

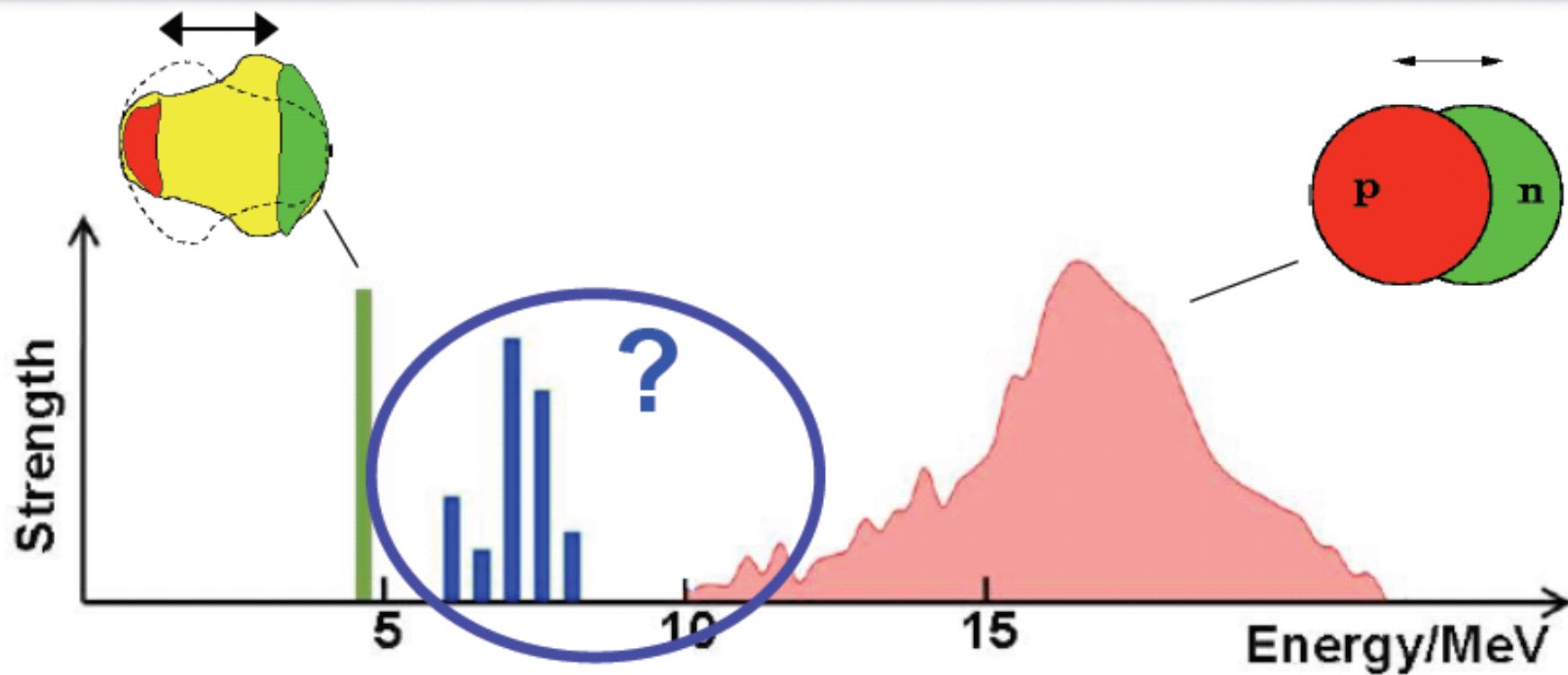
Splitting and Isospin Structure of Pygmy Dipole Resonances

References:

- J. Enders et al., PRC80, 034302(2009),
- N. Paar et al., PRL103, 032502(2009),
- D. Savran, RCNP Seminar, 2006.
- etc.

勉強会, A. Tamii, 2009.12.8

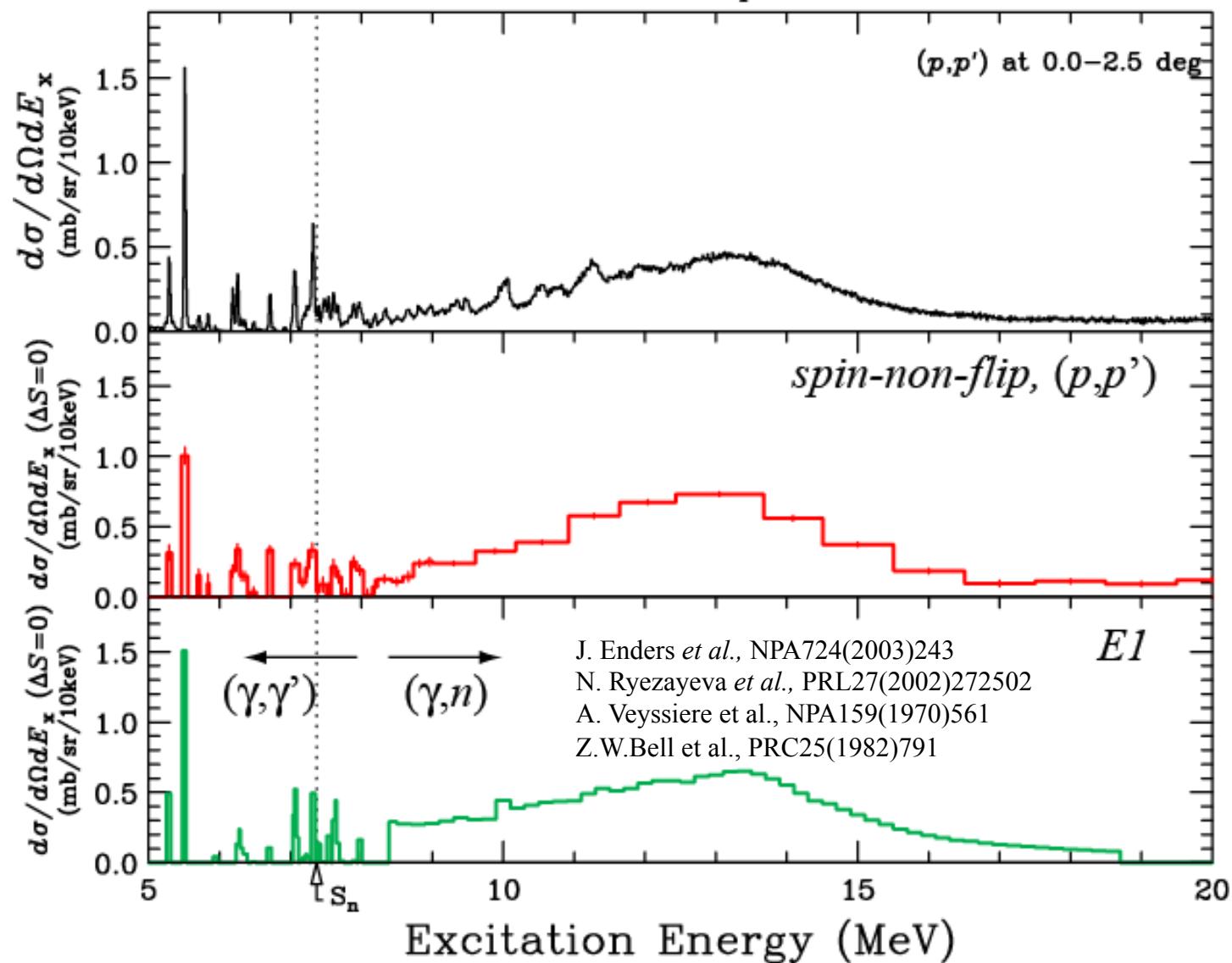
Electric dipole strength in (spherical) atomic nuclei

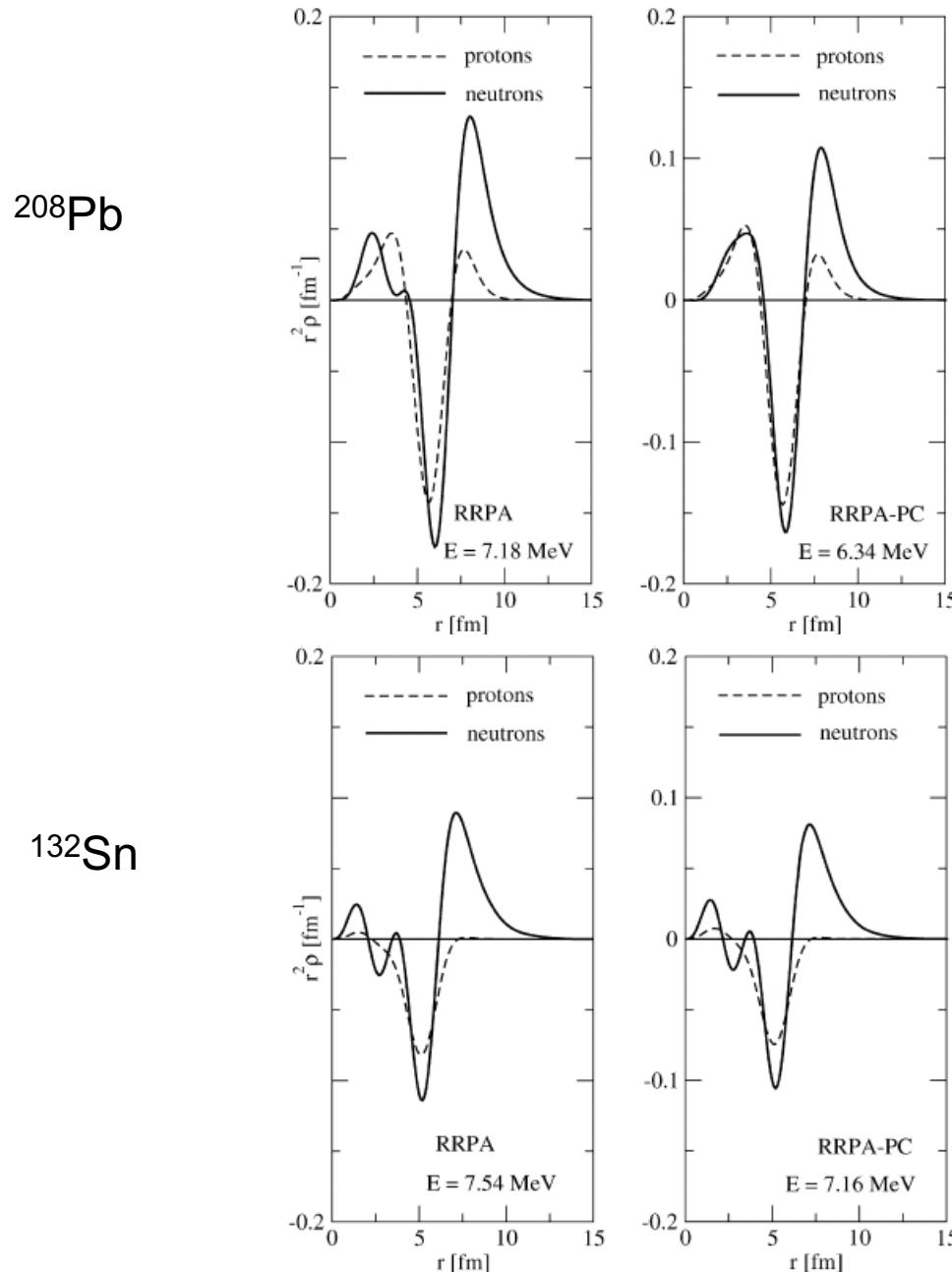


- Two-Phonon excitation ($2^+ \otimes 3^-$)
- Giant Dipole Resonance (GDR)
- Pygmy Dipole Resonance (PDR)

Preliminary

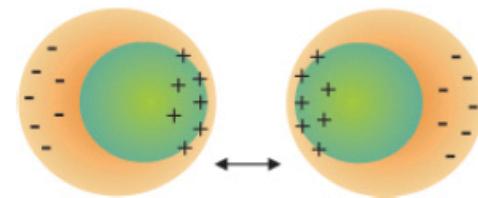
$^{208}\text{Pb}(p,p')$ at $E_p=295$ MeV





Relativistic RPA (RRPA)
Phonon Coupling (PC)

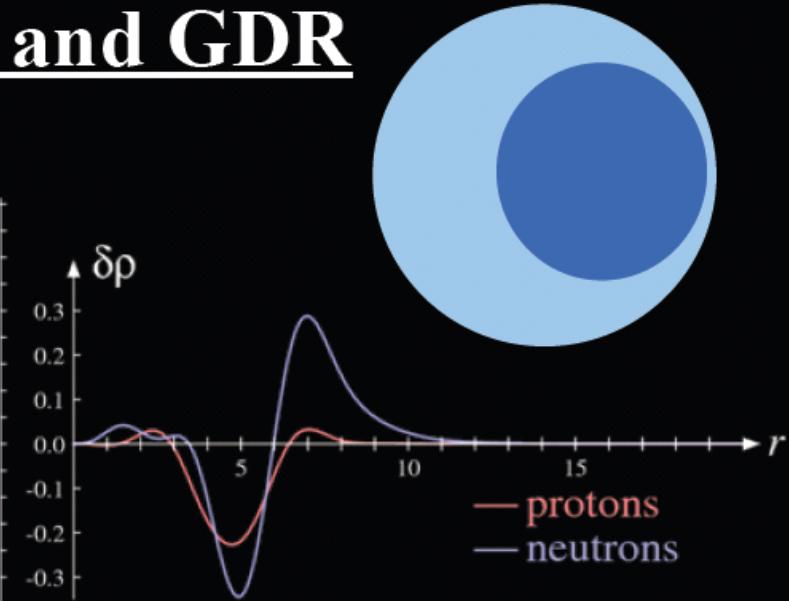
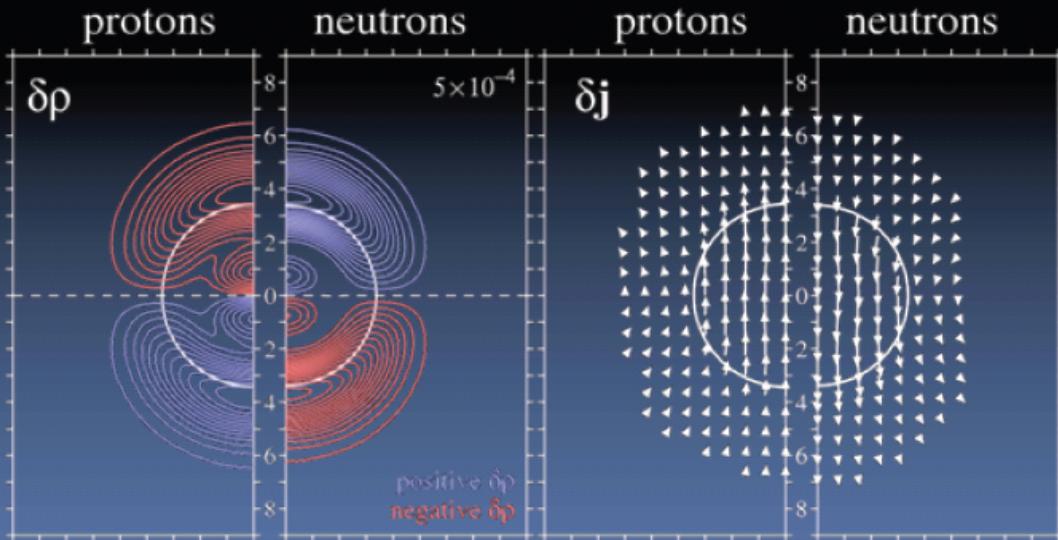
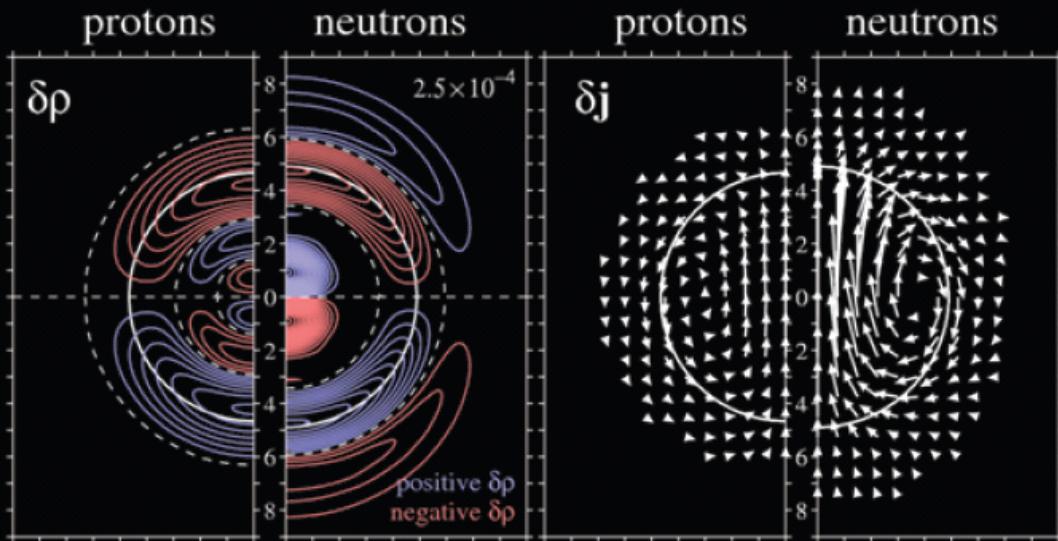
内部でp-nがin-phase (IS)、
表面でnが振動



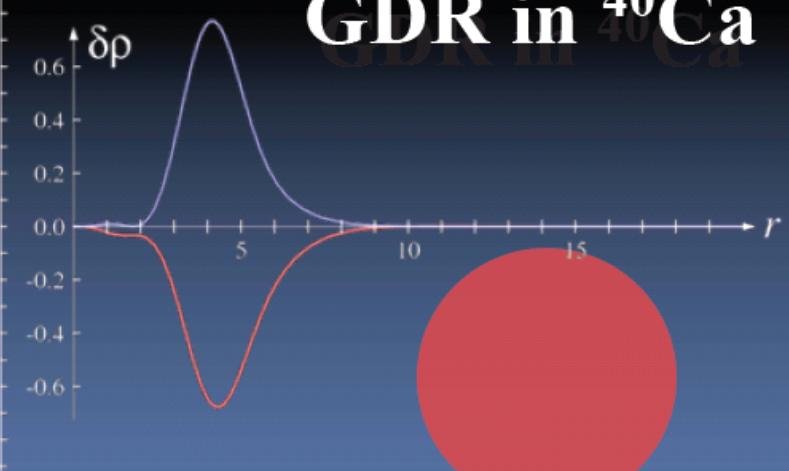
Isospin-Saturated Coreと
中性子(陽子)スキンのDipole振動

この描像では、ISとIVの線形
結合となるはず。

Transition density in PDR and GDR



PDR in ^{132}Sn
PDR in ^{132}Sn
GDR in ^{40}Ca



Abstracts

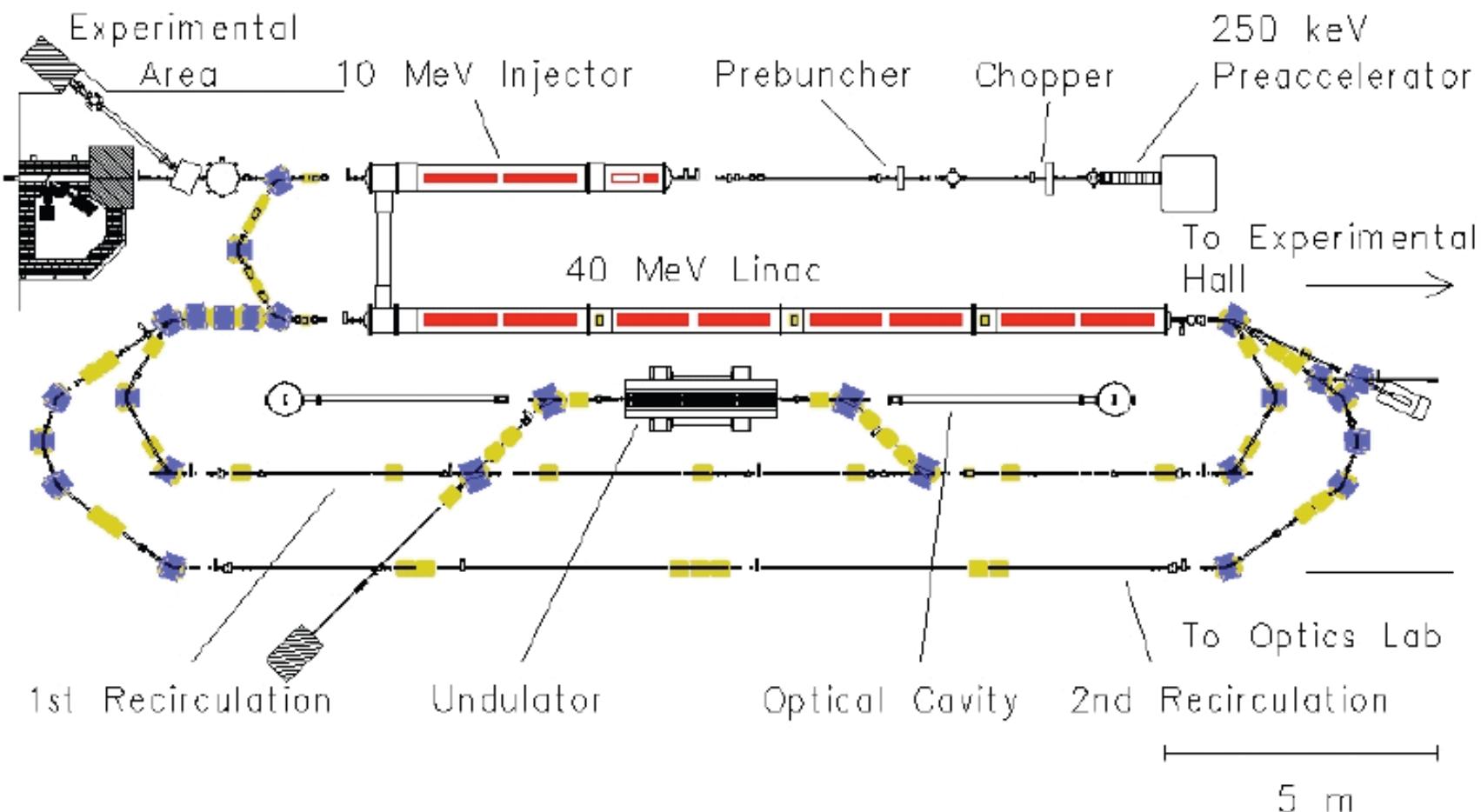
J. Enders et al., PRC80, 034302(2009).

- ^{140}Ce , $^{138}\text{Ba}(\alpha, \alpha\gamma)$ を測定した。
- AGOR at KVI, $E_\alpha = 136$ MeV, BBS + 7-HPGe,
- (γ, γ') との比較で、PDRが“2つの成分から成っていることが分かった。
- $Ex < 6$ MeV: 両測定で観測される。 $Ex > 6$ MeV: $(\alpha, \alpha\gamma)$ で観測されない。

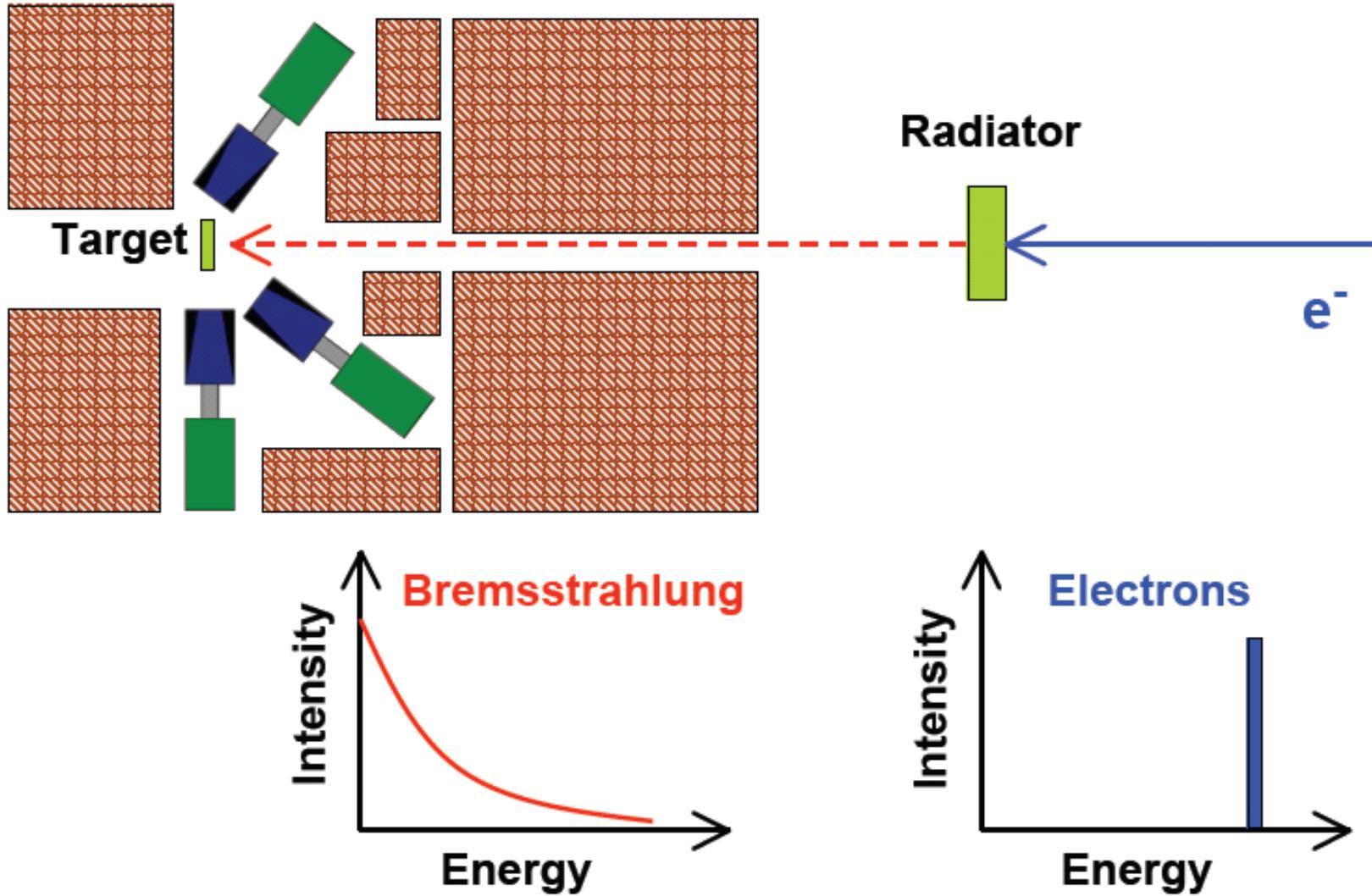
N. Paar et al., PRL103, 032502(2009),

- ^{140}Ce の E1応答を理論的に調べた。
- fully consistent RQRPA
- 低Ex成分(PDR)はisospinの性質により2つのセグメントに分かれる。
- 低Ex側成分: 主にisoscalarで、遷移密度は表面にピークを持つ
- 高Ex側成分: 主にisovectorで、IVGDRと同じ性質を持つ
- (γ, γ') , $(\alpha, \alpha\gamma)$ の実験で見られた性質を定性的に説明する。

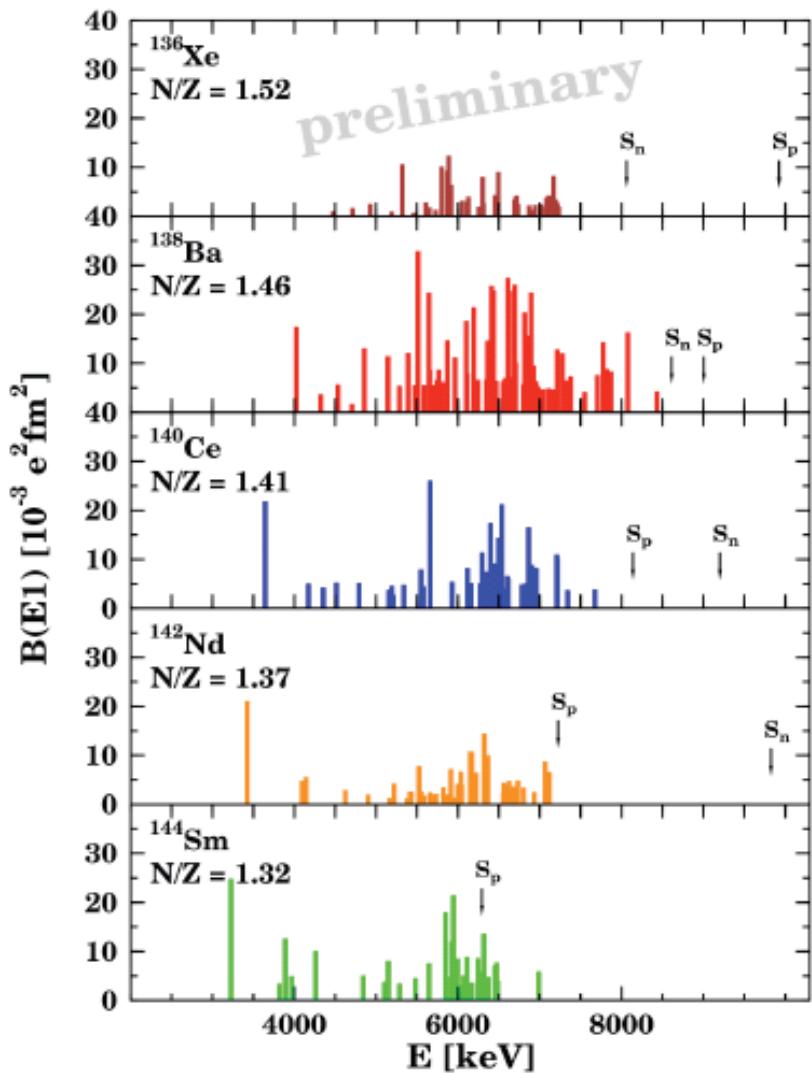
NRF at S-DALINAC



NRF at S-DALINAC



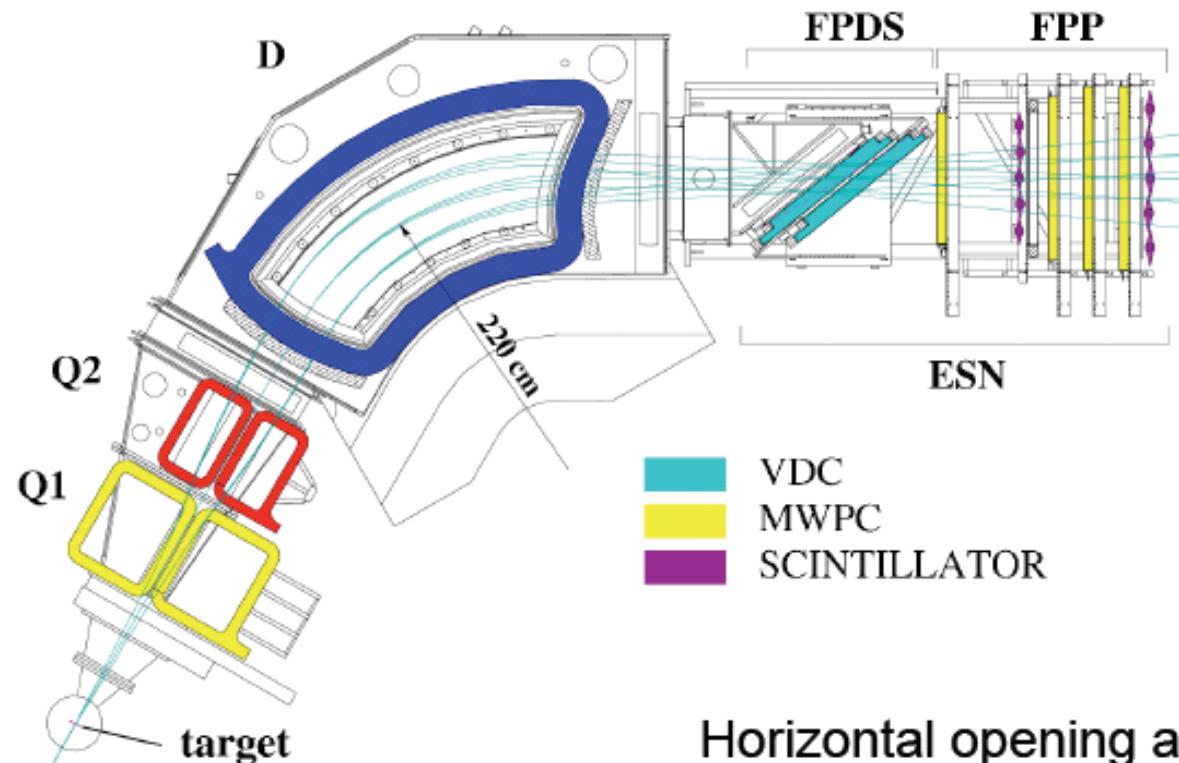
PDR - Results from (γ, γ') in stable N=82 isotones



- Large fragmentation
- Concentrated around 6.0-6.5 MeV
- Observed level spacing about 10-20 keV
- Scaling with N/Z ??

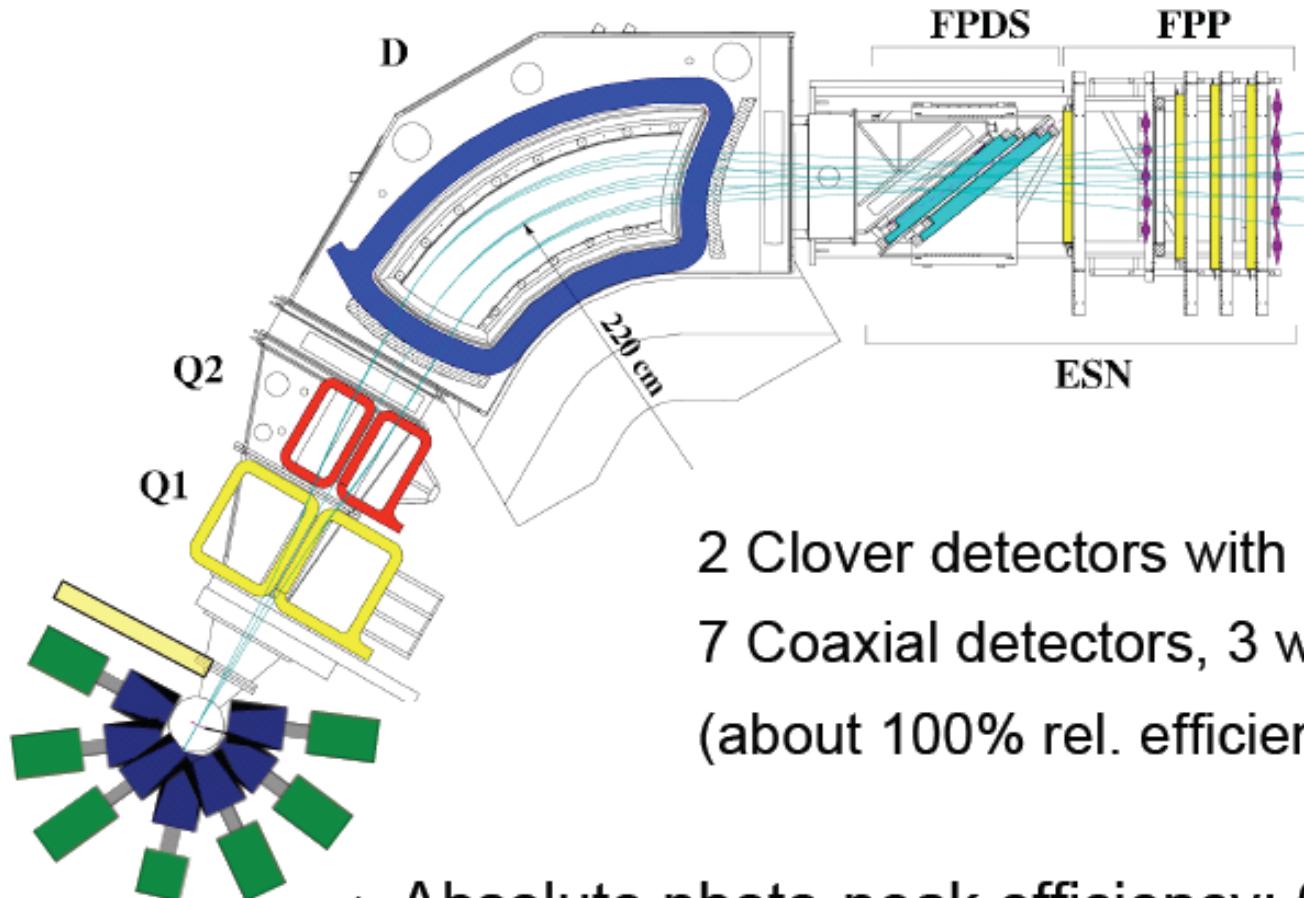
A. Zilges *et al.*, *Phys. Lett. B* **542** (2002) 43
S. Volz *et al.*, *Nucl. Phys. A*, *in press*

Big-Bite Spectrometer (BBS) at KVI:



Horizontal opening angle : 66 mrad
Vertical opening angle : 140 mrad
Energy resolution : ≈ 180 keV
Angle resolution : ≈ 6 mrad

HPGe detectors



2 Clover detectors with BGO
7 Coaxial detectors, 3 with BGO
(about 100% rel. efficiency each)

⇒ Absolute photo-peak efficiency: 0.5% at 1.33 MeV

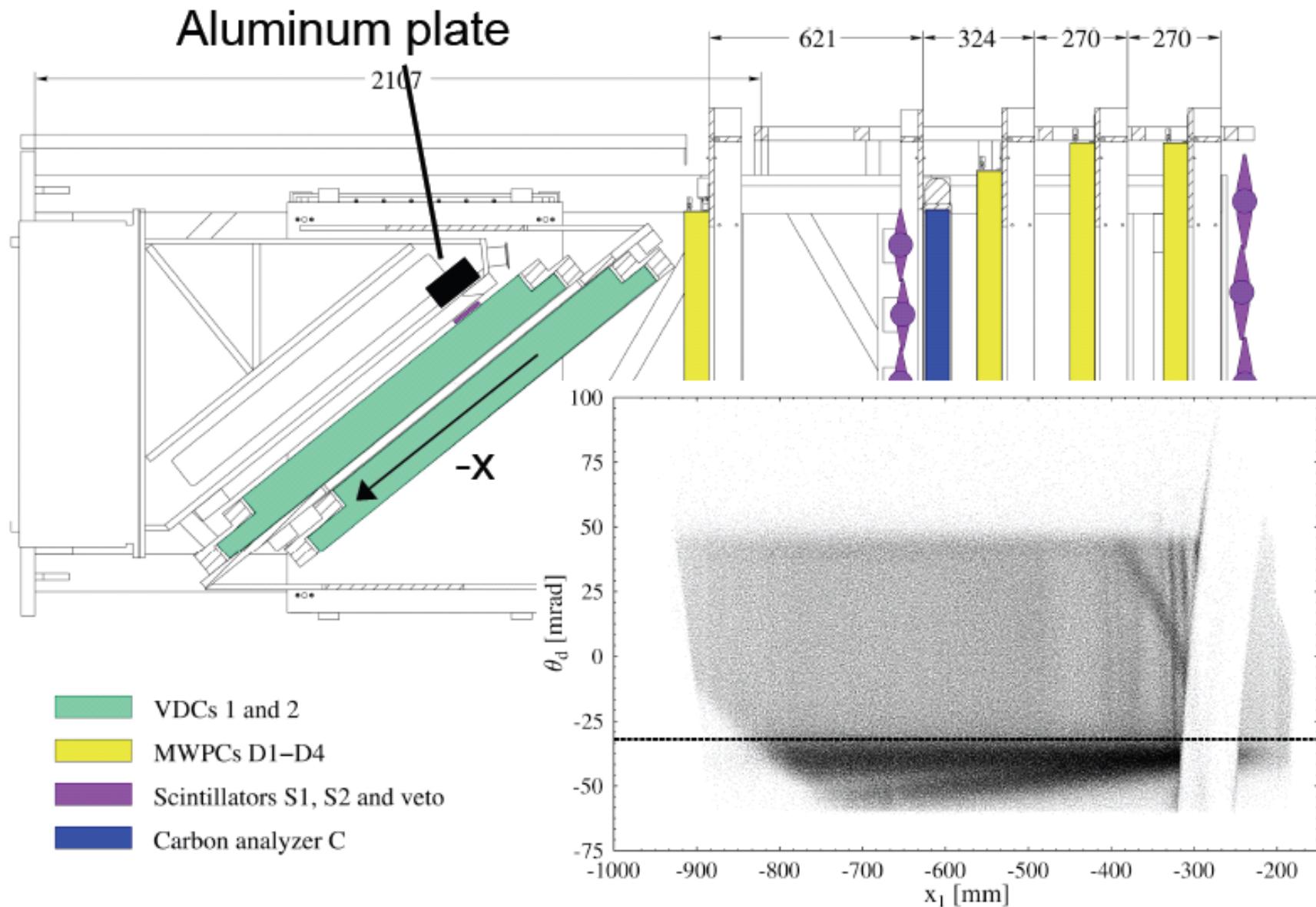
ZUID

BBS

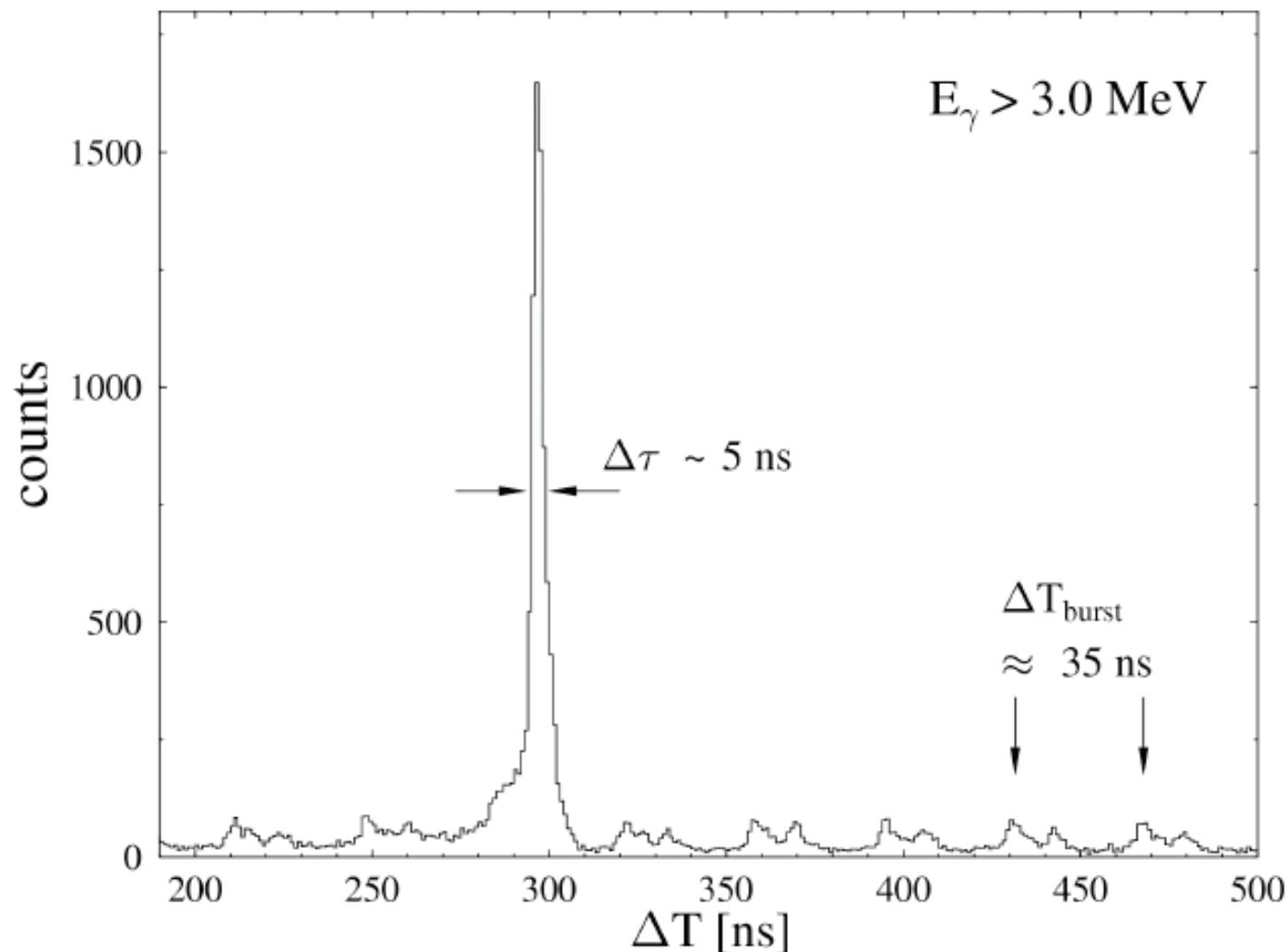
α -beam

50 cm

Problem: elastic scattering



HPGe-Detektor with respect to the RF:



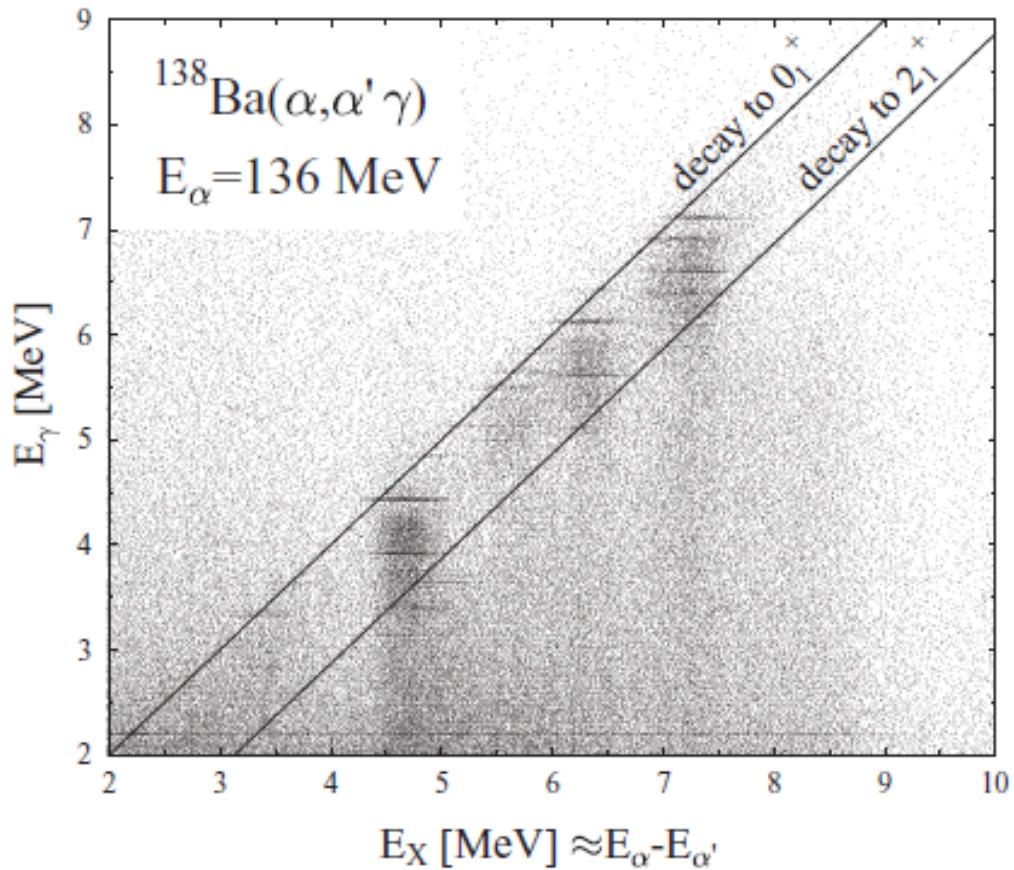


FIG. 1. This α - γ coincidence matrix shows the γ -ray decay energy, E_γ , measured with a germanium detector positioned at backward angles versus the excitation energy, E_x , in the experiment on ^{138}Ba . In this matrix, transitions between bound states occur as thin horizontal lines. The regions of ground-state decays and decays into the 2_1^+ state are marked with diagonal lines.

2+: 1.436 MeV

何故主に線の右側に延びる？

2つの線の間に見えるのは主に
single escape?
その他は？不純物？

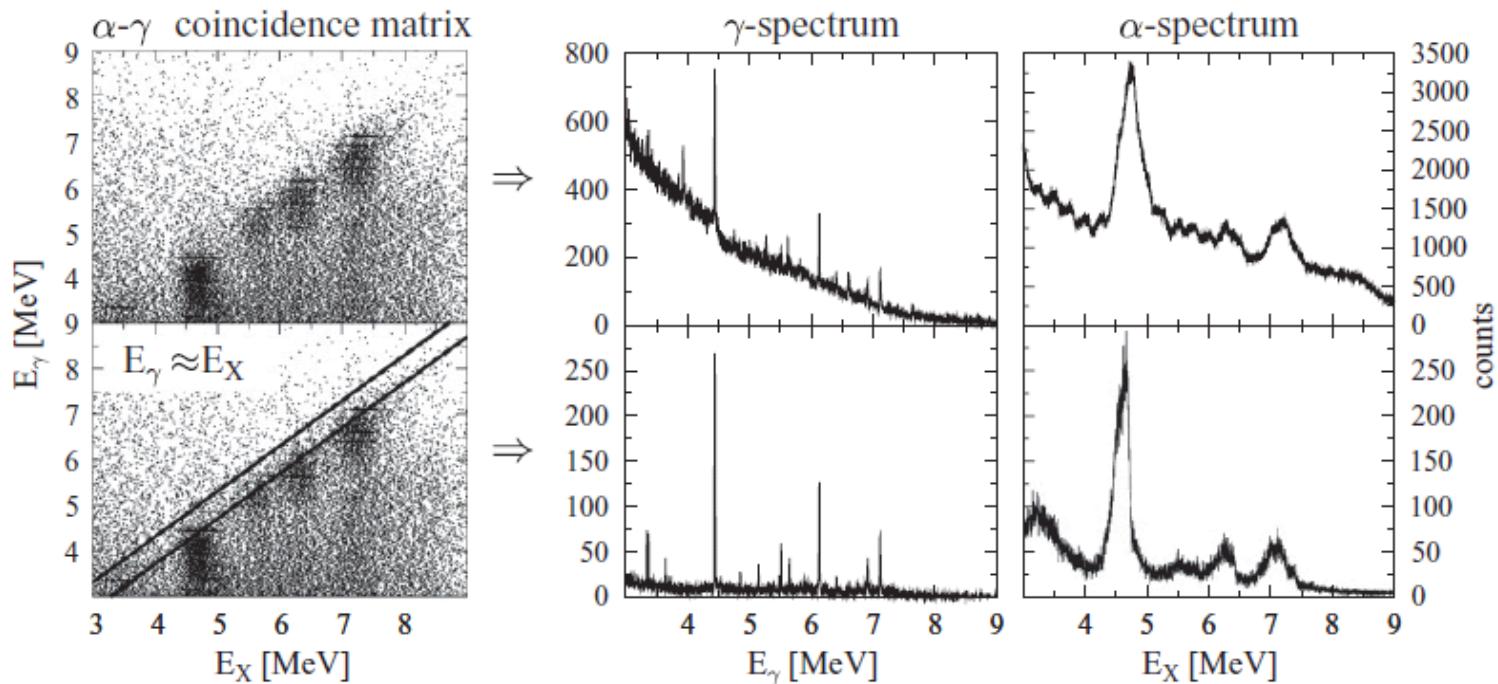


FIG. 2. Two-dimensional scattering matrix and projections for the $^{138}\text{Ba}(\alpha, \alpha'\gamma)$ experiment. Different decay channels can be selected by applying conditions on the α - γ coincidence matrix. Ground-state decays can be selected to study $E1$ ground-state transitions of the PDR. The resulting γ spectrum has a strongly reduced background and shows clearly separated peaks.

$$A = F - B \quad (3)$$

For the statistical error of the peak area including the background we assume:

$$\Delta A = \sqrt{A + 2B} \quad (4)$$

The relative uncertainty of the peak area $p = \frac{\Delta A}{A}$ is required to be smaller than $p \leq 0.3$ to be accepted in the analysis. To indicate a sensitivity limit the minimal peak area is calculated by

$$A \geq \frac{1}{2p^2} + \sqrt{\frac{1}{4p^4} + \frac{2B}{p^2}} \quad (5)$$

$p \neq p_{\max} = 0.3$
 $p \leq p_{\max} = 0.3$
とすべし。

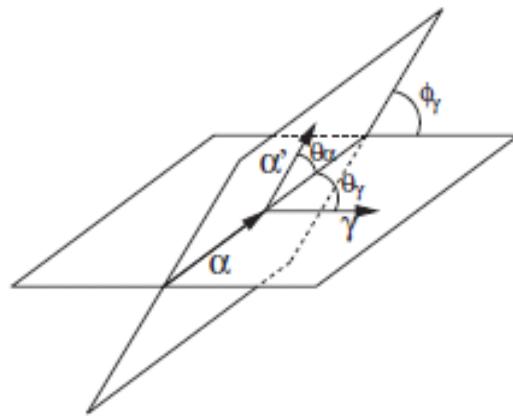
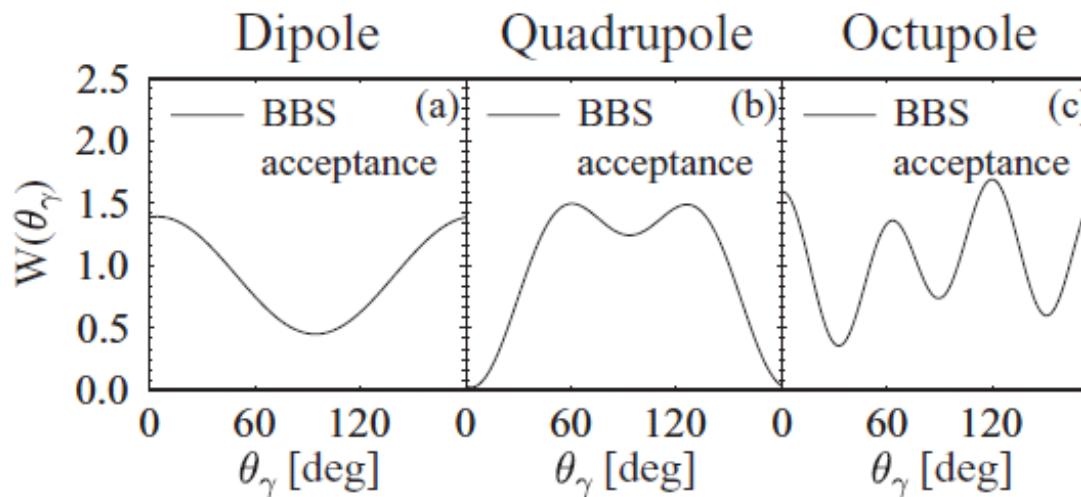
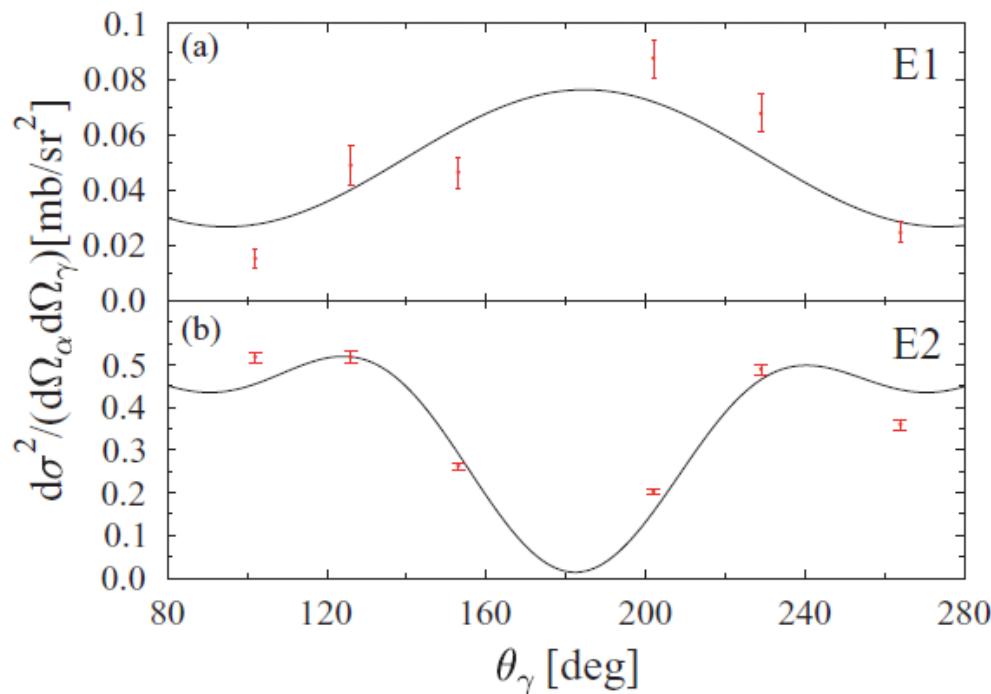


FIG. 3. Illustration of the angles for the α - γ angular correlation.



BBS at 3.5deg
BBS acceptance averaging
with DWBA

FIG. 4. α - γ angular correlations for transitions from states with $J^\pi = 1^-$, 2^+ , and 3^- to the ground state of an even-even nucleus as a function of θ_γ . Each plot shows the distribution of the averaged angular correlation for the full acceptance of the BBS, which was positioned at 3.5°.



g-detector の acceptance
averaging を入れた?

FIG. 6. (Color online) α - γ angular correlations for dipole and quadrupole transitions in ^{138}Ba . The upper plot shows the calculated $E1$ distribution (solid line) and the extracted data points for the 1^- state at $5511.3(10)$ keV. The lower plot shows the corresponding values for the 2_1^+ state at $1435.816(10)$ keV. The given errors are statistical only. Due to a laboratory scattering angle of 3.5° (corresponding to the central BBS angle) the angular correlation is not symmetric around 180° and therefore it has been plotted for angles (θ_γ) from 0° up to 360° in the reaction plane.

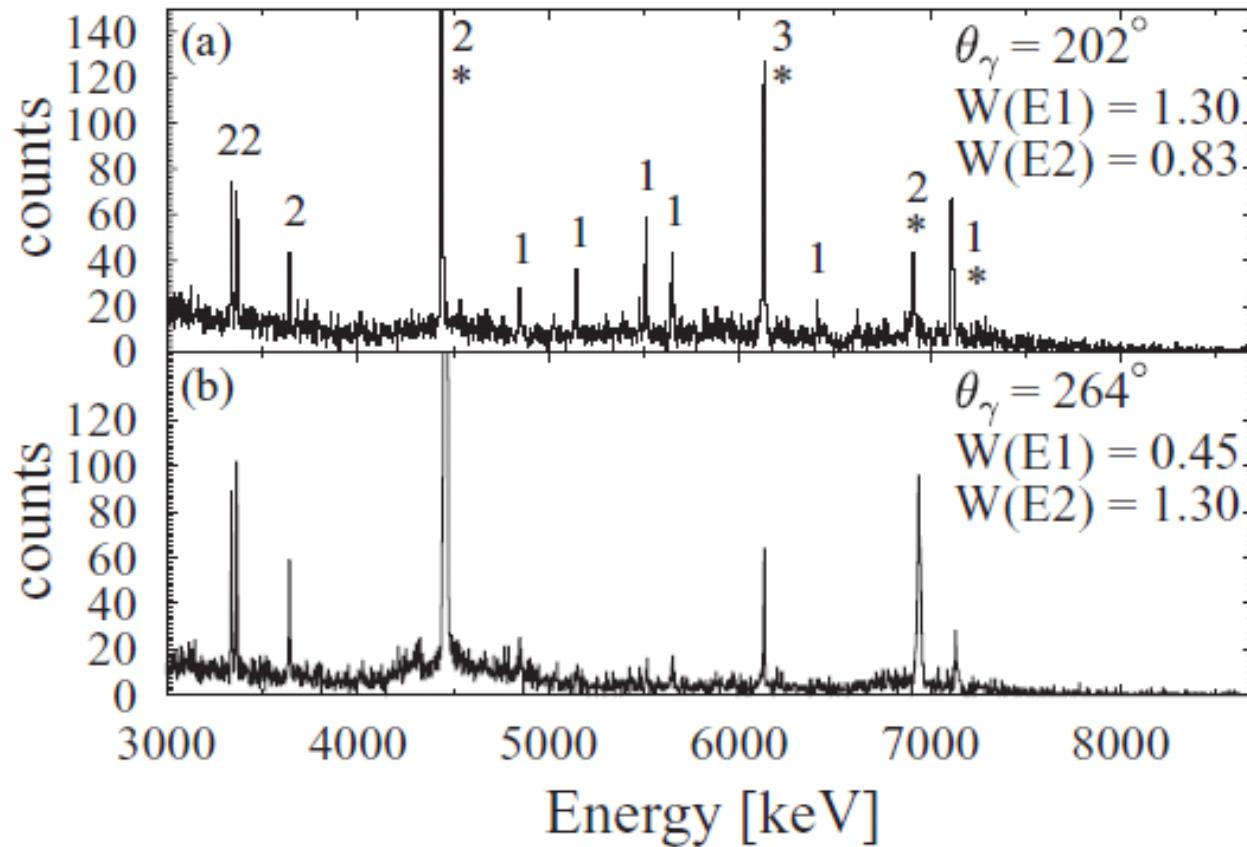


FIG. 5. Ground-state decay spectra obtained with HPGe detectors at different angles for $^{138}\text{Ba}(\alpha, \alpha'\gamma)$. The value of the averaged angular correlation $W(L\pi)$ is denoted for the corresponding angles. Strong transitions are labeled with the angular momentum. Peaks marked with asterisks (*) stem from background transitions in ^{12}C and ^{16}O .

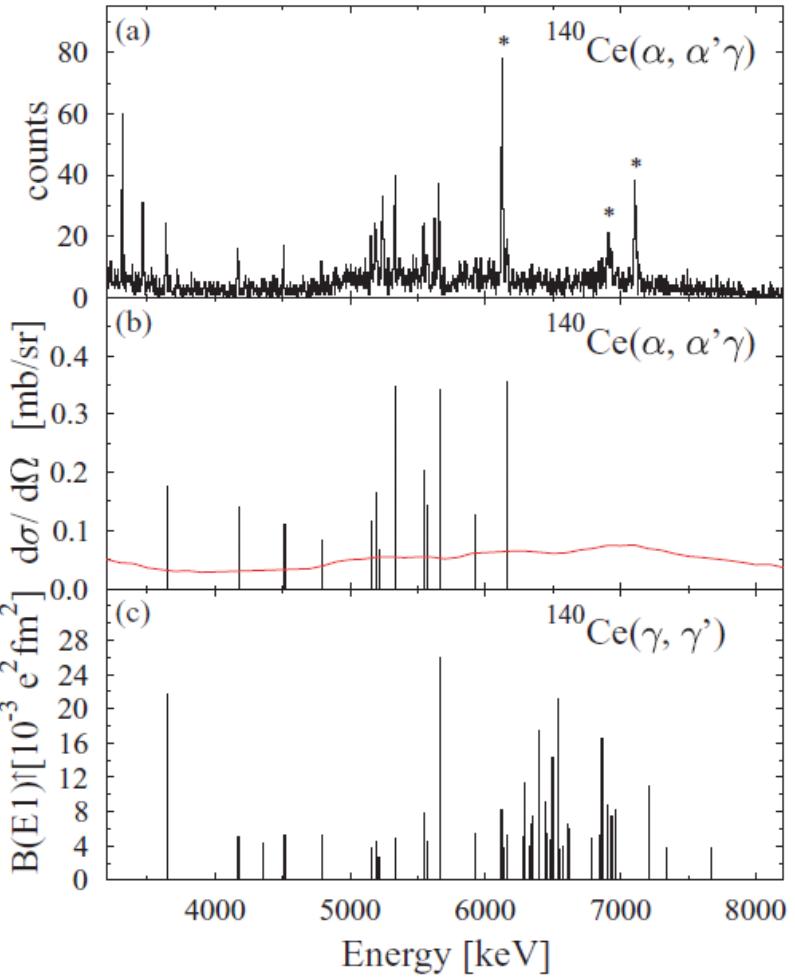


FIG. 7. (Color online) (a) Final γ -ray spectrum for ground-state decay measured in $^{140}\text{Ce}(\alpha, \alpha'\gamma)$ and summed for all the HPGe detectors. Peaks marked with an asterisk (*) stem from transitions in ^{16}O . (b) Single cross sections for the excitation of the 1^- states in ^{140}Ce deduced from $(\alpha, \alpha'\gamma)$ measurement. The solid line shows the energy-dependent sensitivity limit. (c) $B(E1)\uparrow$ strength distribution measured with the (γ, γ') reaction.

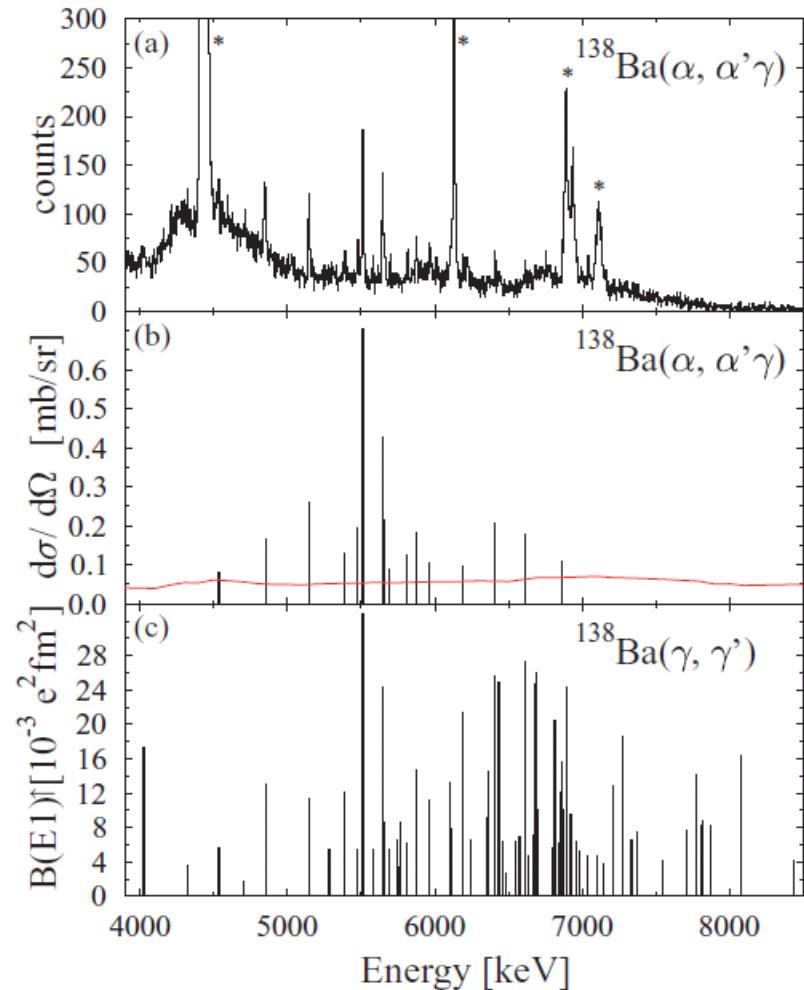


FIG. 8. (Color online) Same as in Fig. 7 but for $^{138}\text{Ba}(\alpha, \alpha'\gamma)$ and $^{138}\text{Ba}(\gamma, \gamma')$. Around 4439 keV the spectrum is dominated by the transition stemming from ^{12}C .

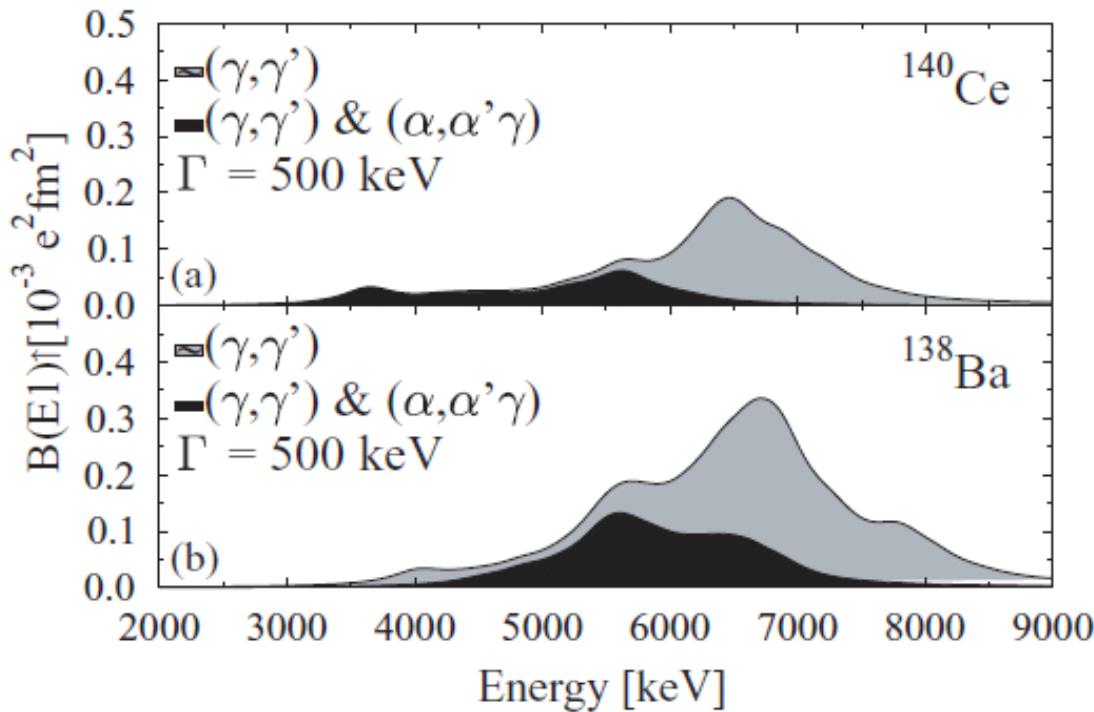


FIG. 9. $B(E1)^\uparrow$ strength distribution measured in (γ, γ') convoluted with a Lorentzian function with $\Gamma = 500$ keV for ^{140}Ce (upper part) and ^{138}Ba (lower part), respectively. All of the 1^- states are included in the gray-shaded distribution. The black-shaded distribution includes only states that could be observed in (γ, γ') as well as in $(\alpha, \alpha'\gamma)$.

fully self-consistent

Relativistic Hartree Bogoliubov (RHB) (基底状態、single-particle orbits)

+ Relativistic Quasiparticle Random Phase Approximation (RQRPA)

$0 < r < 8 \text{ fm}$

$4.25 < r < 8 \text{ fm}$

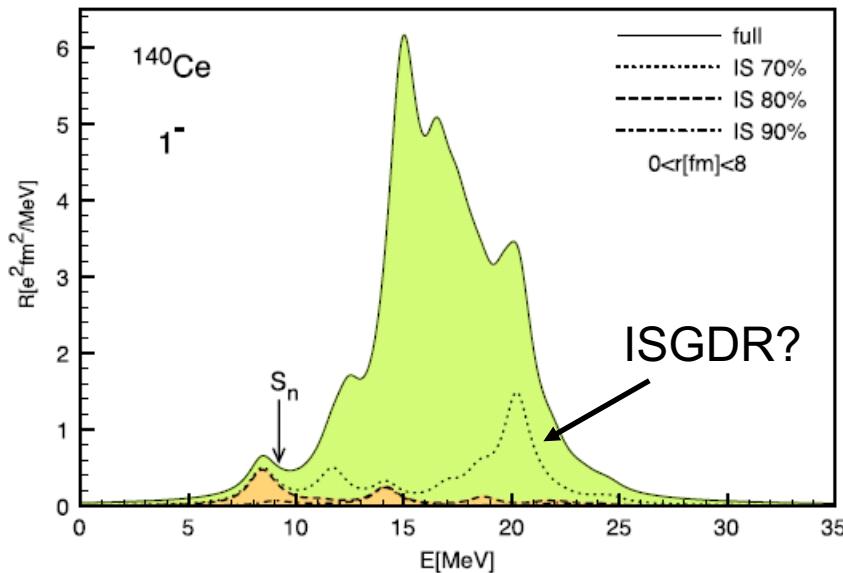


FIG. 1 (color online). The total RHB + RQRPA $E1$ transition strength for ^{140}Ce (solid curve). The dotted, dashed, and dash-dotted curves connect states with predominant (at least 70%, 80%, and 90%, respectively) isoscalar (IS) components, identified by analyzing the corresponding proton and neutron transition densities over the radial interval $[0, 8]$ fm. The vertical arrow denotes the one-neutron separation energy $S_n = 9.2$ MeV.

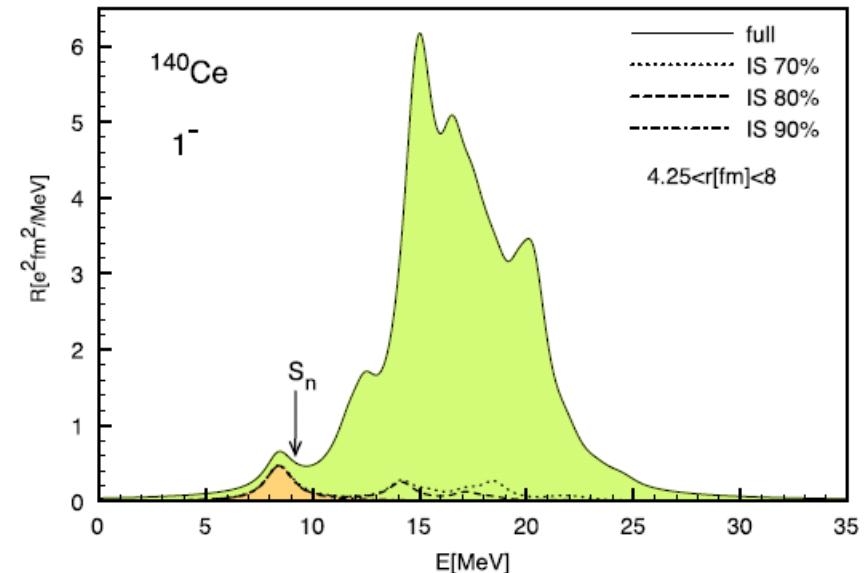


FIG. 2 (color online). Same as in Fig. 1, but the dotted, dashed, and dash-dotted curves are determined from the radial dependence of the neutron and proton transition densities in the surface region: $4.25 < r < 8 \text{ fm}$.

Isoscalar と Isovector の成分比に分けて
プロットしてくれたほうがあがたいが…

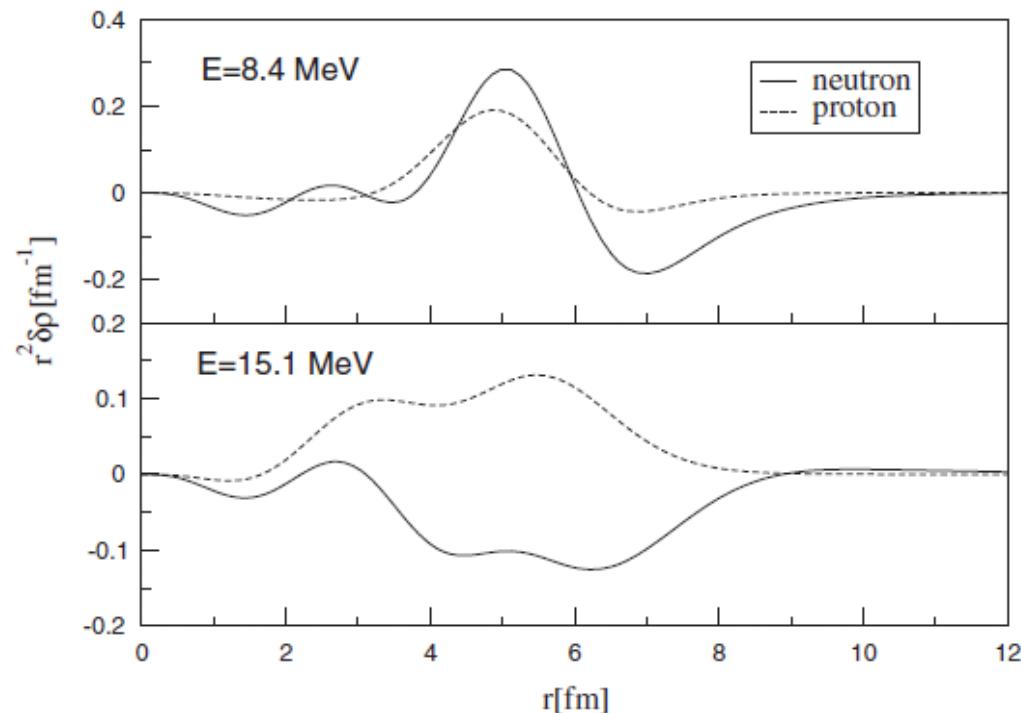


FIG. 3. The RQRPA neutron and proton transition densities for the peaks at 8.4 MeV and 15.1 MeV excitation energy in ^{140}Ce .

IS: 表面励起

IV: 全体で励起

ISの励起エネルギーが実験と合わない(高い)

考えられる理由

× effective mass が小さい? ($m^* < 0.7m_N$)
→ spin-orbit single-nucleon potential でかなり制限されている

× coupling to low-energy surface phonons?
→ 定性的には可能性があるが、QPMなどの試算ではあまり効かない

? 現象論的に $N=82$ shell gap の neutron single-particle energy を入れ
ると、ISが $E_x=5$ MeV程度まで下がる。

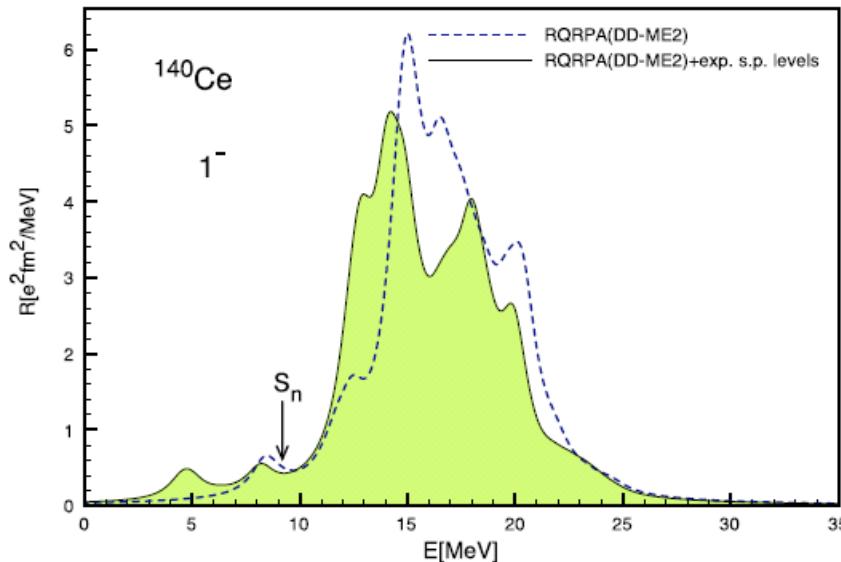


FIG. 5 (color online). The total RHB + RQRPA $E1$ transition strength for ^{140}Ce in comparison with calculation using experimental neutron single-particle energies.

質問、主張

- (中性子)スキンとコアのdipole振動というのは、そもそも描像として可能なのか？
Pauli Blockingは？
- PDRは閾値(S_n)付近に出やすい。
逆に S_n 付近に出やすいものが他にもあるのでは？
スキンの他のタイプの振動、回転、 $\Delta S=1$ 振動, ΔT ?...、バンド構造？
- PDRと同じような励起エネルギー付近にM1共鳴の存在が報告されている。
M1共鳴が S_n 付近に出やすい理由はあるのか？
- single p-h 状態では、スキンのようなものを多くの核で系統的には作れないのでは？
集団運動的なイメージとは対極の状態にある。
single ph 状態でPDRが説明されるとすれば、その物理的描像はどうなるのか？
- Direct に transition density を測る実験。transition form factor q-dependence を測る
実験を考える。**どの程度重要か、どの程度の精度が必要か。実験は可能か？**
- (γ, abs)で安定核isotope abundance の非常に大きいものを対象として、PDR測定を系統的に測定できるか。
効率を上げる工夫、資料の物質量を減らす工夫、E1/M1/...を分ける工夫。
- PDRからのdecayを見る。
single p-h 的描像であれば、崩壊先の状態のpopulationに特徴が出るはず？
集団運動的描像であれば、transition density の特徴(殻のような中性子trans. density)に起因する、特徴的な γ 放射分布、中性子角度分布が見られないか？Prediction
- 中空のtransition density。 (p, p') などの角分布に特徴的な形ができる可能性があるのでは？

- PDRの(アイソスピン)アナログ状態は存在するのか？しないのか？

$$(\nu^{-1}\nu^{+1}) \Leftrightarrow (\nu^{-1}\pi^{+1})$$

(p,p') or (3He,3He') \Leftrightarrow (p,n) or (3He,t)の励起の違いを見る。

IVGDRにはアナログが存在するはず。PDRはある？ない？

- PDRの γ (EM)による励起強度とproton(ハドロン)による励起しやすさは違うかもしれない。

γ (EM)は、中性子スキン部のtransition density やアイソスカラーなコアのtransition density をプローブしにくい？

proton(ハドロン)の核力は励起しやすい？

γ とprotonで差が見えるか？

(p,p')で見えているバンプはPDRをよりprobeしやすいからか？

Zrなど報告されているM1は実はPDRか？散乱角が大きくなるとより顕著化か？

($\alpha, \alpha'\gamma$)と(γ, γ')の差は、本当にT=0とT=1に起因する差を見ているのか？

EMと核力による励起強度の差をみているのではないか？

- Collectiveであること、Collectivity の定義、データによる検証の可能性。

- Reaction Mechanism

- 何故特定の原子核にPDRが見えるのか？あるいは普遍的に存在？

本当にスキンのせいか？N-Zと強度との相関を見るのが本当によいのか。

稻倉モデルでのPDRの理解。PDRの存在条件の明文化。

表面付近に nのtransition density があることと、p の transition density がないことの両方が必要。g.s. の状態に関する条件。Particle起動の条件 s,p,? Or 主量子数の変化？ g.s. でのスキンの存在、集団運動のイメージどうまく結びつくか？

