

HIE-ISOLDE : A look to the Physics

“CERN has agreed to approve the project HIE-ISOLDE, on account of its scientific potential as well as its several unique features for ISOL radioactive beam production. CERN has made many major contributions to ISOL technology and science and this landmark decision will ensure that ISOLDE will have a greatly enlarged capability and will continue to make major contributions to the field of radioactive beam science”

Maria José G^a Borge
Instituto de Estructura de la Materia
CSIC, Madrid (Spain)

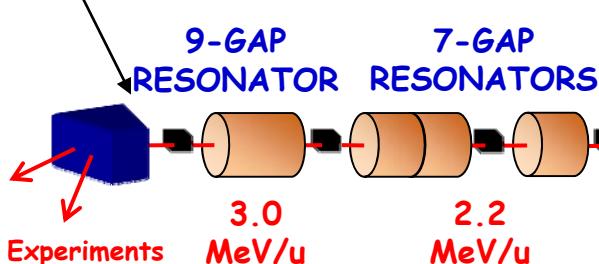
-Nier-spectrometer

- Select the correct A/q and separate the radioactive ions from the residual gases.
- A/q resolution ~ 150

EBIS

- Super conducting solenoid, 2 T
- Electron beam $< 0.4A$ 3-6 keV
- Breeding time 3 to >200 ms
- Total capacity $6 \cdot 10^{10}$ charges
- $A/q < 4.5$

-Optional stripper



-LINAC

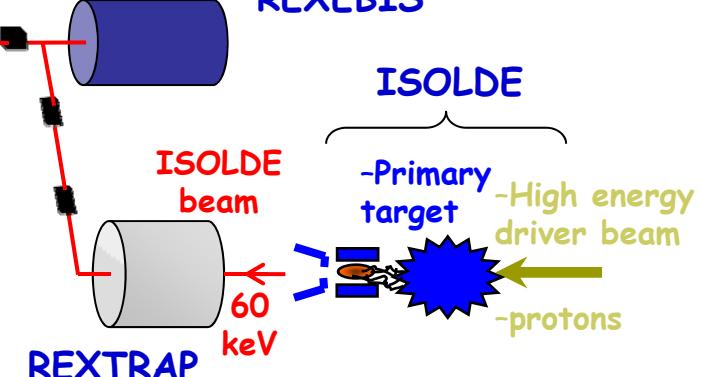
-Length	11 m
-Freq.	101MHz (202MHz for the 9GP)
-Duty cycle	1ms 100Hz (10%)
-Energy	300keV/u, 1.2-3MeV/u
- A/q max.	4.5 (2.2MeV/u), 3.5 (3MeV/u)

-Thanks to Didier Voulot

-Total efficiency : 1 - 10 %

MASS SEPARATOR

REXBIS

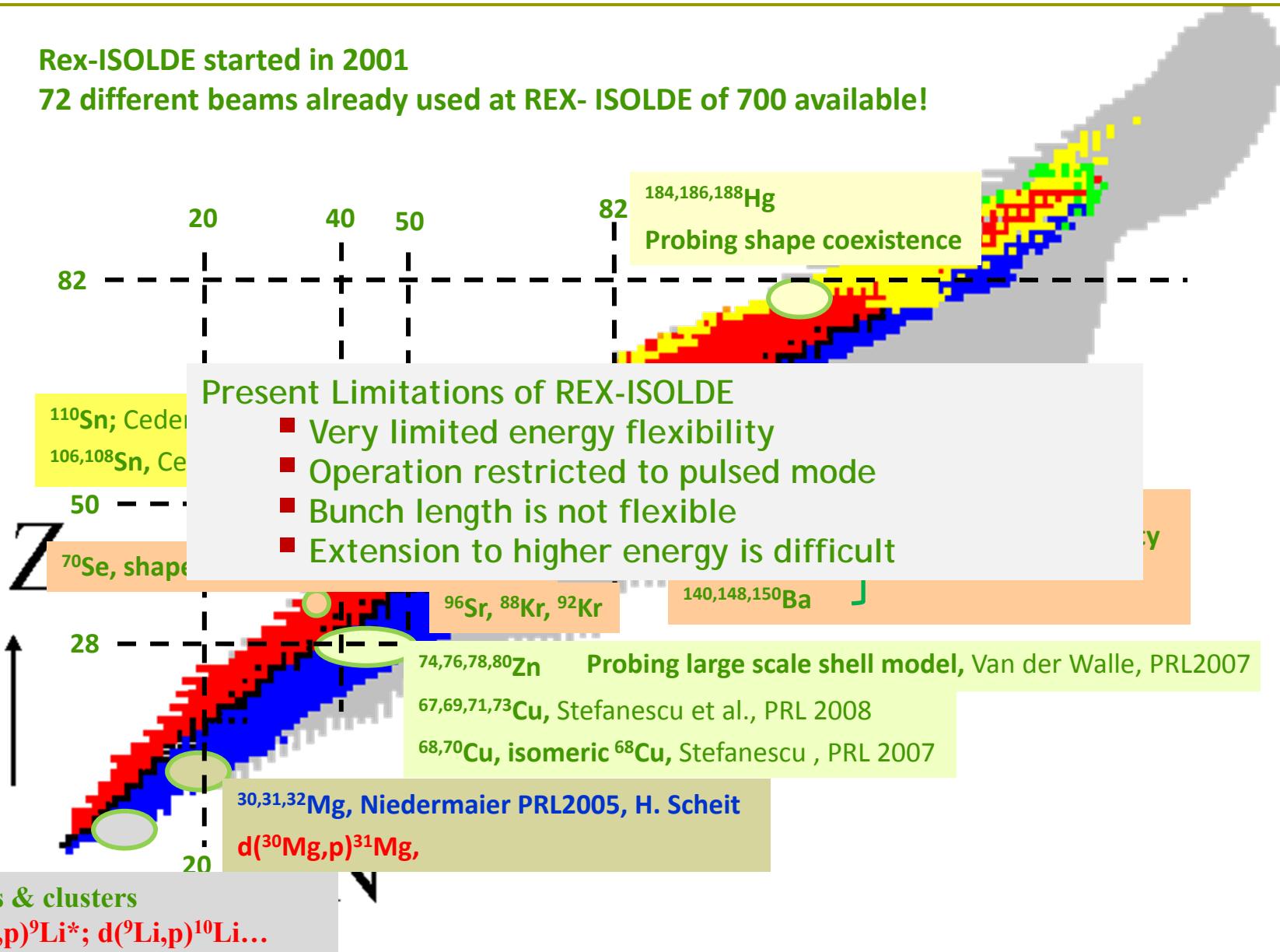


-REX-trap

- Cooling (10-20 ms)
- Buffer gas + RF
- (He), Li,...,U
- 10^8 ions/pulse
- (Space charge effects $>10^5$)

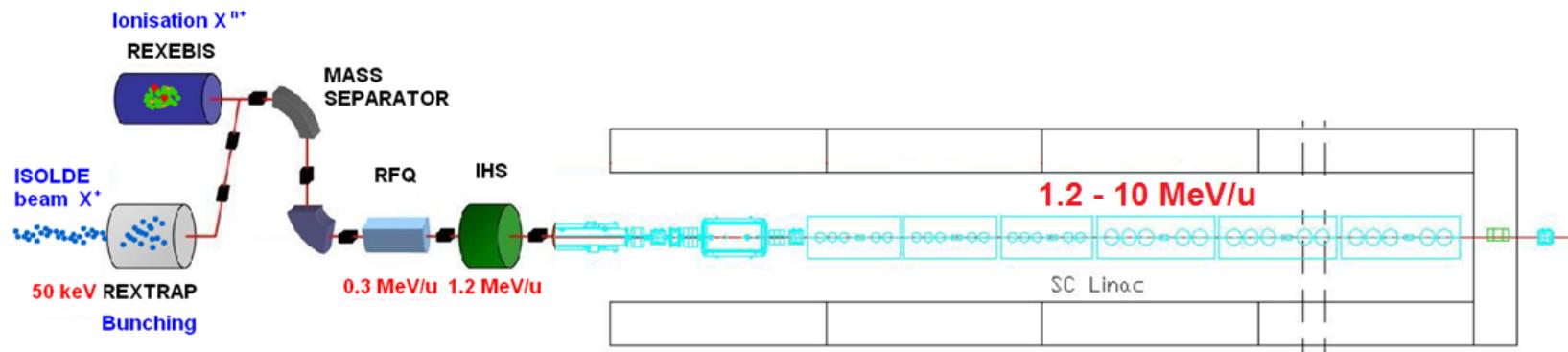
Rex-ISOLDE started in 2001

72 different beams already used at REX- ISOLDE of 700 available!



✓ ENERGY:

- Energy upgrade and lower energy capacity
 - ❖ Wider range of radioactive beams
 - ❖ Variable energy range from 1.2 up to 10 MeV/u



✓ INTENSITY:

ISOLDE proton driver beam intensity upgrade (LINAC4 +PSB)

Increase in Intensity expected of a factor of 3

Secondary beam production efficiency

- ❖ Target and frontend upgrade

Technical
Developments
By Yacine Kadi!!

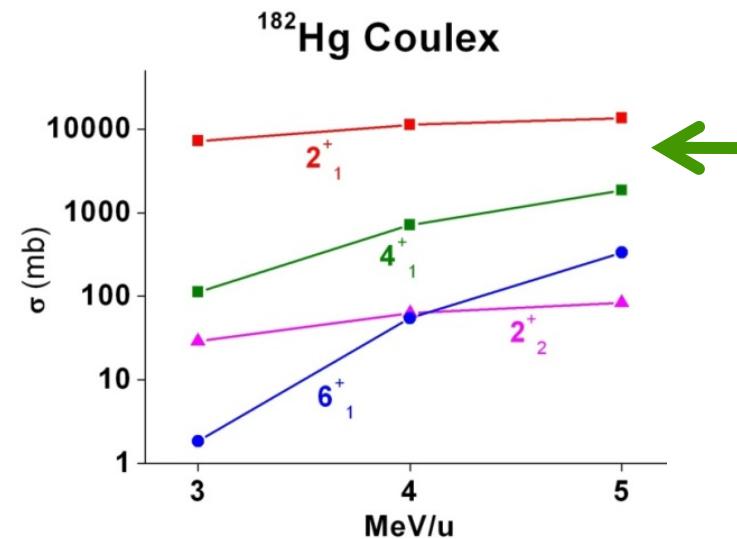
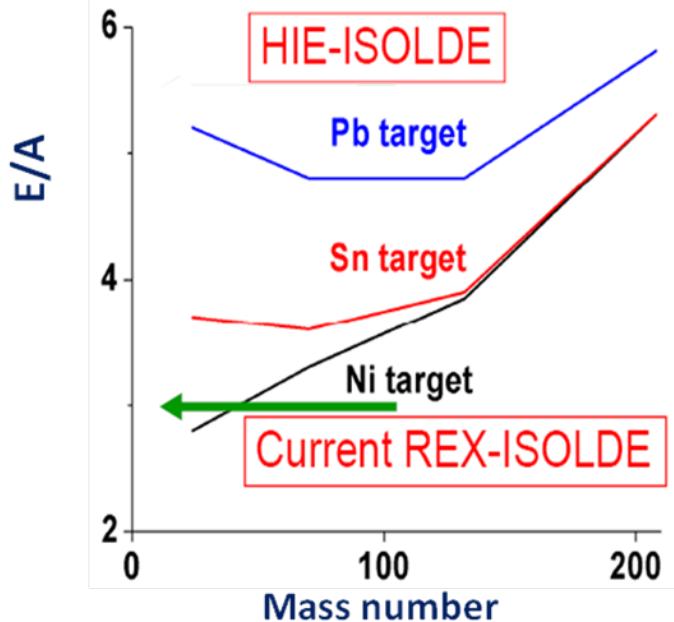
✓ QUALITY:

ISOLDE radioactive ion beam quality:

- ❖ Improvement of secondary beam quality: Reduction of phase space
- ❖ Purity, emittance: Selectivity
- ❖ Time structure: bunching

Aims of the upgrade

- Intensity & Selectivity & Beam quality & Efficiency
- Energy upgrade to 10 MeV /A
 - Coulex for all RIB

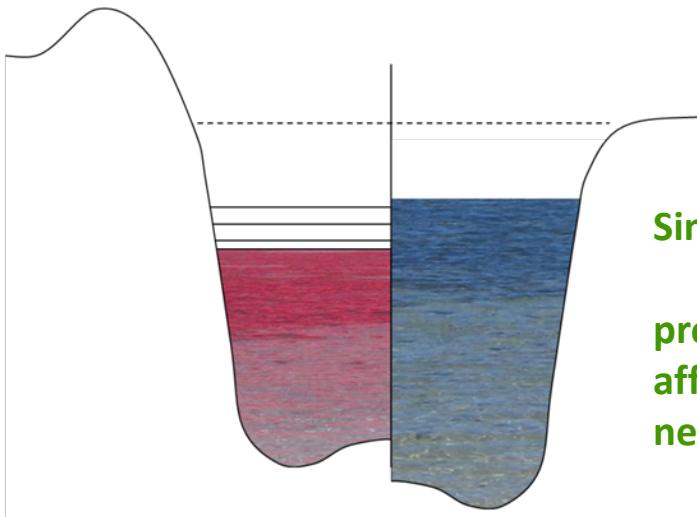


- ✓ Access to a wealth of spectroscopic information
- ✓ From the absolute intensities of $4^+/2^+$
⇒ Access to the sign of deformation

What can we learn from transfer reactions?

- ✓ Ideal tool for probing single particle states
- ✓ Measurement of spin, parity, spectroscopic factors

Single particle states well known for stable nuclei



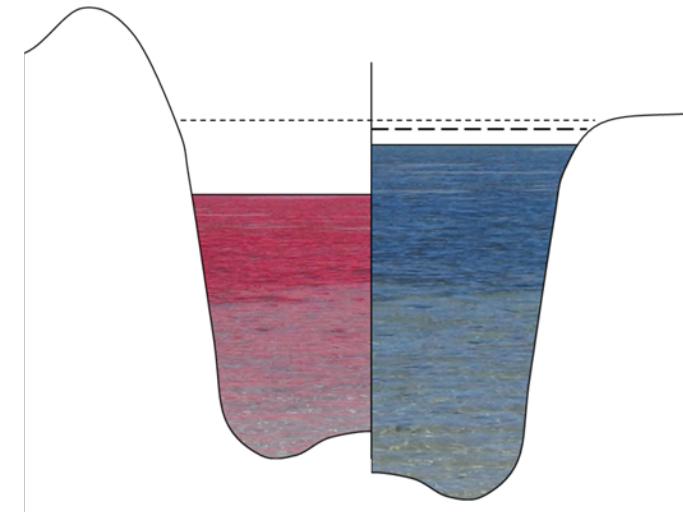
By Transfer Reaction

- ✓ Probing the changed orbitals and their energies
- ✓ As we approach the dripline, we also have to worry about the meaning and theoretical methods for probing resonant orbitals in the continuum

Similarly...
proton filling
affects
neutron orbitals

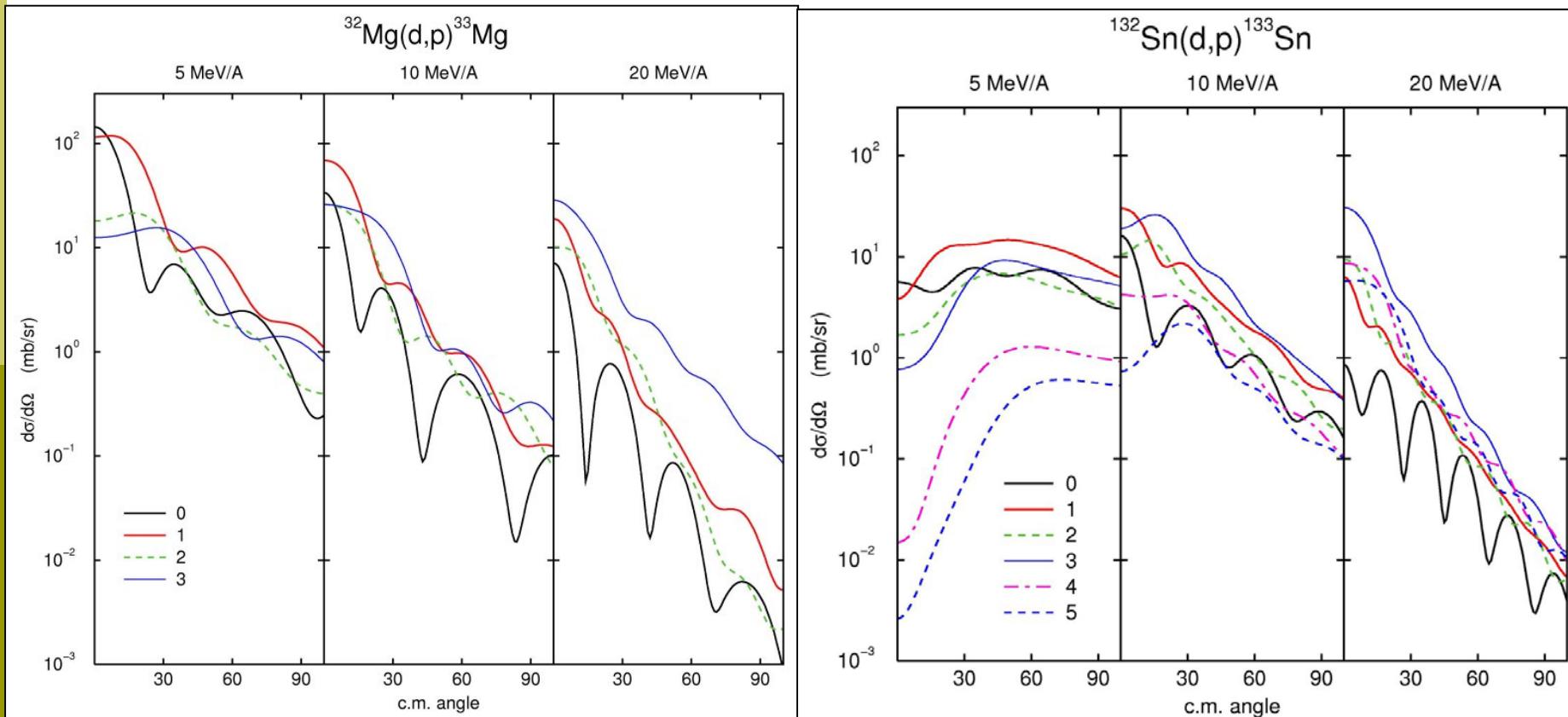
Far from stability....

- ✓ Changes – tensor force, p-n
- ✓ Residual interactions move the mean field levels
- ✓ Magic numbers “migrate” ⇒ changing stability, reactions, collectivity

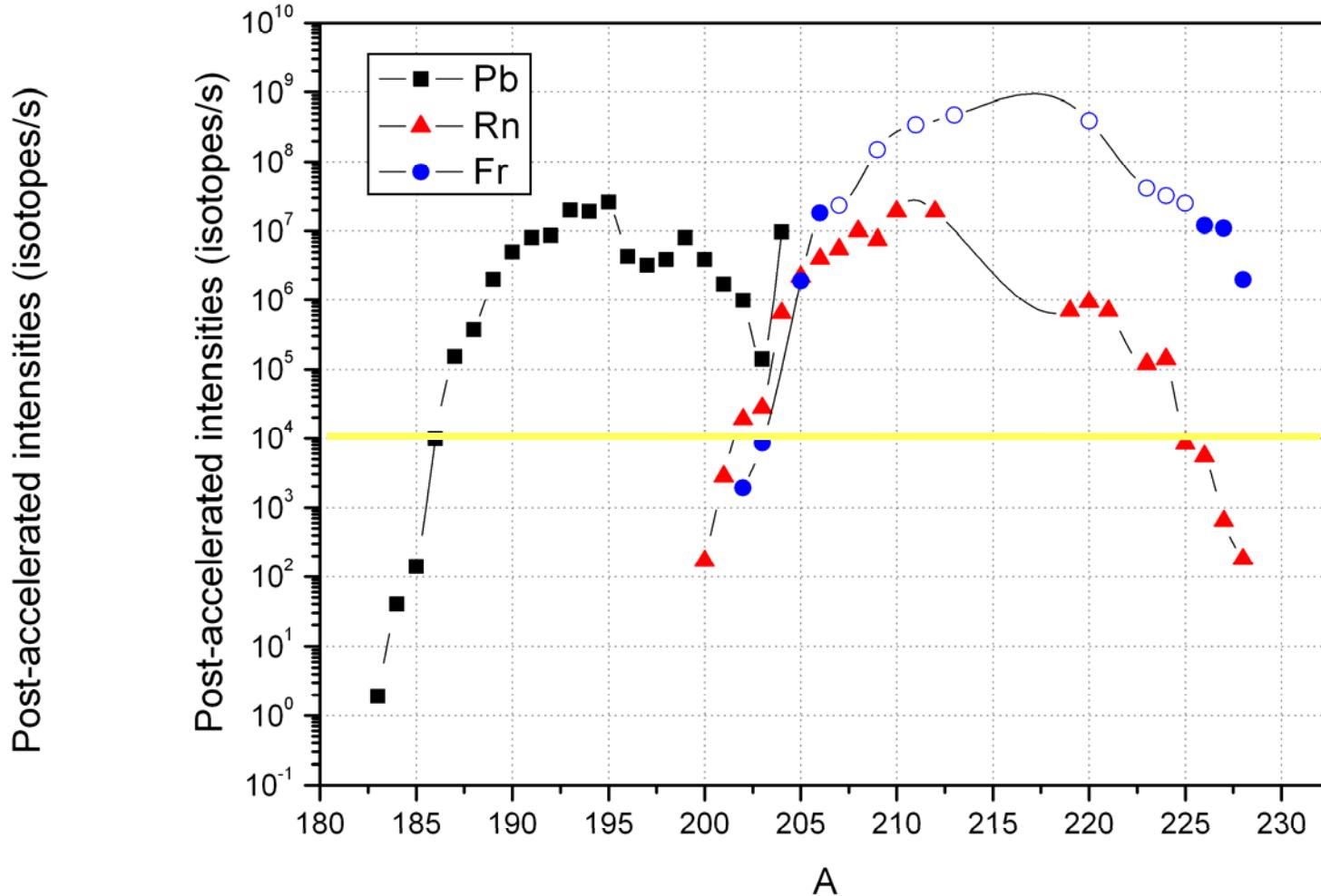


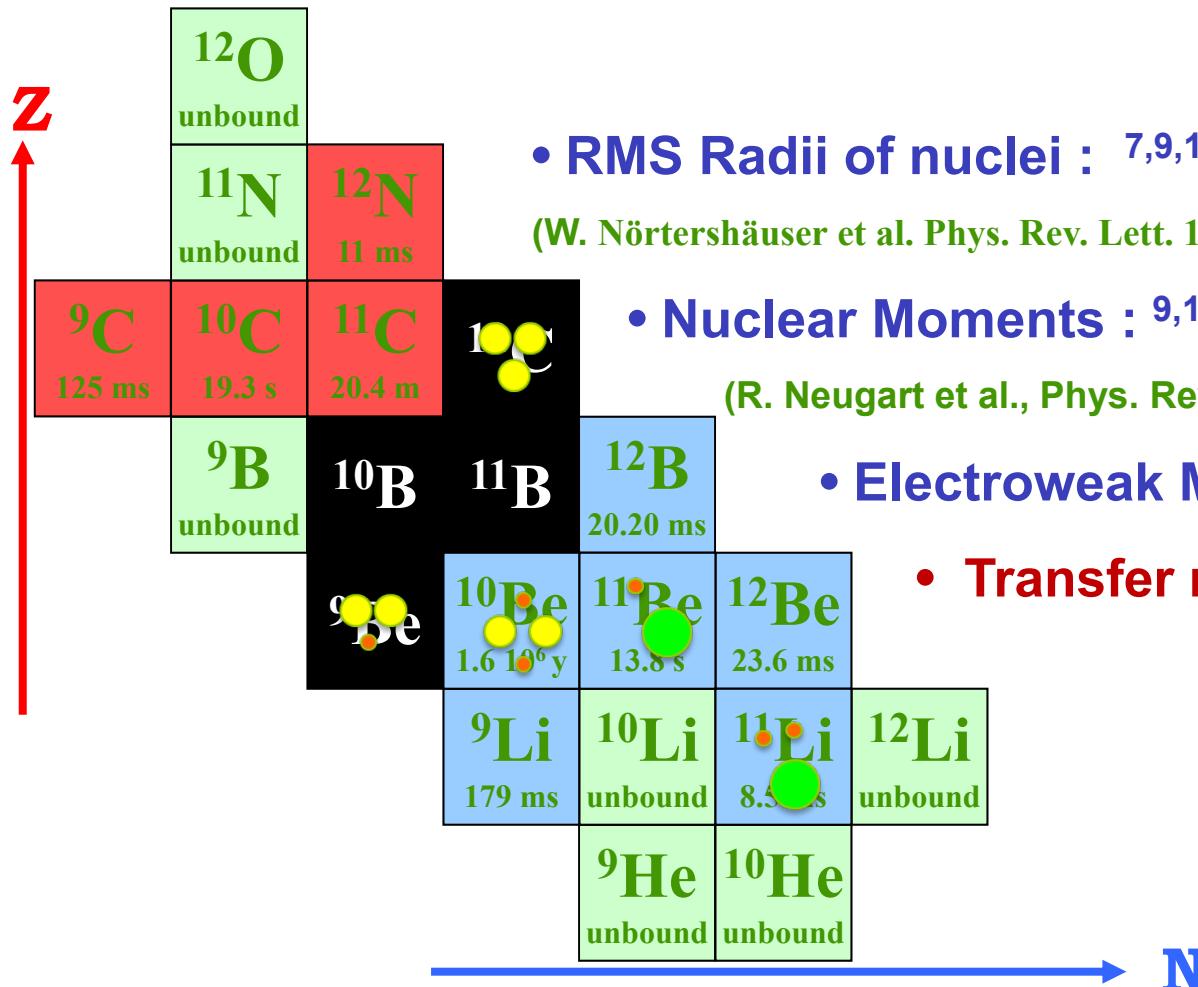
Transfer Reactions

- With radioactive beams done in inverse kinematics
- Single particle information through the spectroscopic factors
- Intensities $> 10^4$ pps (\Rightarrow lower intensities with Active targets)
- High energy needed to learn about the “I” transfer



Some extrapolated yields





- RMS Radii of nuclei : $^{7,9,10}\text{Be}$ and ^{11}Be

(W. Nörtershäuser et al. Phys. Rev. Lett. 102 (2009) 062503)

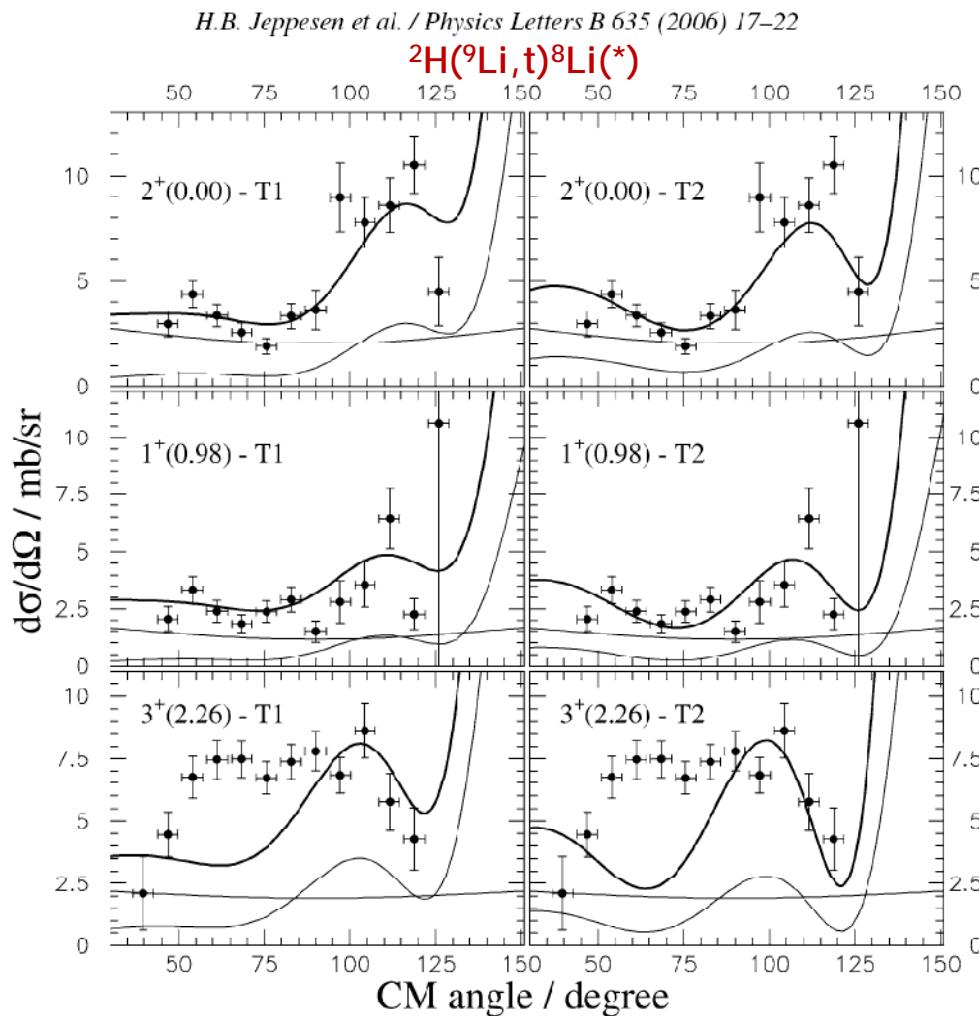
- Nuclear Moments : $^{9,11}\text{Li}$

(R. Neugart et al., Phys. Rev. Lett. 101 (2008) 132502)

- Electroweak Matrix Elements

- Transfer reactions

First Transfer Experiments @ REX



Shape of the angular distribution well described by DWBA
 For all states but the $3^+ \Rightarrow$ excess below 80° must be due to other mechanism producing tritons

^9Li REX-ISOLDE beam @
 2.36 MeV/u:

Reaction channels:

$^2\text{H}(^9\text{Li}, \text{p})^{10}\text{Li}(\ast) - (\text{d}, \text{p})$

$^2\text{H}(^9\text{Li}, \text{d})^9\text{Li}(\ast) - (\text{d}, \text{d})$

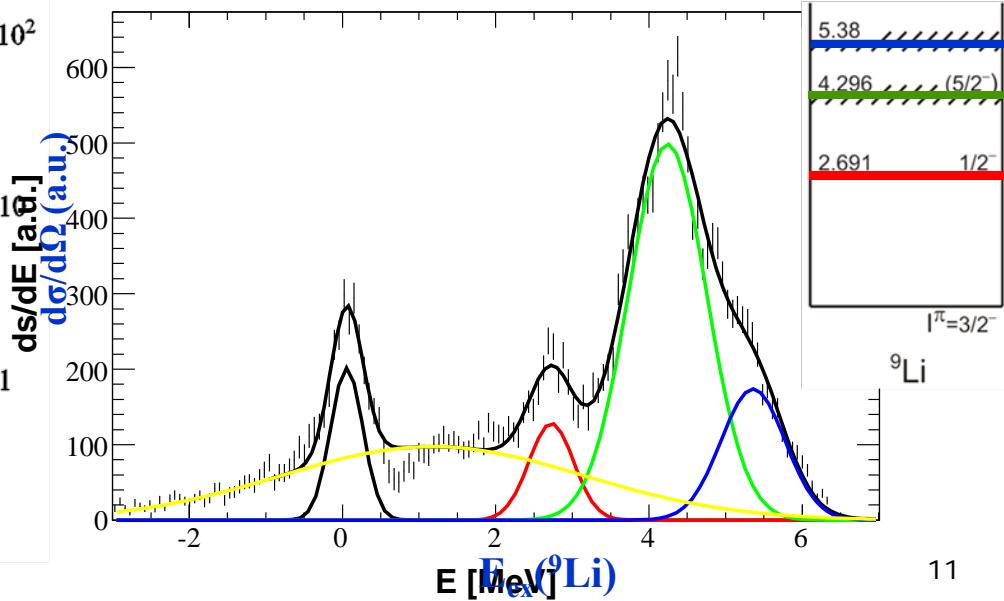
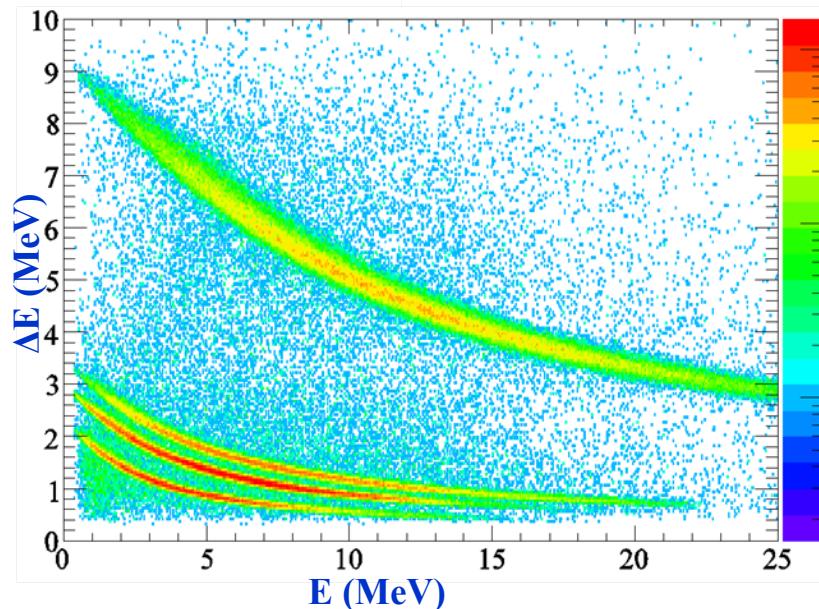
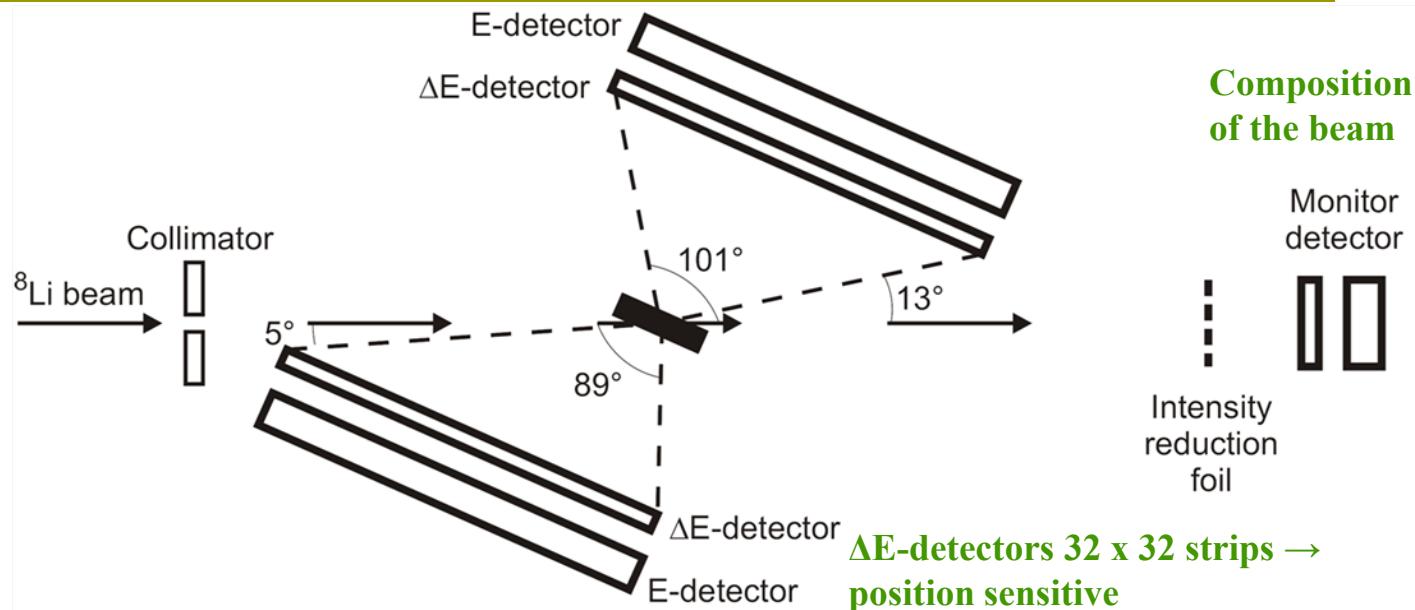
$^2\text{H}(^9\text{Li}, \text{t})^8\text{Li}(\ast) - (\text{d}, \text{t}) \rightarrow$ discrepancy in spectroscopic factors for 3^+

Jeppesen et al.,
 Nucl. Phys. A, 748 (2005) 374-392
 Jeppesen et al.,
 Phys. Lett. B, 635 (2006) 17-22
 Jeppesen et al.,
 Phys. Lett. B, 642 (2006) 449-454

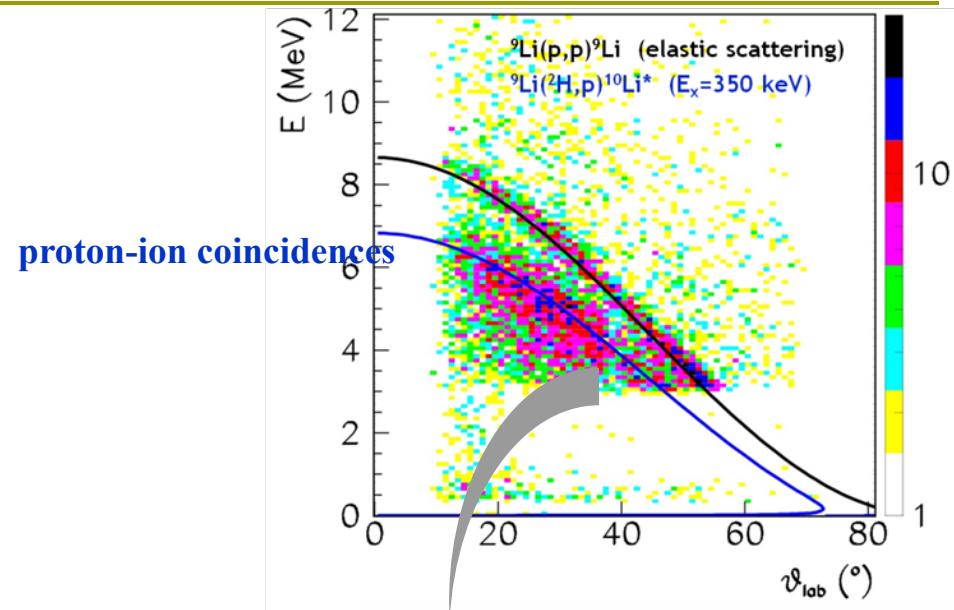
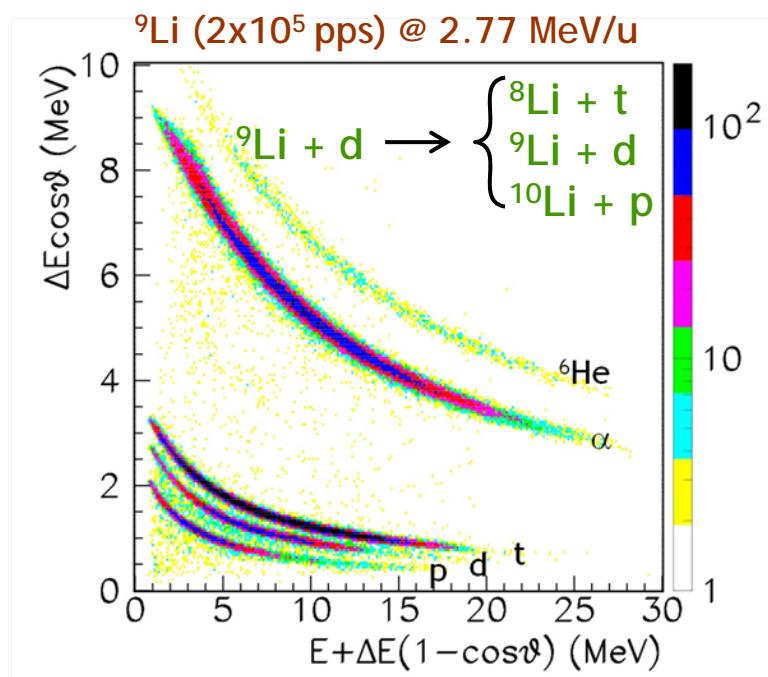
Transfer reaction on ${}^8\text{Li}$

${}^8\text{Li}$ REX-ISOLDE beam
@ 3.15 MeV/u:

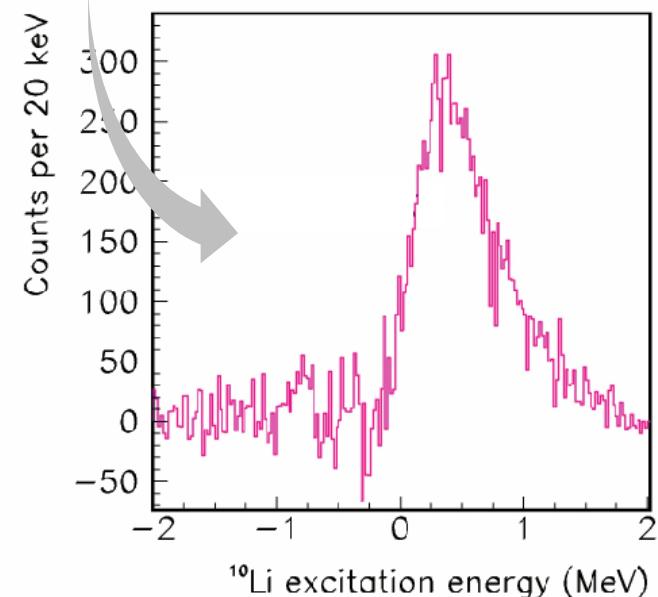
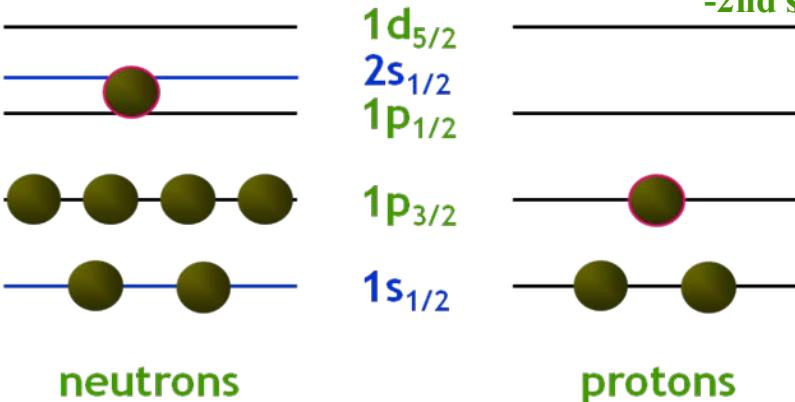
Reaction channels:
 ${}^2\text{H}({}^8\text{Li}, \text{p}) {}^9\text{Li}(\ast) - (\text{d}, \text{p})$
 ${}^2\text{H}({}^8\text{Li}, \text{d}) {}^8\text{Li}(\ast) - (\text{d}, \text{d})$
 ${}^2\text{H}({}^8\text{Li}, \text{t}) {}^7\text{Li}(\ast) - (\text{d}, \text{t})$



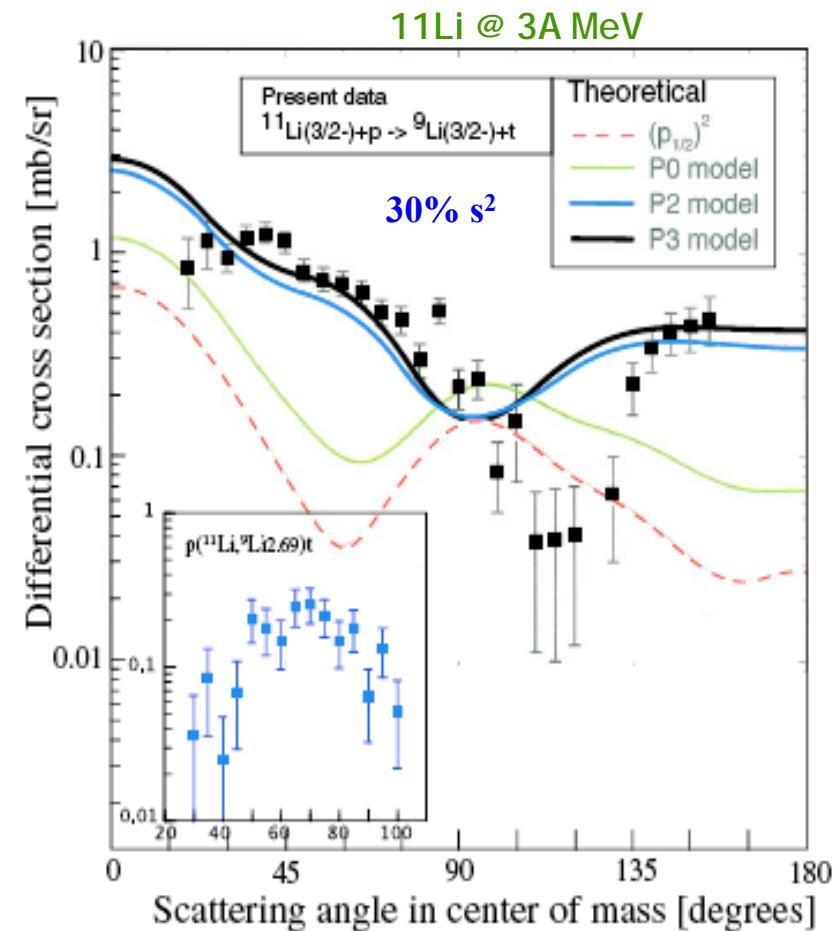
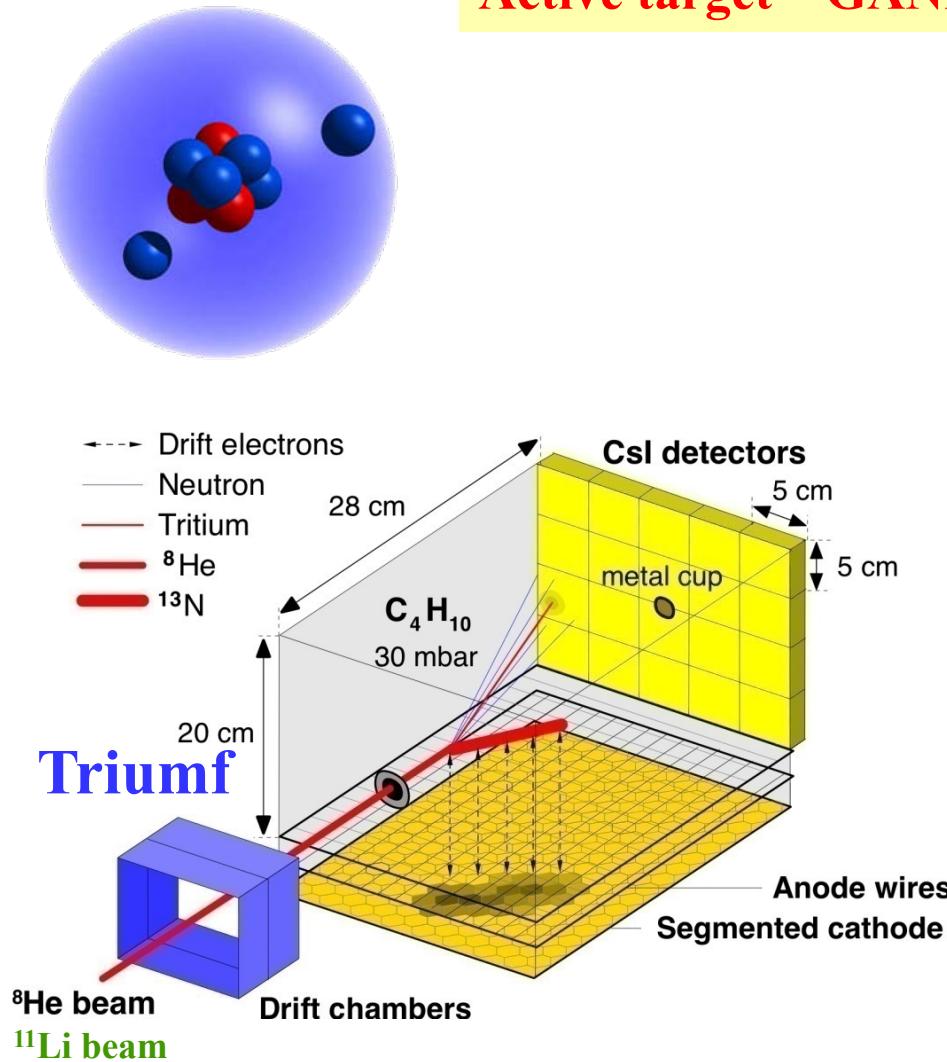
Study of ^{10}Li by $^9\text{Li}(\text{d}, ^{10}\text{Li})\text{p}$



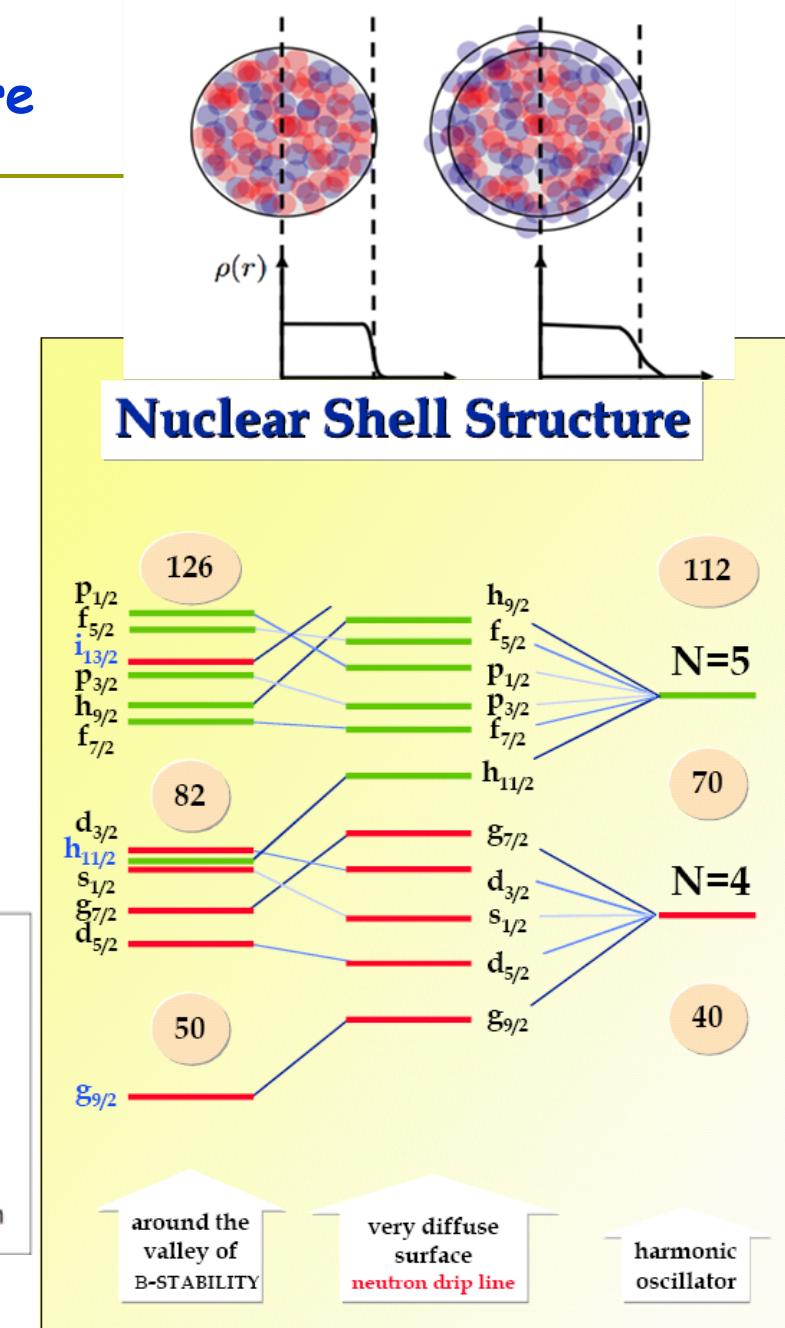
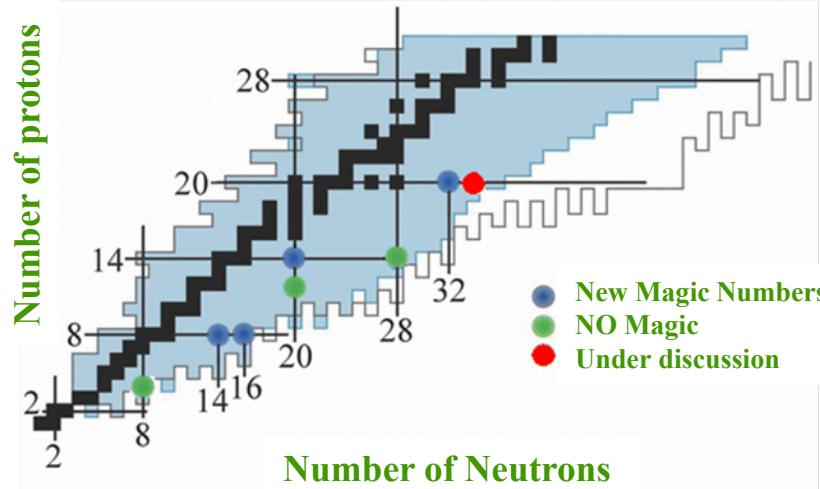
^{10}Li shell model:



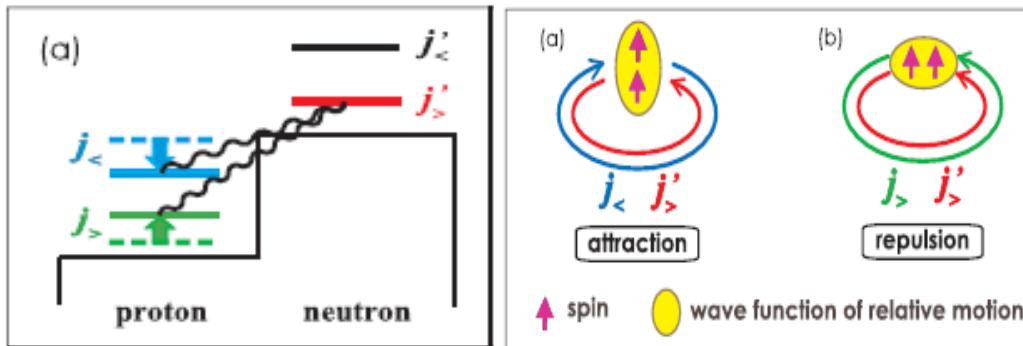
Active target – GANIL /TRIUMF



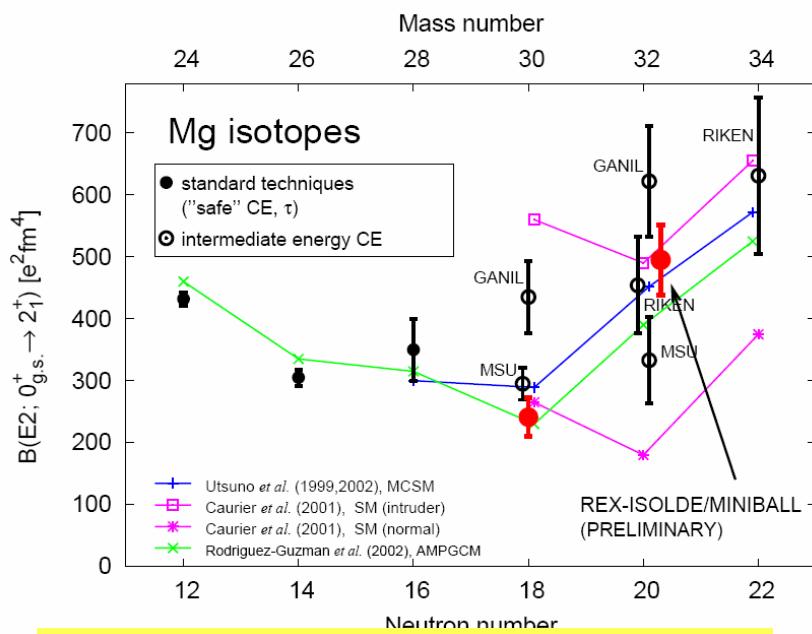
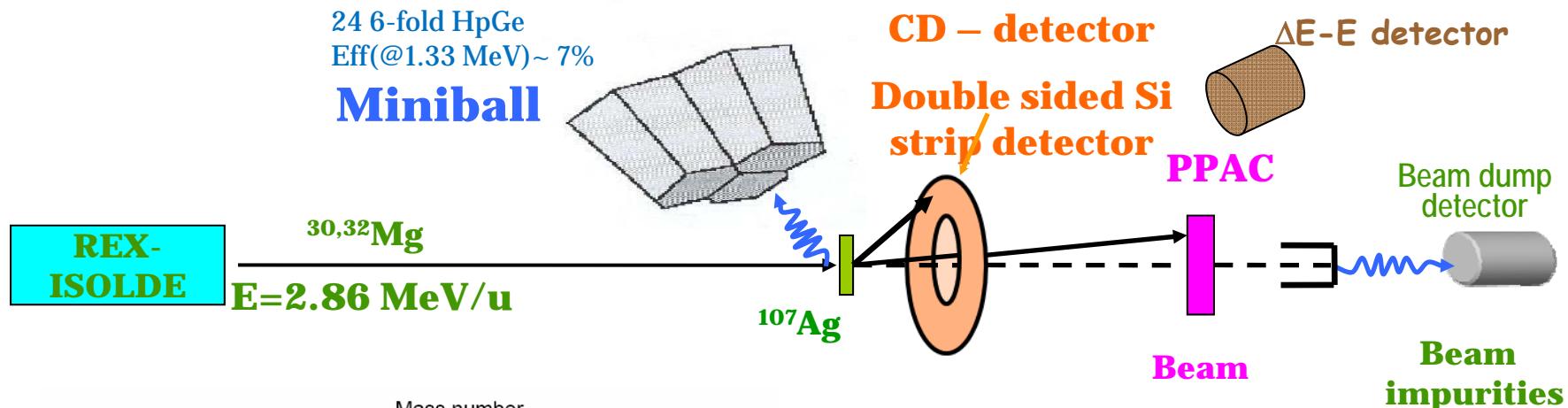
Evolution of shell structure



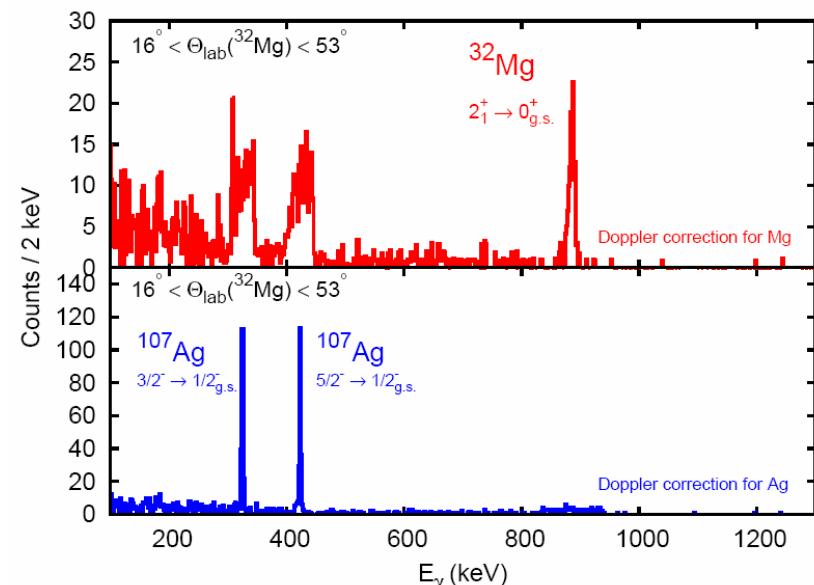
Monopole drift due to the tensor force



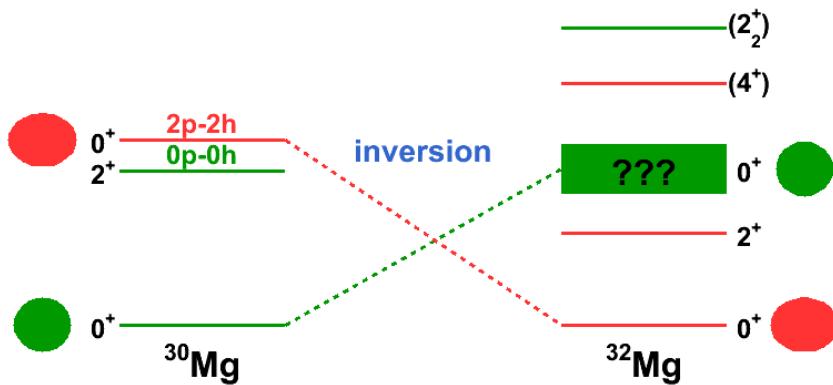
Collective properties studied by Coulomb excitation



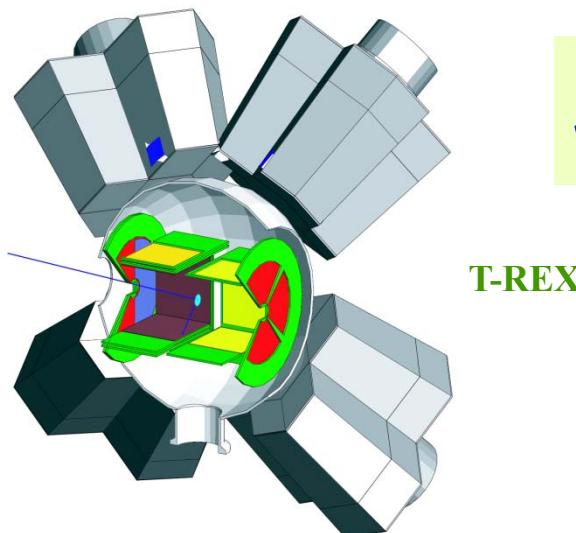
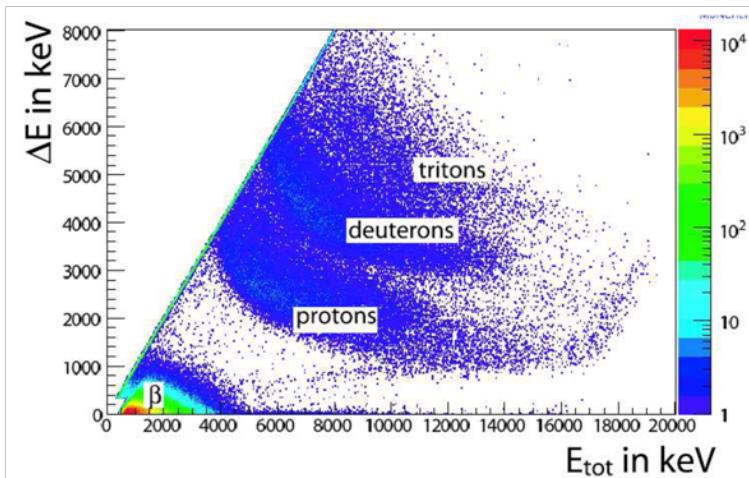
$^{29,30}\text{Na}$ presented by Michael Seidlitz



Radiative beam onto a radioactive target!!



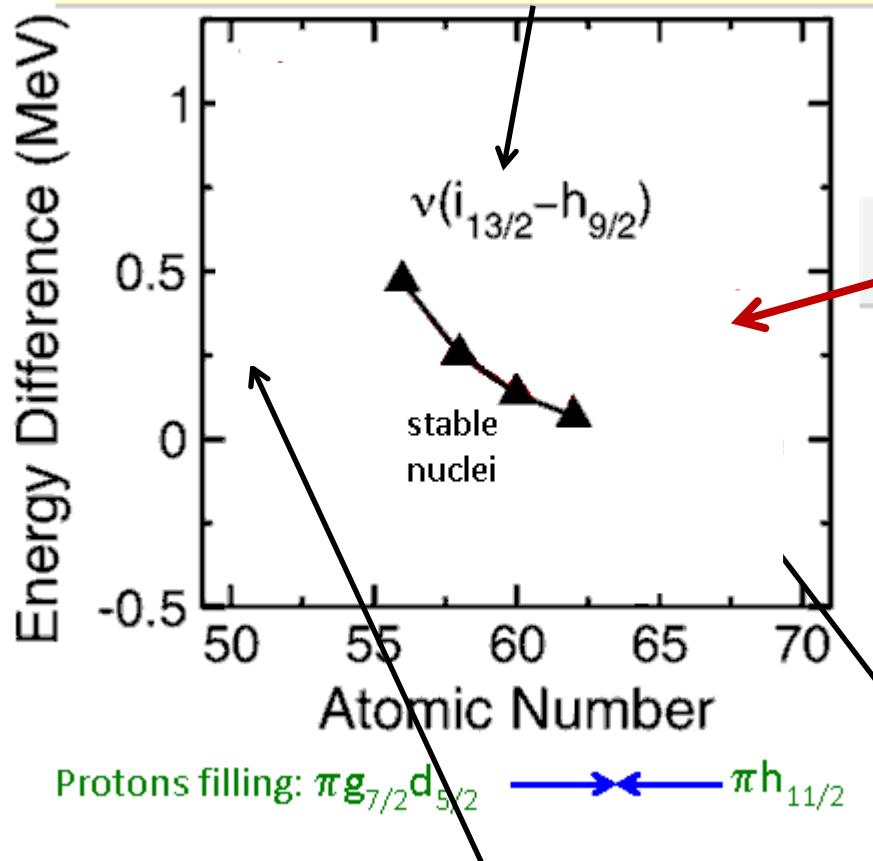
- Due to the higher energy
 - Higher cross sections
 - Better detection sensitivity
 - Less model dependence of spectroscopic factors
 - Dedicated recoil spectrometer



Talk by Kathrin Wimmer!!

Evolution of Shell Structure studied with transfer reactions

Measurements of one-neutron transfer on *stable* nuclei outside N=82



Measurement of stable beams ^{138}Ba , ^{140}Ce , ^{142}Nd and ^{144}Sm by $(\alpha, {}^3\text{He})$
 Kay et al. Phys. Lett. B658 (2008) 216

Expect turn around in trend, if tensor force drives changes, for higher Z.

radioactive beams with high yields:
 ^{132}Sn , ^{134}Te

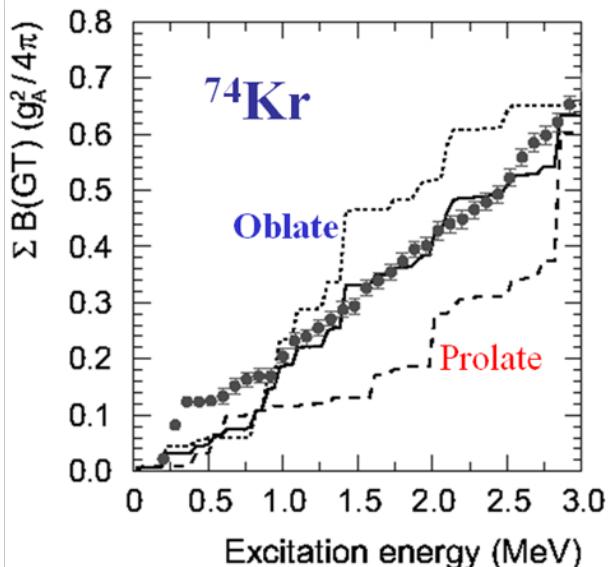
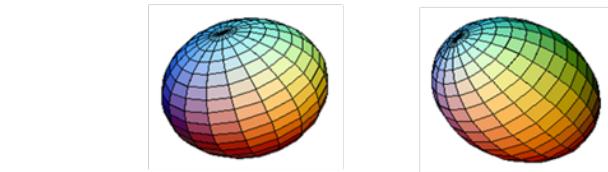
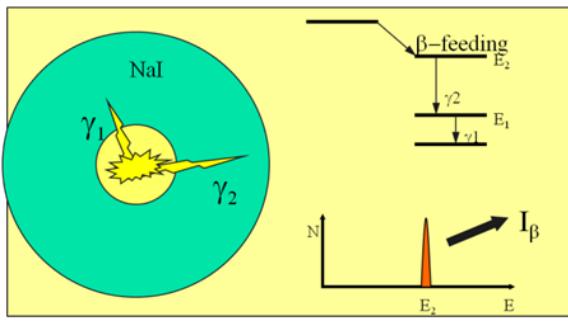
radioactive beams unique to ISOLDE with high yields:
 ^{146}Gd , ^{148}Dy , ^{150}Er

Testing outside Z=50 using beams of n-deficient Sn isotopes

Testing outside N=126 using beams like ^{206}Hg , ^{210}Po , ^{212}Rn and ^{214}Ra

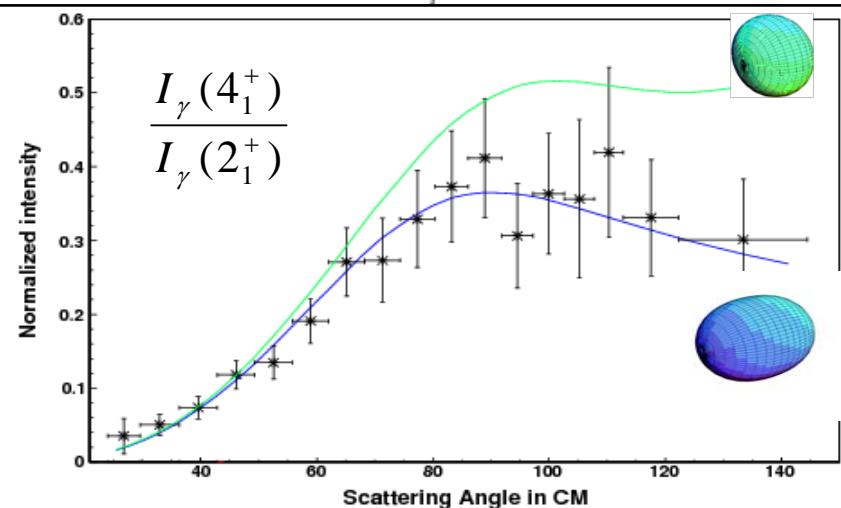
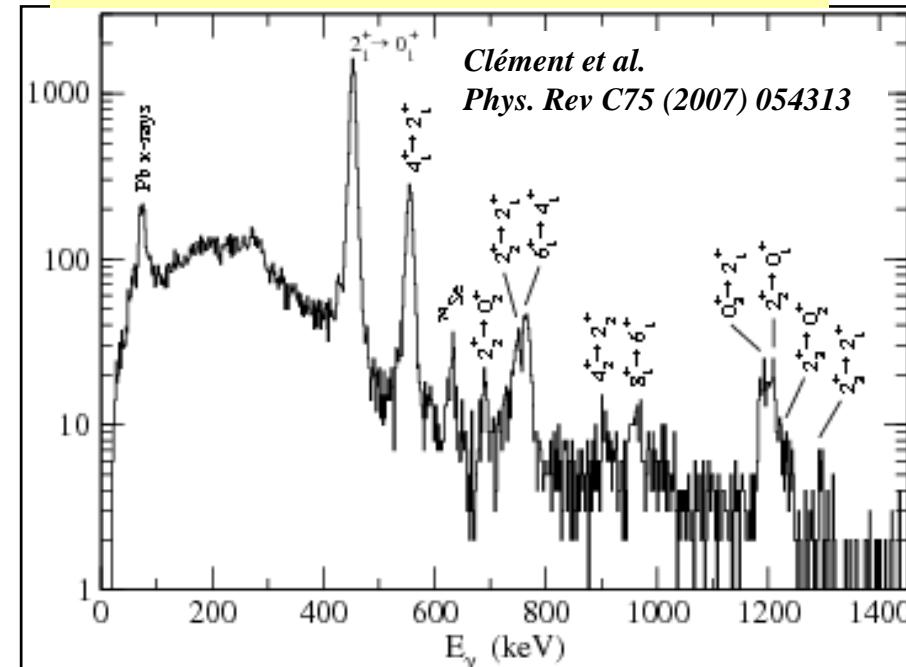
Strong Deformation and Shape Coexistence near A = 70

Beta decay studies at ISOLDE with TAS

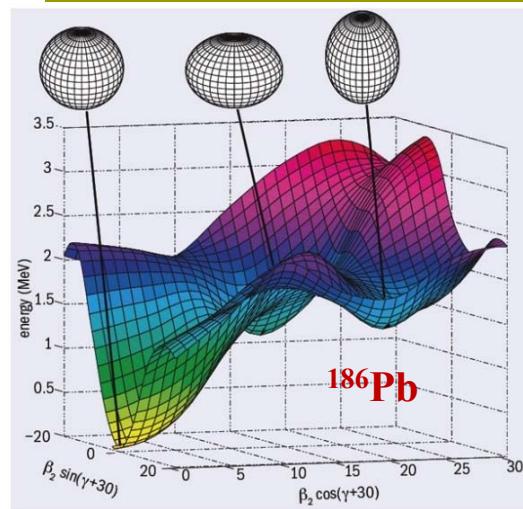


Poirier et al., PRC 69 (2004) 034307

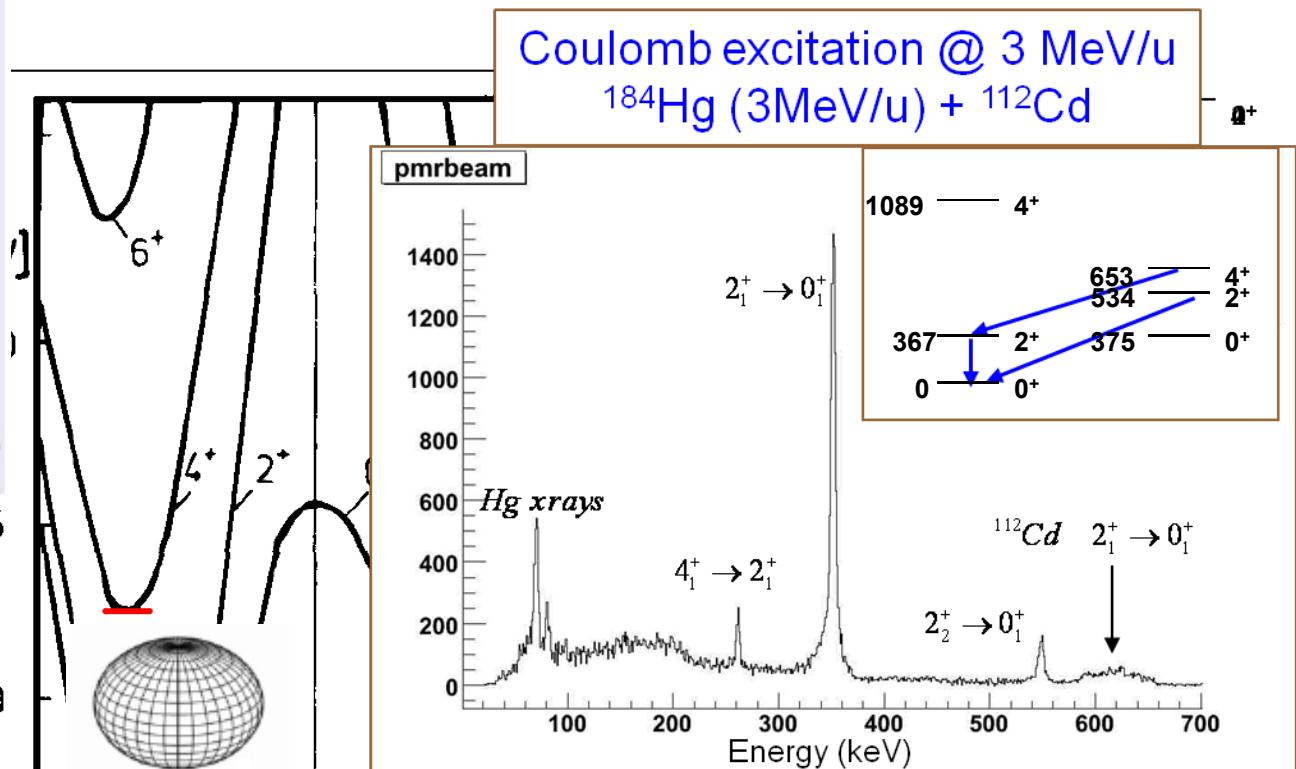
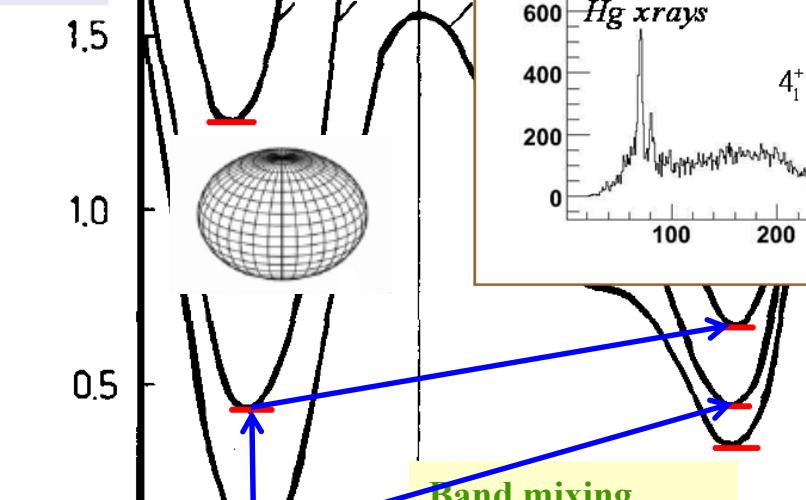
4.7 MeV/u ^{74}Kr radioactive beam - SPIRAL



Evolution of nuclear shapes: quadrupole shapes



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



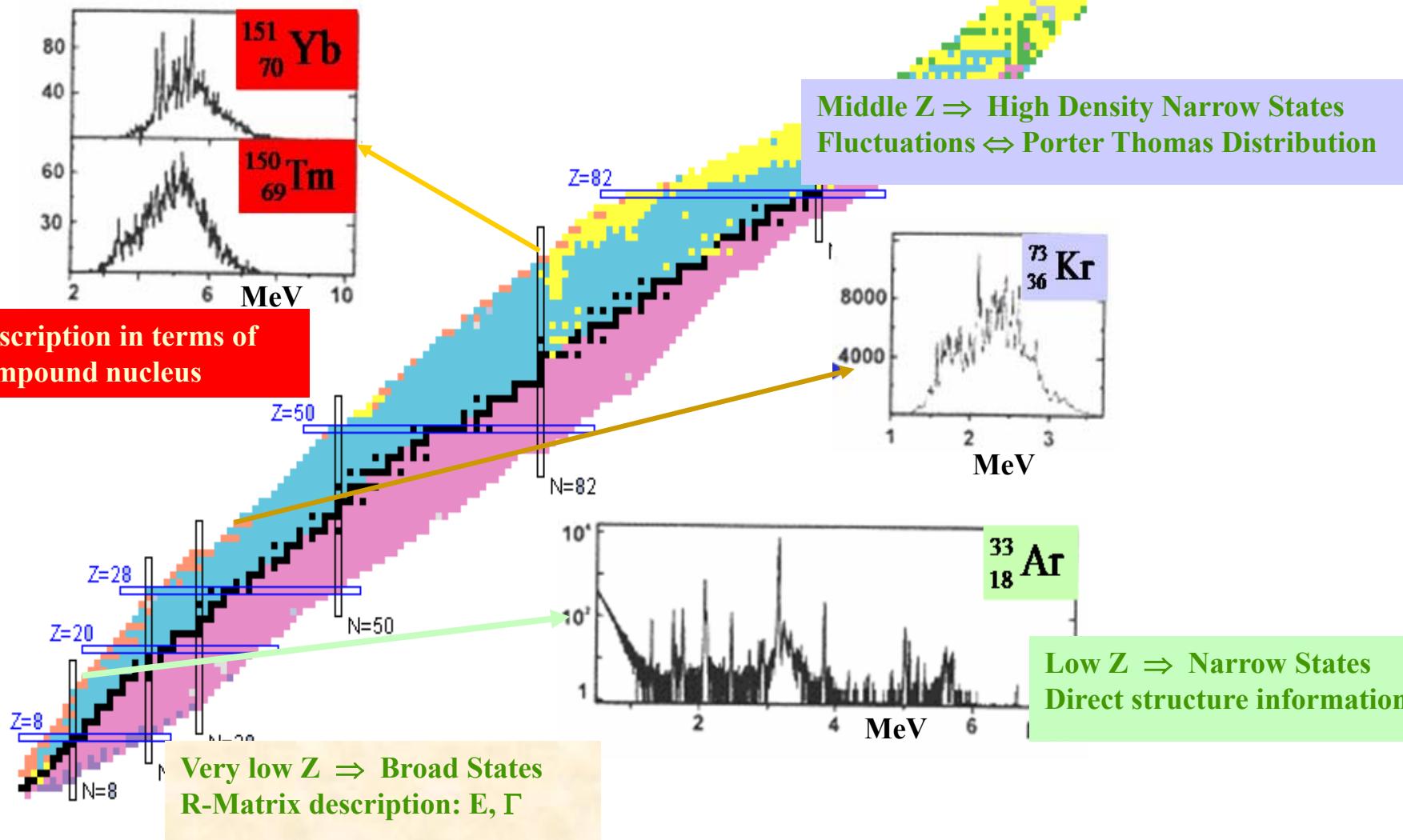
Talk by Nick Bree !!
deformation

One-neutron transfer: $^2\text{H}(^{184}\text{Hg}, p)^{185}\text{Hg}$, $^2\text{H}(^{183m,g}\text{Hg}, p)^{184}\text{Hg}$
and other Pb, Po and Rn (isomeric) beams

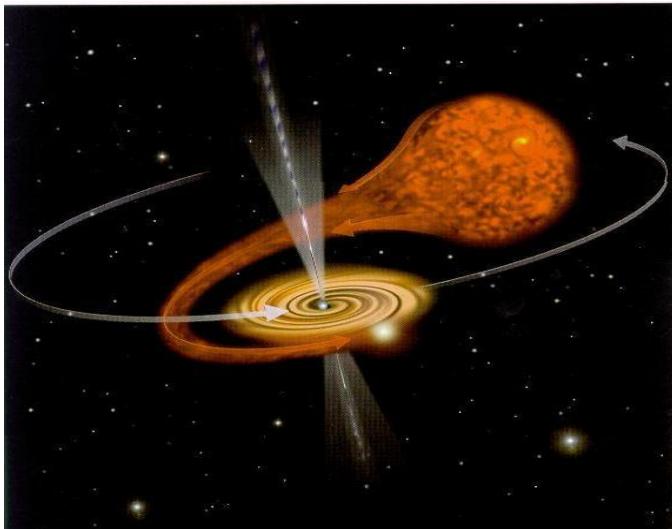
Two-proton transfer: $^3\text{He}(^{184}\text{Hg}, n)^{186}\text{Pb}$

Transition from order to Chaos

- With the intensity upgrade many more beta-delayed emitters will be available
- ✓ β -2p allowing for two nucleon correlation studies
 - ✓ β p from Ar to Kr to learn when and how the transition from order to chaos occurs.



X-ray bursts (rp-process)



Supernovae (r-process)



- Dominated by (p,γ) and (α,p) reactions
 - Direct (p,γ) or $(^3\text{He},d)/(d,n)$ as surrogate of (p,γ)
 - (p,α) as inverse of (α,p) in proton-rich nuclei

- Dominated by (n,γ) reactions
 - r-process pathway largely unknown
 - understanding of shell evolution important
- (d,p) as surrogate of (n,γ)
(J. Cizewski et al. **NIMB 261 (2007) 938**)

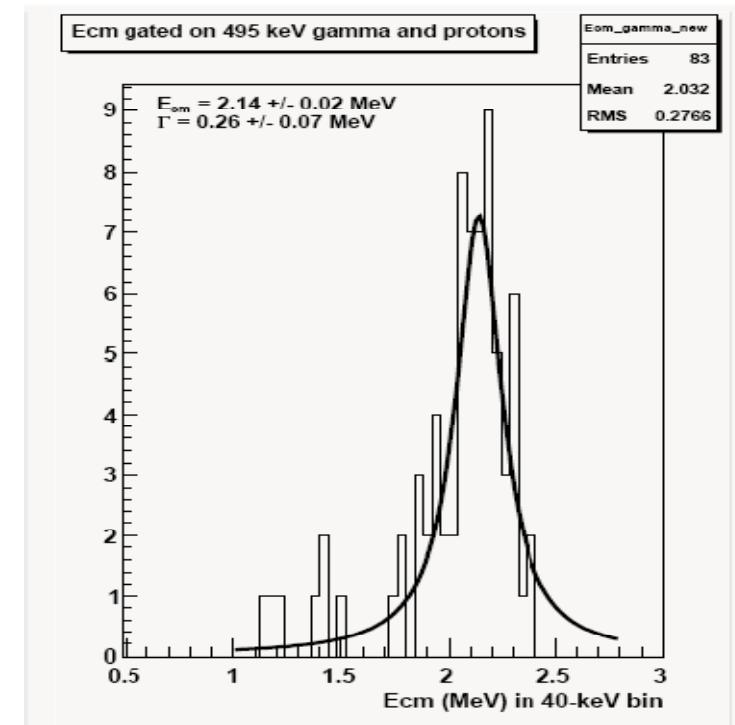
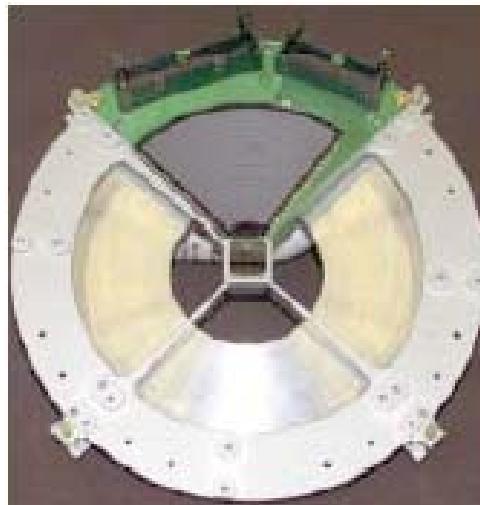
Measurement of global properties such as the mass and lifetime far away from stability

MINIBALL

^{17}F @ 2.4 MeV/u on $(\text{CH}_2)_n$



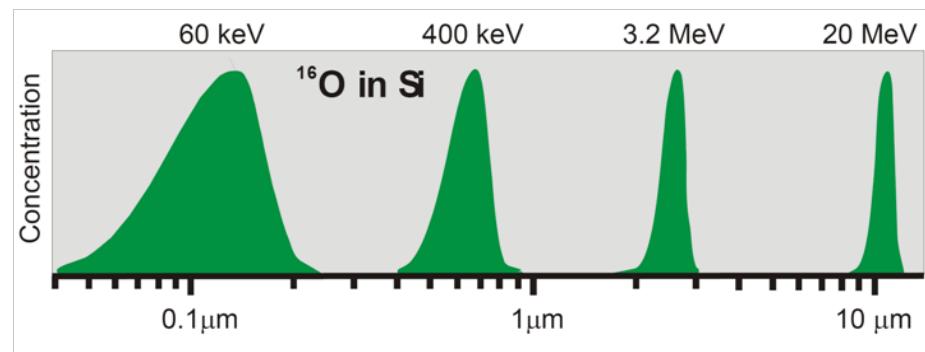
CD detector



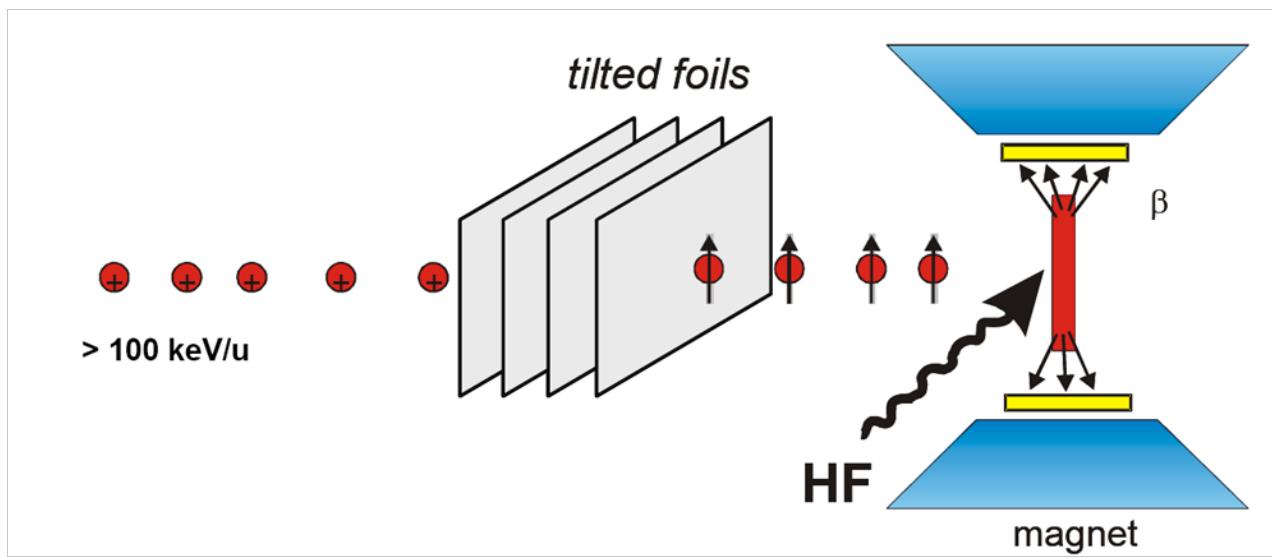
Key resonance identified using CD + Miniball systems

→ Tuneable energies required to apply time reverse technique
to other key X-ray burster reactions eg $^{34}\text{Ar}(\alpha, \text{p})^{37}\text{K}$

Diffusion in highly immiscible systems



Beta-NMR with tilted-foil polarization



- The physics of exotic beams is in great expansion and the *explorers* are approaching very rich systems in the middle and heavy mass region.
- Nuclei far from stability has never been as close to us as they will be in the near future with the advent of the RIB under construction in Europe (HIE-ISOLDE; Spiral2 and FAIR) and USA (FRIB).
- Study properties of bound and un-bound states in light-mass(halo & cluster) nuclei - open quantum systems: using two nucleon transfer reaction: $^3\text{H}(^9\text{Li},\text{p})^{11}\text{Li}$, $^3\text{H}(^{12}\text{Be},\text{p})^{14}\text{Be}$ and heavier masses (C, N and O)
- Evolution of shell structure: Identify energy gaps, spin, parity and the single-particle strength outside an inert core
- Shape Coexistence: Identify the microscopic (particle-hole) origin of shape-coexistence

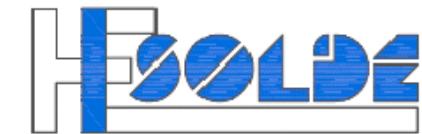
Means: Increase energy first to 5.5 MeV/u up to 10 MeV/u & Intensity & Quality (HIE-ISOLDE)

Multistep Coulex: populates states strongly coupled to g.s.

Transfer reactions requires this high energy for adequate cross sections, angular momentum-transfer assignments and minimise dependency on reaction models

Higher intensity allows decay studies, mass measurement and laser spectroscopy of species approaching the neutron and proton drip lines

New RIB in Europe



Special thanks to

Karsten Riisager

Peter Butler

Mark Huyse

Reiner Krückken



For the yellow Book

“HIE-ISOLDE: the scientific Opportunities”



And thanks to you for your attention!!



B. Jonson