LAB-TO-GENESIS

HOW TO FIND THE ORIGIN OF MATTER IN EXISTING EXPERIMENTS

Marco Drewes
TU München

based on
arXiv:1404.7114 [hep-ph],
Phys.Rev.Lett. 110 (2013) 6, 061801 ,
JHEP 1303 (2013) 096 ,
Phys.Rev. D87 (2013) 093006
and work in progress

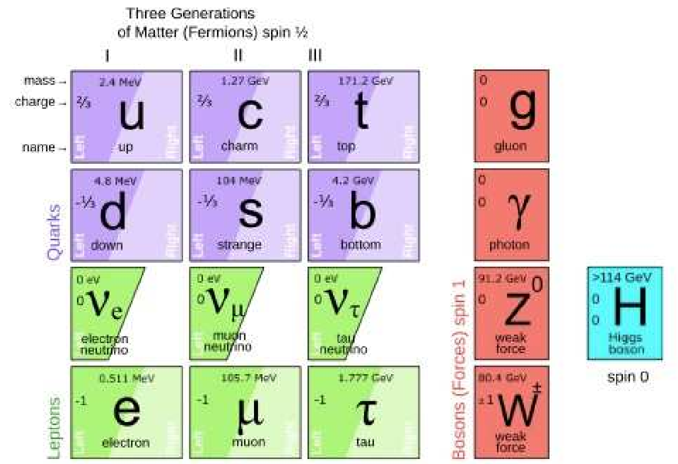
2013 review: **arXiv:1303.6912 [hep-ph] Int.J.Mod.Phys. E22 (2013) 1330019**

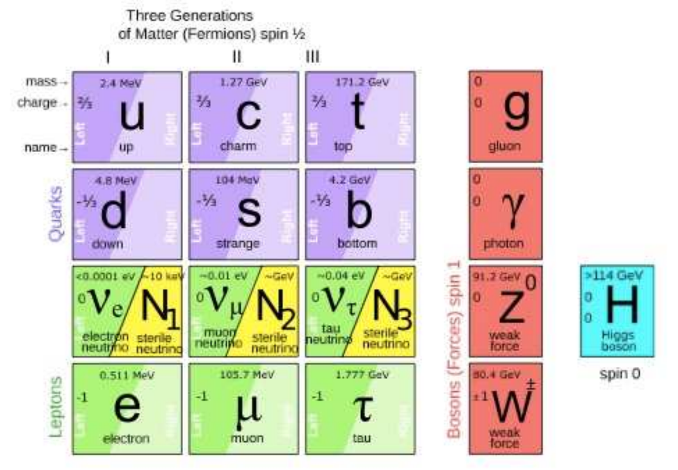
Kosmologietag 2014, Bielefeld

The **Standard Model** and **General Relativity** together explain *almost* all phenomena in nature, but. . .

- gravity is not quantized
- a handful of observations remain unexplained
  - neutrino oscillations
  - baryon asymmetry of the universe
  - dark matter
  - geometry of the universe

Can we probe the New Physics empirically?


Three Generations
of Matter (Fermions) spin ½
I
II
III
mass →
charge →
name →
2.4 MeV
⅔
u
up
1.27 GeV
⅔
c
charm
171.2 GeV
⅔
t
top
4.8 MeV
-⅓
d
down
104 MeV
-⅓
s
strange
4.2 GeV
-⅓
b
bottom
Quarks
0 eV
0
ν_e
electron neutrino
0 eV
0
ν_μ
muon neutrino
0 eV
0
ν_τ
tau neutrino
0.511 MeV
-1
e
electron
105.7 MeV
-1
μ
muon
1.777 GeV
-1
τ
tau
Leptons
Left
Right
0
0
g
gluon
0
0
γ
photon
91.2 GeV
0
Z^0
weak force
80.4 GeV
±1
$W^\pm$
weak force
Bosons (Forces) spin 1
>114 GeV
0
0
H
Higgs boson
spin 0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Neutrino masses: Seesaw mechanism

$$\mathcal{L} = \mathcal{L}_{SM} + i\bar{\nu}_R \partial\!\!\!/ \nu_R - \bar{L}_L F \nu_R \tilde{\Phi} - \bar{\nu}_R F^\dagger L \tilde{\Phi}^\dagger - \frac{1}{2}(\bar{\nu^c}_R M_M \nu_R + \bar{\nu}_R M_M^\dagger \nu_R^c)$$

- Majorana masses M_M introduce new mass scale(s)
- six (Majorana) mass eigenstates
- two sets of mass states with small mixing $\theta \ll 1$
  here $\theta = m_D M_M^{-1} = vFM_M^{-1}$

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  here $\theta = m_D M_M^{-1} = vFM_M^{-1}$
- three light neutrinos $\mathrm{v}_i \simeq U_\nu(\nu_L + \theta\nu_R^c)_i$
  - mostly "active" SU(2) doublet
  - masses $\sim m_\nu = \theta M_M \theta^T$
- three heavy neutrinos $N_I \simeq \nu_R + \theta^T \nu_L^c$
  - mostly "sterile" singlets
  - heavy masses $M_I \sim M_M$

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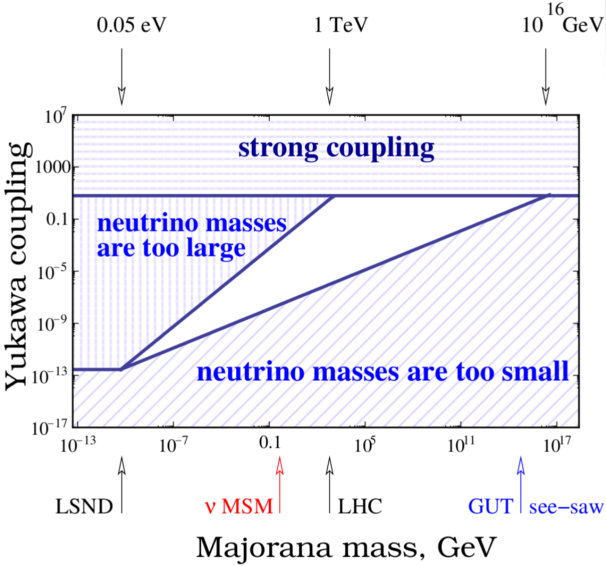

plot from 1204.5379

Leptogenesis

- fermion number violation
  - sphalerons violate B, but conserve $B-L$ at $T > 140$ GeV
  - Yukawa couplings F violate individual lepton flavour numbers
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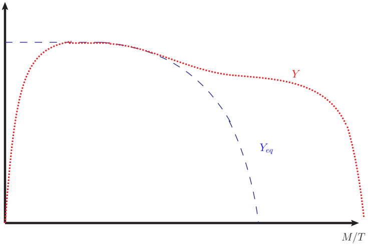
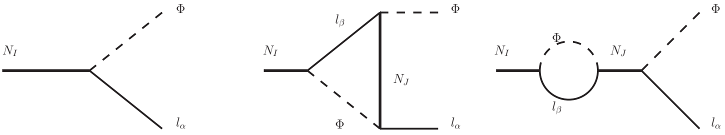
- nonequilibrium
  - N_I production
  - N_I freezeout
  - N_I decay



Leptogenesis during N_I-freezeout/decay

- Majorana fermions N_I can decay into leptons or antileptons
- The probabilities for both decays are different due to the CP-violation in F
- decay violates total lepton number L
- sphalerons convert part of L into B



Fukugita/Yanagida 1986

Leptogenesis during N_I production

- CP-violating oscillations amongst N_I generate $L \neq 0$ during their thermal production
- sphalerons convert part of L into B

Akhmedov/Rubakov/Smirnov 1998, Asaka/Shaposhnikov 2006

- With two RH neutrinos this requires a mass degeneracy $\sim 10^{-3}$

Canetti/MaD/Frossard/Shaposhnikov 1208.4607

- With three RH neutrinos no such degeneracy is needed!

MaD/Garbrecht 1206.5537

Why is 2 RH neutrinos different from 3 RH neutrinos?

- asymmetry is larger if generated at earlier times
  $\Rightarrow$ grows with $|F_{\alpha I}|$ as $\Gamma_I = (F^\dagger F)_{II}\gamma_{av}T$
- but washout rates $\Gamma_\alpha = (FF^\dagger)_{\alpha\alpha}\gamma_{av}T$ also grow with $|F_{\alpha I}|$

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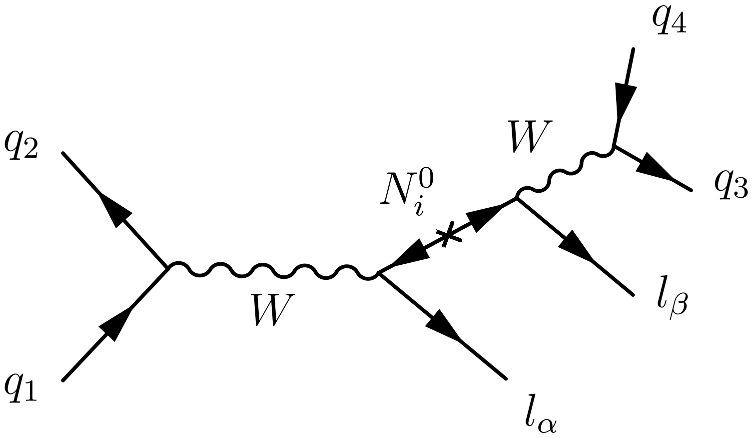
- **two RH neutrinos**:
  N_I-coupling to all flavours governed by only one parameter
    - N_I coupling to different flavours "tied together"
    - large Γ_I necessarily imply large washout for all flavours
    - BAU can only be explained if $|F_{\alpha I}|$ are very small
    - CP-violation must be enhanced by mass degeneracy $\sim 10^{-3}$

- **three RH neutrinos**:
  individual $|F_{\alpha I}|$ can be very different in size
    - flavour asymmetric washout
    - asymmetry in individual flavour(s) can survive in spite of observably large N_I-mixing

Experimental signatures



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- **for** $2\mathrm{GeV} < M_I <$ 5 **GeV** (LHCb, BELLE, SHIP)
  - N_I produced in B-meson decays
  - $B^- \rightarrow N_I \mu^- \rightarrow \pi^+ \mu^- \mu^-$ etc give same sign dilepton signal
    sensitivity $\sim \sqrt{L_{\mathrm{int}}}$
  - BELLE can also do "peak searches" for missing 4-momentum
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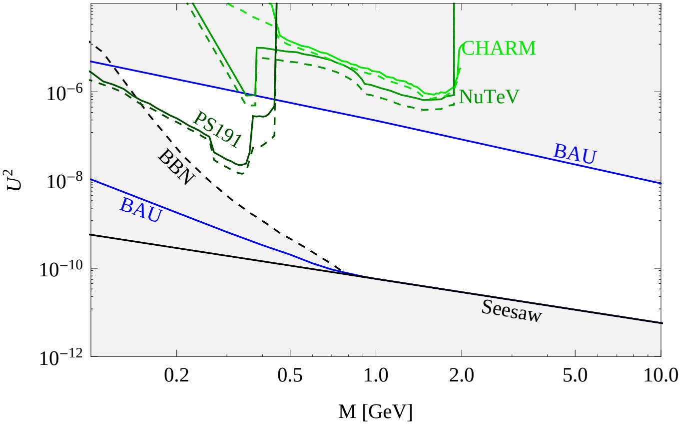
  - BELLE can also do "peak searches" for missing 4-momentum sensitivity $\sim L_{\mathrm{int}}$
- **for** $M_I <$ 2 **GeV** (SHIP)
  - N_I produced in D-meson decays
  - existing bounds very strong $\Rightarrow$ can only be improved by dedicated fixed target experiments

Leptogenesis with two RH neutrinos



$$U^2 \equiv \mathrm{tr}\theta^\dagger\theta$$

Canetti/MaD/Frossard/Shaposhnikov 1208.4607

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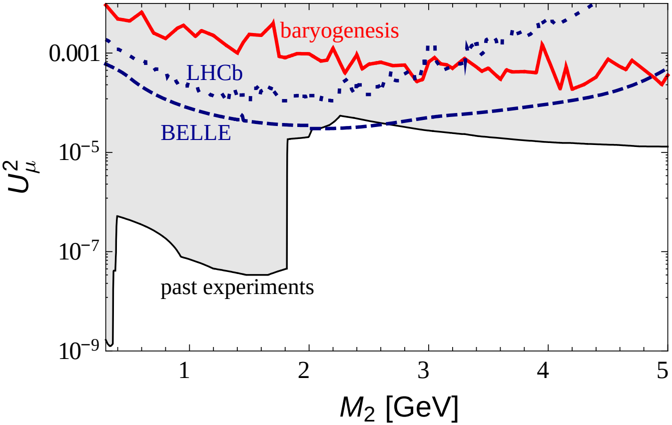
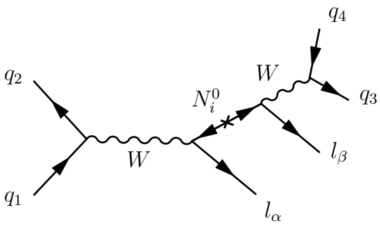
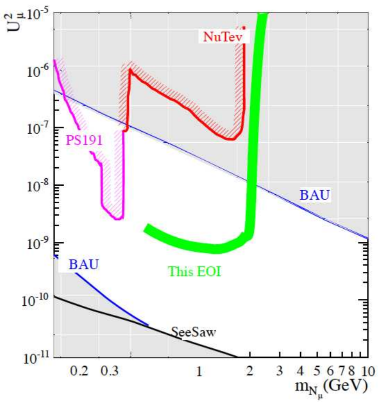


Canetti/MaD/Garbrecht 1404.7114

Probing the origin of matter in the laboratory





	two RH neutrinos	**three RH neutrinos**
baryogenesis	requires mass degeneracy	works without degeneracy
lab searches	SHIP 1310.1762	LHCb, BELLE, SHIP,. . .

Smirnov/Kersten, Atre/Han/Pascoli/Zhang, Canetti/MaD/Shaposhnikov, . . .