NEUTRINO, COSMOLOGY, ASTROPHYSICS, AND NEW PHYSICS

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LES RENCONTRES DE PHYSICS
DE LA VALLEE D'AOSTA

RESULTS AND PERSPECTIVES
IN PARTICLE PHYSICS

NEUTRINO AND COSMOS

IMPRESSIVE SYMBIOSIS

Cosmos-to-neutrinos (only restrictions):

1. Upper bound on nu-mass, possibly measurement (?).

2. Bounds on right-handed currents, mass of W_R.

3. Mixing with sterile neutrinos.

4. Coupling to new light particles.

5. Magnetic moments.

Neutrinos-to-Cosmos:

1. Hot Dark Matter (but not cold if physics is normal).

2. Dark energy (?).

3. UHECP, Z-burst model (?).

4. Bounds for cosmological lepton asymmetry (for LMA solution).

5. Supernovae explosions.

MAYBE COSMOS WILL PRESENT US WITH NEW PHYSICAL EFFECTS RELATED TO NEUTRINOS ?!

WHY ν ?

The only known particle indicating to new physics:

NON-CONSERVATION OF INDIVIDUAL LEPTONIC CHARGES
(electronic, muonic, tauonic)

The only known particle for which Majorana mass is possible:
NON-CONSERVATION OF TOTAL LEPTONIC CHARGE

New light particles connected with neutrinos: (pseudo)goldstone bosons.

Neutrinos may communicate with HIDDEN SECTOR where no principles are respected and this could give rise to

MORE EXOTIC POSSIBILITIES:

BREAKING OF CPT INVARIANCE

BREAKING OF LORENTZ INVARIANCE

MOST EXOTIC POSSIBILITY

BREAKING OF SPIN-STATISTICS RELATION

Did Pauli invent a particle which breaks Pauli exclusion principle?
If so, all above could be broken too.

Fermi, 1934:
MAYBE ELECTRONS ARE A LITTLE BIT NOT IDENTICAL

PAULI PRINCIPLE VIOLATION FOR "NORMAL" MATTER, ELECTRONS, NUCLEONS:

Ignatyev,
Kuzmin,
Okun,
Mohapatra,
Greenberg,
Govorkov

VERY STRONG UPPER BOUNDS.

OBSERVATIONAL SIGNATURES OF BOSONIC NEUTRINOS

1. LARGE SCALE STRUCTURE. COLD (AND HOT) DARK MATTER MADE OF NEUTRINOS.

2. BIG BANG NUCLEOSYNTHESIS.

3. NEUTRINOS FROM SN.

4. Z-BURST MODEL FOR UHECR.

5. DOUBLE BETA DECAY

SPECULATIVE AND EXCITING

NONLOCALITY

FASTER-THAN-LIGHT SIGNALS

BROKEN CPT

UNITARITY-???

NON-POSITIVE ENERGY, UNSTABLE VACUUM ???

THEORETICAL PROBLEMS OR INSPIRATION ?

SCATTERING MATRIX:

$$S = 1 + \sum_n \frac{(-i)^n}{n!} \int \Pi d^4 x_j \\ T\{\mathcal{H}(x_1)...\mathcal{H}(x_n)\}$$

LORENTZ INVARIANT IF $\mathcal{H}$ ARE BOSONIC OPERATORS, in this case T-product does not break Lorentz.

For bosonic ν AMPLITUDES ARE NOT BOSONIC, even for pure statistics, e.g. for $e + p \leftrightarrow n + \nu$.

For mixed statistics AMPLITUDES ARE NOT BOSONIC for any processes with neutrinos.

LORENTZ INVARIANCE MAY BE BROKEN.

UNITARITY IS MAINTAINED IF $\mathcal{H}$ IS HERMITIAN.

Usually all fermions enter all observable quantities in even number. If not, observables do not commute and LOCALITY WOULD BE BROKEN.

ALL THESE EFFECTS APPEAR IN HIGHER ORDERS ONLY.

Maybe Hamiltonian/Lagrangian approach is not applicable?
Or least action principle is A LITTLE violated?

POSTPONE THEORY
(NON-EXISTING)
CONSIDER PHENOMENOLOGY
of neutrinos obeying Bose or mixed statistics.

WHAT DO WE BUY FOR THIS PRICE?

(A. Dolgov, A. Smirnov, hep-ph/0501066)

LARGE SCALE STRUCTURE OF THE UNIVERSE AND DARK MATTER

Normal neutrinos cannot make cosmological cold dark matter for any spectrum of primordial density perturbations and any kind of their interactions.

Tremain-Gunn limit: one cannot put enough light FERMIONS (respecting Gershtein-Zeldovich bound) into galaxies to make the observed dark matter.

either

NEW PARTICLES, OLD PHYSICS

or

OLD PARTICLES AND VERY NEW PHYSICS

BOSONIC NEUTRINOS CAN MAKE ALL OBSERVED COSMOLOGICAL DARK MATTER, COLD AND HOT.

They should form Bose condensate. To this end a large lepton asymmetry,

$$\frac{|n_\nu - n_{\bar{\nu}}|}{n_\gamma} \sim 100$$

is necessary. It may be created in a version of Affleck-Dine model.

Equilibrium distribution for purely bosonic ν:

$$f_{\nu_b} = \frac{1}{\exp[(E-\mu_\nu)/T - 1} + C\delta(k)$$

If chemical potential $\mu_\nu = m_\nu$ (maximum allowed value) and lepton asymmetry is large then ν_b should condense, *i.e.* $C \neq 0$, and become COLD.

With $m_\nu = 0.1$ eV neutrinos would make CDM if

$$n_\nu \sim 10^4 \text{ cm}^{-3}$$

It is TWO ORDERS of magnitude larger than the conventional number.

In galaxies the neutrino number density would be about

$$n_\nu^{(gal)} \sim 10^{10} \text{cm}^{-3}.$$

Double beta decay seems to exclude 100% bosonic neutrinos (see below) and the numbers would be a little different.

MIXED STATISTICS.

Kinetic equation (standard):

$$F = f_1(p_1)f_2(p_2)[1 \pm f_3(p_3)][1 \pm f_4(p_4)] \\ -f_3(p_3)f_4(p_4)[1 \pm f_1(p_1)][1 \pm f_2(p_2)]$$

HOW MIXED STATISTICS CAN BE DESCRIBED?

$$\mathbf{(1 - f_\nu) \rightarrow c^2(1 - f_\nu) + s^2(1 + f_\nu)}$$

where $c = \cos\gamma$ **and** $s = \sin\gamma$**.**
Another possibility:

$$(1 - f_\nu) \rightarrow c^2(1 - c^2 f_\nu) + s^2(1 + c^2 f_\nu).$$

In both cases $\mathbf{(1 - f_\nu) \rightarrow (1 - \kappa f_\nu)}$**,**

$$\kappa = c^2 - s^2$$

is FERMI-BOSE MIXING PARAMETER.

EQUILIBRIUM DISTRIBUTION:

$$f_\nu^{(eq)} = [\exp(E/T) + \kappa]^{-1} \ .$$

κ **runs from** $+1$ **(Fermi) to** $+1$ **(Bose);** $\kappa = 0$ **(Boltzmann).**

MAXIMUM CHEMICAL POTENTIAL:

$$\mu^{(\mathbf{max})} = \mathbf{m}_\nu - \mathbf{T} \ln(-\kappa)$$

Bose condensation might take place for negative κ **only.**

EFFECTS ON BBN.

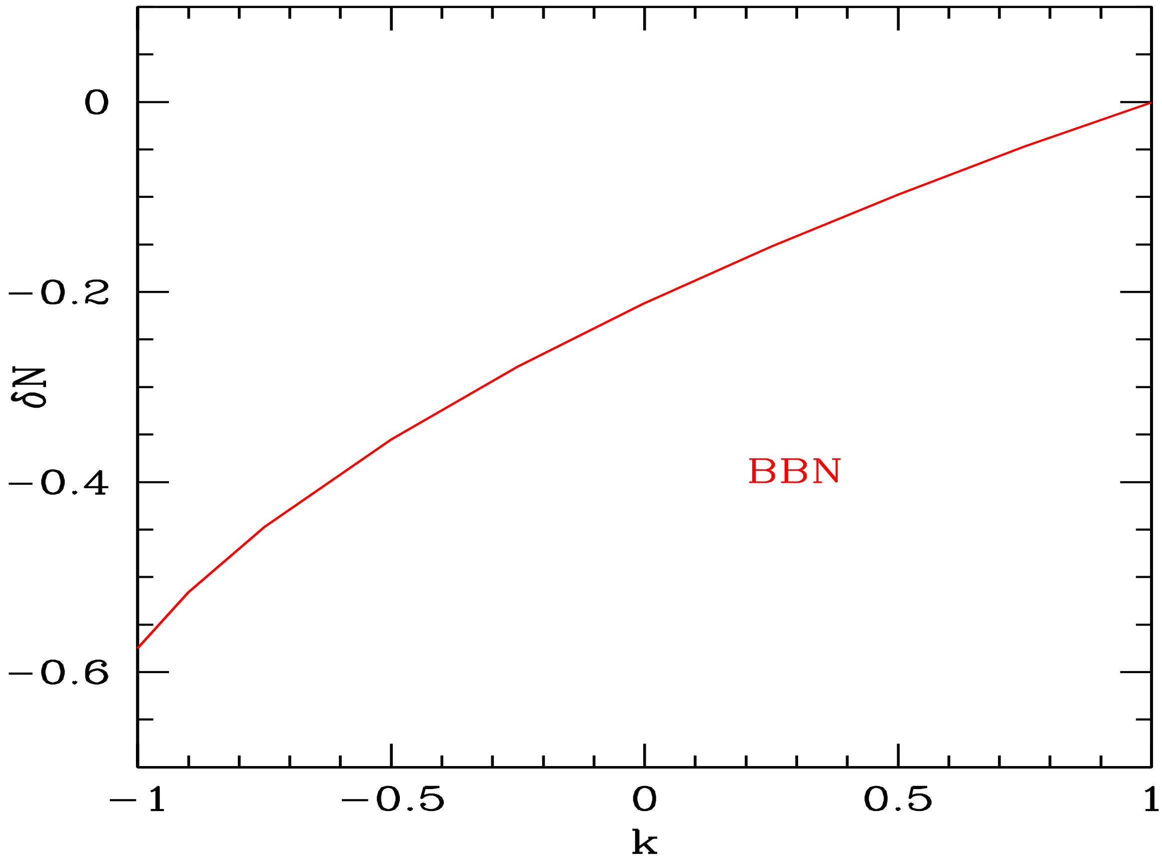
L. Cucurull, J.A. Grifols, R. Toldra. Aspropart.Phys. 4 (1996) 391; A.Dolgov, S. Hansen, A. Smirnov (in preparation)

1. Larger energy density of ν, $N_\nu^{(eff)}$ rises.
2. Larger rate of neutron-proton transformations, $N_\nu^{(eff)}$ drops.

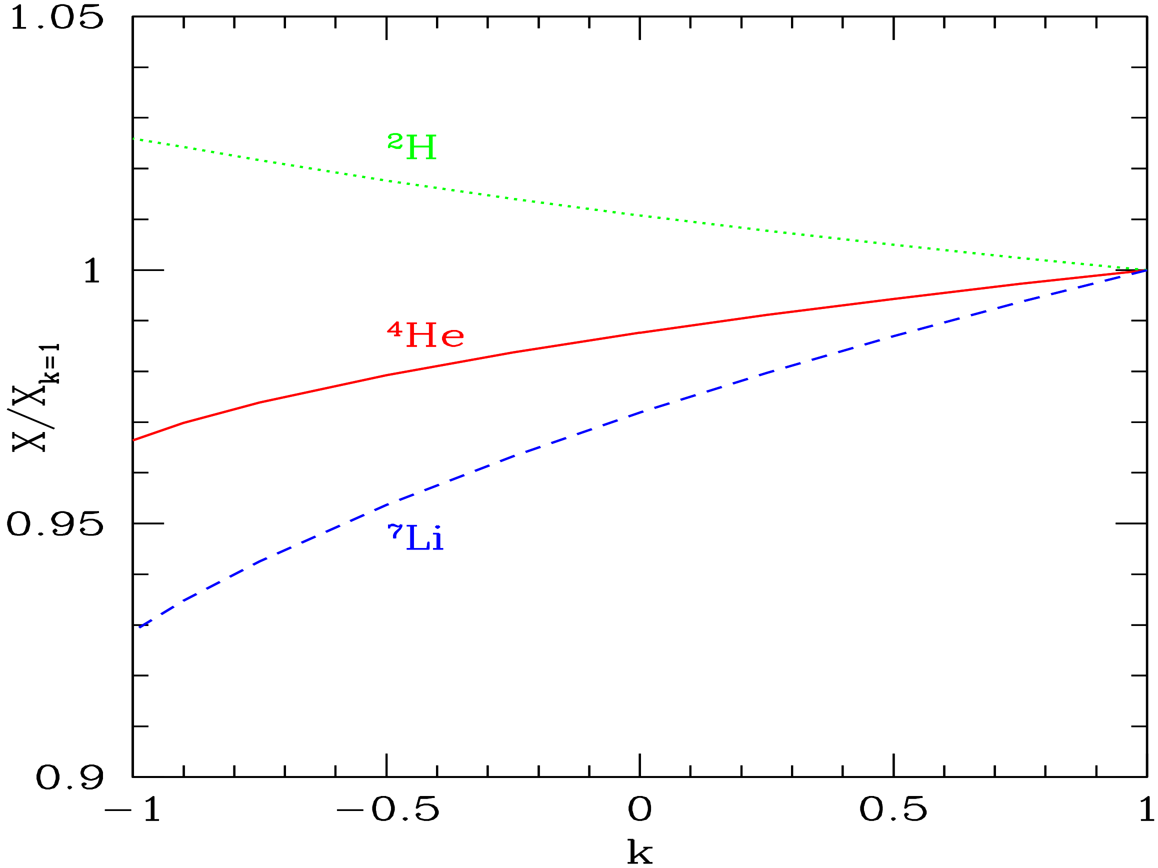
Second effect dominates and

$$\mathbf{N_\nu^{(eff)} < 3}$$

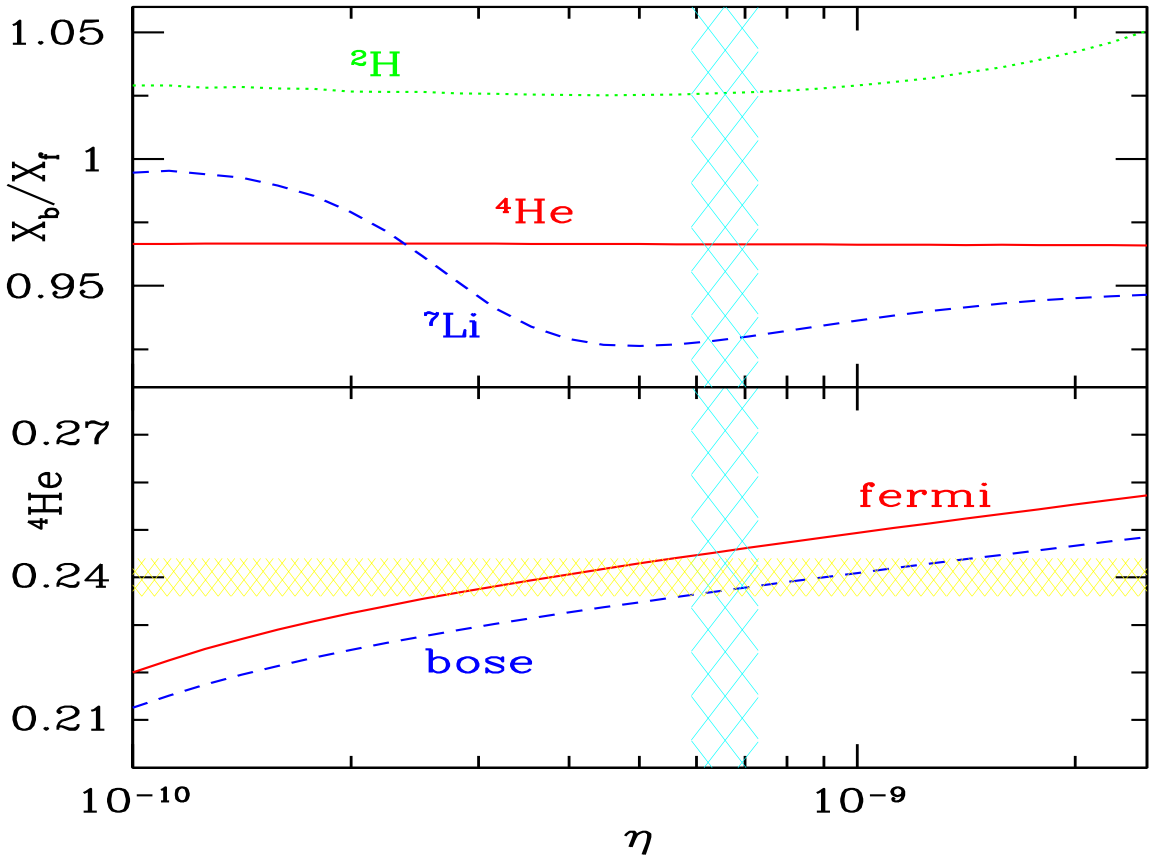
.



WITH ZERO OR NEGLIGIBLE CHEMICAL POTENTIAL OF NEUTRINOS.



1.05
1
0.95
0.9
−1
−0.5
0
0.5
1
k
X/X_{k=1}
²H
⁴He
⁷Li



VERY GOOD AGREEMENT WITH THE DATA.

ANOTHER POSSIBILITY:
TWO NEUTRINO FIELDS WITH THE SAME MASS AND SPIN, BUT DIFFERENT STATISTICS - FERMIONIC AND BOSONIC.

Lagrangian always depends upon the field operator in the combination:

$$\psi_\nu = \mathbf{c}\psi_\mathbf{b} + \mathbf{s}\psi_\mathbf{f}$$

Kinetic equation contains:

$$\mathbf{c^2 f_f (1 - f_f)}$$

and

$$\mathbf{s^2 f_b (1 - f_b)}$$

Equilibrium distributions would be canonical ones. The effect on BBN is similar to the considered above.

DOUBLE BETA DECAY.

Define neutrino state as:

$$|\nu\rangle = c\hat{f}^+|0\rangle + s\hat{b}^+|0\rangle \equiv \hat{a}^+|0\rangle = c|f\rangle + s|b\rangle$$

where $c = \cos\delta$ **and** $s = \sin\delta$**. It would be desirable if** $\delta = \gamma$ **introduced above but cannot be formally proved.**

Need to specify the commutators:

$$\hat{f}\hat{b} = e^{i\phi}\hat{b}\hat{f}, \;\; \hat{f}^+\hat{b}^+ = e^{i\phi}\hat{b}^+\hat{f}^+,$$
$$\hat{f}\hat{b}^+ = e^{-i\phi}\hat{b}^+\hat{f}, \;\; \hat{f}^+\hat{b} = e^{-i\phi}\hat{b}\hat{f}^+,$$

ϕ **is an arbitrary phase.**

Two neutrino state:

$$|k_1, k_2\rangle = \hat{a}_1^+\hat{a}_2^+|0\rangle$$

NORMALIZATION

The n-neutrino state is natural to define as

$$|n\rangle = \left(cf^{+} + sb^{+}\right)^{n} |0\rangle$$

The normalization is

$$\langle n|n\rangle = s^{2(n-1)} \left[n!s^2 + (n-1)!c^2 \left(\frac{\sin(n\phi/2)}{\sin(\phi/2)}\right)^2 \right]$$

The particle number operator:

$$\hat{n} = a^{+}a$$

Diagonal matrix elements:

$$\langle n|\hat{n}|n\rangle = s^{2(n-1)} \left[n\,n!s^4 + 2n!c^2s^2 \cos\frac{\phi(n-1)}{2}\,\frac{\sin n\phi/2}{\sin\phi/2} + c^2\left(n!s^2 + (n-1)!(c^2-s^2)\right)\left(\frac{\sin(n\phi/2)}{\sin(\phi/2)}\right)^2 \right]$$

Amplitude of double-beta decay:

$$A_{2\beta} = \langle k_1, k_2, 2e, A' \Big| \int d^4x_1 d^4x_2 \psi_\nu(x_1) \psi_2(x_2) \mathcal{M}(x_1, x_2) \Big| 0, A \rangle,$$

After simple commutations:

$$A_{2\beta} = A_- \left[c^4 + c^2 s^2 (1 - \cos\phi)\right] + A_+ \left[c^4 + c^2 s^2 (1 + \cos\phi)\right].$$

$$A_{2\beta} = \cos^2\chi\, A_- + \sin^2\chi\, A_+.$$

for any ϕ.

Integrated over neutrinos:

$$W_{tot} = \cos^4\chi\, W_- + \sin^4\chi\, W_+$$

The $0^+ \to 0^+$ amplitude for normal neutrinos is proportional to bilinear combinations of

$$K_n \equiv [E_n - E_i + E_{e1} + E_{\nu 1}]^{-1} + [E_n - E_i + E_{e2} + E_{\nu 2}]^{-1},$$

and

$$L_n \equiv [E_n - E_i + E_{e2} + E_{\nu 1}]^{-1} + [E_n - E_i + E_{e1} + E_{\nu 2}]^{-1}.$$

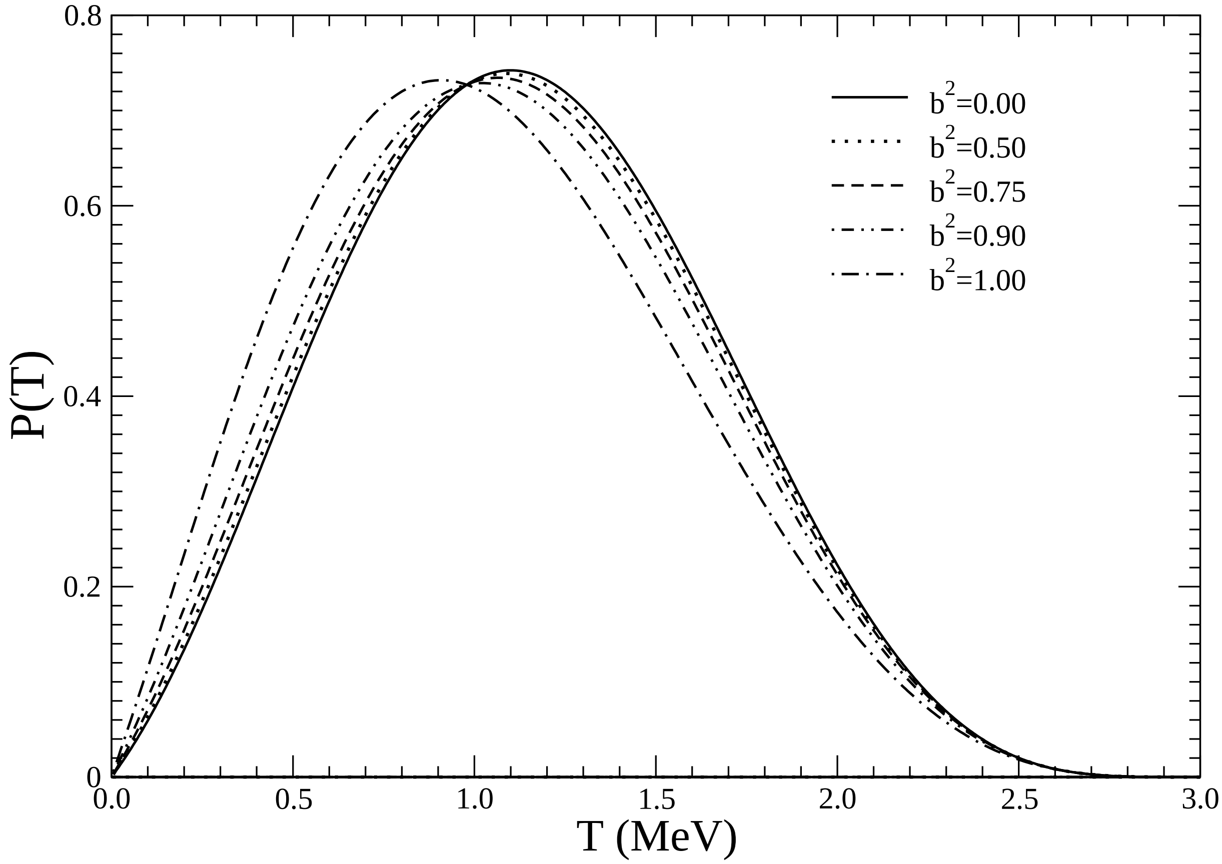
For bosonic neutrinos the sum in each term above changes to difference. PROBABILITY OF THE PROCESS WITH BOSONIC NEUTRINOS IS STRONGLY SUPPRESSED: BY 1/250 FOR ^{56}Ge and by 1/10 for ^{100}Mo.

For $0^+ \to 2^+$ the situation is opposite.

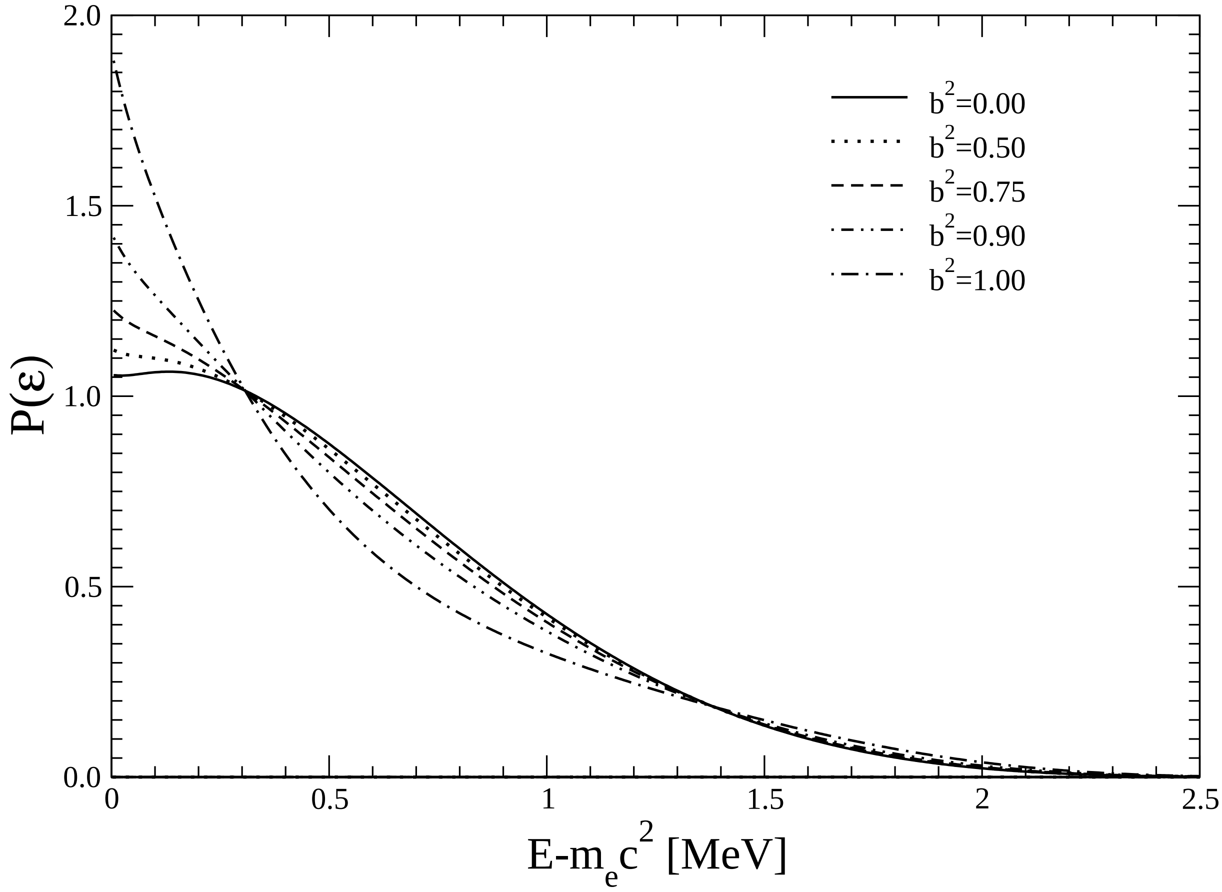
Analysis of total rates, known theoretically with factor 2 accuracy and spectra known with very high precision, about 10%

A.Barabash, A.Dolgov, P.Domin, F.Simkovic, A.Smirnov - preliminary

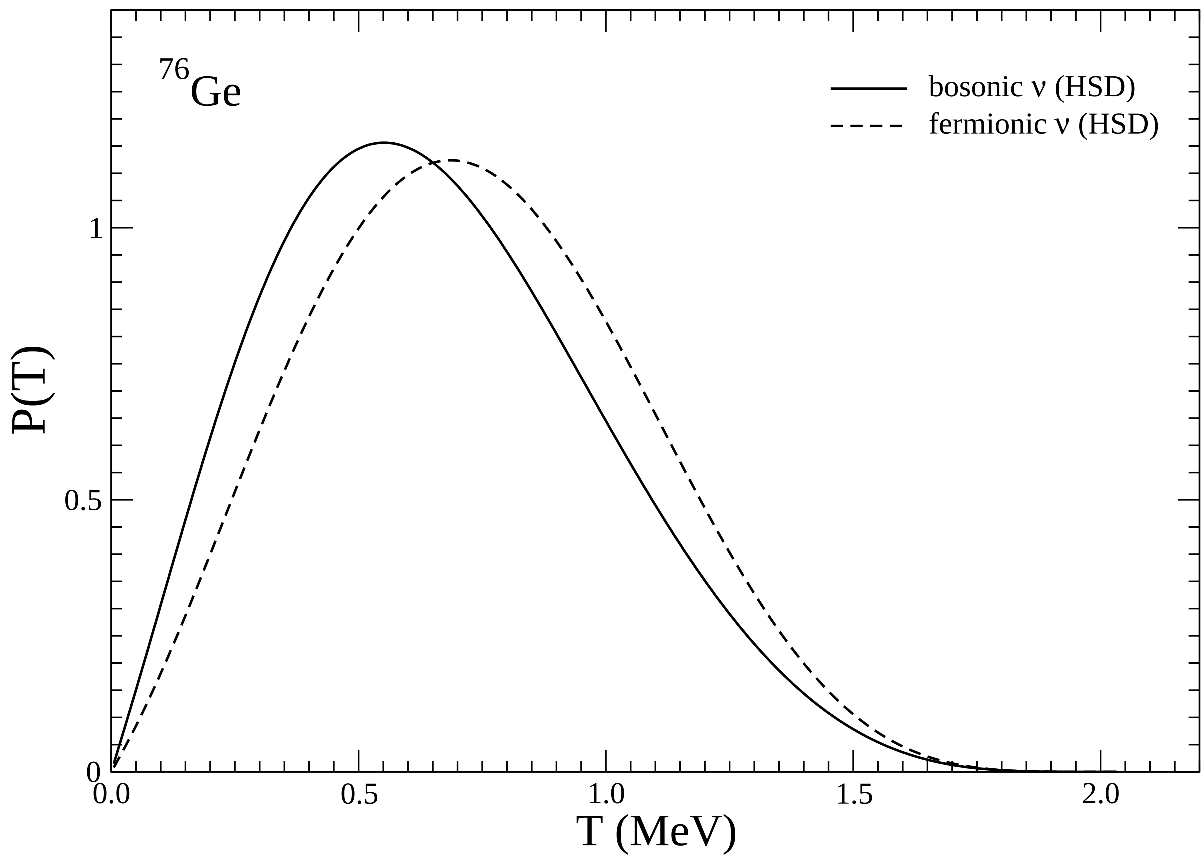
$$s^2 < 0.8$$



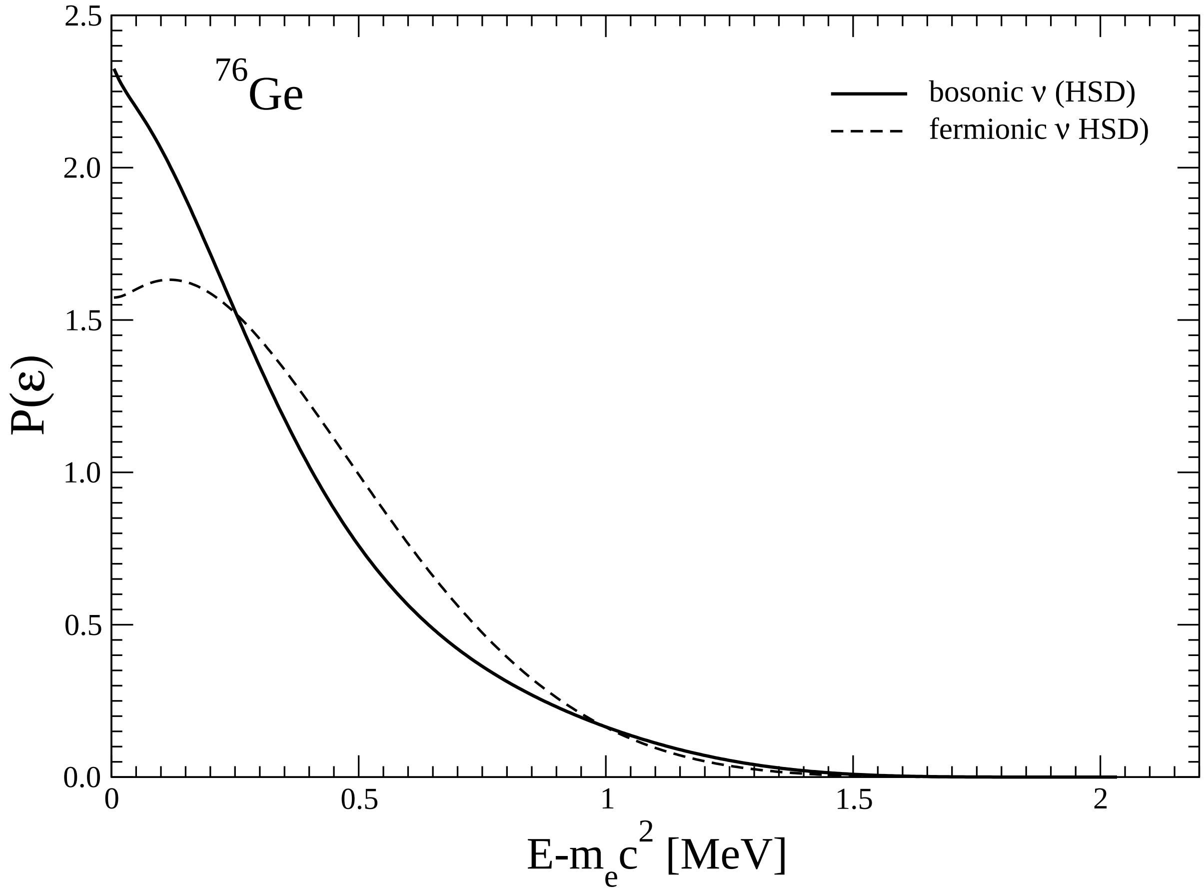
Total energy of two electrons, ^{100}Mo.



Single electron energy, ^{100}Mo.



Total energy of two electrons, ^{76}Ge.



Single electron energy, ^{76}Ge.

CONCLUSION

1. INTERESTING! BUT PLENTY OF THEORETICAL PROBLEMS. A WAY TO BREAK MANY OF SYMMETRIES DISCUSSED TODAY.

2. POSSIBILITY TO MAKE DM OUT OF NEUTRINOS

3. GOOD FOR BBN

4. SOME HINTS TO THE EFFECT IN 2β

5. IF IT WAS CHECKED FOR ELECTRONS AND NUCLEONS, WHY NOT FOR NEUTRINOS.
ODDS ARE HIGHER.