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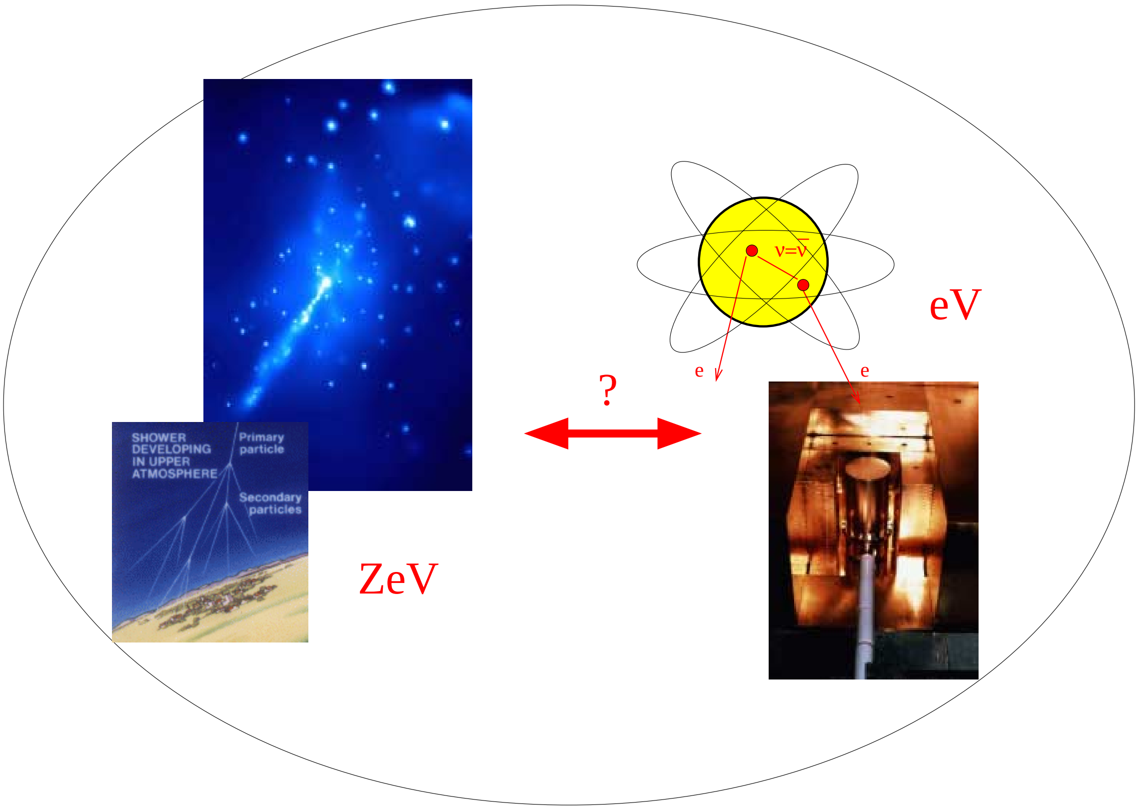
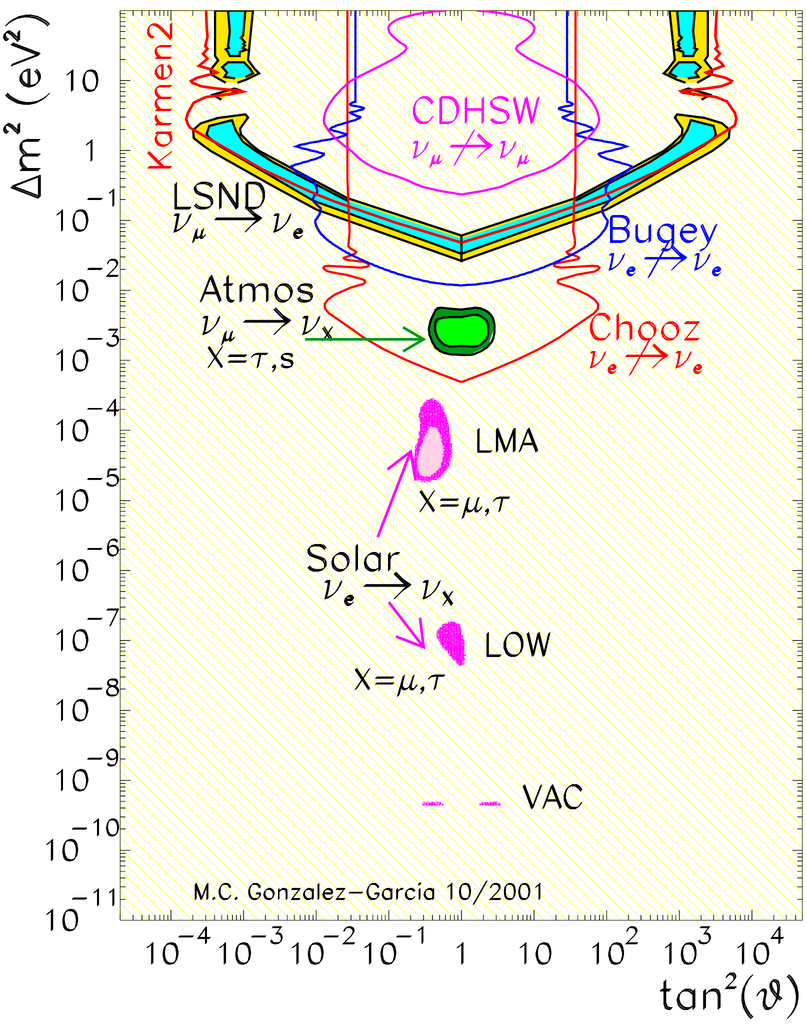
Absolute neutrino mass determination



In Collaboration with:
T.J. Weiler (Vanderbilt University)



Karmen2
CDHSW
$\nu_\mu \not\to \nu_\mu$
LSND
$\nu_\mu \to \nu_e$
Bugey
$\nu_e \not\to \nu_e$
Atmos
$\nu_\mu \to \nu_x$
X=τ,s
Chooz
$\nu_e \not\to \nu_e$
LMA
X=μ,τ
Solar
$\nu_e \to \nu_x$
LOW
X=μ,τ
VAC
M.C. Gonzalez-Garcia 10/2001
Δm^2 (eV^2)
$\tan^2(\vartheta)$

Why to bother about absolute neutrino masses?

- SUSY See-Saw Mechanism:

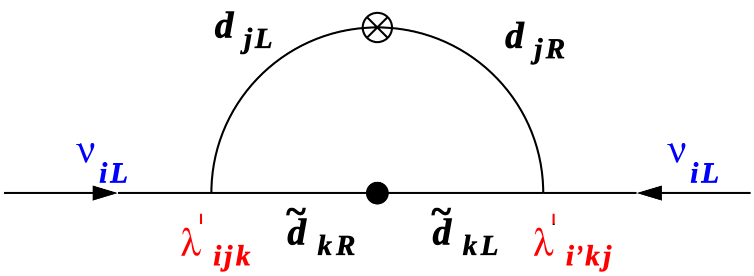
$$\mathcal{M}_\nu = \mathbf{Y}_\nu{}^T \mathcal{M}_\mathcal{R}{}^{-1} \mathbf{Y}_\nu \langle H_2^0 \rangle^2$$

LFV processes: $\Gamma \propto (\mathbf{Y}_\nu \mathbf{Y}_\nu{}^\dagger)^2$

$\Rightarrow$ with $\mathcal{M}_\nu$ one gets information on $\mathcal{M}_\mathcal{R}$

F. Deppisch, H. Päs, A. Redelbach, R. Rückl, Y. Shimizu, hep-ph/0206122
Talk of A. Redelbach

- Radiative Neutrino mass and $\not{R}_p$SUSY:



$\Rightarrow$ $\lambda^{(\prime)}_{ijk}\lambda^{(\prime)}_{ikj}$ products directly constrained from $\mathcal{M}_{\nu_{ii'}}$:

Knowing $\mathcal{M}_\nu$ improves bounds on

SUSY couplings by up to 5 orders of magnitude!

G. Bhattacharyya, H.V. Klapdor-Kleingrothaus, H. Päs, PLB463 (1999) 77)

Absolute neutrino mass determination

Direct measurements:

- arrival time profile of supernova ν's
$\rightarrow$ sensitivity $\lesssim$ 1 eV

- tritium decay $\rightarrow$ sensitivity $\lesssim$ 2.3 (0.3) eV

- π, τ decay $\rightarrow$ much worse

- (cosmological structure formation CMB/LSS $\rightarrow$ sensitivity $\lesssim$ 0.6 – 1.8 eV ($\Omega_m \sim$ 0.3 – large)

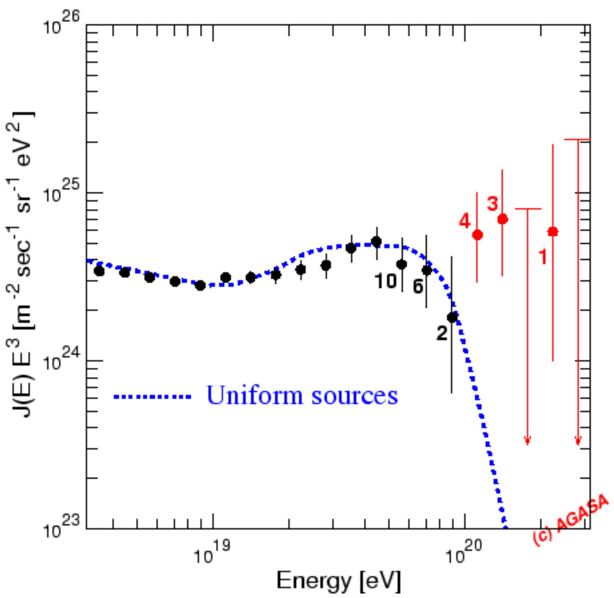
3 assumptions for indirect ν-mass determination:

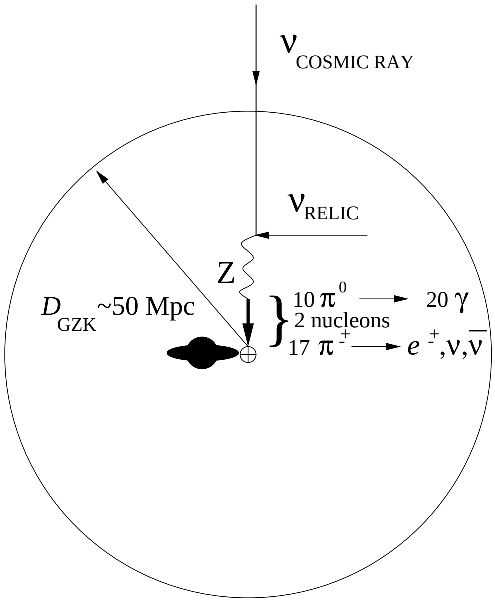
- ν's are Majoranas (see-saw, $R\!\!\!/_p$-generated, etc.)
- only 3 ν's (LSND neglected)
- LMA solar solution realized

Focus:

- Extreme energy cosmic rays in the Z-burst model
- $0\nu\beta\beta$ decay
- (degenerate neutrinos)

Cosmic rays in the Z-burst model





Anomalie: Extreme energy cosmic rays above GZK cutoff (due to scattering on CMB γ's)

Possible solution: Resonant scattering of extreme energy ν's on relic ν background at $E_\nu^R = 2m_Z^2/(2m_\nu)$

(T.J. Weiler, Astroparticle Physics 11 (1999) 303)

(D. Fargion, B. Mele, A. Salis, Astrophys. J. 517 (1999) 725)

$\Rightarrow$ $m_\nu \gtrsim$ 0.1 eV predicted!

$\longrightarrow$ Fit to UHECR spectrum: $m_j = 0.26$ eV

(Z. Fodor, S.D. Katz, A. Ringwald, hep-ph/0105064)

The Z-burst and neutrino masses

Necessary condition:
sufficient flux of ν's with $E \gtrsim 10^{21}$ eV
$\rightarrow$ challenging!

Helpful:

- Neutrino clustering in galactic vincinity
  - Large scales: universe too young
  - Galactic halo: Pauli blocking

$$\frac{n_{\nu_j}}{54\,\text{cm}^{-3}} \lesssim 10^3 \left(\frac{m_j}{\text{eV}}\right)^3 \left(\frac{\sigma}{200\text{km/s}}\right)^3$$

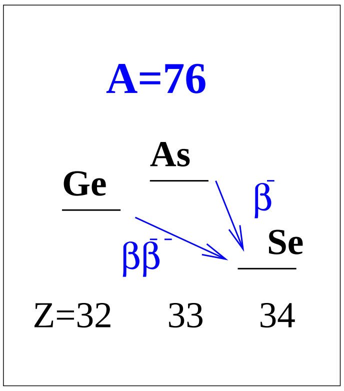
requires $m_j \gtrsim 0.5$ eV for significant increase

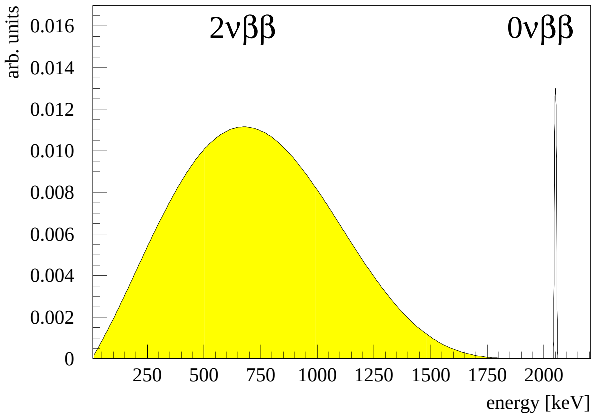
- Majorana neutrinos gives factor 2 in CNB

- Neutrino mass degeneracy gives factor 3

Degenerate neutrino masses
$m_j \sim 0.1 - 1\text{eV} \gg \sqrt{\Delta m^2_{\text{atm}}} \gg \sqrt{\Delta m^2_{\odot}}$
are back in business!

What is double beta decay?



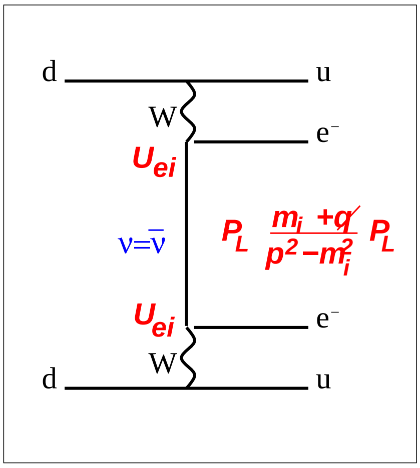


$2\nu\beta\beta$: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+2}X + 2e^- + 2\overline{\nu}_e$

- SM allowed: $T^{2\nu}_{1/2} \simeq 10^{19} - 10^{24}$y
- observed for 10 isotopes

$0\nu\beta\beta$: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+2}X + 2e^-$

- Physics beyond SM (L violation)



Sensitive on:

- effective Neutrino–Majorana mass:

$m_{ee} = \sum_i' |U_{ei}|^2 e^{i\phi_i} m_i$

$m_{ee} \lesssim 0.6$ eV; Evidence $m_{ee} = 0.39$ eV?

(Heidelberg-Moscow-Experiment)

Future Projects: CUORE: 0.1 eV, MOON: 0.03 eV

EXO, GENIUS 1t, XMASS: 0.02 eV

GENIUS 10 t: 0.002 eV

$0\nu\beta\beta$ and ν oscillations

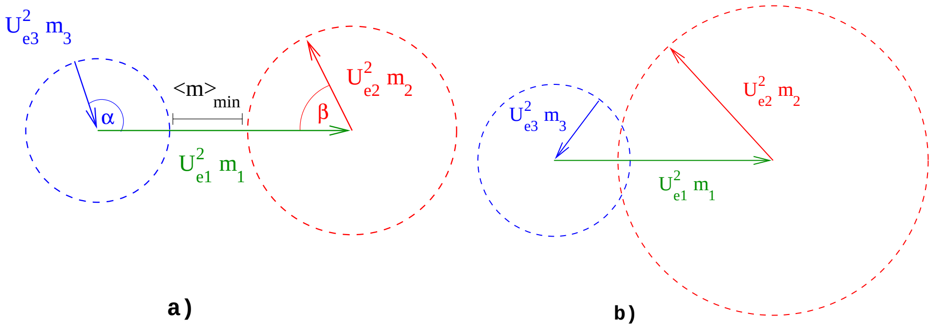
$0\nu\beta\beta$ observable:

$$|m_{ee}| = \left| \sum_j |U_{ej}|^2 e^{i\phi_j} m_j \right|$$

$$m_{ee} = |m_{ee}^{(1)}| + e^{i\phi_2}|m_{ee}^{(2)}| + e^{i\phi_3}|m_{ee}^{(3)}|$$

$$\begin{aligned} |m_{ee}^{(1)}| &= |U_{e1}|^2 m_1 \\ |m_{ee}^{(2)}| &= |U_{e2}|^2 \sqrt{\Delta m_{21}^2 + m_1^2} \\ |m_{ee}^{(3)}| &= |U_{e3}|^2 \sqrt{\Delta m_{31}^2 + m_1^2}. \end{aligned}$$

sum of 3 vectors in complex space:



Neutrino oscillations observables:

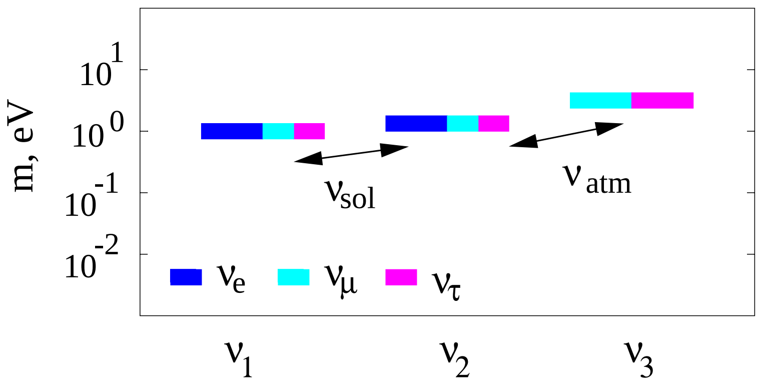
$$U = \begin{pmatrix} \cos\theta_\odot & \sin\theta_\odot & \epsilon \\ -\sin\theta_\odot/\sqrt{2} & \cos\theta_\odot/\sqrt{2} & 1/\sqrt{2} \\ \sin\theta_\odot/\sqrt{2} & -\cos\theta_\odot/\sqrt{2} & 1/\sqrt{2} \end{pmatrix}$$

$\Delta m_{ij}^2 \equiv |m_i|^2 - |m_j|^2$, δ

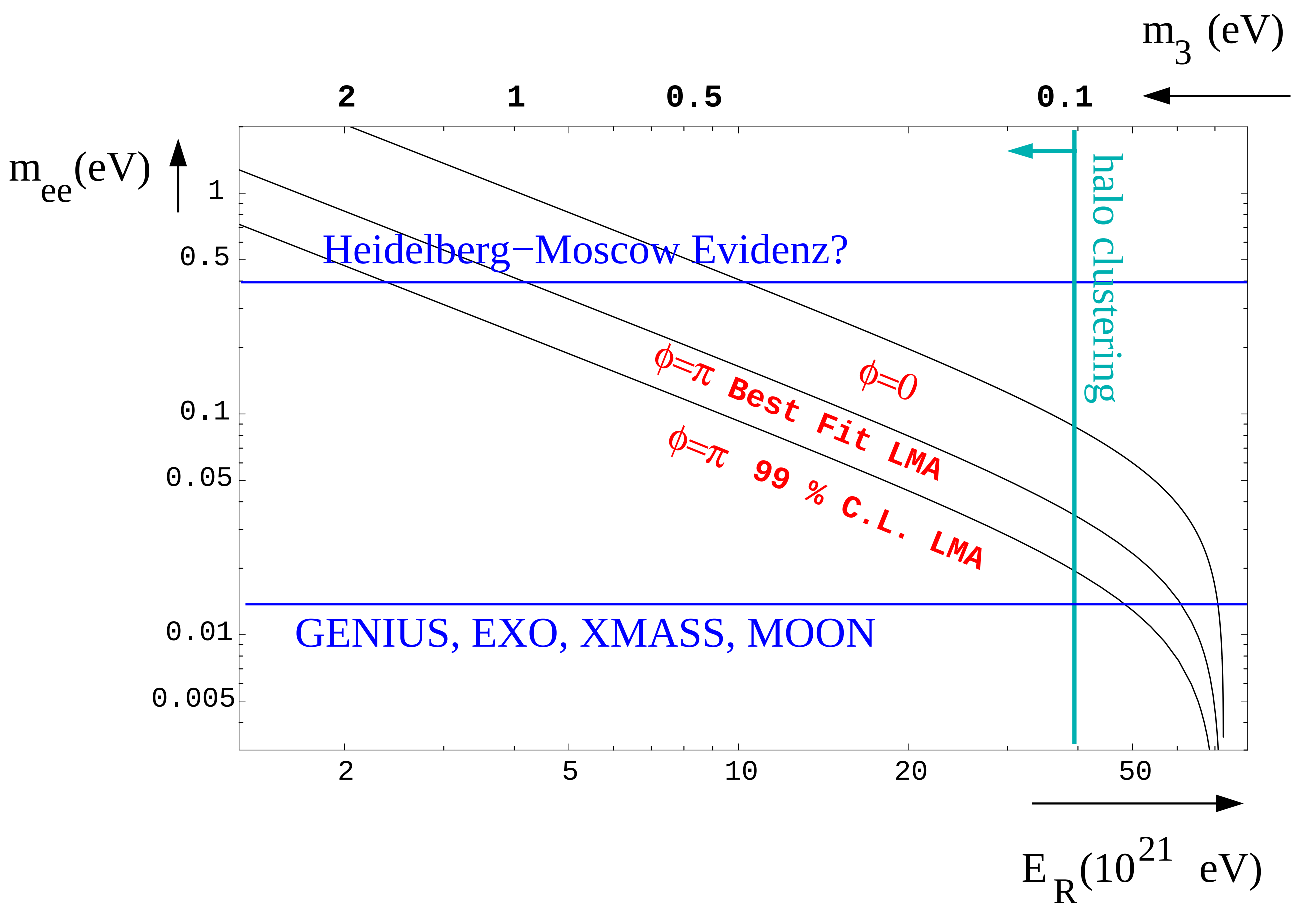
solar neutrinos: Δm_{12}^2, $|U_{e1}|^2$, $|U_{e2}|^2$
atmospheric neutrinos: Δm_{23}^2
CHOOZ, Palo Verde: Δm_{13}^2, $|U_{e3}|^2 = \frac{1}{4}\sin^2(2\theta_{e\not{e}}) < 0.025$

(H.V. Klapdor-Kleingrothaus, H. Päs, A.Y. Smirnov, PRD63 (2001) 073005)

$0\nu\beta\beta$ in degenerate ν mass schemes



$$m_{ee}^{(1)} = \cos^2\theta_\odot \cdot m_1$$
$$m_{ee}^{(2)} = \sin^2\theta_\odot \cdot m_1$$
$$m_{ee}^{(3)} \lesssim 0.025 \text{ eV}$$
$$m_{ee} = (\cos(2\theta_\odot) - 1) \cdot m_1$$



Summary

Future $0\nu\beta\beta$ projects can test all neutrino mass spectra:

- $m_{ee} = 0.39$ eV: $m_1 = m_2 = m_3 = 0.04 - 0.4$ eV
- $m_{ee} > 0.1$ eV: Degenerate neutrinos
- $m_{ee} \simeq 0.01 - 0.1$ eV: Degenerate neutrinos, partial degeneracy or inverse hierarchy
- So far: m_3/E_R will be known with accuracy of $(\cos 2\theta_{\rm sun})^{-1}$, galactic halo clustering may support Z-burst.
- Otherwise: $m_3 \simeq \sqrt{\Delta m^2_{\rm atm}} \sim 0.5$ eV; no halo clustering and no mass-degeneracy supports Z-burst.
- $m_{ee} > 0.001 - 0.01$ eV: Partial degeneracy or inverse hierarchy
- $m_{ee} \lesssim 0.001$ eV: Hierarchical spectrum

(H. Päs, T.J. Weiler, PRD 63 (2001) 113015)