# Spectroscopic Factors from Coulomb Breakup Measurements

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***Gesellschaft für Schwerionenforschung***

*Workshop on*

*Spectroscopic Factors*

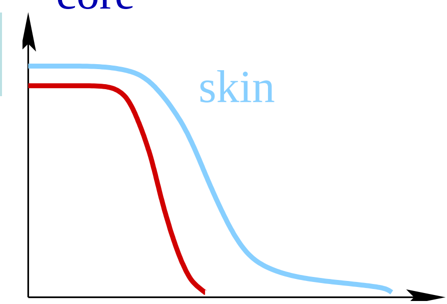
ECT* Trento, March $2^{nd}$ -$12^{th}$ , 2004

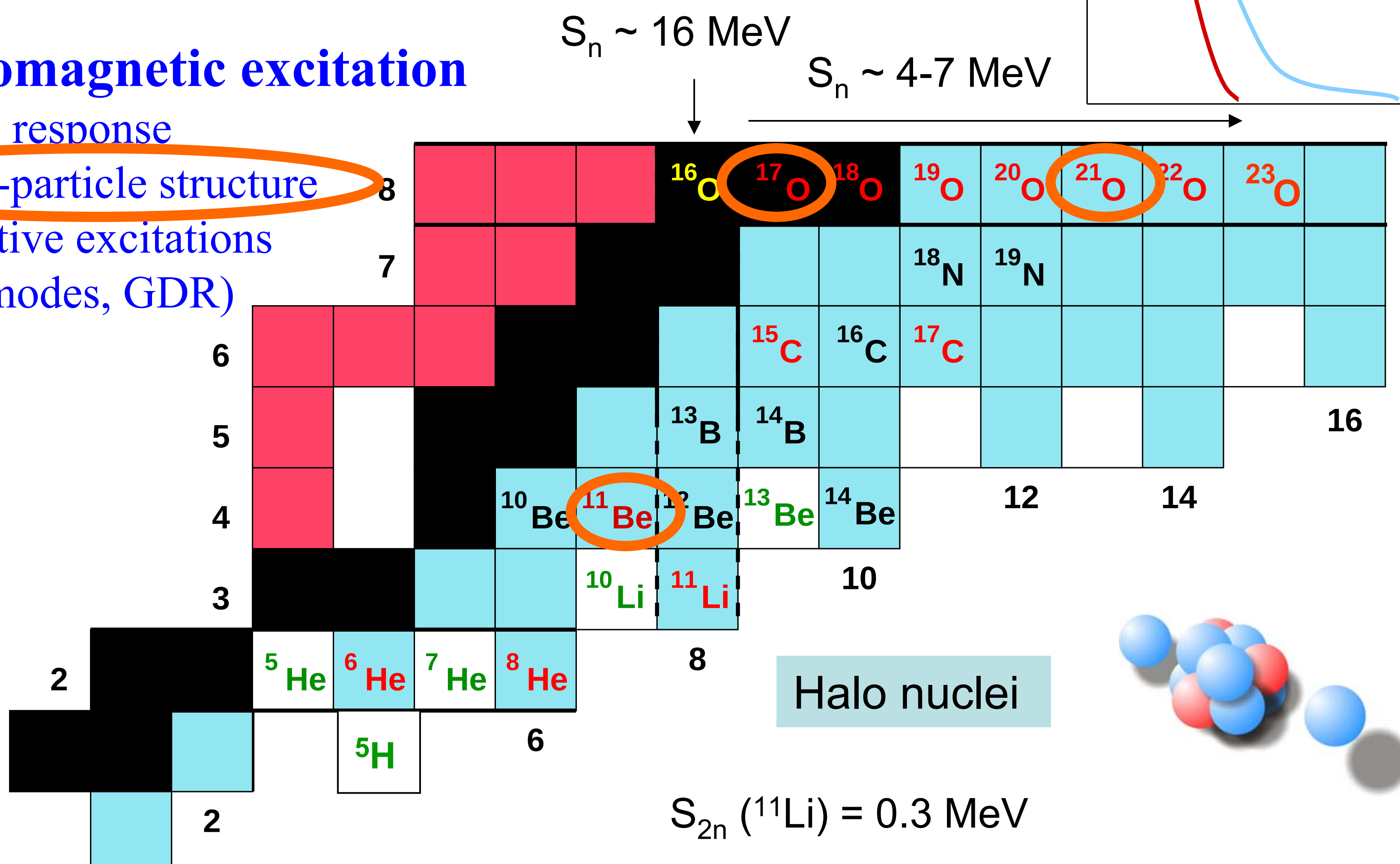
- Experimental Concept
- Results and Discussion
  - Non-resonant dipole transitions and single-particle structure
  - Examples: $^{11}$Be, $^{17-21}$O
  - Electromagnetic vs. Nuclear
- Future Developments

# Scattering of Light Neutron-Rich Nuclei Investigated at LAND@GSI

- **Knockout**
  - single-particle structure
  - unbound states
- **Electromagnetic excitation**
  - dipole response
  - single-particle structure
  - collective excitations (soft modes, GDR)

Neutron skin

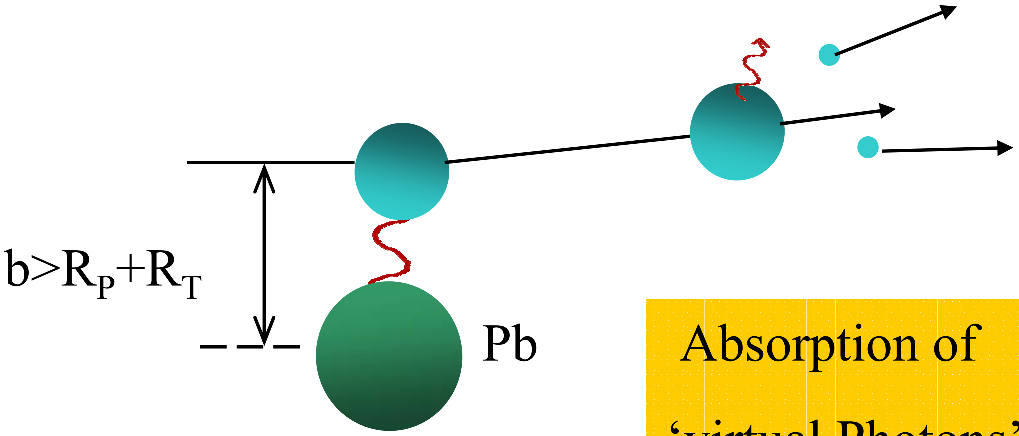



Halo nuclei

$S_{2n}$ ($^{11}$Li) = 0.3 MeV

# Electromagnetic excitation of secondary beams




$\sigma_{elm} \sim Z^2$

Absorption of 'virtual Photons'

Semi-classical theory:

$$d\sigma_{elm} / dE = N_\gamma(E)\, \sigma_\gamma(E)$$

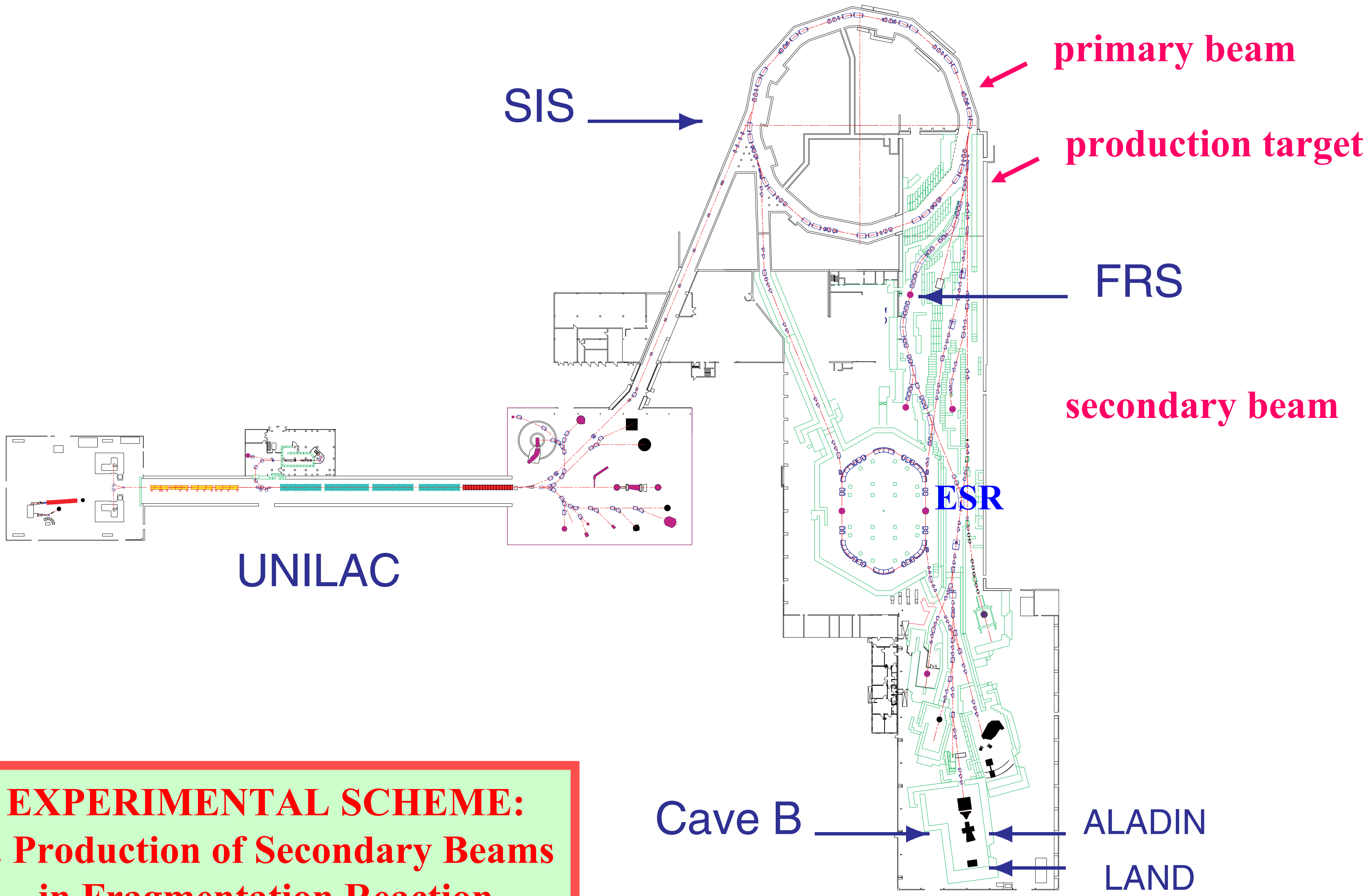
High velocities $v/c \approx 0.6\text{-}0.9$

$\Rightarrow$ High-frequency Fourier components

$E_{\gamma,max} \approx 25$ MeV (@ 1 GeV/u)

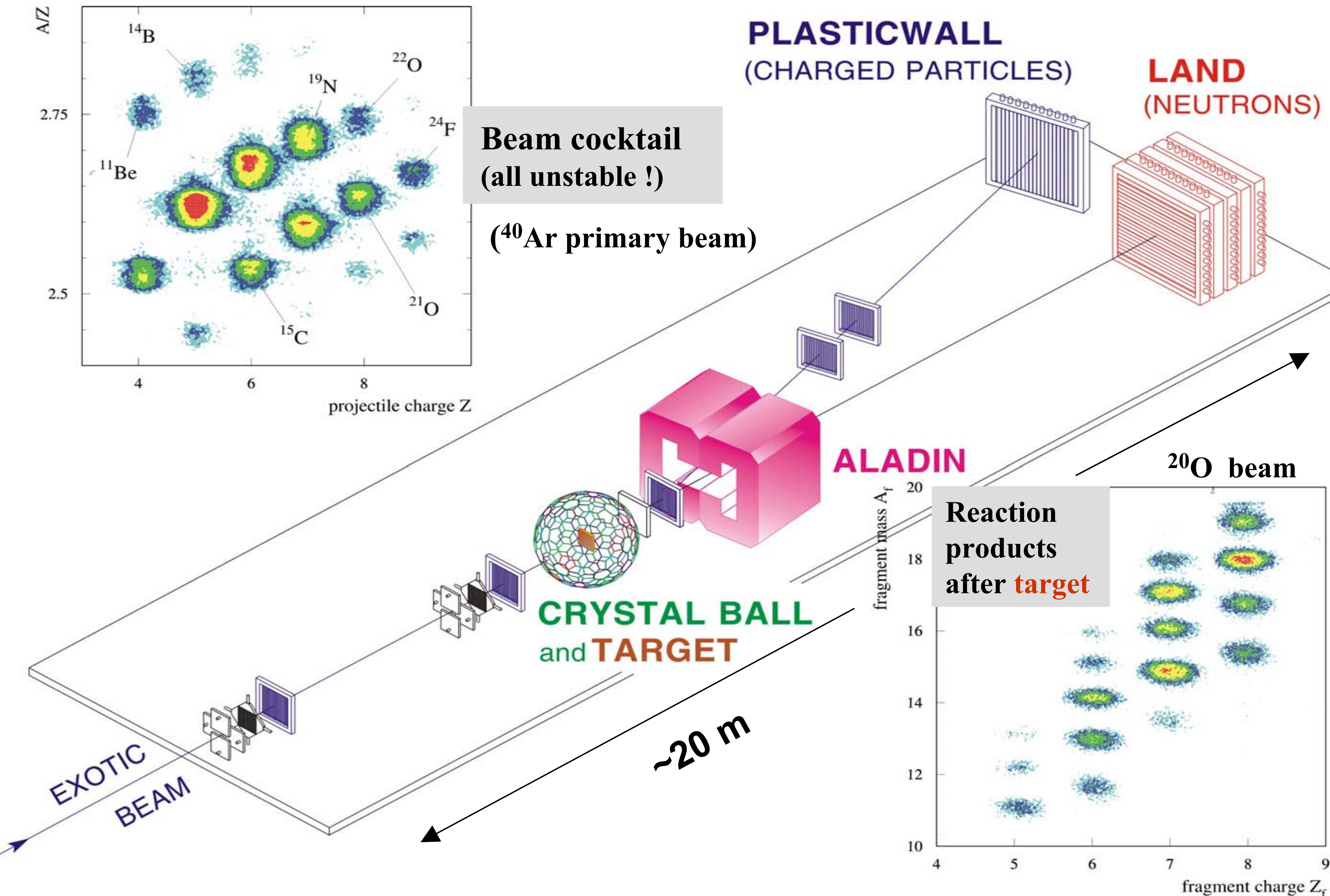
Determination of 'photon energy' (excitation energy) via a kinematically complete measurement of the momenta of all outgoing particles (invariant mass)

# The GSI Accelerator Facilities




**EXPERIMENTAL SCHEME:**
**I. Production of Secondary Beams in Fragmentation Reaction**

# Experimental Scheme: Setup LAND@GSI

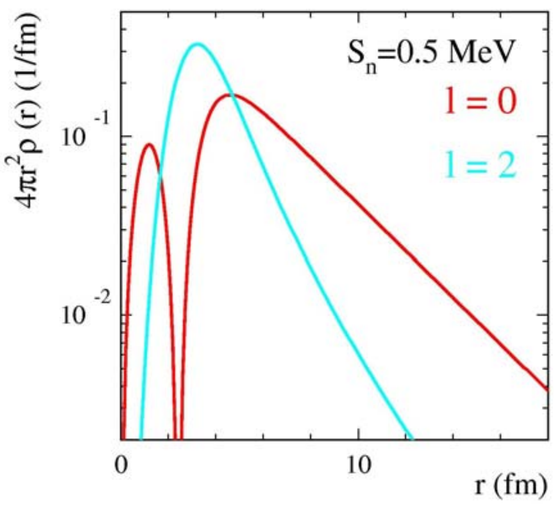


# Low-Lying E1 Strength as Spectroscopic Tool

Wave function: e.g. $|^{11}Be\rangle = \alpha|^{10}Be(0^+)\otimes 2s_{1/2}\rangle + \beta|^{10}Be(2^+)\otimes 1d_{5/2}\rangle + \ldots$

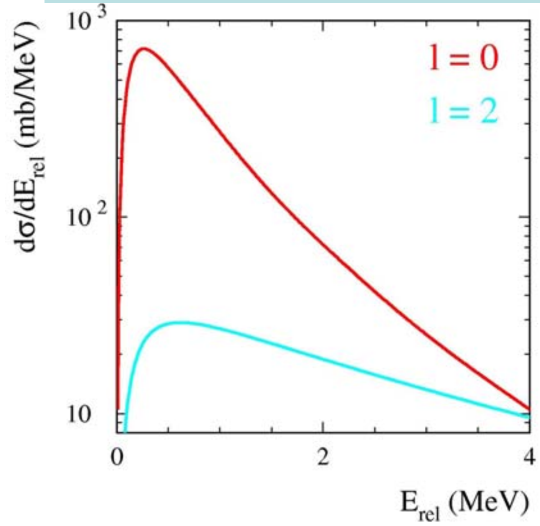
$$d\sigma(I_c^\pi)/dE_{rel} = \frac{16\pi^3}{9\hbar c} N_{E1}(E^*)\ S(I_c^\pi, nlj) \sum_m |\langle q | \frac{Ze}{A} r Y_m^l | \Phi_{nlj} \rangle|^2$$

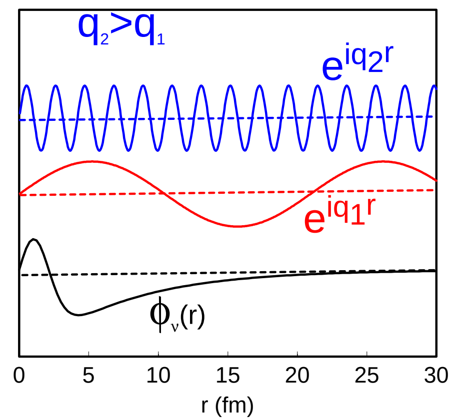
Density distribution




⇔

Differential cross section



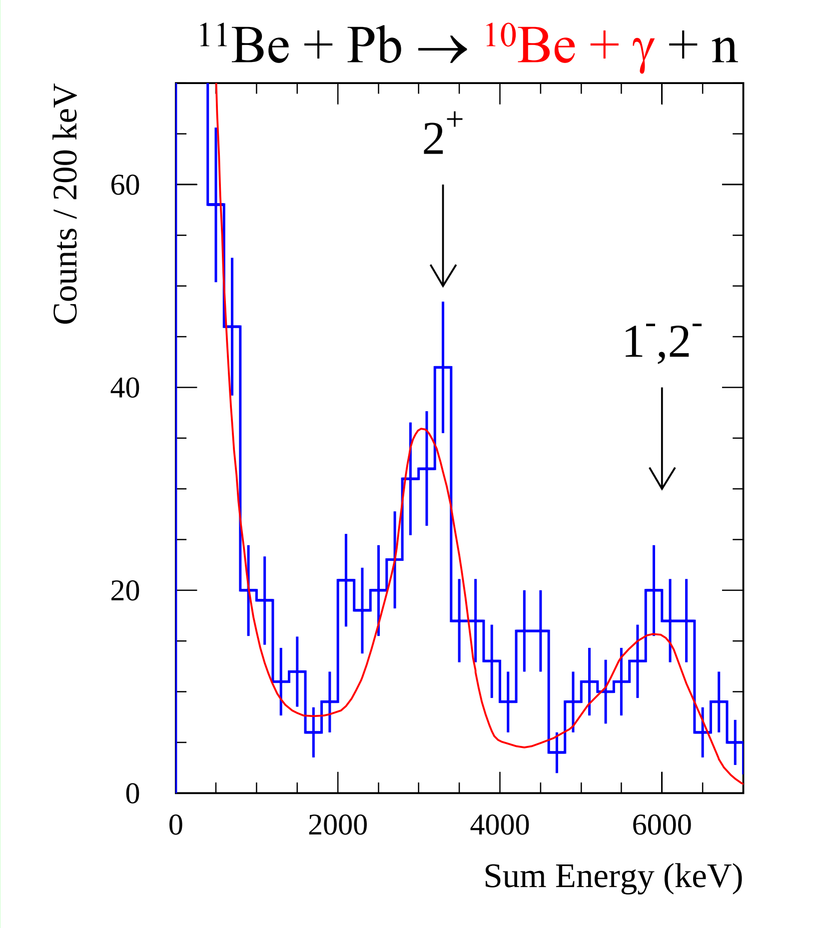

**Shape of differential cross section ⇒ angular momentum *l***

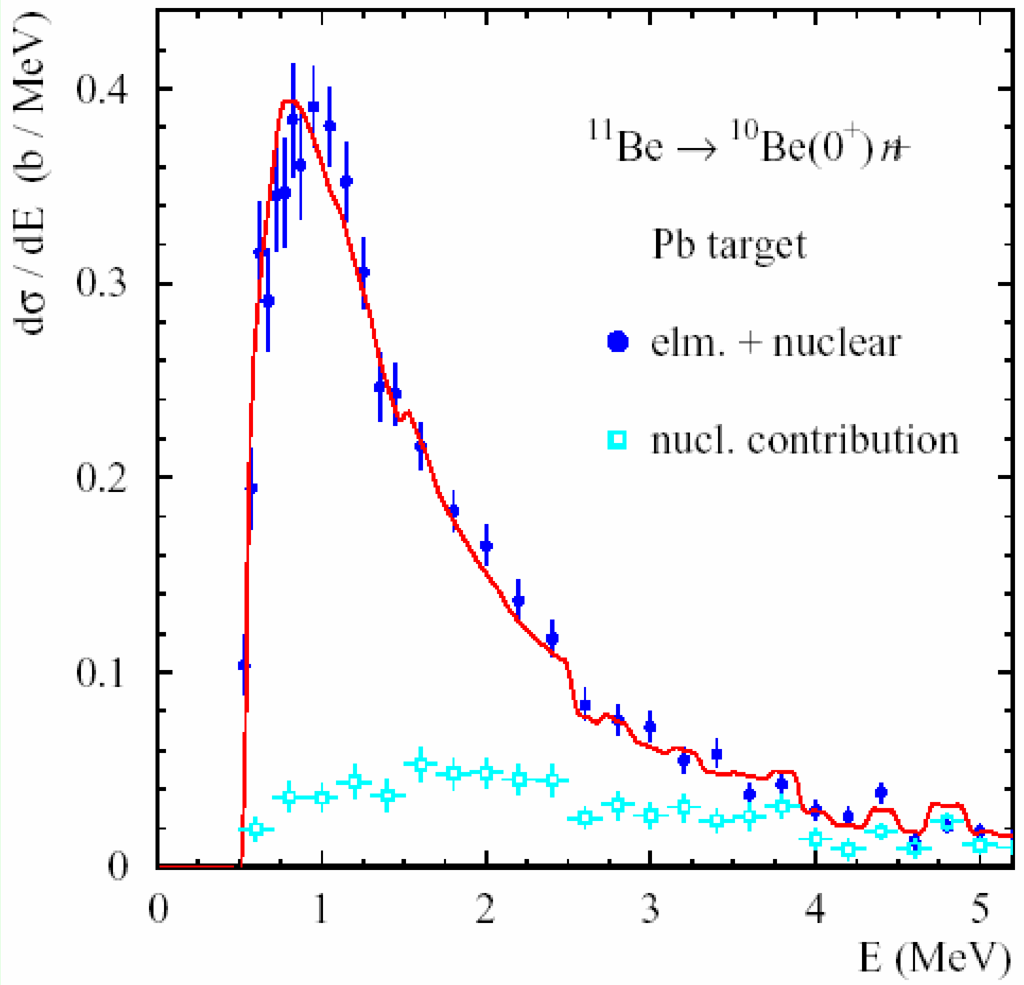
**$\gamma$-ray coincidence ⇒ identification of core state**

**Cross section ⇒ spectroscopic factor**

# Coulomb Breakup of $^{11}$Be: The Classical One-Neutron Halo

$$|^{11}Be\rangle = \sqrt{S(2^+)}\,|^{10}Be(2^+)\otimes 1d_{5/2}\rangle + \sqrt{S(0^+)}\,|^{10}Be(0^+)\otimes 2s_{1/2}\rangle + \ldots$$




**Data: LAND-FRS@GSI**

**R. Palit et al., PRC 68 (2003) 034318**

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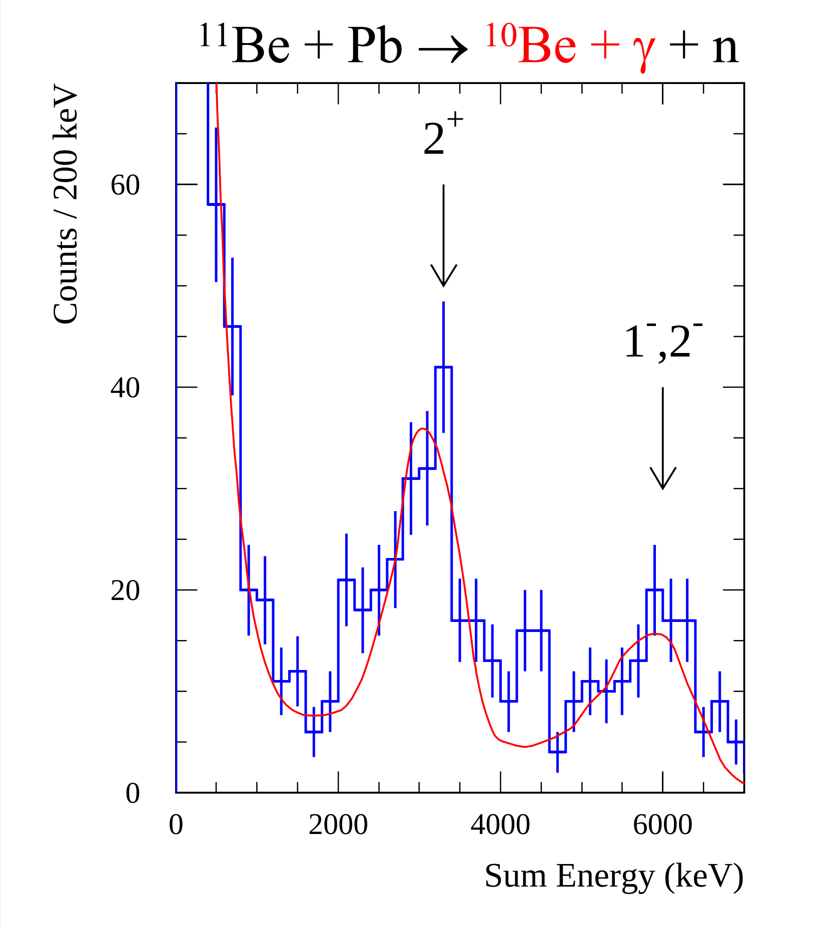


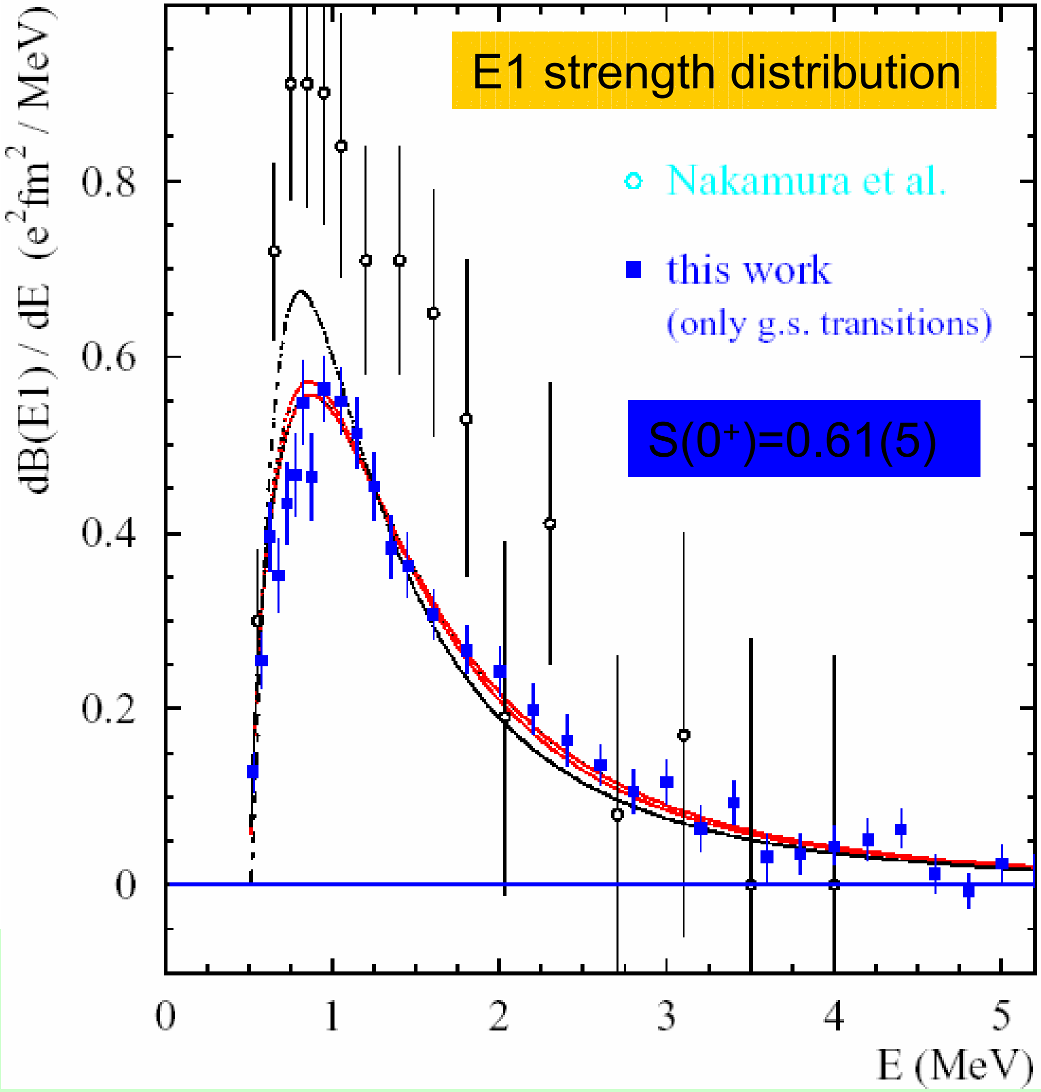


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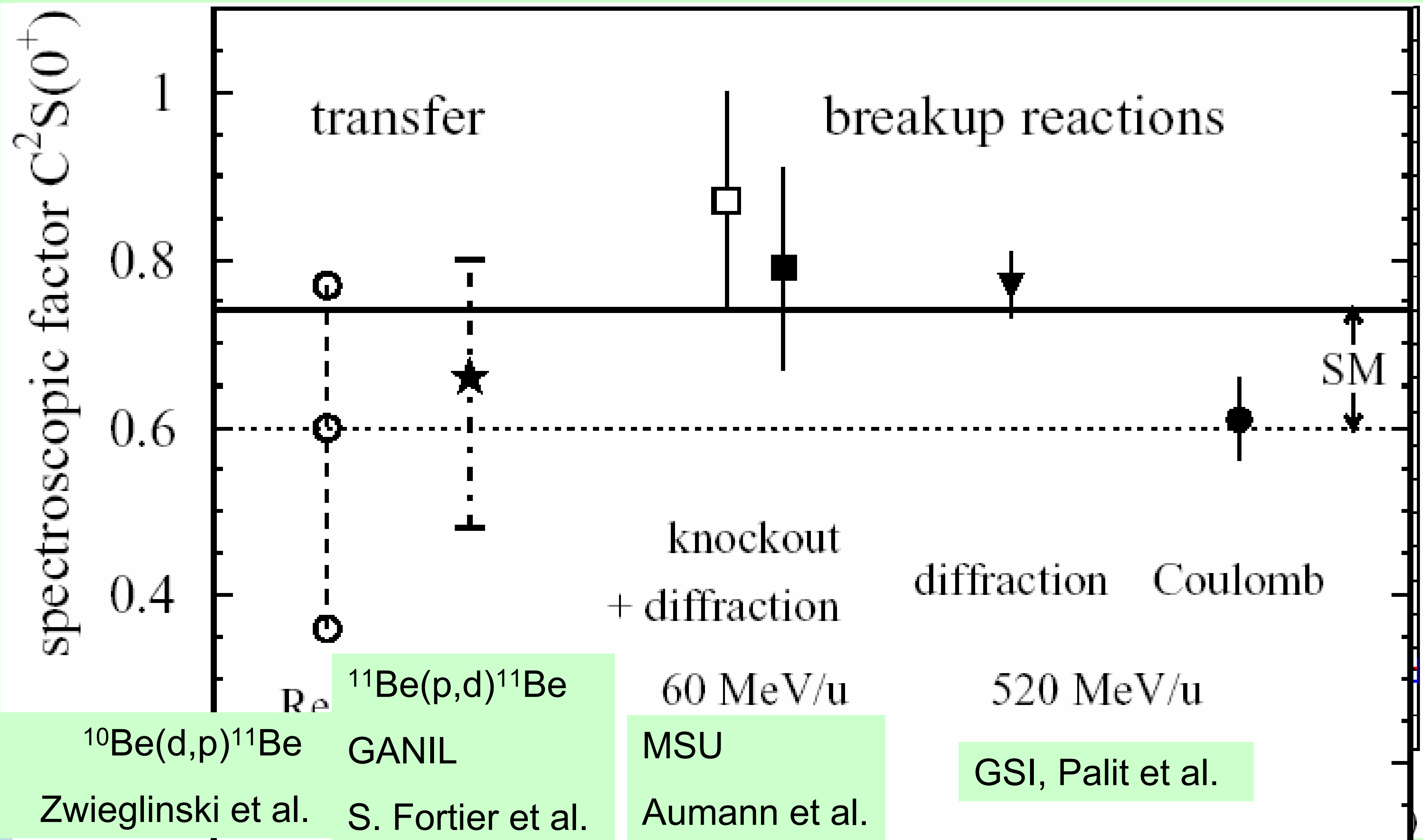



$^{10}$Be(d,p)$^{11}$Be
Zwieglinski et al.

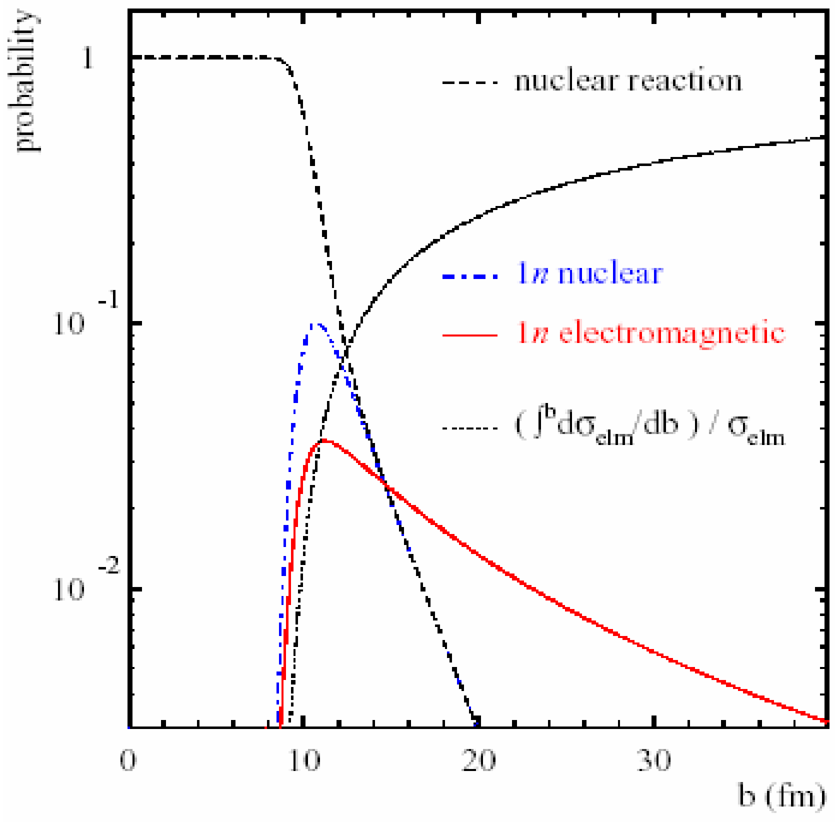
$^{11}$Be(p,d)$^{11}$Be
GANIL
S. Fortier et al.

MSU
Aumann et al.

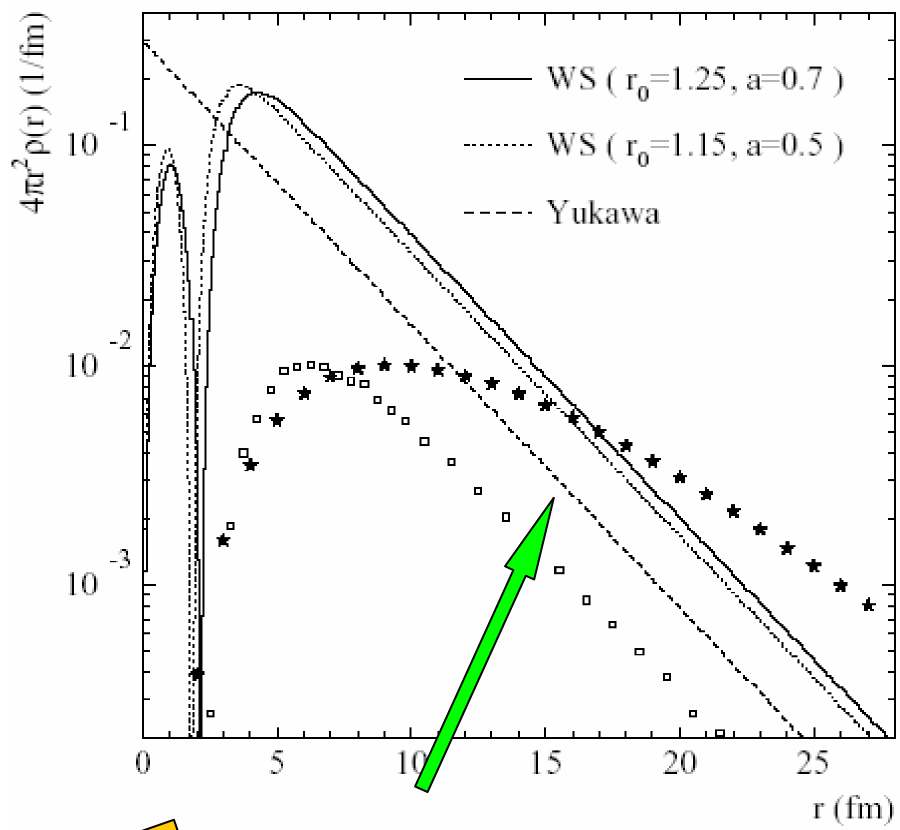
GSI, Palit et al.

# Sensitivity of Coulomb Breakup

## Reaction probabilities



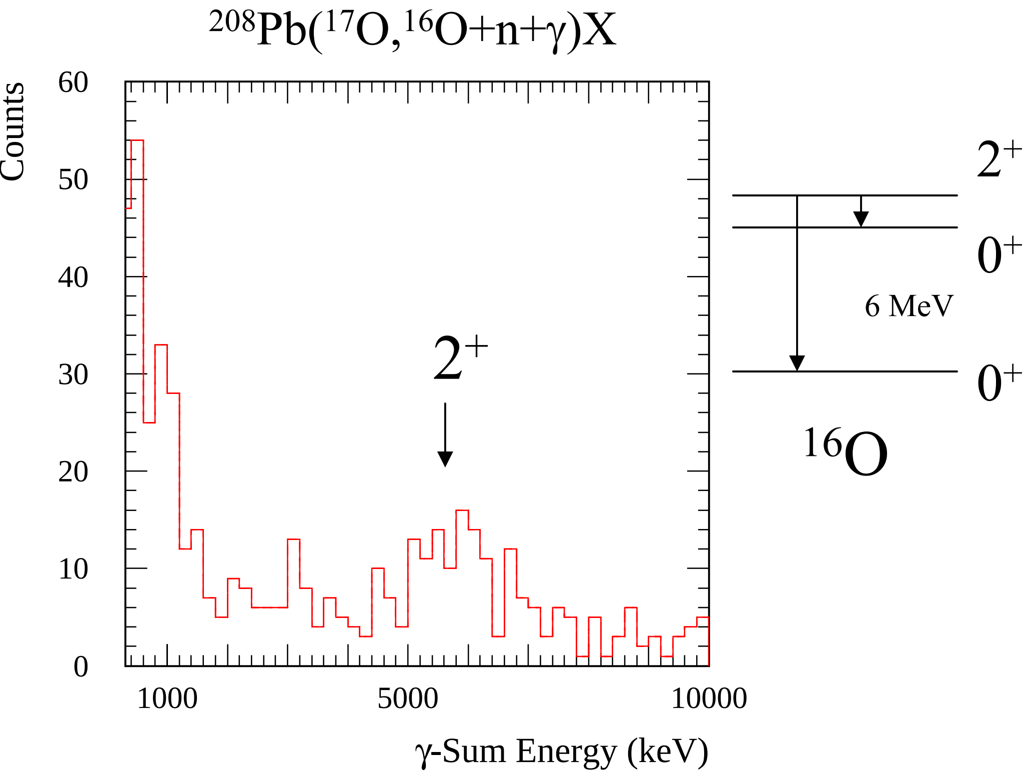

## Halo-Neutron Densities

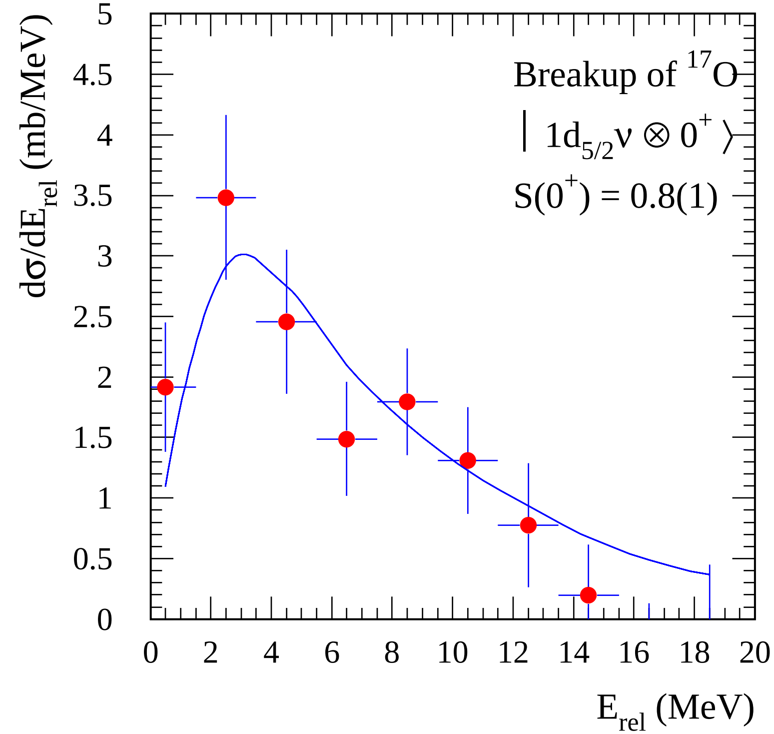



Sensitivity to low-density tail of the wave function

Overlap with continuum wave function

# Coulomb breakup of $^{17}$O: Test of breakup model




Transfer reaction and magnetic electron scattering gives $S(0^+)=1.04\pm0.10$

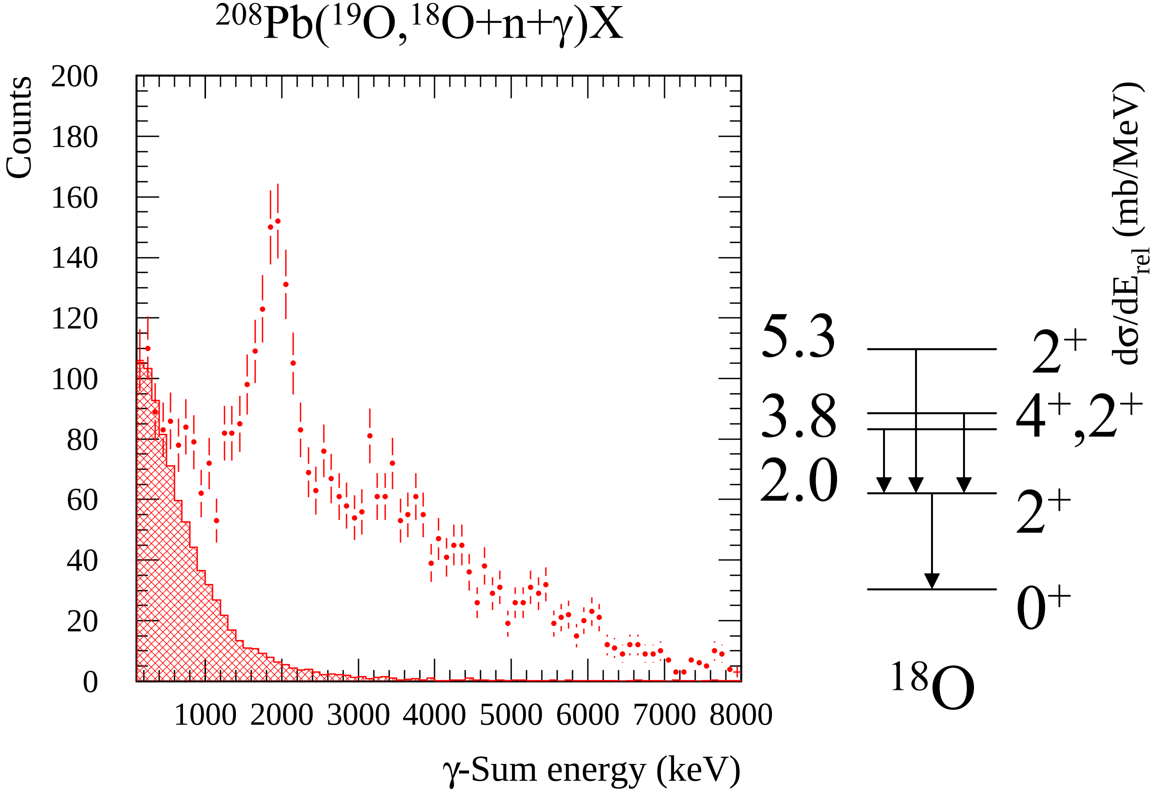
*S. Burzynski et al. Nucl. Phys. A399(1983) 230*

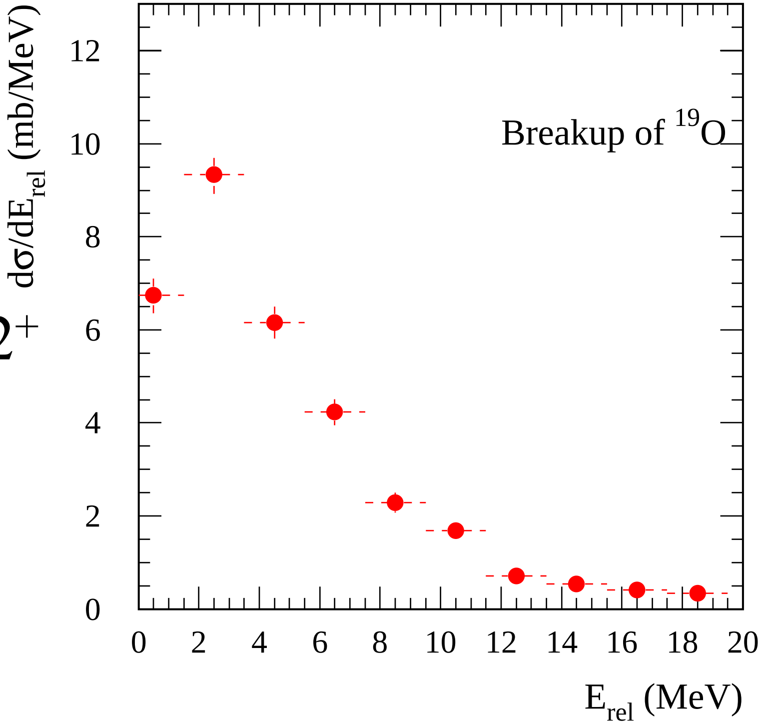
However, a small contribution is also present from excited core states

*H.T. Fortune et al. PRL 41 (1978) 527*

R. Palit et al.

# Coulomb breakup of $^{19}O$



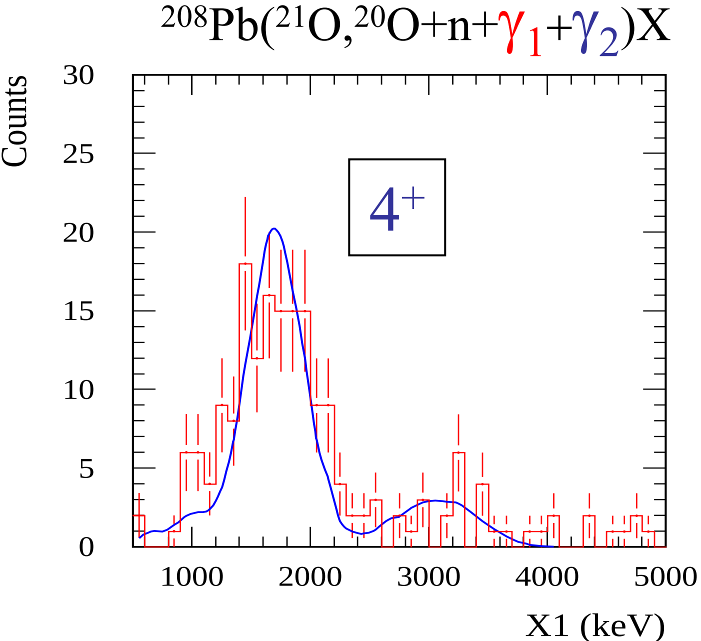

Calculated: $\sigma_{Coul} = 53$ mb

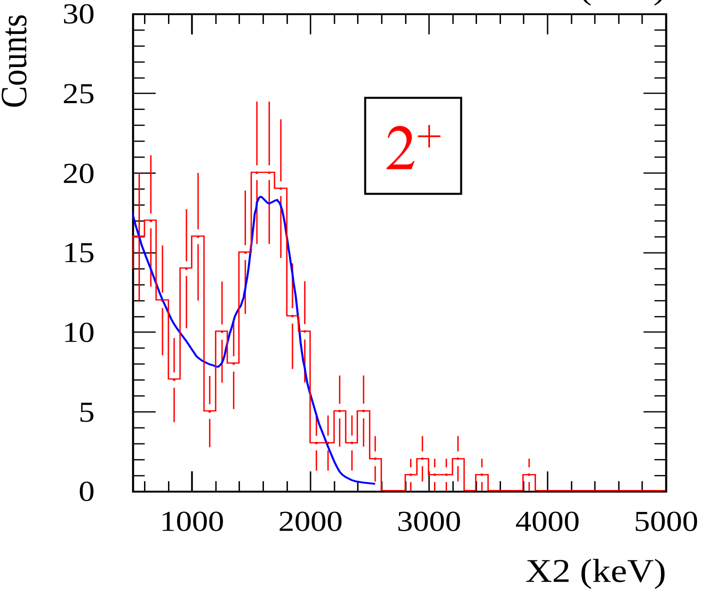
$\sigma_{Coul} = 68 \pm 2$ mb

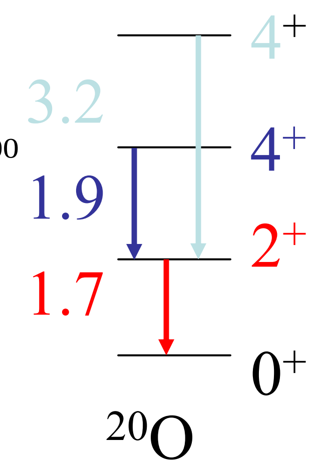
Limiting case because of resolution of γ-detector!

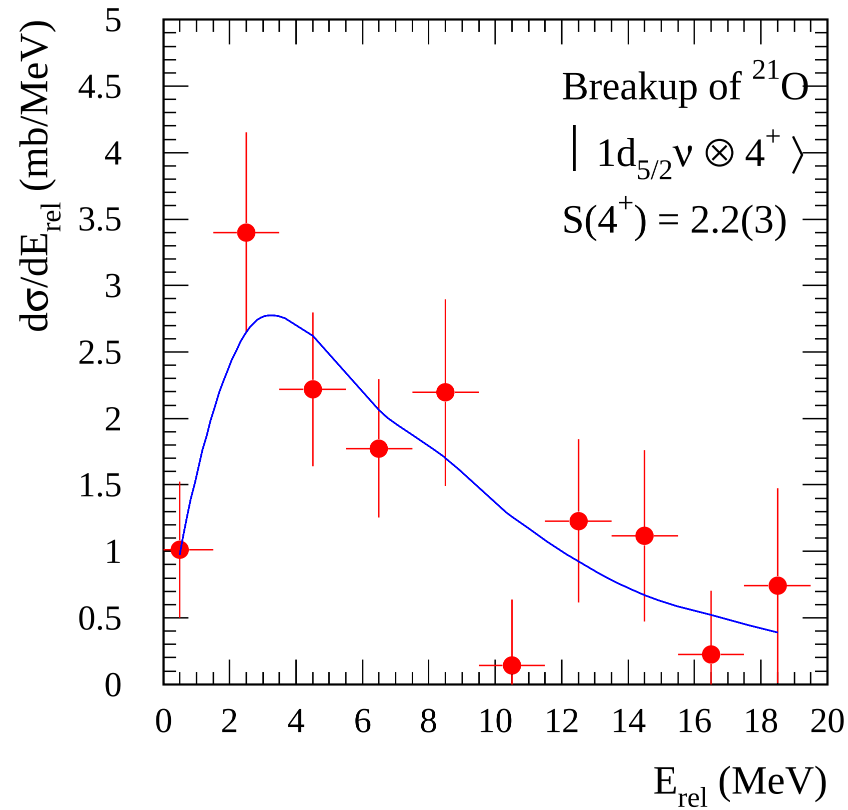
Palit et al.

# Coulomb Breakup of $^{21}$O




Dominant ground state configurations

$$\sqrt{S(0^+)}\ |\,^{20}O(0^+)\otimes\nu 1d_{5/2}> + \sqrt{S(4^+)}\ |\,^{20}O(4^+)\otimes\nu 1d_{5/2}>$$

Confirms the ground state spin of $^{21}$O as $J^{\pi} = 5/2^+$

Shell model: $C^2S(4^+) = 2.59$

R. Palit et al., to be published

# Coulomb / Nuclear Breakup

| Coulomb breakup | Knockout + Diffraction |
|---|---|
| best suited for halo states (-> huge cross sections) | general applicable (for valence nucleon states) |
| well understood reaction mechanism (in particular at high energies) | quantitative reaction theory for knockout part ( and for high beam energies ) |
| sensitivity to low-density tail of w.f. (asymptotic normalization) | surface dominated |
| no parameters in cross section calculations | 'core' absorption has to be taken into account (assuming densities) |
| problem of final state interaction | two mechanisms: knockout + diffraction final state interaction in case of diffraction (resonant excitations) |

The two reaction mechanism are complementary and require different approximations in the reaction calculation

Comparison helps judging how quantitative are spectroscopic factors

# Quasi-free scattering

nucleon and cluster knockout reactions: (p,2p) (p,pn) (p,p$\alpha$), ...

goal: fully exclusive measurement (target recoil p, knocked nucleon/cluster, heavy recoil momentum analyzed, gamma coincidence defines core state)

→ background free measurement

minimization of final state interaction problem due to

- over determination of kinematics
- high beam energy ~ 700 MeV/u

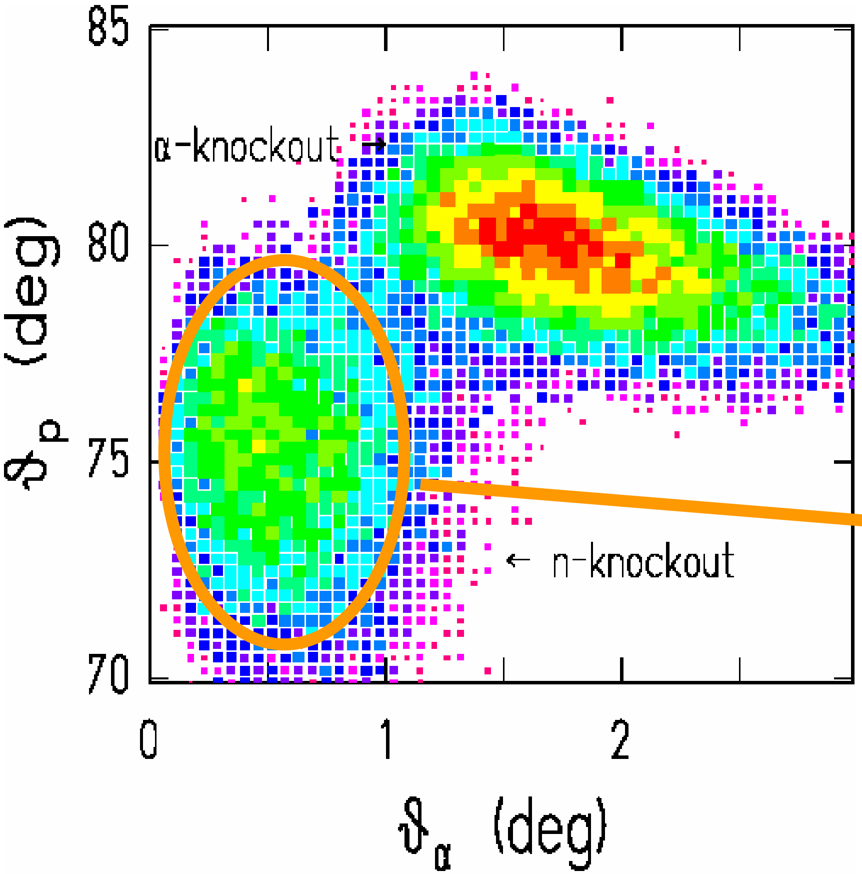
  (both nucleons in minimum of N-N cross section, 200 – 500 MeV)

knockout also from deeply bound states

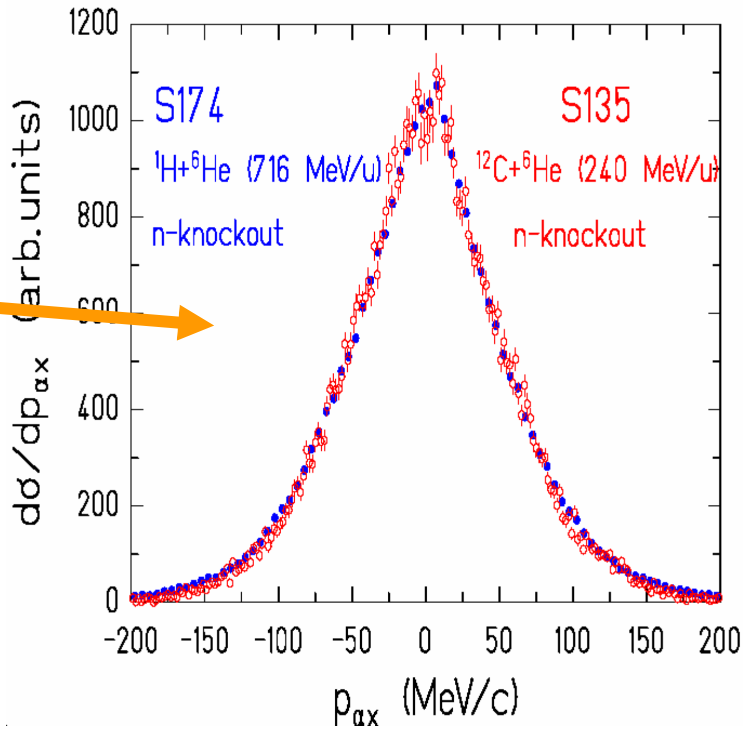
# Quasi-free cluster knockout

$^6He + p \rightarrow \alpha + p' + X$

Experiment S174: Proton elastic scattering (P. Egelhof et al.)



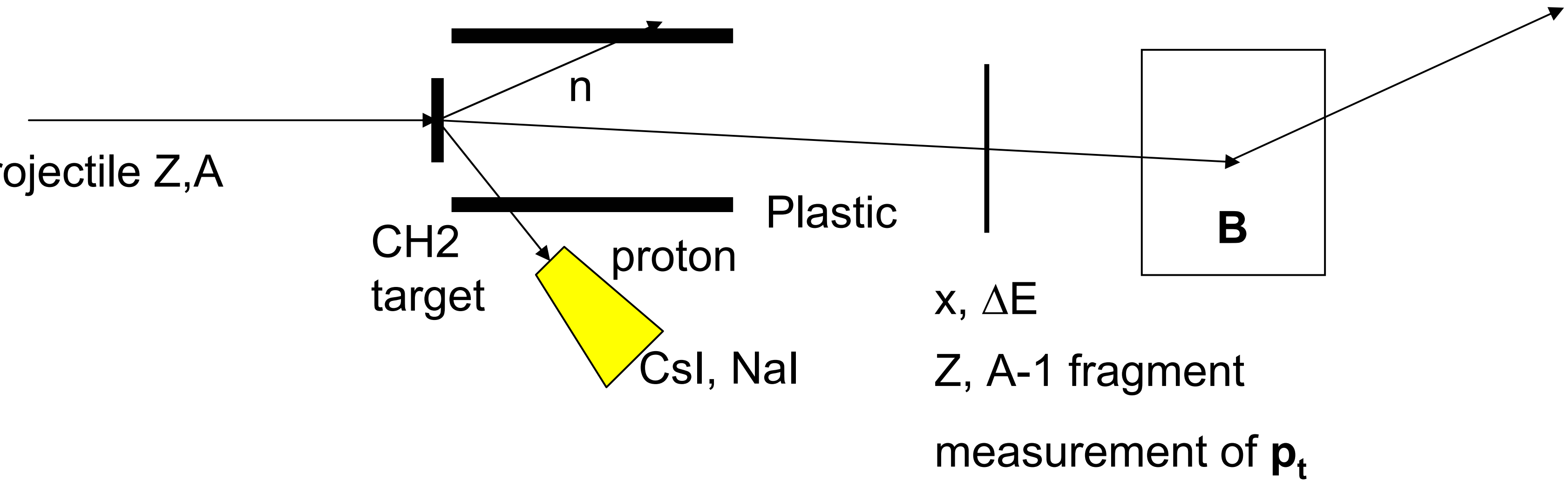

Momentum distribution




**L. Chulkov et al.**

# Towards a fully exclusive measurement of (p,px) reactions

Measurement of proton recoils after knockout reactions with a $CH_2$ target




1) signal of proton recoil provides clean trigger for knockout reaction

2) coincident measurement of A-1 fragment

3) gamma-coincidence identifies final state

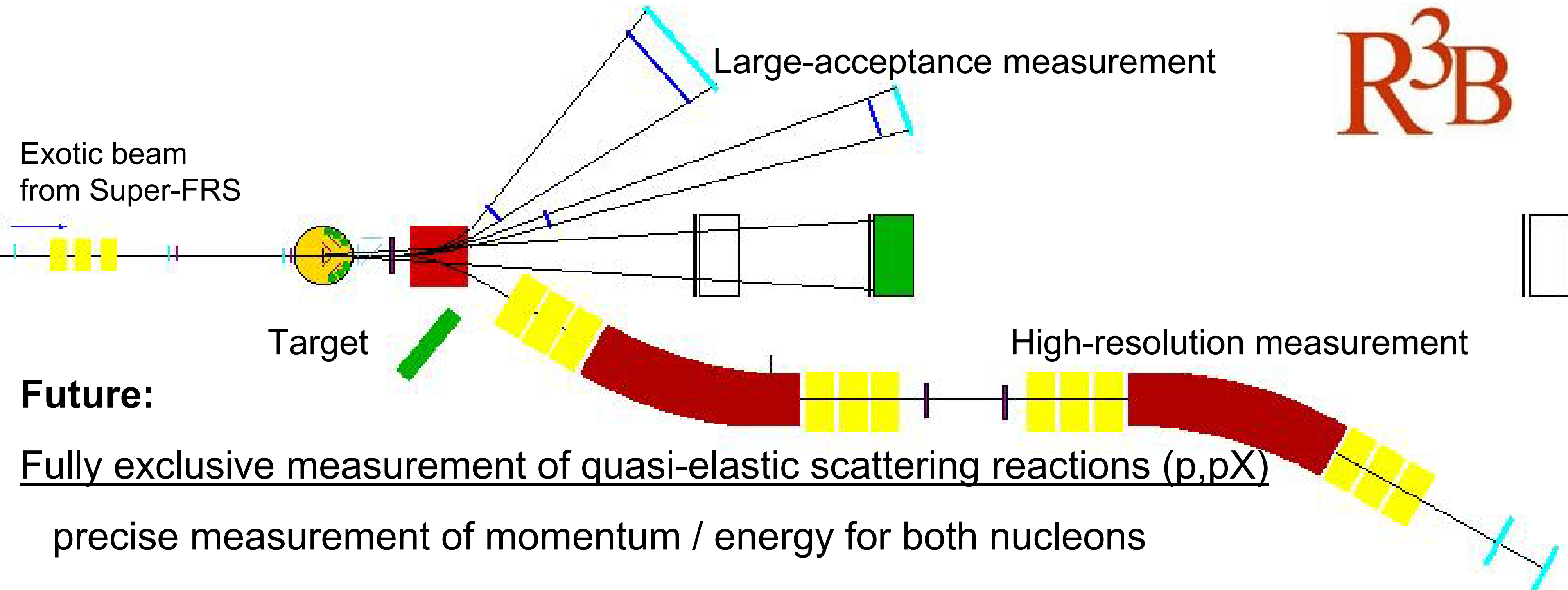
4) transverse momentum measurement provides l-value of knocked out nucleon

5) spectroscopic factors from cross sections

The high-energy branch of the Super-FRS:

A versatile setup for kinematical complete measurements of

# Reactions with Relativistic Radioactive Beams




**Future:**

<u>Fully exclusive measurement of quasi-elastic scattering reactions (p,pX)</u>

precise measurement of momentum / energy for both nucleons

identification and high-resolution momentum measurement of A-x fragment

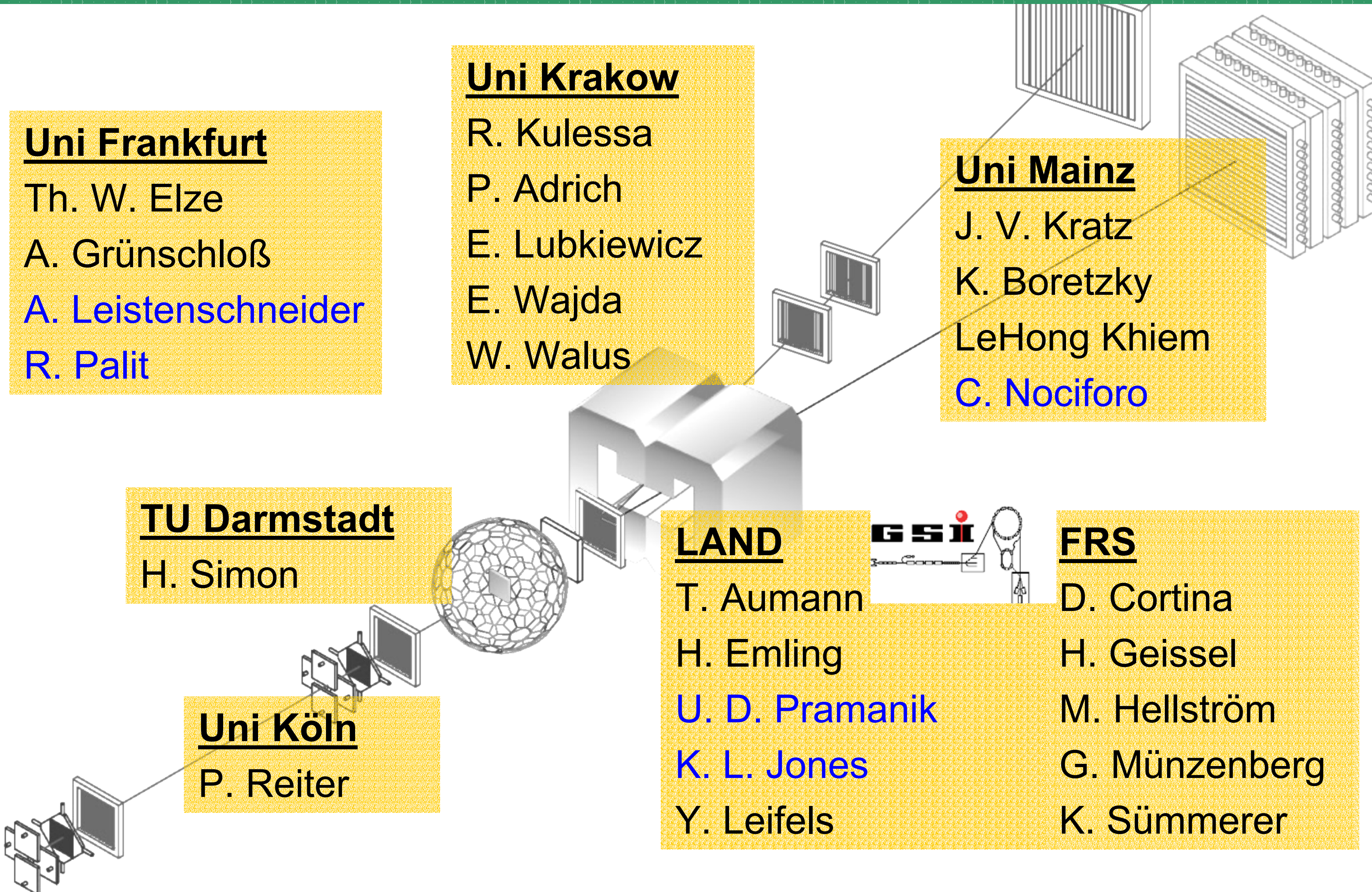
gamma-coincidence measurement

high beam energy: both nucleons in the minimum N-N cross section region

⇨ minimization of final-state interaction ⇨ less absorption

⇨ background-free measurement

# The LAND/FRS Collaboration S188/S233



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# Ground-State Configuration of Neutron-Rich Nuclei studied by Coulomb Breakup

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LAND-FRS@GSI collaboration