γ-ray spectroscopy with scintillator detectors

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OUTLINE

- Scintillators and $LaBr_3$:Ce
- Properties of large volume $LaBr_3$:Ce - HECTOR$^+$
- HECTOR+ measurement : Isospin Mixing in ^{80}Zr
- HECTOR+ measurement : PDR in ^{64}Fe
- HECTOR+ measurement : Inelastic scattering of ^{17}O on stable nuclei
- Conclusions

BEFORE 2006

Scintillator Arrays - not for discrete γ spectroscopy

- Crystal Ball, Spin Spectrometer, Medea, Hector,

Scintillators as a bulk active volume

Scintillators for Anticompton Shields

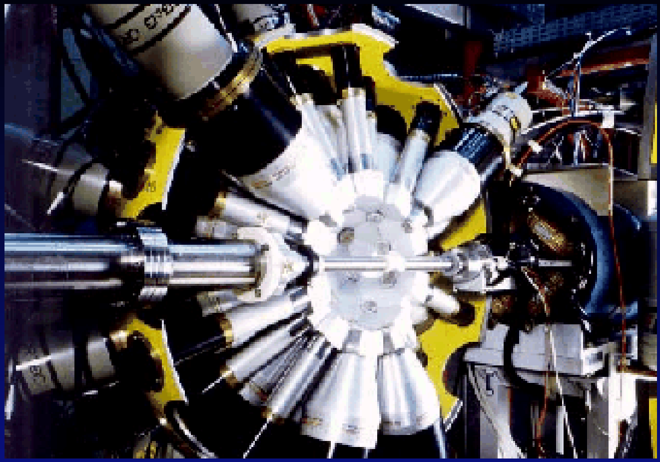
- Scintillators $\Rightarrow$ yes/no information

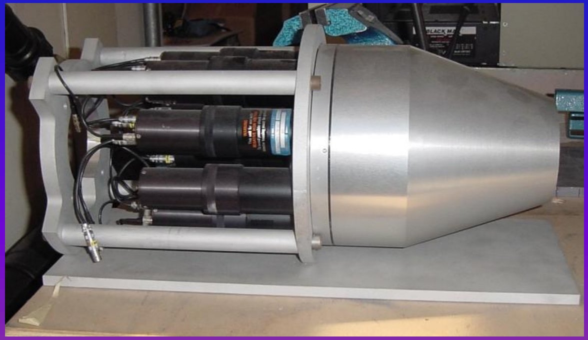
Scintillator Arrays as multiplicity filters - Σ energy

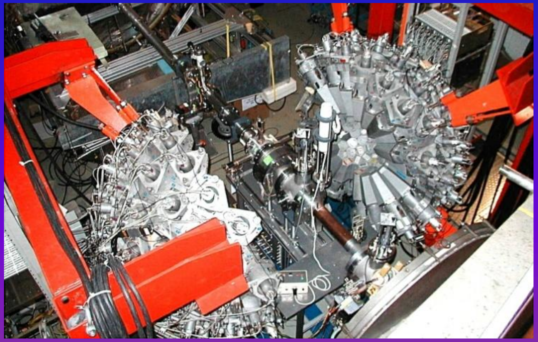
- Nordball $\Rightarrow$ BaF_2 Ball
- GASP $\Rightarrow$ BGO Ball
- Euroball $\Rightarrow$ BaF_2 Ball

Test for the Add Back technique with HPGe

- F. Camera et al NIM **A351**(1994)401-405







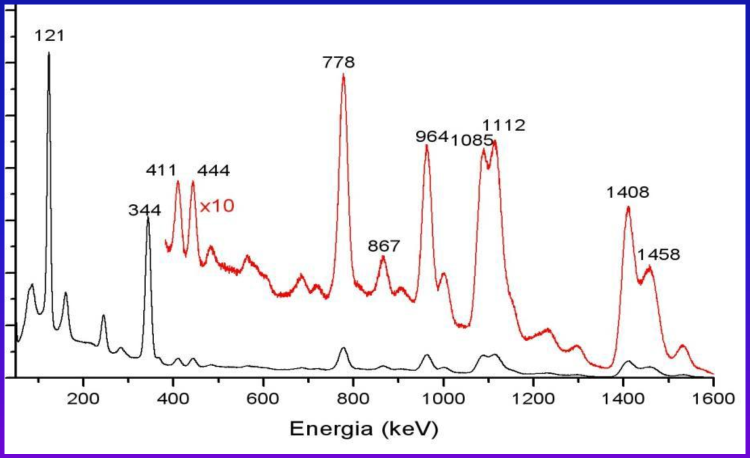
$LaBr_3$:Ce Detectors

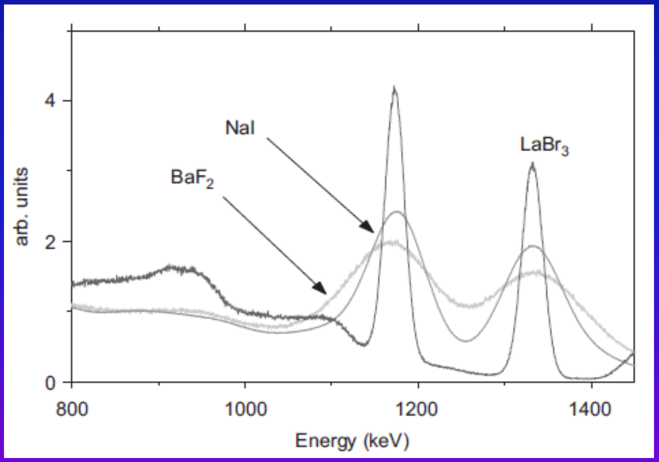
2001 – Discovery - Applied Physics Letter 79(2001)1573

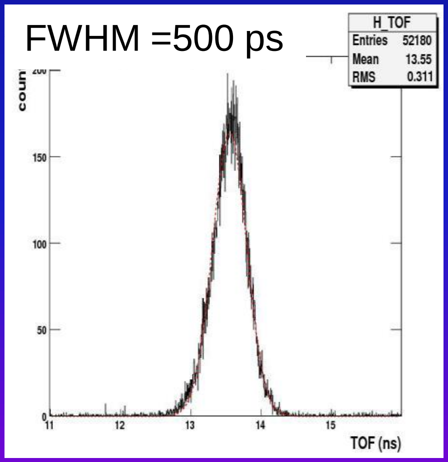
≈ 2005 – 1” x 1” Commercially available
≈ 2006 – 3” x 3” Commercially available
≈ 2007 – 3” x 6” Commercially available
≈ 2008 – 3.5” x 8” Commercially available

- **The History of $LaBr_3$:Ce started 10 years ago**
- **The History of large volume $LaBr_3$:Ce started <u>only</u> 4-5 years ago**

$LaBr_3$:Ce is the scintillator which has the best energy resolution (20 keV at 662 keV, a sub-nanosecond time resolution, almost perfect light yield proportionality and high efficiency (high density, effective ‘Z’ and large volume)







Nicolini et al Nucl. Instr. And Meth. A 582 (2007) 554–561
G.Knoll radiation Detection and Measurements pg 151

Characterization of Large Volume $LaBr_3$:Ce Detectors

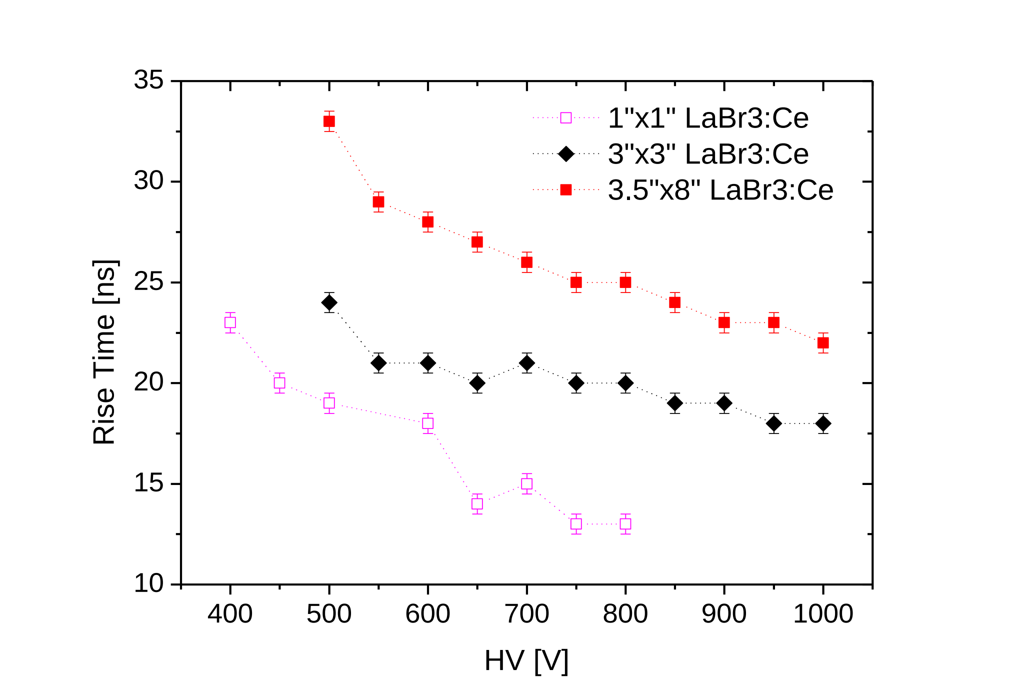
- Rise time
- Pulse line-shape
- Count Rate
- Pulse distortion with γ-rays energy
- Linearity in energy
- Energy resolution and NON homogeneity
- High energy gamma rays
- Efficiency

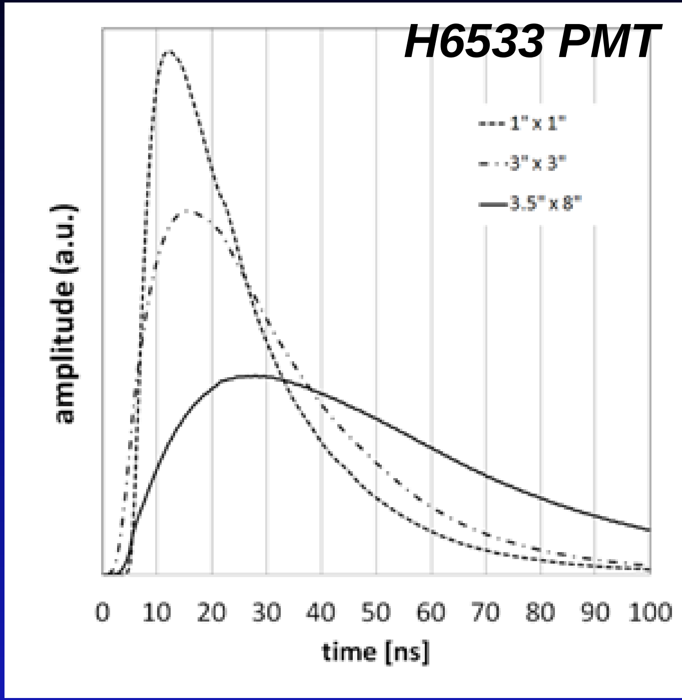
The properties of large volume $LaBr_3$:Ce cannot be easily deduced from those of small crystals

- Long mean free path of scintillation light (enhance Self-absorption,longer rise time)
- Crystal non-homogeneities (change in light yield, energy resolution)
- Efficiency vs. high energy γ-rays
- High count rates
- Large dynamic range (0.1 – 30 MeV)
- Large surface PMT - not ‘ideal’

F.C.L. Crespi et al. Nucl. Instr. and Meth. A620 (2009) 520
Nicolini et al Nucl. Instr. And Meth. A 582 (2007) 554–561
S. Riboldi et al., IEEE NSS/MIC 2011 proc. AN. 6154296 pg.776-778
C.Boiano et al.., IEEE NSS/MIC 2010 proc. AN 5873761, Pg 268-270
F.Quarati et al. Nucl. Instr. and Meth. A629 (2011) 157.
A. Giaz, et al submitted to NIM

Characterization of Large Volume $LaBr_3$:Ce : Rise time





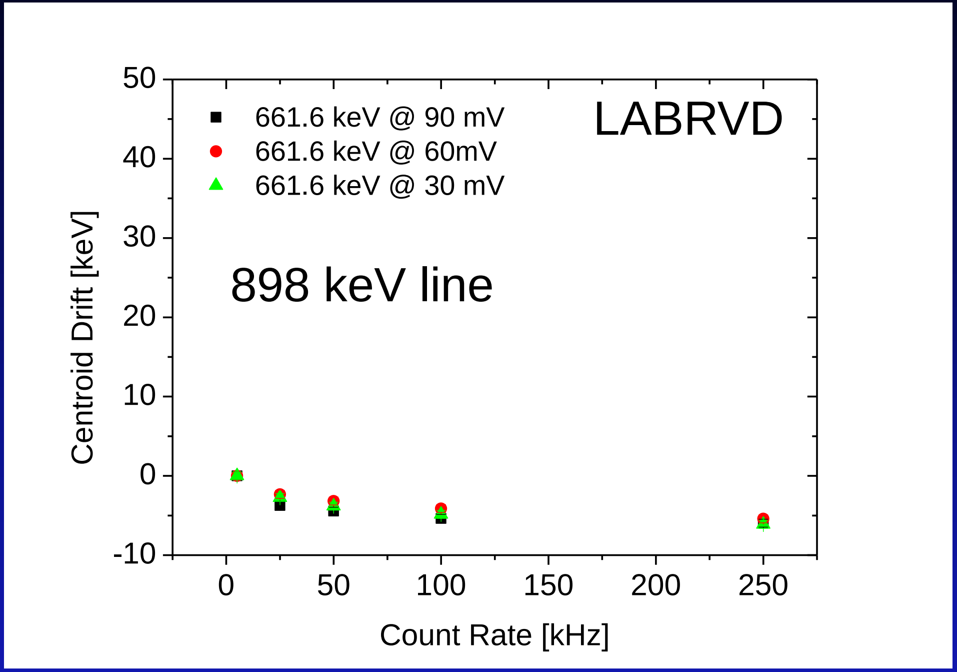
As energy resolution is the same in all these crystals (3-3.3% at 661 keV) self absorption inside the crystal is negligible

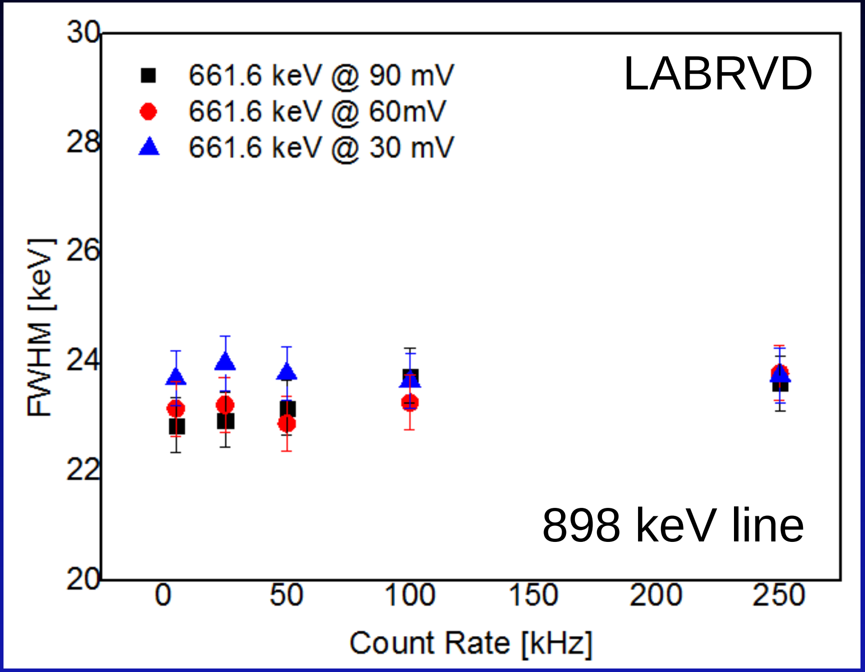
The time required to collect the scintillation light:

≈ 4 ns ⇒ 1” x 1” scintillator
≈ 7 ns ⇒ 3” x 3” scintillator
≈ 14 ns ⇒ 3.5” x 8” scintillator

A. Giaz, et al submitted to NIM

Characterization of Large Volume $LaBr_3$:Ce : Count Rate induced effects





The 898 keV peak centroid drifts less than 10 keV changing the rate from 1 to 250 KHz
- as the gain decreases , we verified that it is a temperature C.R. induced effects

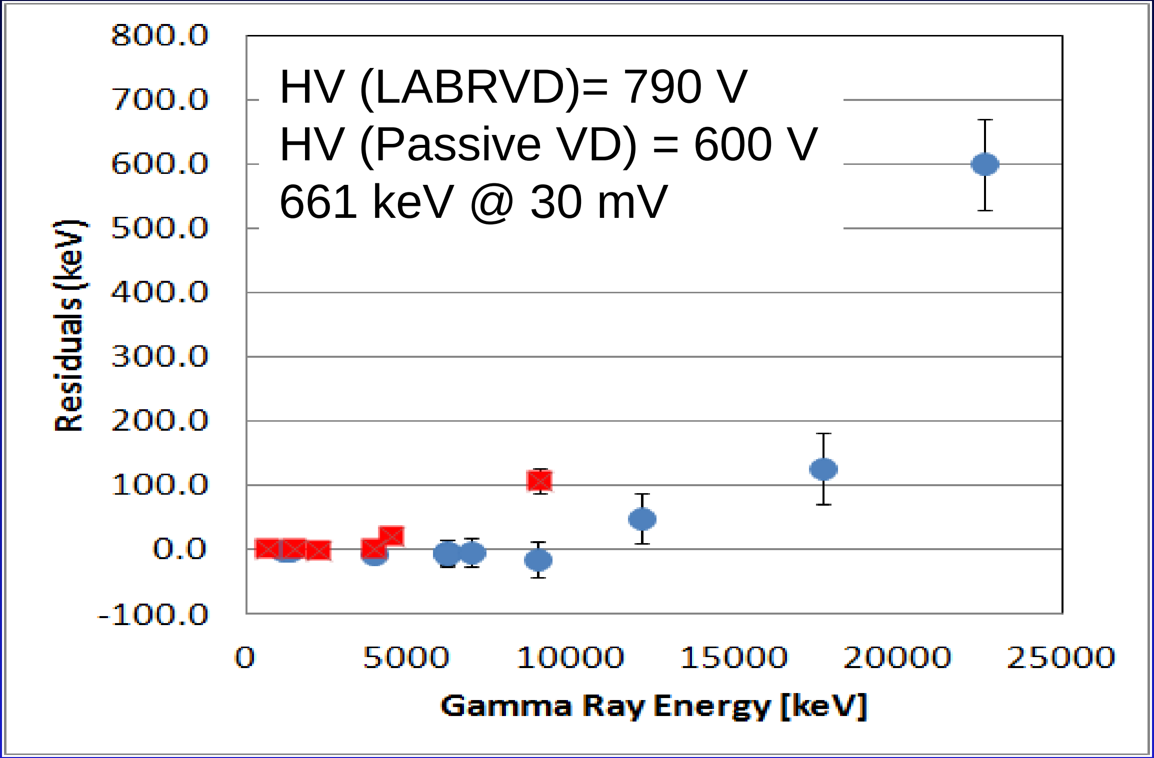
The 898 keV peak energy resolution does not change with count rate

The signal have been digitized (8 bits 400 MHz bw 5 GHz Samp. Freq.) and analyzed

Note: not only the PMT but also the subsequent electronics, e.g. shaping amplifier, analog to digital converter, etc. may easily impair the $LaBr_3$:Ce detector performances, especially in case of high count rate of events and with lack of pile-up rejection

A. Giaz, et al submitted to NIM

Characterization of Large Volume $LaBr_3$:Ce Detectors: Linearity in Energy
- It is a PMT + Voltage divider effect -



Red Points

⇒ Passive Voltage Divider

Blue Points

⇒ LABRVD
⇒ Active Voltage Divider

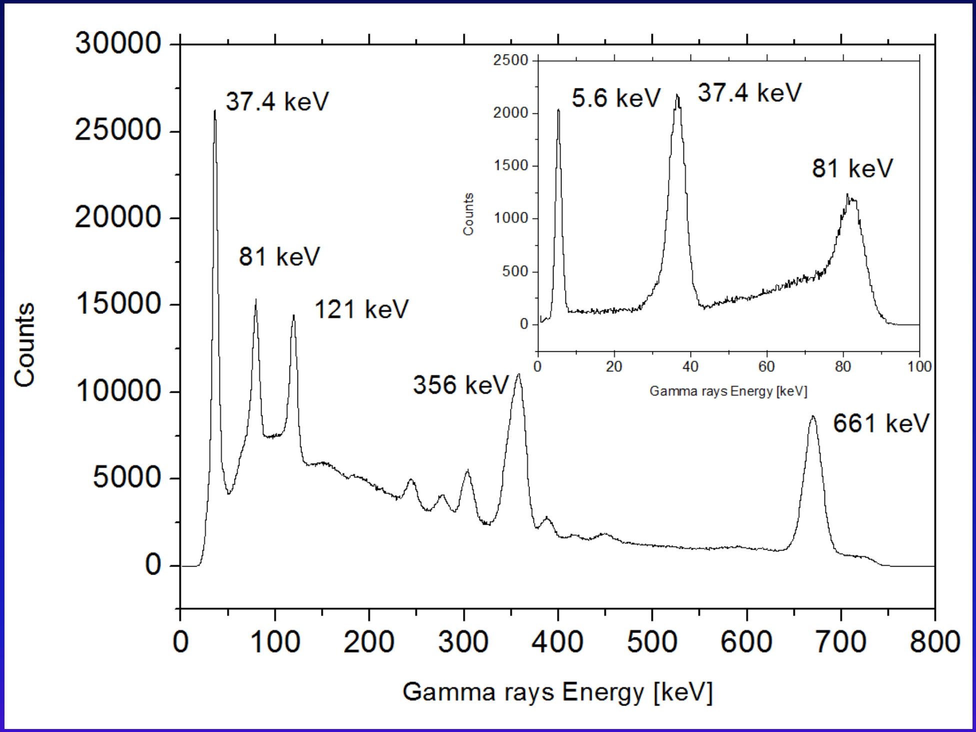
- At 22.6 MeV the NON linearity is of the order of 3%
- PMT Linear response fluctuates between ± 1% from tube to tube
- A lower voltage garantee a linear response for γ-rays of higher energy

A. Giaz, et al submitted to NIM

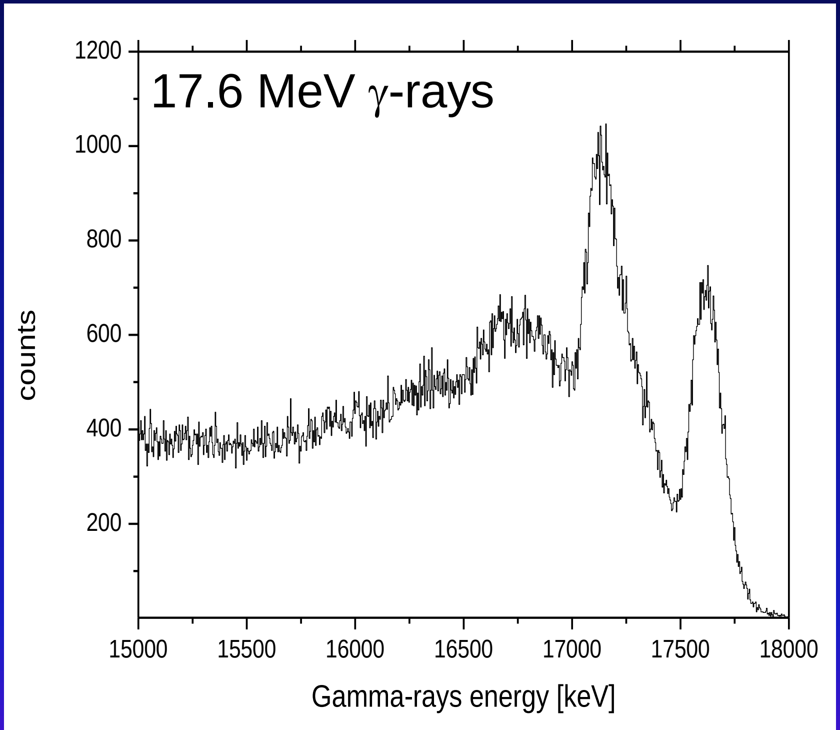
Characterization of Large Volume $LaBr_3$:Ce Detectors

Energy Spectra at 0.01 and 17.6 MeV

3.5” x 8” Large Volume $LaBr_3$:Ce



Internal radiation + ^{133}Ba and ^{137}Cs source

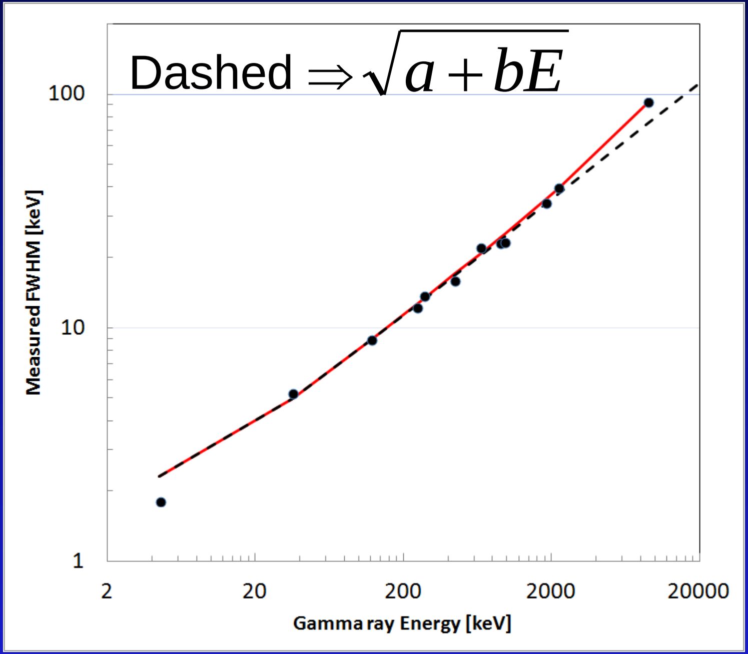


^{7}Li+p = ^{8}Be target $LiBO_2$

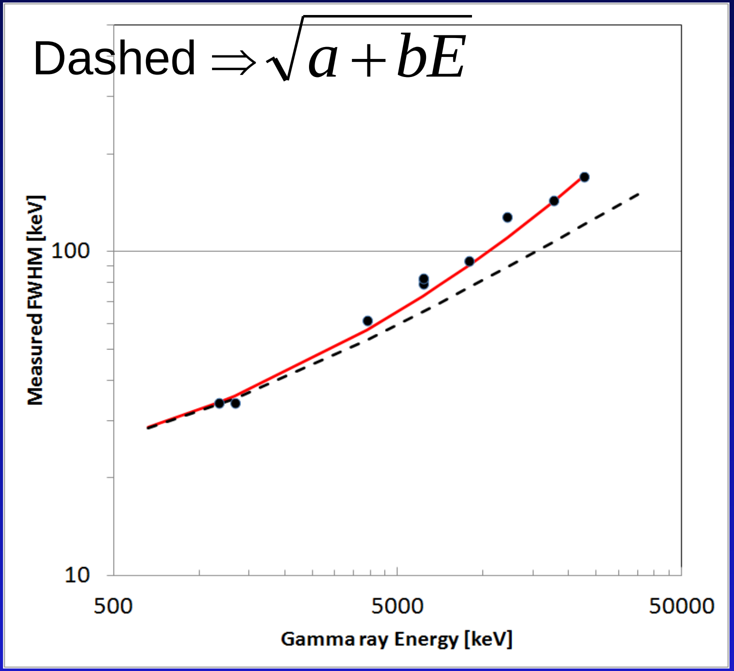
Characterization of Large Volume $LaBr_3$:Ce Detectors

Energy Resolution

Digital electronic (Milano Laboratory)



Analog electronic (Debrecen)



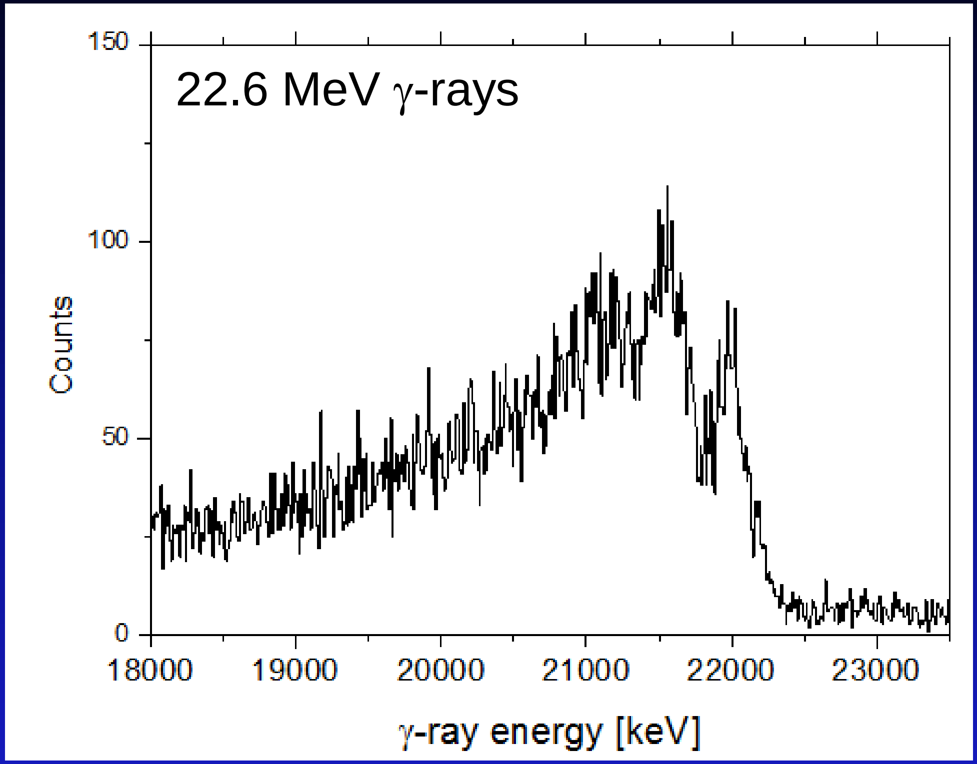
$$FWHM = \sqrt{a + bE + cE^2}$$

continuous red line

a $\Rightarrow$ Electronic noise
b $\Rightarrow$ Poisson Statistics
c $\Rightarrow$ Drift, Temperature, NON homogeneities

A. Giaz, et al submitted to NIM

Unique Feature



LaBr$_3$:Ce detectors provide, at the same time, clean spectroscopic information from a few tens of keV up to tens of MeV, being furthermore able to clearly separate the full energy peak from the first escape one

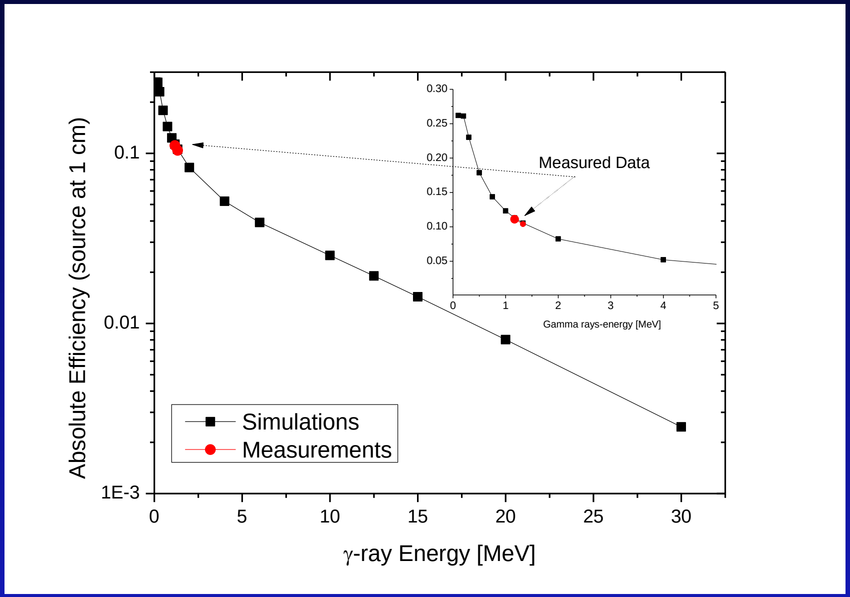
This is particularly true for large volume detectors which have FEP efficiency for high energy γ-rays

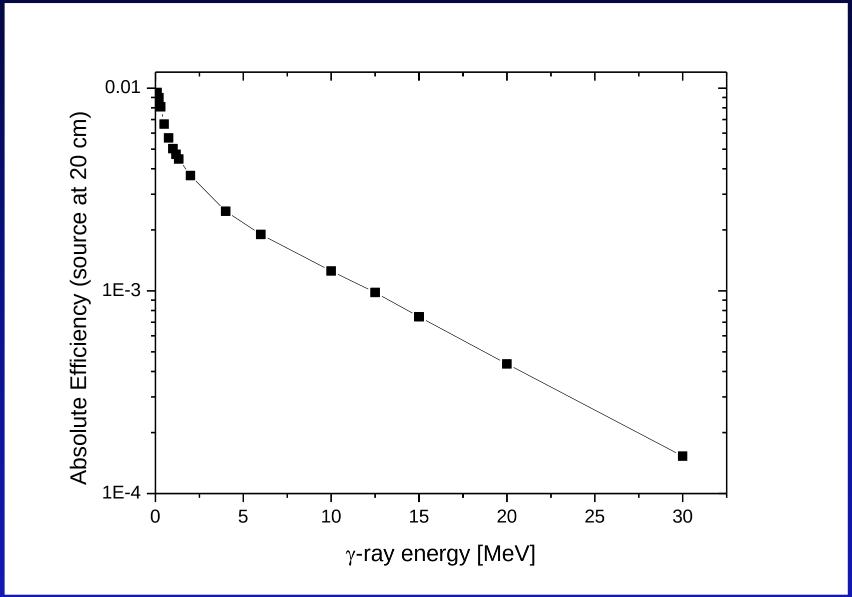
Large volume LaBr$_3$:Ce detectors can perform spectroscopy of high energy γ-rays probably up to 30-40 MeV

HpGe detectors have excellent energy resolution but the small size of the crystal, the low density and Z_{eff} make them several time less efficient than large volume LaBr$_3$:Ce

Characterization of Large Volume $LaBr_3$:Ce Detectors: efficiency

1 detector





^{60}Co Source attached to the front face
Sum peak technique

GEANT Simulations
Source at 20 cm

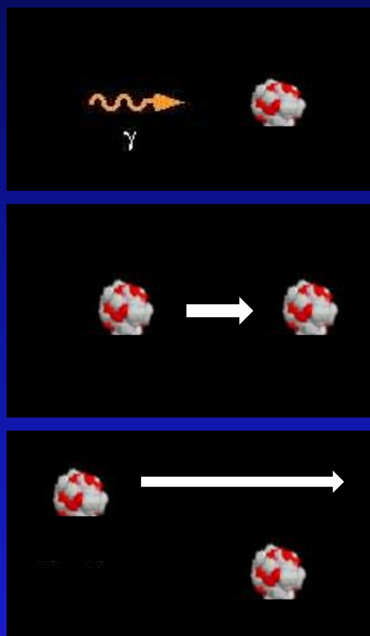
One large volume 3.5"x8" $LaBr_3$:Ce detector at 20 cm from target has ~10% relative full energy peak efficiency for 10 MeV γ-rays.

A 10 detector large volume 3.5"x8" $LaBr_3$:Ce array placed 20 cm from the target has 1% absolute full energy peak efficiency for 10 MeV γ-rays.

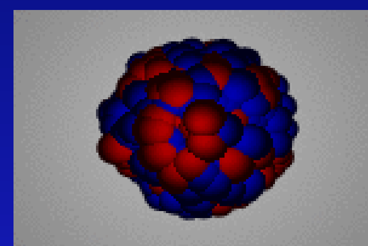
Physics Case

Study of the nuclear collective states

Measurements of the γ-decay from collective states



IVGDR



Measurement of low energy γ-rays (0-5 MeV) ⇒ Reaction Mechanism (ΔE)
Measurement of high energy γ-rays (5-30 MeV) ⇒ Collective States (ΔE, ε)
Background and neutron rejection ⇒ Use of Radioactive Beams (Δt)

HECTOR^{+} Array

- **High efficiency portable scintillator detector array**

- 8 Large Volume BaF_2 Detectors (14 x 17 cm)
- 36 Small Volume BaF_2 Detectors

- **10 large Volume $LaBr_3$:Ce detectors (9 x 20 cm)**

A $LaBr_3$:Ce array, is capable to work in a standalone configuration but, when coupled to a radiation detection system, increases the efficiency and makes much more powerful the physics program of the detection system.

HECTOR+ has already measured in several laboratories

- coupled to HPGe arrays
  - AGATA @ LNL Low Lying pygmy and quadrupole state isospin mixing in ^{80}Zr
  - AGATA @ GSI Pygmy resonance on ^{64}Fe
  - AGATA @ LNL Low Lying Pygmy and GQR states

- coupled to LAND @ GSI
- coupled CACTUS @ OSLO
- RIKEN, DEBRECEN.

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- RIKEN, DEBRECEN.

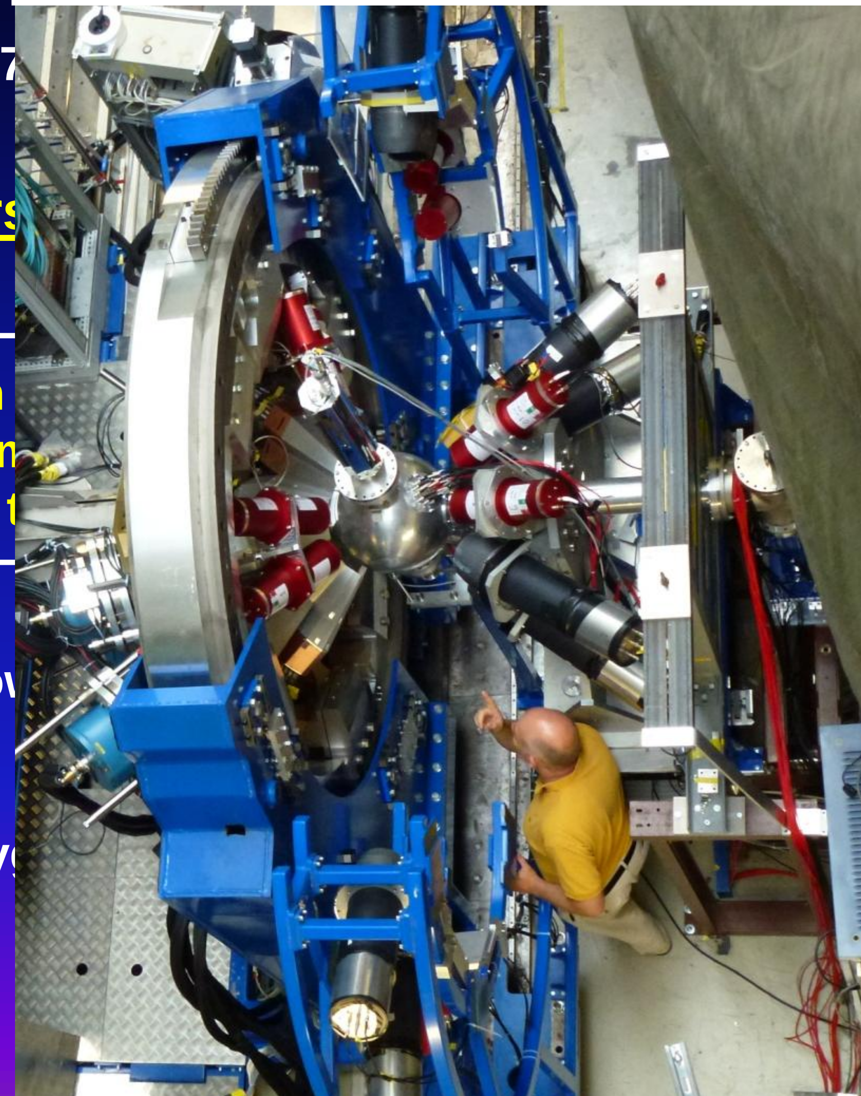
preliminar results

$LaBr_3$:Ce & HpGe

HECTOR$^+$ Array

AGATA-HECTOR$^+$ at LNL

PRESPEC-AGATA-HECTOR$^+$ at GSI



Isospin Mixing in N=Z Nucleus ^{80}Zr at Med-High Temperature

AGATA@LNL Experiment - May 2011

E* →

Almost good quantum number

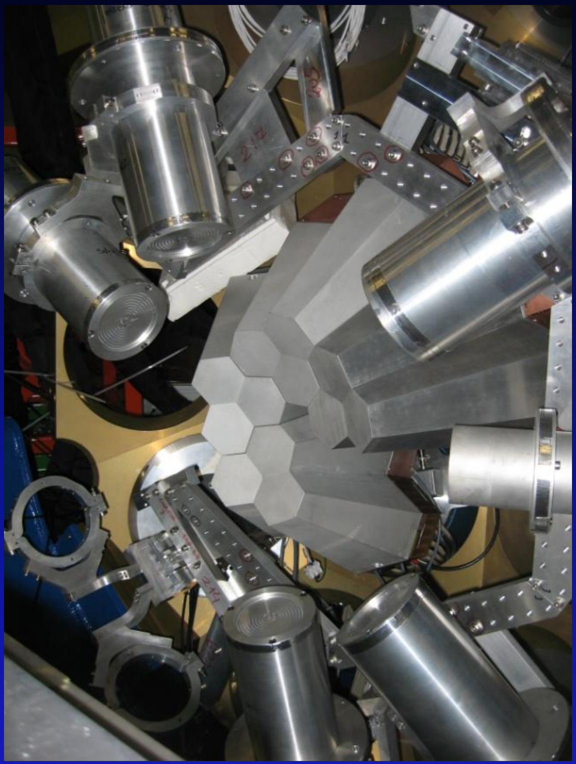
nuclear reactions which involve low-lying states

Simmetry Breaks

Symmetry is restored

fusion-evaporation reactions (E^*>20 MeV)

The CN might decay before isospin mixes.



We used the first step GDR γ-decay in CN :

- $0 \Rightarrow 0$ transition is forbidden in E1 decay in N=Z I=0 nuclei

- Coulomb Spreading Width $\Gamma_c \approx \Gamma_{IAS}$
- Isospin mixing coefficient a_2 at T>0,J=0 and J=<J>$_{CN}$
- Isospin mixing coefficient a_2 at T=0 and J=0

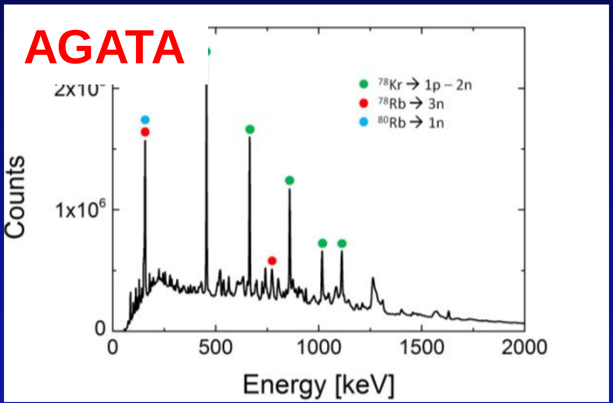
$$(\alpha^{I_0+1\ 1})^2 = \frac{1}{I_0+1} \frac{\tilde{\Gamma}^{\downarrow}_{IAS}(E^*)}{\tilde{\Gamma}_c(E^*) + \tilde{\Gamma}_M(E^*)}.$$

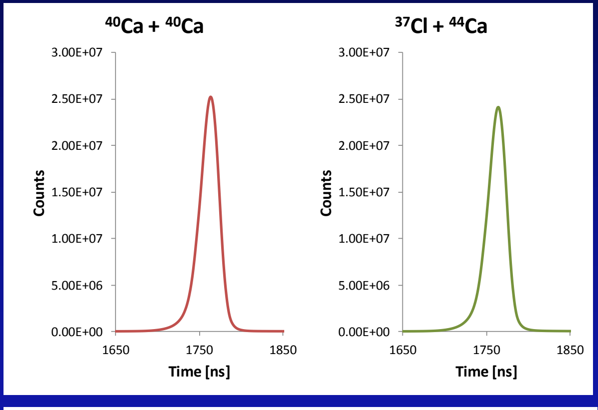
Colo et al PRC R 52(1995)R1175
Sagawa et al PLB B 444 1998. 1–6

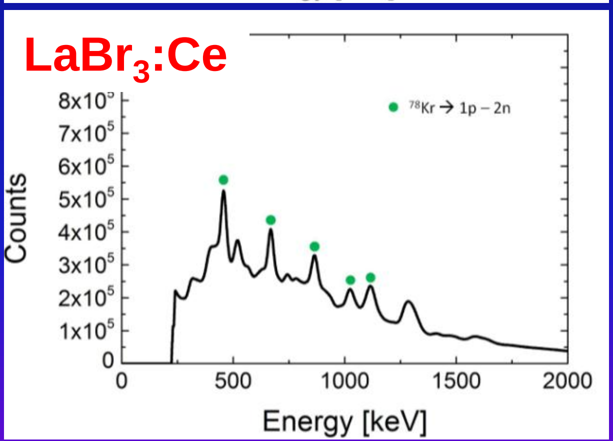
- $\Rightarrow$ beta decay description
- $\Rightarrow$ CKM matrix

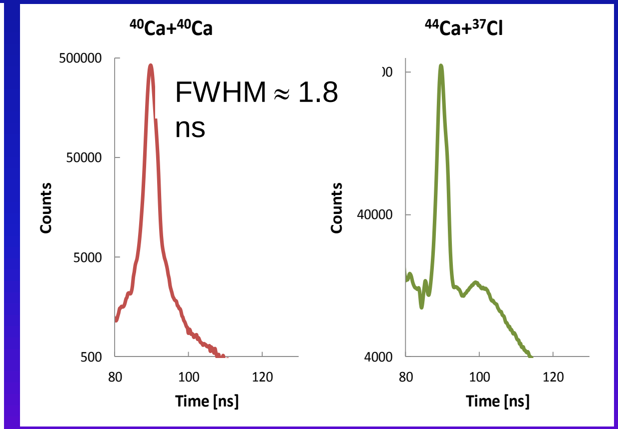
A.Corsi et al. PRC 84, 041304(R) (2011)

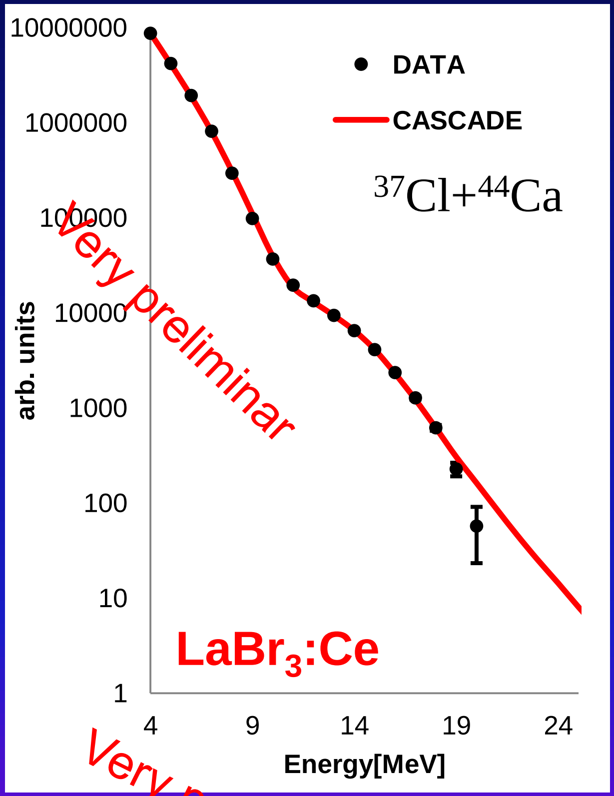
Proj.	target	CN	E_{beam}(MeV)	E*(MeV)	I	setup
^{40}Ca	^{40}Ca	^{80}Zr	200	83	0 → isospin mixing	HECTOR + GARFIELD
^{37}Cl	^{44}Ca	^{81}Rb	153	83	7/2 → reference	
^{40}Ca	^{40}Ca	^{80}Zr	136	54	0 → isospin mixing	HECTOR^{+} + AGATA
^{37}Cl	^{44}Ca	^{81}Rb	95	54	7/2 → reference	











RESIDUES	AGATA1LABR1	AGATA2LABR2
4p	49%	35%
α2p	21%	20%
3p	23%	38%

Very preliminar

E_{GDR} = 16.2 MeV
$Width_{GDR} \approx 7 \pm 0.4$MeV

A.Corsi et al. PRC 84, 041304(R) (2011)

Thank to S.Ceruti and A.Giaz

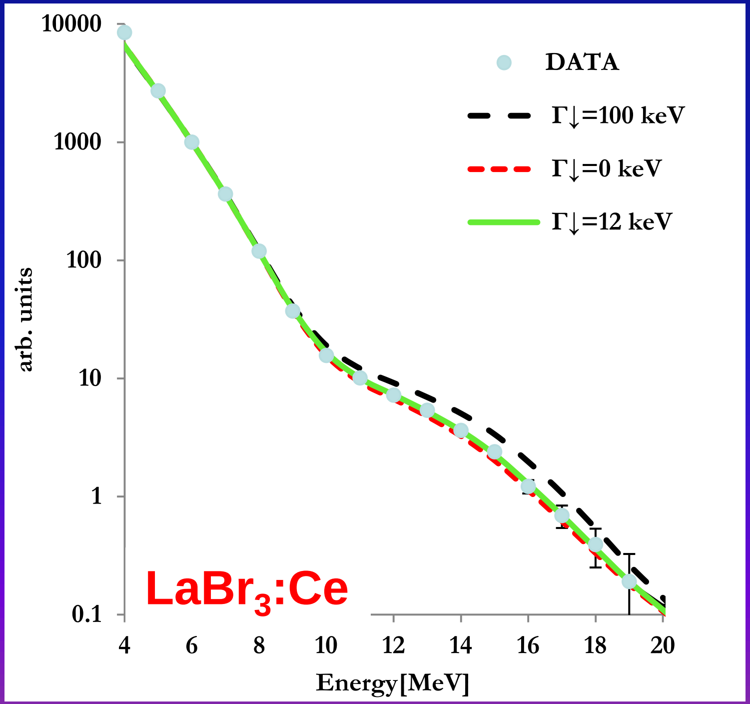
Very Preliminar Analysis

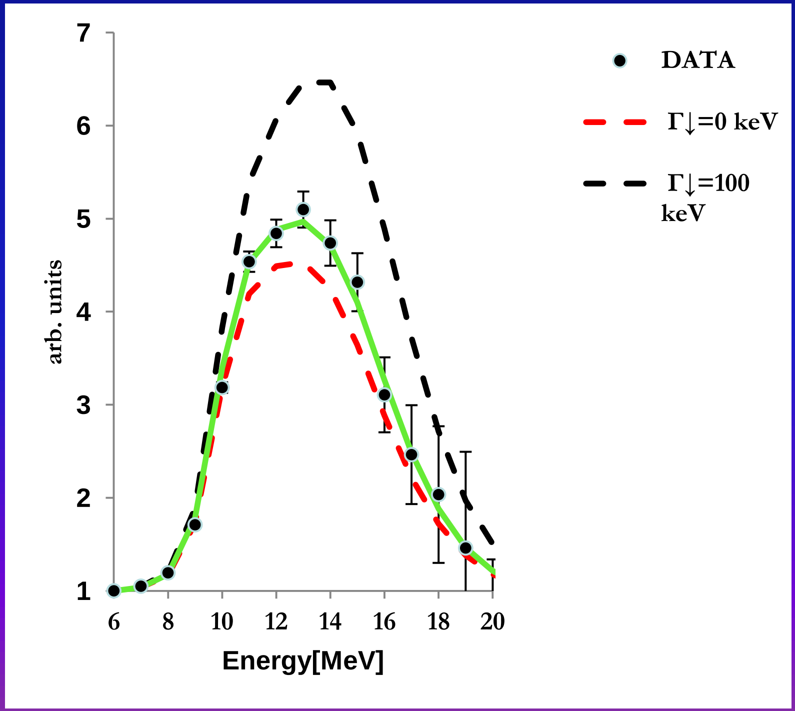
Preliminary fit results→^{80}Zr

Fit procedure:

- **E_{GDR}** fixed to 16.2 MeV.
- **Γ** fixed to 7 MeV
- **χ^2** test to extract the Coloumb Spreading width **Γ$^{\downarrow}$**

Preliminary fit result ⇒ Γ$^{\downarrow}$=12±3 keV to be compared with Γ$^{\downarrow}$=10±3 keV





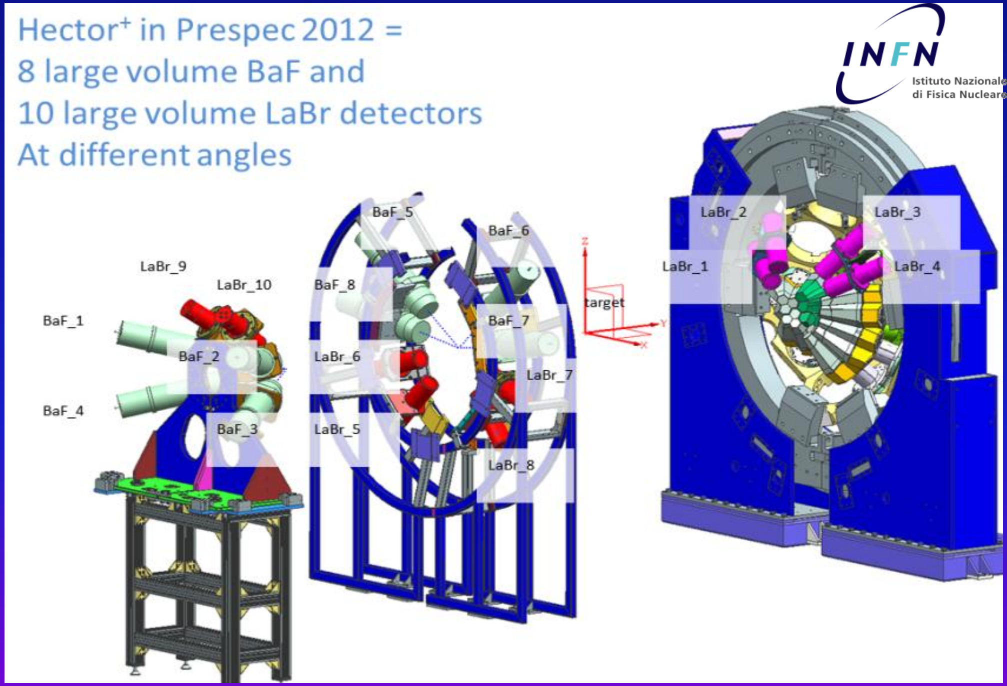
Thank to S.Ceruti

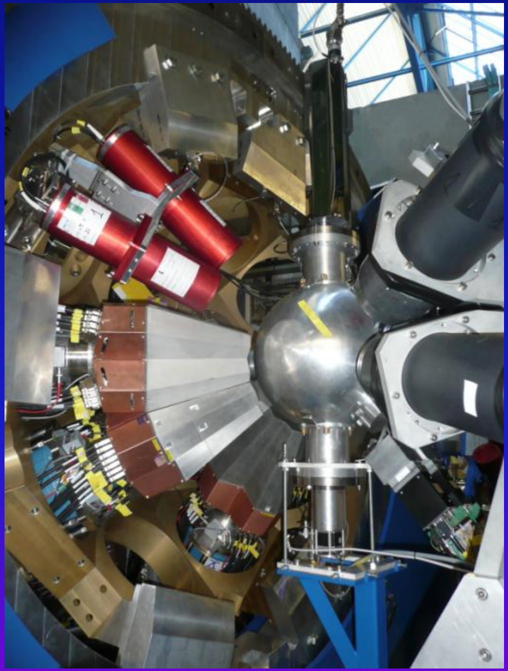
Pygmy Dipole Resonance in ^{64}Fe (November 2012)

Collective oscillation of neutron skin against the core

S430-calib

- Level of collectivity ?
- How (collective) properties change with n ?
- How isospin changes mean field ?
- In exotic nuclei: does PDR strength exist also below neutron threshold ?
- No High resolution measurements available
- Effect of deformation ?



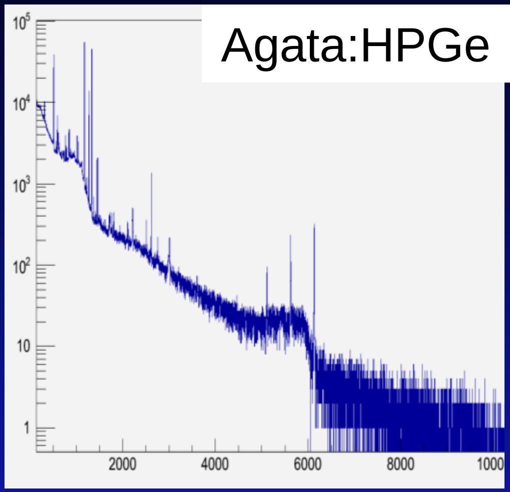


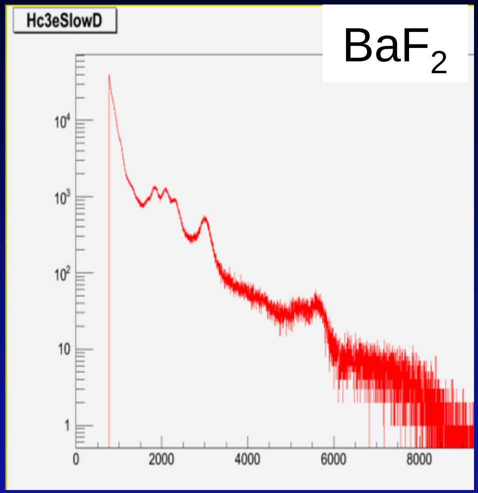
P. Adrich et al., Phys. Rev. Lett. 95, 132501 (2005)
J. Gibelin et al., Phys. Rev. Lett. 101, 212503 (2008)
O.Wieland et al. PRL 102, 092502 (2009) refernces therein and cited by

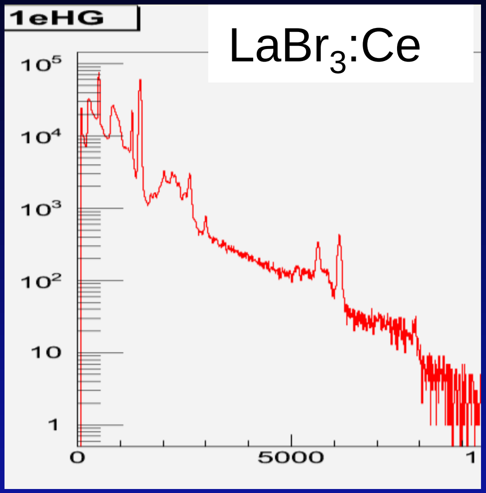
S430 GSI EXP

Analysis in progress

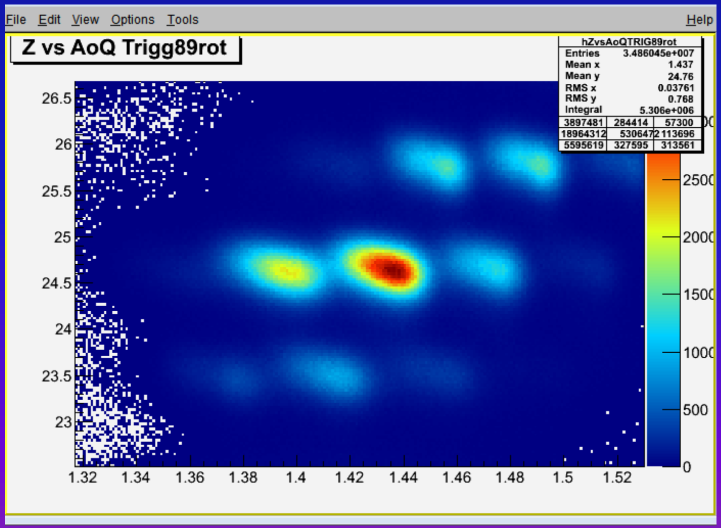
Calibration with PuC source

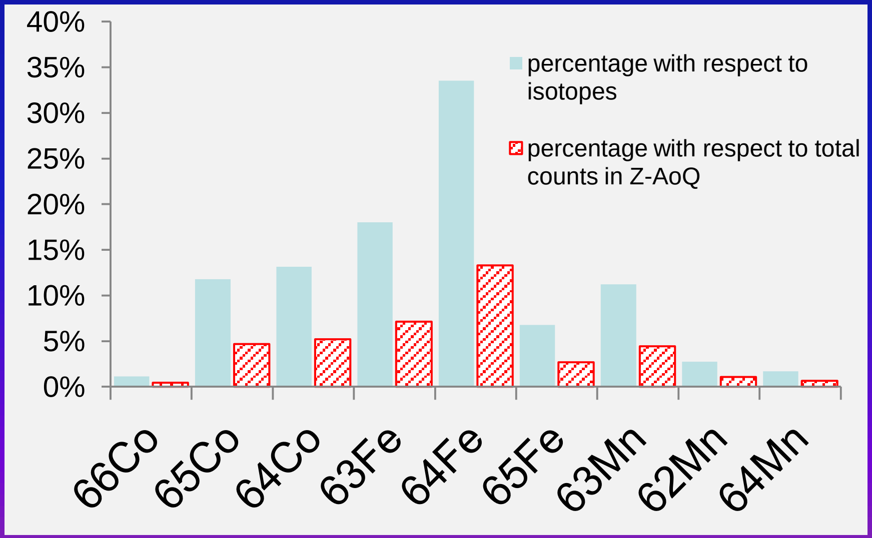






^{64}Fe at 400 MeV/u on Pb target

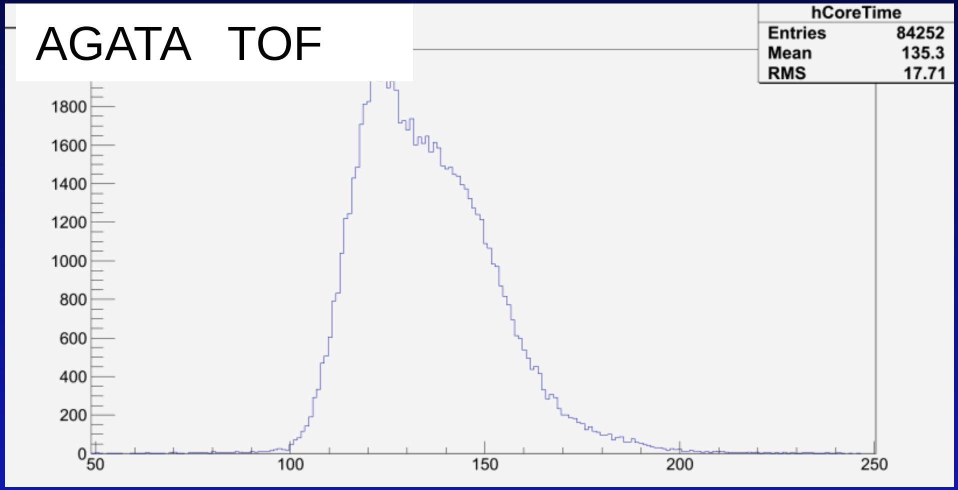


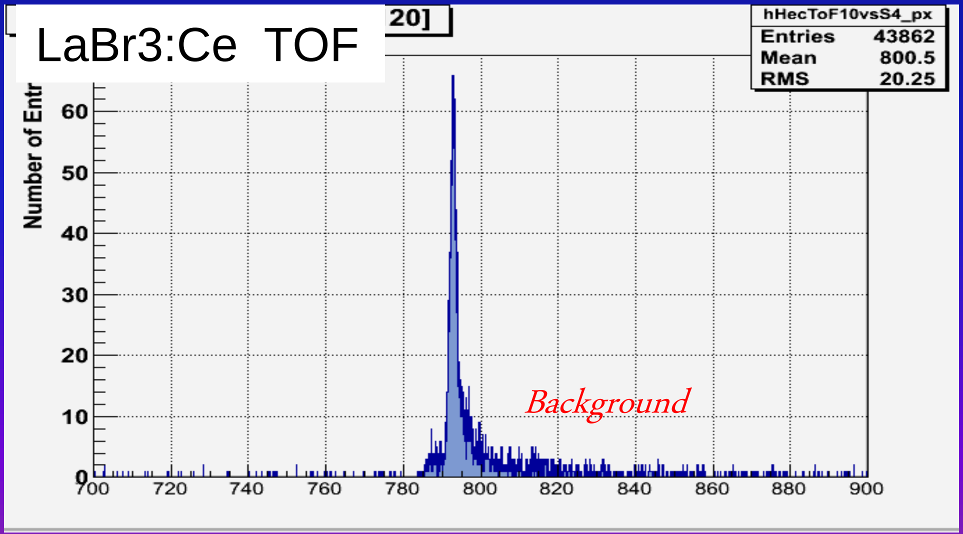


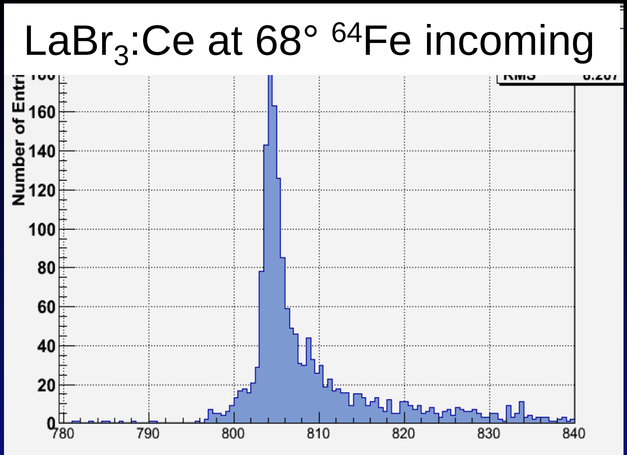
Thanks to R. Avigo and O.Wieland

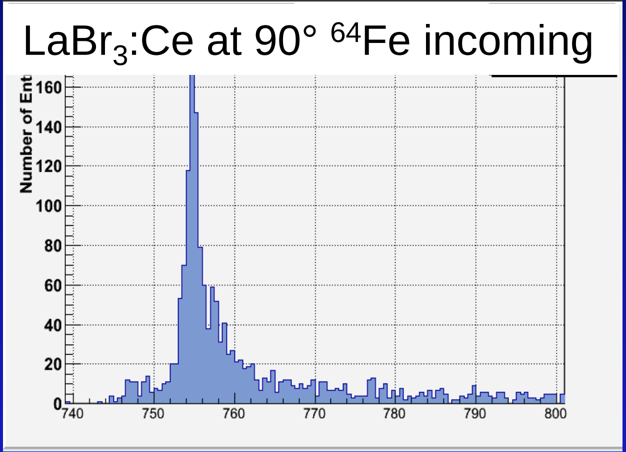
Analysis in progress

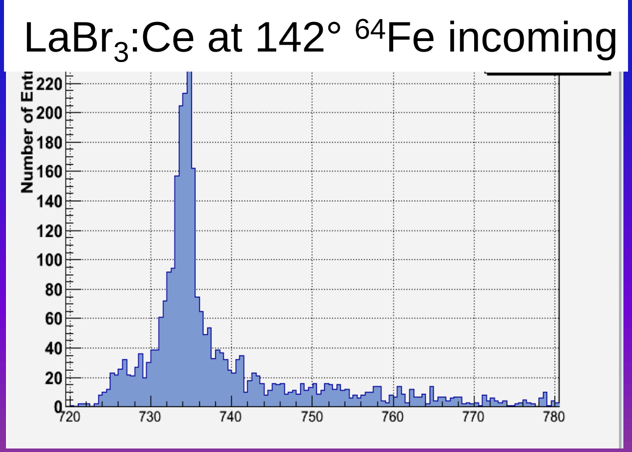
TOF Spectra







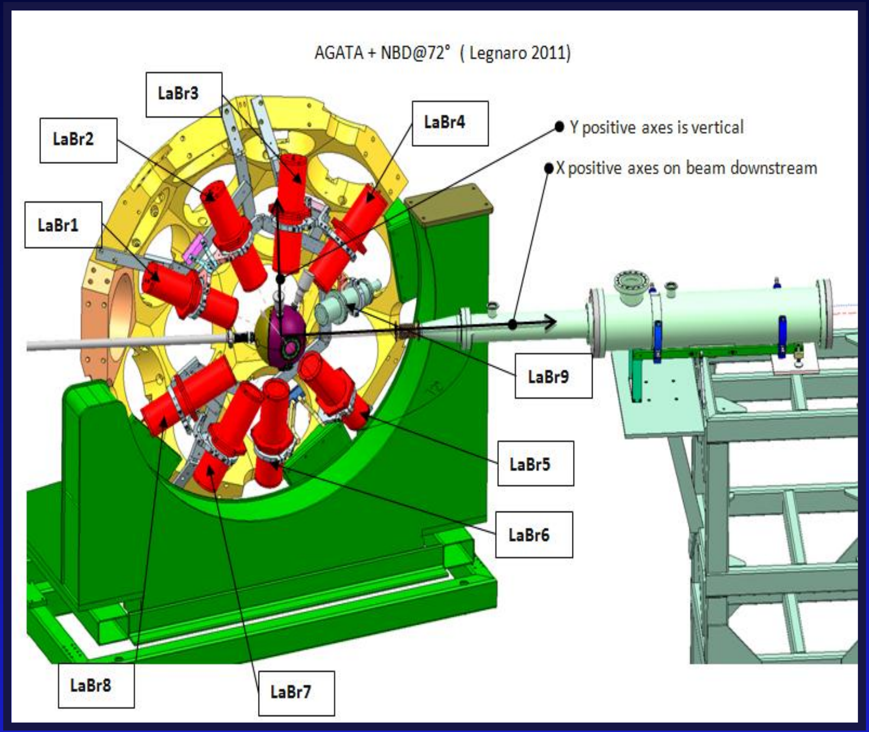


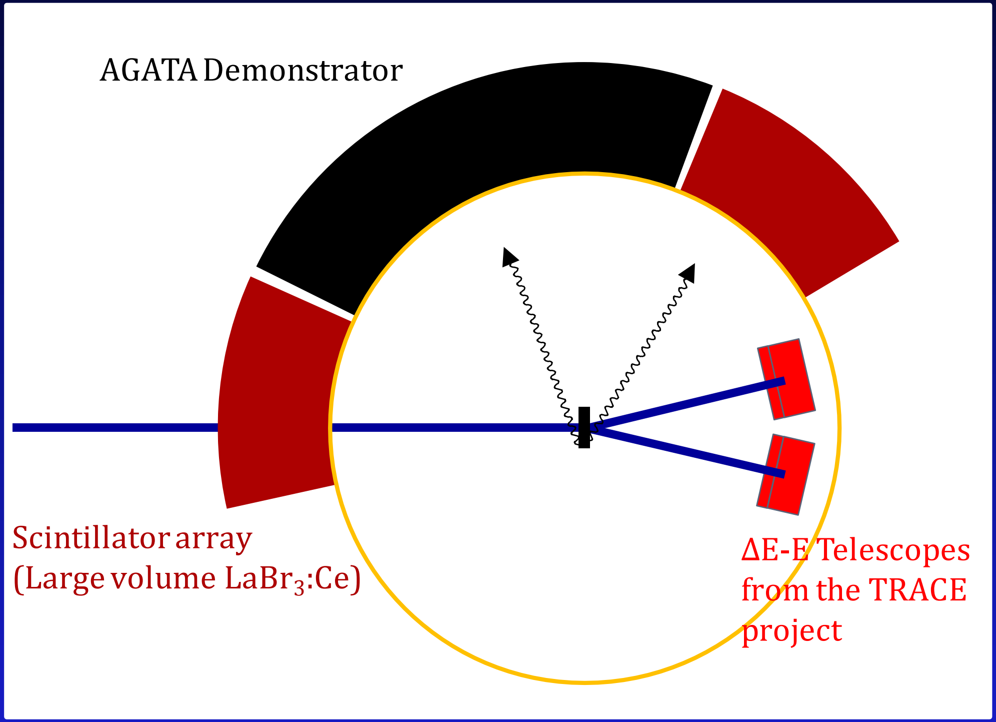


Thanks to R. Avigo and O.Wieland

Inelastic scattering of ^{17}O @ 20 MeV/u on ^{124}Sn (^{208}Pb+^{140}Ce) + γ-rays

AGATA@LNL Experiment - December 2011





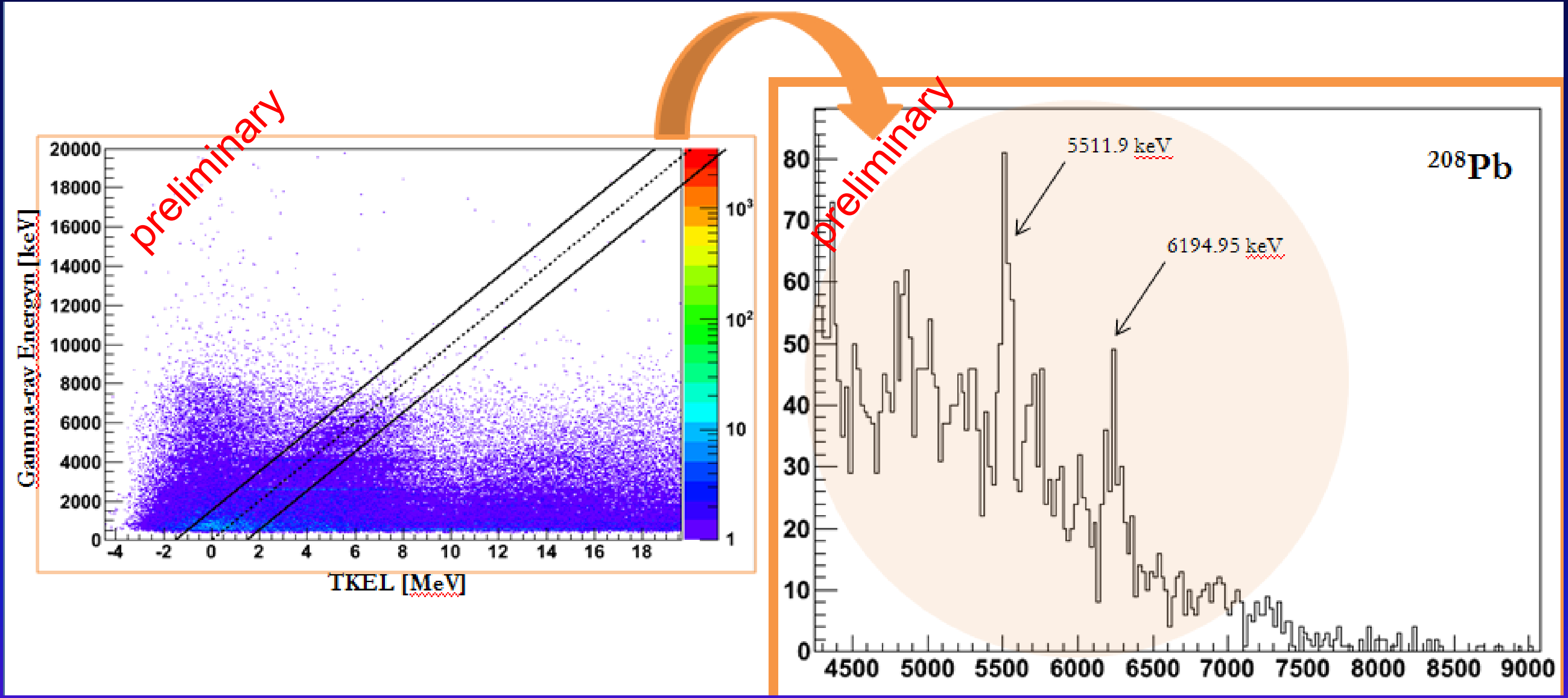
Good efficiency for low-med-high energy γ-rays
–γ–γ coincidence

High energy resolution from HpGe and good energy resolution from $LaBr_3$:Ce
- 'clean' gates for coincidences

Thanks to L. Pellegri and F.C.L. Crespi

Analysis in progress

Inelastic scattering of ^{17}O @ 20 MeV/u on ^{208}Pb + γ-rays in coincidence



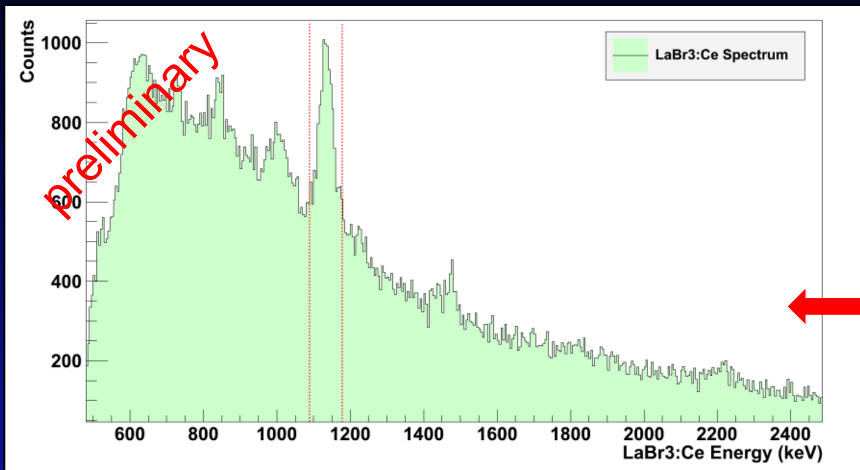
TKE (in Silicon) vs E($LaBr_3$:Ce)
Gate on ^{17}O (inelastic scattering)

LaBr$_3$:Ce spectrum - gated

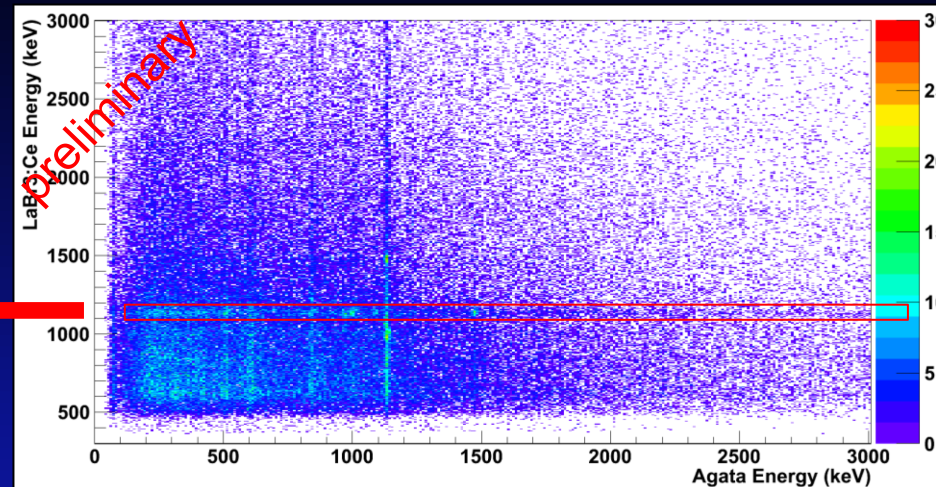
Condition on direct γ-decay to g.s

Thanks to L. Pellegri and F.C.L. Crespi

Inelastic scattering of ^{17}O @ 20 MeV/u on ^{124}Sn + γ-rays in coincidence
Analysis in progress

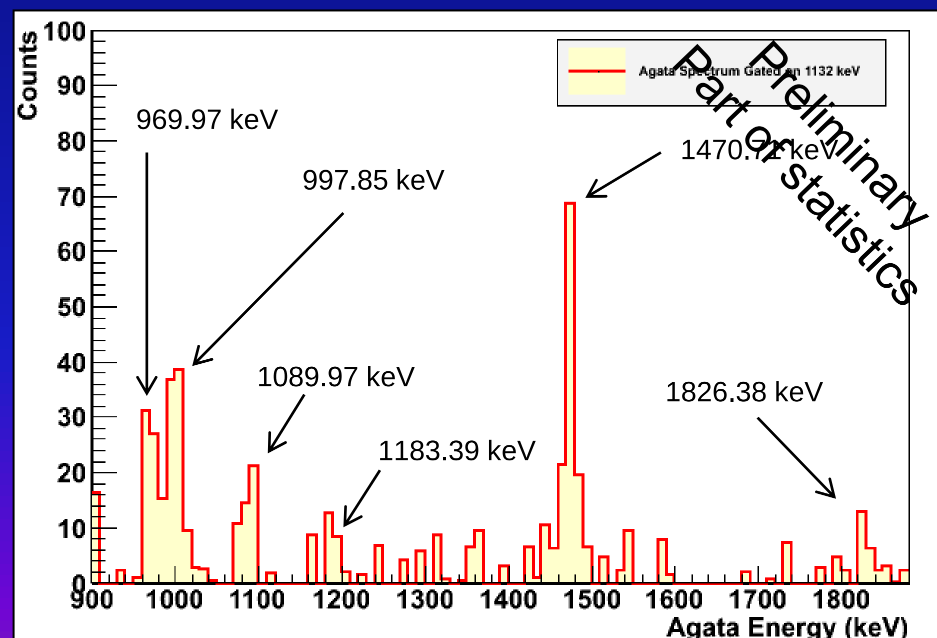


LaBr3:Ce Spectrum: Gate on 1132 keV



The combination of LaBr$_3$:Ce and AGATA permits the measurements of the branching ratio between the g.s. γ-decay and the two step γ-decay from collective states.

From the branching ratio comparison it will be possible to extract the wave function of the collective



AGATA Spectrum (backgruond subtracted) with a gate on 1132 keV in LaBr$_3$:Ce

Thanks to L. Pellegri and F.C.L. Crespi

Conclusions

- $LaBr_3$:Ce scintillators are a breakthrough in detector technology.
  - Excellent timing properties and ...
  - They can provide also spectroscopic data between10 keV up to 22.6 MeV.

- HECTOR+ is a new portable array based on large volume $LaBr_3$:Ce detectors

- **HECTOR+ is capable to work in a standalone configuration but, when coupled to a radiation detection system, increases the efficiency and makes much more powerful the physics program of the detection system.**

- HECTOR+ or part of it has already measured in beam
  - coupled with the AGATA demonstrator at LNL and PRESPEC@GSI
    - Isospin Mixing in ^{80}Zr
    - PDR on ^{64}Fe
    - Elastic scattering on ^{17}O on ^{208}Pb and ^{124}Sn

→ Work in progress

  - coupled with LAND, CACTUS, … or in standalone mode

- Several brand new scintillator are appearing (SrI_2, $CeBr_3$, CLYC, GAGG:Ce, GYGAG, CLLB, CLLC,….)

Thanks to

HECTOR^{+} team in Milano

AGATA@LNL and PRESPEC-AGATA@GSI teams

DEBRECEN, LAND, OSLO, RIKEN, ... teams

Thank you for the attention