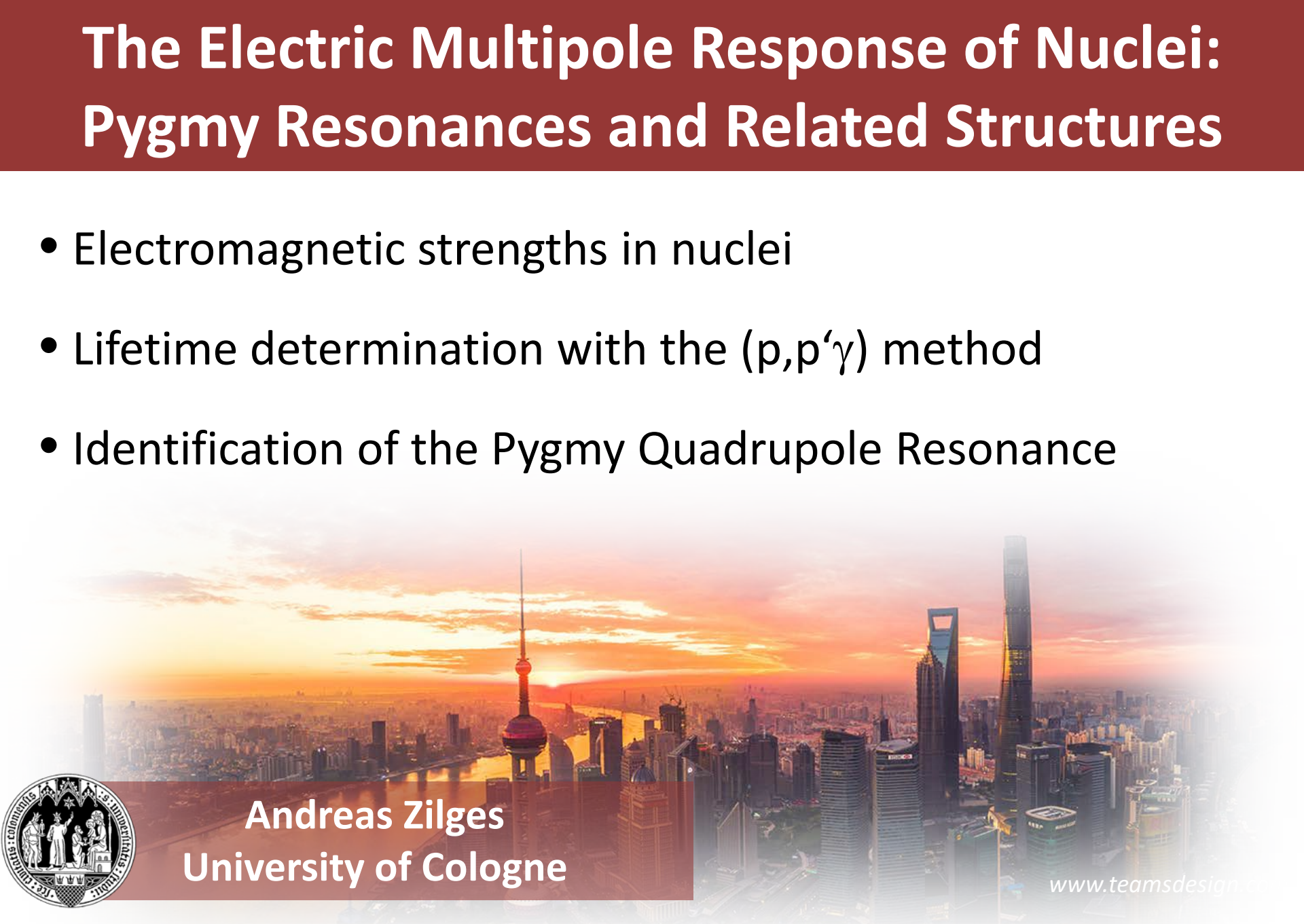
The Electric Multipole Response of Nuclei: Pygmy Resonances and Related Structures

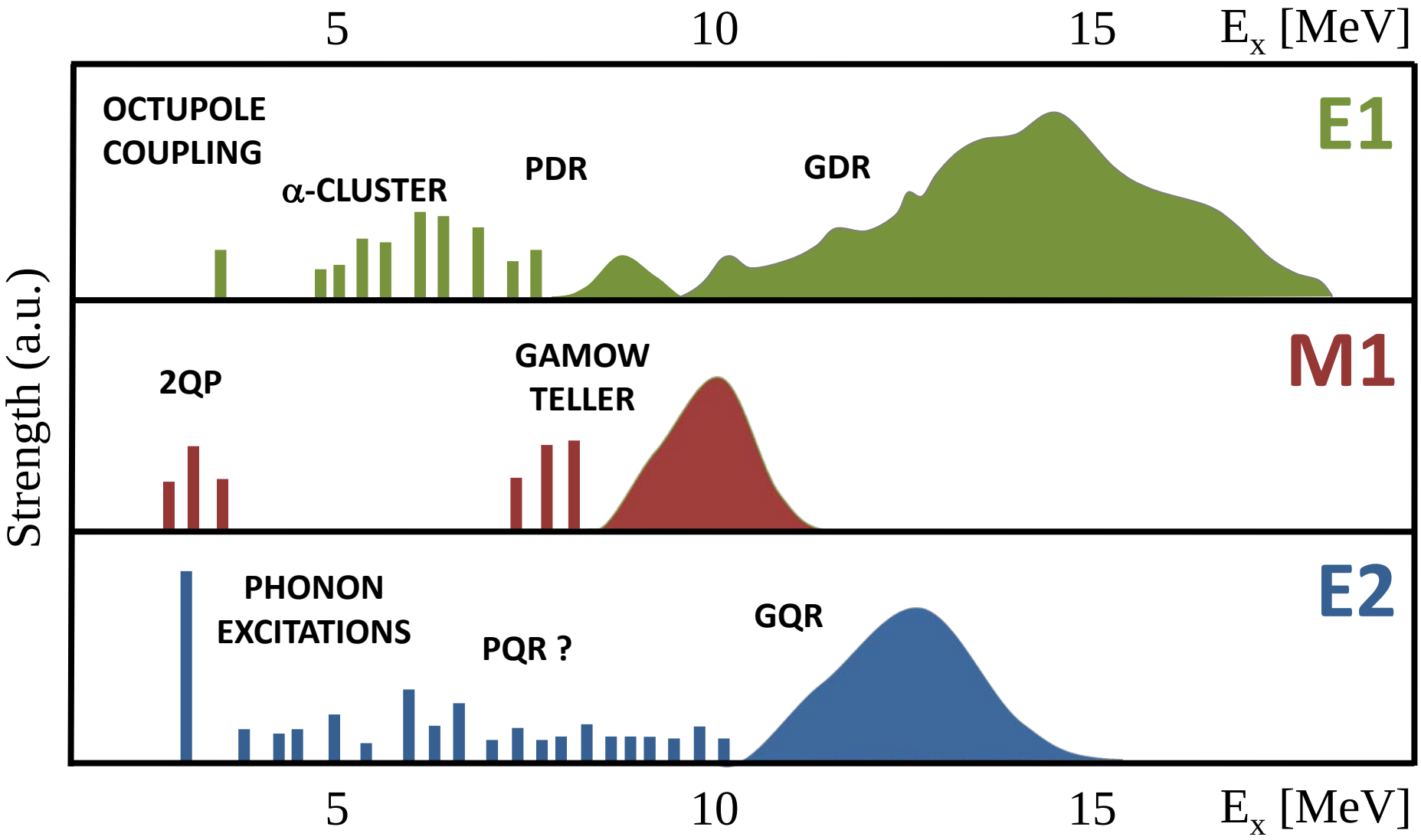
- Electromagnetic strengths in nuclei
- Lifetime determination with the (p,p‘γ) method
- Identification of the Pygmy Quadrupole Resonance



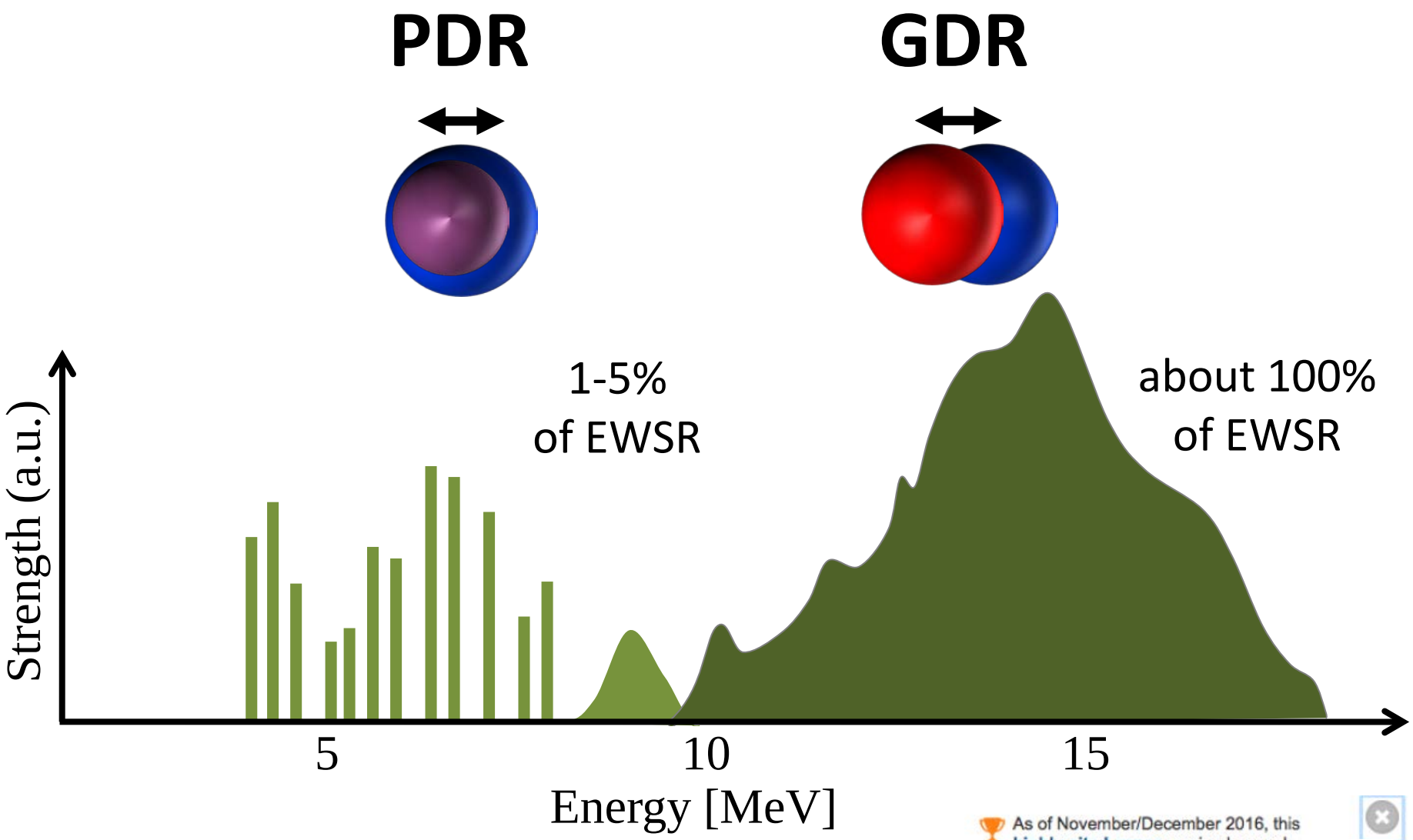
Andreas Zilges
University of Cologne

CGS 16 • Shanghai Jiao Tong University • September 2017

Electromagnetic response of atomic nuclei

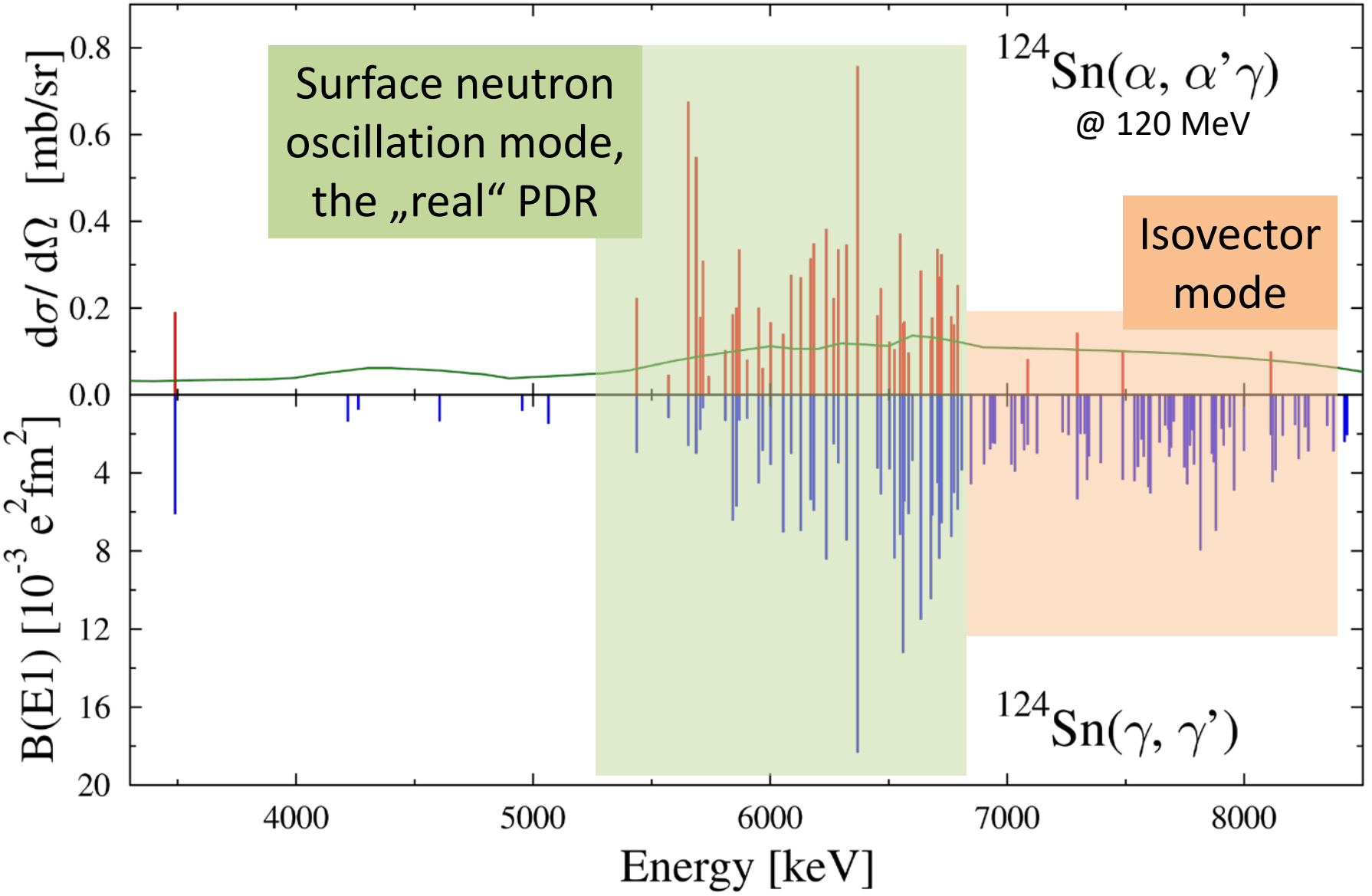


From giants and pygmies



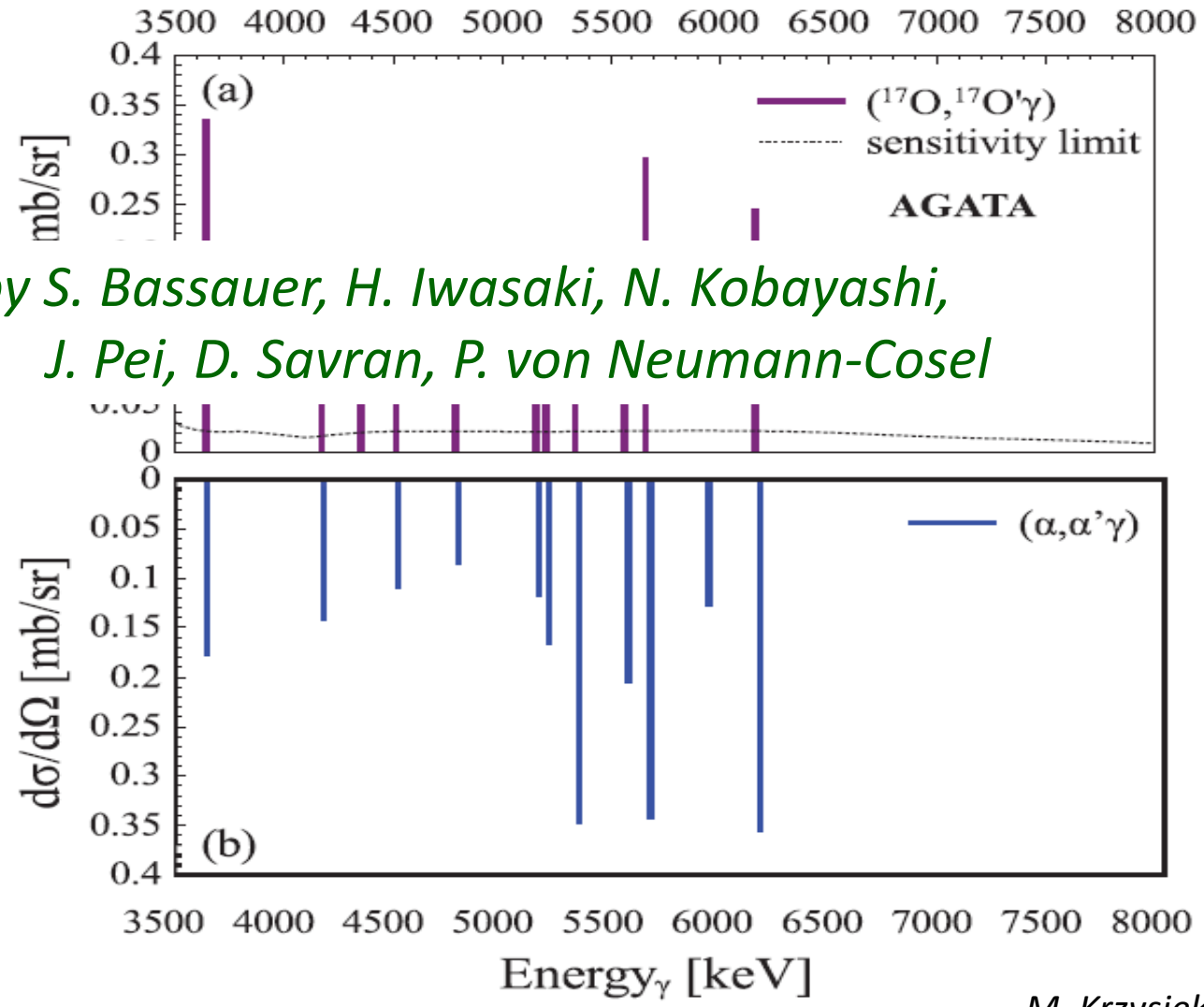
*D. Savran, T. Aumann, and A. Zilges, PPNP **70** (2013) 210*

Splitting of the PDR



*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Result confirmed, e.g., in (^{17}O, ^{17}O') on ^{140}Ce



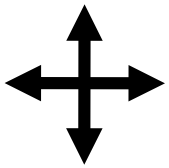
→ *talks by S. Bassauer, H. Iwasaki, N. Kobayashi, J. Pei, D. Savran, P. von Neumann-Cosel*

*M. Krzysiek, A. Bracco et al., PRC **93** (2016) 044330*

From dipole to quadrupole

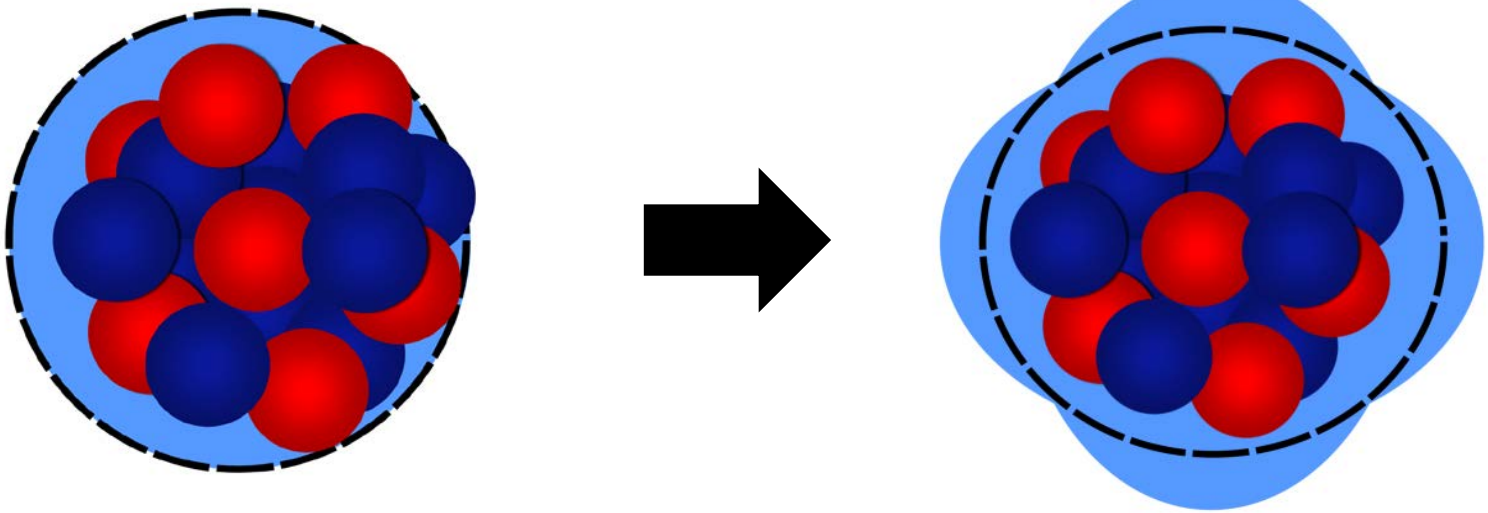
Pygmy Dipole Resonance (PDR)

Pygmy Quadrupole Resonance (PQR) ?

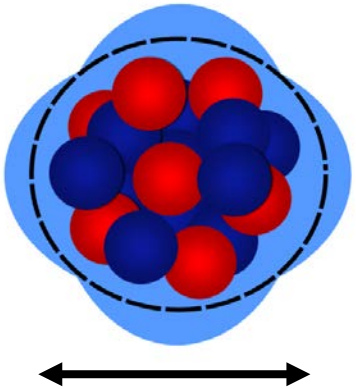


E1

E2

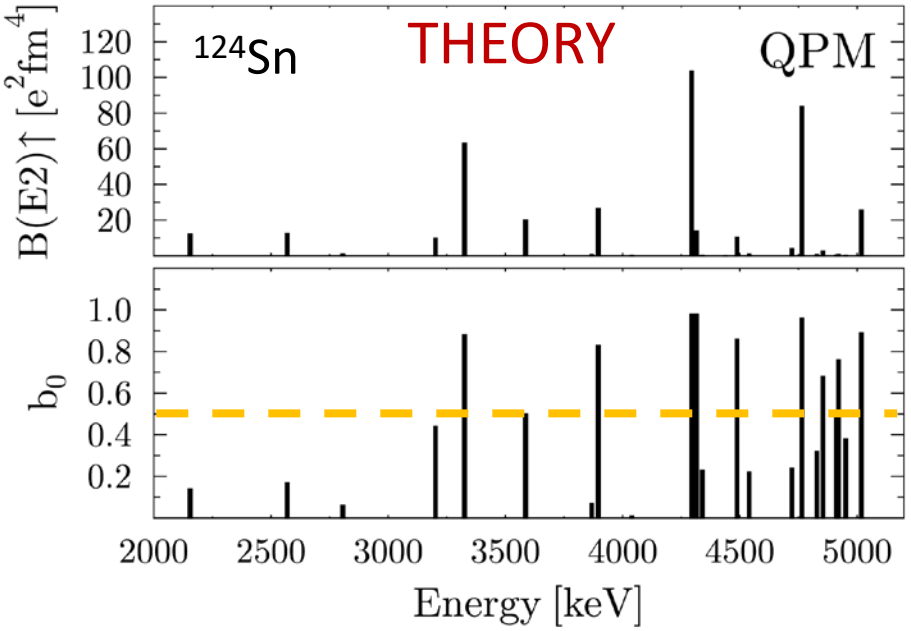


From dipole to quadrupole



Is there evidence for a
Pygmy Quadrupole Resonance (PQR),
a quadrupole-type oscillation
of the neutron skin?

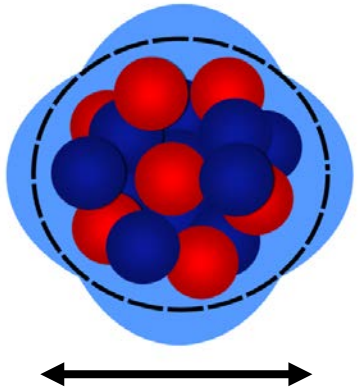
*N. Tsoneva, H. Lenske, PLB **695**, 174 (2011)*



- **considerable E2 strength** between 3-5 MeV
- **dominant decay to groundstate**: $b_0 = \Gamma_0 / \Gamma > 0.5$

*M. Spieker et al., PLB **752**, 102 (2016)*

From dipole to quadrupole



Is there evidence for a
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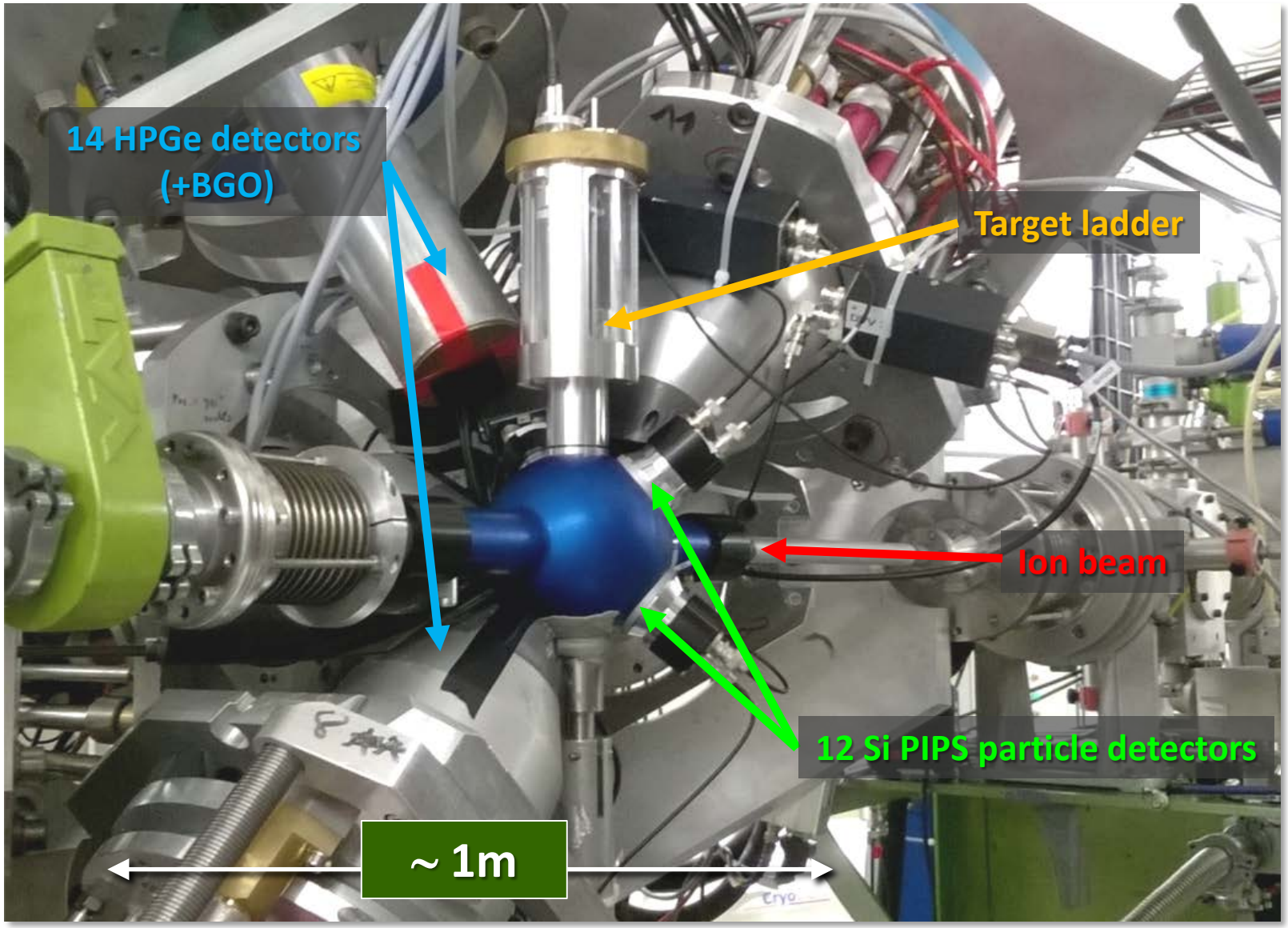
of the neutron skin?

Important observables for the identification of the PQR:

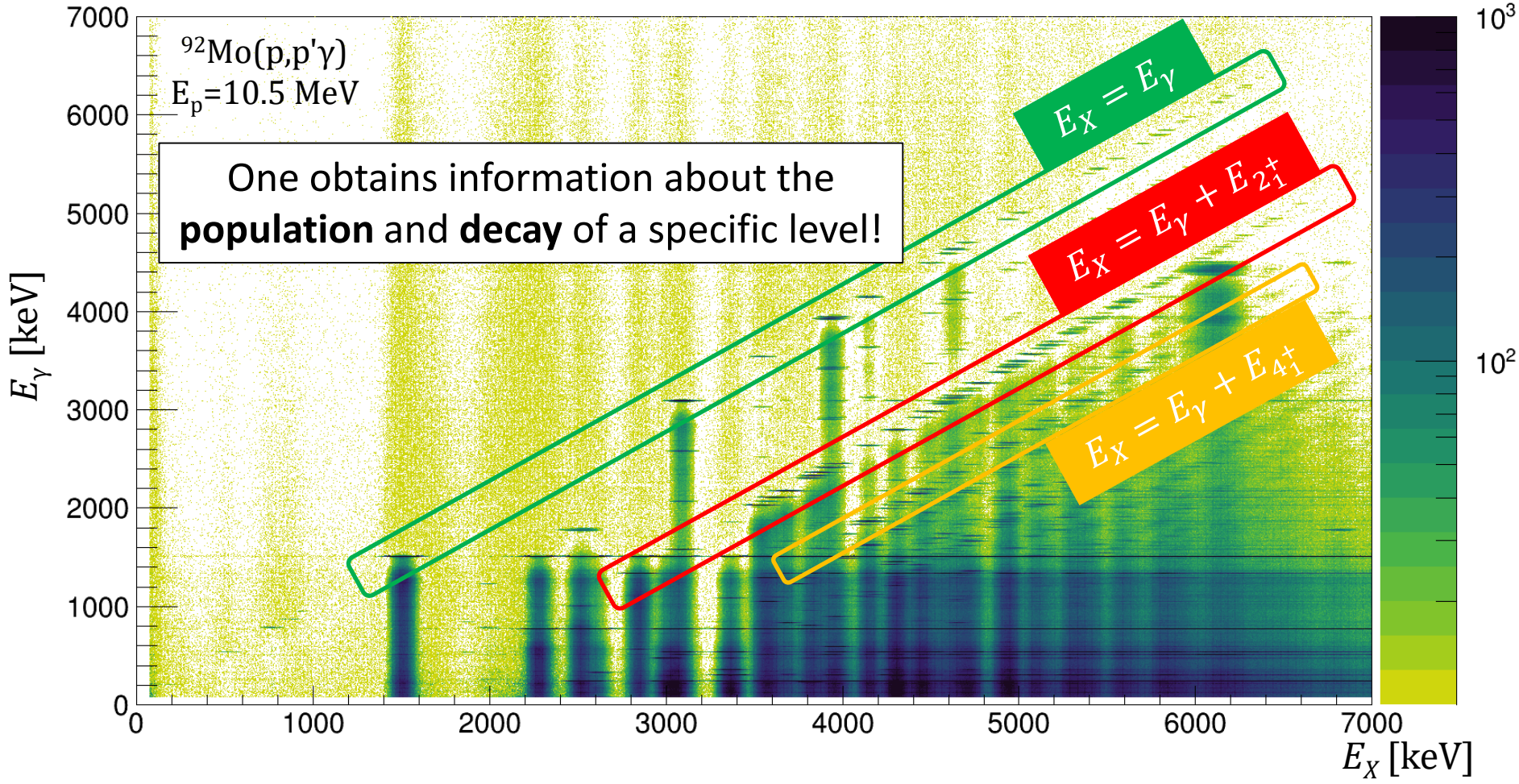
- **B(E2) strength distribution**
- **branching to excited states**
- single-particle structure
- isospin character (however, similar to phonon excitations)

SONIC@HORUS at the University of Cologne



*S.G. Pickstone et al., NIM **A** (2017), in press*

The proton-γ coincidence matrix



Example: Diagonal gates select decay to specific lower lying states, e.g., to the ground state, 2_1^+, or 4_1^+

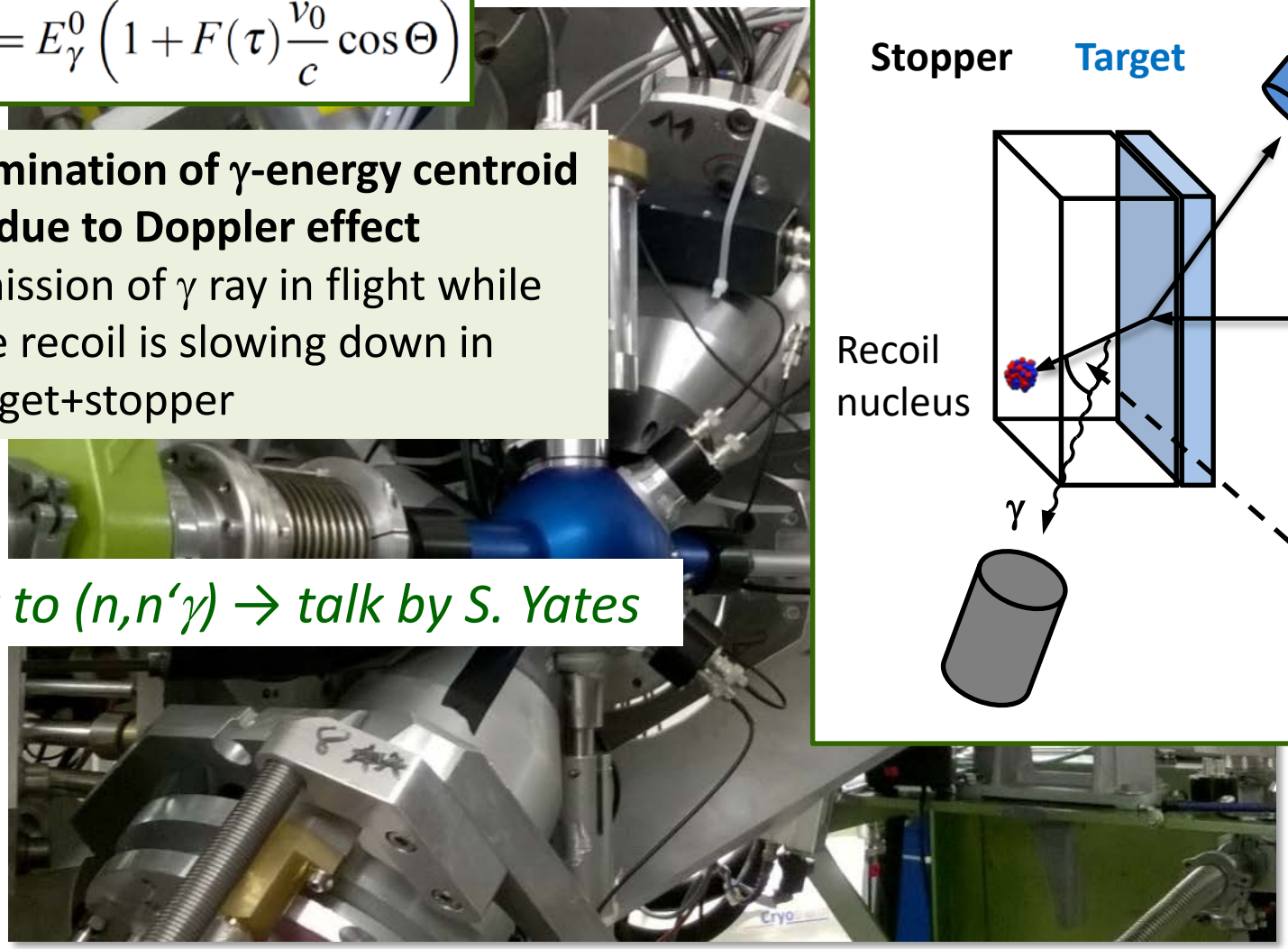
*S.G. Pickstone et al., NIM **A** (2017), in press*

Lifetime determination using the (p,p'γ) Doppler Shift Attenuation (DSA) coincidence method

$$E_\gamma(\Theta,t) = E_\gamma^0\left(1 + F(\tau)\frac{v_0}{c}\cos\Theta\right)$$

Determination of γ-energy centroid shifts due to Doppler effect

→ Emission of γ ray in flight while the recoil is slowing down in target+stopper



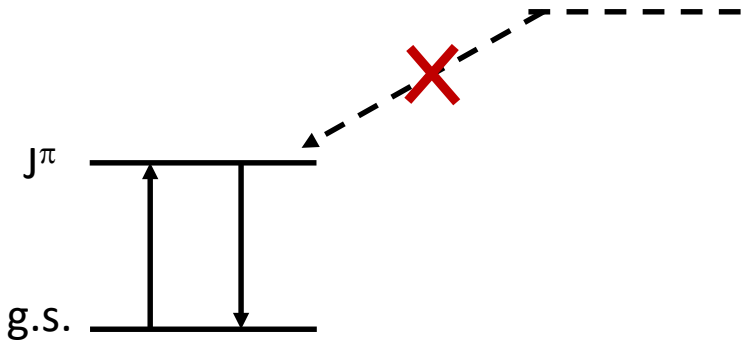
similar to (n,n'γ) → talk by S. Yates

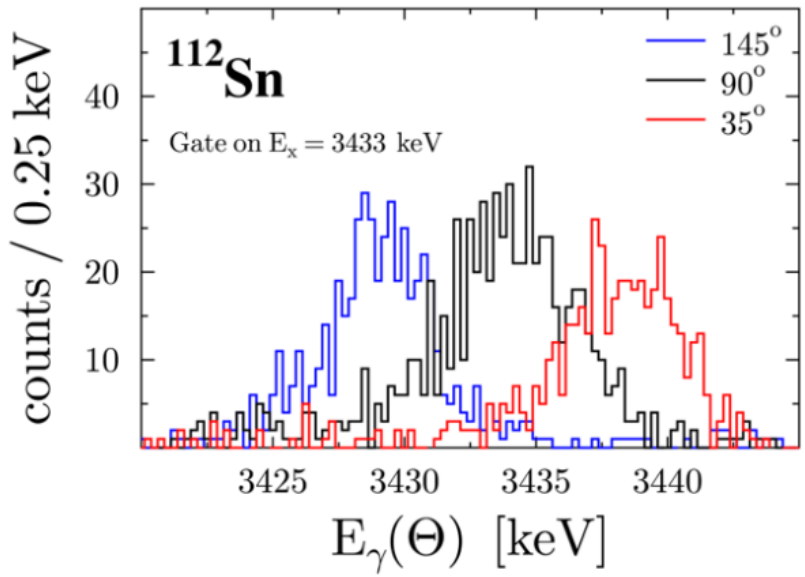
A. Hennig et al., NIM ***A794*** (2015) 171

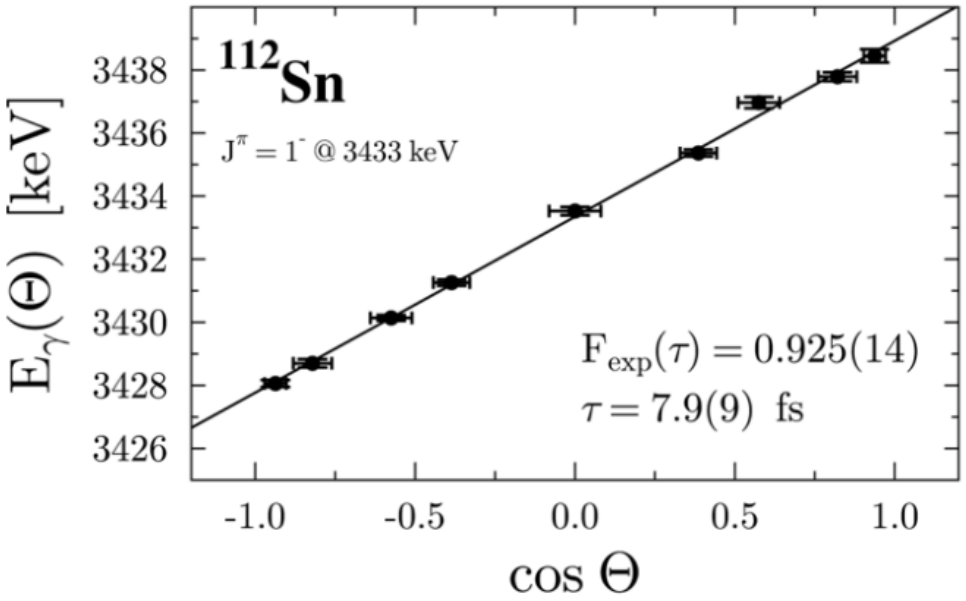
Lifetime determination via (p,p'γ)

Excitation-energy gate (SONIC)

- v_0 is known from kinematics
- feeding can be excluded
  → extraction of real lifetimes!

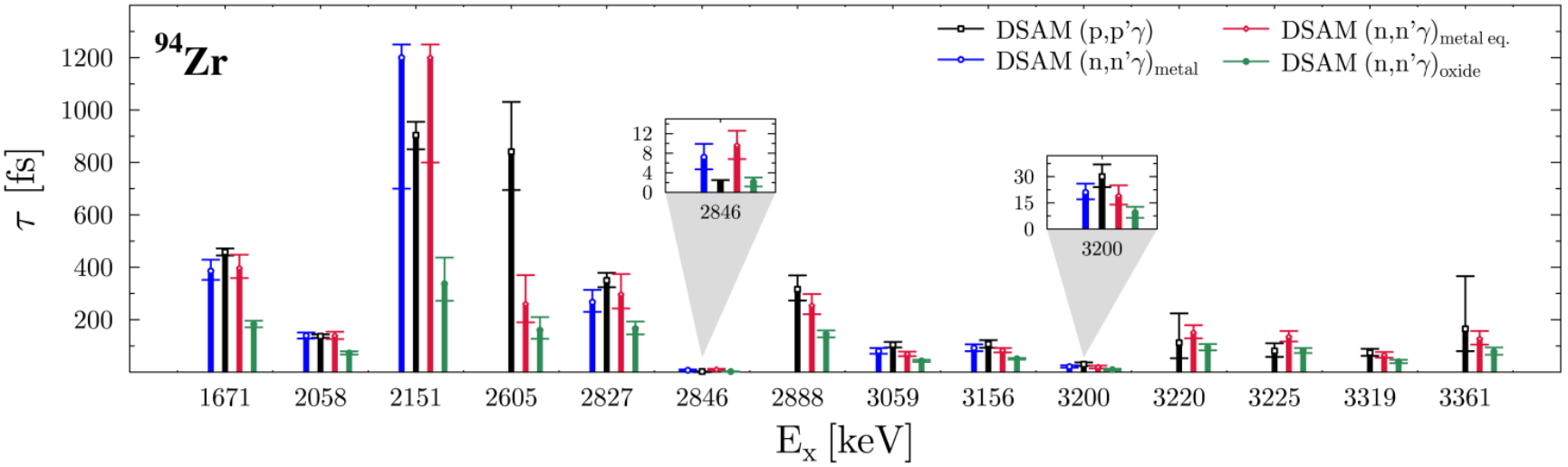


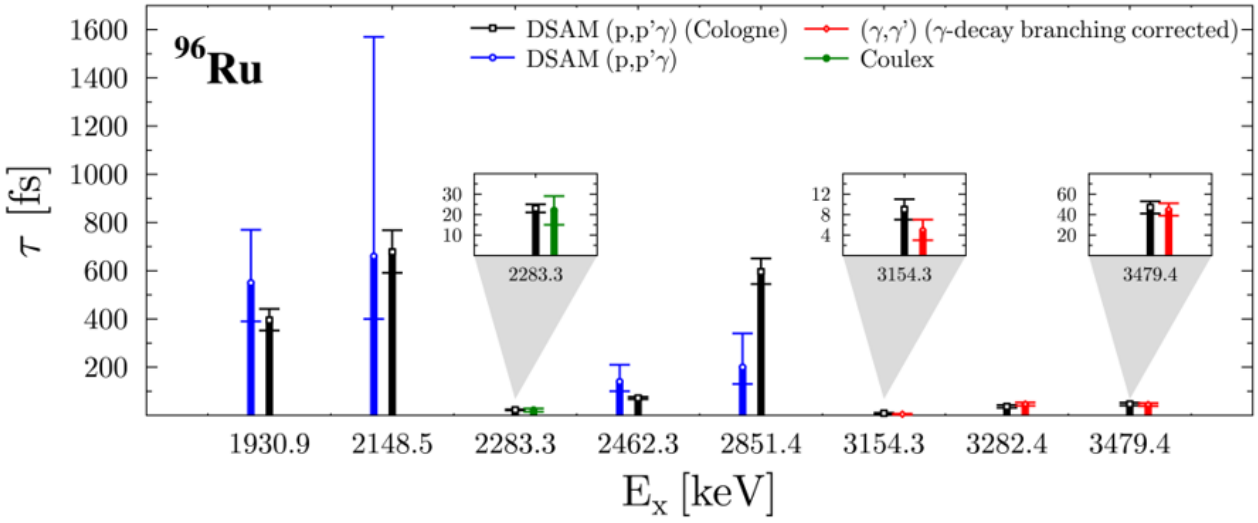


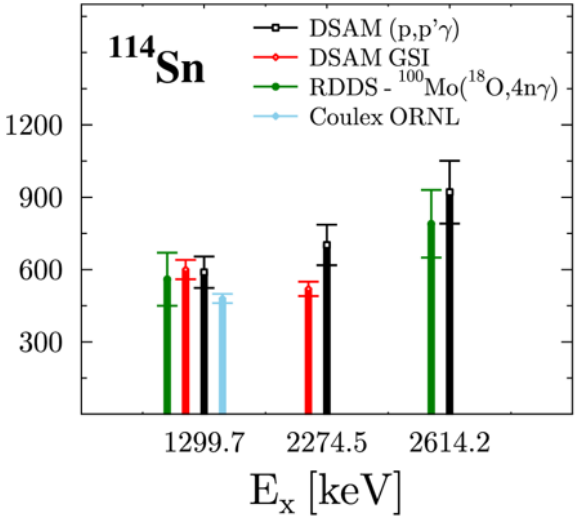


*A. Hennig et al., NIM **A794** (2015) 171*
M. Spieker, PhD thesis, Cologne (2016)

Comparison to existing data

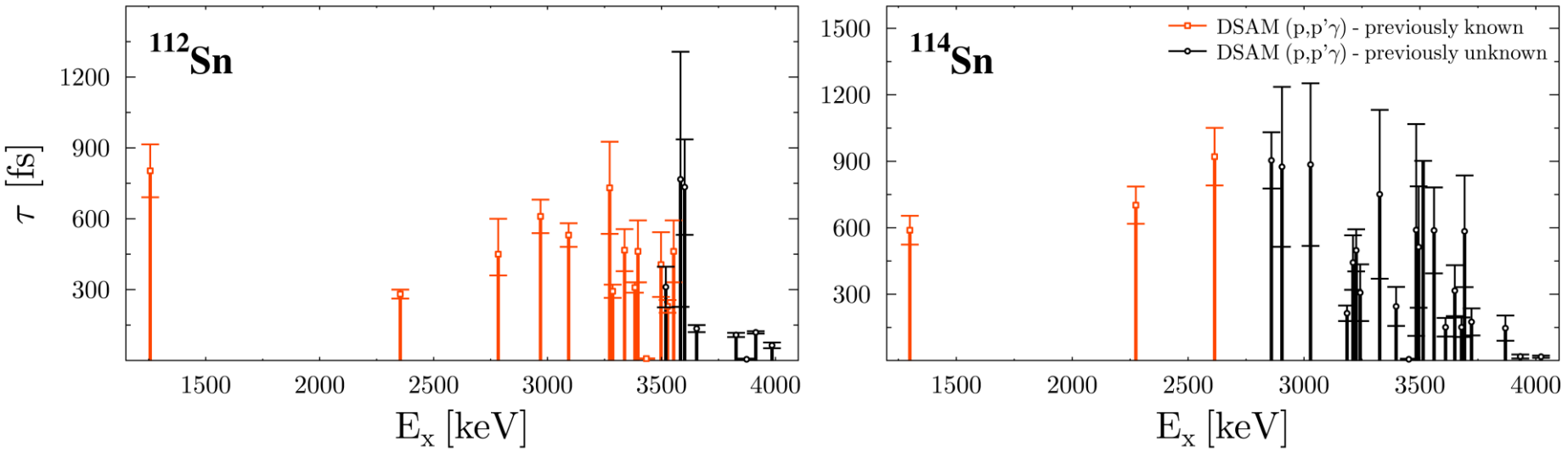






*A. Hennig et al., PRC **92** (2015) 064317*
S. Prill et al., to be published

Newly determined lifetimes in ^{112}Sn and ^{114}Sn

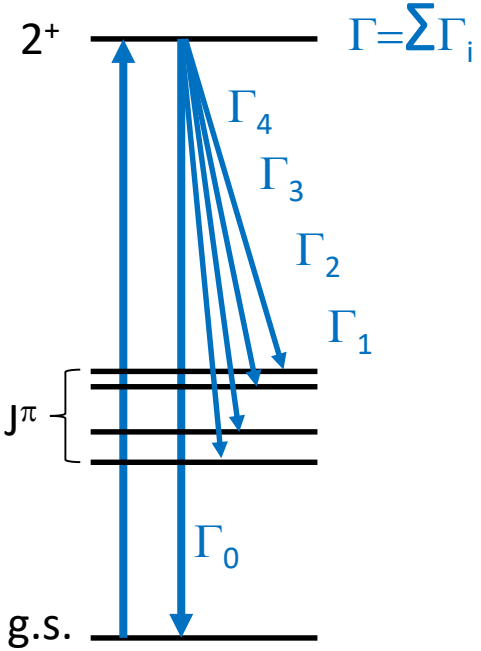


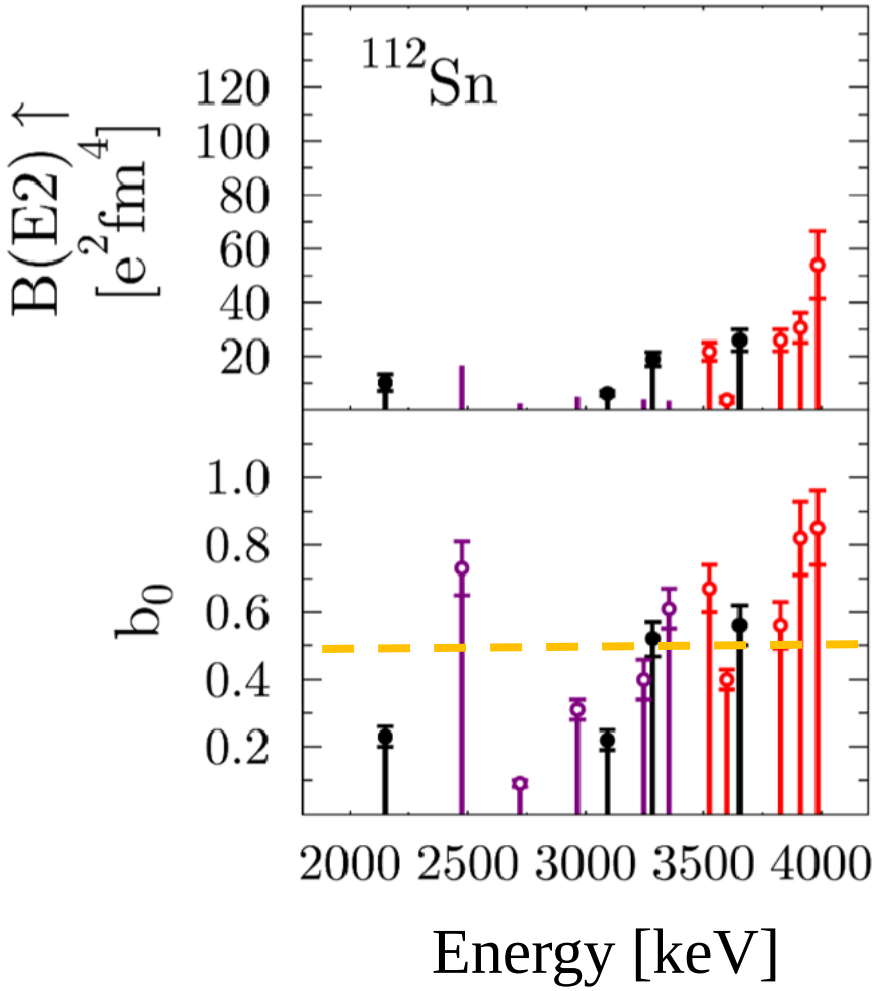
M. Spieker et al., to be published

Many new lifetimes and B(E2) values from a single experiment!
(57 lifetimes in ^{112}Sn and 30 lifetimes in ^{114}Sn)

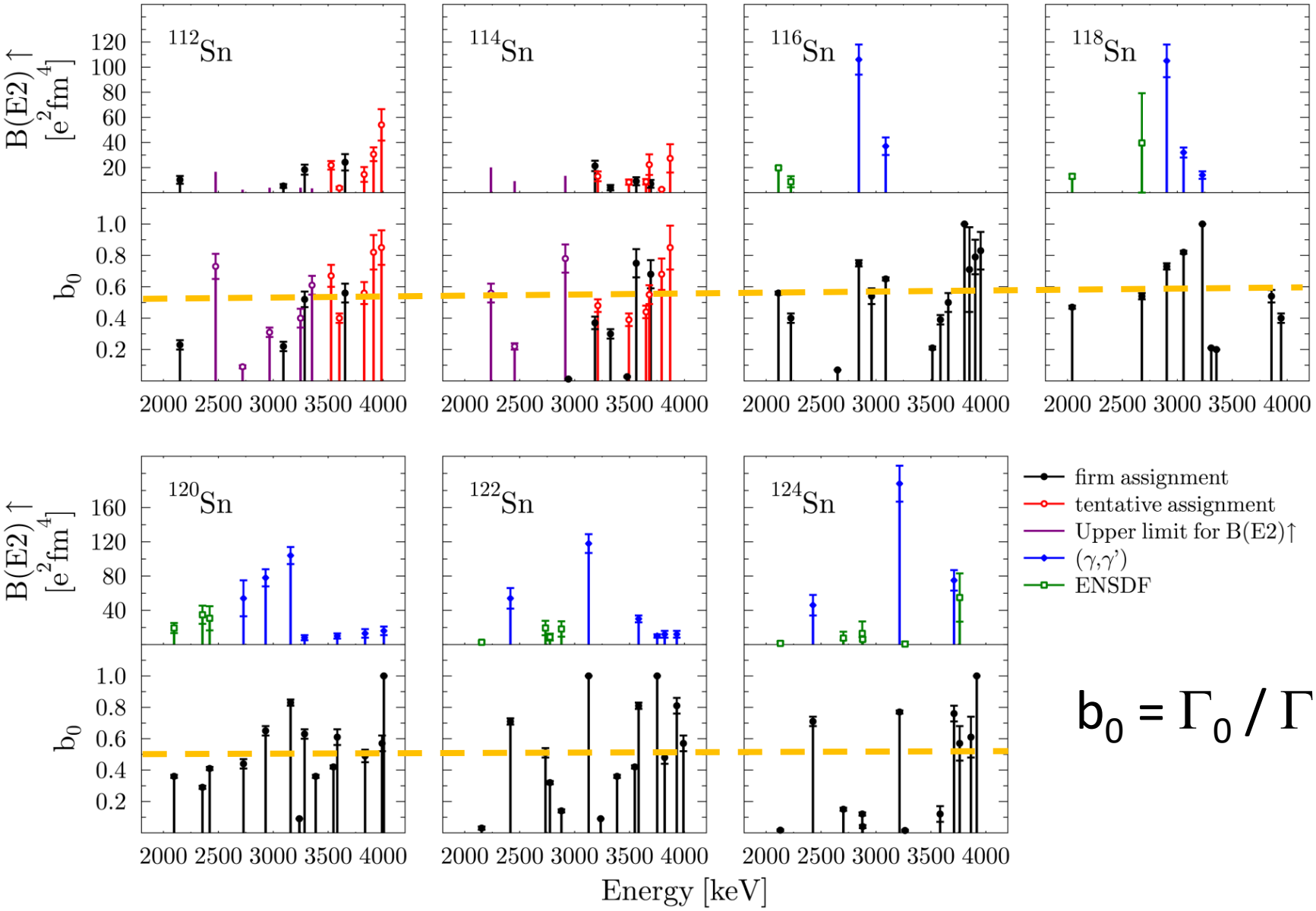
Groundstate decay ratios $b_0 = \Gamma_0 / \Gamma$ in ^{112}Sn

The gate on the excitation energy allows a sensitive measurement of branching ratios!





B(E2) strengths and g.s. decay ratios in Sn isotopes

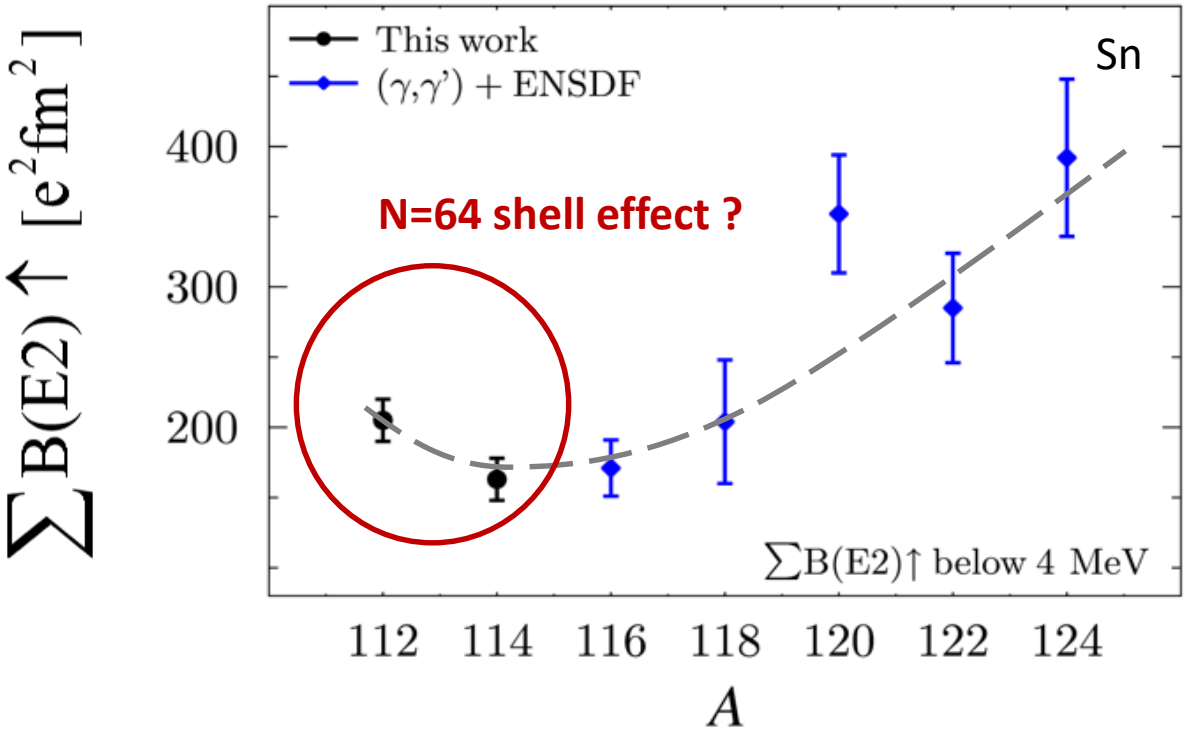


$b_0 = \Gamma_0 / \Gamma$

M. Spieker et al., to be published

Systematics of summed B(E2) strengths in Sn

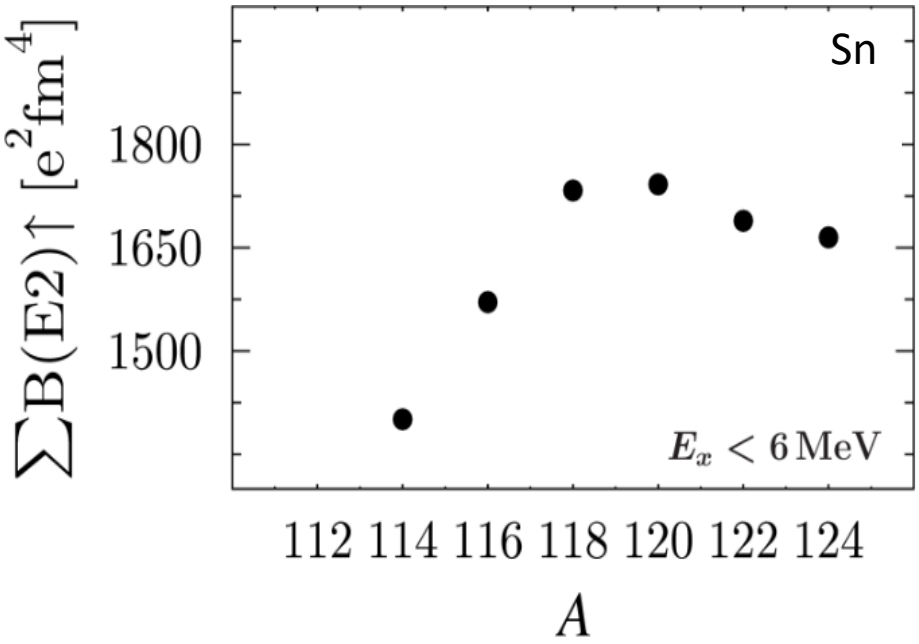
Experiment



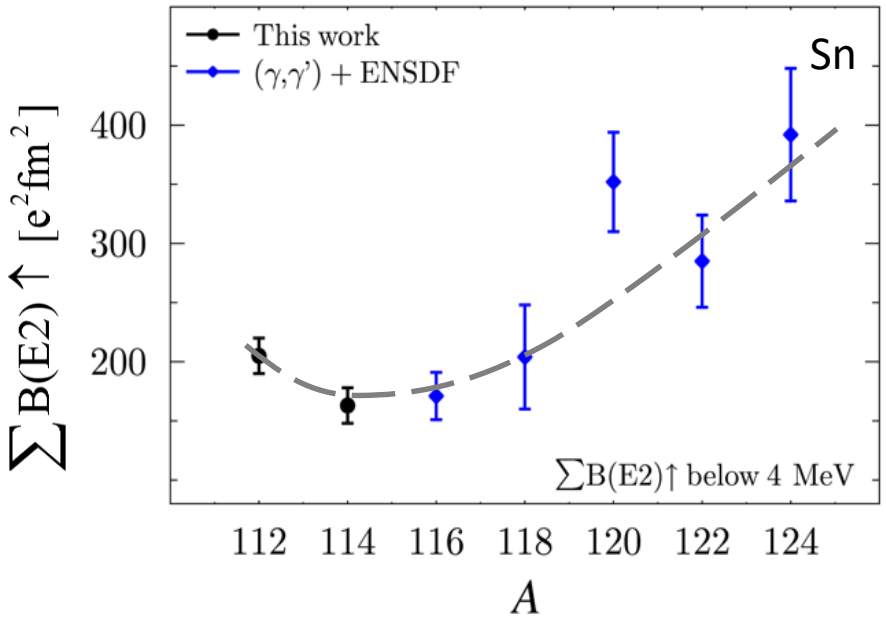
M. Spieker et al., to be published

Summed B(E2) strengths: Theory vs. experiment

Theory: RQTBA



Experiment

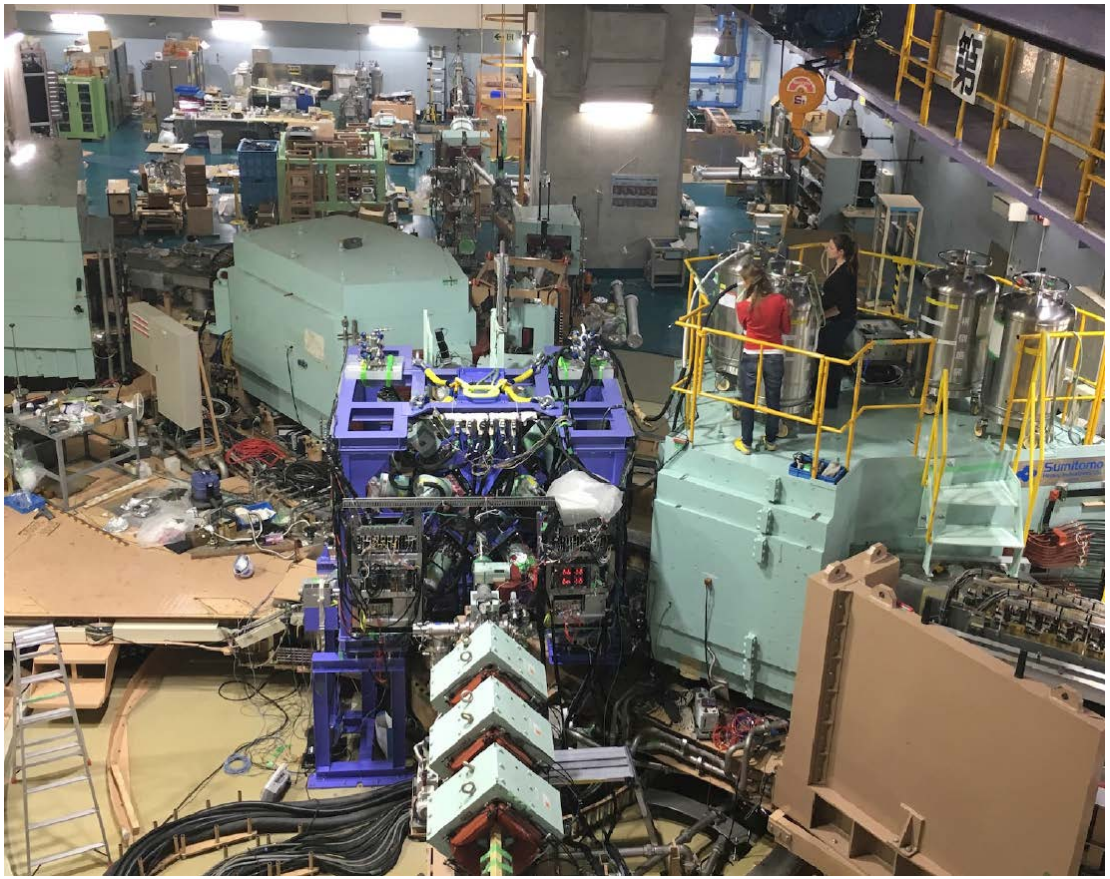


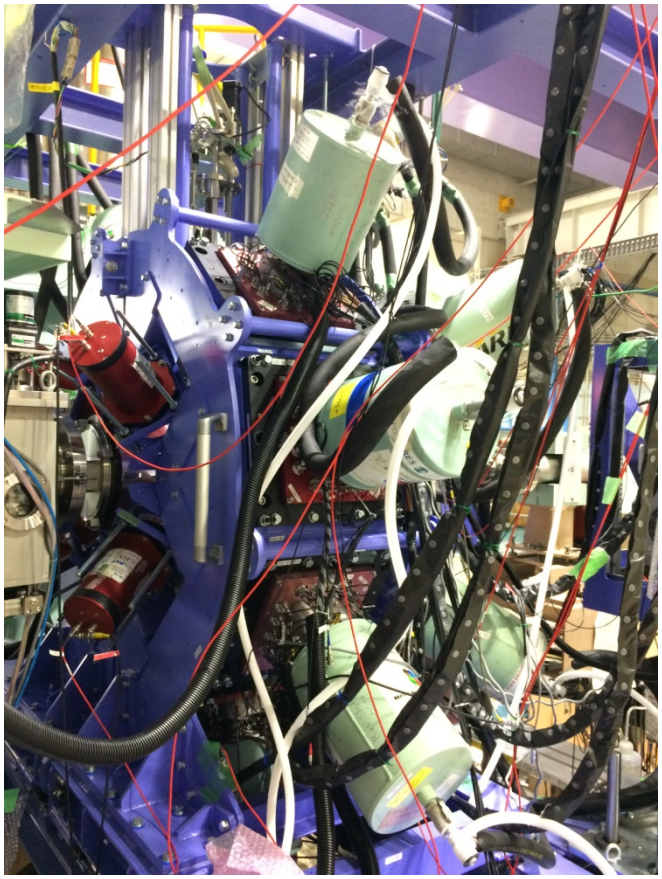
E. Litvinova, priv. com. (2017)

The present experimental data does
support the existence of a Pygmy Quadrupole Resonance

Probing the isospin character of the PQR

CAGRA@Grand Raiden Collaboration, RCNP, Osaka (Japan)

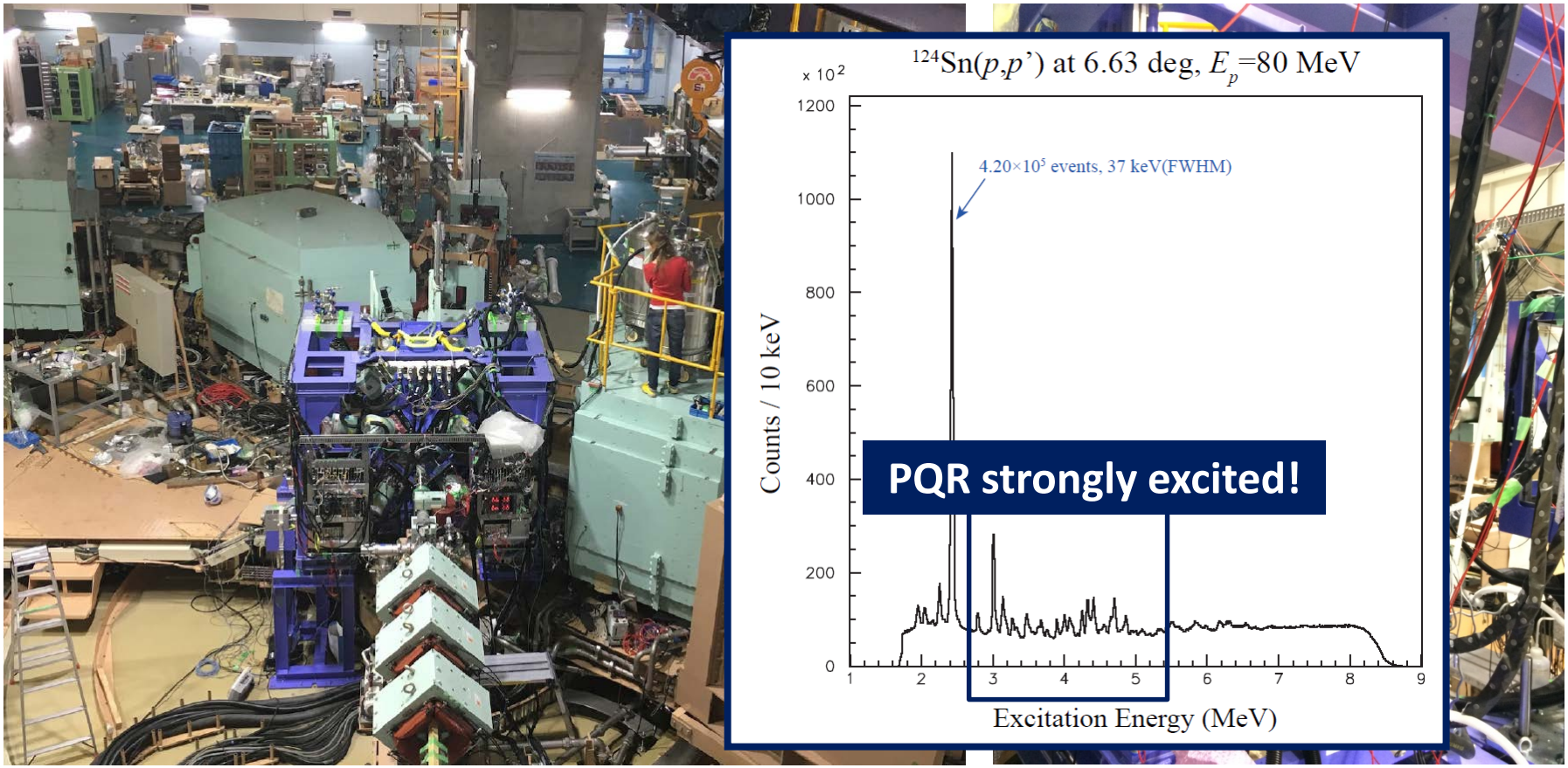




- $(p,p'\gamma)$ @ E_p = 80 MeV and $(\alpha,\alpha'\gamma)$ @ E_α = 130 MeV (Oct 2016 – Dec 2016)
- **CAGRA** (12 Clover HPGe detectors and 4 large-volume $LaBr_3$:Ce detectors)
- **Grand Raiden** spectrometer (very good energy resolution)

Probing the isospin character of the PQR

CAGRA@Grand Raiden Collaboration, RCNP, Osaka (Japan)



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- **CAGRA** (12 Clover HPGe detectors and 4 large-volume $LaBr_3$:Ce detectors)
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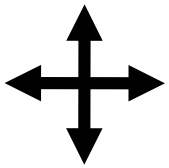
From quadrupole to dipole

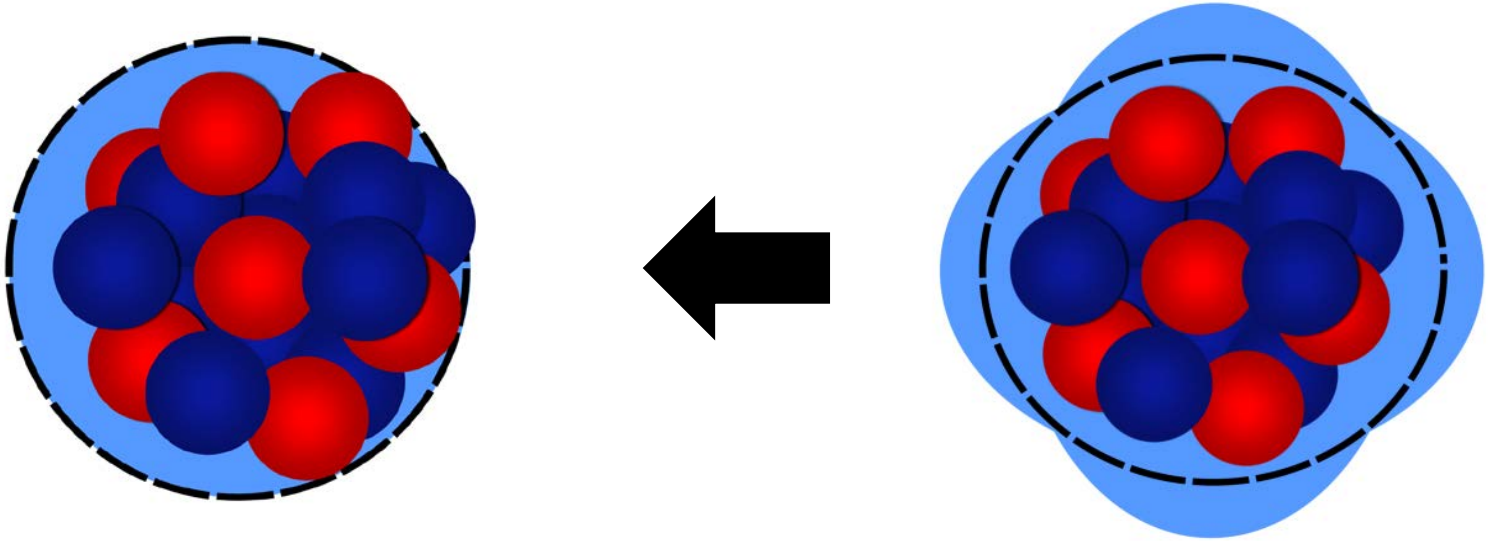
Pygmy Dipole Resonance (PDR)

E1

Pygmy Quadrupole Resonance (PQR) ?



E2



Dipole strength: New horizons with ELI-NP

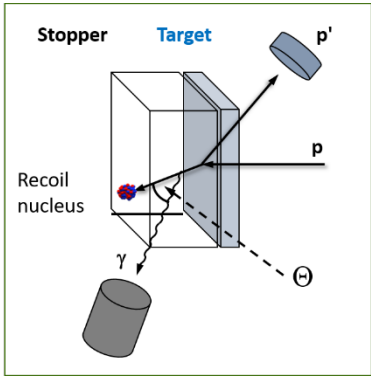
Photons are an ideal probe to study **dipole** excitations

- **bremsstrahlung beams**
  (e.g., TU Darmstadt, HZDR):
  good overview, but no energy selectivity
- **photons from laser Compton backscattering, 1st generation**
  (e.g., HIGS, New SUBARU)
  selection of an energy window, parity information
  → *talks by T. Beck, J. Isaak, A. Tonchev, H. Utsunomiya, J. Wilhelmy*
- **photons from laser Compton backscattering, 2nd generation**
  (ELI-NP)
  selective excitation of single states, parity information
  → *talk by V. Zamfir*

C.A.Ur, A. Zilges, N. Pietralla et al., Rom. Rep. Phys. 68 (2016) S483

Lifetime determination using the (p,p‘γ) Doppler Shift Attenuation (DSA) coincidence method

- Lifetimes from 10 fs to 1 ps can be measured
- Feeding from higher-lying states excluded due to pγ coincidences (excitation gate)
- γ-decay branching can be measured sensitively
- Dozens of lifetimes in one experiment
- Angular momentum transfer in (p,p‘γ): ΔJ = 0-5



→ very versatile tool for low spin nuclear structure studies

The Electric Multipole Response of Nuclei: Pygmy Resonances and Related Structures

- (p,p'γ) experiments at ≈10 MeV/A in Cologne yield lifetimes and branching ratios for low spin excitations
- observables for some 2^+ states agree with theoretical predictions for a Pygmy Quadrupole Resonance
- further experiments on isospin and single-particle character under way for unambiguous identification of PQR
- Photon beams with small bandwidth allow state selective excitation → NUCLEAR PHOTONICS

The Electric Multipole Response of Nuclei: Pygmy Resonances and Related Structures

M. Müscher, S. Pickstone, S. Prill, M. Spieker, V. Vielmetter, M. Weinert, J. Wilhelmy, and A. Z.

Institut für Kernphysik, University of Cologne

supported by DFG **(ZI 510/7-1 and BCGS)**

and by Bundesministerium für Bildung und Forschung **(05P2015 ELI-NP)**

谢谢大家