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DARMSTADT

Report on B04

Electric Dipole Response and Neutron Equation of State

Heiko Scheit



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March 28, 2019



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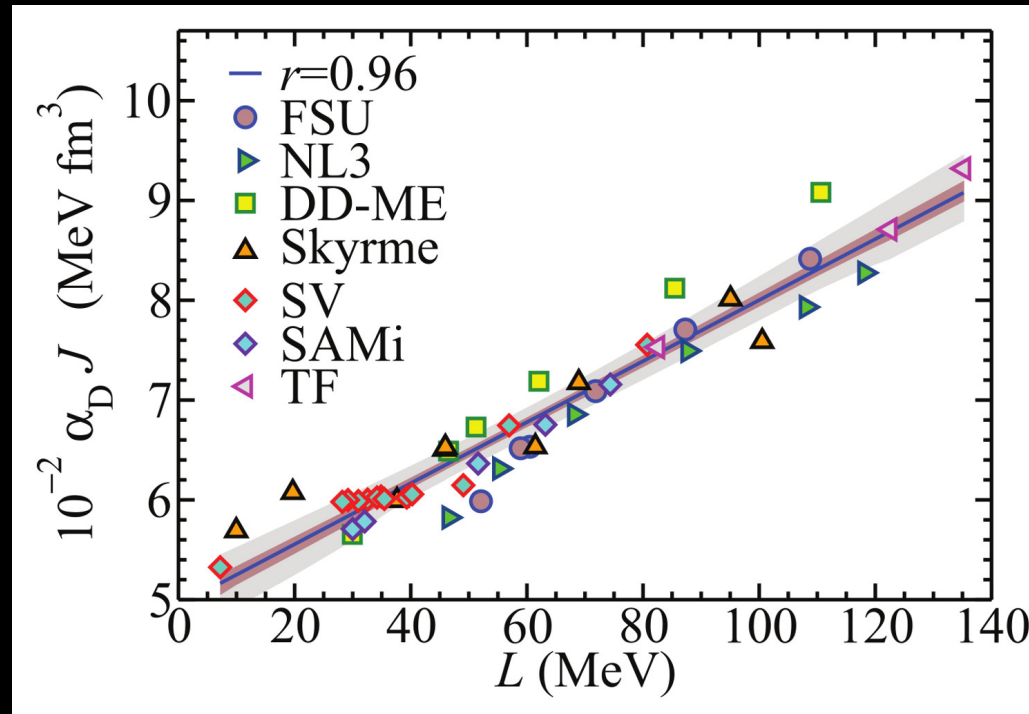
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Symmetry Energy and Dipole Polarizability



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X. Roca-Maza *et al.*
PRC 88, 024316 (2013)

- polarizability

$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \int \frac{\sigma_{abs}(\omega)}{\omega^2} d\omega$$

- photo absorption cross section $\sigma_{abs}(\omega)$ required



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- by probe
 - real photons
 - virtual (equivalent) photons
 - anything else: look at γ decay \rightarrow GSF



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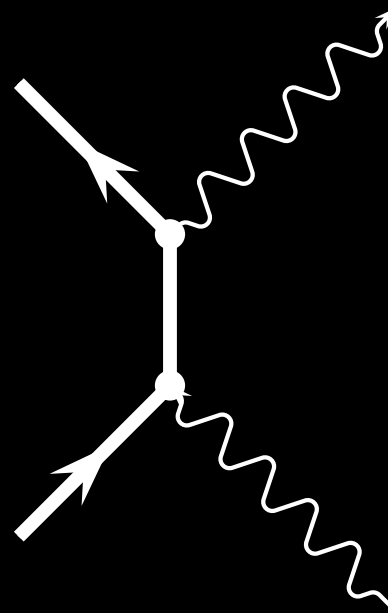
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- by probe
 - real photons
 - virtual (equivalent) photons
 - anything else: look at γ decay \rightarrow GSF
- by spectroscopic tool
 - missing mass
 - invariant mass

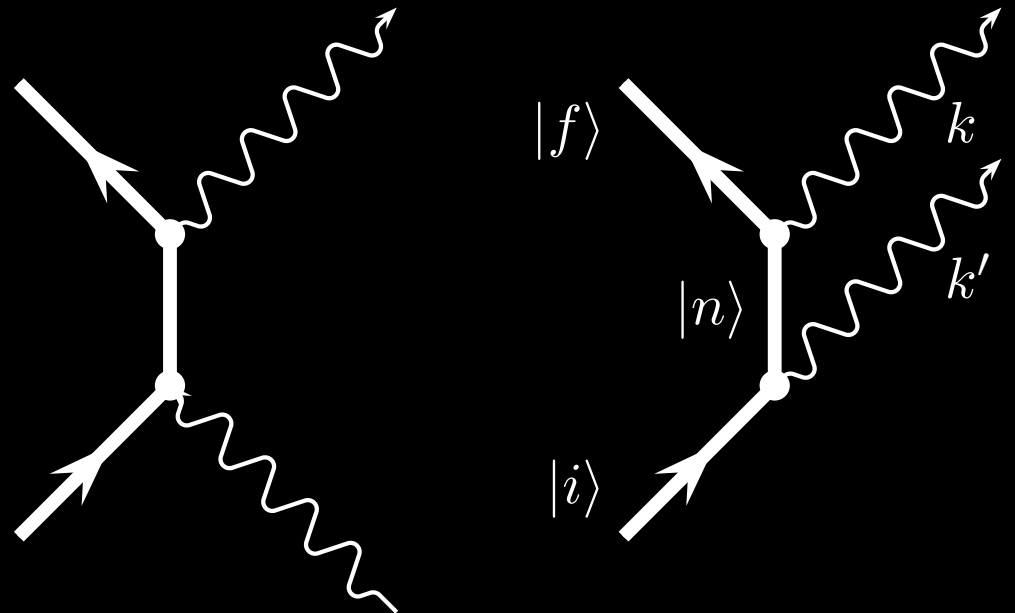
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Grand Raiden Spectrometer



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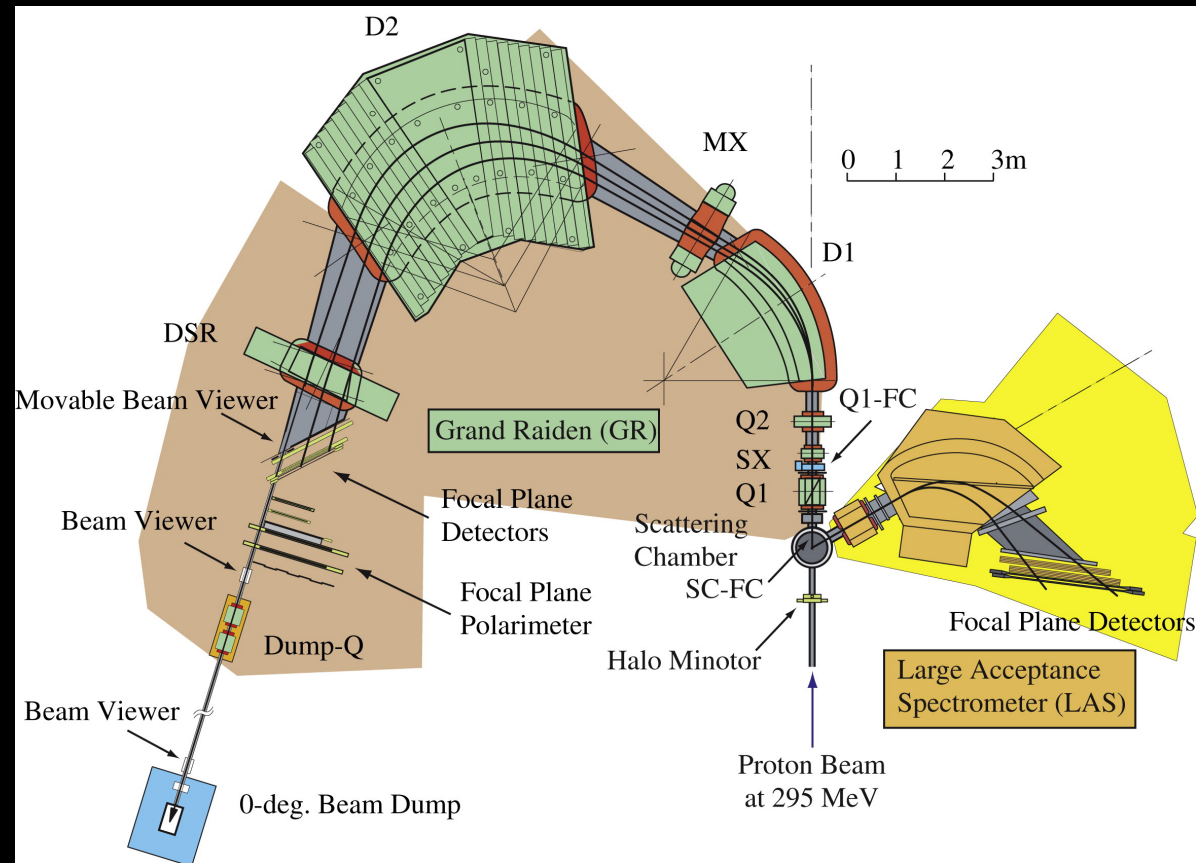
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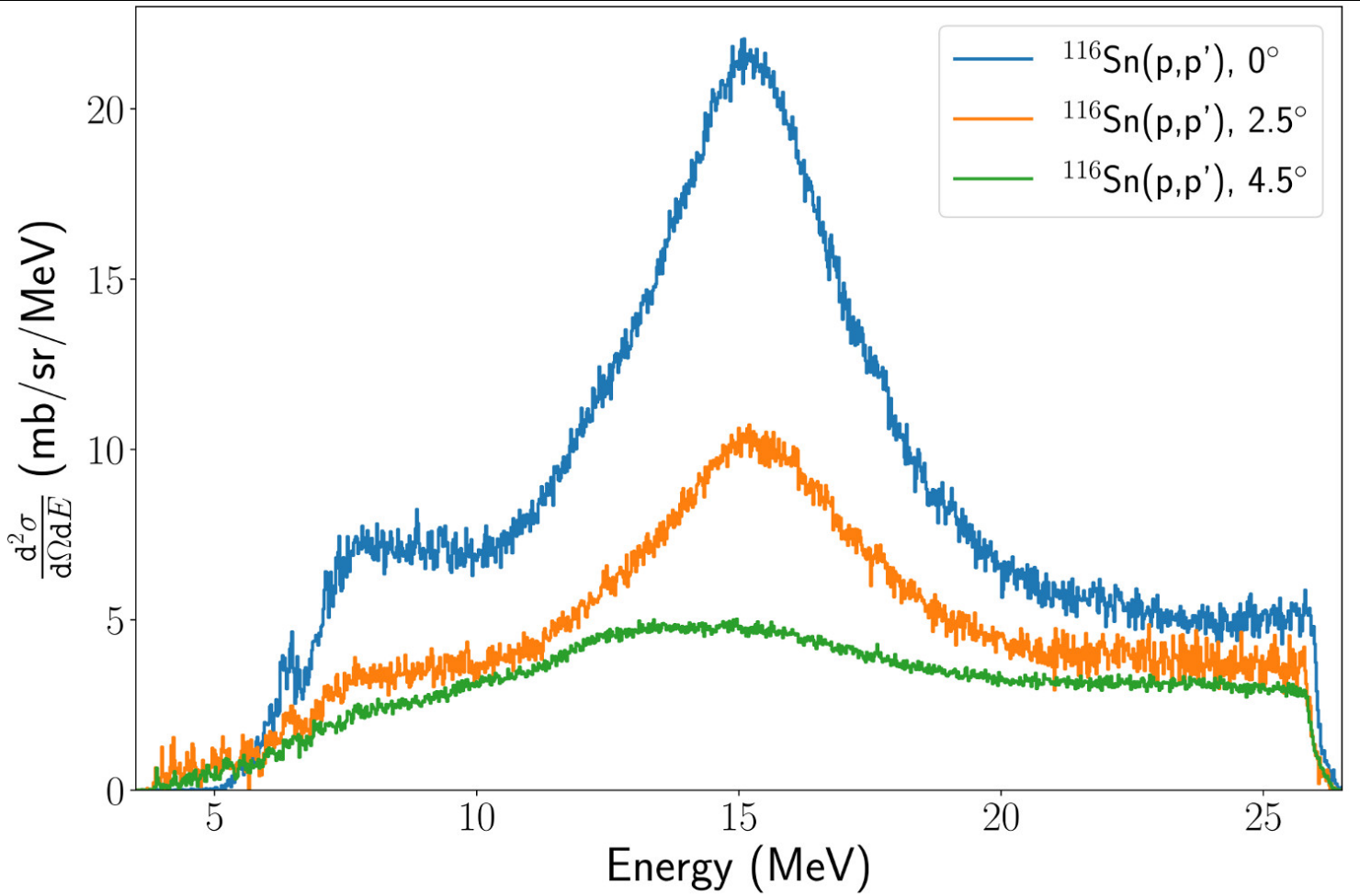


- Reaction: (p, p')
- Beam Energy: 295 MeV
- Resolution: 30 keV

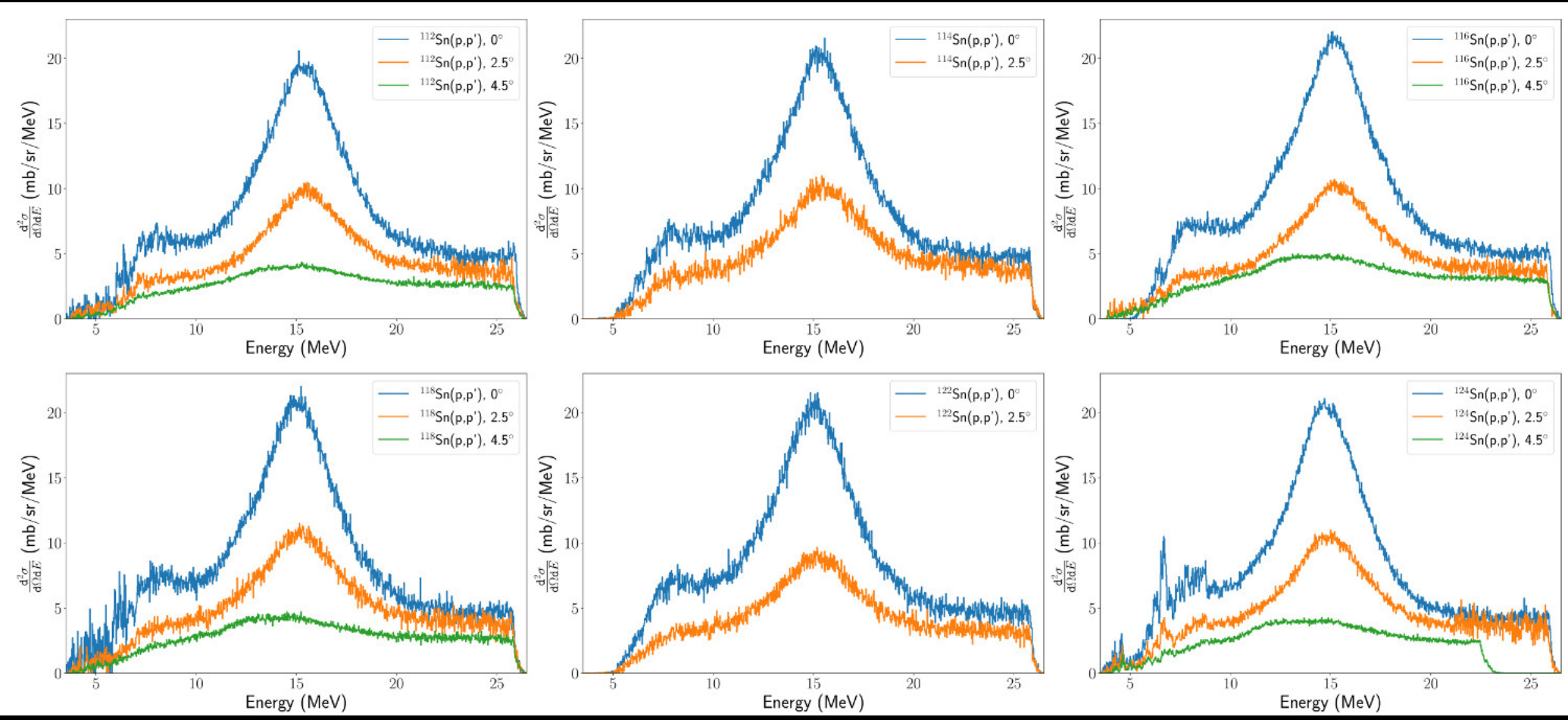
Double differential cross sections (1)



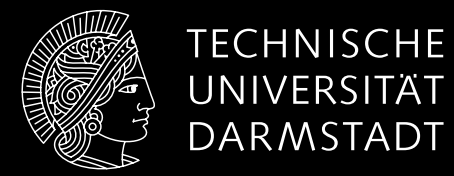
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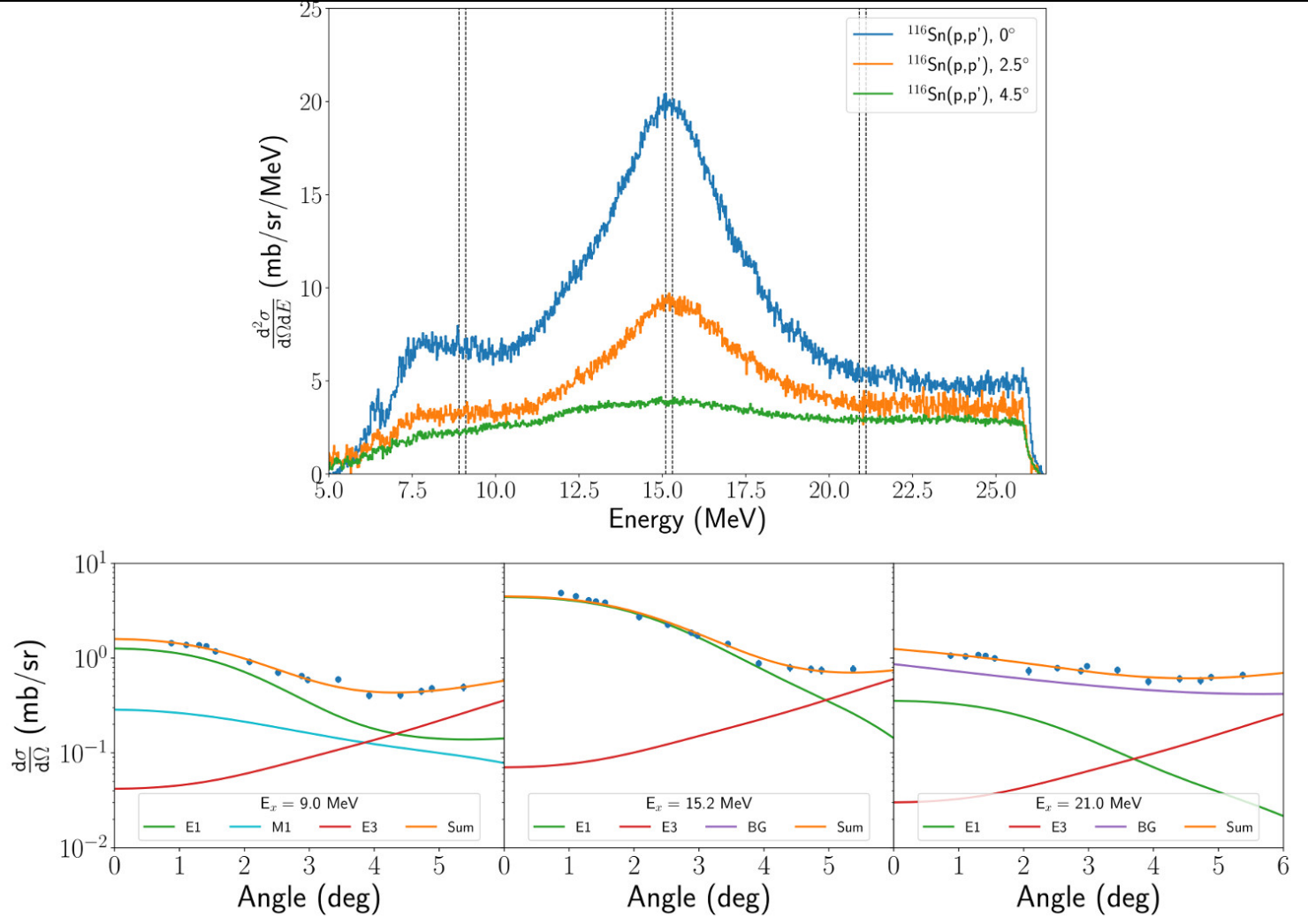
Double differential cross sections (2)



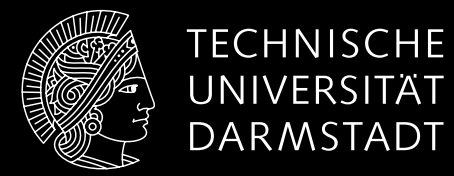
Multipole Decomposition Analysis



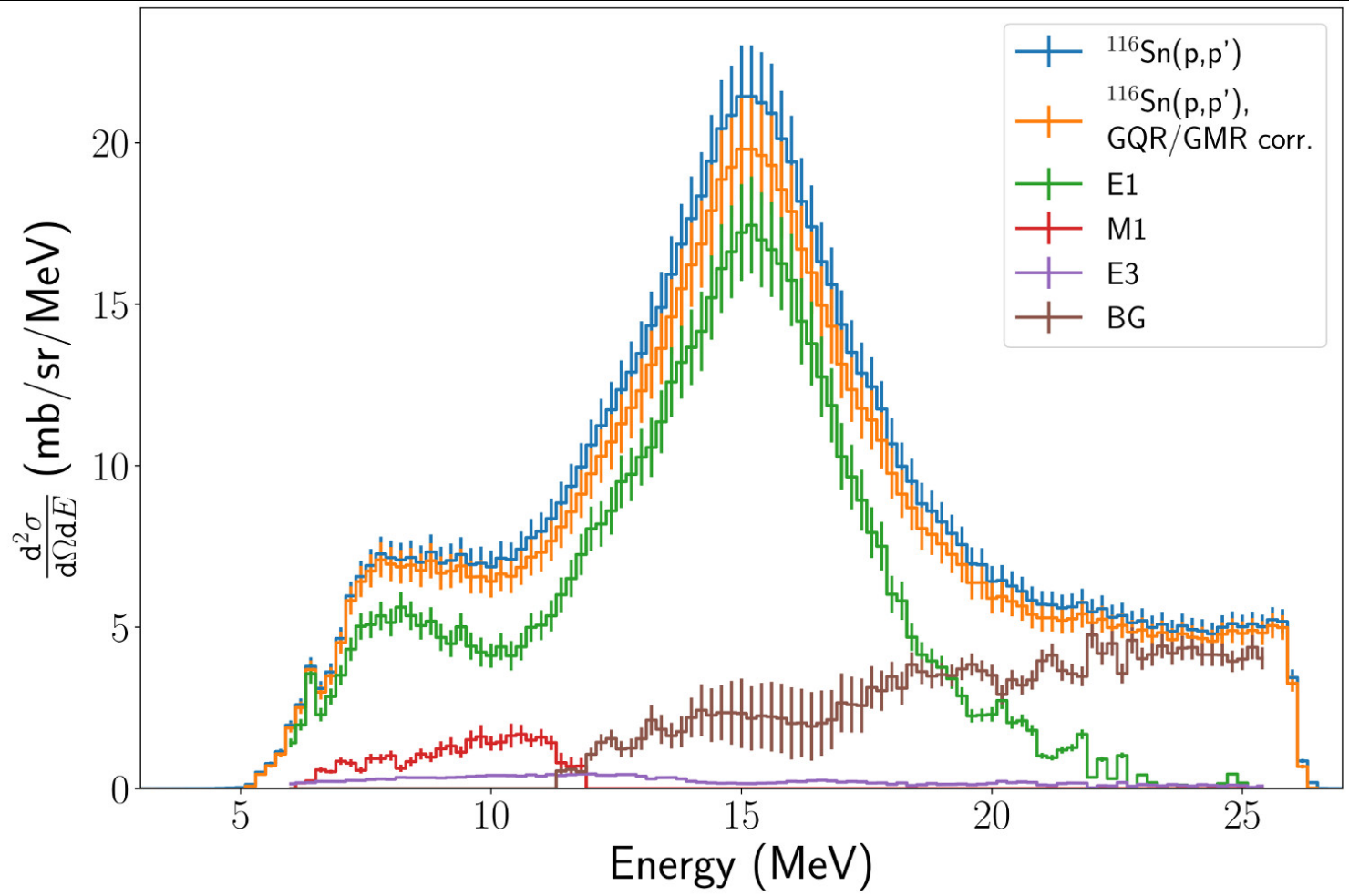
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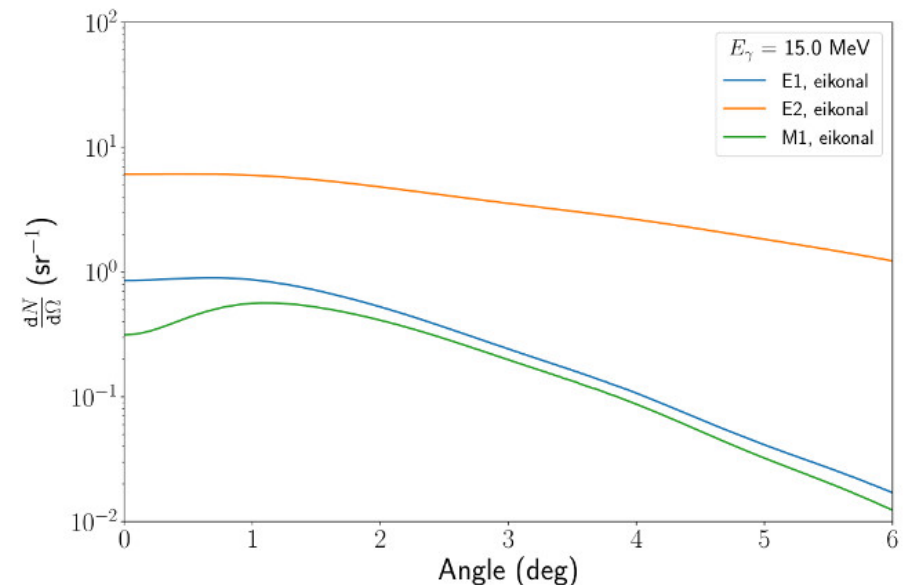
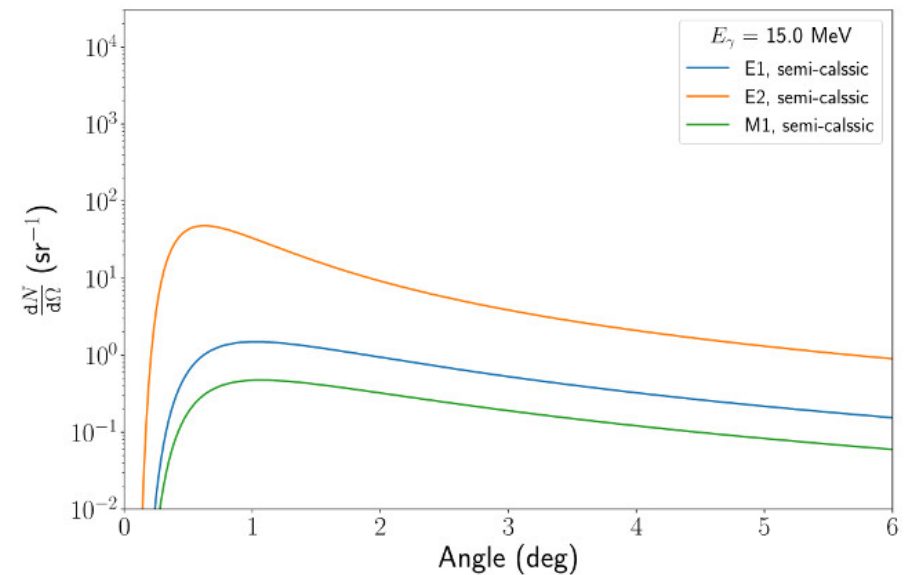
▶
$$\frac{d^2\sigma}{d\Omega dE} = \sum_{\pi\lambda} \frac{1}{E} \frac{dN_{\pi\lambda}}{d\Omega} \sigma_{abs}^{\pi\lambda}$$

▶ Semi-classical approach

- ▶ Simple to calculate
- ▶ Singularity at zero degree

▶ Eikonal approximation

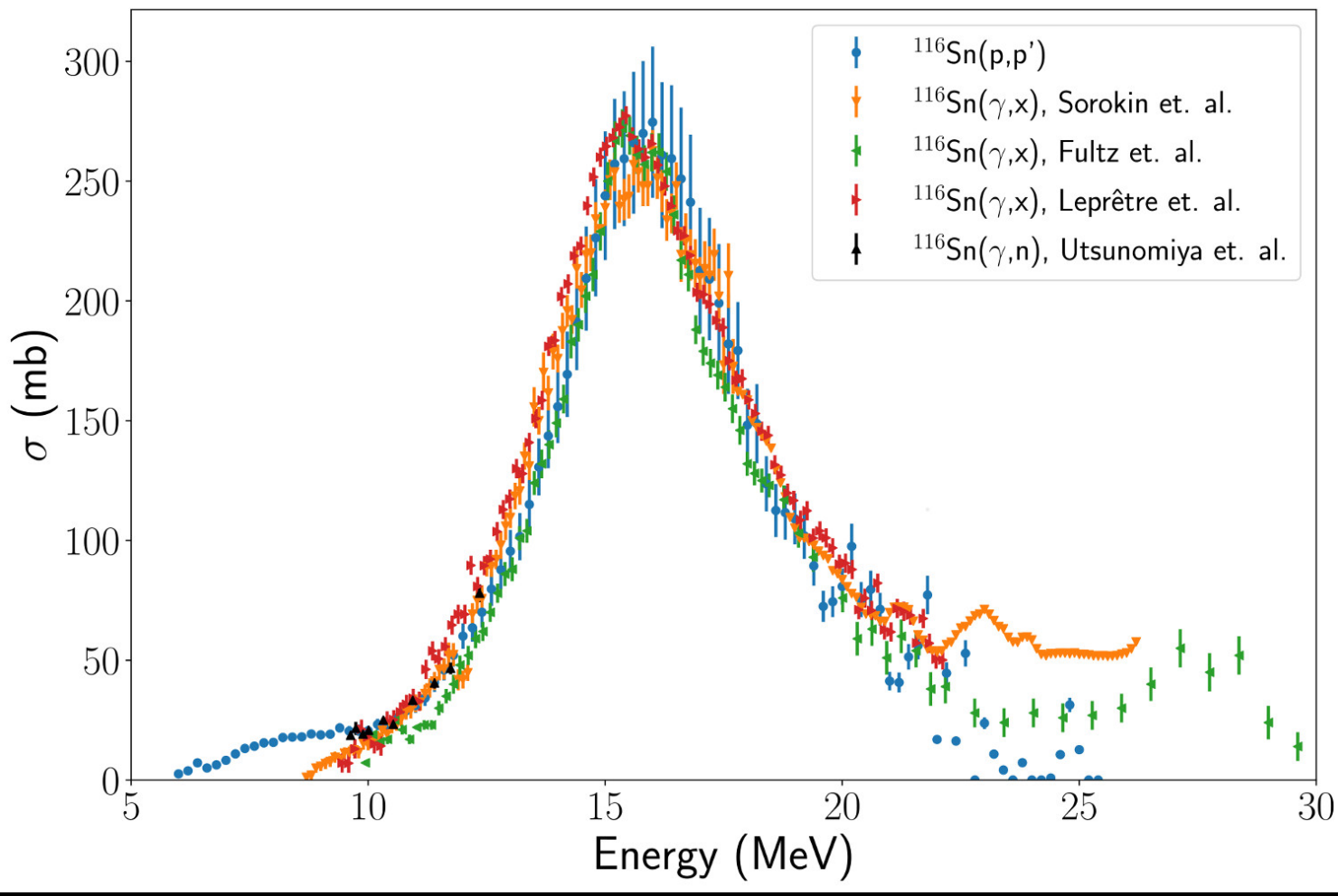
- ▶ strong absorption, relativity and retardation effects are included from the outset



Photoabsorption cross section



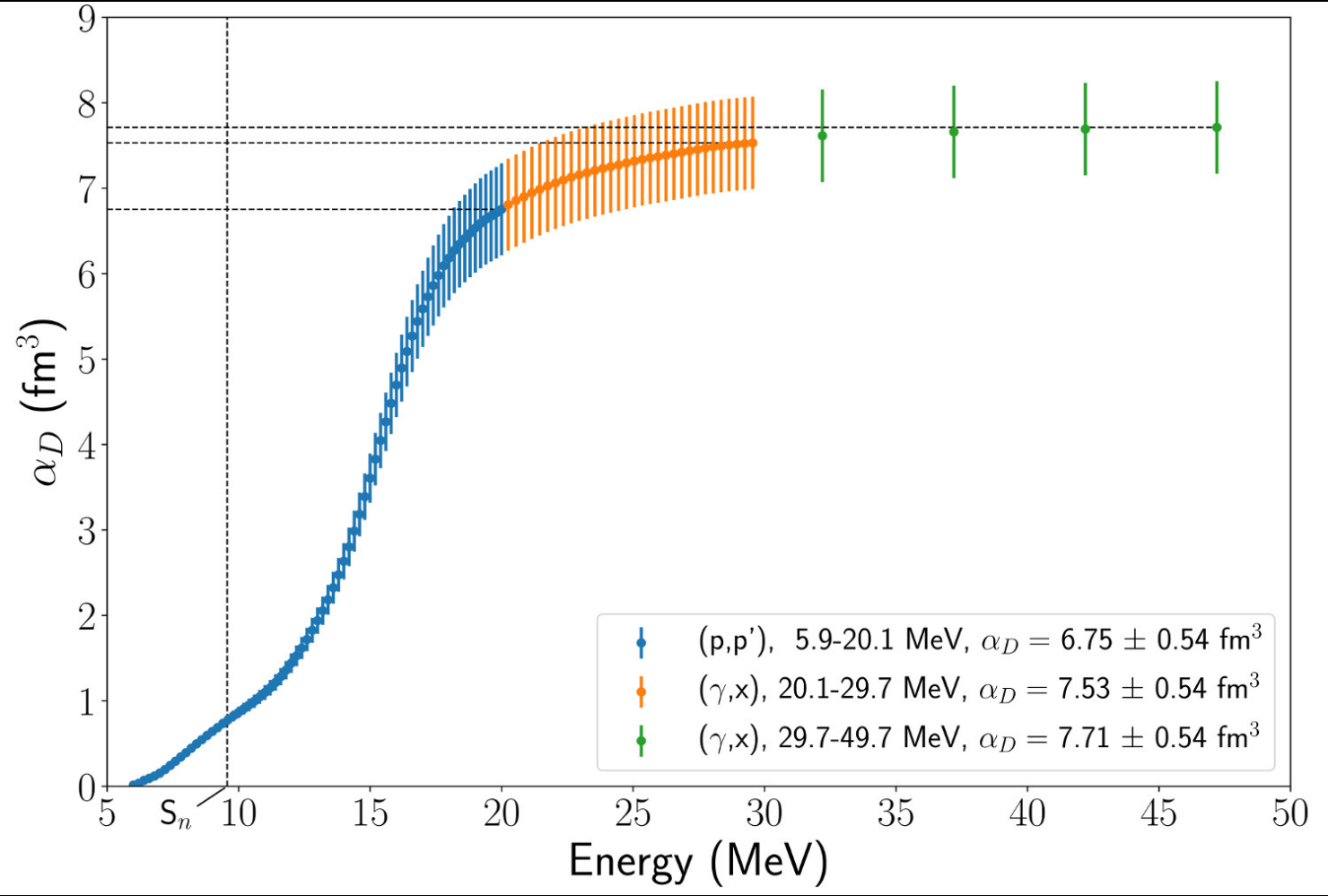
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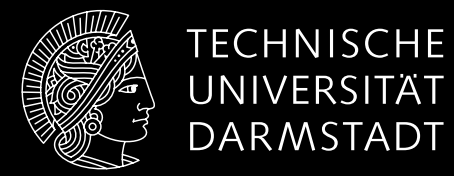
Dipole Polarizability: Running sum



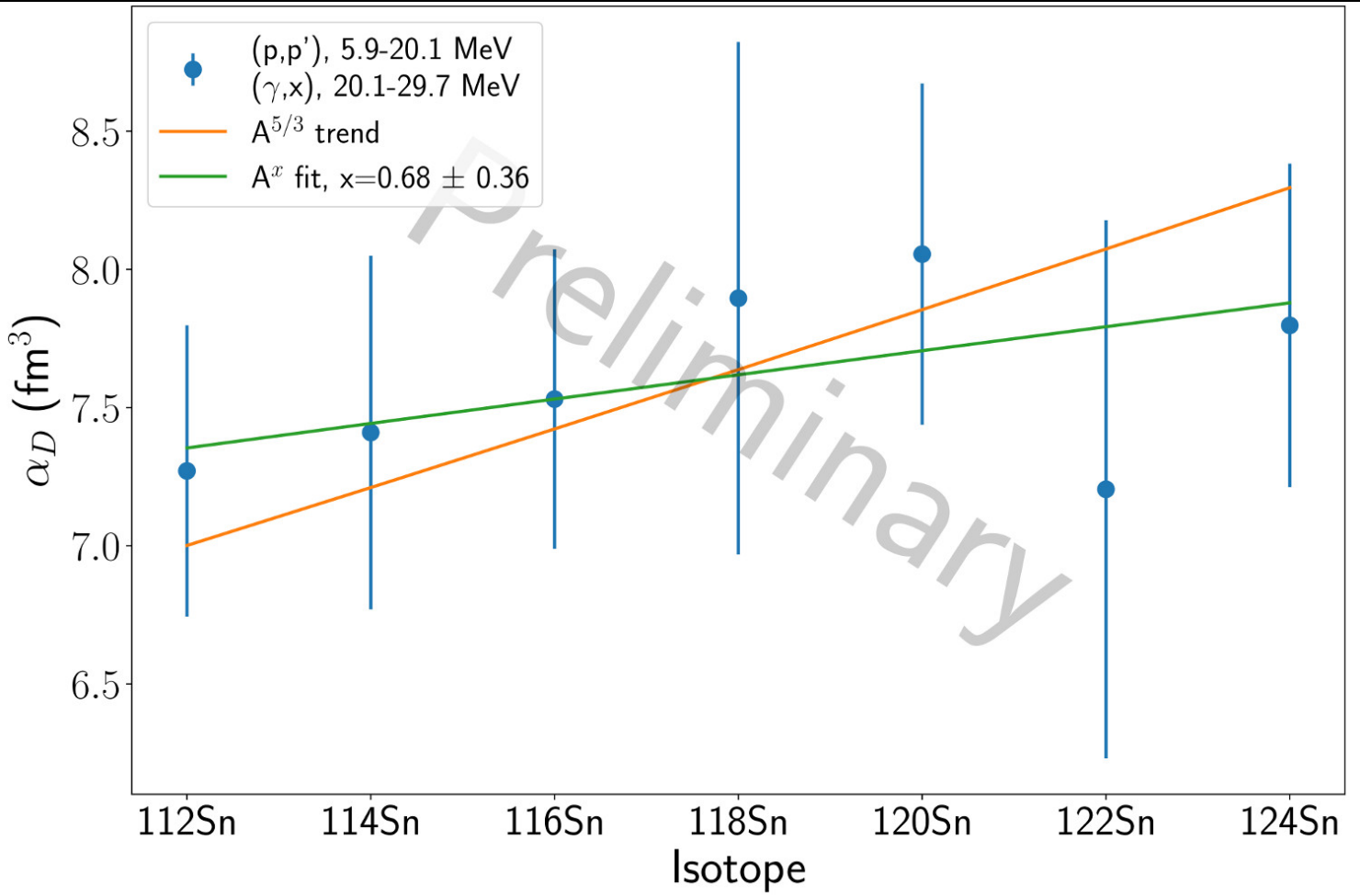
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Polarizability for the Sn isotopic chain



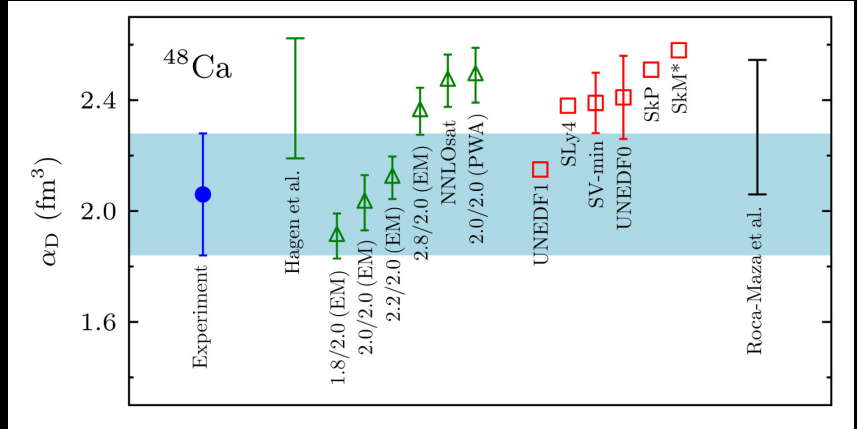
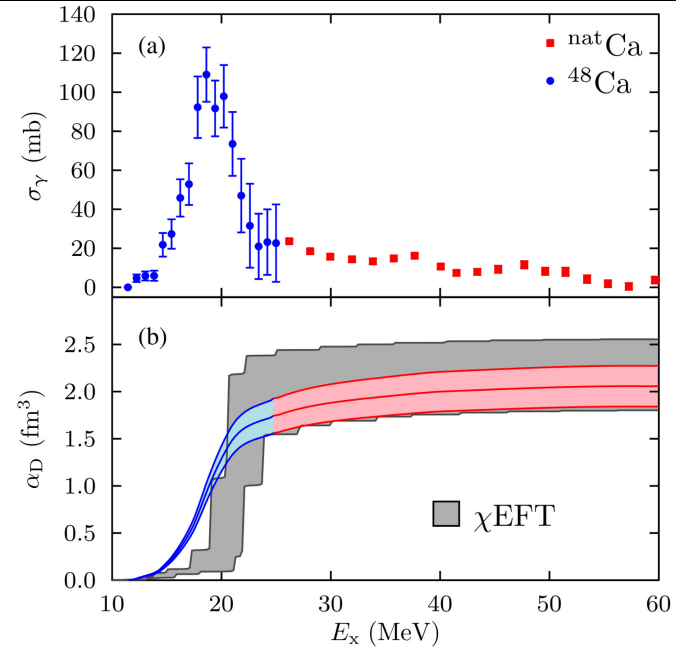
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Polarizability ^{48}Ca



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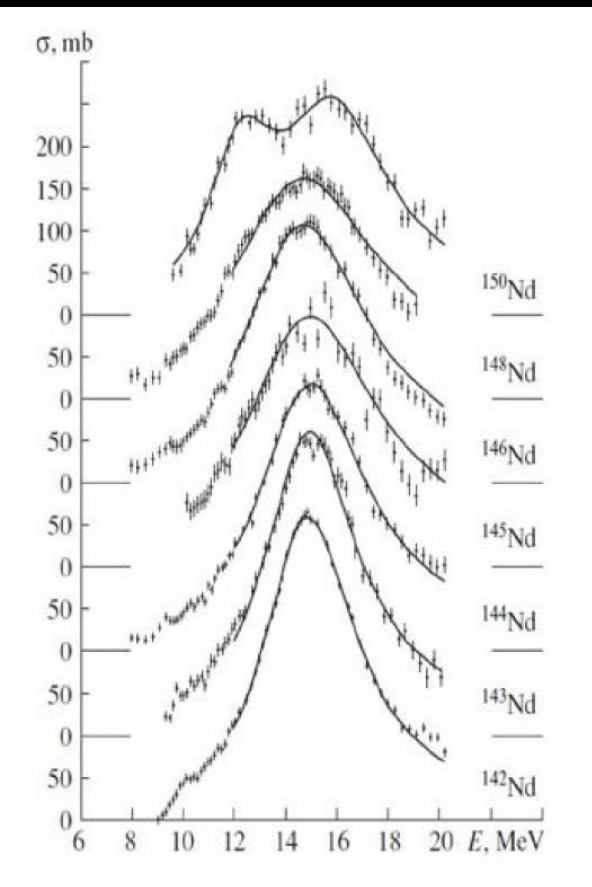


- New α_D result from RCNP for ^{40}Ca : $\alpha_D = 1.56(12)$
- Improved α_D uncertainty possible from combination with other data

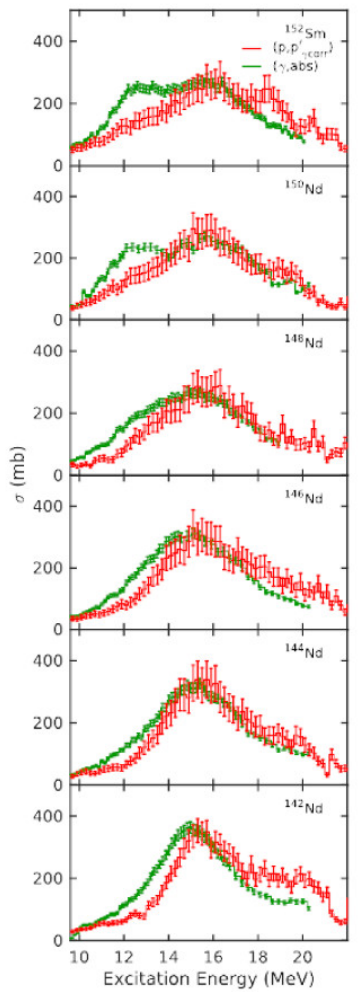
Photoabsorption for the Nd isotopic chain



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A. Bohr, B.R. Mottelson, Nuclear Structure Vol.II (Benjamin, Reading, 1975) p. 490 ff.



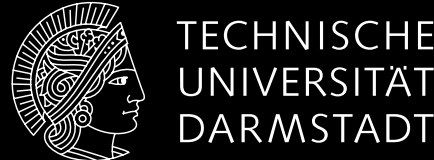
iThemba LABS:
 (p,p') at 200 MeV and 0°

Systematically reduced
 $K=0 / K=1$ ratio compared
 to Saclay data

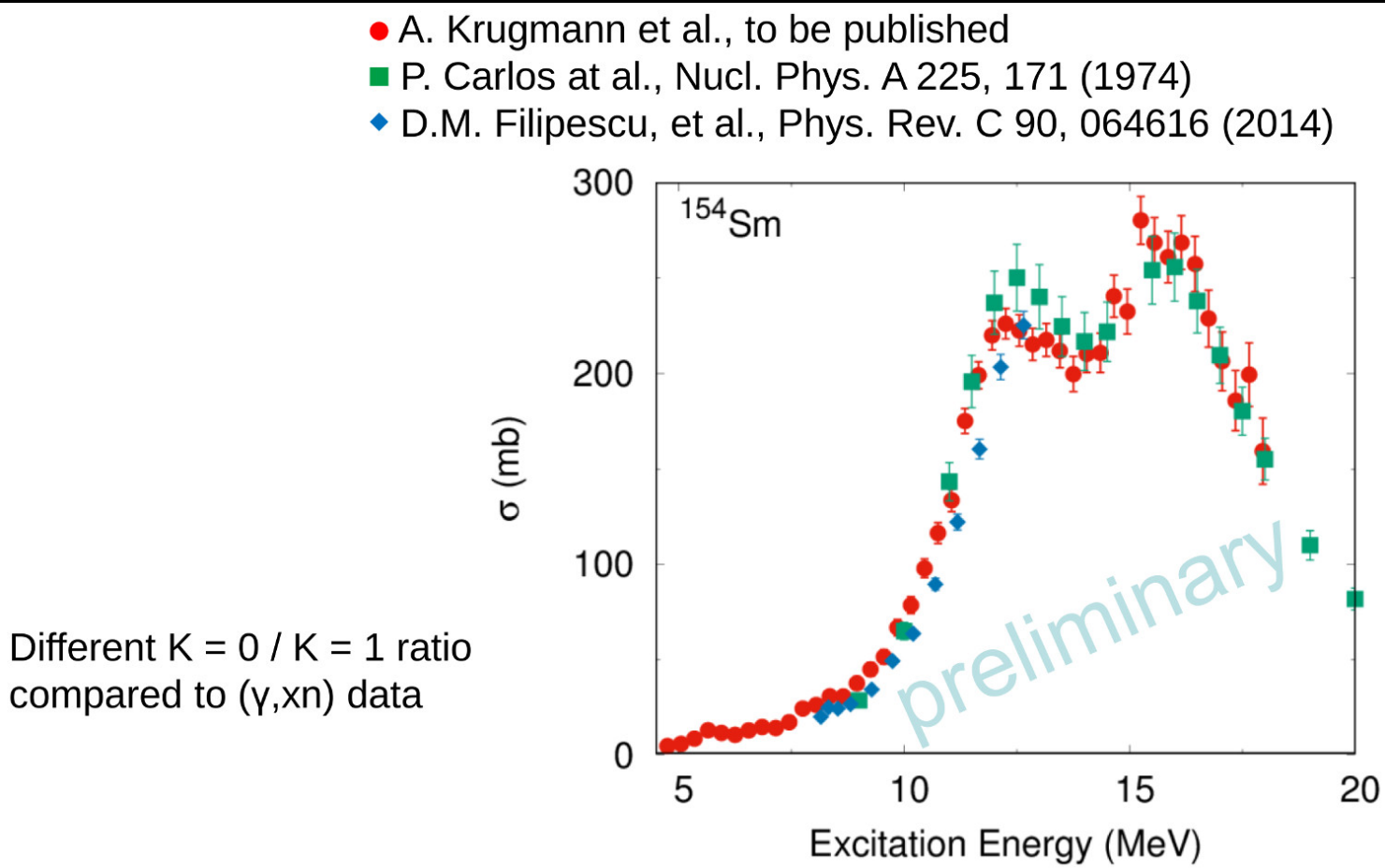
No double-hump structure in
 ^{150}Nd and ^{152}Sm !

L.M. Donaldson et al.,
 Phys. Lett. B 776, 133 (2018)

Photoabsorption ^{154}Sm



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⁴⁸Ca Data

⁴⁸Ca time

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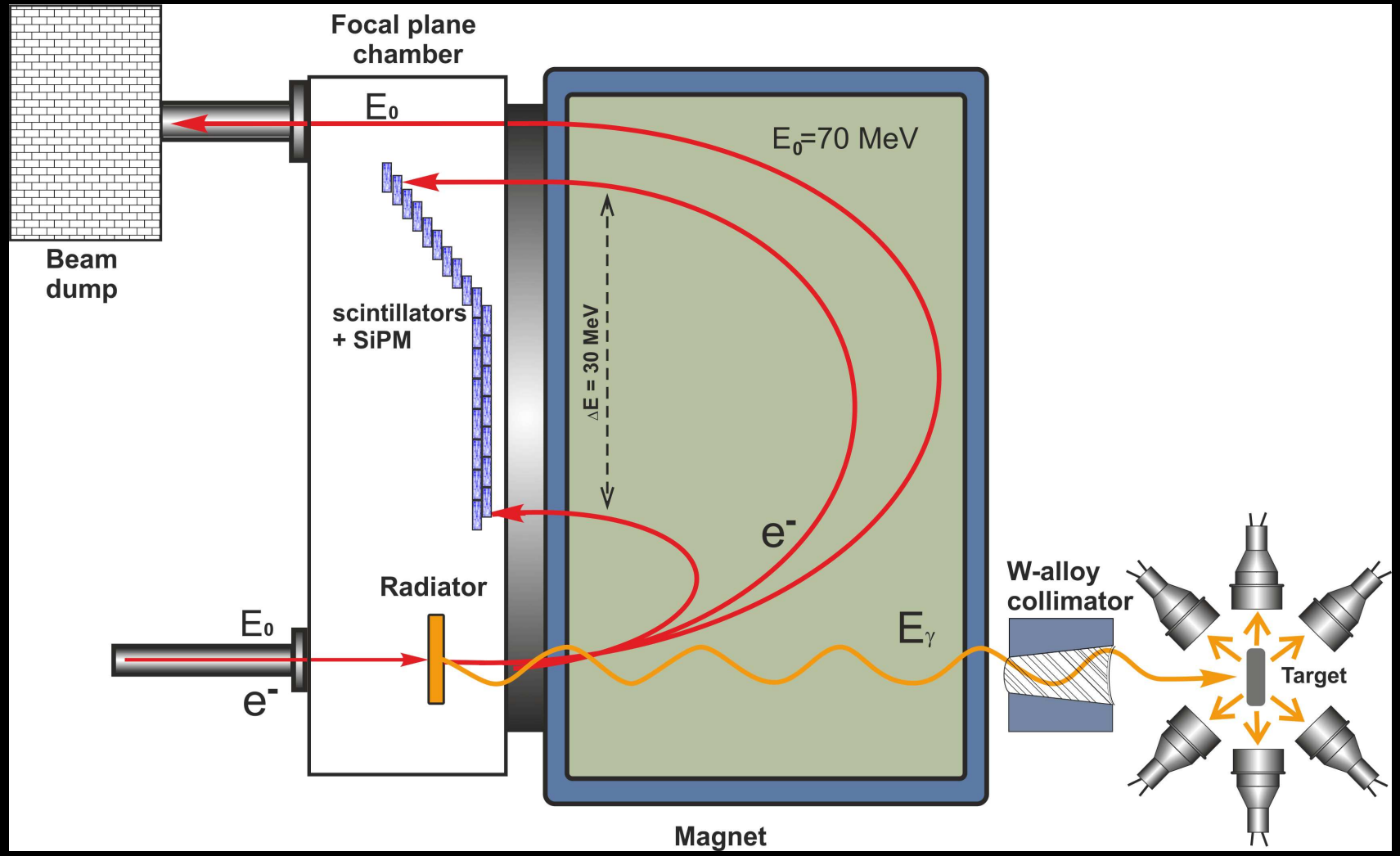
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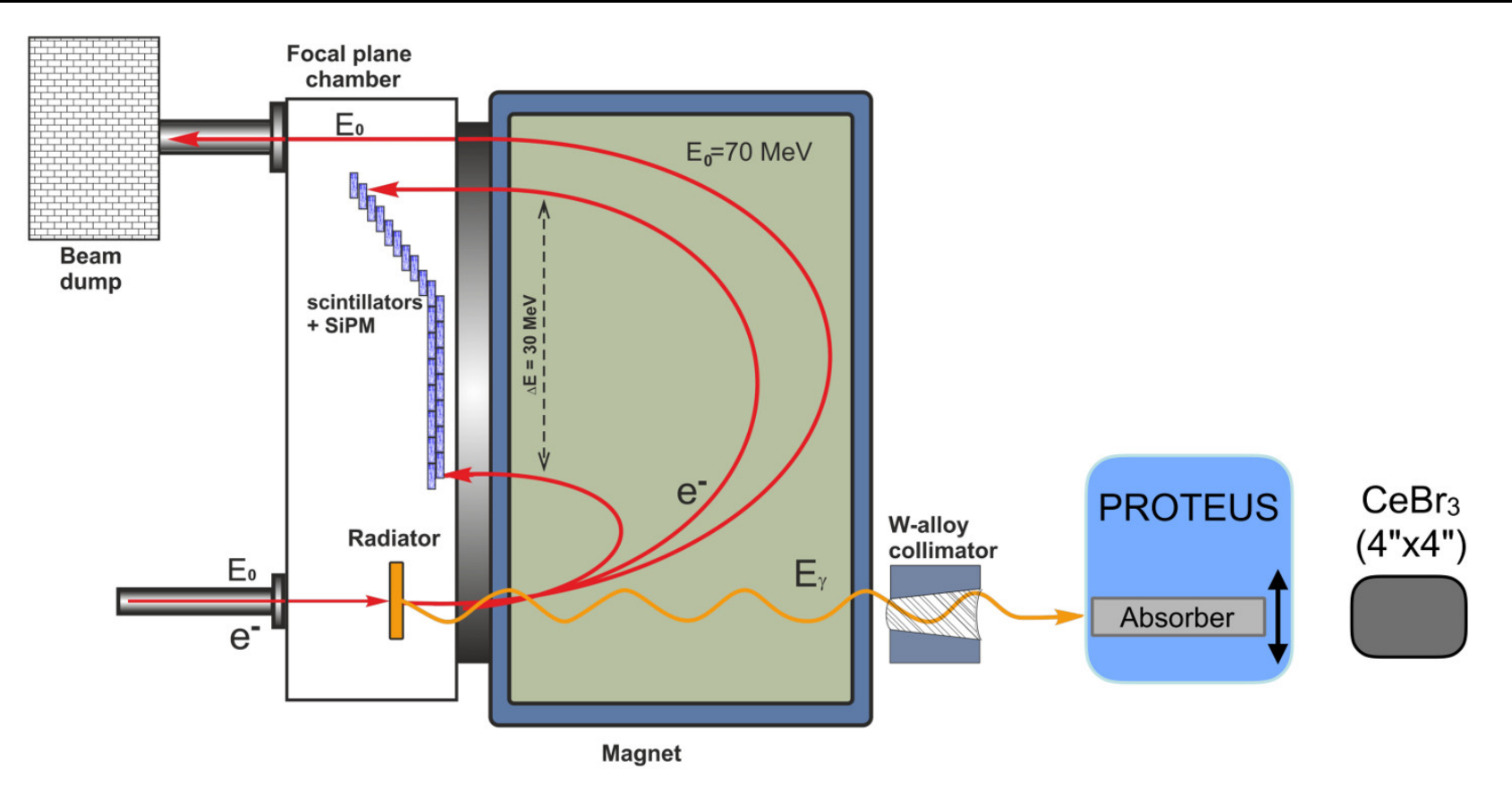


NEPTUN setup



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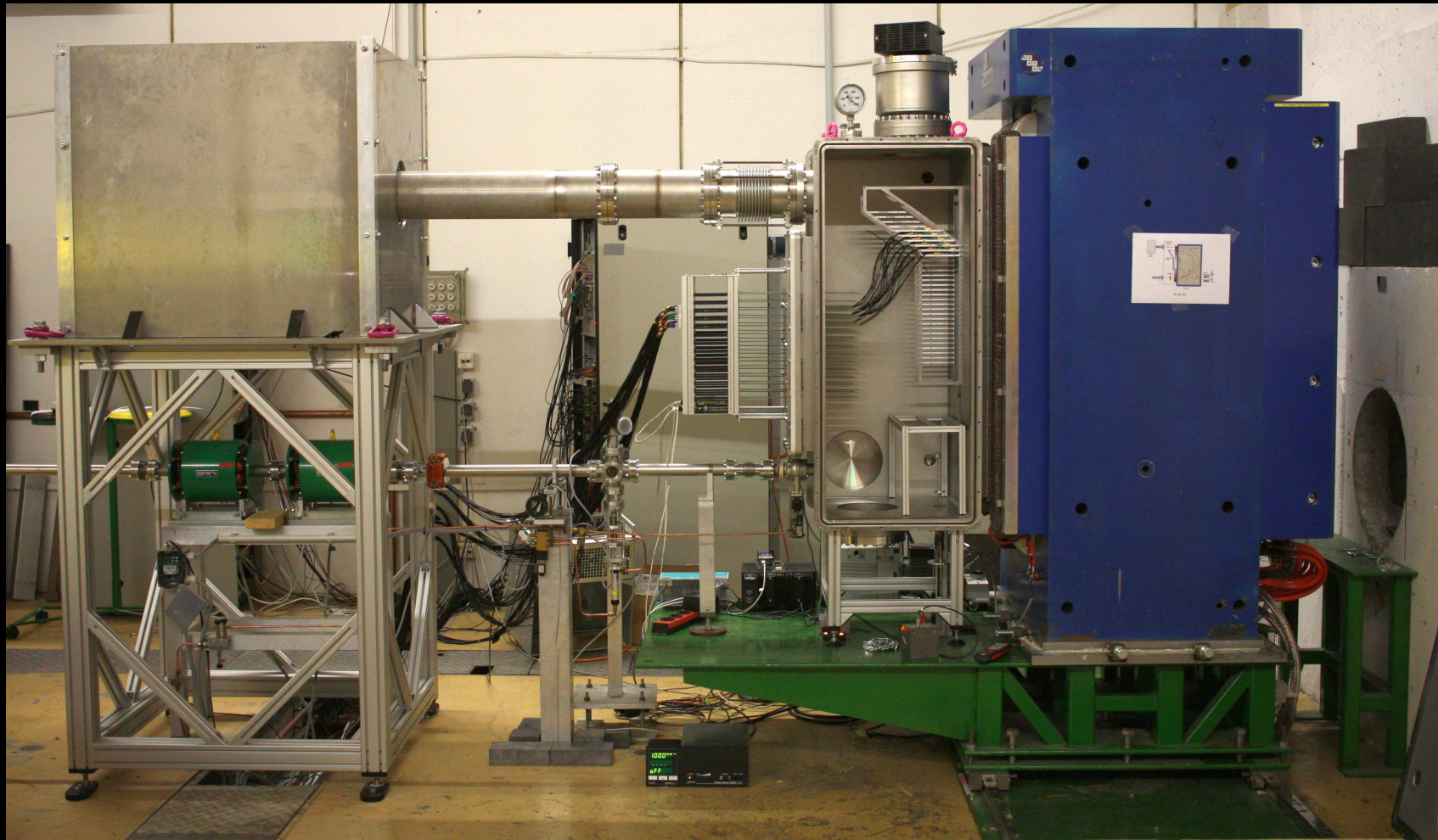
^{48}Ca time

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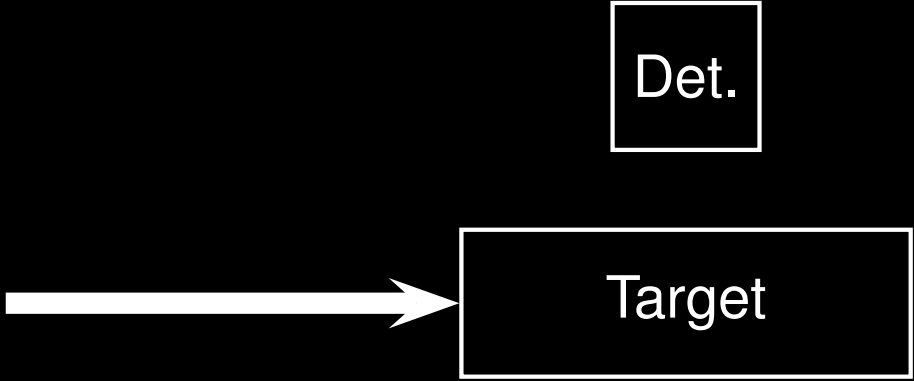
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Nuclear Photo-Absorption



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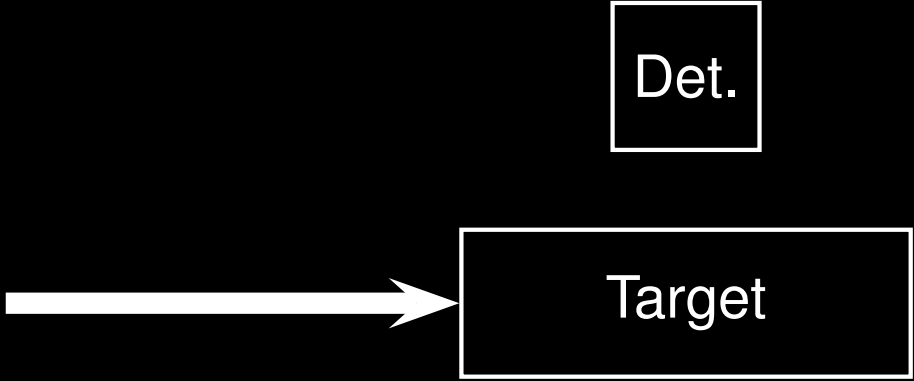


$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma}$$

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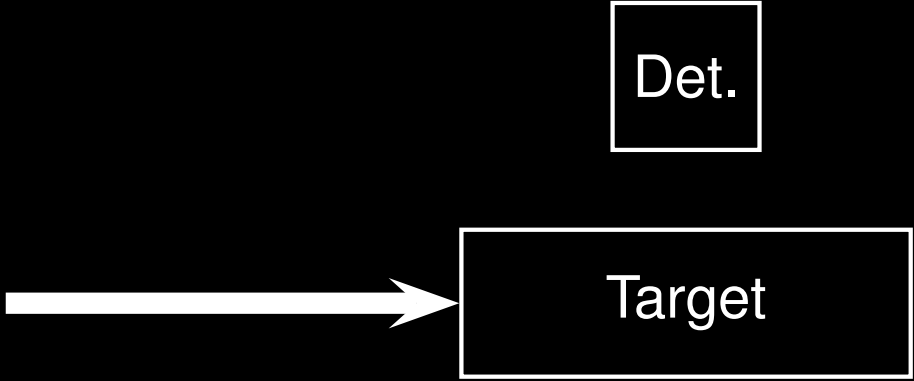


$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'}$$

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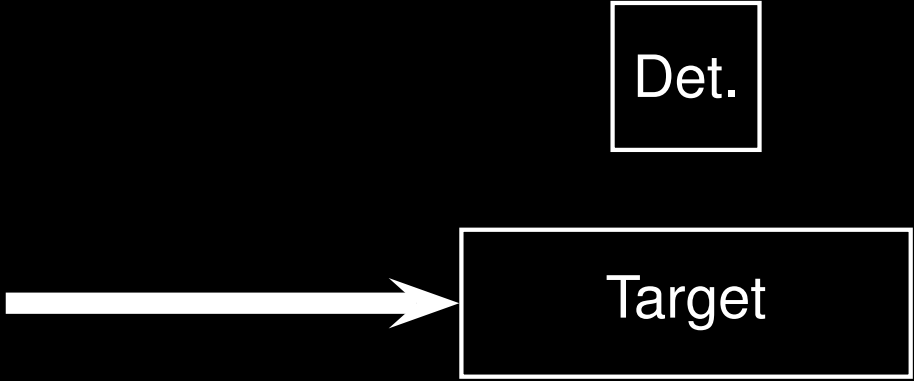


$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n}$$

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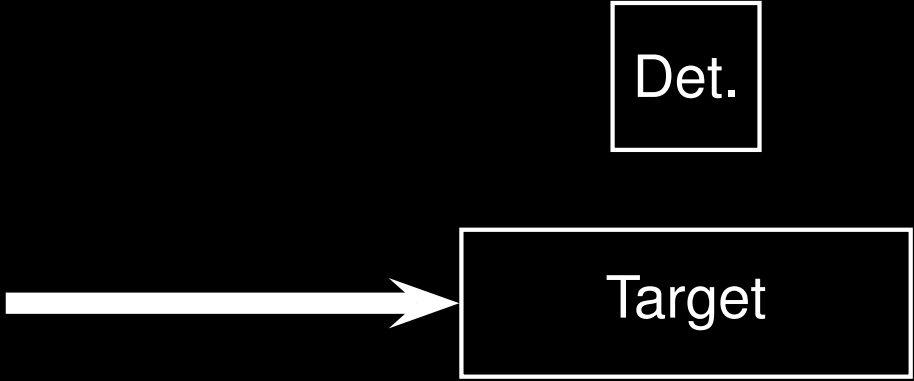


$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n} + \sigma_{\gamma,2n} + \sigma_{\gamma,xn}$$

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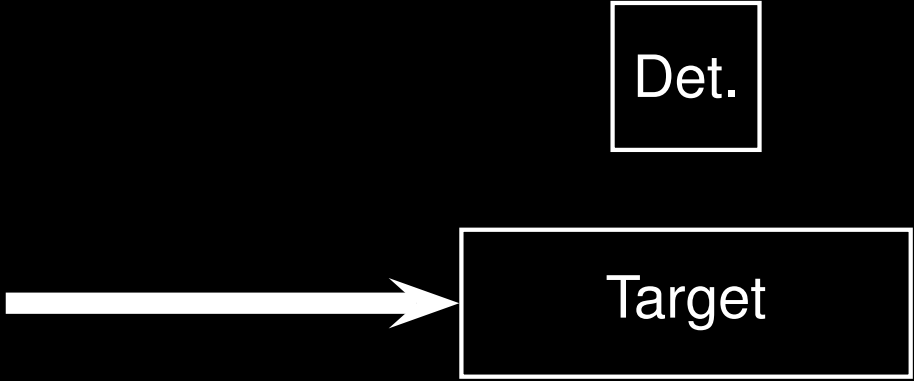


$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n} + \sigma_{\gamma,2n} + \sigma_{\gamma,xn} + \sigma_{\gamma,p}$$

Nuclear Photo-Absorption



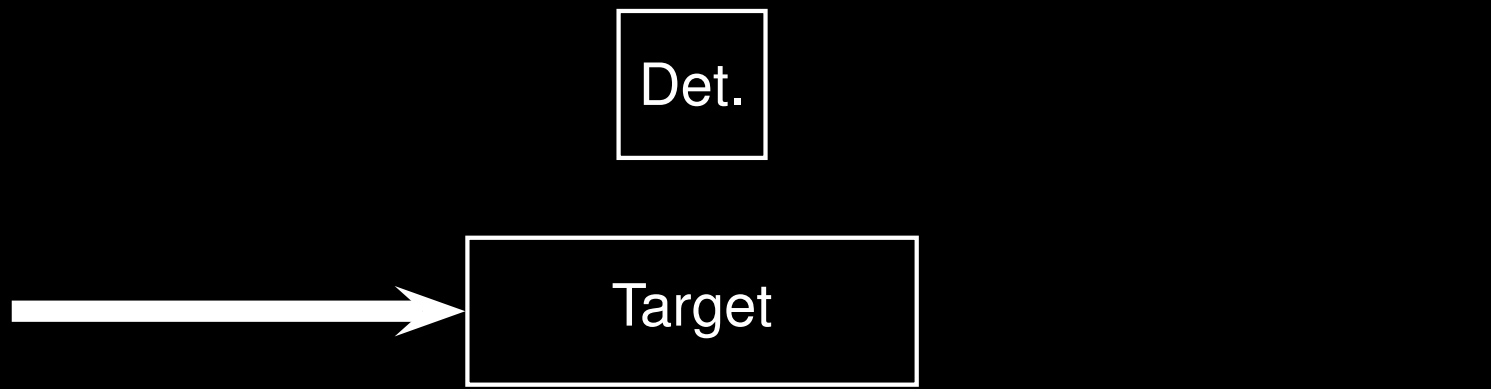
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$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n} + \sigma_{\gamma,2n} + \sigma_{\gamma,xn} + \sigma_{\gamma,p} + \sigma_{\gamma,\alpha} + \sigma_{\dots} + \dots$$

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$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n} + \sigma_{\gamma,2n} + \sigma_{\gamma,xn} + \sigma_{\gamma,p} + \sigma_{\gamma,\alpha} + \sigma_{\dots} + \dots$$

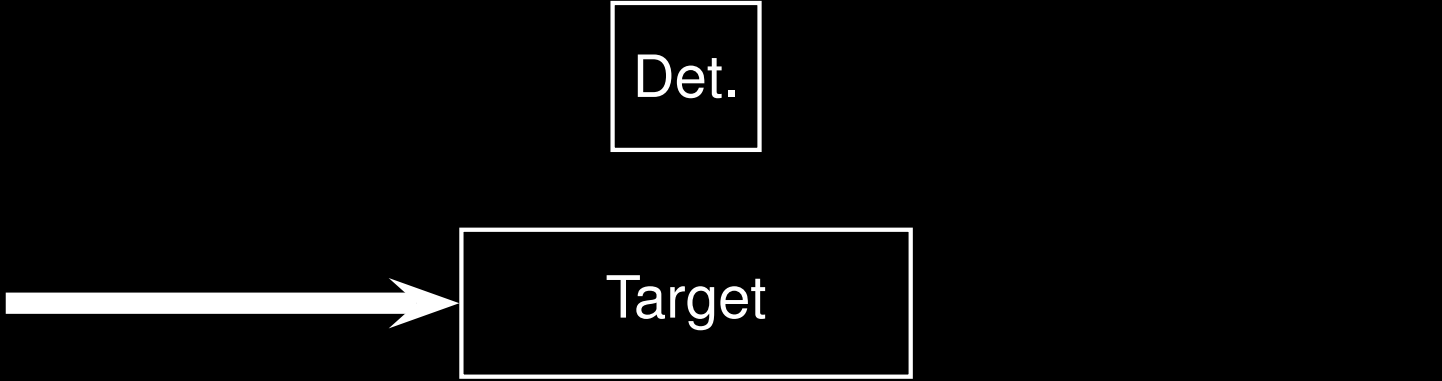


$$N = N_0 e^{-n\sigma_{tot}}$$

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$$\sigma_{\gamma,a} = \sigma_{\gamma,\gamma} + \sigma_{\gamma,\gamma'} + \sigma_{\gamma,n} + \sigma_{\gamma,2n} + \sigma_{\gamma,xn} + \sigma_{\gamma,p} + \sigma_{\gamma,\alpha} + \sigma_{\dots} + \dots$$



$$N = N_0 e^{-n\sigma_{tot}}$$

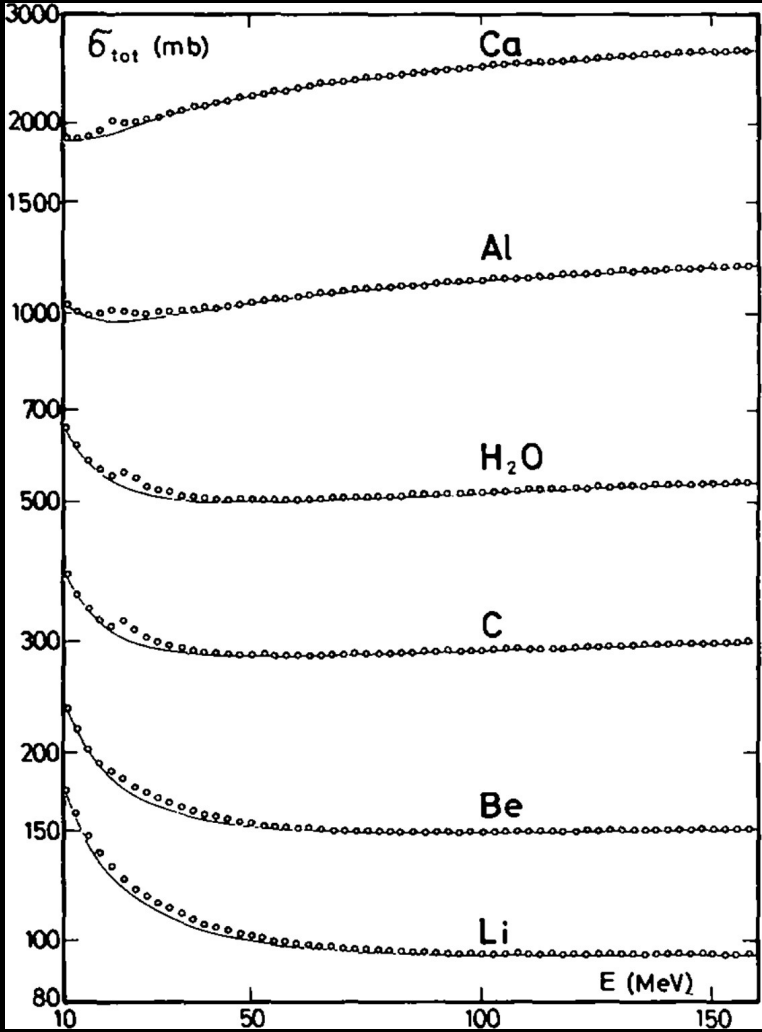
$$\sigma_{tot} = \sigma_{atomic} + \sigma_{\gamma,a}$$

$\sigma_{atomic} \sim$ several barn



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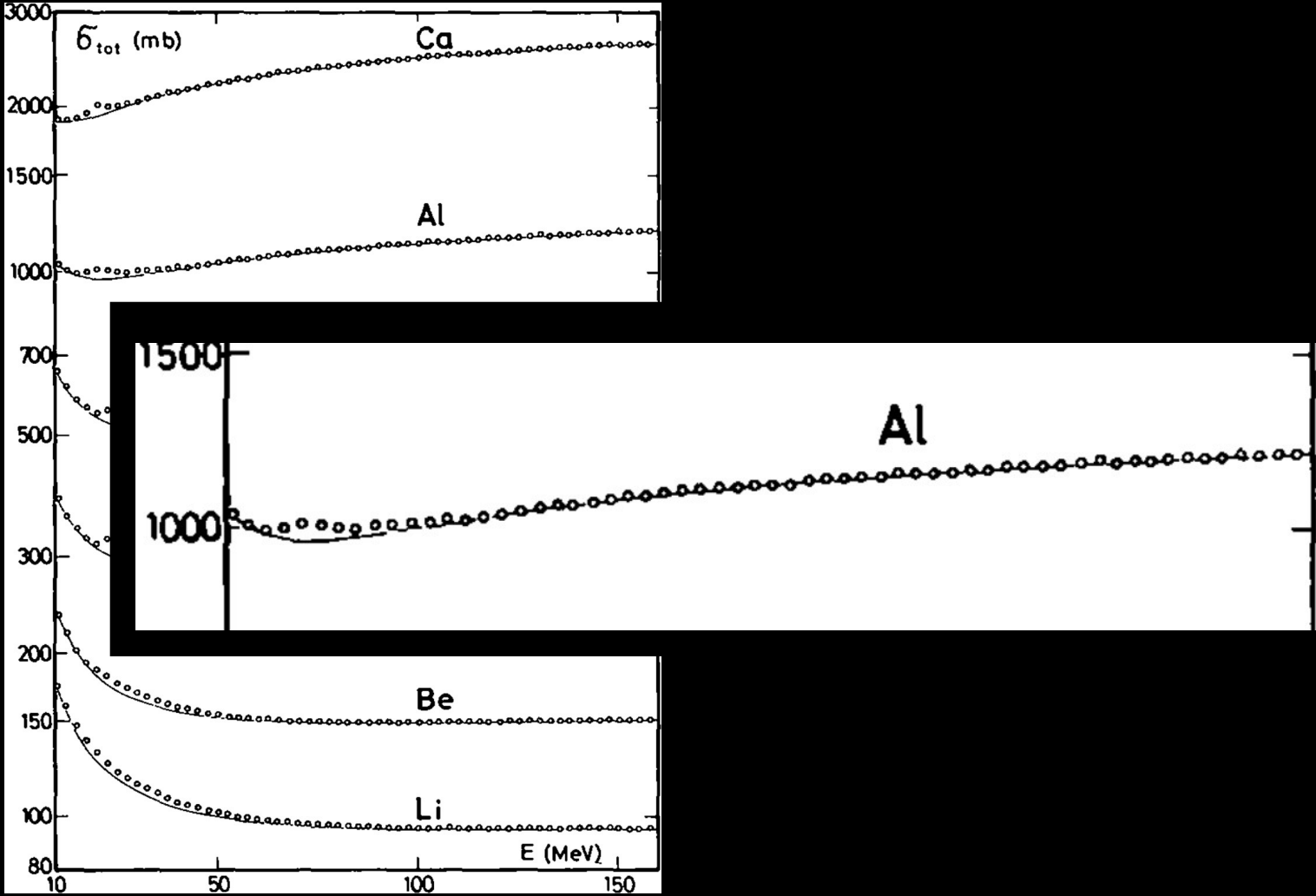
J. Ahrens et al., NPA 251, 479 (1975)





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J. Ahrens et al., NPA 251, 479 (1975)





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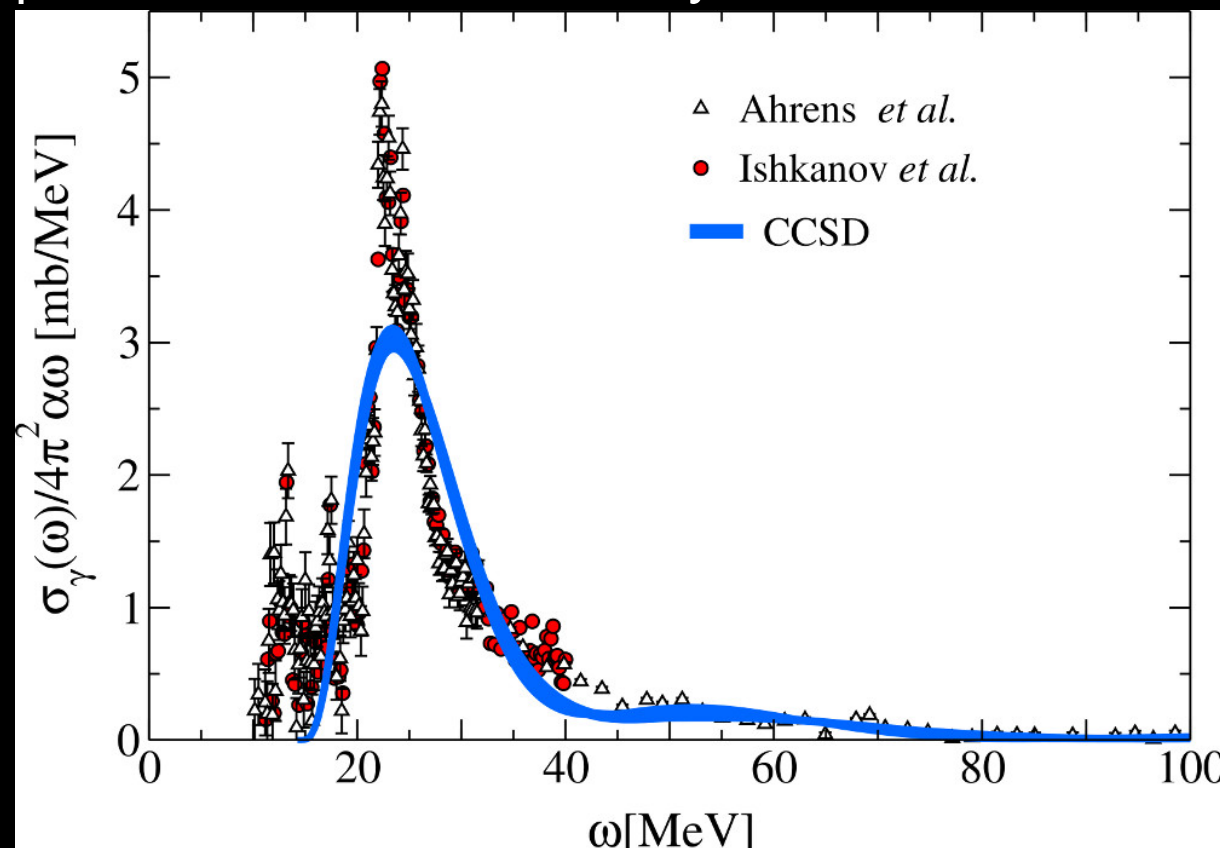
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People

- Experimental:
 - Tagged photons (NEPTUN)
 - fast high-resolution detector (CeBr)
 - fast **target changer**
 - in future: vacuum chamber
- Atomic absorption
 - calculate (currently OK up to $Z \sim 20$)
no improvements recently
 - long-term: dedicated measurement
 - start collaboration to improve calculations
(maybe interest from other communities)
 - Note: atomic absorption is smooth

- commission setup in October NEPTUN run
- production run with Al, maybe O in November



S. Bacca *et al.*, PRL 111, 122502 (2013)

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NEPTUN setup

NEPUTN setup

Nuclear Absorption

Previous work

Improvements

Status and plan

NEPTUN Rate

Absorption Al

^{48}Ca Data

^{48}Ca time

Status (2- γ decay)

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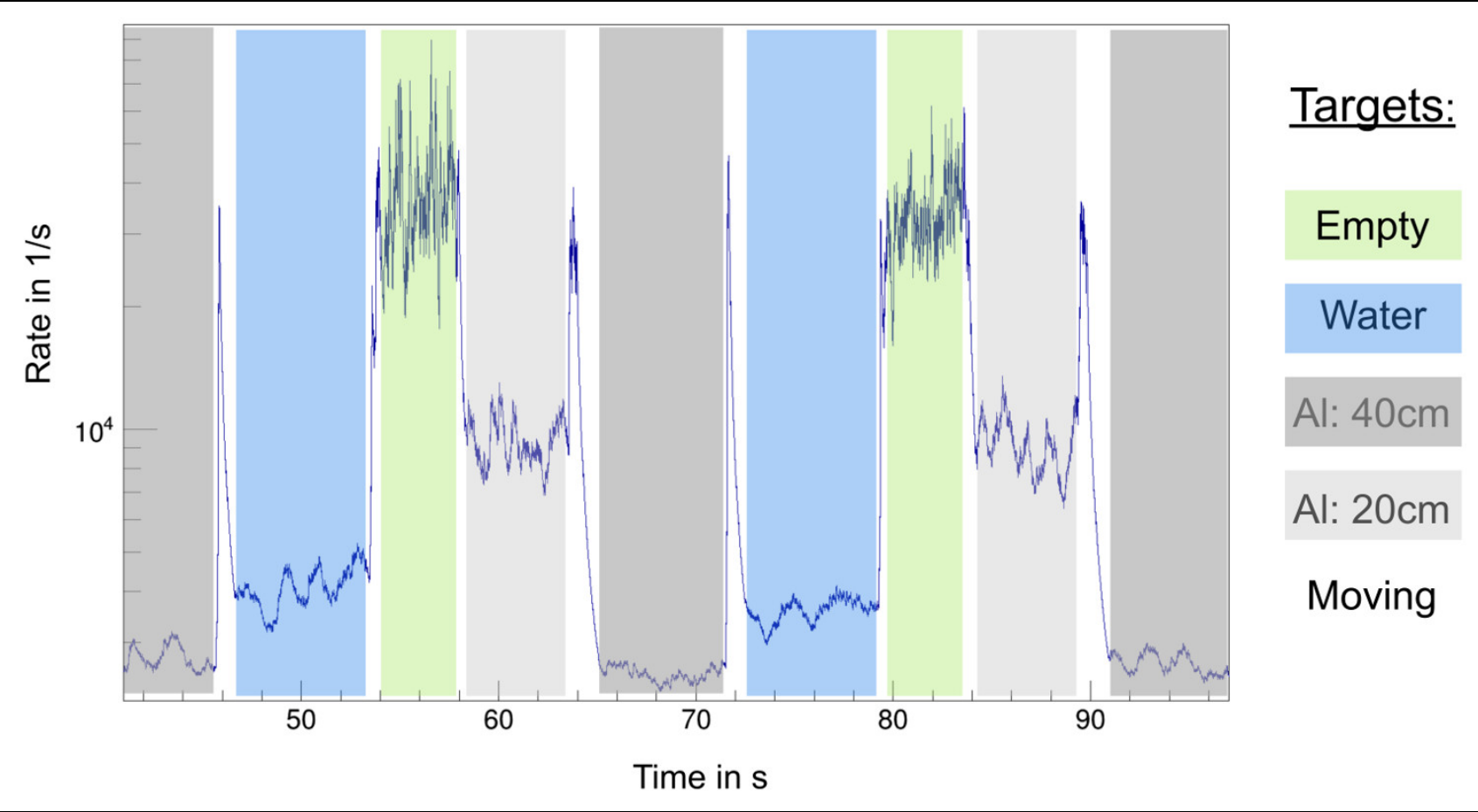
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NEPTUN: Rate with different targets

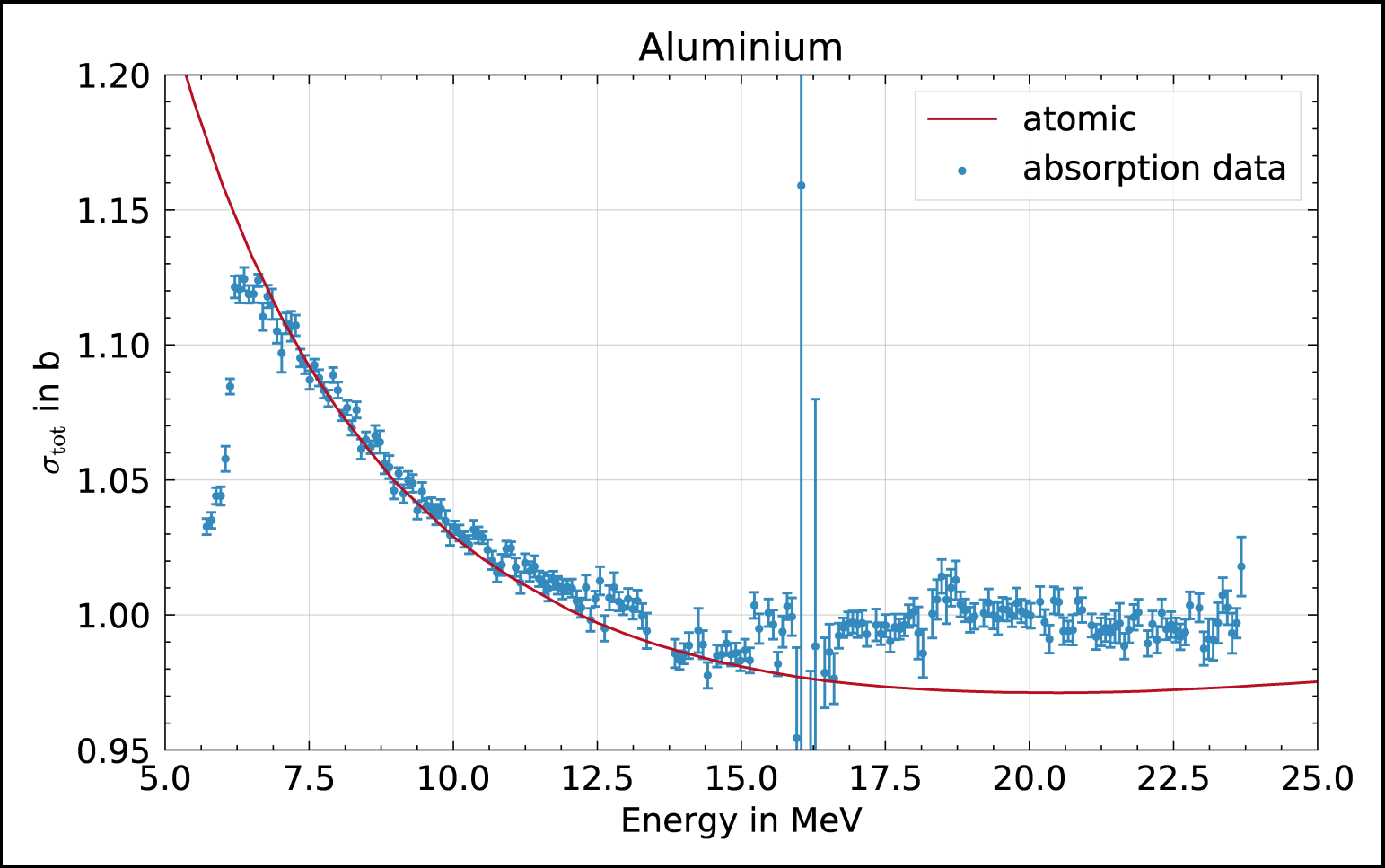


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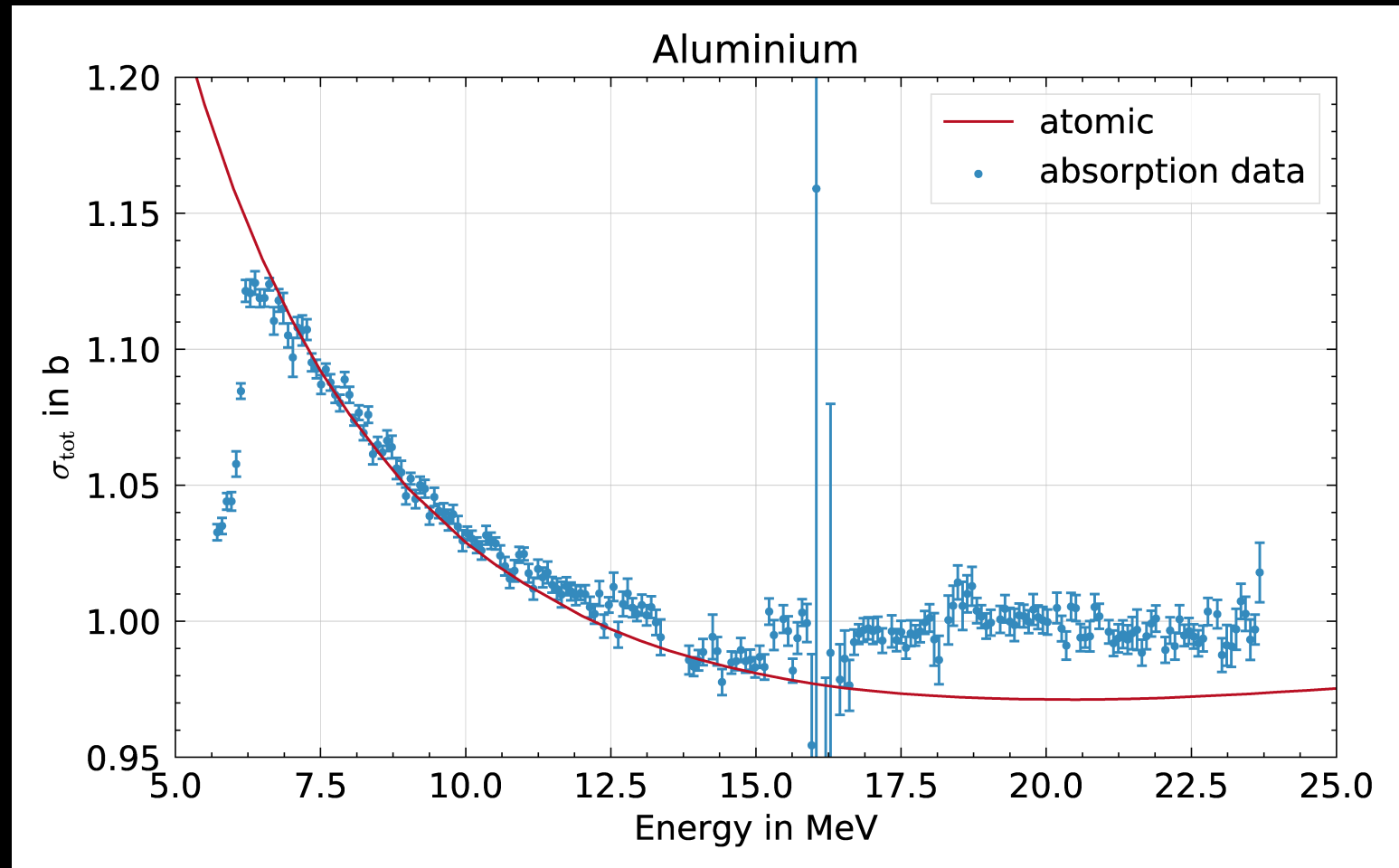


Absorption Al

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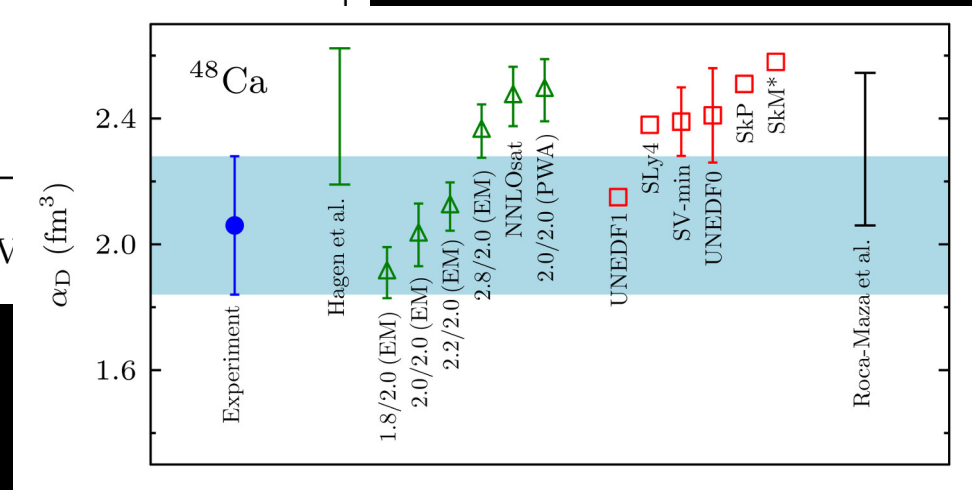
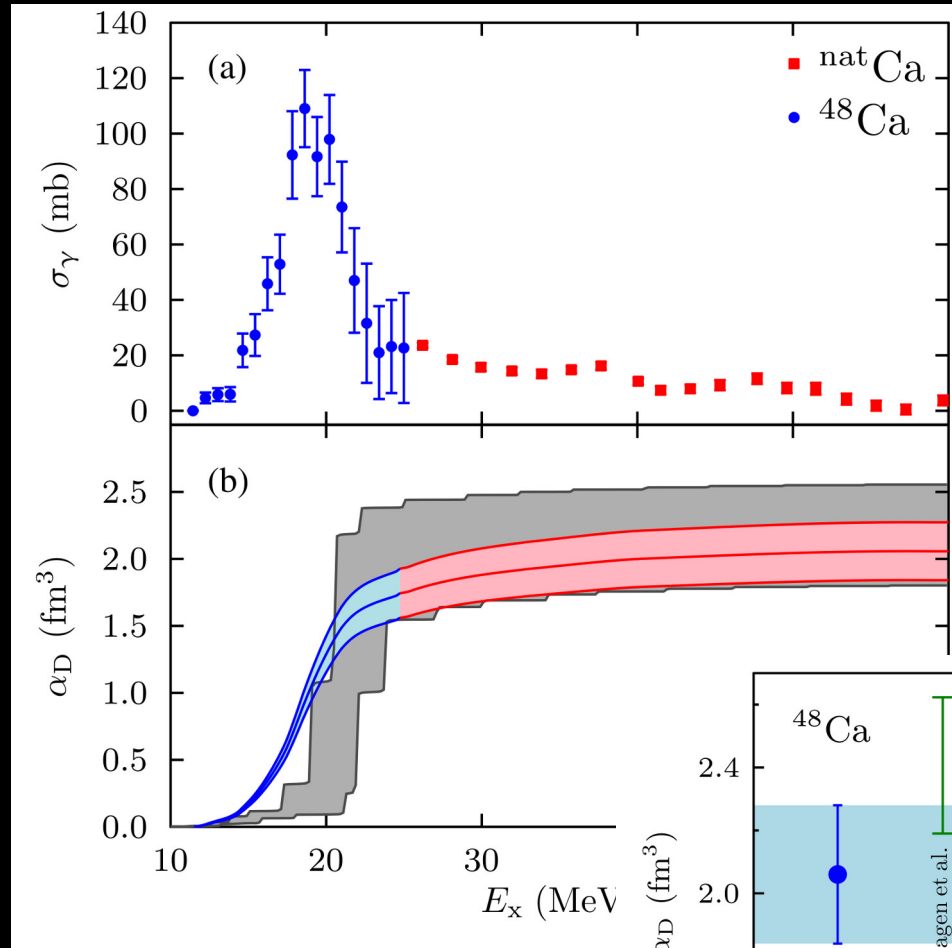


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- uncertainty: $\sigma \sim 10$ mb (x-axis shifted)
- data taking: 1 hour!

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^{48}Ca Measurement Time



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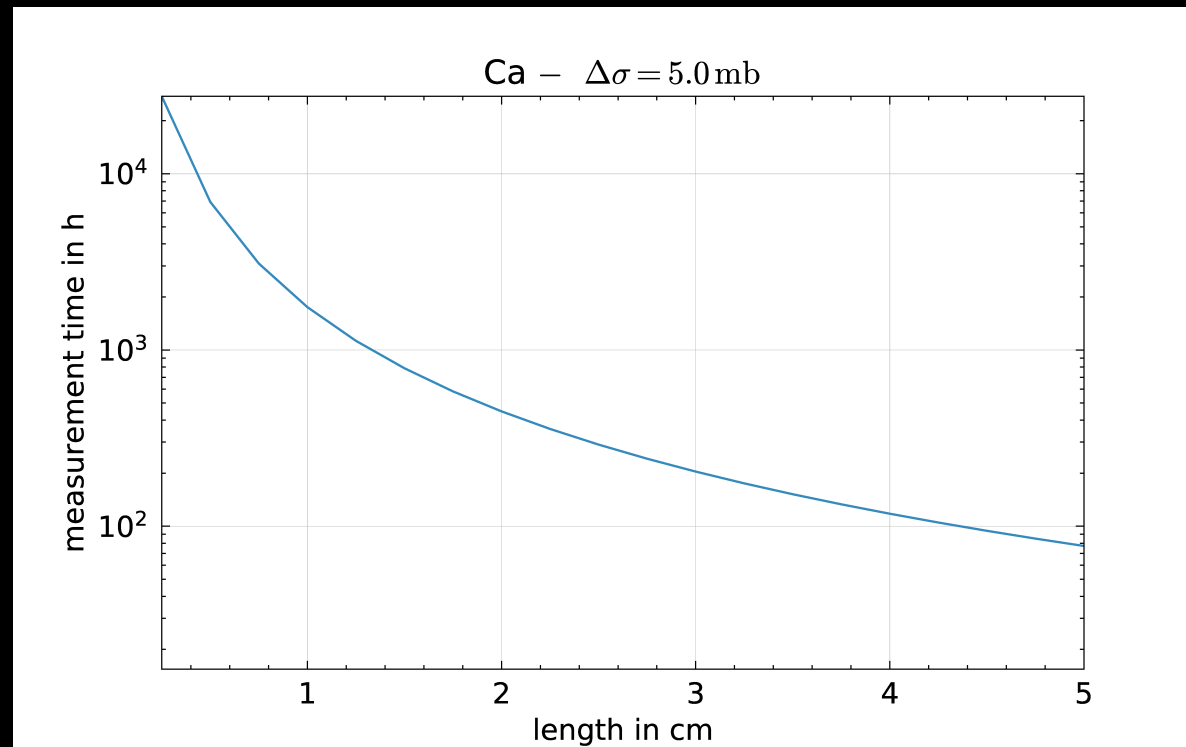
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- ^{90}Zr data being analyzed (Michael Beckstein)
- installation of BACCHUS (anti-compton Pb-shield) complete
- data taking ^{137}Ba starting soon





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- Sonia Bacca (Mainz) will join as PI
- aim: systematic understanding of the electric dipole response in nuclei
- relativistic Coulomb excitation and nuclear photon scattering and absorption
- experimental polarizability of nuclei with ± 1 or 2 particles relative to the doubly magic nuclei
- (p, p') : ^{40}Ca : ^{39}K , ^{42}Ca ^{56}Ni : ^{54}Fe , ^{58}Ni
 ^{90}Zr : ^{88}Sr , ^{89}Y , ^{92}Mo , ^{91}Zr , ^{92}Zr
- photoabsorption: ^{16}O , ^{39}K , $^{40,48}\text{Ca}$
- extend photoabsorption towards Sn: $^{112,116,120,124}\text{Sn}$, ^{150}Nd
- build TPC to measure pair production cross section



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- Highlight

- T. Aumann, C. A. Bertulani, F. Schindler, and S. Typel,
Peeling Off Neutron Skins from Neutron-Rich Nuclei: Constraints on the Symmetry Energy from Neutron-Removal Cross Sections,
Phys. Rev. Lett. 119, 262501 (2017).
- J. Birkhan et al.,
Electric Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin,
Phys. Rev. Lett. 118, 252501 (2017).
- D. Martin et al.,
Test of the Brink-Axel Hypothesis for the Pygmy Dipole Resonance,
Phys. Rev. Lett. 119, 182503 (2017).
- Two papers with explicit collaboration with A04 (1 PRL, 1 PRC)



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- Highlight

- T. Aumann, C. A. Bertulani, F. Schindler, and S. Typel, Peeling Off Neutron Skins from Neutron-Rich Nuclei: Constraints on the Symmetry Energy from Neutron-Removal Cross Sections, Phys. Rev. Lett. 119, 262501 (2017).
- J. Birkhan et al., Electric Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin, Phys. Rev. Lett. 118, 252501 (2017).
- D. Martin et al., Test of the Brink-Axel Hypothesis for the Pygmy Dipole Resonance, Phys. Rev. Lett. 119, 182503 (2017).

- Two papers with explicit collaboration with A04 (1 PRL, 1 PRC)
- collaborations with other projects: CAGRA Campaign (2016) at RCNP
- workshops (co-)organized: COMEX 6, South Africa (2018)
- major successes of young researchers
Sergej Bassauer, SFB 1245 Travel Prize (2017)



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- PI: PvNC, HS
- PostDoc: Dima Symochko
- Doctoral Students: Sergej Bassauer, Patrick van Beek
- MSc: Martin Baumann, Michael Beckstein, Andreas Ebert, Gerhart Steinhilber
- BSc: Maximilian Spall, Alexander Fuchs, Yevhen Kozymka



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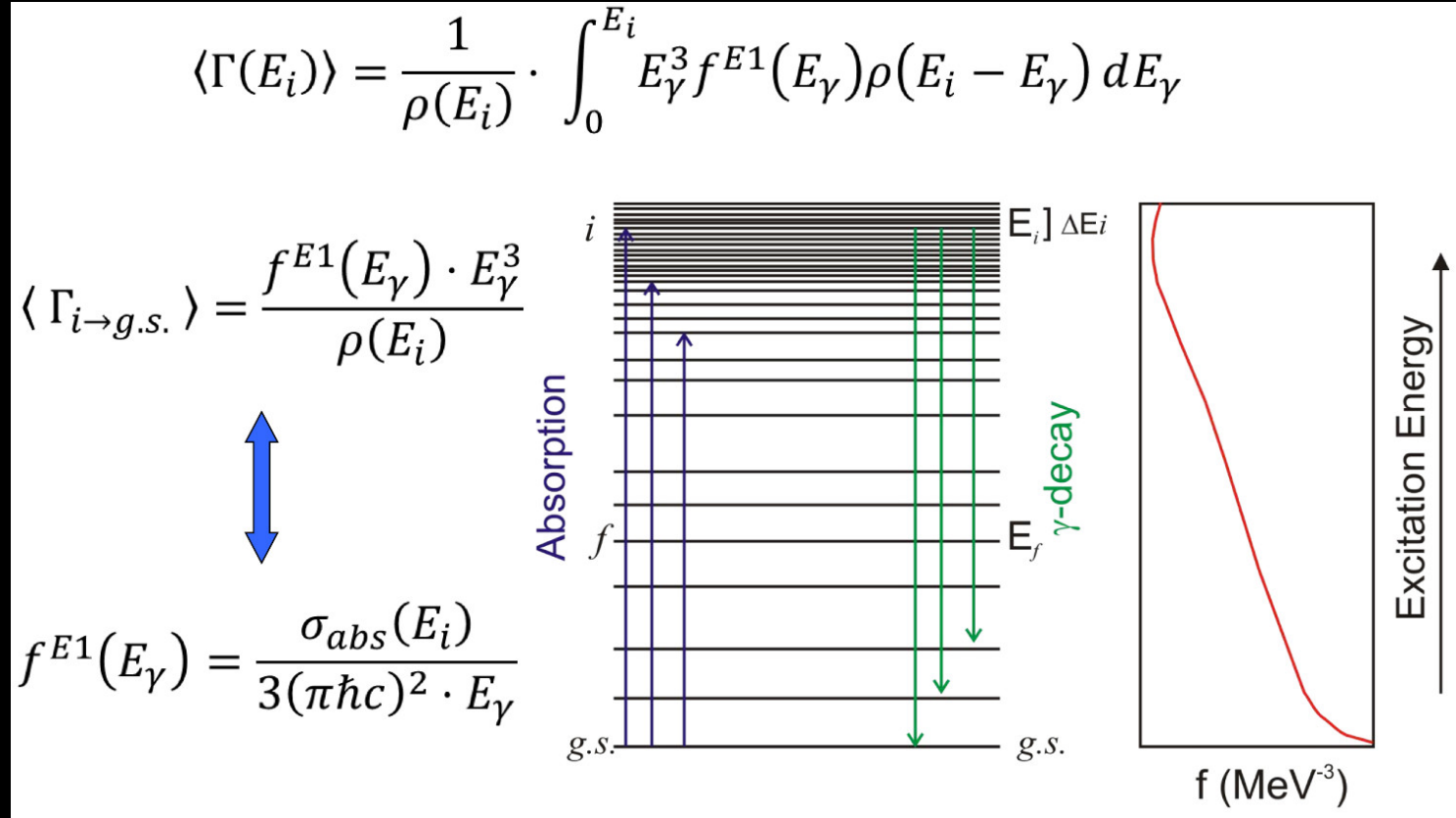
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The End

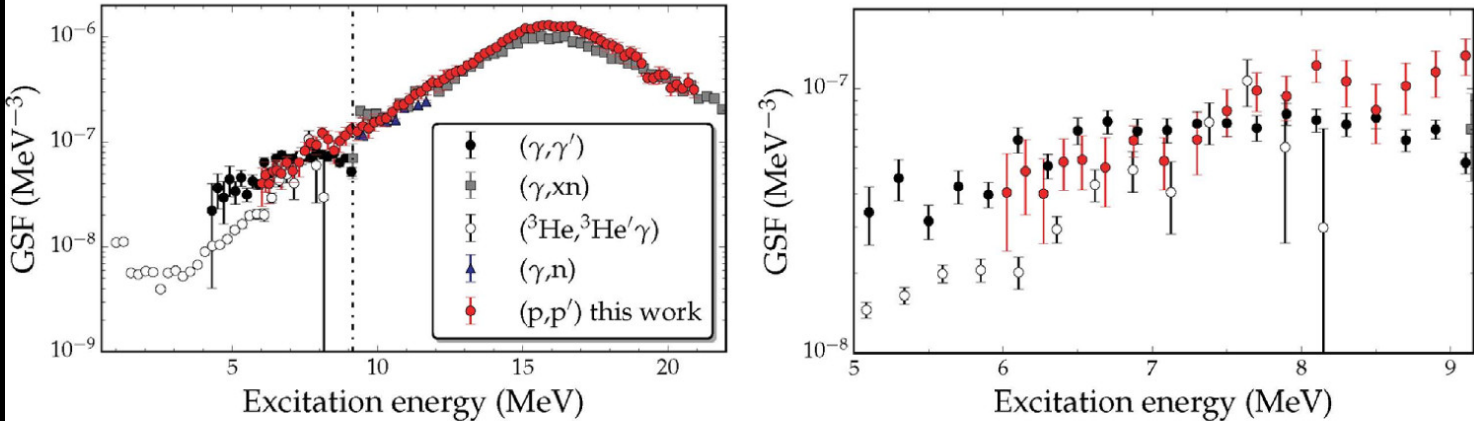
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(p,p'): D. Martin et al., Phys. Rev. Lett. 119, 182503 (2017)
($^3\text{He}, ^3\text{He}'\gamma$): A.C. Larsen, S. Goriely, Phys. Rev. C 82, 014318 (2010)
(γ, γ'): G. Rusev et al., Phys. Rev. C 79, 061302 (2009)



■ Compatible with Oslo results in the PDR region

LD 96Mo



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