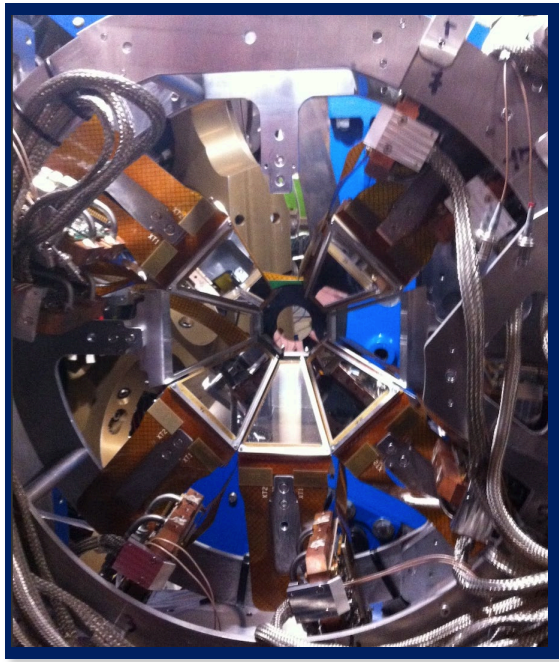
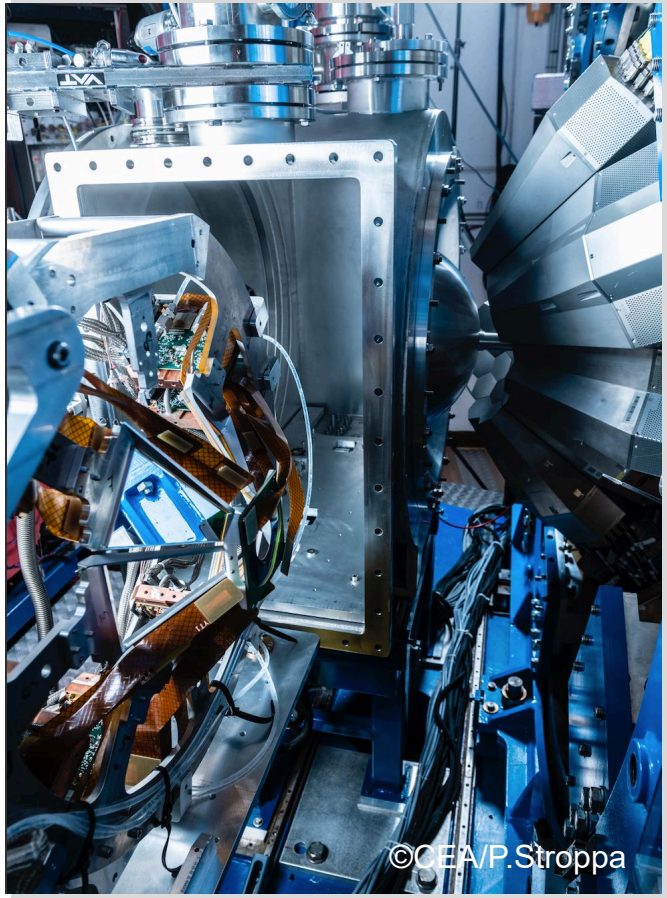


MUGAST-AGATA-VAMOS campaign @ GANIL

Marlène Assié, spokesperson of MUGAST campaign
IPN Orsay, assie@ipno.in2p3.fr

With the help of F. Galtarossa, D. Ramos, V. Alcindor, E. Clément, N. de Séréville, C. Diget, A. Gottardo, I. Stefan and the MUGAST collab.



MUGAST–AGATA-VAMOS set-up @ GANIL with Spiral1 beams

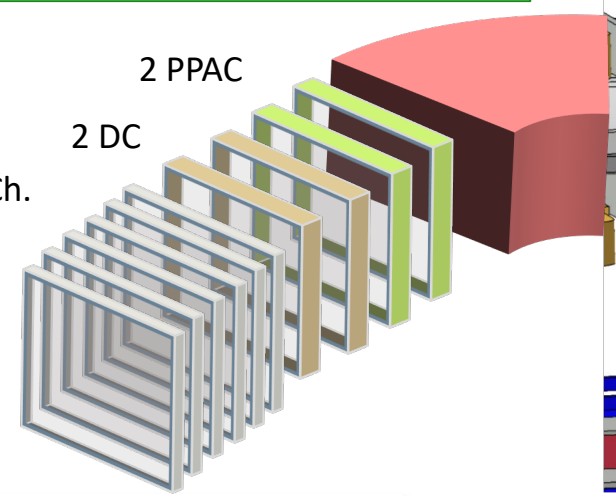
An extremely complete set-up for transfer reactions measurement

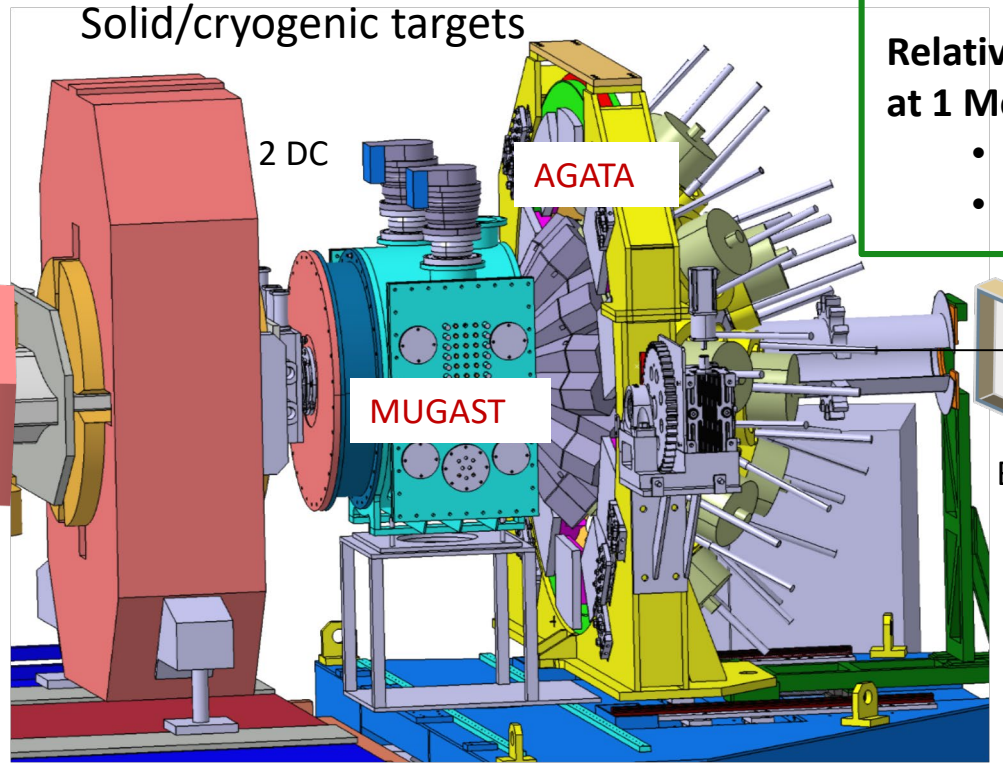
VAMOS

Acceptance of VAMOS : +/- 6 deg

VAMOS-MUGAST relative efficiency : ~80%

Numerical electronics NUMEXO2

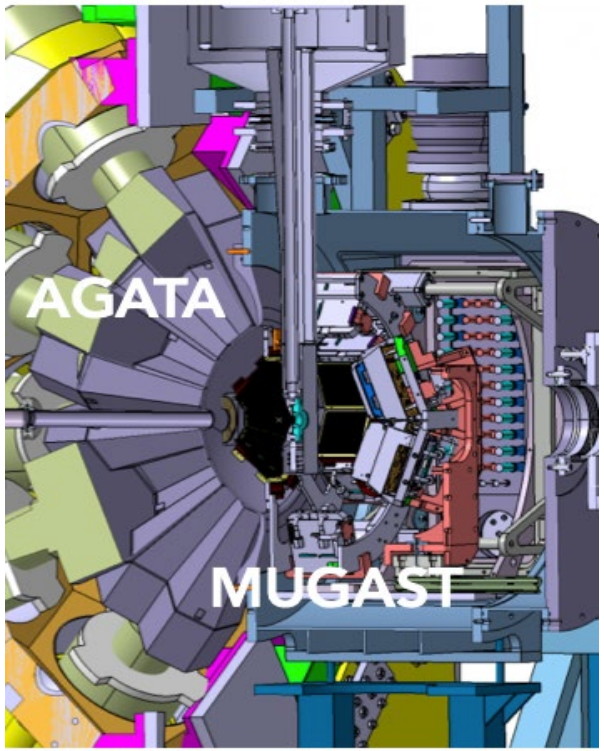


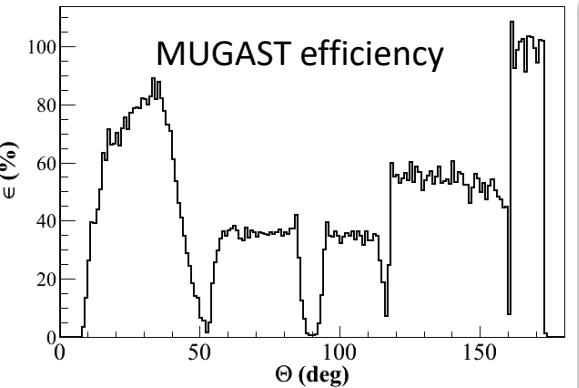


Relative efficiency MUGAST-AGATA (18cm) at 1 MeV:

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

Spiral1 radioactive beams





MUGAST :

Forward : 4 MUST2 (128X+128Y) DSSD 300um + CsI

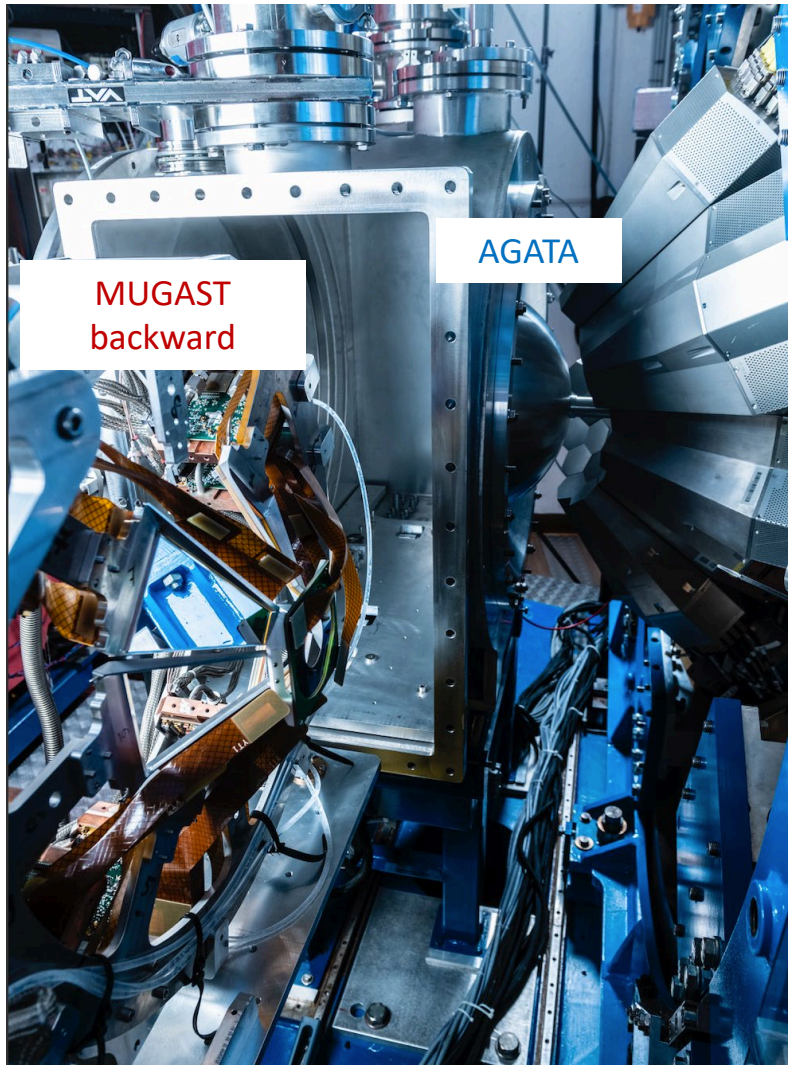
Backward : 5 trapezoid (128X+128Y) DSSD 500um + **Annular (S1)**

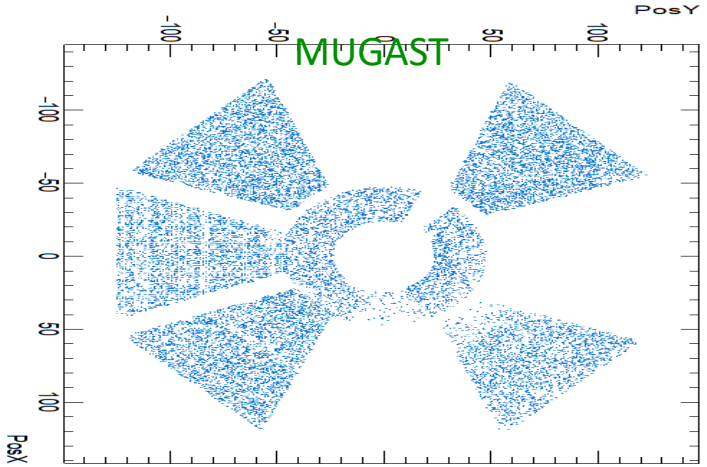
90 deg : 2 square (128X+128Y) DSSD 500um

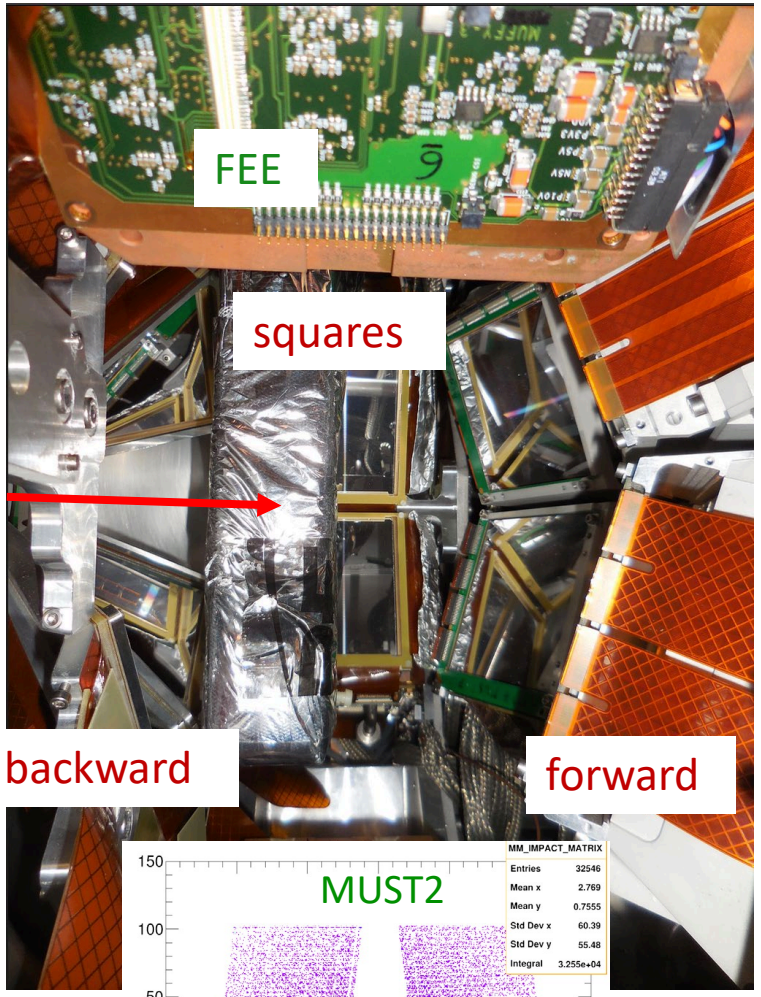
Granularity ~ 0.7 deg

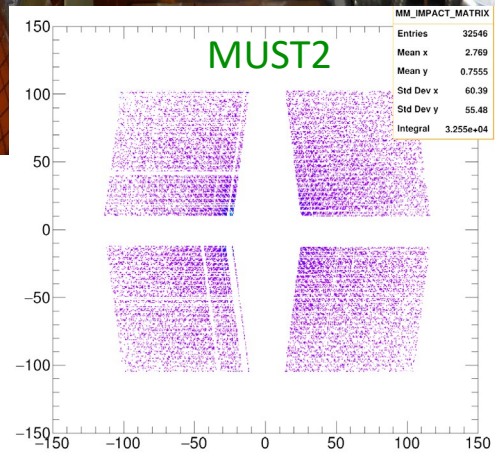
~ 3000 channels all read by MUST2 integrated electronics

MUGAST in pictures



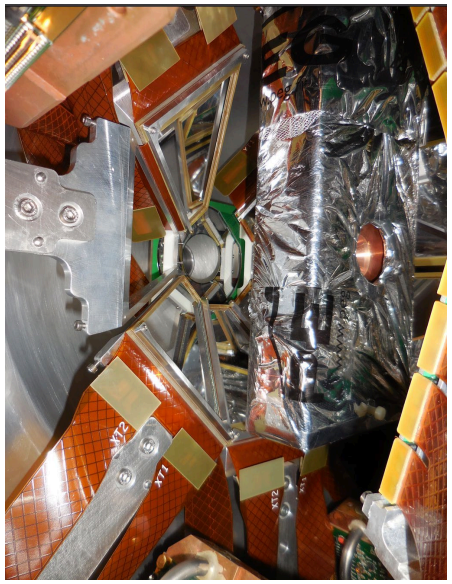


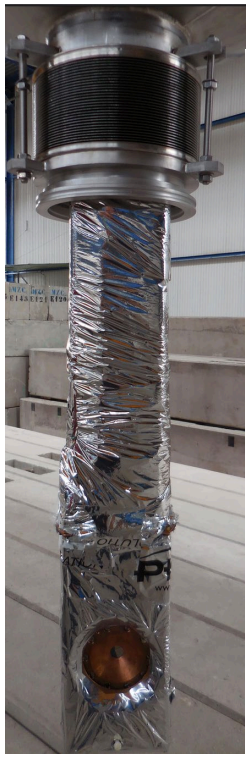


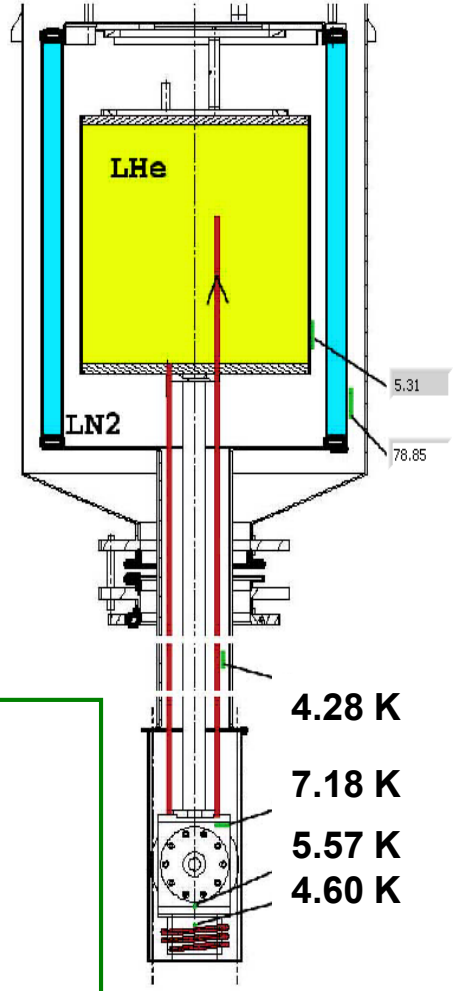


Cryogenic ^{3}He target

M. Pierens, V. Delpech, F. Galet, H. Saugnac (IPN)
A. Giret & J. Goupil (GANIL)



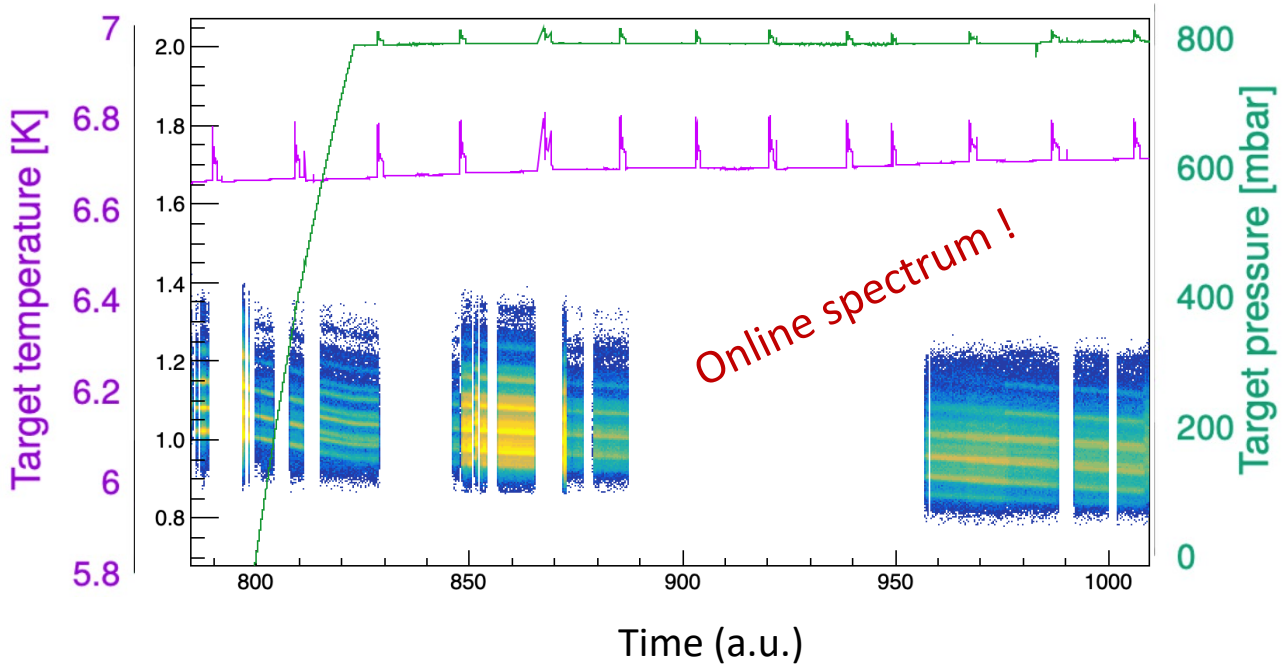




Characteristics :
- Ø 16 mm
- Opening angle 60 deg.
- 3mm thick
- Havar windows=3.8um
- T ~ 6-7 K
- P up to 1 bar
- Equivalent thickness ~2 mg.cm^3
- ^{3}He recycling (2.5l), LHe open circuit

Monitoring of target thickness with VAMOS
Target pressure & temperature stable

Bρ evolution with target filling



Courtesy of F. Galtarossa (IPN)

MUGAST electronics

VACUUM

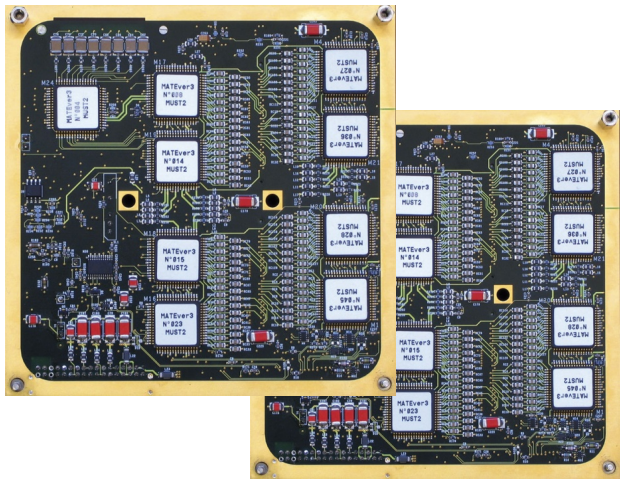
~ 58000 channels

MUFEE boards (MUST2) :

IPN by E. Rauly & E. Wanlin

- 12 MUFEE pairs in total
- 7 MUFEE pairs (X&Y) redone in 2016 (components & cabling) with new chips (ATHED instead of MATE)
  --> validated !

X 12



E,T
all strips
of hit det.

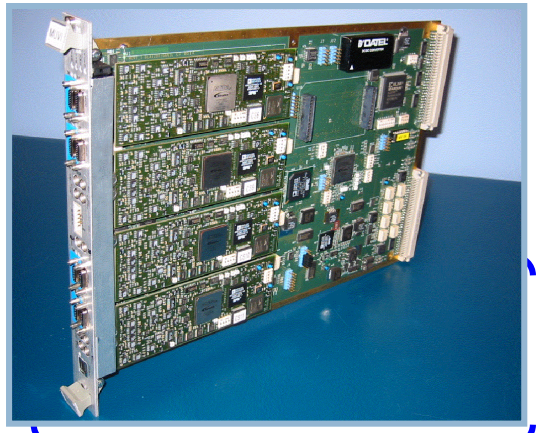
4 analog bus
Control signals
I2C bus

AIR

MUVI + GMT on VXI boards :

GAP GANIL

16 ADC14 bits
2.3K parameters
2MHz
Slow Control I2C
Pedestal substraction



X3 in 2019

X4 in 2020

4 telescopes

ACQUISITION for the MUGAST campaign

MUGAST
VXI1: Master GMT + MUVI1
VXI2: SlaveCentrum +MUVI2
VXI3: Slave Centrum + MUVI3

CATS
VXI4= Centrum + QDC

VAMOS
VXI5 Centrum + ADC

VAMOS
NUMEXO2 (digital)

AGATA
pre-processed data
X,Y,Z,T,E

Merge 1: event nb

GANIL event
MFM format

Merge 2: VAMOS TS

VAMOS
+ GANIL event
MFM format

AGAVA

AGATA TS in MFM Header

AGATA transmitter

AGATA receiver

ADF frame : 41 clusters
+ 42nd =GANIL

Merge 3: AGATA TS

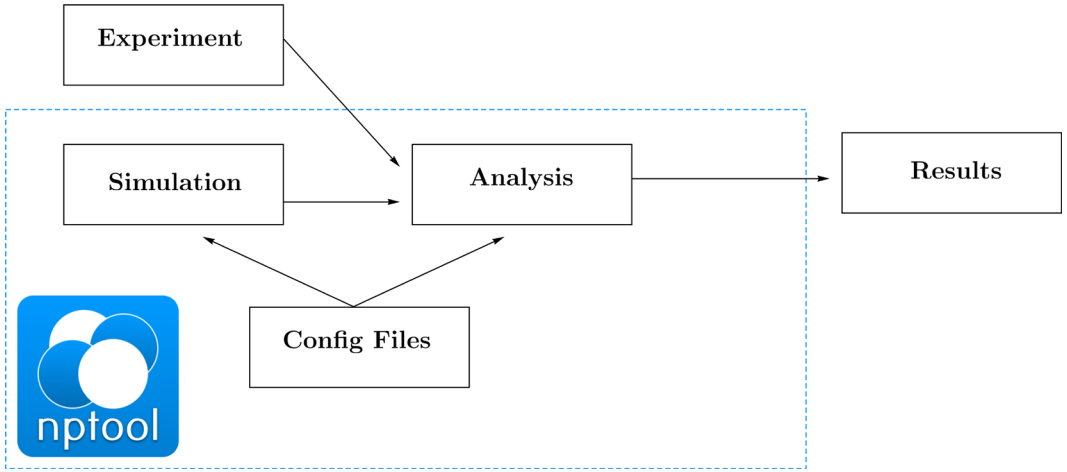
- Trigger given by MUGAST
- VAMOS triggerless (NUMEXO2)
- AGATA triggerless

!! Timing VAMOS-MUGAST-CATS

Analysis with NPTool + VAMOS + AGATA

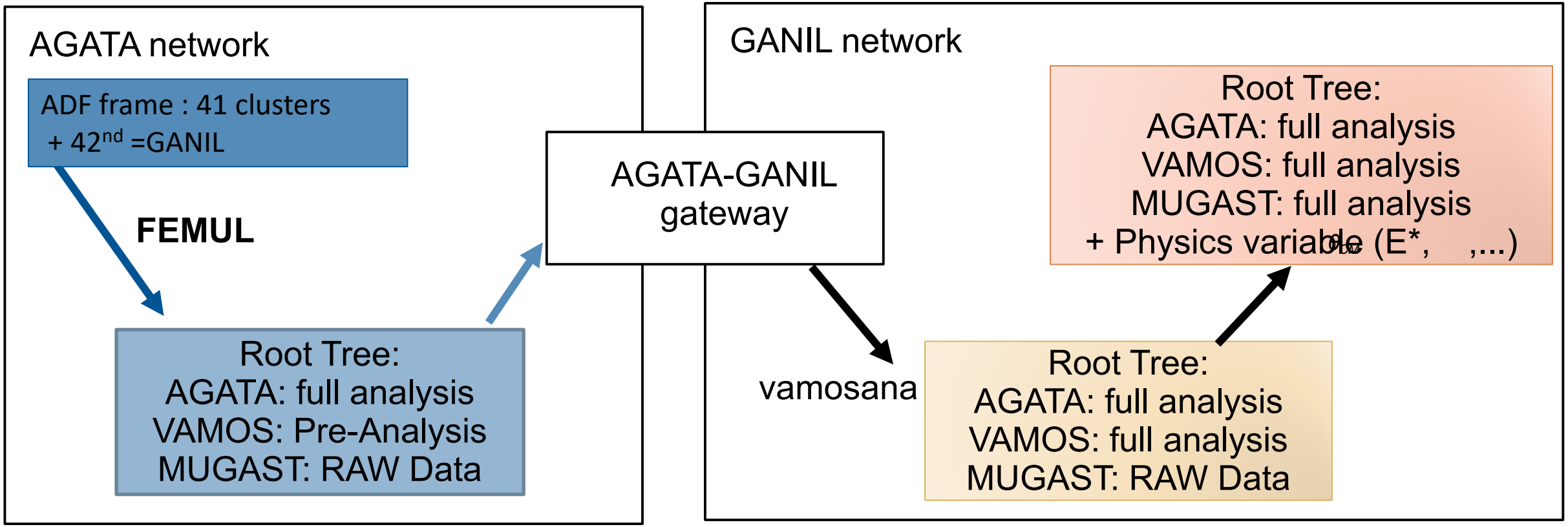
- A common framework for low energy nuclear physics experiment
- Modular and scalable → Any detector, any setup, any physics
- Promote good practices:
  - Framework philosophy → best use of Root and Geant4, readable input, ...
  - Implementation → Well commented, documented, readable code, ...
  - Physics → Validate simulation and analysis together`

- **Publi:** J. of Phys. G, Volume 43, Number 4
- **Website:** nptool.org
- **Repo:** gitlab.in2p3.fr/np/nptool
  - Continuous Integration (CI)
  - Docker image



Courtesy of A. Matta, LPC Caen

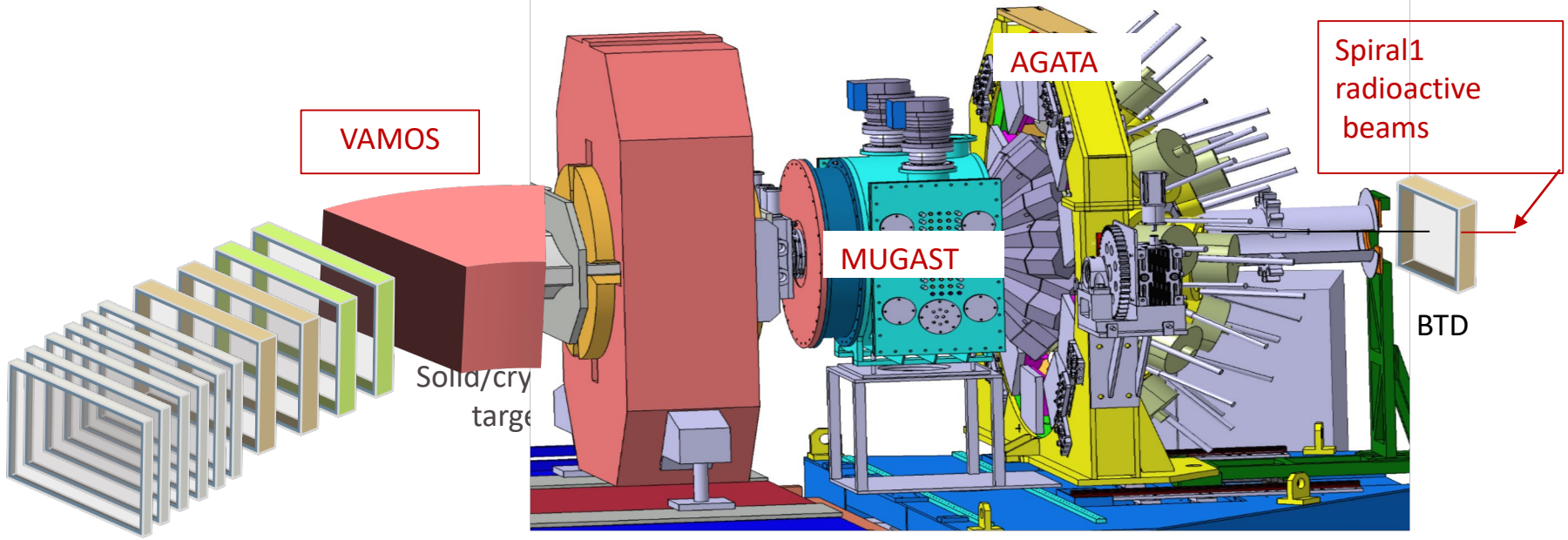
MUGAST-AGATA-VAMOS: analysis workflow



Courtesy of A. Matta, LPC Caen

MUGAST–AGATA-VAMOS set-up @ GANIL with Spiral1 beams

An extremely complete set-up for direct reactions measurement



SHELL MODEL

Is there a problem with protons in N=28 nucleus ^{46}Ar ?

^{46}Ar(^{3}He,dγ)^{47}K to probe proton WF and study vacancies in $s_{1/2}$ and $d_{3/2}$ shells.

^{3}He cryogenic target !

A. Gottardo INFN, M. Assié IPN)

NUCLEAR ASTROPHY.

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

^{15}O(^{7}Li,tγ)^{19}Ne indirect measure

Important reaction for breakout from Hot-CNO cycle to rp-process in Type I X-ray bursts

C. Diget (York), N De Séréville (IPN)

UNBOUND STATES

Above barrier narrow resonances in ^{15}F

^{14}O(p,p') inelastic scattering

- Search for new negative parity states
- Type of two-proton decay
- Gamma transition within unbound nucleus

I. Stefan (IPN), F. de Oliveira (GANIL)

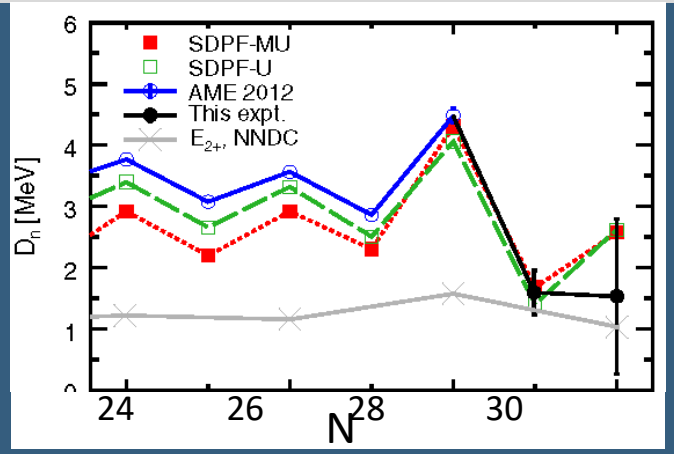
Shell model : Is there a problem with protons in N=28 ^{46}Ar ?

A. Gottardo (INFN), M. Assié (IPN)

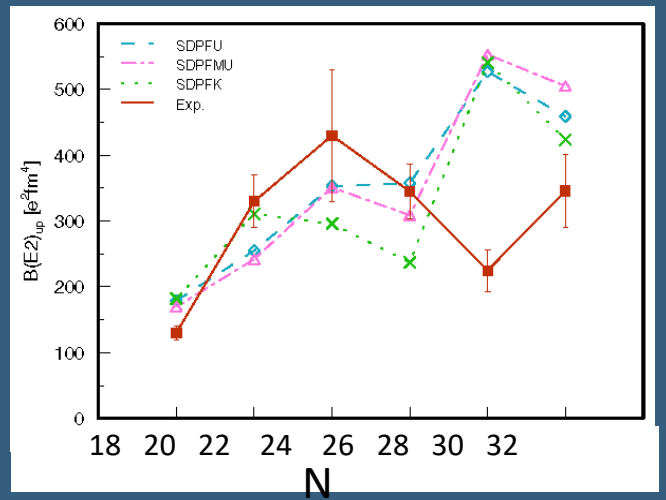
Method: proton stripping ^{46}Ar(^{3}He,dγ)^{47}K to probe proton wave functions

- Spiral1 beam of ^{46}Ar at 10 MeV/u and 4 10^{4} pps with cryogenic ^{3}He target
- Triple coincidence measurement : d (MUGAST)+ γ (AGATA) + ^{47}K (VAMOS)
- Normalisation / ToF : Beam tracking detector (CATS)

Z. Meisel . PRL 114, (2015)



A. Gade et al., PRC 68, (2003)
S. Calinescu et al., PRC 93, (2016)



- **Excellent theory for neutrons WF :**
  -confirming N=28 shell closure in ^{46}Ar
  -SDPF interaction describes valence-core neutrons interaction very well

Large discrepancy with the measured B(E2) value at N=28:
problem with the proton E2 contribution ?

- **Proton shell structure at N=28 :** inversion of $\pi s_{1/2}$ and $\pi d_{3/2}$

Measuring πs1/2 depletion in ^{46}Ar
--> indication on possible change in the π s1/2- π d3/2 positions

Central density depletion linked to spin-orbit splitting reduction

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,tγ)^{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,tγ)^{19}Ne : t (MUGAST)+ γ (AGATA) + ^{19}Ne (VAMOS)
- Mirror reaction ^{15}N(^{7}Li,tγ)^{19}F at same energy and few 10^{8}pps

► Explosive burning on neutron star surface :
breakout to rp-process ^{15}O(α,γ)^{19}Ne and ^{18}Ne(α,p)^{21}Na

- key beak-up route from the Hot-CNO cycle and in the right conditions lead to rp-process
- start-up of Type I X-ray burst on the surface of a neutron star depends critically upon this reaction rate

Resonant reaction rate ^{15}O(α,γ)^{19}Ne expected to dominate through 4033 keV resonance *(to be measured in AGATA)*

► Previous measurements :

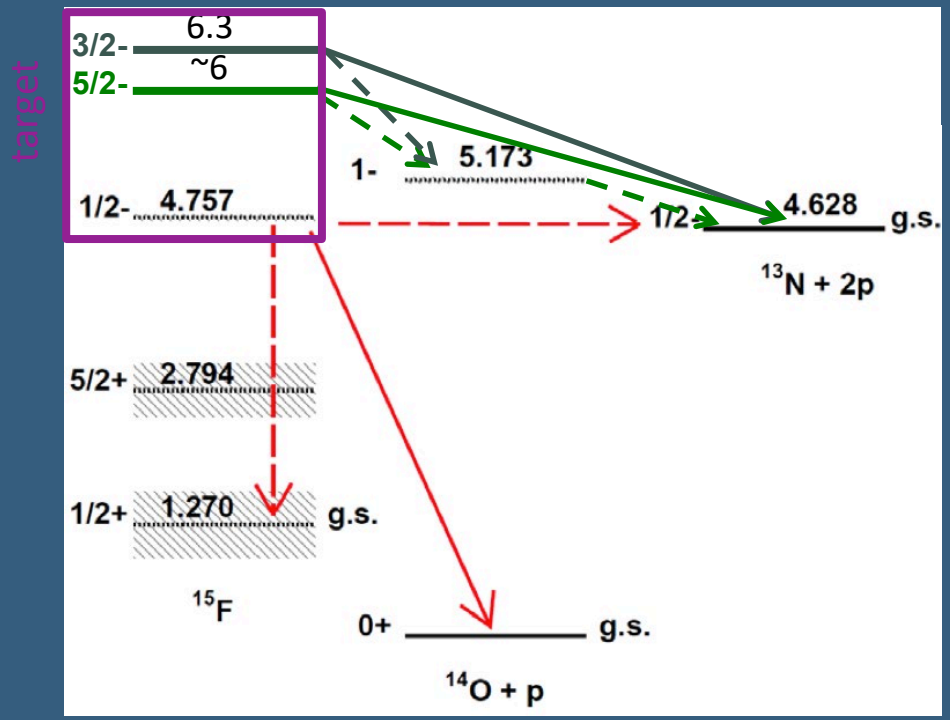
- $\Gamma_{tot} = \Gamma_{\gamma} \propto 1/\tau$ with $\tau = 7.9(15)$ fs from: γ-ray Doppler-shift lineshape
  Tan et al., PRC 72:041302(R) (2005)
  Kanungo et al., PRC 74:045803 (2006)
  Mythili et al., PRC 77:035803 (2008)
- $B_{\alpha} = 2.9(21) \cdot 10^{-4}$ from: ^{19}F(^{3}He, t)^{19}Ne$^{*}(\alpha)^{15}$O
  Difficult: 8 t-α on 35 b.gr.
  $\Gamma_{\alpha} = B_{\alpha} \cdot \Gamma_{tot} = 24(18)\ \mu$eV
  Tan et al., PRL, 98:242503 (2007)
  Tan et al., PRC, 79:055805 (2009)

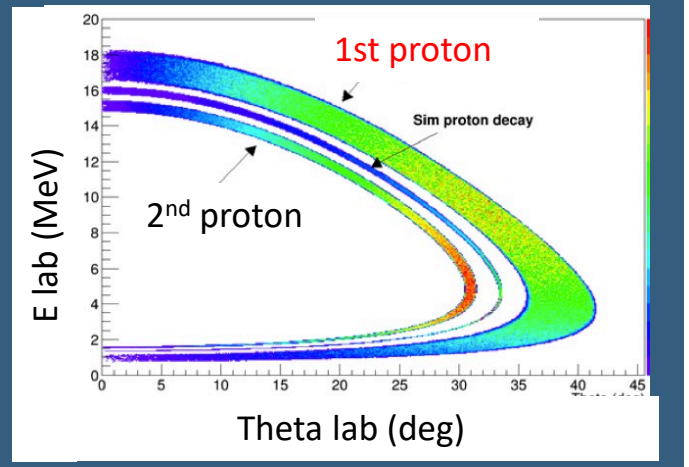
Unbound states : Above barrier narrow resonances in ^{15}F

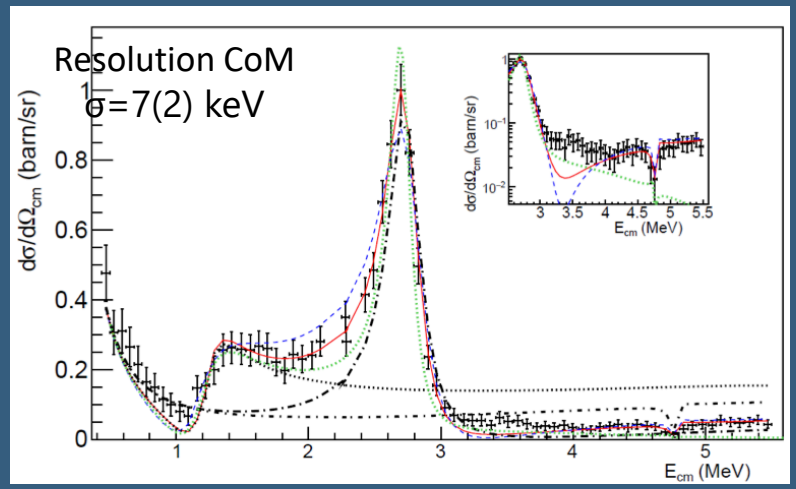
I Stefan (IPN), F. De Oliveira (GANIL)

Method: Resonant elastic scattering & inelastic scattering with thick target technique : ^{14}O(p,p$^{(')}$)

- Spiral1 beam of ^{14}O at 7.6 MeV/u and few 10^5 pps with thick CH_2 target (105 um)
- Coincidence measurement : p-p (MUGAST)+ eventual γ (AGATA) + ^{13}N (VAMOS)
- ToF : Beam tracking detector (CATS)
- VAMOS : ^{14}O and ^{13}N (after 2p decay) / finger remove direct ^{14}O beam / counting rate few 10^5 pps







De Grancey et al PLB 2016

→ **New negative parity states** (5/2-) to be observed`

→ **Two-proton decay** of negative parity states (3/2-, 5/2-) : sequential or simultaneous ?

→ **Gamma transition within an unbound nucleus** (EX ~4 MeV)

Conclusions & perspectives

2019 MUGAST-AGATA-VAMOS campaign at GANIL :

- transfer experiments to study nuclear structure and nuclear astrophysics
  - -> proton shell evolution
  - -> study of unbound states decay properties
  - -> nuclear astrophysics : alpha capture rate

- set-up very well adapted to study transfer reaction (stripping & pick-up)
  - High gamma efficiency, 50 to 80% efficiency for particles (backward/forward)
  - Triple coincidences --> very low-background
  - Correlator techniques implemented (two-proton decay)
  - High & low beam intensity (from Spiral1 beams) with VAMOS
  - Special targets can be integrated ^{3}He cryogenic target, tritium target under study

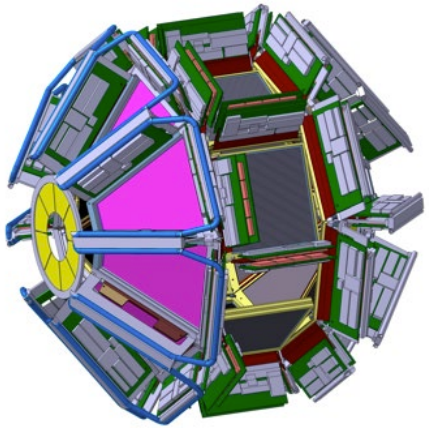
2020 MUGAST-AGATA-VAMOS campaign at GANIL :

- improvement of particle efficiency up to 85%
- transfer reaction + DSAM measurement already accepted by the PAC

2023 GRIT detector will start operating

- 90% efficiency, two to three layers of DSSSD
- 15000 channels read by numerical electornics (iPACI+ PLAS+ FASTER)

http://grit.in2p3.fr



MUGAST collaboration

IPN Orsay M. Assié, D. Beaumel, Y. Blumenfeld, N. de Séréville, F. Flavigny, F. Galtarossa, J. Guillot, F. Hammache, L. Lalanne, I. Stefan

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IPHC Strabourg : K. Rezynkina, G. Duchêne, F. Didierjean

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University of York C. Diget, A. Laird, J. Sanchez-Rojo

University of Surrey : W. Catford

University of Santiago : B. Fernandez-Dominguez

University of Valencia : A. Gadea