The Study of the Pygmy Dipole Resonances via High-Resolution (p, p') reaction

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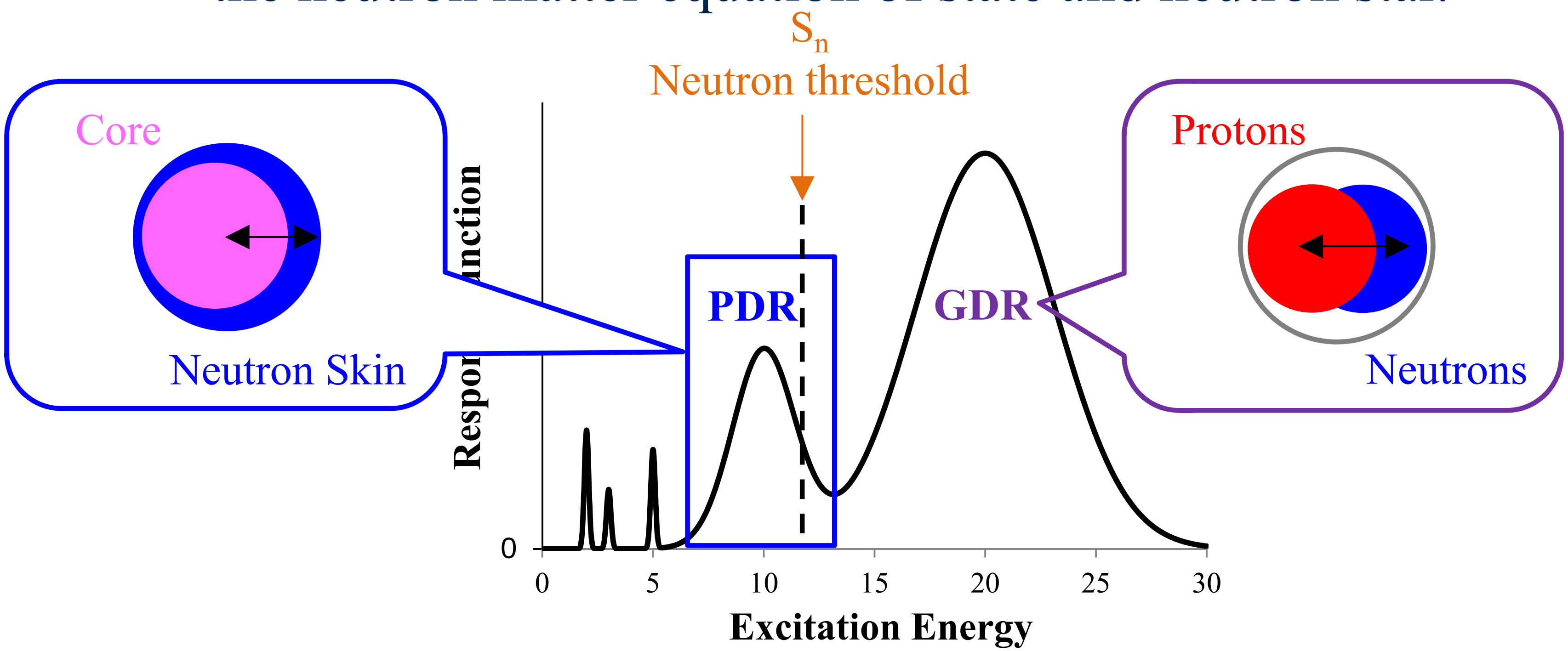
Out line

1. Introduction
   - Pygmy Dipole Resonance and Dipole Polarizability
   - Correlation between the PDR and the valence neutron number
   - Previous Experimental Data of Zr isotopes
2. Experiment : inelastic proton scattering
3. Results and Analysis
   - Spectrum of Zr isotopes
   - E1 strength distributions and Dipole Polarizability in 90Zr
4. Summary

What is the Pygmy Dipole Resonance ?

Pygmy Dipole Resonance…

- **the low-energy *E1* strength around low-energy tail of GDR** in medium-heavy and heavy nuclei with $N > Z$.
- predicted to have a structure like **a dipole oscillation of the neutron skin against the core nucleus**.
  - → the neutron skin thickness.
  - the neutron matter equation of state and neutron star.



The correlation between α_D and neutron skin thickness

- It is appeared from the study for ^{208}Pb that symmetry energy term of the EOS and neutron skin information closely related to the dipole polarizability α_D.

The α_D is an inversely energy-weighted sum value of the B(E1).

$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma_{abs}}{\omega^2}\omega = \frac{8\pi}{9}\int_0^\infty \frac{dB(E1)}{\omega}$$

$B(E1)$: E1 transition probability

σ_{abs} : Photoabsorption cross section

ω : Excitation energy

- Nuclear equation of state (EOS)

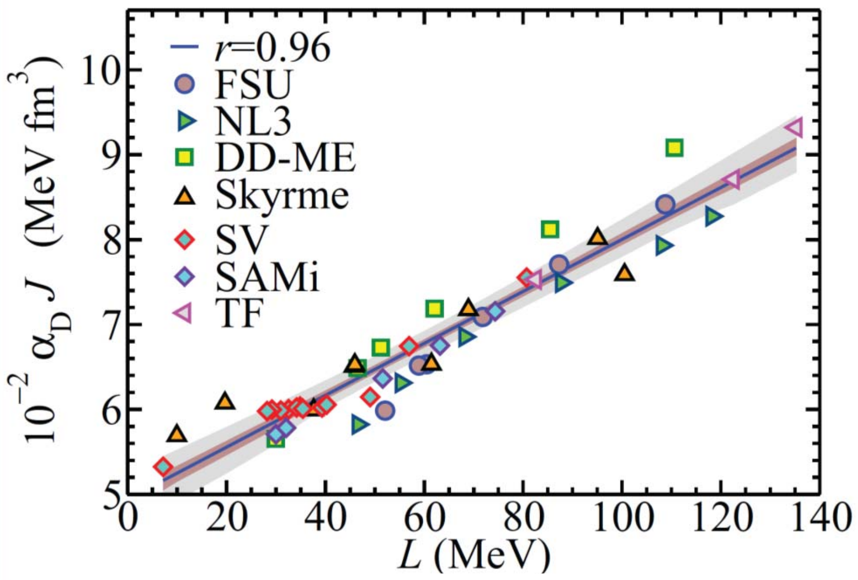
$$\frac{E}{A}(\rho,\delta) = \frac{E}{A}(\rho,0) + S(\rho)\delta^2 + \cdots,$$

- Symmetry energy term

$$S(\rho) = J + \frac{L}{3\rho_0}(\rho - \rho_0) + \cdots,$$

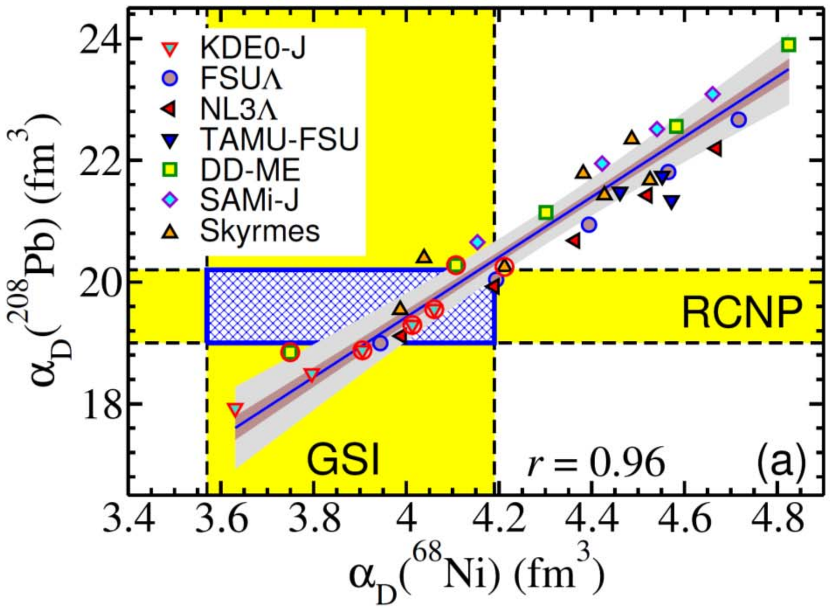
$\rho \equiv \rho_n + \rho_p$, $\delta \equiv \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$, J : the nuclear symmetry energy at saturation energy

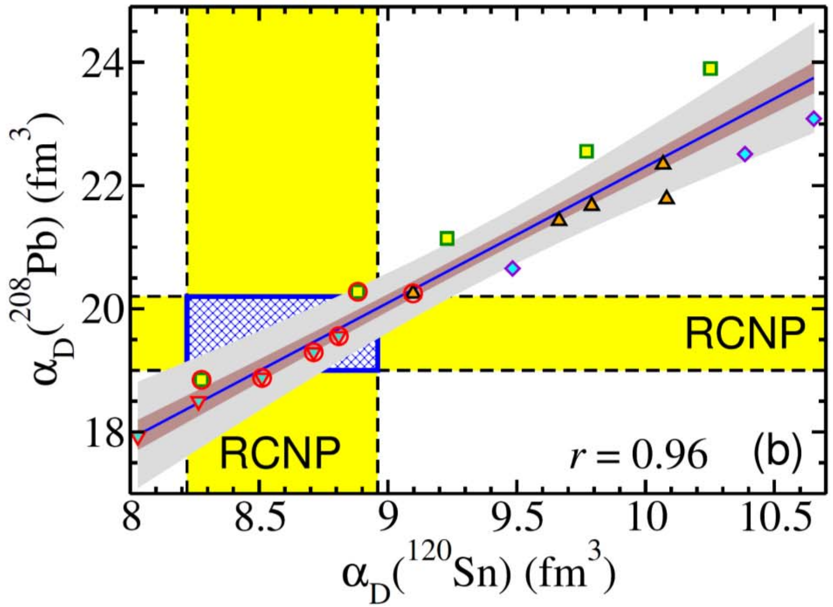
ρ_0 : the saturation density L : slope parameter

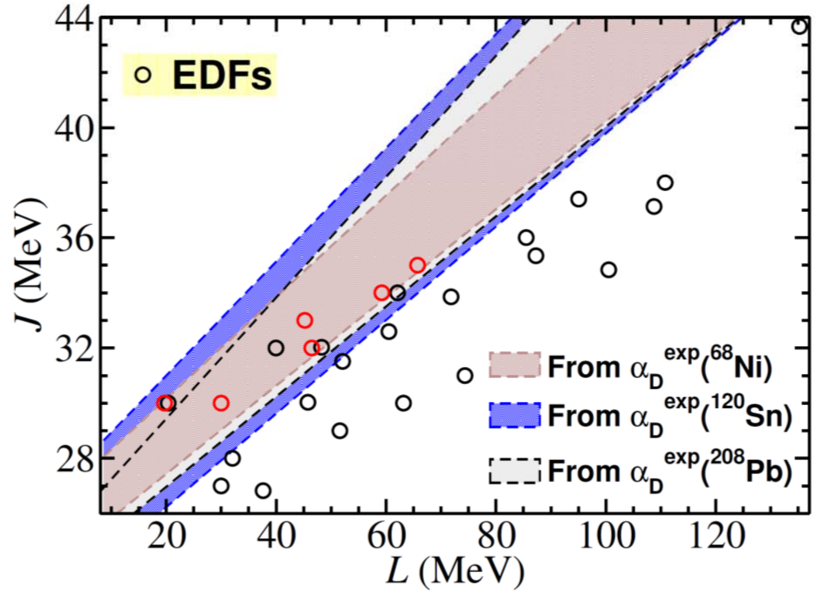


X. Roca-Maza et al., PRC 88, 024316 (2013).

The correlation between α_D and neutron skin thickness







Systematical data of α_D is expected to narrow the parameters of the neutron EOS etc…

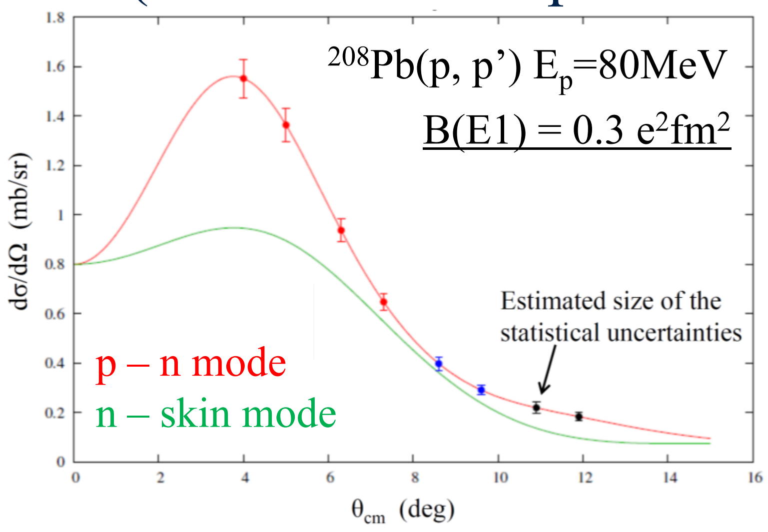
X. Roca-Maza et al., inarXiv:1510.01874v1

The study of the structure of PDR

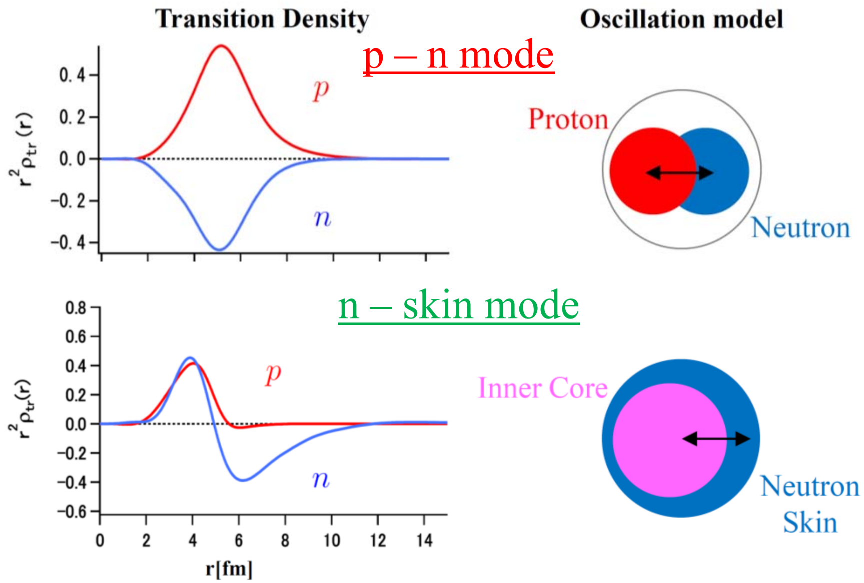
<u>To focus on the correlation between PDR structure and excess neutron.</u>

- The correlation between the PDR strength and the neutron number.
  → The measurement of PDR strength in isotope chain.
  (RCNP-E421 for Zr isotopes) **<u>done on July 2015</u>**

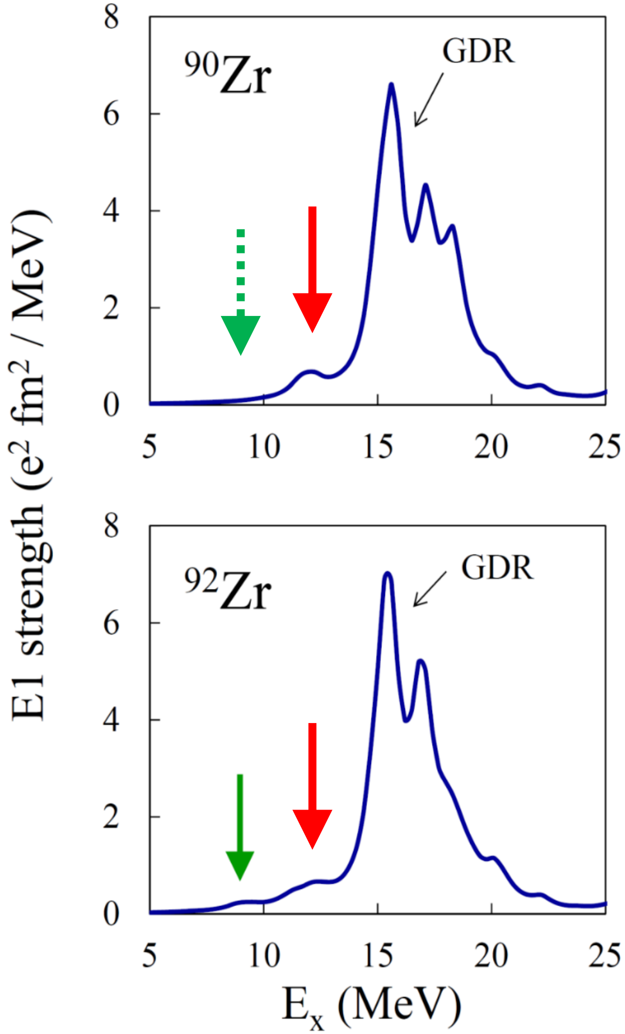
- Experimental investigation of the neutron skin oscillation
  → The measurement of transition density by (*p*, *p'γ*) experiment
  (RCNP-E450 experiment)



V. Ponomarev, Private Comminication

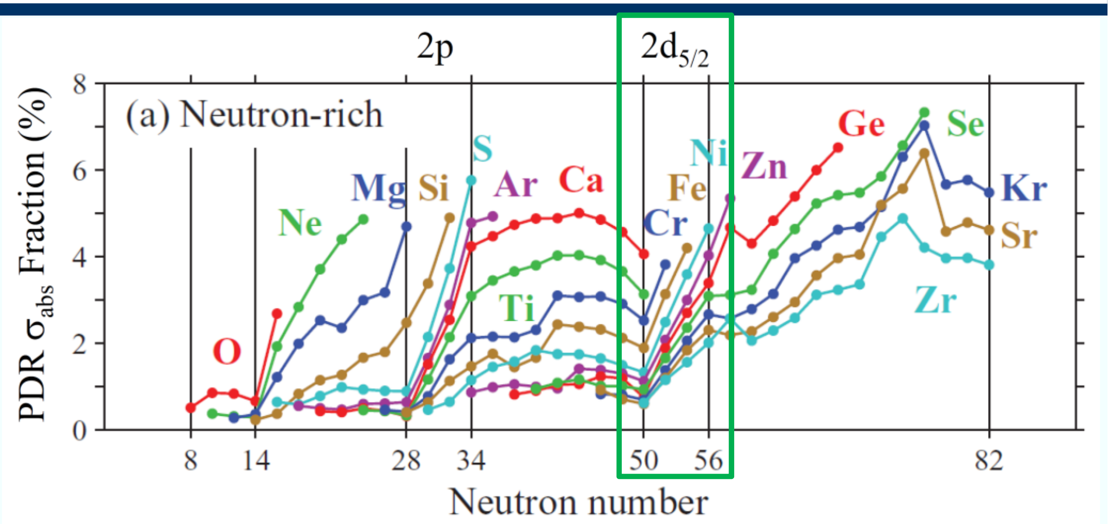


The correlation between the PDR and the neutron number



↓ : by the valence neutrons occupied 1g9/2
↓ : by the valence neutrons occupied 2d5/2

T. Inakura, Private Communication



T. Inakura et al. Phys. Rev. C 84, 021302(R) (2011)

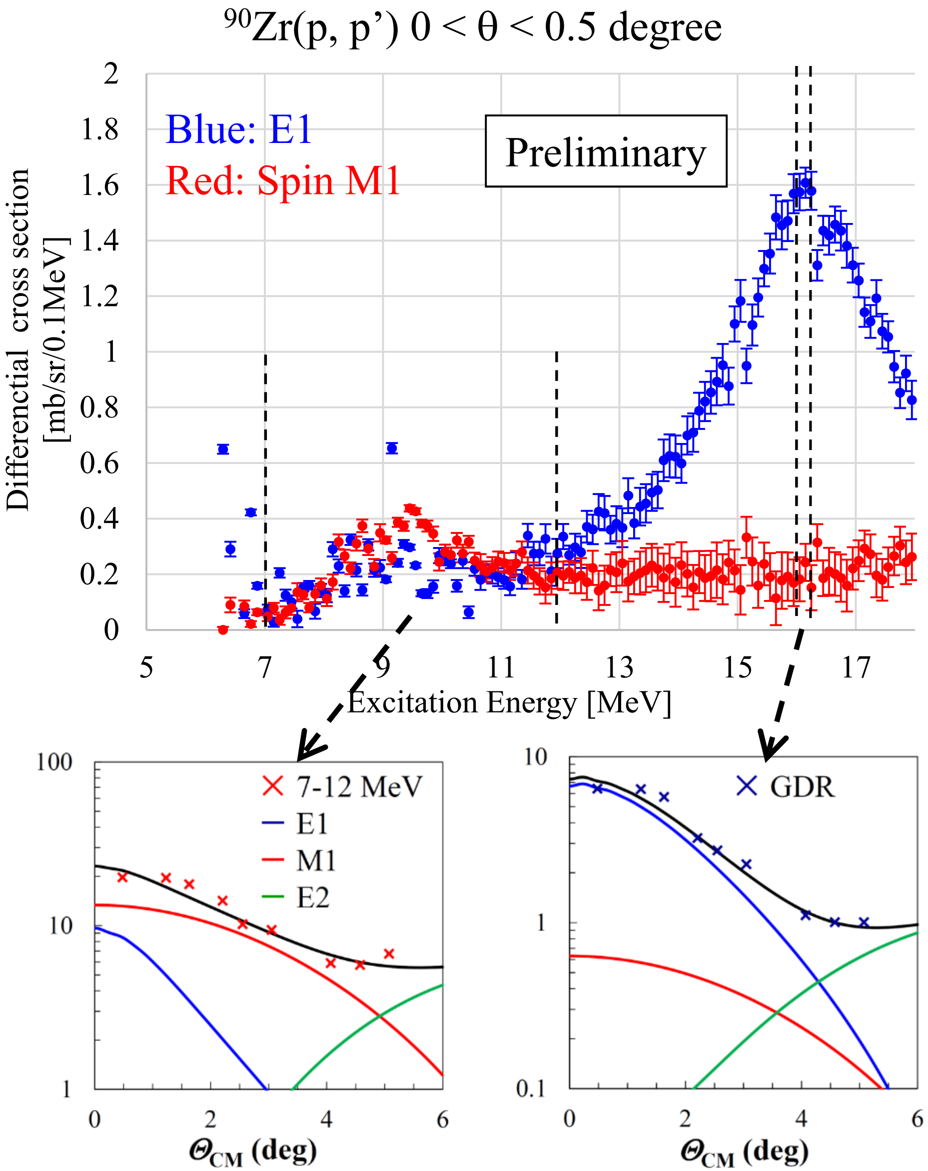
The evolution is predicted in lower energy region by the increase of the valence neutrons occupied a orbit of low-ℓ

<u>For example – stable Zr isotopes –</u>

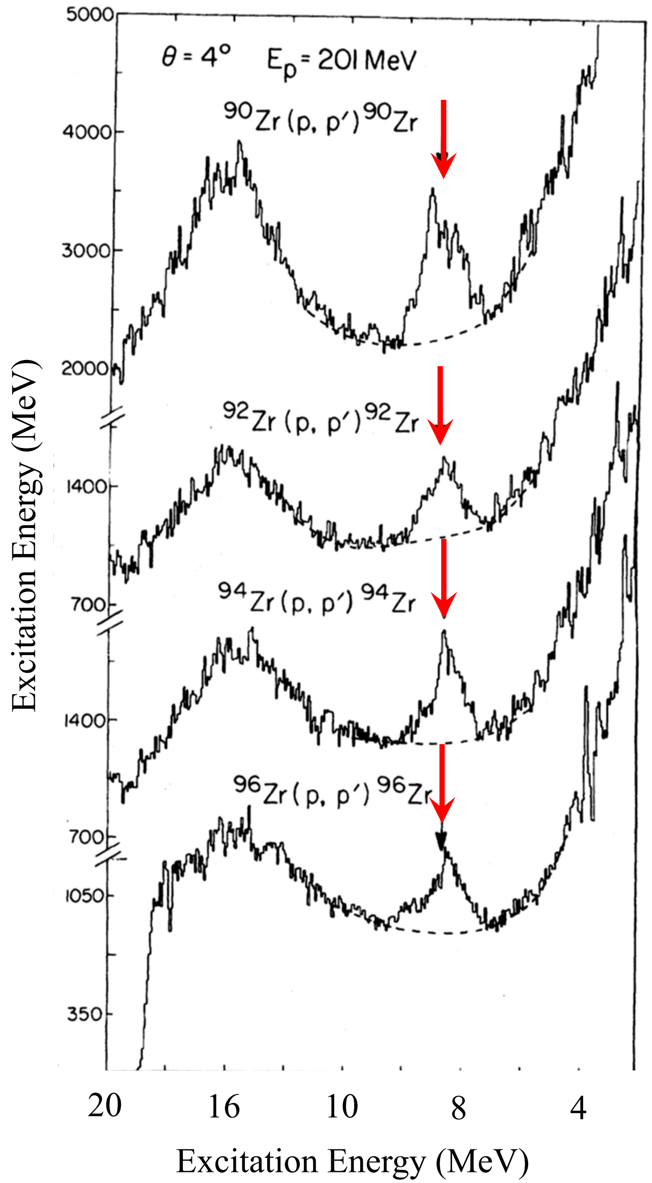
- Spherical nuclear
- Proton subshell closer

→ The role of the neutron number can be separated out

Previous experiment of E1 and M1 component in Zr isotopes



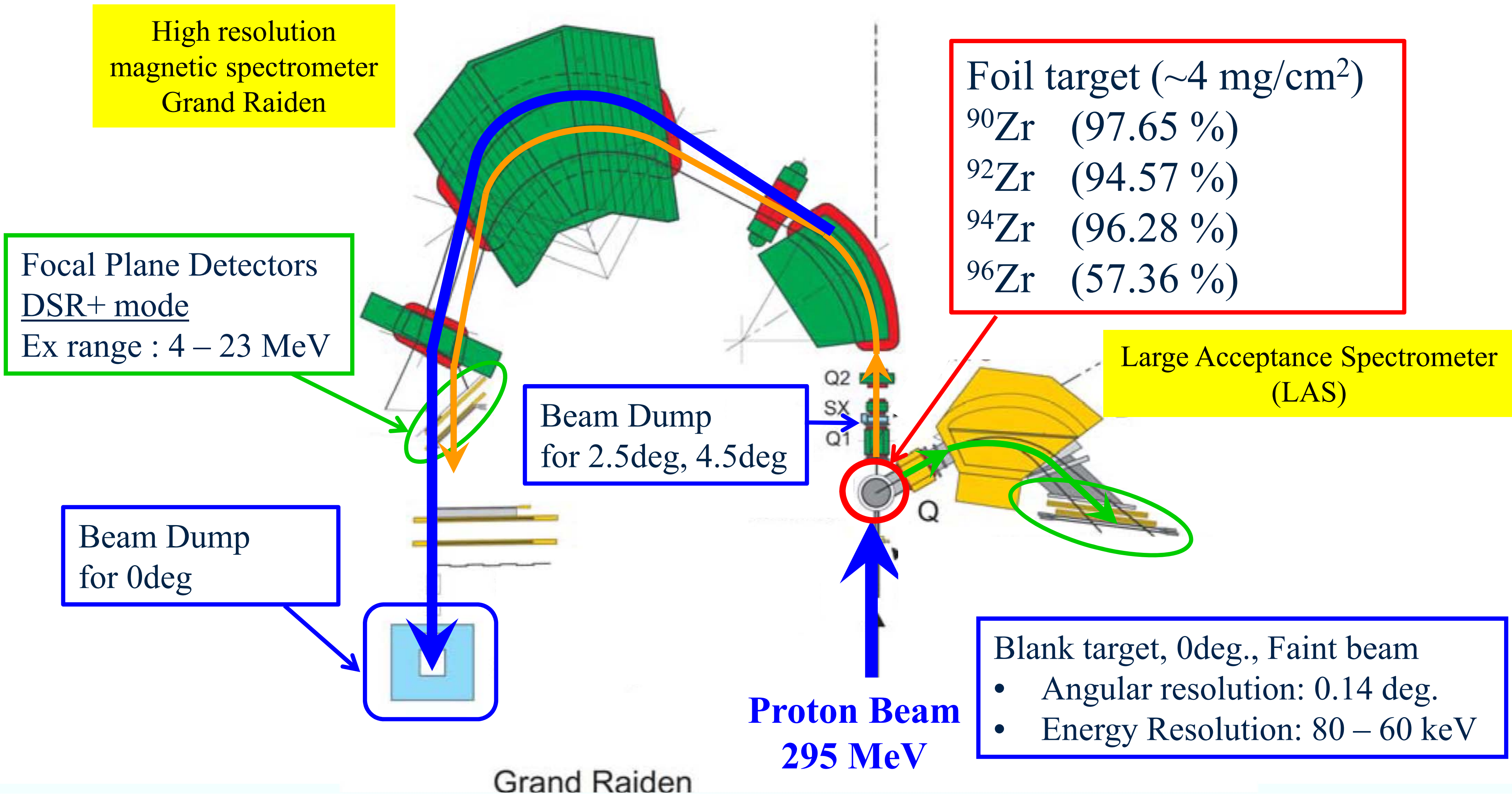
G. M. Crawley et al., PRC 26, 87 (1982).



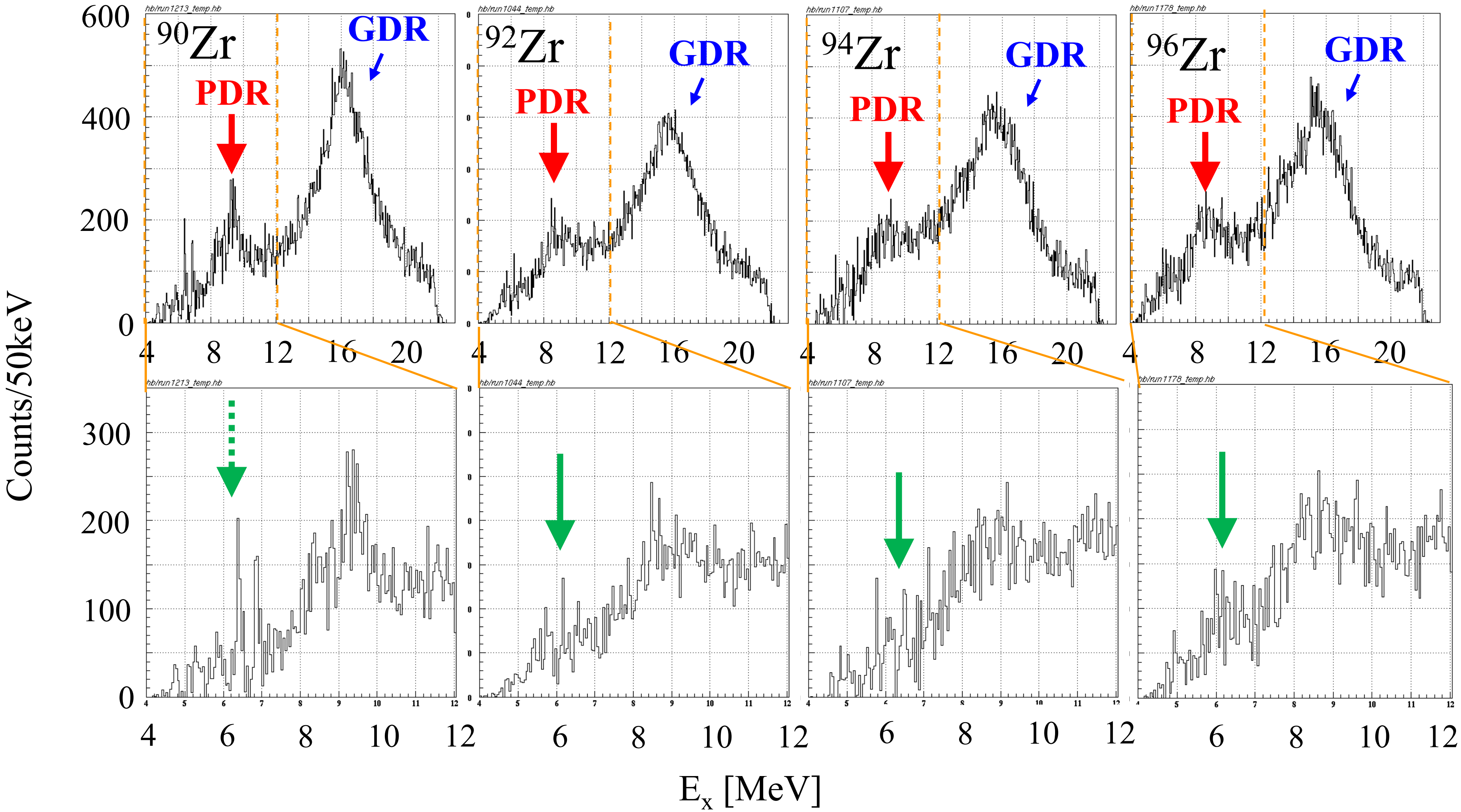
Experimental Setup

At Research Center for Nuclear Physics of Osaka University(RCNP)

- **Setting angles of Grand Raiden ： 0deg, 2.5 deg, 4.5 deg**
  (Range of measured angular distribution) ： 0deg – 5.5 deg)



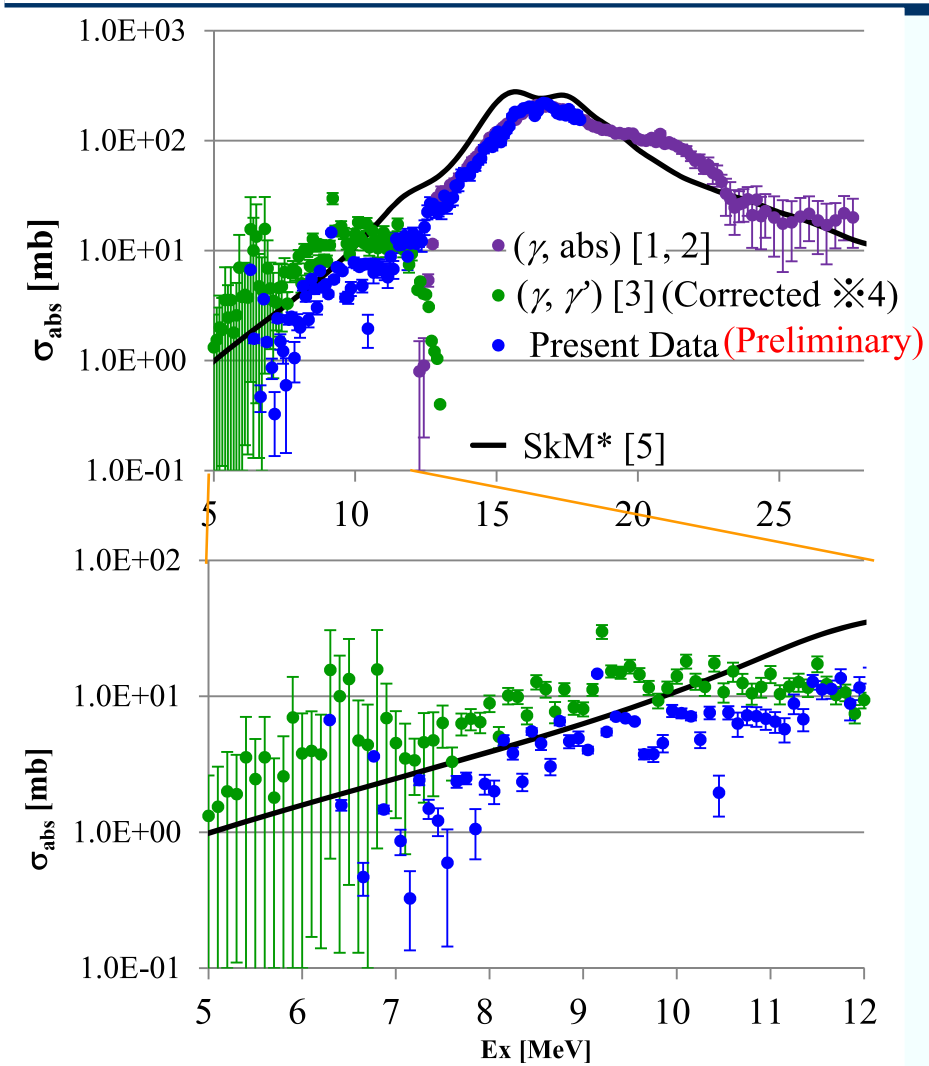
Energy spectra integrated over 0 – 0.5 degree



※ Very Preliminary
※ do NOT separate E1 component and spin-M1 component
※ show a one-tenth of the whole data

※ normalized by beam intensity and target thickness
※ target thickness and detection efficiency are almost same.

Comparison with previous (γ, γ') and (γ, n) data



<u>Energy Weighted Sum Value in ^{90}Zr</u>

6 MeV < Ex < 28 MeV

Σ = 129±11 fm ^{2} MeV (Preliminary)

(97 % of TRK Sum rule)

6-18MeV : Present data

18-28 MeV : (γ, abs) data [1, 2]

※1 Present data is normalized to (γ, abs) cross section at 16.5 MeV

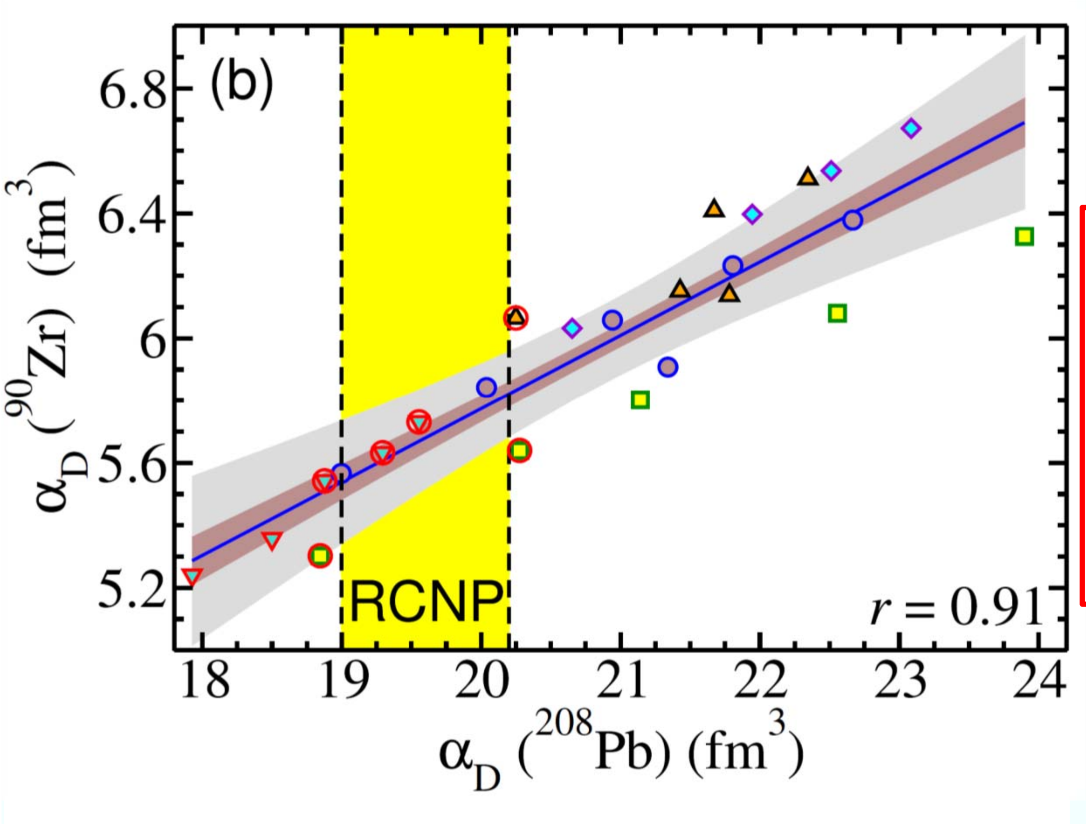
※2 (γ, abs) = (γ, n) + (γ, n+p) + (γ, 2n) + (γ, p)

※3 $\int \sigma_{abs}(E')dE' = \frac{16\pi^3}{9}\alpha \sum_i E_i B(E1)_i$

※4 In Ref [3], they perform a correction for branching transitions

[1] B. L. Berman et al., PR 162, 1098 (1967).
[2] D. Brajnik et al., PRC 13, 1852 (1976).
[3] R. Schwengner et al., PRC 78,064314 (2008).
[4] R. M. Laszewski et al., PRL 59, 431 (1987).
[5] T. Inakura, Private Communication.

Dipole Polarizability in 90Zr



X. Roca-Maza et al., inarXiv:1510.01874v1

Dipole Polarizability in ^{90}Zr
6 MeV < Ex < 28 MeV
α_D = 4.3 ±0.2 fm ^{3} (Preliminary)

6-18MeV : Present data
18-28 MeV : (γ, abs) data [1, 2]

Summary

- High resolution inelastic proton scattering experiment was performed.

- Energy spectra of scattered protons in Zr isotopes were obtained.
  - In ^{92}Zr, ^{94}Zr and ^{96}Zr, We can find strength that was not found in ^{90}Zr
    Are they the evolution of the PDR ?
    → I have to decompose between E1 and M1 in the future.

- The E1 strength distributions and Dipole polarizability in 90Zr was obtained
  - Dipole Polarizability in 90Zr is smaller than theoretical prediction
    → Under discussion…

Collaborators of RCNP-E326 and RCNP-E421

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