Opportunities with MINIBALL and T-REX

- Overview Physics Case
- MINIBALL @ REX-ISOLDE
- News from the ‚Island of Inversion‘
- Perspectives with T-REX & HIE-ISOLDE

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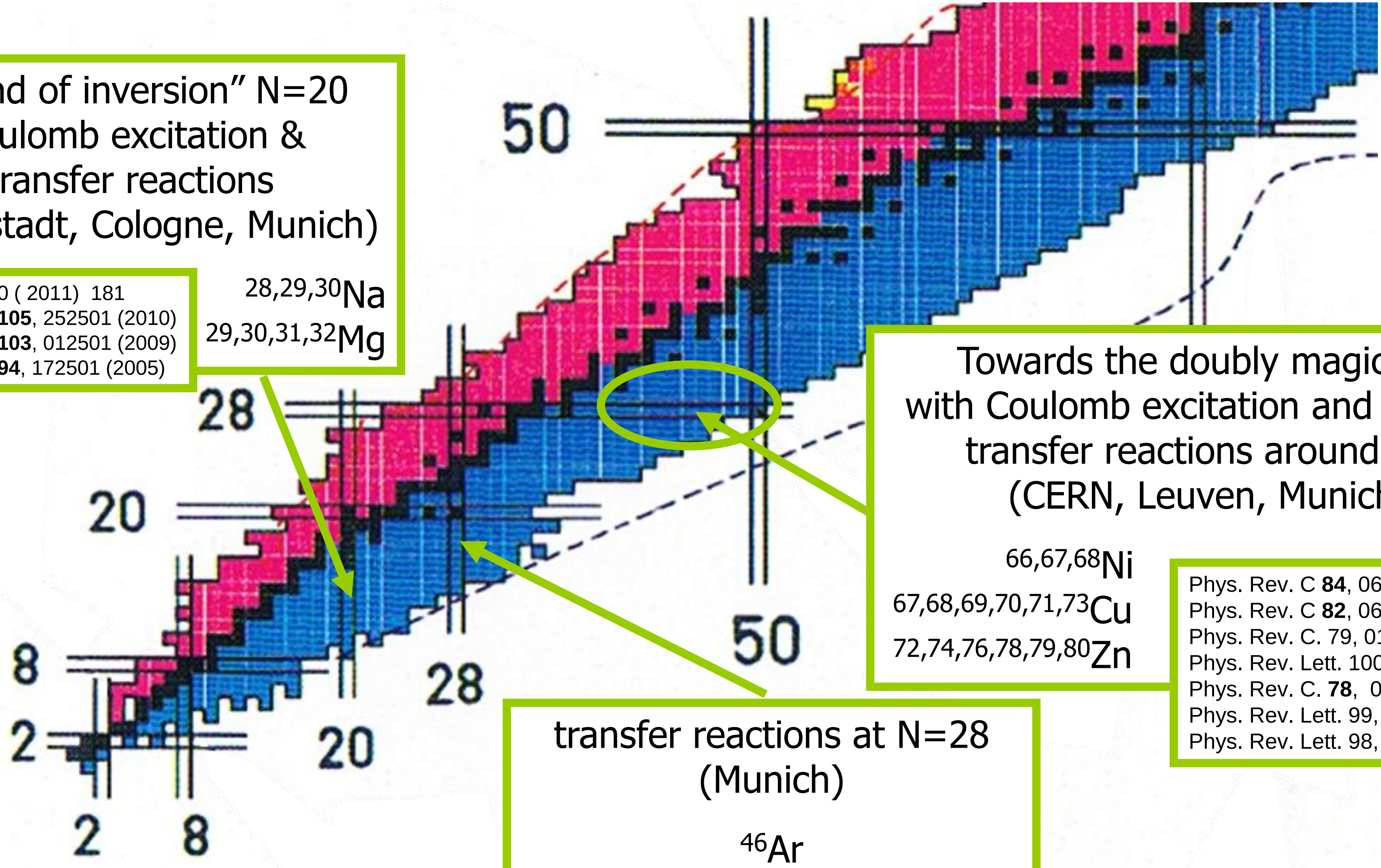
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

FPRIB12 workshop Kolkata, 16-18 May 2012

Shell Model Physics with MINIBALL@REX-ISOLDE



"Island of inversion" N=20
Coulomb excitation &
transfer reactions
(Darmstadt, Cologne, Munich)

^{28,29,30}Na
^{29,30,31,32}Mg

Phys. Lett. B, 700 (2011) 181
Phys. Rev. Lett. **105**, 252501 (2010)
Phys. Rev. Lett. **103**, 012501 (2009)
Phys. Rev. Lett. **94**, 172501 (2005)

Towards the doubly magic ^{78}Ni
with Coulomb excitation and nucleon
transfer reactions around ^{68}Ni
(CERN, Leuven, Munich)

^{66,67,68}Ni
^{67,68,69,70,71,73}Cu
^{72,74,76,78,79,80}Zn

Phys. Rev. C **84**, 064323 (2011)
Phys. Rev. C **82**, 064309 (2010)
Phys. Rev. C. 79, 014309 (2009)
Phys. Rev. Lett. 100, 112502 (2008)
Phys. Rev. C. **78**, 047301 (2008)
Phys. Rev. Lett. 99, 142501 (2007)
Phys. Rev. Lett. 98, 122701 (2007)

transfer reactions at N=28
(Munich)

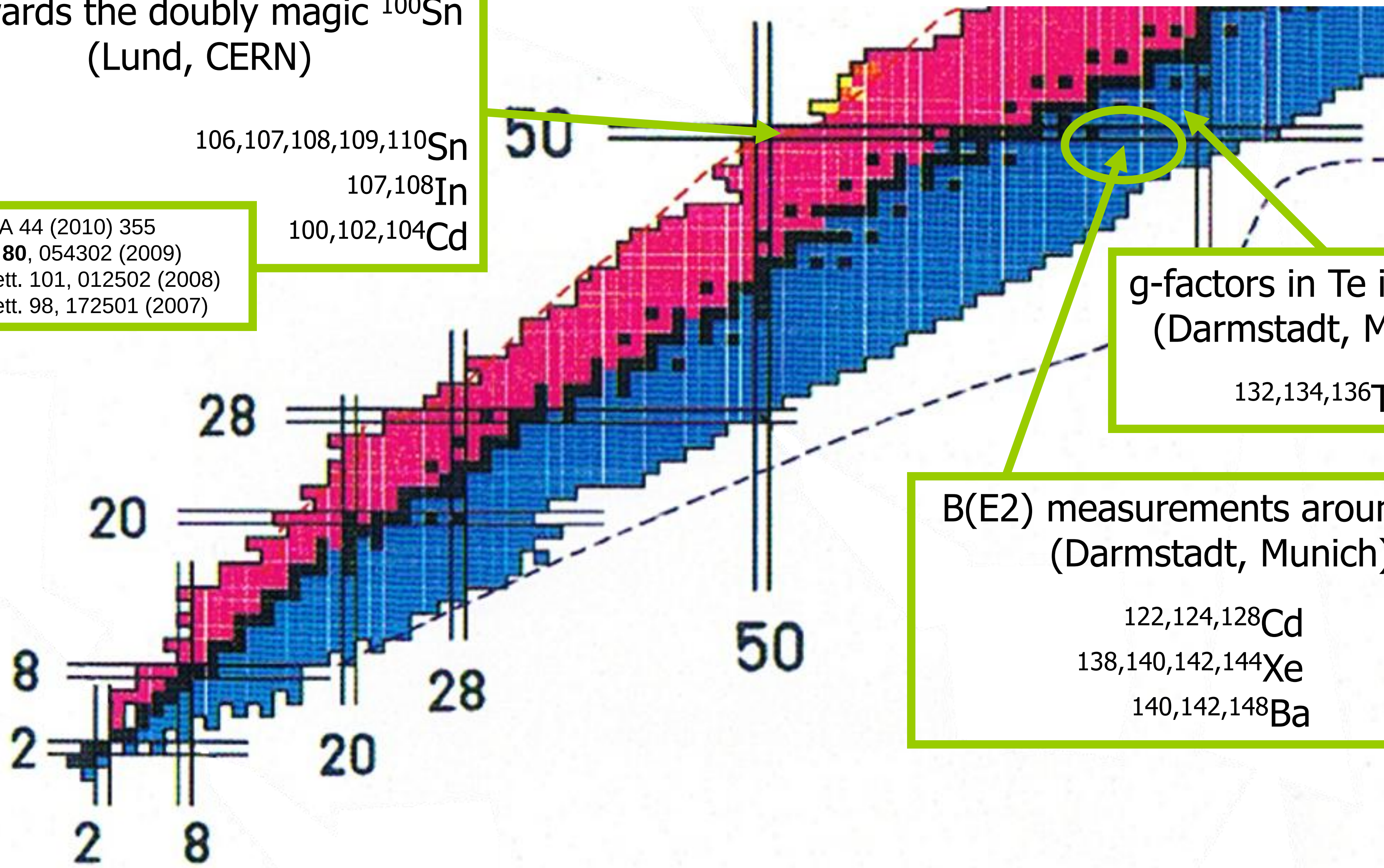
^{46}Ar

Shell Model Physics with MINIBALL@REX-ISOLDE

Towards the doubly magic ^{100}Sn
(Lund, CERN)

$^{106,107,108,109,110}Sn$
$^{107,108}In$
$^{100,102,104}Cd$

Eur. Phys. J. A 44 (2010) 355
Phys. Rev. C **80**, 054302 (2009)
Phys. Rev. Lett. 101, 012502 (2008)
Phys. Rev. Lett. 98, 172501 (2007)



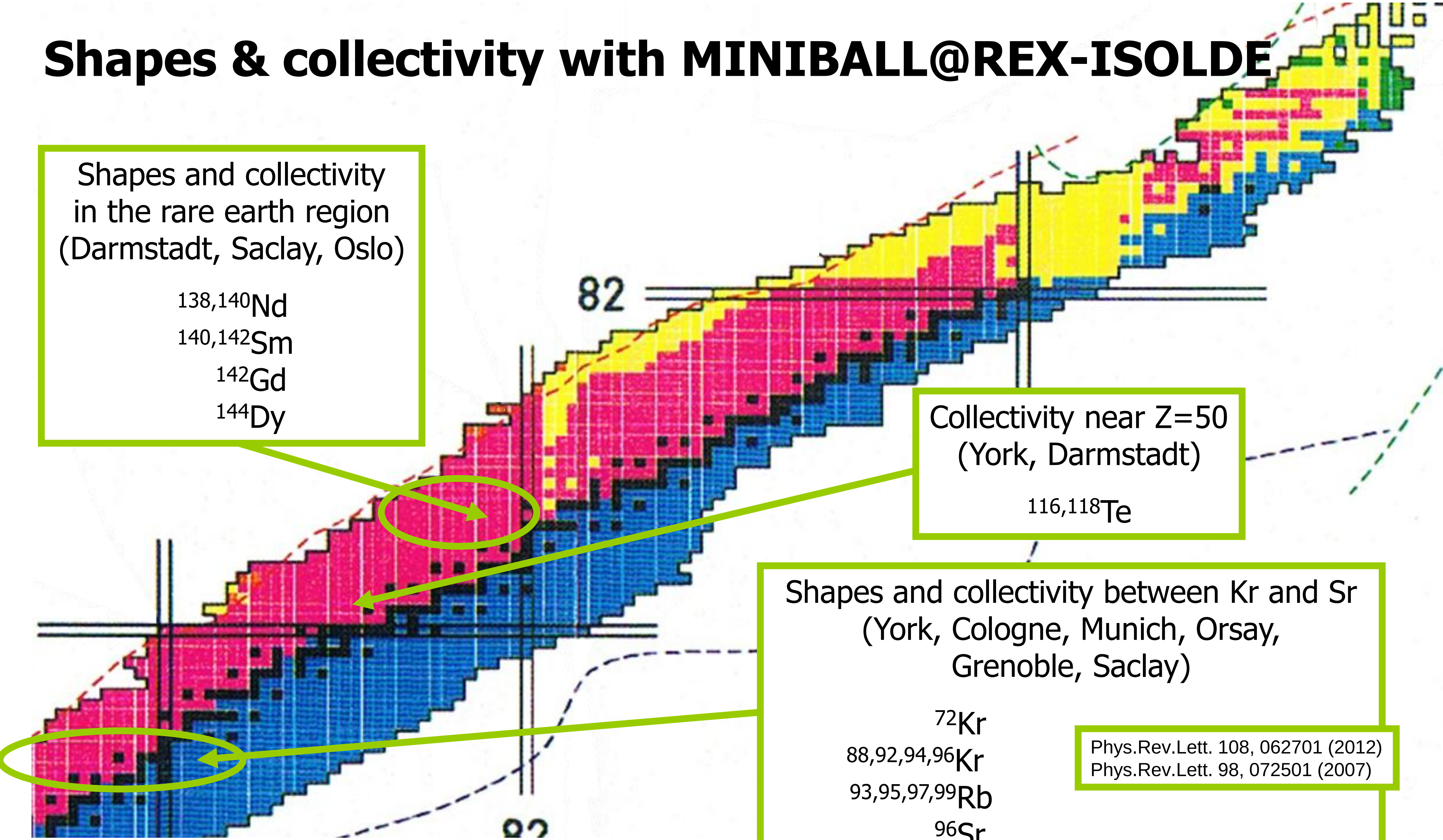
g-factors in Te isotopes
(Darmstadt, Madrid)

$^{132,134,136}Te$

B(E2) measurements around ^{132}Sn
(Darmstadt, Munich)

$^{122,124,128}Cd$
$^{138,140,142,144}Xe$
$^{140,142,148}Ba$

Shapes & collectivity with MINIBALL@REX-ISOLDE



Shapes and collectivity in the rare earth region (Darmstadt, Saclay, Oslo)

^{138,140}Nd
^{140,142}Sm
^{142}Gd
^{144}Dy

Collectivity near Z=50 (York, Darmstadt)

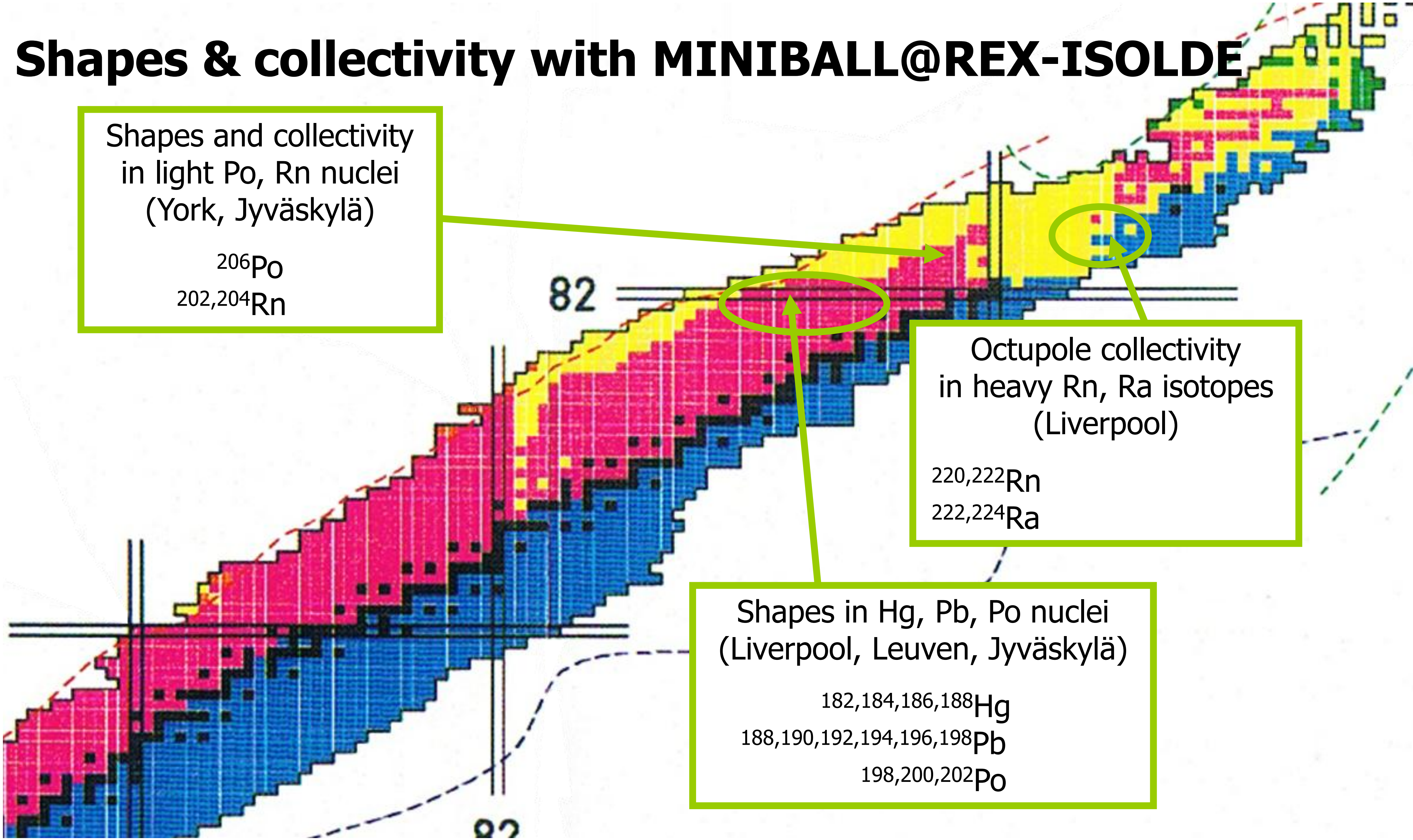
^{116,118}Te

Shapes and collectivity between Kr and Sr (York, Cologne, Munich, Orsay, Grenoble, Saclay)

^{72}Kr
^{88,92,94,96}Kr
^{93,95,97,99}Rb
^{96}Sr

Phys.Rev.Lett. 108, 062701 (2012)
Phys.Rev.Lett. 98, 072501 (2007)

Shapes & collectivity with MINIBALL@REX-ISOLDE



Shapes and collectivity
in light Po, Rn nuclei
(York, Jyväskylä)

^{206}Po
$^{202,204}Rn$

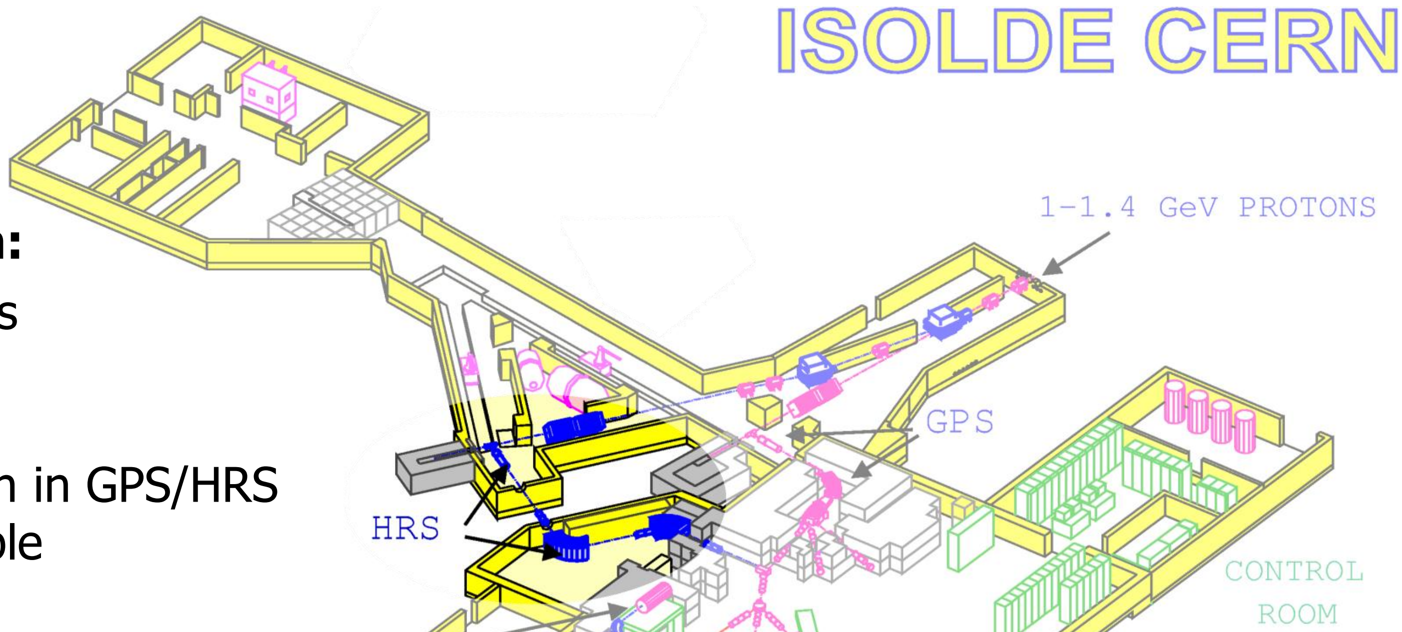
Octupole collectivity
in heavy Rn, Ra isotopes
(Liverpool)

$^{220,222}Rn$
$^{222,224}Ra$

Shapes in Hg, Pb, Po nuclei
(Liverpool, Leuven, Jyväskylä)

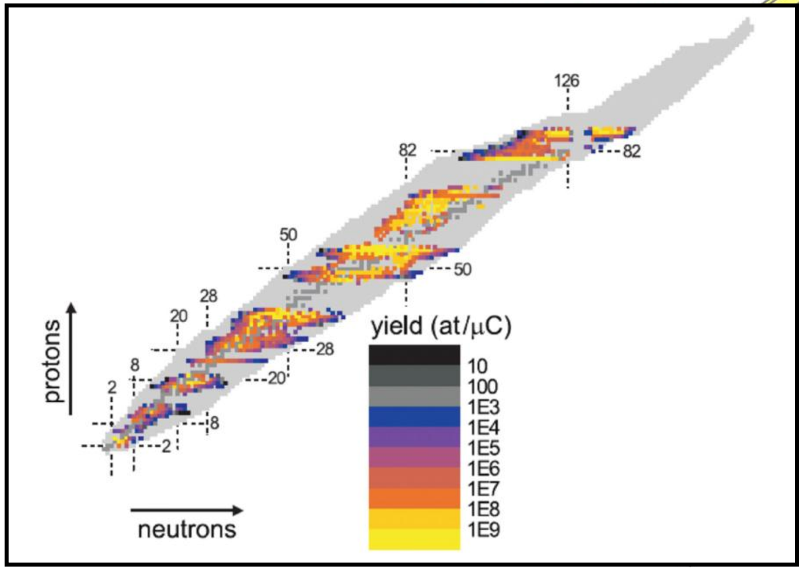
$^{182,184,186,188}Hg$
$^{188,190,192,194,196,198}Pb$
$^{198,200,202}Po$

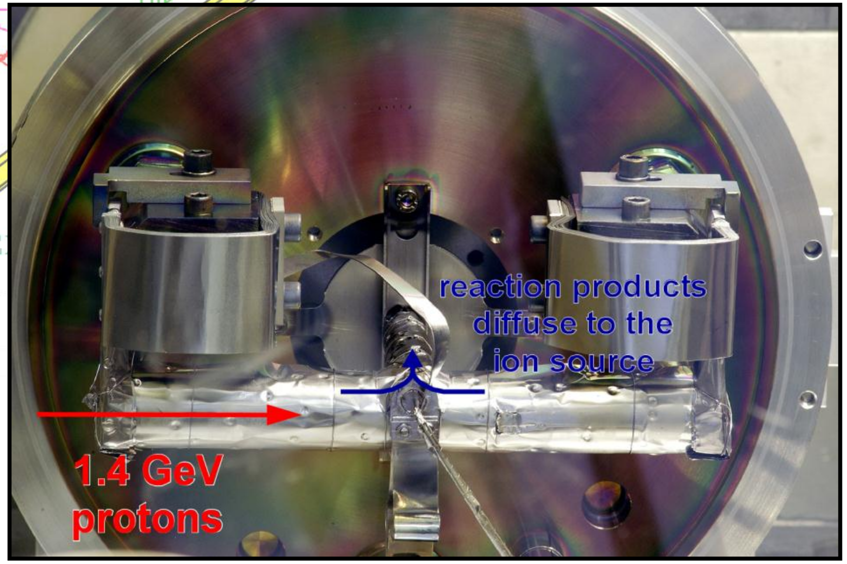
RIB production at ISOLDE



RIB Production:

- 1,4 GeV protons
- various targets
- ionization
- mass separation in GPS/HRS
- 800 RIB available

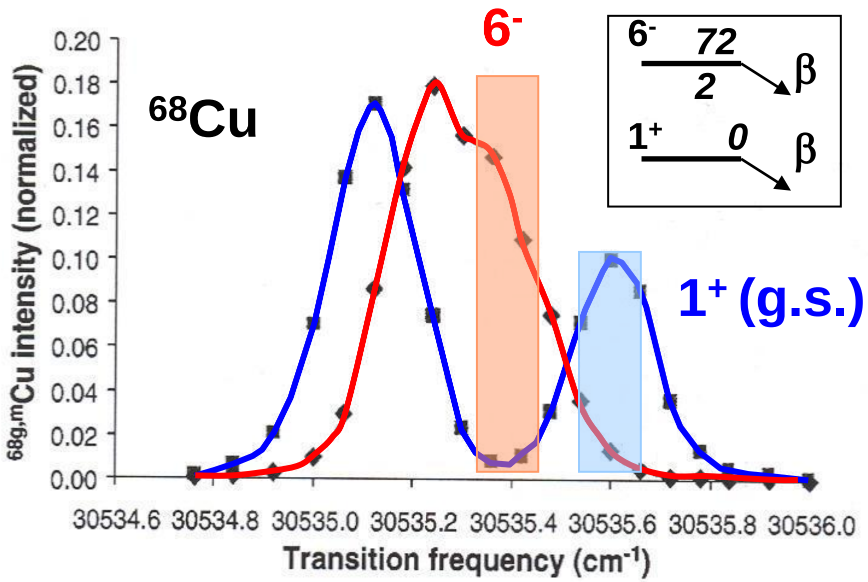


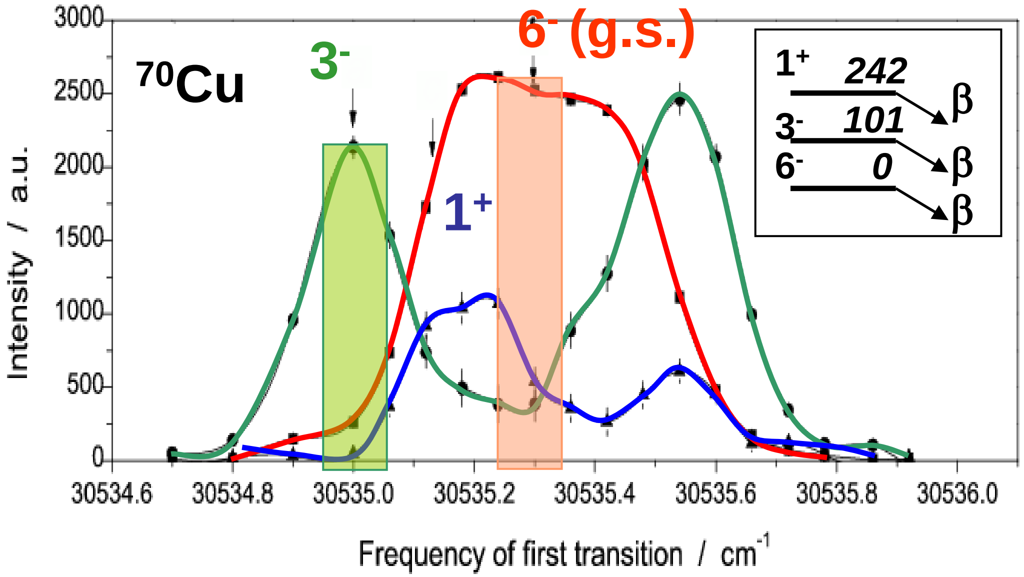


Isomeric beams @ ISOLDE

- technique based on in-source laser spectroscopy
  (U. Köster et al., NIM B160, 528 (2000), L. Weissman et al., PRC 65, 024315 (2000))

- set the laser frequency to select and maximize the production of the isomer of interest





γ-Spectroscopy with Cu isomer beams I. Stefanescu et al. PRL **98**, 122701 (2007), E. Rapisarda et al. PRC **84**, 064323 (2011)

RIB preparation @ REX-ISOLDE

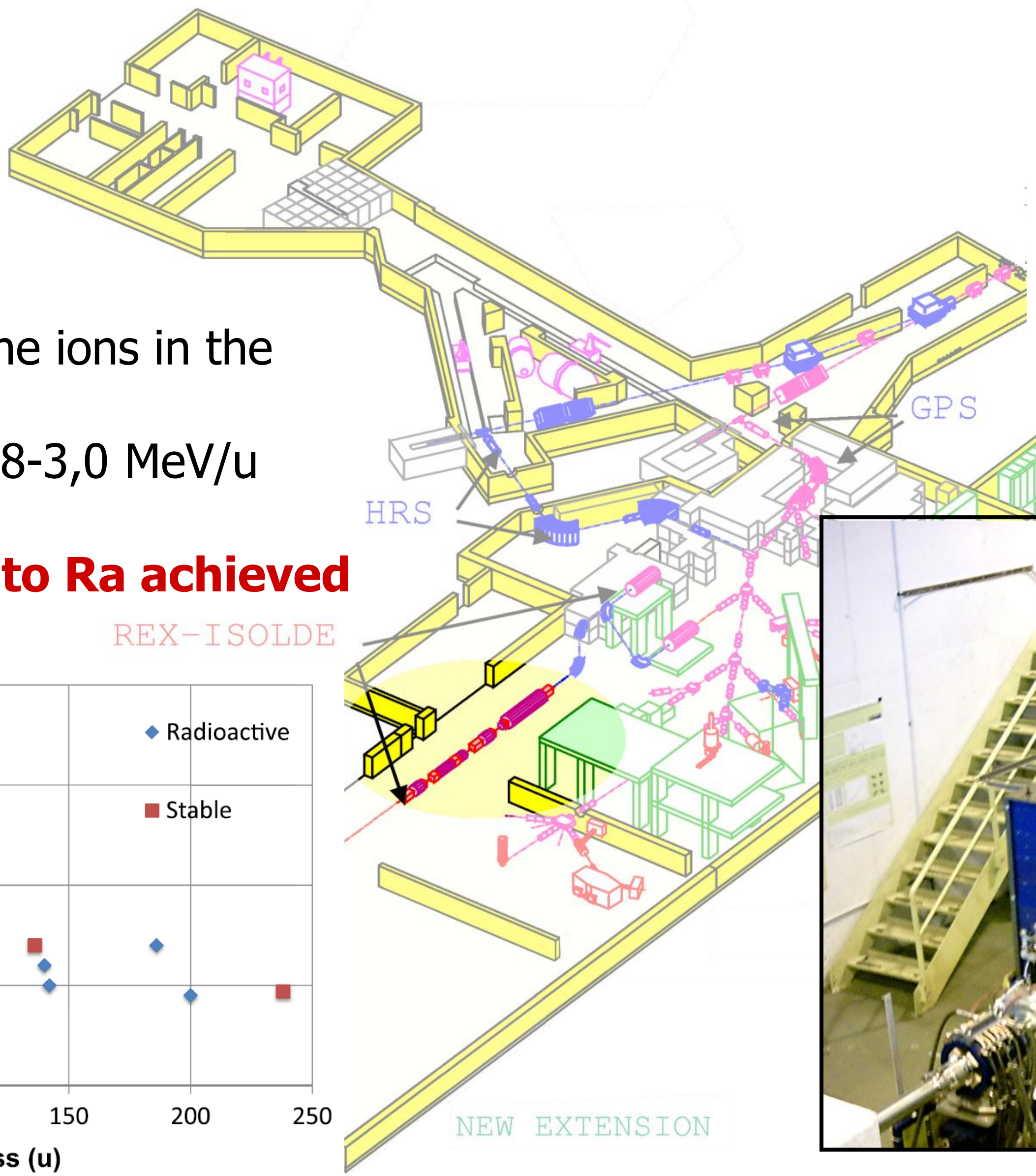
Charge breeding:

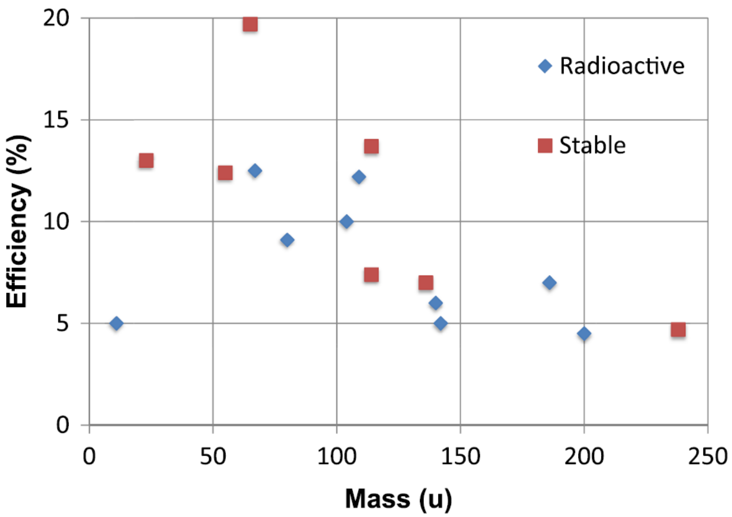
- cooling and bunching of the RIB in the **REXTRAP**
- breeding to higher charge states in the **EBIS** to A/q<4.5
- breeding time up to 400 ms
- A/q selection

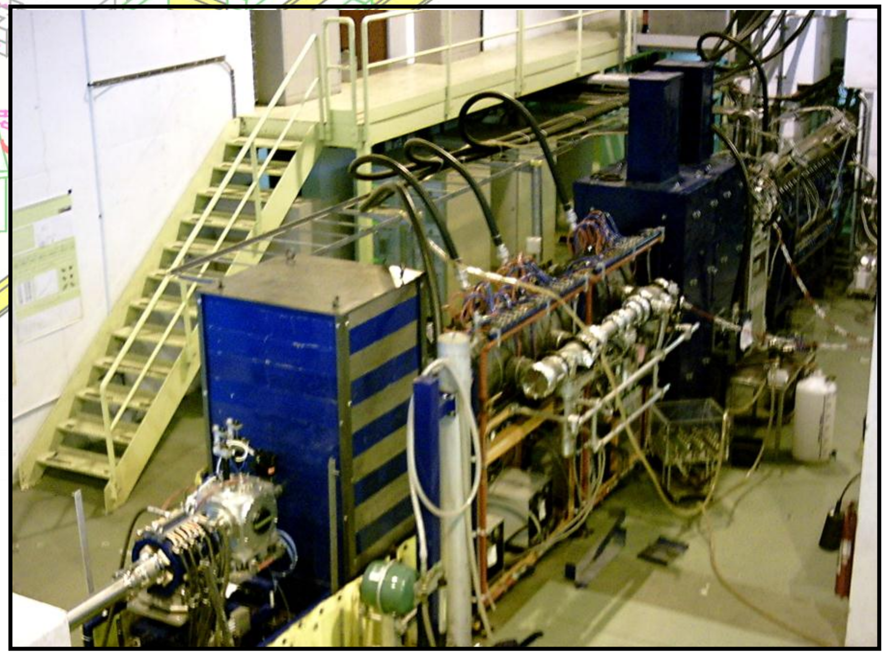
Re-acceleration

- acceleration of the ions in the REX-LINAC
- beam energy: 0,8-3,0 MeV/u

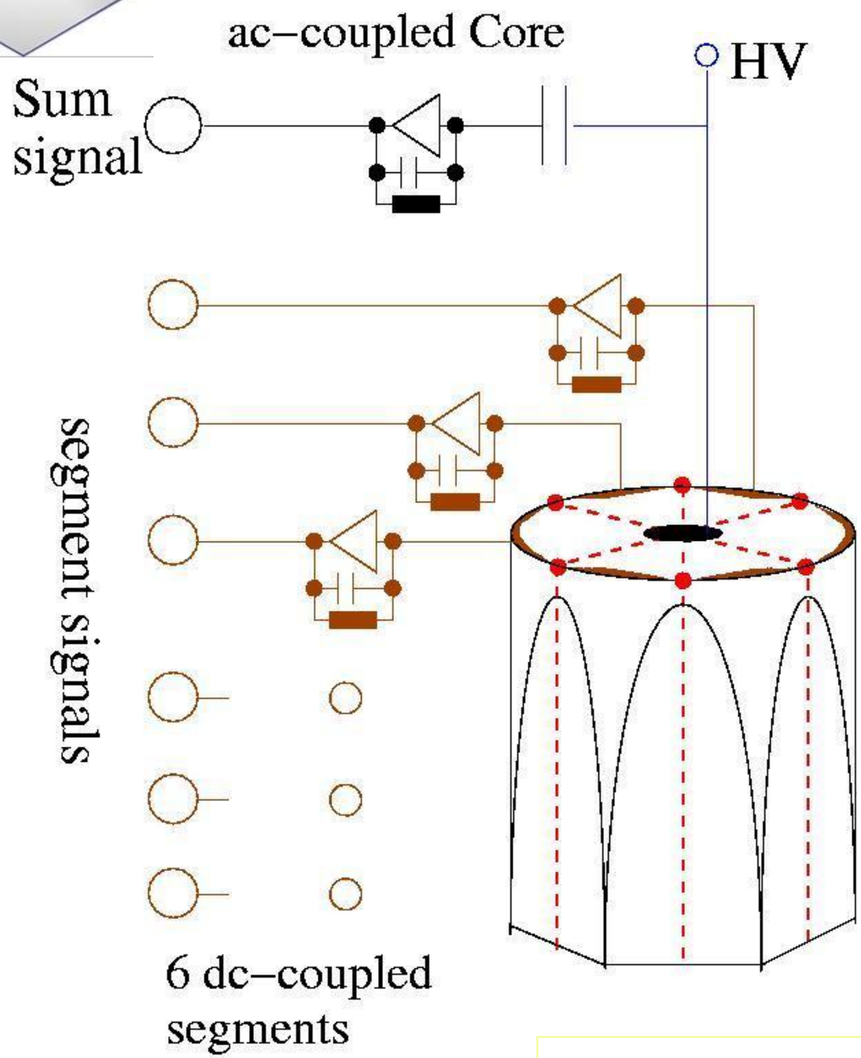
Acceleration up to Ra achieved

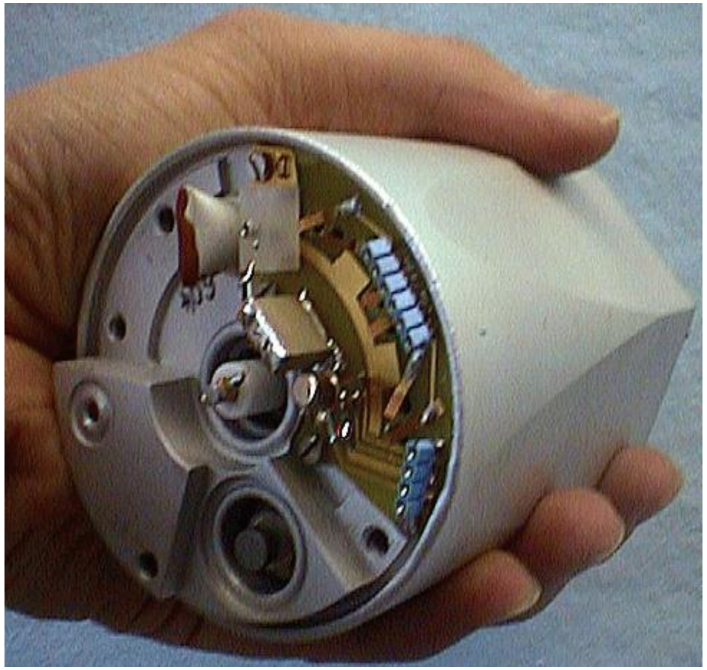


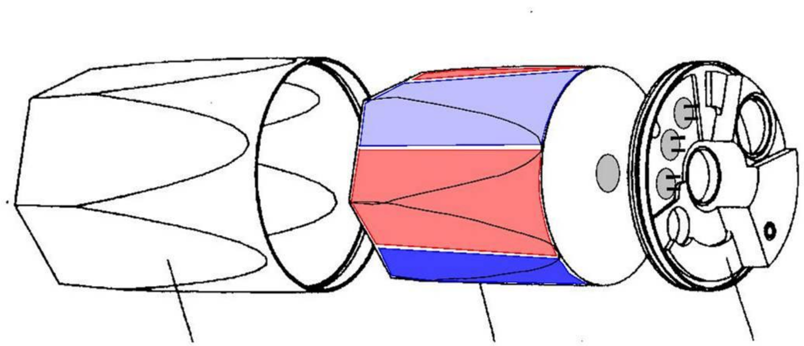




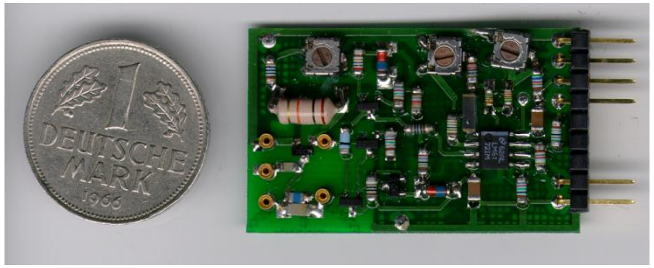
6-fold segmented, encapsulated MINIBALL detector



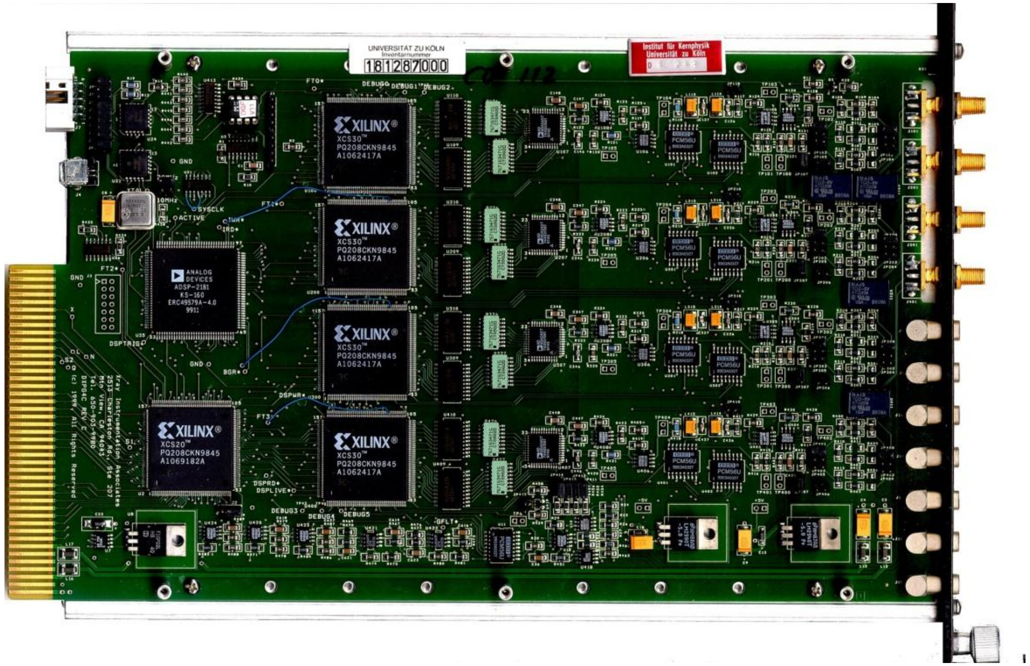




Collaboration: Köln, Heidelberg, München, Leuven



Preamplifier
IKP Köln
MPI-K Hd

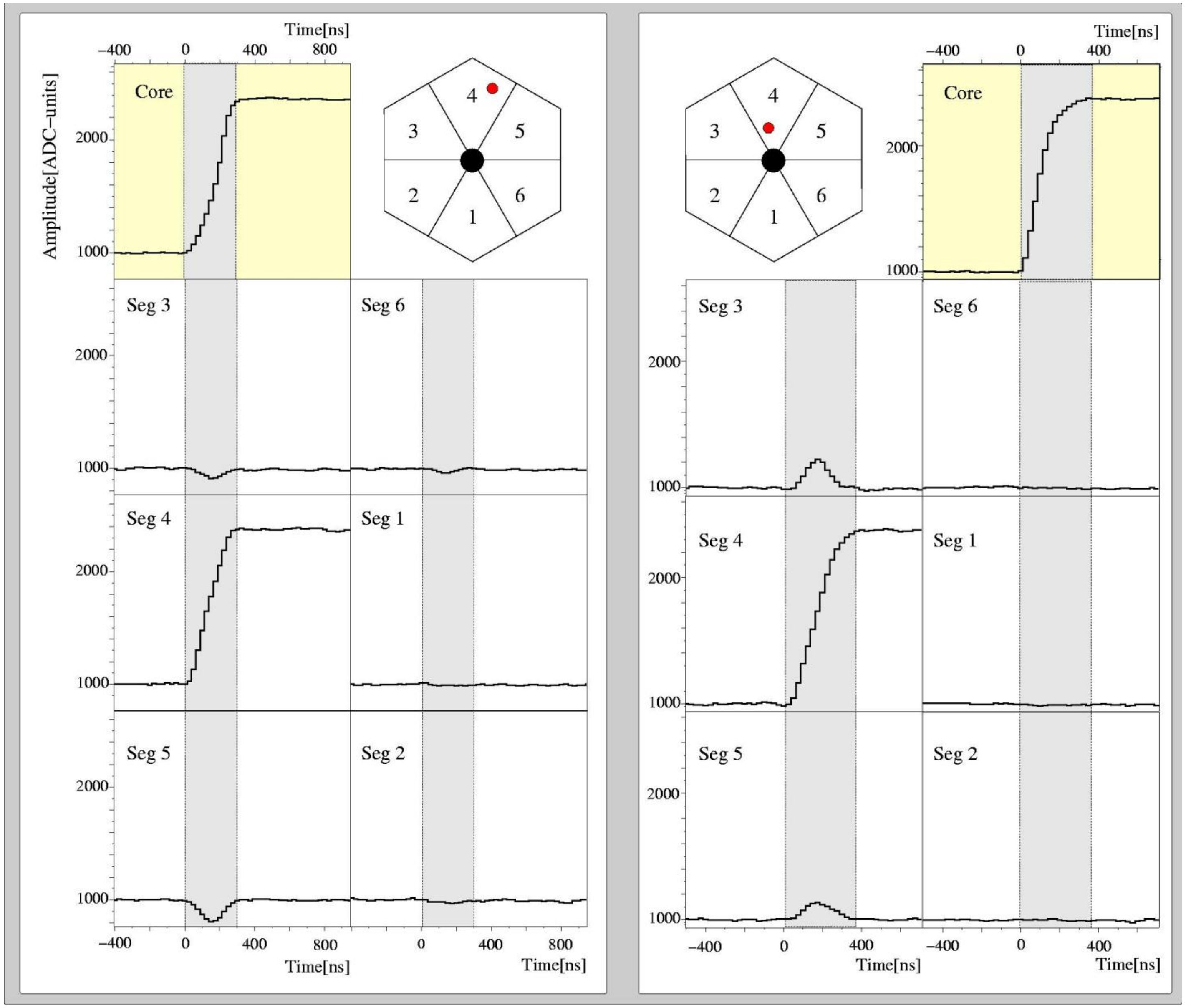


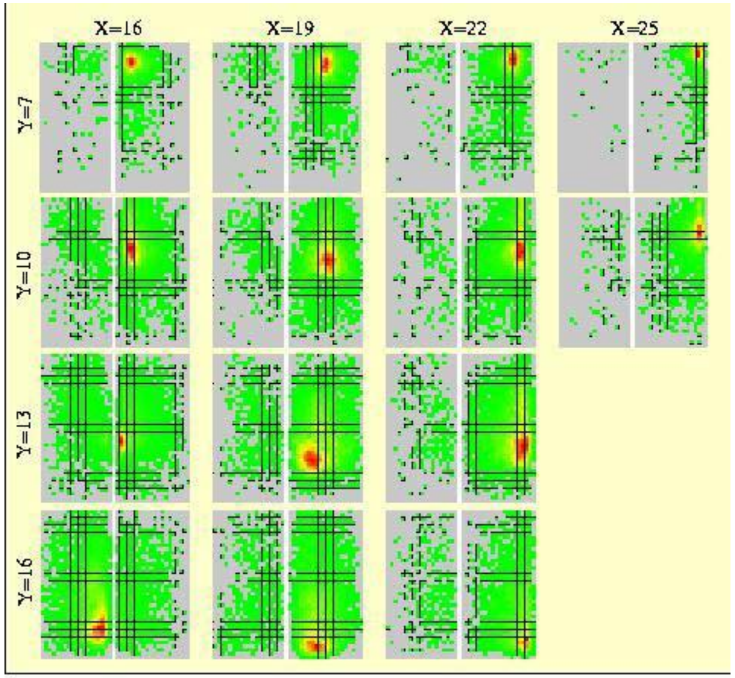
Digital high resolution spectroscopy electronics

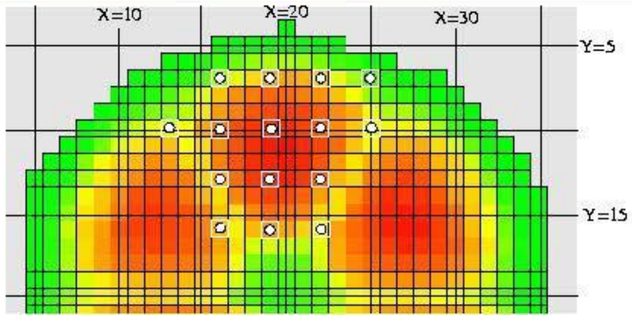
Triple cluster detector
3 x core + 3 x 6 segments
IKP Köln and CTT

40 MHz digitizer: DGF 4C Company XIA

Pulse shape analysis and position sensitivity







in-beam data:

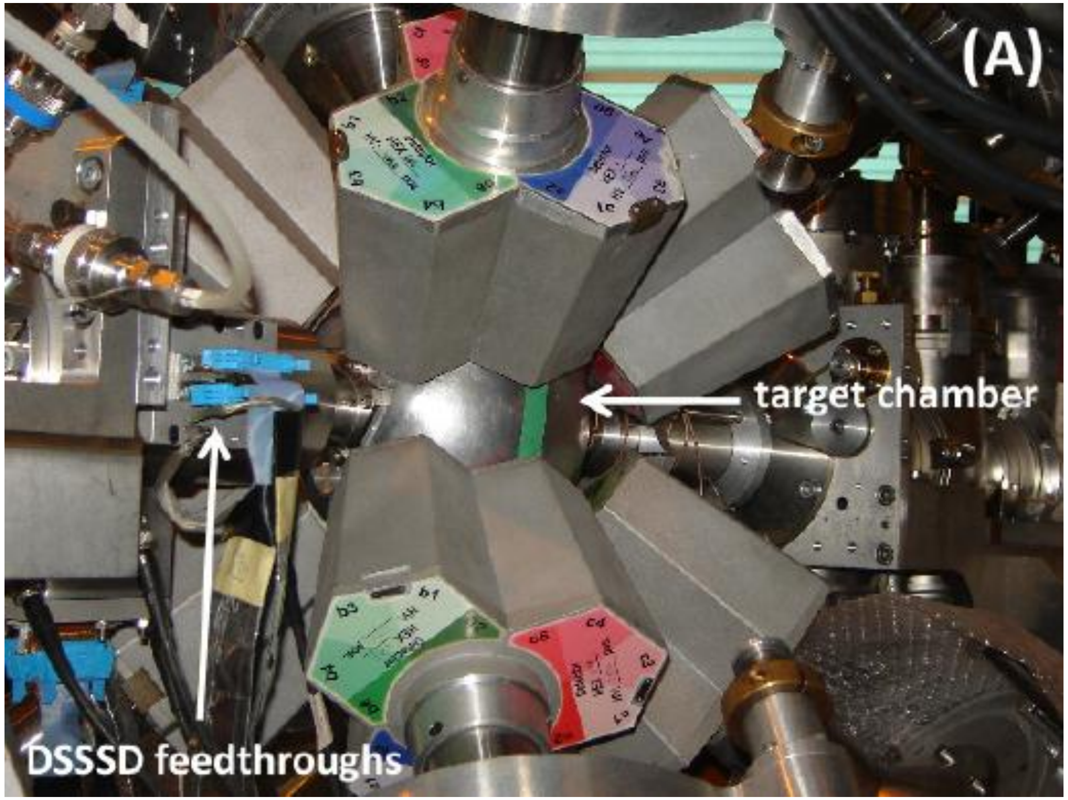
(line width after Doppler correction)

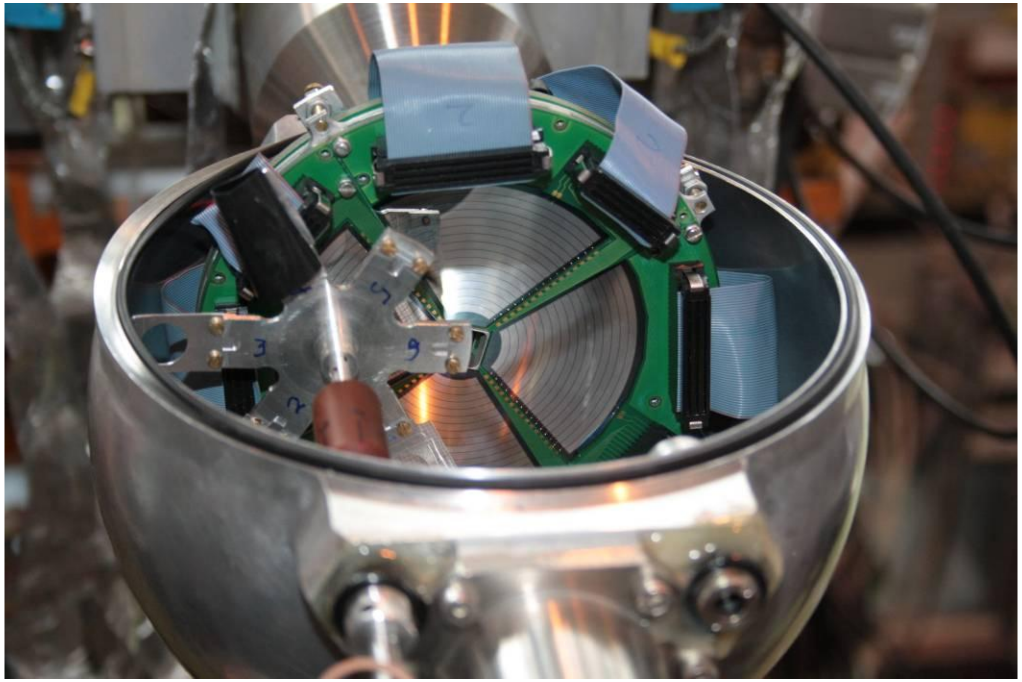
Abs. Eff. 8 %, $\Delta\Theta = 3.3^0$

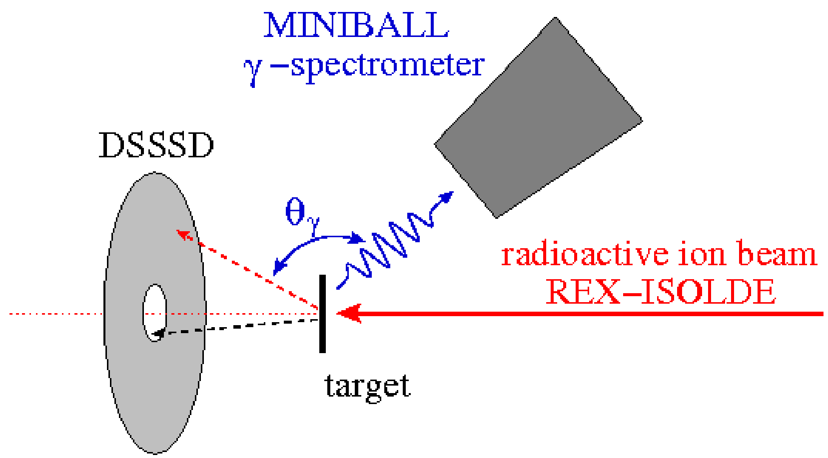
The MINIBALL Coulomb excitation setup

segmented Si detector for particle detection (DSSSD)

- 16 rings (front side)
- 96 strips (back side)
- angle coverage: θ_{lab} = 16-55°
- ΔE-E measurement possible (pad)







The T-REX setup

T-REX: Si detector array for Transfer experiments at REX-ISOLDE

- large solid angle (58% of 4π)
- position sensitive
- PID (ΔE-E): p, d, t, α,

  … and e^- from β-decay (!)

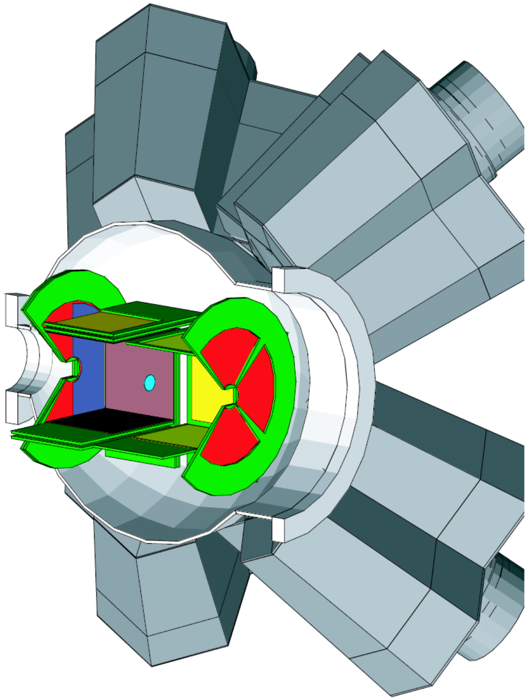
Technical details:

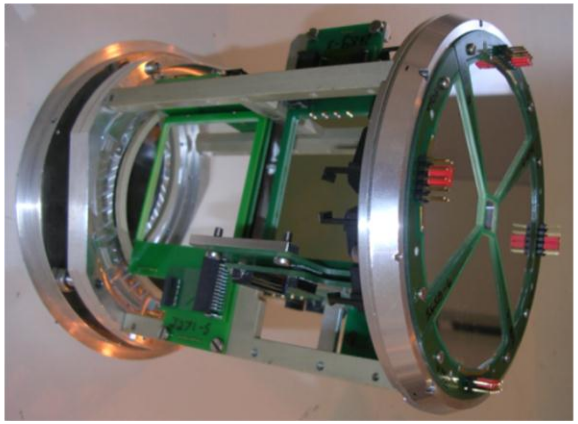
Barrel: 140 mm ΔE / 16 resistive strips

1000 mm E / pad

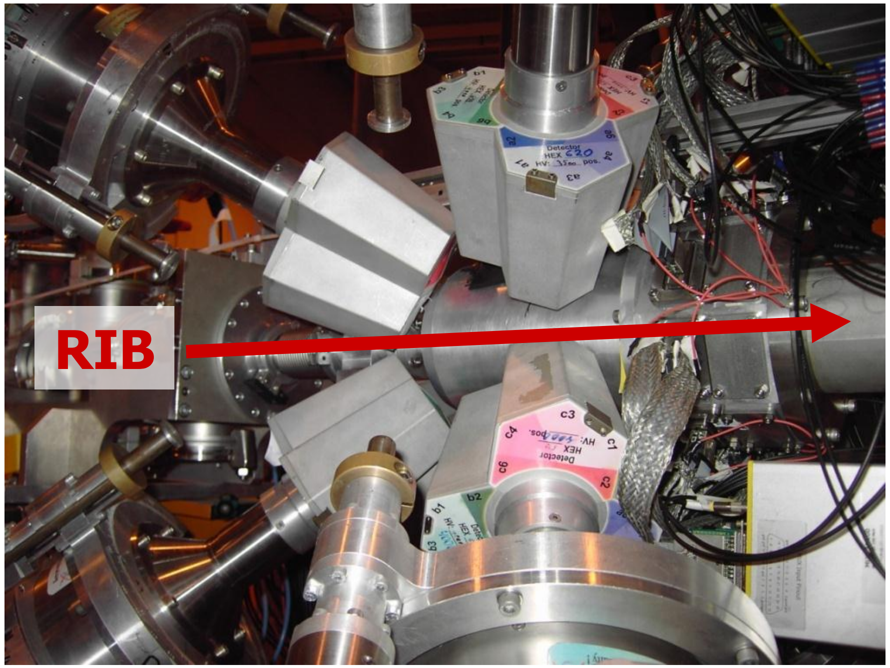
Backward CD: 500 mm ΔE / DSSSD

500 mm E / pad



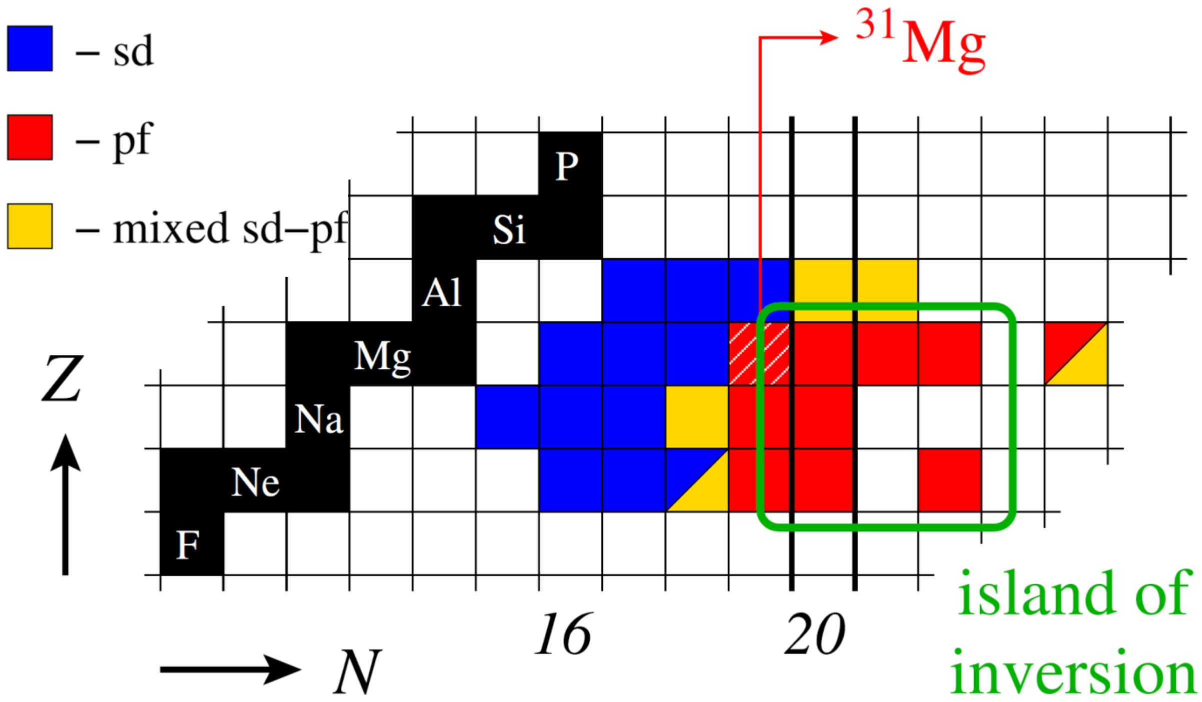


V. Bildstein, K. Wimmer,
Th. Kröll, R. Gernhäuser et al.
(funded by TU München,
KU Leuven, U Edinburgh, CSNSM
Orsay, TU Darmstadt)



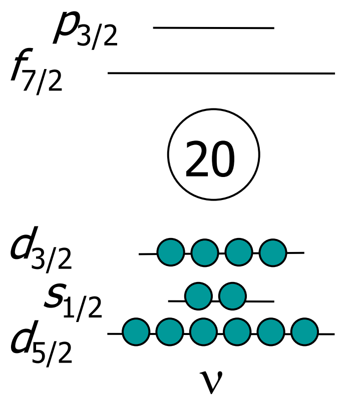
„Island of Inversion“

1975, ISOLDE: C. Thibault *et al.*:
Masses show considerable deviations for nuclei around Z=11, N=20.
⇒ additional binding energy

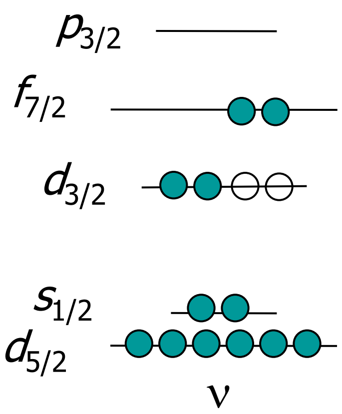


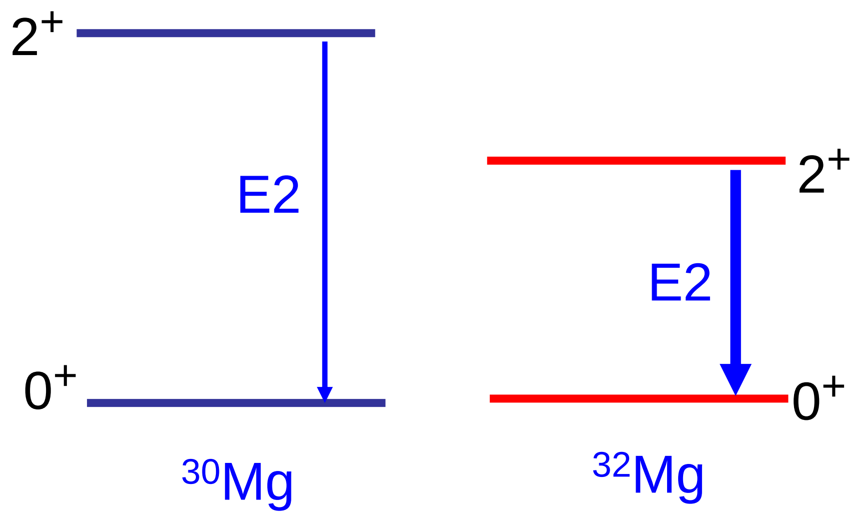
Normal *sd*-shell configuration

0p0h, spherical



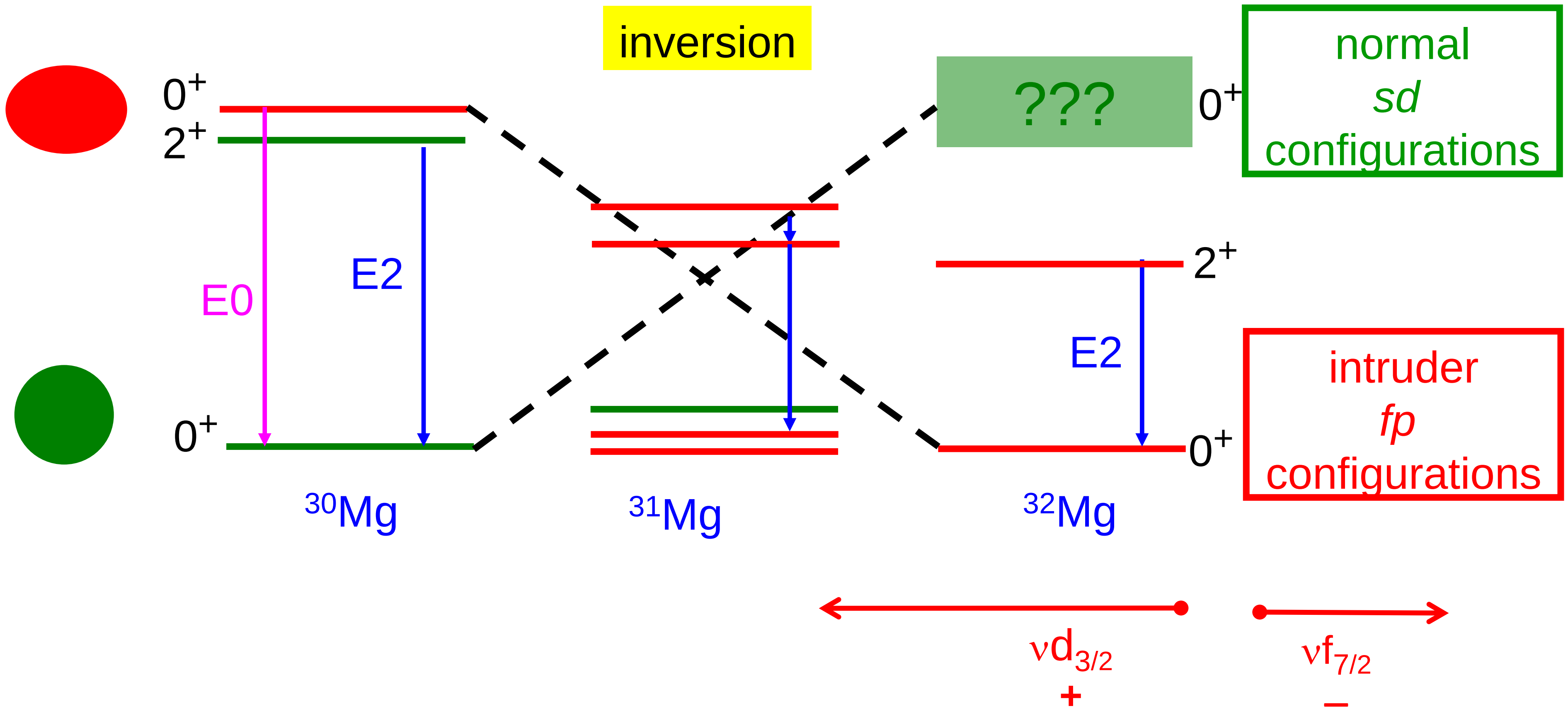
2p2h (intruder), deformed





E.K. Warburton, J. A. Becker and B. A. Brown, PRC **41** (1990) 1147.

T. Motobayashi, et al.; PLB **346** (1995) 9

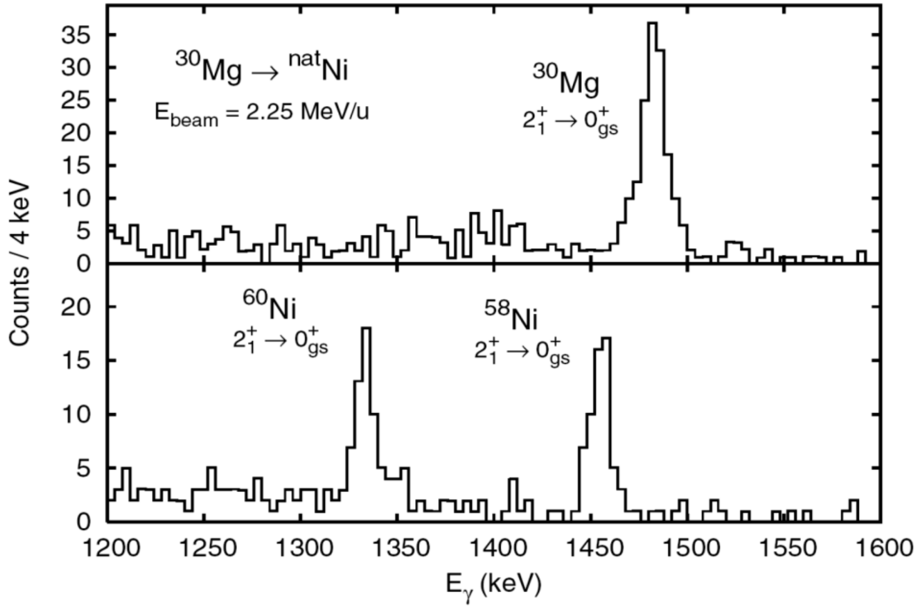


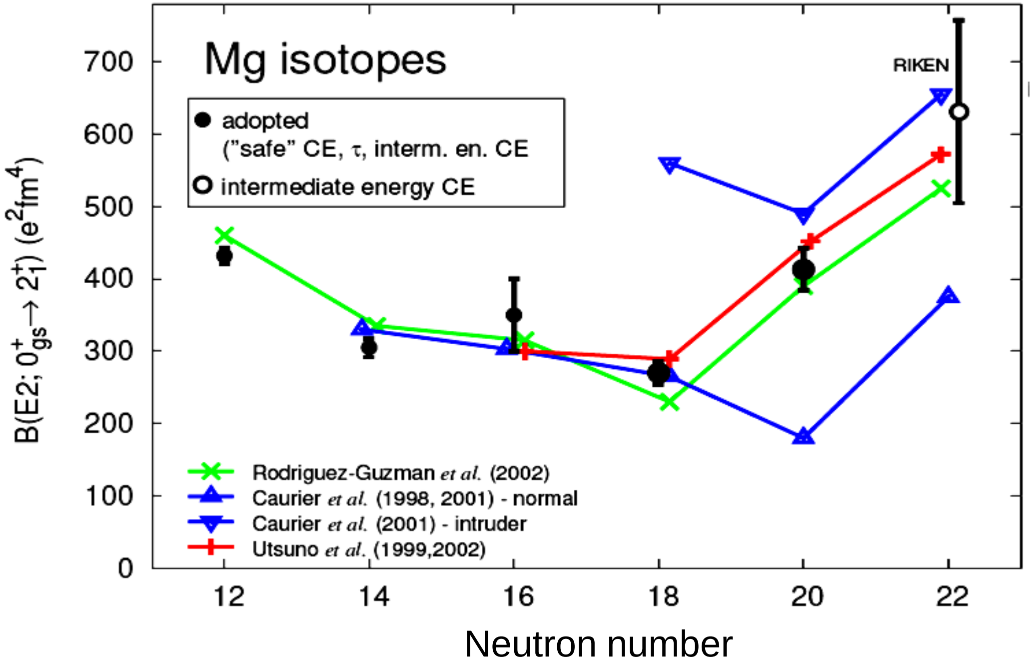
Where are the borders?

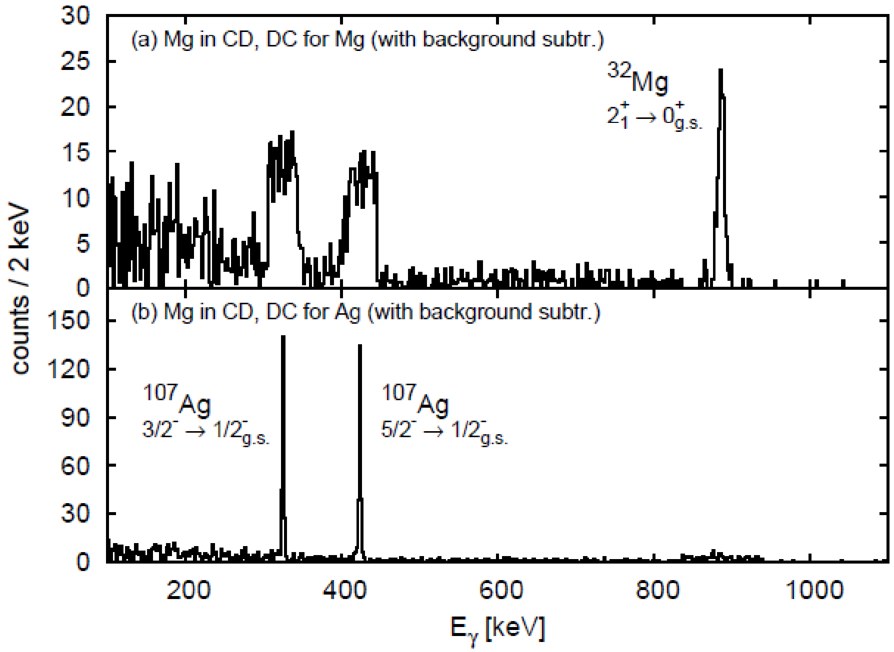
How does transition into island of inversion occur ?

Does picture of shape coexistence hold?

Coulomb excitation of $^{30,32}Mg$







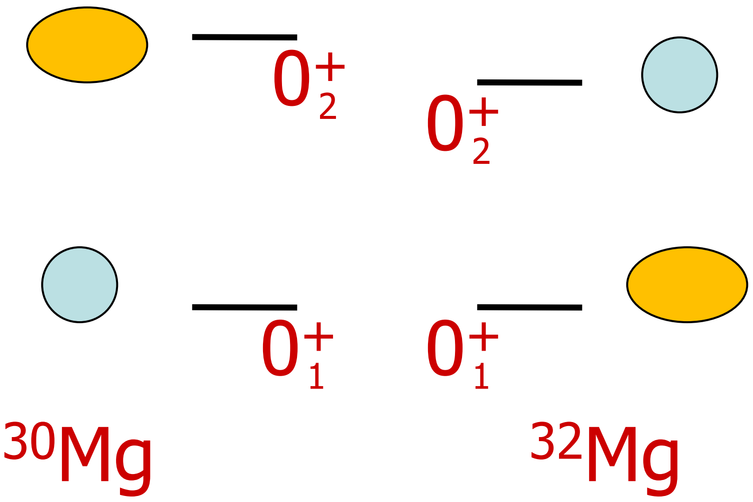
‚Safe' energy Coulomb excitation at 2.25 MeV/u

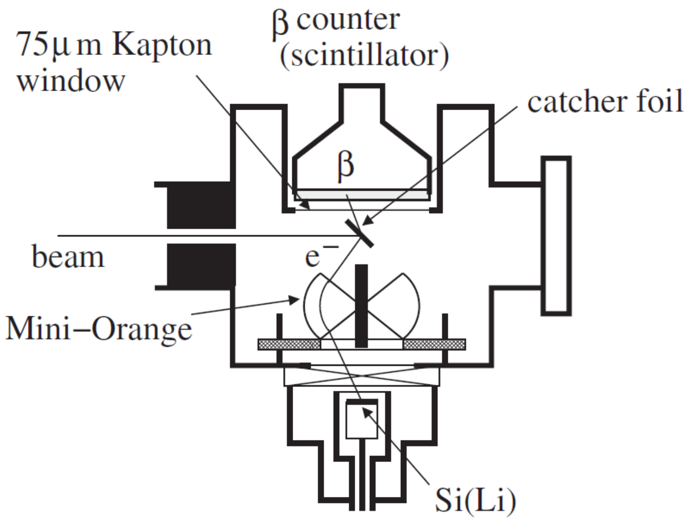
MINIBALL measures with small uncertainty B(E2) values from first excited 2^+ states to ground state in $^{30,32}Mg$

Coulex of ^{31}Mg confirms transition at N=19

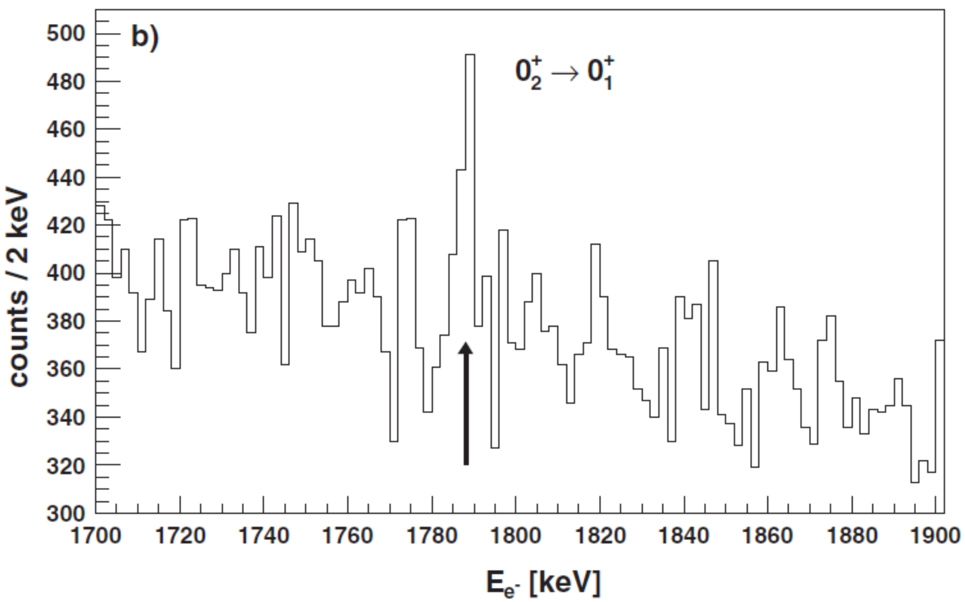
M. Seidlitz et al; PLB 700 (2011) 181
O. Niedermeier *et al.* Phys. Rev. Lett. **94**, 172501 (2005)

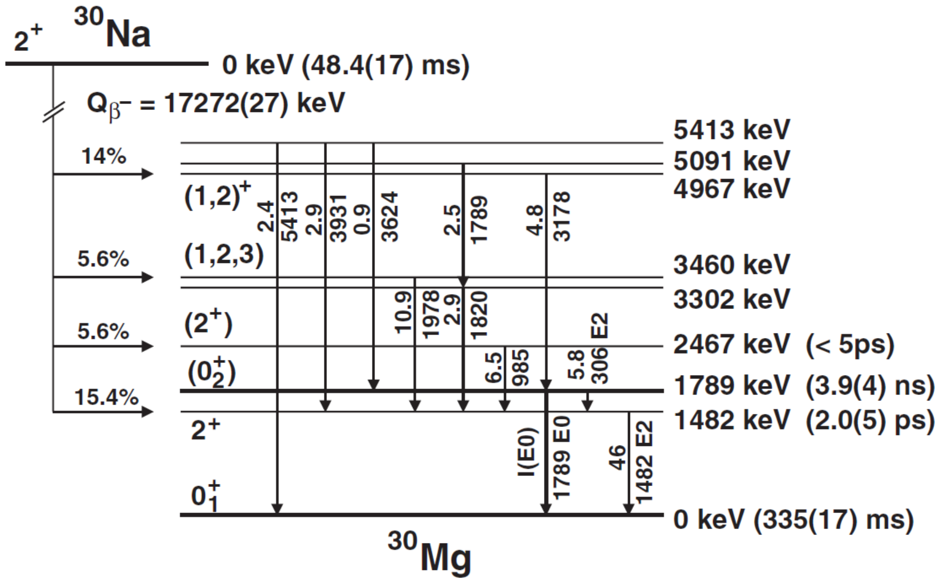
Shape coexistence in ^{30}Mg





- electron spectroscopy after β-decay at ISOLDE
- first excited 0⁺ state at 1789 keV in ^{30}Mg

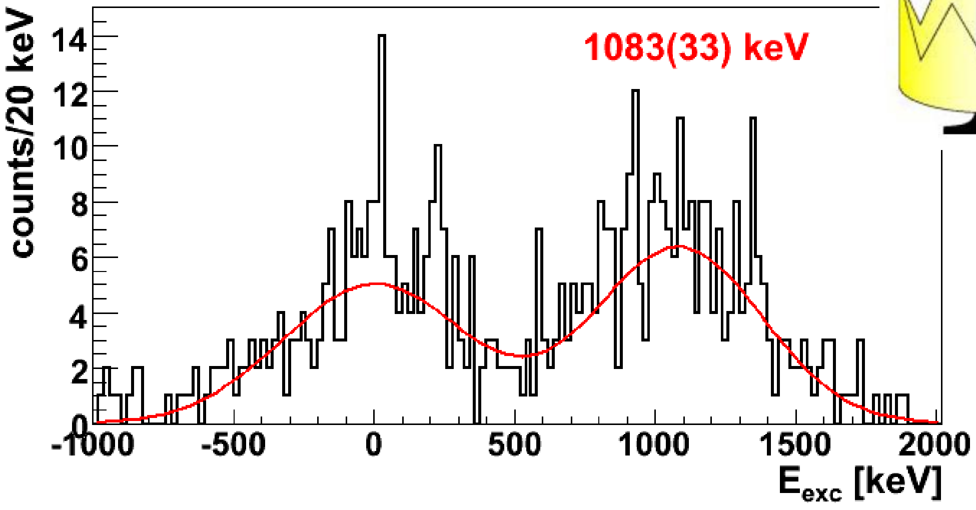


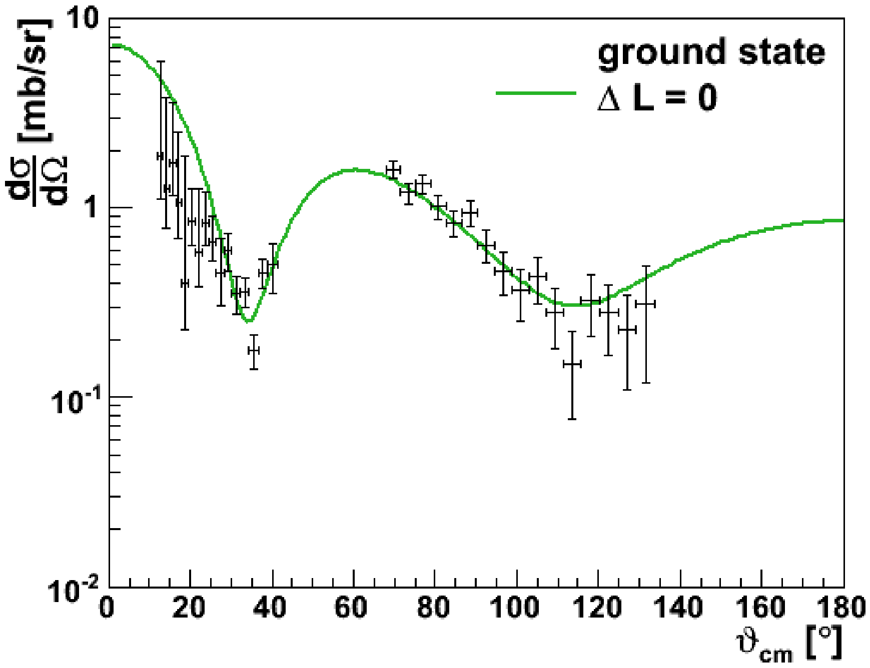


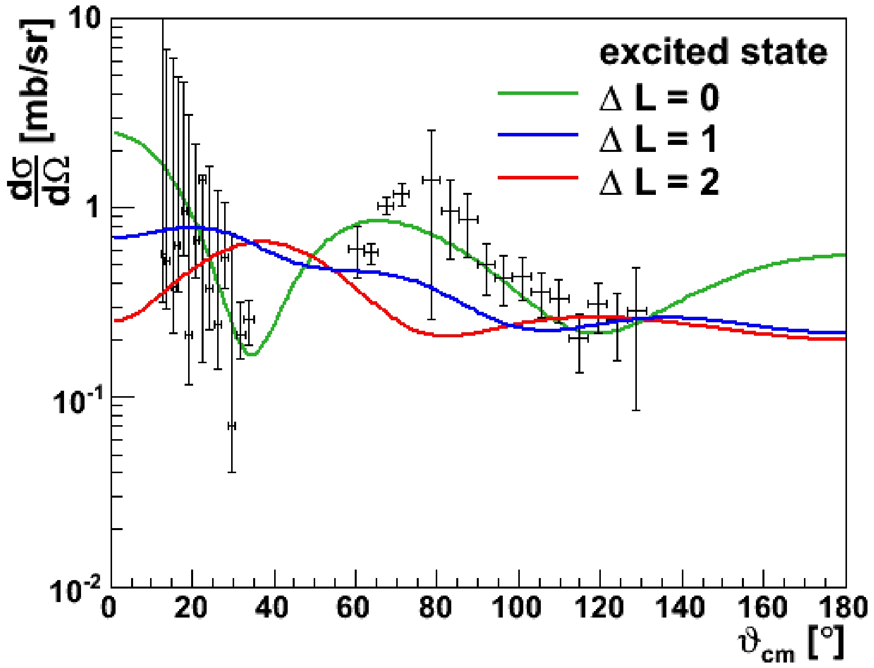
W. Schwerdtfeger, et al; PRL 103, 012501 (2009)

t(^{30}Mg, ^{32}Mg)p – two-neutron transfer

- ^{3}H loaded Ti foil (40 μg/cm^{2} ^{3}H, 10 GBq)
- ^{30}Mg @ 2 MeV/u
- $4 \cdot 10^{4}$ part/s / 150 h beam on target
- Q_{00} = -295(20) keV
- Two states populated: ground state and new state at 1083(33) keV

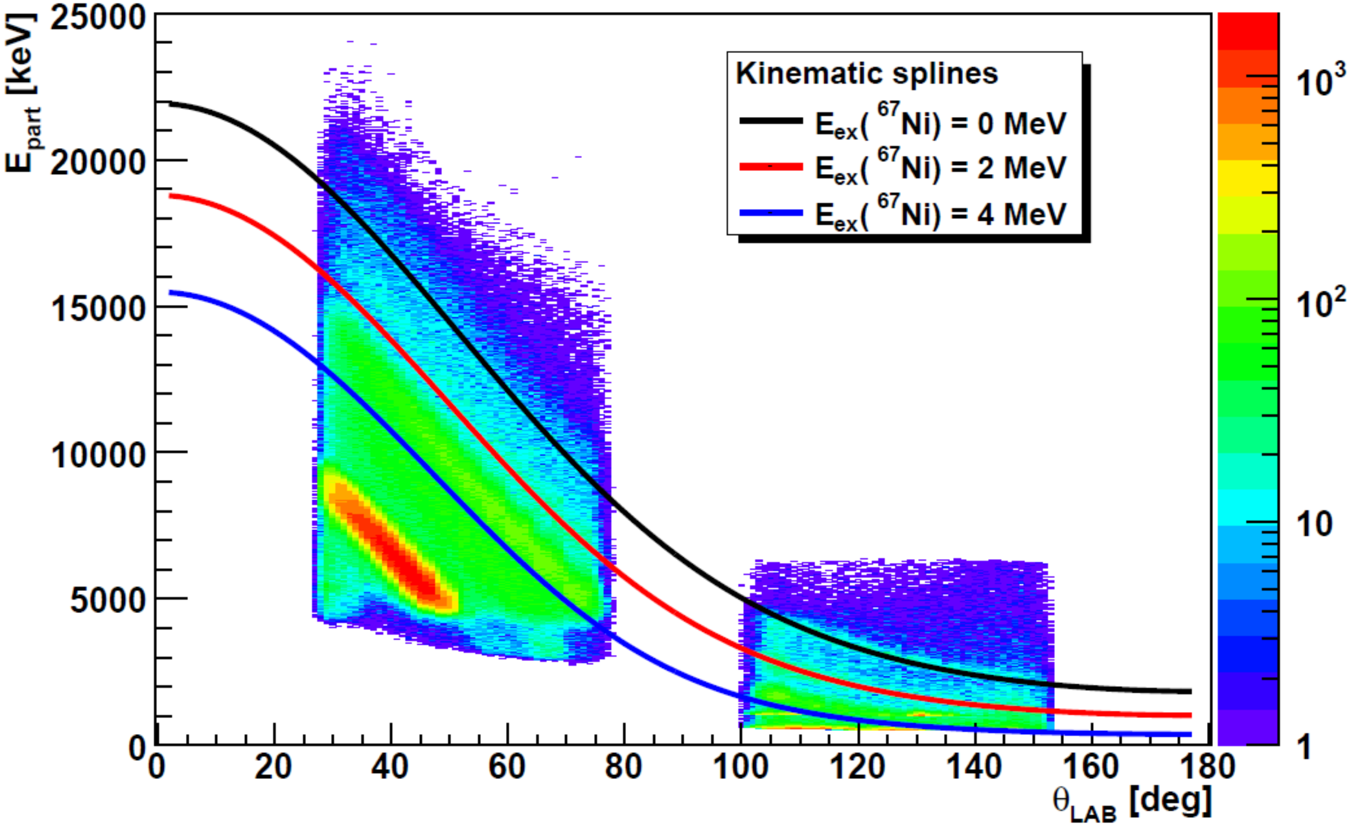






K. Wimmer et al; PRL 105, 252501 (2010)

d(^{66}Ni,^{67}Ni)p – the ^{68}Ni region (N=40)



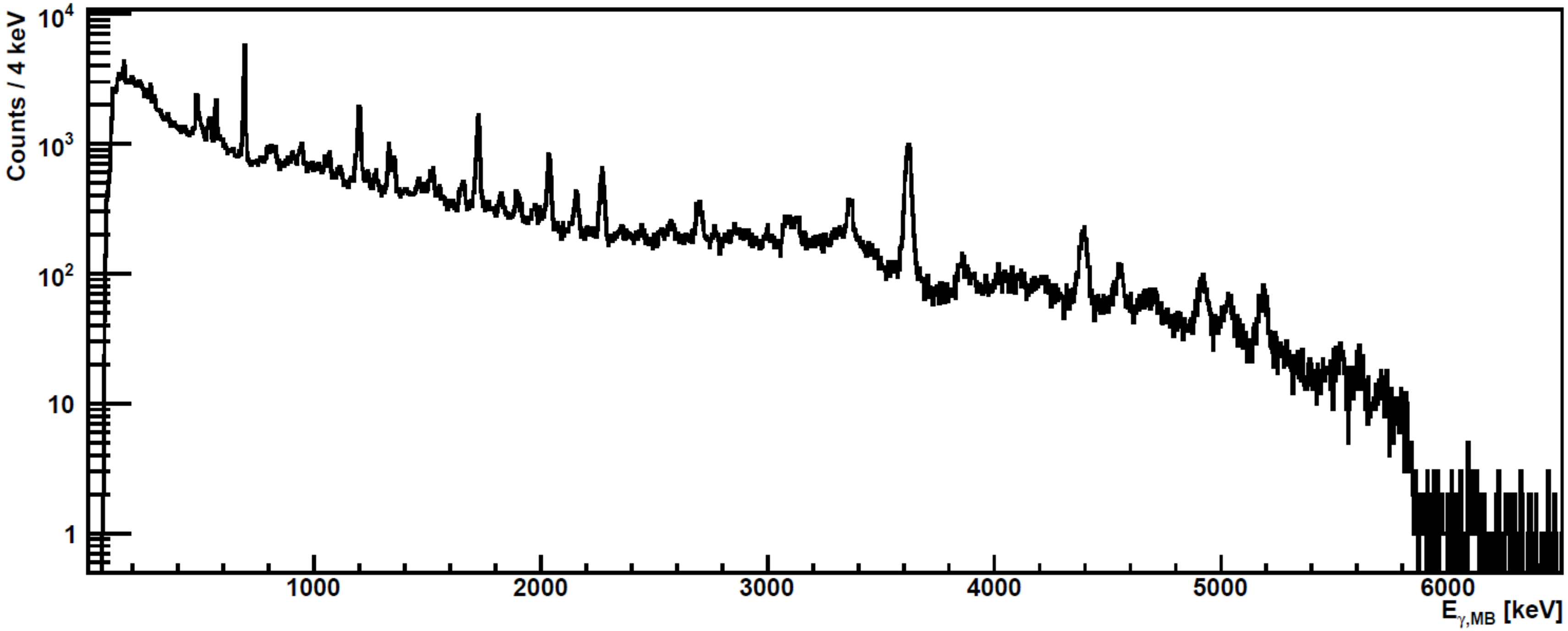
Conditions

- 100 μgr/cm^2 CD_2 target
- 3 10^6 pps
- > 99 % ^{66}Ni
- Laser ionization by RILIS
- 9 days of beam time

- Population of levels up to 6 MeV, strong feeding around 3.6 MeV
- ^{67}Ni excitation energy can be deduced from measured proton energy
- Use as trigger for γ-rays detected by MINIBALL

Jan Diriken, IKS-KU Leuven

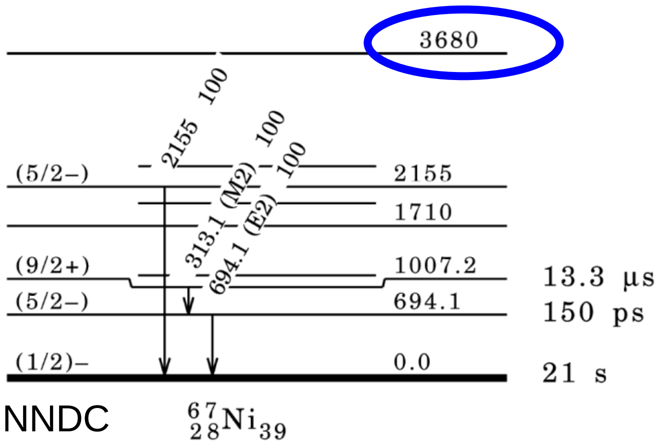
d(^{66}Ni,^{67}Ni)p – the ^{68}Ni region (N=40)

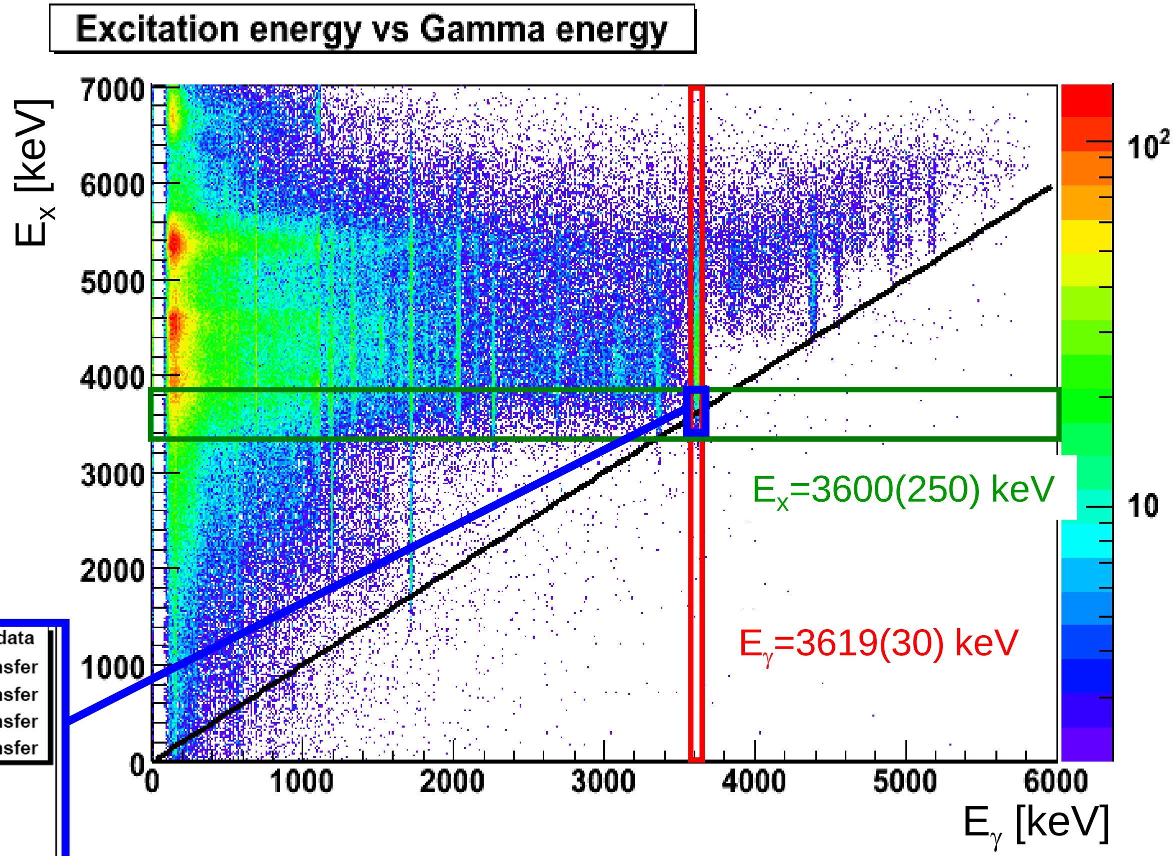


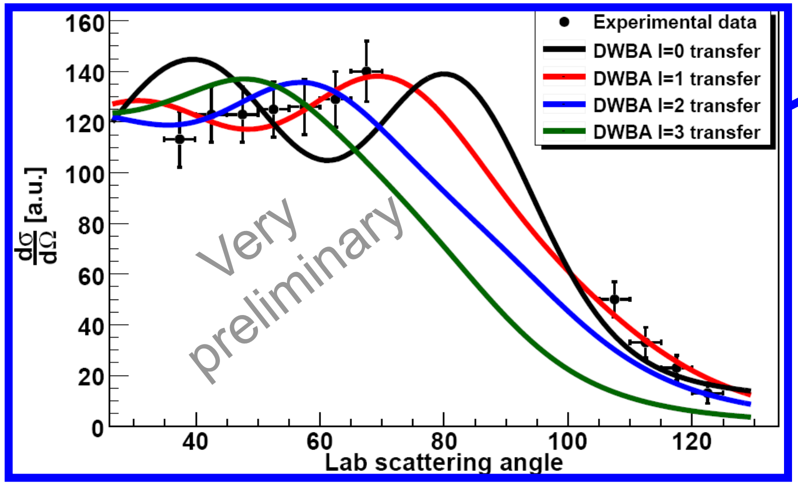
- Very rich proton-gated γ spectrum
- γ-transitions up to 5800 keV are observed
- Possibilities for p-γ-γ coincidences

d(^{66}Ni,^{67}Ni)p – the ^{68}Ni region (N=40)

shell closure at N=40?







High resolution of MINIBALL allows to resolve states and to analyse angular distribution

Jan Diriken, IKS-KU Leuven

Transfer reactions at HIE-ISOLDE

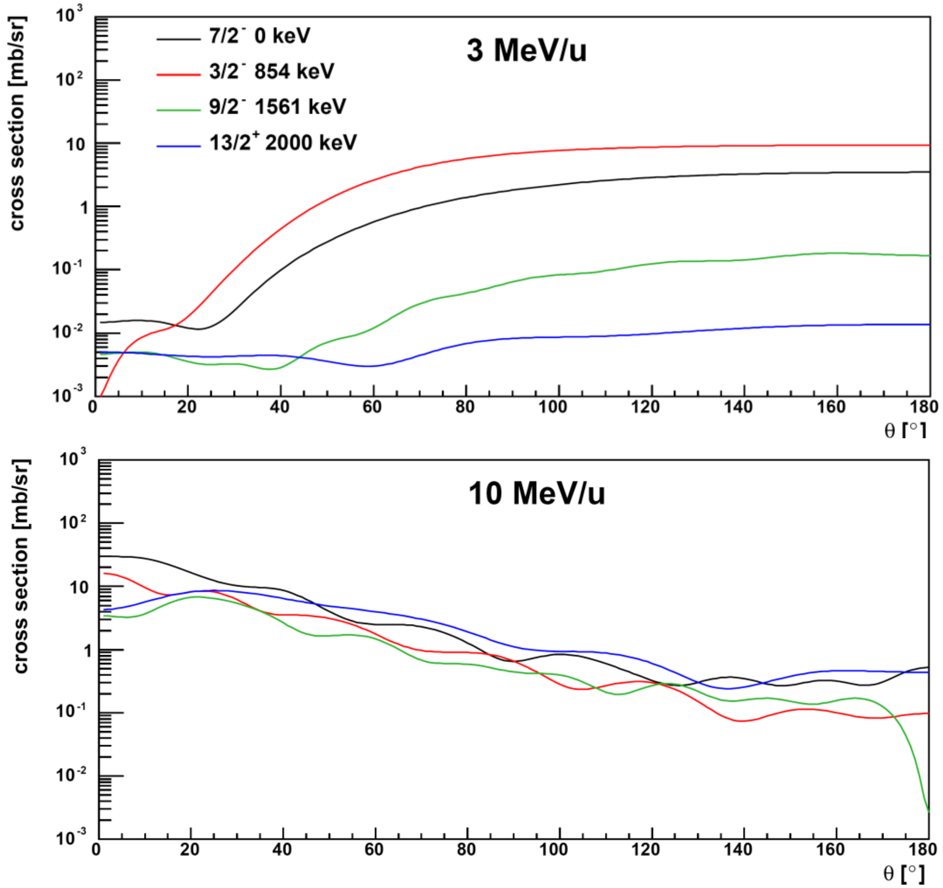
Higher energies at HIE-ISOLDE will allow for transfer reaction studies with heavy beams!

Several LoI's for HIE-ISOLDE involve nucleon transfer reactions with MINIBALL & T-REX:
- shell evolution
- shape coexistence
- pairing correlations ⇔ pair transfer
- nuclear astrophysics:
  (d,p) ⇔ (n,γ) capture reactions

Upgrade of T-REX … more flexible geometry of Si detectors

Spectrometer planned to identify heavy transfer products

Show case example: d(^{132}Sn,^{133}Sn)p



FRESCO calc's by K. Wimmer (NSCL, MSU)

HIE-ISOLDE

instrumentation for energetic beams

- workhorse: MINIBALL + TREX
- New detectors :
  - ❖ MAYA/ACTAR active target
  - ❖ SPEDE - SPectrometer for Electron DEtection in radioactive beam
  - ❖ HELIOS superconducting magnet for charged particle detection
  - ❖ PARIS (**P**hoton **A**rray for studies with **R**adioactive **I**on and **S**table beams)
  - ❖ GASPARD (**GA**mma **S**pectroscopy and **PA**rticle **D**etection)
  - ❖ Neutron detectors
- Magnetic spectrometer or separator for channel selection
- Storage Ring
- Special requirements
  - ❖ Time of Flight detection => buncher + chopper
  - ❖ Slow EBIS extraction
  - ❖ Beam spot

Summary

- MINIBALL spectrometer perfectly suited for REX-ISOLDE
- Physics case covers nuclei in the range from ^{17}F to ^{224}Ra
- First years: Shell model physics and Coulomb excitation
- Recent developments:
  - heavy beams
  - T-REX transfer reactions & γ-ray spectroscopy
- Major perspective: HIE-ISOLDE
- New collaborators, new science

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Hopefully a lot of institutions will be interested in future MINIBALL Experiments.