原子核の電気双極応答の測定による対称エネルギーの研究

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研究目的

原子核の飽和密度付近の対称エネルギーを調べる。
密度依存性

↓ 方法

重い安定原子核の陽子・中性子密度分布差に敏感な観測量を測定する。

↓ 実験

原子核の電気双極応答を精密測定する。
電気双極分極率、巨大双極共鳴、ピグミー双極共鳴

↓ 解析

自己無撞着平均場計算を通して、
対称エネルギーの値を引き出す。

N>~Z

$\rho \sim \rho_0$

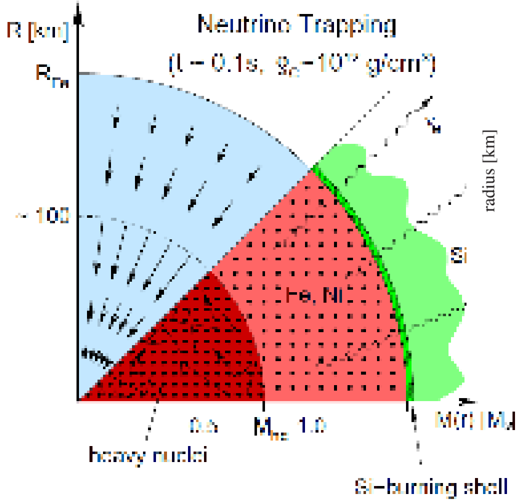
T=0

N_Y=0

→ 議論の出発点

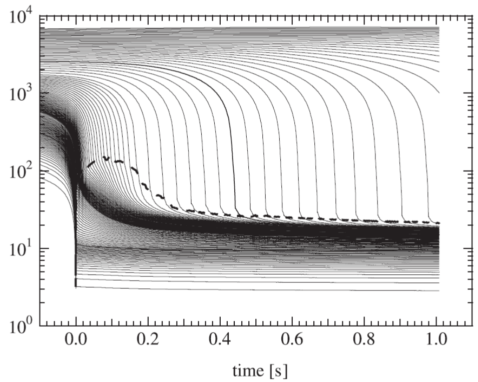
Determination of the Symmetry Energy Term in EOS.

Core-Collapse Supernova



Langanke and Martinez-Pinedo

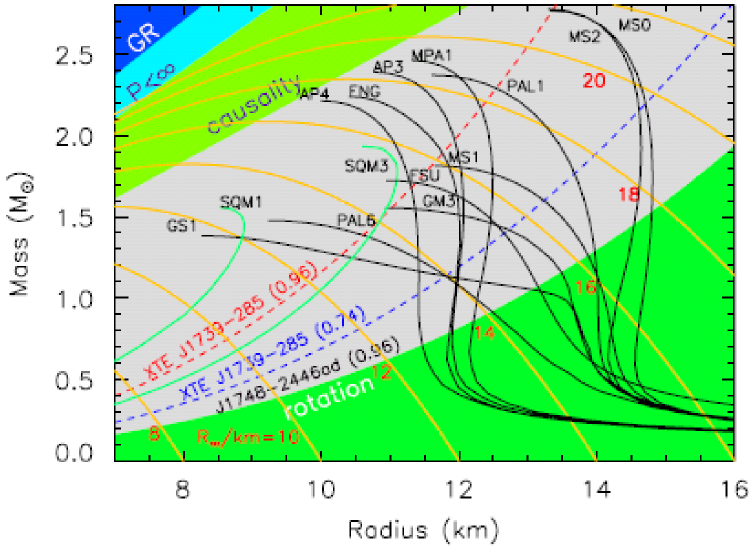
K. Sumiyoshi, Astrophys. J. 629, 922 (2005)



Nucleosynthesis

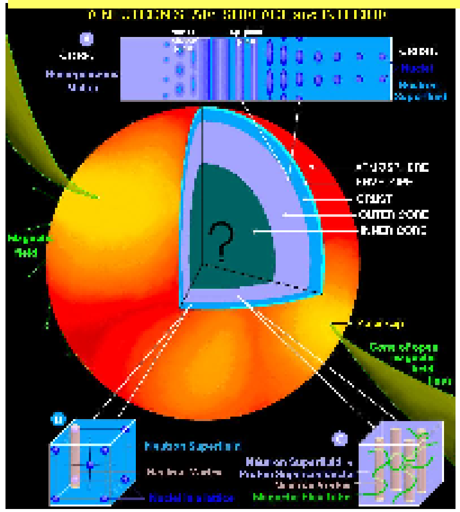
Neutron Star Cooling

Neutron Star Mass and Radius



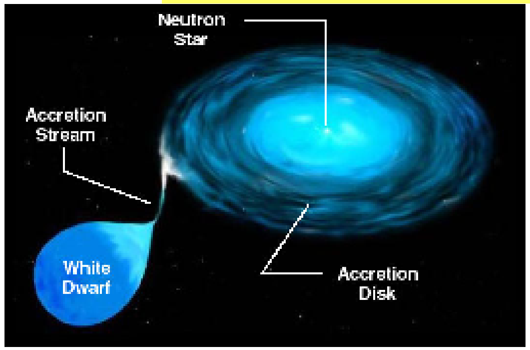
Lattimer et al., Phys. Rep. 442, 109(2007)

Neutron Star Structure



http://www.astro.umd.edu/~miller/nstar.html

Accreting neutron star/white dwarf, X-Ray burst, Superburst



Nuclear Equation of State (EOS)

EOS for Energy per nucleon

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

$$\rho(r)=\rho_n(r)+\rho_p(r)$$

$$\delta(r)=\frac{\rho_n(r)-\rho_p(r)}{\rho_n(r)+\rho_p(r)}$$

Symmetry energy

Saturation Density
~0.16 fm^{-3}
ρ_0 :

$$S(\rho)=J+\frac{L}{3\rho_0}(\rho-\rho_0)+\frac{K_{sym}}{18\rho_0^2}(\rho-\rho_0)^2+\ldots$$

$$L\propto P\propto R^4_{\mathrm{n-star}}$$

(Baryonic Pressure)

Nuclear Equation of State (EOS)

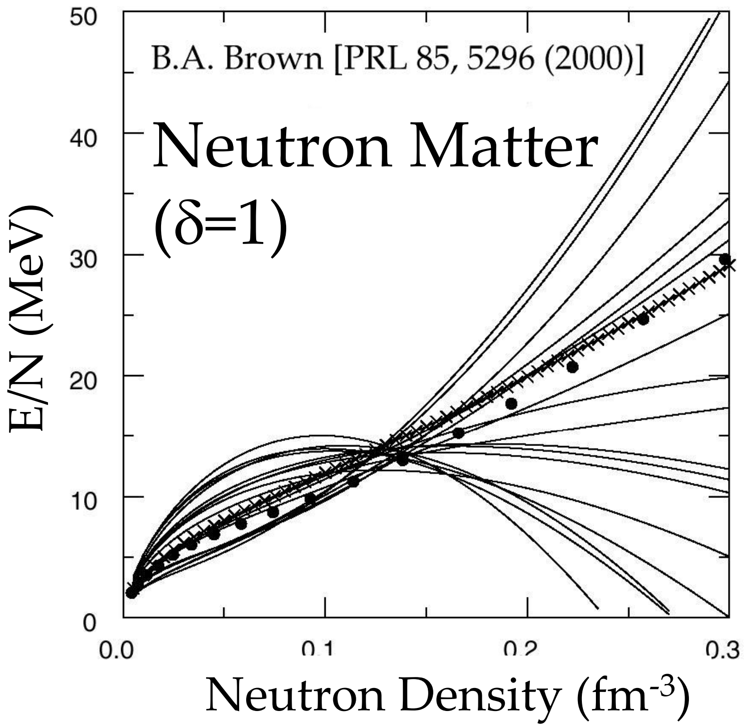
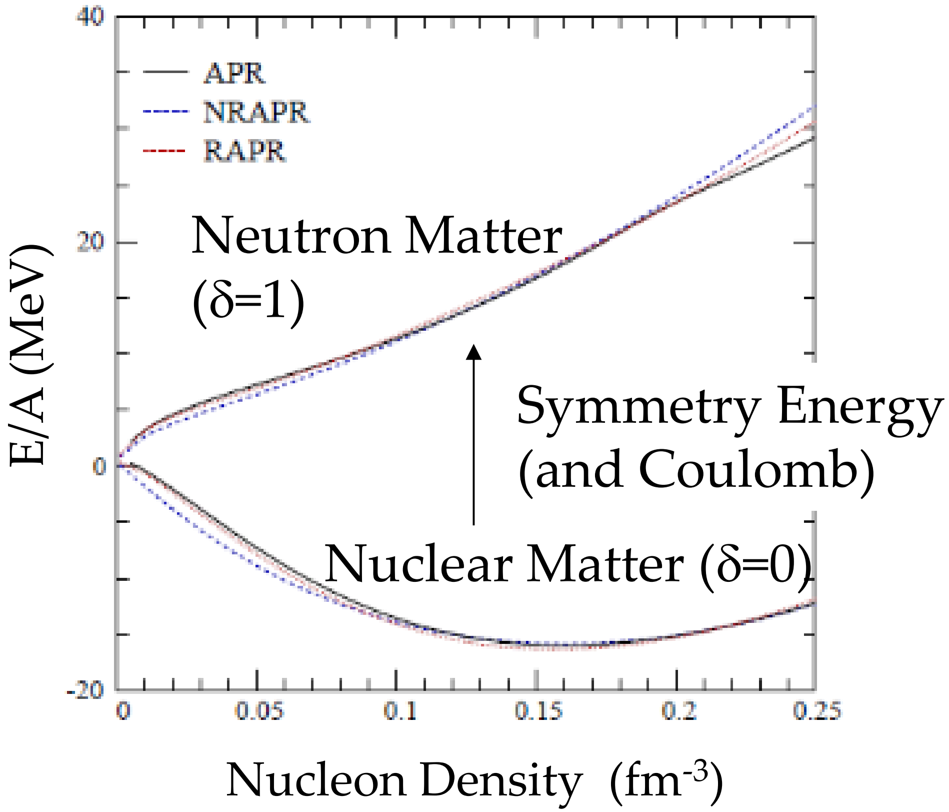


FIG. 2. The neutron EOS for 18 Skyrme parameter sets. The filled circles are the Friedman-Pandharipande (FP) variational calculations and the crosses are SkX. The neutron density is in units of neutron/fm^3.



Steiner et al., Phys. Rep. 411 325(2005)

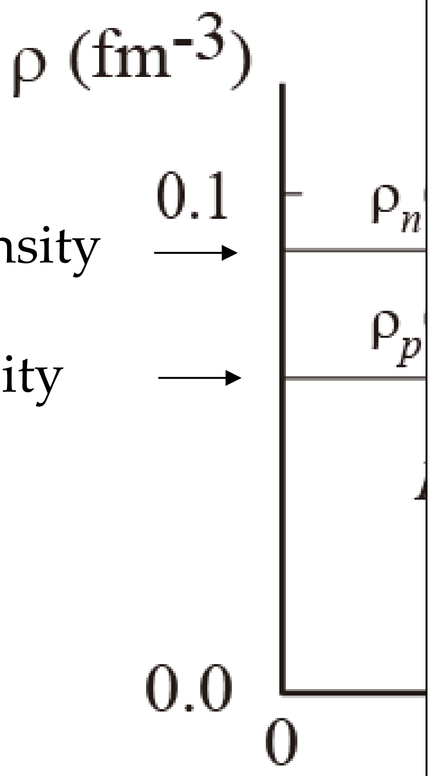
Prediction of the neutron matter EOS is much model dependent.

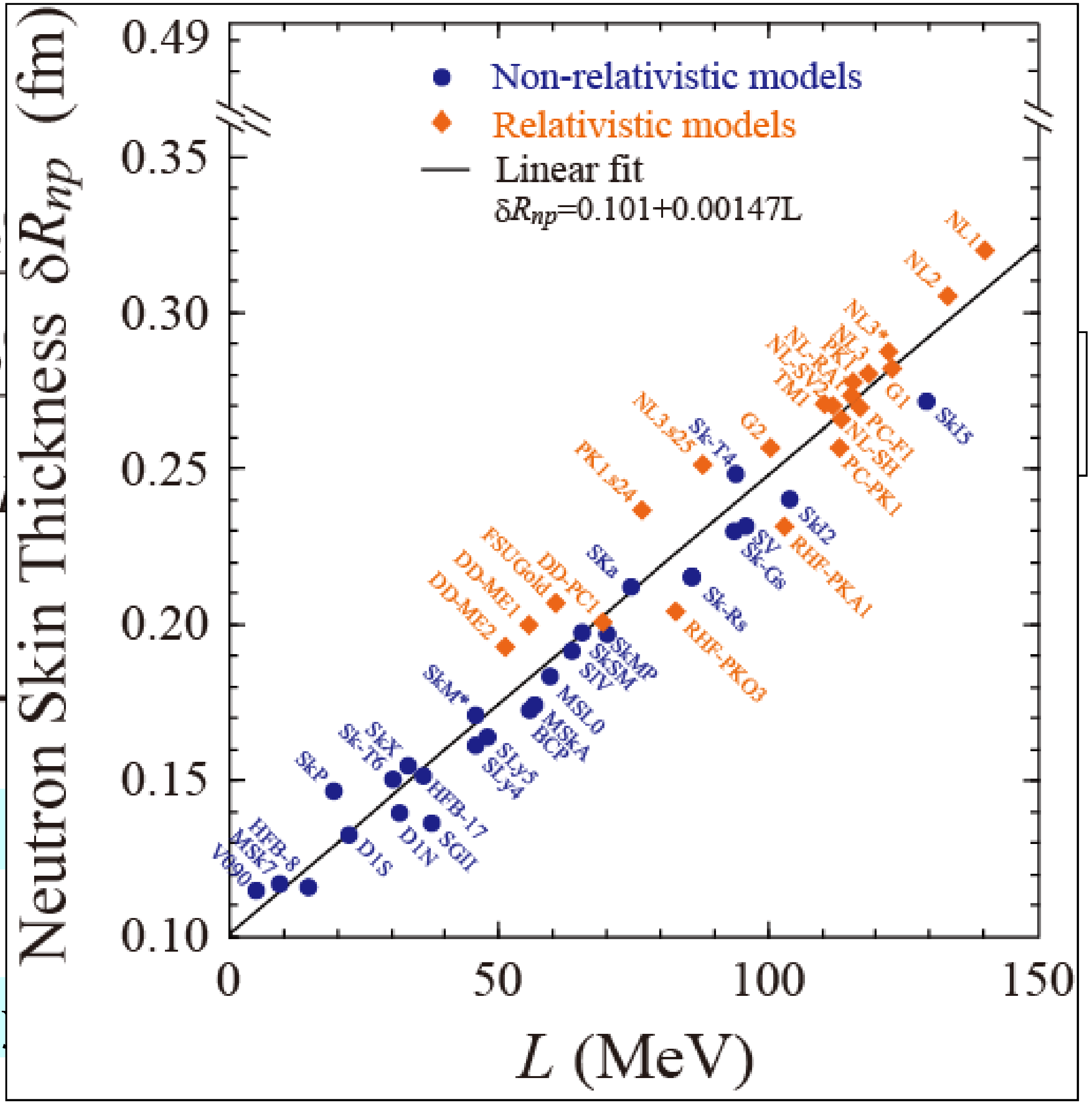
Proton-neutron density distributions and the density dependence of the symmetry energy

X. Roca-Maza *et al.*, PRL**106**, 252501 (2011)

Neutron density →

Proton density →

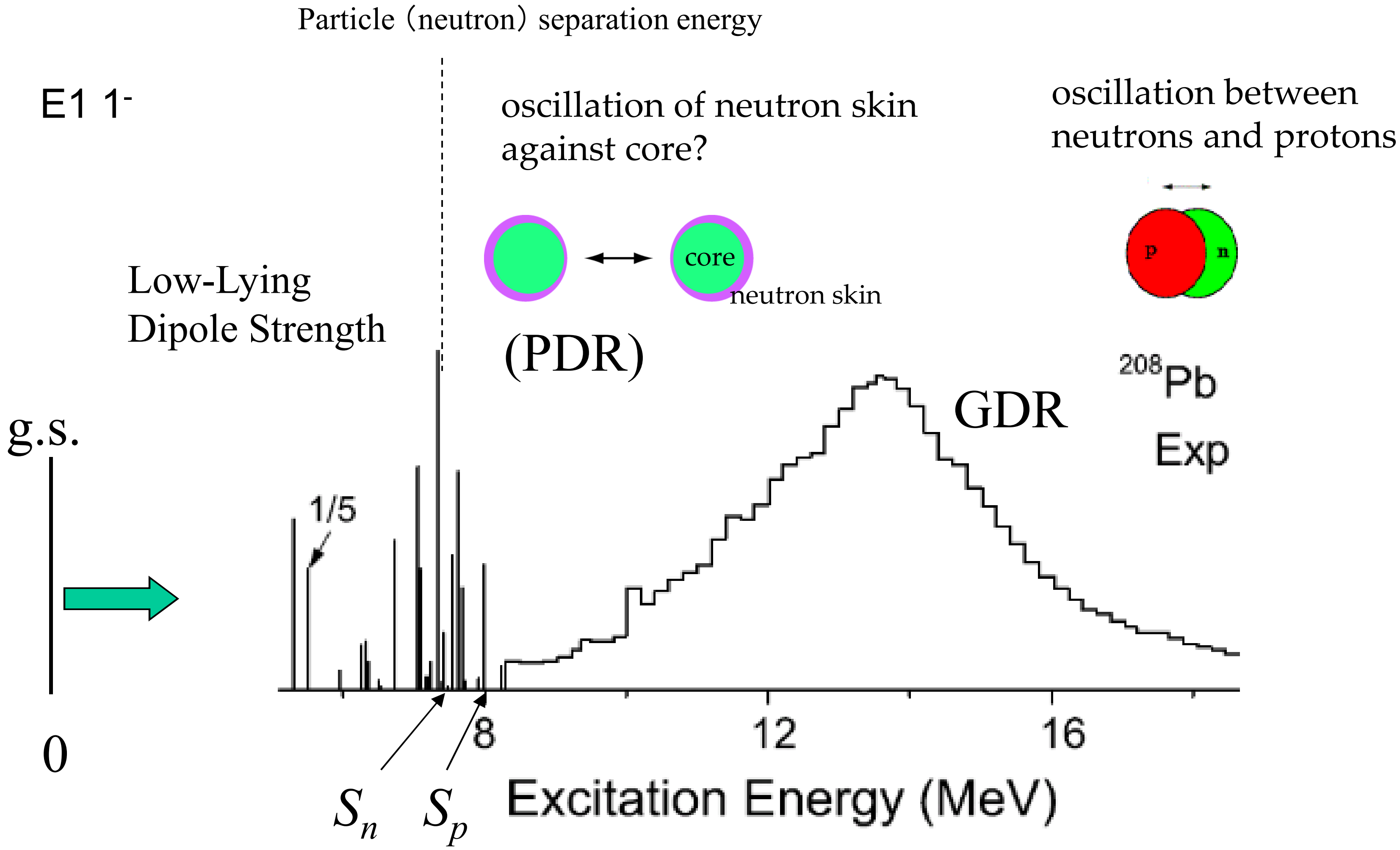




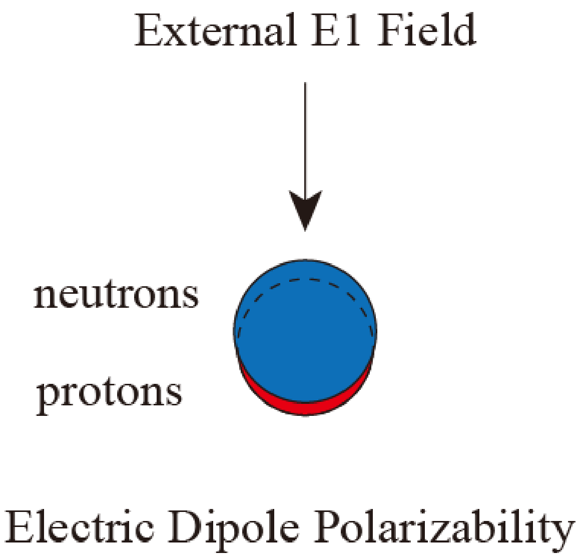
Neutron skin thickness

Density dependence of the s

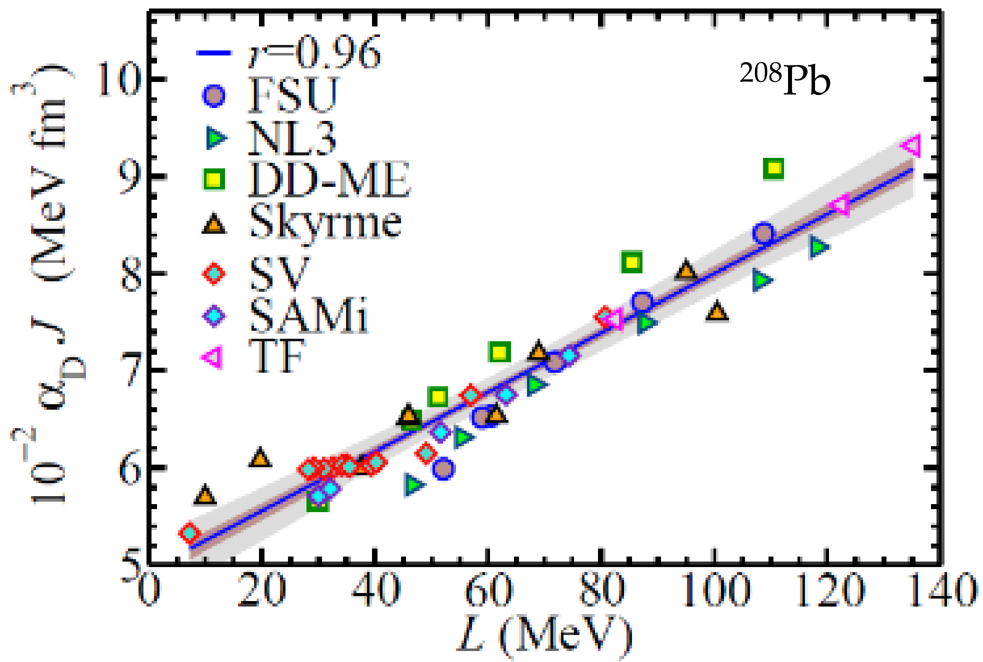
Electric Dipole (E1) Response



(Electric) Dipole Polarizability



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

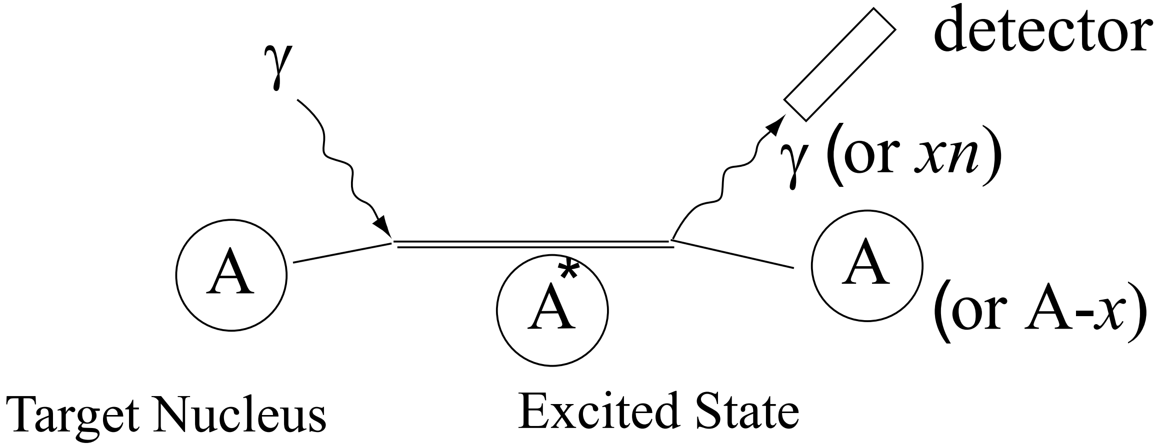


Inversely energy weighted sum-rule of B(E1)

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

Probing EM response of the target nucleus

○ **Real Photon Measurements, NRF and (γ,xn)**

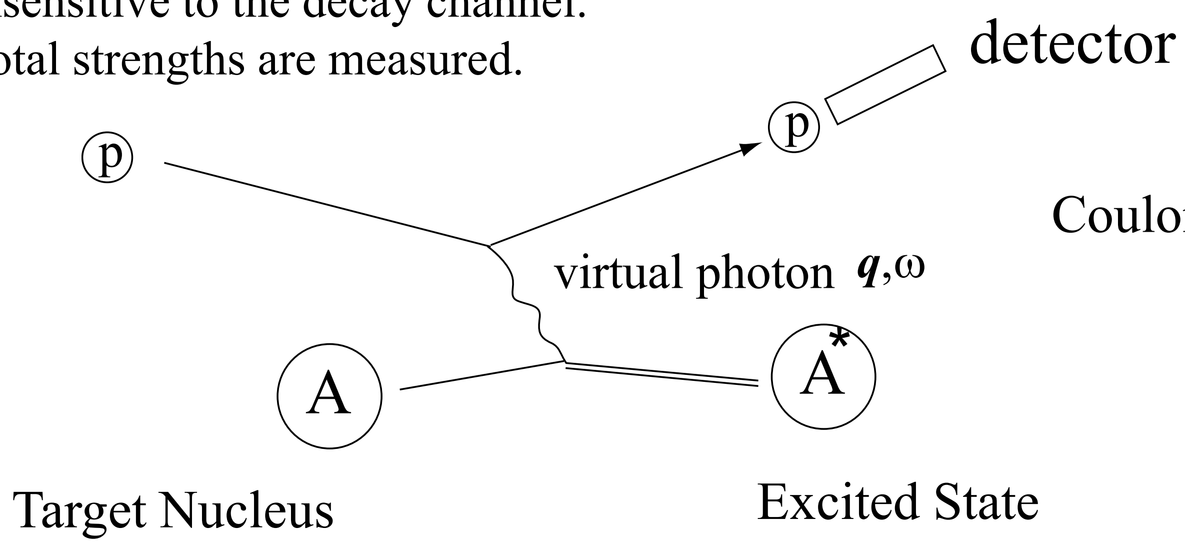


Decay γ-rays or neutrons are measured.

○ **Missing Mass Spectroscopy with Virtual Photon**

Only the scattered protons are measured.

Insensitive to the decay channel.
Total strengths are measured.

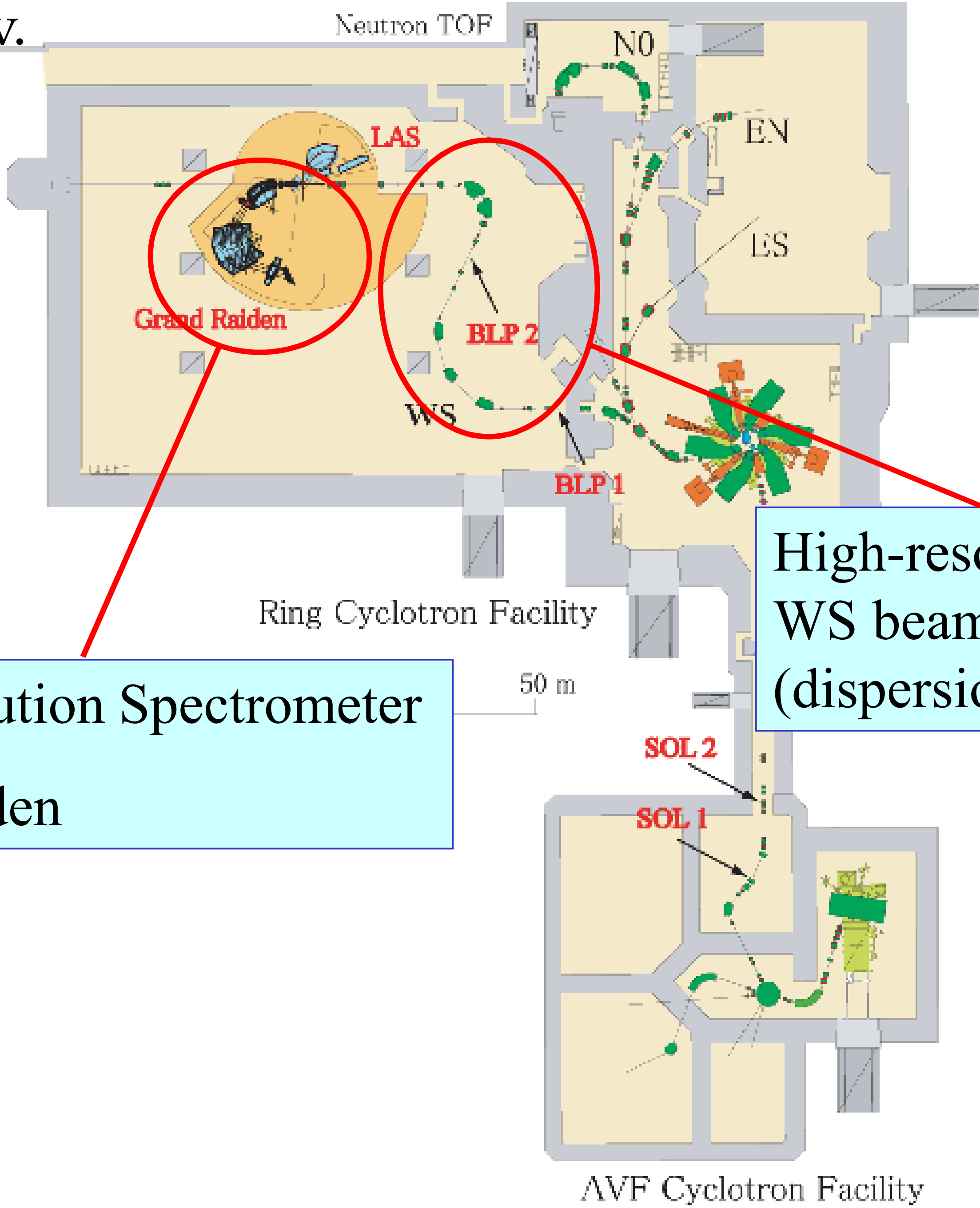


Select low momentum transfer (q~0) kinematical condition, i.e. at zero degrees

Coulomb Excitation at 0 deg.

EM Interaction is well known (model independent)

Research Center for Nuclear Physics, Osaka Univ.



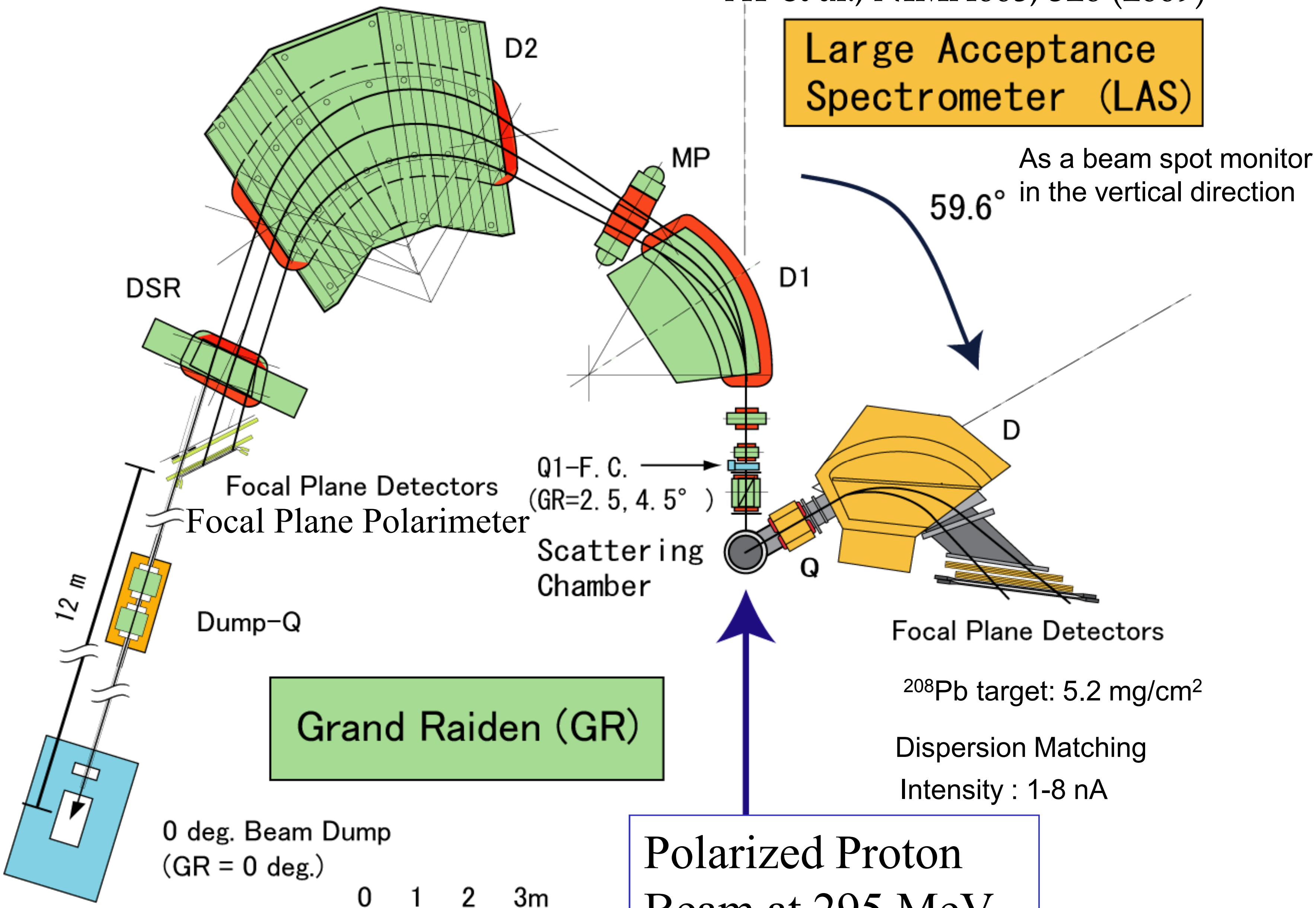
High-resolution Spectrometer

Grand Raiden

High-resolution
WS beam-line
(dispersion matching)

Spectrometers in the 0-deg. experiment setup

AT et al., NIMA605, 326 (2009)



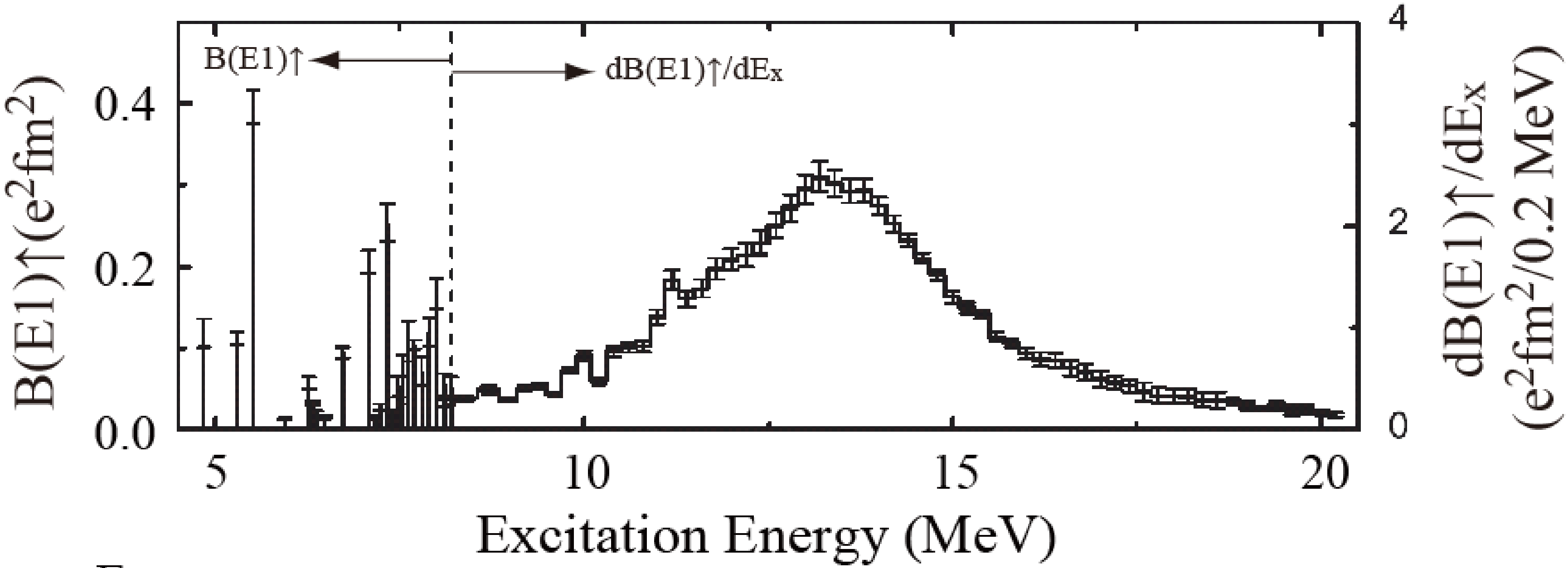
^{208}Pb target: 5.2 mg/cm^2

Dispersion Matching

Intensity : 1-8 nA

Polarized Proton Beam at 295 MeV

E1 Response of ^{208}Pb and α_D



E_x 0 — 10 — 20 — 130 MeV

α_D 2.7 | 16.2 | 1.2 fm^3

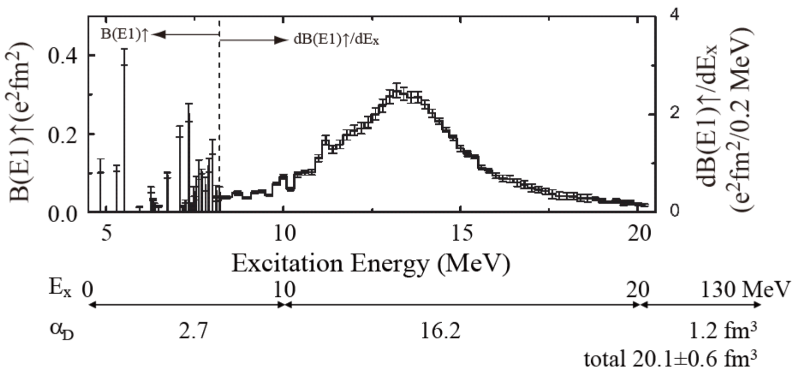
total 20.1±0.6 fm^3

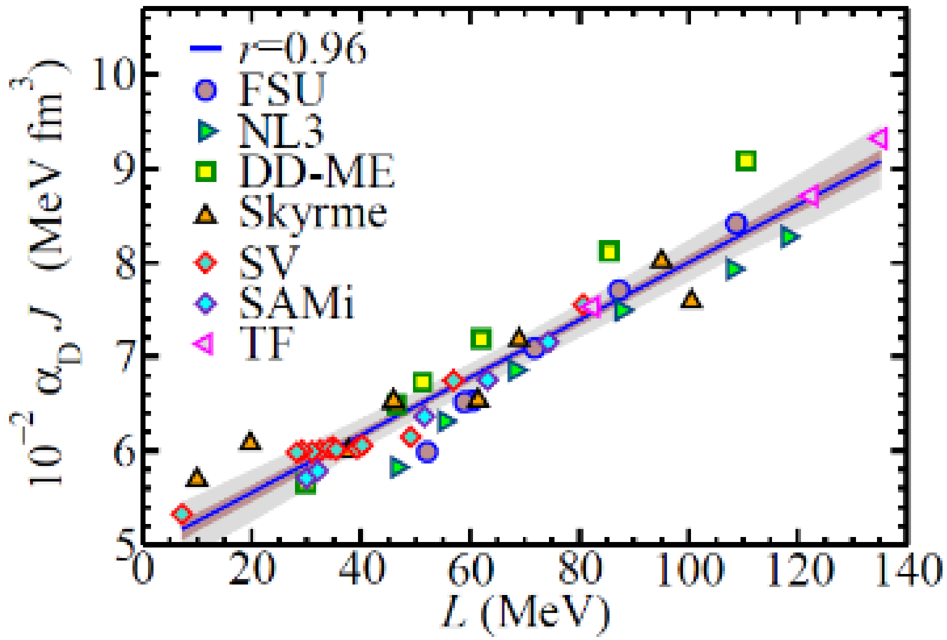
combined data

The dipole polarizability of ^{208}Pb has been precisely determined.

AT et al., PRL107, 062502(2011)

X. Roca-Maza et al., arXiv:1307.4806



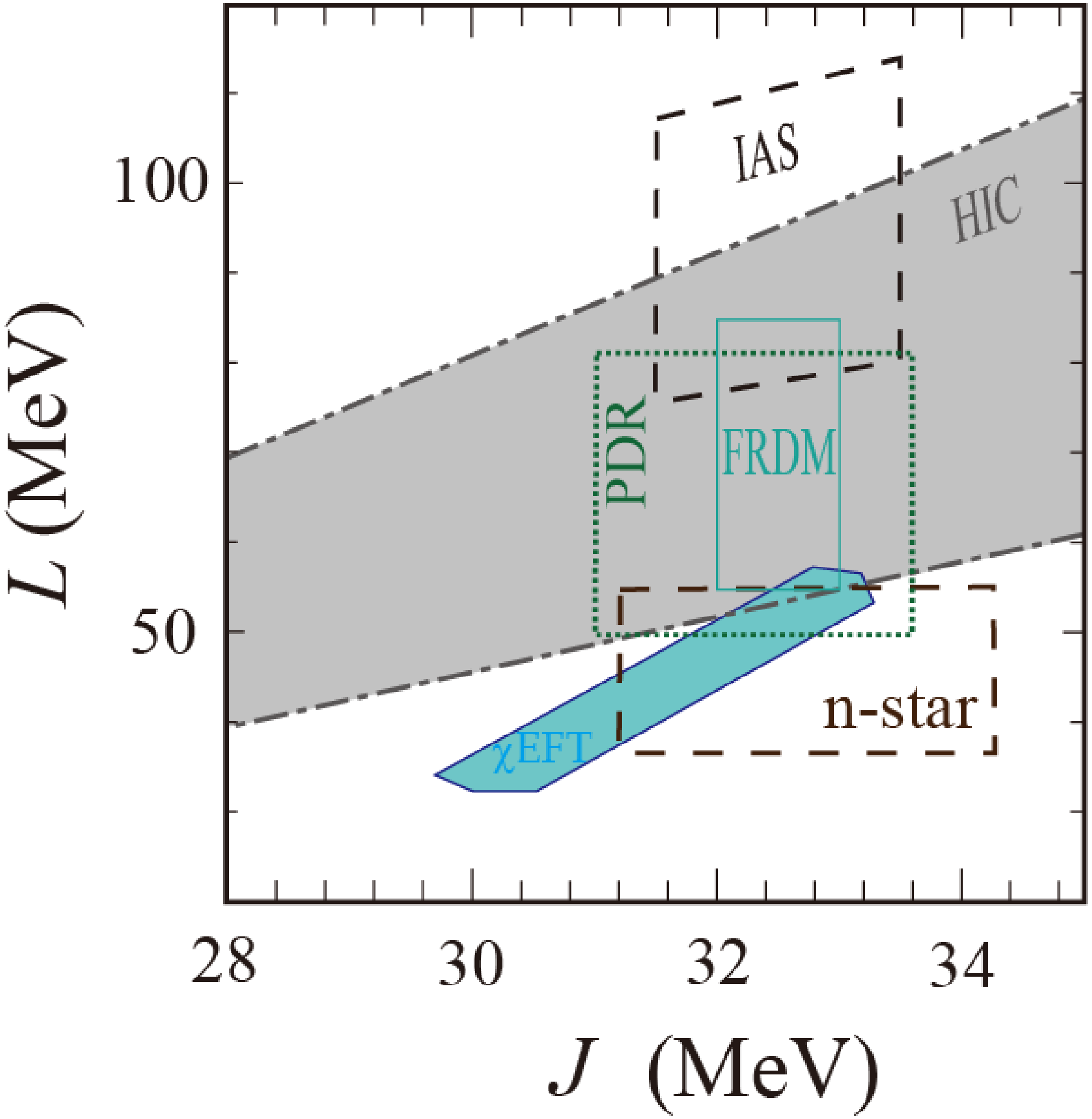


$$10^{-2}\alpha_D J = (4.94 \pm 0.09) + (0.031 \pm 0.001)L$$

$\alpha_D J$ is a strong isovector indicator.

Insights from the droplet model $\alpha_D^{\rm DM} \approx \frac{\pi e^2}{54}\frac{A\langle r^2\rangle}{J}\left[1 + \frac{5}{3}\frac{L}{J}\epsilon_A\right]$

Constraints on J and L

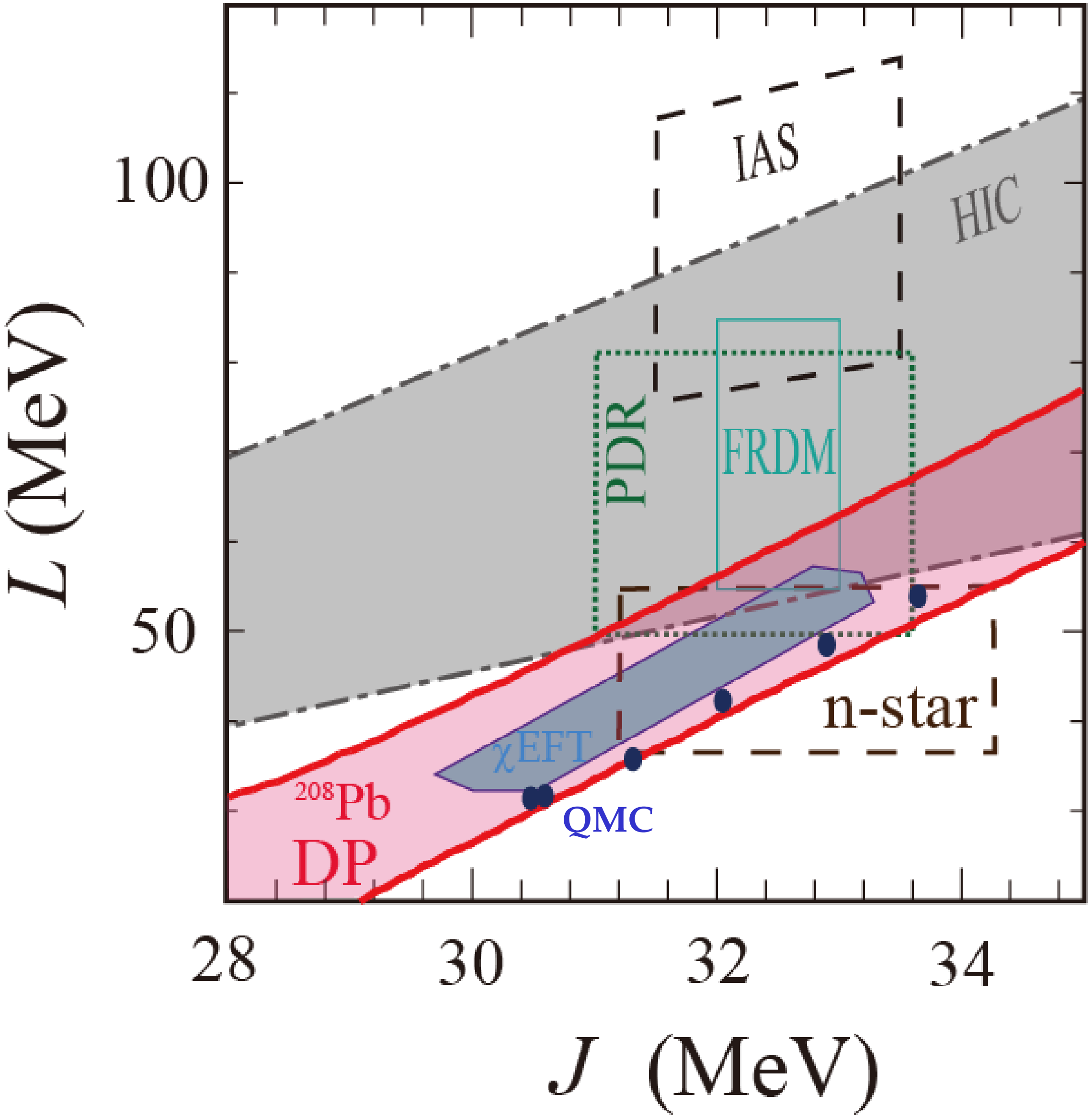


M.B. Tsang *et al.*, PRC**86**, 015803 (2012).

I. Tews et al., PRL110, 032504 (2013)

DP: Dipole Polarizability
HIC: Heavy Ion Collision
PDR: Pygmy Dipole Resonance
IAS: Isobaric Analogue State
FRDM: Finite Range Droplet Model (nuclear mass analysis)
n-star: Neutron Star Observation
χEFT: Chiral Effective Field Theory

Constraints on J and L



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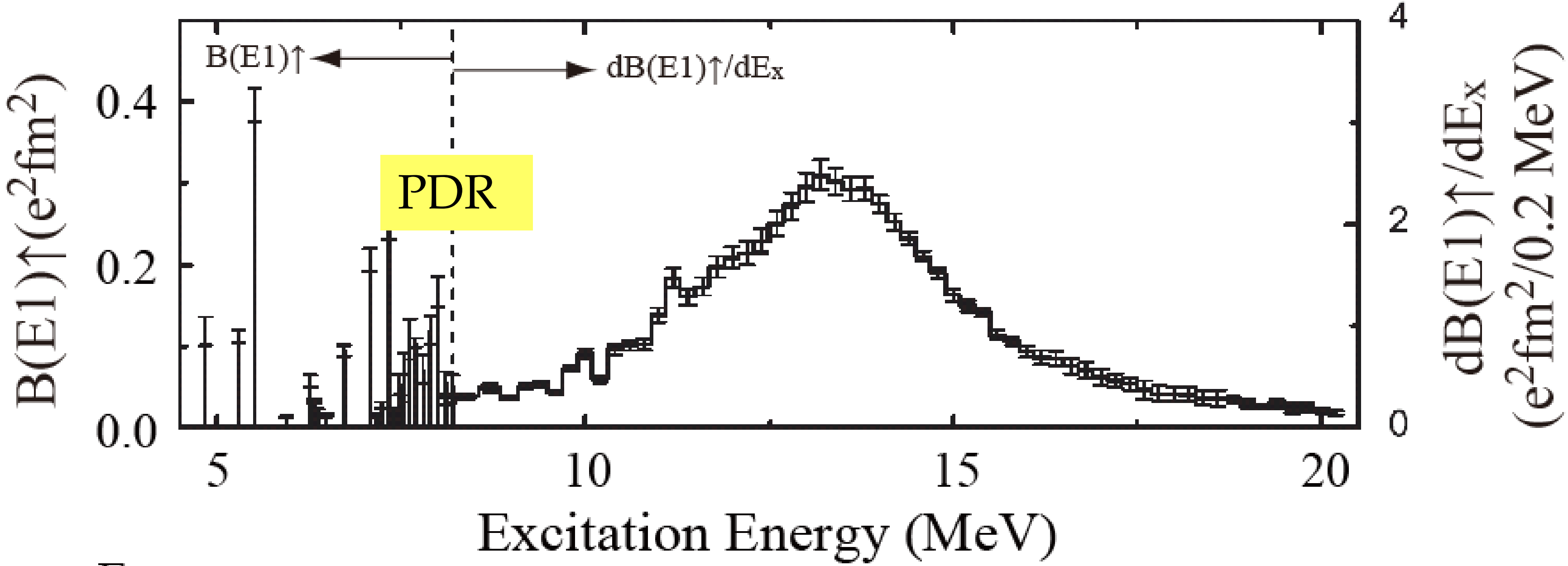
QMC by S. Gandolfi et al

PDR strength

E1 Response of ^{208}Pb and α_D



E_x 0 — 10 — 20 — 130 MeV

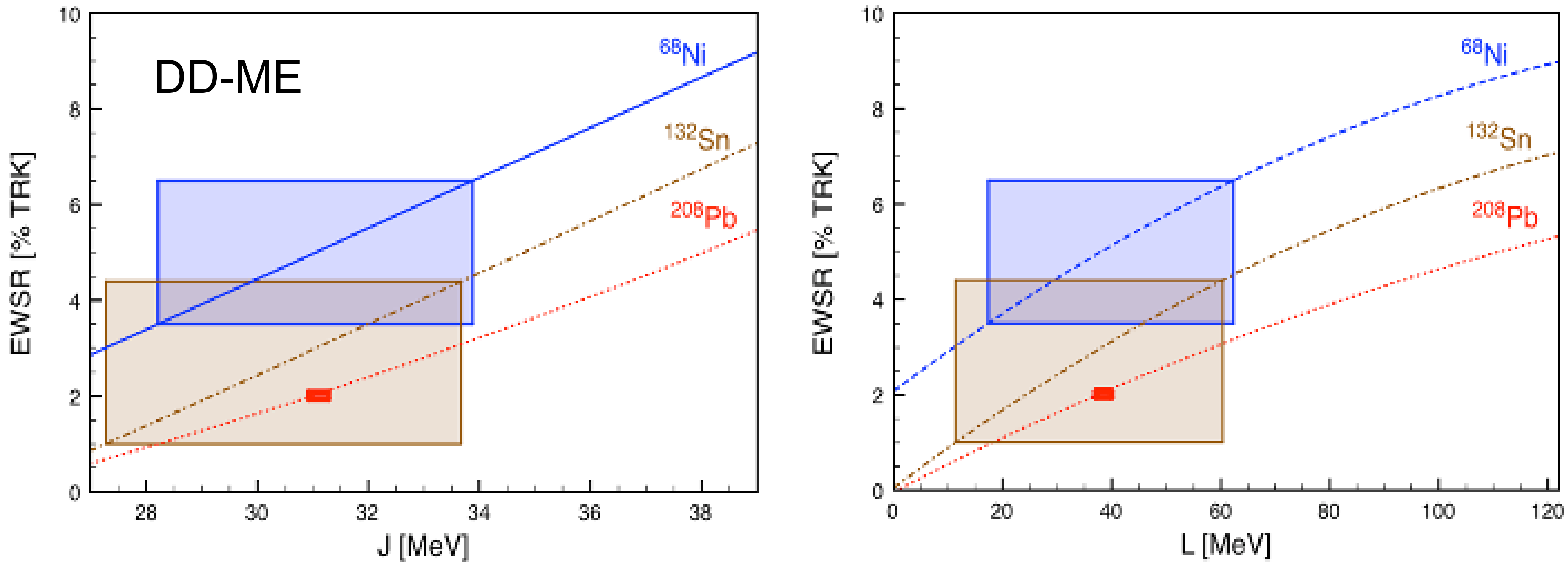
α_D 2.7 | 16.2 | 1.2 fm³

total 20.1±0.6 fm³

combined data

AT et al., PRL107, 062502(2011)

• Theoretical dependences of pygmy EWSR on J and L are determined using relativistic energy density functionals spanning the range of J and L values. Available experimental data provide constraints on theoretical models.

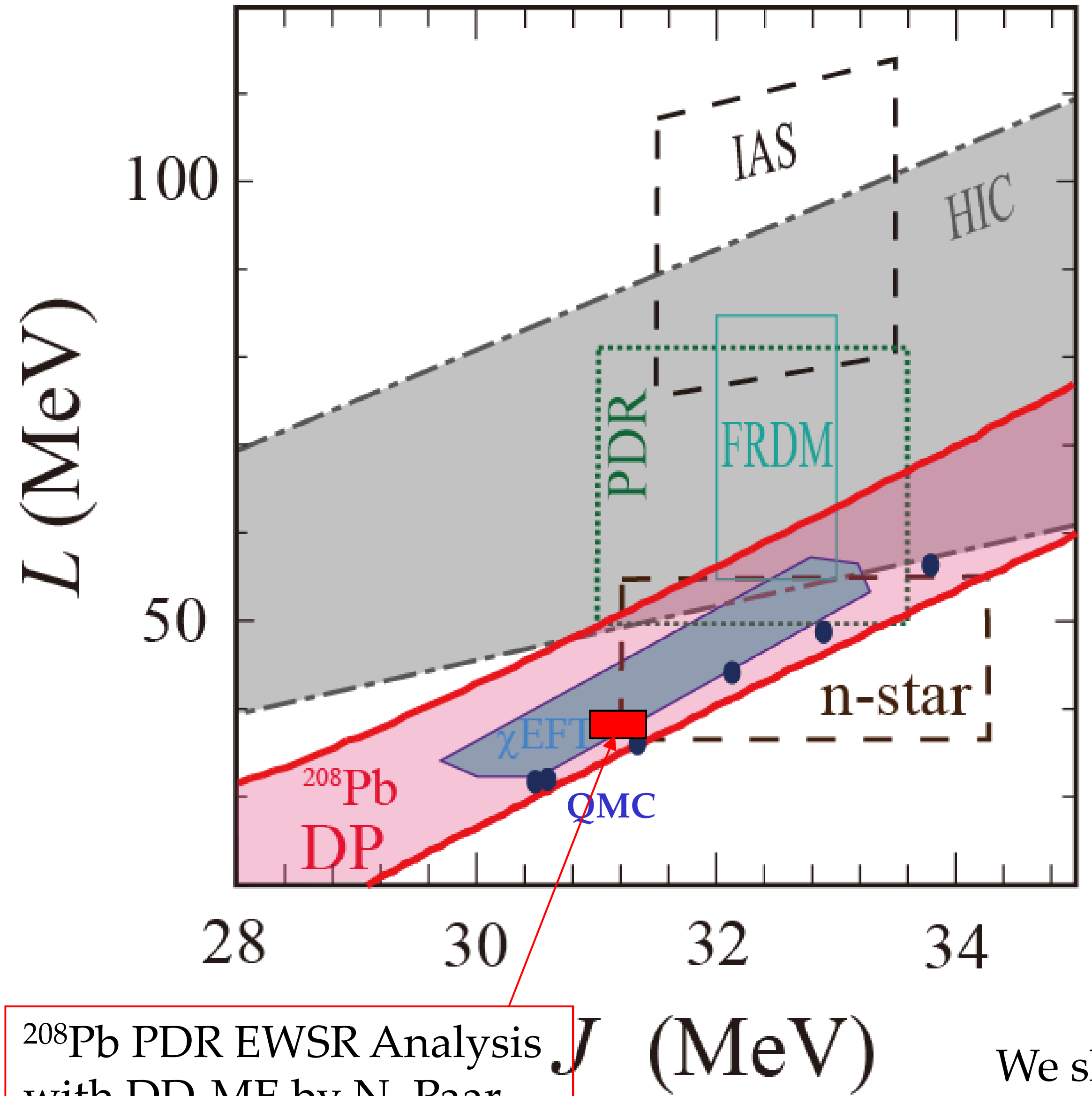


Similar approach but different theory ➔ A. Carbone et al, PRC 81, 041301(R) (2010)

Exp. Data: ^{68}Ni : O. Wieland et al, PRL 102, 092502 (2009)
^{132,130}Sn: A. Klimkiewicz et al., PRC 76, 051603 (R) (2007)
^{208}Pb: I. Poltoratska et al., PRC 85, 041304 (R) (2012)

Courtesy of N. Paar

Determination of Symmetry Energy



208Pb PDR EWSR Analysis with DD-ME by N. Paar

M.B. Tsang *et al.*, PRC**86**, 015803 (2012).

I. Tews et al., PRL110, 032504 (2013)

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We should take care of the model uncertainty.

まとめと今後

- 重い安定核の電気双極励起強度の測定により、飽和密度付近での対称エネルギーの振舞いを調べている。

- ^{208}Pb以外の核についても同様の研究を進め、対称エネルギーに関する知見に矛盾がないか、自己無撞着平均場近似計算により原子核を統一的に記述できているかどうかを調べる。

- 原子核の性質をよりよく記述する理論モデル・有効相互作用を決める。

まとめと今後

- 着目している標的

  - Snアイソトープ(A=112-124)
  - Zr アイソトープ(A=90-96)

- 2013年8月のRCNP課題募集は開催されなかった。
  2014年2月の課題募集に申請し、2014年度のデータ取得、
  2015年度の結果提出をめざす。

- データ取得済みの核(DCS:微分散乱断面積、PT:偏極移行量)

^{96}Mo (DCS and PT): D. Martin
^{48}Ca (DCS): J. Birkhan（M1 data, submitted)
^{90}Zr (DCS): C. Iwamoto (PDR-region, published in PRL**108**, 262501 (2012))
^{120}Sn (DCS and PT): A.M. Krumbholtz, T. Hashimoto
^{154}Sm (DCS and PT): A. Krugmann
^{88}Sr, ^{92}Mo (DCS): C. Iwamoto
^{70}Zn (DCS):

Collaborators

RCNP-E282

RCNP, Osaka University

A. Tamii, H. Fujita, Y. Fujita, K. Hatanaka,
H. Sakaguchi Y. Tameshige and M. Yosoi

IKP, TU-Darmstadt

P. von Neumann-Cosel, A-M. Heilmann,
Y. Kalmykov, I. Poltoratska, V.Yu. Ponomarev,
A. Richter and J. Wambach

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T. Adachi and L.A. Popescu

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B. Rubio and A.B. Perez-Cerdan

Sch. of Science Univ. of Witwatersrand

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K. Nakanishi,
Y. Shimizu and Y. Sasamoto

CYRIC, Tohoku University

M. Itoh and Y. Sakemi

Dep. of Phys., Kyushu University

M. Dozono

Dep. of Phys., Niigata University

Y. Shimbara

Thank You