Double Beta Decay and Charge Exchange Reactions

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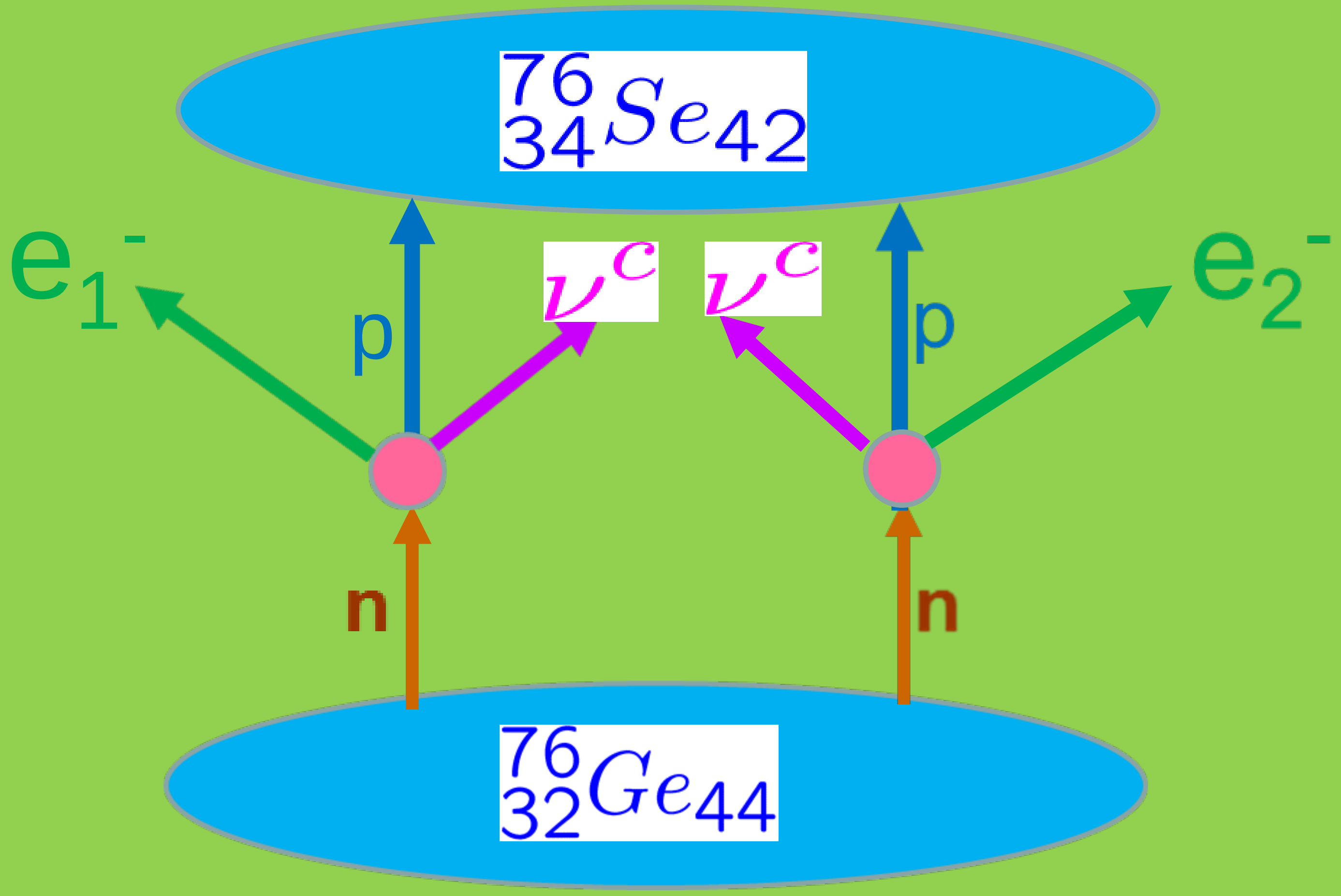
2νββ-Decay (allowed in Standard Model)



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2-Neutrino Matrix Elements Fermi + Gamow-Teller

$$M^{2\nu}_{FERMI} = \sum_m \frac{<f|| \sum_k \tau_{k-}||m><m|| \sum_l \tau_{l-}||i>}{E_m-(Mi+Mf)/2}$$

Single state dominance?

$$M^{2\nu}_{FERMI} = \sum \frac{< f|| \sum_k \tau_{k-}||S >< S|| \sum_l \tau_{l-}||i >}{E_S - (Mi + Mf)/2}$$

$$M^{2\nu}_{GT} = \sum_m \frac{<f|| \sum_k \sigma_k\tau_{k-}||S><S|| \sum_l \sigma_l\tau_{l-}||i>}{E_S - (Mi+Mf)/2}$$

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The best choice: Quasi-Particle Random Phase Approximation (QRPA) and Shell Model

QRPA starts with Pairing:

$$a_i^+ = u_i c_i^+ - v_i c_{\bar{i}}$$

$$A_\alpha^+ = [a_i^+ a_k^+]_{J\alpha}$$

$$Q_m^+ = \Sigma_\alpha [X_\alpha^m A_\alpha^+ - Y_\alpha^m A_\alpha]$$

$$|m> = Q_m^+ |g>$$

$$[A_\alpha, A_\beta^+] = \delta_{\alpha,\beta} + \hat{X}$$

Renomalisation introduces Pauli and stabilizes the solution to higher interaction strength.

$$\hat{H} Q_m^+ |g> = E_m Q_m^+ |g>$$

$$\hookrightarrow \quad X_m^\alpha ; Y_m^\alpha ; E_m$$

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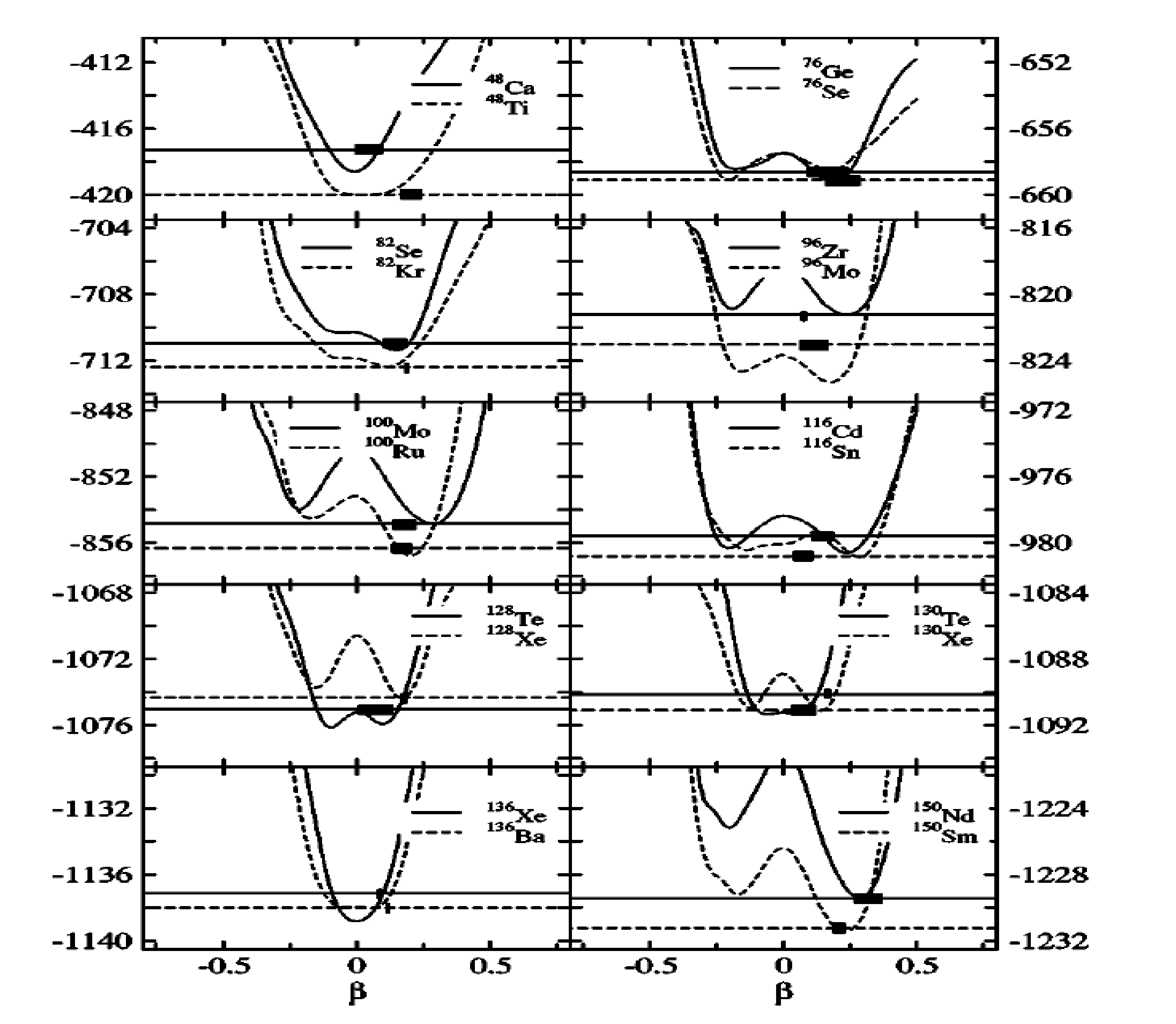
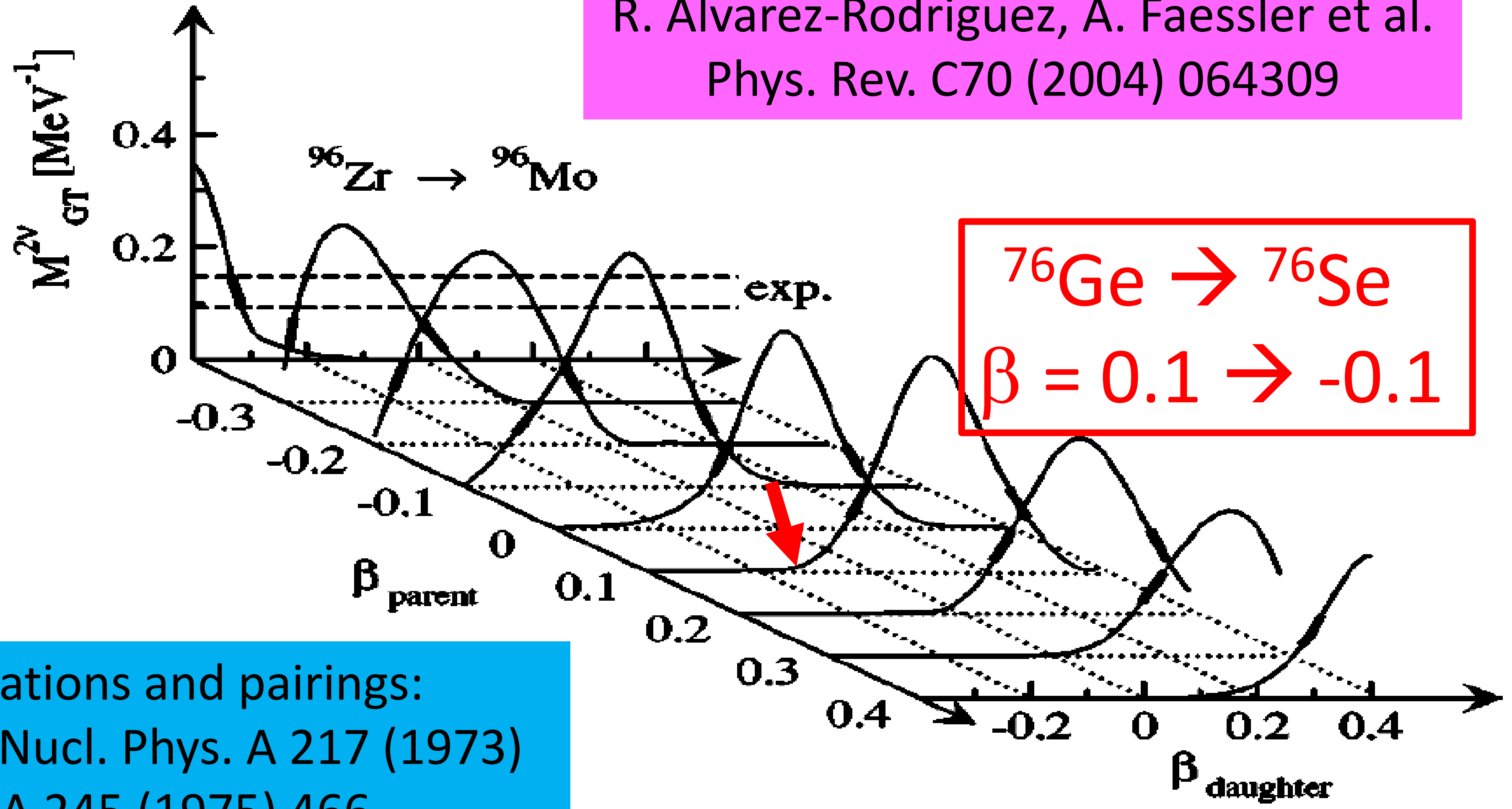
The Deformation of the parent and the daughter nucleus must not be the same.



R. Alvarez-Rodriguez,
A. Faessler et al.
Phys. Rev. C70 (2004) 064309

Reduction of the 2-Neutrino Matrix Element due to different Deformations of initial and final States.

R. Alvarez-Rodriguez, A. Faessler et al.
Phys. Rev. C70 (2004) 064309

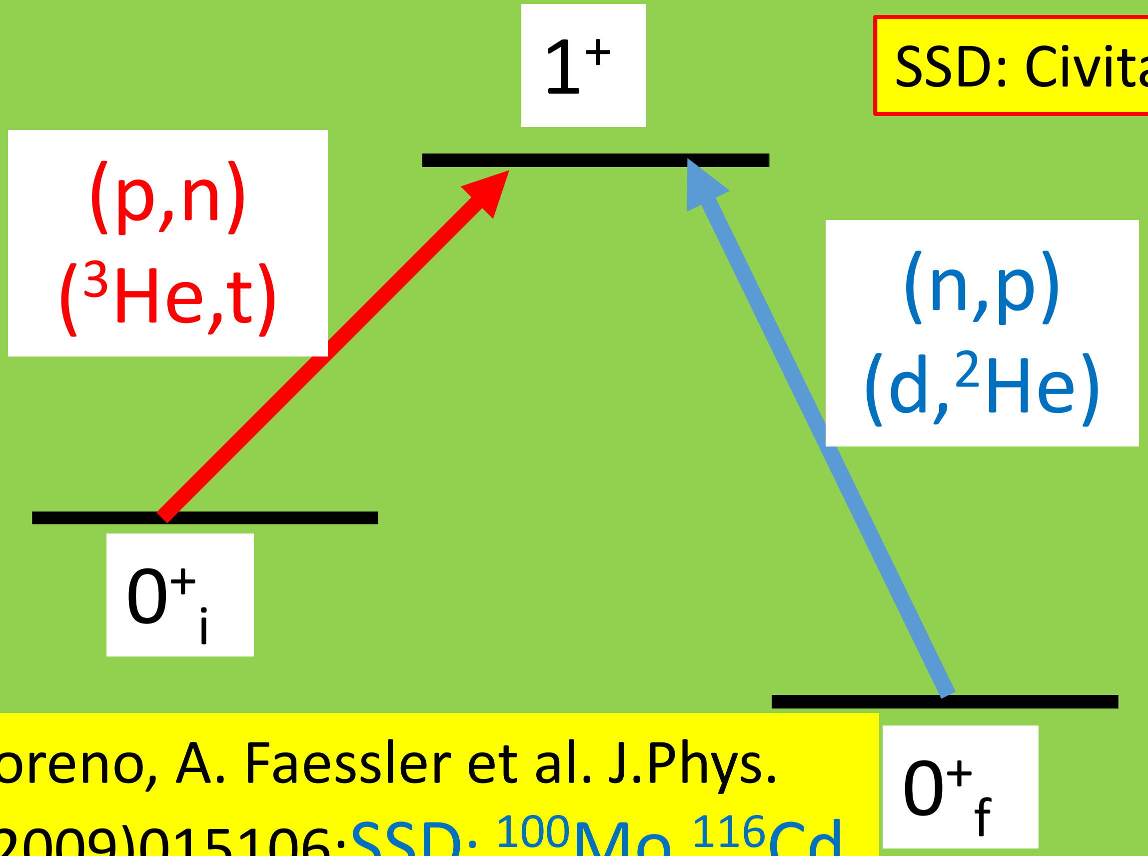


$^{76}Ge \rightarrow ^{76}Se$

$\beta = 0.1 \rightarrow -0.1$

Different deformations and pairings:
A. Faessler et al. Nucl. Phys. A 217 (1973) 420 eq. (11) and A 245 (1975) 466.

Measurement of the Matrix Elements for Single State Dominance for (SSD) Gamow-Teller.



SSD: Civitarese and Suhonen: Phys. Rev. 58 (1998) 1535.

$$B(GT) = \frac{1}{(2Ji+1)} |M_{GT}|^2 =$$

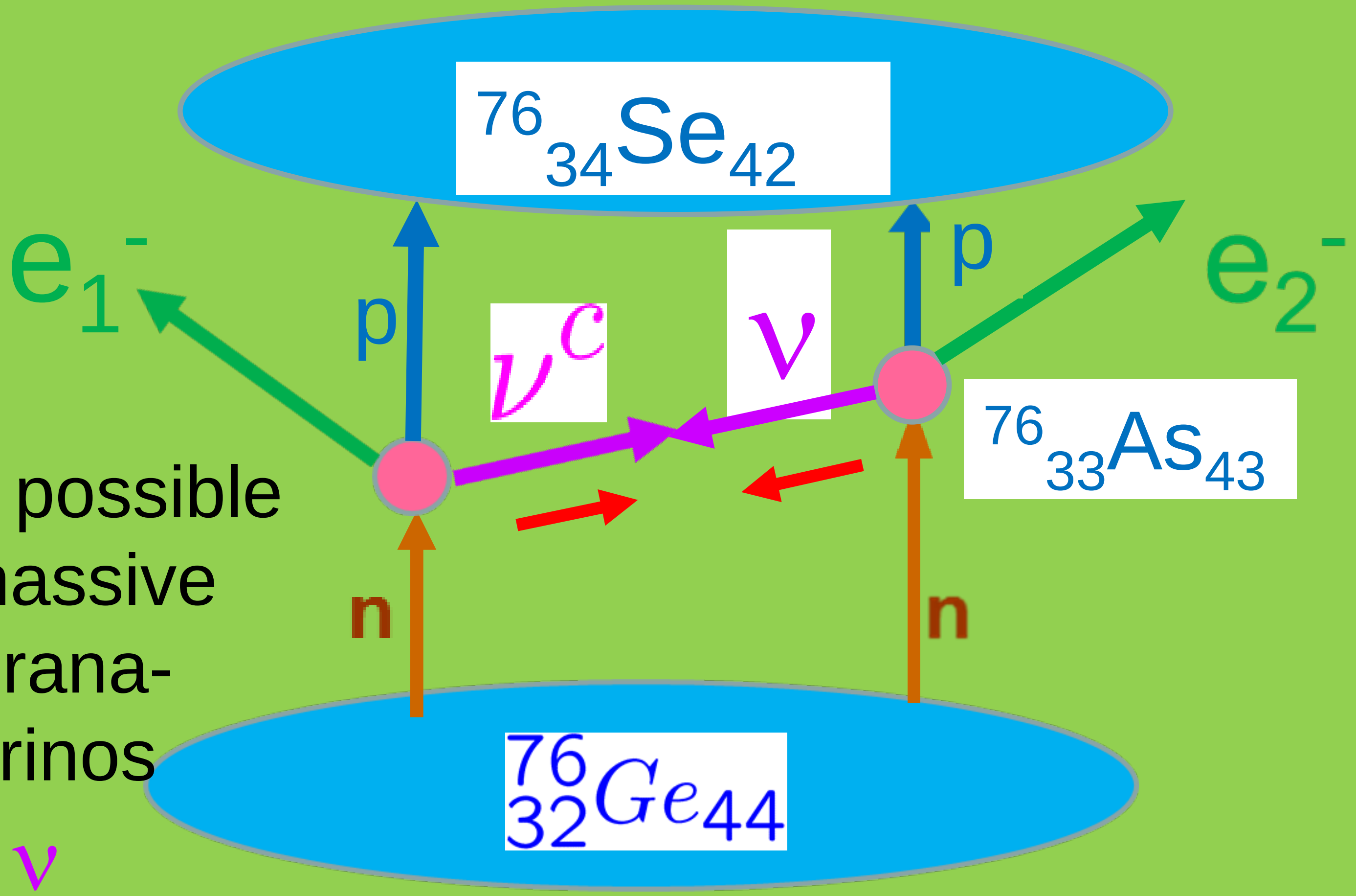
$$= \sigma(GT) \times \frac{d\sigma(q=0)}{d\Omega} \text{ (Frekers)}$$

Absolute value of $|M_{GT}|$.
But no sign.

O. Moreno, A. Faessler et al. J.Phys. G36(2009)015106; SSD: ^{100}Mo, ^{116}Cd (^{96}Zr, ^{110}Pd)
No SSD: ^{100}Tc, ^{116}In, ^{128}In

All GT-contributions the same sign → upper limit

0νββ-Decay (forbidden in Standard Model)



Only possible for massive Majorana-Neutrinos

$\nu^c = \nu$

$m_\nu \neq 0$

Short Range correlations are important ~ „Coulomb".

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Neutrinoless Fermi and GT Transition Operator in the Closure Approximation.

$$W^{0\nu} = \sum_{a\neq b} P_\nu(r_{ab})(g_A{}^2\sigma_a\cdot\sigma_b - g_V{}^2)\,\tau_{a-}\tau_{b-}$$

With: $g_A = 1.26$; $g_V = 1.0$; $P_\nu(r_{ab}) = \frac{1}{r_{ab}}$

FERMI Part:

$$W^{0\nu}{}_{Fermi} = \sum_{a\neq b} g_V{}^2 P_\nu(r_{ab})\tau_{a-}\tau_{b-} = \frac{g_V{}^2}{e^2}\,[T^-,[T^-,H(total)]]$$

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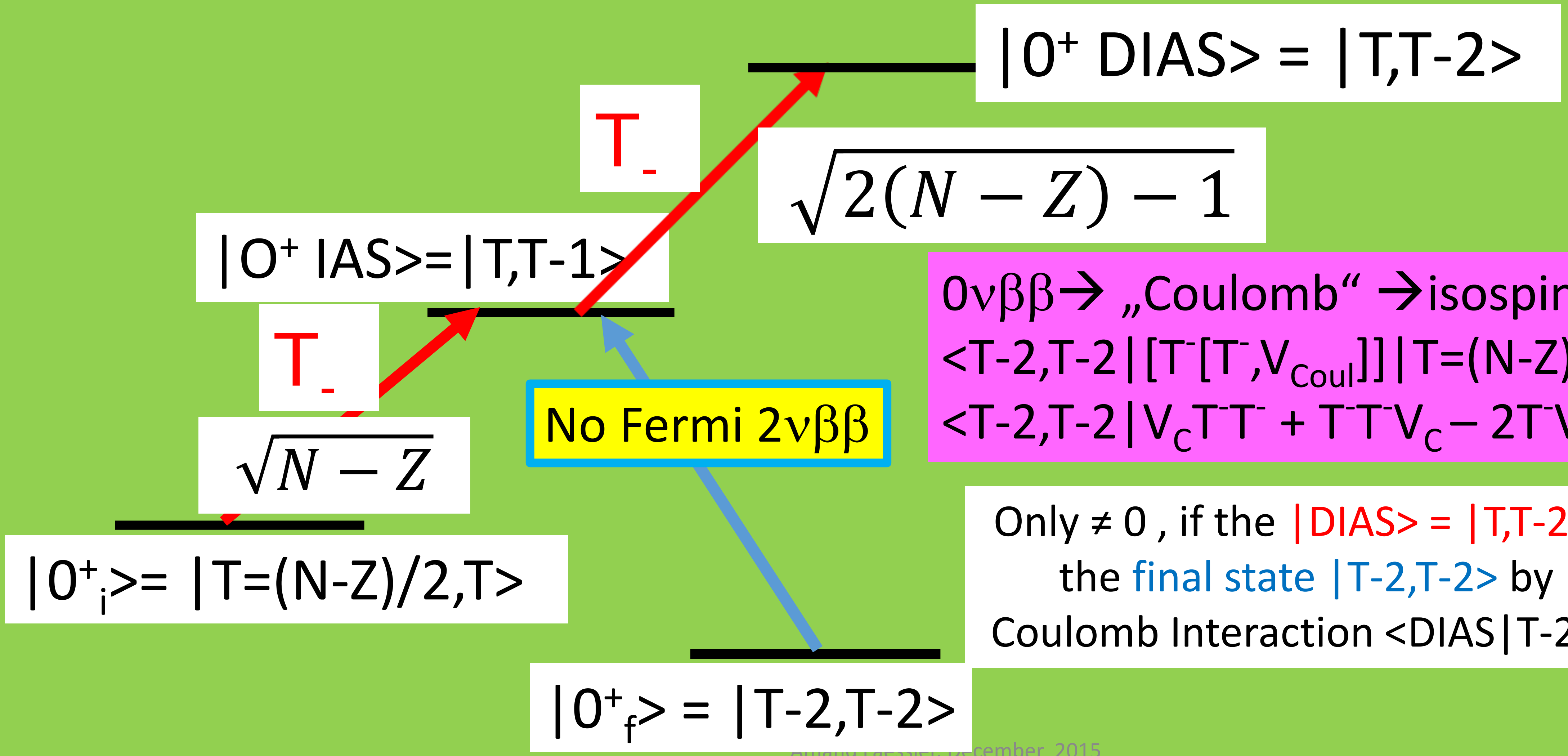
Fermi Transition to the Isobaric (IAS) and Double Isobaric Analog State (DIAS) for $2\nu\beta\beta + 0\nu\beta\beta$



$0\nu\beta\beta \rightarrow$ „Coulomb“ $\rightarrow$ isospin violation:

$<T-2,T-2|[T^-[T^-,V_{Coul}]]|T=(N-Z)/2,T> =$

$<T-2,T-2|V_C T^- T^- + T^- T^- V_C - 2T^- V_C T^-|T,T>$

Only ≠ 0 , if the |DIAS> = |T,T-2> mixes with the final state |T-2,T-2> by Isotensor Coulomb Interaction <DIAS|T-2,T-2>=0.005.

Coulomb-Interaction and Isotensor-Part:

$$V_{Coulomb} = \frac{e^2}{8} \sum_{a \neq b} (1-\tau_{a3})(1-\tau_{b3})/r_{ab}$$

Proton: $\tau_3 = -1$; Neutron: $\tau_3 = +1$

$$V_{Coul\text{-}Tensor} = \frac{e^2}{8} \sum_{a \neq b} [\tau_{a3}\tau_{b3} - (\tau_a \cdot \tau_b)/3\ ]/r_{ab}$$

$$M^{0\nu}_{Fermi} = -\frac{2}{e^2} \sum_S \omega_S < 0^+_f | T^- | 0^+_S >< 0^+_S | T^- | 0^+_i >$$

With: $\omega_S = E_S - (E_{0+i} + E_{0+f})/2$

$W^{0n}_{Fermi} = (g_V^2/e^2)[T^-[T^-,H]]$

Fermi is the subleading contribution rel. to GT → Estimate of $M^{0\nu}_{GT}$

- Due to the short range behavior of the $0\nu\beta\beta$ mainly L=0 pairs involved.

FERMI: $1x|$ T=1, L=0, S=0> = +1 |T=1, L=0, S=0>

GT: $\sigma_1 \cdot \sigma_2$ |T=1, L=0, S=0> = -3 |T=1, L=0, S=0>

$M^{0\nu}_{GT}/M^{0\nu}_{F} = -3$; Higher order currents for GT (Towner+Hardy arXiv: nucl-th 950-1015): $M^{0\nu}_{GT}/M^{0\nu}_{F} = -2.5$

Partial Isospin Restoration: -10% ($g_{pp}^{T=1}$ different from $g_{pp}^{T=0}$):

- $g_{pp}^{T=1}$<pn,T=1|V|p‘n‘,T=1>; $g_{pp}^{T=1} = g_{pair}$
- $g_{pp}^{T=0}$<pn,T=0|V|p‘n‘,T=0> from Fermi 2ν

$$M^{2\nu}_{Fermi} = \sum_m \frac{<f||\sum_k \tau_{k-}||m><m||\sum_l \tau_{l-}||i>}{E_m - (M_i + M_f)/2}$$

With closure; (|p> = t_- |n>; |n> = |t=$\frac{1}{2}$, t_z=$\frac{1}{2}$>):

$$M^{2\nu}_{Fermi} = \frac{<T-2,T-2|T\_T\_|T,T>}{<E>-(Mi+Mf)/2} = 0$$

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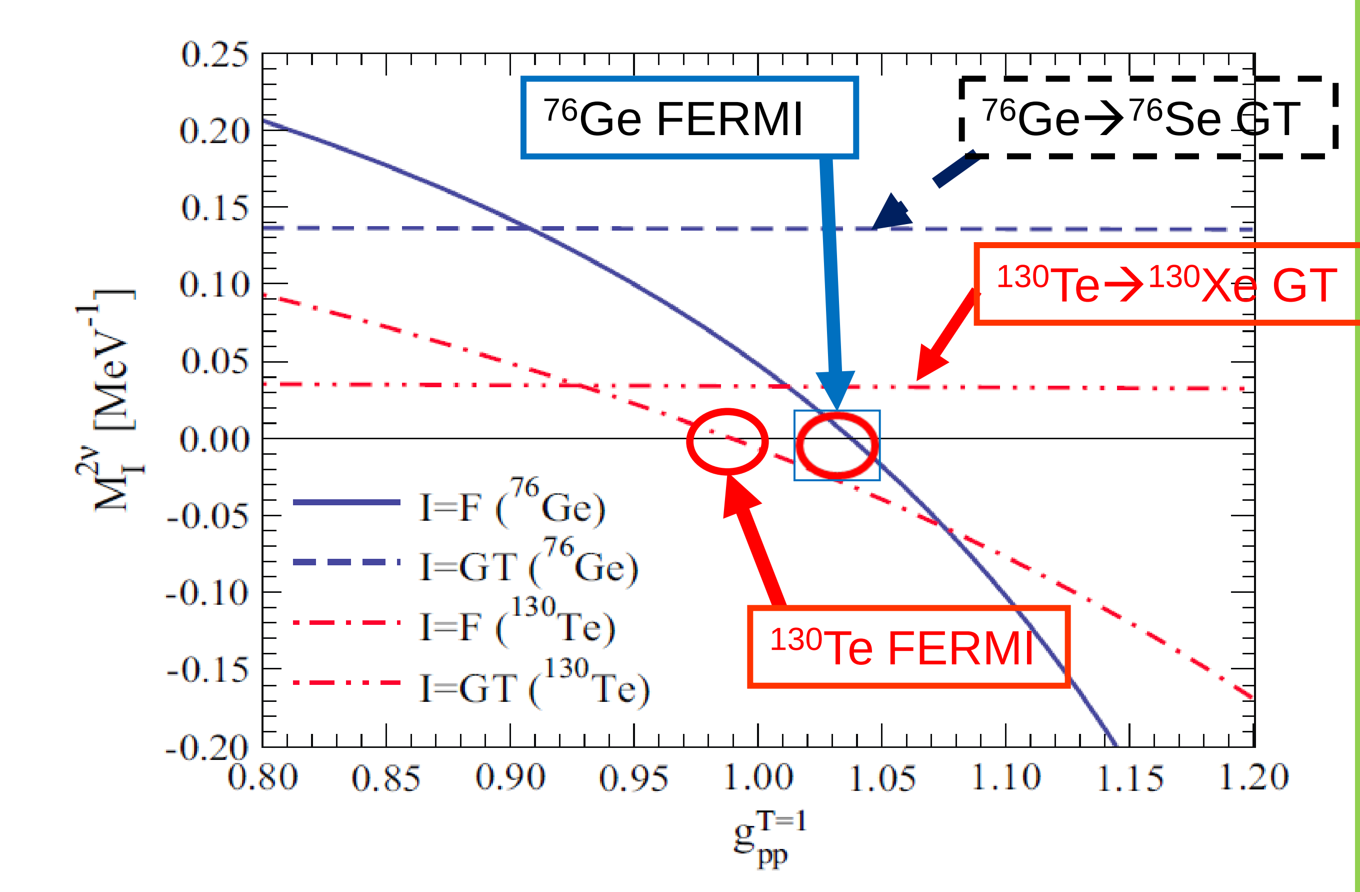
Two-Neutrino Transitions (Argonne V18)

$T = 1 \rightarrow \Delta S=0, \Delta L=0 \rightarrow M^{2\nu}_{FERMI}$;
$T = 0 \rightarrow \Delta S=1, \Delta L=0 \rightarrow M^{2\nu}_{GT}$



$M^{2\nu}_{FERMI} = 0 \rightarrow g_{pp}^{T=1}$

$g_{pp}^{T=1}(^{76}Ge) = 1.04$
$g_{pair}(^{76}Ge) = 1.02$

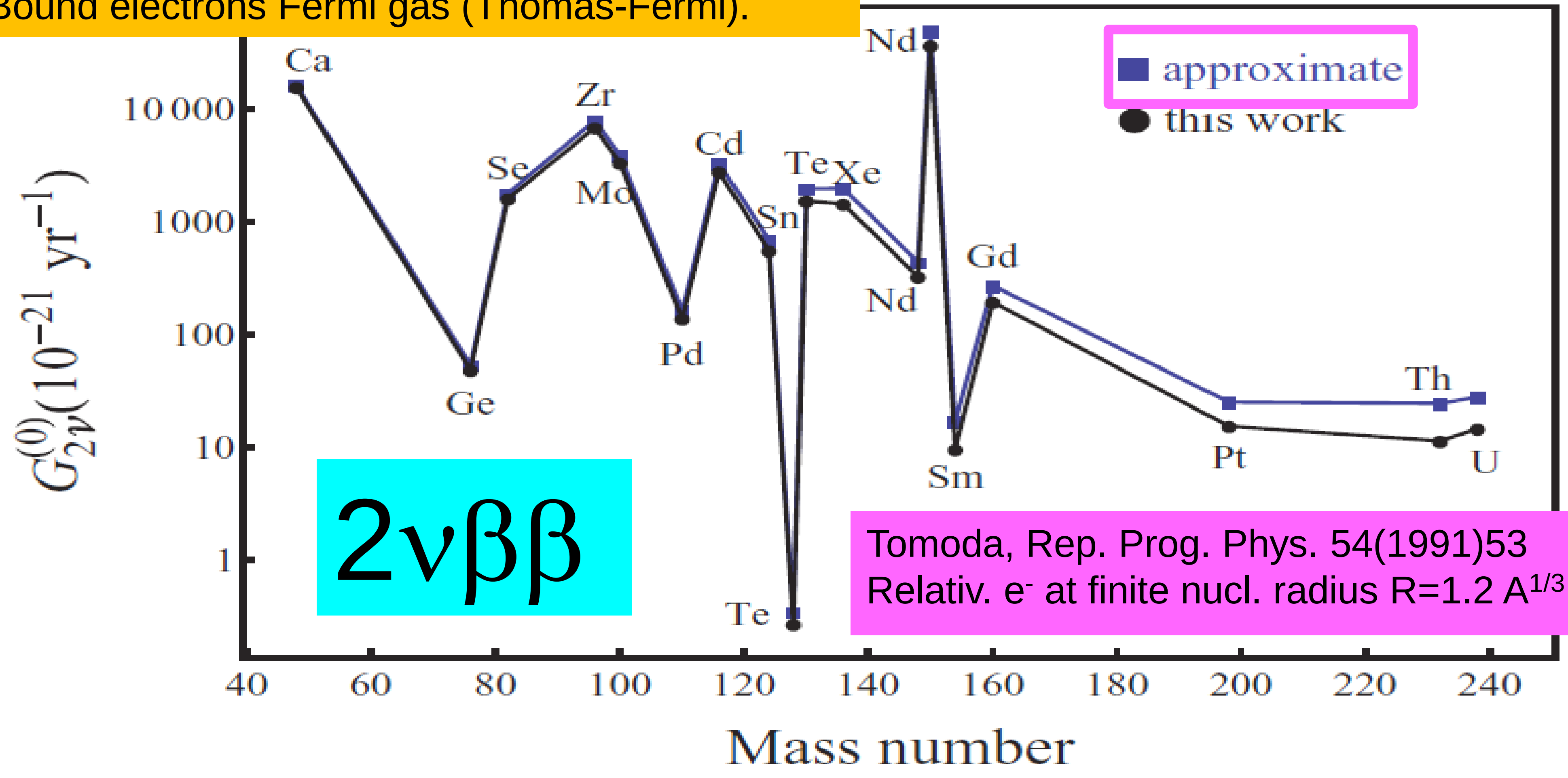
$g_{pp}^{T=1}(^{130}Te) = 0.99$
$g_{pair}(^{130}Te) = 0.96$

0ν Half-Life → $<m_{\beta\beta}>$

- $\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2 \times |<m_{\beta\beta}>|^2$
- $M^{0\nu} = M^{0\nu}_{GT} - \frac{M^{0\nu}_{F}}{g_A^{\,2}} + M^{0\nu}_{Tensor}$
- Results for: $g_A = 1.27$
- $<m_{\beta\beta}>$ 10% larger with partial isospin restoration

Improved Phase Space Factor $G_{2\nu}$:
Kotila-Iachello, Phys. Rev. C85, 034316 (2012).

Continuum Dirac-e-wavefunctions, finite Nucl. Radius;
Bound electrons Fermi gas (Thomas-Fermi).



$2\nu\beta\beta$

Tomoda, Rep. Prog. Phys. 54(1991)53
Relativ. e^- at finite nucl. radius $R=1.2\ A^{1/3}$ fm

Phase Space Factor $G_{0\nu}$:

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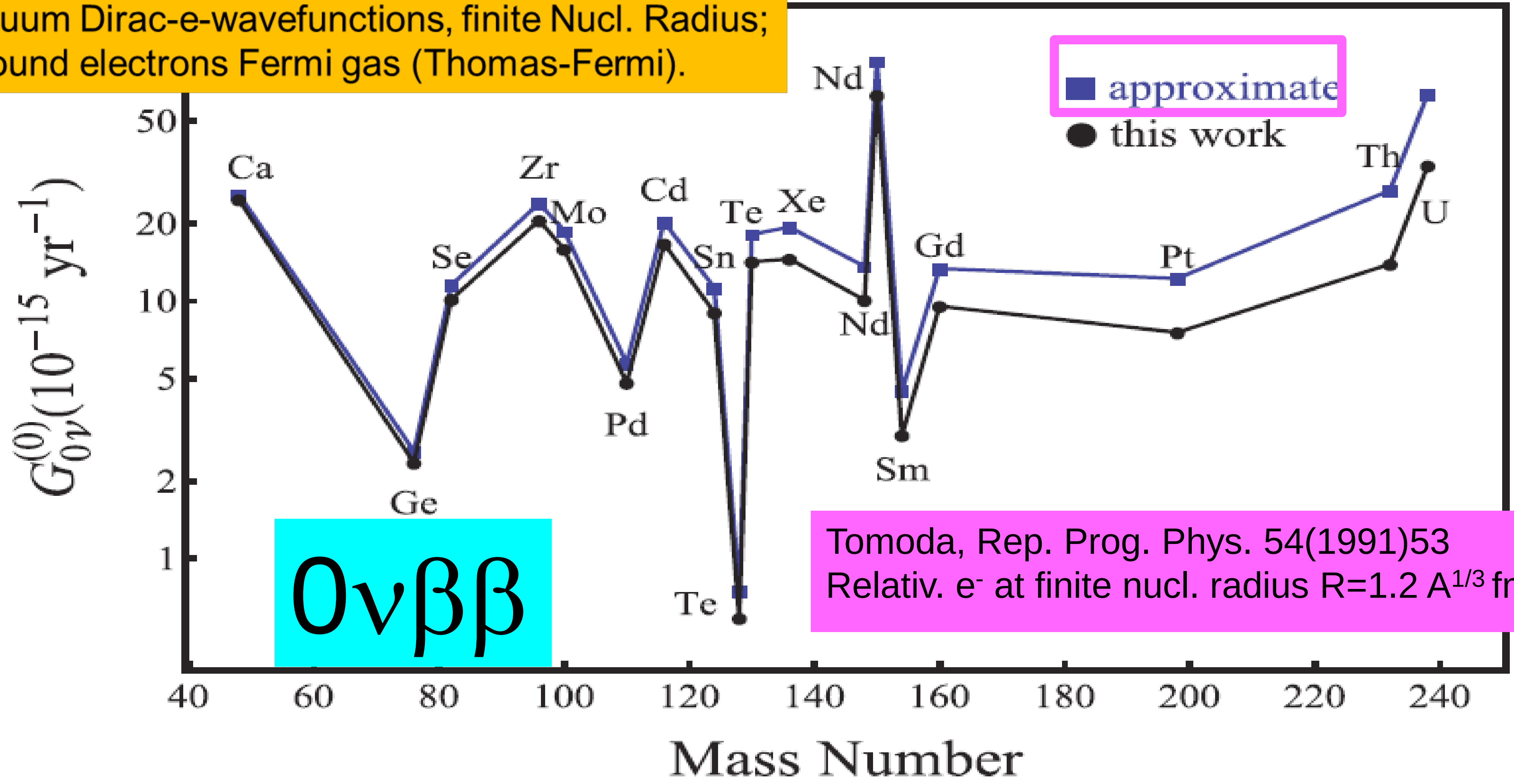


0νββ

Tomoda, Rep. Prog. Phys. 54(1991)53
Relativ. e^- at finite nucl. radius $R=1.2\,A^{1/3}$ fm

The total 0ν Matrix Element reduced by ~10% by isospin restoration (Bonn CD; $g_A = 1.27$).

Nucleus	$M^{2\nu}_F$	$M^{2\nu}_{GT}$	$M^{0\nu}_F$	$M^{0\nu}_{GT}$	$M^{0\nu}_T$	$M^{0\nu}_{total}$
^{76}Ge old	0.22	0.14	-2.73	5.05	-0.52	6.23
^{76}Ge new	0.00	0.14	-1.71	5.02	-0.51	5.57
^{130}Te old	0.10	0.03	-2.33	3.87	-0.50	4.81
^{130}Te new	0.00	0.03	-1.64	3.85	-0.50	4.37

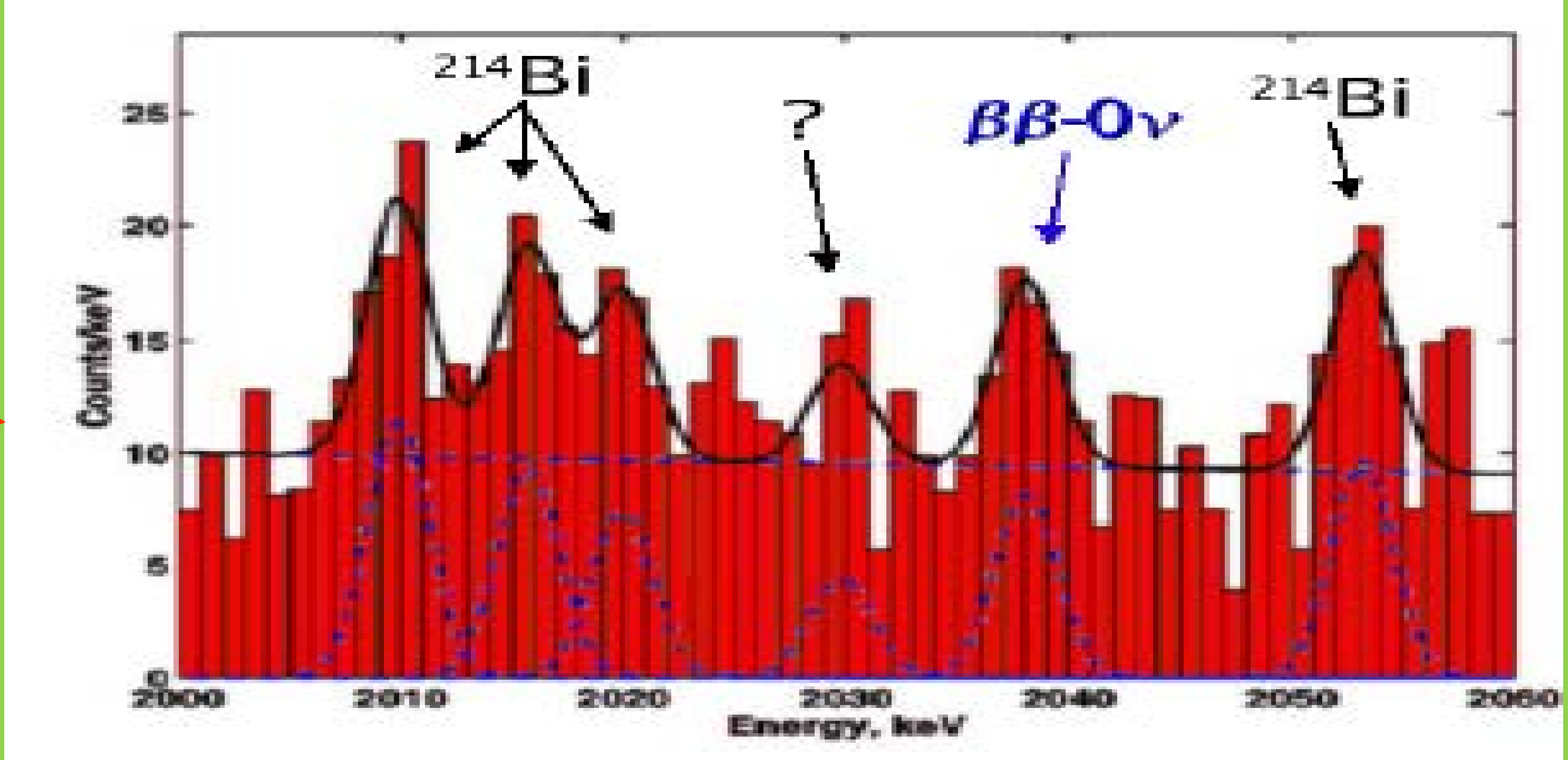
Klapdor claim for Detection of 0ν DBD

hep-ph/0512263 HM collaboration claim the 0νDBD of ^{76}Ge

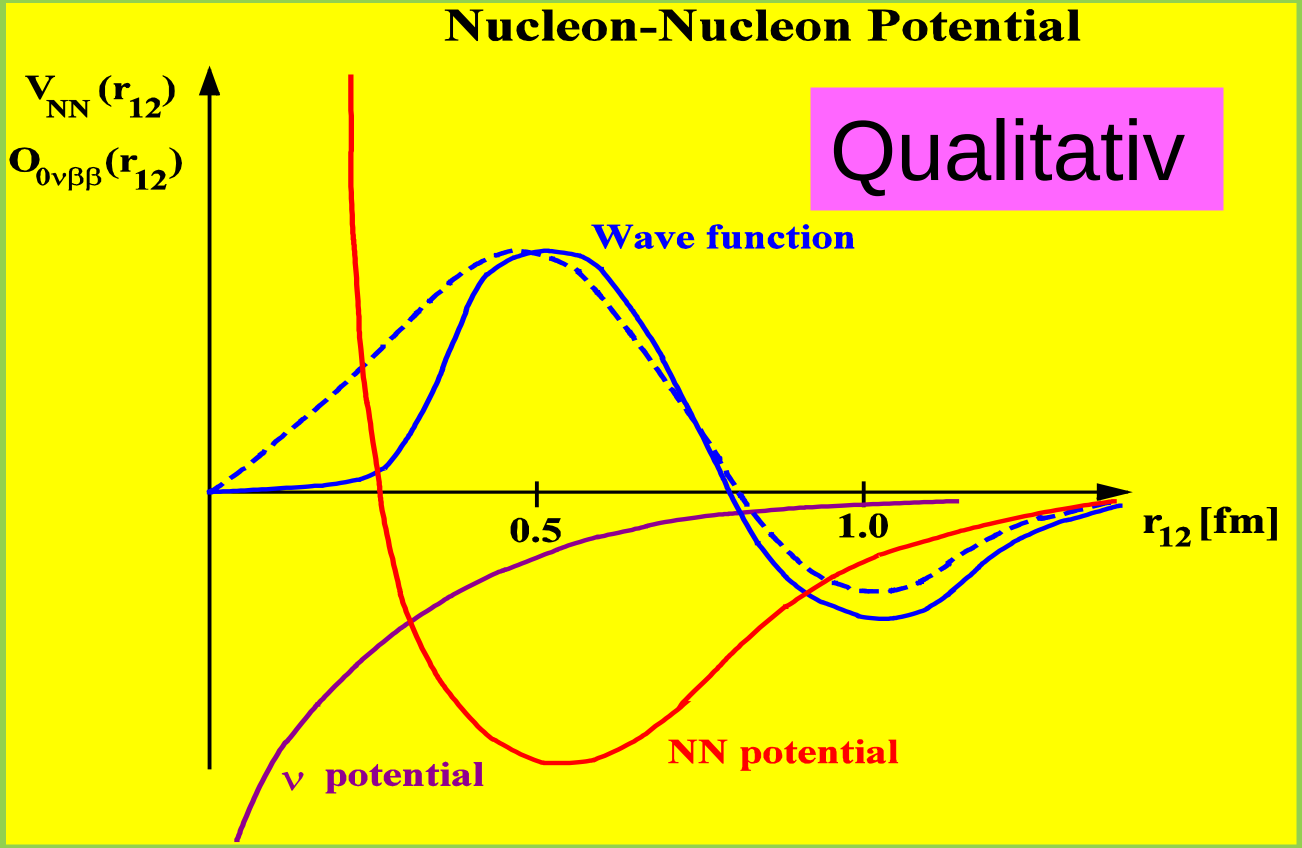
Source = Detector

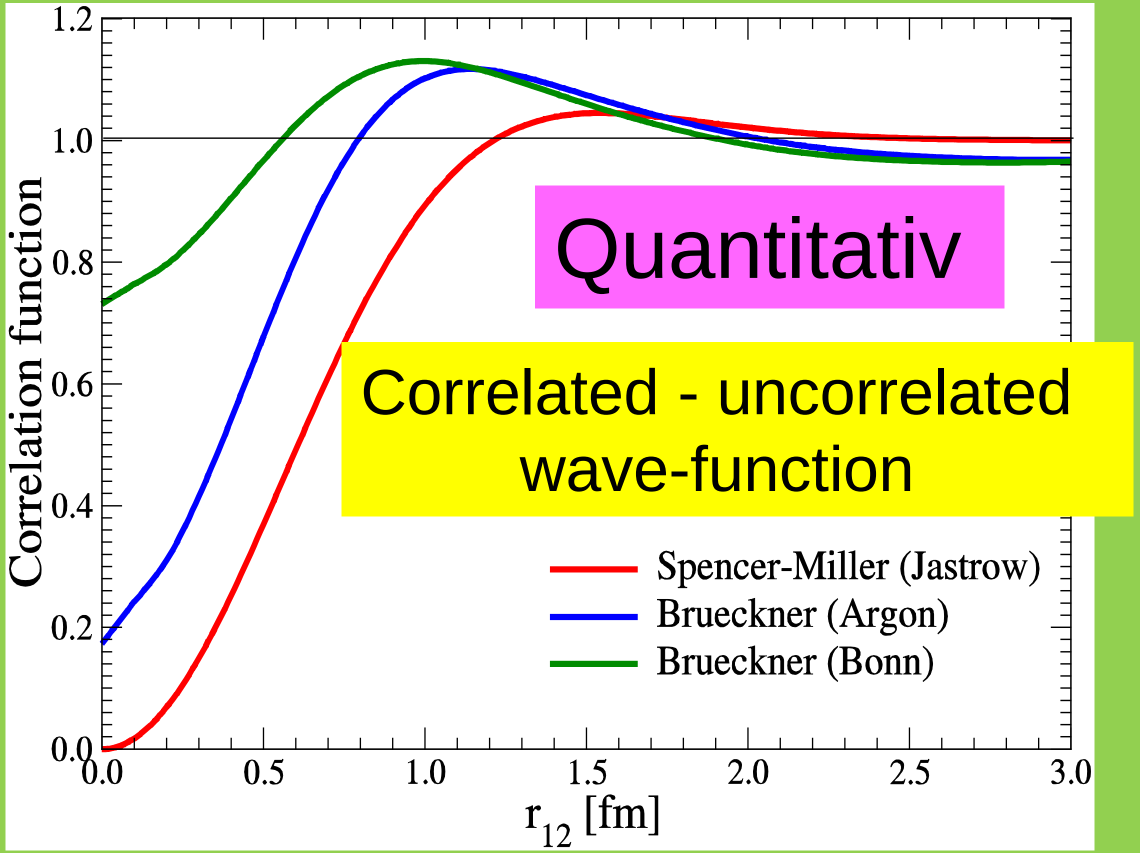
- 10.9 kg - (86% from 8% nat.) ^{76}Ge
- Gran Sasso Laboratory (Italy)

Spectrum with 71.7 kg•y →



Uncorrelated and Correlated Relative N-N-(two neutrons → two protons) Wavefunction in the N-N-Potential





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Summary: Neutrino Mass from $0\nu\beta\beta$ asuming the measurement of Klapdor et al. is correct:

Theory with R-QRPA and g_A =1.25

Exp. Klapdor et al. Mod. Phys. Lett. A21,1547(2006) ; ^{76}Ge

T(1/2; $0\nu\beta\beta$) = (2.23 +0.44 -0.31) x 10^{25} years; 6σ

- **<m(ν)> = 0.22 [eV] (exp+-0.02;theor+-0.01) [eV] → (new) 0.24 [eV]**
  Bonn CD, Consistent Brückner Correlations

- **<m(ν)> = 0.24 [eV] (exp+-0.02; theor+-0.01) → (new) 0.26 [eV]**
  Argonne, Consistent Brückner Correlations

- **<m(ν)> = 0.30 [eV] (exp+-0.03;theor+-0.01) [eV] → (new) 0.33 [eV]**
  Bonn CD, Fermi Hypernetted Chain

- **<m(ν)> = 0.26 [eV] (exp+-0.02;thero+-0.01) Bonn CD, Unitary Correlator Operator Method (Feldmeier, AV18) → (new) 0.29 [eV]**

- **<m(ν)> = 0.31 [eV] (exp +-0.03;theor+-0.02) [eV] Bonn**
  → 0.34 [eV]

THE END