Structure, Shapes from Excited States

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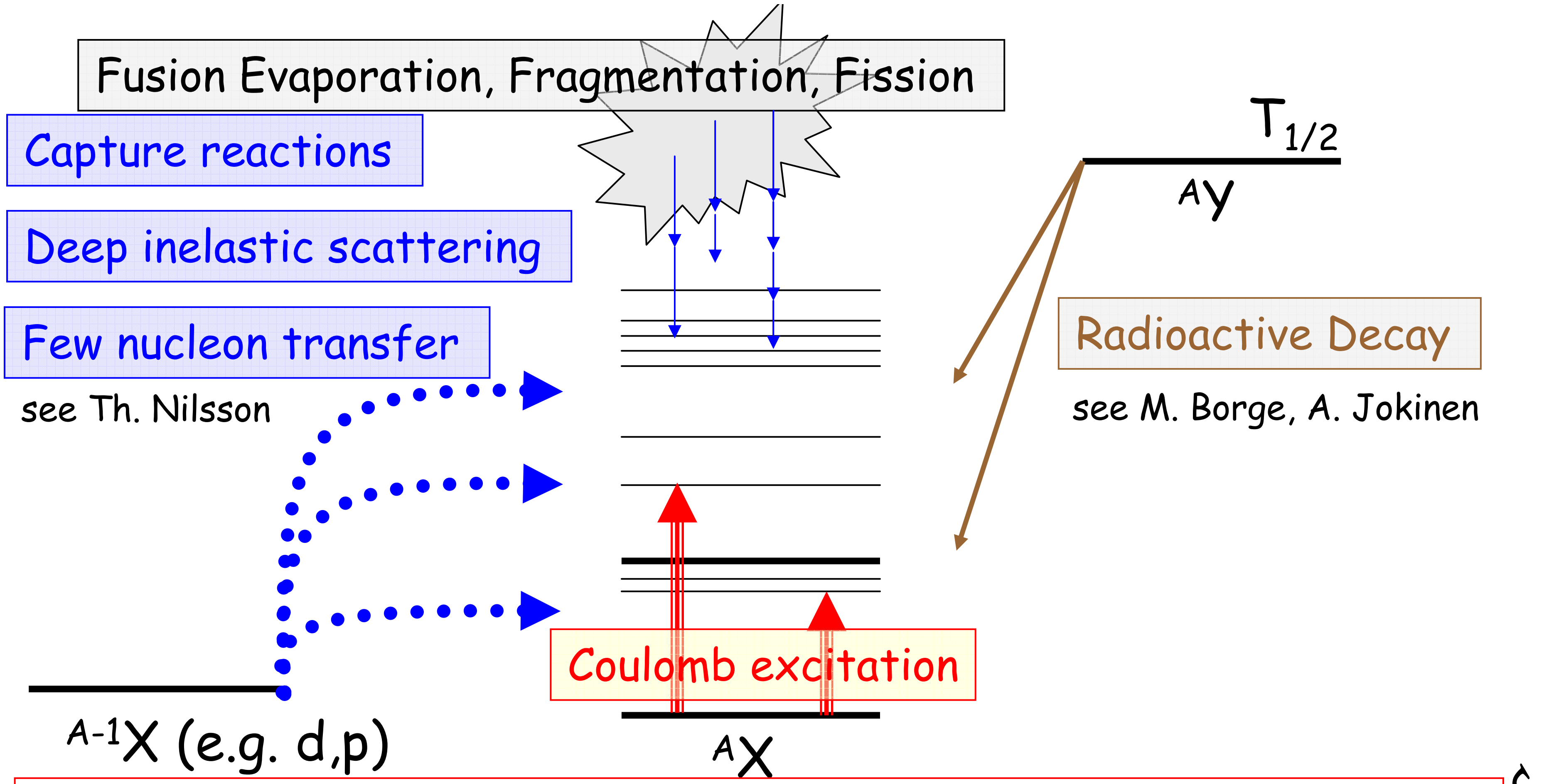
for the MINIBALL Collaboration

- Physics Motivation and Questions (see D. Vretenar)
- ISOLDE has unique possibilities to produce high-quality results that form stringent test for our understanding of the atomic nucleus

Outline

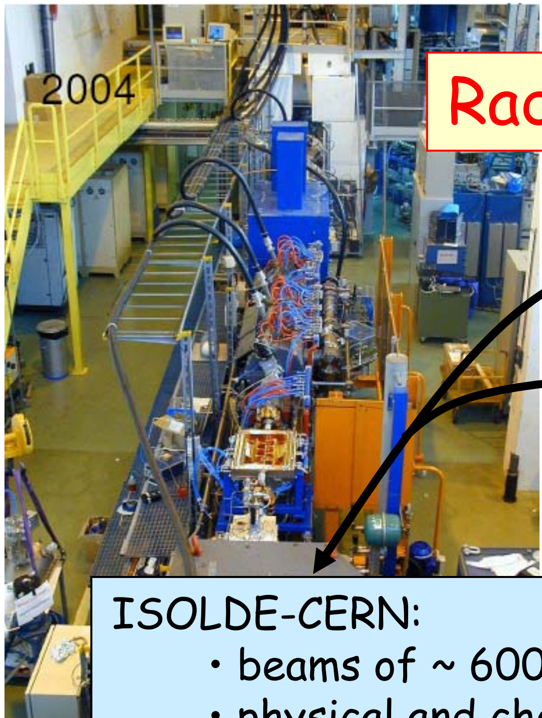
- Introduction (probing excited states, radioactive beam experiments)
- The REX-ISOLDE - MINIBALL Physics Program: a few Selected Cases
- Future Outlook and Conclusion
- Needs



Oak-Ridge - GANIL - GSI - MSU - RIKEN - TRIUMF -LLN

- Energy
- Spin and Parity
- Decay Strength Distributions
- **E.M.**-Transition Matrix Elements
- Spectroscopic Factors
- Shapes and Moments

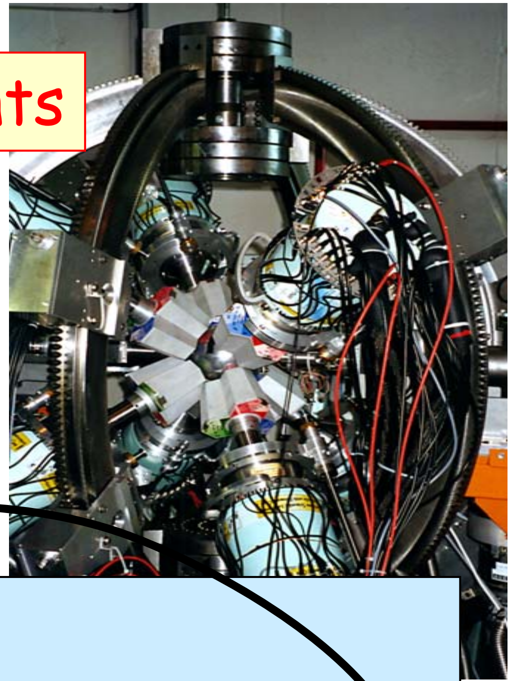
Radioactive Ion Beams



Radioactive Ion Beam Experiments

⇒ **maximize**

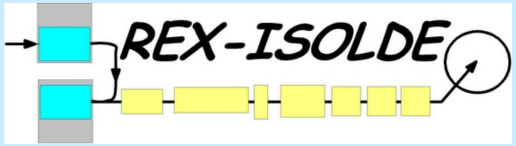
- Intensity
- Selectivity
- Sensitivity



ISOLDE-CERN:

- beams of ~ 600 radioactive isotopes available at 60 keV
- physical and chemical properties to purify (e.g. laser ion source, molecular beams)

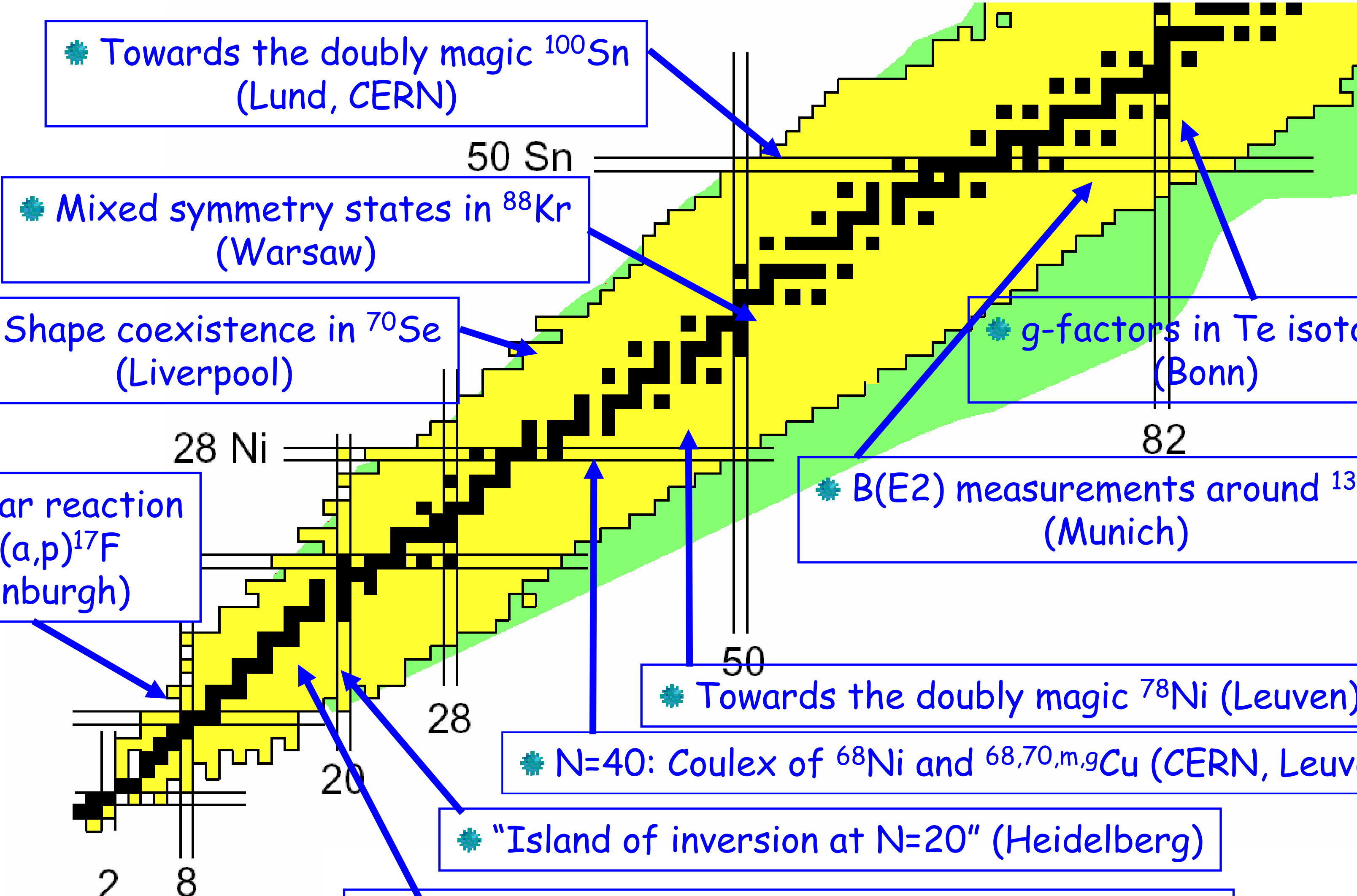
Radioactive ion beam **EX**periment at **ISOLDE**:



- an efficient concept for post-accelerating radioactive isotopes

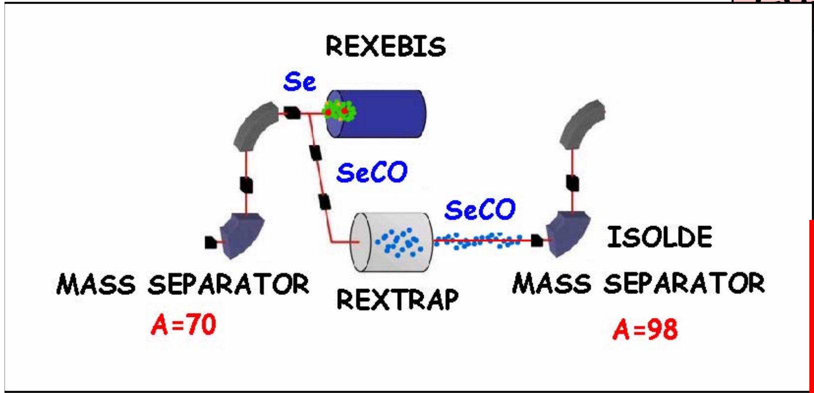
MINIBALL: segmented Ge detectors in combination with segmented Si detector (CD)

The REX-ISOLDE - MINIBALL physics program: Structure and Shapes

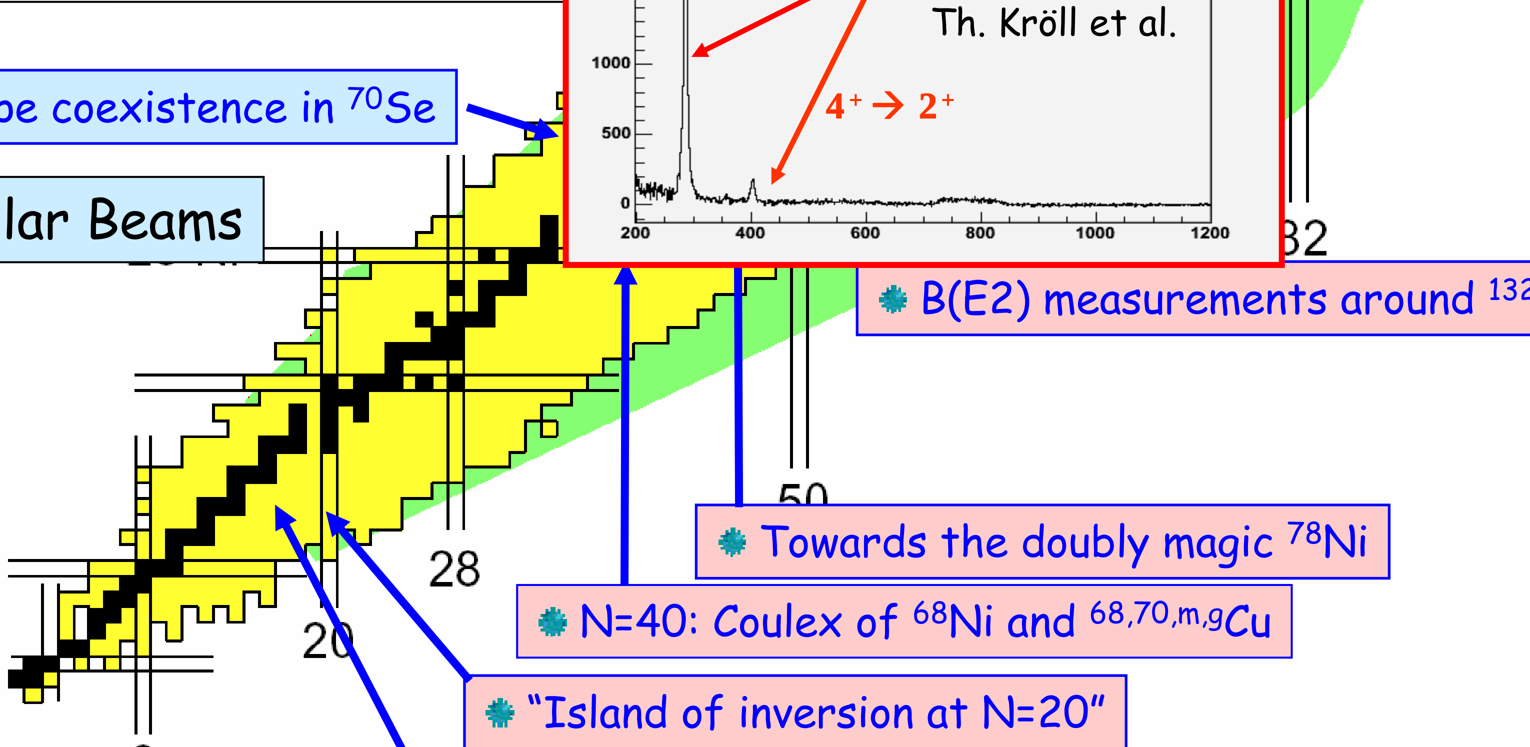


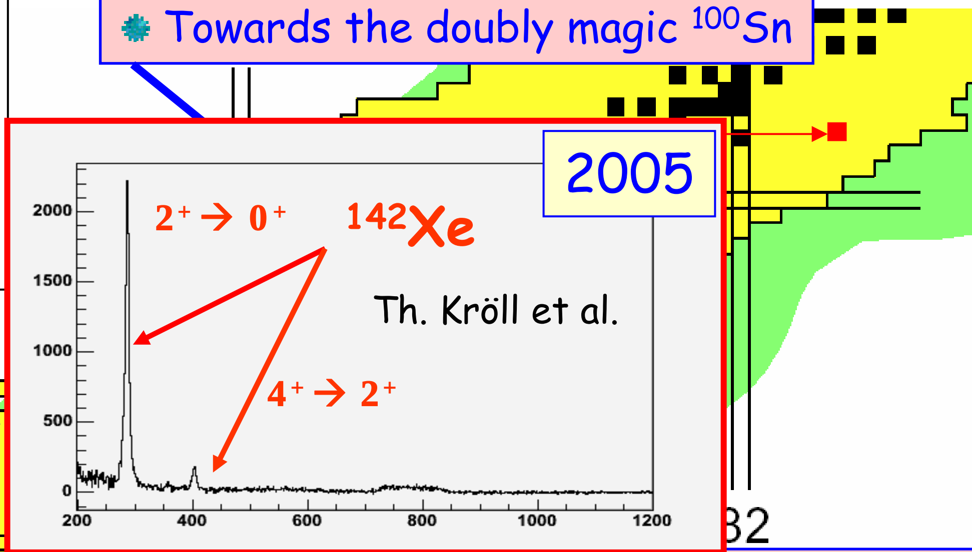
- Towards the doubly magic ^{100}Sn (Lund, CERN)
- Mixed symmetry states in ^{88}Kr (Warsaw)
- Shape coexistence in ^{70}Se (Liverpool)
- Stellar reaction $^{14}O(a,p)^{17}F$ (Edinburgh)
- g-factors in Te isotopes (Bonn)
- B(E2) measurements around ^{132}Sn (Munich)
- Towards the doubly magic ^{78}Ni (Leuven)
- N=40: Coulex of ^{68}Ni and $^{68,70,m,g}Cu$ (CERN, Leuven)
- "Island of inversion at N=20" (Heidelberg)
- Fusion reactions with neutron-rich nuclei (Köln)
- Neutron transfer reactions on ^{30}Mg (Darmstadt)

Laser Ion Source (element/isomer selectivity)



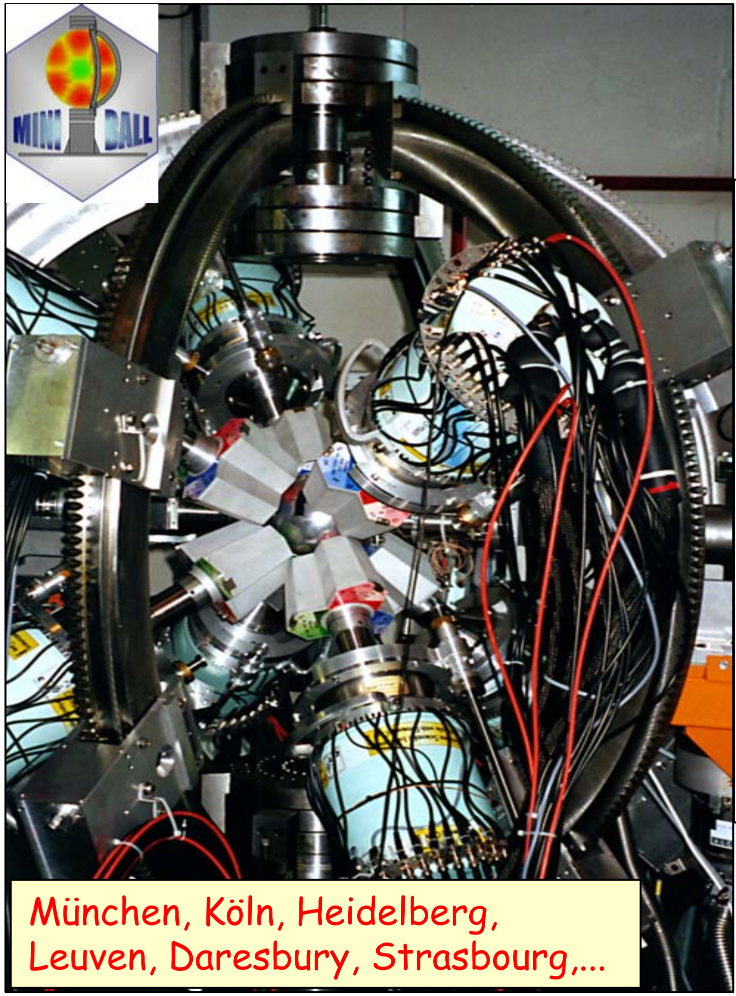
Molecular Beams



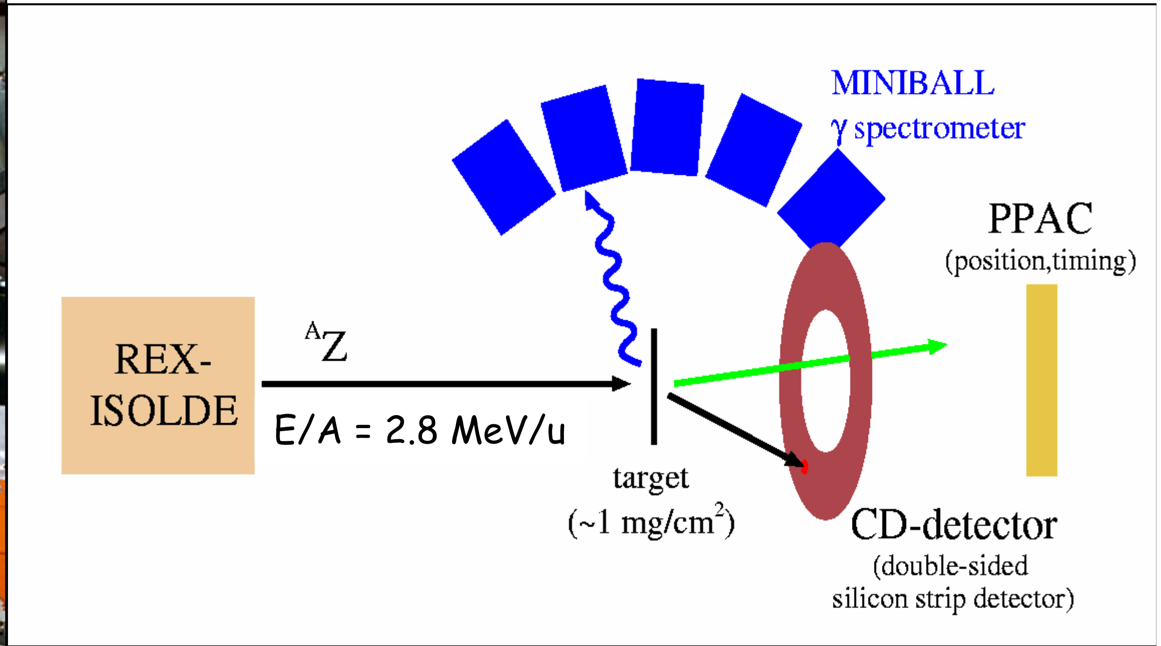


- Towards the doubly magic ^{100}Sn
- Shape coexistence in ^{70}Se
- B(E2) measurements around ^{132}Sn
- Towards the doubly magic ^{78}Ni
- N=40: Coulex of ^{68}Ni and ^{68,70,m,g}Cu
- "Island of inversion at N=20"
- Fusion reactions with neutron-rich nuclei
- Neutron transfer reactions on ^{30}Mg

- "Safe" Coulomb Excitation experiments
  - ➢ particle (CD) - γ correlations

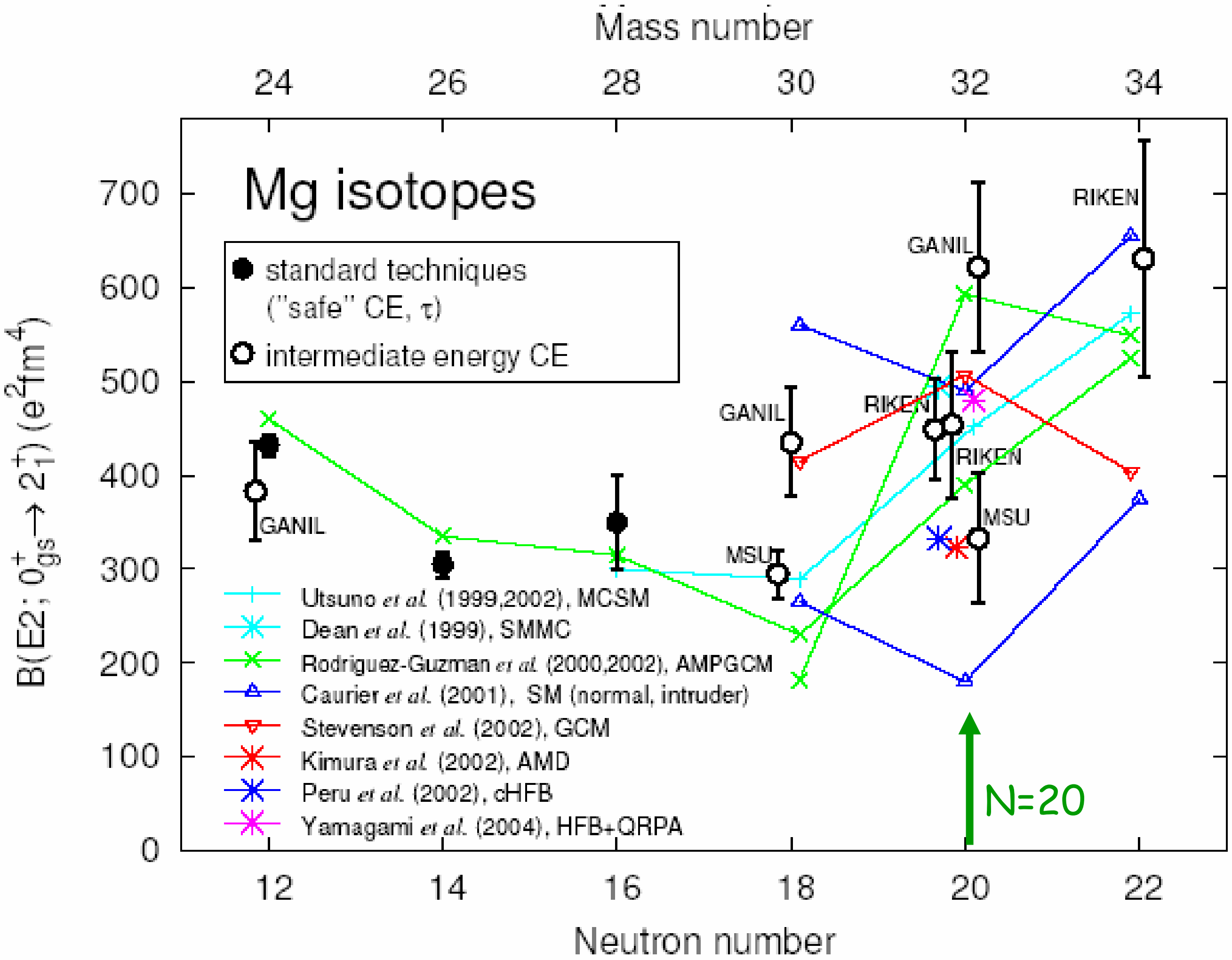


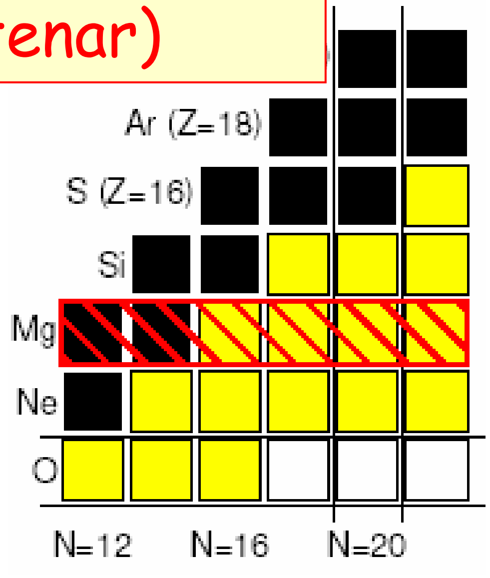
München, Köln, Heidelberg, Leuven, Daresbury, Strasbourg,...



- ✓ **“Island of Inversion” at N=20**
- ✓ Towards the doubly magic ^{78}Ni (Coulex of Zn)
- ✓ N=40: Coulomb excitation ^{68,70mg}Cu
- ✓ Transfer reactions

➢ Collectivity of the neutron-rich Mg isotopes
Island of inversion (see D. Vretenar)



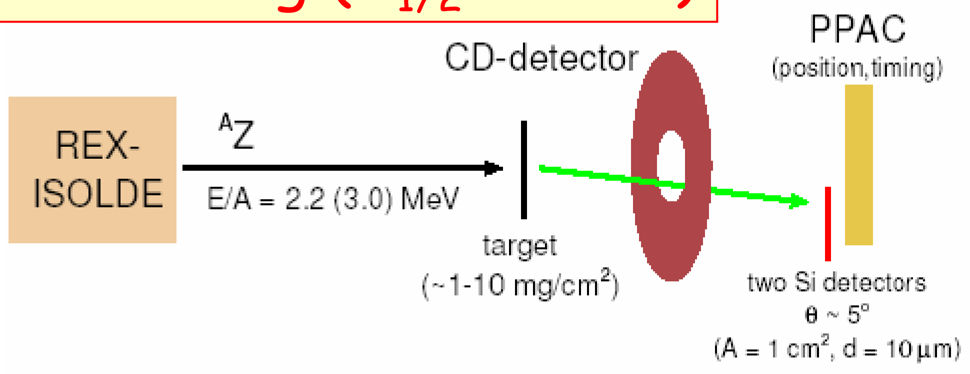


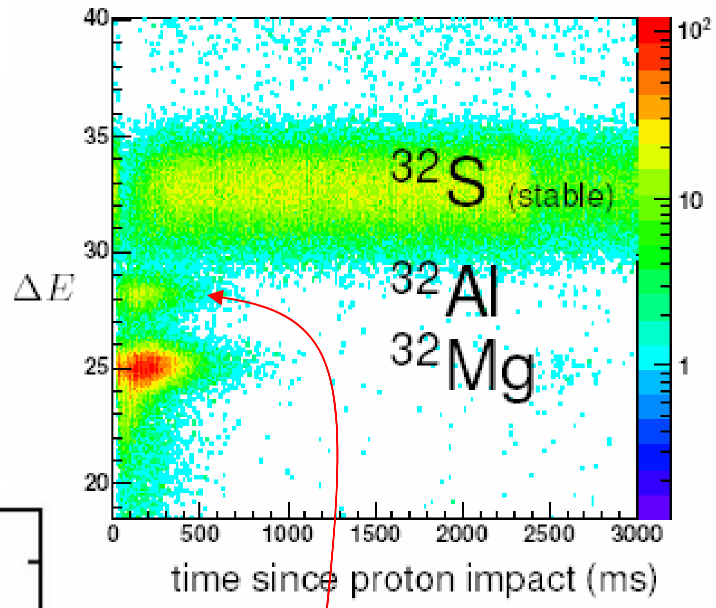
- experimental values inconsistent
- spread in recent theoretical calculations

⇒ ^{30,32}Mg "safe" Coulex @ 2.2→3.0 MeV/u

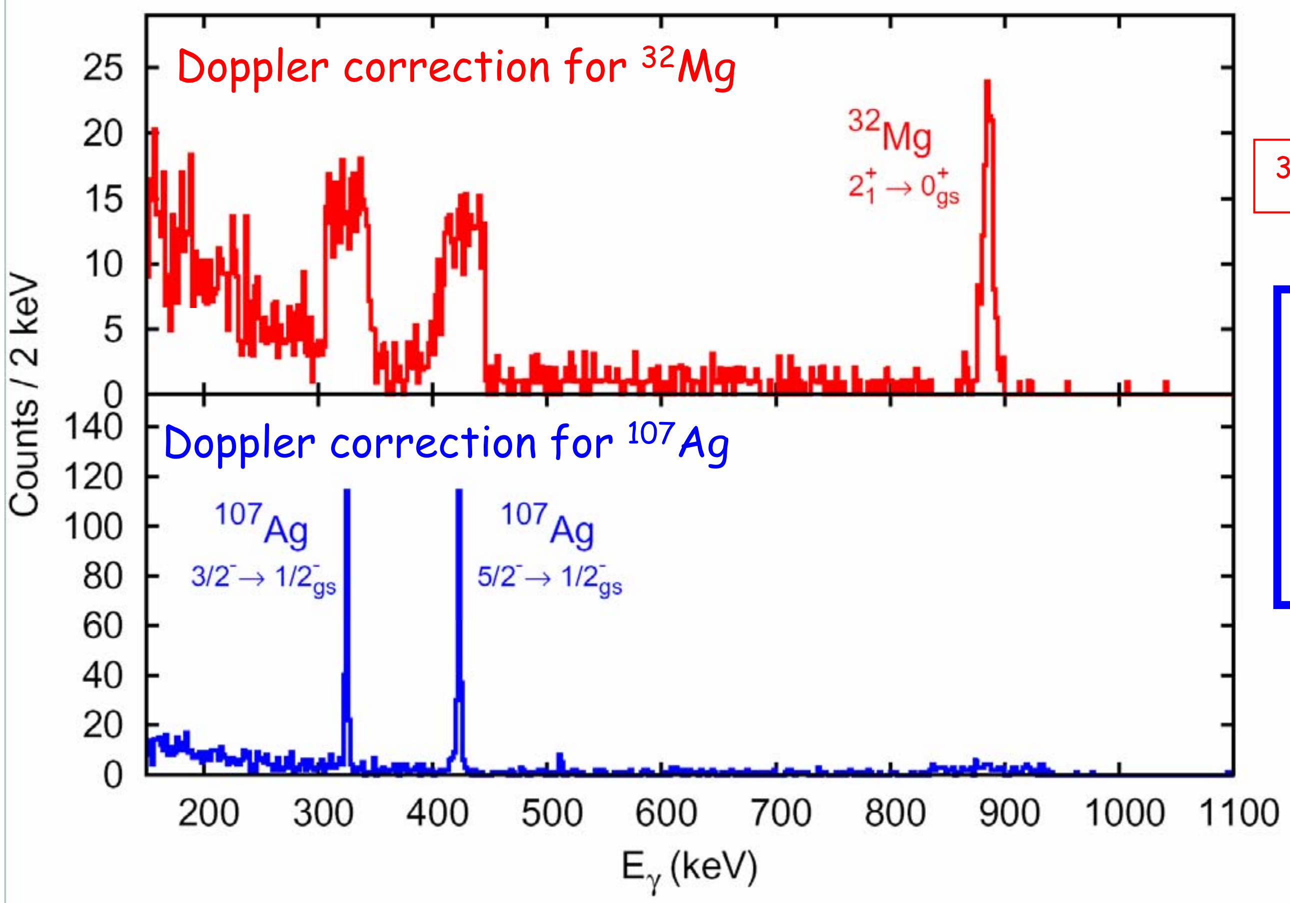
O. Niedermaier, H. Scheit, MPI-Heidelberg

➢ Coulex ^{32}Mg ($T_{1/2}$=95 ms)



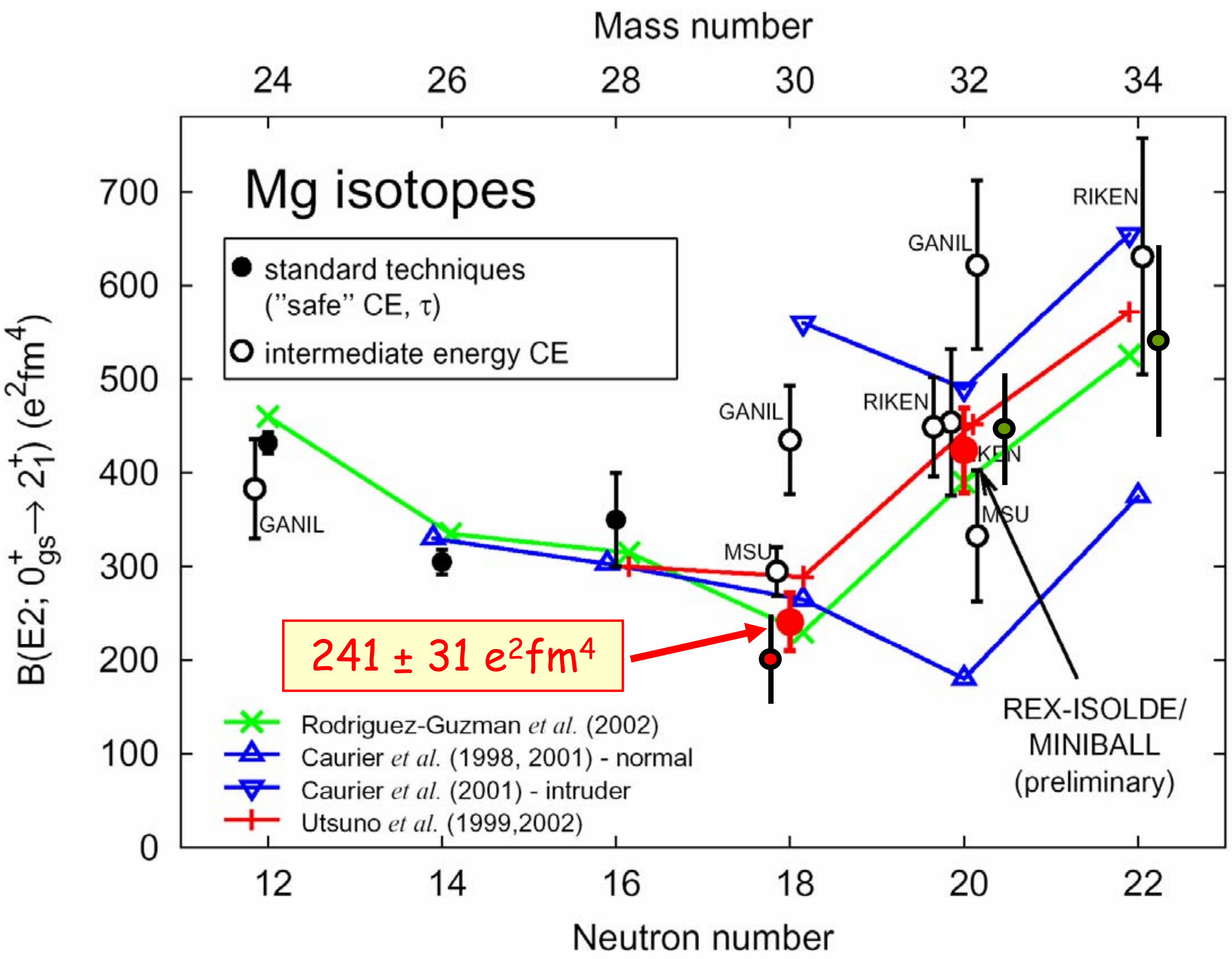


^{32}Al from β decay in trap&EBIS



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

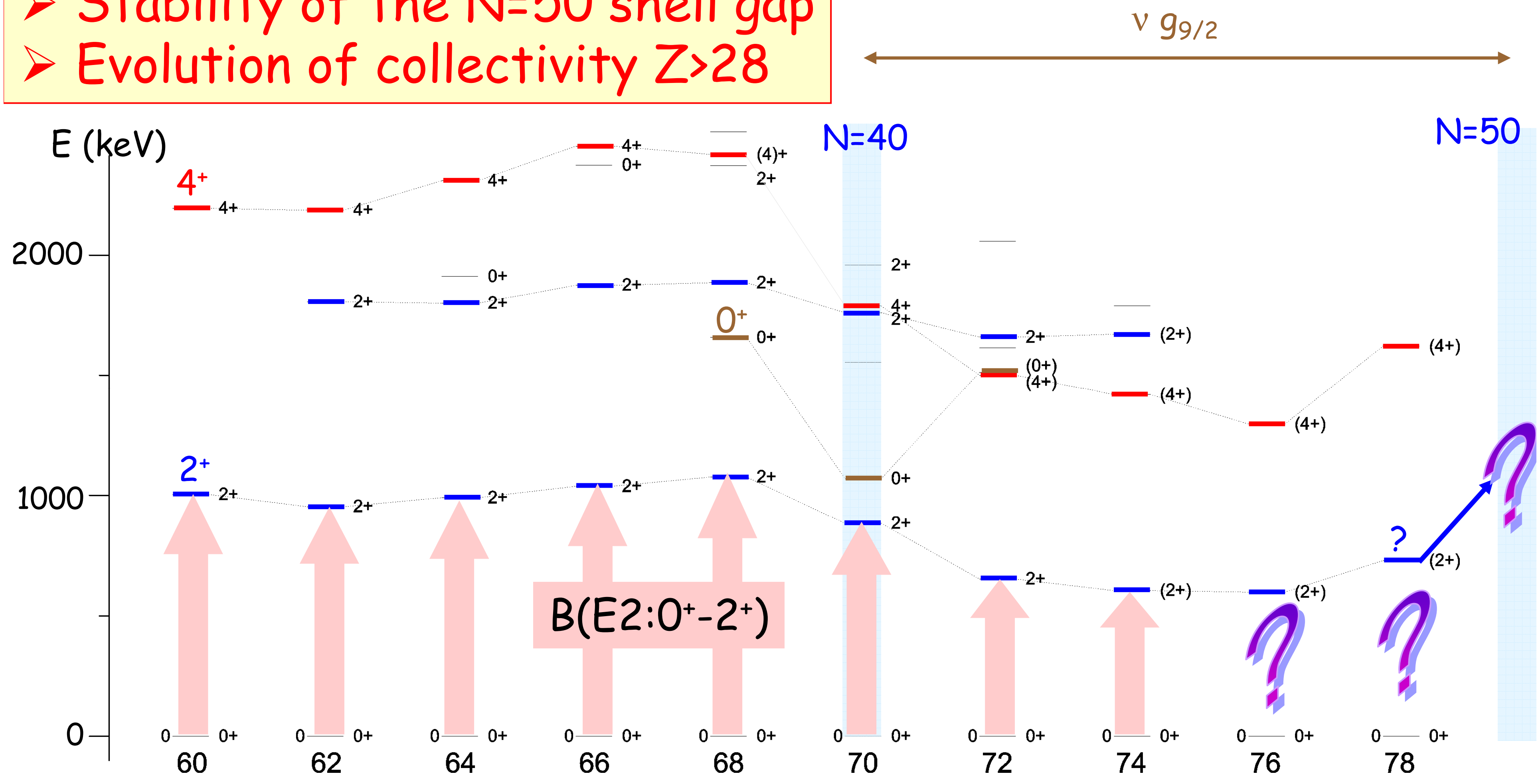
- 2.844 MeV/u
- ~ 1.5·10^4 pps
- purity: 85% ^{32}Mg



^{30}Mg: O. Niedermaier, H. Scheit et al., PRL 94, 172501 (2005)
^{32,34}Mg: J.A. Church et al., new measurement @ MSU, PRC in print
^{30}Mg: $T_{1/2}$ H. Mach et al., ISOLDE

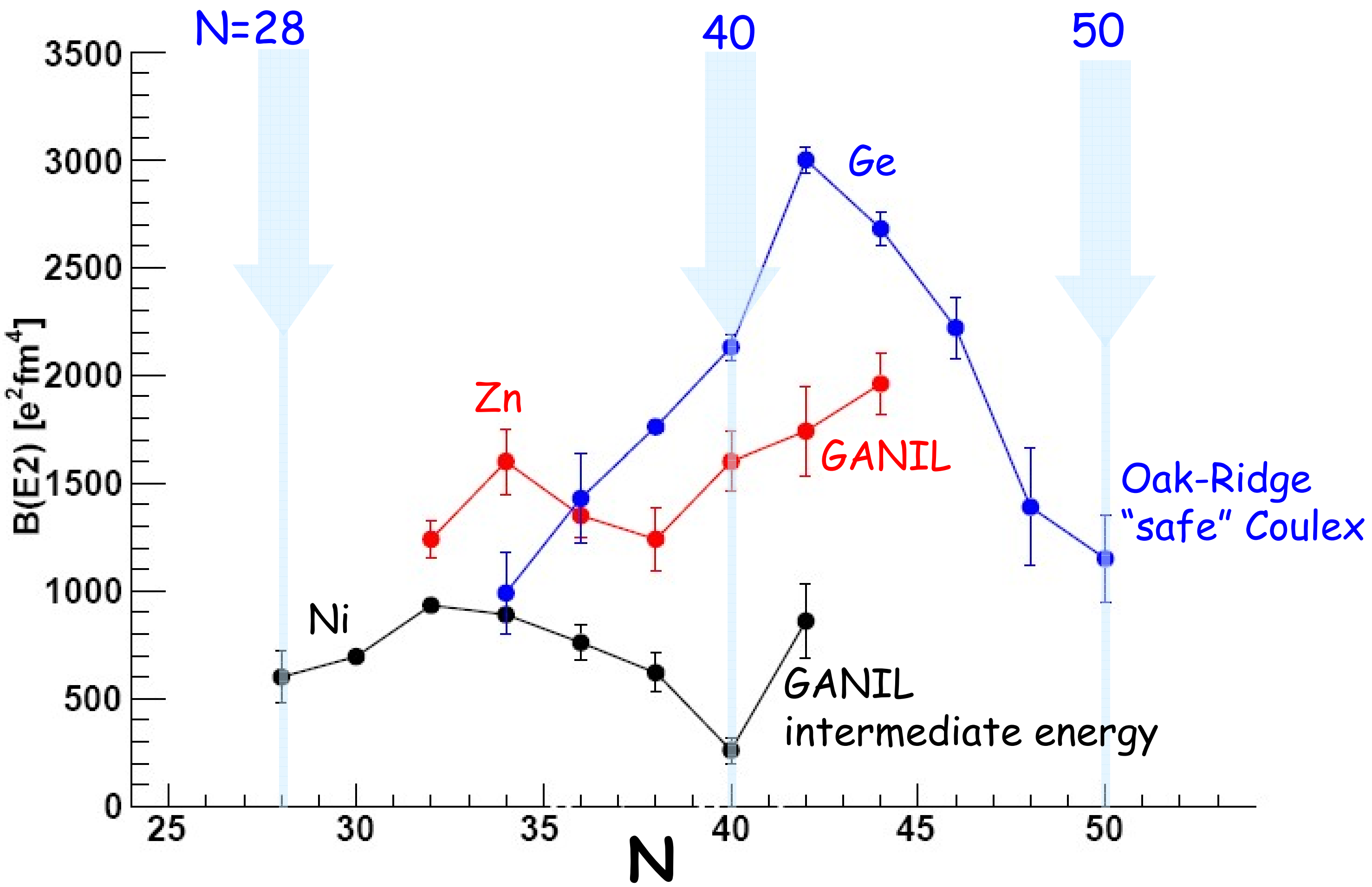
- ✓ “Island of Inversion” at N=20
- ✓ **Towards the doubly magic ^{78}Ni (Coulomb excitation of Zn)**
- ✓ N=40: Coulomb excitation ^{68,70mg}Cu
- ✓ Transfer reactions

- N=40 subshel closure
- Monopole migration: N>40
- Stability of the N=50 shell gap
- Evolution of collectivity Z>28



J. Van Roosbroeck et al., PRC71 (2005) 054307

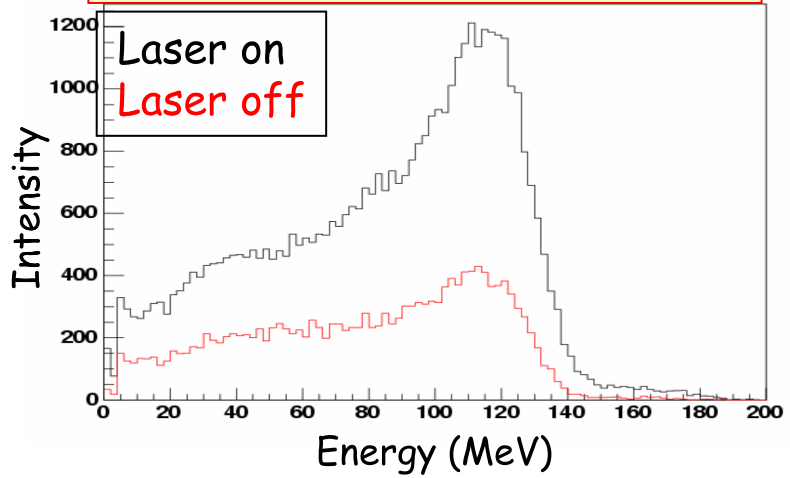
➢ evolution of collectivity Z>28 (Zn, Ge)



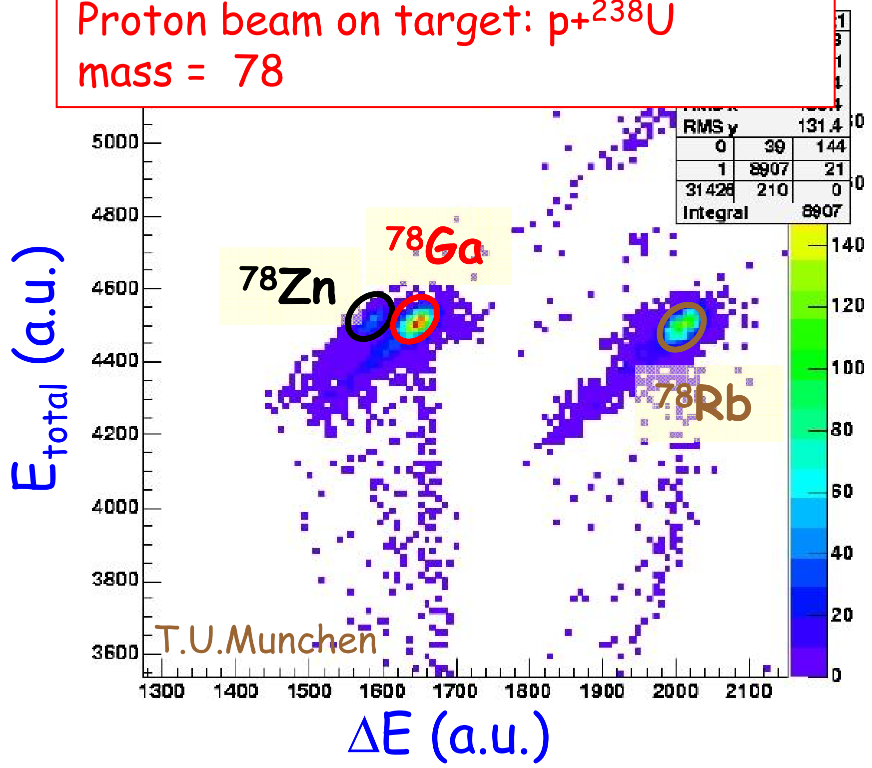
^{72}Zn:S. Leenhardt *et al*, EPJA 14, 2002
^{68}Ni: O. Sorlin et al., PRL 88, 2002
$^{78-82}$Ge: E. Padilla-Rodal *et al*, PRL 94 122501 (2005)
^{74}Zn-^{70}Ni: O. Perru, PhD. Thesis, Orsay

- Beam composition ($^{74,76,78}Zn$)
  - ✓ Laser ON - OFF
    link to γ's from β decay and Coulex γ's
  - ✓ Ion Chamber - Si telescope: ΔE-E
  - ✓ Proton-to-neutron converter
  - ✓ Target development (pure ^{80}Zn)

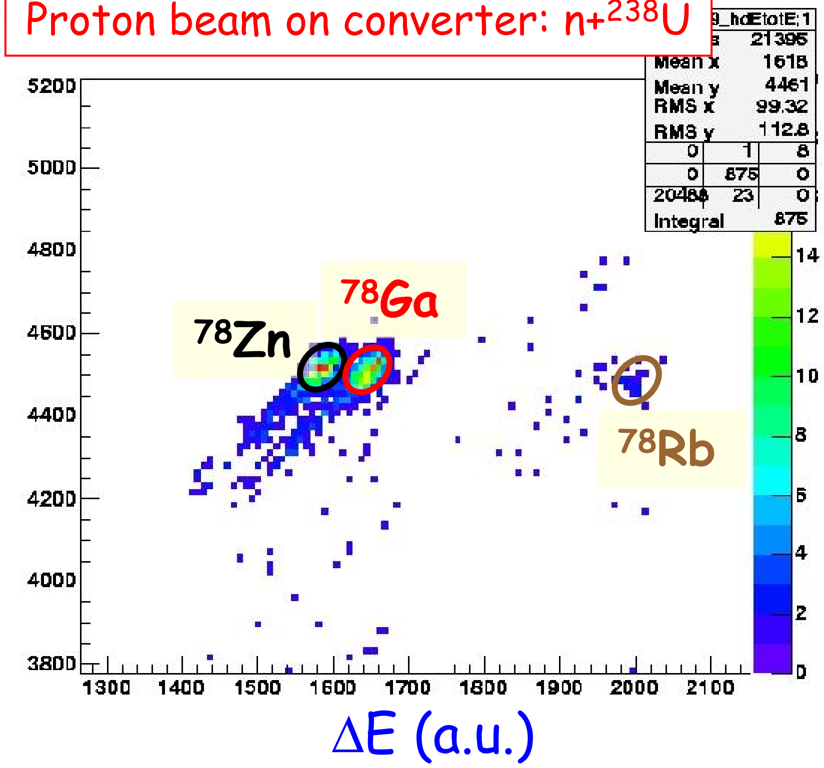
Scattered particles @ mass 76



Proton beam on target: $p+^{238}U$
mass = 78

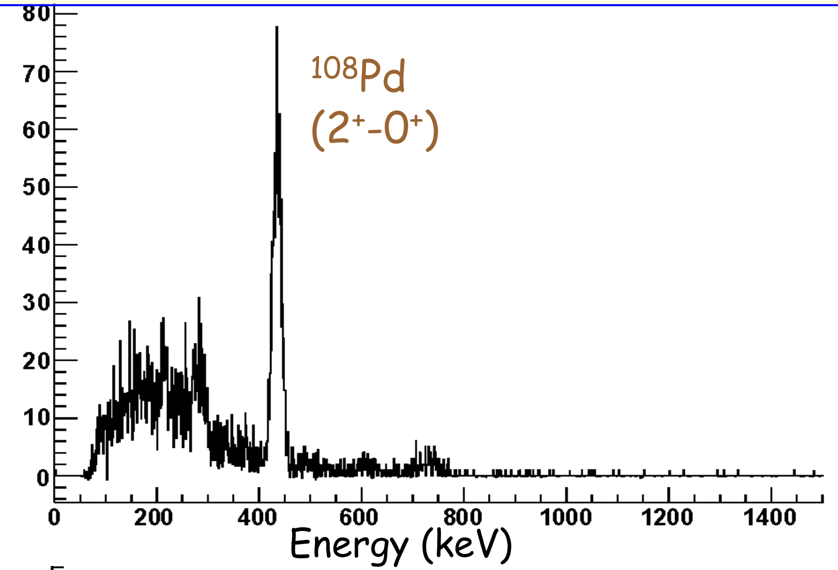


Proton beam on converter: $n+^{238}U$



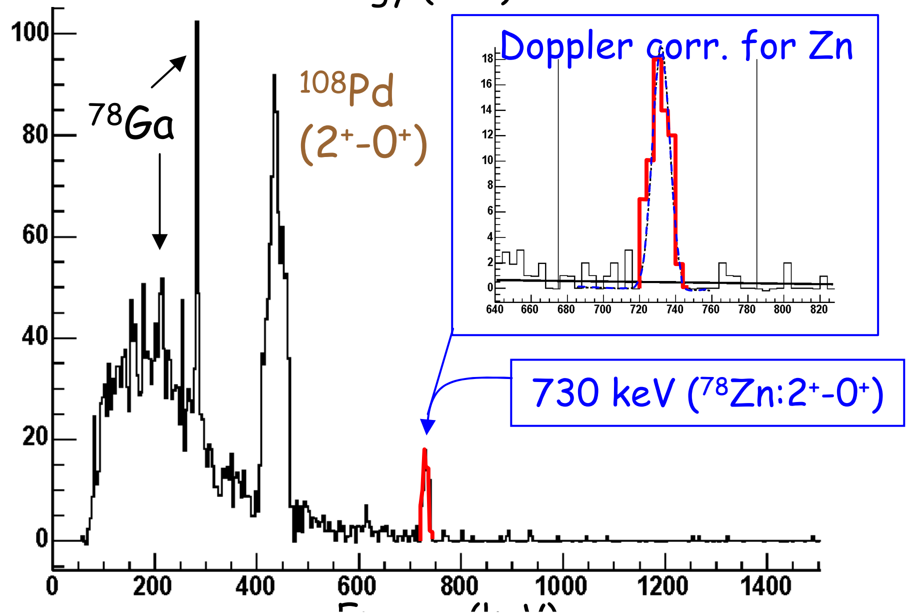
^{78}Zn ($T_{1/2}$=1.5 s, 2.86 MeV/u) @ ^{108}Pd (2.0 mg/cm^2)

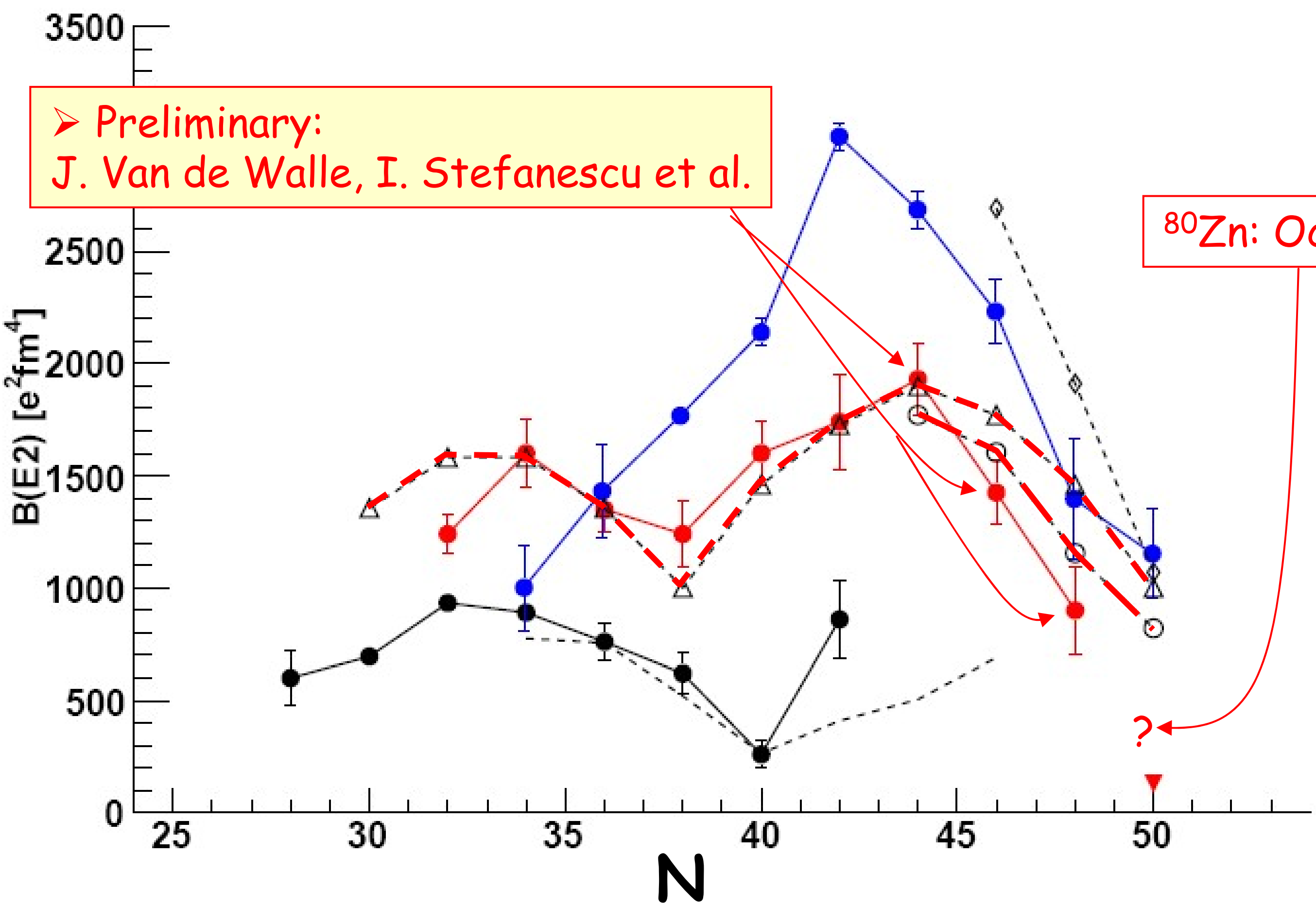
γ - particle spectra
not Doppler corrected



- ~23.5 h beam
- ~8 10^3 ^{78}Zn/s
- ~59% purity

Doppler corrected with respect to the projectile



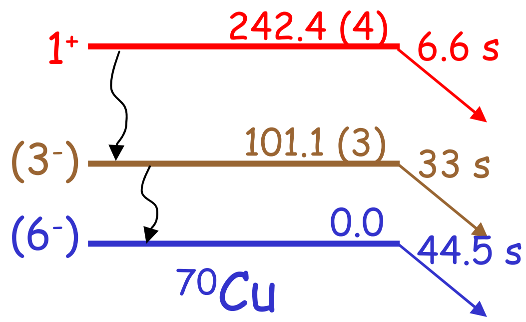


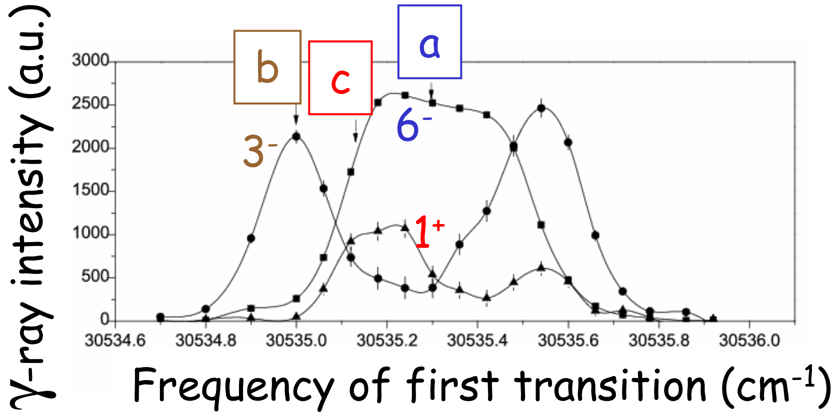
- ^{74}Zn: agreement with intermediate energy Coulex
- Steep drop in B(E2) towards N=50

Ni: O. Sorlin et al., PRL 88, 2002, K.-H. Langanke *et al*, PRC 67, 2003
Ge: E. Padilla-Rodal *et al*, PRL 94 122501 (2005)
Zn: N. Smirnova et al. PRC69 (2004) 044306, I. Deloncle et al., to be published
Zn: W.Z. Jiang et al. Eur.Phys.J. A25 (2005) 29 (RMF calculations, shape coexistence)

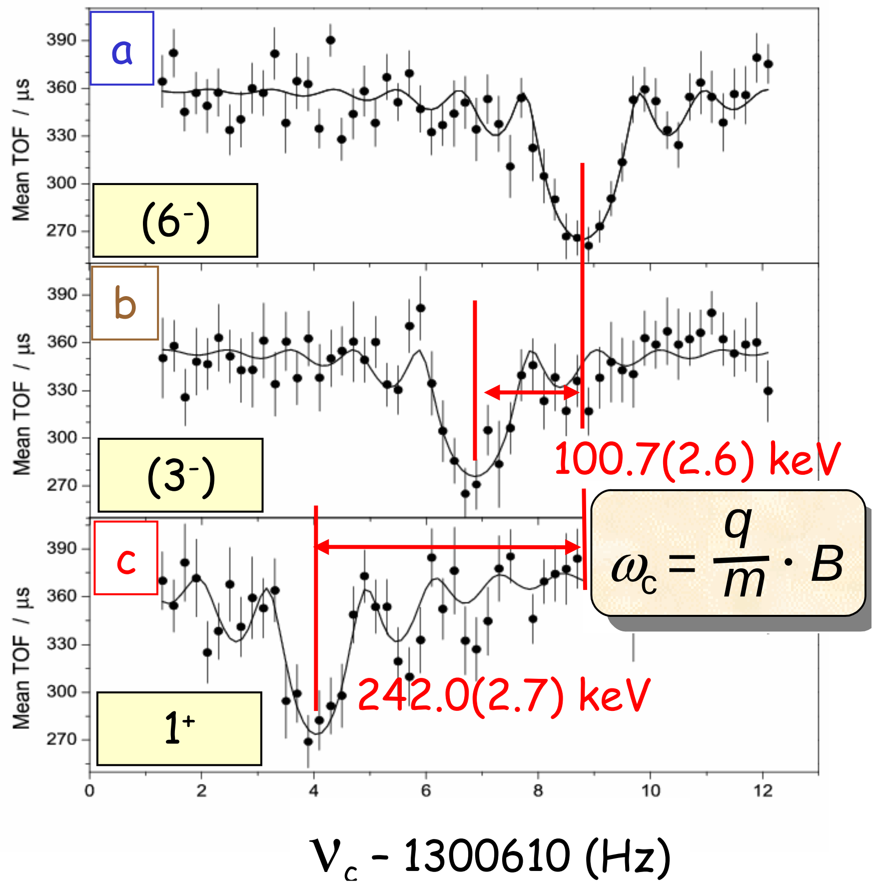
- ✓ "Island of Inversion" at N=20
- ✓ **Towards the doubly magic ^{78}Ni (Coulex of Zn)**
- ✓ **N=40: Coulomb excitation of ^{68,70mg}Cu**
- ✓ Transfer reactions

- N=40 sub-shell closure
- Production of isomeric beams





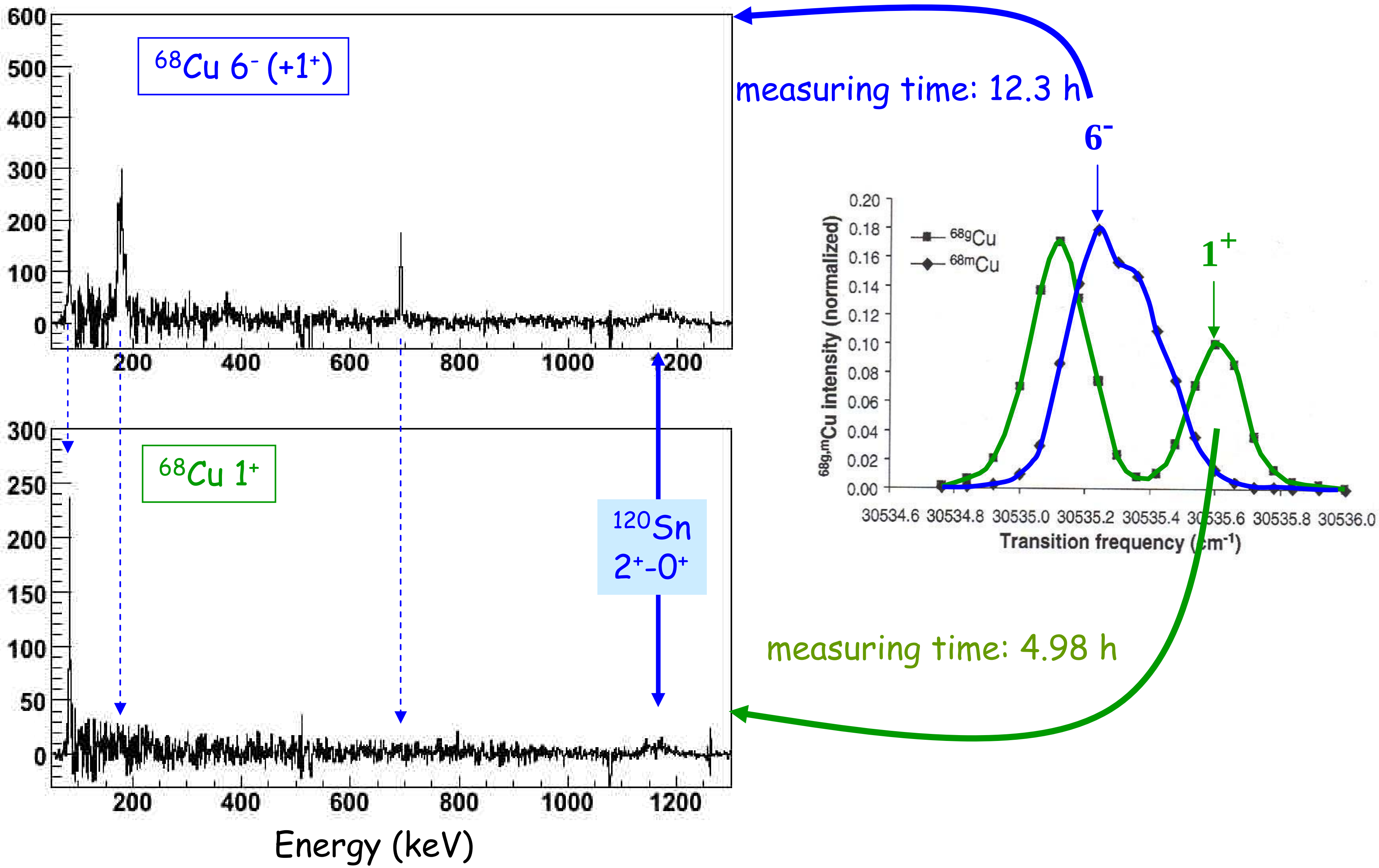
ISOLTRAP: K. Blaum,- NIM B204 (2003) 478
J. Van Roosbroeck,- Phys. Rev. Lett. 92 (2004) 112501
cfr. G. Bollen

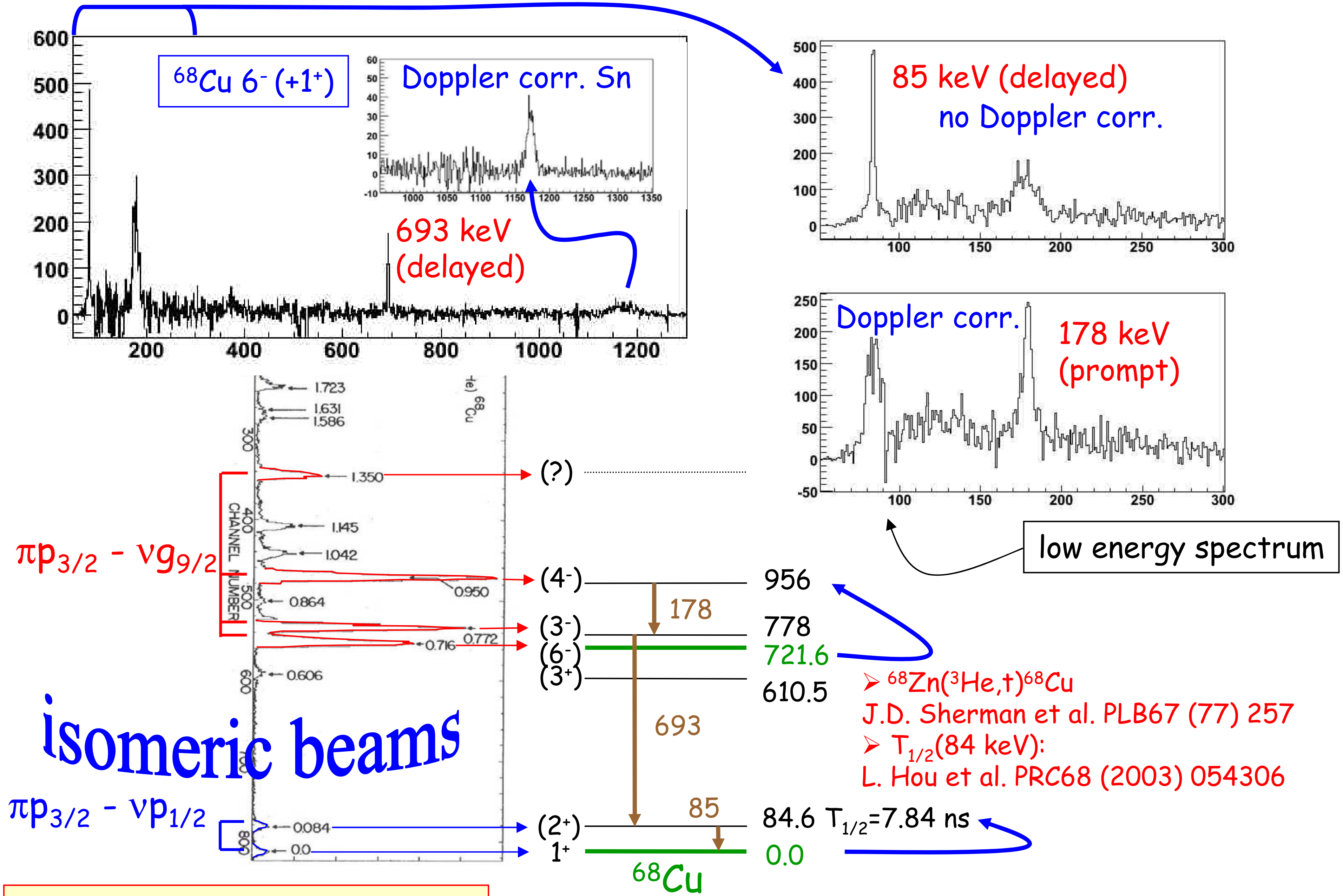


- Purified isomeric beams:
  - Coulomb excitation - transfer reactions (after post-acceleration)

➢ Coulomb excitation: ^{68m,g}Cu (2.86 MeV/u) @ ^{120}Sn (2.3 mg/cm^2)

➢ July 2005: post-accelerated isomeric beams!





PRELIMINARY:
G. Georgiev, I. Stefanescu, et al.

- Transition matrix elements to be compared to large scale shell model calculations

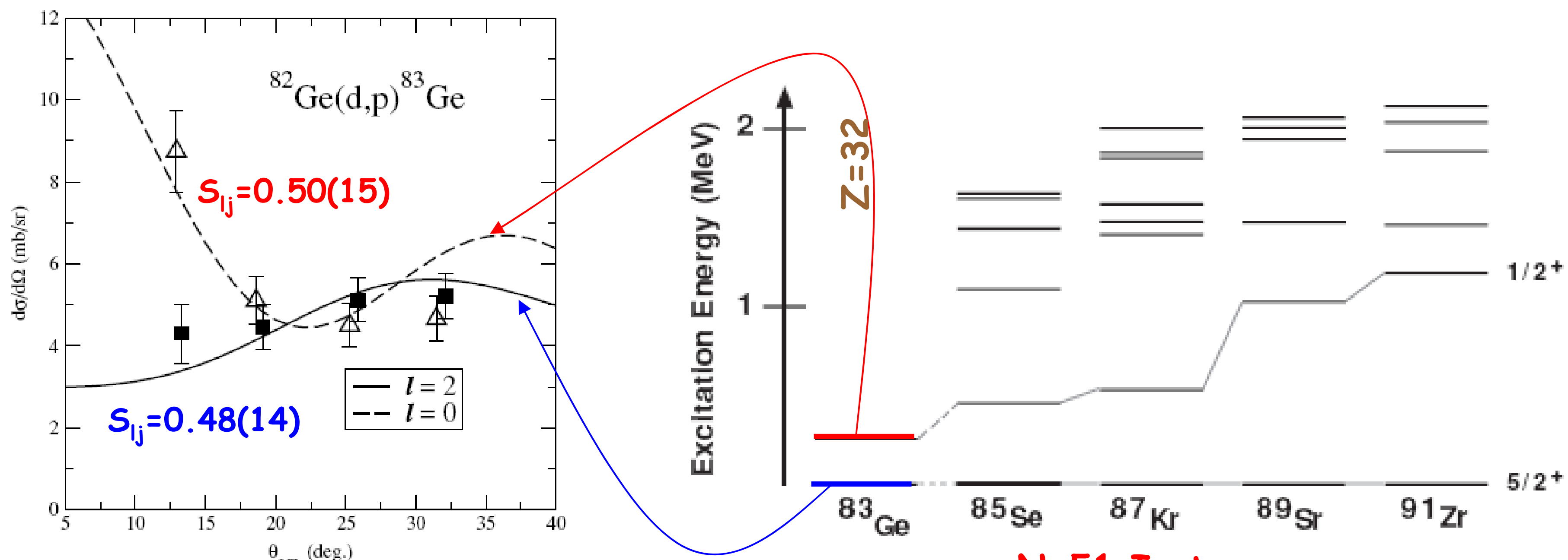
- ✓ "Island of Inversion" at N=20
- ✓ Towards the doubly magic ^{78}Ni (Coulex of Zn)
- ✓ N=40: Coulomb excitation ^{68,70mg}Cu
- ✓ **Transfer reactions**

✓ Transfer reactions

✓ First experiment: $^{2}H(^{30}Mg,p)^{31}Mg$ **E/A=2.25 MeV/u** (cfr. Th. Nilsson)

✓ SPIRAL - GANIL: $^{44,46}Ar$ **@ 10 MeV/u** (O. Sorlin et al.)

✓ $^{2}H(^{82}Ge,p)^{83}Ge$ (^{82}Ge @ 10^{4} pps) **E/A=4.0 MeV/u (ORNL)** cfr. J. D'Auria (J.S. Thomas et al., PRC71 (2005) 021302)



N=51 Isotones

➢ particle - γ correlations - recoils (REX-ISOLDE - MINIBALL) + spectrometer

higher energy needed! (cfr. P. Butler)

✓ Future outlook and Conclusion
"Study of the evolution of shapes and shells"

✓ **Radioactive decay studies** remain a very important tool to study nuclear structure far of stability

✓ **Coulomb excitation** at "safe" energies ⇒ towards heavier masses

⇒ energy, B(E2)

$\alpha + \alpha$

✓ **Single-nucleon transfer reactions** e.g. (d,p) and (^{9}Be,^{8}Be)

particle (Si array) - γ (MINIBALL) coin. - recoils (spectrometer)

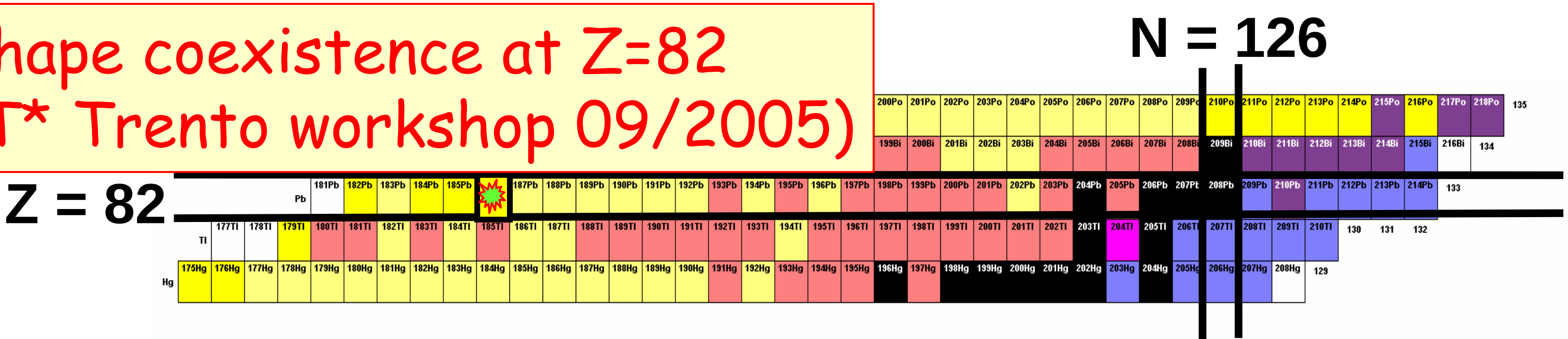
⇒ energy, spin/parity, spectroscopic factor (absolute/relative)

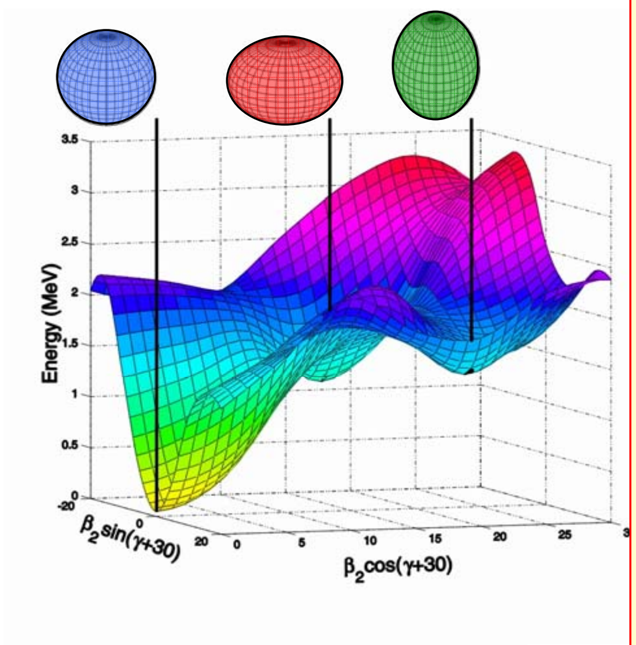
- e.g. ^{2}H(^{80}Zn,p)^{81}Zn: single particle states in ^{81}Zn

➢ **Transfer induced spin orientation**

⇒ nuclear moments

✓ Shape coexistence at Z=82
(ECT* Trento workshop 09/2005)





Potential Energy Surface for ^{186}Pb

A. Andreyev et al., Nature 405 (2000) 430

✓ Coulomb excitation of n-deficient Hg, Pb and Po isotopes (complementary to $T_{1/2}$ meas. performed at JYFL and ANL)

✓ Single-neutron transfer of Hg, Pb and Po isotopes: odd-mass nuclei

✓ Two-proton transfer reactions (underlying π(2p-2h) structure)

✓ β-decay studies (Calorimetric measurements)

ISOLDE has a unique potential and combines unique capabilities: beams (pure, isomeric), techniques and instrumentation

➢ Needs

✓ energy upgrade (Coulex and transfer): 3.1 → 4.2 → > 5 MeV/u
✓ post-acceleration of heavier masses
✓ continuous development for higher intensity, better purity and new radioactive ion beams
✓ longer beam time
✓ new instrumentation:

- Bragg detector (Ch. Barton; University of York)
- New set-up for transfer reactions
- Recoil spectrometer (identification of the reaction products)

Max Planck Institut fur Kernphysik Heidelberg Germany
Institut fur Kernphysik Universitat Koln Germany
TU Darmstadt Germany
TU Munchen Germany
LMU Munchen Germany
Johannes Gutenberg Universitat, Mainz, Germany
GSI-Darmstadt, Germany
University of Gottingen, Germany
University of Frankfurt, Germany
IKS KULeuven Belgium
Chalmers Teknaska Hogskola, Goteborg, Sweden
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