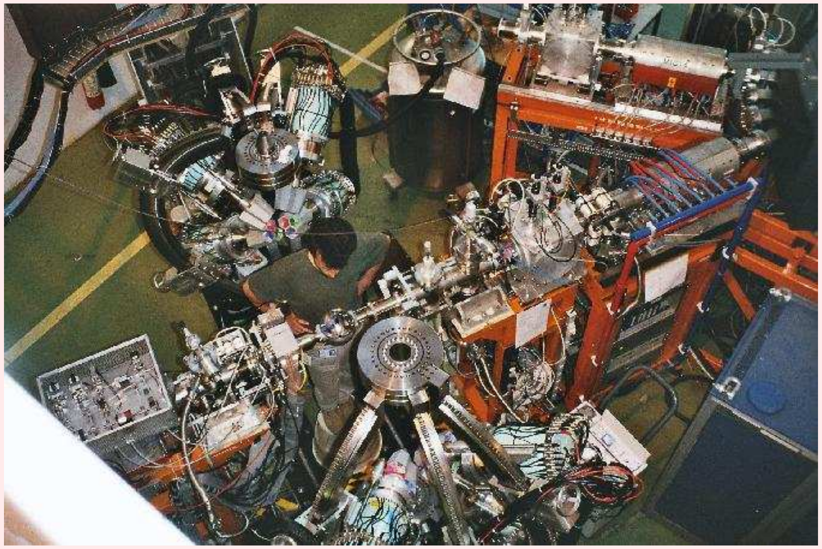
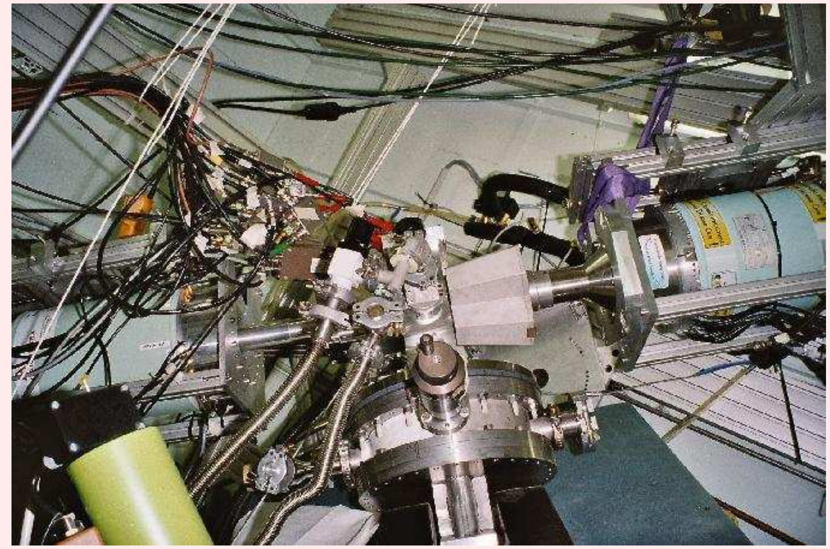
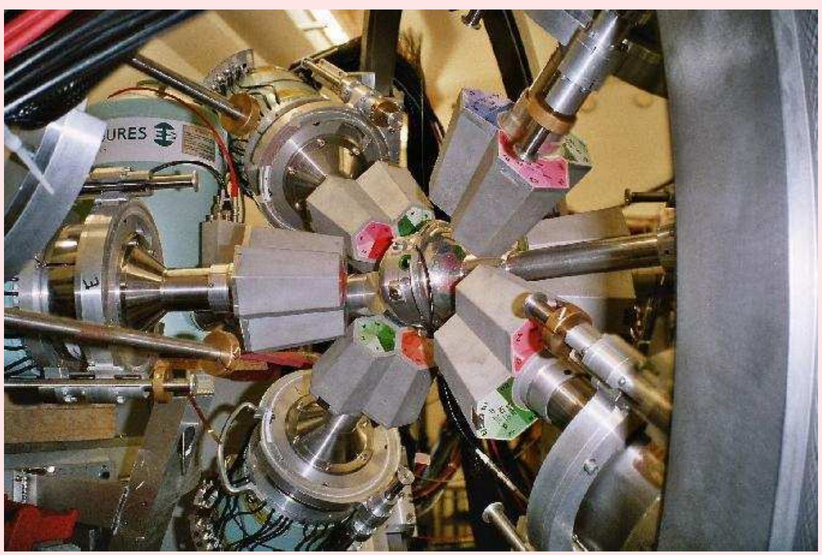
Spectroscopy with radioactive beams: MINIBALL



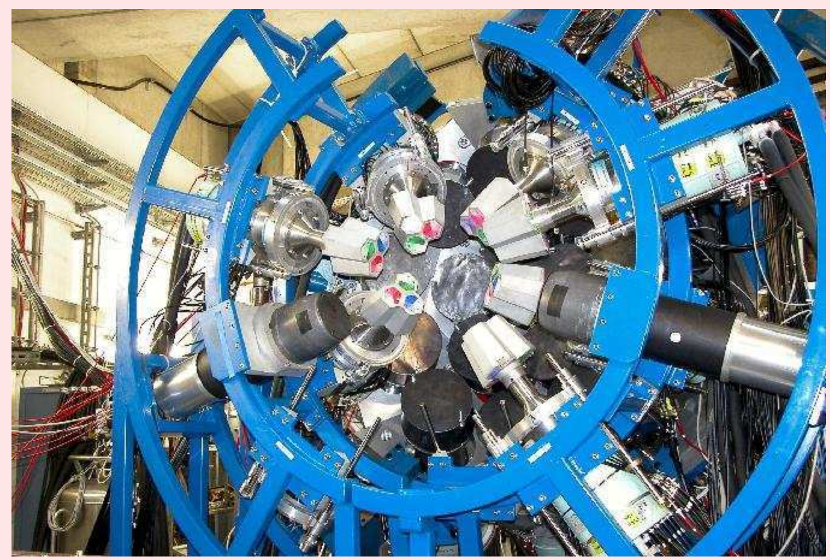
CERN, Geneva (REX-ISOLDE)



ILL, Grenoble (Lohengrin)



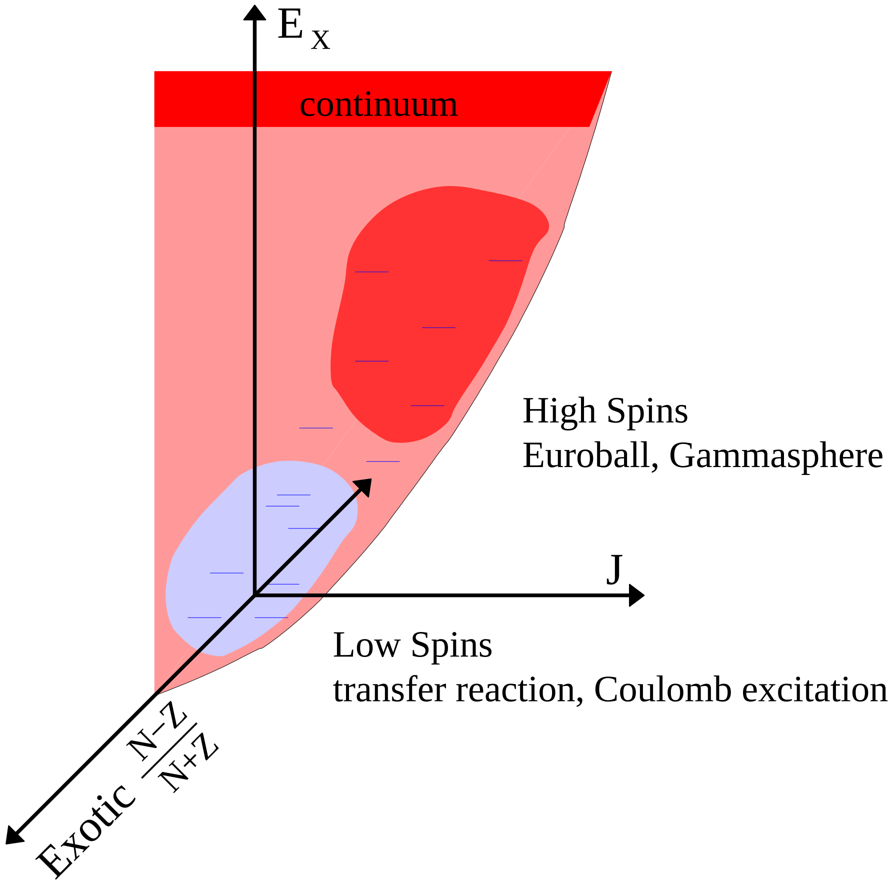
Cologne (with Cologne plunger)



GSI, Darmstadt (Rising)

Where can we find new physics?

IKP



→ **Far from stability**

- **halo nuclei**
- **new shell closures**
- **r-process nuclei**
- **neutron drip line**

  etc.

→ Need radioactive beams

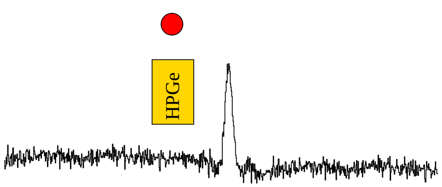
The challenge

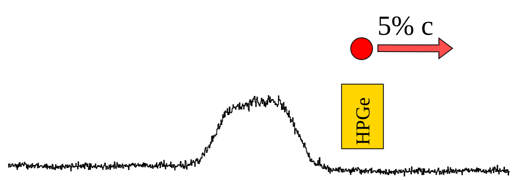
- Very low beam intensities

→ Need high *efficiency* like Euroball or Gammasphere.

→ Need detectors very close to target.

- Inverse kinematics





→ Leads to Doppler broadening.

→ Detector should subtend a small solid angle.

→ Need high *granularity*.

The solution

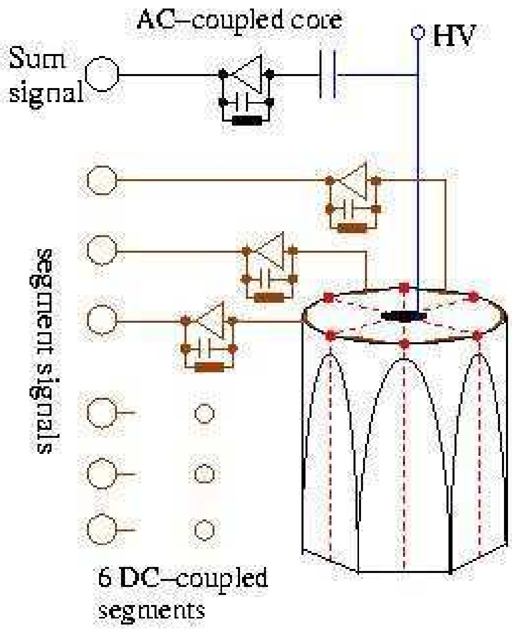
- **Segmented Ge detectors**

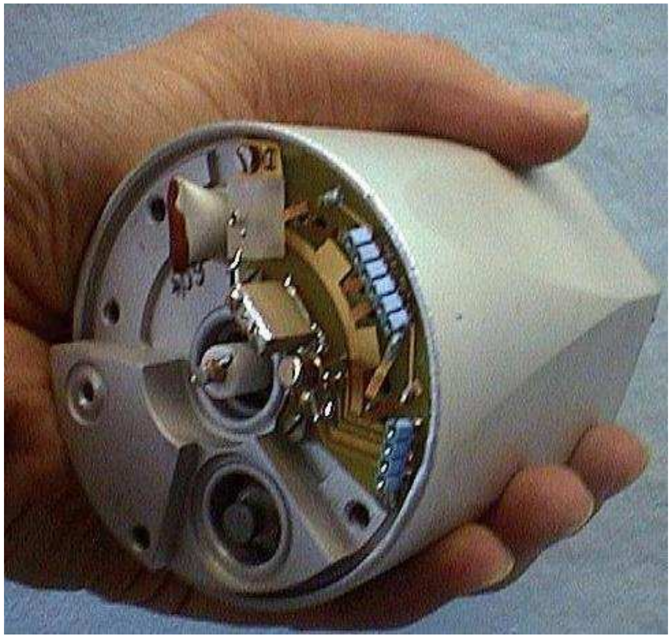
  $\rightarrow$ New technology needed:
  - more compact cold electronics (e.g. Miniball has seven cold FETs in same space where Euroball has just one).
  - new warm preamplifiers with higher bandwidth and smaller physical size.

- **Pulse-shape analysis**

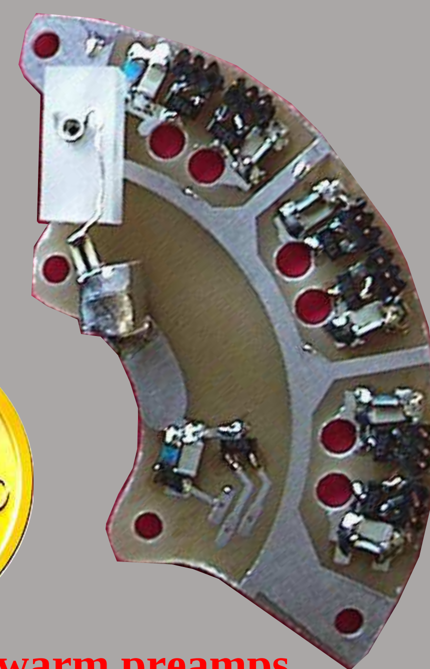
  $\rightarrow$ New techniques also needed
  - new acquisition electronics.
  - Monte-Carlo simulations of pulse-shapes needed.
  - experimental studies of pulse-shapes also needed.

The 6-fold segmented, encapsulated Miniball detector

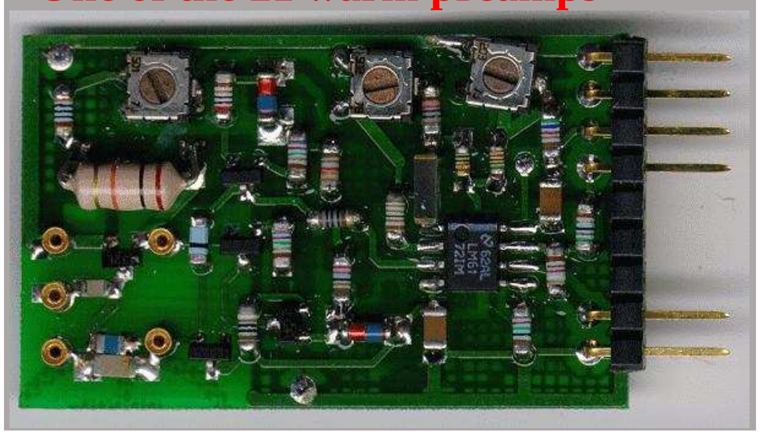




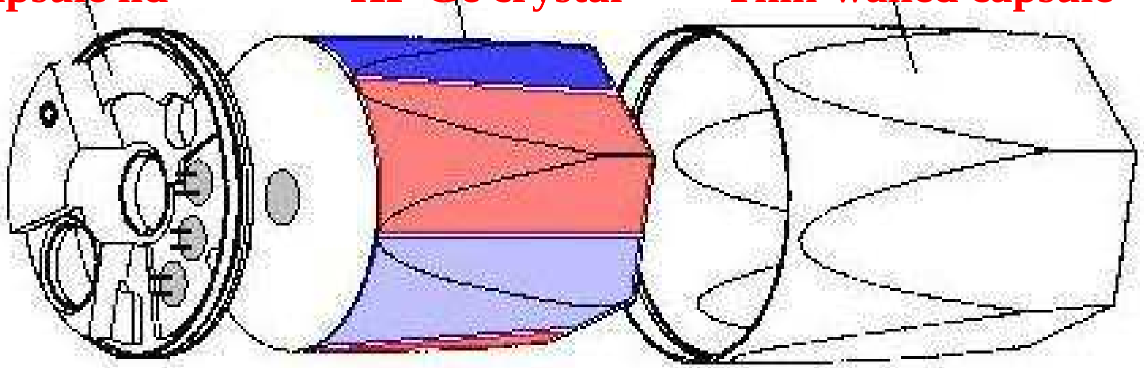
Motherboard with 7 cold FETs



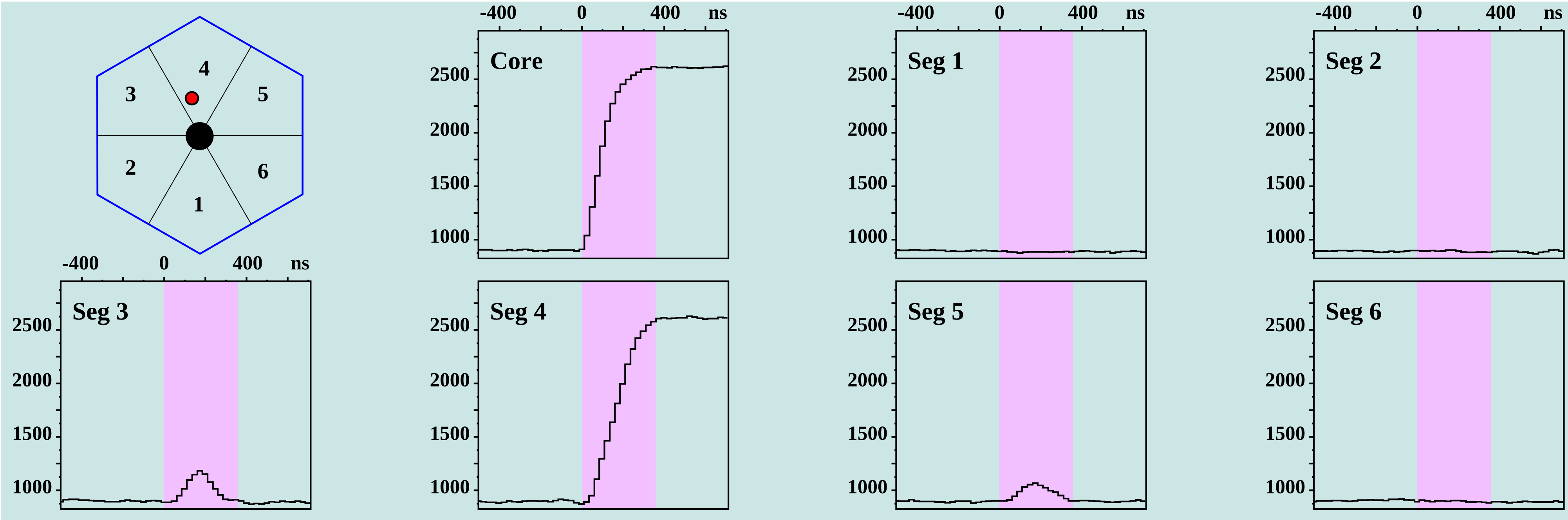
One of the 21 warm preamps

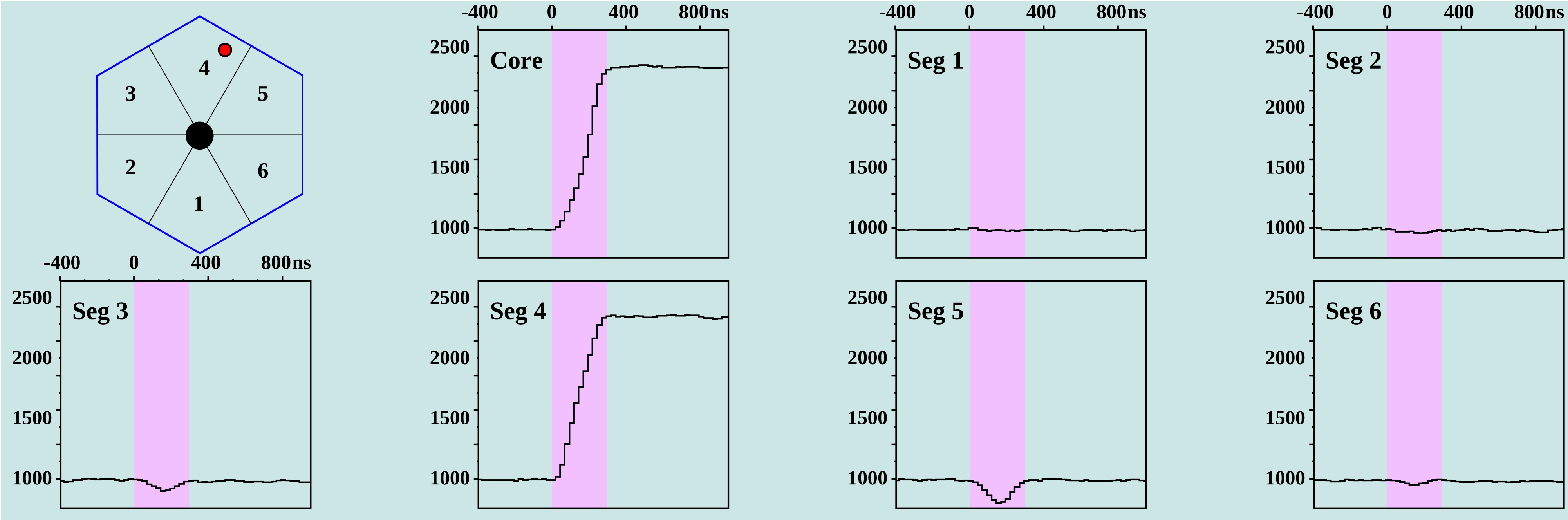


Capsule lid HP Ge crystal Thin-walled capsule

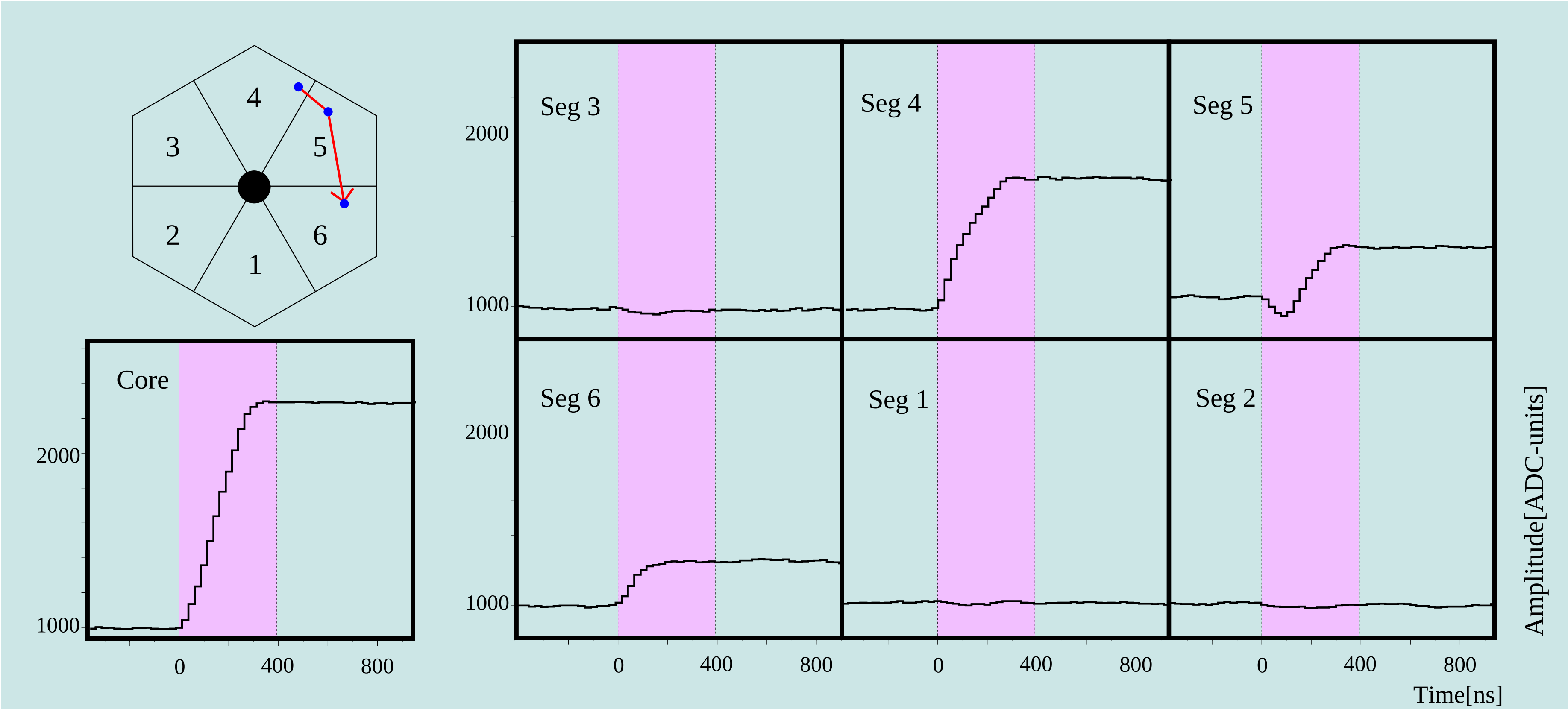


Pulse-shape analysis



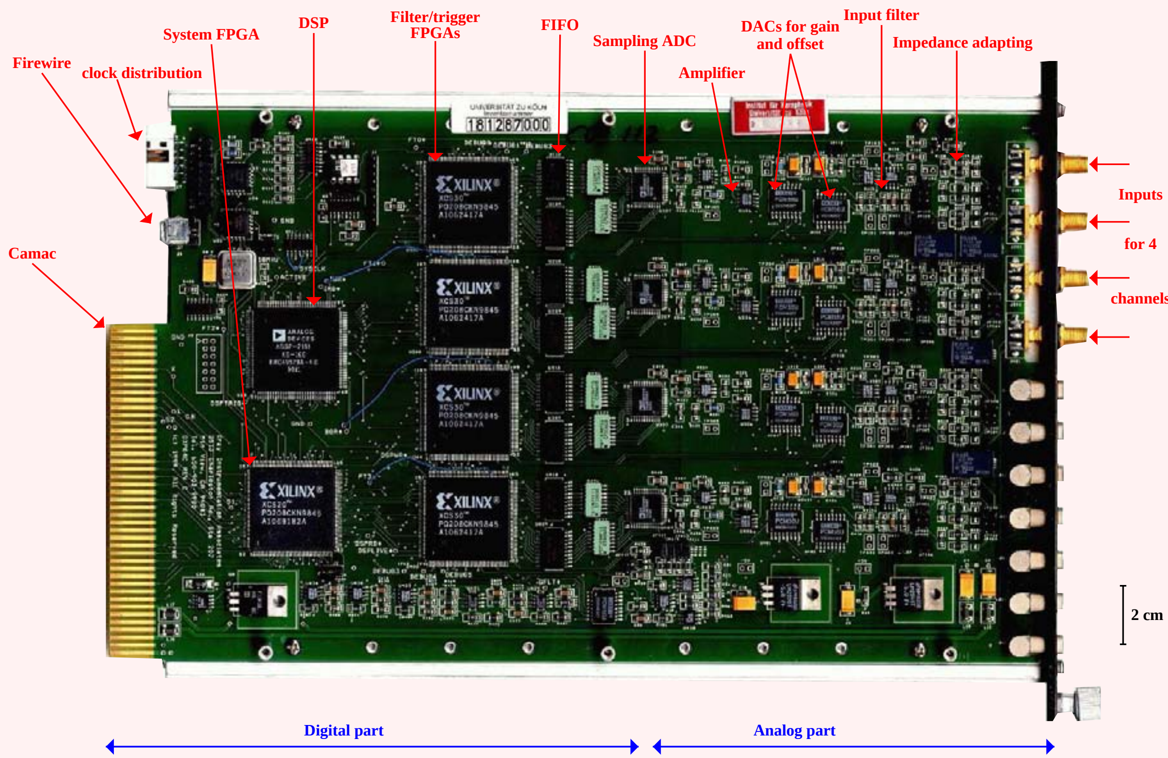


PSA and scattering

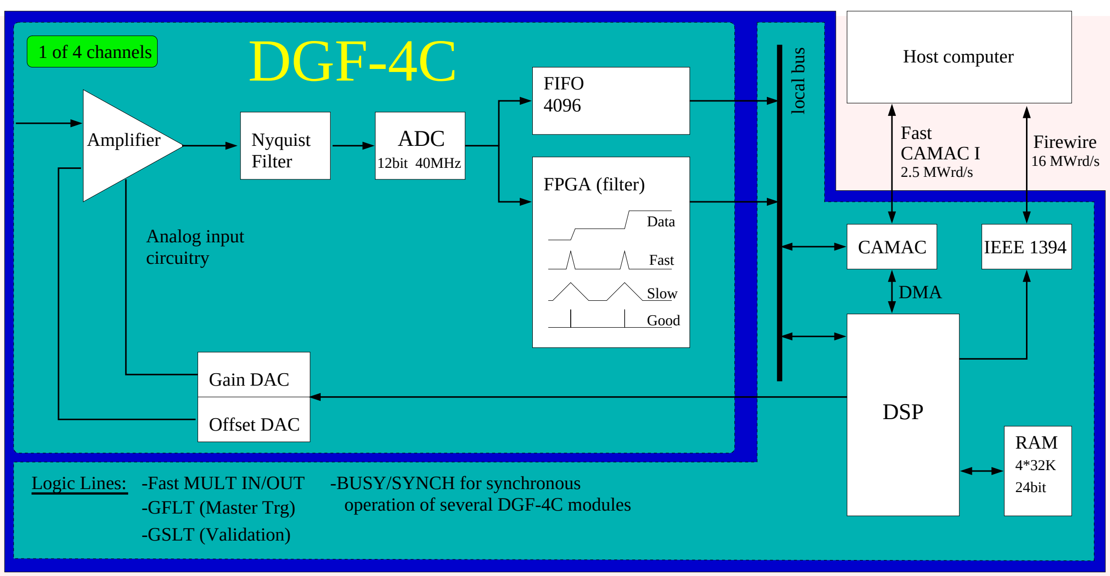


- **Collimated source in front of segment 4. Net signals in segments 4, 5 and 6, i.e. scattering from 4 to 5 to 6.**
- **For PSA, we assume:** *main interaction is first interaction*. **Good assumption at low and high energies. Less good for intermediate energies.**
- **We must subtract net charge from each segment, in order to obtain the mirror-charge amplitudes.**

The Digital Gamma Finder (DGF-4C)

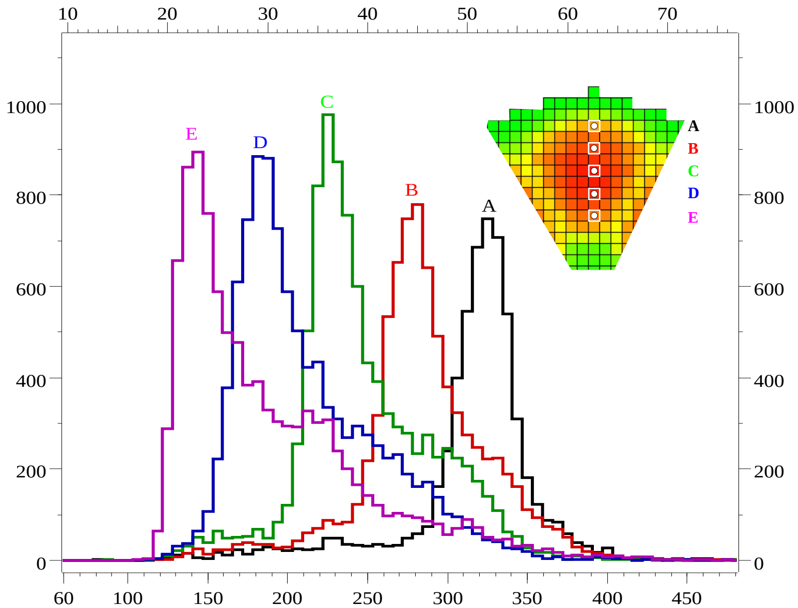


- Commercial product made by Xia (http://www.xia.com)
- Single width CAMAC module
- 4 complete spectroscopic channels
- 40 MHz sampling ADC
- Onboard signal processing by FPGA and DSP
- Possibility of writing user code (Miniball uses this for onboard Pulse-shape analysis)

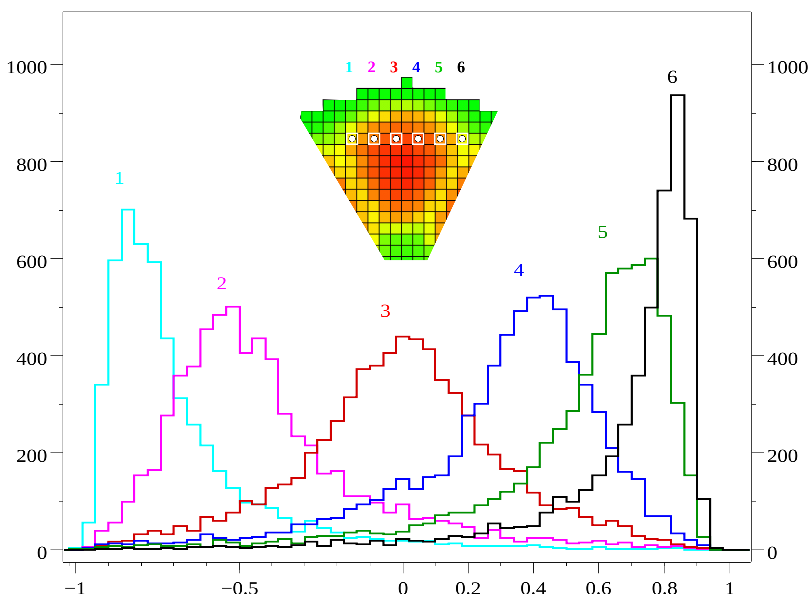


- Separate digital fast and slow filters implemented in FPGA
- Only validated events are processed by DSP
- 8 Kword buffer in DSP + hardware histograms
- Data transfer by fast CAMAC

Scan of Miniball detector



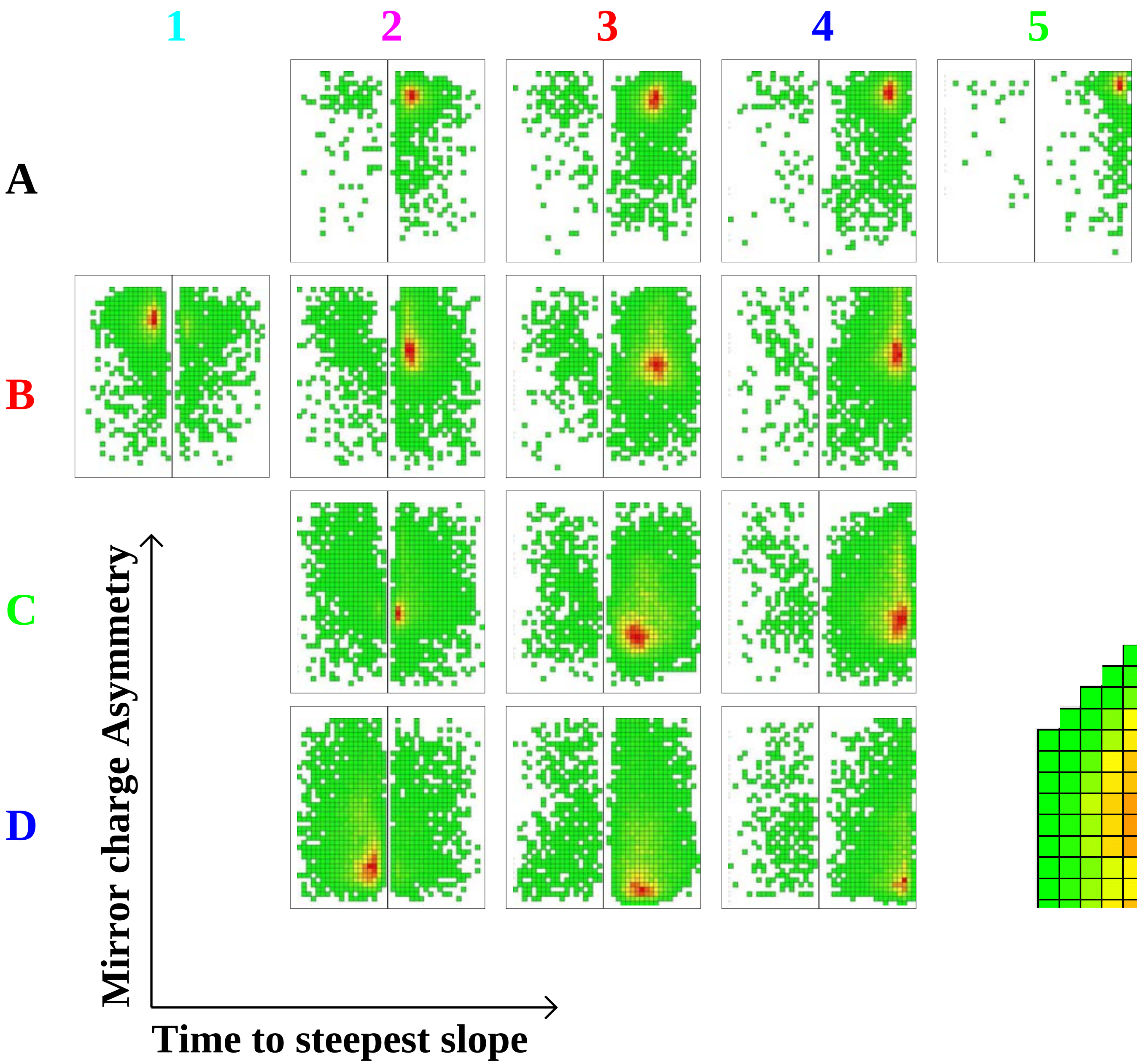
- Detector scanned along radius with a collimated source
- Consider steepest slope of core signal as a function of source position
- Innermost positions have fastest rise time (shortest migration path for electrons)



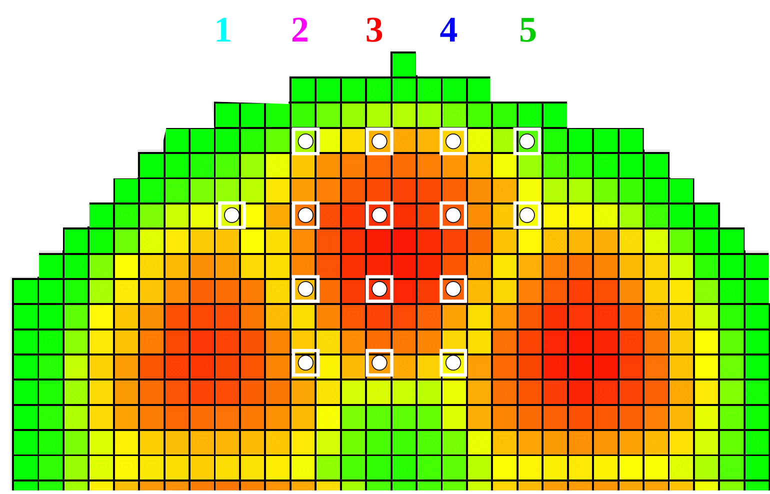
- Detector scanned across a segment with a collimated source
- Consider the ratio of the mirror charge amplitudes in the neighbouring segments
- Asymmetry of mirror charge amplitudes depends on position (mirror charge greatest in closest segment)

2-D scan of Miniball detector

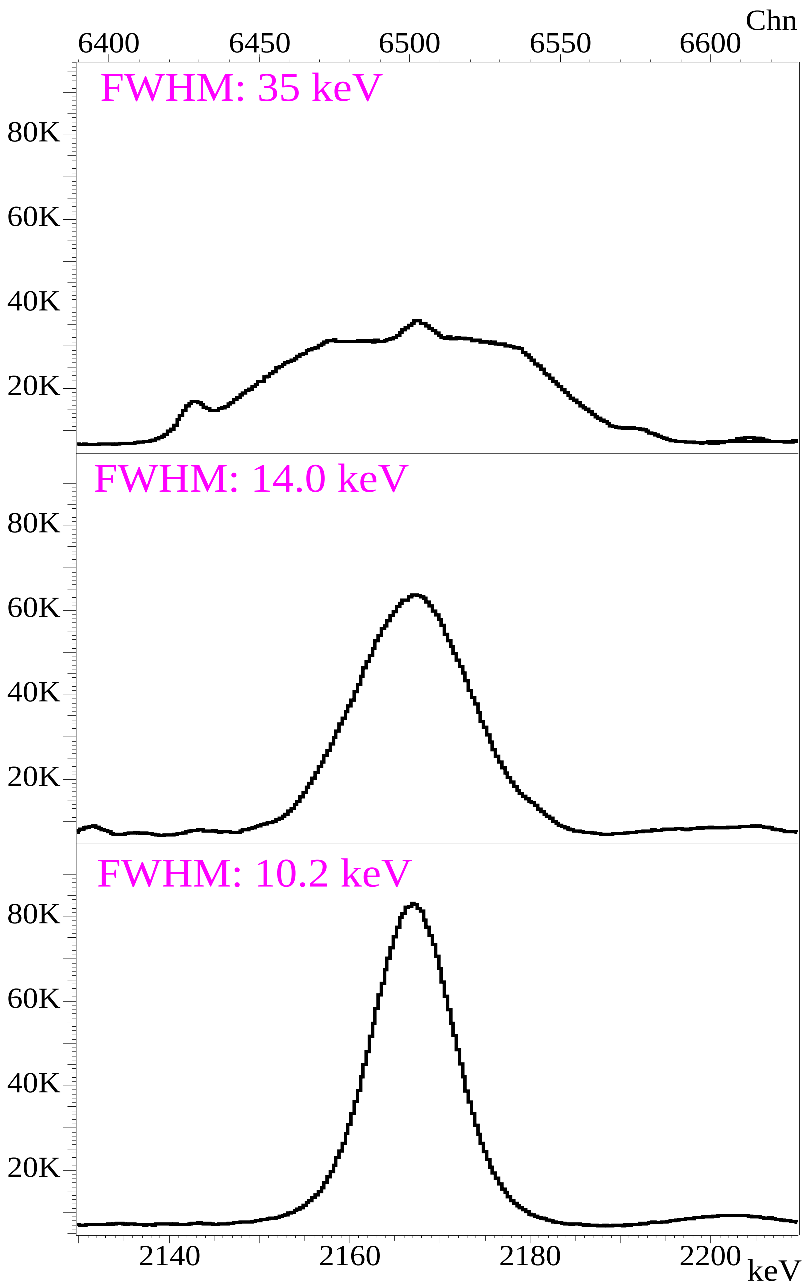
IKP



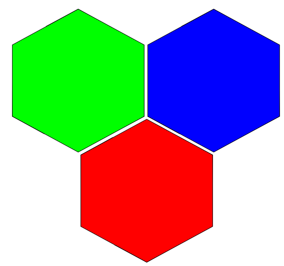
- 14 positions measured with a collimated source
- For each we plot time-to-steepest-slope vs. mirror charge asymmetry for segments 3 and 4
- Position of source can be seen clearly



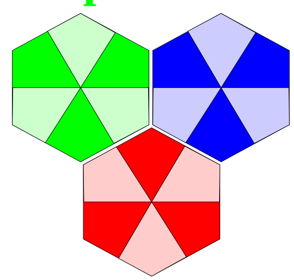
Doppler correction (in beam)



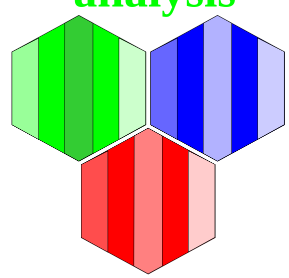
Just core energies



Using segment hit pattern

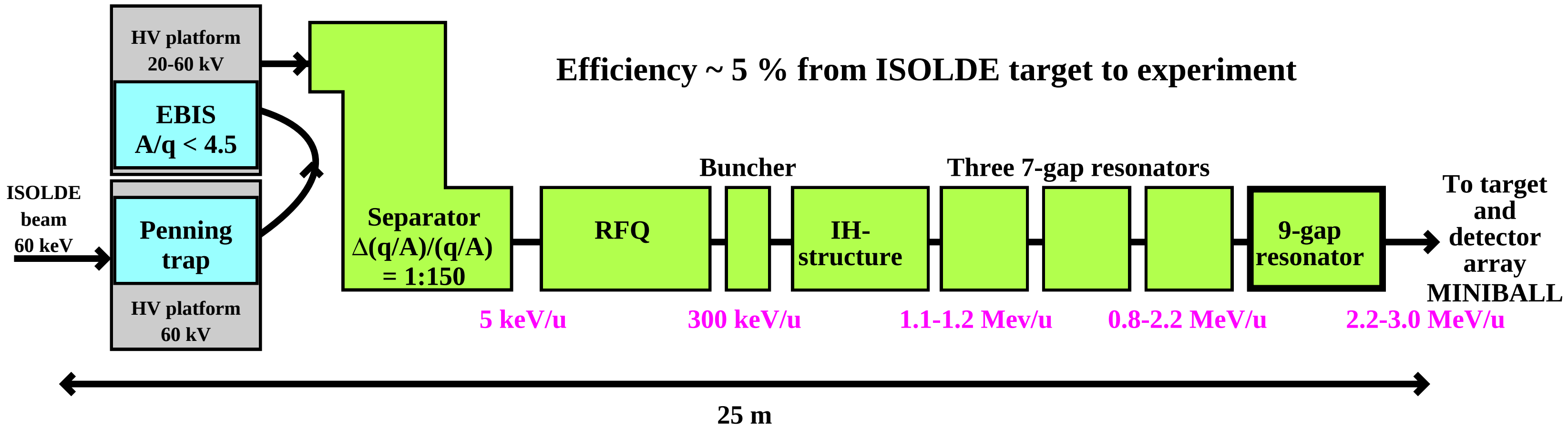


Full pulse-shape analysis



- **In-beam experiment at Cologne tandem**
- **^{37}Cl beam on deuterated Ti target (inverse kinematics)**
- **v/c = 5.7%**
- **A monitor detector placed at 165° far from the target was also used. This detector measured a FWHM of 7.8 keV at this energy (due to angular straggling of outgoing proton). If we use a position-sensitive particle detector, we can reduce this contribution**
- **Combining with intrinsic resolution of 2.2 keV, contribution from uncertainty in position is:**
  - **34.0 keV - just core**
  - **11.4 keV - segment hit pattern**
  - **6.2 keV - full PSA**

REX-ISOLDE



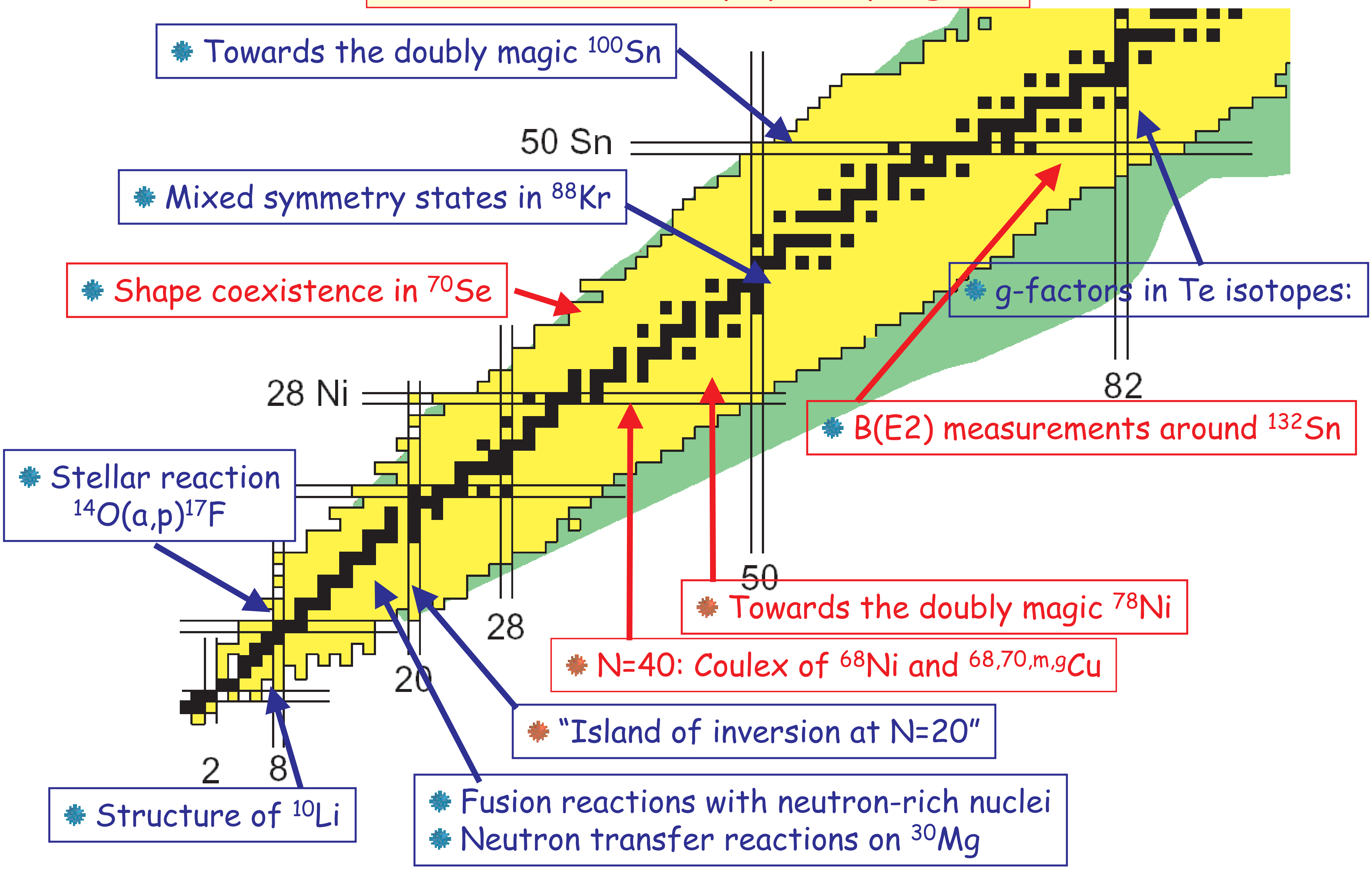
ISOLDE

- → operational since 1967
- → uses CERN PS-booster
- → more than 600 isotopes
- → more than 60 elements
- → Up to 10^{11} ions/s

REX-ISOLDE

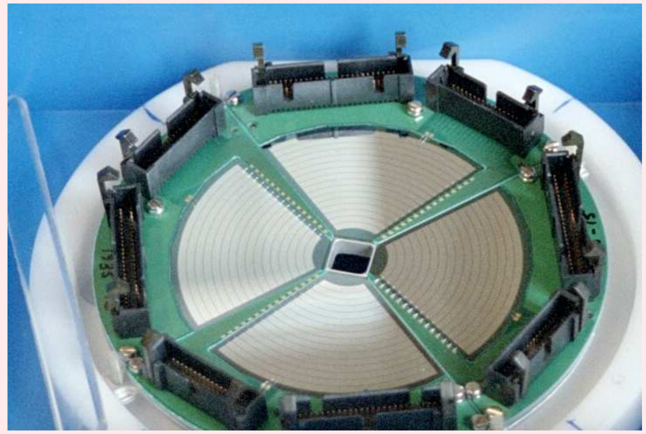
- → operational since 2001
- → Penning trap (REX)
- → Electron-beam ion source (EBIS)
- → Radio-frequency quadrupole (RFQ)
- → Interdigital H-type (IH) structure
- → Three 7-gap resonators
- → 9-gap resonator since 2004
- → Final beam up to 3.0 MeV/u
- → CERN facility since end of 2003

The REX-ISOLDE physics program



Ancillary Detectors

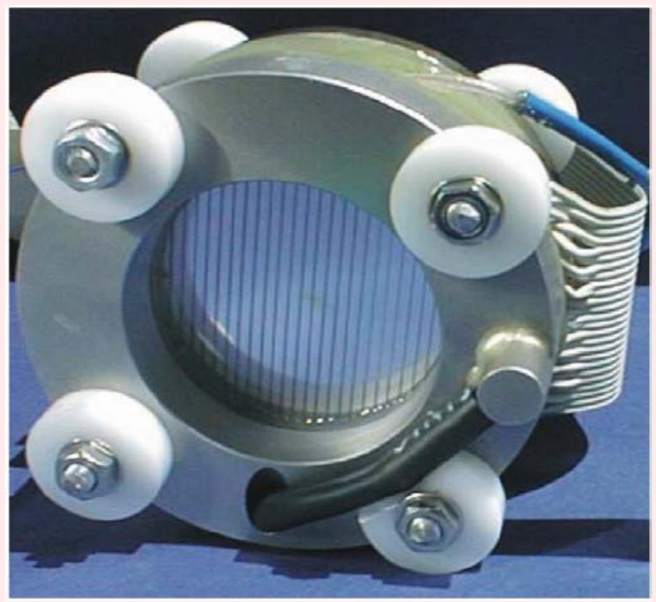
- **Double-sided silicon-strip detector (Edinburgh University)**



- **16 annular p+n junction strips**
- **24 n+n junction strips (sectors) per quadrant**

Davinson *et al.* NIM A454 (2000) 350-358

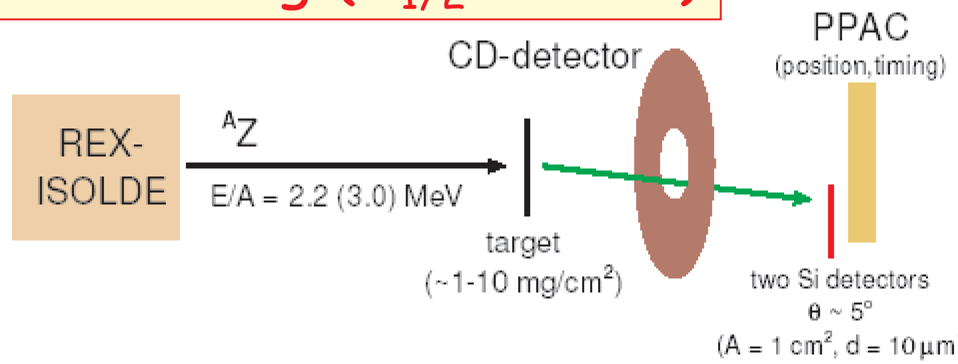
- **Parallel-plate avalanche counter (TU Darmstadt)**

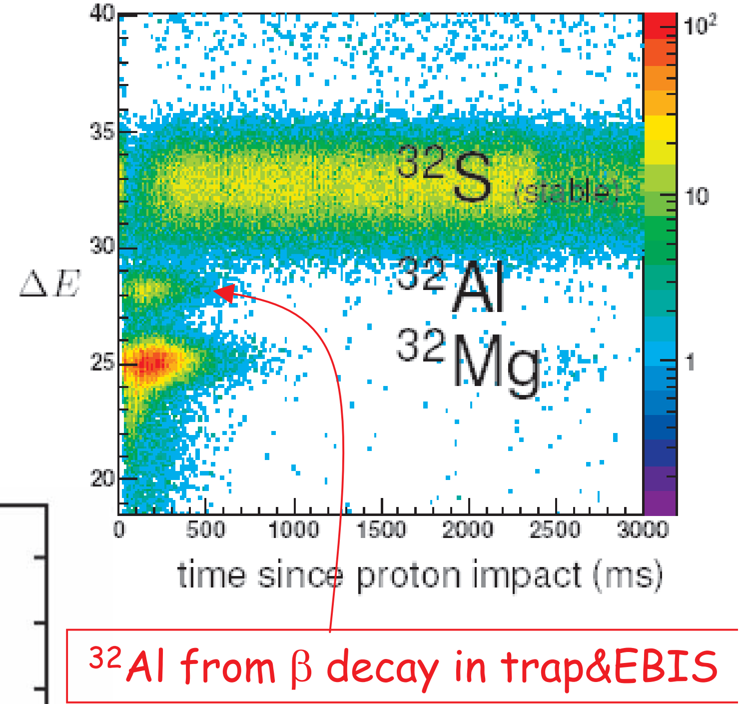


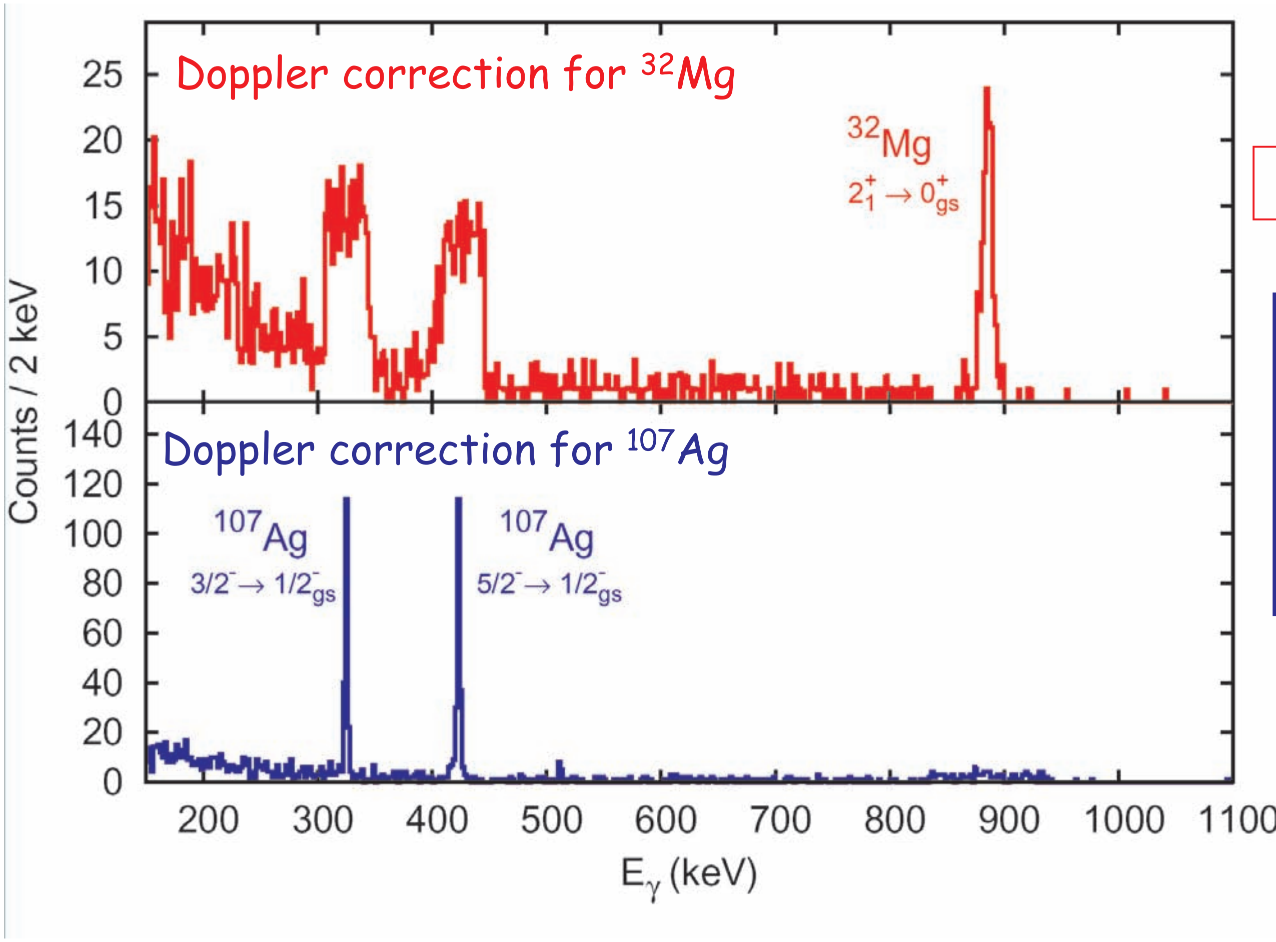
- **25 strips in x and y directions ections**
- **1.6 mm strip resolution**
- **4 - 10 mbar iso-butane**

Cub *et al.* NIM A453 (2000) 522-524

➢ Coulex ^{32}Mg ($T_{1/2}$=95 ms)



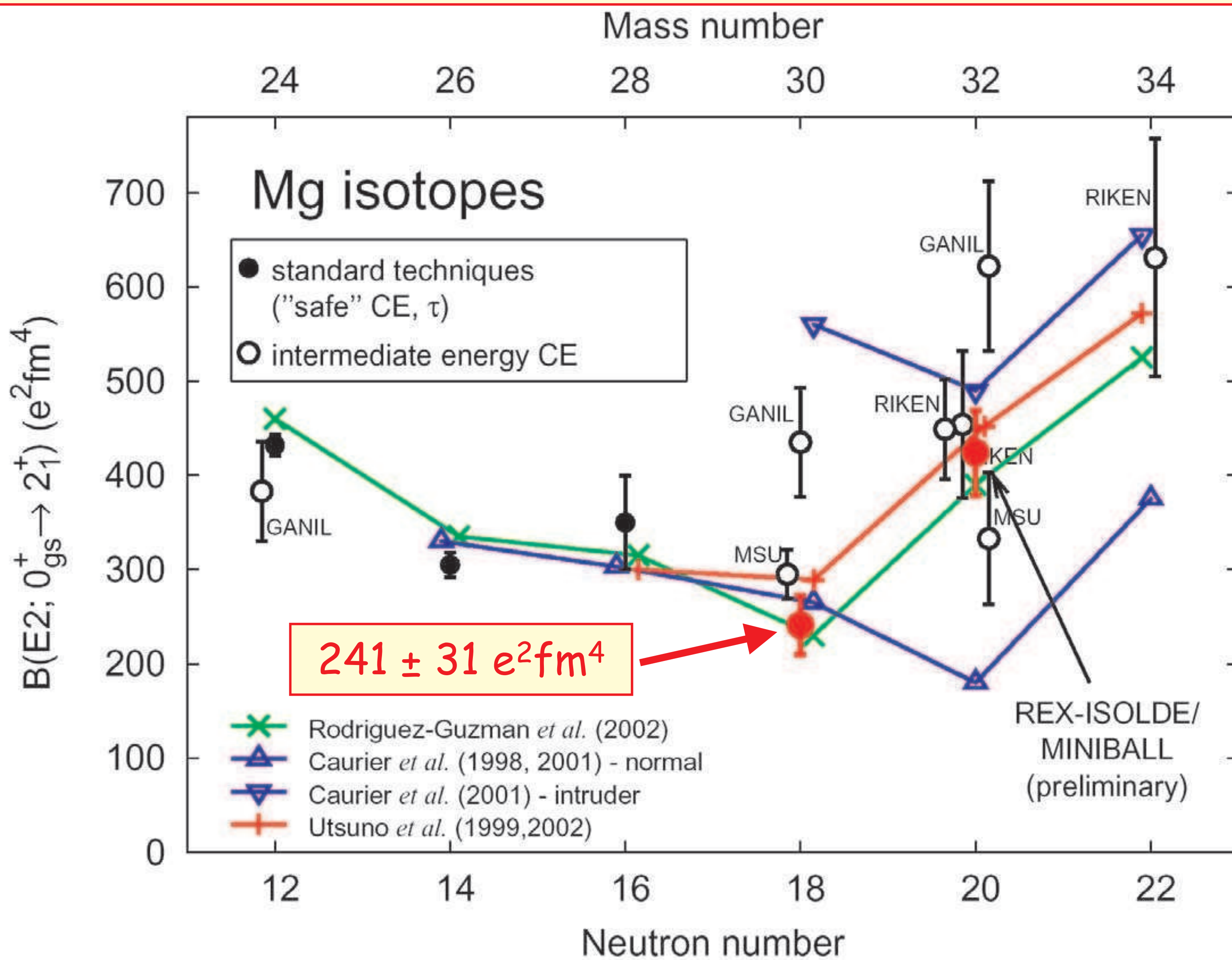




^{32}Mg @ ^{107}Ag (4.4 mg/cm^2)
~ 3 days beam on target

- 2.844 MeV/u
- ~ 1.5·10^4 pps
- purity: 85% ^{32}Mg

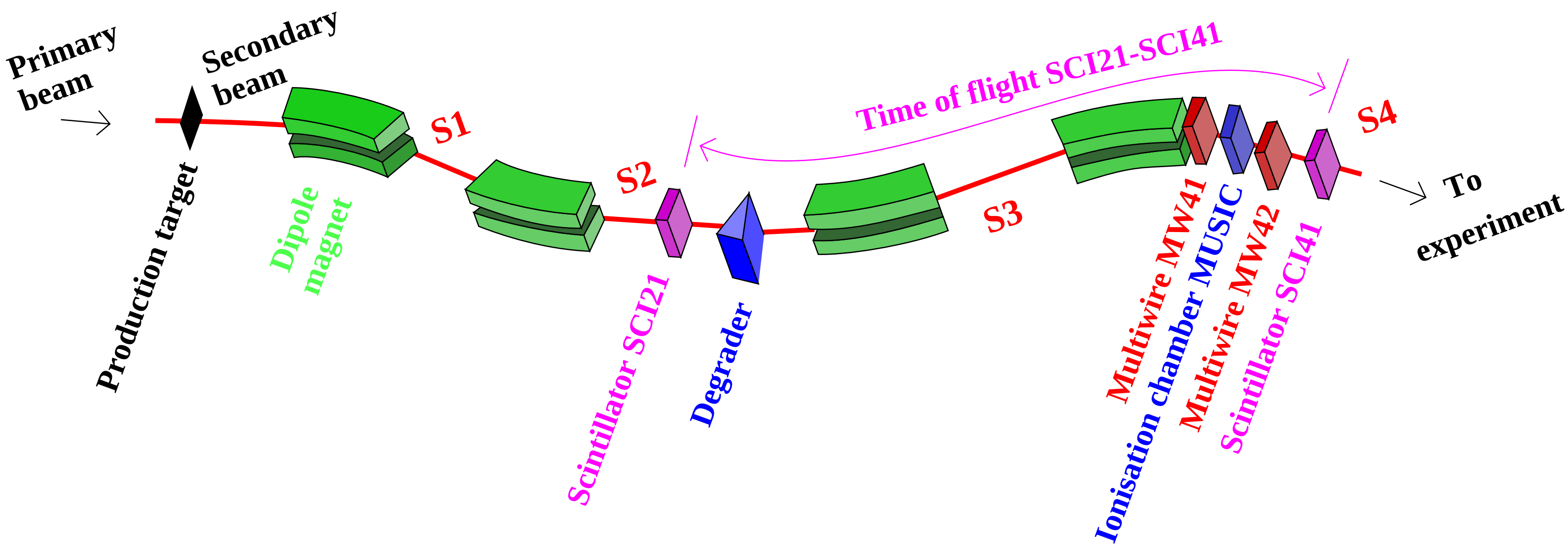
^{30}Mg is OUTSIDE of the "Island of Inversion"
^{32}Mg is INSIDE of the "Island of Inversion"



^{30}Mg: O. Niedermaier, H. Scheit et al., PRL 94, 172501 (2005)
$J^{\pi}(^{31}Mg)=1/2^+$: G. Neyens et al., PRL94 022501 (2005) (COLLAPS - ISOLDE)

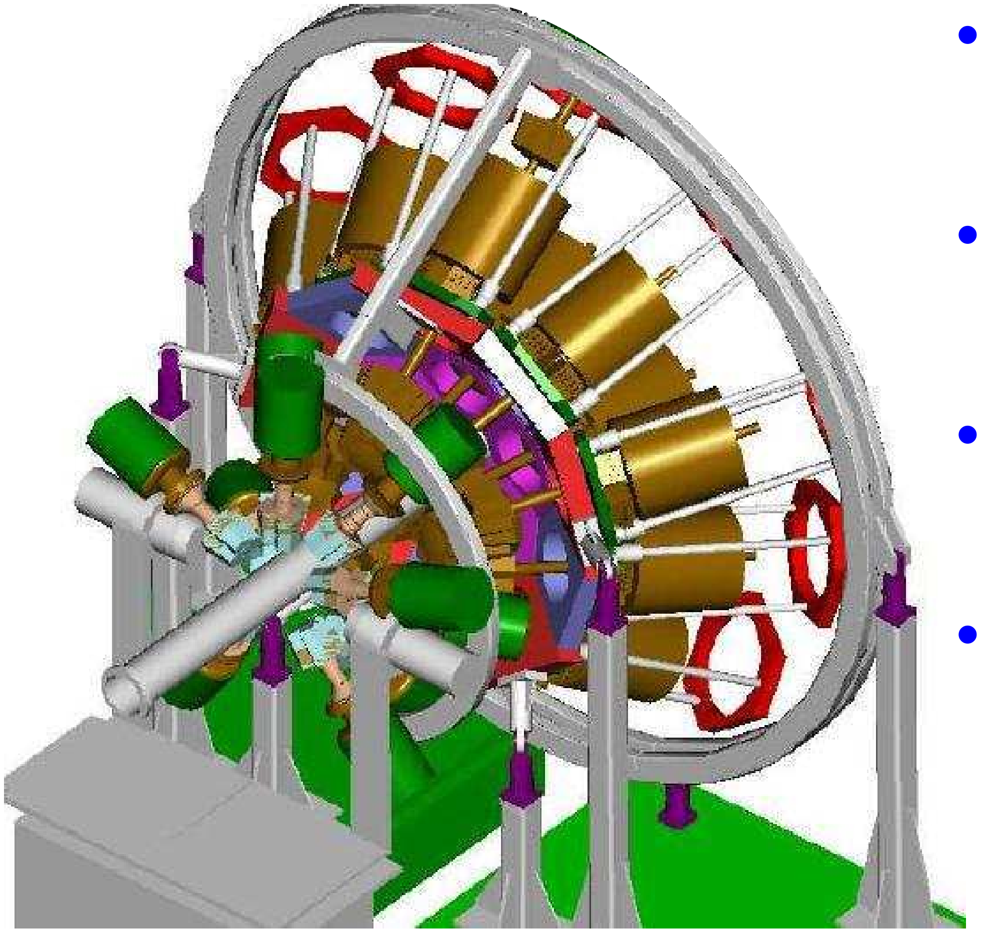
GSI Fragment Recoil Separator

- FRS produces and separates secondary beams with fission or fragmentation.
- Gives fully stripped ions with energies 100-500 Mev/u (i.e. a relativistic beam).



- TOF SCI21-41 gives β. → dE and β give Z.
- Dipole magnet gives Bρ. → Bρ and β give A/Q.
- Multiwires give position and direction of beam (i.e. tracking).
- Ionisation chamber (MUSIC) gives dE.

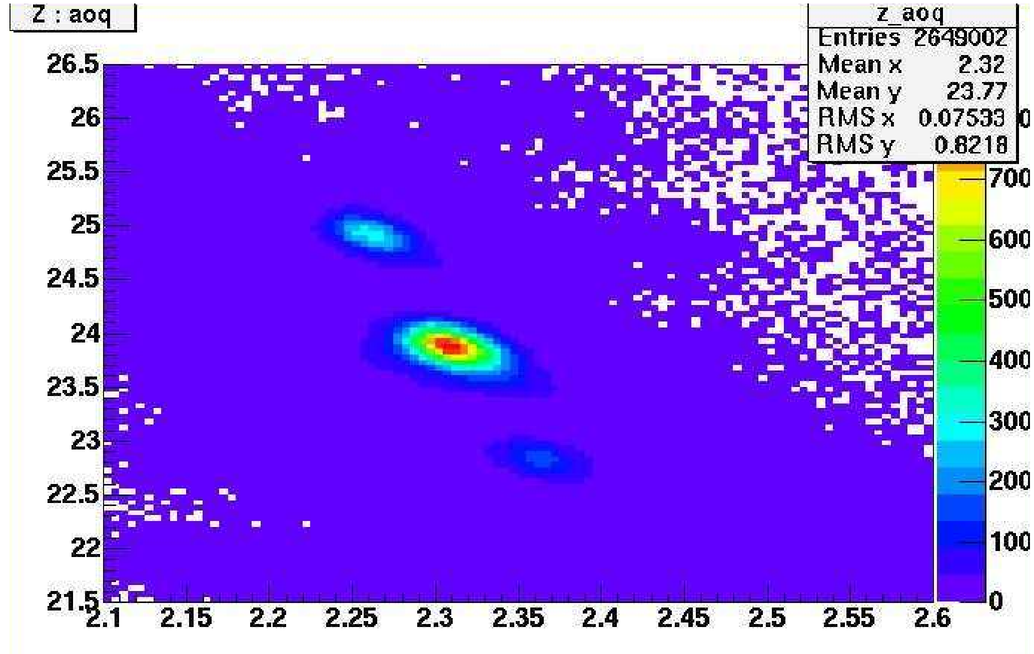
Rare ISotope INvestigations at GSI (RISING)



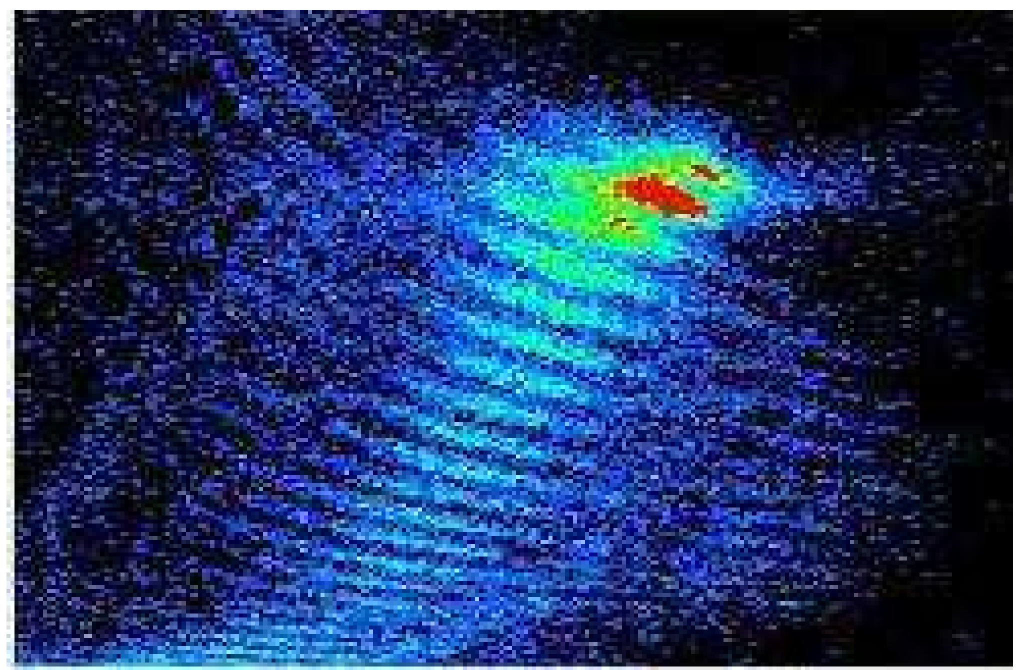
- CATE array of 9 position-sensitive ΔE-E telescopes at 0˚.
- 15 Euroball clusters at forward angles (105 detectors).
- 8 Miniball clusters at ~90˚ (24 detectors).
- Hector (BaF_2) at backward angles.

Particle identification

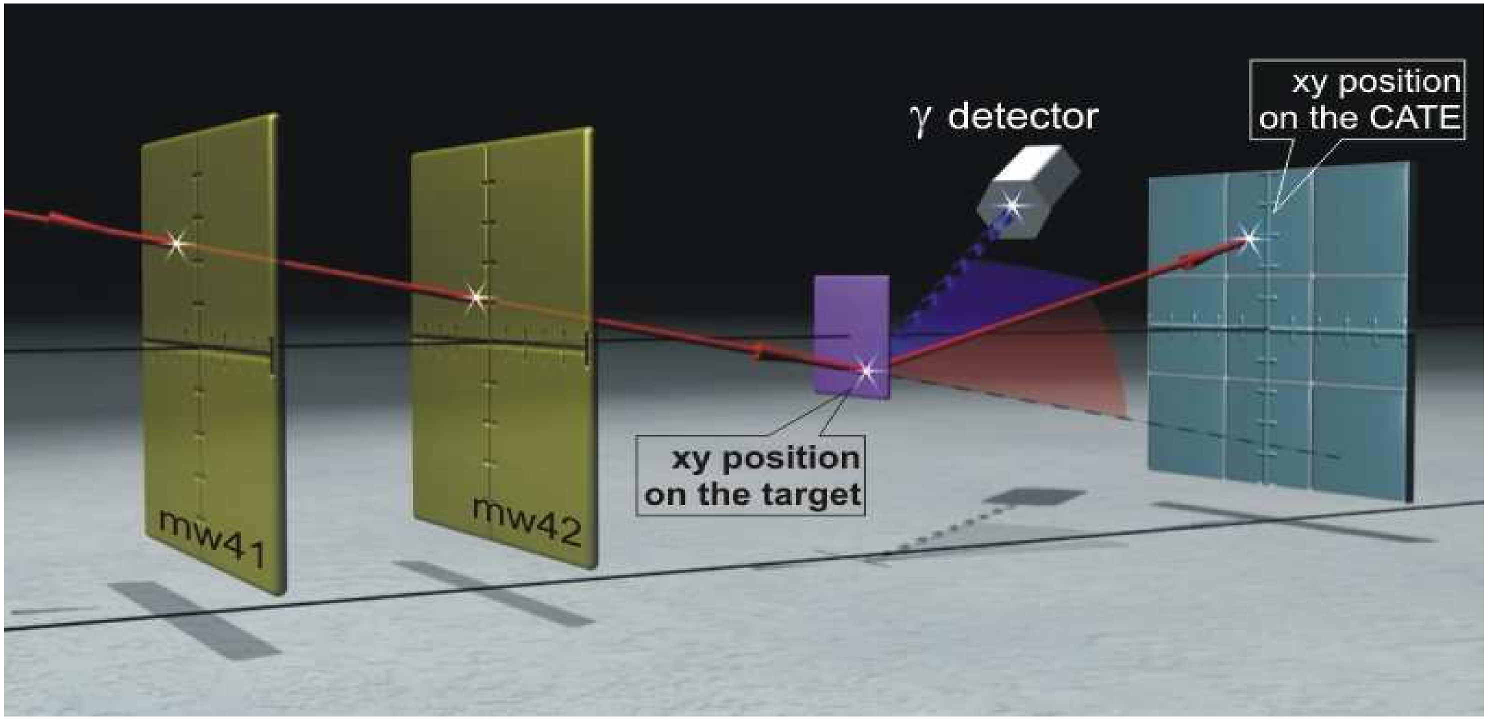
- We can plot Z (from MUSIC) vs. A/q (from TOF).
- This lets us select the beam incident on the RISING target.



- Or we can plot E vs. ΔE in CATE.
- This gives us the product after the reaction at the RISING target.



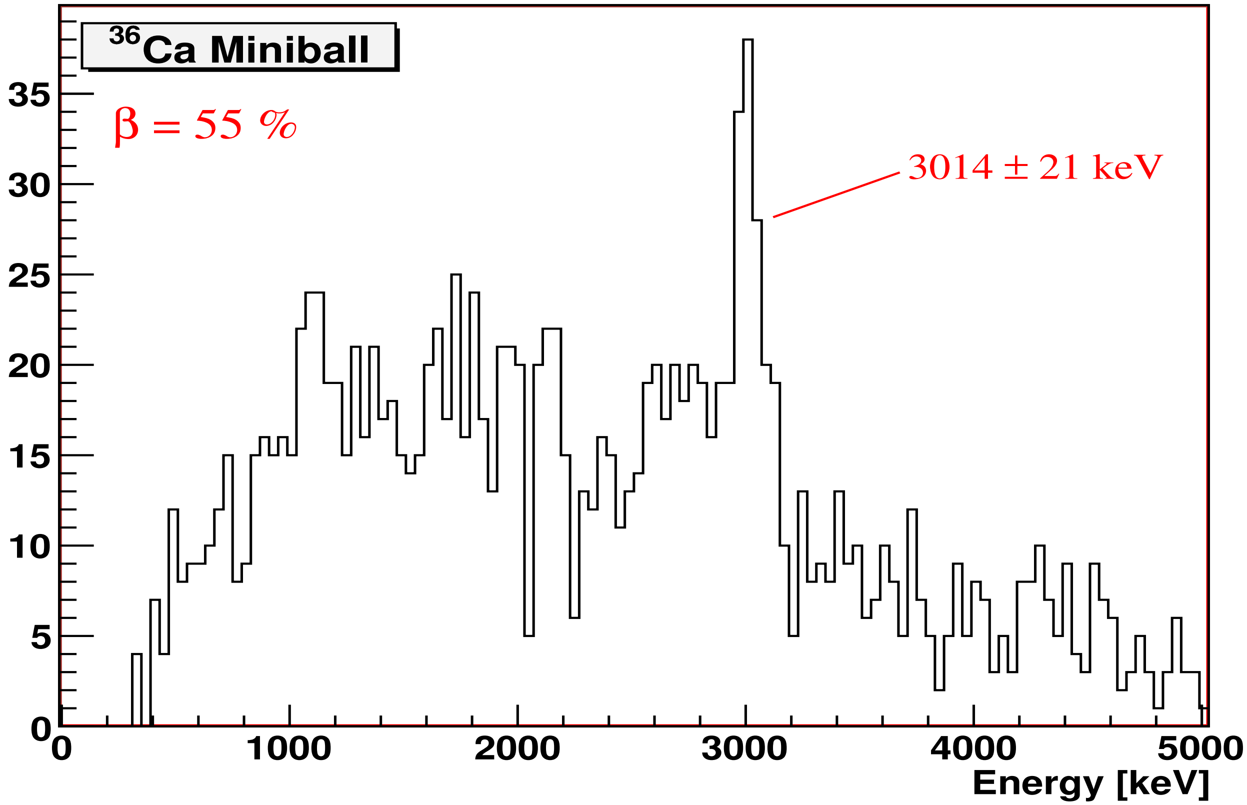
Tracking and Doppler Correction



- Multiwires give direction and position of incoming beam.
- We project onto target to calculate interaction position.
- CATE gives direction of outgoing particle.
- We calculate angle between outgoing particle and detector and perform Doppler correction.

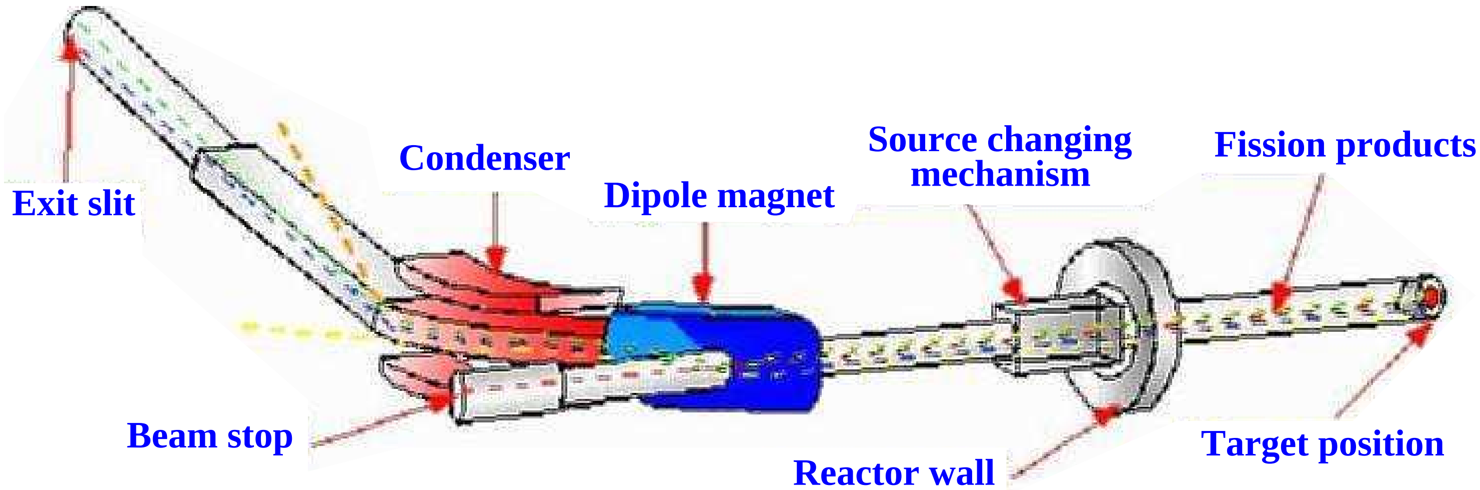
Miniball@RISING - ^{36}Ca

- **Double fragmentation reaction:**
  - → ^{40}Ca(630 A.MeV) + ^{9}Be at entrance to FRS
  - → Select ^{37}Ca with FRS (Bρ + MUSIC + TOF)
  - → ^{37}Ca(200 A.MeV) + ^{9}Be in centre of RISING spectromter
  - → Select ^{36}Ca with CATE (ΔE-E telescope)
- **Analysis by Pieter Doornenbal (GSI) - see his talk for details.**



- The background is mostly from Bremstrahlung.
- Bump to the left of the peak is a single escape peak.
- $2^+_1 \rightarrow 0^+_1$ transition at 3014 keV observed for the first time. Only ground state known previously.
- Despite the high v/c of 55 %, we get resolution of 4.7 %

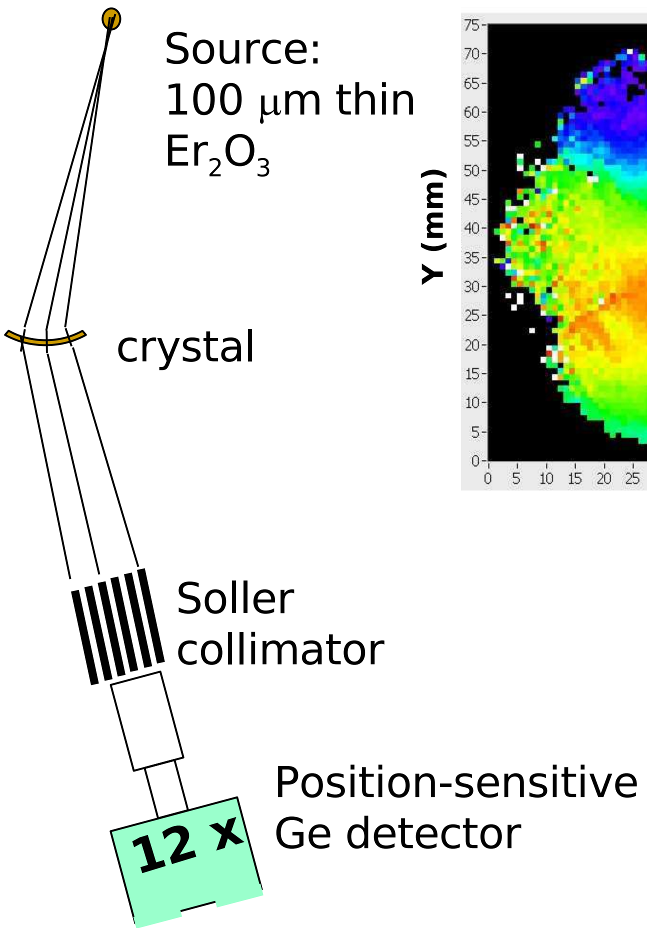
Miniball@Lohengrin (ILL, Grenoble)

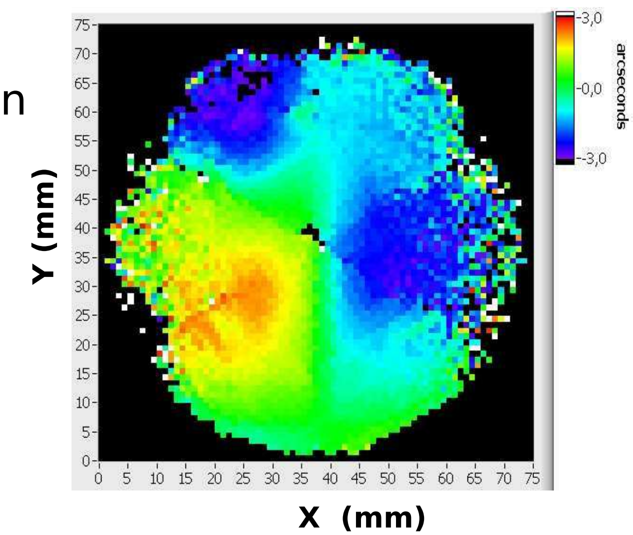


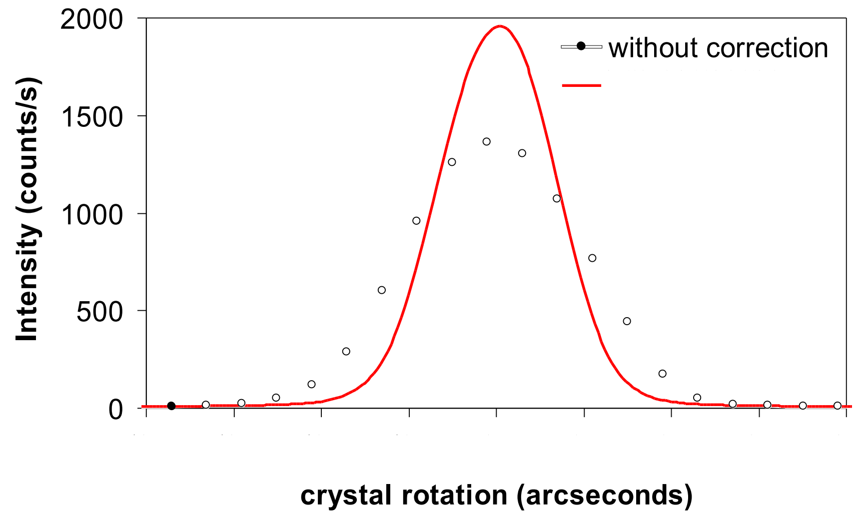
- Fission occurs at target placed inside the reactor.
- A particular fission product is selected with the Lohengrin mass separator and delivered to a mylar catcher foil surrounded by a pin-diode array and Ge detectors (incl. 3 Miniball capsules).
- Microsecond isomers were studied and g-factors measured.
- For details see Gary Simpson's talk this afternoon.
- Published in Phys. Rev. C 71, 064327 (2005)

Scan of GAMS-5 crystal (ILL, Grenoble)

- **Resolution of GAMS-5 curved crystal spectrometer depends on quality of curvature.**
- **Using a Miniball-type 12-fold segmented detector and PSA, we determine position on crystal where each γ ray was diffracted.**







- **Different points on crystal have different scattering angles, giving different apparent energies.**
- **We can use PSA to correct for this and improve the FWHM.**

The Collaboration

(Miniball + RISING + Grenoble)

Bonn: A. Bürger, H. Hübel, A. Al–Khatib, P. Bringel, A. Neußer, A.K. Singh, D. Mehta, T.S. Reddy. **CERN:** J. Aysto, U. Bergmann, P. Delahaye, V. Fedosseev, L. Fraile, H. Fynbo, G. Georgiev, U. Koester, T. Sieber, O. Tengblad. **Cologne:** N. Warr, S. Binder, J. Eberth, F. Finke, C. Fransen, G. Gersch, H. Hess, K. Jessen, J. Jolie, D. Martin, G. Pascovici, P. Reiter, A. Richard, A. Scherillo, M. Seidlitz, T. Striepling, O. Thelen, H.G. Thomas, D. Weißhaar. **Cracow:** M. Kmiecik, A. Maj, W. Meczynski. **Copenhagen:** G. Sletten. **Daresbury:** J. Simpson, D. Warner. **Edinburgh:** T. Davinson, P. Woods. **Göttingen:** K.P. Lieb. **ILL(Grenoble):** H. Börner, H. Faust, M. Jenschel, P. Mutti, R. Orlandi, G. Simpson. I. Tsekhanovich, **Grenoble:** J. Genevey, R. Gugliemini, J.A. Pinston, **GSI:** A. Banu, T. Beck, F. Becker, P. Bednarczyk, P. Doornenbal, H. Geissel, J. Gerl, M. Gorska, H. Grawe, J. Grebosz, M. Hellström, M. Kavatsyuk, O. Kavatsyuk, I. Kojouharov, N. Kurz, R. Lozeva, S. Mandal, I. Mukha, G. Münzenberg, N. Saito, T. Saito, H. Schaffner, H. Wieck, M. Winkler, H.J. Wollersheim. **Heidelberg:** V. Bildstein, H. Boie, C. Gund, J. Fitting, F. Köck, M. Lauer, O. Niedermayer, U. Pal, H. Scheit D. Schwalm, **HMI Berlin:** C. Wheldon. **Jülich:** W. Gast. **Keele:** G. Hammond. **Leuven:** P. van den Bergh, P. van Duppen, M. Huyse, O. Ivanov, K. Krouglov, P. Mayet, R. Raabe, J. van Roosbroeck, R. Sleurs, I. Stefanescu, J.–C. Thomas, J. van de Walle, H. de Witte. **Liverpool:** P. Butler, A. Hurst. **Madrid:** A. Jungclaus. **Mainz:** S. Franchoo, A. Ostrowski. **Milan:** G. Benzoni, A. Bracco, F. Camera, B. Million, O. Wieland. **New Delhi:** S. Muralithar. **Saclay:** E. Clement, A. Görgen. **Strasbourg:** P. Baumann, S. Courtin, P. Dessagne, A. Knipper, M. Krauth, F. Marechal, C. Miehe, F. Perrot, E. Poirier, G. Walter. **Surrey:** Z. Podolyak, J. Walker. **TU Darmstadt:** G. Schrieder, T. Nilsson, M. Pantea, H. Simon. **LMU (Munich):** D. Habs, F. Ames, J. Cederkäll, S. Emhofer, O. Kester, T. Kröll, R. Lutter, K. Rudolf, P. Thirolf, B. Wolf. **TU Munich:** R. Krücken, T. Behrens, T. Festermann, R. Gernhäuser, T. Morgan, M. Paisini, W. Schwerdtfeger. **Warsaw:** J. Iwanicki. **York:** C. Barton, D. Jenkins.