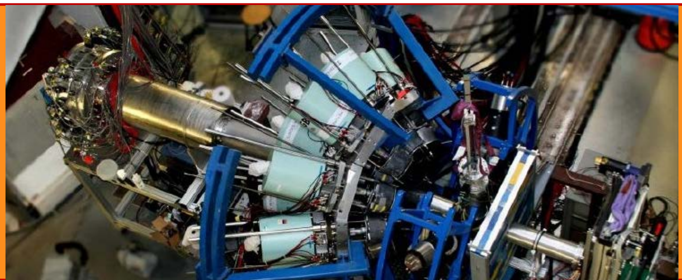
NuSpIn 2019

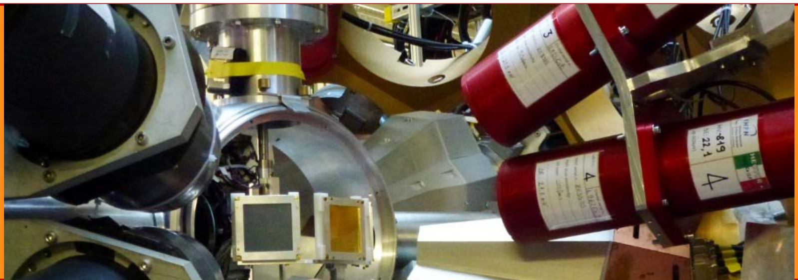
UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA
INFN
ISTITUTO NAZIONALE DI FISICA NUCLEARE
-SEZIONE DI MILANO -

Measurement of and Search for E1 states in neutron rich <u>Fe</u> isotopes with PRESPEC

O. Wieland et al.

- Motivation
- Setup and Experiment
- Analysis
- Results



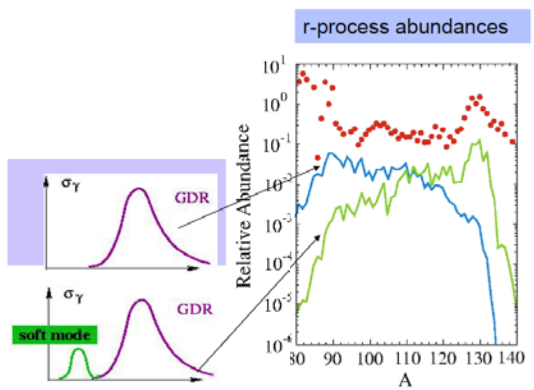


- **Motivation**

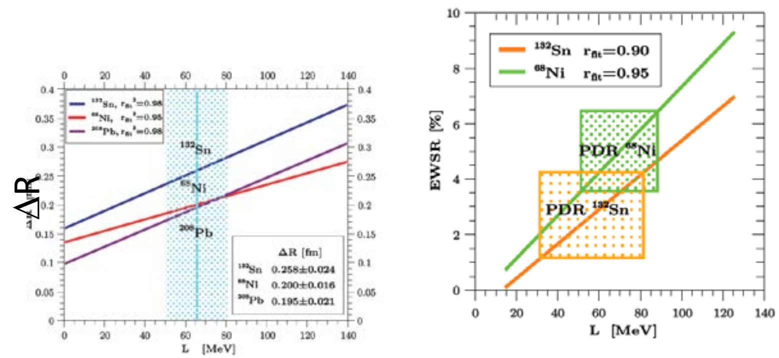
<u>Existence</u> of E1 strength or States especially in <u>n-rich</u> nuclei has an important

- ❑ impact on the **r-process nucleosynthesis**
- ❑ can be used for **Neutron skin thickness** determination
- ❑ can be used for determination **of Nuclear symmetry energy**

(Data on neutron rms radius constrain the isospin-asymmetric part of the Equation Of State of nuclear matter)



S. Goriely, Phys. Lett. B 436 (1998) 10.



*Carbone et al. Phys. Rev. C 81, 041301(R) (2010)

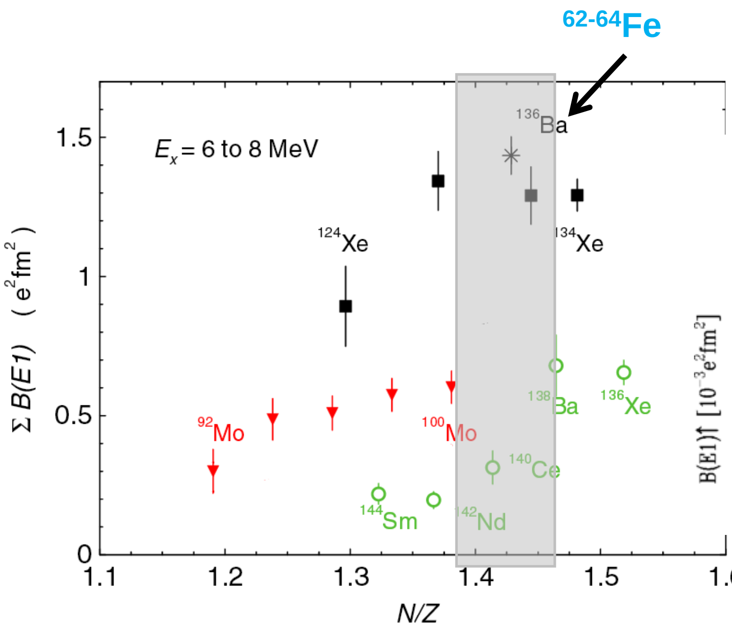
Please note the

- **Relation between neutron skin and <u>neutron stars</u>**

  (built on neutron rich nuclear matter so that one-to-one correlations can be drawn)
- **Relation between EOS and <u>neutron star mergers</u>**

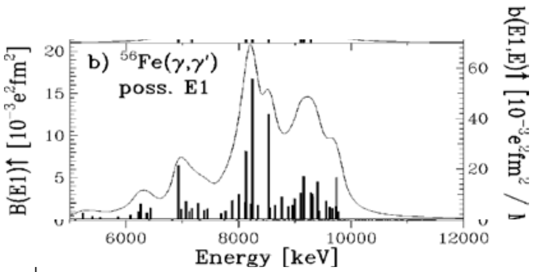
Iso Vector E1 (PDR) strength in Iron

E1 strength around the threshold has attracted big interest and it was measured in different mass region to investigate possible dependances from nuclear structure

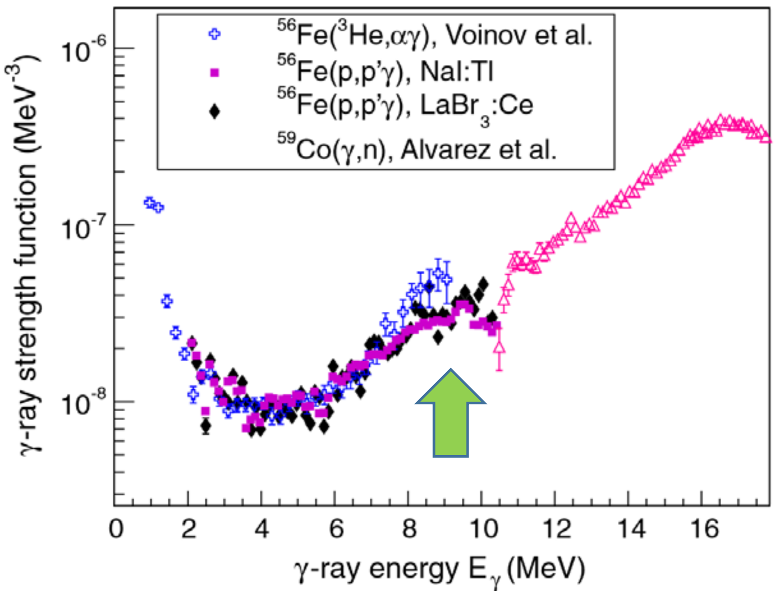


R. Massarczyk et al.,PRL 112, 072501

^{56}Fe



F. Bauwens et al.
PRC62 (2000) 024302



A. C. Larsen et al.,PRL 111,242504 (2013)

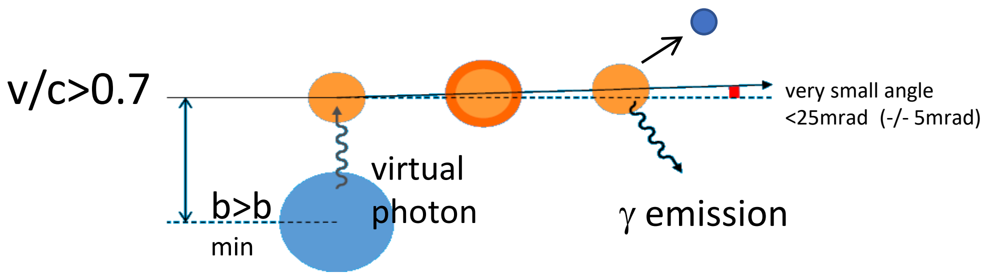
Please note

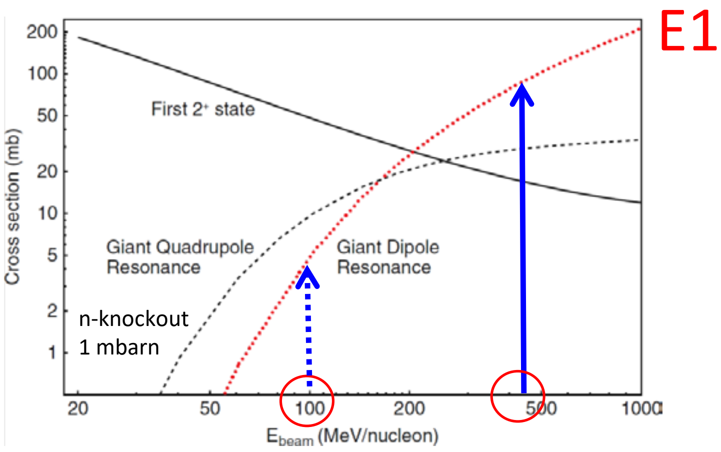
All available measurements of **IRON** are «**only**» with **stable iron** isotopes

We want to measure in $^{62/64}Fe$

HOW TO access **PDR/E1** around the threshold in unstable **neutron rich nuclei** ? → (one method is) **R**elativistic **V**irtual **P**hoton **S**cattering (RVPS)

high selectivity AND high cross section for dipole IV E1 excitation





<u>To excite</u> Dipole states (E_γ>4MeV) **one needs:**

- High beam energy

→ **Large cross sections**

→ Large $\sigma_{GDR}/\sigma_{GQR}$ **ratio**

<u>To Select</u> projectile PDR and states one needs:

- High beam energy

→ Large **Doppler** effects*

→ <u>Background REDUCTION</u>

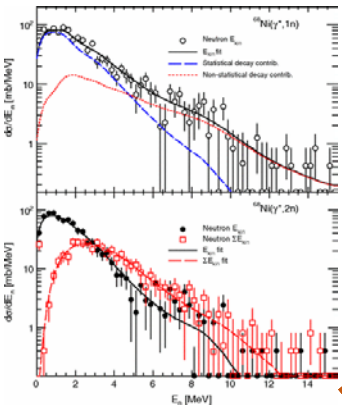
→ Good Z_{proj}/Z_{target} ratio

Please note that

- **Projectile → gamma emission in forward direction**
- **Target → gamma emission in 4π, but Doppler corrected → pronounced only in backward direction**

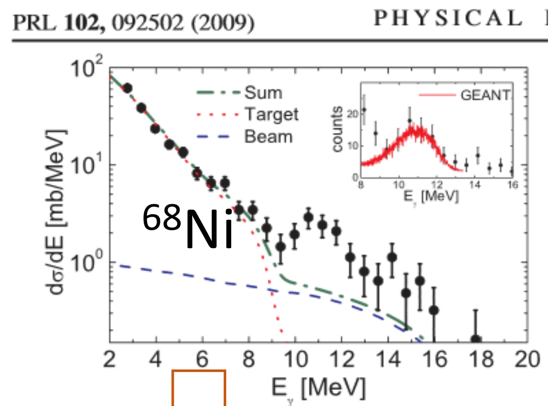
RISING (2004/2005→2009)

It was shown in 2004-2009 that with RVPS
one can measure successfully **Pygmy-strength**
around the threshold **in EXOTIC n-rich NUCLEI !**



LAND/R3B-Method
(γ^*,xn)

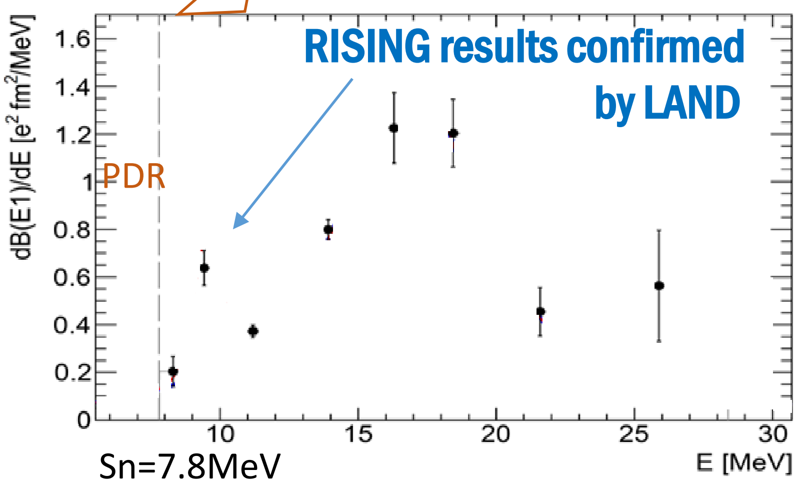
*D. Rossi PRL 111,242503 (**2013**)*



GSI/RVPS Method (γ,γ')**@600AMeV**

$$\frac{d\sigma_{C\gamma}}{dE_\gamma} = RF\left\{\frac{1}{E_\gamma} N_\gamma(E_\gamma)\cdot\sigma_\gamma(E_\gamma)\cdot R_\gamma(E_\gamma)\right\}$$

^{68}Ni R3B@GSI

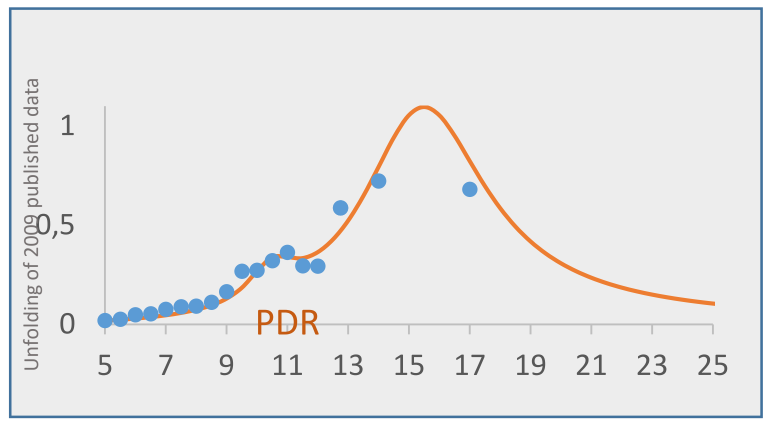


Sn=7.8MeV

Virtual Photon Scattering (γ^*,γ')

O. Wieland et al. PRL 102, 092502 (2009)

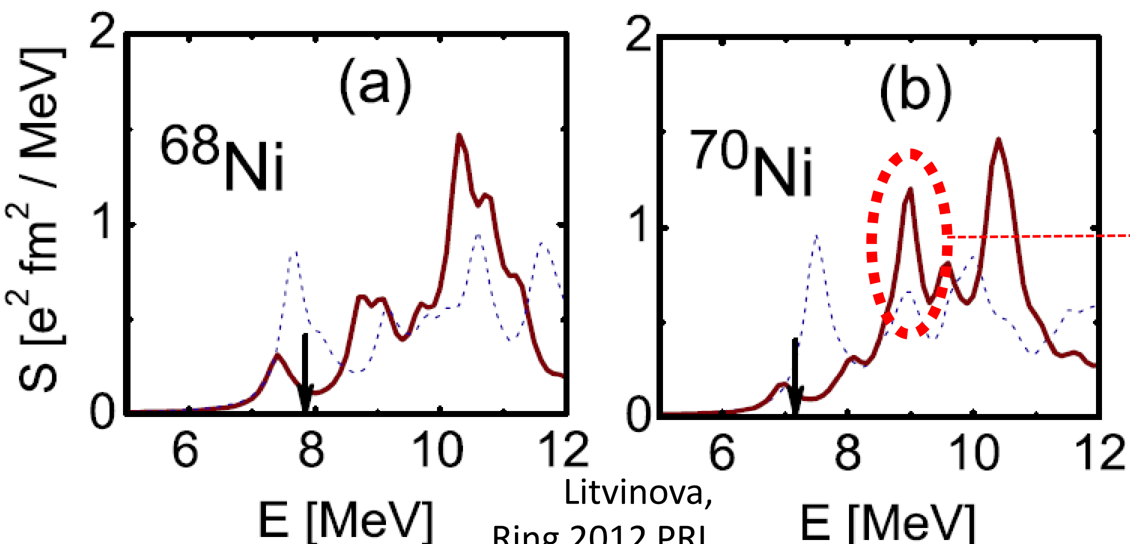
^{68}Ni RISING@GSI



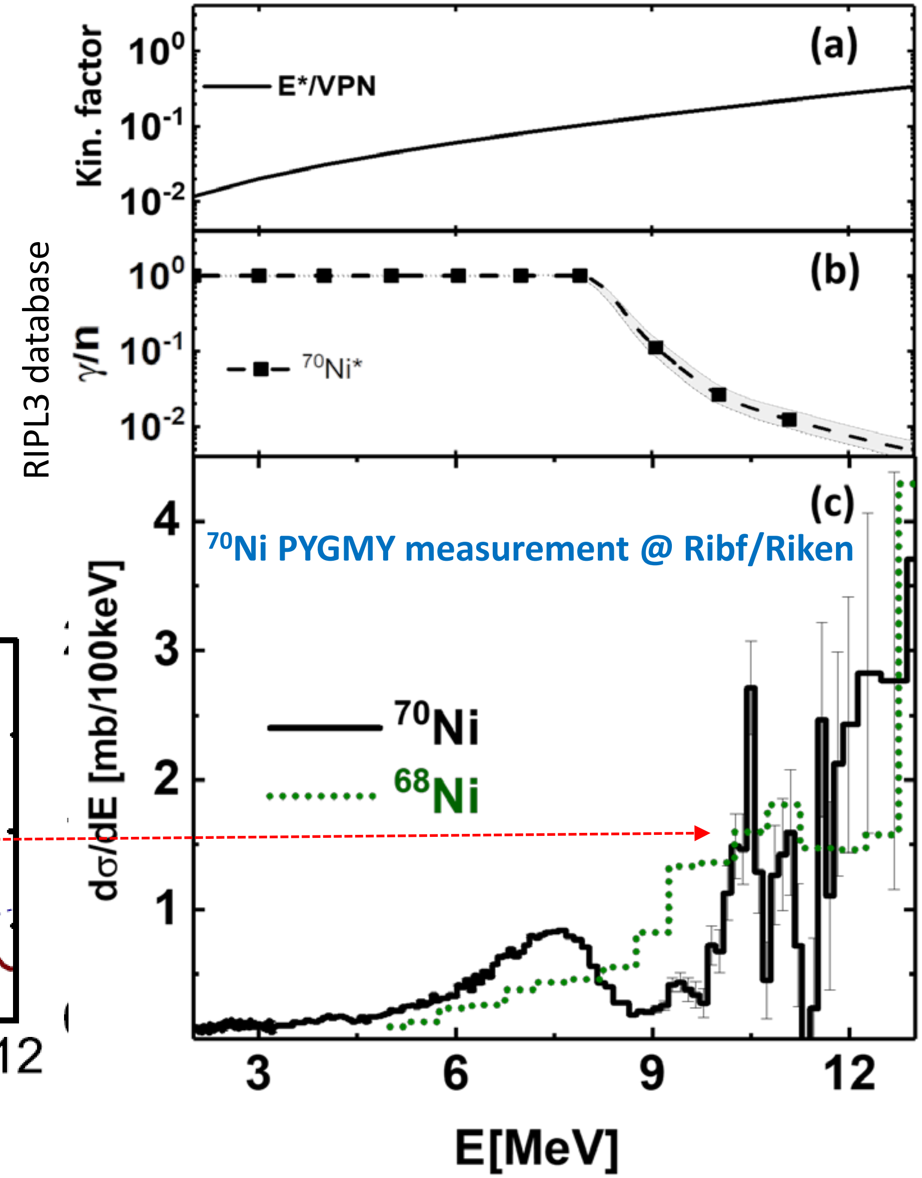
- **The combination with "LAND/R3B-Method" gives for the PDR in ^{68}Ni** (γ^*,xn) (γ^*,γ') the **γ-branching ratio**
- **Confirms that the statistical model works very well also in exotic nuclei**

O Wieland, et al. Phys. Rev. C 98, 064313 – 2018

RISING results confirmed and Extended (2014→2018) at RIBF/RIKEN with HECTOR+



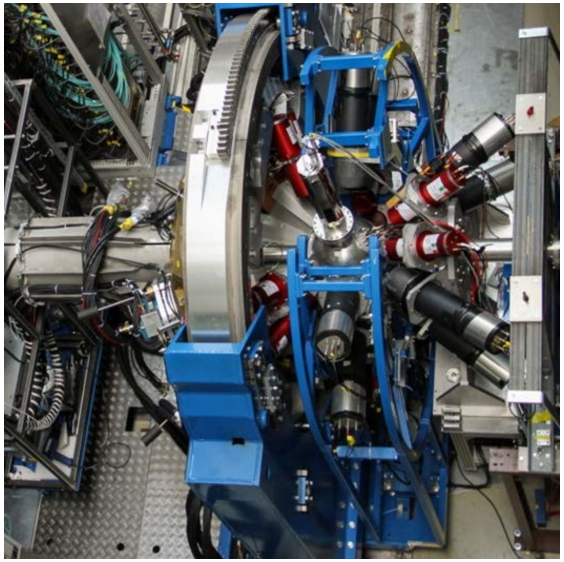
Litvinova, Ring 2012 PRL



→ Obtained also additional information fromOSLO-Beta- Method (^{70}Ni)

Experiment: E1 **strength *in ^{62,64}Fe***

PreSPEC – AGATA setup @ GSI



Relativistic coulomb excitation (RVPS) of ^{62,64}Fe was performed in GSI laboratory with use of **AGATA and Hector**+

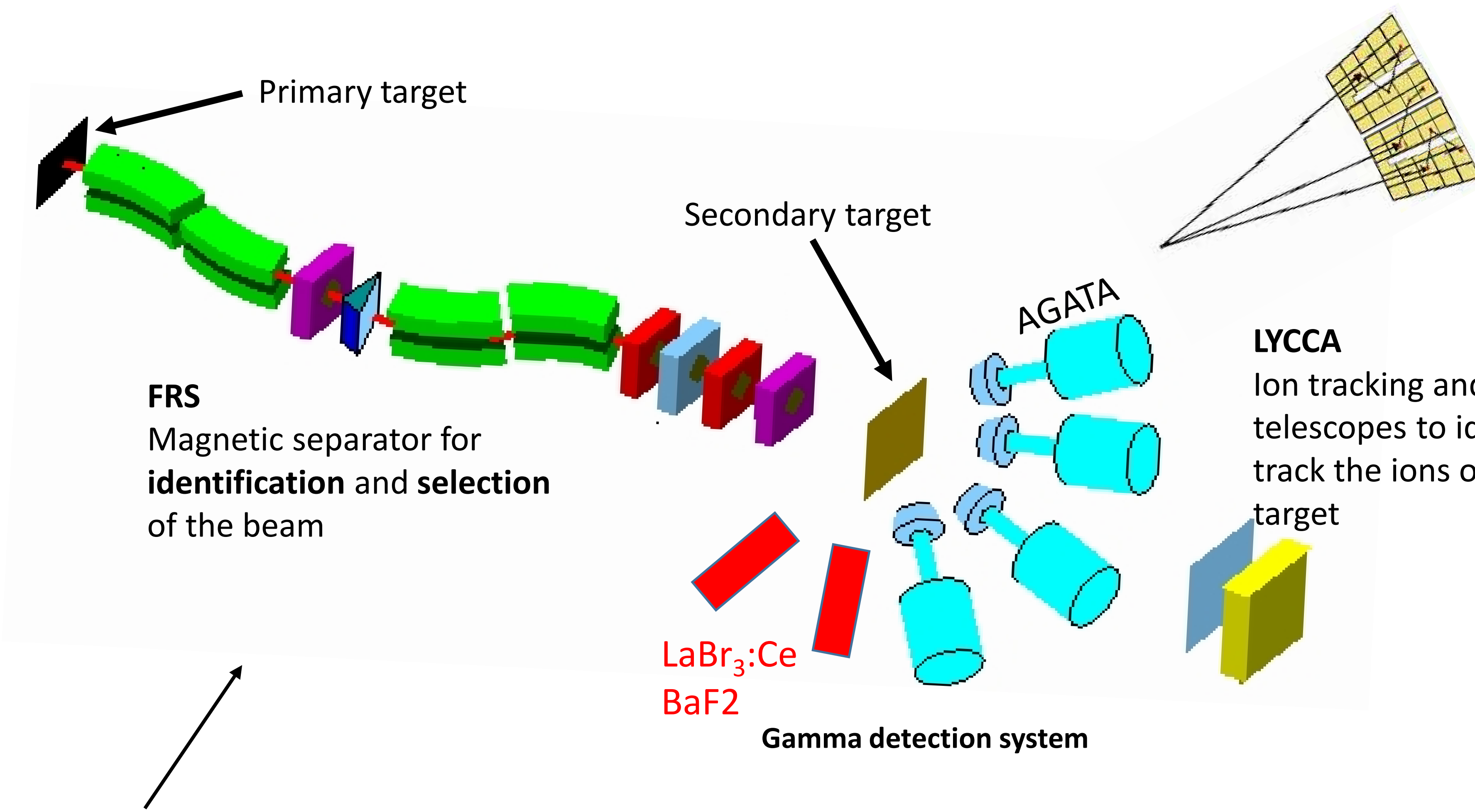
^{62,64}Fe beam at circa 73% of speed of light was produced (**400-440AMeV**). Huge **Doppler** effects*

The exotic beam was brought to collide with **High Z thick target** (Pb for ^{64}Fe and Au for ^{62}Fe and ^{64}Fe) and the gamma emission of the projectile after the collision was measured.

The experiment was performed in 2012 (test **1,5** days) and **2014** (**3** days) during the PreSPEC-AGATA campaign with very low beam intensity

- @25° & @v/c=0.73: E_γ=4MeV → 8.1MeV
- $FWHM_{DC}$=**0.55**MeV
- with PSA→ $FWHM_{DC}$=**0.05**MeV

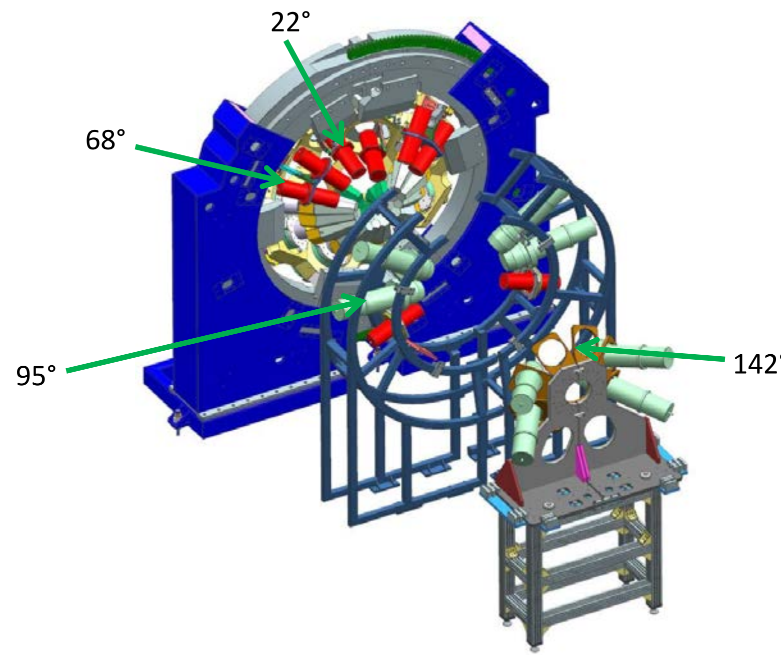
Beam identification system



Crucial to deal with high intensity !
Finger Scintillator Detector (@S2)

Gamma detection system

AGATA array provides an high resolution energy in gamma detection, suppression of the doppler broadening and suppression of background



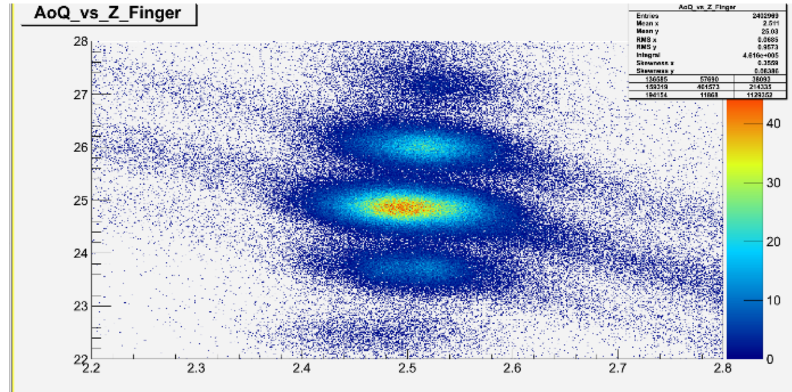
HECTOR array (**$LaBr_3$:Ce** and **BaF_2** scintillator detectors) provides efficiency in a wide range of angles

AGATA	From 15° to 60°
HECTOR+	22°, 68°, 95°, 142°

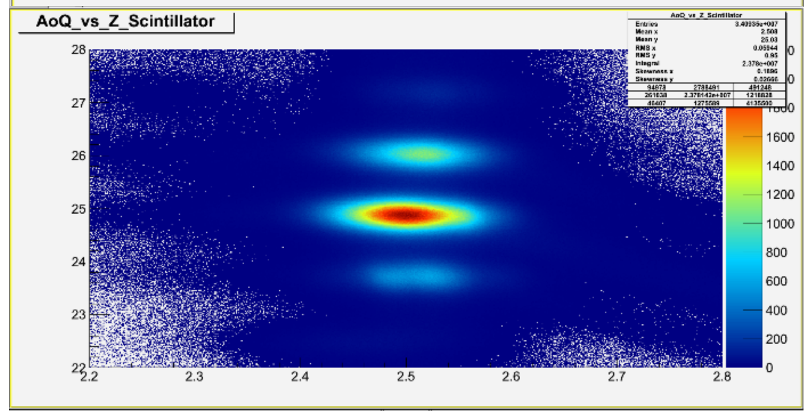
Identification of the incoming beam

FRS-Z-AoQ Plots

^{6X}Fe

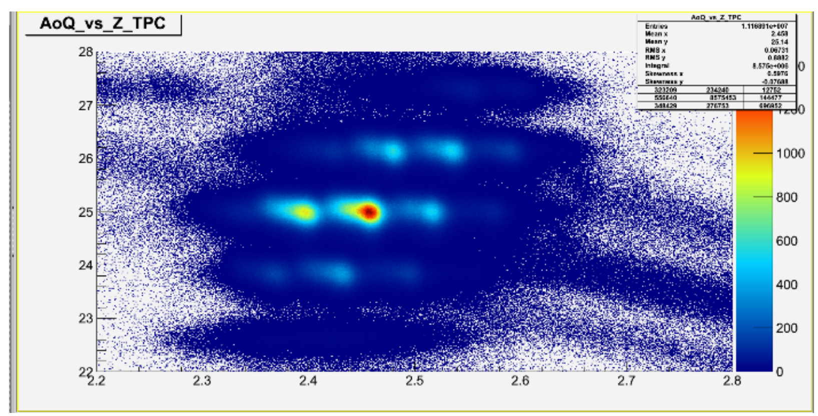


^{6X}Fe



With TPC and AoQ correction
Ca. 30% of total statistics
Recovered

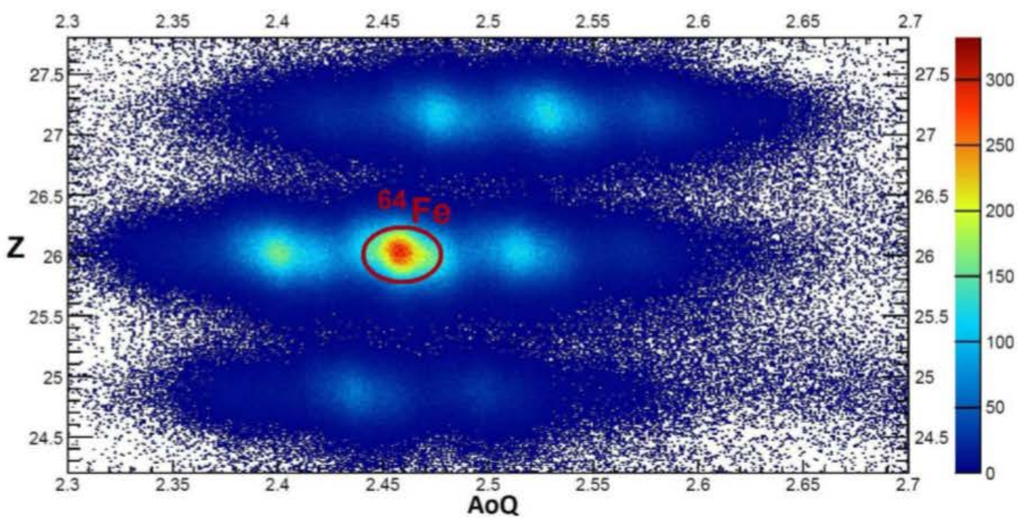
^{63,64,65}Fe

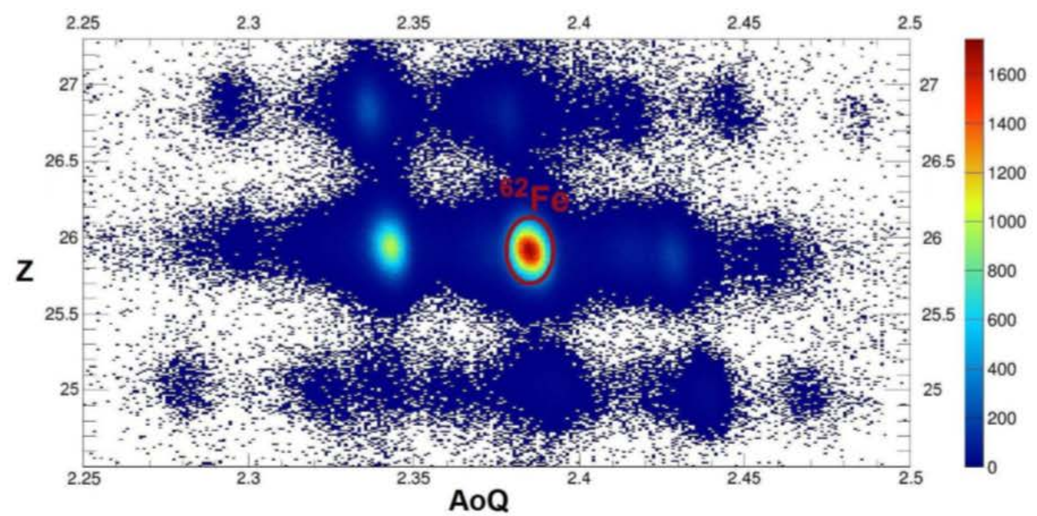


Identification of the incoming beam

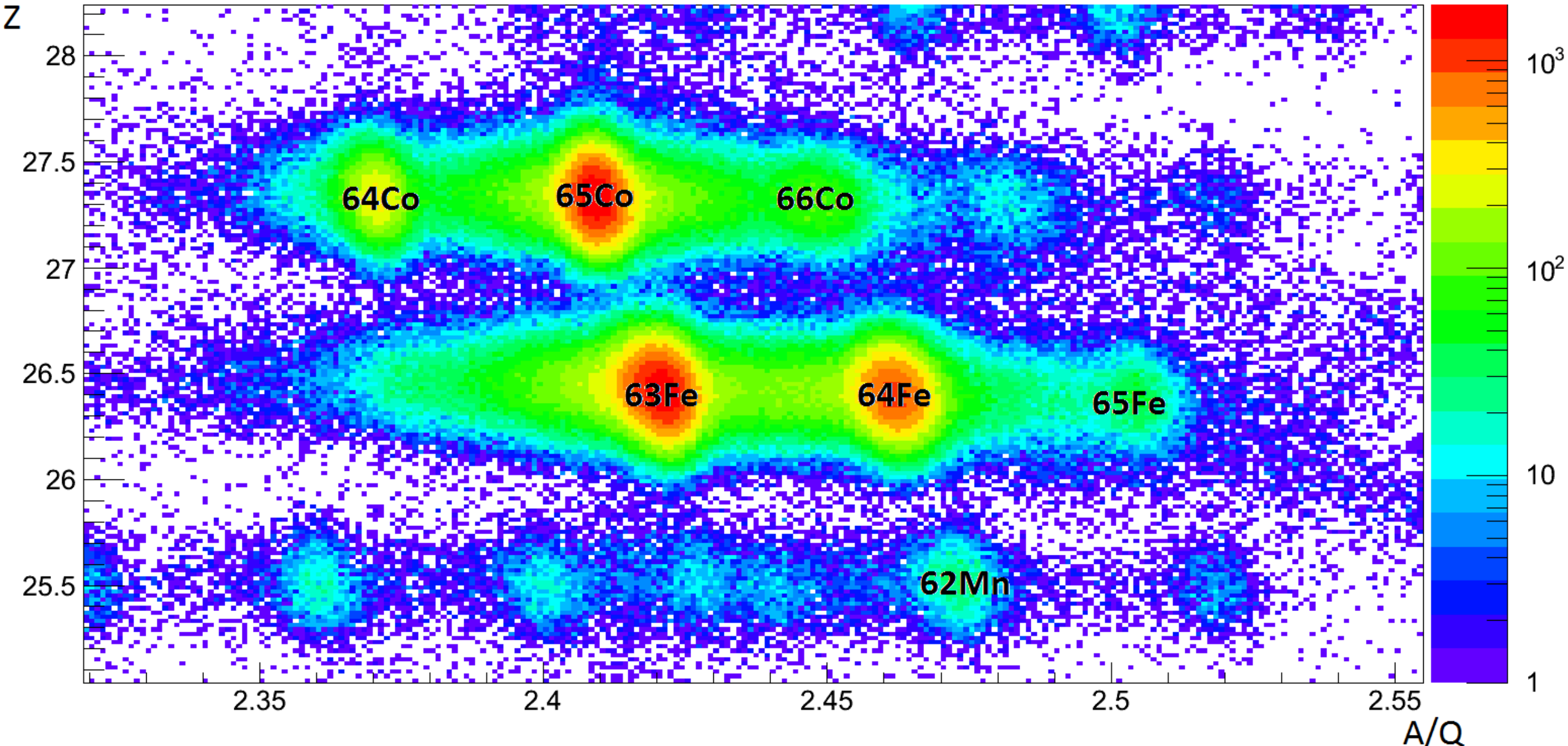
FRS was used to obtain identification plot (Z vs AoQ) in order to select the beam of interest.

The 64Fe setup was affected by low efficiency of (defect) tracking detectors caused by the high intensity of the previous beam.





Statistics with 64Fe setting



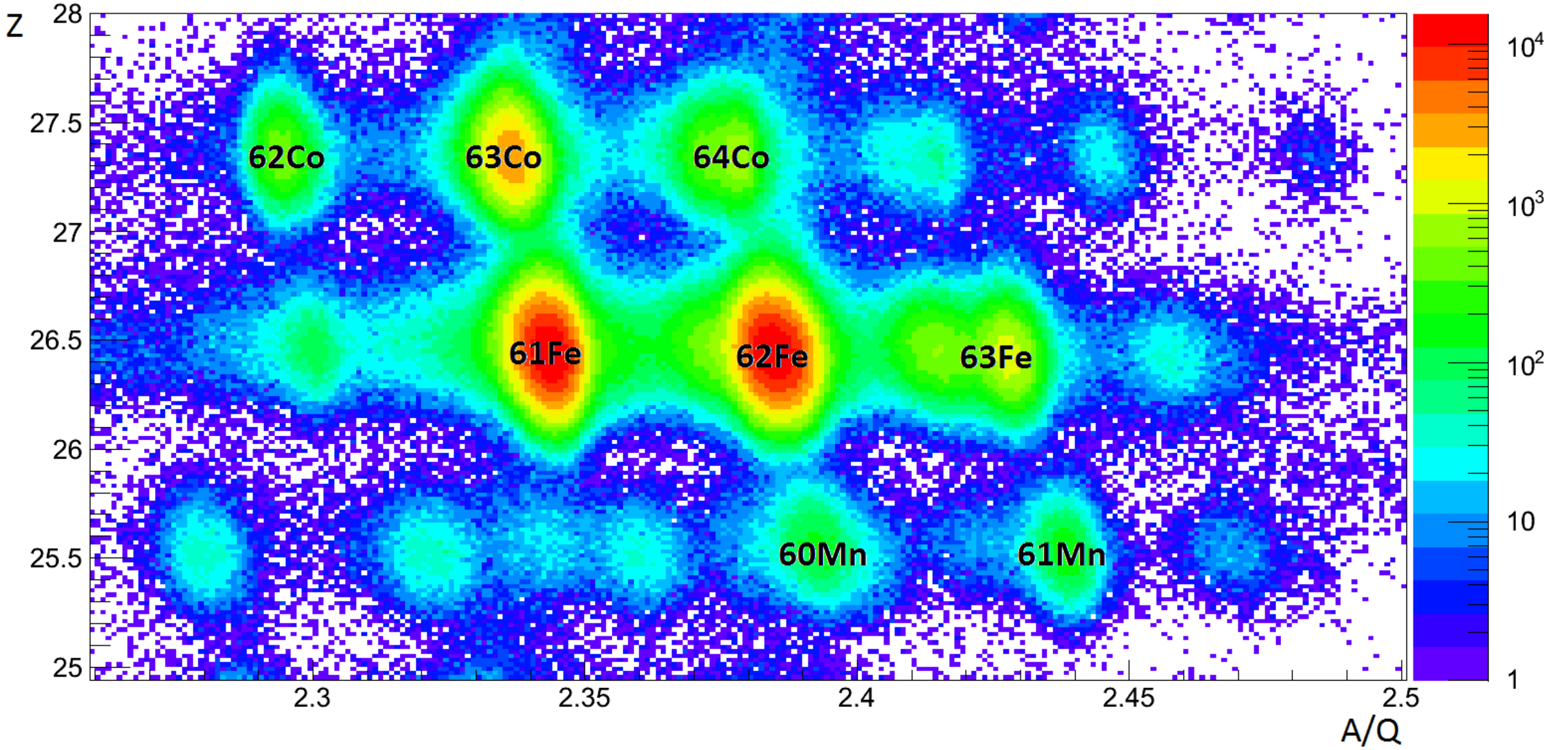
Numbers:

1,4 10^5 ^{64}Fe identified with TPCs and completely traced
0,6 10^5 ^{64}Fe gated also on the outcoming

0,9 10^2 gammas>2 MeV D.C. in AGATA (gate on ^{64}Fe incoming-outcoming)
0,9 10^2 gammas>2 MeV D.C. in HECTOR (gate on ^{64}Fe incoming-outcoming)

Expected 25 times more

Statistics with 62Fe setting



Numbers:

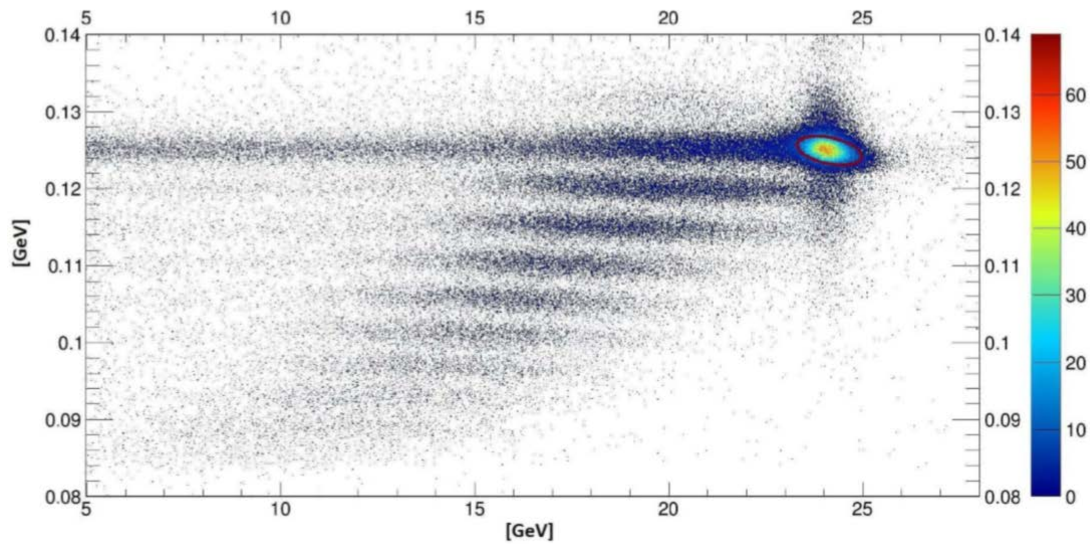
1,8 10^6 ^{62}Fe identified with TPCs and completely traced
0,8 10^6 ^{62}Fe gated also on the outcoming

0,9 10^3 gammas>2 MeV D.C. in AGATA (gate on ^{62}Fe incoming-outcoming)
0,9 10^3 gammas>2 MeV D.C. in HECTOR (gate on ^{62}Fe incoming-outcoming)

Expected 25 times more

Identification of outcoming beam→ E -ΔE telescopes LYCCA

E -ΔE telescopes were exploited in the PreSPEC setup to identify the ions outcoming from reaction target



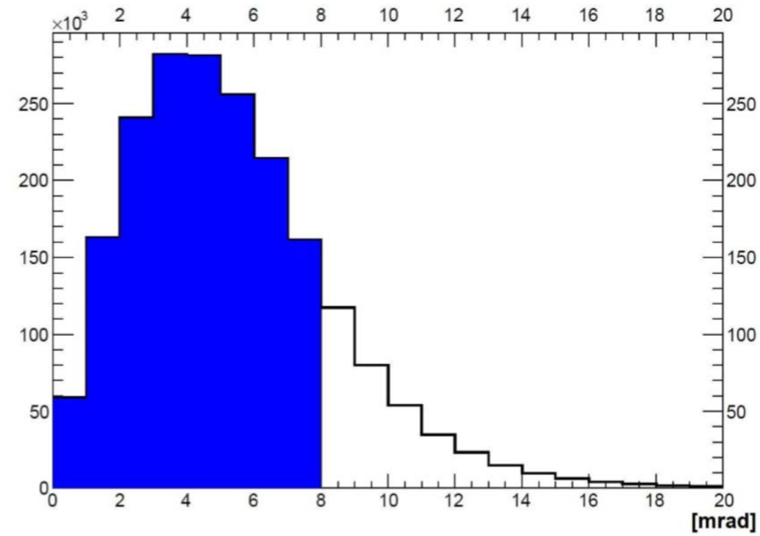
In offline analysis
LYCCA worked very WELL

Angular selection of outgoing particles

Silicon stripped detectors were used in PreSPEC to track the ions and to select the angle of scattering.

The selection of scattering angle applied in the data analysis took in the account the uncertainity of the setup.

The angular condition applied ensures that more than 90% of the events are related to a minimum approach higher than the sum of the radii (13 fm) → <u>5% of nuclear contribution are at maximum</u> expected (relativistic ECIS)

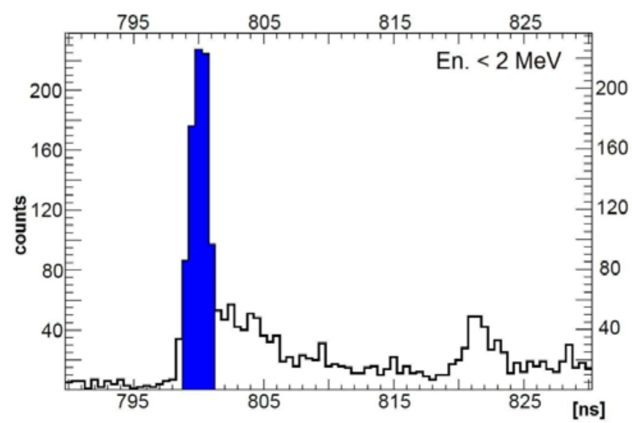


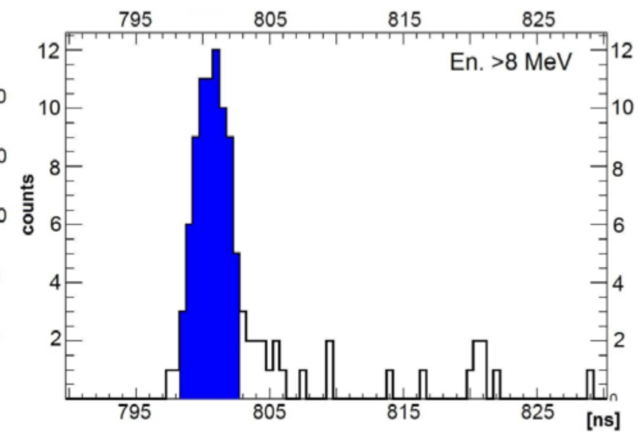
In comparison
the ZDS setup tat RIKEN gives only ± 5 mrad of precision.
Up to 20% of nuclear interaction events have to be considered

Filters for gamma ray energy spectra (1)

Timing condition was applied to select gamma ray coming from the target
This condition was used for scintillators **and AGATA** detectors.

Thanks to high timing resolution this condition was used to clean background not beam correlated from the spectra





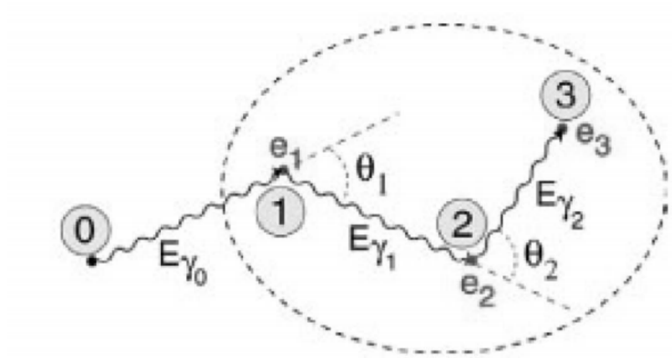
TOF

Filters for gamma ray energy spectra (2)

AGATA array, thanks to the electronical segmentation, provide positions of gamma ray interactions in the detectors and the energy release.

These informations are used by gamma ray **tracking** algorithm to reconstruct the direction of the gamma ray.
In this way it is possible to disentangle interactions of gammas coming from the target and coming from the environment background.

PSA→position determination → → →



Experimental results

PSA and Tracking at relativistic energies (v/c=0.73) with AGATA

Measurement of known 2^+ states
proofs that AGATA & Prespec (PSA+Tracking)
setup works very well at E_{beam}=440AMeV.

Experimental results

PSA and Tracking at relativistic energies (v/c=0.73) with AGATA

$2g/cm^2$ Gold Target & v/c= 0.73 !

Measurement of known 2^+ states
proofs that AGATA & Prespec (PSA+Tracking)
setup works very well at E_{beam}=440AMeV.

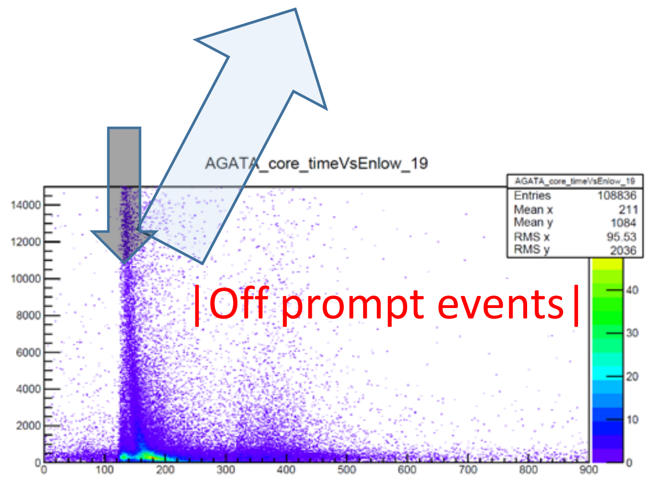
B(E2) value confirmed
(l.t. 7% γ–γ branching from E1 region)

High energy gamma ray spectra

Even if the statistics collected with **AGATA** is quite low,
some structures appear in the region of 6-8 MeV

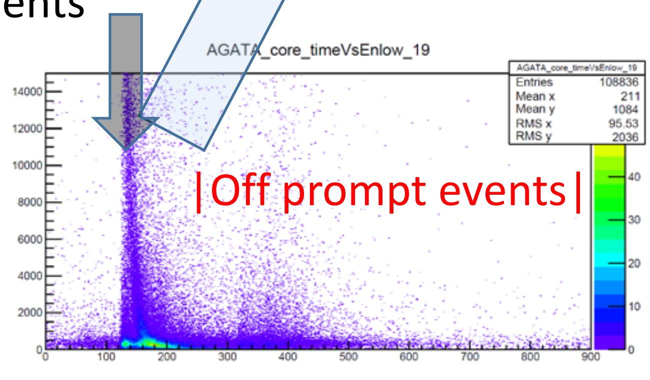
High Energy Tracking
[F.Crespi et al. 10.1109/NSSMIC.2011.6154591]

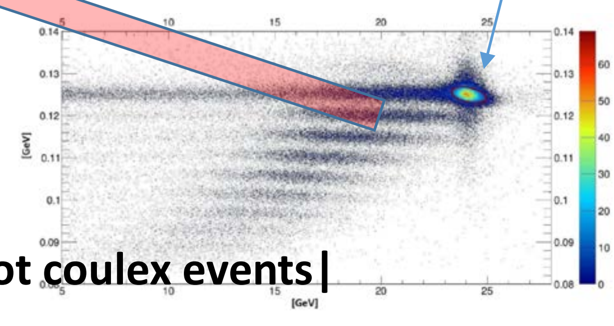
High energy gamma ray spectra…. and Background



High energy gamma ray spectra…. and Background

Prompt events

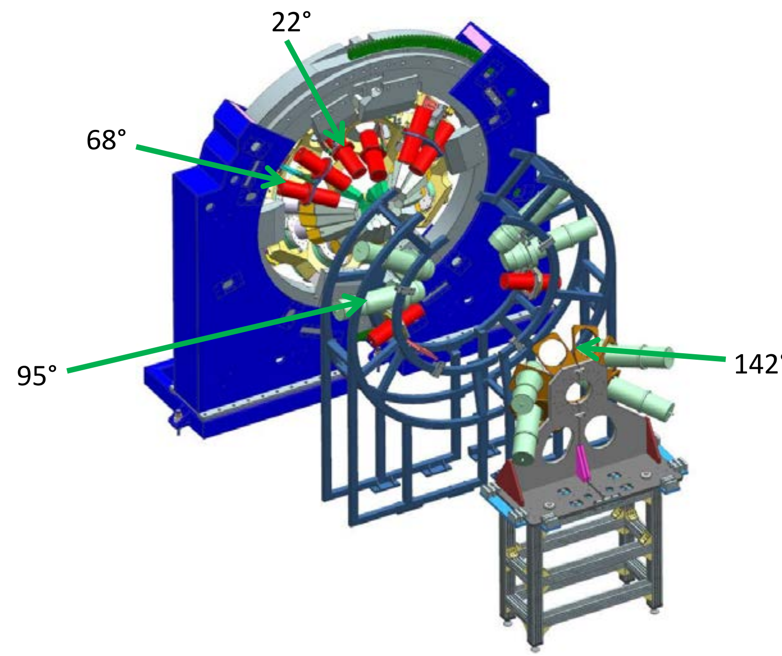




Outgoing LYCAA

Further Background estimation

Scintillators at **backward angles** can be used to evaluate the beam and TARGET correlated background and CONTRIBUTION:
in fact these detectors are more affected by the radiation coming with the beam at target stage **and from the target itself !**



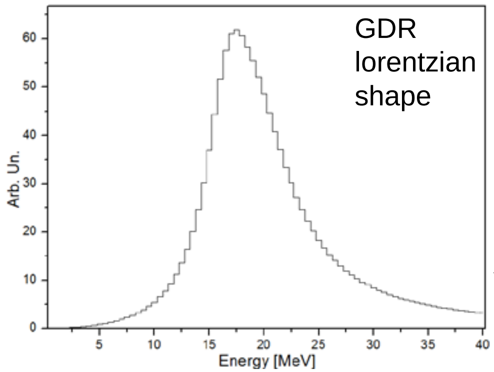
The «Background» is at lower energy mainly of «atomic-type»

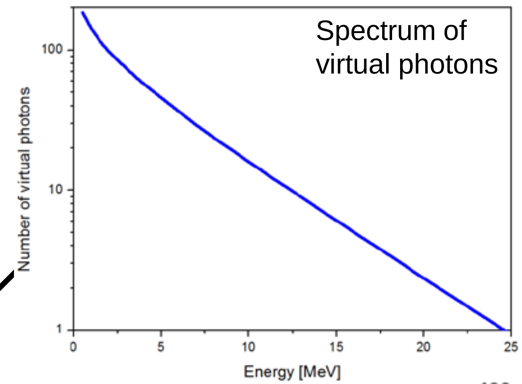
At higher energy the «Background» originates from the Tail of the statistical decay part of the GDR !
→thus is a contribution that can be calculated from systematics.

Background from Statistical decay of excited nuclei from tail of GDR

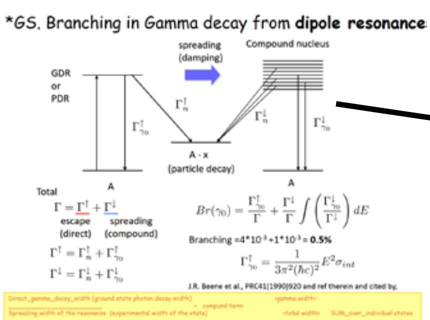
How would be the spectrum if the GDR response is pure lorentzian?

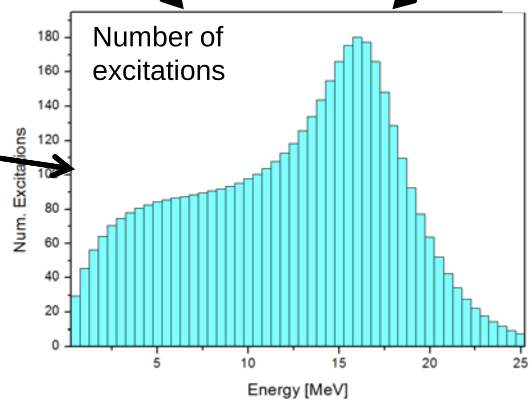
Pure Lorentzian GDR shape and spectrum of virtual photons used to obtain excitation spectrum



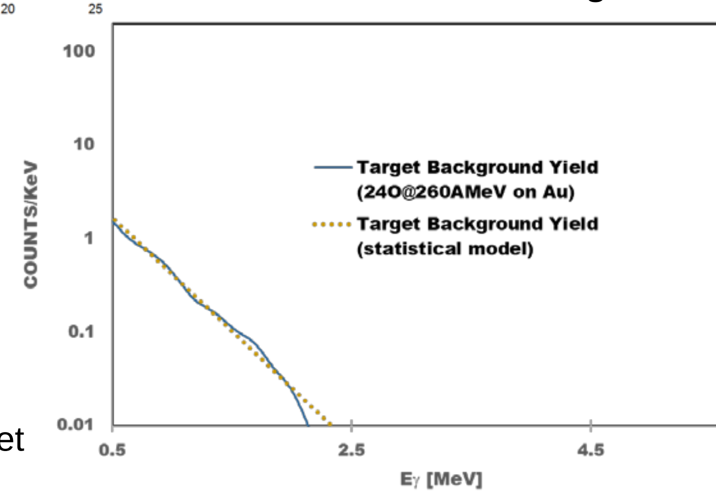


«Tail» statistical
Part of
GDR → Background





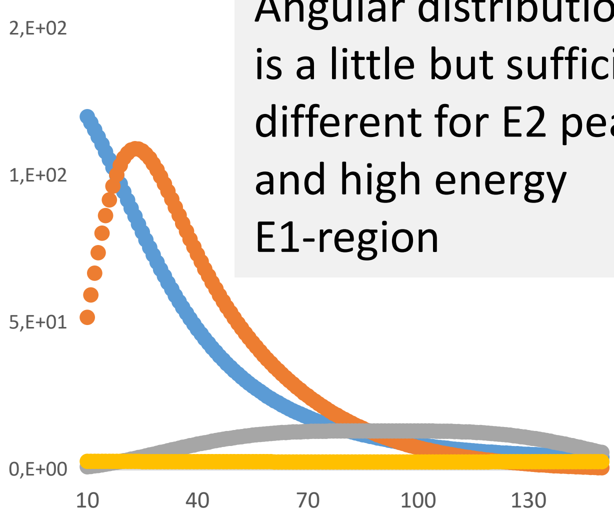
Gammas emission
Statistical part
[GEMINI++]
+Detector response
for
Projectile AND Target



E1 Type (angular distribution) ?

ang. Distr. @ up to 440*A*MeV

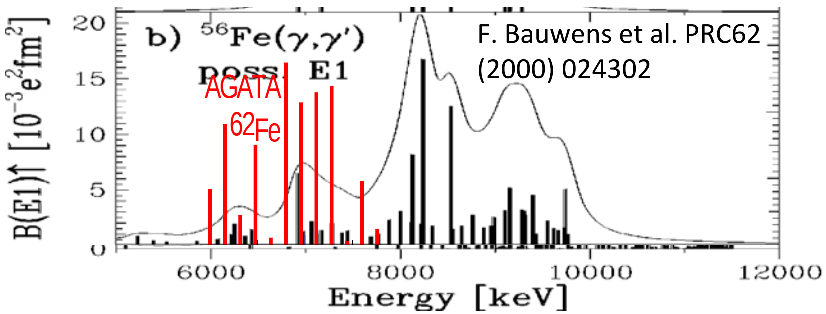
«Terrible» Lorentz boost



Angular distribution is a little but sufficient different for E2 peak and high energy E1-region

Cumulative Angular Distribution

Measured E1 strength in AGATA in comparison with:

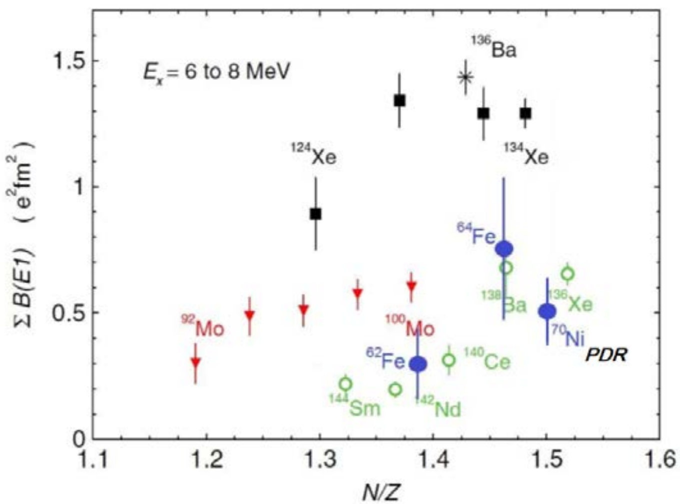


$$\sigma_{E1} = \frac{32\pi^2}{9}\frac{Z_T^2\alpha}{\hbar c}B(E1)\left(\frac{c}{v}\right)^2\left[\xi K_0 K_1 - \frac{v^2\xi^2}{2c^2}\left(K_1^2 - K_0^2\right)^2\right]$$

Comparison of experimental integrated B(E1) [6-8 MeV]

B(E1) values were summed over the energy range 6-8 MeV and compared with the values of the nuclei avilable in literature:

R. Massarczyk et al., PRL 112, 072501 (2014)



B_{6-8MeV}(E1)=0.3 ± 0.1 e^2fm^2 for ^{62}Fe

B_{6-8MeV}(E1)=0.77 ± 0.27 e^2fm^2 for ^{64}Fe

^{62}Fe : 0.9% ± 0.3 % EWSR

^{64}Fe : 2.3% ± 0.78 % EWSR

$$\sum_{6\text{–}8\ \mathrm{MeV}} B(E1) \approx r\frac{NZ}{A}\left(\frac{N}{Z}-1\right)$$

Stable nuclei r ≈ 0.08

n-rich nuclei ^{62,64}Fe and ^{70}Ni <r> ≈ 0.0787 → universal LAW for stable and exotic nuclei ?

Conclusions and perspectives

- ***High resolution*** *information on high energy γ ray transitions of IV E1 type in* ***exotic Iron*** *nuclei.*

- $^{62,64}Fe$ showed a **significant excess of strength respect** to the tail of the GDR.

- QPM calculation **within the 3 phonon model reproduce the ratio of** the B(E1) sum of the two nuclei

- ***The scaling*** *law of the integrated strength* ***looks universal***

→ One should go to measure the Iso Scalar characteristics of $^{62,64}Fe$ as done in the work of N.S.Martorana (LNS Catania) and with active Targets !

→One should go to more exotic Fe isotopes to learn about influence of deformation on E1 strength

Thanks to the collaboration

Thanks to support from FP7 ENSAR no. 262010, BMBF under Nos. 05P09RDFN4, 05P12RDFN8, and by the LOEWE center HIC for FAIR and INFN