Complete electric dipole response in ^{120}Sn: A test of the resonance character of the pygmy dipole resonance

Anna Maria Heilmann

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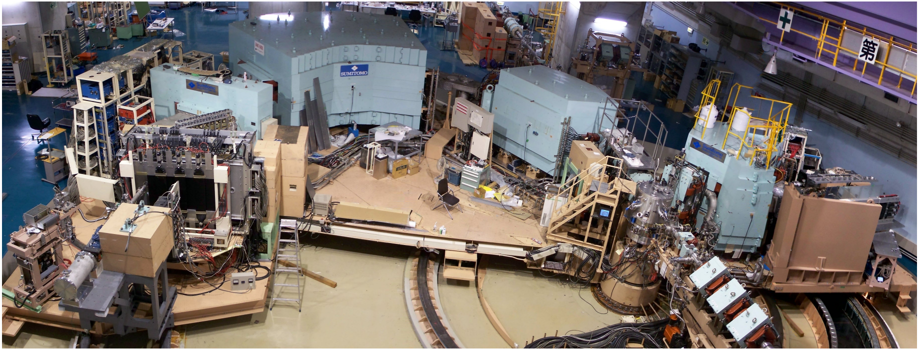

Outline

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- Motivation
- Inelastic Proton Scattering
  - Nucleon-Nucleus Scattering
  - Coulomb Excitation
  - Polarized Proton Scattering
- Proton scattering experiment at RCNP
- Experiment
- Analysis steps
- Results
- Outlook

Motivation

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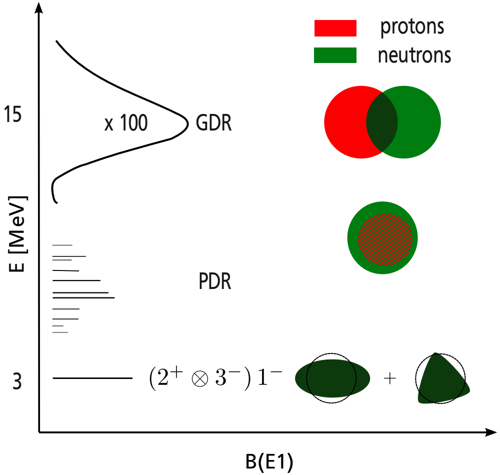
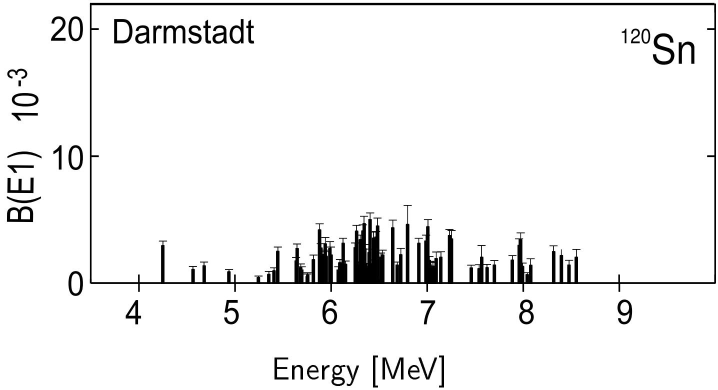
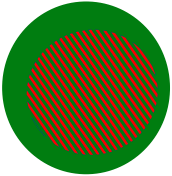


Extracted transition strength for ^{120}Sn with nuclear resonance flourescence



B. Özel, Ph.D.-Thesis, Çukurova University, Adana, Turkey (2008)

Open questions



- various models concerning the PDR
- qualitative agreement on collective motion
- different theories return different quantitative results
- strength of PDR propably depend on the thickness of neutron skin
- experimental progress opens new opportunities
- case study of tin isotope chain

Comparison Theory vs. Experiment
Summed BE1 strenghts

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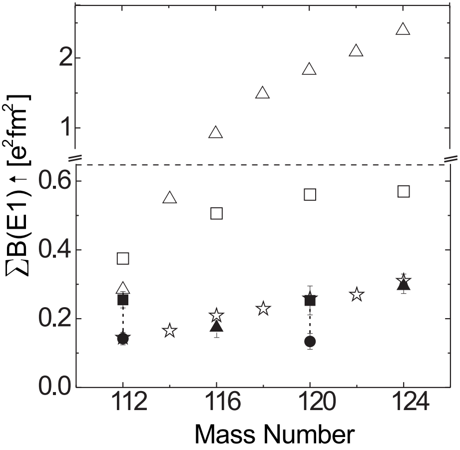

theory

- △ RQRPA (N.Paar et.al)
- □ QPM (V.Yu. Ponomarev)
- ☆ QPM (N.Tsoneva, H.Lenske)

NRF measurements

- ▲ @ Gent
- ● @ Darmstadt (discrete only)
- ■ @ Darmstadt (incl. unresolved)

B. Özel *et.al*, submitted 2008

Comparison theory vs. experiment
Centroid Energy

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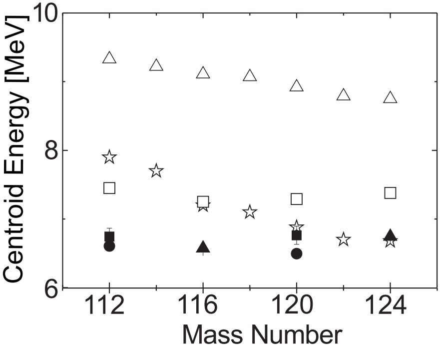

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NRF measurements

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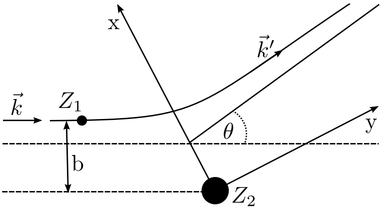
B. Özel *et.al*, submitted 2008

Inelastic proton scattering

- coulomb excitation
- nucleon-nucleus scattering
- polarized proton scattering

Coulomb Scattering
Classical



$$\left(\frac{d\sigma}{d\Omega}\right)_{Ruth} = a^2 \sin^{-4}\left(\frac{\theta}{2}\right)$$

$$\text{with } a = \frac{1}{4\pi\epsilon_0}\frac{Z_1 Z_2 e^2}{4E}$$

Coulomb Scattering
Relativistic (1)

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$$\sigma(E_\gamma) = \sum_{\pi\lambda} \int \sigma_{\gamma,\pi\lambda}(E_\gamma)\, n_{\pi\lambda} \frac{1}{E_\gamma} \mathrm{d}E_\gamma .$$

Coulomb Scattering Relativistic (1)

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$$\sigma(E_\gamma) = \sum_{\pi\lambda} \int \sigma_{\gamma,\pi\lambda}(E_\gamma)\, n_{\pi\lambda} \frac{1}{E_\gamma} \mathrm{d}E_\gamma .$$

Photon numbers are:

$$n_{E1} \approx \frac{Z^2\alpha}{\pi^2} \frac{1}{\gamma^2 - 1} \left(g_0\left(\xi\right) + \gamma^2 g_1\left(\xi\right)\right),$$

$$n_{E2} \approx \frac{Z^2\alpha}{\pi^2} \frac{1}{\gamma^2 - 1} \left(3\gamma^2 g_0\left(\xi\right) + (\gamma^2 + 1) g_1\left(\xi\right) + \gamma^2 g_2\left(\xi\right)\right),$$

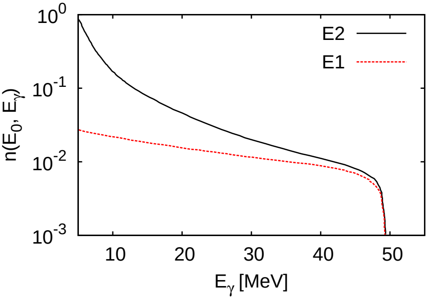
$$n_{M1} \approx \frac{Z^2\alpha}{\pi^2} g_1\left(\xi\right).$$

The argument of g_m: adiabaticity parameter

$$\xi = \frac{\omega b}{\gamma v_0} \qquad \text{with } \omega = E_\gamma/\hbar$$

Coulomb Scattering
Relativistic (2)

$$\sigma(E_\gamma) = \sum_{\pi\lambda} \int \sigma_{\gamma,\pi\lambda}(E_\gamma)\, n_{\pi\lambda} \frac{1}{E_\gamma} \mathrm{d}E_\gamma .$$



E.Wolynec *et.al*, Phys. Rev. Lett. 42 (1979) 27.

Nucleon-Nucleus Scattering (1)

Protons may excite resonances:

- isoscalar non-spin-flip ($\Delta T = 0, \Delta S = 0$),
- isoscalar spin-flip ($\Delta T = 0, \Delta S = 1$),
- isovector non-spin-flip ($\Delta T = 1, \Delta S = 0$),
- isovector spin-flip ($\Delta T = 1, \Delta S = 1$).

Nucleon-Nucleus Scattering (2)

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$$V_{ip}(r_{ip}) = V^C(r_{ip}) + V^{LS}(r_{ip})\,\vec{L}\cdot\vec{S} + V^T(r_{ip})\,S_{ip}\,.$$

central term V^C, spin-orbit term V^{LS} and a tensor component V^T

Nucleon-Nucleus Scattering (2)

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$$V_{ip}(r_{ip}) = V^C(r_{ip}) + V^{LS}(r_{ip})\,\vec{L}\cdot\vec{S} + V^T(r_{ip})\,S_{ip}\,.$$

central term V^C, spin-orbit term V^{LS} and a tensor component V^T

$\vec{L}$	relative angular momentum	
$\vec{S}$	relative spin	$\vec{S} = \vec{\sigma_i} + \vec{\sigma_p}$
$\vec{L}\cdot\vec{S}$	spin-orbit operator	
S_{ip}	tensor operator	$\vec{S_{ip}} = 3\vec{\sigma_i}\cdot\hat{r}\ \vec{\sigma_p}\cdot\hat{r} - \vec{\sigma_i}\cdot\vec{\sigma_p}\,, \quad \hat{r} = \vec{r}/\lvert\vec{r}\rvert$
$\vec{\sigma}$	Pauli spin matrices	

For small angles $\rightarrow$ small momentum transfer $q < 1\ \mathrm{fm}^{-1}$, spin-orbit and tensor part of the interactio are small compared to the central interaction

Nucleon-Nucleus Scattering (3)

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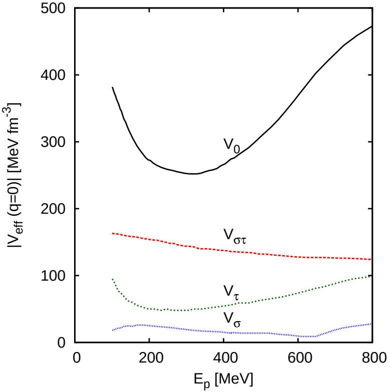
$$V_{ip}(r_{ip}) = V_0^C(r_{ip}) + V_\sigma^C(r_{ip})\,\vec{\sigma}_i\cdot\vec{\sigma}_p + V_\tau^C(r_{ip})\,\vec{\tau}_i\cdot\vec{\tau}_p + V_{\sigma\tau}^C(r_{ip})\,\vec{\sigma}_i\cdot\vec{\sigma}_p\vec{\tau}_i\cdot\vec{\tau}_p$$



W.G. Love and M.A. Franey *Phys. Rev.* C24 (1981) 1073

- small momentum transfer
  $q < 1\ \mathrm{fm}^{-1}$

Nucleon-Nucleus Scattering (3)

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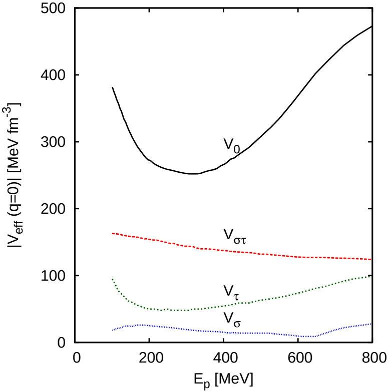

W.G. Love and M.A. Franey *Phys. Rev.* C24 (1981) 1073

- small momentum transfer
  $q < 1\ \mathrm{fm}^{-1}$

Interactions with

- $\vec{\tau}_i \cdot \vec{\tau}_p \longrightarrow$ isospin-flip transitions
- $\vec{\sigma}_i \cdot \vec{\sigma}_2 \longrightarrow$ spin-flip transitions.

Nucleon-Nucleus Scattering (3)

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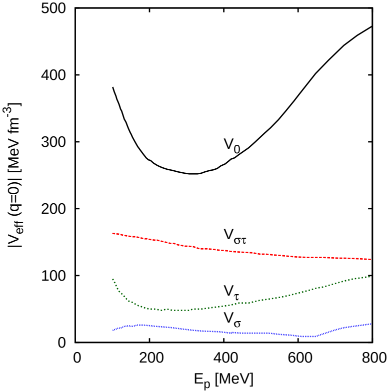
$$V_{ip}(r_{ip}) = V_0^C(r_{ip}) + V_\sigma^C(r_{ip})\,\vec{\sigma}_i\cdot\vec{\sigma}_p + V_\tau^C(r_{ip})\,\vec{\tau}_i\cdot\vec{\tau}_p + V_{\sigma\tau}^C(r_{ip})\,\vec{\sigma}_i\cdot\vec{\sigma}_p\vec{\tau}_i\cdot\vec{\tau}_p$$



W.G. Love and M.A. Franey *Phys. Rev.* C24 (1981) 1073

- small momentum transfer $q < 1\ \mathrm{fm}^{-1}$

Interactions with

- $\vec{\tau}_i\cdot\vec{\tau}_p \longrightarrow$ isospin-flip transitions
- $\vec{\sigma}_i\cdot\vec{\sigma}_2 \longrightarrow$ spin-flip transitions.

- measurements with E=300 MeV

Polarized Proton Scattering (1)

Nucleon-nucleon scattering amplitude in PWIA:

$$M(q) = A + B\sigma_{i\hat{n}}\sigma_{p\hat{n}} + C\left(\sigma_{i\hat{n}} + \sigma_{p\hat{n}}\right) + E\sigma_{i\hat{q}}\sigma_{p\hat{q}} + F\sigma_{i\hat{p}}\sigma_{p\hat{p}}.$$

Polarized Proton Scattering (1)

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amplitude coefficients consists of isoscalar and isovector terms: $A = A_0 + A_\tau \vec{\tau_1} \cdot \vec{\tau_2}$

Polarized Proton Scattering (1)

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amplitude coefficients consists of isoscalar and isovector terms: $A = A_0 + A_\tau \vec{\tau_1} \cdot \vec{\tau_2}$

$$M(q) = A + \frac{1}{3}(B+E+F)\vec{\sigma_i} \cdot \vec{\sigma_p} + C(\sigma_i + \sigma_p) \cdot \hat{n} + \frac{1}{3}(E-B)S_{ip}(\hat{q}) + \frac{1}{3}(F-B)S_{ip}(\hat{p})$$

Polarized Proton Scattering (1)

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$$M(q) = A + \frac{1}{3}(B+E+F)\vec{\sigma_i}\cdot\vec{\sigma_p} + C(\sigma_i + \sigma_p)\cdot\hat{n} + \frac{1}{3}(E-B)S_{ip}(\hat{q}) + \frac{1}{3}(F-B)S_{ip}(\hat{p})$$

In the PWIA the T-matrix for the NN scattering is given by

$$T = \left\langle f|M(q)e^{-i\vec{q}\cdot\vec{r}}|i\right\rangle.$$

Polarized Proton Scattering (2)

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$$T = \left\langle f | M(q) e^{-i\vec{q}\cdot\vec{r}} | i \right\rangle .$$

Polarized Proton Scattering (2)

$$T = \left\langle f|M(q)e^{-i\vec{q}\cdot\vec{r}}|i\right\rangle.$$

From the T-matrix to cross section and polarisation transfer:

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\mathrm{Tr}(TT^\dagger), \qquad D_{ij} = \frac{\mathrm{Tr}(T\sigma_j T^\dagger \sigma_i)}{\mathrm{Tr}(TT^\dagger)}$$

Polarized Proton Scattering (2)

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For spin-flip transitions under 0°:

$$\begin{aligned} D_{SL} &= D_{LS} = 0\,, \\ D_{SS} &= D_{NN} = \frac{\left(|B_i|^2 - |F_i|^2\right) X_T^2 - |B_i|^2 X_L^2}{\left(|B_i|^2 + |F_i|^2\right) X_T^2 + |B_i|^2 X_L^2}\,, \\ D_{LL} &= \frac{\left(-3|B_i|^2 + |F_i|^2\right) X_T^2 + |B_i|^2 X_L^2}{\left(|B_i|^2 + |F_i|^2\right) X_T^2 + |B_i|^2 X_L^2}\,. \end{aligned} \tag{1}$$

X_T, X_L: spin-transverse and spin-longitudinal form factors

Polarized Proton Scattering (3)

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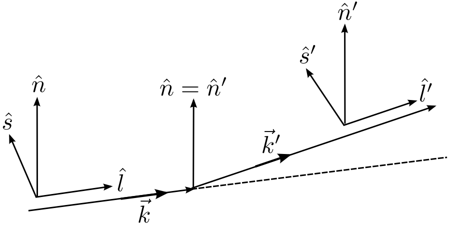
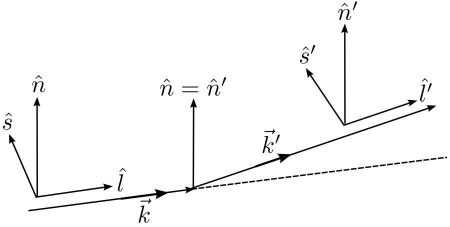


For spin-flip transitions under 0°:

$$D_{SS} = D_{NN} = \cdots$$
$$D_{LL} = \cdots$$

Polarized Proton Scattering (3)



For spin-flip transitions under 0°:

$$D_{SS} = D_{NN} = \cdots$$
$$D_{LL} = \cdots$$

$$\Sigma = \frac{3 - (D_{SS} + D_{NN} + D_{LL})}{4}$$

At forward angles total spin transfer

$$\Sigma = \left\{ \begin{array}{ll} 1 & \text{spinflip} \\ 0 & \text{non-spinflip} \end{array} \right\}$$

From PT measurements the spinflip and non-spinflip cross sections can be extracted

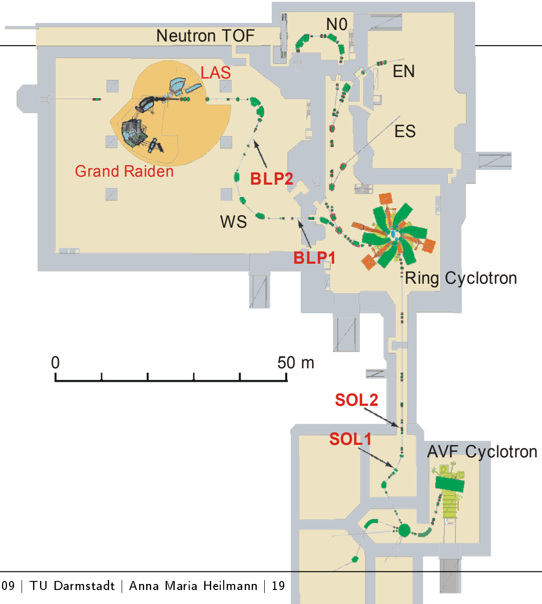
$$\frac{d\sigma}{d\Omega}(\Delta S = 1) \equiv \Sigma \left(\frac{d\sigma}{d\Omega} \right),$$
$$\frac{d\sigma}{d\Omega}(\Delta S = 0) \equiv (1 - \Sigma) \left(\frac{d\sigma}{d\Omega} \right).$$

Summing-Up: Inelastic Proton Scattering

- Nucleon-Nucleus Scattering
- Coulomb Excitation
- Polarized Proton Scattering

nonspin-flip cross sections $\longrightarrow$ E1 excitations
spinflip cross sections $\longrightarrow$ M1 exciations

RCNP facility



RCNP facility

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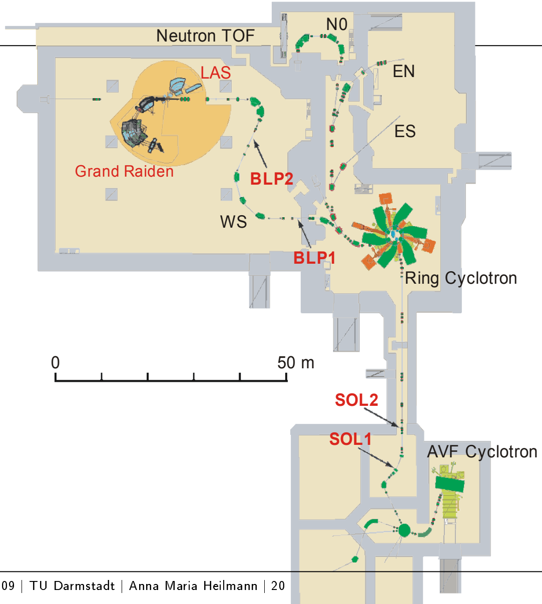
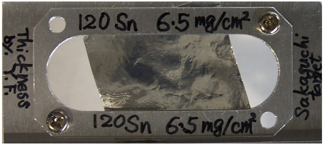
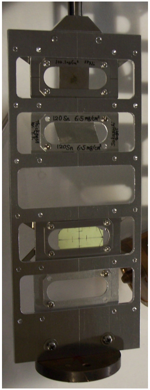


- 295 MeV
- beam intensity 2-3 nA
- high resolution
- degree of polarization: 70%

Targets

- tin foil isotropically enriched to 98.39 % ^{120}Sn
- thickness 6.5 mg$\cdot$ cm^{-2}
- further targets: ^{12}C, ^{208}Pb





Spectrometer hall

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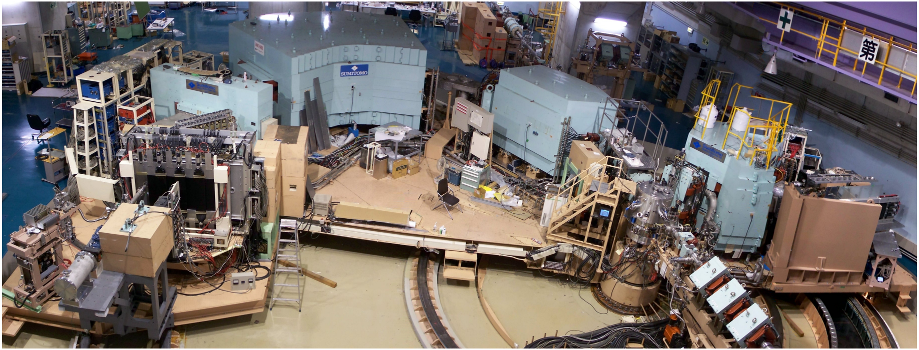
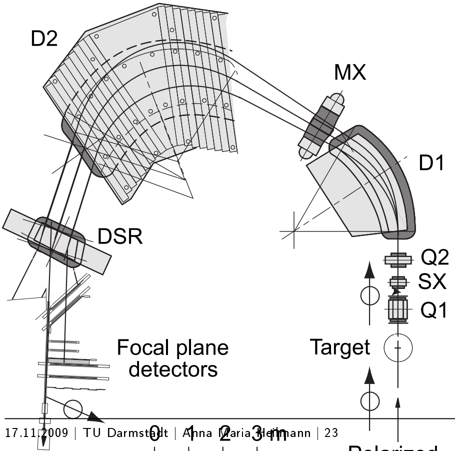


Spectrometer Grand Raiden



Properties:

- total deflecting angle 162°
- high momentum resolution: $p/\Delta p \approx 37\,000$
- momentum acceptance $\pm 2.5\%$
- dipole magnet for spin rotation (DSR) for polarization measurements

Detector system of Grand Raiden

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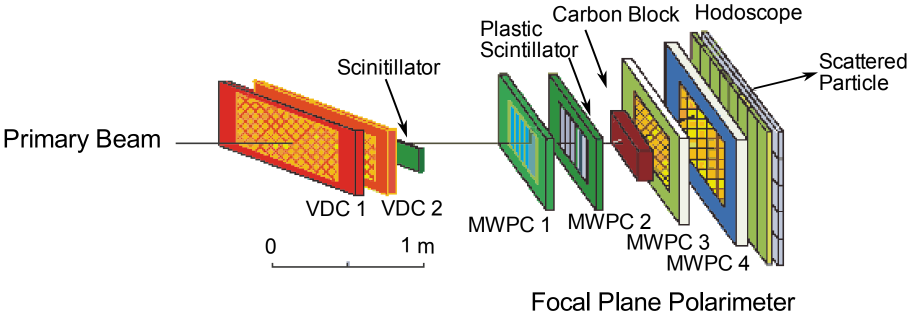

- momentum and trajectory of scattered protons

- nonspin-flip excitations $\longrightarrow$ E1
- spin-flip excitations $\longrightarrow$ M1

Experiments

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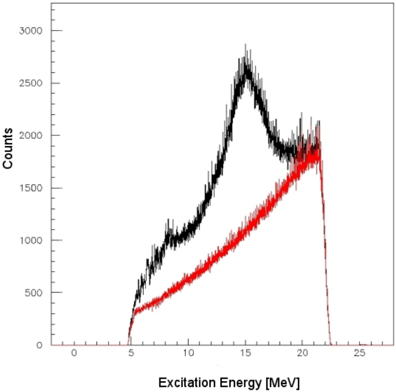
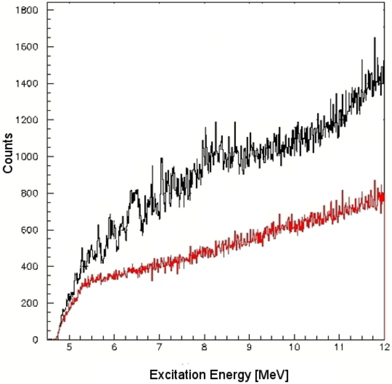
- 14 days of measurements
- Scattering angles of 0° and 2.5°

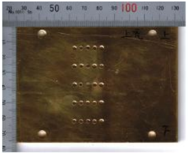
Online spectra from (p,p′) reaction at 0° of ^{120}Sn:

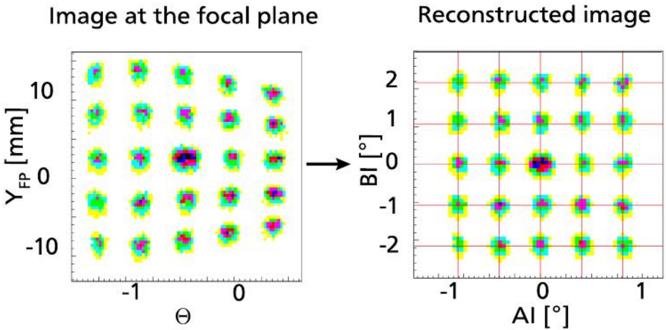




Reconstruction of scattering angles

- Sieve–slit placed in front of GR
- $AI = f(\Theta, Y)$ dominated by Θ
- $BI = f(\Theta, Y)$ dominated by Y





High resolution correction - vertical direction

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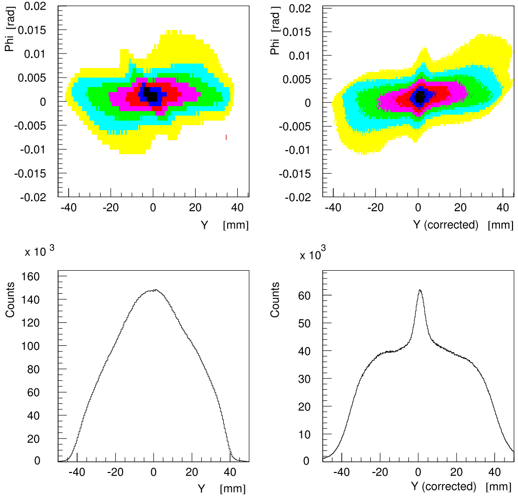

High resolution correction - horizontal direction

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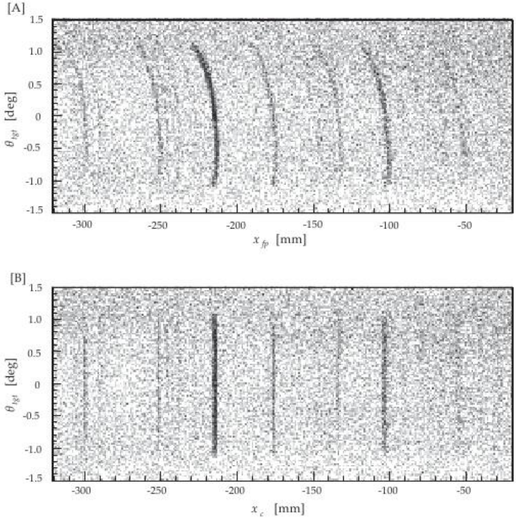

Determination of the background

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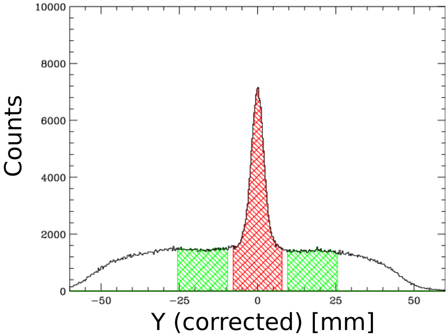
vertical position of protons projected on vertical focal plane

Gates on Y

- central region:
  true + background
- side region: background



^{120}Sn(p,p')-spectra

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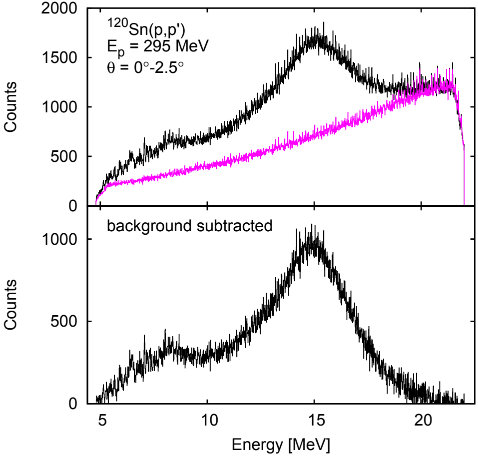

Comparison with γ,γ' experiment

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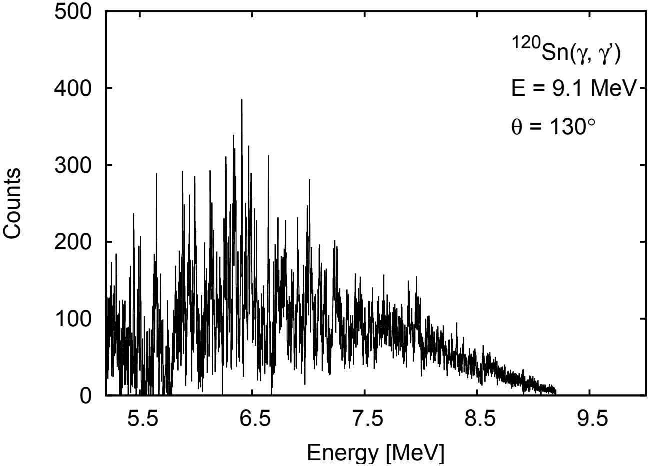
- $^{120}Sn(\gamma,\gamma')$ data from B. Özel
- folded with $\Delta E = 30$ keV



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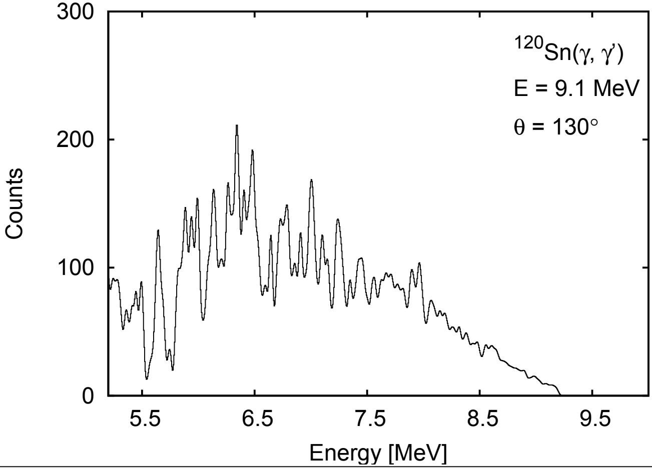

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TECHNISCHE UNIVERSITÄT DARMSTADT

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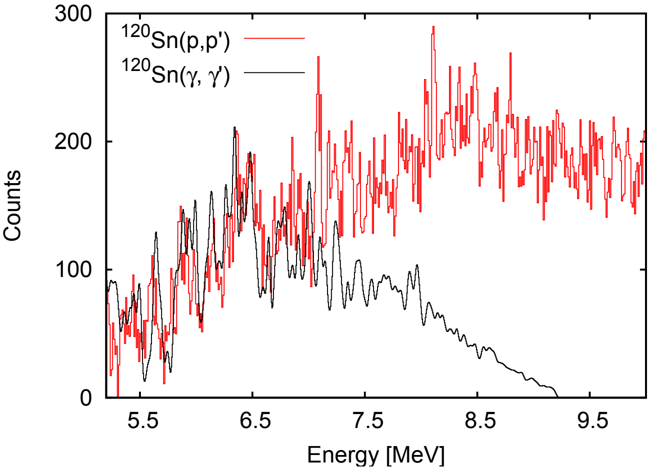
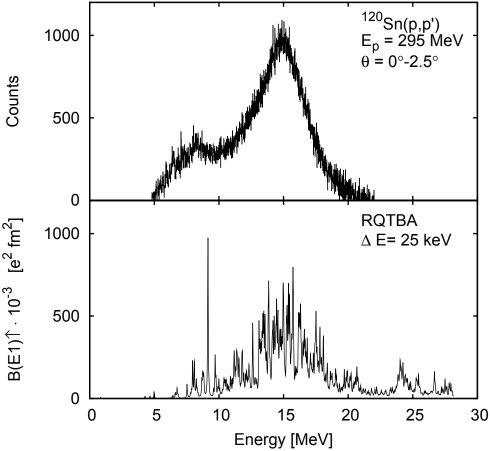


Comparison with theory RQTBA

- RQTBA – E.Litvinova



Comparison with theory
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Theoretical models predictions differ

- ^{120}Sn(γ,γ') data from B. Özel
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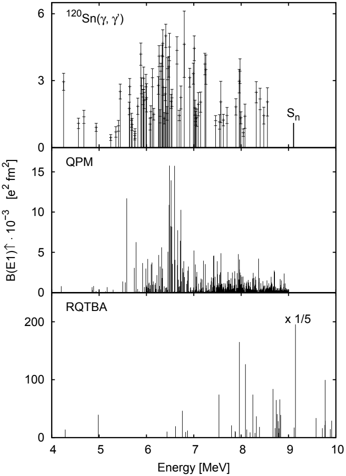
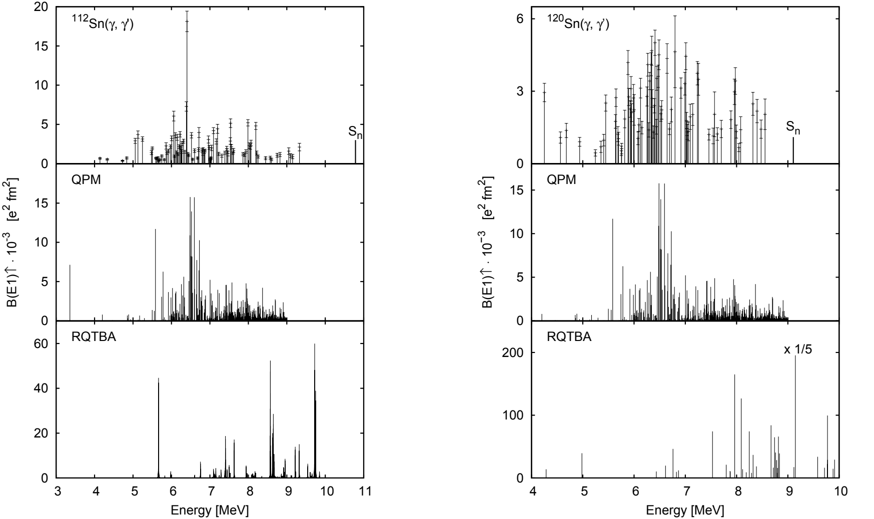


Comparison with theory
^{112}Sn and ^{120}Sn



Comparison with theory RQTBA

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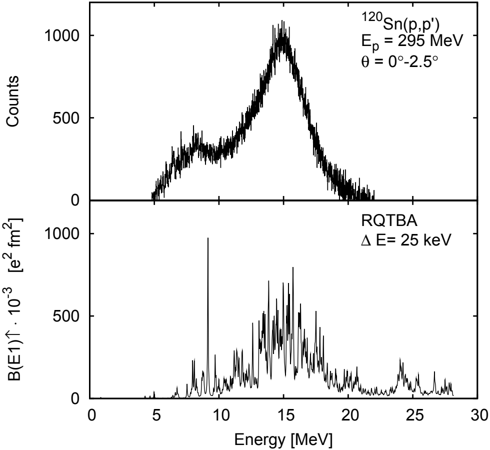

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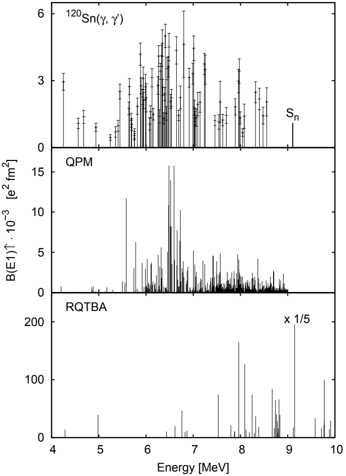

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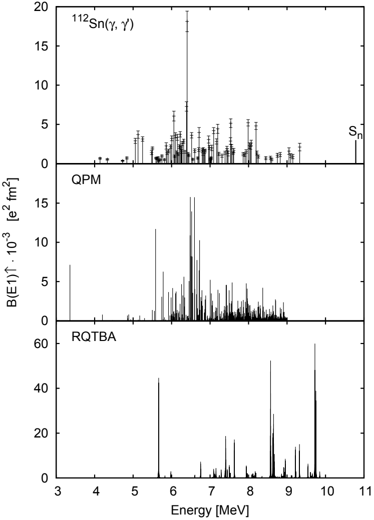

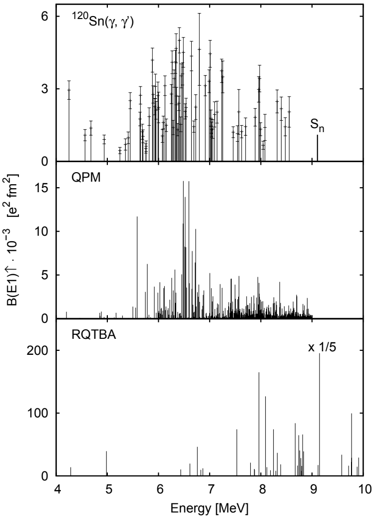

Outlook

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- extraction of the differential cross section
- analysis for 2.5°
- another measurement with longitudinal polarized beam
- identification of M1 excitations possible
- comparision with theoretical models
- better understanding of the pygmy dipole resonance

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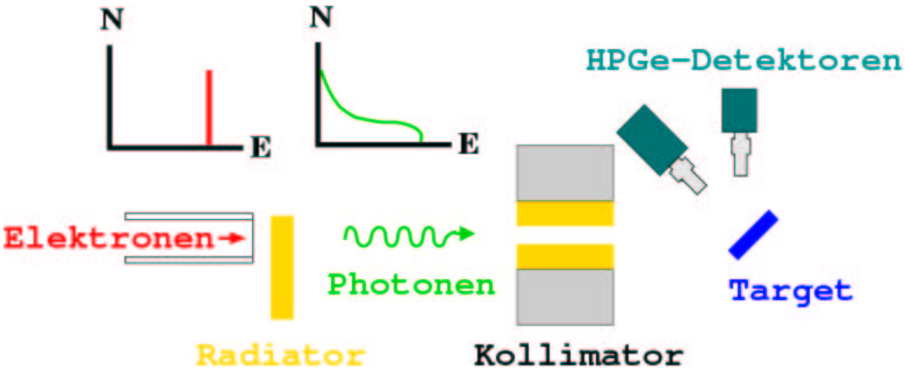
Thank you for your attention

Setup of nuclear resonance flourescence measurements



Systematics of the neutron skin in the Sn isotope chain

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VOLUME 82, NUMBER 16 PHYSICAL REVIEW LETTERS 19 APRIL 1999

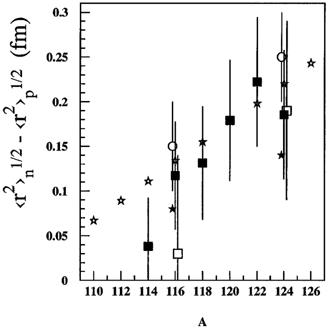

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FIG. 3. The difference of the neutron and proton root-mean-square radii as a function of the mass number of the Sn isotopes. The full squares with error bars show the present results. The previous experimental results measured in (p, p') reaction [5] and by using the GDR excitations [6] are shown as open circles and squares with error bars, respectively. The open and full stars show the theoretical results of Angeli *et al.* [19] and Dechargé *et al.* [21], respectively.