Instrumentation for Nuclear γ-Spectroscopy

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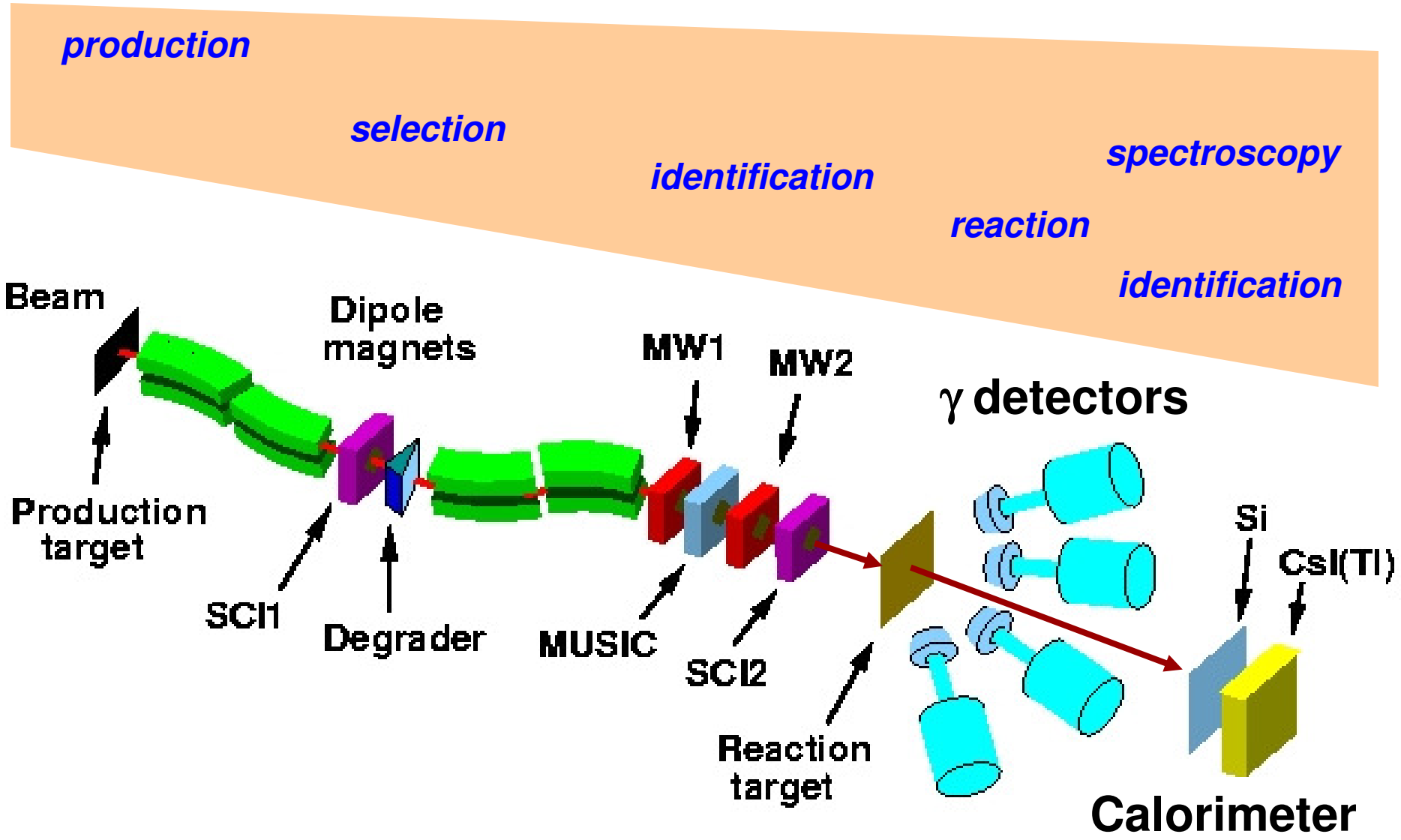
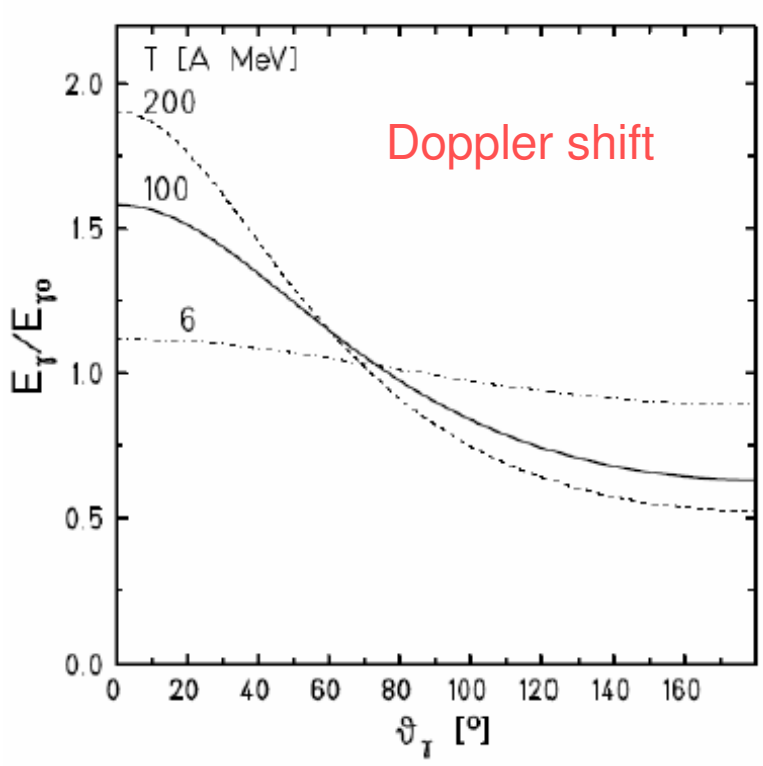
GSI Darmstadt, Germany

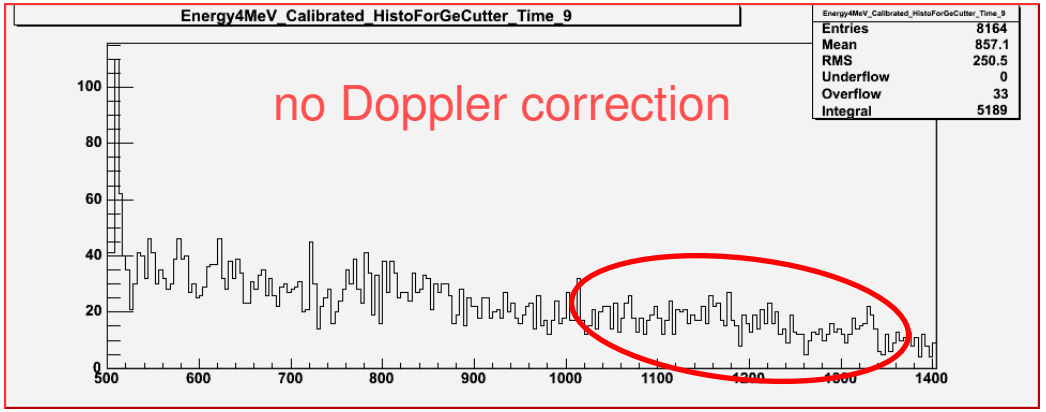
EMMI-Workshop on
Opportunities for Nuclear Astrophysics in Space
Darmstadt, December 7, 2011

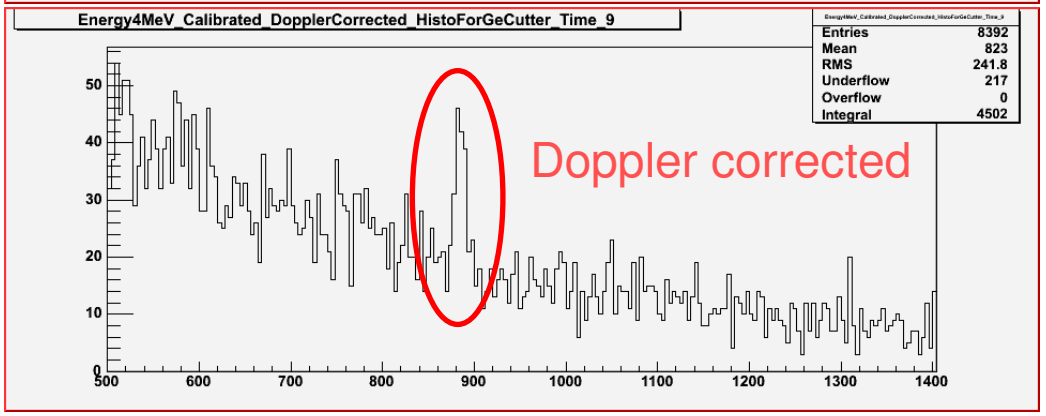
Fragment Identification, Reaction and Spectroscopy

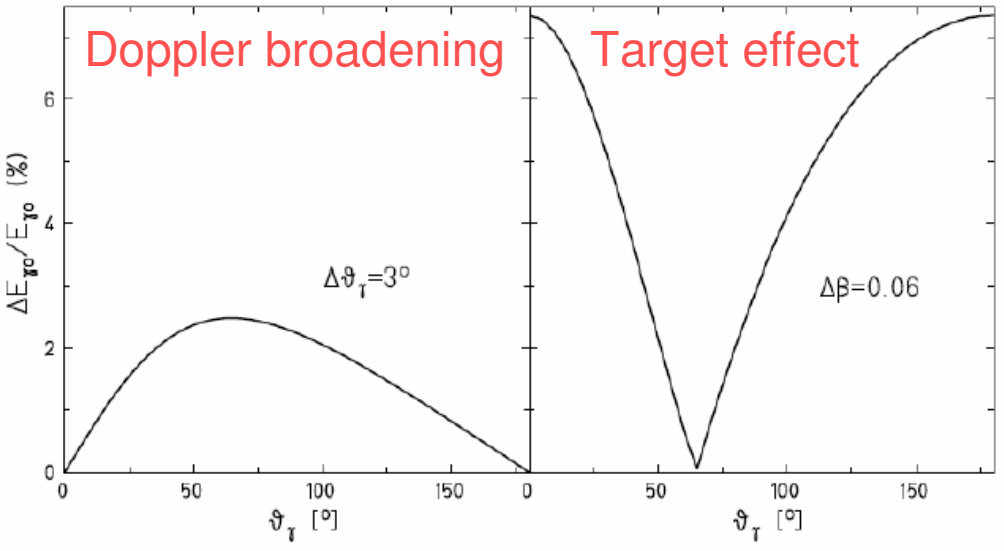


Doppler effect

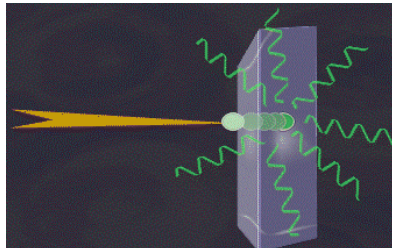








Atomic Background Radiation Bremsstrahlung



- Radiative electron capture (REC)

capture of target electrons into bound states of the projectile:

$$\sigma \sim Z_p^2 \cdot Z_t$$

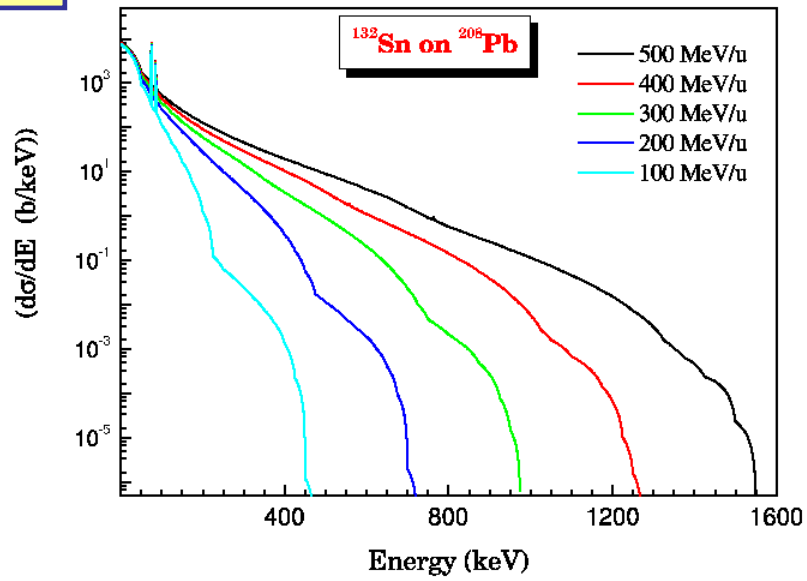
- Primary Bremsstrahlung (PB)

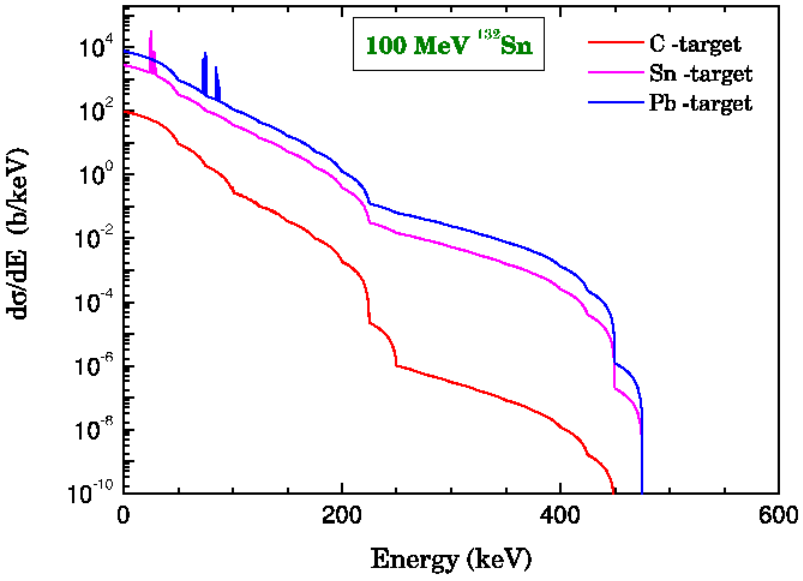
capture of target electrons into continuum states of the projectile:

$$\sigma \sim Z_p^2 \cdot Z_t$$

- Secondary Bremsstrahlung (SB)

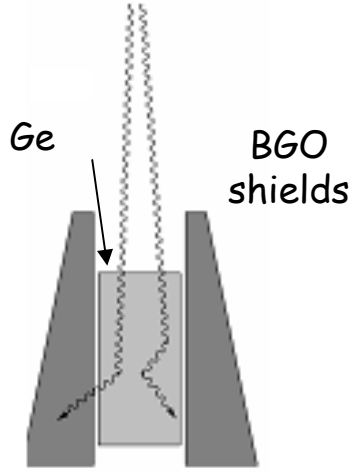
Stopping of high energy electrons in the target: $\sigma \sim Z_p^2 \cdot Z_t^2$





Ge detector concepts

SHIELDED DETECTORS

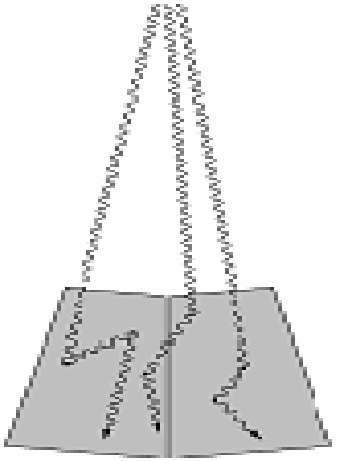


Suppress the Compton scattered events

30% of total solid angle covered by Ge

Past

COMPOSITE DETECTORS

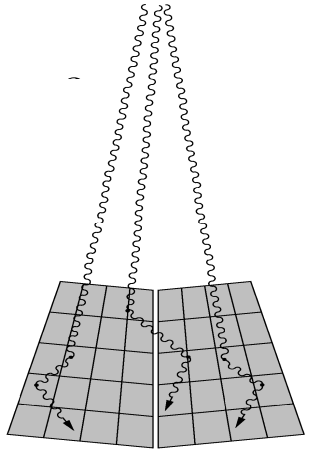


Adjacent Ge crystals operated in **ADD BACK** mode

For high multiplicity Mγ, wrong summing of energies takes place

Present

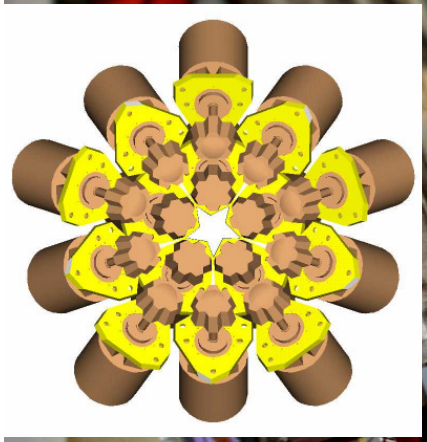
SEGMENTED DETECTORS



Discrimination between scattered events and individual hits possible with TRACKING

Future

Previous RISING/PRESPEC In-Flight Set-up



LYCCA

Target: Au,Be

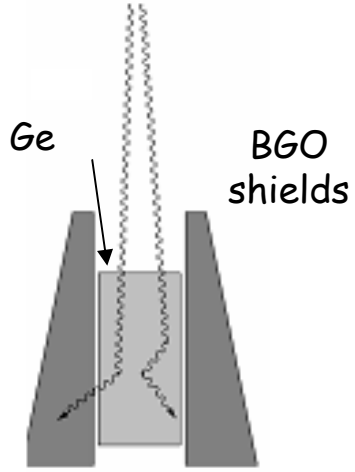
FRS tracking & identification

EUROBALL
Cluster array
15 x 7 Ge crystals
R = 70 cm
$\varepsilon_{Ph} \approx 3\%$
$\Delta E \approx 1\%$

PreSPEC

Ge detector concepts

SHIELDED DETECTORS



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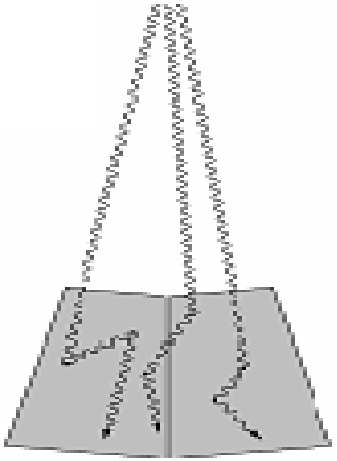

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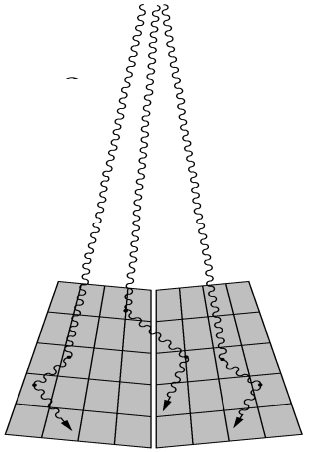
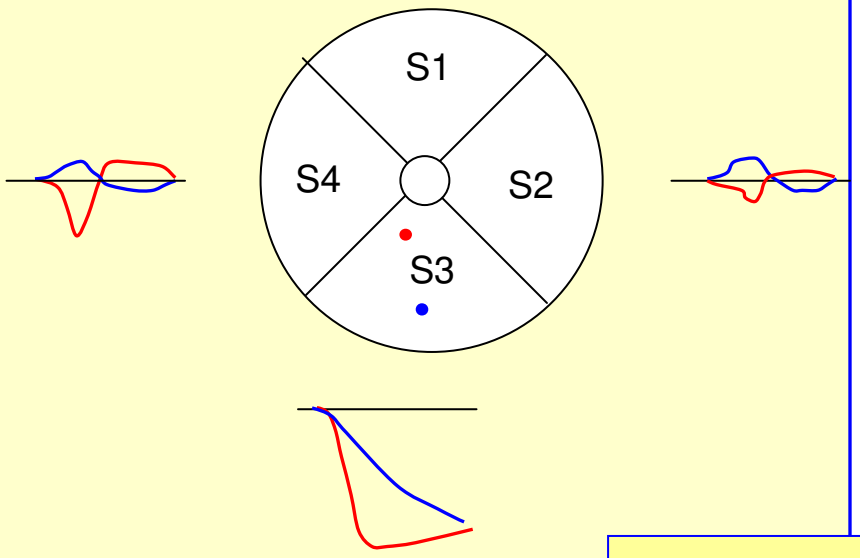


Discrimination between scattered events and individual hits possible with TRACKING

Future

Pulse Shape Analysis

Segmented detector signals



Interaction position is uniquely defined in 3D by pulse shapes

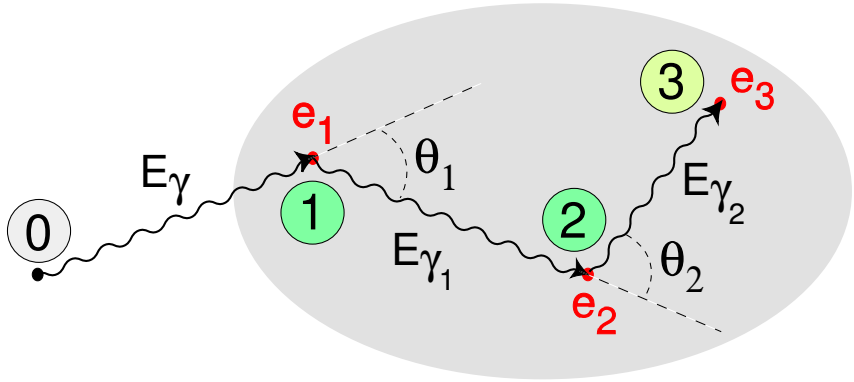
Mapping of pulse shapes with pre-determined one‘s to obtain position

S3: real charges, S2/4: mirror charges

Radius: S3 signal rise time
Azimuthal angle: S4-S2/(S4+S2) Asymmetry

Gamma ray tracking

- Recognize the individual 3D interaction points
- Reconstruct the track of photon using Compton scattering formula and energy dependent absorption probability
- Full energy events distinguished from scattered events => Improved photopeak efficiency
- Determining the incoming direction with a very good position resolution(2-3mm) => Improved Doppler correction

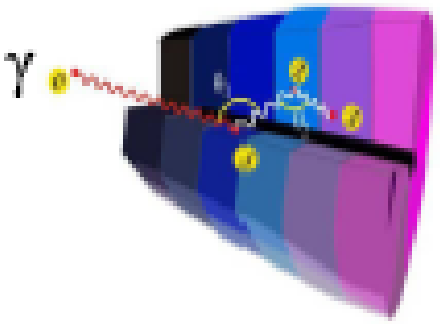


$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}}(1 - \cos(\theta))$$

Ingredients of γ-tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

3

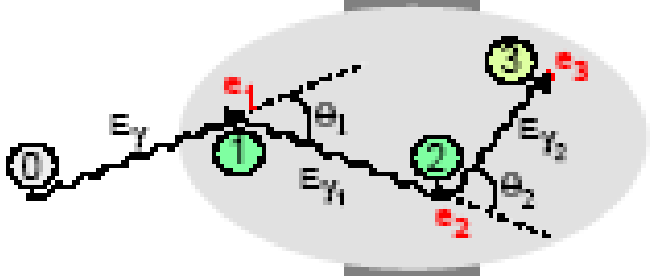
Pulse Shape Analysis to decompose recorded waves

Identified interaction

$(x,y,z,E,t)_i$

4

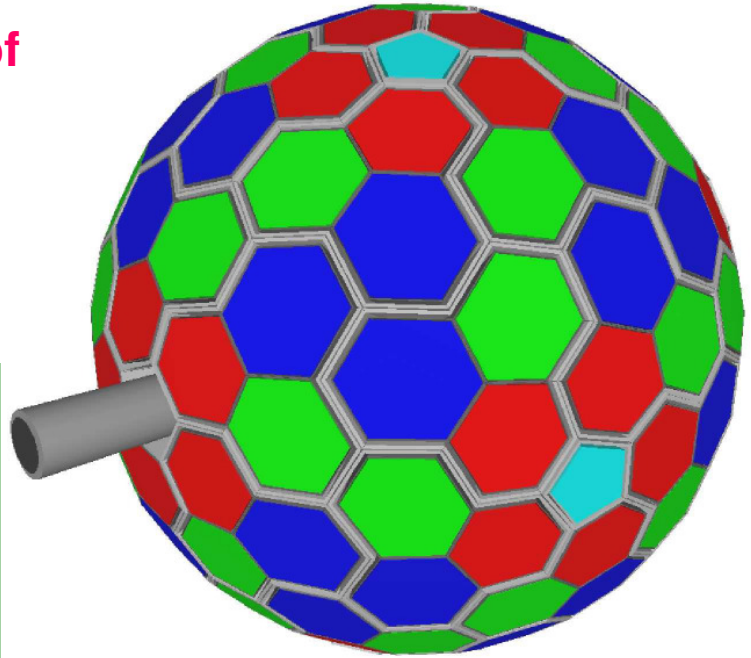
Reconstruction of tracks e.g. by evaluation of permutations of interaction points



reconstructed γ-rays

AGATA

43 institutes of
11 countries



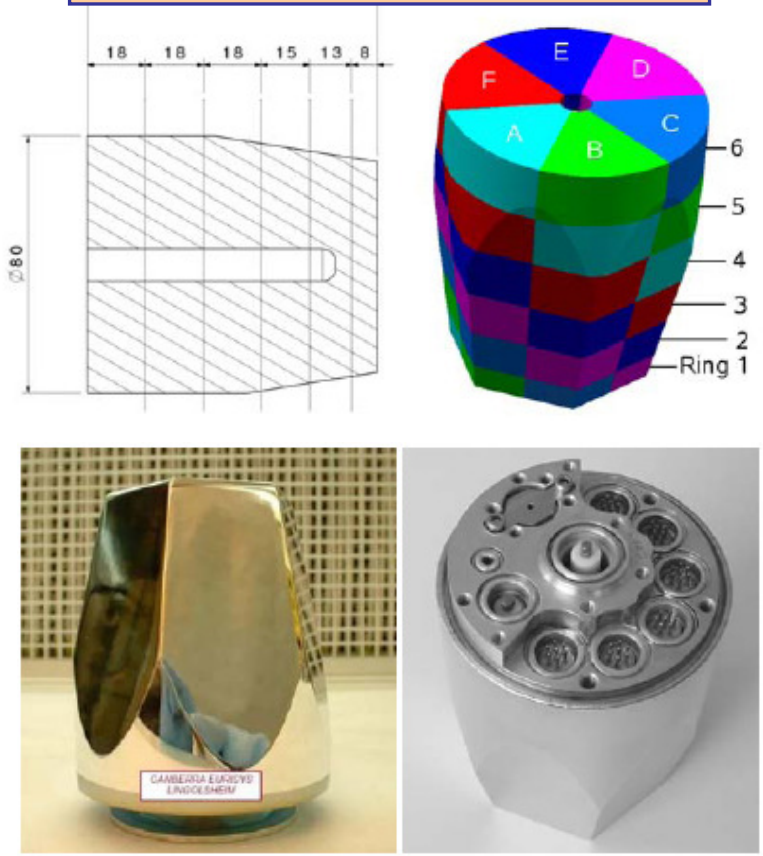
Advanced GAmma Tracking Array

4π segmented Ge detector shell
17 cm inner radius
82% Ge solid angle
180 irregular hexagons (3 types)

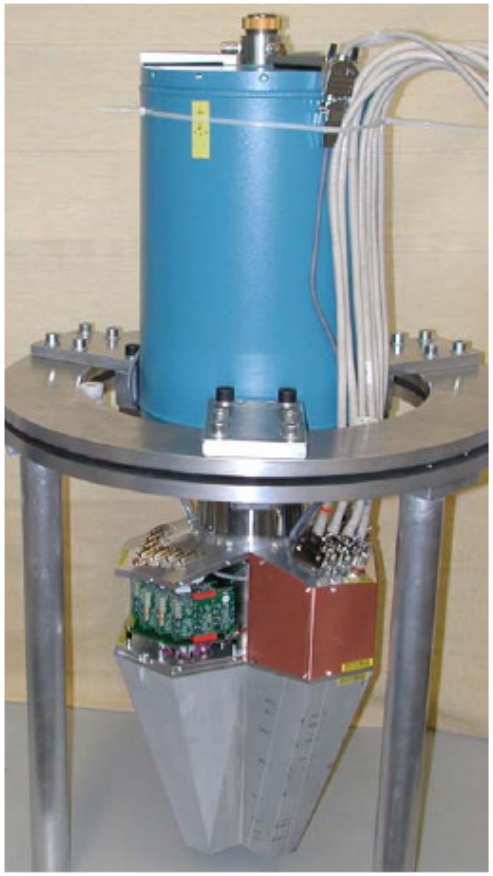
Photo-peak efficiency	P_{ph} (E=1.0 MeV, M_γ=1, β<50%)	43%
	P_{ph} (E=1.0 MeV, M_γ=30, β<50%)	28%
	P_{ph} (E=10 MeV, M_γ=1)	10%
Peak-to-total ratio	P/T (M=1)	60%
Angular resolution	$\Delta\theta_\gamma$	< 1°
Event rates	for Mγ=1	3 MHz
	for Mγ=30	0.3 MHz

AGATA Detector unit

Large volume 36-fold segmented, encapsulated Ge detector

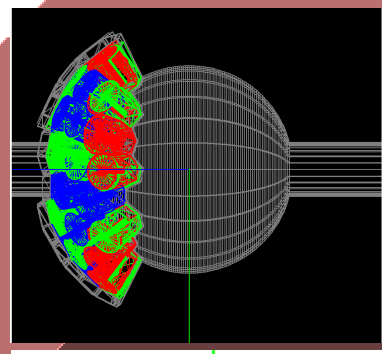


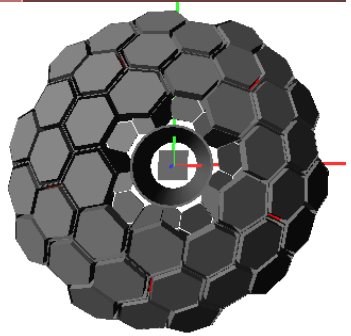
Triple Cluster unit



New PRESPEC-AGATA Set-up

AGATA
Tracking array
5x2+10x3 crystals
R = 12 – 40 cm
$\varepsilon_{Ph} \approx 17\%$
$\Delta E \approx 0.4\%$

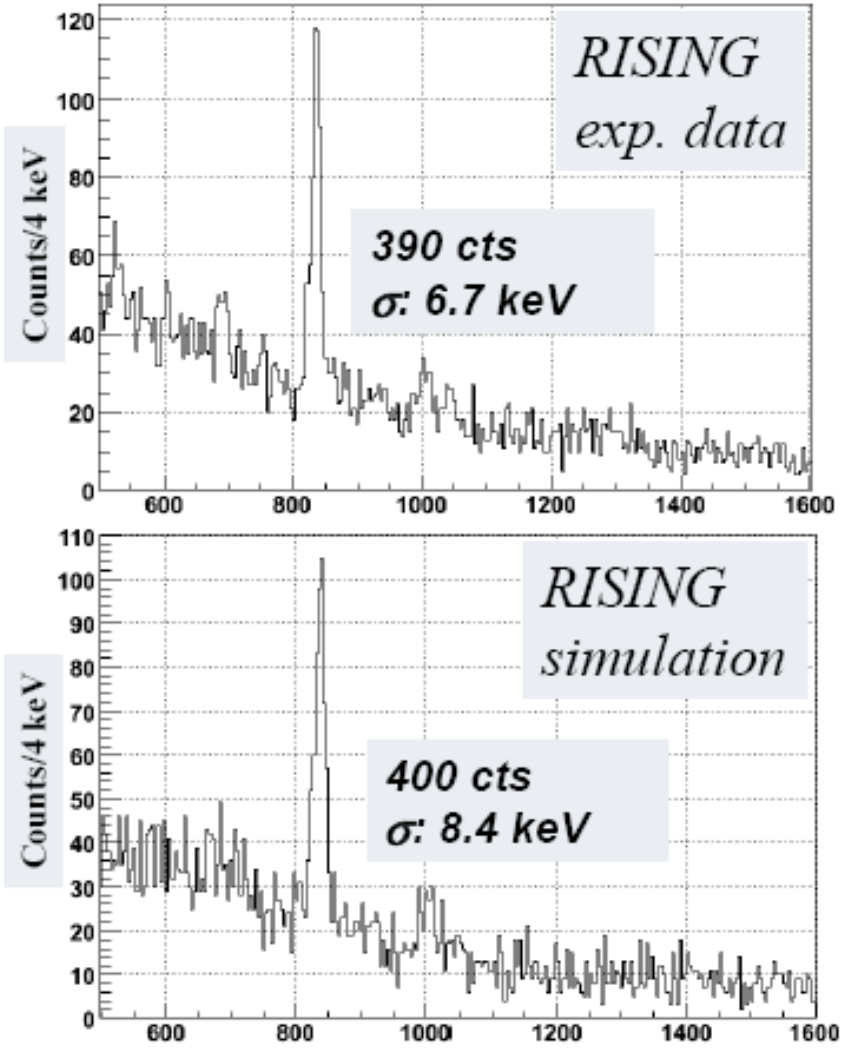


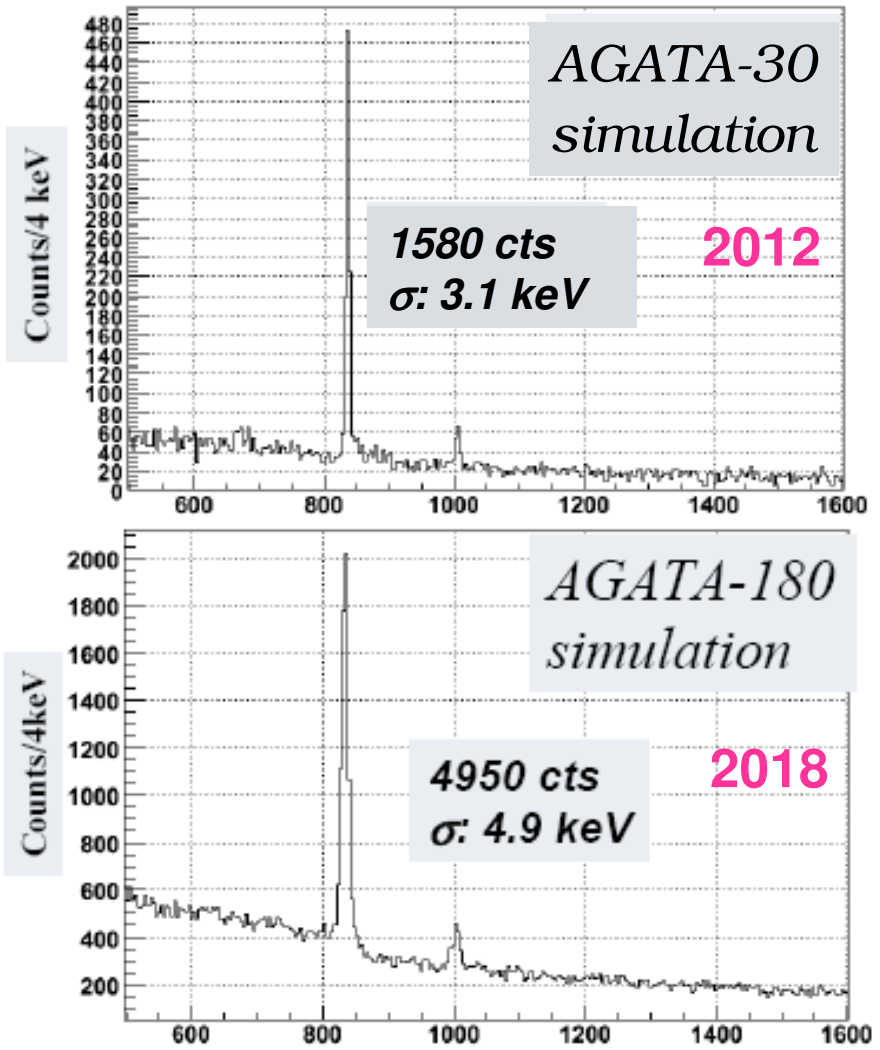


AGATA
ADVANCED GAMMA TRACKING ARRAY

PreSPEC

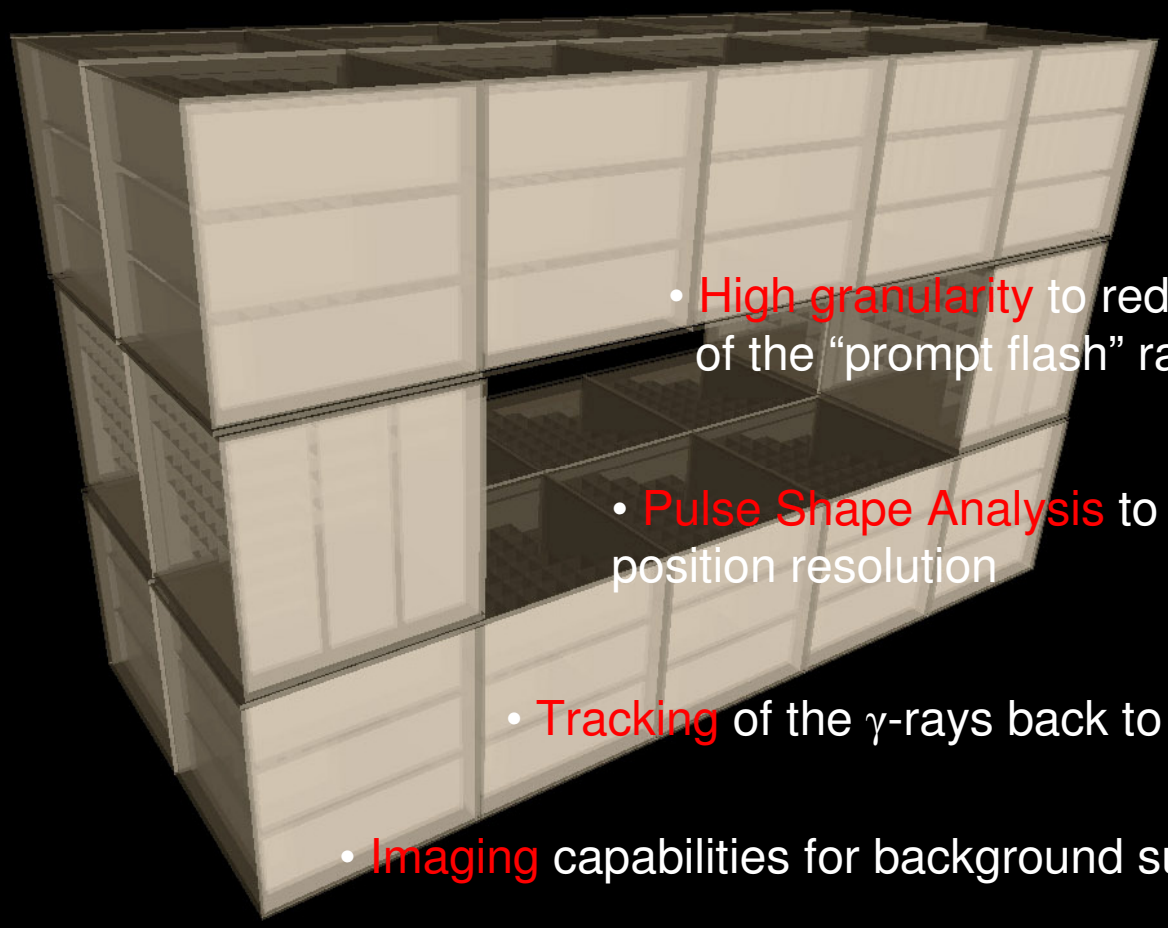
AGATA vs. RISING Coulomb excitation of ^{54}Cr





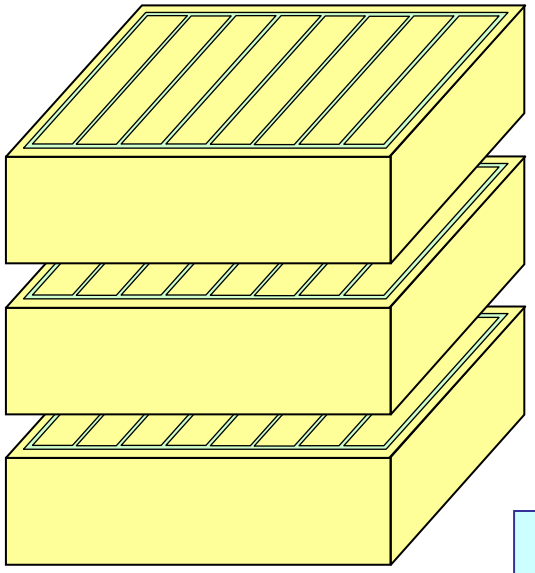
Sensitivity gain x10…x30

DESPEC γ-tracking/imaging array



- High granularity to reduce the effect of the "prompt flash" radiation
- Pulse Shape Analysis to improve the position resolution
- Tracking of the γ-rays back to the origin
- Imaging capabilities for background suppression
- Polarization sensitivity

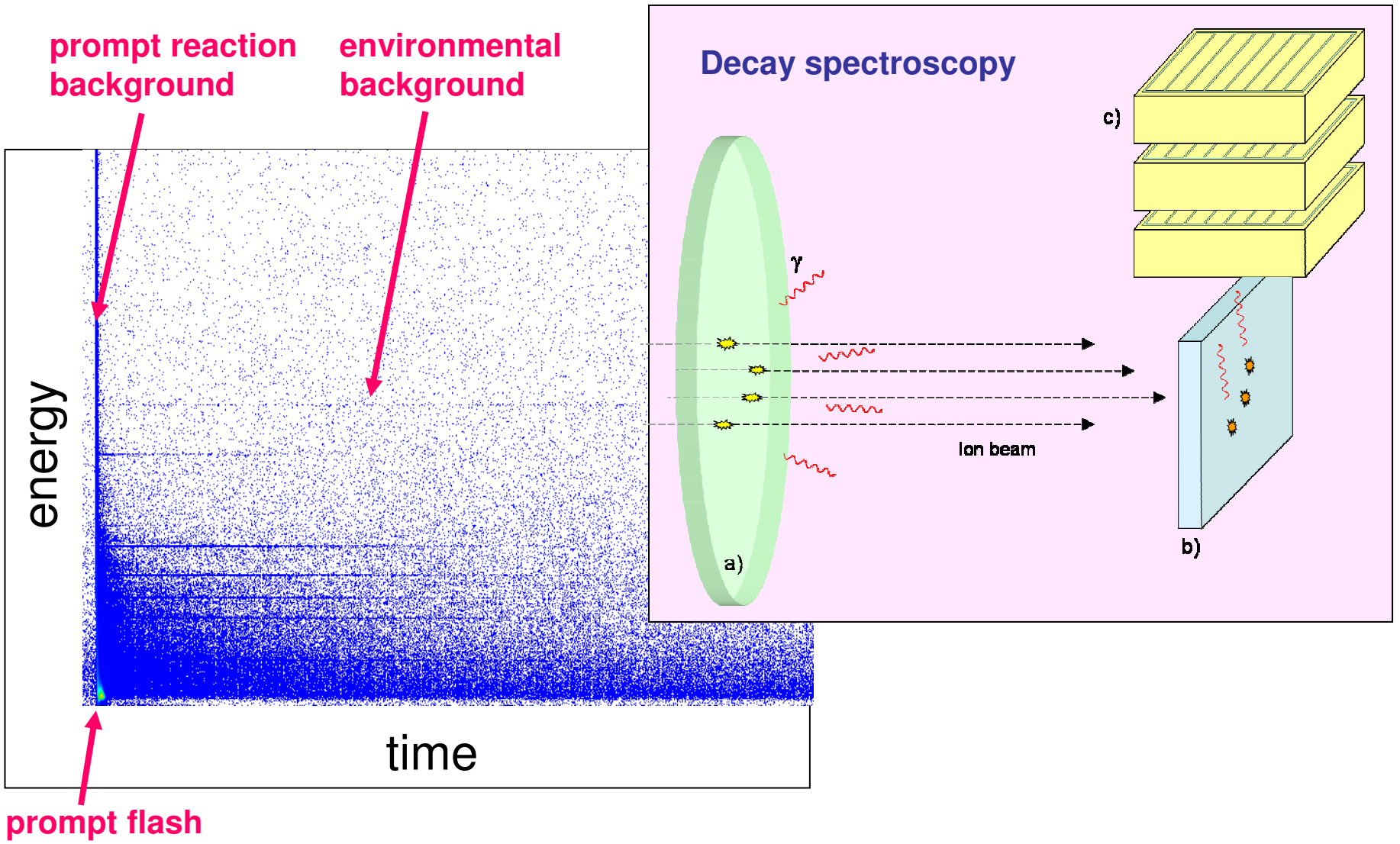
Detector Module



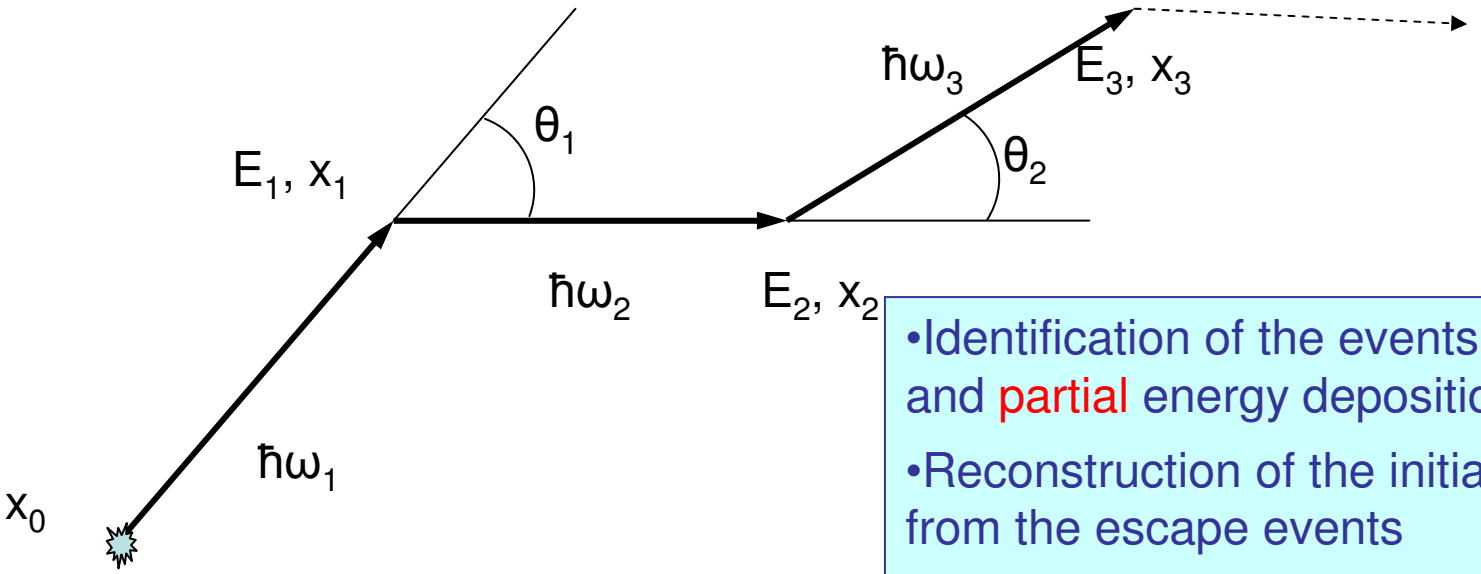
- Stack of 3 planar 2D stripe Ge detectors
- $68mm^2$ x $68mm^2$ x $20mm^2$ + 2mm guard ring
- 6mm gap between crystals
- 8x8 segmentation
- 1 – 3 mm 3D position resolution with PSA
- Energy resolution: 0.2%

- Increase of correlation time range between implantation and decay for isomers
- Distinction of gamma events from background sources
- Suppression of Compton escape background (software anti-Compton shield)
- Increase of absolute efficiency by reconstruction of incomplete events

Motivation: background suppression



Tracking algorithms



- Identification of the events with total and partial energy depositions
- Reconstruction of the initial energy from the escape events
- Rejection of the events from background sources

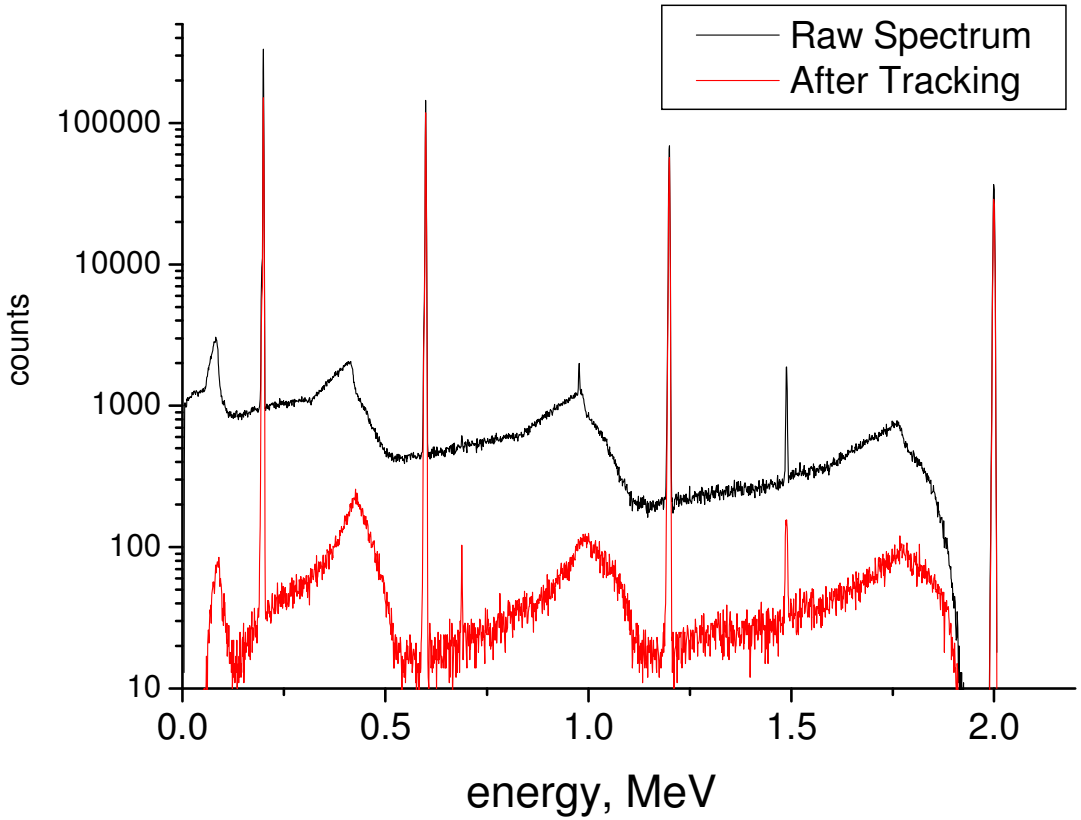
TANGO algorithm:

Construction of the "Figure of Merit"

- for each possible order of interactions
- for the case of total and partial energy deposition

Selecting the case with the maximum Figure of Merit

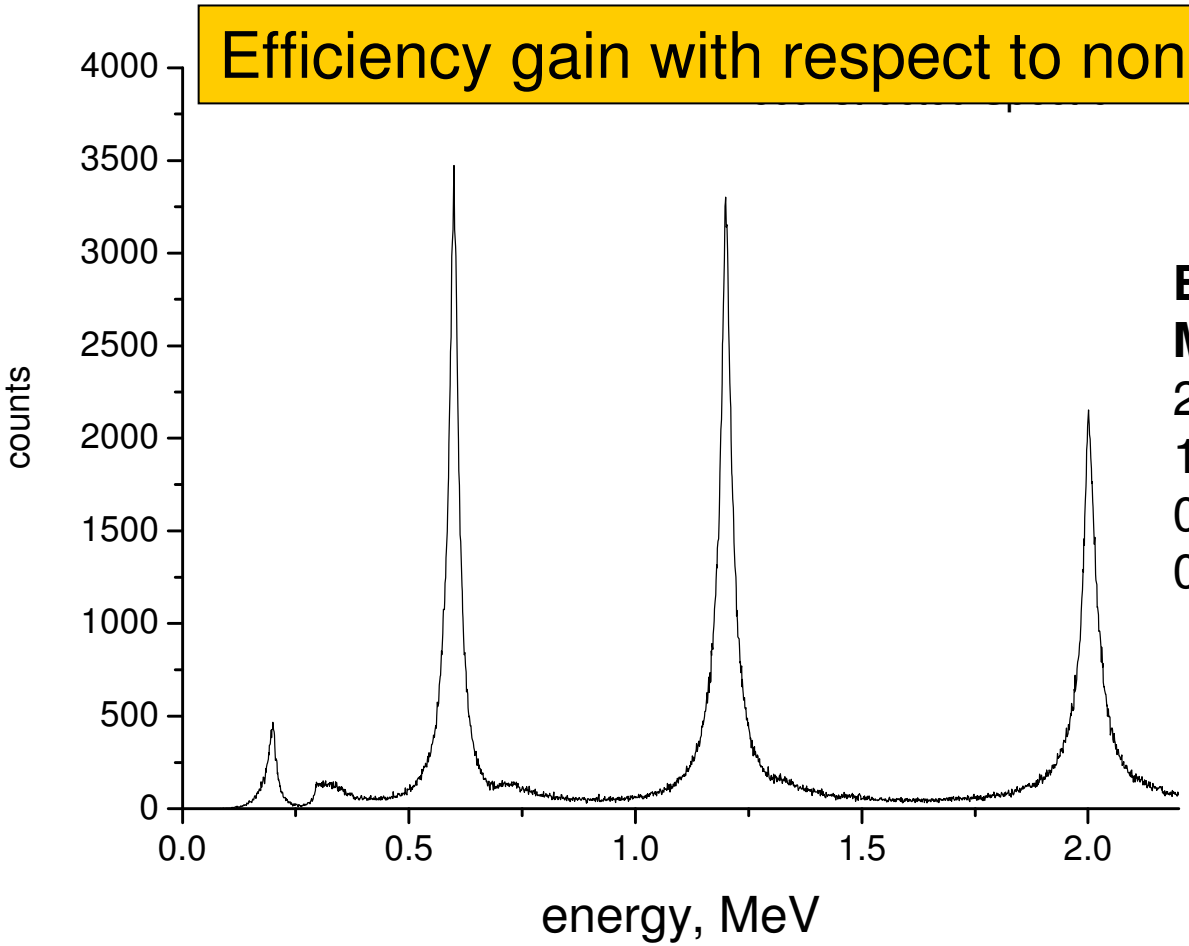
Results of tracking:
events, identified as total energy deposition



Energy MeV	Tracking Efficiency	Compton Background Suppression
2	0.79	7.5
1.2	0.81	13
0.6	0.82	13
0.2	0.51	57

GEANT4 simulation

Results of tracking: events, identified as partial energy deposition (escapes)

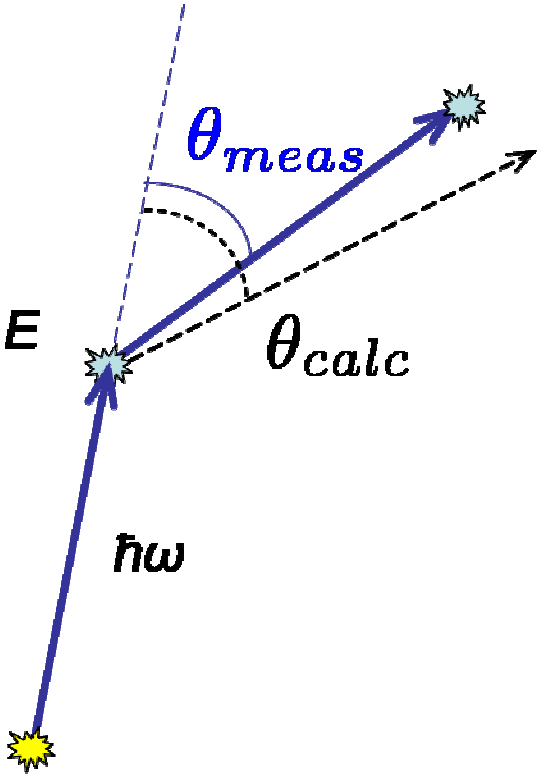


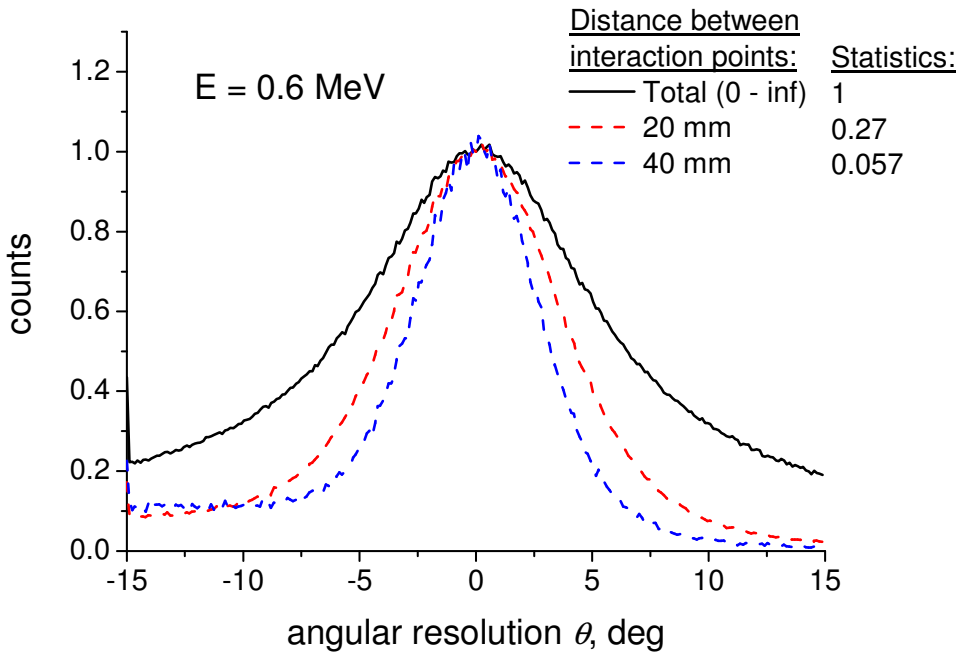
Efficiency gain with respect to non-tracking detectors

Energy MeV	Tracking Efficiency (escape)	Tracking Efficiency (total)
2	0.7	1.5
1.2	0.65	1.5
0.6	0.35	1.2
0.2	0.02	0.5

Energy Resolution:
FWHM: ~1.5%
Lorentzian Profile

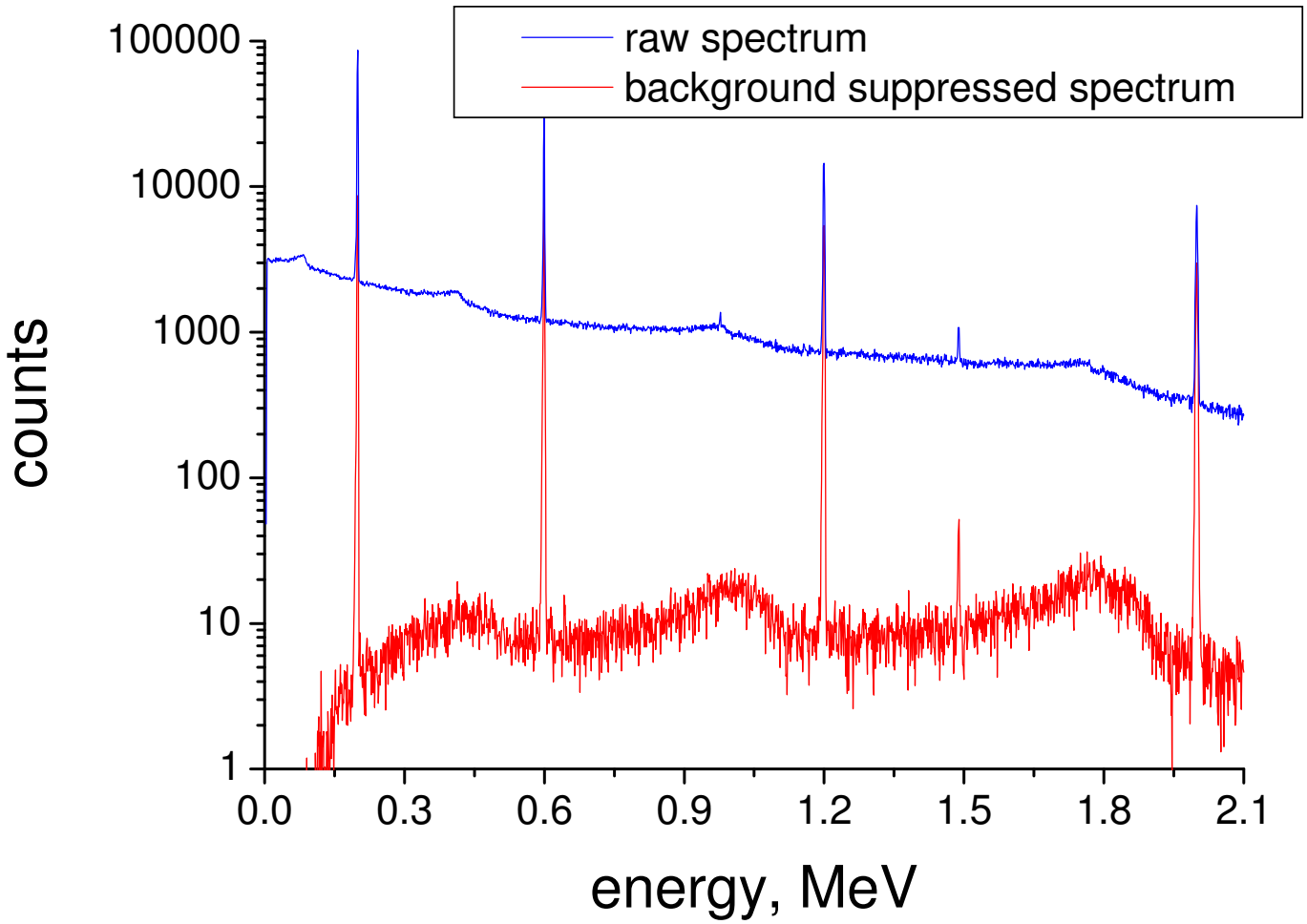
Background suppression via Imaging





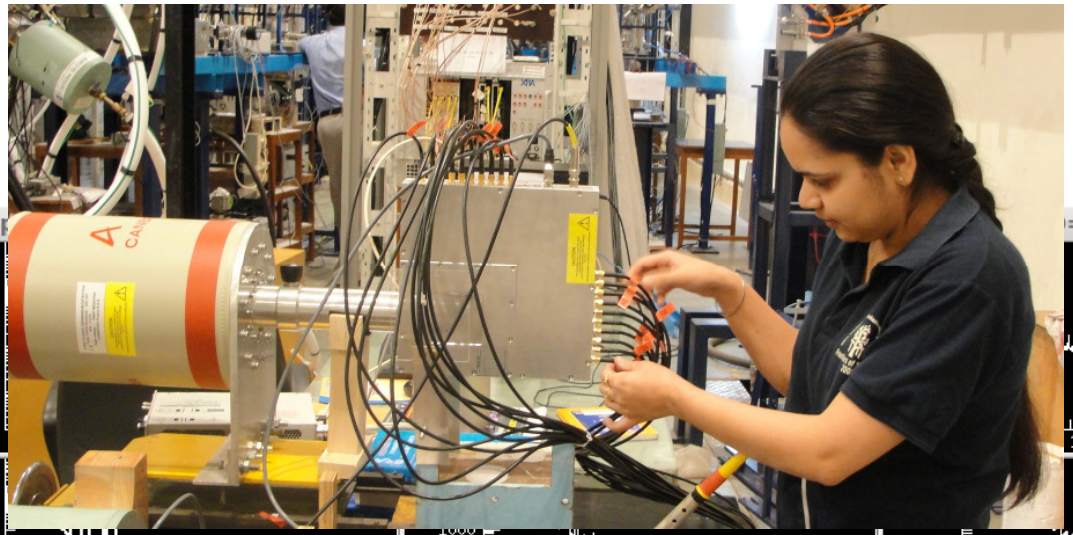
$$\Delta\theta = \theta_{meas} - \theta_{calc}$$

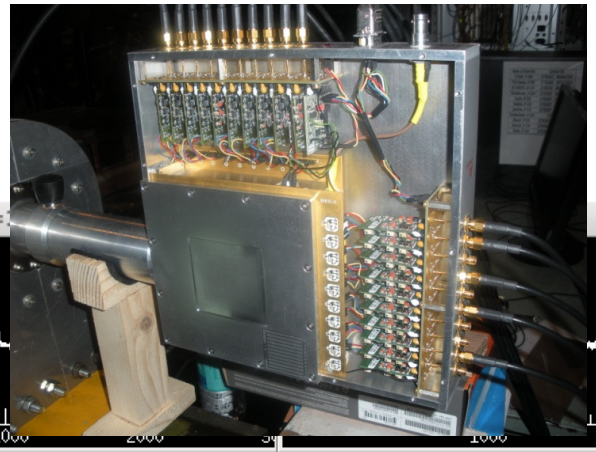
Environmental background suppression



"Ideal" (100% efficient) tracking was assumed for simulations

Planar Ge detector prototype at TIFR Mumbai





- ✓Energy Characterization is completed.
- ➢Imaging studies is planned using DSP.
- ➢Study of heavy nuclei through decay spectroscopy.

Triple Cryostat

Status:

Design finished

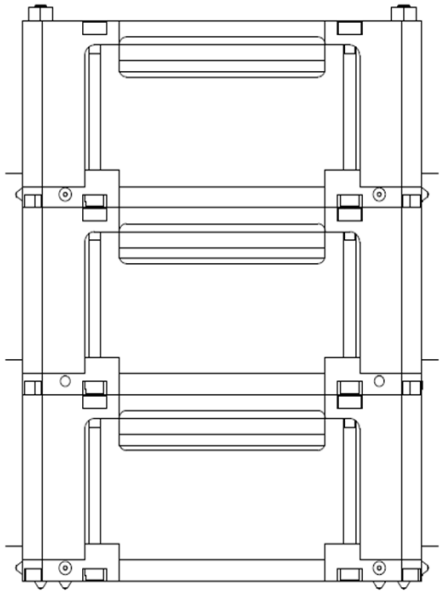
Parts delivered

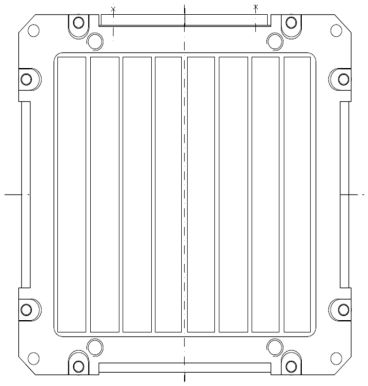
Planning:

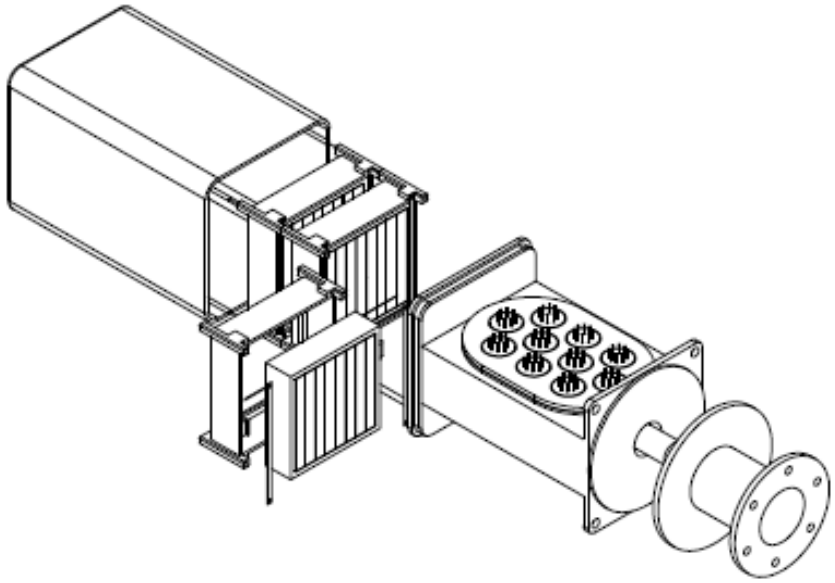
11.2011: Assembly

01.2012: Cooling and cabling tests

05.2012: Ge detector mounting and tests



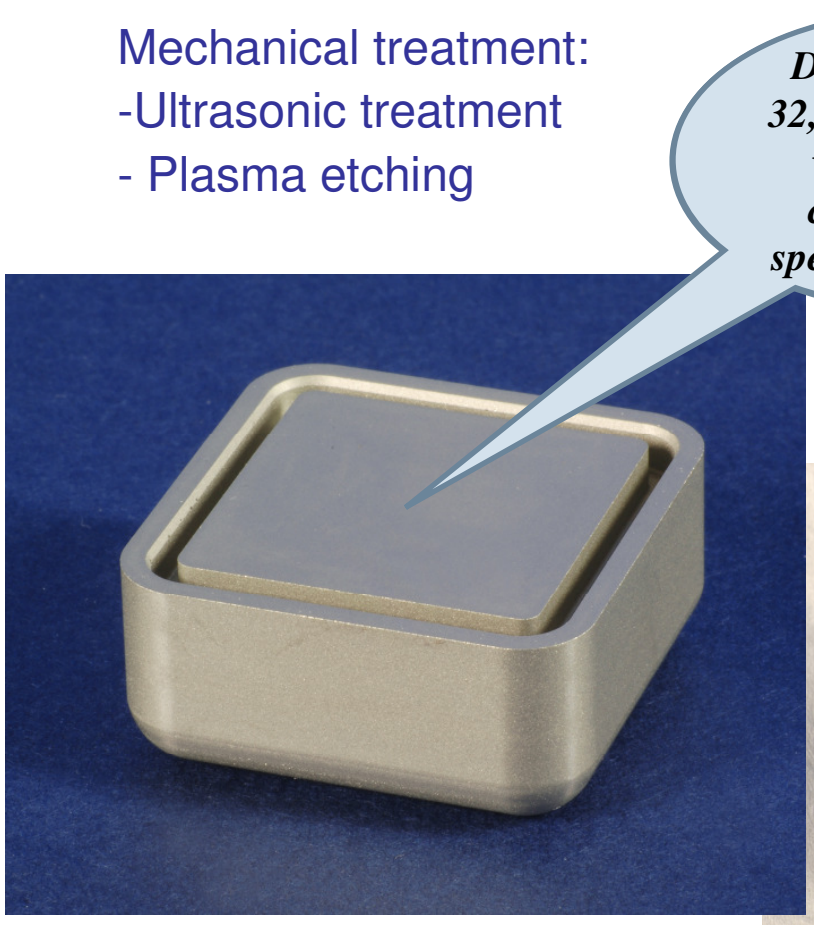


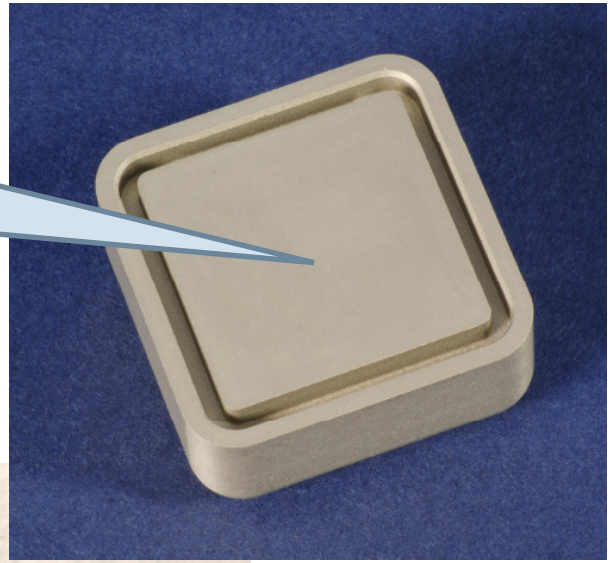


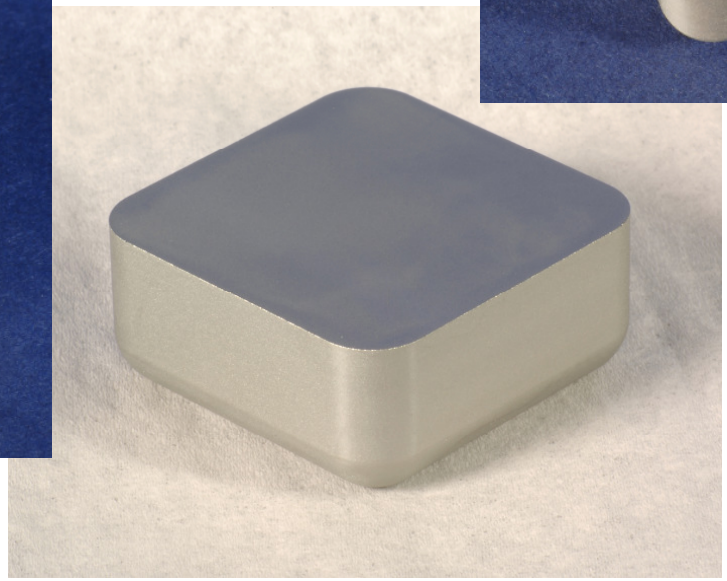
Quasiplanar demonstrator

Mechanical treatment:
-Ultrasonic treatment
- Plasma etching

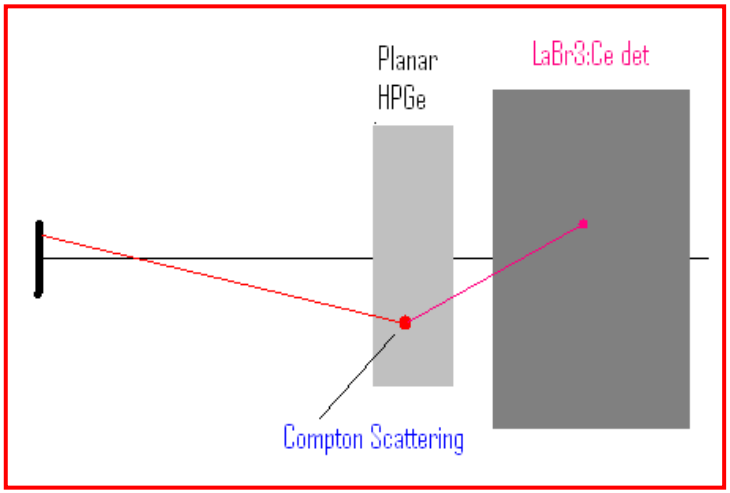
Dimensions are 32,5x32,5x12 mm^3 with rounded corners and a special guard ring







Hybrid detector



-larger solid angle coverage

-high efficiency

-fast timing

-reduced energy resolution

-similar tracking/imaging

Planar+AGATA Hybrid detector

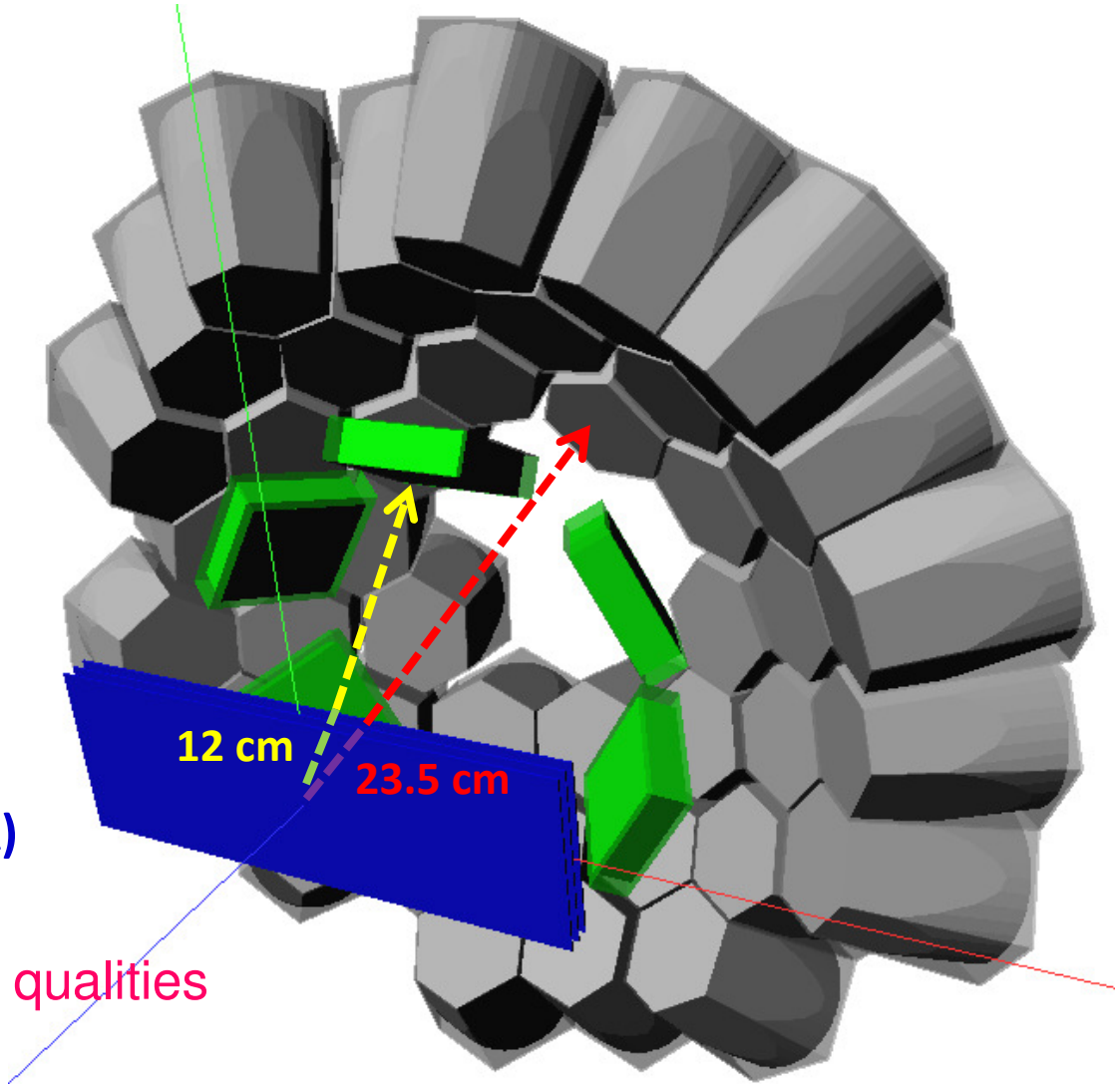
AGATA:
40 tapered coaxial HPGe crystals (9 cm long)

+

6 planar HPGe detectors ($7x7x2\ cm^3$) in DAISY configuration

+

Si implantator detector (AIDA)



→ Promising imaging qualities

Conclusions

γ-tracking detectors have been developped to be used at GSI from 2012 for In-flight spectroscopy employing radioactive ion beams

Such detectors will increase the sensitivity for nuclear structure investigations by a factor 10-30!

Tracking/Imaging detectors are under development for NUSTAR at FAIR

These future detectors will be able to discriminate background radiation by several orders of magnitude

Obviously the novel concepts are beneficial for many other γ detection taks in basic research as well as in technical applications

... Thank you

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