Gamma-Spectroscopy Experiments with PRESPEC-AGATA at GSI

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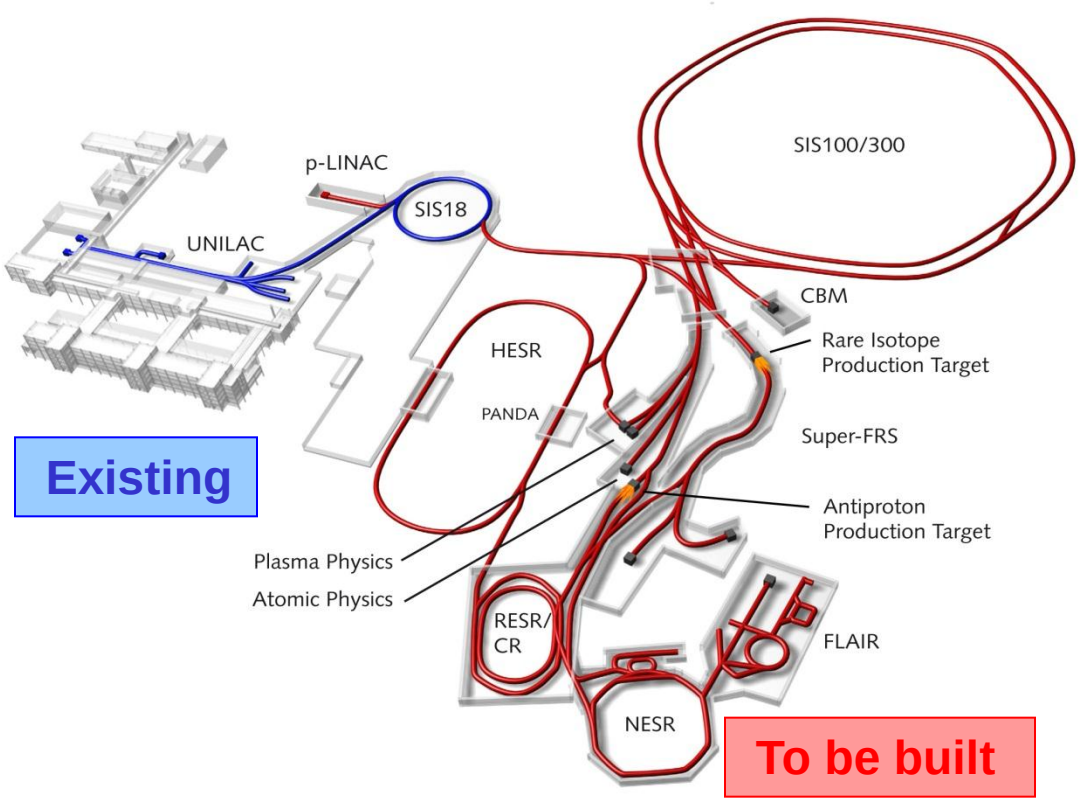
GSI Darmstadt, Germany

DPG Frühjahrstagung 2013

Dresden

8.3.2013

FAIR – The Science



Nuclear Structure Physics and Nuclear Astrophysics with RIBs

Structure of exotic nuclei far off stability;

Nuclear synthesis in stars and star explosions;

Fundamental interactions and symmetries

Hadron Physics with Antiproton Beams

Quark gluon structure and dynamics of "strong" interacting particles;

Origin of the confinement and mass of hadrons

Transversity measurement via polarized antiprotons and pol. protons

Physics of Nuclear Matter with Relativistic Nuclear Collisions

Studies of hadronic matter at high densities;

Phase transitions in quark matter;

Properties of neutron stars

Plasma Physics with highly Bunched Beams

Bulk matter at very high pressures, densities, and temperatures

Atomic Physics and Applied Science

Highly charged atoms; Low energy anti-protons

Laser cooling

NUclear STructure Astrophysics and Reactions

What are the limits for existence of nuclei?

- Where are the proton and neutron drip lines situated?
- Where does the nuclear chart end?

How does the nuclear force depend on varying proton-to-neutron ratios?

- What is the isospin dependence of the spin-orbit force?
- How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?

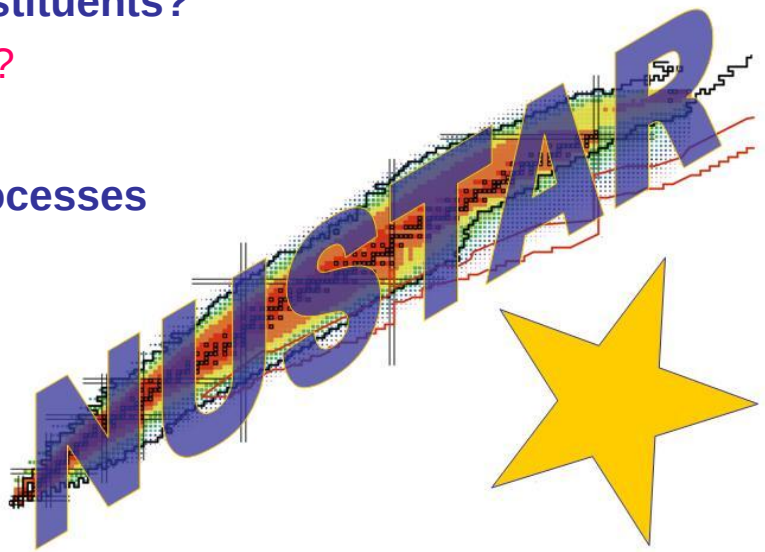
- What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?

- What is the effective nucleon-nucleon interaction?
- How does QCD constrain its parameters?

Which are the nuclei relevant for astrophysical processes and what are their properties?

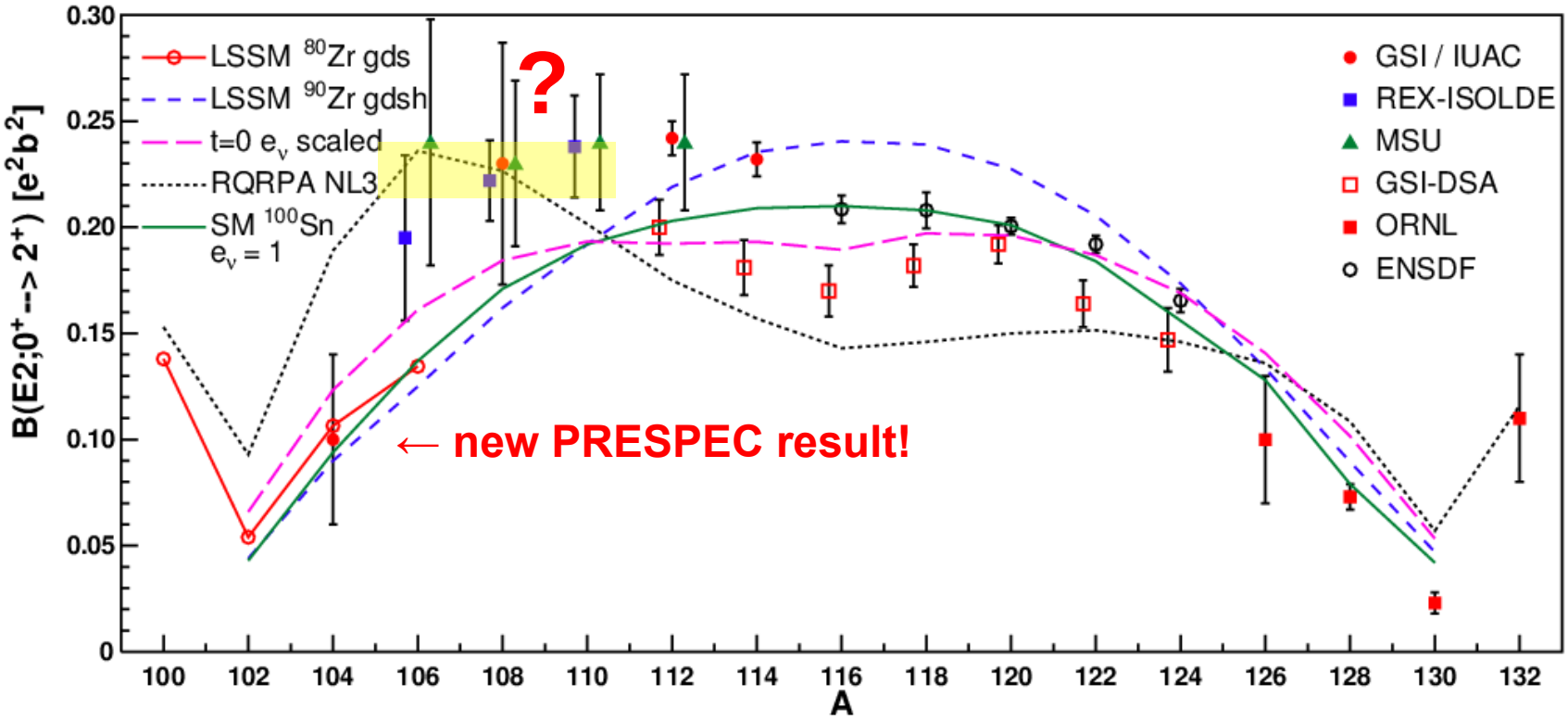
- What is the origin of the heavy elements?



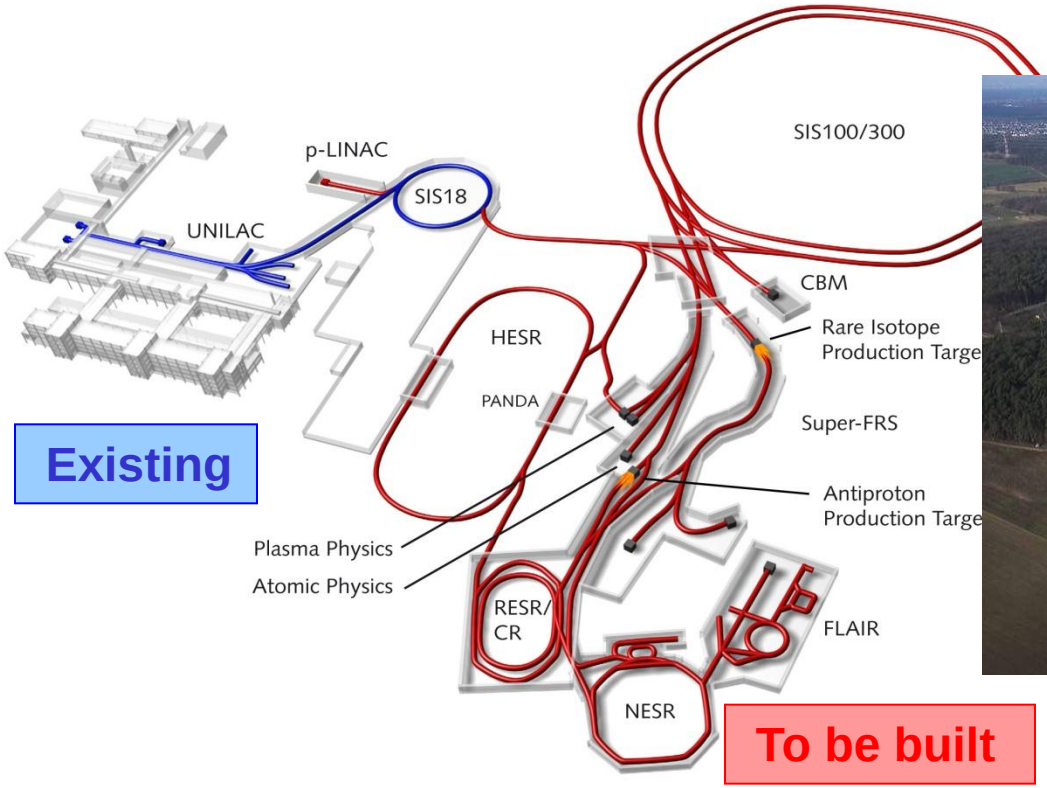
Unexpected B(E2) strength in Sn isotopes

Sn: Z=50 magic
N=50, 82 doubly magic

B(E2) values not well described by shell model towards 100Sn?!

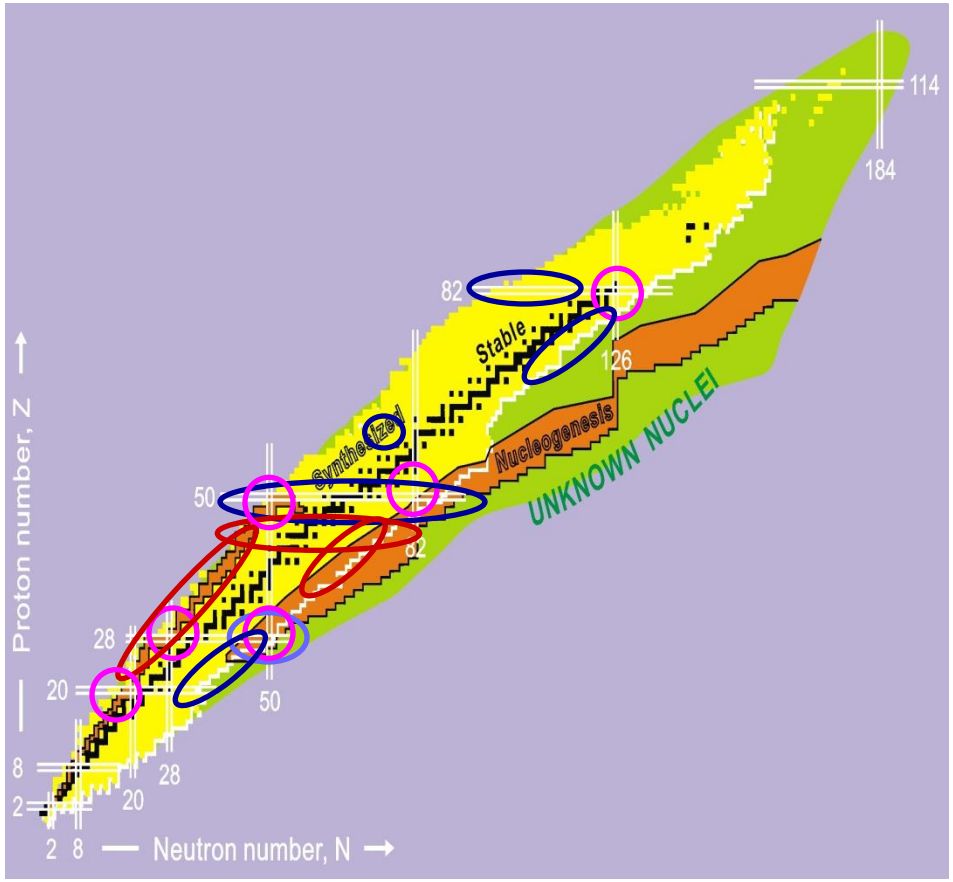


FAIR – Todays Reality



NUSTAR follows an evolutionary approach,
constantly improving their instrumentation until FAIR becomes reality,
using radioactive beams from the FRS at GSI for methodology development
and to perform NUSTAR physics experiments

Nuclear Spectroscopy employing RIBs at GSI



Nuclear Shell structure

- N ≈ Z
- N>>Z

Nuclear shapes

- Quadrupole, Octupole, Triaxiality
- Shape transitions
- High K-isomers

Collective modes

- N>>Z : GDR soft mode

Nuclear Symmetries

- mirror-isospin, pn-pair correlation

Nuclear astrophysics

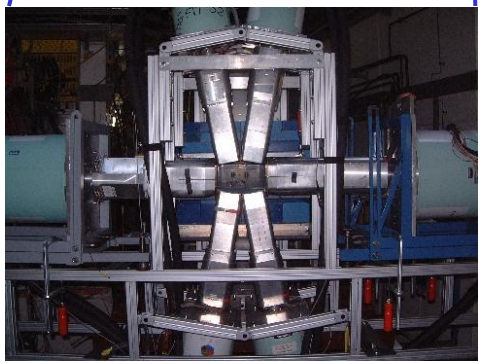
- r, rp process

Coulomb excitation, Fragmentation and Decay studies using Rare Isotope Beams and high-resolution γ Spectroscopy

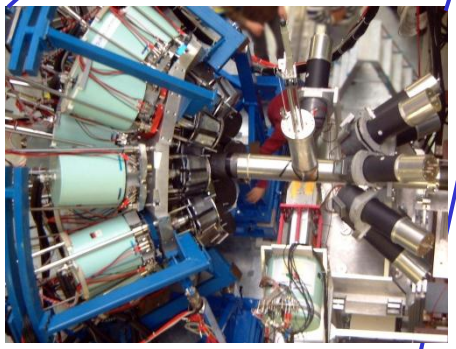
History...

1998 2000 2002 2004 2006 2008

VEGA
Isomer campaign

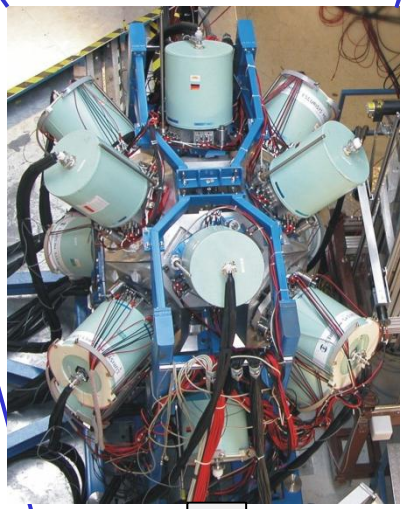


RISING
Fast campaign



g-RISING

RISING
Stopped campaign



EURIKA

From RISING to HISPEC/DESPEC

RISING at GSI stopped in August 2009

HISPEC/DESPEC at FAIR starts in 2019

Want to continue successful spectroscopy programme

Need to commission and implement new instrumentation

Decay and In-beam spectrocopy programme at the FRS until HISPEC/DESPEC starts

Employing new instrumentation as it becomes available

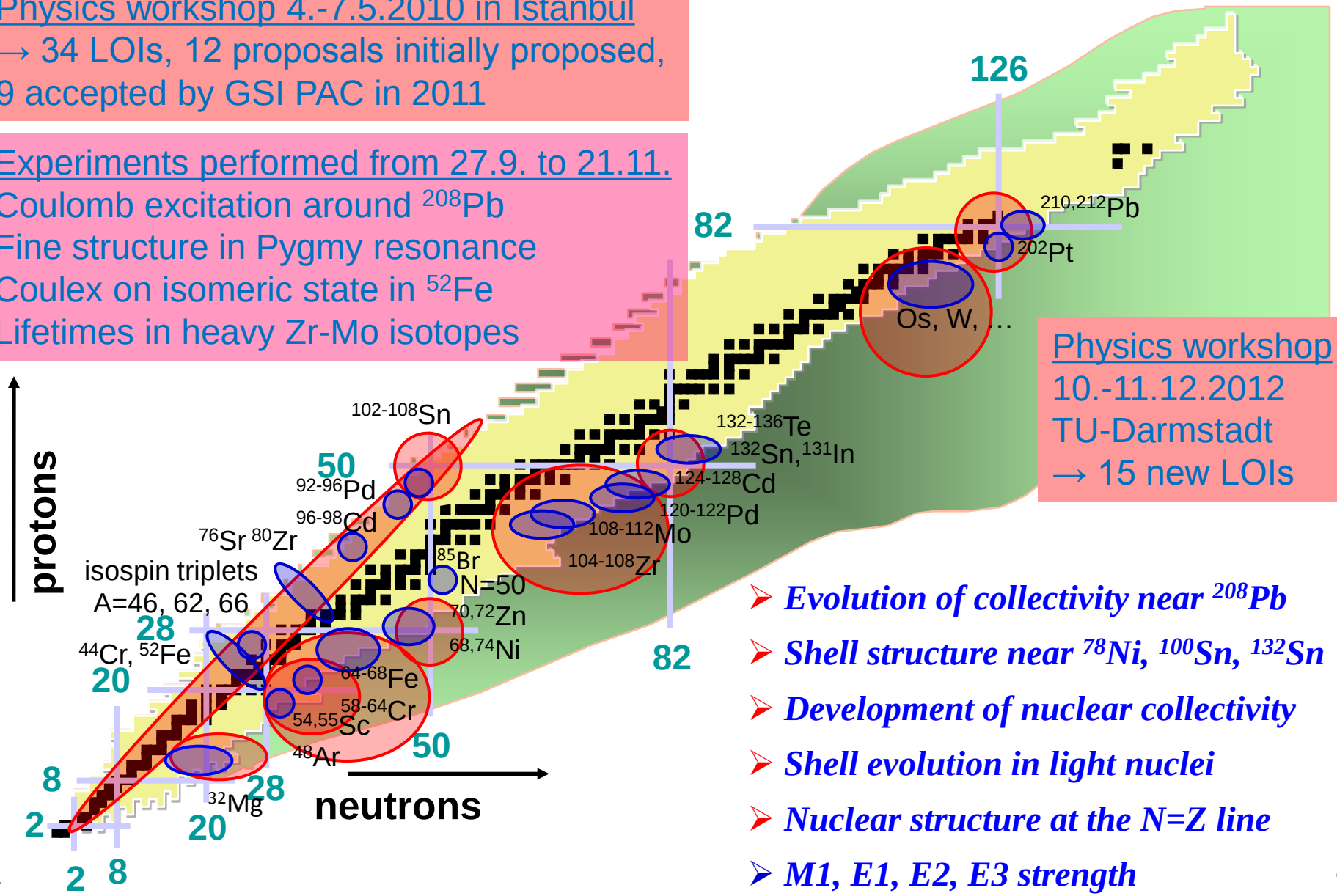
Platform for coordinated test and commisioning of HISPEC/DESPEC components

Organisational framework of the spectroscopy community at GSI/FAIR

PRESPEC-AGATA Physics Campaign 2012/2013

Physics workshop 4.-7.5.2010 in Istanbul
→ 34 LOIs, 12 proposals initially proposed, 9 accepted by GSI PAC in 2011

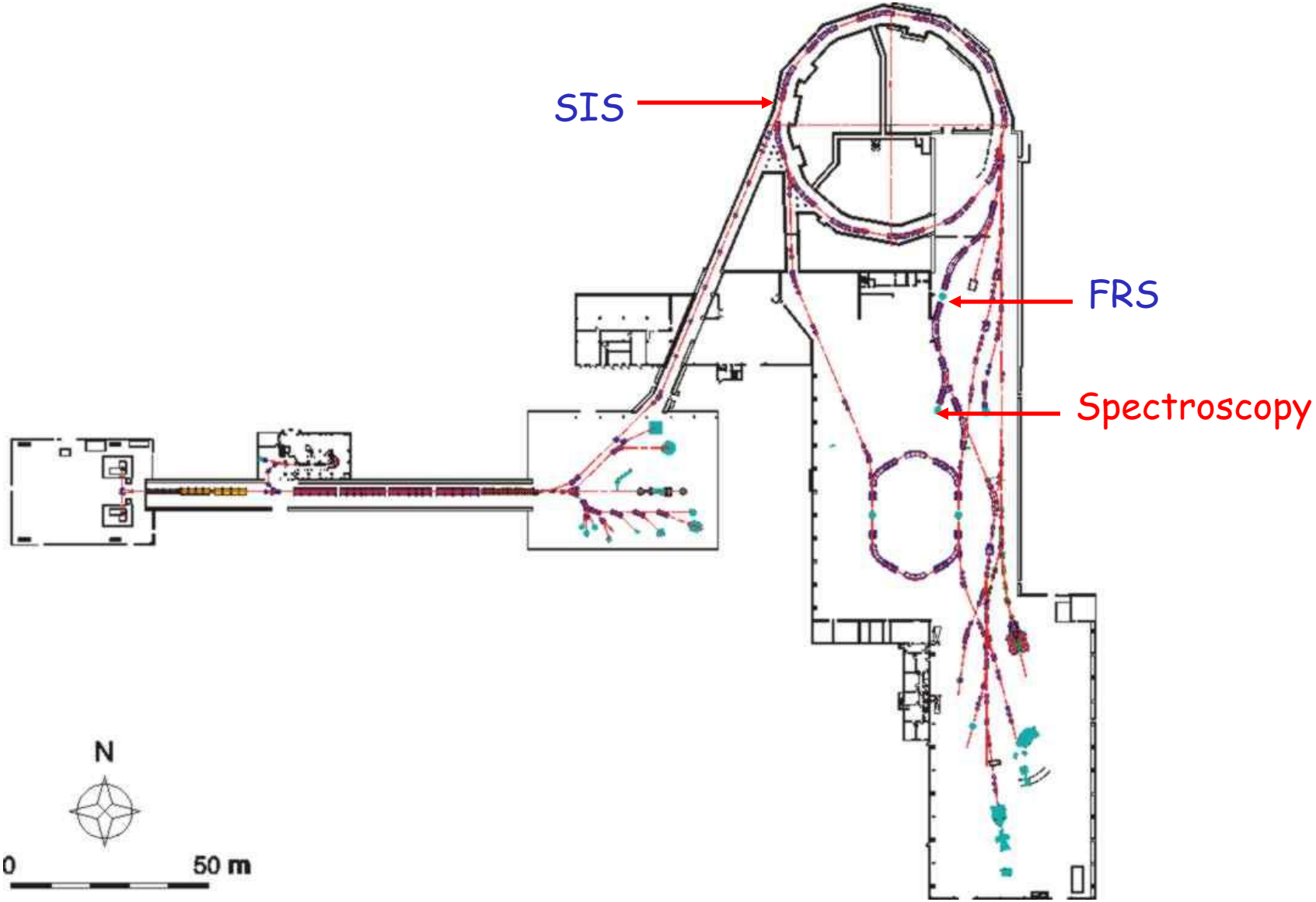
Experiments performed from 27.9. to 21.11.
Coulomb excitation around ^{208}Pb
Fine structure in Pygmy resonance
Coulex on isomeric state in ^{52}Fe
Lifetimes in heavy Zr-Mo isotopes



Physics workshop
10.-11.12.2012
TU-Darmstadt
→ 15 new LOIs

- ***Evolution of collectivity near ^{208}Pb***
- ***Shell structure near ^{78}Ni, ^{100}Sn, ^{132}Sn***
- ***Development of nuclear collectivity***
- ***Shell evolution in light nuclei***
- ***Nuclear structure at the N=Z line***
- ***M1, E1, E2, E3 strength***

Layout of the GSI facility



In-beam Spectroscopy

production

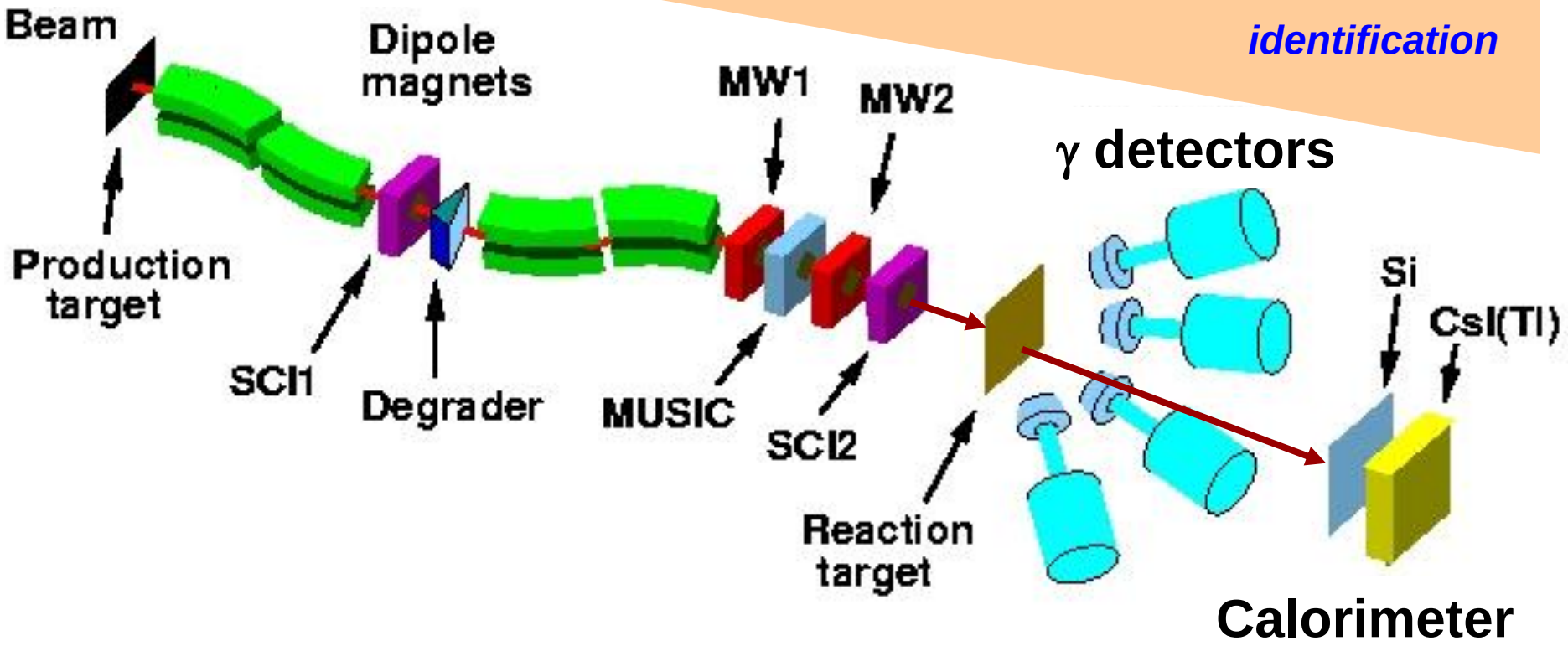
selection

identification

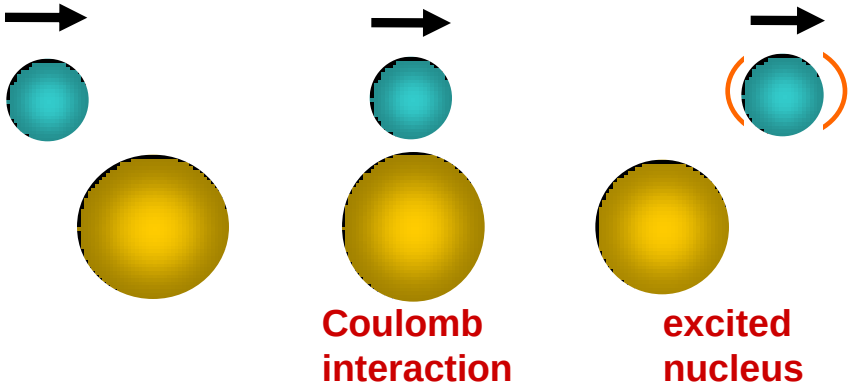
reaction

identification

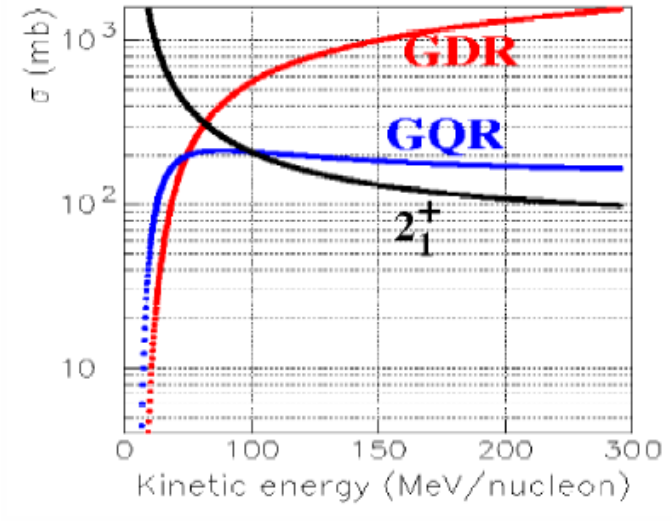
spectroscopy

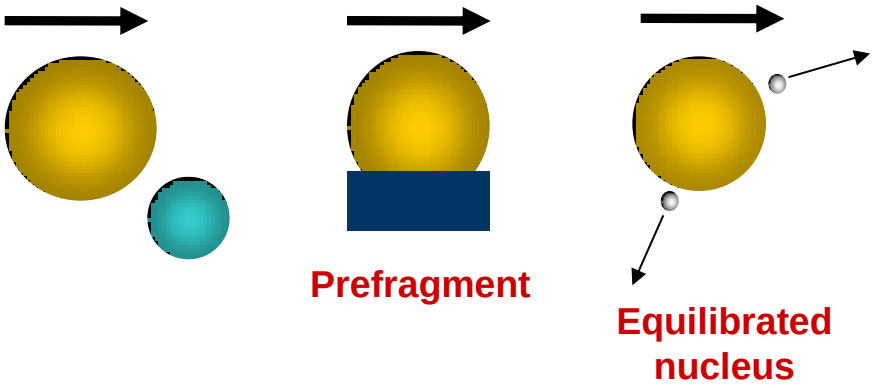


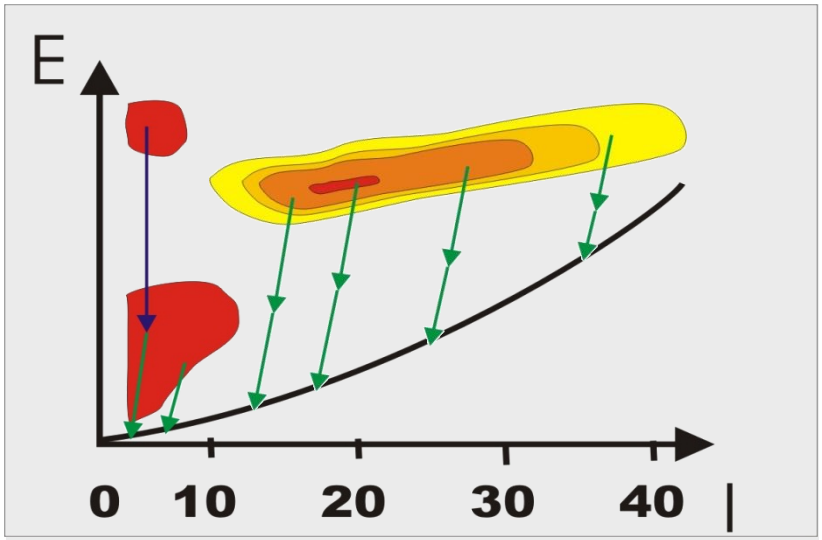
Relativistic Coulomb excitation / fragmentation



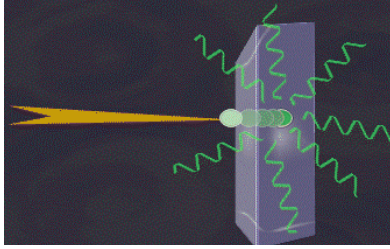
^{112}Sn →Au







Atomic Background Radiation
Bremsstrahlung



- Radiative electron capture (REC)

capture of target electrons into bound states of the projectile:

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

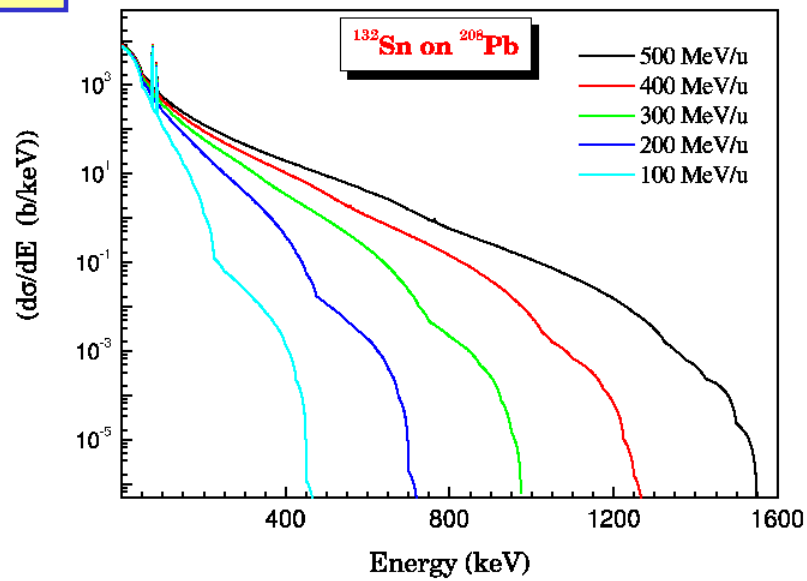
- Primary Bremsstrahlung (PB)

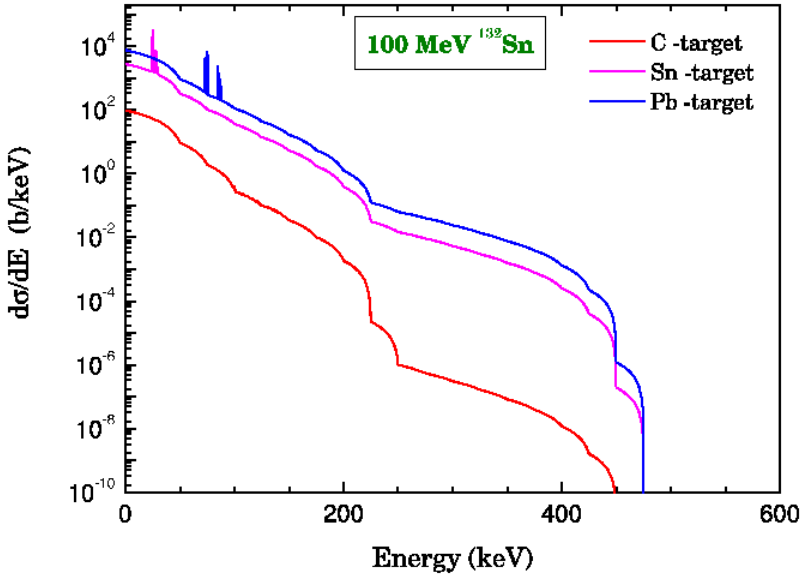
capture of target electrons into continuum states of the projectile:

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

- Secondary Bremsstrahlung (SB)

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

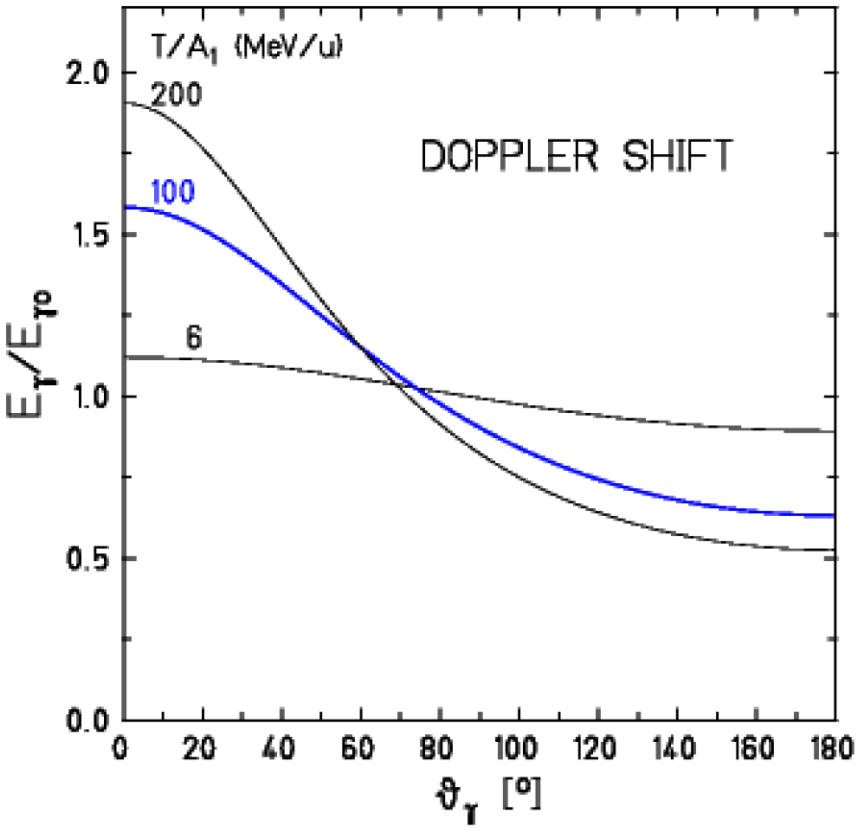




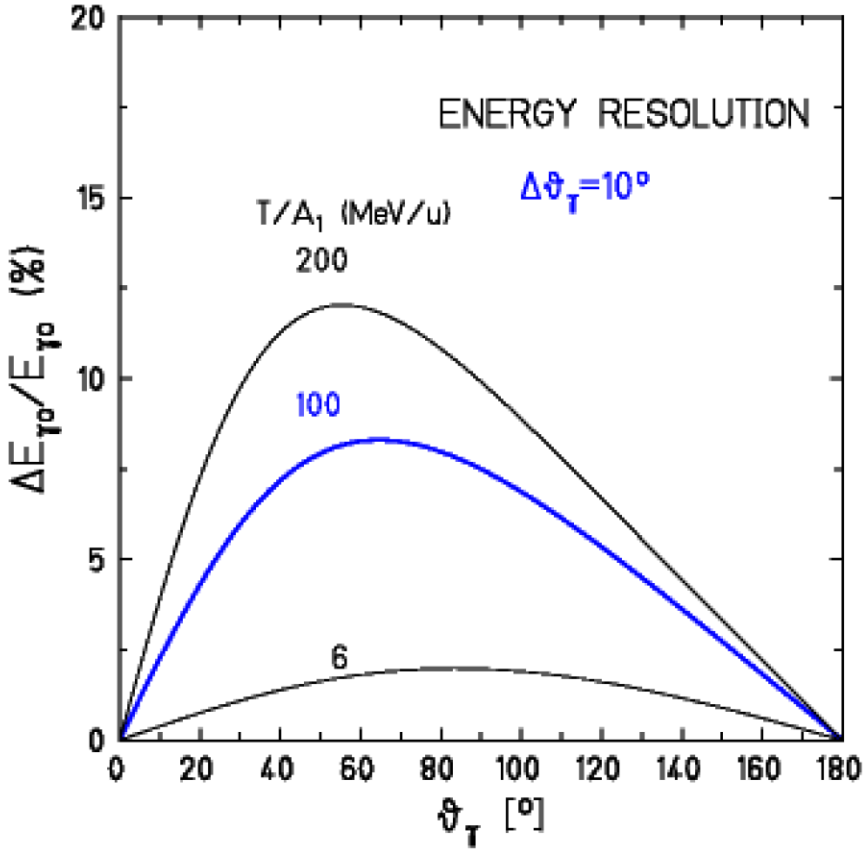
High granularity γ detector

Doppler Effect

Doppler shift



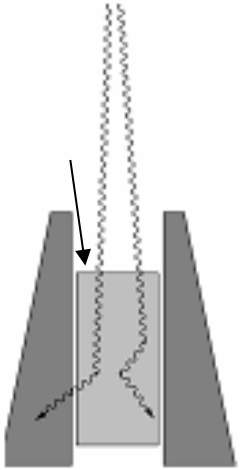
Doppler broadening



position sensitive γ detector

Ge detector concepts

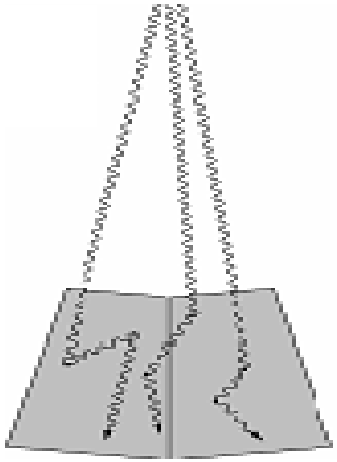
SHIELDED DETECTORS



Suppress the Compton scattered events

30% of total solid angle covered by Ge

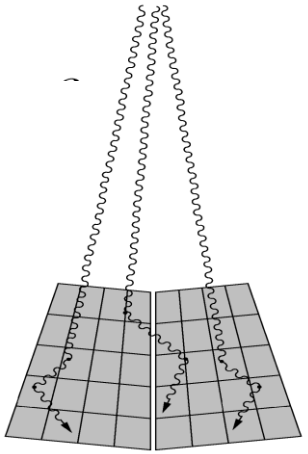
COMPOSITE DETECTORS



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

For high multiplicity Mγ, wrong summing of energies takes place

SEGMENTED DETECTORS

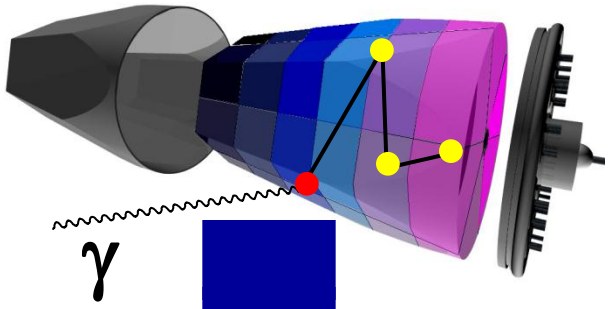


Discrimination between scattered events and individual hits possible with TRACKING

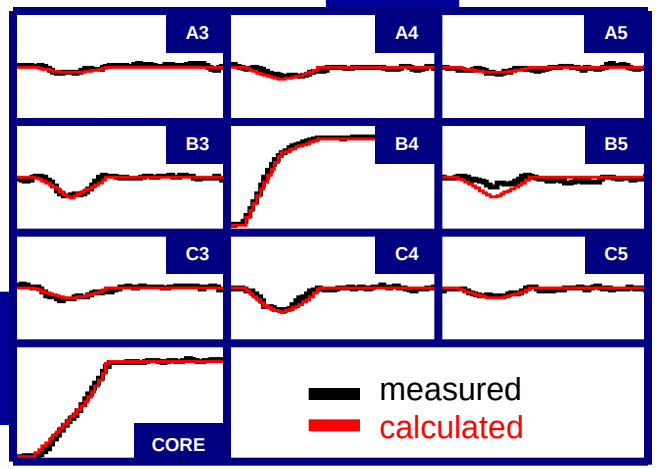
γ-ray Tracking Arrays

AGATA
ADVANCED GAMMA TRACKING ARRAY

Electrically segmented HPGe detectors



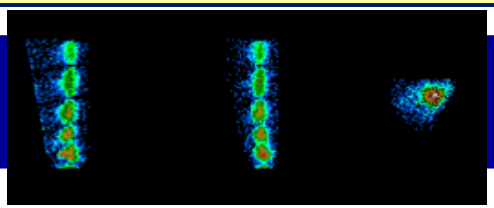
Digital electronics to record and process segment signals



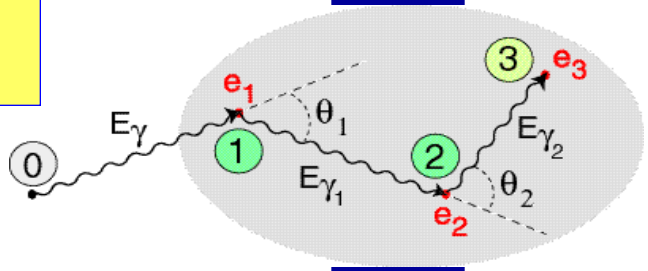
Deconvolution of the recorded waves through comparison with reference signals

Identification of the individual interaction points

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



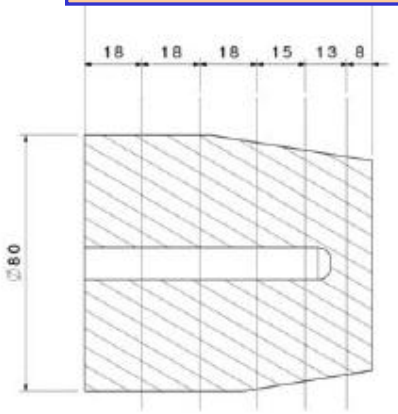
Reconstruction of tracks evaluating permutations of interaction points

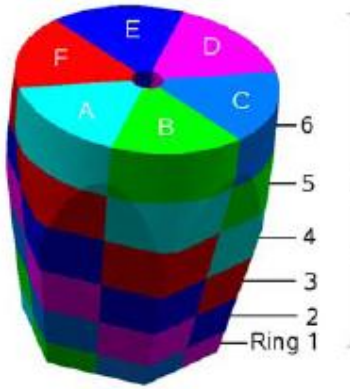


Energy and direction of γ-rays

AGATA Detector unit

Large volume 36-fold segmented, encapsulated Ge detector

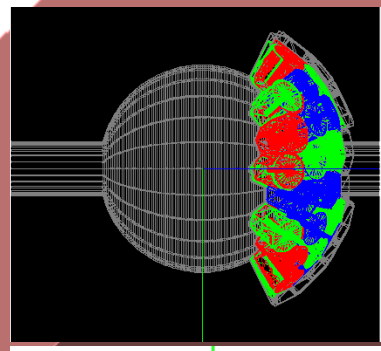


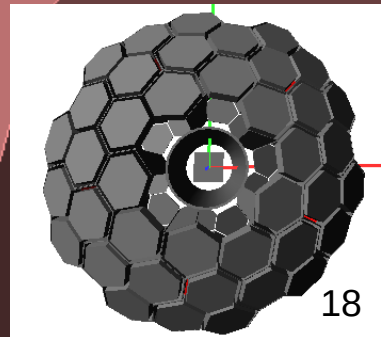


Triple Cluster unit

PRESPEC-AGATA Set-up = Early Implementation of HISPEC

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



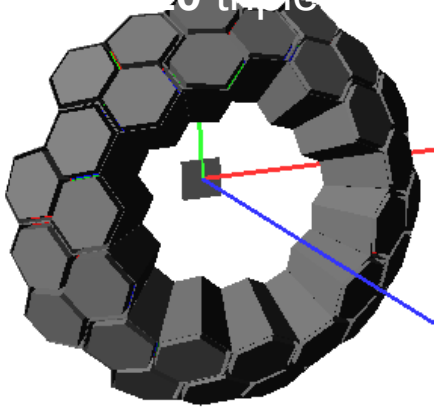


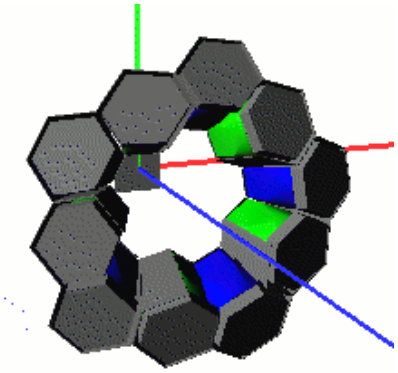
PreSPEC

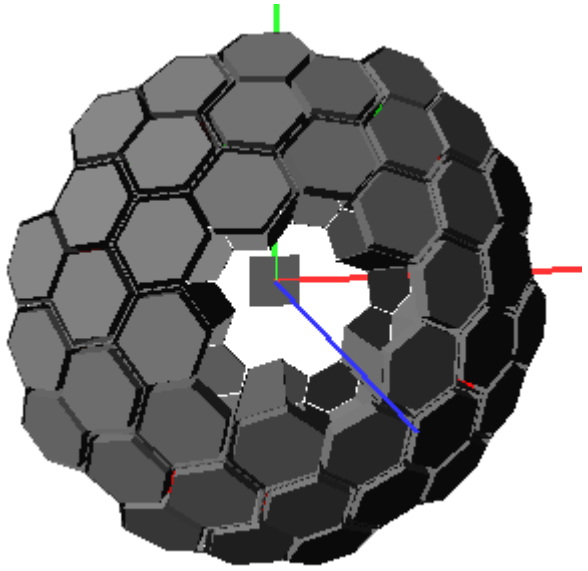
AGATA at GSI set-up

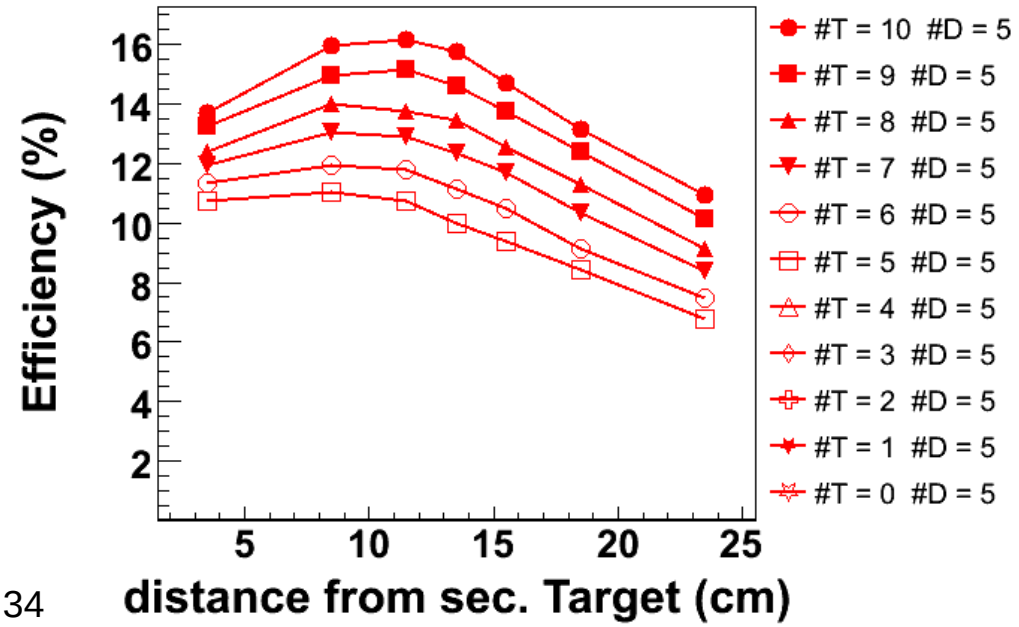
Challenge: FRS beam size!!!

double







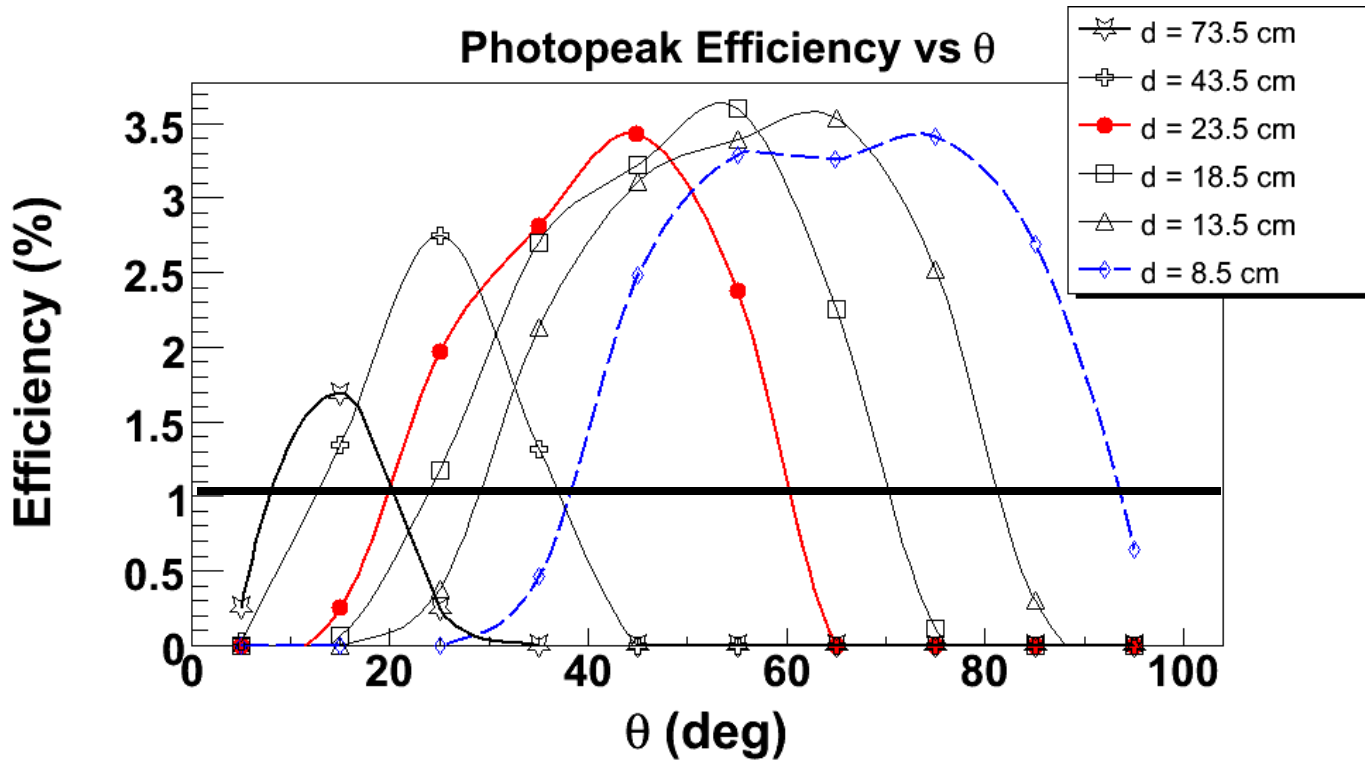


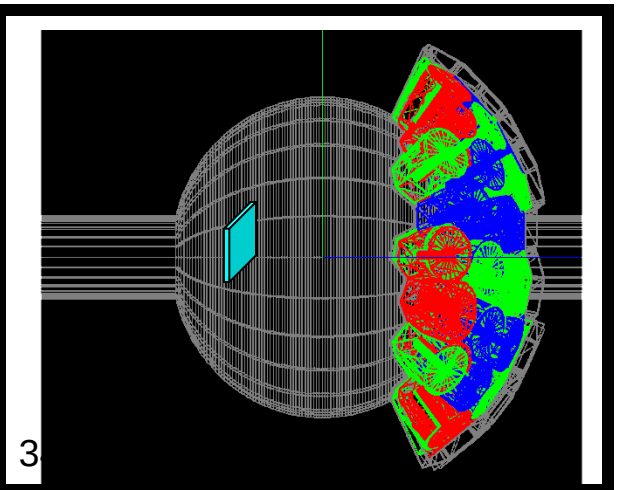
S2' Geometry:

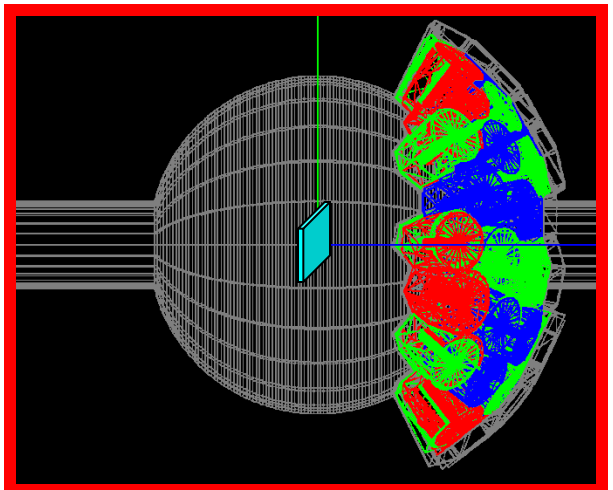
$P_{ph} \leq 17\%$; $\Delta E = 0.4\ \%$

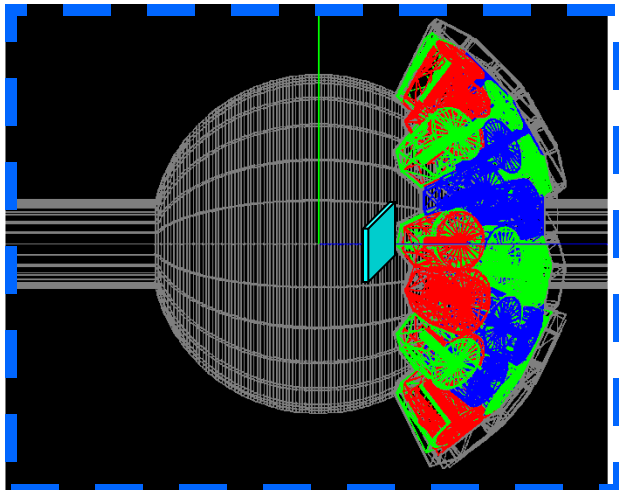
(sensitivity gain 30x RISING)

AGATA angular coverage

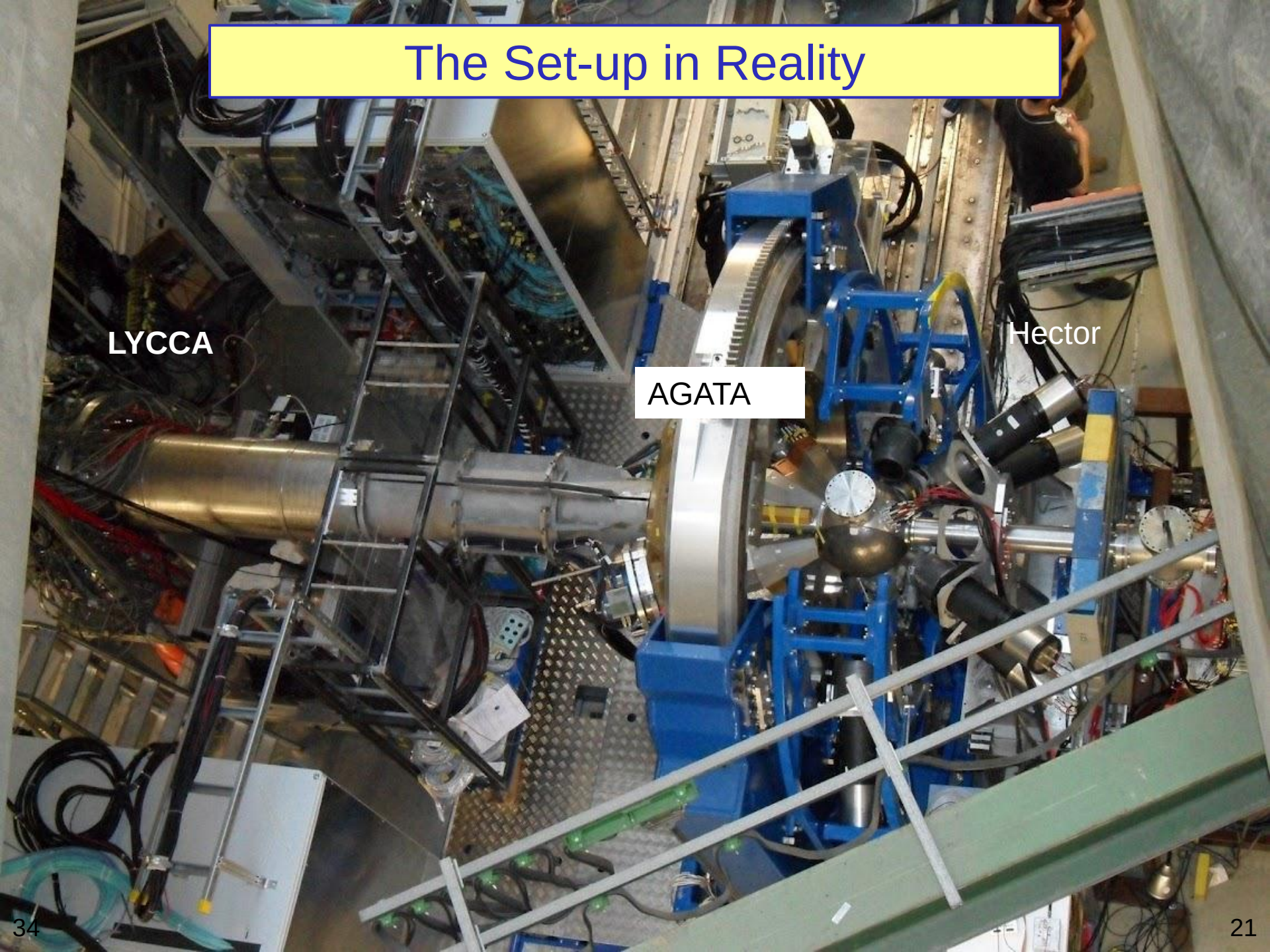




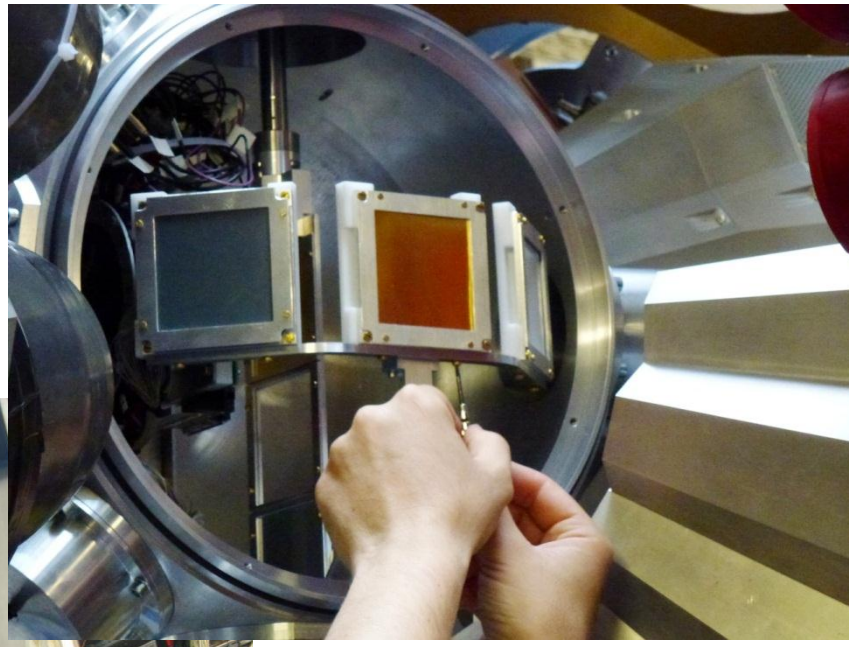


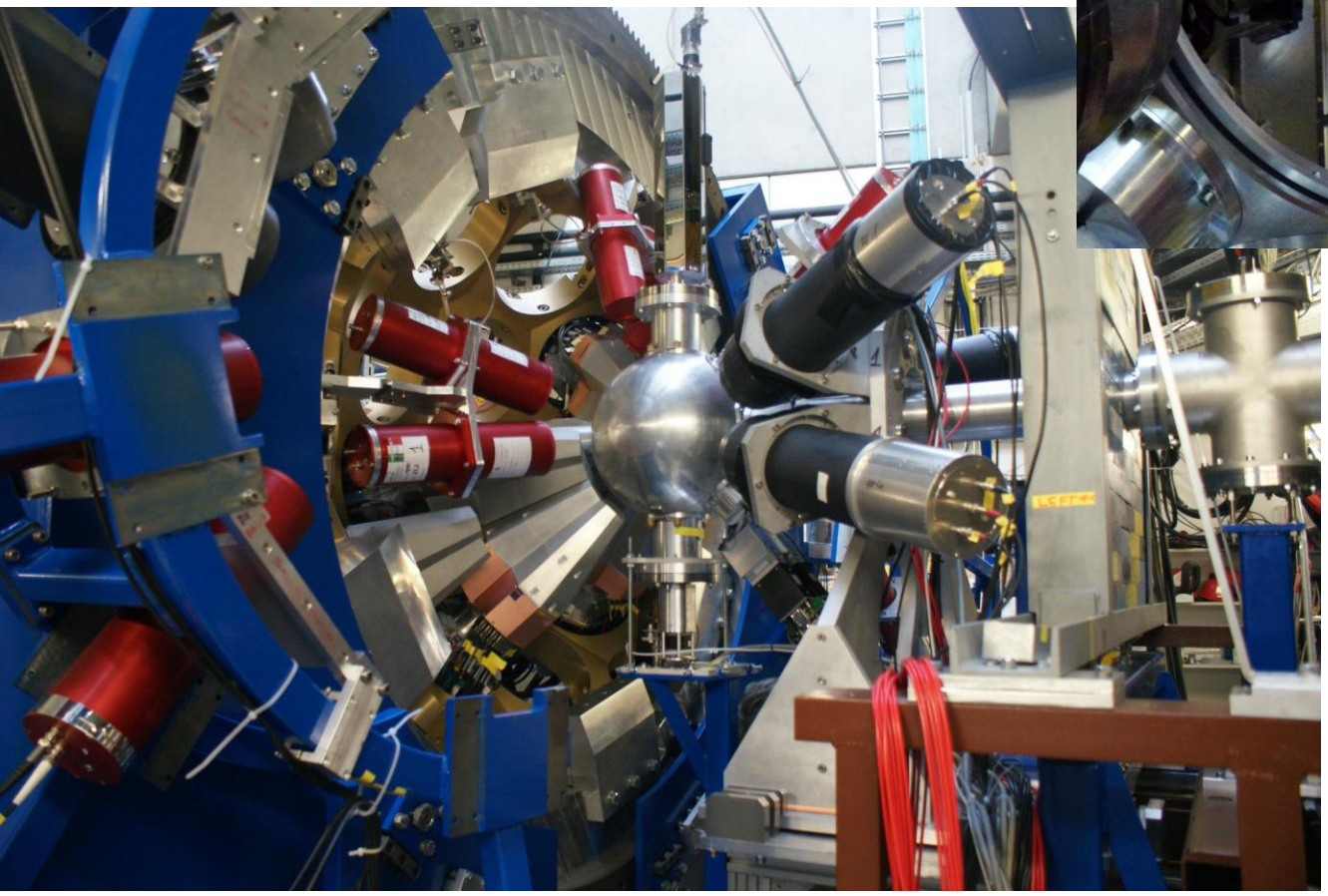


The Set-up in Reality

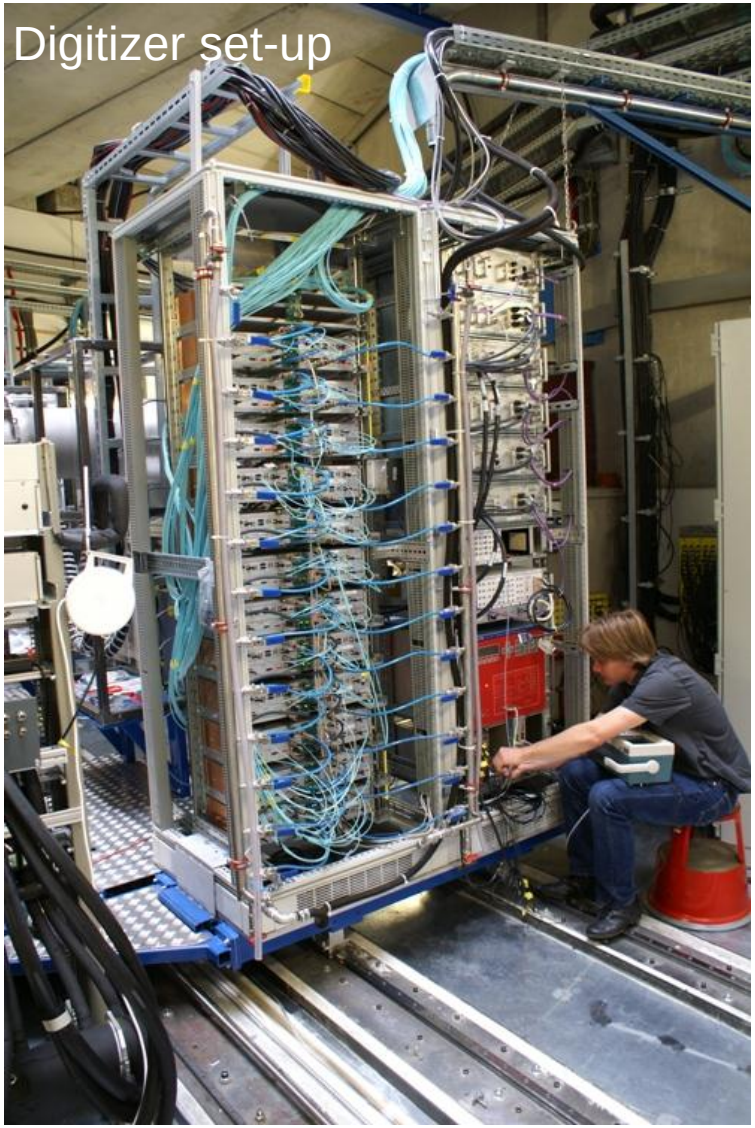


Target chamber





EDAQ



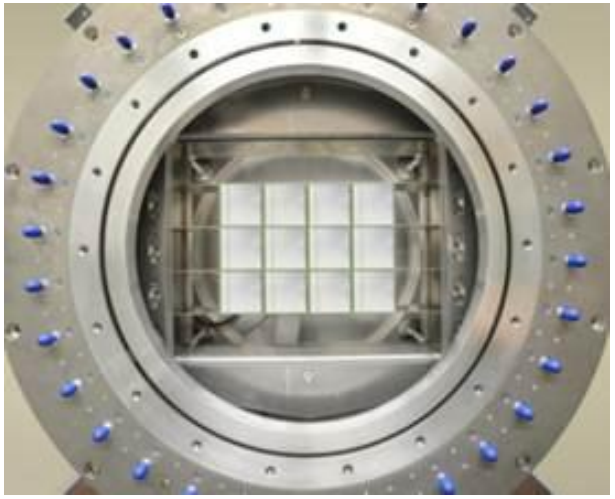
>2000 Channels (mainly high-resolution)
≈300 Gbyte/s (front-end)
≈1 Tbyte/d (after trigger and pre-processing)

11 VME Crates + AGATA DAQ

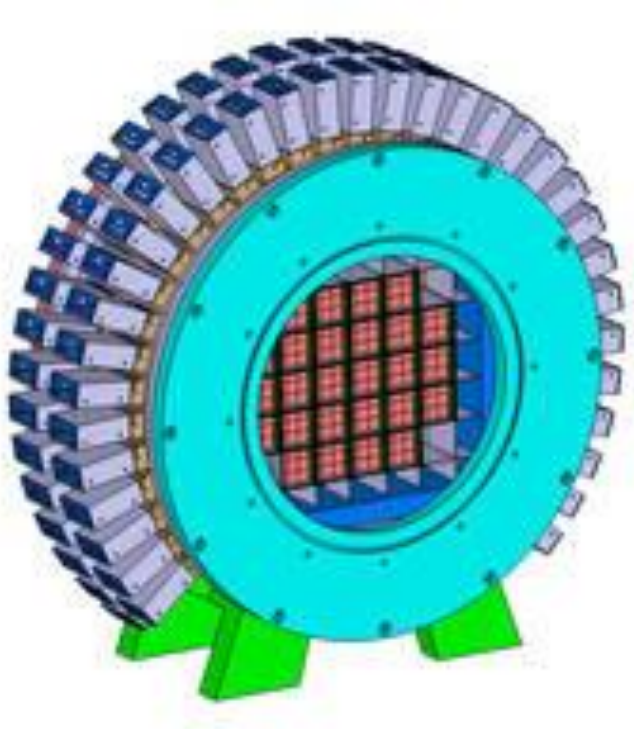
LYCCA

Position sensitive
ΔE-E calorimeter with
ToF capability

Detects projectile-like reaction product after the secondary target

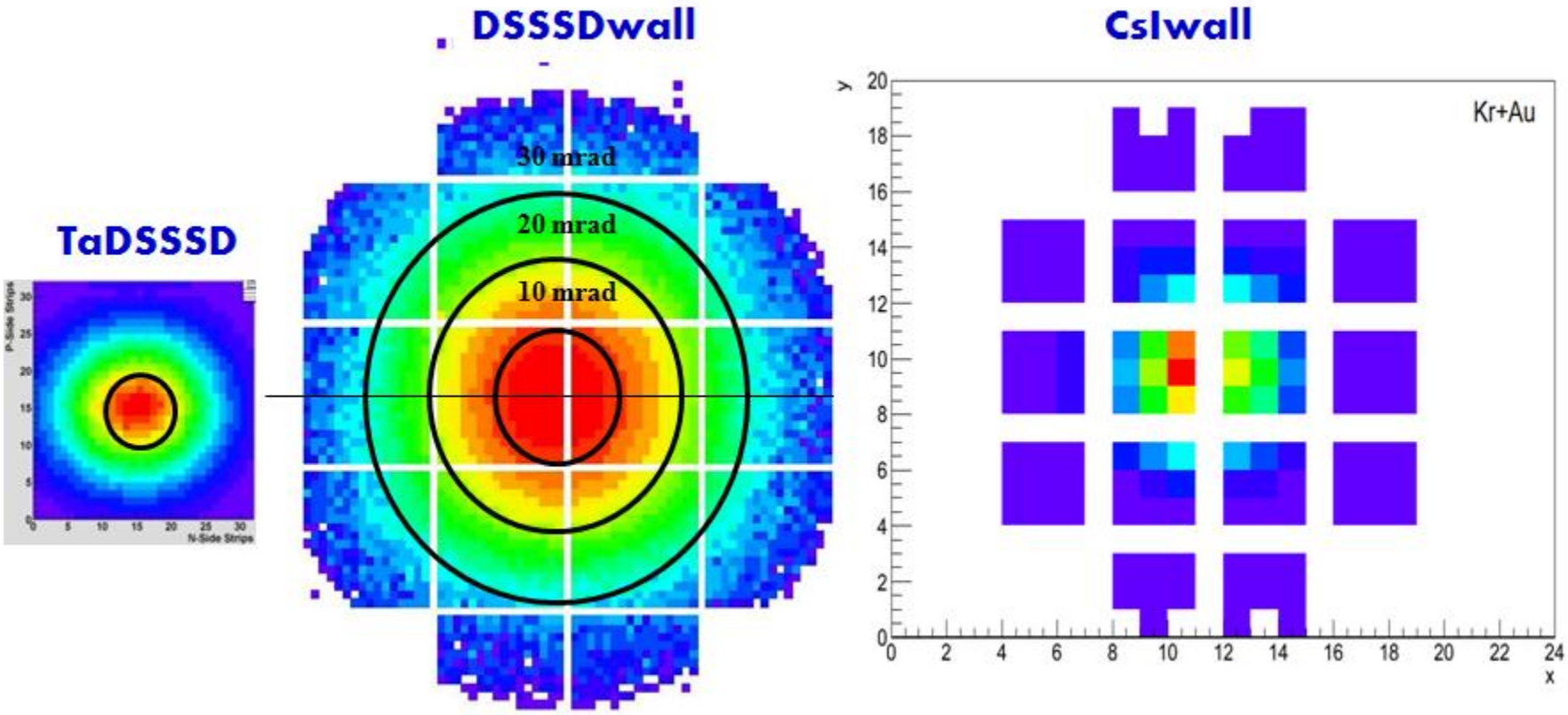


12 DSSDs + 12x9 CsI(Tl)

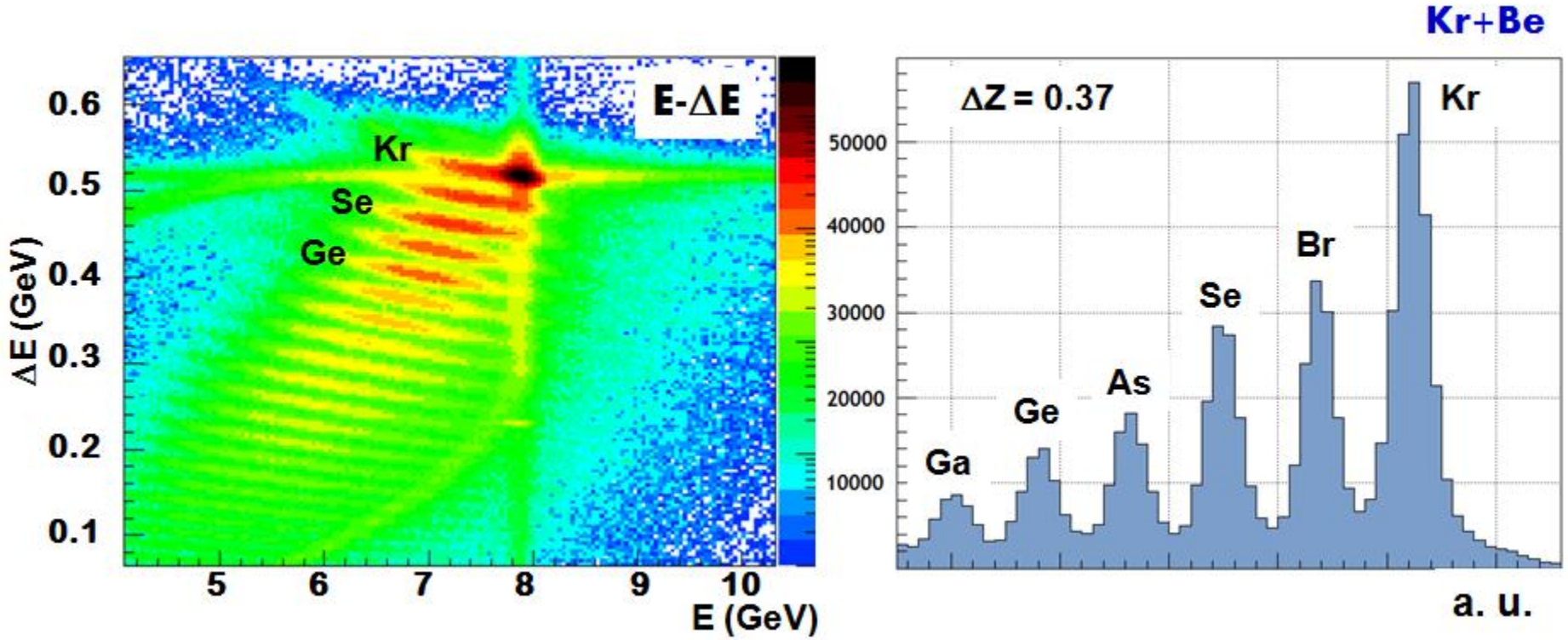


Tof Plastic membrane

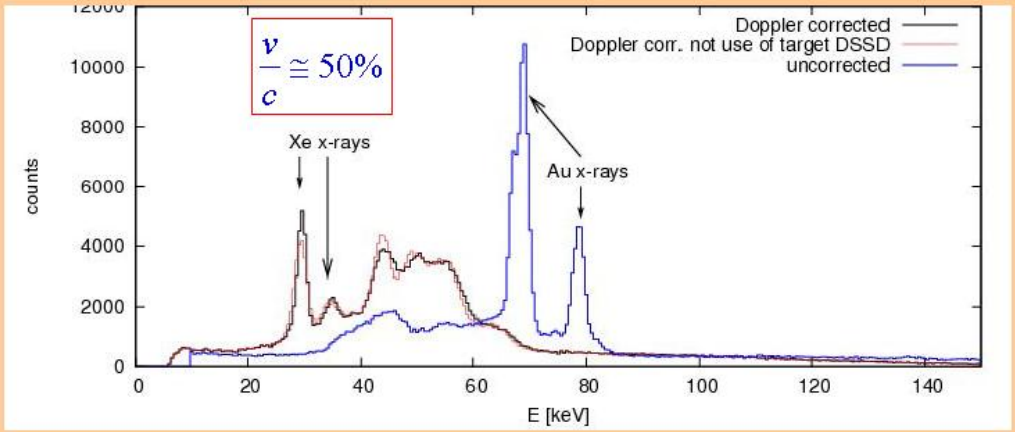
Position measurement



Z- determination with Kr beam

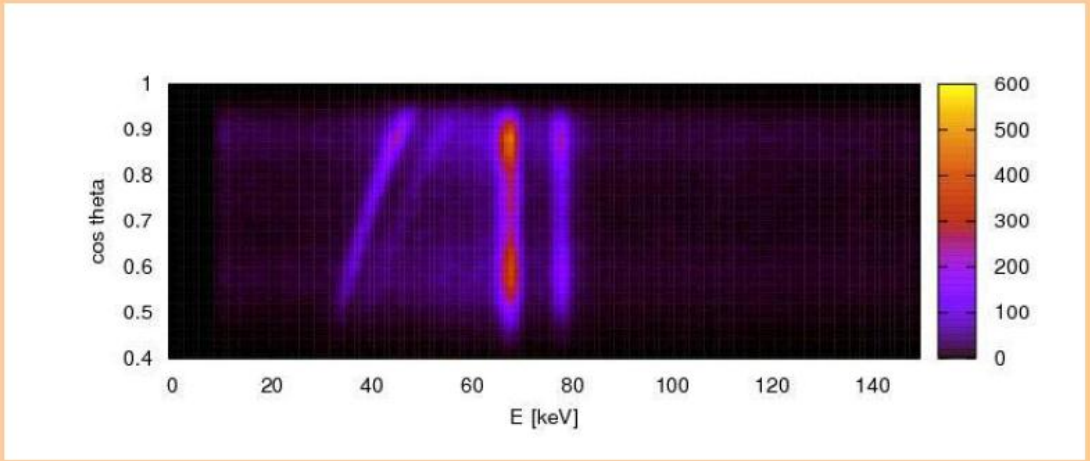


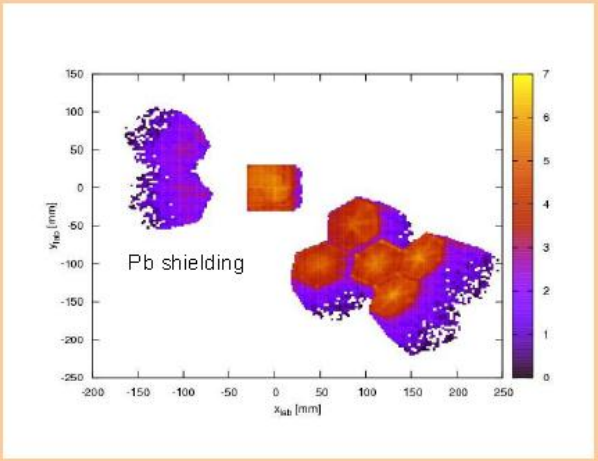
First Doppler correction with AGATA



$^{136}Xe \rightarrow {}^{197}Au$, 137 MeV/u

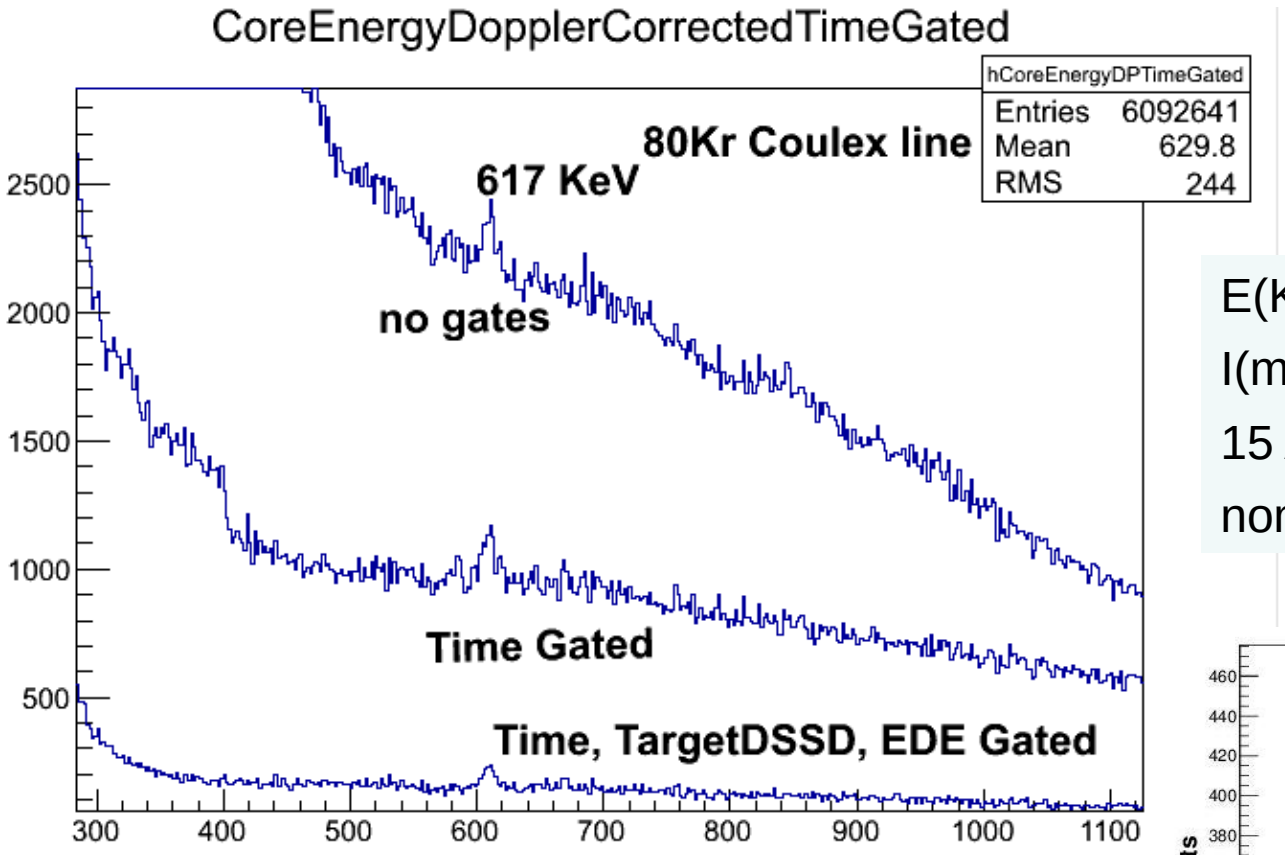
atomic excitations





hit pattern of AGATA detectors

^{80}Kr Coulomb Excitation

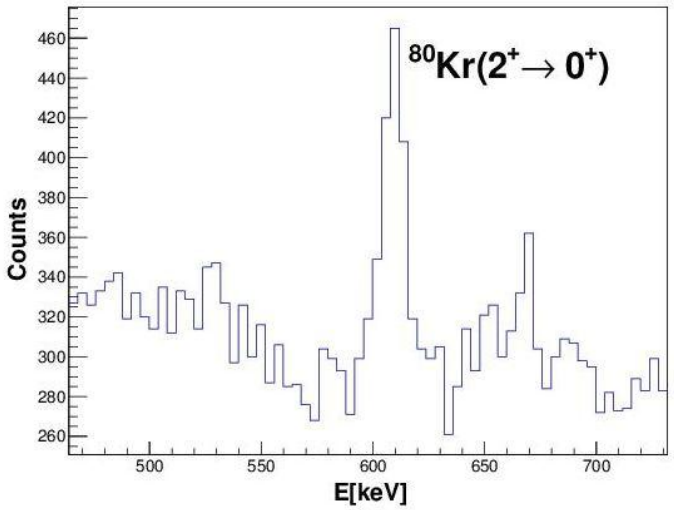


E(Kr) = 150 AMeV

I(max) = 30 kHz

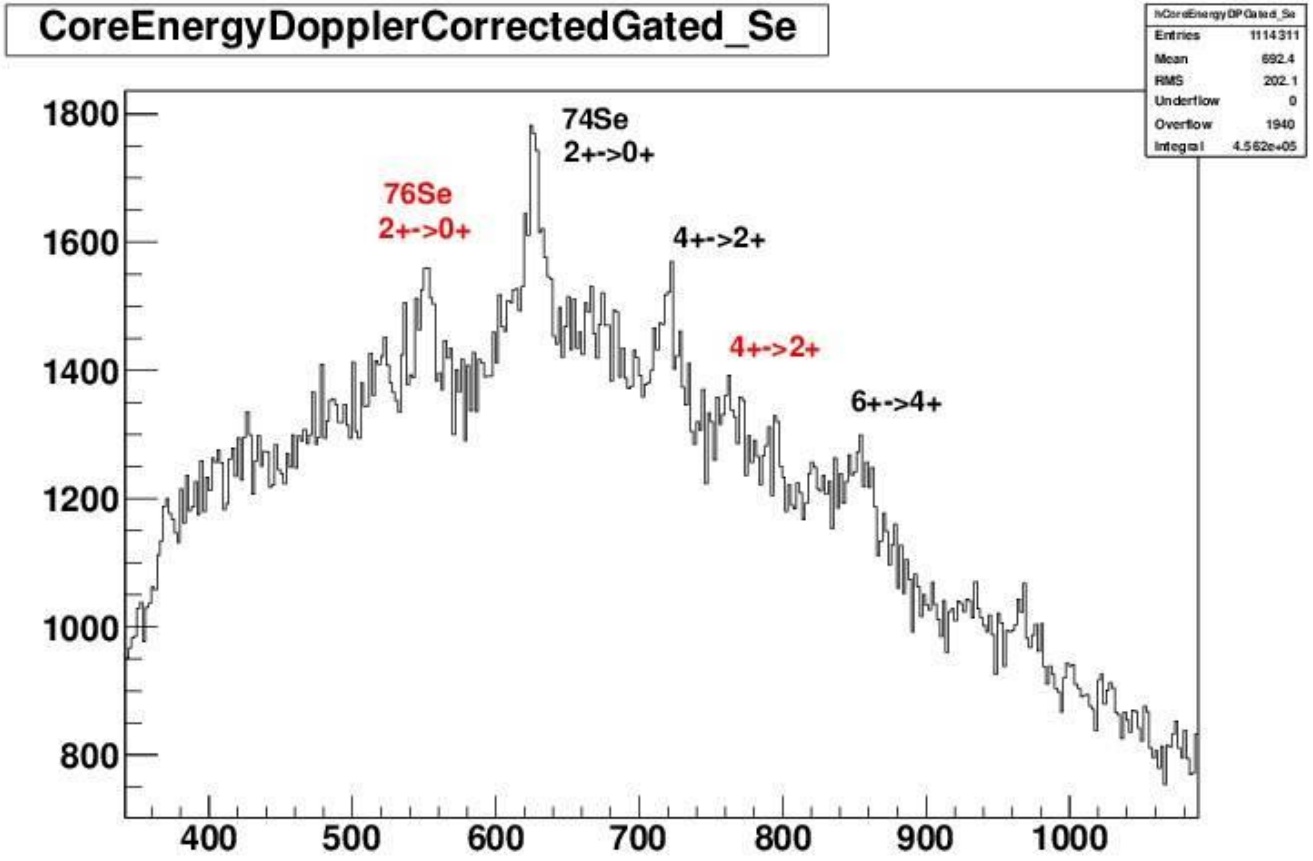
15 AGATA crystals

nominal target position



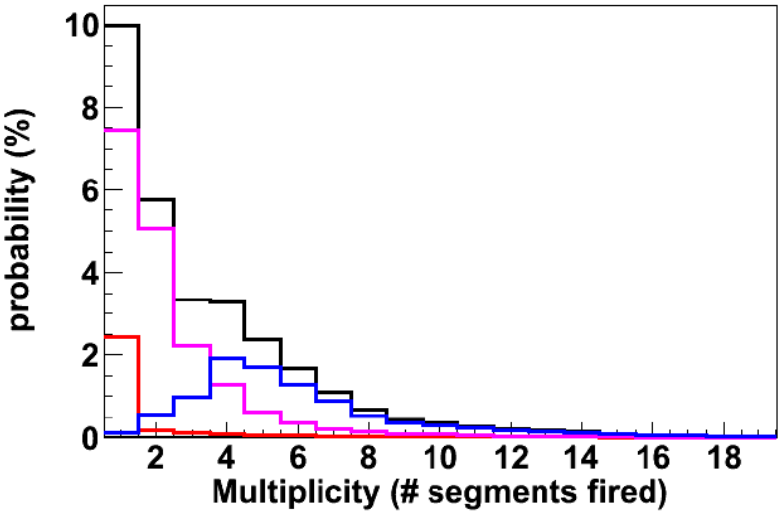
Preliminary analysis without full AGATA tracking

^{80}Kr secondary fragmentation

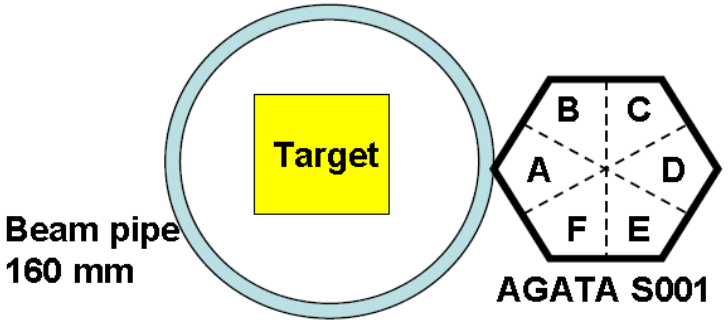


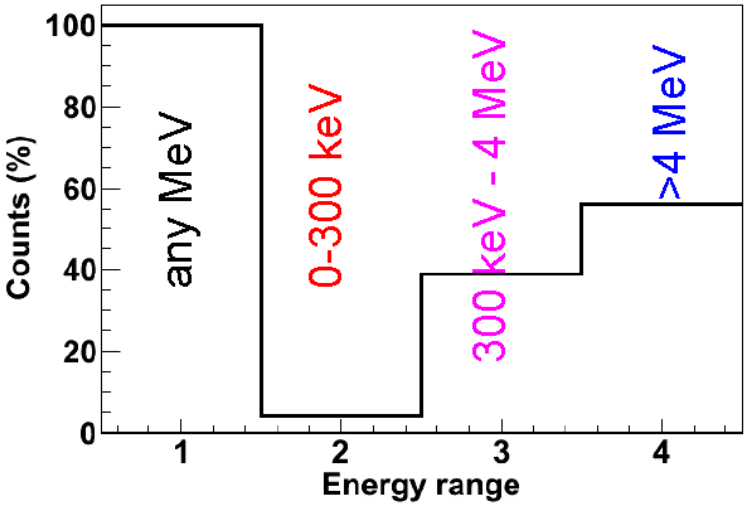
Preliminary analysis without
LYCCA mass gate

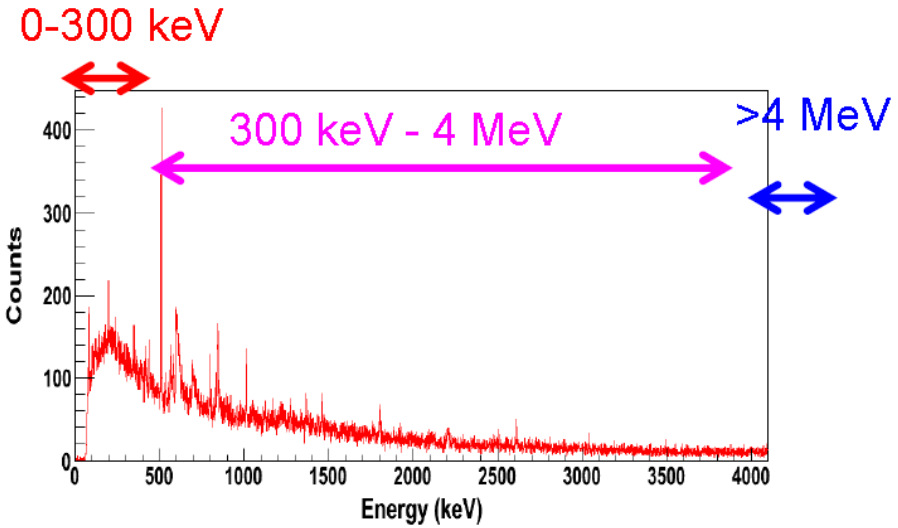
AGATA multiplicity distribution



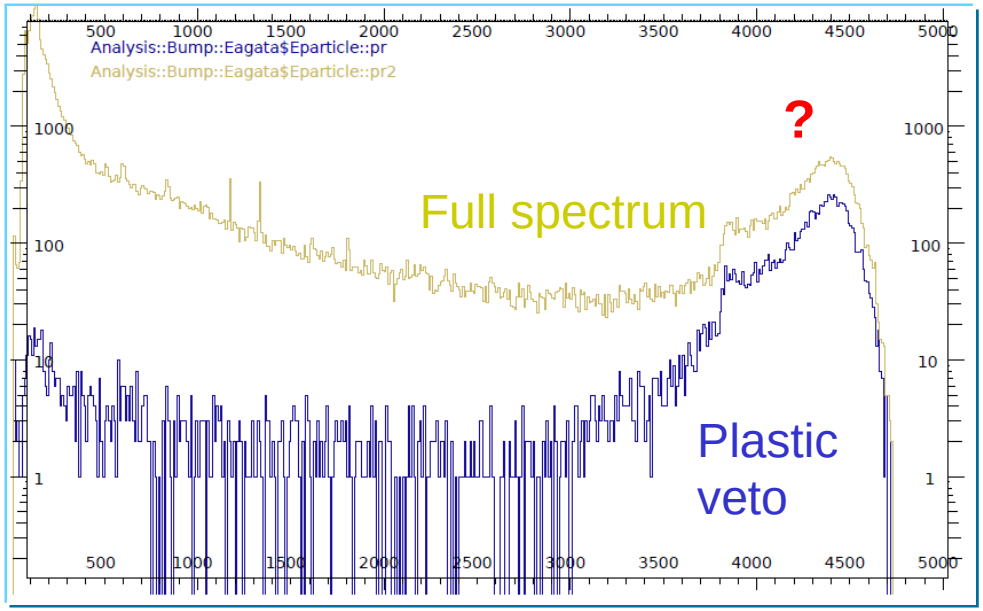
• Cross-section view of the setup:

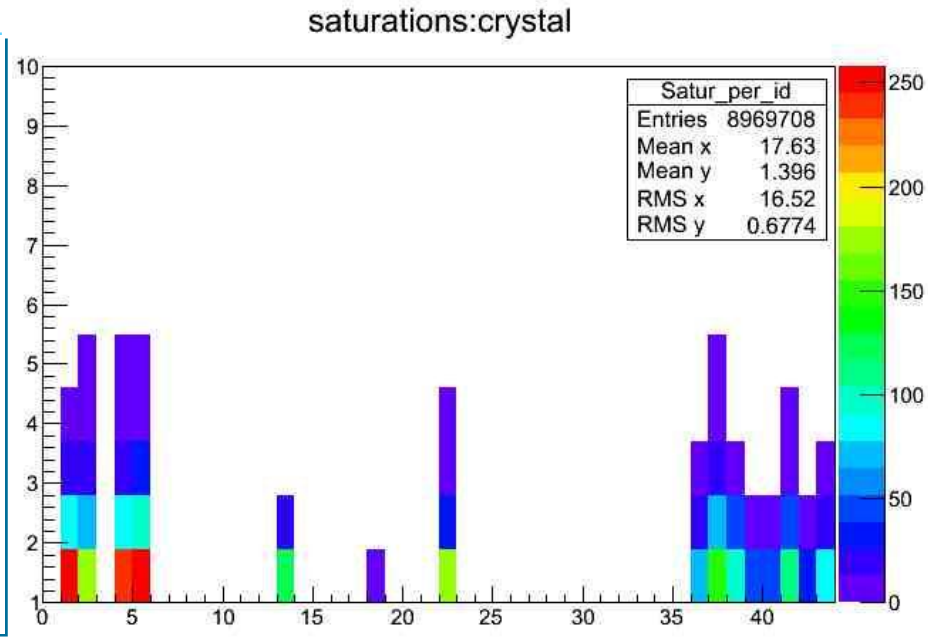






AGATA High-energy bump



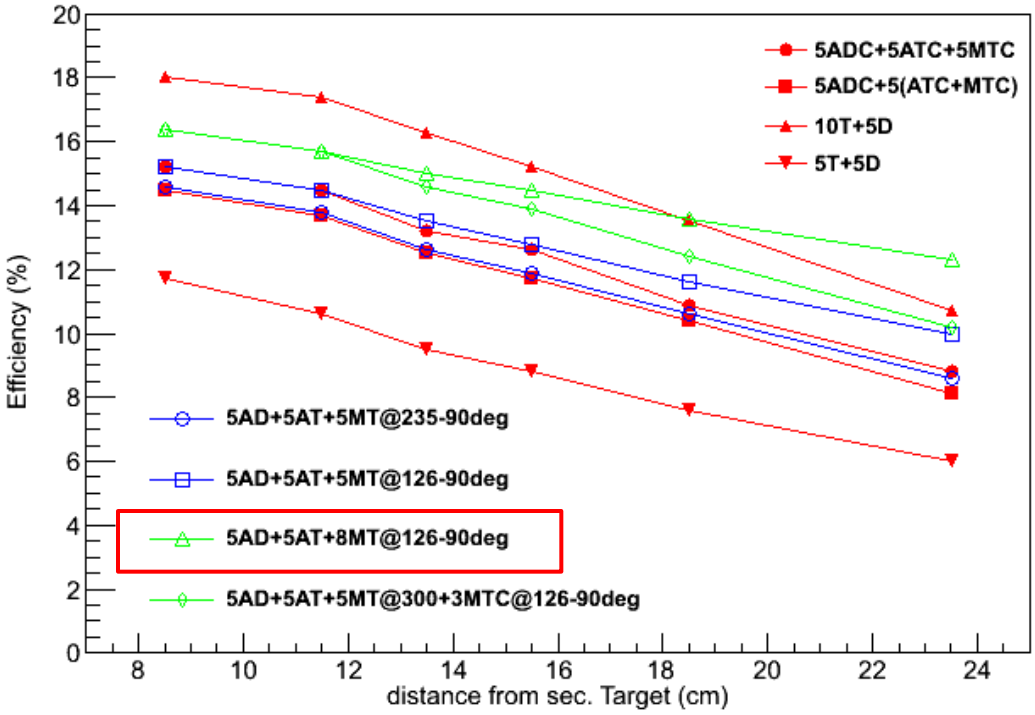


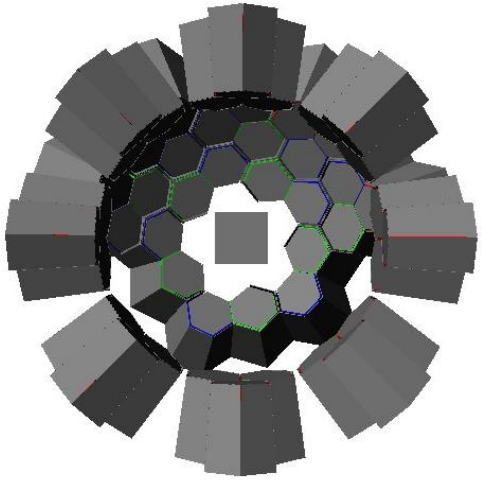
Crystal no. (~increasing θ)

→ Protonen, $E_P \leq 120$ MeV

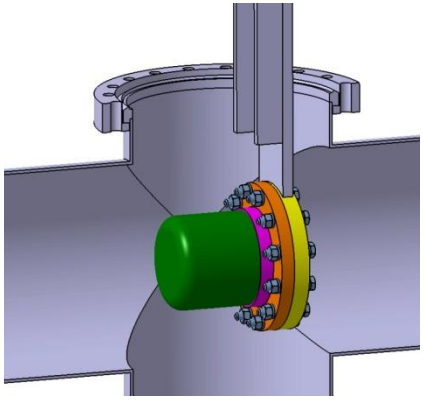
Campaign 2013

1. AGATA + MINIBALL





2. Hydrogen target



Conclusions

- NUSTAR follows and evolutionary approach and first experiments have already started
- NUSTAR instrumentation is fairly advanced and ready for FAIR
- PRESPEC-AGATA = HISPEC is the most complex nuclear spectroscopy experiment in the world
- The commissioning was successfully performed in 2012
- Gamma-tracking detectors boost the sensitivity for subtle nuclear structure effects by at one order of magnitude
- AGATA allows to detect and discriminate all kinds of background events
- First PRESPEC-AGATA experiments were performed in Fall 2012, more to come in 2013

A Great Collaboration