New physics at GeV scale?

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Dubna Round Table
Theoretical and Experimental Physics
after the discovery of BEH:
What next ?

JINR, Dubna, Russia

Outline

1. Where is new physics ?
2. Neutrino oscillations: NP is below EW scale
3. Elusive NP: portals to a hidden World
   - To be tested at LHC
   - To be tested at fixed target
   - νMSM: 3 in 1 flask
     (neutrino oscillations, dark matter, baryon asymmetry of the Universe)
4. Summary

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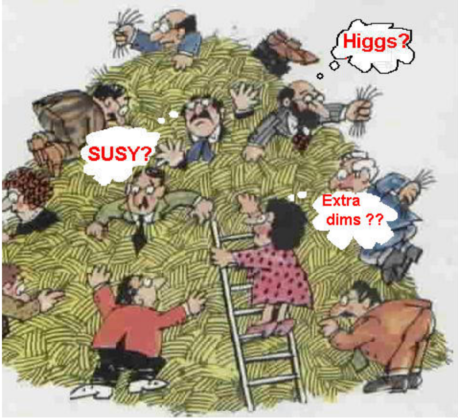
Searches at LHC



Finally…

Higgs boson has been recognized

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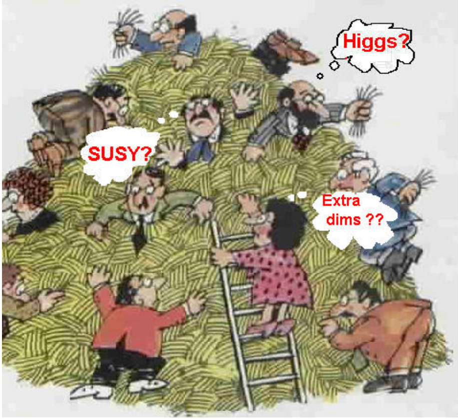

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RG evolution of the SM couplings

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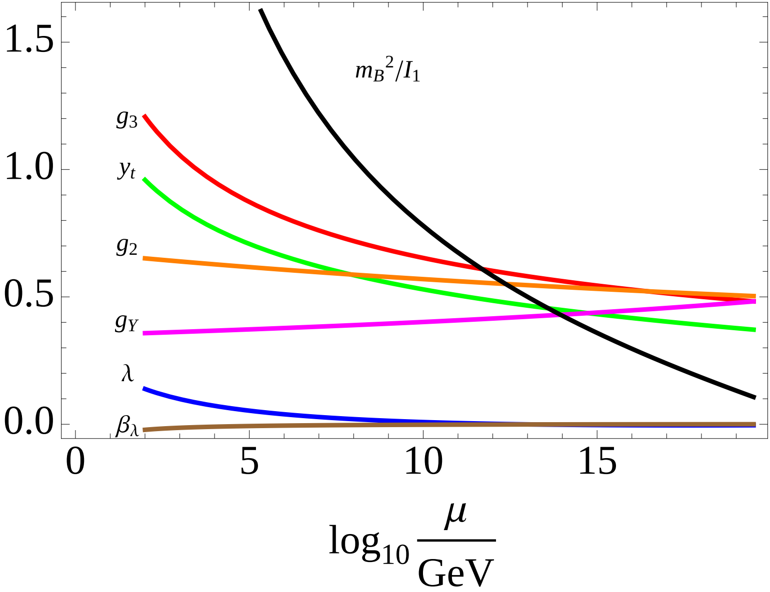
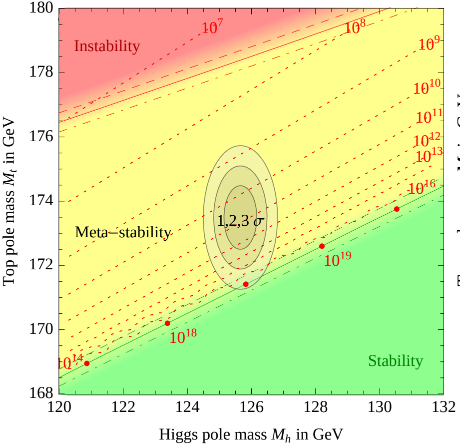
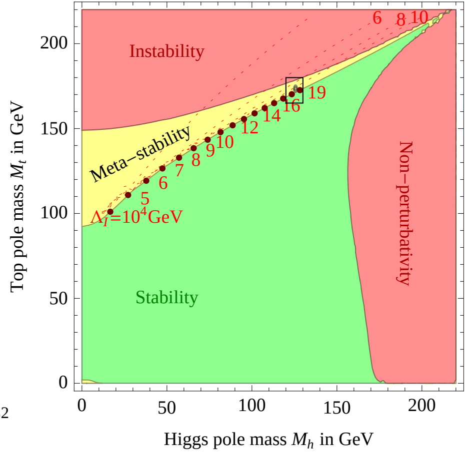


How “natural” the 126 GeV. . .





1307.7879

At the crossroads

What we have at present

- We certainly need NP
- Any NP contribute
  to the Higgs boson mass,
  which is 126 GeV
- No clear signal of NP
  (no SUSY) at 8 TeV

Logically possible ways out

- NP is right at 13-14 TeV
  (why hidden so well at 8 TeV ?)
  (why no hints in flavor ?)
- NP is
  at the gravity (Planck) scale
- NP is below EW scale
  motivated by neutrino
  oscillations

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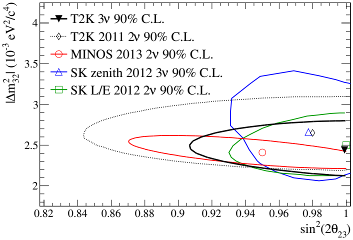
Neutrino oscillations: masses and mixing angles



“atmospheric” 2 × 2 sector

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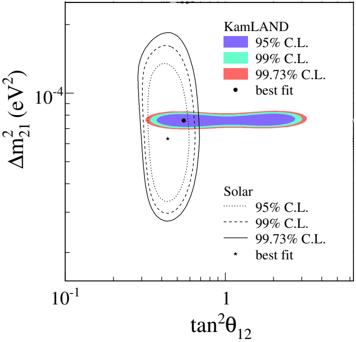

“solar” 2 × 2 sector

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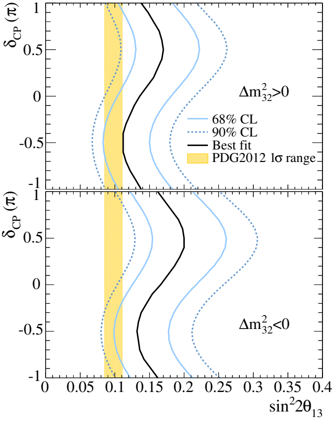

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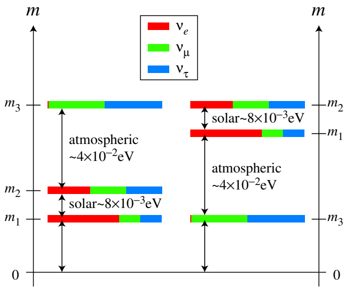
“Normal” and “Inverted” neutrino mass hierarchies

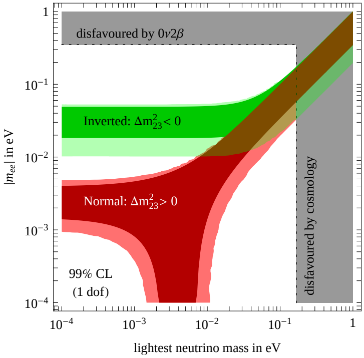
Only two squared mass differences are determined, there are options for masses. . .

may be, the hierarchy will be fixed by T2K & Noνae



normal inverted
hierarchy

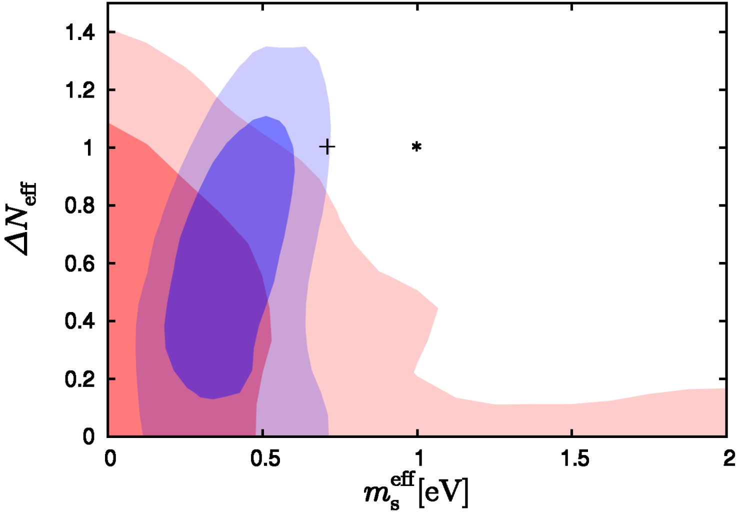
neutrinoless 2β-decay $Z->(Z+2)+2e^-$ CP ??



may be Cosmology will help...
Planck (2014)? . . . EUCLID (galaxy survey)

$|m_{ee}| = \left|\sum U^2_{ei} m_i\right|$, for Majorana masses

Planck, SZ-clusters, BAO, Hubble parameter, vs 1 eV anomalies: $+$ for LSND, $*$ for reactor and Gallium



With 3 light neutrinos $\Delta N_{\rm eff} = 0$
Planck & BAO @ 95 CL:

$\sum m_\nu < 0.23\,\text{eV}$

But with more cosmological ingredients, like 1-eV sterile neutrinos: Planck, & combined

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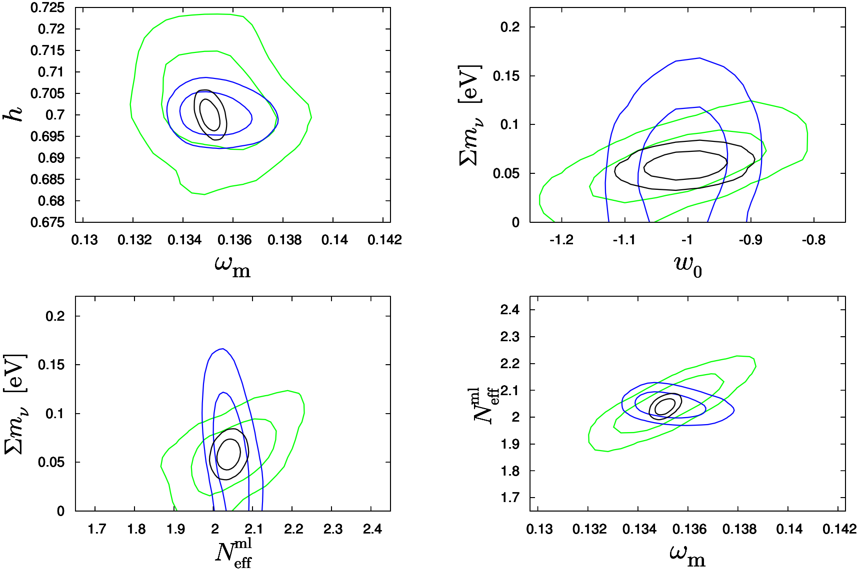
Future: EUCLID-like survey of galaxies

1304.2321



Active neutrino masses without new fields

Dimension-5 operator $\Delta L = 2$

$$\mathscr{L}^{(5)} = \frac{F_{\alpha\beta}}{4\Lambda}\bar{L}_\alpha \tilde{H} H^\dagger L^c_\beta + \text{h.c.}$$

L_α are SM leptonic doublets, $\alpha = 1,2,3$, $\tilde{H}_a = \varepsilon_{ab} H^*_b$, $a,b = 1,2$; in a unitary gauge $H^T = \left(0, (v+h)/\sqrt{2}\right)$ and

$$\mathscr{L}^{(5)}_{\nu\nu} = \frac{v^2\, F_{\alpha\beta}}{4\,\Lambda} \times \frac{1}{2}\bar{\nu}_\alpha \nu^c_\beta + \text{h.c.} = m_{\alpha\beta} \times \frac{1}{2}\bar{\nu}_\alpha \nu^c_\beta + \text{h.c.}$$

where

Λ is the scale of new dynamics

$F_{\alpha\beta}$ is the strength of new dynamics

only their ratio is fixed by the scale of active neutrino masses

Perturbative regime for model parameters

$$F_{\alpha\beta} \lesssim 1 \qquad \Longrightarrow \qquad \Lambda \lesssim 3\times 10^{14}\,\mathrm{GeV}\times\left(\frac{3\times 10^{-3}\,\mathrm{eV}^2}{\Delta m^2_{\mathrm{atm}}}\right)^{1/2}$$

The model has to be UV-completed at the scale Λ → New physics

- The scale is certainly below the Planck (string) scale, and hence is most probably at (below) EW scale
- Why no hints recognized at this scale?

couplings to the SM fields are tiny

- which probably implies not a GUT-like new physics (all is $\propto g$) hence coupling to new gauge singlets
- that is usually nonrenormalizable interactions... however, there are exceptions...

thus we arrive at the portals

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Three Portals to the hidden World

Renormalizable interaction including SM field and new (hypothetical) fields singlets with respect to the SM gauge group

Attractive feature: couplings are insensitive to energy in c.m.f., hence low energy experiments (intensity frontier) are favorable

- Scalar portal: SM Higgs doublet H and hidden scalar S

  the simplest dark matter

$$\mathscr{L}_{\text{scalar portal}} = -\beta\, H^\dagger H S^\dagger S$$

- Spinor portal: SM lepton doublet L, Higgs congugate field $\tilde{H} = \varepsilon H^*$ and hidden fermion N

  sterile neutrino !!

$$\mathscr{L}_{\text{spinor portal}} = -y\bar{L}\tilde{H}N$$

- Vector portal: SM gauge field of $U(1)_Y$ and gauge hidden field of abelian group $U(1)'$

$$\mathscr{L}_{\text{vector portal}} = -\frac{\varepsilon}{2} B_{\mu\nu}^{U(1)_Y} B_{\mu\nu}^{U(1)'}$$

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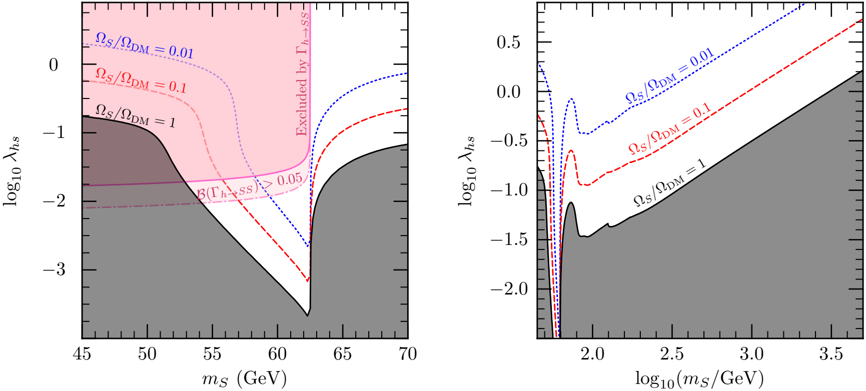
scalar as dark matter: $V = \frac{\mu_S^2}{2} S^2 + \frac{\lambda_S}{2} S^2 H^\dagger H$



$m_S^2 = \mu^2 + \frac{\lambda_S}{2} v^2$

scalar portal

1306.4710

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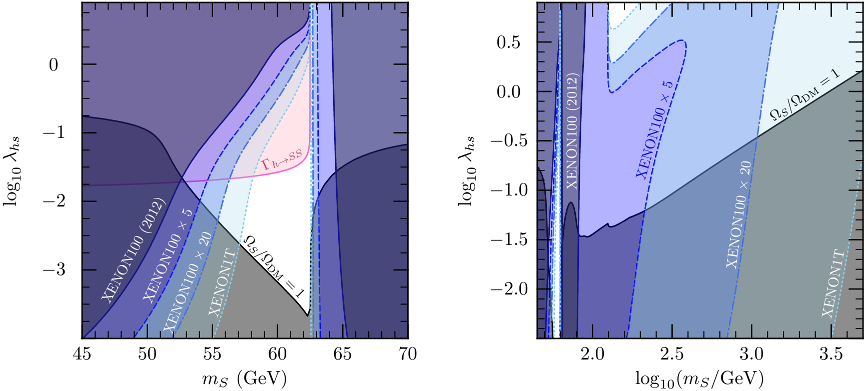

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scalar portal

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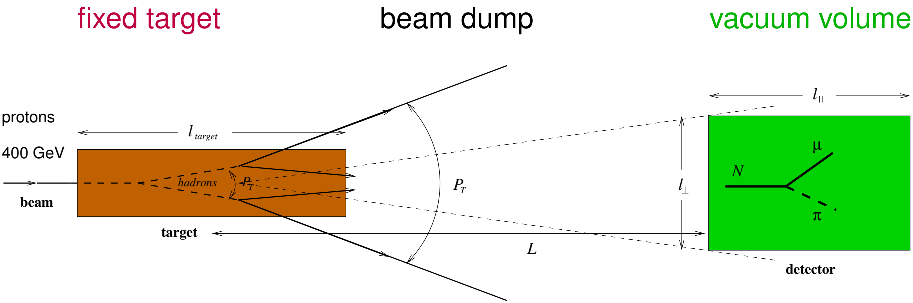
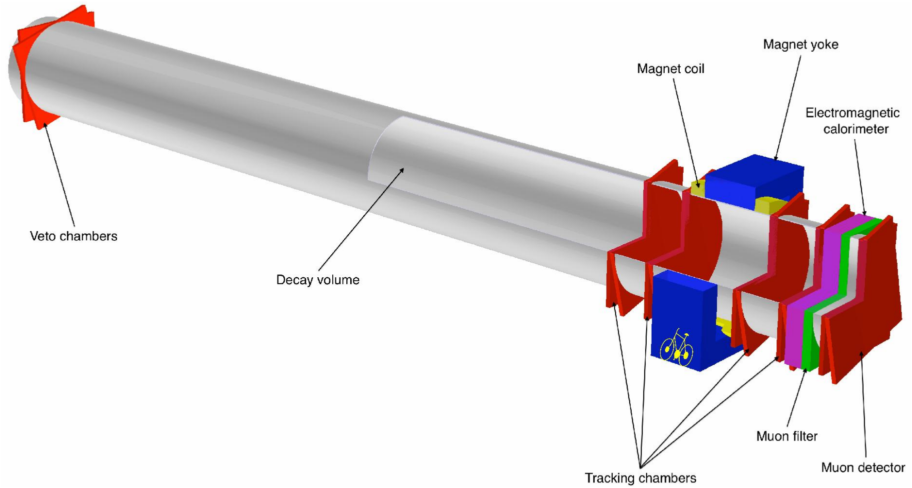
The experiment under discussion: a scheme



Searches for any BSM with

Neutral Unstable but Long Lived Particles Lighter than D-meson

The experiment under discussion: a sketch



Physics to be tested

- weak interactions (neutrino beam scatterings off matter)
- light, very weakly interacting, yet unstable particles:
  produced (in)directly on target, then decaying in the detector fiducial volume
  - light sgoldstinos (superpartners of goldstino in SUSY models)
    e.g., D.S. Gorbunov (2001) e.g. $D \to \pi X$, then $X \to l^+ l^-$
  - R-parity violating neutralinos in SUSY models
    e.g., A. Dedes, H.K. Dreiner, P. Richardson (2001) e.g. $D \to l \tilde{\chi}$, then $\tilde{\chi} \to l^+ l^- \nu$
  - massive paraphotons (in secluded dark matter models)
    e.g., M. Pospelov, A. Ritz, M.B. Voloshin (2008) e.g. $\Sigma \to p V$, then $V \to l^+ l^-$
- light, fairly weakly interacting, unstable particles:
  produced in beam dump (rock), right in front of detector, then decaying in the detector fiducial volume
  - sterile neutrinos with transition dipole moments
    e.g., S.N. Gninenko (2009,2010) $\nu A \to N A$, then $N \to \nu \gamma$

as compared to CHARM
longer lifetimes and smaller couplings will be accessible

Under the name. . . SHIP

- νMSM: T.Asaka, S.Blanchet, M.Shaposhnikov (2005), T.Asaka, M.Shaposhnikov (2005), see also review A. Boyarsky, O. Ruchayskiy, M.Shaposhnikov (2009)
- direct tests of νMSM: D.G., M.Shaposhnikov (2007)
- searches for dark matter A. Boyarsky, O. Ruchayskiy, M.Shaposhnikov, I.Tkachev, etc...
- proposal for direct searches submitted to European Strategy Group, 2012 D.G., M.Shaposhnikov
- sketch of realistic experiment S.Gninenko, D.G., and M.Shaposhnikov (2013)
- Expression Of Interests: Proposal to Search for Heavy Neutral Leptons at the SPS W. Bonivento et al, 1310.1762

Search
for
HIdden
Particles

To
Host
Rats
from
the SUSY ship. . .

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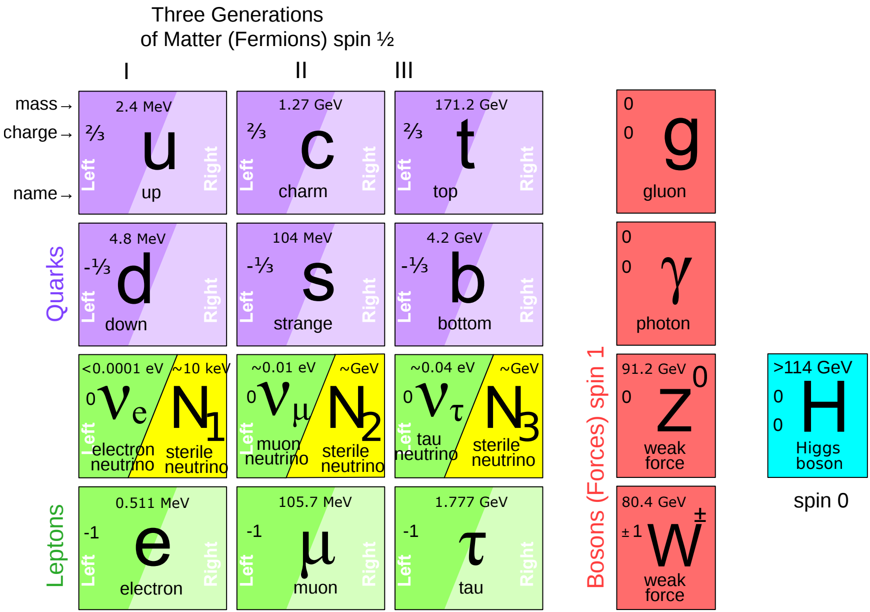
Possible new physics: Sterile neutrinos

Minimal extension of SM to explain neutrino oscillations

sterile: new fermions uncharged under the SM gauge group
neutrino: explain observed oscillations by mixing with SM (active) neutrinos

Attractive features:

- only 3 Majorana fermions (6 d.o.f.) is enough
- true renormalizable theory not worth then the SM (e.g. may work up to the Planck scale)
- baryon asymmetry via leptogenesis through redistribution of the leptonic charge between active and sterile neutrinos and transfering of the lepton asymmetry into baryon asymmetry by electoweak sphalerons
- dark matter: lightest sterile neutrino (1-50 keV)



Three Generations
of Matter (Fermions) spin ½

mass →
charge →
name →

	I	II	III	Bosons (Forces) spin 1	
Quarks	2.4 MeV ⅔ u up Left Right	1.27 GeV ⅔ c charm Left Right	171.2 GeV ⅔ t top Left Right	0 0 g gluon	
Quarks	4.8 MeV -⅓ d down Left Right	104 MeV -⅓ s strange Left Right	4.2 GeV -⅓ b bottom Left Right	0 0 γ photon	
Leptons	<0.0001 eV 0 ν_e electron neutrino Left ~10 keV N_1 sterile neutrino	~0.01 eV 0 ν_μ muon neutrino Left ~GeV N_2 sterile neutrino	~0.04 eV 0 ν_τ tau neutrino Left ~GeV N_3 sterile neutrino	91.2 GeV 0 Z^0 weak force	>114 GeV 0 0 H Higgs boson
Leptons	0.511 MeV -1 e electron Left Right	105.7 MeV -1 μ muon Left Right	1.777 GeV -1 τ tau Left Right	80.4 GeV ±1 $W^\pm$ weak force	spin 0

Seesaw type I mechanism: $M_N \gg m_{active}$

$$\mathscr{L}_N = \overline{N}_I i\partial\!\!\!/ N_I - f_{\alpha I}\overline{L}_\alpha \tilde{H} N_I - \frac{M_{N_I}}{2}\overline{N}_I^c N_I + \text{h.c.}$$

where $I = 1,2,3$ and $\alpha = e,\mu,\tau$ $\tilde{H}_a = \varepsilon_{ab} H_b^*$

When Higgs gains $\langle H \rangle = v/\sqrt{2}$ we get in neutrino sector

$$\mathscr{V}_N = v\,\frac{f_{\alpha I}}{\sqrt{2}}\,\overline{\nu}_\alpha N_I + \frac{M_{N_I}}{2}\overline{N}_I^c N_I + \text{h.c.} = \frac{1}{2}\left(\overline{\nu}_\alpha\,,\overline{N}_I^c\right)\begin{pmatrix} 0 & v\,\frac{\hat{f}}{\sqrt{2}} \\ v\,\frac{\hat{f}^T}{\sqrt{2}} & \hat{M}_N \end{pmatrix}\left(\nu_\alpha^c\,,N_I\right)^{\mathrm{T}} + \text{h.c.}$$

Then for $M_N \gg \hat{M}_D = v\,\frac{\hat{f}}{\sqrt{2}}$ we find the eigenvalues:

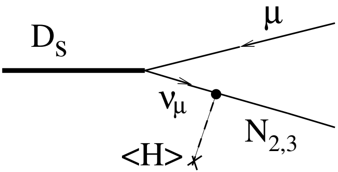
$$\simeq \hat{M}_N \qquad \text{and} \qquad \hat{M}^\nu = -\hat{M}_D\frac{1}{\hat{M}_N}\hat{M}_D^T \propto f^2\frac{v^2}{M_N} \lll M_N$$

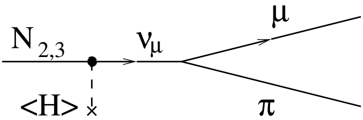
Mixings: flavor state $\nu_\alpha = U_{\alpha i}\nu_i + \theta_{\alpha I} N_I$

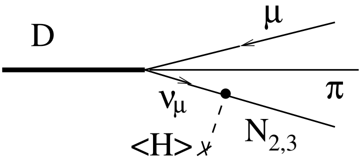
active-active mixing: (PMNS-matrix U) $U^T\hat{M}^\nu U = diag\,(m_1\,,m_2\,,m_3)$

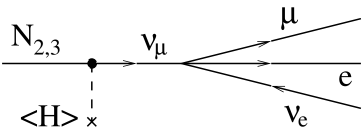
active-sterile mixing: $\theta_{\alpha I} = \frac{M_{D_{\alpha I}}}{M_I} \propto \hat{f}\,\frac{v}{M_N} \ll 1$

Sterile neutrinos: production and decays

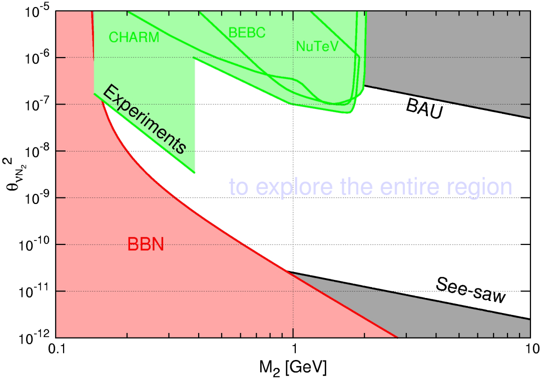








Probing leptogenesis SHIP upgrading to Aerocarrier



to explore the entire region

D.G, M.Shaposhnikov (2007)

lower bound at $\times 10^{-4}$

$$\mathrm{Br}\,(D \to lN) \lesssim 2\cdot 10^{-8}$$

$$\mathrm{Br}\,(D_s \to lN) \lesssim 3\cdot 10^{-7}$$

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$$\mathrm{Br}\,(B \to DlN) \lesssim 7\cdot 10^{-8}$$

$$\mathrm{Br}\,(B \to D^* lN) \lesssim 4\cdot 10^{-7}$$

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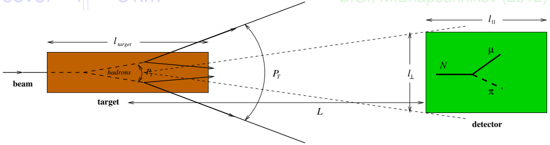
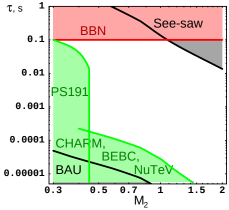
For 10^{20} PoT at 400 GeV (SPS) detectors have to cover $l_{||} \sim 3$ km

D.G., M.Shaposhnikov (2012)





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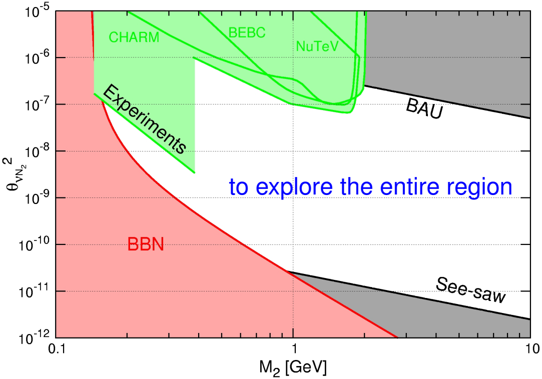

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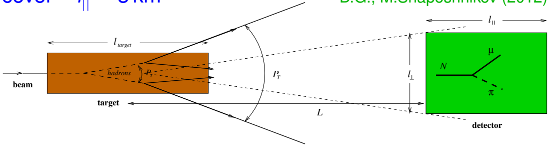

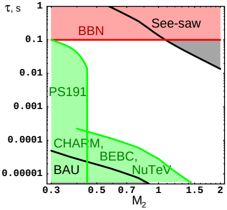

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Summary: intensity frontier

- We definitely need New Physics
- There are arguments in favour of NP below EW scale. . .
- Then above GeV scale we can test it with LHC
- While at GeV scale a fixed-target experiment is much more sensitive

new project SHIP proposed at CERN

- Submit a detailed project (LoI/TDR) to SPS by March 2015

On 10-12 of June we organize a Workshop in Zurich (ETH)

- two half-days on physics case at SPS beam-dump
- and then two half-days on detector and discussion of formal collaboration

All of you and your laboratories are welcome
to attend the meeting
and enter the Collaboration

http://ship.web.cern.ch/ship/

Summary: intensity frontier

- We definitely need New Physics
- There are arguments in favour of NP below EW scale. . .
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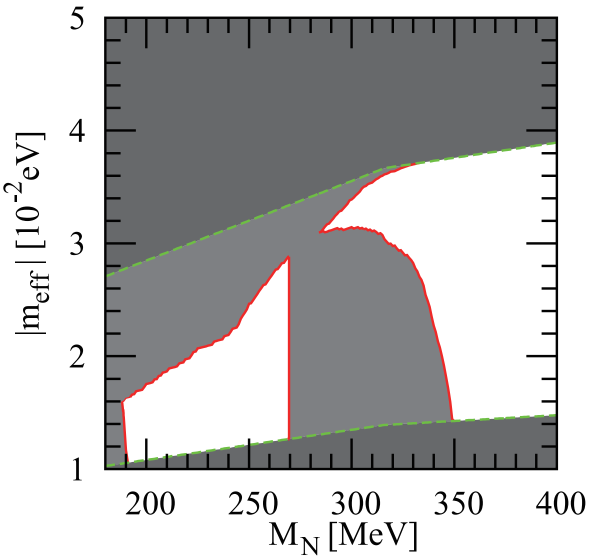
Backup slides

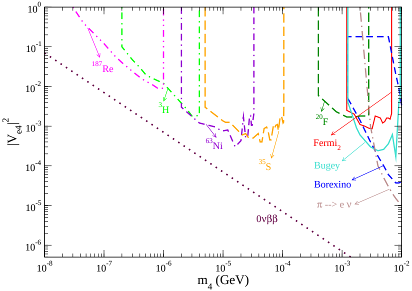
Leptogenesis in $2+1$ scheme: $0\nu 2\beta$ decay region

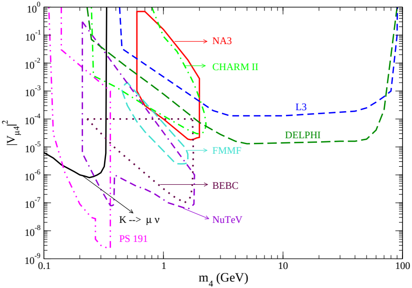


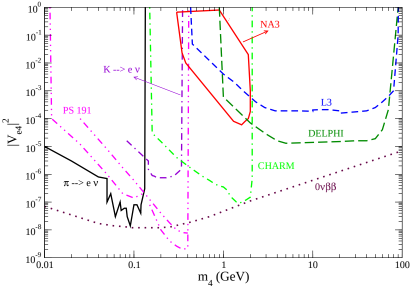
Inverse hierarchy 1308.3550

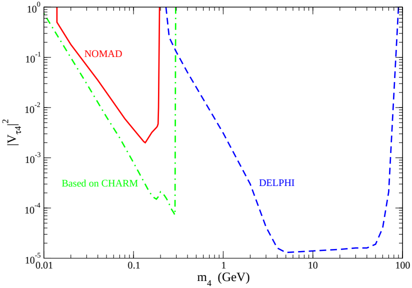
Present limits

0901.3589: 1) $0\nu\beta\beta$-bound is stronger by 10, 1205.3867 2) limits from LHCb and CMS







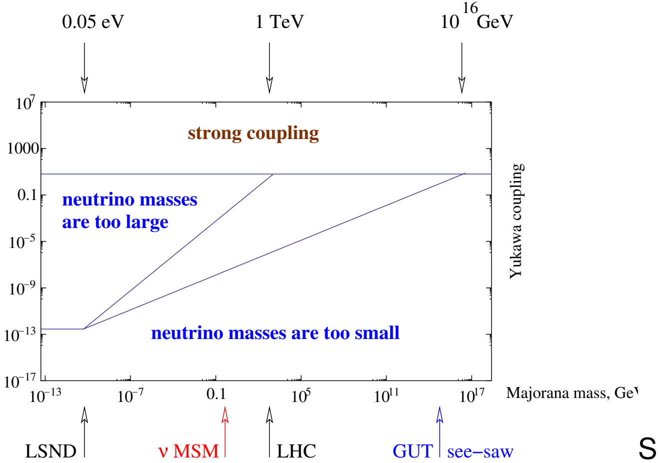


Sterile neutrino mass scale: $\hat{M}_\nu = -v^2 \hat{f}^T \hat{M}_N^{-1} \hat{f}$

NB: With fine tuning in $\hat{M}_N$ and $\hat{f}$ we can get a hierarchy in sterile neutrino masses, and 1 keV and even 1 eV sterile neutrinos

$L_e - L_\mu - L_\tau$ or discrete symmetries
Froggatt-Nielsen mechanism

Extended seesaw



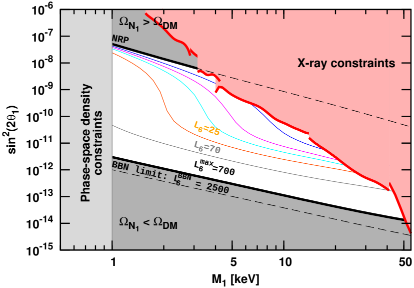
Seesaw diagram

Lightest sterile neutrino N_1 as Dark Matter

Non-resonant production
(active-sterile mixing) is ruled out

Resonant production (lepton asymmetry) requires $\Delta M_{2,3} \lesssim 10^{-16}$ GeV

arXiv:0804.4542, 0901.0011, 1006.4008



Dark Matter production
from inflaton decays in plasma at $T \sim m_\chi$

Not seesaw neutrino!

M.Shaposhnikov, I.Tkachev (2006)

$$M_{N_I} \bar{N}_I^c N_I \leftrightarrow f_I X \bar{N}_I N_I$$

Can be “naturally” Warm ($250\,\text{MeV} < m_\chi < 1.8\,\text{GeV}$)

F.Bezrukov, D.G. (2009)

$$M_1 \lesssim 15 \times \left(\frac{m_\chi}{300\text{ MeV}} \right) \text{keV}$$

Light sgoldstinos in SUSY models

SUSY is spontaneously broken (no scalar electron with mass of 510 keV !!)

breaking of $SU(2)_W \times U(1)_Y$ by the $\langle H \rangle = v$

Goldstones bosons couple to all massive fields

(Goldberger–Treiman formula like for pion)

$$\mathscr{L} = \frac{1}{v} J^{\mu}_{SU(2)_W \times U(1)_Y} \partial_\mu H$$

Higgs mechanism: three modes of H are eaten giving masses to Z, $W^{\pm}$

breaking of SUSY by $\langle F_\varphi \rangle = F$

Goldstone fermion: goldstino

$$\mathscr{L}_\psi \propto \frac{1}{F} J^{\mu}_{SUSY} \partial_\mu \psi$$

Super-Higgs mechanism: goldstino is eaten giving mass to gravitino

ψ — goldstino $\xrightarrow{SUGRA}$ longitudinal gravitino

Physics of Goldstino supermultiplet: (boson φ (sgoldstino), fermion ψ (goldstino))

~~SUSY~~ $\longleftrightarrow$ $F \equiv \langle F_\varphi \rangle \neq 0$ $\qquad$ $\Phi = \varphi + \sqrt{2}\theta\psi + F_\varphi \theta\theta$ $\qquad$ $\frac{1}{\sqrt{2}}\left(\varphi + \varphi^\dagger\right) \equiv S$ — scalar

sgoldstino: $\quad \mathscr{L}_{S,P} \propto \frac{M_{soft}}{F}$ $\qquad$ $F \sim$ (~~SUSY~~ scale)^2 $\qquad$ $\frac{1}{i\sqrt{2}}\left(\varphi - \varphi^\dagger\right) \equiv P$ — pseudoscalar

M_{soft}: MSSM soft terms

superpartner masses and trilinear couplings,

massless at tree level

naturally may be light...

gauginos:

$$M_\lambda \lambda\lambda \longrightarrow \frac{M_\lambda}{F} S F_{\mu\nu} F^{\mu\nu}\,, \quad \frac{M_\lambda}{F} P F_{\mu\nu} \tilde{F}^{\mu\nu}$$

squarks, sleptons:

$$A_{ij} h_u \tilde{q}_i \tilde{u}_j \longrightarrow \frac{A_{ij}}{F} S h_u q_i u_j\,, \quad \frac{A_{ij}}{F} P h_u q_i u_j$$

Light sgoldstinos at the new fixed-target

Why is it interesting?

- allows to probe the scale of SUSY breaking
- *R*-even, hence single production and decay into SM particles
- may be responsible for HyperCP anomaly in $\Sigma \to p\mu^+\mu^-$: $m_P = 214.3$ MeV

hep-ph/0509147

Phenomenology is defined by MSSM soft terms and scale of SUSY breaking

sgoldstinos produced in heavy meson decays		
	hep-ph/0610066 :	tested at Belle (1005.1450)
	1112.5230:	tested at LHCb (1303.1092)

At the beam-dump experiment

Sgoldstino production and lifetime are naturally dominated by gluons

$$\tau_X = 10^{-6}\,\mathrm{s} \times \left(\frac{\sqrt{F}}{1000\,\mathrm{TeV}}\right)^4 \left(\frac{3\,\mathrm{TeV}}{M_{\lambda_g}}\right)^2 \left(\frac{1\,\mathrm{GeV}}{m_{S,P}}\right)^3$$

produced in D-meson decays fly for several kilometers and then decay into

$$X \to \gamma\gamma, \;\; \mu^+\mu^-, \;\; \pi^+\pi^-, \;\; \pi^0\pi^0, \;\; e^+e^-$$

For 2×10^{20} POTs we expect for number of signal $\pi^+\pi^-$ pairs in $L \simeq 100$ m detector

$$N_{\pi^+\pi^-} \simeq 2 \times \left(\frac{1000\,\mathrm{TeV}}{\sqrt{F}}\right)^8 \left(\frac{M_{\lambda_g}}{3\,\mathrm{TeV}}\right)^4 \left(\frac{m_{S,P}}{1\,\mathrm{GeV}}\right)^2$$

R-parity violating neutralinos in SUSY models

Superpotential (SUSY-invariant part) gives Yukawa-like couplings for SM fermions

$$W_{\not R} = \lambda_{ijk} L_i^a \varepsilon_{ab} L_j^b \bar{E}_k + \lambda'_{ijk} L_i^a \varepsilon_{ab} Q_j^b \bar{D}_k + \lambda''_{ijk} \bar{U}_i^\alpha \varepsilon_{\alpha\beta\gamma} \bar{D}_j^\beta \bar{D}_k^\gamma$$

Yet the proton is stable if $\lambda'' = 0$ (baryon parity), or $\lambda, \lambda' = 0$ (lepton parity) and proton is lighter than LSP: $R_p = (-1)^{(3B+L+2S)}$

But LSP is unstable in these models, so no problems with overproduction (but we need another candidate to be dark matter...)

Nevertheless cosmology and astrophysics exclude

BBN: $0.1\,\mathrm{s} < \tau_{\mathrm{LSP}}$ cosmic γ-rays (FERMI): $\tau_{\mathrm{LSP}} < 10^{18}\,\mathrm{yr}$

hence, the allowed range:

$$3 \times 10^{-23} < (\lambda, \lambda', \lambda'') < 3 \times 10^{-10}$$

Direct searches at LHC (and TeVatron) probe:

$$(\lambda, \lambda', \lambda'') > 10^{-6}$$

otherwise LSP decays outside ATLAS and CMS

R-parity violating neutralinos at the fixed-target

The range remains to be directly tested:

$$3 \times 10^{-10} < (\lambda, \lambda', \lambda'') < 10^{-6}$$

hep-ph/0106199: "Fixed-target experiments with remote detectors can probe significantly longer lifetimes than collider experiments and are thus an ideal environment for closing this gap in sensitivity"

production in meson decays: 0905.2051 — probed by BaBar, Belle

$B^{\pm} \to l^{\pm}\tilde{\chi}_0$, $B^0 \to \nu\tilde{\chi}_0$ — R-violating

neutralinos decay into SM particles, e.g.

$\tilde{\chi}_0 \to \mu^+\mu^-\nu$ — R-violating

$\lambda \neq 0$ was discussed after NuTeV dimuon events — hep-ex/0104037, hep-ph/0007195

Number of events at the proposed experiment with N_D D-mesons and detector length $L \simeq 100\,\text{m}$

R-conserving (double neutralino production)

$$N \simeq 10 \times \left(\frac{m_{\tilde{\chi}_0}}{1\,\text{GeV}}\right)^6 \left(\frac{\lambda}{3 \times 10^{-8}}\right)^2 \left(\frac{N_D \cdot \text{Br}\,(D \to \tilde{\chi}_0 + \ldots)}{10^6}\right)$$

Massive vectors (paraphotons)

Vector portal to a secluded sector: e.g. with Dark matter Ψ

one more $U(1)'$ gauge group [spontaneously broken] in secluded sector: mixing with $U(1)_Y$ is naturally expected and unsuppressed by high energy scale 0711.4866

$$\mathscr{L}_{\text{DM+mediator}} = \bar{\Psi}\left(i\gamma^\mu\partial_\mu - e'\gamma^\mu A'_\mu - m_\Psi\right)\Psi - \frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + \frac{m_{\gamma'}^2}{2}A'_\mu A'^\mu + \varepsilon A'_\mu \partial_\nu B^{\mu\nu}$$

when $m_\Psi > m_{\gamma'} \sim 1\,\text{GeV}$

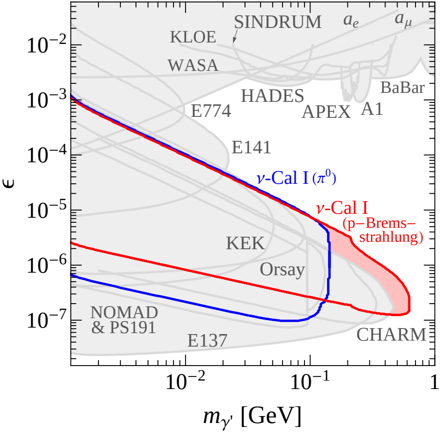
Cosmology:

- Limits from BBN:

$$\tau_V < 1\,\text{s}\,, \quad \Longrightarrow \varepsilon^2\left(\frac{m_{\gamma'}}{1\,\text{GeV}}\right) \gtrsim 10^{-21}$$

- For DM particles to be in thermal equilibrium in primordial plasma:

$$\varepsilon^2\left(\frac{m_{\gamma'}}{1\,\text{GeV}}\right) \gtrsim 10^{-11} \times \left(\frac{m_\Psi}{500\,\text{GeV}}\right)^2$$



1311.5104

Production by virtual photon $\sigma \propto \varepsilon^2$

Decay through virtual photon, $\Gamma \propto \varepsilon^2$

$V \to e^+e^-$, $\mu^+\mu^-$, etc

Paraphotons: improvement of CHARM

$$\mathscr{L}_{\text{DM+mediator}} = \bar{\Psi}\left(i\gamma^\mu\partial_\mu - e'\gamma^\mu A'_\mu - m_\Psi\right)\Psi - \frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + \frac{m^2_{\gamma'}}{2}A'_\mu A'^\mu + \varepsilon A'_\mu\partial_\nu B^{\mu\nu}$$

when $m_\Psi > m_{\gamma'} \sim 1$ GeV

Constraints on mixing ε

- Limits from above:
  decays before reaching CHARM

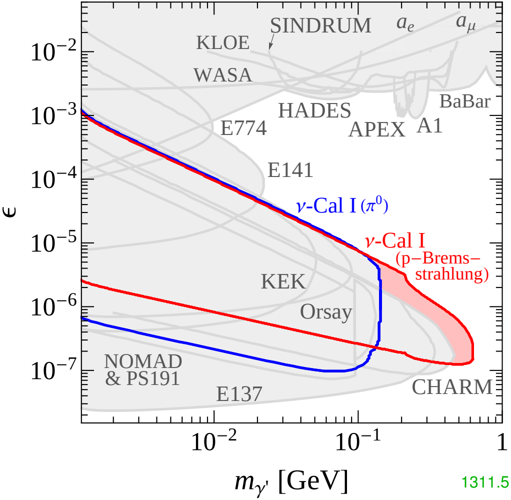
  $$L_{\text{CHARM}} = 400\,\text{m} > l_{\text{decay}} \propto \frac{1}{\varepsilon^2 m^2_{\gamma'}}$$

  $L = 50$ m, hence
  a factor of 3 improvement

- Limits from below:
  too few events in CHARM

  $$\sigma_{\text{production}} \propto \varepsilon^2\,, \quad \Gamma_{\text{decay}} \propto \varepsilon^2$$

  Luminosity, geometry,. . .
  2 orders of magnitude improvement



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