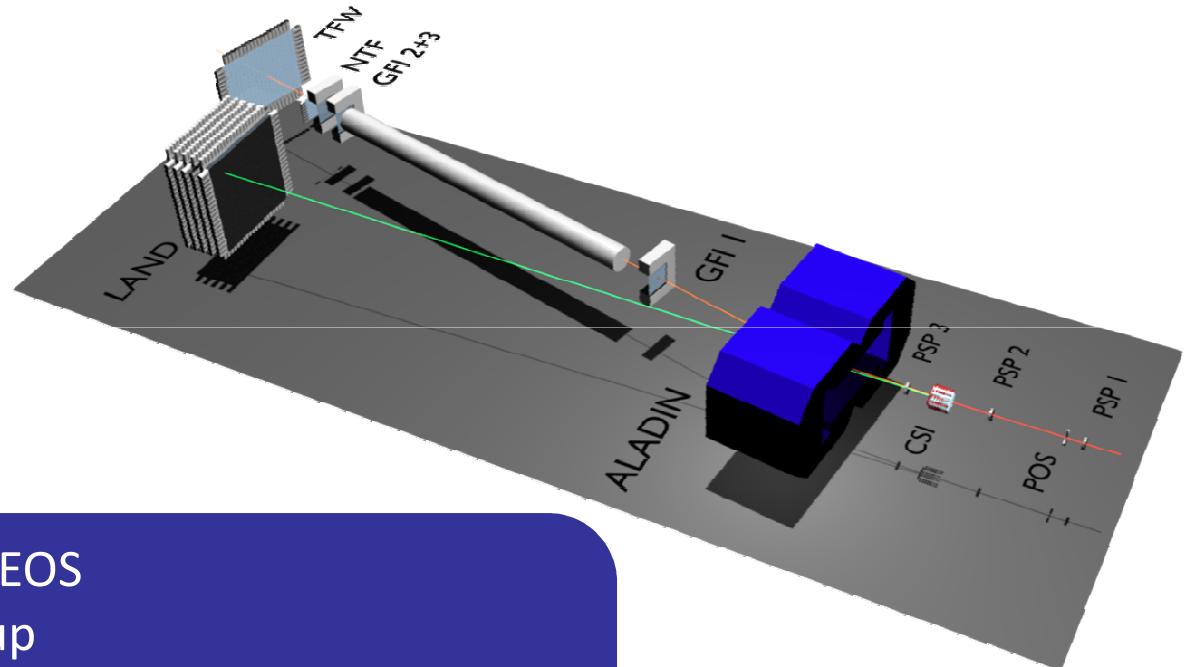
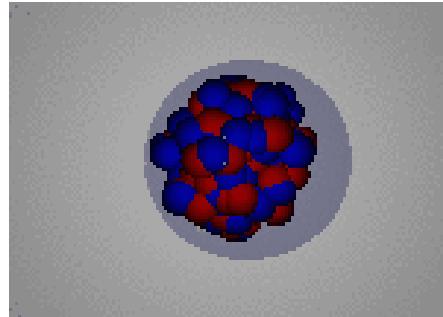


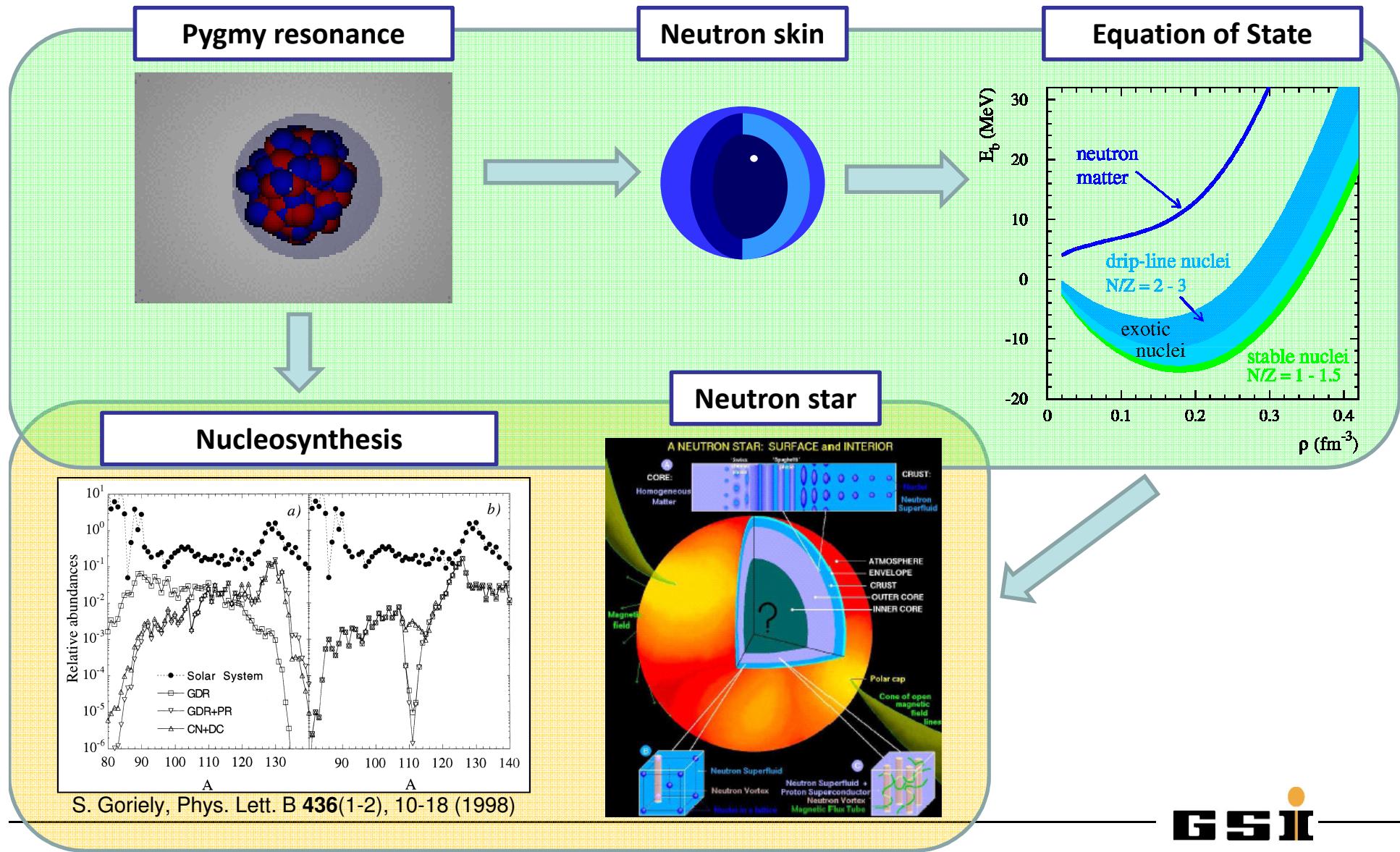
Experimental Results on the Coulomb Excitation of Exotic Nuclei at the R³B-LAND Setup

Dominic Rossi (GSI Darmstadt),
for the R³B collaboration

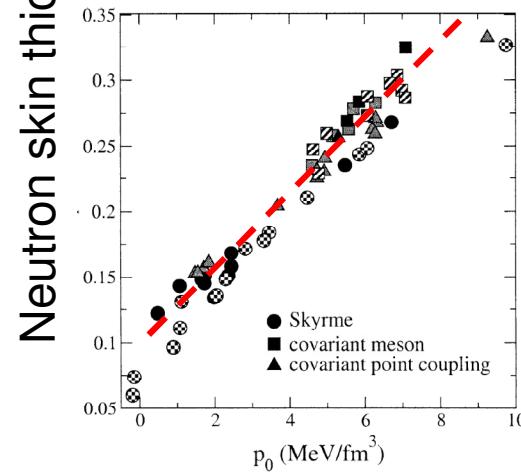
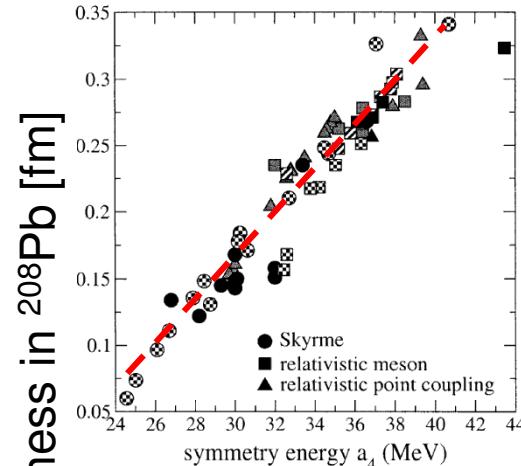


- Electric dipole strength and EOS
- LAND-R³B experimental setup
- Measurement principle
- Dipole strength in neutron-rich Sn and Ni isotopes
- Dipole strength in neutron-deficient Cl and Ar isotopes
- Summary and outlook

What can we learn from measurements of low-lying E1 strength?



Nuclear Equation-Of-State



R.J. Furnstahl NPA **706**, 85-110 (2002)

$$E(\rho, \alpha) = E(\rho, 0) + S_2(\rho) \alpha^2 + O(\alpha^4), \quad \alpha = \frac{N - Z}{A}$$

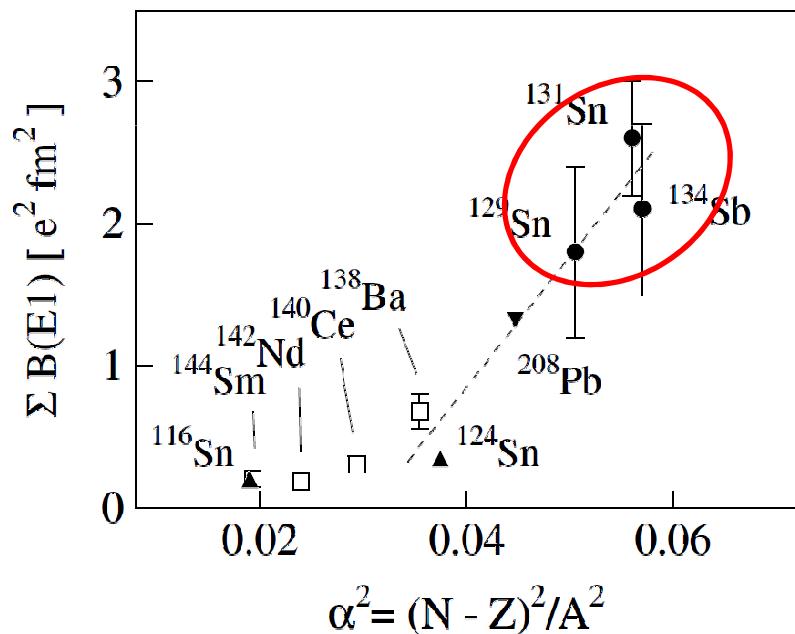
$$E(\rho, 0) = -a_V + \frac{K_0}{18\rho_0^2} (\rho - \rho_0)^2 + \dots$$

$$\begin{aligned} S_2(\rho) &= \frac{1}{2} \frac{\partial^2 E(\rho, \alpha)}{\partial \alpha^2} \Big|_{\alpha=0} = \\ &= a_4 + \frac{p_0}{\rho_0^2} (\rho - \rho_0) + \frac{\Delta K_0}{18\rho_0^2} (\rho - \rho_0)^2 + \dots \end{aligned}$$

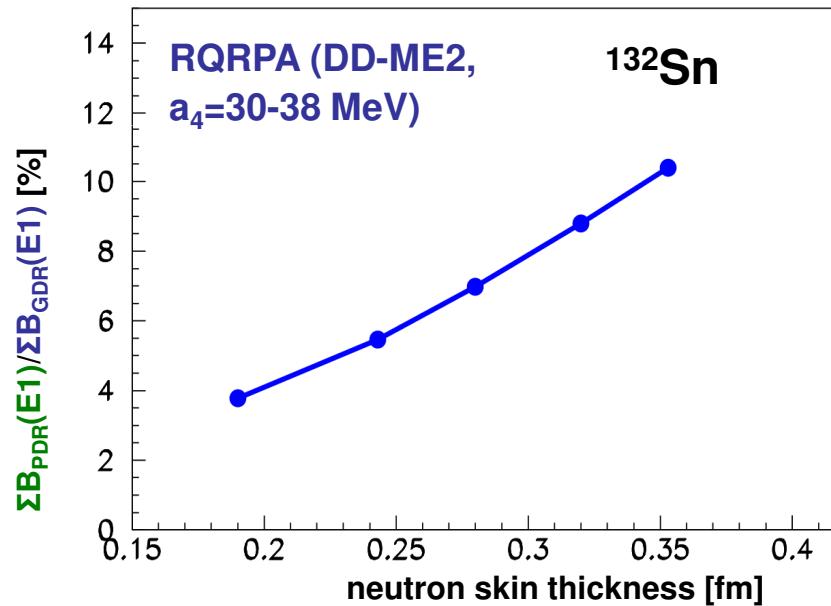
- a_4 : symmetry energy per nucleon in pure neutron matter
- p_0 : symmetry energy pressure
- Linear correlation between neutron skin thickness and a_4 and p_0 parameters of nuclear Equation-Of-State for various mean-field models for ^{208}Pb case

Link between PDR and EOS

- Experiment provides E1 strength at larger neutron-to-proton ratios
- RQRPA calculations provide a link between the measured PDR strength and the neutron skin thickness

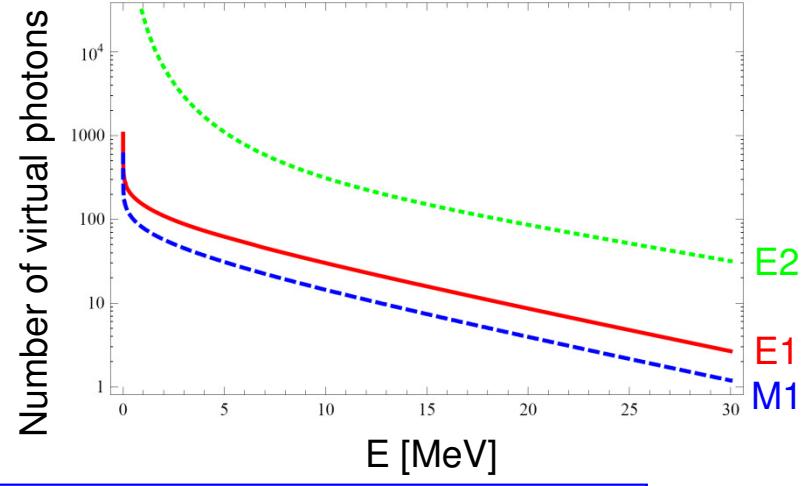
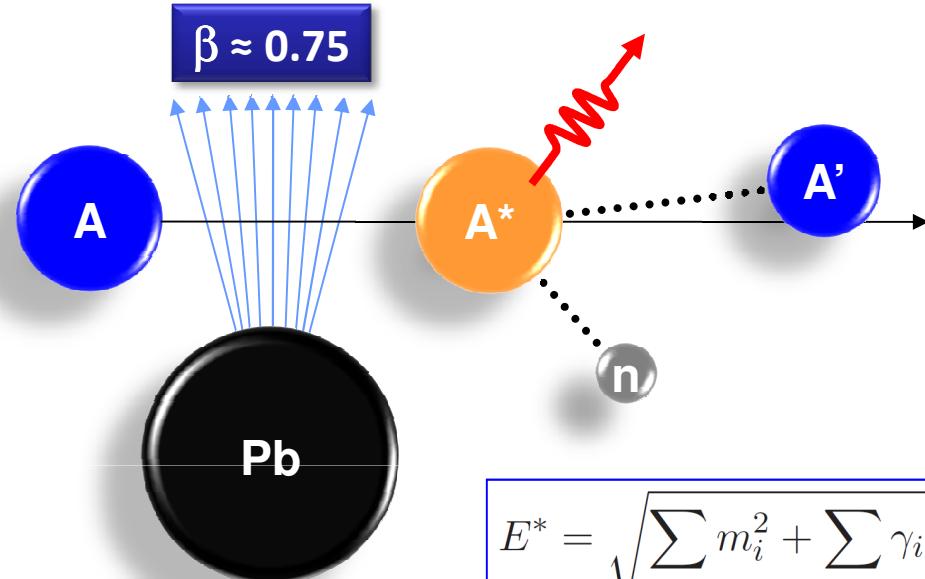


A. Klimkiewicz *et al.*, PRC **76**, 051603(R) (2007)



Calculation performed by N. Paar

Measurement principle

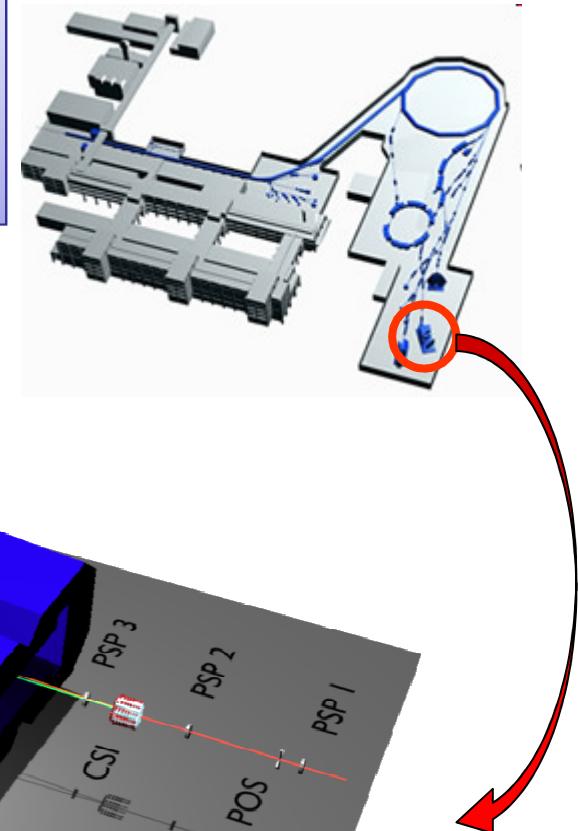


$$E^* = \sqrt{\sum_i m_i^2 + \sum_{i \neq j} \gamma_i \gamma_j m_i m_j (1 - \beta_i \beta_j \cos \vartheta_{ij})} + E_\gamma - m_{proj}$$

- Heavy-ion-induced electromagnetic excitation, *via* the virtual photon approach
- Short lifetime of projectile \Rightarrow requires experiment in inverse kinematics
- Reconstruction of excitation energy (using invariant mass) of each event requires detection of **ALL** participating species (identification and momentum)
- Measurements on Pb, C and empty targets allows the separation of the electromagnetic, nuclear and background components

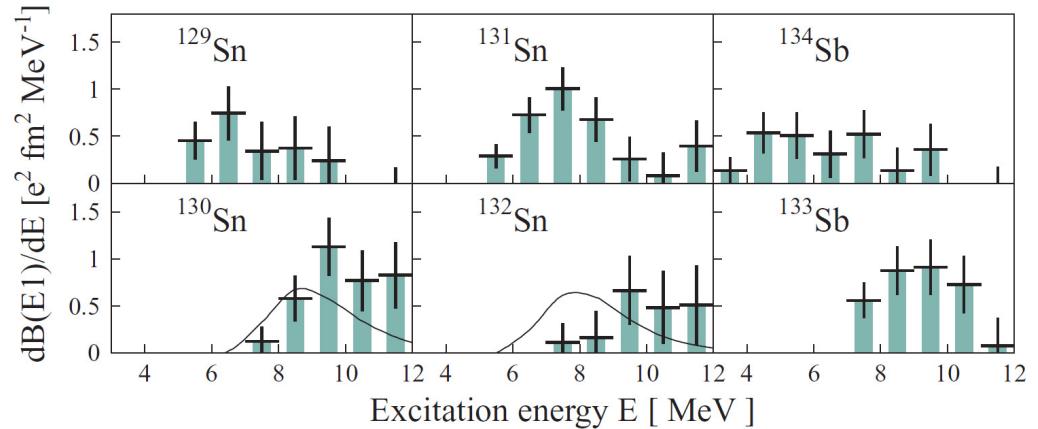
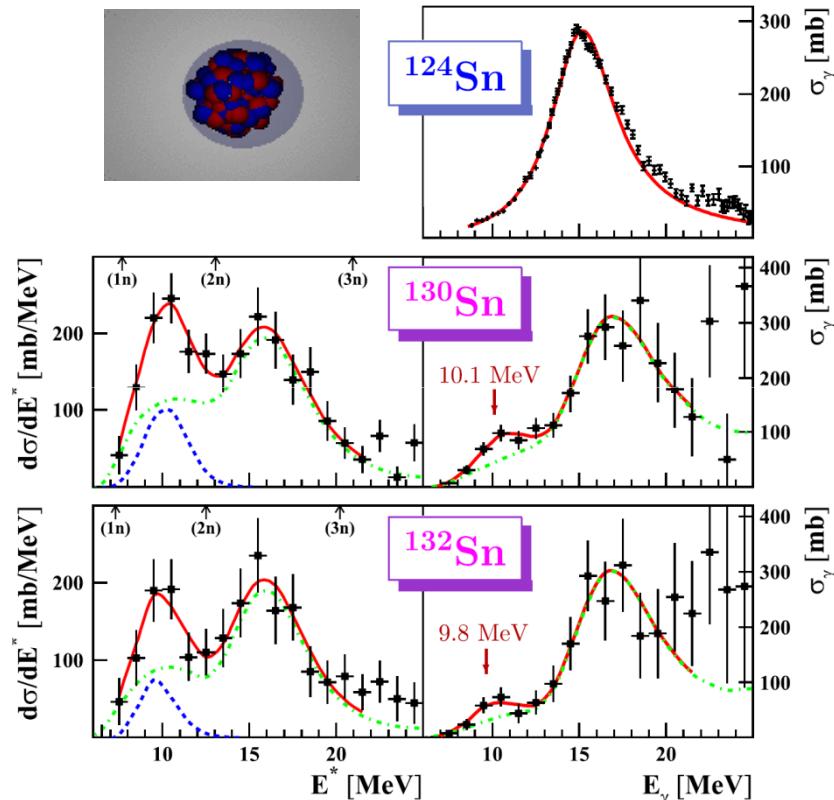
Experimental setup

- Beam tracking in Cave C: Si detectors (PSP) and scintillation detectors (POS, GFI, TFW)
- Kinematic forward-focusing (relativistic beam energies)
→ high-acceptance measurement (almost full coverage of solid angle)



- Neutron detection with LAND (Fe converter + organic scintillator)
- Charged fragments are detected in TFW scintillation detector
- Gamma detection with CsI or NaI detector

E1 measurement in neutron-rich Sn isotopes

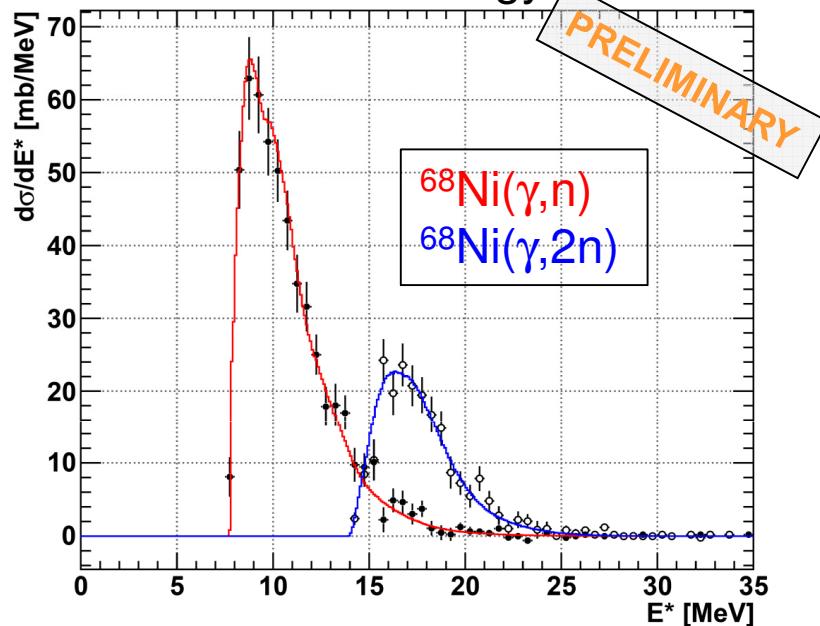


A. Klimkiewicz *et al.*, Phys. Rev. C **76**, 051603(R) (2007)

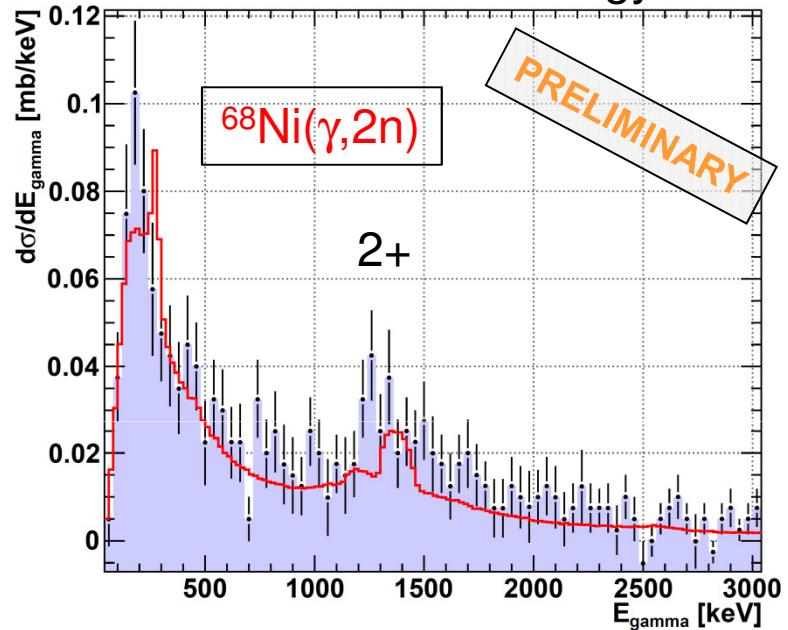
- E1 Coulomb excitation and photoabsorption cross sections show excessive E1 strength compared to GDR alone
- Excess E1 strength distributions for odd and even Sn and Sb isotopes
→ 4-7 % of TRK sum rule strength
- Staggered PDR distributions in odd / even isotopes
- PDR strength also below neutron threshold, or varies with threshold?

$^{68}\text{Ni}(\gamma, \text{xn})$

Excitation energy



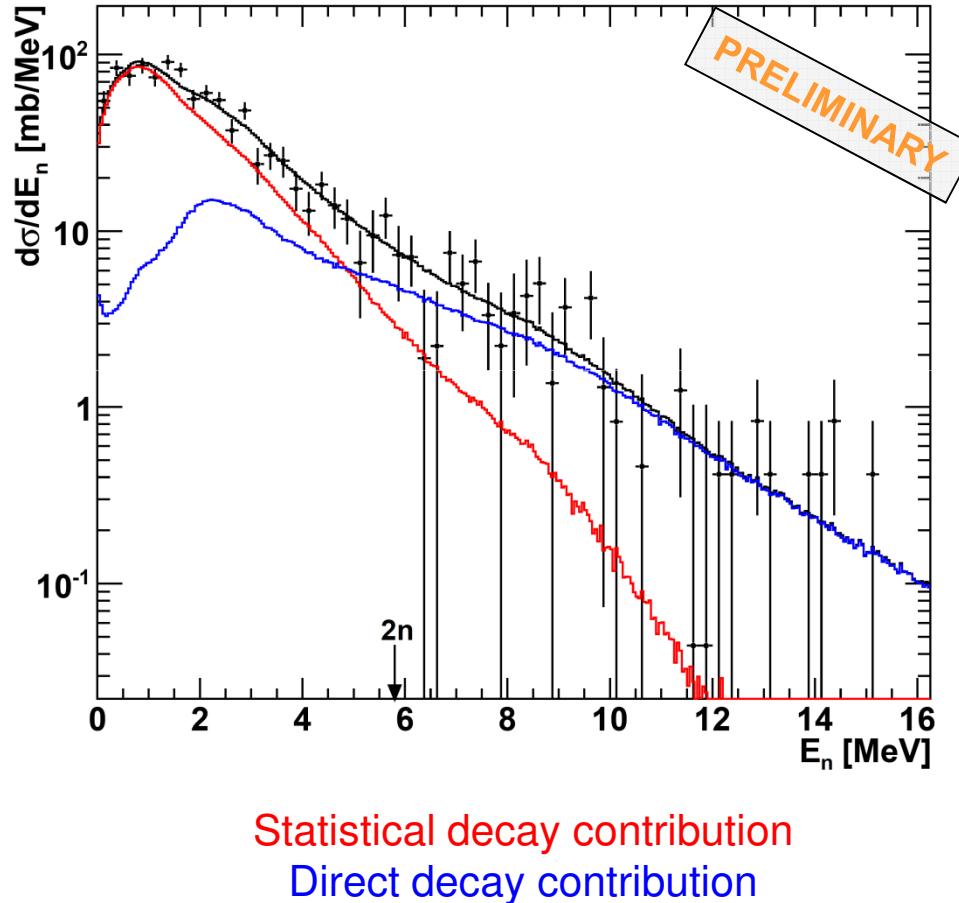
Gamma sum energy



- Fit function: 1 Breit-Wigner function (GDR) + 7 individual bins (1 MeV wide, from 8 to 14 MeV)

GDR in ^{68}Ni	Fit	Junghans <i>et al.</i> , Phys. Lett. B 670(3), 200-204 (2008)
E_m [MeV]	18.1(5)	18.17
Γ [MeV]	6.1(5)	5.17
S_{TRK} [%]	97(9)	100

$^{68}\text{Ni}(\gamma, \text{n})$: neutron kinetic energy

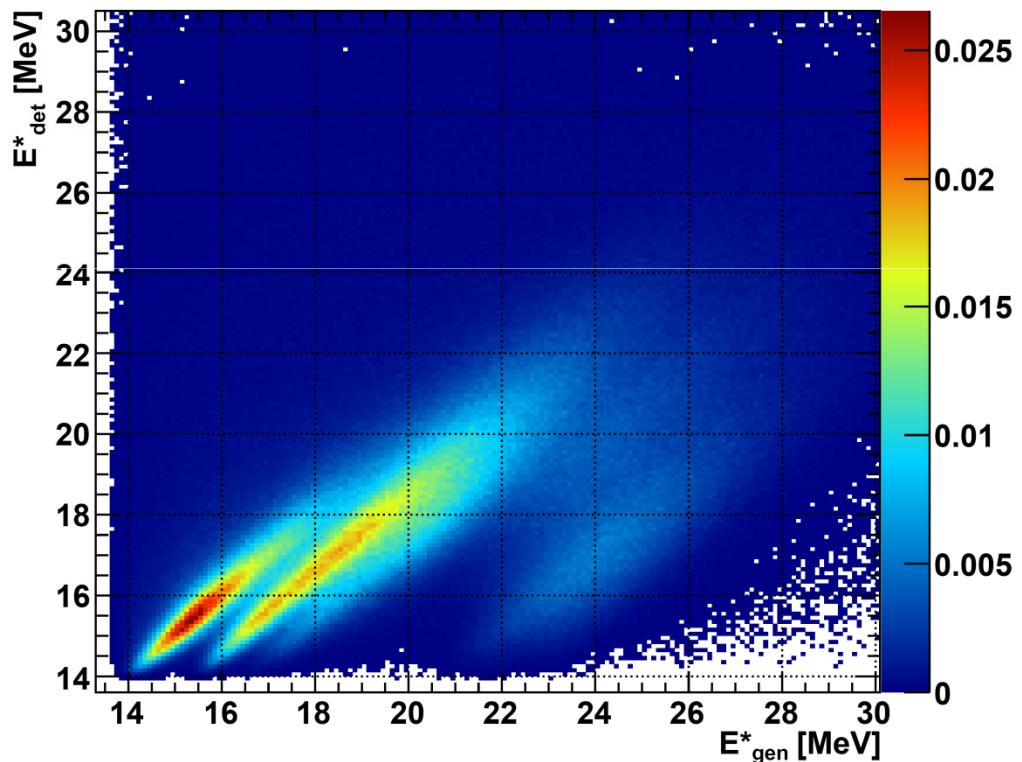


- Neutron kinetic energies reach well beyond the 2n threshold
→ Not expected with a pure statistical decay
- Only direct decay to the A-1 ground state was considered
- Direct decay branching ratio obtained from fit to neutron energies

$$R_{\text{direct}} = 24(4) \%$$

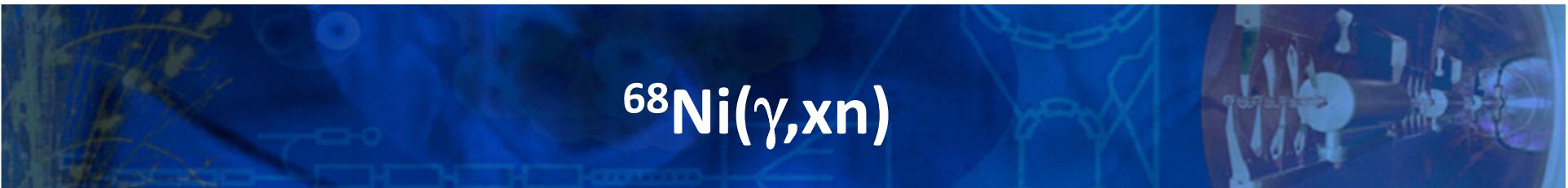
Accounting for the experimental response

Example for $^{68}\text{Ni}(\gamma, 2n)^{66}\text{Ni}$

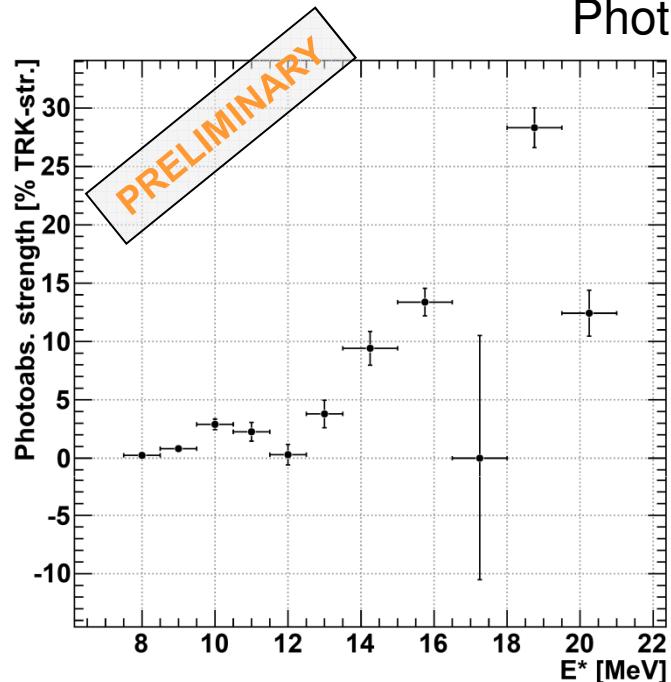


- Strong experimental response (broadening + distortion) due to complex detectors and algorithms
- Removal of response requires precise response matrices
- One matrix per channel and observable
- Iterative procedure
 - 1. Folding of trial input
 - 2. Calculate χ^2 from comparison with data
 - 3. Adjustment of trial input

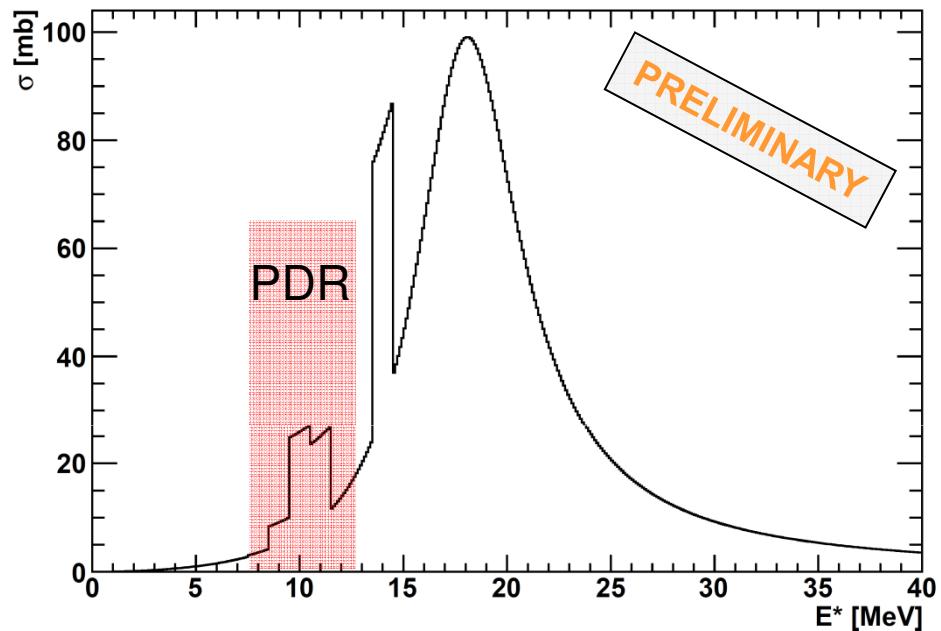
$^{68}\text{Ni}(\gamma, \text{xn})$



Photoabsorption c.s.

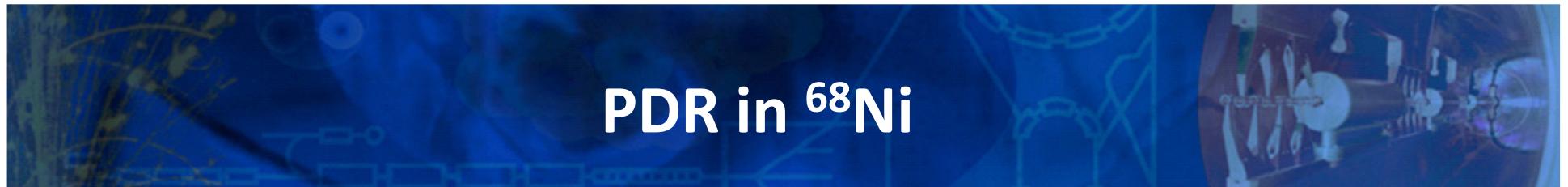


Individual bins for PDR
and GDR

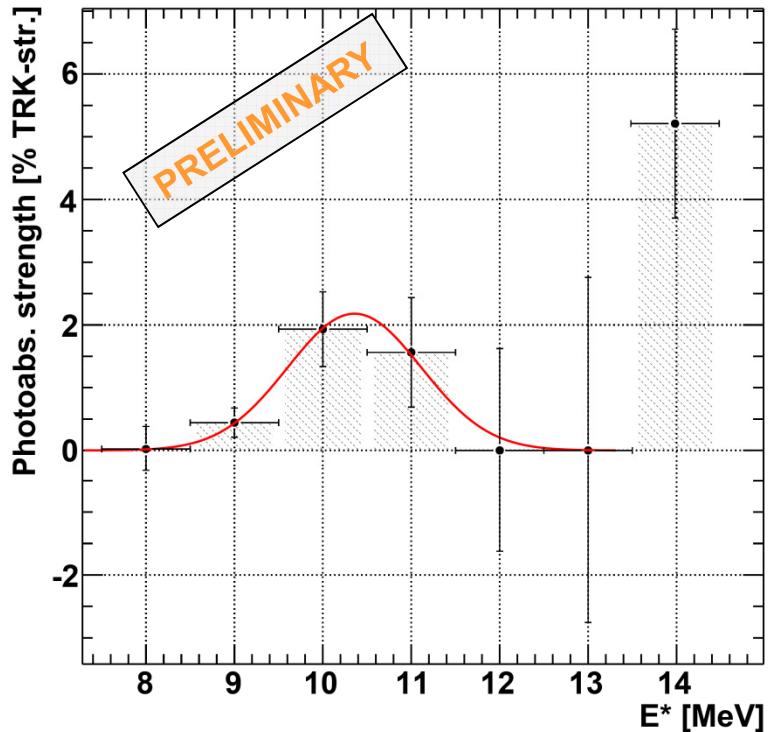


Breit-Wigner for GDR and
individual bins for PDR

- Both approaches show non-negligible low-lying strength around 10-11 MeV
- Fit in left figure does not require assumptions on the resonance shape



PDR in ^{68}Ni



^{68}Ni
 (γ, xn)

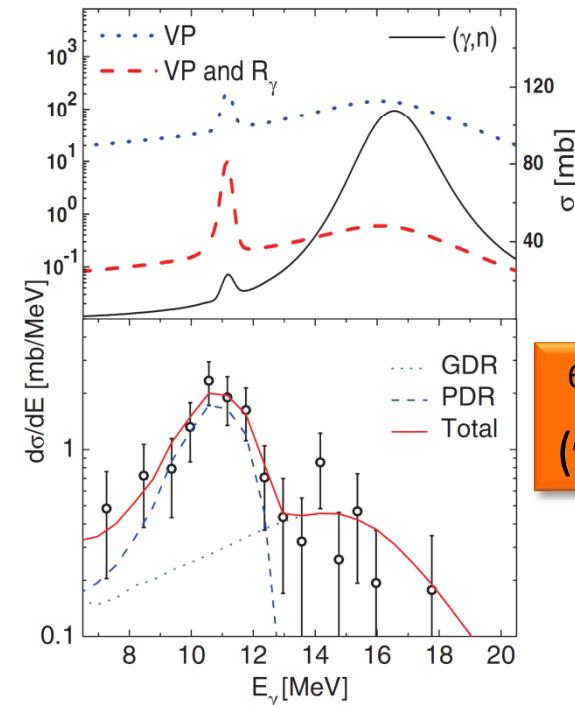
PRL 102, 092502 (2009)

PHYSICAL REVIEW LETTERS

week ending
6 MARCH 2009

Search for the Pygmy Dipole Resonance in ^{68}Ni at 600 MeV/nucleon

O. Wieland,¹ A. Bracco,^{1,2} F. Camera,^{1,2} G. Benzoni,¹ N. Blasi,¹ S. Brambilla,¹ F. C. L. Crespi,^{1,2} S. Leoni,^{1,2} B. Million,¹ R. Nicolini,^{1,2} A. Maj,³ P. Bednarczyk,³ J. Grebosz,³ M. Kmiecik,³ W. Mecynski,³ J. Styczen,³ T. Aumann,⁴ A. Banu,⁴ T. Beck,⁴ F. Becker,⁴ L. Caceres,^{4,*} P. Doornenbal,^{4,†} H. Emeling,⁴ J. Gerl,⁴ H. Geissel,⁴ M. Gorska,⁴ O. Kavatsyuk,⁴ M. Kavatsyuk,⁴ I. Kojouharov,⁴ N. Kurz,⁴ R. Lozeva,⁴ N. Saito,⁴ T. Saito,⁴ H. Schaffner,⁴ H. J. Wollersheim,³ J. Jolie,⁵ P. Reiter,⁵ N. Warr,⁵ G. deAngelis,⁶ A. Gadea,⁶ D. Napoli,⁶ S. Lenzi,^{7,8} S. Lunardi,^{7,8} D. Balabanski,^{9,10} G. LoBianco,^{9,10} C. Petrache,^{9,‡} A. Saltarelli,^{9,10} M. Castoldi,¹¹ A. Zucchiatti,¹¹ J. Walker,¹² and A. Bürger^{13,§}

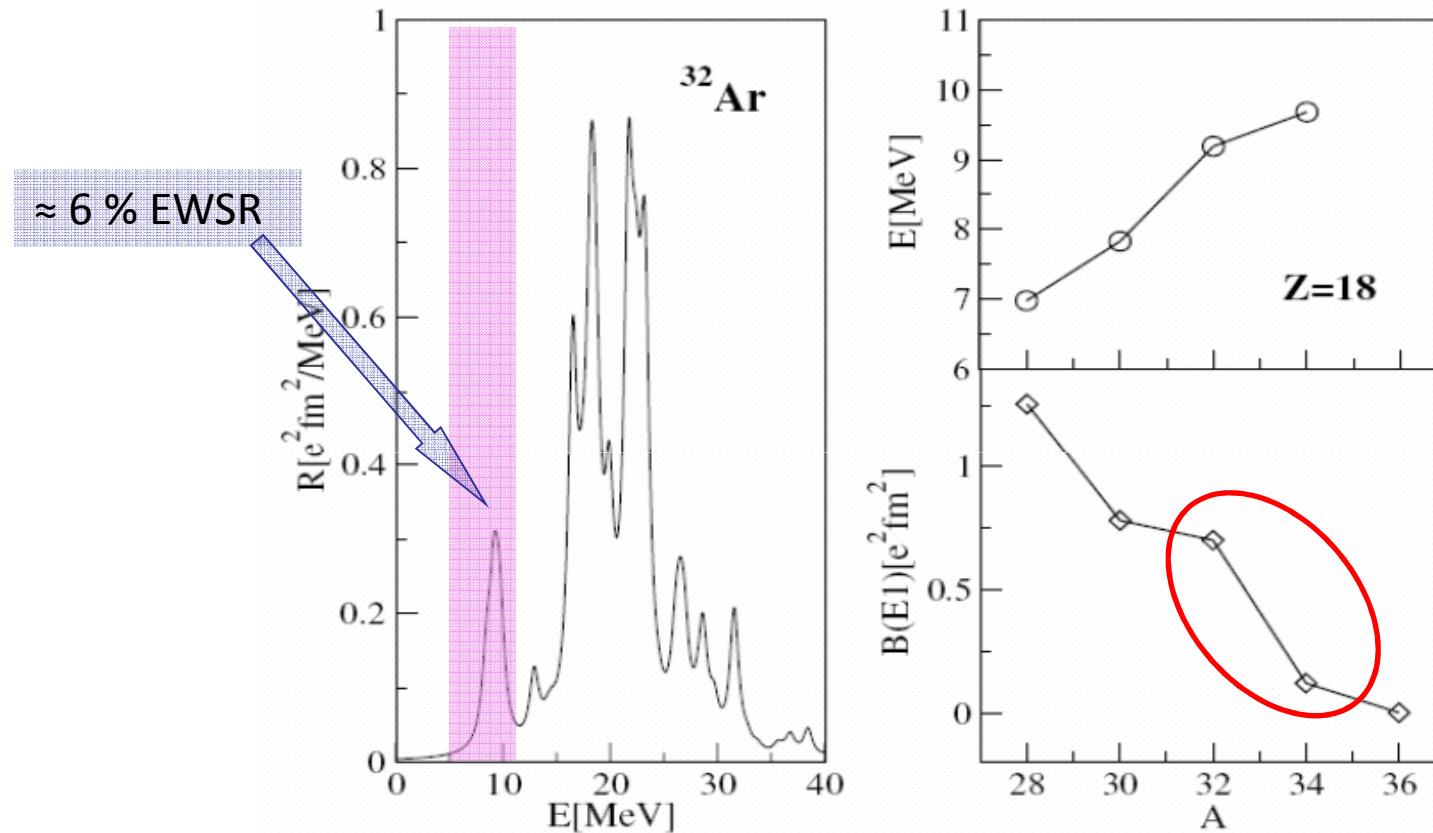


^{68}Ni
 (γ, γ')

- Pronounced peak structure around 10-11 MeV
- Gaussian fit

PDR in ^{68}Ni	(γ, xn)	(γ, γ')
E_m [MeV]	10.4(4)	11
σ [MeV]	0.8(3)	< 1
S_{TRK} [%]	4.1(1.9)	5

Predicted Proton PDR in ^{32}Ar and ^{34}Ar

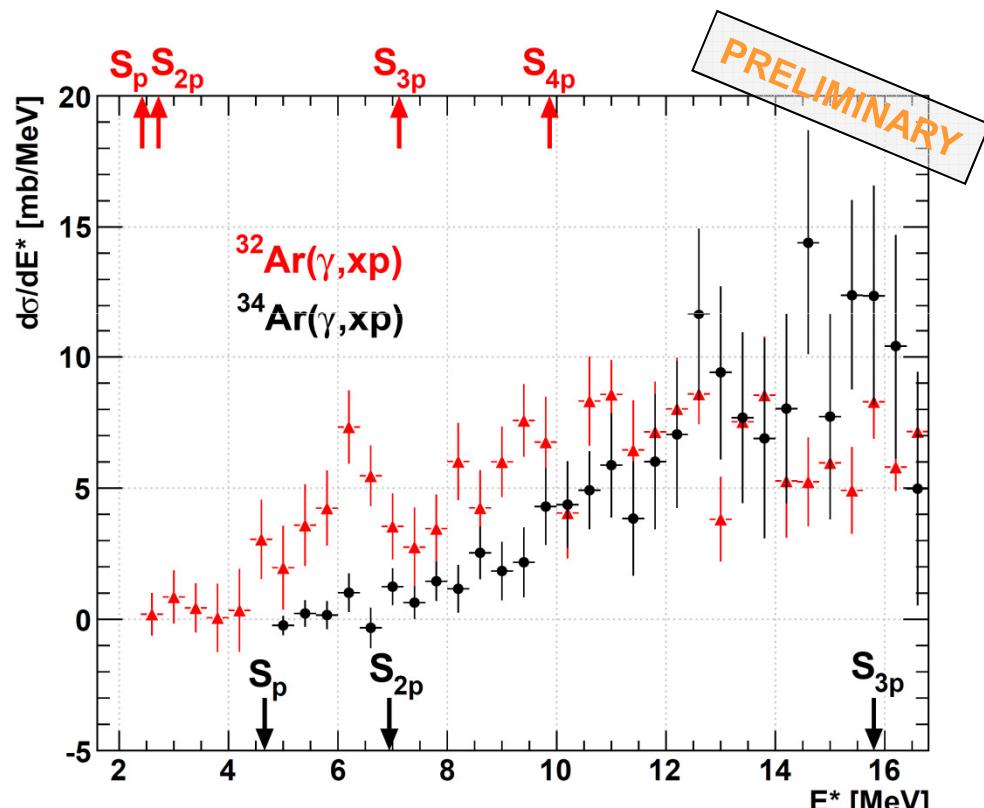


N.Paar *et al.*,
Phys. Rev. Lett. **94**,
182501 (2005)

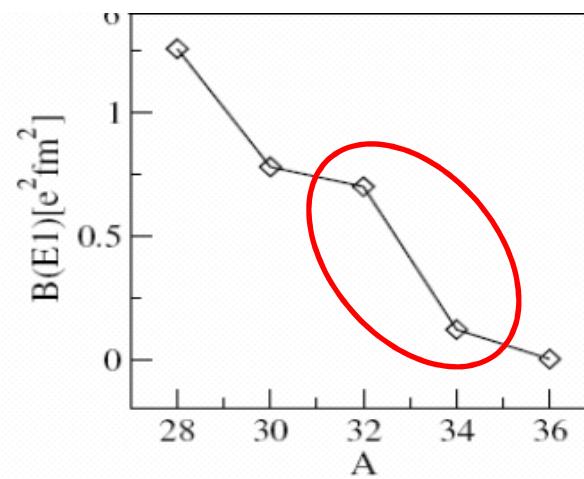
Fig.1: The isovector dipole strength distribution in ^{32}Ar , calculated in the framework of RHB and QRPA (left panel). In the right panel the mass dependence of the pygmy peak and the corresponding integrated dipole strength below 10 MeV are shown. From [Paa-05b].

Observed Proton PDR in ^{32}Ar and ^{34}Ar

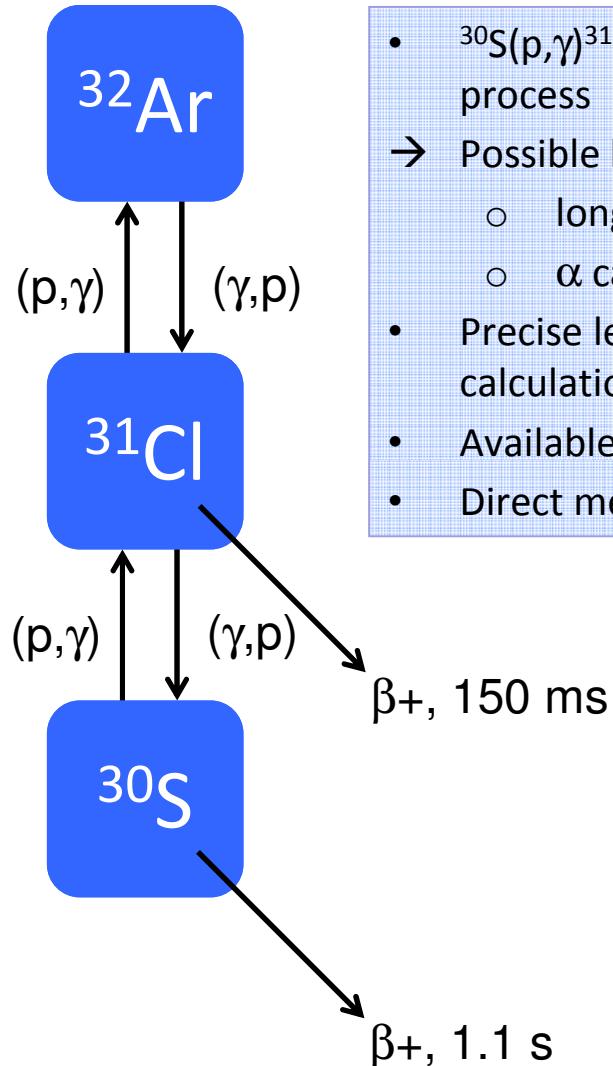
(γ, p) and $(\gamma, 2p)$ channels



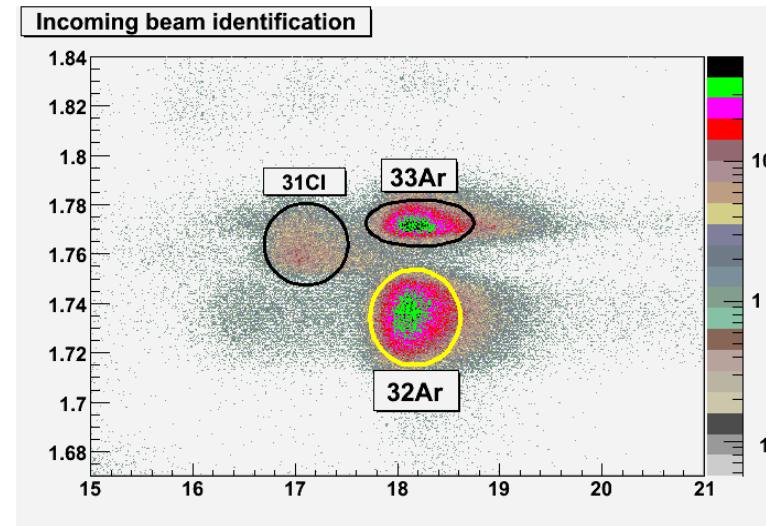
- Differential cross section for ^{32}Ar and ^{34}Ar
- Only 1p and 2p channels
- Integral cross sections (0-10 MeV):
 - ^{34}Ar : 17 mb
 - ^{32}Ar : **71 mb**
- Extraction of shape and strength:
→ Requires response simulation



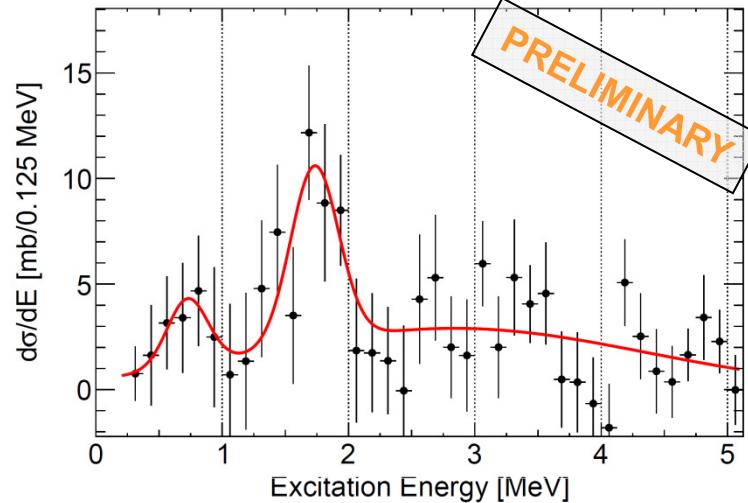
^{31}Cl and the rp-process



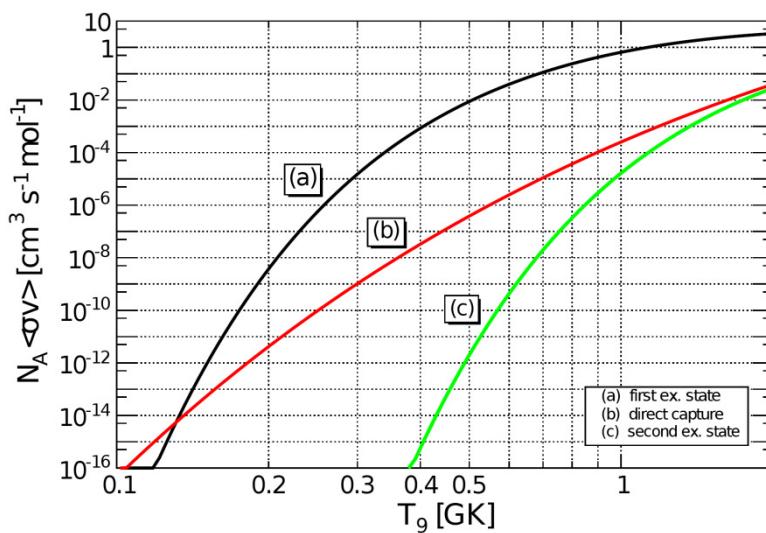
- $^{30}\text{S}(\text{p},\gamma)^{31}\text{Cl}$ reaction is important for the low-mass region of the rp-process
→ Possible bottleneck:
 - long-lived ^{30}S
 - α capture hindered due to Coulomb barrier
- Precise level structure of ^{31}Cl is a key ingredient for rp-process calculations
- Available data from β^+ decay of ^{31}Ar
- Direct measurement of level structure with Coulex of ^{31}Cl @ 630 MeV/u



$^{31}\text{Cl}(\gamma, \text{p})$



- No significant population of first excited state in ^{30}S (2^+ , 2.21 MeV)
- Two narrow resonances observed:
 - 0.73(4) MeV ($1/2^+$): 15(6) mb
 - 1.73(8) MeV ($5/2^+$): 30(9) mb
- One broad component: direct capture
- Resonance widths mainly resolution



- Production rates for the $^{30}\text{S}(\text{p}, \gamma)^{31}\text{Cl}$ reaction
- Stellar conditions
- Direct capture: E1
- Temperature range corresponds to typical T for X-ray burst of type I
- First excited state clearly dominates reaction rate

PhD thesis, C. Langer

New E1 measurement of Sn isotopes

Beam intensity less than expected

New measurement from $A = 124$ to 134 with high statistics

Unknown isospin character of low-lying strength

Use of different probes:
 γ , d, ..., (α)

Experimental method only sensitive above neutron threshold

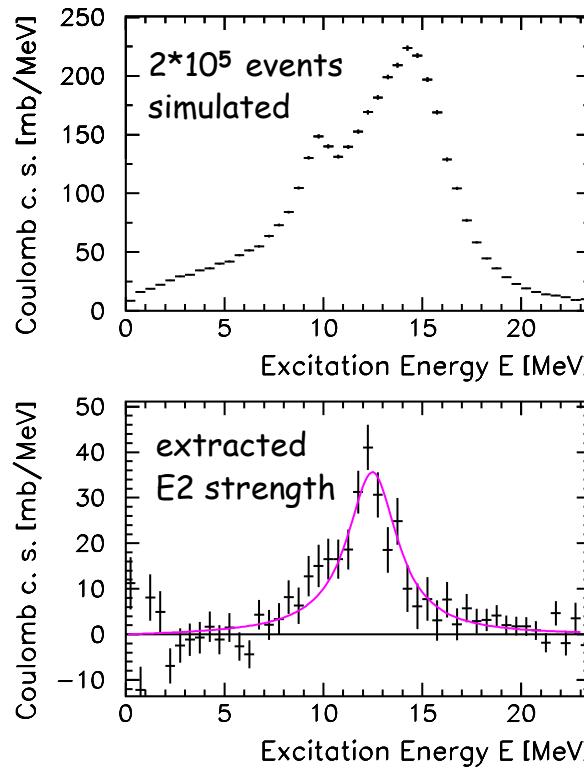
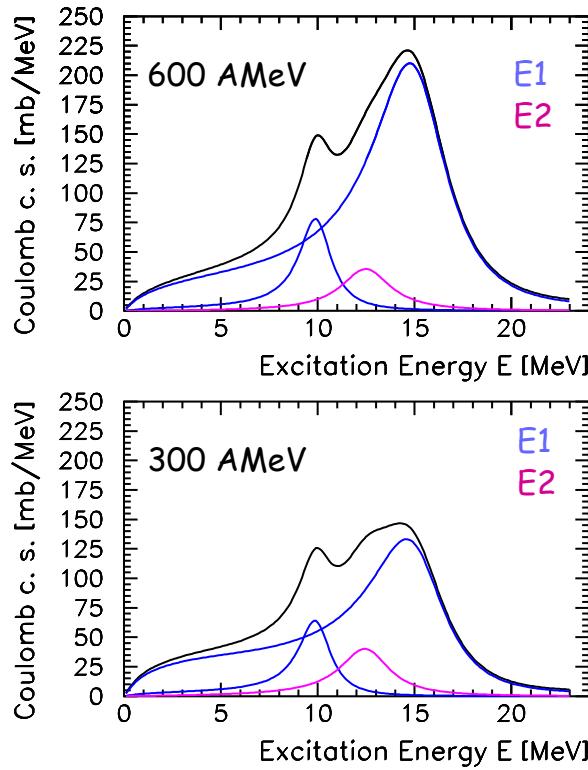
Observation of not only (γ, xn) , but also of (γ, γ') channel

Unknown Giant Quadrupole Resonance parameters

Measurement of GQR in Sn

Measurement of GQR in ^{124}Sn to ^{128}Sn

- Two beam energies required to disentangle E1 and E2 components
- Requires total E1+E2 strength distribution with good statistics



- Example:
 - ^{132}Sn at 600 and 300 AMeV
 - 100% TRK sum rule strength for E1
 - 100% EWSR strength for E2

Summary

LAND-R³B setup

Coulomb excitation of stable
and radioactive beams

Complete kinematics at energies
from 200 to 1000 MeV/u

Neutron-rich Sn

Measurement of PDR: 4-7% TRK sum-rule
strength

Extraction of a_4 and p_0 parameters of EOS

Proton-rich Ar and Cl

Analysis in progress

Low-lying strength in ³²Ar

2 states observed in ³¹Cl

Neutron-rich Ni

Measurement of PDR in ⁶⁸Ni: approx. 4% TRK sum-rule
strength (preliminary results)

Analysis of ⁷⁰⁻⁷²Ni in progress

Neutron-rich Sn (2)

Measurement of PDR (above and below threshold); E2 measurement;
improved statistics for E1; connection with stable isotopes



Collaborators

P. Adrich¹, F. Aksouh¹, Y. Aksyutina¹, H. Alvarez-Pol², T. Aumann^{1,3}, S. Beceiro², K.H. Behr¹, J. Benlliure², T. Berg⁴, M. Boehmer⁵, K. Boretzky¹, A. Bruenle¹, E. Casarejos², M. Chartier⁶, A. Chatillon¹, L. Chulkov¹, D. Cortina-Gil², U. Datta Pramanik⁷, Th. W. Elze⁸, H. Emling¹, O. Ershova⁸, M. Fallot¹, B. Fernandez-Dominguez⁹, H. Geissel¹, R. Gernhäuser⁵, M. Gorska¹, M. Heil¹, M. Hellström¹, G. Ickert¹, H. Johansson¹⁰, K. Jones¹, B. Jonson¹⁰, A. Junghans¹¹, A. Kelic-Heil¹, O. Kiselev⁴, A. Klimkiewicz¹², J.V. Kratz⁴, R. Krücken⁵, R. Kulessa¹², N. Kurz¹, M. Labiche⁶, C. Langer⁸, K. Larsson¹⁰, T. Le Bleis⁵, R. Lemmon⁶, O. Lepyoshkina⁵, Y. Litvinov¹, P. Maierbeck⁵, J. Marganiec¹, K. Mahata¹, A. Movsesyan³, T. Nilsson¹⁰, C. Nociforo¹, N. Paar¹³, R. Palit¹, V. Panin³, S. Paschalis³, R. Plag^{1,8}, W. Prokopowicz¹, R. Reifarth^{1,8}, V. Ricciardi¹, D. Rossi¹, S. Schwertel⁵, H. Simon¹, K. Sümmerer¹, G. Surowka¹², B. Streicher⁴, J. Taylor⁹, J. Vignote¹, D. Vretenar¹³, A. Wagner¹¹, W. Walus¹², F. Wamers³, H. Weick¹, C. Wimmer⁸, M. Winkler¹ and P. Wu⁹.

1) GSI Darmstadt (Germany)

2) Univ. Santiago de Compostela (Spain)

3) TU Darmstadt (Germany)

4) Univ. Mainz (Germany)

5) TU München (Germany)

6) Daresbury Laboratory (UK)

7) SINP Kolkata (India)

8) Univ. Frankfurt (Germany)

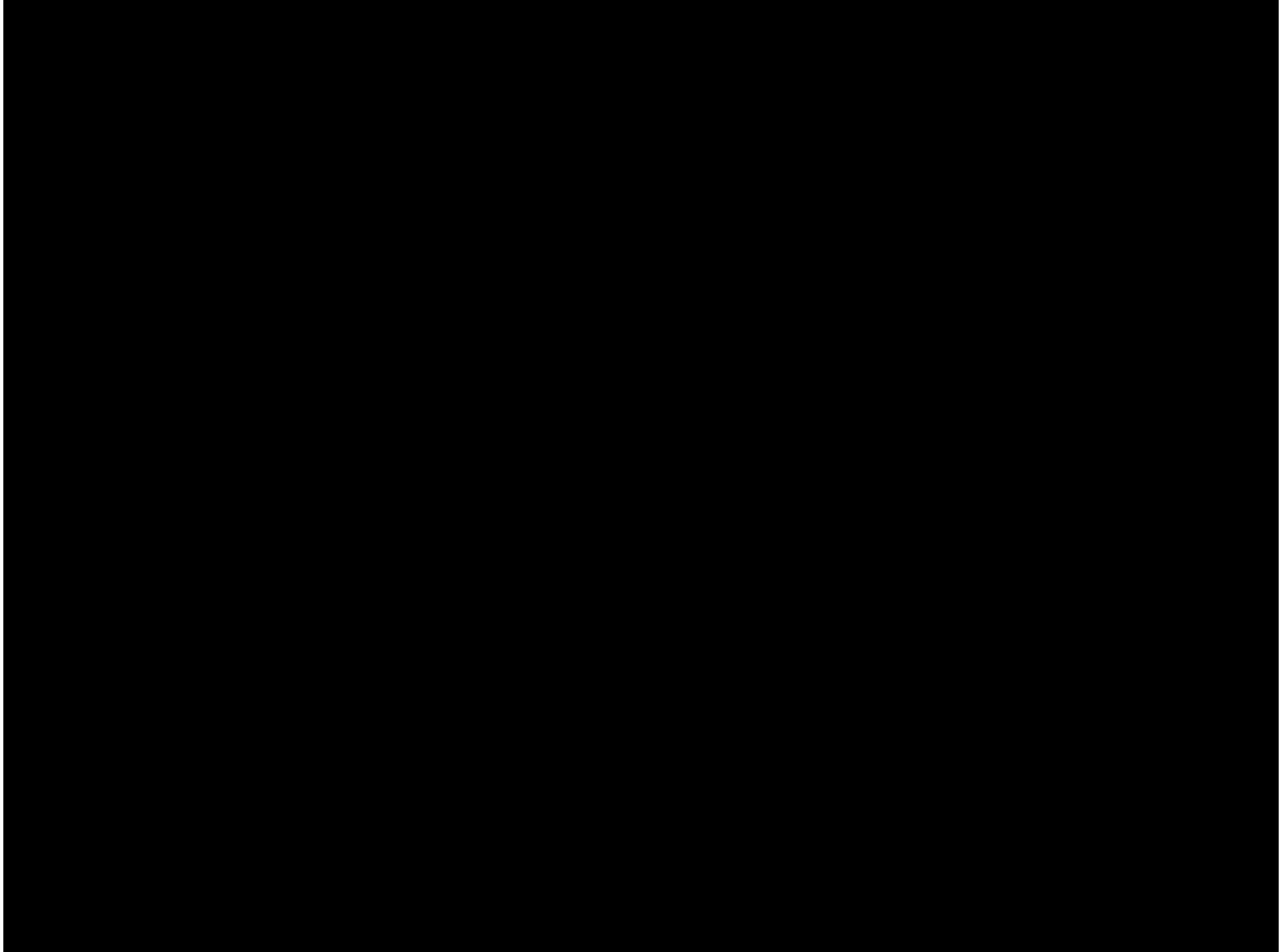
9) Univ. Liverpool (UK)

10) Univ. Göteborg (Sweden)

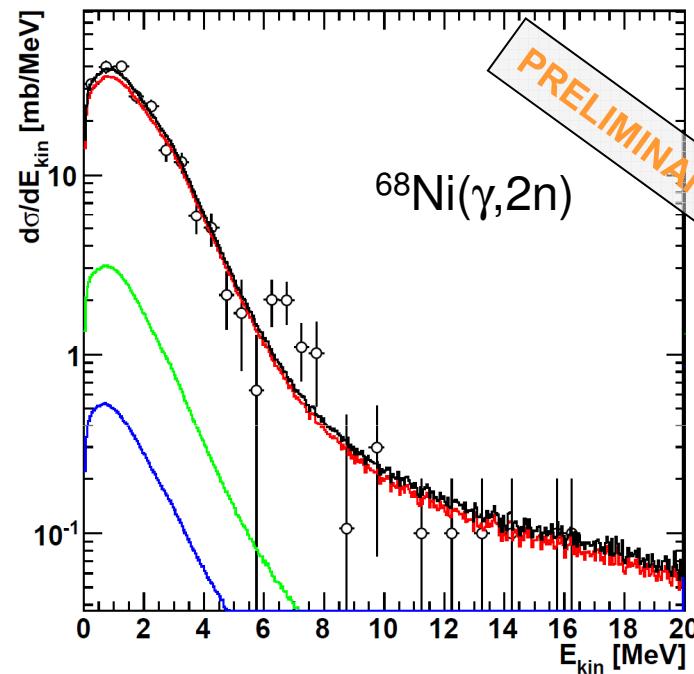
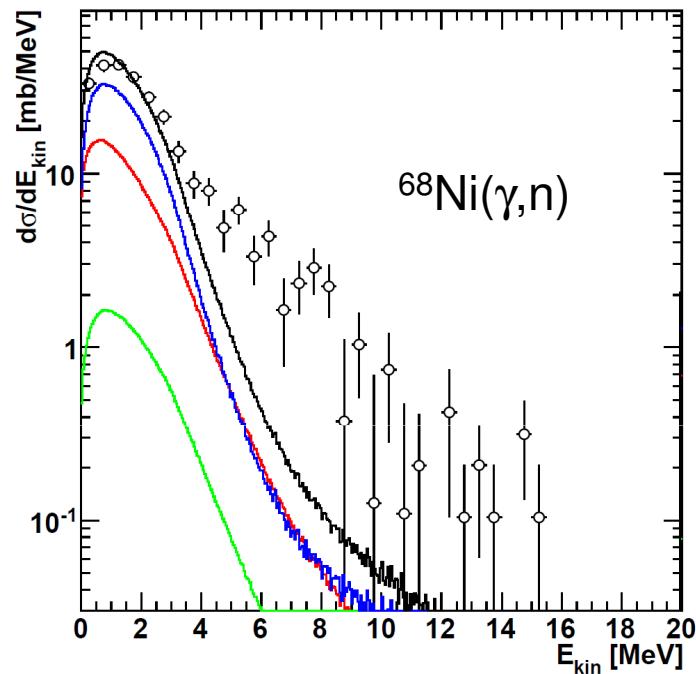
11) HZDR Rossendorf (Germany)

12) Univ. Krakow (Poland)

13) Univ. Zagreb (Croatia)

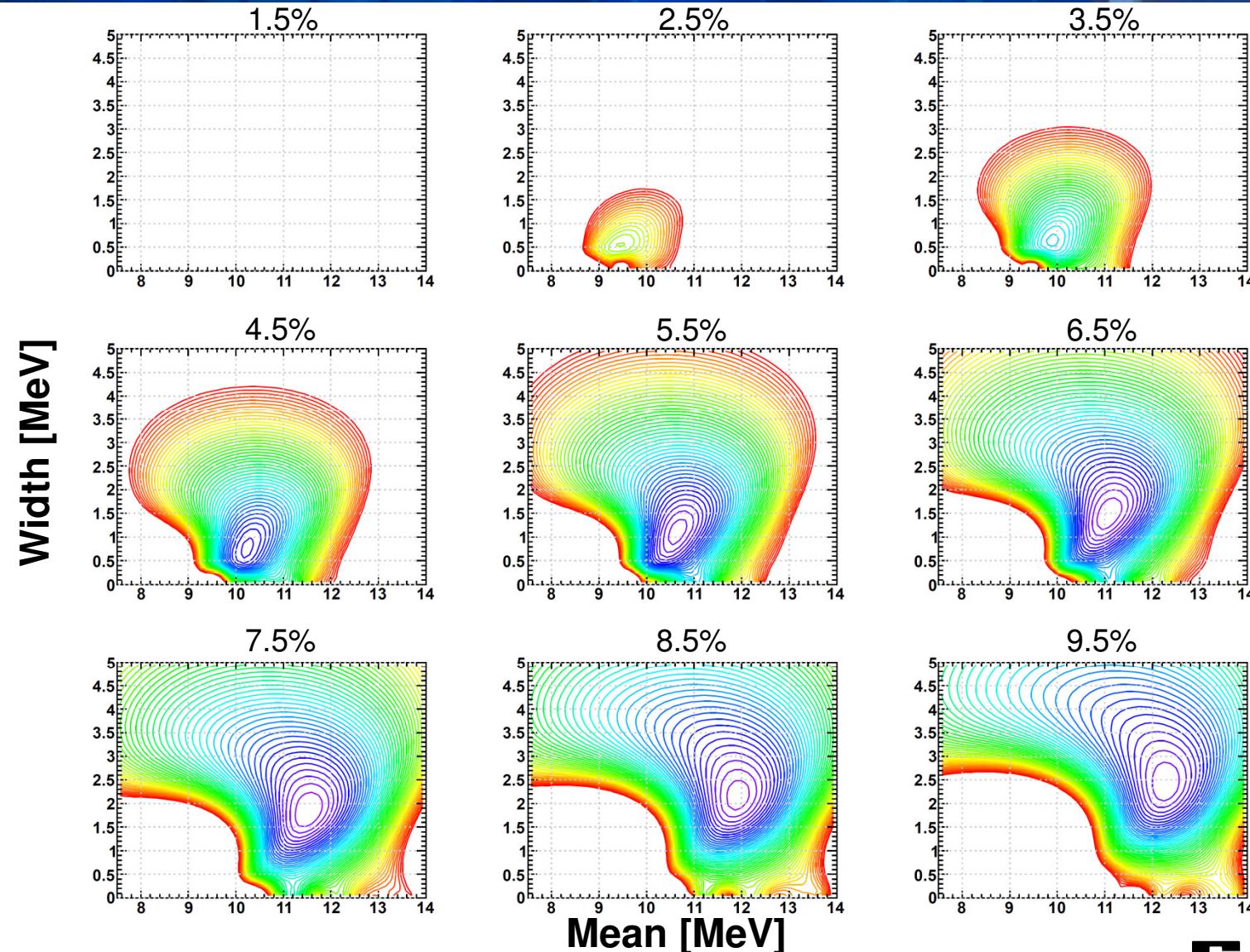


^{68}Ni : neutron kinetic energies



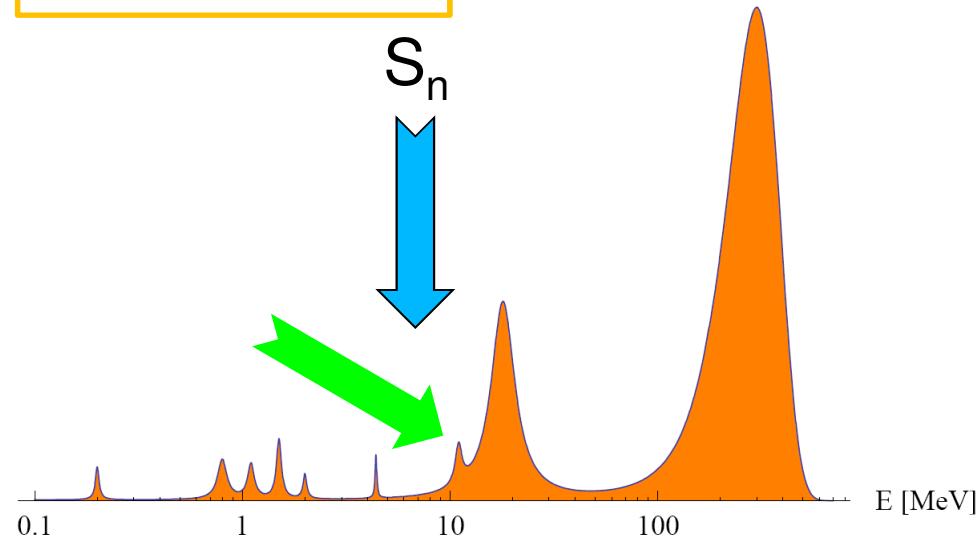
Total E1+E2 strength
GDR
PDR
ISGQR (80% EWSR)

^{68}Ni : PDR parameter χ_{ν}^2 maps



What are Giant Resonances?

Excitation function



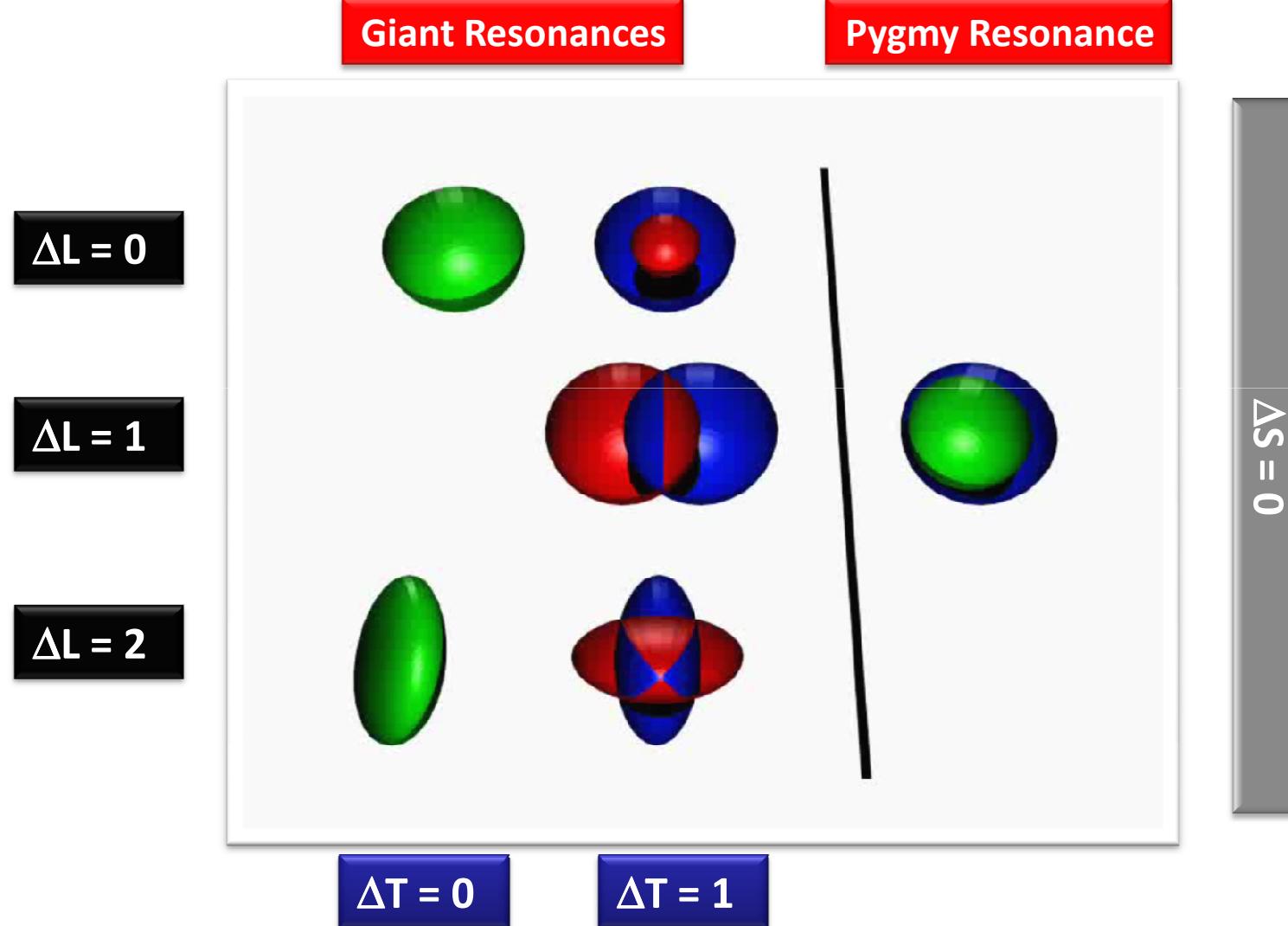
Single-particle, rotation
and vibration states

GR

PDR

- Collective states
 - Many/all nucleons participate in the resonance
- Transitions are labeled with quantum numbers:
 - ΔL : Multipolarity
 - ΔT : Isospin
 - ΔS : Spin
- Excitation:
 - Photons: (γ, γ') , $(\gamma, xn+yp)$, (γ, f)
 - Electrons: $(e, e'X)$
 - Hadrons: (p, p') , (d, d') , (α, α') ,
heavy ions (e.g. ^{12}C or ^{16}O)

Giant Resonances



General properties of Giant Dipole Resonances

$$\int_0^\infty \sigma(E) dE = \frac{2\pi^2 \hbar A e_{eff}^2}{mc} \cong 60 \frac{NZ}{A} \text{ MeV mb}$$

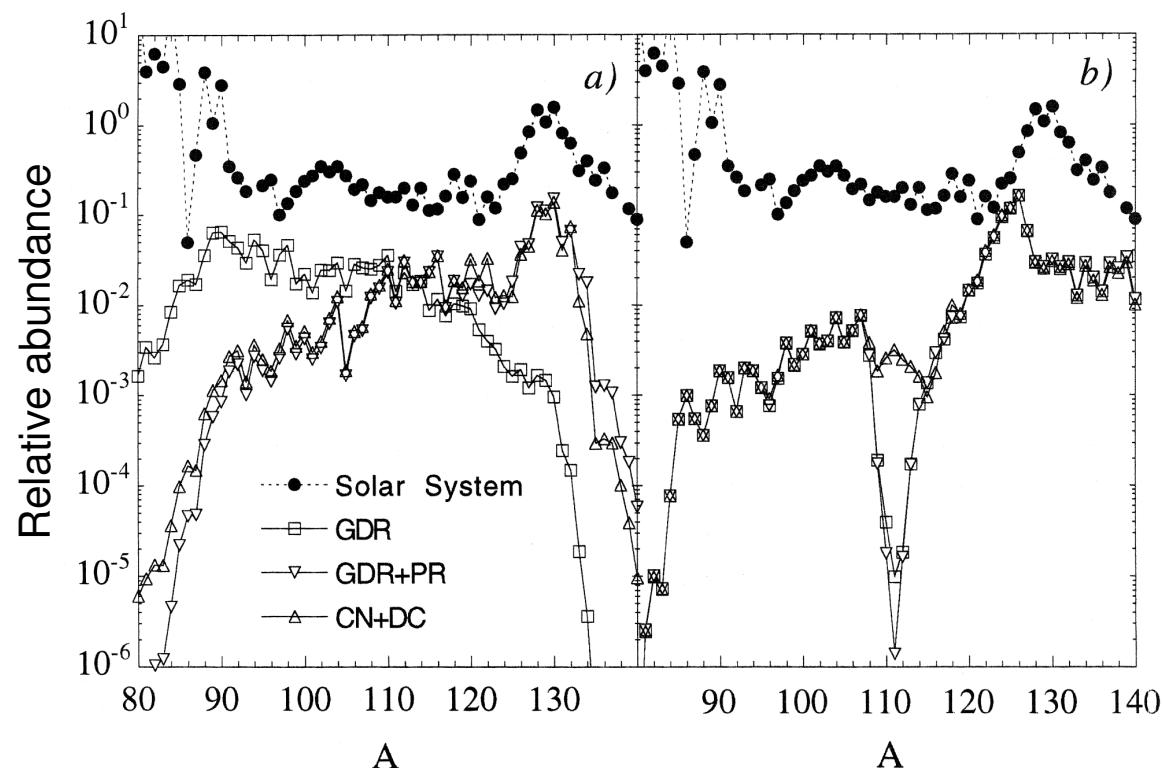
- **Thomas-Reiche-Kuhn sum rule:** prediction of integral cross section, based on the effective charge of the nucleus

- **Breit-Wigner distribution:**
 - σ_m : peak cross section
 - E_m : peak mean energy
 - Γ : peak width
- **Mean energy and width** depend on mass number A and on nuclear deformation
- Giant Resonances are **split** into up to three components in **deformed nuclei**

$$\sigma_\gamma(E) = \frac{\sigma_m}{1 + \left(\frac{E^2 - E_m^2}{E\Gamma}\right)^2}$$

- **Parametrization of E_m and Γ :**
 - Junghans *et al.*, Phys. Lett. B **670**(3), 200-204 (2008)
 - Systematics:
 $E_m = 31.2 A^{-1/3} + 20.6 A^{-1/6} \text{ MeV}$ (Jensen-Steinwedel + Goldhaber-Teller)
 $\Gamma = 2.3 + 14 A^{-2/3} + 21 A^{-1/2} \text{ MeV}$

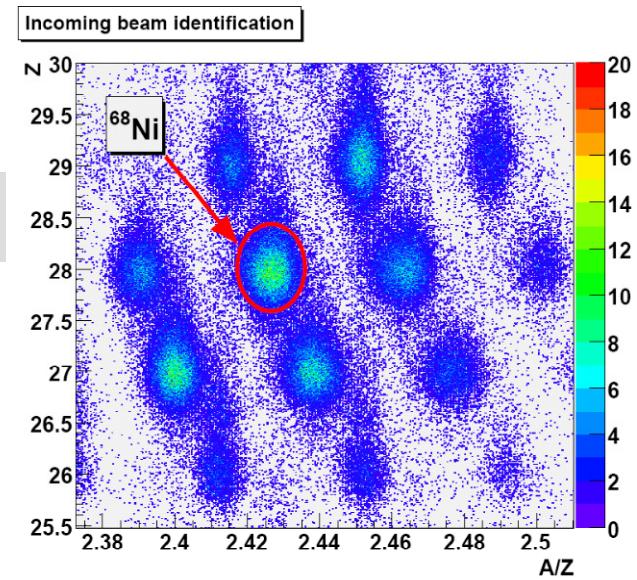
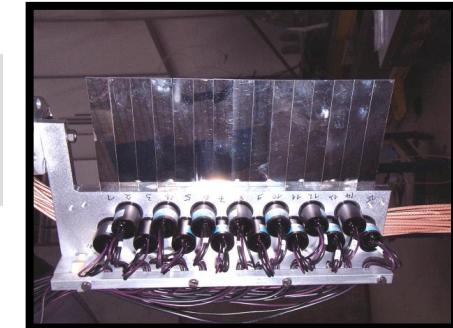
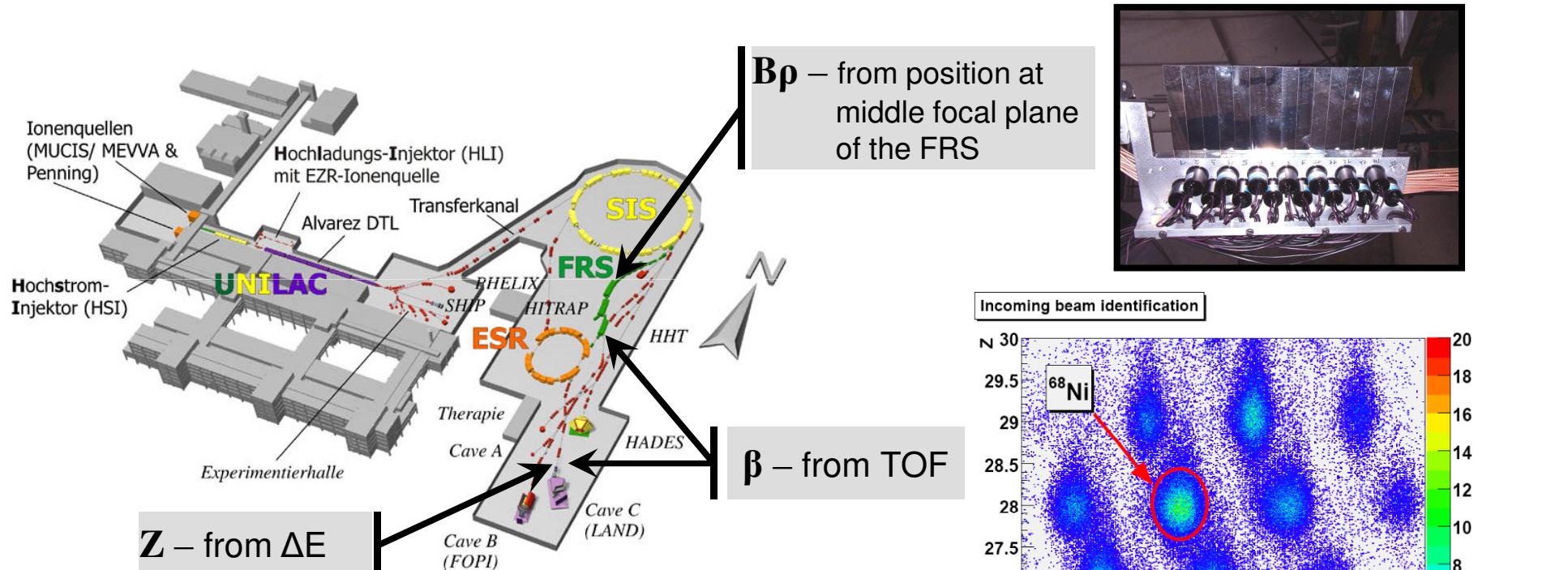
r-process



S. Goriely, Phys. Lett. B 436(1-2), 10-18 (1998)

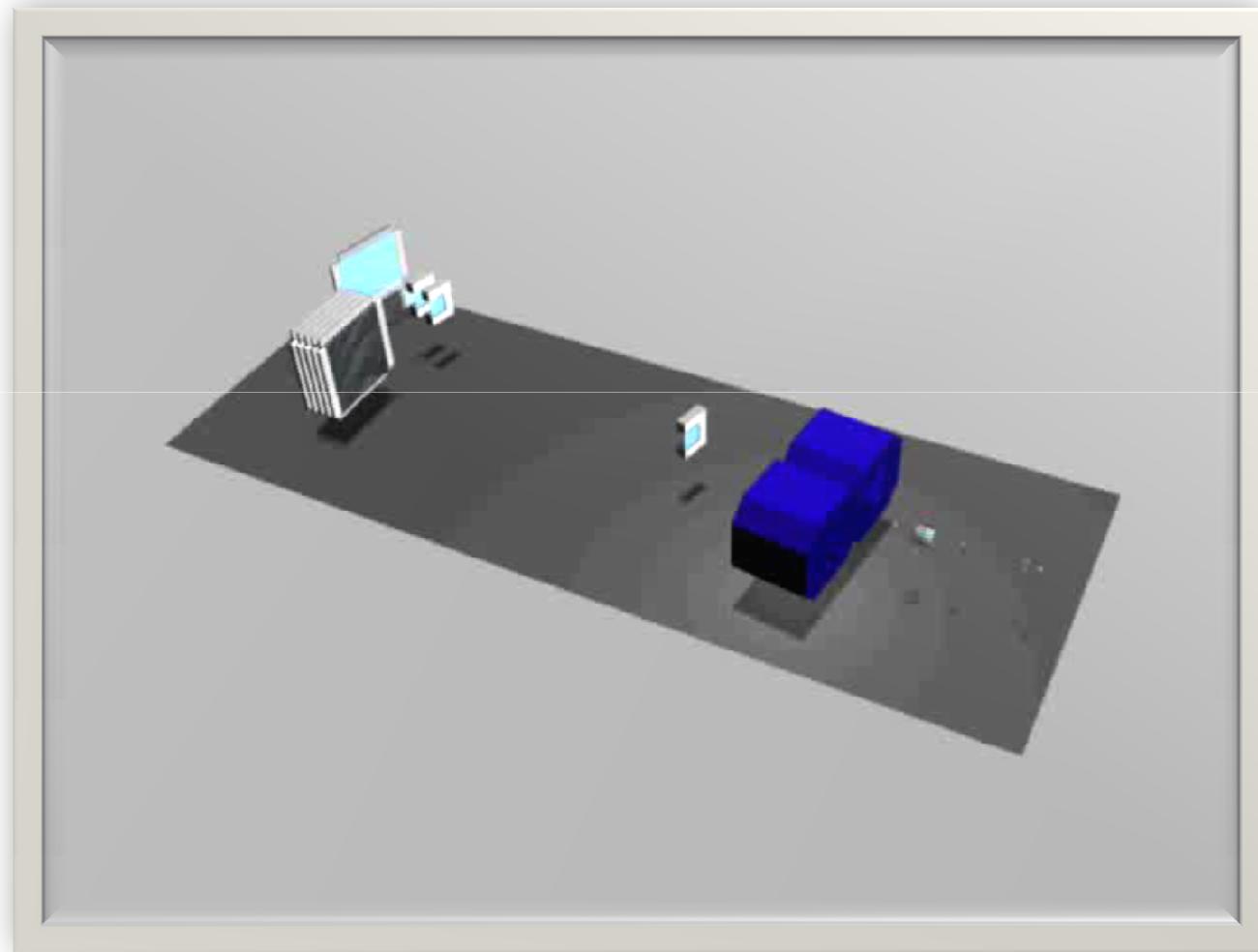
Experimental setup

- Stable beams from SIS, fragmentation on Be target or in-flight fission
- Production of radioactive beams in Fragment Separator (FRS)



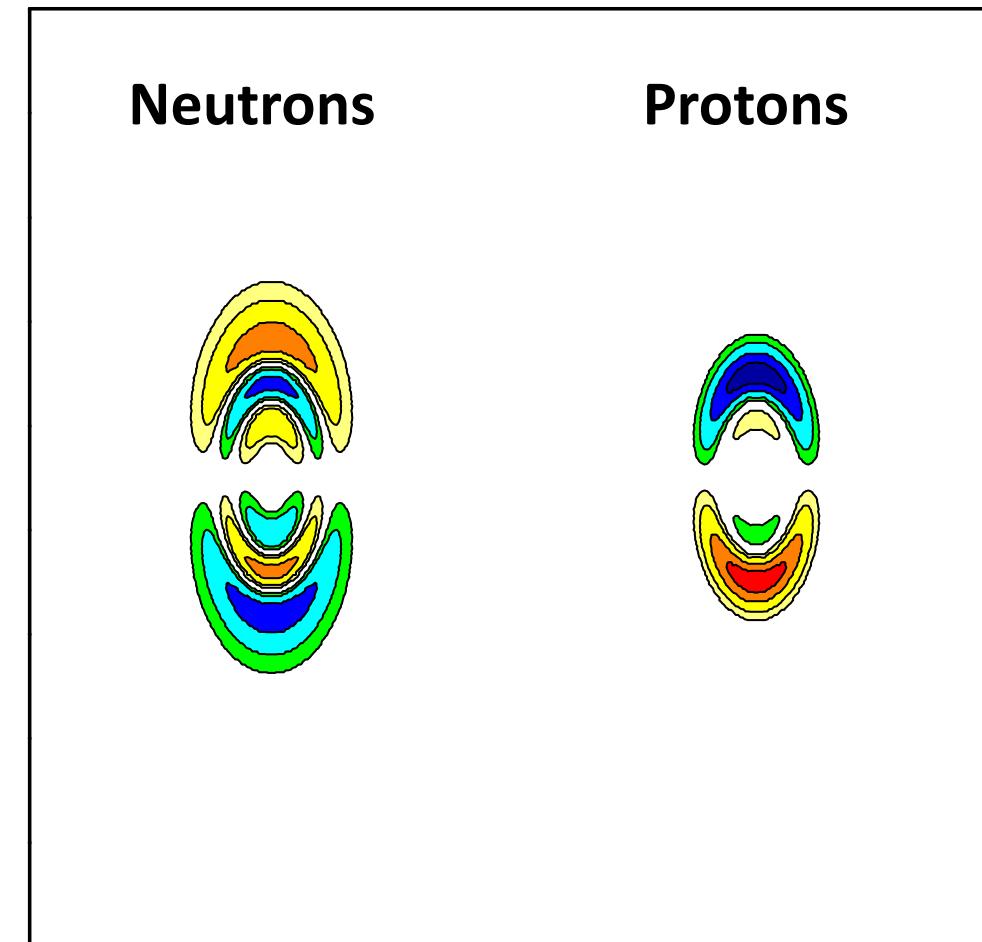
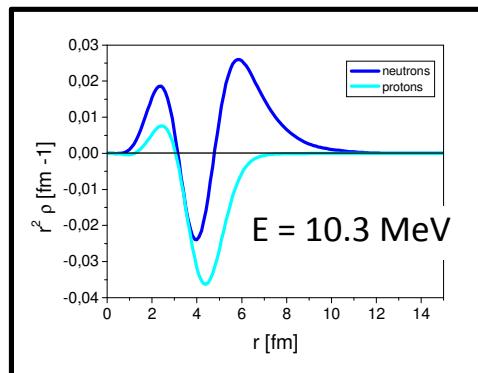
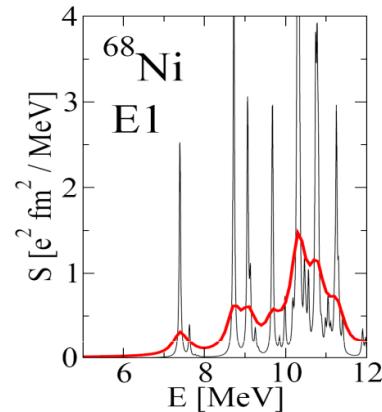
$$\frac{A}{Z} = \frac{e}{m_u c} \frac{B\rho}{\beta\gamma}$$

Experimental setup



RQTBA dipole transition densities in ^{68}Ni at 10.3 MeV

Theory:
RQTBA-2



E. Litvinova, private communication

^{68}Ni

PHYSICAL REVIEW C 81, 051303(R) (2010)

Information content of a new observable: The case of the nuclear neutron skin

P.-G. Reinhard¹ and W. Nazarewicz^{2,3,4,5}

¹Institut für Theoretische Physik II, Universität Erlangen-Nürnberg, Staudtstrasse 7, D-91058 Erlangen, Germany

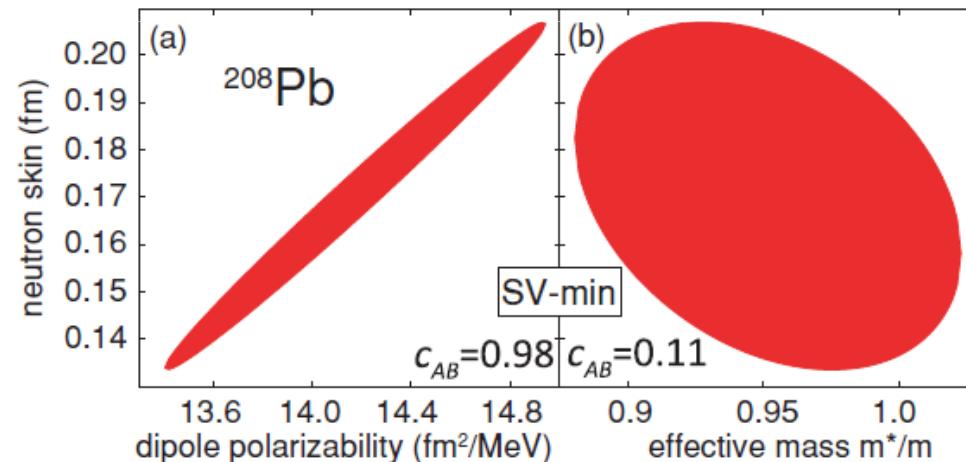
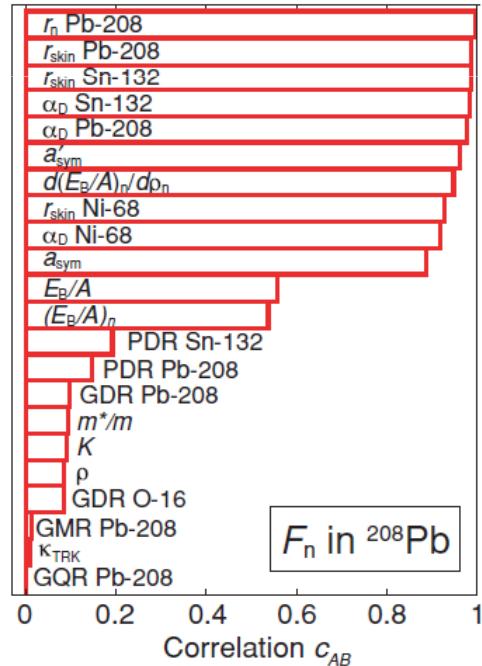
²Department of Physics & Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA

³Physics Division, Oak Ridge National Laboratory, Post Office Box 2008, Oak Ridge, Tennessee 37831, USA

⁴Institute of Theoretical Physics, University of Warsaw, ul. Hoża 69, PL-00-681 Warsaw, Poland

⁵School of Engineering and Science, University of the West of Scotland, Paisley PA1 2BE, United Kingdom

(Received 22 February 2010; published 28 May 2010)





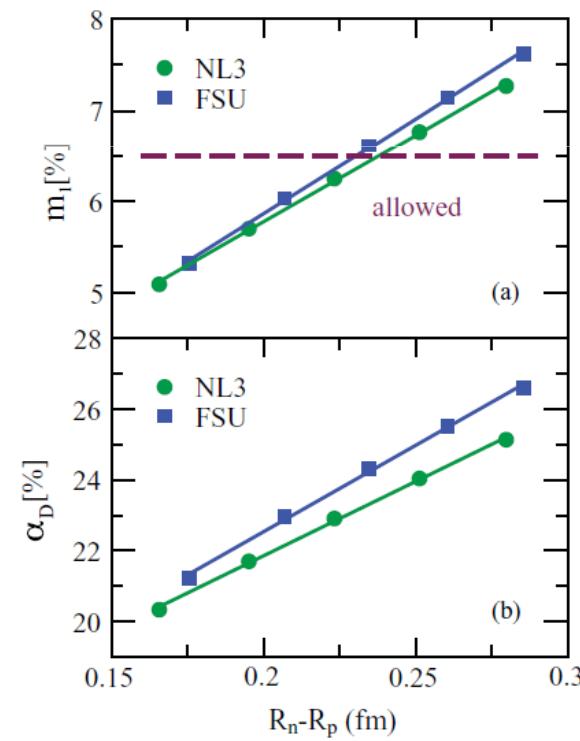
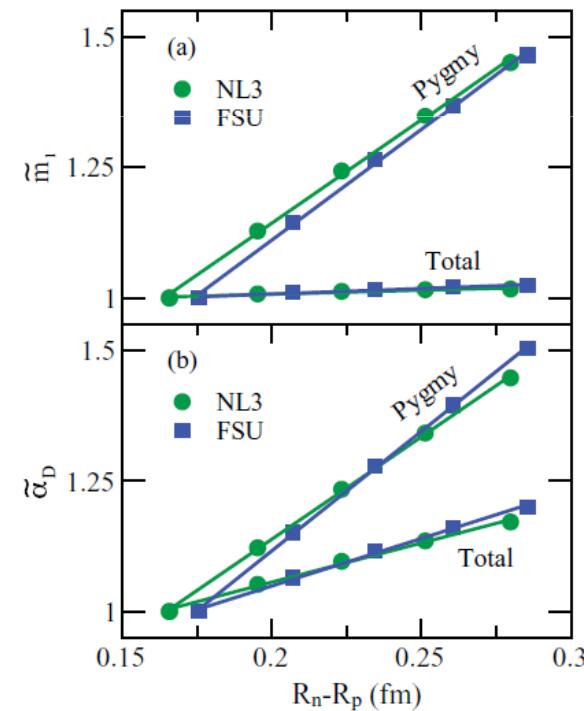
PHYSICAL REVIEW C **83**, 034319 (2011)

Pygmy resonances and neutron skins

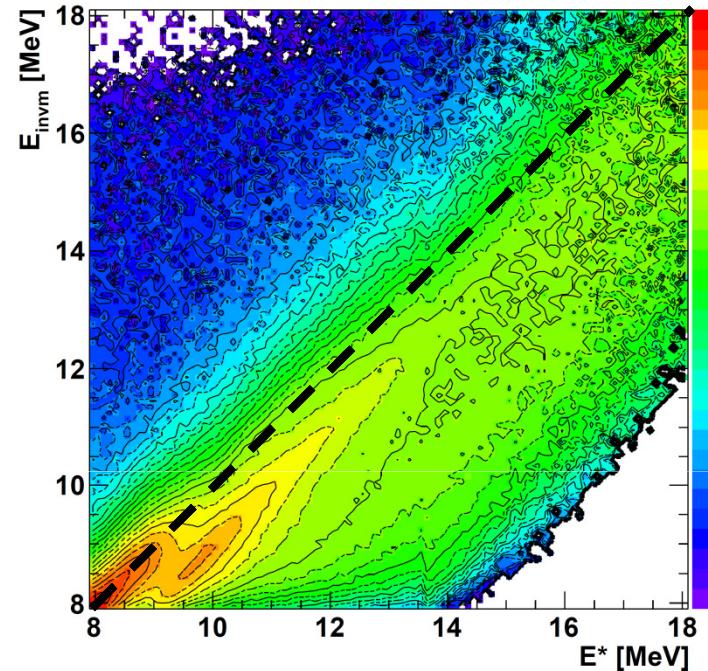
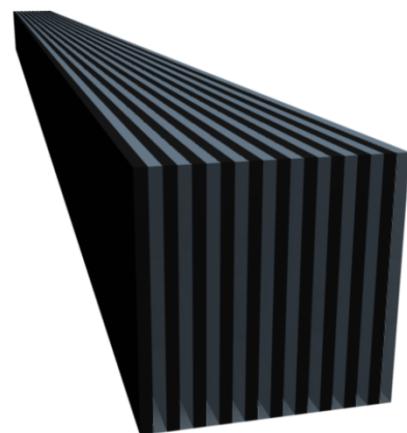
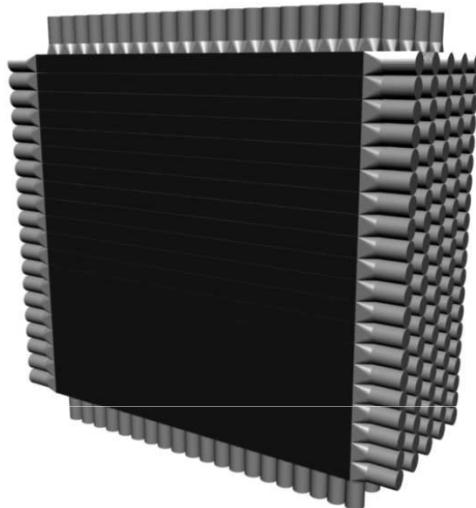
J. Piekarewicz

Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

(Received 8 December 2010; published 24 March 2011)

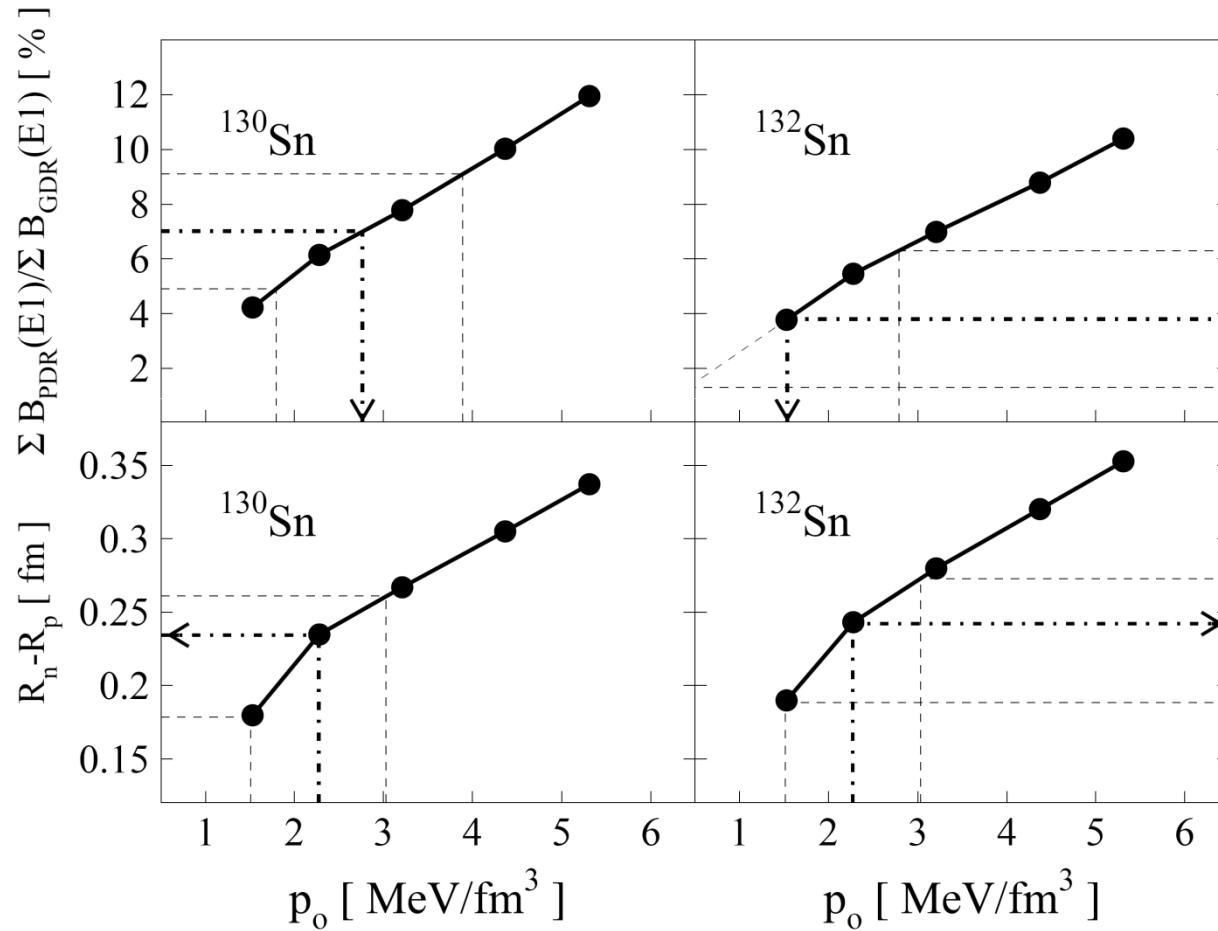


Large Area Neutron Detector (LAND)



- 200 scintillator paddles (each $10 \times 10 \times 200 \text{ cm}^3$)
- High efficiency ($> 90\%$ for $E_n > 400 \text{ MeV}$)
- 5 mm passive Fe converter + 5 mm organic scintillator
- 1 neutron = several hits in detector
 - \Rightarrow Shower algorithm reconstructs neutron hits
 - \Rightarrow Introduces detector-specific response

Nuclear Equation-Of-State

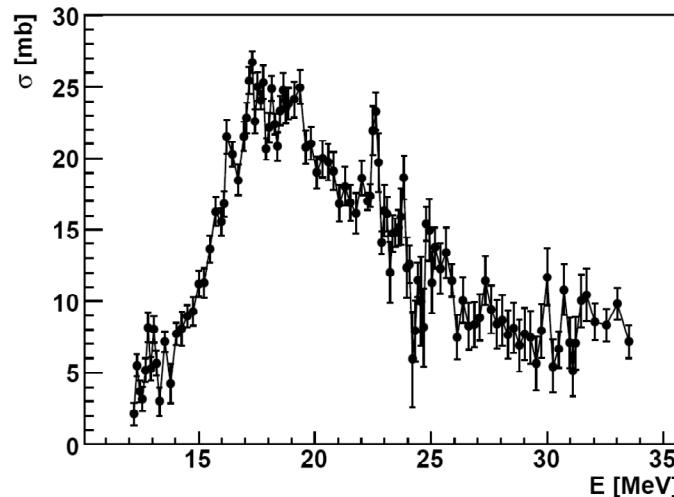


- RQRPA calculations performed by N. Paar
- Analysis of $^{130,132}\text{Sn}$ provide mean EOS parameters:
 - ⇒ $\langle a_4 \rangle = 32.0(1.8)$ MeV
 - ⇒ $\langle p_0 \rangle = 2.3(0.8)$ MeV/fm³
- Values of the neutron skin thickness are also obtained:
 - ⇒ $^{130}\text{Sn}: 0.23(4)$ fm
 - ⇒ $^{132}\text{Sn}: 0.24(4)$ fm

A. Klimkiewicz, N. Paar *et al.*, Phys. Rev. C **76**, 051603(R) (2007)

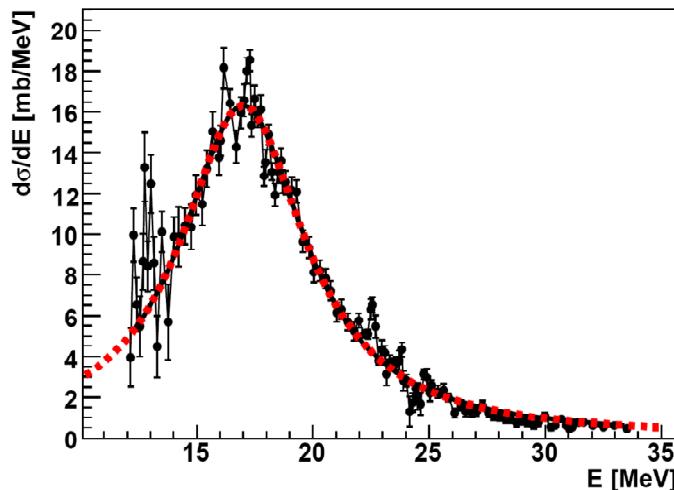
^{58}Ni Coulomb excitation

Photoabsorption cross section



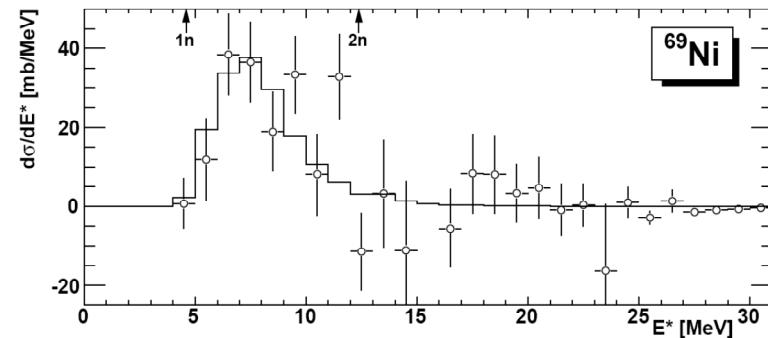
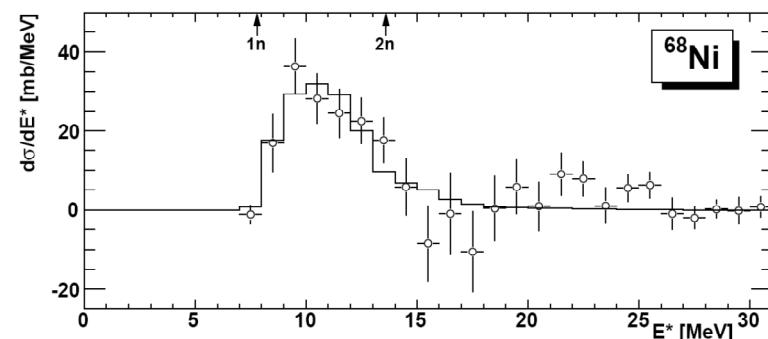
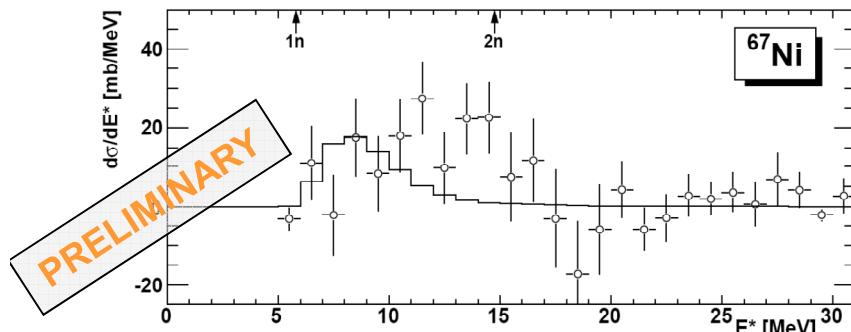
Data set	$\sigma(1n)$ [mb]	$\sigma(1np)$ [mb]	$\sigma(1n+1np)$ [mb]	Syst. error [mb]
Fultz <i>et al.</i>	-	-	123(6)	15
Present experiment	111(4)	25(4)	136(8)	8

Coulomb excitation cross section



- Photoabsorption data from S. C. Fultz *et al.*, PRC **10**, 608 (1974)
- Inclusive measurement: contains (γ,n) and (γ,np) cross-sections
- In ^{58}Ni : $S_p = 8.17 \text{ MeV}$, $S_n = 12.2 \text{ MeV}$ and $S_{np} = 19.6 \text{ MeV}$
- ⇒ Only 30% TRK sum rule strength observed; non-Lorentzian photoabsorption distribution

67-69Ni: Additional E1-Strength

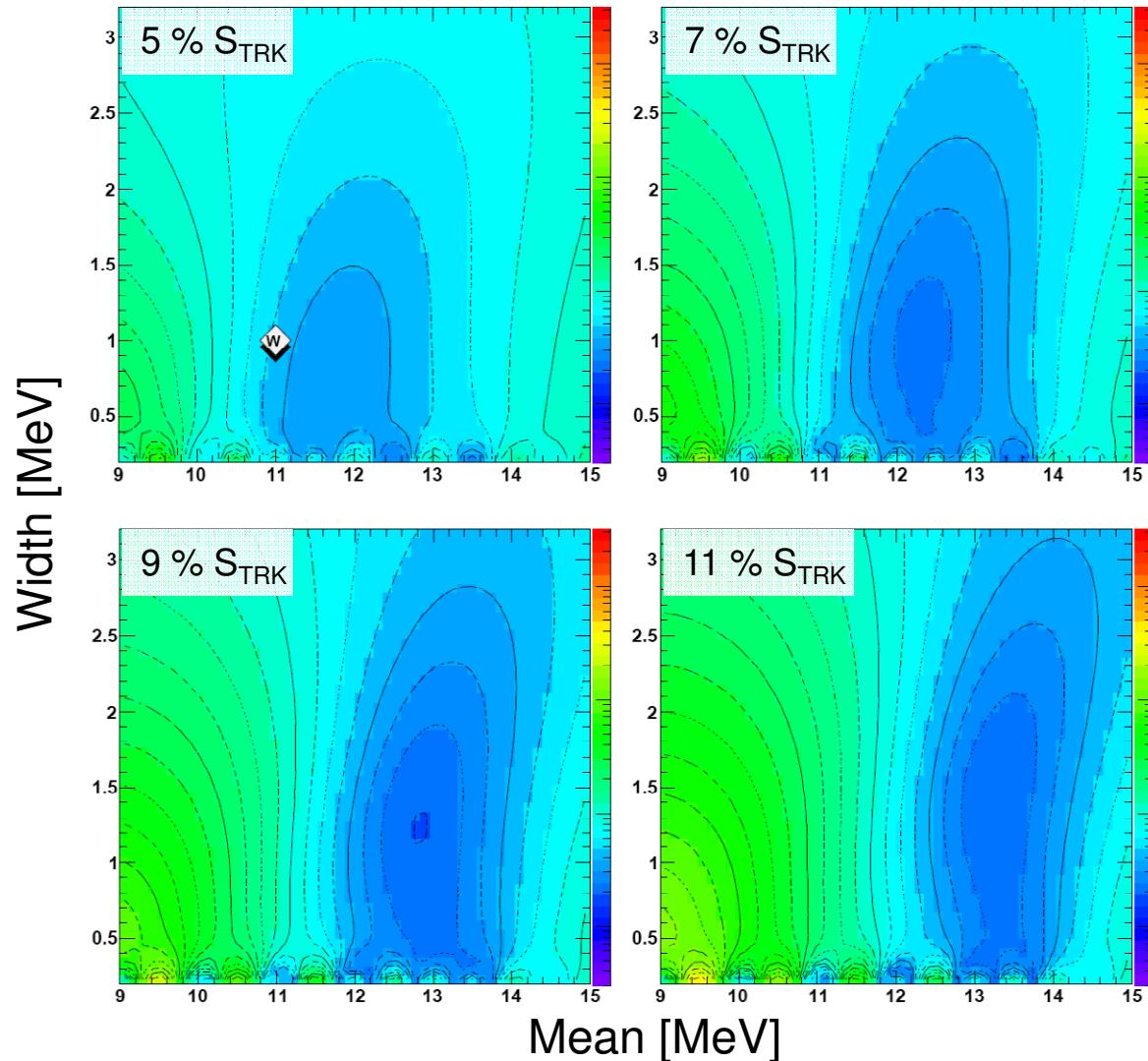


Additional E1 cross section

^A Z	Junghans <i>et al.</i>	Systematics
67Ni	146(44) mb	83(45) mb
68Ni	168(31) mb	139(31) mb
69Ni	127(51) mb	94(52) mb

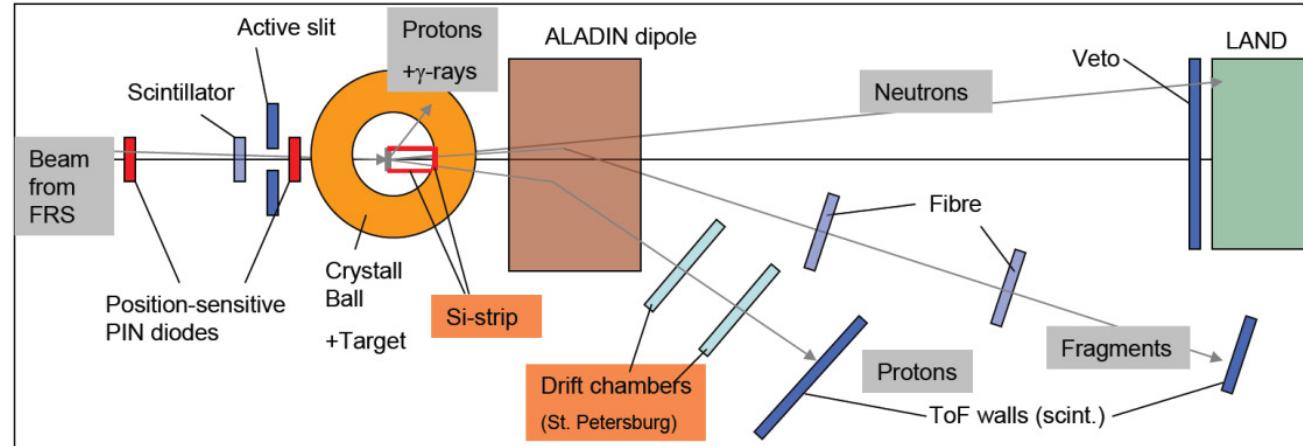
- PDR parameters cannot be extracted from data in a model-independent manner
- Excess cross section in 1n channel cannot be explained even by 100% GQR
- Observed PDR strength in ⁶⁸⁻⁶⁹Ni: between 5 and 15 % TRK sum rule strength
- PDR parameters can be evaluated using χ^2 map of parameter space

^{68}Ni : PDR parameter χ_v^2 maps

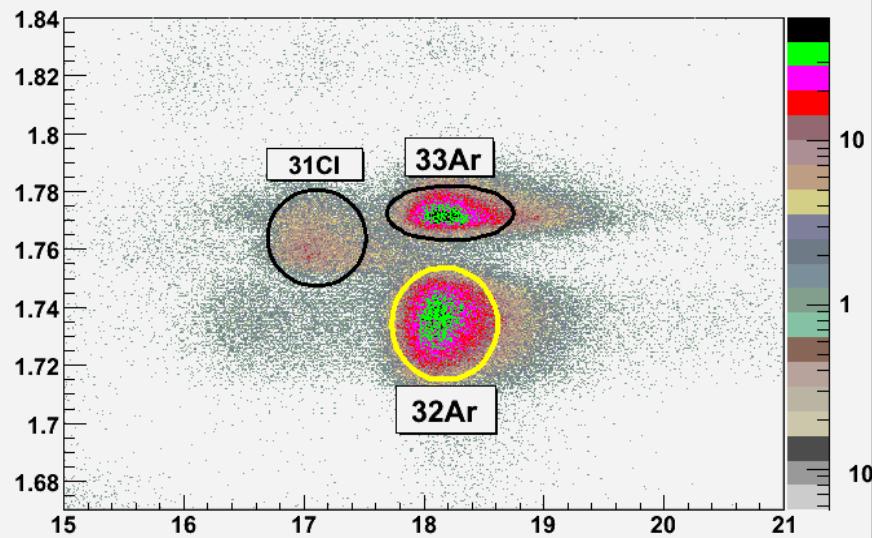


- Calculation of χ_v^2 for all combinations of the mean, width and strength of the PDR distribution
- Representation of the PDR parameter space for mean (horizontal axis) and width (vertical axis)
- $\chi_v^2 = 1$ labeled by blue region
- Wieland *et al.* measurement labeled by „W“ in 5% S_{TRK} plot

Dipole response studies in ^{32}Ar and ^{34}Ar



Incoming beam identification

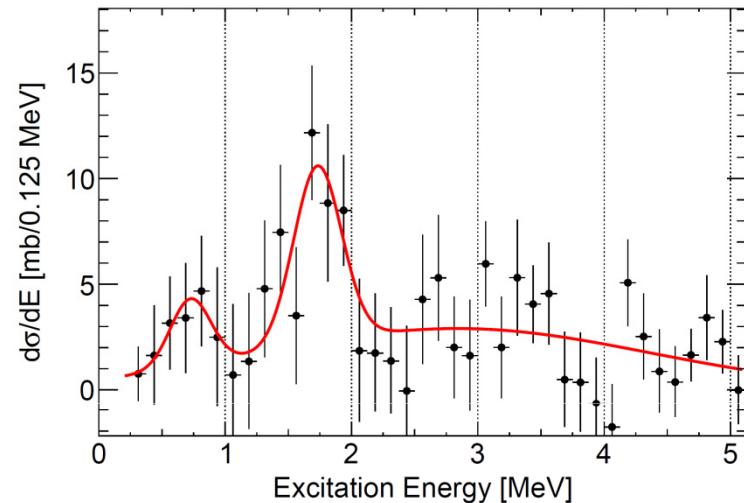


statistics expected:

~500 events in PDR region, ~1000 in GDR region

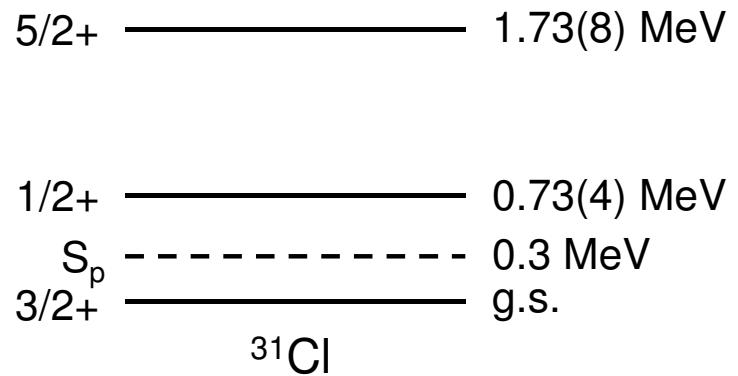
~150 events in PDR region, ~1500 in GDR region

$^{31}\text{Cl}(\gamma, \text{p})$

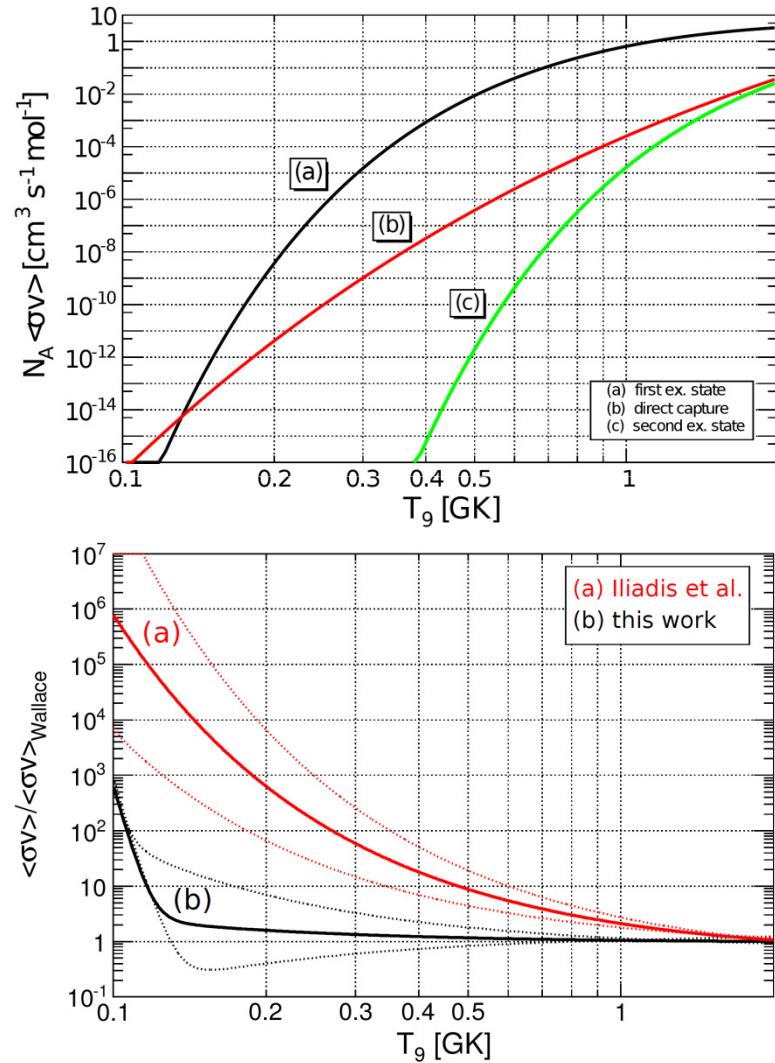


- No significant population of first excited state in ^{30}S (2^+ , 2.21 MeV)
- Two resonances observed:
 - 0.73(4) MeV
 - 1.73(8) MeV
- One broad component: direct capture
- Resonance widths mainly resolution

J^π	Cross section [mb]
$\frac{1}{2}^+$	15(6)
$\frac{5}{2}^+$	30(9)

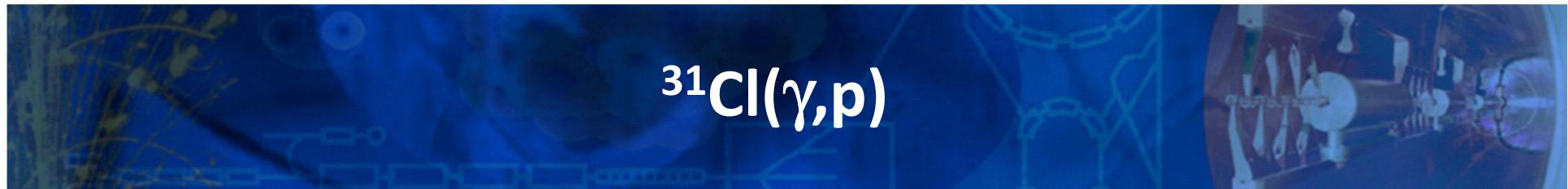


$^{31}\text{Cl}(\gamma, \text{p})$

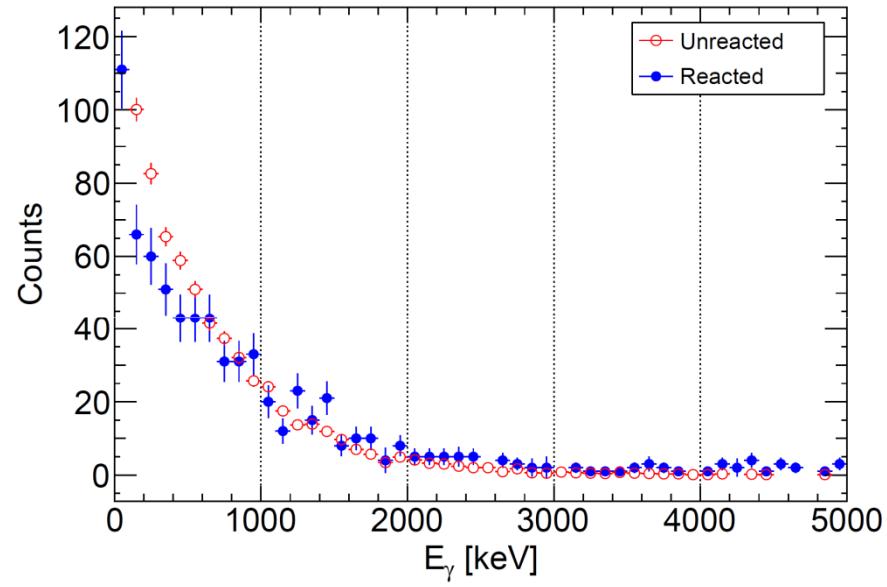
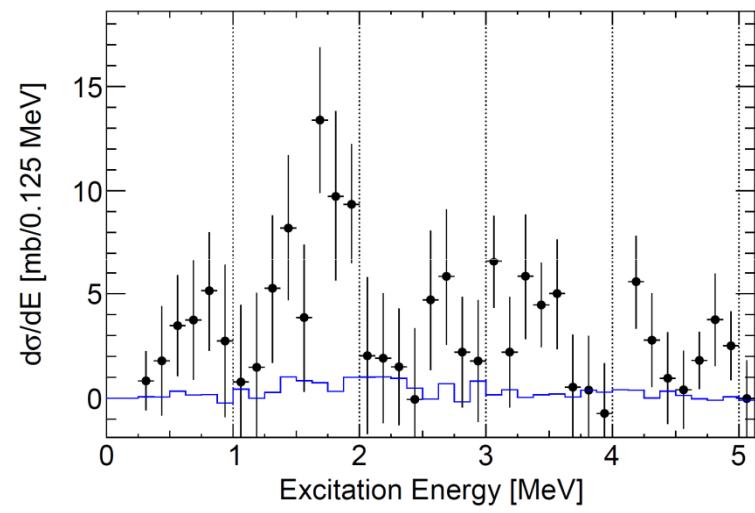


- Production rates for the $^{30}\text{S}(\text{p}, \gamma)^{31}\text{Cl}$ reaction
- Stellar conditions
- Direct capture: E1
- Temperature range corresponds to typical T for X-ray burst of type I
- First excited state clearly dominates reaction rate

- Comparison with rate of Wallace and Woosley (*Astrophysical Journal Suppl. Series* **45**, 389-420 (1981))
- Good agreement above $T_9 = 0.2$



$^{31}\text{Cl}(\gamma, \text{p})$

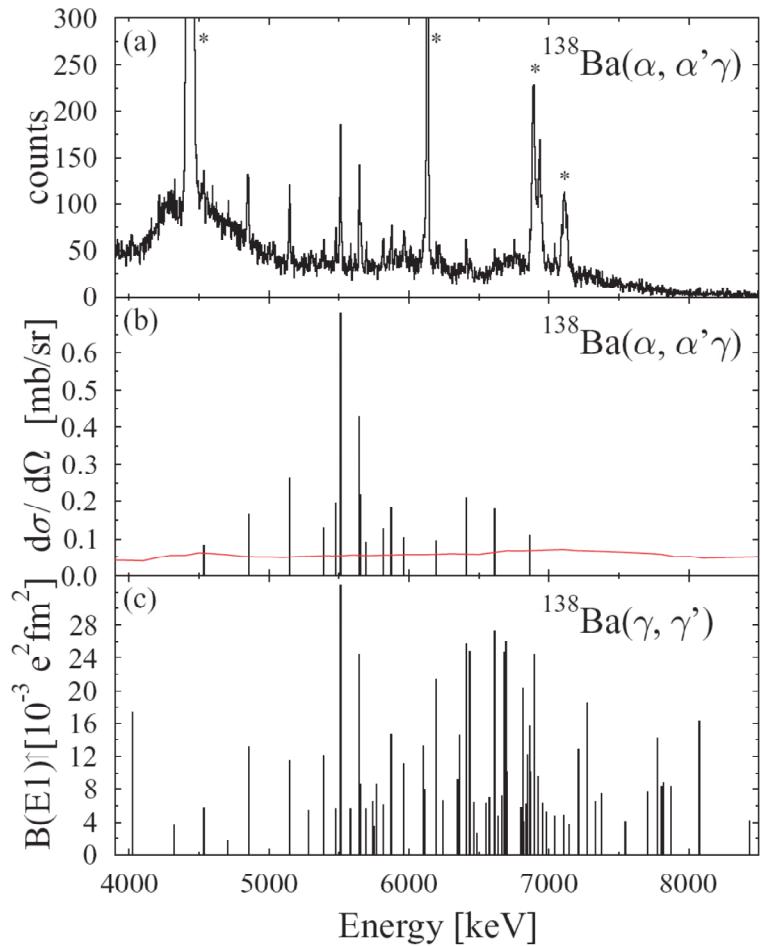


New E1 measurement of Sn isotopes

- 1. Measurement of isovector GDR in complete Sn isotopic chain from A = 124 to 134 with high statistics**
 - Reduce statistical error for the systematical extraction of GDR parameters
 - Observation of direct photon-decay of GDR
 - Measurement of stable isotope for comparison with other experimental data

- 2. Measurement of PDR in complete Sn isotopic chain below and above the neutron threshold**
 - Measurement of (γ, xn) and (γ, γ') channels
 - ⇒ PDR strength distribution independent of neutron threshold

New E1 measurement of Sn isotopes (cont'd)

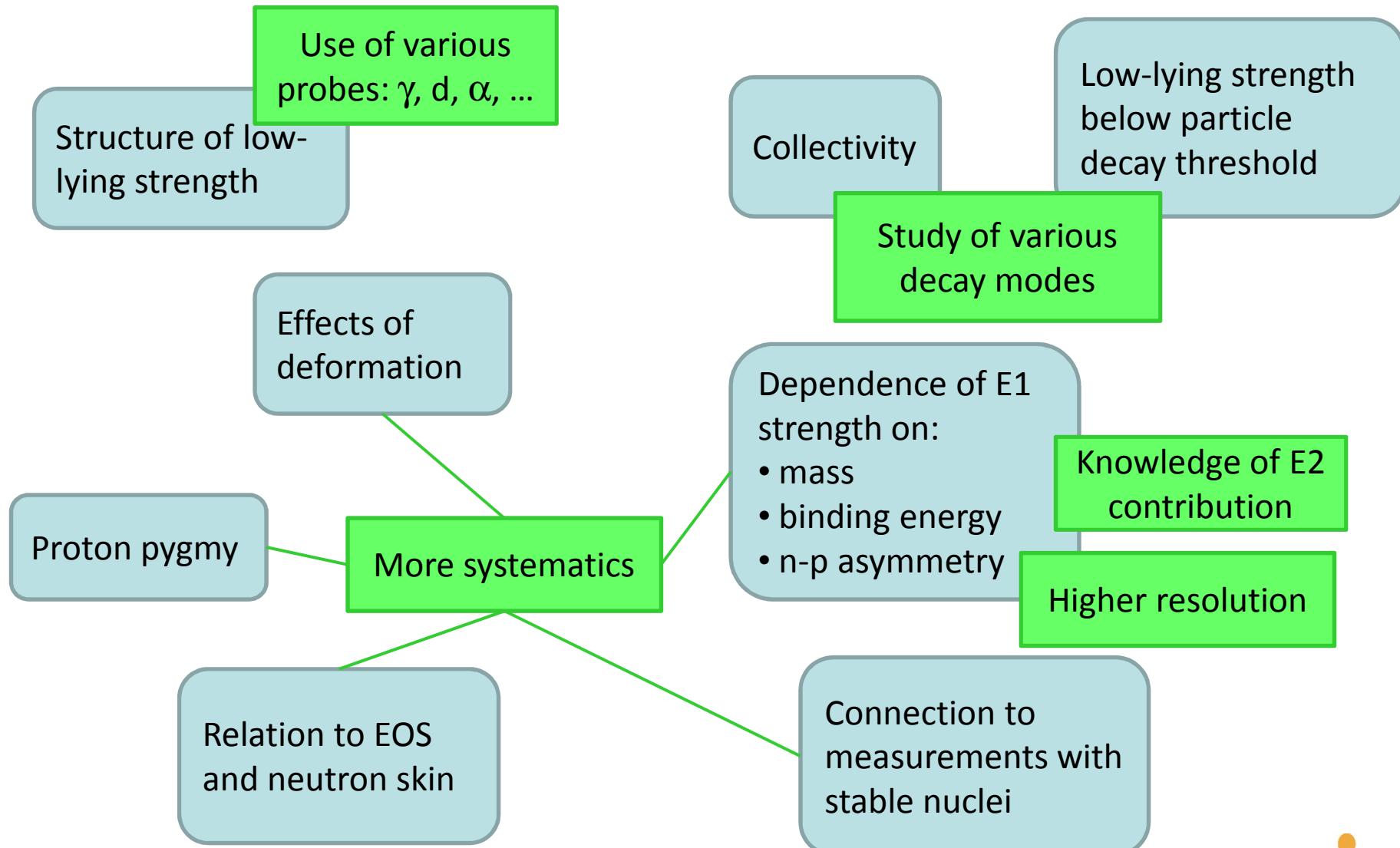


4. Investigation of the isospin character of the low-lying dipole strength

- Nuclear inelastic scattering with an isoscalar probe, using $(d,d'\gamma)$
- Analysis of photon decay branch allows the selection of dipole excitations
- Foreseen for high-statistics beams, such as ^{124}Sn and ^{128}Sn

J. Endres *et al.*, Phys. Rev. C **80**, 034302 (2009)

Questions to be answered experimentally



Questions to be answered by experiment

- E1 strength (both PDR and GDR) dependence on mass, binding energy and n-p asymmetry
 - Requires more systematics, higher resolution, extraction of E2 contribution
- Collectivity?
 - Study of decay modes: direct gamma decay, particle decay to A-1 states
- Low-lying strength below threshold?
 - Measurements below and above threshold
- Connection to measurements with stable nuclei
- Structure of low-lying dipole strength?
 - Use of various probes: γ , d, α
- Relation to EOS and neutron skin
 - Measure various nuclei and mass regions
- Proton pygmy?
 - Measurement of $^{32,34}\text{Ar}$ (data analysis in progress)
- Effect of deformation?



LAND collaboration

$^{127-132}\text{Sn}$ (Exp. S221) – $^{57-72}\text{Ni}$ (Exp. S287)

A. Klimkiewicz^{1,2}, N. Paar³, P. Adrich^{1,2}, M. Fallot¹, T. le Bleis^{4,5}, D. Rossi⁶, K. Boretzky¹,
T. Aumann¹, H. Alvarez-Pol⁷, F. Aksouh¹, K.H. Behr¹, J. Benlliure⁷, T. Berg⁶,
M. Boehmer⁸, A. Bruenle¹, E. Casarejos⁷, M. Chartier⁹, A. Chatillon¹, D. Cortina-Gil⁷,
U. Datta Pramanik¹⁰, Th.W. Elze⁵, H. Emling¹, O. Ershova^{1,4}, B. Fernando-Dominguez⁹,
H. Geissel¹, M. Gorska¹, M. Heil¹, M. Hellström¹, G. Ickert¹, H. Johansson^{1,11}, K. Jones¹,
A. Junghans¹², O. Kiselev⁶, J.V. Kratz⁶, R. Kulessa², N. Kurz¹, M. Labiche¹³, R. Lemmon¹⁴,
Y. Litvinov¹, K. Mahata¹, P. Maierbeck⁸, T. Nilsson¹¹, C. Nociforo¹, R. Palit¹,
S. Paschalis⁹, R. Plag^{1,6}, W. Prokopowicz¹, R. Reifarth^{1,6}, H. Simon¹, K. Sümmerer¹,

G. Surówka², D. Vretenar³, A. Wagner¹², W. Waluś², H. Weick¹, and M. Winkler¹

¹*GSI, Darmstadt, Germany*, ²*Uniwersytet Jagielloński, Kraków, Poland*, ³*University of Zagreb, Croatia*,

⁴*University of Strasbourg, France*, ⁵*Johann Wolfgang Goethe - Universität, Frankfurt am Main, Germany*,

⁶*Johannes Gutenberg - Universität, Mainz, Germany*, ⁷*Universidade de Santiago de Compostela, Spain*,

⁸*Technische Universität München, Germany*, ⁹*University of Liverpool, UK*, ¹⁰*SINP, Kolkata, India*,

¹¹*Chalmers University of Technology, Sweden*, ¹²*FZD, Rossendorf, Germany*, ¹³*University of Paisley, UK*,

¹⁴*CCLRC Daresbury Laboratory, UK*