Mapping pairing vibration strength toward the experimental determination of pairing polarizability

Masanori Dozono (Kyoto)

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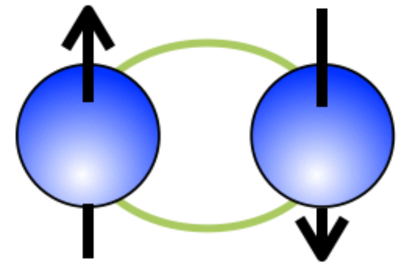
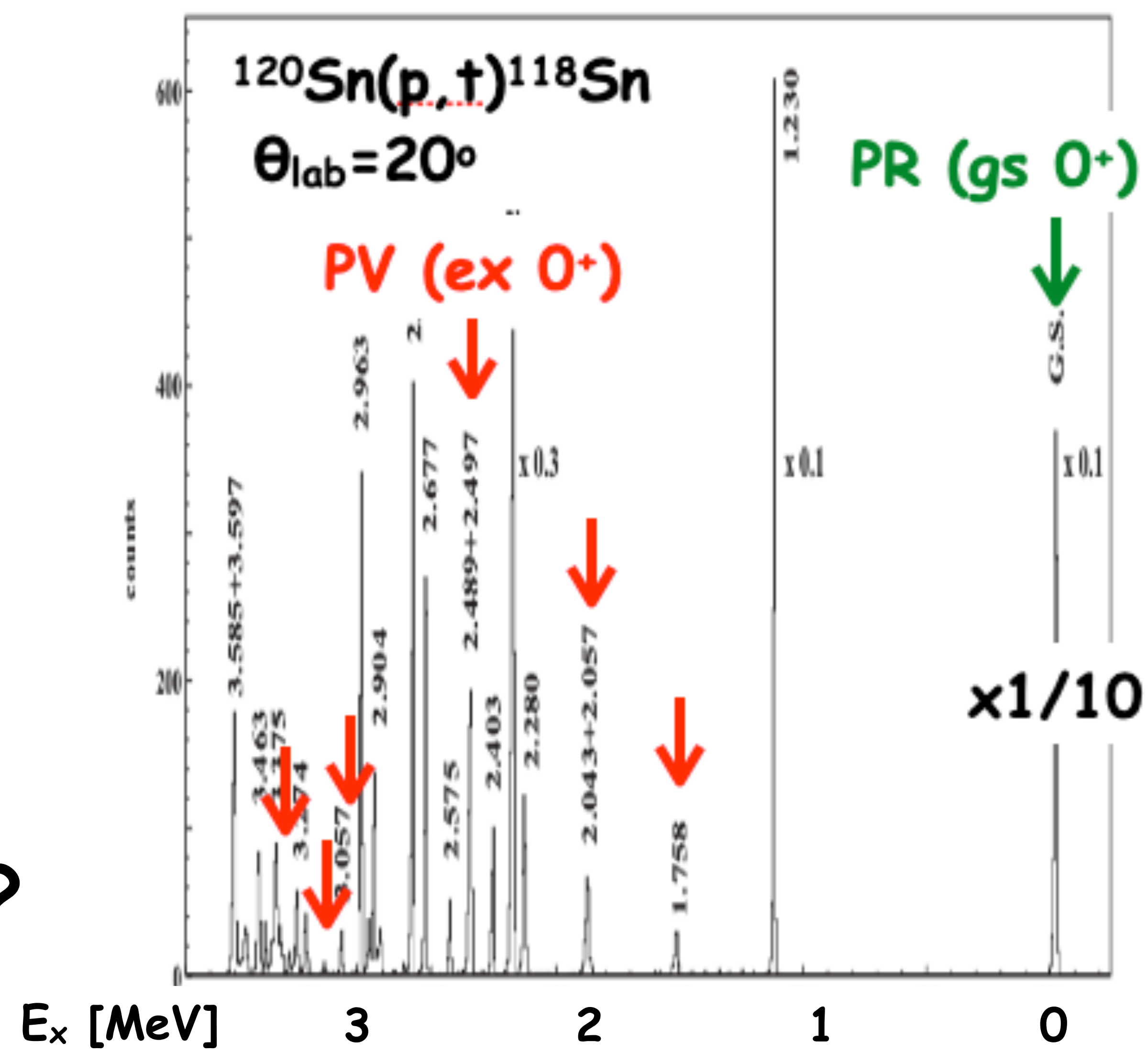
Nuclear pairing

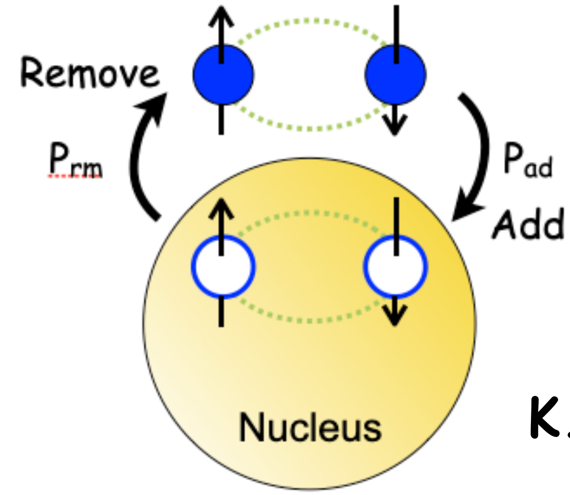


- Plays an important role in various properties of atomic nuclei
  - Odd-even mass staggering, Moments of inertia, …
  - **Collective pair-transfer modes provide the most direct probe**
    - Pair rotation
      - Collective g.s. transition
      - Signature of pair condensation
    - Pair vibration
      - Transitions to excited 0^+
      - Response of pairing field —> How can we quantify this response ?

P.Guazzoni et al., PRC78,064608(2008)



Pair polarizability



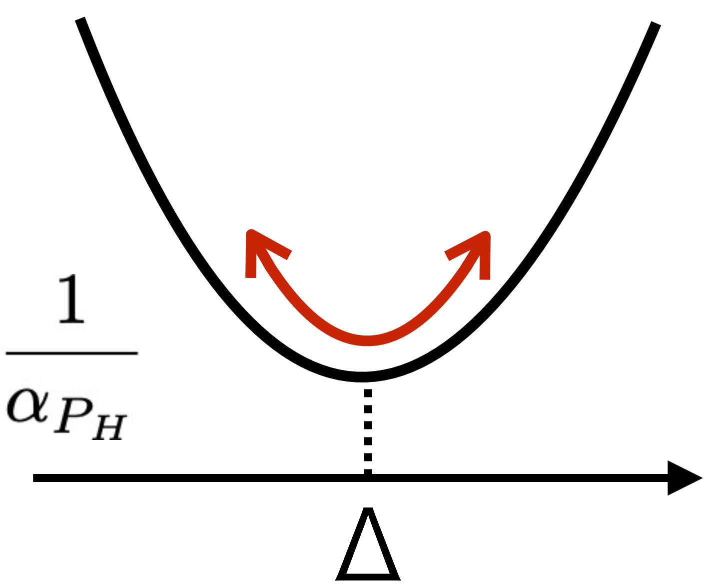
K.Takahashi, Y.Matsuda, M.Matsuo, PTEP 2023, 083D01 (2023).

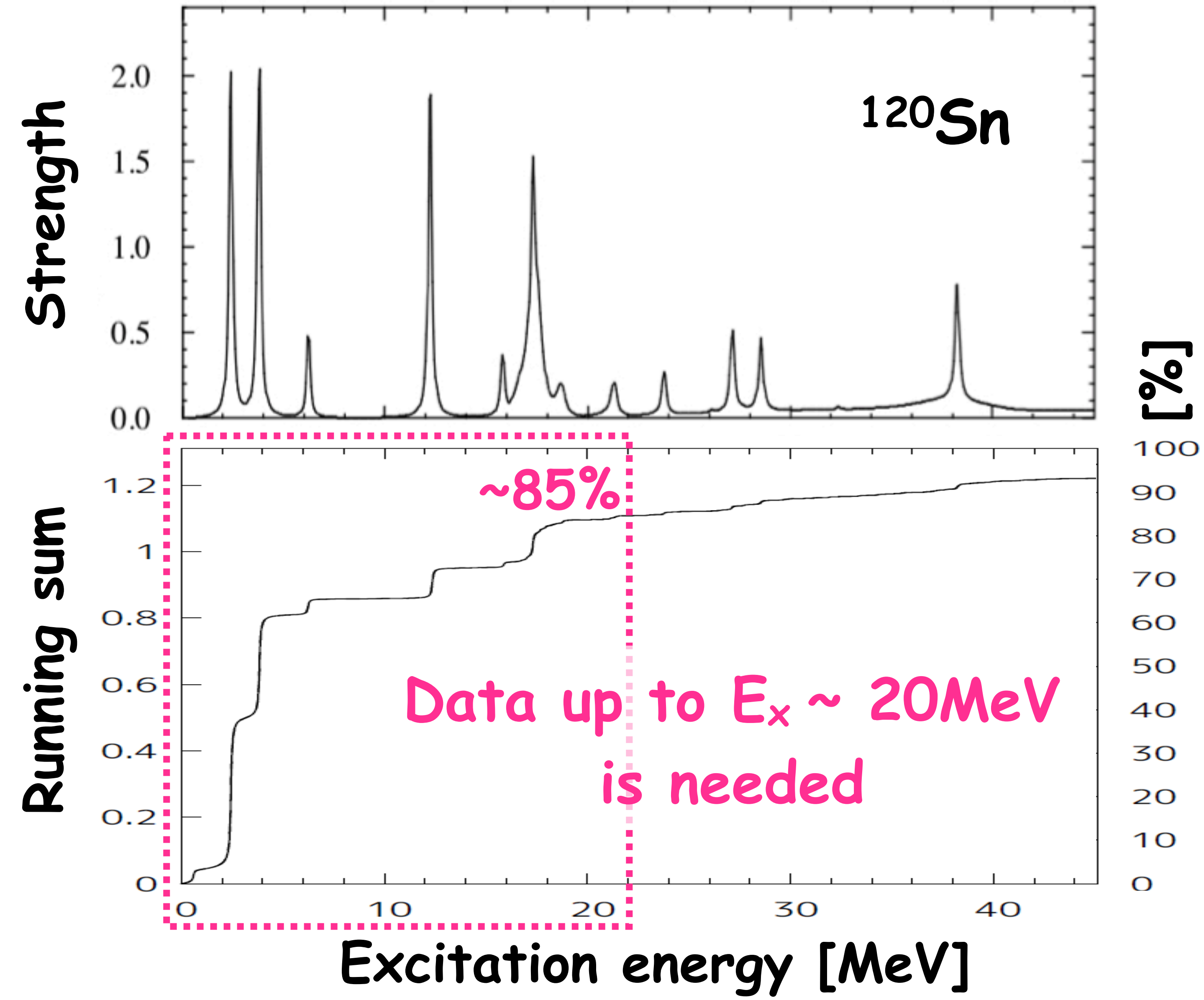
- Static polarizability for $P_H = P_{ad} + P_{rm}$

$$\alpha_{P_H} = 2M_{-1}^{P_H} = 2\int_0^\infty d\omega \frac{S_{P_H}(\omega)}{\hbar\omega}$$

- Related to the curvature of the effective pairing potential (cf Hellman-Feynman theorem)

$$C_{cond} = \frac{1}{\alpha_{P_H}}$$



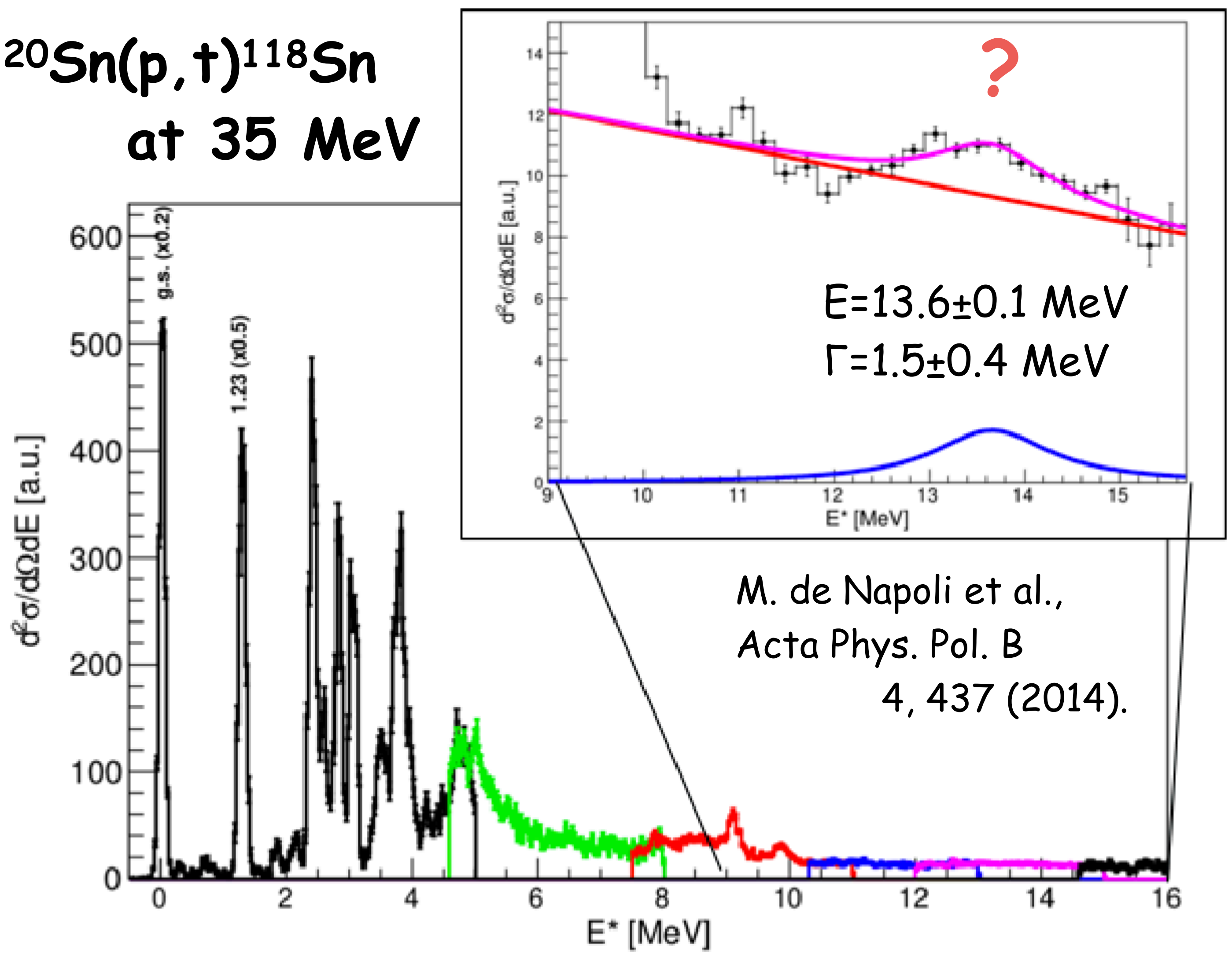


Sytematic pair-vib. data is essential for an experimental determination of pair energy curvature

Experimental attempts for High-lying PV

- **Sn(p,t) at 42MeV** G.M.Crawley et al., PRL 39, 1451 (1977)
- **^{120}Sn,^{208}Pb(p,t) at 50,60MeV** B. Mouginot et al., PRC 83, 037302 (2011)
- **^{120}Sn(p,t)^{118}Sn at 35MeV** M. de Napoli et al., Acta Phys. Pol. B 4, 437 (2014).

^{120}Sn(p,t)^{118}Sn at 35 MeV



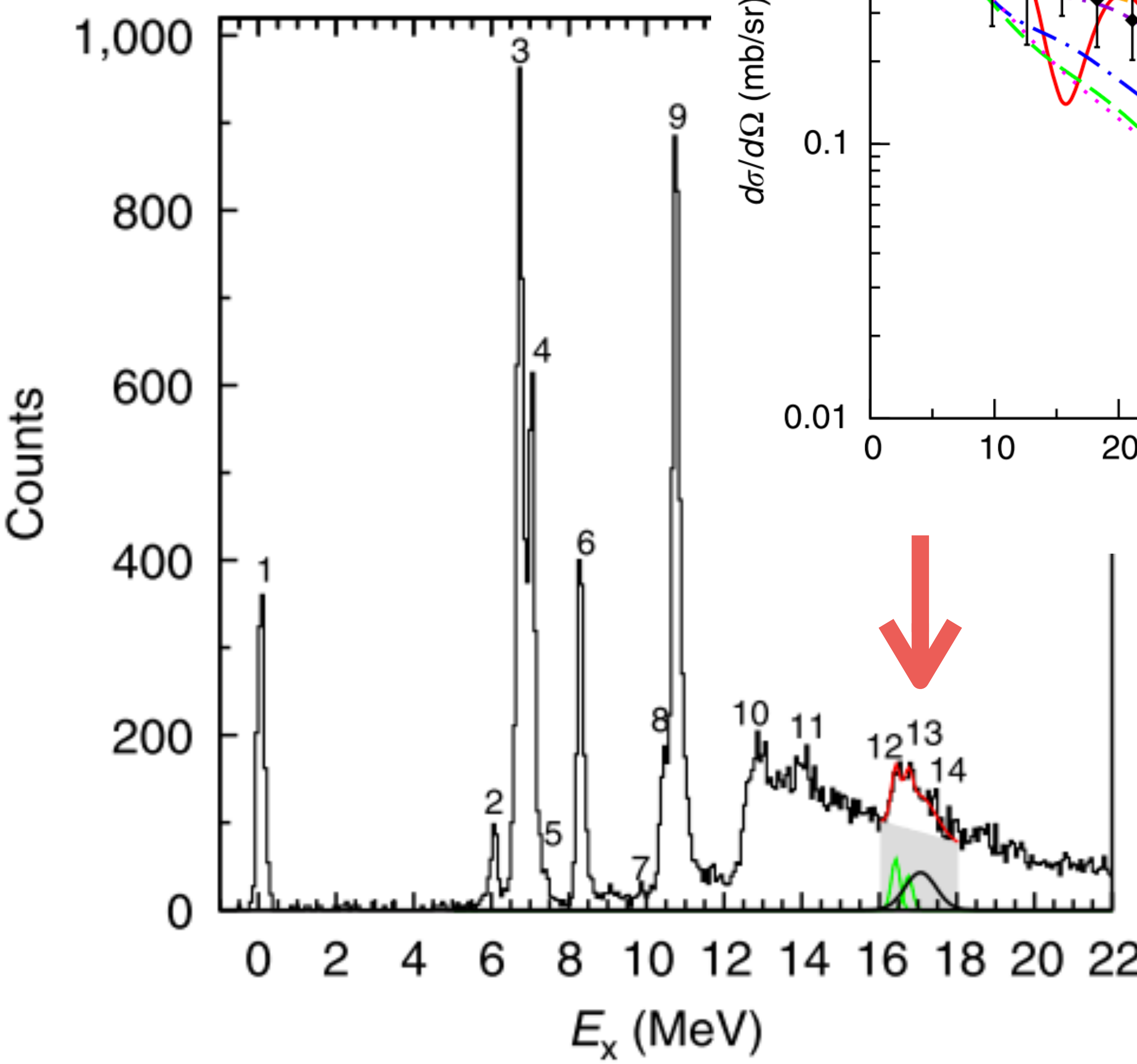
M. de Napoli et al., Acta Phys. Pol. B 4, 437 (2014).

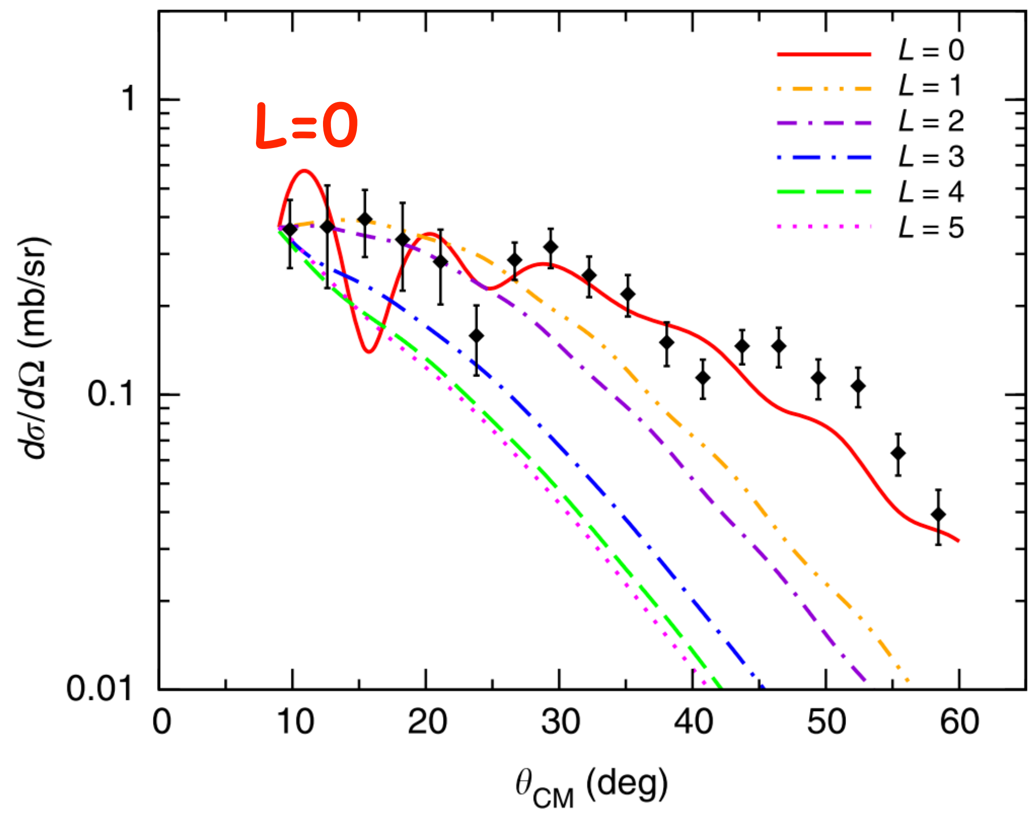
A possible PV at ~13MeV, but still inconclusive…

A more efficient probe is required

Experimental attempts for High-lying PV

- $^{12,13}C(^{18}O,^{16}O)$ at 84MeV F.Cappuzzello et al., Nat. Commun. 6, 6743 (2015).





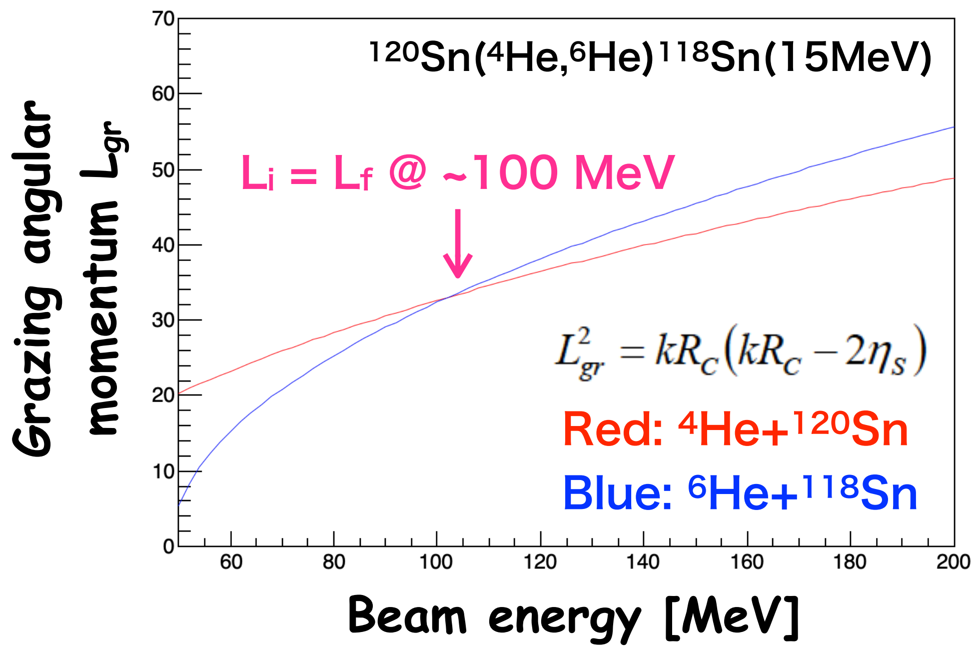
Fist signature of giant pair vibration, but in LIGHT nuclei

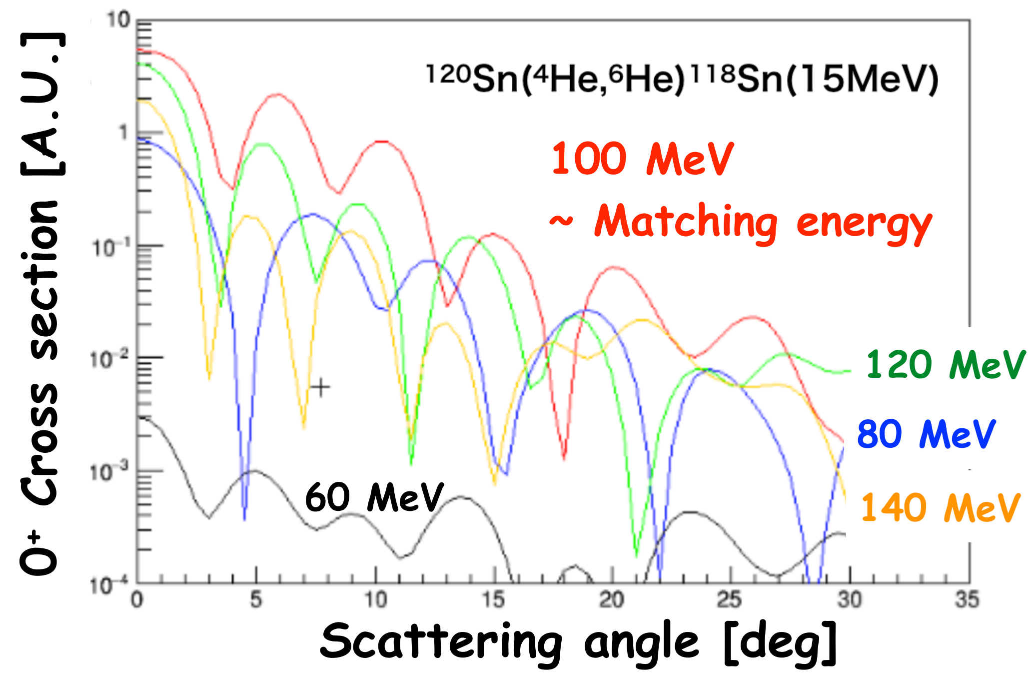
Identification in HEAVY nuclei remains an open question Further experimental studies are awaited

(α,^{6}He) reaction

A probe to high-lying pair vibrations !

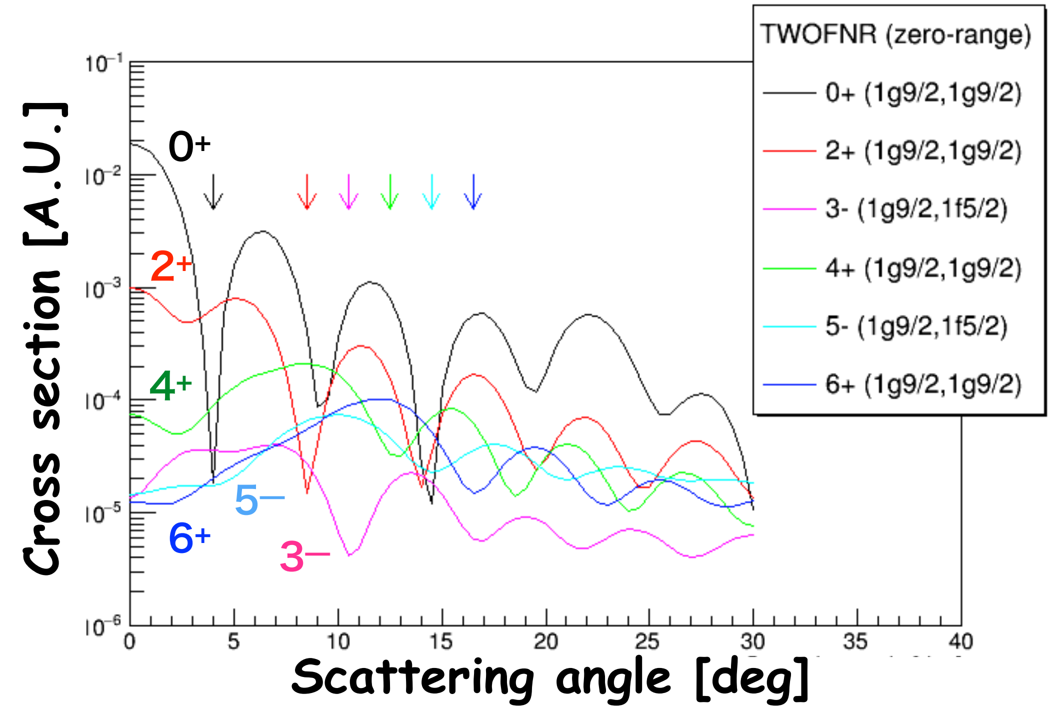
- L=0 transfer matching —> Maximize population of high-lying PV (0^+)





- Sharp diffraction pattern of angular distribution (because of strong absorption)

—> Reliable J^π assignment using multipole decomposition analysis



(α, ^{6}He) reaction

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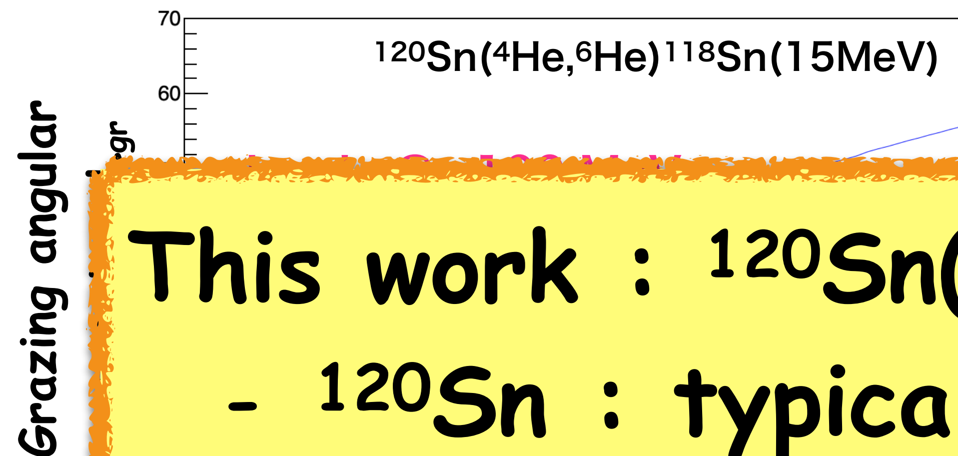
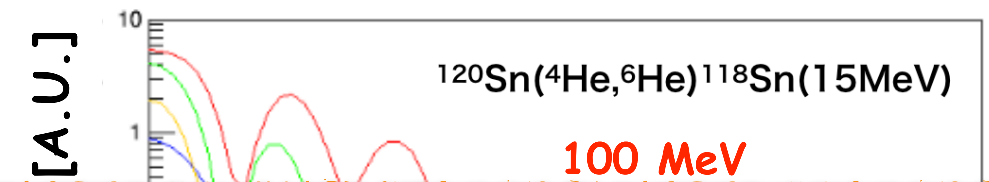


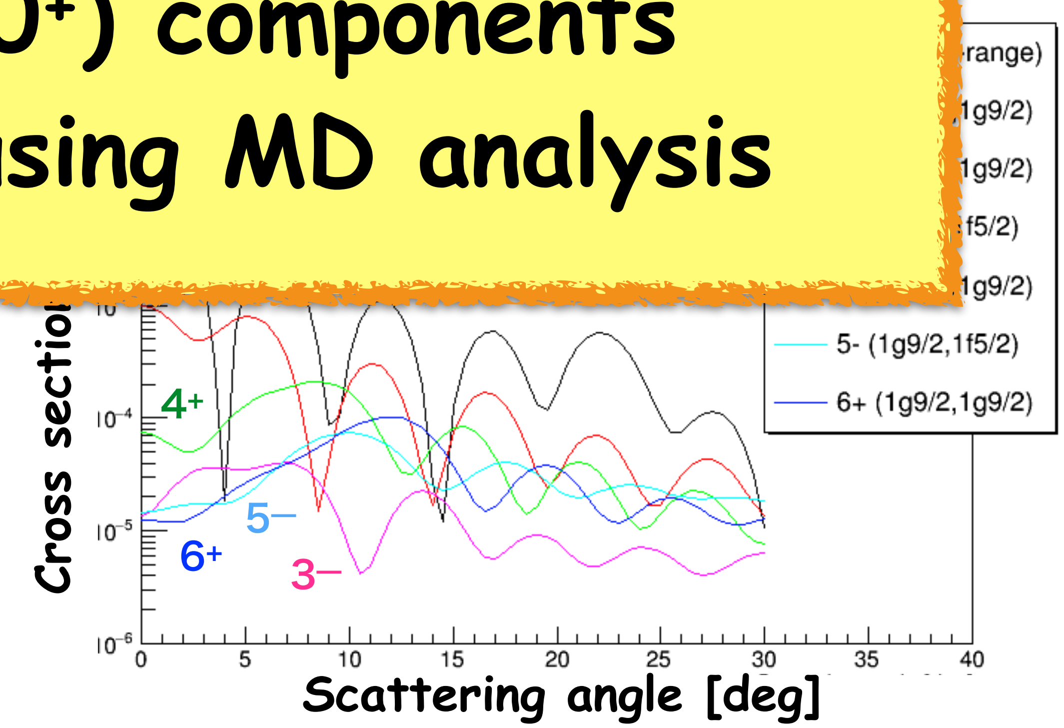


This work : ^{120}Sn(α,^{6}He)^{118}Sn @ 100MeV

- **^{120}Sn : typical superfluid nucleus**
- **L=0 transfer matching at E_x~14MeV**
- **Extraction of PV (0^+) components using MD analysis**

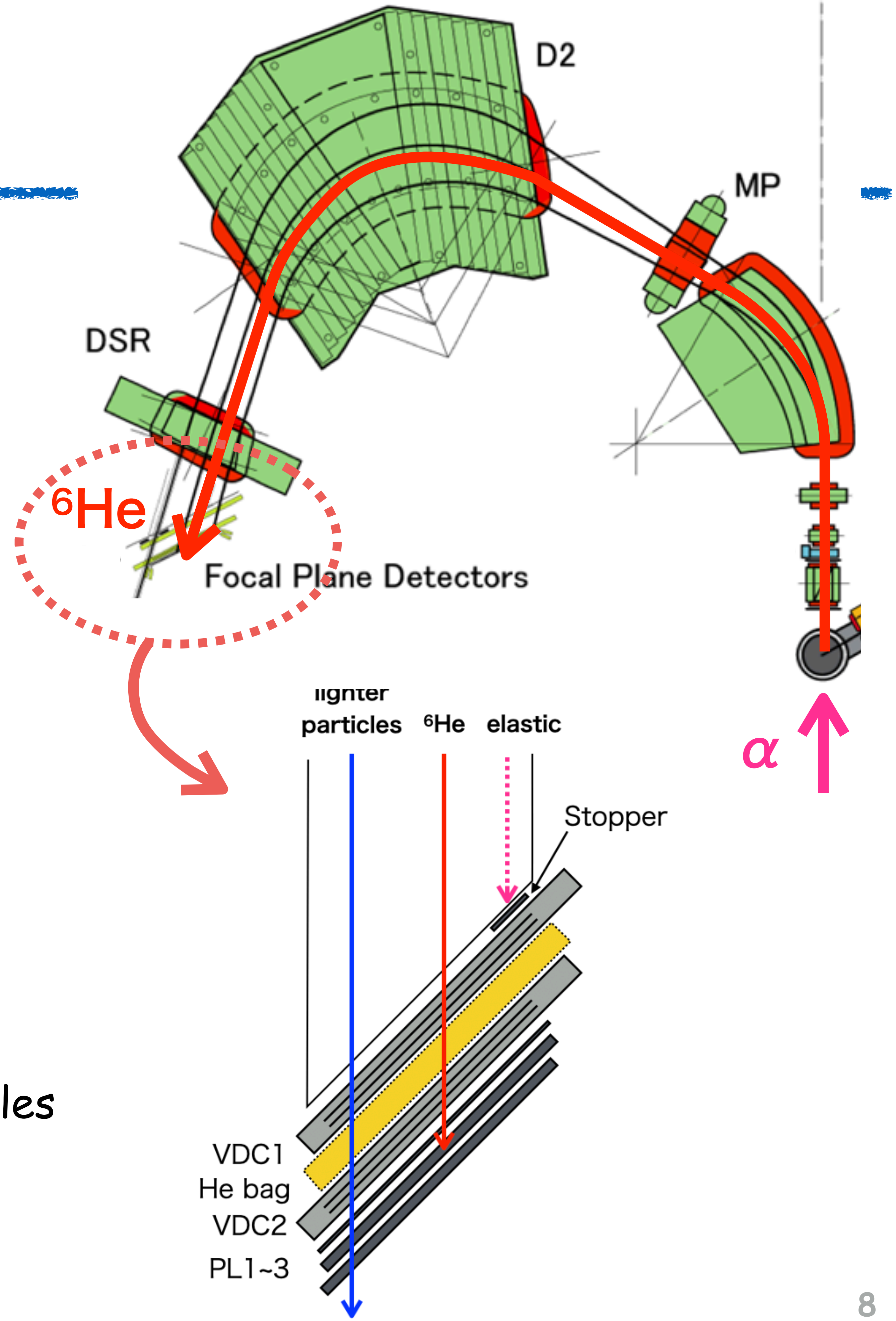
- Sh... ang... (because of strong absorption)

—> Reliable J^π assignment using multipole decomposition analysis



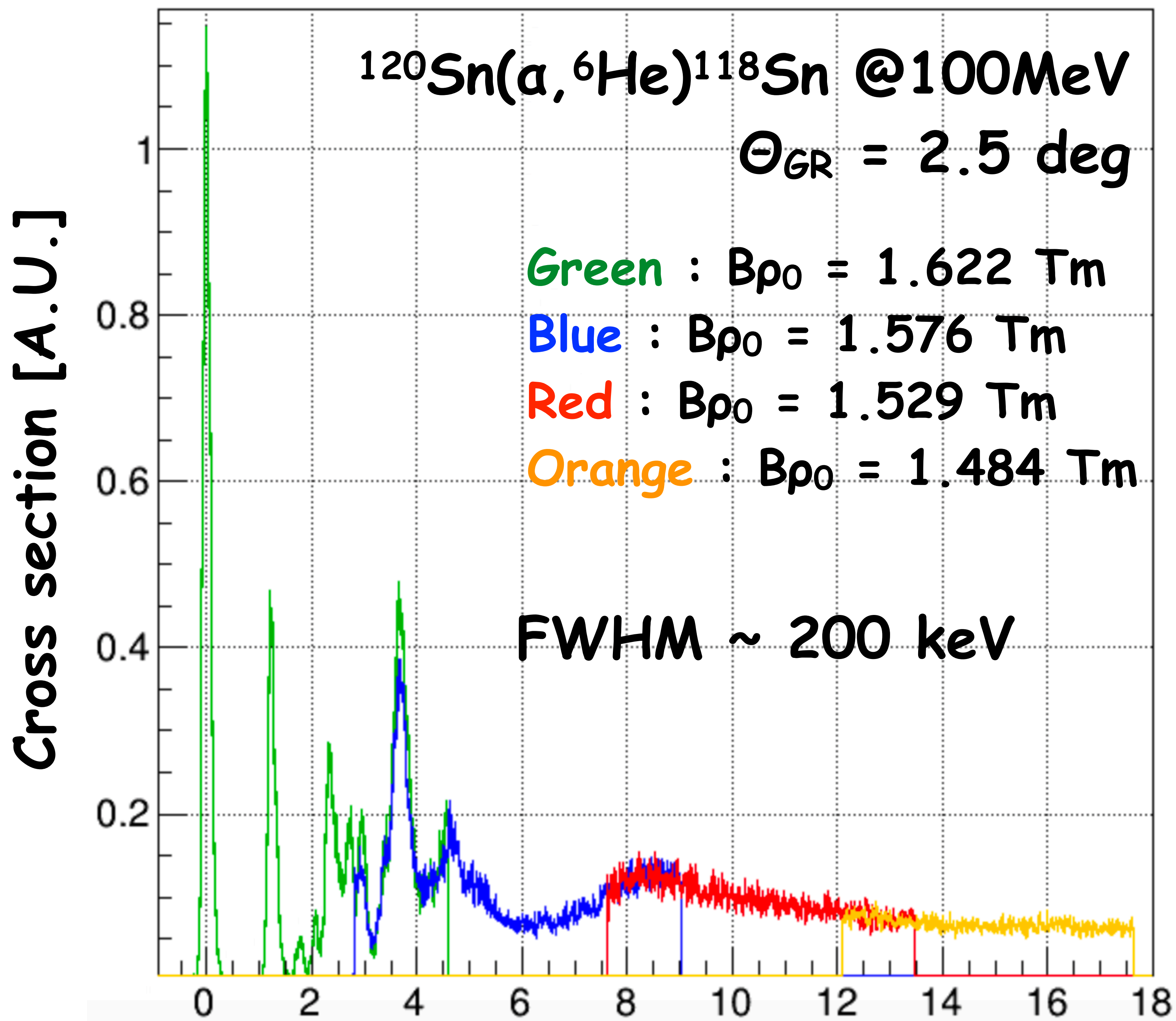
Experiment

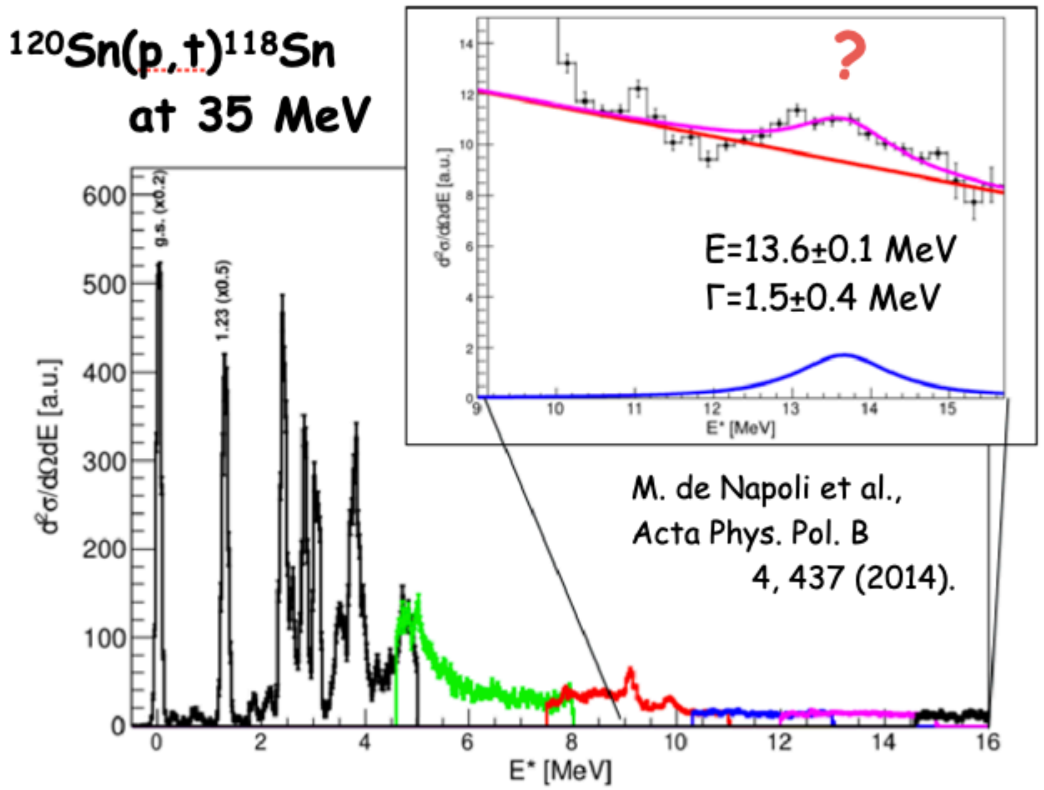
- α beam
  - 100 MeV
  - 500 enA
- ^{120}Sn target
  - 2.7 mg/cm^2 for low-E_x meas.
  - 7.0 mg/cm^2 for high-E_x meas.
- ^{6}He detection
  - VDCs : Tracking
  - Plastic scintillators
    - 1st (1mm^t) : ΔE
    - 2nd (3mm^t) : Total E
    - 3rd (10mm^t) : Veto for light particles
  - E_x = 0 — 17 MeV, θ_{lab} = ~2 — ~11 deg



Experimental results

- Excitation energy spectrum of ^{118}Sn @ θ_{GR} = 2.5 deg

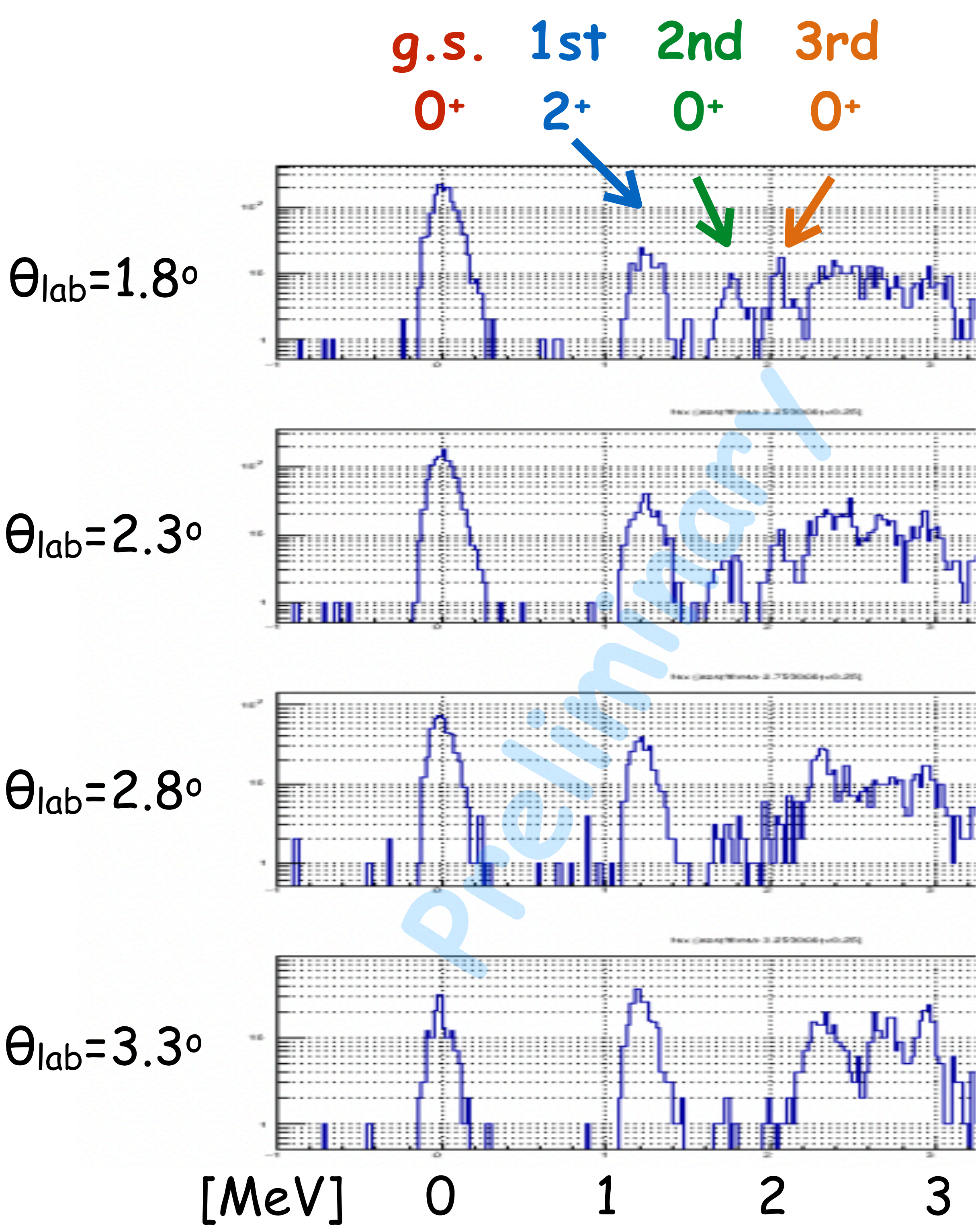


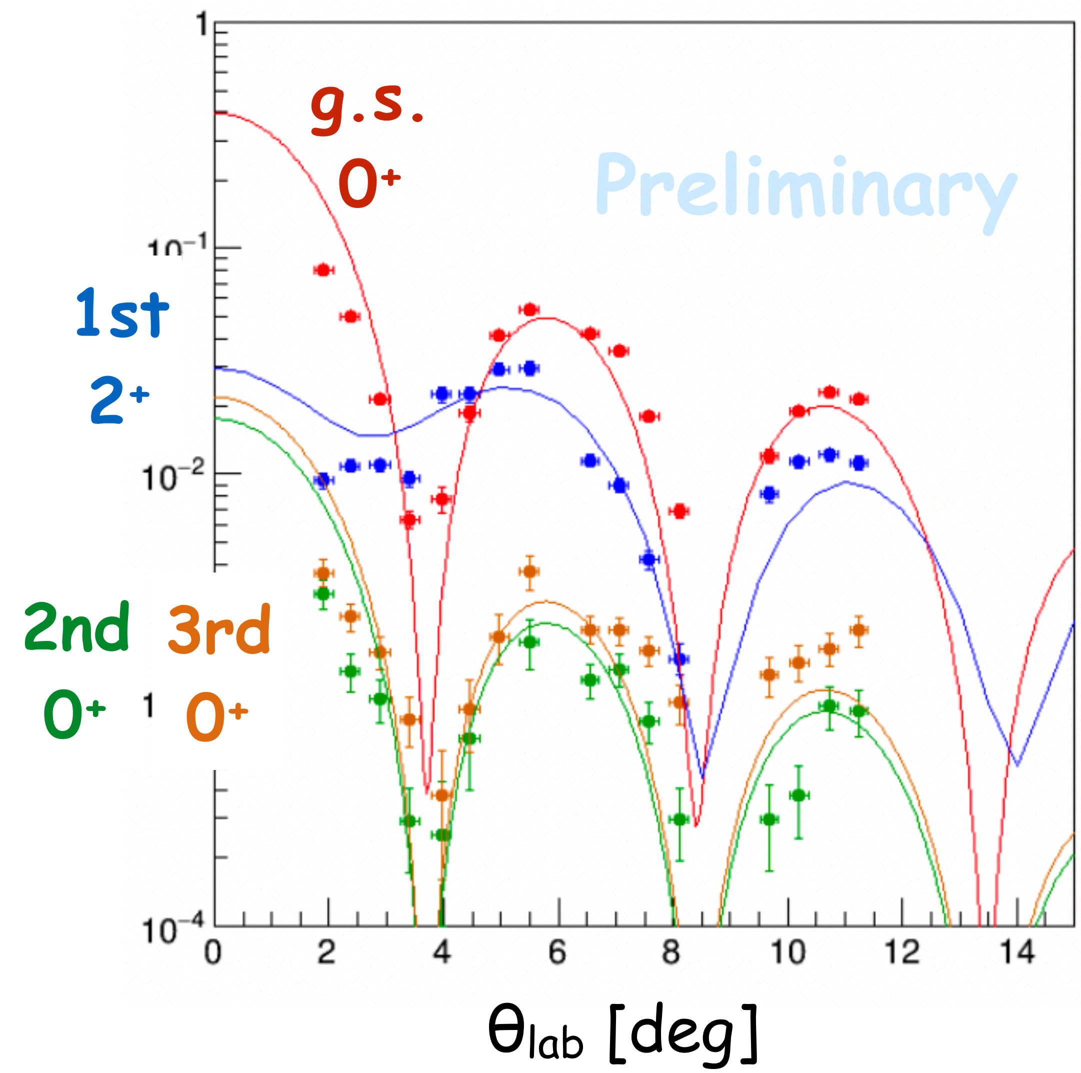


Similar structure as (p,t)

Experimental results

- Angular distributions for low-lying states





- Distinct oscillatory patterns depending on J^{π} (L)
- 0^+ show a pronounced forward peak
  —> Indicator of PV 0^+ components

Multipole Decomposition Analysis (MDA)

- Exp. σ is fitted with linear combination of calc. σ for different ΔL's

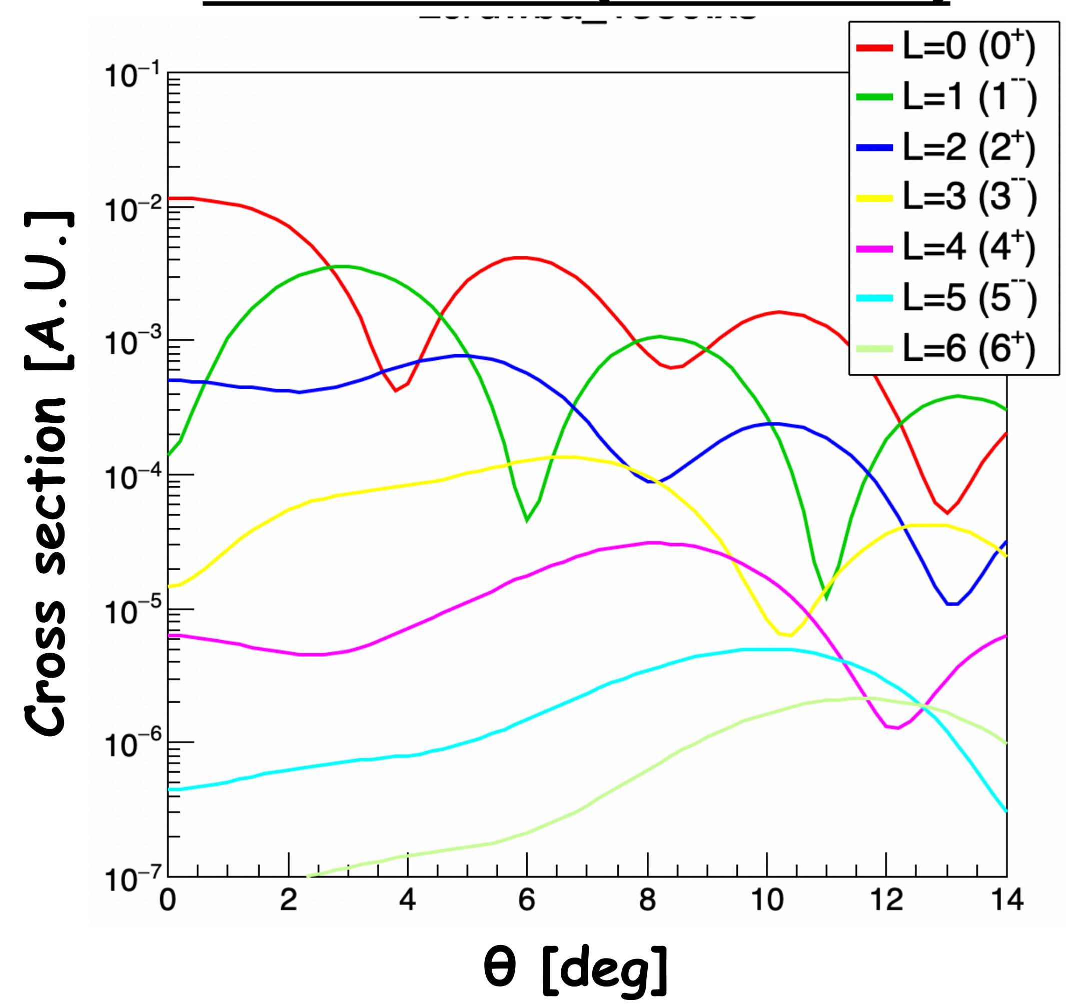
$$\sigma^{\exp}(\theta, E_x) = \sum_L a_L(E_x)\sigma_L^{\mathrm{DWBA}}(\theta, E_x)$$

a_L : fitting coefficient
σ_L^{DWBA} : DWBA σ

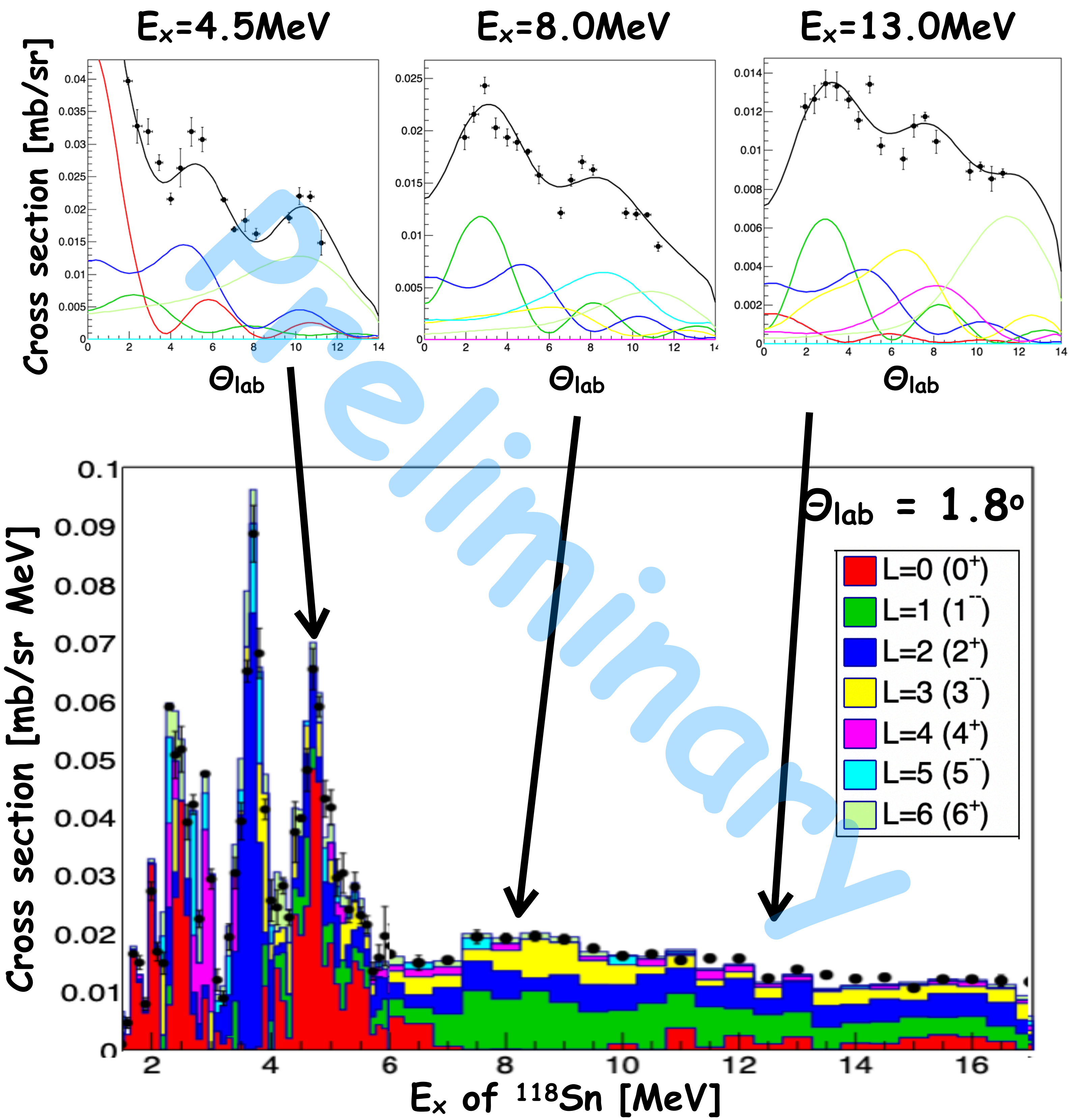
- zero-range DWBA calculations
  - Program : TWOFNR
  - Optical potential
    - ^{4}He+^{120}Sn : ^{4}He+^{124}Sn @ 104MeV
      NPA128,81(1969).
    - ^{6}He+^{118}Sn : ^{6}Li+^{124}Sn @ 73.7MeV
      PRC22,1522(1980).
  - Transition density in ^{120}Sn : HFB+QRPA
    - Skyrme interaction (SkP)

H.Shimoyama and M.Matsuo, PRC88, 054308 (2013).

DWBA results (E_x=13.5MeV)



MDA results (Preliminary)



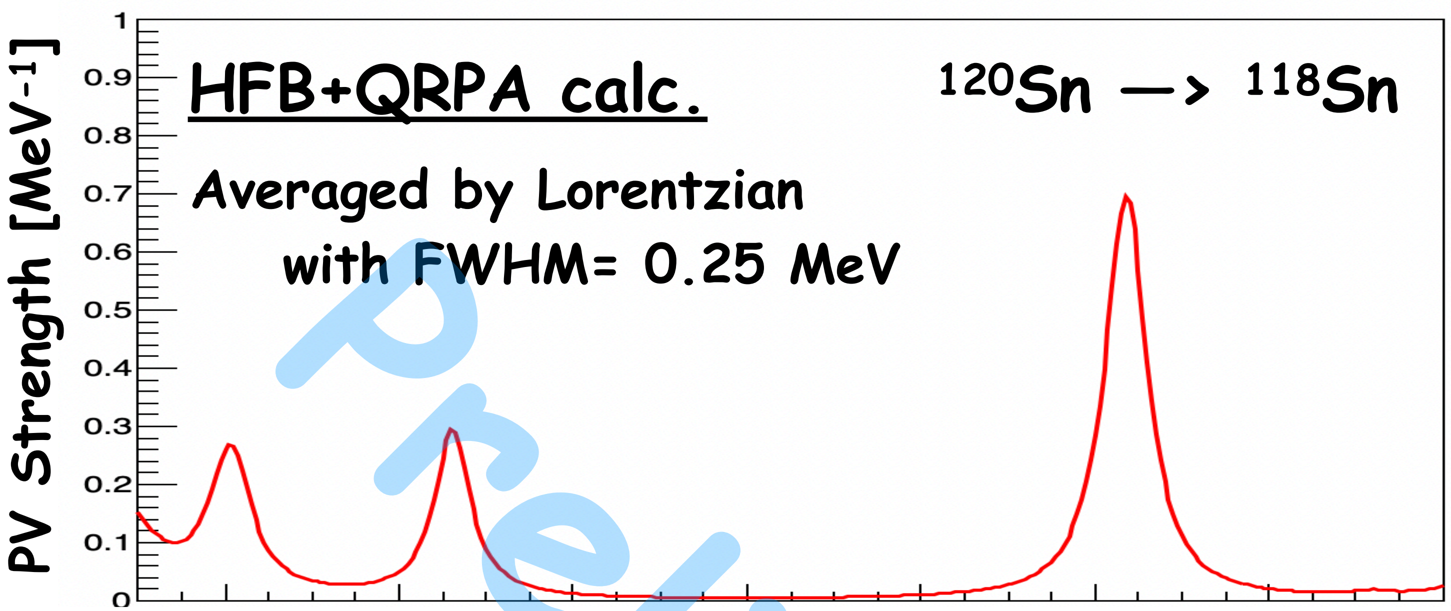
- E_x=4.5 MeV
  - Exp. : forward peak
  - MDA : large PV contribution
- E_x=8, 13 MeV
  - Exp. : no forward peaking
  - MDA : PV contribution is small/negligible

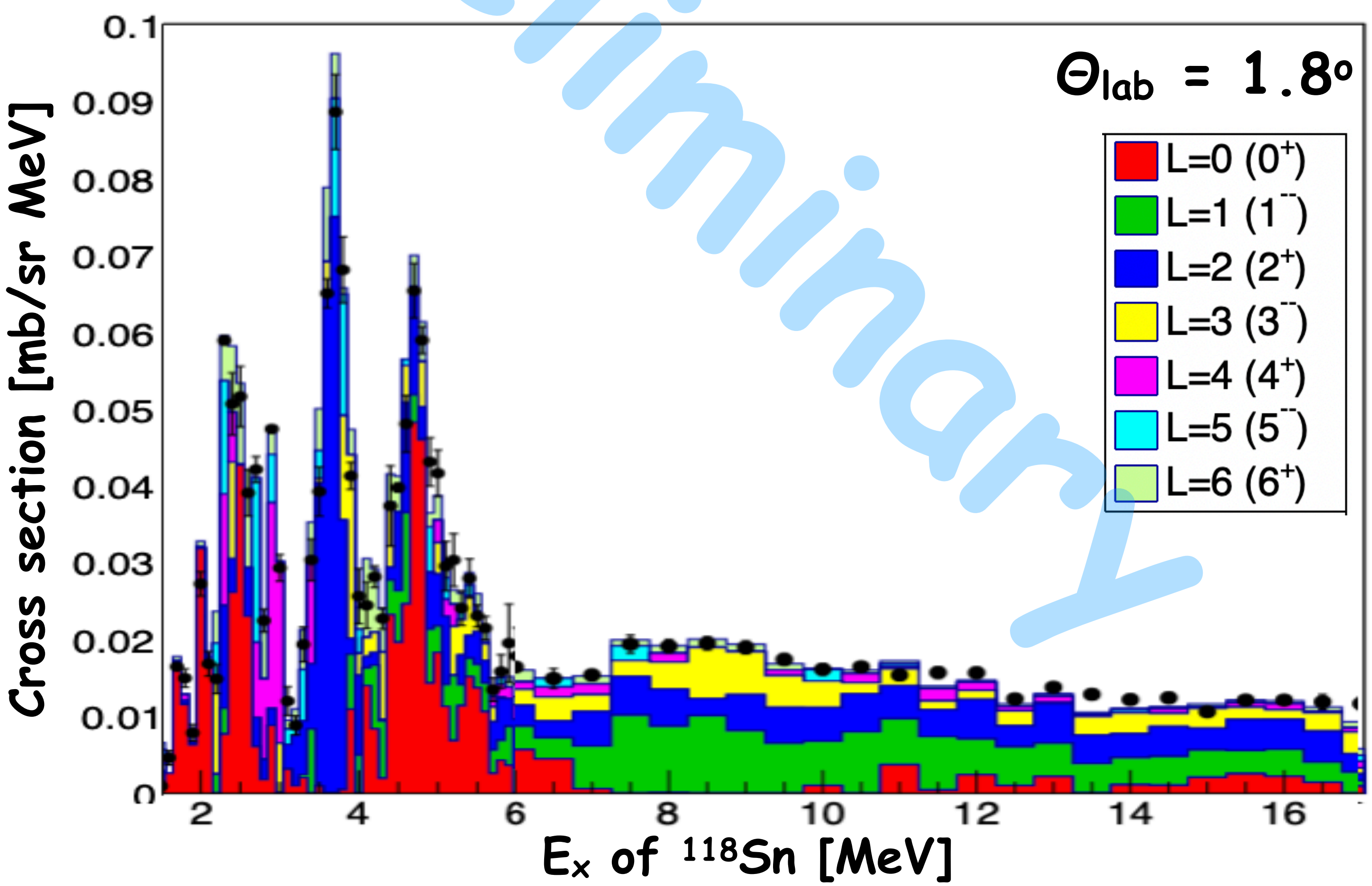
Black point : exp. Data

Histograms : MDA results

- Red : PV (L=0, 0^+)

MDA results (Preliminary)





PV distribution (L=0, 0^+)

- Roughly consistent with HFB+QRPA
- High-lying strength is FRAGMENTED
  - It may explain why high-lying PV have not been clearly identified in previous experiments
  - Continuum effects beyond QRPA may play an important role ?

Summary

- Pair vibrations (PV) provide a key probe of pair correlations.
- Pair polarizability is a promising quantity to determine the pair-energy curvature, but, systematic PV data (E_x<~20 MeV) are required.
- We proposed the (α,^{6}He) reaction as a probe of pair vibrations.
- A new experiment on ^{120}Sn(α,^{6}He)^{118}Sn was performed at RCNP.
  - E_x = 0 — 17 MeV, θ_{lab} = ~2 — ~11 deg
- PV (L=0) components were extracted up to E_x~17MeV using MD analysis.
- High-lying PV strength is highly FRAGMENTED. It may explain why high-lying PV have not been clearly identified in previous experiments.

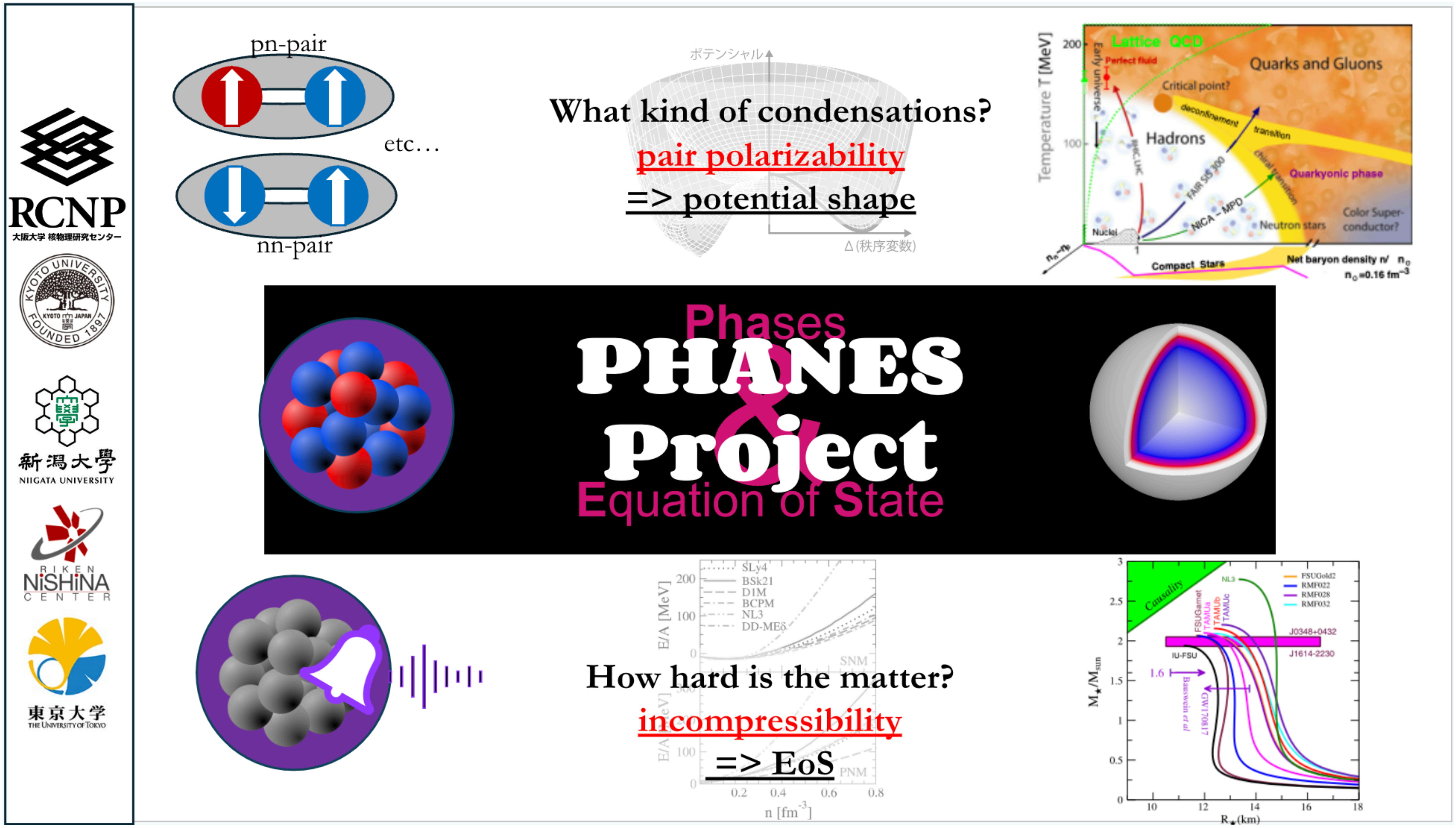
Future plan

- This is the first step toward
  - Exploring pair-vibration strength function
  - Determining the pair-field polarizability

- Based on this work, we will extend the method to
  - Other targets (Sn/Ni isotopes, ^{208}Pb, …)
  - Pair-addition mode <— counterpart required for the determination of the pair polarizability
    (What probe is best ? (^{18}O,^{16}O) ? (^{6}He,α) ?)

- Through systematic studies,
  we hope to establish an experimental approach
  to quantifying macroscopic properties in nuclear matter

PHANES project



Collaboration between experiment and theory !

S.Ota (RCNP/CNS), M.Dozono (Kyoto/CNS), K.Yoshida (RCNP), M.Matsuo (Niigata), S.Shimoura (RIKEN), F.Endo (RCNP), et al.

We welcome your collaborations !!

Collaborators for RCNP-E585 exp.

- Experimental group
  - Kyoto Univ.
    - M. Dozono, J. Zenihiro, Y. Hijikata, S. Ogio, R. Tsuji, K. Yahiro, R. Yoshida, T. Yano
  - RCNP, Osaka Univ.
    - S. Ota, N. Aoi, A. Tamii, E. Ideguchi, N. Kobayashi, A. Inoue, M. Khandelwal
  - CNS, Univ. of Tokyo
    - N. Imai, S. Michimasa, N. Kitamura, K. Kawata, S. Hanai, F. Endo
  - CYRIC, Tohoku Univ.
    - M. Itoh, S. Adachi
  - RIKEN Nishina Center
    - S. Shimoura
- Theoretical support
  - Niigata Univ.
    - M. Matsuo
  - Kyoto Univ.
    - K. Yoshida

Collaboration between experiment and theory !