# Low-lying Gamow-Teller excitations and beta-decay properties of neutron-rich Zr isotopes

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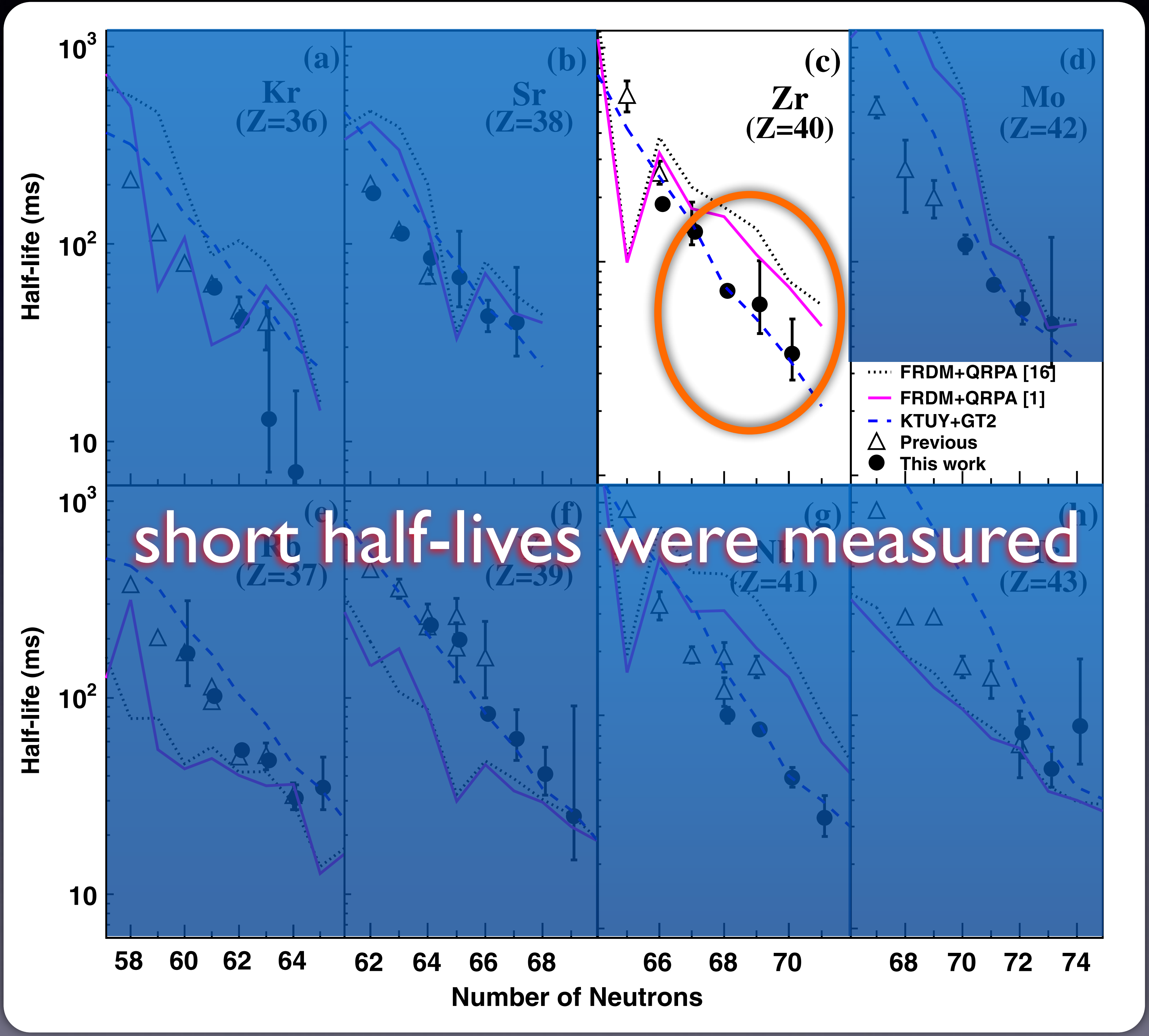
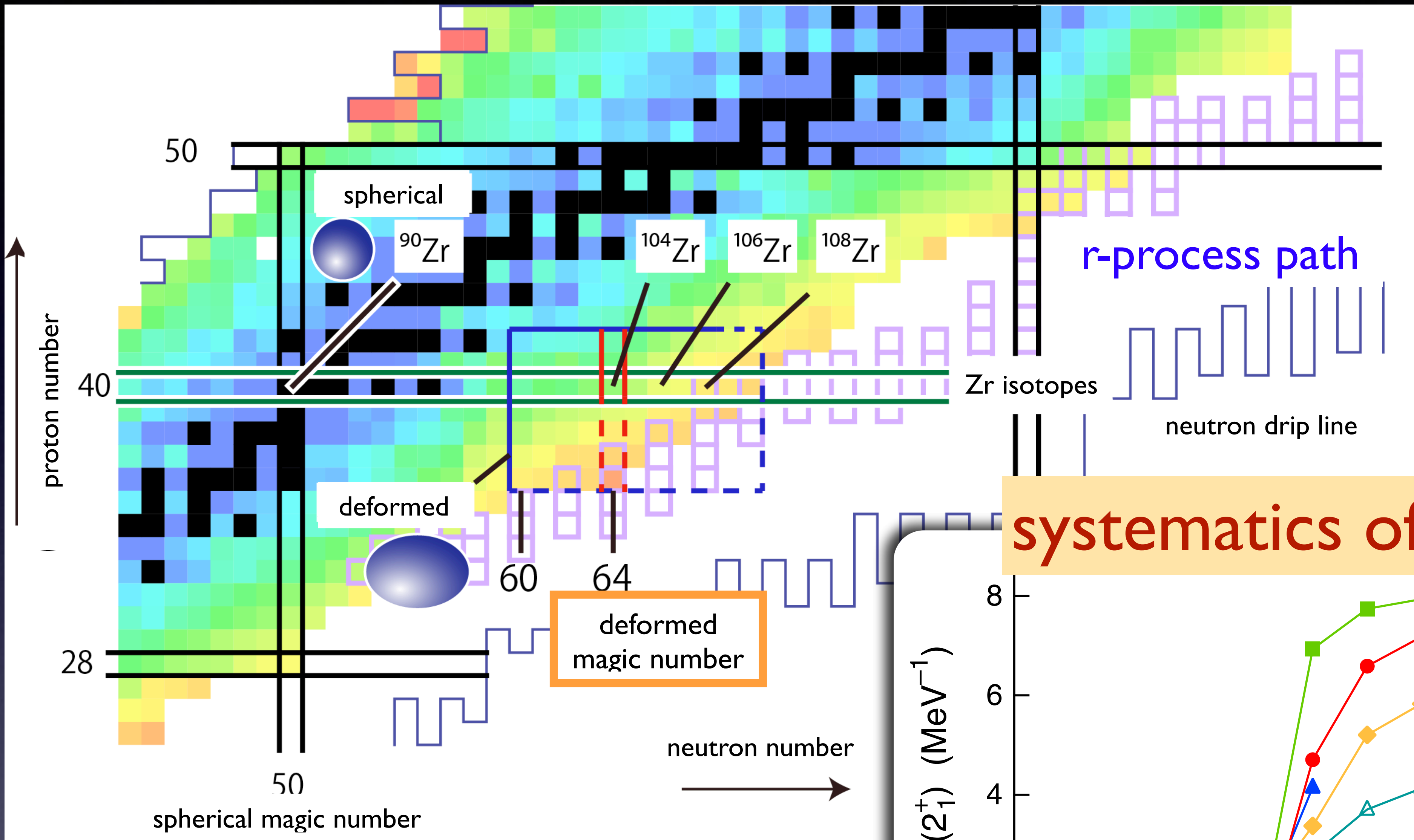
# β-decay half-lives in neutron-rich Zr isotopes

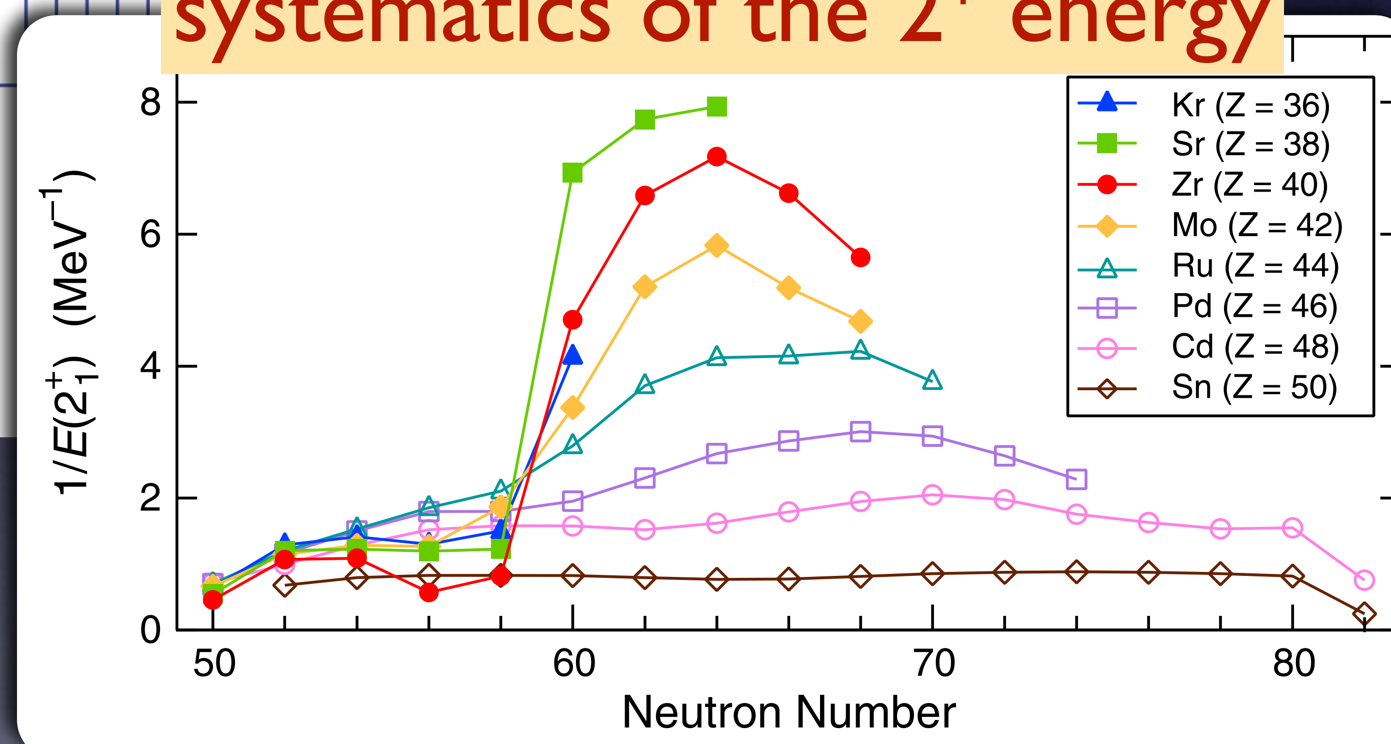
S. Nishimura et al., PRL106(2011)052502



# Deformed Zr isotopes on the r-process path




## systematics of the 2$^+$ energy




T. Sumikama et al., PRL106(2011)202501

KY, PTEP2013,113D02

# Self-consistent pnQRPA for spin-isospin responses in deformed nuclei

starting point: Skyrme EDF $\mathcal{E}[\rho(\boldsymbol{r}), \tilde{\rho}(\boldsymbol{r})]$

variation w.r.t densities

The coordinate-space Hartree-Fock-Bogoliubov eq. for ground states

J. Dobaczewski et al., NPA422(1984)103

$$\begin{pmatrix} h^q(\boldsymbol{r},\sigma) - \lambda^q & \tilde{h}^q(\boldsymbol{r},\sigma) \\ \tilde{h}^q(\boldsymbol{r},\sigma) & -(h^q(\boldsymbol{r},\sigma) - \lambda^q) \end{pmatrix} \begin{pmatrix} \varphi^q_{1,\alpha}(\boldsymbol{r},\sigma) \\ \varphi^q_{2,\alpha}(\boldsymbol{r},\sigma) \end{pmatrix} = E_\alpha \begin{pmatrix} \varphi^q_{1,\alpha}(\boldsymbol{r},\sigma) \\ \varphi^q_{2,\alpha}(\boldsymbol{r},\sigma) \end{pmatrix}$$

$q = \nu,\ \pi$

"s.p." hamiltonian and pair potential: $h^q = \dfrac{\delta \mathcal{E}}{\delta \rho^q}, \qquad \tilde{h}^q = \dfrac{\delta \mathcal{E}}{\delta \tilde{\rho}^q}$

quasiparticle basis $\alpha, \beta \cdots$

The proton-neutron quasiparticle RPA eq. for excited states $[\hat{H}, \hat{O}^\dagger_\lambda]|\Psi_\lambda\rangle = \omega_\lambda \hat{O}^\dagger_\lambda |\Psi_\lambda\rangle$

Collective excitation = coherent superposition of 2qp excitations:

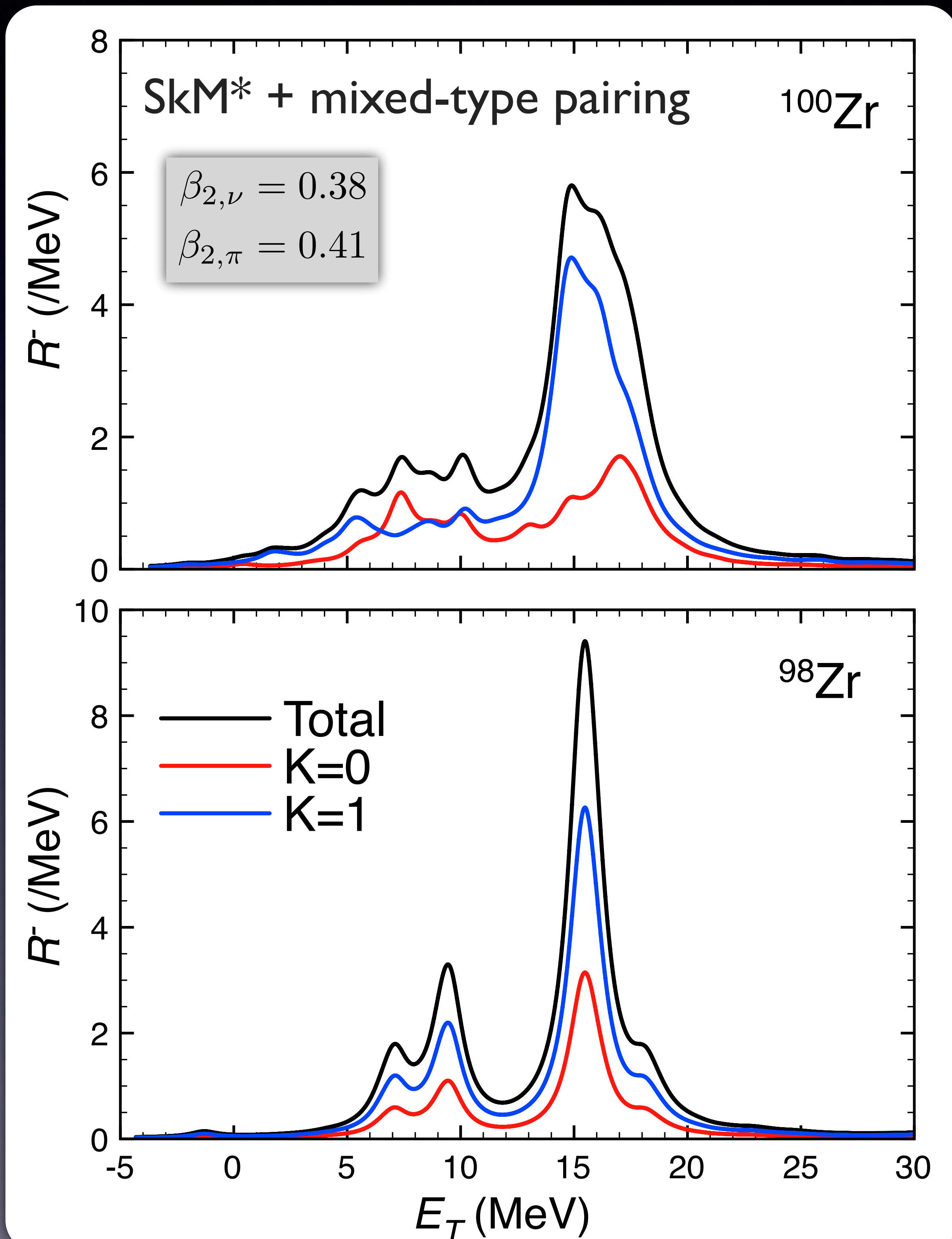
$$\hat{O}^\dagger_\lambda = \sum_{\alpha\beta} X^\lambda_{\alpha\beta} \hat{a}^\dagger_{\alpha,\nu} \hat{a}^\dagger_{\beta,\pi} - Y^\lambda_{\alpha\beta} \hat{a}_{\bar{\beta},\pi} \hat{a}_{\bar{\alpha},\nu}$$

residual interactions derived self-consistently :

$$v_{\rm res}(\boldsymbol{r}_1, \boldsymbol{r}_2) = \frac{\delta^2 \mathcal{E}}{\delta \rho_{1t_3}(\boldsymbol{r}_1) \delta \rho_{1t_3}(\boldsymbol{r}_2)} \boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2 + \frac{\delta^2 \mathcal{E}}{\delta \boldsymbol{s}_{1t_3}(\boldsymbol{r}_1) \delta \boldsymbol{s}_{1t_3}(\boldsymbol{r}_2)} \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2 \boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2$$

# GT giant resonance

$$\hat{F}_K^{t_3} = \sum_{\sigma,\sigma'}\sum_{\tau,\tau'}\int d\boldsymbol{r}\hat{\psi}^\dagger(\boldsymbol{r}\sigma\tau)\langle\sigma|\boldsymbol{\sigma}_K|\sigma'\rangle\langle\tau|\boldsymbol{\tau}_{t_3}|\tau'\rangle\hat{\psi}(\boldsymbol{r}\sigma'\tau')$$




1 MeV smearing width

✓sudden onset of deformation at N=60

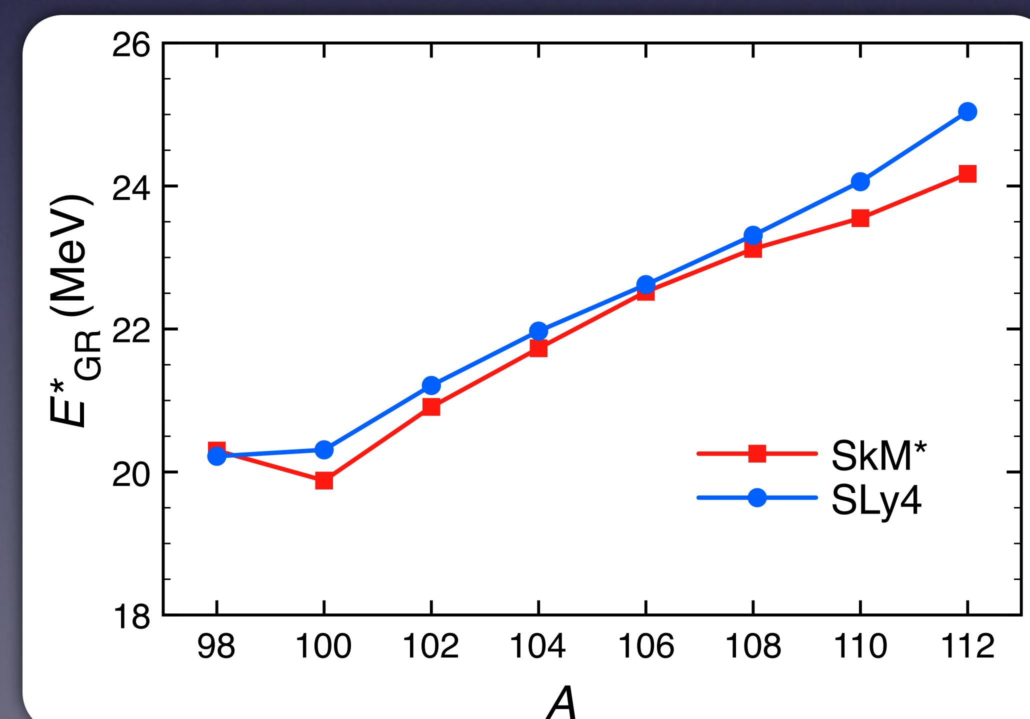
SLy4: A. Blazkiewicz et al., PRC71(2005)054321

✓fragmentation of strength distribution due to deformation

separable pnRPA:
P. Urkedal et al., PRC64(2001)054304

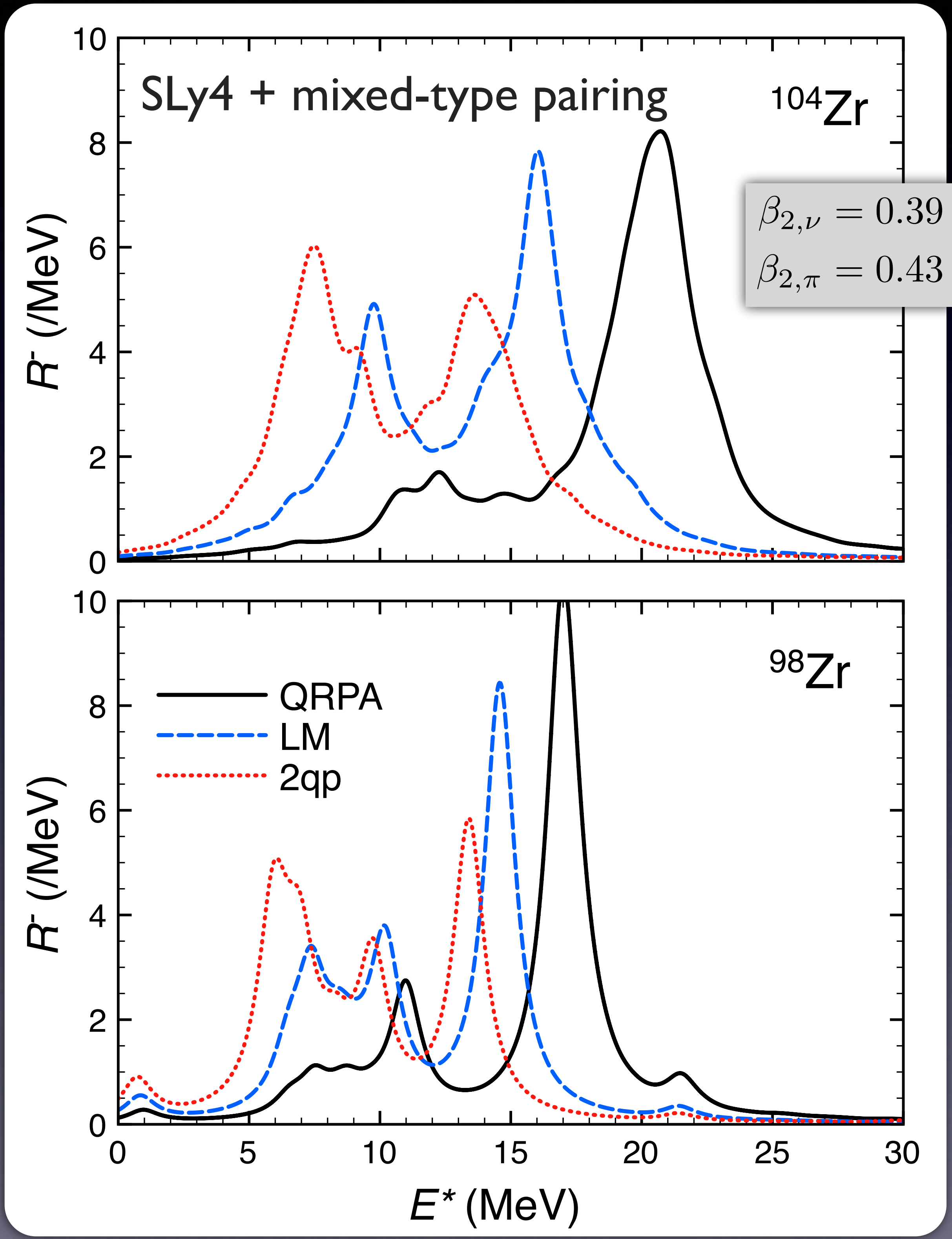
✓SkM* and SLy4 give almost the same excitation energies of GTGR

$g_0$'=0.94 (SkM*), 0.90 (SLy4)




excitation energy w.r.t. the g.s of daughter

# GTGR: the need of self-consistency




✓a repulsive character of the residual interaction raises the peak energy

✓the low-lying strengths are absorbed to the high-energy peak

strong collectivity of the GTGR

✓the collectivity generated by the Landau-Migdal approximation is weak

$$v_{\rm ph}(\boldsymbol{r}_1 \boldsymbol{r}_2) = N_0^{-1} \left[ f_0' \tau_1 \cdot \tau_2 + g_0' \sigma_1 \cdot \sigma_2 \tau_1 \cdot \tau_2 \right] \delta(\boldsymbol{r}_1 - \boldsymbol{r}_2)$$

LM parameter:
M. Bender et al., PRC65(2002)054322

self-consistency is needed for a quantitative description of the GTGR

# T=0 (S=1) pairing

✓affects the GT response

**if we have (a) T=1 pairing condensate(s)**

due to the coupling between the p-h and p-p excitations

➡ we may see the effect in the low-lying states that are generated by 2qp excitations around the Fermi levels

✓does not affect the gs properties in N>Z nuclei

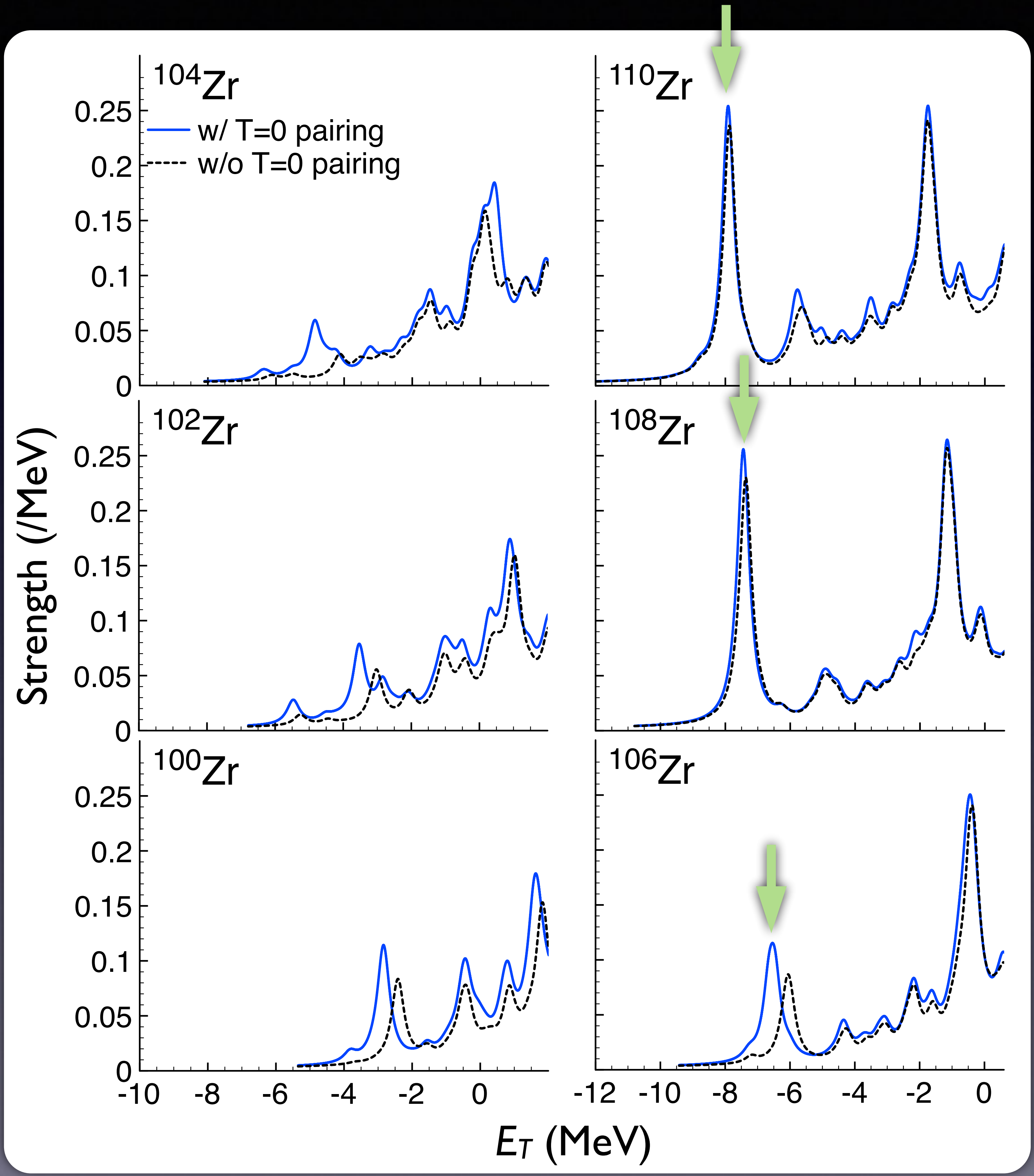
➡ a form of the interaction or an np-pairing EDF is seldom known

## Take the simplest one;

$$v_{\rm pp}^{T=0}(\boldsymbol{r}, \boldsymbol{r}') = \frac{1+P_\sigma}{2}\frac{1-P_\tau}{2}V_0\delta(\boldsymbol{r}-\boldsymbol{r}')$$

the pairing strength determined to reproduce the β-decay half-life of $^{100}$Zr (7.1 s)

# Low-lying GT states




selection rule for GT-

$$|\langle \pi[Nn_3\Lambda]\Omega = \Lambda + 1/2 | t_- \sigma_{+1} | \nu[Nn_3\Lambda]\Omega = \Lambda - 1/2 \rangle| = \sqrt{2}$$

$^{106}$Zr

constructed dominantly by

$\pi[413]7/2 \otimes \nu[413]5/2$

particle-like particle-like

✓T=0 pairing effective

neutrons added

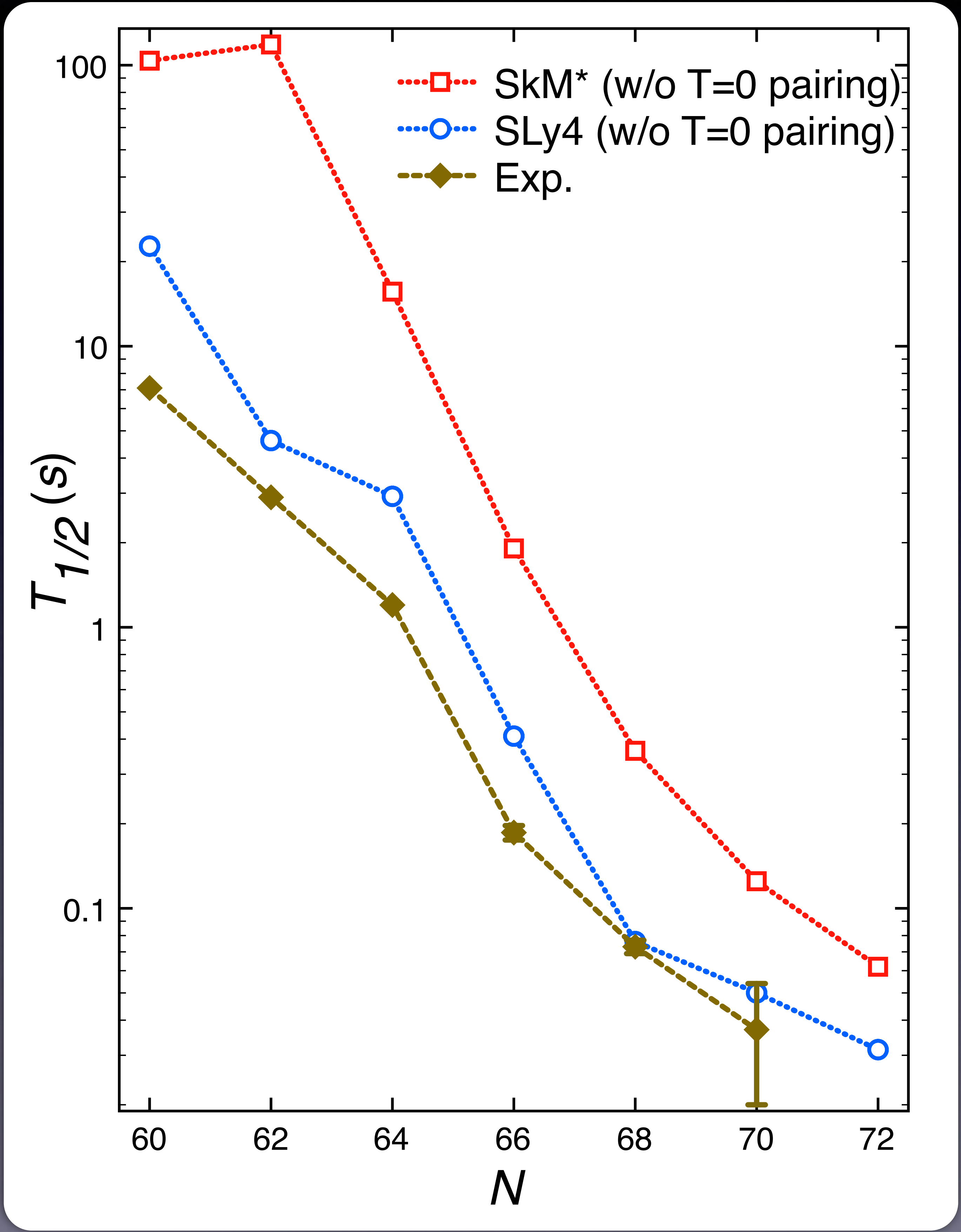
$^{108, 110}$Zr

$\pi[413]7/2 \otimes \nu[413]5/2$

particle-like hole-like

✓T=0 pairing ineffective

# Beta-decay half-lives




✓Fermi's golden rule

N. B. Gove, M. J. Martin,
At. Data Nucl. Data Tables 10(1971)205

✓Fermi and Gamow-Teller strengths included

✓SkM* produces longer half-lives

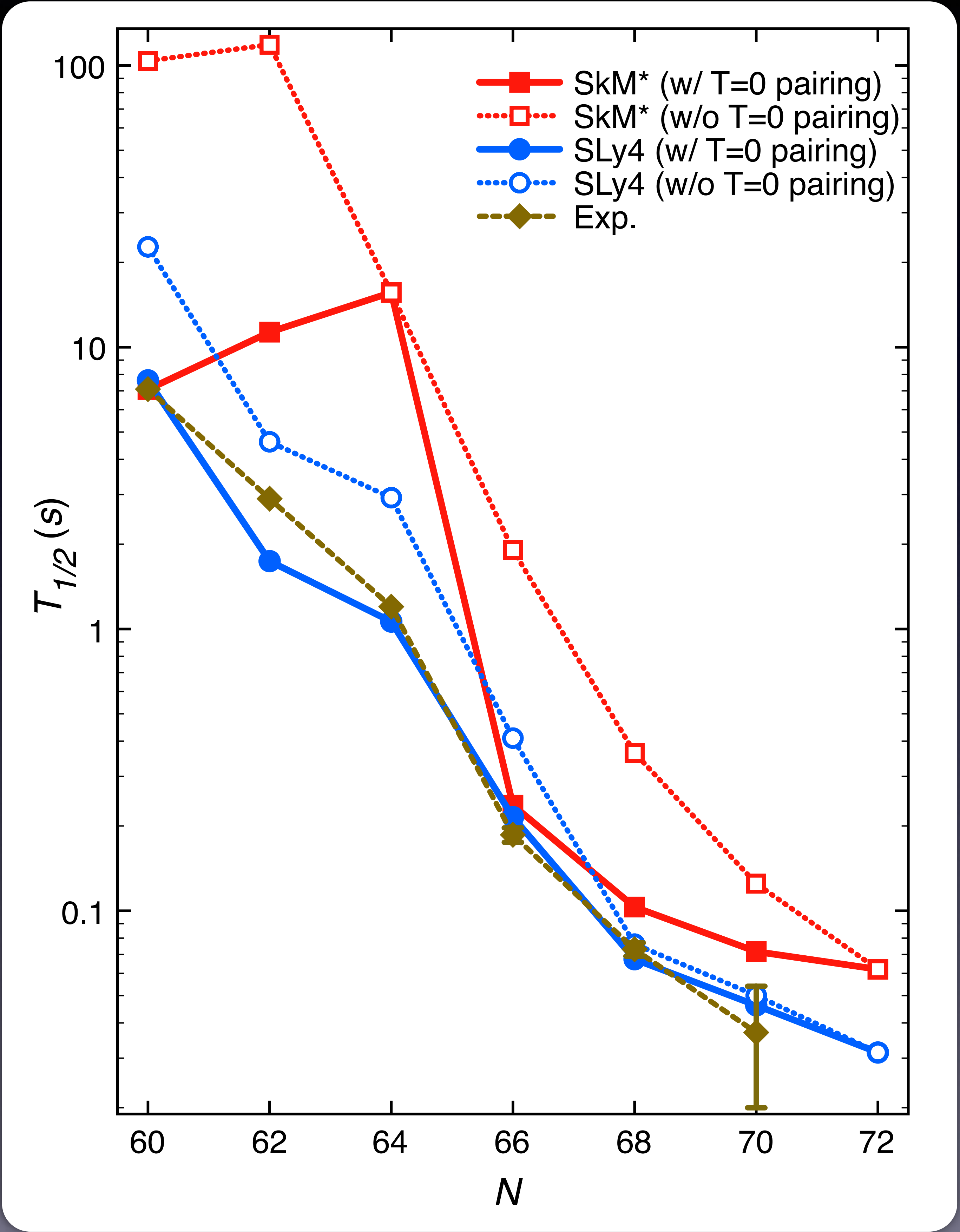
primarily due to a small Q-value

Q-value calculated approximately

$$Q_{\beta^-} = \Delta M_{\mathrm{n-H}} + B(A, Z+1) - B(A, Z)$$
$$\simeq \Delta M_{\mathrm{n-H}} + \lambda_\nu - \lambda_\pi - E_0$$
$$E_0 = \min[E_\nu + E_\pi]$$

cf. J. Engel et al., PRC60(1999)014302

# Beta-decay half-lives with T=0 pairing




✓Strength of T=0 pairing determined at N=60

## SLy4

✓reproduces well the observed isotopic dependence with T=0 pairing

✓Effect of the T=0 pairing is small beyond N=68

## SkM*

✓gives a strong deformed gap at N=64

# Summary

## Fully-selfconsistent deformed pnQRPA is developed in a Skyrme EDF framework

KY, PTEP2013,113D02

Microscopic and quantitative description of spin-isospin excitations in nuclei with arbitrary mass number whichever they are spherical or deformed, located around the stability line or close to the drip line

## Deformation effects on spin-isospin responses

Tiny deformation splitting in Gamow-Teller excitation

→ Fragmentation of GTGR

## Effects of T=0 pairing

Low-lying GT states: Sensitive to the location of the Fermi levels

Beta-decay half-lives are shortened due to the attractive nature