Enhancement of E1 strength in nuclei with the neutron skin and halo

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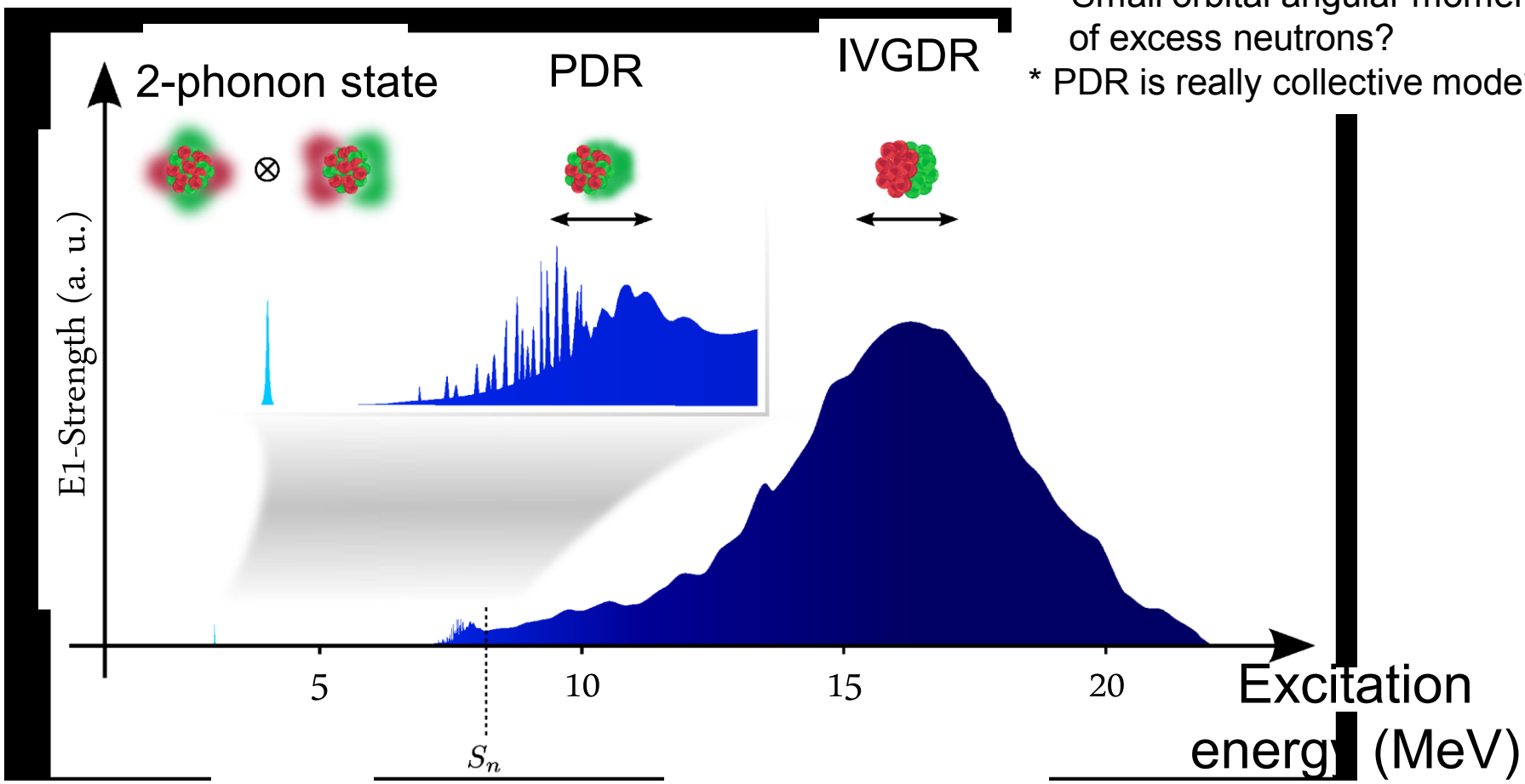
Research Center for Nuclear Physics (RCNP),
Osaka University

Outline

- **Motivation**
- **CAGRA+GR campaign**
- **Recent progress in analysis of ^{208}Pb(p,$p\gamma$)**

Electric Dipole (E1) response

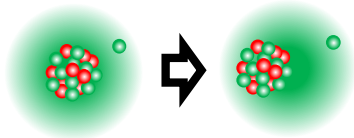
(Open) Questions
* What is the origin of PDR?
  - Neutron excess?
  - Small S_n / threshold effect?
  - Small orbital angular momentum of excess neutrons?
* PDR is really collective mode?

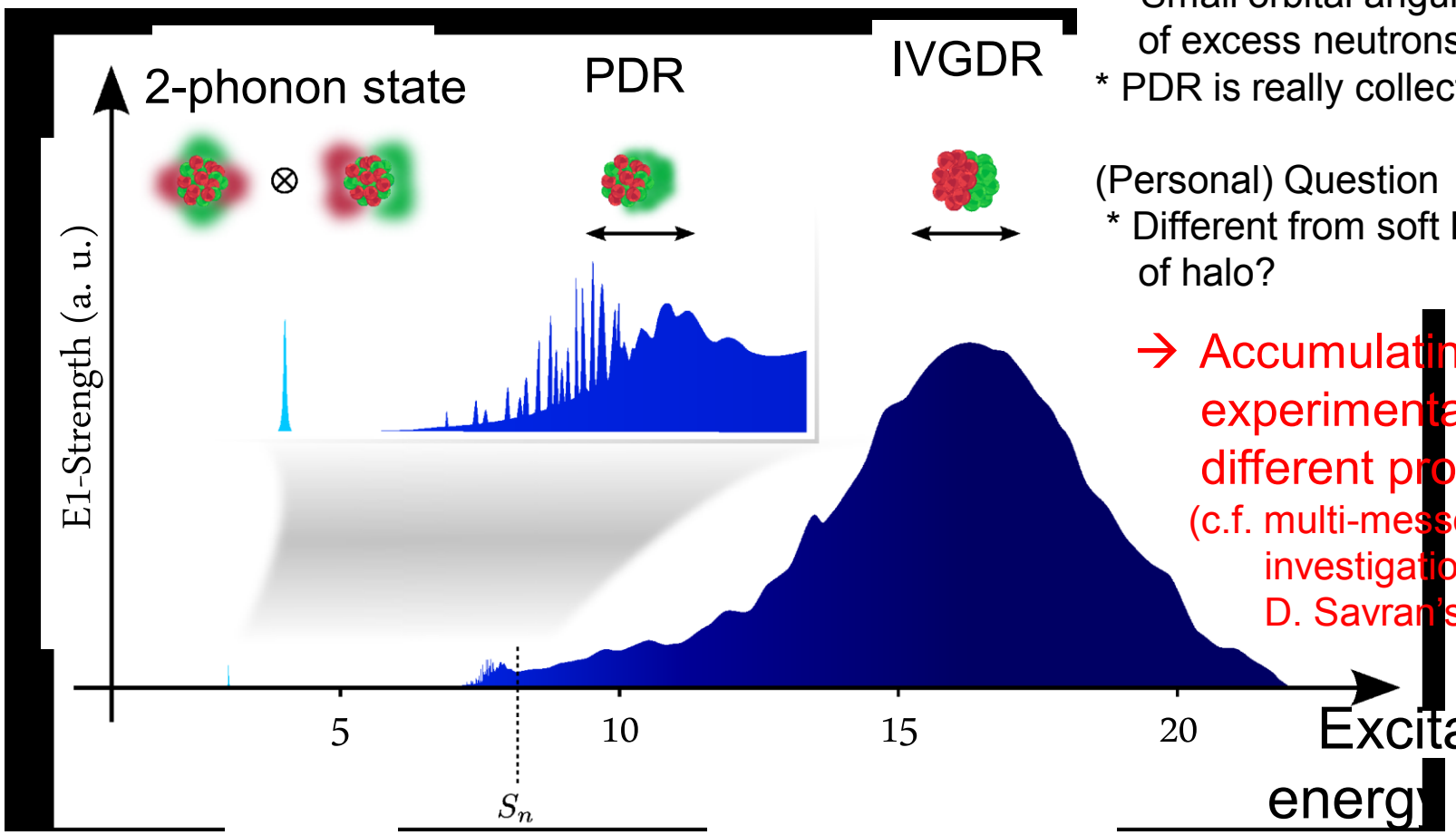


Modified from Johann Isaak's slide

Electric Dipole (E1) response

Soft E1 excitation





(Open) Questions
* What is the origin of PDR?
  - Neutron excess?
  - Small S_n / threshold effect?
  - Small orbital angular momentum of excess neutrons?
* PDR is really collective mode?

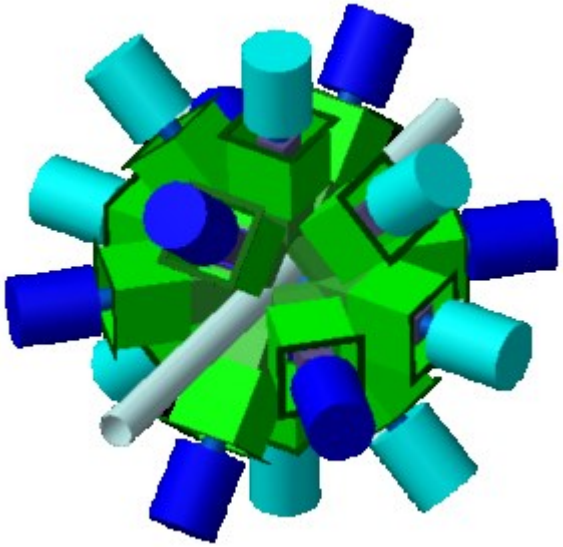
(Personal) Question
* Different from soft E1 excitation of halo?

→ Accumulating experimental data with different probes
(c.f. multi-messenger investigation in D. Savran's talk)

Modified from Johann Isaak's slide

CAGRA + Grand Raiden (GR)

→ Measurement in (p, $p'\gamma$), (α, $\alpha'\gamma$), (^{6}Li, ^{6}Li*γ) etc.



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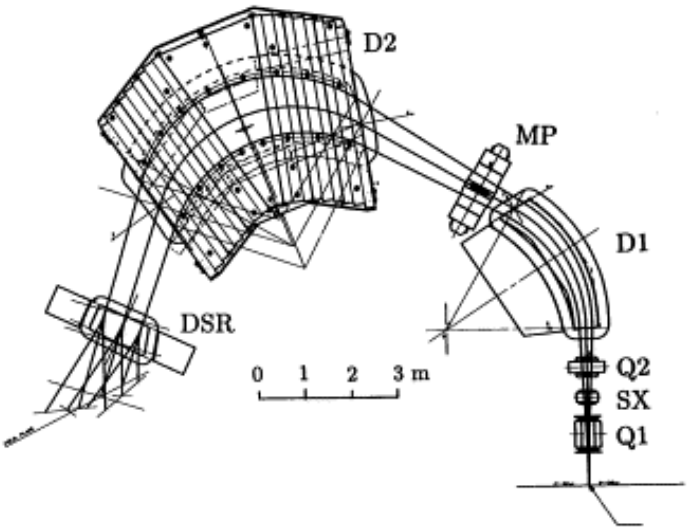


CAGRA collaboration

lead by E. Ideguchi and M. P. Carpenter
Clover
Array
Gamma-ray spectrometer at
RCNP/RIBF for
Advanced research

Large efficiency for γ rays

Grand Raiden (GR)

maintained by A. Tamii and Nobu Kobayashi *et al*.

Resolving power: 37,000

Solid angle acc.: ~4 msr
Momentum acc.: 5%
Angle: 0-70 deg.

High resolution and quality data by proper background subtraction

Physics Cases

1. Structure of the PDR via (p,p'γ) and (α,α'γ)

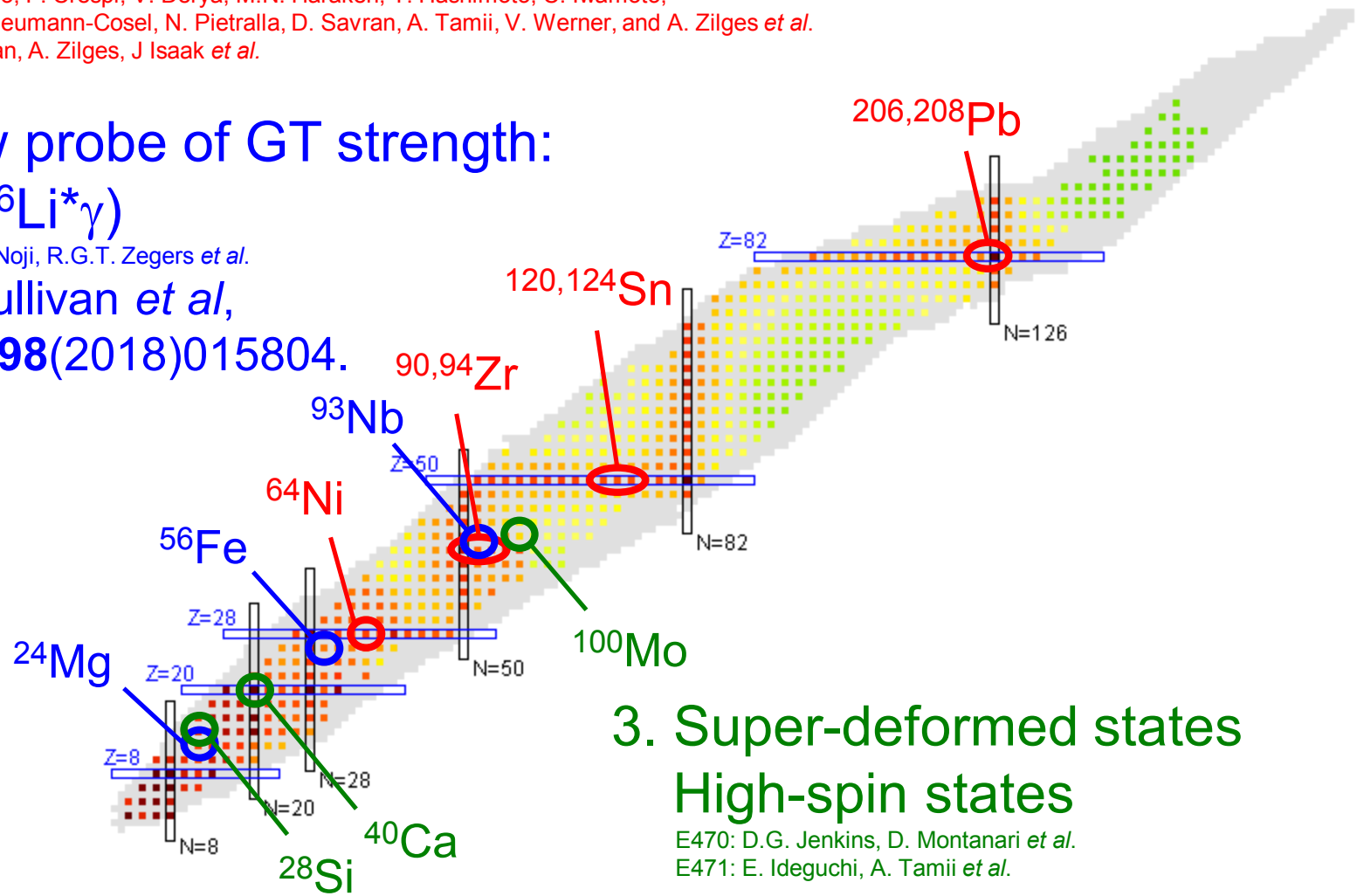
E450: A. Bracco, F. Crespi, V. Derya, M.N. Harakeh, T. Hashimoto, C. Iwamoto, P. von Neumann-Cosel, N. Pietralla, D. Savran, A. Tamii, V. Werner, and A. Zilges *et al.*

E454: D. Savran, A. Zilges, J Isaak *et al.*

2. New probe of GT strength: (^{6}Li,^{6}Li*γ)

E441: S. Noji, R.G.T. Zegers *et al.*

C. Sullivan *et al*, PRC**98**(2018)015804.



3. Super-deformed states High-spin states

E470: D.G. Jenkins, D. Montanari *et al.*

E471: E. Ideguchi, A. Tamii *et al.*

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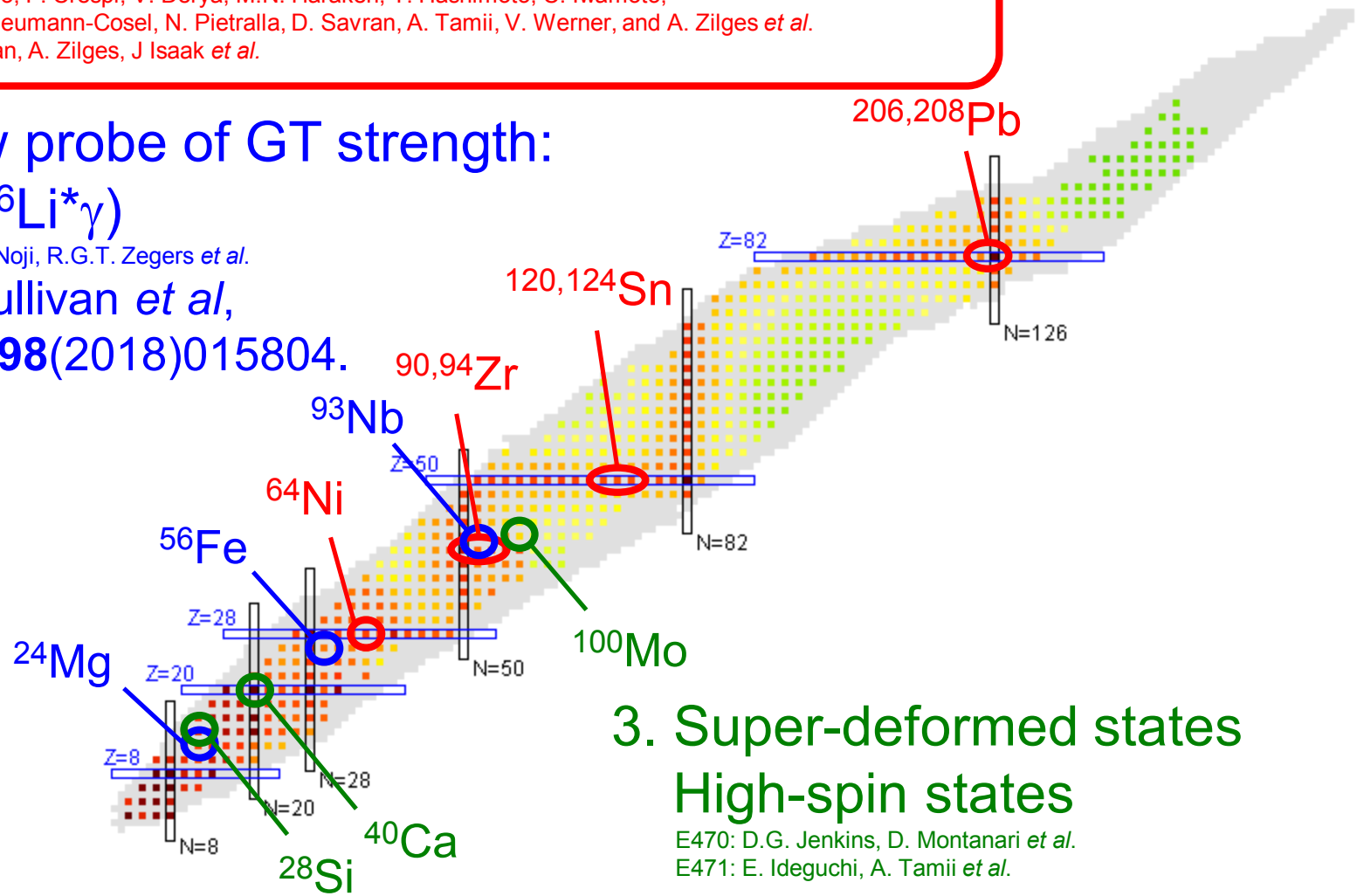

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Measurement of the angular distribution of ^{208}Pb (p,p') at 80 MeV

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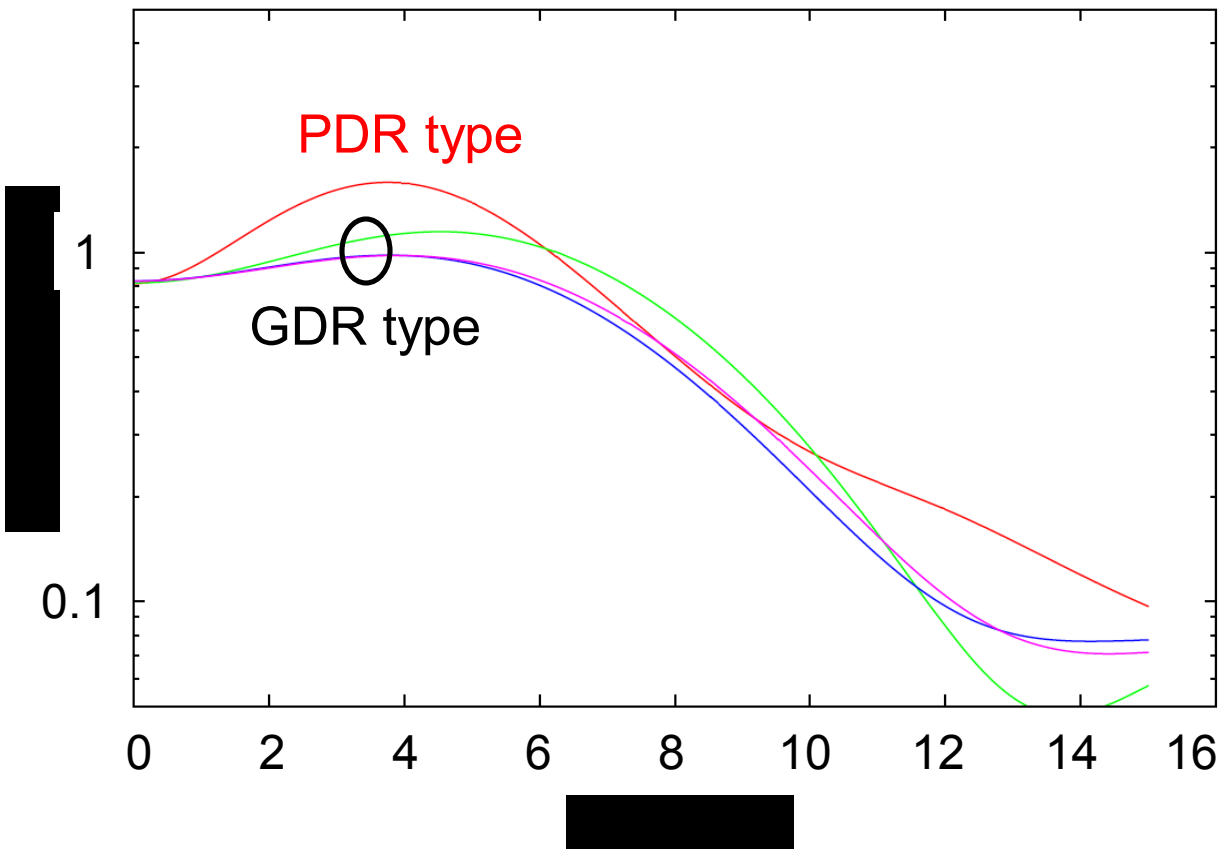
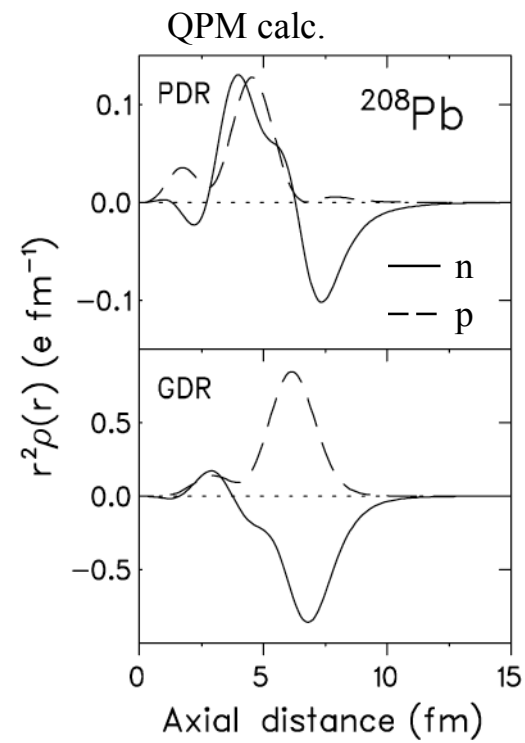




N. Ryezayeva *et al.*, PRC**89**(2002)272502

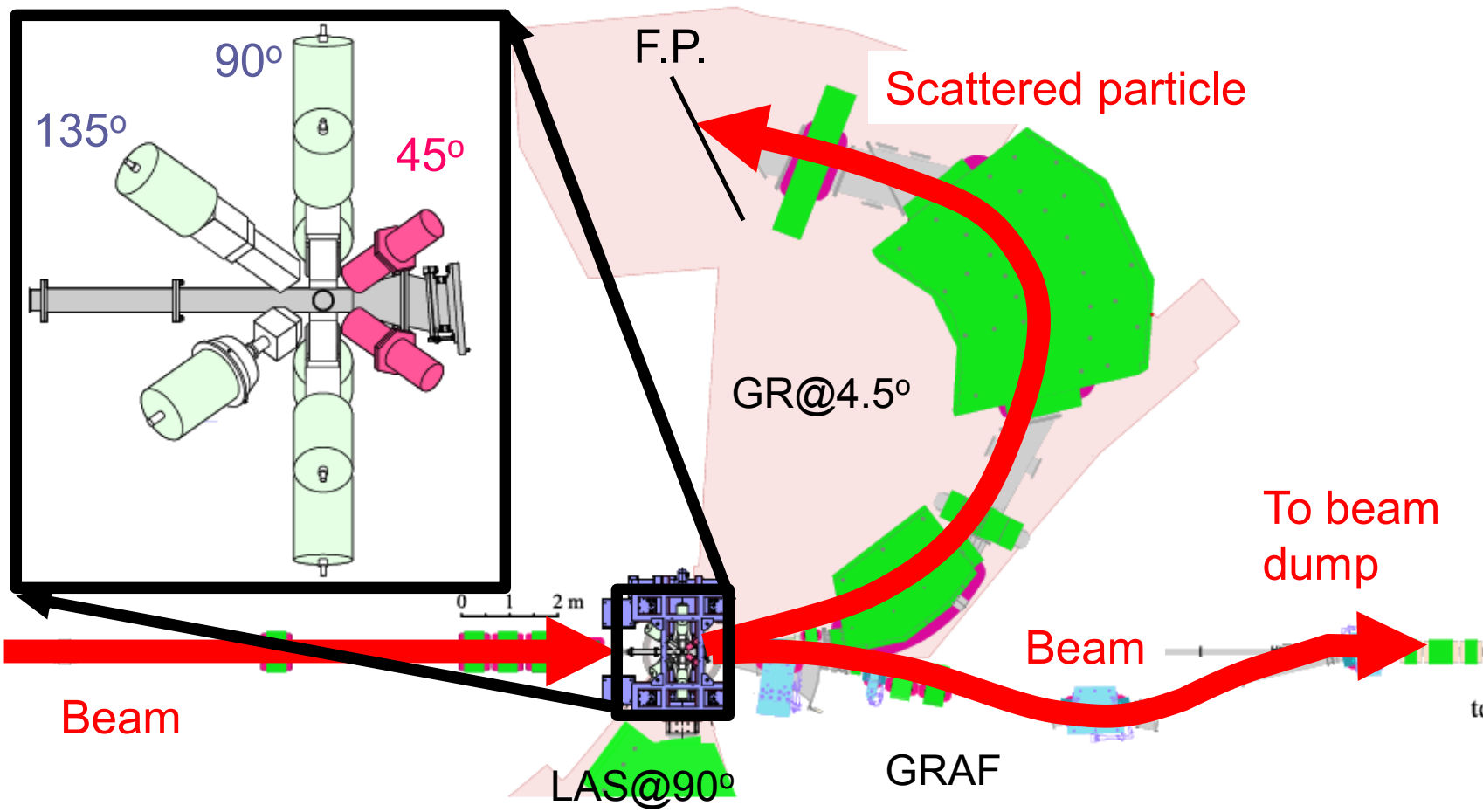
DWBA Calculation by Quasi-particle Phonon Model
I. Poltoratska, private communication

C.f. Pioneering work: I. Poltoratska et al, "Pygmy dipole resonance in ^{208}Pb", PRC85(2012)041304(R).

Campaign experiments in Oct. – Dec. 2016 at RCNP

CAGRA
12 Clovers from
ANL, ARL, (Tohoku,) and IMP
+ 4 $LaBr_3$
w/ large volume from Milano

CAGRA+ GR+ GRAF setup
(p, $p'\gamma$) at 4.5 deg.



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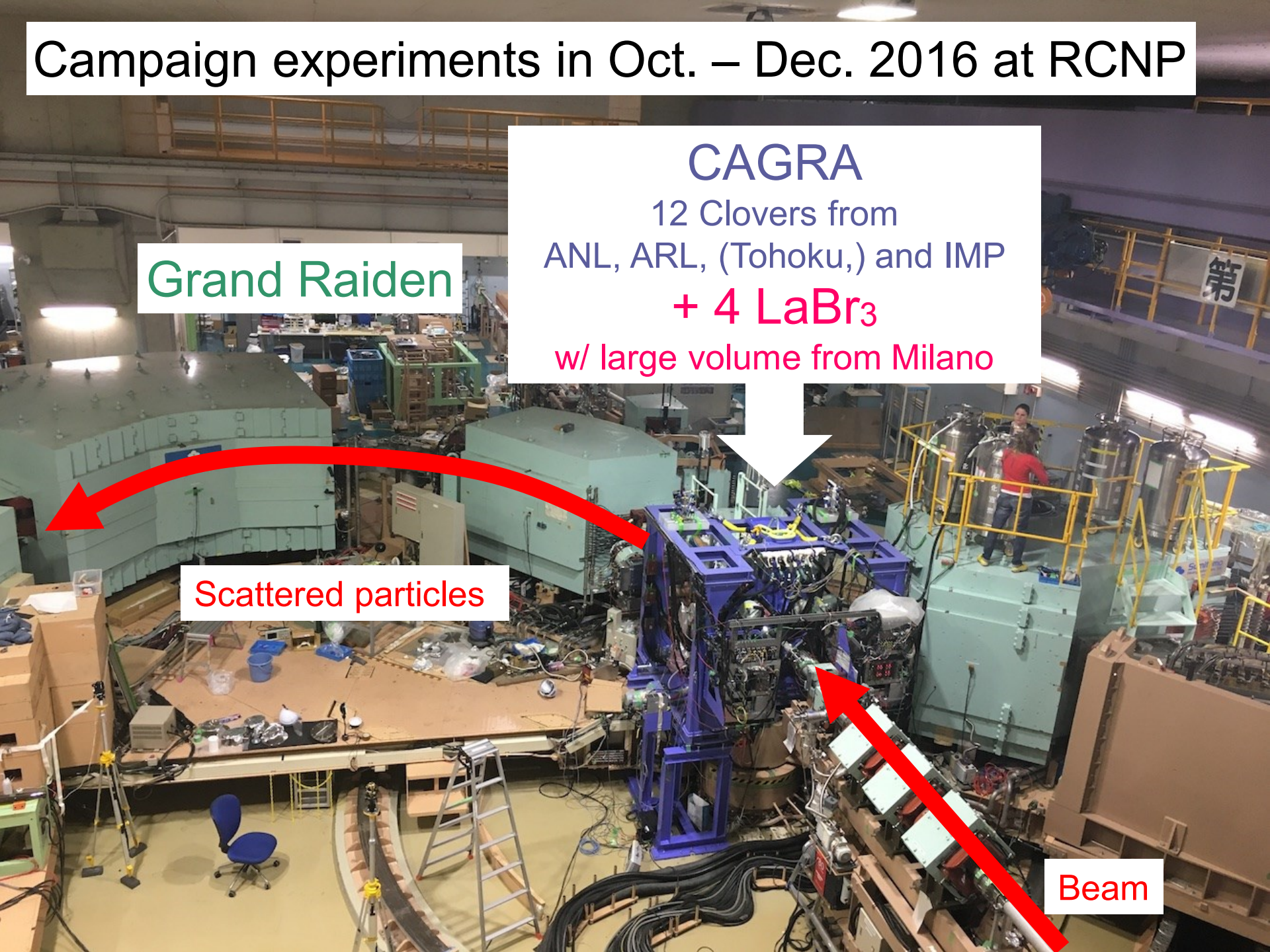

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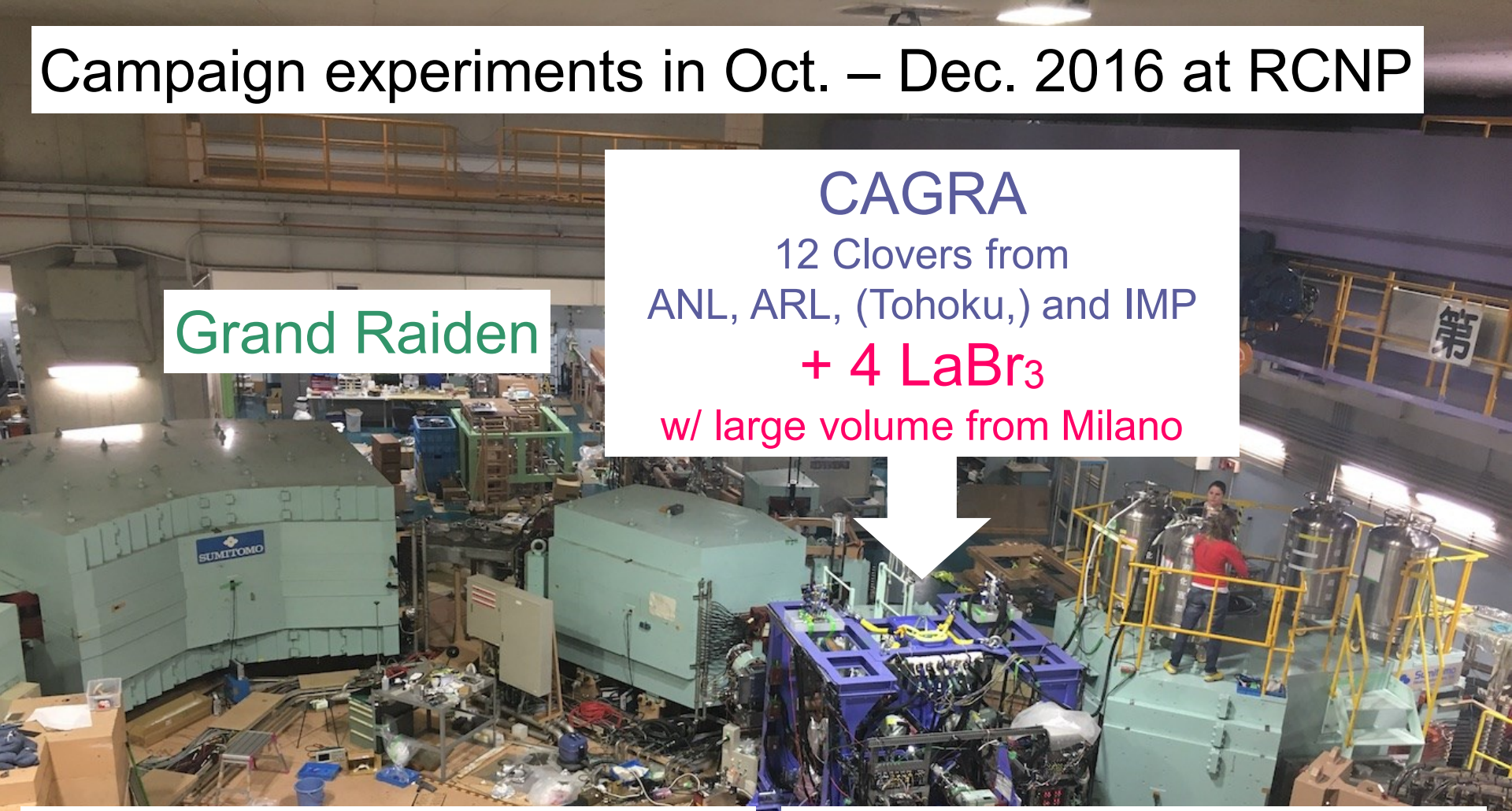


CAGRA

12 Clovers from
ANL, ARL, (Tohoku,) and IMP

+ 4 $LaBr_3$

w/ large volume from Milano

Beam time

1. Structure of the PDR via (α,$\alpha'\gamma$) and (p,$p'\gamma$): 31 days
2. Inelastic ν-nucleus response: 5 days
3. Super-deformed states, High-spin states: 9 days

In total 45 days

Participants

from abroad: 9 countries, 15 institutes, 43 people

from Japan: 19 people

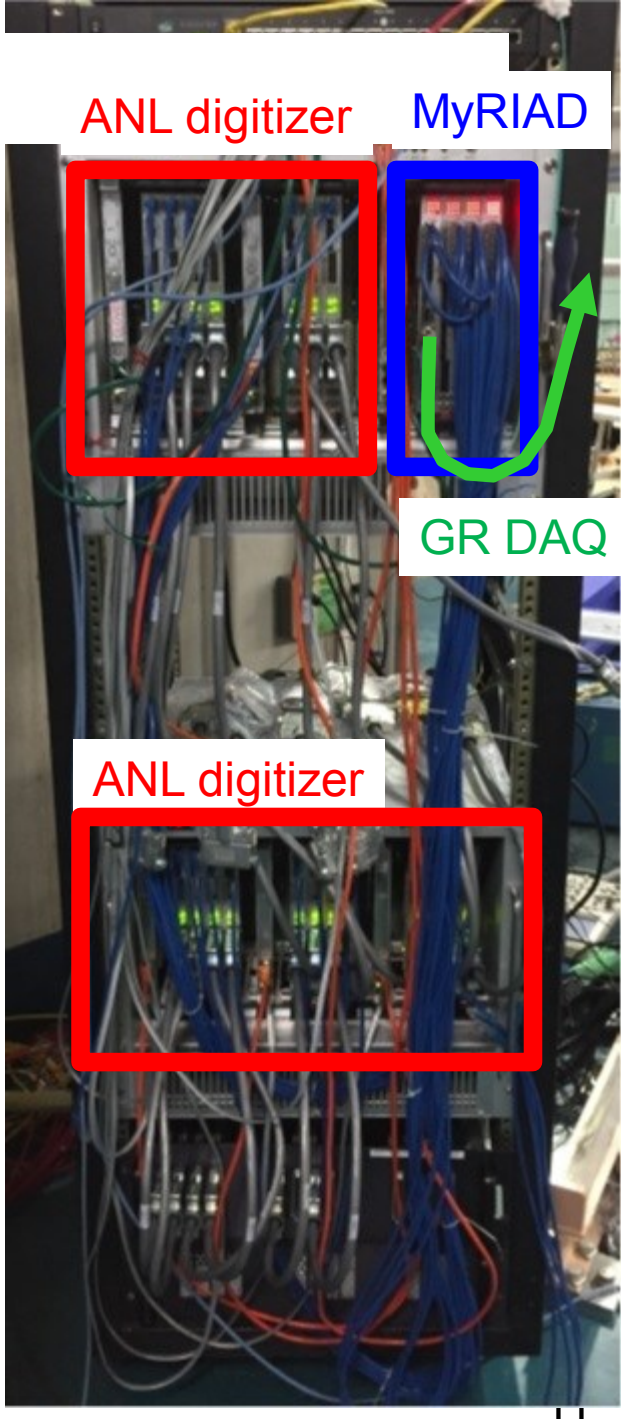
Data analysis is in progress at 5 institutes
Regular meeting is held every month

Technical things

- ✓ CAGRA data was taken by ANL digitizer
- ✓ Synchronization between CAGRA DAQ and GR DAQ by time stamp and trigger modules MyRIAD
- ✓ Liquid nitrogen filling → twice a day
  * Manual filling system for the south sphere
  * Auto filling system for the north sphere
- ✓ The neutron fluence ← ^{72}Ge(n,n') peak at 693.4 keV less than 4 x 10^9 neutrons/cm^2
- ✓ Annealing of clovers → twice during the campaign
- ✓ Count rate dependence of the energy calibration parameters

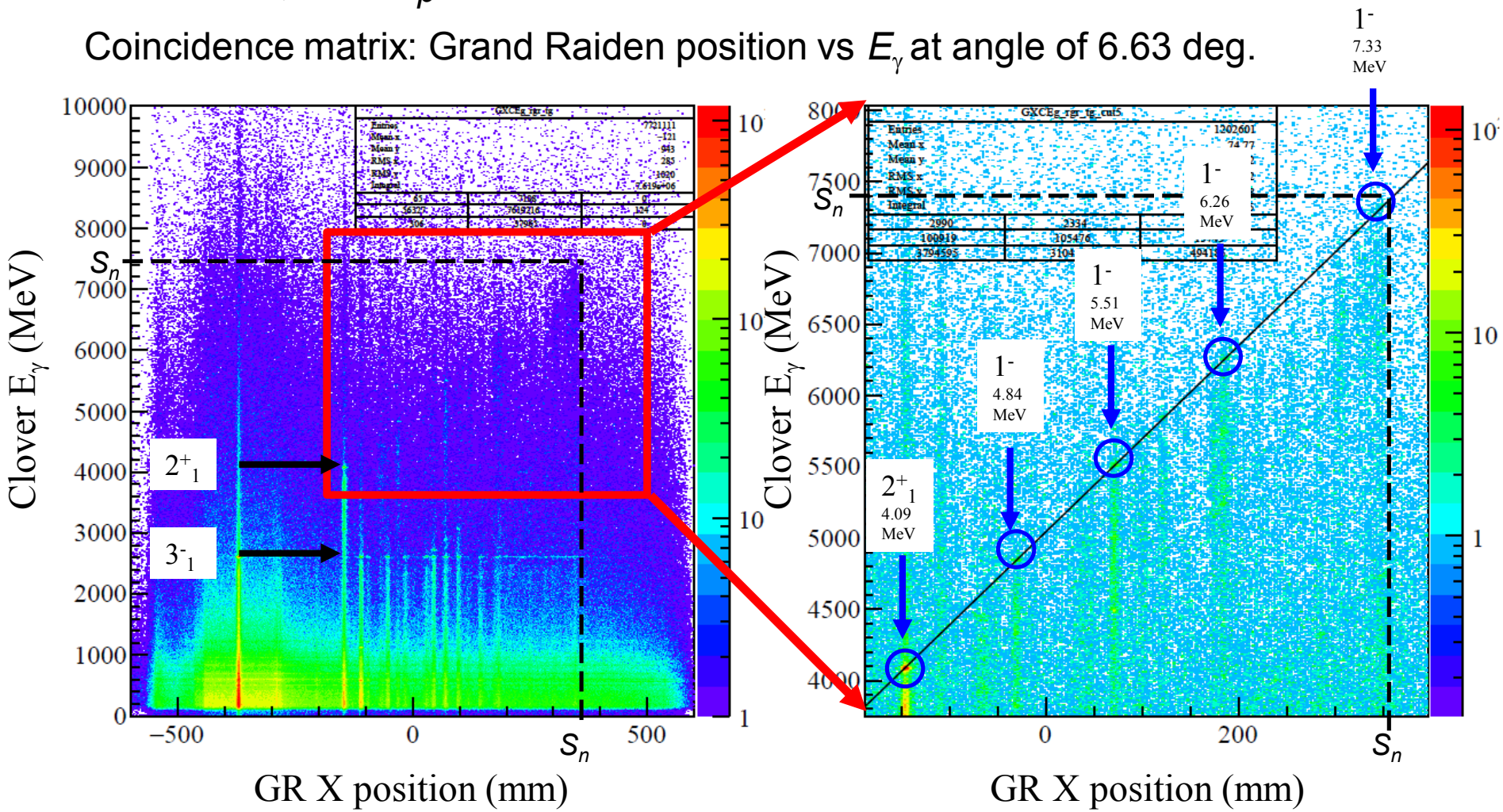
Ref. CAGRA+GR Collaboration, "CAGRA+GR Campaign Experiments", RCNP Annual Report 2016.

E. Ideguchi and M. Carpenter et al.,
a NIM paper in preparation



^{208}Pb(p, $p'\gamma$) at E_p = 80 MeV

Coincidence matrix: Grand Raiden position vs E_γ at angle of 6.63 deg.

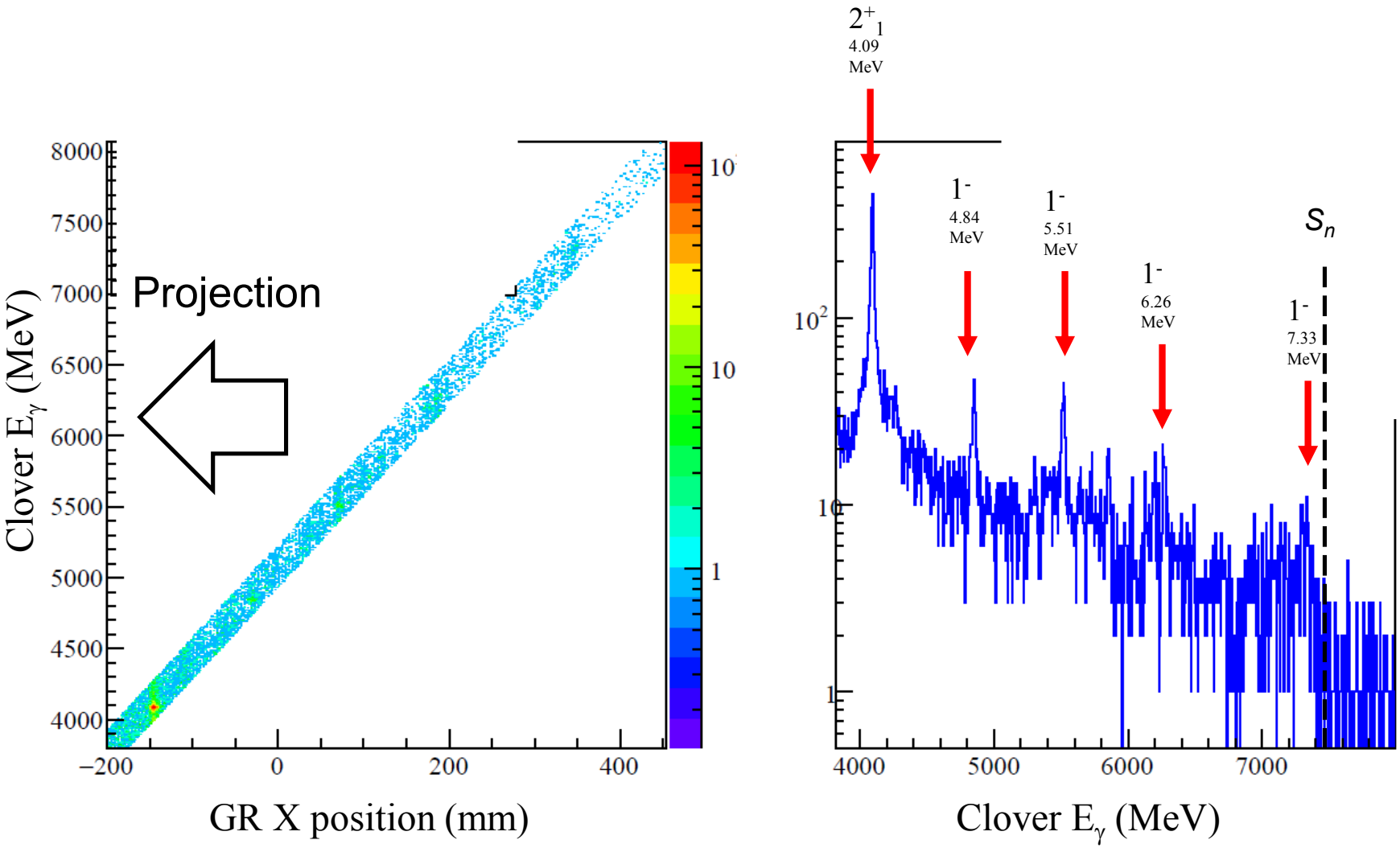


Direct decay to the g.s. is dominant in for 1^- states because level density is low and the energy of 2^+_1 state is relatively high (at 4.09MeV)

→ 1^- states are emphasized in the coincidence matrix

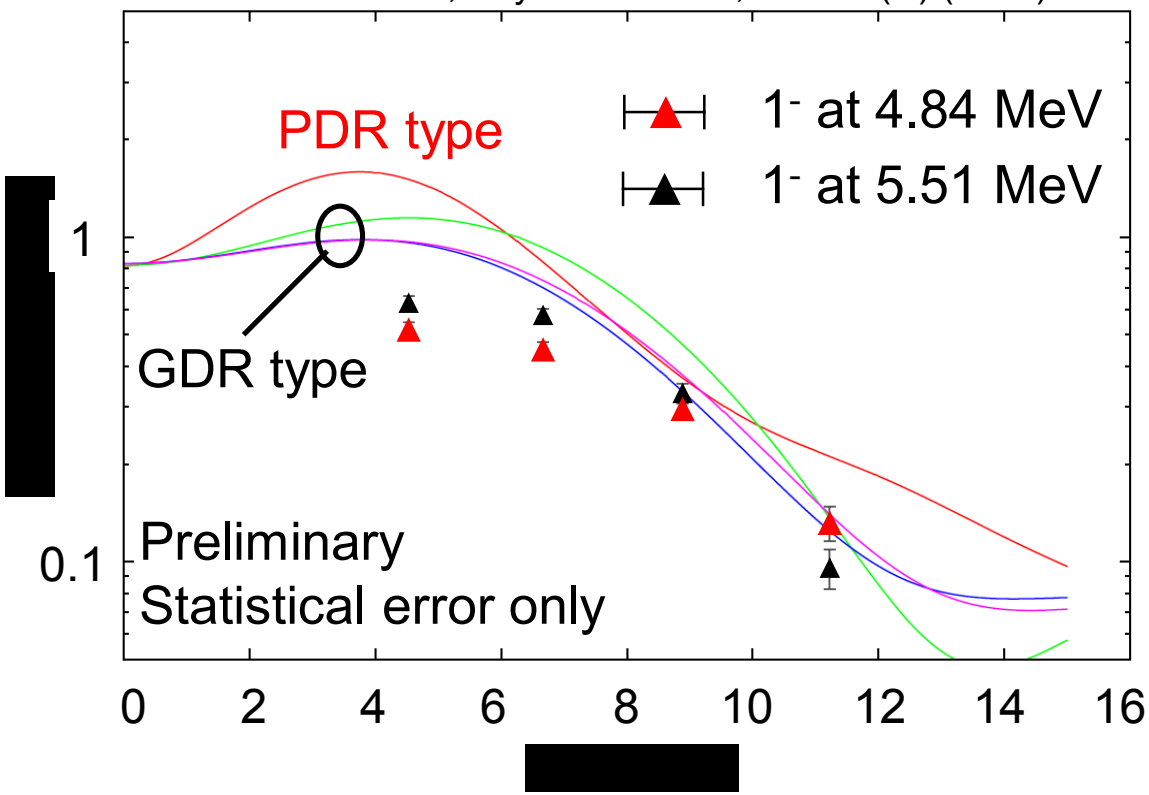
^{208}Pb(p, $p'\gamma$) at E_p = 80 MeV

Grand Raiden position vs E_γ at GR angle of 6.63 deg.



Angle differential cross section for ^{208}Pb(p, $p'\gamma$) at E_p = 80 MeV

DWBA Calculation by Quasi-particle Phonon Model
I. Poltoratska *et al*., Phys. Rev. C **85**, 041304(R) (2012).



Assumption:
γ-ray efficiency: 1%
Acceptance of GR: 2.4 msr
(In fact, full acc.)

- Dominated by GDR-type transition in 5.51-MeV and 4.84-MeV states?
- How about other 1^- stats at 6.26- and 7.33 MeV?
  → Systematic study for all 1^- states
- Interpretation of the data?

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A lot of papers will be published (soon)

Future work

- Rate dependence of energy-calibration parameters
- Background reduction & subtraction
- $LaBr_3$ data?

CAGRA+GR Campaign Exps. in Oct-Dec 2016

Participants from abroad

Mike Carpenter	ANL
Agnieszka Czeszumska	Berkley
Dimiter Balabanski	ELI-NP
Shumpei Noji	FRIB
Denis Savran	GSI
Maria Kmiecik	IFJ-PAN, Krakow
Mateusz Krzysiek	IFJ-PAN, Krakow
Michal Lukasz Ciemala	IFJ-PAN, Krakow
Adam Maj	IFJ-PAN, Krakow
Barbara Wasilewska	IFJ-PAN, Krakow
Sandrine Courtin	IPHC – CNRS, Strasbourg
Guillaume Fruet	IPHC – CNRS, Strasbourg
Daniele Montanari	IPHC – CNRS, Strasbourg
Simon Glynn Pickstone	Koeln
Mark Spieker	Koeln
Julius Wilhelmy	Koeln
Muhsin Harakeh	KVI
Nives Blasi	Univ. Milano, INFN
Angela Bracco	Univ. Milano, INFN
Franco Camera	Univ. Milano, INFN
Fabio Crespi	Univ. Milano, INFN
Oliver Wieland	Univ. Milano, INFN
Daniel Basin	NSCL
Juan Carlos Zamora Cardona	NSCL
Samuel Israel Lipschutz	NSCL
Jaclyn Marie Schmitt	NSCL
Chris Sullivan	NSCL
Rachel Charlotte Taverner Titus	NSCL
Remco Godfried Theo Zegers	NSCL
Carol Guess	Swarthmore College
Emily Hudson	Swarthmore College
Charles Kacir	Swarthmore College
Sergej Bassauer	TU-Darmstadt
Tobias Klaus	TU-Darmstadt
Peter von Neumann-Cosel	TU-Darmstadt
Gerhart Steinhilber	TU-Darmstadt
Volker Werner	TU-Darmstadt
Lindsay Donaldson	Univ. Witwatersrand
Adam Sebastian Brown	Univ. York
David Jenkins	Univ. York
Paul John Davies	Univ. York
Luke Morris	Univ. York
Shaofei Zhu	ANL

Participants from Japan

Nori Aoi	RCNP
Atsushi Tamii	RCNP
Eiji Ideguchi	RCNP
Yoshitaka Fujita	RCNP
Hirohiko Fujita	RCNP
Ong Hooi Jin	RCNP
Johann Isaak	RCNP
Nobuyuki Kobayashi	RCNP
Fang Yongde	RCNP
Kumar Raju	RCNP
Satoshi Adachi	RCNP
Azusa Inoue	RCNP
Tetsuya Yamamoto	RCNP
Yasutaka Yamamoto	RCNP
Hang Thi Ha	RCNP
Takeshi Koike	Tohoku Univ.
Yuni Watanabe	Tokyo Univ.
Chiriro Iwamoto	CNS

Contributors in commissioning experiments.

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Satoru Terashima	Beihang Univ.
Lei Yu	Beihang Univ.
Motonobu Takaki	CNS
Masatoshi Itoh	CYRIC
Takashi Hashimoto	IBS
Hiroyuki Fujioka	Kyoto Univ.
Takahiro Kawabata	Kyoto Univ.
Noritsugu Nakatsuka	Kyoto Univ.
Akane Sakaura	Kyoto Univ.
Yassid Ayyad	LBNL
Ou Iwa	Okayama Univ.
Makoto Sakuda	Okayama Univ.
Atsuko Odahara	Osaka Univ.
Shinnosuke Yoshida	Osaka Univ.
Phaik Ying Chan	RCNP
Guillaume Gey	RCNP
Gaku Isago	RCNP
Takeshi Ito	RCNP
Masaki Miura	RCNP
Hirotaka Suzuki	RCNP
Tomokazu Suzuki	RCNP
Mana Tanaka	RCNP
Hidetada Baba	RIKEN
Natsumi Ichige	Tohoku Univ.
Kenjiro Miki	Tohoku Univ.
Hirokazu Tamura	Tohoku Univ.
Tomoyuki Ozaki	Tokyo Inst. Tech.
Yasuhiro Togano	Tokyo Inst. Tech.

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Keiichi Nagayama	RCNP
Michio Uraki	RCNP

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Thank you