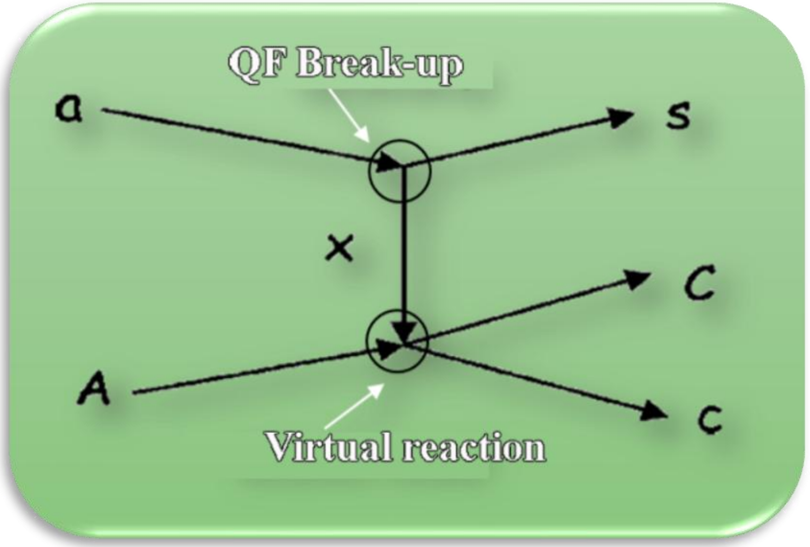
Detector arrays for indirect experiments with RIBs in Nuclear Astrophysics

NUSDAF 2025 - 1st Collaboration Meeting on NUclear Structure, Dynamics and Astrophysics at FRIB

G.L. Guardo
on behalf of the AsFiN group

The Trojan Horse Method

*The idea of the **THM** is to extract the cross section of an astrophysically relevant two-body reaction **A+x→c+C** at low energies from a suitable three-body reaction **a+A→c+C+s***



Quasi free kinematics is selected

✓ **only *x* - A interaction**

✓ ***s* = spectator (p_s~0)**

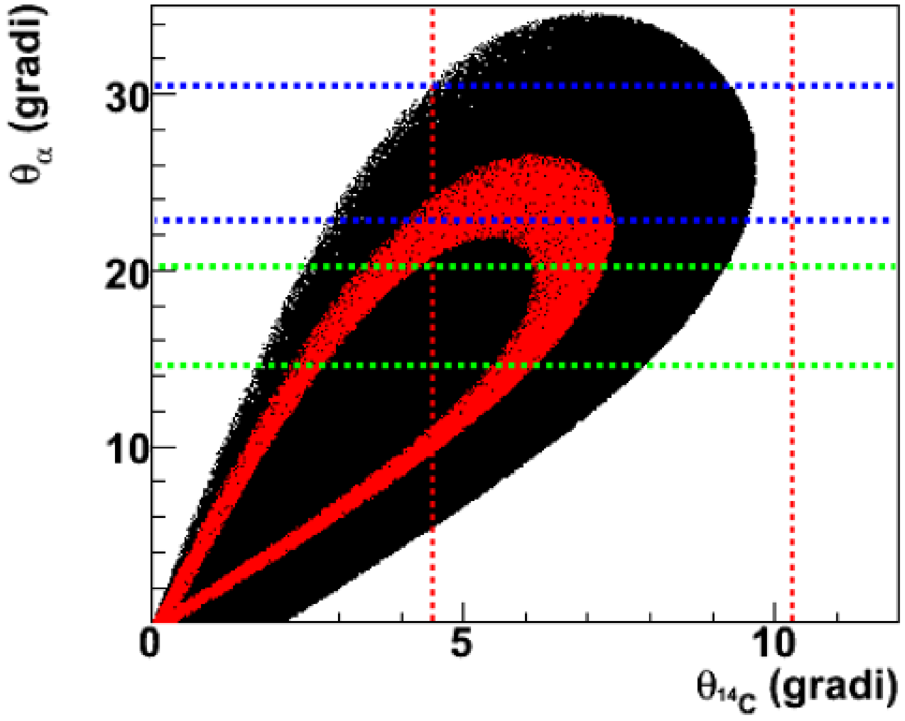
$E_A > E_{Coul}$ →

- **NO coulomb suppression**
- **NO electron screening**
- **NO centrifugal barrier**

- ***THM Review paper →*** ***Spitaleri C. et al., Prob. of Fund. Mod. Phys., 1991***
  Tumino A. et al., An. Rev. Nuc. and Part. Sci. 2021

Preliminary Study

Study of the $^{17}O(n,\alpha)^{14}C$ reaction: extension of the Trojan Horse Method to neutron induced reactions



Black points: kinematic calculations
Red points: kinematic calculations + $|p_s|<5$ MeV/c

$$E_{cm} + B_{xs} = E_{ax} \approx 2.45 MeV = E_{fascio} \frac{m_N}{m_N + m_{^{17}O}}$$

$^{17}O + ^{2}H$, E_{beam}=43.3 MeV

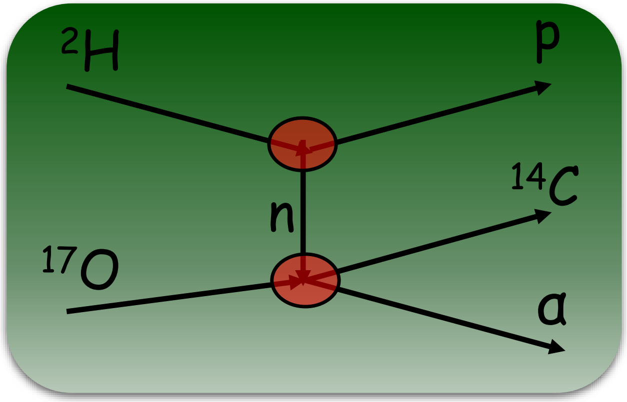
Deuteron as source of virtual neutrons!!

This allows then to determine the experimental apparatus:

^{14}C detection → $6° < \theta_C < 10°$

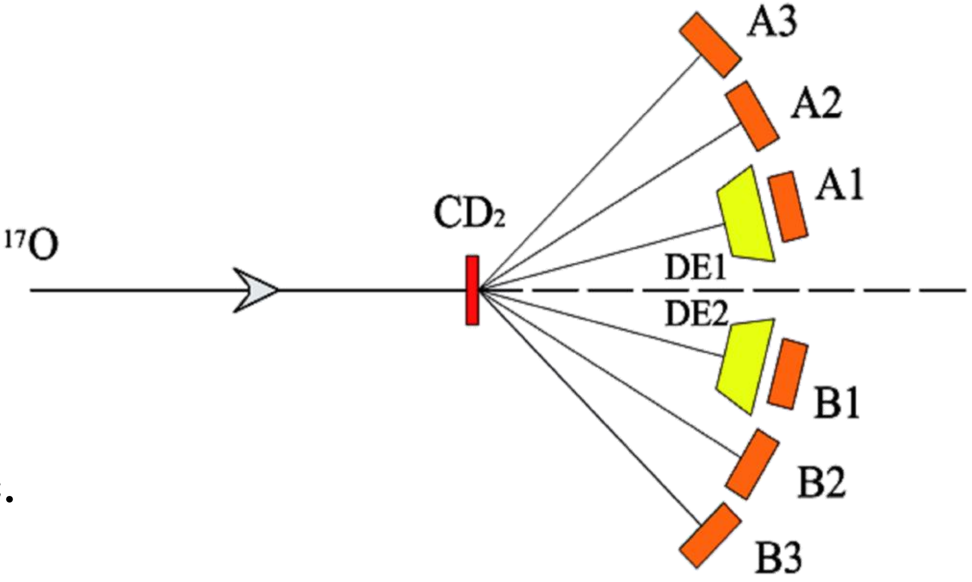
α detection → $15° < \theta_\alpha < 20°$
→ $23° < \theta_\alpha < 31°$

Experimental Setup



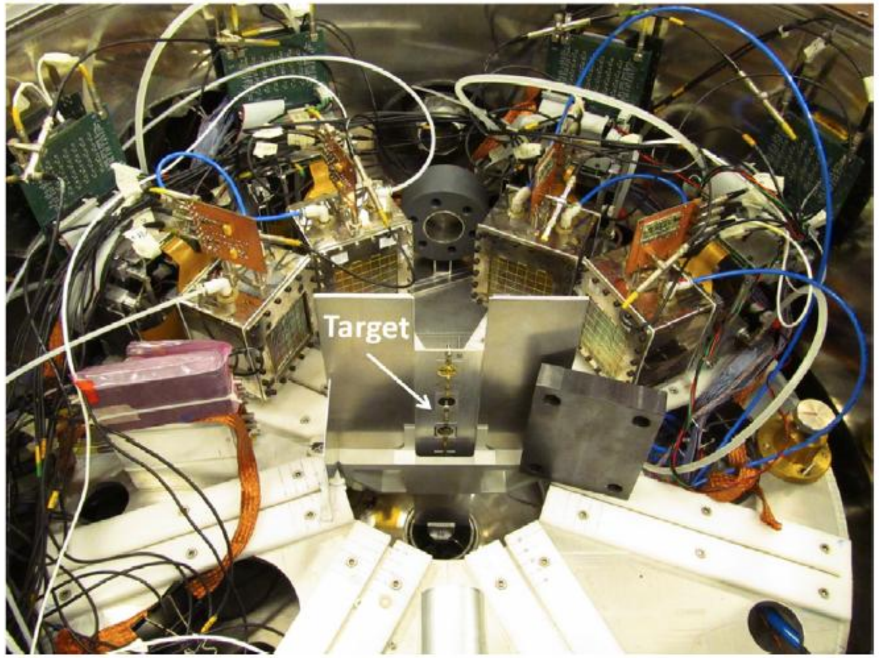
- The reaction $^{17}O(n,\alpha)^{14}C$ was studied via the $^{2}H(^{17}O,\alpha^{14}C)p$, V_{coul}=2.3 MeV;
- The deuteron is the TH nucleus. Strong cluster n+p; B=2.2 MeV, $|p_s|$=0 MeV/c .

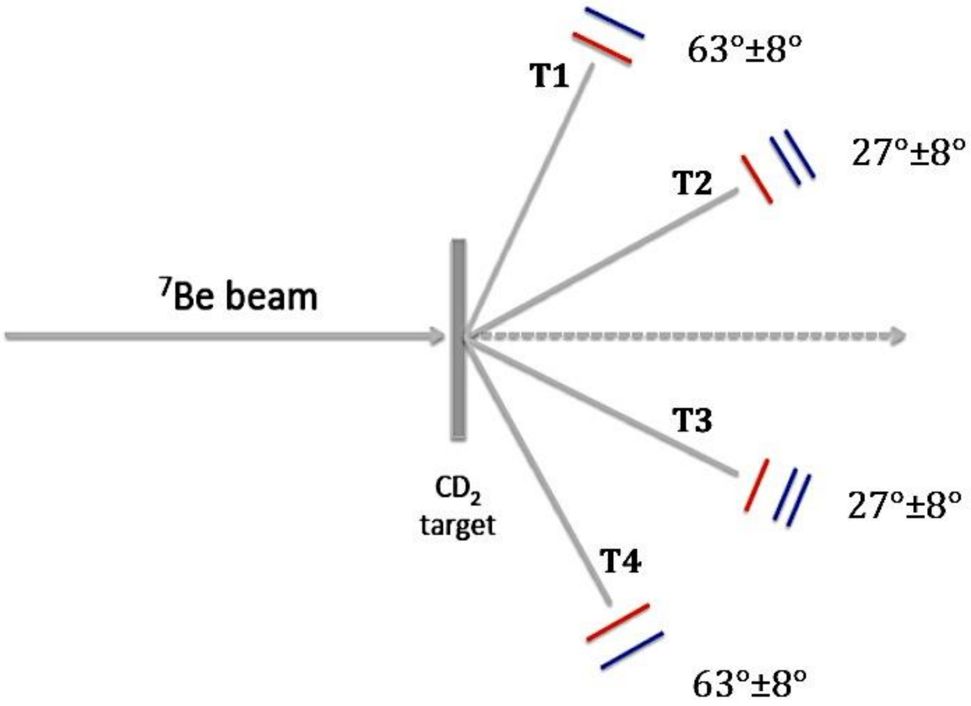
- ✓ Experiments performed at ISNAP at the University of Notre Dame (USA) and LNS of Catania;
- ✓ $E_{beam}(^{17}O)$= 43.5 MeV;
- ✓ Target thickness CD_2 ~150 μg/cm^2;
- ✓ IC filled with ~50 mbar isobutane gas;
- ✓ Angular position to cover the QF angular region
- ✓ Symmetric set-up in order to increase the statistic.



The BELICOS Experimental Setup

The ^{7}Be(n,α)α reaction via THM





- 400 μg/cm^2 CD_2 target;
- EXPADES detection system

Pierroutsakou, D. et al. 2016, NIMPA, 834, 46

T2(T3)→ IC + DSSSD (300 μm) **+ SPad** (300 μm)
T1(T4)→ IC + DSSSD (300 μm)

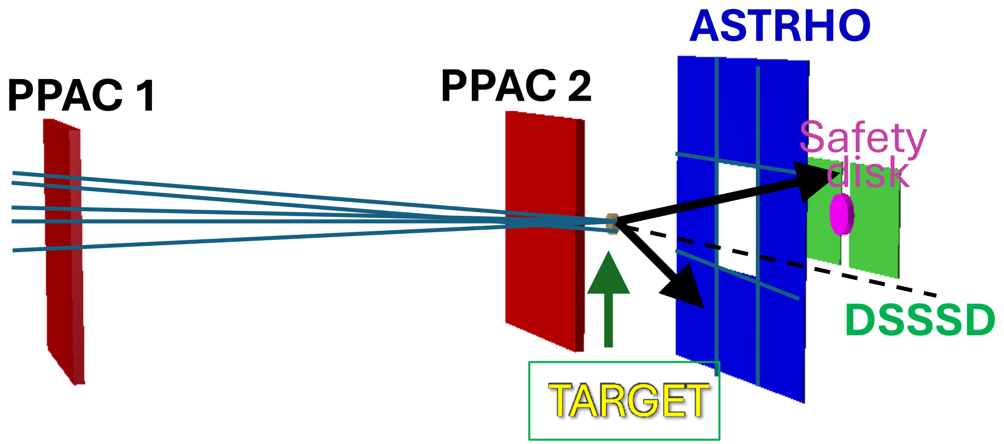
100 mbar isobuthane for IC

Setup symmetrical, respect to the beam line, in the reaction plane

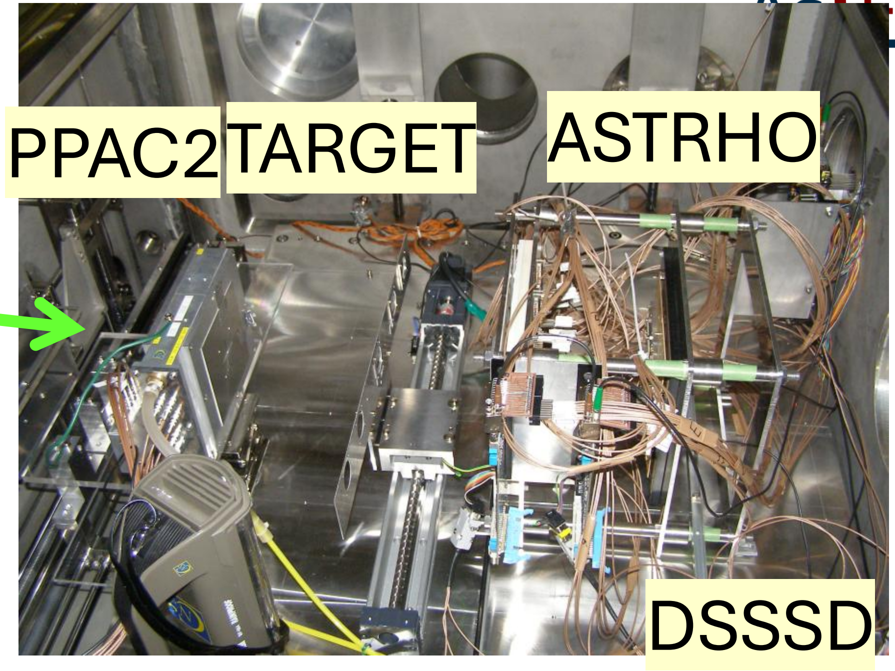
Trigger: coincidence between two telescopes

Calibration with ^{7}Li beam on ^{12}C, ^{197}Au and CH_2

THM study of $^{18}F(p,\alpha)^{15}O$ @ CRIB



BEAM



CD_2 TARGET 150-200 μg/cm^2

ASTRHO → α

n. 8 bidimensional position-sensitive detectors (BPSD, 45 x 45 mm^2, 500 μm thick

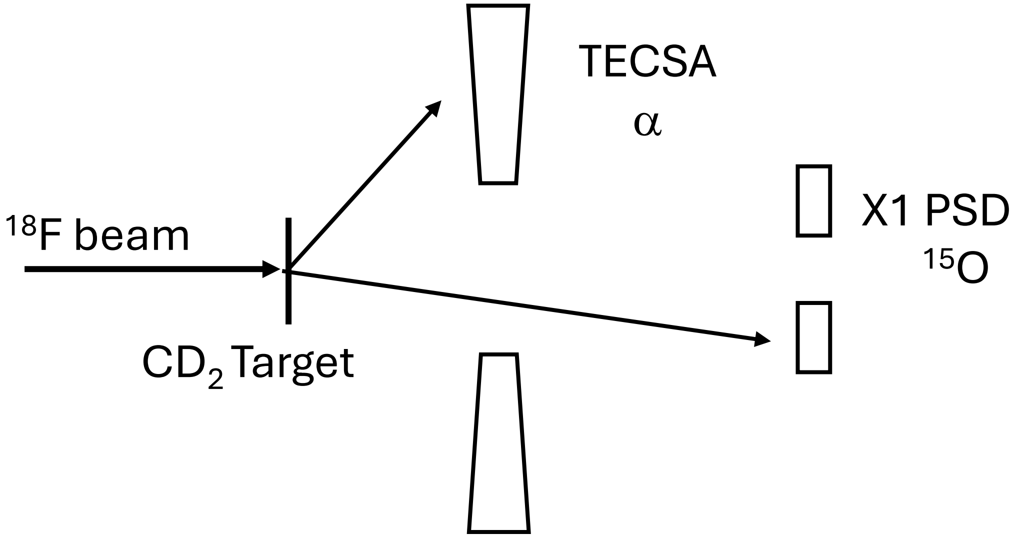
DSSSD → ^{15}O

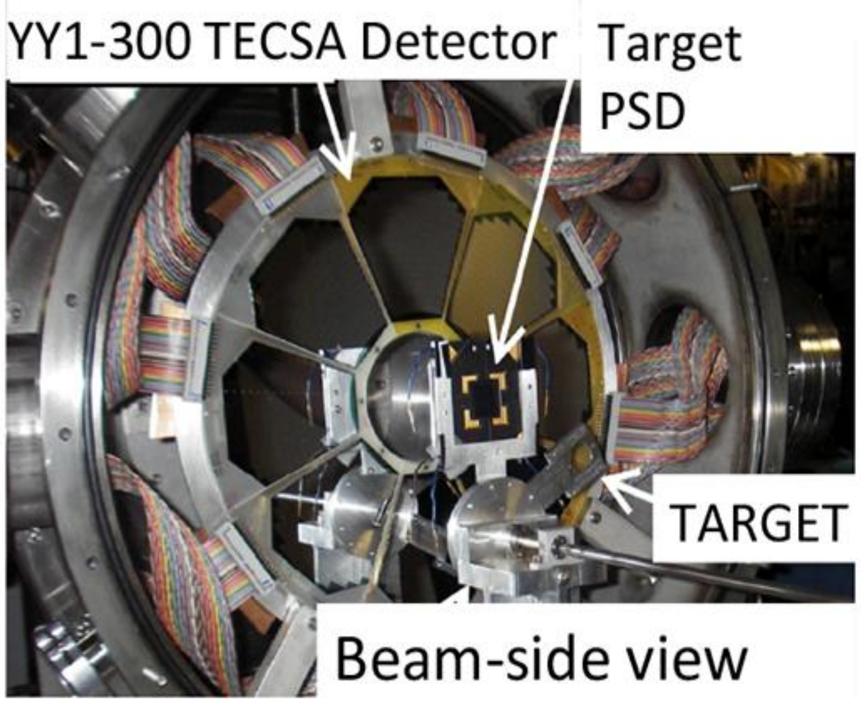
n. 2 Double Sided Silicon Strip Detectors (16 strips x-y)

Trigger: total or, off-line multiplicity 2 fixed

	DSSSD	ASTRHO
Angular range	2° - 11°	11° - 31°
Angular resolution	0.5° (tracking+ detectors)	0.5° (tracking+ detectors)
Energy resolution	0.8%	0.8%

THM study of $^{18}F(p,\alpha)^{15}O$ @ TAMU





Trigger: TECSA X1-PSD coincidence

CD_2 TARGET 400-800 μg/cm^2

TECSA → α
n. 8 16 arch strip YY1-300 um
B.T. Roeder et al. NIM A634, 71 (2011)

X1-PSD → ^{15}O
n. 2 16 strips each, position sensitive

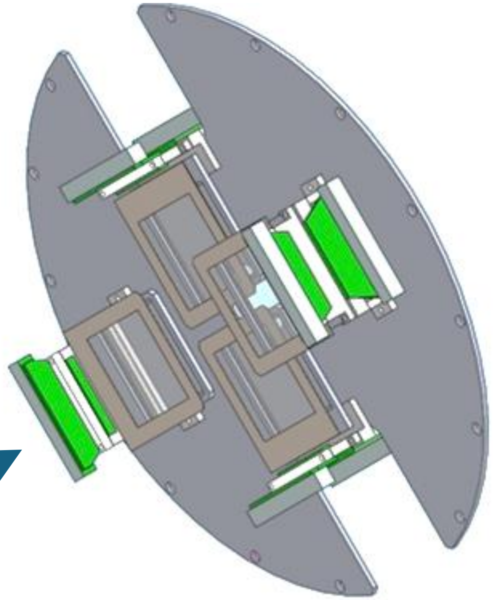
	X1-PSD	TECSA
Angular range	3° - 12°	15° - 40°
Angular resolution	0.7°	1.1°
Energy resolution	0.8%	0.8%

THM study of $^{26}Al(n,p)^{26}Mg$ @ TRIUMF

NEFASTA

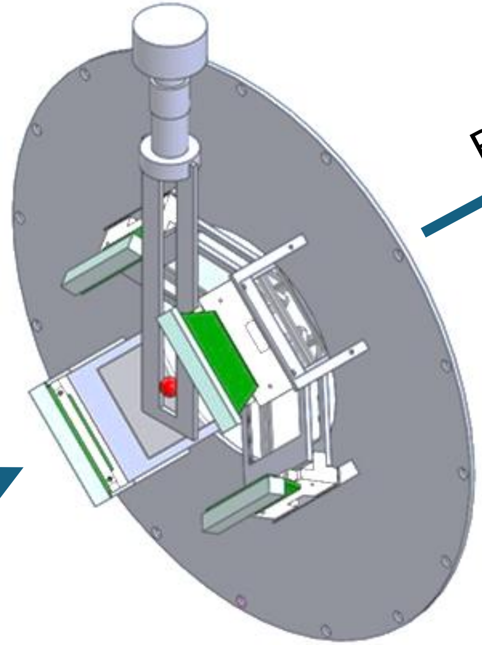
<u>8 telescopes arranged into two groups:</u>

- group **A** 60 mm away from the target, made up of two couples of telescopes, set in the vertical (**A1**) and in the horizontal (**A2**) planes. Each telescope will be composed of one DSSSD 1000 μm thick (32x32 strips, 51.2x51.2 mm^2) and one pad detector 1500 μm thick



B1 detectors will cover the 2°-6.1° angular range, while B2 telescopes will cover the 2.9°-7.1° interval

BEAM DIRECTION

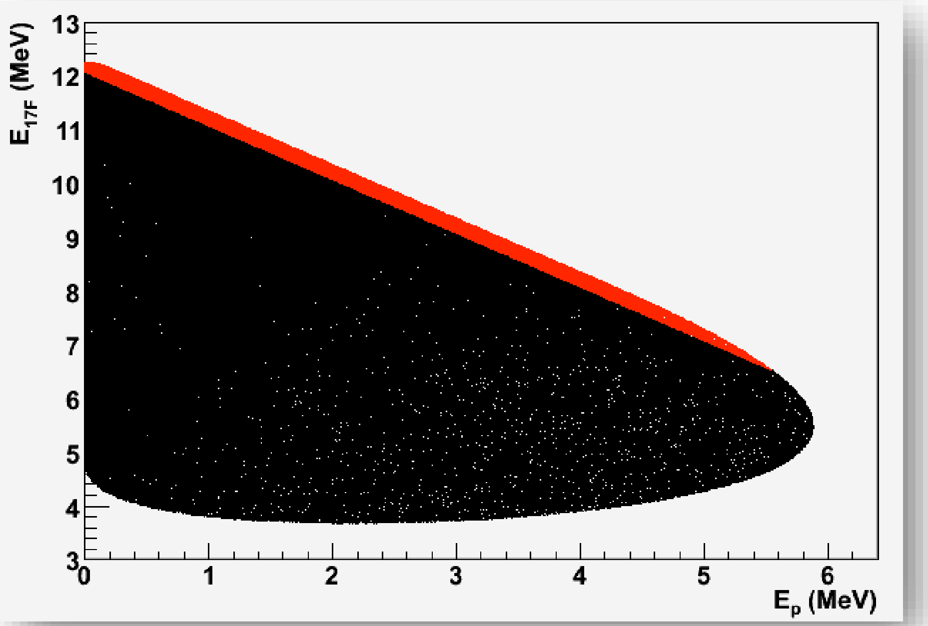


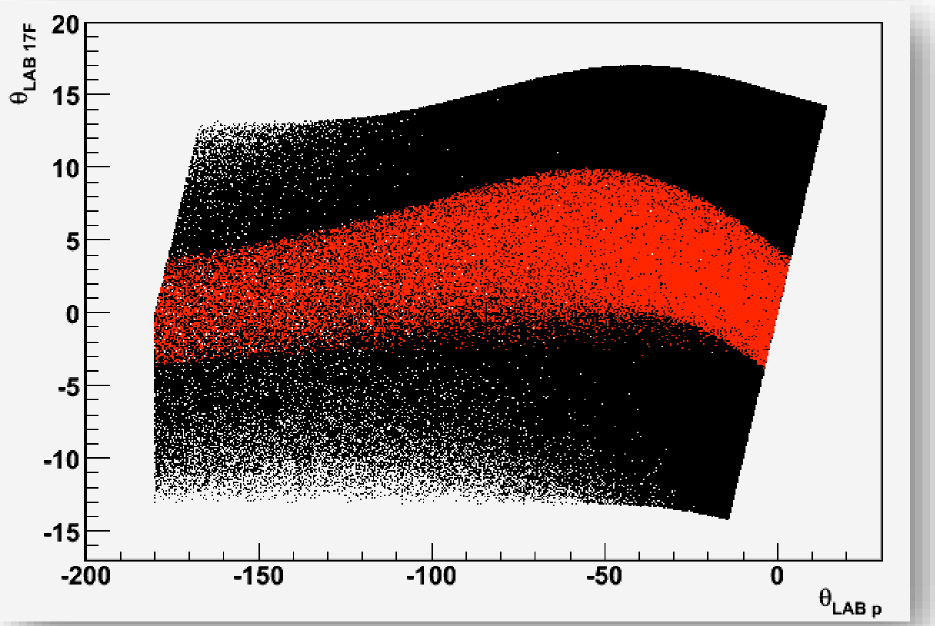
A1 group will cover the angular ranges 9.4°-55.6°, while those in A2 will cover 32.9°-79.1°

- The second group of detectors (named **B)** will be placed at about 700 mm from the target position. Two couples of telescopes, set in the vertical (**B1**) and in the horizontal (**B2**) planes, each composed of a 20 μm SSSSD and a 1000 μm DSSSD

Mechanical drawings by Dr. M. Costa

THM study of $^{14}O(\alpha,p)^{17}F$ @ FRIB





Requirements:

- Large area coverage
- Low detection threshold
- No PSD or DE techniques are viable for particle ID
- High energy and angular resolution for kinematical particle ID

THM study of $^{14}O(\alpha,p)^{17}F$ @ FRIB

Nuclear Instruments and Methods in Physics Research A 711 (2013) 160–165

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

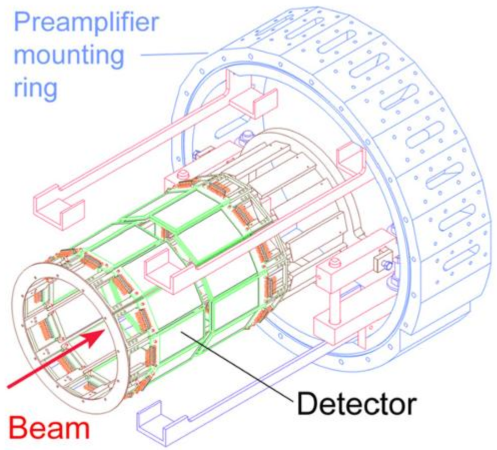
journal homepage: www.elsevier.com/locate/nima

Construction and commissioning of the SuperORRUBA detector

D.W. Bardayan [a,*], S. Ahn [b], J.C. Blackmon [c], A.J. Burkhart [d], K.Y. Chae [a,e], J.A. Cizewski [f], J. Elson [g], S. Hardy [h], R.L. Kozub [d], L. Linhardt [c], B. Manning [f], M. Matoš [c], S.D. Pain [a], L.G. Sobotka [g], M.S. Smith [a]

Technical detail

SuperORRUBA consists of two rings of silicon detectors designed to operate with one ring forward of 90° in the laboratory and the second backward of 90°. The silicon detectors are based on double-sided non-resistive silicon strip technology. The detectors cover an area, 7.5 cm by 4 cm, with the front sides divided into 64 1.2 mm by 4 cm strips, and the back sides segmented into 4 7.5 cm by 1 cm strips. The 1.2-mm strips are oriented perpendicular to the beam direction, while the 1-cm strips were parallel. The angular resolution in polar angle is less than 1-deg. The azimuthal angular resolution is less important, and thus larger strip pitches are used on the backside.



Nuclear Inst. and Methods in Physics Research, A 870 (2017) 1–11

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ANASEN: The array for nuclear astrophysics and structure with exotic nuclei

E. Koshchiy [a,c,*], J.C. Blackmon [b], G.V. Rogachev [a,c], I. Wiedenhöver [c], L. Baby [c], P. Barber [c], D.W. Bardayan [d], J. Belarge [c], D. Caussyn [c], E.D. Johnson [c], K. Kemper [c], A.N. Kuchera [c], L.E. Linhardt [b], K.T. Macon [b], M. Matoš [d], B.S. Rasco [b], D. Santiago-Gonzalez [b,c]

Technical detail

ANASEN uses a 43-cm long position-sensitive proportional counter surrounding the beam axis to enable an active-target mode. Silicon-strip detectors surround the proportional counter in a barrel configuration with 3 rings of 12 rectangular Super X3 and annular QQQ3 detectors at forward angles form the cap of the barrel. All detectors in the array are backed by trapezoidal-shaped 2-cm thick CsI(TI) crystals.

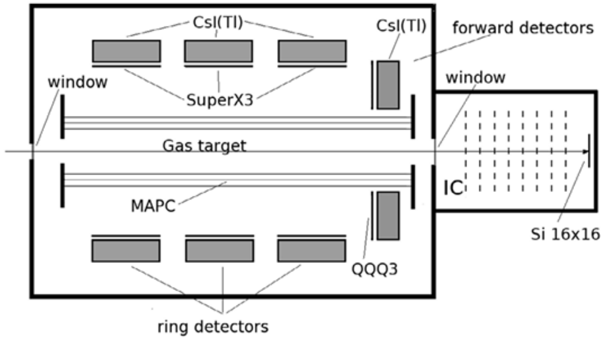
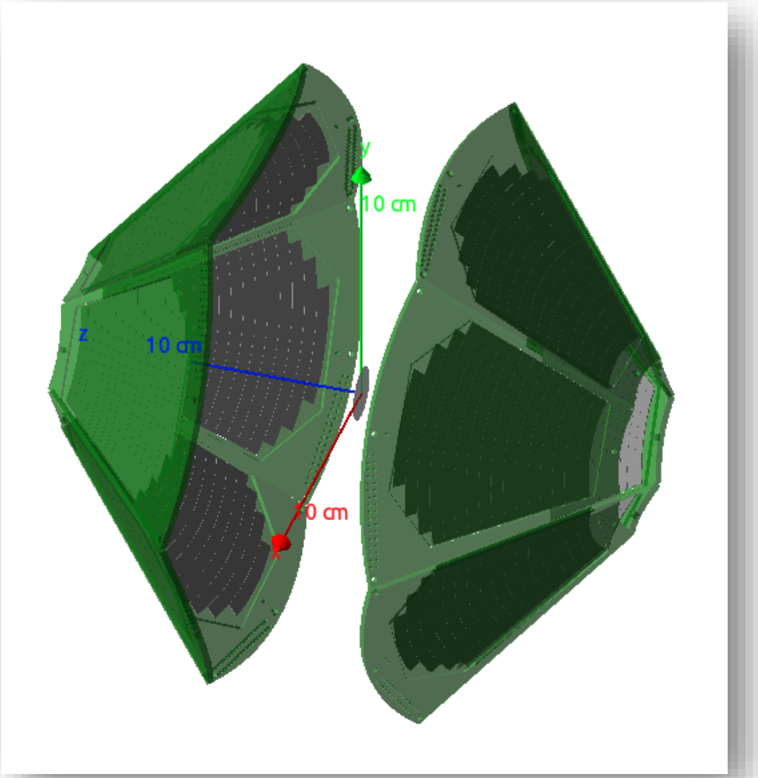


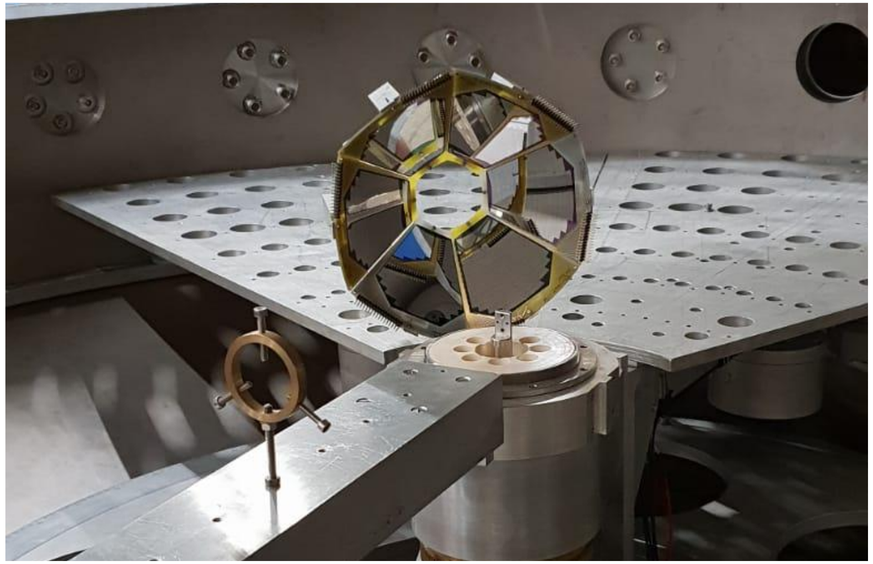
Fig. 1. Schematic cross-section view of ANASEN.

Large High-resolution Array of Silicon for Astrophysics

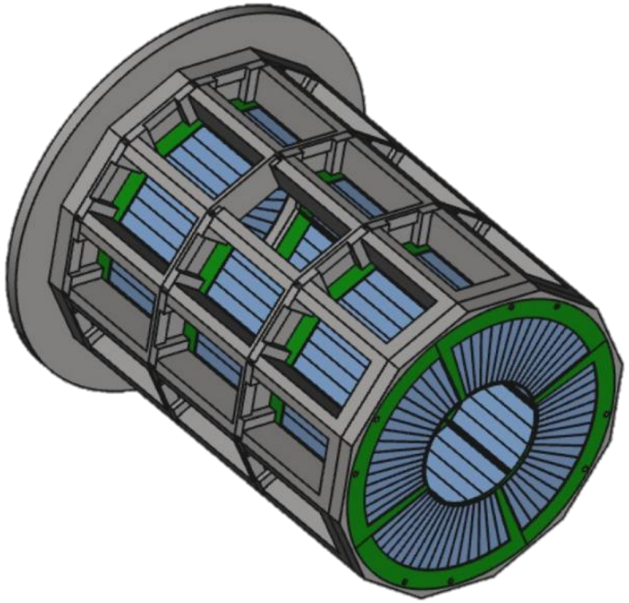


Characteristics:

- Wide angular range coverage
- Low energy threshold
- Compactness
- High energy resolution
- Angular resolution allows for PID



Extreme Light Infrastructure Silicon Strip Array



Characteristics:

- Wide angular range coverage
- Low energy threshold
- Compactness
- Angular resolution better than 0.5 cm
- Energy resolution better than 1%
- Kinematical identification of outgoing particle

Barrel configuration:

✓ 3 rings of 12 position sensitive X3 silicon-strip detectors by Micron

✓ 2 end cap detectors made up of 4 QQQ3 DSSSD by Micron

✓ >550 channels readout with standard/digital electronics

Perfectly suited for nuclear astrophysical studies!!

G. L. Guardo et al. EPJ Web of Conf. 165, 01026 (2017)

Extreme Light Infrastructure Silicon Strip Array

ELISSA

- 12 Micron X3 PSD
- 1000 µm thick
- 96 channels of electronics
- 0.3% energy resolution
- 0.3 mm position resolution
- 35° to 60° (lab frame) angular coverage

- Analog and digital
- Mesytec mvme and DELILA

Photo-diode

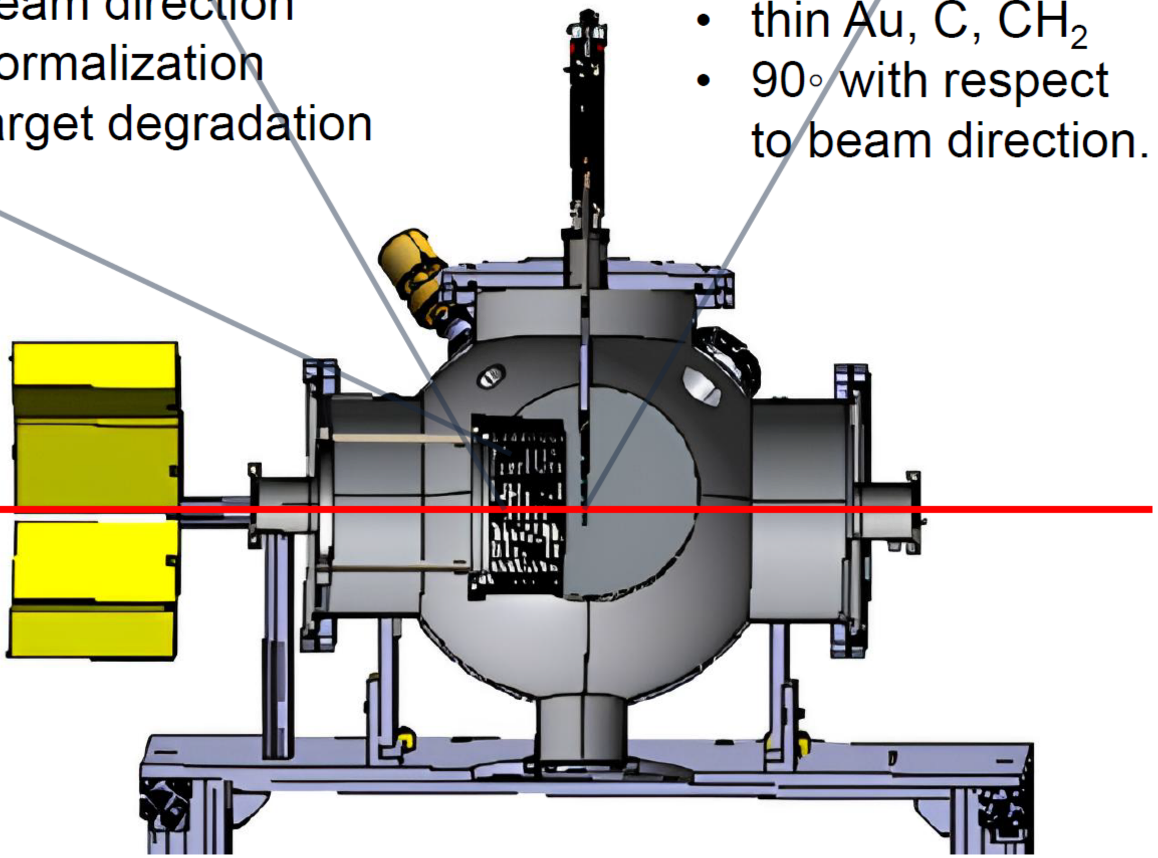
- 32° with respect to beam direction
- normalization
- target degradation

Target

- thin Au, C, CH_2
- 90° with respect to beam direction.

Beam

- ^{7}Li, ^{19}F
- 3 to 15 MeV



Asfin Data Acquisition

The ASFIN DAQ is based on a **commercial solution** provided by MESITEC. It involves a single VME controller (MVLC) and provides an easy-to-setup, easy-to-use, cross-platform data acquisition system with basic data visualization and analysis capabilities.

- High-rate, low-latency VME module readout
- With the **MVLC VME Controller**:
  - 127 MB/s sustained transfer rate via **USB3**
  - Full utilisation of GBit **Ethernet** bandwidth allowing up to 105 MB/s
- Multiple event triggers are possible (NIM, IRQ, periodic readout)
- Multiple modules can be read out per trigger: ADC, QDC, TDC, digitizers
- Flexible VME module setup using configuration scripts
- Live histogramming of readout data (1D and 2D)
- Graphical analysis UI
- Replays of recorded listfile data
- Rate Monitoring

The characteristics of the DAQ are:

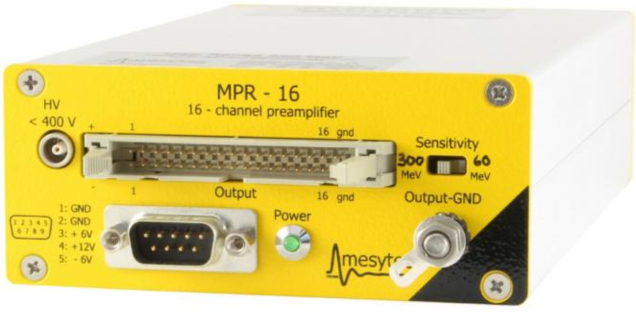
- Compactness
- High portability
- High rate
- Possibility to manage a large number of electronics channels

Asfin Data Acquisition

The electronics is based on charge preamplifiers (MPR32) and 32-channel digitizers MDPP-32) which are fast high resolution time an amplitude digitizers. It is internally realized as a 32-channel adjustable low noise **amplifier** and a variable **differentiation stage**, followed by filters and 80 MHz sampling **ADCs**.

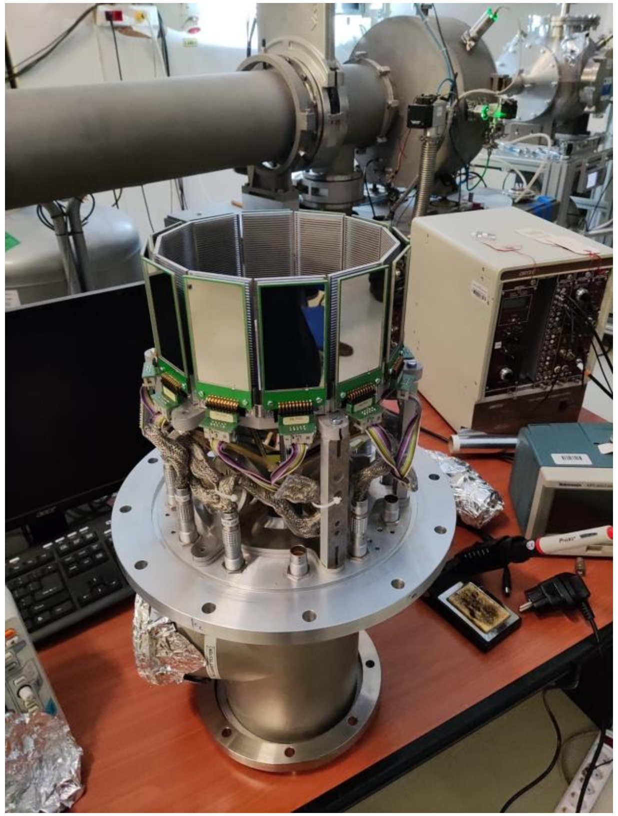
The logic of the acquisition, the trigger and the dead time with can be managed with the MVLC controller.

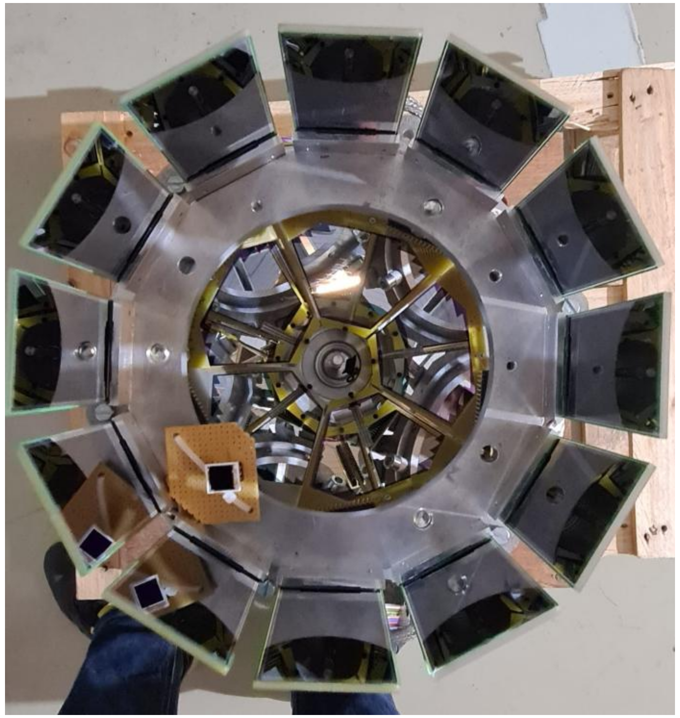
This make the DAQ system very **compact** and **highly portable** since a very small numner of electronics modules is needed.

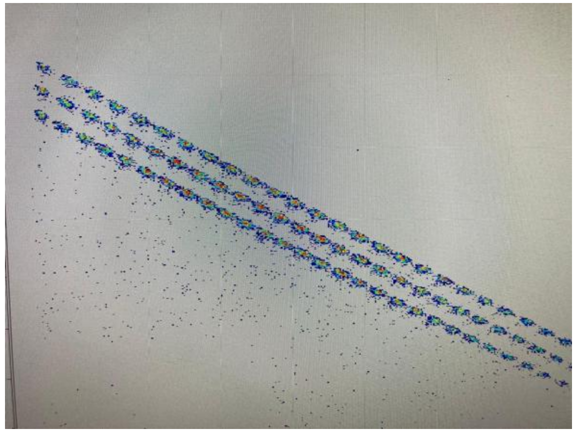


Direct Experiments with ELISSA&LHASA

The $^{19}F(p,\alpha)$ reaction

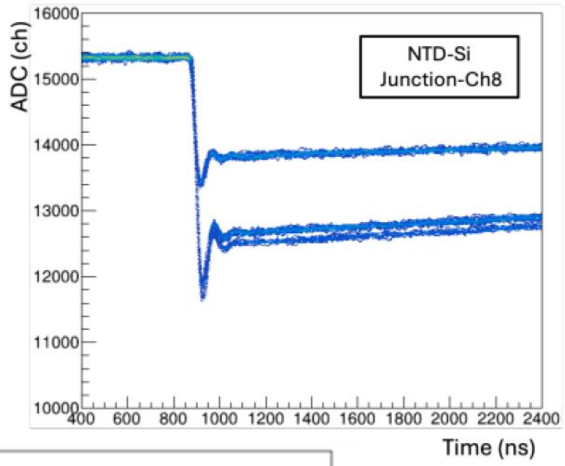


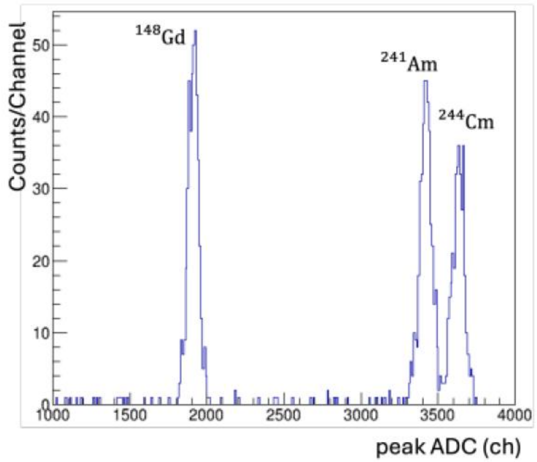


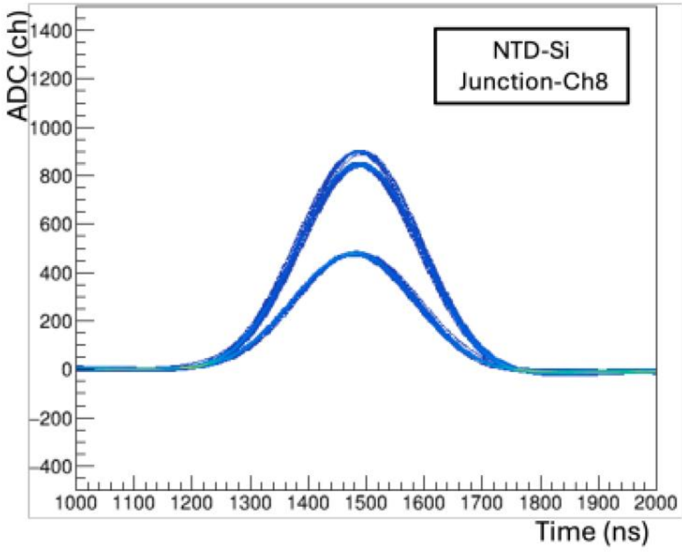


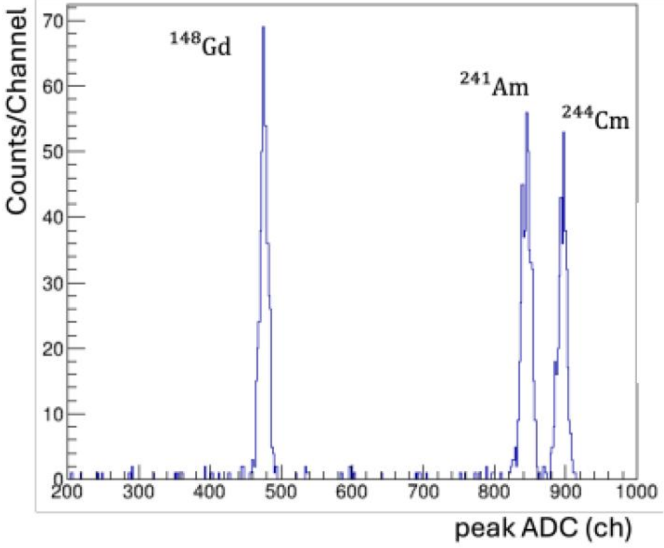
Particle Identification with Pulse Shape Analysis

	Incident side	Si type	Preamplifier
(a)	Rear	NTD-Si	A1442B
(b)	Front	NTD-Si	A1442B
(c)	Rear	Normal-Si	A1442B
(d)	Rear	NTD-Si	MPR-16





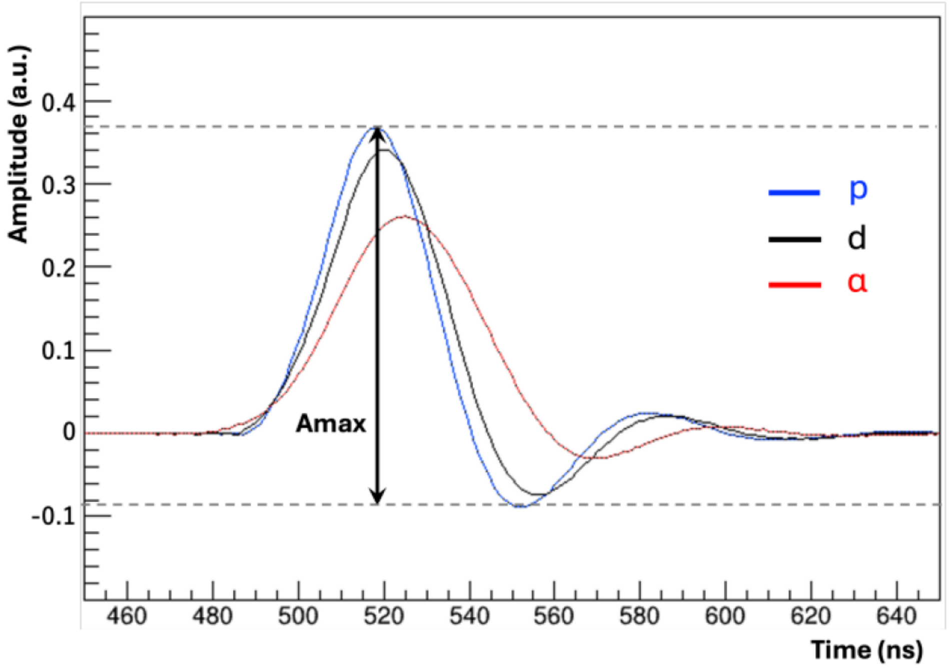


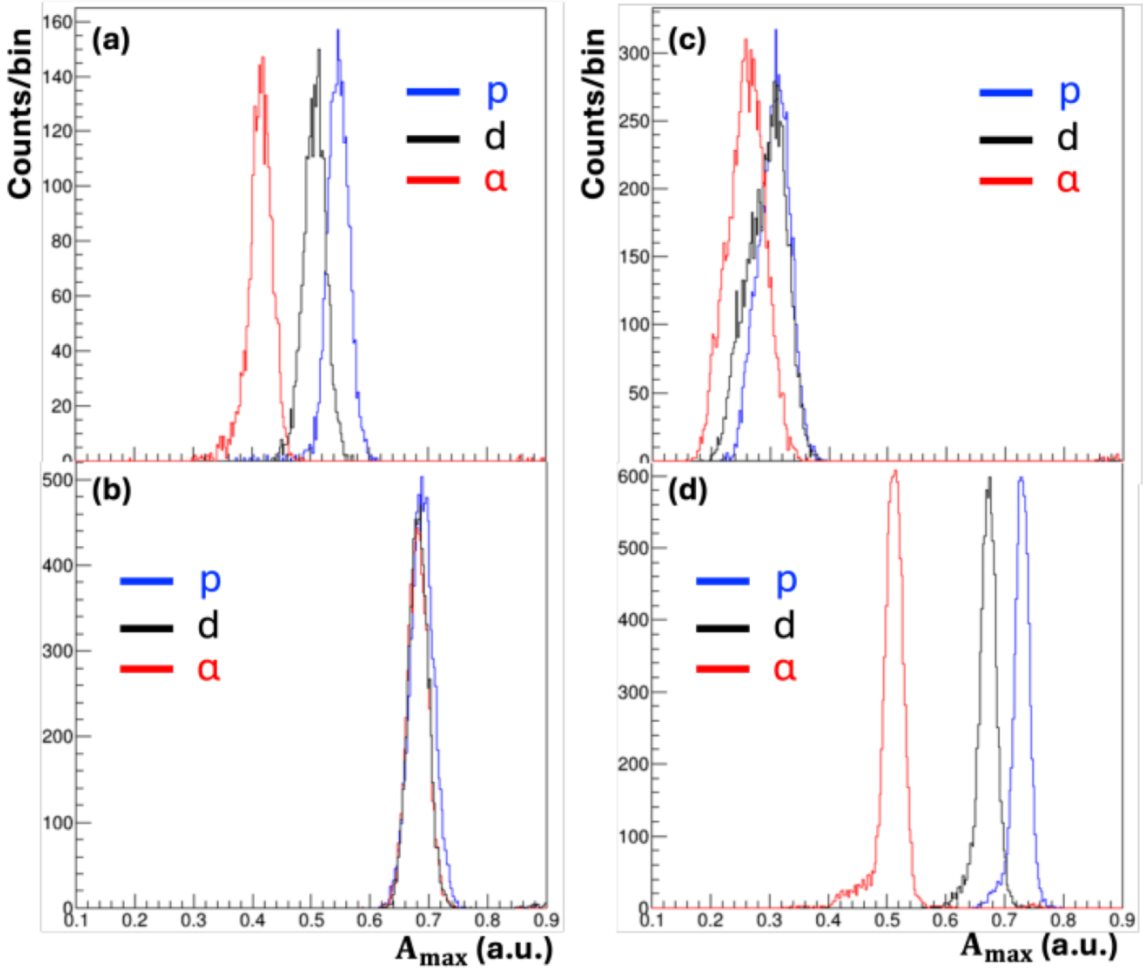


$$y_i = \frac{\left(\sum_{k=0}^{L-1} x_{i+k}\right) - \left(\sum_{k=-L}^{-1} x_{i+k}\right)}{L}$$

K. Sakanashi

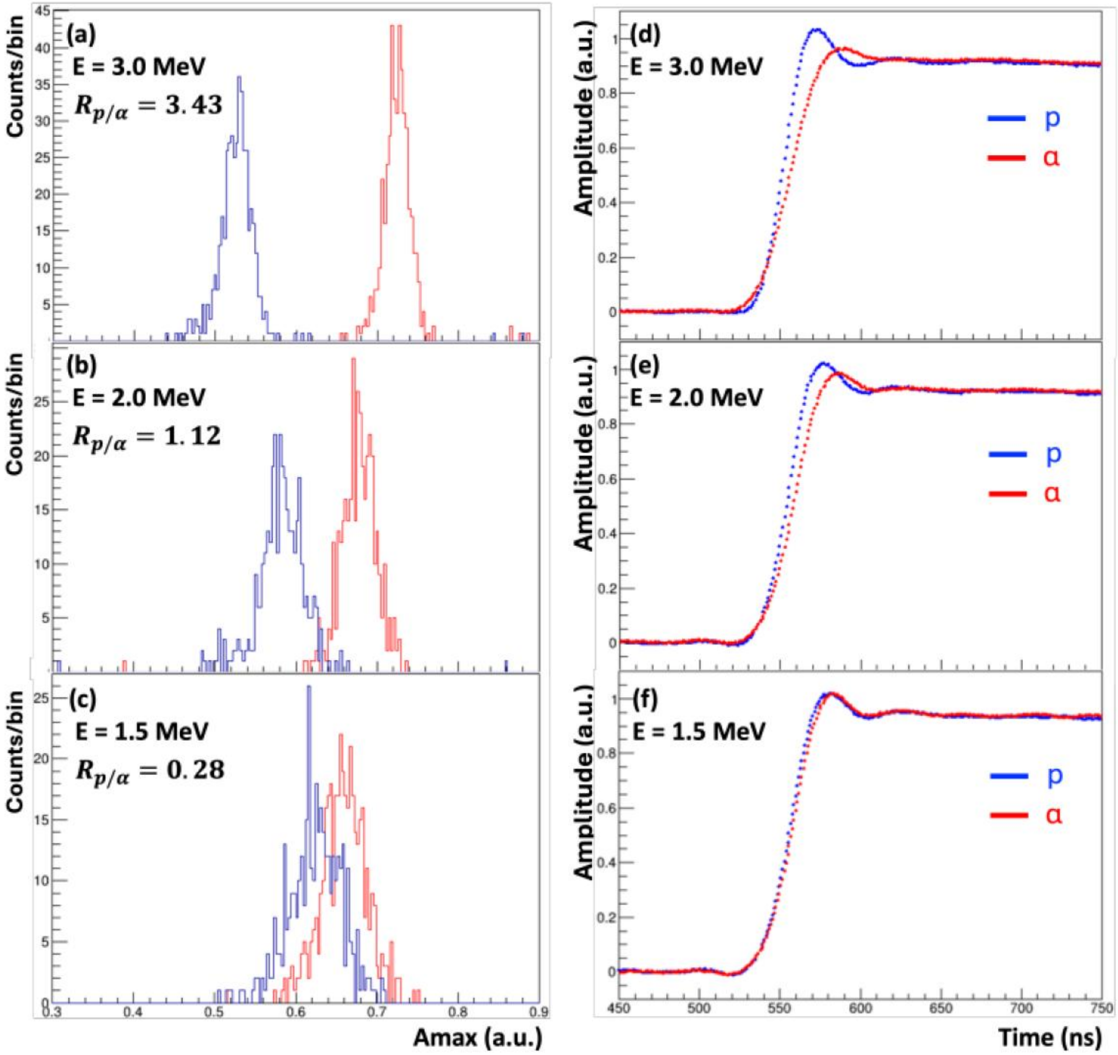
Particle Identification with Pulse Shape Analysis

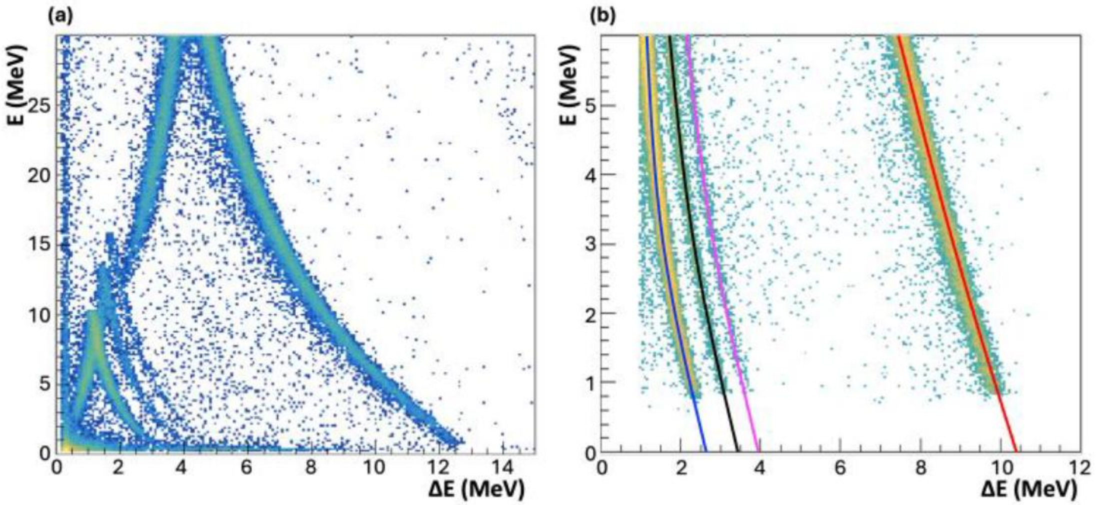


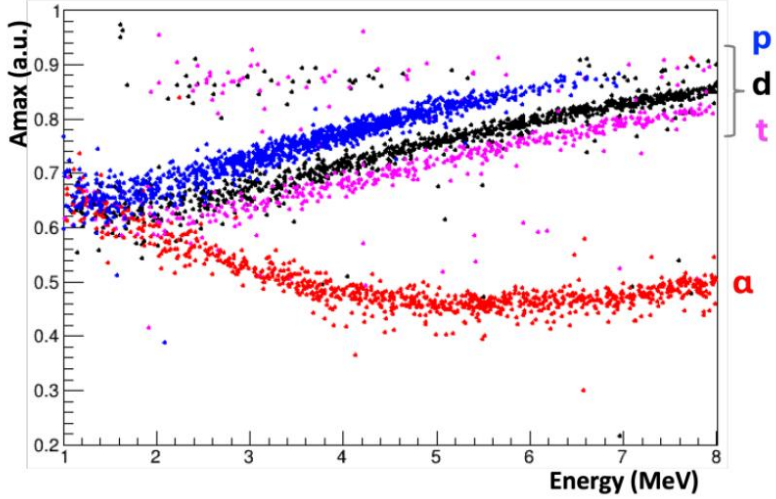


K. Sakanashi

Particle Identification with Pulse Shape Analysis







Conclusions

- The availability of radioactive ion beams at facilities like FRIB is a unique opportunity for nuclear astrophysics, as a number of reaction of primary astrophysical importance can be measured for the first time

- To catch these experimental opportunities, the Asfin group is developing new arrays with peculiar characteristics: high-resolution, low-threshould, high-efficiency, compactness…

- Preliminary results on methods and arrays make us confident for the new perspectives and open the way for new experimental campaigns

Thank you for your attention

Collaborations

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