Possible direct reactions studies using slowed-down beams with the GRIT array

D.Beaumel, IPN Orsay

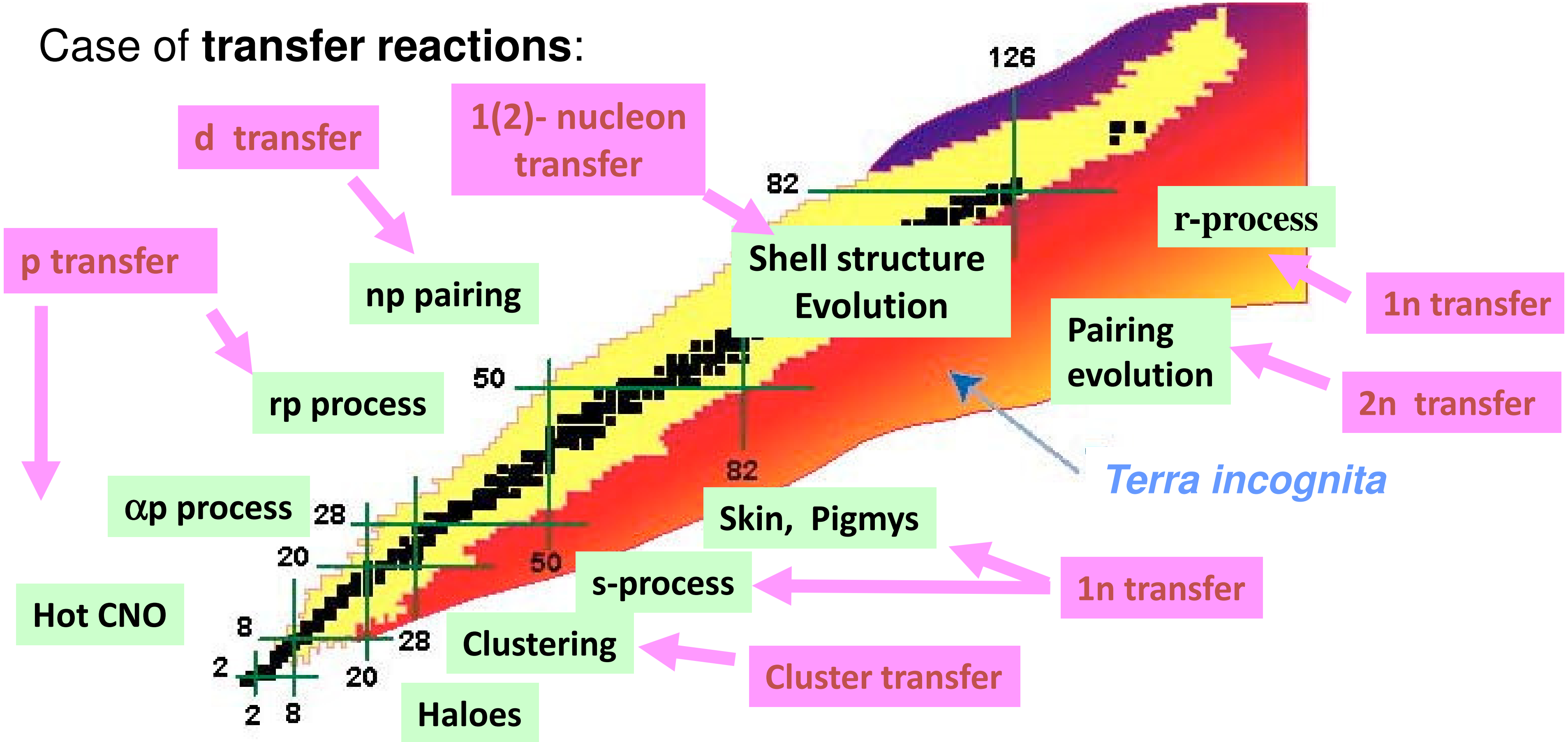
- Introduction
- The GRIT array
  First step : MUGAST campaign at GANIL/VAMOS
- DR studies with Slowed-down beams at RIKEN
- Possible application at the LEB of FAIR

NUSTAR Week 2019

Direct reactions

A great tool to investigate Exotic Nuclei and Astrophysical processes

Case of **transfer reactions**:



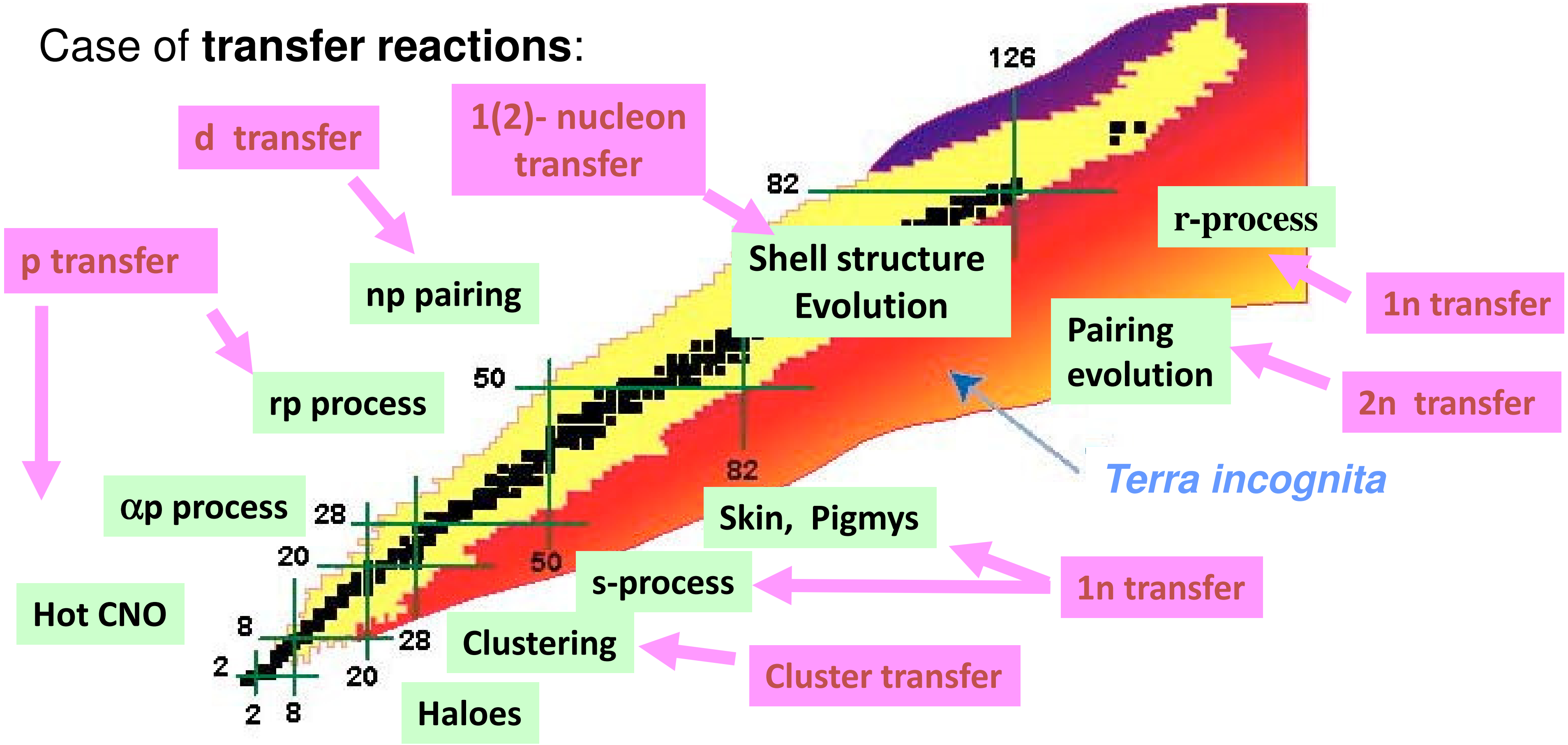
Good energy regime : 5 ~ 50 MeV/u → **Core program for ISOL facilities**
Application for slowed-down beams

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

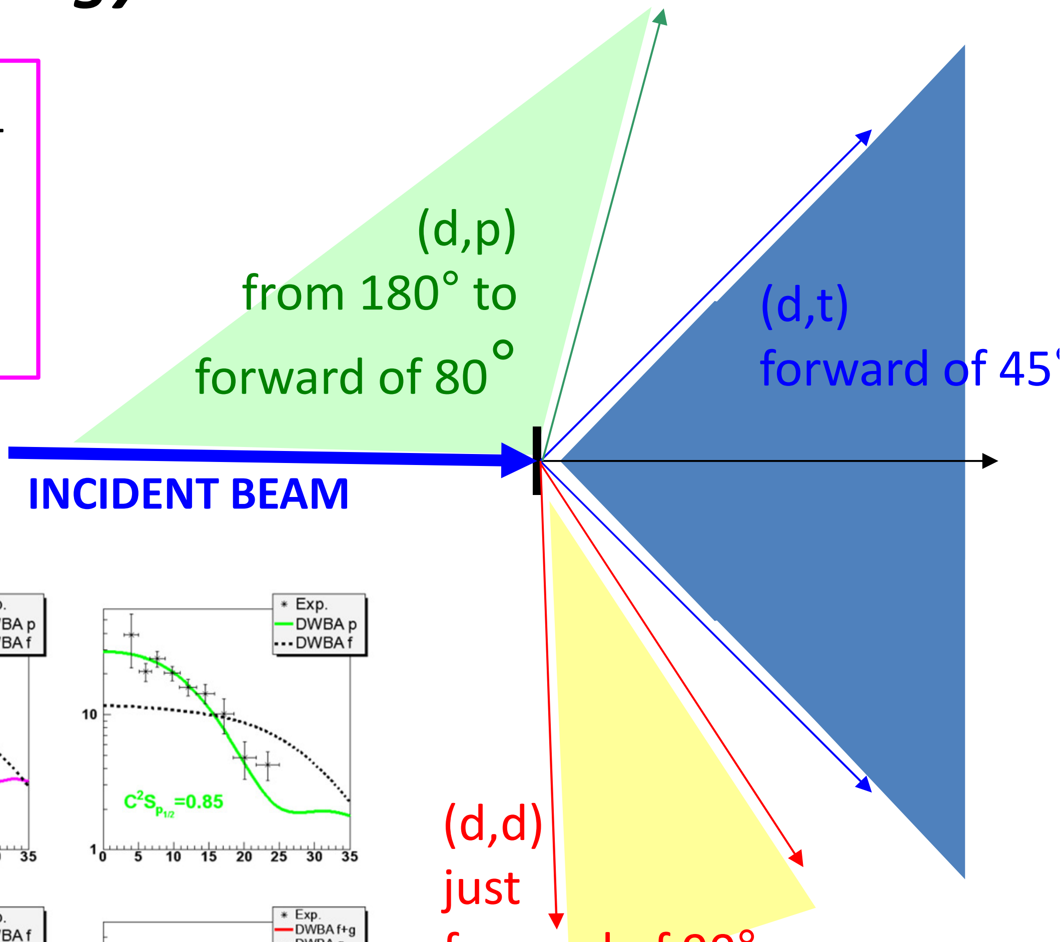
Case of **transfer reactions**:



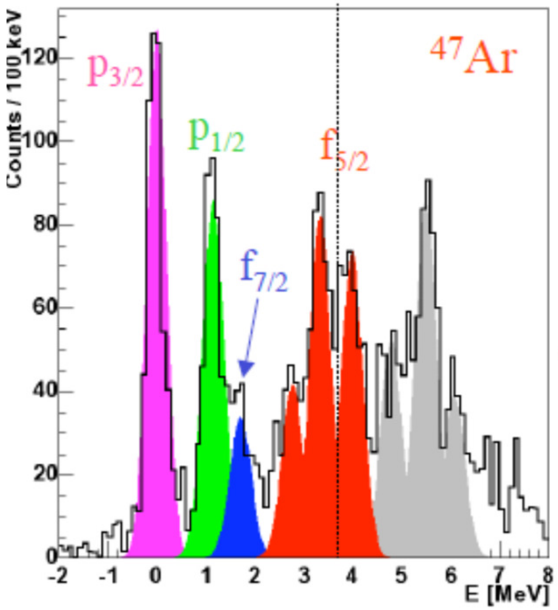
Methodology : **Radioactive Ion Beam → Light target (H,He…)**
Detect the recoil particle with high accuracy

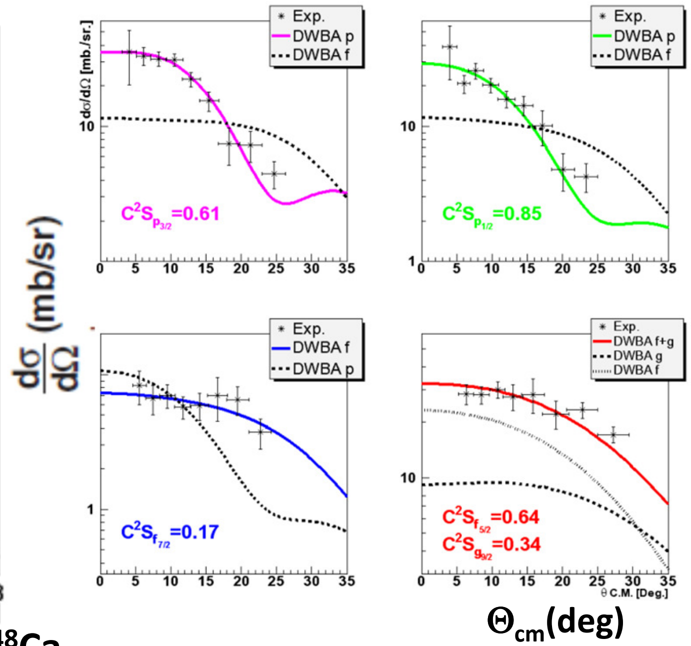
(Initial) methodology with exotic beams

Detect the light recoiling particle E_L , Θ_L
→ Excitation energies
→ Differential cross-sections
Residue is detected to improve channel selection

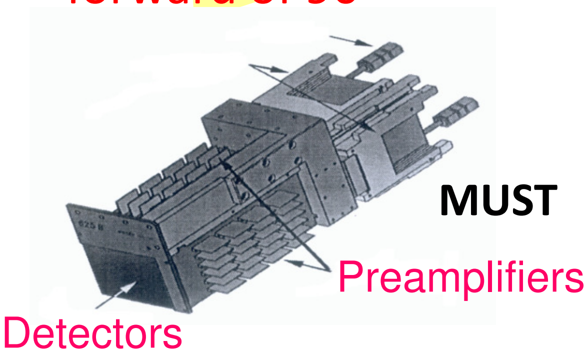


Ex: ^{46}Ar(d,p) @ GANIL/SPEG
using the MUST array





Reduction of N=28 gap w/r ^{48}Ca
L.Gaudefroy, et al., PRL (2006)



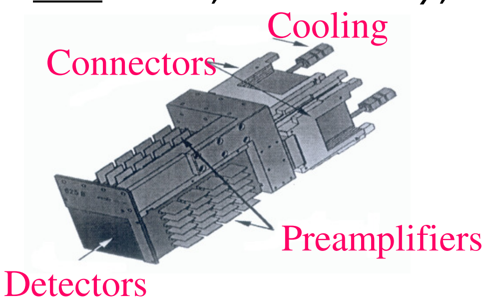
Few 100's keV resolution although very thin target

Silicon arrays developments

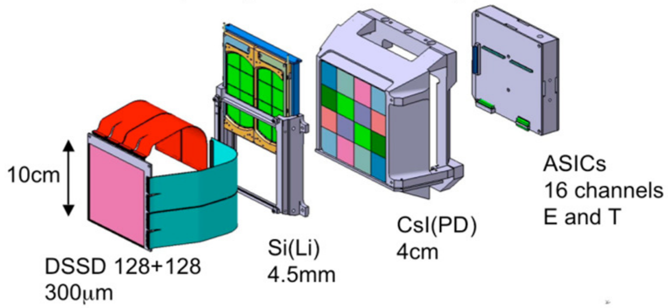
Light beams — **Heavier fragments**

1997 — 2007 — 2019/23

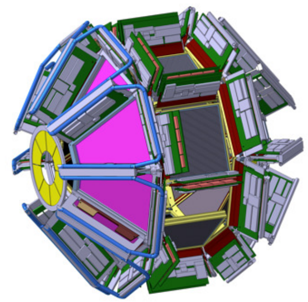
MUST
Coll.: IPN,CEA-Saclay, DAM



MUST2
Coll.: IPN,CEA-Saclay, GANIL



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



Particle spectroscopy

E_x resolution: ~500 keV

Particle-γ Spectroscopy

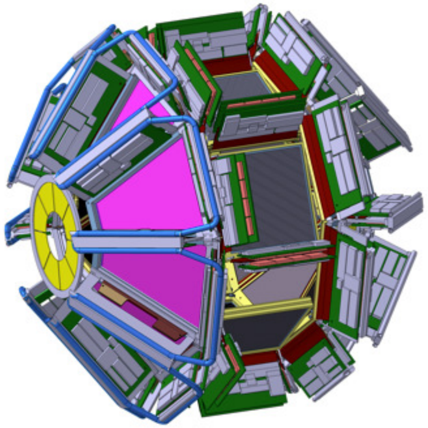
E_x resol.: ~5keV (AGATA)

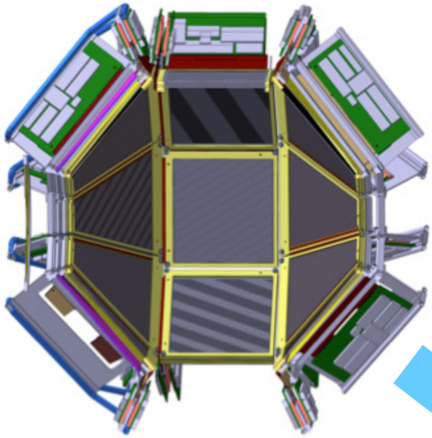
The GRIT project

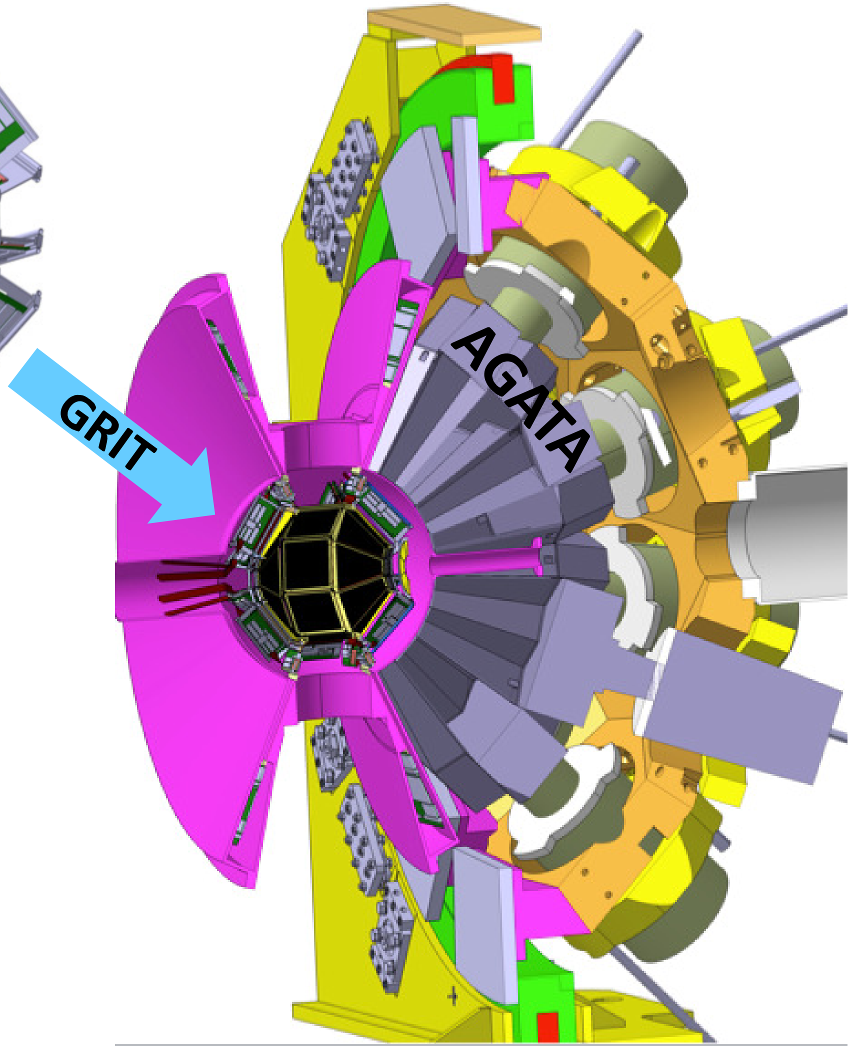
(Granularity, Resolution, identification, Transparency)

(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
- 1.5 mm DSSD pitch ~5mm

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

Collaboration

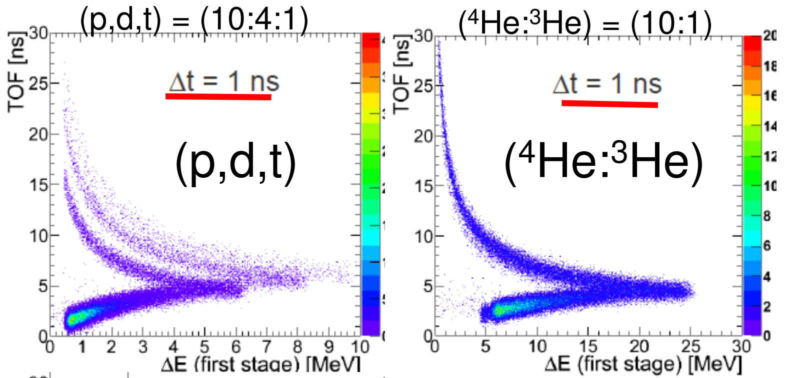
- IPN Orsay, GANIL, LPC Caen (France), CEA-Saclay
- INFN Univ. of Padova, INFN-LNL Legnaro , INFN Univ. of Milano (Italy), Univ. Of Firenze
- Univ. of Valencia, Univ. of Santiago de Compostella, Univ. of Huelva (Spain)
- Univ. of Surrey, STFC Daresbury (UK)
- BARC, Mumbai (India).

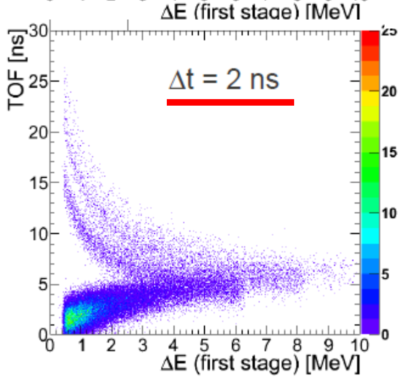
R&D on Pulse Shape Discrimination

Motivation: improve (TOF-based) PID of low-E charged particles

Simulations (N.De Séréville)

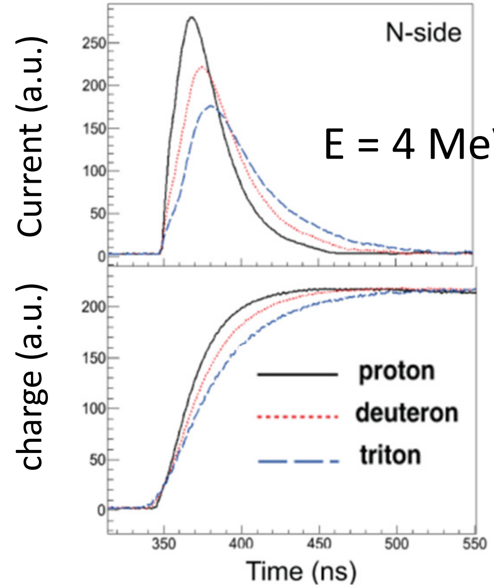
Z = 1 **Z = 2**





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

PULSE SHAPE DISCRIMINATION
Based on signal sampling



- More compact device (crucial!)
- Digital electronics

Initial R&D program by GASPARD / HYDE / TRACE collaboration

GRIT

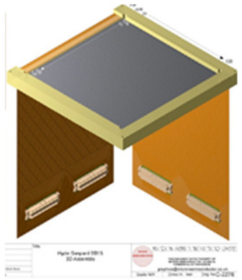
Granularity, Resolution, Identification, Transparency

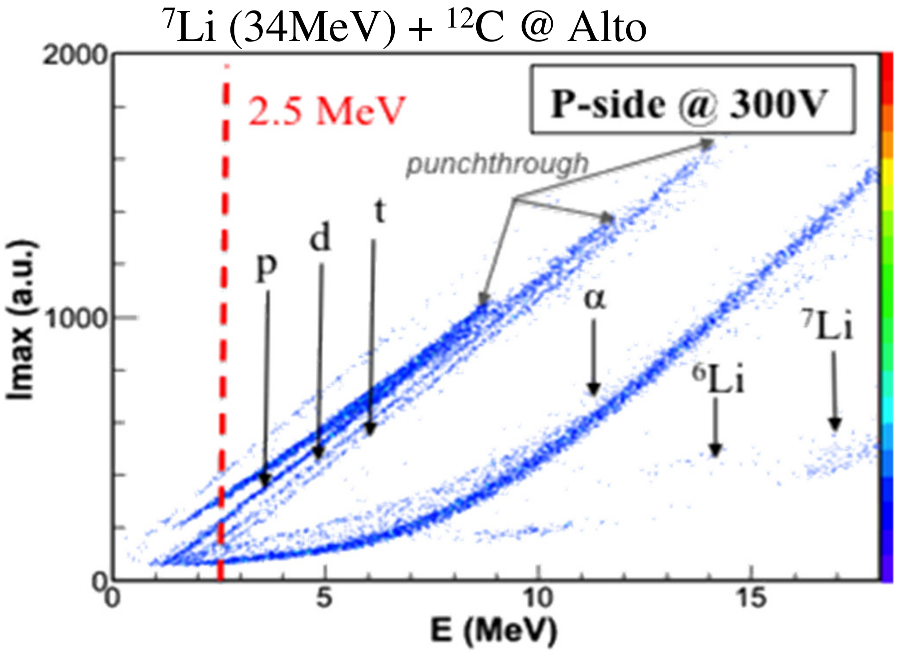
J. Duenas et al, NIMA 2012
J. Duenas et al, NIMA 2013
B. Genolini et al, NIMA 2013
J. Duenas et al, NIMA 2014
D. Mengoni et al, NIMA 2014
M. Assié et al, EPJA 2015
M. Assié et al, NIMA 2018

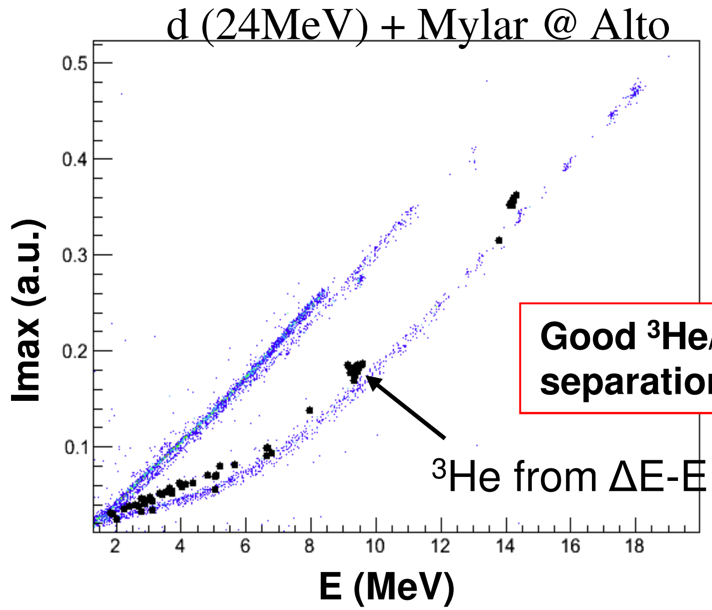
R&D on Pulse Shape Discrimination

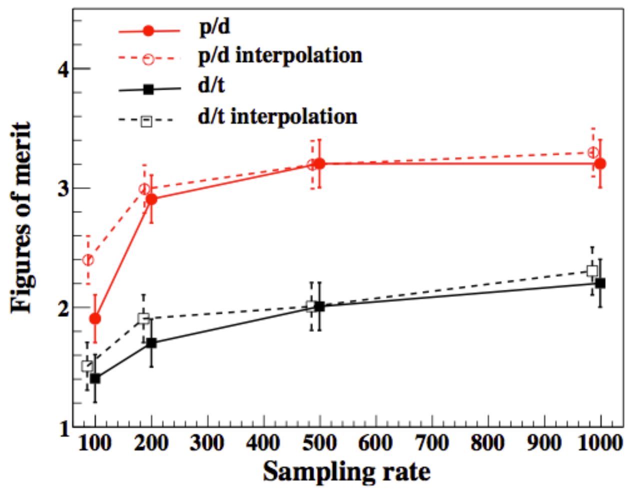
Initial detector:

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









New data under analysis

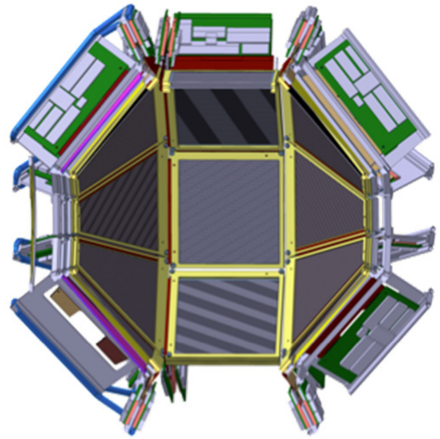
- Test of PSD with trapezoid
- Effect of radiation damage

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

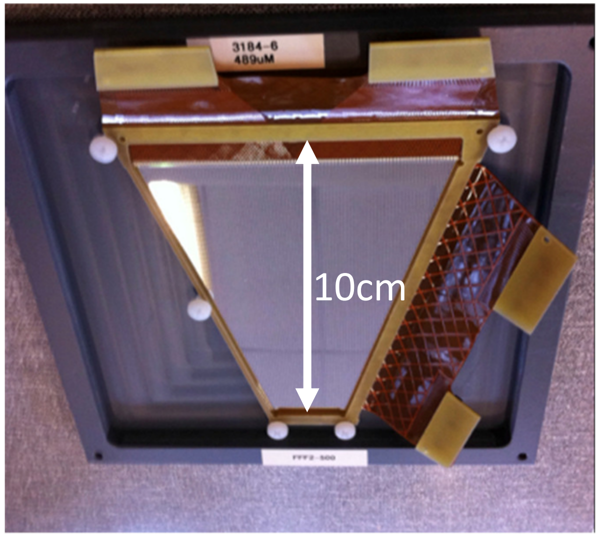
Detectors for GRIT

Detectors for the first layer

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



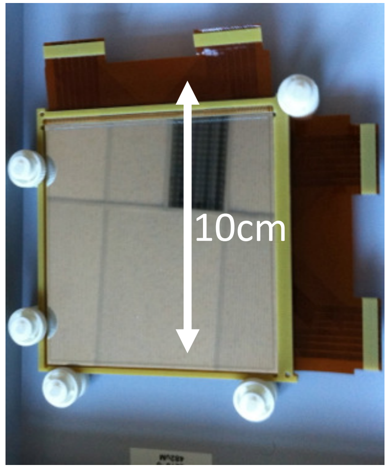
Trapezoidal DSSD



Commissioned:

- ✓ 2 prototypes 500um IPNO
- ✓ 4 pre-series (Surrey U., IPNO, Santiago) (MICRON SC Ltd., UK)

Squared DSSD



Commissioned :

- ✓ 2 prototypes 500um INFN (MICRON SC Ltd, UK)

Under development

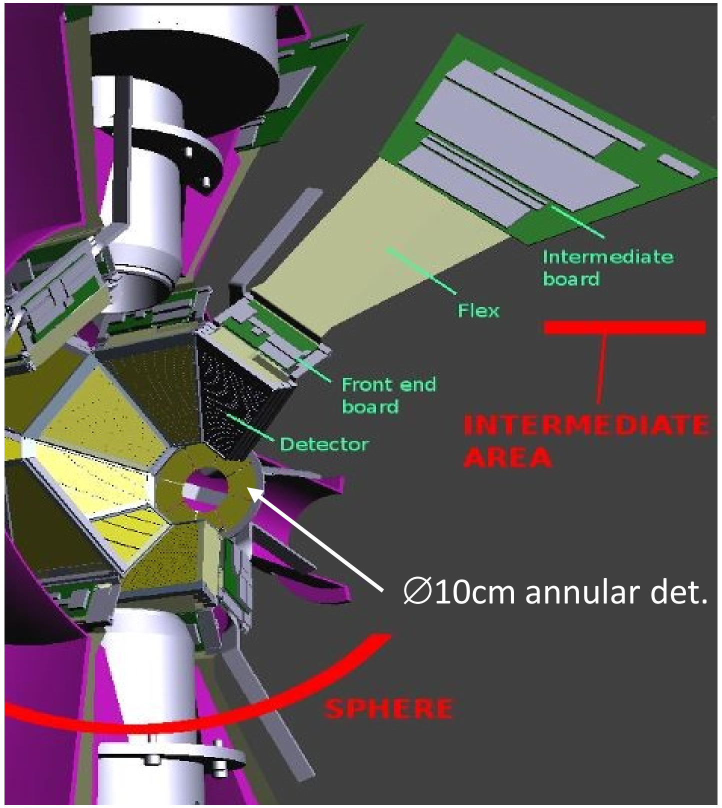
- ✓ 2 proto 500 um BARC Mumbai (Semiconductor Lab , Chandigarh, India)

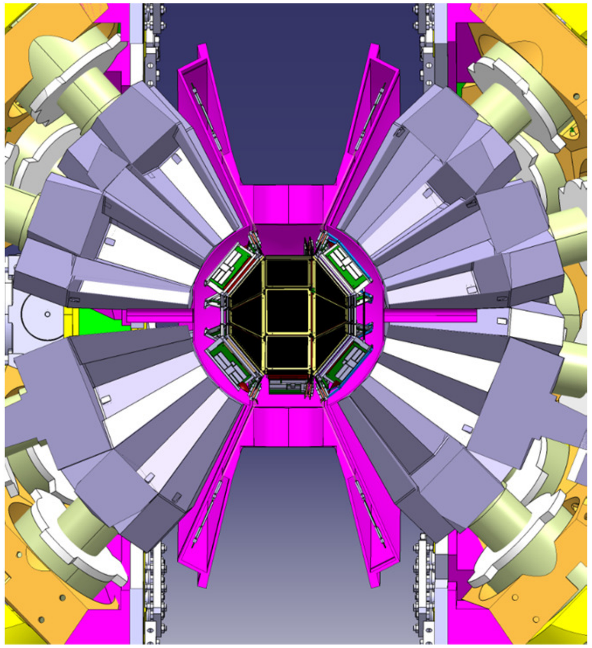
Detectors for the second layer to be developed

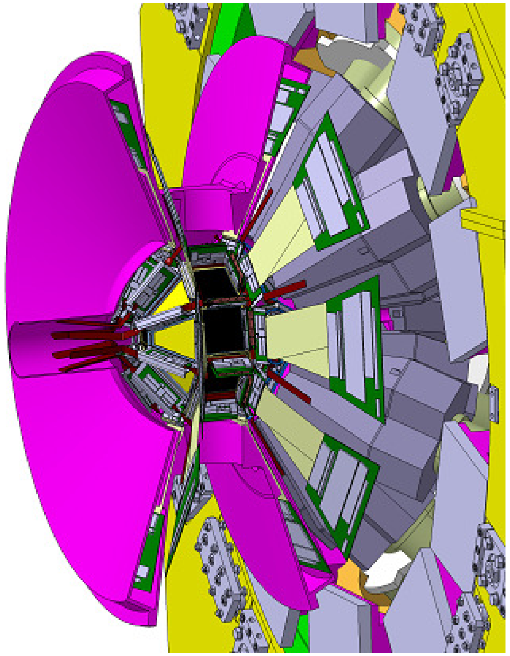
GRIT Mechanical design

Constraints

- **AGATA inner radius = 23cm**
- **Transparency to gamma-rays**
- **Special targets integration (CHyMENE, Orsay He)**
- **7000 electronics channels**
  FEE under vacuum -> few KW
  Connectics and feedthroughs
- **…**





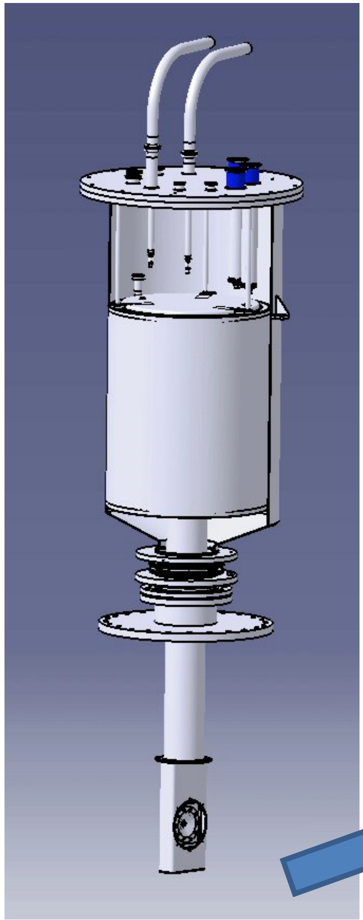


➢ **Preliminary detailed design is achieved**

Special targets for GRIT

The Orsay Helium target

Cooled gas cell at T~ 5K
^{4}He and ^{3}He versions



Reactions with ^{3,4}He probe

- **(^{3}He,d) *proton* shell evolution**
- **(^{3}He,p) for np pairing**
- **(^{4}He,^{3}He) for neutron shells selective for high-L orbitals Complementary to (d,p)**

….

Ø 16 mm,
2-3mm-thick cell
Havar windows 3.8µm
T = 5K , P = 1 bar

Status:

- ^{3}He version has been developed
- Used in 2019 MUGAST-AGATA campaign at GANIL

The CHyMENE system

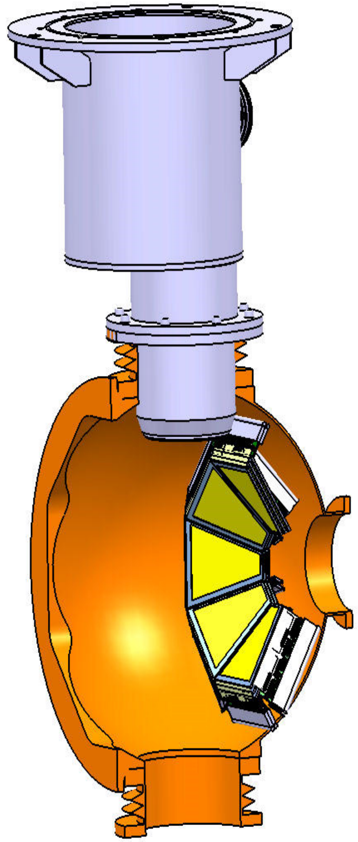
Continuous extrusion of ^{1}H or ^{2}H through an extruder nozzle

Collaboration**:** CEA/IRFU Saclay (*project coordinator: A. Gillibert)*
CEA/DAM Bruyères, IPN Orsay
Funded by the French agency ANR

Suppresion of ^{12}C-induced background
(in CH2 and CD2 targets)

Status:

- Tested under beam at ALTO in May 2019 20 and 100 µm ^{1}H
- ^{2}H version to be developed



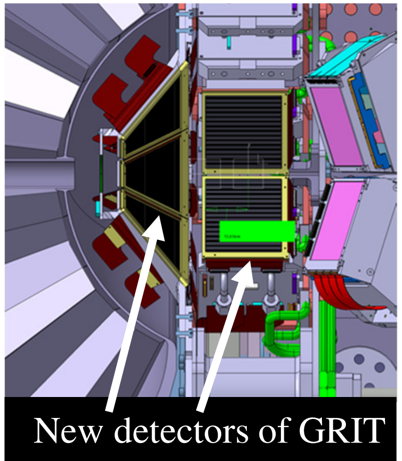
MUGAST: an intermediate step towards GRIT

[MUst2 – GASpard – Trace]

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

- *Coupled with AGATA @ VAMOS*

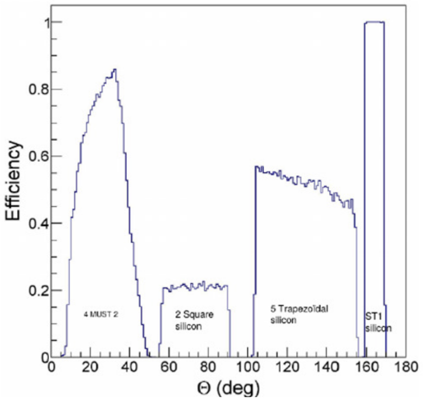
⇒ ***First High resolution Direct Reactions studies at Ganil (new SPIRAL1 beams)***



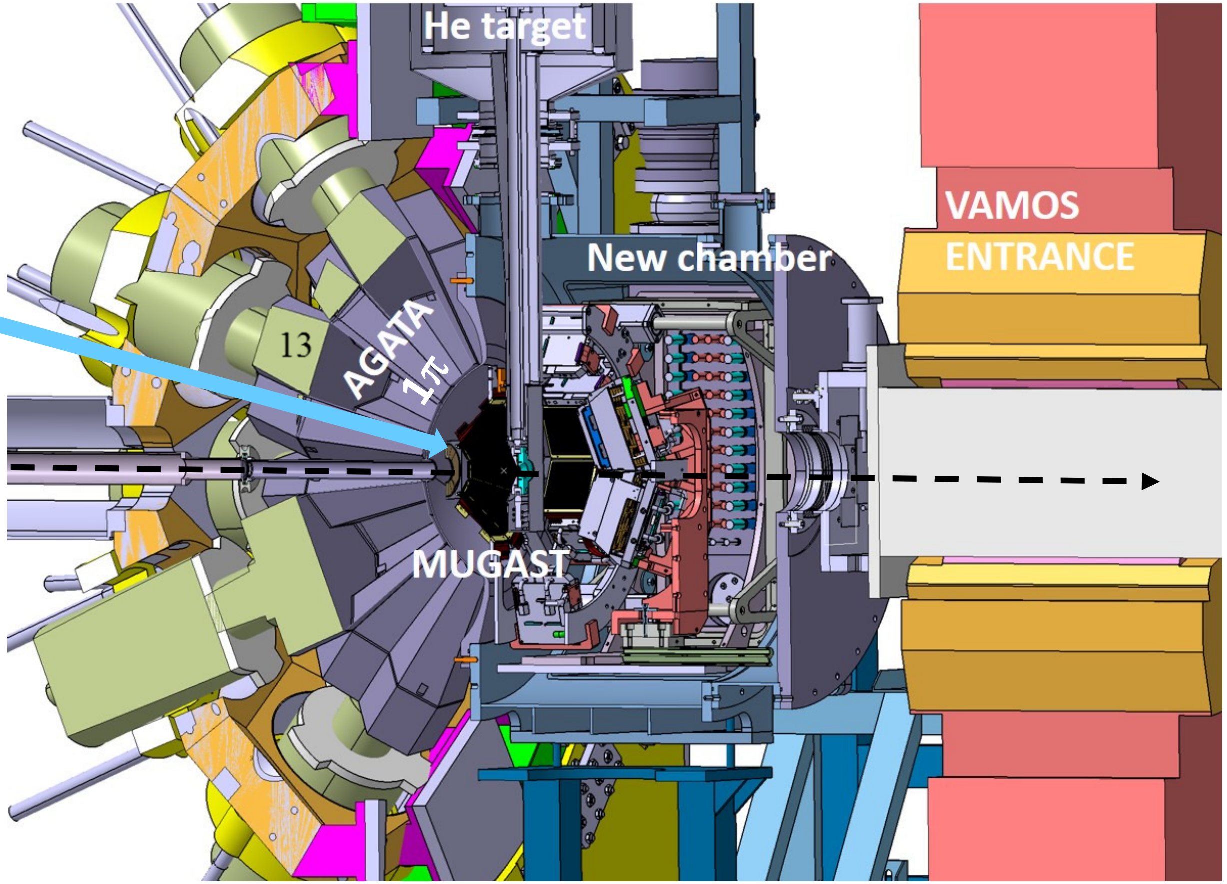
~ 3000 channels

MUGAST configuration:

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



RI Beam



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

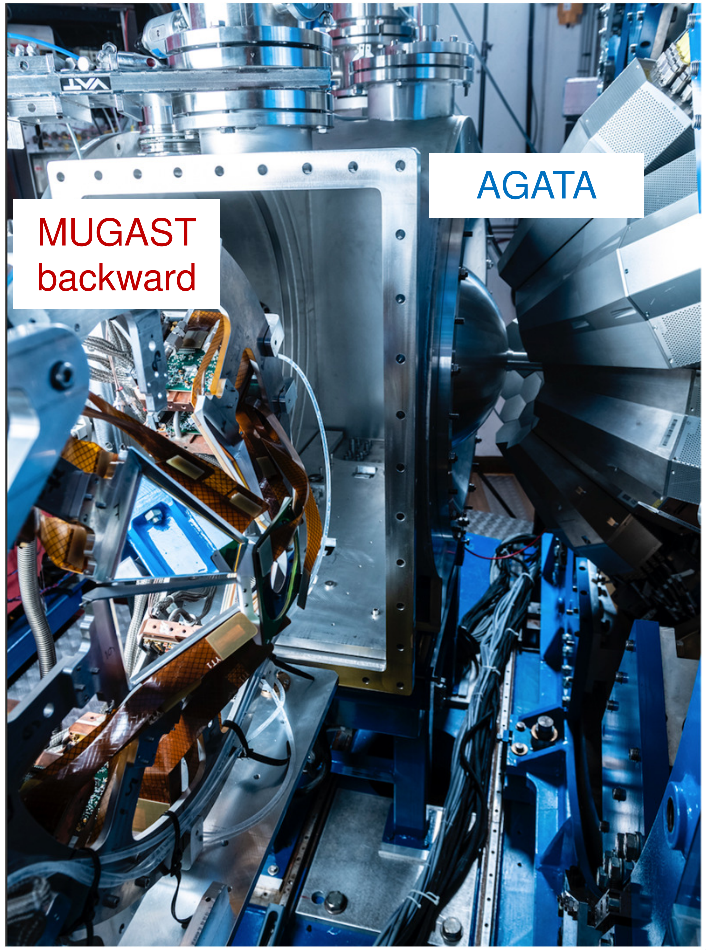
Funding: In2p3,P2iO,INFN,GANIL
Surrey, Santiago

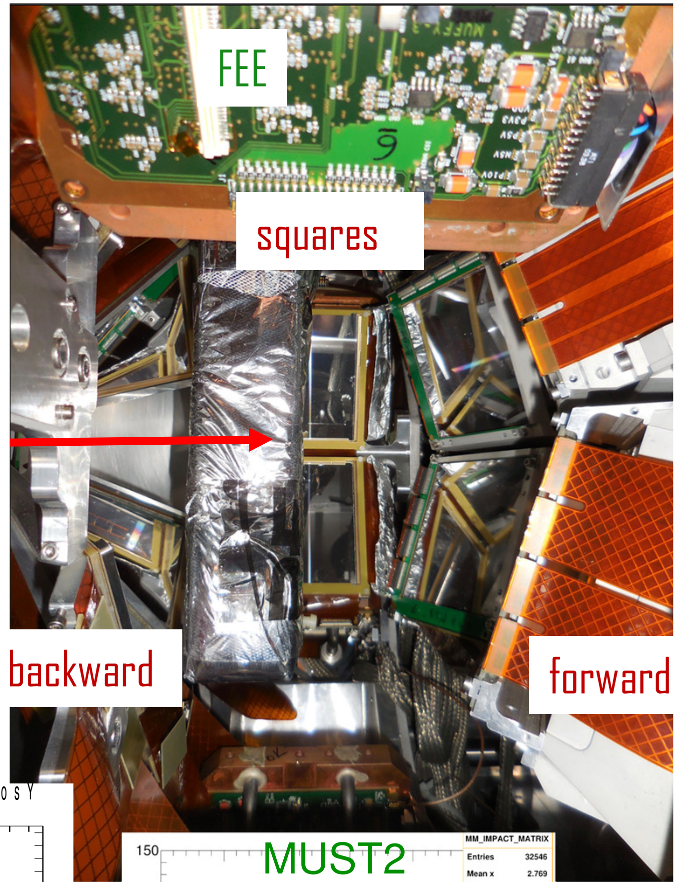
First Campaign in 2019

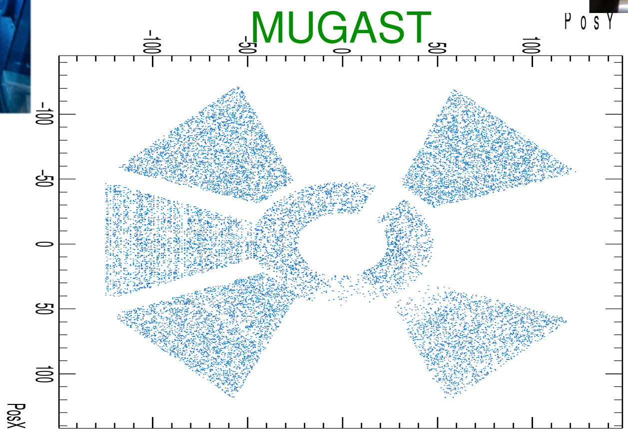
Coordinator: M. Assié, IPNO

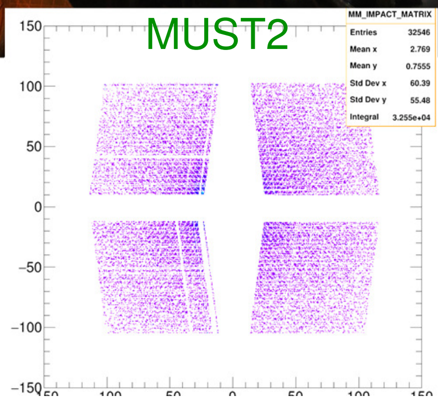
MUGAST-AGATA @ VAMOS/GANIL

Spring-summer 2019

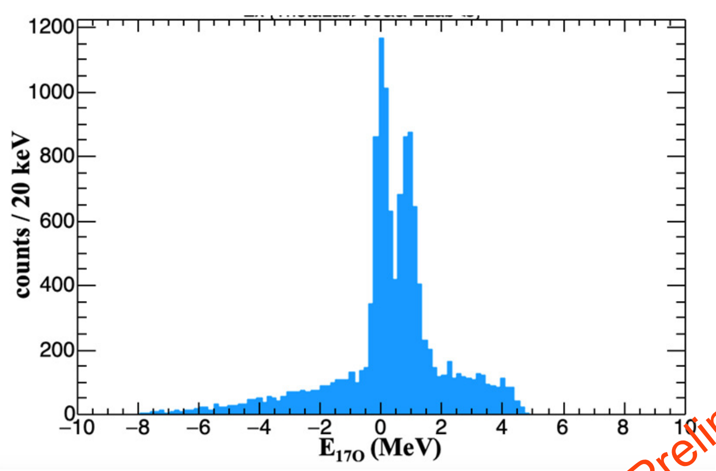


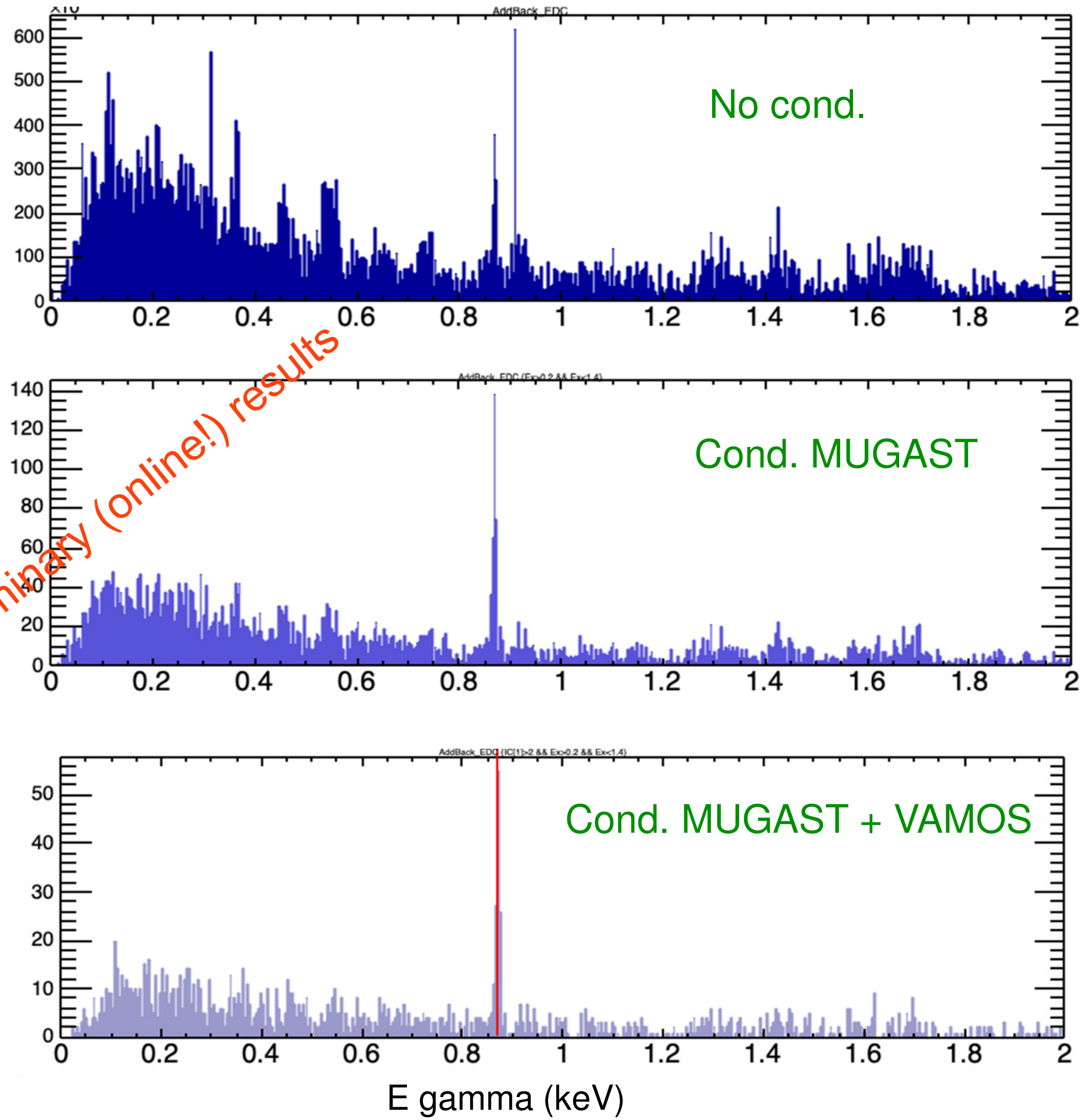






MUGAST commissioning : $^{16}O(d,p)^{17}O$





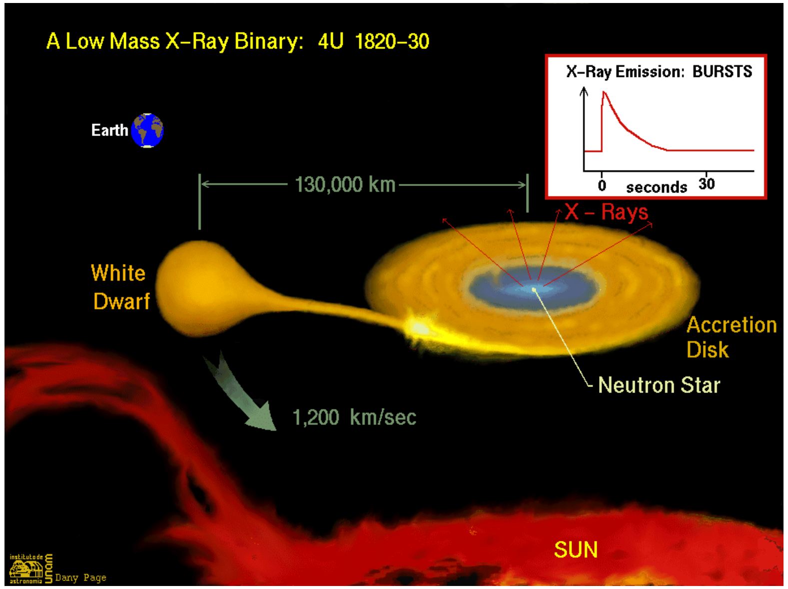
Relative eff. MUGAST-AGATA:

- before add-back : 5.5%
- after add-back : ~8%

From: M.Assié

Type I X-ray bursts

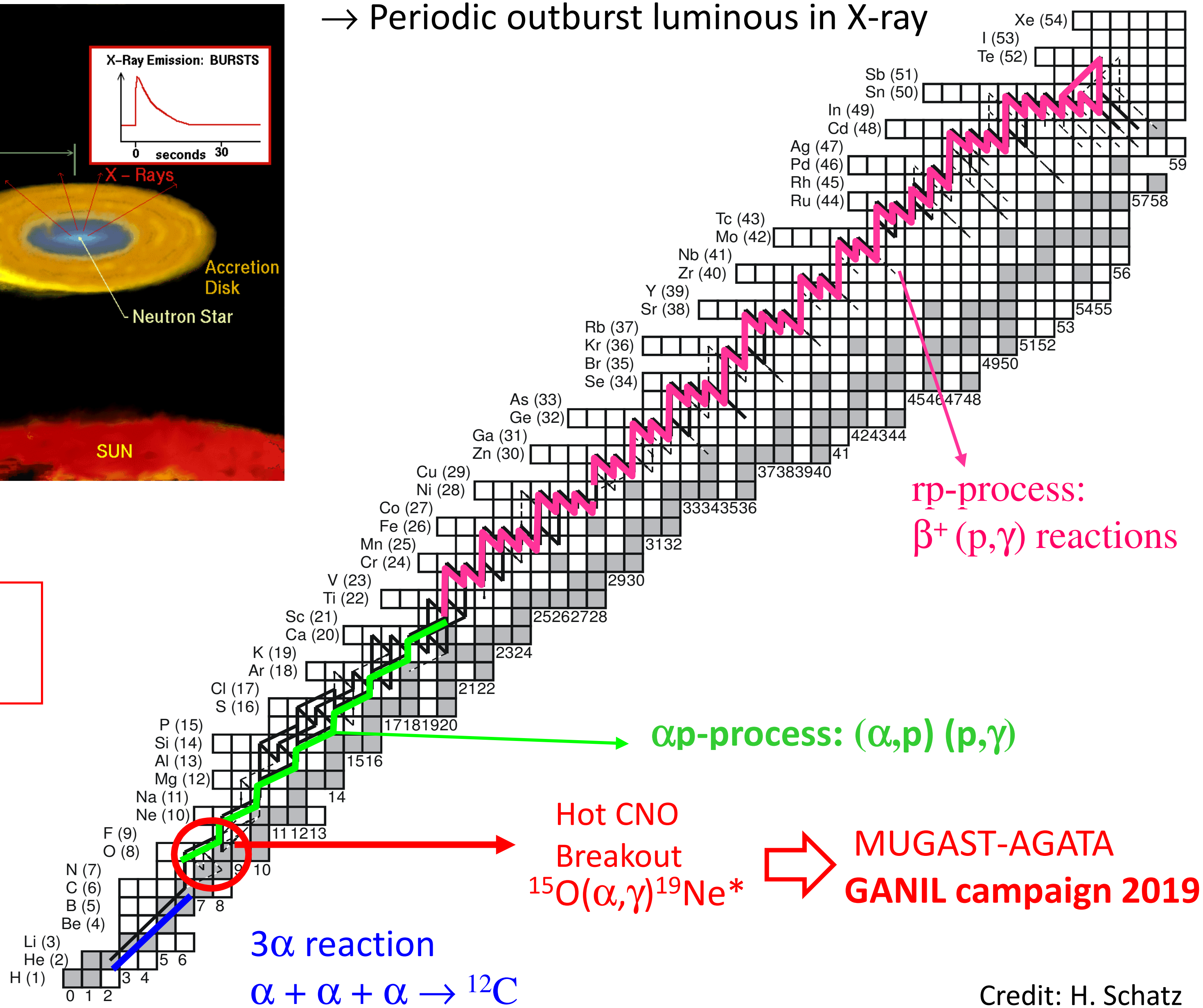
Accretion from companion star



→ Periodic outburst luminous in X-ray

T ~ 10^9 K

ρ ~ 10^6 g cm^{-3}



rp-process:
β⁺ (p,γ) reactions

αp-process: (α,p) (p,γ)

Hot CNO
Breakout
$^{15}O(\alpha,\gamma)^{19}Ne^*$

⇨ MUGAST-AGATA
GANIL campaign 2019

3α reaction
$\alpha + \alpha + \alpha \rightarrow {}^{12}C$

Credit: H. Schatz

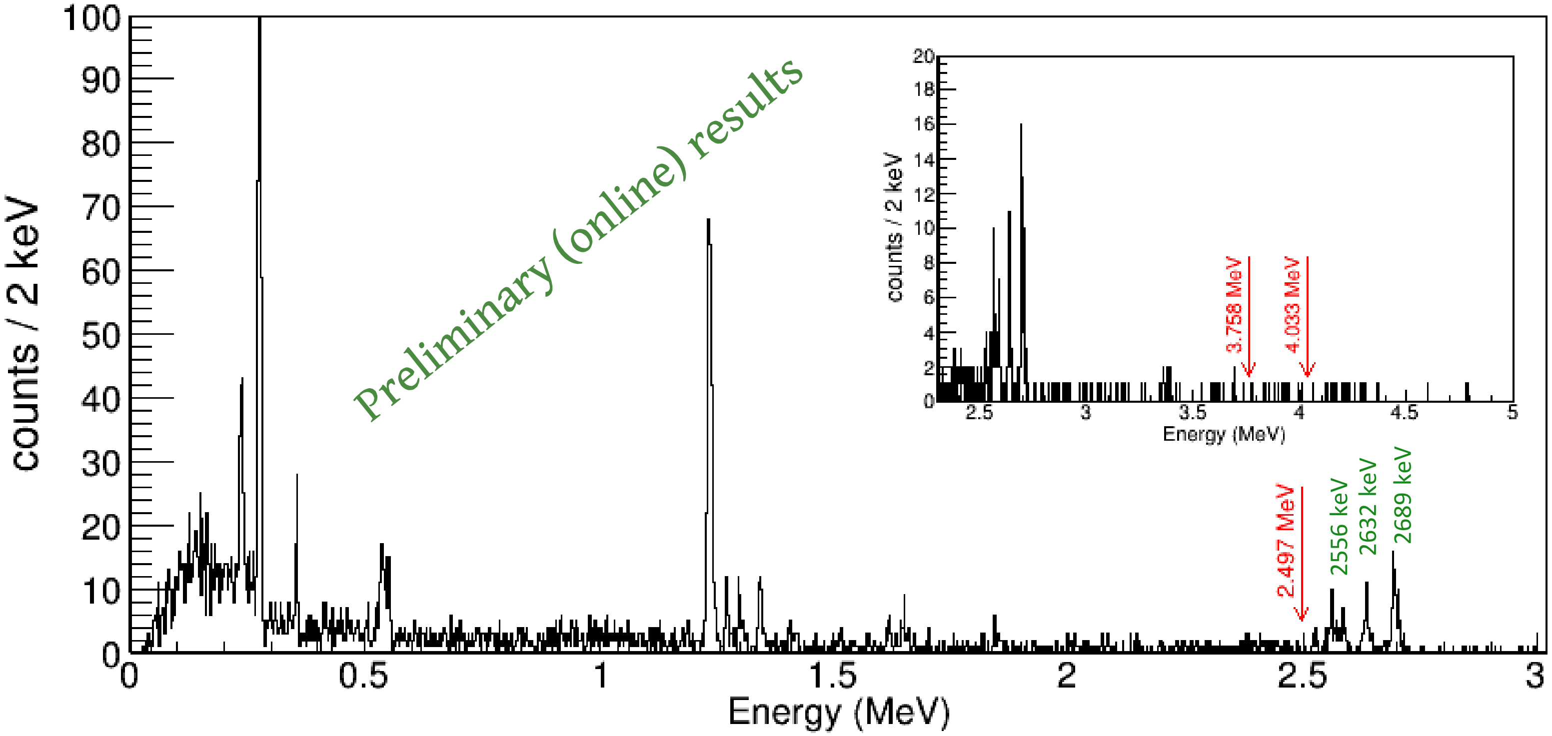
Nuclear astrophysics : Determining the α+^{15}O radiative capture rate

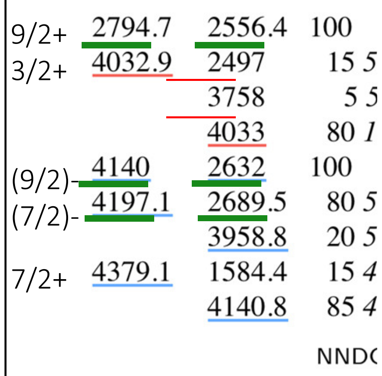
Spokespersons : C. Diget, N. De Séréville

Method: Indirect measurement of alpha capture rate through alpha stripping $^{15}O(^{7}Li, t\gamma)^{19}Ne$

- **Spiral1 beam of ^{15}O at 4.7 MeV/u and 2 10^7 pps with 1.25 mg/cm^2 LiF target**
- **Triple coincidence measurement of $^{15}O(^{7}Li,t\gamma)^{19}Ne$: t (MUGAST)+ γ (AGATA) + ^{19}Ne (VAMOS)**
- **Mirror reaction $^{15}N(^{7}Li,t\gamma)^{19}F$ at same energy and few 10^8pps**

Gamma spectrum in triple coincidence: ^{19}Ne in VAMOS + MUGAST





Partial level scheme of ^{19}Ne

--> Very clean spectrum : almost no background !

From: M.Assié

Present: MUGAST@GANIL/VAMOS

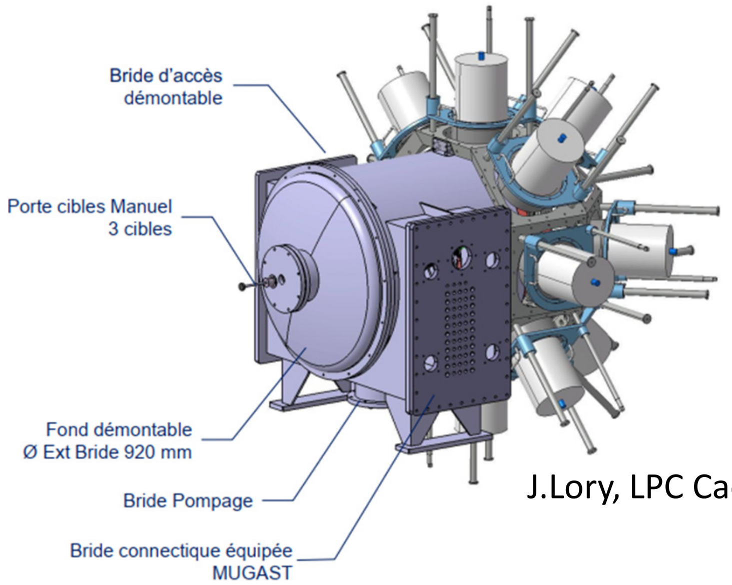
First step towards
GRIT

- **Positive scientific evaluations**
  - ✓ GANIL PAC
  - ✓ GANIL Scientific committee
  - ✓ IPNO Scientific committee
- **Selected for AGATA campaigns at GANIL in 2019 and 2020**

Next Step: MUGAST@GANIL/LISE

A new compact, 2-layer Si configuration
12 EXOGAM modules at 15cm from target

- **Detectors for 2^{nd} layer (1.5mm)**
  Status: to be ordered in 2019-20
- **New chamber /connectics**
  Status: Designed / to be designed



J.Lory, LPC Caen

Global strategy

	2019	2020	2021	2022	2023	2024 ~
MUGAST@VAMOS						
MUGAST@LISE						
GRIT (GANIL, SPES, Isolde?)						

Direct reaction studies using SD beams

- **Take advantage of chemical independence and fast production process of in-flight beams**
- **Reactions at intermediate energies (10~50 MeV/u)**

A broad physics program of direct reaction studies can be envisioned

Purpose of SD beams : implement reactions/techniques of the low energy regime

Stripping reactions

- Nucleon, pair or cluster **addition modes**
  - ✓ unique selectivity
  - ✓ no high-energy equivalent (as e.g. quasifree scattering ↔ pickup reaction)

(d,p) reaction : neutron shell structure seen to populate unoccupied orbitals
+ surrogate reaction for (n,γ)

(α,^{3}He) and (α,^{3}He) at 20~50 MeV/u to populate high-L orbitals

Cluster transfer (^{6}Li,d) or (^{7}Li,t)

Others

(p,t) pair transfer

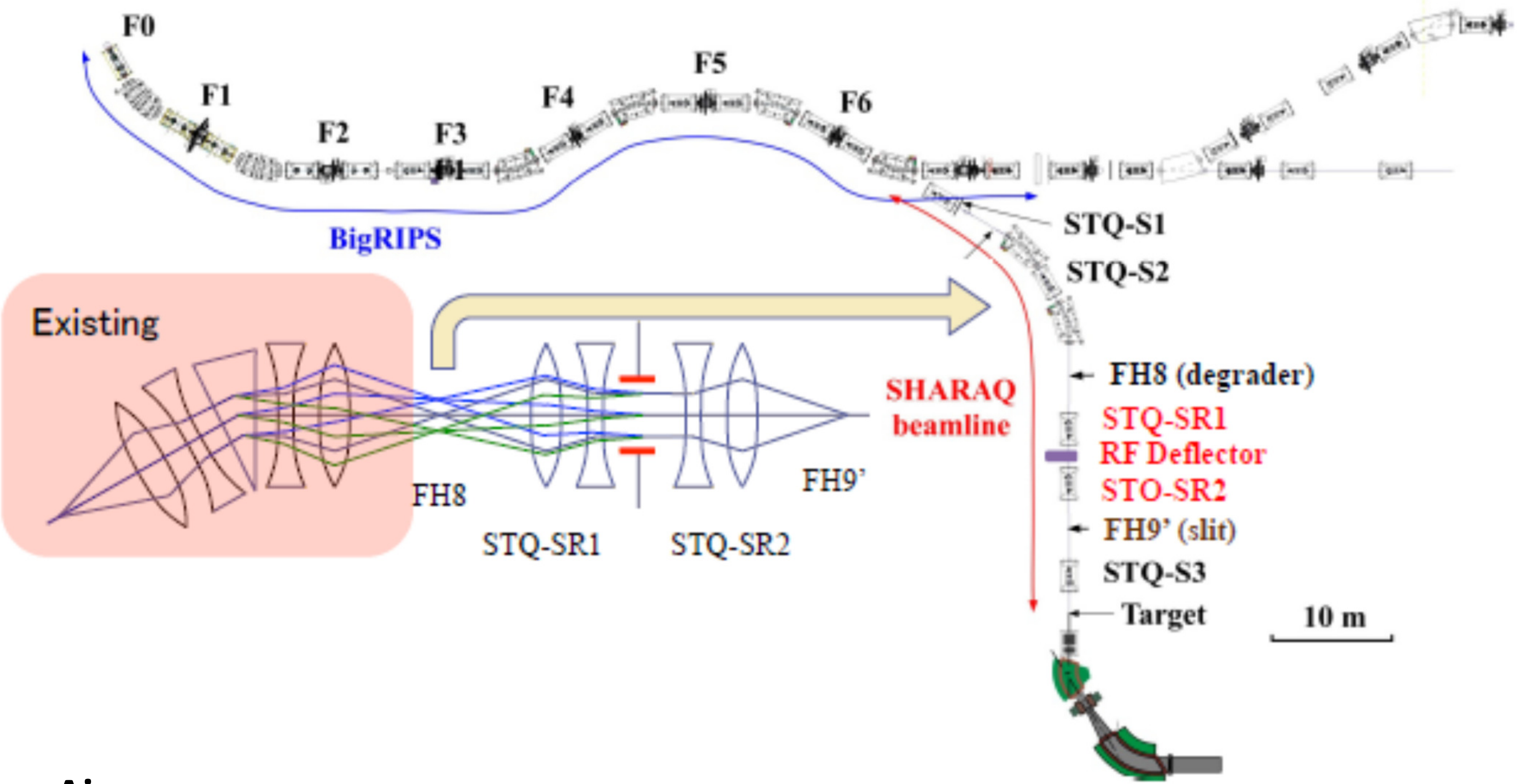
Coulex

....

Key Issues: Beam characteristics, Background

OEDO @ RIKEN

Optimized Energy Degrading Optics



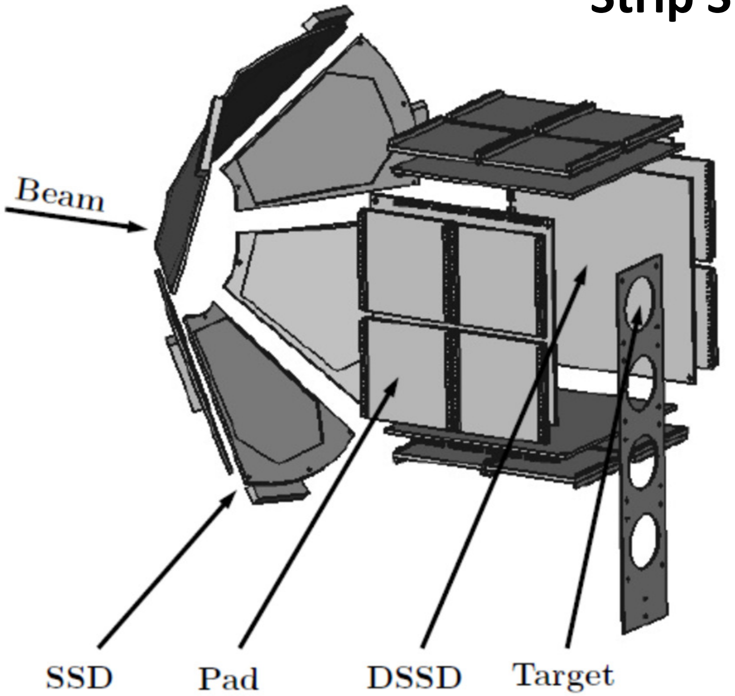
Aim:

- ➢ slow down RIBF beams to 5~50 MeV/u
- ➢ Improve beam characteristics

From: S.Shimoura
OEDO proposal

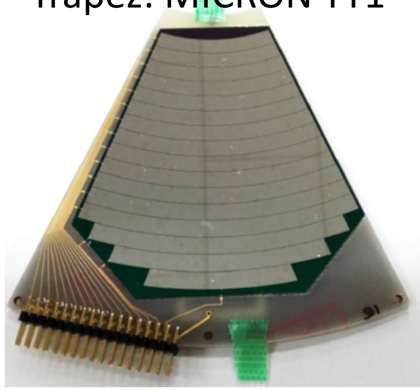
The TINA detector array

Strip Si + CsI recoil particle system



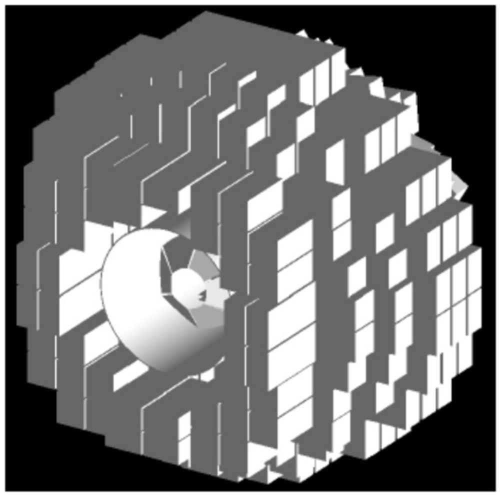
TRAPEZOID & SQUARED Shaped DSSD's

Trapez: MICRON YY1

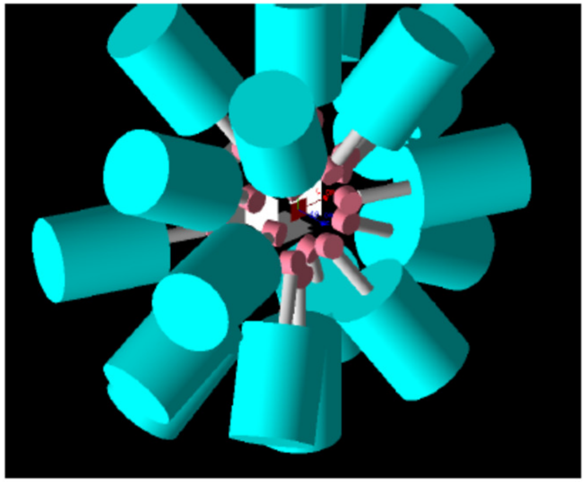


Squared: MICRON TTT

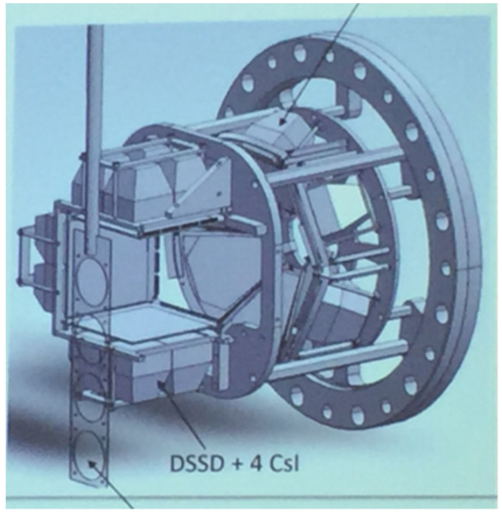
Signal processing: GET electronics



DALI2+
$(\Delta E/E \approx 7\%,\ \epsilon \approx 18\%)$



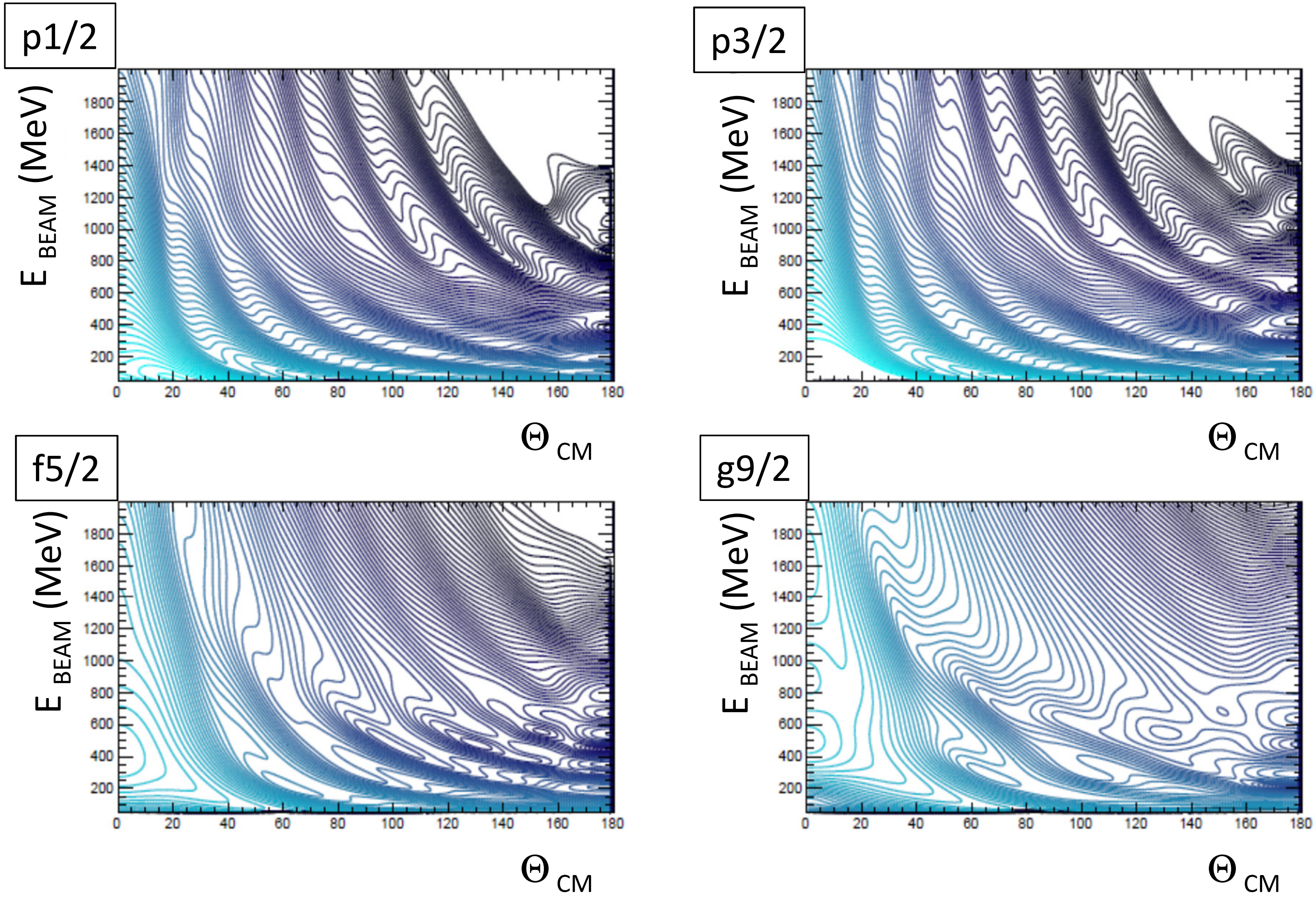
GRAPE
$(\Delta E/E \approx 1\%,\ \epsilon \approx 1\%)$



Evolution of diff. cross-sections with E_{BEAM}

(AWBA Calculations)

Case of $^{54}Ti(d,p)$



SIMULATIONS of direct reactions using SD beams

NPTool package for simulations of Direct reactions

A.Matta et al., JPG 43 (2016)

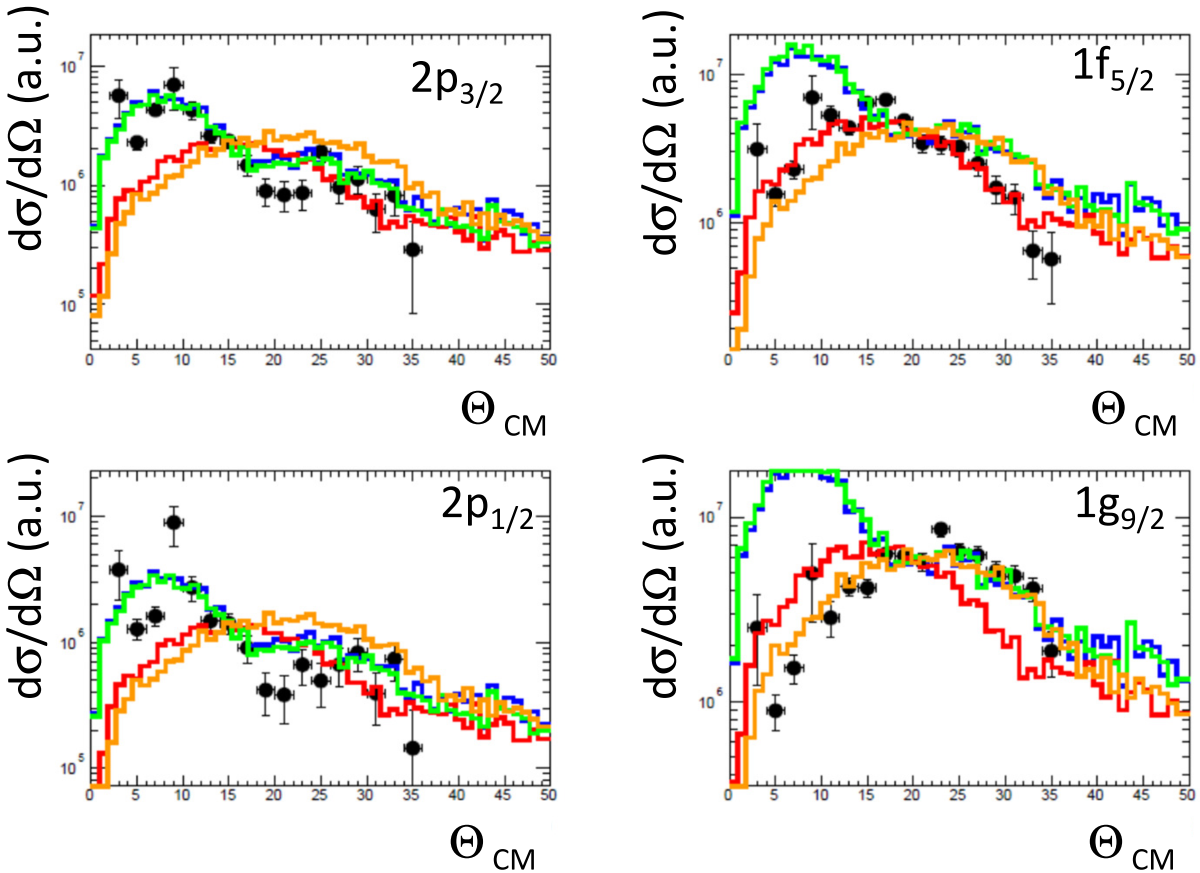
- Event generator: 2-Body kinematics and DWBA cross-sections
- Realistic detector configuration
- Detector's resolutions
- Target effects

New event generator :
Includes
- ❑ beam energy distribution
- ❑ ADWA for each energy

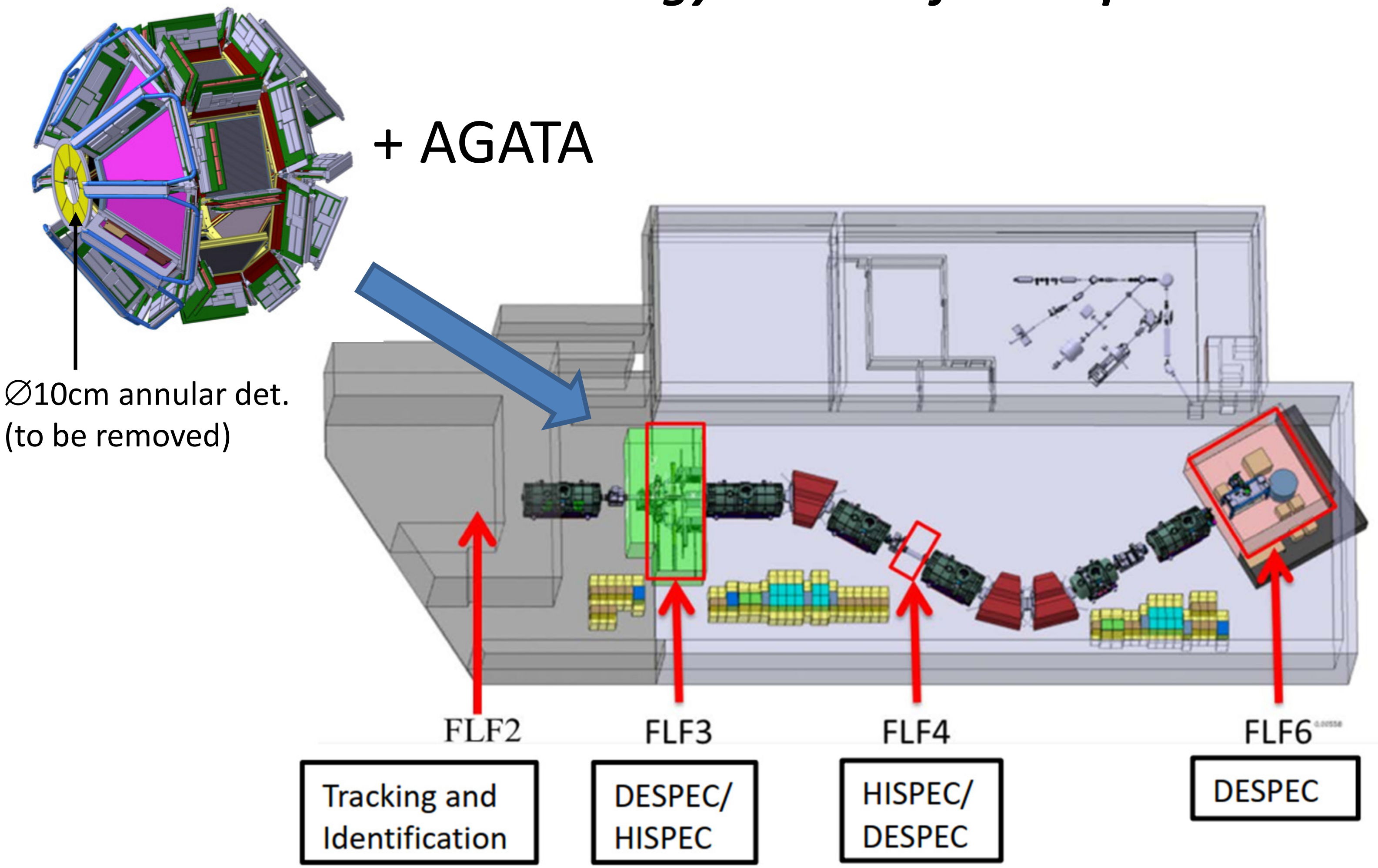
Simulation results for **^{54}Ti(d,p)** at RIKEN

- Population of p,f,g orbits
- $E_{beam} = (15 \pm 3)$ MeV/u

(E-integrated) diff X-sections sensitive to transferred L



Low Energy Branch of the super-FRS



Present Scheme (from TDR)

- ❑ Degrader at FLF2 E ~ 100 MeV/u
- ❑ + Degrader at FLF3 E ~ 10 MeV/u

NEED

- ➢ Beam tracking
- ➢ Beam TOF
- ➢ Residue detection