Systematics of the Electric Dipole Response in Stable Tin Isotopes*

Sergej Bassauer, Peter von Neumann-Cosel, Atsushi Tamii
and the E422 collaboration
Institut für Kernphysik, TU Darmstadt

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*Supported by the DFG within SFB 1245

SFB 1245

Outline

- Motivation

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- Experimental method

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- The case of ^{120}Sn

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- Preliminary results
- The case of ^{120}Sn
- Summary and outlook

Electric Dipole Response in Nuclei

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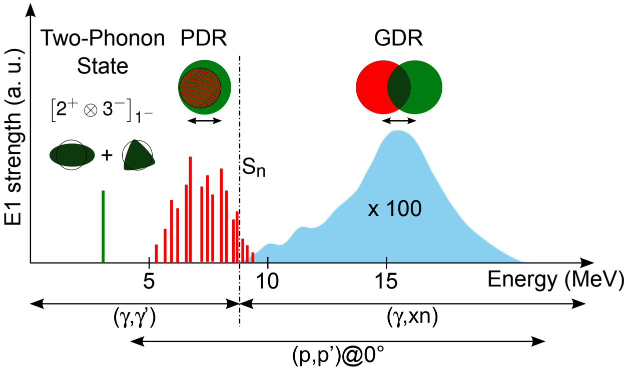

D. Martin, Master's thesis, TU Darmstadt (2013)

- Pygmy Dipole Resonance (PDR)

Electric Dipole Response in Nuclei

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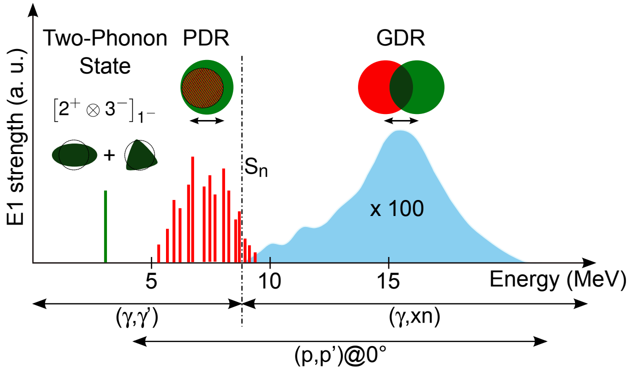

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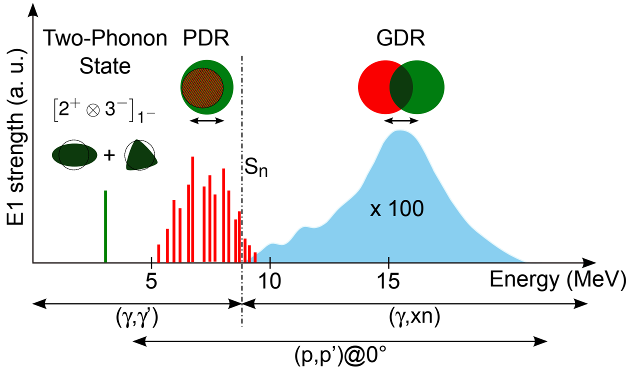

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- Pygmy Dipole Resonance (PDR)
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- Giant Dipole Resonance (GDR)

Electric Dipole Response in Nuclei

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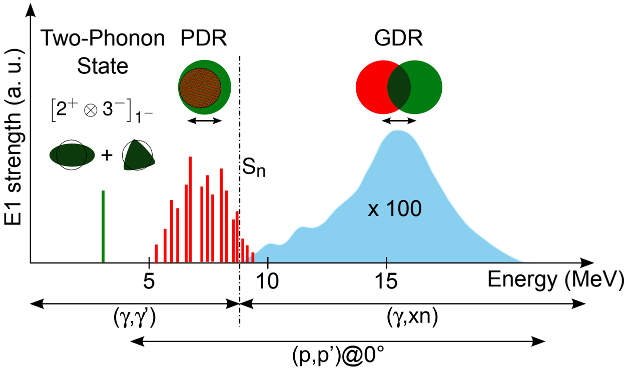

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- Pygmy Dipole Resonance (PDR)
  - Oscillation of neutron skin against core
- Giant Dipole Resonance (GDR)
  - Oscillation of neutrons against protons

Motivation: Electric Dipole Response
What can be learned?

- Dipole polarisability

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- Dipole polarisability
- Gamma strength function covering PDR and GDR
- Level densities in the GDR region

Dipole Polarisability

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- Static dipole polarisability

$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \sum \frac{\sigma_{abs}(E_x)}{E_x^2} = \frac{8\pi}{9} \sum \frac{B(E1)(E_x)}{E_x} \left[\mathrm{fm}^3/\mathrm{e}^2\right]$$

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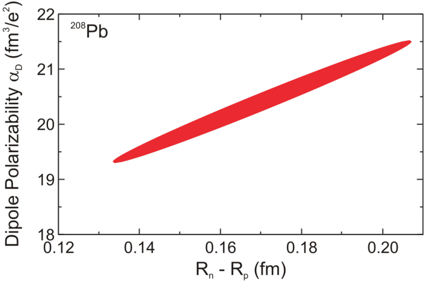

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- PDR strength related to neutron skin

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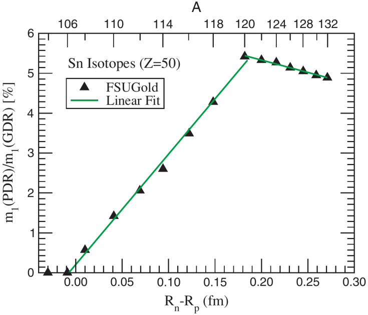
  - J. Piekarewicz, PRC **73** (2006) 044325



Gamma Strength Function (GSF) for E1 transitions

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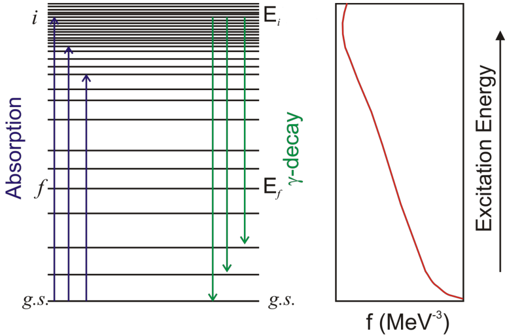
$$\langle\Gamma(E_i)\rangle = \frac{1}{\rho(E_i)} \int_0^{E_i} E_\gamma^3 f^{E1}(E_\gamma)\rho(E_i - E_\gamma)\mathrm{d}E_\gamma$$



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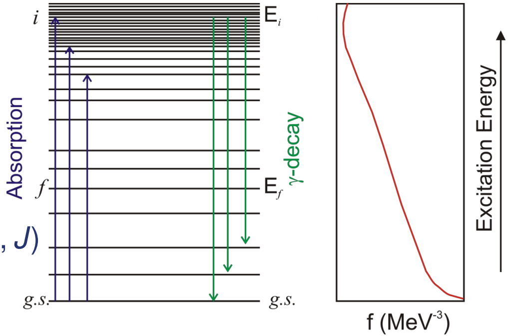

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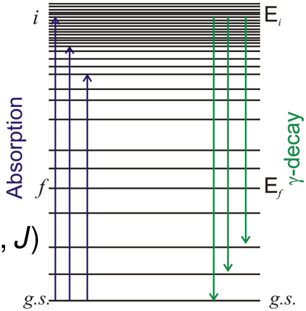

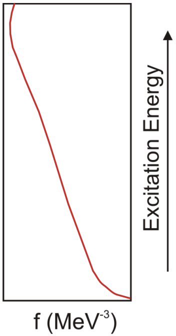

- Brink-Axel hypothesis

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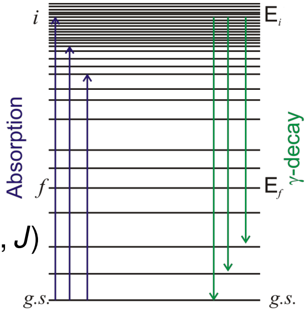

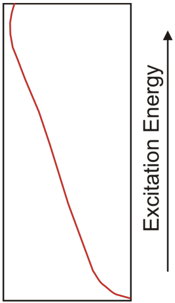

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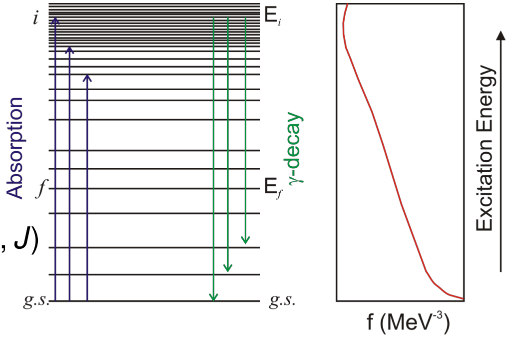

- Brink-Axel hypothesis
  - GSF depends only on E_γ
  - Independent of the structure of initial state

Determination of the level density

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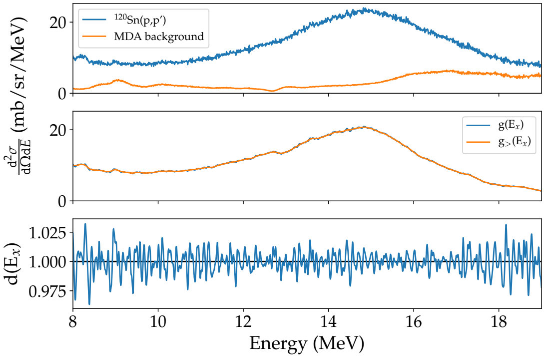
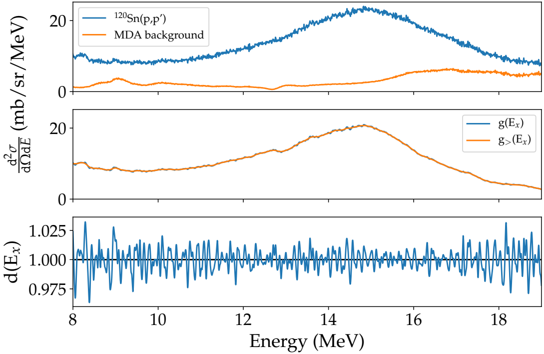
- Background from MDA



Determination of the level density

- Background from MDA
- Stationary spectrum

$$d(E_x) = \frac{g(E_x)}{g_>(E_x)}$$



Determination of the level density

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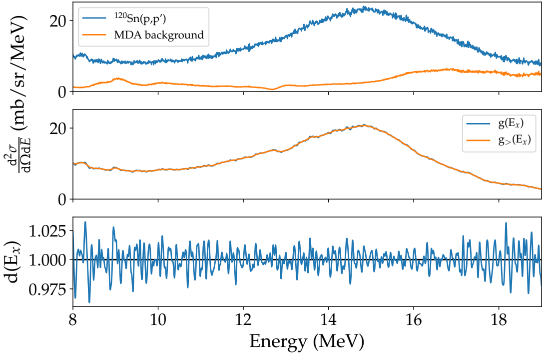
- Background from MDA
- Stationary spectrum

$$d(E_x) = \frac{g(E_x)}{g_>(E_x)}$$

- Autocorrelation function

$$C(\varepsilon) = \frac{\langle d(E_x) \cdot d(E_x + \varepsilon) \rangle}{\langle d(E_x) \rangle \cdot \langle d(E_x + \varepsilon) \rangle}$$



Determination of the level density

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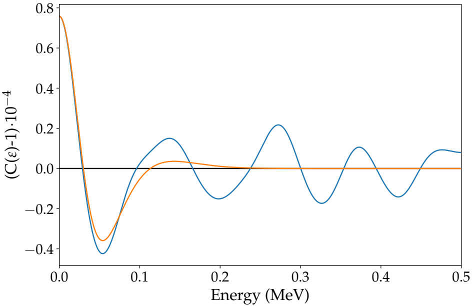
- Variance of the autocorrelation function

$$C(0) - 1 = \frac{\langle d(E_x)^2 \rangle - \langle d(E_x) \rangle^2}{\langle d(E_x) \rangle^2}$$



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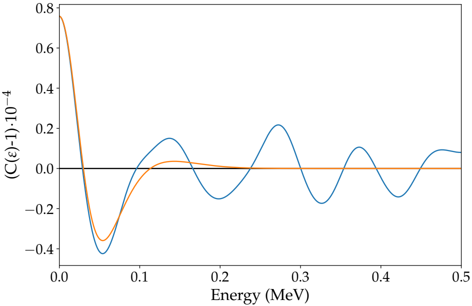
$$C(0) - 1 = \frac{\langle \mathrm{d}(E_x)^2 \rangle - \langle \mathrm{d}(E_x) \rangle^2}{\langle \mathrm{d}(E_x) \rangle^2}$$

- Model for the approximation of the exp. autocorrelation function



$$C(0) - 1 = \frac{\alpha \langle D \rangle}{2\sigma\sqrt{\pi}} \left(1 + \frac{\sigma}{\sigma_>} - \sqrt{\frac{8}{1 + (\frac{\sigma_>}{\sigma})^2}} \right) \quad \text{where} \quad \rho(E) = \frac{1}{\langle D \rangle}$$

P. Hansen, B. Jonson, und A. Richter, Nuclear Physics A **518** (1990) 13 , ISSN 0375-9474

Why Tin Isotope Chain?

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112Sn	113Sn	114Sn	115Sn	116Sn	117Sn	118Sn	119Sn	120Sn	121Sn	122Sn	123Sn	124Sn	...	132Sn
STABLE	115.09 D	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE	27.03 H	STABLE	129.2 D	STABLE		39.7 S
0.97%		0.66%	0.34%	14.54%	7.68%	24.22%	8.59%	32.58%		4.63%		5.79%		
	ϵ: 100.00%								β-: 100.00%		β-: 100.00%			β-: 100.00%

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- Wide mass range with little change of the underlying structure

Why Tin Isotope Chain?

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112Sn STABLE 0.97%	113Sn 115.09 D ϵ: 100.00%	114Sn STABLE 0.66%	115Sn STABLE 0.34%	116Sn STABLE 14.54%	117Sn STABLE 7.68%	118Sn STABLE 24.22%	119Sn STABLE 8.59%	120Sn STABLE 32.58%	121Sn 27.03 H β-: 100.00%	122Sn STABLE 4.63%	123Sn 129.2 D β-: 100.00%	124Sn STABLE 5.79%	...	132Sn 39.7 S β-: 100.00%

- Wide mass range with little change of the underlying structure
- Experiment: Data available in stable and unstable isotopes
  - NRF: ^{112}Sn, ^{116}Sn, ^{120}Sn, ^{124}Sn
  - Coulomb dissociation: $^{124-132}$Sn
  - Alpha scattering: ^{128}Sn, ^{132}Sn
  - Proton scattering: ^{120}Sn, ^{112}**Sn**, ^{116}**Sn**, ^{118}**Sn**, ^{124}**Sn**

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- Theory: Many calculations for PDR available
  - N. Tsoneva *et al.*, NPA **731** (2004); PRC **77** (2008)
  - N. Paar *et al.*, PLB **606** (2005)
  - J. Piekarewicz, PRC **73** (2006)
  - S. Kamerdizhiev, S.F. Kovaloo, PAN **65** (2006)
  - J. Terasaki, J. Engel, PRC **74** (2006)
  - E. Litvinova *et al.*, PLB **647** (2007); PRC **78** (2008)

Experiment at RCNP:
E422 campaign

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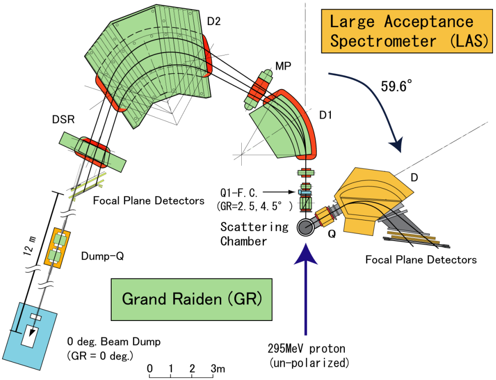
- Reaction: (p,p’)



A. Tamii, Seminar, TU Darmstadt (2005)

Experiment at RCNP: E422 campaign

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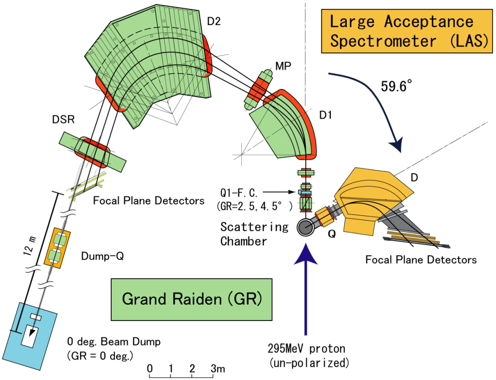
- Reaction: (p,p')
- Beam energy: 295 MeV



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Experiment at RCNP: E422 campaign

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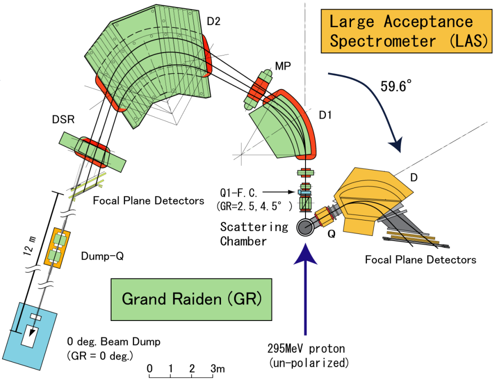
- Reaction: (p,p')
- Beam energy: 295 MeV
- Energy resolution: $\sim$ 40 keV



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Experiment at RCNP: E422 campaign

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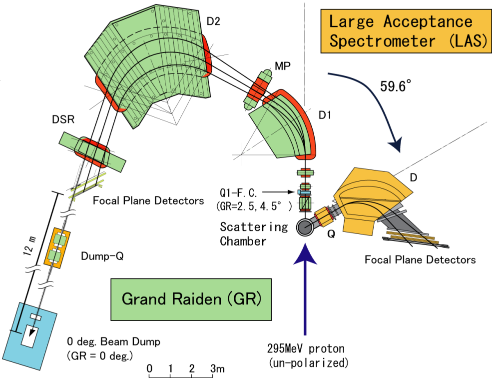
- Reaction: (p,p')
- Beam energy: 295 MeV
- Energy resolution: $\sim$ 40 keV
- Measured angles: 0°, 2.5°, 4.5°



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Experiment at RCNP: E422 campaign

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- Reaction: (p,p')
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- Main targets:
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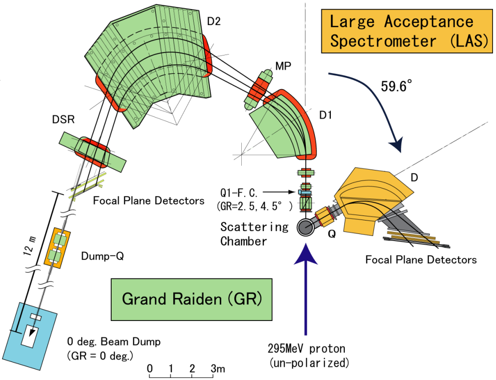

A. Tamii, Seminar, TU Darmstadt (2005)

Preliminary Results

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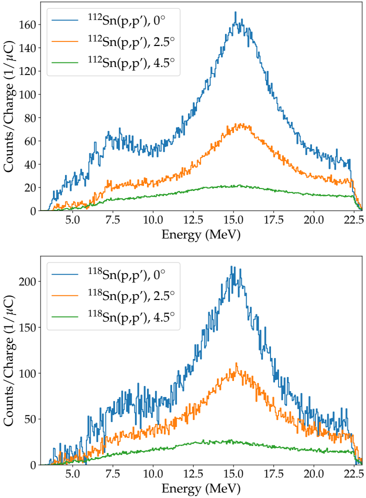

Preliminary Results

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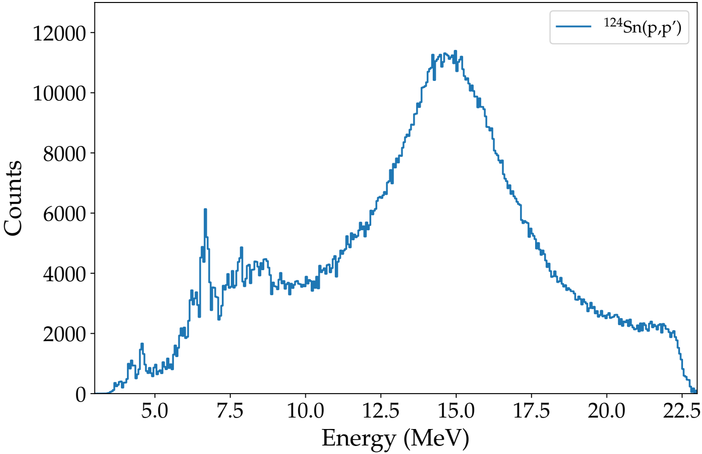

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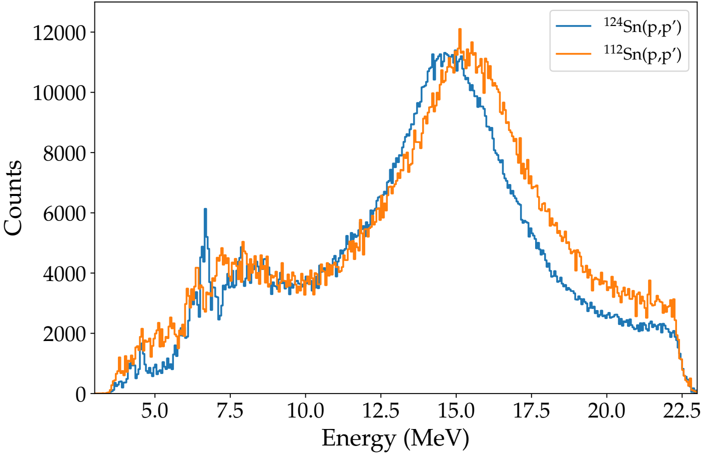

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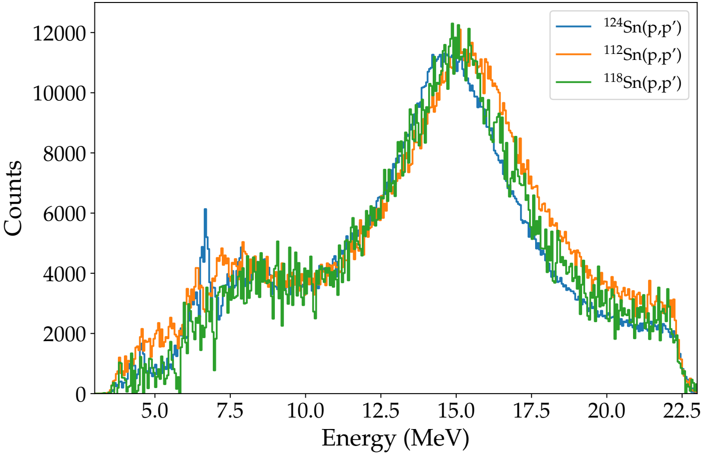

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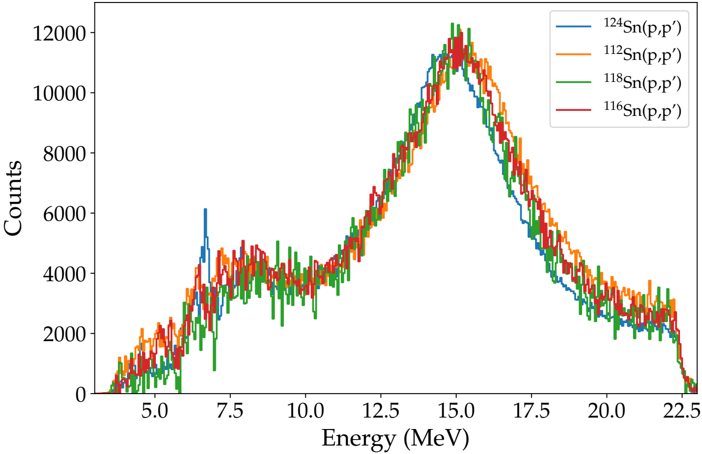

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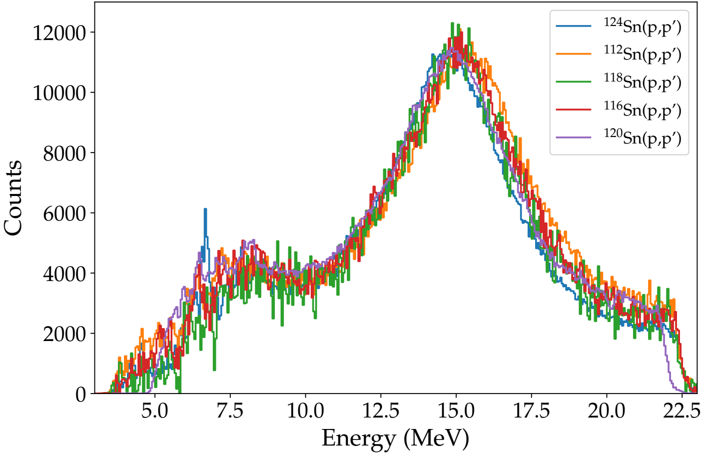
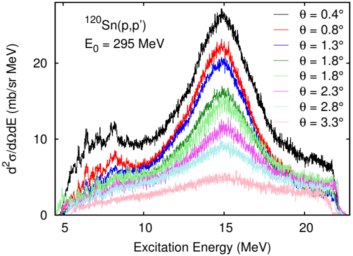


The Case of ^{120}Sn(p,p')

- ^{120}Sn(p,p') experiment conducted at RCNP, Japan



A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305

The Case of ^{120}Sn(p,p')

- ^{120}Sn(p,p') experiment conducted at RCNP, Japan
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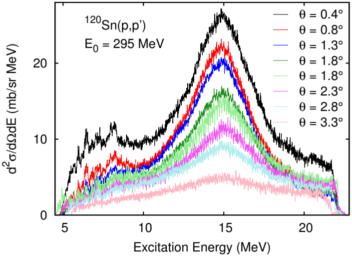

A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305

The Case of ^{120}Sn(p,p')

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- ^{120}Sn(p,p') experiment conducted at RCNP, Japan
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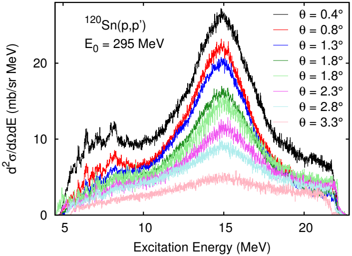
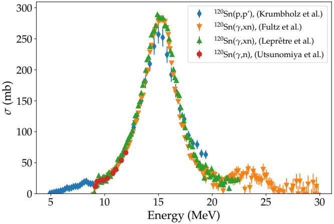
- E1 gamma strength function determined from photoabsorption cross section



A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305



The Case of ^{120}Sn(p,p')

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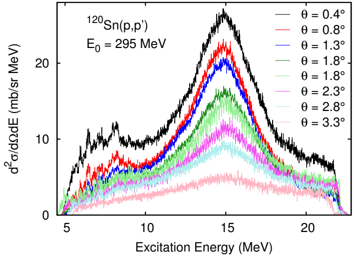
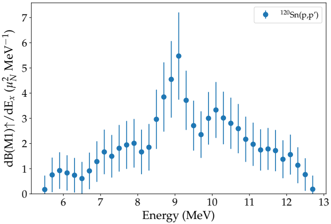
- DDCS converted to photoabsorption cross section using Virtual Photon Method
- E1 gamma strength function determined from photoabsorption cross section
- M1 gamma strength function determined from M1 strength which was obtained using the unit cross section technique

J. Birkhan *et al.*, PRC 93 (2016) 041302



A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305



E1 and M1 Gamma Strength Functions

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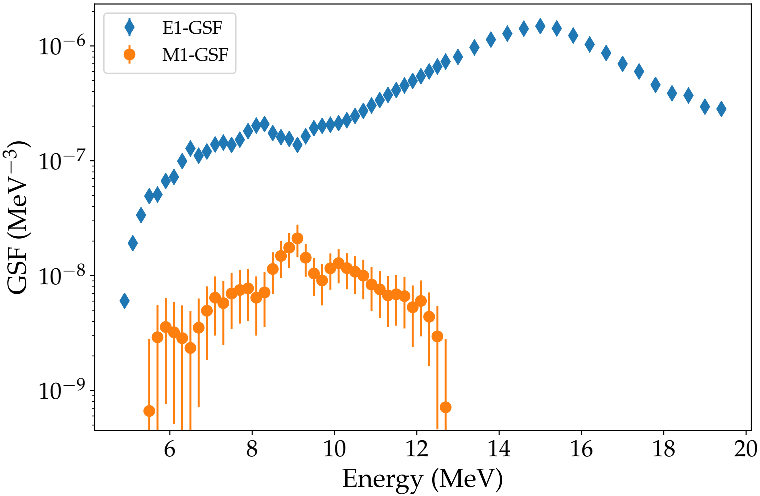
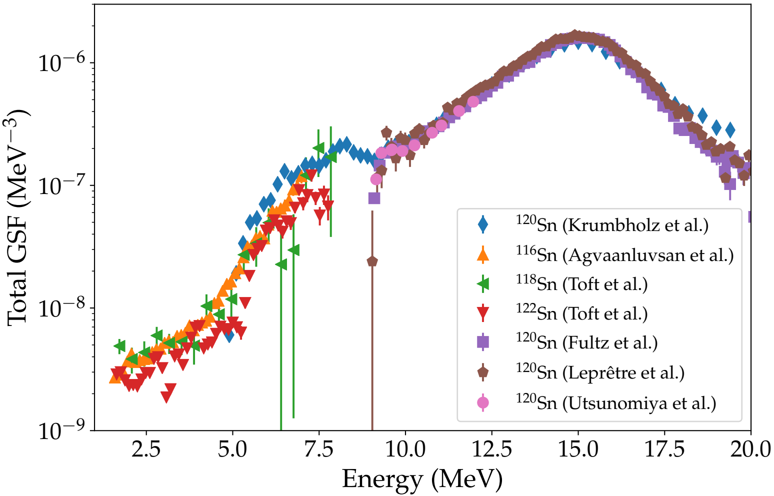
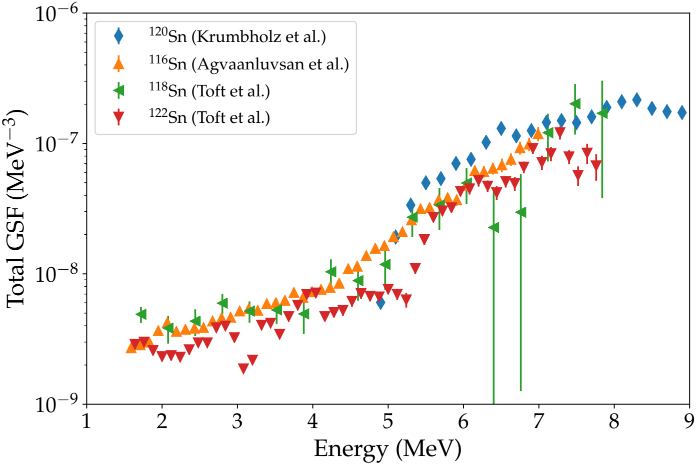


Total Gamma Strength Function



Total Gamma Strength Function



Total Gamma Strength Function

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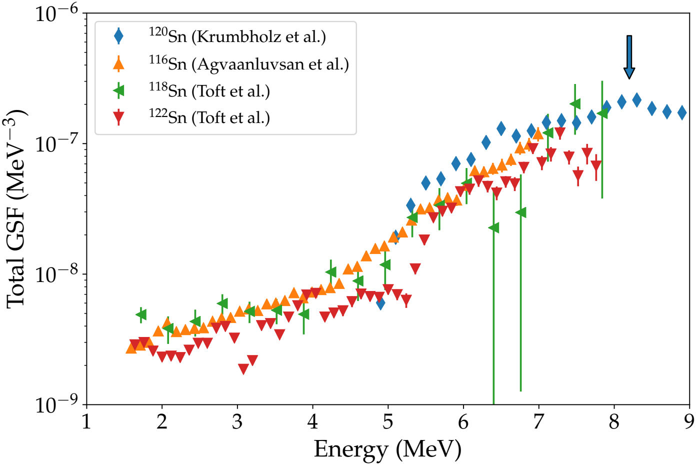

Total Gamma Strength Function

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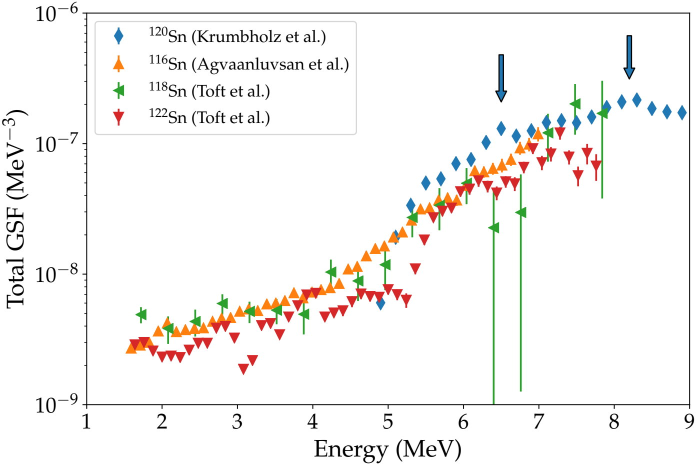

Total Gamma Strength Function

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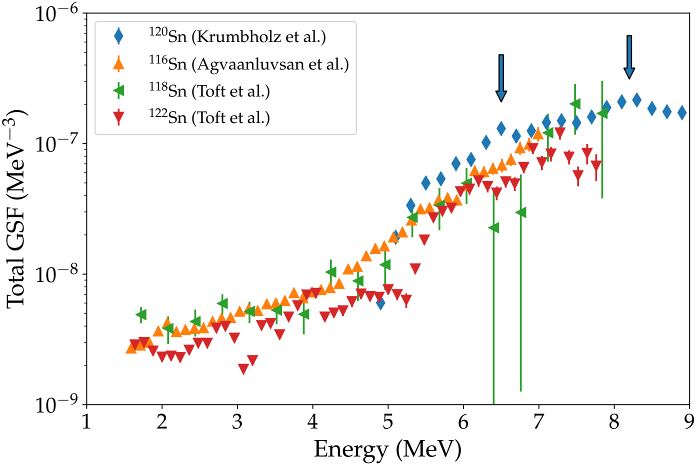

- Brink-Axel hypothesis violated?

Comparison with Isoscalar Probe

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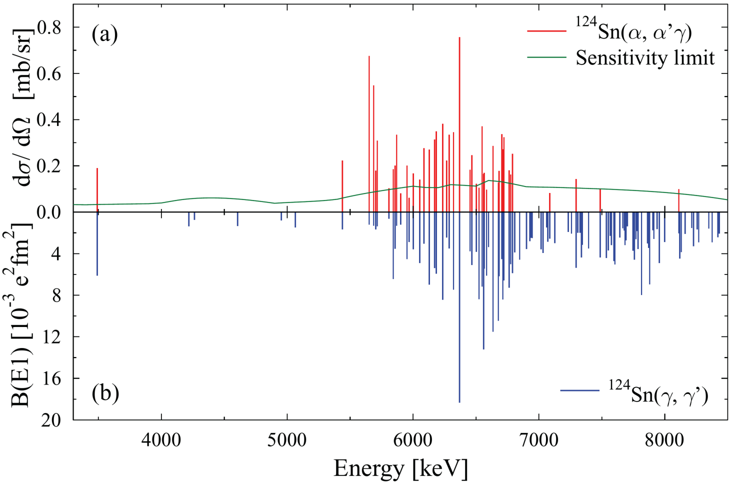
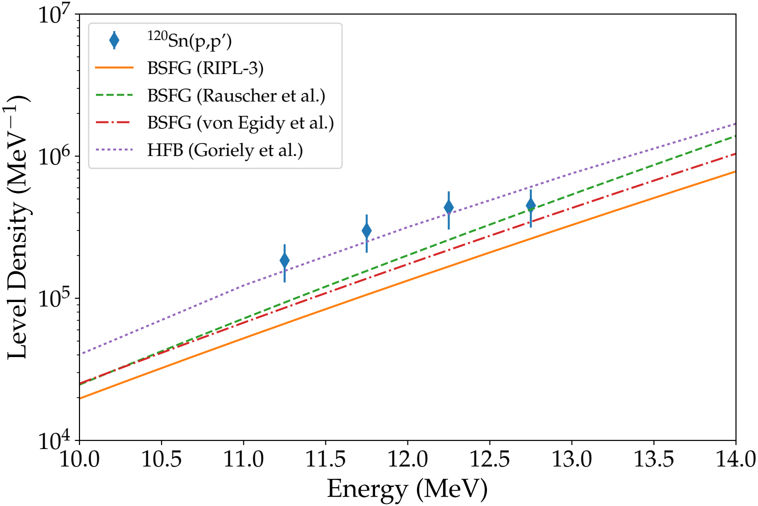


J. Endres *et al.*, Phys. Rev. C **85** (2012) 064331

Level Densities of 1^- States



Comparison of the Total Level Density

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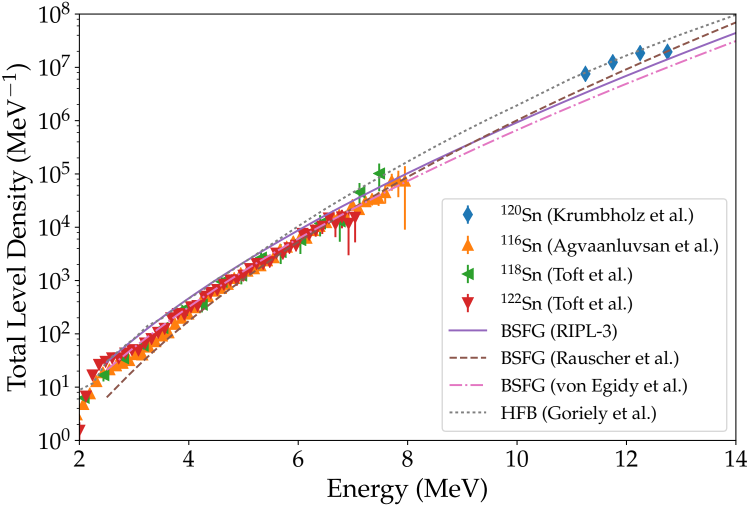

Summary and Outlook

Summary and Outlook

Summary

Summary and Outlook

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Summary

- Preliminary results

Summary and Outlook

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Outlook

Summary and Outlook

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Summary

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- Determination of the double differential cross section

Summary and Outlook

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- Determination of the double differential cross section
- Begin with Multipole Decomposition Analysis

Summary and Outlook

TECHNISCHE UNIVERSITÄT DARMSTADT

Summary

- Preliminary results
  - Comparison of tin isotopes
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  - Gamma strength function
  - Level densities

Outlook

- Determination of the double differential cross section
- Begin with Multipole Decomposition Analysis
- Start doing physics!

Collaborators

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Institut für Kernphysik, TU Darmstadt, Germany

S. Aslanidou, M. Hilcker, A. Krugmann, A. M. Krumbholz, P. von Neumann-Cosel, N. Pietralla, V. Yu. Ponamorev, R. Roth, M. Singer, G. Steinhilber, V. Werner, J. Wambach, M. Zweidinger

RCNP, Osaka, Japan

S. Adachi, T. Adachi, N. Aoi, P. Y. Chan, H. Fujita, Y. Fujita, G. Gey, H. T. Ha, T. Hashimoto, K. Hatanaka, F. Hattori, E. Ideguchi, A. Inoue, T. Ito, C. Iwamoto, H. J. Ong, I. Ou, A. Tamii, Y. N. Watanabe, T. Yamamoto, M. Yosoi

...and many others!

References I

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- P.-G. Reinhard und W. Nazarewicz, Phys. Rev. C **81** (2010) 051303.
- J. Piekarewicz, Phys. Rev. C **73** (2006) 044325.
- P. Hansen, B. Jonson, und A. Richter, Nuclear Physics A **518** (1990) 13 , ISSN 0375-9474.
- T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305.
- J. Endres *et al.*, Phys. Rev. C **85** (2012) 064331.

Preliminary Results

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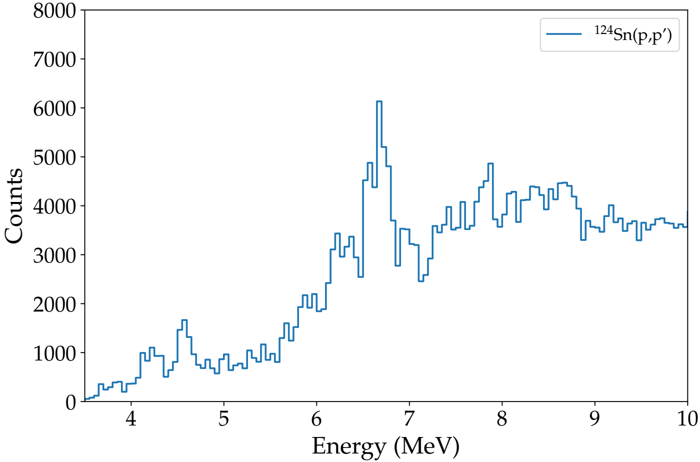

Preliminary Results

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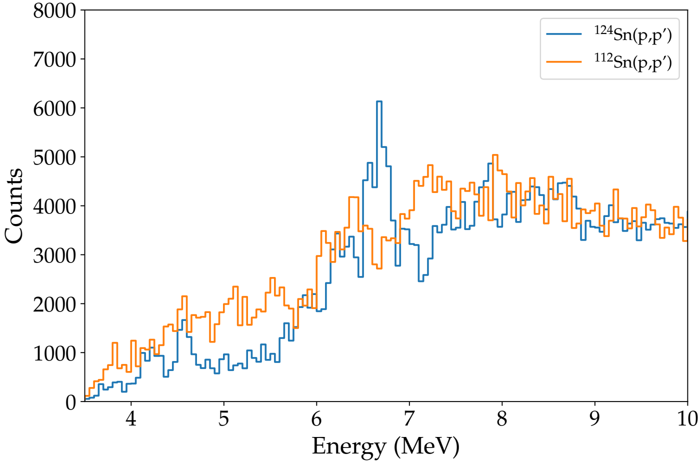

Preliminary Results

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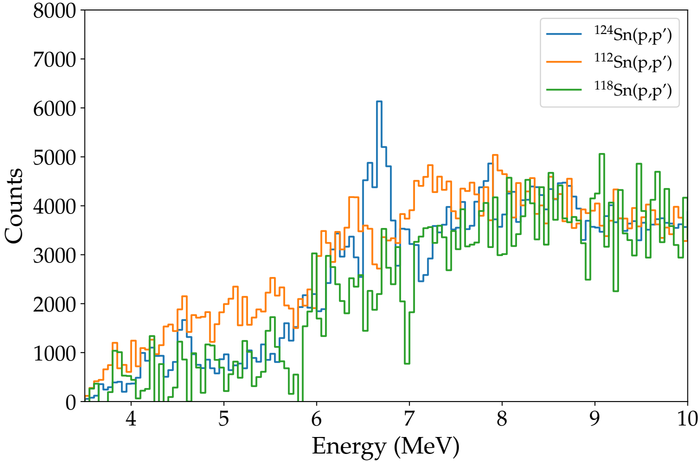

Preliminary Results

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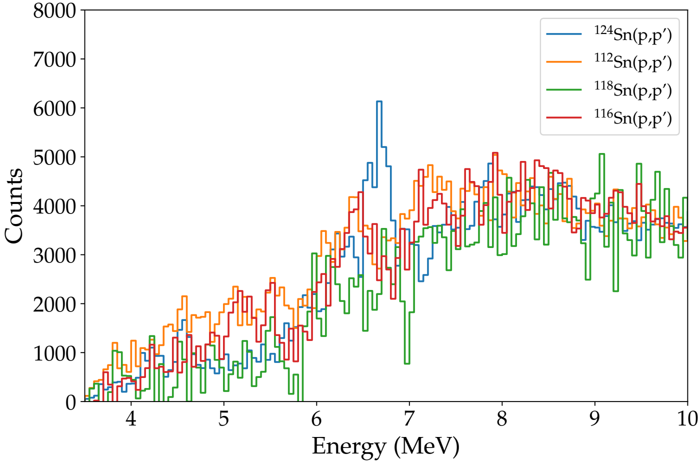

Preliminary Results

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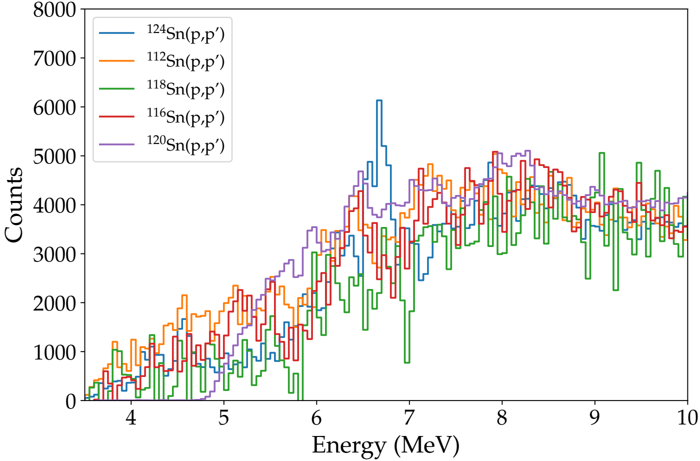

Low energy B(E1) in ^{120}Sn

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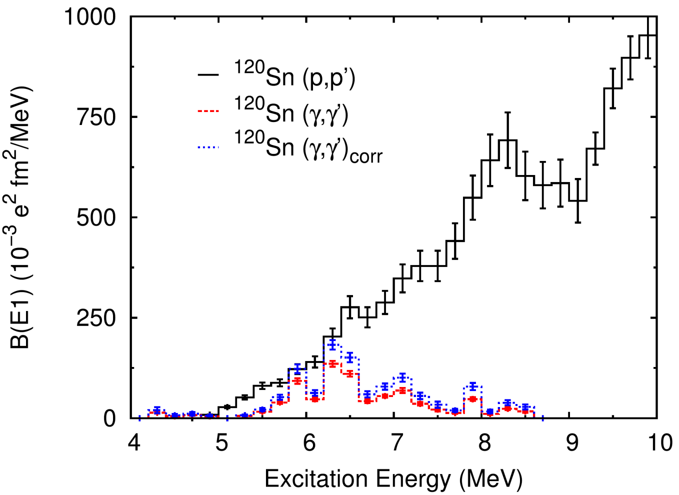

Sieve Slit Analysis: Scattering Angle Calibration

- Measure ^{58}Ni(p,p') at 16° varying the magnetic field of the dipoles

Sieve Slit Analysis: Scattering Angle Calibration

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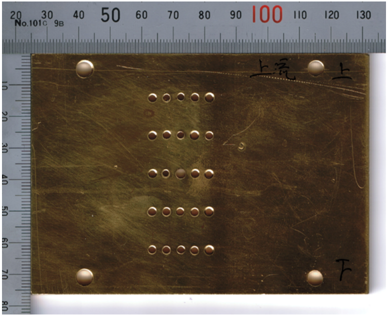
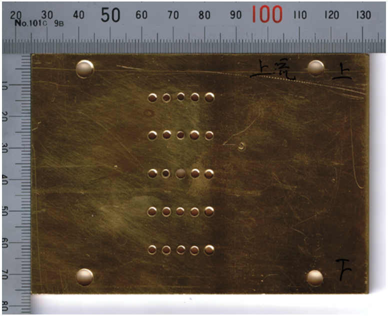
- Measure ^{58}Ni(p,p') at 16° varying the magnetic field of the dipoles
- Brass sieve slit was placed at the entrance of the spectrometer



A. Tamii, Seminar, TU Darmstadt (2005)

Sieve Slit Analysis: Scattering Angle Calibration

- Measure ^{58}Ni(p,p') at 16° varying the magnetic field of the dipoles
- Brass sieve slit was placed at the entrance of the spectrometer
- Horizontal angle θ_t and vertical angle ϕ_t from multidimensional fitting



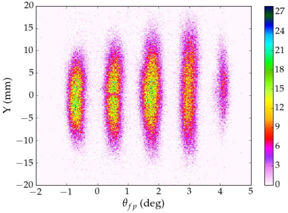
A. Tamii, Seminar, TU Darmstadt (2005)

$$\theta_t = \sum_{i=0}^{1}\sum_{j=0}^{1} a_{ij} x_{fp}^{i} \theta_{fp}^{j}$$

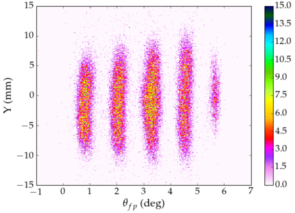
$$\phi_t = \sum_{i=0}^{1}\sum_{j=0}^{1}\sum_{k=0}^{1}\sum_{l=0}^{1} b_{ijkl} x_{fp}^{i} \theta_{fp}^{j} y_{fp}^{k} \phi_{fp}^{l} + \sum_{m=0}^{1} c_m x_{fp}^{m} y_{LAS}$$

Sieve Slit Analysis: Scattering Angle Calibration

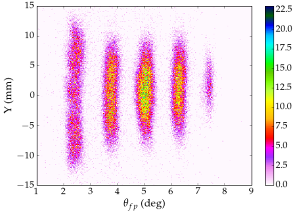
B = +1.2%, $E_x \sim$ 6.5 MeV



B = +2.6%, $E_x \sim$ 13.5 MeV



B = +4.2%, $E_x \sim$ 21 MeV



Sieve Slit Analysis:
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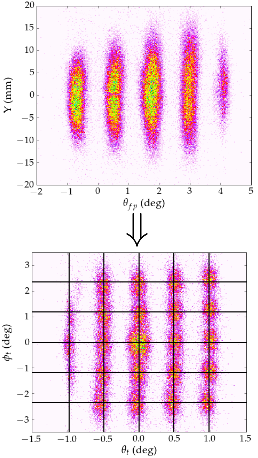

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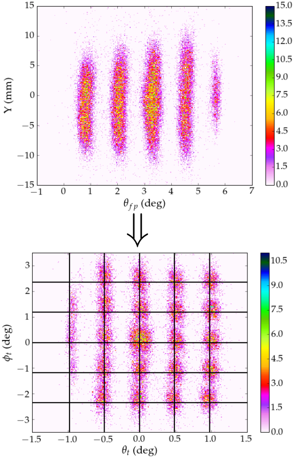

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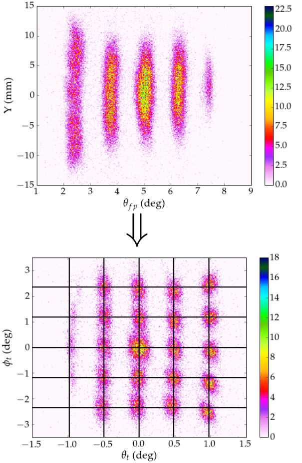

Background Subtraction

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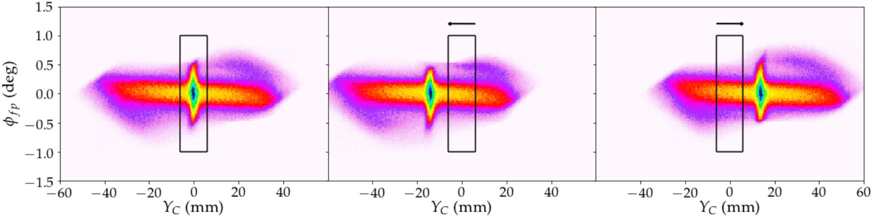

Background Subtraction

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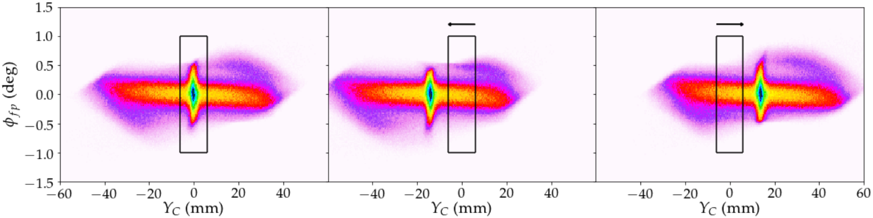

- Background: flat distribution in non-dispersive focal plane

Background Subtraction

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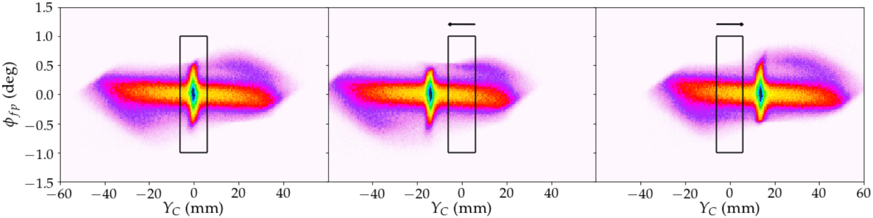

- Background: flat distribution in non-dispersive focal plane
- True events around $Y_C = 0$

Background Subtraction

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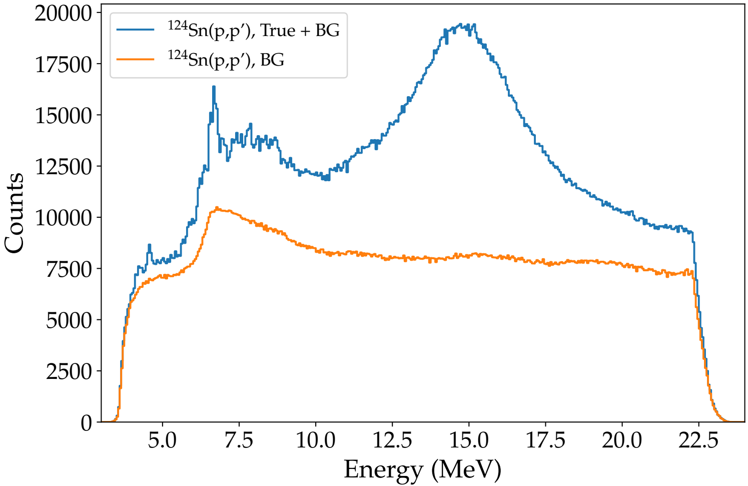

Background Subtraction

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