# *Low-energy dipole response: the plot thickens?*

—— Advances in Nuclear Many-Body Theory, Primosten, Croatia, June 2011 ——

*Herzlichen Glückwunsch!*


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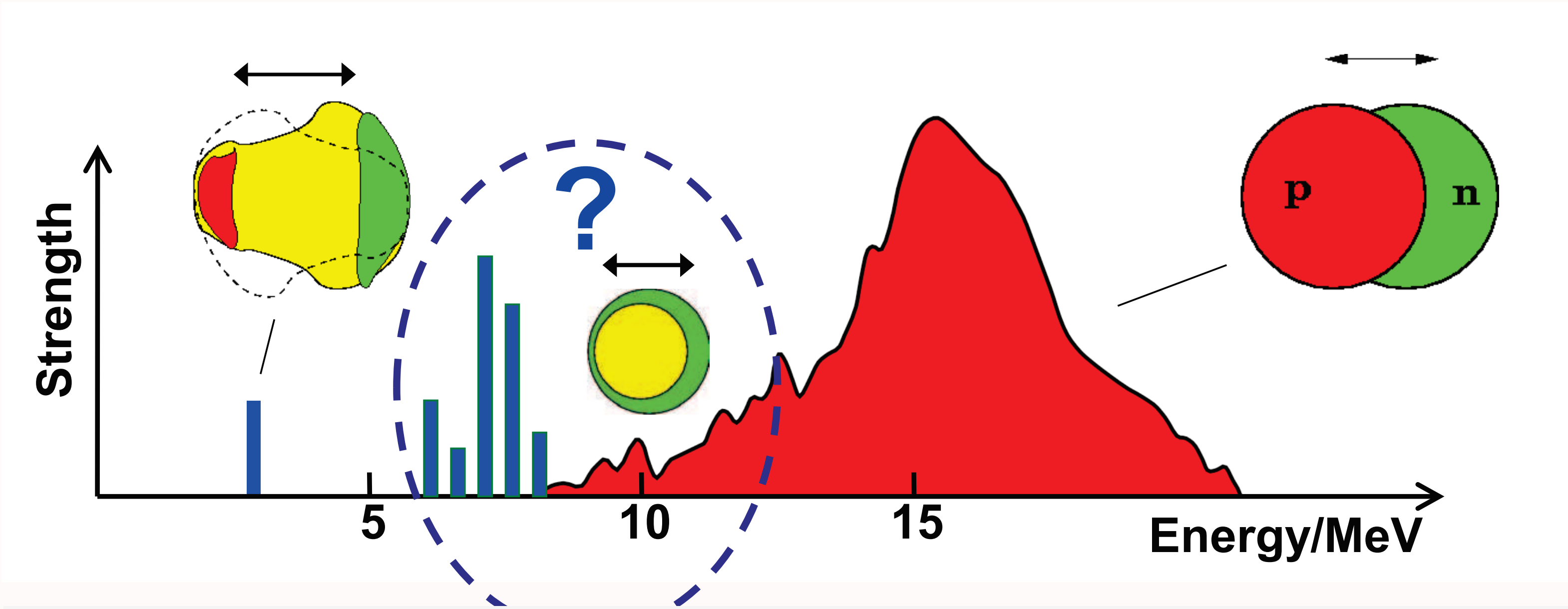
# Electric dipole strength vs. collectivity




## E1 strength below / around threshold

- There tends to be more of it in neutron-rich isotopes

  ... though the variation with N is not always monotonic!

- Microscopic models predict the existence of a neutron-skin mode

  ... though that alone cannot explain the observed systematics

- Incoherent concentration of strength is still possible

# Case studies and moral stories

- **Isoscalar-dipole response of N=Z nuclei**
  - On “isospin-forbidden” E1 transitions
- **Isoscalar vs electromagnetic response**
  - along Ca isotopes, etc

☞**Dipole collectivity at low energies does not *require* a neutron (or proton...) skin**

☞**E1 strength is not *necessarily* a good absolute measure of collectivity (i.e., the coherence of a vibrational state)**

# Isoscalar vs E$\lambda$ strength

- Consider **perfectly isoscalar** mode of multipolarity $\lambda > 1$:

$$\delta\rho_p(r) = \delta\rho_n(r) = \frac{1}{2}[\delta\rho_p(r) + \delta\rho_n(r)] = \frac{1}{2}\delta\rho_{\mathrm{IS}}(r)$$

- Isoscalar strength:

$$\int \delta\rho_{\mathrm{IS}}(r) r^{\lambda+2} dr$$

- $E\lambda$ strength:

$$\int \delta\rho_p(r) r^{\lambda+2} dr = \frac{1}{2} \int \delta\rho_{\mathrm{IS}}(r) r^{\lambda+2} dr$$

☞ A large/small B(E$\lambda$) value implies large/small isoscalar strength too

# Isoscalar vs E1 strength

- Consider **perfectly isoscalar** mode of multipolarity $\lambda = 1$:

$$\delta\rho_p(r) = \delta\rho_n(r) = \frac{1}{2}[\delta\rho_p(r) + \delta\rho_n(r)] = \frac{1}{2}\delta\rho_{\rm IS}(r)$$

- Isoscalar strength:

$$\int \delta\rho_{\rm IS}(r) r^5 dr$$

- $E1$ strength vanishes:

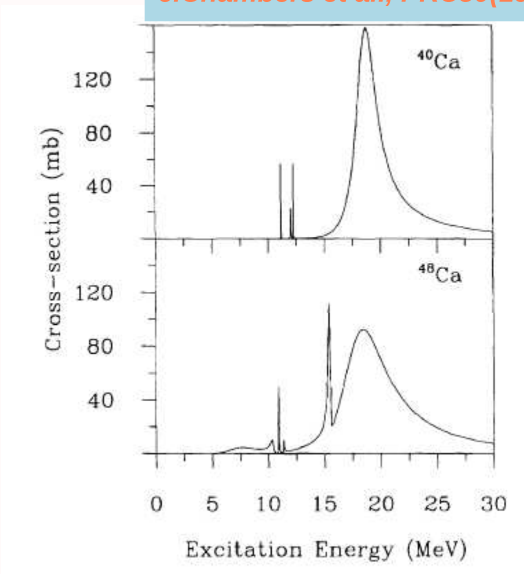
$$\int \delta\rho_p(r) r^3 dr = \frac{1}{2}\int \delta\rho_{\rm IS}(r) r^3 dr = 0$$

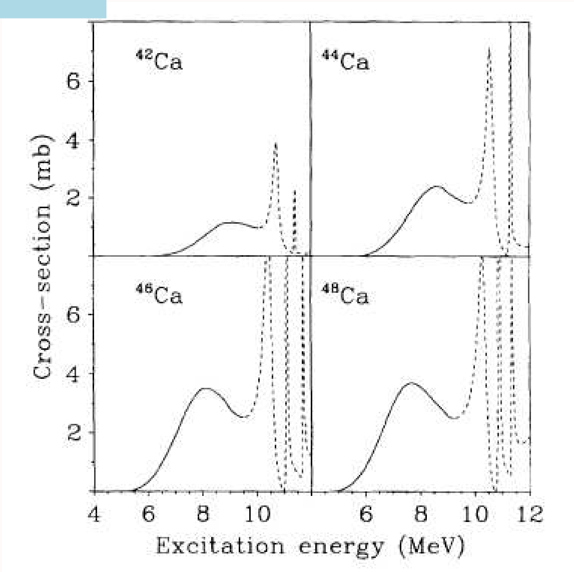
due to **translational invariance**,

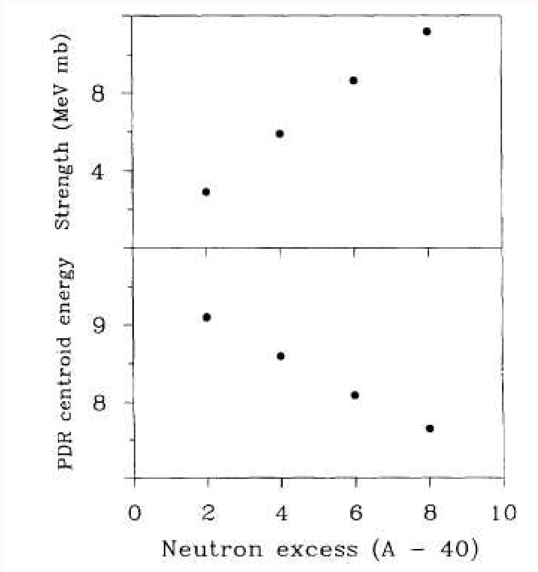
☞ but the transition **is no less collective for this reason**, in the IS channel

# Pygmy Dipole Strength in Ca isotopes

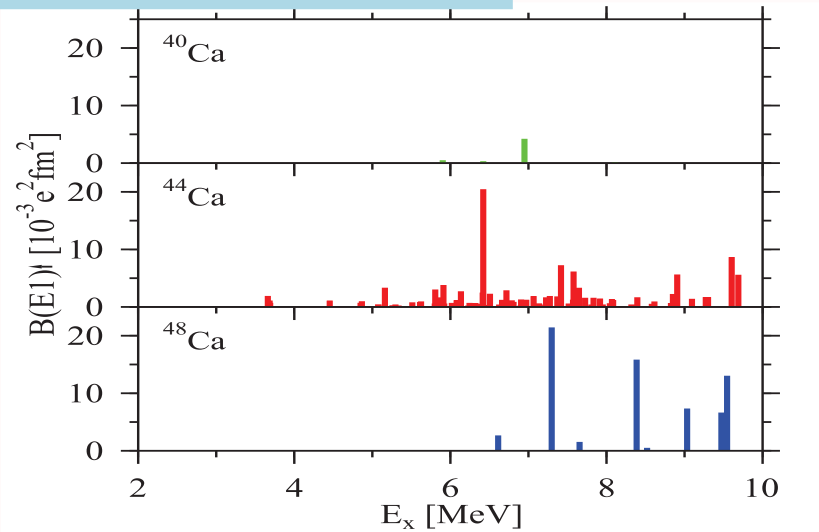
*J.Chambers et al., PRC50(1994)R2671*

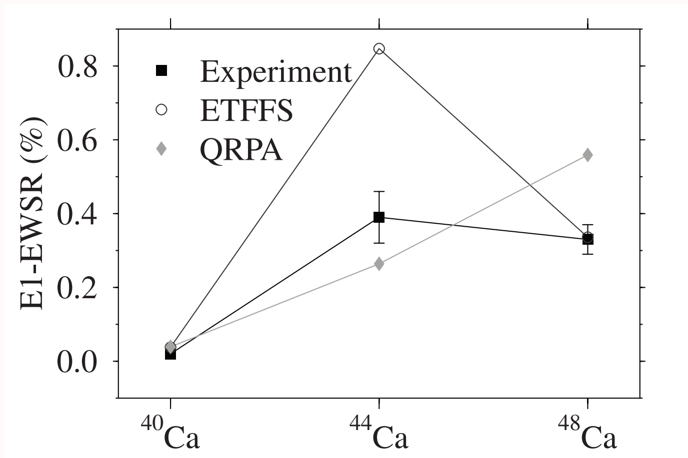


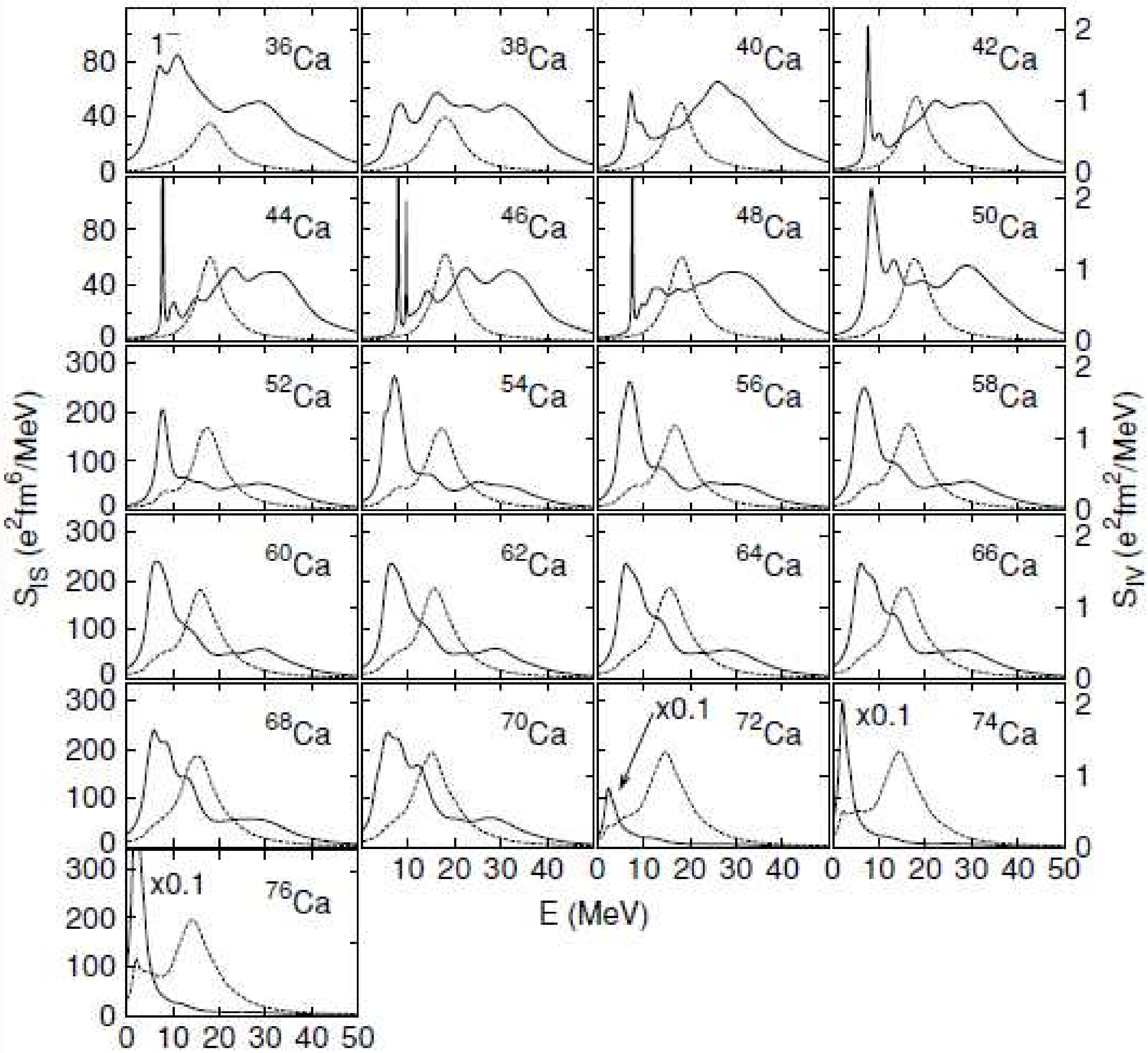




*T.Hartmann et al., PRL93(2004)192501*



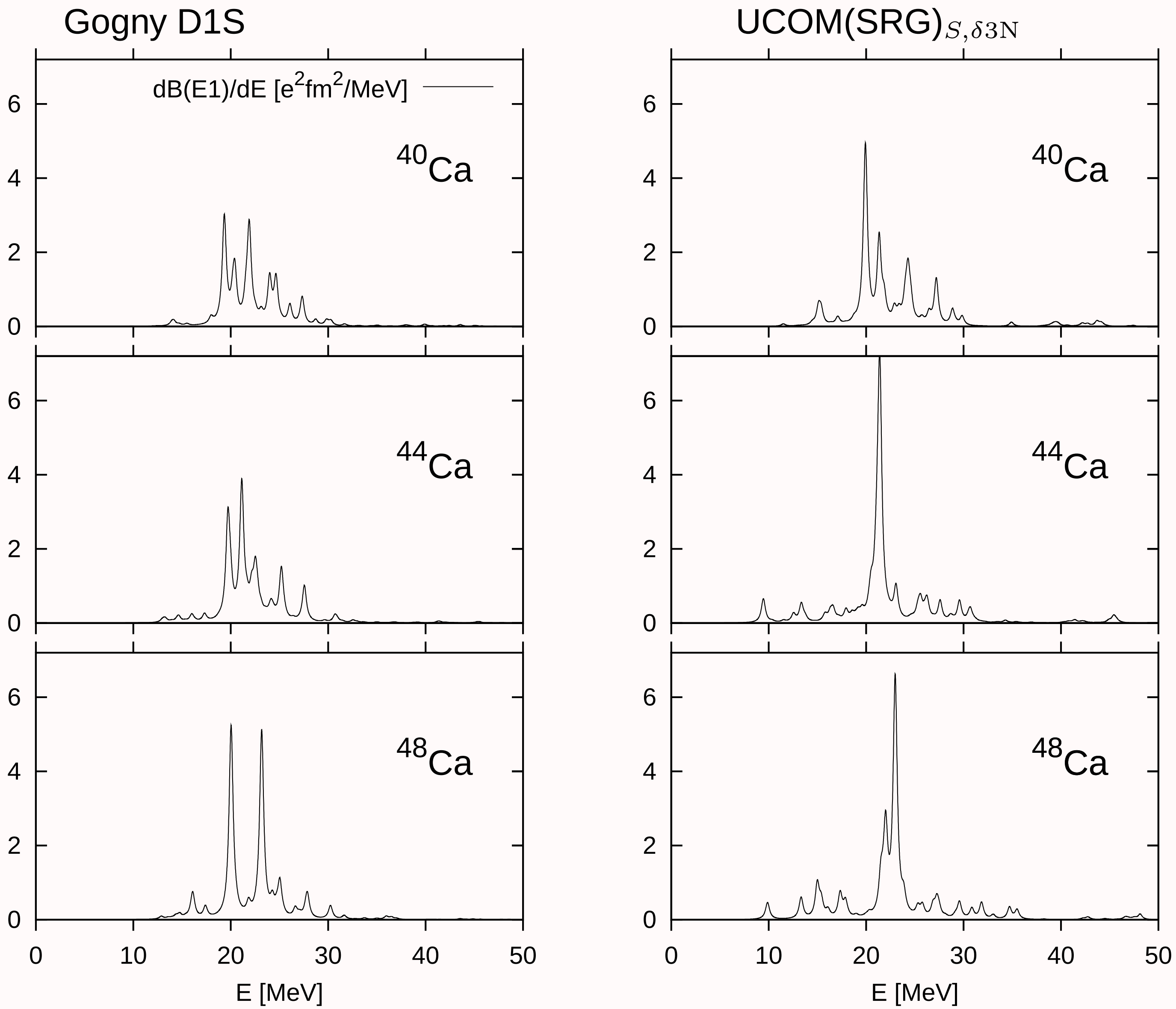
# Dipole response of Ca isotopes with Skyrme



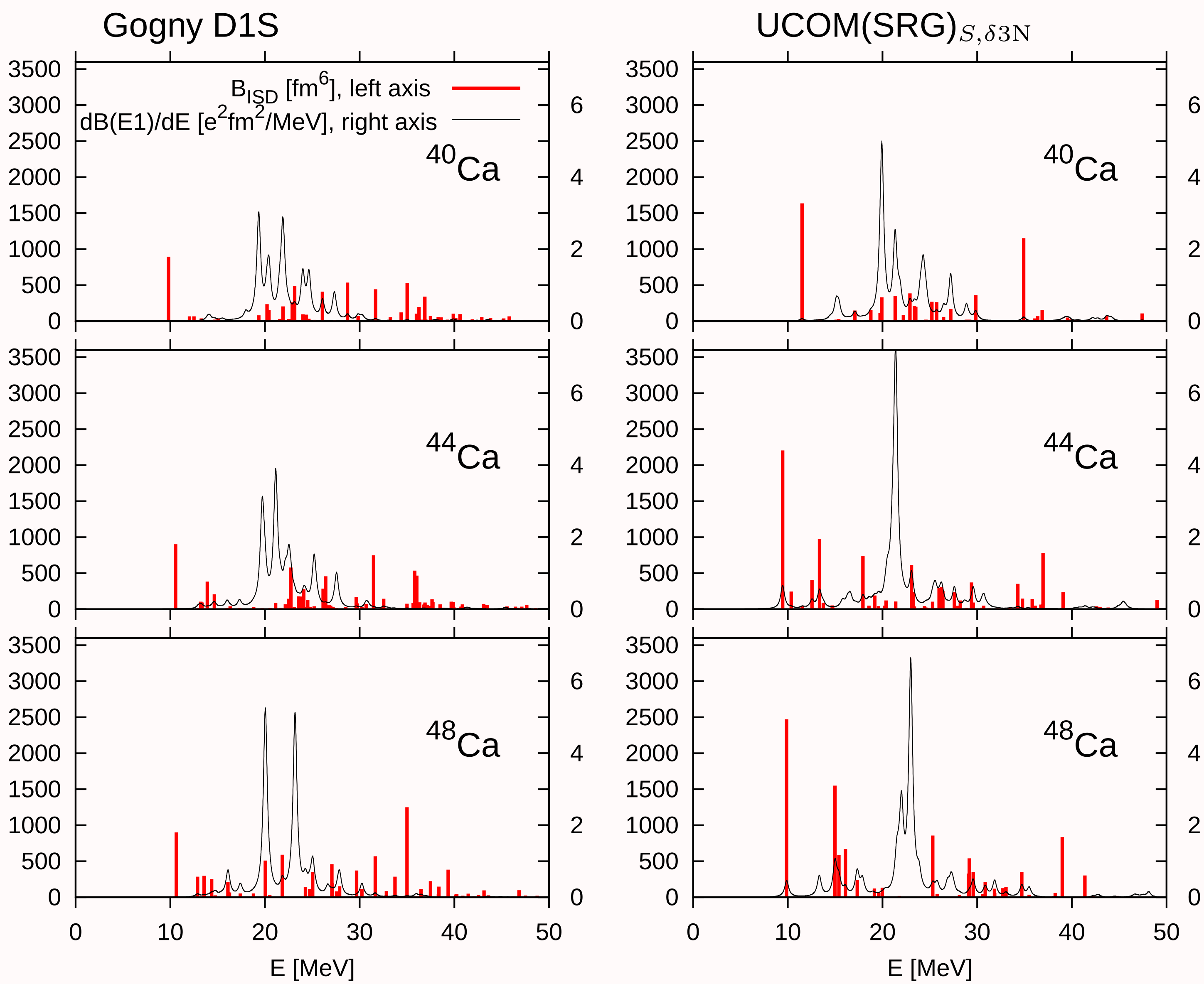

Terasaki&Engel, PRC74

SGII

# Pygmy Dipole Strength in Ca isotopes



# Pygmy Dipole Strength in Ca isotopes



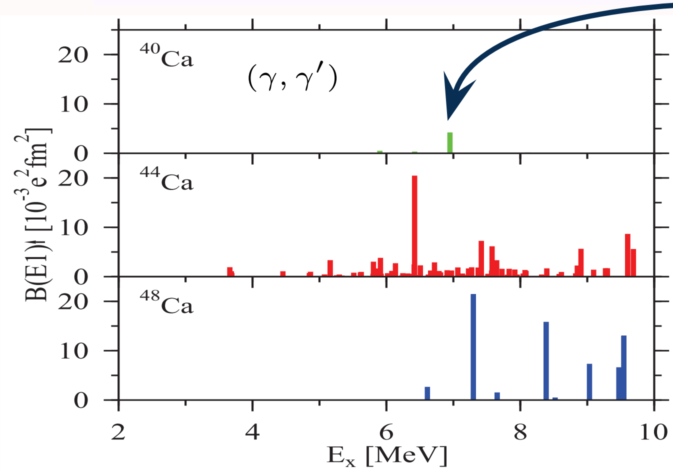
# A collective dipole excitation hidden in the attic

## “Isospin-forbidden” E1 transitions explained

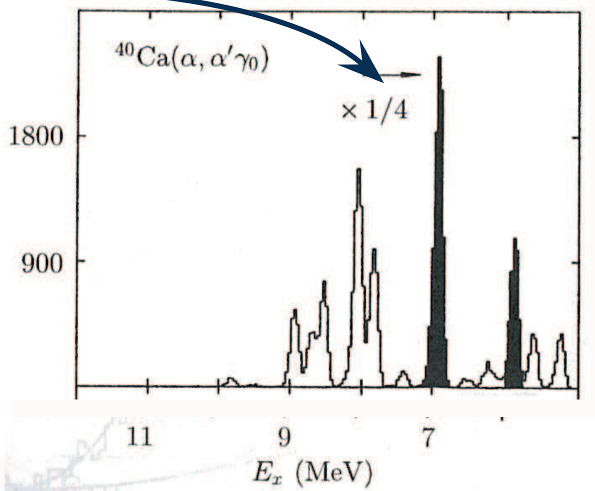
- N=Z nuclei undergo **collective**, **isoscalar** $1\hbar\omega$ dipole transitions.
- E1 strength: isospin mixing

*PP,Ponomarev,Roth,Wambach, Eur.Phys.J.A47(2011)14*

$10^{-4}$ of the TRK... ...but **4%** of the isoscalar EWSR!

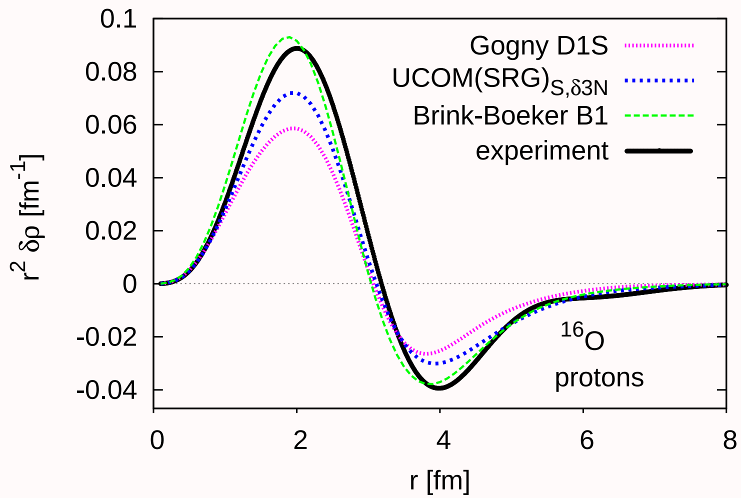



*T.Hartmann et al., PRL93(2004)192501*



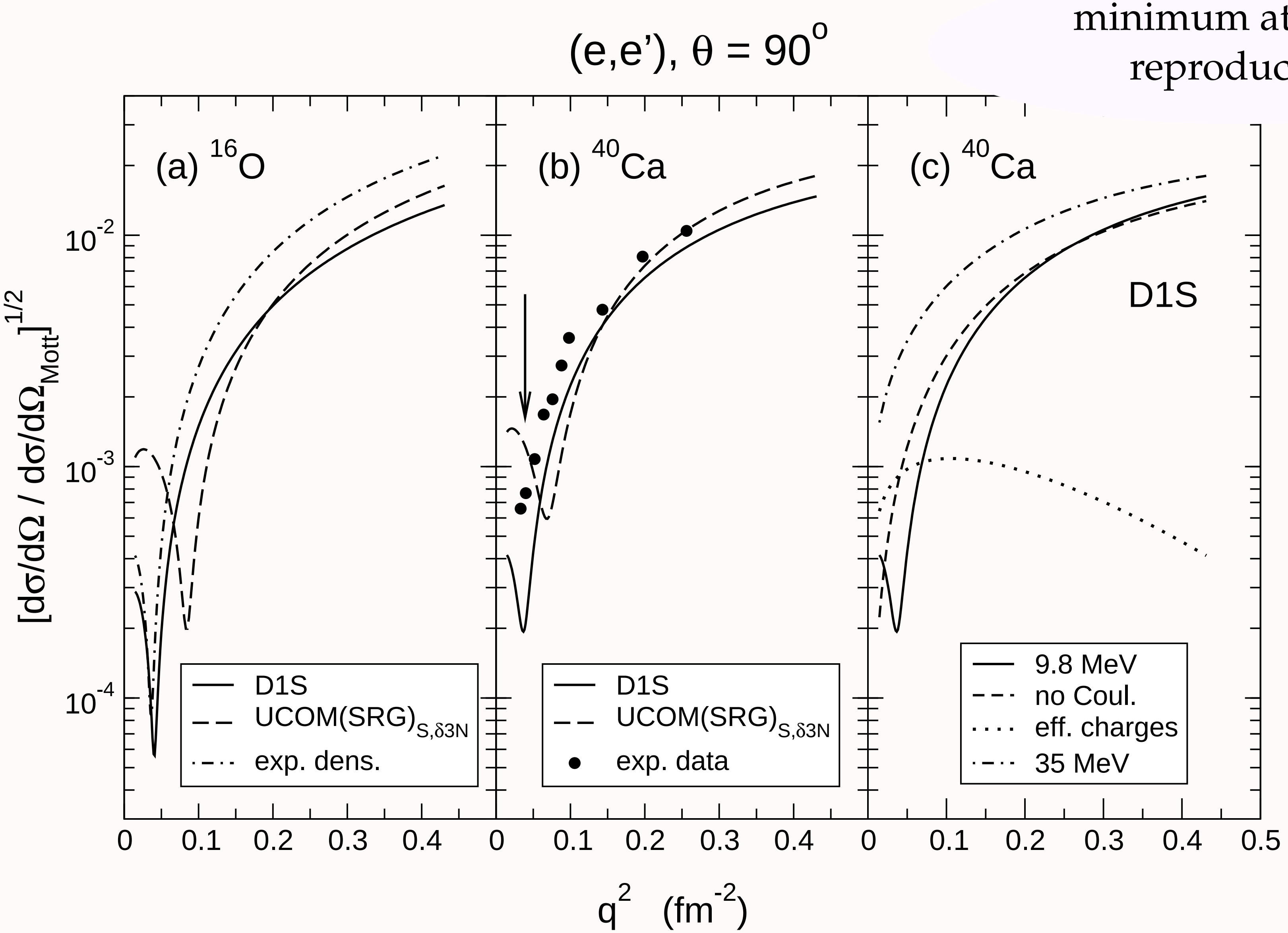

*T.Poelhakken et al., PLB278(1992)423*

☞**Prediction**: up to $^{100}$Sn



# Electroexcitation form factor

minimum at low q reproduced!



# Reality check

## What models predict a strong IS-LED mode?

(✘)Valence shell model *-nothing in the literature-*

(✘)Valence RPA

*V.Yu.Ponomarev, priv. comm.*

(✘)QPM

✘ Almost self-consistent CRPA (Skyrme)

*PP et al., 2011*

✔ Self-consistent RPA with finite-range forces

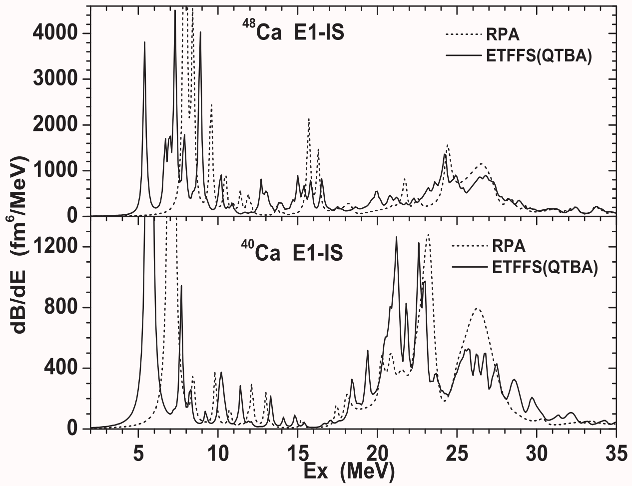
✔ “Self-consistent” Second RPA *PP*

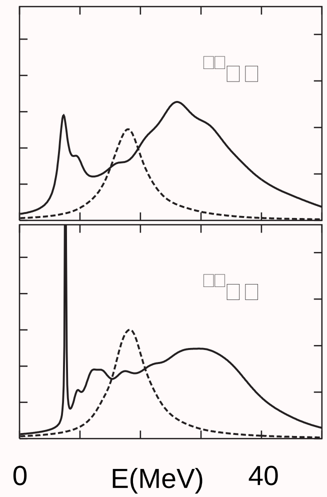
✔ Self-consistent Vlasov equations *M.Urban, priv.comm.*

(✔)ETFFS *Tertychny et al., 2006*

(✔)Self-consistent RPA with Skyrme interactions *Terasaki&Engel, 2006*

?? Self-consistent Relativistic RPA



# Low-Energy Isoscalar Dipole Strength

$(\alpha, \alpha'\gamma)$

ISOSCALAR $\Delta L = 1$ STRENGTH 175

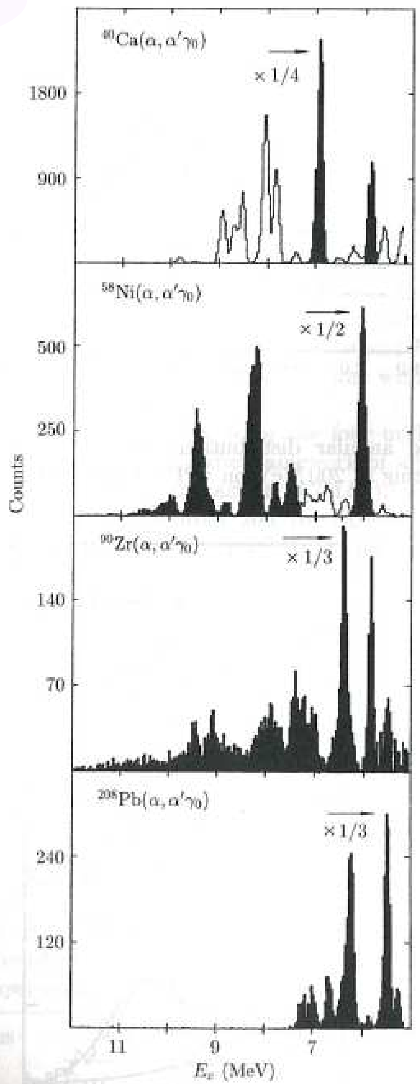



FIG. 4.10. The observed dipole strength in $^{40}$Ca, $^{58}$Ni, $^{90}$Zr and $^{208}$Pb below the neutron-decay threshold using the $(\alpha, \alpha'\gamma_0)$ reaction in a small angular interval around 0°. The isoscalar dipole strength is indicated in black. From

*Harakeh and van der Woude, "Giant Resonances"*

4% – 14% ISD EWSR at low energies!

*T.Poelhakken et al., PLB278(1992)423*

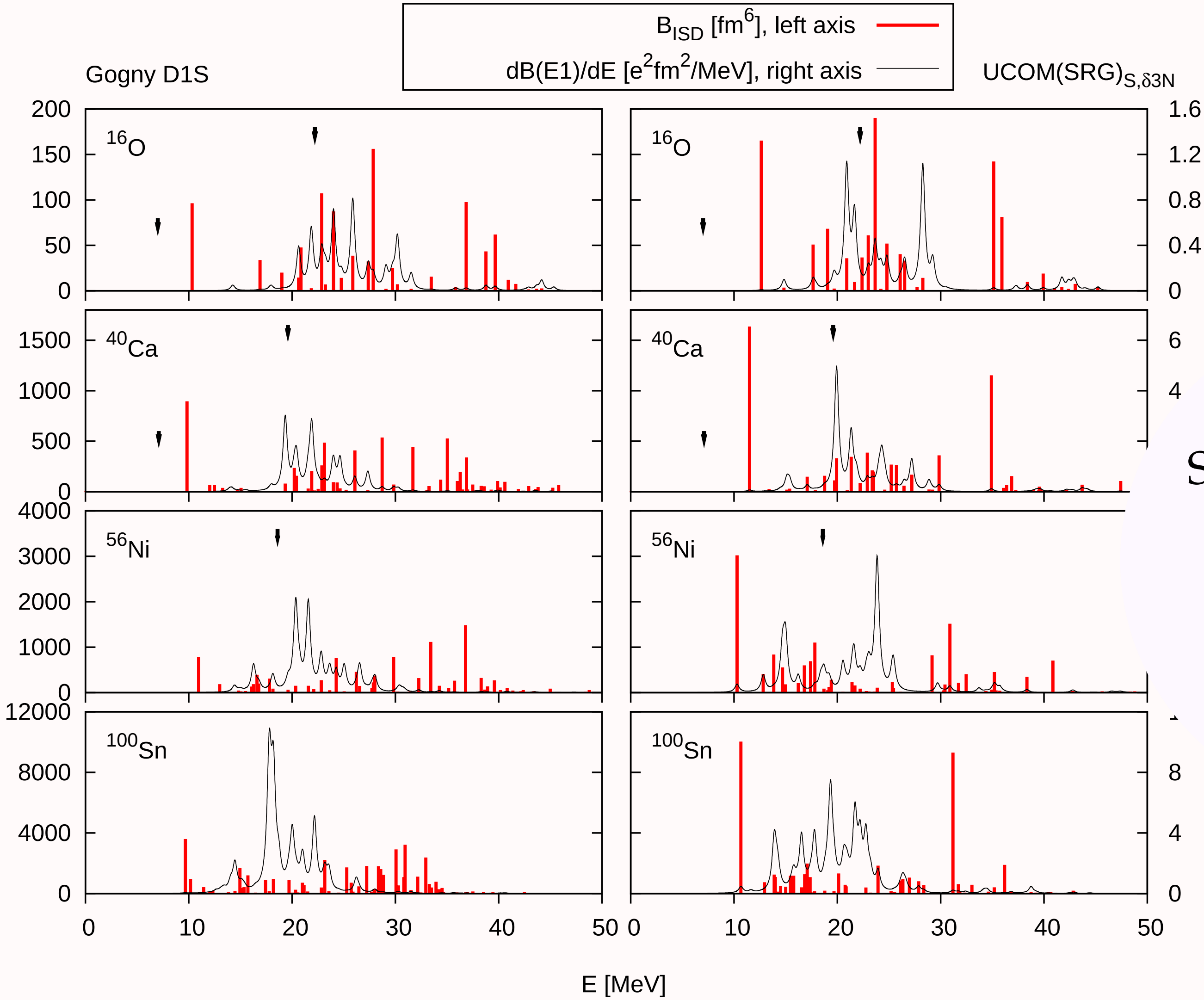
isoscalar dipole states are listed in table 1. The $^{40}$Ca target served as a test for the $\alpha$–$\gamma$ angular correlation method, since both isoscalar dipole states have been known for a long time [19]. Although for $^{58}$Ni dipole

*M.Harakeh et al., PLB62* ***(1976)*** *155*

In conclusion, the excitation of the $1^-$, $T = 0$ state at 7.12 MeV in $^{16}$O by inelastic $\alpha$-particle scattering now seems to be well understood. Besides, it provides a sensitive test for the predicted wave functions due

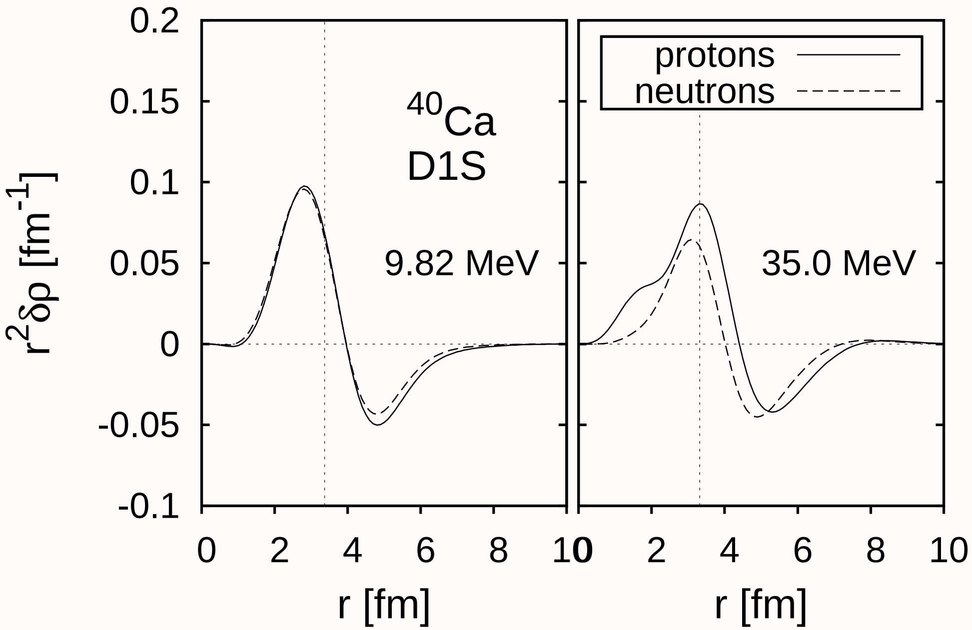
**Isospin-forbidden E1 transitions in N=Z nuclei**

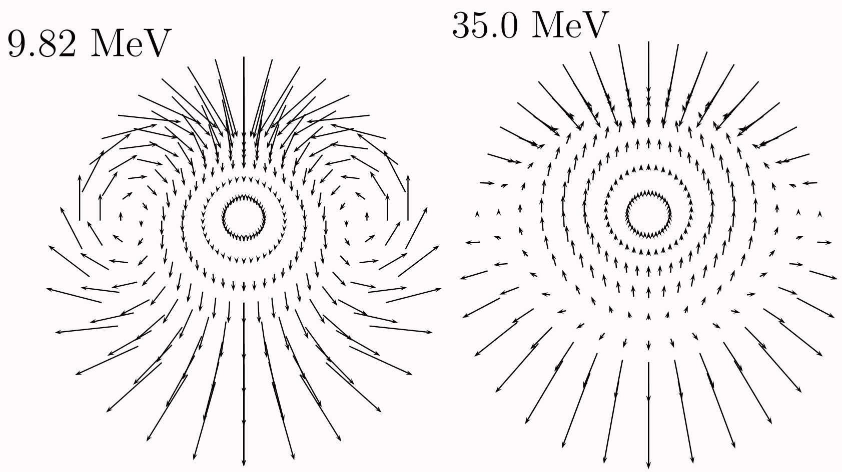
# Dipole response of N=Z nuclei



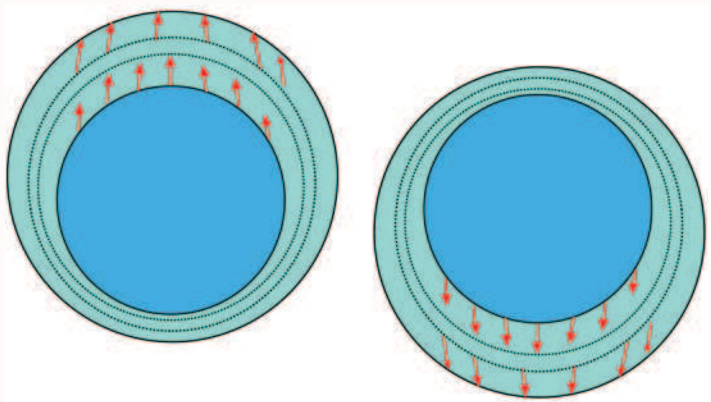

Strong ISD state at low energy with very little E1 strength!

# IS-LED vs compression mode




- Transition density: node @ surface
- ... but no compression

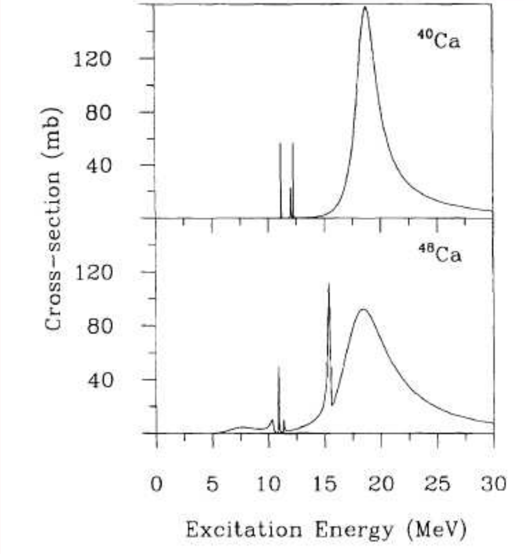


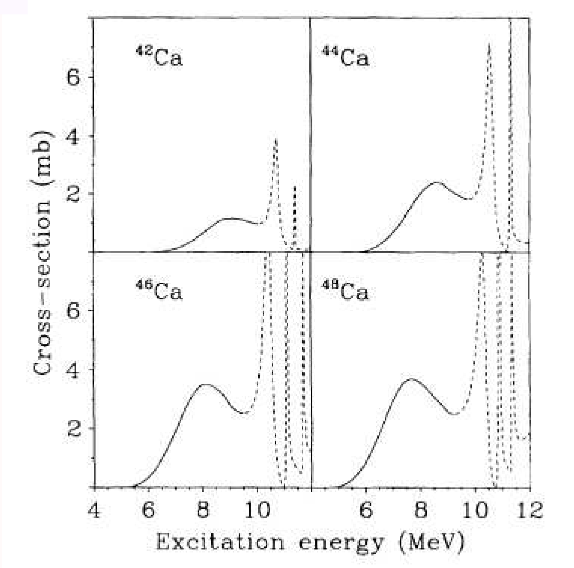
??

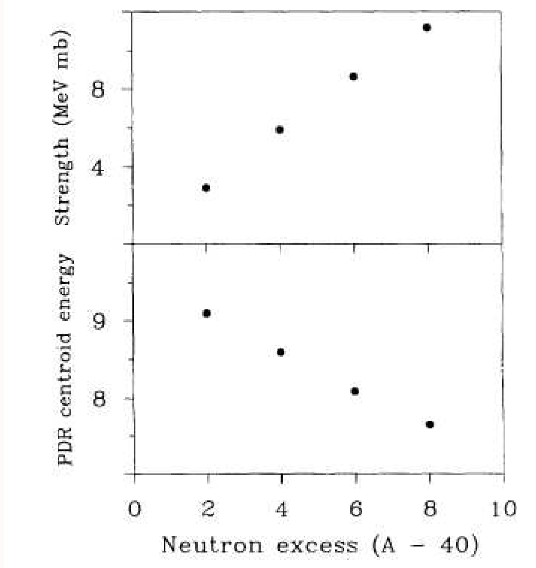
*from Bastrukov et al., PLB664(2008)*

# Pygmy Dipole Strength in Ca isotopes

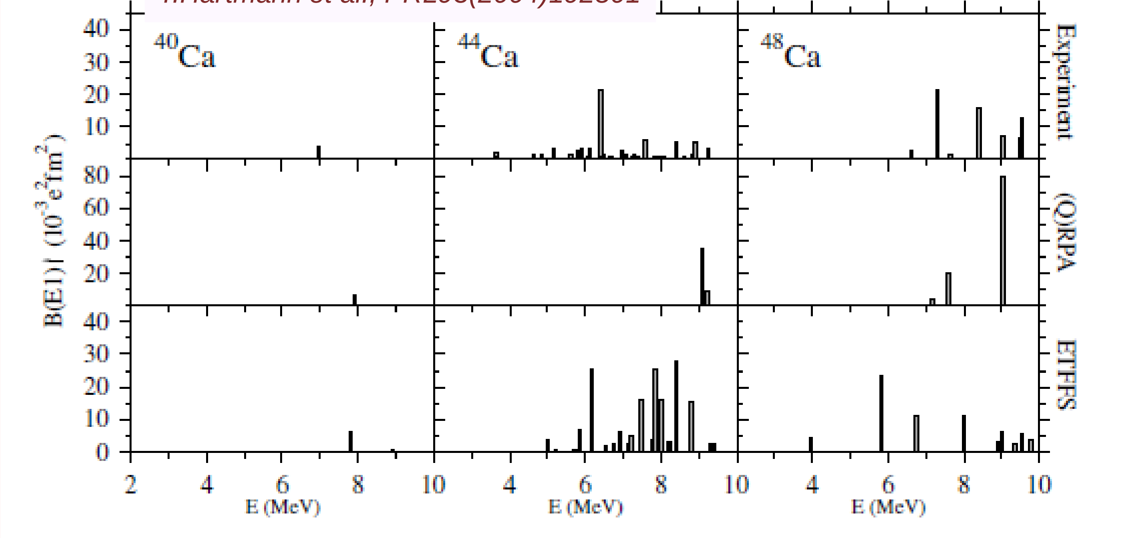
J.Chambers et al., PRC50(1994)R2671

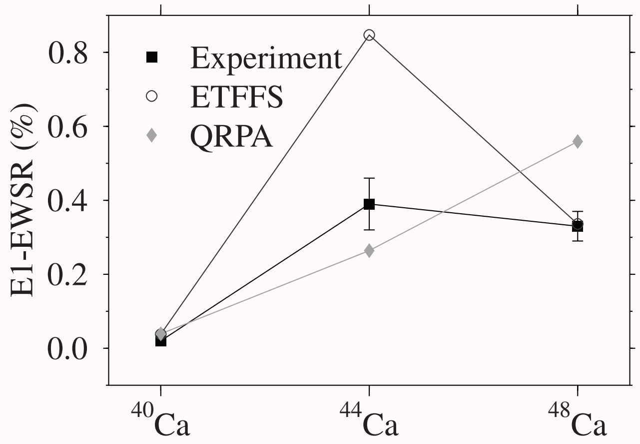


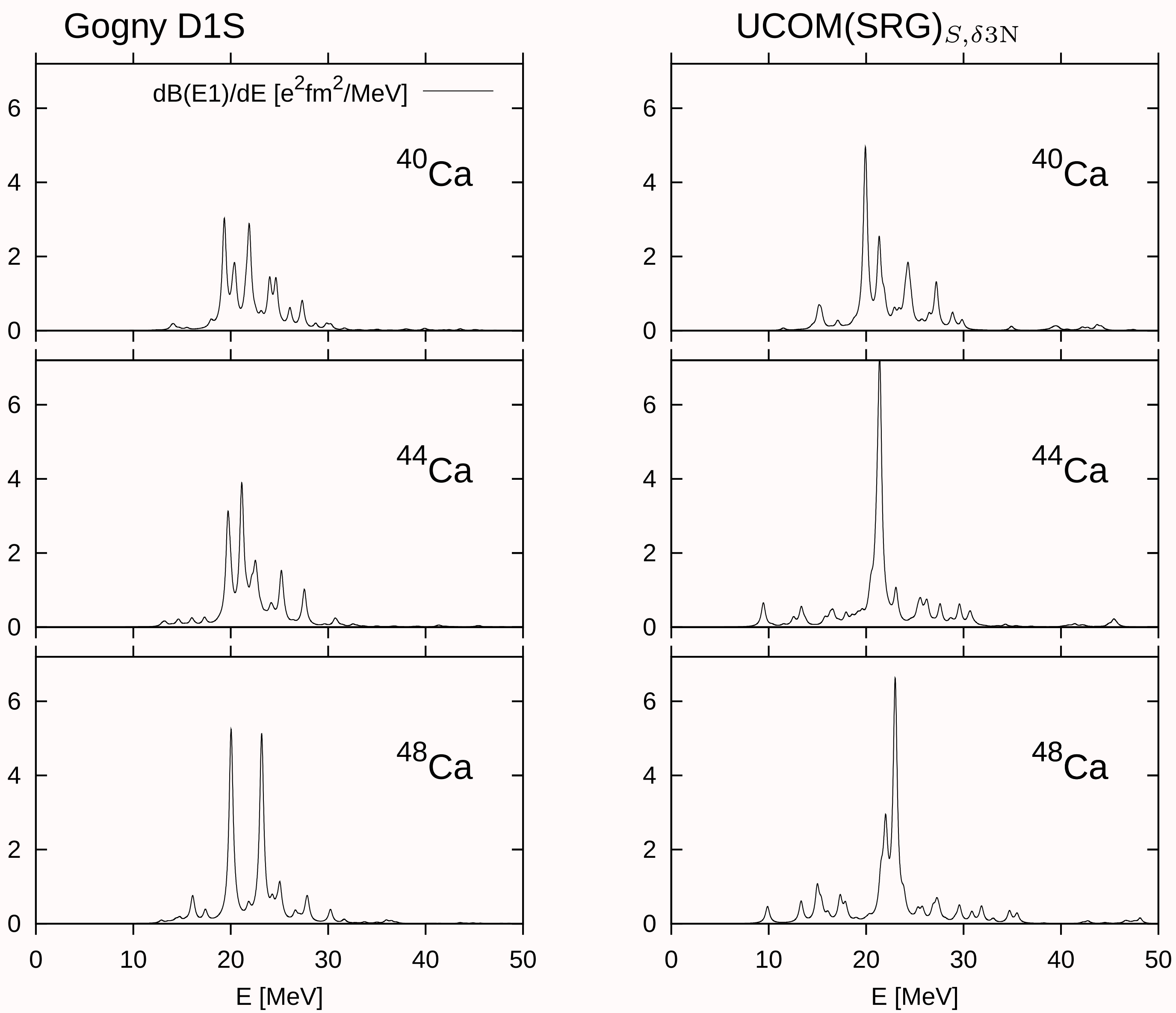




T.Hartmann et al., PRL93(2004)192501

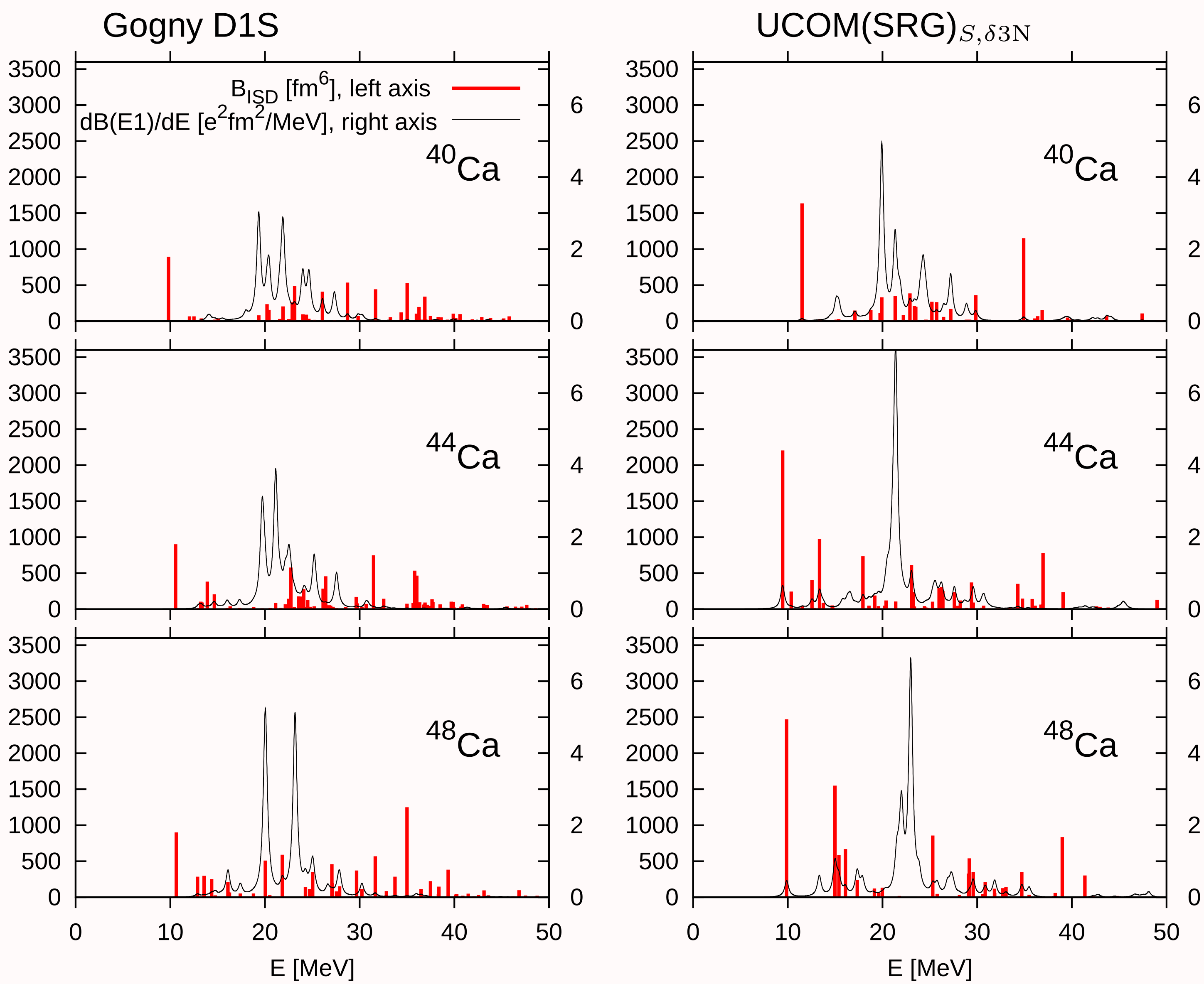


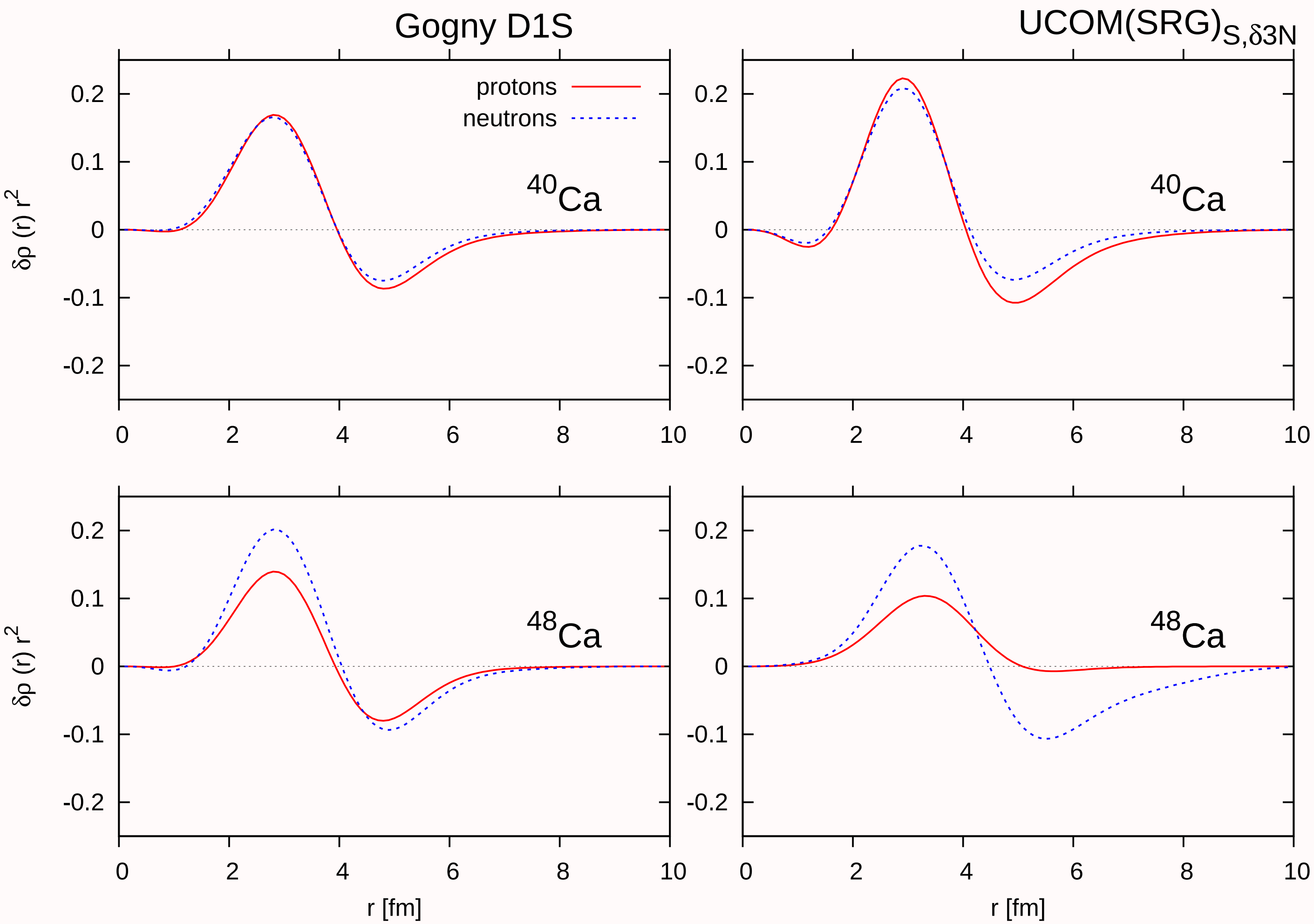
# Pygmy Dipole Strength in Ca isotopes



# Pygmy Dipole Strength in Ca isotopes

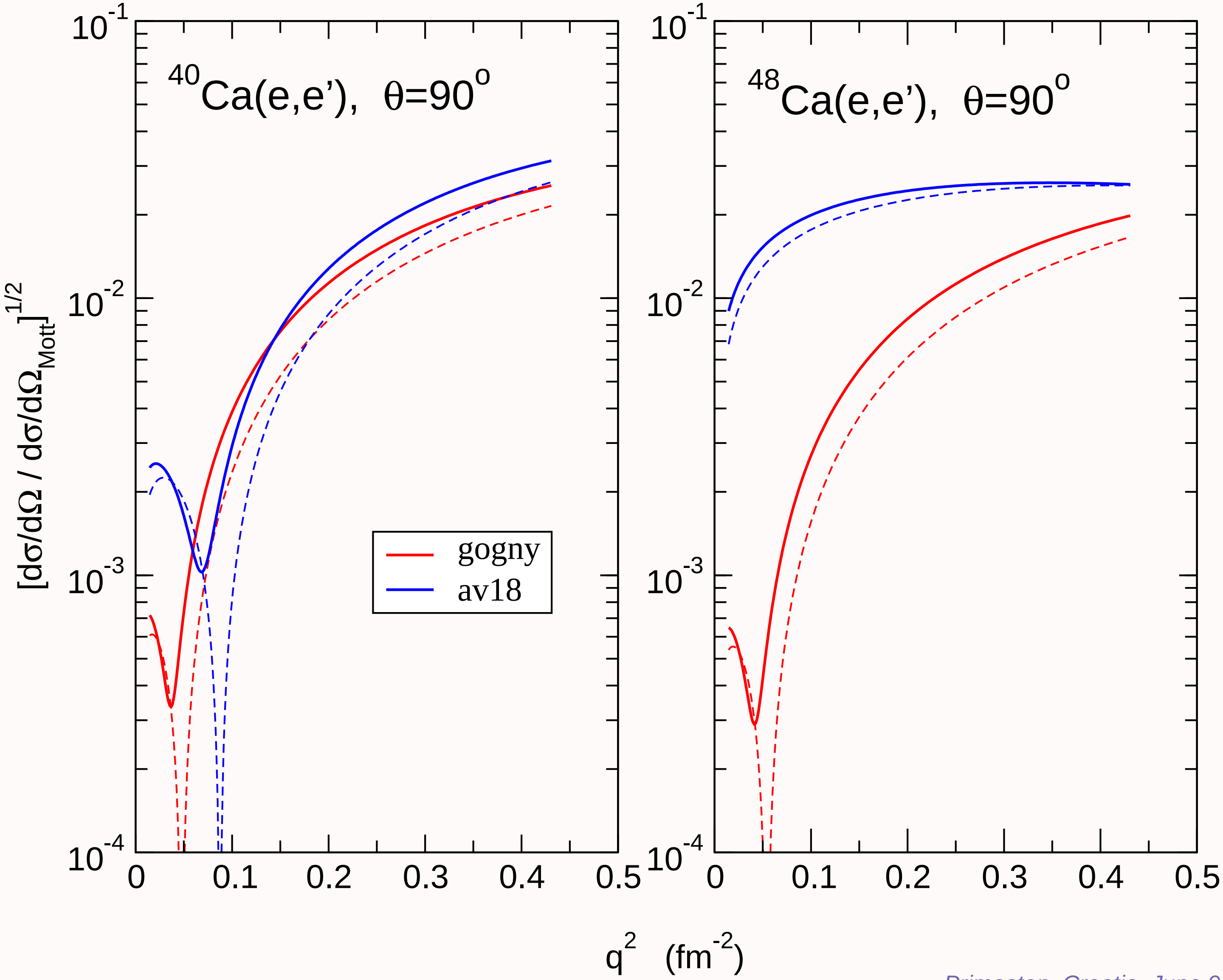


# Transition densities in $^{40}$Ca, $^{48}$Ca



# Electroexcitation in $^{48}$Ca?

Excitation of low-lying $1^-$ state in (e,e') reaction



# Summary

- **Low-energy dipole response**
  - Revisiting isospin-“forbidden” transitions: **Dipole collectivity does not require a neutron or proton skin**
  - A predominantly “isoscalar” vibrational mode can acquire increased E1 strength simply as a consequence of neutron-proton asymmetry, but does not necessarily become more coherent

    *See also: M.Urban, arXiv:1103.0861*

    ☞**Increased E1 strength** (*e.g.*, along an isotopic chain) **may indicate a structural change for a coherent mode, but not necessarily enhanced coherence**
- **The low-energy collective state in Ca isotopes:**
  - Two very different predictions were presented for $^{48}$Ca: IS-LED-type and neutron-skin type
  - An IS probe could locate it; electron scattering could distinguish between the two types of vibration ... and tell us which models are wrong!
  - Other similar cases may exist among stable nuclei...

  *are there two different modes, maybe?*
- **...**

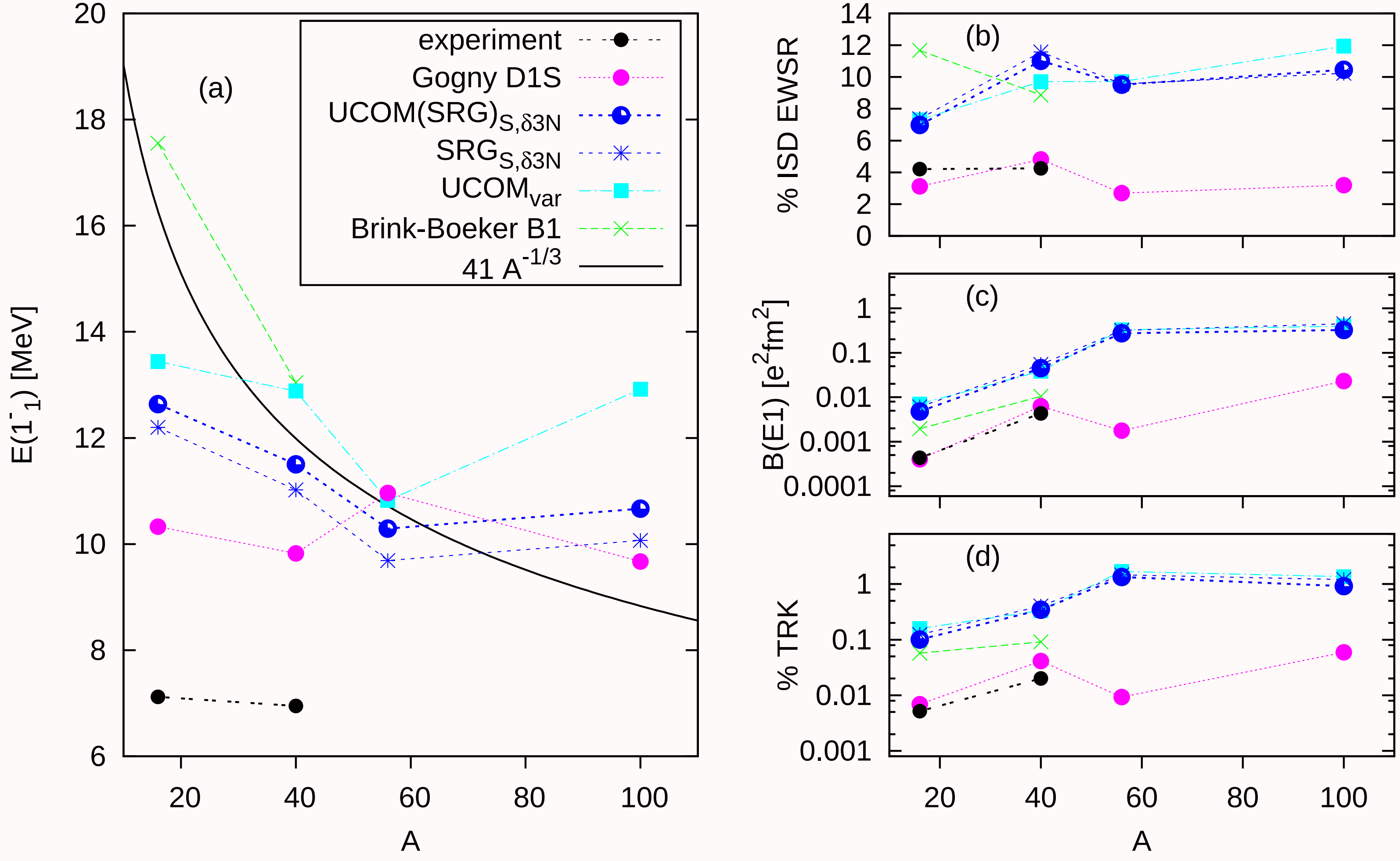
# Stay tuned!

### Many thanks to ...

- R. Roth and the TNP++ group, V.Yu.Ponomarev, J.Wambach, P. von Neumann-Cosel, ... (Institut für Kernphysik, TU Darmstadt, Germany), A. Richter, (TUD,ECT*), H.Hergert (MSU) ...

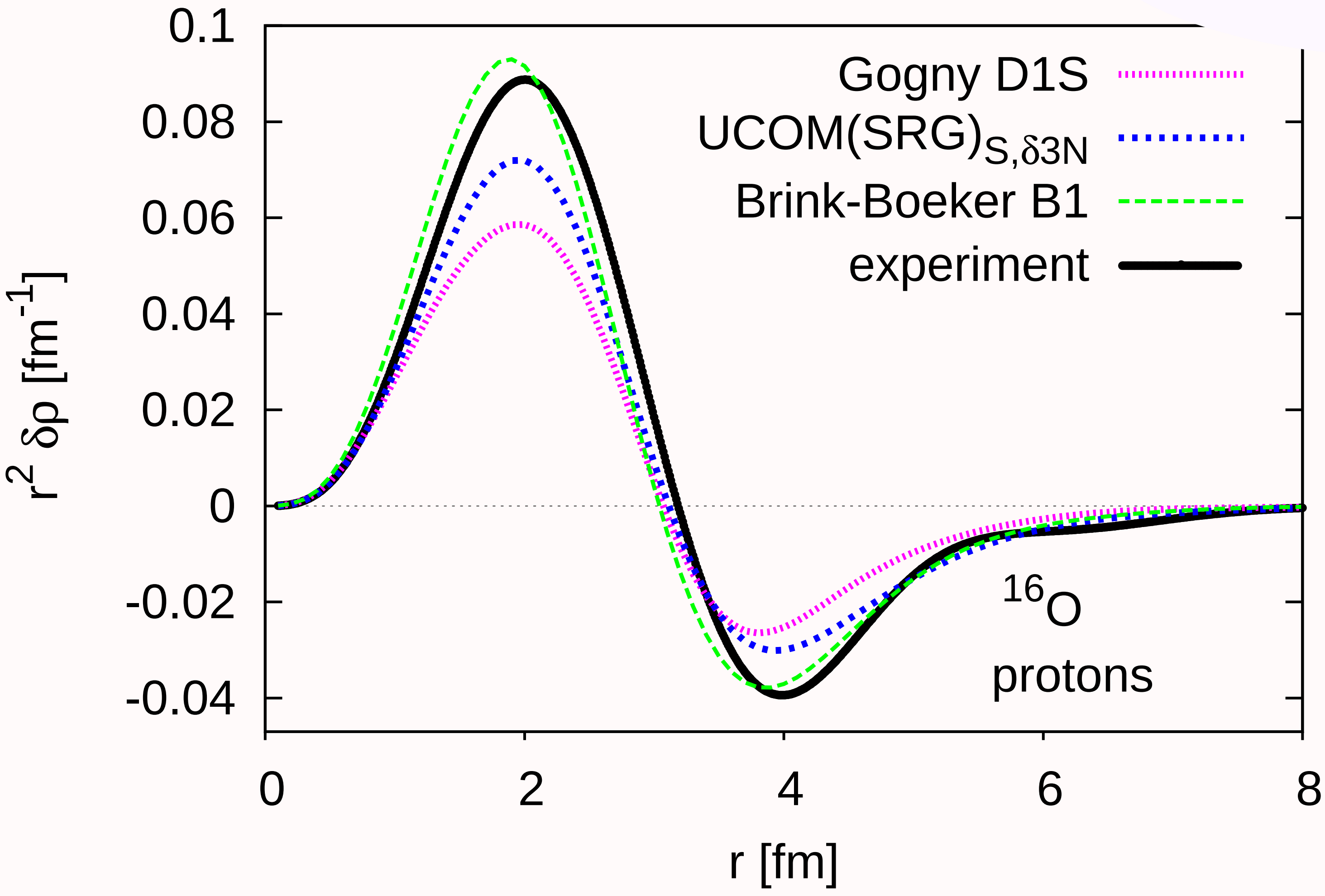
# Thank you!

# IS-LED : energy and strength



# Transition density

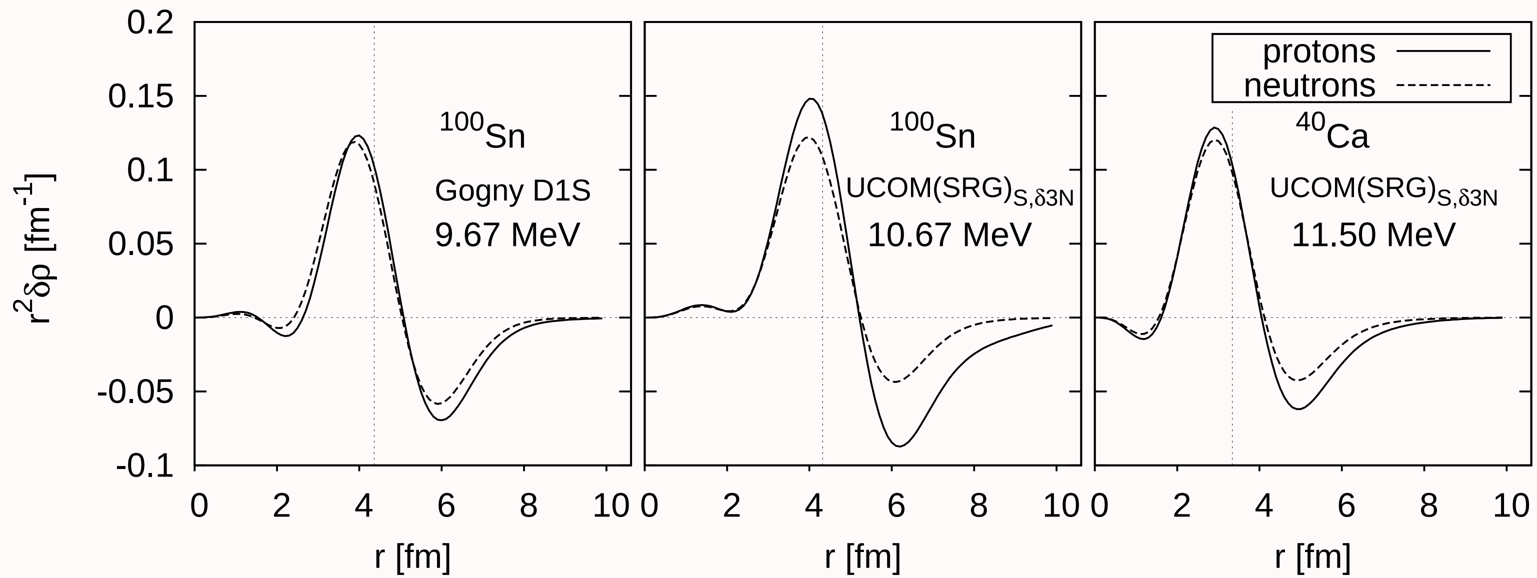
Experimental transition density with node reproduced!

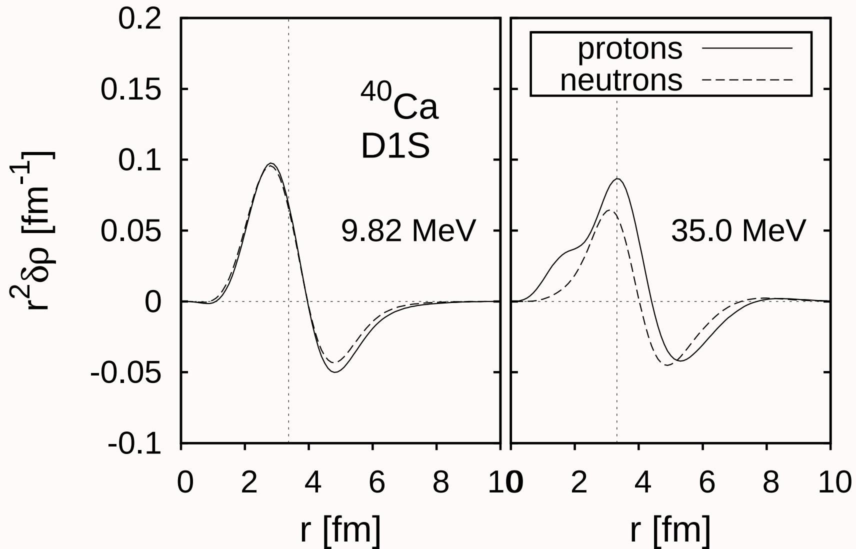



*exp: MIT Bates; Buti et al, PRC33(1986)755*

# Transition density

E1 strength solely due to Coulomb interaction




**role of symmetry energy?**