

MUGAST: reaction and structure studies with the AGATA setup @ VAMOS

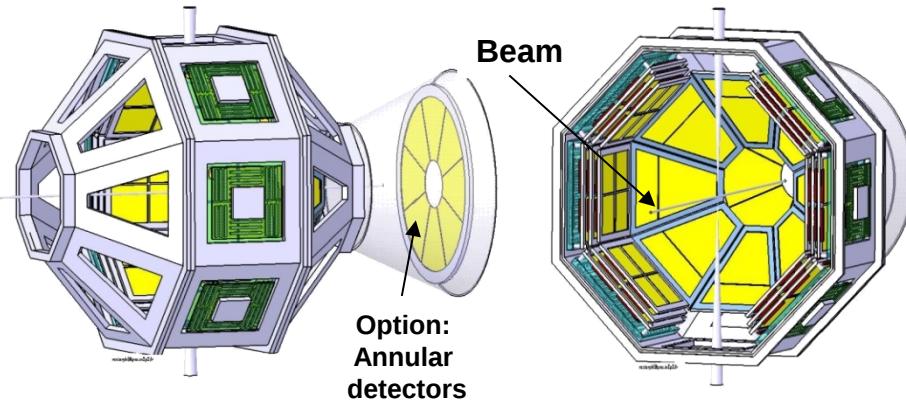
Daniele Mengoni¹

For the collaboration

¹University of Padova, INFN Padova

A new Si array **TRACE** for structure and reaction study

“GASPARD-TRACE” design



4 π , fully integrable in PARIS and AGATA

Layers of Silicon

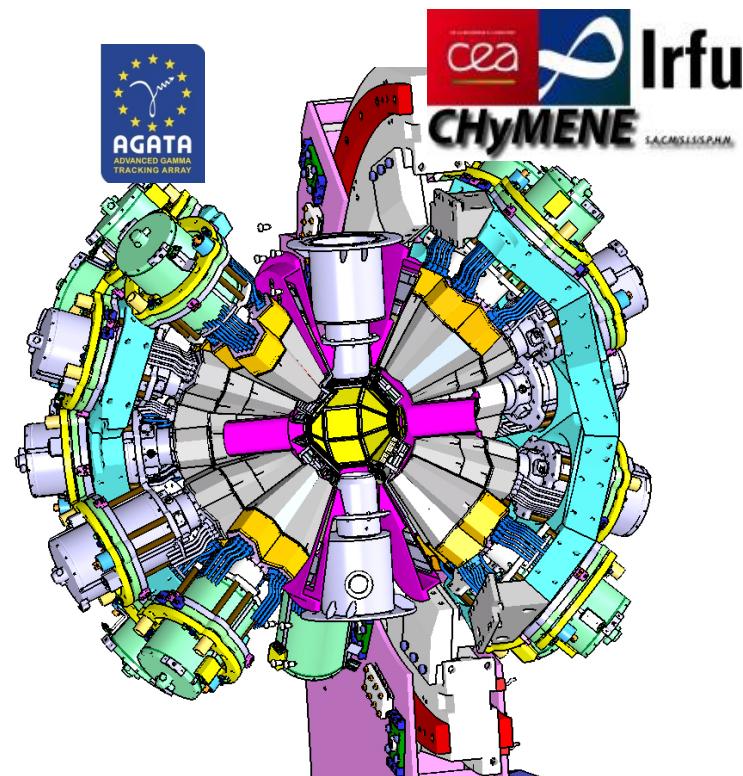
- 500 μm DSSD pitch < 1mm
 - 1(or 2) x [1.5 mm DSSD pitch~3mm]
- 2 main shapes : square & trapezoid,
large area**

Electronics :

~ 10000 channels (Digital)
high transparency to γ -rays
→ Big integration challenge

Motivations

- Intermediate and heavier masses
- Higher excitation energies – Low sp strength
- Sometimes at mid-shell
- Detect/identify several channels altogether



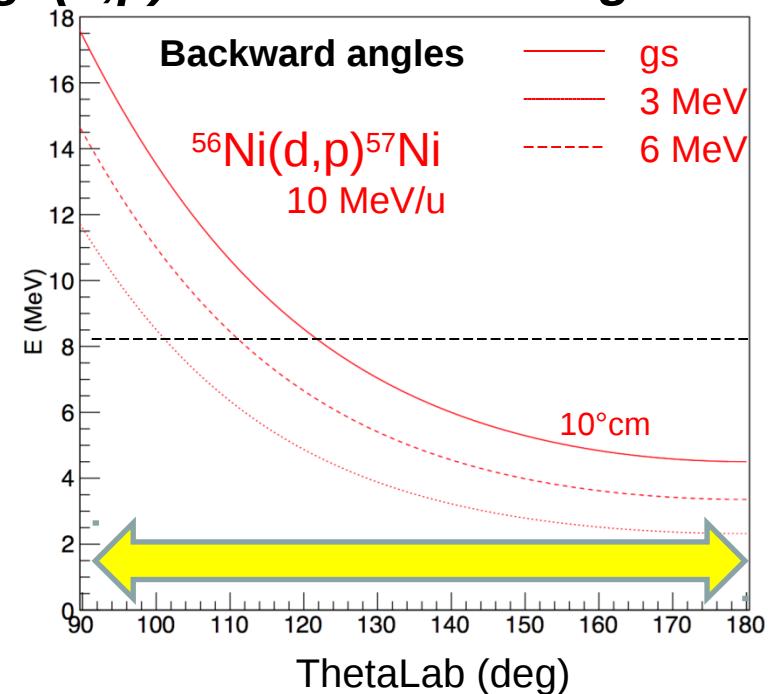
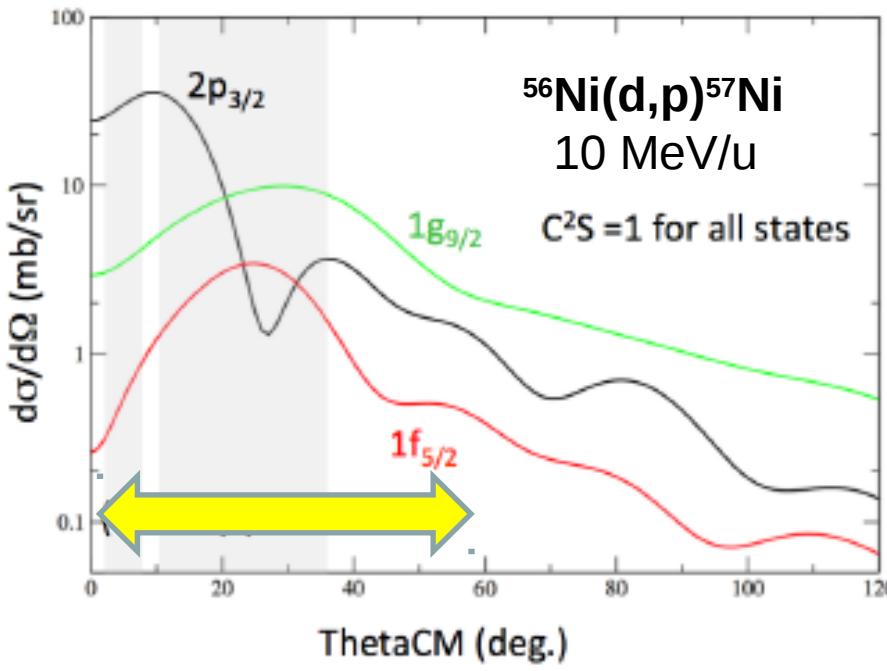
MUGAST: motivations

MUST2+GASPARD+TRACE

To perform *high resolution reaction and spectroscopy studies* using

- AGATA**@ VAMOS – GANIL for some years
- The new SPIRAL1 beam + upgrade
- Some Si dets of future array progressively available

Focus on *stripping reactions* e.g. $(d,p) \Rightarrow$ *backward angles*



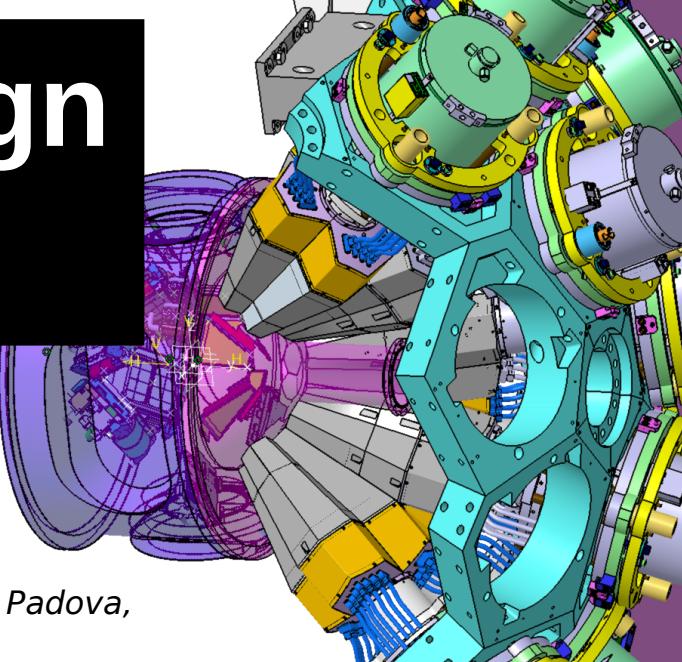
Lols Science campaign

MUGAST+AGATA@GANIL

Spiral 1 beams

Nuclear astrophysics:

- ▶ $^{15}\text{O}(\text{d},\text{p})^{16}\text{O}$ (*C.Diget, Univ. of York, N. de Sérerville, IPNO*)
- ▶ $^{25}\text{Al}(\text{d},\text{p})$ (*N.de Sérerville, F. Hammache, IPNO*)
- ▶ $^{30}\text{P}(\text{d},\text{p})$ or (d,p) (*N.de Sérerville, F.Hammache, IPNO*)
- ▶ $^{60}\text{Fe}(\text{d},\text{p})$ (*A.Matta, W.Catford, University of Surrey*)
- ▶ $^{79}\text{Se}(\text{d},\text{p})^{80}\text{Se}$ (*G. de Angelis, INFN-LNL, D.Mengoni, University of Padova, C.Domingo Pardo, CSIC Valencia*)



Shell evolution

- ▶ $^{56}\text{Ni}(\text{d},\text{p})(\text{d},\text{t})$ (*F.Flavigny, IPNO, O.Sorlin, GANIL*)
- ▶ $^{28}\text{Mg}(\text{d},\text{p})$ (*A.Matta, W.Carford, University of Surrey*)
- ▶ $^{74}\text{Kr}(\text{d},\text{p})$ (*A.Matta, W.Carford, University of Surrey*)
- ▶ $^{48}\text{Cr}(\text{d},\text{p})^{49}\text{Cr}$ (*A.Gadea, CSIC Valencia*)
- ▶ $^{30}\text{Mg}(\text{d},\text{d})(\text{d},\text{p})$ (*B.Fernandez-Dominguez, University of Santiago, W.Catford, University of Surrey*)
- ▶ $^{67}\text{As},^{63}\text{Ga}(\text{d},\text{p})$ (*D.Mengoni, University of Padova*)
- ▶ $^{44,46}\text{Ar}(\text{t},\text{p})$ (*D.Mengoni, University of Padova*)
- ▶ $^{66}\text{Ni}(\text{t},\text{p}),^{44}\text{Ar}(\text{t},\text{p})$ ($^{14}\text{C},^{12}\text{C}$) ($^{18}\text{O},^{16}\text{O}$) (*L.Fortunato, J.A.Lay, University of Padova*)

Clusters, pairing, correlations & others

- ▶ $^{56}\text{Ni}(\text{d},\text{p})(\text{d},\text{t})$ (*M.Assie, IPNO*)
- ▶ $^{45}\text{K} + ^7\text{Li} \rightarrow ^{46}\text{Ca} + \alpha$ (*S.Leoni, University of Milano, B.Fornaciari, IPNO*)
- ▶ $^{16}\text{O} + {}^{\text{A}}\text{Z}$ (*G.Verde, INFN Catania and IPNO*)
- ▶ $^{14}\text{O}(\text{p},\text{p})$ (*I.Stefan, IPNO*)

- **8 independent Lol + Umbrella Lol**
- **Mostly stripping reactions**
(backward)

MUGAST+AGATA @ VAMOS

☐ LoI for AGATA+MUGAST+VAMOS for the PAC @ GANIL

Reaction studies using the MUGAST+AGATA setup at VAMOS

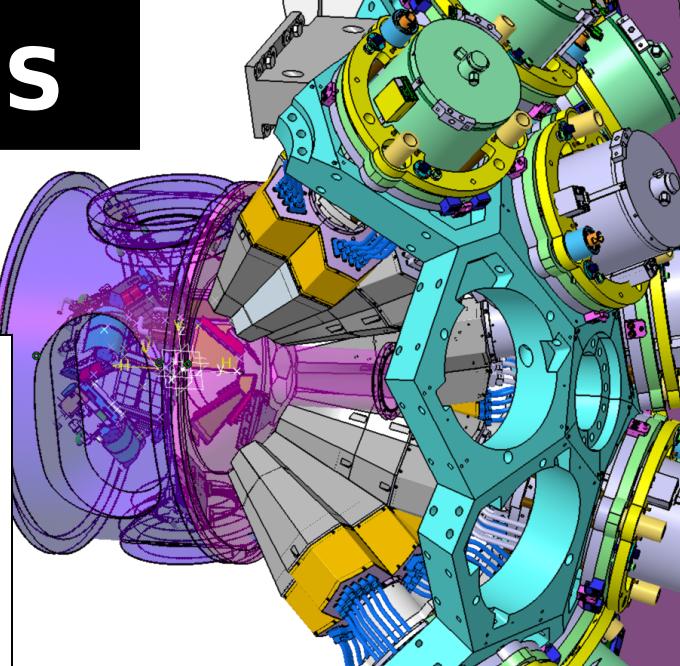
Letter of Intent to the AGATA collaboration

D.Beaumel, IPN Orsay

D.Mengoni, University and INFN Padova

1. Introduction

The GASPARD and TRACE high granularity Silicon arrays have been natively designed for optimal integration in new generation gamma detectors such as AGATA with the aim of performing high-resolution reaction studies. Indeed, the coupling to AGATA allows a very large gain in excitation energy resolution, in comparison with the case where the excitation energy is deduced from the recoil charged-particle measurement. The GASPARD and TRACE collaboration are now converging to build such new-generation Si ensemble in common, with a timeline of 2019-20 for completion of the final 4π array, ready for the emerging ISOL facilities, like SPES and SPIRAL1. A view of such ultimate GASPARD-TRACE setup sitting inside AGATA is shown in Fig.1.



MUGAST: LoI-16-11 gave the overall case for the combination of MUGAST with VAMOS and AGATA.

This is a powerful combination that would position GANIL as a leading laboratory for exotic transfer studies; one of the most sensitive probes of shell structure and shell evolution. This remains an area of high interest as it is one of the most stringent tests of nuclear theory – especially the nuclear shell model and the associated interactions. In addition it is proposed to develop helium-3 and tritium targets. The PAC would give its strongest support for this development and would be extremely keen to see the GANIL management prioritise a campaign based on this development.

MUGAST: configuration

MUST2+GASPARD+TRACE

■ Intermediate configuration: MUGAST (MUST2-GASPARD-TRACE)

Particle detection:

- 4 GASPARD trapezoid DSSSD (backward/AGATA side)
- 1 Annular (S1-like) (backward close to 180°)
- 2 TRACE square detectors (@90°)
- 4 MUST2 Telescope (forward)
- Existing electronics (MUFEE+MUVI)

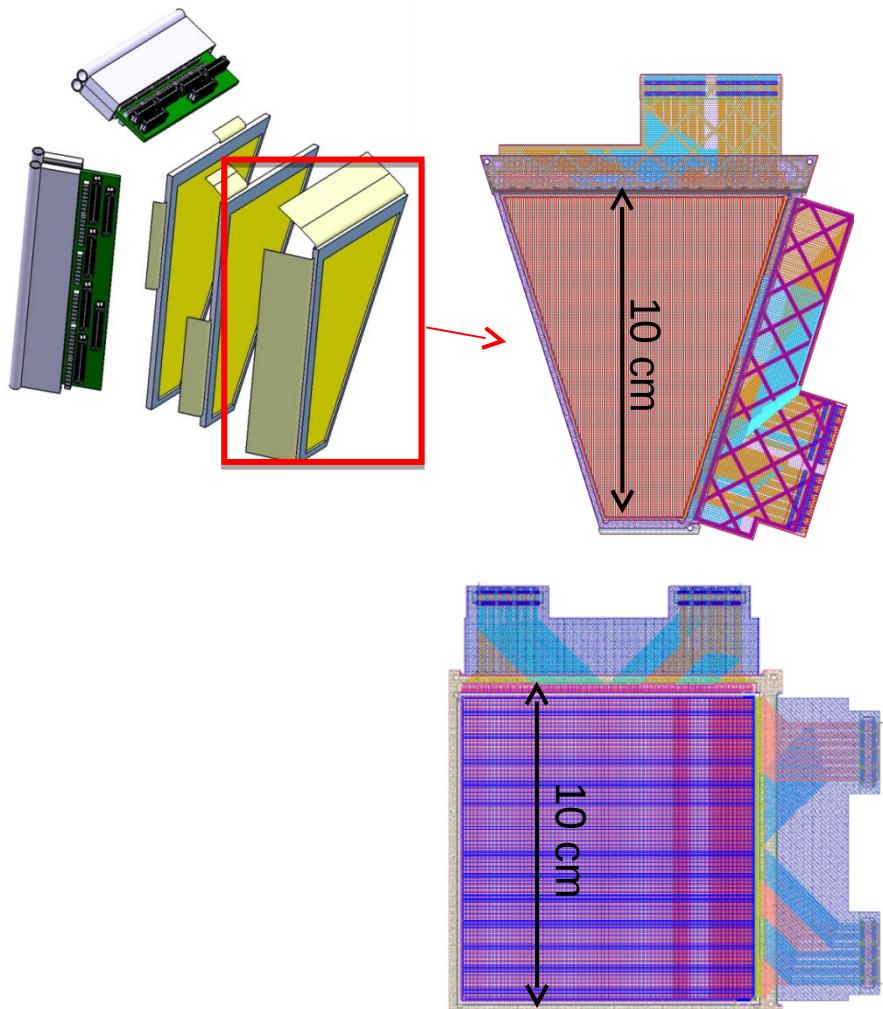


γ-detection (AGATA):

- Maximize eff: $\approx 8\%$ @1 MeV @ 18cm (for 11 triples)
- Benefit from very good energy resolution (\approx few keV)

Silicon developments

- New geometries
- New packaging : thin frame, kapton at 90°
- 6", NTD, random cut, reverse-mount
- Thin (500um) and thick (1.5mm)



Si detectors plan

1st layer (500 um, pitch~700 um)

Trapezoid shape

2 prototypes commissioned [IPNO]

3 pre-serie ordered [Surrey, Santiago, IPNO]
(MICRON SC)

Square shape

2 prototypes ordered [INFN-Padova]

2nd layer (1.5mm, pitch~3mm)

2nd layer square

1 prototype ordered [INFN-Padova]
(MICRON SC)

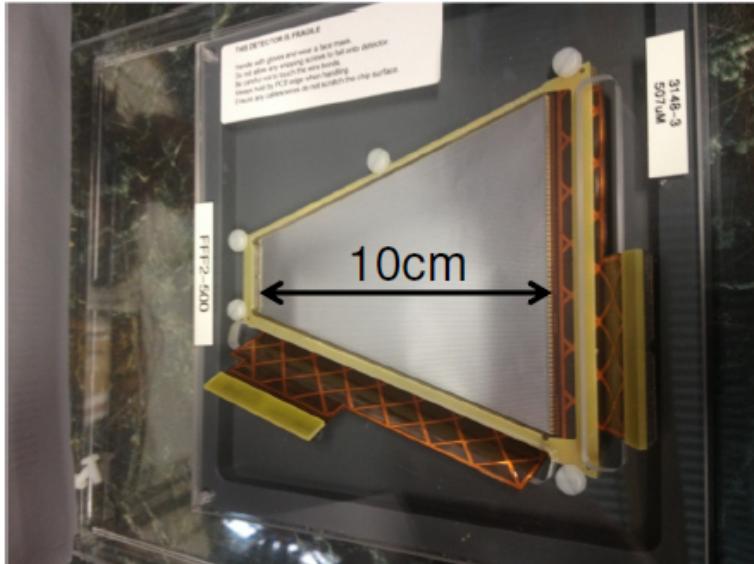
Collaboration with BARC Mumbai foreseen

Commissioning of the trapezoid

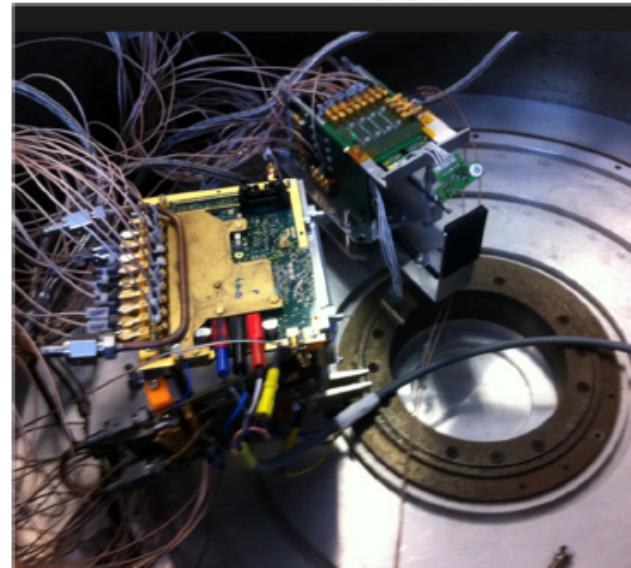
Test bench at IPNO

>> 2 numerical test bench : PACI & iPACI

- PACI : 4X+4Y voies
- iPACI : 9X+9Y voies (short and long strips)



Kaptions will be modified



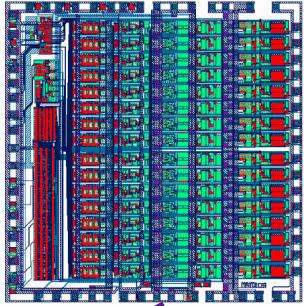
>> Analogic test bench (MUST2 electronics & GANIL DAQ) now being implemented

256 channels

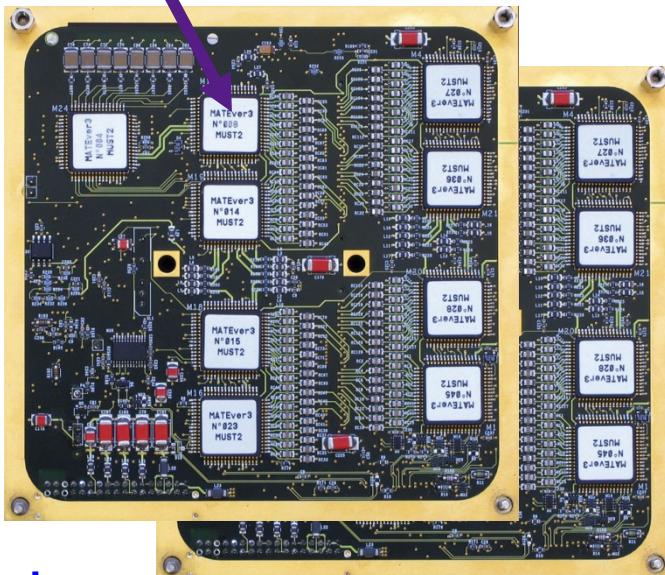
- test of new detectors (prototypes)
- test of new MUFEET boards for MUGAST

MUGAST Electronics : MUFEE + MUFI

- 16 channels 28 mW/ch
- Energy & Time
- Si, Si(Li) and CsI
- Multiplexer
- I2C interface
- High linear. pulser
- T sensor



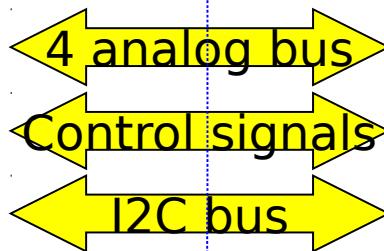
MOTHER BOARDS (IPNO)



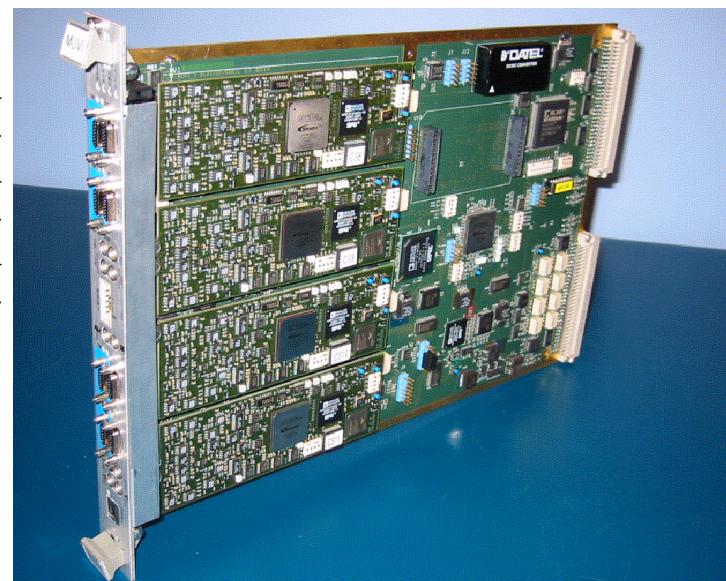
1 telescope

VACUUM

AIR



VXI board (GANIL)
16 ADC14 bits
2.3K parameters
2MHz
Slow Control I2C
Pedestal subtraction
DNL correction

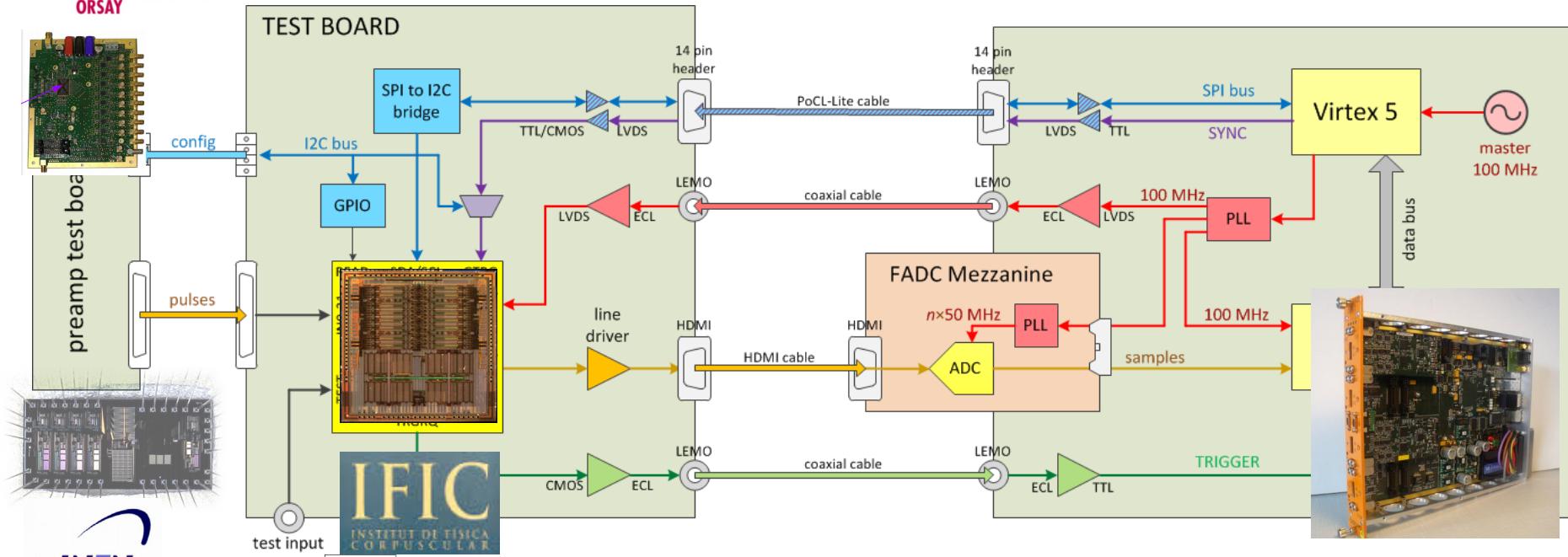


4 telescopes

Test bench: Det. Board + RO unit

- Current and charge output (IPN)
- Charge + extended dynamics (INFN)

- different input polarities and signal Ranges
- 32 inputs with independent trigger
- Samples pulses @ 200 MSPS
- 224 samples from each pulse: 32 beforetrigger (30 valid) 192 after trigger
- Generates common Trigger Request signal
- No deadtime

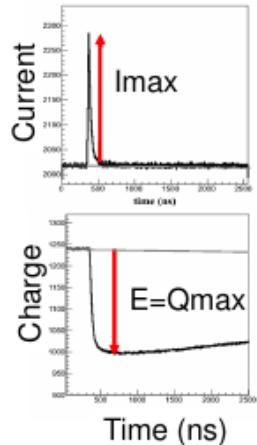
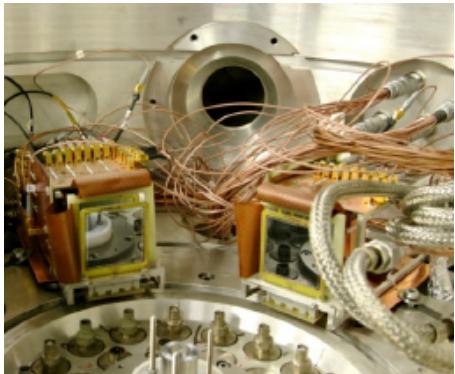


CONSEJO SUPERIOR
DE INVESTIGACIONES
CIENTÍFICAS

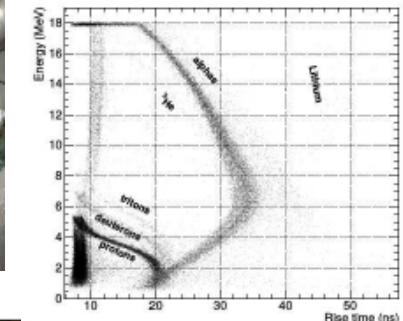
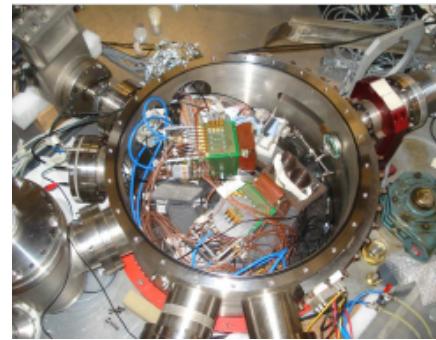
GANIL
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS
LABORATOIRE COMMUN CSIC-IPNL-CEA-GANIL

R&D on pulse shape analysis

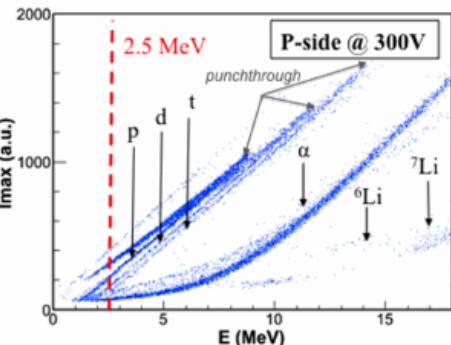
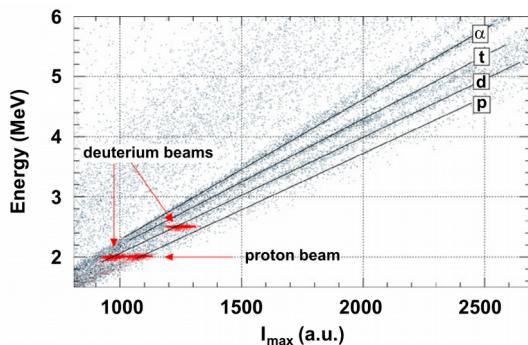
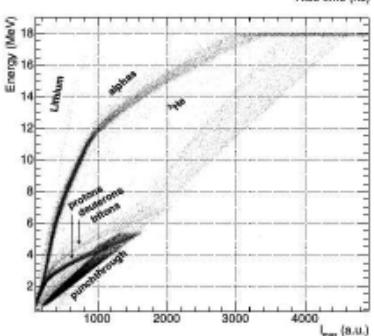
NTD, strips



FZ pad



Gamma dets



- NTD Single pad
- Segmented dets (DSSS&PAD)
- Gamma -ray dets

J.Duenas et al., NIMA(2012)

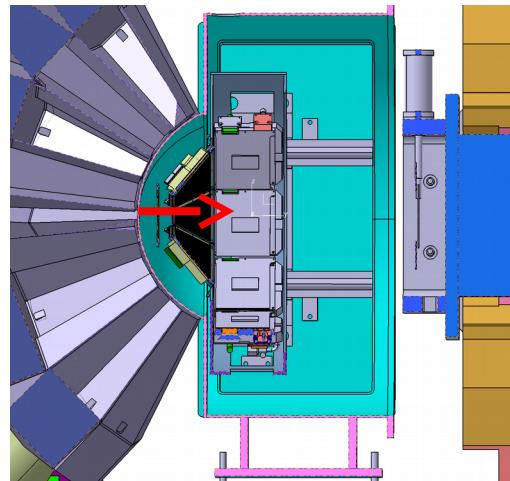
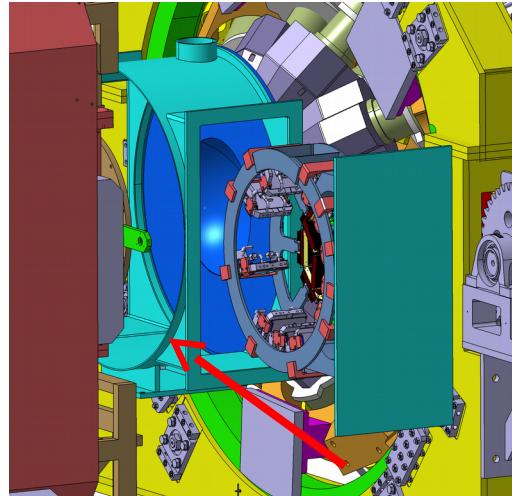
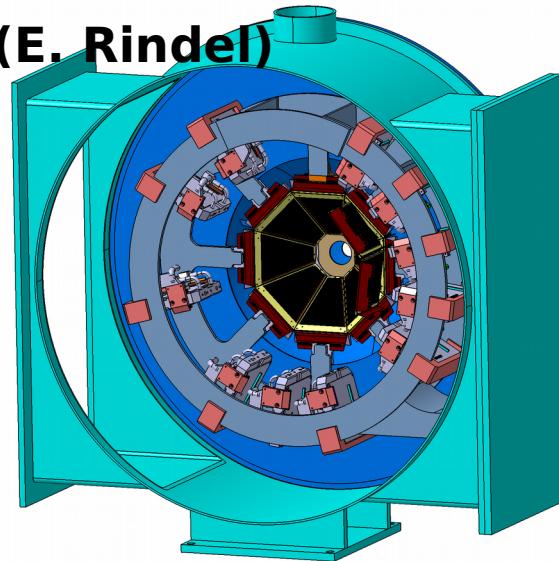
M.Assié et al., EPJA(2015)

D.Mengoni et al., NIMA(2014)

reaction chamber

Design of the reaction chamber @IPN (E. Rindel)

- Distance AGATA-target = 18 cm
- No electronics behind trapezoid detector
- Capability of handling more trapezoids
- Possibility of second layer.
- Fully removable backward array
- Option for cryogenic target

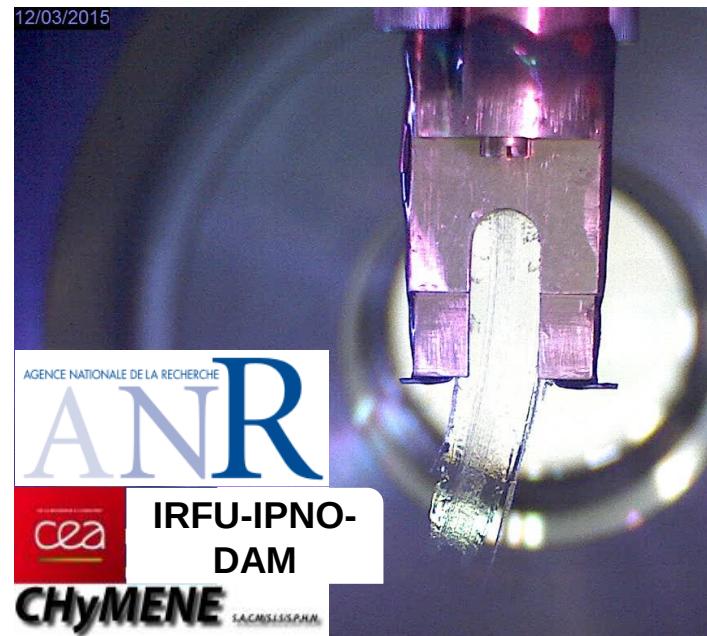
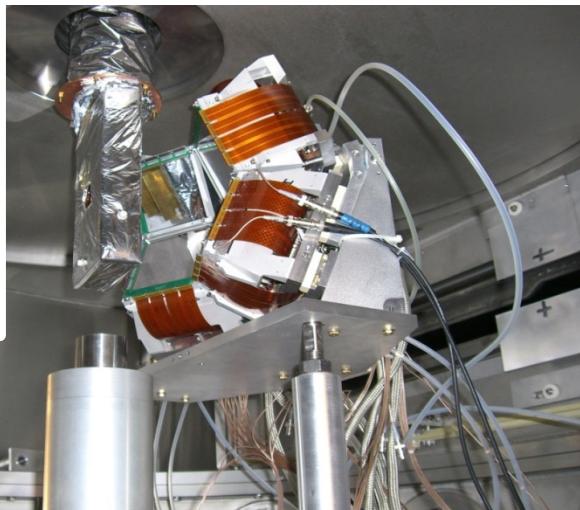


→ Financed: 42kE
Univ. of Surrey
(W. Catford)

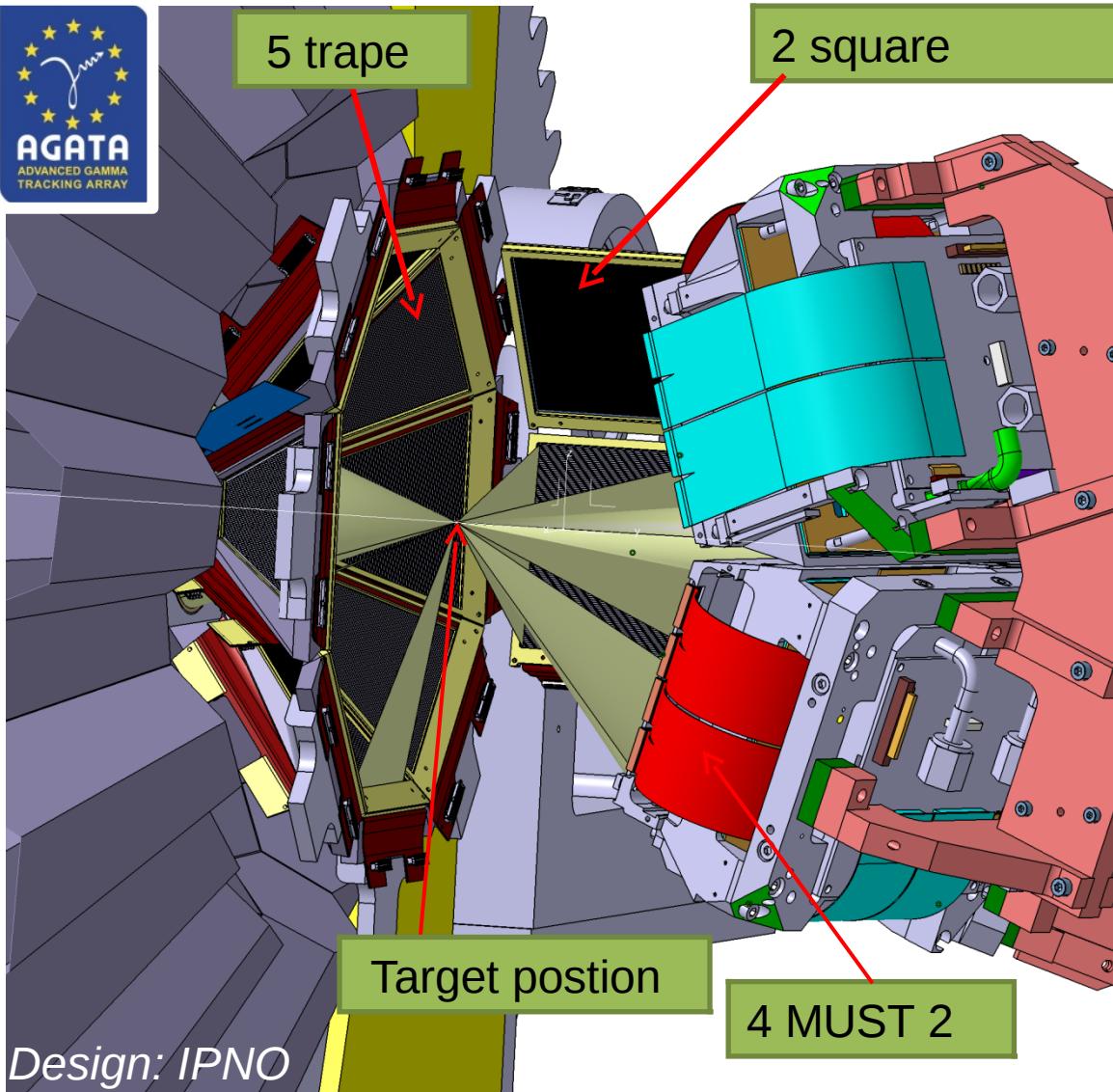
Special targets

- He gas target
- cooled gas cell at 5~8 K to maximize density
- Havar windows, 3.8 microns
- Used at SPEG – GANIL
- 3He version under study

- Hydrogen (h,d) target in a solid phase near triple point (~17K)
- Thickness 50 – 200 μm
- No window - C free
- Continuous flow in vacuum 2-10mm/sec
- Compatible with particle detection



MUGAST+AGATA



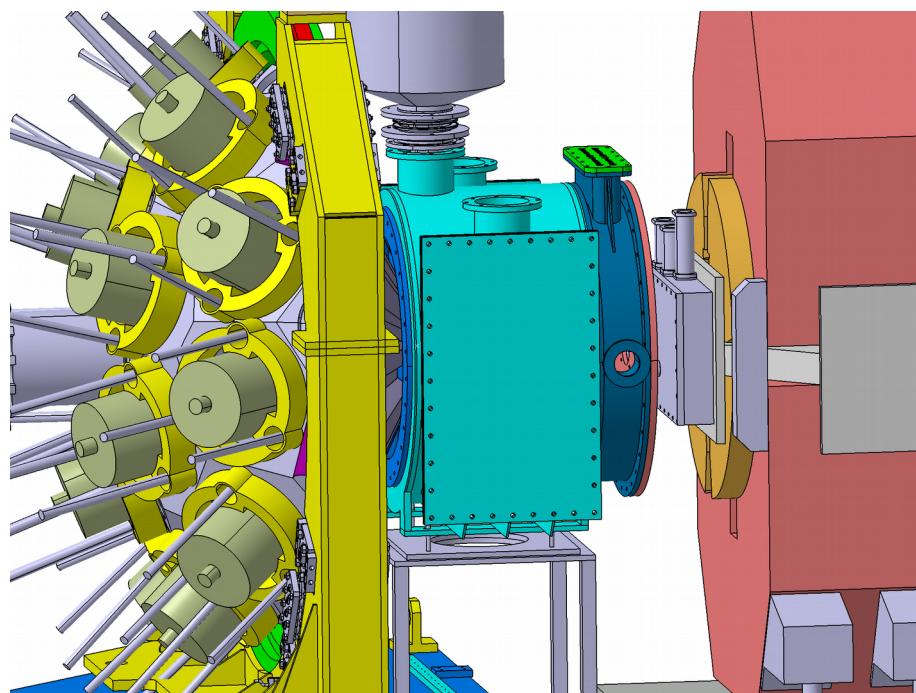
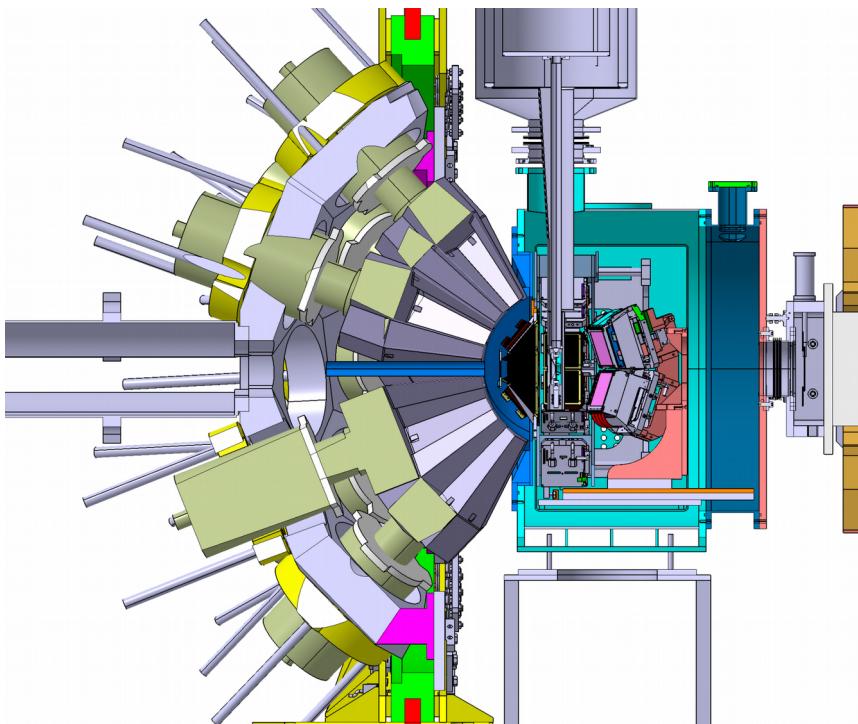
Design: IPNO

Si detectors configuration

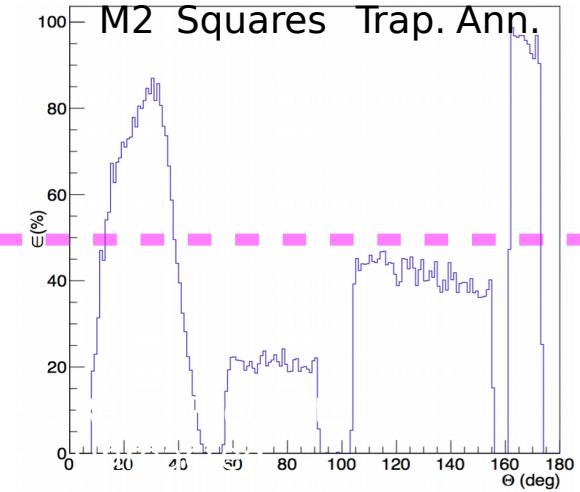
- 5 Trapezoids + 1 Annular at bck angles
 - Distance : **10.5 cm**
 - Ann: 12.5cm
 - Angles: [104.2-155.2] $^{\circ}$ + [159-169.2] $^{\circ}$
- 2 Squares around 55.8 $^{\circ}$ - 90 $^{\circ}$:
Distance : 13.5 cm
Angles:
[60,90] $^{\circ}$
- 4 MUST2 telescopes at fwd angles
Angles : [10-50] $^{\circ}$

AGATA distance: 18 cm

MUGAST+AGATA @VAMOS



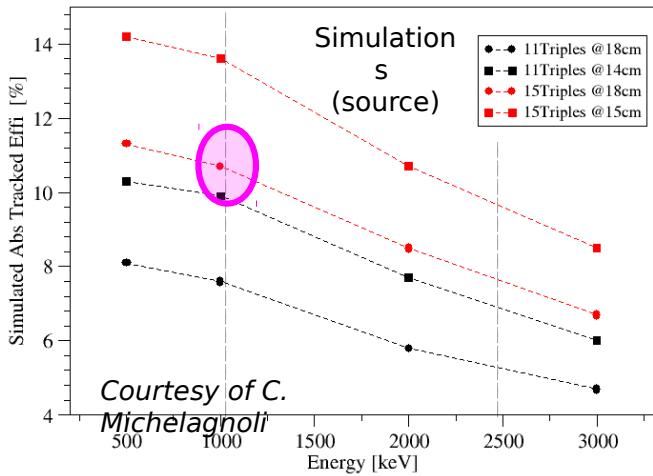
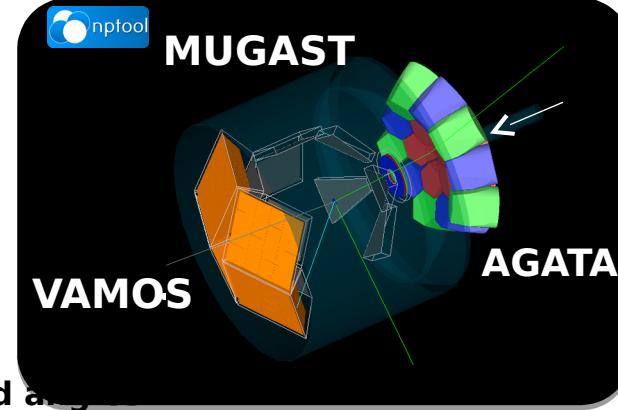
Simulations



Particle detection

- **4 MUST2 Telescopes at forward angles:**
 - Distance : 18 cm [10-50] $^{\circ}$
- **2TRACE squares around 90 $^{\circ}$:**
 - Distance : 13.5 cm [60,90] $^{\circ}$
- **5 Trapezoids and one Annular:**
 - Distance : 10.5 cm - Ann: 13.4cm
 - Angles: [105-155] $^{\circ}$ + [161-174] $^{\circ}$

A. Matta et al.,
J.Phys.G 43 045113 (2016)



γ detection

At 18 cm (current goal)

- $\epsilon(1.0 \text{ MeV}) \sim 8\%$
 - $\epsilon(2.5 \text{ MeV}) \sim 5\%$
- 33 det.
- $\epsilon(1.0 \text{ MeV}) \sim 11\%$
 - $\epsilon(2.5 \text{ MeV}) \sim 8\%$
- 45 det.

>> DETECTORS

| | | |
|----------------------------------|----------------|------------------------------|
| Trapezoids proto (x2) | Commissionning | IPNO, P2IO |
| Trapezoids pre-serie (x3) | Ordered | Surrey/IPN O +Santiago |
| Squared proto (x2) + Thick proto | Ordered | INFN- Padova |
| Annular (x1) th = 500um | Available | IPNO, Surrey |

>> ELECTRONICS

| | | |
|---|-------------------|-------------------------|
| MUST2 FEE boards x10 +1? | Available | |
| (MUST2 FEE new boards x7 boards+components+ASIC | Order 2016 | IPNO, Saclay, LPC |
| MUST2 Digital boards (x4) | Available | |
| Kaptons prototypes | Ordered: 09/16 | test |
| Final Kaptons (x48) | Designed | IPNO |
| Cables & feedthroughs | 2016-2017 | IPNO |

>> MECHANICS

| | | | | | |
|------------------|-------|-----|------------|---------|--------|
| Chamber supports | VAMOS | and | Final 2016 | for end | Surrey |
|------------------|-------|-----|------------|---------|--------|

- **Reaction chamber** design ongoing (**fully funded**)
- Test bench mounted @ IPN and operational
- Kaptons:
 - design close to final:
 - Prototypes ordered for test
- ASIC for MUST2: OK
- new MUFEE : OK
- Cryogenic target possibility (under discussion)

Summary & Conclusions

- High-resolution structure and reaction studies using transfer reactions
- MUGAST array available in 2018
- Physics program at GANIL using AGATA @ VAMOS acknowledge by the PAC

MUGAST collaboration

- IPN Orsay , CEA Saclay, GANIL, LPC Caen (France)
- INFN Univ. of Padova, INFN-LNL Legnaro , INFN Univ. of Milano (Italy).
- Univ. of Huelva, Univ. of Santiago de Compostella, Univ. of Valencia (Spain)
- Univ. of Surrey, STFC Daresbury (UK)
-

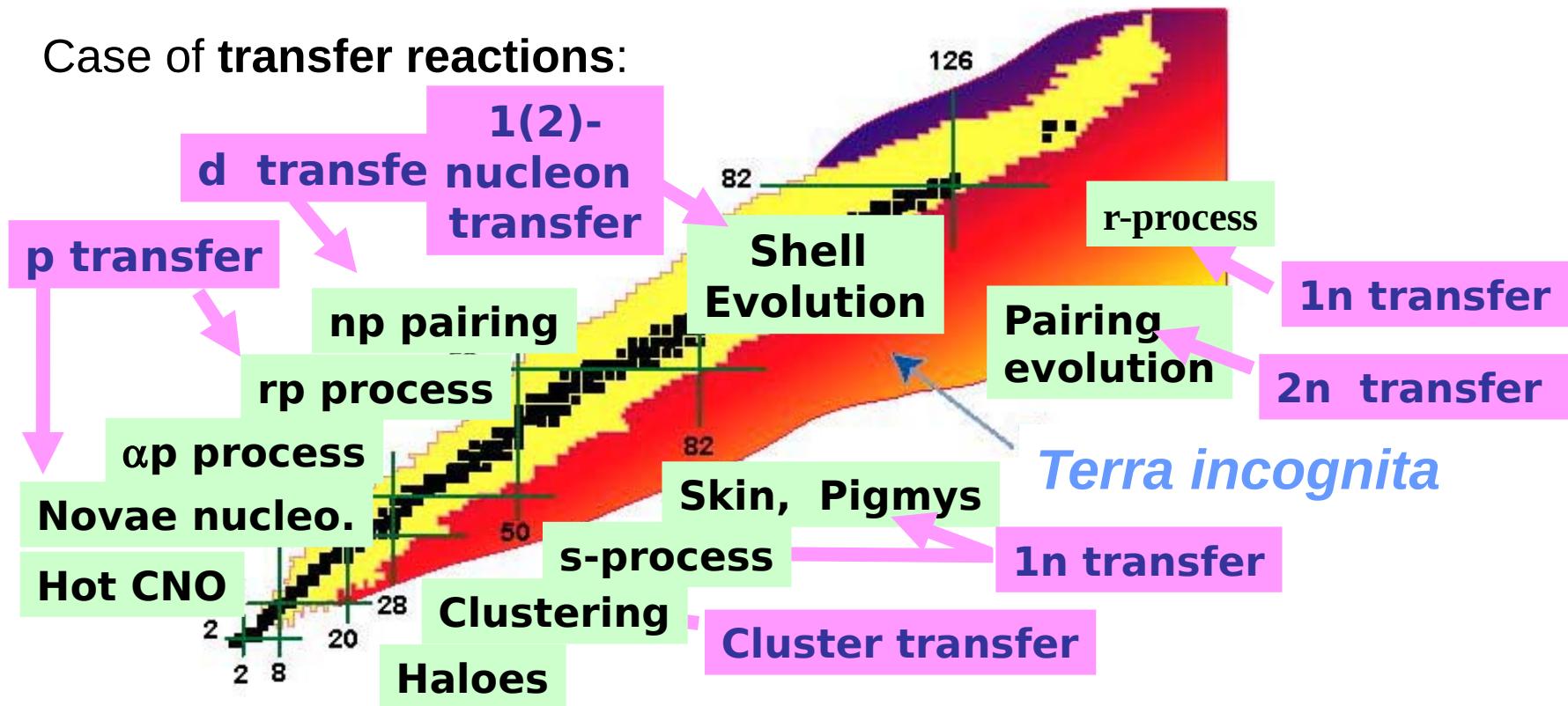


| ITEM | STATUS | who |
|---|----------------------------|---------------------------------|
| DETECTORS | | |
| Trapezoids proto (x2) | Commissioning | IPNO |
| Trapezoids pre-serie (x3) | Ordered | Surrey + IPNO + Santiago |
| Squared proto (x2) + Thick proto | Ordered | INFN Padova |
| Annular (x1) th = 500um | Available | -- |
| MUST2 (x4) | Available | -- |
| ELECTRONICS | | |
| MUST2 FEE boards (x10) | Available | -- |
| (MUST2 FEE new boards (x5) boards+components+ASICs) | To be ordered | |
| MUST2 Digital boards (x4) | Available | -- |
| Kaptongs (x48) | To be designed and ordered | |
| Cables & feedthroughs | To be ordered | |
| MECHANICS | | |
| Chamber and supports | Under design | Surrey |
| Cooling blocks | Under design | Surrey |

Direct Reactions

A great tool to investigate Exotic Nuclei and Nucleosynthesis

Case of transfer reactions:



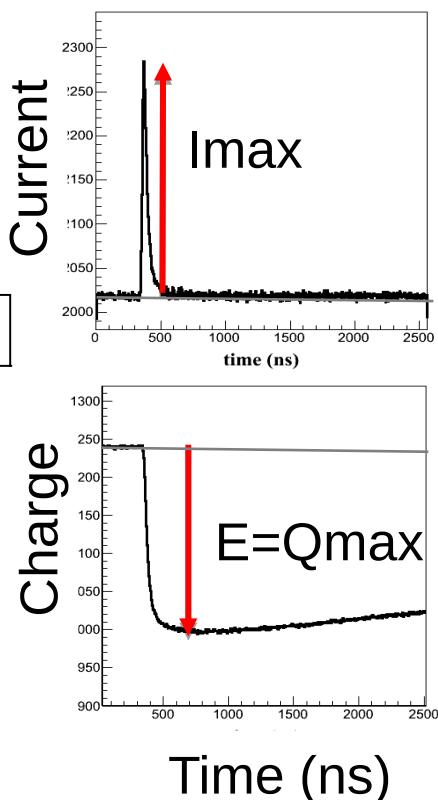
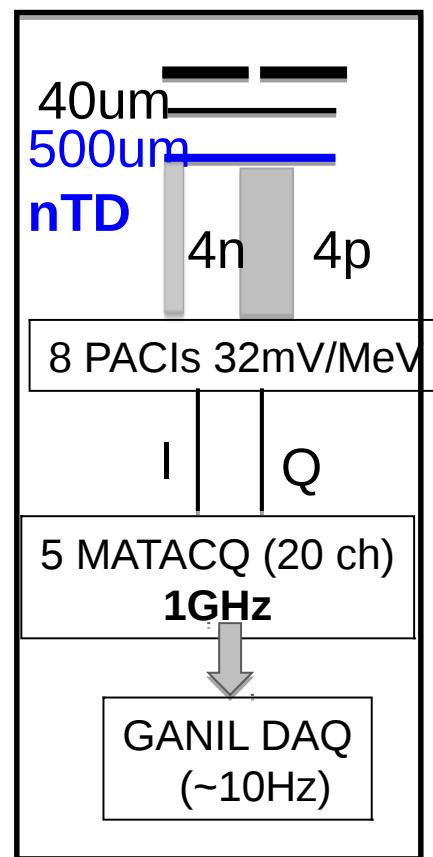
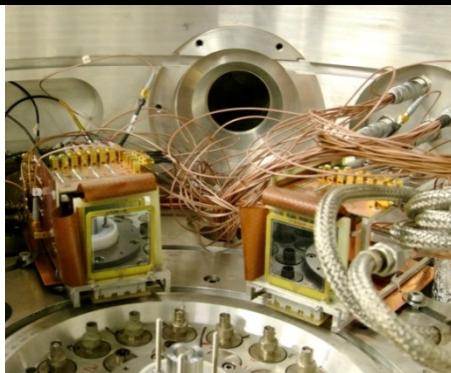
Good energy regime : few MeV/u → few tenths of MeV/u

Methodology : Radioactive Ion Beam $\xrightarrow{\text{ }} \text{Light target (H,He...)}$
Detect the recoil particle with high accuracy

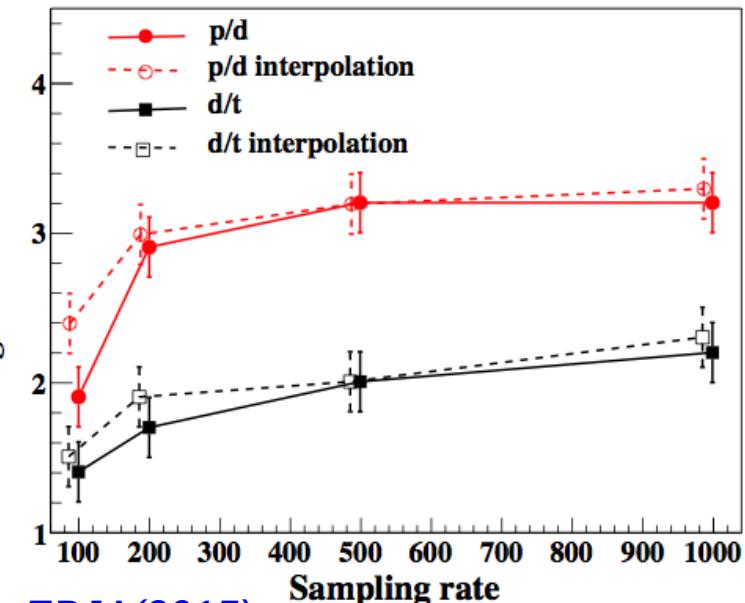
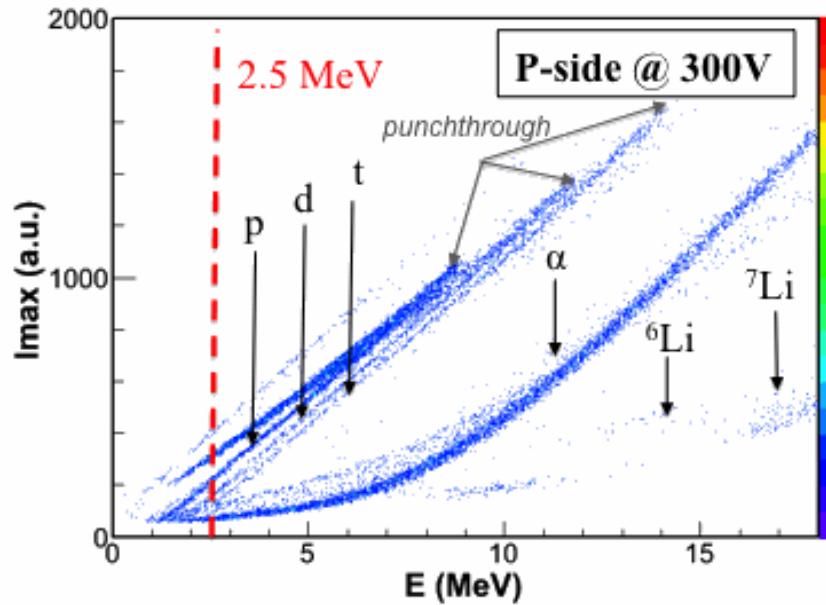
Silicon technology

PSD for Z=1 particles

Test experiment
(IPNO tandem)
 $^7\text{Li} + ^{12}\text{C}$ @ 35 MeV

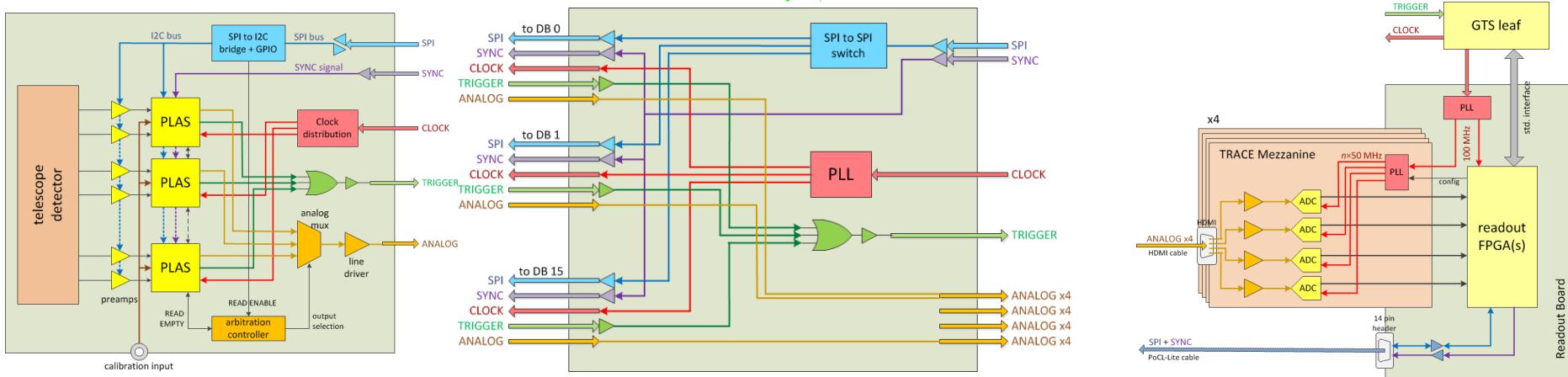
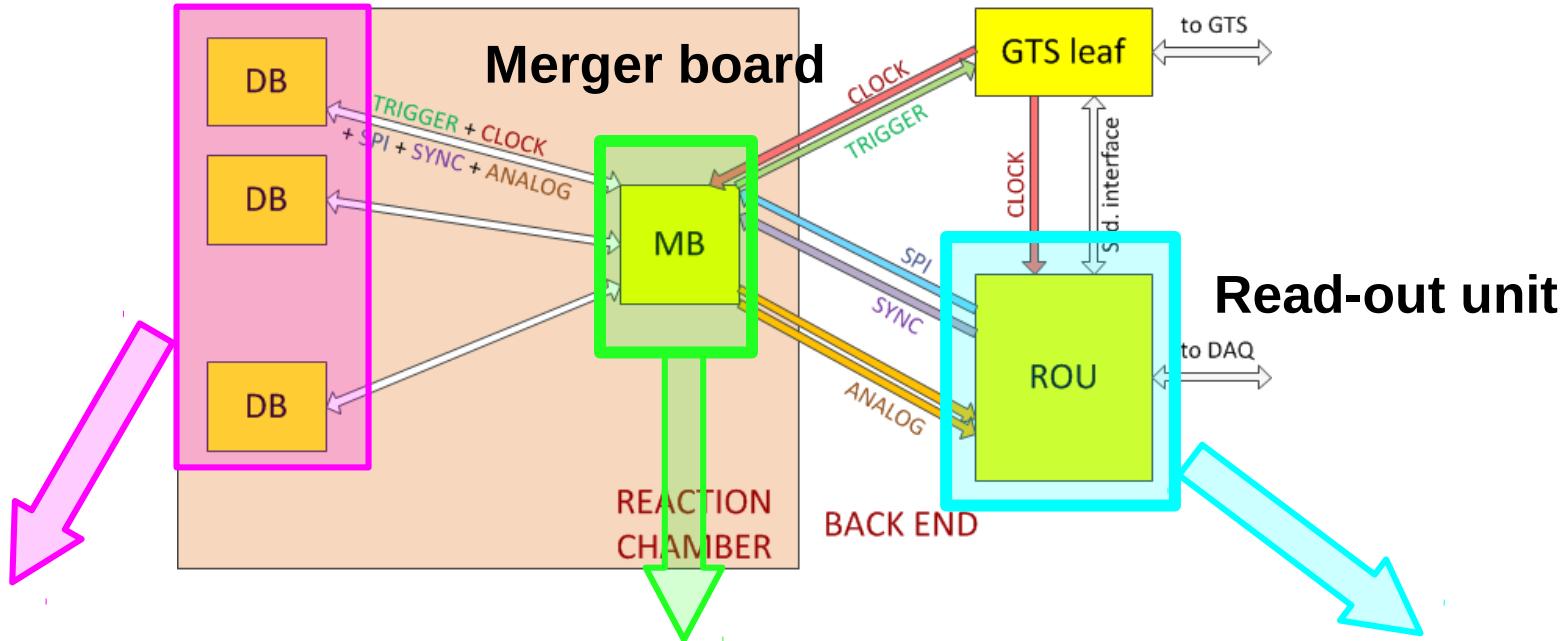


RESULTS



Electronics architecture

Detector board



Physics with MUGAST

2 dedicated workshops organized at Orsay and Padova

➤ Shell structure evolution & deformation

- Mapping of neutron orbitals around N=28
- Oblate driving force in n-deficient nuclei above ^{56}Ni
- Shape transition along and across N=28
- Interplay of single-part and collective structures in ^{46}Ca
- Shell evolution toward the island of inversion
- Island of Inversion and shape coexistence in $^{30,31}\text{Mg}$
- 75Kr: Shape coexistence in characterisation in light Kr

F.Flavigny, O.Sorlin et al.
A.Goasduff, D.Mengoni, et al.
L.Fortunato, D.Mengoni et al.
S.Leoni et al.
A.Matta, W.Catford, N.Orr, et al.
B.Fernandez-Dominguez et al.
A.Matta, W.Catford, N.Orr, et al

➤ Neutron-proton pairing

- np-pairing in fp-shell

M. Assié et al.

➤ Astrophysics

- Breakout from hot CNO to rp process
- Explosive H-burning in Novae
- s-process $^{79}\text{Se}(\text{n},\gamma)$
- s-process $^{60}\text{Fe}(\text{n},\gamma)$

C.Diget et al.
N.de Sereville, F.Hammache et al.
G.de Angelis et al.
A.Matta, W.Catford, N.Orr, et al.

➤ Reaction dynamics

- Space-time characterization of emitting sources
in HI collisions

G. Verde, A.Chbihi, Q.Fable

“Reaction and structure studies using the MUGAST+AGATA setup at VAMOS”

D.Beaumel & D. Mengoni

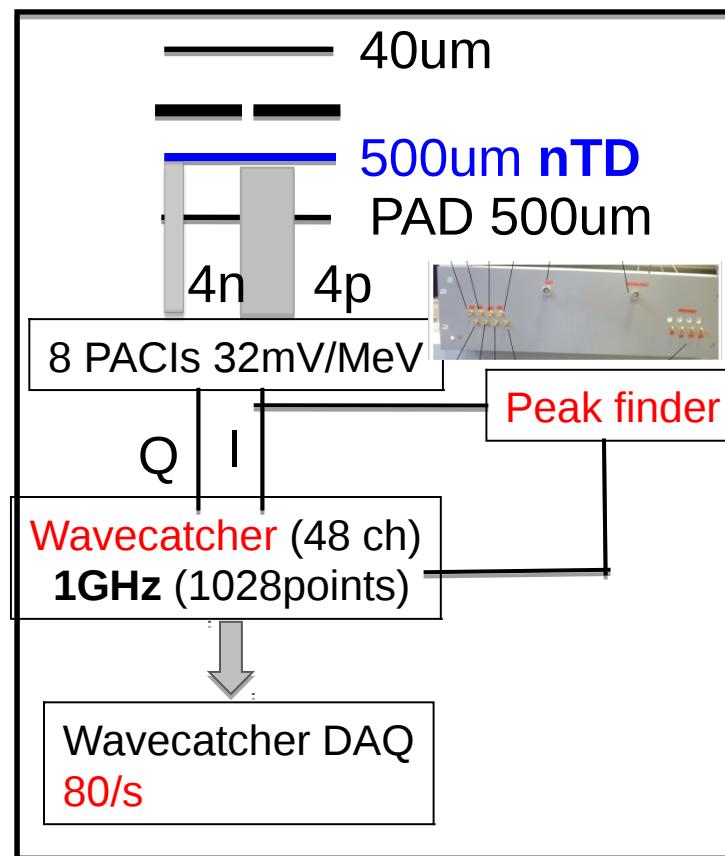
“Umbrella” *LoI submitted to the coming GANIL PAC*

PSD for Z=2 particles

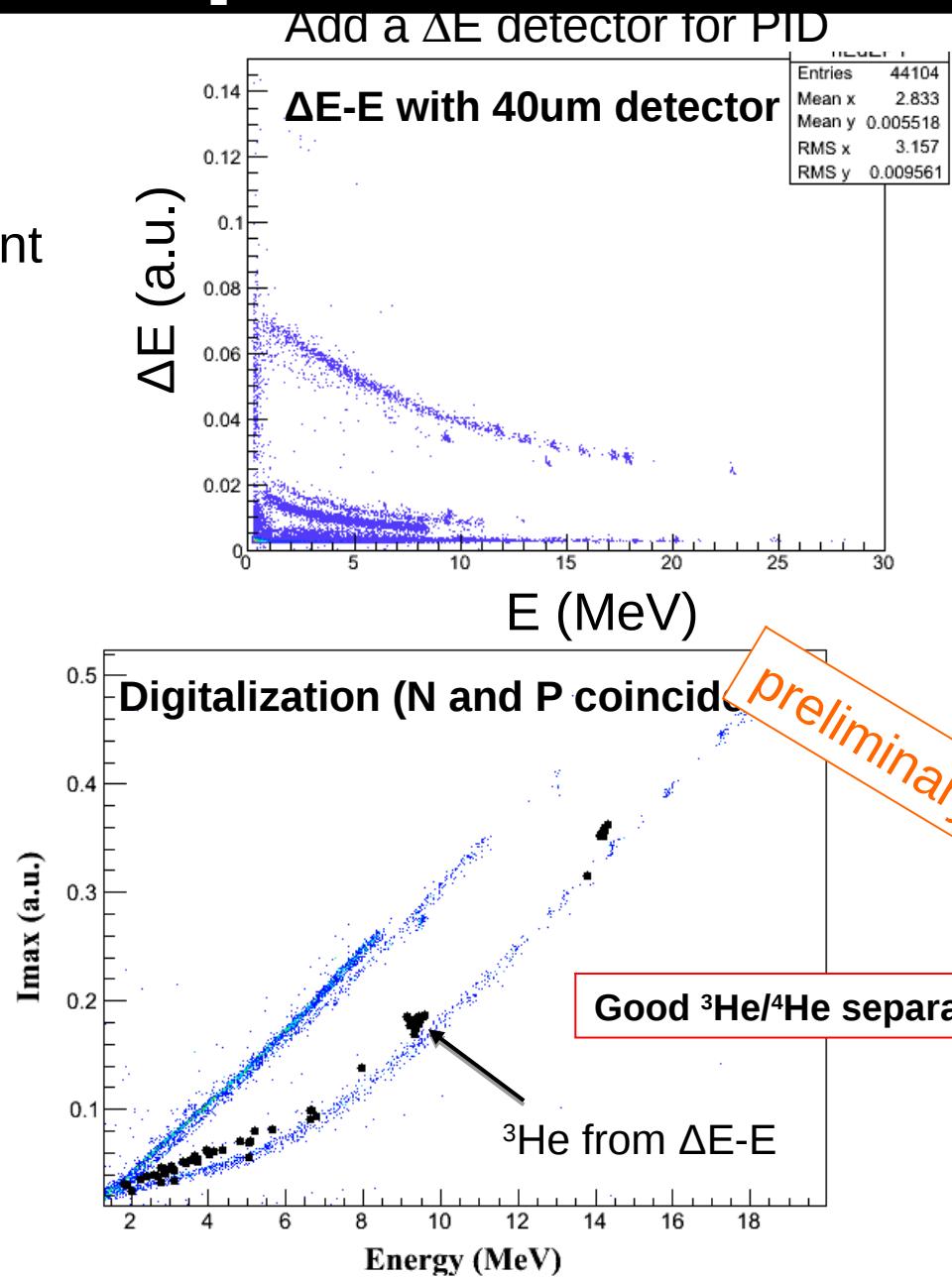
(d,³He) on mylar
@ 26 MeV

(IPNO tandem)

- ³He/⁴He discrimination
- test of analog peak finder on current



Under analysis



Trapezoid detectors and test bench

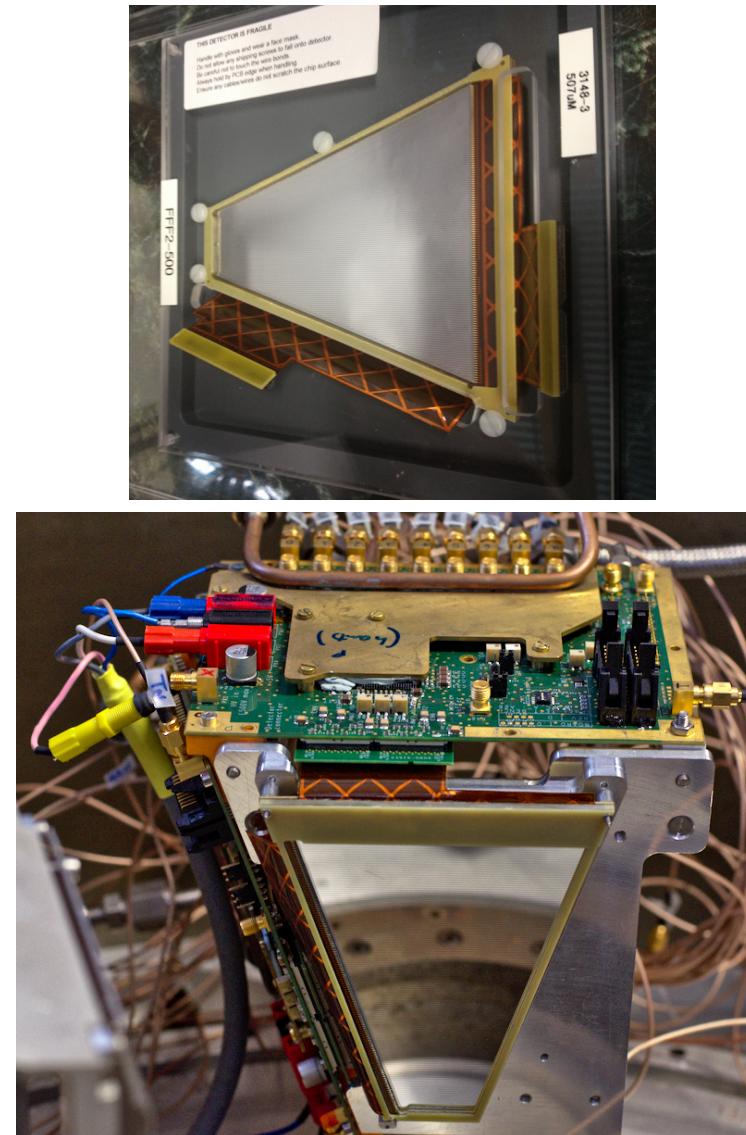
Ordered to Micron semiconductors :

- **2 trapez.** prototypes nTD DSSSD ordered by IPN
(delivered end of june 2015)
- **3 more trapezoid « series » ordered**
(1 Surrey, 1 Santiago University, 1 IPN)
- **2 square proto. nTD DSSSD + 1 thick sq. DSSSD**
(ordered by INFN end of 2014, under fabrication)

Test bench mounted @ Orsay :

- Digital test bench (GASPARD purposes)
- **Analog test bench** (256 channels) :
Trapezoid + MUFEE + MUVE + GANIL acq.

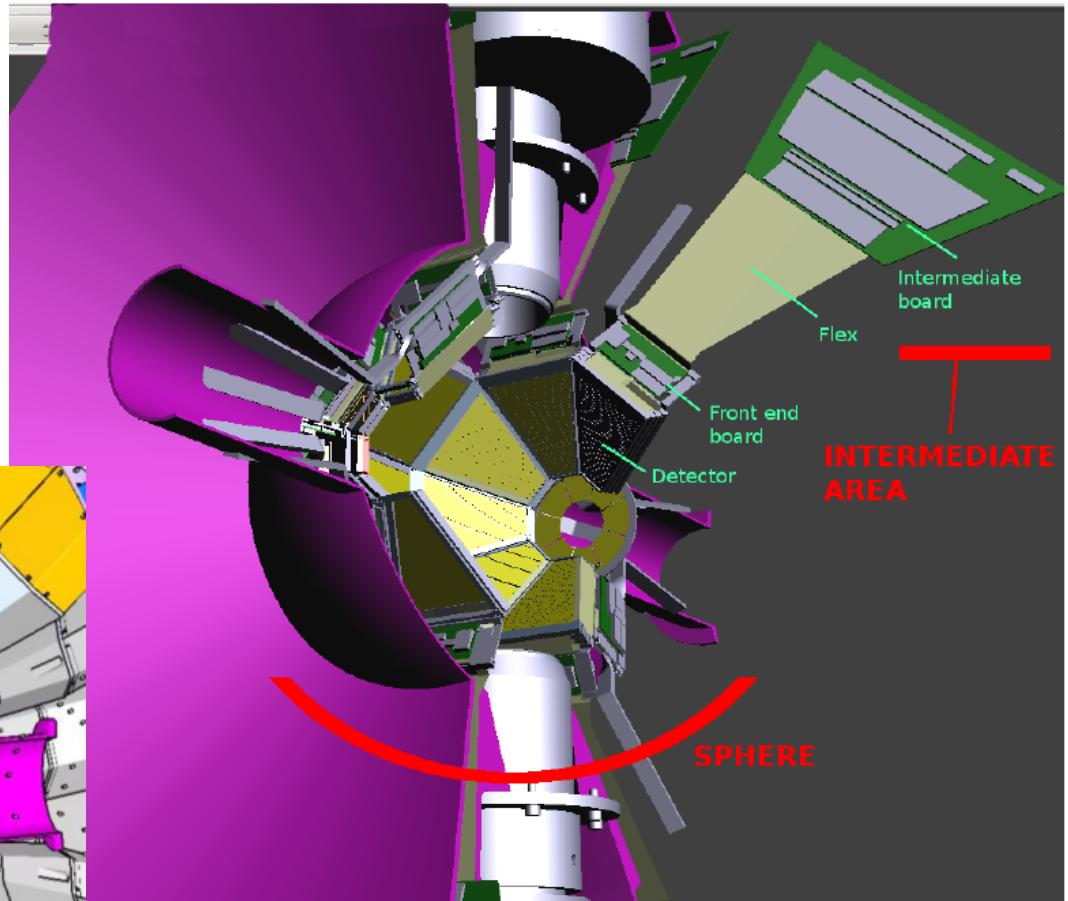
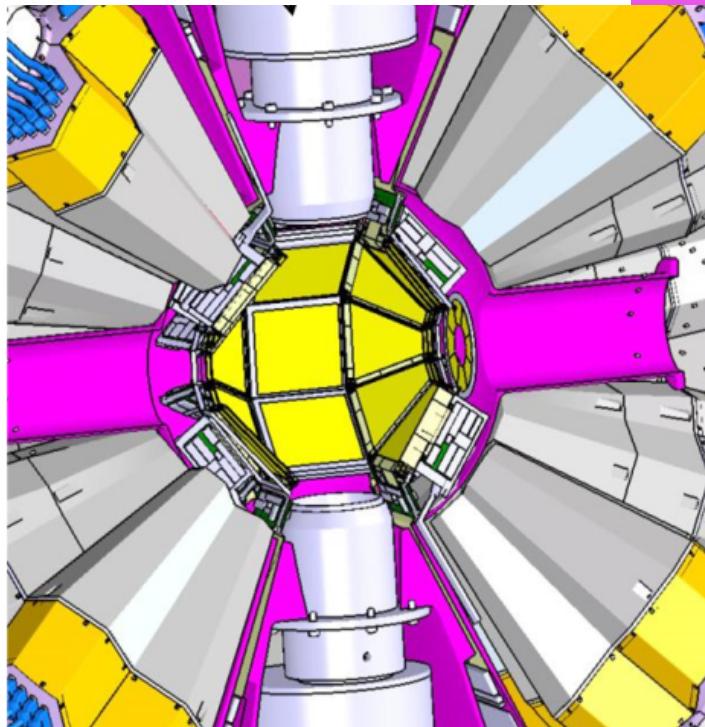
Aim ☐ **End of 2016 validation of prototypes**



Electronics / Integration

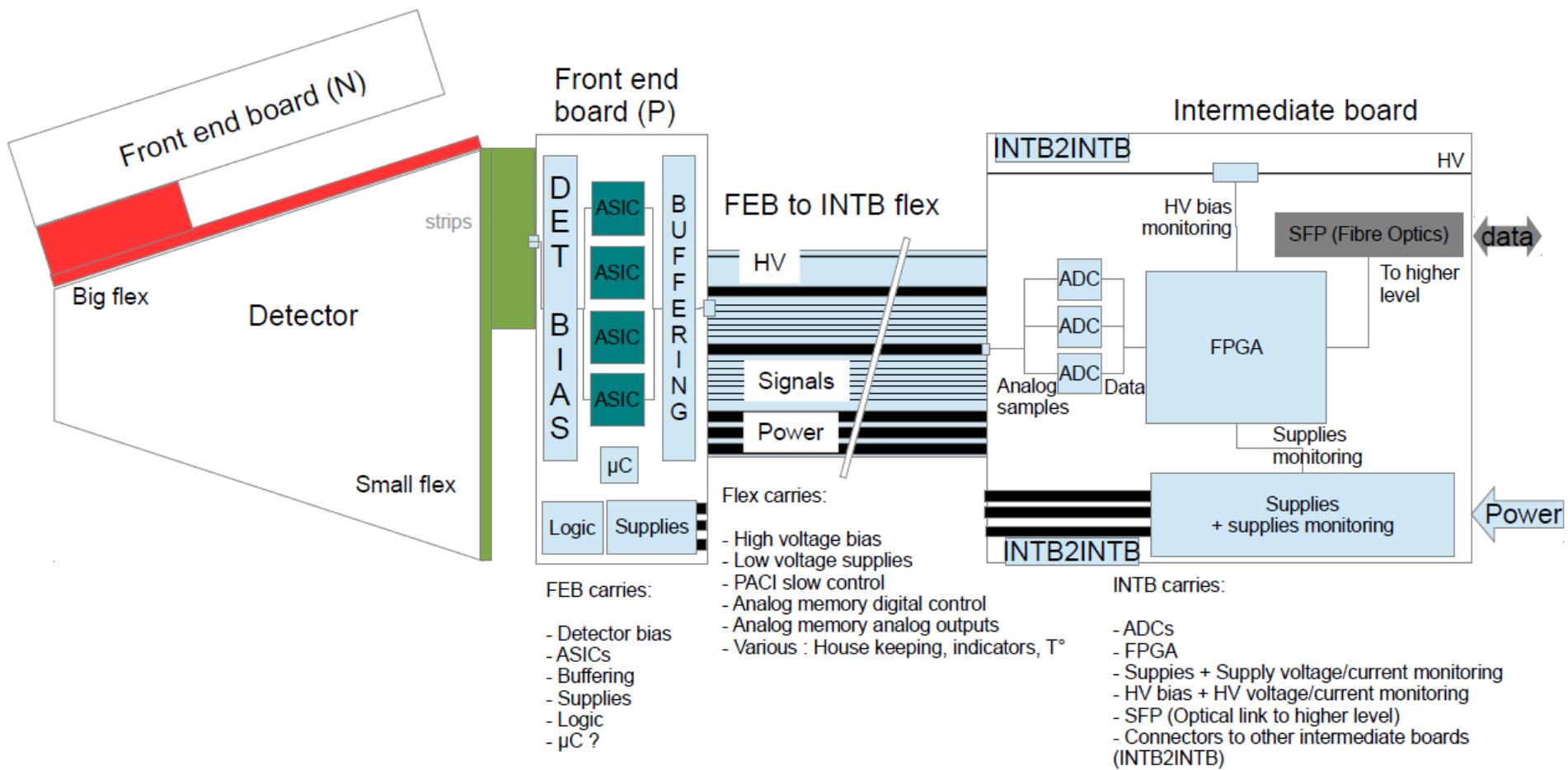
Our challenge:

- ~ 10.000 channels
- Transparency to γ -rays



Detailed design under elaboration (IPNO)

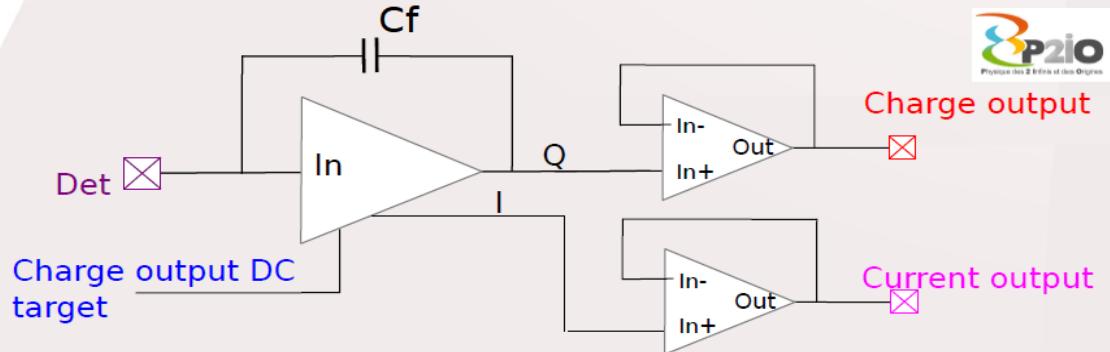
Electronics architecture



iPAC1 : 9 channel integrated *charge* and *current* output preamplifier



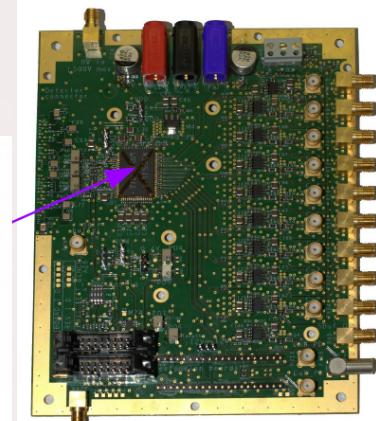
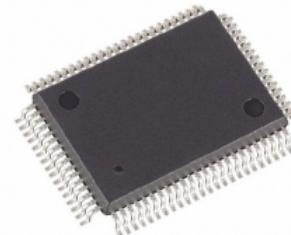
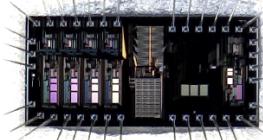
**1-Channel
performance
(simulated!)**



| Charge Output | |
|---|--------------------|
| Energy max (Si) | 50 MeV |
| Charge signal swing (50MeV) | 1.6V single ended |
| Charge gain | 32mV/MeV |
| Equivalent noise charge (Input-refered, FWHM) | 7 keV 830 e- Si |
| Charge resolution | 12.8 bits ENOB |
| Charge non-linearity | < 2% |
| Charge output recovery time | 100µs |
| Current Output | |
| Current gain | 7kΩ |
| Current signal swing | 1.5V single ended |
| Current signal BW | [4MHz .. 120MHz] |

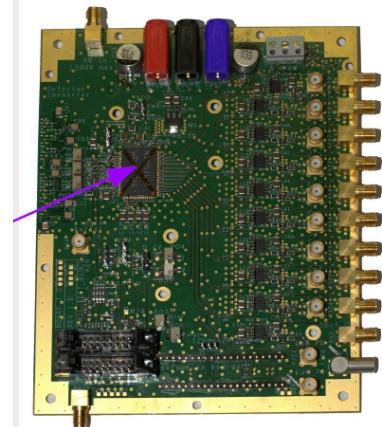
| System data | |
|------------------------------|--|
| Technology | AMS 0.35µm BICMOS |
| Supply | 3.3V |
| Detector's input capacitance | Compatible with [10pF .. 40pF] range |
| Compensation cap | Digitally tunneable within [0.5pF .. 2.25pF], step 0.25pF |
| Current consumption | 12mA (40mW) / Channel |
| Size | 220 x 100µm (PAC1 block) + 130 x 70µm (Buffer ch) + 130 x 70µm (Buffer cu) |

Other development: **multichannel CSP ASIC**
A.Pullia, S.Capra
INFN / Univ. Milano

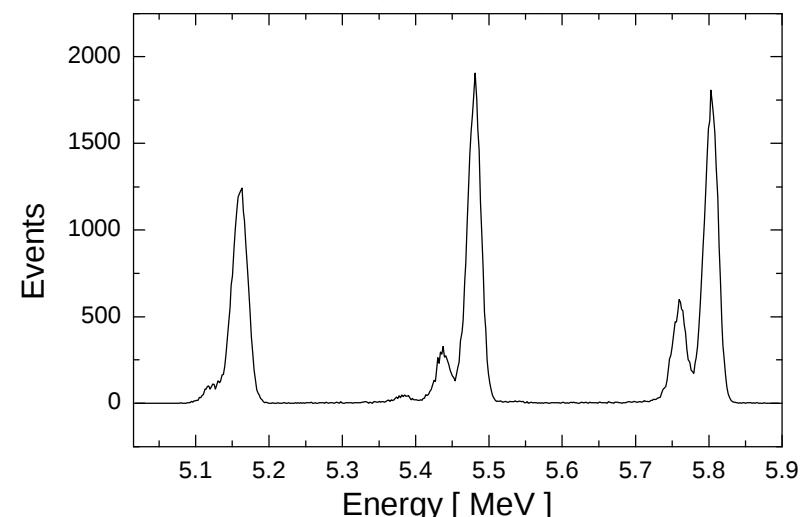
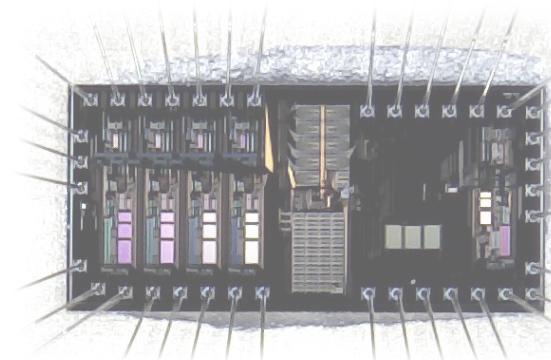


Preamplifier ASIC

- Current and charge output
- Presently 9 ch



- Charge output and extend dynamics
- Presently 4 ch



| ITEM | STATUS | who |
|---|----------------------------|---------------------------------|
| DETECTORS | | |
| Trapezoids proto (x2) | Commissioning | IPNO |
| Trapezoids pre-serie (x3) | Ordered | Surrey + IPNO + Santiago |
| Squared proto (x2) + Thick proto | Ordered | INFN Padova |
| Annular (x1) th = 500um | Available | -- |
| MUST2 (x4) | Available | -- |
| ELECTRONICS | | |
| MUST2 FEE boards (x10) | Available | -- |
| (MUST2 FEE new boards (x5) boards+components+ASICs) | To be ordered | |
| MUST2 Digital boards (x4) | Available | -- |
| Kaptongs (x48) | To be designed and ordered | |
| Cables & feedthroughs | To be ordered | |
| MECHANICS | | |
| Chamber and supports | Under design | Surrey |
| Cooling blocks | Under design | Surrey |

R&D on pulse shape analysis

Goal: establish the method for light particles and highly segmented detectors

- Effect of segmentation
- Lower E threshold for each particle ?
- Minimum sampling frequency (Digital elec)
- n-side or p-side ?
- Filters (e.g. Haar wavelets transform, ...)
- Other possible observable : Rise time ?
- Radiation damage
-

test experiments
at the IPNO tandem

Detector:

- 500 um nTD DSSD
- BB13 design of MSL
- 8° cut
- 128X+128Y
- pitch<500um
- special package
 - 90° kapton readout
 - high density
 - connectors



The CHyMENE H/D target system

Cible d'HYdrogène Mince pour l'Etude des Noyaux Exotiques

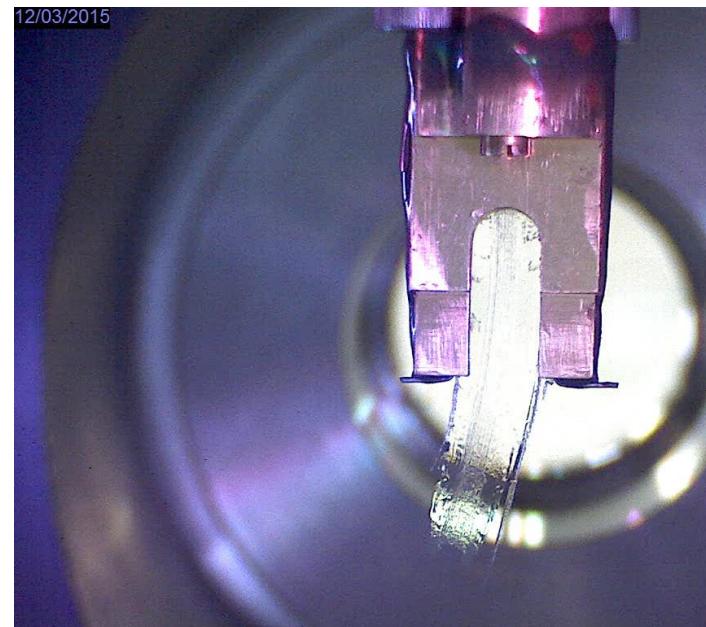
System providing continuous extrusion of ^1H or ^2H through a rectangular nozzle defining the target-film thickness

- Hydrogen target in a solid phase near triple point
 $\text{sH}_2 \sim 17 \text{ K}$
- Thickness 50 – 200 μm
- No window - C free
- Continuous flow in vacuum
2-10mm/sec
- Compatible with particle detection

CHyMENE collaboration :

- CEA/IRFU Saclay
project coordinator: A. Gi
- IPN Orsay
- CEA/DAM Bruyères

Grant from French ANR ~550k€

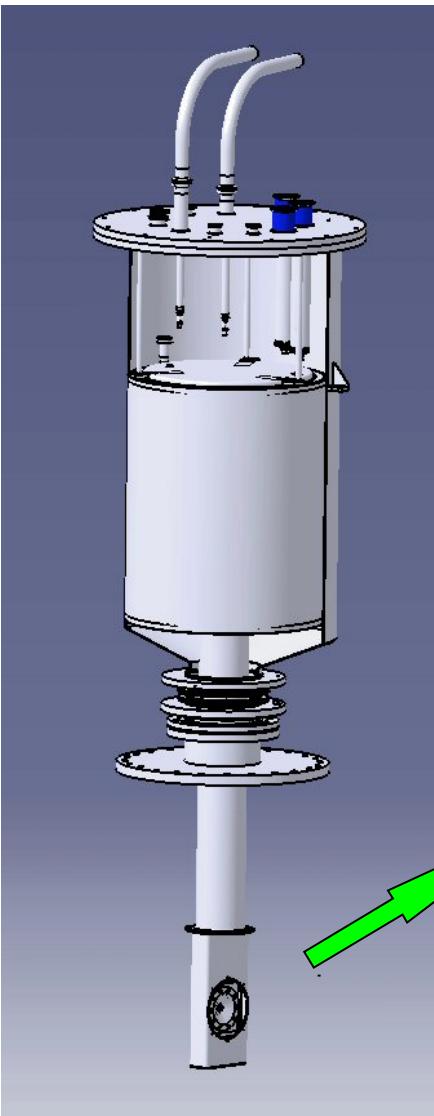


*Tests undergoing using
alpha source*

Designed for the use of direct reactions with $^{3,4}\text{He}$ probe in Inverse kinematics

Concept : cooled gas cell at 5~8 K to maximize density

Possible reactions: $(\alpha, {}^3\text{He})$, (α, t) , $(\alpha, {}^6\text{He})$, ...



Previously used
at SPEG / GANIL



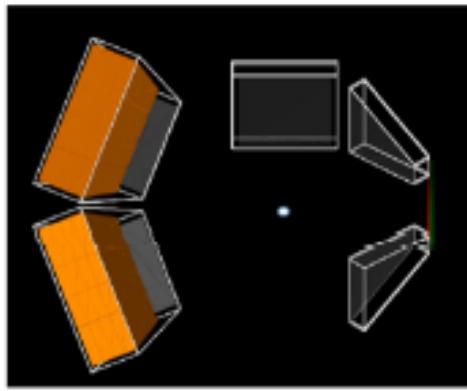
$\varnothing 16 \text{ mm}$, 3mm thick
Havar windows, 3.8 microns
 $T = 8.5 \text{ K}$
 $P = 1 \text{ bar}$

Now under study : **${}^3\text{He}$ version**
 $({}^3\text{He}, d)$ proton stripping
 $({}^3\text{He}, p)$ d transfer for np pairing

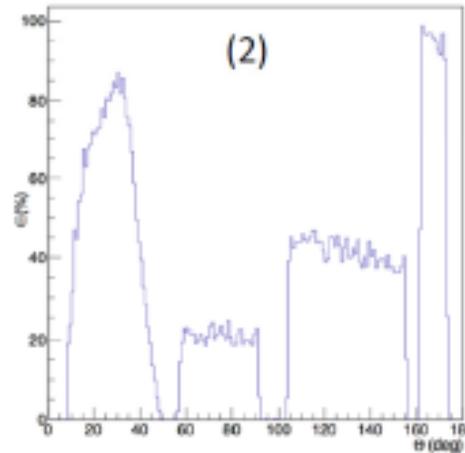
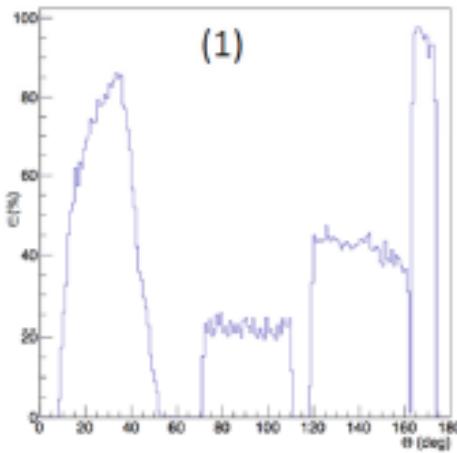
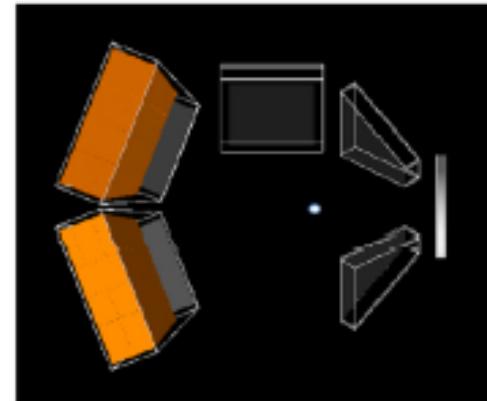
Simulations / Detection efficiency

Using NPTool package

Config Initiale



Translation Trapézes +carrés vers M2 (~4cm)
+ update géométrie carrés



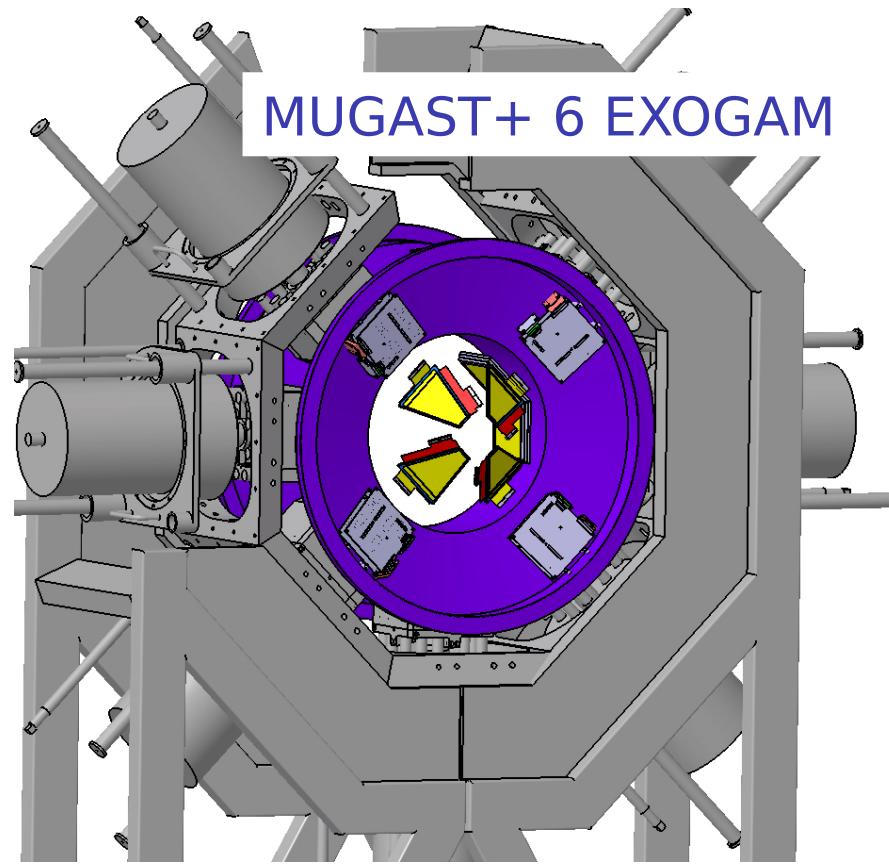
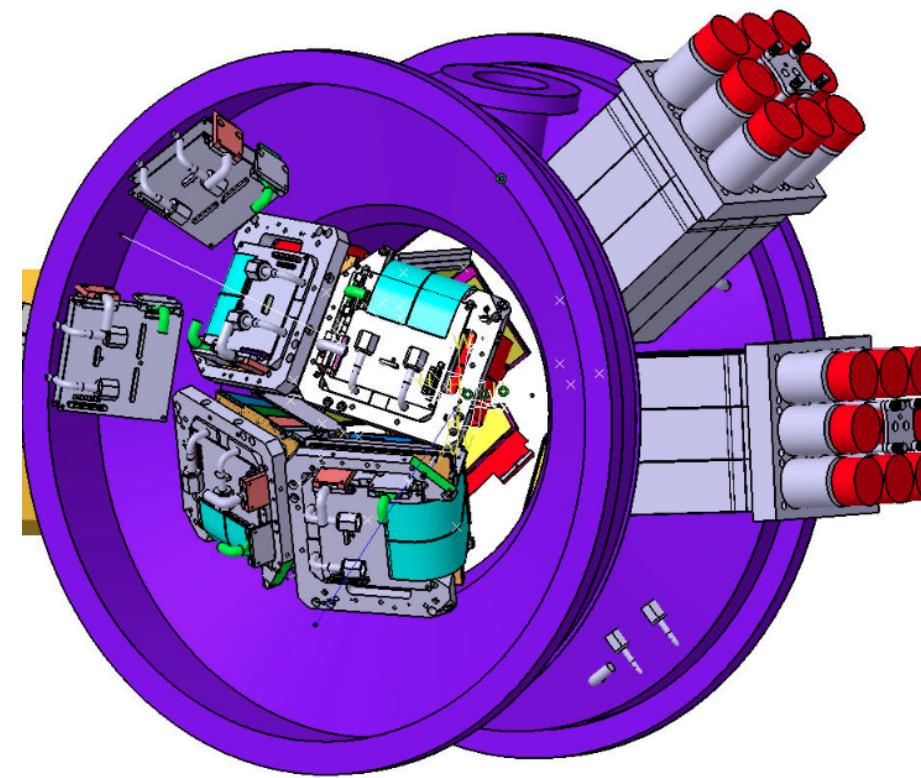
Last geometrical configuration available on demand

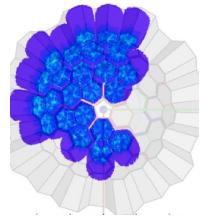
MUGAST with EXOGAM & PARIS

« MUGAST » configuration = MUST2 + GASPARD (trapeze) + TRACE (square)
available for AGATA campaign at GANIL (2017)
read by **MUST2 electronics (MUFEE+MUVI)**

Possible gamma detector's configurations :

- 6 PARIS clusters (if available)
- 6 EXOGAM





MUGAST: reaction and structure studies with the AGATA setup @ VAMOS

Daniele Mengoni¹

For the collaboration

¹University of Padova, INFN Padova

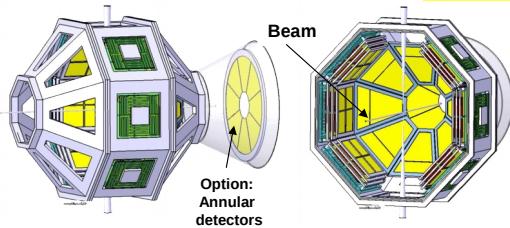


**towards a new Silicon array for
high resolution structure and
reaction studies**



A new Si array **TRACE** for structure and reaction study

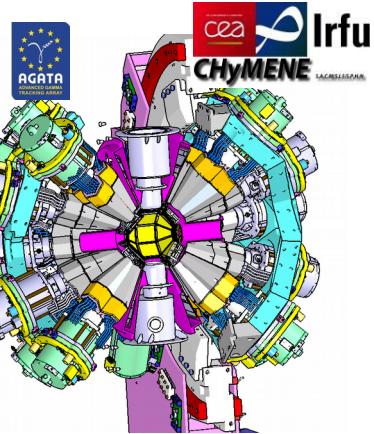
"GASPARD-TRACE" design



4 π , fully integrable in PARIS and AGATA

Layers of Silicon

- 500 μ m DSSD pitch < 1mm
 - 1(or 2) x [1.5 mm DSSD pitch~3mm]
- 2 main shapes : square & trapezoid,
large area



Electronics :

- ~ 10000 channels (Digital)
 - high transparency to γ -rays
- Big integration challenge

Motivations

- Intermediate and heavier masses
- Higher excitation energies – Low sp strength
- Sometimes at mid-shell
- Detect/identify several channels altogether

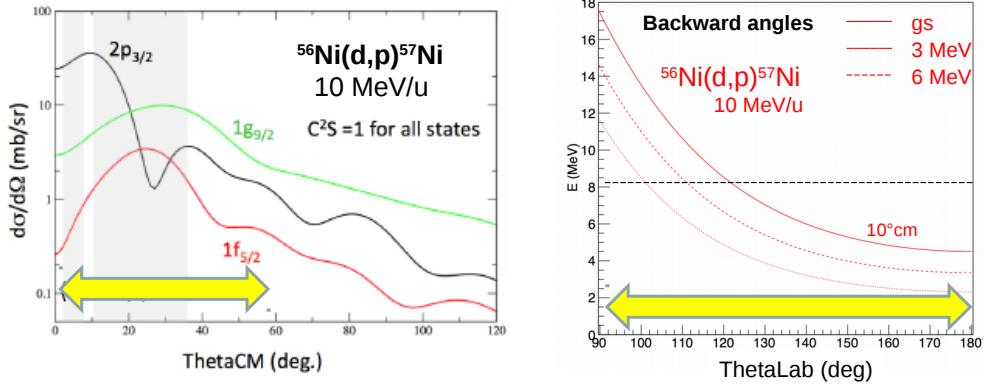
MUGAST: motivations

MUST2+GASPARD+TRACE

To perform **high resolution reaction and spectroscopy studies** using

- AGATA@ VAMOS – GANIL for some years
- The new SPIRAL1 beam + upgrade
- Some Si dets of future array progressively available

Focus on **stripping reactions** e.g. $(d,p) \Rightarrow$ **backward angles**



Intermediate configuration

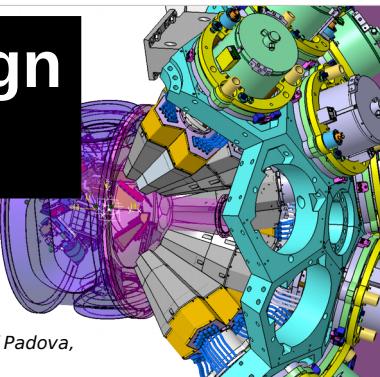
Lols Science campaign

MUGAST+AGATA@GANIL

Spiral 1 beams

Nuclear astrophysics:

- $^{15}\text{O}(^6\text{Li}, \text{d})^{19}\text{Ne}$ (C.Diget, Univ. of York, N. de Sérerville, IPNO)
- $^{25}\text{Al}(^3\text{He}, \text{d})$ (N.de Sérerville, F. Hammache, IPNO)
- $^{30}\text{P}(^3\text{He}, \text{d})$ or (d, p) (N.de Sérerville, F.Hammache, IPNO)
- $^{60}\text{Fe}(\text{d}, \text{p})$ (A.Matta, W.Carford, University of Surrey)
- $^{79}\text{Se}(\text{d}, \text{p})^{80}\text{Se}$ (G. de Angelis, INFN-LNL, D.Mengoni, University of Padova, C.Domingo Pardo, CSIC Valencia)



Shell evolution

- $^{56}\text{Ni}(\text{d}, \text{p})(\text{d}, \text{t})$ (F.Flavigny, IPNO, O.Sorlin, GANIL)
- $^{28}\text{Mg}(\text{d}, \text{p})$ (A.Matta, W.Carford, University of Surrey)
- $^{74}\text{Kr}(\text{d}, \text{p})$ (A.Matta, W.Carford, University of Surrey)
- $^{48}\text{Cr}(\text{d}, \text{p})^{49}\text{Cr}$ (A.Gadea, CSIC Valencia)
- $^{30}\text{Mg}(\text{d}, \text{d})(\text{d}, \text{p})$ (B.Fernandez-Dominguez, University of Santiago, W.Carford, University of Surrey)
- $^{67}\text{As}, ^{63}\text{Ga}(^3\text{He}, \text{d})$ (D.Mengoni, University of Padova)
- $^{44,46}\text{Ar}(\text{t}, \text{p})$ (D.Mengoni, University of Padova)
- $^{66}\text{Ni}(\text{t}, \text{p}), ^{44}\text{Ar}(\text{t}, \text{p})$ ($^{14}\text{C}, ^{12}\text{C}$) $(^{18}\text{O}, ^{16}\text{O})$ (L.Fortunato, J.A.Lay, University of Padova)

Clusters, pairing, correlations & others

- $^{56}\text{Ni}(^3\text{He}, \text{p})(^6\text{Li}, \alpha)$ (M.Assie, IPNO)
- $^{45}\text{K} + ^7\text{Li} \rightarrow ^{46}\text{Ca} + \alpha$ (S.Leoni, University of Milano, B.Forna)
- $^{16}\text{O} + {}^{\text{A}}\text{Z}$ (G.Verde, INFN Catania and IPNO)
- $^{14}\text{O}(\text{p}, \text{p})$ (I.Stefan, IPNO)

• **8 independent Lol + Umbrella Lol**

• **Mostly stripping reactions**
(backward)

MUGAST+AGATA @ VAMOS

□ LoI for AGATA+MUGAST+VAMOS for the PAC @ GANIL

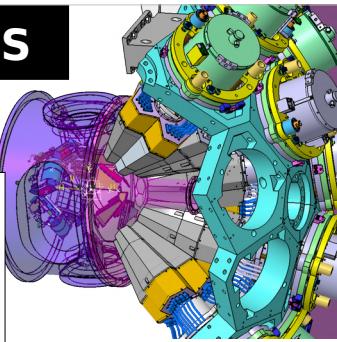
Reaction studies using the MUGAST+AGATA setup at VAMOS

Letter of Intent to the AGATA collaboration

D.Beaumel, IPN Orsay
D.Mengoni, University and INFN Padova

1. Introduction

The GASPARD and TRACE high granularity Silicon arrays have been natively designed for optimal integration in new generation gamma detectors such as AGATA with the aim of performing high-resolution reaction studies. Indeed, the coupling to AGATA allows a very large gain in excitation energy resolution, in comparison with the case where the excitation energy is deduced from the recoil charged-particle measurement. The GASPARD and TRACE collaboration are now converging to build such new-generation Si ensemble in common, with a timeline of 2019-20 for completion of the final 4π array, ready for the emerging ISOL facilities, like SPES and SPIRAL1. A view of such ultimate GASPARD-TRACE setup sitting inside AGATA is shown in Fig.1.



MUGAST: LoI-16-11 gave the overall case for the combination of MUGAST with VAMOS and AGATA.

This is a powerful combination that would position GANIL as a leading laboratory for exotic transfer studies; one of the most sensitive probes of shell structure and shell evolution. This remains an area of high interest as it is one of the most stringent tests of nuclear theory – especially the nuclear shell model and the associated interactions. In addition it is proposed to develop helium-3 and tritium targets. The PAC would give its strongest support for this development and would be extremely keen to see the GANIL management prioritise a campaign based on this development.

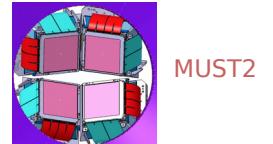
MUGAST: configuration

MUST2+GASPARD+TRACE

■ Intermediate configuration: MUGAST (MUST2-GASPARD-TRACE)

Particle detection:

- 4 GASPARD trapezoid DSSSD (backward/AGATA side)
- 1 Annular (S1-like) (backward close to 180°)
- 2 TRACE square detectors (@90°)
- 4 MUST2 Telescope (forward)
- Existing electronics (MUFEET+MUVI)



MUST2

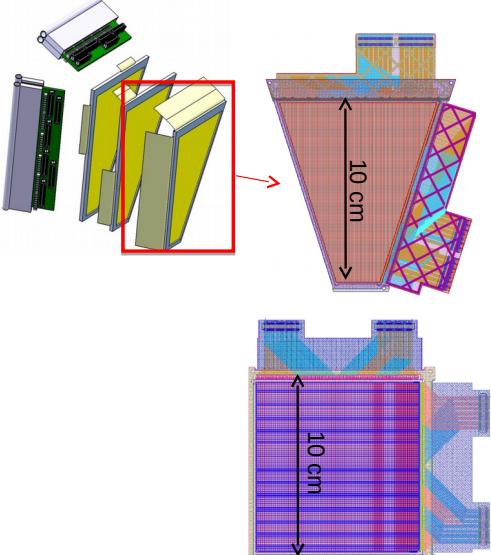
TRAPEZ.
+SQUARE

γ-detection (AGATA):

- Maximize eff: $\approx 8\%$ @1 MeV @ 18cm (*for 11 triples*)
- Benefit from very good energy resolution (\approx few keV)

Silicon developments

- New geometries
- New packaging : thin frame, kapton at 90°
- 6", NTD, random cut, reverse-mount
- Thin (500um) and thick (1.5mm)



Si detectors plan

1st layer (500 um, pitch~700 um)

- Trapezoid shape
 - 2 prototypes commissioned [IPNO]
 - 3 pre-serie ordered [Surrey, Santiago, IPNO] (MICRON SC)
- Square shape
 - 2 prototypes ordered [INFN-Padova]

2nd layer (1.5mm, pitch~3mm)

- 2nd layer square
 - 1 prototype ordered [INFN-Padova] (MICRON SC)

Collaboration with BARC Mumbai foreseen

This effort we share on an equal basis with colleagues from Padova in terms of investment money , namely

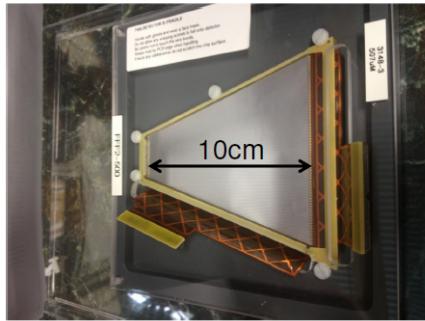
Commissioning of the trapezoid

Test bench at IPNO

>> 2 numerical test bench : PACI & iPACI

- PACI : 4X+4Y voies

- iPACI : 9X+9Y voies (short and long strips)



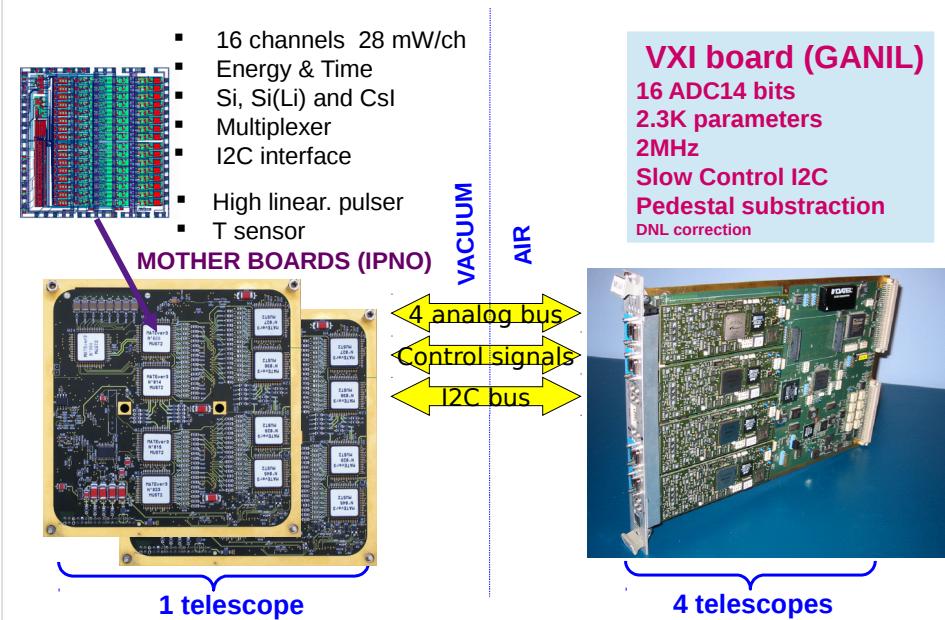
Kaptons will be modified

>> Analogic test bench (MUST2 electronics & GANIL DAQ) now being implemented

256 channels

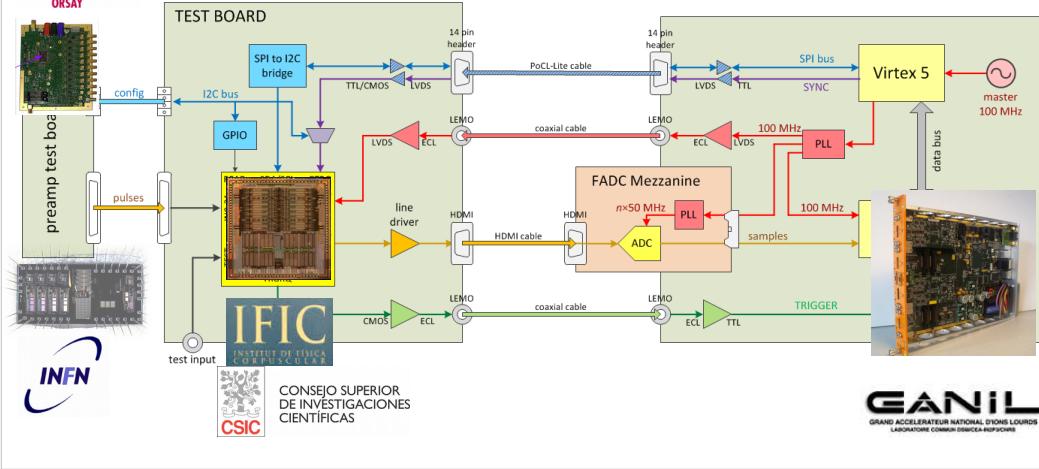
- test of new detectors (prototypes)
- test of new MUFEET boards for MUGAST

MUGAST Electronics : MUFEE + MUFI



Test bench: Det. Board + RO unit

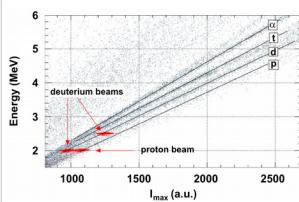
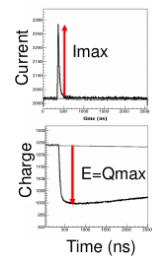
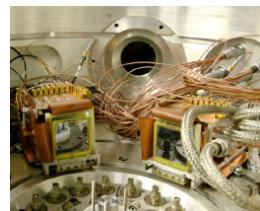
- Current and charge output (IPN)
- Charge + extended dynamics (INFN)
- different input polarities and signal Ranges
- 32 inputs with independent trigger
- Samples pulses @ 200 MSPS
- 224 samples from each pulse: 32 beforetrigger (30 valid) 192 after trigger
- Generates common Trigger Request signal
- No deadtime



First version of the ASIC just received. To be commissioned

R&D on pulse shape analysis

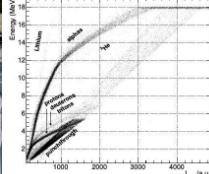
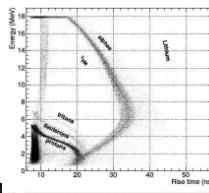
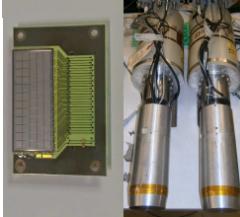
NTD, strips



FZ pad



Gamma dets



- NTD Single pad
- Segmented dets (DSSS&PAD)
- Gamma -ray dets

J.Duenas et al., NIMA(2012)

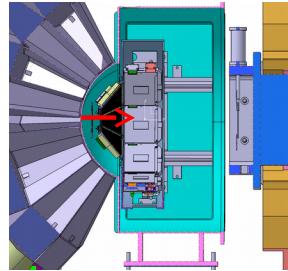
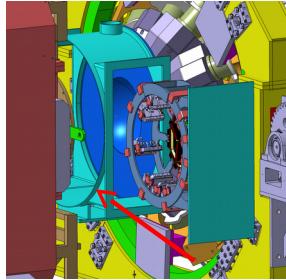
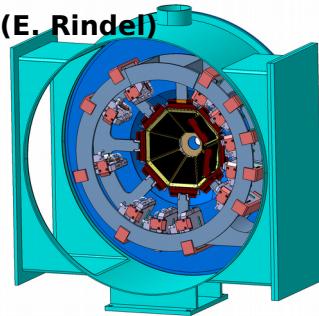
M.Assié et al., EPJA(2015)

D.Mengoni et al., NIMA(2014)

reaction chamber

Design of the reaction chamber @IPN (E. Rindel)

- Distance AGATA-target = 18 cm
- No electronics behind trapezoid detector
- Capability of handling more trapezoids
- Possibility of second layer.
- Fully removable backward array
- Option for cryogenic target

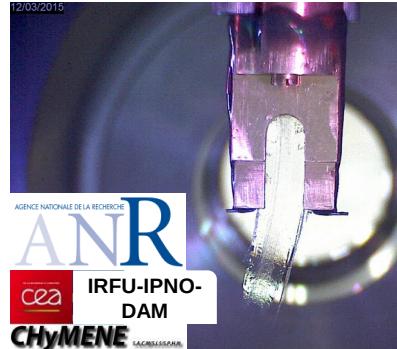


→ Financed: 42kE
Univ. of Surrey
(W. Catford)

Special targets

- He gas target
- cooled gas cell at 5–8 K to maximize density
- Havar windows, 3.8 microns
- Used at SPEG – GANIL
- ^3He version under study

- Hydrogen (h,d) target in a solid phase near triple point (~17K)
- Thickness 50 – 200 μm
- No window - C free
- Continuous flow in vacuum 2-10mm/sec
- Compatible with particle detection

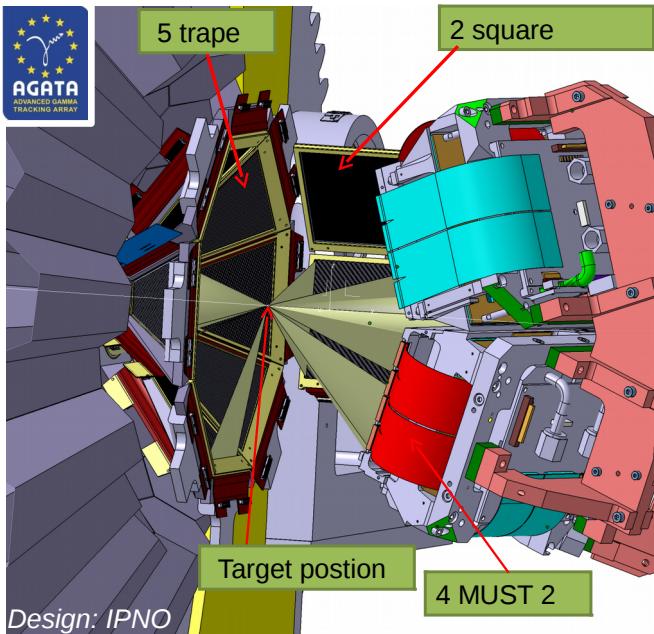


Special target to be used in inverse kinematics in reaction with particles to be detected into a silicon detector

System providing continuous extrusion of ^1H or ^2H through a rectangular extruder nozzle defining the target-film thickness

Unique setup for combining Chymene with particle and gamma

MUGAST+AGATA

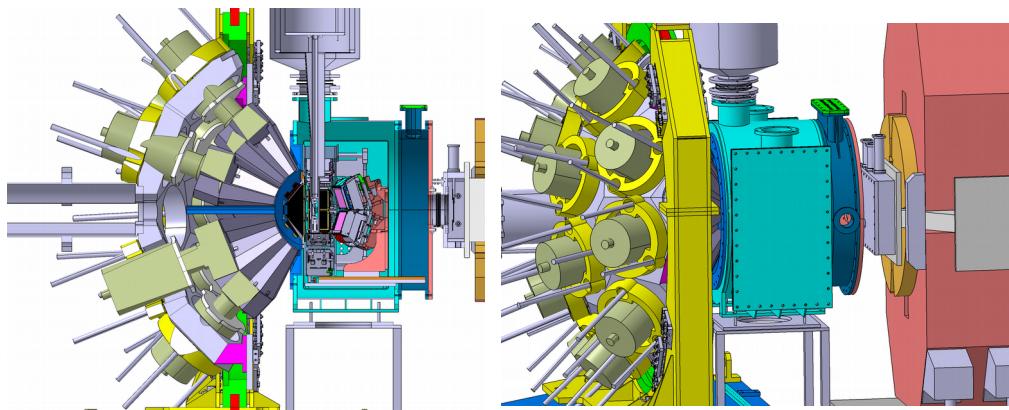


Si detectors configuration

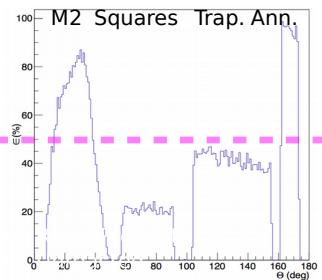
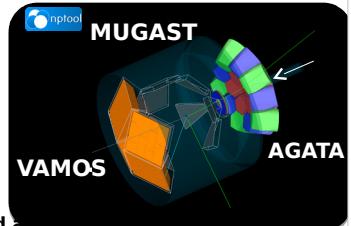
- 5 Trapezoids + 1 Annular at bck angles
 - Distance : **10.5 cm**
 - Ann: 12.5cm
 - Angles: [104.2-155.2]° + [159-169.2]°
- 2 Squares around 55.8° - 90°:
 - Distance : 13.5 cm
 - Angles: [60,90]°
- 4 MUST2 telescopes at fwd angles
 - Angles : [10-50]°

AGATA distance: 18 cm

MUGAST+AGATA @VAMOS



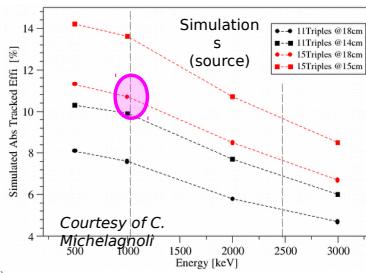
Simulations



Particle detection

- 4 MUST2 Telescopes at forward angles:**
 - Distance : 18 cm [10-50] $^{\circ}$
- 2TRACE squares around 90 $^{\circ}$:**
 - Distance : 13.5 cm [60,90] $^{\circ}$
- 5 Trapezoids and one Annular:**
 - Distance : 10.5 cm - Ann: 13.4cm
 - Angles: [105-155] $^{\circ}$ + [161-174] $^{\circ}$

A. Matta et al.,
J.Phys.G 43 045113 (2016)



γ detection

At 18 cm (current goal)

- $\epsilon(1.0 \text{ MeV}) \sim 8\%$
- $\epsilon(2.5 \text{ MeV}) \sim 5\%$
- $\epsilon(1.0 \text{ MeV}) \sim 11\%$
- $\epsilon(2.5 \text{ MeV}) \sim 8\%$

| >> DETECTORS | | | | | |
|---|-------------------|------------------------------|------|--------|--|
| Trapezoids proto (x2) | Commissionning | IPNO, P2IO | | | |
| Trapezoids pre-serie (x3) | Ordered | Surrey/IPN O +Santiago | | | |
| Squared proto (x2) + Thick proto | Ordered | INFN- Padova | | | |
| Annular (x1) th = 500um | Available | IPNO, Surrey | | | |
| >> ELECTRONICS | | | | | |
| MUST2 FEE boards x10 +1? | Available | | | | |
| (MUST2 FEE new boards x7 boards+components+ASIC | Order 2016 | IPNO, Saclay, LPC | | | |
| MUST2 Digital boards (x4) | Available | | | | |
| Kaptons prototypes | Ordered: 09/16 | test | IPNO | | |
| Final Kaptons (x48) | Designed | IPNO | | | |
| Cables & feedthroughs | 2016-2017 | IPNO | | | |
| >> MECHANICS | | | | | |
| Chamber supports | VAMOS and | Final for 2016 | end | Surrey | |

- **Reaction chamber design ongoing (fully funded)**
- Test bench mounted @ IPN and operational
- Kaptons:
 - design close to final:
 - Prototypes ordered for test
- ASIC for MUST2: OK
- new MUFEE : OK
- Cryogenic target possibility (under discussion)

Summary & Conclusions

- ❑ High-resolution structure and reaction studies using transfer reactions
- ❑ MUGAST array available in 2018
- ❑ Physics program at GANIL using AGATA @ VAMOS acknowledge by the PAC

MUGAST collaboration

- IPN Orsay , CEA Saclay, GANIL, LPC Caen (France)
- INFN Univ. of Padova, INFN-LNL Legnaro , INFN Univ. of Milano (Italy).
- Univ. of Huelva, Univ. of Santiago de Compostella, Univ. of Valencia (Spain)
- Univ. of Surrey, STFC Daresbury (UK)
-



GASPARD

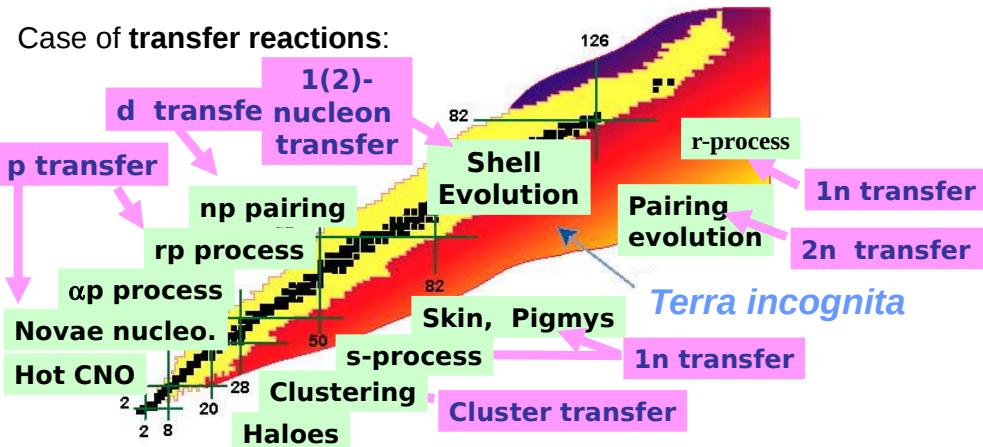
TRACE

The collaboration behind this development nowadays

| ITEM | STATUS | who |
|---|----------------------------|---------------------------------|
| DETECTORS | | |
| Trapezoids proto (x2) | Commissioning | IPNO |
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| Annular (x1) th = 500um | Available | -- |
| MUST2 (x4) | Available | -- |
| ELECTRONICS | | |
| MUST2 FEE boards (x10) | Available | -- |
| (MUST2 FEE new boards (x5) boards+components+ASICs) | To be ordered | |
| MUST2 Digital boards (x4) | Available | -- |
| Kaptons (x48) | To be designed and ordered | |
| Cables & feedthroughs | To be ordered | |
| MECHANICS | | |
| Chamber and supports | Under design | Surrey |
| Cooling blocks | Under design | Surrey |

Direct Reactions

A great tool to investigate Exotic Nuclei and Nucleosynthesis



Good energy regime : few MeV/u → few tenths of MeV/u

Methodology : Radioactive Ion Beam $\xrightarrow{\text{ }} \text{Light target (H,He...)}$

Detect the recoil particle with high accuracy

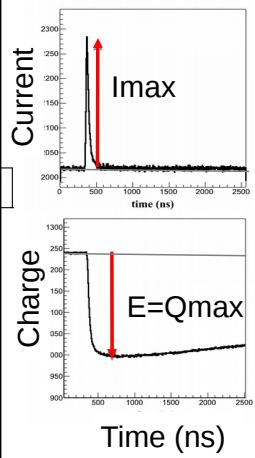
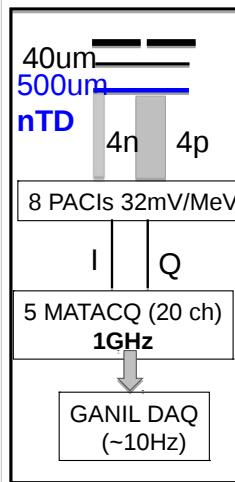
Silicon technology

PSD for Z=1 particles

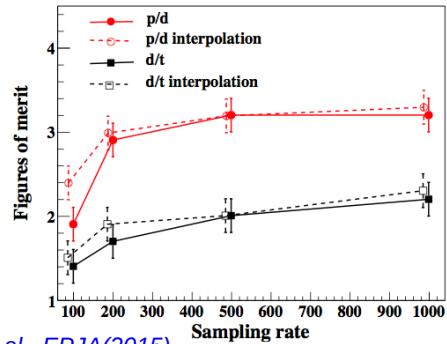
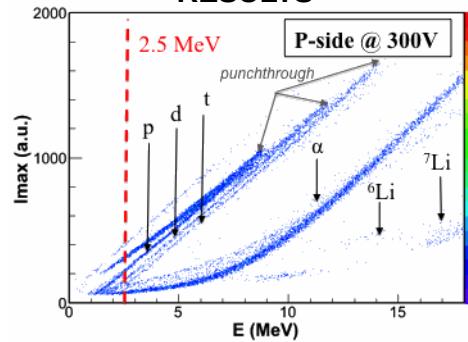
Test experiment

(IPNO tandem)

$^7\text{Li} + ^{12}\text{C}$ @ 35 MeV



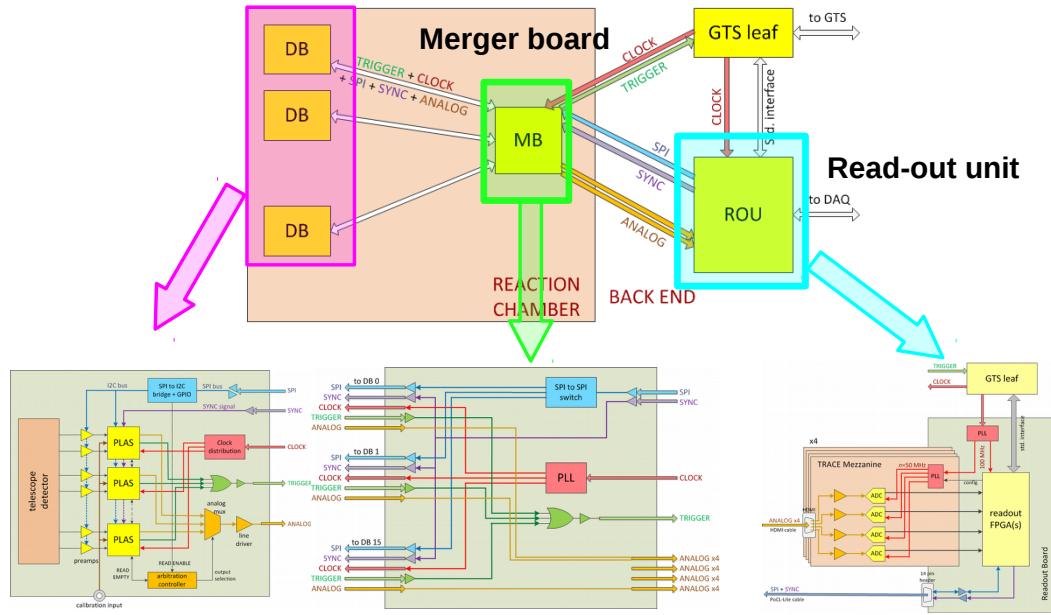
RESULTS



M.Assié et al., EPJA(2015)

Electronics architecture

Detector board



Physics with MUGAST

2 dedicated workshops organized at Orsay and Padova

- Shell structure evolution & deformation
 - Mapping of neutron orbitals around N=28
 - Oblate driving force in n-deficient nuclei above ^{56}Ni
 - Shape transition along and across N=28
 - Interplay of single-part and collective structures in ^{46}Ca
 - Shell evolution toward the island of inversion
 - Island of Inversion and shape coexistence in $^{30,31}\text{Mg}$
 - ^{75}Kr : Shape coexistence in characterisation in light Kr
- Neutron-proton pairing
 - np-pairing in fp-shell
- Astrophysics
 - Breakout from hot CNO to rp process
 - Explosive H-burning in Novae
 - s-process $^{79}\text{Se}(\text{n},\gamma)$
 - s-process $^{60}\text{Fe}(\text{n},\gamma)$
- Reaction dynamics
 - Space-time characterization of emitting sources in HI collisions

F.Flavigny, O.Sorlin et al.

A.Goasduff, D.Mengoni, et al.

L.Fortunato, D.Mengoni et al.

S.Leoni et al.

A.Matta, W.Catford, N.Orr, et al.

B.Fernandez-Dominguez et al.

A.Matta, W.Catford, N.Orr, et al

M. Assié et al.

C.Diget et al.

N.de Sereville, F.Hammache et al.

G.de Angelis et al.

A.Matta, W.Catford, N.Orr, et al.

G. Verde, A.Chbihi, Q.Fable

"Reaction and structure studies using the MUGAST+AGATA setup at VAMOS"

D.Beaumel & D. Mengoni

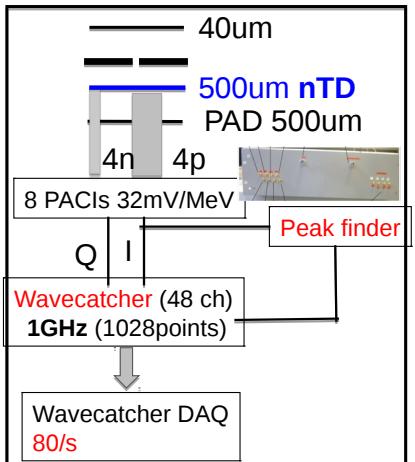
"Umbrella" *Lol submitted to the coming GANIL PAC*

PSD for Z=2 particles

(d,³He) on mylar
@ 26 MeV

(IPNO tandem)

- ³He/⁴He discrimination
- test of analog peak finder on current

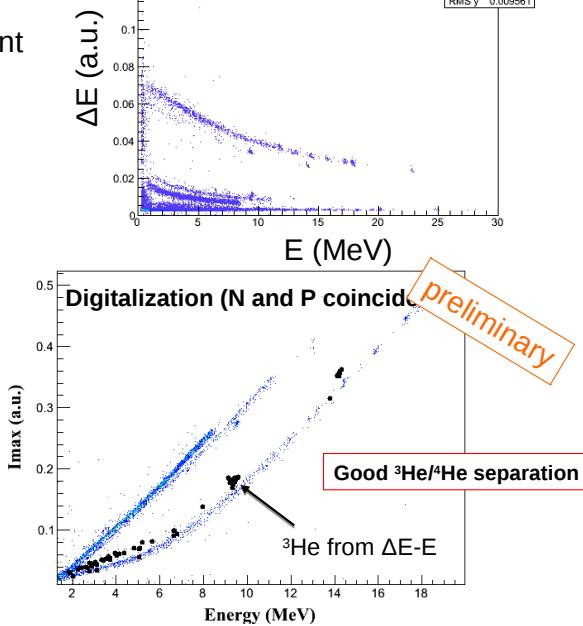


Under analysis

Add a ΔE detector for PID

ΔE-E with 40μm detector

| | |
|---------|----------|
| Entries | 44104 |
| Mean x | 2.833 |
| Mean y | 0.005518 |
| RMS x | 3.157 |
| RMS y | 0.009561 |



Trapezoid detectors and test bench

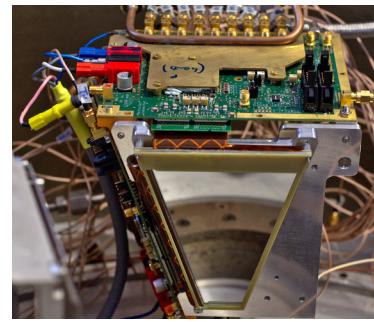
Ordered to Micron semiconductors :

- 2 trapez. prototypes nTD DSSSD ordered by IPN
(delivered end of june 2015)
- 3 more trapezoid « series » ordered (1 Surrey, 1 Santiago University, 1 IPN)
- 2 square proto. nTD DSSSD + 1 thick sq. DSSSD
(ordered by INFN end of 2014, under fabrication)

Test bench mounted @ Orsay :

- Digital test bench (GASPARD purposes)
- Analog test bench (256 channels) : Trapezoid + MUFEE + MUFI + GANIL acq.

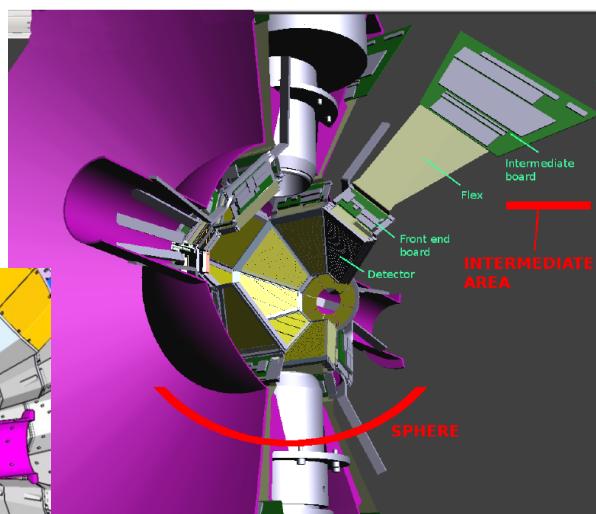
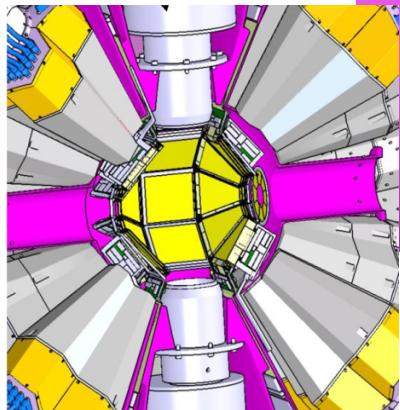
Aim End of 2016 validation of prototypes



Electronics / Integration

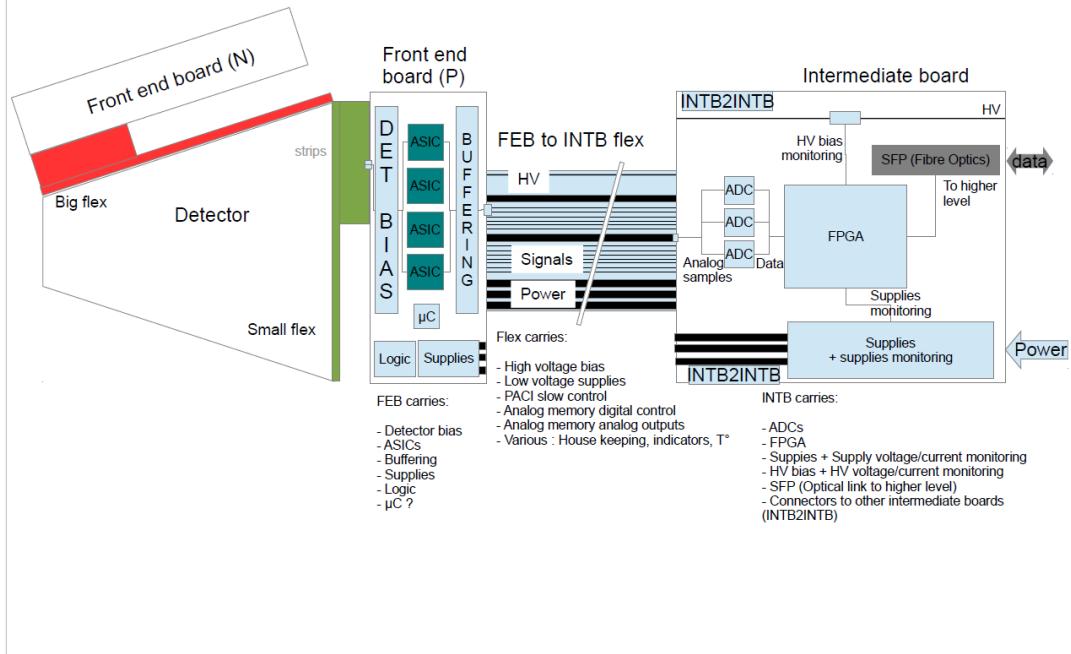
Our challenge:

- ~ 10.000 channels
- Transparency to γ -rays



Detailed design under elaboration (IPNO)

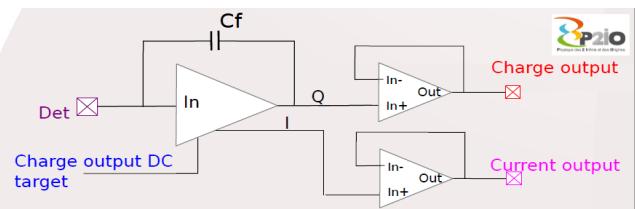
Electronics architecture



iPACI : 9 channel integrated charge and current output preamplifier



1-Channel performance (simulated!)



| Charge Output | |
|---|--------------------|
| Energy max (Si) | 50 MeV |
| Charge signal swing (50MeV) | 1.6V single ended |
| Charge gain | 32mV/MeV |
| Equivalent noise charge (Input-refered, FWHM) | 7 keV 830 e- Si |
| Charge resolution | 12.8 bits ENOB |
| Charge non-linearity | < 2% |
| Charge output recovery time | 100µs |
| Current Output | |
| Current gain | 7kΩ |
| Current signal swing | 1.5V single ended |
| Current signal BW | [4MHz .. 120MHz] |

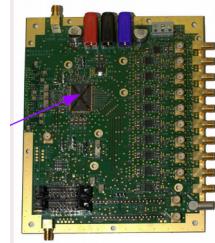
| System data | |
|------------------------------|--|
| Technology | AMS 0.35µm BICMOS |
| Supply | 3.3V |
| Detector's input capacitance | Compatible with [10pF .. 40pF] range |
| Compensation cap | Digitally tunneable within [0.5pF .. 2.25pF], step 0.25pF |
| Current consumption | 12mA (40mW) / Channel |
| Size | 220 x 100µm (PACI block) + 130 x 70µm (Buffer ch) + 130 x 70µm (Buffer cu) |

Other development: **multichannel CSP ASIC**
A.Pullia, S.Capra
INFN / Univ. Milano

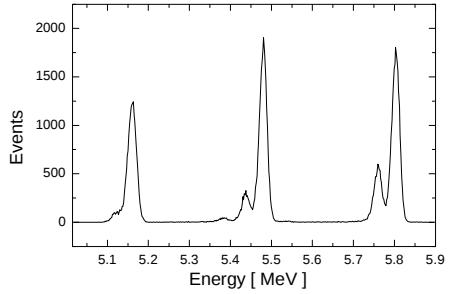
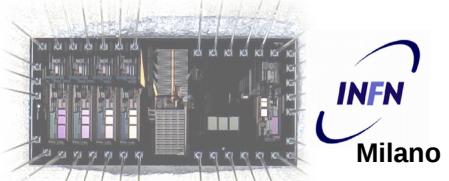


Preamplifier ASIC

- Current and charge output
- Presently 9 ch



- Charge output and extend dynamics
- Presently 4 ch



| ITEM | STATUS | who |
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| MECHANICS | | |
| Chamber and supports | Under design | Surrey |
| Cooling blocks | Under design | Surrey |

R&D on pulse shape analysis

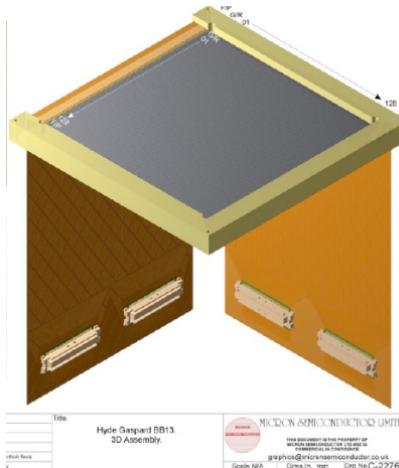
Goal: establish the method for light particles and highly segmented detectors

- Effect of segmentation
- Lower E threshold for each particle ?
- Minimum sampling frequency (Digital elec)
- n-side or p-side ?
- Filters (e.g. Haar wavelets transform, ...)
- Other possible observable : Rise time ?
- Radiation damage
-

test experiments
at the IPNO tandem

Detector:

- 500 um nTD DSSD
- BB13 design of MSL
- 8° cut
- 128X+128Y
- pitch<500um
- special package
- 90° kapton readout
- high density
- connectors



Title: Hydrex Gaspax BB13
3D Assembly.
Version No.:
Y
Scale: N/A
Dims: in mm Org No: C-2276
MICRON SEMICONDUCTOR LIMITED
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REPRODUCTION IN WHOLE OR PART
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graphical@micronsemiconductor.co.uk

The ChyMENE H/D target system

Cible d'HYdrogène Mince pour l'Etude des Noyaux Exotiques

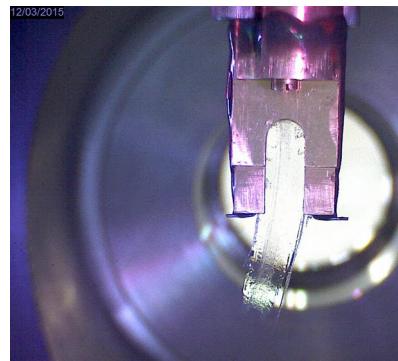
System providing continuous extrusion of ^1H or ^2H through a rectangular nozzle defining the target-film thickness

- Hydrogen target in a solid phase near triple point
 $\text{sH}_2 \sim 17 \text{ K}$
- Thickness 50 – 200 μm
- No window - C free
- Continuous flow in vacuum
2-10mm/sec
- Compatible with particle detection

ChyMENE collaboration :

- CEA/IRFU Saclay
project coordinator: A. Giacoppo
- IPN Orsay
- CEA/DAM Bruyères

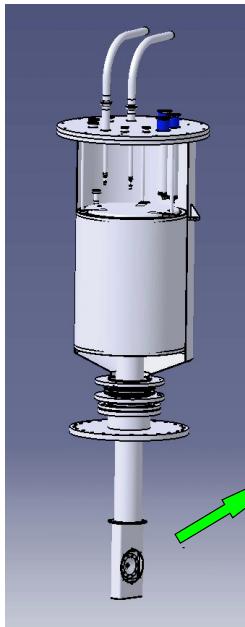
Grant from French ANR ~550k€



Cooled Helium gas target IPNO/ Accelerator division

Designed for the use of direct reactions with $^{3,4}\text{He}$ probe in Inverse kinematics
Concept : cooled gas cell at 5~8 K to maximize density

Possible reactions: $(\alpha, {}^3\text{He})$, (α, t) , $(\alpha, {}^6\text{He})$, ...



Previously used
at SPEG / GANIL



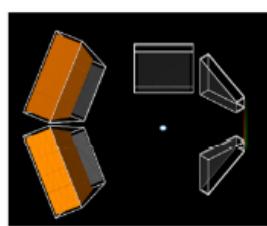
$\varnothing 16 \text{ mm}, 3\text{mm thick}$
Havar windows, 3.8 microns
 $T = 8.5 \text{ K}$
 $P = 1 \text{ bar}$

Now under study : **${}^3\text{He}$ version**
 $({}^3\text{He}, d)$ proton stripping
 $({}^3\text{He}, p)$ d transfer for np pairing

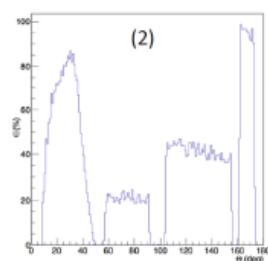
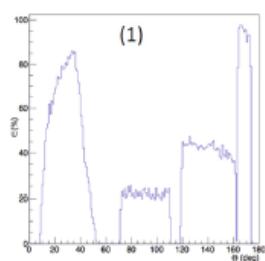
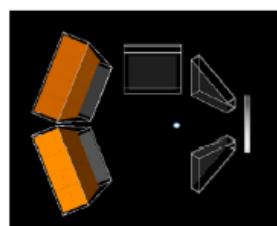
Simulations / Detection efficiency

Using NPTool package

Config Initiale



Translation Trapézes +carrés vers M2 (~4cm)
+ update géométrie carrés



Last geometrical configuration available on demand

MUGAST with EXOGAM & PARIS

« MUGAST » configuration = MUST2 + GASPARD (trapeze) + TRACE (square)
available for AGATA campaign at GANIL (2017)
read by MUST2 electronics (MUFEE+MUVI)

Possible gamma detector's configurations :

- 6 PARIS clusters (if available)
- 6 EXOGAM

