Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin

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Collaboration

Experiment: S. Bassauer (TUD), J. Birkhan (Darmstadt), H. Matsubara (RCNP), P. von Neumann-Cosel (TUD), N. Pietralla (TUD), A. Richter (TUD), A. Tamii (RCNP)

Theory: S. Bacca (TRIUMF), G. Hagen (ORNL), M. Miorelli (TRIUMF), T. Papenbrock (U Tennessee), A. Schwenk (TUD)

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SFB 1245

Polarizability and Neutron Skin

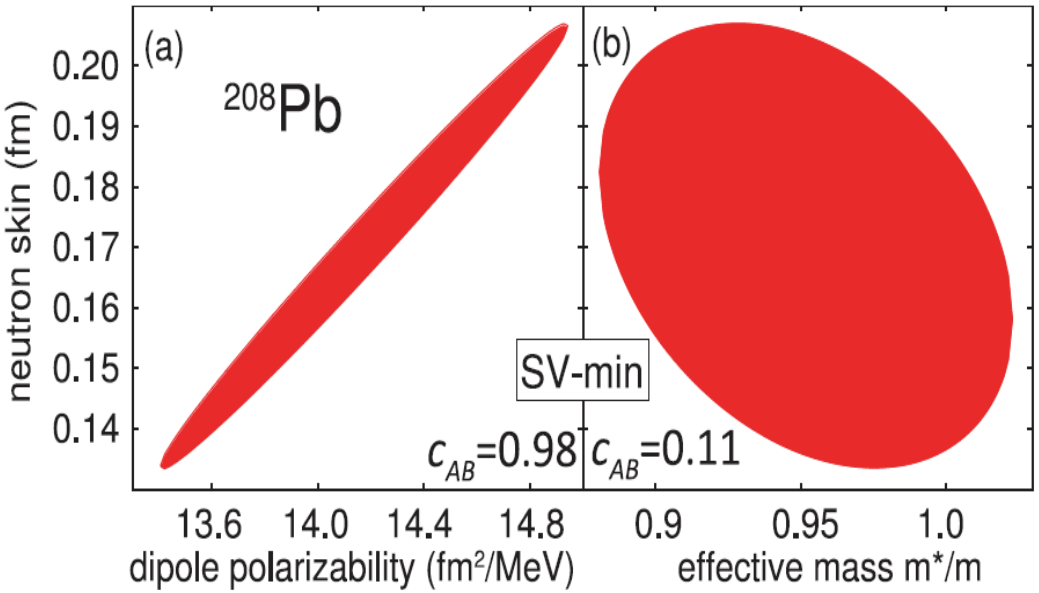
- Static nuclear dipole polarizability

$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \cdot \sigma_{-2} = \frac{\hbar c}{2\pi^2 e^2} \cdot \sum \frac{\sigma_{abs}(E_x)}{{E_x}^2} =$$

$$= \frac{8\pi}{9} \cdot \sum \frac{B(E1)(E_x)}{E_x} \quad \left[{fm^3}/{\epsilon} \right.$$

- α_D is measure of neutron skin

P.G. Reinhard and W. Nazarewicz, Phys. Rev. C 81 (2010) 051303(R)



Polarizability, Neutron Skin and Symmetry Energy

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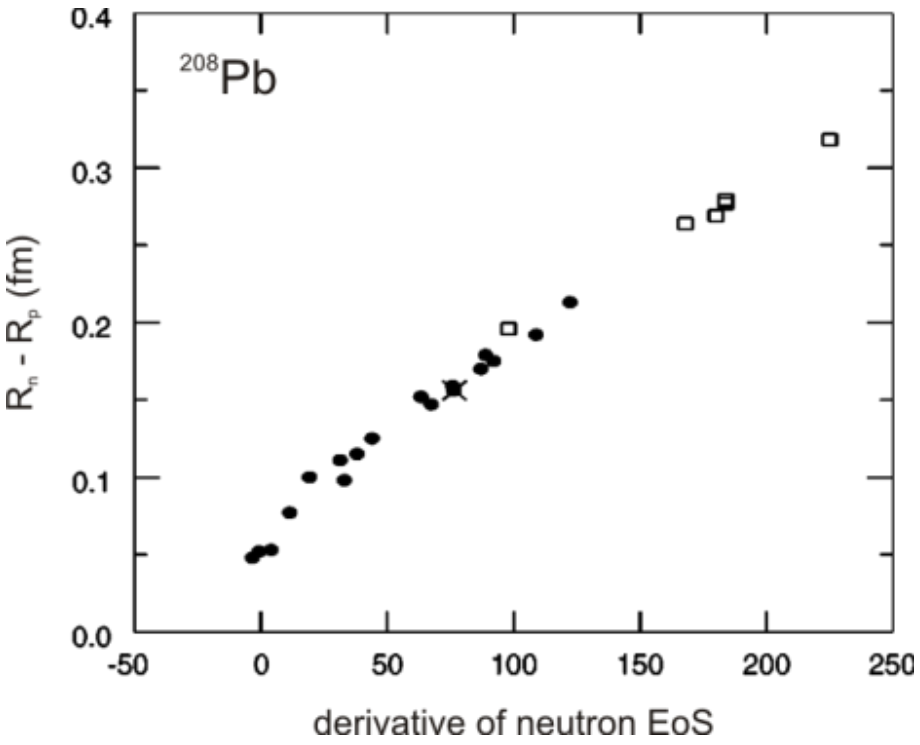
S. Typel and B. A. Brown, Phys. Rev. C 64, 027302 (2001)



- Neutron skin correlated with density dependence of symmetry energy
- Relevance of polarizability data → plenary talk of Atsushi Tamii tomorrow

The Case of ^{48}Ca

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- New predictions from EDFs based on presently available polarizability data

  X. Roca-Maza et al., Phys.Rev. C 92, 064304 (2015)

- Recent coupled-cluster results based on interactions derived from χEFT

  G. Hagen et al., Nature Physics 12, 186 (2016)

- CREX Experiment proposed at JLAB to measure weak (i.e., neutron) form factor with parity-violating elastic electron scattering

Experimental Approach

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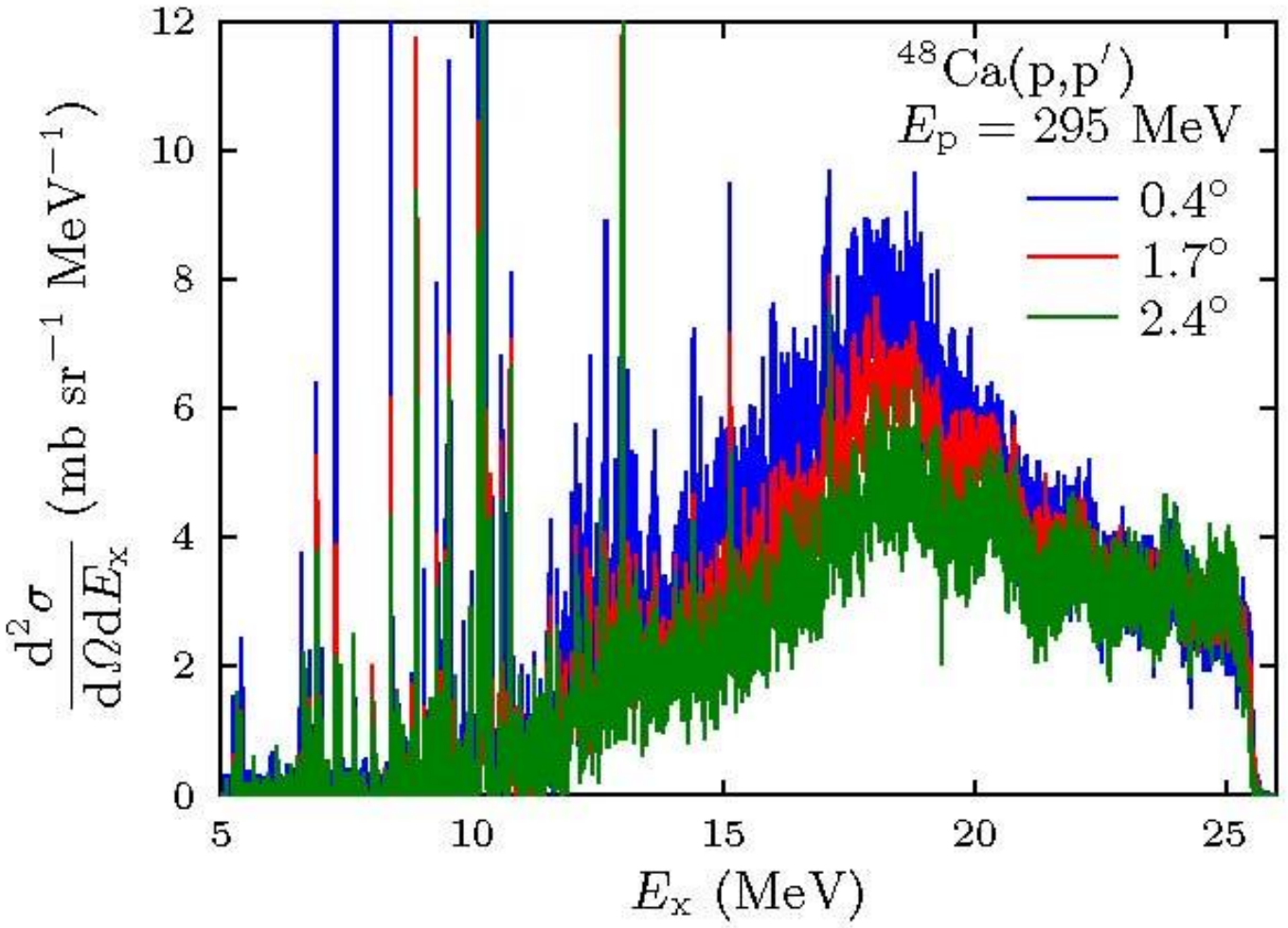
- 300 MeV proton scattering at and close to 0º
  - strong Coulomb excitation of 1^- states: E1 strength up to 25 MeV
  - high resolution: ΔE = 25 - 30 keV (FWHM)
  - angular distributions: E1 / M1 separation by MDA
  - polarization observables: spinflip / non-spinflip separation

- ^{208}Pb and ^{120}Sn as reference cases

  A. Tamii et al., Phys. Rev. Lett. 107 (2011) 062502
  I. Poltoratska et al., Phys. Rev. C 85 (2012) 041304(R)
  A.M. Krumbholz et al., Phys. Lett. B 744 (2015) 7
  T. Hashimoto et al., Phys. Rev. C 92 (2015) 031305(R)
  J. Birkhan et al., Phys. Rev. C 93 (2016) 041302(R)

^{48}Ca(p,p‘) Data from RCNP



Multipole Decomposition Analysis

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- DWBA analysis:
  - Code: DWBA07
  - Effective proton-nucleus interaction (Love & Franey)
  - QPM wave functions

- Multipole decomposition $$\frac{d\sigma}{d\Omega}_{DATA} = \sum_{J^\pi} a_{J^\pi} \cdot \frac{d\sigma}{d\Omega}_{J^\pi, DWBA}$$

- Variants for ^{48}Ca compared to MDA in heavy nuclei
  - M1 neglected
  - E2 (ISGQR) an E0 (ISGMR) subtracted from spectra prior to MDA
  - Angular distribution of nuclear background assumed to be constant

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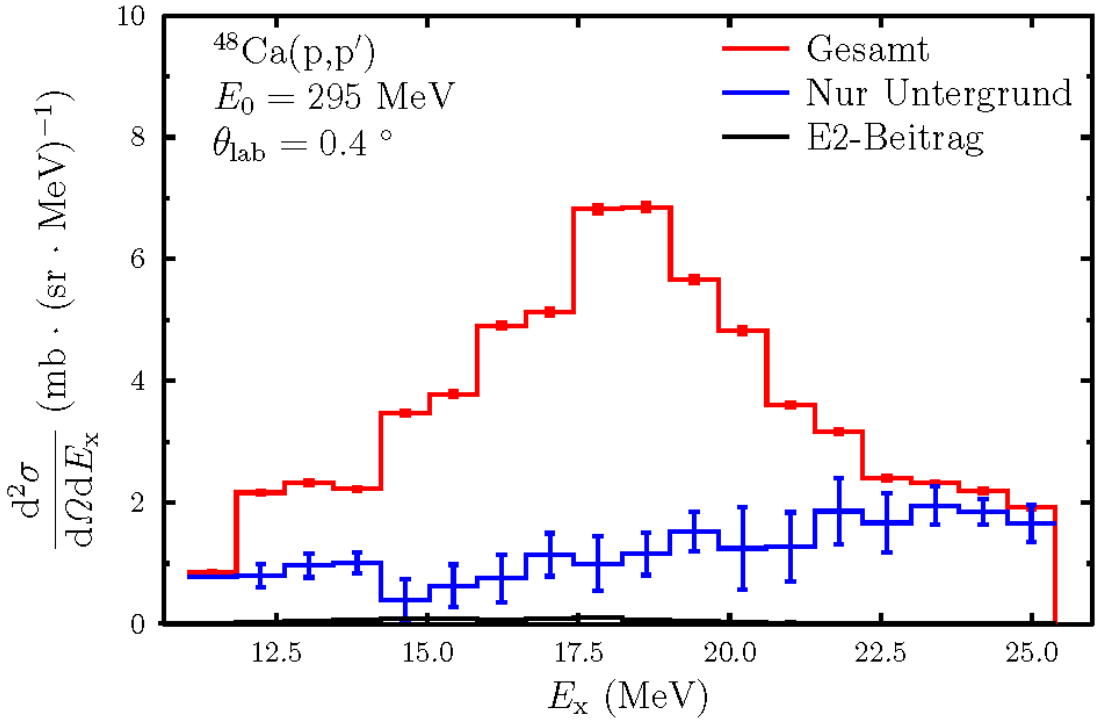
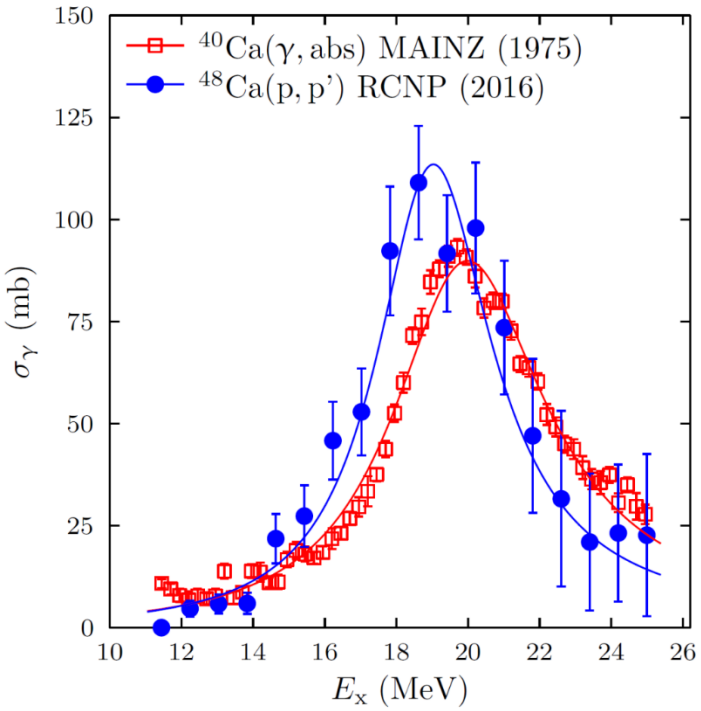
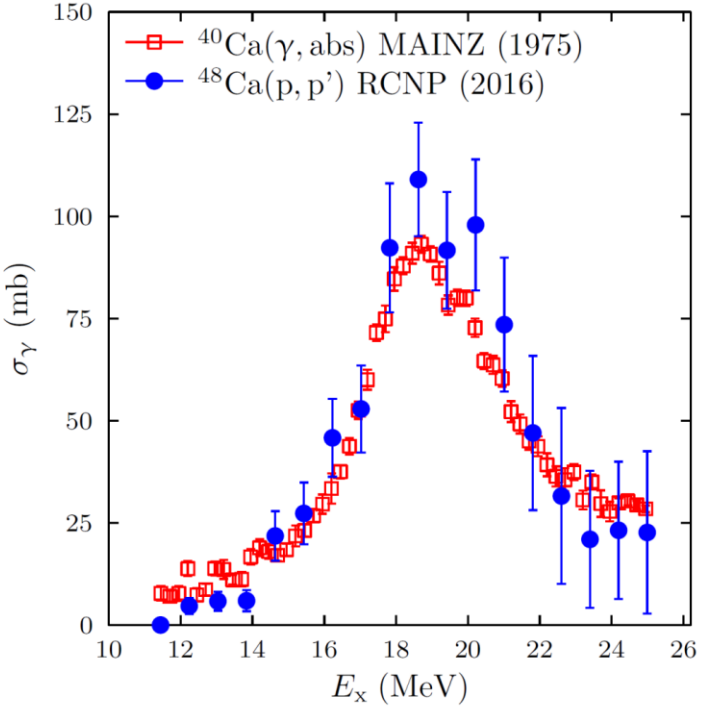
MDA Results



- E2 and E0 cross sections very small
- Resulting background has similar shape as observed in heavy nuclei

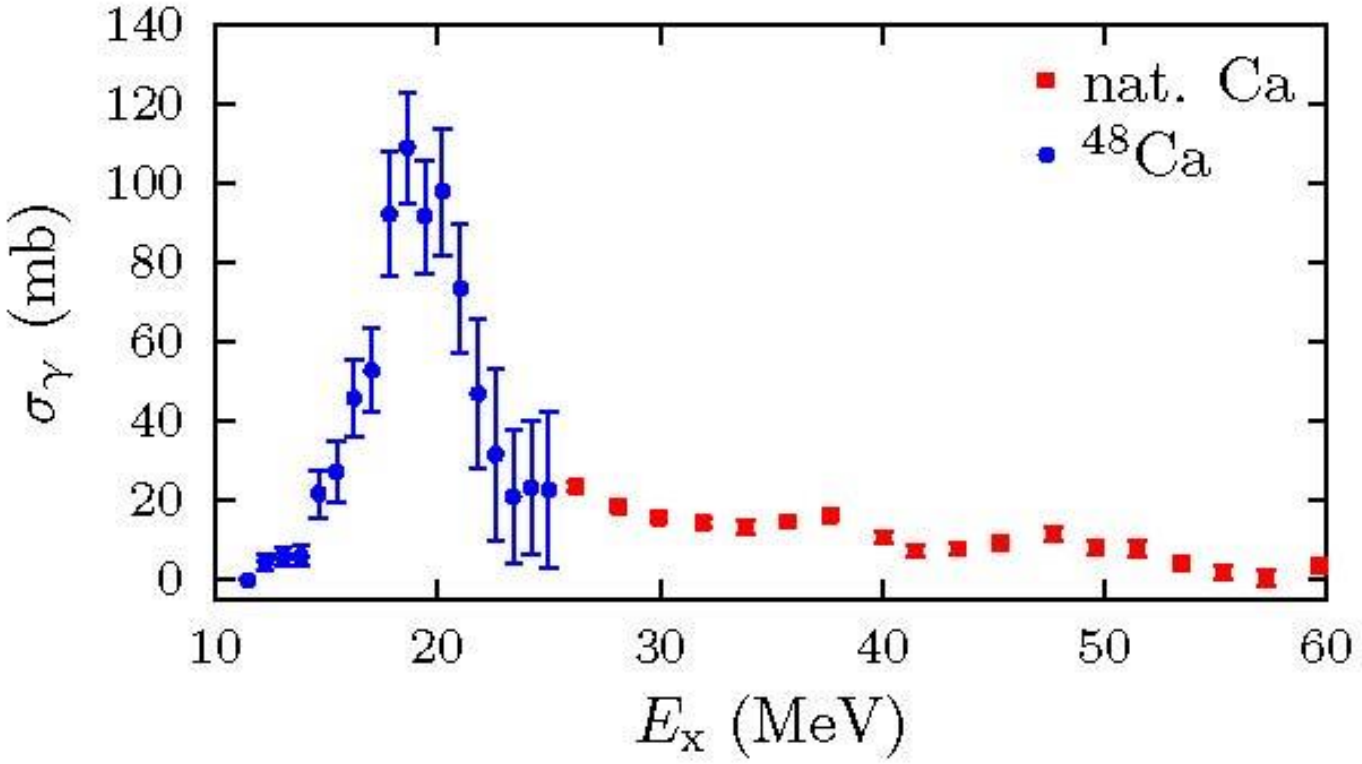
Comparison of ^{40}Ca/ ^{48}Ca in the GDR Region





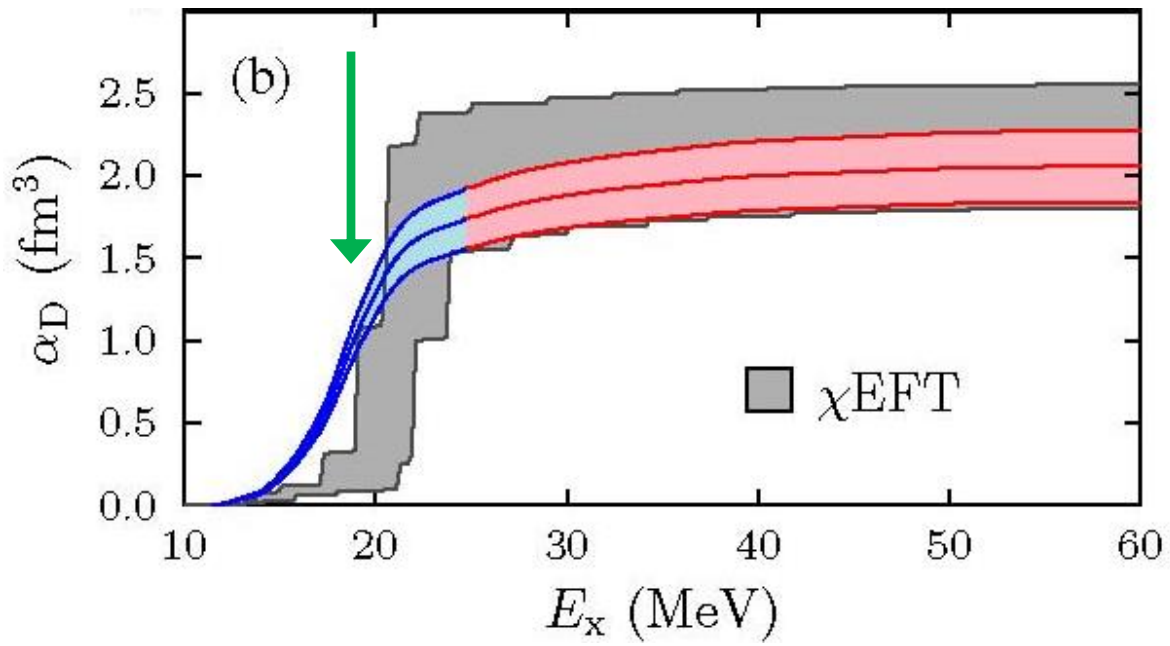
- Cross sections are comparable but there is an energy shift of (1.0 ± 0.3) MeV
- ^{48}Ca (GDR): α_D = (1.73 ± 0.18) fm^3 ^{40}Ca (GDR): α_D = (1.50 ± 0.02) fm^3

Photoabsorption Cross Sections



- $\alpha_D(10 – 60\ \text{MeV}) = (2.07 \pm 0.22)\ \text{fm}^3$
- Uncertainty dominated by parametrization of nuclear background in MDA

New Ab-Initio Calculations



- Strength distribution from Lorentz-integral method
- 2 MeV discrepancy due to truncation of Hilbert space
- Effects are currently investigated by Marco Miorelli

Present Status of Experiment and Theory for the Dipole Polarizability of ^{48}Ca

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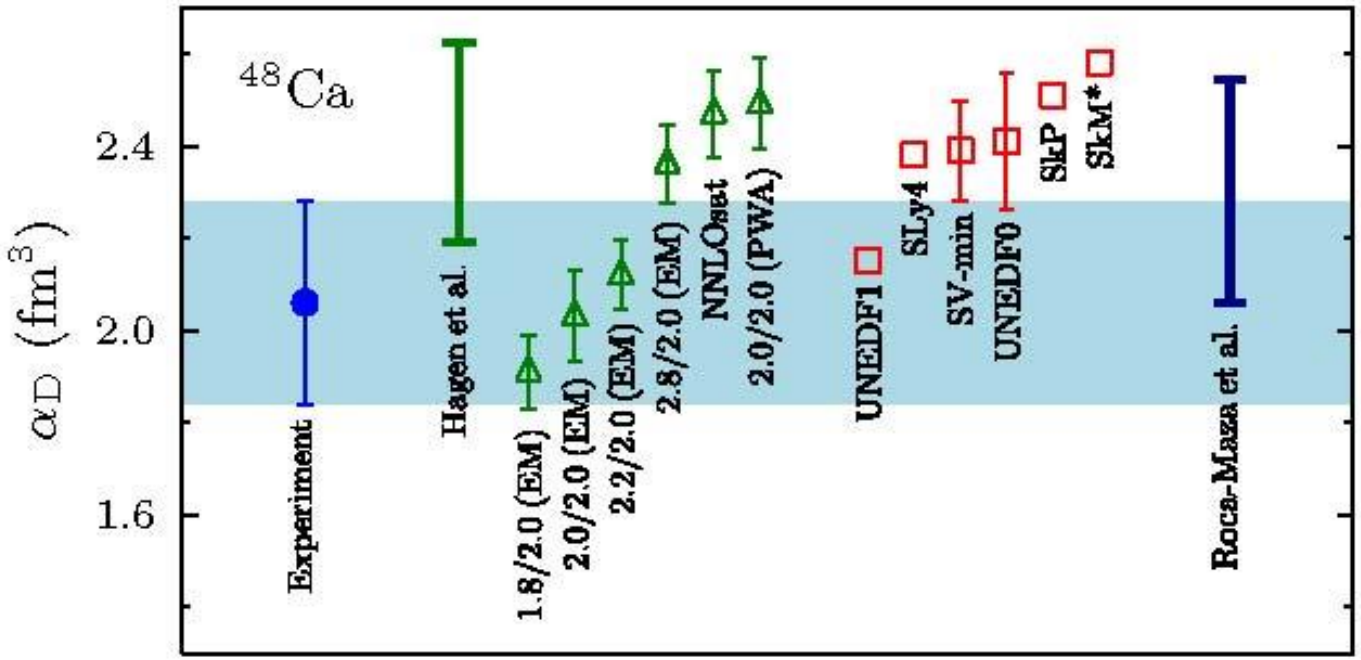
χEFT: G. Hagen et al., Nature Physics 12, 681 (2016}
EDFs: X. Roca-Maza et al., Phys .Rev. C 92, 064304 (2015)



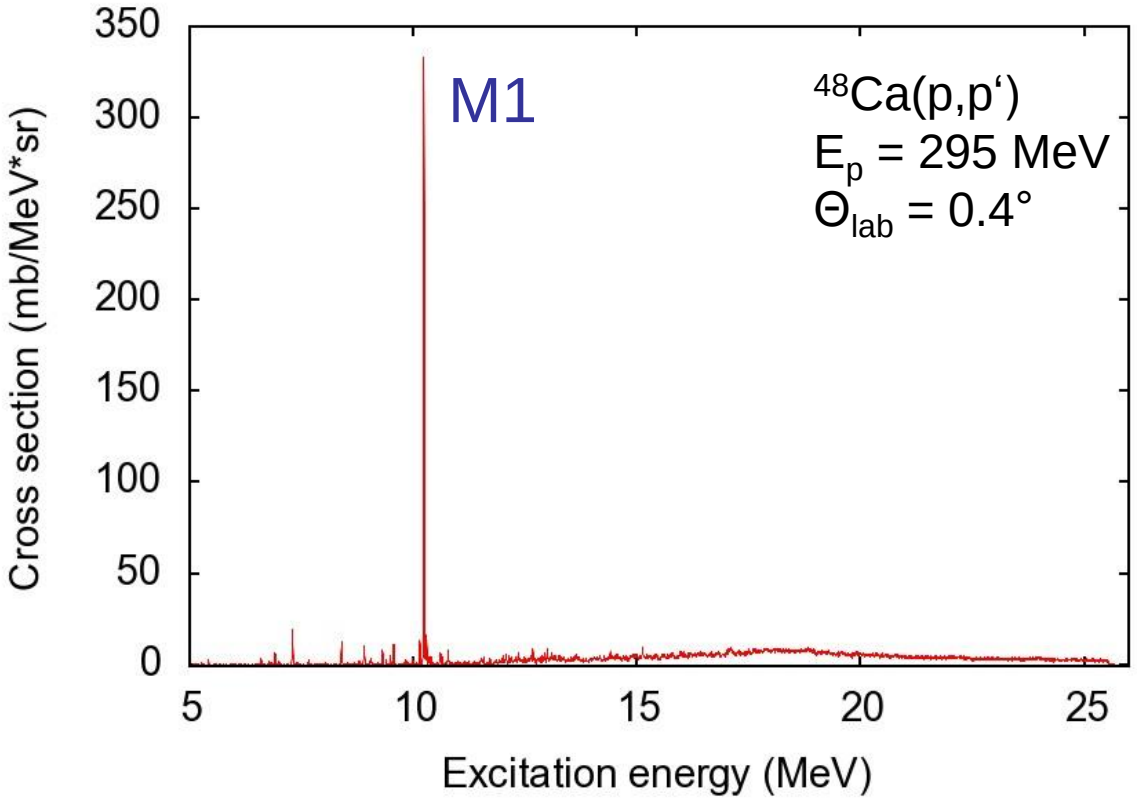
- Neutron skin predicted from χEFT: 0.15 fm
- Neutron skin predicted from EDFs: 0.15 - 0.20 fm, no correlation with α_D

this needs to be understood!

Thank you for your attention!

M1 Cross sections

J. Birkhan et al., Phys. Rev. C 93, 041302(R) (2016)

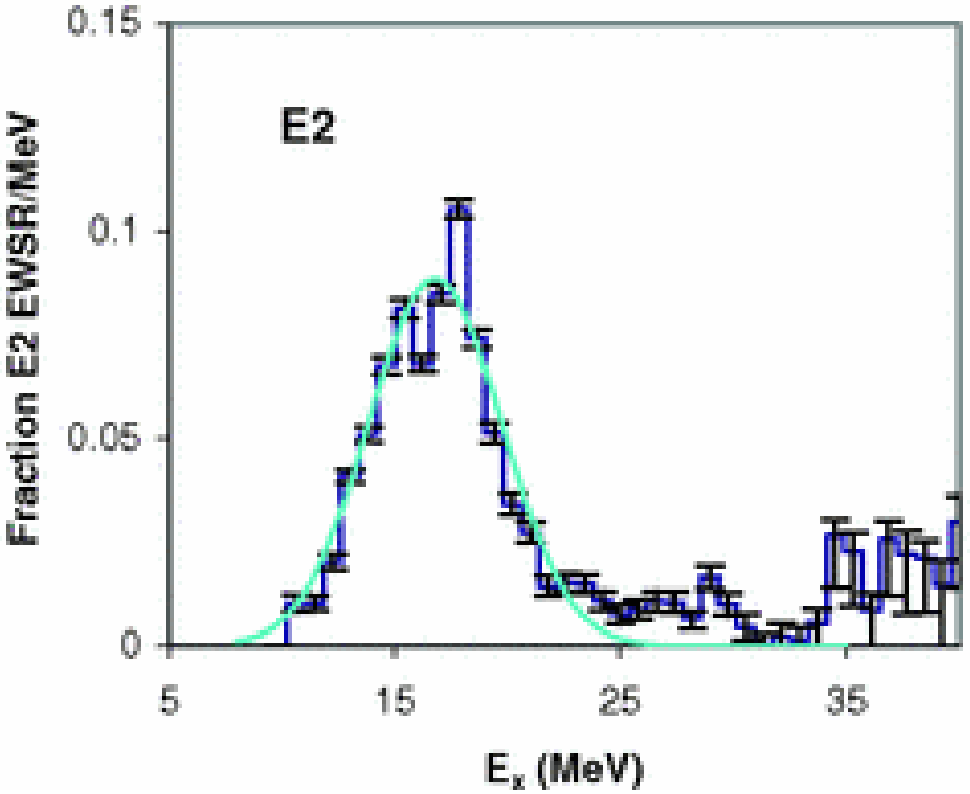


- M1 strength concentrated in single transition

E2 cross sections

From MDA of ^{48}Ca(α,α‘) data

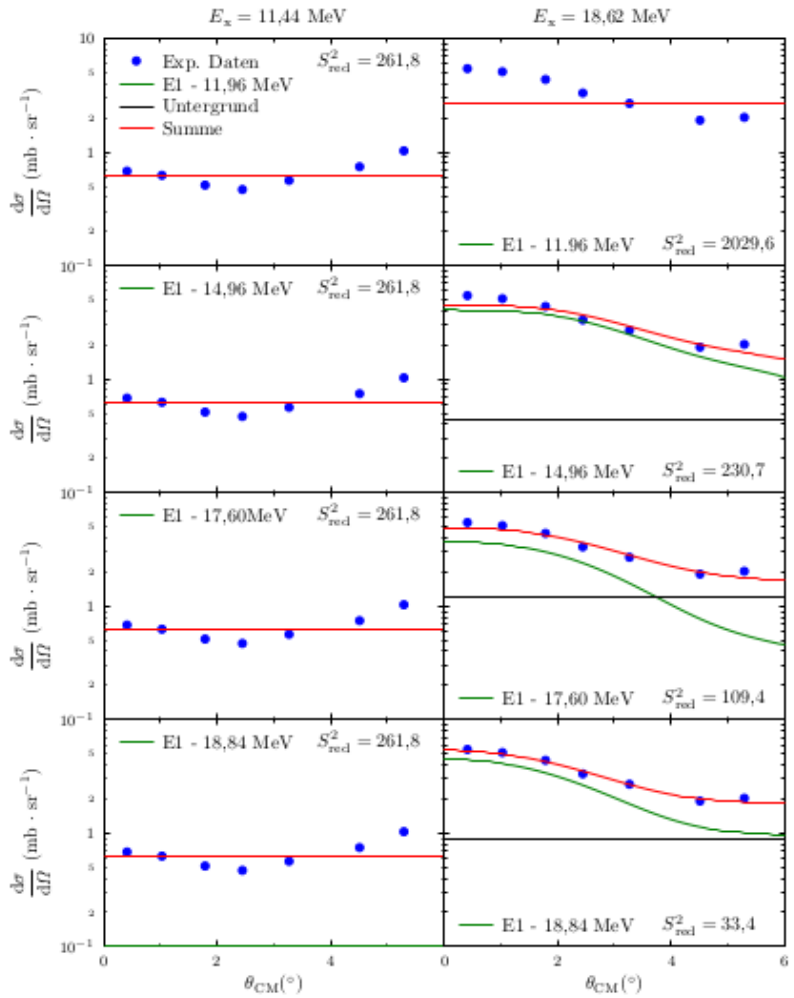
→ input to DWBA calculation of corresponding (p,p‘) cross sections



Y.-W. Lui et al., Phys. Rev. C 83, 044327 (2011)

MDA Uncertanties

- Statistical and systematic errors of cross sections
- MDA uncertainties: variance of χ2-weighted averaging over all possible combinations
- All contributions taken into account in MC simulation
- Uncertainty dominated by MDA errors



B(E1) Strength in ^{48}Ca

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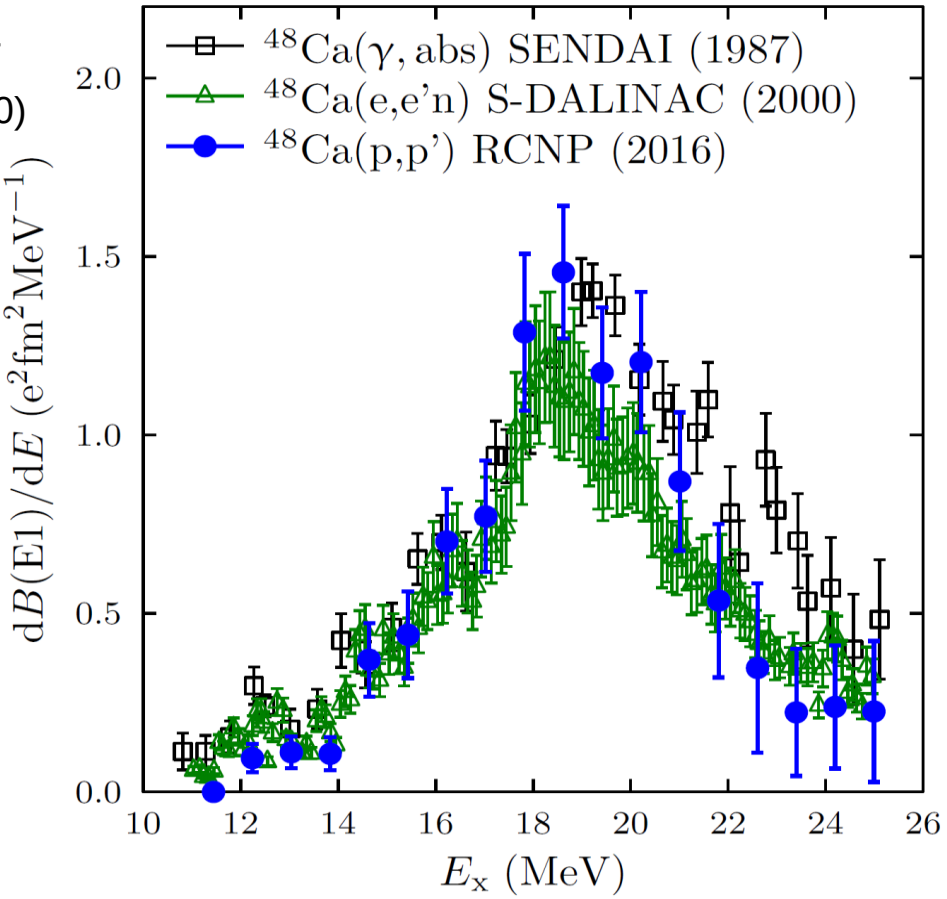
G.J. O'Keefe et al. Nucl. Phys. A 469, 239 (1987

S. Strauch et al., Phys. Rev. Lett. 85, 2913 (2000)



- O'Keefe et al: result discarded because of method
- Strauch et al: (e,e'p) channel missing

Polarizability Contribution from E1 Strength Below Threshold

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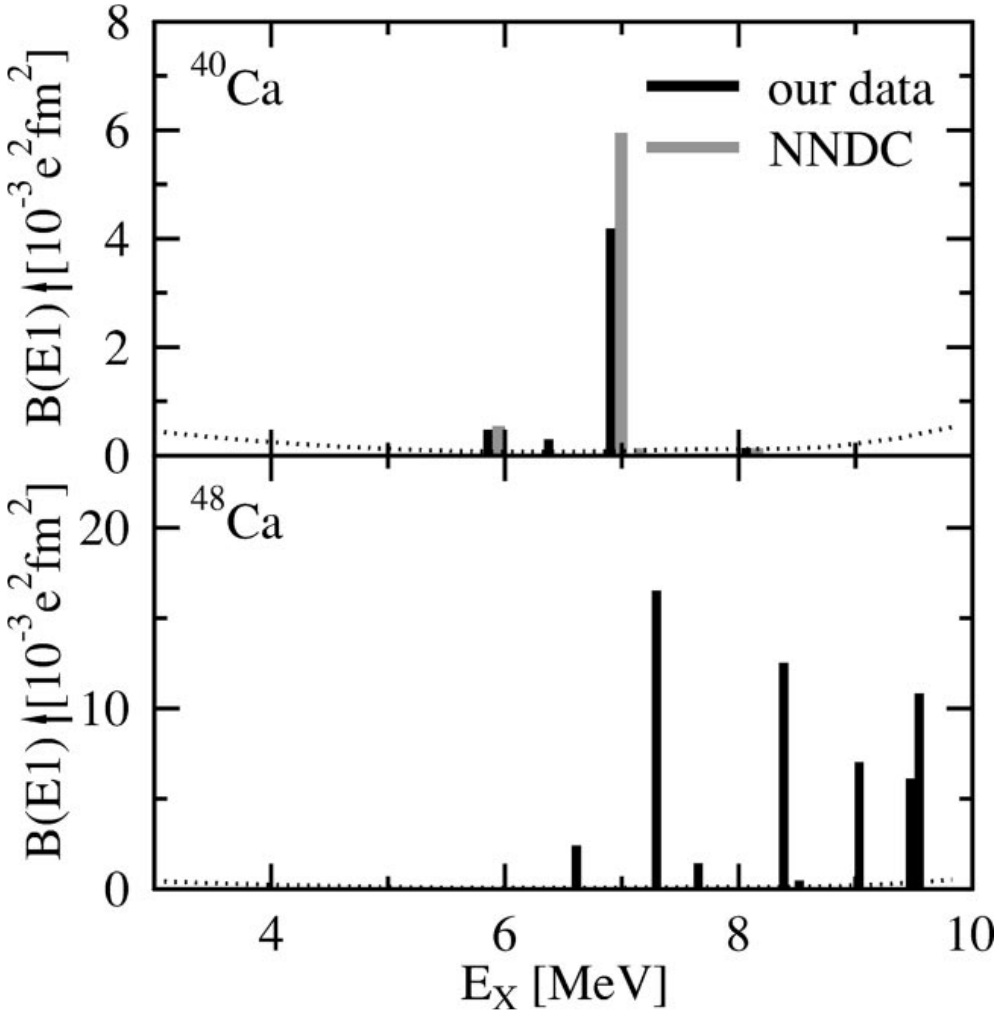
- α_D(0 - 10 MeV) = 0.0101 ± 0.0006 fm^3

T. Hartmann et al., Phys. Rev. C 65, 034301 (2002)



Photoabsorption Cross Section in ^{40}Ca up to 160 MeV

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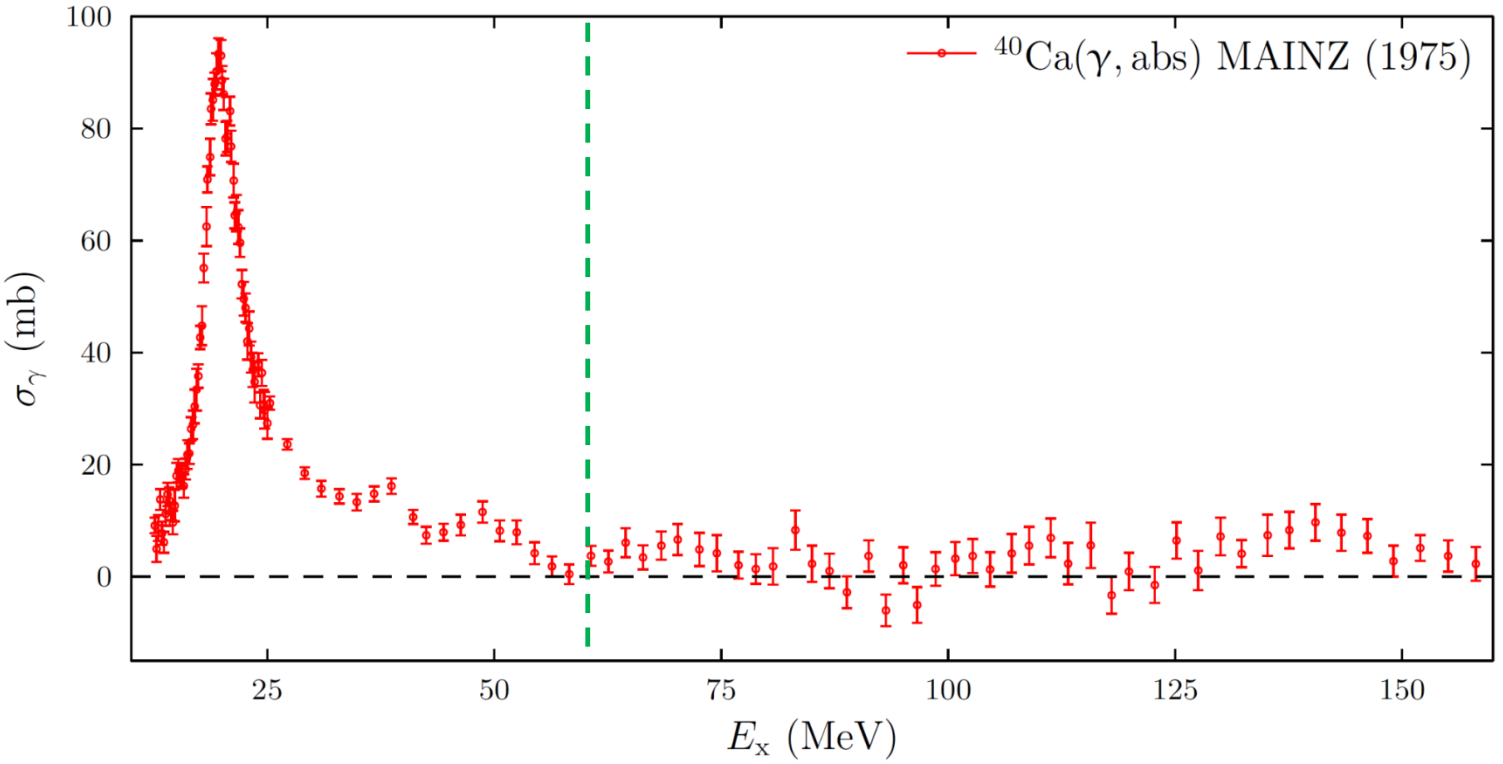
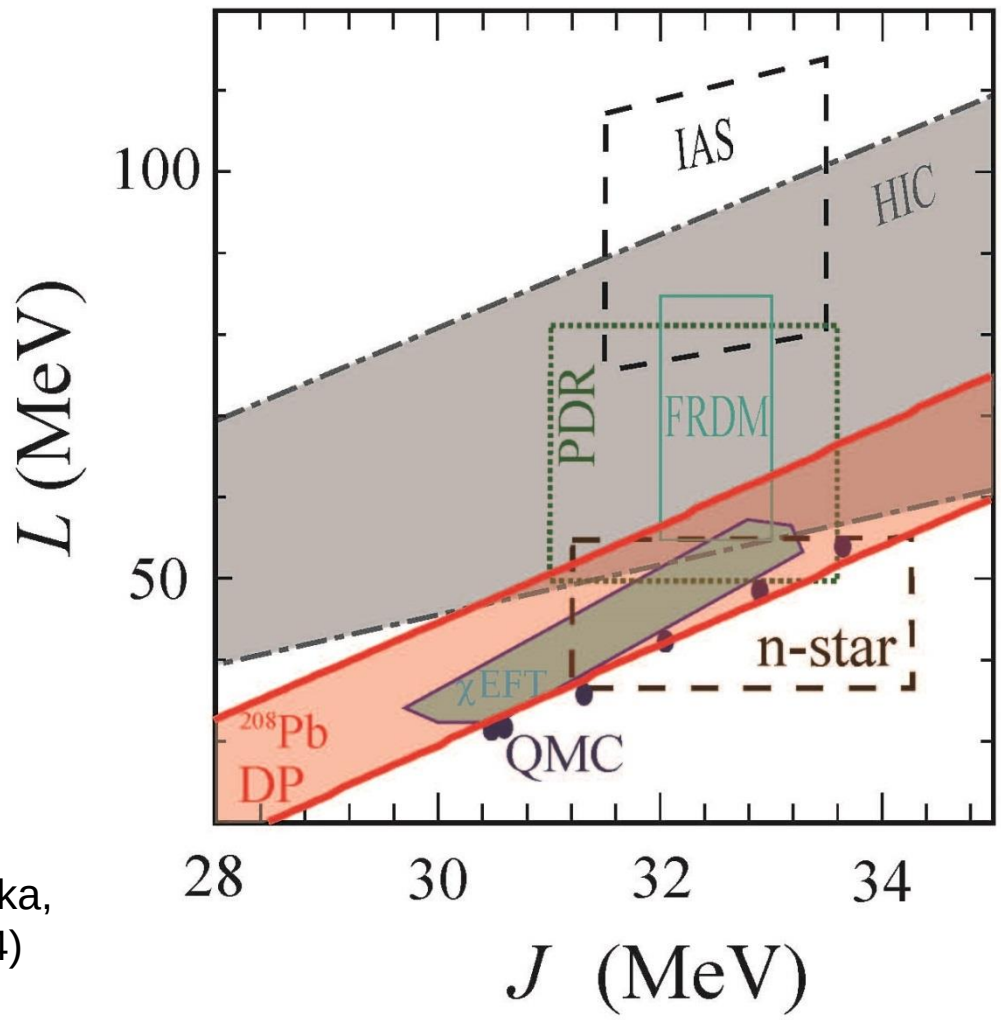
J. Ahrens et al., Nucl. Phys. A 251, 479 (1975)



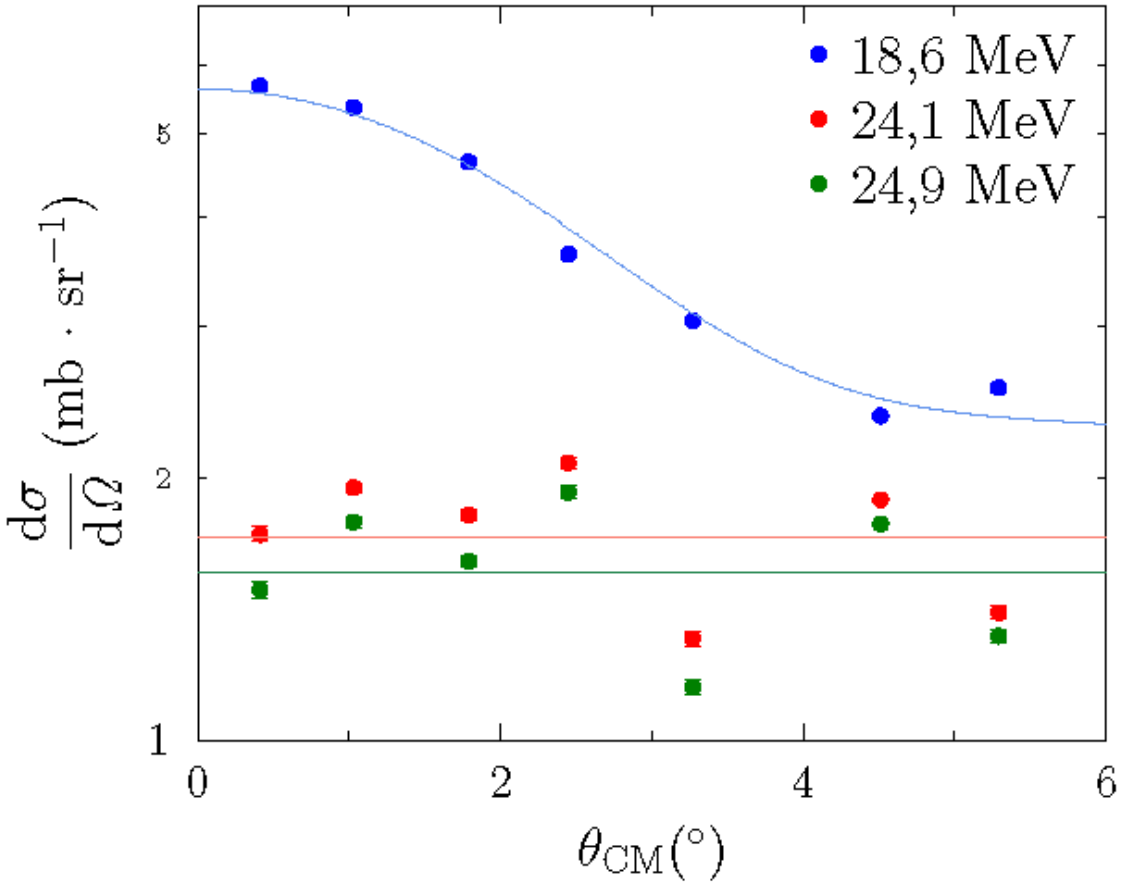
- Note: above E_x = 60 MeV cross section is negligibly small
- Data in GDR region differ from original paper (see EXFOR data base)

Constraints on Symmetry Energy Parameter



A. Tamii, PvNC, I. Poltoratska,
Eur. Phys. J. A 50, 28 (2014)

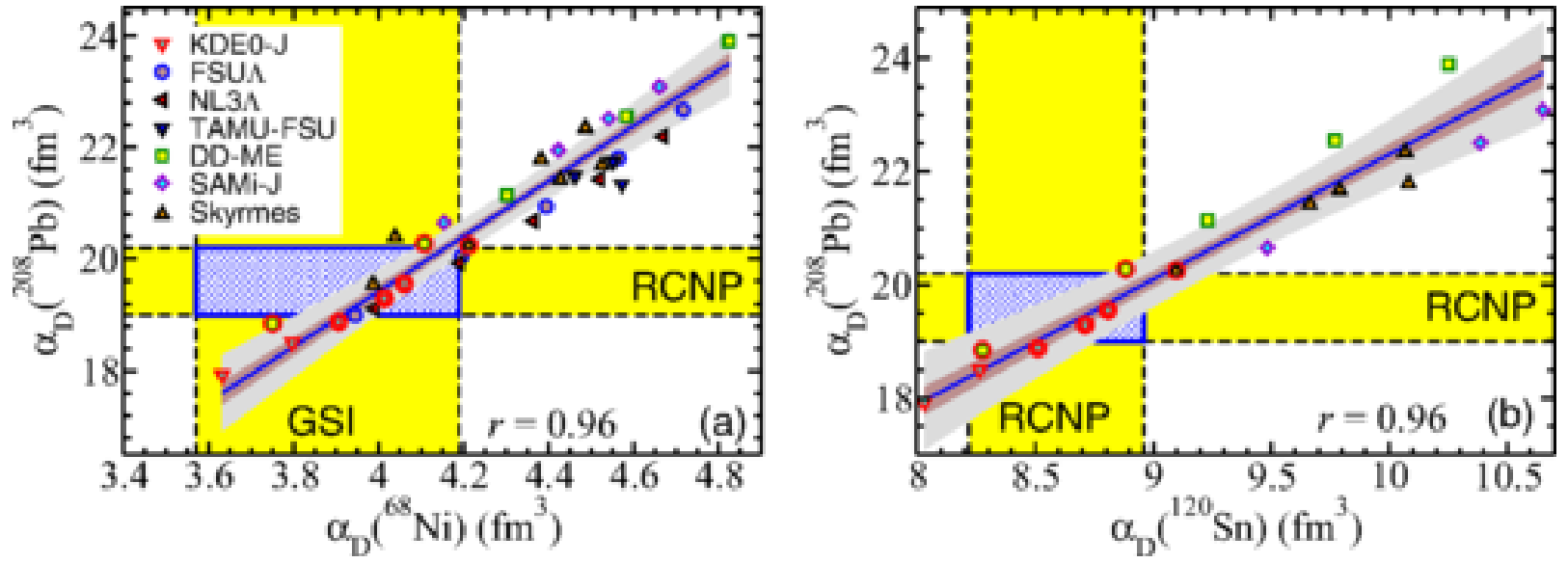
Nuclear Background



- At E_x = 24 – 25 MeV cross sections approximately constant

^{48}Ca Polarizability from EDF predictions

X. Roca-Maza et al., Phys .Rev. C 92, 064304 (2015)



- Prediction of $\alpha_D(^{48}Ca)$ based on EDFs which simultaneously describe the polarizability of ^{68}Ni, ^{120}Sn and ^{208}Pb

^{48}Ca Polarizability from χEFT Predictions

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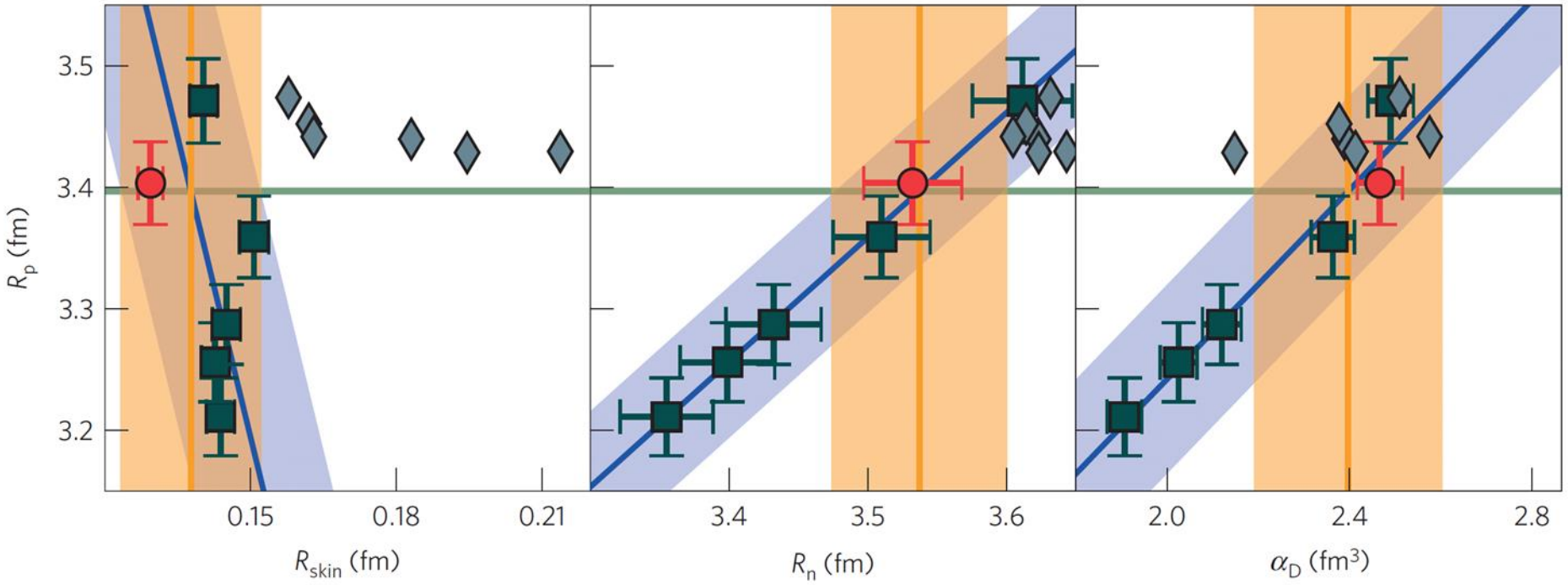
G. Hagen et al., Nature Physics 12, 186 (2016)



- Correlation of $\alpha_D(^{48}Ca)$ with proton and neutron radius

Polarizability and Symmetry Energy Parameters

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X. Roca-Maza et al., Phys.Rev. C 88, 024316 (2013)