

# Rare ISotope INvestigation at GSI Spectroscopy at relativistic energies

- Physics case & overview
- Spectrometer
- Relativistic Coulomb excitation
  - example Cr isotopes
- Summary

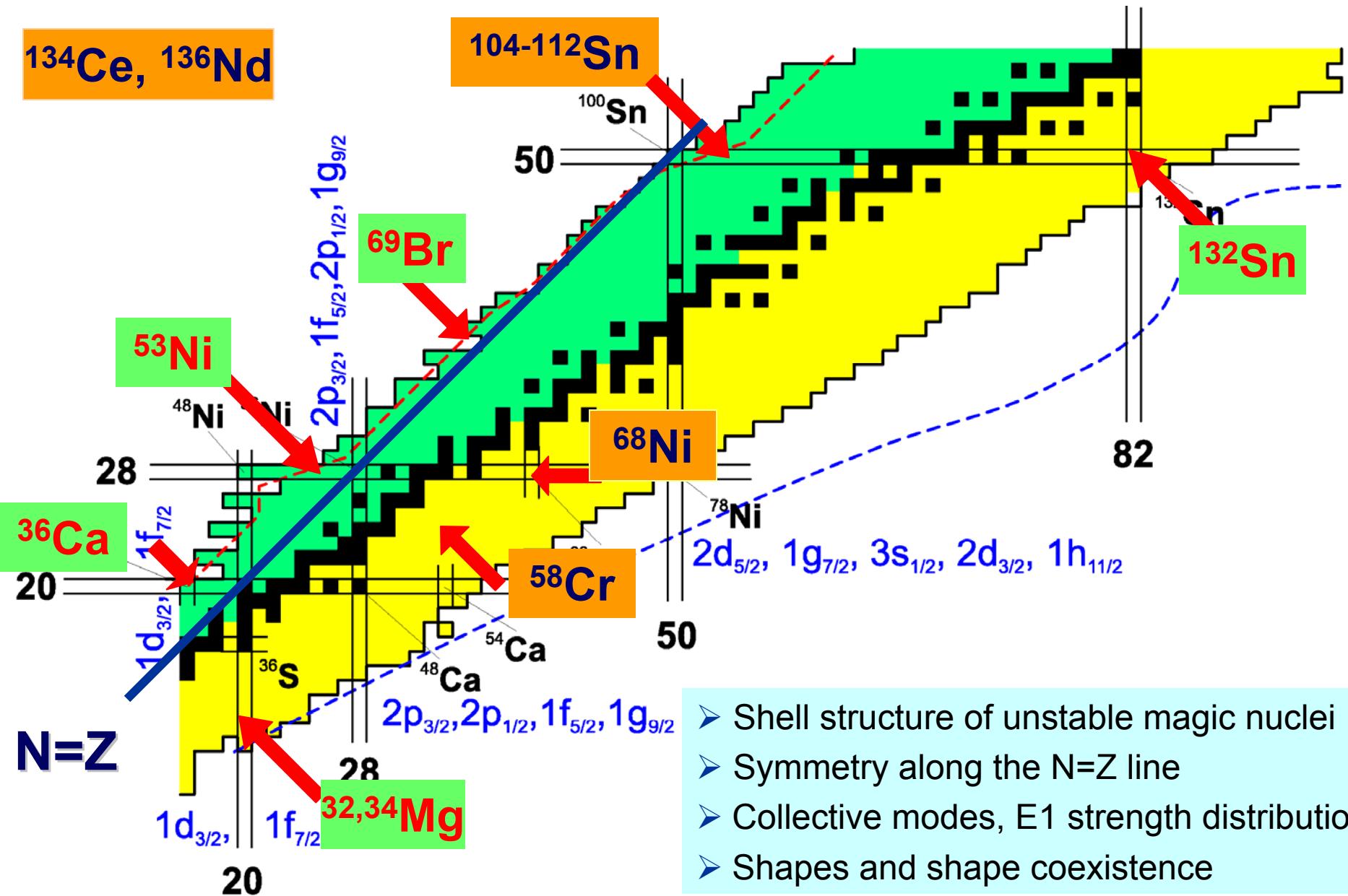
P. Reiter, University of Cologne

*Gamma-Ray Spectroscopy in Europe:*

*Present and Future Challenges*

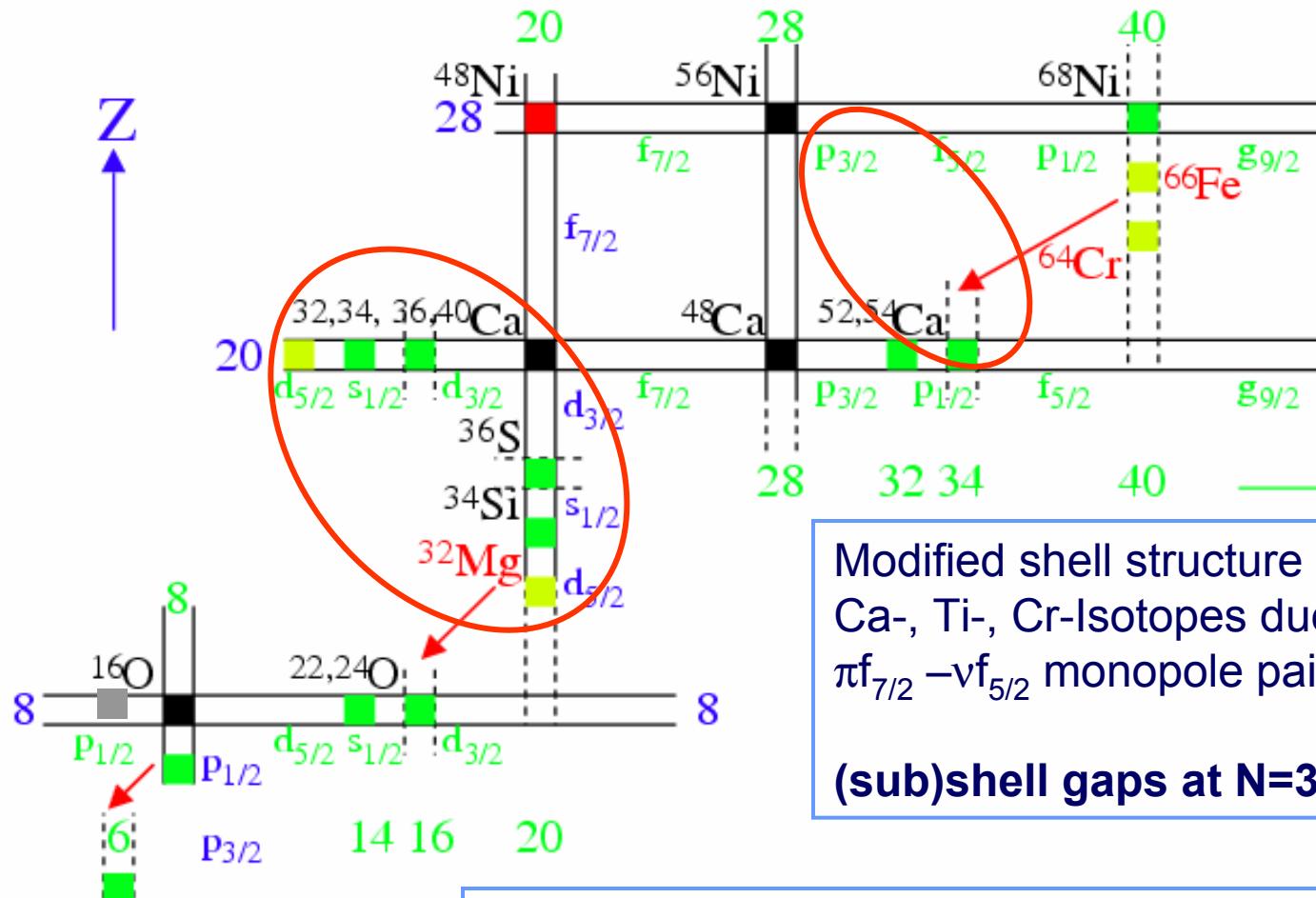
ECT Trento, May 8 – 12, 2006

# Physics program - Nuclei of interest



# New Shell Structure at N>>Z

## Mirror symmetry of (sub)shell closures



Modified shell structure in neutron-rich Ca-, Ti-, Cr-Isotopes due to weaker  $\pi f_{7/2} - \nu f_{5/2}$  monopole pairing interactions?

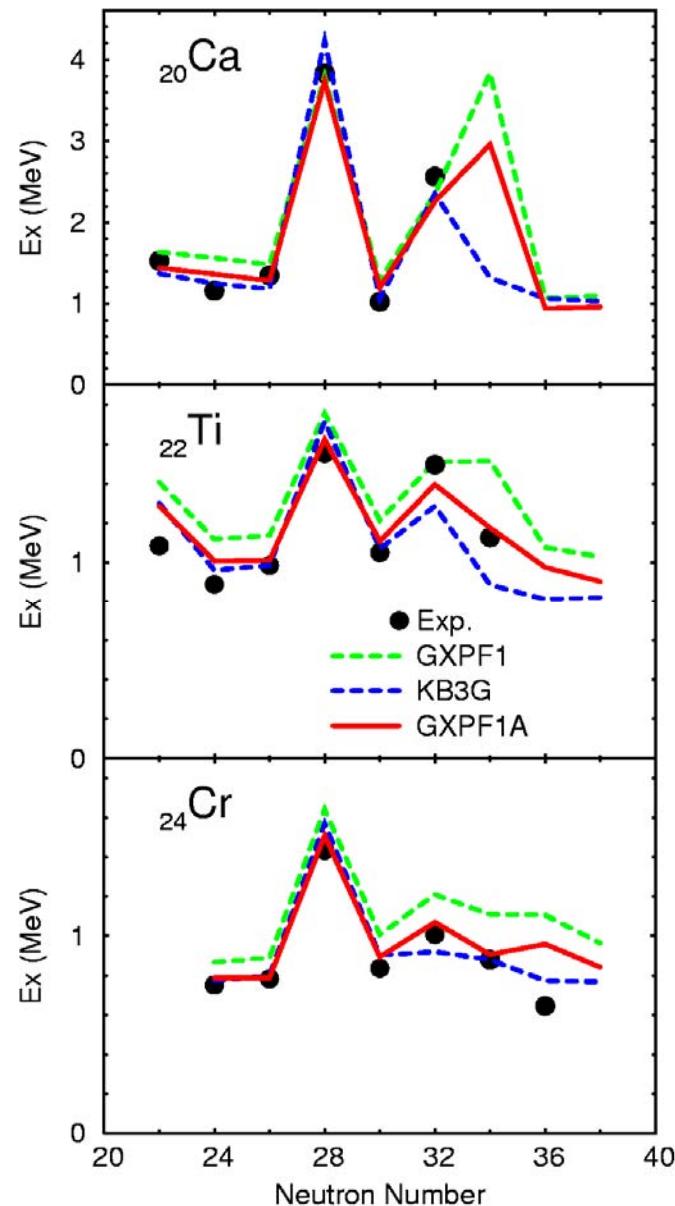
(sub)shell gaps at N=32 and N=34?

Z=14(16) shell stabilisation and Z=12 shell quenching in N=20 isotones.

(sub)shell gaps at N=14,16 for Ca isotopes?

# New Shell Structure at N>>Z Relativistic Coulex in N=28-34 Nuclei

- Large scale shell model calculations
  - GXPF1, GXPF1A  
*M.Honma et al,*  
*Phys. Rev. C65(2002)061301*
  - KB3G  
*E.Caurier et al,*  
*Eur.Phys.J. A 15, 145 (2002)*
- Transition matrix elements
  - B(E2) in  $^{52,54,56}\text{Ti}$  (MSU)
  - B(E2) in  $^{54,56,58}\text{Cr}$  (GSI)



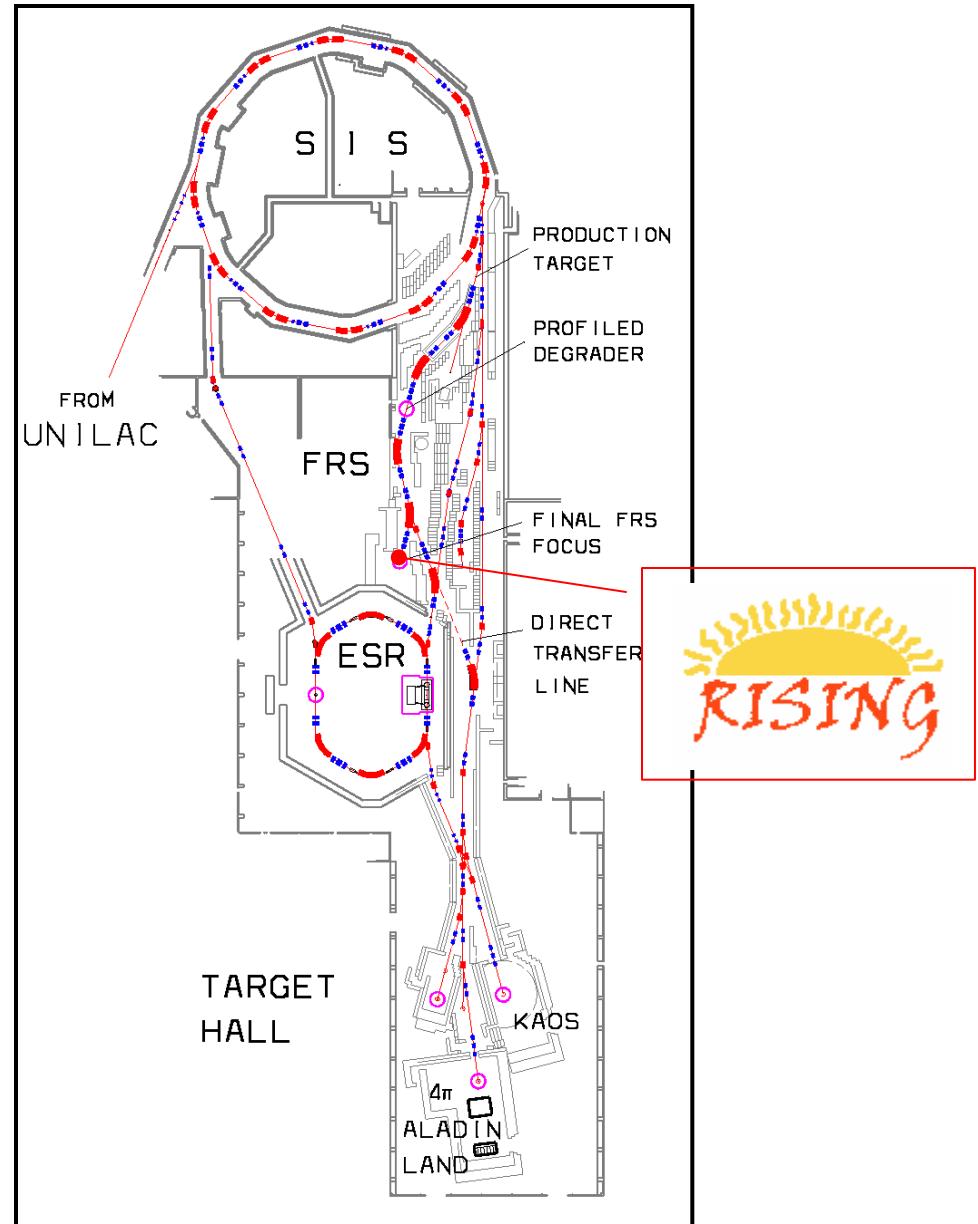
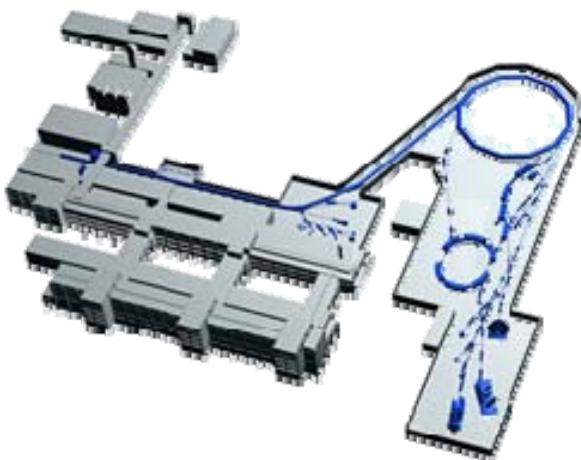
# Relativistic beams at GSI

accelerators:

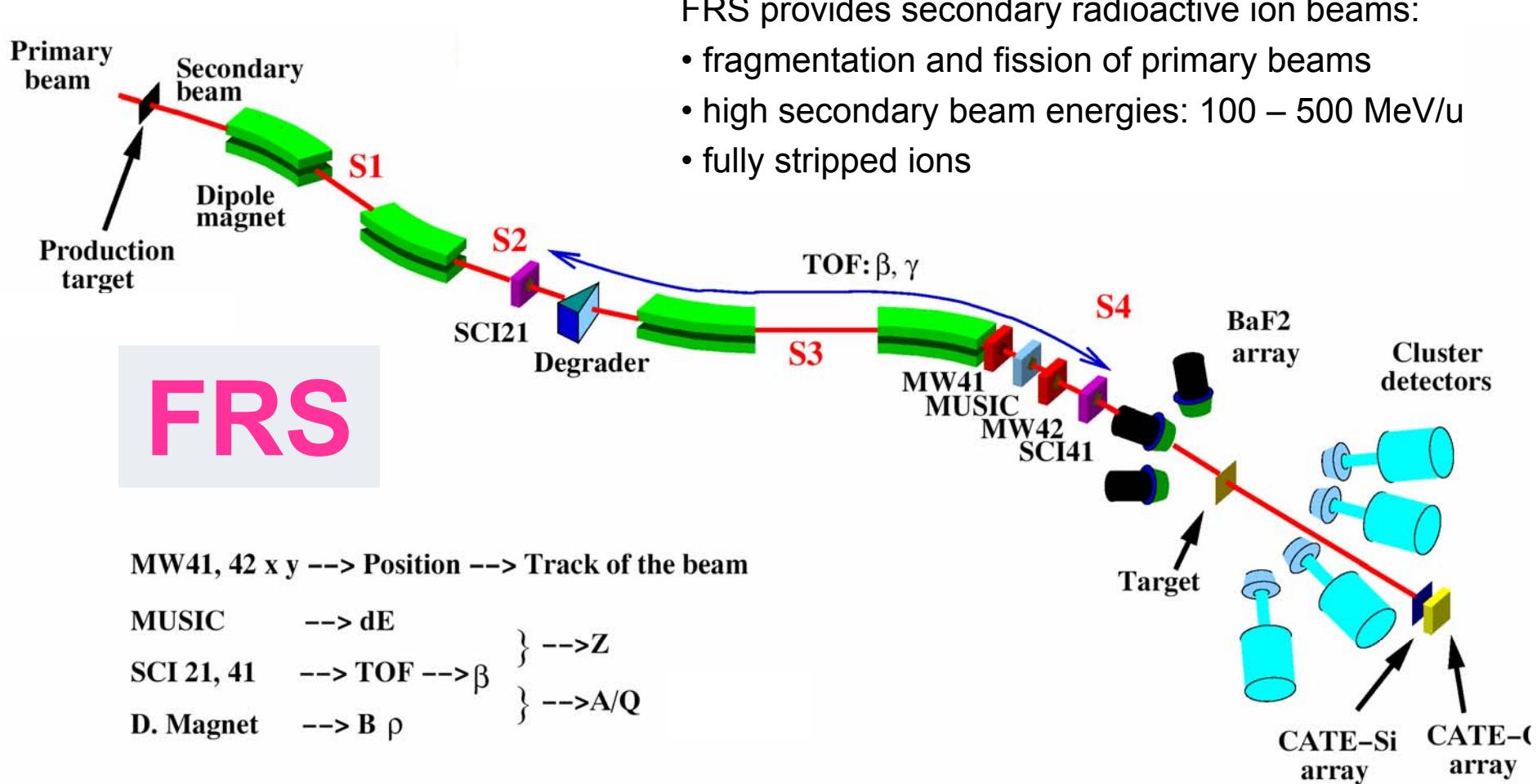
- UNILAC (injector) -  $E < 15 \text{ AMeV}$
- SIS -  $E < 1 \text{ AGeV}$

beams:

- All ion species up to  $^{238}\text{U}$
- Currents:
  - $^{238}\text{U}$  -  $2 * 10^8 \text{ pps}$
  - medium mass nuclei-  $10^9 \text{ pps}$



# High resolution $\gamma$ -spectroscopy at the FRS



FRS provides secondary radioactive ion beams:

- fragmentation and fission of primary beams
- high secondary beam energies: 100 – 500 MeV/u
- fully stripped ions

RISING

# $\gamma$ -spectroscopy at relativistic energies

## High cross sections

- Coulomb excitation
- Secondary fragmentation

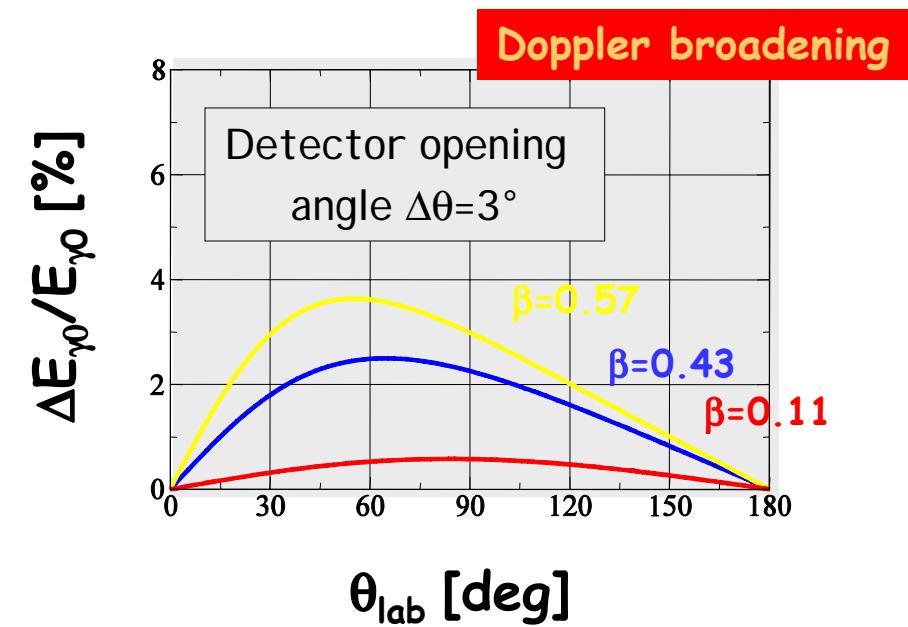
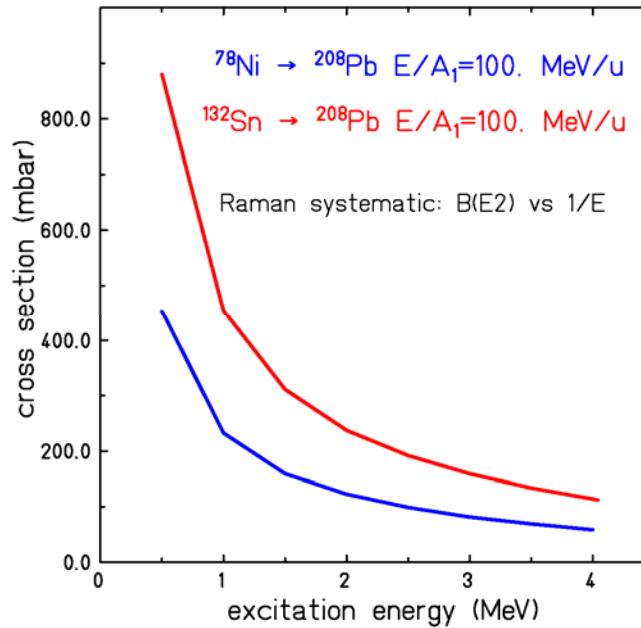
## Thick targets

## Lorentz boost of $\gamma$ -rays

- Doppler shift
- Gain in geometrical efficiency
- Doppler broadening

## Atomic background, a limiting factor

- X-rays from target atoms
- Radiative electron capture
- Primary Bremsstrahlung
- Secondary Bremsstrahlung
- $\sigma$  (atomic)  $\sim 10000 * \sigma$  (nuclear)



## High energetic reactions

# Coulomb excitation at relativistic energies

- Sommerfeld Parameter  $\eta \gg 1$

- adiabaticity parameter  $\xi$

$$\xi \equiv \frac{\omega_{\text{ph}}}{\omega_{\text{coll}}} \equiv \frac{\Delta E}{\hbar} \tau_{\text{coll}} = \frac{\Delta E}{\hbar c} \frac{b}{\gamma \beta} \quad \text{for } \xi = 1 \quad \Delta E_{\text{max}} = \frac{\gamma \beta \hbar c}{b_{\text{min}}}$$

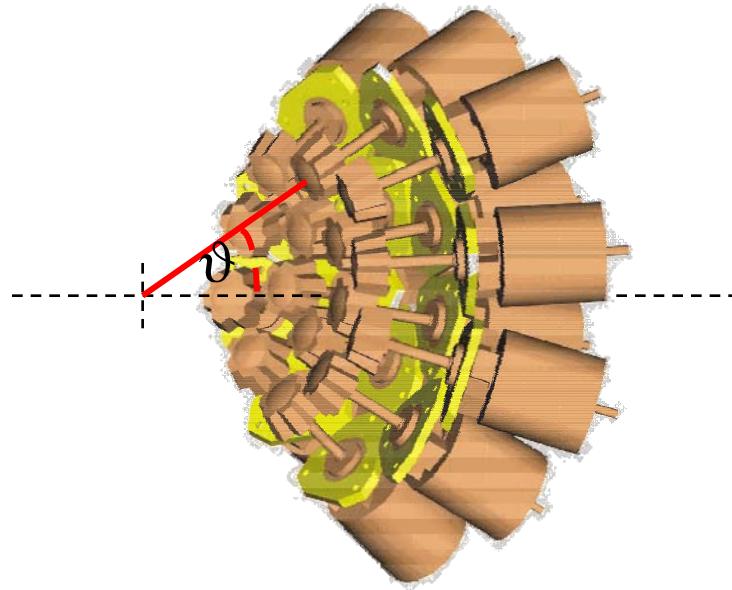
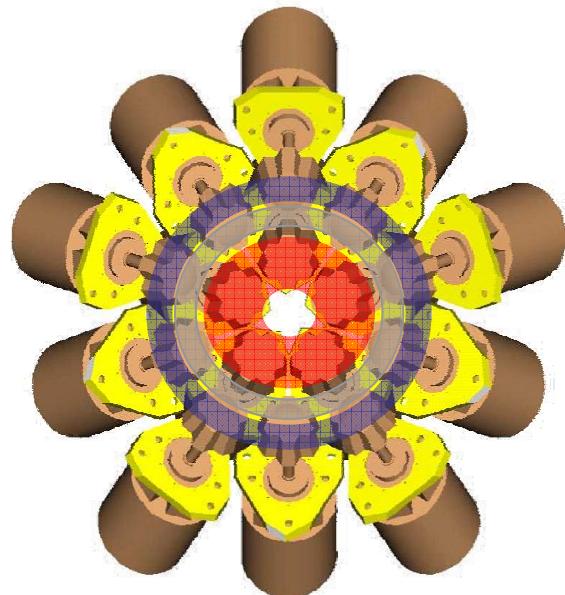
- higher excitation energies at relativistic energies
- access to GDR range 10 - 20 MeV

- excitation strength parameter  $\chi$

$$\chi^{(\pi\pi\lambda)}(b) \approx \frac{V_\lambda(b) \cdot \tau_{\text{coll}}}{\hbar} \approx \frac{Z_t e \langle f | M(\pi(\pi\lambda|i) \rangle}{\hbar \gamma v b^\lambda}$$

- only single step excitation at relativistic energies

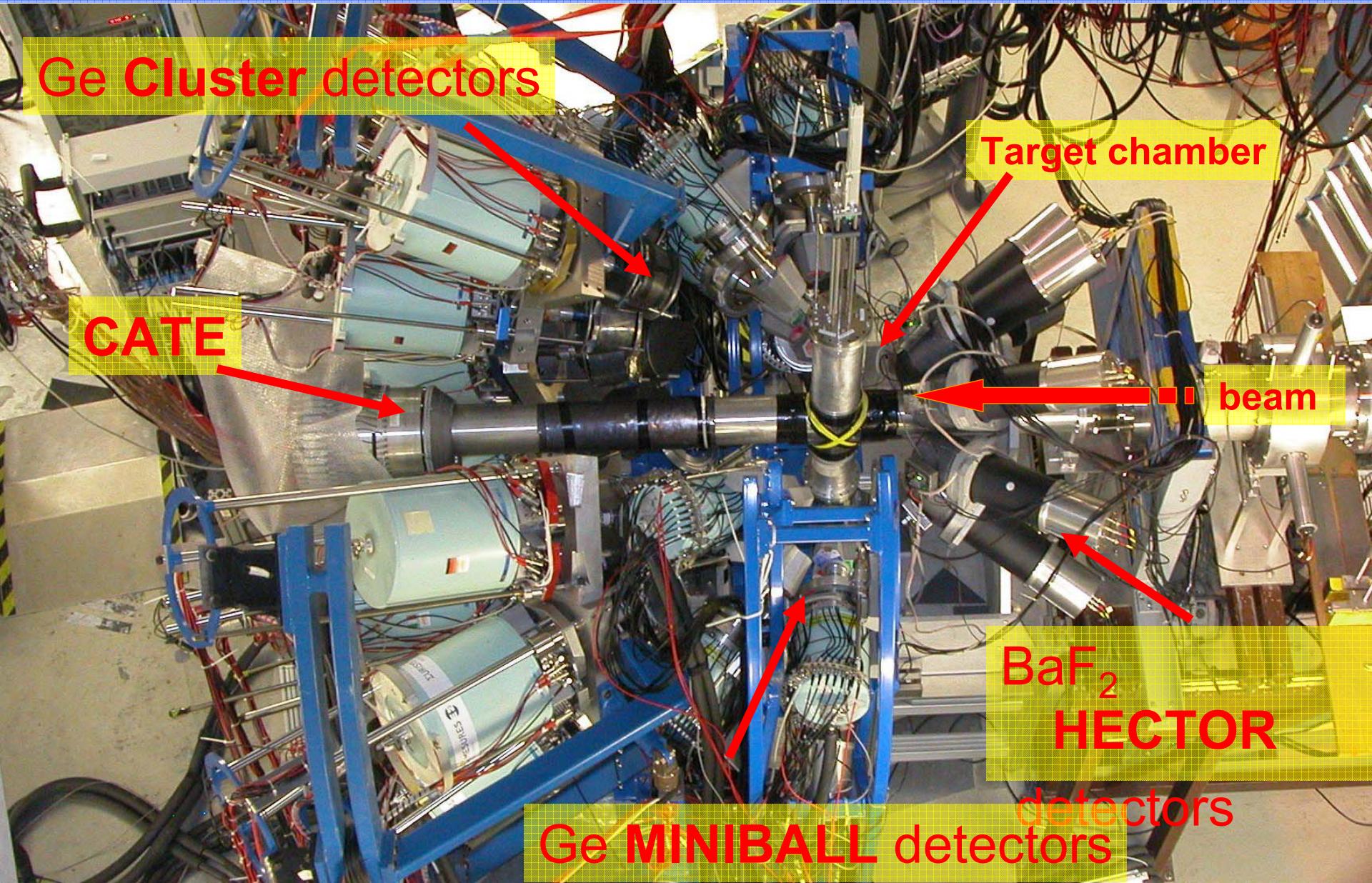
# EUROBALL-Cluster array



15 EUROBALL  
Cluster detectors  
without ACS  
105 Ge crystals

Ring	Angle [deg]	Distance [mm]	Resolution [%]	Efficiency [%]
1	15.9	700	1.00	1.00
2	33.0	700	1.82	0.91
3	36.0	700	1.93	0.89
Total:			1.56	2.81

# RISING experimental setup

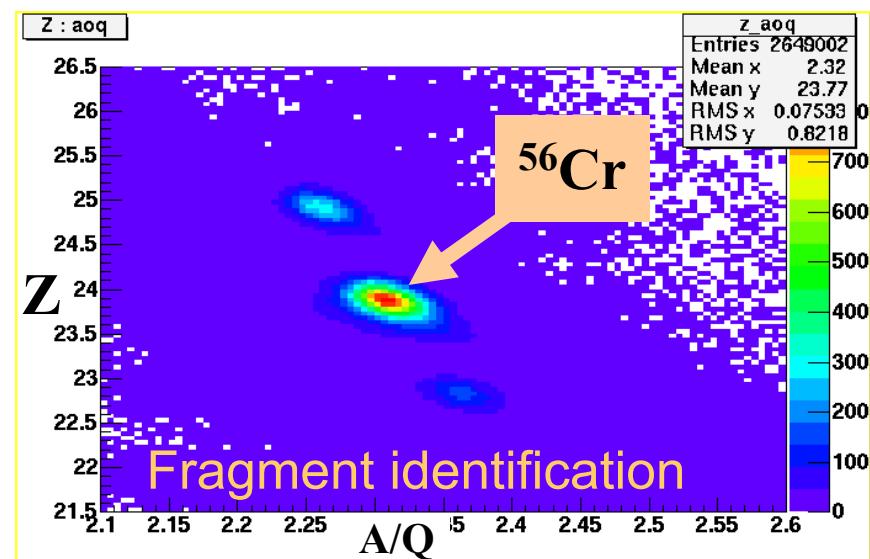


# RI beam: fragment identification and tracking

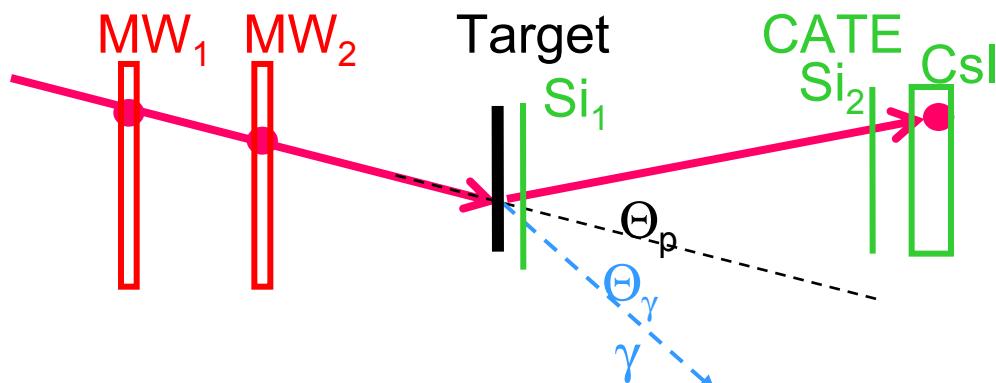
Primary beam  $^{86}\text{Kr}$ , 480 MeV/u,  $10^9$  p/sec

Secondary beams, 136 MeV/u:

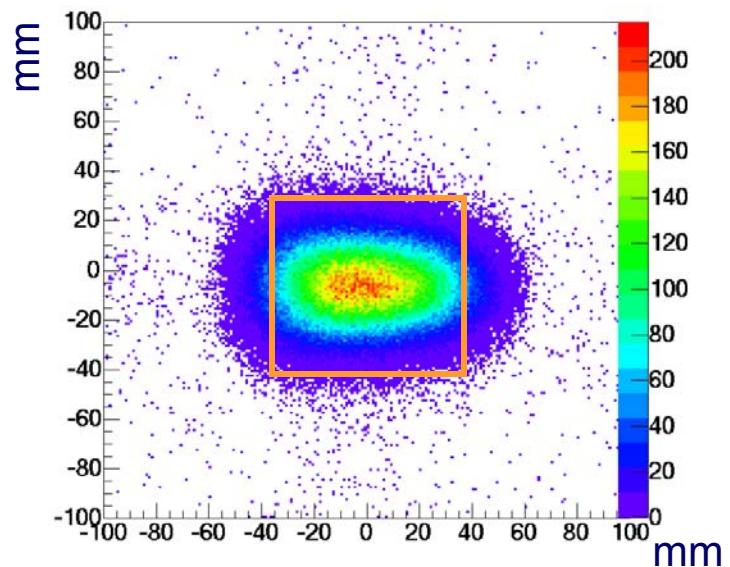
- $^{54}\text{Cr}$ :  $4 \times 10^3$  part./s, 22 h, 45%  $^{54}\text{Cr}$
- $^{56}\text{Cr}$ :  $1 \times 10^3$  part./s, 20 h, 35%  $^{56}\text{Cr}$
- $^{58}\text{Cr}$ :  $3 \times 10^2$  part./s, 55 h, 25%  $^{58}\text{Cr}$



## Tracking before target



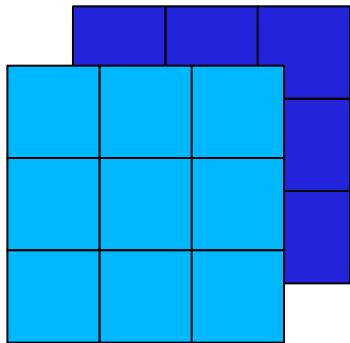
## Multiwire extrapolation to target



# CAlorimeter TElescope CATE

## Particle Identification and Tracking after Target

R. Lozeva et al, NIM B, 204 (2003) 678

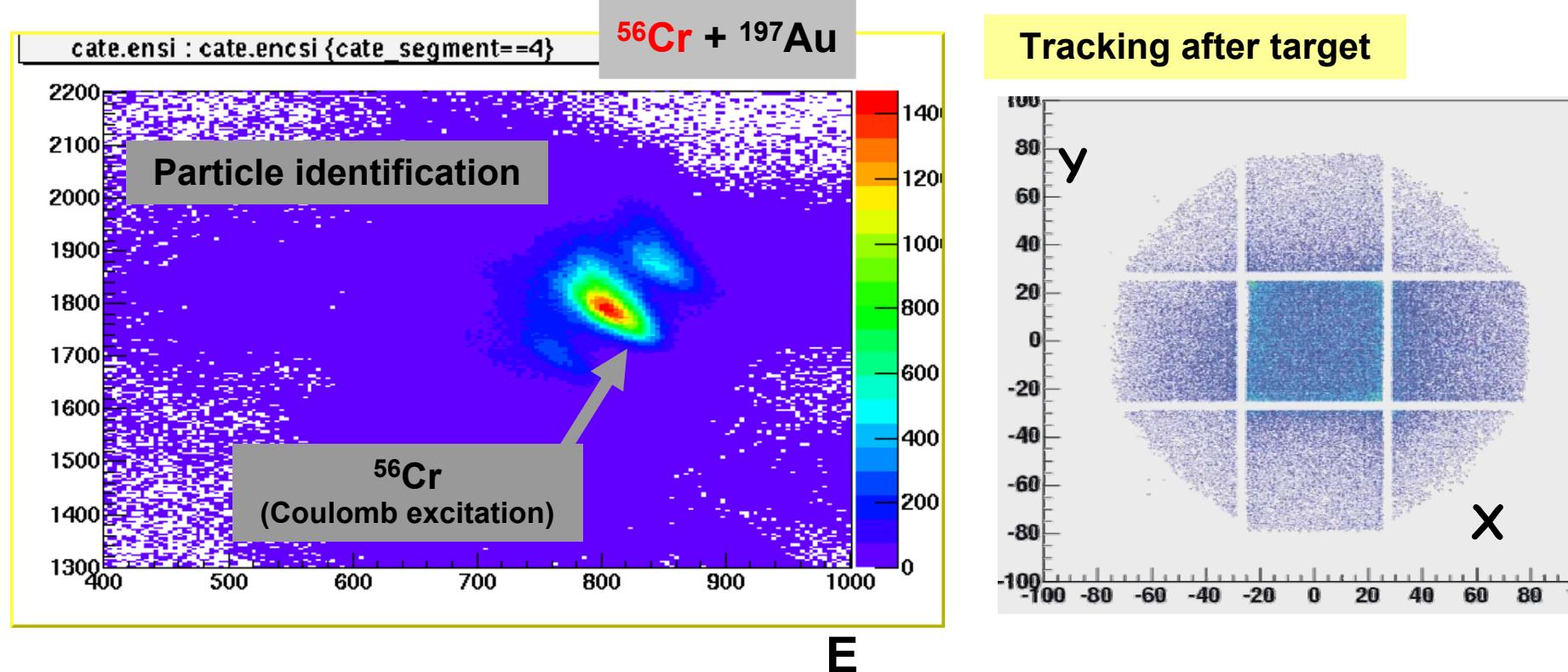


$\Delta E$

- 0.3 mm thick Si detectors
- Z identification
- Position sensitive

$E$

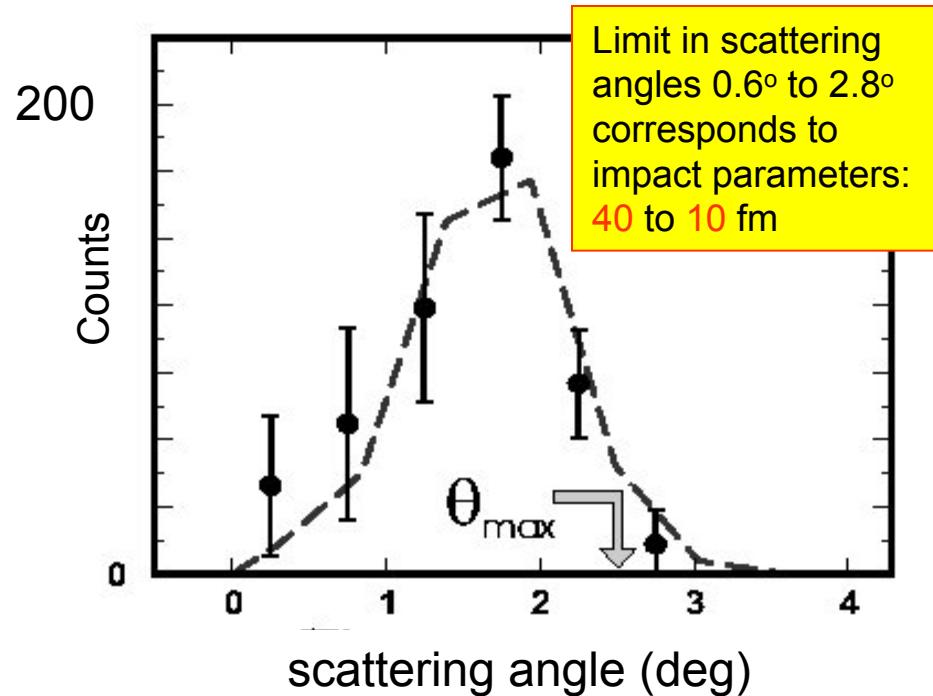
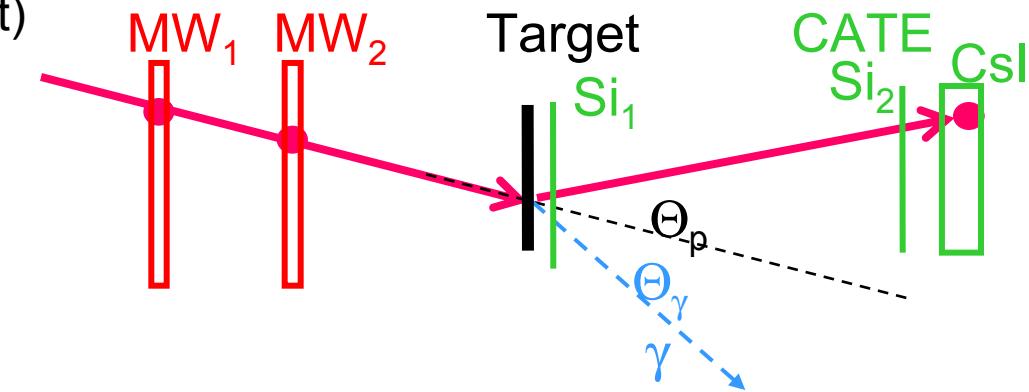
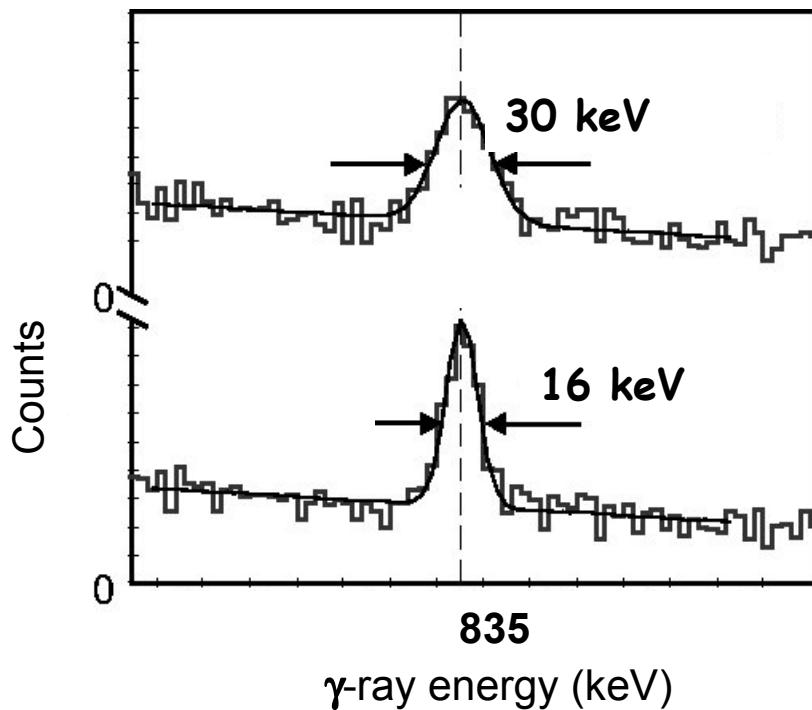
- CsI detectors
- Z identification



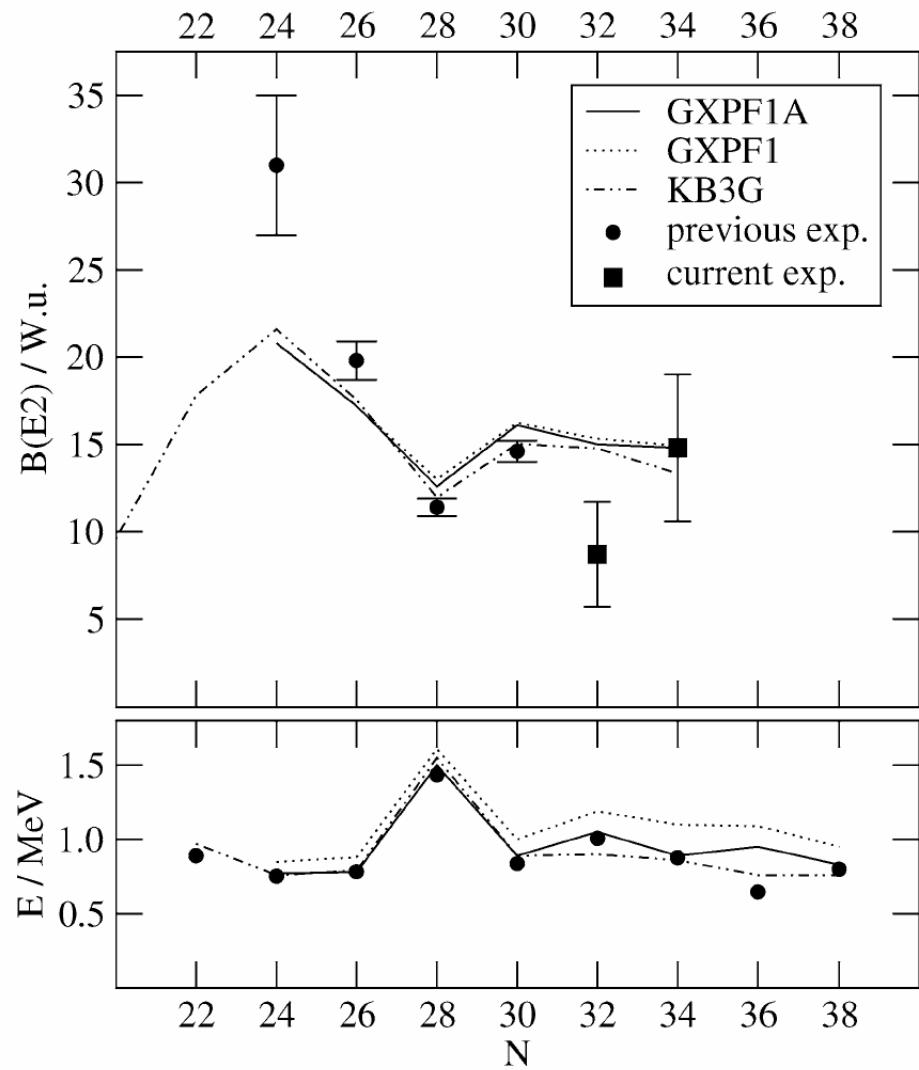
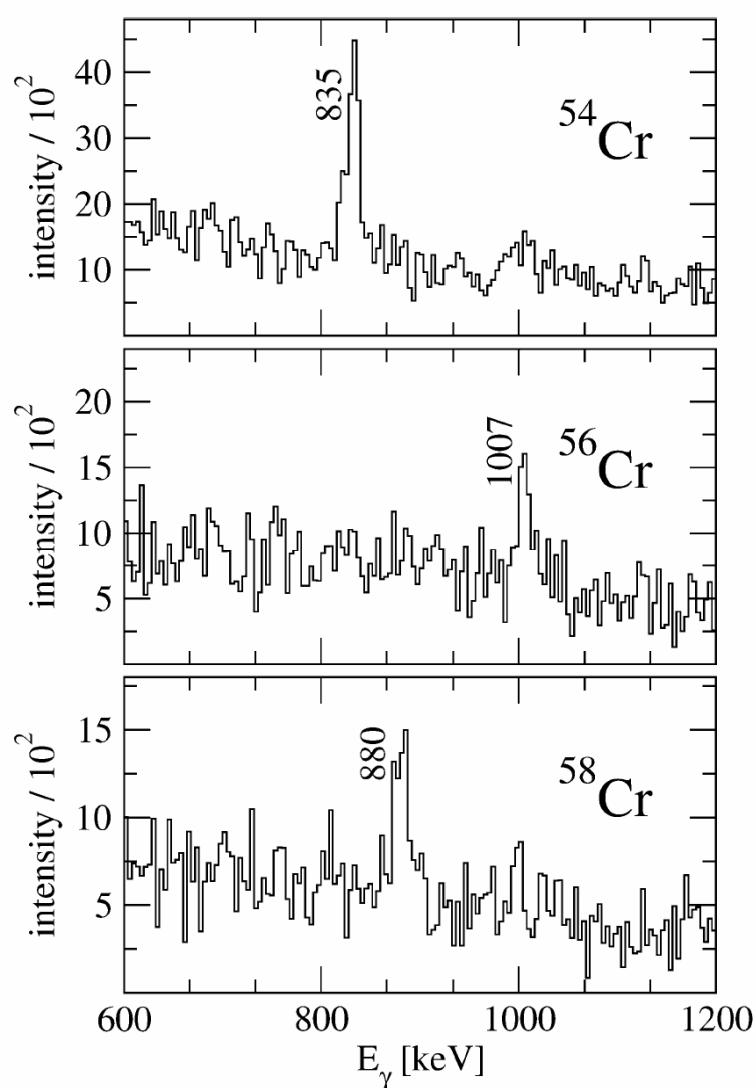
Tracking: - Doppler correction  
- scattering angle

- velocity v/c from TOF (event-by-event)
- tracking of ions:  $\gamma$ -ray emission angle

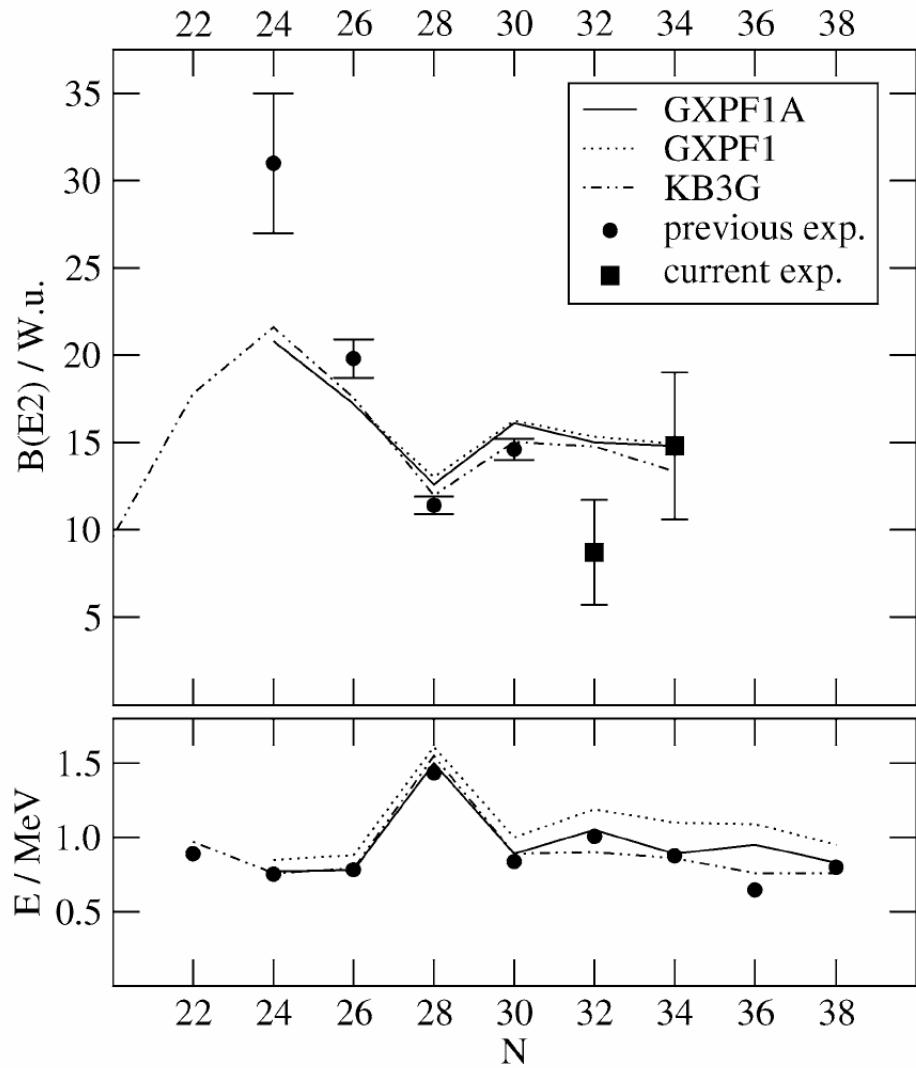
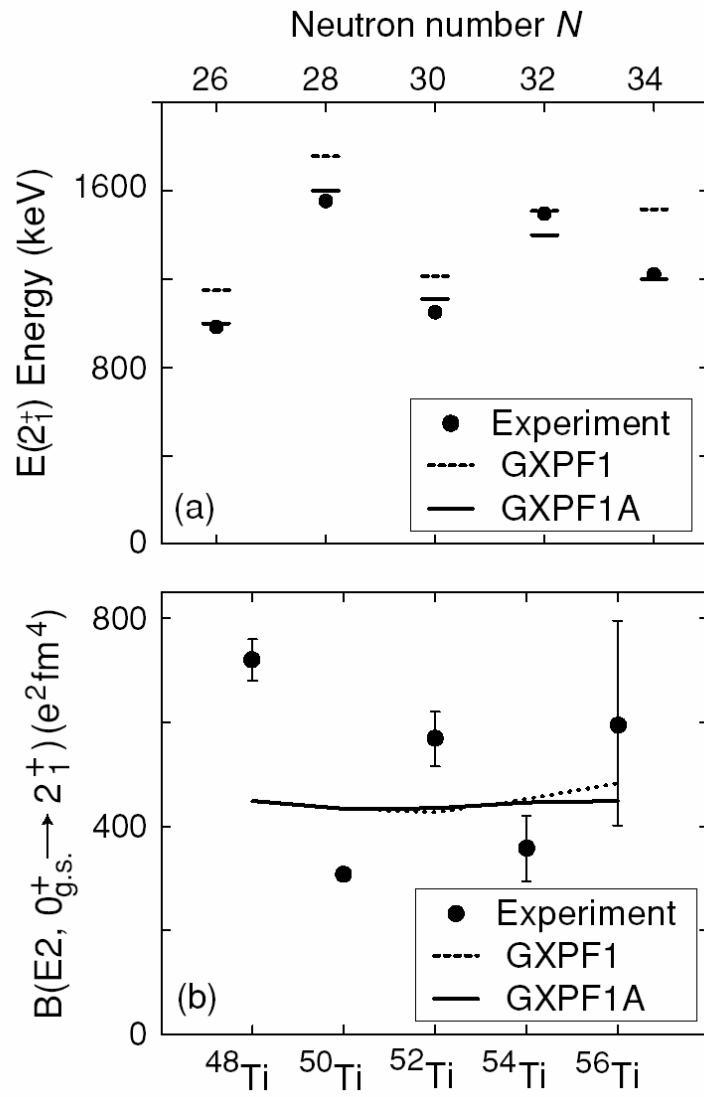
$\Rightarrow \gamma$ -ray energy resolution  
 $\Rightarrow$  scattering angle



# New Shell Structure at $N \gg Z$ Relativistic Coulex in $N=28-34$ Nuclei

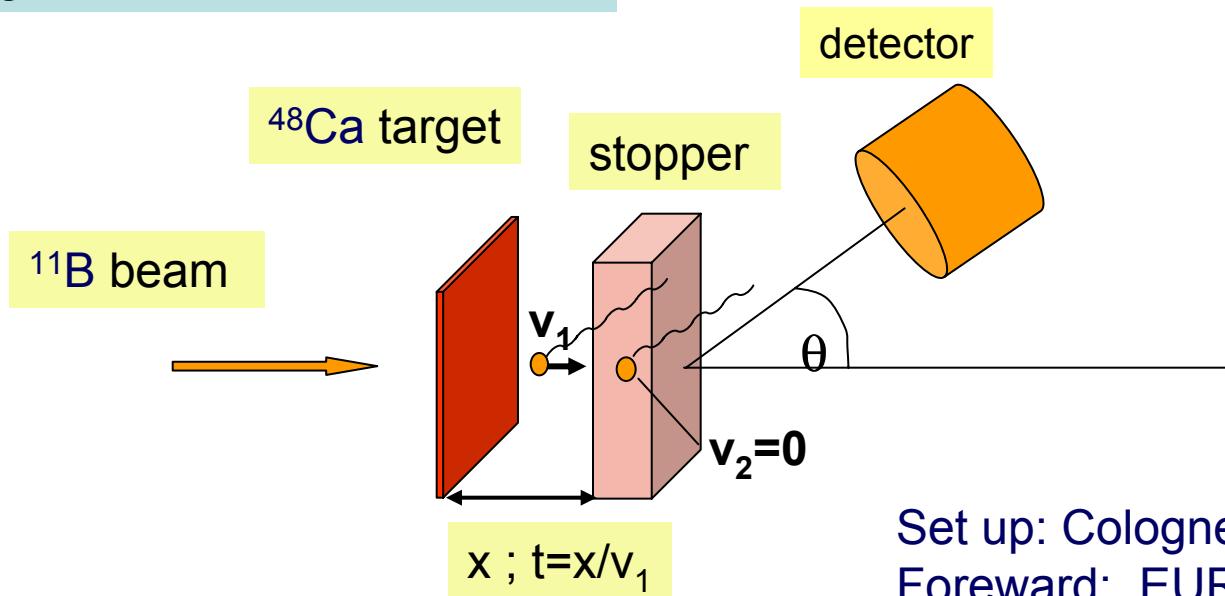


# Comparison with $^{52,54,56}\text{Ti}$

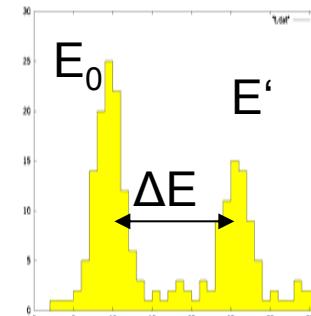


# Stable beam lifetime measurement in $^{56}\text{Cr}$

Recoil Distance Doppler Shift  
Plunger Method



Doppler shift:  
 $\Delta E = E_0 \cdot v/c \cdot \cos(\theta)$



$^{48}\text{Ca}(^{11}\text{B},p2n)^{56}\text{Cr}$  @ 30 MeV  
Cologne tandem accelerator

Set up: Cologne plunger  
Forward: EUROBALL Cluster  
Backward: 5 Ge-detector

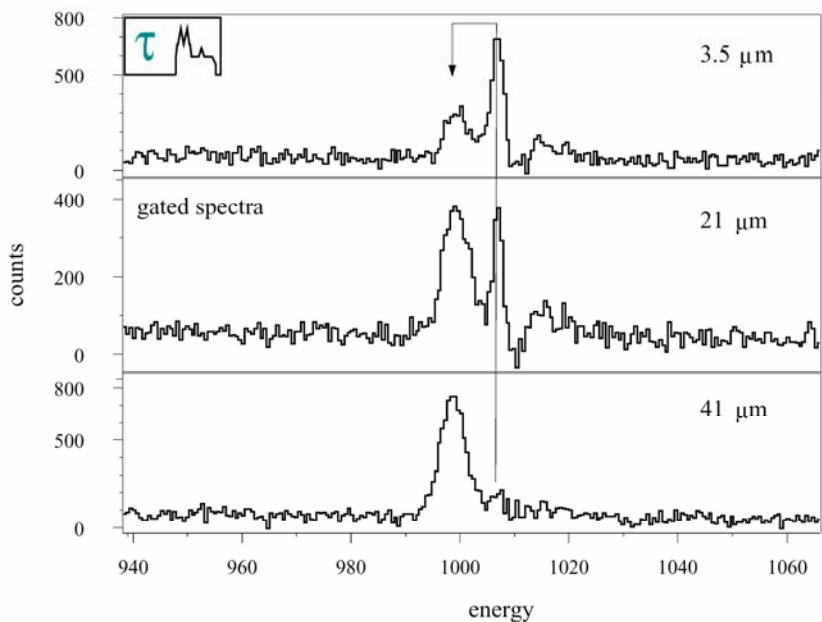
Potential difficulties:

Feeding: observed; unobserved  
Deorientation, ....



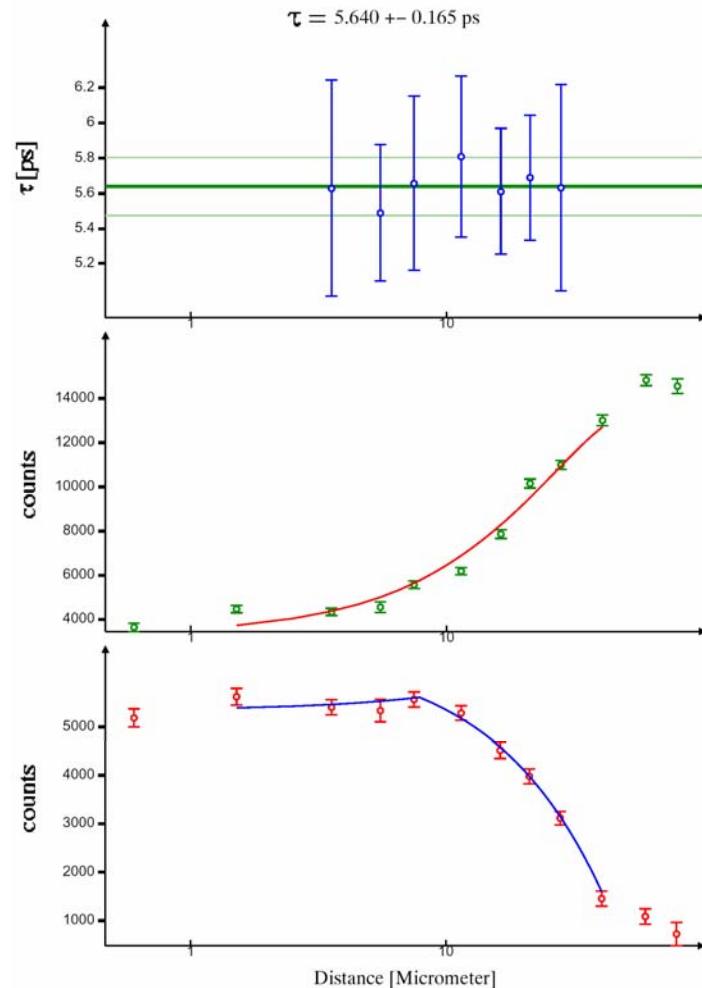
$\gamma\gamma$  coincidences with plunger  
Differential Decay Curve method

# stable beam, lifetime measurement in $^{56}\text{Cr}$



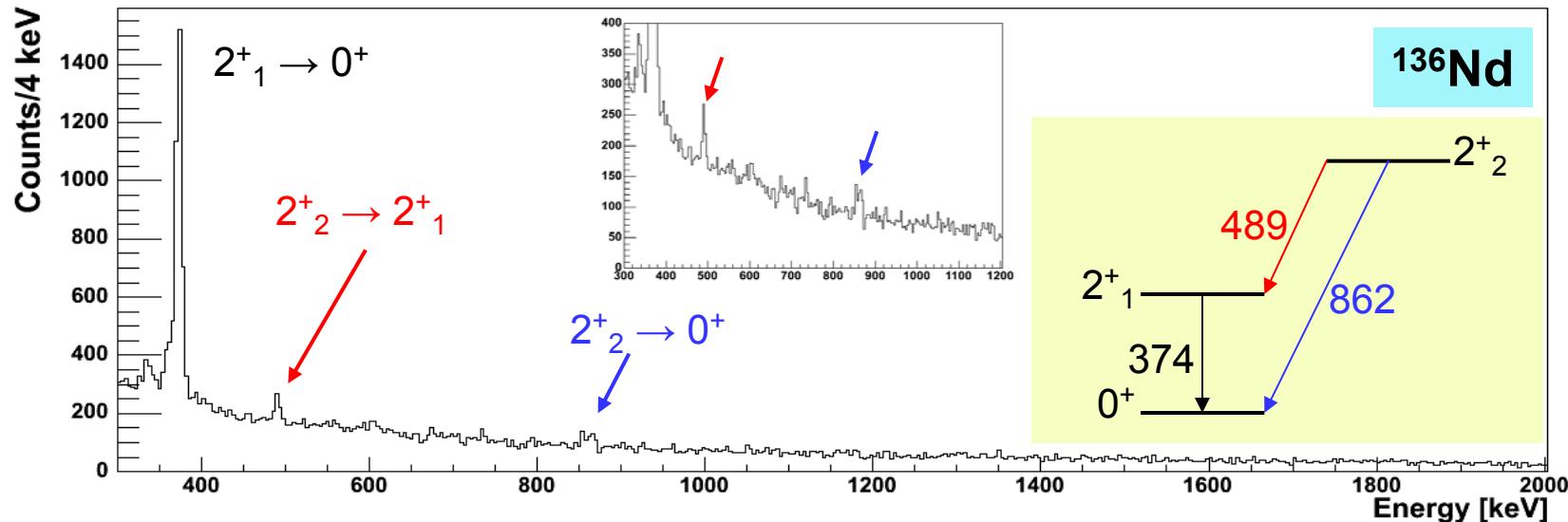
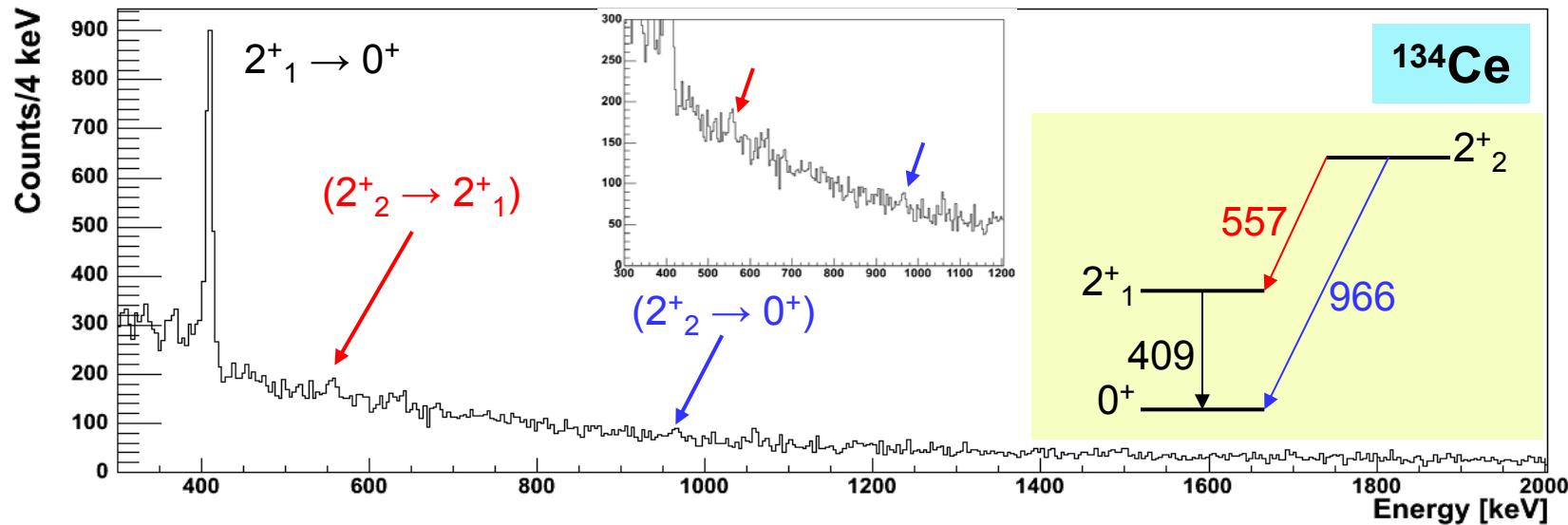
	$E_{\gamma}$ [keV]	RISING B(E2) [Wu]	Plunger B(E2) [Wu]	B(E2) [Wu]
$^{54}\text{Cr}$	835	Normalisation		14.6(6)
$^{56}\text{Cr}$	1006	<b>8.7 (3.0)</b>	<b>11.1 (3)</b>	---
$^{58}\text{Cr}$	880	<b>14.3 (4.2)</b>		---

## Differential Decay Curve method



- RISING result confirmed ~ 3 % error
- $^{58,60,62...}\text{Cr}$  radioactive beams or deep inelastic reactions

# Triaxiality in even-even core nuclei of N=75 odd-odd isotones



# AGATA performance in FAIR experiments

RISING

(2004/5)

AGATA-15

~2010

Efficiency : 1-3%

10.5%

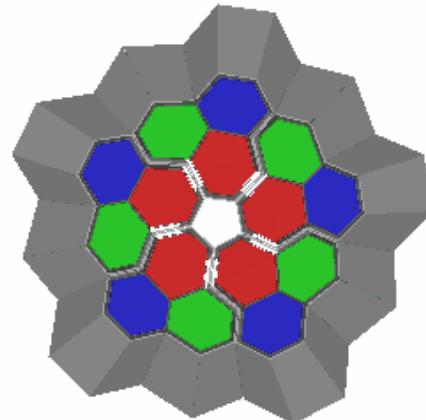
FWHM: 25 keV

~7 keV

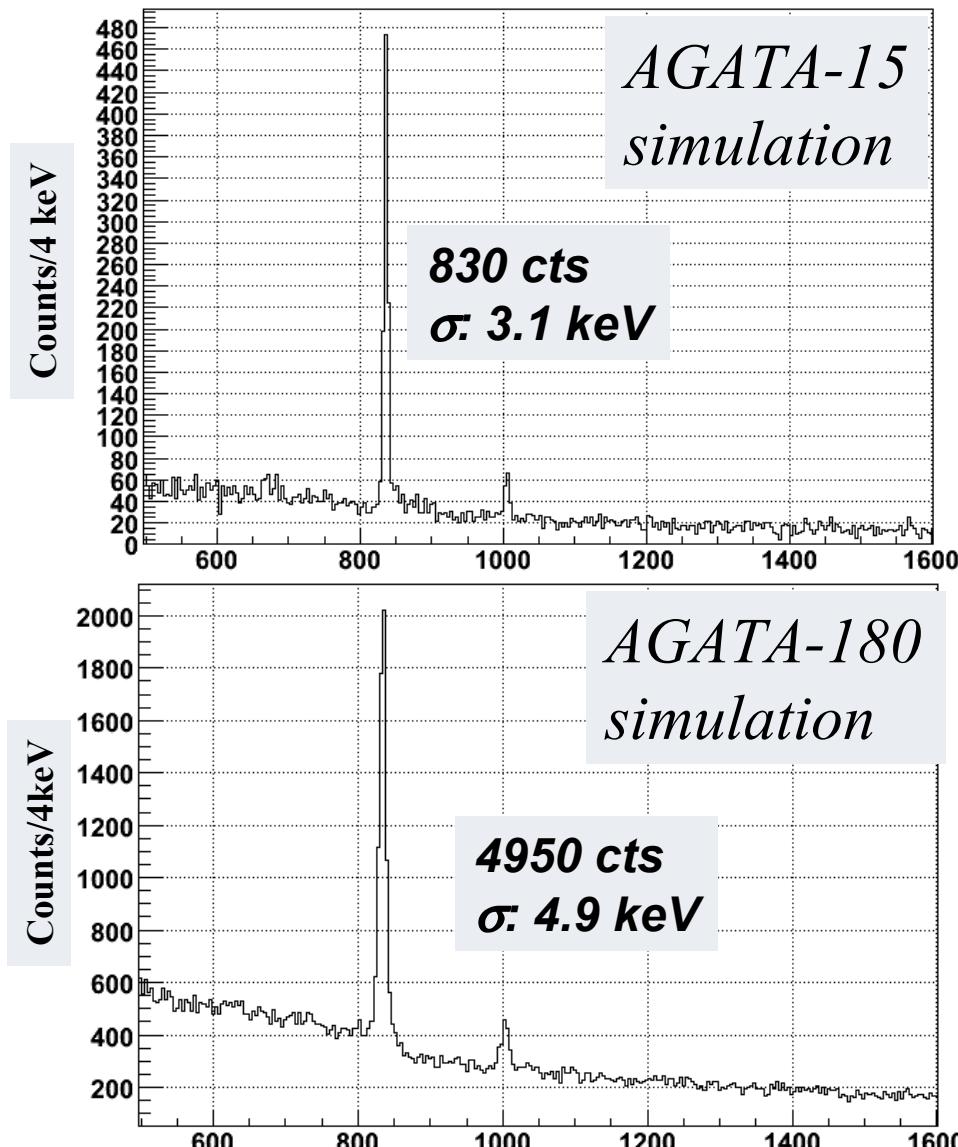
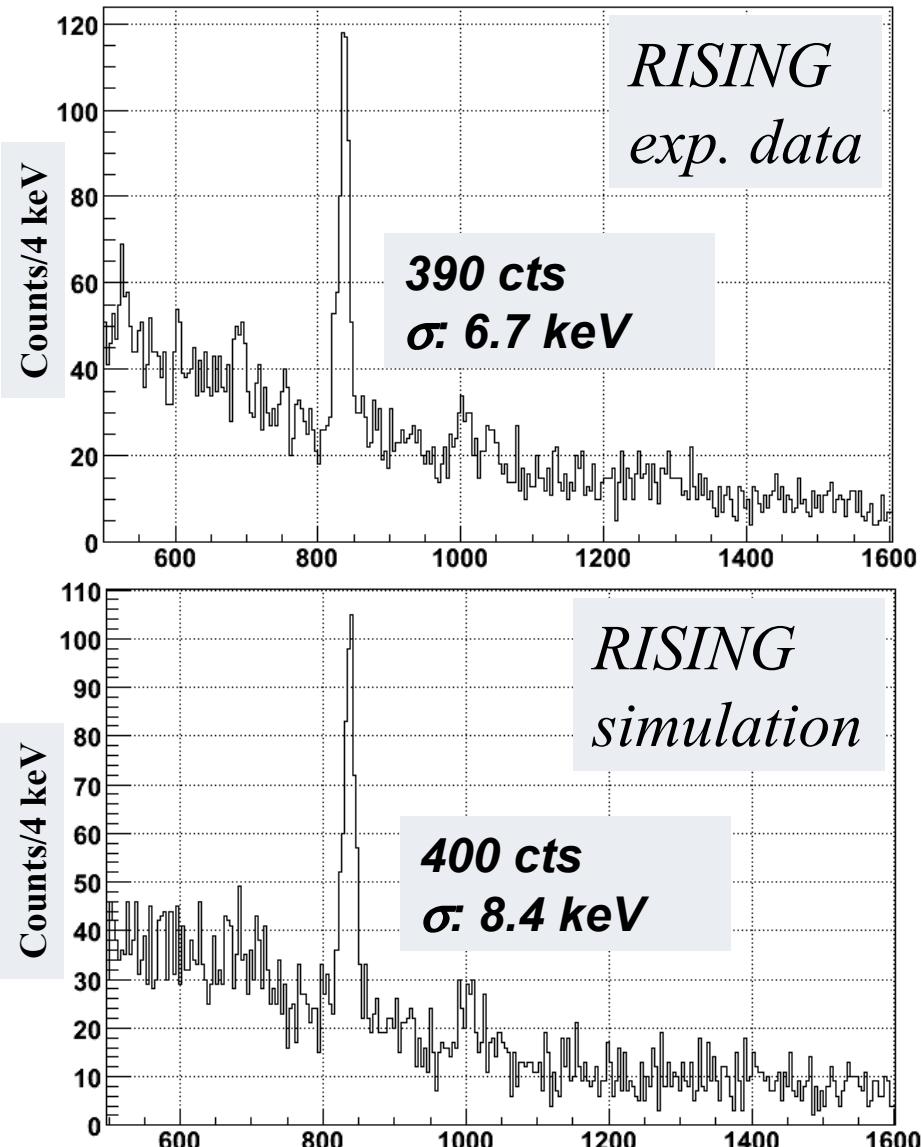
at  $v/c \sim 0.5$ , multiplicity: 1-5, target-detector distance: 15 cm

Much increased sensitivity

Angular distribution and polarisation measurements,  
 $\gamma\gamma$ -coincidence measurements, g-factors  
background suppression through determination of source



# AGATA vs. RISING Coulomb excitation of $^{54}\text{Cr}$



Calculation by A. Bürger, W. Korten

# Summary

## **Coulomb excitation results from fast beam RISING**

- Coulex at 130-150 MeV established
- Coulomb excitation of  $2^+_1$  in  $^{108,112}\text{Sn}$   
*A. Banu et al., Phys. Rev. C 72, 061305(R) (2005)*
- Coulomb excitation of  $2^+_1$  in  $^{54,56,58}\text{Cr}$   
*A. Bürger et al., Phys. Lett B 622, 29 (2005)*
- RDDS results confirms B(E2) of  $^{56}\text{Cr}$
- Collective modes and E1 strength distribution:  $^{68}\text{Ni}$   
talk by F. Camera
- Coulomb excitation of  $2^+_1$  and  $2^+_2$  in  $^{134}\text{Ce}$ ,  $^{136}\text{Nd}$   
talk by T. Saito

## **Future challenges**

- ✓ fast beam RISING
- ✓ AGATA demonstrator

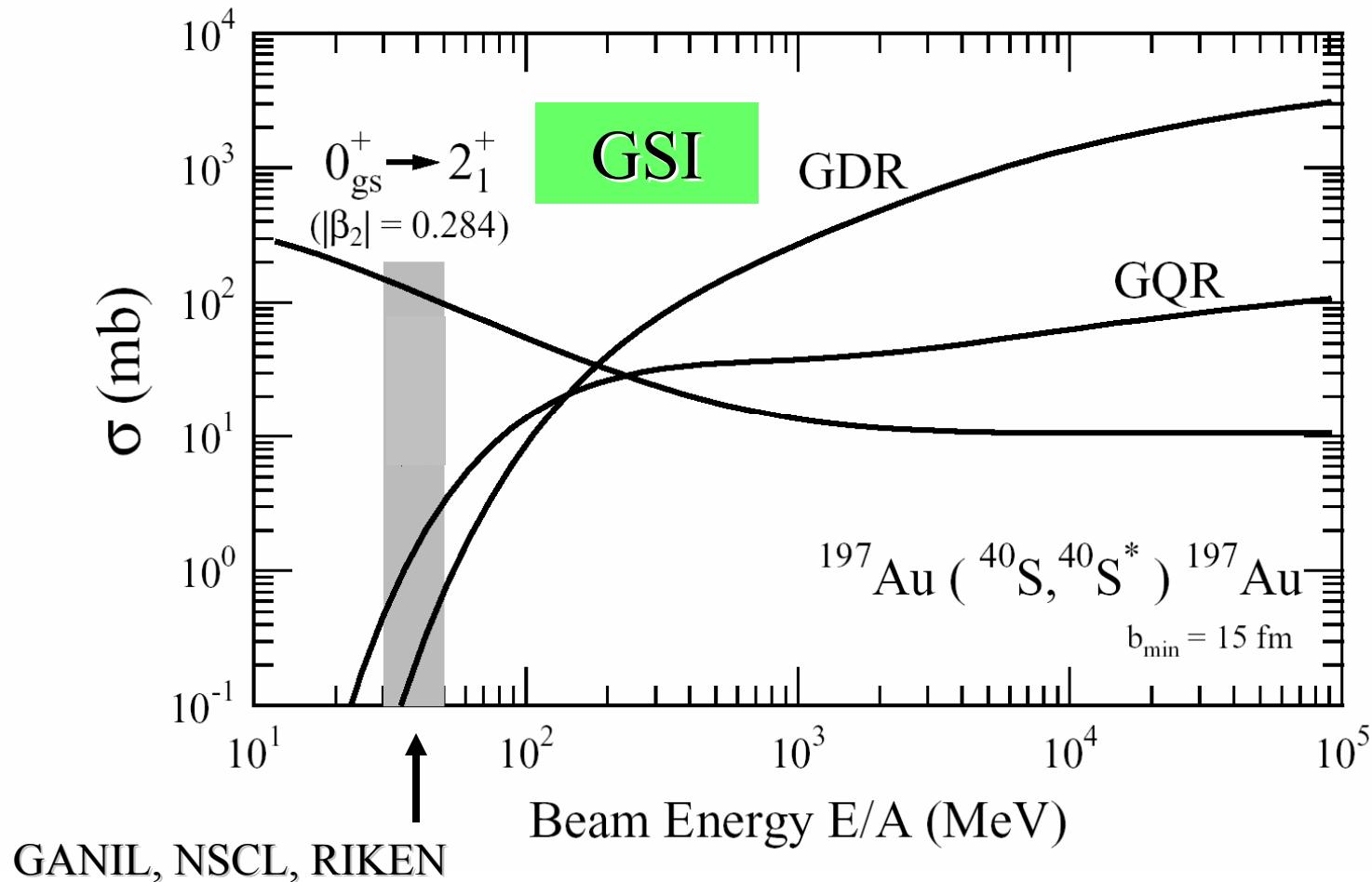
# RISING collaboration

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M. Mutterer<sup>g</sup>, P.J. Nolan<sup>i</sup>, G. Neyens<sup>q</sup>, J. Nyberg<sup>r</sup>, W. Prokopowicz<sup>a</sup>,  
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H. Geissel, J. Gerl, M. Gorska, J. Grębosz, M. Hellström, M. Kavatsyuk,  
O. Kavatsyuk, I. Kojouharov, N. Kurz, R. Lozeva, S. Mandal, N. Saito, T. Saito,  
H. Schaffner, H. Weick, M. Winkler, H.J. Wollersheim

# Coulomb excitation cross section



# Coulomb excitation parameters

**Coulomb excitation:  $^{56}\text{Cr} \rightarrow ^{197}\text{Au}$**

E/A	5 AMeV	60 AMeV	130 AMeV	500 AMeV
Adiabaticity parameter	0.6	0.17	0.11	0.05
$E_{\max}$	1.6 MeV	5.7 MeV	8.6 MeV	18.6 MeV
Strength parameter*		0.15	0.11	0.07

\* For  $2^+$  excitation  $B(E2) = 300 \text{ e}^2\text{fm}^4$