Systematic investigation of *E1* strength below S_n in the tin isotopic chain using the (d,pγ) reaction

Markus Müllenmeister, Michael Weinert,
Florian Kluwig, Miriam Müscher,
and Andreas Zilges

Institute for Nuclear Physics – University of Cologne

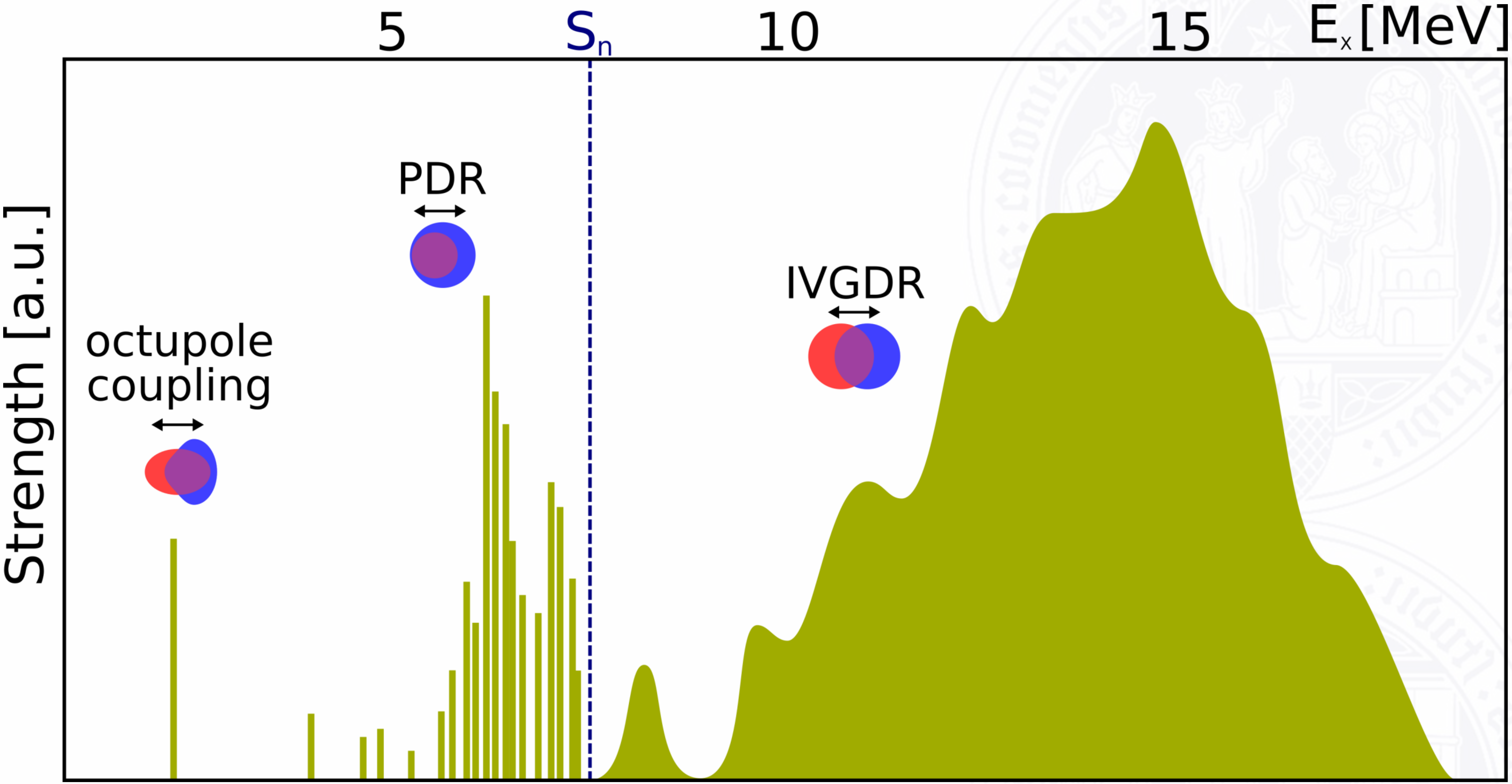
COMEX 7

Catania, June 2023

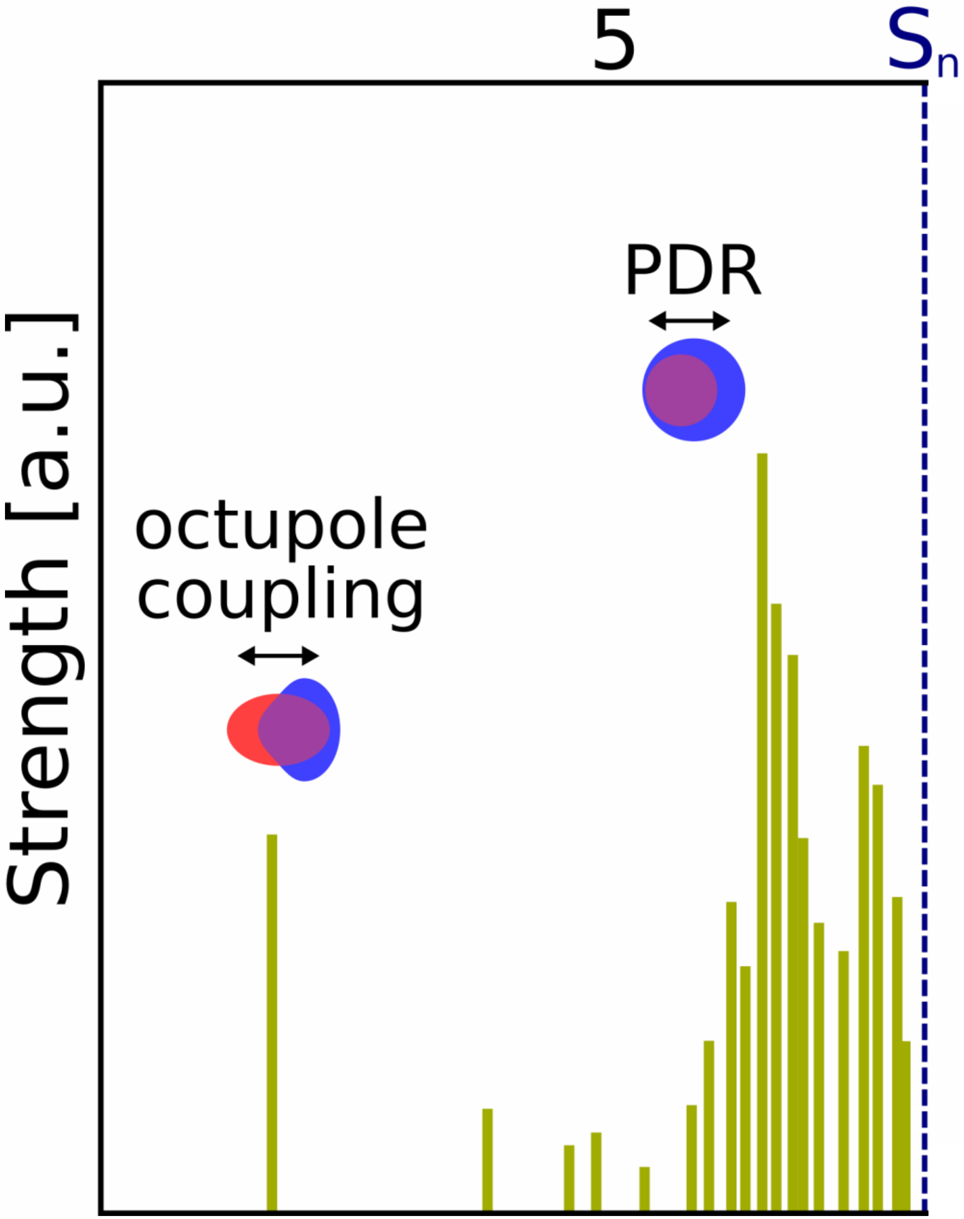
Supported by the DFG (ZI 510/10-1)

mmuellenmeister@ikp.uni-koeln.de

E1 strength below S_n

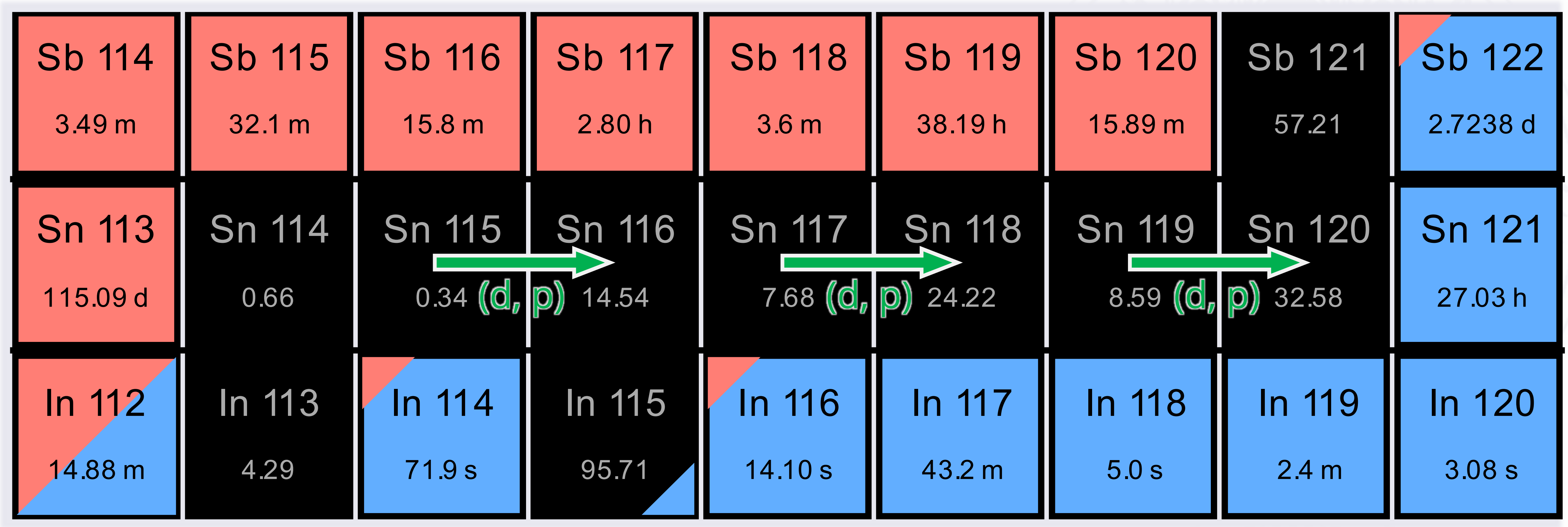


E1 strength below S_n



- Pygmy Dipole Response
- Common explanation:
  Neutron skin oscillation
- Here: probe 1 particle - 1 hole states

Motivation – Tin isotopic chain

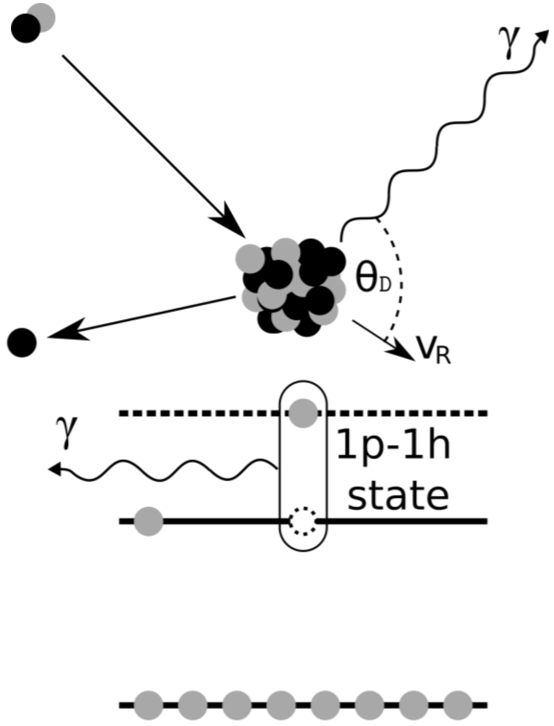


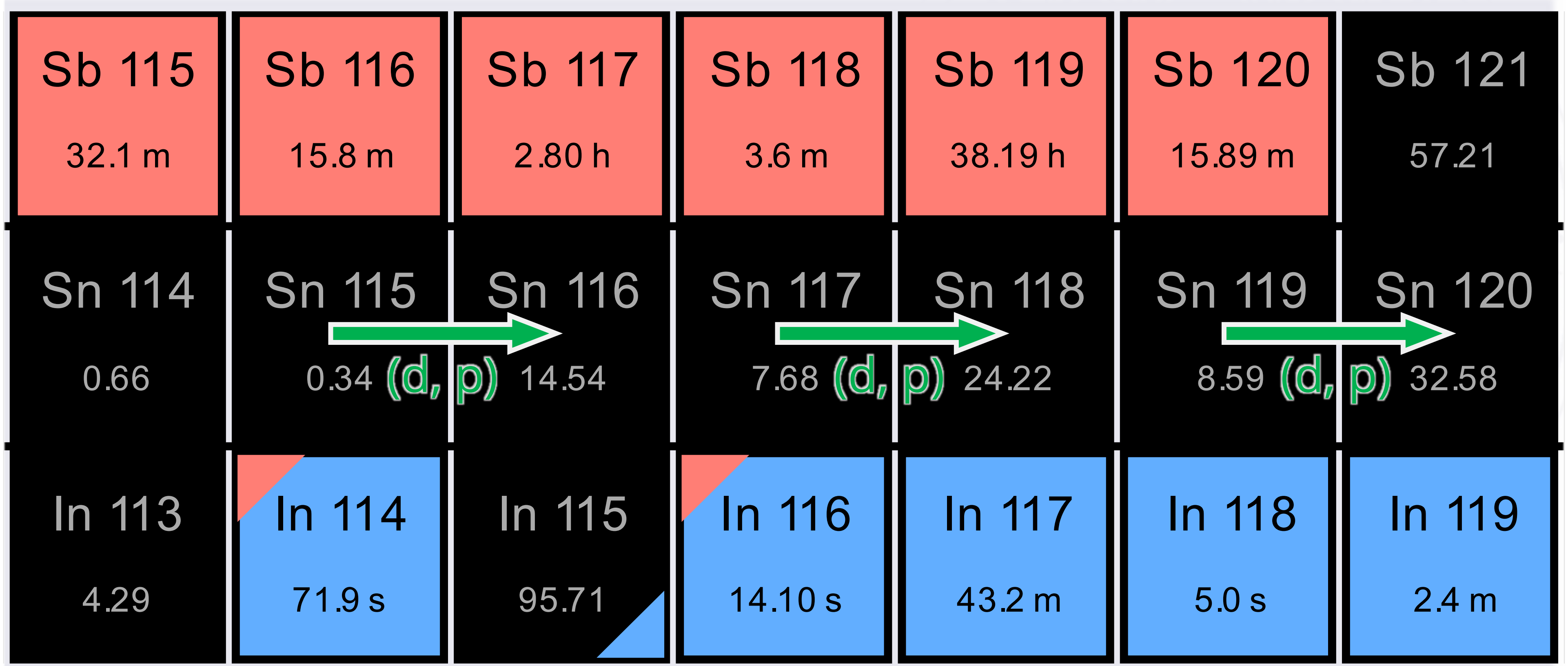
Sb 114 3.49 m	Sb 115 32.1 m	Sb 116 15.8 m	Sb 117 2.80 h	Sb 118 3.6 m	Sb 119 38.19 h	Sb 120 15.89 m	Sb 121 57.21	Sb 122 2.7238 d
Sn 113 115.09 d	Sn 114 0.66	Sn 115 0.34	Sn 116 14.54	Sn 117 7.68	Sn 118 24.22	Sn 119 8.59	Sn 120 32.58	Sn 121 27.03 h
In 112 14.88 m	In 113 4.29	In 114 71.9 s	In 115 95.71	In 116 14.10 s	In 117 43.2 m	In 118 5.0 s	In 119 2.4 m	In 120 3.08 s

For even-even nuclei:

- Tin has three candidates for (d,pγ)
- All three isotopes have the same g.s. spin
  - ν: $(3s_{1/2})^1$

Motivation – Tin isotopic chain





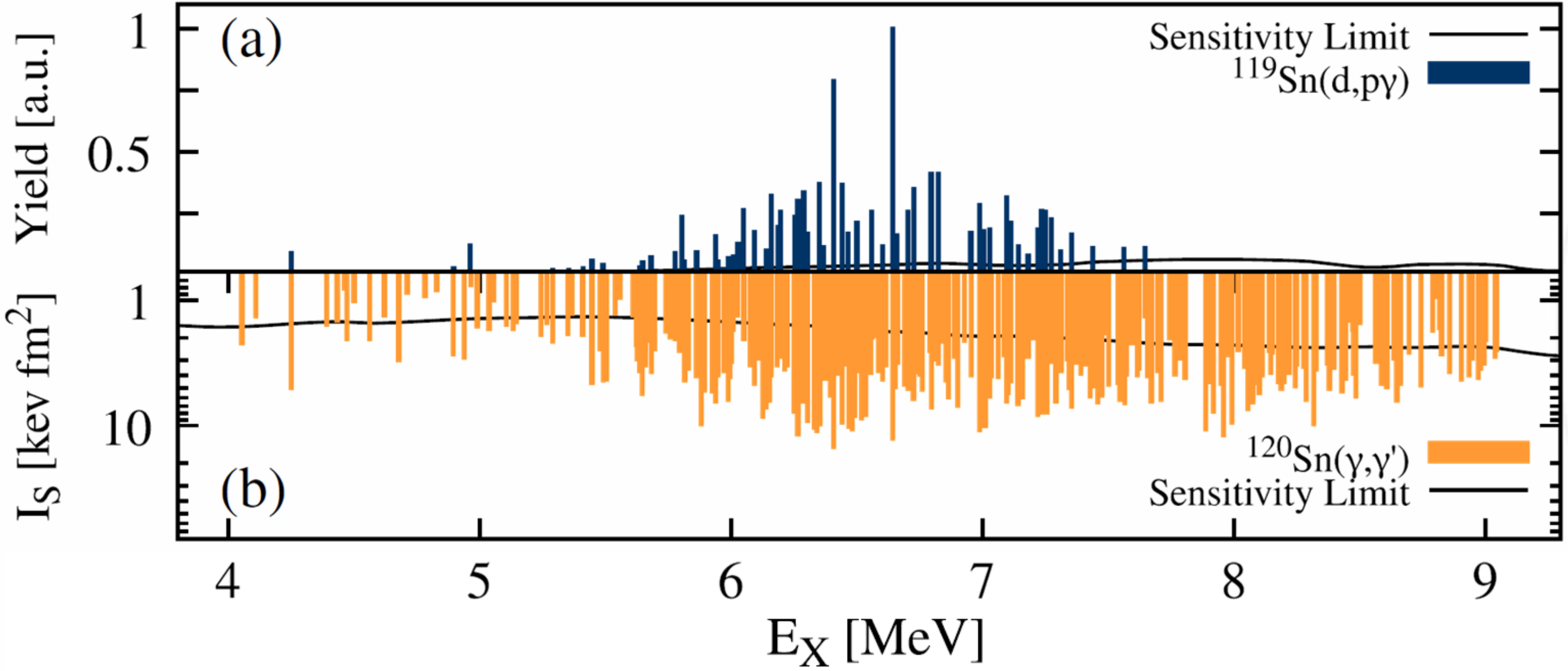
Sb 115 32.1 m	Sb 116 15.8 m	Sb 117 2.80 h	Sb 118 3.6 m	Sb 119 38.19 h	Sb 120 15.89 m	Sb 121 57.21
Sn 114 0.66	Sn 115 0.34	Sn 116 14.54	Sn 117 7.68	Sn 118 24.22	Sn 119 8.59	Sn 120 32.58
In 113 4.29	In 114 71.9 s	In 115 95.71	In 116 14.10 s	In 117 43.2 m	In 118 5.0 s	In 119 2.4 m

For even-even nuclei:

- Tin has three candidates for (d,pγ)

- All three isotopes have the same g.s. spin
  - ν: $(3s_{1/2})^1$

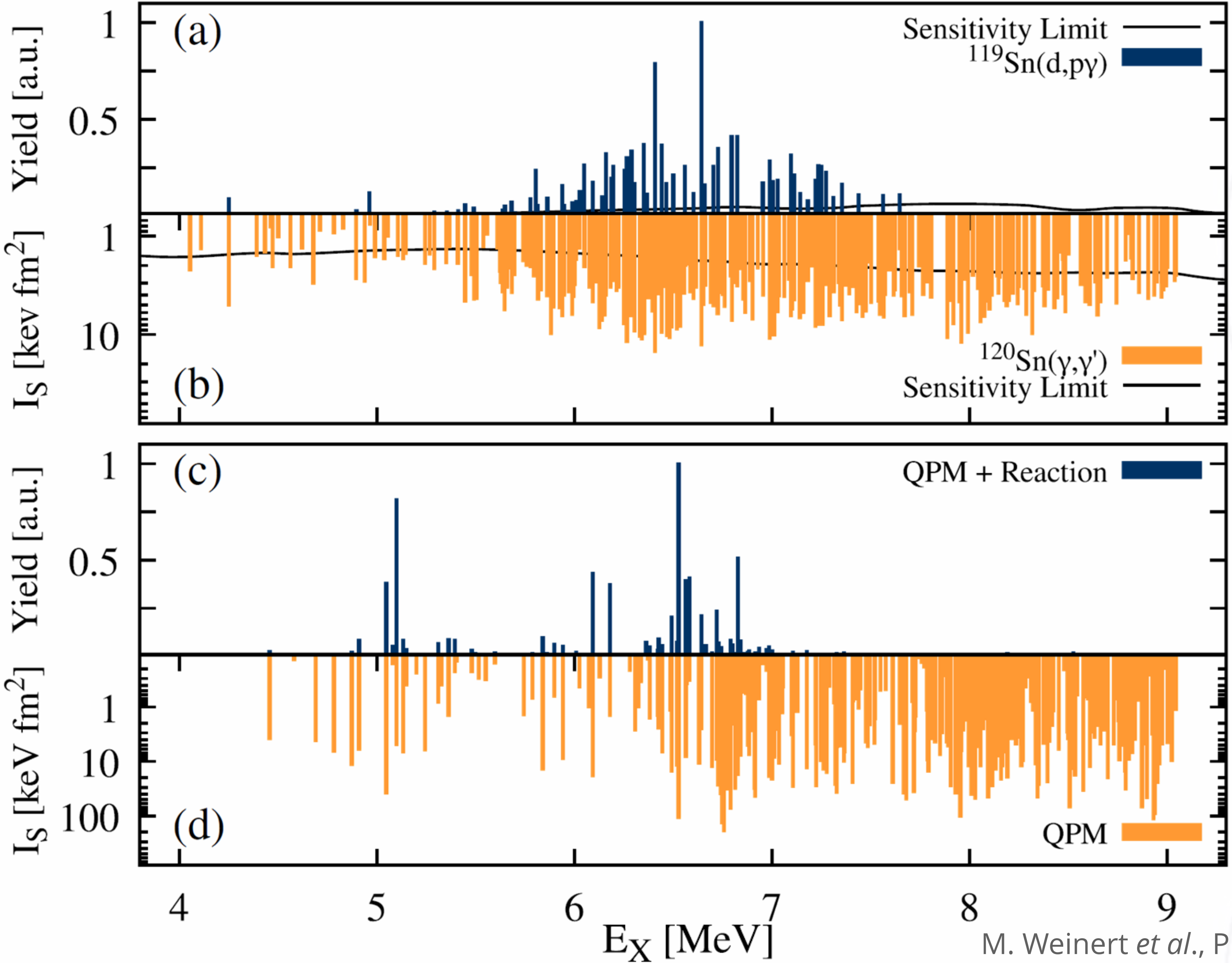
Motivation – Results in ^{120}Sn



- ^{119}Sn(d,pγ): single accumulation
- ^{120}Sn(γ, γ'): uniform distribution

M. Weinert *et al.*, Phys. Rev. Lett. **127**, 242501 (2021)

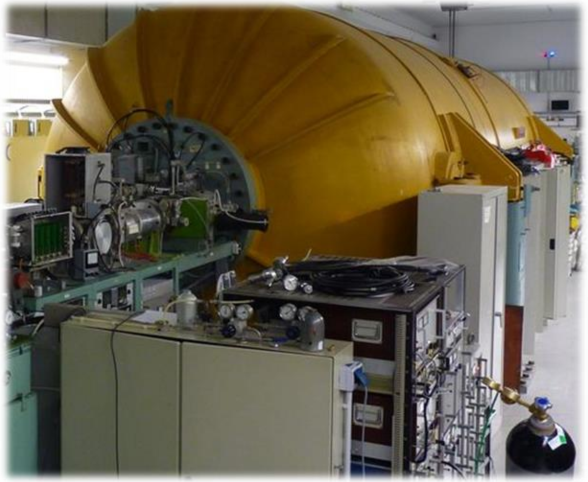
Motivation – Results in ^{120}Sn



- ^{119}Sn(d,pγ): single accumulation
- ^{120}Sn(γ, γ'): uniform distribution
- Supported by QPM calculations
- Caused by dominant 1p – 1h contribution

M. Weinert *et al*., Phys. Rev. Lett. **127**, 242501 (2021)

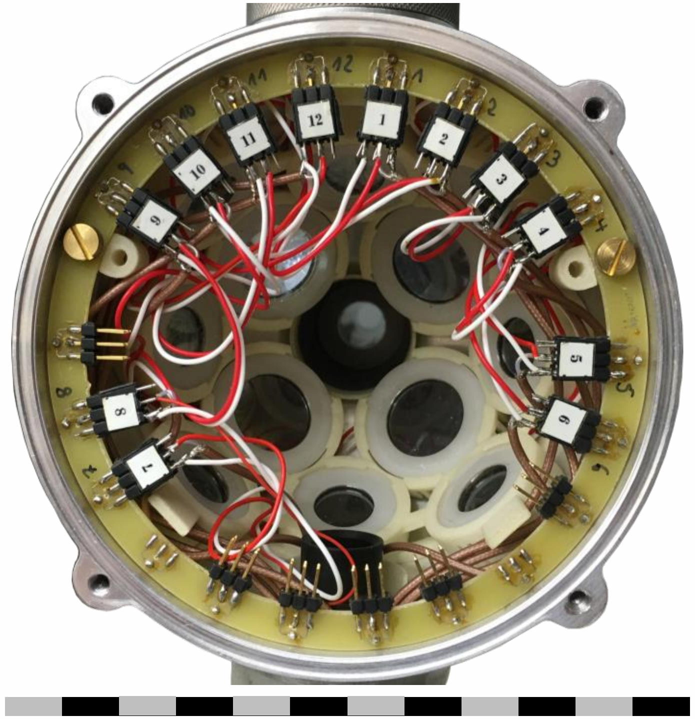
Experiment – SONIC@HORUS



10 MV FN Tandem Accelerator at the University of Cologne

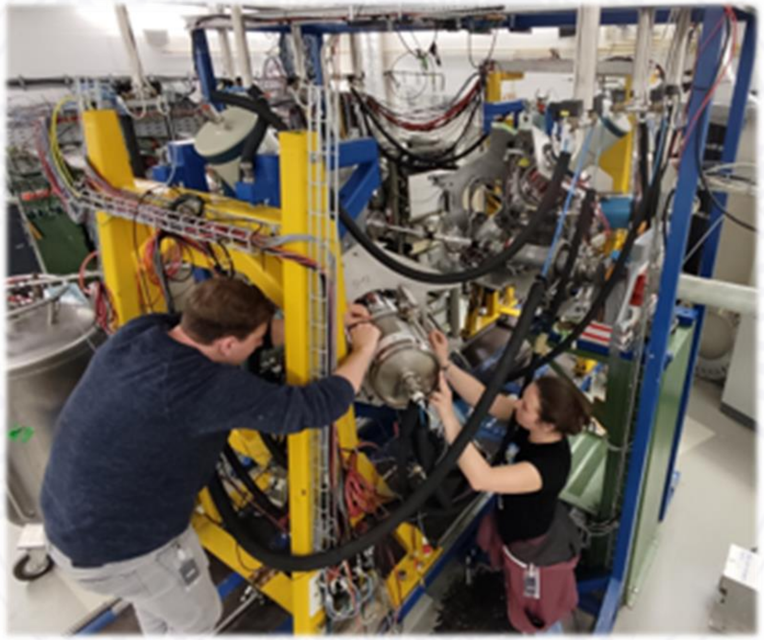
SONIC V3 ΔE-E

- Target chamber
- Up to 12 Si-telescopes



12.8 cm

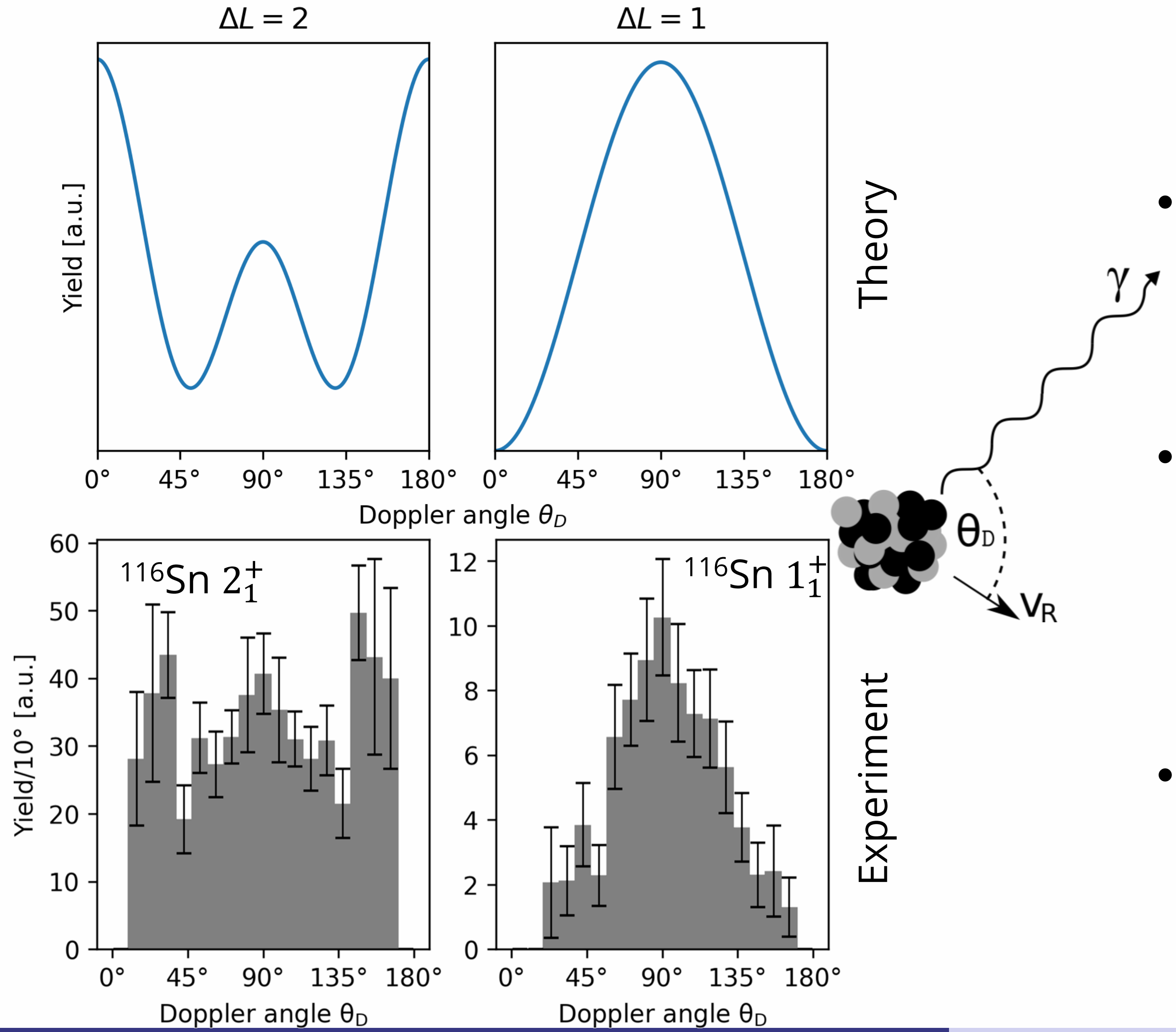
@



HORUS

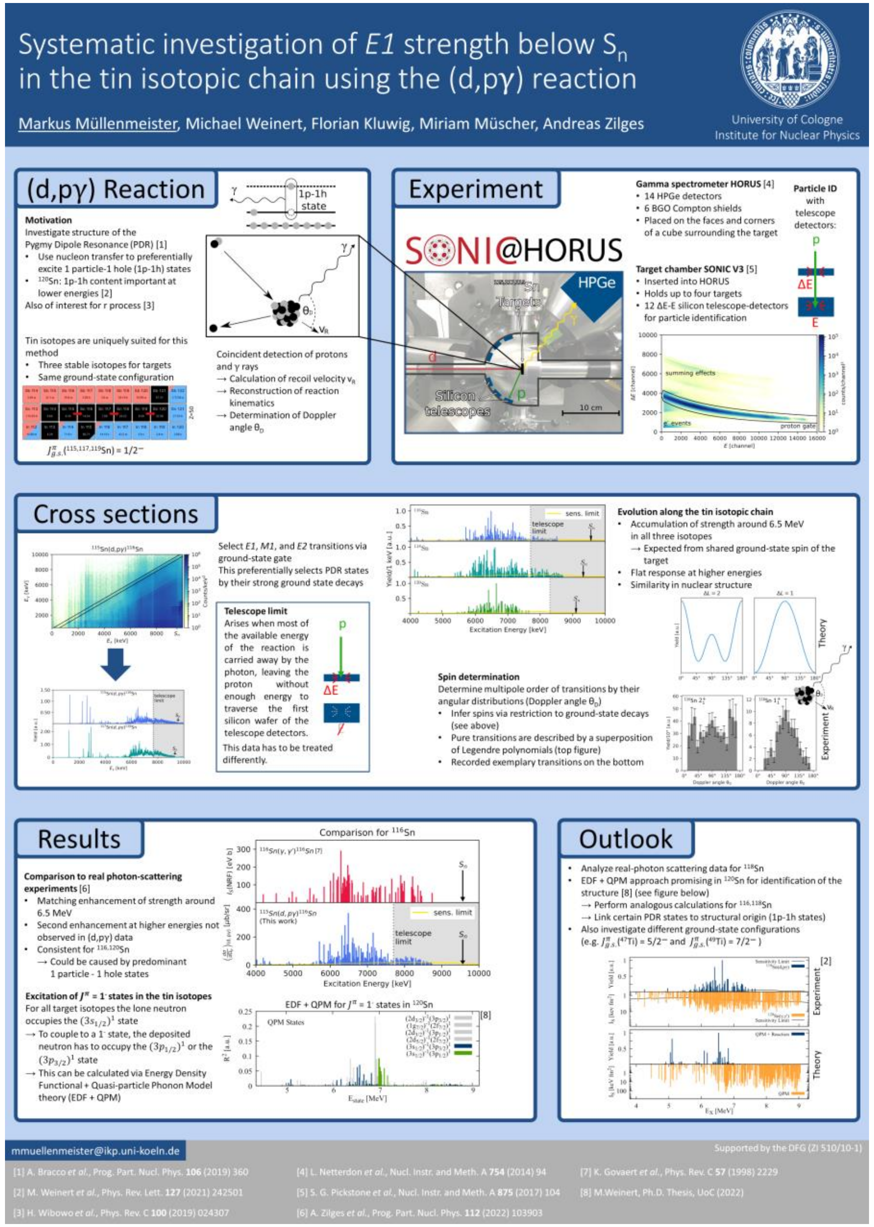
- γ-ray spectrometer
- Up to 14 HPGe detectors

Spin determination



- Determination of multipole order via angular distributions
- Theoretical angular distribution of γ rays well defined
- Restriction to g.s. decays
  → Spin of initial state

Results



Systematic investigation of *E1* strength below S_n in the tin isotopic chain using the (d,pγ) reaction

Markus Müllenmeister, Michael Weinert, Florian Kluwig, Miriam Müscher, Andreas Zilges

University of Cologne
Institute for Nuclear Physics

(d,pγ) Reaction

Motivation
Investigate structure of the Pygmy Dipole Resonance (PDR) [1]
- Use nucleon transfer to preferentially excite 1 particle-1 hole (1p-1h) states
- ^{120}Sn: 1p-1h content important at lower energies [2]

Also of interest for r process [3]

Tin isotopes are uniquely suited for this method
- Three stable isotopes for targets
- Same ground-state configuration

$J^{\pi}_{g.s.}(^{115,117,119}\mathrm{Sn}) = 1/2^{-}$

Coincident detection of protons and γ rays
→ Calculation of recoil velocity v_R
→ Reconstruction of reaction kinematics
→ Determination of Doppler angle θ_D

Experiment

Gamma spectrometer HORUS [4]
- 14 HPGe detectors
- 6 BGO Compton shields
- Placed on the faces and corners of a cube surrounding the target

Target chamber SONIC V3 [5]
- Inserted into HORUS
- Holds up to four targets
- 12 ΔE-E silicon telescope-detectors for particle identification

Particle ID with telescope detectors:

Cross sections

Select *E1*, *M1*, and *E2* transitions via ground-state gate
This preferentially selects PDR states by their strong ground state decays

Telescope limit
Arises when most of the available energy of the reaction is carried away by the photon, leaving the proton without enough energy to traverse the first silicon wafer of the telescope detectors.
This data has to be treated differently.

Evolution along the tin isotopic chain
- Accumulation of strength around 6.5 MeV in all three isotopes
  → Expected from shared ground-state spin of the target
- Flat response at higher energies
- Similarity in nuclear structure

Spin determination
Determine multipole order of transitions by their angular distributions (Doppler angle θ_D)
- Infer spins via restriction to ground-state decays (see above)
- Pure transitions are described by a superposition of Legendre polynomials (top figure)
- Recorded exemplary transitions on the bottom

Results

Comparison to real photon-scattering experiments [6]
- Matching enhancement of strength around 6.5 MeV
- Second enhancement at higher energies not observed in (d,pγ) data
- Consistent for ^{116,120}Sn
  → Could be caused by predominant 1 particle - 1 hole states

Excitation of $J^{\pi} = 1^{-}$ states in the tin isotopes
For all target isotopes the lone neutron occupies the $(3s_{1/2})^1$ state
→ To couple to a 1^- state, the deposited neutron has to occupy the $(3p_{1/2})^1$ or the $(3p_{3/2})^1$ state
→ This can be calculated via Energy Density Functional + Quasi-particle Phonon Model theory (EDF + QPM)

Outlook

- Analyze real-photon scattering data for ^{118}Sn
- EDF + QPM approach promising in ^{120}Sn for identification of the structure [8] (see figure below)
  → Perform analogous calculations for ^{116,118}Sn
  → Link certain PDR states to structural origin (1p-1h states)
- Also investigate different ground-state configurations (e.g. $J^{\pi}_{g.s.}(^{47}\mathrm{Ti}) = 5/2^{-}$ and $J^{\pi}_{g.s.}(^{49}\mathrm{Ti}) = 7/2^{-}$)

mmuellenmeister@ikp.uni-koeln.de

Supported by the DFG (ZI 510/10-1)

[1] A. Bracco *et al.*, Prog. Part. Nucl. Phys. **106** (2019) 360
[2] M. Weinert *et al.*, Phys. Rev. Lett. **127** (2021) 242501
[3] H. Wibowo *et al.*, Phys. Rev. C **100** (2019) 024307
[4] L. Netterdon *et al.*, Nucl. Instr. and Meth. A **754** (2014) 94
[5] S. G. Pickstone *et al.*, Nucl. Instr. and Meth. A **875** (2017) 104
[6] A. Zilges *et al.*, Prog. Part. Nucl. Phys. **112** (2022) 103903
[7] K. Govaert *et al.*, Phys. Rev. C **57** (1998) 2229
[8] M.Weinert, Ph.D. Thesis, UoC (2022)

- Outline of analysis
- Determination of cross sections
- Comparison to real-photon scattering data
- Evolution along the tin isotopic chain