Symmetry Energy from Pigmy Dipole and Giant Resonances

F. Camera
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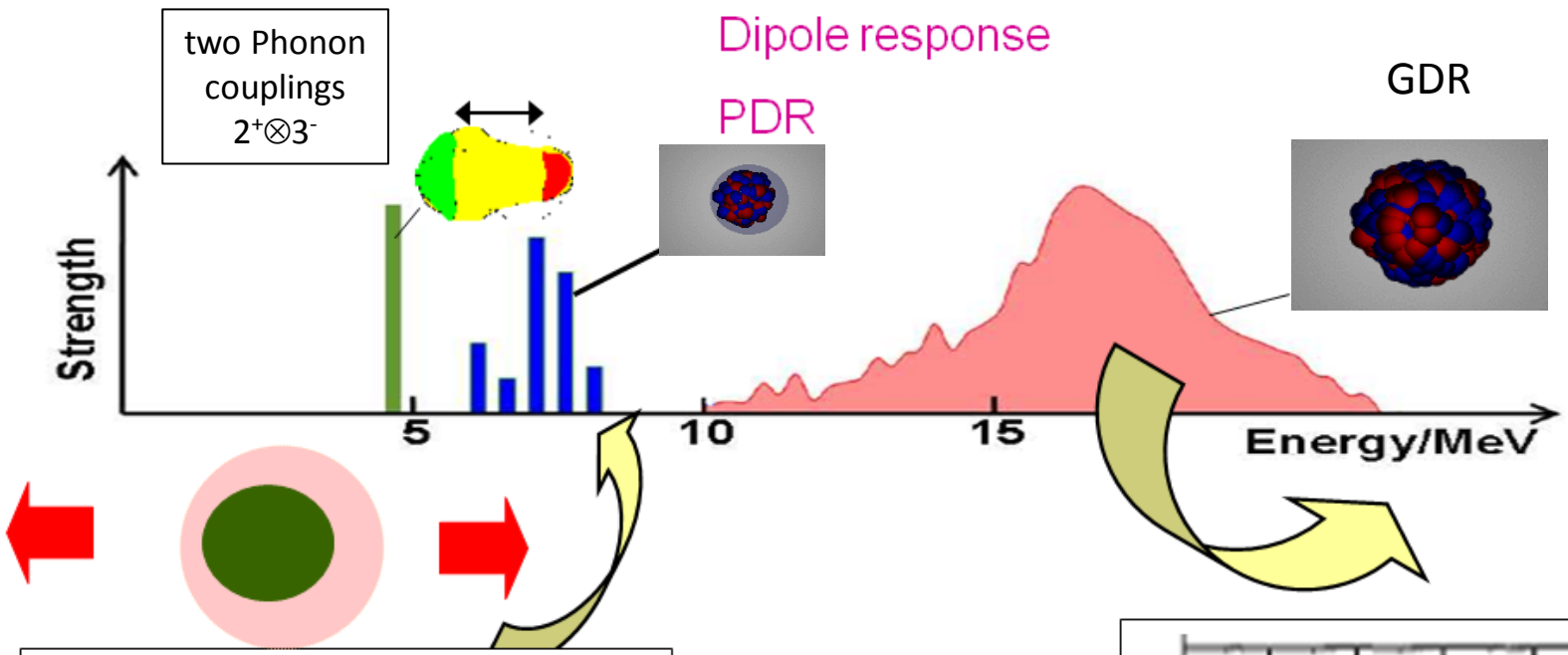
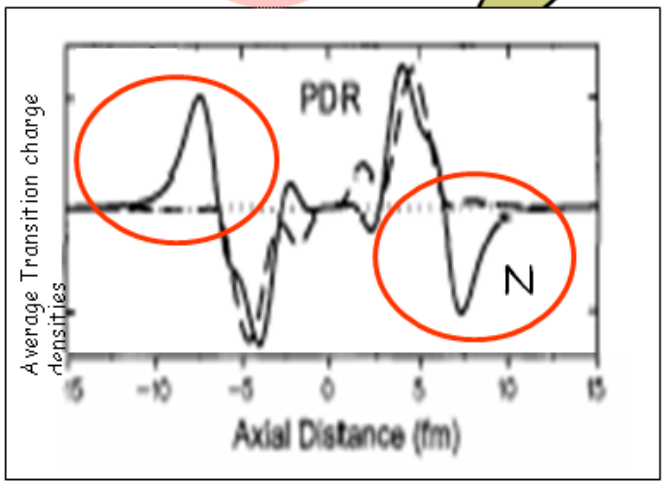
OUTLINE

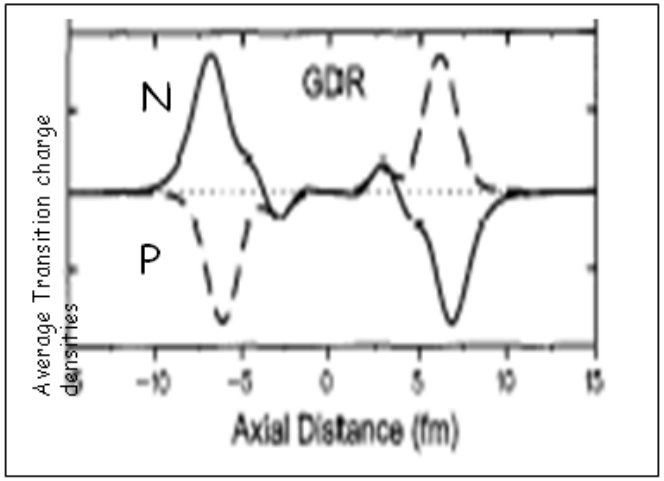
- Motivation
- Experiment description
- Results
- Comparison with theory
- Conclusions and perspectives

Electric Dipole response in Nuclei



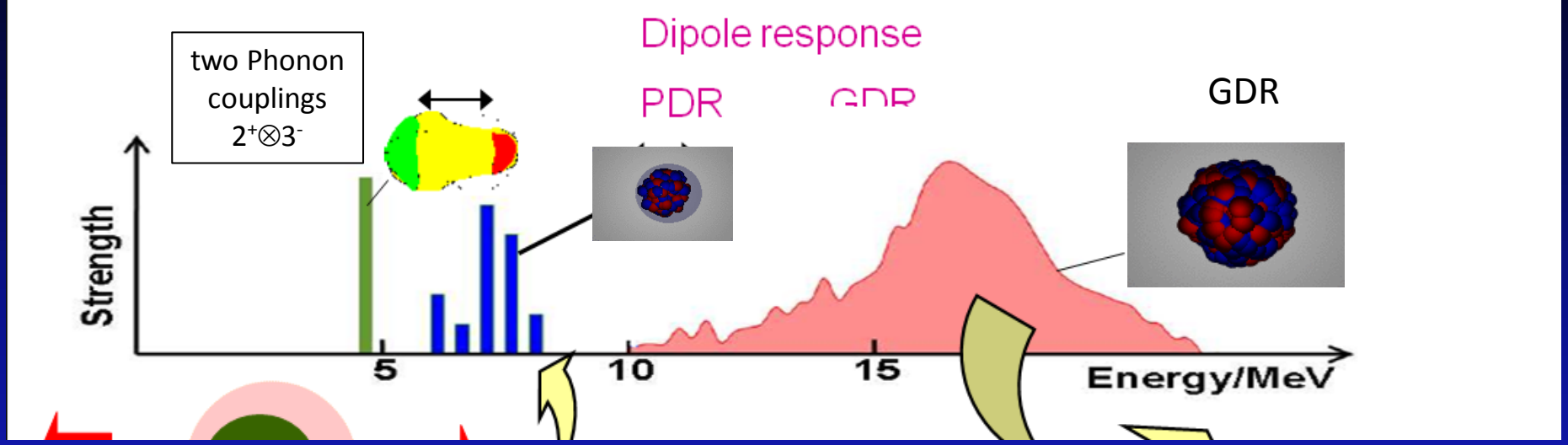


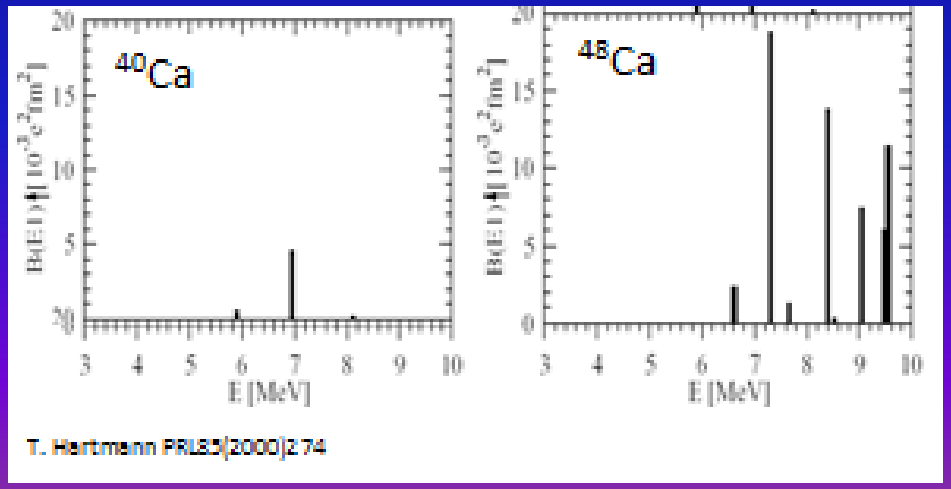
Average Transition charge densities



Richter NPA 731(2004)59

Electric Dipole response in Nuclei

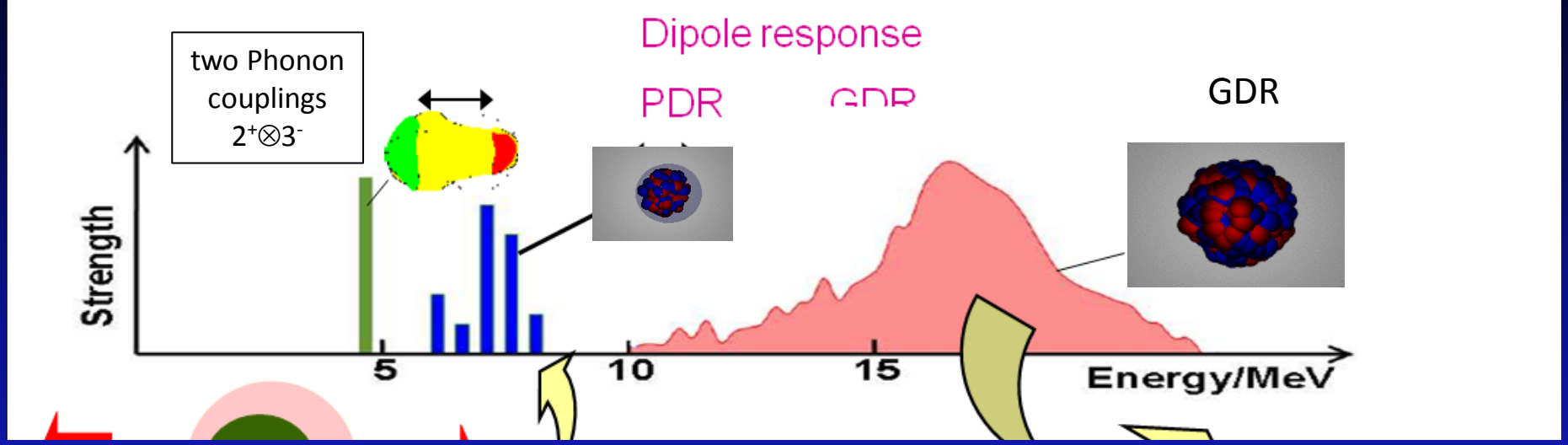


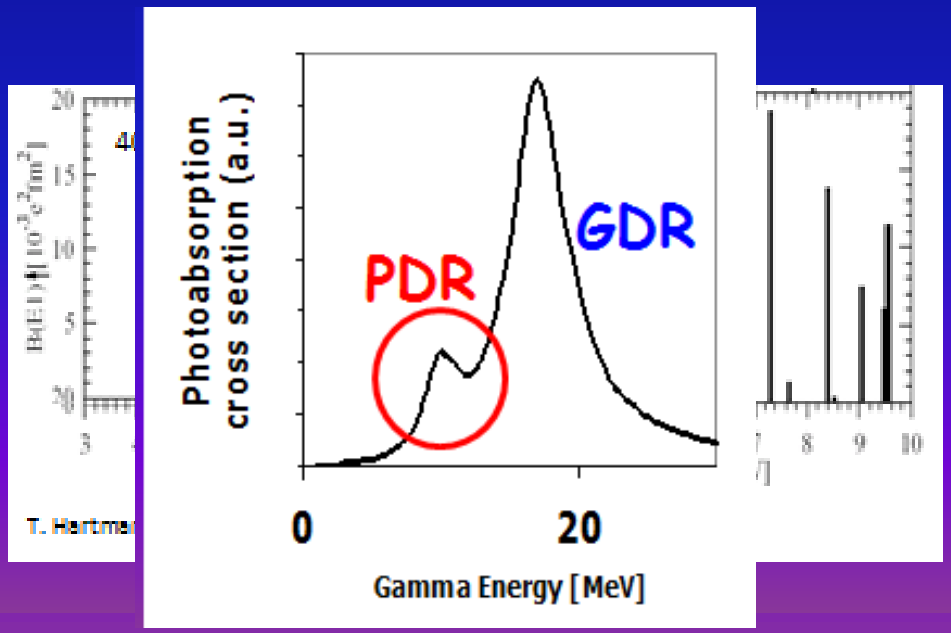


Dipole strength shifts at low energy

Stable Nuclei $\Rightarrow$ Photoabsorption

Electric Dipole response in Nuclei





Dipole strength shifts at low energy

Stable nuclei ⇒ Photoabsorption

Neutron rich nuclei

⇒ Virtual photon scattering

⇒ Neutron breakup

Why the Pygmy Resonance is important ?

- **Is it collective ?**
- **How collective properties change with neutron number ?**
- **How deformation acts ?**

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NUPECC long range Plan 2004

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NUPECC long range Plan 2004

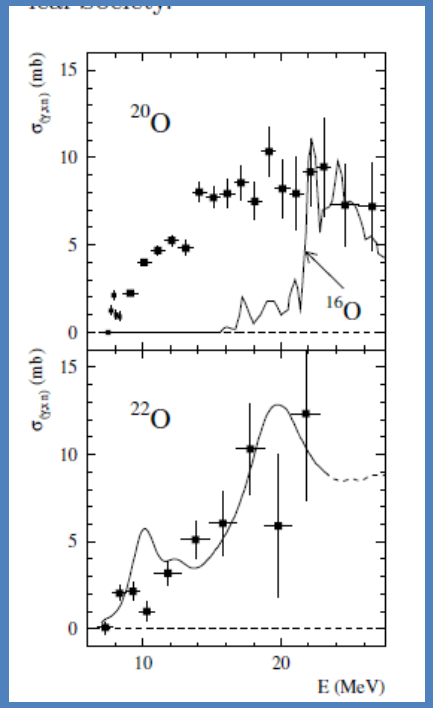
- **As in a hydrodynamic approach the excitation energy of IVGDR depends on a combination of volume and surface symmetry energy, can PDR provide information on L and neutron skin ?**

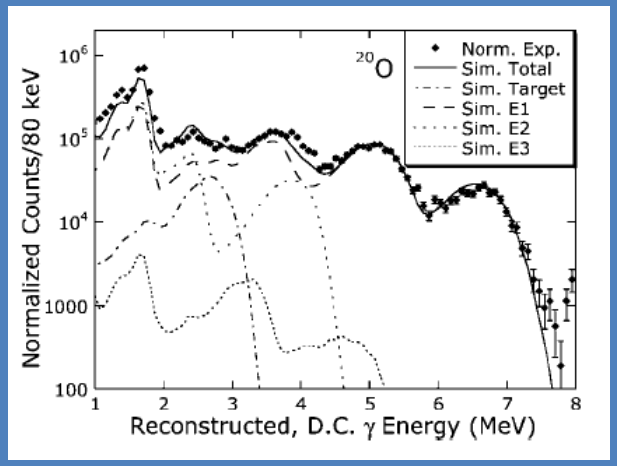
"we suggest that the electromagnetic excitation of both the pygmy and giant dipole resonances will continue to provide powerful constraints on the density dependence of the symmetry energy"
Piekarewicz PRC83(2011)034319

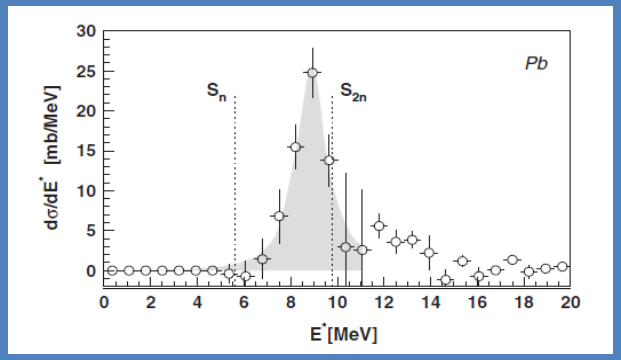
"We can conclude that our more general analysis of the extraction of the slope parameter L from the PDR is able to provide a firm result"
A.Carbone et al. PRC81(2010)041301

PDR in neutron rich nuclei

Light nuclei







Leistenschneider et al. Phys. Rev. Lett. 86, 5442 (2001).
E. Tryggestad et al. Phys. Lett. B 541, 52 (2002).
J. Gibelin et al PRL 101, 212503 (2008)

Lots of work but few data available

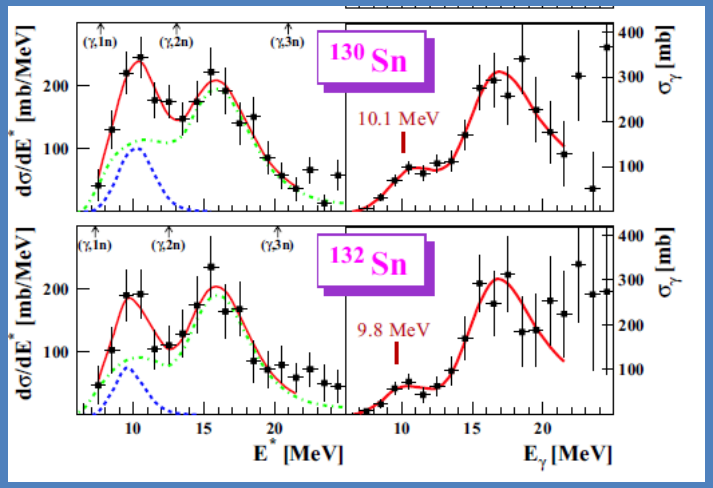
Virtual photon breakup

Riken, GSI experiments

Virtual photon scattering

MSU, RISING experiments

Medium Mass nuclei



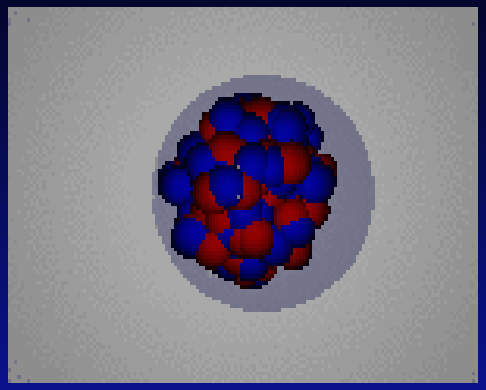
P. Adrich et al. Phys. Rev. Lett. 95, 132501 (2005).

+

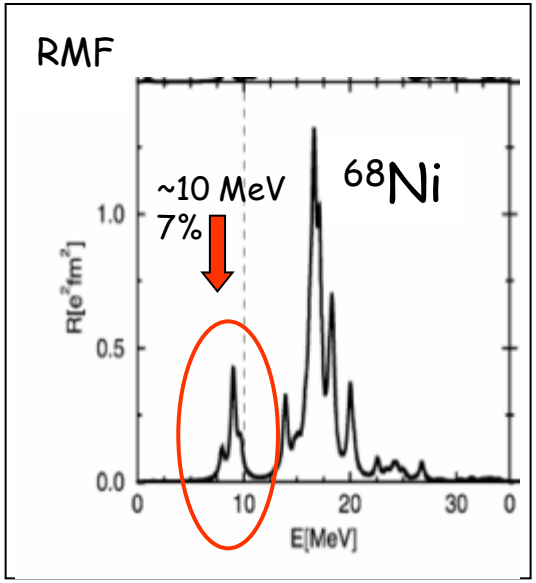
this work on ^{68}Ni

Search for pygmy strength in ^{68}Ni in theory

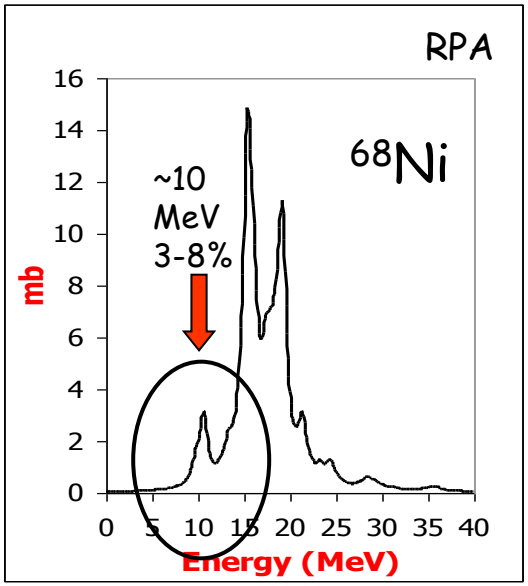
Different approaches give similar predictions in terms of collectivity, strength and line-shape of the pygmy resonance



Theoretical predictions before the experiments



D. Vretnar et al. NPA 692(2001)496



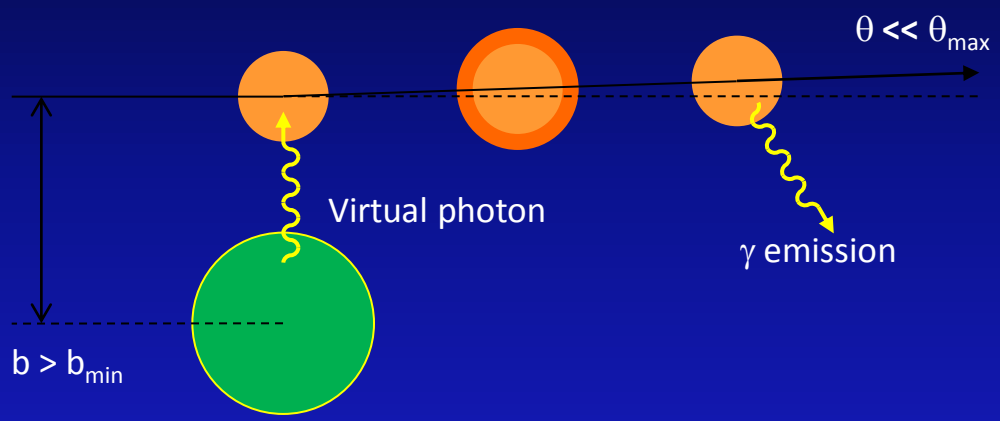
G. Colo private communications

J. Liang et al., PRC75(2007)

fRPA: 7-8%:

Virtual photon scattering technique

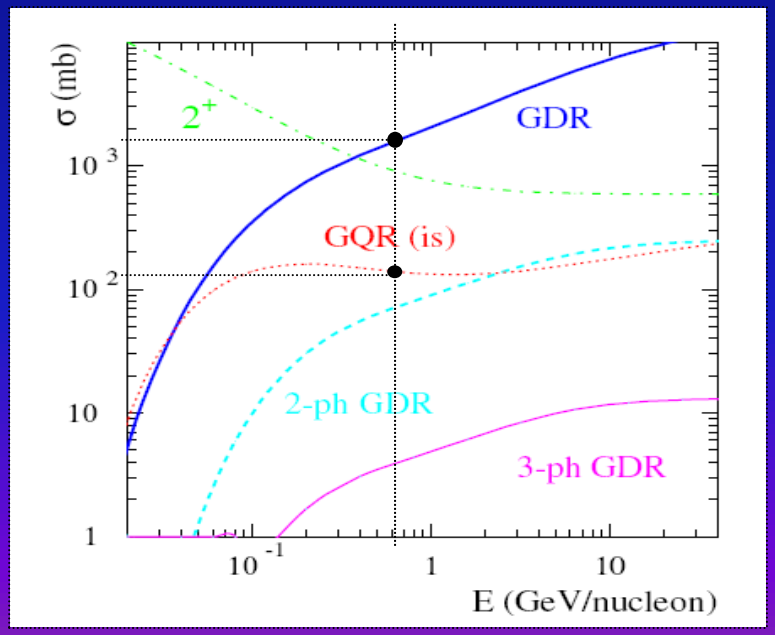
- Peripheral heavy-ion collision on a high Z target at relativistic energies
- Virtual photon excitation and decay
- Relativistic Coulomb excitation has very high <u>selectivity</u> for dipole excitation



$$\frac{\sigma(GDR)}{\sigma(GQR)} \approx 20$$

$^{197}Au(^{68}Ni, ^{68}Ni^{*} + \gamma)^{197}Au$

600 MeV/u ^{68}Ni + ^{197}Au
400 MeV/u ^{68}Ni + ^{197}Au



T.Aumann et al EPJ 26(2005)441

Maximum excitation energy (adiabatic cut off) ca. E = 18.5 MeV

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- Peripheral heavy-ion collision on a high Z target at relativistic energies
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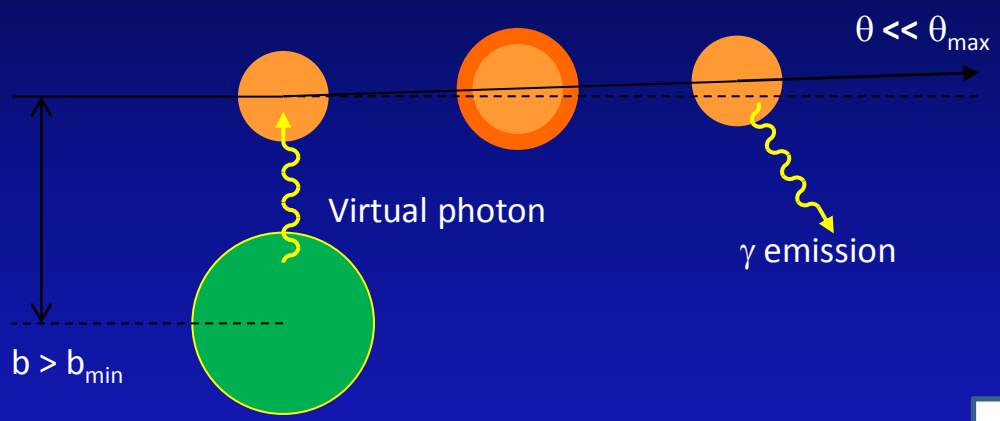

$^{197}Au(^{68}Ni, ^{68}Ni^{*} + \gamma)^{197}Au$

600 MeV/u ^{68}Ni + ^{197}Au
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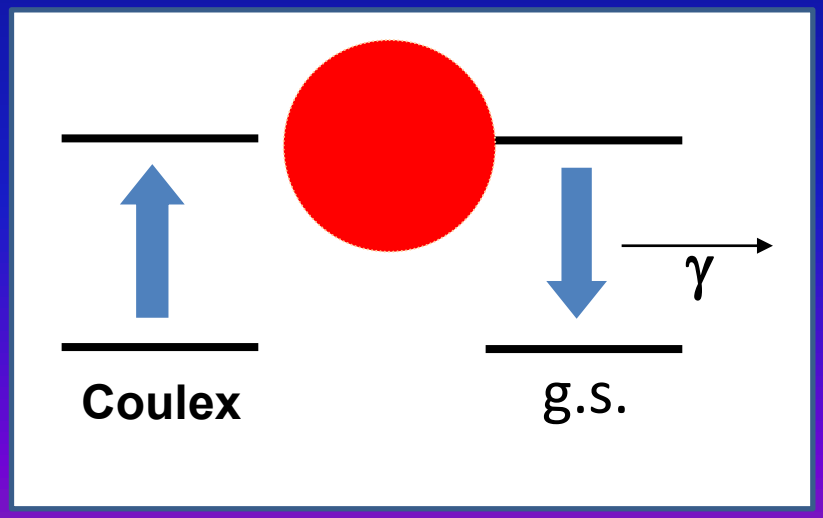
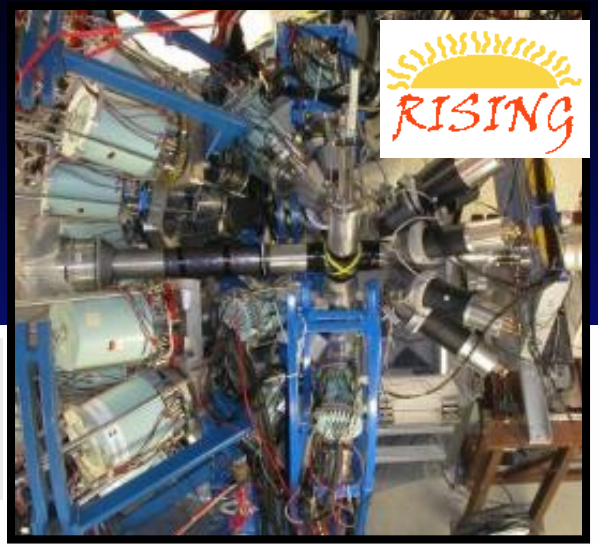
Virtual photon excitation and decay of **GDR + PYGMY**



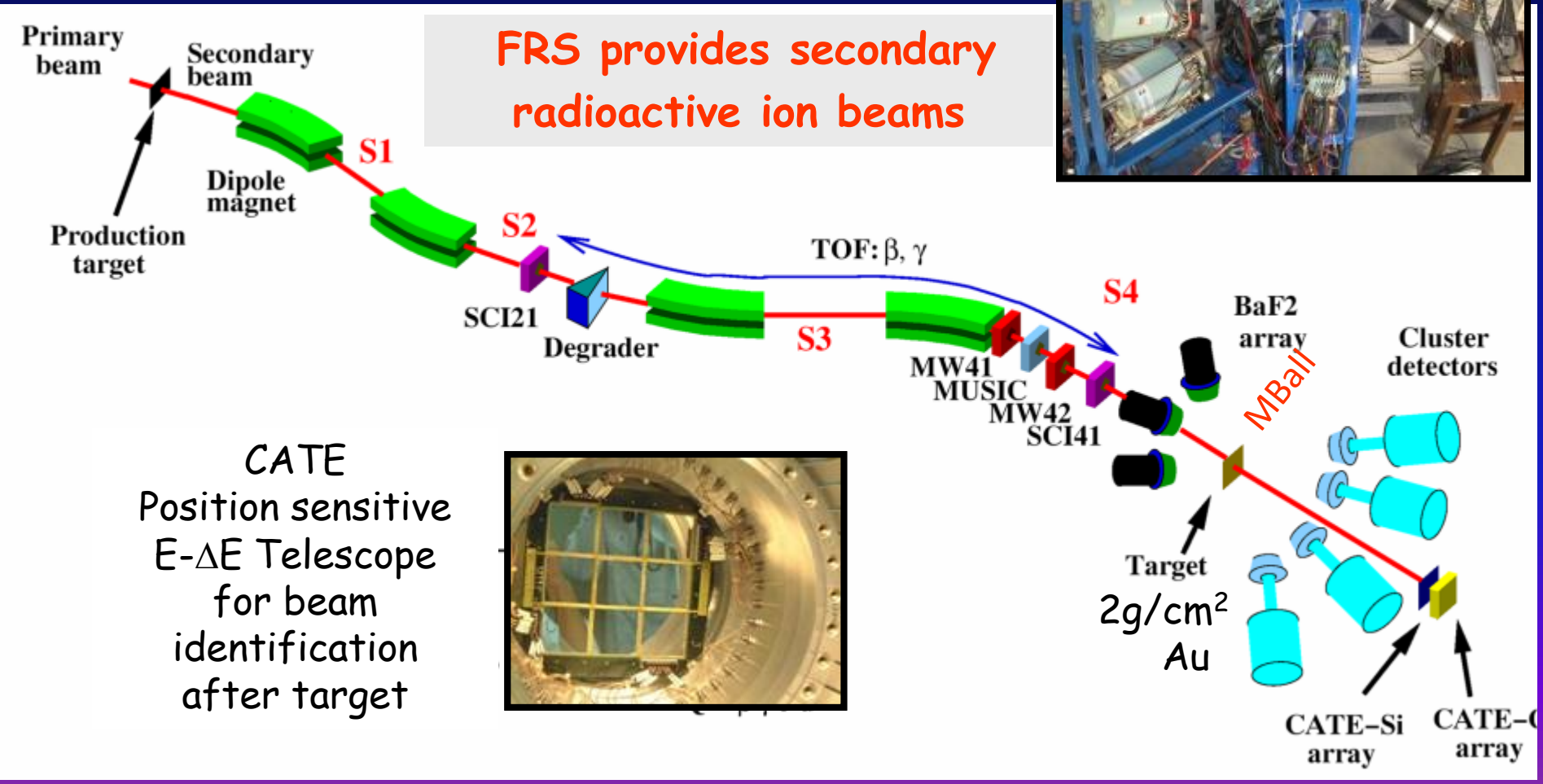
Maximum excitation energy (adiabatic cut off) ca. E = 18.5 MeV

High resolution γ-spectroscopy at the FRS of GSI

- ^{86}Kr @ 900 MeV/u on Be target (4g/cm^2) ⇒ ^{68}Ni
- 10^{10} ppspill ^{86}Kr, Spill length 6s, period 10 s
- ^{68}Ni @ 600 MeV/u on Au target (1g/cm^2)
- cocktail of 10^4 pps ions Spill length 6s, period 10 s

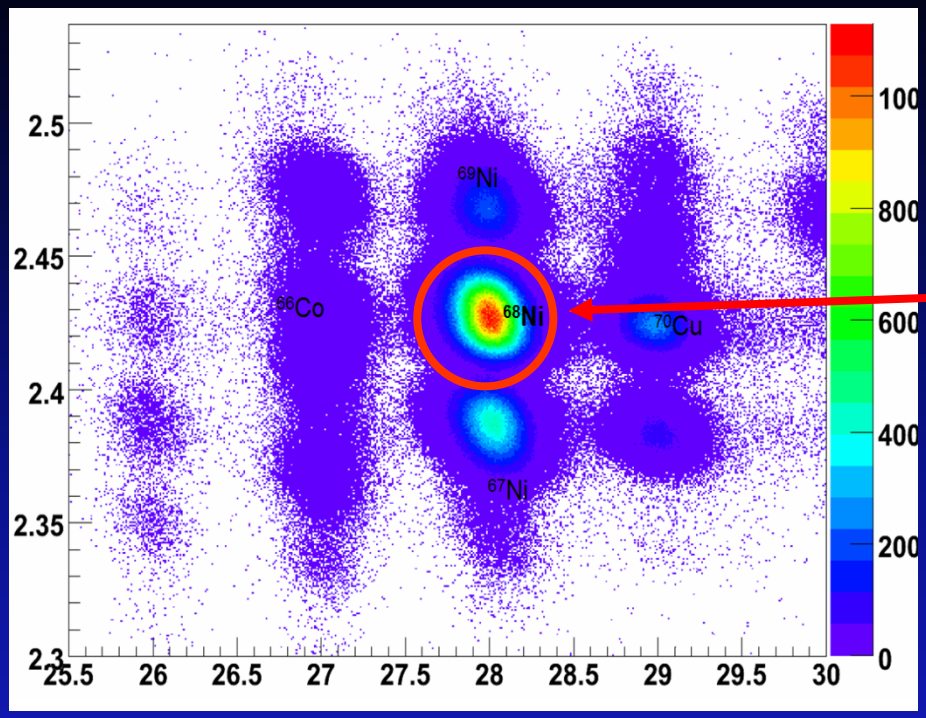


FRS provides secondary radioactive ion beams



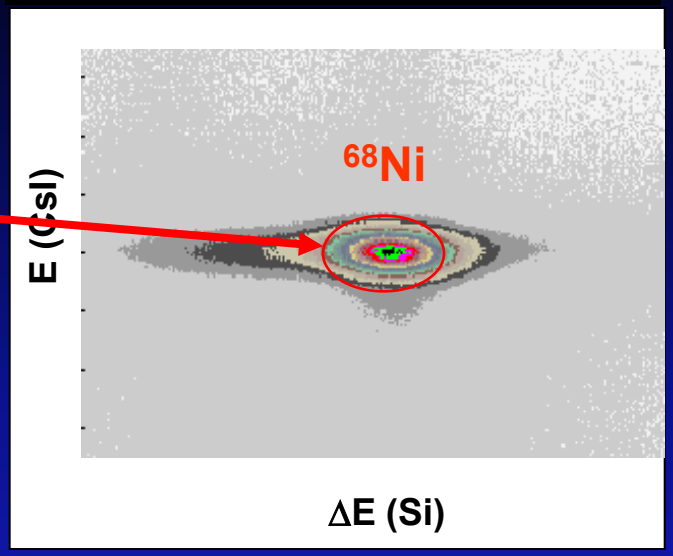
CATE
Position sensitive
E-ΔE Telescope
for beam
identification
after target

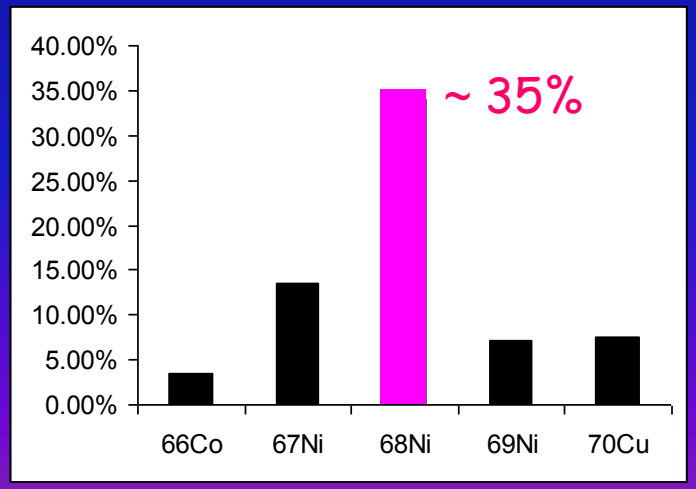
Incoming ^{68}Ni beam



GATE

Outgoing ^{68}Ni

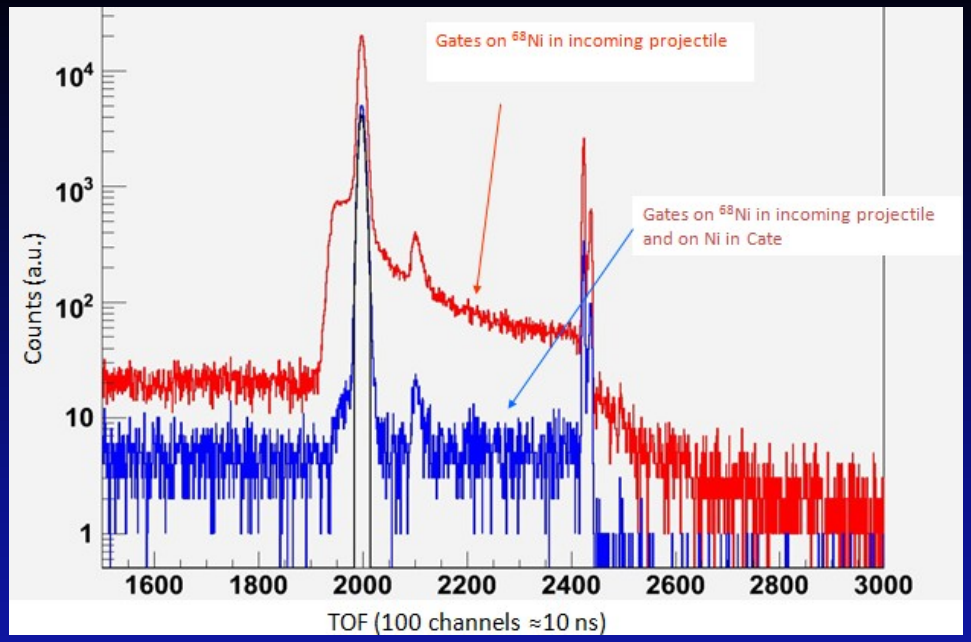


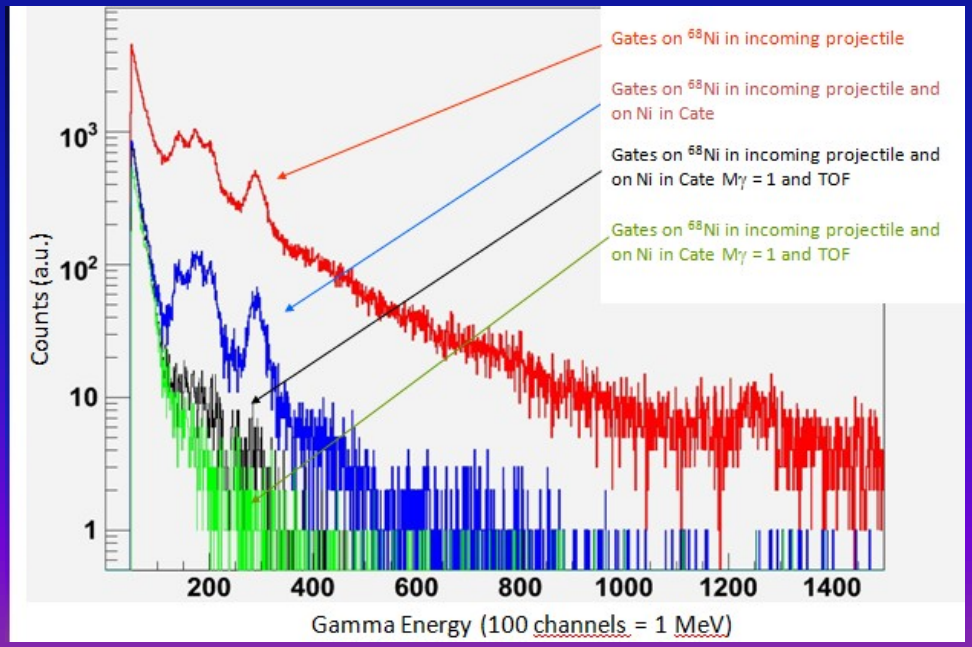


Beam cocktail of 5 isotopes

~ 6 Days of effective beam time
~ 400 GB of data recorded

~ $1 \cdot 10^8$ ' **good ^{68}Ni events** '



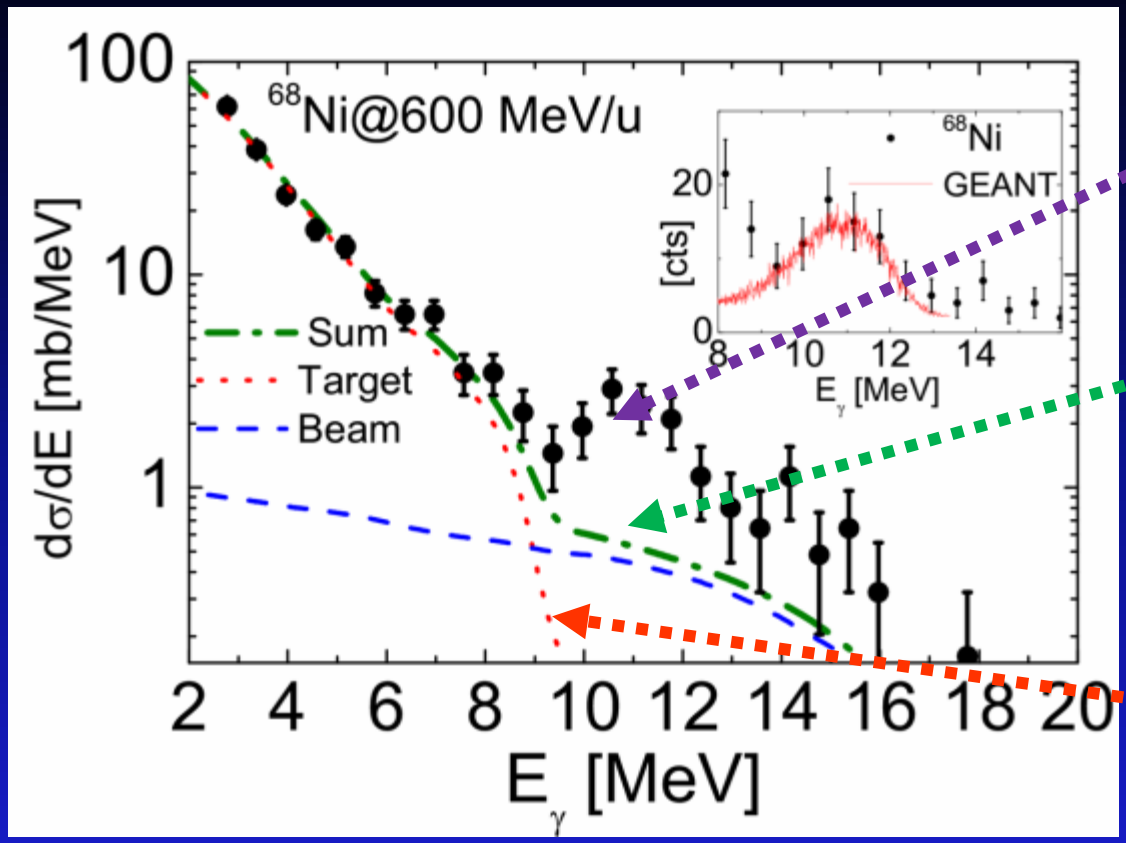


Higly selective gates

- Large reduction in statistics
- Conditions:

- ^{68}Ni-incoming-selection
- ^{68}Ni-outgoing-selection
- TOF-in prompt
- Outgoing angle check
- Doppler correction
- mγ=1
- Detector specific (PSA, AddBack)

γ-rays spectrum of BaF_2 detectors



Excess γ-ray yield

Emission from target

Folded with Response Function including Doppler correction

Emission from Beam -only GDR, no PDR -

Folded with Response Function including Doppler correction

- High energy γ-ray spectra measured in BaF_2 detectors evidence a clear excess of γ-rays between 10-12 MeV
- Same evidence in HPGe cluster detectors

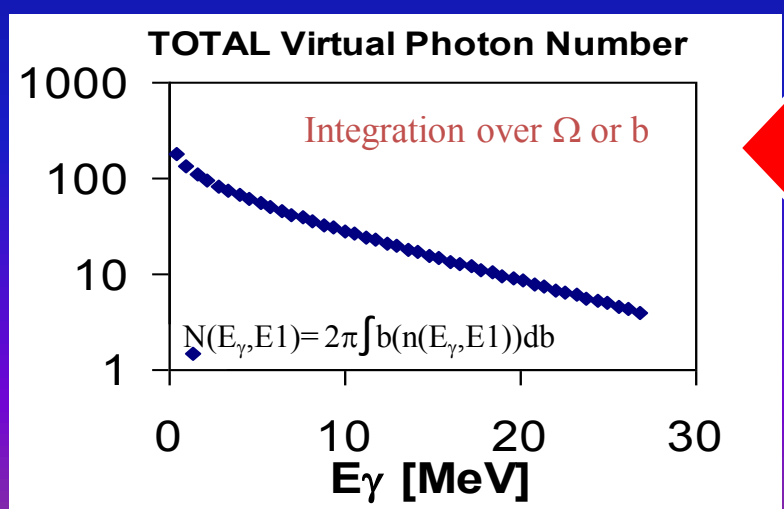
Ground state γ decay from a GDR state after a Coulomb excitation

The measured γ-ray yield is due to the product of 3 terms:

Virtual photon number, σ photoabsorption, Branching Ratio

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma)$$

Beene, Bortignon, Bertulani



Known from theory

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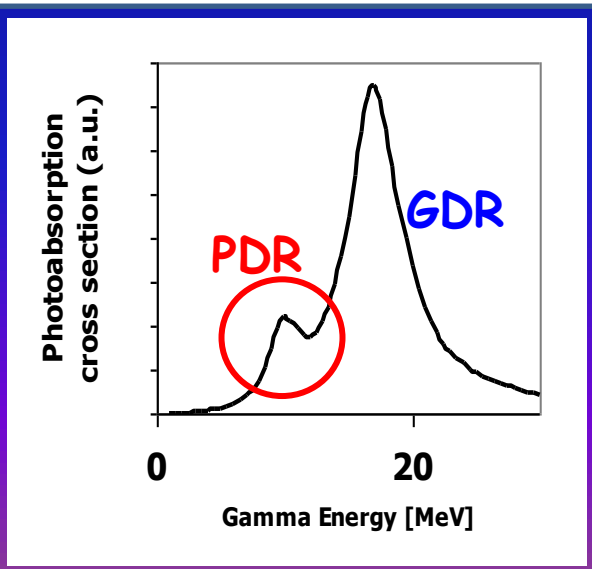
Beene, Bortignon, Bertulani

Our final objective



J. R. Beene, G. F. Bertsch, P. F. Bortignon, and R. A. Broglia Phys. Lett. B 164, 19 (1985)

Thanks to J. Alhassid

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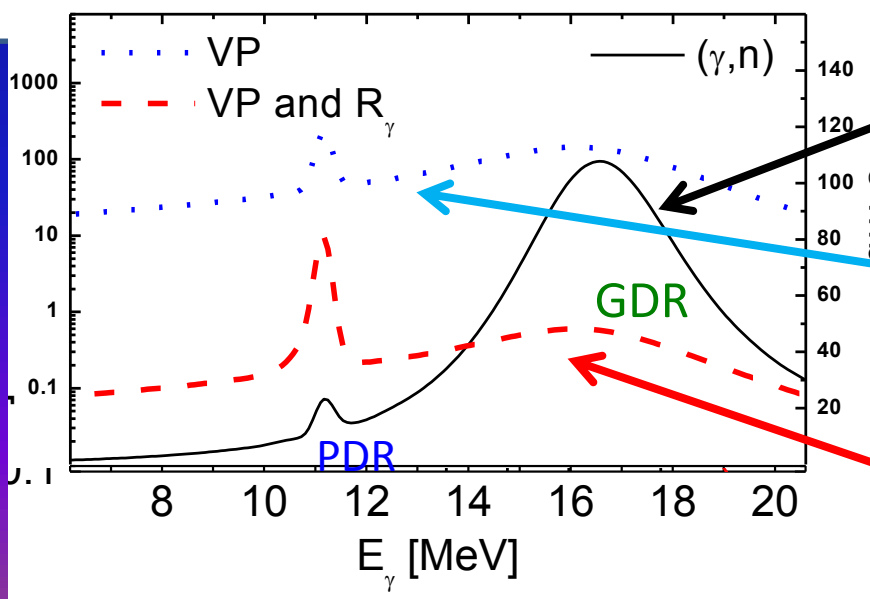
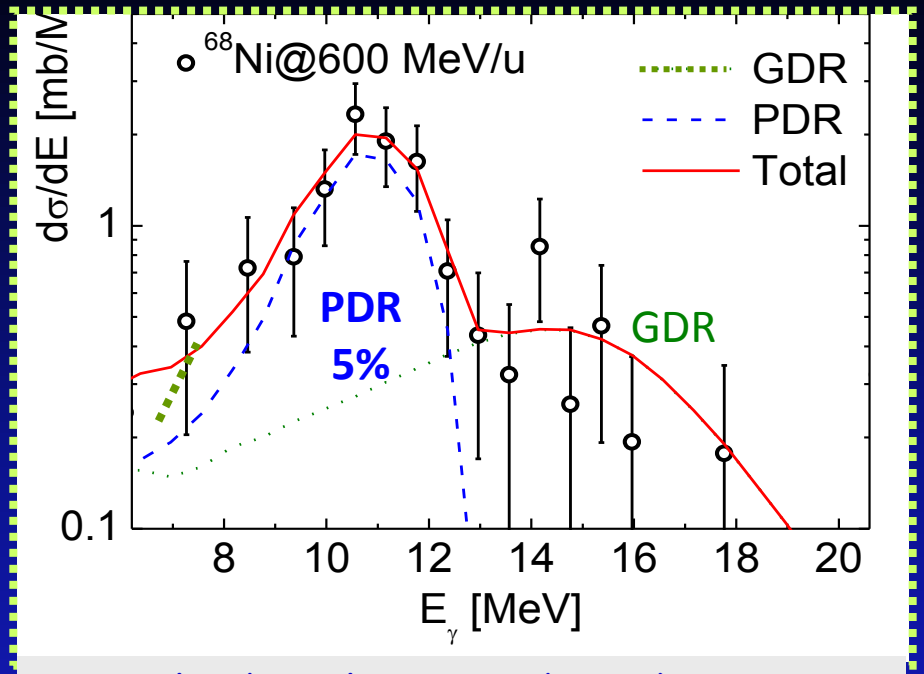


$$\sigma_\gamma(E_\gamma)$$

$$\frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\bullet\sigma_\gamma(E_\gamma)$$

$$\frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\bullet\sigma_\gamma(E_\gamma)\bullet R_\gamma(E_\gamma)$$

RESULT: Pygmy dipole resonance in ^{68}Ni



O. Wieland et al., PRL102(2009)092502

Centroid ≈ 11 MeV

Width ≈ 2 MeV
Instrumental (Doppler Broadening)

Strength = 5 (±1.5) % of the EWSR

B(E1) = 1.2 e^2fm^2

Next steps :

- Deduce L
- Deduce the Neutron radius

Correlation between L and the PDR

Several theoretical works have shown that PDR properties can be correlated and provide constraint to the symmetry energy slope

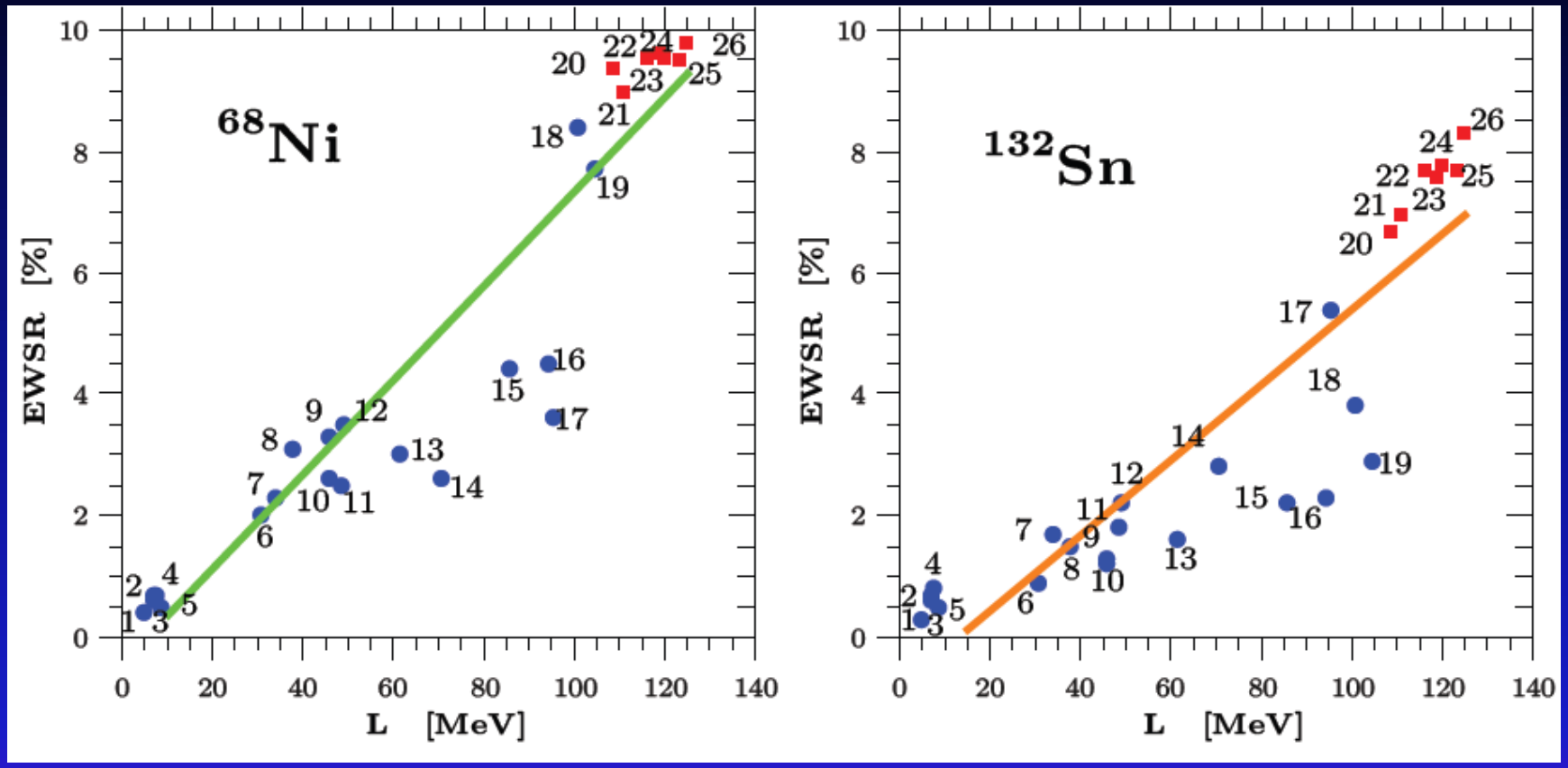
However this approach:

- is not fully accepted
- gives predictions which strongly depends on the used nuclear force

we belive that PDR measurements are a valuable tool in the study of symmetry energy and that a correlation between PDR and L exist.

- see talk of X. Roca-Maza

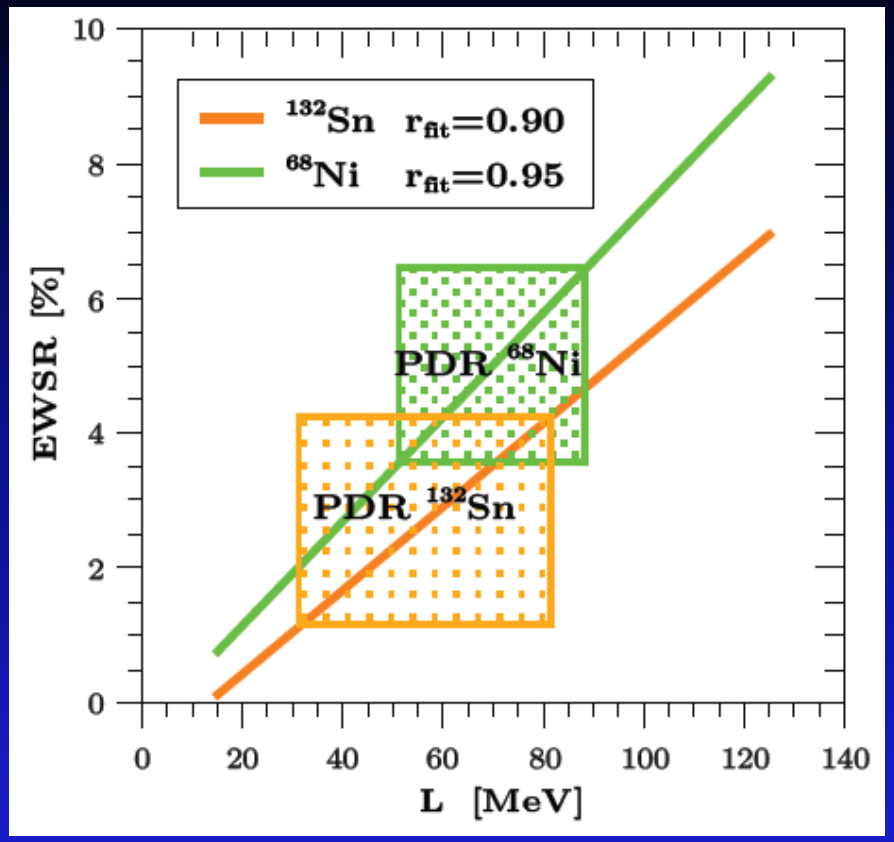
Correlation between L and the PDR



A.Carbone et al. PRC81(2010)041301
See talk of X. Roca-Maza

This technique has been previously used but here the approach has been pursued using different nuclei and different classes of forces (Blue=Skyrme; red=RMF)

Correlation between L and the PDR



L=65.1±15.5 MeV

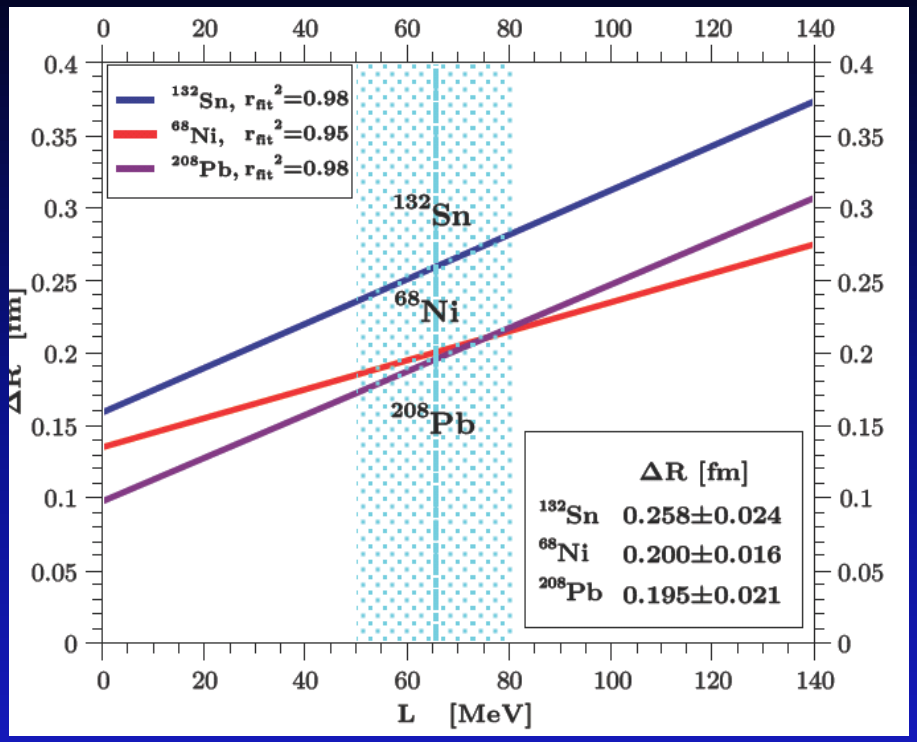
Once extracted a value for L it is possible to infer, using the same technique, a value for the neutron skin thickness.

B.A. Brown, PRL 85, 5296 (2000);
S. Typel and B.A. Brown, PRC 64, 027302(R) (2001).
R.J. Furnstahl, NPA 706, 85 (2002);
S. Yoshida and H. Sagawa, PRC 69, 024318 (2004).

Exp. values from
O. Wieland et al., PRL 102, 092502 (2009);
P. Adrich et al .PRL 95, 132501 (2005)
A. Klimkiewicz et al., PRC 76, 051603(R) (2007).

Theory
A.Carbone et al. PRC81(2010)041301

Extract the neutron radius for ^{208}Pb



R_n-R_p = 0.195 +/- 0.021 fm for ^{208}Pb

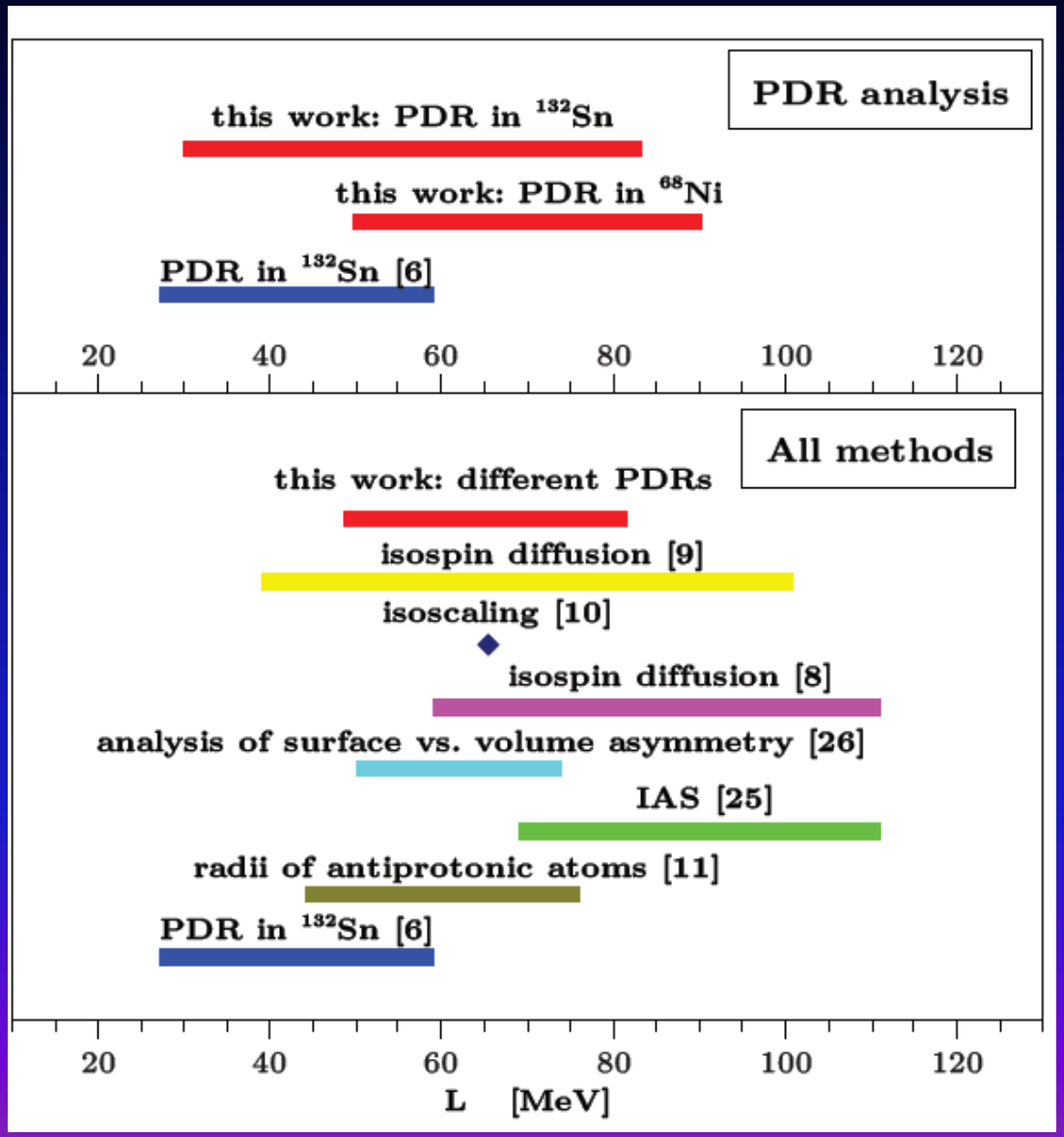
R_n-R_p = 0.25 +/- 0.045 fm for ^{132}Sn

R_n-R_p = 0.20 +/- 0.02 fm for ^{68}Ni

The analysis of Klimkiewicz et al. based on ^{132}Sn data gave for ^{208}Pb

R_n-R_p = 0.18 +/- 0.035 for ^{208}Pb

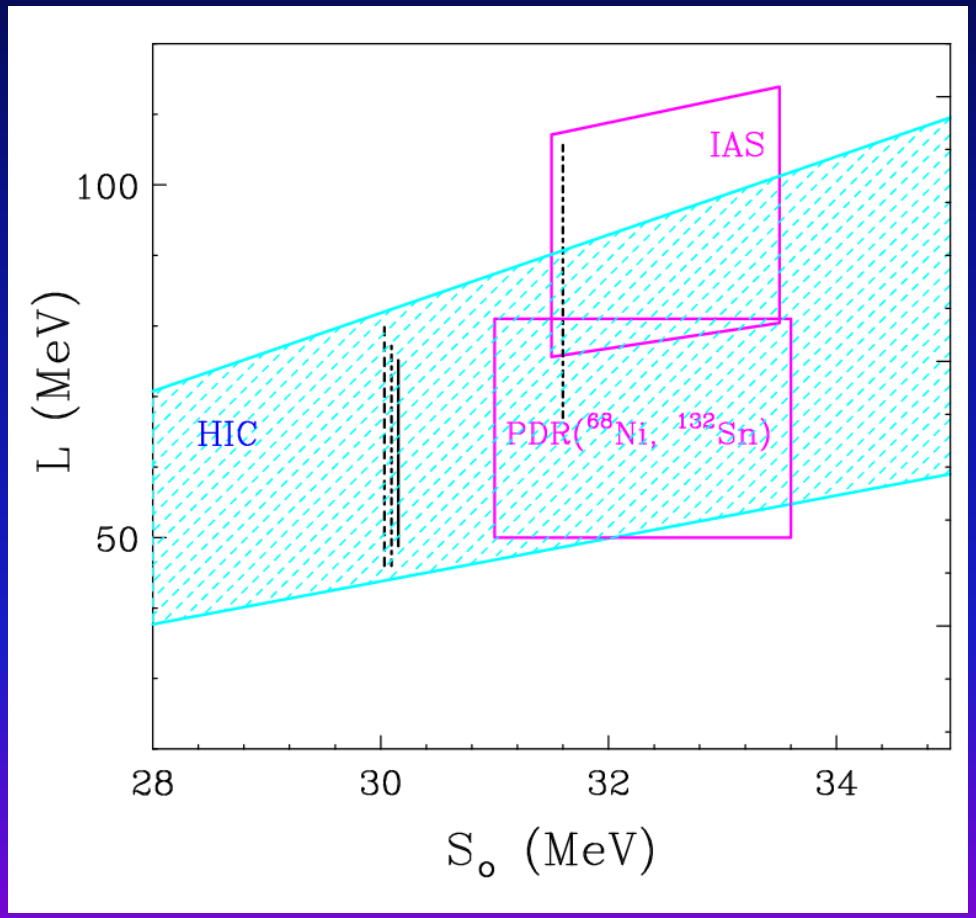
Comparison with other ways of constraining L



The used approach to extract L from the measured PDR EWSR produce a results which is compatible/comparable to the experimental results from data analysis of heavy-ion collisions experiment.

Comparison with heavy ions fragmentation reactions

Two different analysis and measured quantities give consistent constraints to the symmetry energy !



Constraints on the Density dependence of the Symmetry Energy

This work

S_0 = 32.3 $\pm$ 1.3 MeV

L = 64.8 $\pm$ 15.7 MeV

M.B. Tsang et al. PRL102(2009)122701 + this analysis

Conclusions + Perspectives

- We have measured the Pygmy Dipole Resonance in ^{68}Ni using the virtual photon scattering technique

- Combined analysis of our ^{68}Ni PDR data and that of ^{132}Sn have provided a value for L and for ΔR

- Data from LAND on ^{68}Ni

- We have planned experiments on ^{70,72}Ni and on ^{64}Fe using an array $LaBr_3$:Ce
- Experiment planned for $^{20\text{-}24}$O in Riken (Baba) using an array $LaBr_3$:Ce
- Hopefully others

- Theoretical work and data are needed to fix the correlation between PDR and L

A. Bracco[a], G. Benzoni[a], N. Blasi[a], S. Brambilla[a], F. Camera[a],F.C.L. Crespi[a], S. Leoni[a], B. Million[a], R.Nicolini[a]
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[d]University of Koeln, Germany
[e]National Laboratory of Legnaro, INFN, Italy
[f]University of Padova and INFN Section of Padova, Italy
[g]University of Camerino, and INFN Section of Perugia, Italy
[h]INFN Section of Genova, Italy
[i]University of Surrey, United Kingdom
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RISING PYGMY Collaboration

Analysis using theory.....
A.Carbone, P.F. Bortignon, A. Bracco, F. Camera, G. Colò, O. Wieland (University of Milano and INFN)
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