Soft Electric Dipole Modes in Heavy Nuclei: Some Selected Examples

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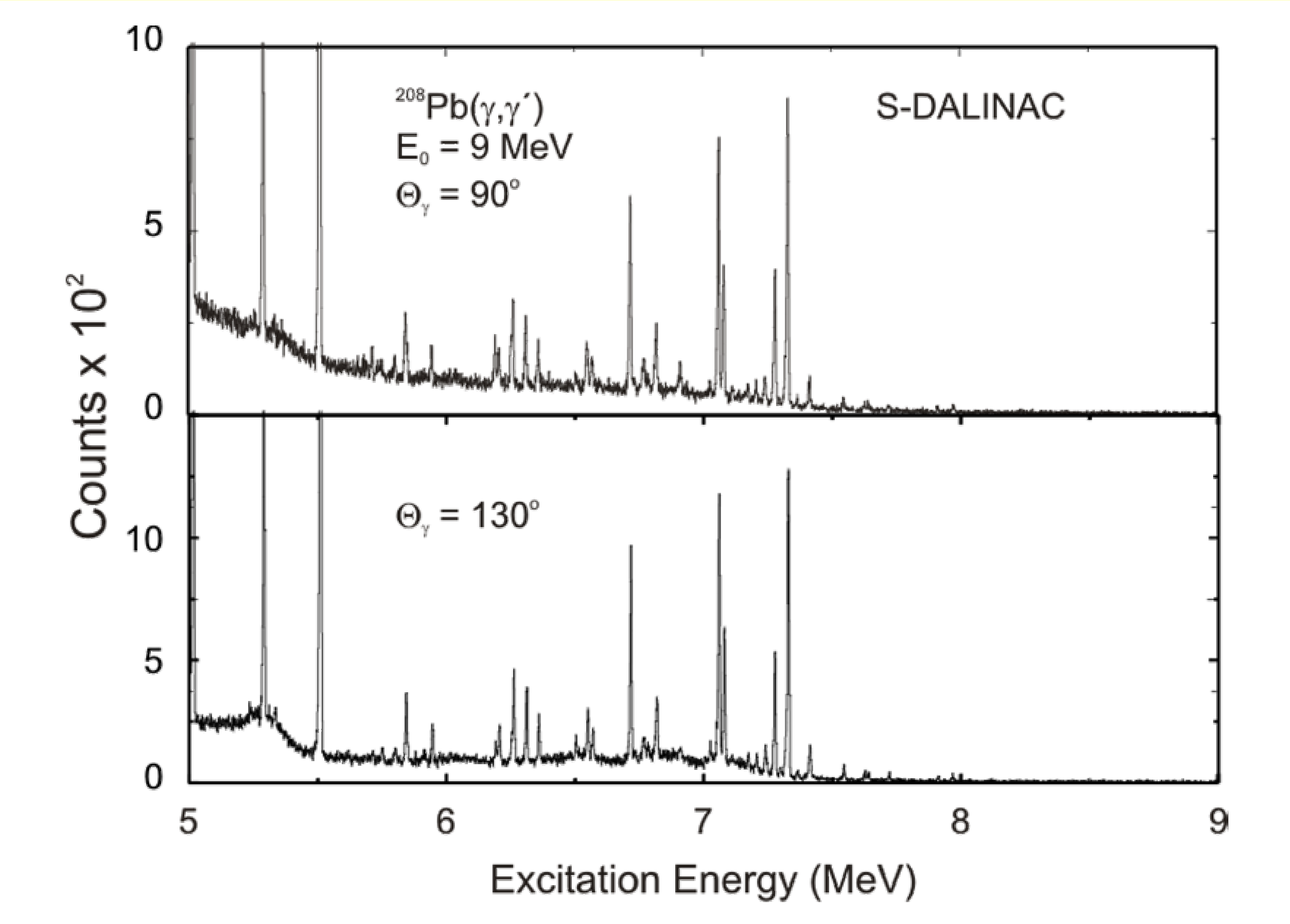
- Soft E1 modes: the case of ^{208}Pb
- Systematics of the PDR in Sn isotopes

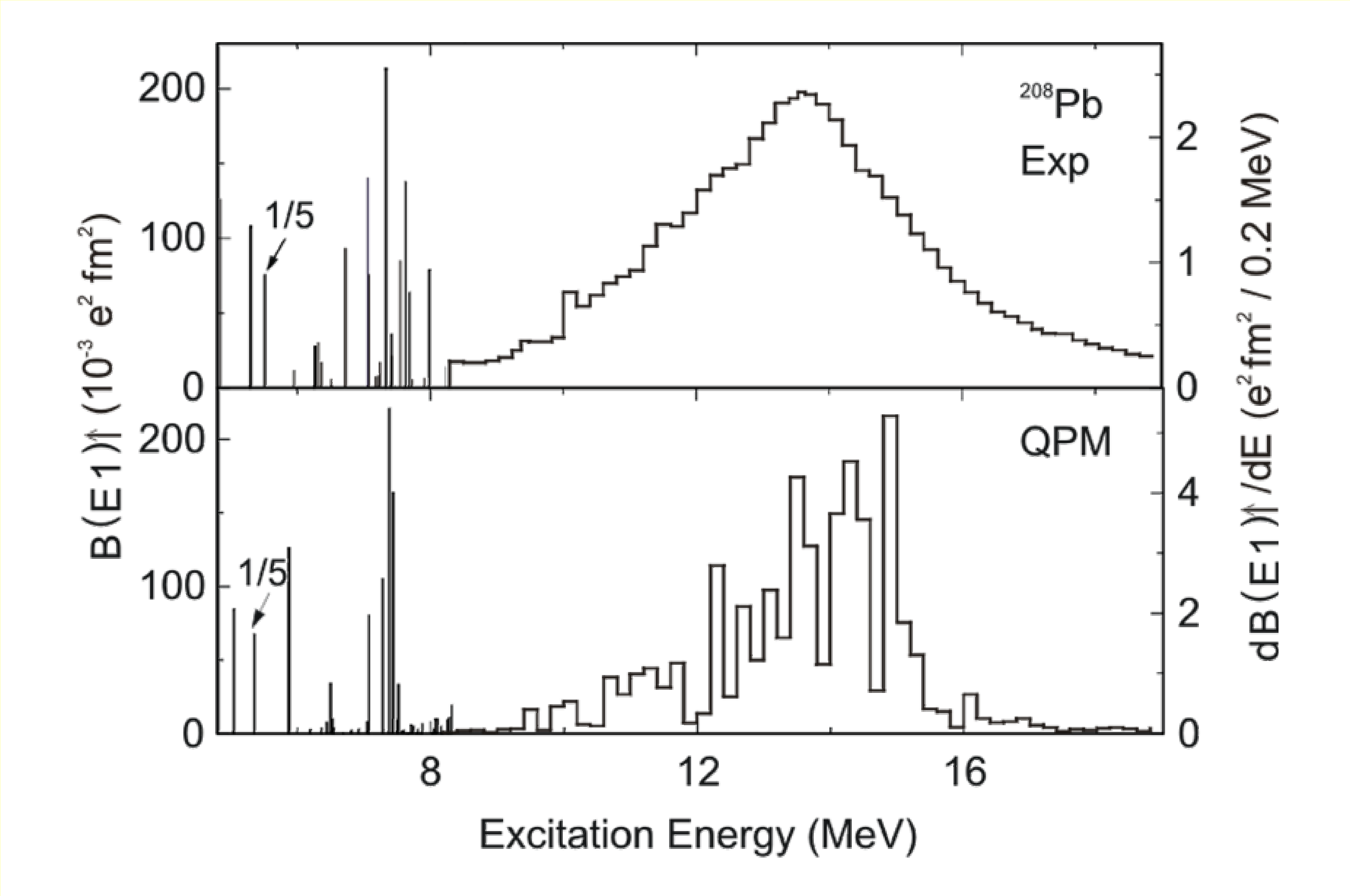
* Supported by DFG under contracts SFB 634, 446-JAP-113/0/2, and by the DAAD

Reminder: The Pygmy Dipole Resonance in ^{208}Pb



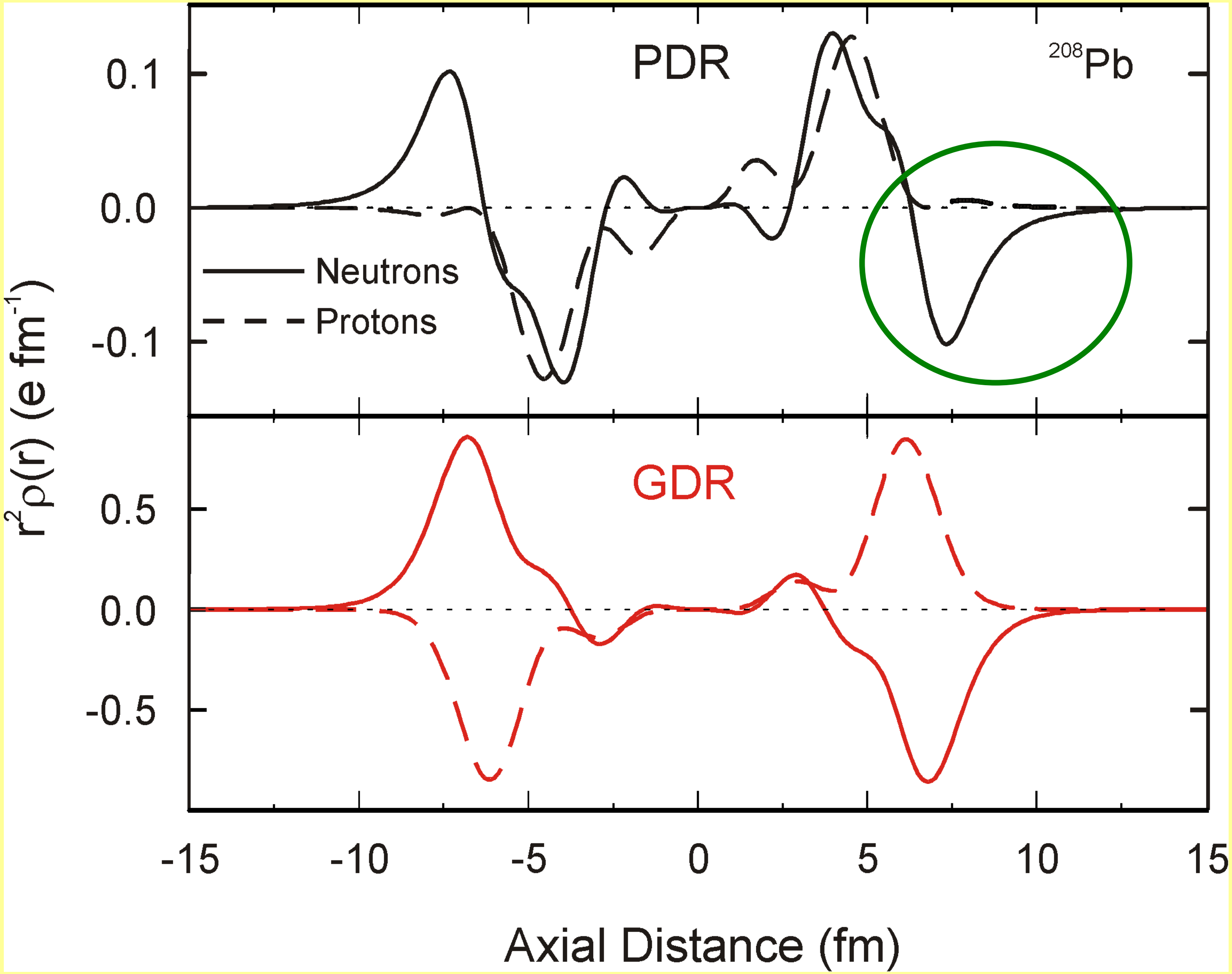
N. Ryezayeva et al., PRL 89 (2002) 272502

E1 Response in ^{208}Pb



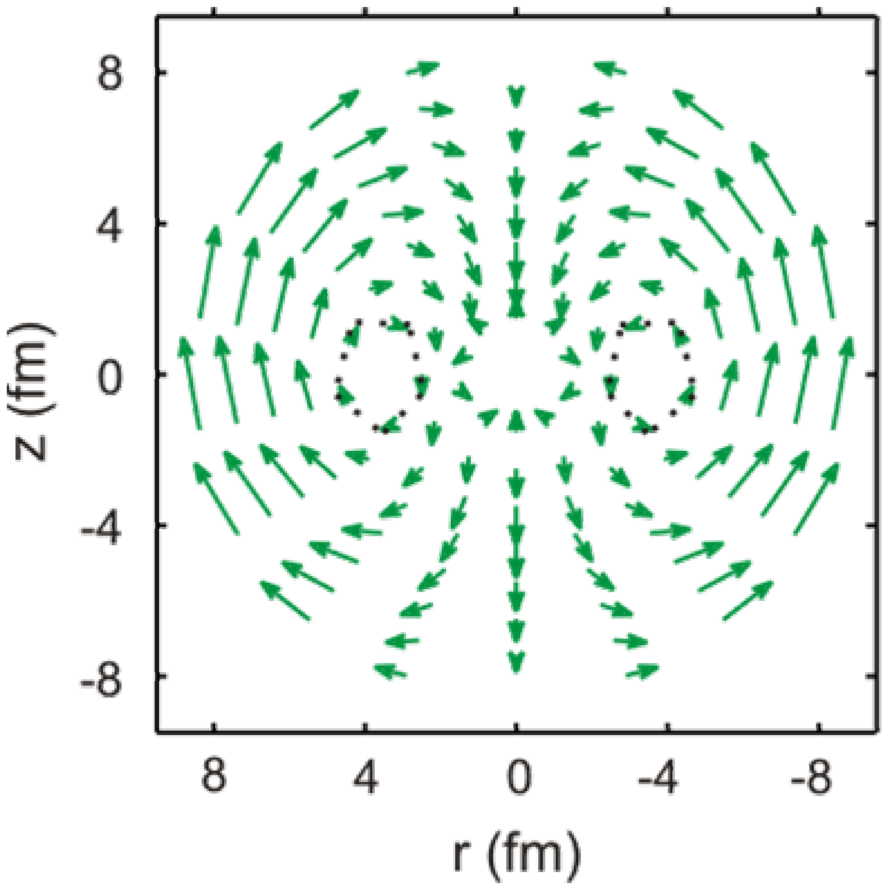
- Excellent agreement of QPM with experiment

Transition Densities



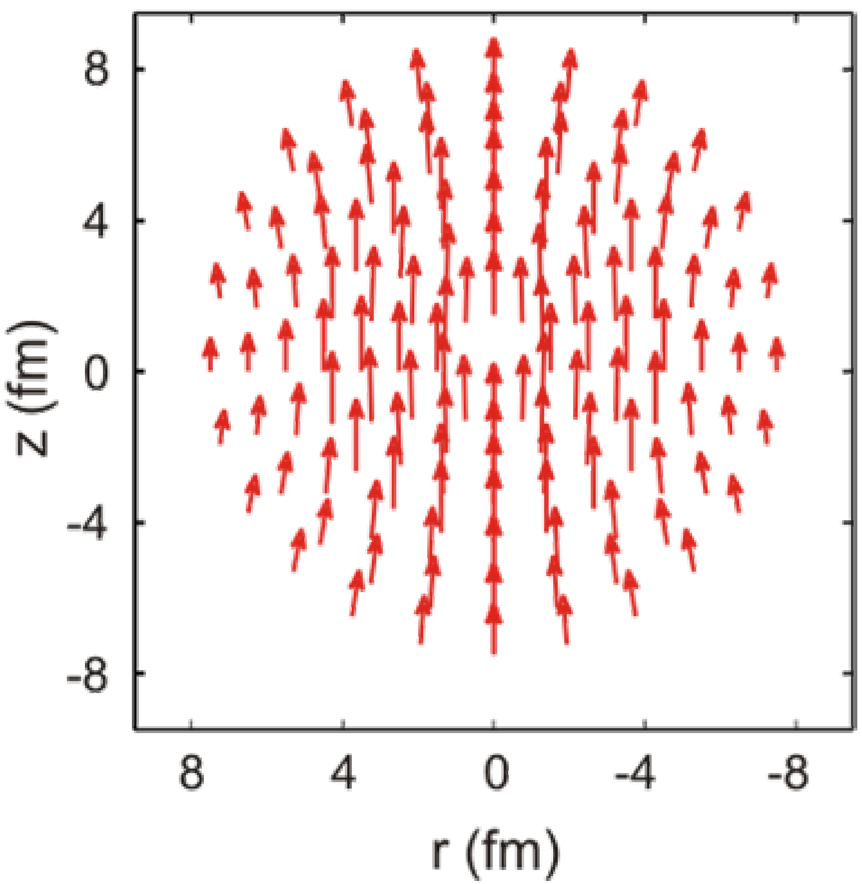
Velocity Distributions

Toroidal



$E_x = 6.5 – 10.5$ MeV

GDR



$E_x > 10.5$ MeV

Structure of Low-Energy E1 Modes

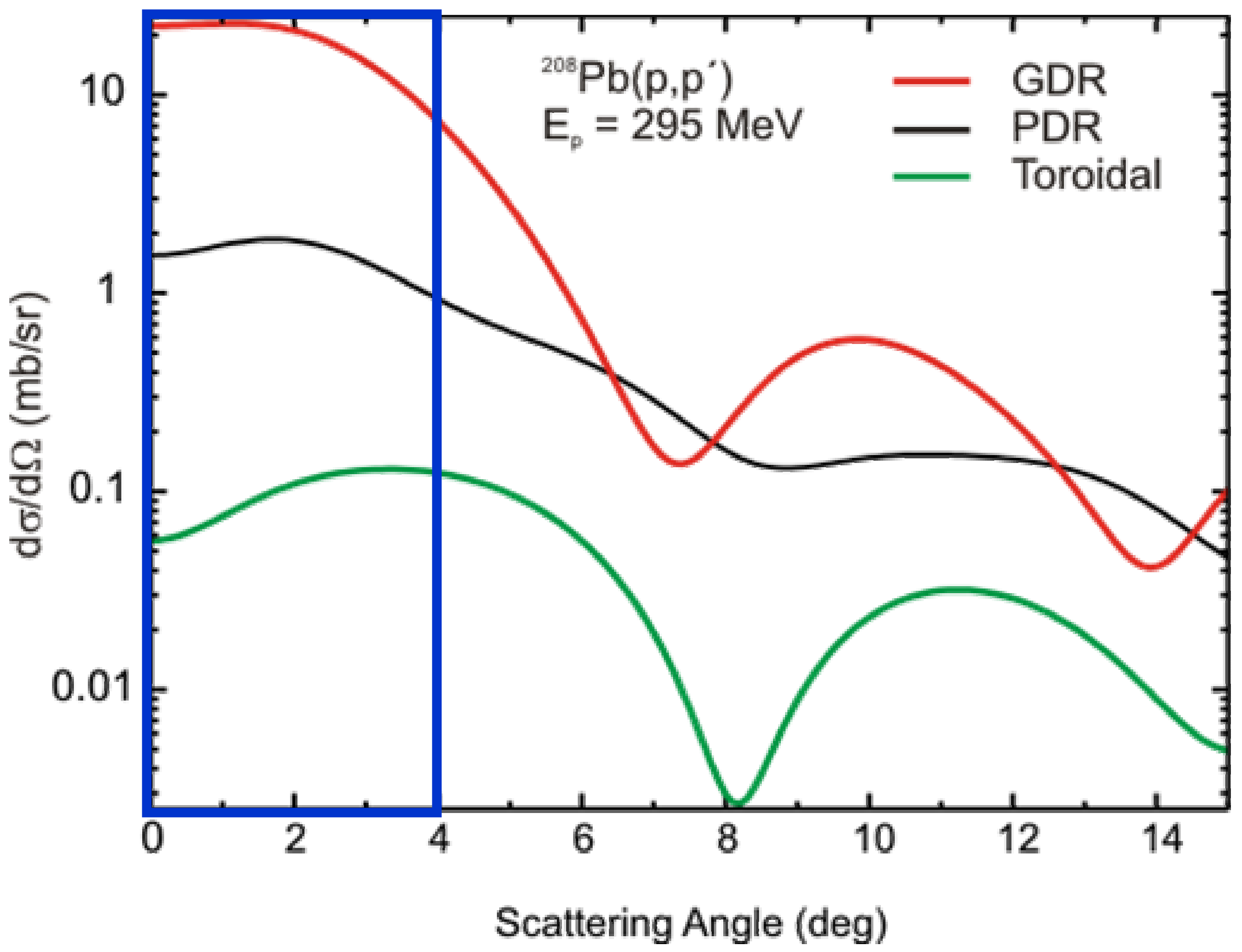
How can we elucidate the structure of these low-energy E1 modes ?

- Proton scattering at 0^o
  - intermediate energy (300 MeV optimal)
  - high resolution
  - angular distribution (E1 / M1 separation)
  - polarization observables (spinflip / non-spinflip separation)

- Electron scattering (preferentially at 180^o)
  - high resolution
  - transverse form factors needed
  - very sensitive to structure of the different modes

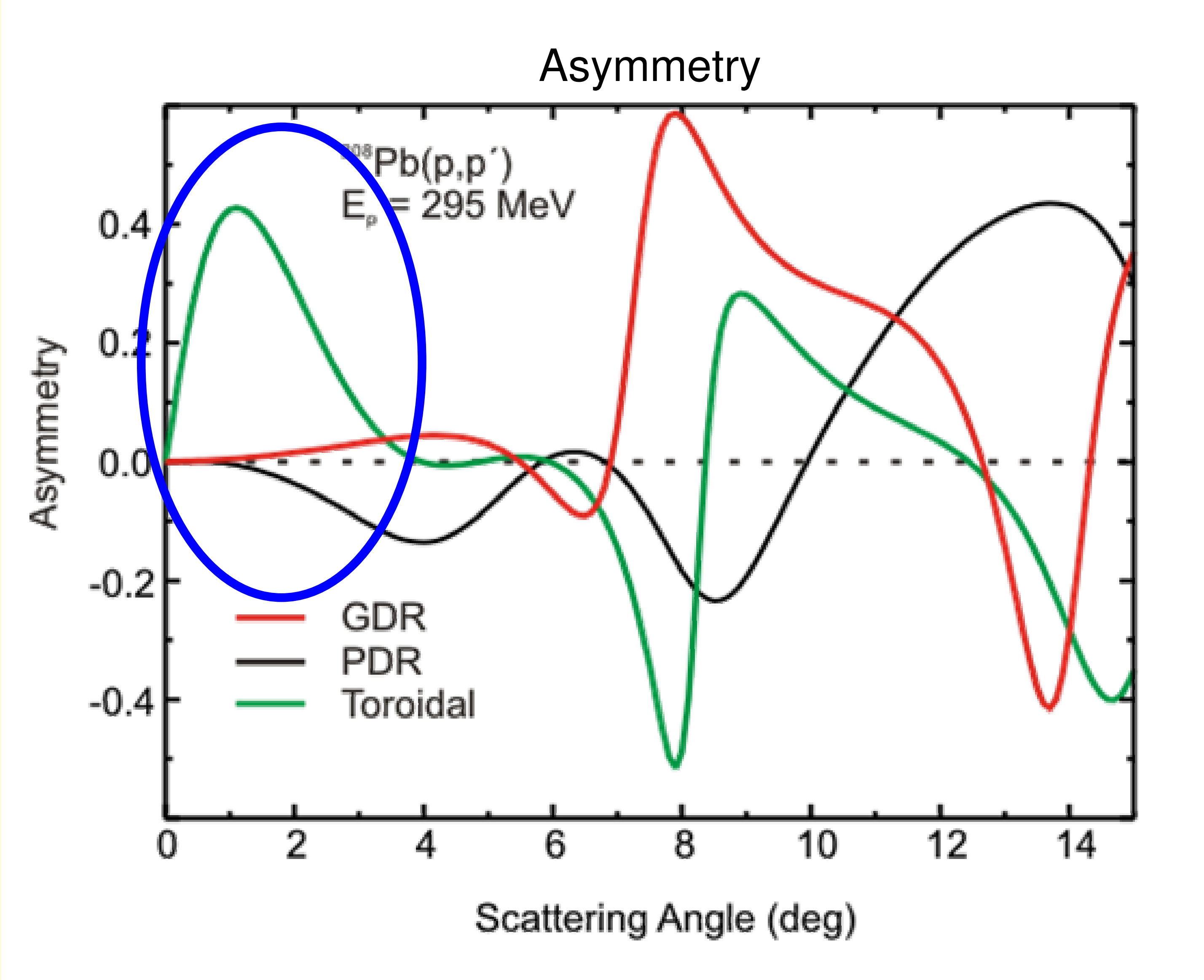
Signatures of Different E1 Modes in ($\vec{p},\vec{p}'$)

Angular Distribution



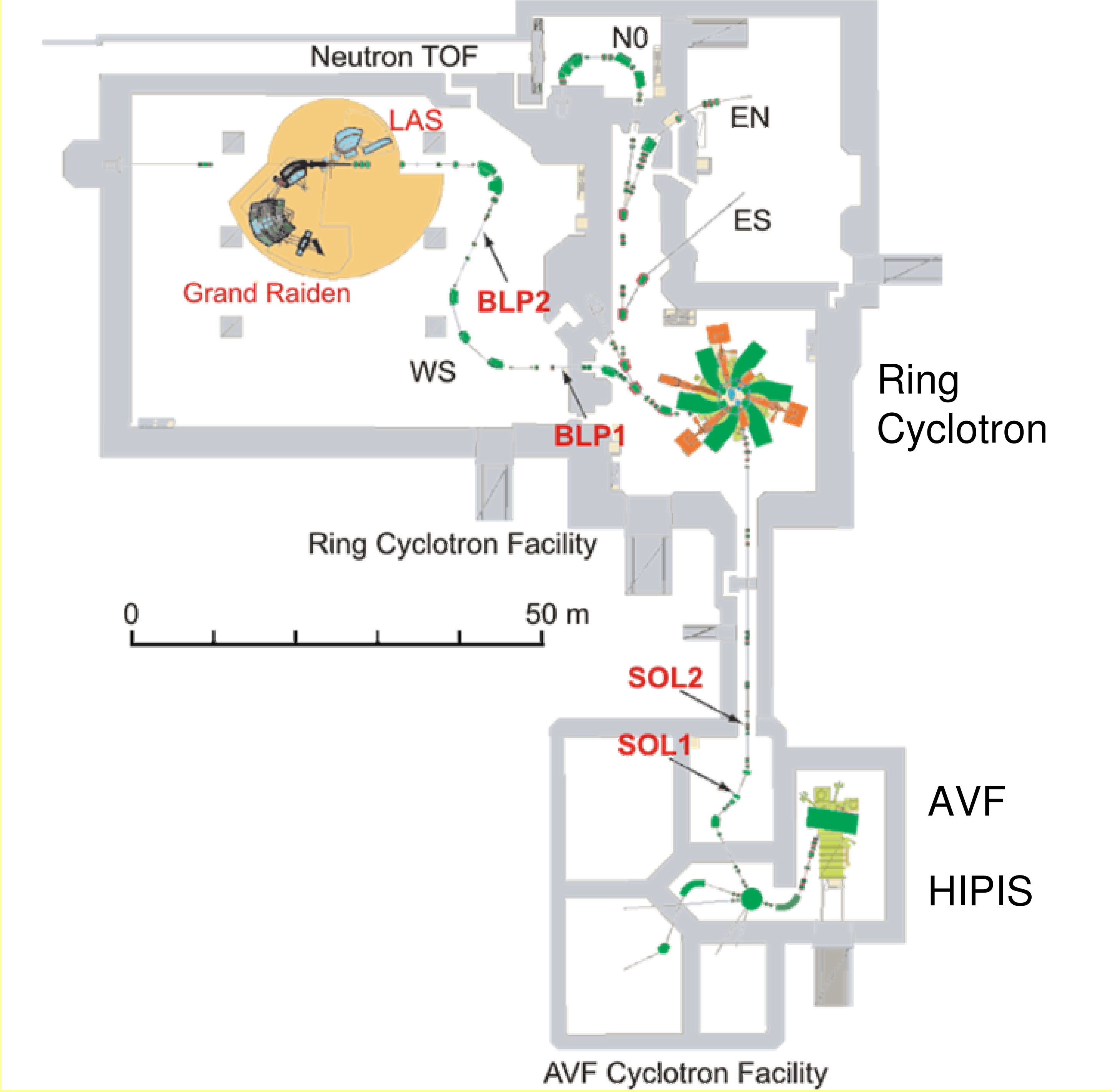
- Pronounced differences at small angles due to Coulomb-nuclear interference

Signatures of Different E1 Modes in $(\vec{p},\vec{p}')$

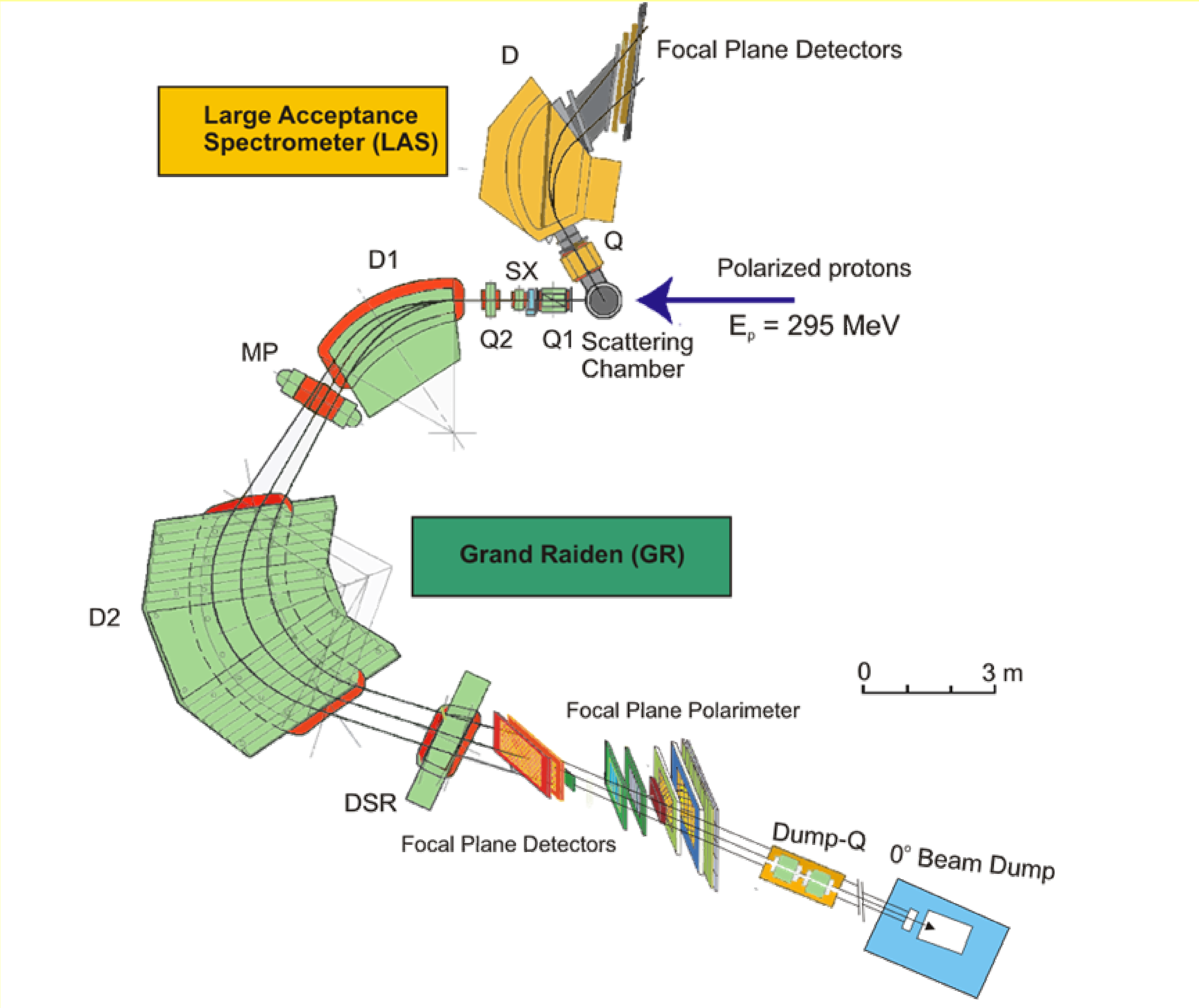


- Signature of toroidal mode in the asymmetry at small angles ?

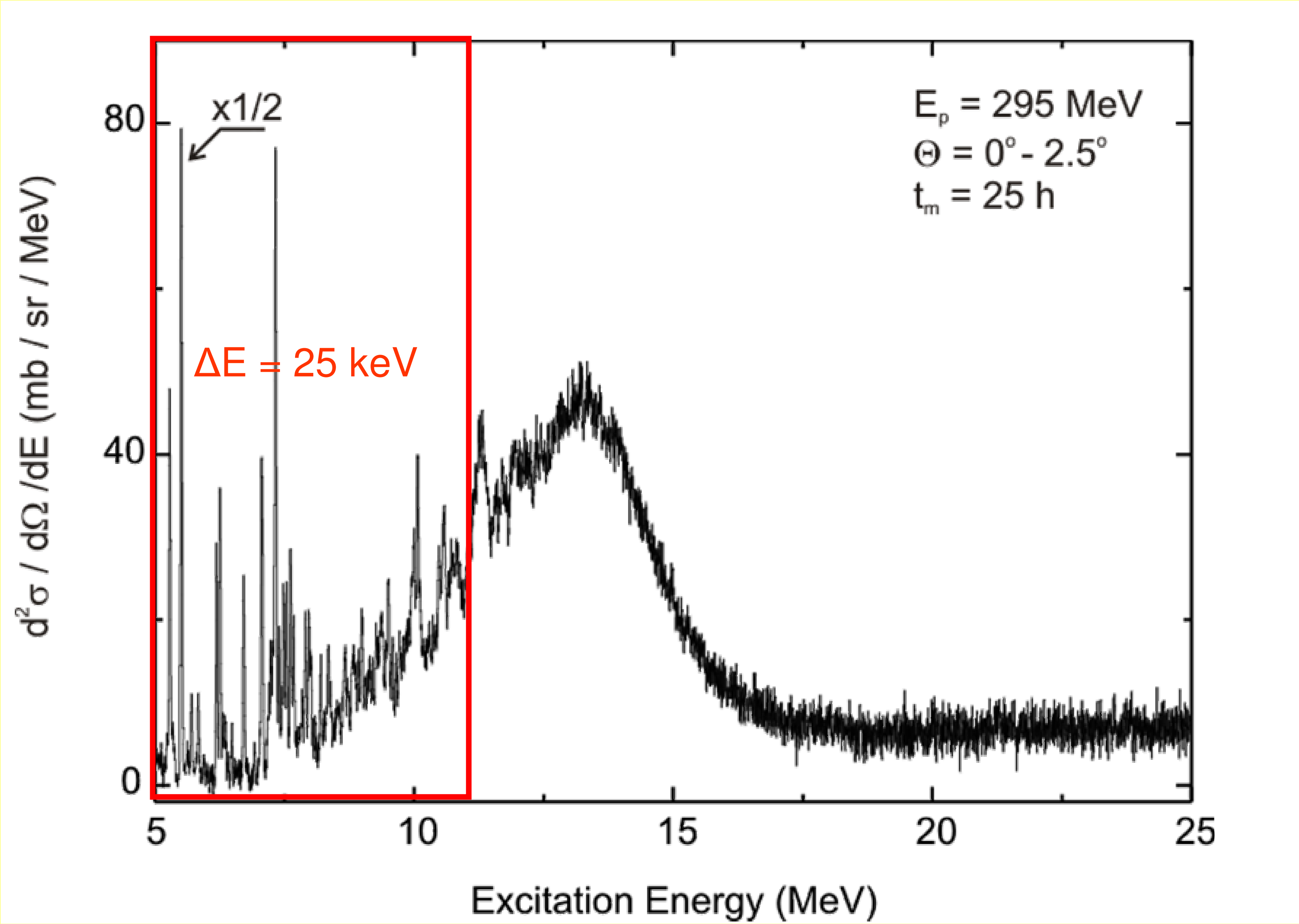
Polarized Proton Scattering Experiment at RCNP



0º Setup at RCNP

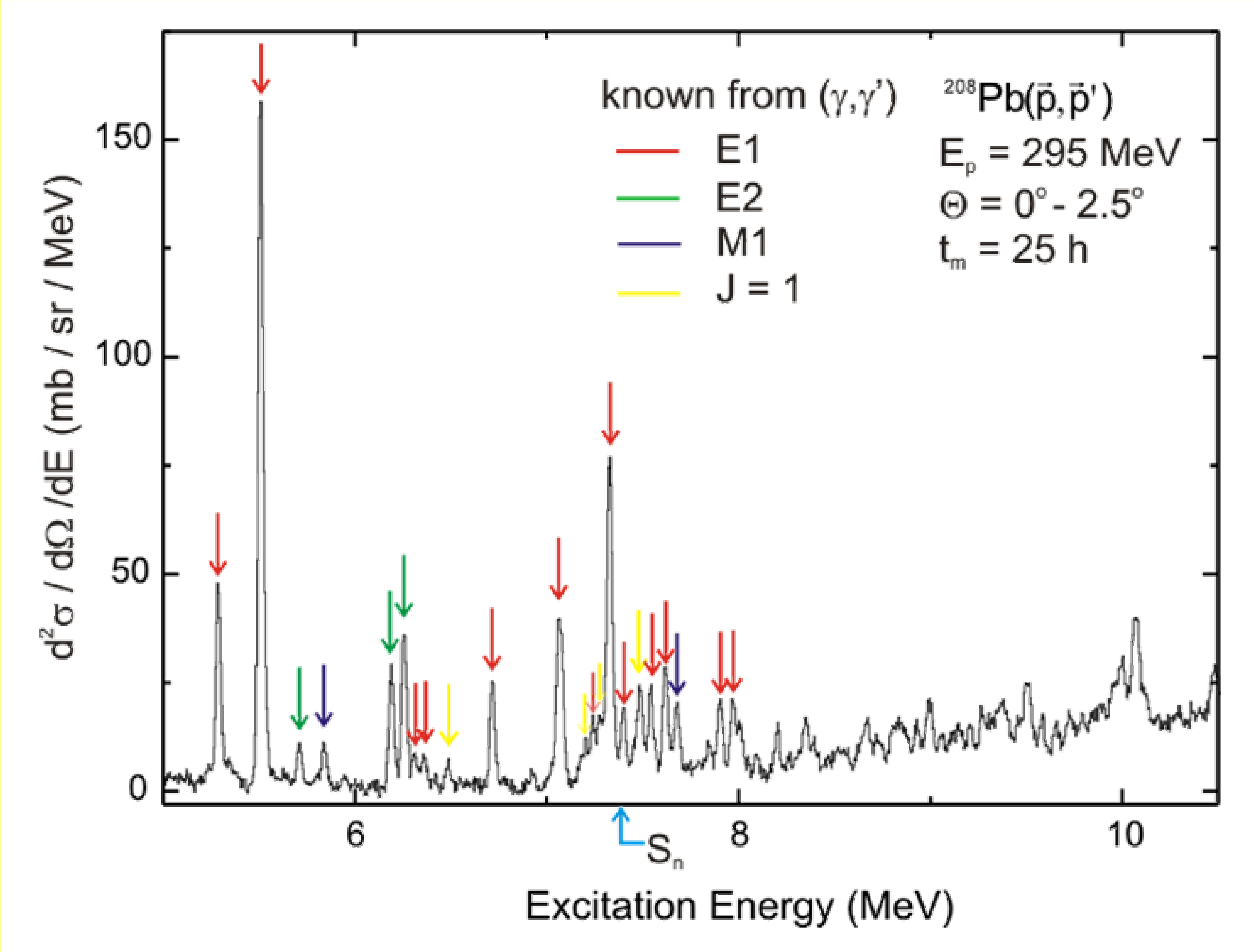


Background-subtracted Spectrum



- Pronounced fine structure of the GDR

Spectrum (expanded)

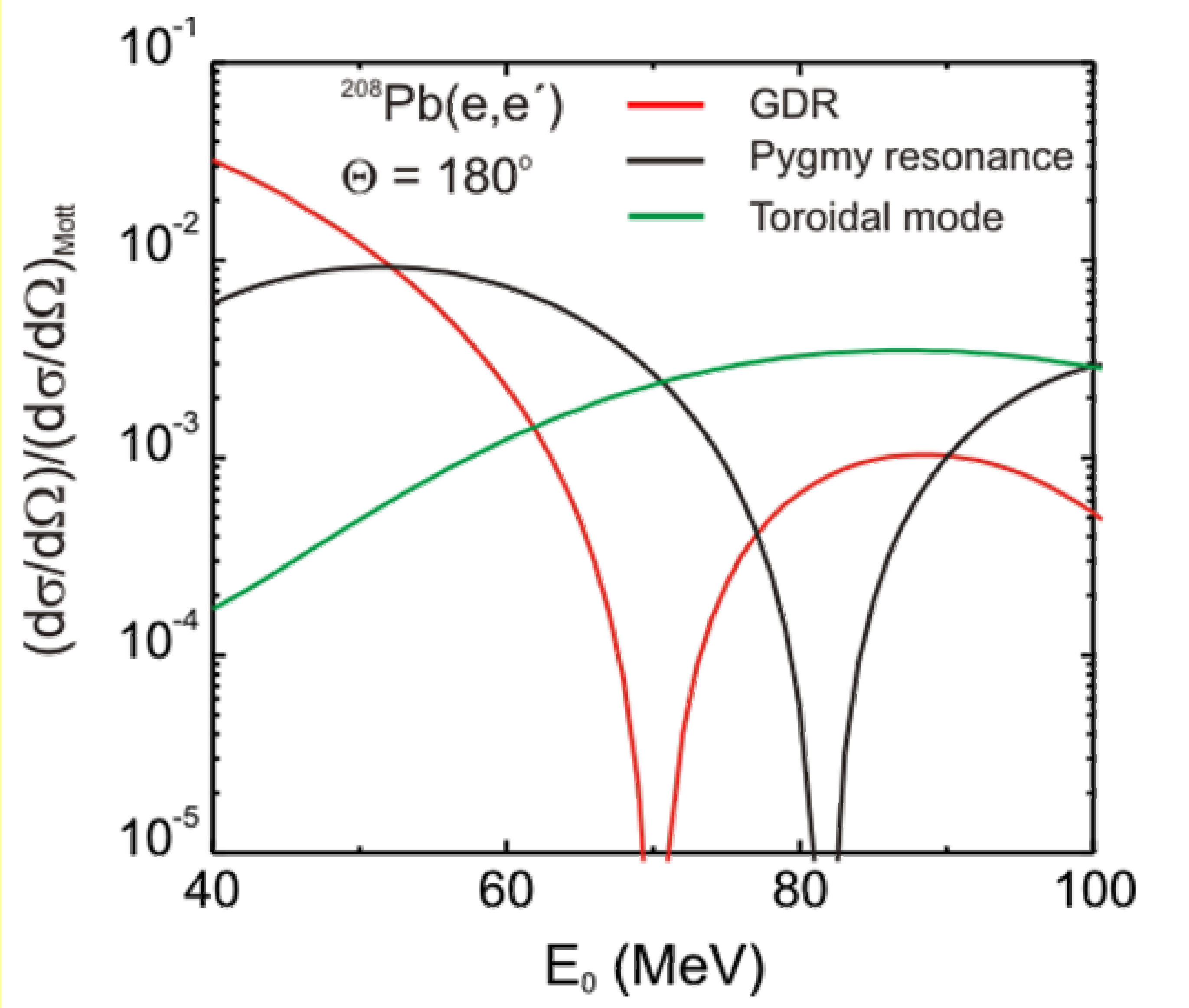


Status and Outlook

- First high-resolution 0° polarized proton scattering experiment performed on ^{208}Pb
- Energy resolution ΔE = 25 - 30 keV FWHM achieved
- $d\sigma/d\Omega$, D_{ss} measured

- Polarisation transfer measurements of D_{NN} and D_{LL} to be completed
- Completion of data analysis
- Comparison with $^{208}Pb(e,e')$

Signatures of Low – Energy E1 modes in (e,e´)



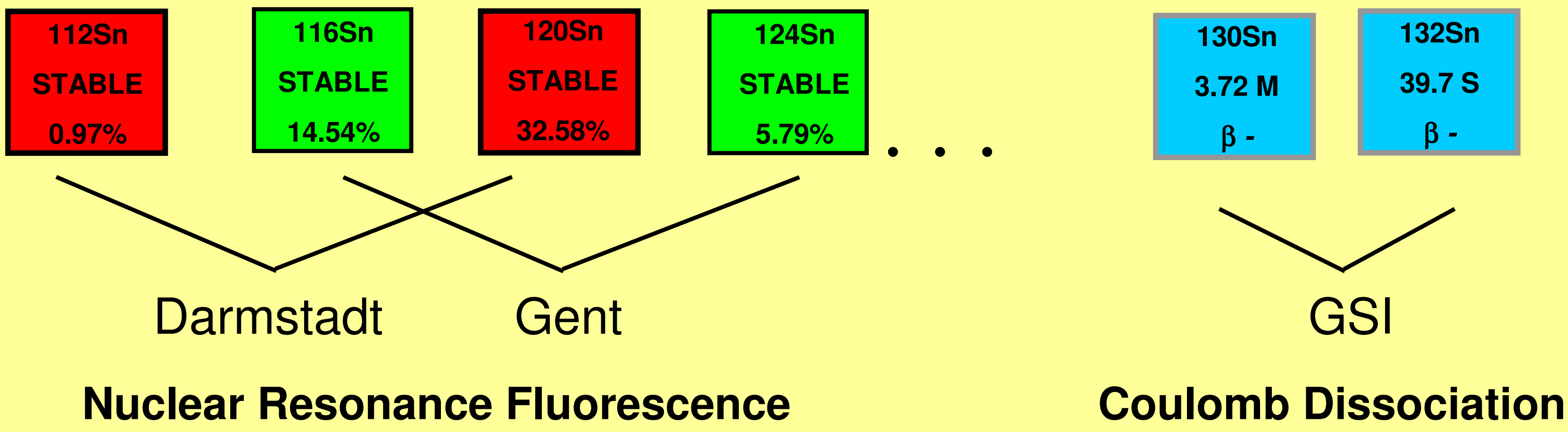
- Large difference in the momentum transfer dependence

Systematics of the PDR in the Sn Isotope Chain

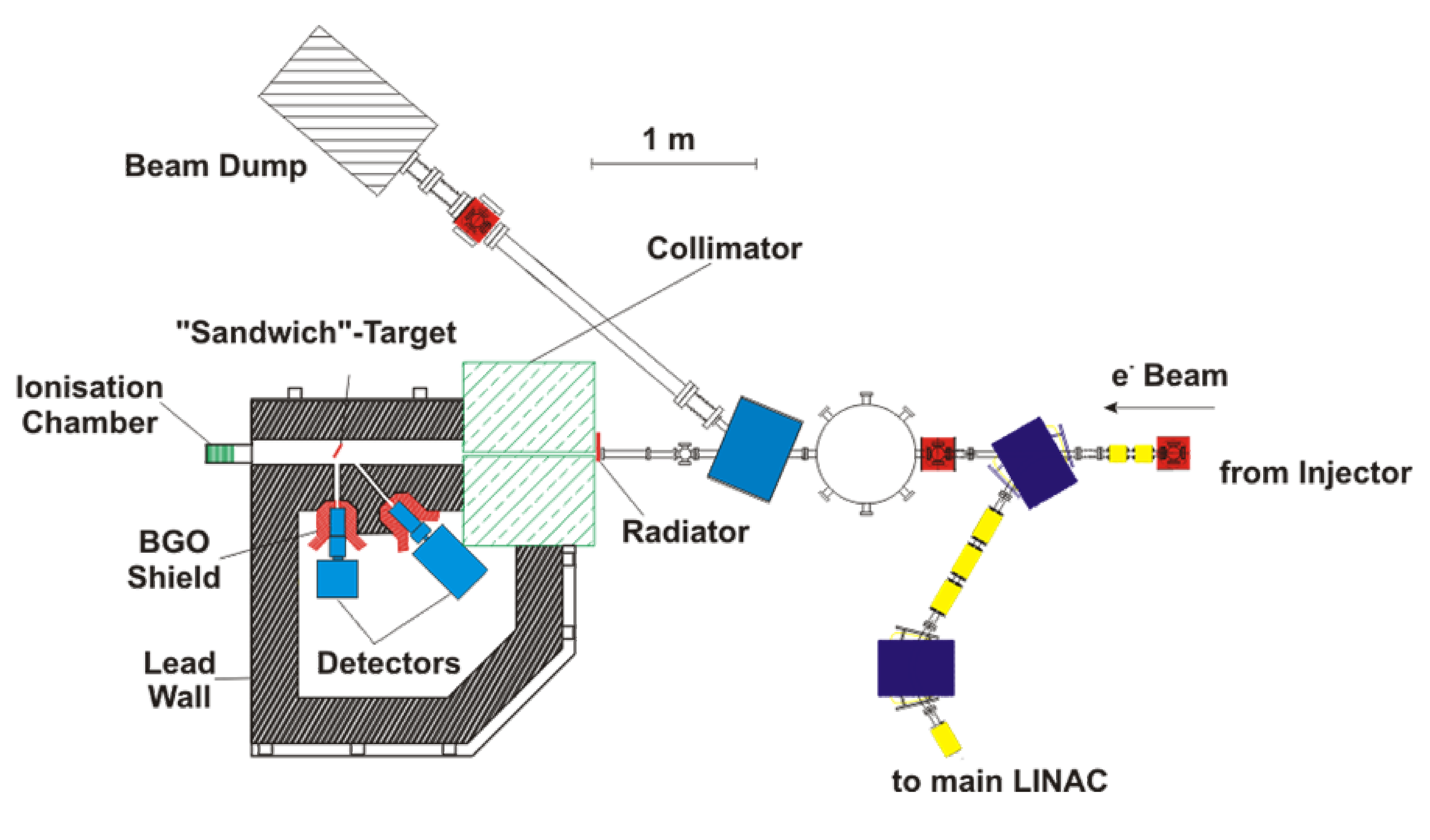
- Test case for theory, many calculations

  N. Tsoneva et al. , NPA 731 (2004) 273
  D. Sarchi et al. , PLB 601 (2004) 27
  N. Paar et al., PLB 606 (2005) 288
  J. Piekarewicz, PRC 73 (2006) 044325
  S. Kamerdizhiev, S.F. Kovaloo, PAN 65 (2006) 418
  J. Terasaki, J. Engel, PRC 74 (2006) 044325
  E. Litvinova et al., PLB 647 (2007) 111

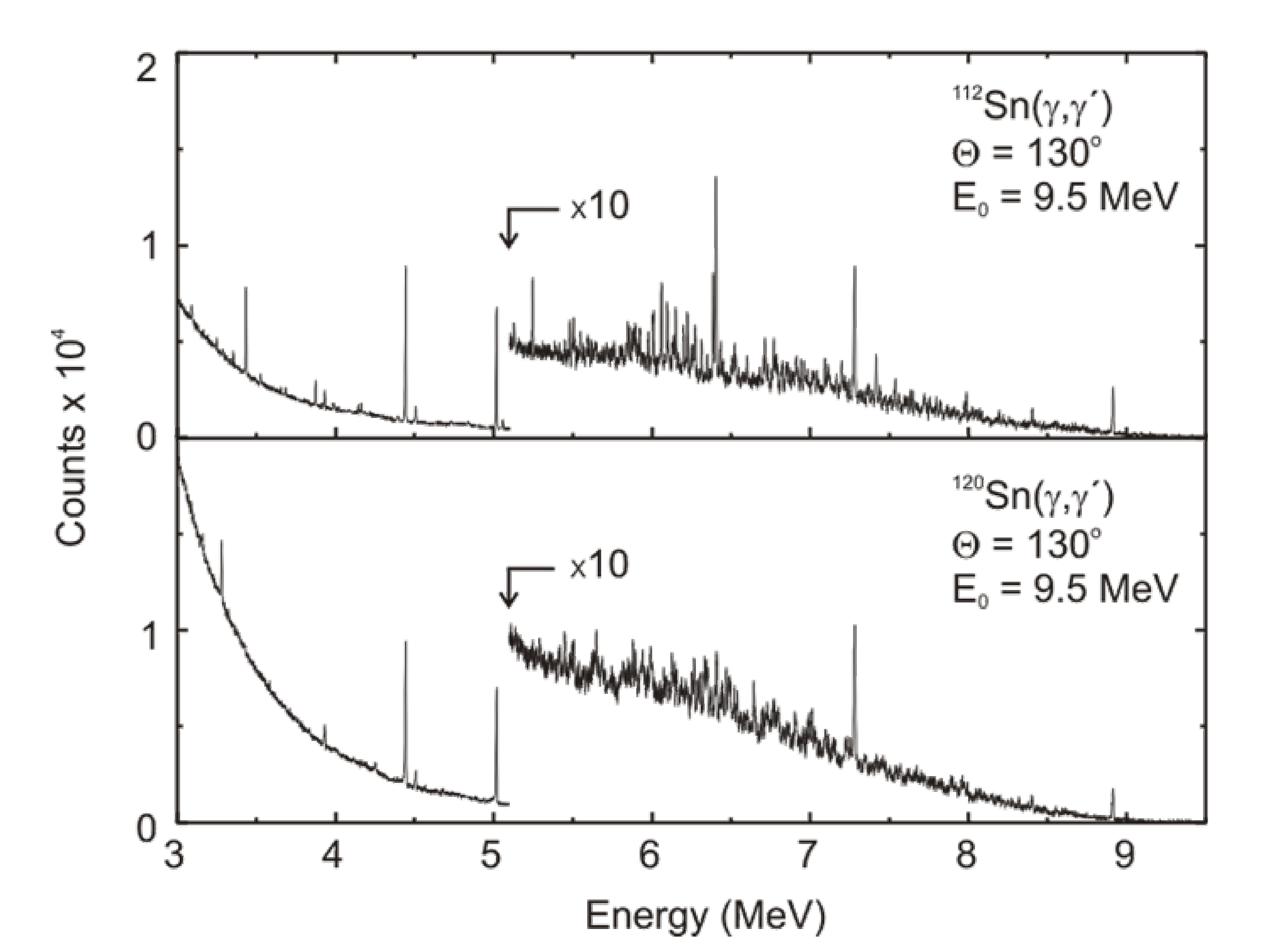
- Experimental data in stable and unstable Sn isotopes available



Real Photon Scattering Experiments at the S-DALINAC

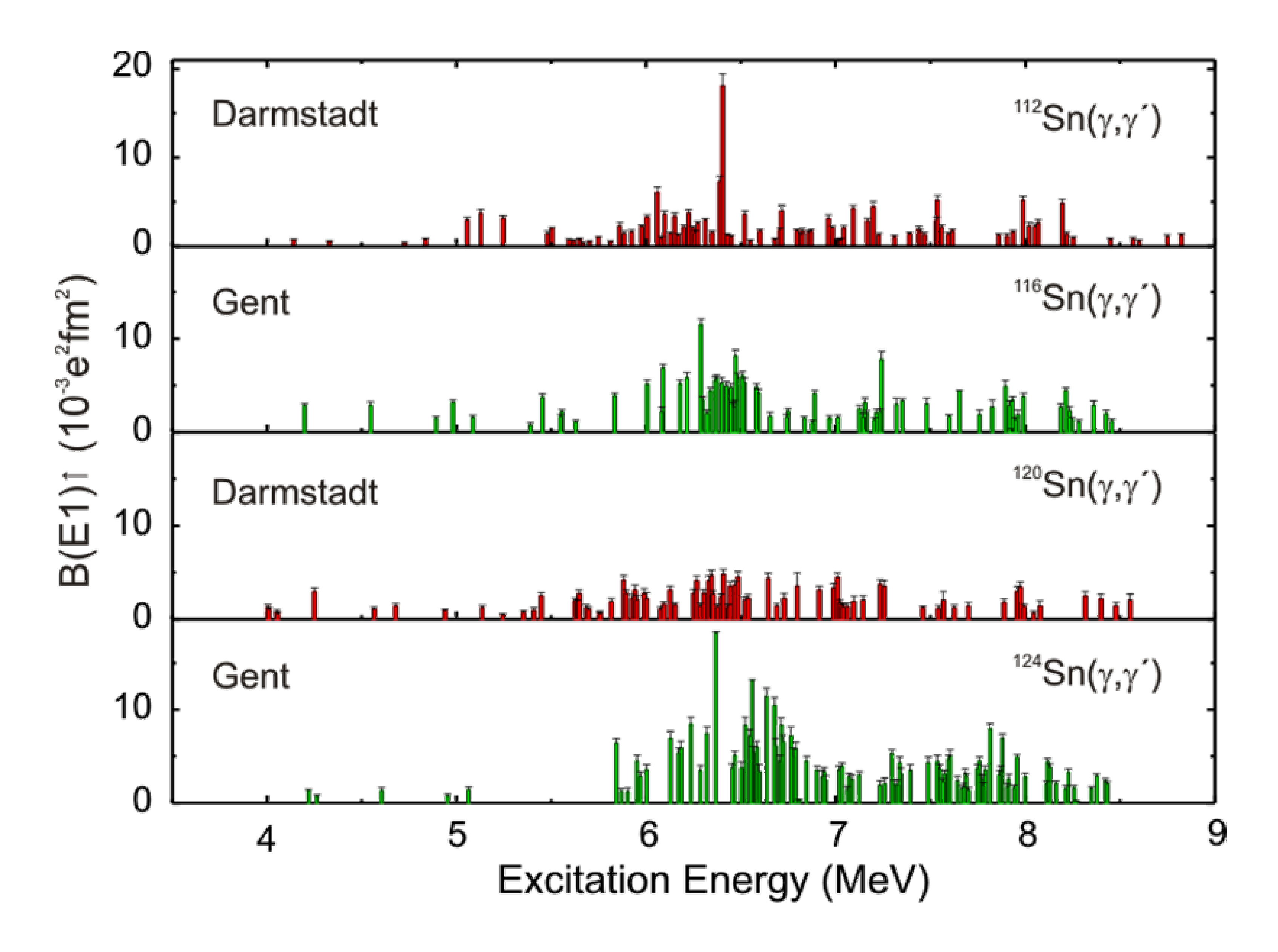


Spectra

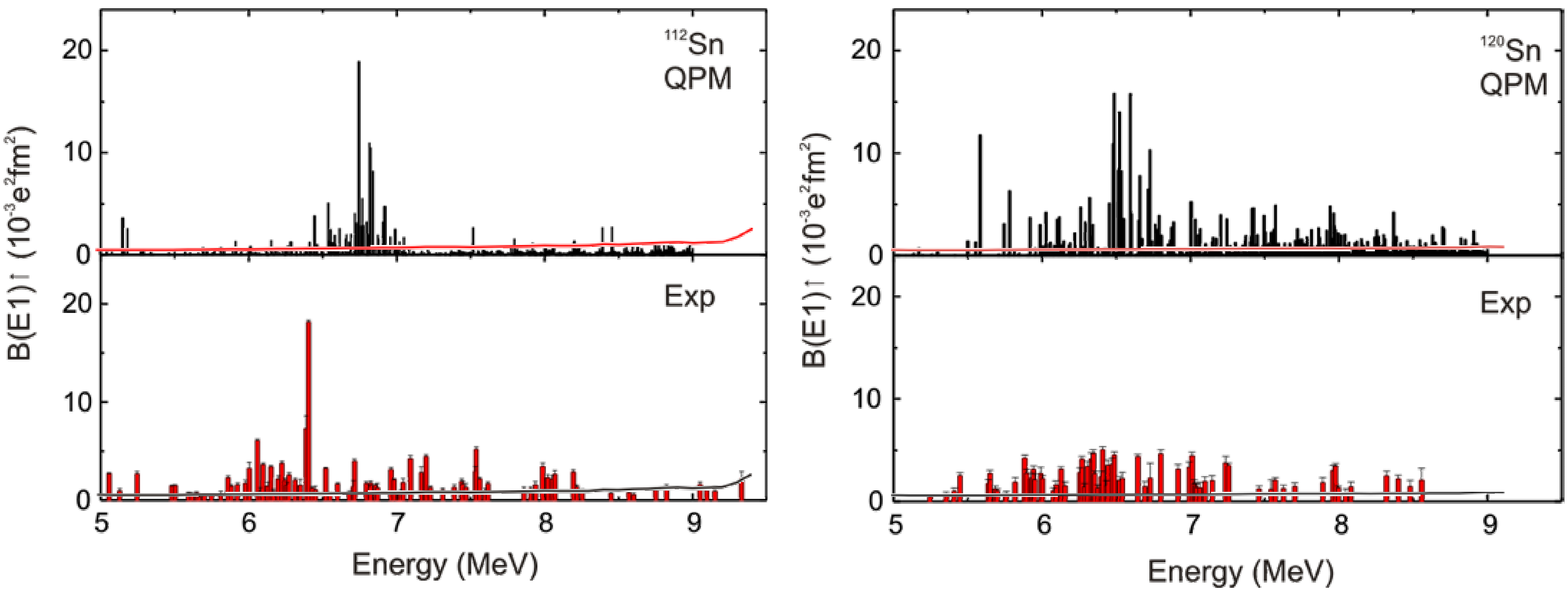


$^{112}Sn(\gamma,\gamma')$
$\Theta = 130°$
$E_0 = 9.5$ MeV
x10
$^{120}Sn(\gamma,\gamma')$
$\Theta = 130°$
$E_0 = 9.5$ MeV
x10
Counts x 10^4
0
1
2
0
1
3
4
5
6
7
8
9
Energy (MeV)

E1 Strength Distributions in Stable Sn Isotopes

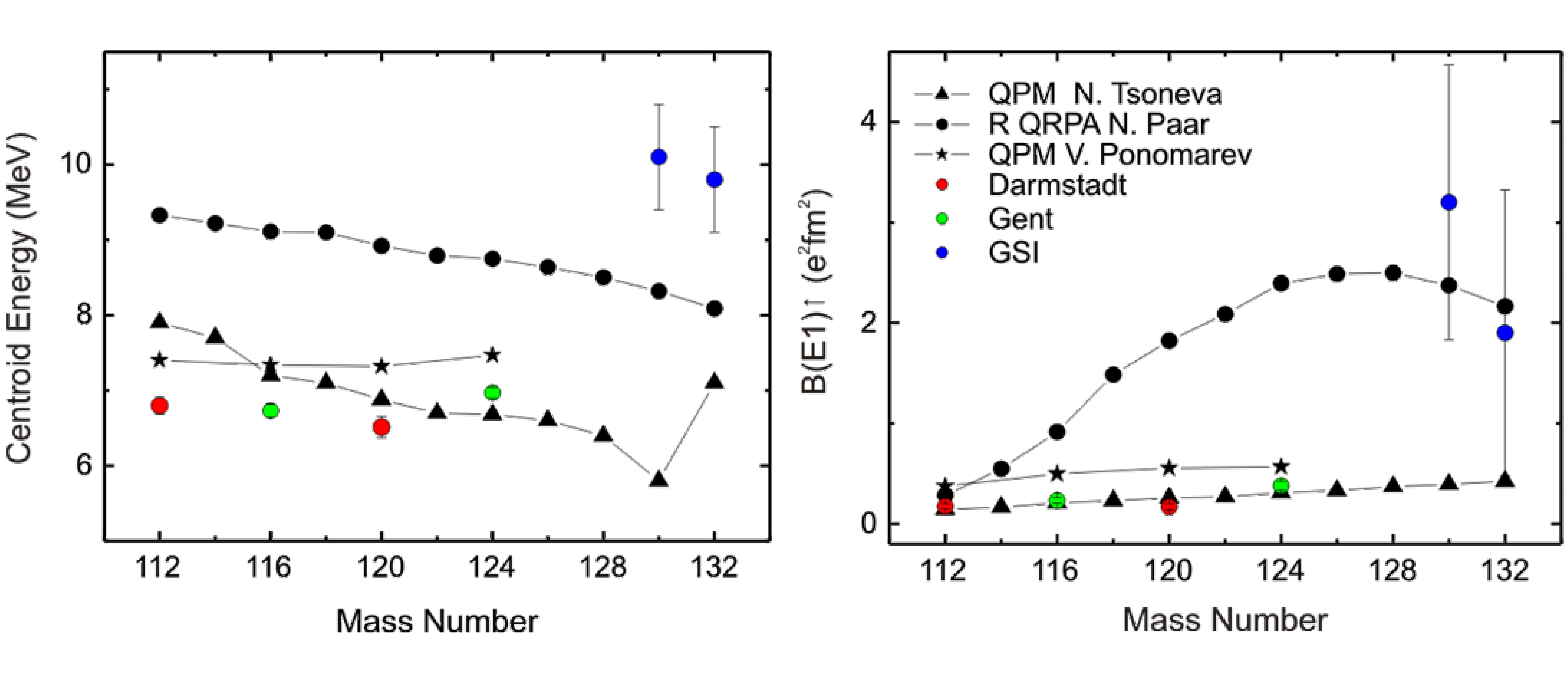


Comparison with Theory: Fragmentation



- QPM calculation: V.Yu. Ponomarev

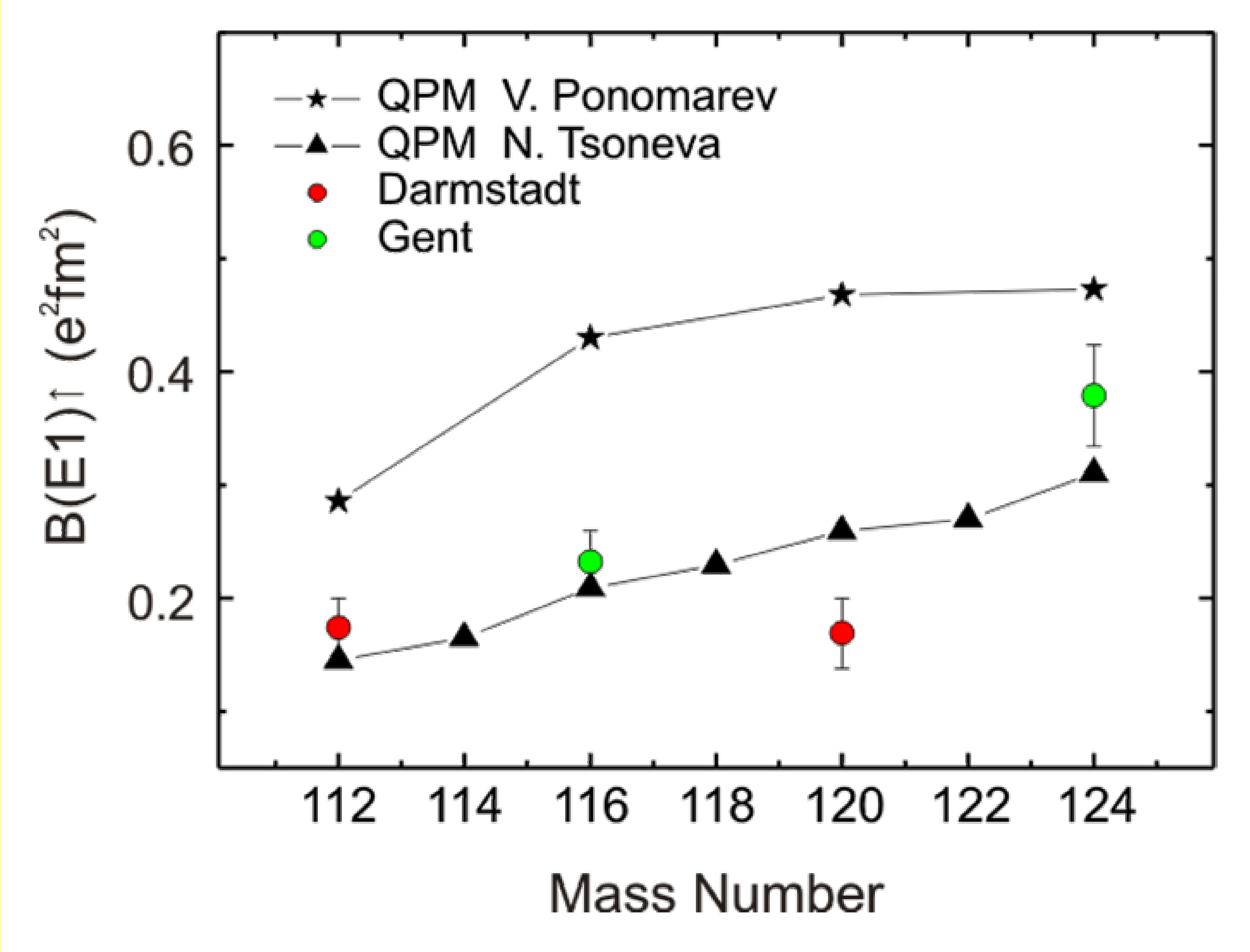
Comparion with Theory: Centroid and Cumulative Strength



Note: (γ,γ´) measures strength <u>below</u> threshold only

Coulomb dissociation measures strength <u>above</u> threshold only

Comparison with Theory: Cumulative Strengths



- No simple dependence on neutron excess (or N/Z ratio)
  - single-particle structure important
  - shift across threshold ?

Unresolved Strength in the Background

Is there unresolved strength in background?

➡ Fluctuation Analysis

J. Enders et al., PRL 79 (1997) 2010

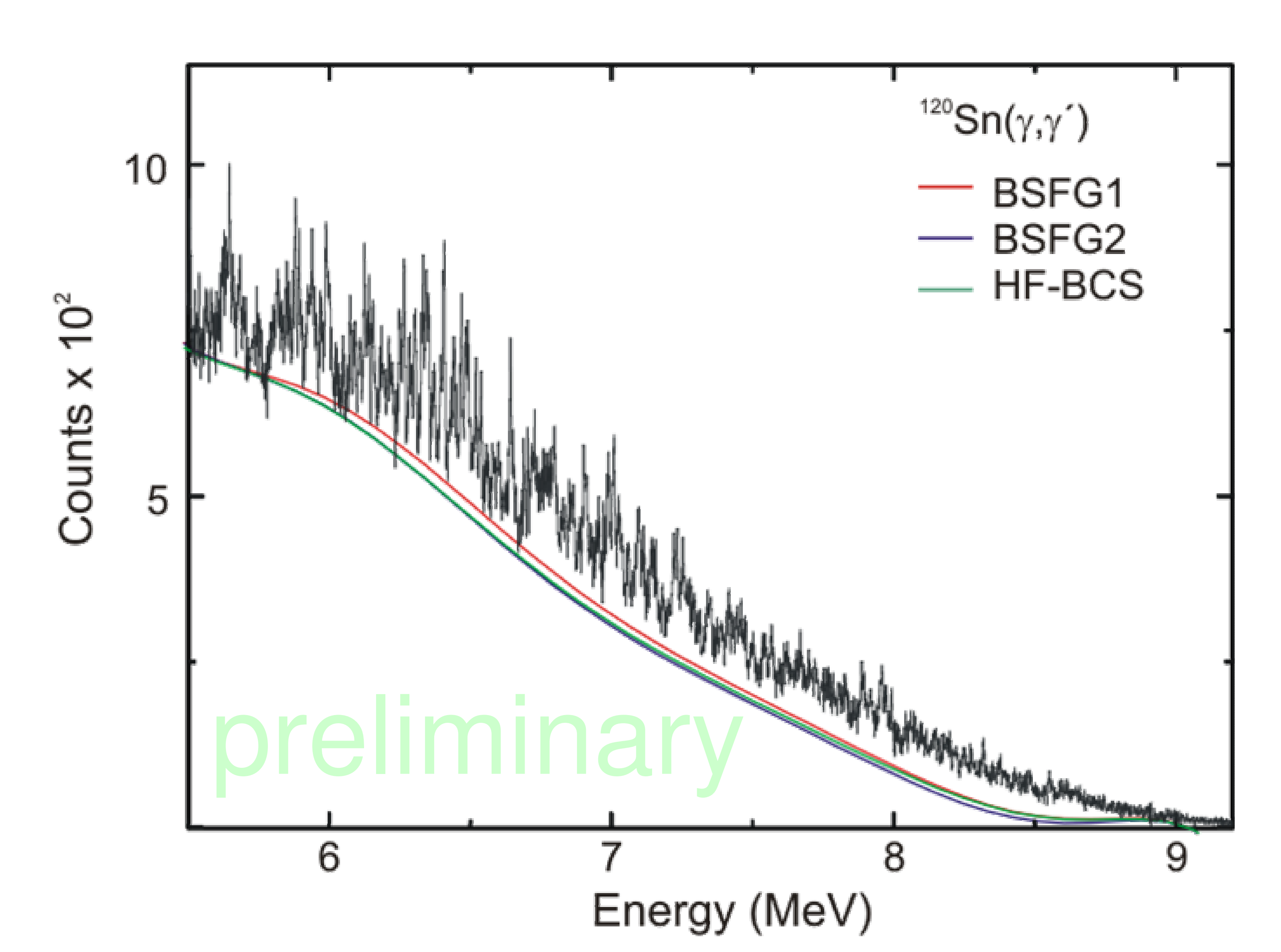
- Applicable in region where $< D > \; > \; \Delta E \; > \; \Gamma$
- Chaotic regime, level properties follow RMT
- Level density from models

T. Rauscher et al., PRC 56 (1997) 1613	BSFG1
T. von Egidy, D. Bucurescu, PRC 72 (2005) 044311	BSFG2
P. Demetriou, S. Goriely, NPA 695 (2001) 95	HF-BCS

➡ Background shape from discrete wavelet transform

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

Unresolved Strength in the Background



Summary

- Systematic of PDR in stable Sn isotopes established
- Models close to results either in stable or in unstable nuclei, but not both
- No simple dependence of total strength on neutron excess
- We need consistent measurements across the neutron treshold
  - NEPTUN tagger at S-DALINAC
  - High resolution (p,p´) at 0°

Collaborations

- Proton scattering

RCNP Osaka / U Osaka / iThemba LABS / Wits U / TU Darmstadt / IFIC Valencia / Kyoto U/ U Tokyo

T. Adachi, J. Carter, H. Fujita, Y. Fujita, K. Hatanaka, Y. Kalmykov, M. Kato, H. Matsubara, P. von Neumann-Cosel, H. Okamura, I. Poltoratska, V.Yu. Ponomarev, A. Richter, B. Rubio, H. Sakaguchi, Y. Sakemi, Y. Sasamoto, Y. Shimizu, F.D. Smit, Y. Tameshige, A. Tamii, J. Wambach, M. Yosoi, J. Zenihiro

- Sn Isotopes

TU Darmstadt / U Giessen / FSU Tallahassee / U Zagreb

J. Enders, Y. Kalmykov, H. Lenske, P. von Neumann-Cosel, B. Özel, N. Paar, J. Piekarewicz, V.Yu. Ponomarev, A. Richter, D. Savran, N. Tsoneva, A. Zilges

Discrete wavelet transform

- $$C(\delta E, E_X) = \frac{1}{\sqrt{\delta E}} \int_{-\infty}^{+\infty} \sigma(E) \Psi^* \left(\frac{E_X - E}{\delta E} \right) dE$$ wavelet coefficients

- Discrete wavelet transform *

  $\delta E = 2^j$ and $E_X = k \cdot \delta E$ with j, k = 1, 2, 3, …

  exact reconstruction is possible

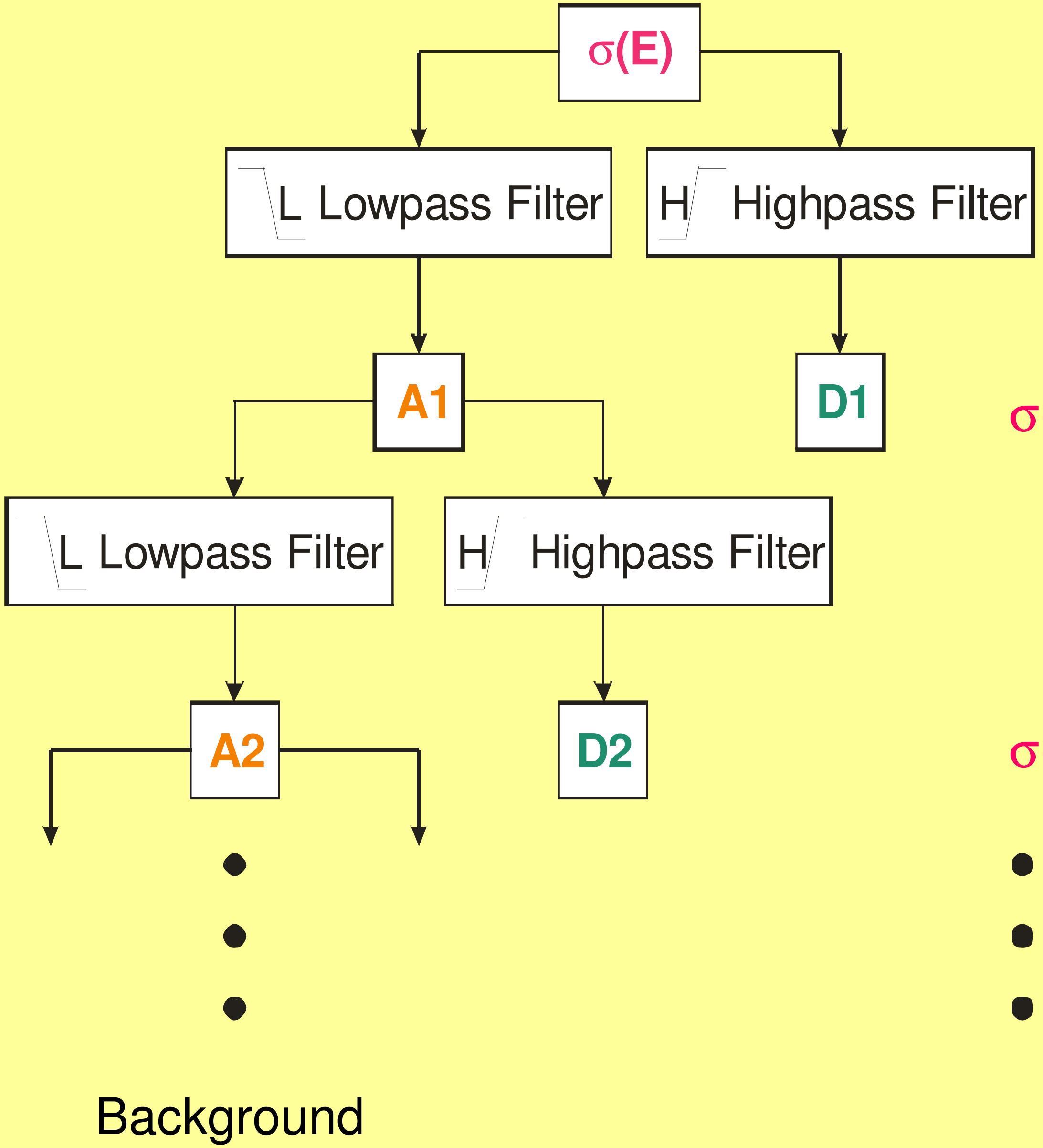
  is fast

- $$\int_{-\infty}^{+\infty} E^n \Psi^* \left(\frac{E_X - E}{\delta E} \right) dE = 0, \quad n = 0,1 \ldots m-1$$ vanishing moments

  this defines the shape and magnitude of the background

* http://www.mathworks.com/products/wavelet/

Decomposition of spectra

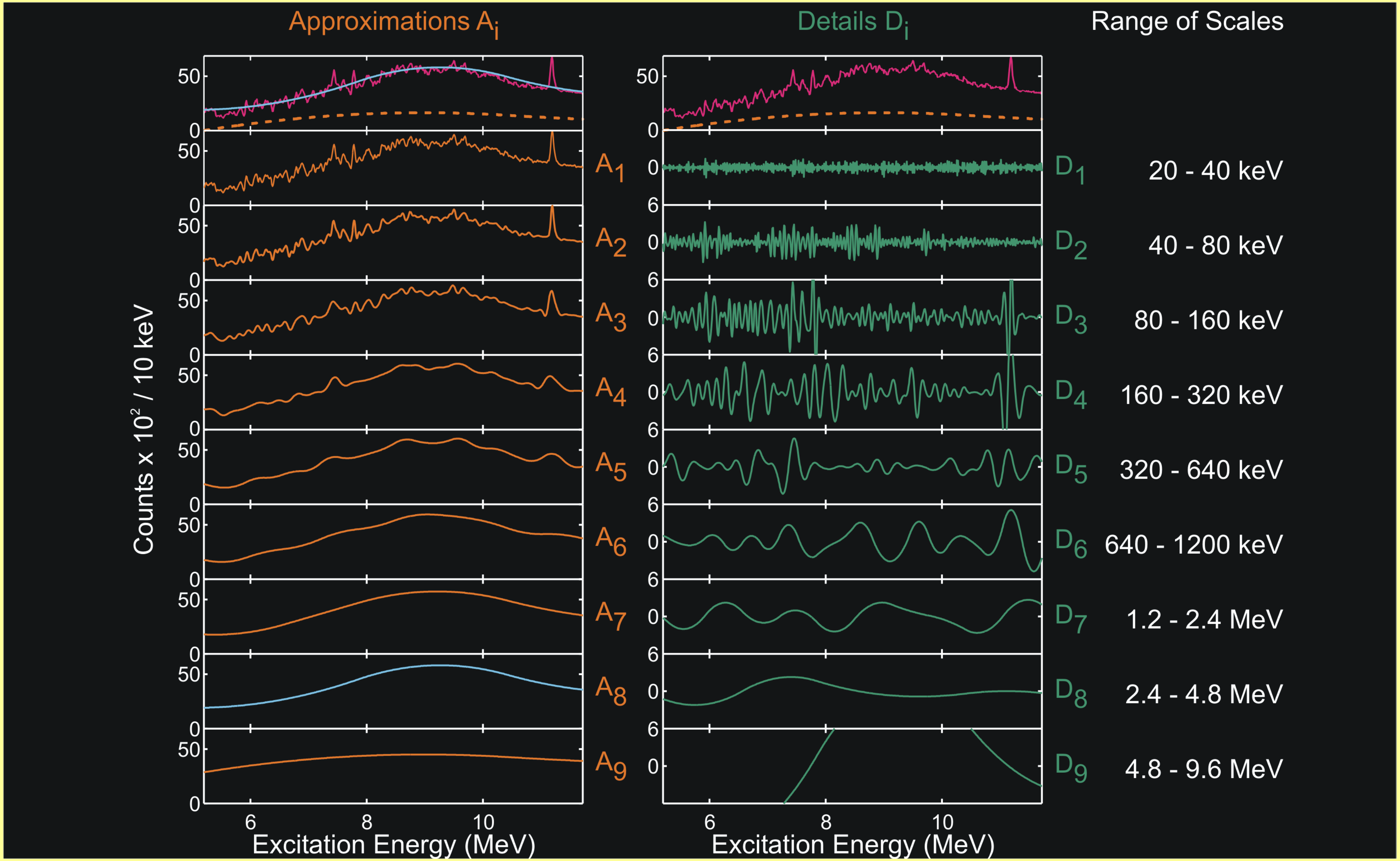


$\sigma(E) = A1 + D1$

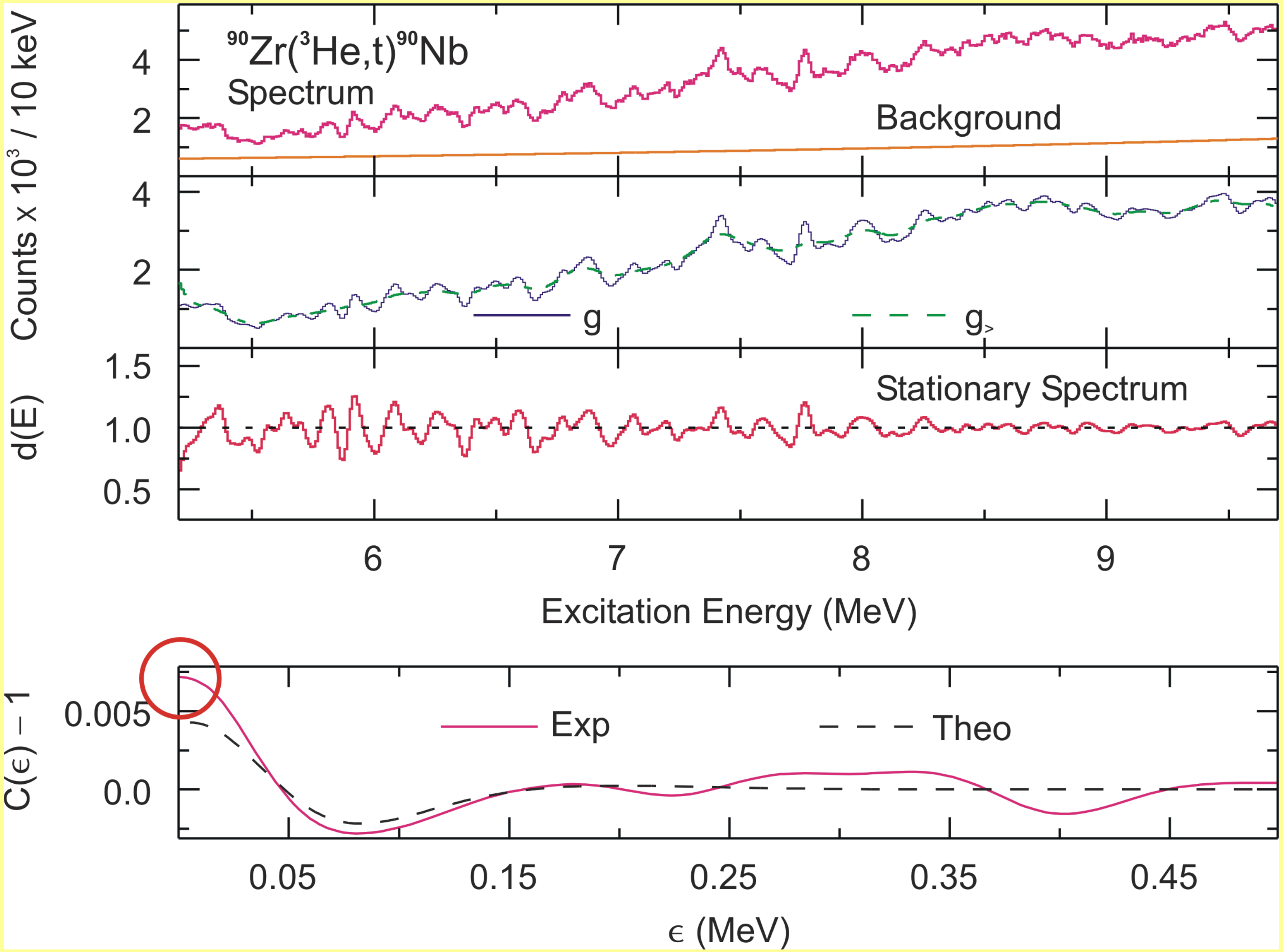
$\sigma(E) = A2 + D2 + D1$

⋮

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



Fluctuation analysis



- Background
- 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, Phys. Lett. 113B (1982) 362
P.G. Hansen, B. Jonson, and A. Richter, Nucl. Phys. A518 (1990) 13

Measured Spectrum