INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

The MUGAST/GRIT project for direct reaction studies

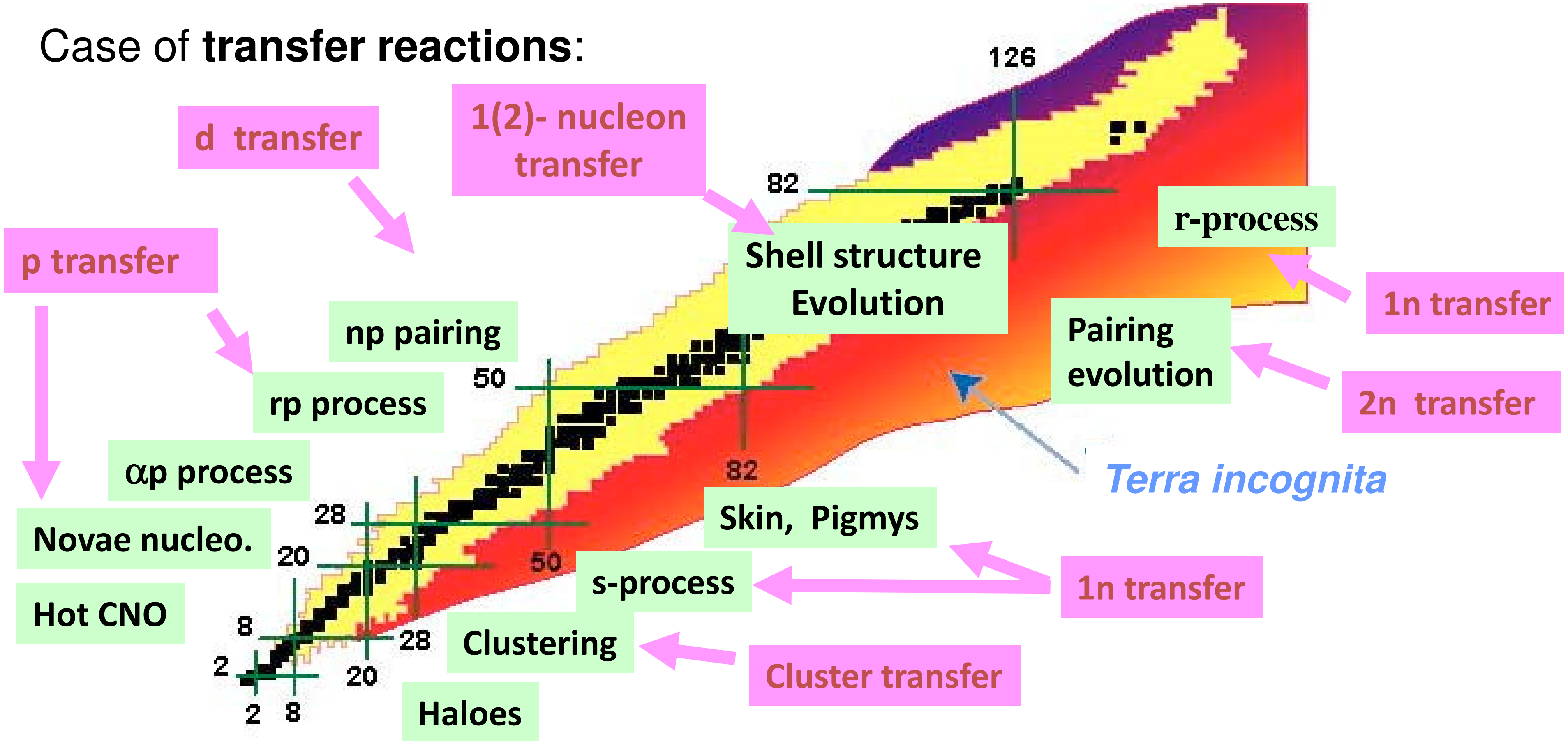
- Introduction
- General features of the GRIT array
- MUGAST: an intermediate step
- Few physics cases for MUGAST
- Current developments towards GRIT

D.Beaumel,
IPN Orsay

Direct reactions

A great tool to investigate Exotic Nuclei and Astrophysical processes

Case of **transfer reactions**:



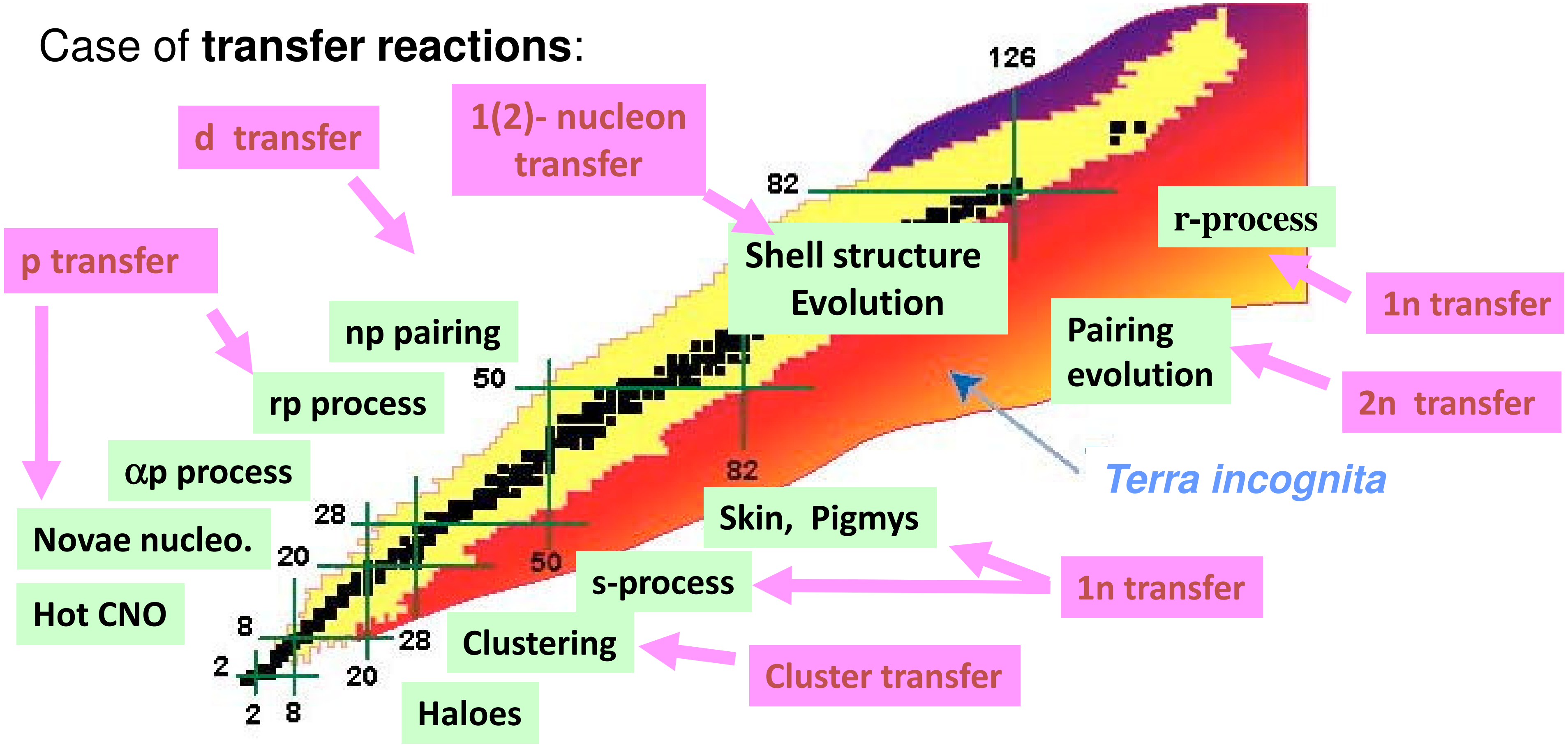
Good energy regime : 5 ~ 50 MeV/u → **Core program for ISOL facilities**

GANIL spiral2 laboratoire commun CEA/DRF CNRS/IN2P3 — SPES exotic beams for science — ISOLDE — FAIR ? Low Energy Branch

Direct reactions

A great tool to investigate Exotic Nuclei and Astrophysical processes

Case of **transfer reactions**:



Good energy regime : 5 ~ 50 MeV/u ➡ **Core program for ISOL facilities**

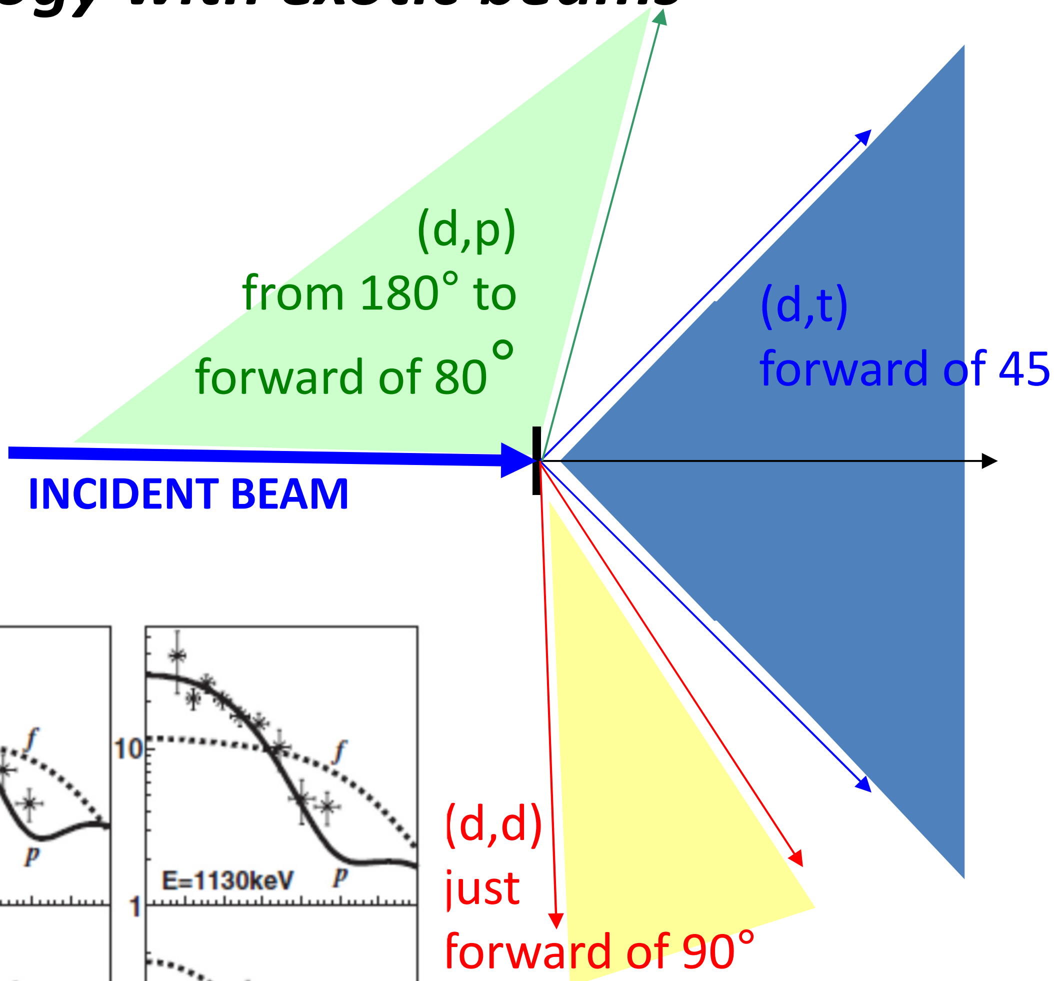
Methodology : **Radioactive Ion Beam** ➡ **Light target (H,He…)**
Detect the recoil particle with high accuracy
Silicon technology

Initial methodology with exotic beams

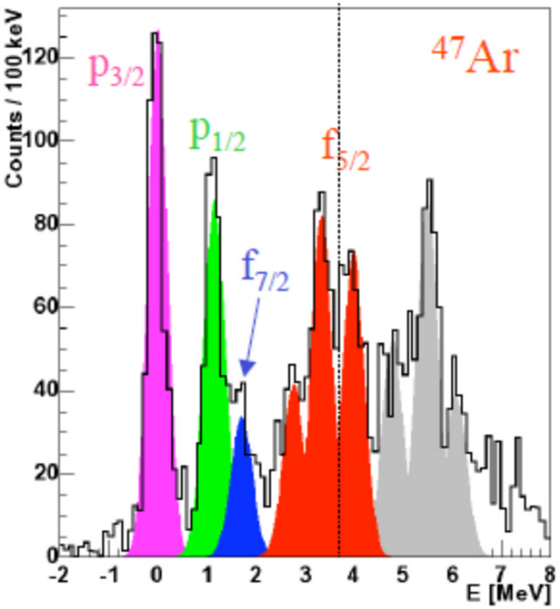
Detect the light recoiling particle E_L , Θ_L

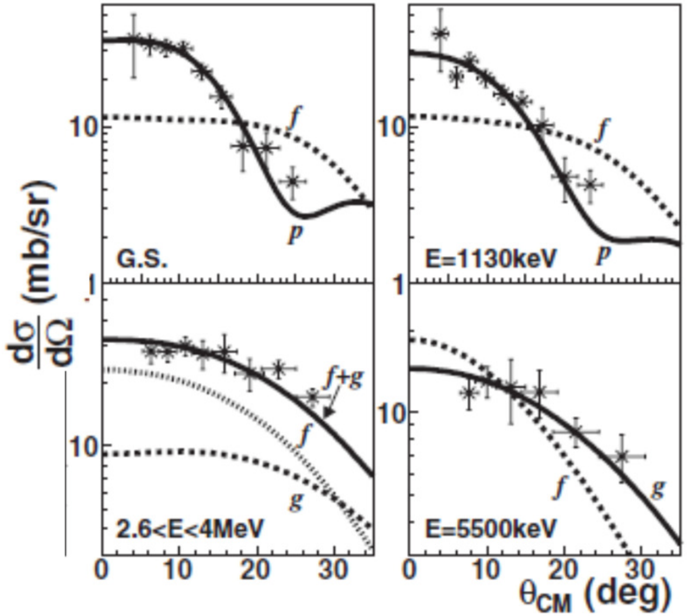
- Excitation energies
- Differential cross-sections

⇨ **Spin, parities and**
Overlaps < i|f >
(Shell Model, ab initio,..)

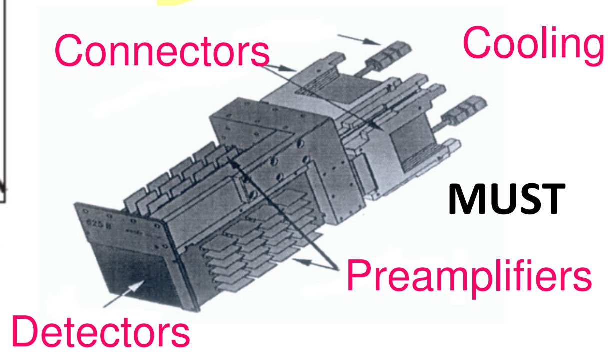


Ex: ^{46}Ar(d,p) @ GANIL/SPEG
using the **MUST** array





Reduction of N=28 gap
L.Gaudefroy, et al., PRL (2006)



Y.Blumenfeld et al., NIM A421 (1999)

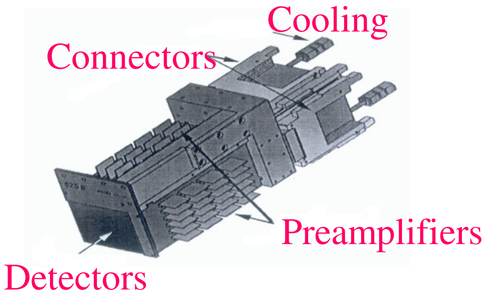
Silicon arrays landscape at IPN-Orsay

Light beams | **Fission fragments**

1997 — 2007 — 2019/23

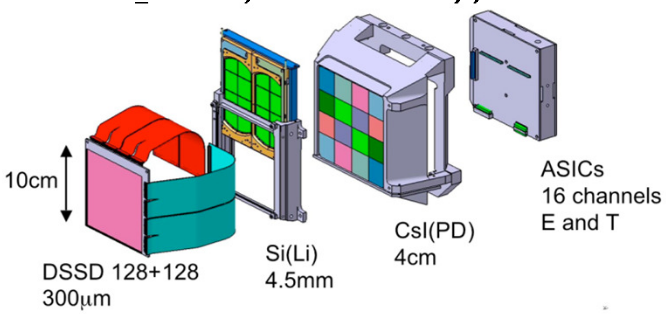
MUST

Coll.: IPN,CEA-Saclay, DAM



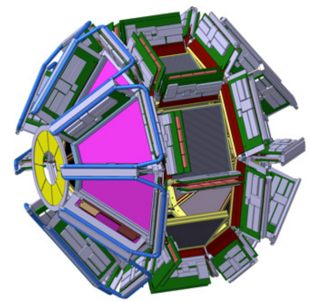
MUST2

Coll.: IPN,CEA-Saclay, GANIL



MUGAST/GRIT

Coll.: IPN, LPC, INFN, BARC, Surrey,GANIL, Valencia,Santiago,Huelva



Particle spectroscopy → **Particle-γ Spectroscopy**

E_x resolution: ~500 keV

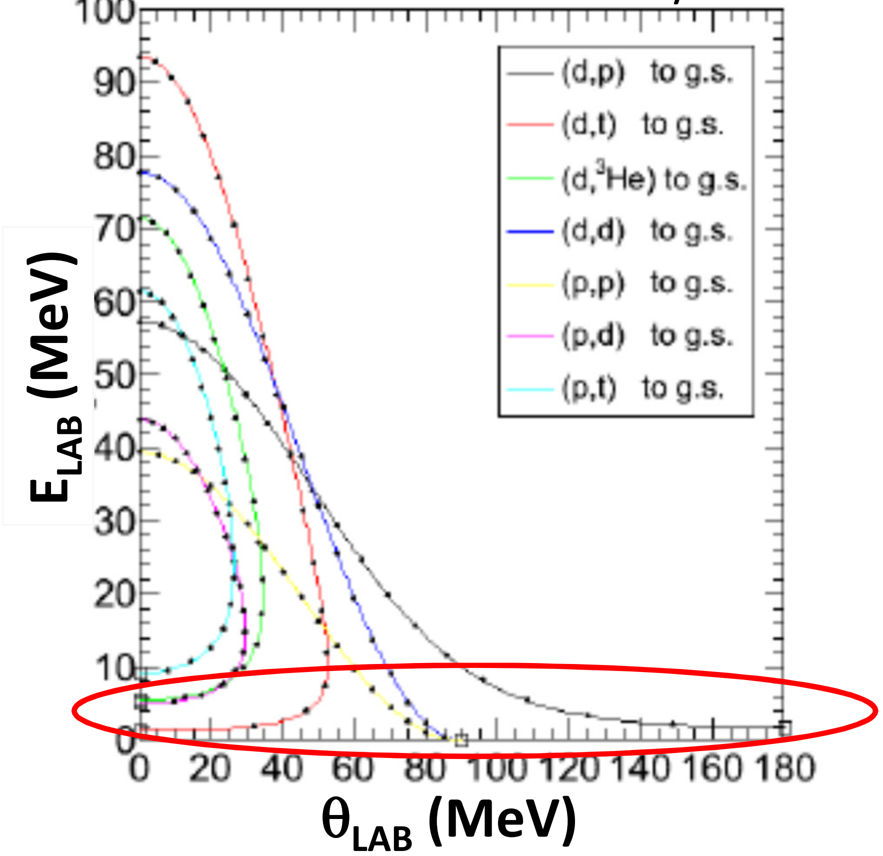
E_x resol.: ~5keV (AGATA)

Constraints due to kinematics

Need

- **Large angular acceptance**
- **Large dynamic range**
- **Low threshold**
- **Thin target**

^{132}Sn beam at 10 MeV/u



Kinematics weakly dependent
On mass (and on E) of the beam

General purpose system

Limitations

- **Target thickness**
- **Kinematical compression**
  (d,p) with 1mg/cm2 CD2
  ΔEp ~100 keV $\Rightarrow$ ΔEx ~ 400 keV

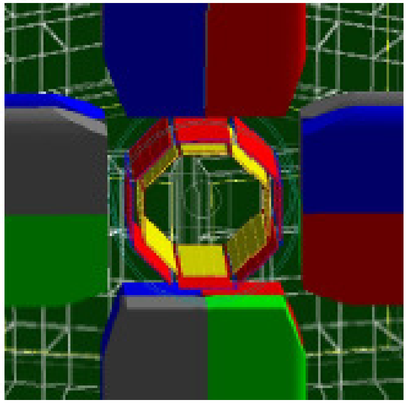
NB: Need also

- **Good PID for the recoil and the beam-like residue**

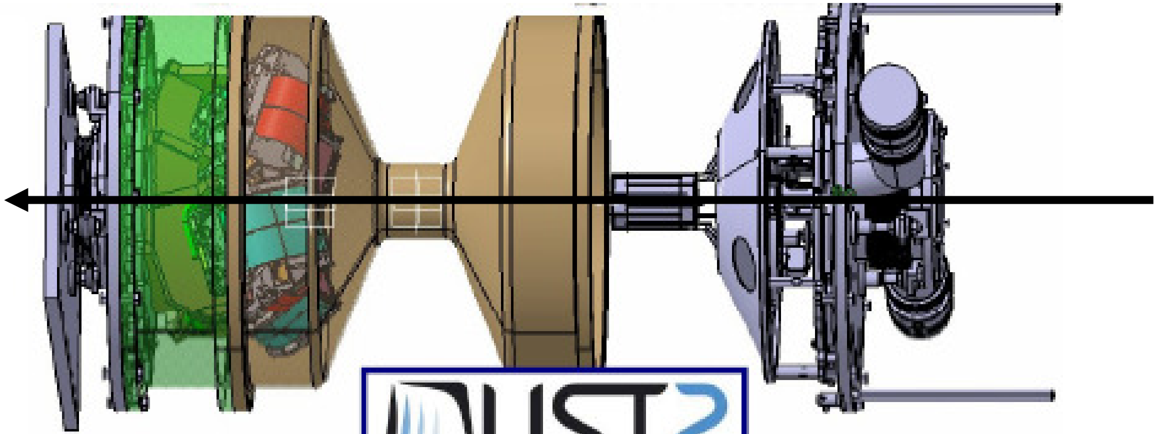
Development of new systems / combinations

Si-based systems currently operating for p-γ coincidence measurements

γ-rays $\Rightarrow E_x$



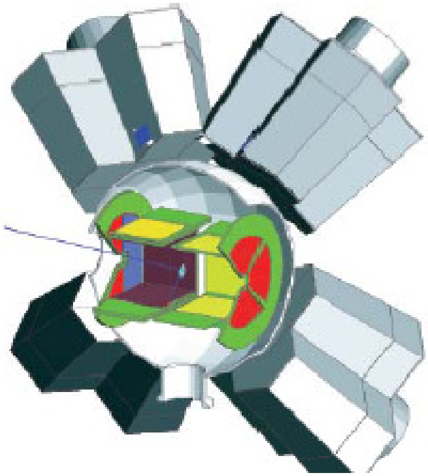
4 EXOGAM

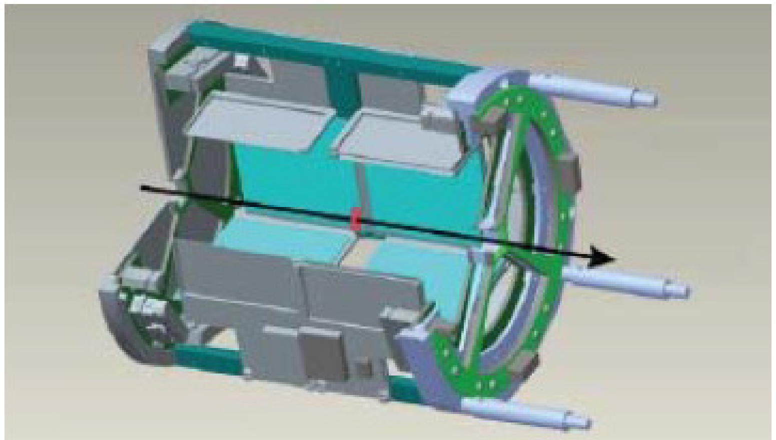


MUST2

TIARA

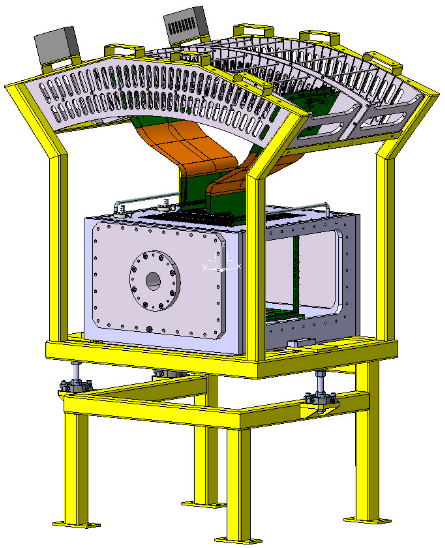
T-REX + MINIBALL



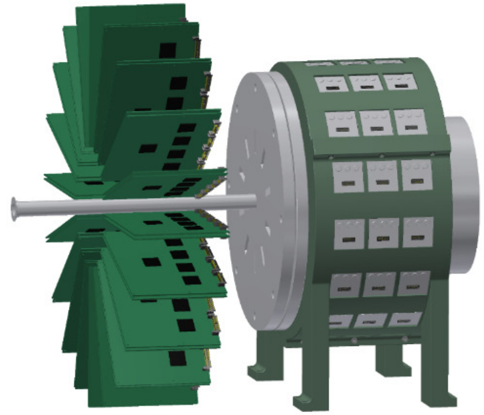


New Instruments for Direct Reactions studies in Europe

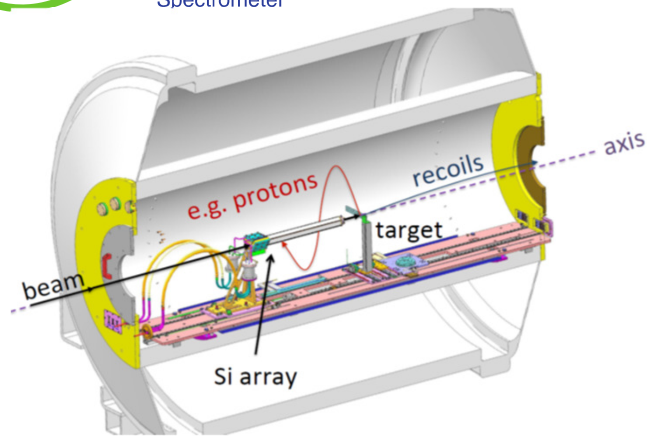
actar TPC



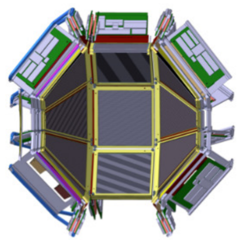
SpecMAT
Spectroscopy in a Magnetic Active Target

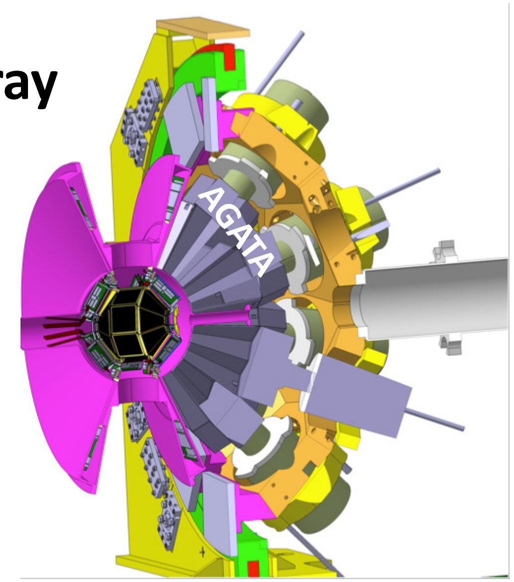


ISOLDE Solenoidal Spectrometer



GRIT Si array



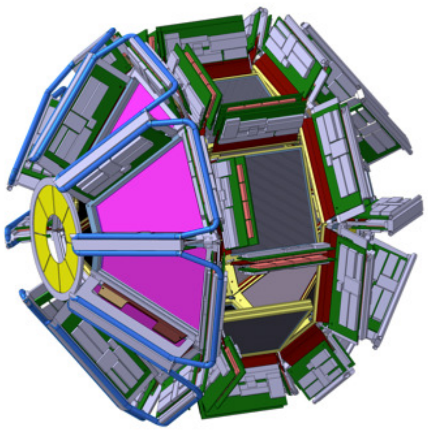


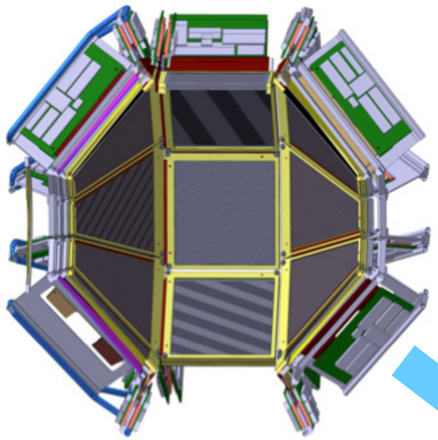
The GRIT project

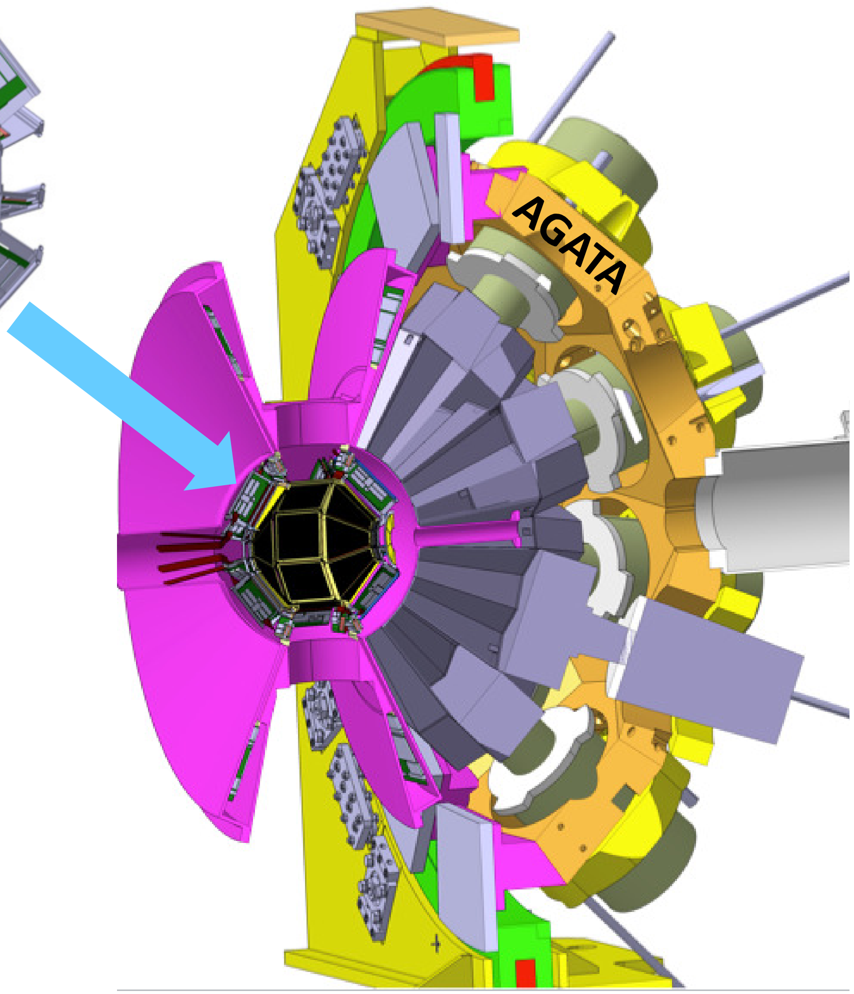
(Granularity, Resolution, identification, Transparency)

(GASPARD-TRACE collaboration)

4π Si array fully integrable in AGATA & PARIS







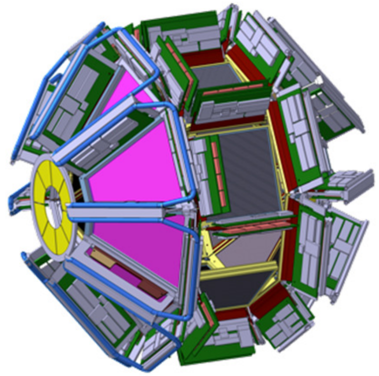
- High efficiency for particles
- High granularity (strip pitch < 1 mm)
- Large dynamical range

Layers of Silicon

- 500 um DSSD pitch < 1mm
- 1(or 2) x [1.5 mm DSSD pitch~3mm]

- Special targets (Cooled ^{3,4}He cell, pure H, tritium)
- PID using Pulse Shape Analysis techniques
- New Integrated electronics

The GRIT collaboration



Management Board:

D. Beaumel (Orsay)= spokesperson, **M. Assié** (Orsay),
D. Mengoni (INFN Padova), **A. Pullia** (INFN Milano)

Steering committee :

R. Bougault (LPC Caen), Y. Blumenfeld (IPN Orsay), S. Leoni (INFN-Milano), G. De Angelis (LNL, Italy) , A. Gadea (Valencia, Spain), W. Catford (U. of Surrey, UK), A. Shrivastava (BARC Mumbai, India), G. De France (GANIL) = chair

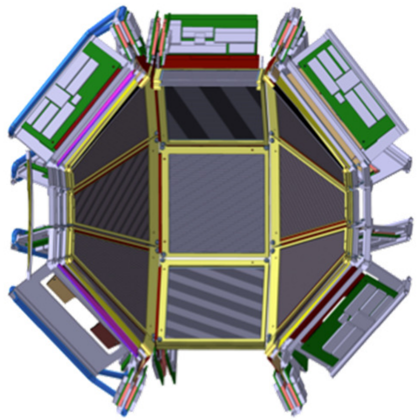
Collaboration:

France: **In2p3 (IPNO, LPC), GANIL**
India: **BARC Mumbai**
Italy: **INFN/U. Padova, INFN Legnaro, INFN/U. Milano, INFN/U.Firenze**
Spain: **Univ. of Valencia, Univ. of Santiago,** Univ. of Huelva
UK: **Univ. of Surrey,** STFC Daresbury

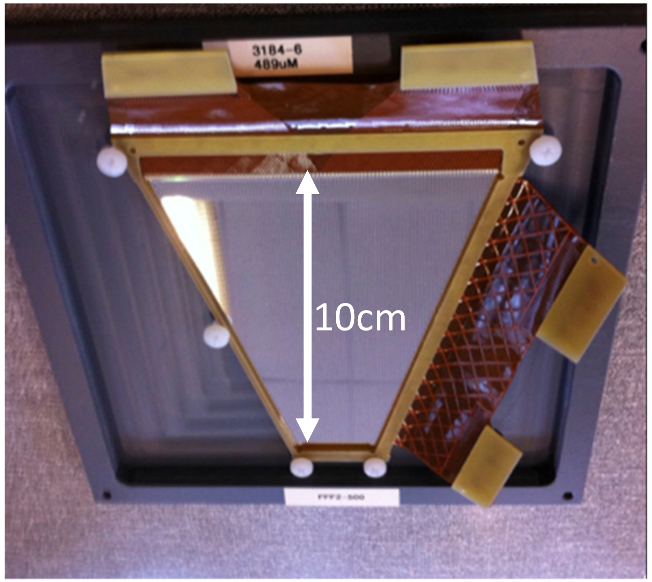
MoU in progress

Detectors for GRIT

- Trapezoid and squared geometries
- 6'' wafers, 128 X + 128 Y
- Special packaging: very thin frame Kapton readout at ~90°
- NTD, random cut, reverse mount
- Thin and thick

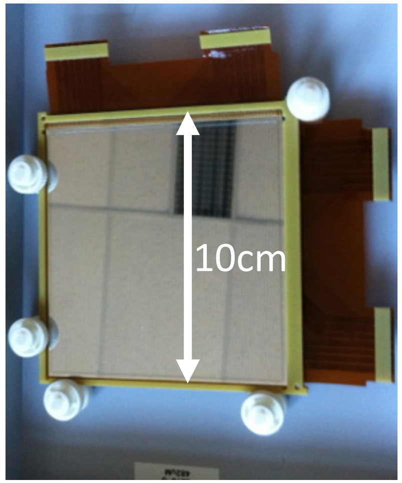


Trapezoidal DSSD



Commissioned (Micron SC Ltd) :
- 2 prototypes 500um IPNO
- 4 pre-series (Surrey U., IPNO, Santiago)

Squared DSSD



Commissioned (Micron SC Ltd) :
- 2 prototypes 500um INFN
- 1 prototype 1.5mm INFN

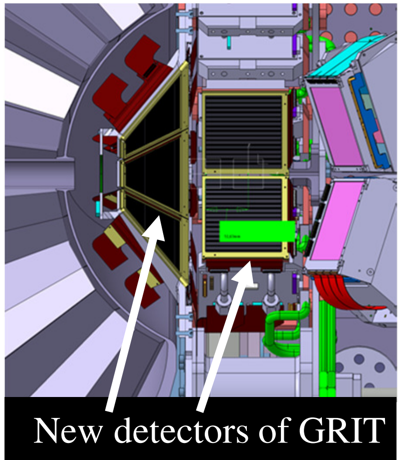
Under development
- 2 proto 500 um BARC Mumbai (Semiconductor Lab , Chandigarh)

MUGAST: an intermediate step towards GRIT

MUGAST: *- New detectors of GRIT + MUST2 electronics + few telescopes*

- Coupled with AGATA @ VAMOS

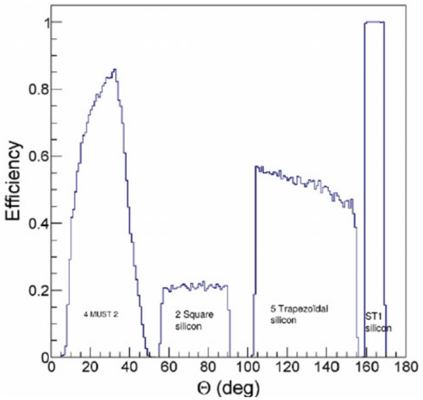
$\Rightarrow$ ***First High resolution Direct Reactions studies at Ganil (new SPIRAL1 beams)***



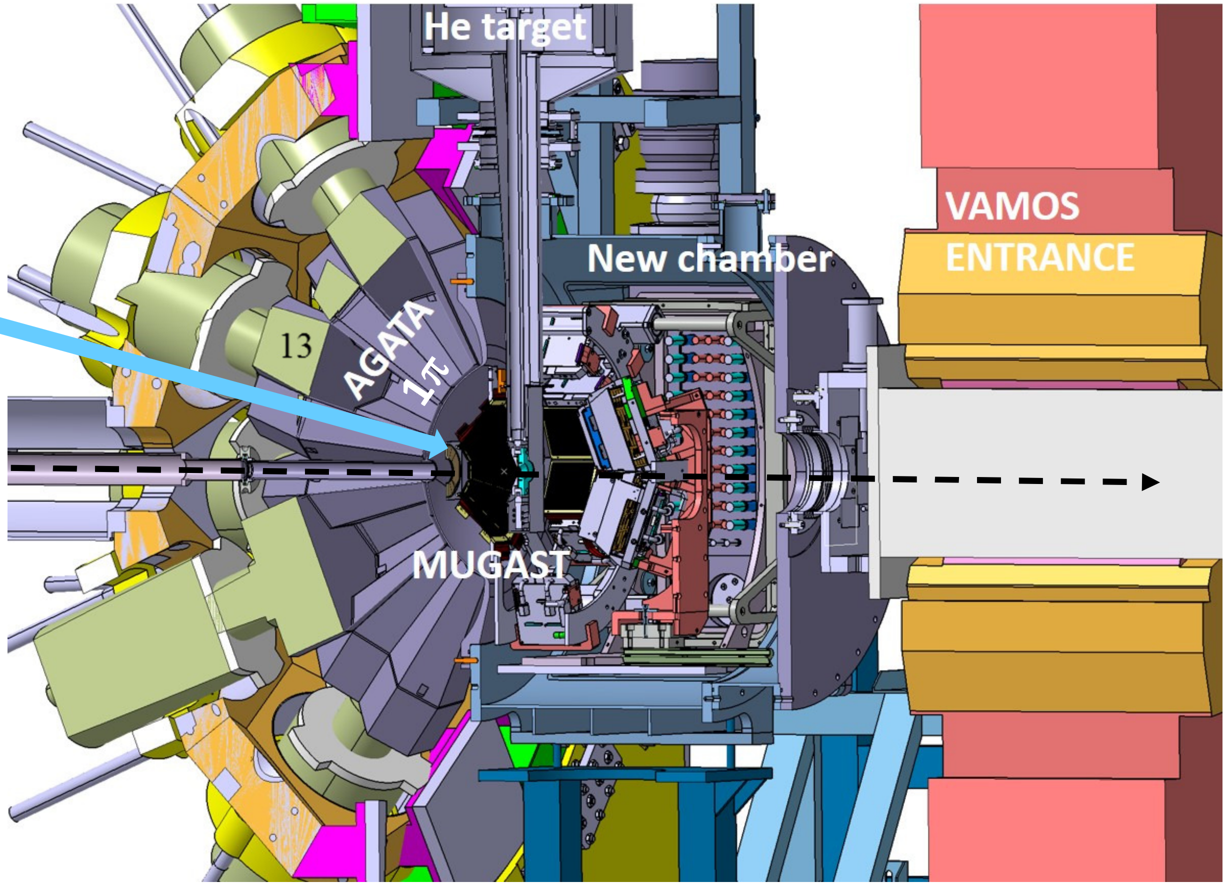
~ 3000 channels

MUGAST configuration:

- 5 trapezoids backward
- 2 Squared around 90deg.
- 4 MUST2 telescopes forward



RI Beam



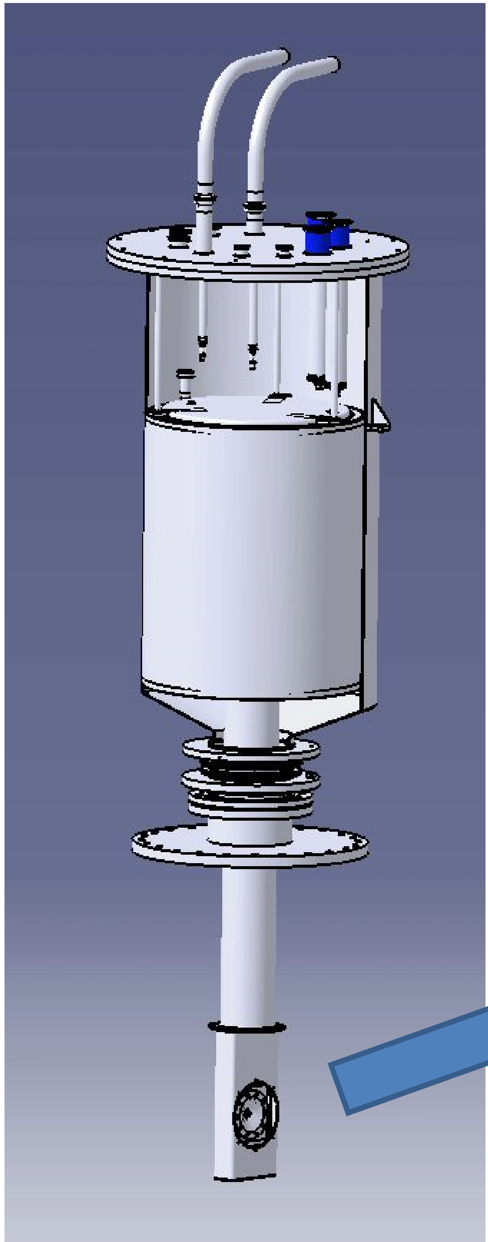
Efficiency for 1π AGATA : ~10% at 1 MeV

Funding: In2p3, P2iO, GANIL
INFN, Surrey, Santiago

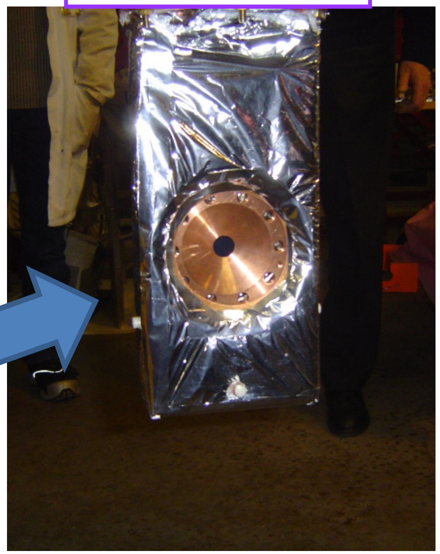
First Campaign in 2019

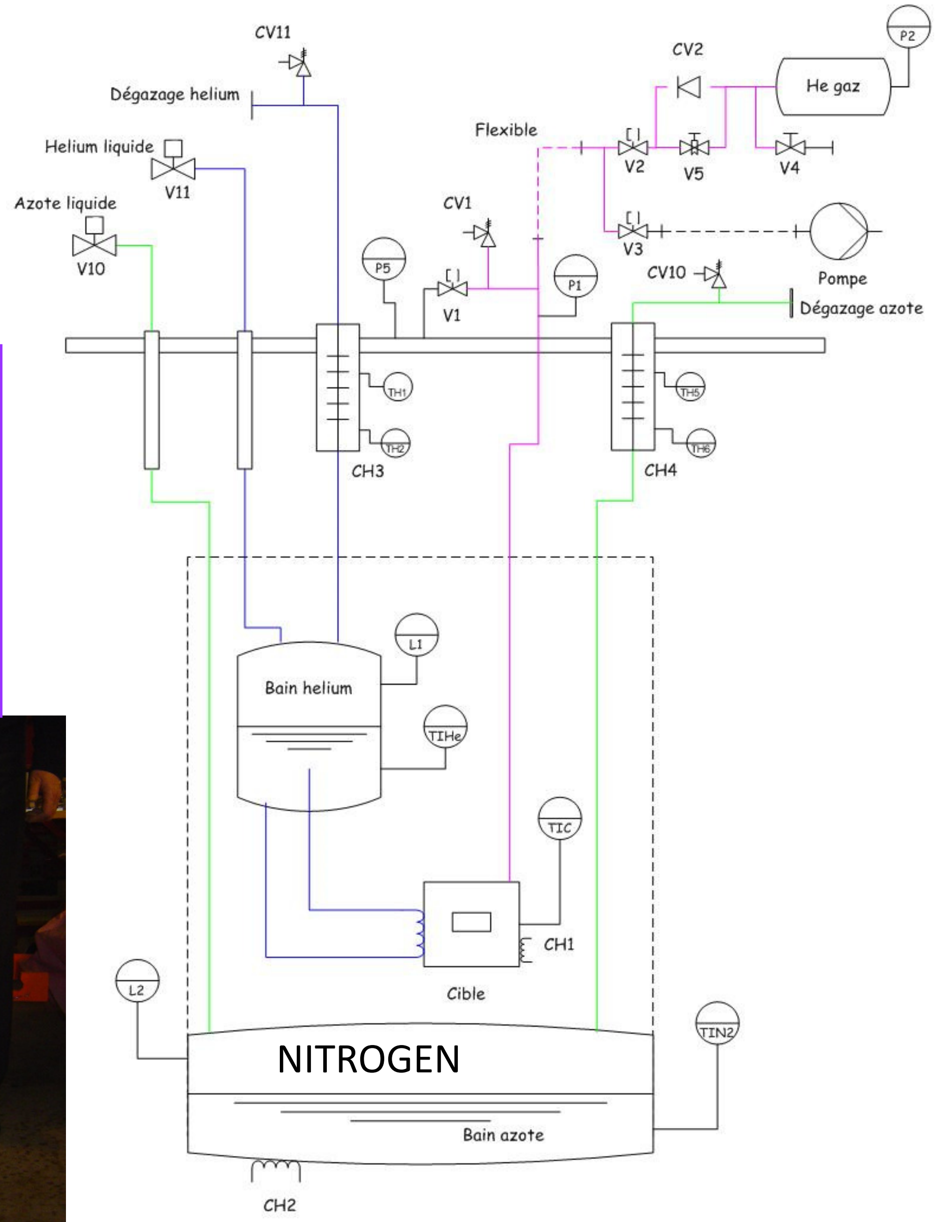
Coordinator: M. Assié, IPNO

Helium cryogenic target (IPNO)



Ø 16 mm,
3mm thick
Havar wind.
3.8 microns
T = 8.5 K
P = 1 bar





Cible GANIL - schéma fonctionnement

MUGAST-AGATA-VAMOS – Scientific evaluations

2015

Single LoI submitted including a list of reactions

PAC comments:

> The PAC found the proposition of combining MUGAST+AGATA with VAMOS compelling, and it was clear that much progress had already been made in realising this ambition, with significant development of the instrumentation. The aim to deliver a campaign around transfer reactions (including stripping) was well received as it was believed that this should be a core component of the future scientific programme of GANIL, building on the rich heritage of the programme that the present collaboration has led. The PAC is therefore supportive of this development and it would seem that the best course of action is to present this proposition to the GANIL Scientific Council as directed by the GANIL Director.

2016

"Umbrella" LoI + 7 Physics LoI's submitted

PAC comments:

> **Summary**
> The science programme described by the LoIs was strong. In particular the PAC recognises the opportunity that the combination of MUGAST, VAMOS and AGATA presents and it suggests that this programme be made a priority for future calls for proposals.

2017

Two proposals submitted, one accepted with highest priority.

2018

- **High priority given to the program by the Scientific Council of GANIL**
- **MUGAST included in the last call for expt proposal. 2 proposals accepted**

2019

- **First MUGAST campaign (3 experiments)**
- **^{56}Ni SPIRAL beam development scheduled**

Physics with MUGAST

2 dedicated workshops organized at Orsay and Padova

Shell evolution & deformation

- Mapping of neutron orbitals around N=28 — *F.Flavigny, O.Sorlin et al.*
- Oblate driving force in n-deficient nuclei above ^{56}Ni — *A.Goasduff, D.Mengoni, et al.*
- Shape transition along and across N=28 — *L.Fortunato, D.Mengoni et al.*
- Interplay of single-part and collective structures in ^{46}Ca — *S.Leoni et al.*
- Shell evolution toward the island of inversion — *A.Matta, W.Catford, N.Orr, et al.*
- Shape coexistence in Kr isotopes — *A.Matta, W.Catford, et al.*
- Island of Inversion and shape coexistence in ^{30,31}Mg — *B.Fernandez-Dominguez et al.*

Neutron-proton pairing

- np-pairing in fp-shell — *M. Assié et al.*

Astrophysics

- Breakout from hot CNO to rp process — *C.Diget et al.*
- Explosive H-burning in Novae — *N.de Sereville, F.Hammache et al.*
- Surrogate method for s-process reactions — *G.de Angelis et al.*
- ^{60}Fe — *A.Matta, W.Catford, et al.*

Reaction dynamics

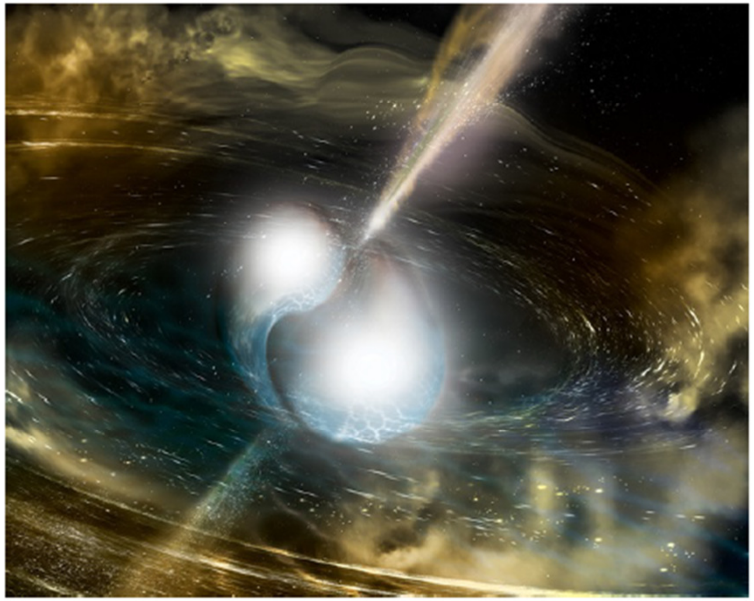
- Space-time characterization of emitting sources in HI collisions — *G. Verde, A.Chbihi, Q.Fable et al*

Mostly stripping reactions

Neutron star mergers – common-envelope precursers

"On August 17, 2017 at 12:41:04 UTC the Advanced LIGO and Advanced Virgo gravitational-wave detectors made their first observation of a binary neutron star inspiral... GRB 170817A, detected by Fermi-GBM 1.7 s after the coalescence."

B.P. Abbott et al. Phys. Rev. Lett. 119, 161101 (2017)
LIGO Scientific Collaboration and Virgo Collaboration (16 October 2017)



National Science Foundation/LIGO/Sonoma State University/A. Simonnet

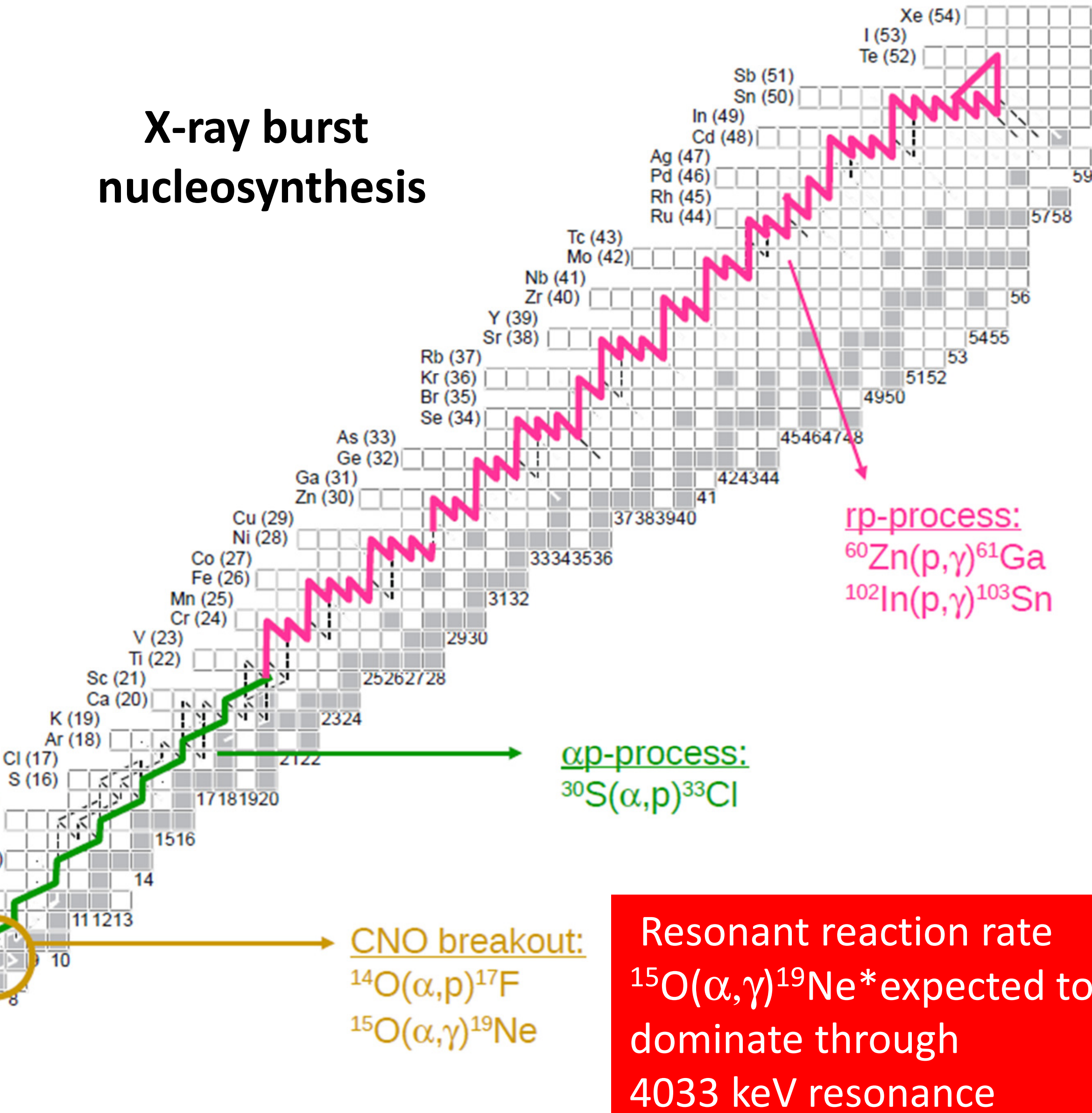
Likely precursor to n-star merger is a common-envelope system with the neutron star embedded into the envelope of its binary (giant) companion.

Slide: C.Aa. Diget

Explosive burning on neutron-star surfaces

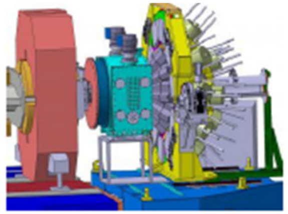
- Accretion from companion star (X-ray burster or common-envelope).

X-ray burst nucleosynthesis



Resonant reaction rate $^{15}O(\alpha,\gamma)^{19}Ne^*$ expected to dominate through 4033 keV resonance

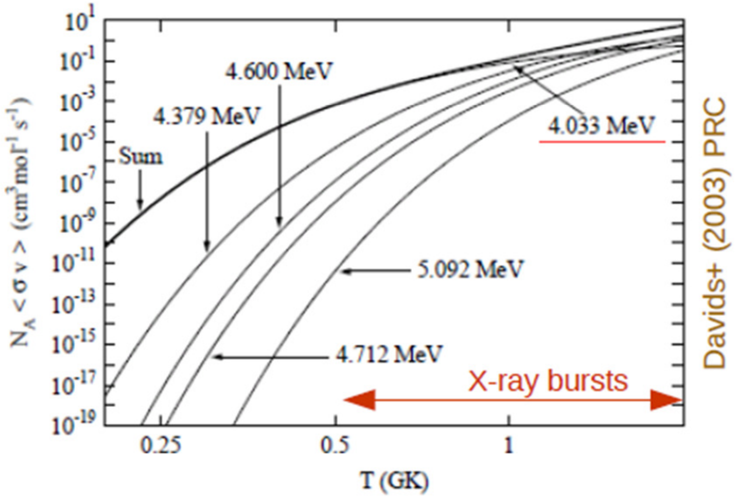
The $^{15}O(\alpha,\gamma)^{19}Ne$ reaction



Present status

- Gamow window: 0.5 – 2 MeV (0.5 – 1.5 GK)
- 4.033 MeV state dominates up to 1 GK
- $N_A < \sigma v > \propto (2J_R+1)\dfrac{\Gamma_\alpha \Gamma_\gamma}{\Gamma_{tot}} e^{-E_R/k_B T}$
- E_R, J^π: known
- $\Gamma_{tot} = \Gamma_\gamma \propto 1/\tau$ with τ = 6.9 (15) fs Mythili+ (2008) PRC

Missing spectroscopic information: Γ_α in ^{19}Ne

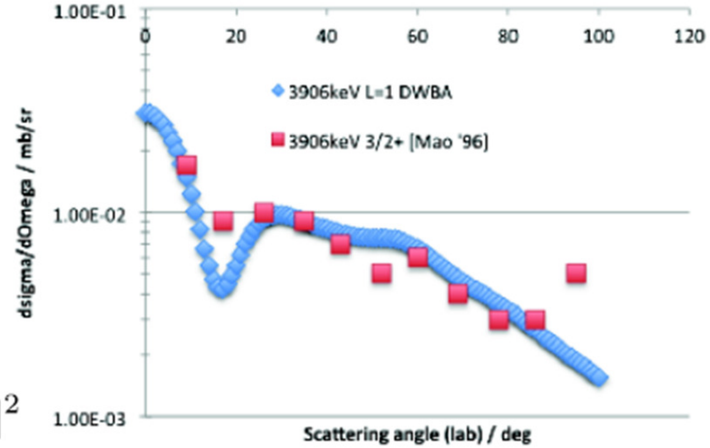


Alpha-transfer reaction: $^{15}O(^6Li,d\gamma)^{19}Ne_{4.033}$ in inverse kinematics

Diget+ exp. accepted

- Intense ^{15}O RIB ~ 10^7 pps @ 4.7 MeV/u
- State of the art detection system
  - VAMOS magnetic spectrometer
    → reaction channel identification (^{19}Ne)
  - AGATA γ-ray spectrometer
    → identification of the 4.033 MeV state
  - MUGAST charged particle array
    → angular distribution measurement

$^{15}N(^6Li,d)^{19}F$ @ 3.7 MeV/u



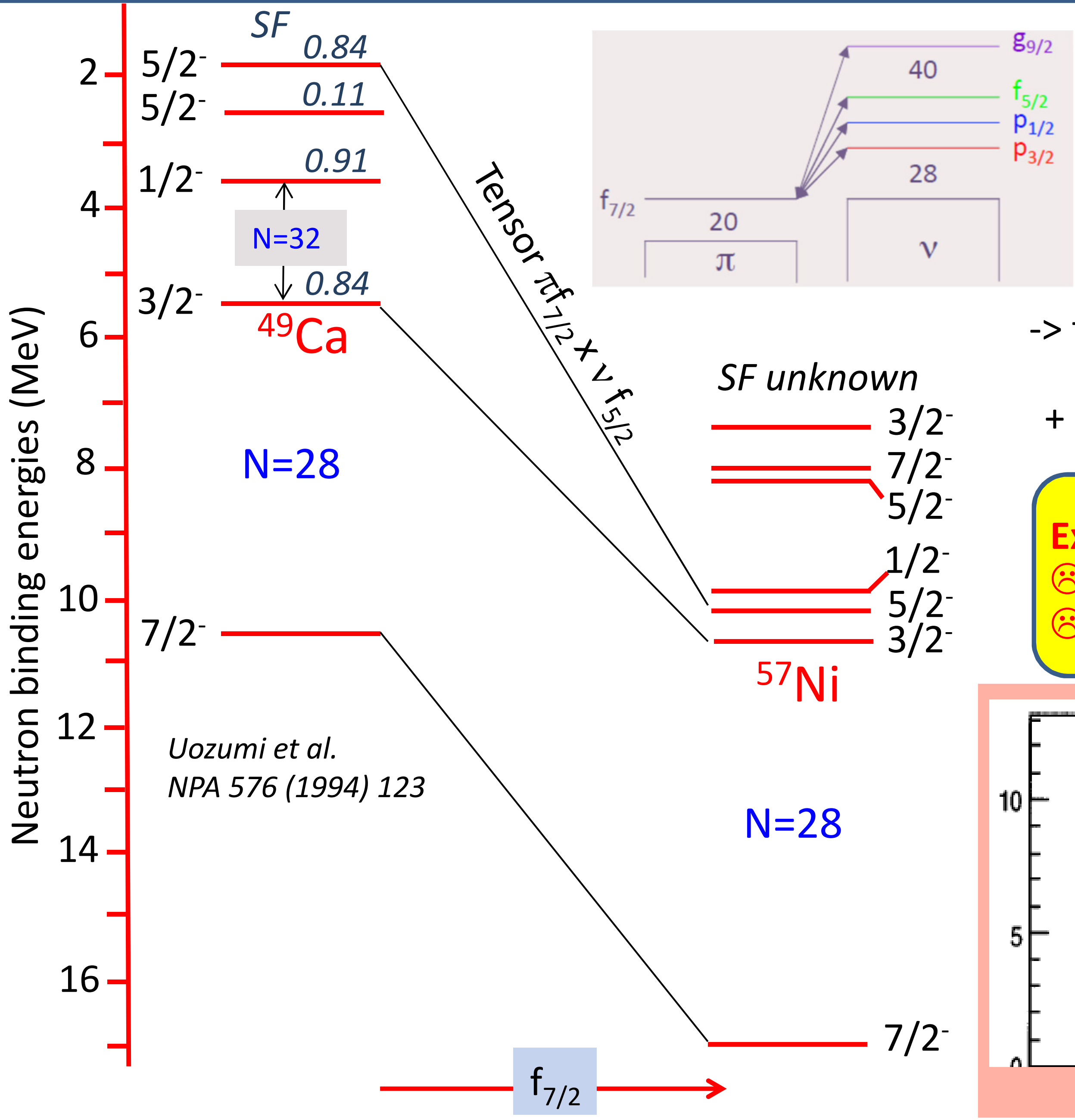
$$\left.\frac{d\sigma}{d\Omega}\right)_{exp} = C^2 S_\alpha \left.\frac{d\sigma}{d\Omega}\right)_{DWBA} \rightarrow \quad \Gamma_\alpha = 2P_L(r,E)\frac{\hbar^2 r}{2\mu} C^2 S_\alpha \, |\phi(r)|^2$$

Proposal:C.Diget, N.De Séréville, et al.

To be scheduled in July 2019

Courtesy N. De Séréville

Shell evolution in the N=29 nuclei



Disappearence of N=32 gap

&

Reduction of SO splittings

&

shell re-ordering

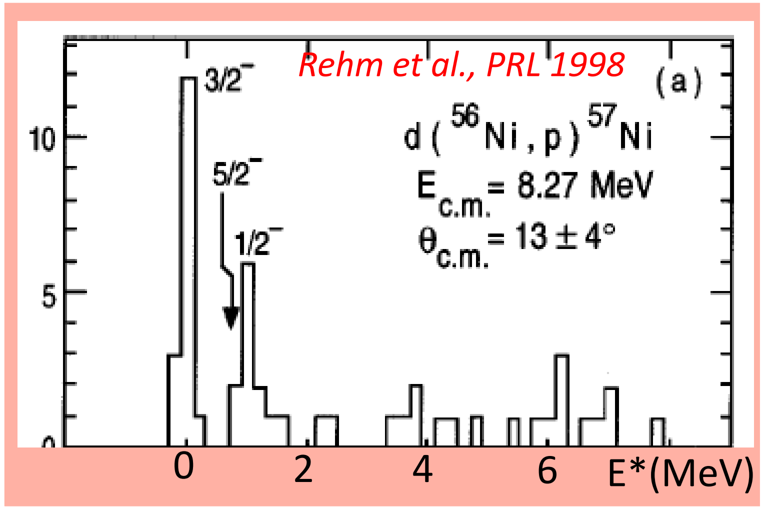
-> tensor component of NN forces ?

+ search for g9/2

Existing data on ^{57}Ni:

☹ s.p. states not well known

☹ SF values not measured



MUGAST LoI submitted 2016, (F.Flavigny, O.Sorlin et al.)

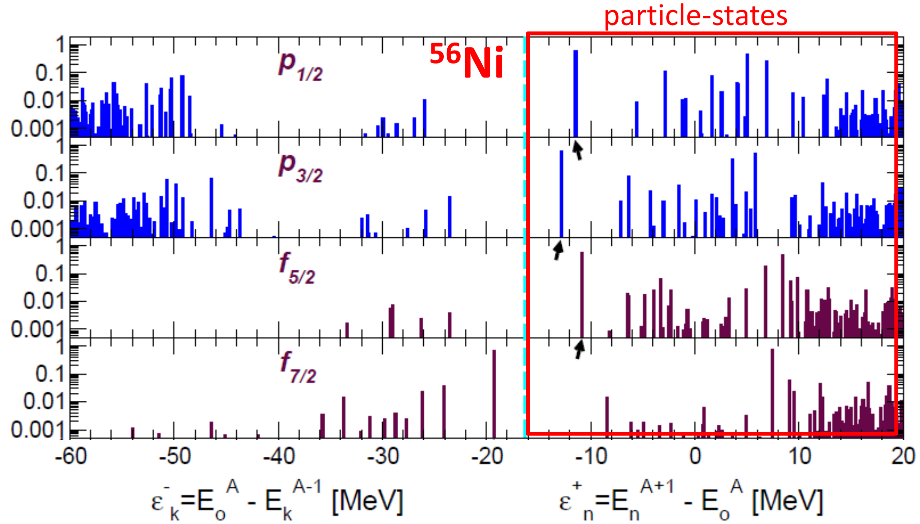
Need of benchmark data

- Quantitative study along N=28 of the $\pi f7/2 \leftrightarrow \nu(f5/2, p3/2, p1/2, g9/2)$ interaction
  Tensor component of NN forces
- ^{56}Ni as core for SM interaction -> ESPE based on N+1 nucleus data

- *ab initio* calculations progressively available for medium mass nuclei (Ca,Ni)

New calculations in SC Gorkov-Green function currently being done
(T.Duguet,V.Soma et al.)

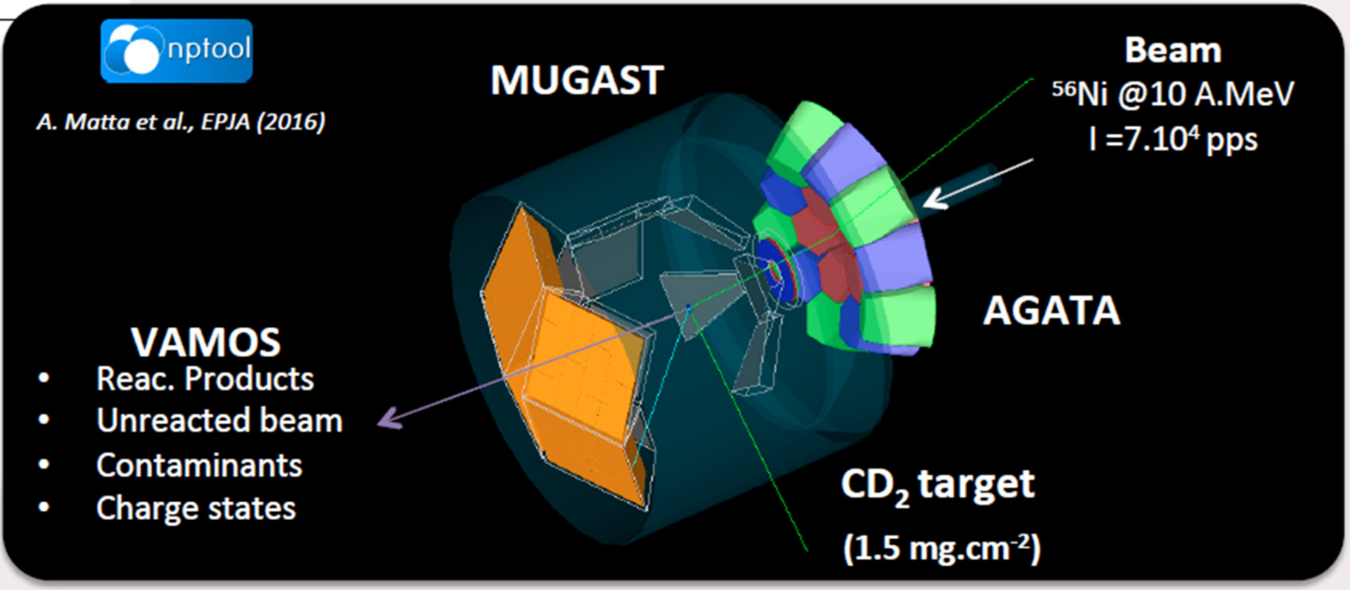
C. Barbieri M. Horth-Jensen ,PRC 79 064313 (2009)

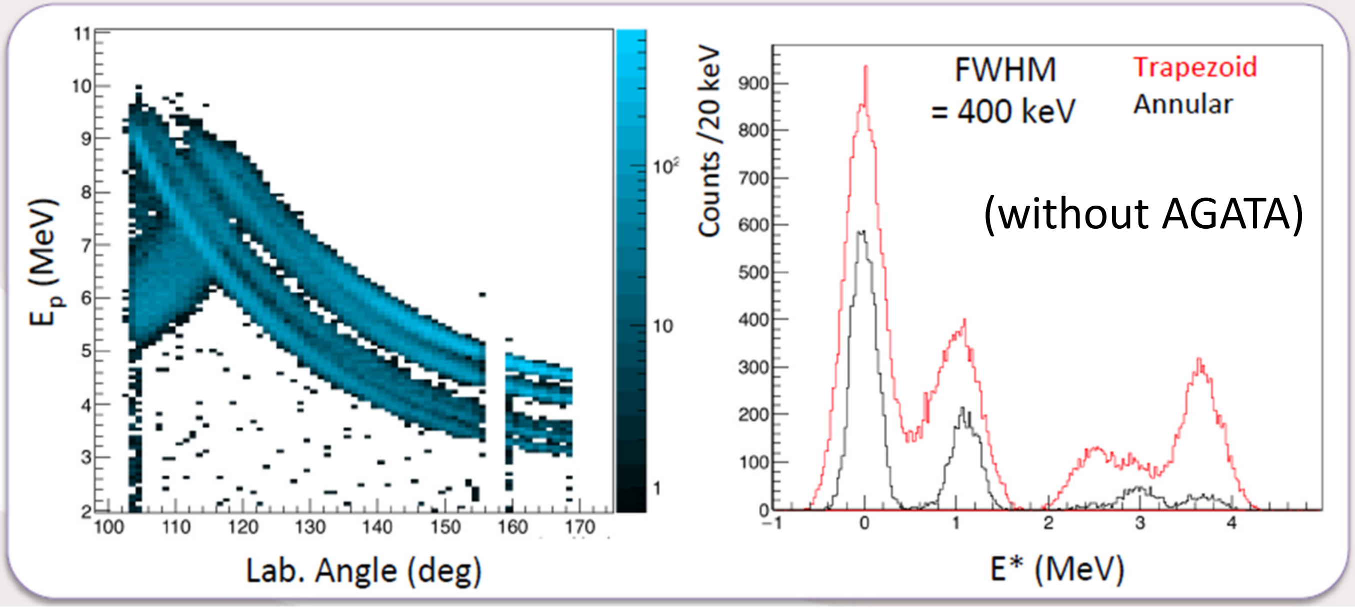


Method : study of ^{56}Ni(d,p)(d,t) with MUGAST-AGATA-VAMOS

- **Both reactions measured simultaneously, plus elastic channel**
- **High resolution in excitation energy of populated states**
- Take advantage of new spiral1 beam
  $\Rightarrow$ **relatively high intensity at the perfect incident energy** (~10MeV/u)
  (angular distributions $\Rightarrow$ **unambiguous L assignment)**
- **Sensitive to spectroscopic factors down to 0.1 for (d,p)**

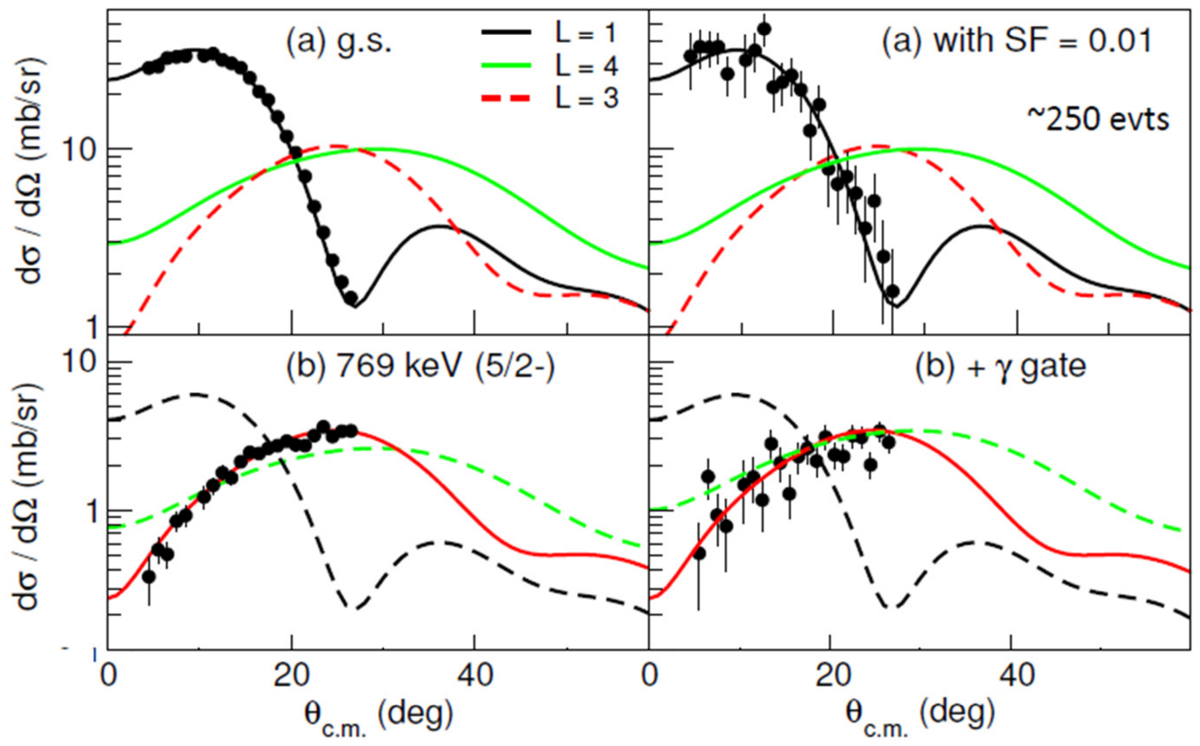
Experimental setup and simulations





F.Flavigny, IPNO

Simulations: $^{56}Ni(d,p)^{57}N$



Now waiting for the development of ^{56}Ni SPIRAL beam (March 2019)

Lifetime measurements of excited states in ^{20}O populated by direct nucleon transfer

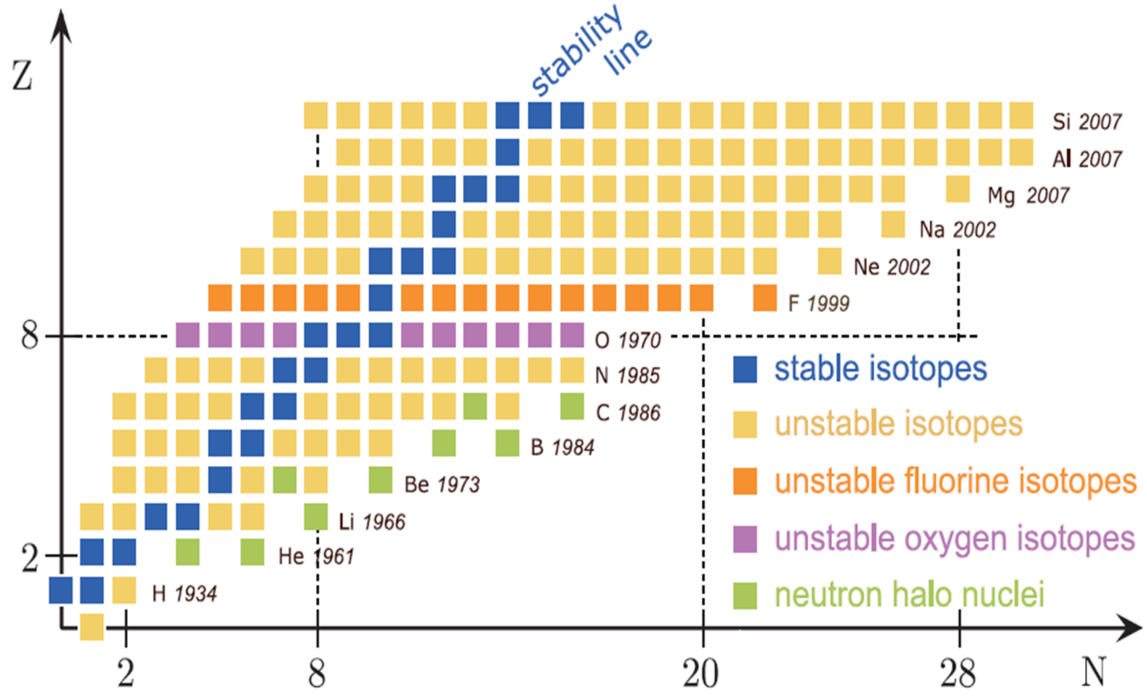
Spokespersons: E. Clément (GANIL), A. Goasduff (INFN)

For The AGATA – MUGAST – VAMOS Collaborations

- ^{24}O is the last bound isotopes
- This anomaly is not reproduced in shell model calculations derived from microscopic two-nucleon forces
- Explanation based on 3N forces

  T.Otsuka et al., PRL 105 (2010)

The oxygen "anomaly"



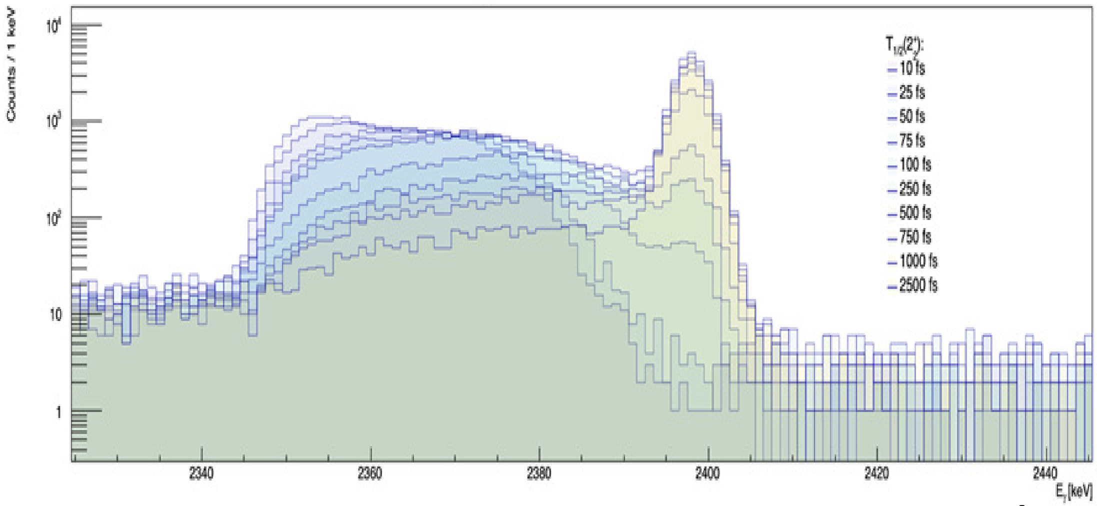
Proposed experiment

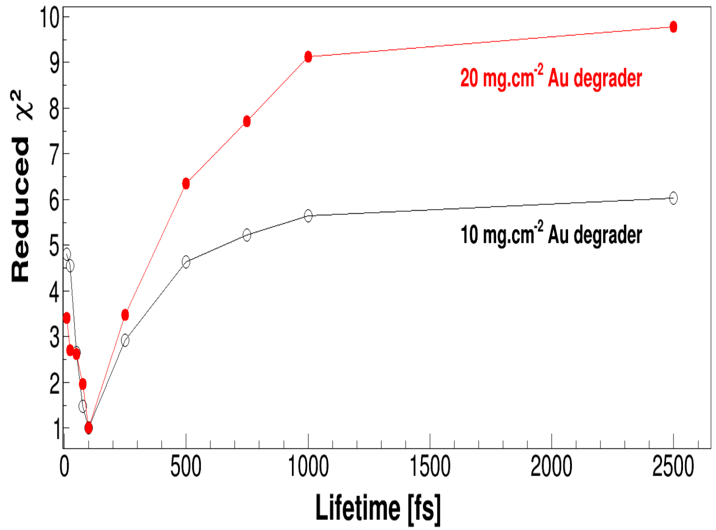
We will measure an accurate and relevant quantity ($T_{1/2}$) which is sensitive to $s_{1/2} - d_{3/2,5/2}$ relative spacing

- ✓ Within an ab-initio framework it can be related to the 3-body contribution
- ✓ Within the SM approach, it can be related to the position of the single particle orbit

- Populating the relevant neutron states by the selective $^{19}O(d,p)^{20}O$
- ^{19}O beam from SPIRAL1 at 6.6 MeV/ and at 7. 10^4 pps
- DSAM dedicated target CD2 (0.3mg/cm²) + Au (20mg/cm²)
- ^{20}O identified in VAMOS and γ-ray in AGATA placed at backw angles
- The entry point is constrained by the proton spectroscopy in MUGAST
- Lifetime measurement of the 2^+_2 and 3^+ state, feeding free, by DSAM

Simulated ^{20}O 2_2^+ decay with backing of 20 mg/cm² of Au





Accepted Dec. 2018

from E.Clement

Other cases

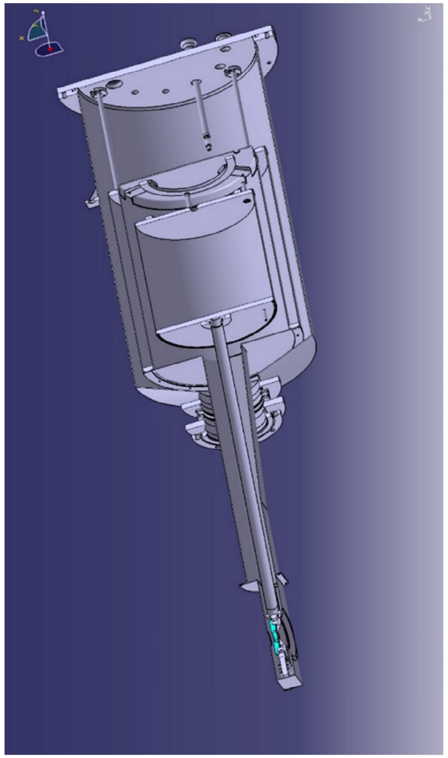
- **Neutron-proton pairing using d-transfer**
  M.Assié et al.
  ^{56}Ni(^{3}He, p)
  awaiting ^{56}Ni beam …

- **Proton shell occupancies in N=28 ^{46}Ar**
  A.Gottardo et al.
  ^{46}Ar(^{3}He, d)
  scheduled in May 2019

- **s-process using surrogate method**

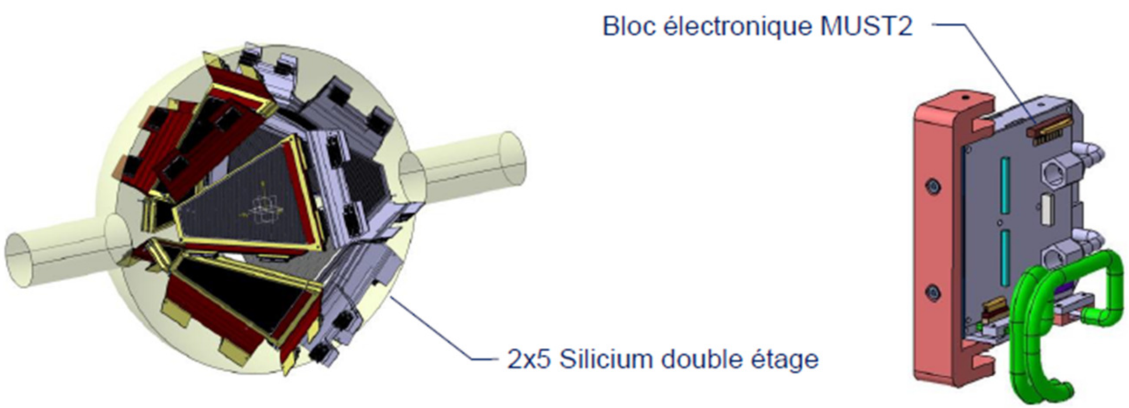
- **….**

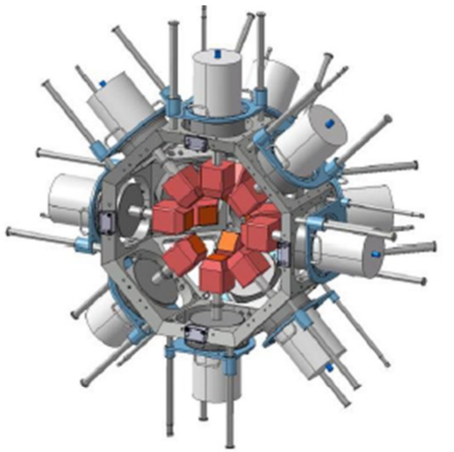
^{3}He target

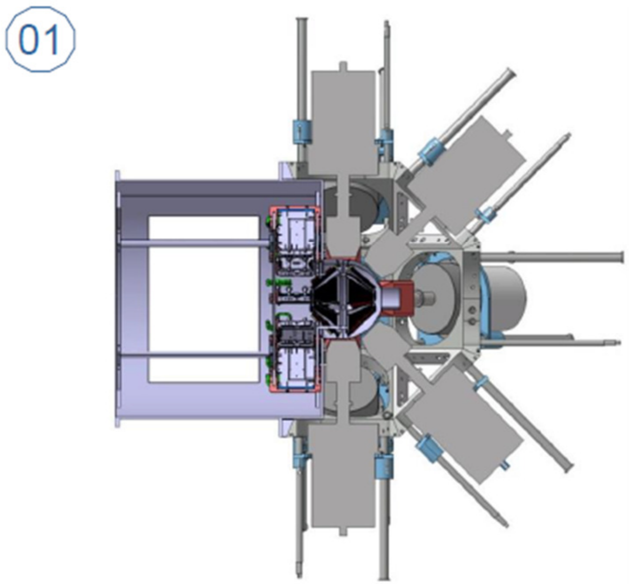


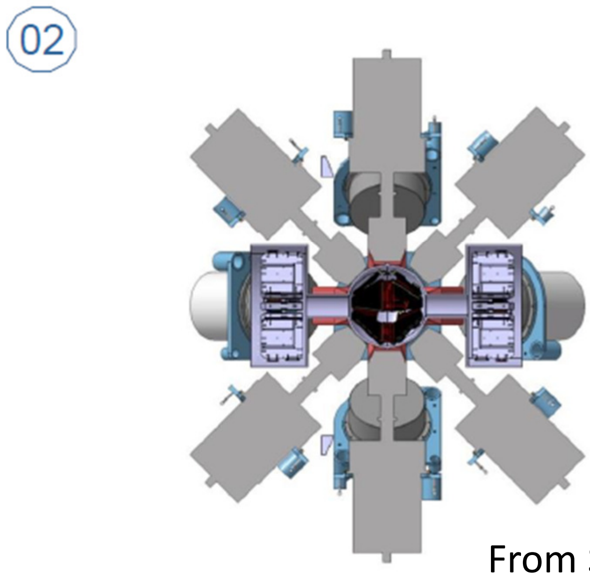
Prospects for MUGAST : a LISE version ?

To be coupled with EXOGAM









From S.Lory, LPC Caen

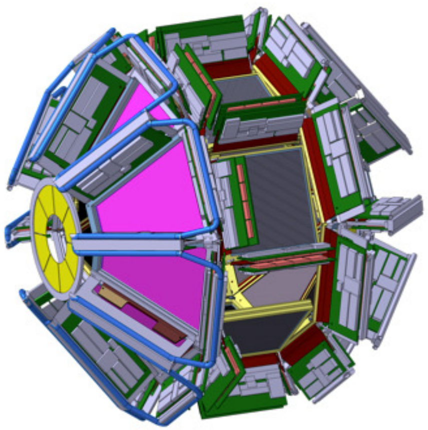
- Detailed design available - to be finalized
- Issue of the 2nd stage of Si

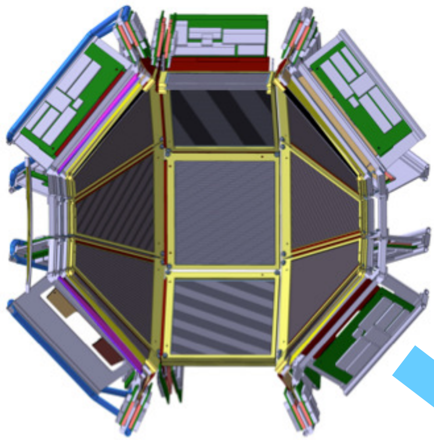
The GRIT project

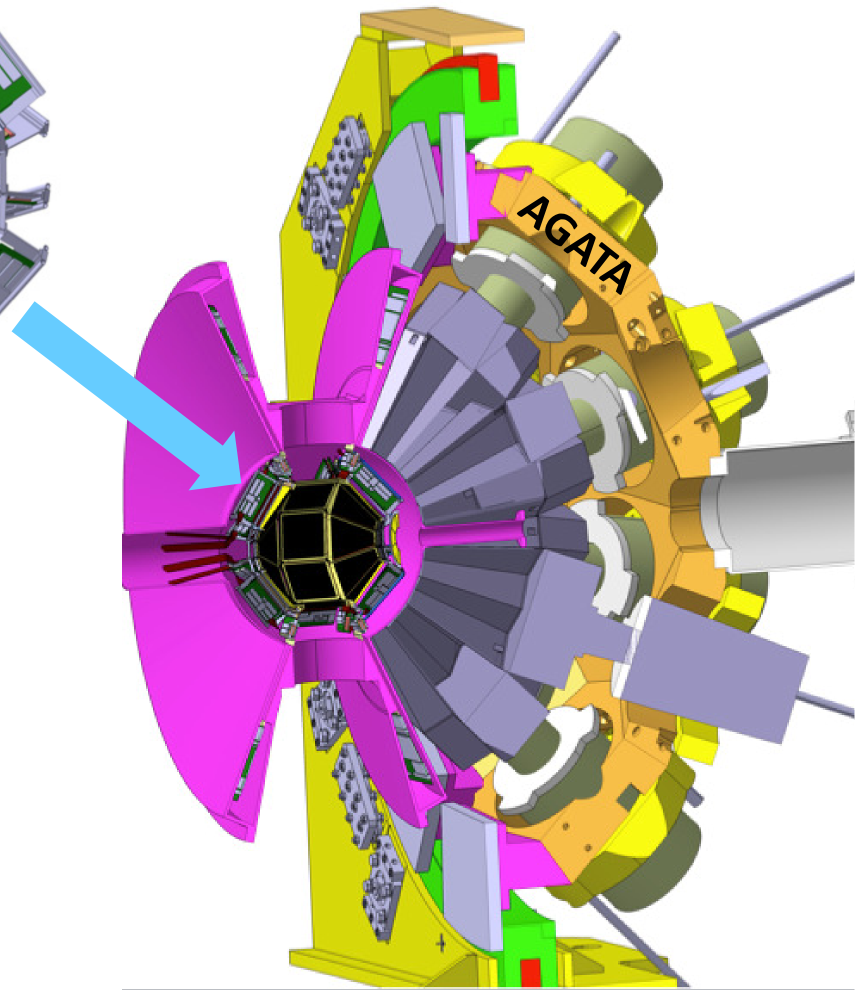
(Granularity, Resolution, identification, Transparency)

(GASPARD-TRACE collaboration)

4π Si array fully integrable in AGATA & PARIS







- High efficiency for particles
- High granularity (strip pitch < 1 mm)
- Large dynamical range

Layers of Silicon

- 500 um DSSD pitch < 1mm
- 1(or 2) x [1.5 mm DSSD pitch~3mm]

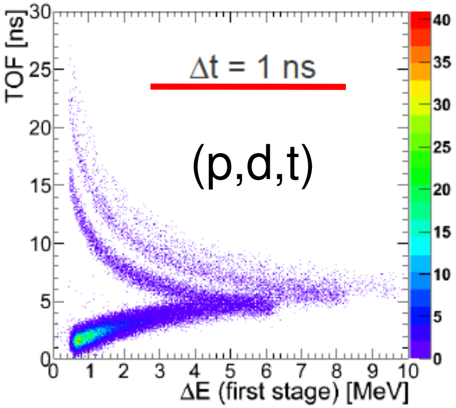
- Special targets (Cooled ^{3,4}He cell, pure H, tritium)
- PID using Pulse Shape Analysis techniques
- New Integrated electronics

Simulations for PID of low-E light particles

TIME OF FLIGHT

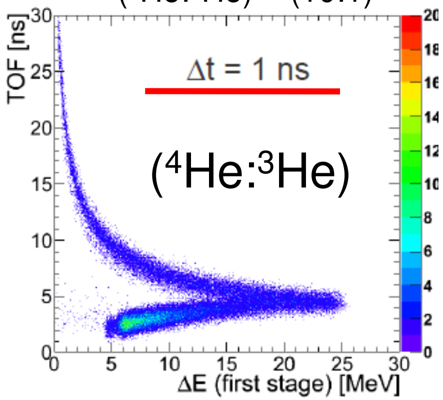
Z = 1

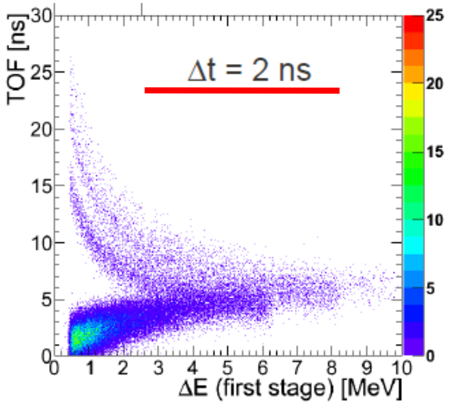
(p,d,t) = (10:4:1)



Z = 2

(^{4}He:^{3}He) = (10:1)





No separation for t/^{3}He, ^{6}He/^{6}Li

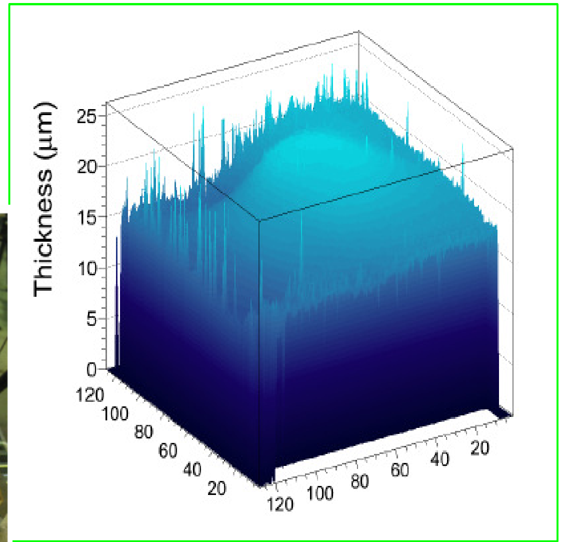
From N. de Séréville

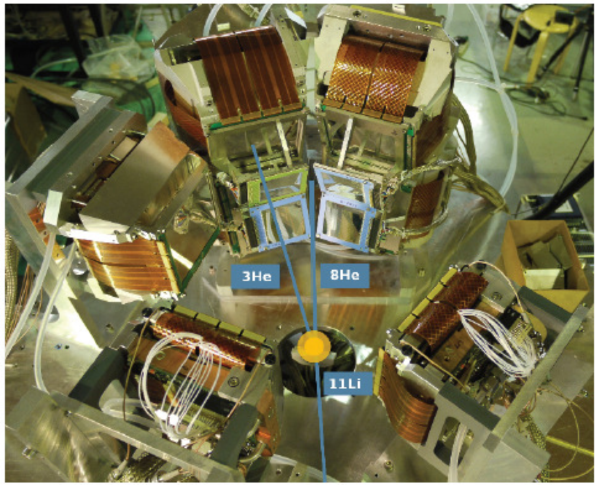
1st option: Thin Si

- **handling problems**
  - **strong inhomogeneities**
  - **dead layers, thresholds**

used for ^{9,11}Li(d,^{3}He) @ 50 MeV/u at RIKEN with MUST2

Detector#2 Thickness map





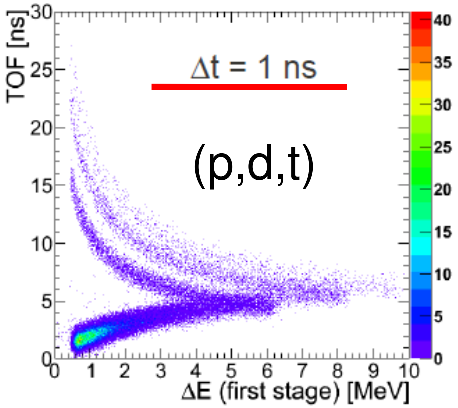
STRONG THICKNESS INHOMOGENEITIES

Simulations for PID of low-E light particles

TIME OF FLIGHT

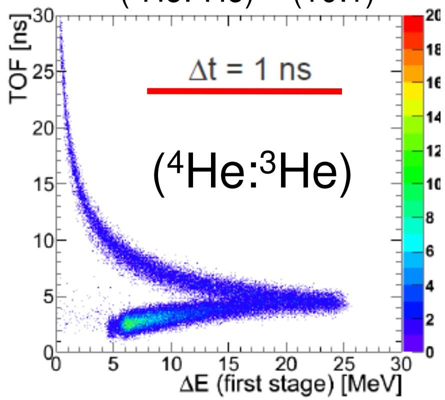
Z = 1

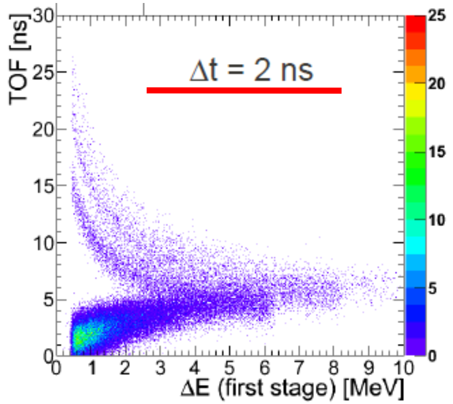
(p,d,t) = (10:4:1)



Z = 2

(^{4}He:^{3}He) = (10:1)

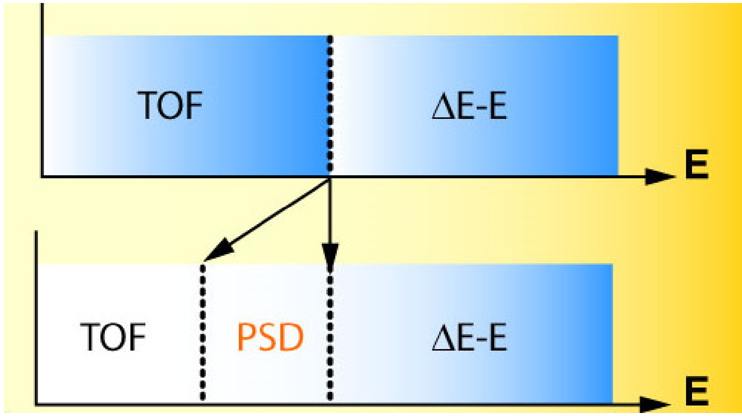




No separation for t/^{3}He, ^{6}He/^{6}Li

From N. de Séréville

2nd option: PSA



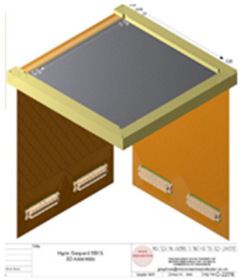
- More compact device (crucial !)
- Less Si layers
- Need nTD
- Digital electronics

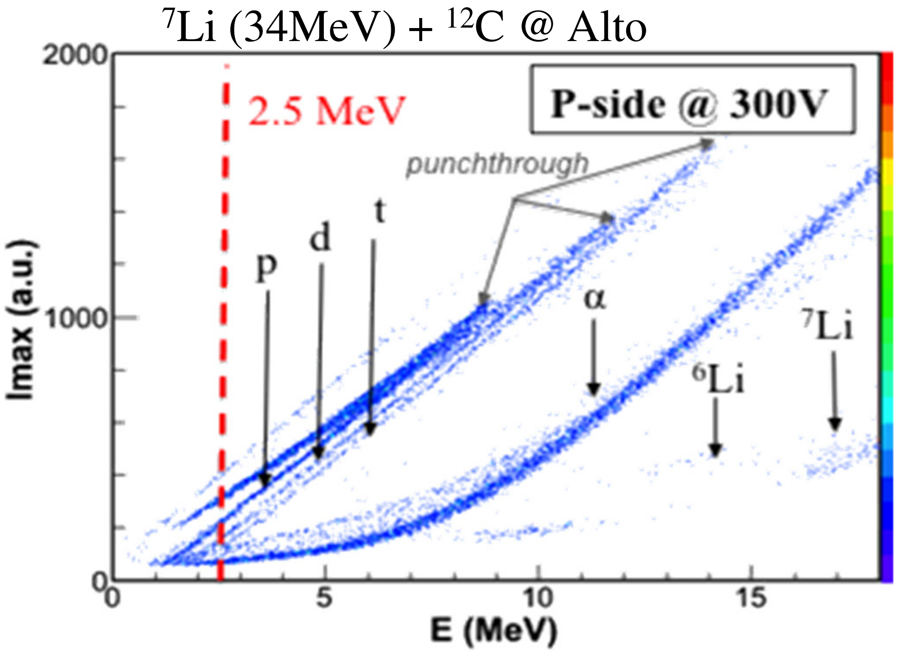
R&D on Pulse Shape Discrimination

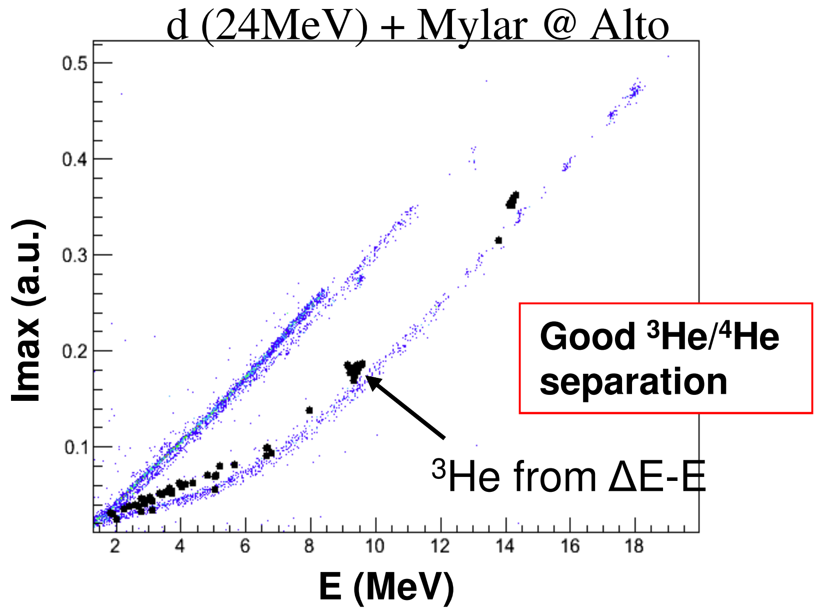
J. Duenas et al, NIMA 2012
J. Duenas et al, NIMA 2013
B. Genolini et al, NIMA 2013
J. Duenas et al, NIMA 2014
D. Mengoni et al, NIMA 2014
M. Assié et al, EPJA 2015
M. Assié et al, NIMA 2018

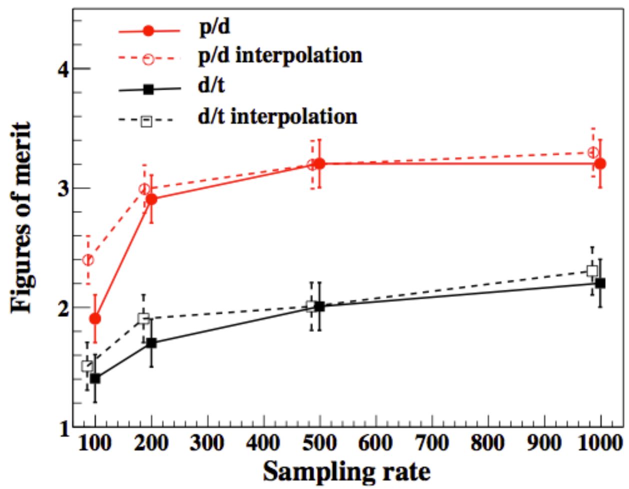
Initial detector:

- 500 um nTD DSSD
- 128X+128Y, 8° cut
- Pitch<500um
- Special packaging









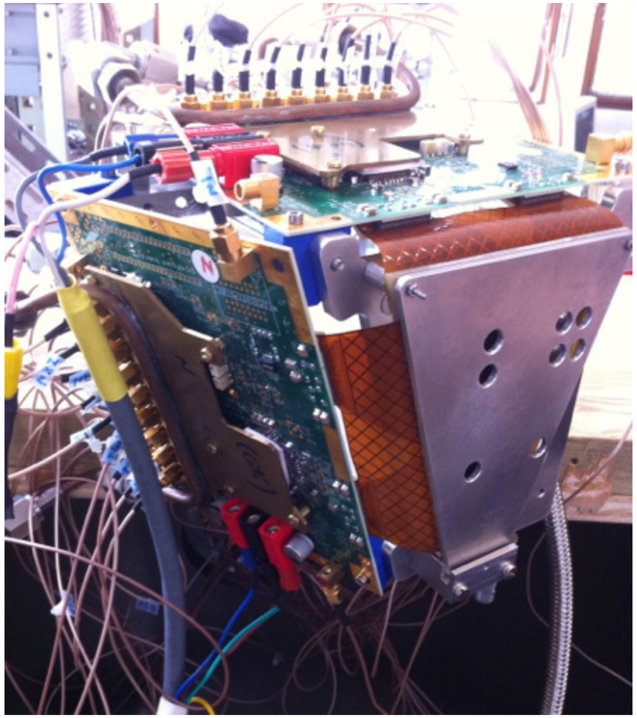
New data under analysis

- Test of PSD with trapezoid
- Effect of radiation damage

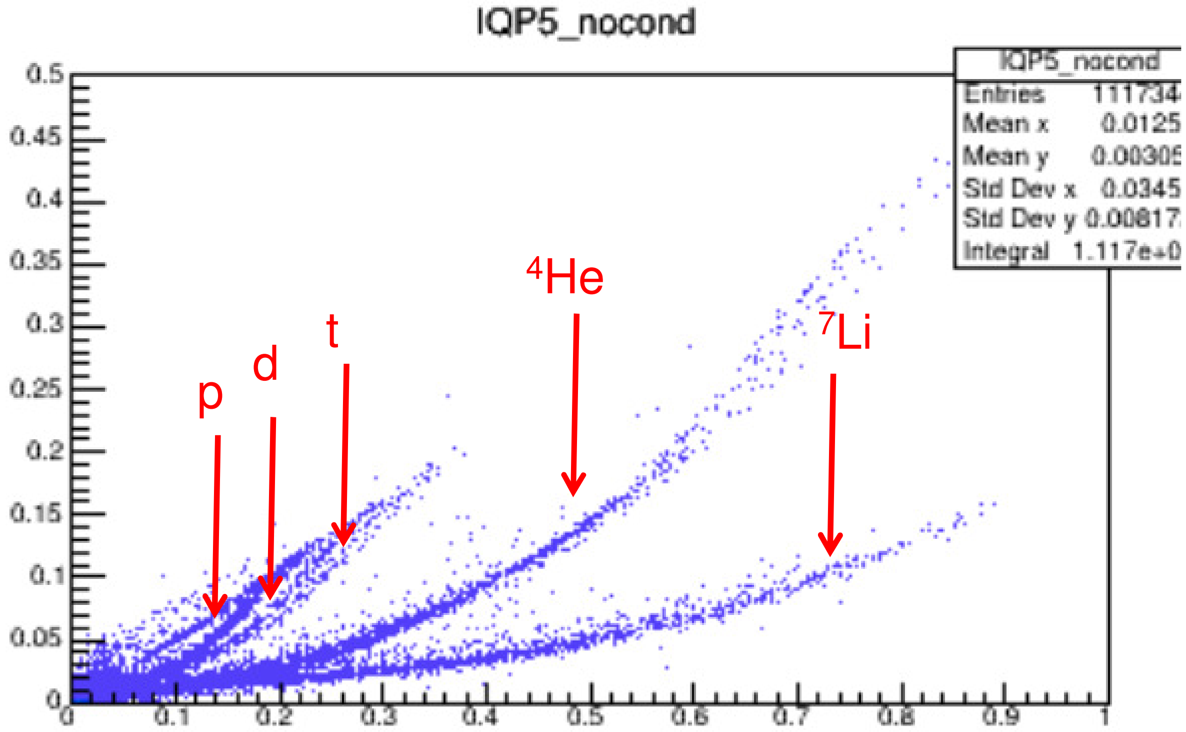
Crucial to set electronics specs. (e.g. sampling rate,…)

Pulse shape analysis with trap. detectors

--> Test expt at ALTO for PSA with trapezoidal detectors



^{7}Li + ^{12}C at 35 MeV



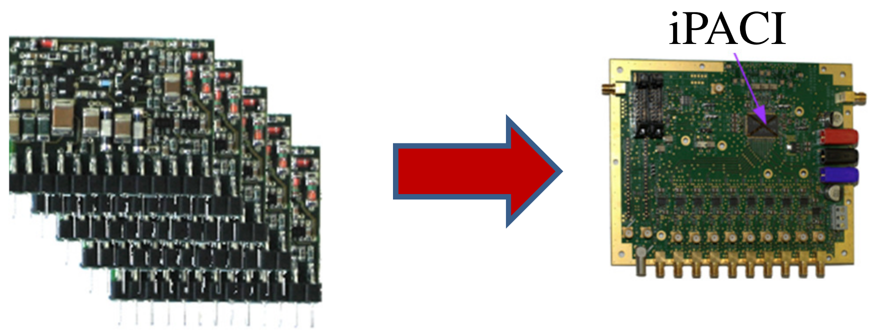
Currently under analysis

From: M.Assié

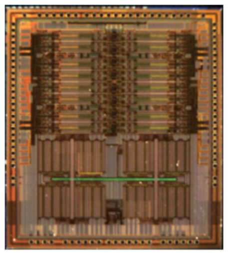
Electronics for GRIT

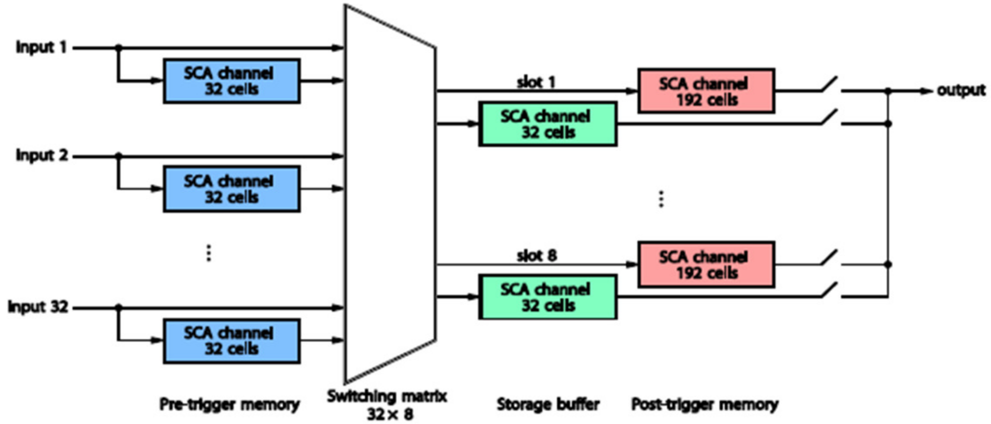
BUILDING BLOCKS

- ASIC version of the PACI preamp



- PLAS Analog memory circuit
  R.Aliaga et al., NIM A800(2015)

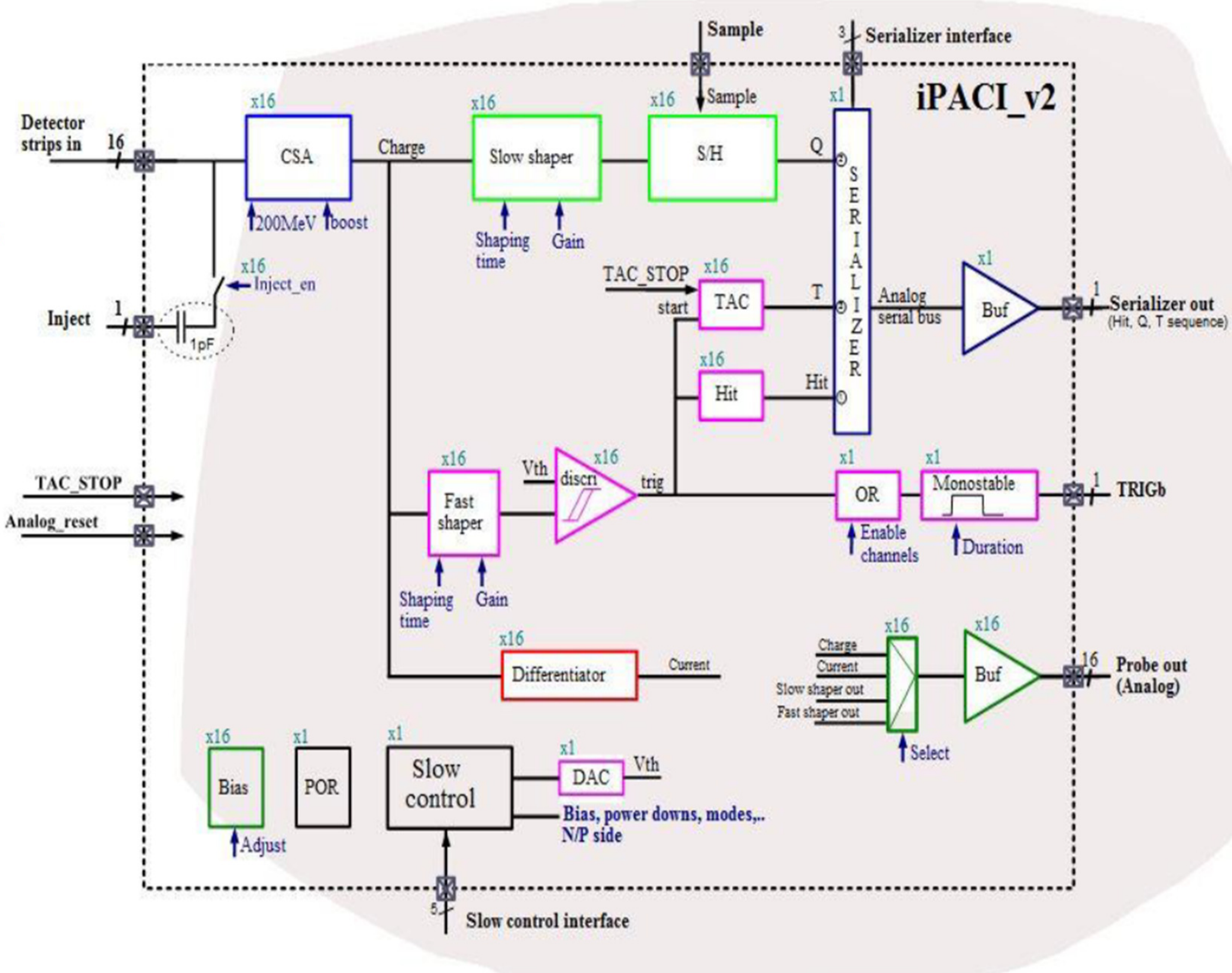




- FASTER backend

iPACIv2: architecture

- 2 gammes d'énergie : 70 et 200MeV
- 2 gammes de mesure de temps : 400ns et 800ns
- Configuration de l'ASIC par slow control
- Signaux de controle à fournir à iPACIv2
- Données Energie et temps sur 1 bus analogique



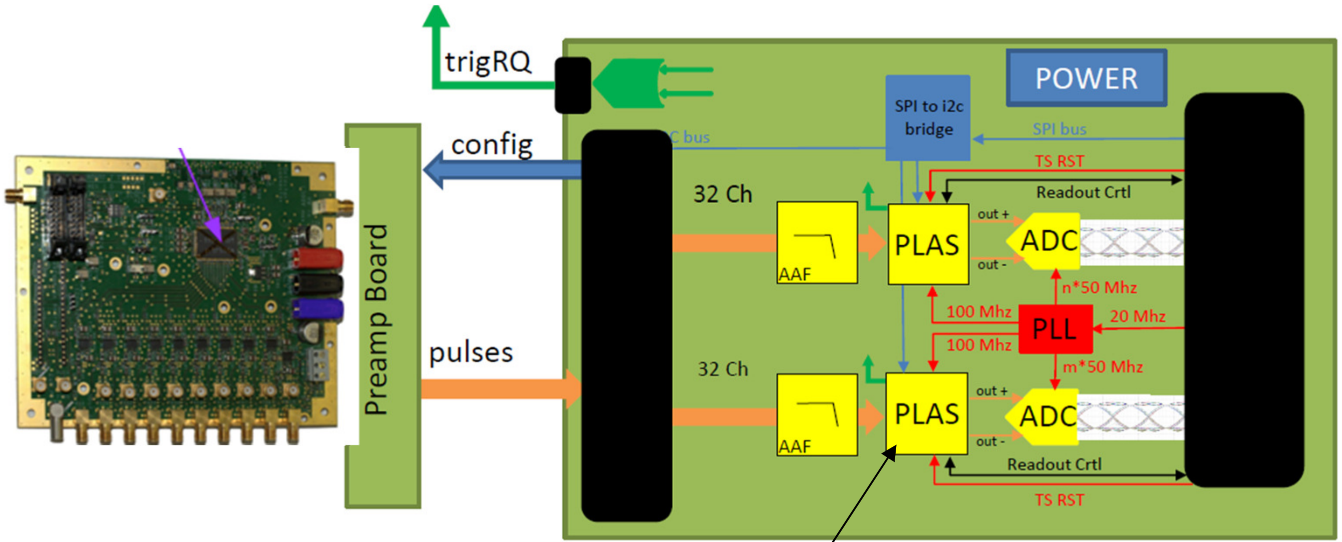
JJ Dormard, E.Rauly, IPNO

Development plan for 2019

- Commissioning of iPACI V2

- Submission of PLAS V2

- Test of FEE-BEE with FASTER



PLAS V1

The CHyMENE H/D windowless target

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

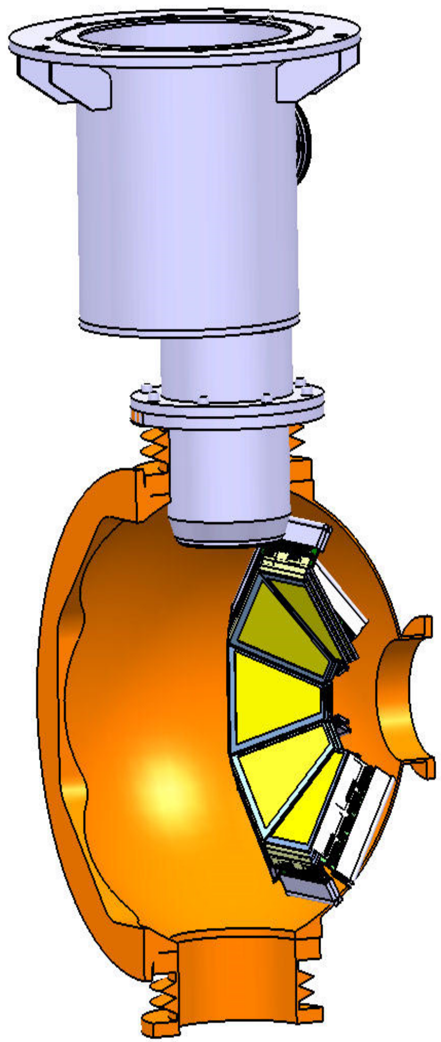
System providing continuous extrusion of ^{1}H or ^{2}H through a rectangular extruder nozzle defining the target-film thickness

CHyMENE collaboration :

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

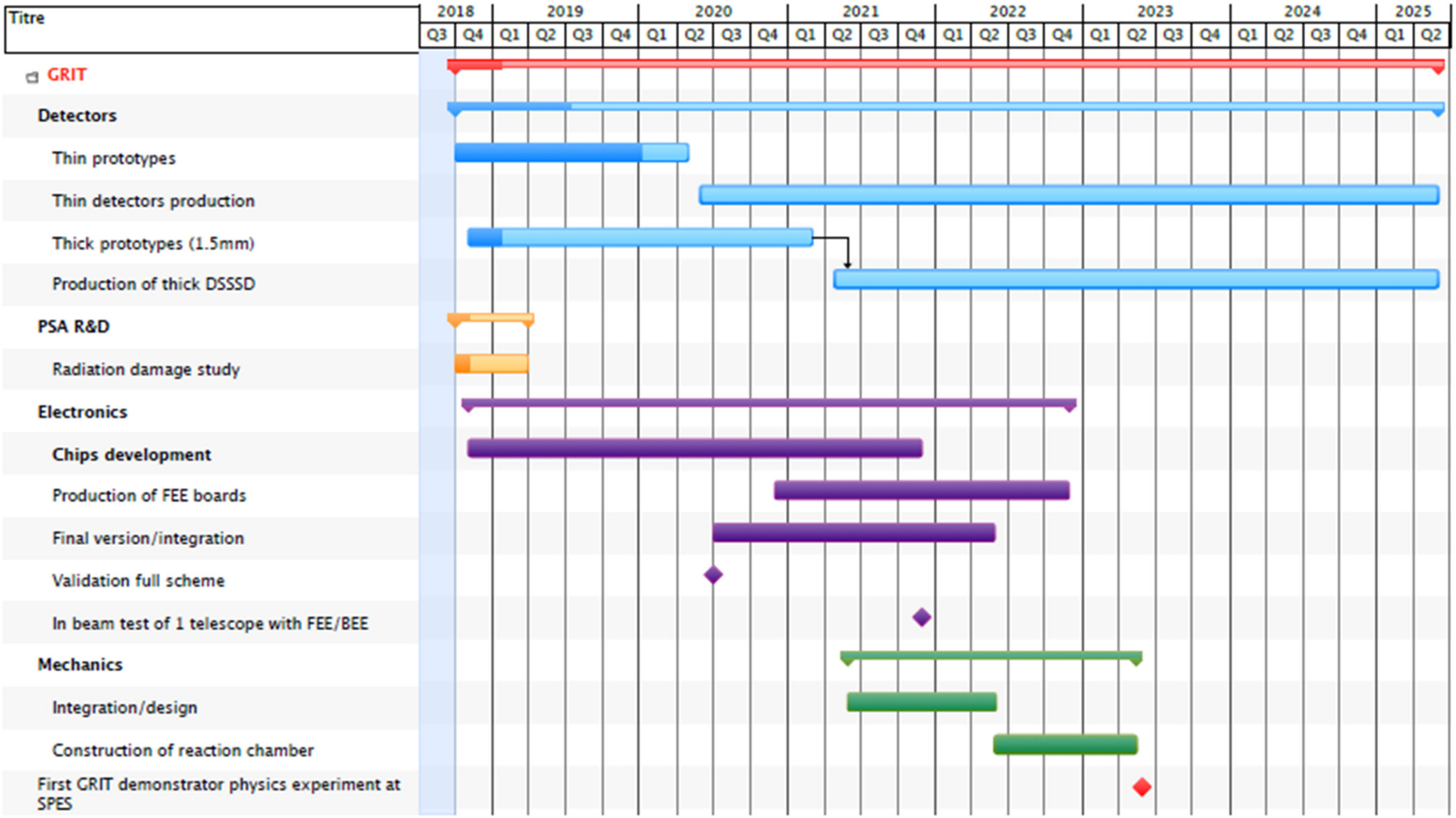
Fully funded by the French agency ANR
~ 550 k€ over 4 years

Initially designed for integration in GASPARD



Test under beam at ALTO scheduled (April-May 2019)

Gantt chart of GRIT



Thank you