FLORIDA STATE
UNIVERSITY

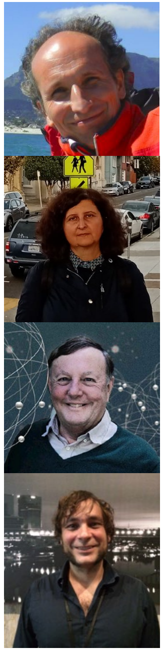
Accessing the Single-Particle Structure of the PDR

Mark-Christoph Spieker

COMEX7 [Catania, Sicily (Italy)], June 2023

Thank you!

Collaborators



A. Zilges (University of Cologne, Cologne, Germany) and his research group.

N. Tsoneva (ELI-NP, Bucharest-Magurele, Romania)

B.A. Brown (FRIB/MSU, East Lansing, MI, USA)

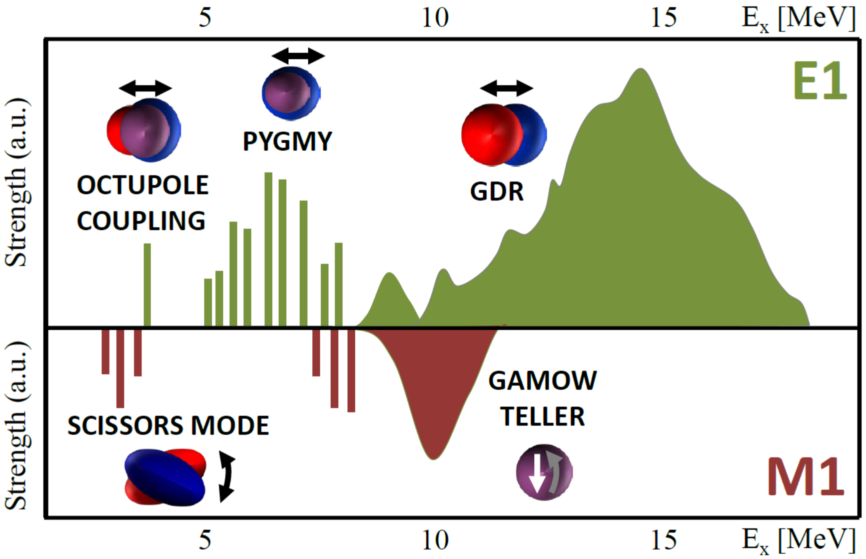
G. Potel Aguilar (LLNL, Livermore, CA, USA)

Special thanks to T. Faestermann (TU Munich), R. Hertenberger (LMU Munich), A. Heusler, V. Yu Ponomarev, D. Savran (GSI), M. Scheck (UWS), H.-F. Wirth (LMU Munich), and to all colleagues at FSU including my students Alex Conley, Dennis Houlihan, and Bryan Kelly.

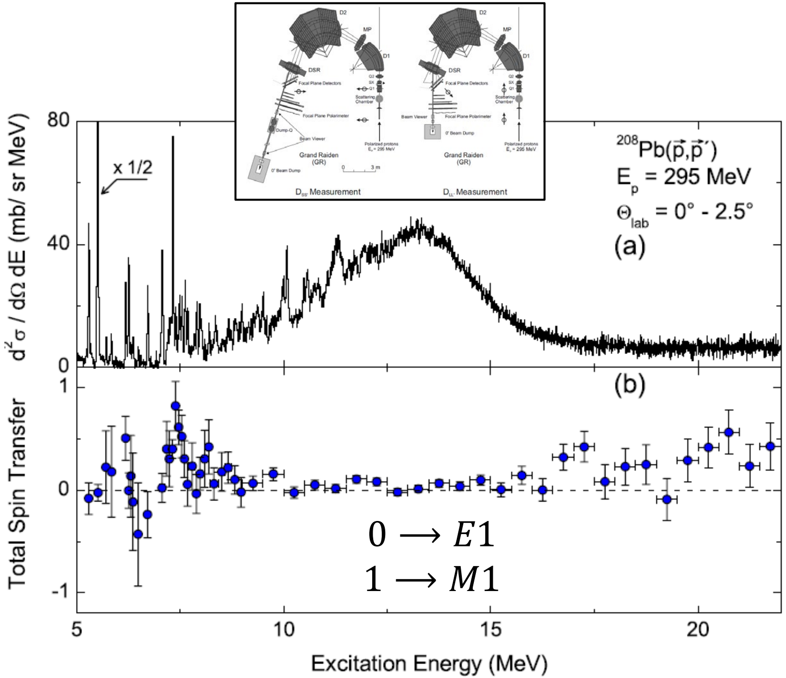
This work was supported by the National Science Foundation (NSF) under Grant No. PHY-2012522 (WoU-MMA: Studies of Nuclear Structure and Nuclear Astrophysics) [M. Spieker/FSU].

Dipole strength distribution in nearly spherical atomic nuclei

Cartoon vs. Reality



Courtesy of A. Zilges (University of Cologne);
see older version in, *e.g.*, FRIB400 white book and in A. Zilges, Journal of Physics: Conference Series **590**, 012006 (2015).



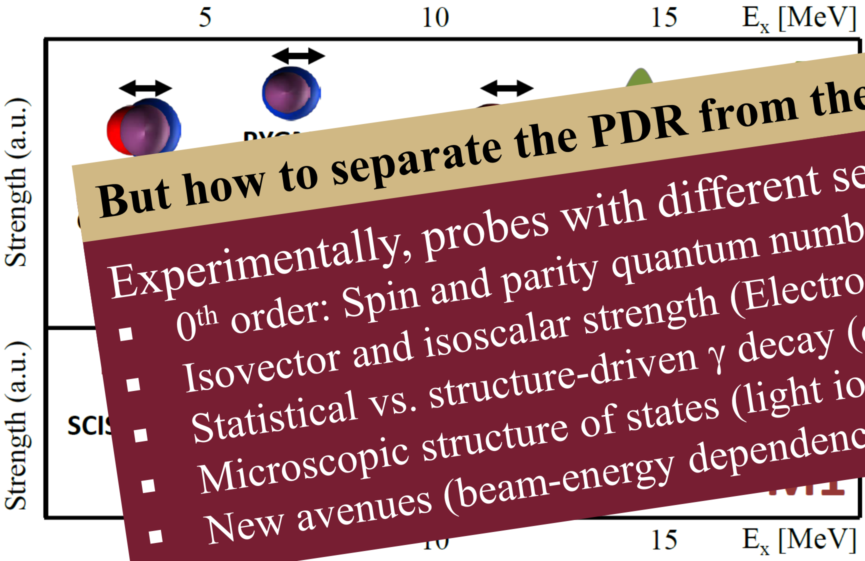
$0 \longrightarrow E1$
$1 \longrightarrow M1$

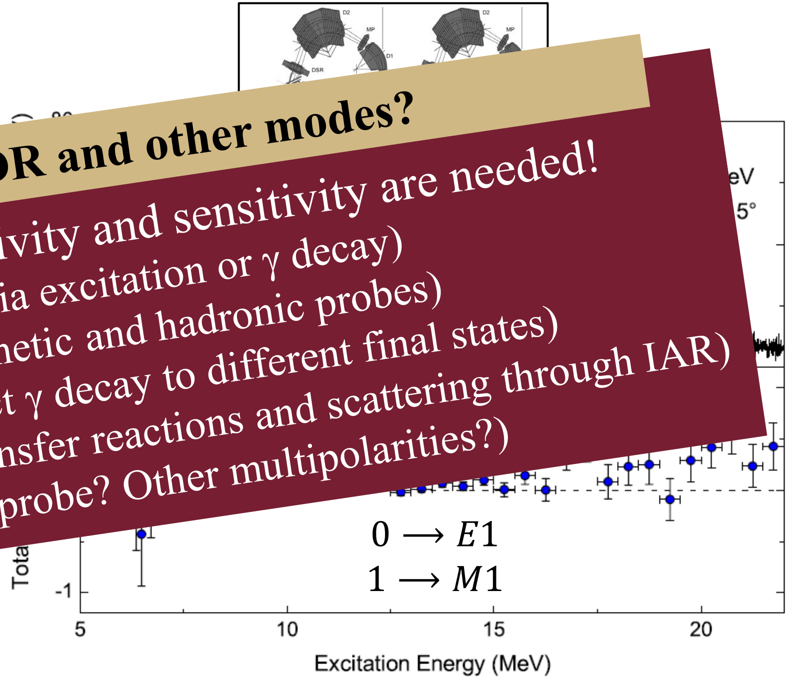
A. Tamii *et al.*, PRL **107**, 062502 (2011)

[Review-article selection: D. Savran, T. Aumann, and A. Zilges, PPNP **70**, 210 (2013) and A. Bracco, E.G. Lanza, and A. Tamii, PPNP **106**, 360 (2019)]

Dipole strength distribution in nearly spherical atomic nuclei

Cartoon vs. Reality





But how to separate the PDR from the GDR and other modes?

Experimentally, probes with different selectivity and sensitivity are needed!

- 0th order: Spin and parity quantum number (via excitation or γ decay)
- Isovector and isoscalar strength (Electromagnetic and hadronic probes)
- Statistical vs. structure-driven γ decay (detect γ decay to different final states)
- Microscopic structure of states (light ion transfer reactions and scattering through IAR)
- New avenues (beam-energy dependence of probe? Other multipolarities?)

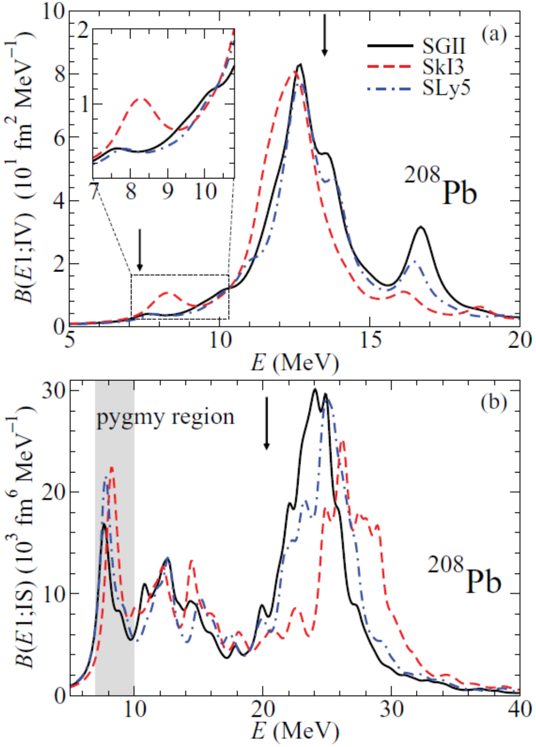
Courtesy of A. Zilges (University of Cologne);
see older version in, *e.g.*, FRIB400 white book and in A. Zilges, Journal of Physics: Conference Series **590**, 012006 (2015).

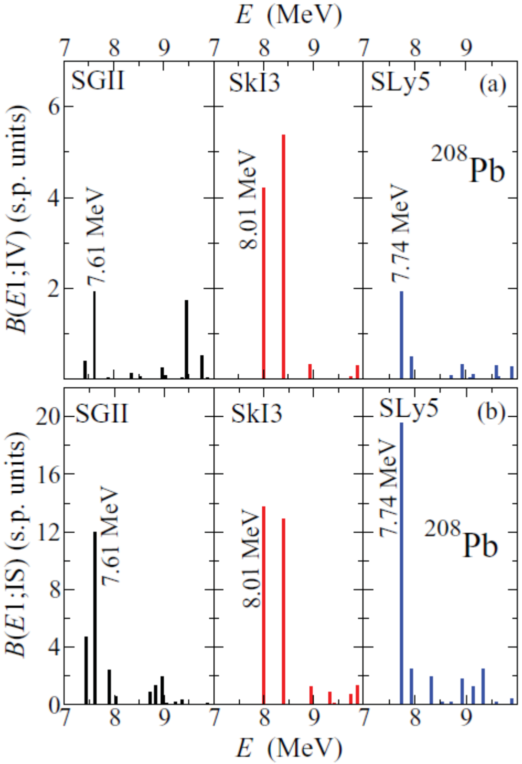
A. Tamii *et al.*, PRL **107**, 062502 (2011)

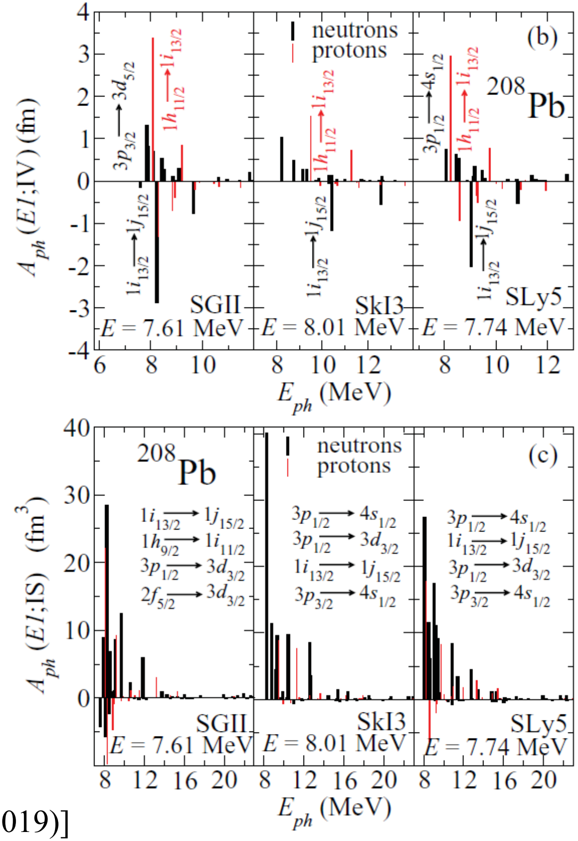
[Review-article selection: D. Savran, T. Aumann, and A. Zilges, PPNP **70**, 210 (2013) and A. Bracco, E.G. Lanza, and A. Tamii, PPNP **106**, 360 (2019)]

An open question – How collective is the PDR?

(What is the single-particle structure of the PDR?)



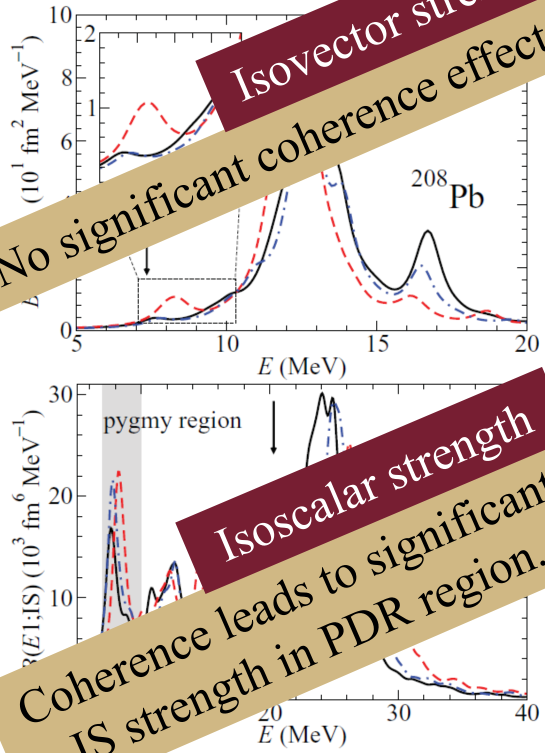




[X. Roca-Maza *et al.*, PRC **85**, 024601 (2012); see also A. Bracco *et al.*, PPNP **106**, 360 (2019)]

An open question – How collective is the PDR?

(What is the single-particle structure of the PDR?)

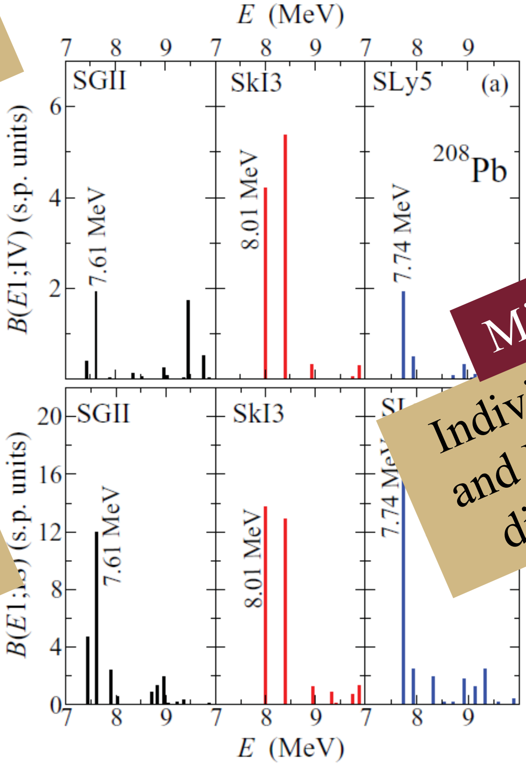


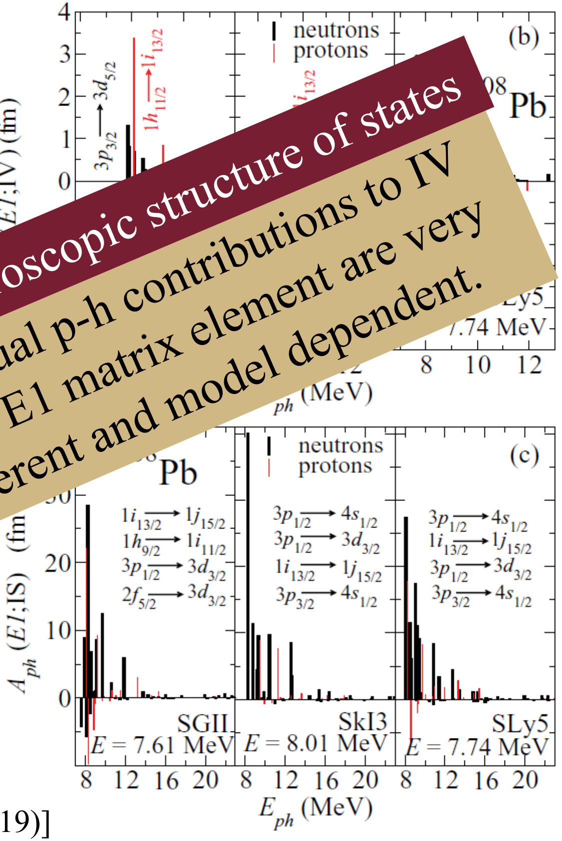
Isovector strength

No significant coherence effects?

Isoscalar strength

Coherence leads to significant IS strength in PDR region.





Microscopic structure of states

Individual p-h contributions to IV and IS E1 matrix element are very different and model dependent.

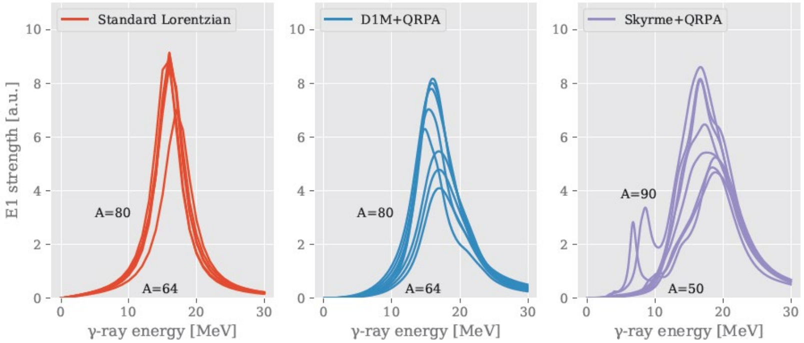
[X. Roca-Maza *et al.*, PRC **85**, 024601 (2012); see also A. Bracco *et al.*, PPNP **106**, 360 (2019)]

Introduction

Existence of PDR can influence (n,γ) rates of nuclei involved in the *r* process

Different theoretical γSF for Zn isotopes

Implemented in TALYS code



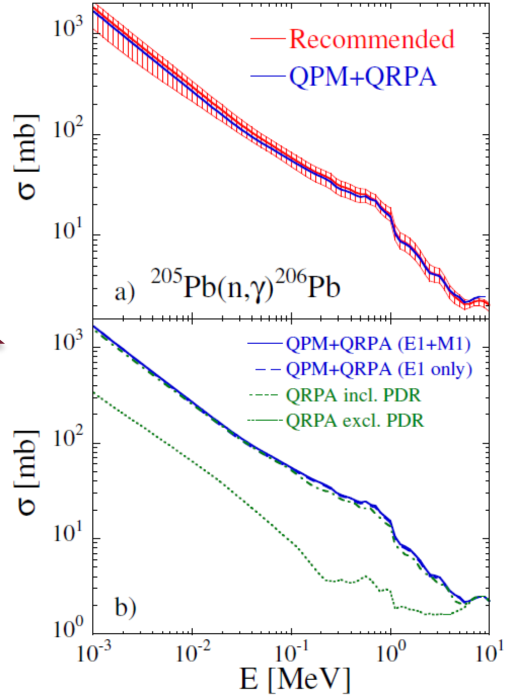
... Some γSFs have no low-lying E1 or M1 component, only a "tail" of the IVGDR.

[**Figure 1:** P. Scholz, PhD thesis, University of Cologne (2019)]
[**Figure 2**: H. Lenske and N. Tsoneva, EPJA **55**, 238 (2019)]
[**Review article:** A.C. Larsen *et al.*, PPNP **107**, 69 (2019)]

Variations of up to a factor of 100!

Influence of the γ-ray strength function

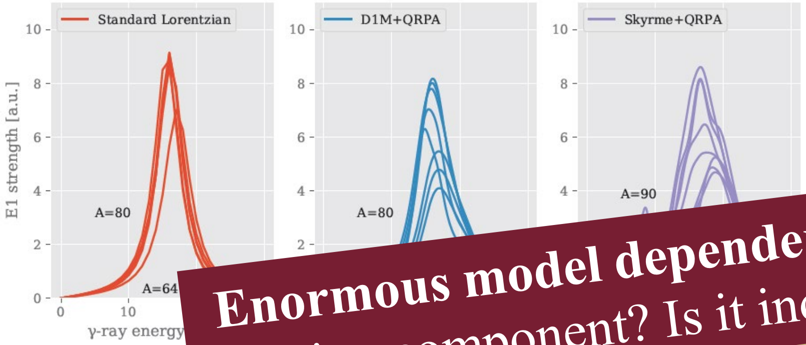
PDR effect!



Existence of PDR can influence (n,γ) rates of nuclei involved in the *r* process

Different theoretical γSF for Zn isotopes

Implemented in TALYS code



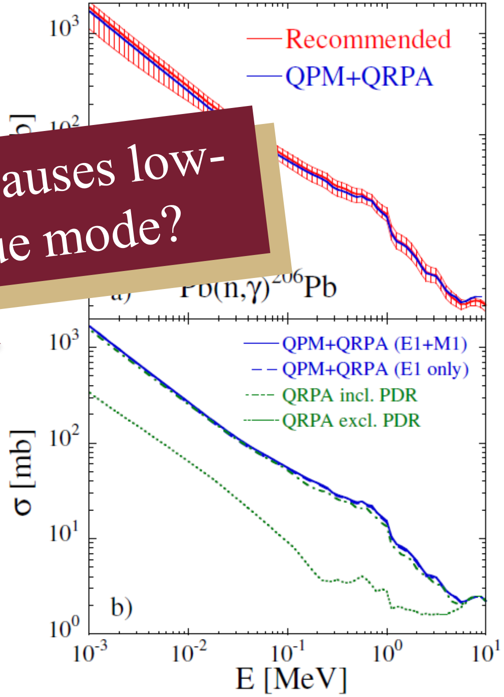
Enormous model dependency! What causes low-lying component? Is it indeed a unique mode?

... Some γSF's have no low-lying E1 or M1 component, only a "tail" of the IVGDR.

Variations of up to a factor of 100!

Influence of the γ-ray strength function

PDR effect!

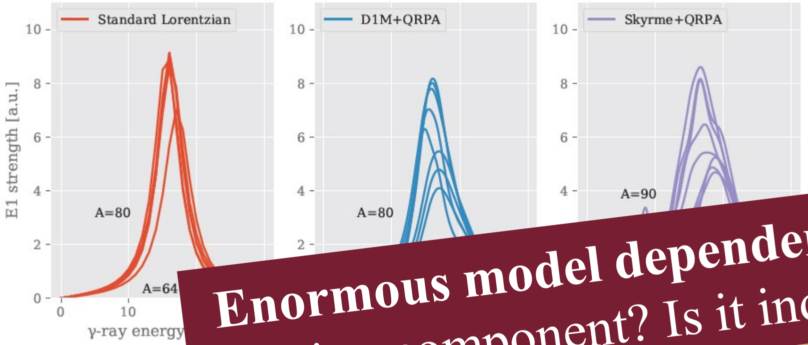


[**Figure 1:** P. Scholz, PhD thesis, University of Cologne (2019)]
[**Figure 2**: H. Lenske and N. Tsoneva, EPJA **55**, 238 (2019)]
[**Review article:** A.C. Larsen *et al.*, PPNP **107**, 69 (2019)]

Existence of PDR can influence (n,γ) rates of nuclei involved in the *r* process

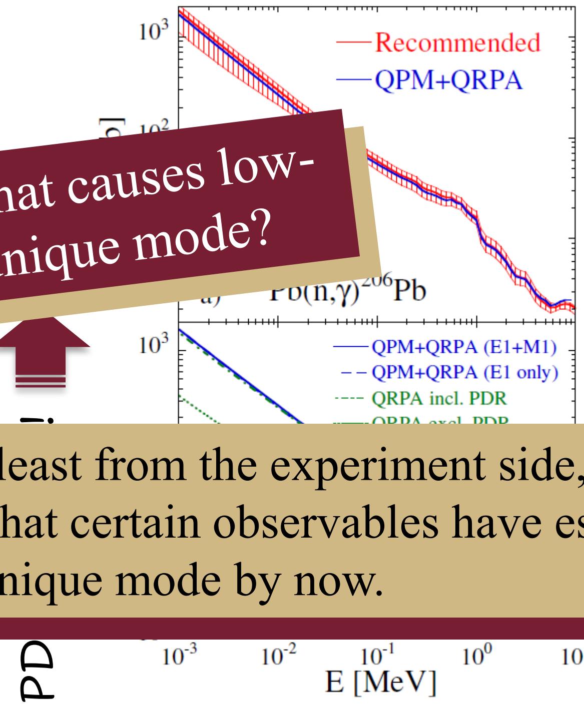
Different theoretical γSF for Zn isotopes

Implemented in TALYS code



Variations of up to a factor of 100!

Influence of the γ-ray strength function



Enormous model dependency! What causes low-lying component? Is it indeed a unique mode?

... Some γSF's have no low-lying E1 or M1 component, only a “tail” IVGDR.

!

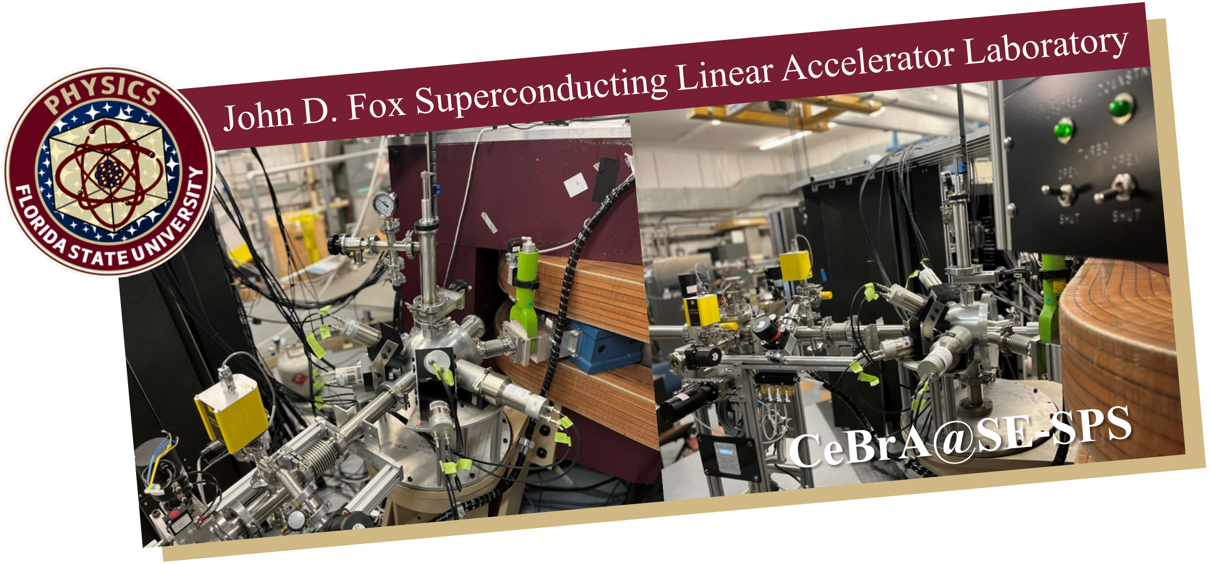
I guess, at least from the experiment side, we can claim that certain observables have established a unique mode by now.

[**Figure 1:** P. Scholz, PhD thesis, University of Cologne
[**Figure 2**: H. Lenske and N. Tsoneva, EPJA **55**, 238 (2019)]
[**Review article:** A.C. Larsen *et al.*, PPNP **107**, 69 (2019)]

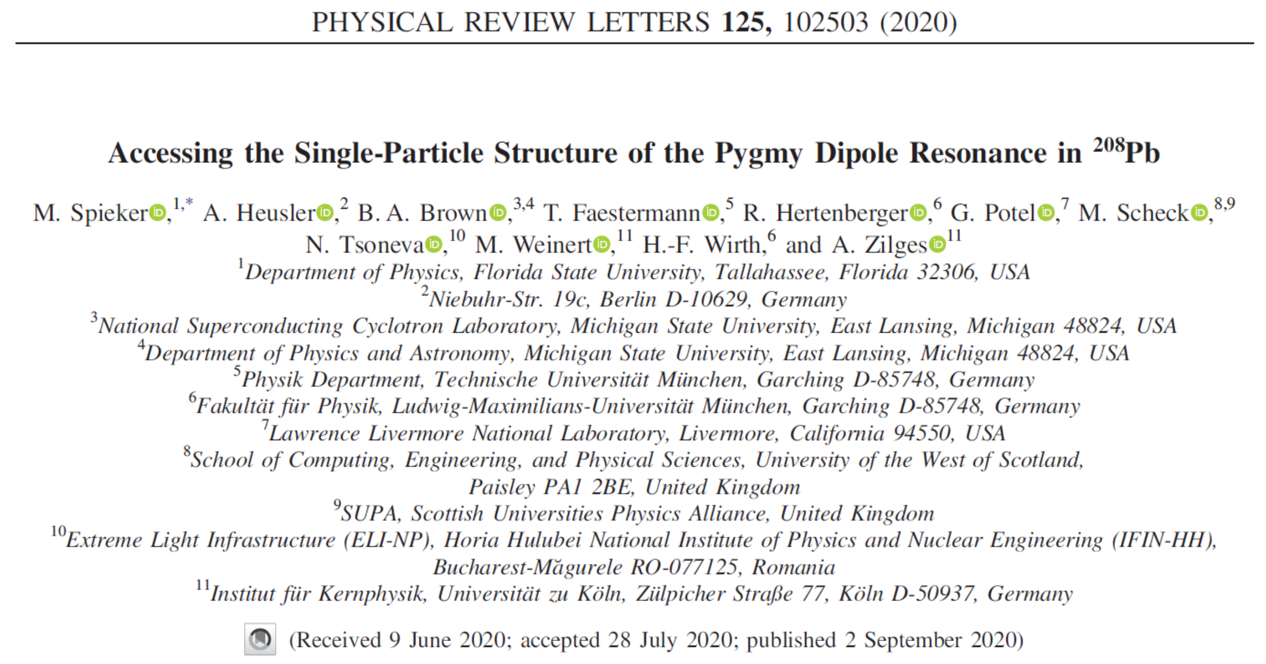
Outline

The single-particle structure of the PDR in ^{208}Pb and the A=50-70 mass region

1) ^{207}Pb(d,p)^{208}Pb with Q3D@MLL (Garching, Germany)
2) ^{47,49}Ti(d,p)^{48,50}Ti and ^{61}Ni(d,p)^{62}Ni at FSU SE-SPS (Tallahassee, Florida)
    - Commissioning of the CeBrA demonstrator for particle-γ coincidence experiments [only an outlook if time left!]



Part I



PHYSICAL REVIEW LETTERS **125,** 102503 (2020)

Accessing the Single-Particle Structure of the Pygmy Dipole Resonance in ^{208}Pb

M. Spieker,[1,*] A. Heusler,[2] B. A. Brown,[3,4] T. Faestermann,[5] R. Hertenberger,[6] G. Potel,[7] M. Scheck,[8,9]
N. Tsoneva,[10] M. Weinert,[11] H.-F. Wirth,[6] and A. Zilges[11]
[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306, USA*
[2] *Niebuhr-Str. 19c, Berlin D-10629, Germany*
[3] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[4] *Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[5] *Physik Department, Technische Universität München, Garching D-85748, Germany*
[6] *Fakultät für Physik, Ludwig-Maximilians-Universität München, Garching D-85748, Germany*
[7] *Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[8] *School of Computing, Engineering, and Physical Sciences, University of the West of Scotland,*
Paisley PA1 2BE, United Kingdom
[9] *SUPA, Scottish Universities Physics Alliance, United Kingdom*
[10] *Extreme Light Infrastructure (ELI-NP), Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH),*
Bucharest-Măgurele RO-077125, Romania
[11] *Institut für Kernphysik, Universität zu Köln, Zülpicher Straße 77, Köln D-50937, Germany*

(Received 9 June 2020; accepted 28 July 2020; published 2 September 2020)

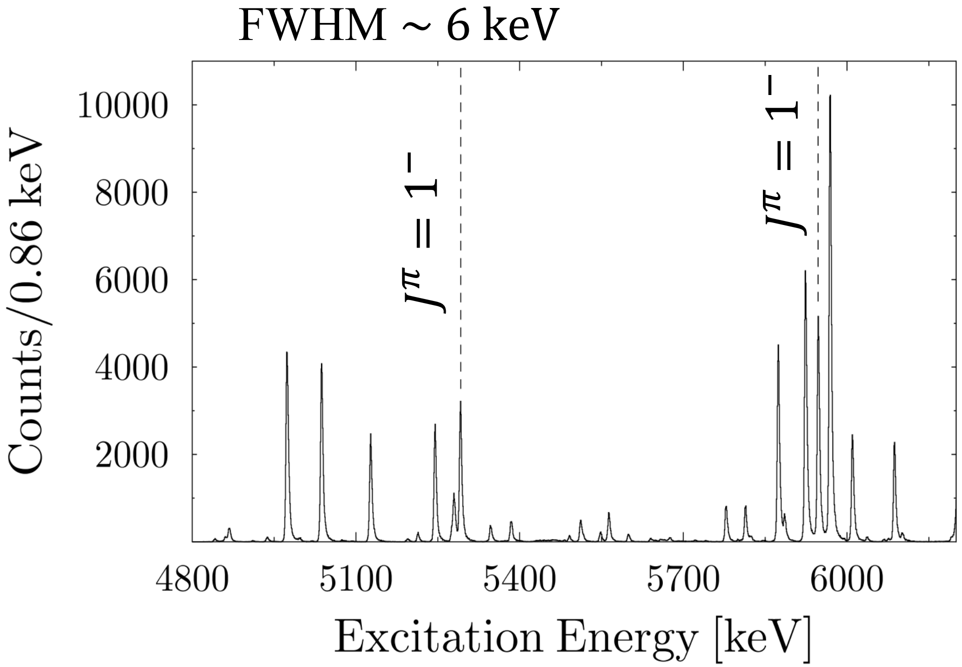
Yes, it is a lockdown paper…

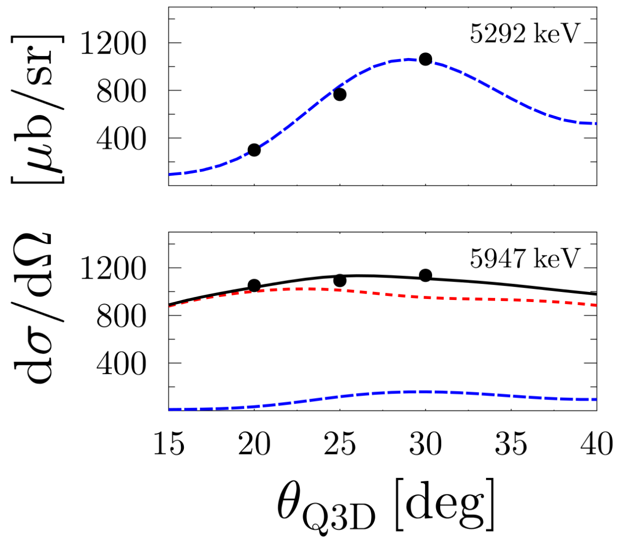
^{207}Pb(d,p)^{208}Pb @ Q3D at MLL (Garching, Germany)

Disclaimer:
(d,p) only populates neutron 1p-1h configurations in even-even nuclei, which can be reached from the ground state of the odd-A nucleus. It is, thus, a very selective probe meaning that not all neutron 1p-1h configurations can be probed in a nucleus and in one experiment.

^{207}Pb(d,p)^{208}Pb @ Q3D at MLL (Garching, Germany)

Experiment





- $E_d = 22$ MeV
- ^{207}Pb target (0.11 mg/cm^2; 99% enrichment) on thin Carbon backing.

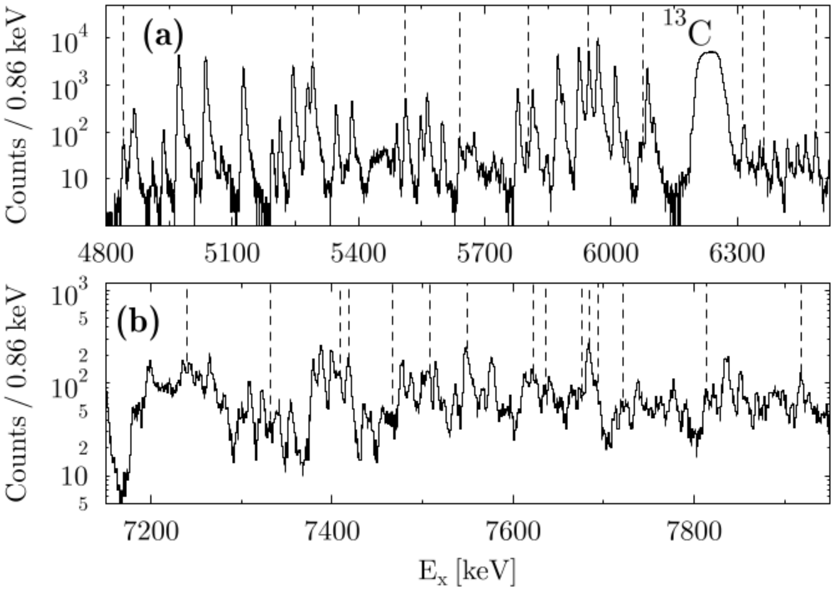
Lines DWBA calculations for:

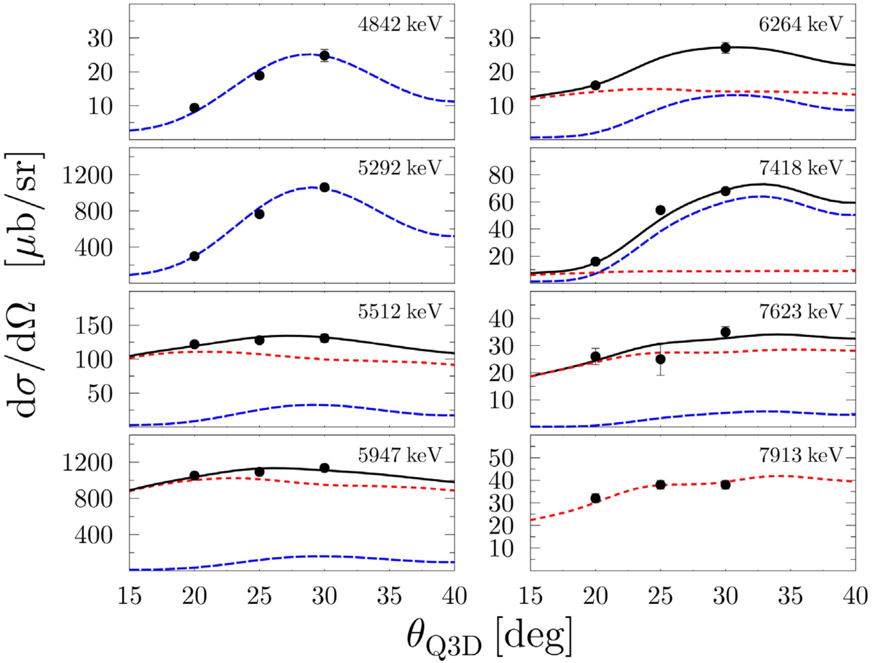
Blue: $(3p_{1/2})^{-1}(4s_{1/2})^{+1}$ $(l = 0)$

Red: $(3p_{1/2})^{-1}(3d_{3/2})^{+1}$ $(l = 2)$

^{207}Pb(d,p)^{208}Pb @ Q3D at MLL (Garching, Germany)

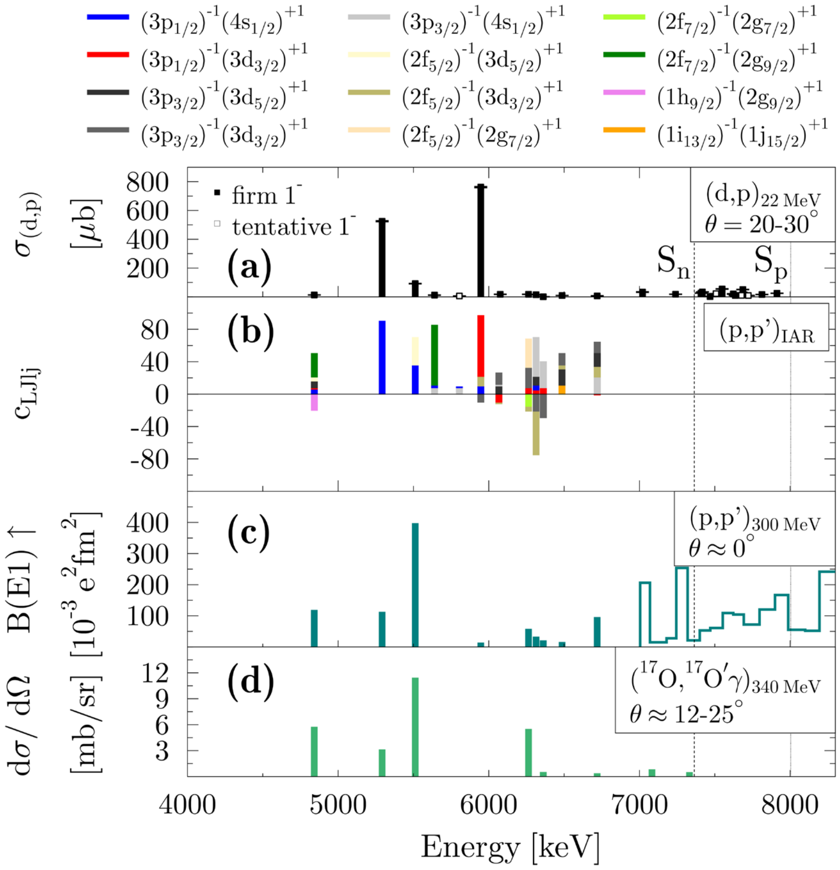
- - - $J^\pi = 1^-$ states





Excitation energies of 1$^-$ states were known from previous experiments.
Calculated angular distributions are in **excellent agreement with data**.

(d,p) and (p,p')$_{\mathrm{IAR}}$ data compared to other probes (Experiment)



Main observations:

Two strong states. Remaining strength fragmented up to S_p.

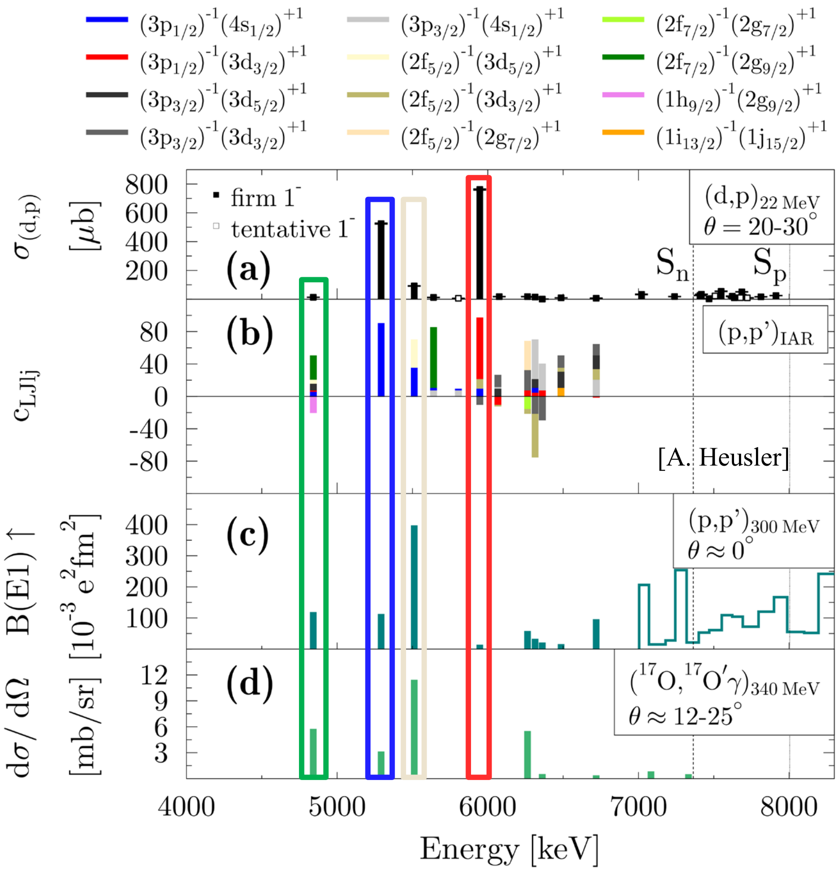
Dominant fragments for some p-h excitations at "low" E_x. In general, strength is fragmented among several states.

One dominating state but significant IV strength below S_n. (PDR < 8.3 MeV?)

IS strength below S_n carried by four states.

[(p,p')$_{300\ \mathrm{MeV}}$: I. Poltoratska *et al.*, PRC **85**, 041304(R) (2012)]
[(^{17}O,^{17}O'γ): F.C.L. Crespi *et al.*, PRL **113**, 012501 (2014)]
[(p,p')$_{\mathrm{IAR}}$ analysis: A. Heusler]

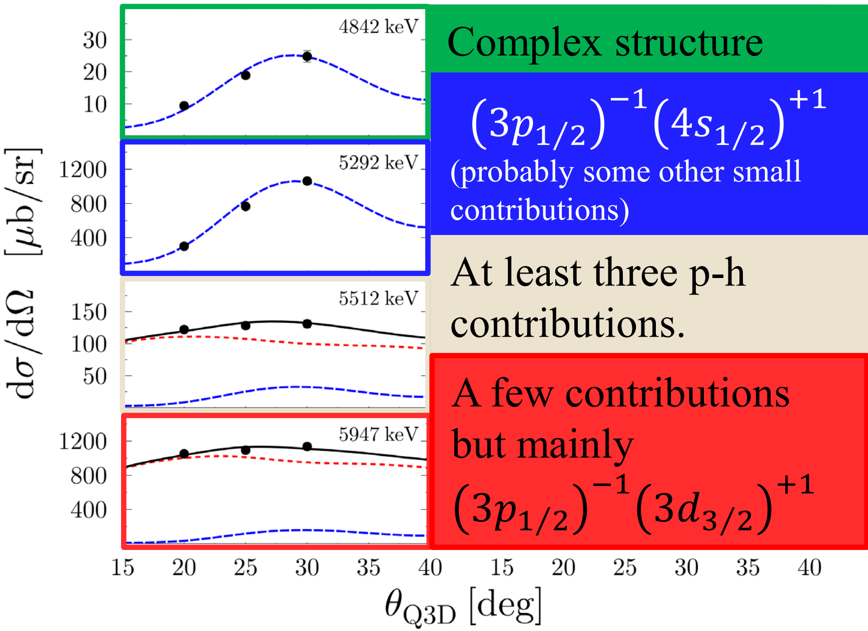
(d,p) and (p,p')$_{\mathrm{IAR}}$ data compared to other probes (Experiment)



Detailed spectroscopy can provide access to some of the p-h E1 matrix elements.

Provide an idea about cancellation effects.

(d,p) angular distributions



Complex structure

$(3p_{1/2})^{-1}(4s_{1/2})^{+1}$

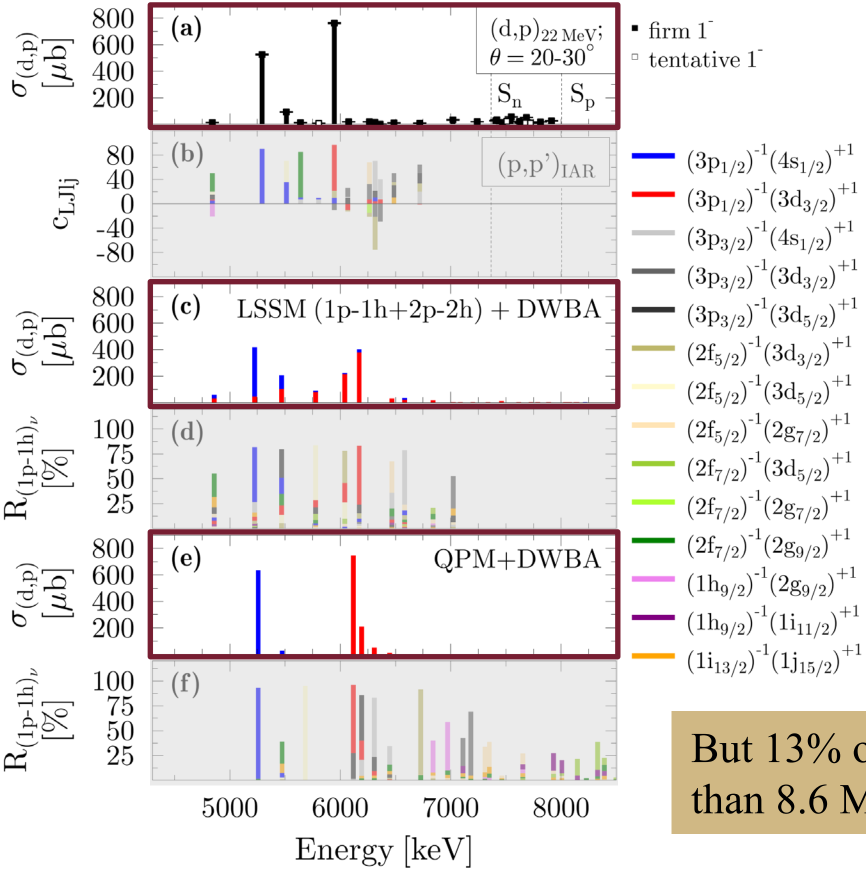
(probably some other small contributions)

At least three p-h contributions.

A few contributions but mainly $(3p_{1/2})^{-1}(3d_{3/2})^{+1}$

Experimental observables compared to LSSM and QPM calculations

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]



- Below S_n:

$$\sum \sigma_{(d,p);\text{exp.}} = 1524(17)\ \mu b$$

$$\sum \sigma_{(d,p);\text{LSSM}} = 1470\ \mu b$$

$$\sum \sigma_{(d,p);\text{QPM}} = 1676\ \mu b$$

✓

- Above S_n and up to S_p:

$$\sum \sigma_{(d,p);\text{exp.}} = 254(9)\ \mu b$$

$$\sum \sigma_{(d,p);\text{LSSM}} = 22\ \mu b$$

✗

But 13% of $d_{3/2}$ and 9% of $s_{1/2}$ pushed to energies higher than 8.6 MeV (LSSM).

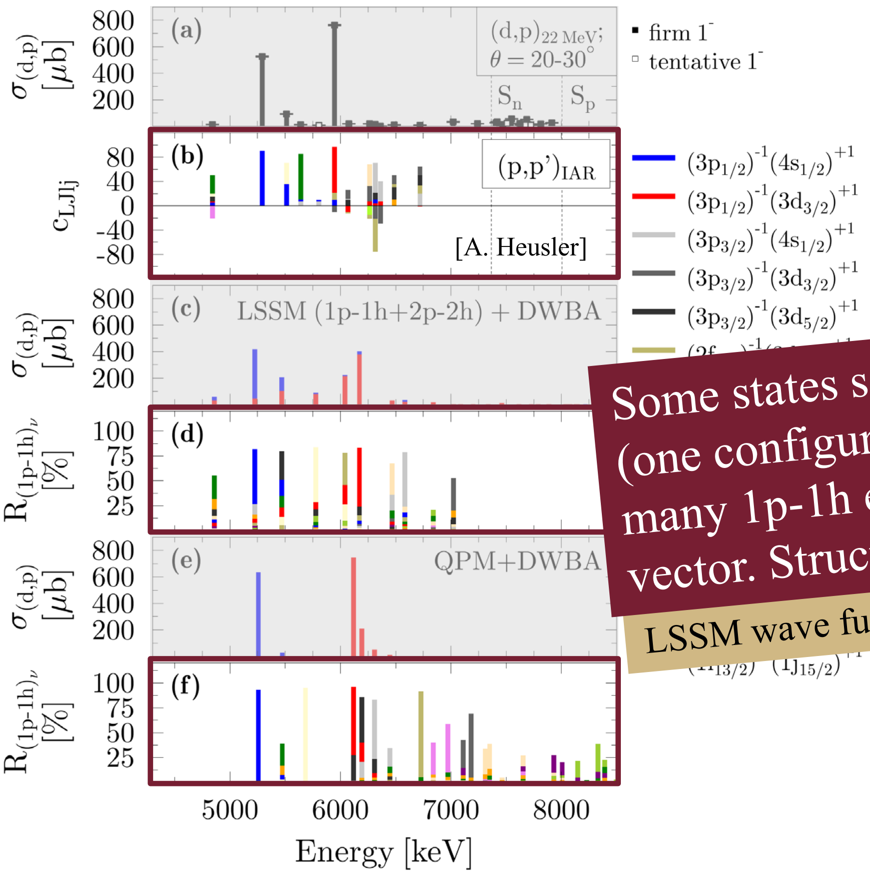
@S_n ~ 99 μb, @S_p ~ 82 μb.

7% ($d_{3/2}$) and 3.4% ($s_{1/2}$) are fragmented in QPM.

Results

Experimental observables compared to LSSM and QPM calculations

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]



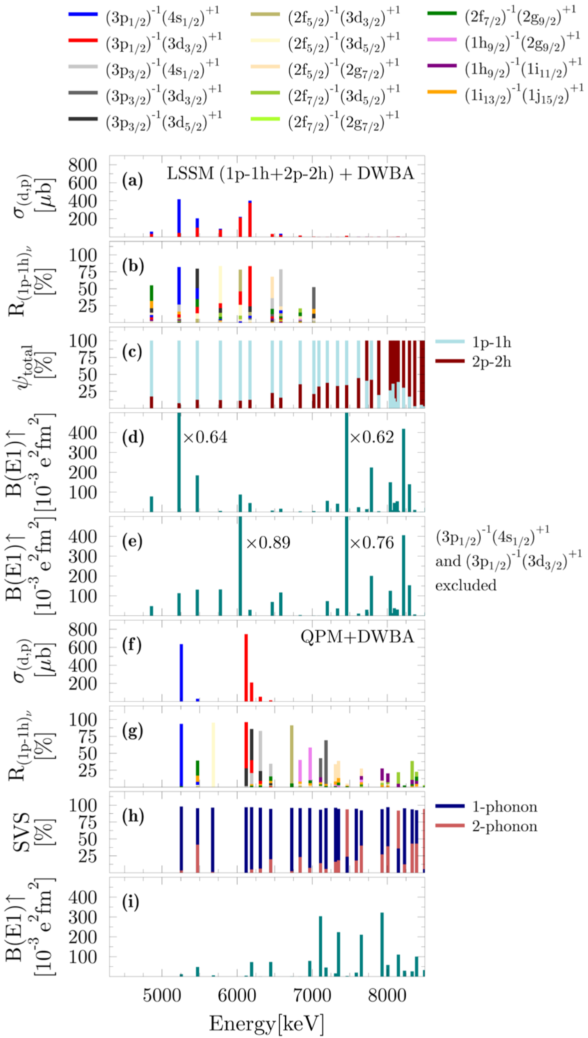
Microscopic structure:

Some states seem to be rather pure 1p-1h excitations (one configuration clearly dominates), others have many 1p-1h excitations contributing to their state vector. Structures become more complex at higher E_x.

LSSM wave functions more complex than QPM.

Comparison LSSM and QPM

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]



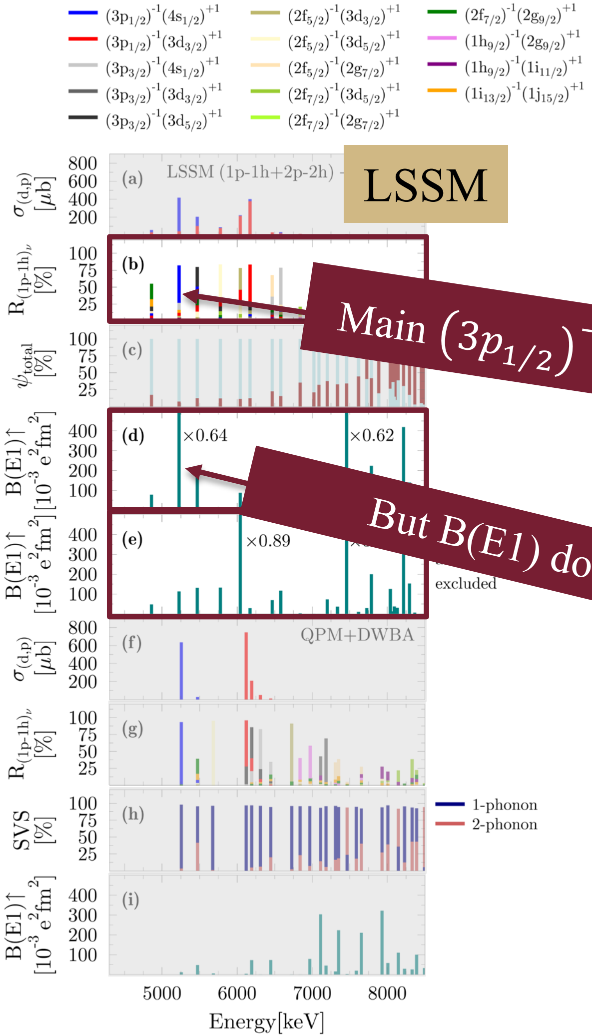
Lots of information in this graph. I will only highlight a few things. Happy to discuss details with anyone who is interested.

[M. Spieker *et al.*, PRL **125**, 102503 (2020)]

Comparison LSSM and QPM

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]

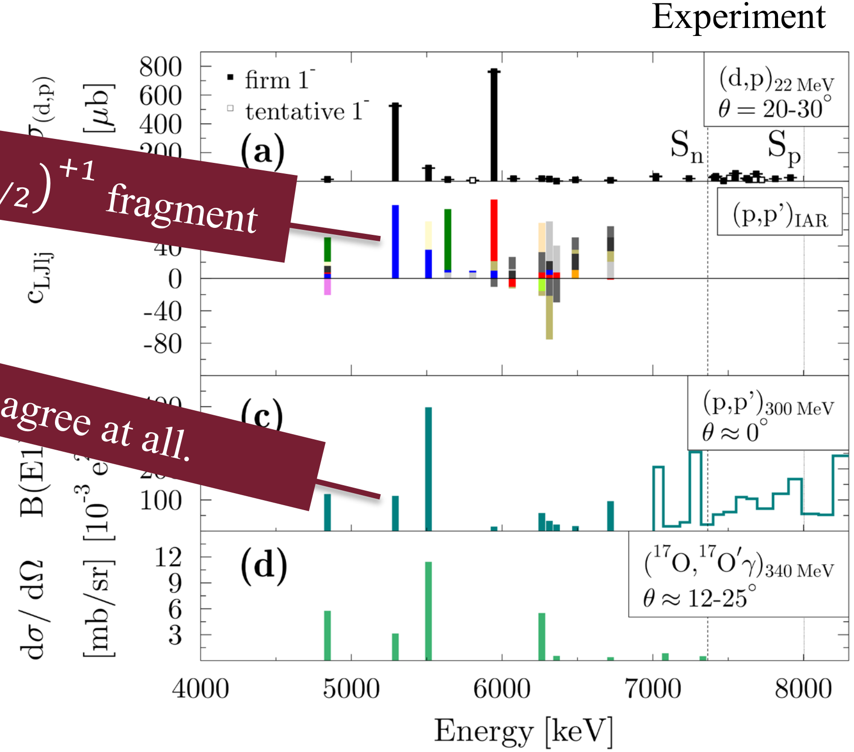
Results



Main $(3p_{1/2})^{-1}(4s_{1/2})^{+1}$ fragment

But B(E1) does not agree at all.

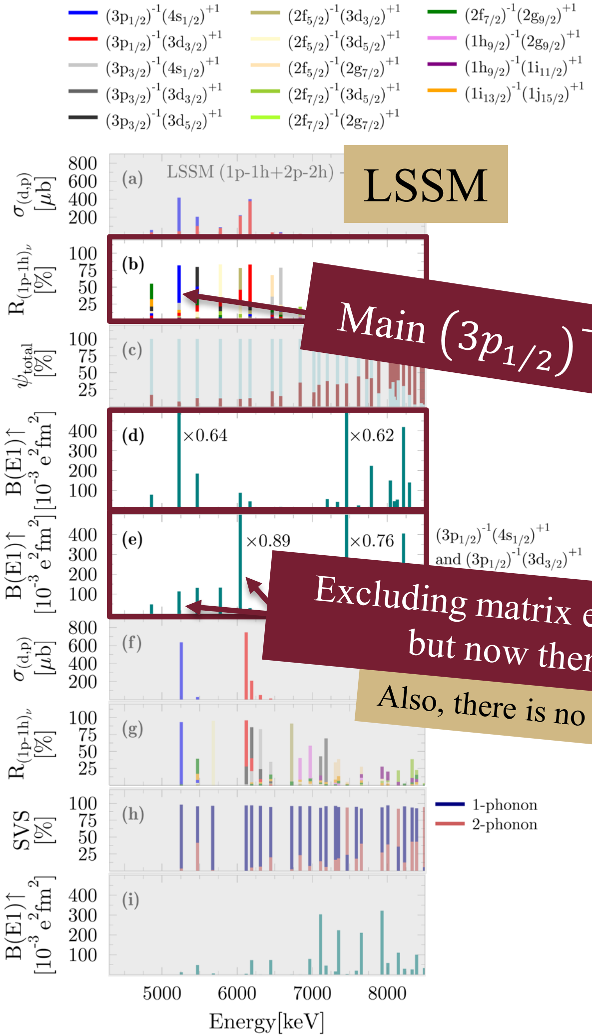
Experiment

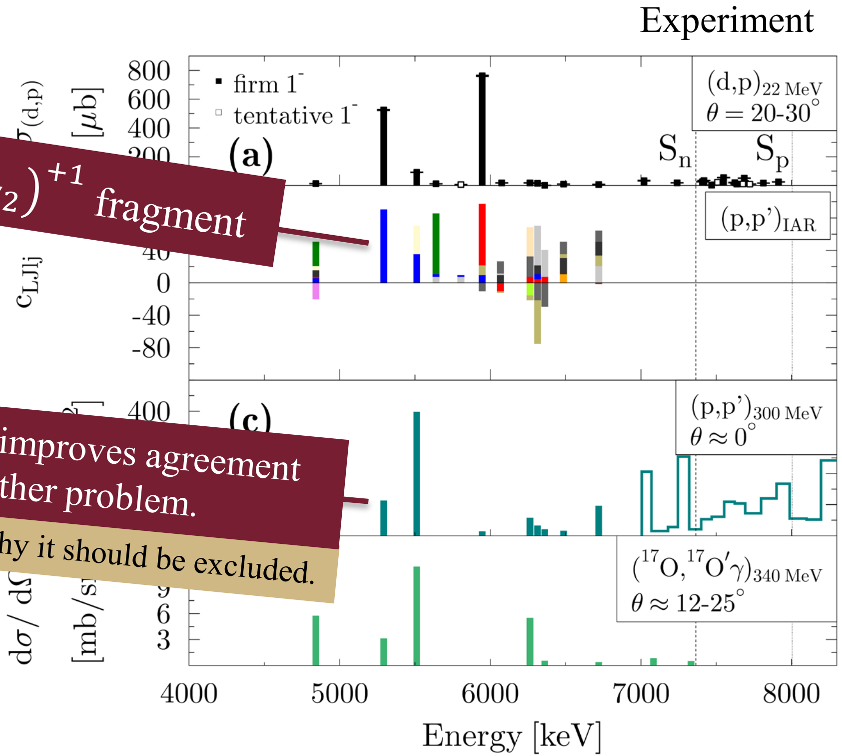


Comparison LSSM and QPM

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]

Results





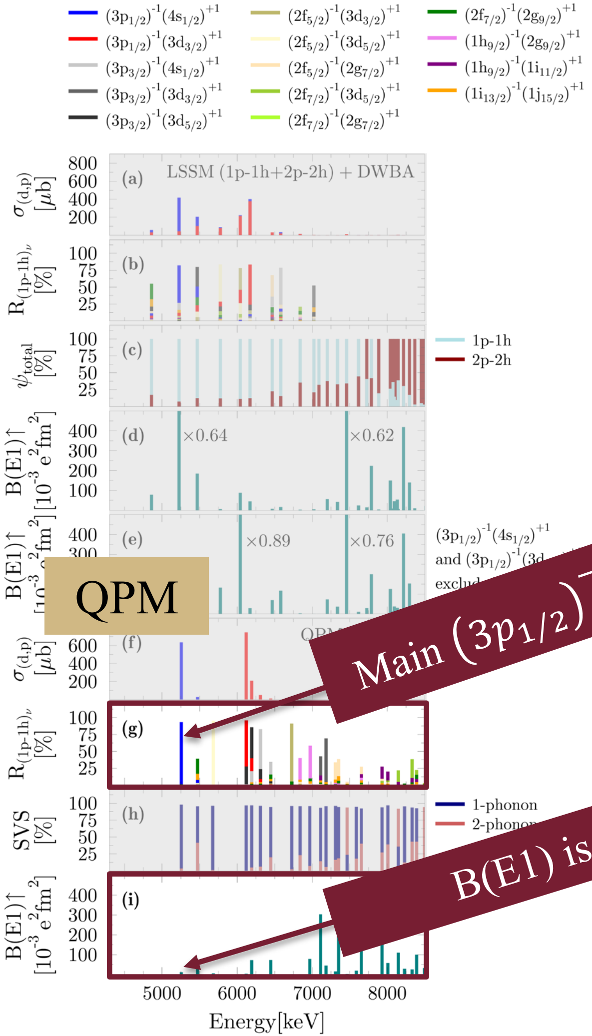
Main $(3p_{1/2})^{-1}(4s_{1/2})^{+1}$ fragment

Excluding matrix element improves agreement but now there is another problem.

Also, there is no reason why it should be excluded.

Comparison LSSM and QPM

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]

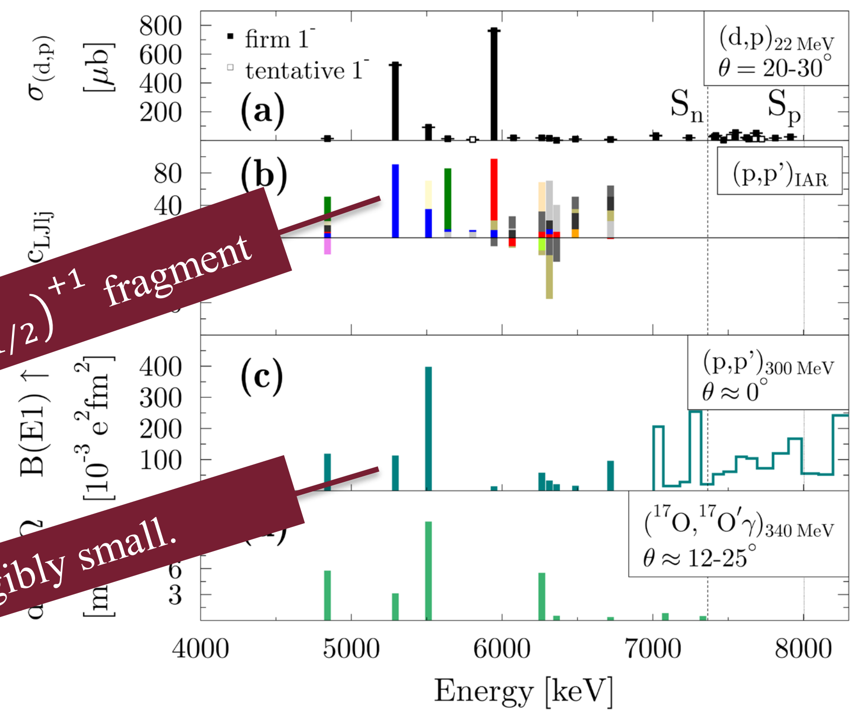


QPM

Main $(3p_{1/2})^{-1}(4s_{1/2})^{+1}$ fragment

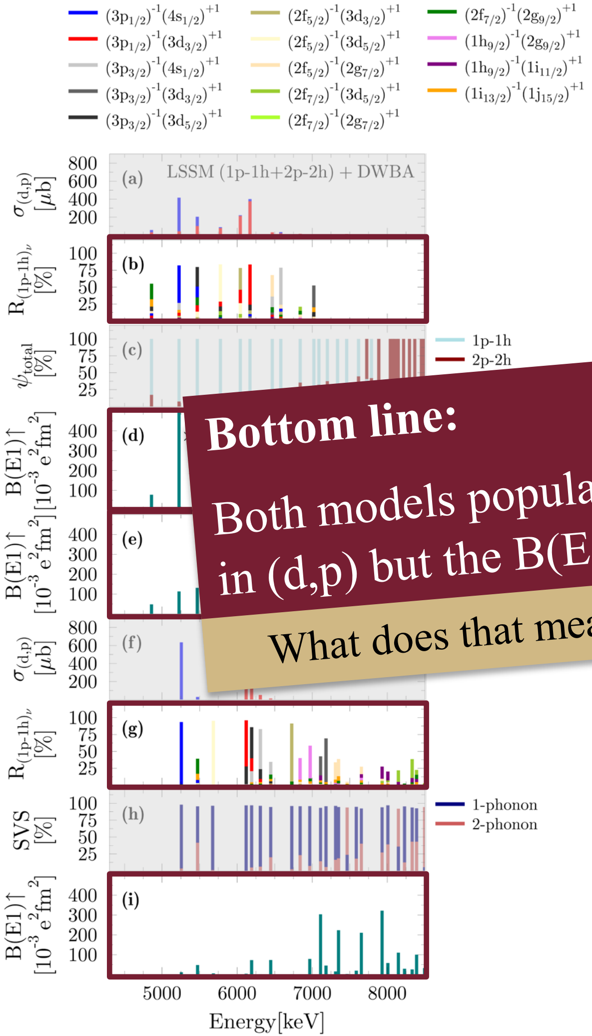
B(E1) is negligibly small.

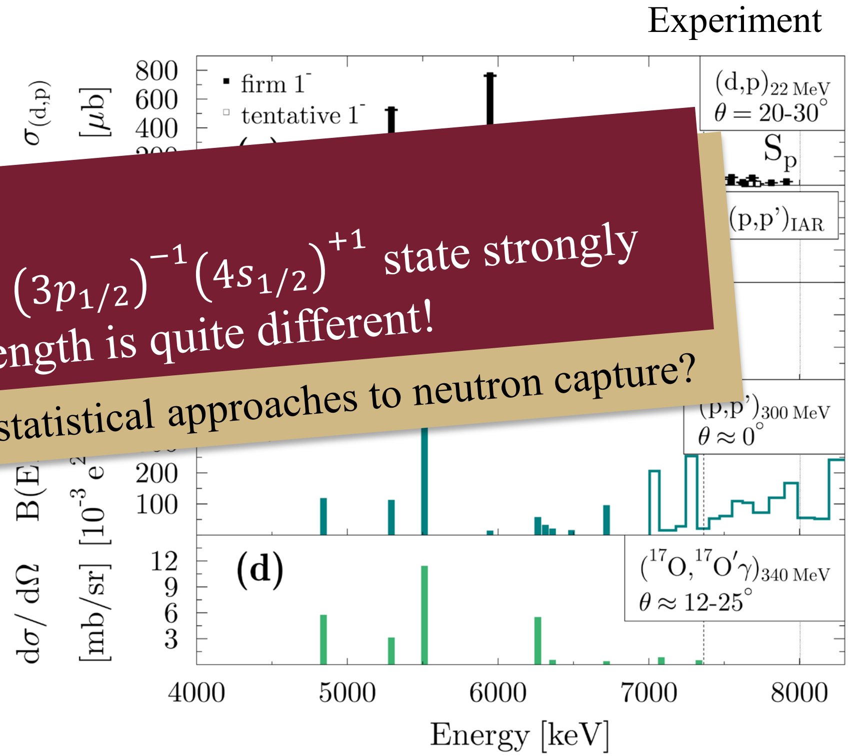
Experiment



Comparison LSSM and QPM

[B.A. Brown (LSSM) and N. Tsoneva (QPM)]



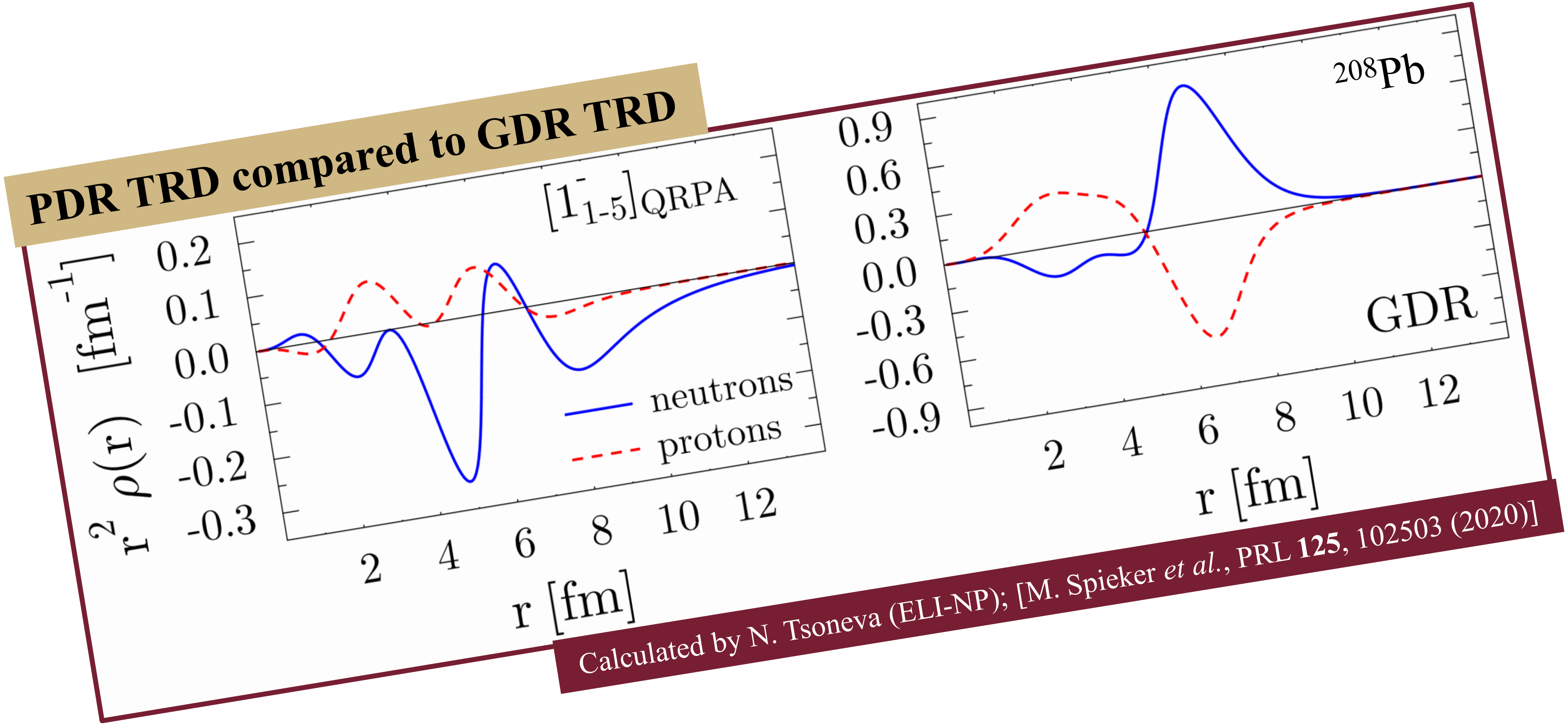


Bottom line:

Both models populate the $(3p_{1/2})^{-1}(4s_{1/2})^{+1}$ state strongly in (d,p) but the B(E1) strength is quite different!

What does that mean for statistical approaches to neutron capture?

PDR or just 1p-1h? Neutron skin or toroidal or something entirely different?

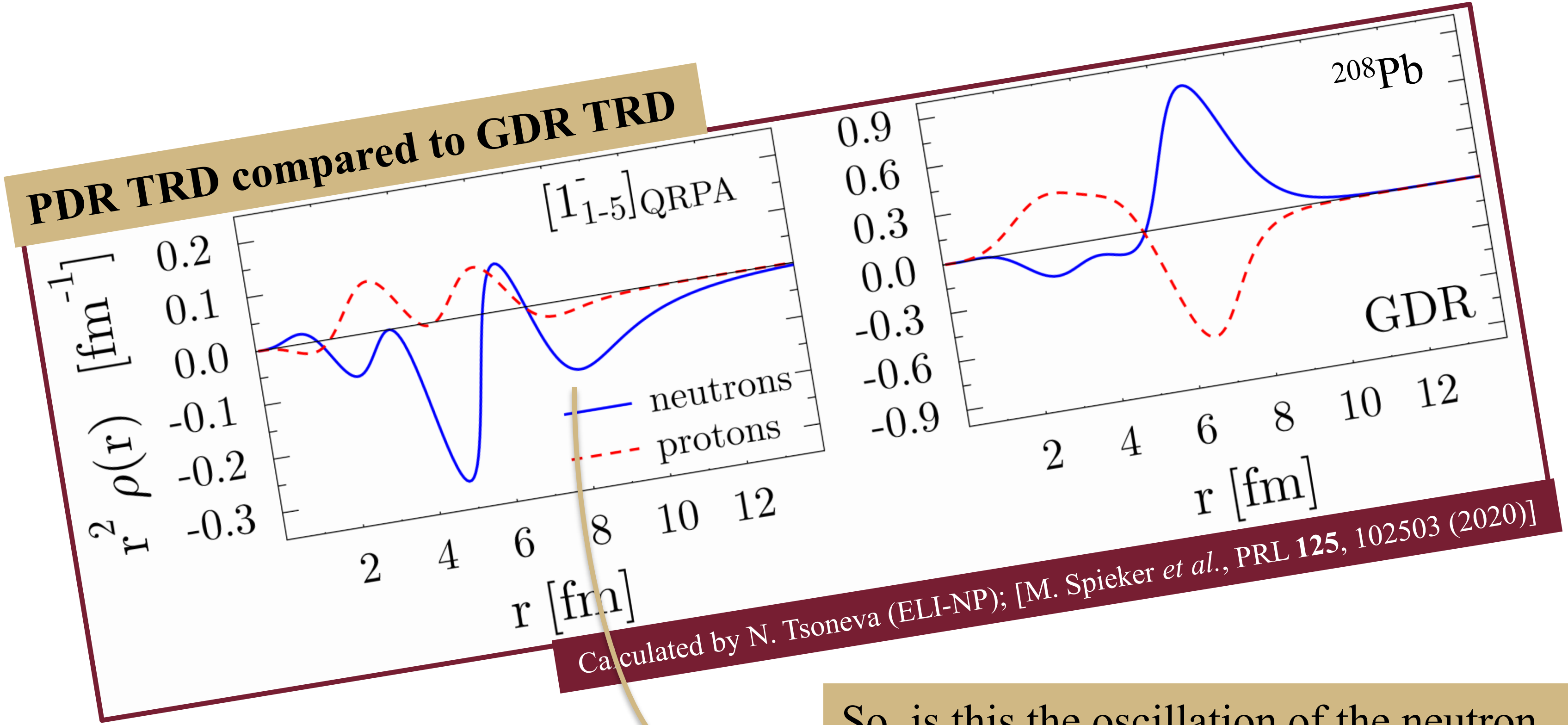


PDR TRD compared to GDR TRD

Calculated by N. Tsoneva (ELI-NP); [M. Spieker *et al.*, PRL **125**, 102503 (2020)]

PDR or just 1p-1h? Neutron skin or toroidal or something entirely different?

PDR TRD compared to GDR TRD

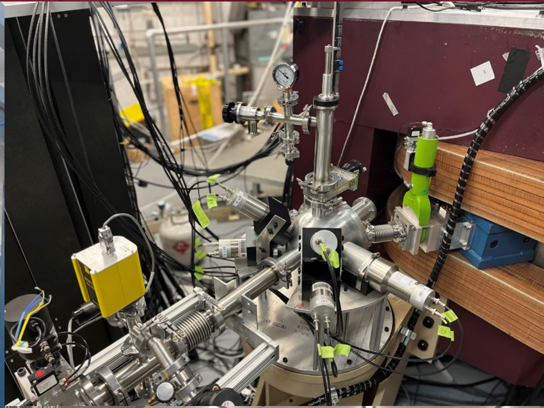


Calculated by N. Tsoneva (ELI-NP); [M. Spieker *et al.*, PRL **125**, 102503 (2020)]

So, is this the oscillation of the neutron skin? The jury is still out.

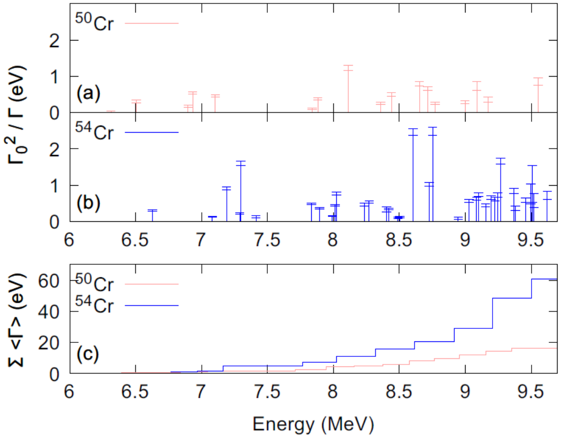
Part II

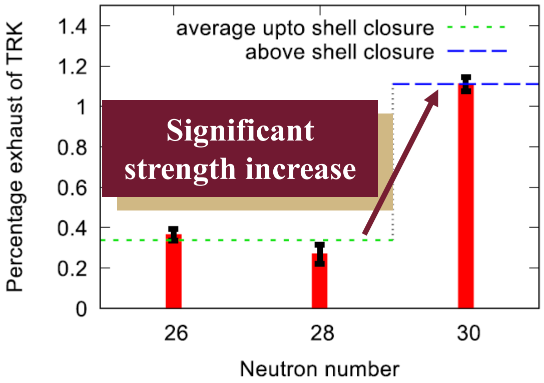
(d,p) and (d,pγ) experiments with the FSU SE-SPS and CeBrA



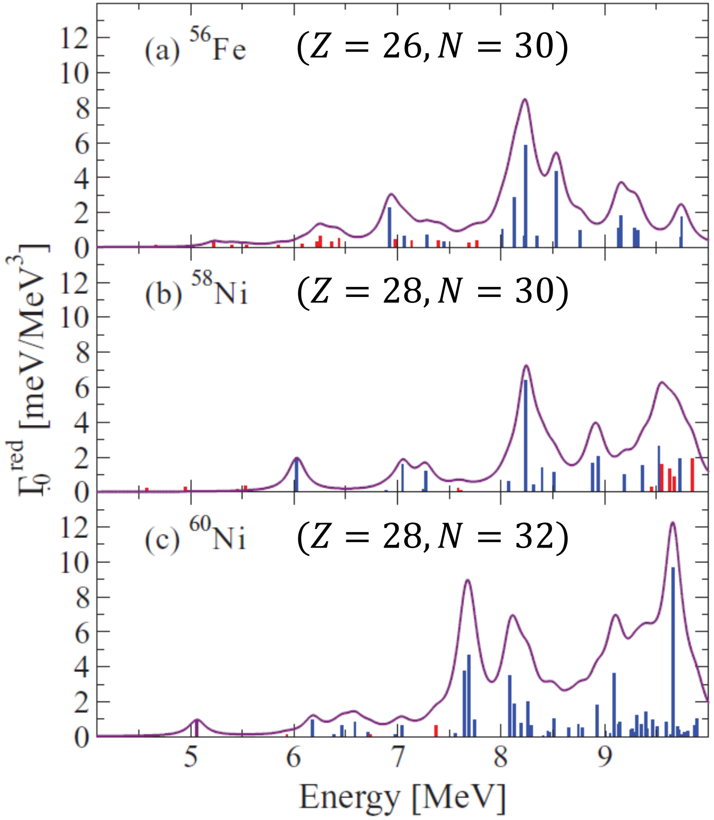
E1 strength increase beyond $N = 28$ – Onset of a PDR?

(Word of caution: These results are for resolved states!)





Significant strength increase

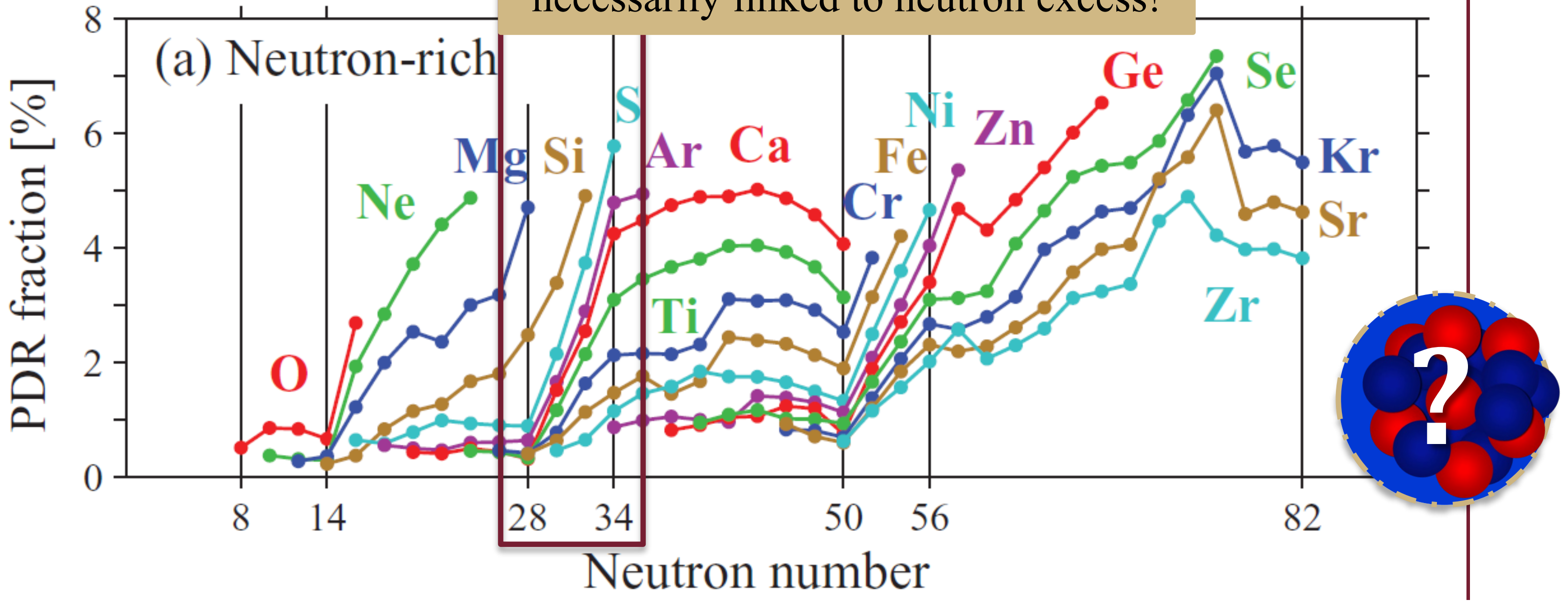


[P. Ries *et al.*, PRC **100**, 021301(R) (2019) and M. Scheck *et al.*, PRC **88**, 044304 (2013)]

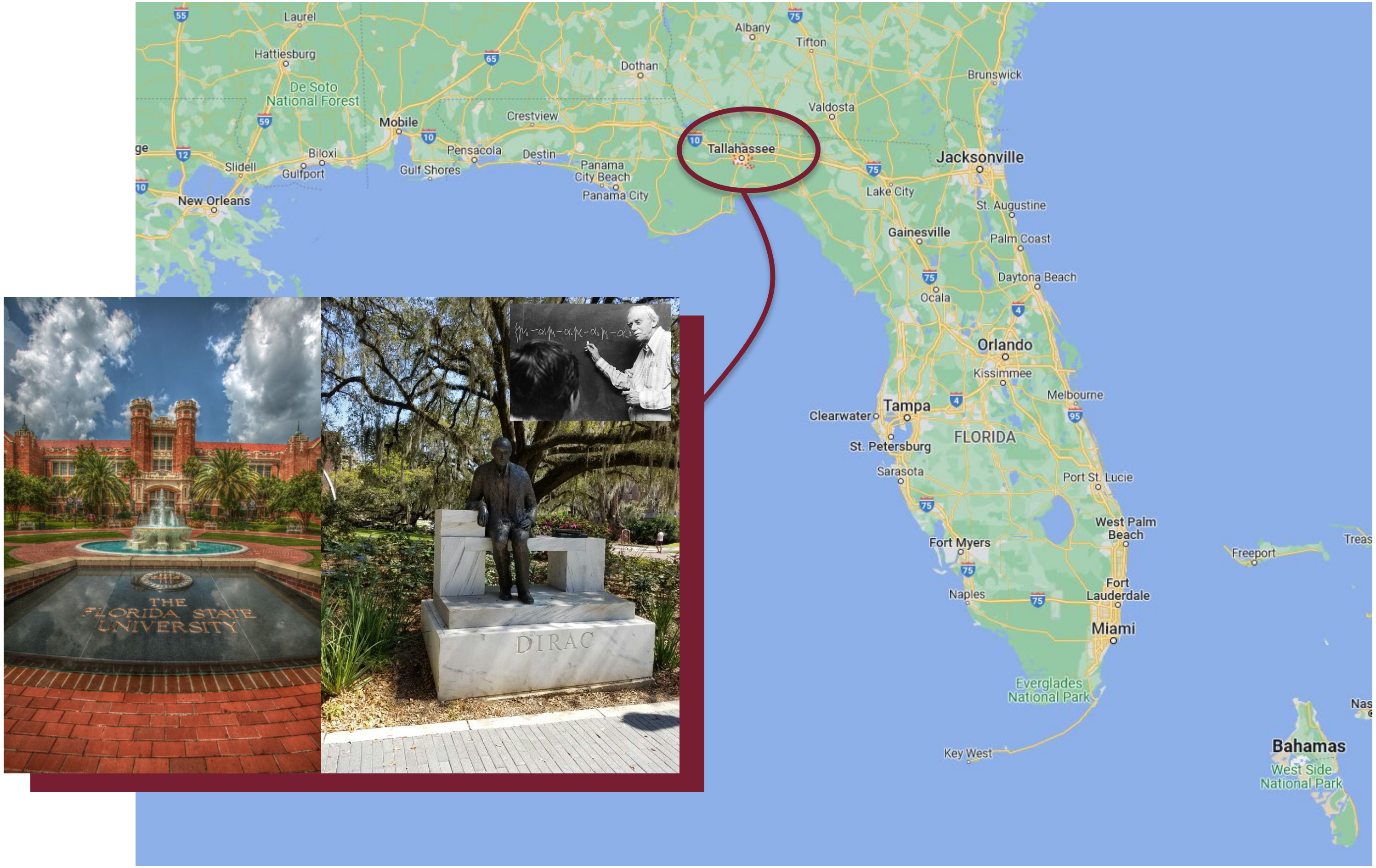
The microscopic structure of the PDR and its influence on the B(E1) distribution

The *E*1 strength of the PDR strongly depends on the position of the Fermi level and **shows a clear correlation with the occupation of the orbits with the orbital angular momenta less than 3ℏ ($l \leq 2$).** We also found a strong correlation between the isotopic dependence of the neutron skin thickness and the pygmy dipole strength. [T. Inakura *et al.*, PRC **84**, 021302(R) (2011)]

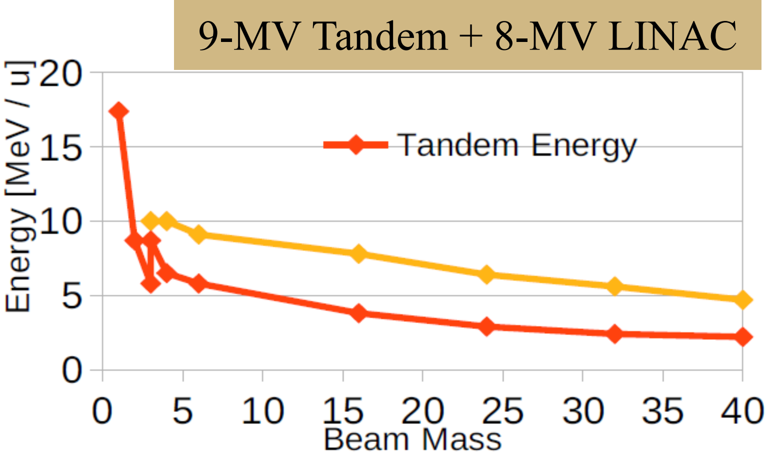
Strength increase is predicted and not necessarily linked to neutron excess!



Physics at FSU and the John D. Fox Laboratory

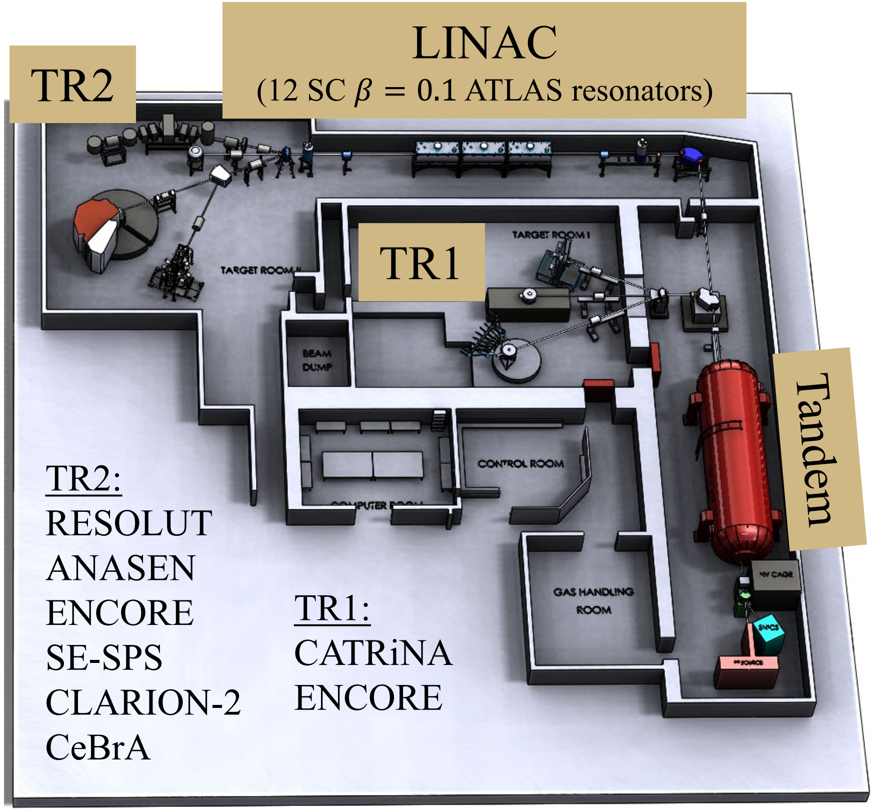


The John D. Fox Laboratory at Florida State University



Four main experimental programs:

- In-flight radioactive beams with RESOLUT
- High-resolution spectroscopy with Super-Enge Split-Pole Spectrograph (SE-SPS)
- CLARION-2 Clover γ-ray array (w. ORNL)
- Neutron detection with CATRiNA

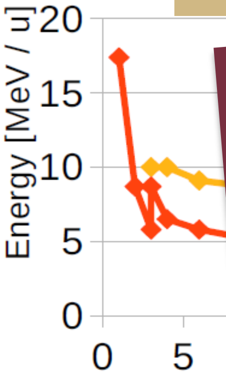


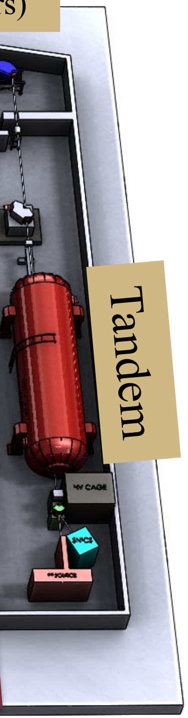
TR2:
RESOLUT
ANASEN
ENCORE
SE-SPS
CLARION-2
CeBrA

TR1:
CATRiNA
ENCORE

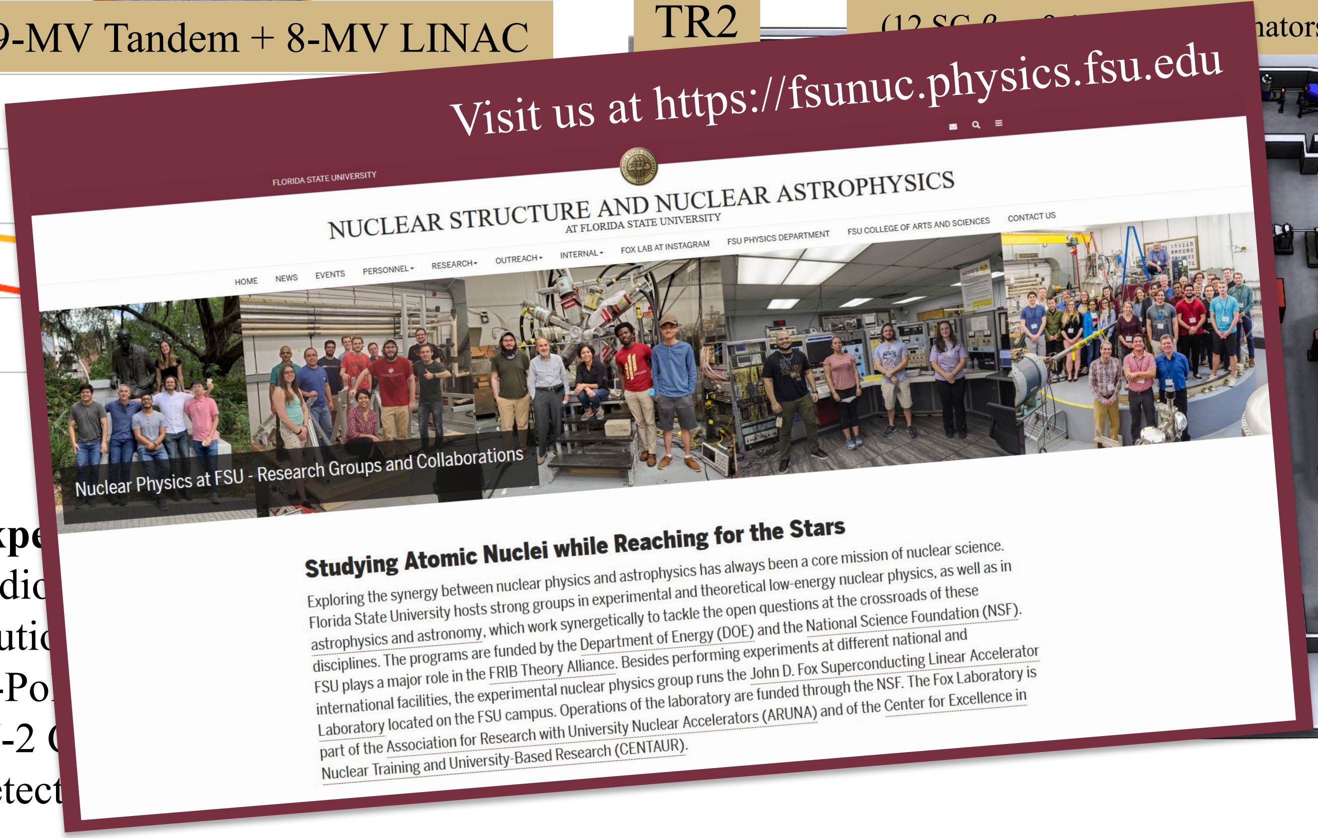
The John D. Fox Laboratory at Florida State University

9-MV Tandem + 8-MV LINAC





Visit us at https://fsunuc.physics.fsu.edu



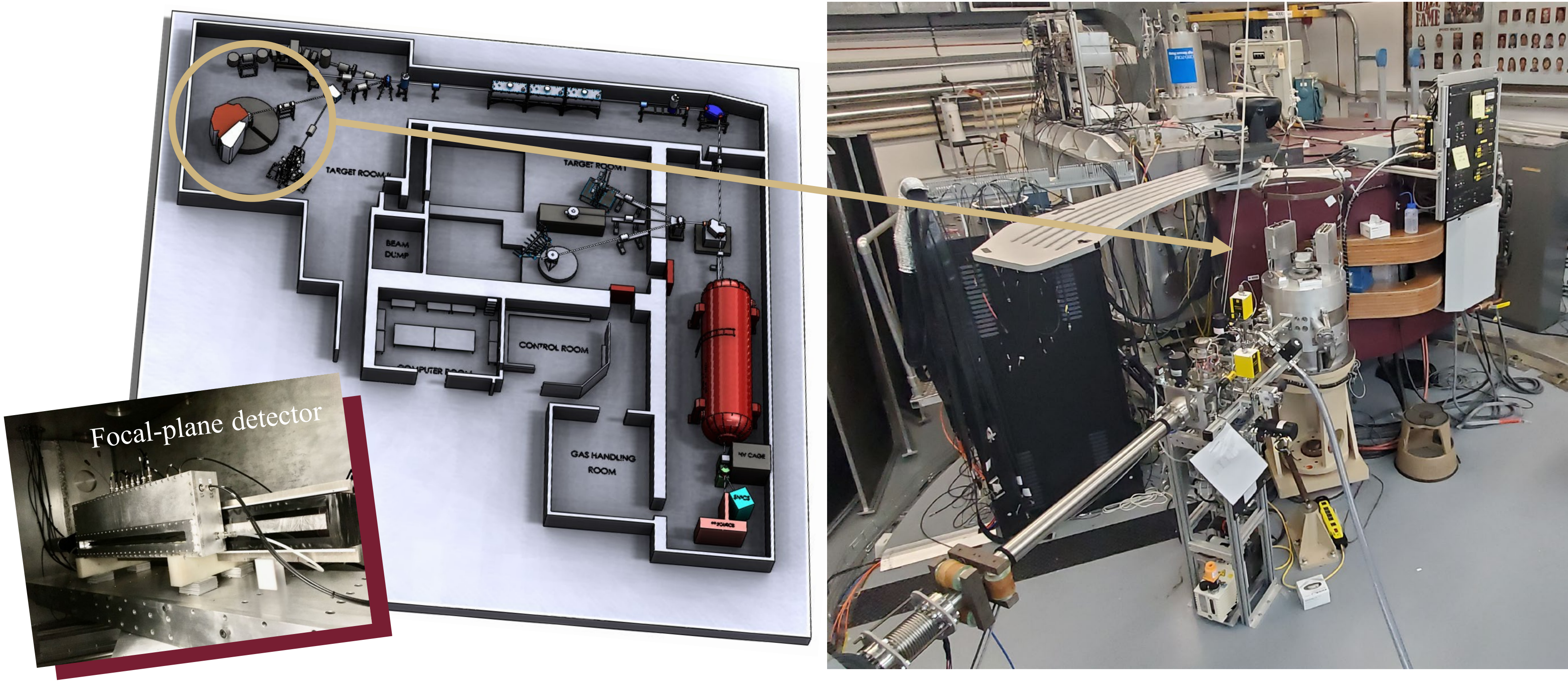
Studying Atomic Nuclei while Reaching for the Stars

Exploring the synergy between nuclear physics and astrophysics has always been a core mission of nuclear science. Florida State University hosts strong groups in experimental and theoretical low-energy nuclear physics, as well as in astrophysics and astronomy, which work synergetically to tackle the open questions at the crossroads of these disciplines. The programs are funded by the Department of Energy (DOE) and the National Science Foundation (NSF). FSU plays a major role in the FRIB Theory Alliance. Besides performing experiments at different national and international facilities, the experimental nuclear physics group runs the John D. Fox Superconducting Linear Accelerator Laboratory located on the FSU campus. Operations of the laboratory are funded through the NSF. The Fox Laboratory is part of the Association for Research with University Nuclear Accelerators (ARUNA) and of the Center for Excellence in Nuclear Training and University-Based Research (CENTAUR).

Four main expe

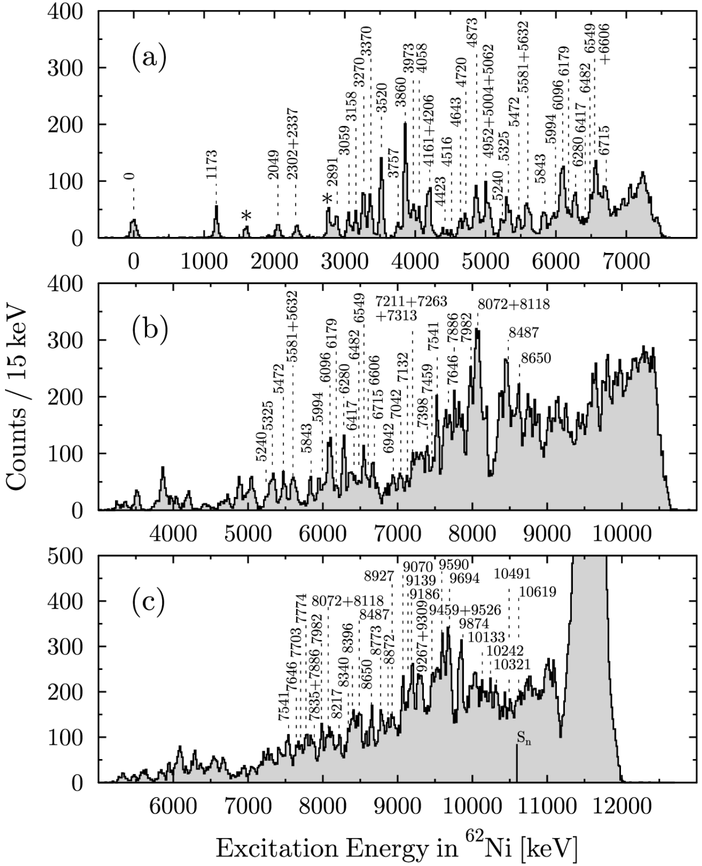
- In-flight radic
- High-resolutic
  Enge Split-Po
- CLARION-2 (
- Neutron detect

The Super-Enge Split-Pole Spectrograph @ FSU John D. Fox Laboratory

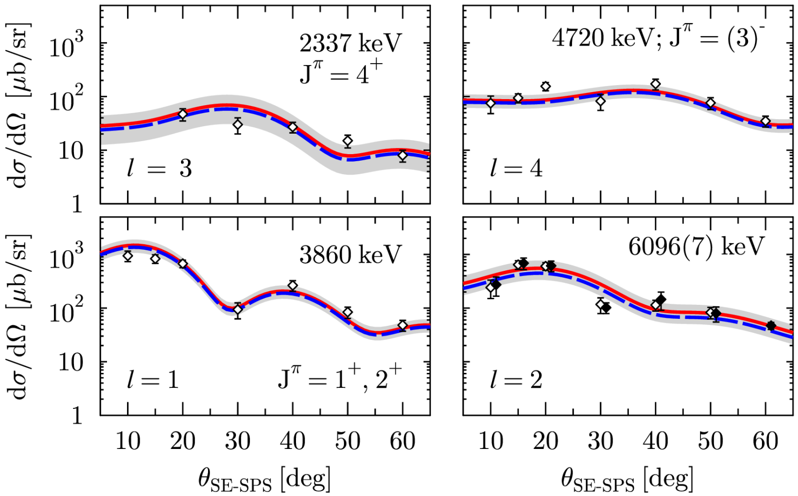


Solid-angle acceptance comparable to Q3D, larger momentum acceptance, but energy resolution is worse by a factor of two or more (target and kinematics dependence).

^{61}Ni(d,p)^{62}Ni at $E_d = 16$ MeV with FSU SE-SPS

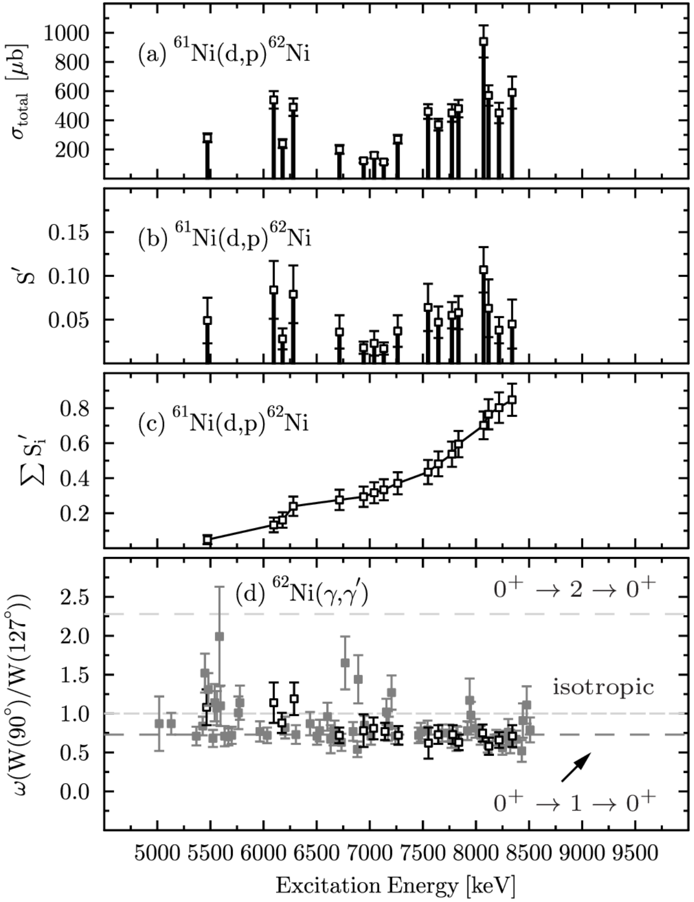


[MS *et al.*, submitted for publication (2023)]



- Three magnetic settings to cover excitation-energy range up to neutron-separation threshold.
- Angular distributions measured from 10° to 60°.
- (γ,γ') data from Cologne group to identify $J = 1$ states up to 8.5 MeV.
- $J^\pi = 1^-$ states populated through $l = 2$ transfers in (d,p) from $J^\pi = 3/2^-$ ground state of ^{61}Ni.

Results for possible PDR states populated in ^{61}Ni(d,p)^{62}Ni



[MS *et al.*, submitted for publication (2023)]

- Intensity ratios from ^{62}Ni(γ,γ') were used to identify $J = 1$ states up to 8.5 MeV.
  [T. Schüttler, M. Müscher, A. Zilges, *et al.*]
- 17 $J^{\pi} = 1^{-}$ candidates populated in ^{61}Ni(d,p)^{62}Ni through $l = 2$ angular momentum transfers.

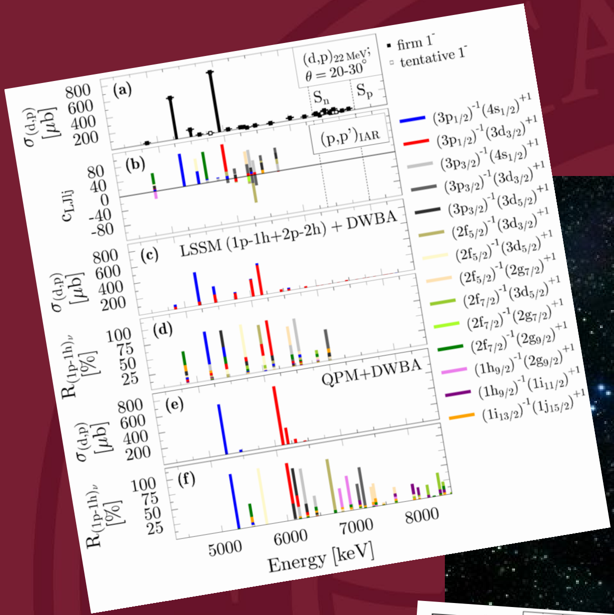
→ No $l = 0$ transfers were observed below S_n!

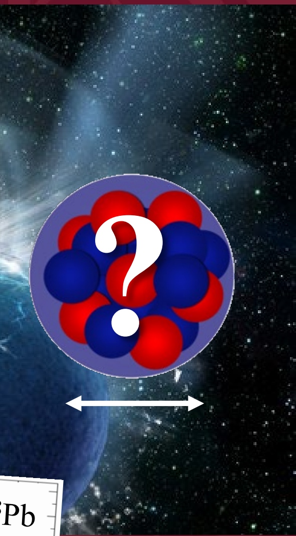
→ Consequently, if E1 strength increases further in ^{62}Ni (N=34) and if Inakura's predictions are correct, then $(2p_{3/2})^{-1}(2d_{5/2})^{+1}$ and $(2p_{3/2})^{-1}(2d_{3/2})^{+1}$ need to be responsible for the strength increase.

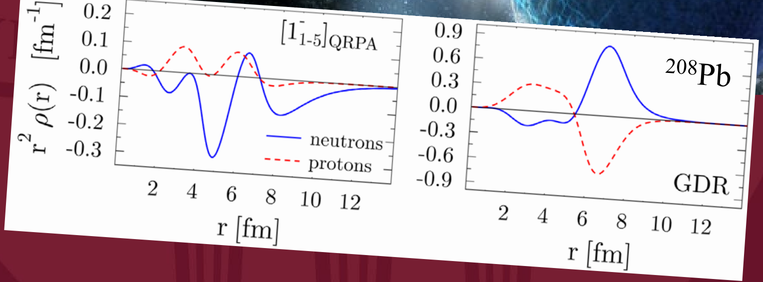
- ^{62}Ni(γ,γ') up to threshold will show whether strength increases further and whether more 1^{-} states, populated in (d,p) and (γ,γ'), can be identified.
- Detailed theoretical calculations will then be needed (LSSM, SSRPA, RQTBA+PVC, QPM, …).

FLORIDA STATE
UNIVERSITY

Conclusions & Outlook







Conclusions

- One-nucleon transfer experiments [here (d,p)] can provide important information on the microscopic components of the PDR wave functions.

→ Getting these microscopic components right is critical to understand the generation of low-lying E1 strength and to predict it correctly.

→ Incorrect nuclear structure might lead to incorrect E1 distribution (γSF) and, thus, (maybe) incorrect predictions for (n,γ) rates.

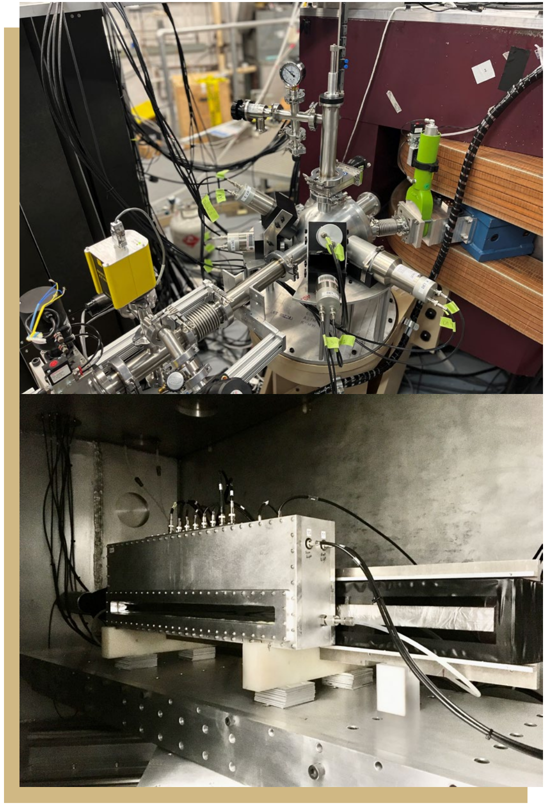
→ PDR E1 strength seems to be intimately connected to certain 1p-1h structures.

→ Immediate question: Is the PDR only a part of the ground-state γSF?

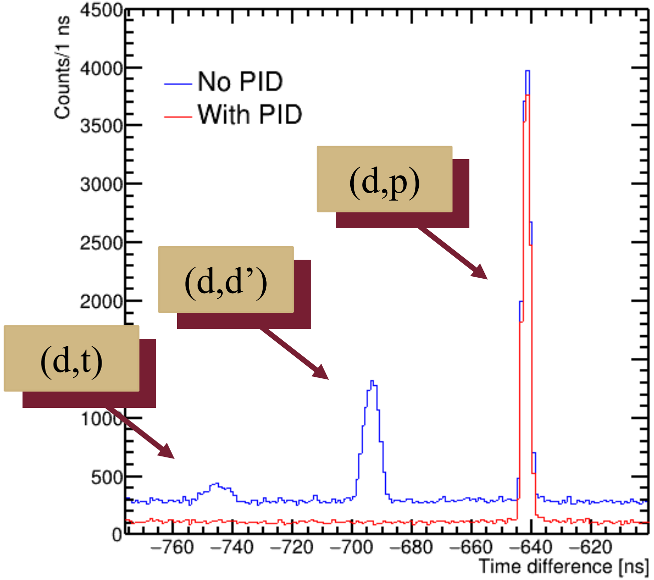
- Different stable-beam facilities (e.g., UoC, iThemba, RCNP, FSU, TU Darmstadt, HZ Dresden-Rossendorf, HIγS, ELI-NP) allow to continue the detailed structure studies of the PDR across the nuclear chart in “conventional” experiments.

- FRIB, RIKEN, FAIR, HIE-ISOLDE give access to more neutron-rich nuclei.

Commissioning of CeBrA demonstrator for particle-γ coincidence experiments

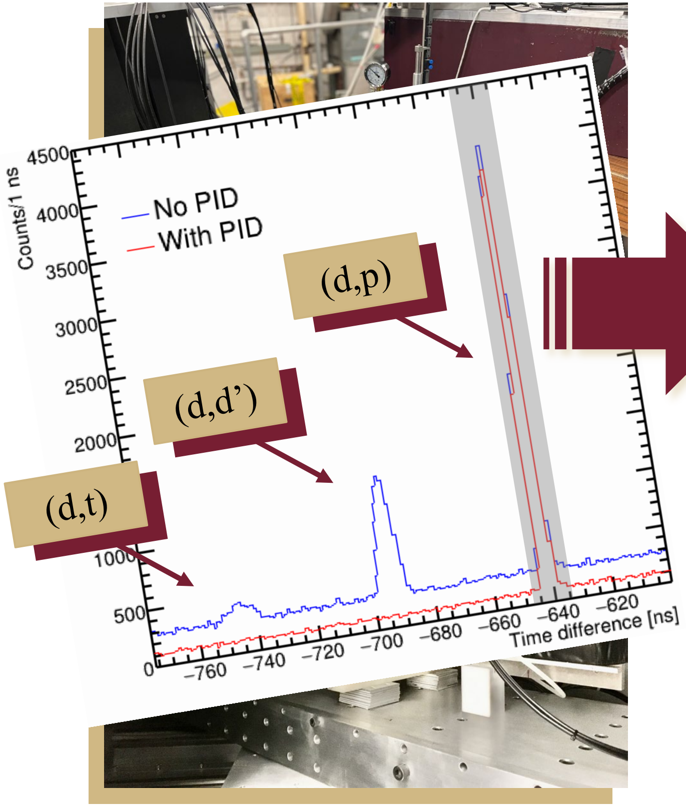


Coincidence timing between CeBr$_3$ γ-ray detectors and focal-plane scintillator.

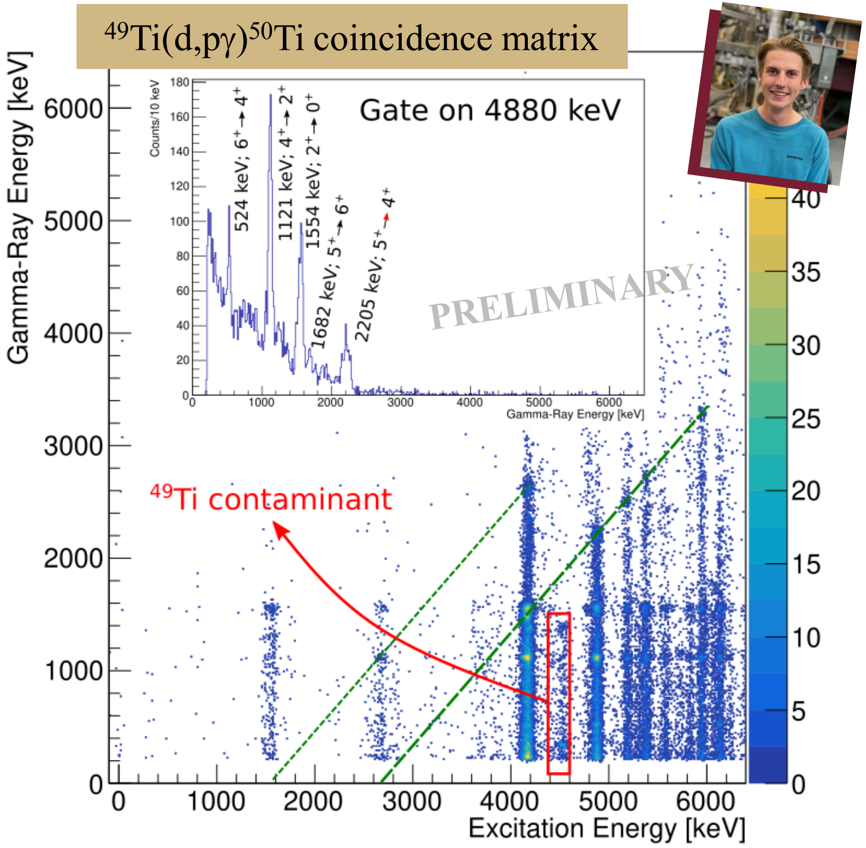


PID eliminates prompt events resulting from other reactions. To eliminate random background, further timing gates are needed.

Commissioning of CeBrA demonstrator for particle-γ coincidence experiments



^{49}Ti(d,pγ)^{50}Ti coincidence matrix

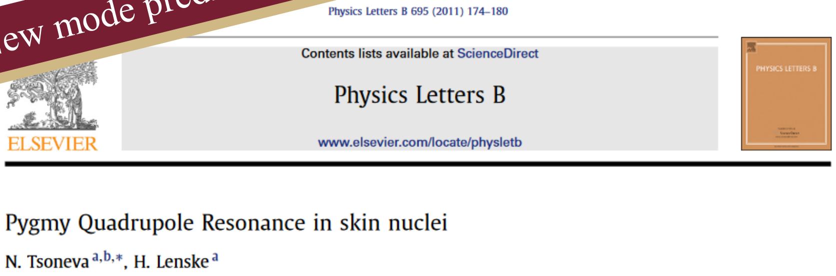


With prompt timing correlation gate.

Collective or not? Universal mode? Other multipolarities present?

A side note

New mode predicted (2011)



Physics Letters B 695 (2011) 174–180

Contents lists available at ScienceDirect

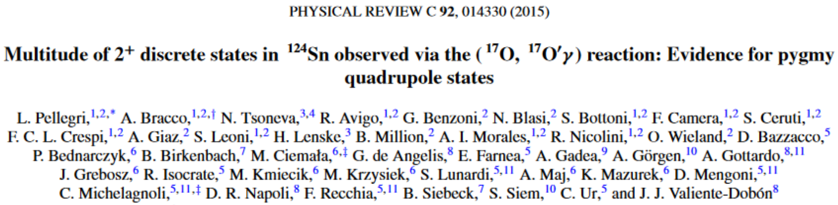
Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Pygmy Quadrupole Resonance in skin nuclei

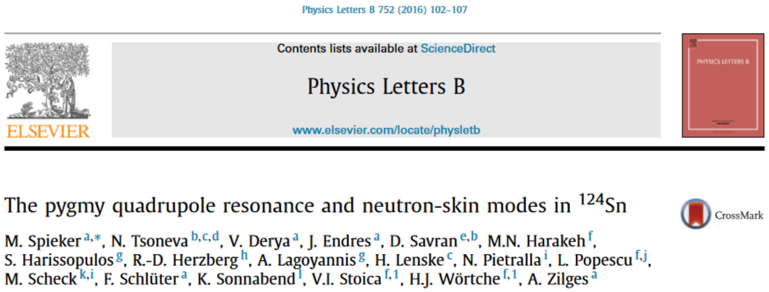
N. Tsoneva[a,b,*], H. Lenske[a]



PHYSICAL REVIEW C **92**, 014330 (2015)

Multitude of 2^+ discrete states in ^{124}Sn observed via the $(^{17}\mathrm{O}, ^{17}\mathrm{O}'\gamma)$ reaction: Evidence for pygmy quadrupole states

L. Pellegri,[1,2,*] A. Bracco,[1,2,†] N. Tsoneva,[3,4] R. Avigo,[1,2] G. Benzoni,[2] N. Blasi,[2] S. Bottoni,[1,2] F. Camera,[1,2] S. Ceruti,[1,2] F. C. L. Crespi,[1,2] A. Giaz,[2] S. Leoni,[1,2] H. Lenske,[3] B. Million,[2] A. I. Morales,[1,2] R. Nicolini,[1,2] O. Wieland,[2] D. Bazzacco,[5] P. Bednarczyk,[6] B. Birkenbach,[7] M. Ciemała,[6,‡] G. de Angelis,[8] E. Farnea,[5] A. Gadea,[9] A. Görgen,[10] A. Gottardo,[8,11] J. Grebosz,[6] R. Isocrate,[5] M. Kmiecik,[6] M. Krzysiek,[6] S. Lunardi,[5,11] A. Maj,[6] K. Mazurek,[6] D. Mengoni,[5,11] C. Michelagnoli,[5,11,‡] D. R. Napoli,[8] F. Recchia,[5,11] B. Siebeck,[7] S. Siem,[10] C. Ur,[5] and J. J. Valiente-Dobón[8]



Physics Letters B 752 (2016) 102–107

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

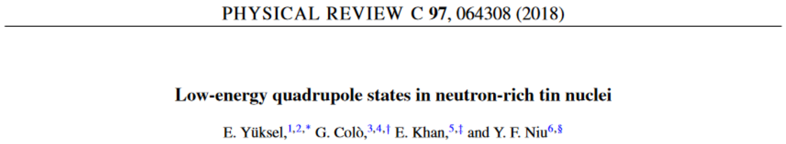
The pygmy quadrupole resonance and neutron-skin modes in ^{124}Sn

CrossMark

M. Spieker[a,*], N. Tsoneva[b,c,d], V. Derya[a], J. Endres[a], D. Savran[e,b], M.N. Harakeh[f], S. Harissopulos[g], R.-D. Herzberg[h], A. Lagoyannis[g], H. Lenske[c], N. Pietralla[i], L. Popescu[f,j], M. Scheck[k,i], F. Schlüter[a], K. Sonnabend[l], V.I. Stoica[f,1], H.J. Wörtche[f,1], A. Zilges[a]

- **Open question:** Is there are quadrupole-type oscillation of the neutron skin?

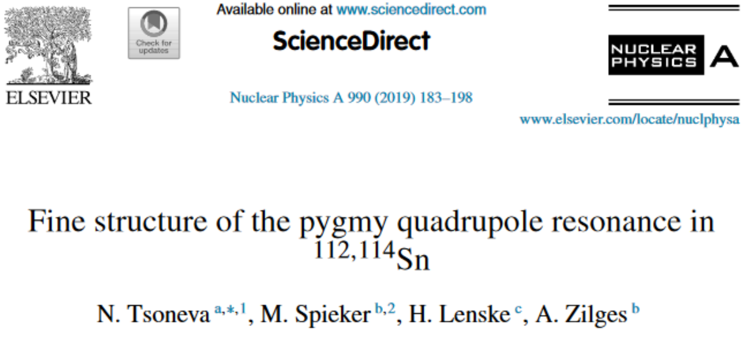
→ **Has been controversially discussed!** Not many experimental and theoretical studies exist [to my knowledge].



PHYSICAL REVIEW C **97**, 064308 (2018)

Low-energy quadrupole states in neutron-rich tin nuclei

E. Yüksel,[1,2,*] G. Colò,[3,4,†] E. Khan,[5,‡] and Y. F. Niu[6,§]



ELSEVIER

Check for updates

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 990 (2019) 183–198

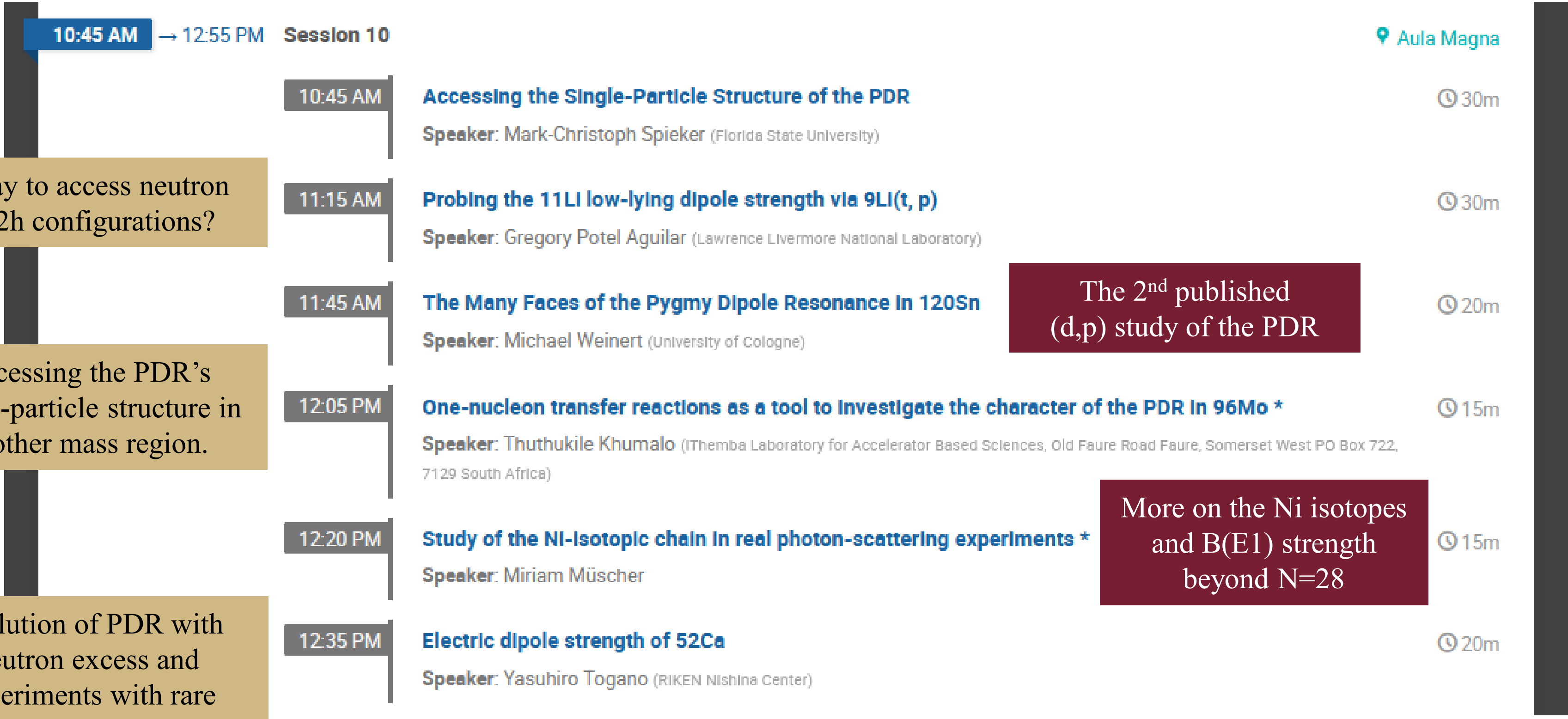
NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Fine structure of the pygmy quadrupole resonance in ^{112,114}Sn

N. Tsoneva[a,*,1], M. Spieker[b,2], H. Lenske[c], A. Zilges[b]

What else can we expect in this session?



10:45 AM → 12:55 PM **Session 10**

Aula Magna

10:45 AM **Accessing the Single-Particle Structure of the PDR** 30m
Speaker: Mark-Christoph Spieker (Florida State University)

11:15 AM **Probing the 11Li low-lying dipole strength via 9Li(t, p)** 30m
Speaker: Gregory Potel Aguilar (Lawrence Livermore National Laboratory)

11:45 AM **The Many Faces of the Pygmy Dipole Resonance in 120Sn** 20m
Speaker: Michael Weinert (University of Cologne)

12:05 PM **One-nucleon transfer reactions as a tool to investigate the character of the PDR in 96Mo *** 15m
Speaker: Thuthukile Khumalo (iThemba Laboratory for Accelerator Based Sciences, Old Faure Road Faure, Somerset West PO Box 722, 7129 South Africa)

12:20 PM **Study of the Ni-isotopic chain in real photon-scattering experiments *** 15m
Speaker: Miriam Müscher

12:35 PM **Electric dipole strength of 52Ca** 20m
Speaker: Yasuhiro Togano (RIKEN Nishina Center)

A way to access neutron 2p-2h configurations?

The 2nd published (d,p) study of the PDR

Accessing the PDR's single-particle structure in another mass region.

More on the Ni isotopes and B(E1) strength beyond N=28

Evolution of PDR with neutron excess and experiments with rare isotope beams

Conclusions

- One-nucleon transfer experiments [here (d,p)] can provide important information on the microscopic components of the PDR wave functions.

→ Getting these microscopic components right is critical to understand the generation of low-lying E1 strength and to predict it correctly.

→ Incorrect nuclear structure might lead to incorrect E1 distribution (γSF) and, thus, (maybe) incorrect predictions for (n,γ) rates.

→ PDR E1 strength seems to be intimately connected to certain 1p-1h structures.
→ Immediate question: Is the PDR only a part of the ground-state γSF?

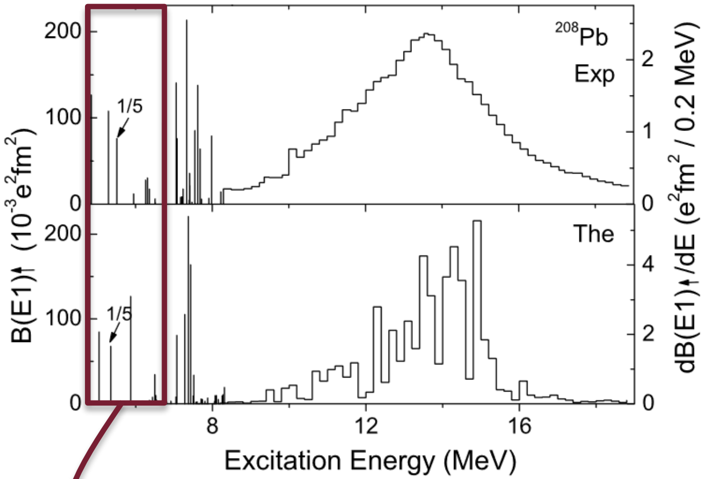
- Different stable-beam facilities (e.g., UoC, iThemba, RCNP, FSU, TU Darmstadt, HZ Dresden-Rossendorf, HIγS, ELI-NP) allow to continue the detailed structure studies of the PDR across the nuclear chart in “conventional” experiments.

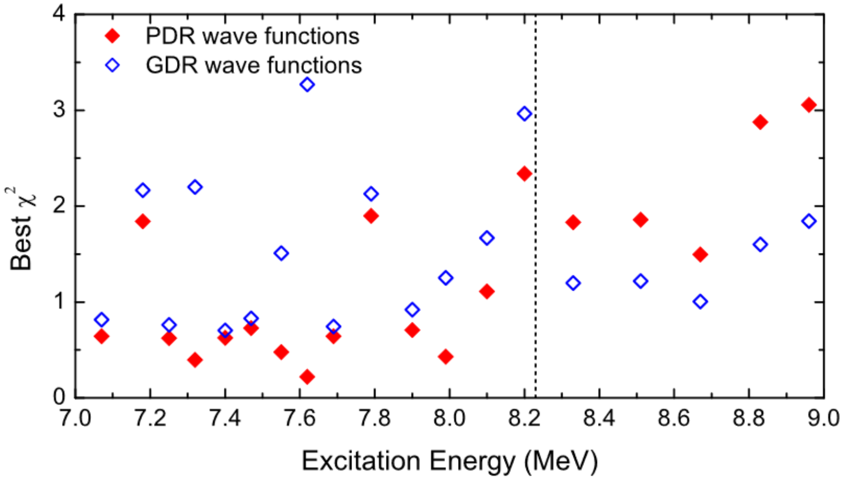
- FRIB, RIKEN, FAIR, HIE-ISOLDE give access to more neutron-rich nuclei.

FLORIDA STATE
UNIVERSITY

^{207}Pb(d,p)^{208}Pb [backup]

PDR or 1p-1h? The case of ^{208}Pb





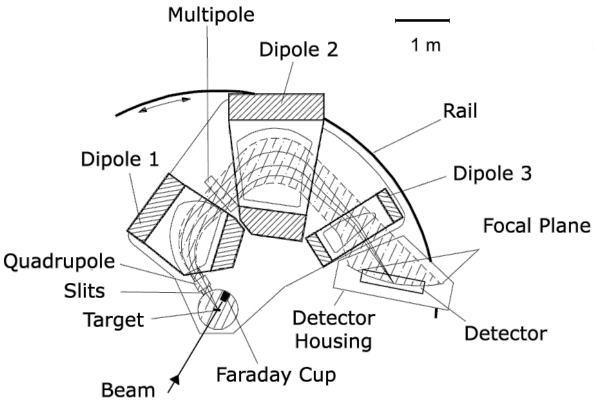
[N. Ryezayeva *et al.*, PRL **89**, 272502 (2002) and I. Poltoratska *et al.*, PRC **85**, 041304(R) (2012)]

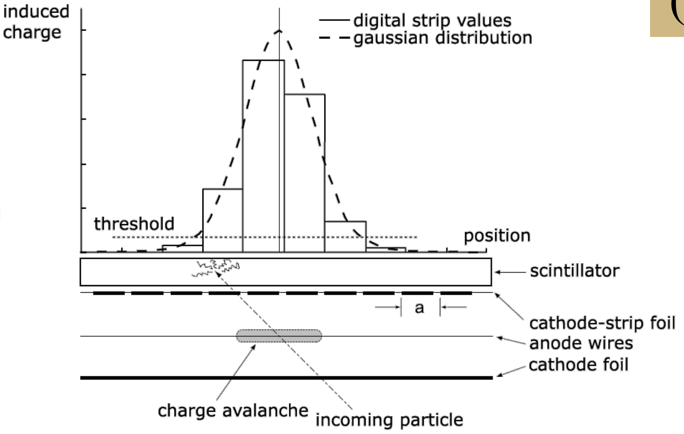
Claimed to be 1p-1h excitations and not PDR!

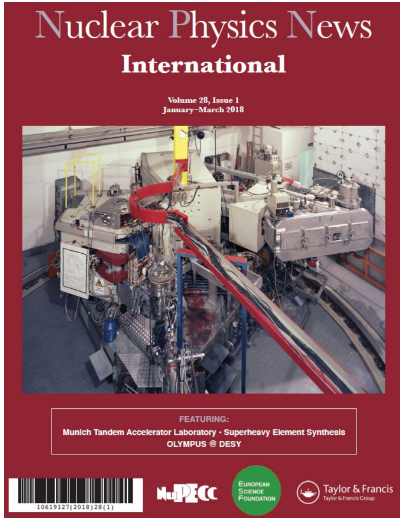
Our picture of a possible unique mode has changed since. Lower energy part, which is also observed in (α,α’), is considered to feature signatures of a possible neutron-skin mode. Higher lying excited states have a more complex structure (+2p-2h, …).

Q3D at MLL (Garching, Germany): $(p,p')_{IAR}$, (d,d') and (d,p) for ^{208}Pb

(† Facility closed)






Nuclear Physics News

International

Volume 28, Issue 1

January–March 2018

FEATURING:

Munich Tandem Accelerator Laboratory · Superheavy Element Synthesis

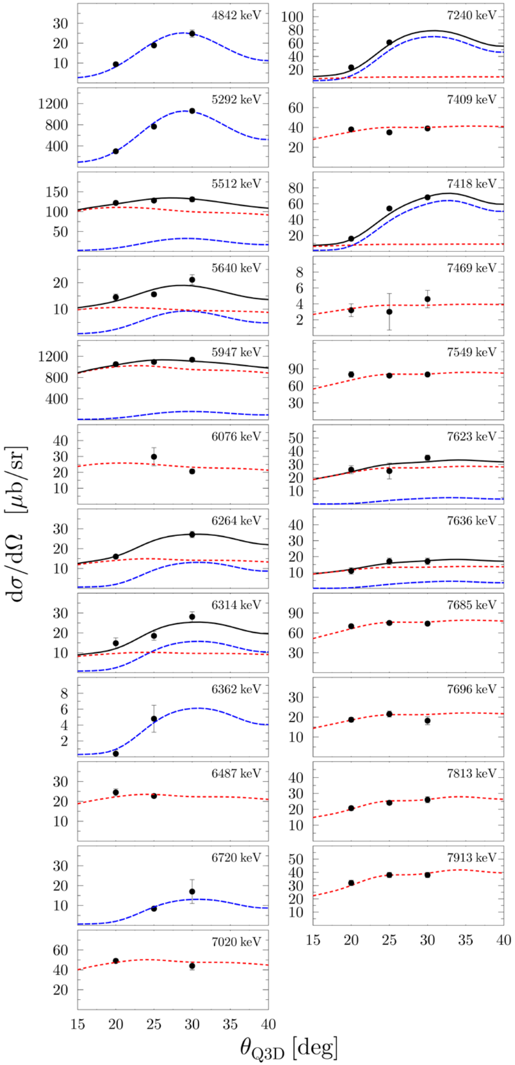
OLYMPUS @ DESY

[January – March 2018 issue]

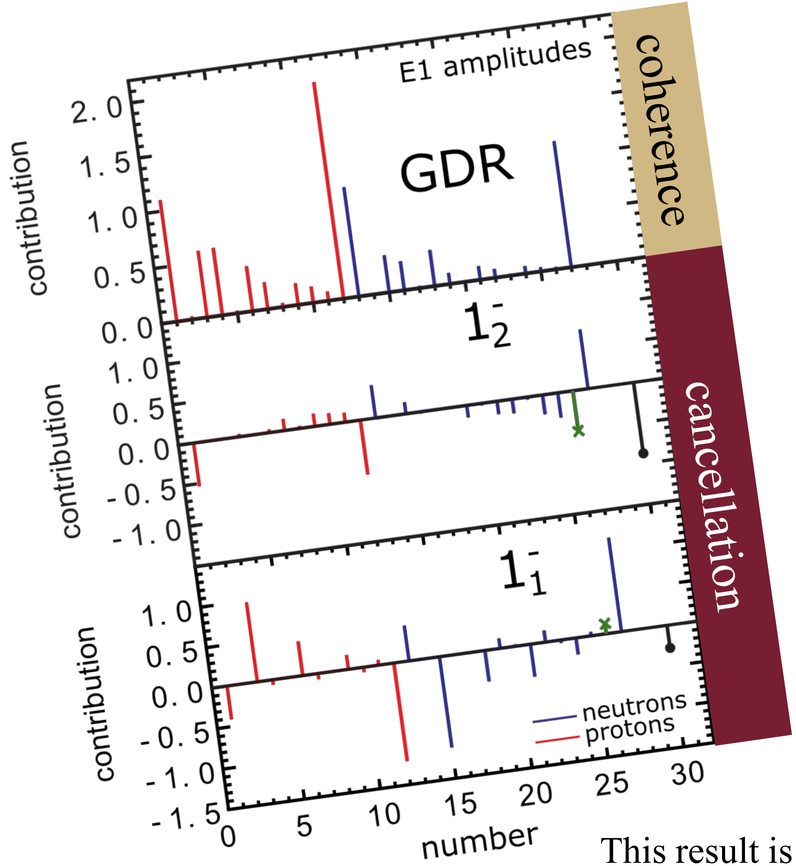
- **Excellent particle-energy resolution:**
  $\Delta E/E = 2 \times 10^{-4}$ (6 keV @ E_d= 22 MeV)
- **Spatial resolution of focal-plane detector:**
  3.5 mm repetition length, 255 cathode strips (length: 0.9 m)
  → half of the focal plane
- **Low background** due to coincidence requirements between anode and scintillator signals ($\Delta t \leq 1\mu s$) and additional offline cuts

[**Focal plane detector:** H.F. Wirth, Dissertation, TU München (2001)]

All firm 1^- states



IV strengths: Cancellation effects in PDR region (LSSM; B.A. Brown)



This result is in agreement with earlier findings by X. Roca-Maza et al. [PRC **85**, 024601 (2012)]

The effect of excluding certain E1 matrix elements