First Taste of HISPEC @ FAIR: PreSPEC-AGATA in Operation

TECHNISCHE UNIVERSITÄT DARMSTADT

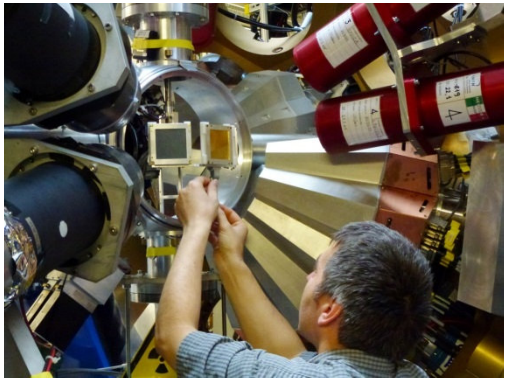
N. Pietralla for …

Campaign: D. Rudolph, W. Korten, M. Bentley, **et al. for PreSPEC-AGATA**

GSI: J. Gerl, M. Gorska, I. Kojouharov, H. Schaffner, N. Kurz et al.

FAIR@GSI: H.-J.Wollersheim, P. Boutachkov, S.Pietri et al.

TU Darmstadt: L. Cortes, A. Givechev, G. Guastalla, C. Louchard-Henning, M. Lettmann, E. Merchan, H. Pai, D. Ralet, **M. Reese**, P. Singh, C. Stahl et al.



Bundesministerium für Bildung und Forschung

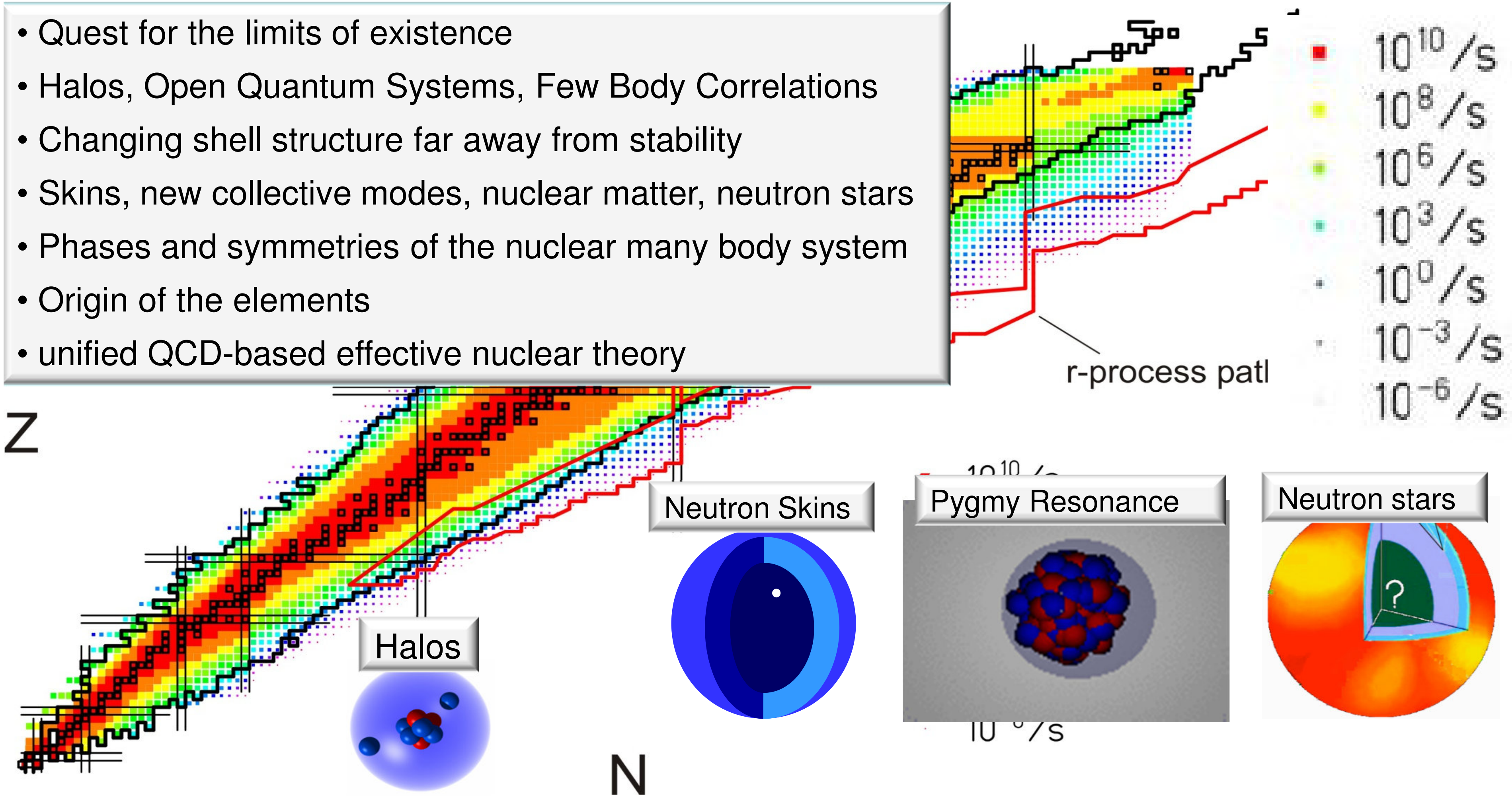
BMBF

HIC for FAIR

Helmholtz International Center

Central Topics for NUSTAR at FAIR

- Quest for the limits of existence
- Halos, Open Quantum Systems, Few Body Correlations
- Changing shell structure far away from stability
- Skins, new collective modes, nuclear matter, neutron stars
- Phases and symmetries of the nuclear many body system
- Origin of the elements
- unified QCD-based effective nuclear theory



HISPEC – High Resolution Gamma Spectroscopy

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Purpose:

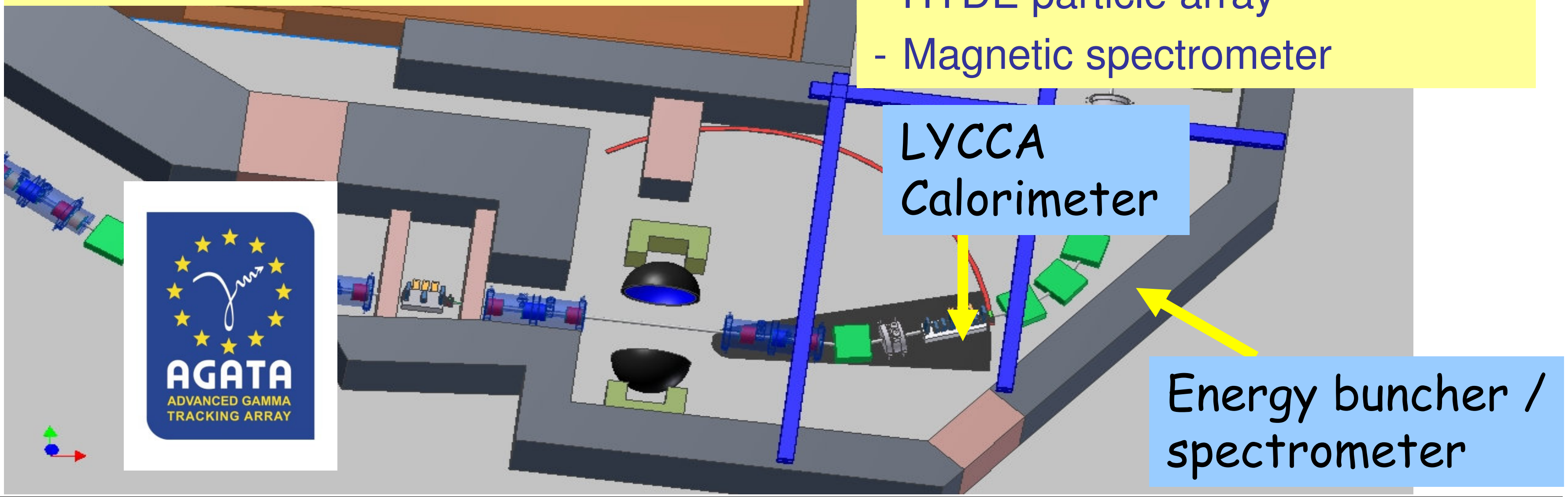
High-resolution in-flight spectroscopy of exotic nuclei using Super-FRS RIB beams at 3 – 400 A·MeV

Methods:

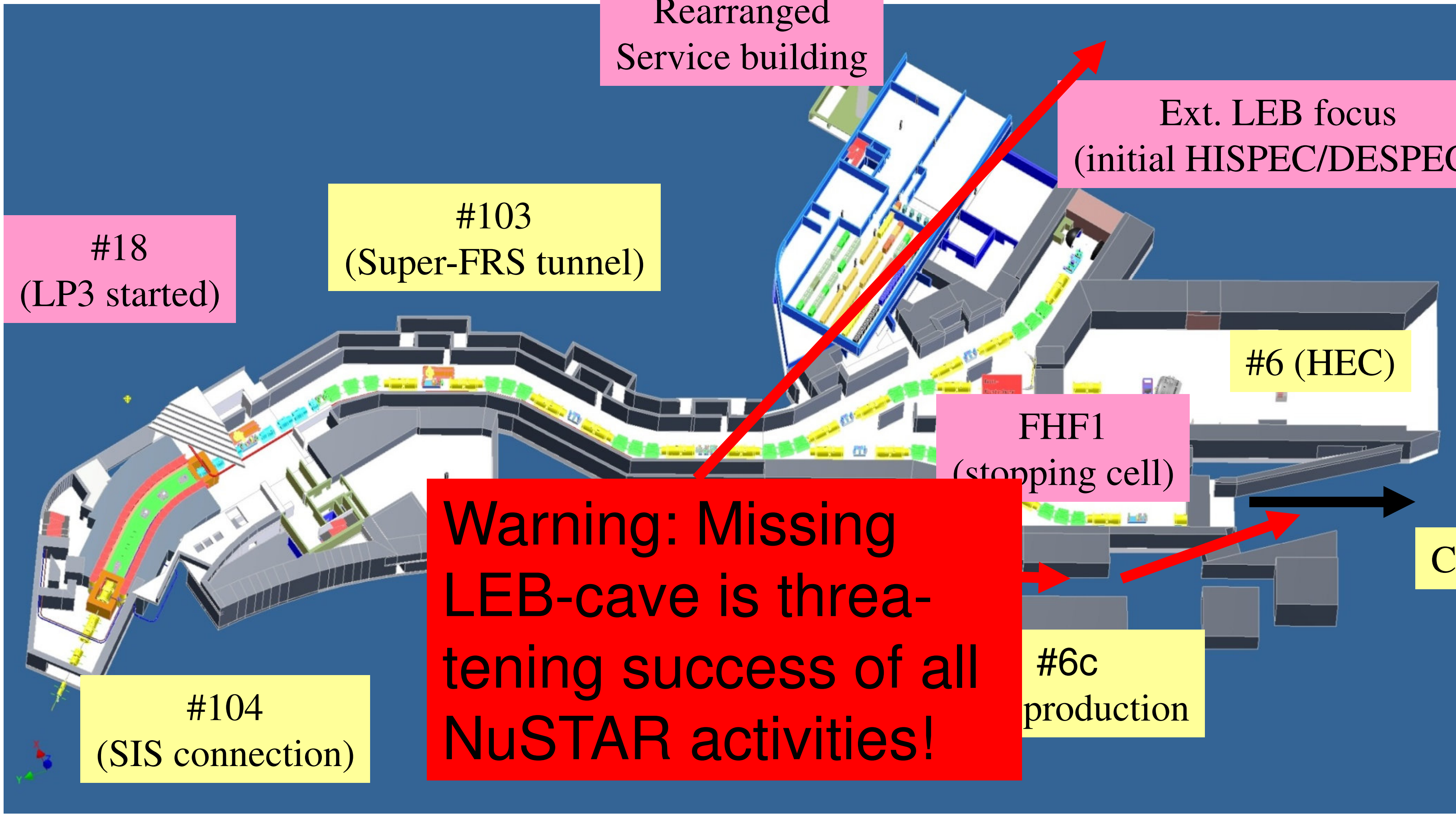
- Coulex, knock-out, fragmentation at relativistic energies, direct reactions,…

Set-up:

- Beam tracking and identification (LYCCA)
- Active target
- AGATA
- Fast timing
- HYDE particle array
- Magnetic spectrometer



Super-FRS Buildings (FAIR MSV version)



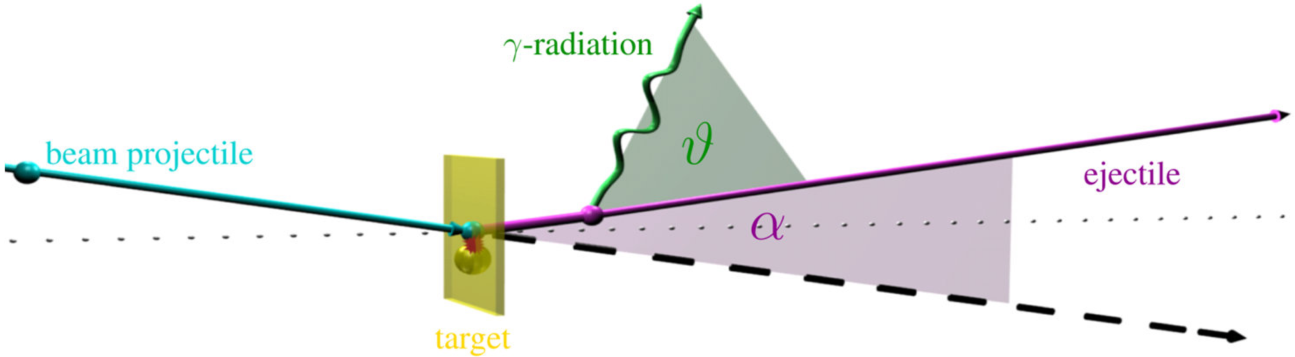
Warning: Missing LEB-cave is threatening success of all NuSTAR activities!

Outline of Presentation

- **Experimental challenges for HISPEC**
- **Doppler effect in γ-spectroscopy**
- **History of HISPEC**
- **PreSPEC**
- **New experimental techniques (M1 Coulex)**
- **First week of PreSPEC-AGATA @ FRS 2014**

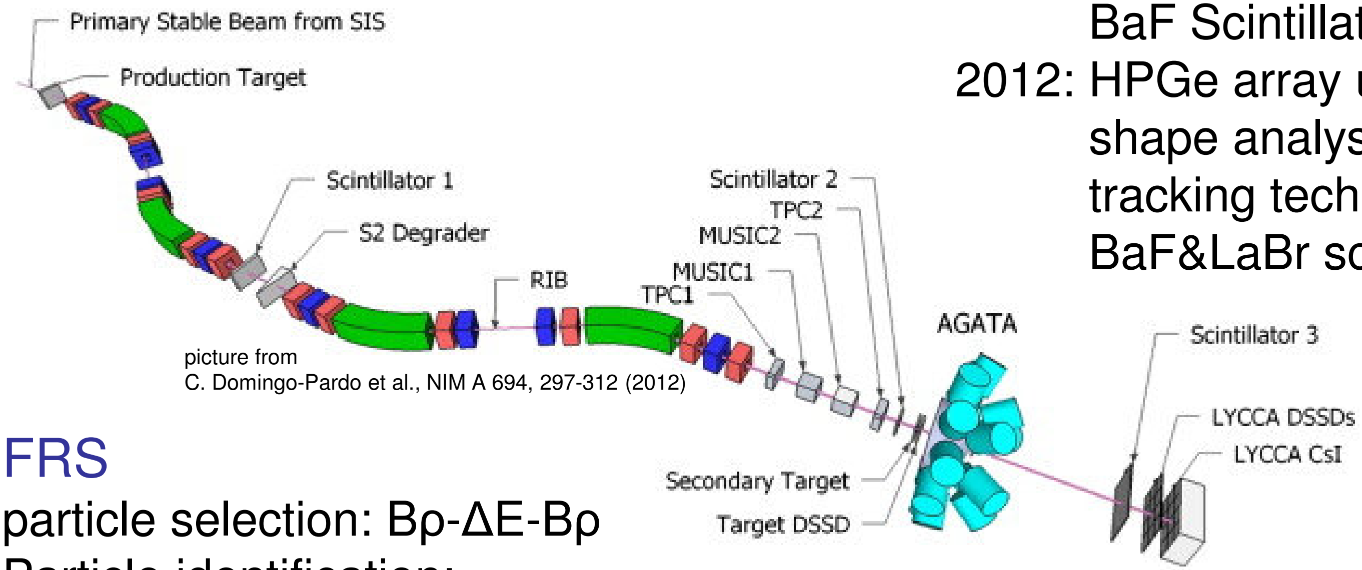
Experimental Challenges

1. Relativistic secondary RI Beam from in-fight separator
2. Nuclear reaction in stationary target
3. Excited reaction products leave the target (flight direction changes)
4. Emission of Doppler-shifted γ-Radiation



- Need γ-energy in rest frame of emitting nucleus (Doppler-correction)
- → Need tracks of particle and γ-ray(s)
- Spectroscopic resolution depends on **accurate track reconstruction of both, γ-ray and particle!**

PreSPEC Schematic Setup



picture from
C. Domingo-Pardo et al., NIM A 694, 297-312 (2012)

Gamma-ray detection

2011: 105 HPGe detectors (Euroball)
BaF Scintillators (HECTOR)

2012: HPGe array using pulse-shape analysis and γ-ray tracking techniques (AGATA)
BaF&LaBr scintillators (HECTOR+)

FRS

particle selection: Bρ-ΔE-Bρ

Particle identification:
- TPC tracking detectors
- ToF measurement
- Energy-loss measurement

LYCCA

Outgoing particle tracking and identification:
- Z identification via E-ΔE
- Mass identification via E-ToF

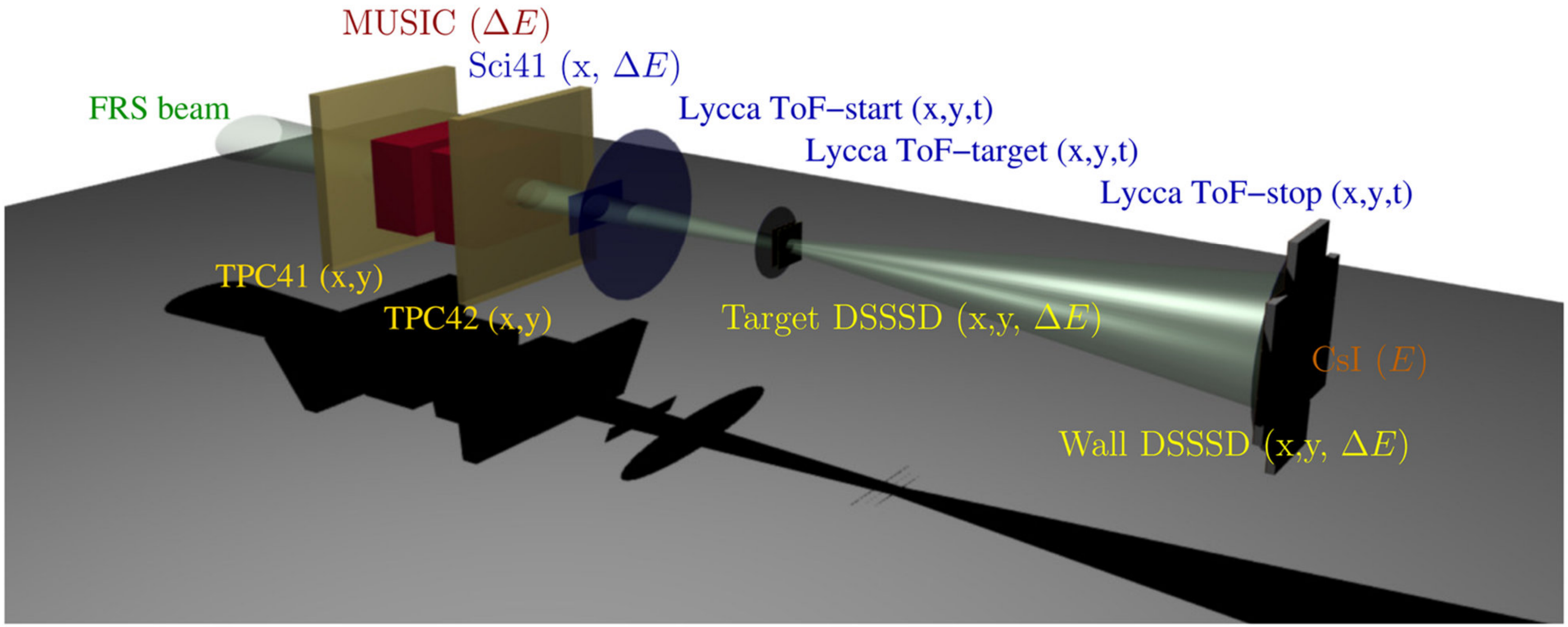
Particle Tracking & Identification

FRS detectors

- 2 TPCs for trajectory
- 2 Ionization chambers for Z identification

LYCCA detectors

- **17 silicon DSSSD detectors for tracking and energy loss**
- **144 CsI scintillators for particle energy**
- **3 fast plastic scintillators for time of flight and tracking**

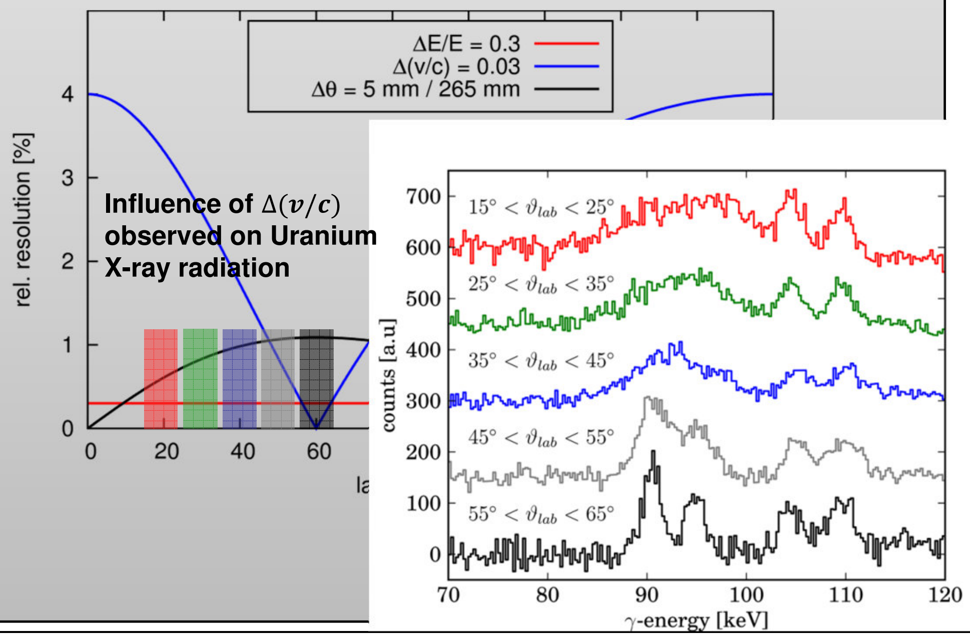


Doppler-Effect in γ-Spectroscopy

Doppler shift for photons emitted at $\beta = v/c$:

$$E_{\text{laboratory}} = E_{\text{rest}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\vartheta_{\text{lab}})}$$

Achievable resolution for typical PreSPEC-AGATA conditions (analytic Gaussian error propagation):



More effects depend on half-life and J^{π} of excited state and geometry:

- peak shapes
- centroid shifts
- angular distribution

Discussion of these effects:
P. Doornenbal, et. al., NIM A, 613, 2, (2010), 218

Peak shape from Doppler shift effects have been used to measure lifetimes:
A. Lemasson, et. al., Phys. Rev. C, 85, 041303, (2012)

Software for peak-shape calculation, fitting, and scientific usage is developed at TU-Darmstadt (C. Stahl / M.Lettmann) → M.Reese

Ge-Spectroscopy at Relativistic Velocities

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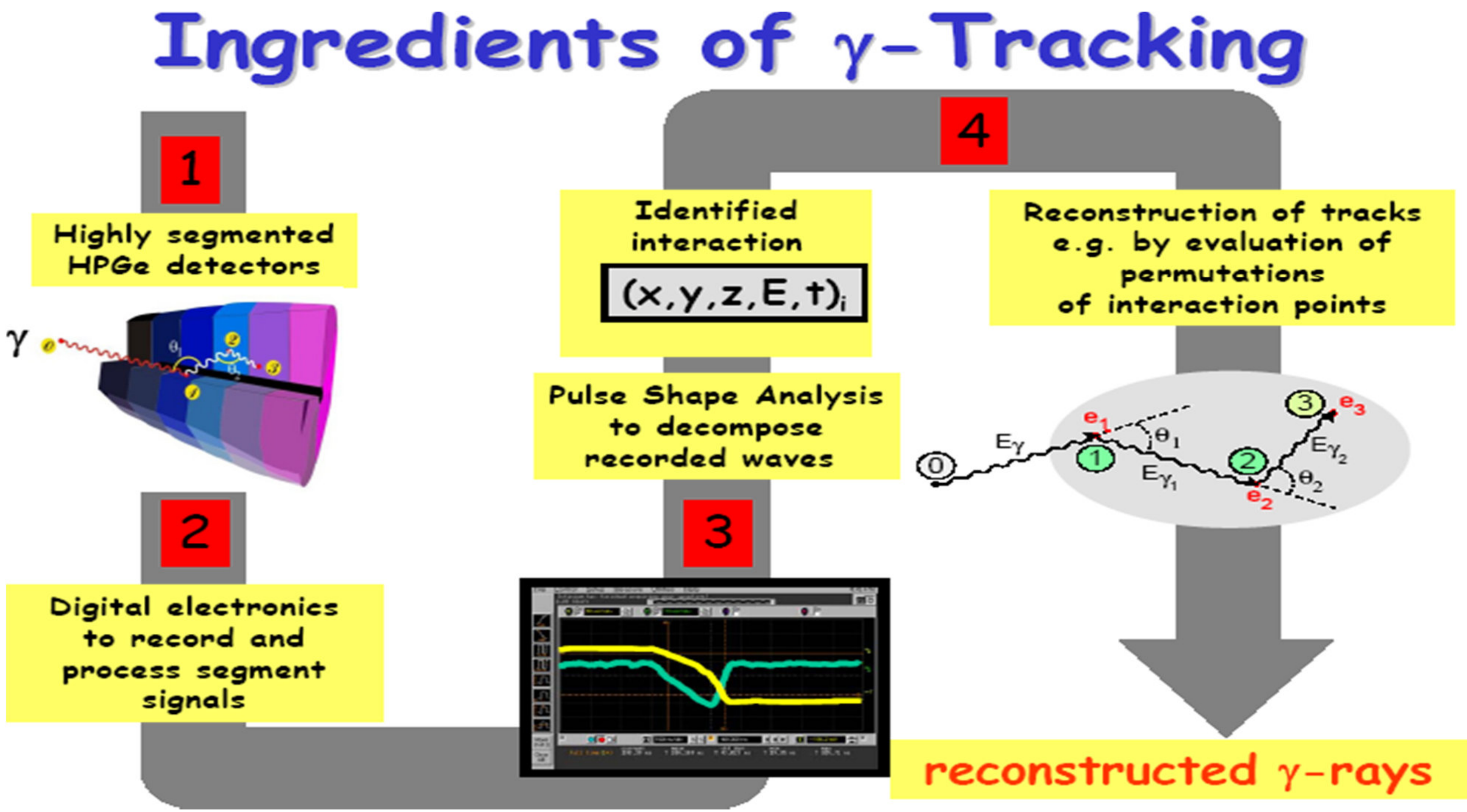
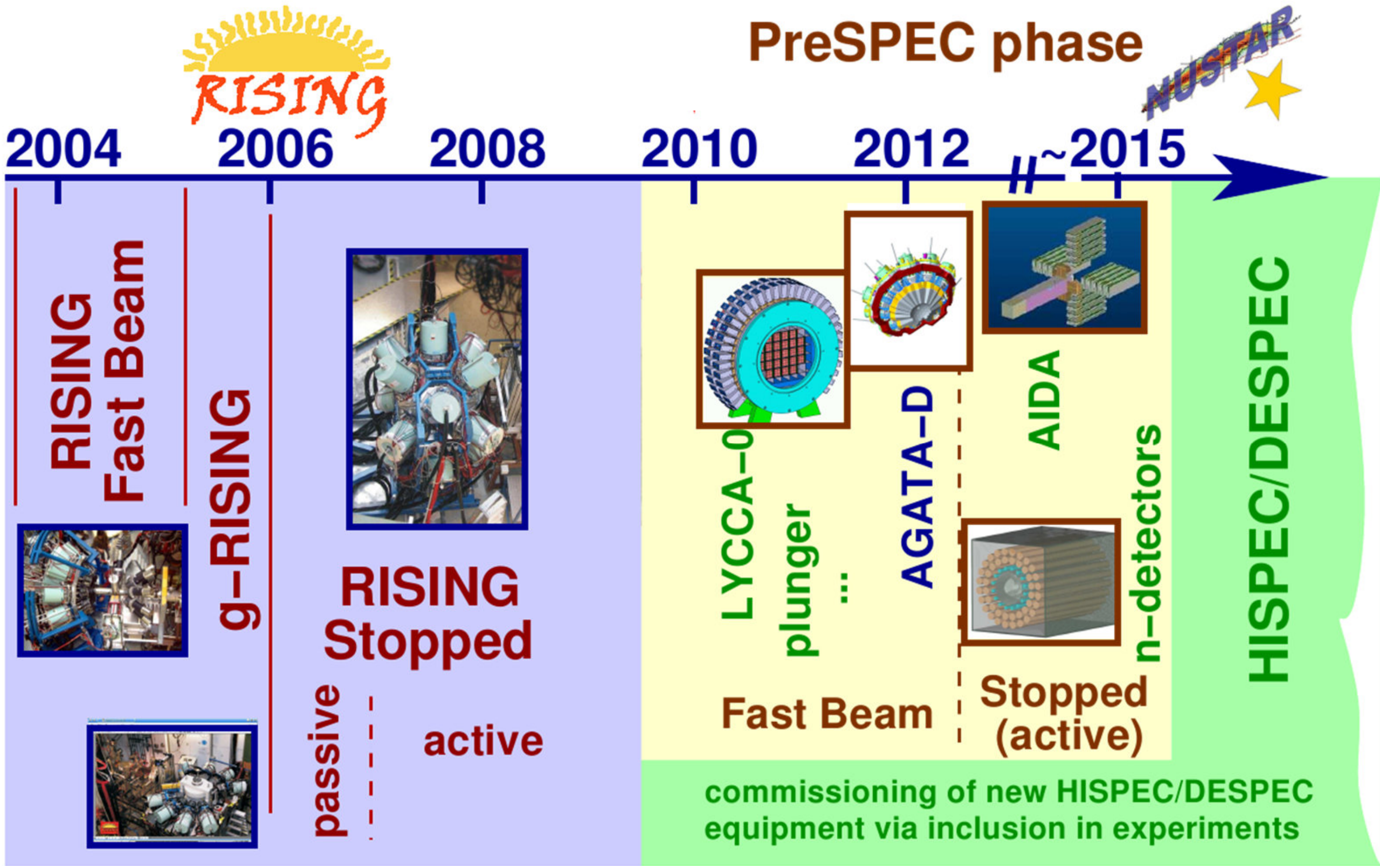
- Doppler-shift extremely large
  - $\rightarrow$ precision measurement of gamma and particle positions
    - **either HPGe detector at large distance (RISING)**
    - **or segmented HPGe detector with pulse-shape analysis (PSA): AGATA**

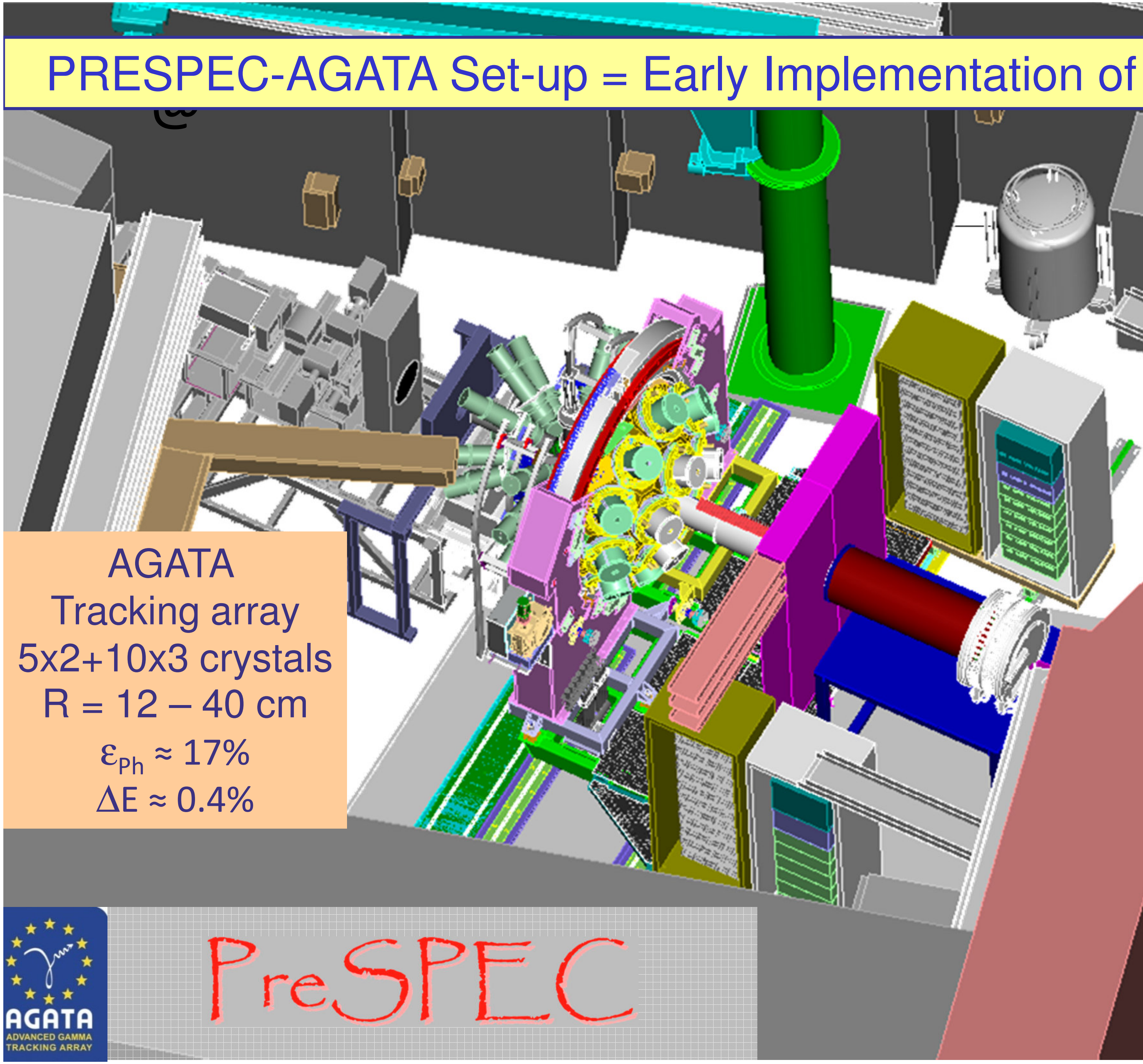
PSA and γ-Tracking in AGATA



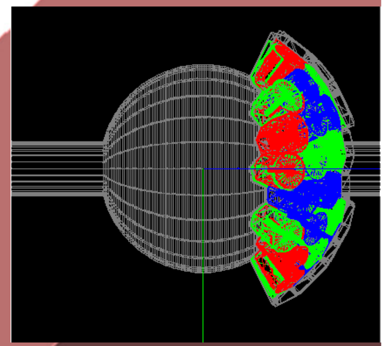
History of HISPEC

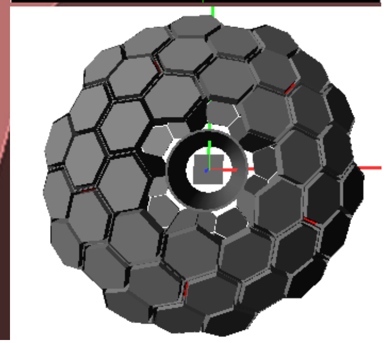


PRESPEC-AGATA Set-up = Early Implementation of HISPEC



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





AGATA ADVANCED GAMMA TRACKING ARRAY

PreSPEC

From PreSPEC to HISPEC

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2010	2011	2012	2013	2014	2015

RISING

PRESPEC In-beam
LYCCA-0 Commis.

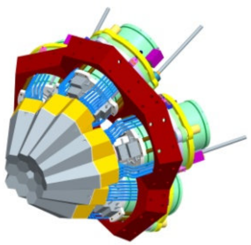
AGATA Demonst.
Legnaro

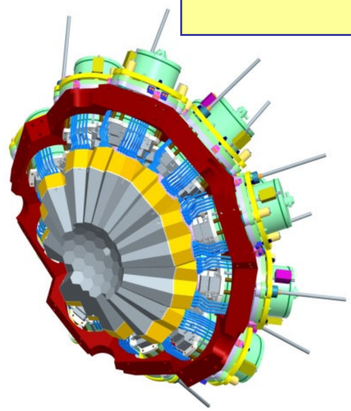
PRESPEC in-beam
with AGATA

active stopper
g-factors

Min. 25% bei
FAIR, GANIL,
Legnaro

AGATA .in GANIL



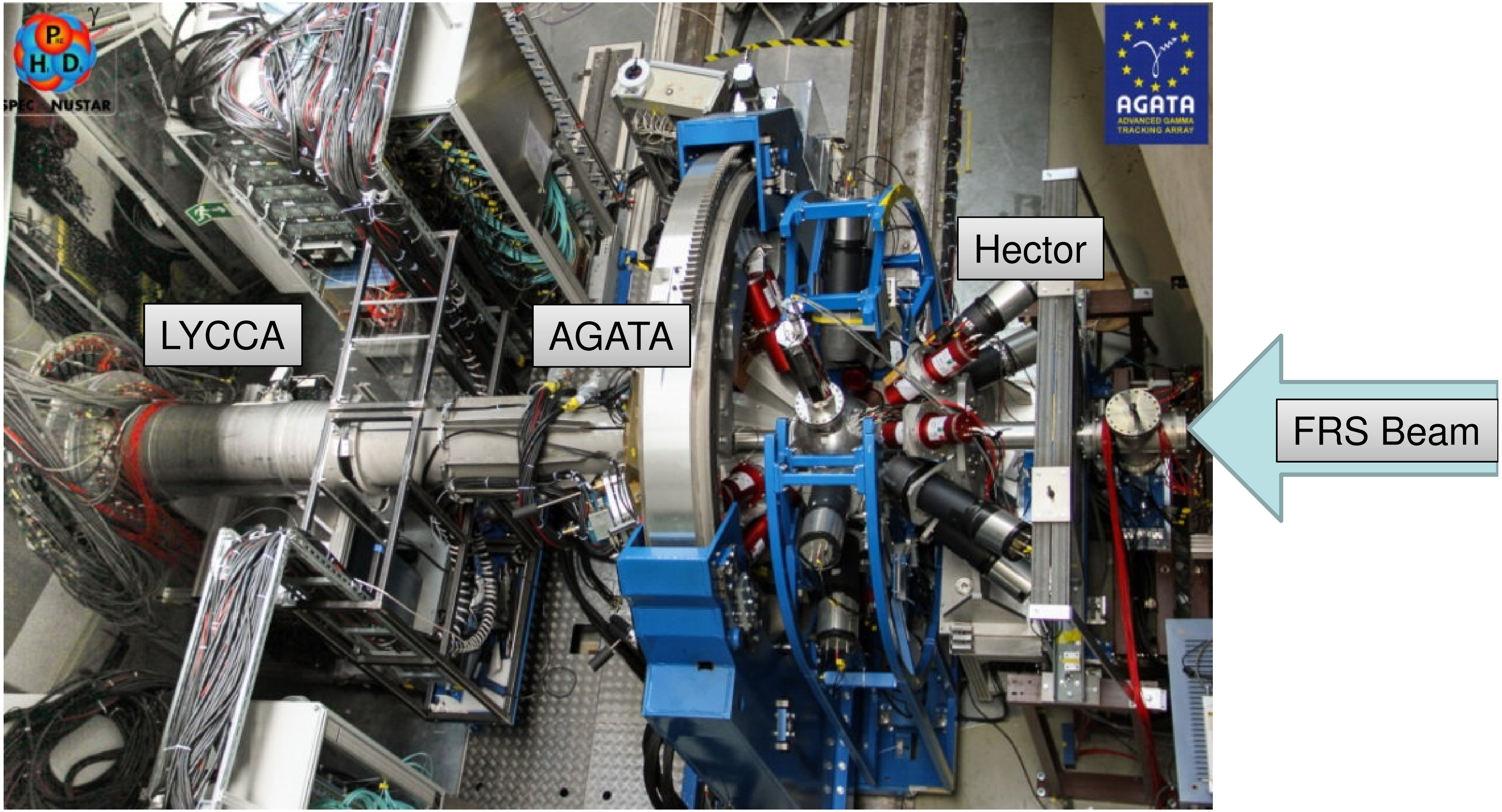


AGATA
ADVANCED GAMMA TRACKING ARRAY

Experimental program 2010-2015: running!

- First experiments with AGATA Demonstr. at Legnaro (2010 – early 2012)
- PRESPEC Experiments at GSI-FRS (2012 - 2014 with AGATA)

PreSPEC in Operation March 2014



PreSPEC experiments

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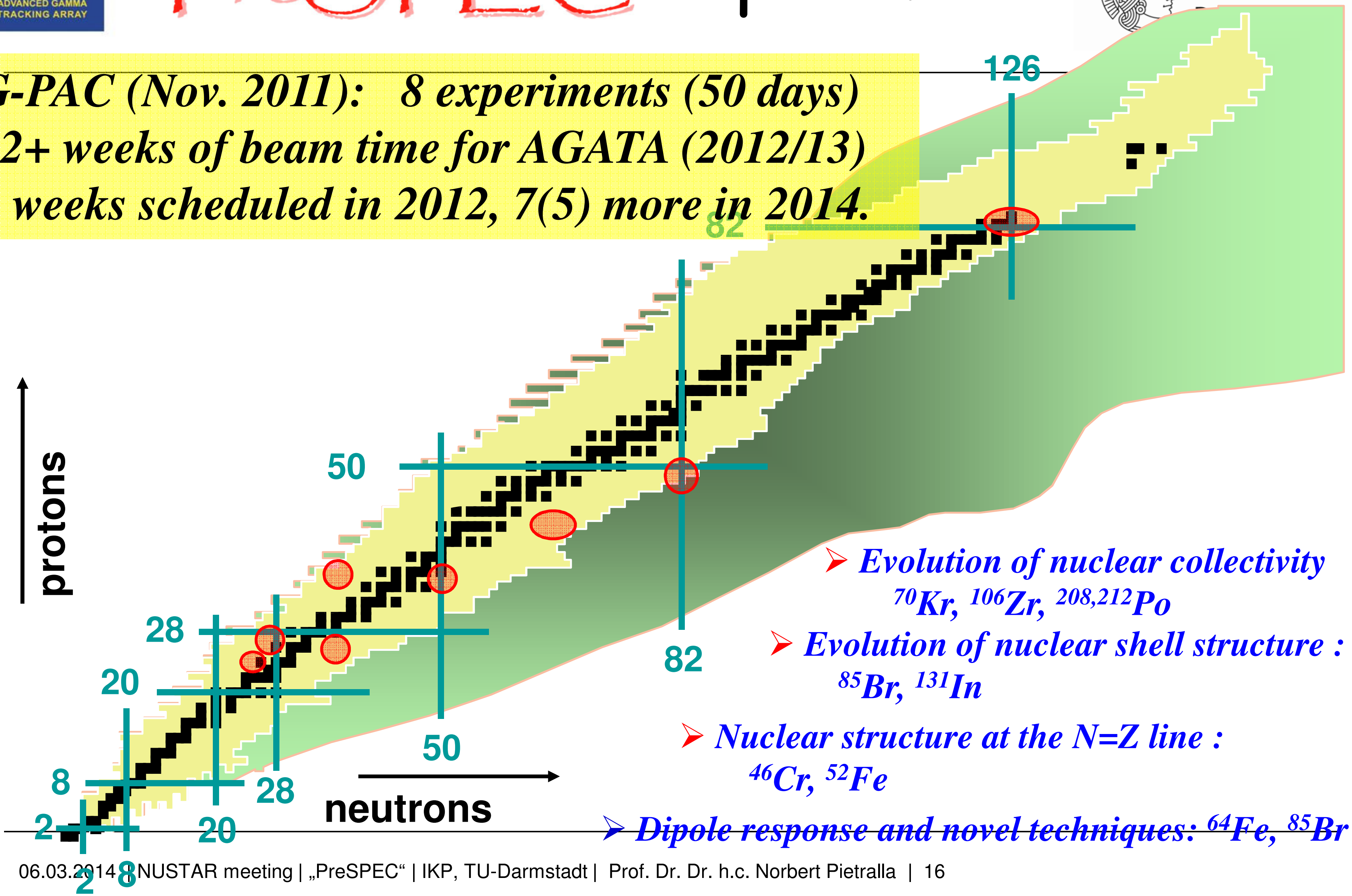
G-PAC (Nov. 2011): 8 experiments (50 days)
12+ weeks of beam time for AGATA (2012/13)
5 weeks scheduled in 2012, 7(5) more in 2014.



- ***Evolution of nuclear collectivity***
  ^{70}Kr, ^{106}Zr, ^{208,212}Po
- ***Evolution of nuclear shell structure :***
  ^{85}Br, ^{131}In
- ***Nuclear structure at the N=Z line :***
  ^{46}Cr, ^{52}Fe
- ***Dipole response and novel techniques:*** ^{64}Fe, ^{85}Br

Successful Commissioning of Liquid Hydrogen Target

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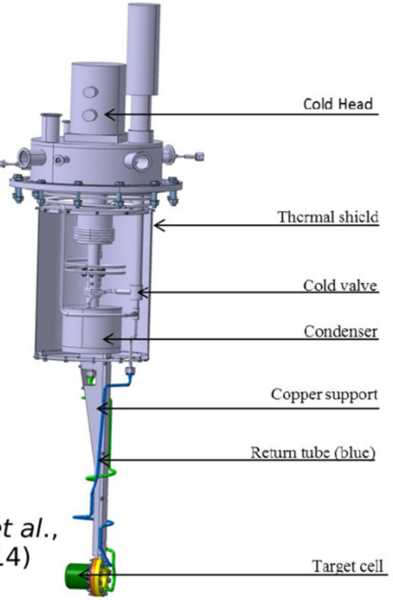
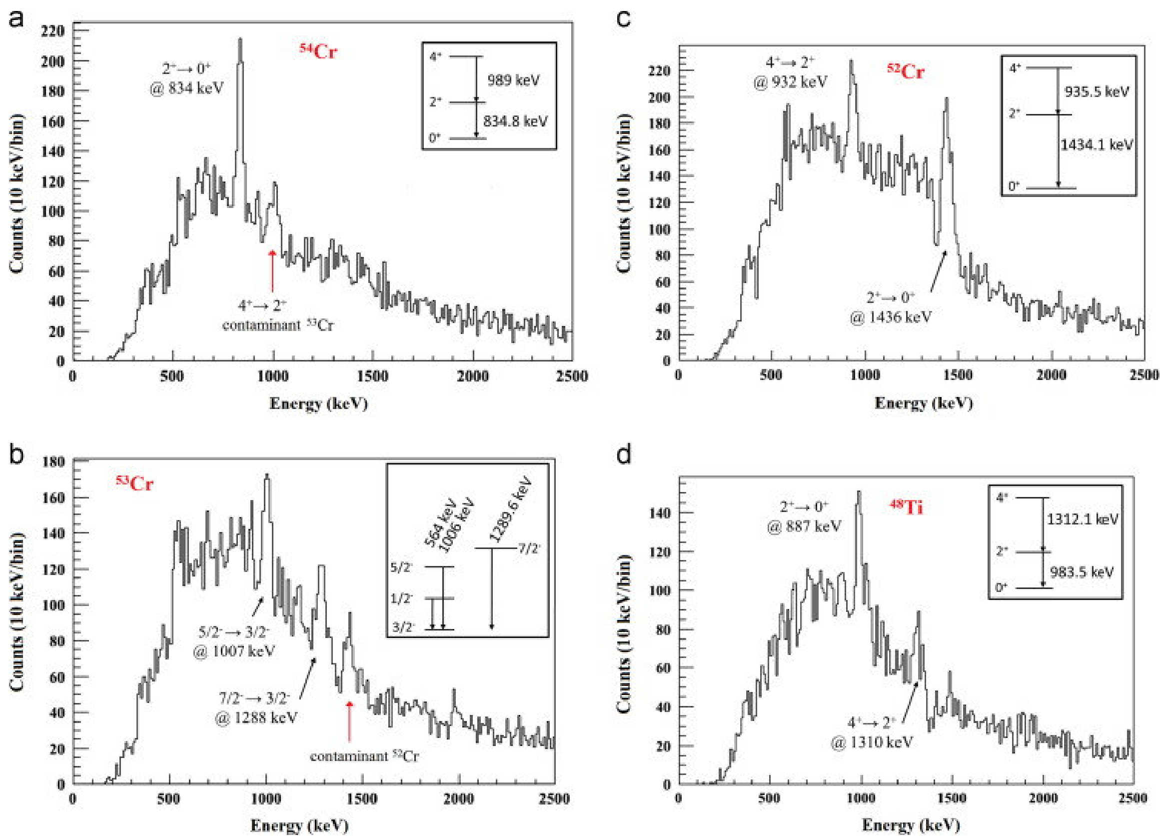


C. Louchart-Henning *et al.*, NIM A 736, 81-87 (2014)

Gamma spectra with gates on outgoing fragments, identified with LYCCA:

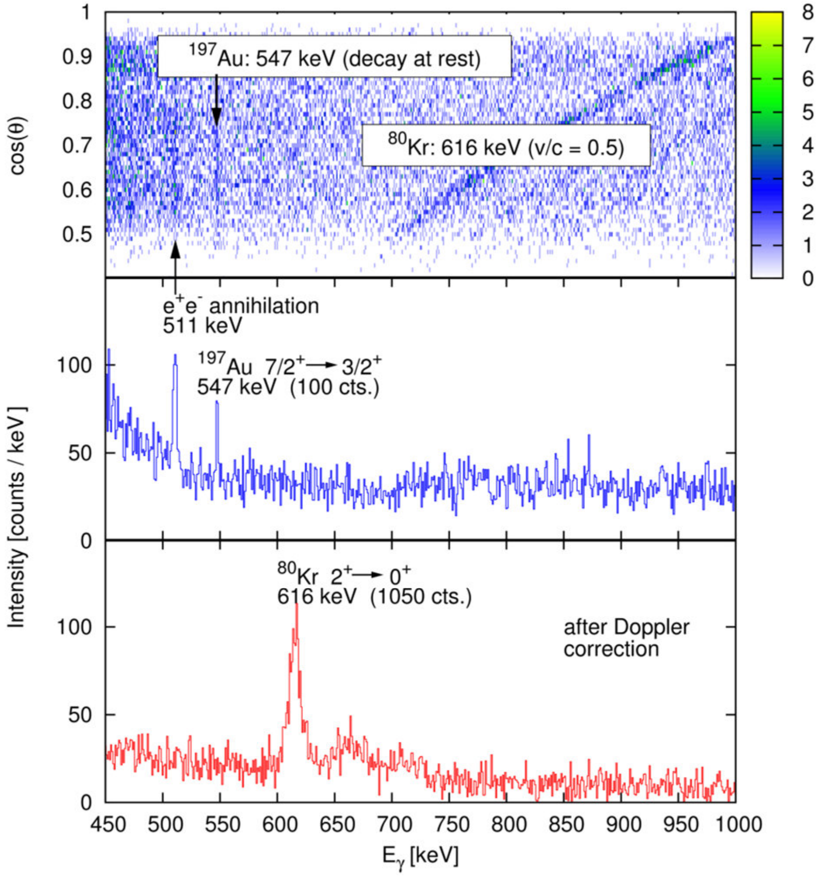


GSI in June 2012:

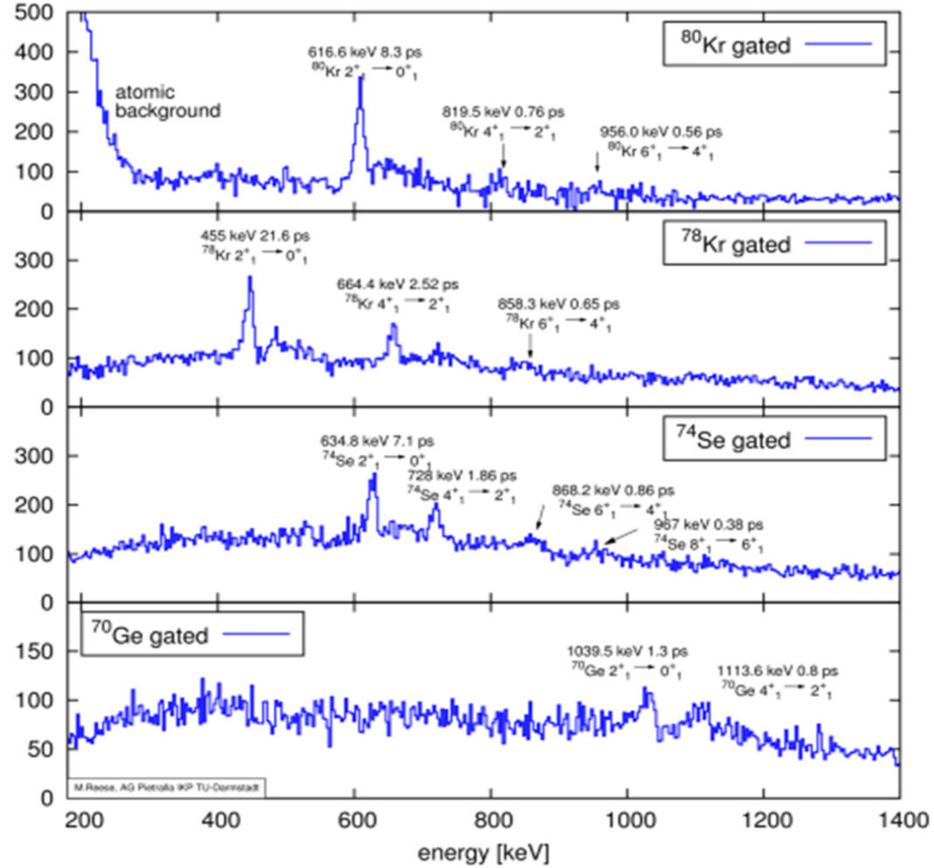
- ^{54}Cr beam with 130 MeV/u at the target position
- thickness of LH_2 target: 20mm

PreSPEC-AGATA Commissioning, 2012
(see next talk)

Coulomb excitation of ^{80}Kr



Secondary fragmentation of ^{80}Kr



Physics Topics of PreSPEC

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- S426 ^{85}Br M1 spin-flip Coulomb excitation
- S427 ^{70}Kr energies
- S428 Zr shape evolution
- S429 B(E2) in the Pb region
- S430 ^{64}Fe Pygmy fine structure
- S431 ^{132}Sn shell structure
- S433 ^{52}Fe isomer Coulex
- S434 $T_z = -2$ Lifetime measurements, ^{44,46}Cr

Direct Characterization of Spin-Orbit Splitting (Tensor Force): ^{85}Br as Test Case

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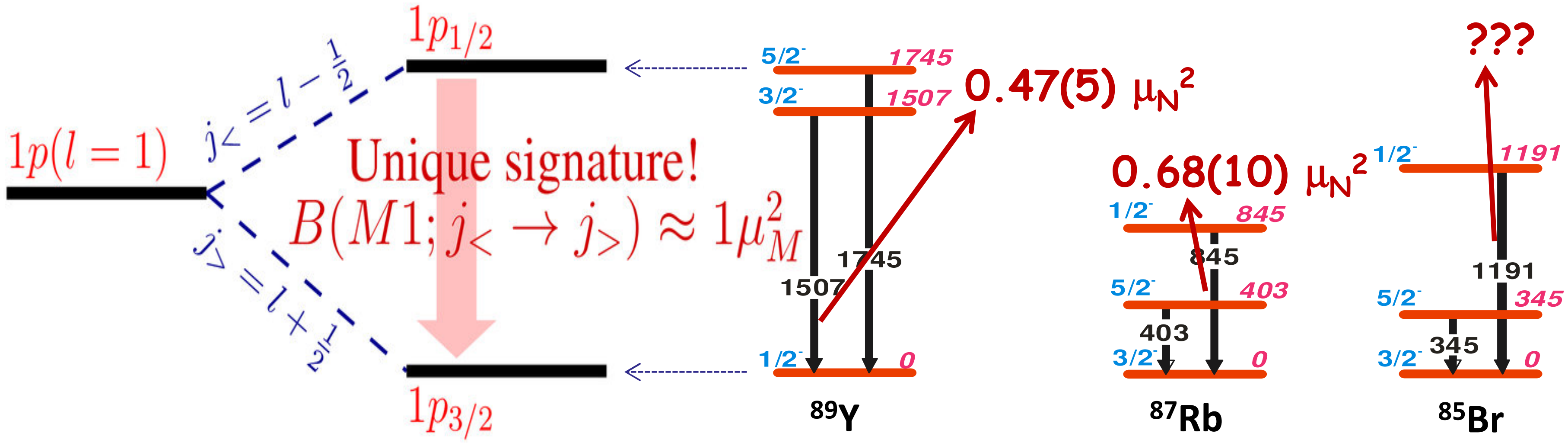


- Direct identification of spin-orbit partners via B(M1) strength measurement
- How to measure on exotic ions?
  - (γ, γ'), or (e, e')? No radioactive target !
  - Coulomb excitation ? E2 dominated !
  - But…

Spin-Flip M1: Coulex?

Coulomb excitation only E2 dominated for low energy.

In-flight separation produces excotic ions with high velocity

M1 Coulomb excitation is small in realtion to E2 excitation for nonrealtivistic beams.

For high velocities, M1 can have significant contribution to the total cross-section!

$$\sigma_C(E2) \propto (1/\beta)^2$$

$$\sigma_C(M1) \ \text{(independent)}$$

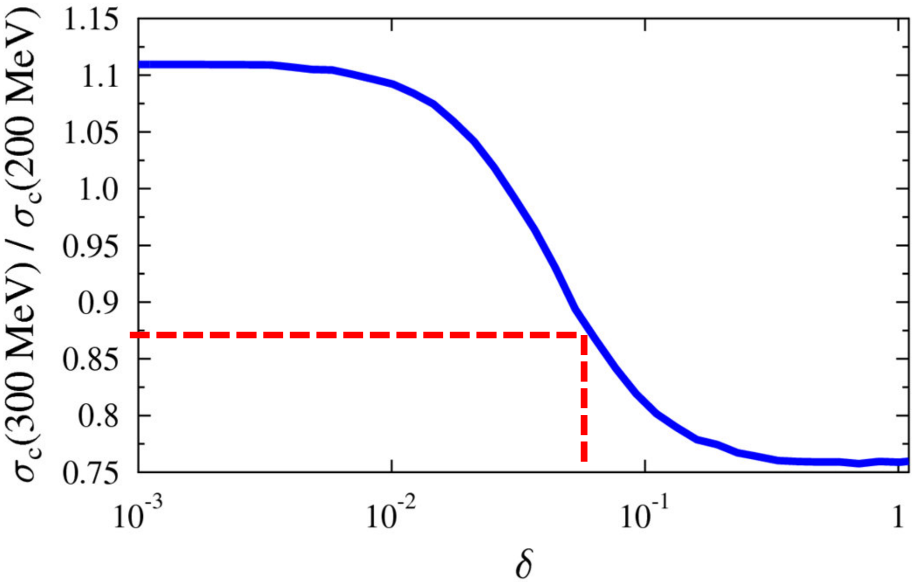
$$\Rightarrow \quad \frac{\sigma_C(M1)}{\sigma_C(E2)} \propto \left(\frac{v}{c}\right)^2$$

Discriminate E2 vs M1-contribution?
I.e. how to measure the multipole mixing ratio?

Two Beam Energies

- Energy dependence: decreasing E2 contribution for high energies
- Ratio of total cross-sections at different energies is sensitive to multipole mixing ratio

$$\delta \propto \frac{\langle f \| \hat{T}_{E2} \| i \rangle}{\langle f \| \hat{T}_{M1} \| i \rangle}$$

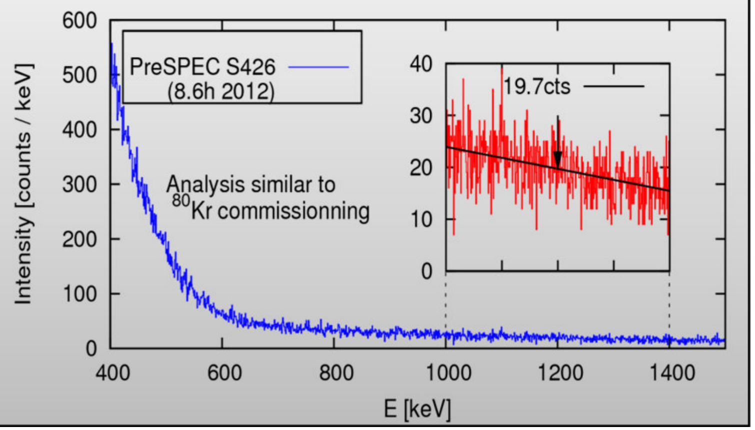


M1 Coulex test-shift in 2012

Neutron-rich ^{85}Br ideal test-case because of high rate of ^{86}Kr primary beam at GSI.
Produce ^{85}Br by one proton knockout

One shift of data taking with ^{85}Br

- ^{85}Br beam: 300 MeV/u
- Mean particle rate: 26kHz (> 50kHz in spill)
- Target: 400 mg/cm^2 gold:



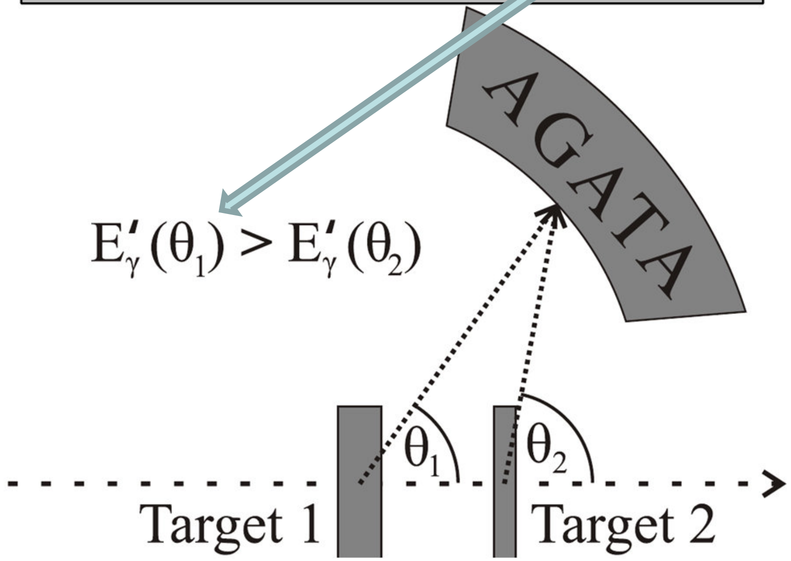
- Background higher than initially anticipated, consistent with commissioning
- Need two measurements at different energies
- Improvements: double-target solution: „Coulex-multipolarimetry by active degrader“

Two-Target Solution: Idea (C. Stahl)

Idea: 2 targets. First target thick enough to slow down beam from 300 to 200 MeV/u at the second target. All information in one measurement!

Reminder: Doppler effect

$$E_{\text{laboratory}} = E_{\text{rest}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\vartheta_{\text{lab}})}$$

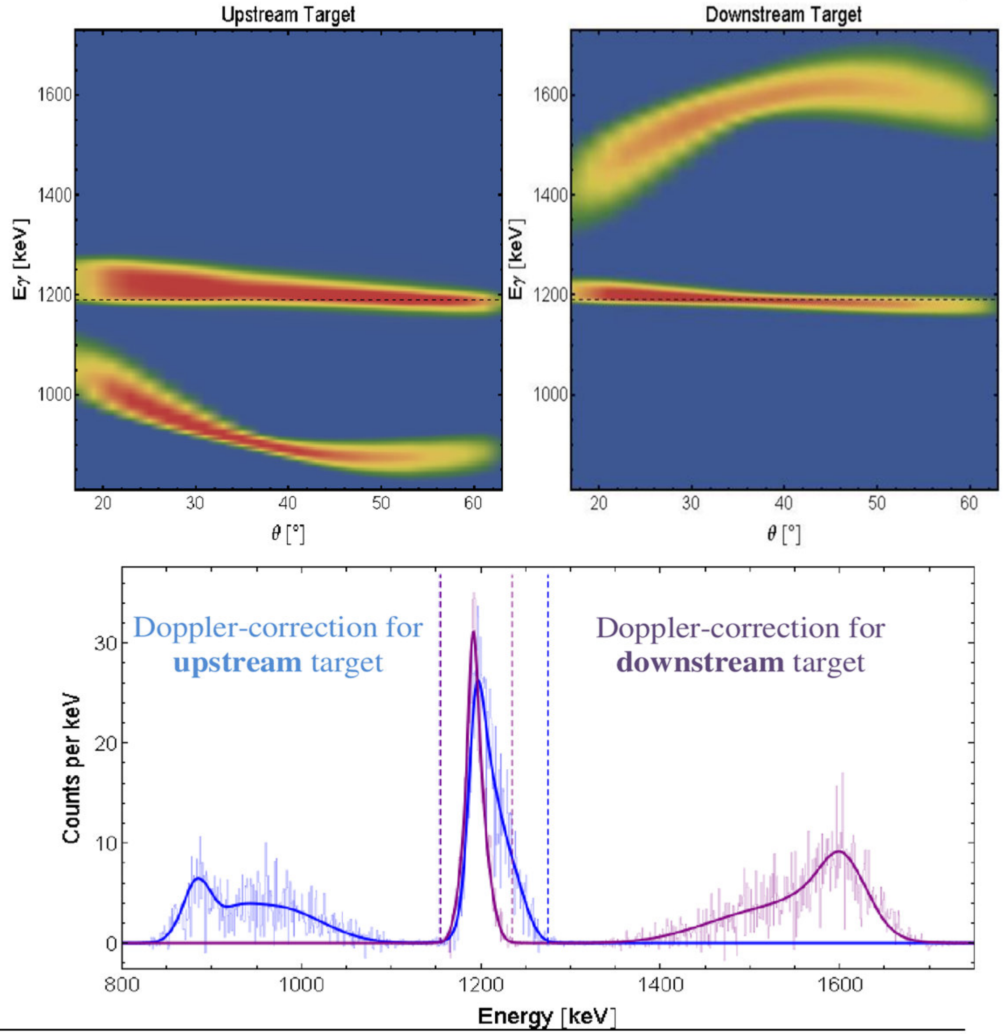


Working principle:

- Lifetime of excited state ~50 fs.
- Decay happens directly after excitation.
- Decay position equal to exitation position
- Two peaks will appear due to different detection angles (Doppler-effect)
- Excitation in first target happens at high energy (300 MeV/u)
- Exitation in second target happens at lower energy (200 MeV/u)

Two-Target Solution: Simulations

Simulated Peak shapes (Doppler-corrected Energy vs. detection angle):



Pro's:

- one beam energy
  - one FRS setting
  - same conditions for both energies
- thick target
  - increased excitation prob.
  - better peak to background ratio

Con's:

- thick target
  - increased angular straggling
  - increased energy straggling
  - increaded velocity uncertainty

Summary

HISPEC is ready, 1st phase (while waiting for the S-FRS)

evolution of nuclear collectivity

direct access to shell evolution (spin-orbit splitting)

several new ideas and methods

too little beam time!

Thank you for attention !