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ECFA/DESY 00

PROSPECTS FOR SIGNALS OF HEAVY MAJORANA NEUTRINOS AT THE L.C. IN THE ABSENCE OF NEUTRINOLESS DOUBLE BETA DECAY.

OUR UNEXPECTEDLY SUCCESSFUL

STANDARD MODEL

IS CLEARLY DEFICIENT IN ITS DESCRIPTION OF

THE NEUTRAL LEPTON SECTOR.

IT DECREES

- NEUTRINOS ARE MASSLESS

- THERE ARE NO RIGHT-HANDED NEUTRINOS
  - (NO HELICITY FLIP)

- THERE IS NO CERTIFIED NEUTRINO FIELD OPERATOR:

  DIRAC? MAJORANA?
  MASS TERM IN THE LAGRANGEAN

- HIGHER SYMMETRY SCHEMES MAKE THIS A

  <u>VERY UNLIKELY SCENARIO</u>

- NEUTRINO MASSES

3 known generations:

$$\left.\begin{array}{l}\nu_e\\ \nu_\mu\\ \nu_\tau\end{array}\right\}\ \text{masses are small, may vanish.}$$

IF $m(\nu_i) = 0$, NO HELICITY FLIP POSSIBLE

→ LEPTON NUMBER MAY BE A MEANINGLESS CONCEPT

DIRAC EQUATION "ALLOWS" FOR THE PARTICLE/ANTIPARTICLE CONCEPT VIA EL. CHARGE

→ IN THE ABSENCE OF CHARGE, HELICITY CONSERVATION MAY BE THE ONLY REASON WHY ν AND $\bar{\nu}$ LOOK DIFFERENT:

$$CPT\ |\ldots;\lambda\rangle \rightarrow |\ldots;-\lambda\rangle$$

FOR $m(\nu) = 0$, THERE IS NO MEANING TO A DIFFERENCE BETWEEN

$$\left.\begin{array}{l}\text{DIRAC}\\ \text{MAJORANA}\end{array}\right\}\ \text{MASSES}$$

BUT

~1 TeV neutrinos are easily found in right-handed singlet states in decompositions of

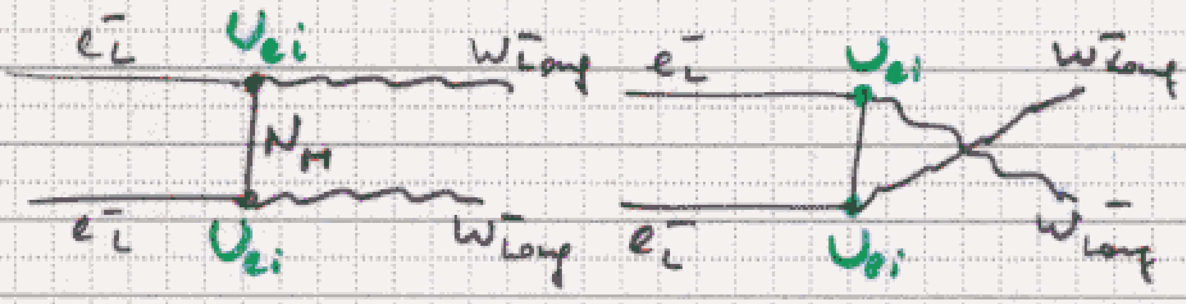
$E6 \to SO(10) \to \ldots$

$\boxed{\text{C. Heusch}}$

Expect **Majorana masses**

CAH, P. Minkowski

WE HAVE BEEN SUGGESTING THE e^-e^- LC AS THE PREFERRED DISCOVERY MACHINE FOR THE POTENTIAL DISCOVERY OF TeV MAJORANA NEUTRINOS:



$$\sigma(e_L^- e_L^- \to W^-_{long} W^-_{long}) \cong \left(\frac{s}{4\pi}\right)^2 \frac{1}{M_N^4} |U_{eN}^2| \; (4 \times 10^5 \text{ fb})$$

NOTE CHARACTERISTIC RISE WITH s^2 •

DECREASE WITH M_N^{-4} •

→ spectacular signals: $\mu^-\mu^-+\ldots$, $\mu^-e^-+\ldots$, back-to-back W^-W^-

→ respectable counting rates

→ clearly recognizable final states

→ easy "switch-off" by helicity reversal $e_L \to e_R \,|_{in}$

→ constrained by low-energy rare decay data $\mu \to e\gamma$, $\mu \to eee$, ...

→ manageable backgrounds → ...

BUT: does it stand up to the "classical" method for Majorana mass searches?

NEUTRINOLESS DOUBLE β DECAY

"$\beta\beta_{0\nu}$"

crucial factor in <u>leptonic</u> matrix element:

$$A \sim \quad P = \frac{q\, m_\nu}{q^2 + m_\nu^2}$$

light ν: $\quad \approx \dfrac{m_\nu}{q} \longrightarrow$ range?

heavy N: $\quad \approx \dfrac{q}{M_N} \longrightarrow$ range?

DISCOVERY LIMITS:

CONSTRAINTS FROM LOW-ENERGY DATA

$$\boxed{U_{eN}^2 < 4\times 10^{-3}}$$

from charged-current universality

dominate for larger masses

FOR SMALLER MASSES, $m_N \sim 600$ GeV,

$\beta\beta_{0\nu}$ LIMITS MORE STRINGENT

Non-observation of $\mu \to e\gamma$

$$\boxed{\left|\sum_N U_{\mu N} U_{eN}^{*}\right| < 2\times 10^{-4}}$$

?

→ no more stringent than above

Non-observation of neutrinoless double β decay,

$\beta\beta_{0\nu}$

(best evidence on $\boxed{\tau\left({}^{76}Ge \to {}^{76}Se\, e^- e^-\right) > 5\times 10^{24}\, y}$

for light neutrinos: $\left|\sum_\nu U_{e\nu}^2 m_\nu\right| \leq$ a few eV

ok for m_ν ...

for heavy N_M, $\left|\sum_N U_{eN}^2 \frac{1}{m_N}\right|^2 \times \left|\mathcal{M}_{had}\right|^2 \leq \frac{1}{\tau_{1/2}}$

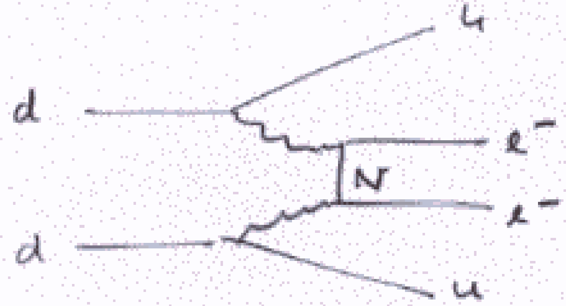
has been strongly overestimated in the literature

MISCONCEPTION WHILE COMPARING

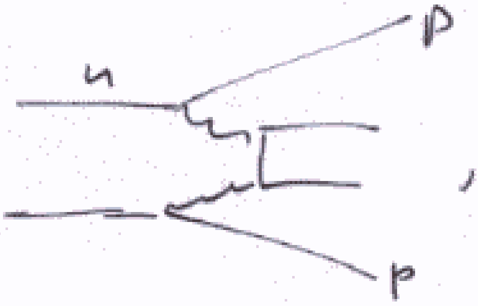
$e^-e^- \to W^-W^-$

WITH $N^{A,Z} \to N'^{A,Z+2}\, e^-e^-$,

THE QUARK-LEVEL GRAPH

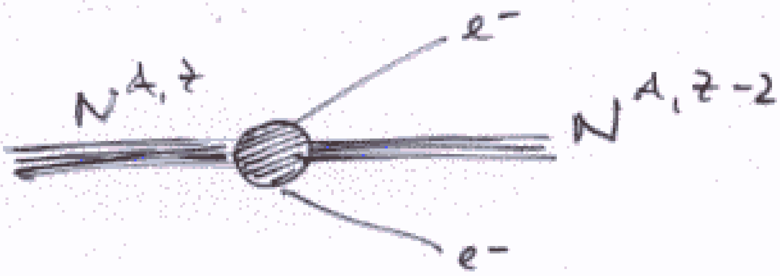


IS CONSTRAINED BY



,

WHICH IN TURN IS CONSTRAINED BY



A DETAILED EVALUATION WAS DONE AND LEAD

TO SUPPRESSIONS THAT "NIX"

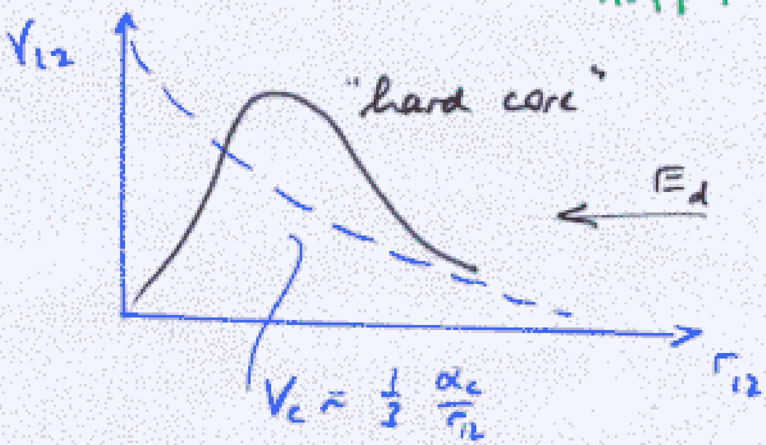
QUOTED LIMI

TRUE "INVERSE $\beta\beta_{0\nu}$ DECAY" WOULD BE, E.

$e^-e^-\,{}^{76}Se \to {}^{76}Ge$

TWO d QUARKS FROM 2 NEUTRONS INSIDE THE NUCLEI NEED TO APPROACH WITHIN 10^{-16} cm !

THE COLOR COULOMB BARRIER WILL TRY TO FORBID THAT:



2 neutrons (color-saturated ddu grouping) will have to approach such that 2 d's – one from each n – will be within $\sim 10^{-16}$ cm of each other

- COLOR FACTOR OF 3
- COULOMB "HARD CORE" PENETRATION
- BREAKING UP COLOR-SATURATED

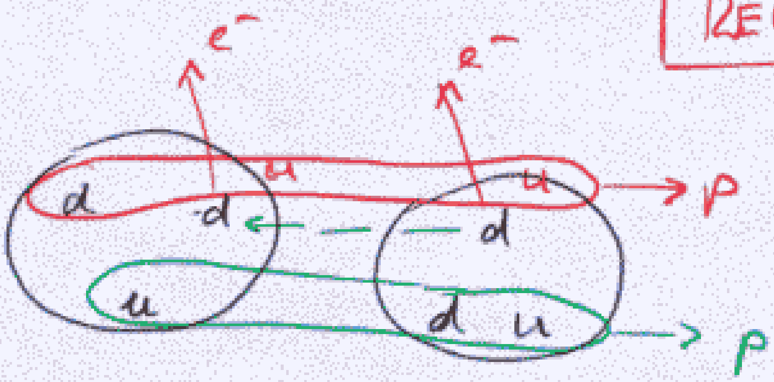
2 possibilities:

○ SPIN - SINGLET $d\,d$

→ EXCLUSION PRINCIPLE DICTATES

○ COLOR $\underset{\sim}{6}$ $d\,d$

REPULSIVE



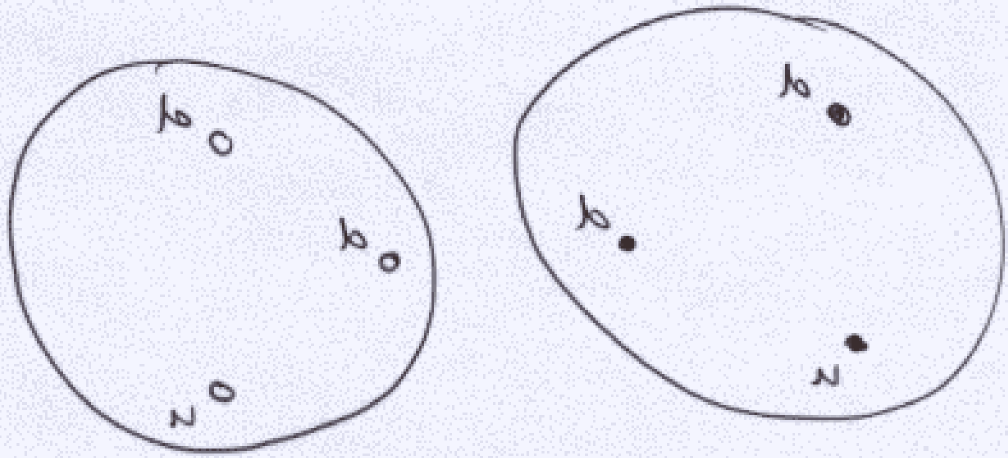
WE ETIMATE DEPRESSION
BY A FACTOR OF > 100!

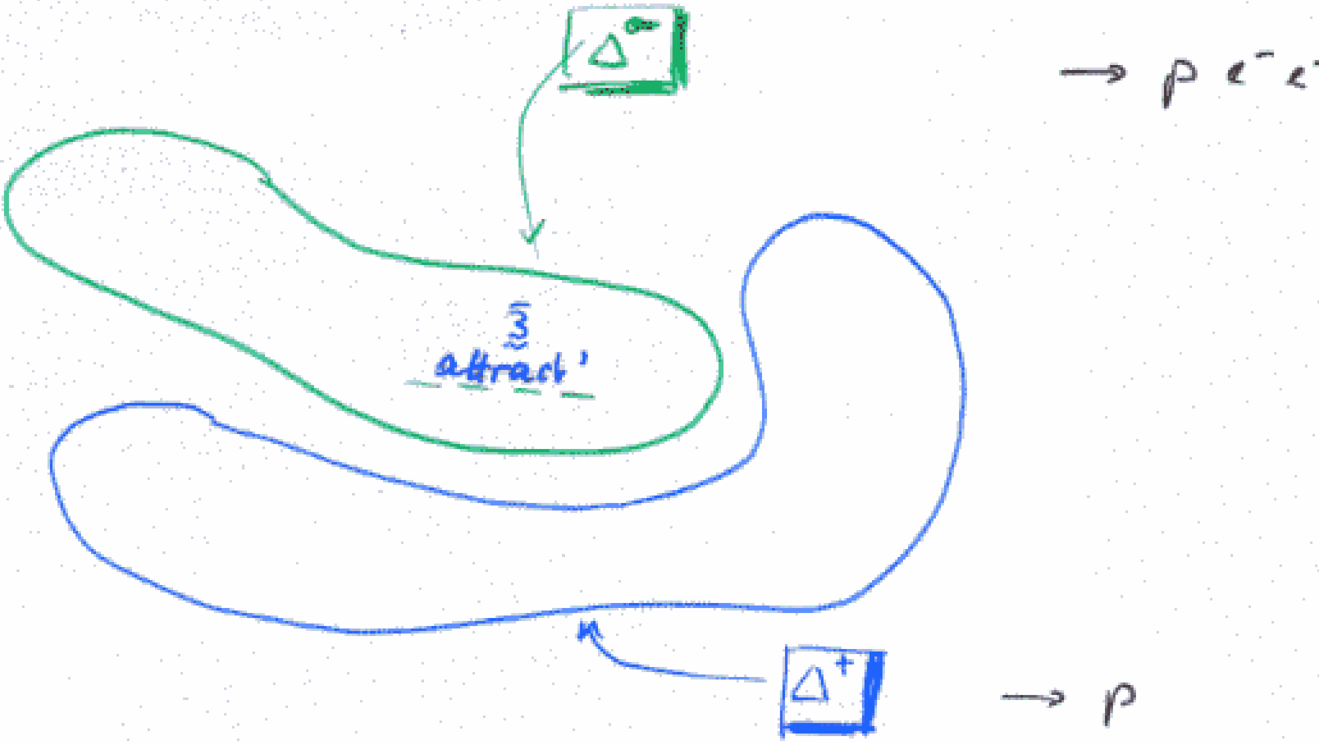
○ SPIN - TRIPLET $d\,d$

○ COLOR $\underset{\sim}{\bar{3}}$ $d\,d$

ATTRACTIVE

BUT: ANOTHER SUPPRESSION FROM SPIN dd
$\underset{\sim}{3}$ CONFIGURATION, POSSIBLE ONLY IN
Δ (inside nucleus)



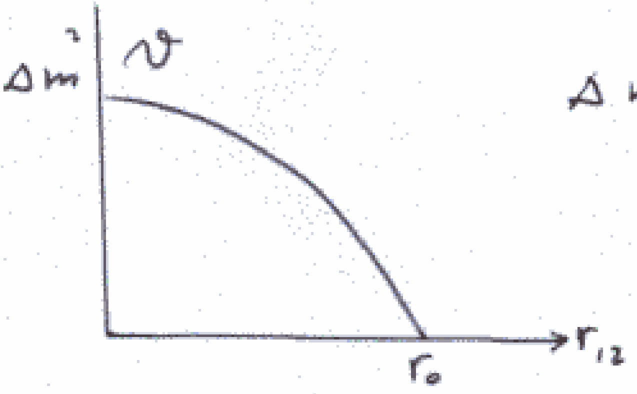


and, of course, the two protons have to find their home in the daughter nucleus

$$N^{A,Z} \longrightarrow N^{A,Z-2}\, e^- e^-$$

Estimate the threshold ("hard core") to penetrate in this case

$$\frac{s_{dd}}{2} \sim \Delta m^2 \longrightarrow p^2 + V$$



$$\Delta m = m(\Delta) - m(n) \simeq 0.3\ \text{GeV}$$

$$V_2 \sim \Delta m^2 \left(1 - \frac{r^2}{r_0^2}\right)$$

So, altogether we're looking at a factor

for $s \to nn \to \Delta^+\Delta^-$

with $\Delta m^2 = m_\Delta^2 - m_n^2$

$$s \sim \underbrace{\frac{\pi}{4}\sqrt{\Delta m^2}}_{600\ \text{MeV}}\ r_{12}\,(dd)$$

choose $r_{12} \sim 1$ fm for triplet case

$$s = \sqrt{\Delta m^2}\int_0^{r_0} dr\sqrt{1-\frac{r^2}{r_0^2}}$$

$\rightsquigarrow$ a more refined treatment leads to a suppression factor of 50 – 80, to be multiplied by the color suppression factor 3.

BOTH $\left.\begin{array}{l}\text{spin } \underset{\sim}{1}\text{, color } \underline{6} \\ \text{spin } \underset{\sim}{3}\text{, color } \underline{\bar{3}}\end{array}\right\}$ eventually lead

to strong suppression of N_H exchange in nuclei

PRESENT OR EXPECTED NON-OBSERVATION OF $\beta\beta_{0\nu}$ DOES NOT CONSTRAIN $e^-e^- \xrightarrow[N_H]{} W^-W^-$ SIGNAL

There is another possible way for 2 d's from two different nucleons to come into close range:

$$\left.\begin{array}{l} \text{virtual photon} \to d\bar{d} \\ \text{pion}^- : d\bar{u} \end{array}\right\} \text{emission, reabsorption}$$

from neighboring neutrons

We evaluated this ($\to$ Proc' e^+e^- 99)

and VERY small weight,

no noticeable effect.

CONCLUSIONS

- The possible existence of TeV-level Majorana neutrino singlets N_M remains an attractive, viable possibility to

  SOLVE 2 CONUNDRUMS OF THE S.M.

  $\rightarrow$ m_M vs. m_D

  $\rightarrow$ very light m_e, m_μ, m_τ

- The e^+e^- Collider at 0.5 $\rightarrow$ 1.5 TeV has a fair chance of revealing this scenario *if* correct.

- The parameters m_M and U_{eN} are straight-forward to determine from $\sigma(s)$

- $\beta\beta_{0\nu}$ has intrinsic chances of doing similar tasks, but

- Coulomb barrier penetration etc. depress the rates beyond early accessibility

- Nuclear matrix elements
  SUSY parameters
  ⋮
  will likely prohibit any interpretable observation.