RISING

Rare ISotope INvestigation at GSI

- experimental set-up

- sub-shell closure (N=32 gap) for Cr nuclei
- pairing interaction in semi-magic Sn nuclei
- shapes and shape coexistence: ^{136}Nd, ^{134}Ce
- Pygmy dipole resonance in ^{68}Ni
- T=2 mirrors ^{36}Ca and ^{36}S

- future: PreSPEC

RISING

***R**are **IS**otope **IN**vestigation at **G**SI*

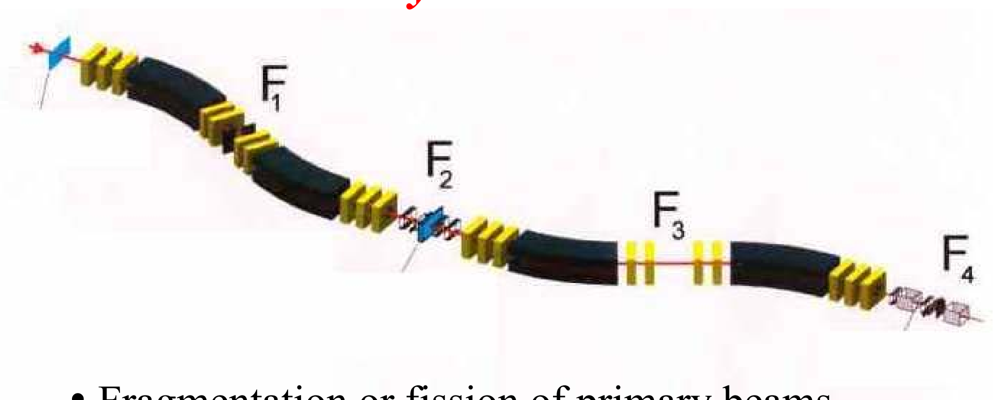
The Accelerators:

- **UNILAC** (injector) - E<15 AMeV
- **SIS 18Tm** ^{238}U 1 AGeV

Beam currents:

- ^{238}U — 10^9 pps
- medium mass nuclei — 10^{10} pps

FRS → secondary radioactive ion beams:



- Fragmentation or fission of primary beams
- High secondary beam energies (100 - 400 AMeV)
- Fully stripped ions
- Reactions on a secondary target
- Implantation inside a stopper

- **Nuclear structure of exotic nuclei studied by *secondary fragmentation* and *relativistic Coulomb excitation***
- **g-factor measurements**
- **Isomeric γ- and β-decay studies**

Rare ISotope INvestigation at GSI

The Accelerators:

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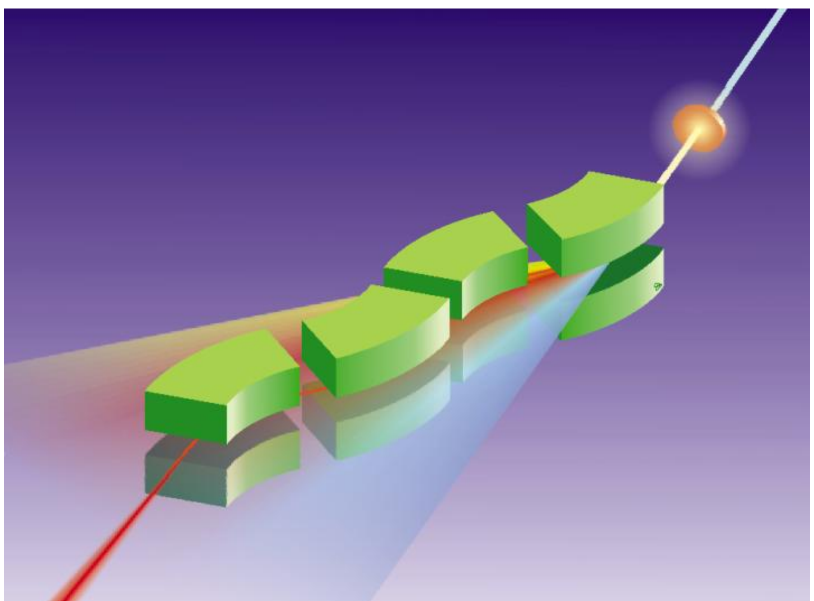
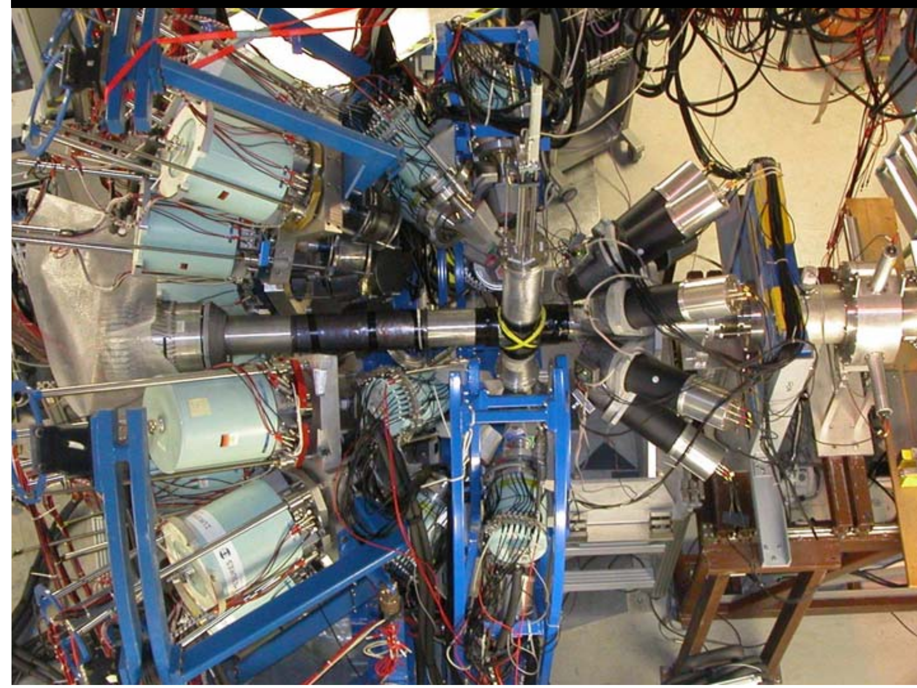


Fast beam campaign (2003-2005)



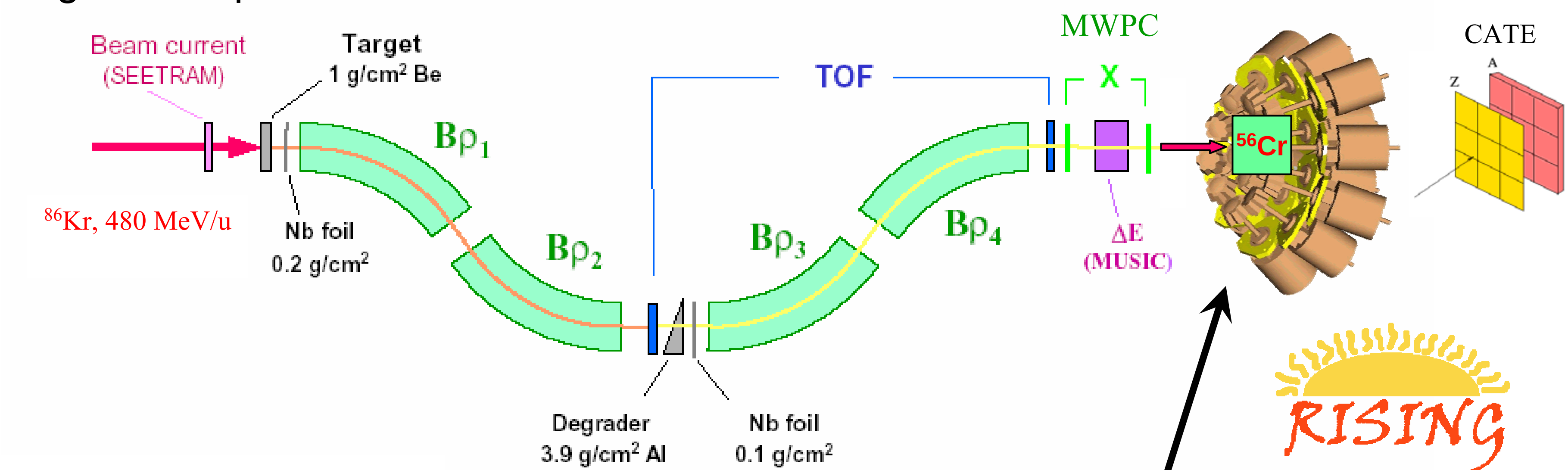
- ***FRS*: excellent in-flight A and Z selection**

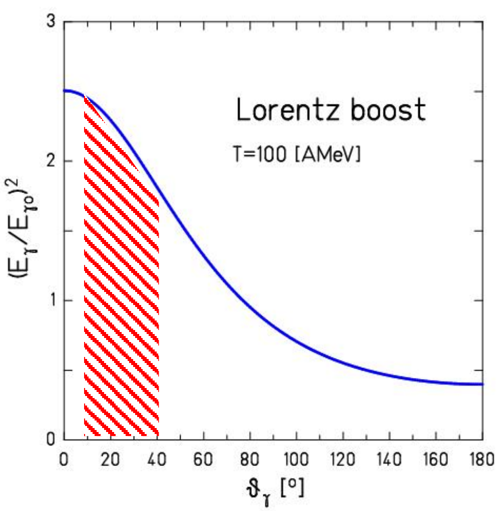
  energy resolution: ~ 1 GeV ^{131}Sn ^{132}Sn
- ***EUROBALL*: excellent γ-ray spectrometer**

  intrinsic energy resolution: ~ 2 keV

Experimental set-up

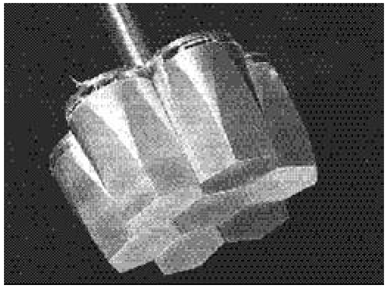
FRagment Separator



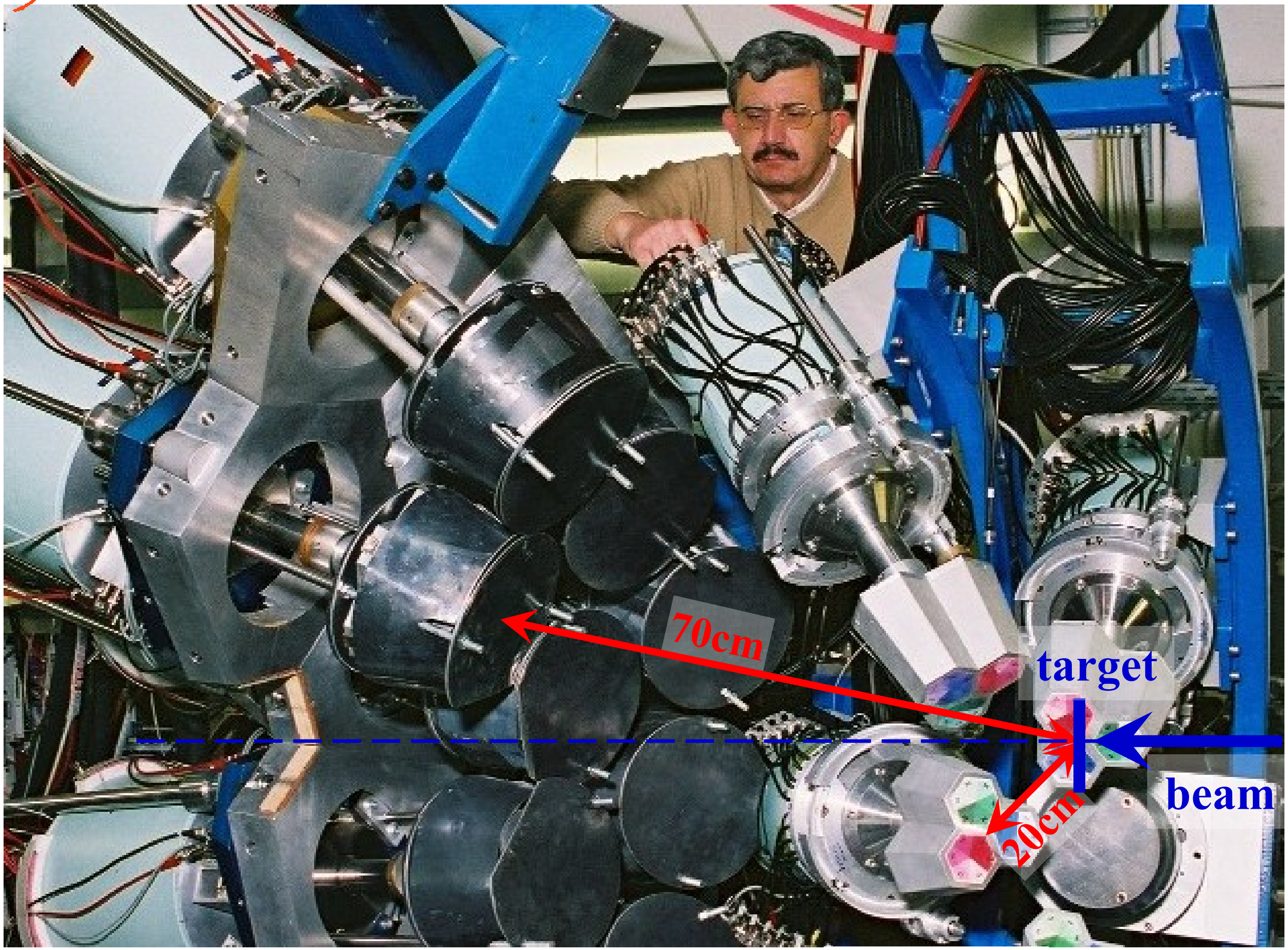


Ring	angular range
1	10.5^0-21.3^0
2	27.6^0-38.4^0
3	30.6^0-41.4^0

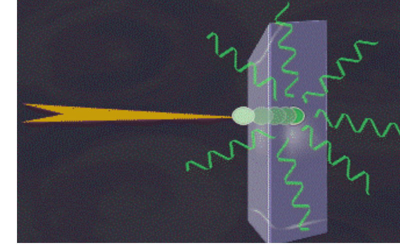
- 15 EUROBALL Clusters (105 Ge crystals)
- ΔE_γ=1.6% (1.3 MeV, d = 70 cm)
- ε_γ = 2.8%



γ-ray set-up with higher efficiency



Atomic Background Radiation
Bremsstrahlung



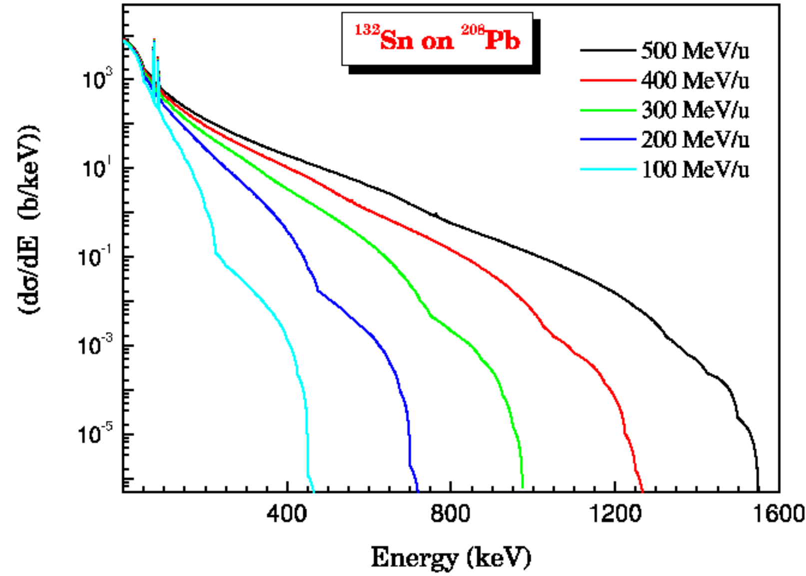
➢Radiative electron capture (REC)
capture of target electrons into bound states of the projectile:

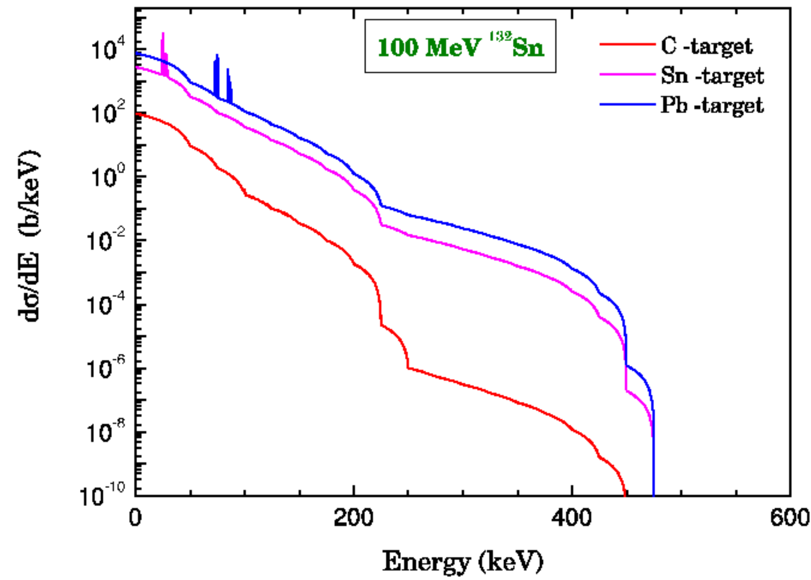
$$\sigma \sim Z_p^2 \cdot Z_t$$

➢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: $\sigma \sim Z_p^2 \cdot Z_t^2$





Bremsstrahlung: slowing down of a moving point-charge

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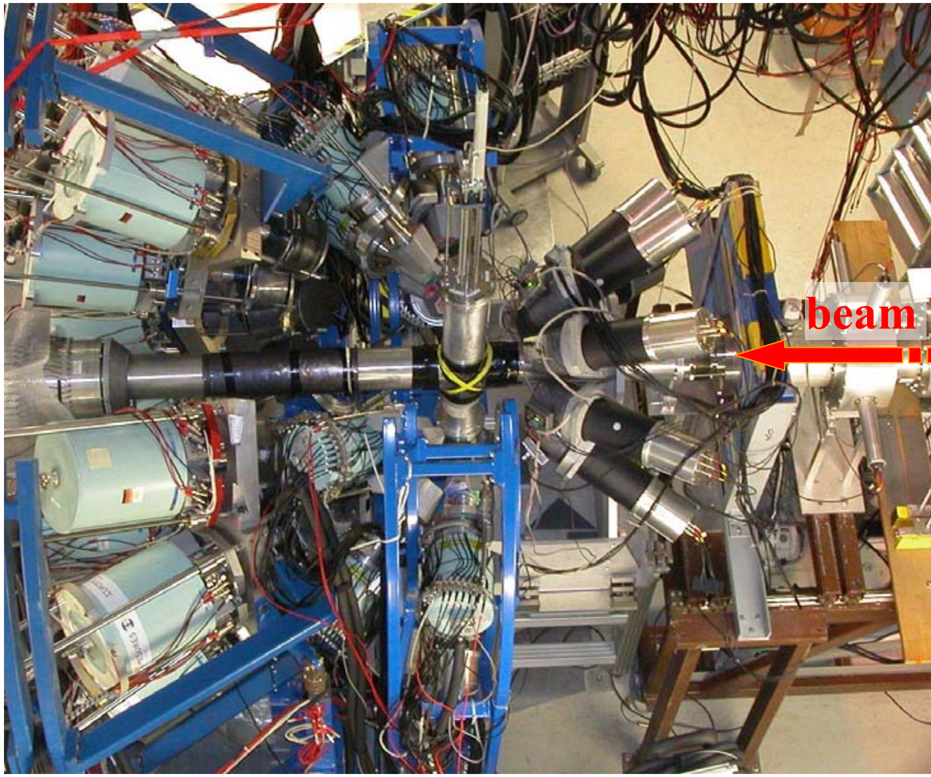
Rare ISotope INvestigation at GSI

EUROBALL Cluster Detectors
Miniball: HPGe segmented detectors

HECTOR
Large 14.5 x 17 cm BaF_2 Detectors

CATE : ΔE-E telescope
event by event beam identification



Coulomb Excitation at Relativistic Energy

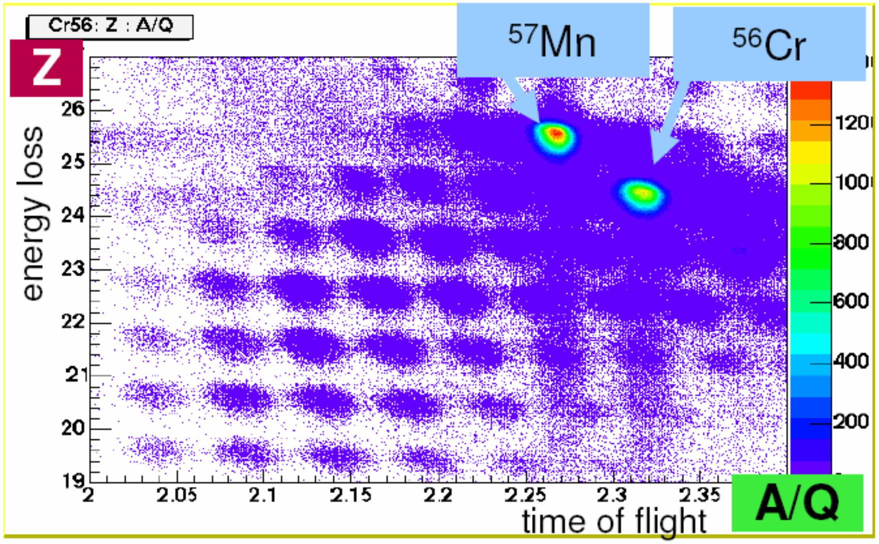
- ✓ **New Shell structure at N>>Z**
- ✓ **Relativistic Coulomb excitation of nuclei near ^{100}Sn**
- ✓ **Triaxiality in even-even core nuclei of N=75 isotones**
- ✓ **E1 Collectivity in neutron rich nuclei ^{68}Ni**

nucleus	*σ (mb)*
^{56}Cr	91
^{108}Sn	314
^{136}Nd	338 / 2180

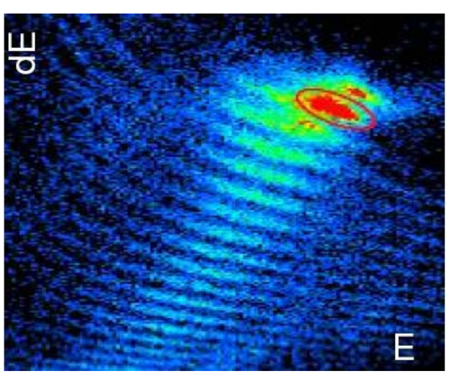
H.J. Wollersheim NIM A537, 637(2005)

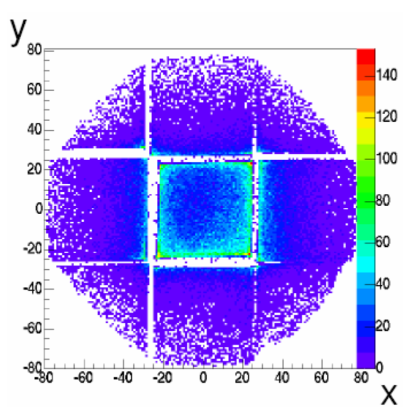
Relativistic Coulomb Excitation
of $^{54,56,58}Cr \rightarrow {}^{197}Au$

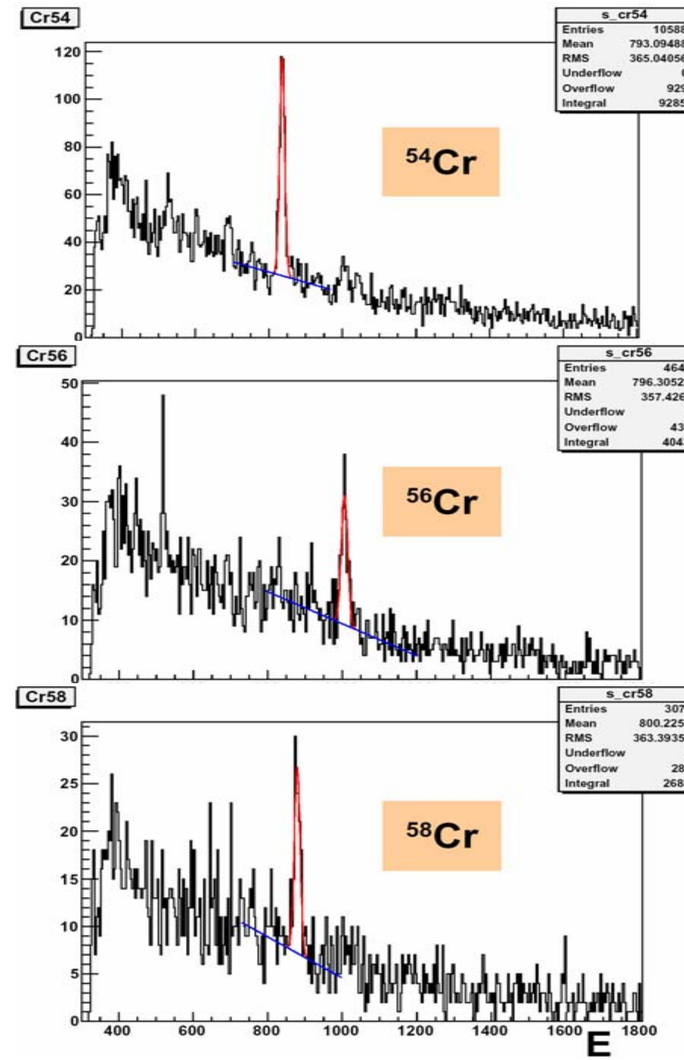
Identification before the secondary target



after secondary target





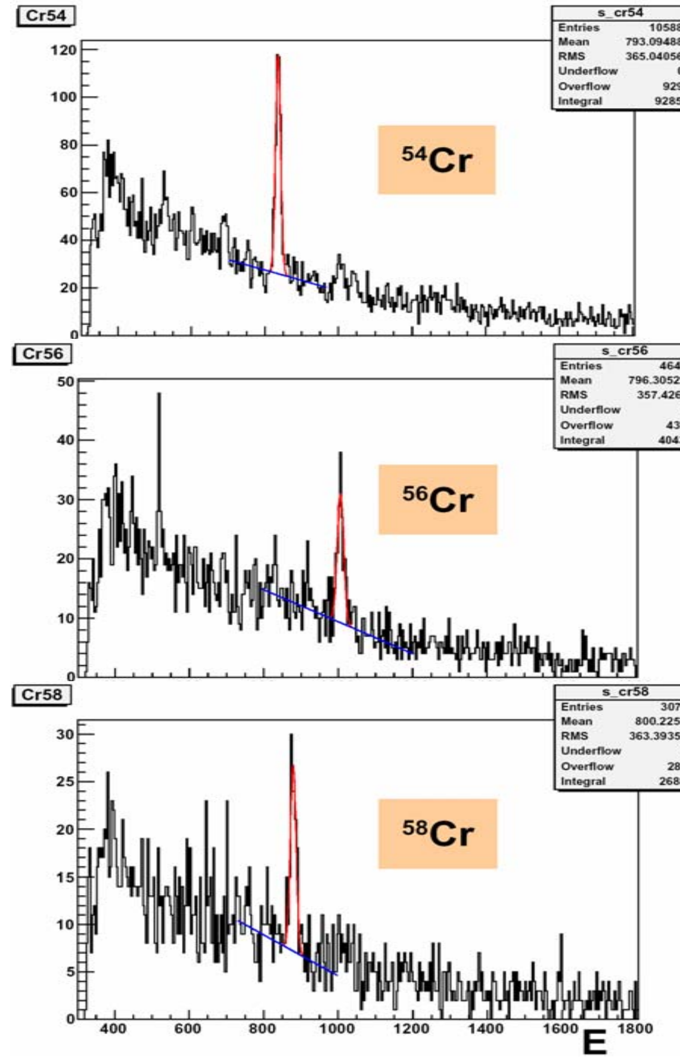


γ-efficiency = 2.8% , ΔE_γ = 1.6% (1.3 MeV, d=70 cm)

Relativistic Coulomb Excitation
of $^{54,56,58}Cr \rightarrow {}^{197}Au$

	E_γ [keV]	B(E2) [Wu]
^{54}Cr	835	14.6 (6)
^{56}Cr	1006	8.7 (3.0)
^{58}Cr	880	14.8 (4.2)

Indication for N=32 sub-shell closure



A. Bürger et al., Phys. Lett B622, 29 (2005)

RISING

The ^{100}Sn / ^{132}Sn region

Single particle energies

Z = 50

$g_{7/2}$

Sn102	Sn103	Sn104	Sn105	Sn106	Sn107	Sn108	Sn109	Sn110	Sn111
	7 s	20.8 s	31 s	115 s	2.90 m	10.30 m	18.0 m	4.11 h	35.3 m
0+		0+		0+	(5/2+)	0+	5/2(+)	0+	7/2+
	EC	EC	ECp	EC	EC	EC	EC	EC	EC

$d_{5/2}$ $s_{1/2}$ $d_{3/2}$

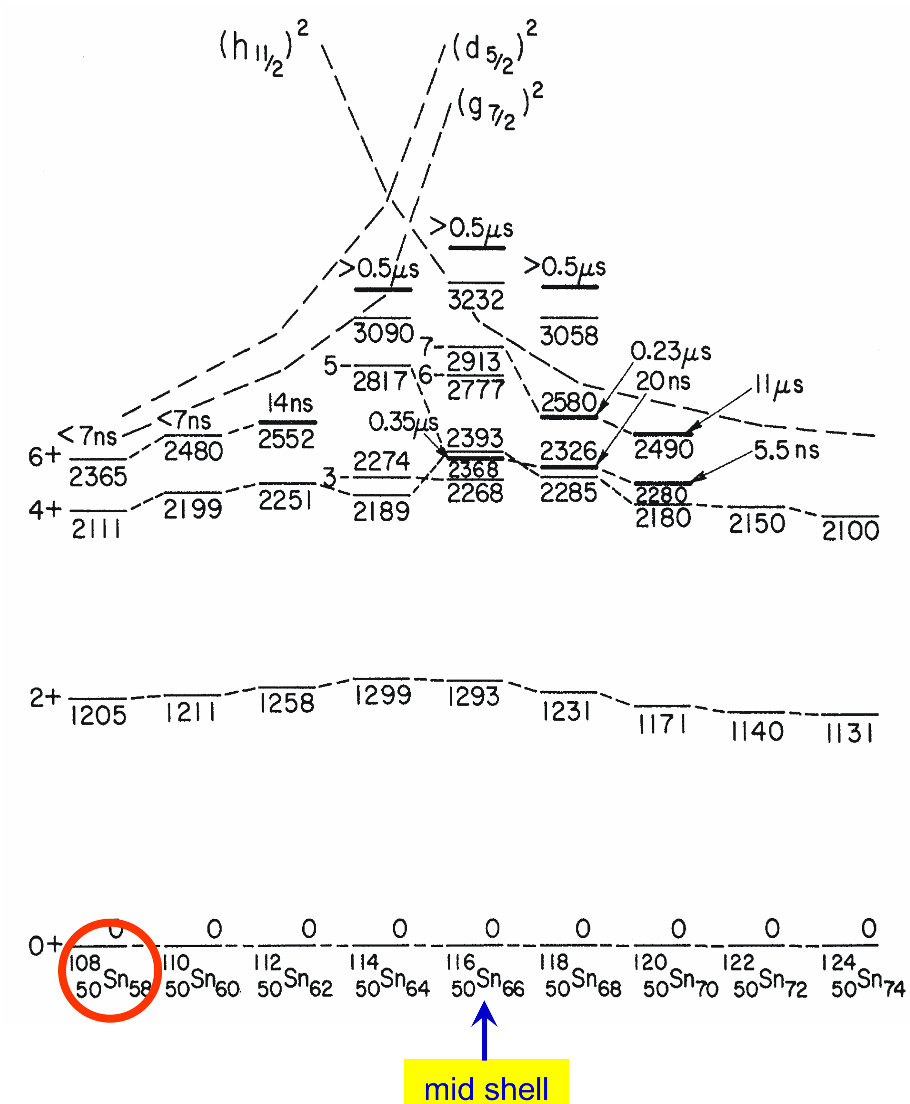
Sn112	Sn113	Sn114	Sn115	Sn116	Sn117	Sn118	Sn119	Sn120
	115.09 d							
0+ *	1/2+ *	0+ *	1/2+ *	0+ *	1/2+ *	0+ *	1/2+ *	0+ *
0.97	EC	0.65	0.34	14.53	7.68	24.23	8.59	32.59

Naïve single particle filling

$h_{11/2}$

Sn121	Sn122	Sn123	Sn124	Sn125	Sn126	Sn127	Sn128	Sn129	Sn130	Sn131	Sn132
27.06 h		129.2 d		9.64 d	1E+5 y	2.10 h	59.07 m	2.23 m	3.72 m	56.0 s	39.7 s
3/2+ *	0+ *	11/2- *	0+ *	11/2- *	0+	(11/2-) *	0+ *	(3/2+) *	0+ *	(3/2+) *	0+
β-	4.63	β-	5.79	β-	β-	β-	β-	β-	β-	β-	β-

The ^{100}Sn / ^{132}Sn region



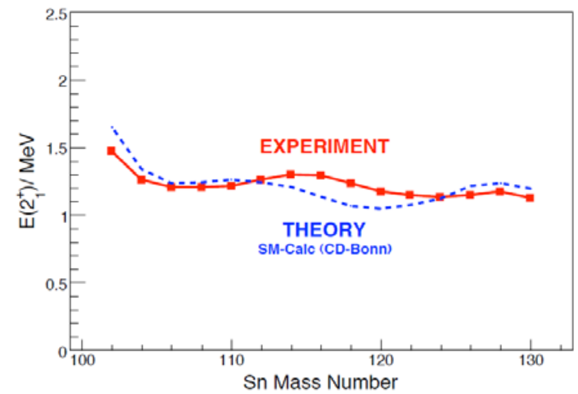
Pairing interaction:
Large spin-orbit splitting implies a jj-coupling scheme

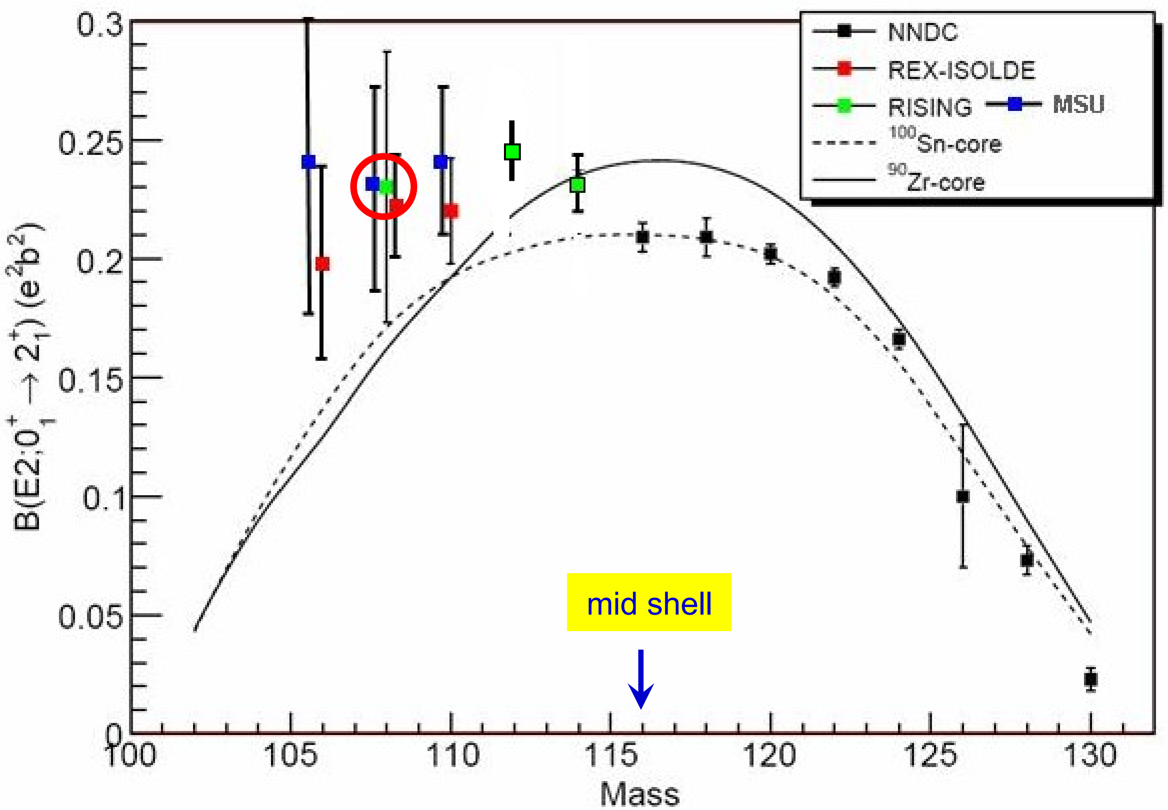
Relativistic Coulomb Excitation
of $^{108}Sn \rightarrow {}^{197}Au$

Seniority: a broken-pair model

- Constant 2^+ energy
- Simple B(E2) trend as function of shell filling

  $B(E2) \sim N_{particles} * N_{holes}$

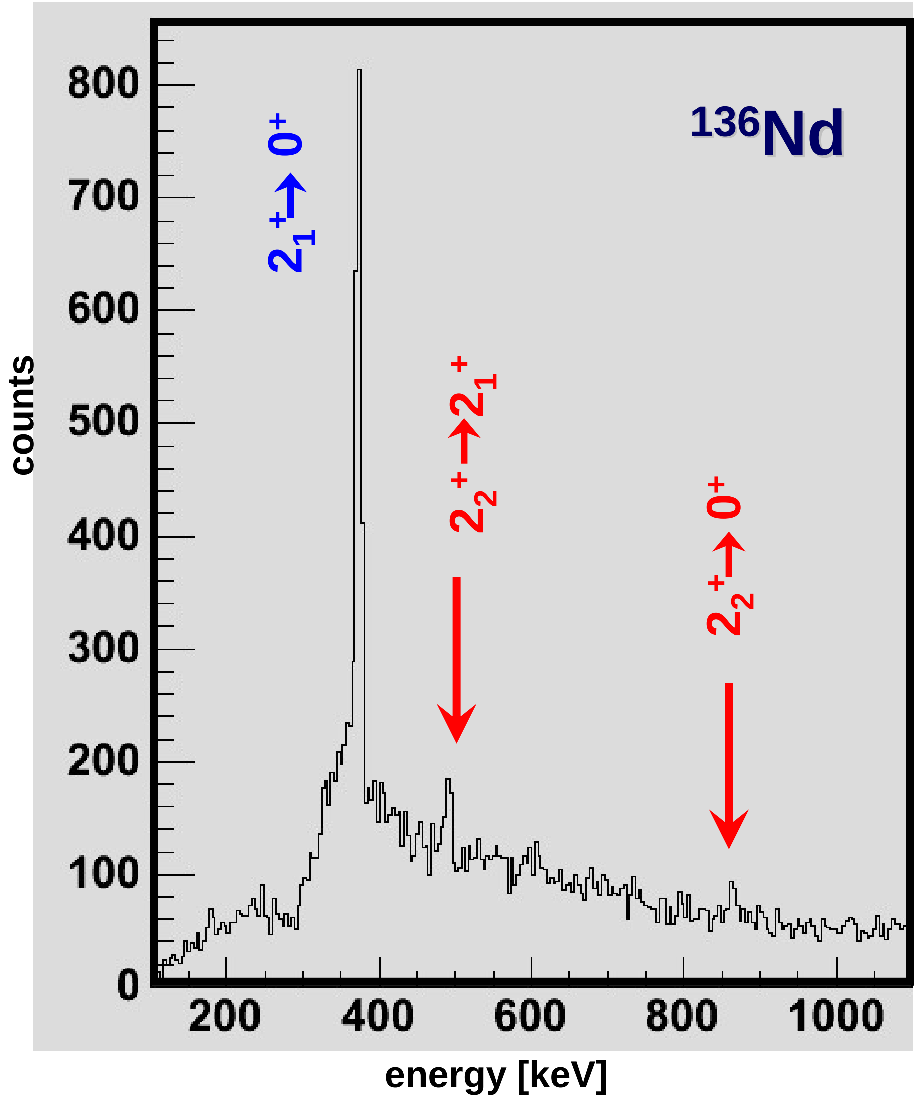


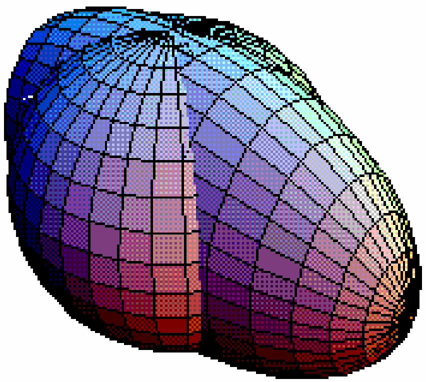


Emerging discrepancy:
Do we need to open the proton space near ^{100}Sn or do we need to improve the effective interaction?

A. Banu, Phys Rev C72, 061305 (2005)

Relativistic Coulomb Excitation of $^{136}Nd \rightarrow {}^{197}Au$





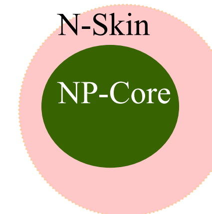
First observation of a second excited 2^+ state populated in a Coulomb experiment at 100 AMeV using EUROBALL and MINIBALL Ge detectors.

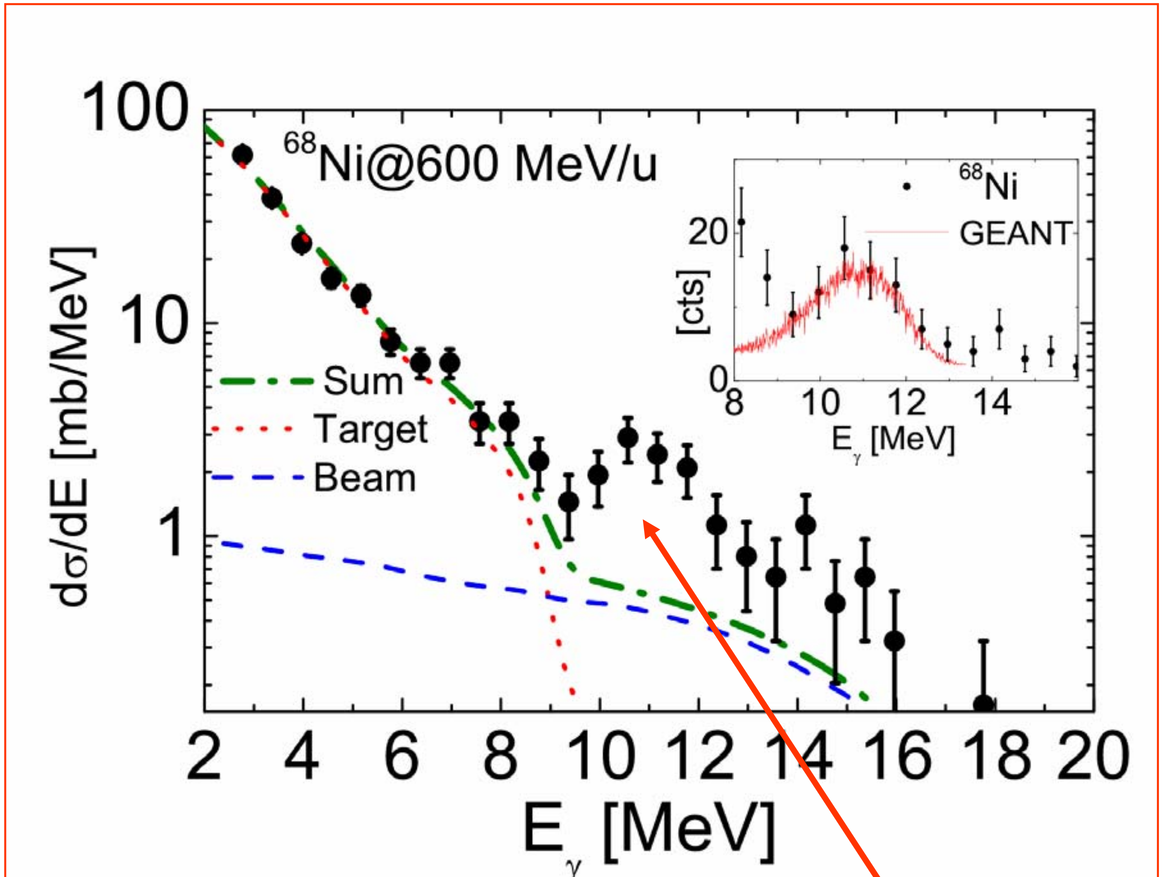
- collective strength
- shape symmetry
- triaxiality (in N=76) in even-even core nuclei of the odd-odd chiral isotones

T.R. Saito, Phys.Lett B669, 19 (2008)

Pygmy Dipole Resonance

Collective oscillation of neutron skin against the core



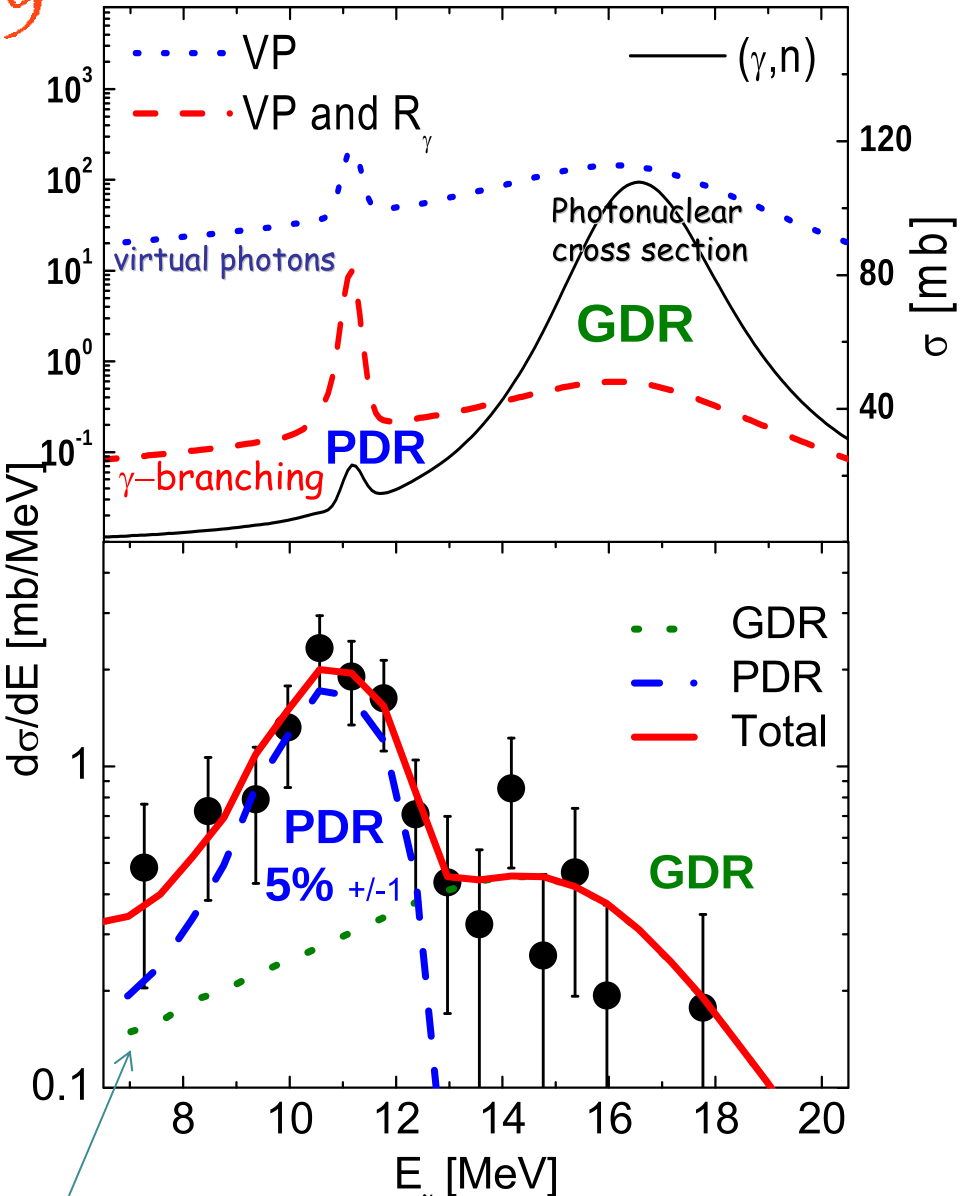


Statistical model (Cascade) calculation of γ-rays following statistical equilibration of excited **target** nuclei (^{197}Au) and of the excited **beam** nuclei (^{68}Ni) folded with RF and in the CM system

Excess Yield

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

Pygmy Dipole Resonance



Folded with the **detector response function**

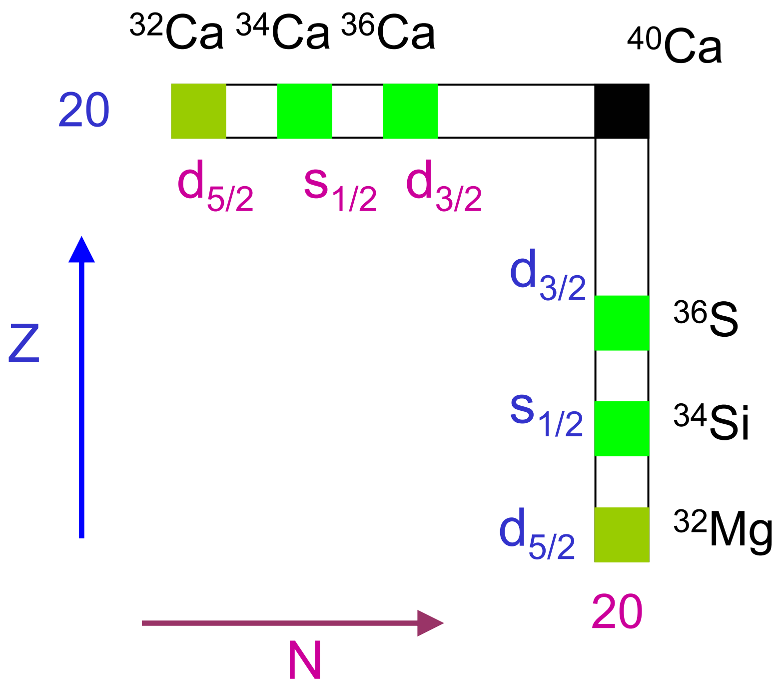
without pygmy

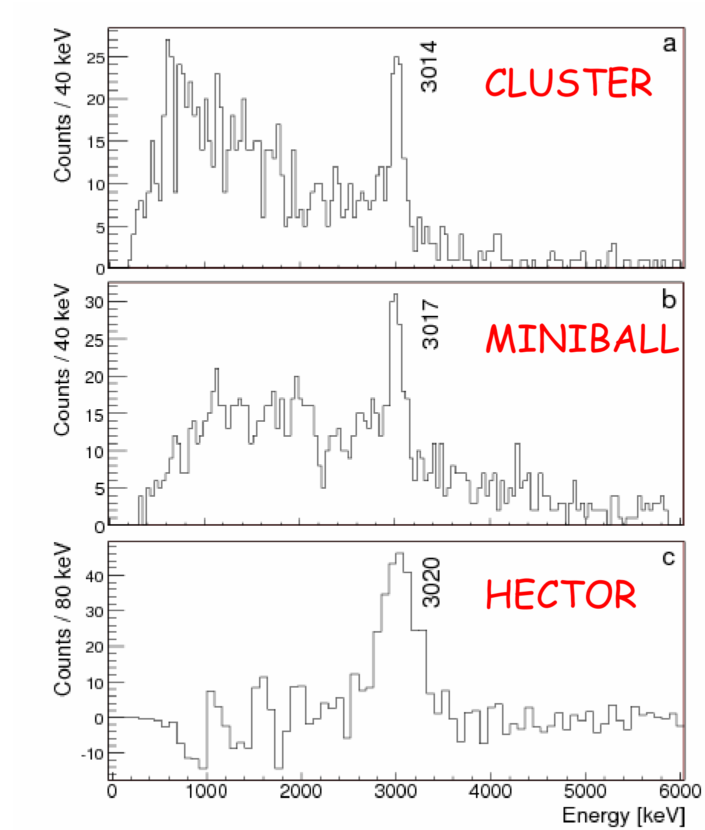
O.Wieland et al. PRL 102, 092502 (2009)

RISING

Mirror symmetry at the proton drip-line: ^{36}Ca – ^{36}S

Deviations from the classical shell model





Double fragmentation reaction:

Primary: ^{40}Ca, 420 A·MeV,
3·10^{8} ions/s, 4 mg/cm^{2} ^{9}Be

Secondary: ^{37}Ca, 196·A MeV,
2·10^{3} ions/s, 0.7 mg/cm^{2} ^{9}Be

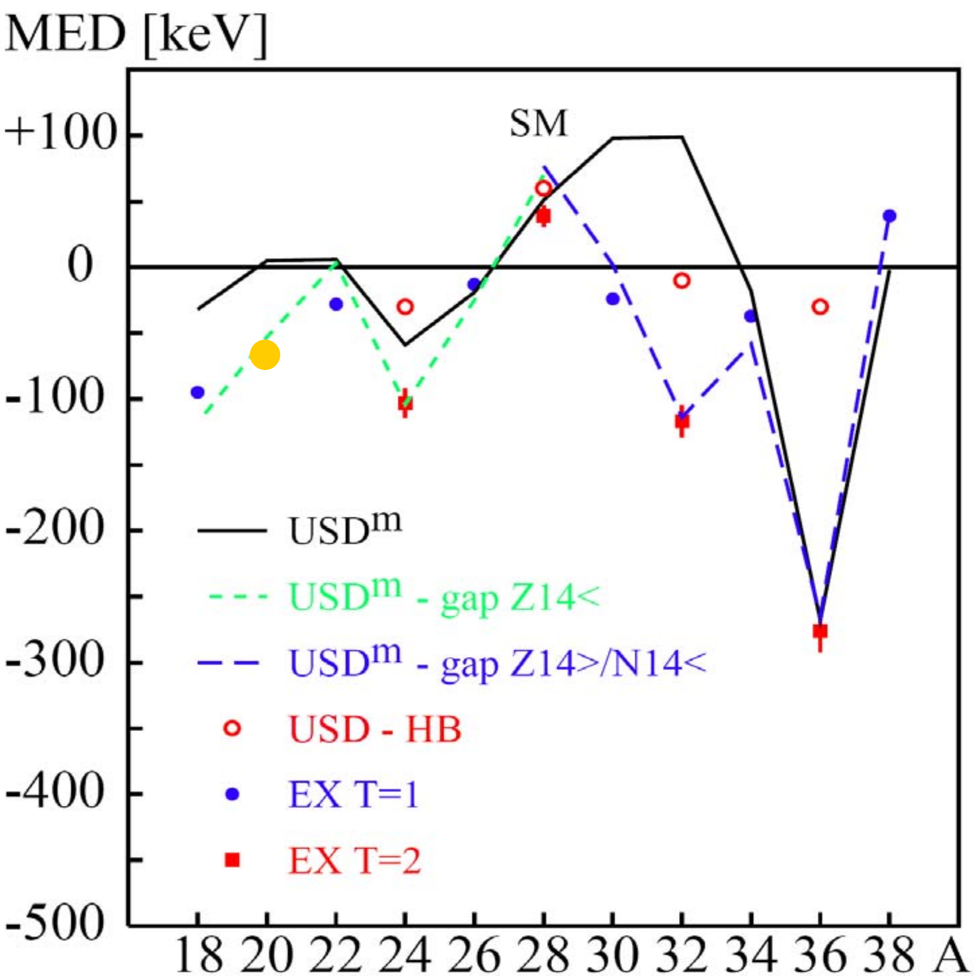
E_{2+} (^{36}Ca) - E_{2+} (^{36}S) = -276(16) keV

too large to result from Coulomb corrections

P. Doornenbal et al., Phys. Lett. B647, 237 (2007)

Mirror energy differences for T=1,2 nuclei

Deviations from the classical shell model

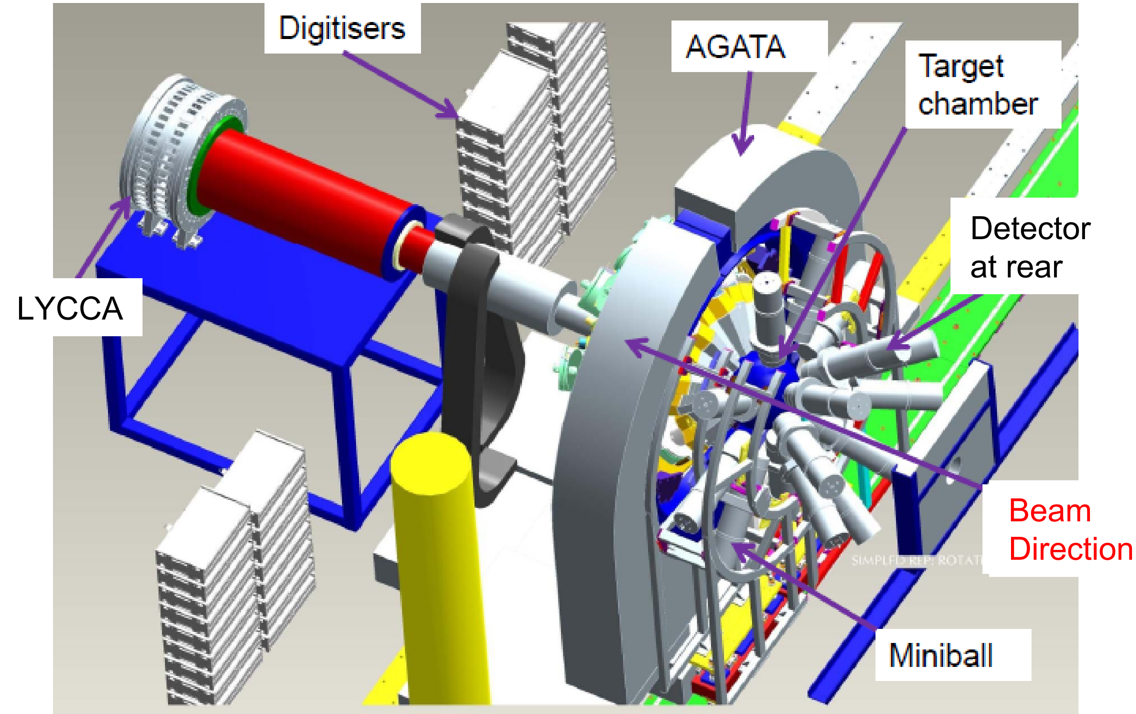


*H. Herndl et al., Phys. Rev. C 52 (1995) 1078

P. Doornenbal et al., Phys. Lett. B647, 237 (2007).

● A. Gade et al. Phys. Rev. C 76, 024317 (2007)

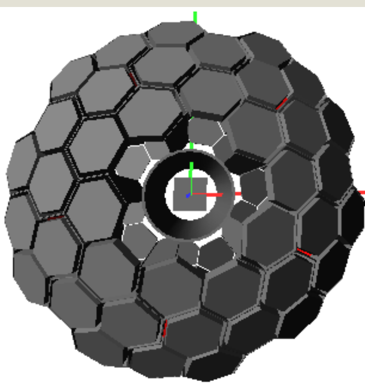
Future: PreSPEC and AGATA



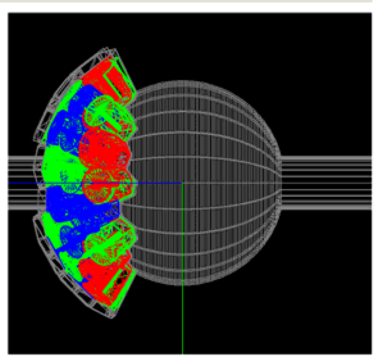
S2´-configuration:
10 AGATA Triple Cluster
+ 5 double Cluster detectors

γ-efficiency = 17.5%
γγ-efficiency = 2.5%

resolution (FWHM)	intrinsic spatial resolution
8.5 keV	5 mm
4 keV	2 mm



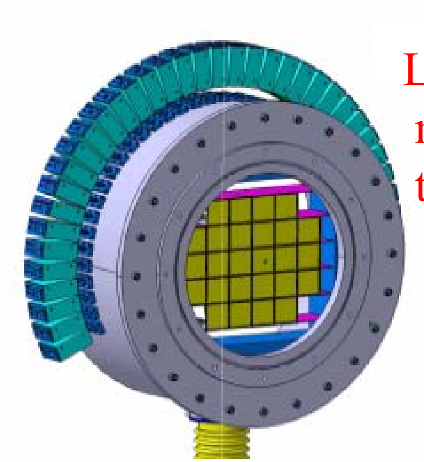
10 ATC
+ 5 double
Cluster
detectors



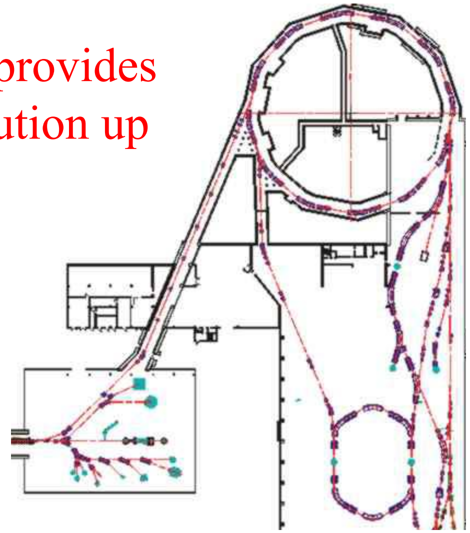
beam pipe diameter = 12cm
chamber diameter = 46 cm

PreSPEC fast-beam campaign

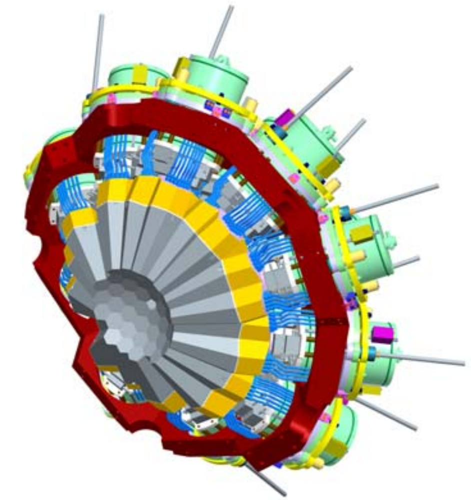
great perspectives ...



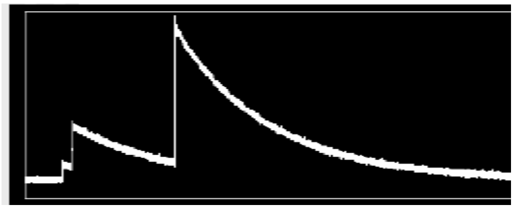
LYCCA-0 provides mass resolution up to A ≈ 100



SIS/FRS intensities increase up to ≈ 10x



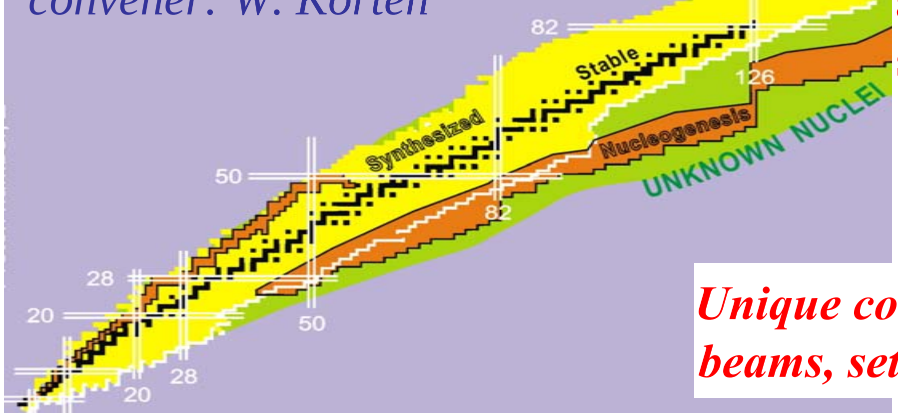
AGATA increases γ-sensitivity ≈ 10x



Tracking det. and EDAQ upgrade increase max. rate and throughput 10x

PreSPEC Fast Beam Campaign

convener: W. Korten



Very attractive and competitive spectroscopy themes

Unique combination of beams, set-up and people