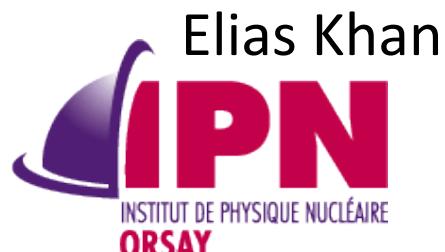


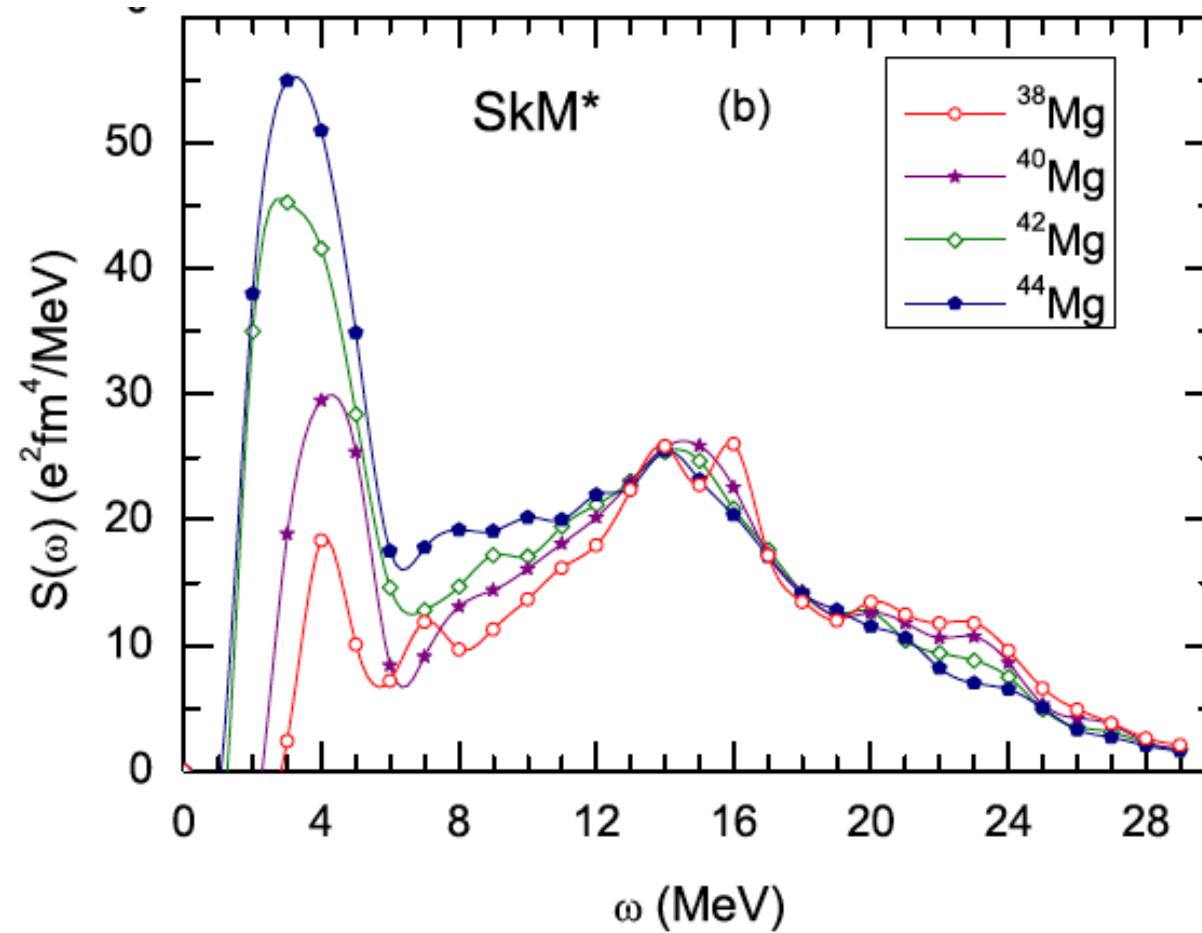
Recent theoretical and experimental advances on giant resonances in unstable nuclei

- 1) What's new on soft modes ?
- 2) Exp. and theo. breakthroughs
- 3) Astrophysics



1) What's new on soft modes ?

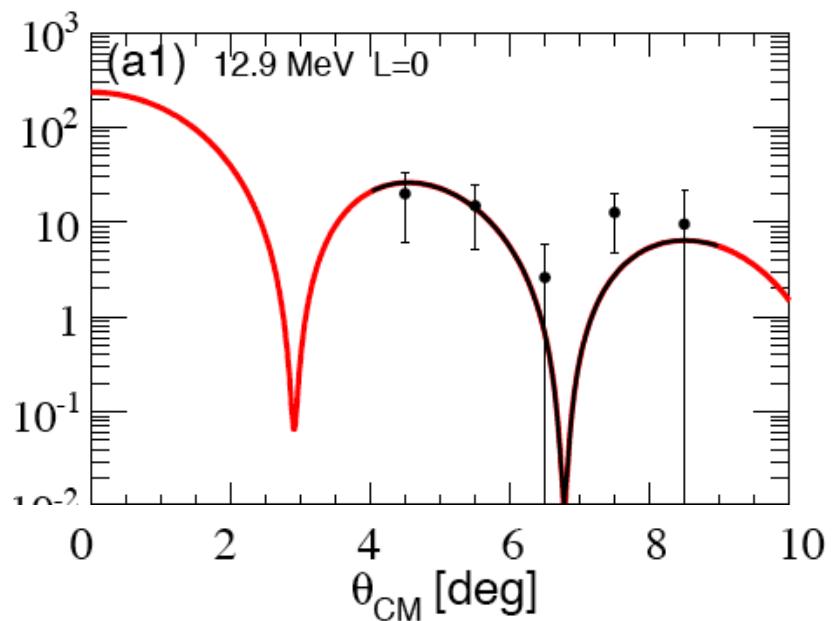
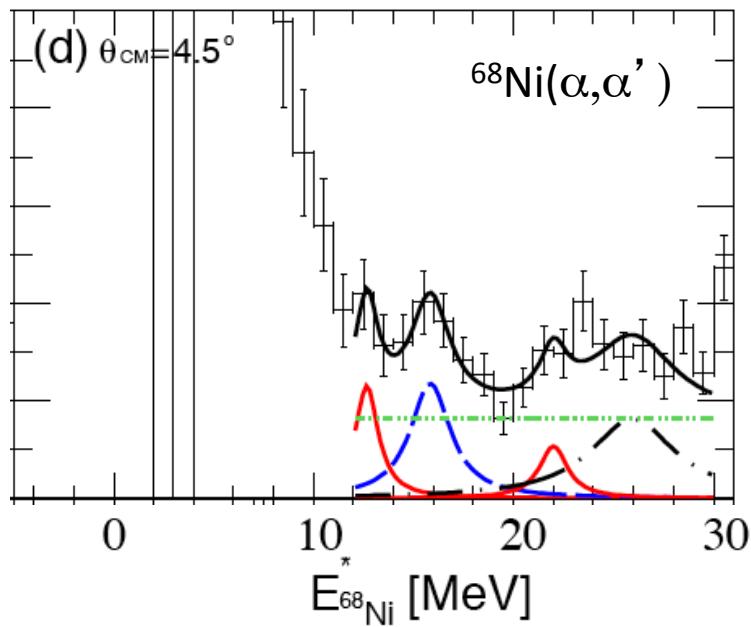
New soft modes: the soft GMR



J.C. Pei et al, PRC90(2014)051304(R)

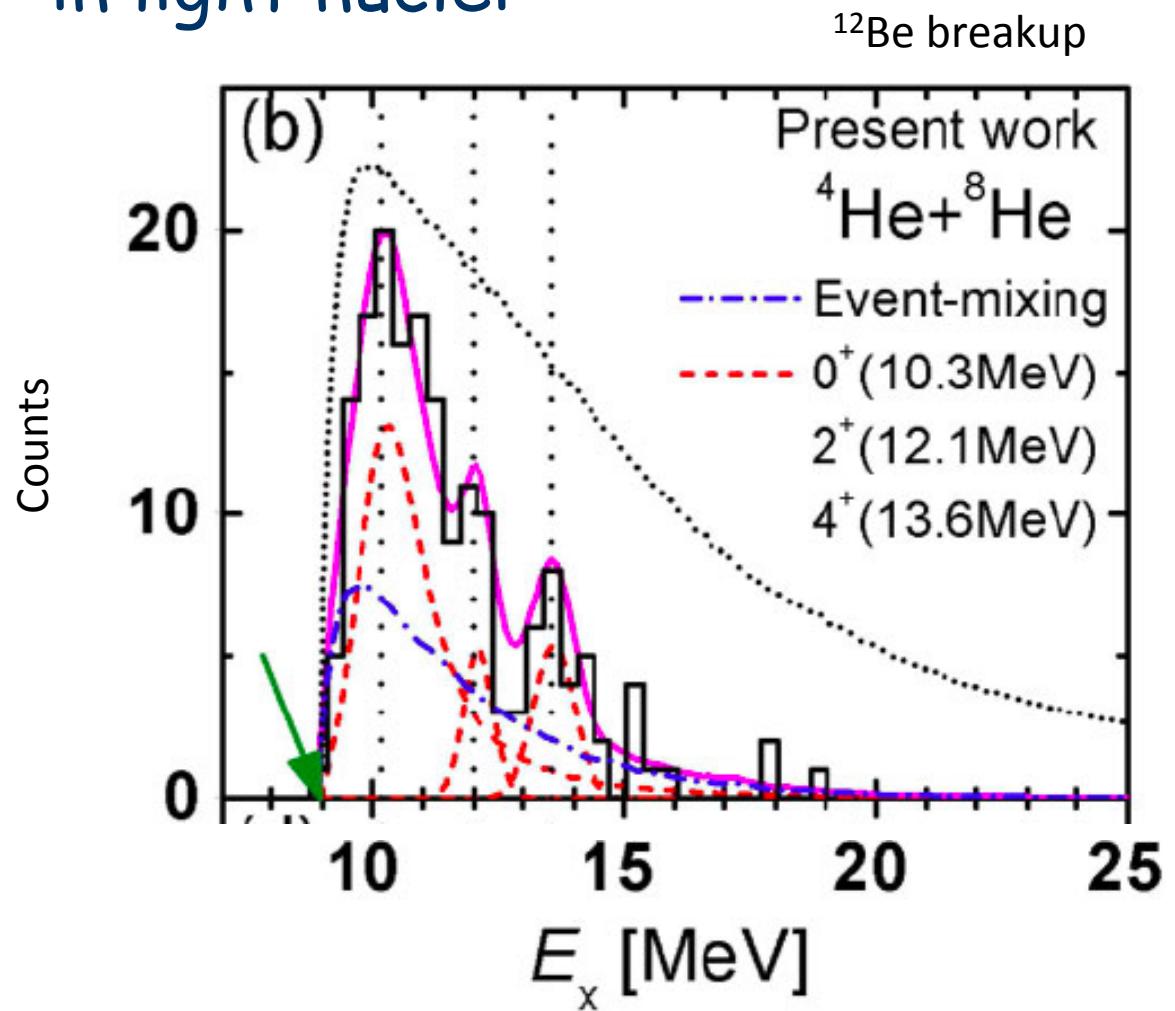
Deformation and continuum coupling effects, FAM method

New soft modes: the soft GMR



M.Vandebrueck et al. Phys Rev. Lett. 113, 032504 (2014)

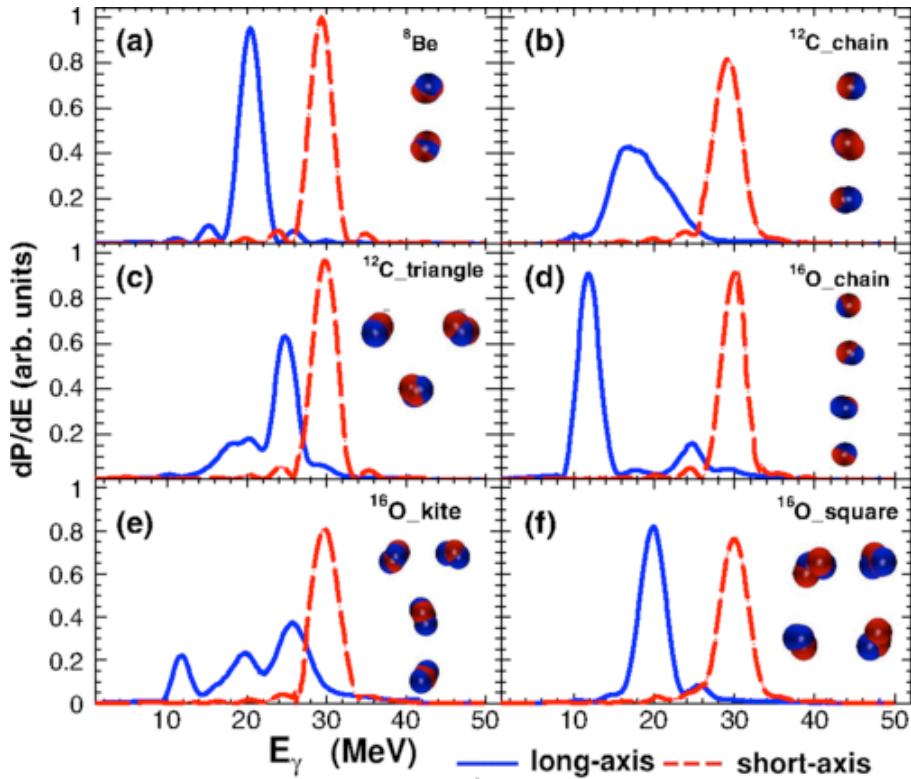
New soft modes: the monopole strength in light nuclei



Z.H. Yang et al, PRL112(2014)162501
PRC9152015)024304

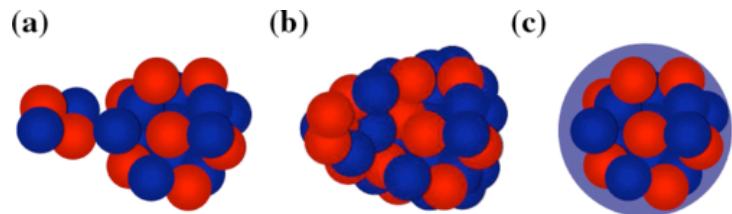
Enhanced soft monopole transition due to clusters ?

The (soft) E1 for clusters



Prediction of enhanced
GDR and soft E1 strength
due to cluster configurations

Nd, Sm, Gd, Dy



W.B. He et al, PRL113(2014)032506

M. Spieker et al, PRL114(2015)192504

Prediction for n-rich nuclei ?

Specific cluster modes of excitation ?

$$\begin{aligned}\mathcal{L}_m = & \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu \\ & - \frac{1}{4}\vec{R}_{\mu\nu}\vec{R}^{\mu\nu} + \frac{1}{2}m_\rho^2\vec{\rho}_\mu\vec{\rho}^\mu - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}\end{aligned}$$

$$E_{\text{RHB}}[\hat{\rho}, \hat{k}, \phi] = E_{\text{RMF}}[\hat{\rho}, \phi] + E_{\text{pair}}[\hat{k}].$$

^{20}Ne



$$\begin{aligned}E_{\text{RMF}}[\hat{\rho}, \phi] = & \text{Tr}[(-i\alpha\boldsymbol{\nabla} + \beta m)\hat{\rho}] + \sum_m \text{Tr}[(\beta\Gamma_m\phi_m)\hat{\rho}] \\ & \pm \frac{1}{2}\sum_m \int d^3r \left[(\partial_\mu\phi_m)^2 + m_m^2 \right].\end{aligned}$$

$$\begin{aligned}\mathcal{L}_{\text{int}} = & -g_\sigma\bar{\psi}\sigma\psi - g_\omega\bar{\psi}\gamma^\mu\omega_\mu\psi - g_\rho\bar{\psi}\gamma^\mu\vec{\tau}\vec{\rho}_\mu\psi \\ & - e\bar{\psi}\frac{1}{2}(1-\tau_3)\gamma^\mu A_\mu\psi,\end{aligned}$$

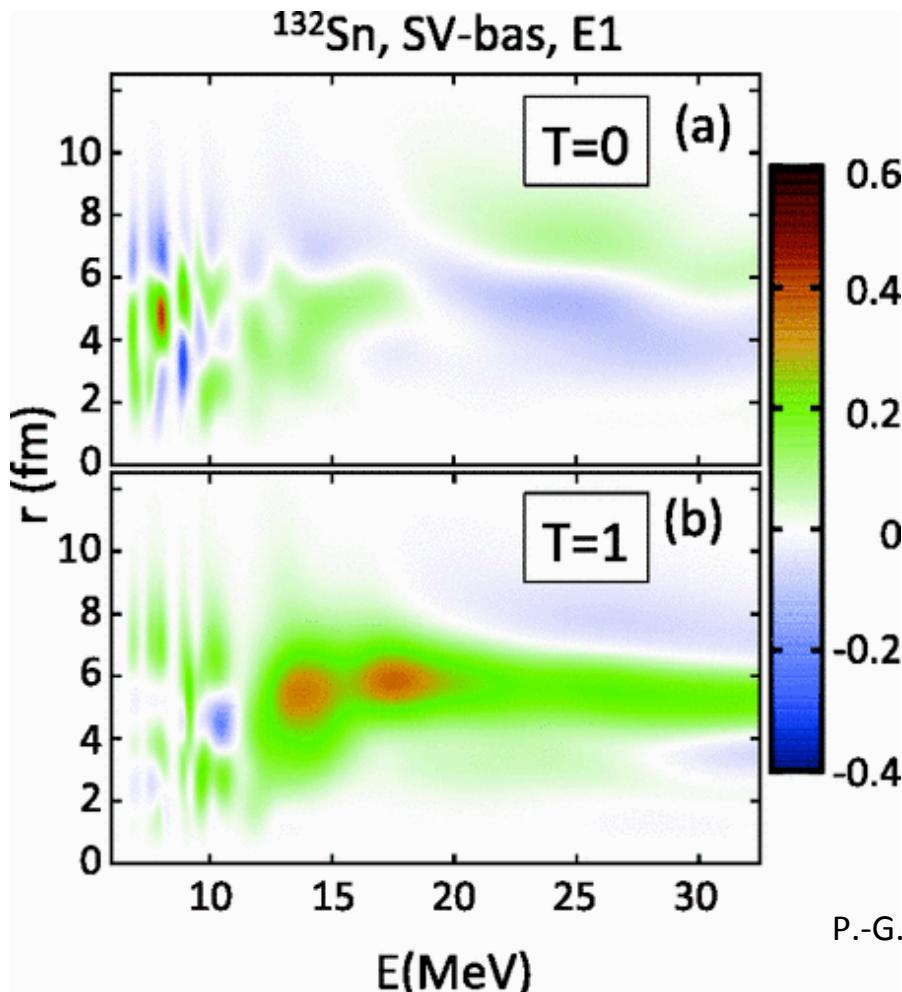
$$V_{kl'k'l}^{ph} = \langle kl' | \hat{V}^{ph} | k'l \rangle = \frac{\delta^2 E_{\text{RHB}}}{\delta \rho_{k'k} \delta \rho_{ll'}}$$

D. Peña Arteaga
(QRPAz)

$$\begin{pmatrix} A & B \\ -B^* & -A^* \end{pmatrix} \begin{pmatrix} X^{(v)} \\ Y^{(v)} \end{pmatrix} = \Omega^{(v)} \begin{pmatrix} X^{(v)} \\ Y^{(v)} \end{pmatrix} \quad \langle 0 | \hat{\mathcal{O}} | v \rangle = \sum_{kk'} (\mathcal{O}_{k'k} X_{kk'}^{(v)} + \mathcal{O}_{kk'}^* Y_{kk'}^{(v)}) (u_k v_{k'} + \tau v_k u_{k'})$$

The pygmy status

- > 2000 Difficult to interpret the PDR in unstable nuclei → 2015: Large activity on stable nuclei: isospin features, effect of deformation, neutron excess
- Soft E1 in n-rich: IS component (Schiff moment), complex pattern : pn mode, ...

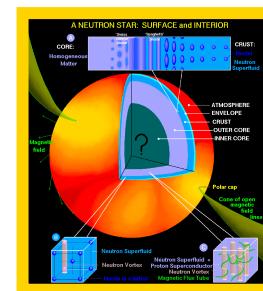
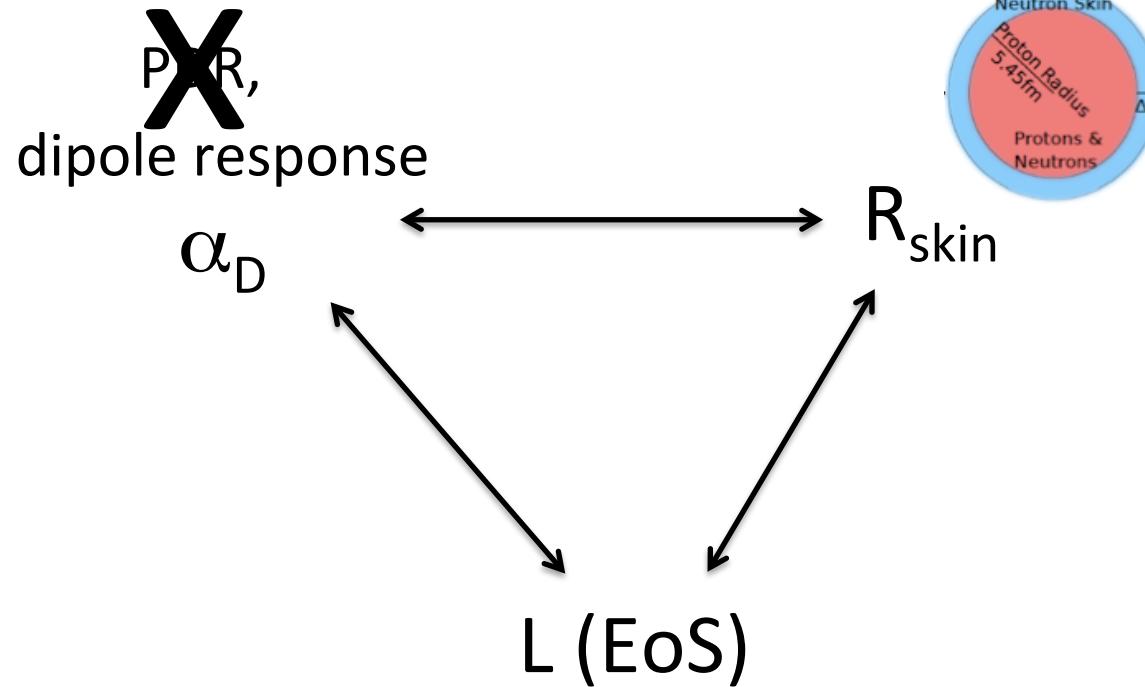
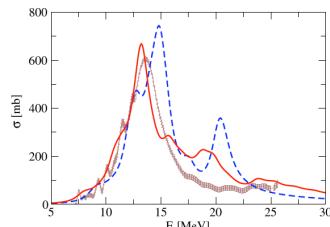


N. Auerbach et al., PRC89(2015)014335
H. Nakada et al., PRC87(2013)034302

Soft E1 is has a complex non-collective pattern, rather $\text{IS} \neq \text{pygmy}$

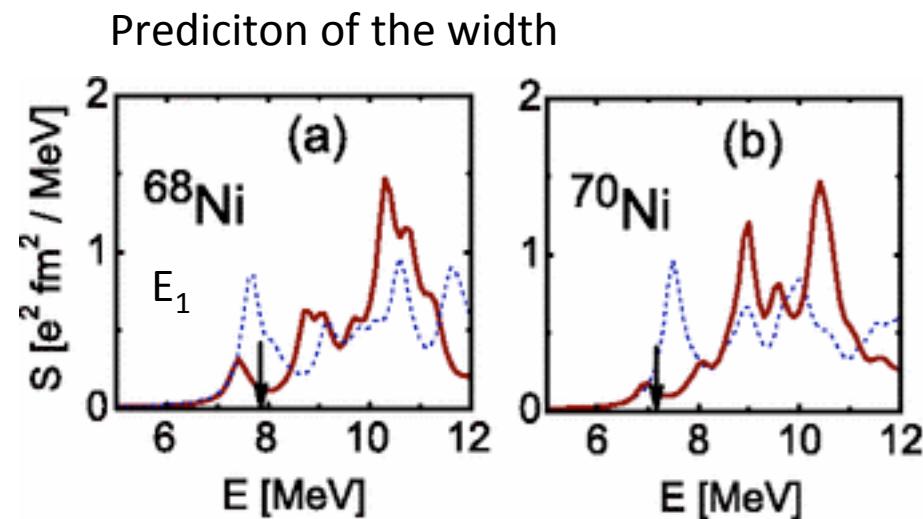
P.-G. Reinhard and W. Nazarewicz, PRC87(2013)014324

The pygmy status: the n-rich triangle

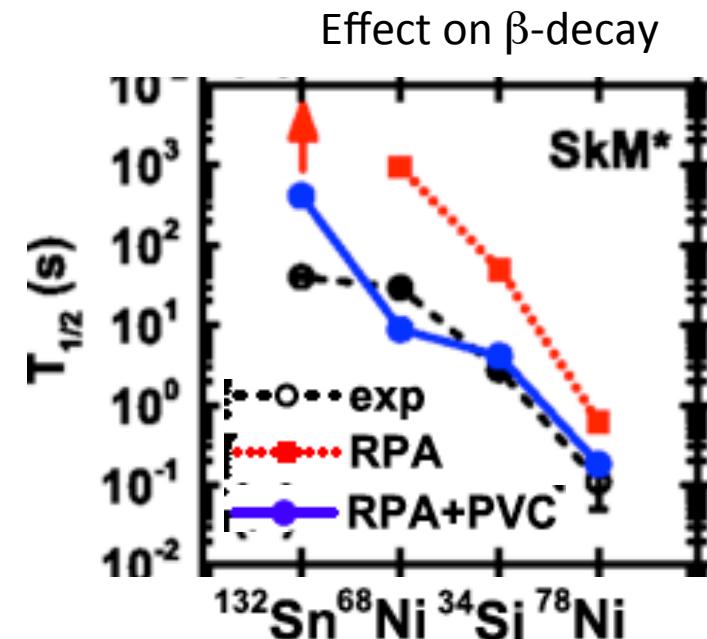


2) Exp. and theo breakthroughs

Particle-vibration coupling



E. Litvinova et al., PRL105(2010)022502



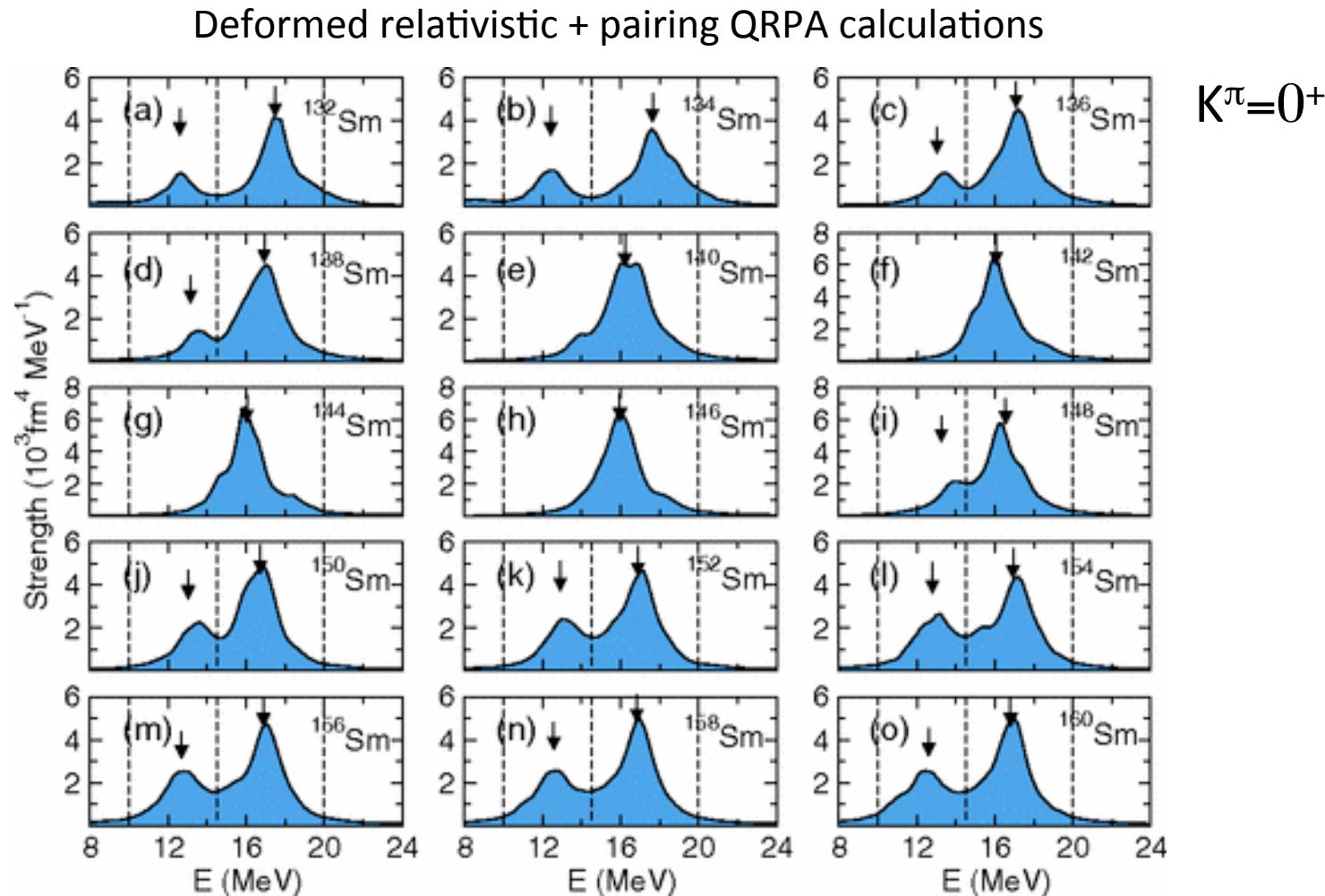
Y.F. Niu et al., PRL114(2015)142501

Particle-vibration coupling with continuum

K. Mizuyama et al., PRC86(2012)034318

Finite Amplitude Method

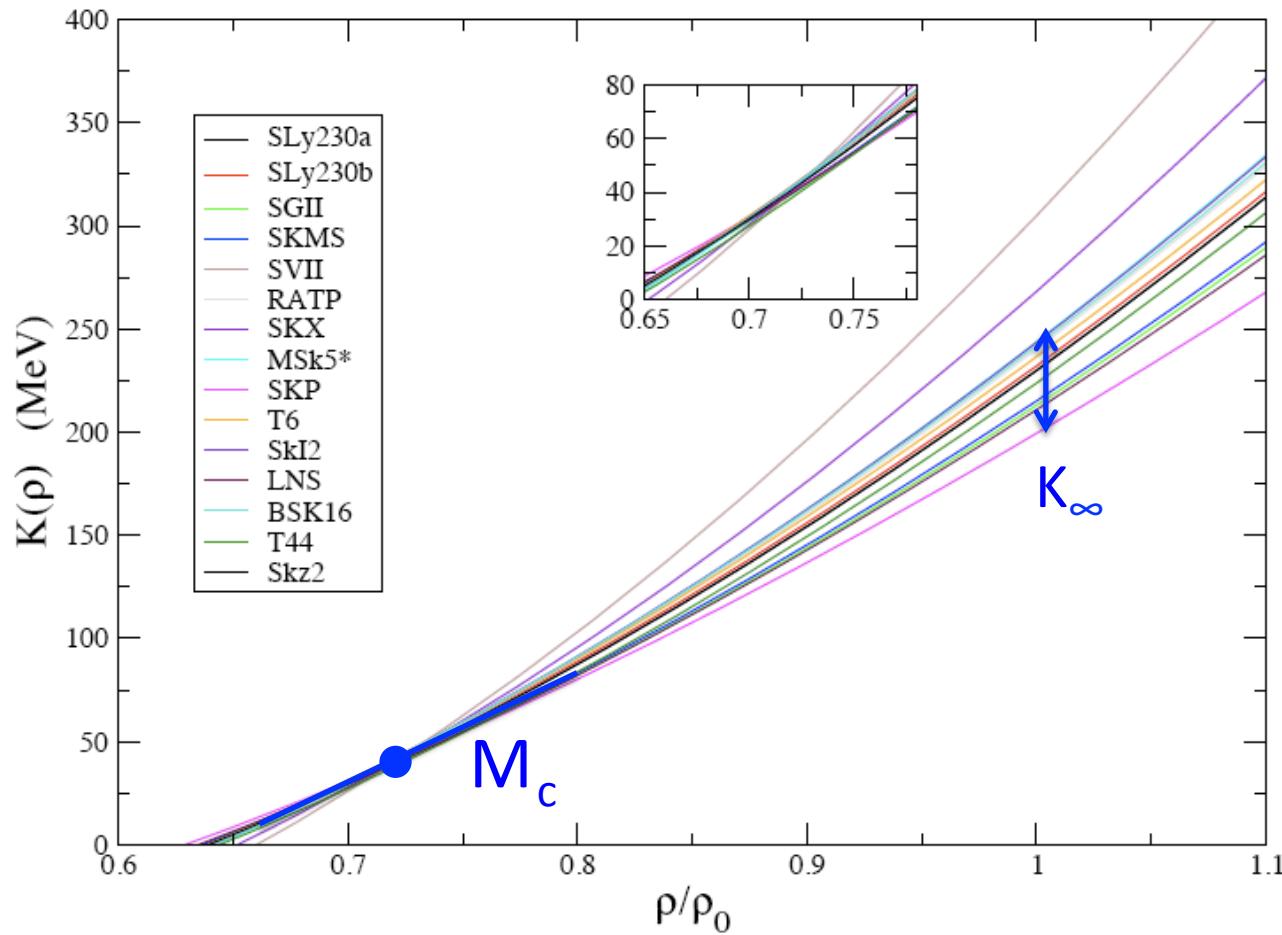
- Allows for large scale QRPA calculations P. Avogadro and T. Nakatsukasa, PRC87(2013)014331



T. Niksic et al., PRC88(2013)044327

The dens. dep of K

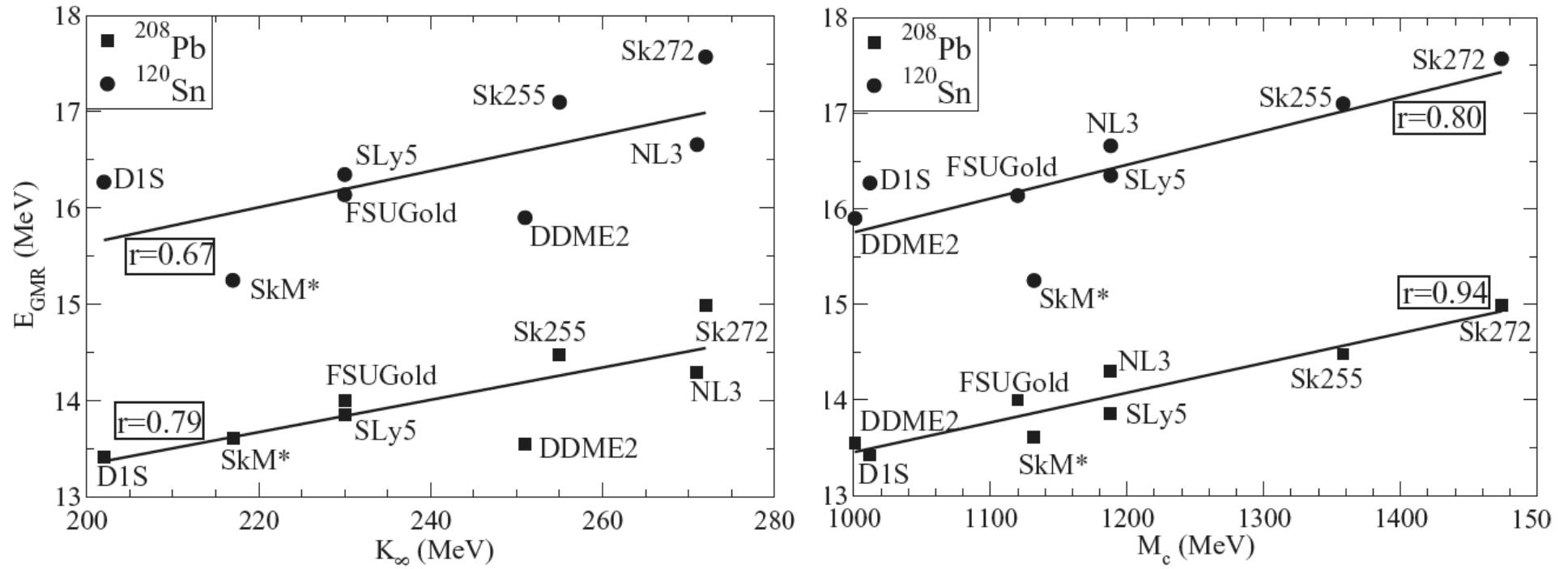
$M_c = 3\rho K'(\rho)|_{\rho=\rho_c}$: third derivative of EoS at the crossing density



E. Khan et al., PRL109(2012)092501

E. Khan and J. Margueron, PRC88(2013)034319

From the GMR to nuclear matter



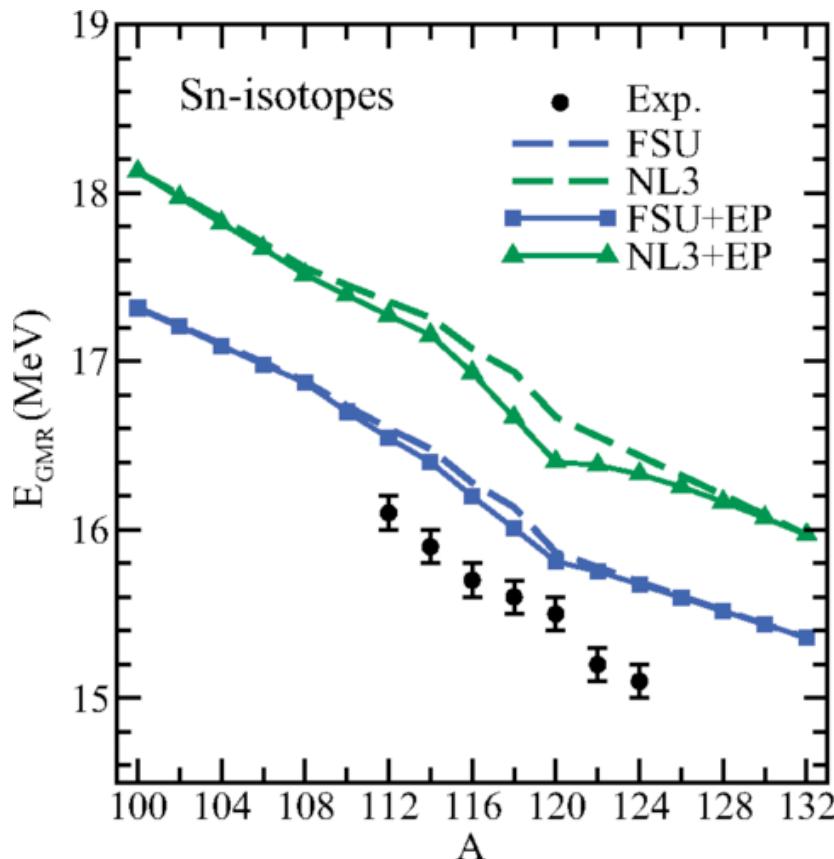
$$K_\infty = 240 \pm 30 \text{ MeV}$$

$$M_c = 1050 \pm 100 \text{ MeV}$$

M_c better constrained by the data than K_∞

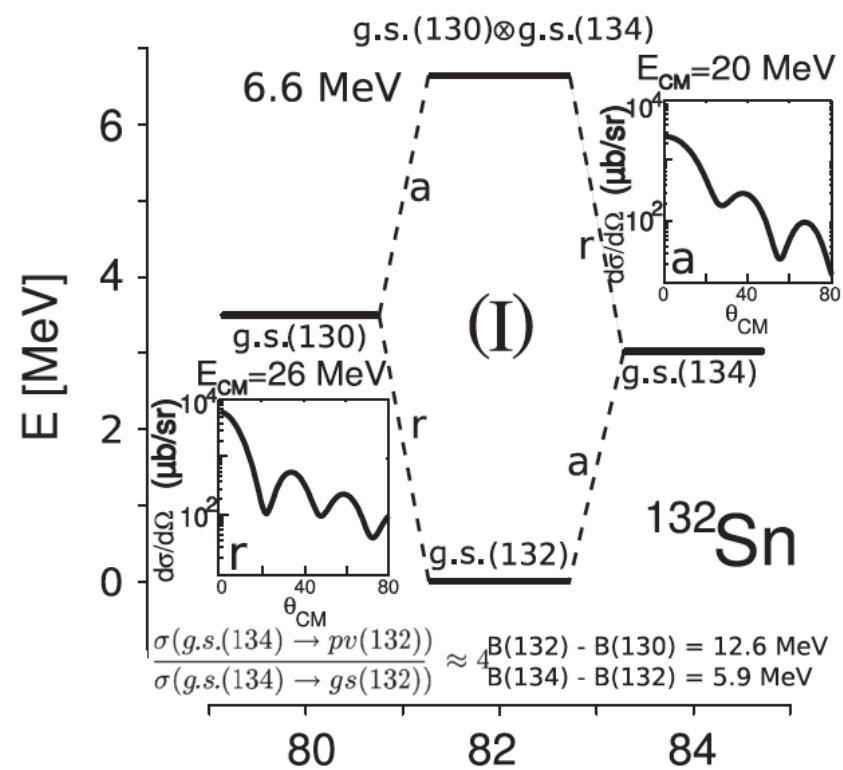
Pairing related excitations

Small pairing effect on GMR



W.-C. Chen et al., PRC89(2014)014321

Pairing vibration prediction



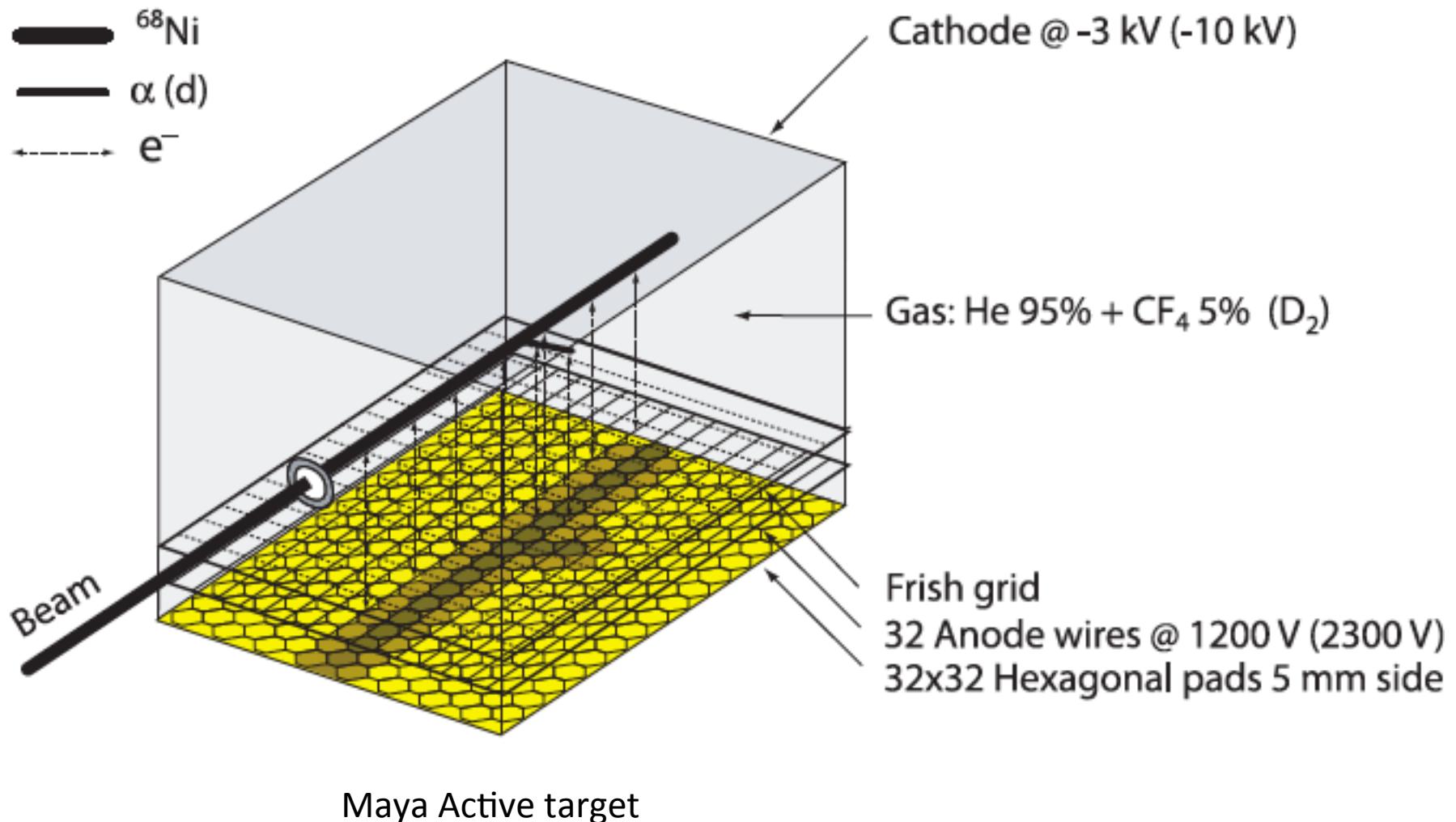
G. Potel et al., PRL107(2011)092501

Softness of Sn isotopes requires relevant density dependence on incompressibility

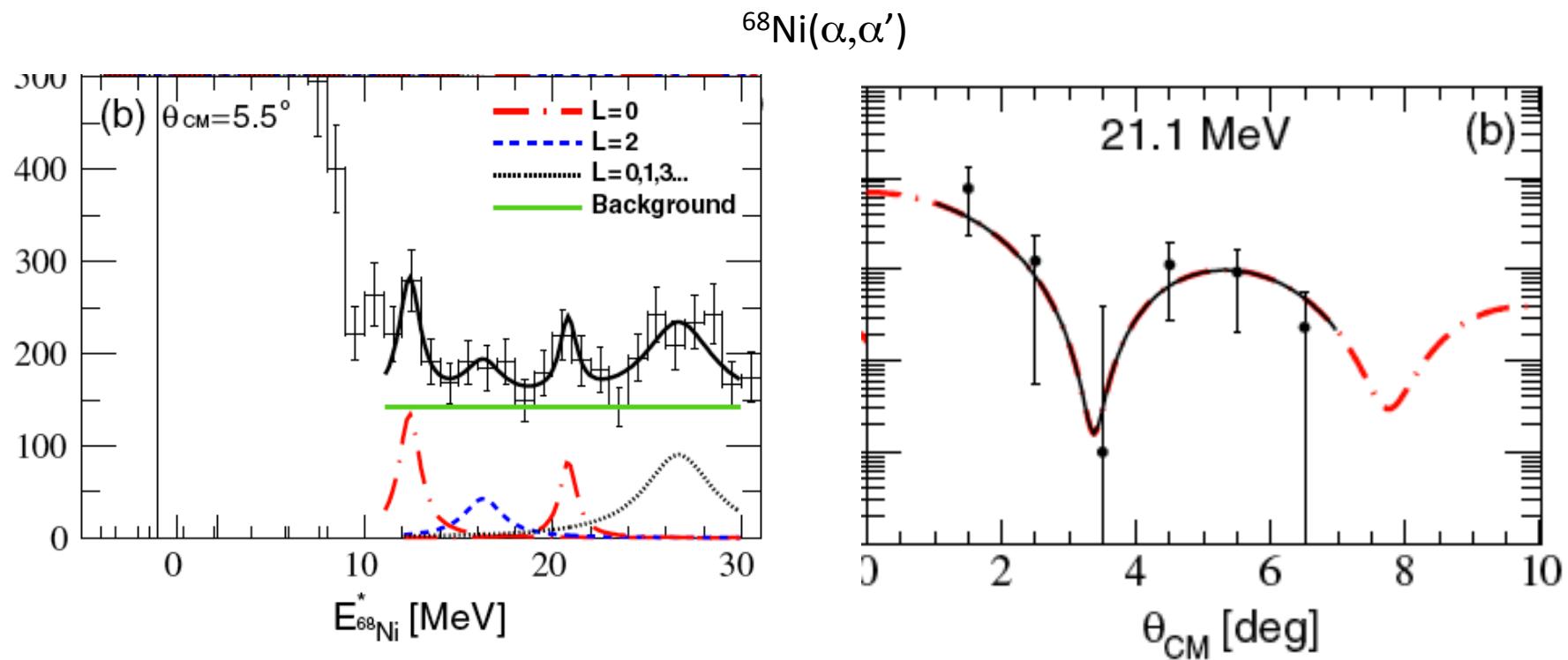
The external detector way

- Coulex in inverse kinematics
- $^{132}\text{Sn}(\alpha, \alpha')$ in Riken
- See K. Boretzky's talk
- Soft E1 in n-rich Oxygen, Tin, Ni

The active target way



The active target way



Results: M.Vandebruck et al. Phys Rev. Lett. 113, 032504 (2014)
Method: C. Monrozeau et al., Phys Rev. Lett. 100, 042501 (2008)

MAYA : ^{56}Ni
AT-TPC (MSU)
Actar
CAT (Riken)



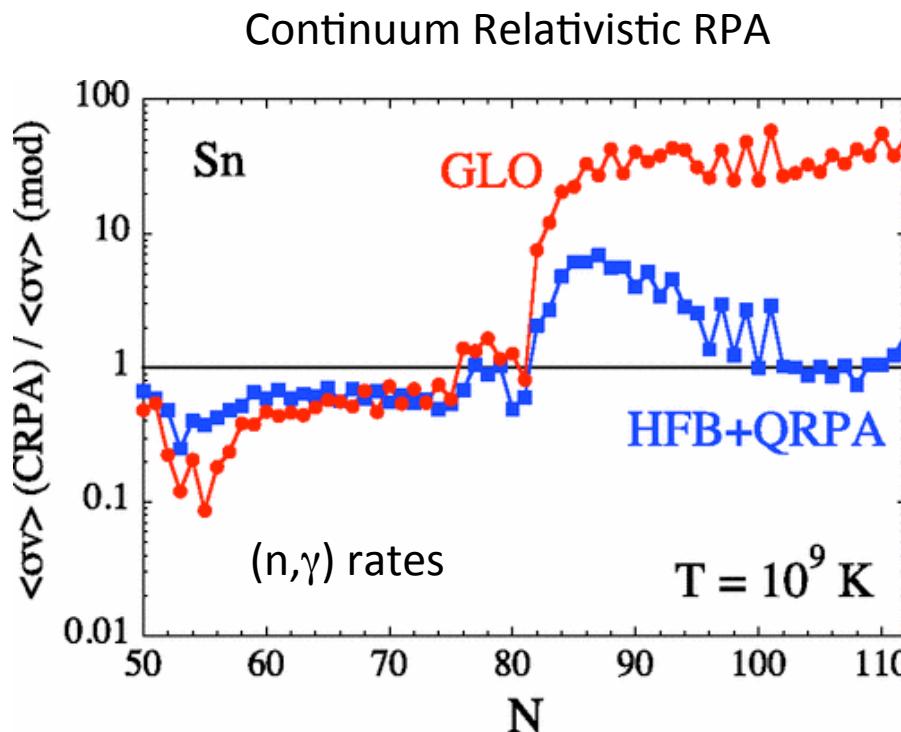
ISGMR in unstable nuclei

The storage ring way

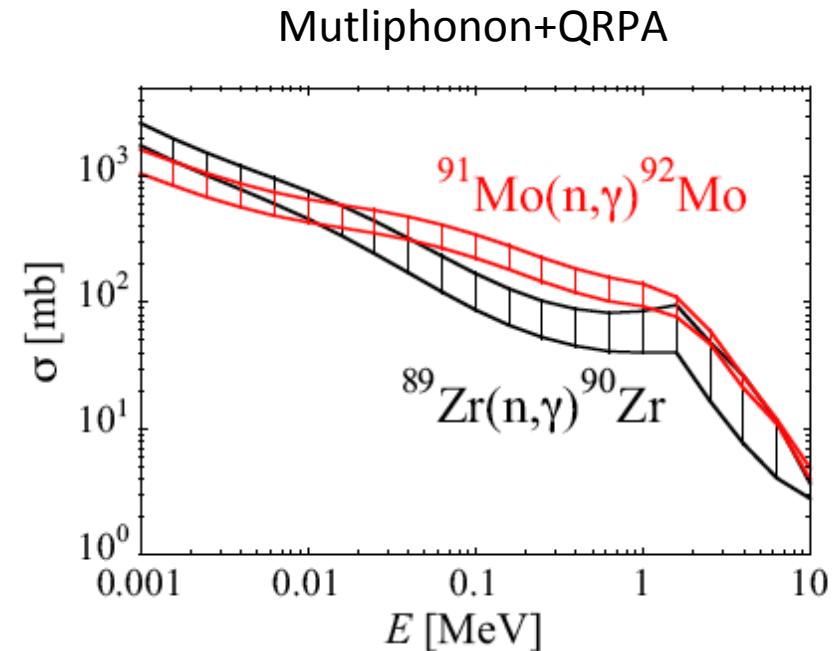
See e.g. the EXL collaboration (GSI)

3) Astrophysics

The r-process



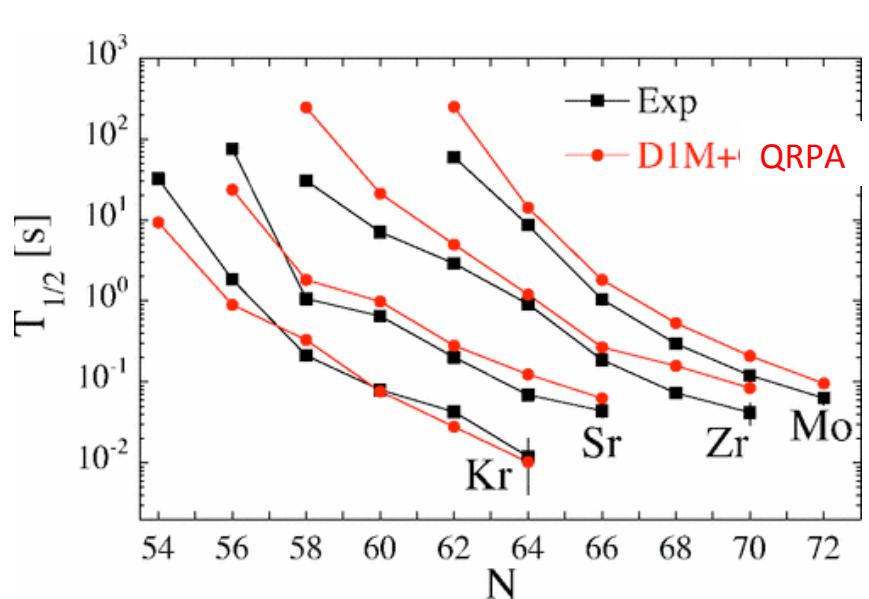
I. Daoutidis and S. Goriely, PRC86(2012)034328



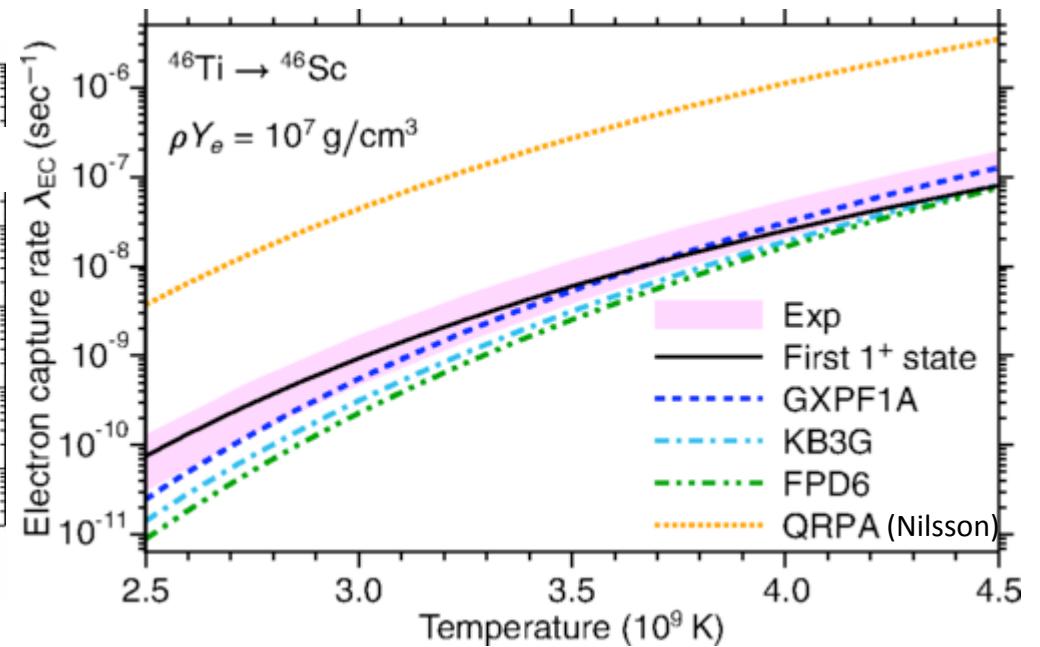
N. Tsoneva et al., PRC91(2015)044318

β decay ; Electron capture

Deformed+finite range GT strength



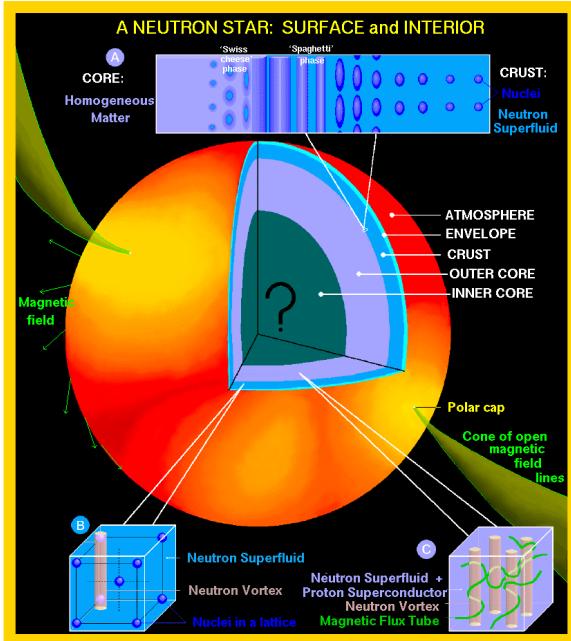
Exp. from $^{46}\text{Ti}(t, {}^3\text{He} + \gamma)$



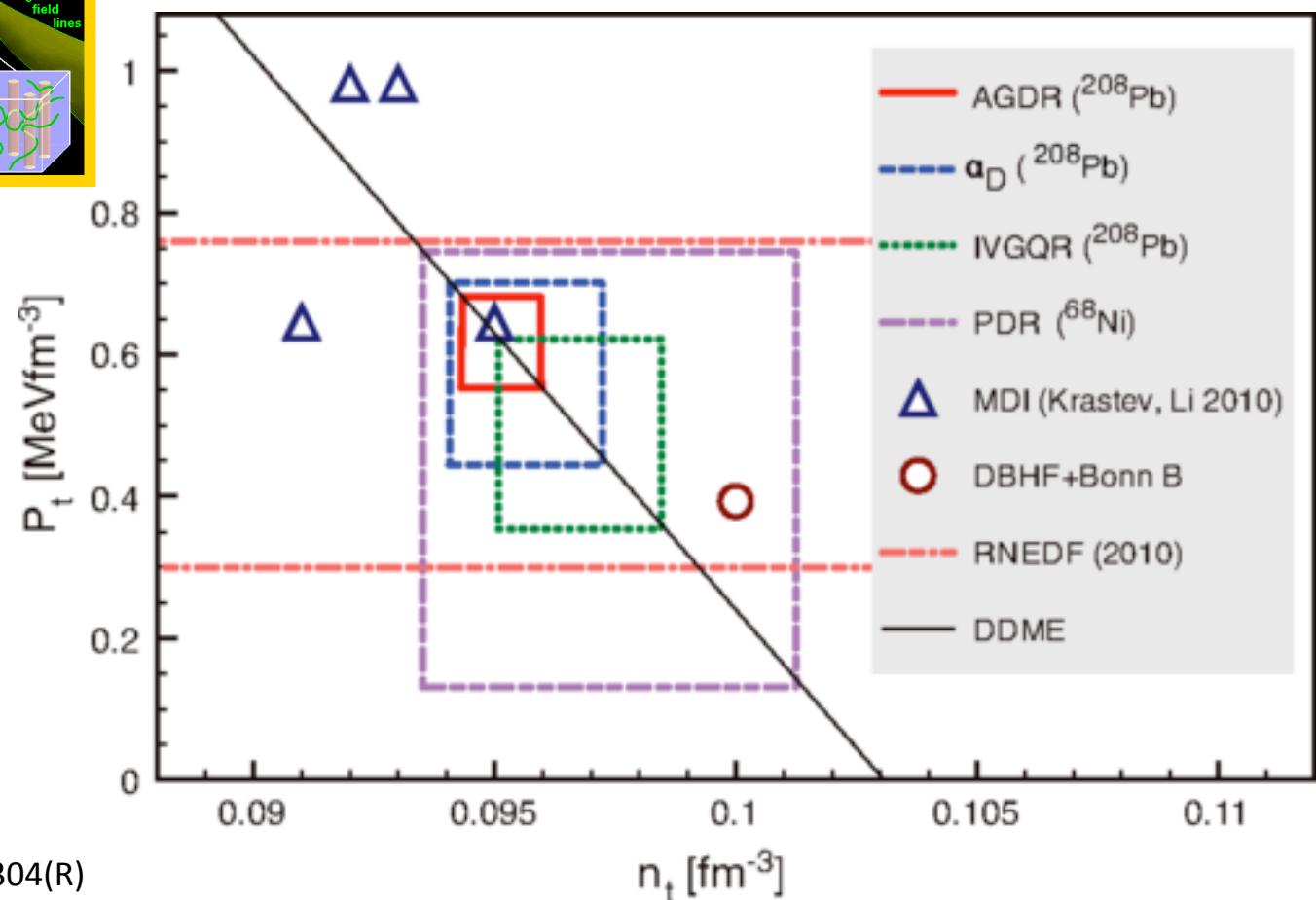
M. Martini et al., PRC89(2014)044306

S. Noji et al., PRL112(2014)252501

Neutron stars



Liquid to solid transition



Outlook

- Soft modes: monopole ?
- Cluster mode ?
- PDR : stable nuclei ?
- Active targets and storage rings
- Deformation+continuum+finite range+vibration coupling+ relativistic
- Density dependence of nuclear incompressibility
- Astrophysical impact: r-process, e-capture and neutron stars