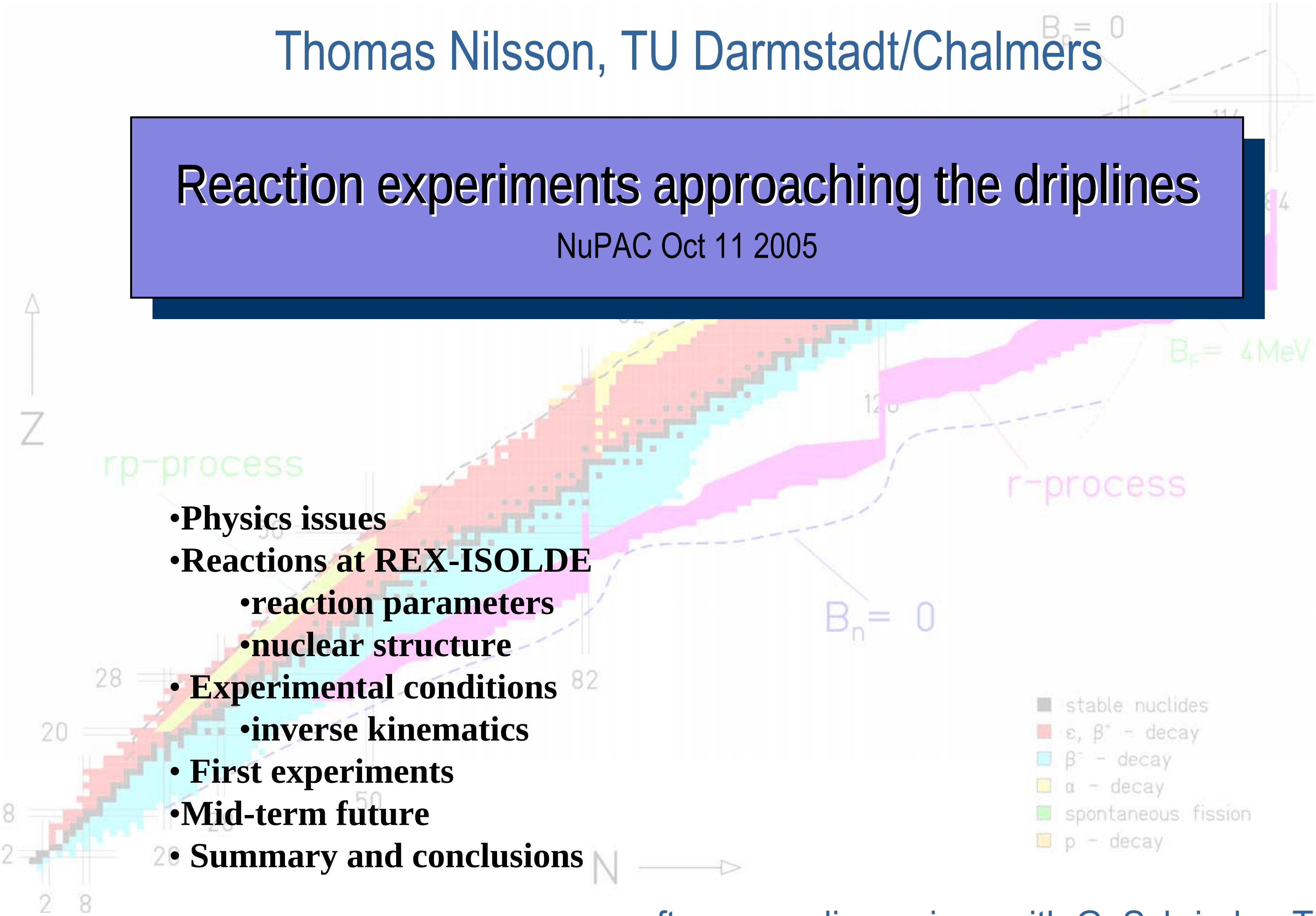
Thomas Nilsson, TU Darmstadt/Chalmers

Reaction experiments approaching the driplines

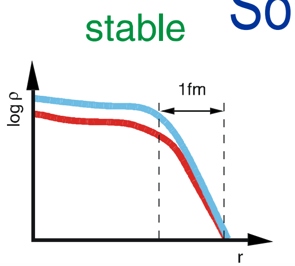
NuPAC Oct 11 2005



- Physics issues
- Reactions at REX-ISOLDE
    - reaction parameters
    - nuclear structure
- Experimental conditions
    - inverse kinematics
- First experiments
- Mid-term future
- Summary and conclusions

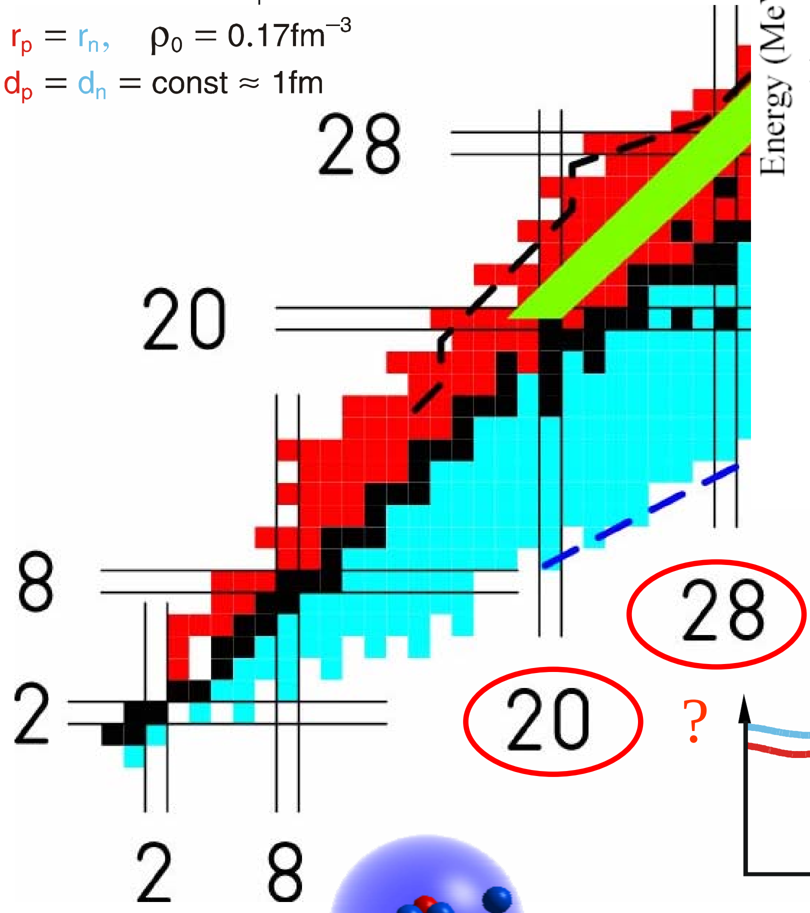
…after many discussions with G. Schrieder, TUD

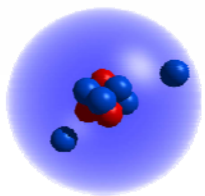
Some burning issues

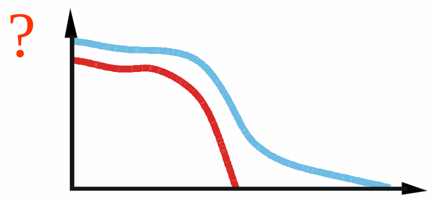


$r_p = r_n, \quad \rho_0 = 0.17\text{fm}^{-3}$

$d_p = d_n = \text{const} \approx 1\text{fm}$



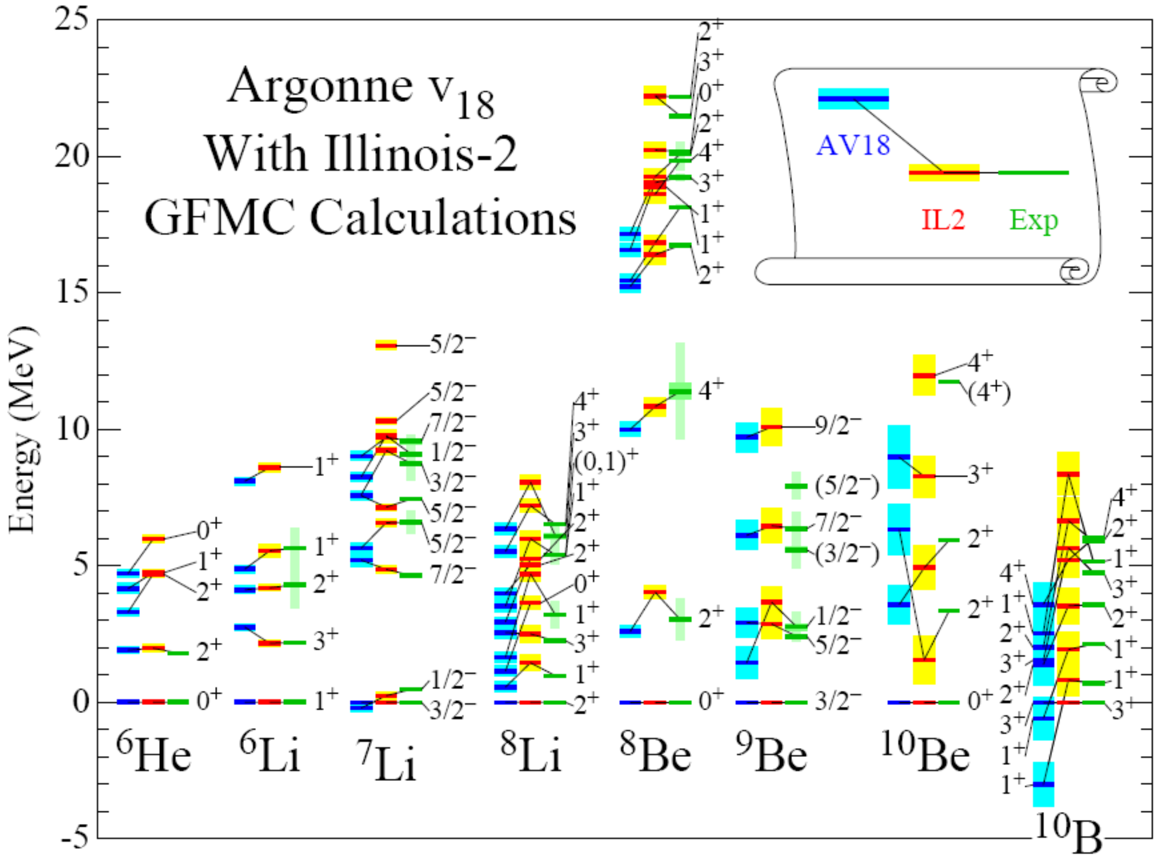




halo

$r_p \neq r_n$

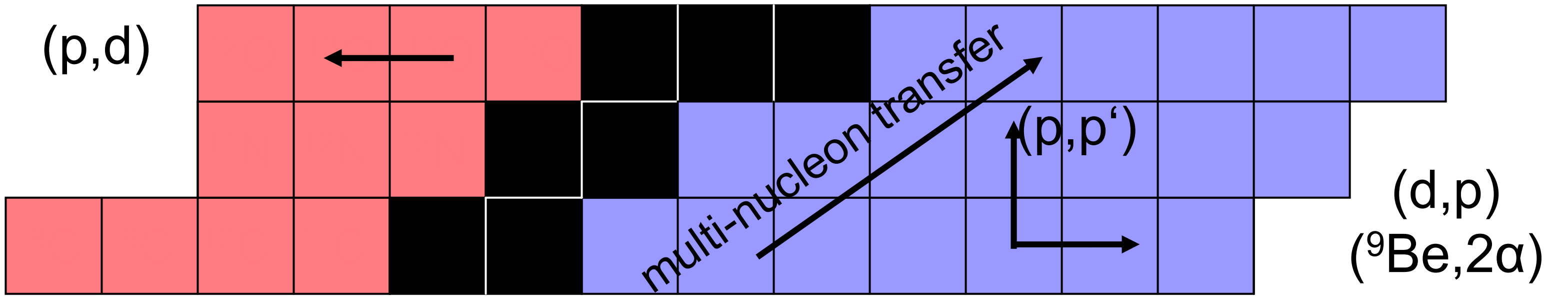
$d_p \neq d_n$



- Halos and unbound subsystems – ^{10}Li
- Structure of the states in the lightest nuclei – ^{8}Li
- Shell erosion – ^{31}Mg

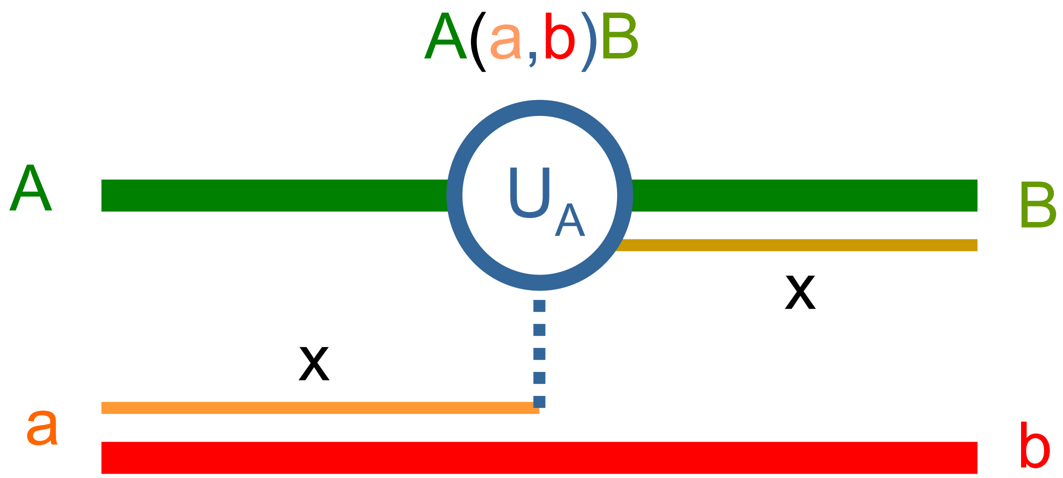
Reactions at REX-ISOLDE energies

- Few-nucleon transfer
  - (d,p), (^{9}Be,2α), (p,d), (d,t), (^{3}He,d)…
- Fusion
- (Elastic resonance scattering)
- (Coulomb excitation $\rightarrow$ P. Van Duppen)



H.G. Bohlen et al., NPA 616 (1997) 254c

Transfer reactions



$$T_{\beta\alpha} = \left\langle \chi_\beta^{(-)} \middle| F_{\beta\alpha} \middle| \chi_\alpha^{(+)} \right\rangle$$ DWBA

$$F_{\beta\alpha} = \Phi_B U_{\beta\alpha} \Phi_a$$ Nuclear structure

$\Phi \rightarrow$ Factorized in $\sqrt{S}$ and F_n

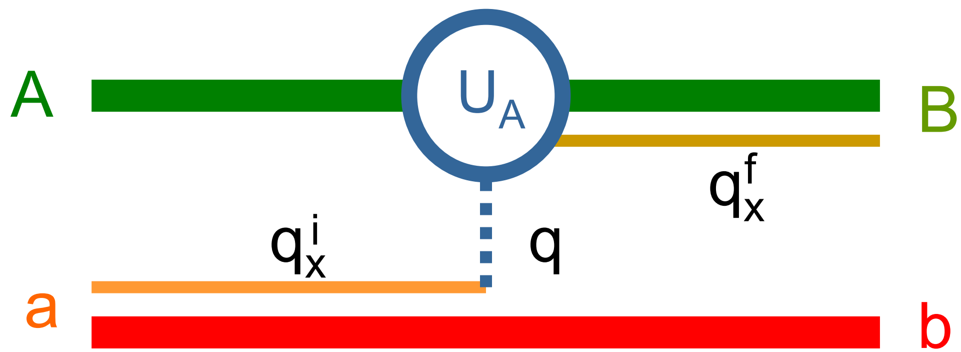
Transfer:

- only two particles in final state
- direct reaction
- pure mean field process
- single particle properties

Successful separation of reaction dynamics from structure if:

- one step process - example: (d,p) stripping, (p,d) pickup reactions
- pure **single particle states** or at least linear combinations of such states with weak coupling

Matching



optimal cross section $q_x^f = q_x^i + q \rightarrow$ matching

linear momentum q depends on beam energy, scattering angle and Q-value

Beams

well below 25 MeV/u

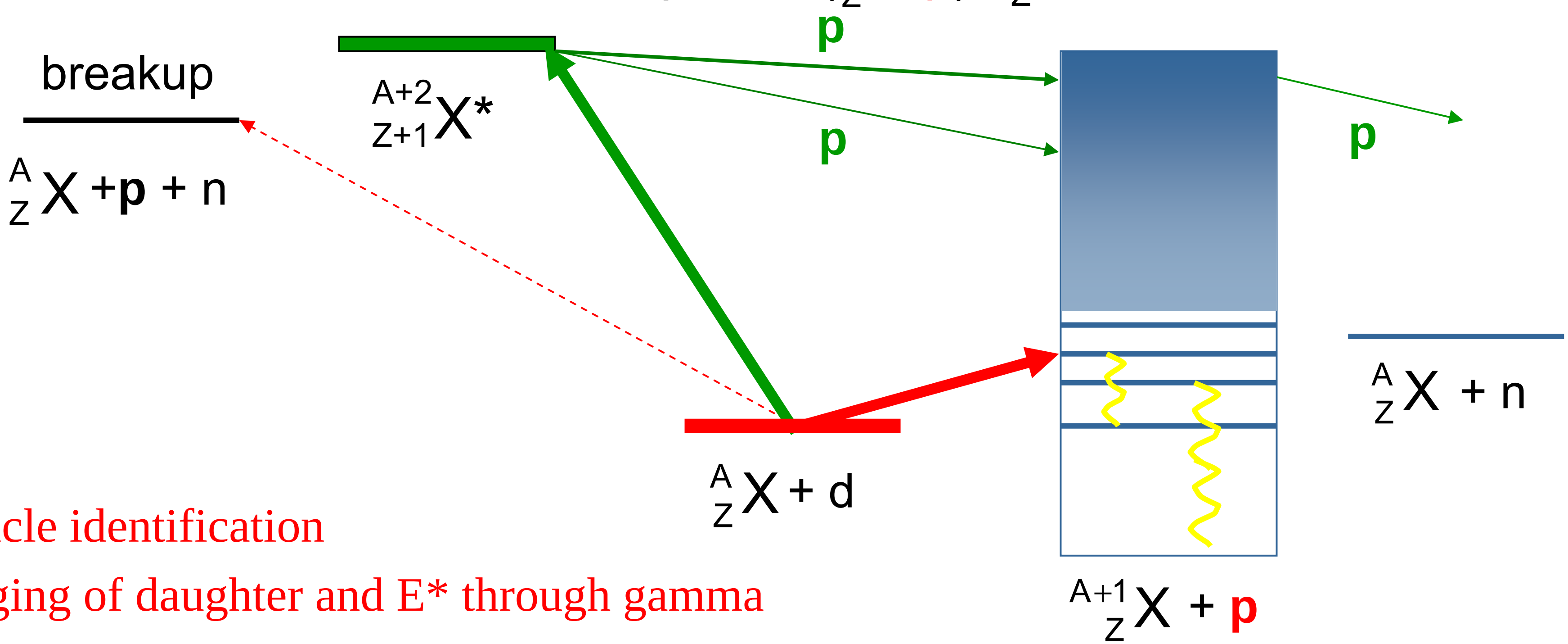
Avoiding:

- breakup
- nucleon knockout
- fragmentation

$\rightarrow$ three- or many-body final channels

Direct vs. Compound Processes

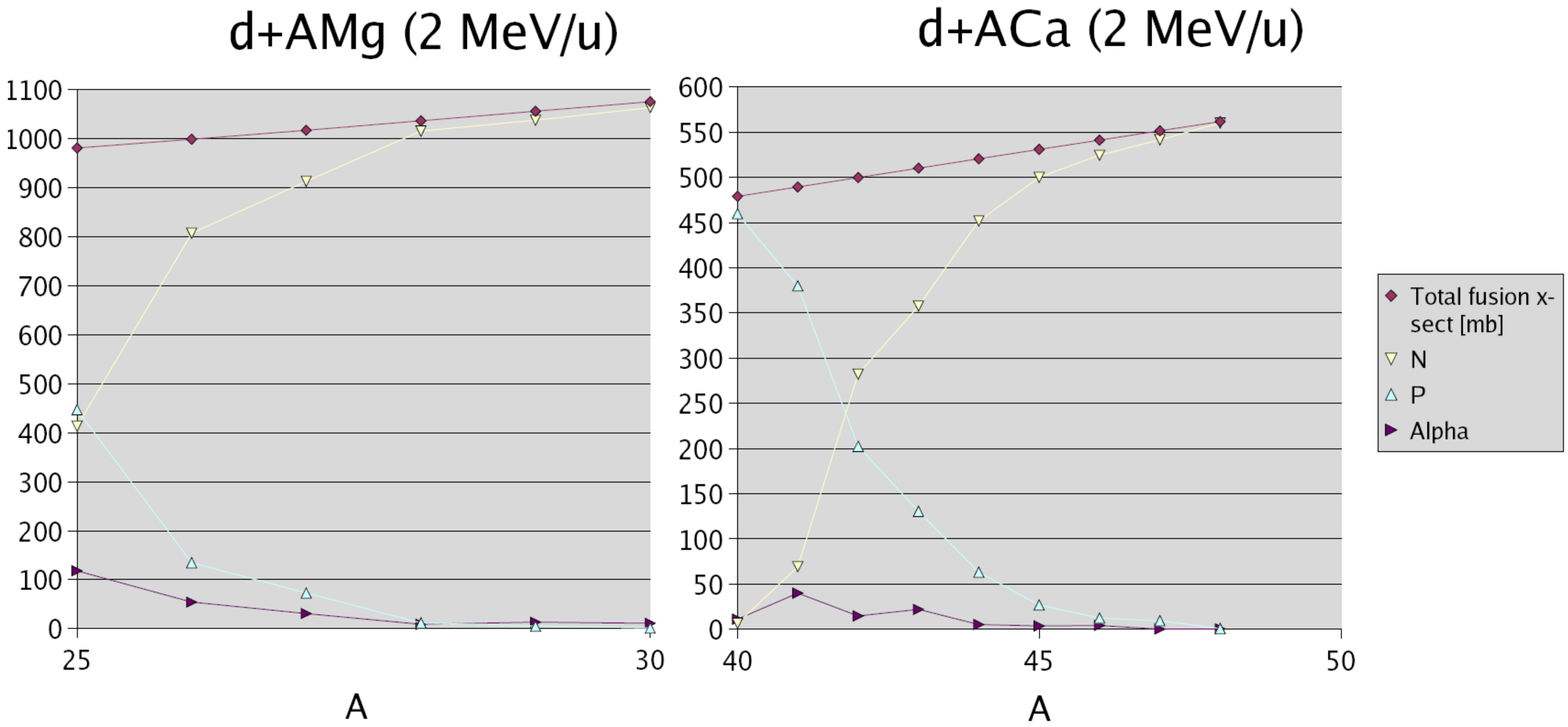
Example: $^{2}H(^{A}_{Z}X,p)^{A+1}_{Z}X$



- Particle identification
- Tagging of daughter and E* through gamma rays
    - RIB – few or no states, low multiplicity
- Compound?
    - Calculations
    - Angular distribution

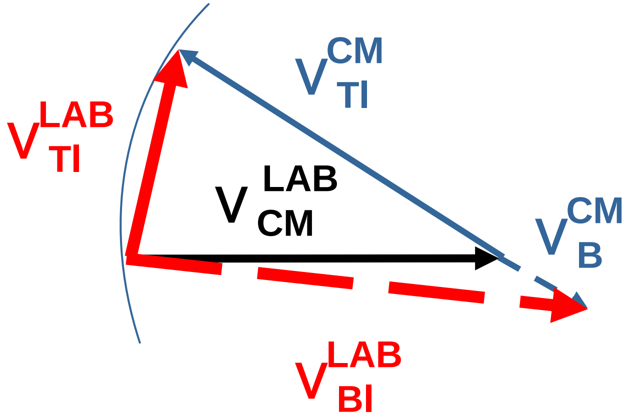
Compound contributions

- EMPIRE calculations for Mg- and Ca-isotopes

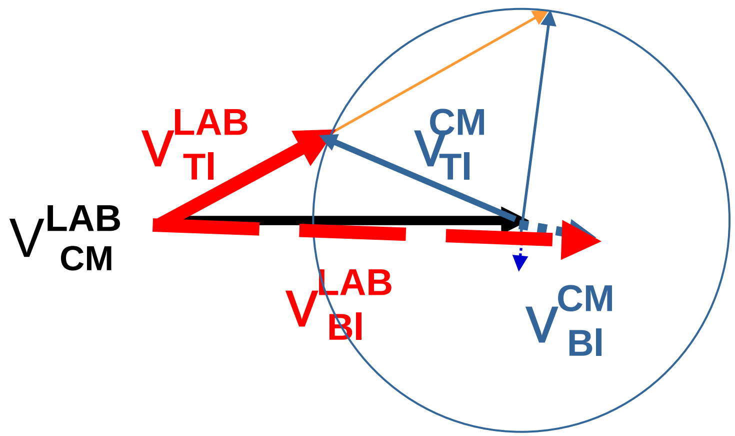


Velocity Vector Diagrams of the Final State in Inverse Kinematics

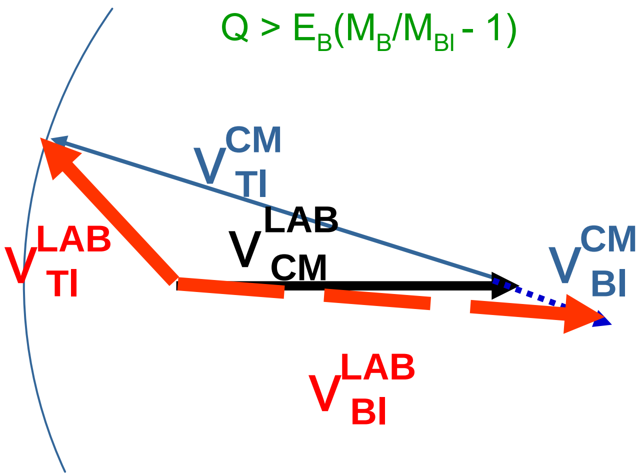
(a) elastic scattering



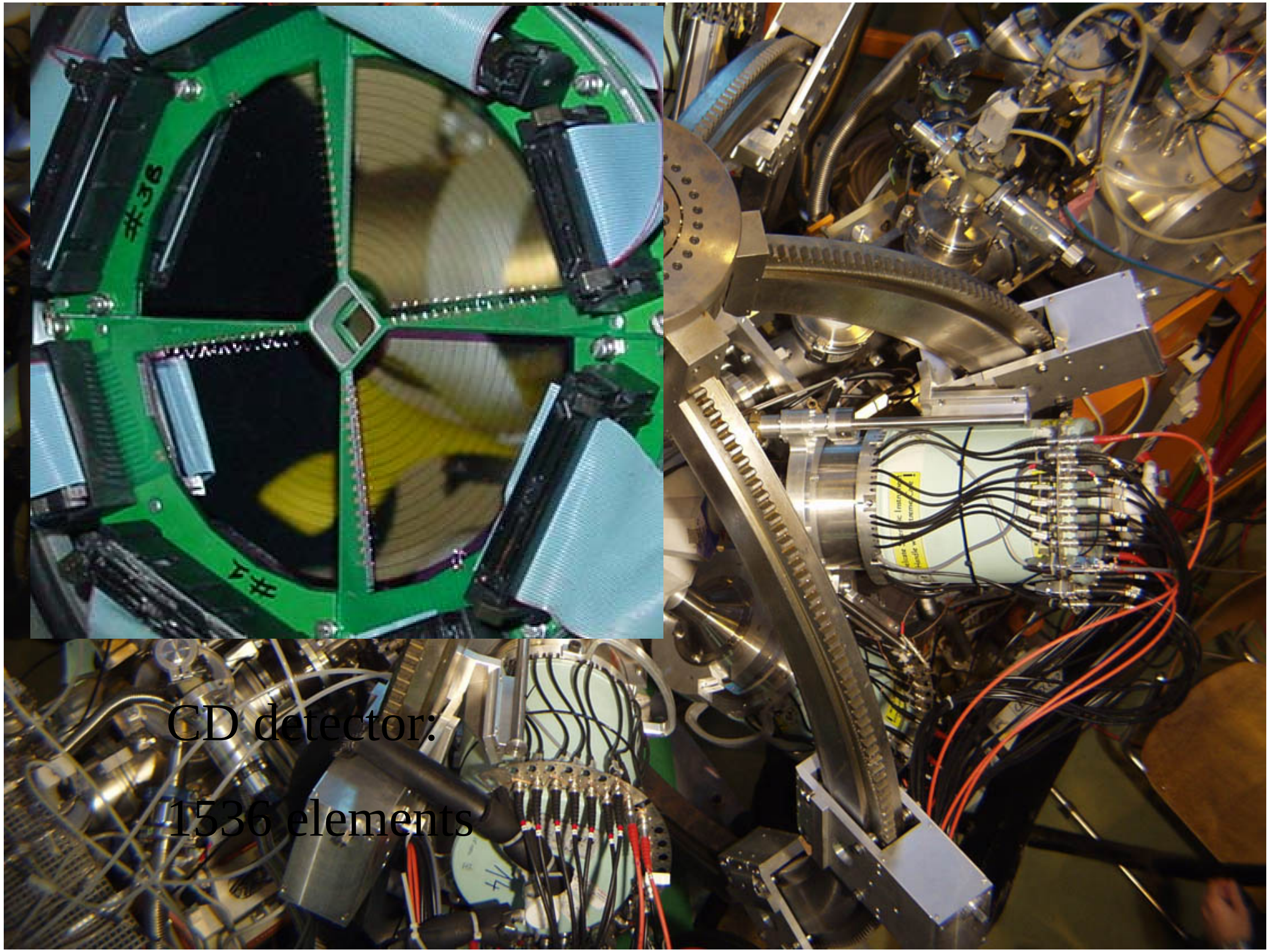
(b) pickup from target



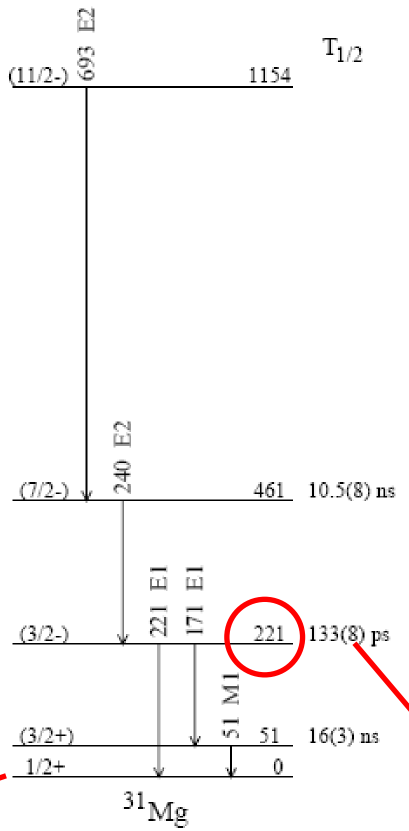
(c) stripping from target



MINIBALL: 24 crystals – gran. ~ 2400



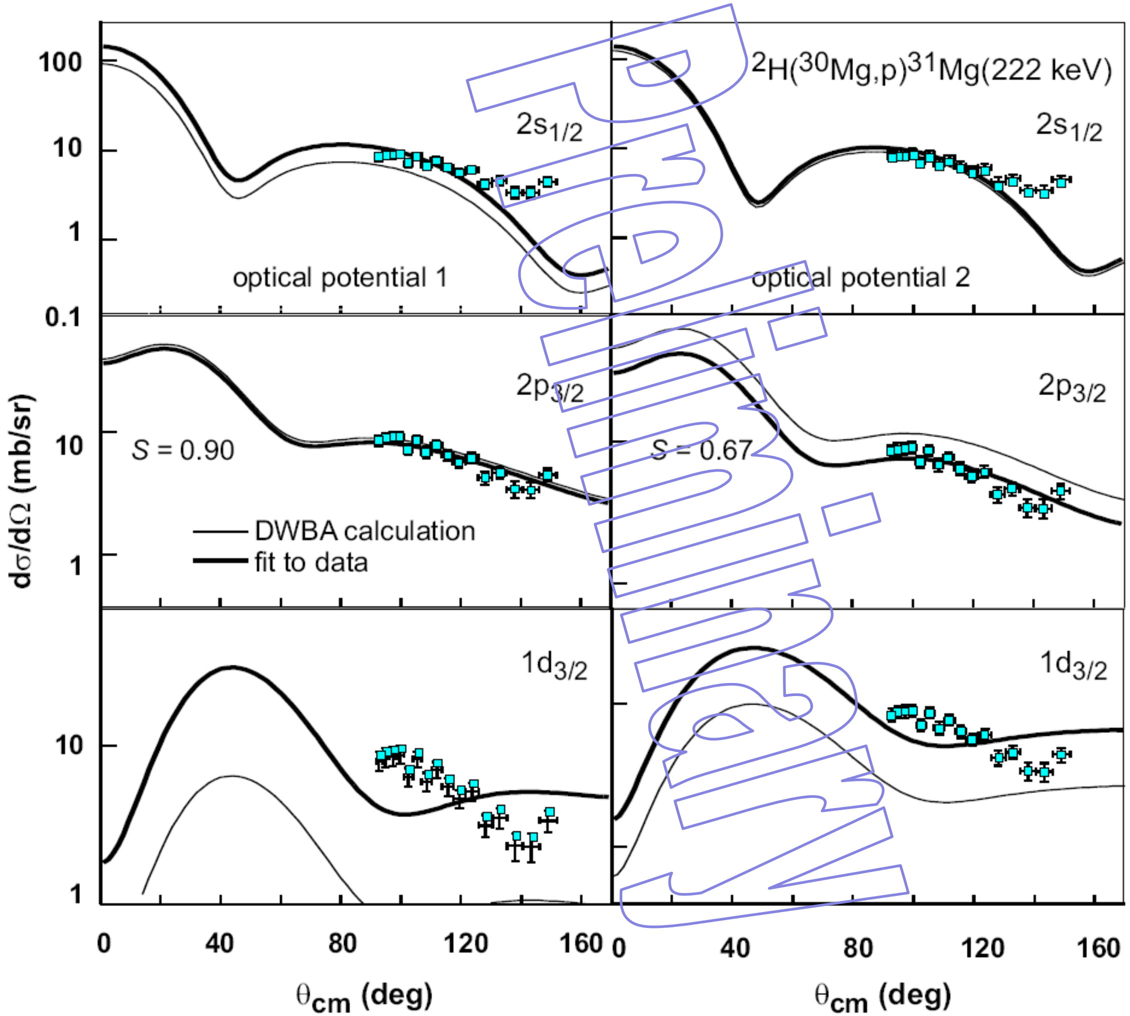
$^{2}H(^{30}Mg,p\gamma)$ at REX-MINIBALL



G. Neyens et al, PRL 94(2005)22501

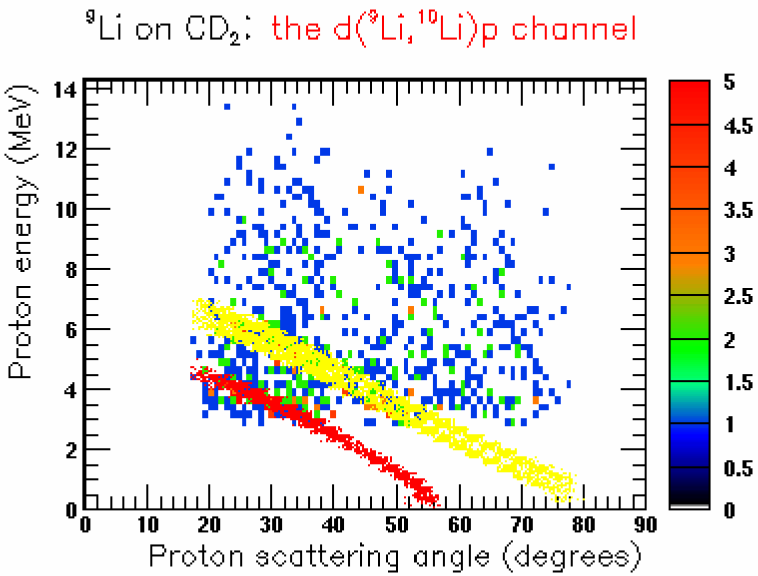
H.Mach et al, ENAM 2004 proc.

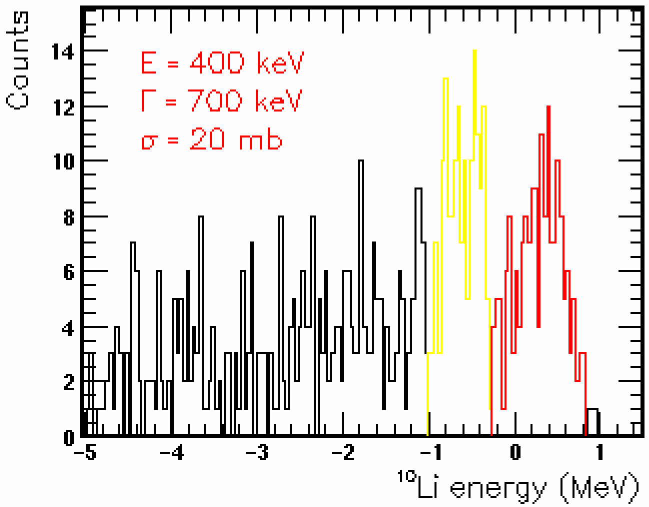
Calculations by H. Lenske

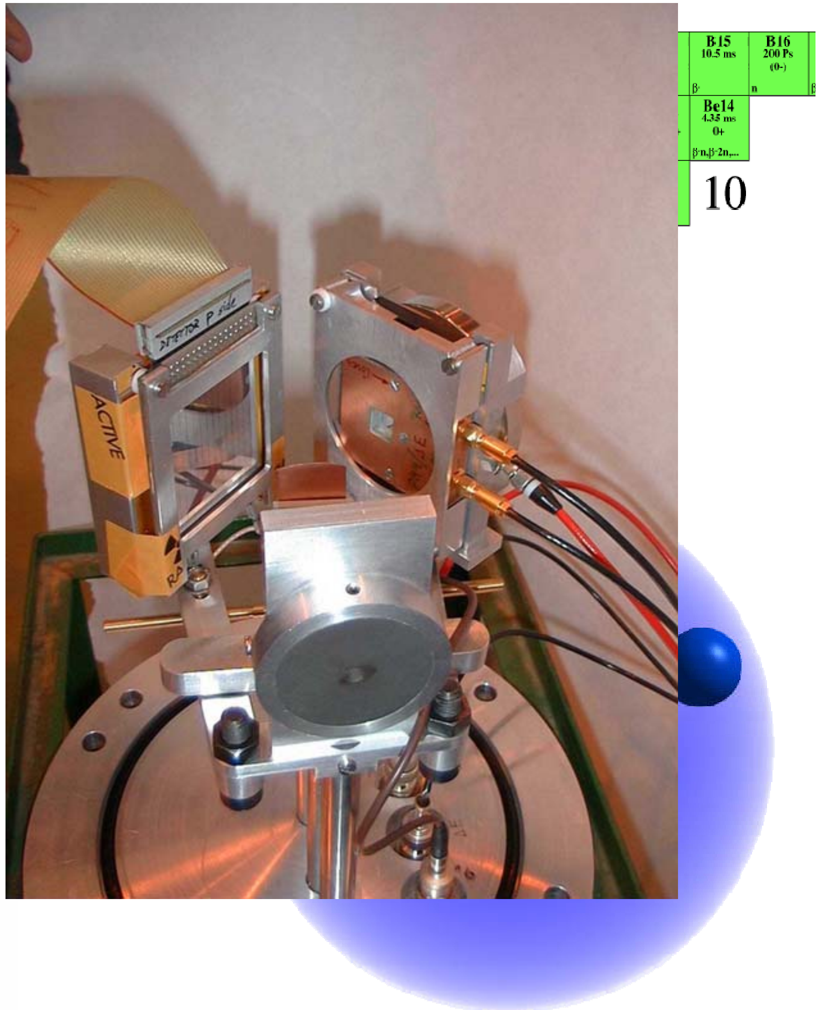


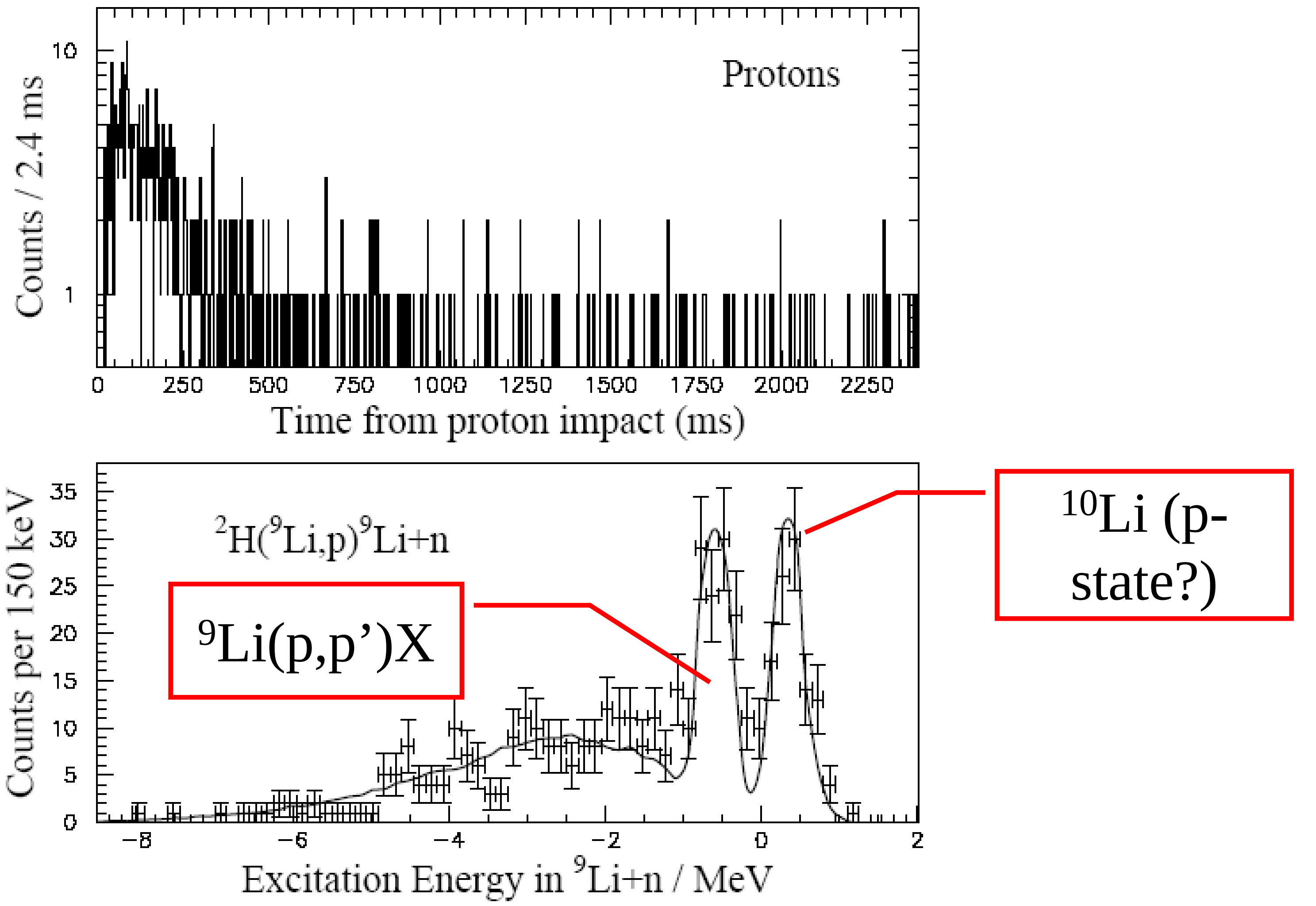
MAGISOL

Probing Halo Nuclei



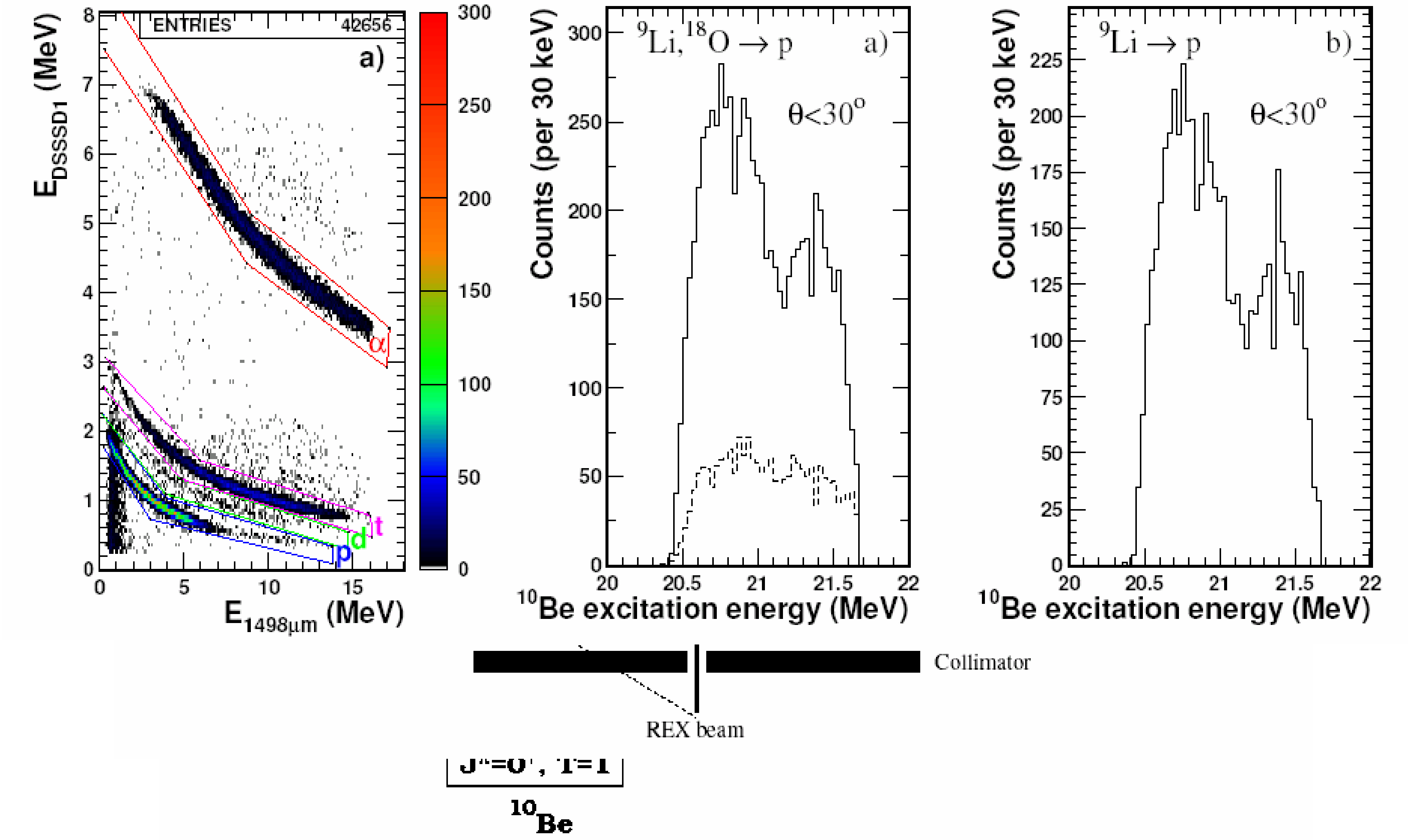


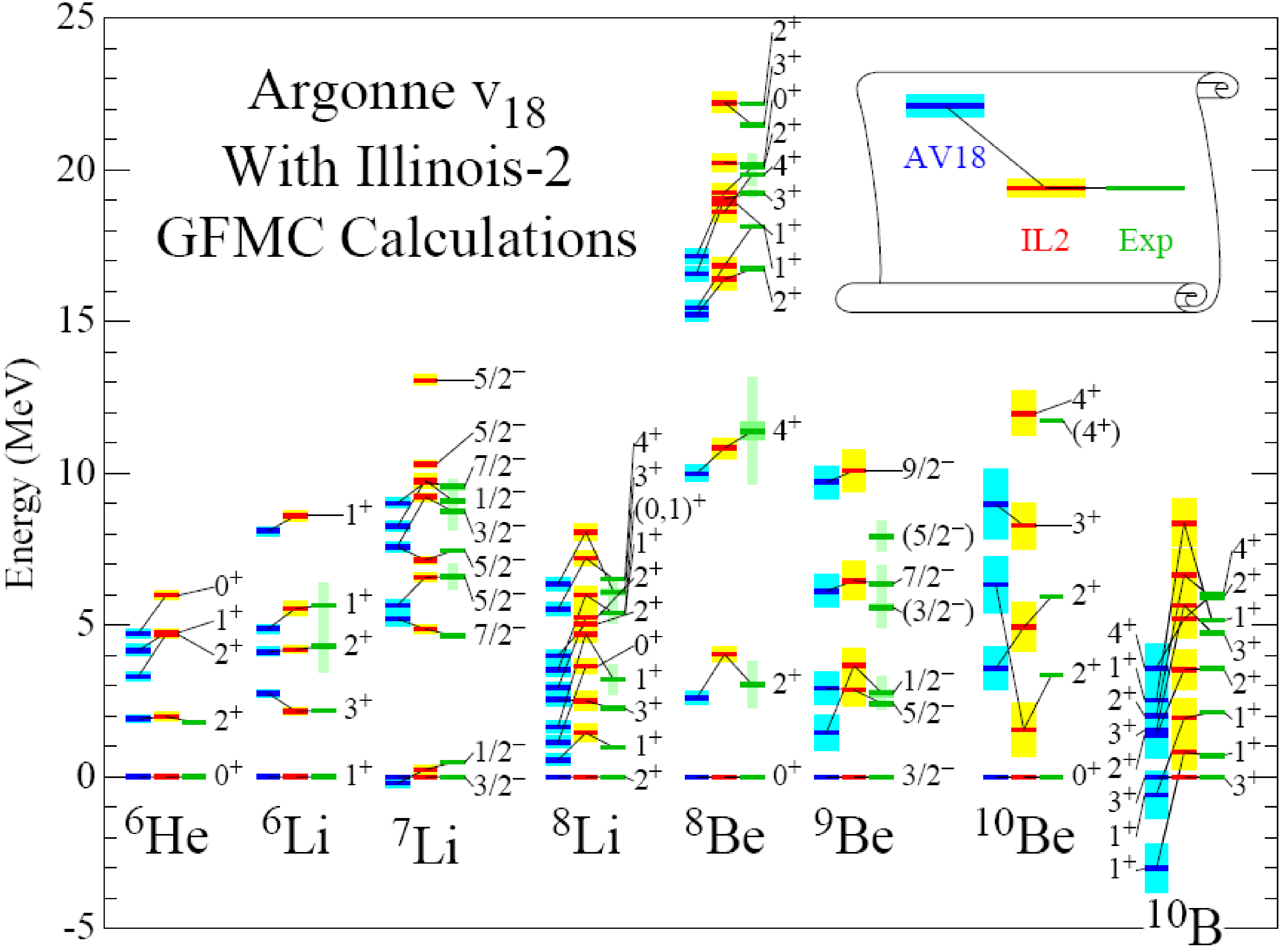




H.B. Jeppesen et al, Nucl. Phys. A748(2005) 374-392

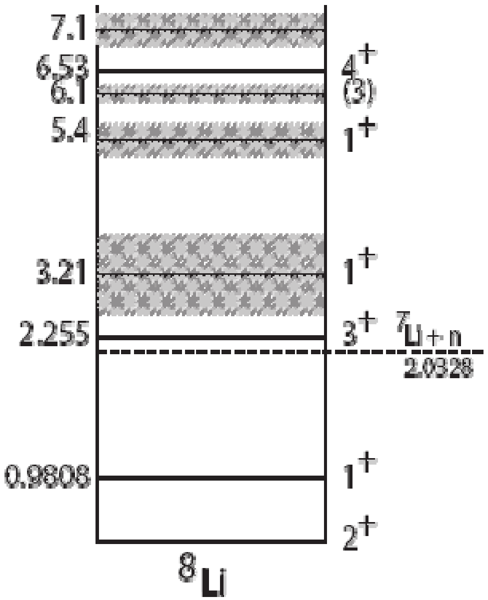
IS371 ^{9}Li(p,p') elastic resonance scattering

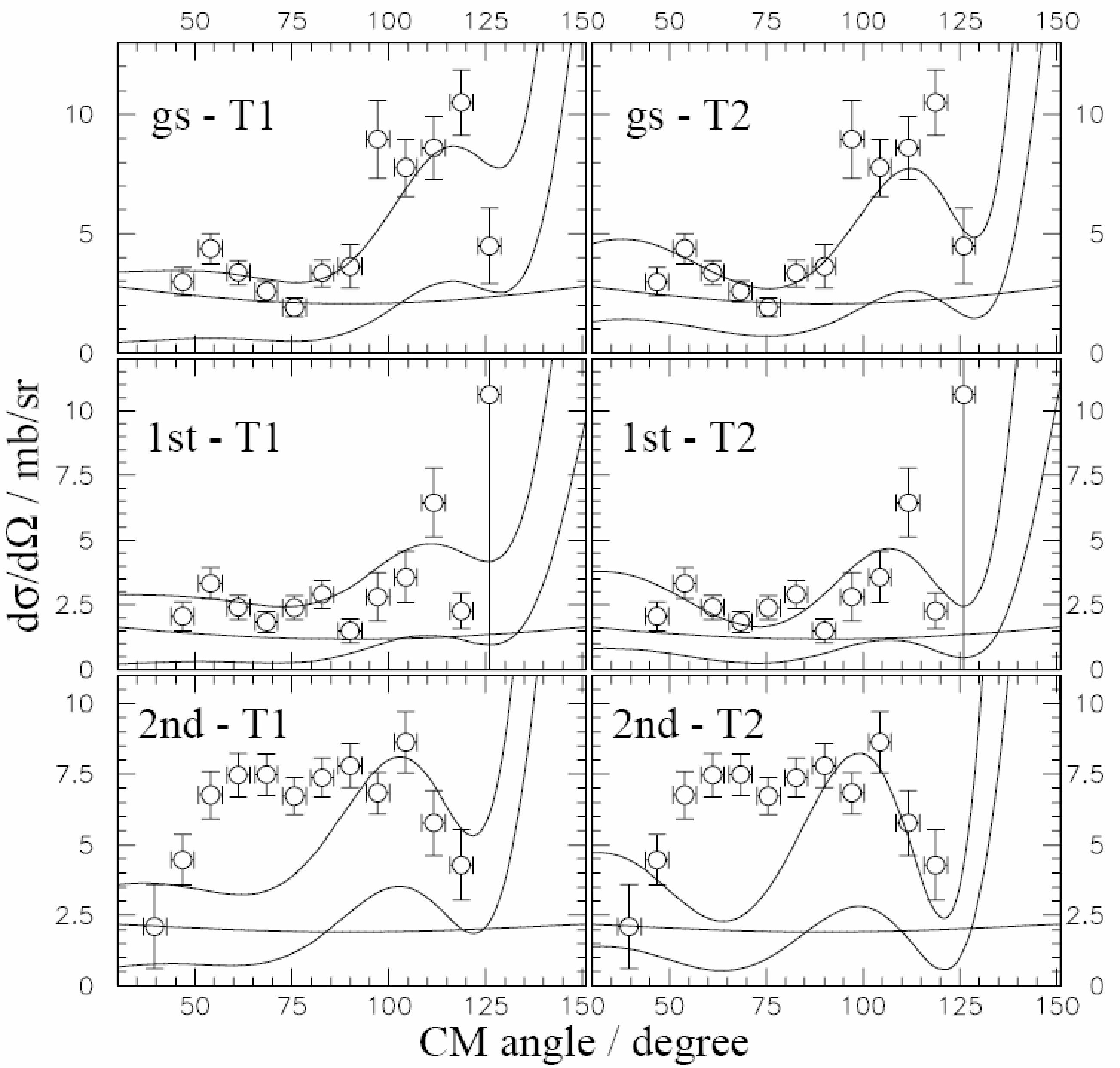




S.C. Pieper, Nuclear Physics A 751 (2005) 516c–532c

$^{2}H(^{9}Li,t)$



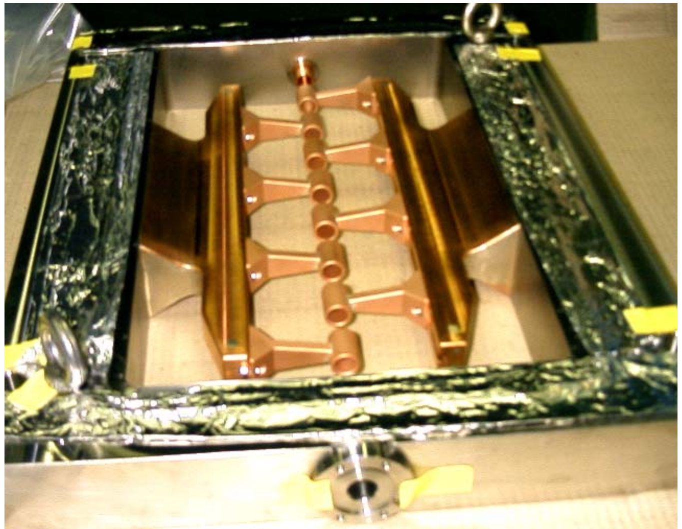


H.B. Jeppesen et al, in preparation

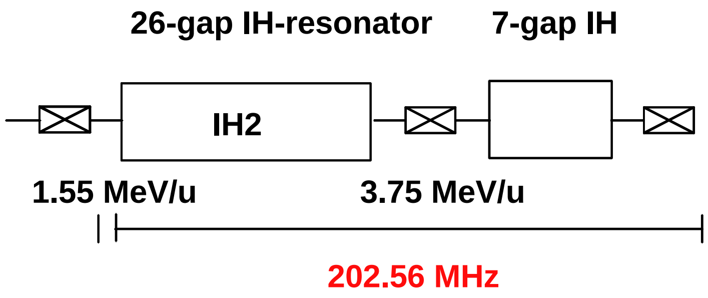
Next steps

- Higher beam energy will permit populating higher excited states and studies of heavier nuclei
- Target and post-accelerator developments for new and enhanced beams
  - Target/ion source, charge breeding, energy, ε
- Further optimize detection systems
  - Lower thresholds, new PID methods, better coverage
- Topics – a selection
  - Further info on light nuclei and resonances ex. $^{11,12}Be$, ^{13}Be, C
  - Elastic resonant scattering
  - Dipole polarizability of ^{11}Li
  - Direct cluster transfer
  - Map island of inversion, N~20,28

REX-ISOLDE beams - outlook

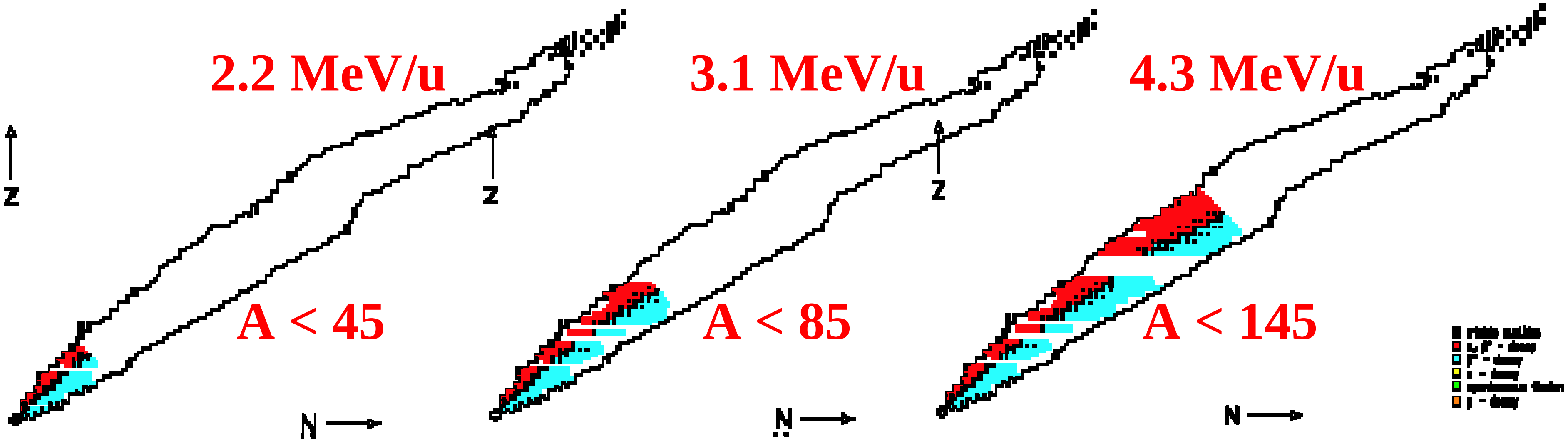


Additional 9-gap accelerating structure



Exchange existing 7-gap with IH accelerating structures

2003 → **2004** → **2006-7**

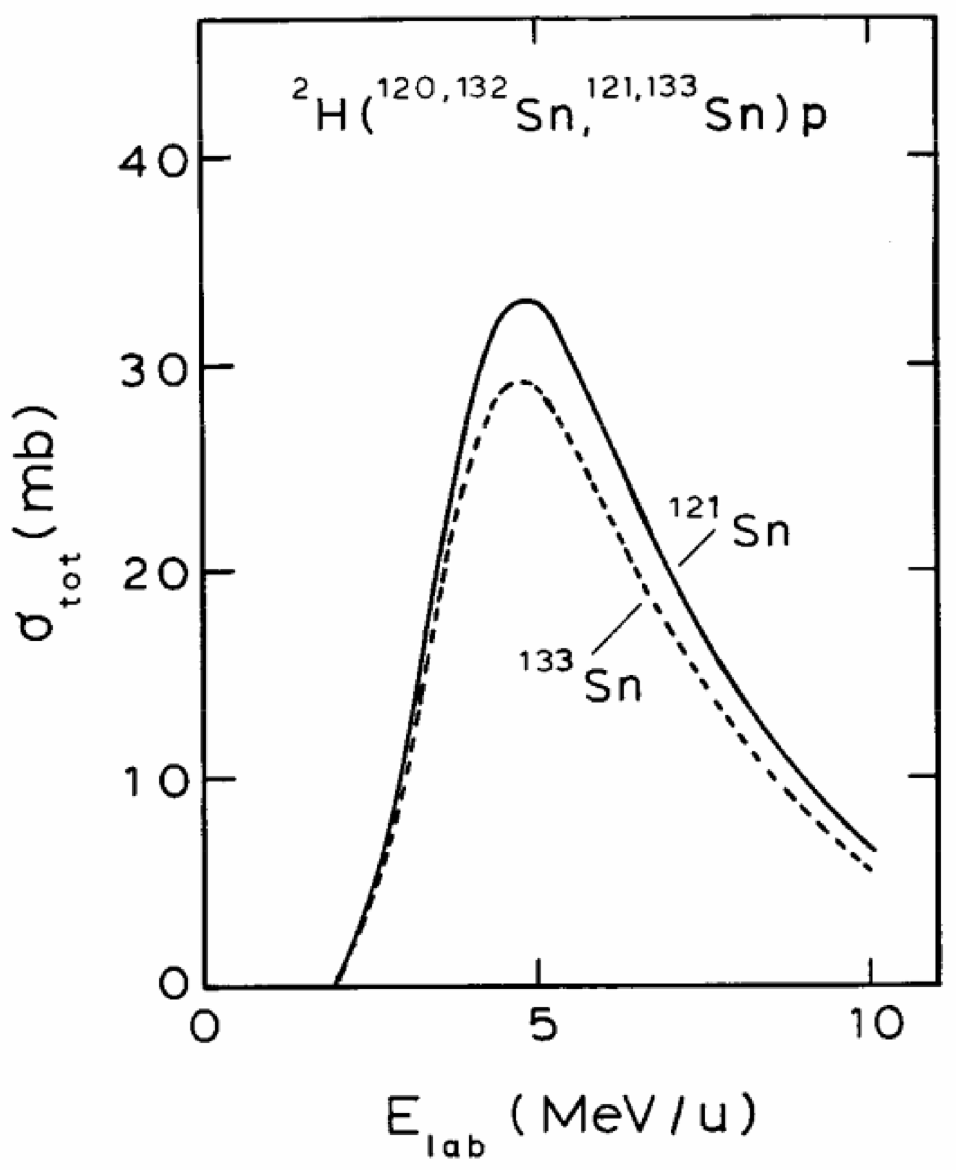


RIBs reaching the Coulomb barrier

Optimum energy?

- Optimize:
  - Cross section
  - Excitation energy
  - Suppression of unwanted channels
  - Energy matching and localization of transfer
  - Compound contributions
  - Detection efficiency

Cross Sections of Single Neutron Transfer



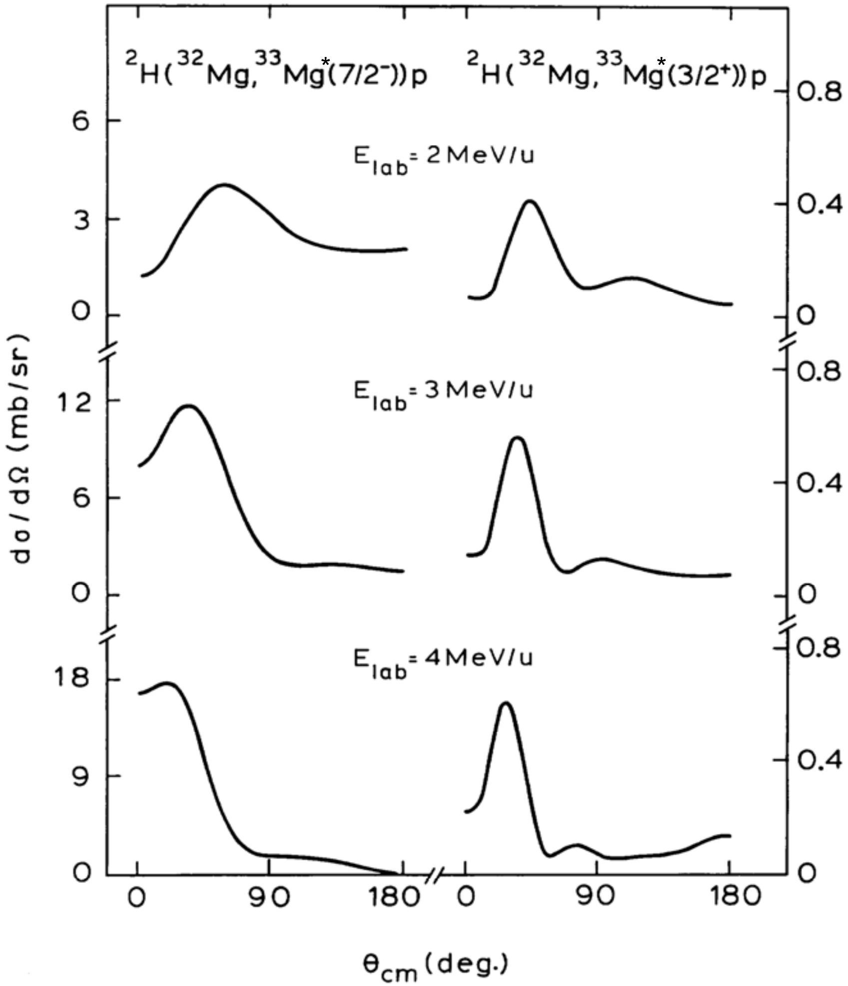
- Single-nucleon transfer reactions on ^{2}H and ^{9}Be targets and low beam energies most favorable → Q-value/momentum matching

- Cross section maximal for ^{9}Be target, range from some tens to a few 100 mb and decrease strongly to higher Z targets

- Transfer to excited states rather than to g.s.

H. Lenske,G. Schrieder
Eur. Phys. J A2(1998)41

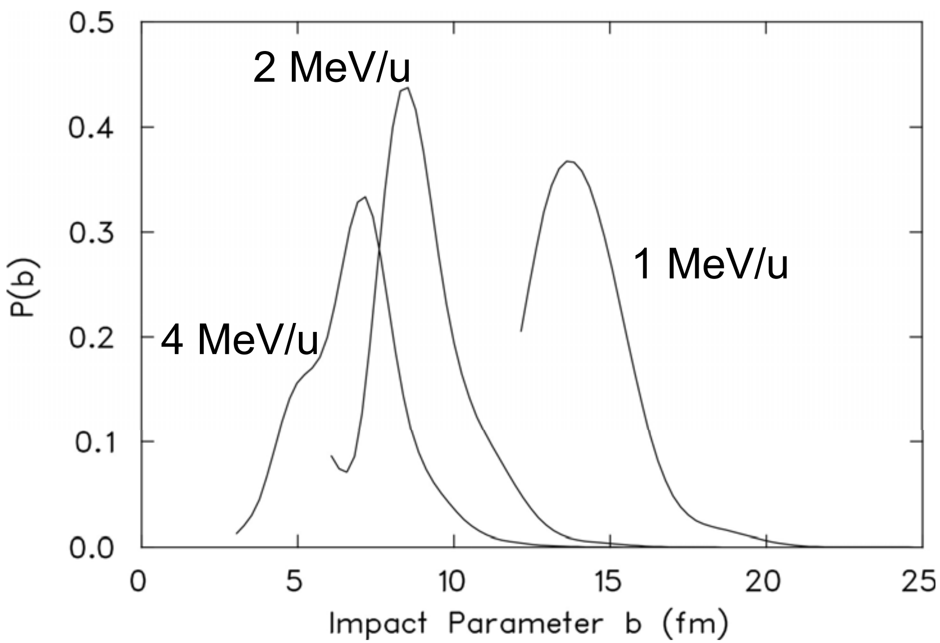
Angular distributions



- forward peaked (direct reaction)
- relative narrow width

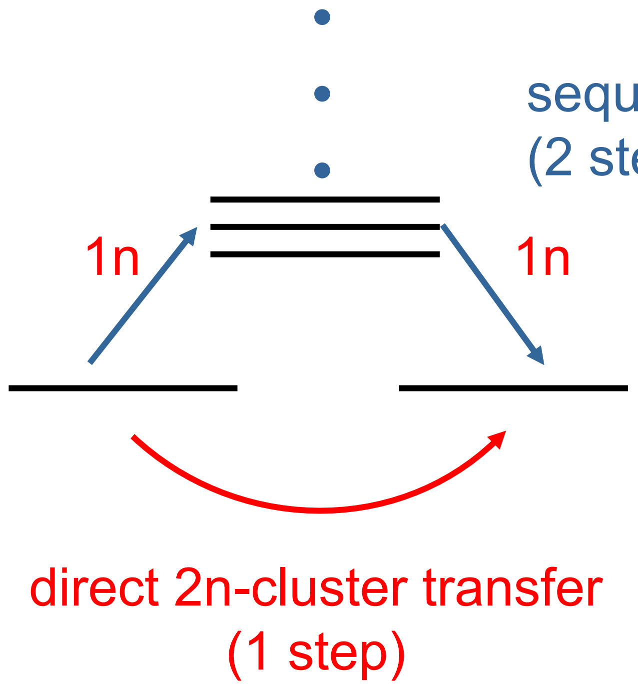
Localization of Transfer

$^{2}H(^{36}S,^{37}S^{*}(3/2^{-}))p$

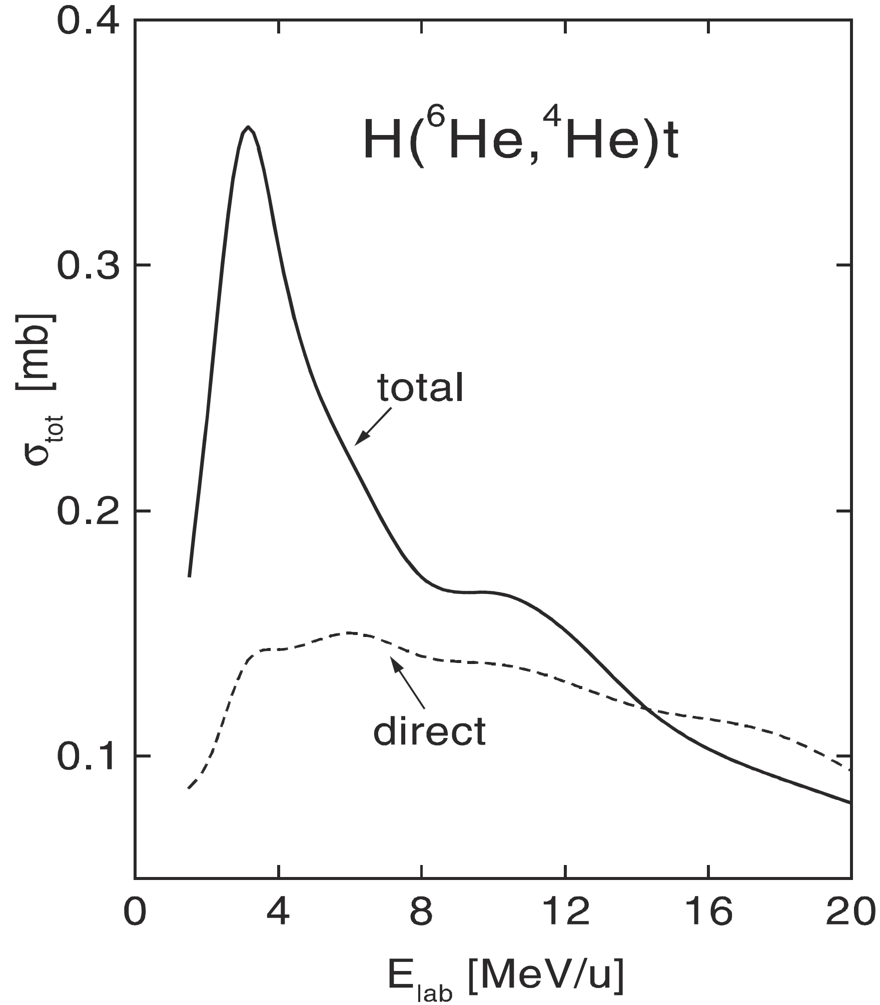


strong sensitivity to radial dependence of single-particle wavefunctions

2n Transfer Reactions



$$^{10}Be(^{A}_{Z}X,2\alpha)^{A+2}_{Z}X$$



A.N.Ostrowski PRC 63(2001)024605,
N.K.Timefeyuk and I.J.Thompson PRC 61(2000)044608

Conclusions

- Low-energy transfer reactions can address several contemporary hot topics in very exotic nuclei
  - We have only started to exploit these possibilities
- Interpretation feasible
  - Established methods
  - Compound contributions manageable
  - Continuum couplings still a challenge?
- Higher and tuneable energy needed for REX-ISOLDE