Beyond standard neutrinos

Pedro A N Machado

Blois 2016

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Beyond standard neutrinos

physics with

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Consejo Superior de Investigaciones Científicas

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Beyond standard ~~uses of~~ neutrinos

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Importance of SM for BSM

Mixing parameters

nu-fit.org

$\sin^2\theta_{12}$ @ 4%

$\sin^2\theta_{13}$ @ 6%

$\sin^2\theta_{23}$ @ 10%-ish

Mass squared differences

Δm^2_{21} @ 3%

$|\Delta m^2_{atm}|$ @ 2%

Kate Scholberg's talk

Hierarchy unknown

CP phase unknown

Mass scale unknown

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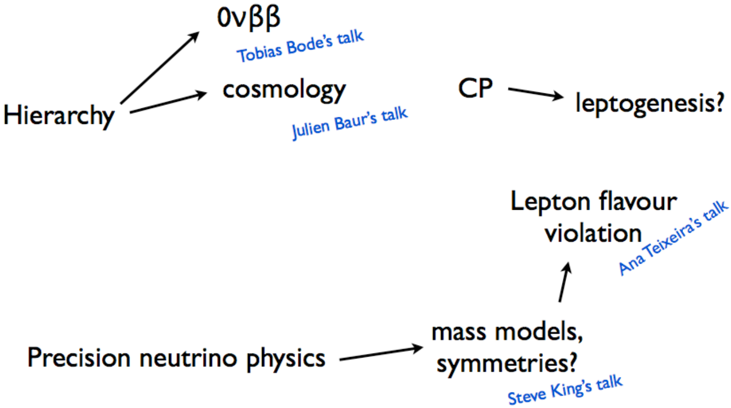
Importance of SM for BSM



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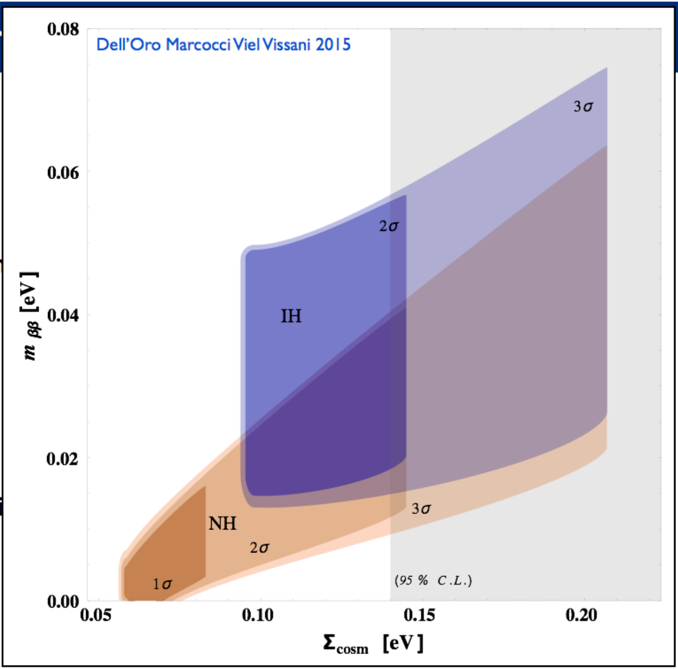
In

Hierarch

Precisi



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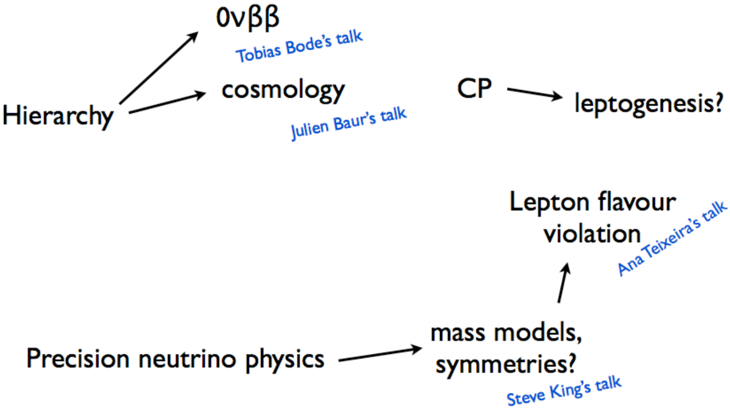

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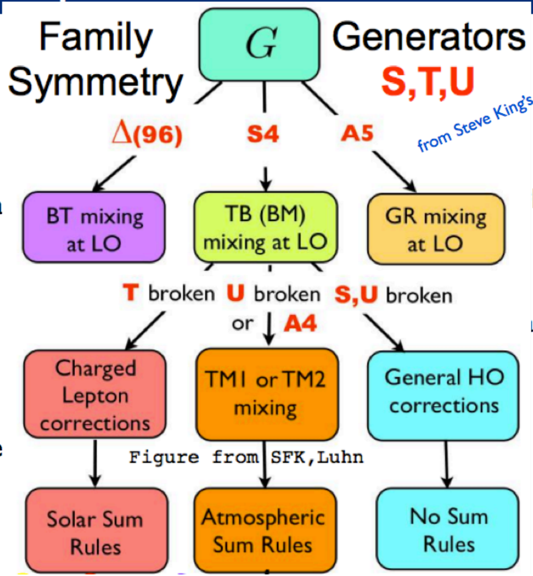
Importance of SM for BSM

Hiera



from Steve King's slides @ Planck!

ptogenesis?

flavour

tion

Pre

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What kind of BSM can be probed by neutrino experiments?

Can neutrinos probe reasonable new physics beyond the reach of collider experiments?

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Beyond standard physics with neutrinos

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Non standard interactions

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F\varepsilon_{\alpha\beta}^{fP}(\bar{\nu}_\alpha\gamma^\mu\nu_\beta)(\bar{f}\gamma_\mu P f)$$

$$\Big\downarrow ?$$

$$\frac{1}{\Lambda^2}(\bar{L}_\alpha\gamma^\rho L_\beta)\,(\bar{L}_\gamma\gamma_\rho L_\delta\,)$$

Flavour changing in charged lepton sector

Too big to be true

...

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Flavour below G_F scale

Flavour remnants below G_F can show up in neutrino oscillation experiments

Babu Friedland PANM Mocioiu, to appear soon

Gauge B-L of 3rd family

	ϕ_1	ϕ_2	s
$SU(2)_L$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$
$U(1)_Y$	$+1$	$+1$	0
$U(1)_{B-L}^{(3)}$	$+1/3$	0	$+1/3$

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breaks EW and new symmetry

Z-X mixing:

$$Z_\mu \simeq -s_w B_\mu + c_w W^3_\mu - s_X X^0_\mu,$$
$$X_\mu \simeq s_X (s_w B_\mu - c_w W^3_\mu) + X^0_\mu,$$

$$s_X \equiv \frac{2}{3} \frac{g_X}{\sqrt{g^2 + g'^2}} \frac{v_1^2}{v^2}.$$

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Flavour changing neutral currents in quark sector:

$$\frac{g_X}{3} \overline{\mathbf{Q}}_L \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \gamma^\mu \mathbf{Q}_L X_\mu \longrightarrow \frac{g_X}{3} \overline{\mathbf{u}}_L \begin{pmatrix} V_{ub}^2 & V_{ub}V_{cb} & V_{ub} \\ V_{ub}V_{cb} & V_{cb}^2 & V_{cb} \\ V_{ub} & V_{cb} & 1 \end{pmatrix} \gamma^\mu \mathbf{u}_L X_\mu + \ldots$$

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No FCNC (at tree level) in charged lepton sector!

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Flavour remnants below G_F can show up in neutrino oscillation experiments

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No FCNC (at tree level) in charged lepton sector!

Neutrinos may experience large non standard matter effects

$$V_X \propto \mathrm{diag}\,(0, \quad 0, \quad \varepsilon_{\tau\tau})$$

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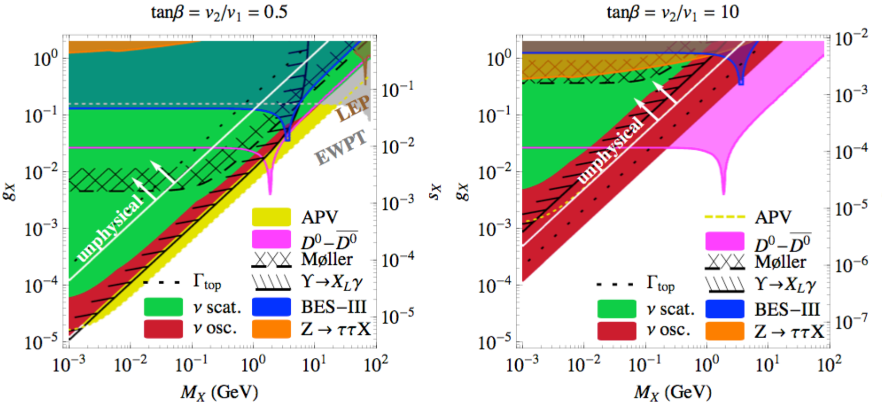
Flavour below G_F scale

Flavour remnants below G_F can show up
in neutrino oscillation experiments



Babu Friedland PANM Mocioiu, to appear soon

see also Farzan 2015, Farzan Shoemaker 2015

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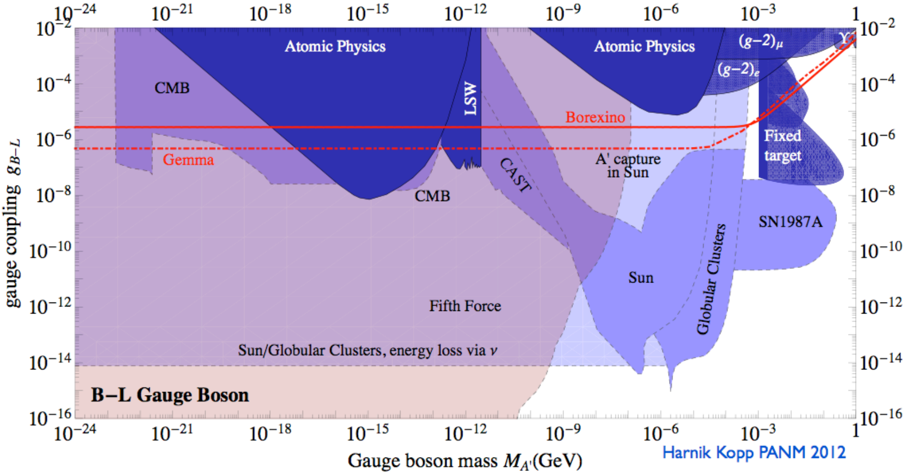
Light weakly coupled physics

Low scale gauged (universal) B-L symmetry



Harnik Kopp PANM 2012

see also Pospelov 2011, Bilmis et al 2015

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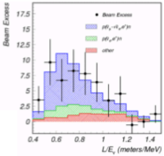
Sterile neutrinos

LSND



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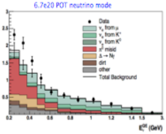
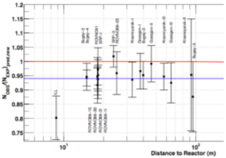
MiniBooNE



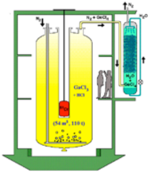
Reactor anomaly

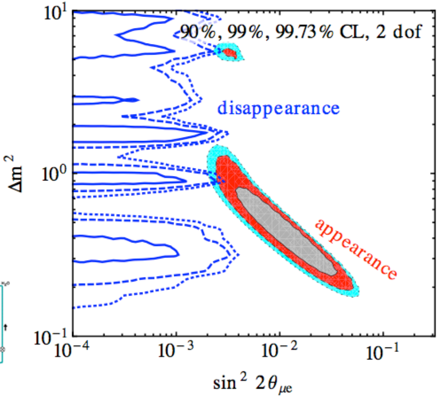
+



Gallium anomaly

+





Kopp, PANM, Maltoni, Schwetz 2013

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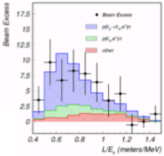
Sterile neutrinos

LSND



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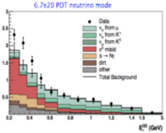

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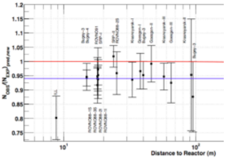

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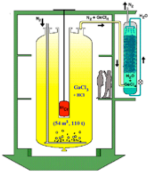

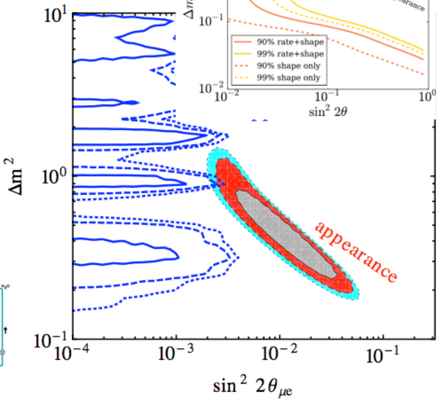

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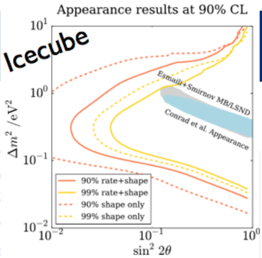

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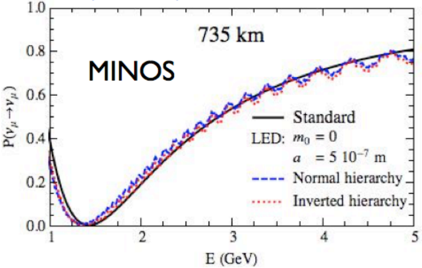
Neutrino masses

Neutrino masses from extra dimensions

Arkani-Hamed, Dimopoulos, March-Russel, Dienes, Dudas, Gherghetta, Dvali, Smirnov, Barbieri, Creminelli, Strumia, ...

$$m^D_{\alpha\beta} = h_{\alpha\beta}\,\langle H\rangle\, M_{Pl(4+\delta)}/M_{Pl}$$

PANM, Nunokawa, Zukanovich-Funchal 2011



Could explain the reactor anomaly

PANM, Nunokawa, dos Santos, Zukanovich-Funchal 2011

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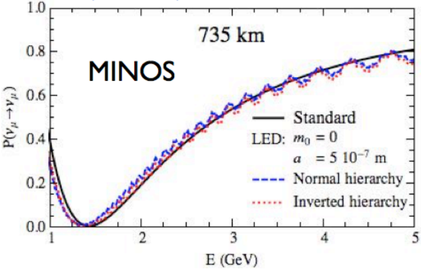
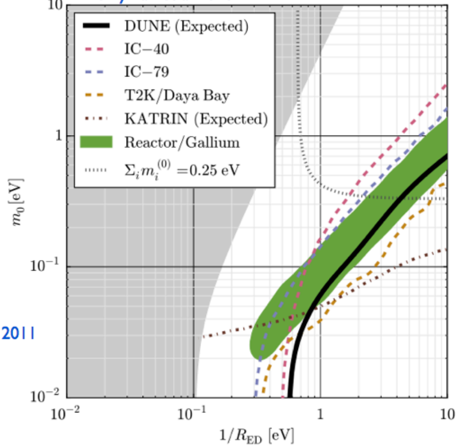


Berryman et al 2016



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Beyond standard uses of neutrinos

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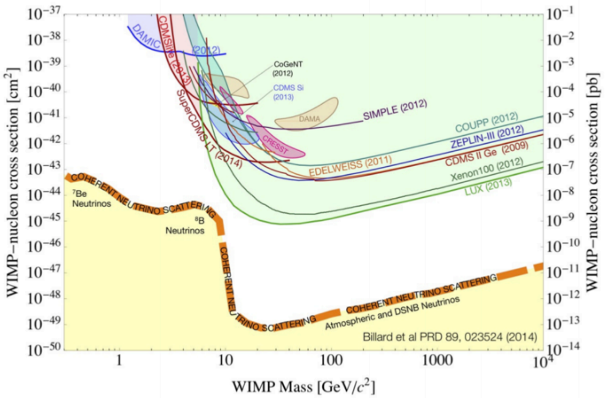
DM direct detection experiments



Neutrino floor

DM-nucleus cross section for which the solar neutrino background hinders the experimental sensitivity

$$\frac{d\sigma_{\nu N}}{dE_R} = \frac{G_F^2}{4\pi} Q_v^2 m_N \left(1 - \frac{m_N E_R}{2E_\nu^2}\right) F^2(E_R)$$

$$Q_v = N - (1 - 4\sin^2\theta_W) Z$$

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DM direct detection experiments

signal ⟵⟶ **background**

see Adam Ritz's talk for DM in neutrino experiments

What can be learned with solar neutrinos in dark matter detectors?

Boehm, Cerdeno, Fairbairn, Jubb, PANM, Vincent 2016

Standard solar model
(opacity, metallicity, neutrinos)

BSM physics
(light mediators)

Standard model
(Coherent ν-N, $\sin^2\theta_w$)

Pospelov 2011, Harnik Kopp PANM 2012, Baudis et al 2014, Ruppin et al 2014, Billard et al 2015, Schumann et al 2015, Bilmis et al 2015, Dutta et al 2016, Strigari 2016, ...

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Neutrinos in DM experiments

Experiment	ϵ (ton-year)	$E_{th,n}$ (keV)	$E_{th,o}$ (keV)	E_{max} (keV)	$R(pp)$	$R(^8\mathrm{B})$	$R(\mathrm{CNO})$
G2-Ge	0.25	0.35	0.05	50	–	[62 – 85]	[0 – 3]
G2-Si	0.025	0.35	0.05	50	–	[3 – 3]	0
G2-Xe	25	3.0	2.0	30	[2104 – 2167]	[0 – 64]	0
Future-Xe	200	2.0	1.0	30	[17339 – 17846]	[520 – 10094]	0
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Super-CDMS-like: 50 (5) kg Ge (Si) x 5 years

LZ-like: 5 ton Xe (fiducial) x 5 years

Darwin-like: 200 ton x y

Dark matter sensitivity of multi-ton liquid xenon detectors

Marc Schumann,[a,1] Laura Baudis,[b] Lukas Bütikofer,[a] Alexander Kish,[b] Marco Selvi[c]

With an exposure of $200\,\text{t} \times \text{y}$ and assuming detector parameters which have been already demonstrated experimentally, spin-independent cross sections as low as $2.5 \times 10^{-49}\,\text{cm}^2$ can be probed for WIMP masses around $40\,\text{GeV}/c^2$. Additional improvements in terms of background

Neutrinos in DM experiments

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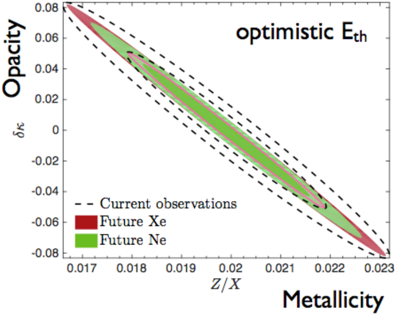
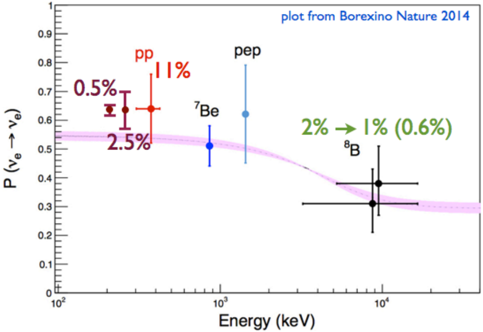
Solar properties



Solar neutrino fluxes



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Neutrinos in DM experiments

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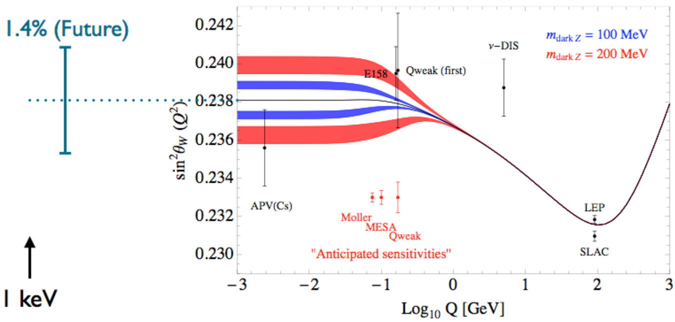
Electroweak $\sin^2\theta_w$

Davoudiasl Lee Marciano PRD 2014



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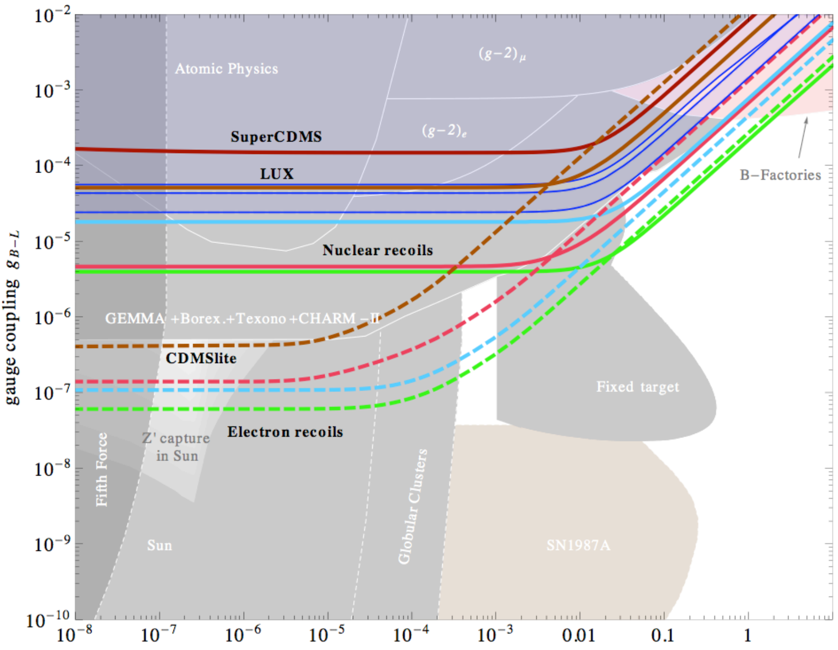

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Conclusions

Neutrinos experiments can be sensitive to
physics beyond the reach of collider experiment

Low scale flavour models
Light mediator physics
Sterile neutrinos ...

Neutrinos may become an important probe in
dark matter experiments

Solar model parameters
Neutrino fluxes (pp, ^8B)
$\sin^2\theta_w$ at very low scales

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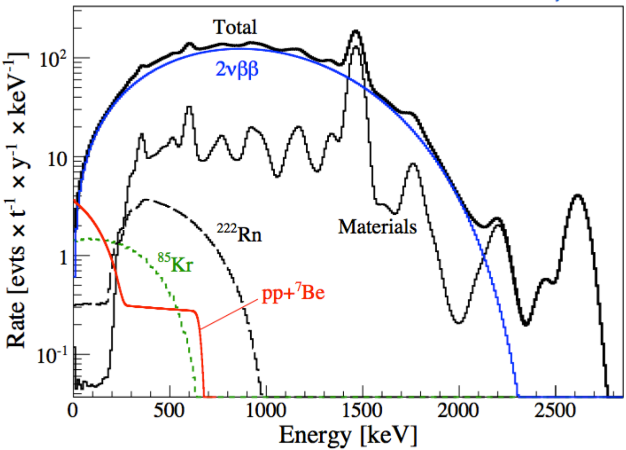
Backgrounds

Baudis et al JCAP 2014



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Backup

$$\mathcal{L}^q_{yuk} = \overline{\mathbf{Q}}_L \begin{pmatrix} y^u_{11}\widetilde{\phi}_1 & y^u_{12}\widetilde{\phi}_1 & y^u_{13}\widetilde{\phi}_2 \\ y^u_{21}\widetilde{\phi}_1 & y^u_{22}\widetilde{\phi}_1 & y^u_{23}\widetilde{\phi}_2 \\ 0 & 0 & y^u_{33}\widetilde{\phi}_1 \end{pmatrix} \mathbf{u}_R + \overline{\mathbf{Q}}_L \begin{pmatrix} y^d_{11}\phi_1 & y^d_{12}\phi_1 & 0 \\ y^d_{21}\phi_1 & y^d_{22}\phi_1 & 0 \\ y^d_{31}\phi_2 & y^d_{32}\phi_2 & y^d_{33}\phi_1 \end{pmatrix} \mathbf{d}_R + \text{h.c.}$$

We choose to generate the CKM mixing on the up sector

$$R^{uL}_{12}.M_u.R^{uR\dagger}_{12} \approx \begin{pmatrix} m_u & 0 & V^0_{ub}m_t \\ 0 & m_c & V^0_{cb}m_t \\ 0 & 0 & m_t \end{pmatrix} \quad \text{and} \quad R^{dL}_{12}.M_d.R^{dR\dagger}_{12} \approx \begin{pmatrix} m^0_d & 0 & 0 \\ 0 & m^0_s & 0 \\ 0 & 0 & m^0_b \end{pmatrix}$$

$$\mathcal{L}_{\text{X-FCNC}} = \frac{g_X}{3}\overline{\mathbf{Q}}_L \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \gamma^\mu X_\mu \mathbf{Q}_L$$

$$\mathcal{L}_{\text{X-FCNC}} \approx \frac{g_X}{3}\overline{\mathbf{u}}_L \begin{pmatrix} V^2_{ub} & V_{ub}V_{cb} & V_{ub} \\ V_{ub}V_{cb} & V^2_{cb} & V_{cb} \\ V_{ub} & V_{cb} & 1 \end{pmatrix} \gamma^\mu X_\mu \mathbf{u}_L + \frac{g_X}{3}\overline{\mathbf{d}}_L \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \gamma^\mu X_\mu \mathbf{d}_L$$

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