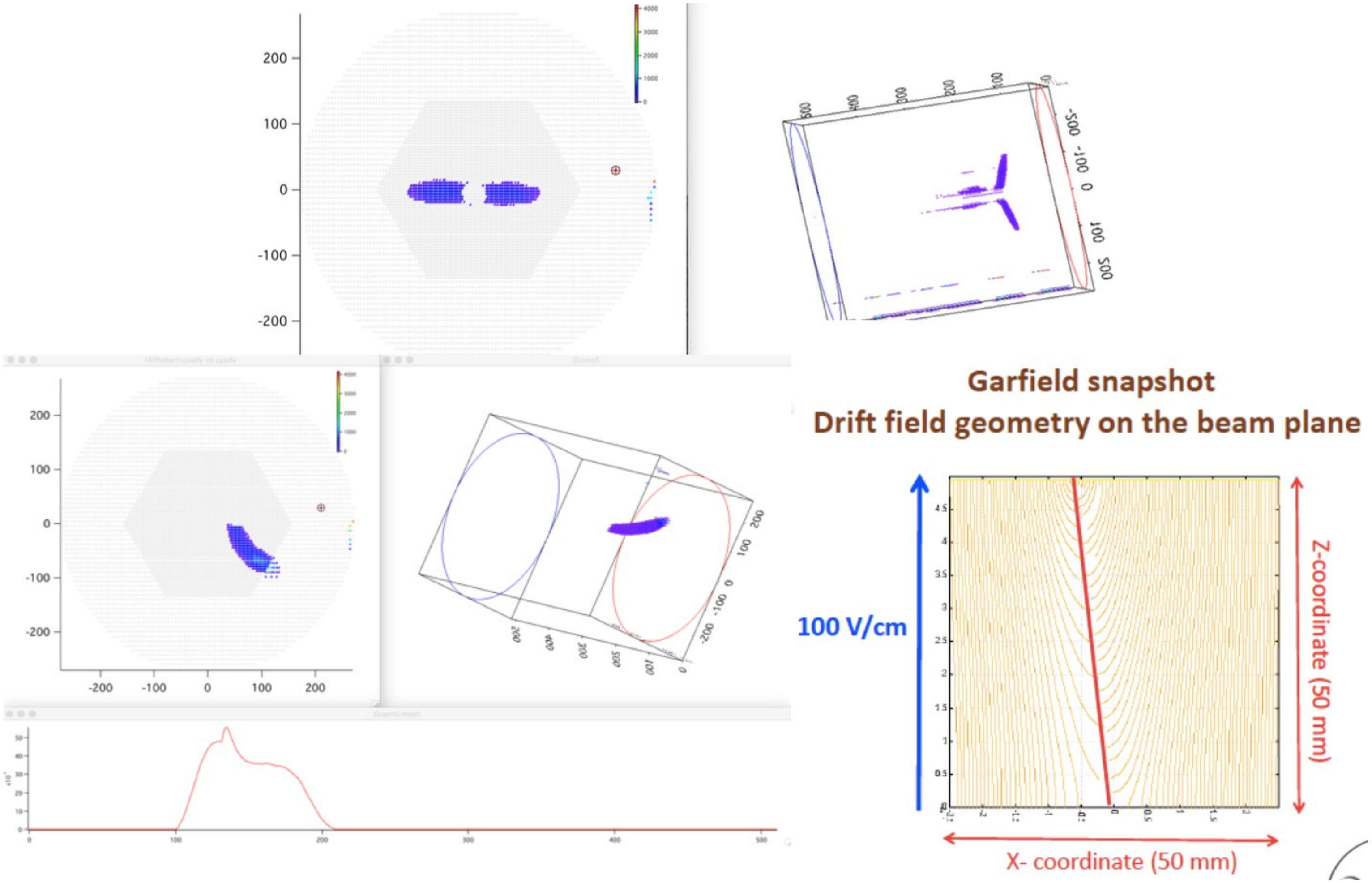
High intensity and heavy ion effects

Fission in MAYA (Carmen Rodríguez)



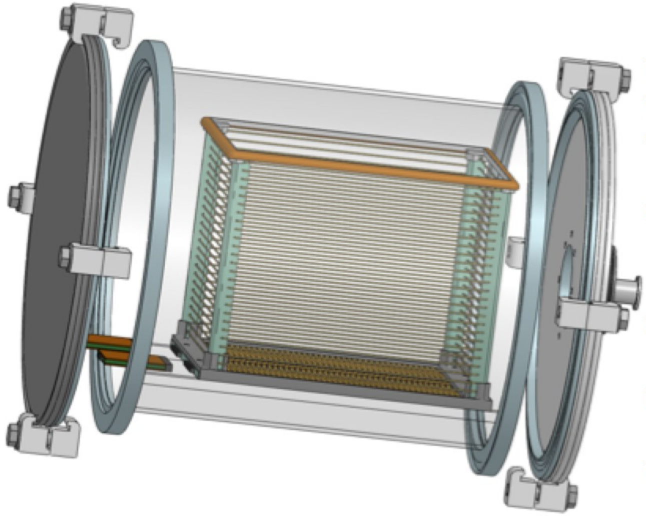
High intensity and heavy ion effects

Charge effects in ATTPC (Yassid Ayyad)



Active Targets: future setups

ATTPC (Clementine Santamaria)



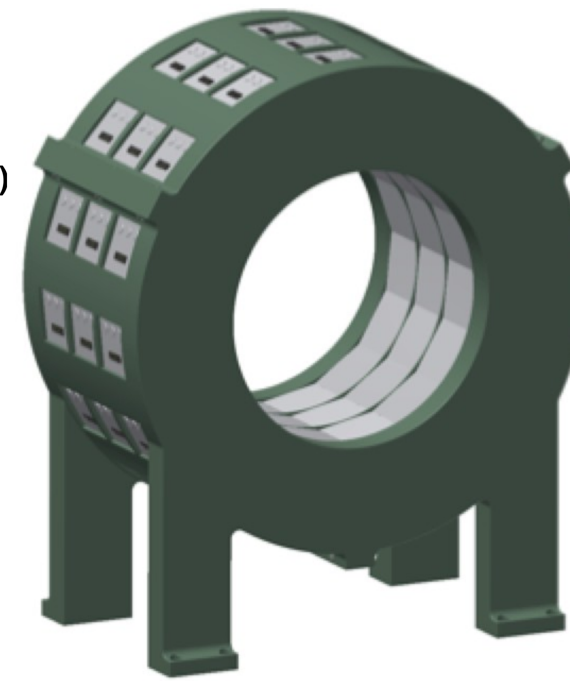
★ smaller TPC (200 mm diameter)
★ smaller drift time
➡ Higher count rates

★ Exit window possible in the design for higher beam energies

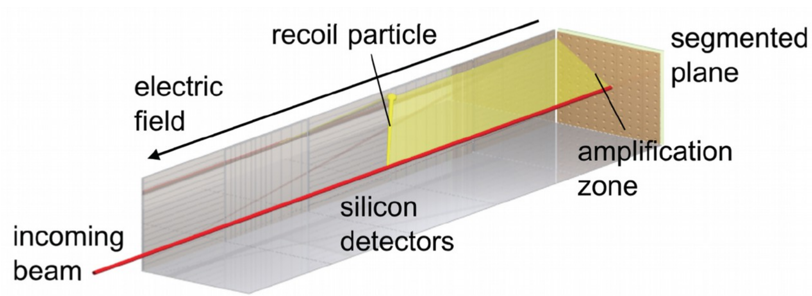
★ Different pad plane orientation for beam tracking
★ Coupling with gamma detection & neutron detection
★ example: (d,n) reactions

SpecMAT

(Ricardo Raabe, Oleg Poleschuk)



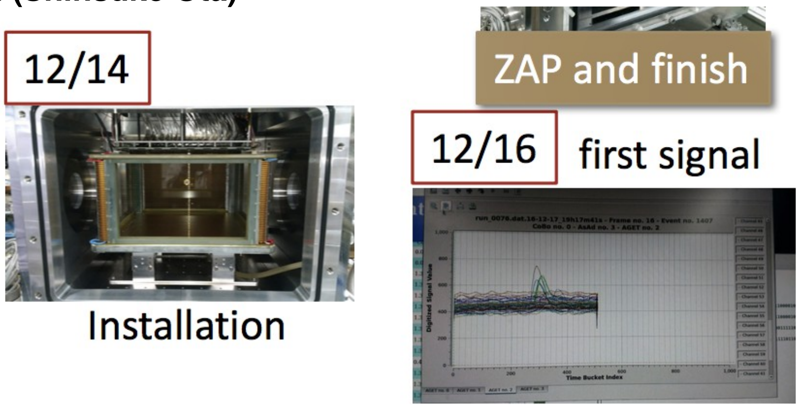
AT for GMR (Simone Cerruti)



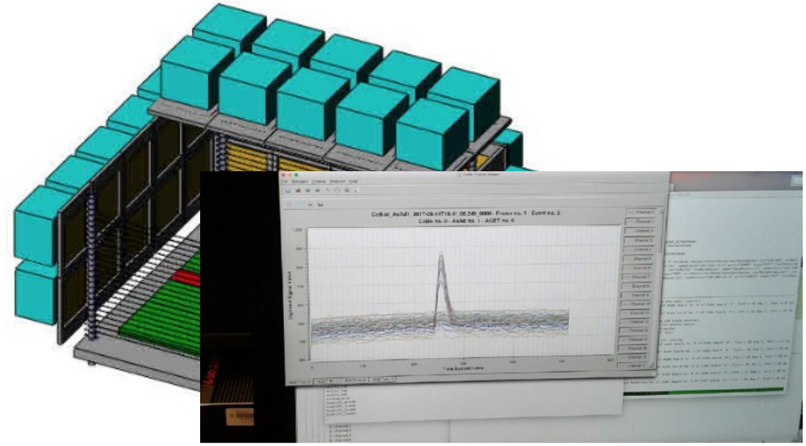
- ISGMR is a powerful tool to study the nuclear incompressibility
- New experimental data are needed, also in unstable nuclei
- Inverse kinematics is needed→ Active Target

Active Targets: welcome to the new detectors!

CAT-M (Shinsuke Ota)

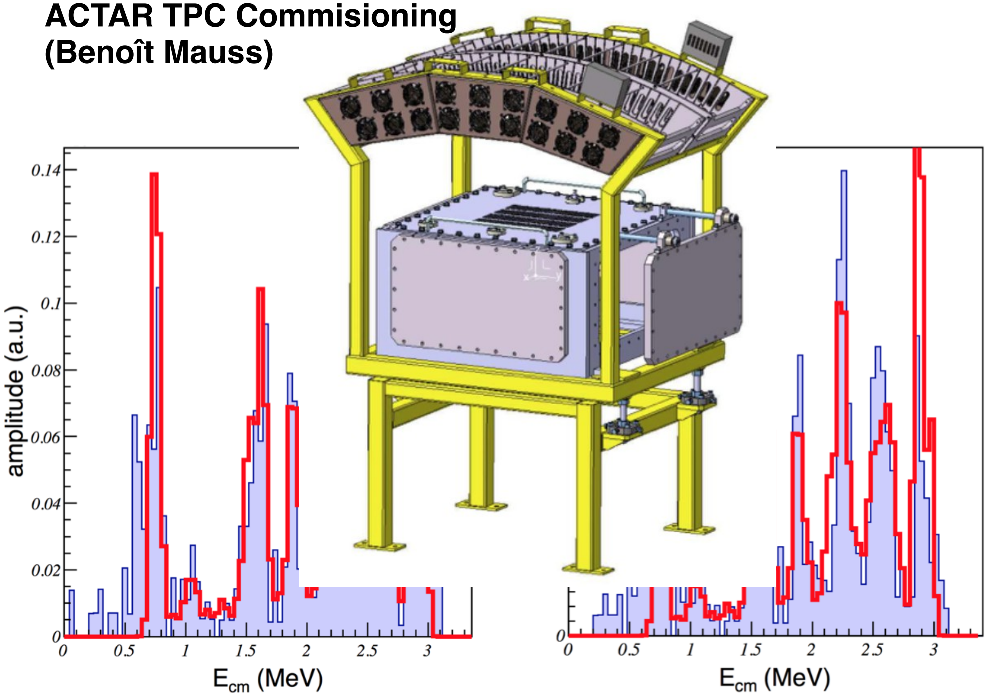


TexAT (Grigory Rogachev)



FIRST EVER BEAM EVENT IN TexAT
August 14, 2017 19:54:03

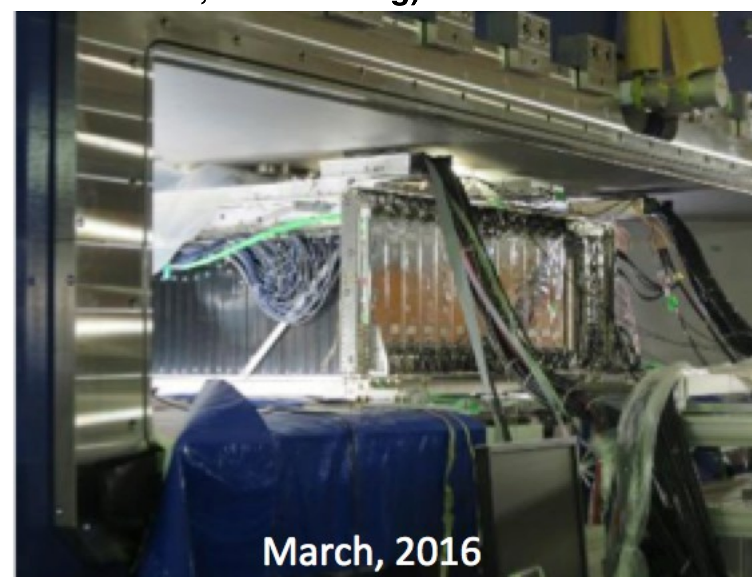
ACTAR TPC Commisioning (Benoît Mauss)



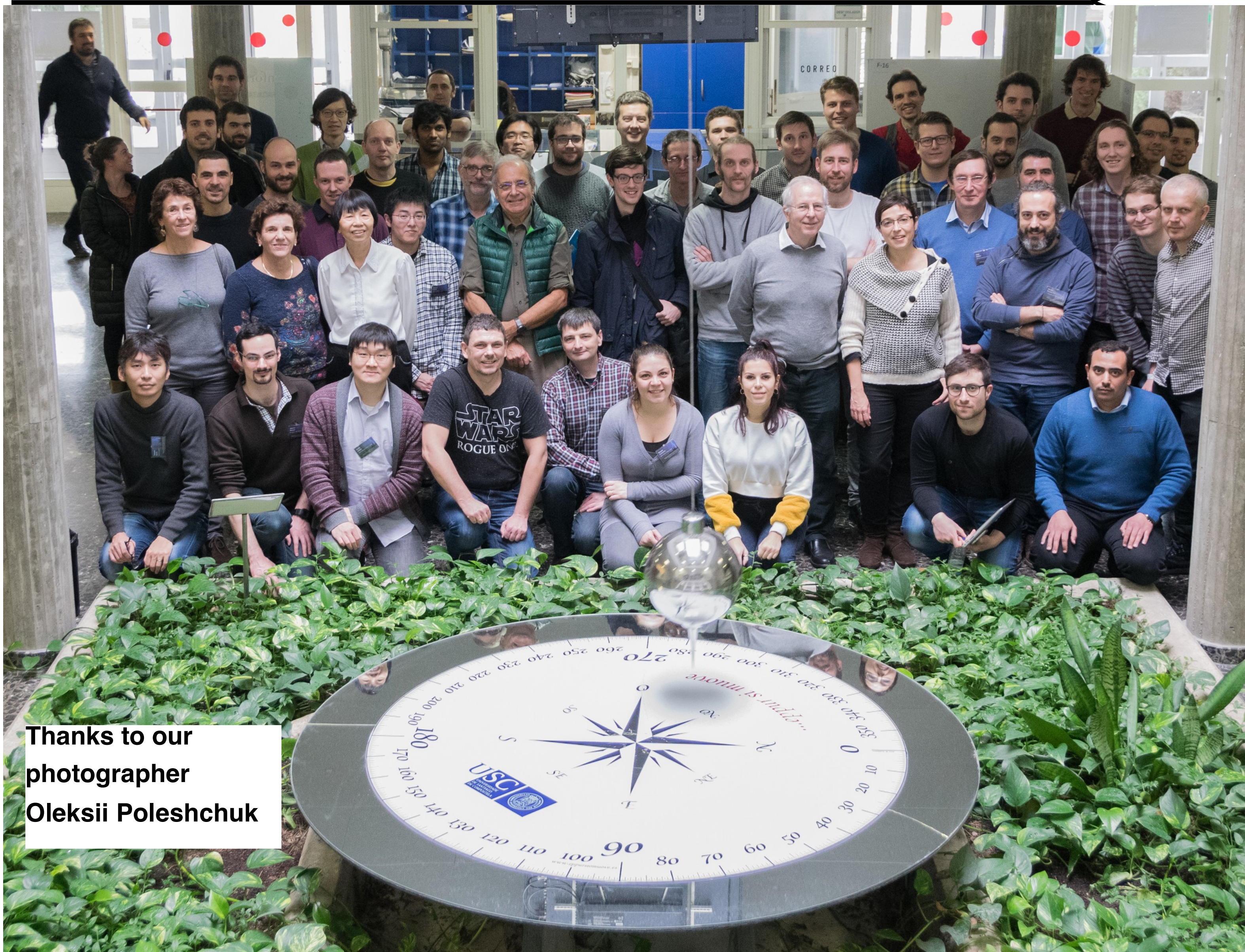
Projected on kinematic line

After iteration on the reaction energy

SPiRIT-TPC (Tadaake Isoke, B. Tsang, Justin Estee, Genie Jhang)



Thank you very much for your participation!



Thanks to our photographer Oleksii Poleshchuk