Fest-Colloquium for the 60. Birthday of Jochen Wambach.

Can one measure the Neutrino Mass in the Double Beta Decay ?

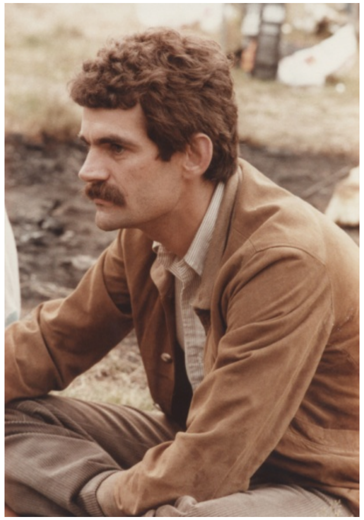
Amand Faessler,

University of Tuebingen

Preparation for the legendary Football Game in Jülich against Solar Energy ~1977

The successful Nuclear Physics Football Team in Jülich-Broich ~1975

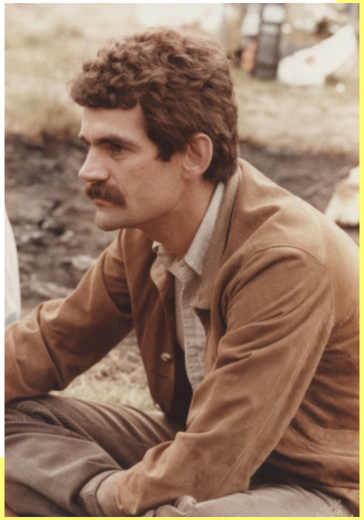
Jochen Wambach * July 7. 1950



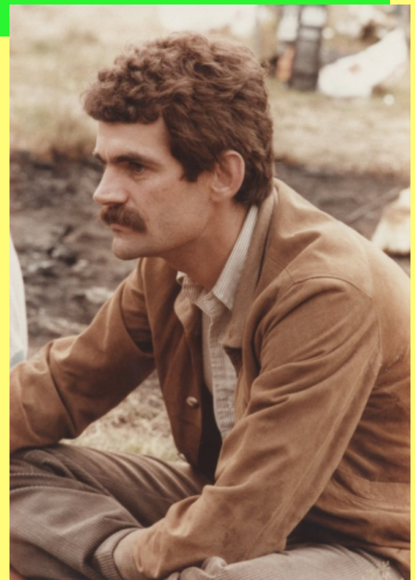
- Studies at Univ. Bonn
- 1974-79 Dipl. + Ph. D. in Jülich/Bonn
- 1979-83 Stony Brook
- 1984-96 Univ. Illinois 1990 Full Prof.
- 1990-95 Univ. Bonn
  + Vice-Director Jülich
- 1996- Full Prof. TU Darmstadt
- 2004- Head Theory Group Hadrons + QCD at GSI.

Honors and Service of Jochen Wambach

- 2003- Fellow of American Phys. Soc.
- 2002- 2008 Senat of DFG
- 2007- Editor: European J. of Phys. A
- 2007- Editor: Phys. Rev. Lett.
- Member of many National and International Committees.



SPIRES: Famous Publication



- „Famous paper“ with 436 citations with R. Rapp: Chiral Symmetry Restoration and Dileptons in Relativistic HI Collisions. Published in Annals of Physics 2000.

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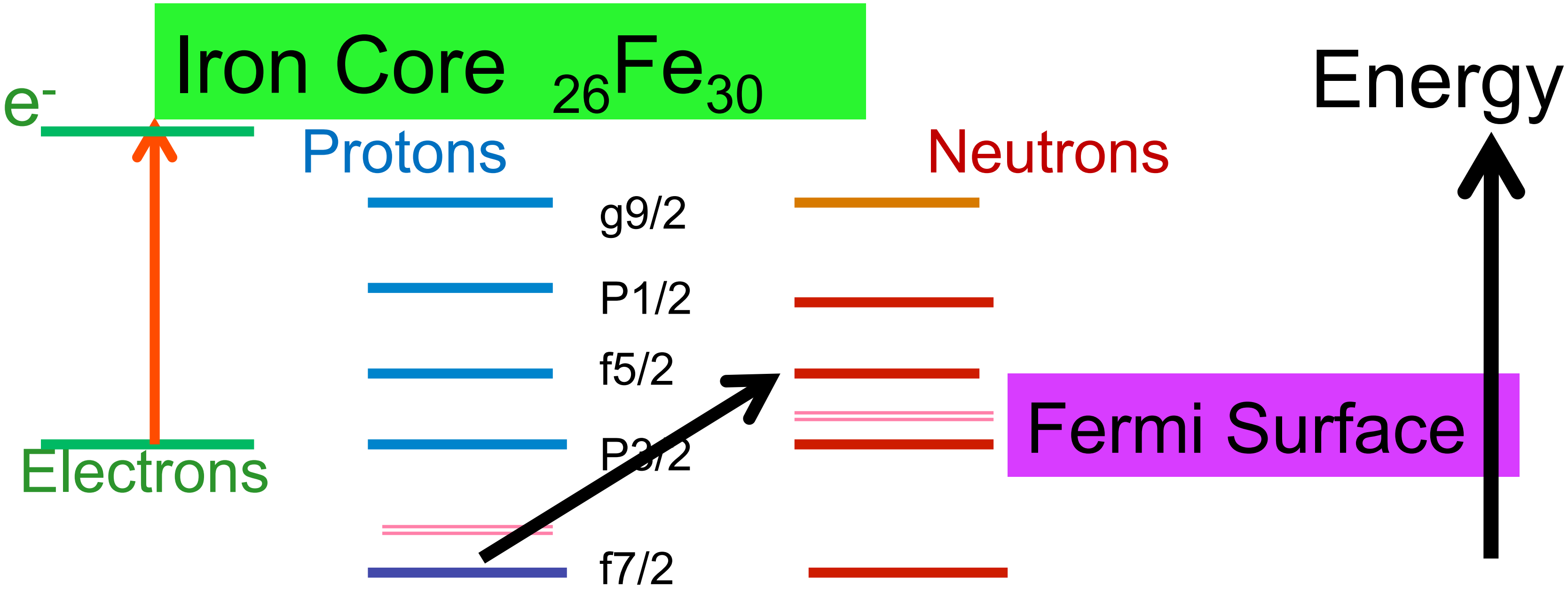
1) Cooperstein, Wambach: Electron capture in Stellar Collaps ; Nucl. Phys. A420(1984)
2) Chanfray, Rapp, Wambach: Medium Modifications of the ρ Meson at SPS Energies; Phys. Rev. Lett. 76 (1996)

1) What triggers the presupernova stellar collaps?

Wambach, Cooperstein. Nucl. P.A420(1984)



Bethe+Brown 1979: $e^- + p\ f_{7/2} \rightarrow n\ f_{5/2} + \nu_e$

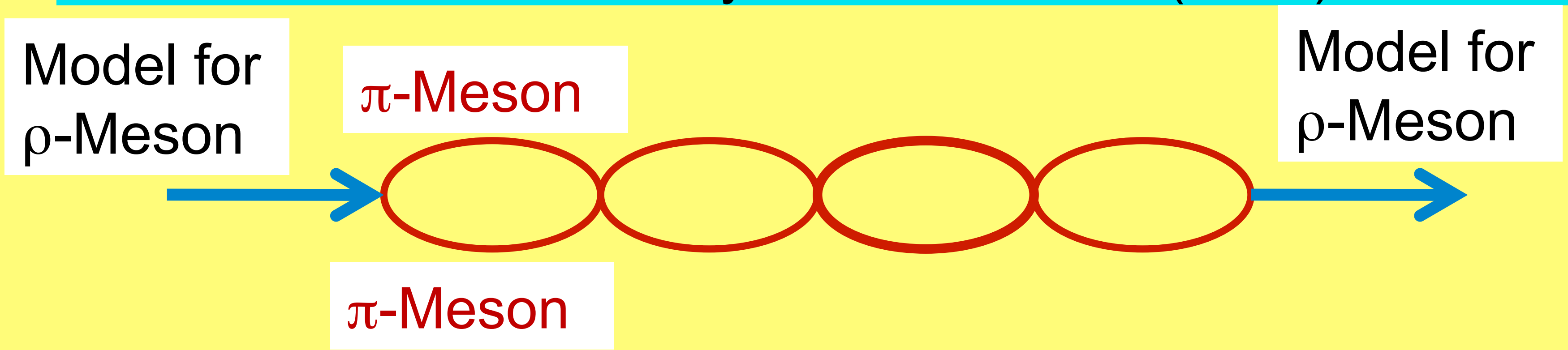
Fuller soon blocked 1982: $n\ f_{5/2}$ full

Wambach 1984: Thermal unblocking:

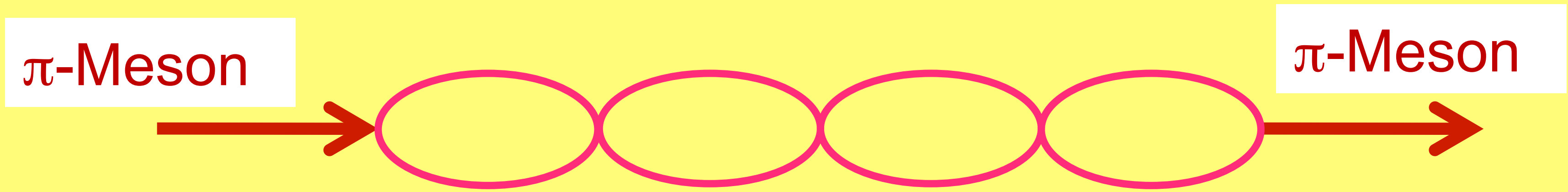
$p\ g_{9/2} \rightarrow n\ g_{9/2}$; $p\ g_{9/2} \rightarrow n\ g_{7/2}$

2) Propagation of the ρ-Meson in hot and dense Nuclear Matter (CERES Data)

Wambach et al. Phys. Rev. Lett. 76 (1996)436

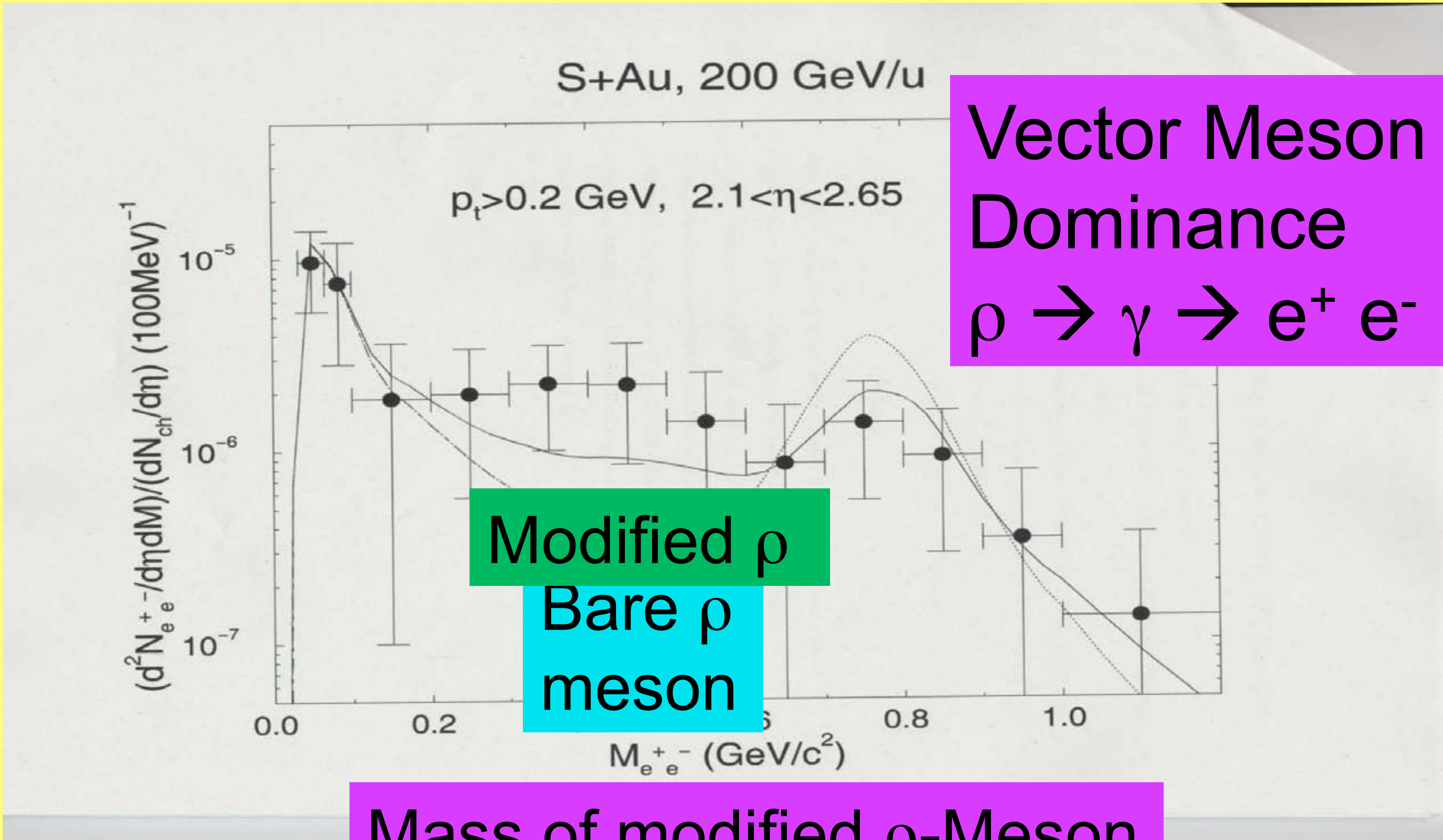


Pion propagation in hot and dense nuclear matter:



$N\,N^{-1}$; $\Delta\,N^{-1}$; $N\,\Delta^{-1}$; $\Delta\,\Delta^{-1}$

Explanation of the CERES-Dilepton-Data CERN PPE 1995



Vector Meson Dominance

$\rho \rightarrow \gamma \rightarrow e^+ e^-$

Modified ρ

Bare ρ meson

Mass of modified ρ-Meson

Can one measure the Neutrino Mass in the 0ν Double Beta Decay ?

Fest-Colloquium for the 60. Birthday of Jochen Wambach
July 7. 2010.

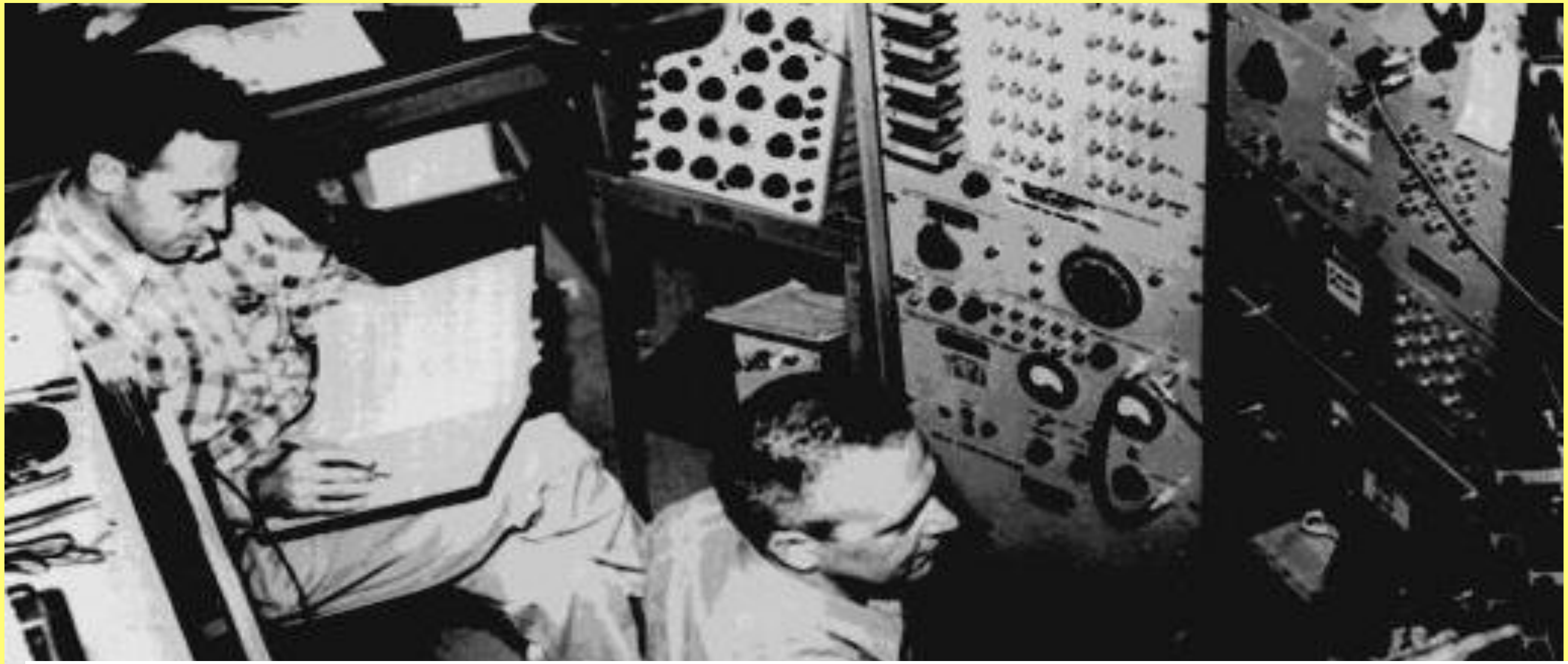
Amand Faessler,
University of Tuebingen

Sehr geehrte radioaktiven

Damen und Herren:

Invention of the Neutrino in a letter from Zuerich to Tuebingen on December 4th, 1930: Conservation of Energy and Angular Momentum in β-Decay.

Reines and Cowen and the Neutrino-Detection (1956 at Suvanna River Reactor)



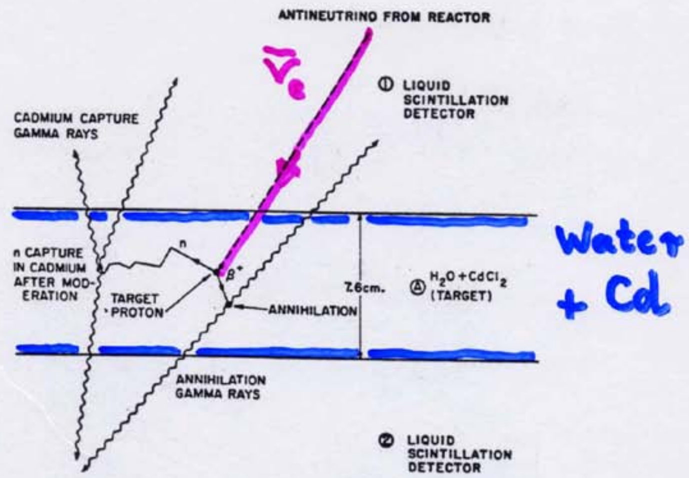
$$\nu_e^c(from\ reactor) + p \rightarrow n + e^+$$

$$e^+ + e^- \rightarrow 2 * \gamma(511[keV])$$

$$delayed:\ \ Gd(n, \sum \gamma' s = 8MeV)$$

Detection of the Neutrino 1955/56: by Fred Reines and Clyde Cowen

F. Reines: „40 years of neutrino physics"
Progr. Part. Nucl. Phys. 32 (1994) 1 (Erice School 1993)



Savannah River Reactor

$$p + \bar{\nu}_e \rightarrow n + e^+$$

Fission of Uranium Nuclei produce Neutron rich Medium Mass Nuclei, which beta decay:

$$n \rightarrow p + e^- + \nu_e^c$$

$m_p = 938.27 MeV \quad m_n = 939.56 MeV$

$m_e = 0.511 MeV$

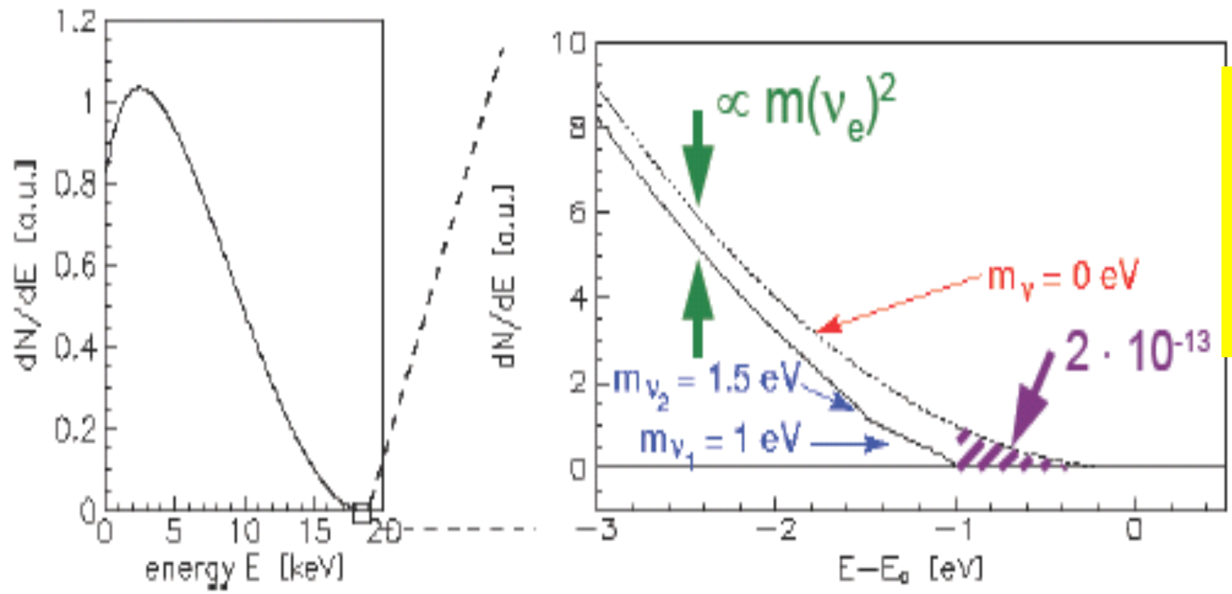
1) Direct Determination of $m(\nu_e)$ from β decay

β decay: $(A,Z) \rightarrow (A,Z+1)^{+} + e^{-} + \bar{\nu}_e$

β electron energy spectrum:

$$dN/dE = K\ F(E,Z)\ p\ E_{tot}\ (E_0-E_e)\ \Sigma\ |U_{ei}|^2 [\ (E_0-E_e)^2 - m(\nu_i)^2\ ]^{1/2}$$

(modified by electronic final states, recoil corrections, radiative corrections)



Mainz + Troisk
Triton Beta-Decay
$m_\nu < 2.3$ eV

Need: low endpoint energy → Tritium ^{3}H (^{187}Re)

1)Mass of the Electron Neutrino? Tritium decay (Mainz + Troisk)

$$^3H \rightarrow \ ^3He + e^- + \nu_e^c$$

$$E_0 = Q + m_e; \quad Q = 18.$$

$$E_e = \sqrt{m_e^2 + p_e^2} \qquad E$$

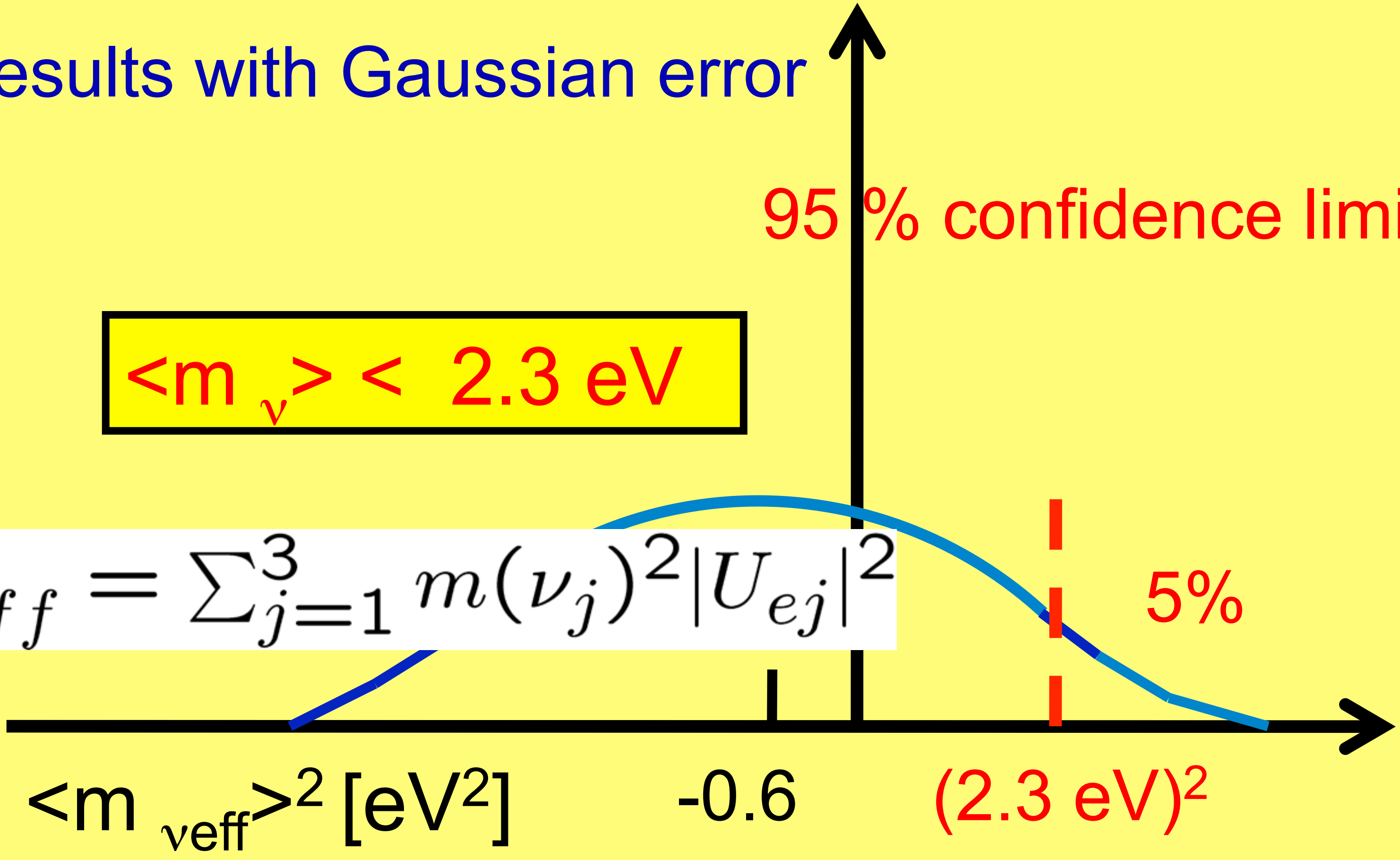
Mainz + Troisk
Triton Beta-Decay
$m_\nu < 2.3$ eV

$$\frac{dN_e}{dE} = K \cdot F(E,Z) \cdot p_e E_e (E_0 - E_e) \sum_{j=1}^{3} |U_{ej}|^2 \sqrt{(E_0 - E_e)^2 - m(\nu_j)^2}$$

Distinguish flavor (production) e, μ, τ and mass $j = 1, 2, 3$ eigenstates.

Upper limit of Neutrino mass from the Mainz(Troisk) Experiment

Results with Gaussian error



$<m_\nu> \, < \, 2.3 \text{ eV}$

$$m^2_{\nu eff} = \sum_{j=1}^{3} m(\nu_j)^2 |U_{ej}|^2$$

Tranformation from Mass to Flavor Eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Single Beta Decay
Electron Capture

$$Sensitive\ to: \ m^2(\nu_e) = \sum_{i=1,2,3} |U_{ej}|^2 m_j^2$$

$$aim : m(\nu_e) < 0.3[eV]$$

KATRIN Spectrometer tank on the way from the Rhine to the FZ Karslsruhe

2) Neutrino Mass from Astrophysics: (Power Spectrum of Matter Distribution)

$$P(k) \propto \int_0^\infty \left(\frac{(\rho(r)-\bar{\rho})}{\bar{\rho}}\right)^2 \exp(ikr) r^2 dr$$

wave number: $k = \frac{2\pi}{\lambda}$

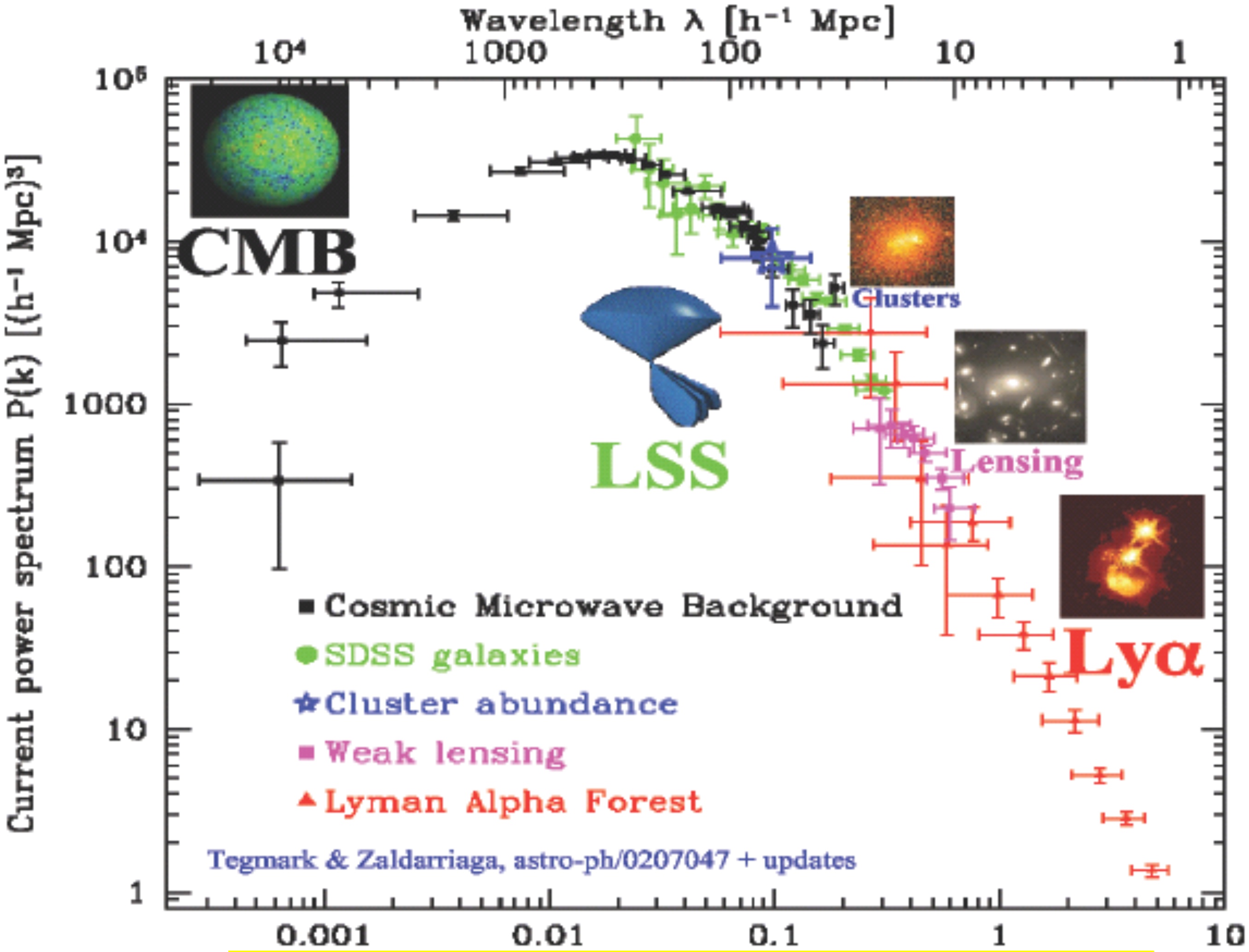
$k[h/Mpc] = 0.1 \qquad \lambda = 50 Mpc$

$k[h/Mpc] = 1 \qquad \lambda = 5.0 Mpc$

$k[h/Mpc] = 10 \qquad \lambda = 0.5 Mpc$

h = 0.71

Neutrino mass from cosmology



$k = 2\pi/\lambda$ [(h=0.71)/ Mpc]

$\Omega_0 = 1.0$

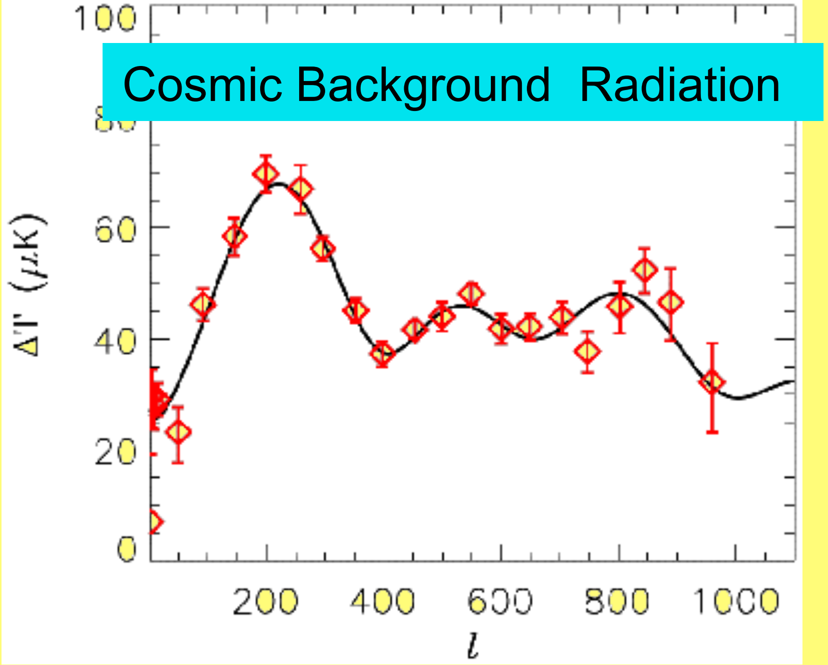
$\Omega_\Lambda = 0.66$

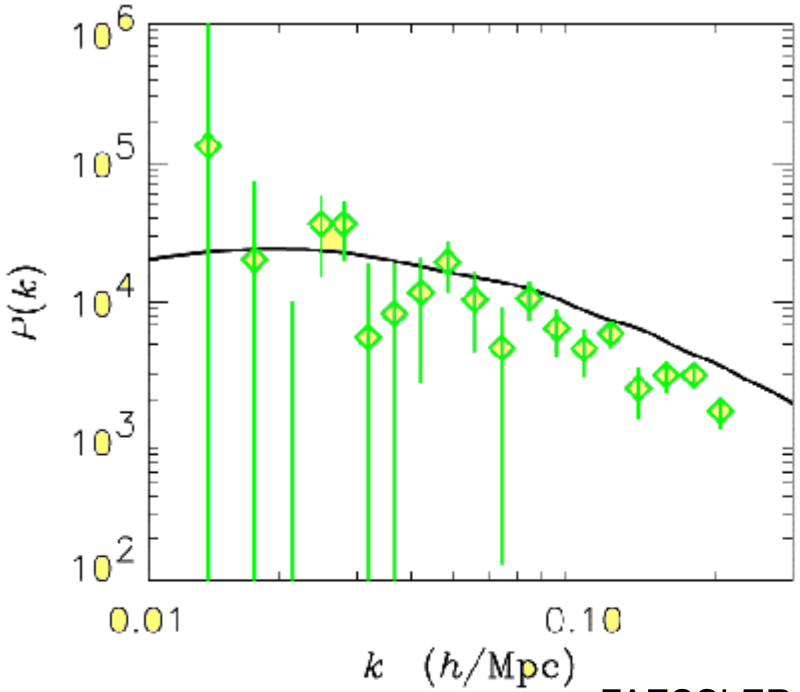
$\Omega_b = 0.04$

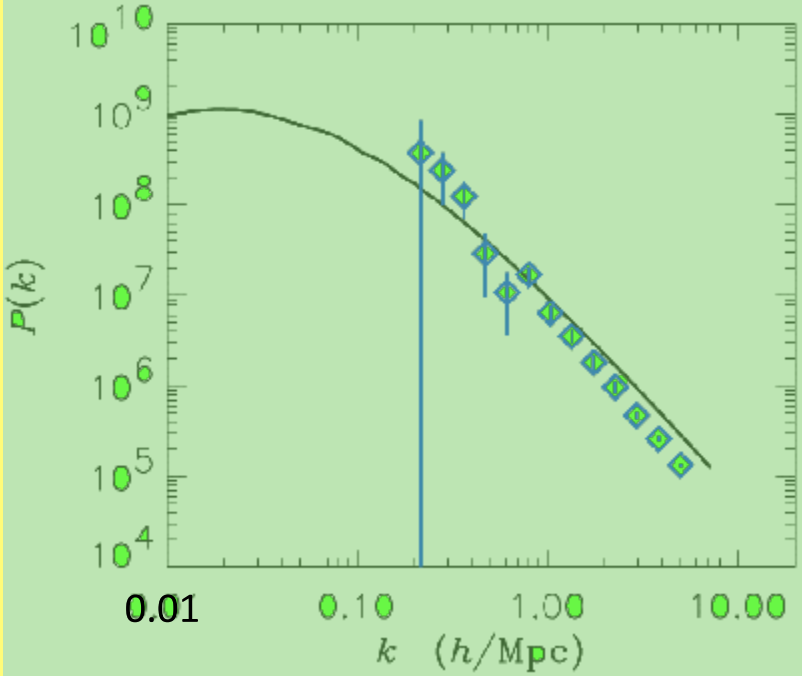
$H_0 = 72[km/(sec*Mpc]$

$n_s = 0.94$

$\Omega_\nu = 0$







$\Omega_0 = 1.0$

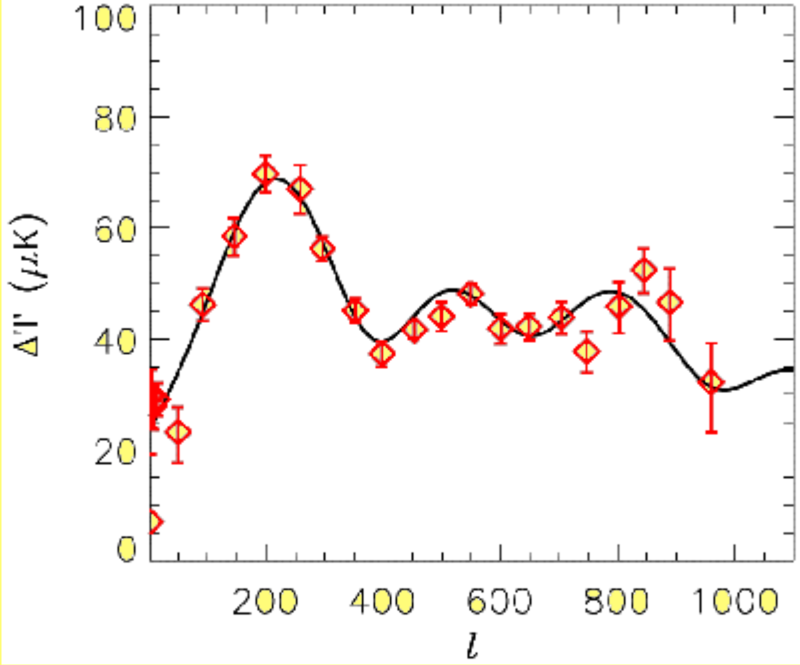
$\Omega_\Lambda = 0.66$

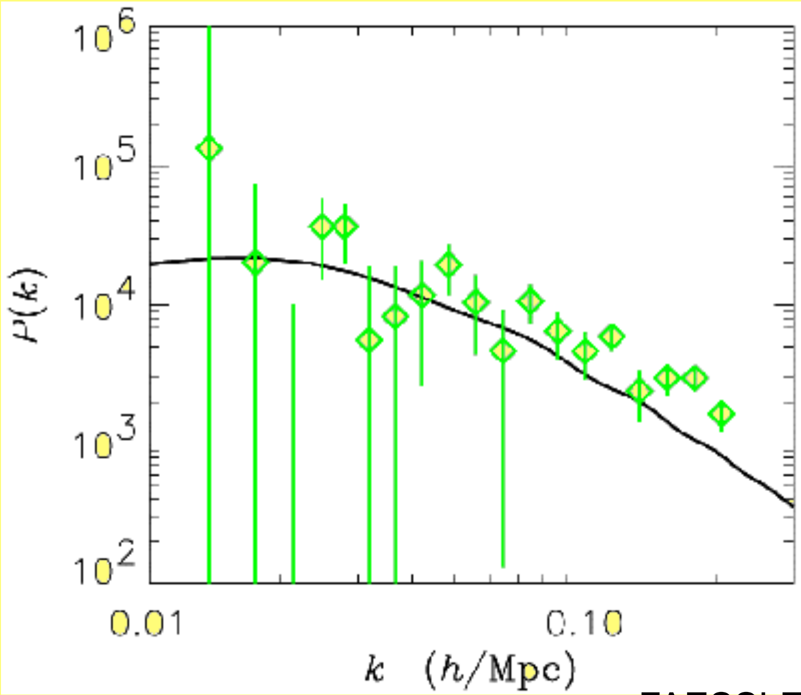
$\Omega_b = 0.04$

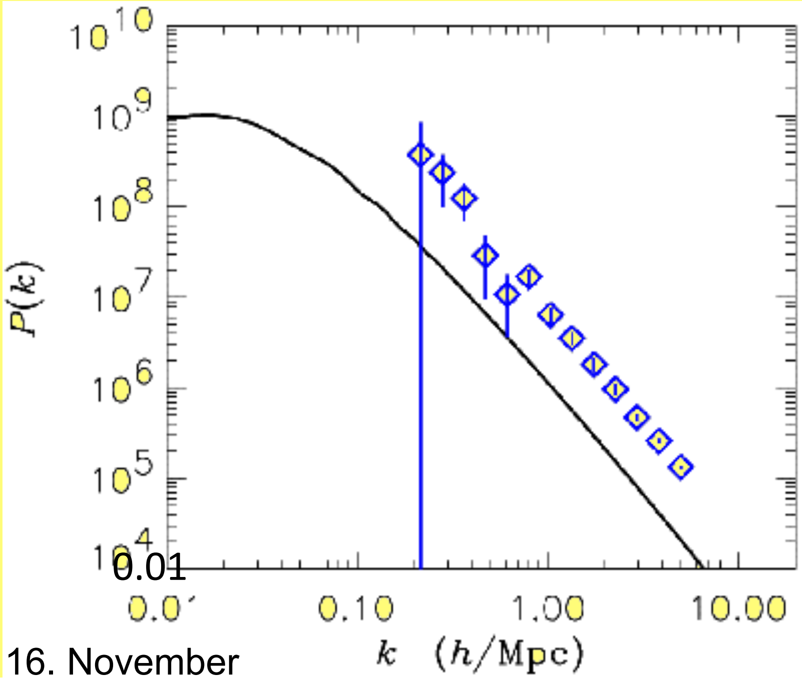
$H_0 = 72$

$n_s = 0.94$

$\Omega_\nu = 0.05$







$\Omega_0 = 1.0$

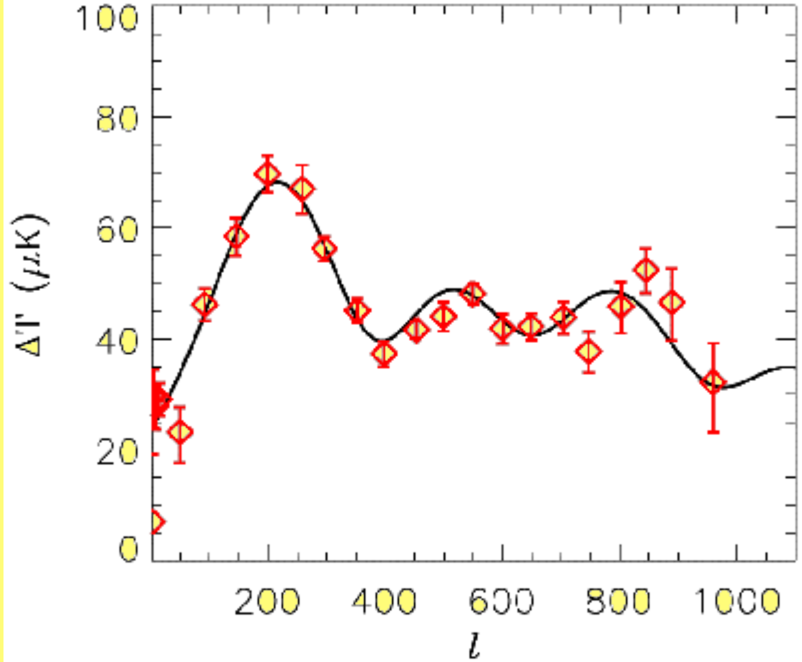
$\Omega_\Lambda = 0.66$

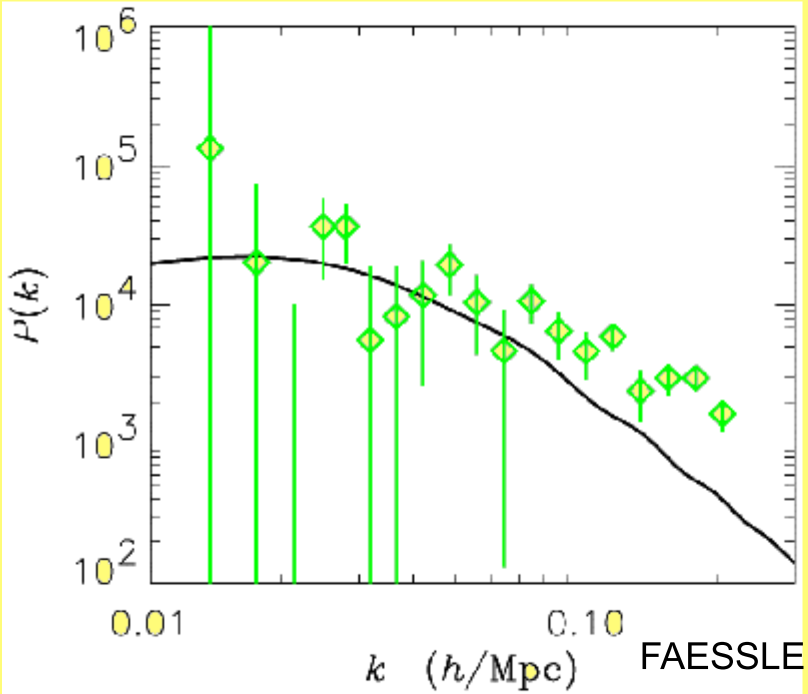
$\Omega_b = 0.04$

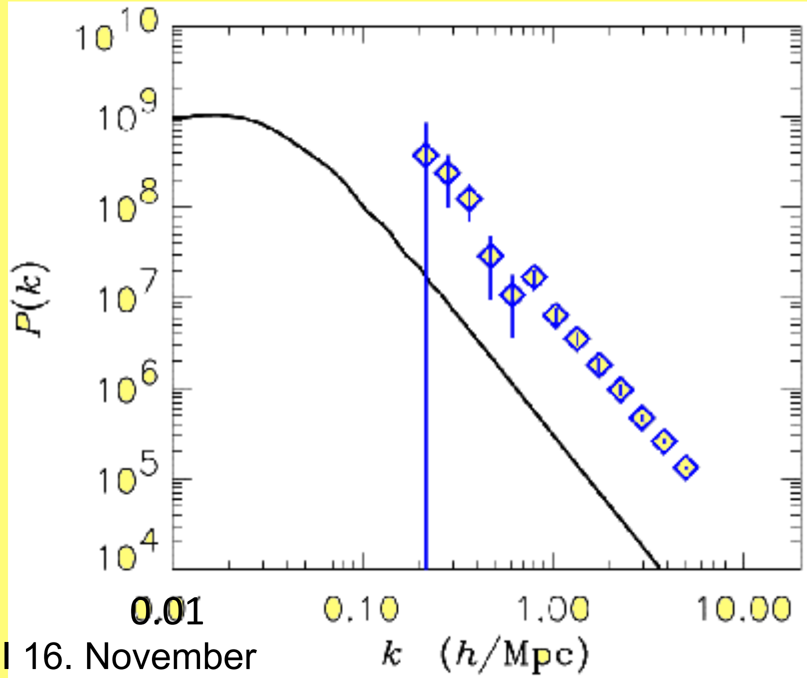
$H_0 = 72$

$n_s = 0.94$

$\Omega_\nu = 0.1$







$\Omega_0 = 1.0$

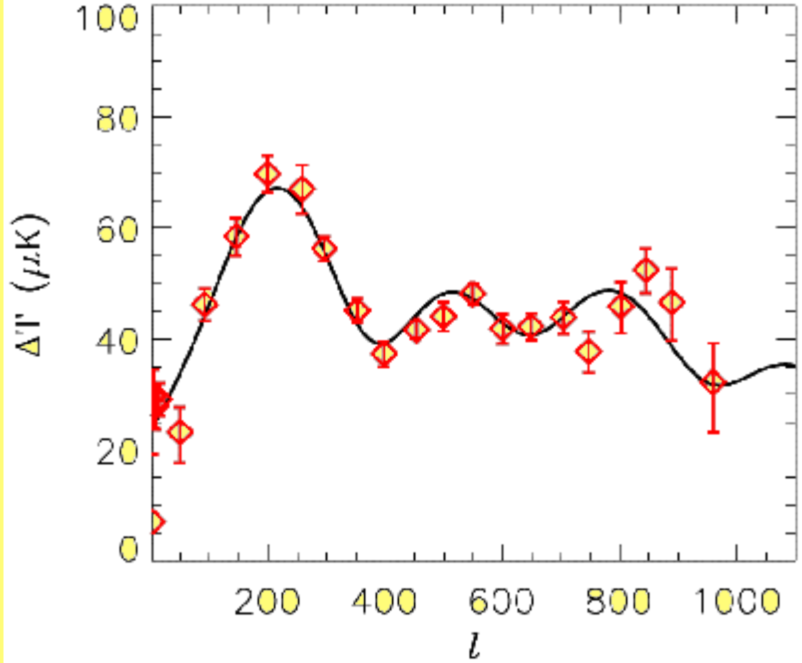
$\Omega_\Lambda = 0.66$

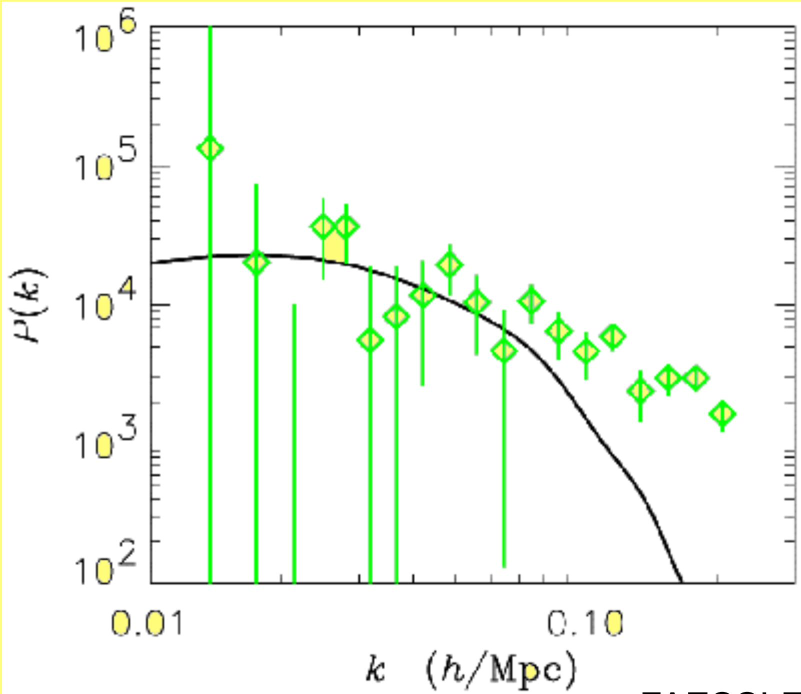
$\Omega_b = 0.04$

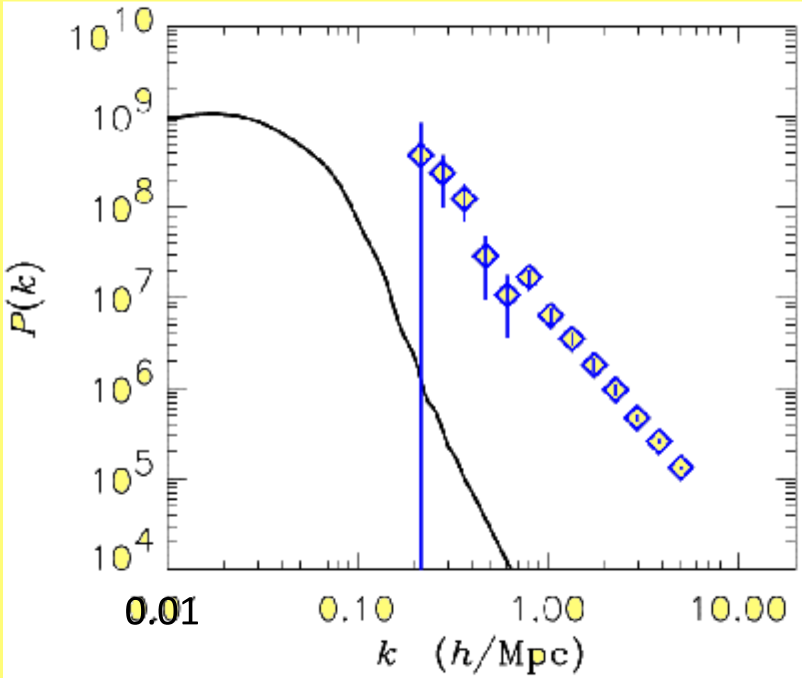
$H_0 = 72$

$n_s = 0.94$

$\Omega_\nu = 0.25$







Neutrino mass from cosmology

D.N. Spergel et al. (WMAP)

(astro-ph/0302209) $\Sigma m(\nu_i) < 0.7$ eV →

WMAP+ACBAR+CBI+2dFGRS +Lyα Daten

S. Hannestad et al.

(astro-ph/0303076) $\Sigma m(\nu_i) < 1\text{-}2$ eV

same data, more conservative asumptions

S.W. Allen et al.

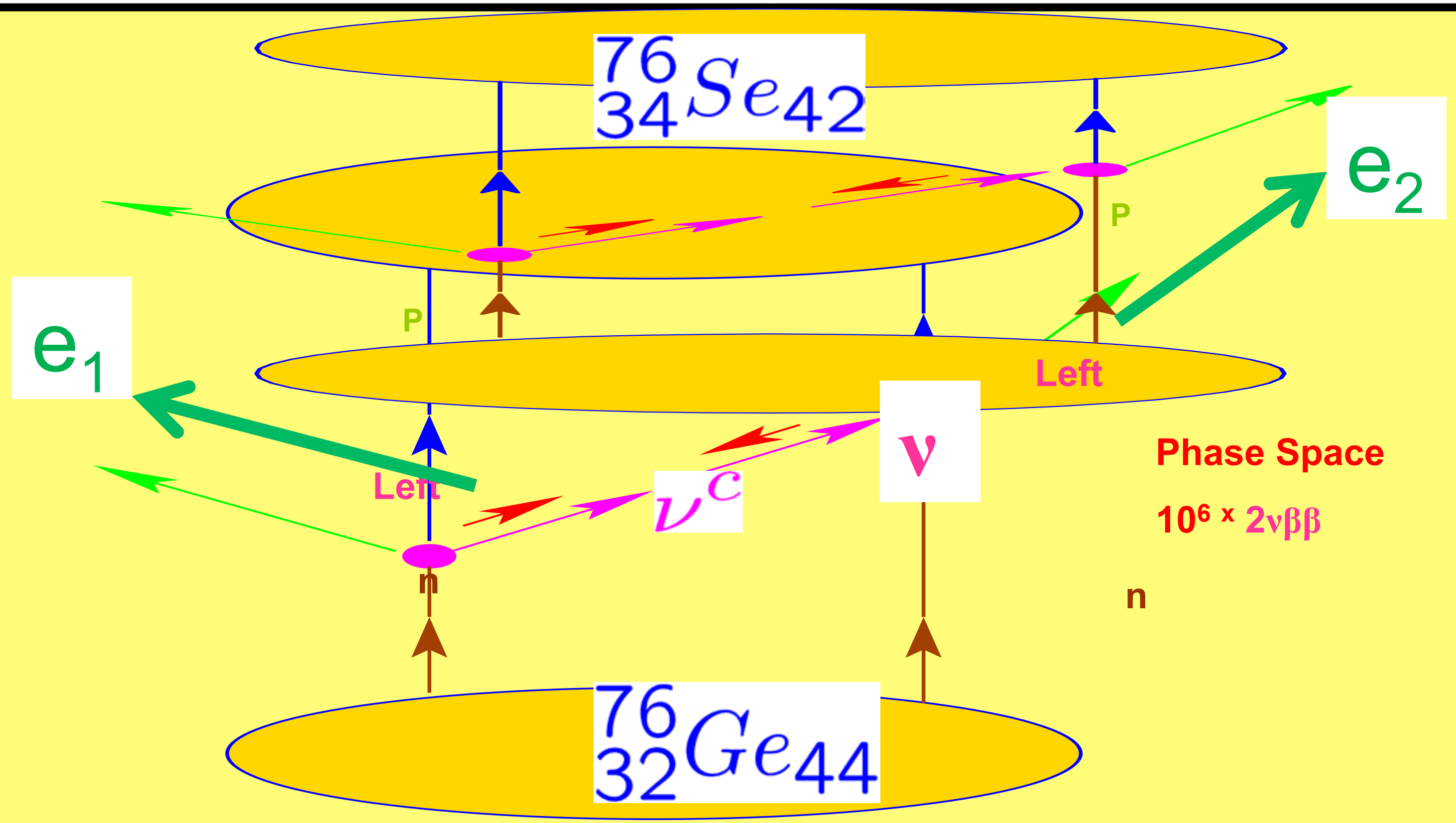
(astro-ph/0306386) $\Sigma m(\nu_i) \approx 0.64$ eV →

WMAP+2dFGRS

+f_{gas}+XLF (x-ray cluster data) data

- WMAP = Wilkinson Microwave Anisotropy Probe.
- ACBAR = Arcminute Cosmology Bolometer Array Receiver (Berkeley)
- CBI = Cosmic Background Imager (CALTEC)
- 2dFGRS = 2 degree Field Galaxy Redshift Survey

3) Neutrino mass from 0νββ-Decay (forbidden in Standard Model)



$\nu = \nu^c$ Majorana Neutrino

Neutrino must have a Mass

GRAND UNIFICATION

Left-right Symmetric Models SO(10)

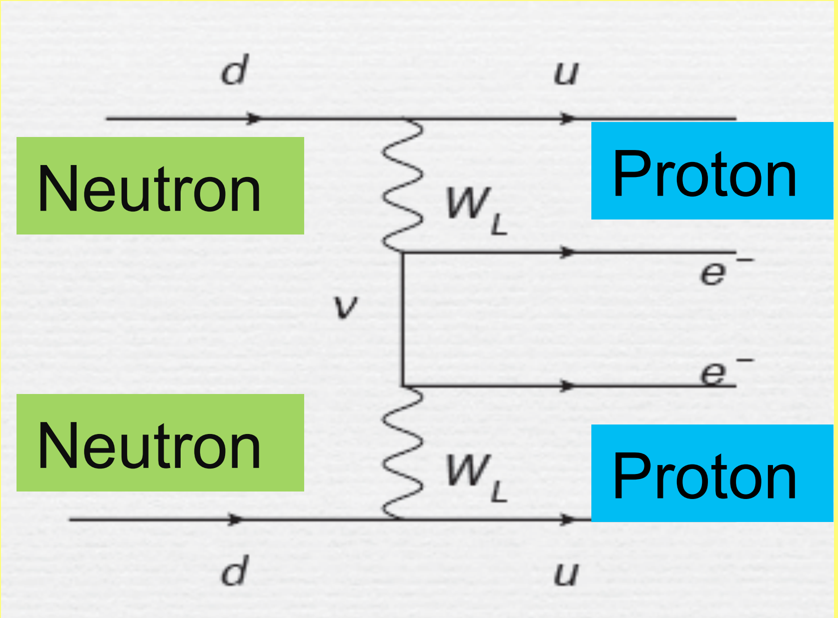
$$W_L^{\pm}; W_R^{\pm}; \qquad \nu = \nu^c$$

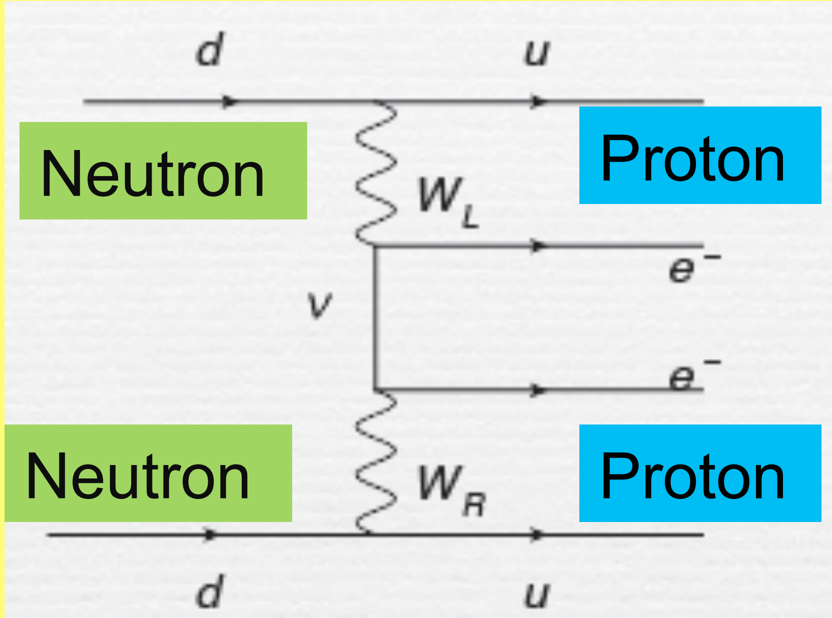
Majorana Mass: $\mathcal{L} = \ldots + m_\nu \bar{\nu^c} \nu + m_\nu^* \bar{\nu} \nu^c$

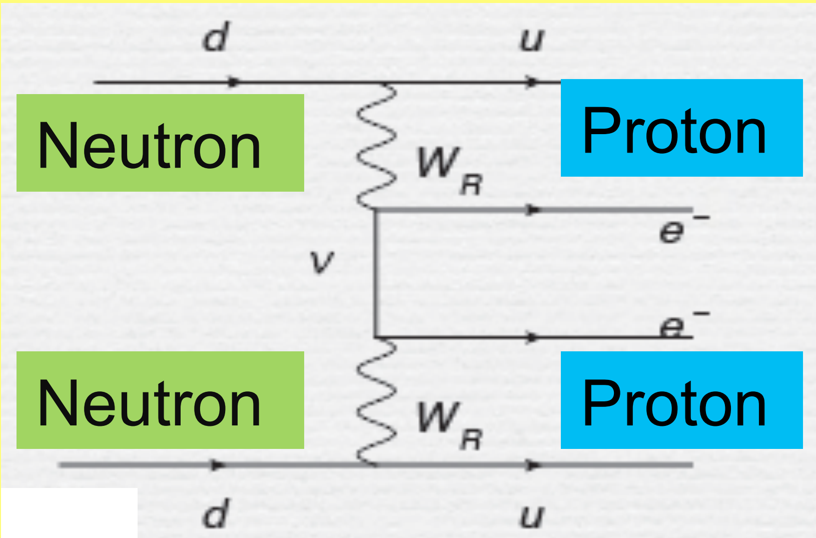
$$W_1^{\pm}(81 GeV) = cos\vartheta W_L^{\pm} + sin\vartheta W_R^{\pm}$$

$$W_2^{\pm}(? GeV) = -sin\vartheta W_L^{\pm} + cos\vartheta W_R^{\pm}$$

Grand Unified left-right Symmetry

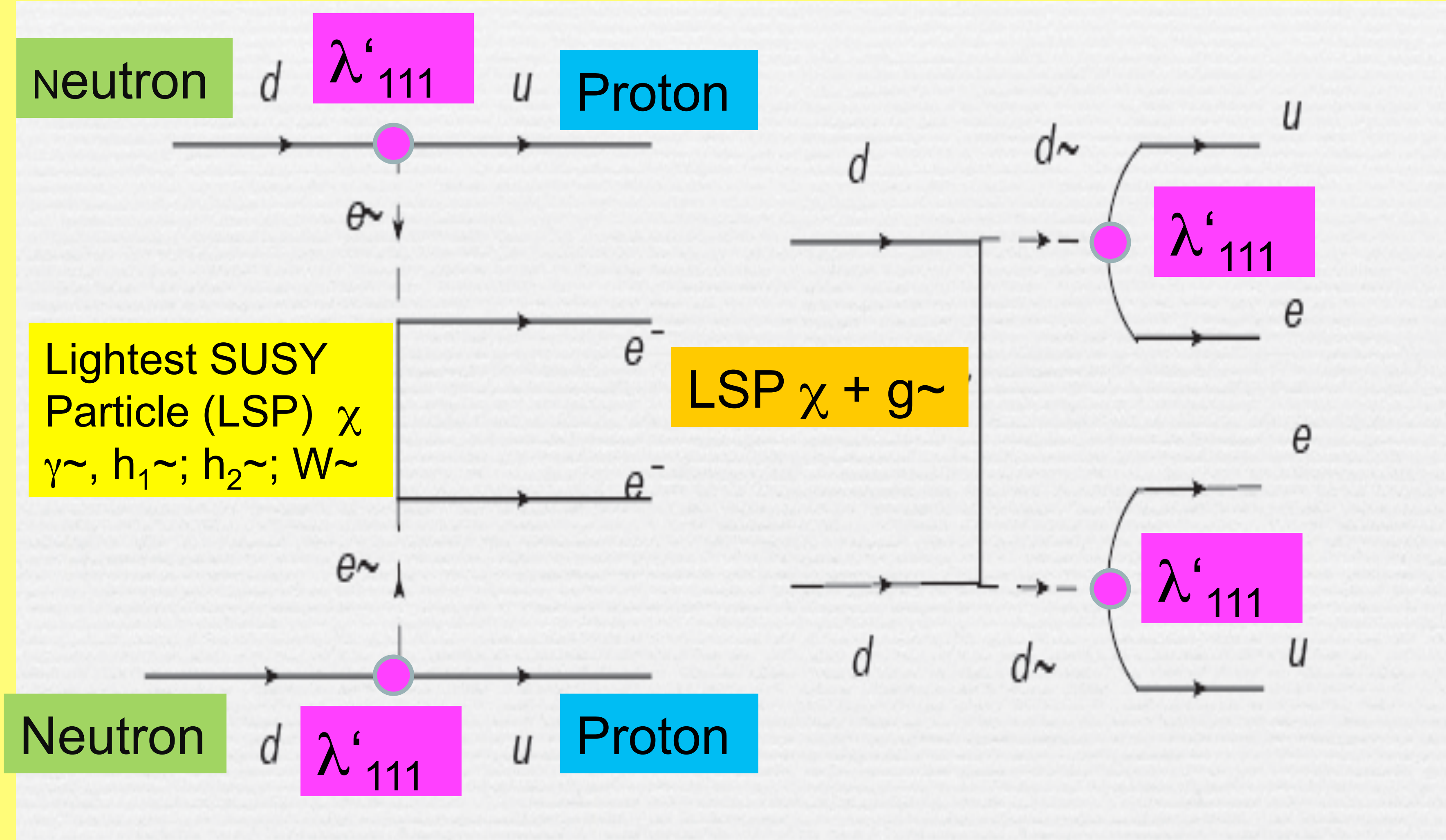






First and Third Diagram ~ Neutrino Mass

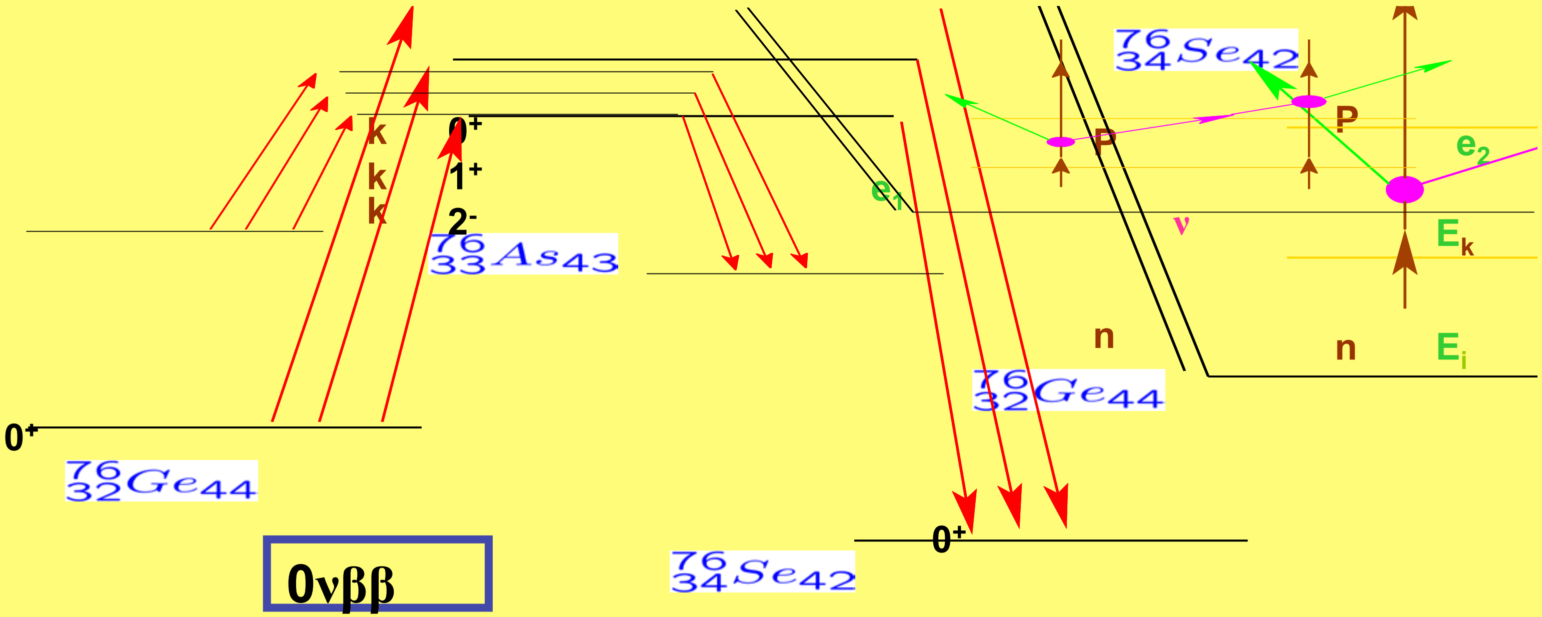
Supersymmetric Diagrams for the Neutrinoless Double Beta decay.



2010

Theoretical Description of Nuclei:

Vadim Rodin, Fedor Simkovic,
Amand Faessler, Saleh Yousef



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

QRPA starts with Pairing:

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

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

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

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

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

$$\hat{H} Q_m^{+}|g> = E_m Q_m^{+}|g> \hookrightarrow X_m^\alpha ; Y_m^\alpha ; E_m$$

V. Rodin, F. Simkovic, S. Yousef, D. L. Fang, A. Escuderos

Neutrinoless Double Beta-Decay Probability

$$T = \int dE_k(\nu) \Sigma_k \frac{< f|\hat{H}_W|k >< k|\hat{H}_W|i >}{E_{0^+}(^{76}Ge) - [E_k(e_1^-) + E_k(\nu) + E_{Kern}(^{76}As; k)]}$$

$$T = M_m < m_\nu > + M_\theta < tg\vartheta > + M_{WR} < \left(\frac{M_1}{M_2}\right)^2 >$$

$$+ M_{SUSY} \lambda'^2_{111} + M_{VR} < \frac{m_p}{M_{VR}} > + \ldots$$

$$w = \frac{2\pi}{\hbar} |T|^2 \rho_f \leq 4.4 \cdot 10^{-33} [sec^{-1}]$$ ^{128}Te

Single Beta Decay
Electron Capture

Effective Majorana Neutrino-Mass for the $0\nu\beta\beta$-Decay

$$m^2(\nu_e) = \sum_{i=1,2,3} |U_{ei}|^2 m_i^2$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$|< m_{\beta\beta} >| = |m_1 |U_{e1}|^2 + m_2 |U_{e2}|^2 e^{i\alpha_{21}} + m_3 |U_{e3}|^2 e^{i\alpha_{31}}|$$

CP → Time reversal

$$= |m_1 |U_{e1}|^2 \pm m_2 |U_{e2}|^2 \pm m_3 |U_{e3}|^2|$$

CPT

Neutrinoless Double Beta-Decay Probability

$$T = \int dE_k(\nu) \Sigma_k \frac{< f|\hat{H}_W|k >< k|\hat{H}_W|i >}{E_{0^+}(^{76}Ge) - [E_k(e_1^-) + E_k(\nu) + E_{Kern}(^{76}As;k)]}$$

$$T = M_m < m_\nu > + M_\theta < tg\vartheta > + M_{WR} < \left(\frac{M_1}{M_2}\right)^2 >$$

$$+ M_{SUSY}\lambda'^2_{111} + M_{VR} < \frac{m_p}{M_{VR}} > + \ldots$$

$$w = \frac{2\pi}{\hbar}|T|^2\rho_f \leq 4.4 \cdot 10^{-33}[sec^{-1}] \quad {}^{128}Te$$

QRPA (TUE), Shell Model (Madrid-Strassburg), IBM2, PHFB

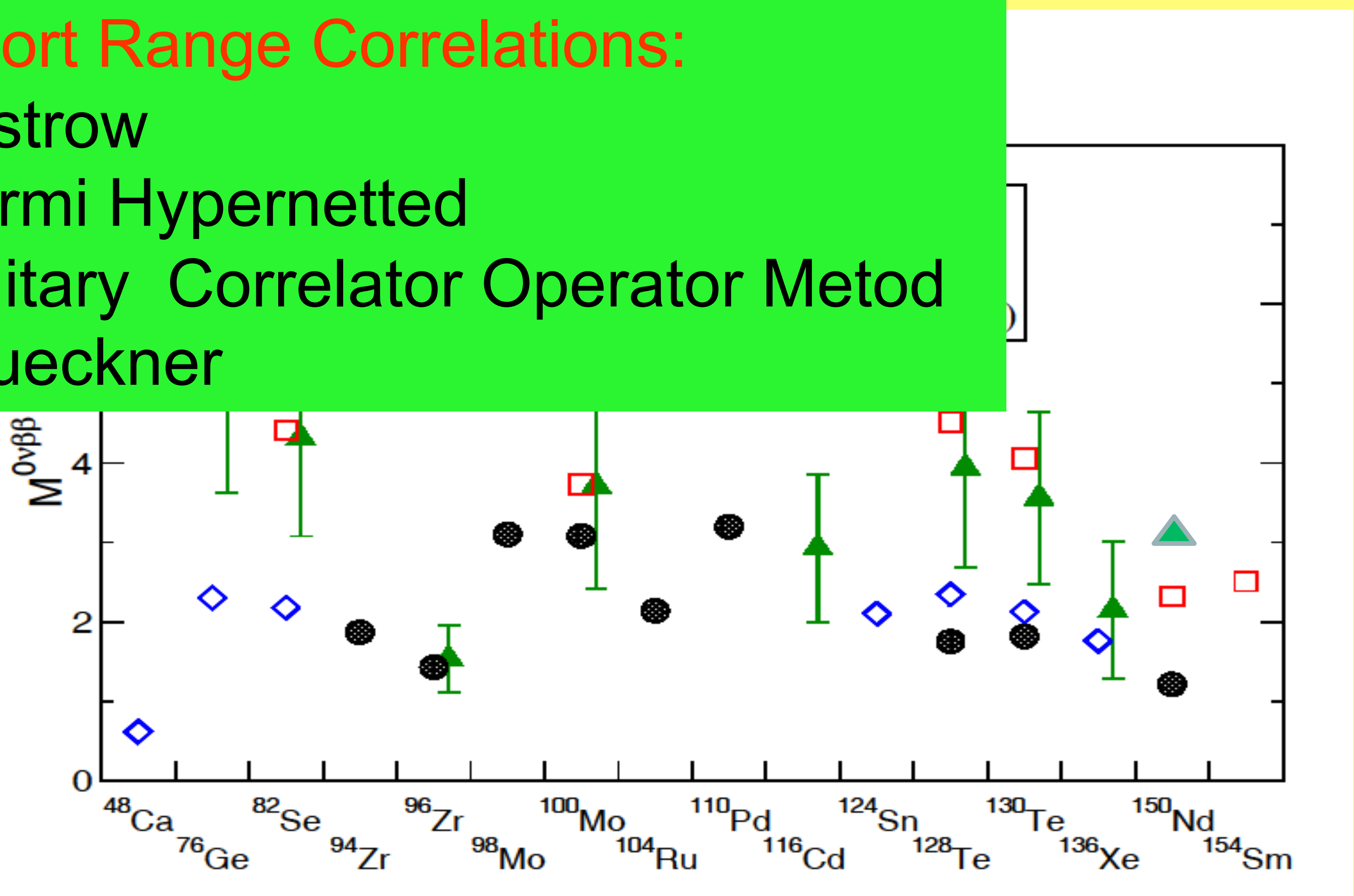
Short Range Correlations:

Jastrow

Fermi Hypernetted

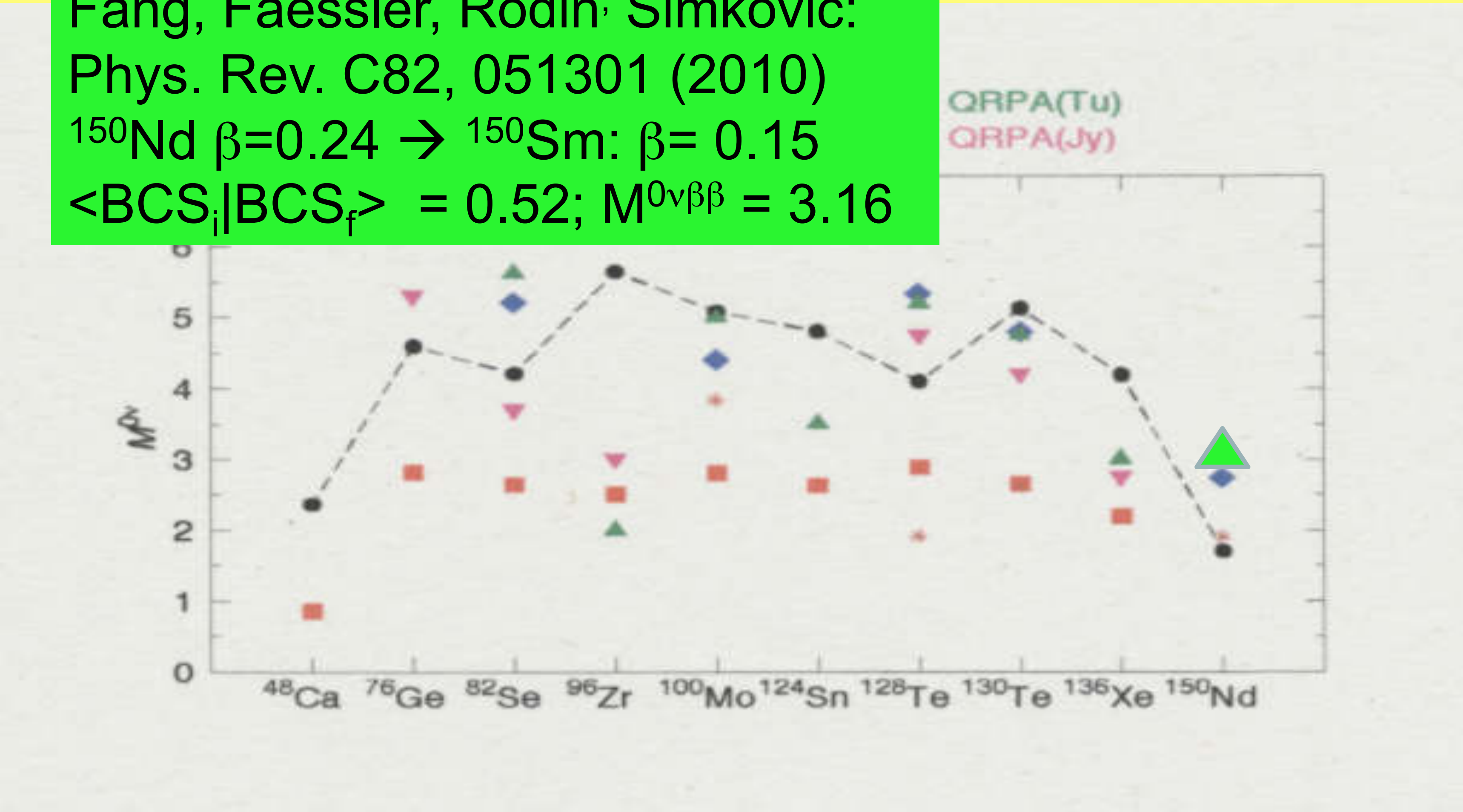
Unitary Correlator Operator Metod

Brueckner



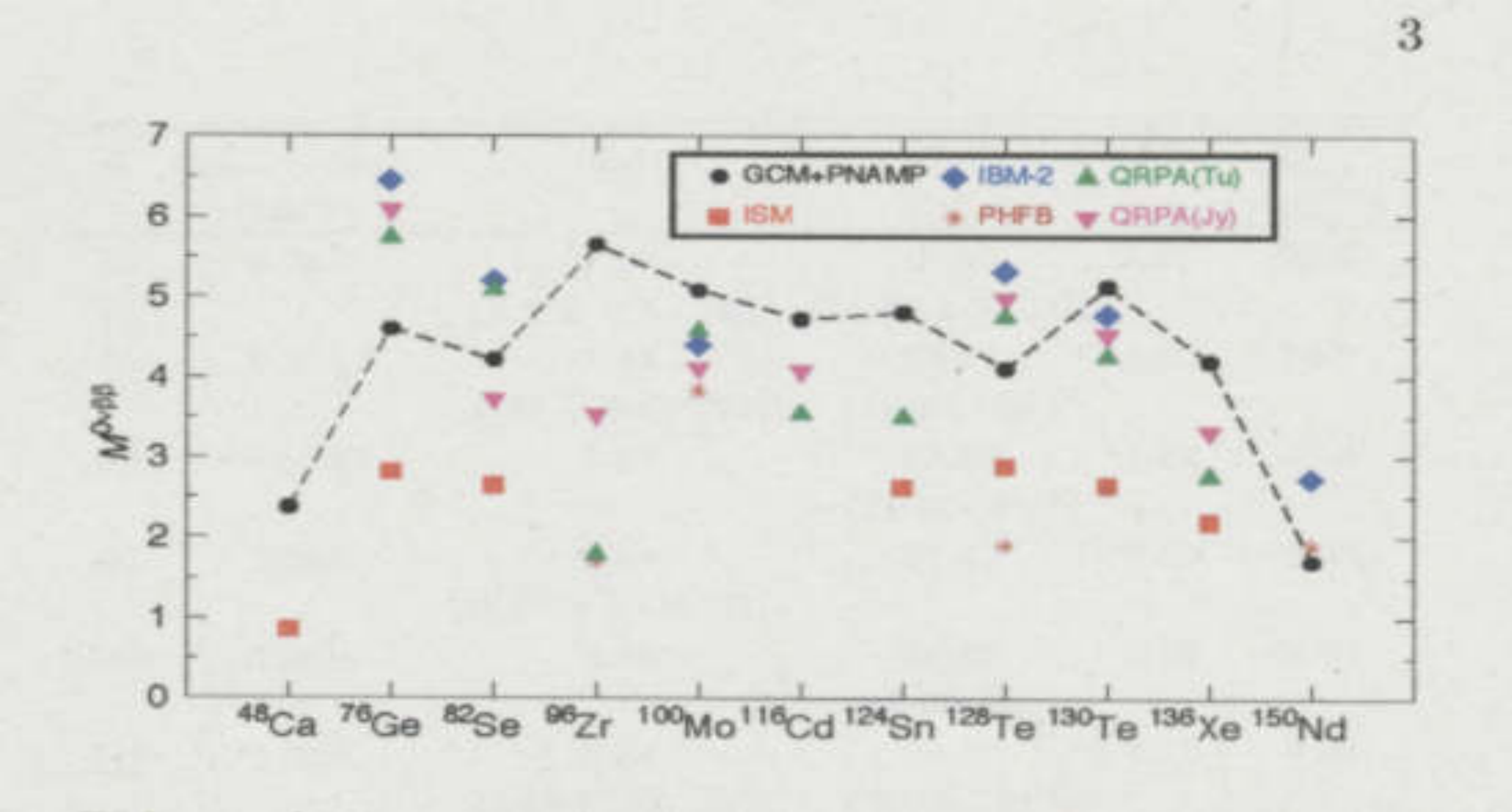
Rodriguez, Martinez-Pinedo: projected-HFB, Gogny force, GCM; arXiv1008.5260; beta(Nd) = 0.35; beta(Sm) = 0.21

Fang, Faessler, Rodin, Simkovic:
Phys. Rev. C82, 051301 (2010)
^{150}Nd β=0.24 → ^{150}Sm: β= 0.15
$\langle BCS_i|BCS_f\rangle$ = 0.52; $M^{0\nu\beta\beta}$ = 3.16



Rodriguez, Martinez-Pinedo

Energy Density functional + Generator Coordinate Method

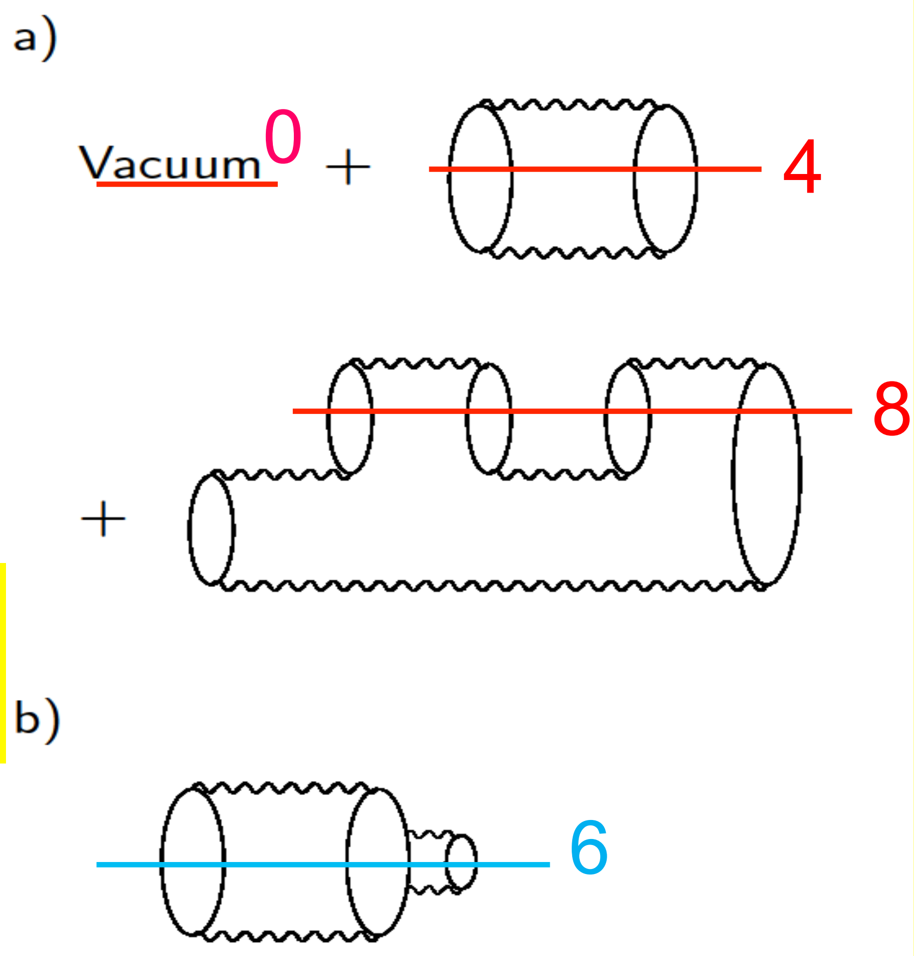


- Quasi-Particle Random Phase Approach (QRPA; Tübingen).
- Shell Model   Caurier et al.
- Angular Momentum Projected Hartee-Fock-Bogoliubov (Tübingen; P. K. Rath et al.; Rodriguez & Martinez-Pinedo+GCMβ).
- Interacting Boson Model (Barea+Iachello)

Which Angular Momentum J^{π} Neutron Pairs contribute to the Neutrinoless Double Beta decay?

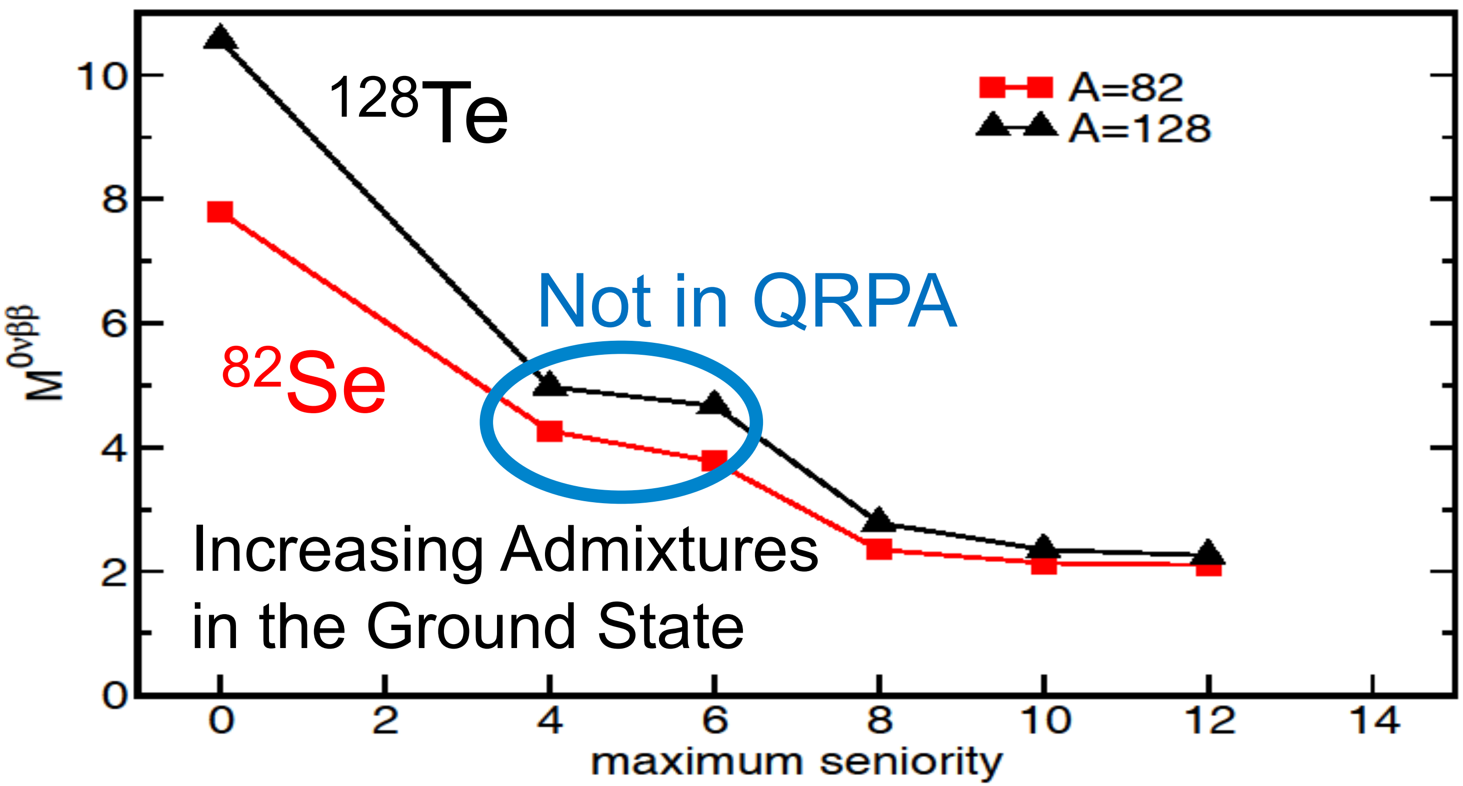
a) QRPA all the Ring digrams:
Ground State: 0, 4, 8, 12 , … quasi- particles (seniority)

b) The Shell Model
Ground state: 0, 4, 6, 8, ….

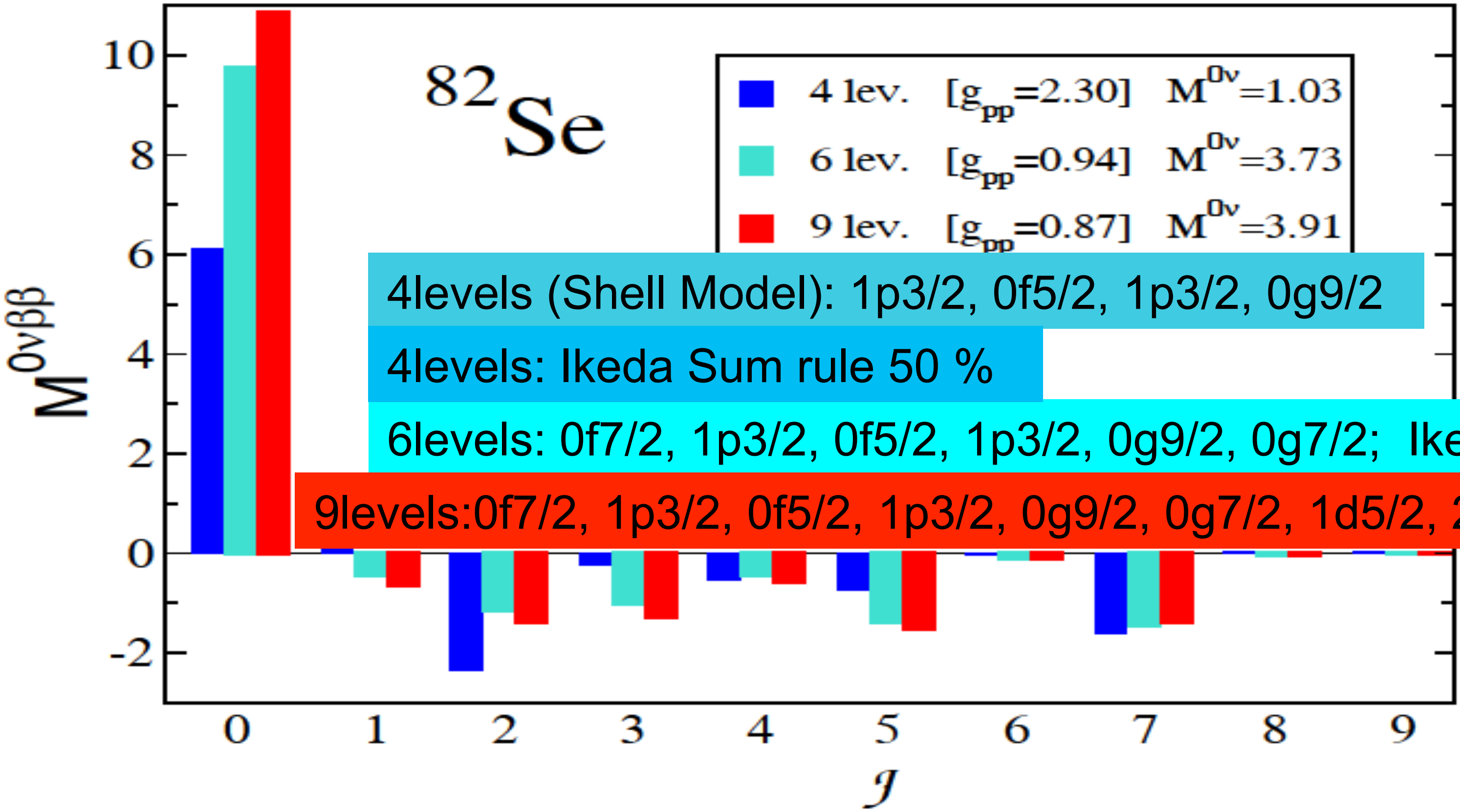


Problem for SM: Size of the Single Particle Basis.

Additive Contributions of 0, 4, 6, … Quasi-Particle States in the SM (Poves et al.).



Basis Size Effect for ^{82}Se on the Neutrinoless Double Beta Decay.



4levels (Shell Model): 1p3/2, 0f5/2, 1p3/2, 0g9/2

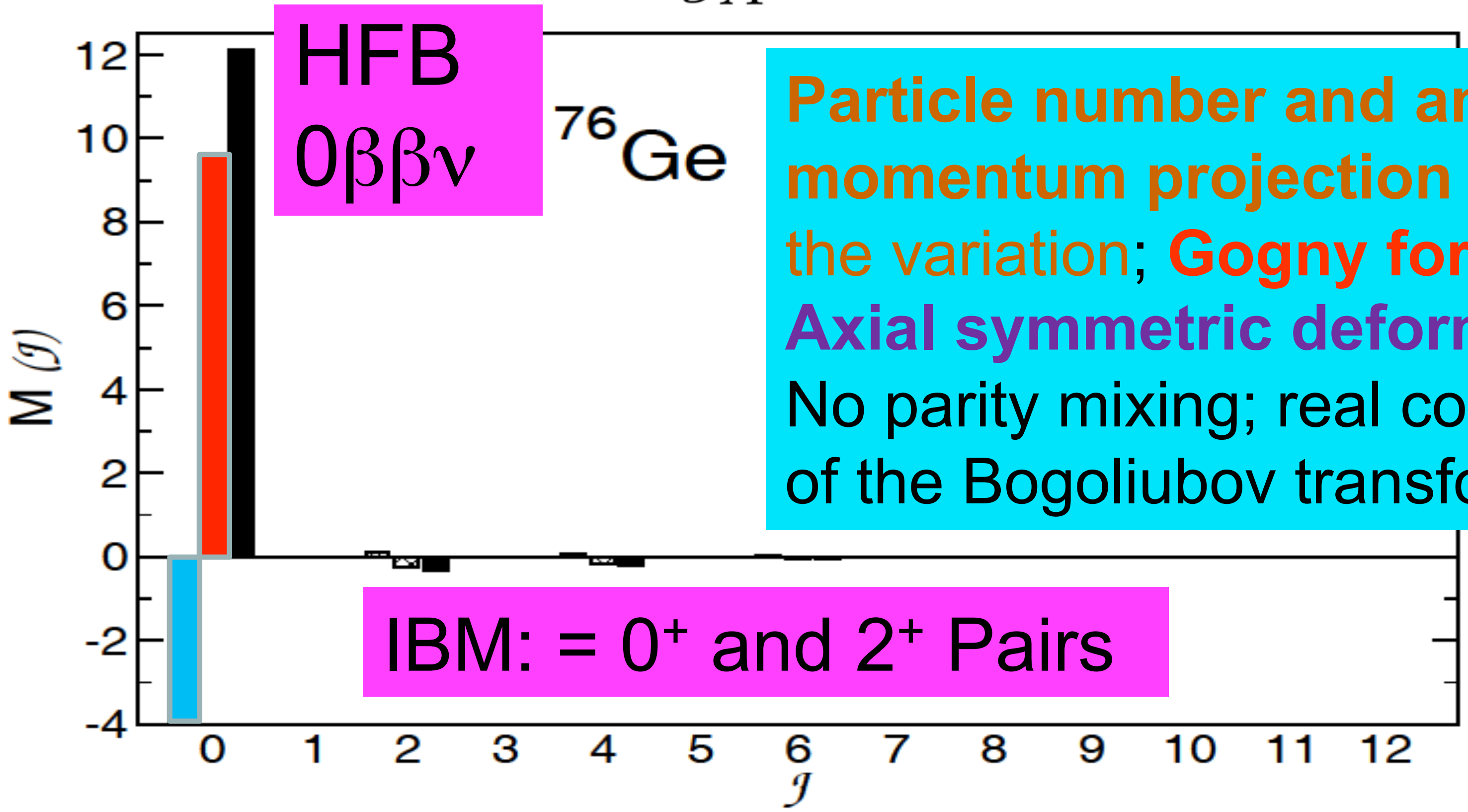
4levels: Ikeda Sum rule 50 %

6levels: 0f7/2, 1p3/2, 0f5/2, 1p3/2, 0g9/2, 0g7/2; Ikeda 100%

9levels:0f7/2, 1p3/2, 0f5/2, 1p3/2, 0g9/2, 0g7/2, 1d5/2, 2s1/2, 1d3/2

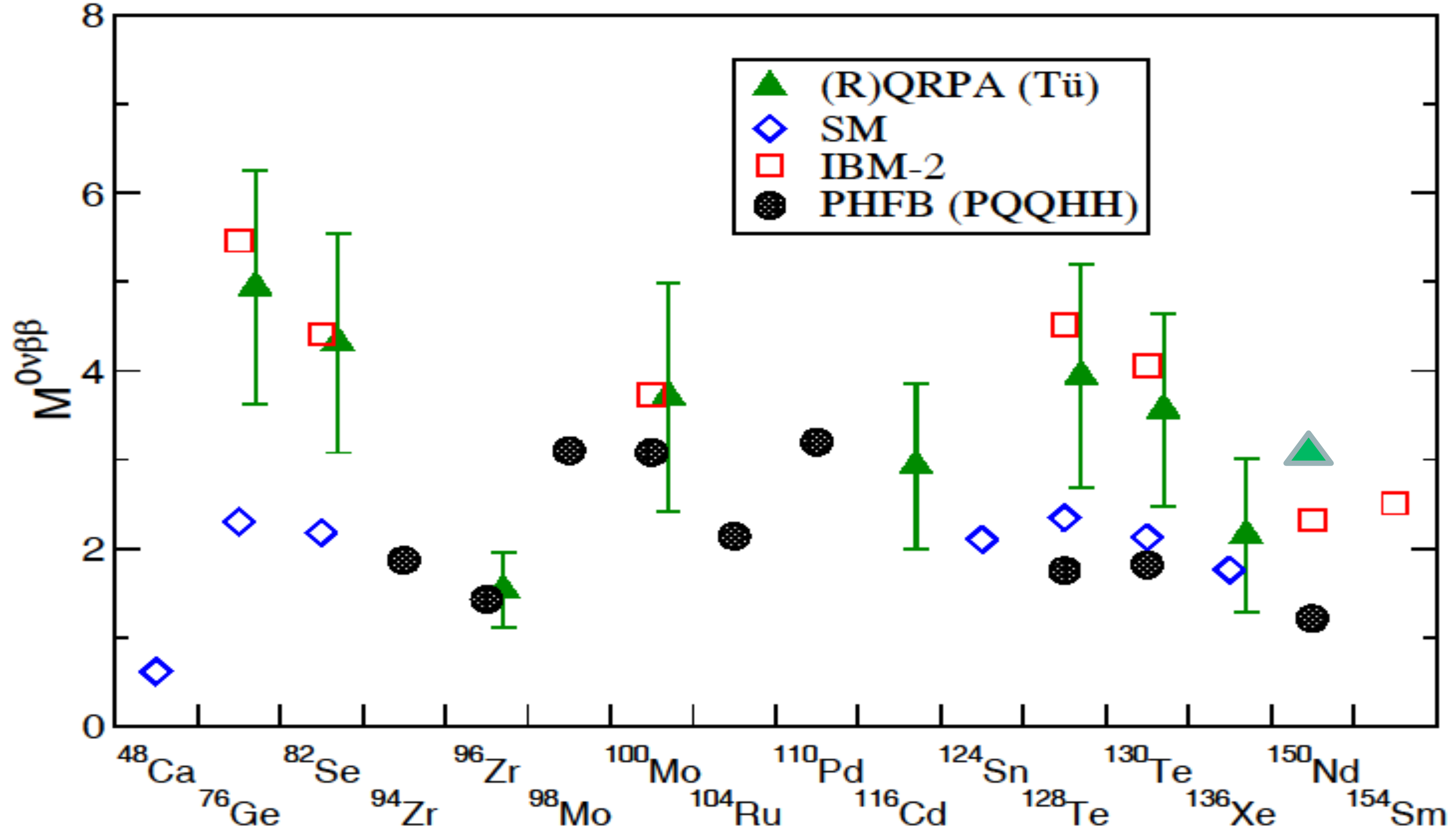
Contribution of Higher Angular Momentum Pairs in Projected HFB (Tübingen).

$$M^{0\nu\beta\beta} = M_{GT}^{0\nu\beta\beta} - [(\frac{g_V}{g_A})^2 = 0.64] M_F^{0\nu} - M_T^{0\nu}$$



Particle number and angular momentum projection before the variation; **Gogny force; Axial symmetric deformation;** No parity mixing; real coefficients of the Bogoliubov transformation

QRPA (TUE), Shell Model (Madrid-Strassburg), IBM2 (Iachello), PHFB (P. Rath)



2010

HD claim for Detection of 0ν DBD

hep-ph/0512263

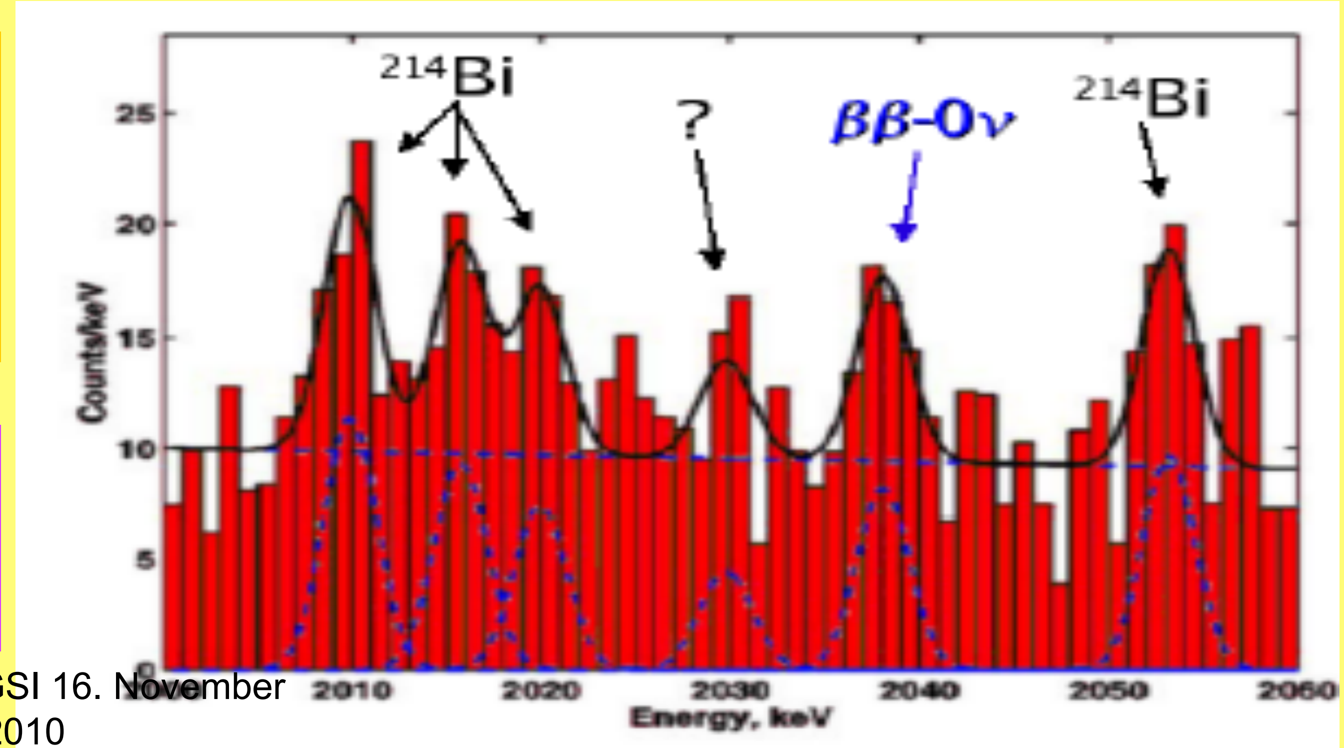
Source = Detector

***Exp.Heidelberg-Moscow: Klapdor and coworkers in Heide**lberg claim, they have detected 0νββ of ^{76}Ge*

10.9 kg 86% enriched ^{76}Ge from 8 % ^{nat}Ge in Russia

Spectrum with 71.7 kg•y

Q(0νββ) = 2038 keV



Neutrino Mass from $0\nu\beta\beta$

Experiment Heidelberg-Moskau:
Klapdor's et al. Claim
^{76}Ge Mod. Phys. Lett. A21,1547(2006) ;
$T(1/2; 0\nu\beta\beta) = (2.23 +0.44 -0.31) \times 10^{25}$ years; 6σ

Matrix Elements: QRPA Tuebingen

- **$<m(\nu)> = 0.24$ [eV]**
  (exp+-0.02; theor+-0.01) [eV]

Summary

1) QRPA seems presently a reliable method
2) Shell Model: to small basis IKEDA sum rule violated by 50%
3) Projected Hartree Fock Bogoliubov: Pairing +Quadrupole and Gogny force; mainly 0+ neutron pairs change in proton pairs.
4) Interacting Boson Model: Changes only s(0^+) and d(2^+) neutron pairs into protons pairs.
5) **To prove the mass mechanism is leading, one needs to measure several nuclear systems**. Only if proved, the neutrino mass can be measured in the neutrinoless Double BetaDecay.

THE END