Complete Dipole Strength Distributions from Polarized Proton Scattering at Zero Degrees

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- Complete M1 and E1 strength distributions: what can be learned?
- Polarized proton scattering at 0°: a new spectroscopic tool
- ^{208}Pb: a reference case

TU Darmstadt / iThemba LABS / U Kyoto / U Miyazaki / U Niigata / RCNP Osaka / U Witwatersrand Collaboration

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SFB 634

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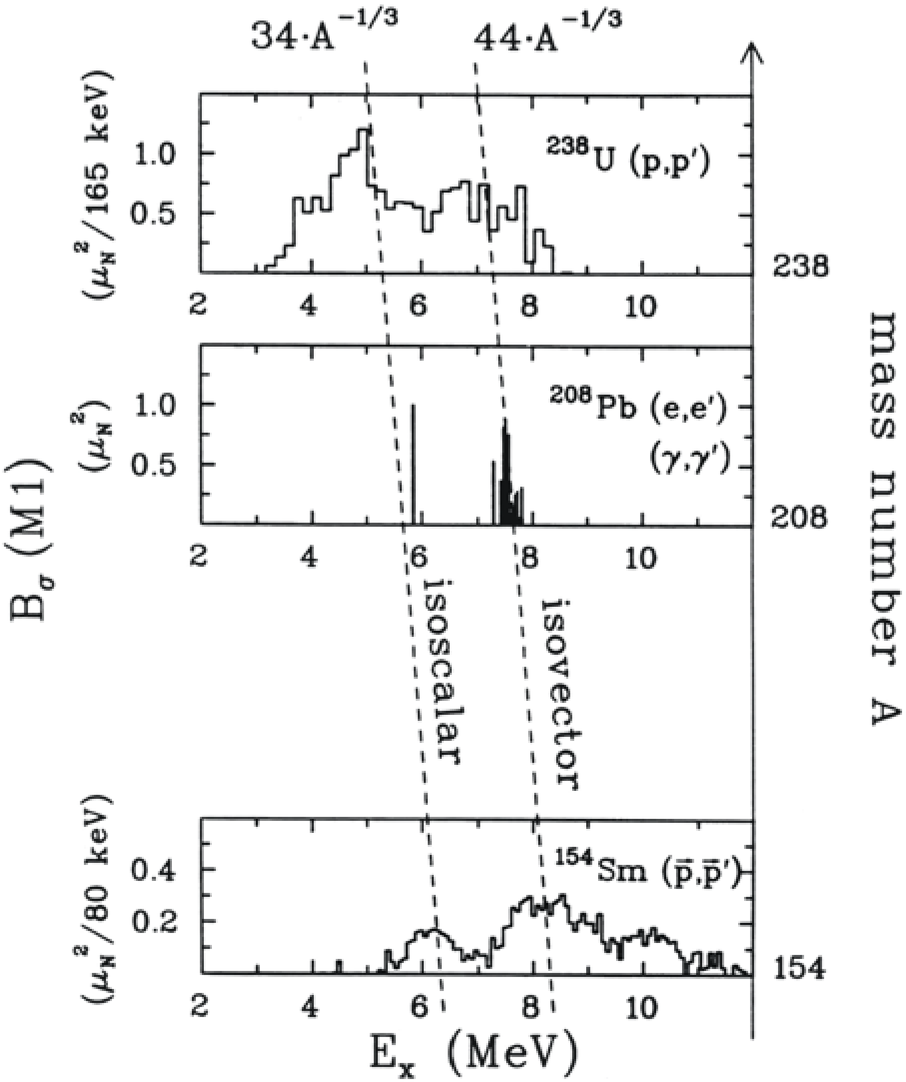
Spinflip M1 Strength

- Isovector part: analog of GT modes with $T = T_0$
- Appears in heavy nuclei at 1ħω energy ($E \approx 40 \cdot A^{-1/3}$)
- Quenching: in fp-shell nuclei similar to GT strength
  in heavy nuclei – little data
- Strength distribution: double hump structure?

Systematics in Heavy Nuclei



K. Heyde, PvNC, A. Richter, RMP, in press (arXiv: 1004.3429)

Recently also observed in ^{138}Ba (N=82)
A. Tonchev et al, PRL 104 (2010) 072501

Electric Pygmy Dipole Resonance (PDR)

- PDR: resonance-like structure, typically close to neutron threshold

- Strength related to neutron excess
  $\longrightarrow$ measure of neutron skin
  $\longrightarrow$ measure of the isospin dependence of the symmetry energy

- Strength distribution around neutron threshold relevant for nucleosynthesis (r-process)

Problem: Mean-Field Dependence of Microscopic Predictions in Tin Isotopes

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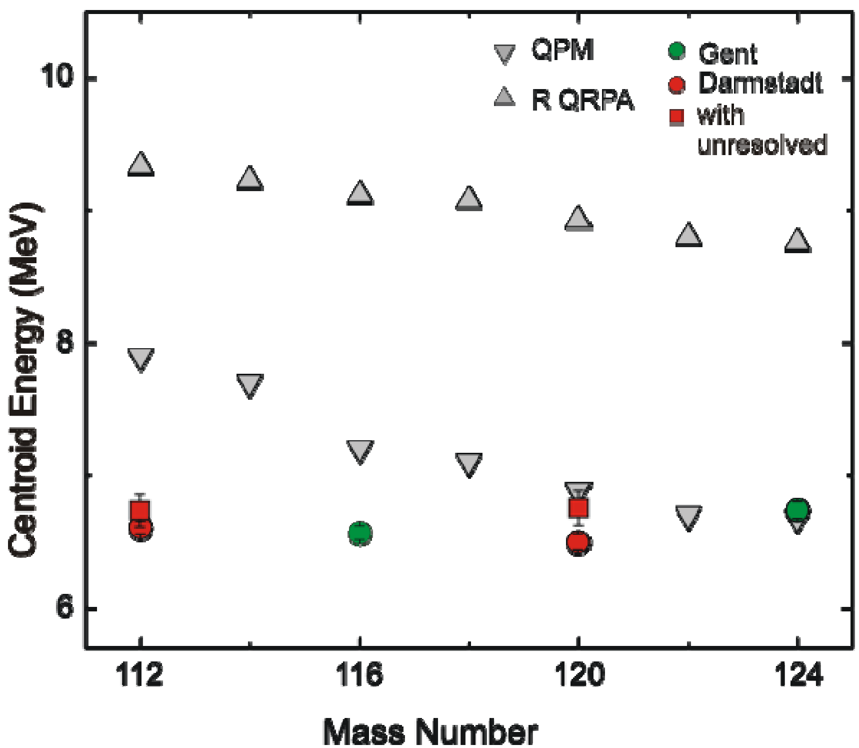
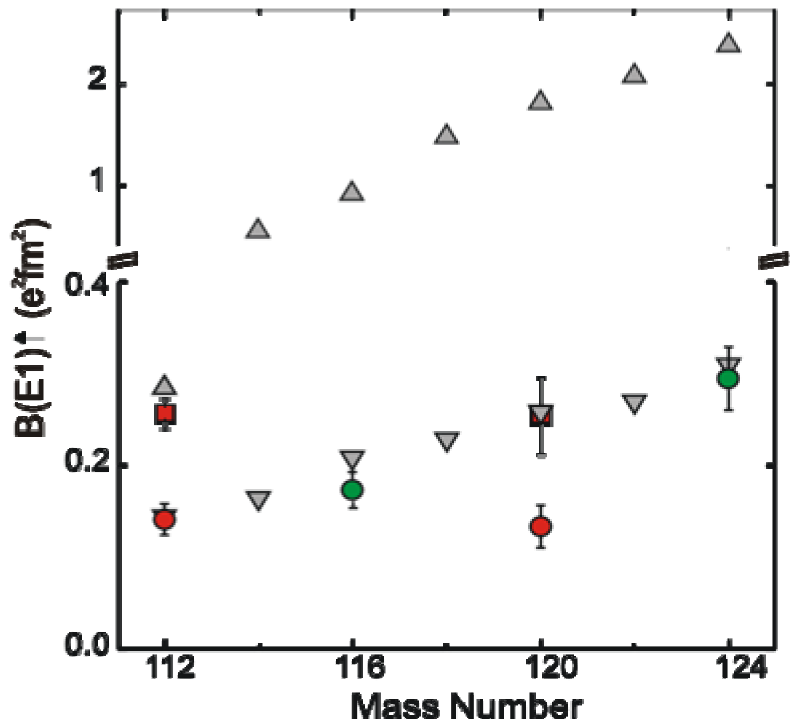
Centroid



ΣB(E1)



B. Özel-Tashenov et al, PLB (submitted)

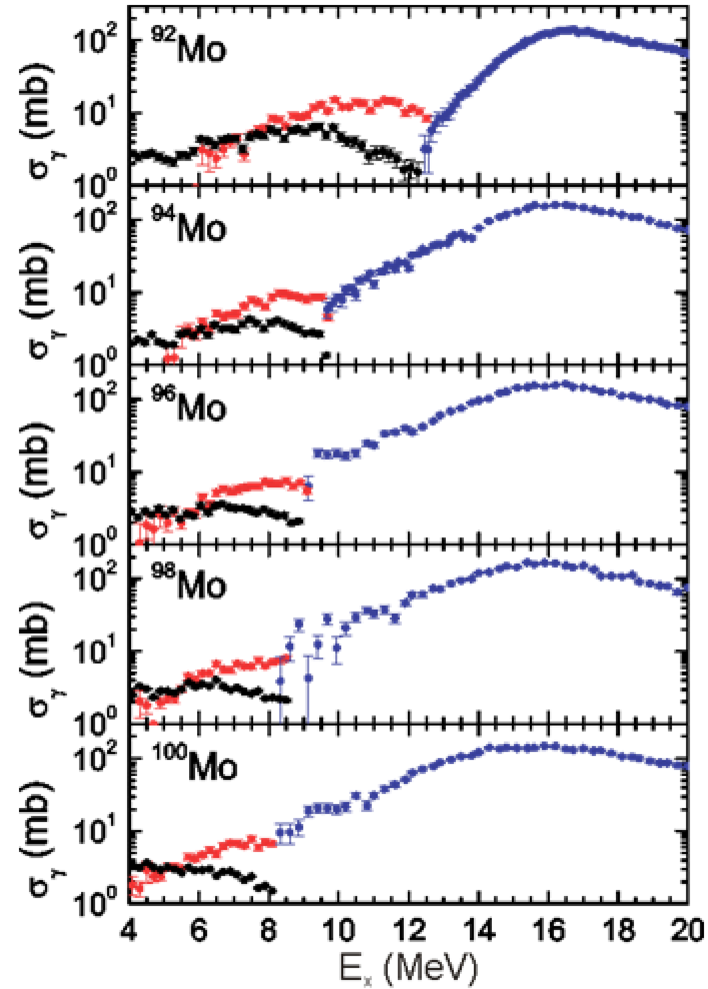
Problem: Missing Strength

- (γ,γ´) reaction measures strength (roughly) up to threshold only
- Experimental quantity $\propto \Gamma_0 \cdot \frac{\Gamma_0}{\Gamma}$

→ assumption in most analyses

$$\frac{\Gamma_0}{\Gamma} = 1 \rightarrow \text{lower limit}$$

→ alternatively correction with statistical model calculation → upper limit



G. Rusev et al., PRC 79 (2009) 061302

Complete E1 Strength Distributions

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- Consistent test of microscopic models
- Extract upward γ-strength function: Test of Axel-Brink hypothesis
- Extract polarizability $\alpha_D \propto \sum_i B(E1)_i / E_{x,i}$

  → measure of the neutron skin rather than PDR

  P.G. Reinhard, W. Nazarewicz, PRC 81 (2010) 051303(R)

Experimental Tool

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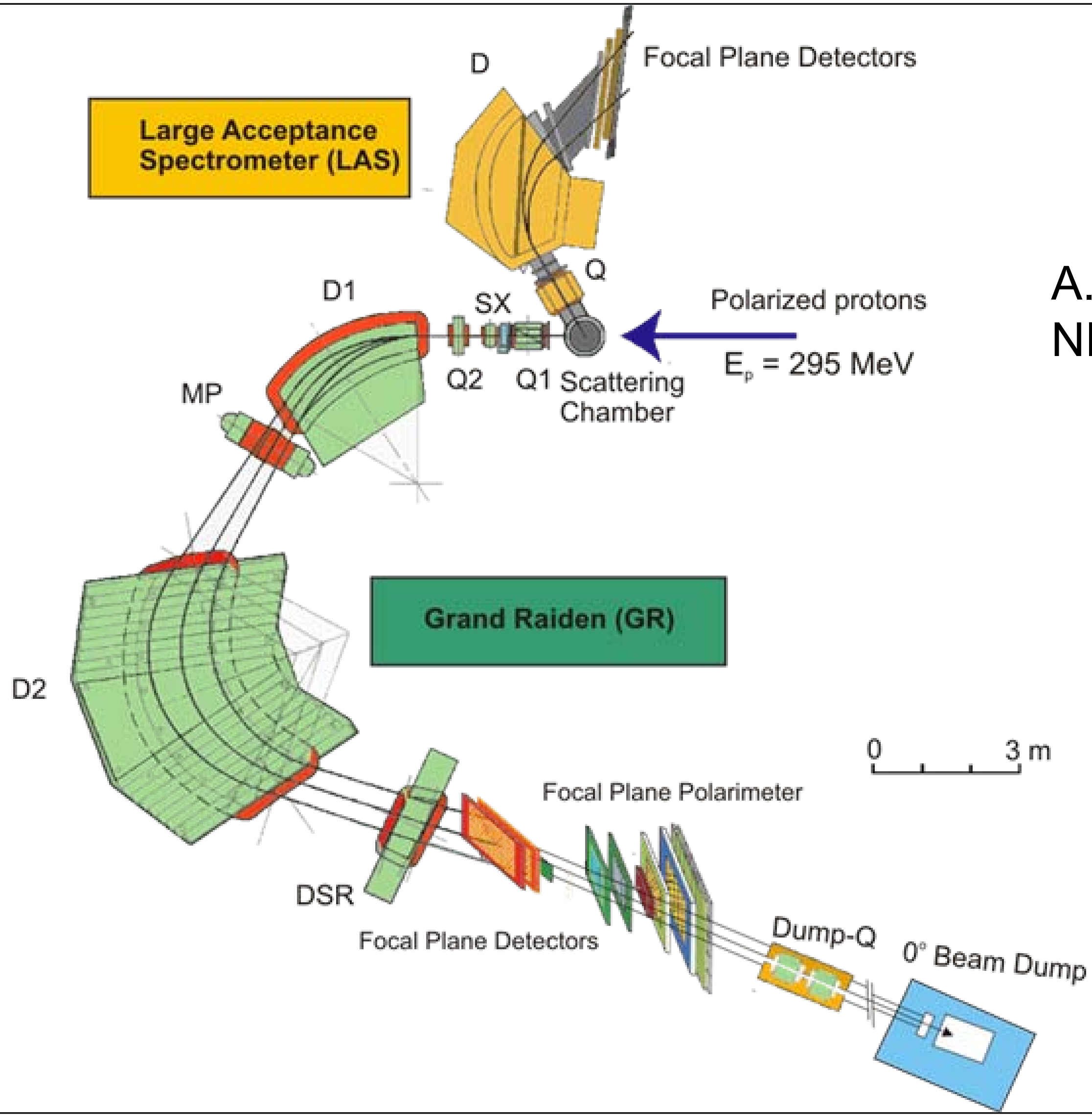
- Polarized proton scattering at 0°
  - intermediate energy: 300 MeV optimal
  - high resolution: ΔE = 25 keV (FWHM)
  - angular distributions: E1 / M1 separation
  - polarization observables: spinflip / non-spinflip separation

- ^{208}Pb as a reference case

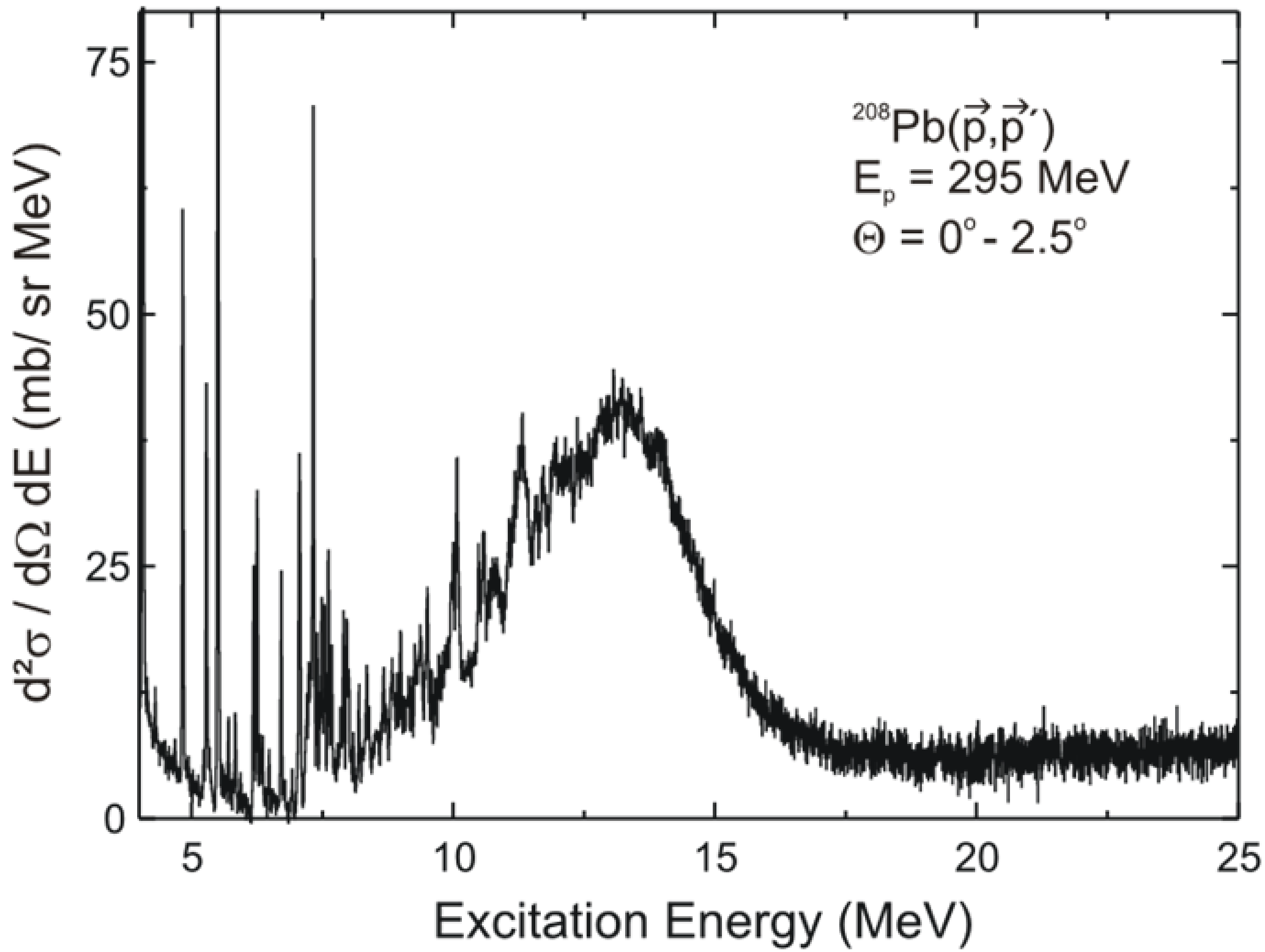
- Applications to
  - ^{120}Sn (role of missing strength)
  - ^{154}Sm (role of deformation)

0° Setup at RCNP

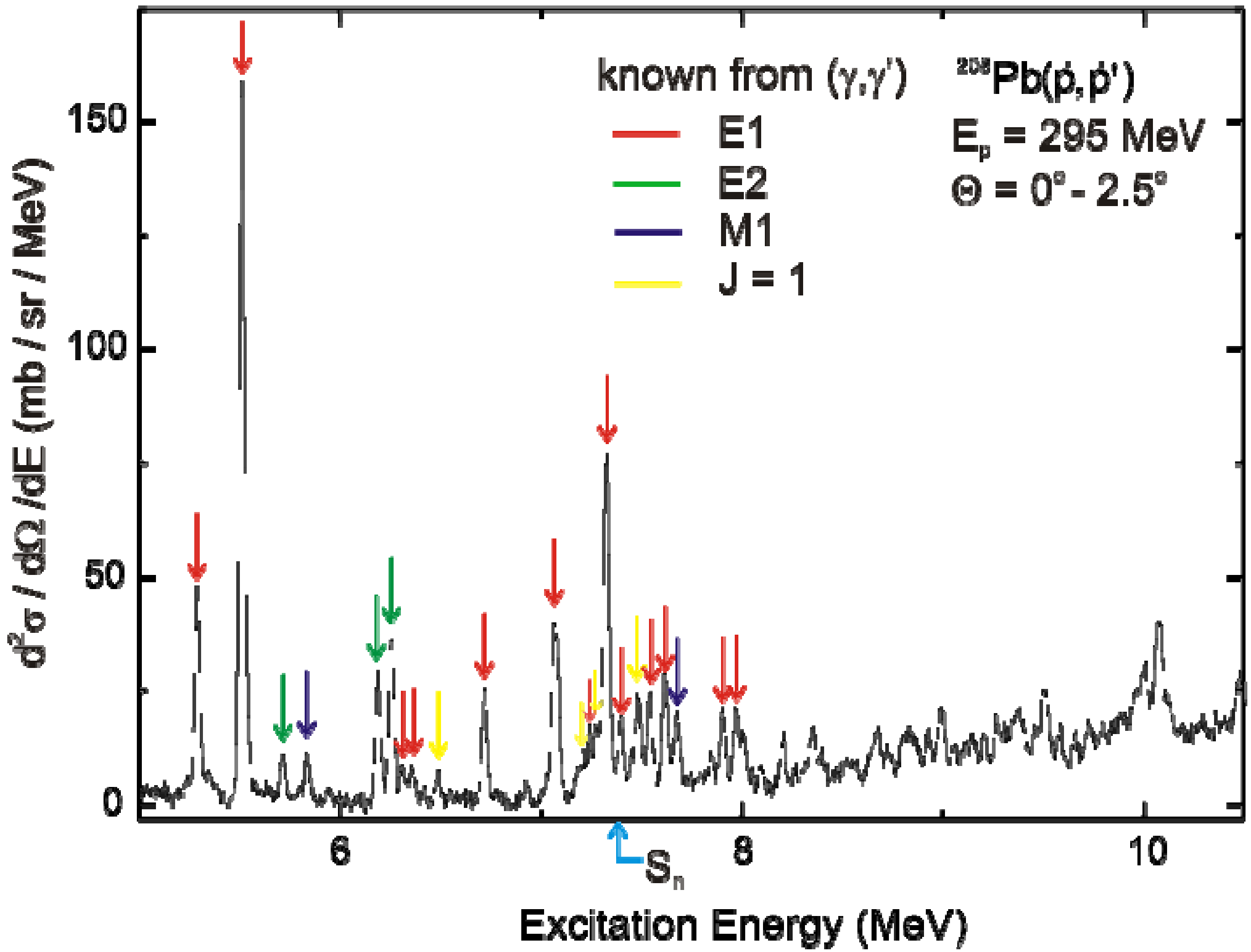


A. Tamii et al.,
NIMA 605 (2009) 326

Background-Subtracted Spectrum of ^{208}Pb



Spectrum (Low-Energy Part)



Measurement of Spin Observables

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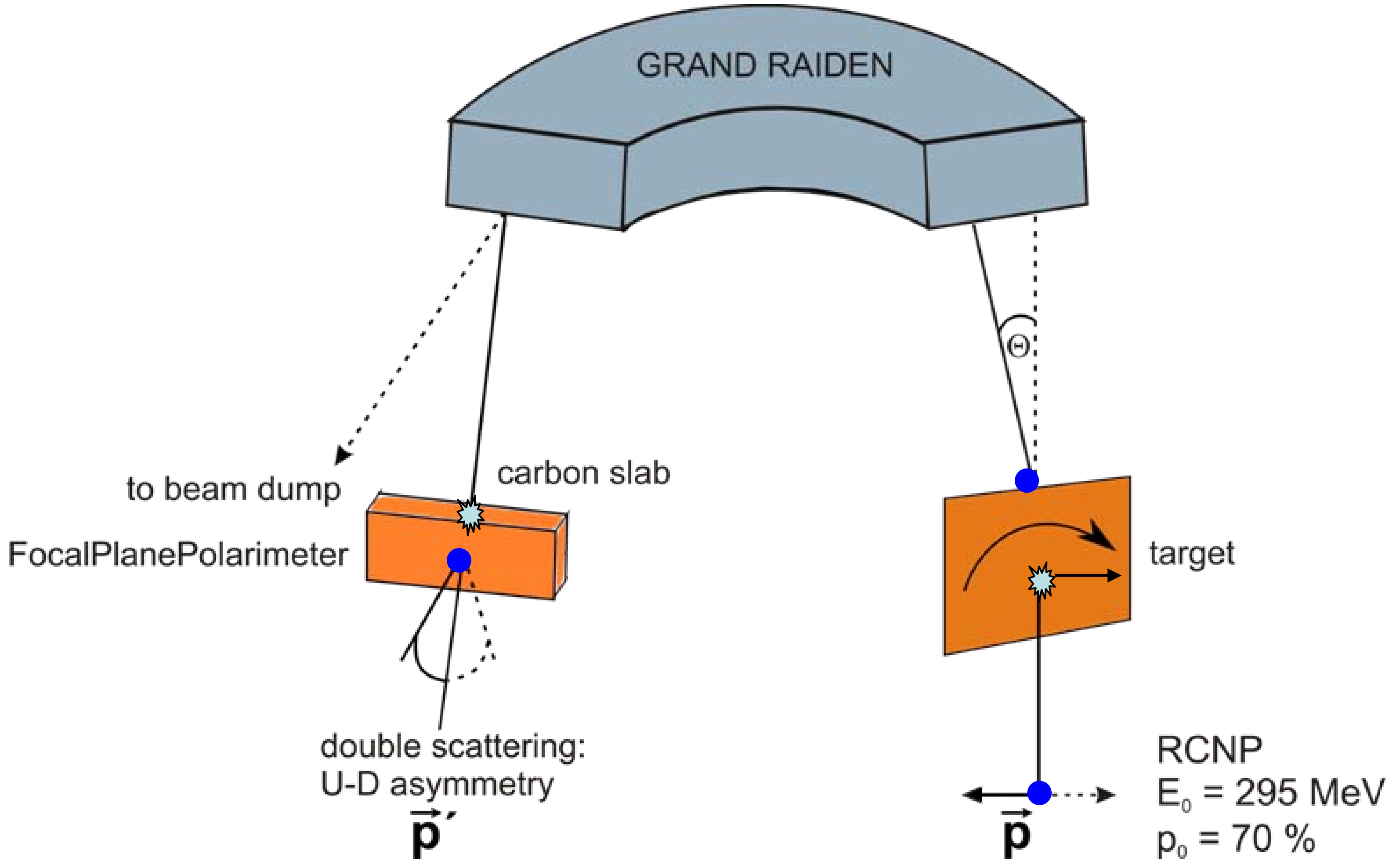
Scheme of the FPP / Grand Raiden Setup



E1/M1 Decomposition by Spin Observables

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- Polarization observables at 0° → spinflip / non-spinflip separation*

(model-independent)

$$D_{SS} + D_{NN} + D_{LL} = \begin{cases} -1 \text{ for } \Delta S = 1, \text{ M1 excitations} \\ 3 \text{ for } \Delta S = 0, \text{ E1 excitations} \end{cases}$$

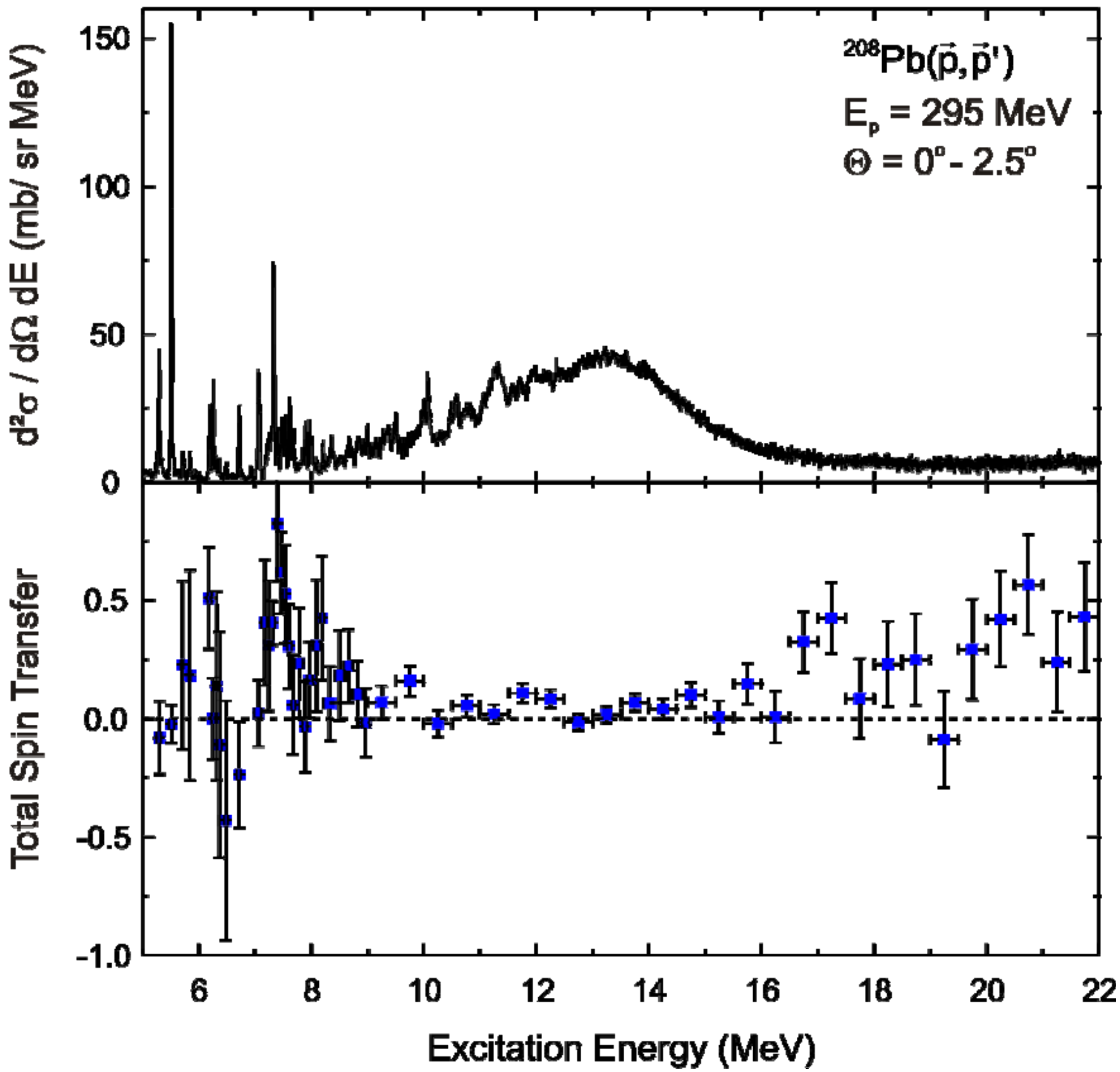
→ E1 and M1 cross sections can be decomposed

At 0° $D_{SS} = D_{NN}$

Total Spin Transfer $$\Sigma \equiv \frac{3-(2D_{SS}+D_{LL})}{4} = \begin{cases} 1 \text{ for } \Delta S = 1 \\ 0 \text{ for } \Delta S = 0 \end{cases}$$

T. Suzuki, PTP 103 (2000) 859

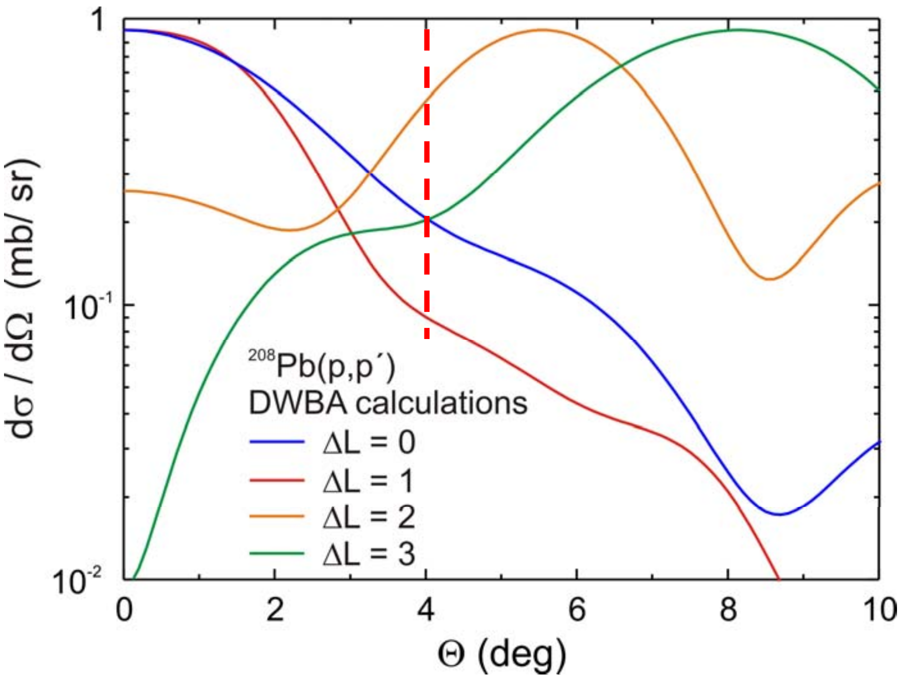
Spin Transfer



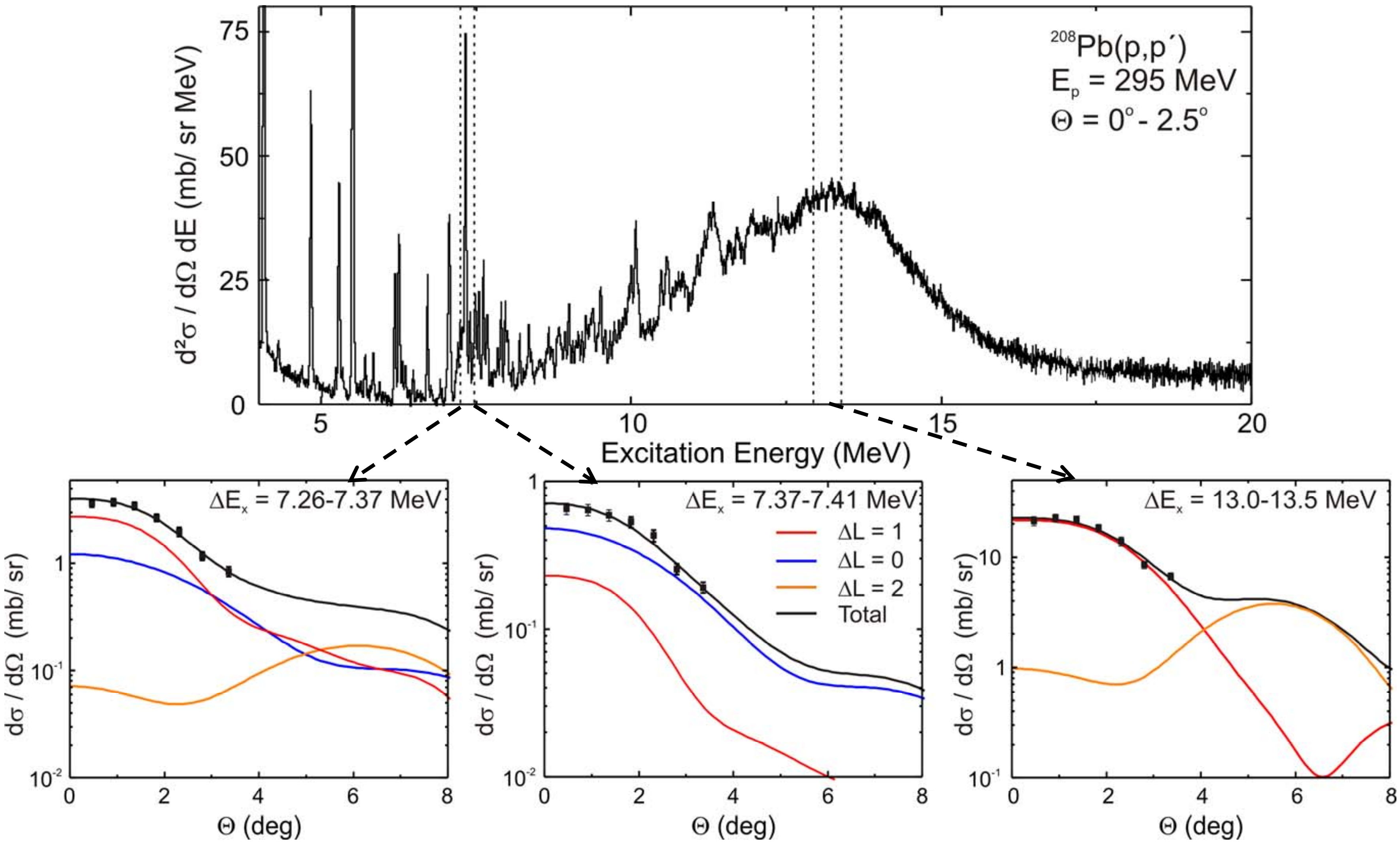
Multipole Decomposition of Cross Section

$$\left.\frac{d\sigma(\Theta)}{d\Omega}\right|_{\text{data}} = \sum_{\Delta L} a_{\Delta L} \left.\frac{d\sigma(\Theta)}{d\Omega}\right|_{\text{DWBA}}$$

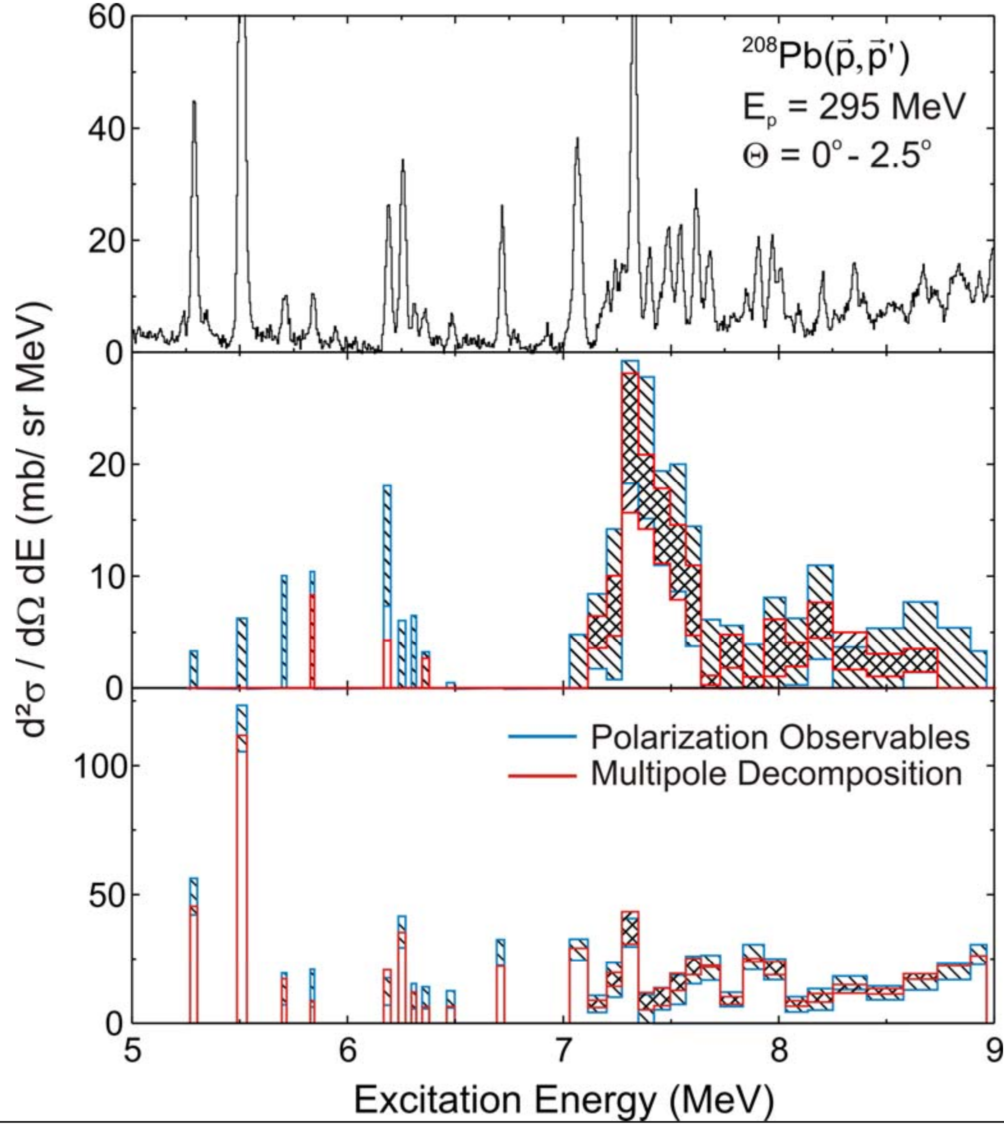
- Restrict angular distribution to $\Theta = 4°$
  (response at larger angles too complex)
- $\Delta L = 0 \rightarrow$ isovector spin M1
- $\Delta L = 1 \rightarrow$ E1 (Coulomb + nuclear)
- $\Delta L > 1 \rightarrow$ only E2 (or E3) considered



Multipole Decomposition: Examples



Comparison of Both Methods I



Total

ΔS = 1

ΔS = 0

Comparison of Both Methods II

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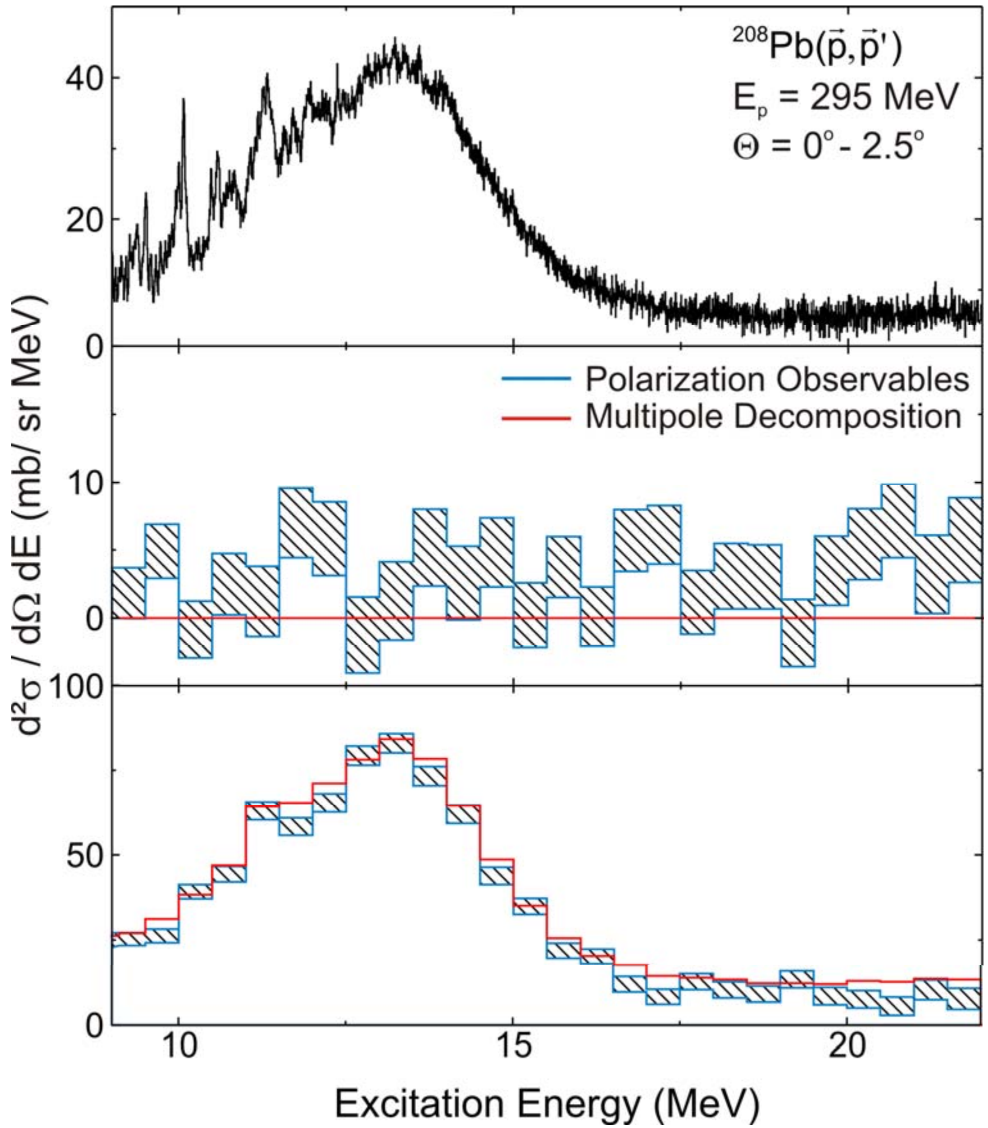
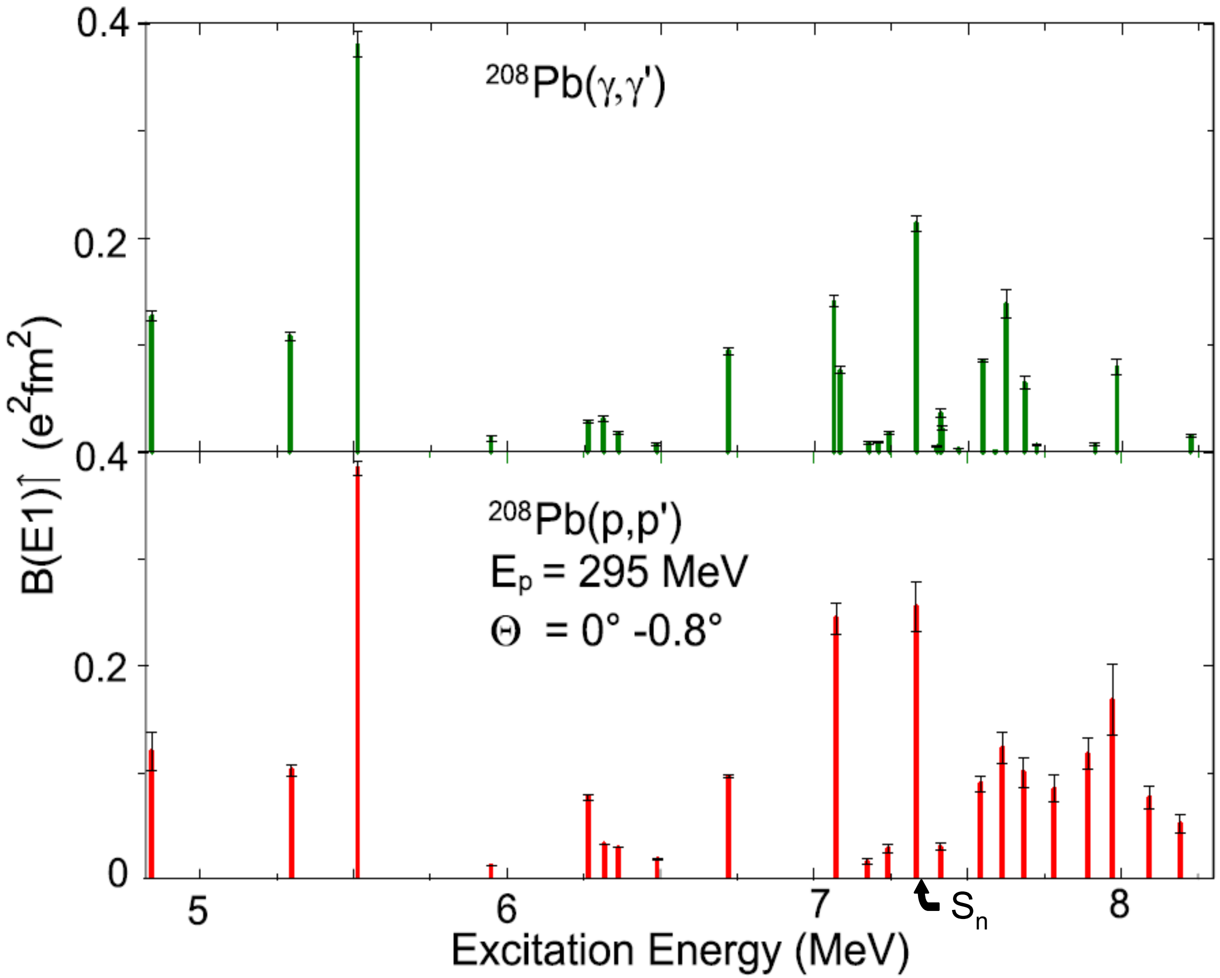


Total

ΔS = 1

ΔS = 0

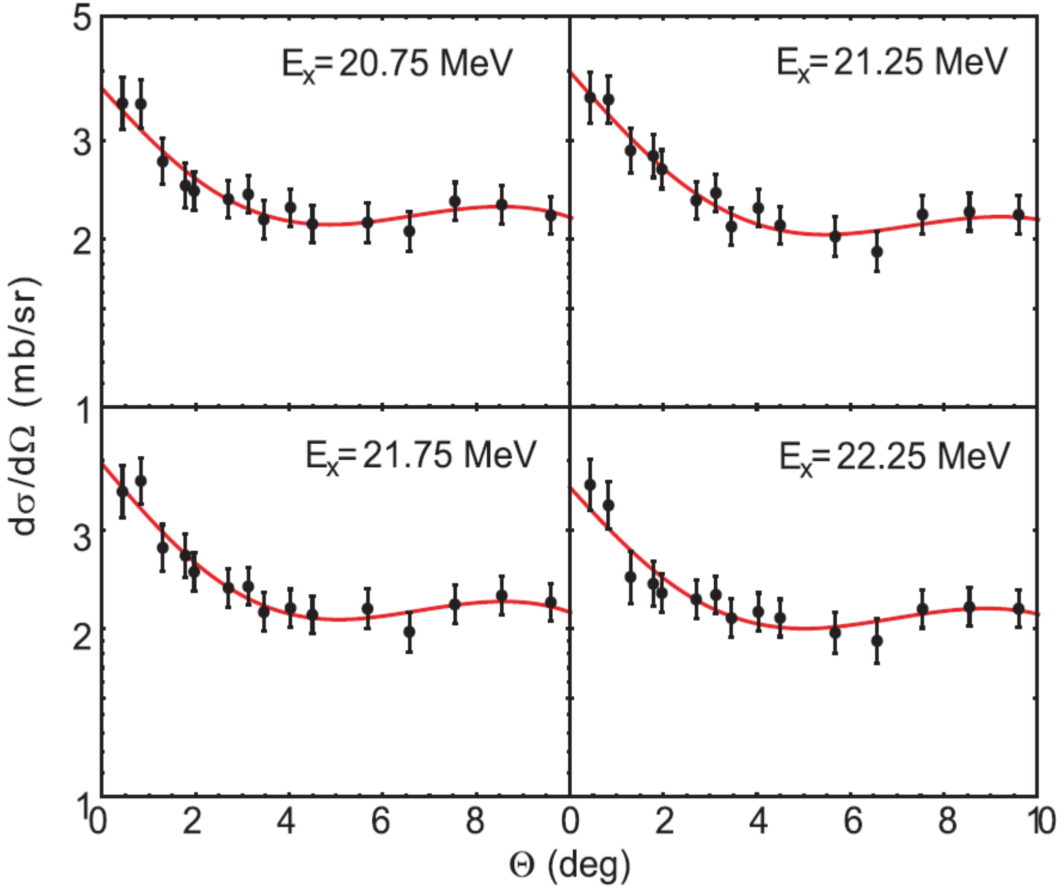
B(E1) Strength: Low-Energy Region



N. Ryezayeva et al., PRL 89 (2002) 272502

- Extracted assuming semiclassical Coulomb excitation

Multipole Decomposition in the GDR Region



→ identical angular distributions

- determines phenomenological background

B(E1) Strength: GDR

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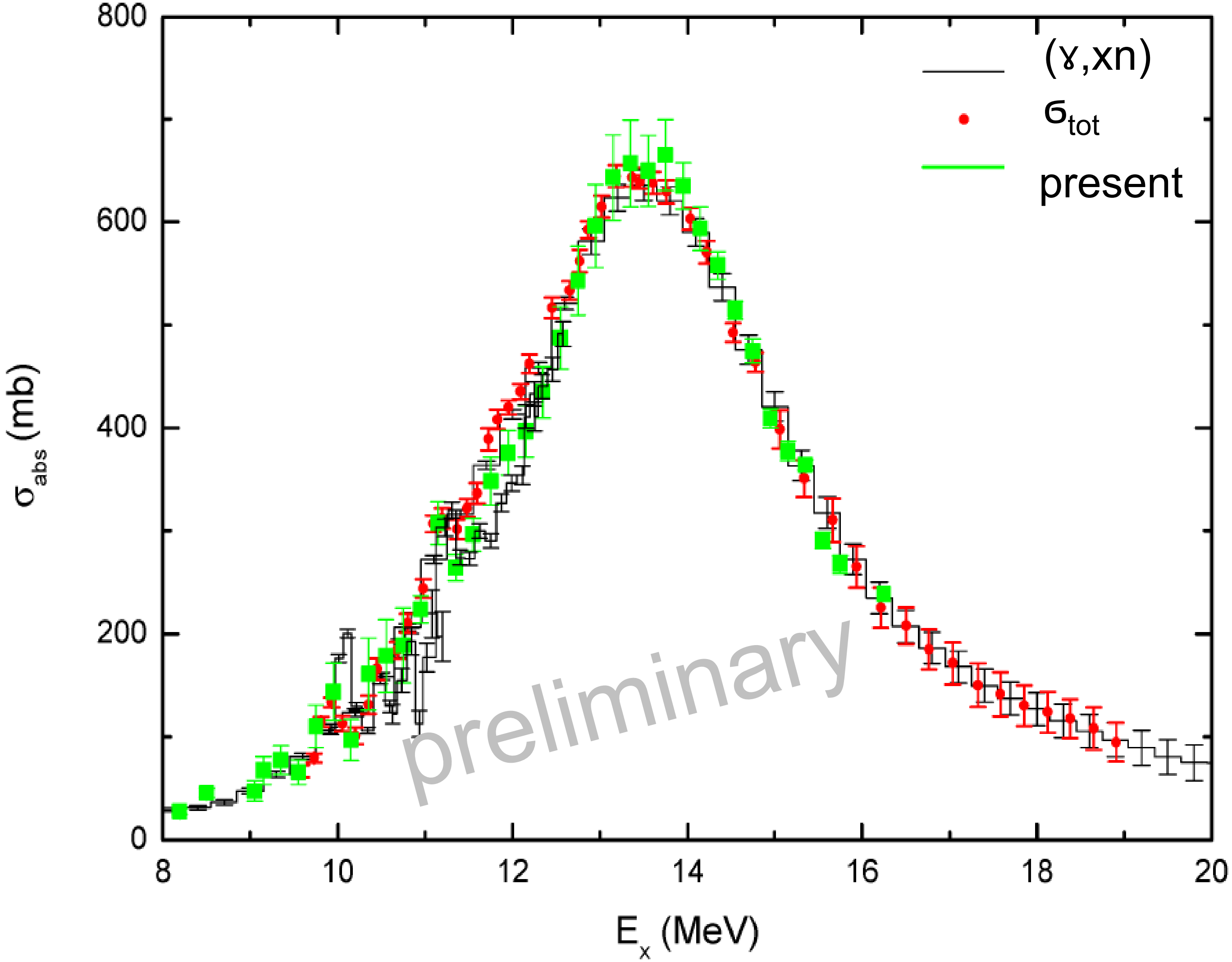
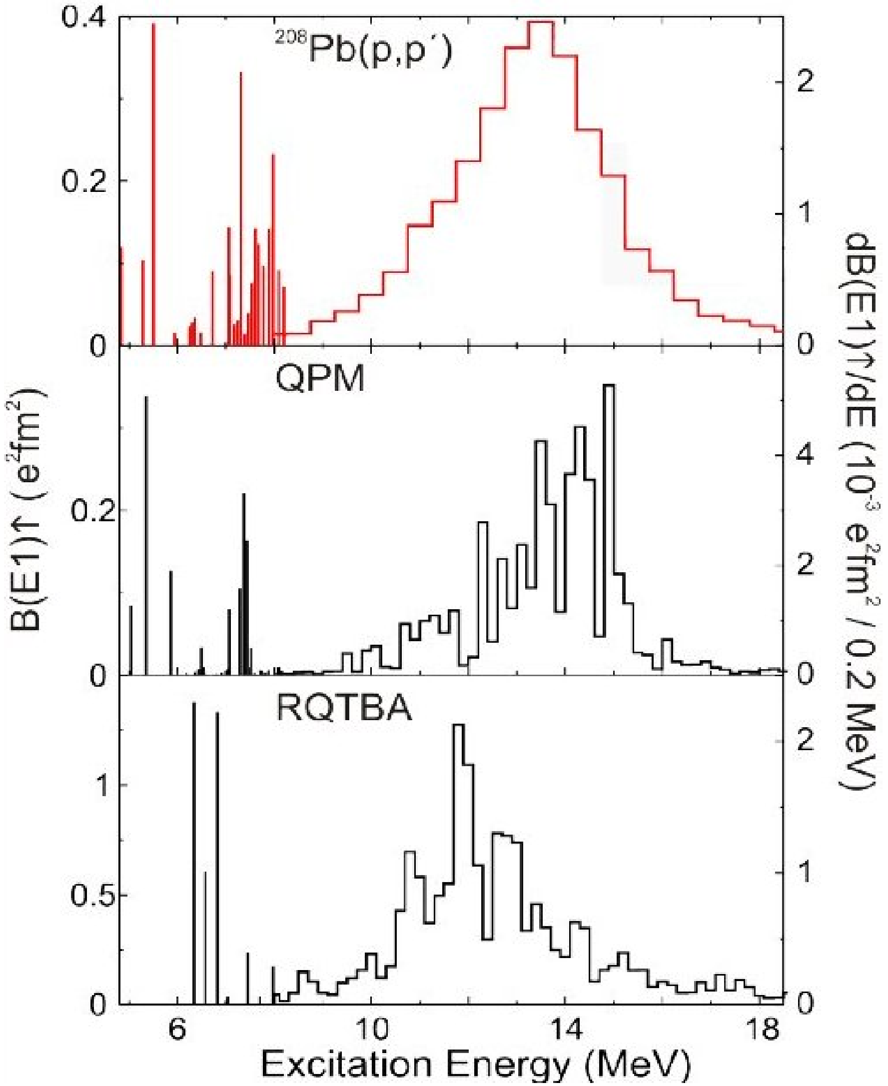


E1 Response in ^{208}Pb



V.Yu. Ponomarev

E. Litvinova et al.,
PRC 78 (2008) 014312,
PRC 79 (2009) 054312

Polarizability as a Measure of the Neutron Skin

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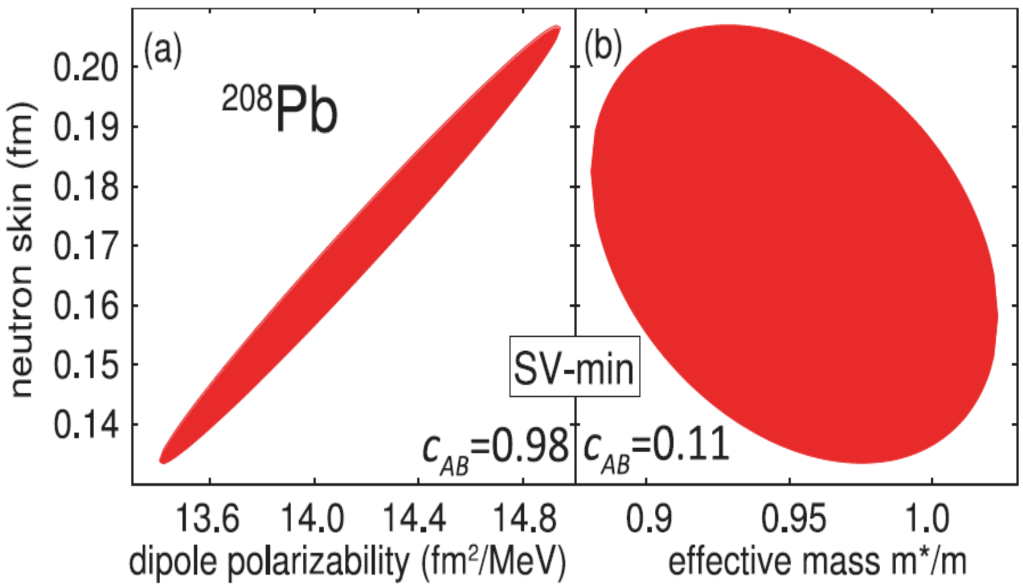
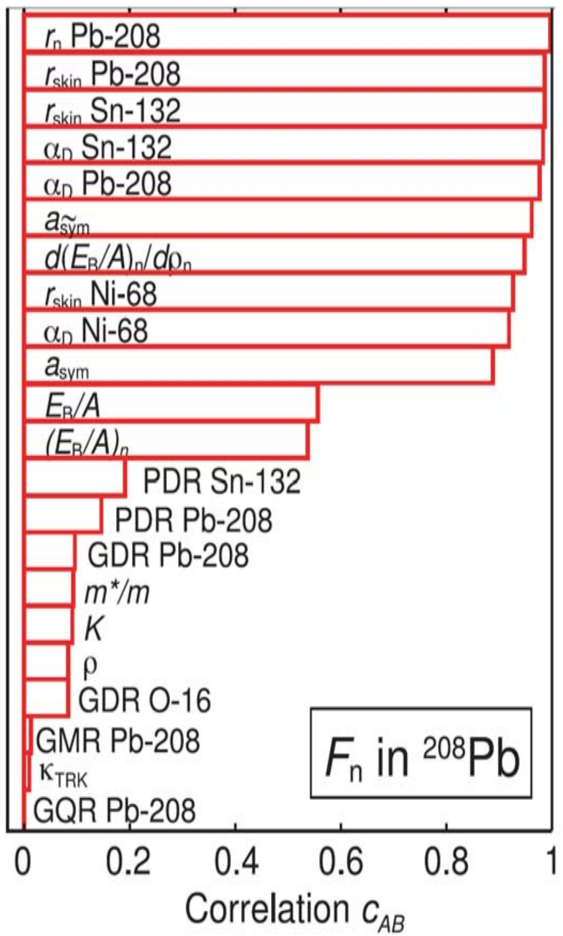
Examples of Correlations with Neutron Skin





P.G. Reinhard and W. Nazarewicz,
PRC 81 (2010) 051303(R)

Dipole Polarizability of ^{208}Pb

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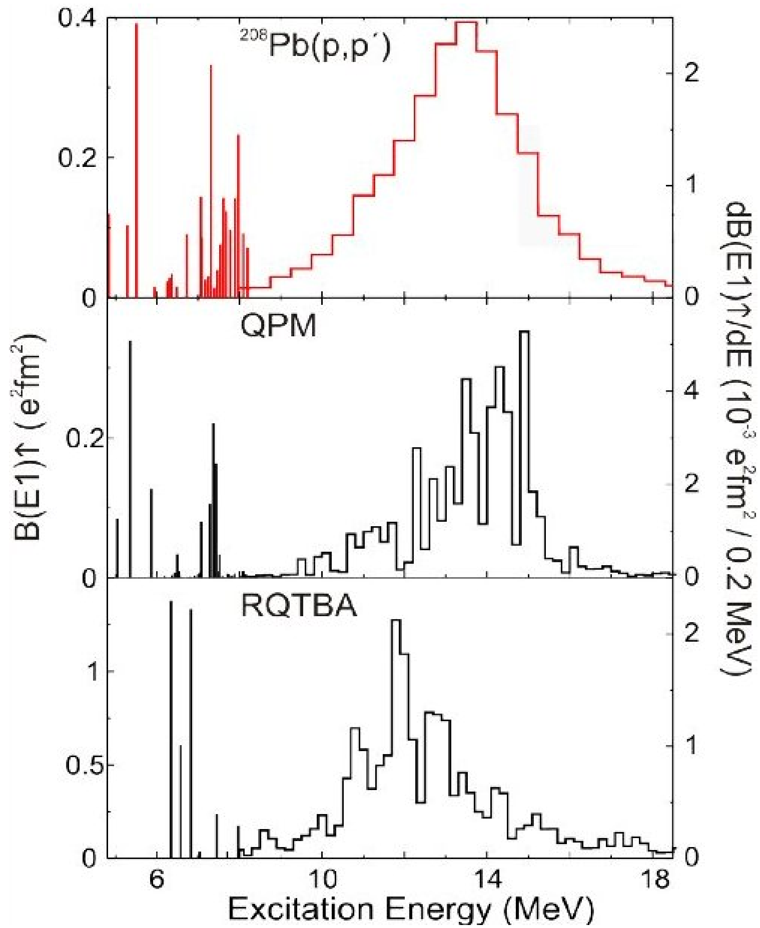

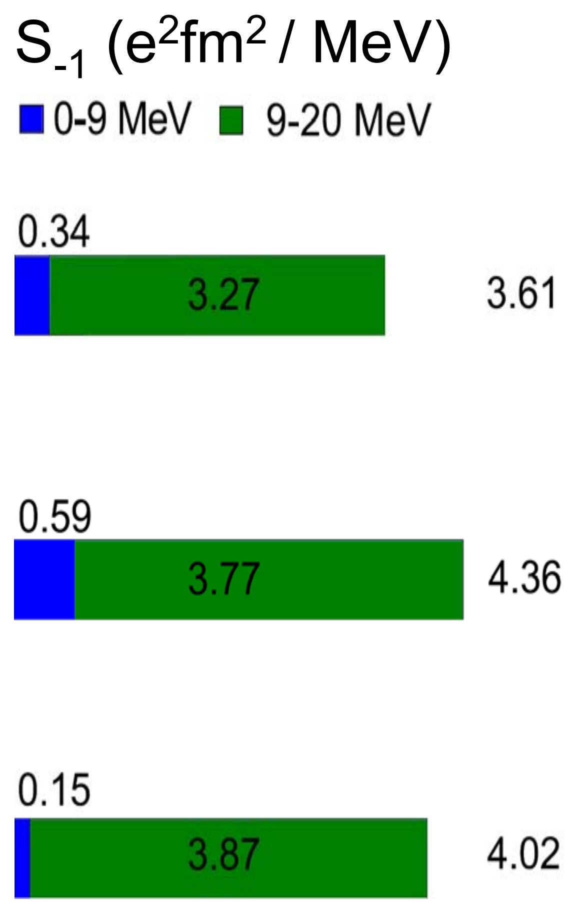

Test of Axel-Brink Hypothesis

Present experiment provides simultaneous information on

- $\Gamma\uparrow$ strength function
- level densities (from fluctuation analysis of the fine structure)

$\longrightarrow$ compare with measurement of $\Gamma\downarrow$

Collaboration

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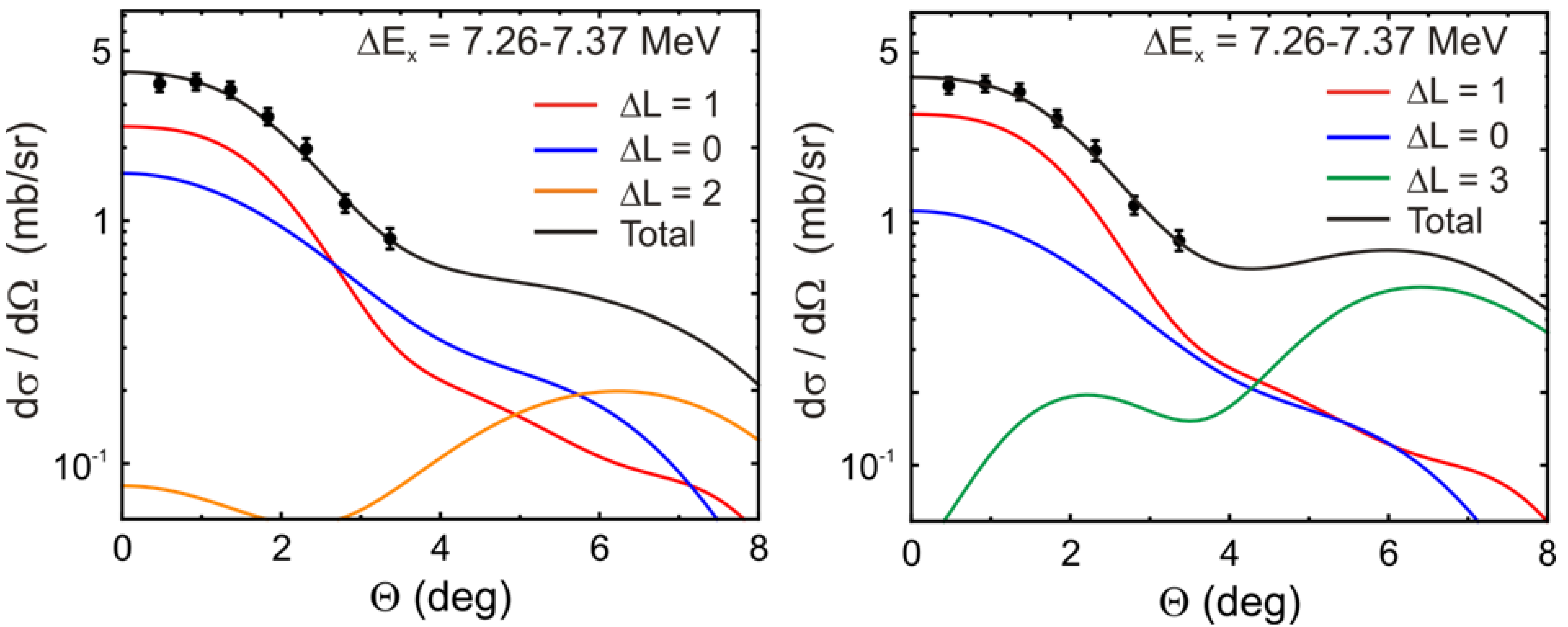
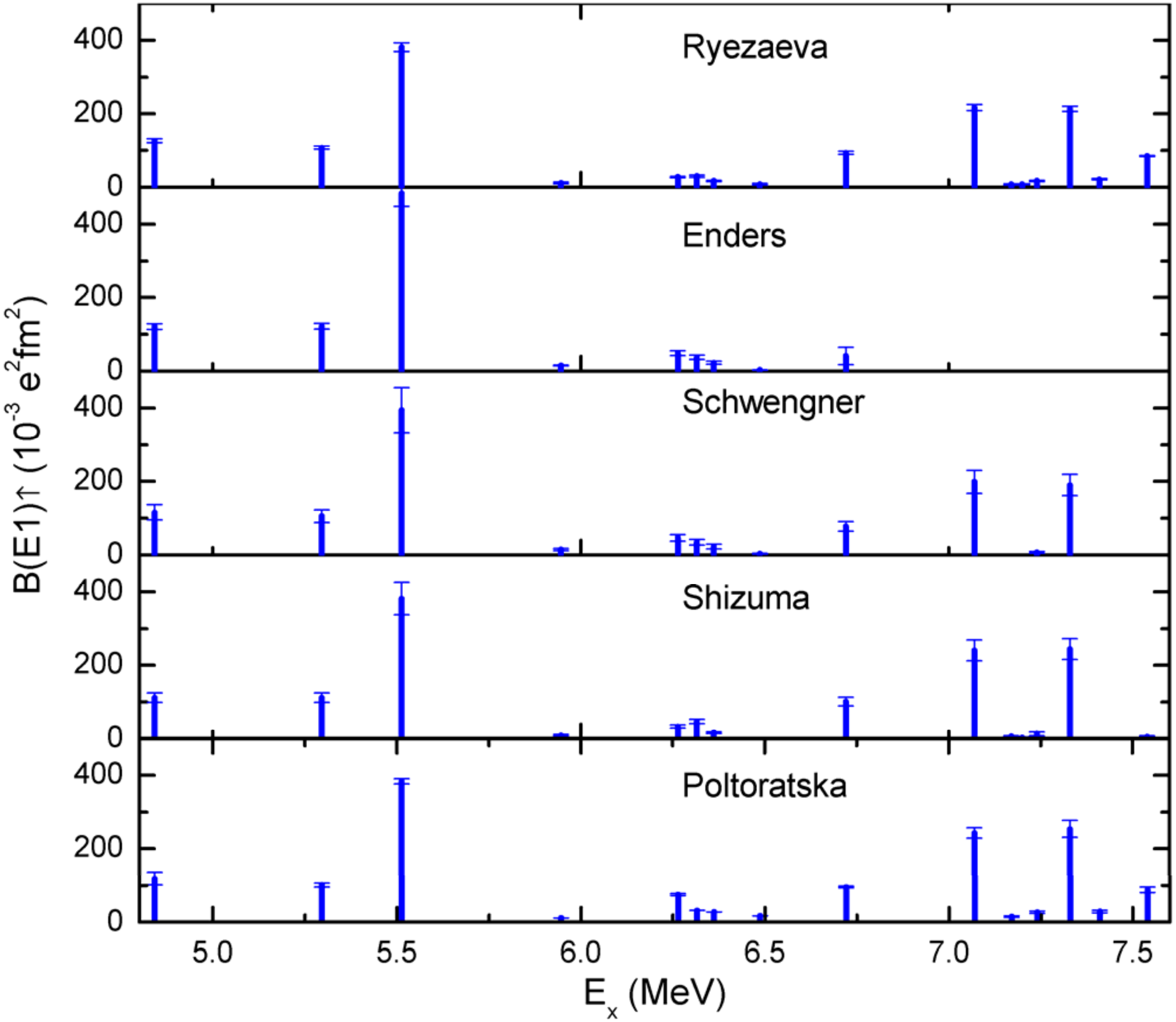
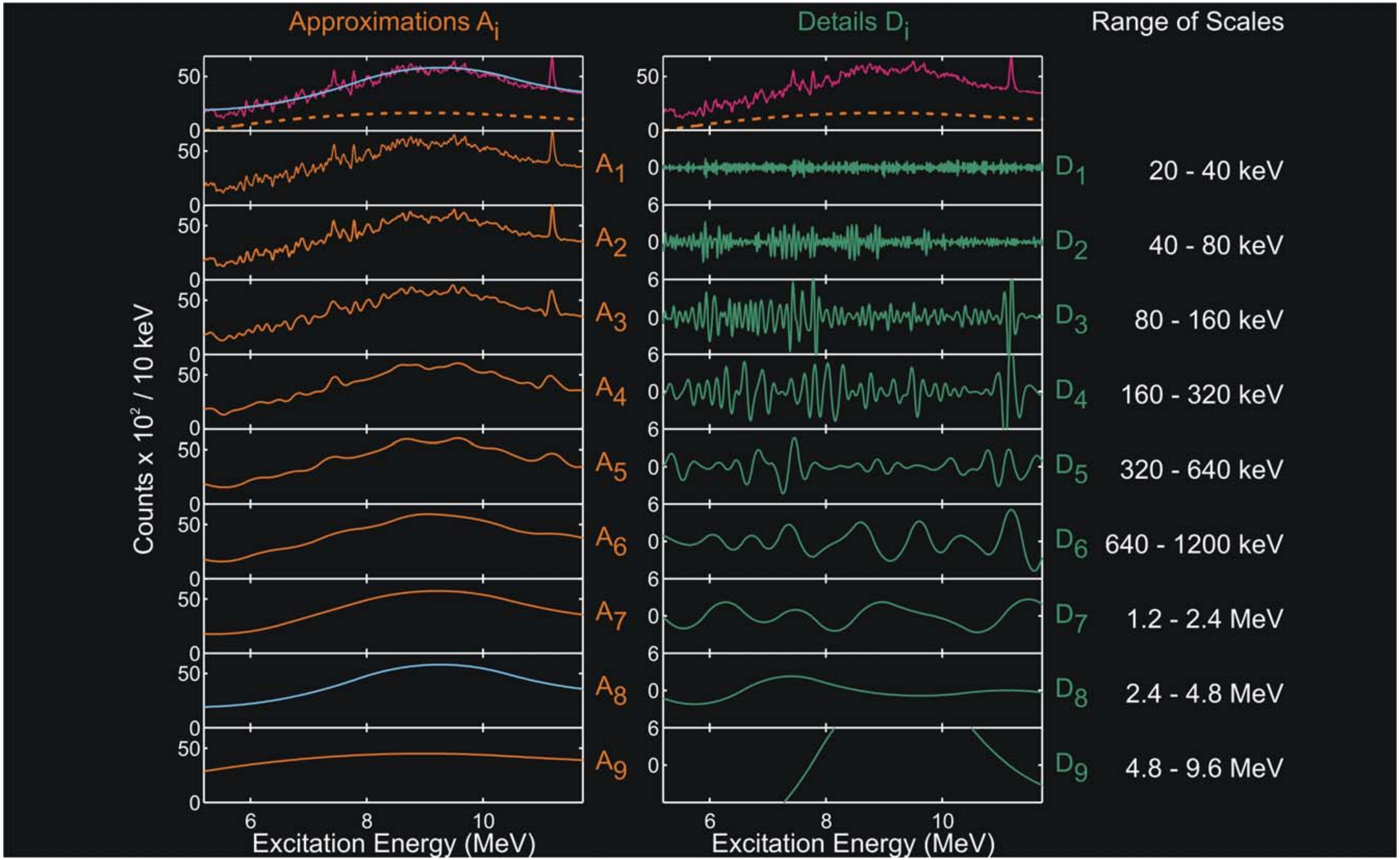
Multipole Decomposition



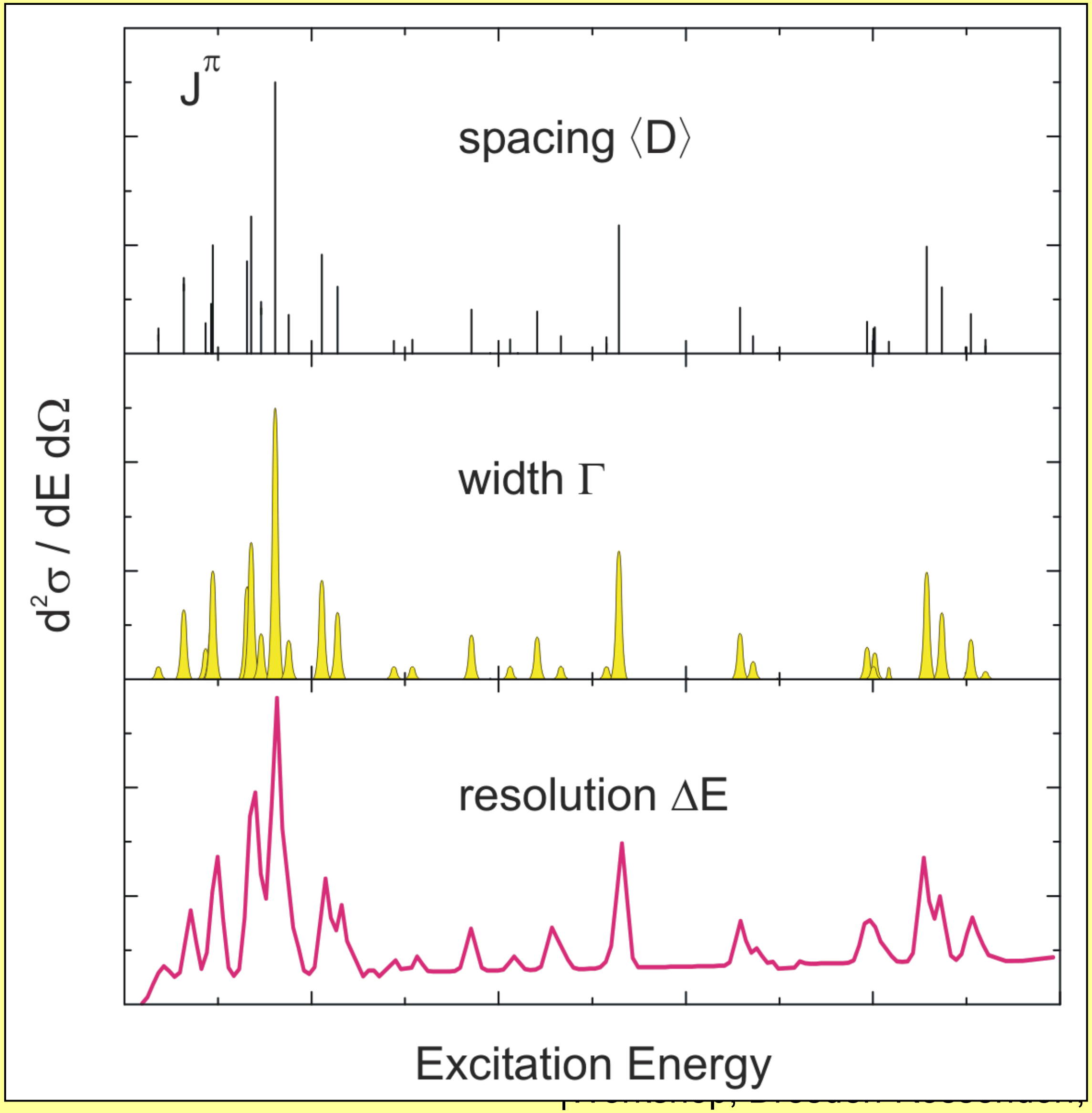
Comparison of B(E1) strengths in ^{208}Pb



Decomposition of $^{90}Zr(^3He,t)^{90}Nb$ spectrum



Fluctuations and Level Densities



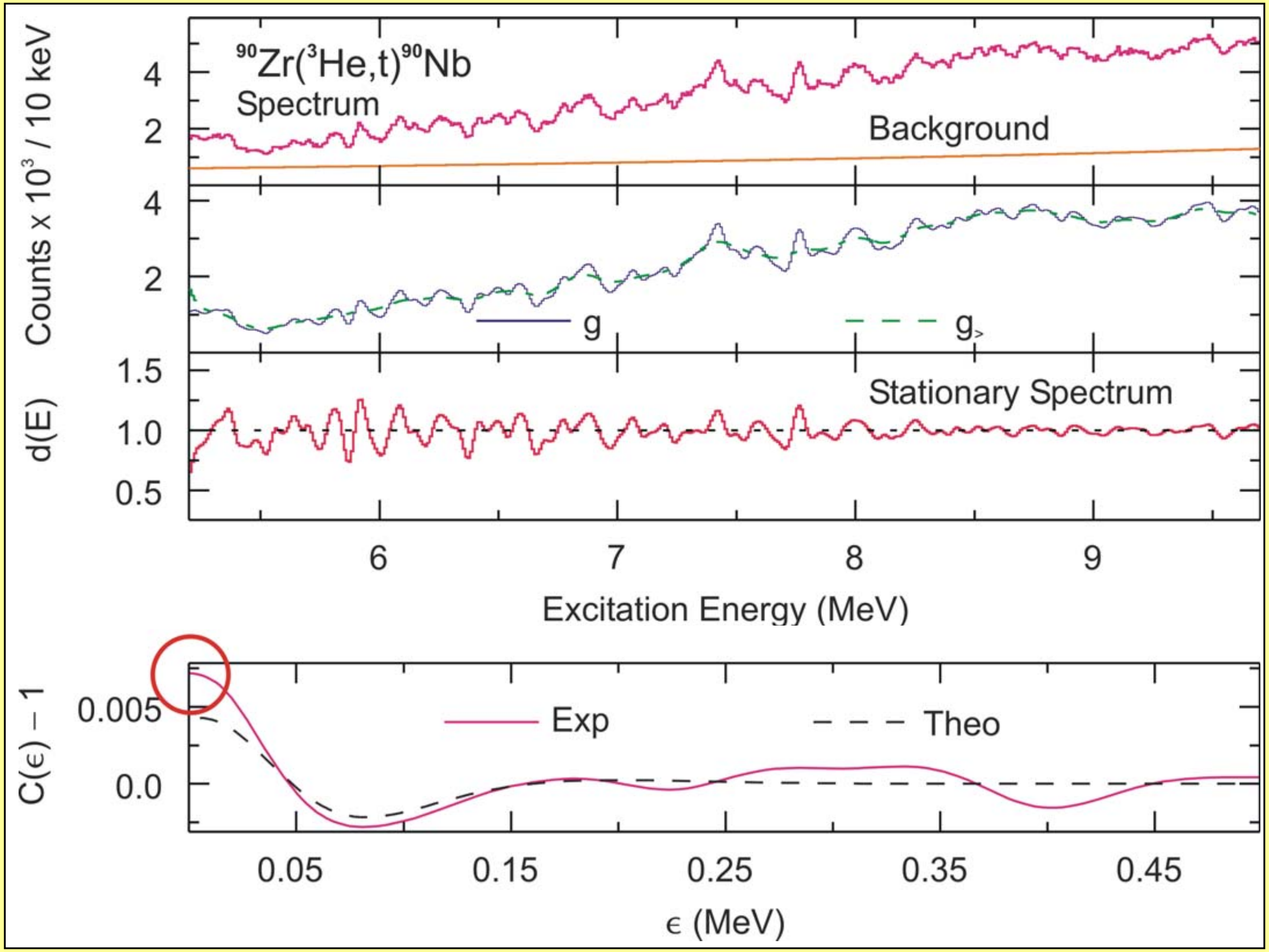
- $D / \langle D \rangle$ Wigner

  $I / \langle I \rangle$ Porter-Thomas

- $\Gamma < \langle D \rangle$

- $\Gamma < \langle D \rangle < \Delta E$

Fluctuation Analysis



- Background
  from
  wavelet analysis
- Statistics,
  local features
- Local
  fluctuations
- Autocorrelation
  function

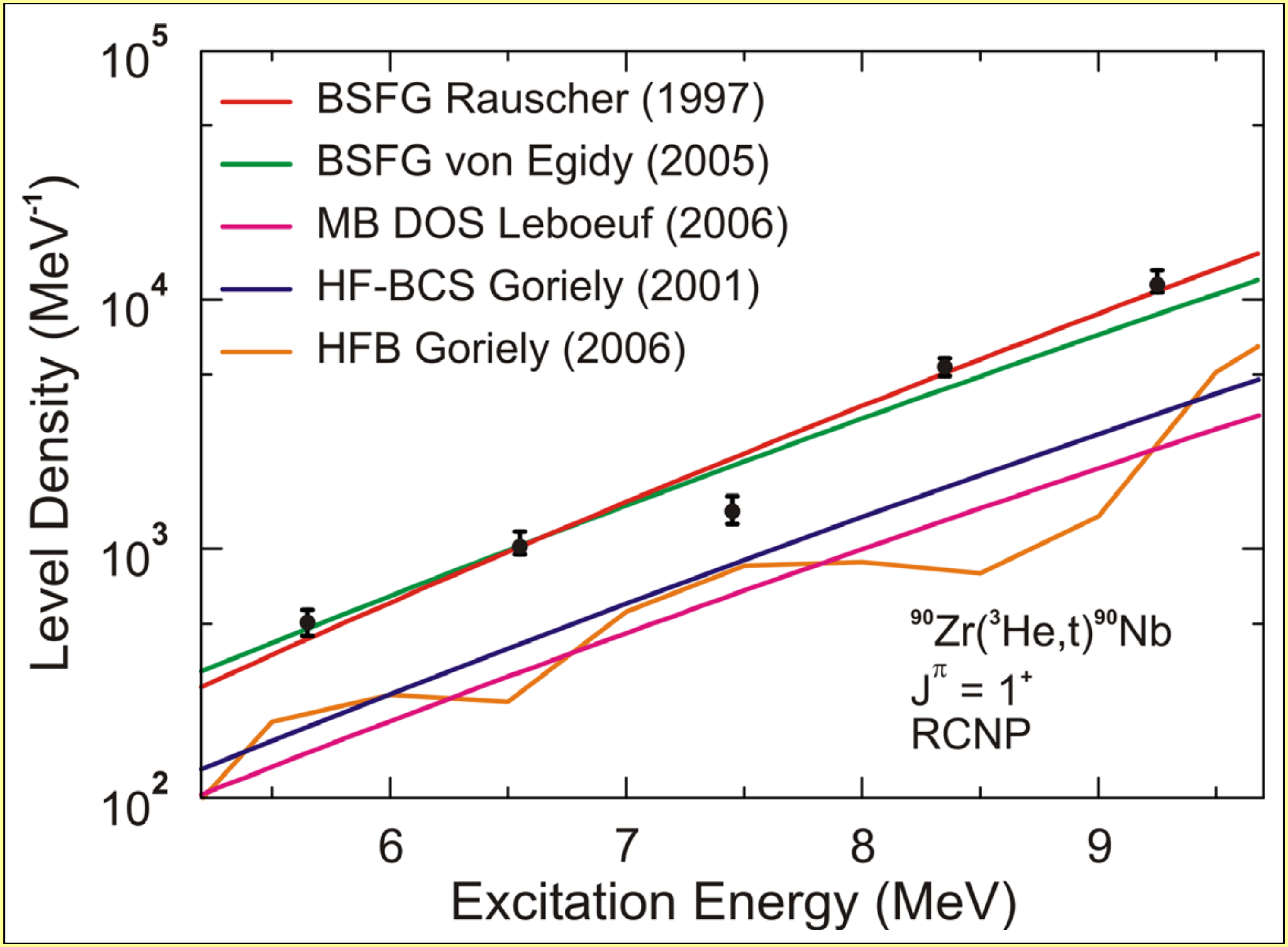
Autocorrelation Function and Mean Level Spacing

- $$C(\varepsilon) = \frac{\langle\, d(E_x)\, d(E_x + \varepsilon)\,\rangle}{\langle\, d(E_x)\,\rangle \langle\, d(E_x + \varepsilon)\,\rangle}$$ autocorrelation function
- $$C(\varepsilon = 0) - 1 = \frac{\langle\, d^2(E_x)\,\rangle - \langle\, d(E_x)\,\rangle^2}{\langle\, d(E_x)\,\rangle^2}$$ variance
- $$C(\varepsilon) - 1 = \frac{\alpha \langle\, D\,\rangle}{2\sigma\sqrt{\pi}} \times f(\sigma, \varepsilon)$$ level spacing ⟨D⟩
- $\alpha = \alpha_{PT} + \alpha_W$ selectivity
- σ resolution

S. Müller, F. Beck, D. Meuer, and A. Richter, PLB 113 (1982) 362

P.G. Hansen, B. Jonson, and A. Richter, NPA 518 (1990) 13

Results and Model Predictions: A = 90, $J^{\pi} = 1^+$



Y. Kalmykov et al., PRL 96 (2006) 012502