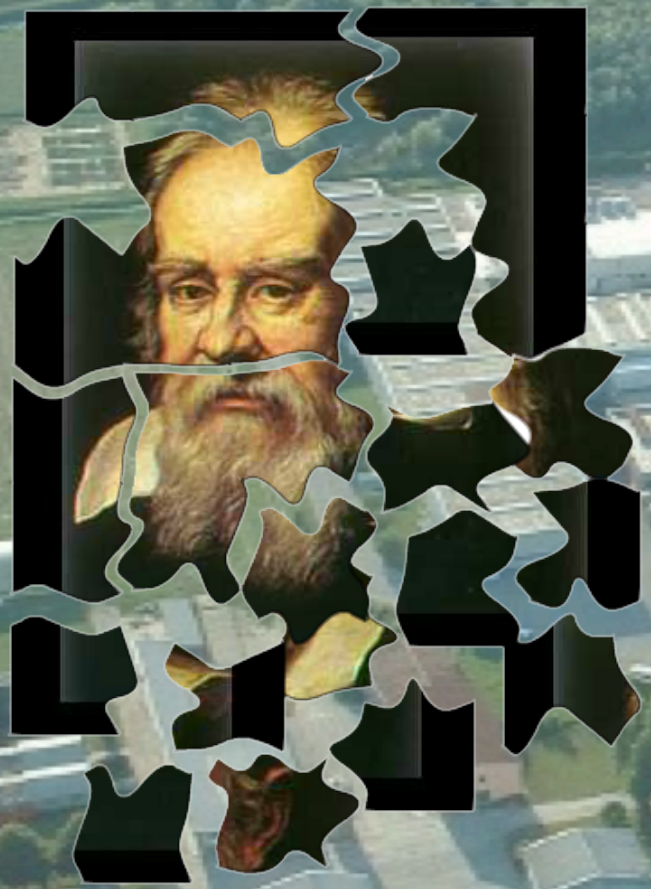
Gamma – Ray Spectroscopy with GALILEO at LNL



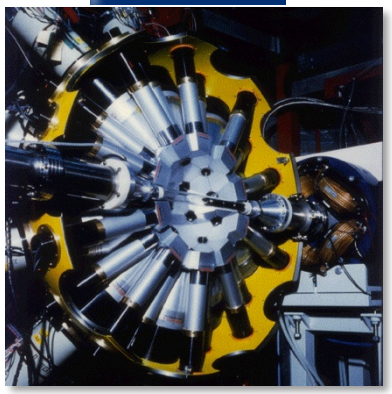
Calin A. Ur
INFN Sezione di Padova

5/6/2012

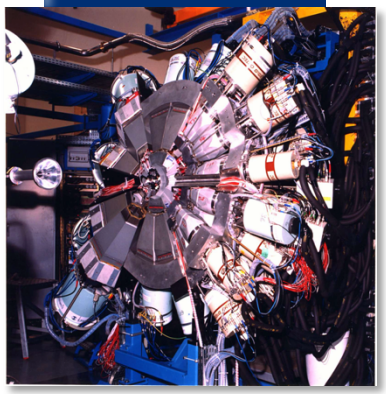
2nd COPIGAL Workshop on Studies of Exotic Nuclei

Large Gamma–Ray Arrays at LNL

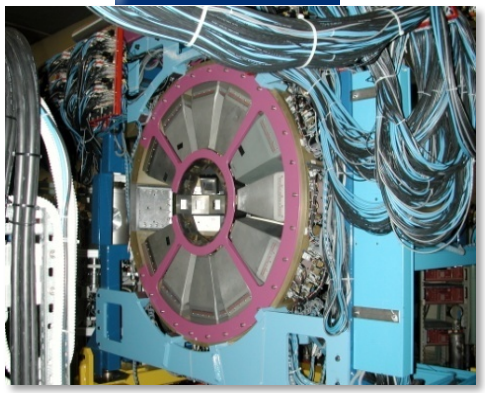
GASP



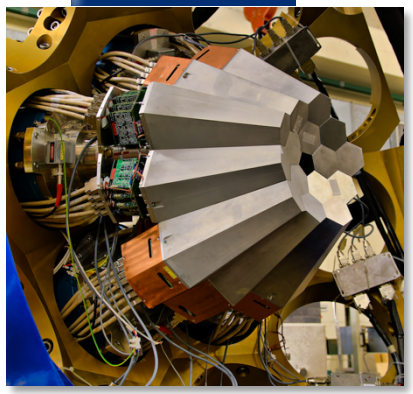
EUROBALL

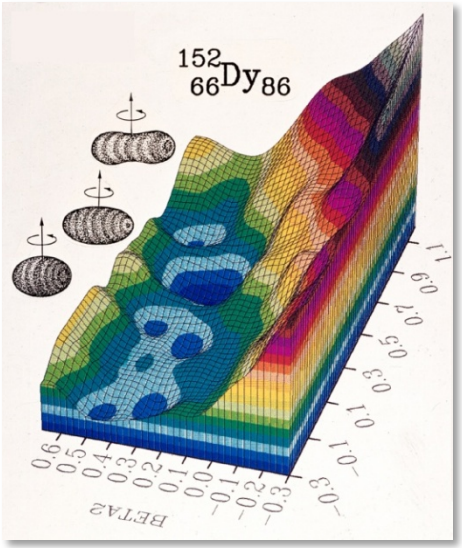


CLARA

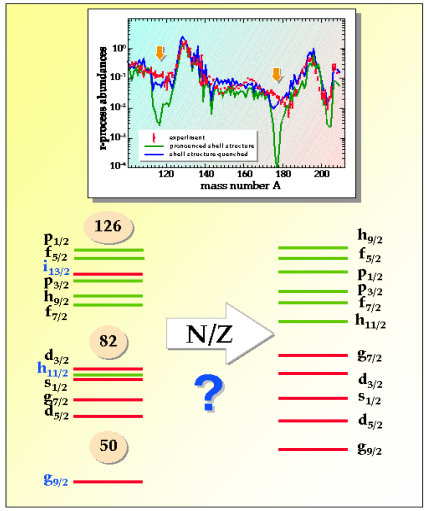


AGATA



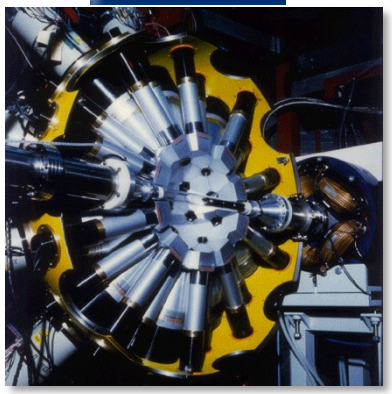


- High spin states
- Collectivity and shell model
- Isospin symmetries
- Isospin mixing in N=Z nuclei
- Spectroscopy at the dripline
- Shell stability and evolution in neutron rich nuclei
- Symmetries at the critical point
- Rotational damping



Large Gamma–Ray Arrays at LNL

GASP



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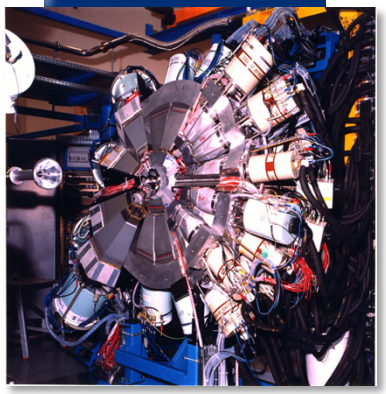
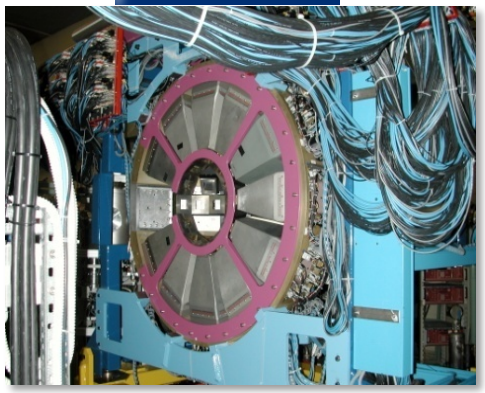


CLARA



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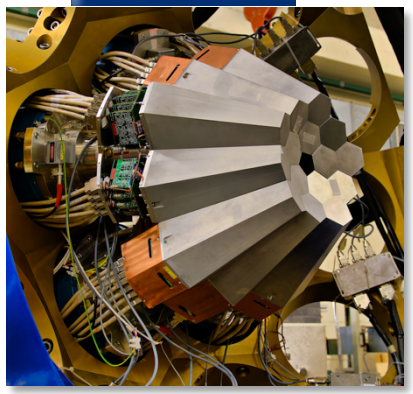

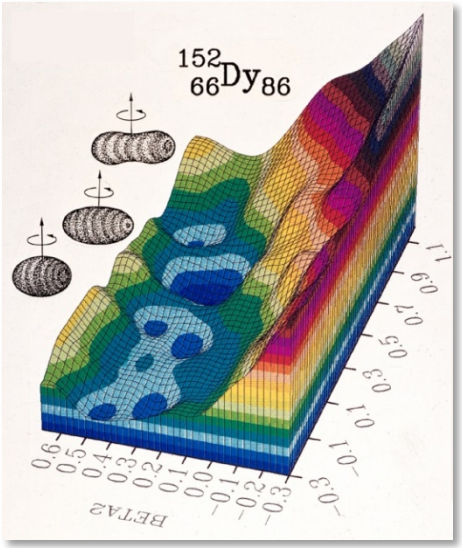

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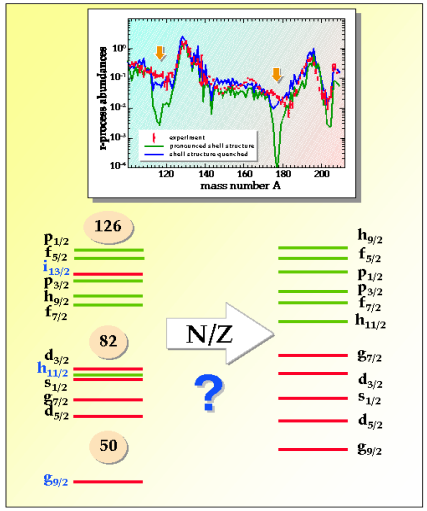
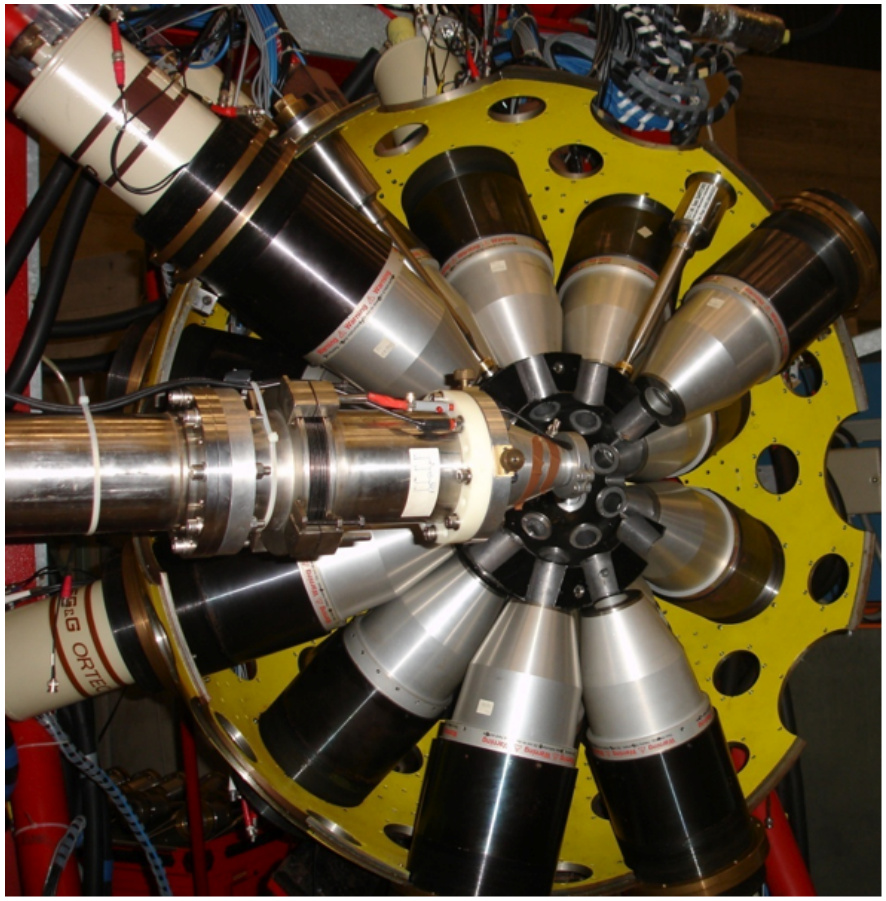


The GASP Gamma–Ray Array



GASP

Operational since 1992

40 HPGe (80%) + AC
ε_{ph} (1.3MeV) ~ 3% (@ 27 cm) I
~ 5.8% (@ 22 cm) II
P/T ~ 60%

BGO multiplicity filter – 80 elements

Mainly high–spin states populated in fusion–evaporation reactions coupled to ancillary detectors such as EUCLIDES, Plunger, n-Ring, RFD, LuSiA

GASP – first results

VOLUME 74, NUMBER 6 PHYSICAL REVIEW LETTERS 6 FEBRUARY 1995

$N = 40$ Neutron Subshell Closure in the ^{68}Ni Nucleus

R. Broda, B. Fornal, W. Królas, and T. Pawłat
H. Niewodniczański Institute of Nuclear Physics, PL-31-342 Kraków, Poland

D. Bazzacco, S. Lunardi, C. Rossi-Alvarez, and R. Menegazzo
Dipartimento di Fisica dell'Universitá di Padova and INFN, I-35131 Padova, Italy

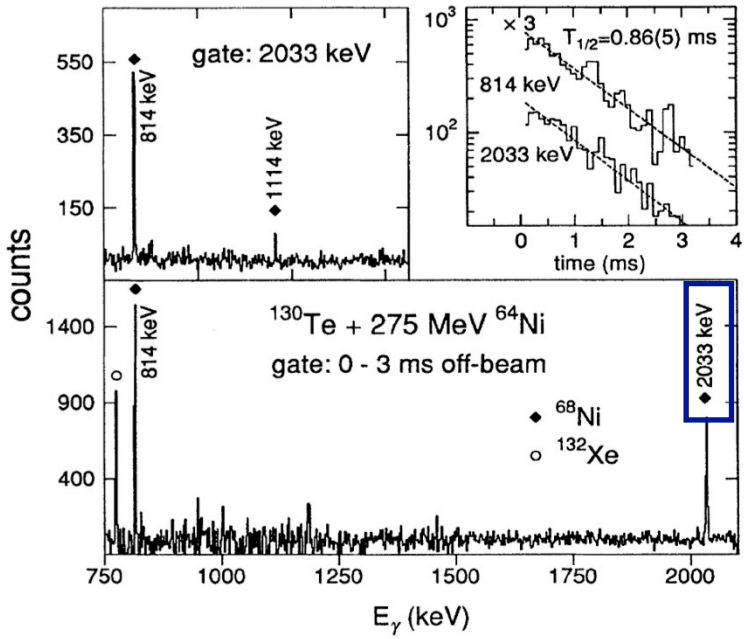
G. de Angelis, P. Bednarczyk, J. Rico, and D. De Acuña
INFN Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy

P. J. Daly, R. H. Mayer, and M. Sferrazza
Chemistry Department, Purdue University, West Lafayette, Indiana 47907

H. Grawe, K. H. Maier, and R. Schubart
Hahn–Meitner–Institut Berlin, D-14109 Berlin, Germany
(Received 28 June 1994)

GASP 1995

The increase of the ^{68}Ni 2^+ excitation energy, by more than 600 KeV compared with ^{66}Ni, indicates a significant subshell closure at N=40



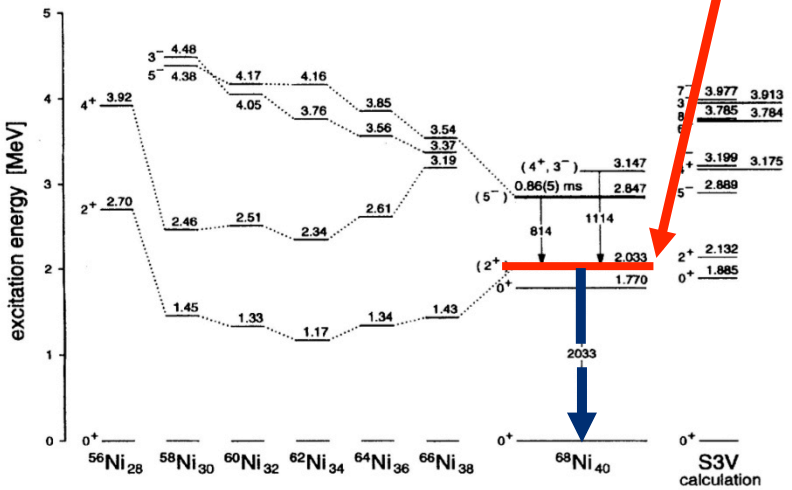
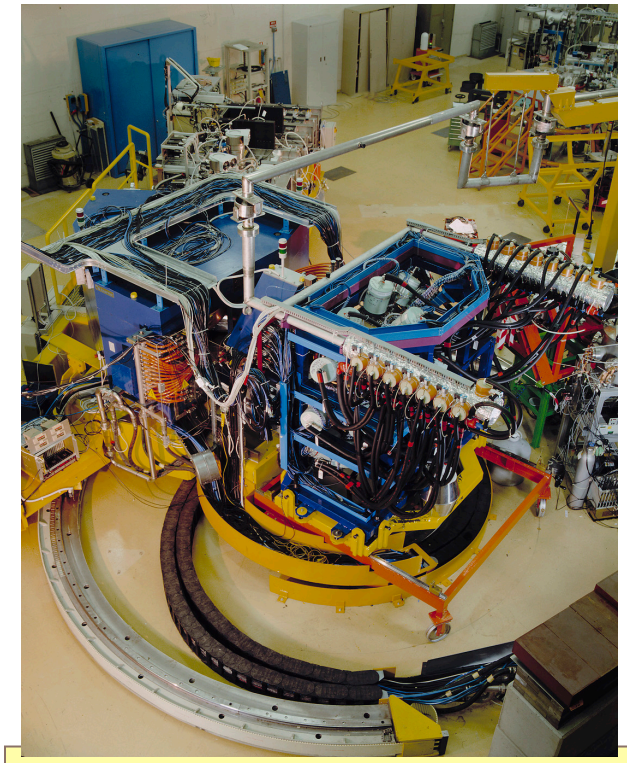
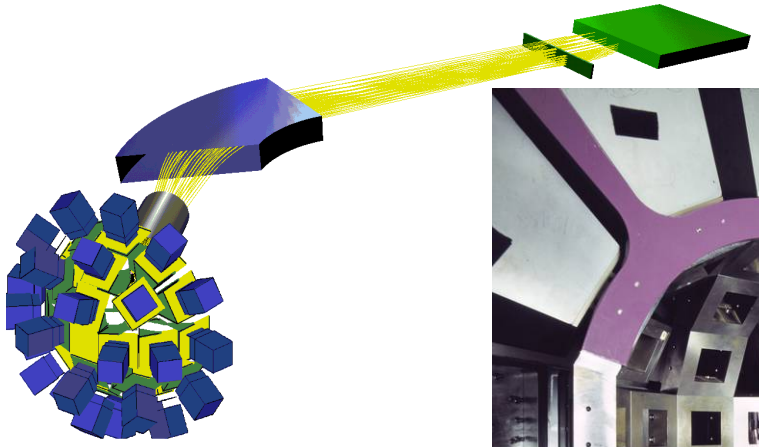


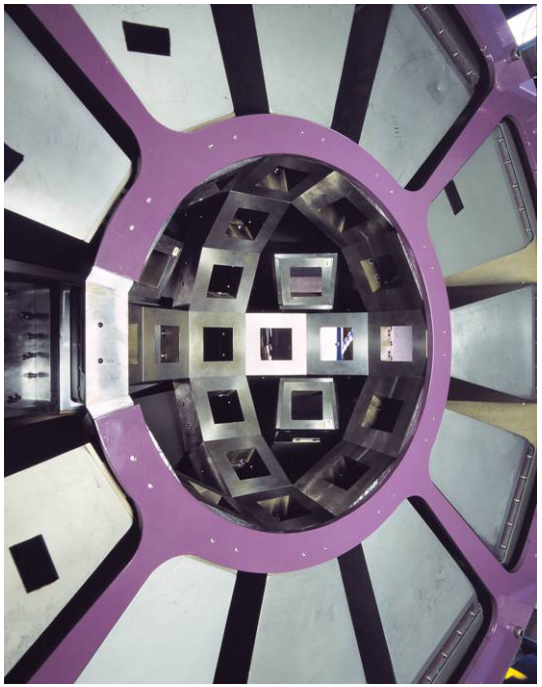
FIG. 3. Systematics of selected states in even Ni isotopes. The ^{68}Ni results are prominently displayed and compared with the S3V shell model calculations (see text).

The CLARA Gamma–Ray Array





Coupled to the PRISMA spectrometer



- 24 Clovers setup
- Efficiency ~ 3 % @ 1.3 MeV
- Peak/Total ~ 45 %
- Position θ = 103°–180°
- FWHM ~ 10 keV for E_γ = 1.3MeV @ v/c = 10 %

Clover detectors placed, with respect to the PRISMA entrance, at:

$\theta = 102.9^\circ$

$\theta = 128.6^\circ$

$\theta = 141.4^\circ$

$\theta = 154.3^\circ$

$\theta = 180.0^\circ$

The CLARA Gamma–Ray Array

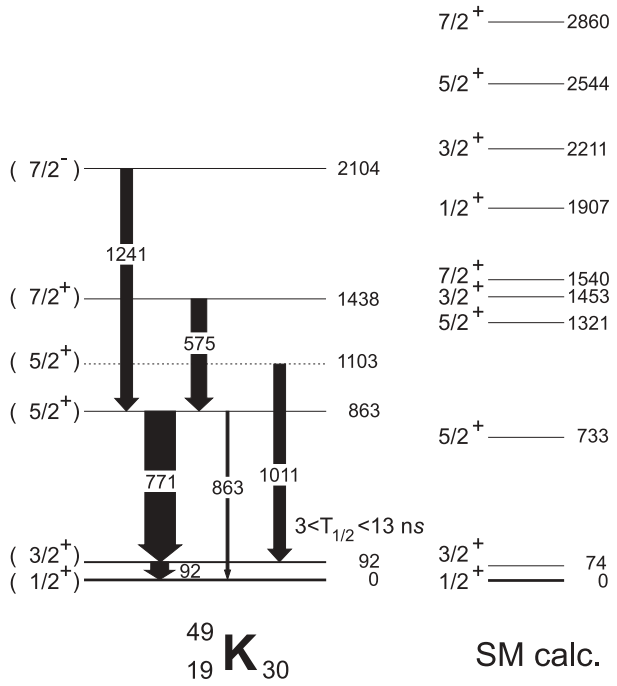
PHYSICAL REVIEW C **82**, 034319 (2010)

Proton-hole states in the $N = 30$ neutron-rich isotope ^{49}K

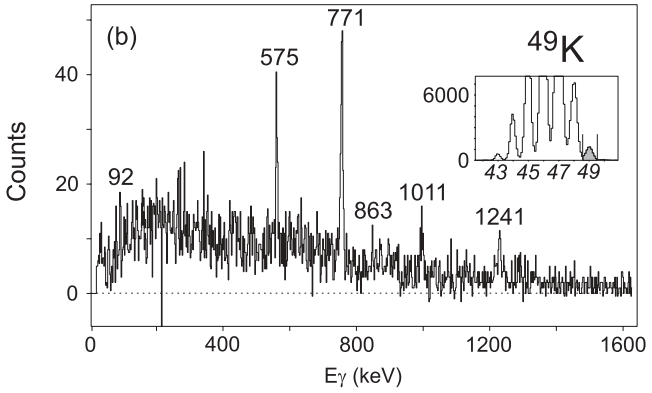
R. Broda,[1] J. Wrzesiński,[1] A. Gadea,[2,9] N. Mărginean,[2,7] B. Fornal,[1] L. Corradi,[2] A. M. Stefanini,[2] W. Królas,[1] T. Pawłat,[1] B. Szpak,[1] S. Lunardi,[3] J. J. Valiente-Dobón,[2] D. Mengoni,[3,10] E. Farnea,[3] M. P. Carpenter,[5] G. De Angelis,[2] F. Della Vedova,[2] E. Fioretto,[2] B. Guiot,[2] R. V. F. Janssens,[5] P. F. Mantica,[6] P. Mason,[3] G. Montagnoli,[3] D. R. Napoli,[2] R. Orlandi,[2] I. Pokrovskiy,[2] G. Pollarolo,[11] E. Sahin,[2] F. Scarlassara,[3] R. Silvestri,[2] S. Szilner,[8] C. A. Ur,[3] M. Trotta,[4] and S. Zhu[5]

[1]*Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland*
[2]*INFN Laboratori Nazionali di Legnaro, Legnaro, Italy*
[3]*Dipartimento di Fisica dell' Università and INFN Sezione di Padova, Padova, Italy*
[4]*INFN-Sezione di Napoli, Italy*
[5]*Argonne National Laboratory, Illinois 60439, USA*
[6]*National Superconducting Cyclotron Laboratory, Michigan State University, Michigan 48824, USA*
[7]*National Institute for Physics and Nuclear Engineering, Bucharest, Romania*
[8]*Ruder Bošković Institute, Zagreb, Croatia*
[9]*Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Spain*
[10]*School of Engineering and Science, University of the West of Scotland, Paisley, United Kingdom*
[11]*Dipartimento di Fisica Teorica, Università di Torino, Torino, Italy*

(Received 28 May 2010; published 22 September 2010)

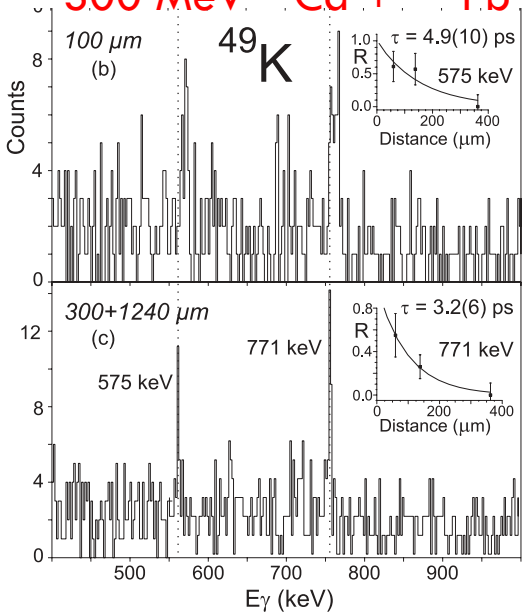


330 MeV ^{48}Ca + ^{238}U
CLARA + PRISMA

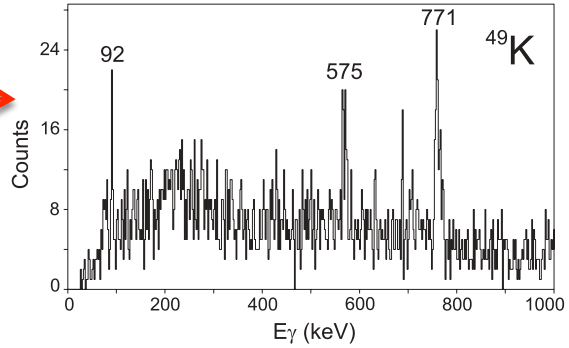


and GAMMASPHERE thick target data (γγγ coincidences)

Differential plunger
300 MeV ^{48}Ca + ^{208}Pb



Sum over all the distances



The CLARA Gamma–Ray Array

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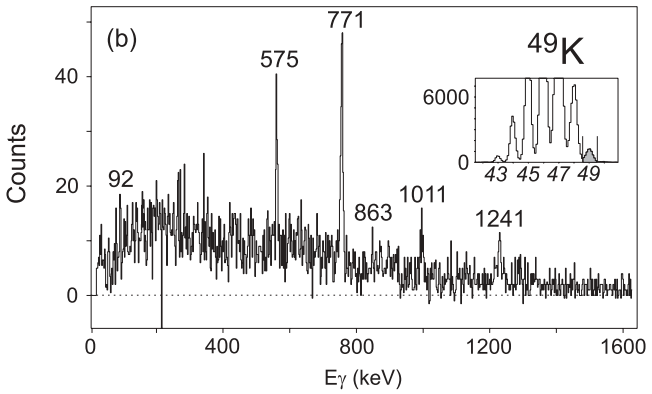

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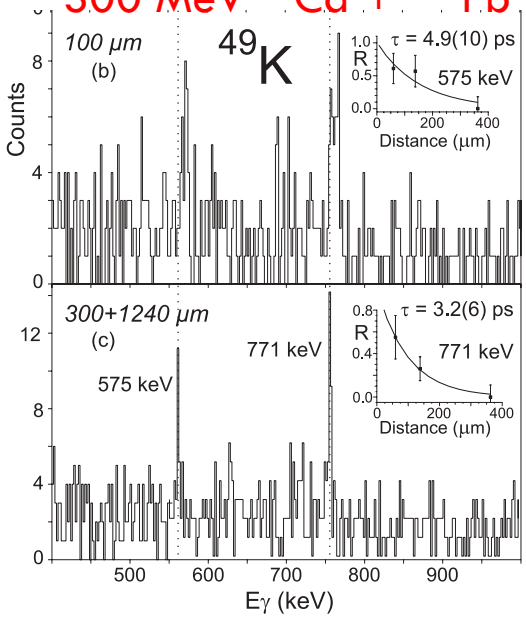
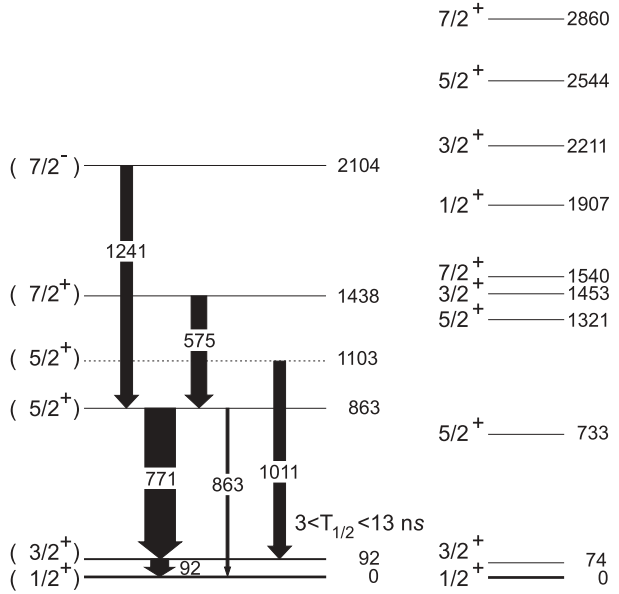
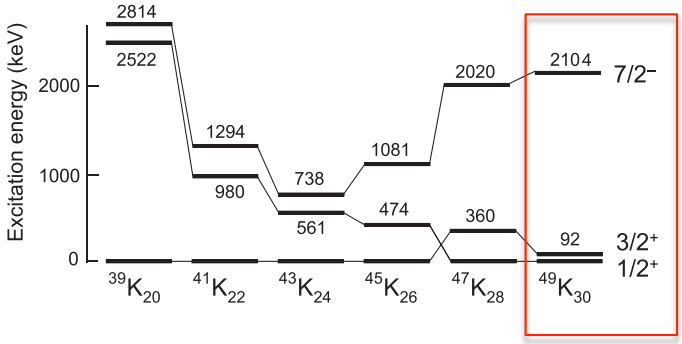
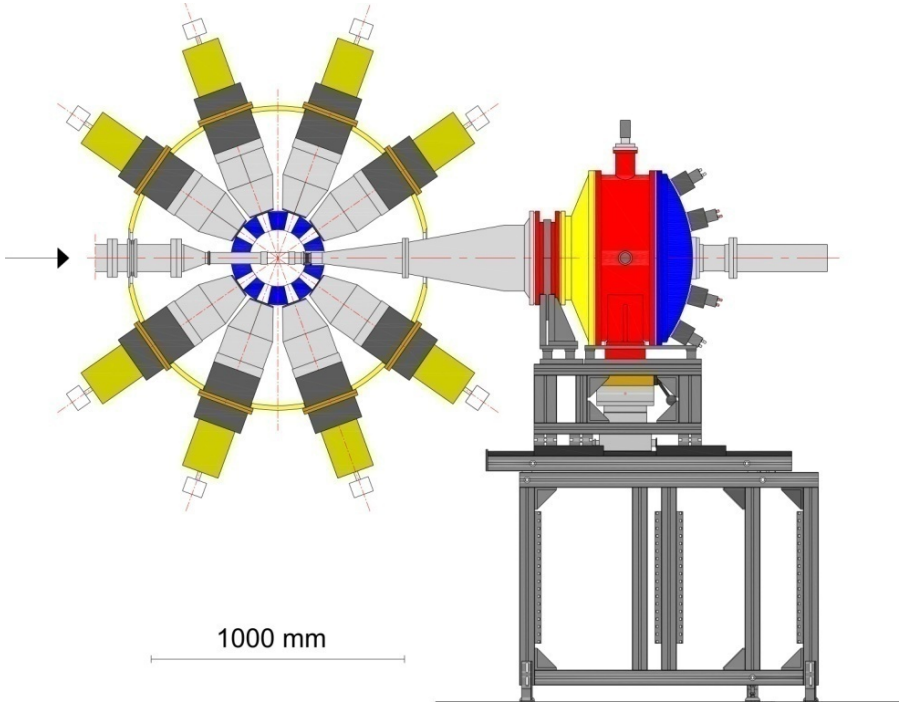


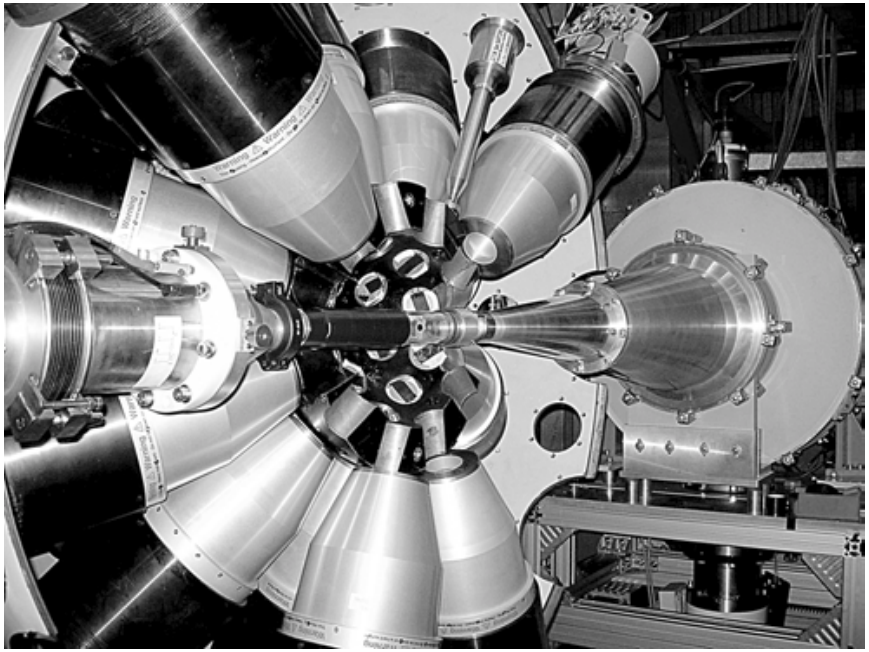


$^{49}_{19}K_{30}$ SM calc.



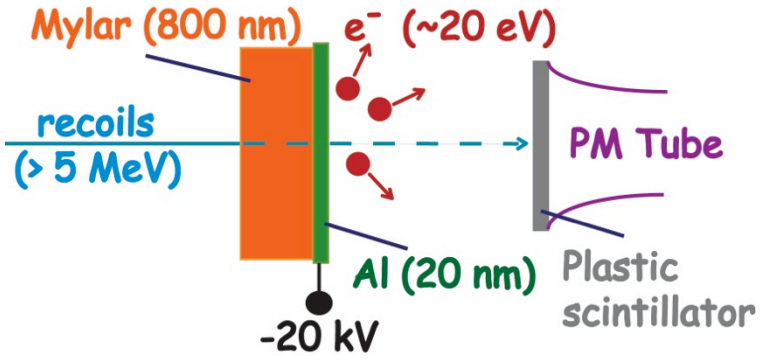
GASP and the Recoil Filter Detector





RFD measures recoils in coincidence with γ–rays detected in Ge–arrays

- selection of the recoils of interest by ToF technique
- determination of the recoil velocity vector event–by–event



W.Męczyński et al. - NIM A580, 1310 (2007)

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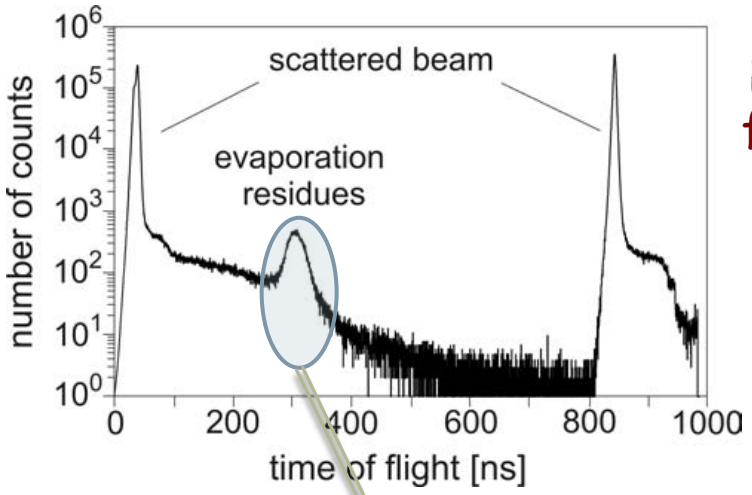
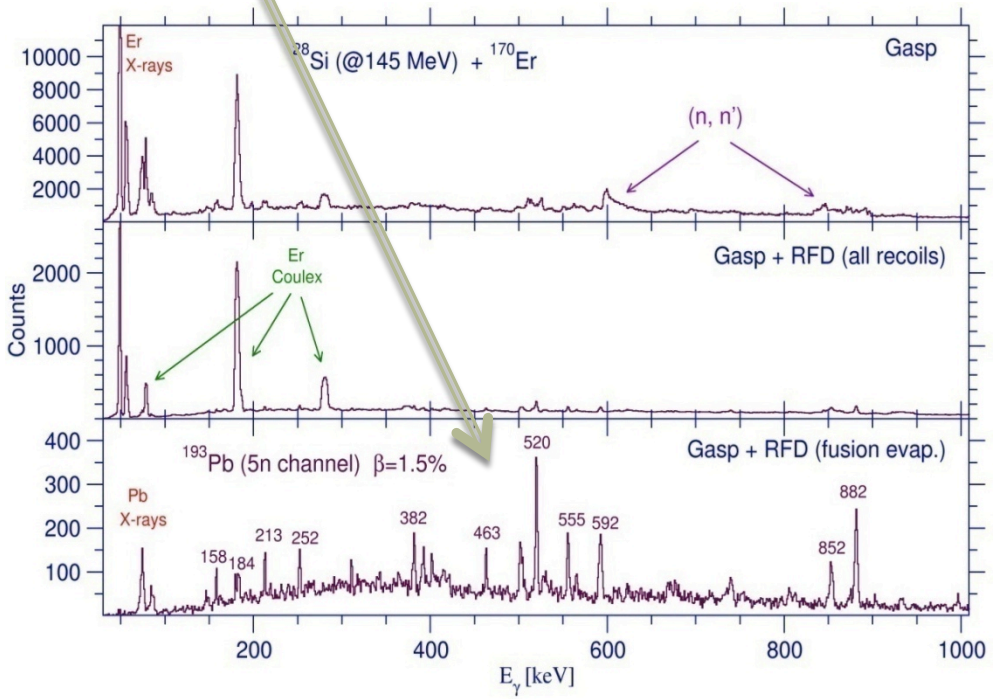


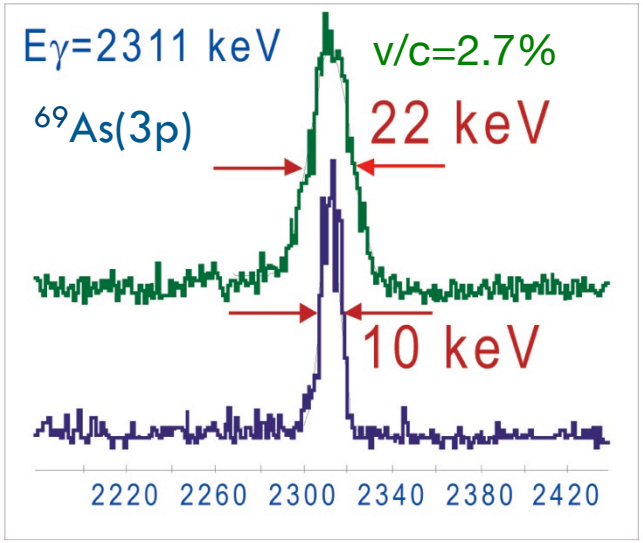
Efficient selection of weak fusion-evaporation channels

^{28}Si(145MeV) + ^{170}Er(0.5mg/cm^2)



Event-by-event Doppler correction

^{32}S(95MeV) + ^{40}Ca(0.5mg/cm^2)



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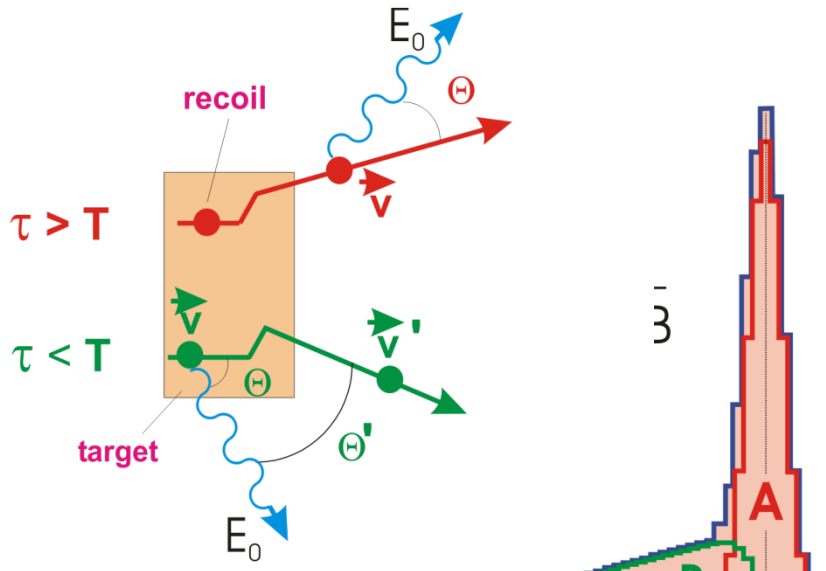
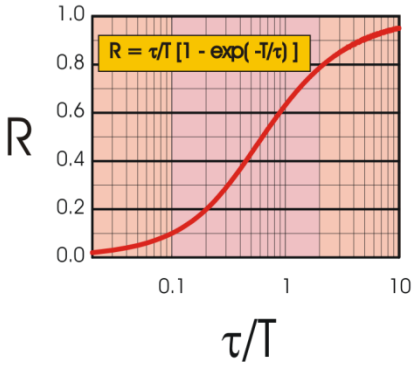
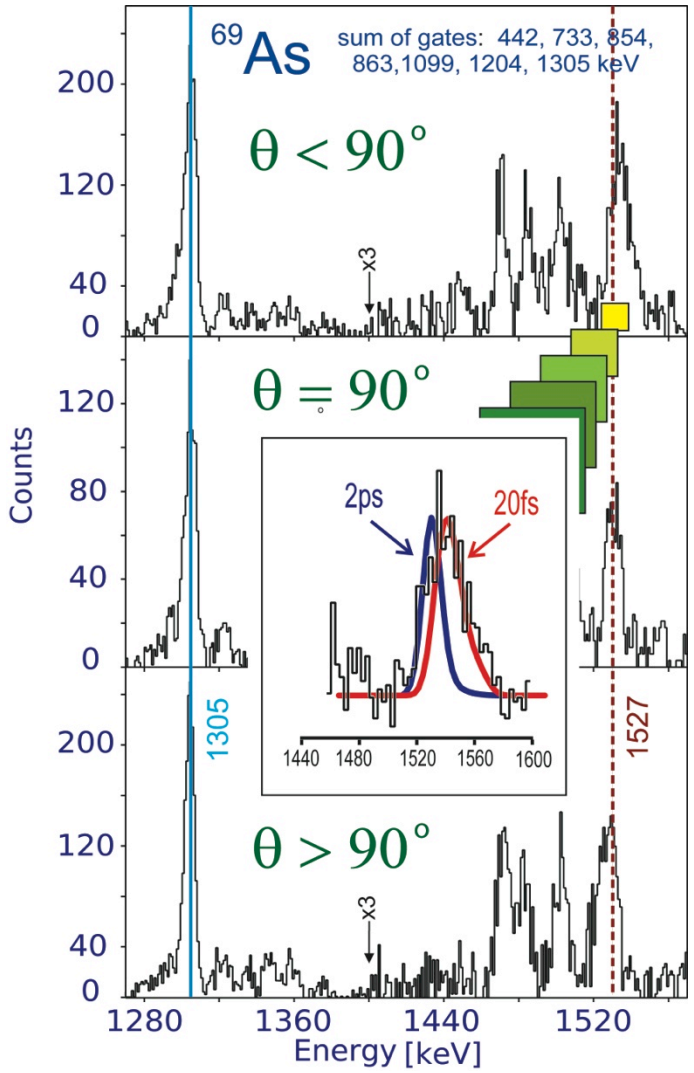




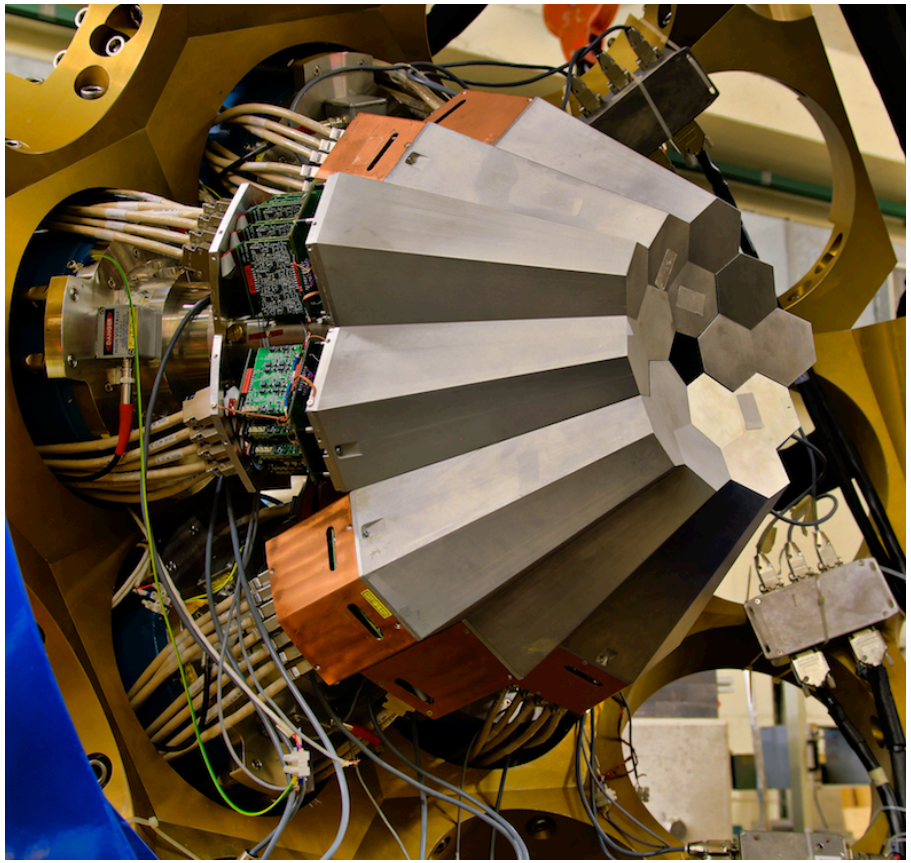
$$R = \frac{A}{A+B} \rightarrow \tau$$



Lifetimes: tens – hundreds fs

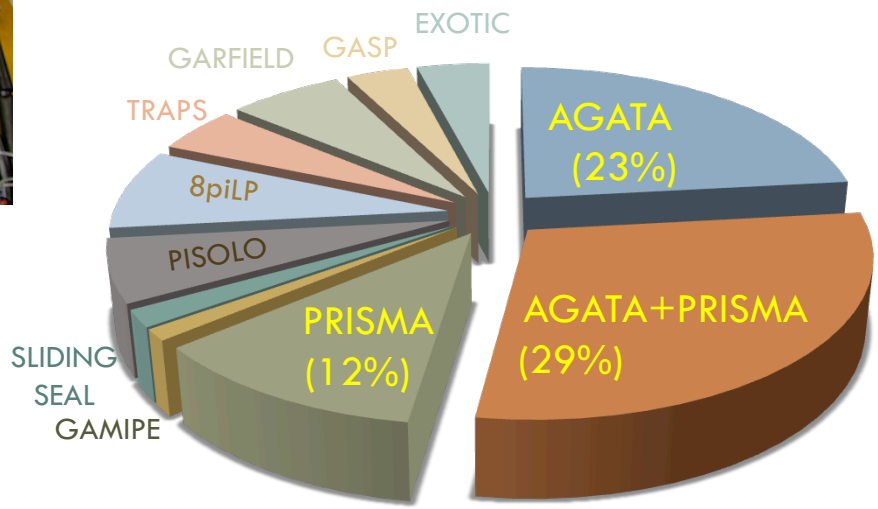
P.Bednarczyk et al., LNL Annual Report 2009

The AGATA Gamma–Ray Tracking Array

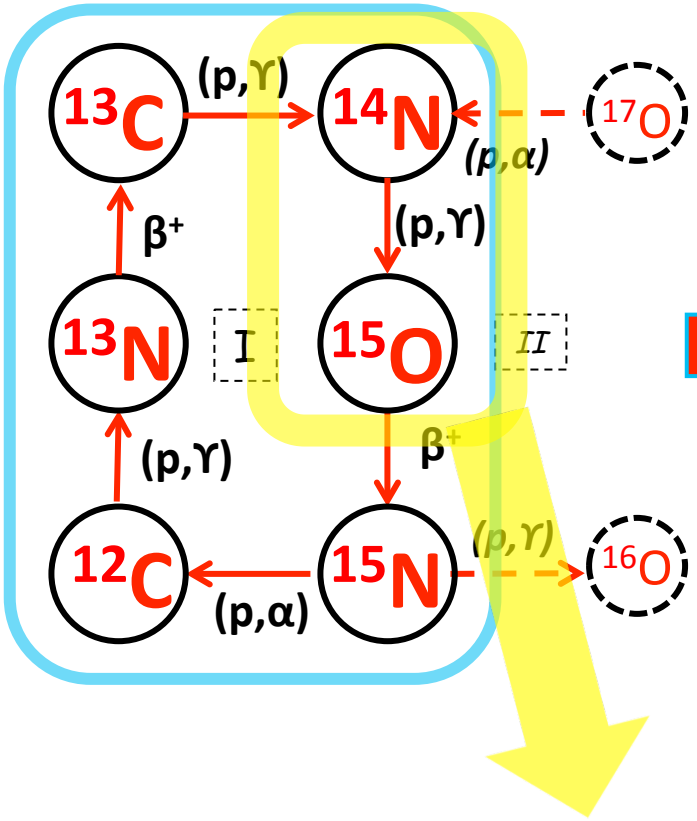


AGATA D – 2010
European Collaboration
5 triple cluster detector
ε_{ph} (1.3MeV) ~ 6%
Coupled to the PRISMA

Feb. 28, 2011 – Mar. 14, 2012
14 experiments
86 days over 170 total



The CNO cycle and the $^{14}N(p,\gamma)^{15}O$ reaction



nuclear *x*-sections are precisely known

C,N abundances in the solar core can be obtained by measuring the neutrino fluxes

[W.C.Haxton et al., As.J.687(2008)678]

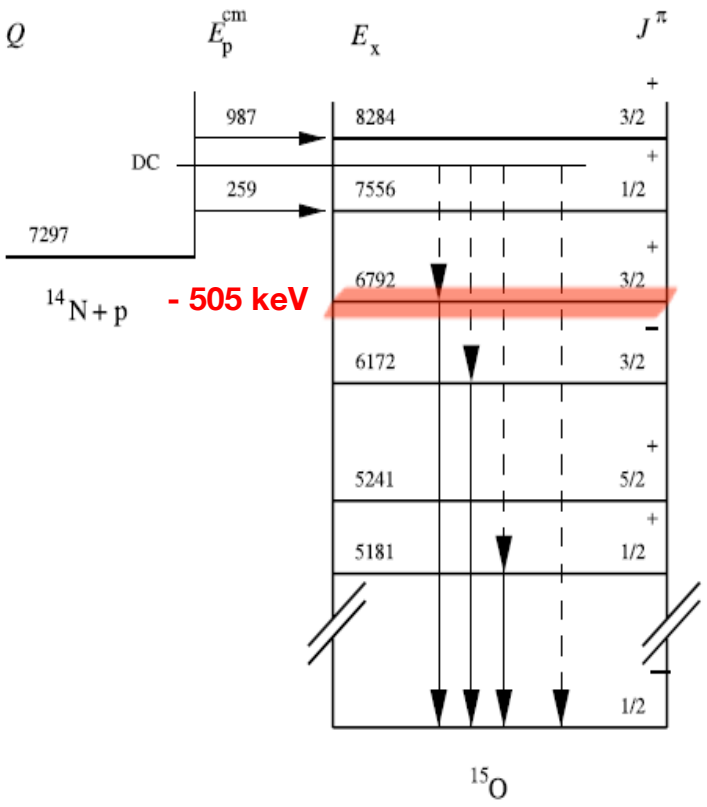
possible solution for the "solar composition problem"

[A.M.Serenelli et al., As.J.Lett. 705, L123-L127 (2009)]

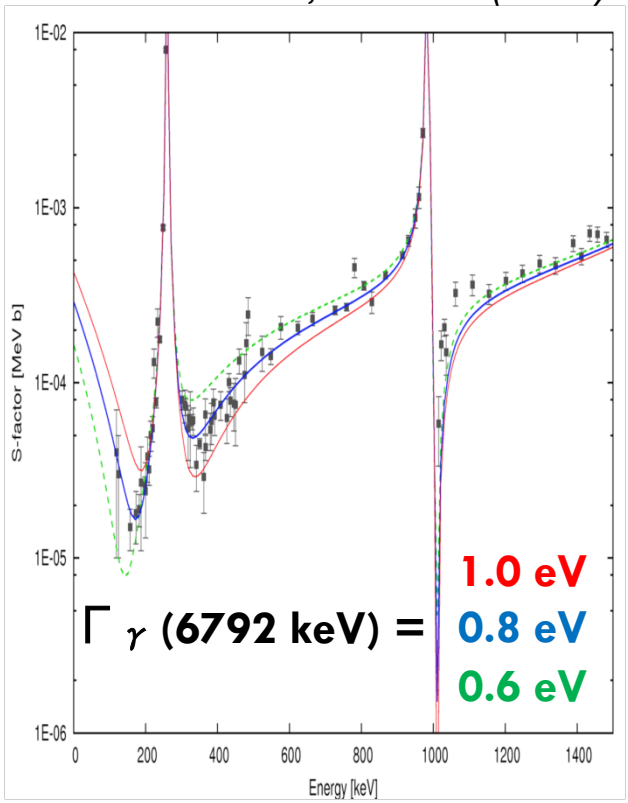
$^{14}N(p,\gamma)^{15}O$ is the "bottle neck"

The CNO cycle and the $^{14}N(p,\gamma)^{15}O$ reaction

M. Marta / Progress in Particle and Nuclear Physics 66 (2011) 303–308



Captures to different excited states in ^{15}O contribute to the x-section.
The one to the gs in ^{15}O is dominated by the tail of the sub-threshold resonance at -505 keV (**6.79 MeV state in ^{15}O**)
[C.Angulo et al., NP A690 (2001) 755, M.Marta et al., PR C78 (2008) 022802(R), ….]



H.P. Trautvetter et al., JPG 35 (2008) 014019 and courtesy of M. Marta

change of ≈20% in $\Gamma=\hbar/\tau$

change of ≈30% in $S_{gs}(0)$

Adopted Γ_γ (6792 keV)= 0.9 ± 0.2 eV

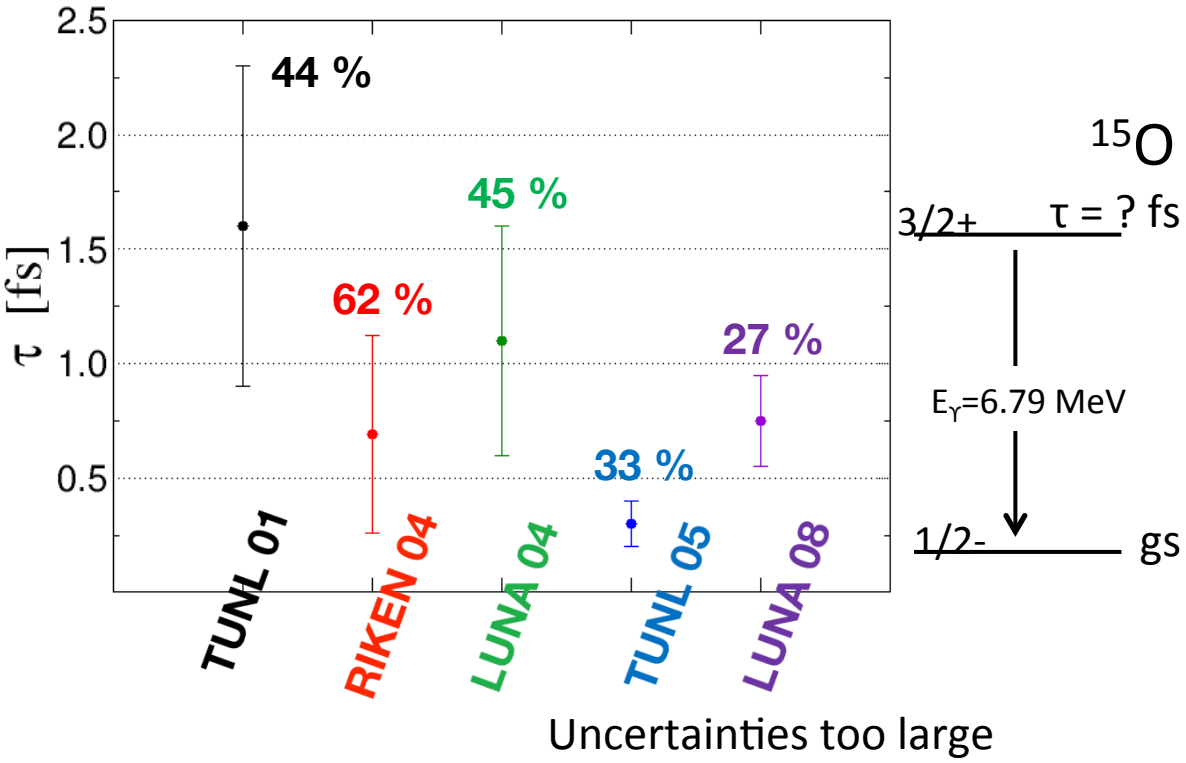
$S_{GS}(0)$ = 0.20 ± 0.05 keV·b

M. Marta et al., Phys. Rev. C 78, 022802(R) (2008)

Lifetime of the 6.79 MeV state in ^{15}O

GROUP	METHOD	T [fs]	*Ref.*
Oxford 1968	DSAM d(14N,15O)n	< 28	W. Gill et al., NP A121, 209 (1968)
TUNL 2001	DSAM 14N(p,γ)15O	1.6±0.7	P.F. Bertone et al., PRL 87, 152501 (2001)
RIKEN 2004	CE 208Pb(15O,15O*)	0.69±0.43	K. Yamada et al., PL B579, 265 (2004)
LUNA 2004	X-section+R matr. fit	1.1±0.5	A. Formicola et al., PL B591, 61 (2004)
TUNL 2005	X-section+R matr. fit	0.3±0.1	R. Runkle et al., PRL 94, 082503 (2005)
Bochum 2008	DSAM 14N(p,γ)15O	< 0.77	D. Schuermann et al., PR C77, 055803 (2008)
LUNA 2008	X-section+R matr. fit	0.75±0.20	M. Marta et al., PR C78, 022802(R) (2008)

DSAM (Doppler Shift Attenuation Method) **(DIRECT!) lifetime measurement** in inverse kinematics exploiting the detection efficiency and energy resolution of the **AGATA HPGe array**

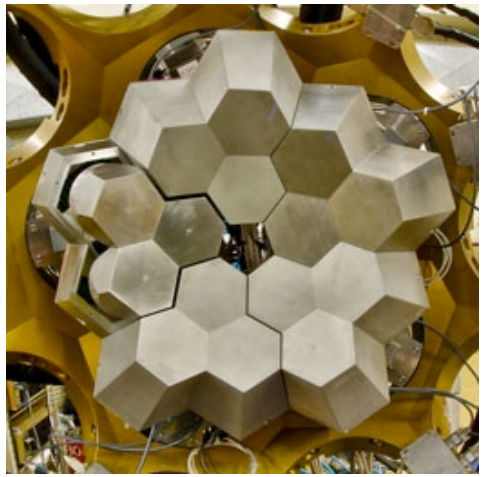


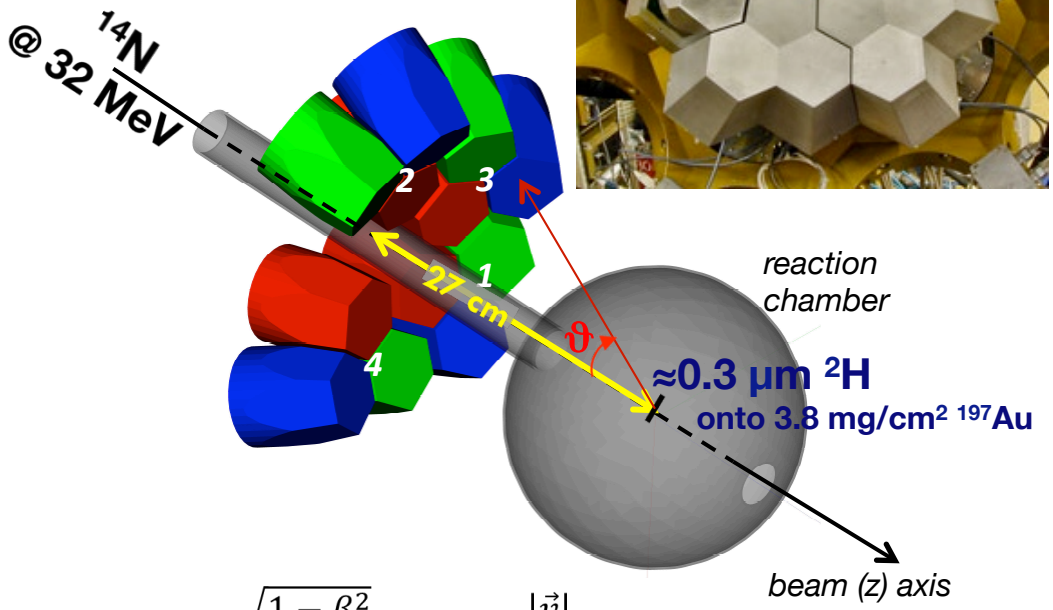
Uncertainties too large

The experiment: reaction and setup

$^{14}N + {}^{2}H$ @ 32 MeV (Tandem XTU, LNL) → **^{15}O** (Q_{gs}=5.1 MeV)
^{15}N (Q_{gs}=8.6 MeV)

ϑ ≈ 160 deg →
cos ϑ ≈ -0.94





$$E_\gamma = E_{0\gamma}\frac{\sqrt{1-\beta^2}}{1-\beta cos\theta_\gamma} \qquad \beta = \frac{|\vec{v}|}{c}$$

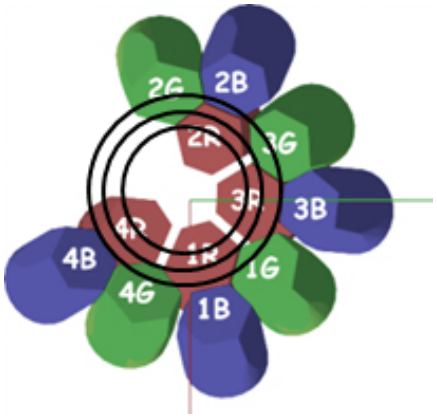
Advanced**GA**mma**T**racking**A**rray
Demonstrator

4 asymmetric triple-clusters:
12 36-fold **segmented** HPGe

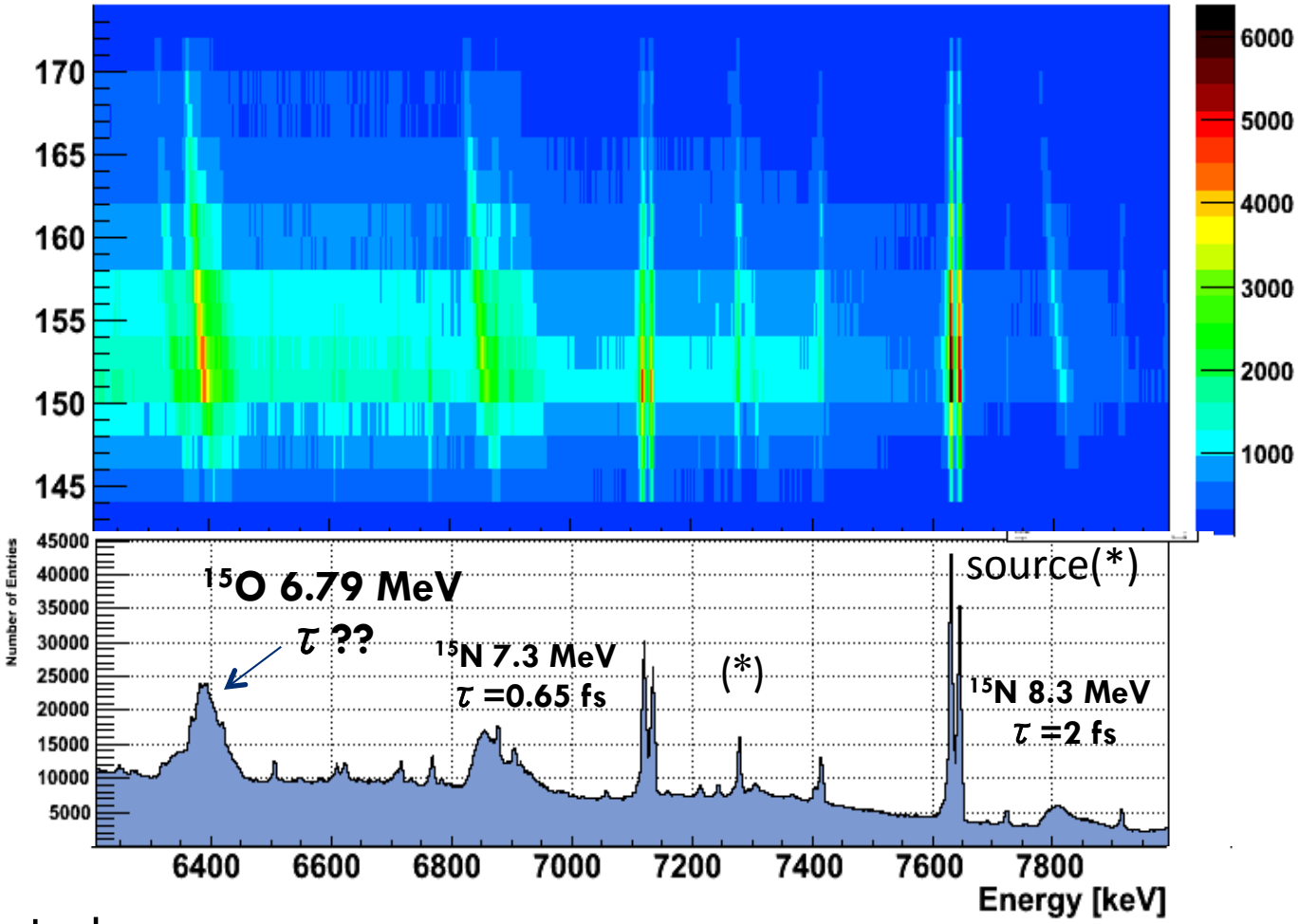
Efficiency and Energy resolution
@ 1.3MeV : ≈2%, 2.5 keV
@ 7 MeV : ≈0.5% , 4.8 keV

digital electronics → decomposition of signal shapes → pulse Shape Analysis → gamma-ray tracking

Data analysis



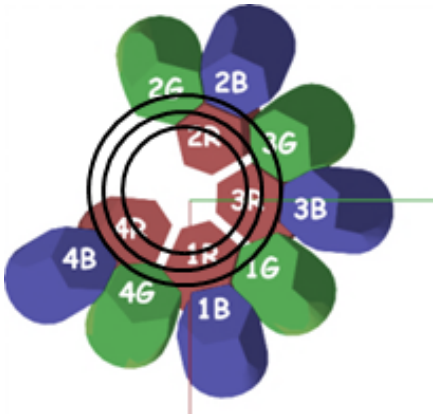
first interaction point of each gamma–ray reconstructed event–by– event with a 4mm indetermination



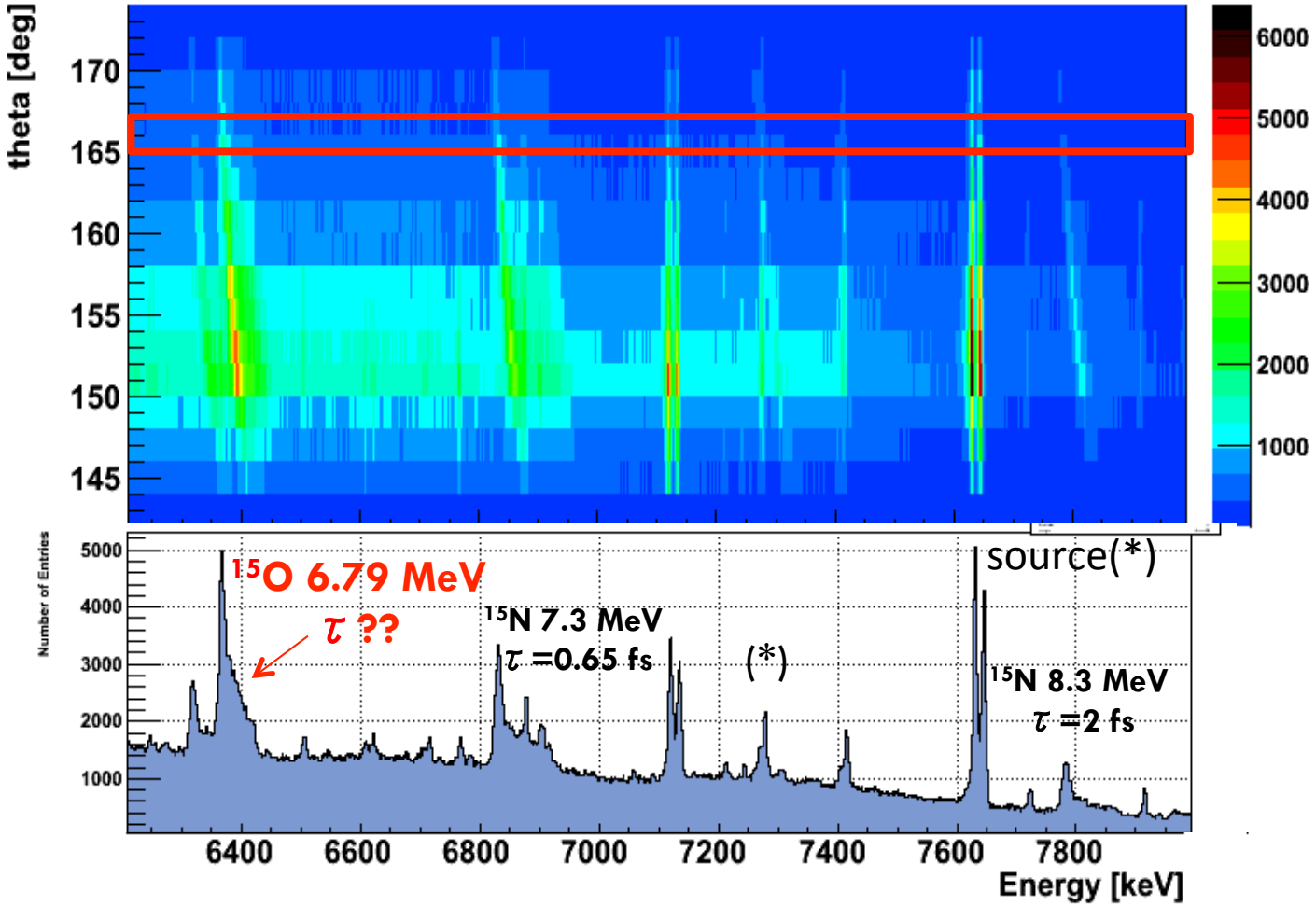
detected gamma-rays can be sorted in few degrees θ “slices”

by C. Michelagnoli

Data analysis



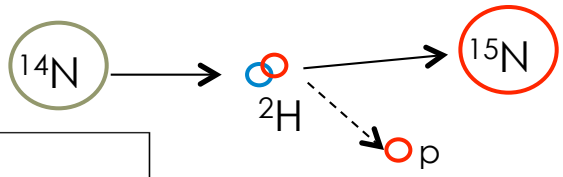
lineshape analysis on the 12 2-degrees "slices"

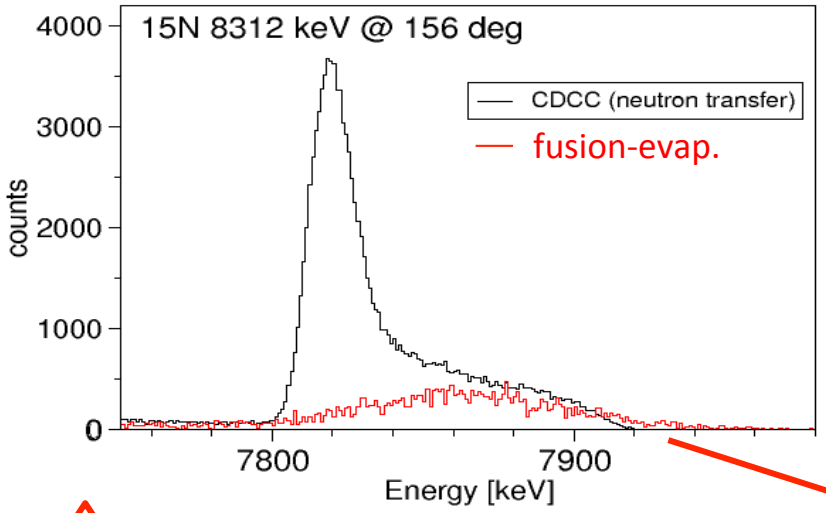


by C. Michelagnoli

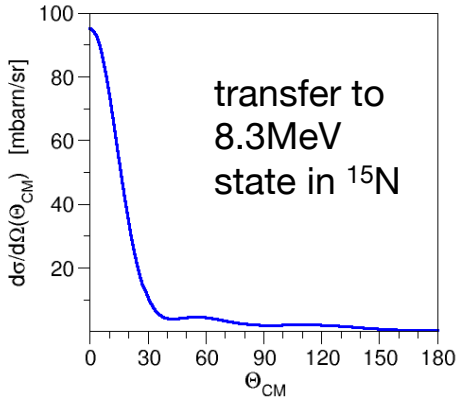
Data analysis: reaction kinematics

both ^{15}O and ^{15}N excited levels are mainly populated *via* nucleon (proton and neutron, respectively) transfer reactions





center of mass x-section angular distribution:

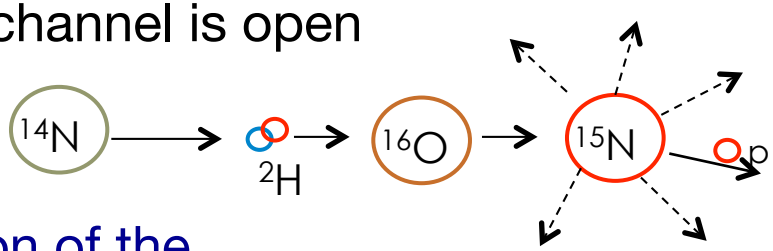


CDCC calculations of the nucleon transfer process by N. Keeley (Warsaw)**

***Continuum-Discretized Coupled Channels*

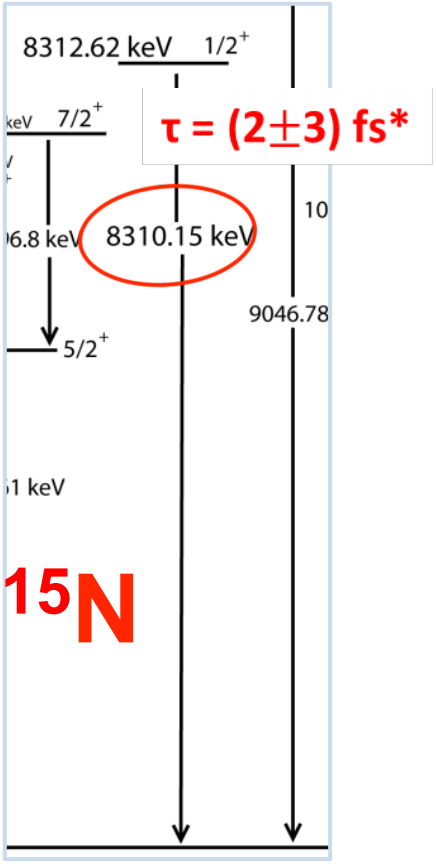
ratio between the two different mechanism and (energy) spectrum of the evaporated particle

but also the fusion-evaporation channel is open

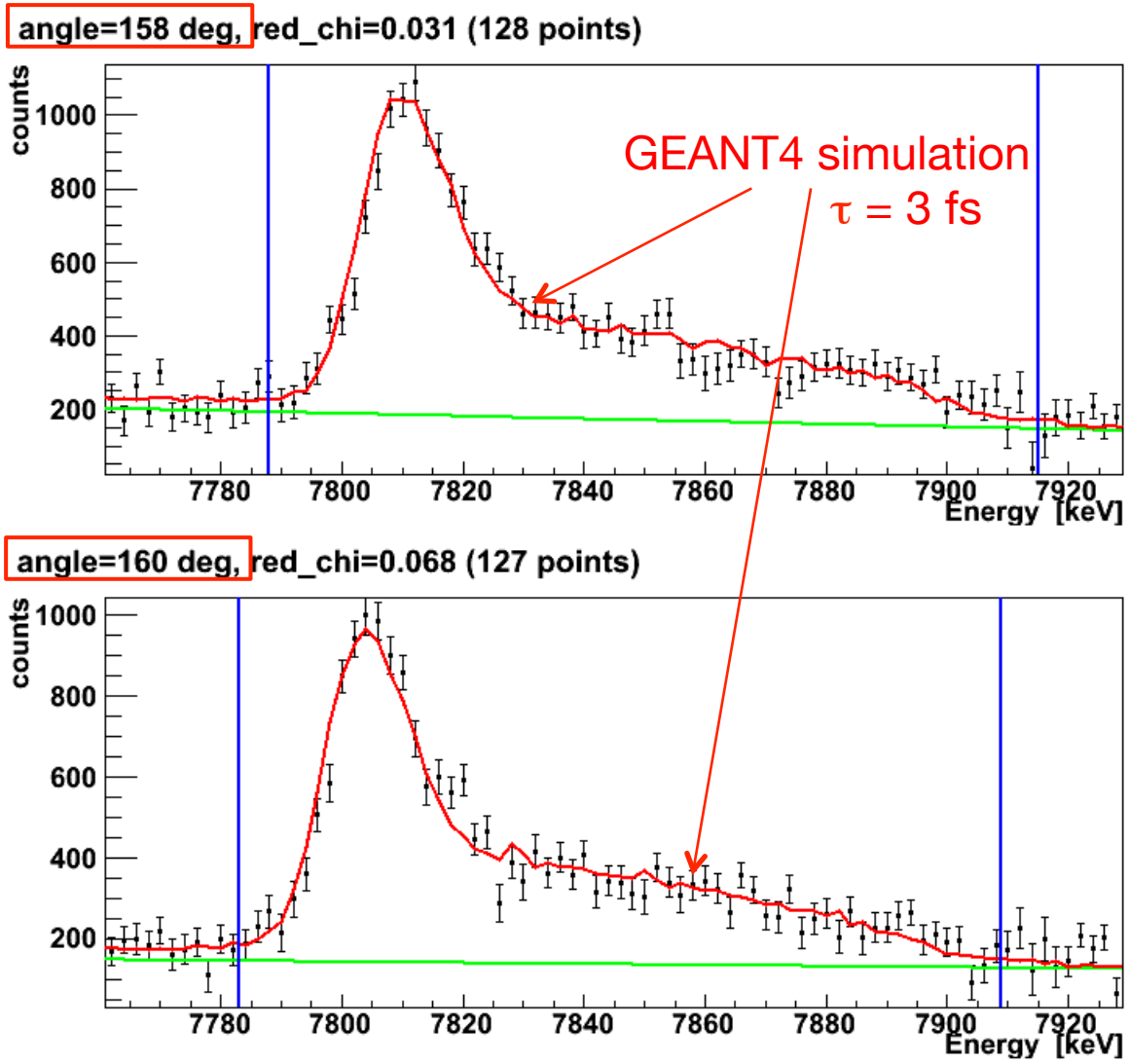


full GEANT4 simulation of the reaction and detection processes

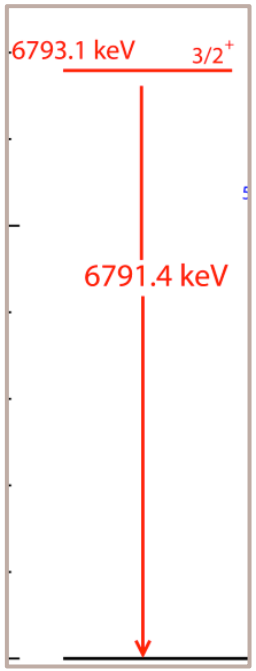
Data analysis: test case ^{15}N

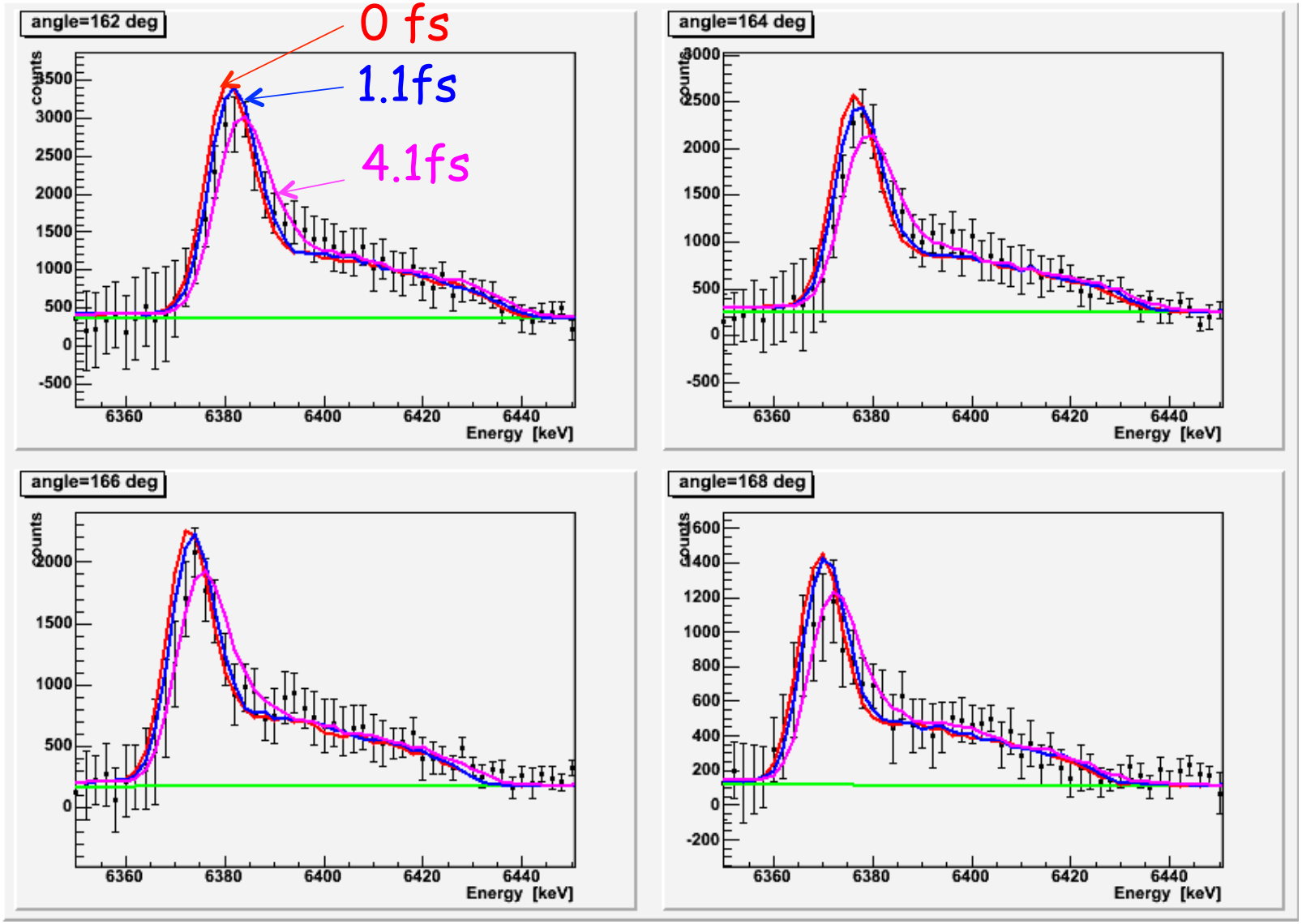


(*from Γ=(0.3±0.2) eV
[R. Moreh et al., PRC 23 (1981) 988])

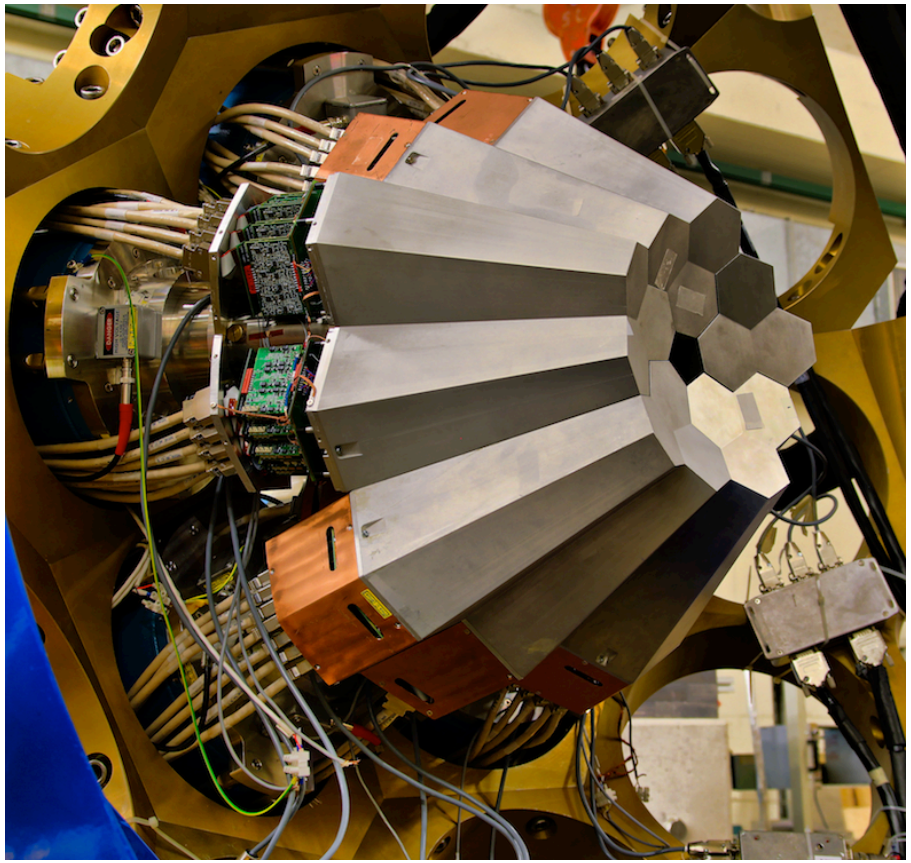


Data analysis: the 6.79 MeV state in ^{15}O





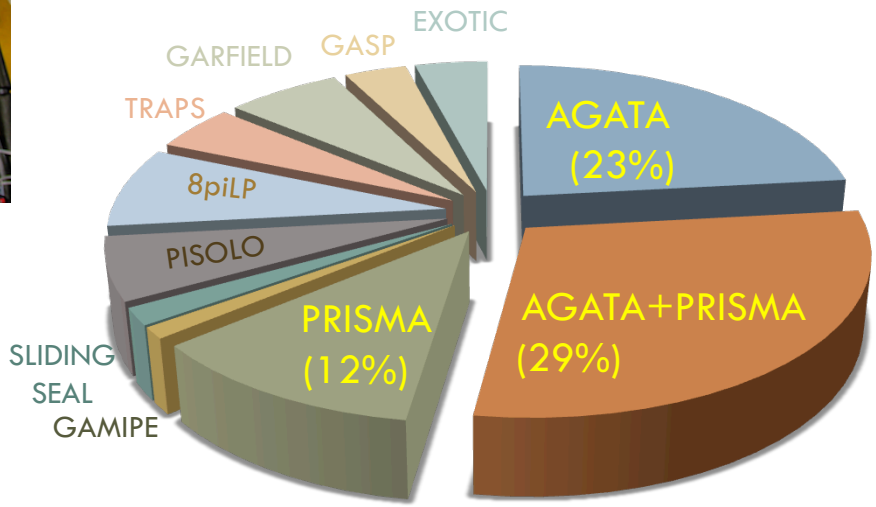
The AGATA Gamma–Ray Tracking Array



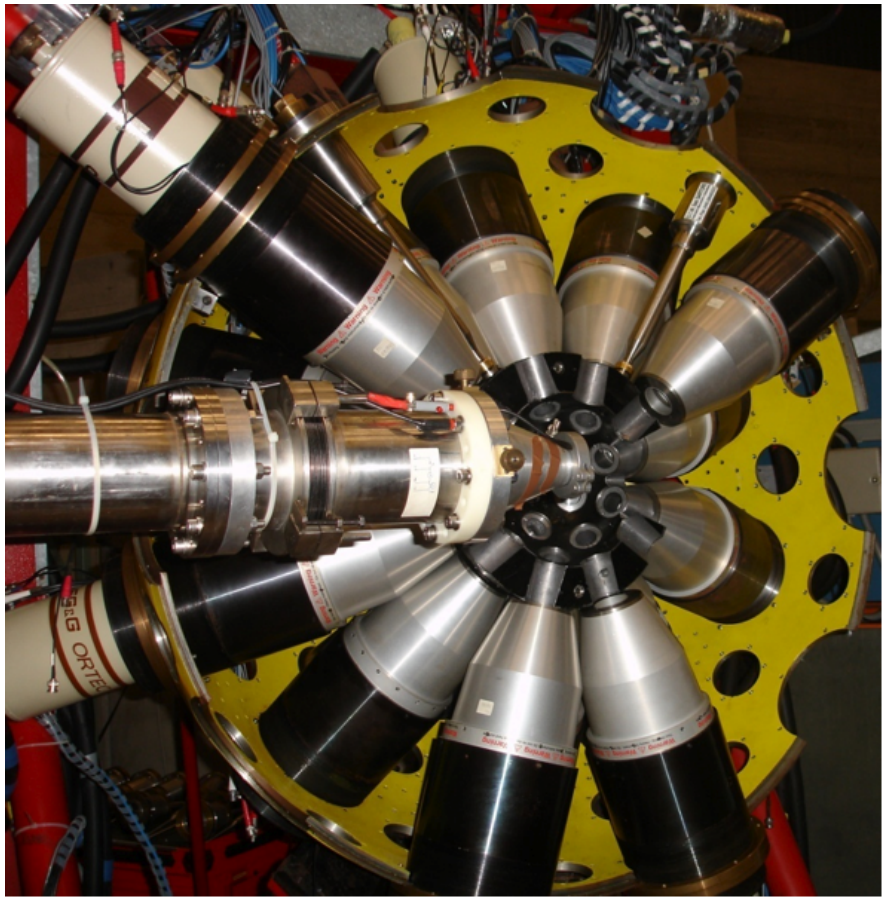
AGATA D – 2010
European Collaboration
5 triple cluster detector
ε_{ph} (1.3MeV) ~ 6%
Coupled to the PRISMA

Feb. 28, 2011 – Mar. 14, 2012
14 experiments
86 days over 170 total

AGATA concluded the physics campaign at LNL at the end of December 2011



The GASP Gamma–Ray Array



GASP
1992 – 2012

40 HPGe (80%) + AC
ε_{ph} (1.3MeV) ~ 3% (@ 27 cm) I
~ 5.8% (@ 22 cm) II
P/T ~ 60%

BGO multiplicity filter – 80 elements

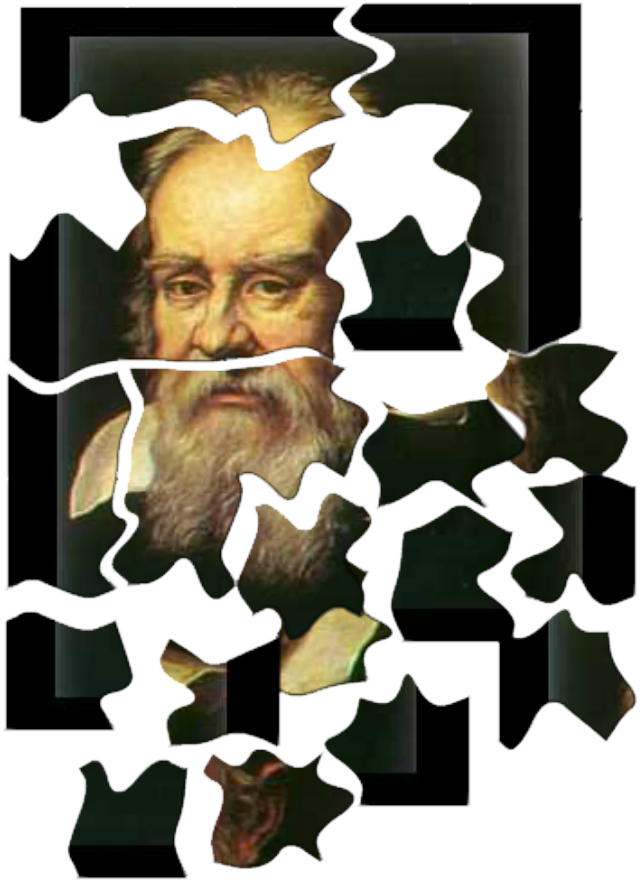
Mainly high–spin states populated in fusion–evaporation reactions coupled to ancillary detectors such as EUCLIDES, Plunger, n-Ring, RFD, LuSiA

March 6 – 12 last experiment

April 4 – official shutdown

Perspectives

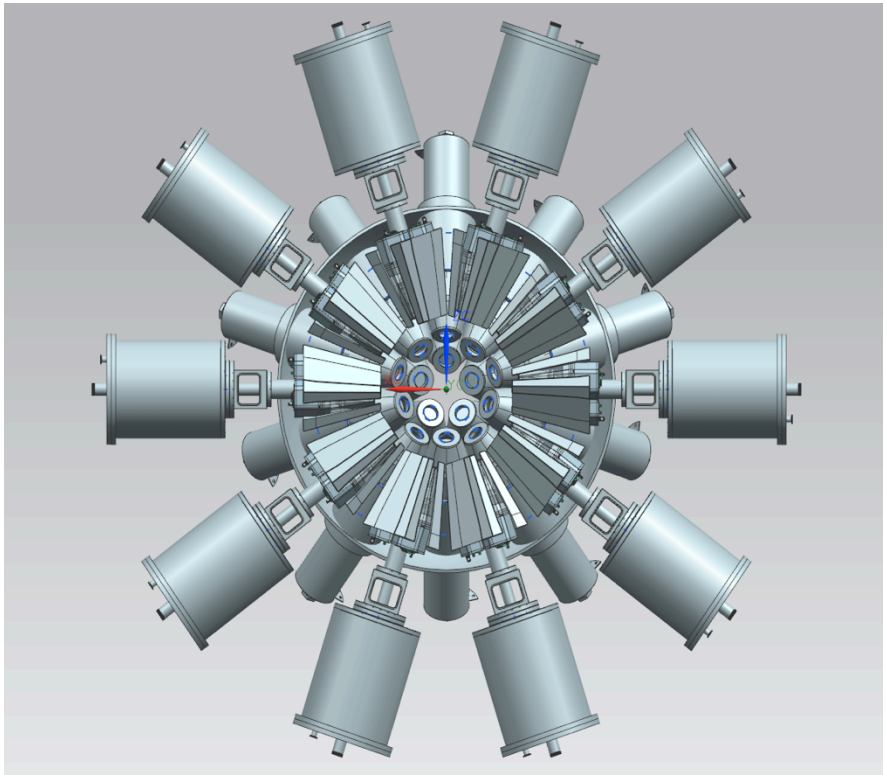
Assembling GALILEO



The GALILEO project

GALILEO – 2012

new gamma–ray array



European Collaboration

take advantage of the recent technical developments for AGATA

- preamplifiers, digital sampling, preprocessing, DAQ
  - → **high counting rates (30–50 kHz/det)**

use of existing detectors

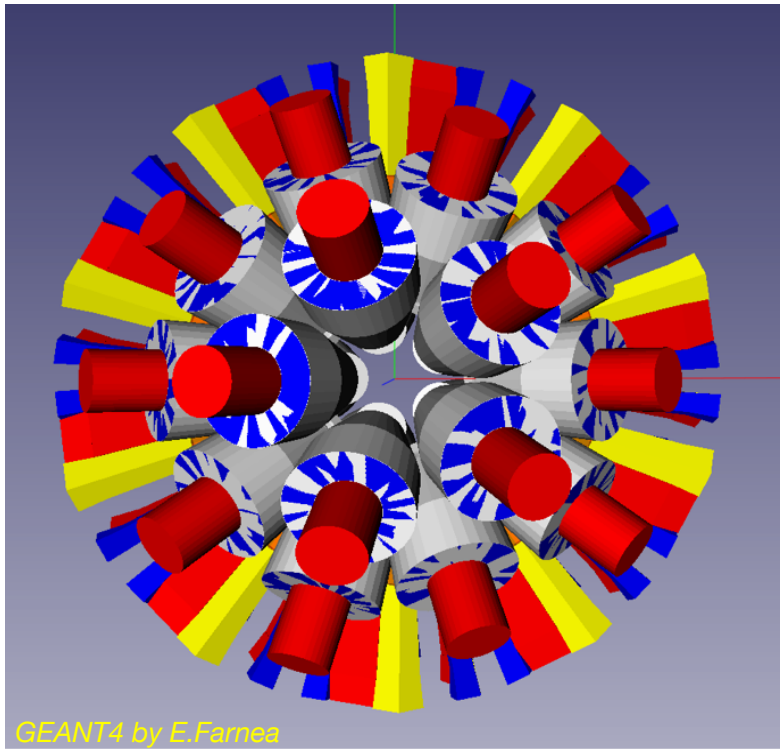
- EB cluster detectors capsules
- GASP detectors
  - → **high photopeak efficiency**

use beam facilities at LNL

- Tandem, ALPI, PIAVE – stable
- SPES – RIB

→ **production of new nuclei**

GALILEO – GEANT4 Simulations



Mixed configuration

30 GASP detectors @ 22.5cm

5	5	5	5	5	5
29°	51°	59°	121°	129°	151°

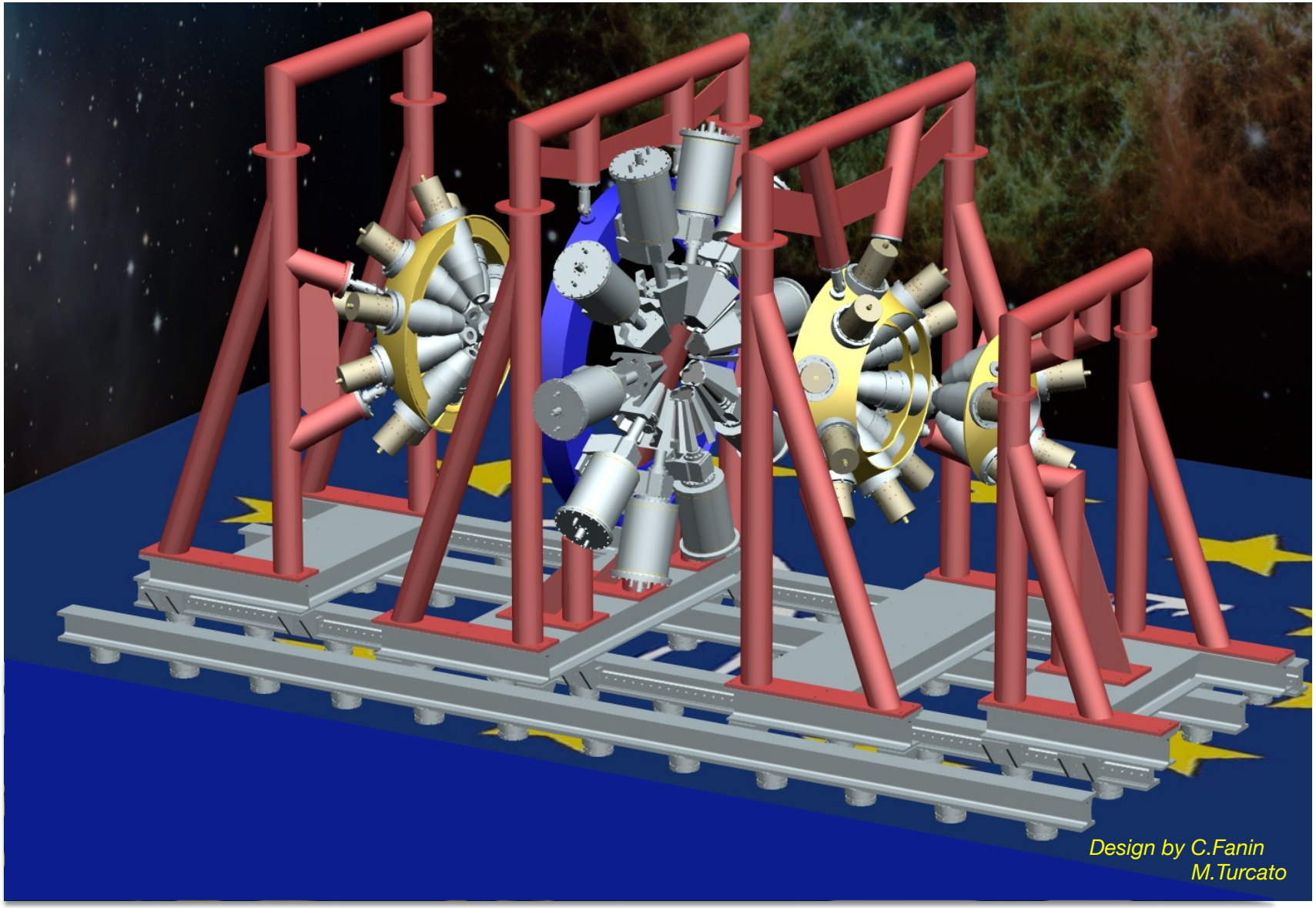
10 triple cluster (EB clusters) @ 24cm

90°

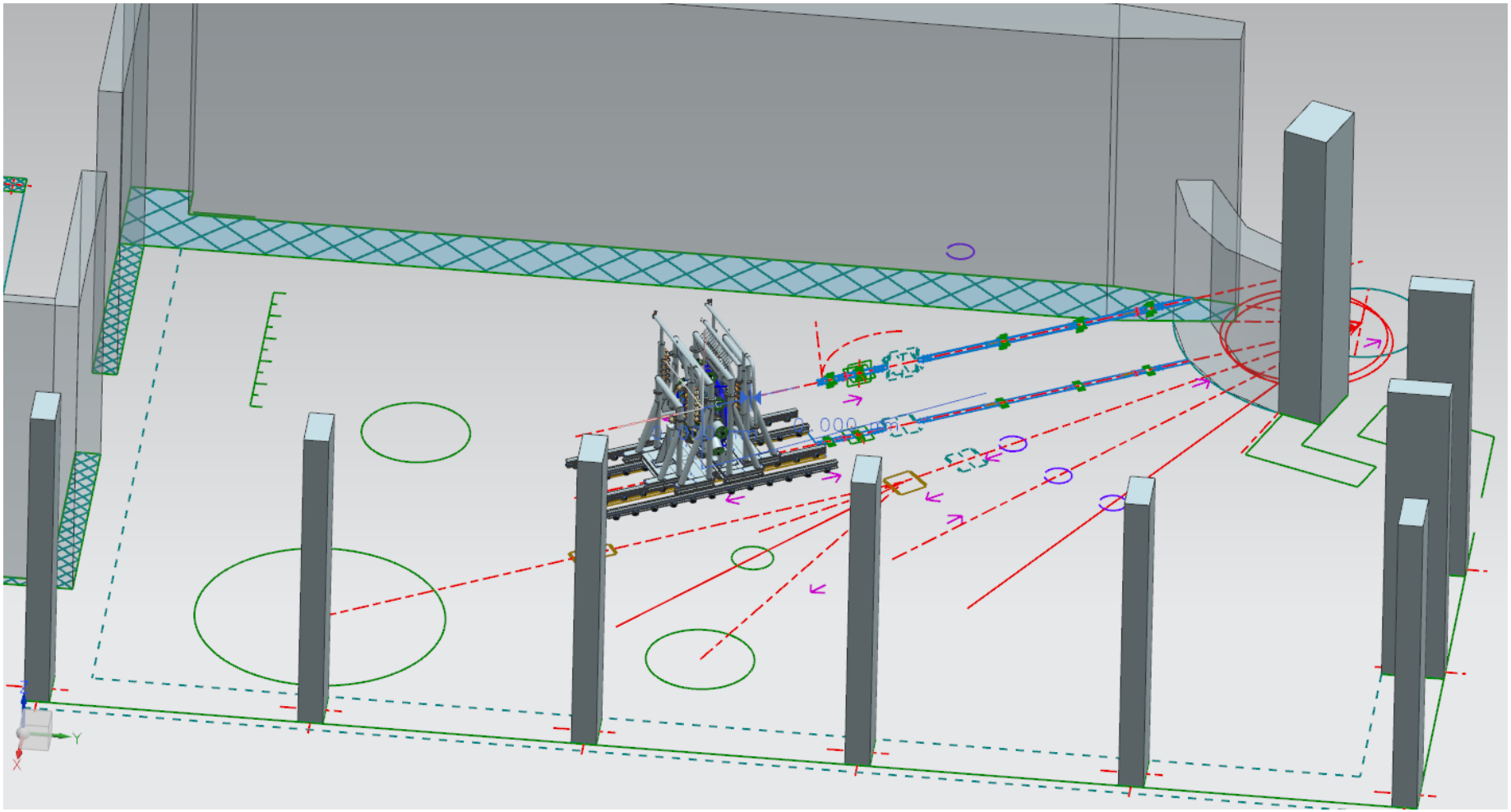
- symmetrical coverage of the solid angle (ang. distr., DSAM)
- good granularity
- at 90° detectors have relatively lower solid angle aperture
- anti–Compton shields
  - for GASP detectors already available
  - for the triple clusters new AC shields
- limited impact on the array performance when dismounting the first ring of detectors to allow insertion of ancillary detectors

ε_{ph} ~ 8% P/T ~ 50%

The GALILEO Gamma–Ray Array

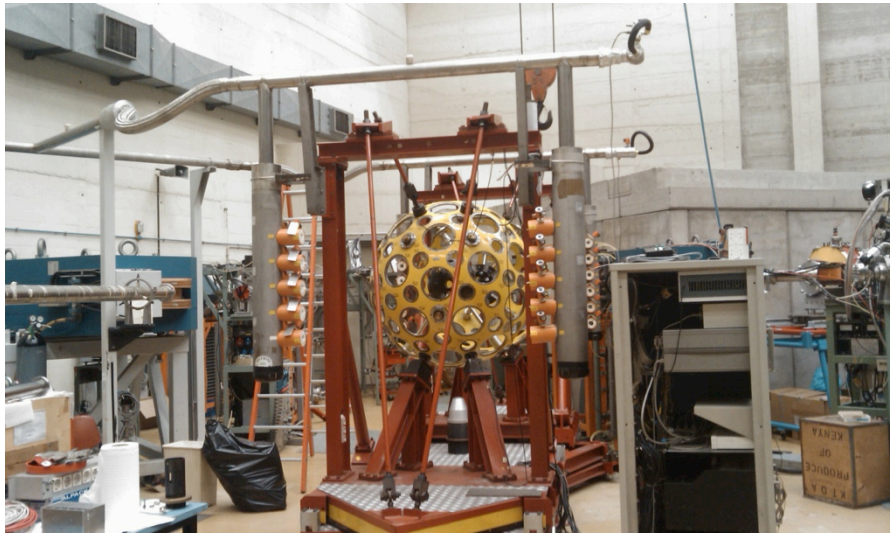


GALILEO – Location



Experimental Hall II – replacing GASP

GASP – Dismounting



GALILEO – Parts

SCM
Modena

Triple Cluster Detector – R&D

Development of the triple cryostat

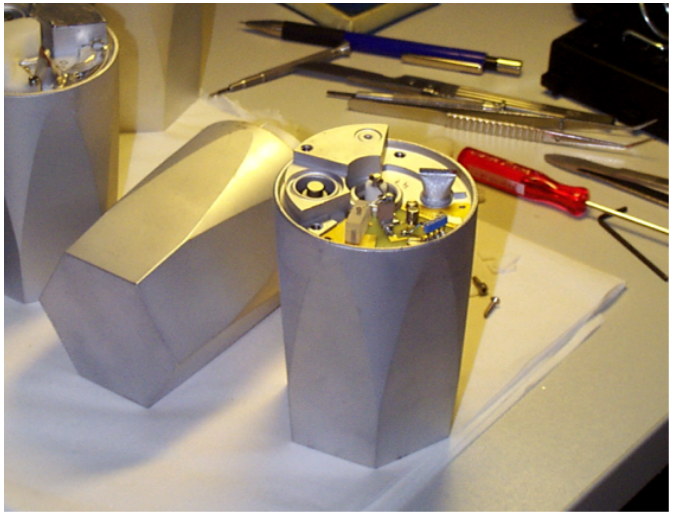
- end–cap in carbon fiber
- dewar
- internal cabling
- optimizing the thermal conduction (LN_2 consumption)

EB cluster detectors

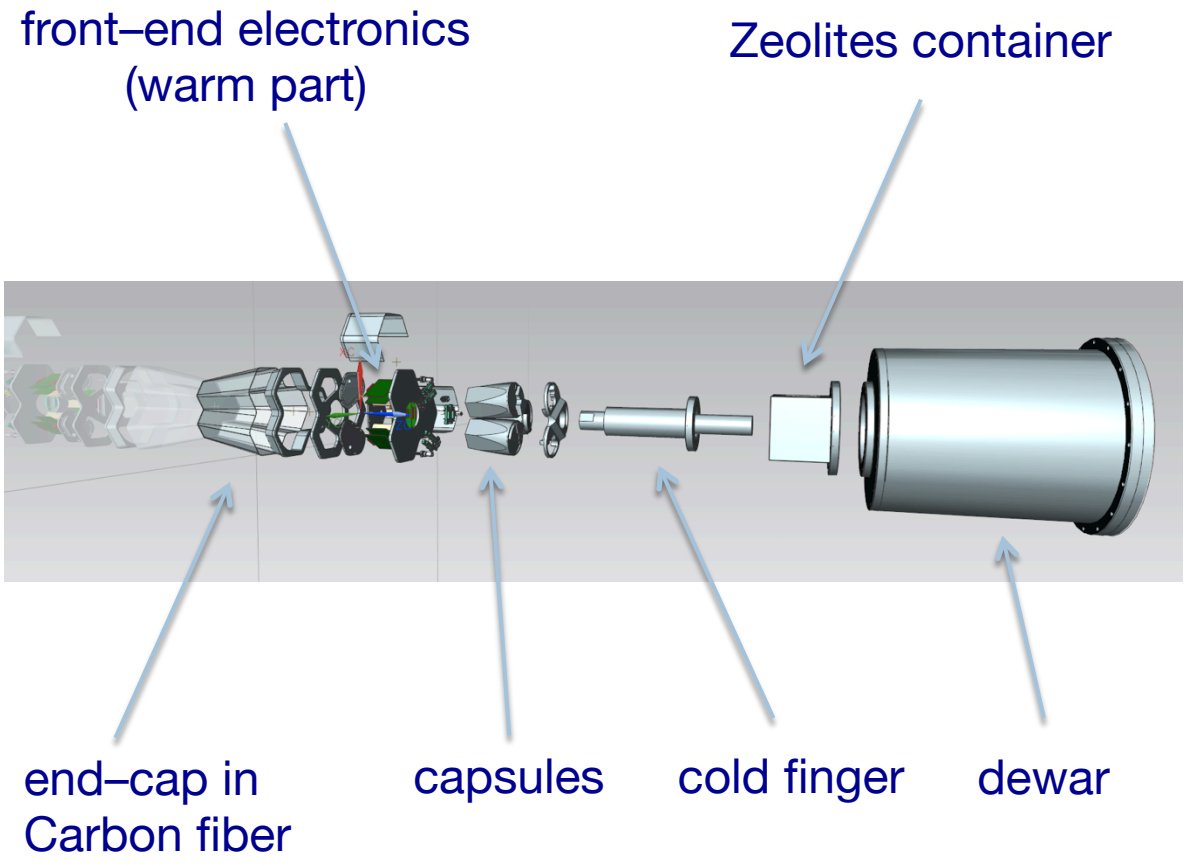
- 7 encapsulated n–type HPGe detectors
- FWHM < 2.4 keV @ 1332.5 keV
- ε_{int} ~60% @ 1332.5 keV

common cryostat

independent HV/LV/FE



Triple Cluster Detector – First Prototype



GALILEO – Electronics R&D

New electronics is being built in close synergy with AGATA

* low–noise, fast, low–power consumption *

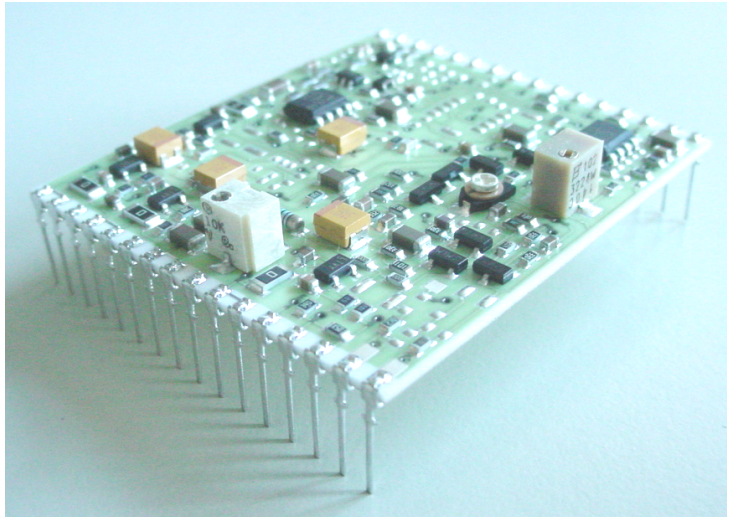
- new cold part (AGATA FET)
- use solutions already developed for AGATA
  - core type preamplifiers
  - GTS
  - AGAVA interface with the VME electronics (colab. with Kracow)
- new developments for AGATA and GALILEO
  - low power digitizers
  - readout and preprocessing on PCI express boards
- anti–Compton shields signal readout
  - digital (similar to the Ge detectors)

GALILEO – Preamplifiers

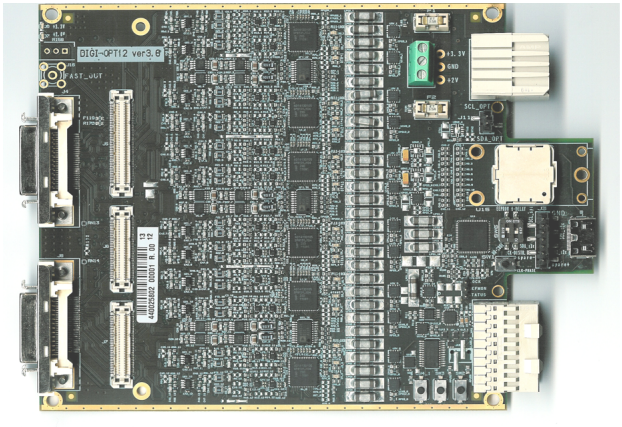
Property	Value	Tolerance
Conversion gain	100 mV / MeV (terminated)	±10 mV
Noise	0.6 keV FWHM (C_d=0 pF @ 150K)	
Noise slope	8 eV / pF	±2 eV
Rise time	~13 ns (0 pF)	±2 ns
Rise-time slope	~0.2 ns / pF	
Decay time	50 µs	±2 µs
Integral non linearity	< 0.025% (dyn.~3.5V)	
Output polarity	Differential, Z_o=100Ω	
Fast reset speed	10 MeV/µs	
Inhibit output	LVDS or CMOS	
Power supply	± 6.5 V, ± 12.5 V	±0.5V
Power consumption FET	< 20 mW	
Power consumption (except diff. buffer)	< 350 mW	
Supplementary power at very high counting rates	~230 mW	
Mechanical dimension	1.6 x 1.8 inch	

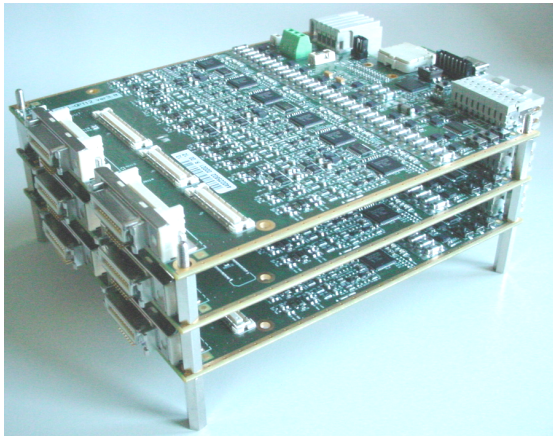
A.Pullia, G.Pascovici, C.A.Ur
submitted to IEEE Nuclear Science Symposium

- a fast low–noise charge sensitive preamplifier based on the core–type AGATA preamplifier
- over–threshold fast reset circuitry – to reduce dead–time due to preamp/ADC saturation
- ToT signal – recover energy information up to 180 MeV
- a fast analog trigger signal can be produced – useful for ancillary detectors
- used for both tapered and triple cluster detectors



GALILEO – Digital Sampling





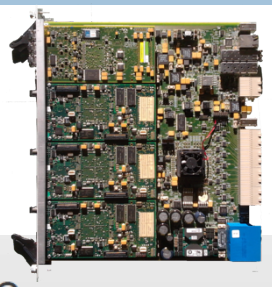
A.Pullia,

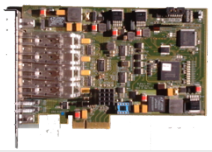
Digi-opt12: 12-channel 14/16-bit 100/125-MS/s digitizer with optical output for GALILEO/ AGATA

- single–ended/differential analog input signals
- end termination for both differential– and common–mode components of the input signals
- AC or DC coupling to the ADC,
- introduction and remotely-controlled adjustment of a differential DC offset, useful for dynamic range maximization
- remotely controlled dynamic-range selection,
- easily tuned anti-aliasing filter
- precise inter-channel time synchronization
- optional interleaved mode for equivalent sampling-frequency multiplication

Power consumption < 10 W

GALILEO – Readout & Preprocessing





Current Architecture

2 carriers
1 GTS mezz.
7 seg. mezz.

PCI Express
Triggered data

1 PC
2 LINCO1
(1 LINCO2)

Raw
Triggerless
data

AGATA Crystal → Digitiser 38 ch. → Preprocessing → Readout (narval node)

7 cables
x12fibres
(6 used)

1 cable
x8 fibres

~30 k€
~320 W

~2K€
~0W

New Architecture

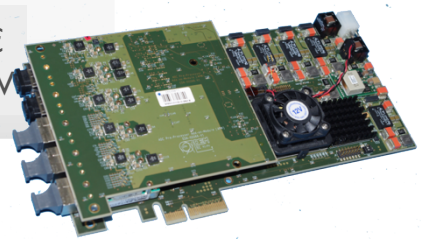
AGATA Crystal → Digitiser 38 ch. → Fibre Rearrangement → Preprocessing & readout (narval node)

7 cables
x12fibres
(6 used)

~500€
~0W

4 cables
x12fibres
(12 used)

~7 k€
~60 W



GALILEO – Electronics & DAQ

Fully synchronous system with global 100 MHz clock and time-stamp distribution

New AGATA core–like preamplifiers differential output, one 10 MeV range - done

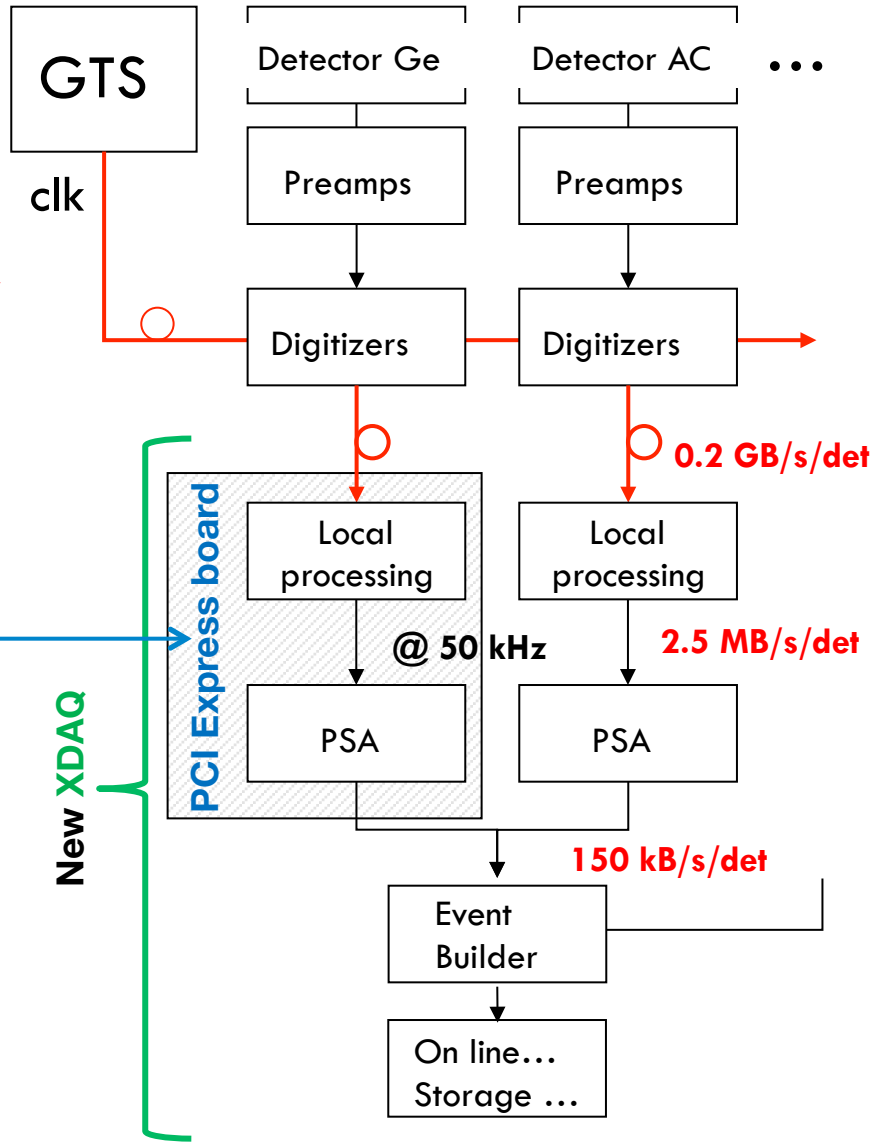
New Digitizers: 100 Ms/s, 14 bit – prototype ready Optical fiber read-out of full data stream to pre-processing electronics

New local processing: determine energy, time and isolate ~ 600 ns of signal around rise-time First prototype fully operational 38 channels

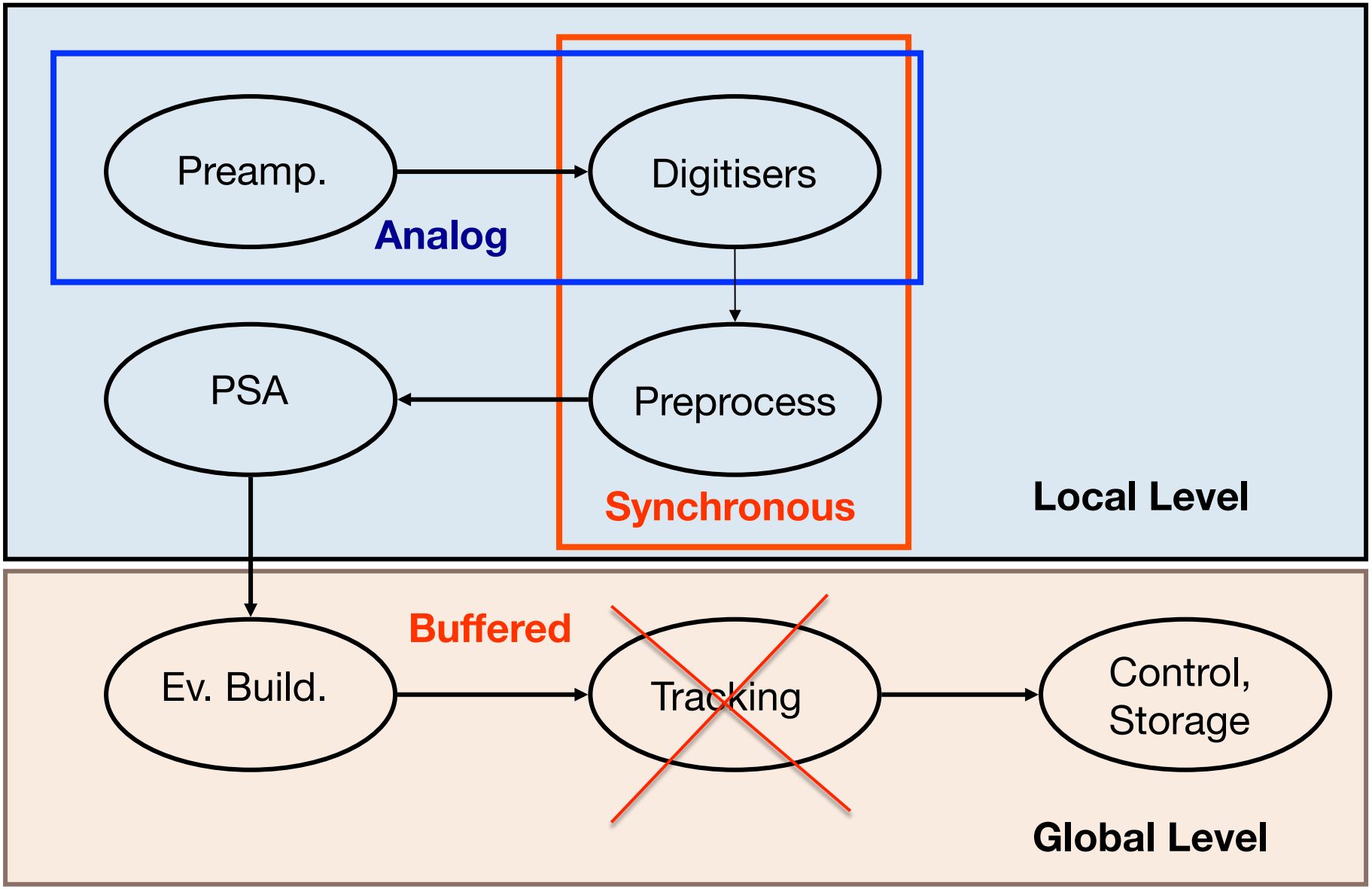
Buffers of time-stamped local events sent to PSA if needed neutron damage correction

Global event builder and software trigger

Control and storage, …

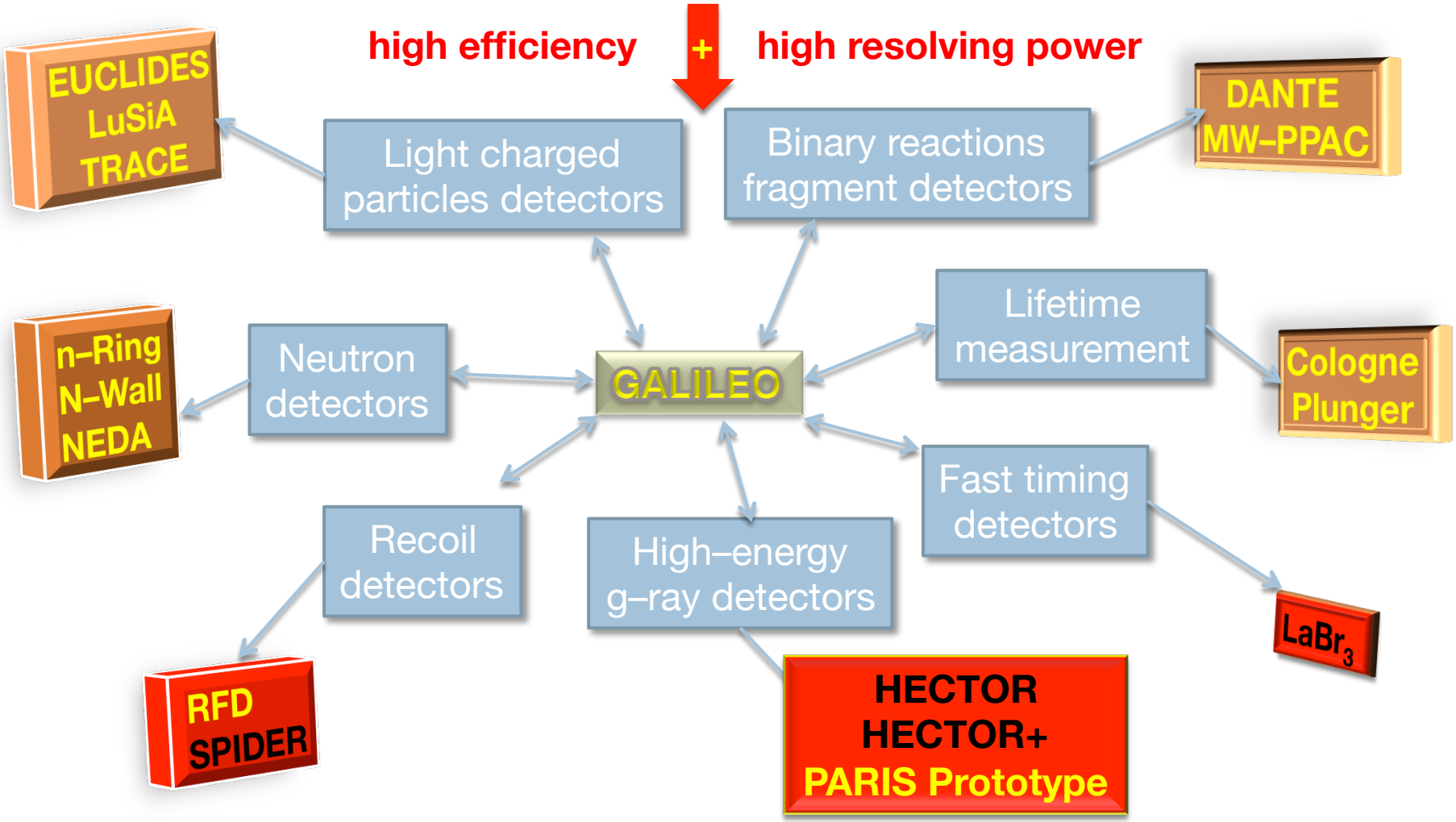


GALILEO – Electronics & DAQ



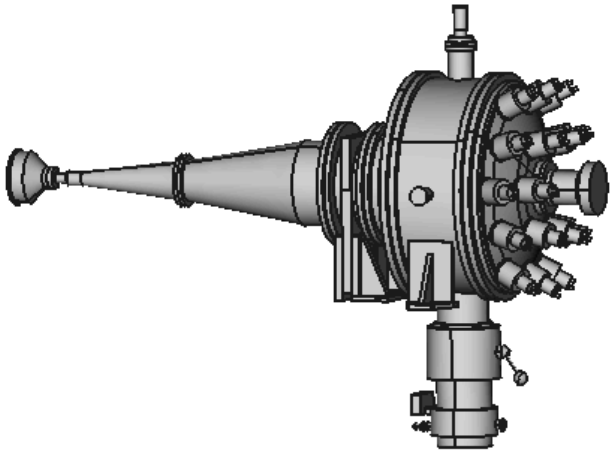
GALILEO – Ancillary Detectors

Study of weak reaction channels or weakly populated structures
LoI 2009–2012

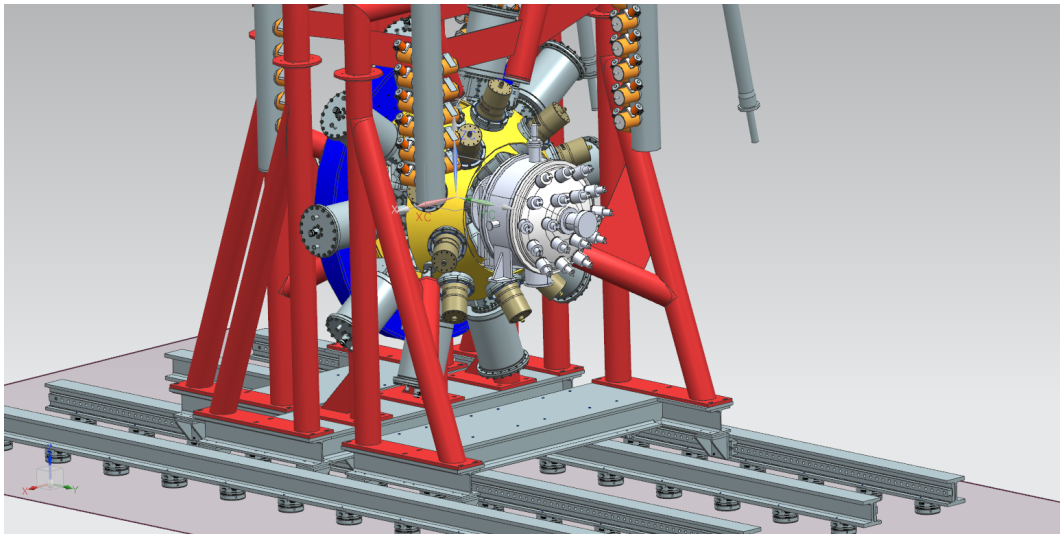


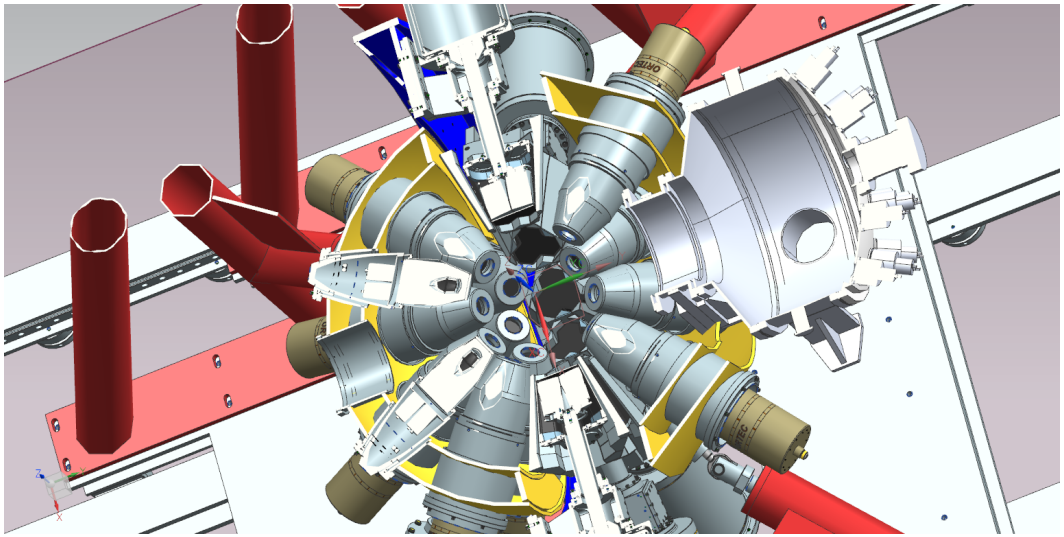
GALILEO – RFD

3D Model



RFD Kracow





GALILEO & RFD – Physics Case

"Collective Modes of Excitation"

Milano-Krakow

Configuration 1: GALILEO + Scintillators $LaBr_3$ + RFD:

- Search for Jacobi transition in neutron rich Ba isotopes
- Study of very heavy Th, Rn, Ra nuclei at high spins and $T \neq 0$
- Rapidly rotating nuclei in A=60 region

Configuration 2: GALILEO + Scintillators $LaBr_3$ + TRACE:

- Inelastic scattering of ^{17}O ions : pygmy dipole states and GQR

Configuration 3: GALILEO + Plunger + PPAC:

- In-beam spectroscopy by transfer reactions with Heavy Ions: search for particle-phonon couplings (Ni, Fe, …)

Summary

Long–term collaboration in the frame of nuclear structure studies through the means of gamma–ray spectroscopy

- common experiments
- development of detectors
- theoretical calculations

A new gamma-ray array GALILEO is under development at LNL

R&D for improving detectors and electronics

- higher detector granularity
- improved efficiency at high energies (composite configuration)
- low noise, fast electronics
- digital treatment of the signals

Common physics interest

- use of PARIS prototype
- use of RFD detector