WP2: NEUTRINO PHYSICS

Coordinators:

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PRIN 2012
Theoretical Astroparticle Physics
Midterm Review Workshop,
Torino July 9-10 2015

All PRIN nodes working on ν physics aspects

1/3 of publications on neutrinos (~57/164)

3 new PRIN contracts (out of 7) on ν topics

PRIN ν – INFN synergy: TAsP, What Next?

PRIN ν co-organiz.: NOW 2014, TAUP 2015

PRIN ν external collaborations:

Too many to be listed: # comparable to PRIN members ($\approx$ 80)

Expected activities (from PRIN program abstract):

NEUTRINO PHYSICS. All aspects of neutrino physics will be covered in a threefold way. Masses and mixings: theory/phenomenology of neutrino mixing/oscillations (with special care to CP violation and mass hierarchy); neutrinoless beta decay, Dirac/Majorana nature and absolute masses. Cosmology: massive/sterile neutrinos in precision cosmology and primordial nucleosynthesis; generation of neutrino masses and its connection to baryon asymmetry through leptogenesis. Astrophysics: neutrino spectra from the Sun, stars, supernovae, the Earth.

Fully covered by performed activities.

Topics and Highlights →

Masses and mixings – standard 3ν framework

Trieste: PDG 2014 review ➔

14. Neutrino mixing 1

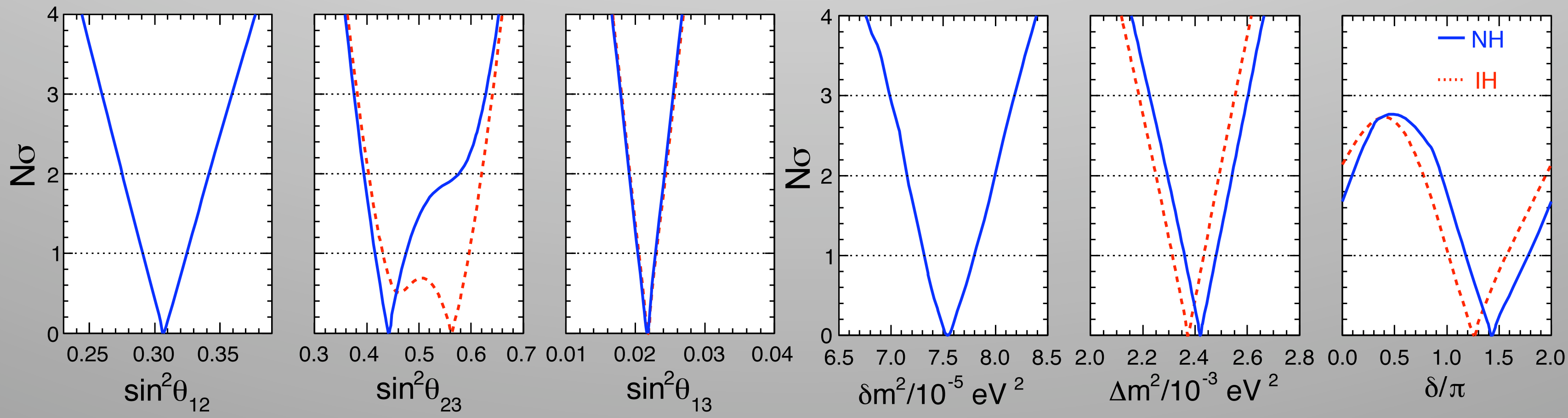
14. NEUTRINO MASS, MIXING, AND OSCILLATIONS

Updated May 2014 by K. Nakamura (Kavli IPMU (WPI), U. Tokyo, KEK), and S.T. Petcov (SISSA/INFN Trieste, Kavli IPMU (WPI), U. Tokyo, Bulgarian Academy of Sciences).

The experiments with solar, atmospheric, reactor and accelerator neutrinos have provided compelling evidences for oscillations of neutrinos caused by nonzero neutrino masses and neutrino mixing. The data imply the existence of 3-neutrino mixing in vacuum. We review the theory of neutrino oscillations, the phenomenology of neutrino mixing, the problem of the nature - Dirac or Majorana, of massive neutrinos, the issue of CP violation in the lepton sector, and the current data on the neutrino masses and mixing parameters. The open questions and the main goals of future research in the field of neutrino mixing and oscillations are outlined.

Bari: Global 3ν osc. analysis ⬇

octant hierarchy CPV



(unstable) (no clue) (hints?)

1312.2878 [hep-ph]

Octant, hierarchy and CPV as discriminators of 3ν models/symmetries

Trieste: systematics of CPV predictions
with current/prospective constraints on osc. param.

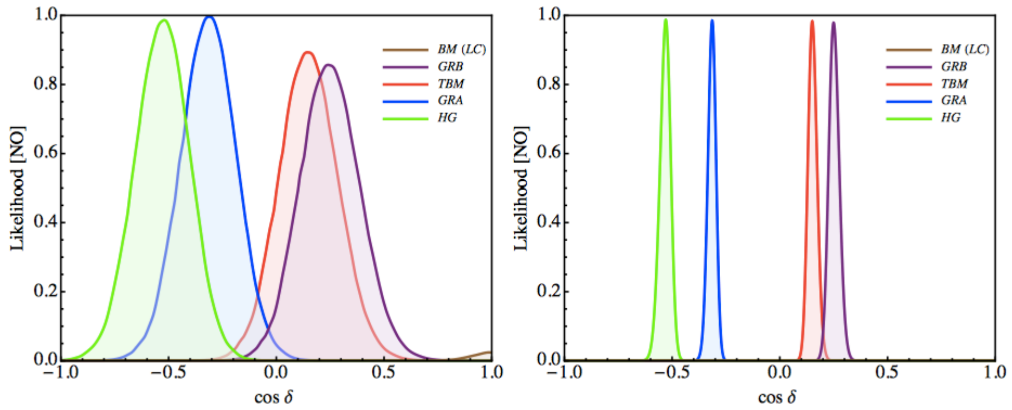
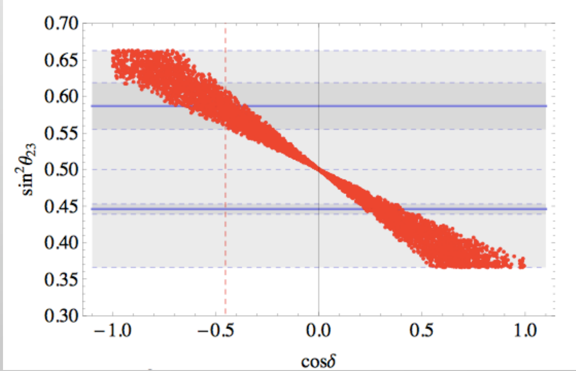
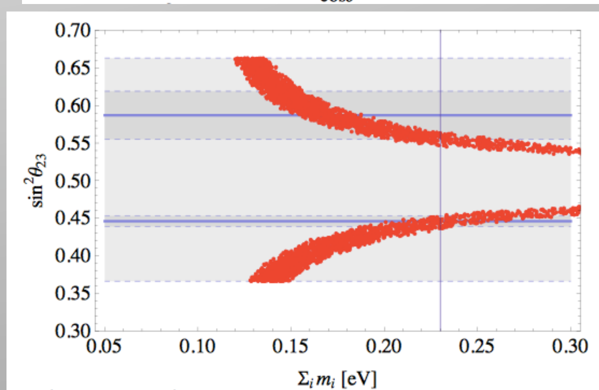


Figure 1: The likelihood function versus $\cos\delta$ for NO neutrino mass spectrum after marginalising over $\sin^2\theta_{13}$ and $\sin^2\theta_{23}$ for the TBM, BM (LC), GRA, GRB and HG symmetry forms of the matrix $\tilde{U}_\nu$ in the $(\theta^e_{13}, \theta^e_{23}) - (\theta^\nu_{23}, \theta^\nu_{12})$ set-up. The results shown are obtained using eq. (45) and i) the latest results on the mixing parameters $\sin^2\theta_{12}$, $\sin^2\theta_{13}$, $\sin^2\theta_{23}$ and δ found in the global analysis of the neutrino oscillation data [11] (left panel), and ii) the prospective 1σ uncertainties on $\sin^2\theta_{12}$, $\sin^2\theta_{13}$, $\sin^2\theta_{23}$ and the Gaussian approximation for the likelihood function (right panel) (see text for further details).

1504.00658 [hep-ph];
see also:
1504.02042 [hep-ph]
1410.8056 [hep-ph]
1405.6006 [hep-ph]
1501.04336 [hep-ph]

Frascati/Rome: param. correlations
under textures or discrete simmetries





1401.3207 [hep-ph];
see also:
1408.7118 [hep-ph]

More on theory/models: links of low-E ν physics with leptogenesis (LG)

Frascati/Rome: LG in SO(10)

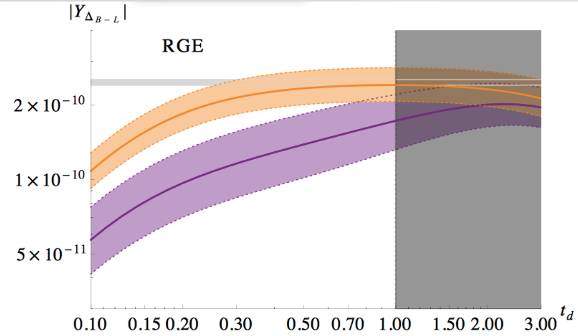


Figure I. *The B-L asymmetry produced with the MN-RGE data set of ref. [1] plotted as a function of t_d. The horizontal grey band represents the experimental limit, the orange curve depicts the asymmetry generated via $N_j \to H\ell_\alpha$ decays alone, while the purple band includes also the $N_j \to \Delta e^c_\alpha$ decays. The width of the orange and purple bands correspond to a 3% variations in the N_j masses.*

1412.4776 [hep-ph]

Trieste: LG in SU(5)xA_5

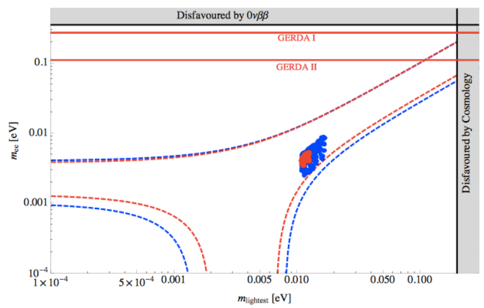


Figure 5: Prediction for the effective neutrino mass m_{ee} accessible in neutrinoless double beta decay experiments as a function of the lightest neutrino mass m_1. The allowed experimental 3σ (1σ) regions for the masses and mixing angles in the case of normal ordering are limited by blue (red) dashed lines. Blue (red) points are in agreement within 3σ (1σ) of the low energy neutrino masses and mixings and Y_B in our model. The grey region on the right side shows the bounds on the lightest mass from cosmology [20] and the grey region in the upper part displays the upper bound on the effective mass from the EXO experiment [22]. The red, straight lines represent the sensitivity of GERDA phase I respectively GERDA phase II [23].

1502.00110 [hep-ph]

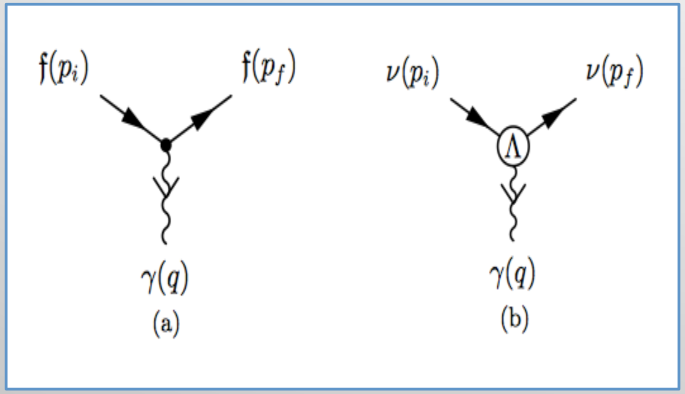
Salerno: LG in f(R) grav.

(generalizing Starobinsky Model)

PRD 90, 064050 (2014)

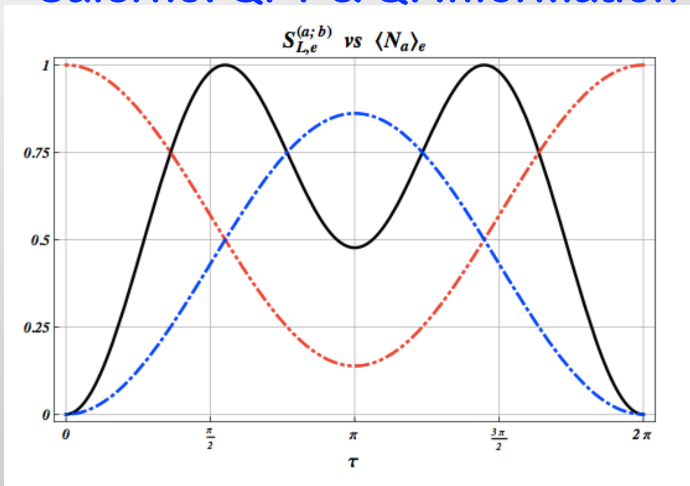
More on theory/models: other links of low-E ν physics with QFT/BSM

Turin: neutrino EM properties



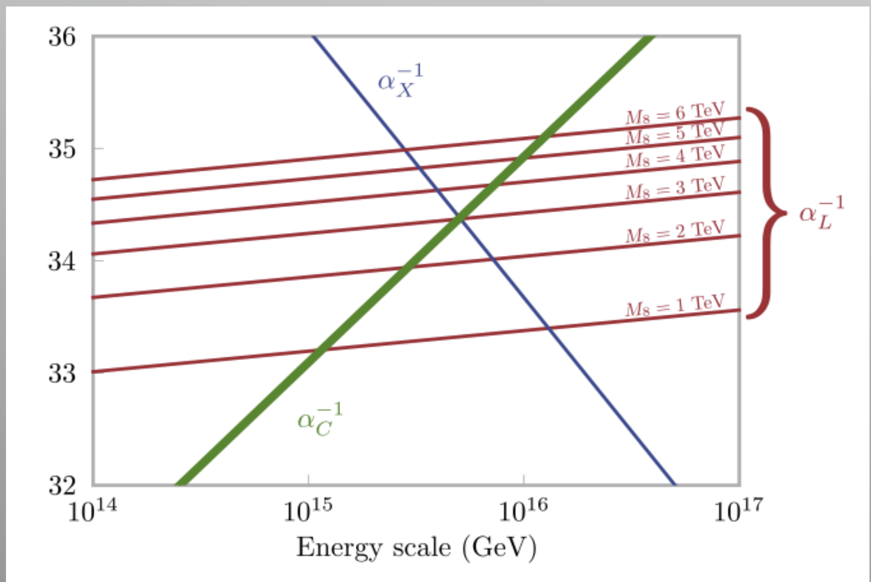
1403.6344 [hep-ph]

Salerno: QFT & Q. Information



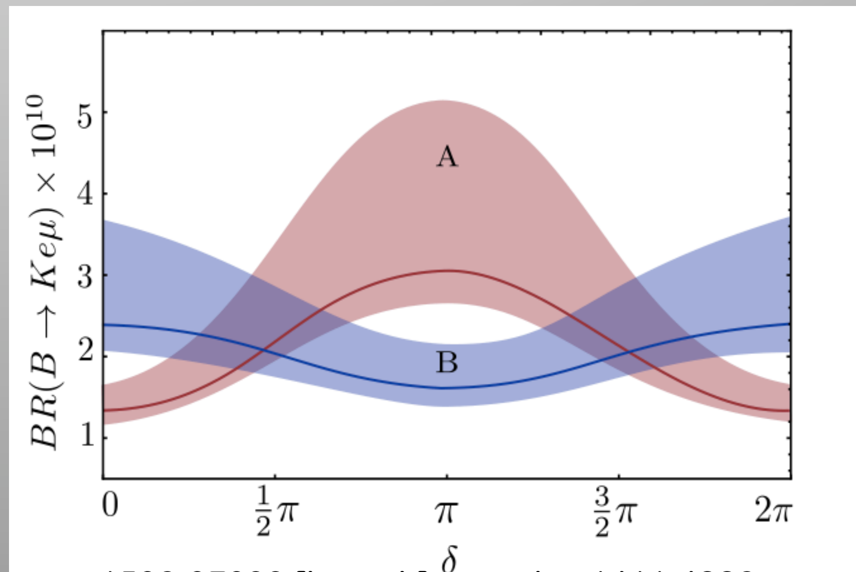
1401.7793 [quant-ph]

Frascati: gauge coupling unif.



1411.0566 [hep-ph]

Frascati: CPV(ν) ←→ CPV(q)



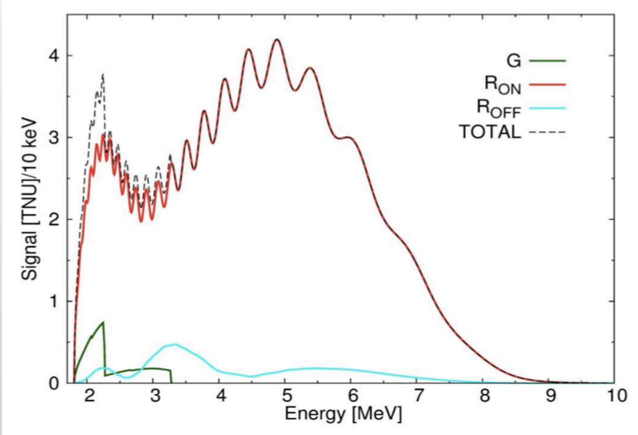
1503.07099 [hep-ph]; see also 1411.4883

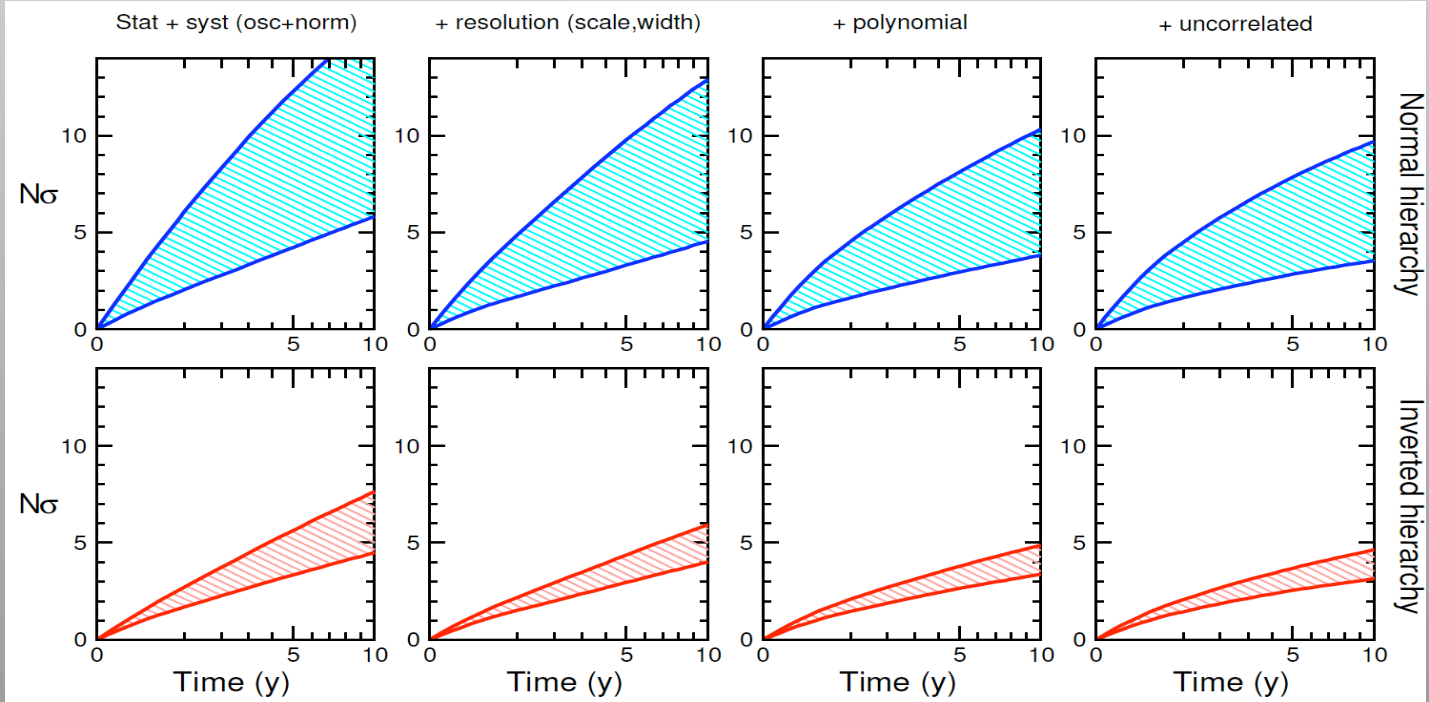
Back to standard 3ν framework: sensitivity to mass hierarchy

Ferrara: reactors (JUNO) ➔

Bari: atmospheric (PINGU) ➔

1412.3324 [physics.geo-ph]

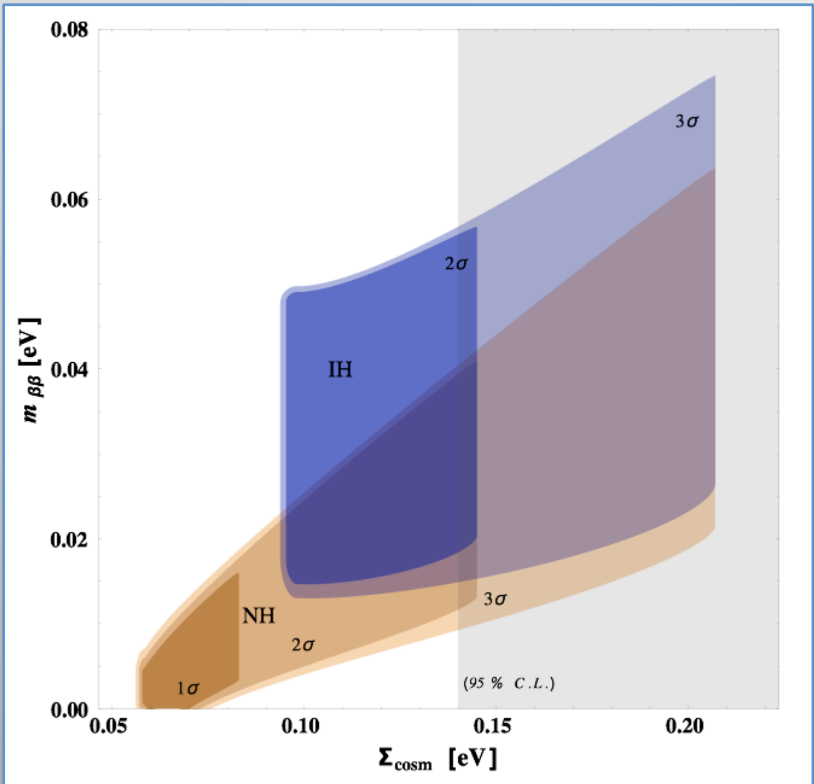




1503.01999 [hep-ph]

Back to standard 3ν framework: Neutrinoless double beta decay

Gran Sasso: ~1σ preference for NH



1505.02722 [hep-ph]

Turin: Review on particle/nuclear aspects

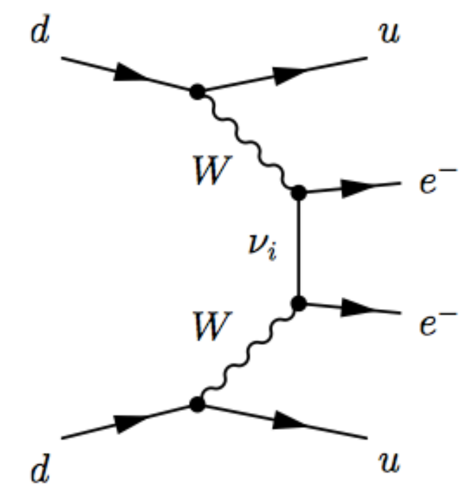
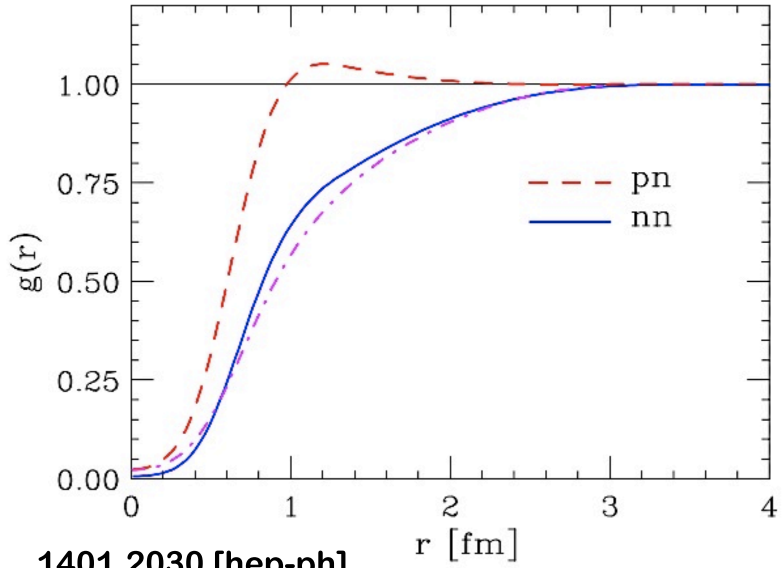


Figure 3: Feynman diagram of the transition $dd \to uue^-e^-$ which induces $\beta\beta_{0\nu}$ decay.

1411.4791 [hep-ph]

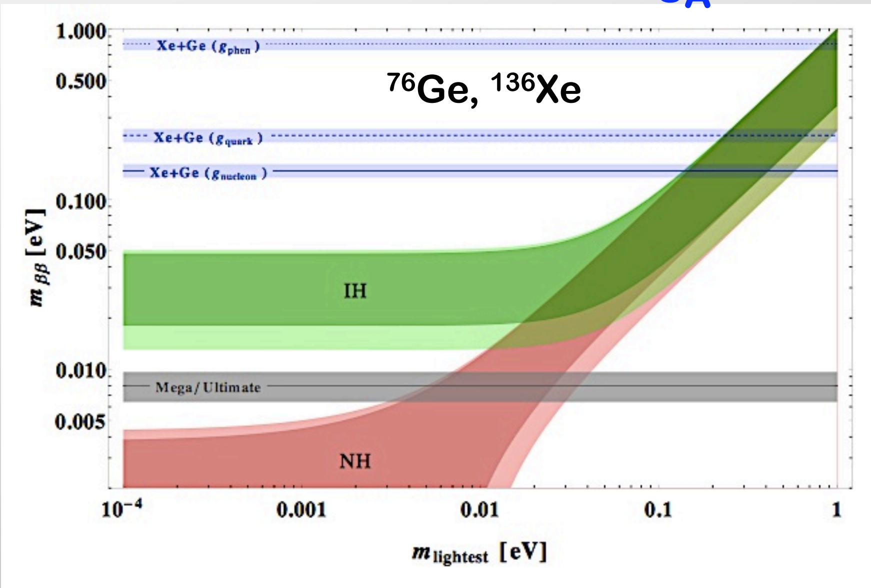
Neutrinoless ββ decay: implications of nuclear uncertainties

Rome: N-N correlations



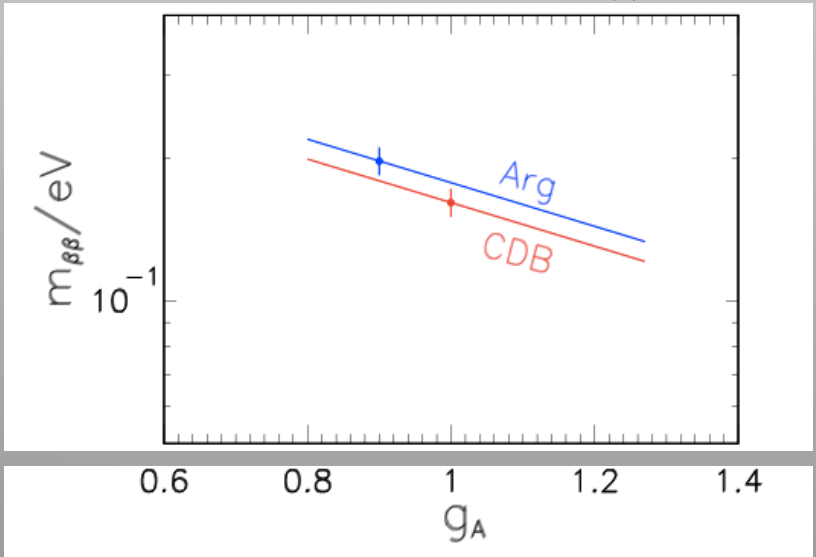
1401.2030 [hep-ph]

Gran Sasso: effective $g_A < 1$



1404.2616 [hep-ph]

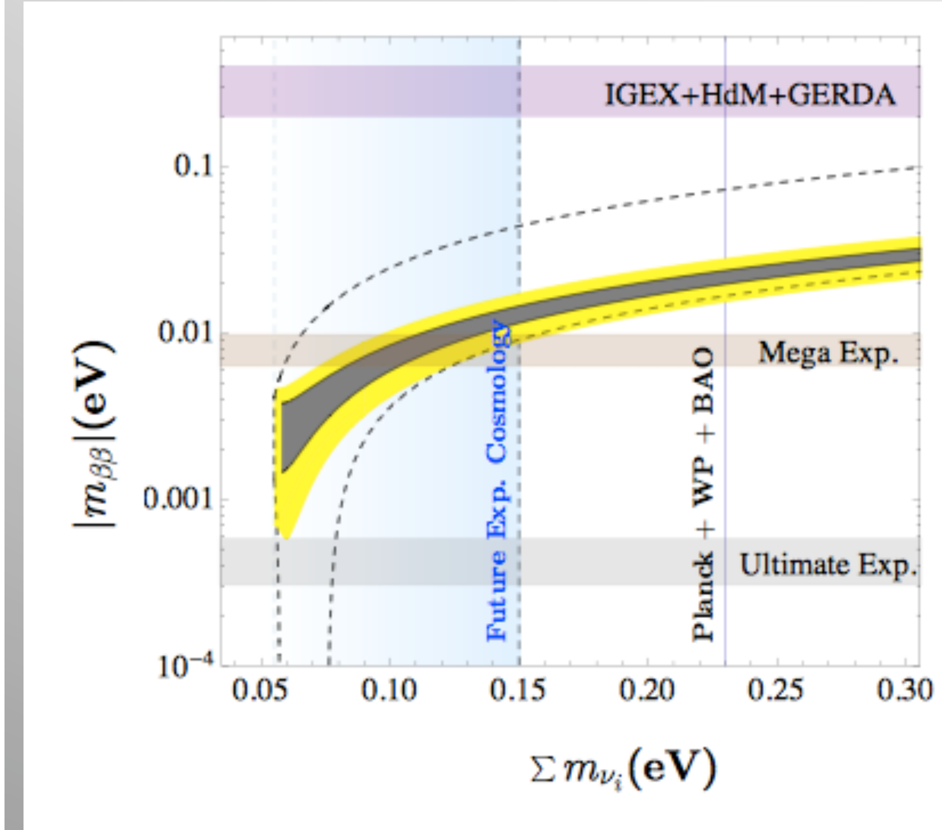
Bari: N-N corr. and $g_A < 1$



1506.04058 [hep-ph]

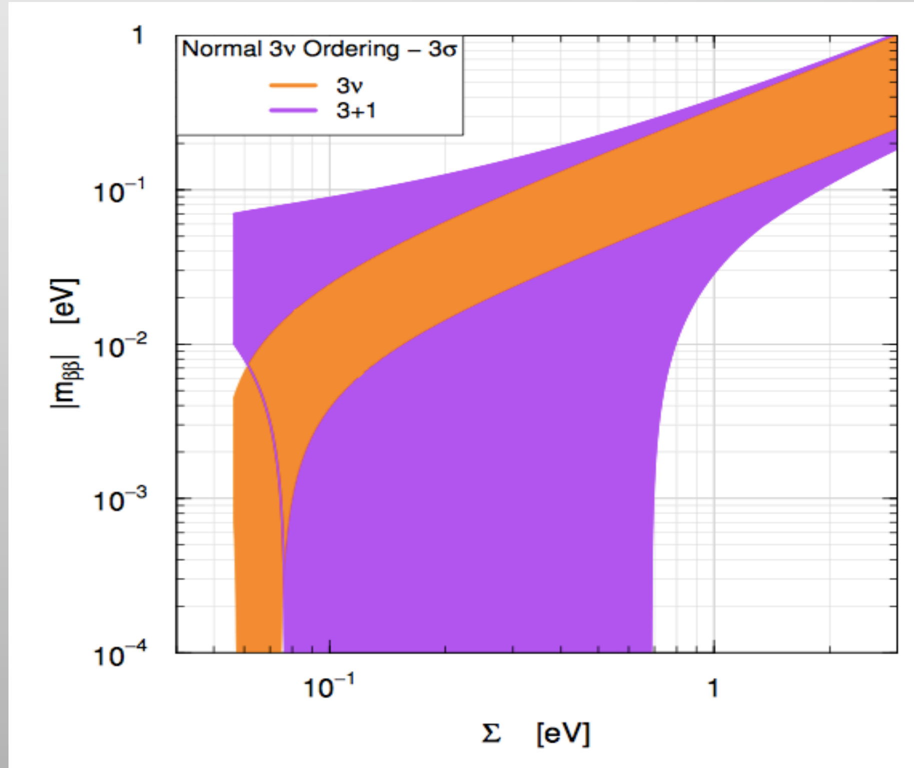
Neutrinoless ββ decay: particle physics mechanism variants

Rome/Frascati: pseudo-Dirac ν
(“less phase space”)



1406.3990 [hep-ph]

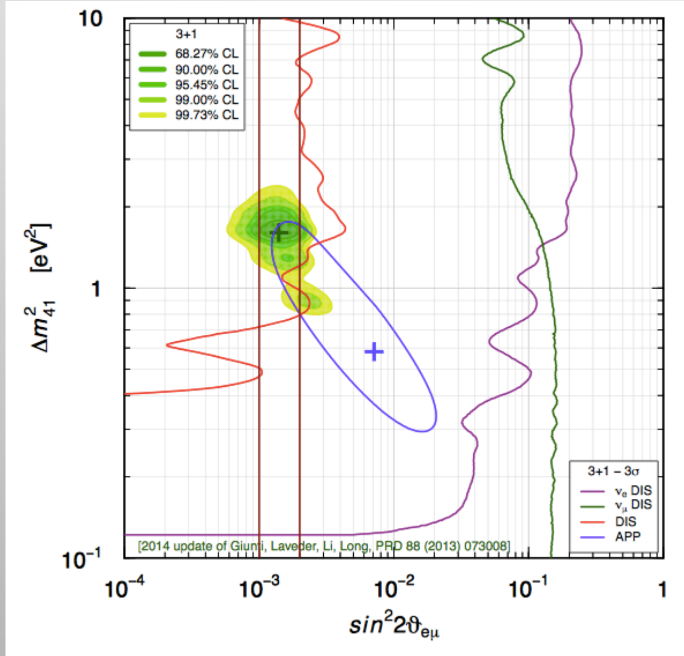
Turin: additional sterile ν
(“more phase space”)

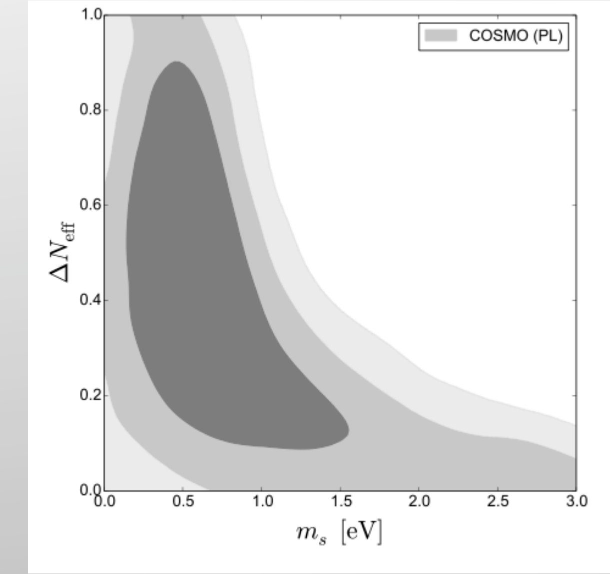


1505.00978 [hep-ph]

Light sterile neutrinos: “standard” phenomenology

Turin/Padua: light ν_S review MPLA 30 (2015) 1530015





some tension between SBL appearance/disappearance

Naples

some tension between SBL and cosmological data

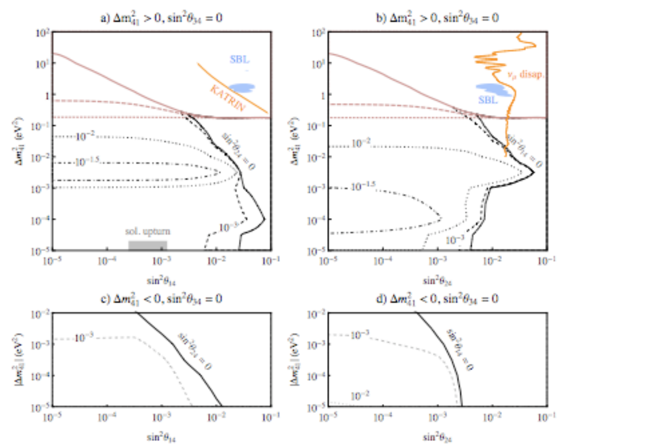


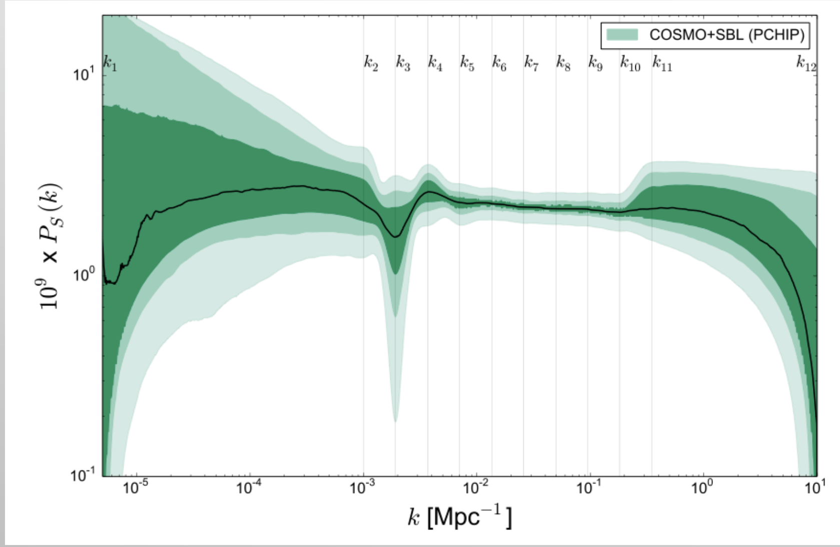
FIG. 3: Active normal mass hierarchy NH. Exclusion plots for the active-sterile neutrino mixing parameter space for SNH (upper panels) and SIH (lower panels) cases from N_{eff} (black curves) and $\Omega_\nu h^2$ (red curves) at 95 % C.L. The contours refer to different values of $\sin^2\theta_{i4}$: $\sin^2\theta_{i4} = 0$ (continuous curves), $\sin^2\theta_{i4} = 10^{-3}$ (dashed curves), $\sin^2\theta_{i4} = 10^{-2}$ (dotted curves), $\sin^2\theta_{i4} = 10^{-1.5}$ (dot-dashed curves). (see the text for details).

see also 1404.1794 [astro-ph.CO]

Ways out ? →

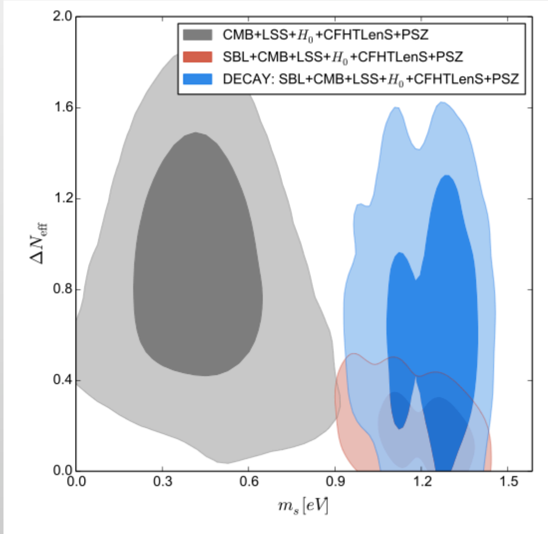
Light sterile neutrinos + "nonstandard" physics/cosmology

Padua/Turin: ν_S + inflationary freedom...



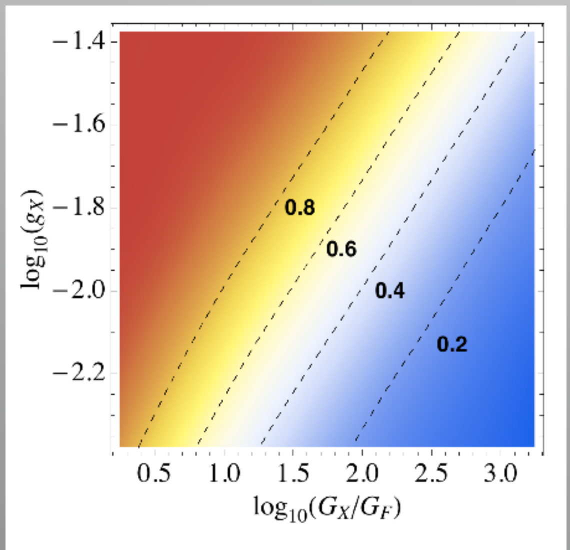
1412.7405 [astro-ph.CO]

... or ν_S + neutrino decay



1404.6160 [astro-ph.CO]

Naples/Bari: ν_S + secret interactions



1409.1680
[astro-ph.CO]

1410.1385
[hep-ph]

See also:

Turin: ν_S + MOND
1407.1207 [astro-ph.CO]

Trieste: ν_S + atomic rad. emission
1411.7459 [hep-ph]

Trieste: ν_S + low-scale see-saw
1406.2961 [hep-ph]
1311.2614 [hep-ph]

Naples+Bari: ν_S + chemical potential
1206.1046 [hep-ph]

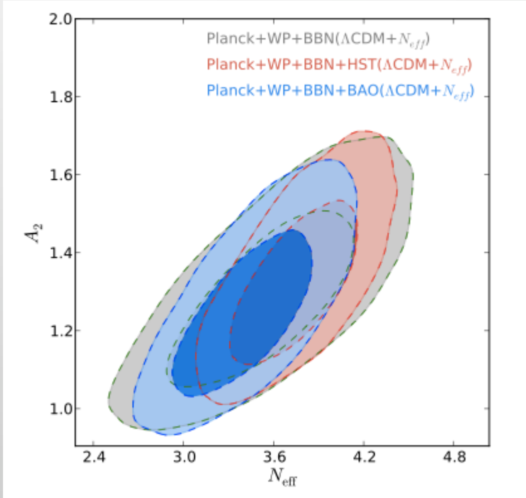
Back to "standard" neutrinos & cosmology

Rome: Planck (+other) constraints

Parameter	Planck+WP	Planck+WP+HST
$\Omega_b h^2$	0.02215 ± 0.00050	0.02260 ± 0.00033
$\Omega_c h^2$	0.1222 ± 0.0068	0.1273 ± 0.0056
θ	1.0405 ± 0.0010	1.0408 ± 0.0011
τ	0.094 ± 0.015	0.099 ± 0.015
n_s	0.966 ± 0.021	0.987 ± 0.012
$log[10^{10} A_s]$	3.115 ± 0.035	3.122 ± 0.037
H_0[km/s/Mpc]	68.7 ± 3.9	72.5 ± 2.2
$N_{\rm eff}$	3.26 ± 0.48	3.70 ± 0.30
α^{NID}	-0.0031 ± 0.0053	0.0002 ± 0.0031

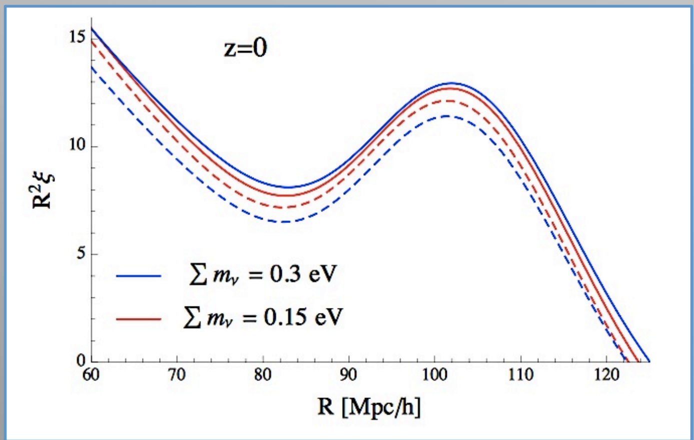
1405.5418 [astro-ph.CO]

Rome/Naples: Planck vs BBN



1404.7848 [astro-ph.CO]

Padua/Trieste: massive ν and BAO



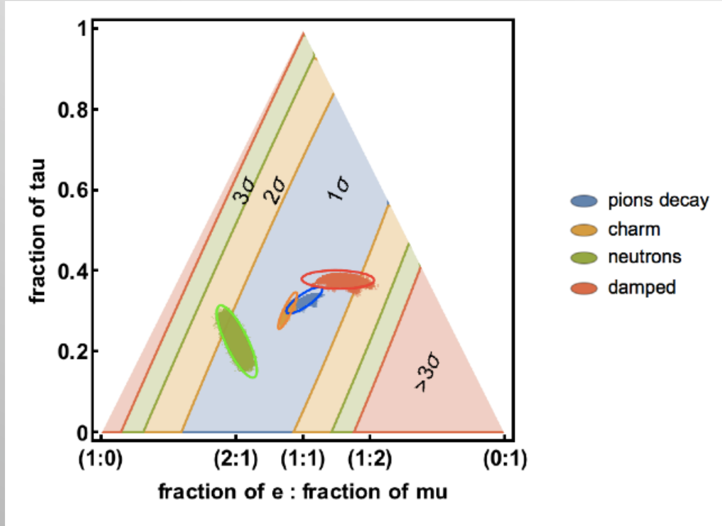
1505.07477 [astro-ph.CO]

See also:

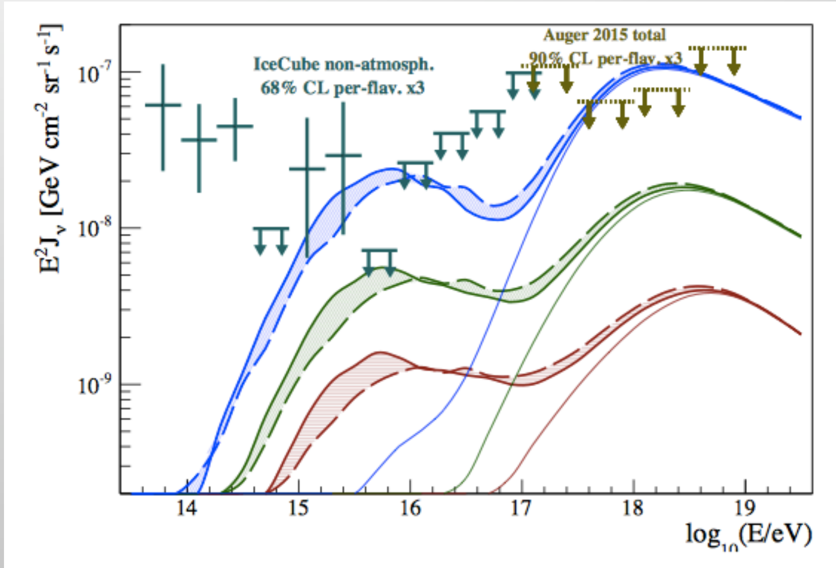
Rome: relic neutrinos and axions
1403.4852 [astro-ph.CO]

From cosmology to astrophysics: Neutrinos as probes of their sources

L'Aquila/Gran Sasso: Icecube HE events and their flavor composition



L'Aquila/Gran Sasso: Icecube HE events and cosmogenic ν fluxes



1504.05238 [hep-ph]
1502.02923 [astro-ph.HE]

for ν decay, see also
1506.02624 [hep-ph]

1505.04020 [astro-ph.HE]

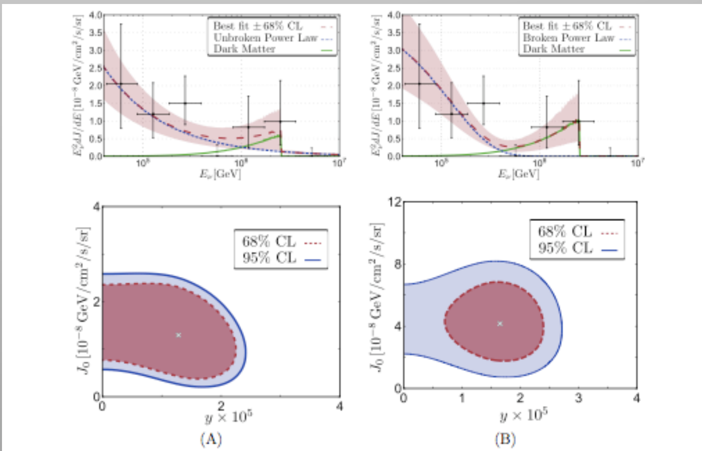


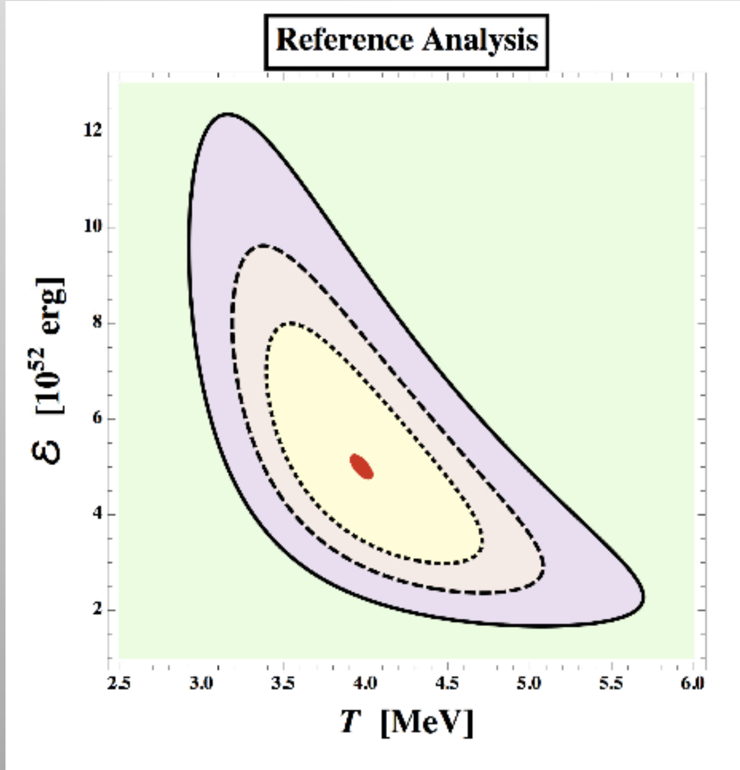
Figure 1. Results of the analysis for model 1). First row shows the differential neutrino flux as a function of the energy for the DM + UPL (column A) and DM+BPL (column B) models. The red (long-dashed) line is the best fit for the total neutrino flux of Eq. (5.1), and its band represents the 68% C.L. resulting from the fit. The blue (dashed) and green (solid) lines are the astrophysical and DM contributions to the total neutrino flux, respectively. The black points are the IC data of Ref. [5]. In the second row we report the 68% C.L. (dashed) and 95% C.L. (solid) contours for the two parameters y and J_0 corresponding to DM + UPL (column A) and DM+BPL (column B). The crosses are the best-fit points.

Naples: Icecube HE from DM decays

1507.01000 [hep-ph]

From cosmology to astrophysics: Neutrinos as probes of their sources

L'Aquila/Gran Sasso: SN 1987A, reanalysis of data



1409.4710 [astro-ph.HE]

for future observations, see also
1402.6953 [astro-ph.SR]

Bari/Naples: collective effects of SN neutrinos and their instabilities

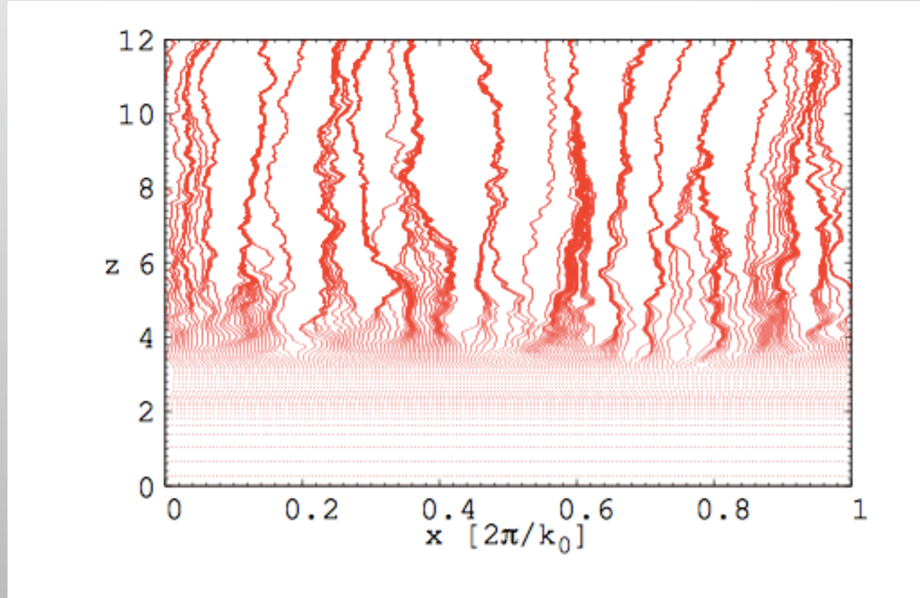


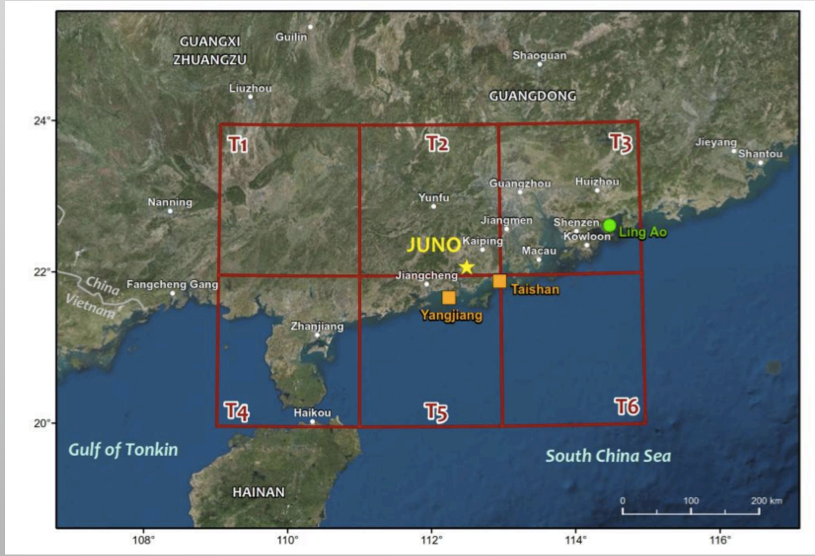
FIG. 4: Streamlines of the ν_e flux (in vertical direction).

1503.03485 [hep-ph]

see also:
effects of inhomegeneities,
1403.1892 [hep-ph];
effects of turbulence,
1310.7488 [astro-ph.SR]

From cosmology to astrophysics: Neutrinos as probes of their sources

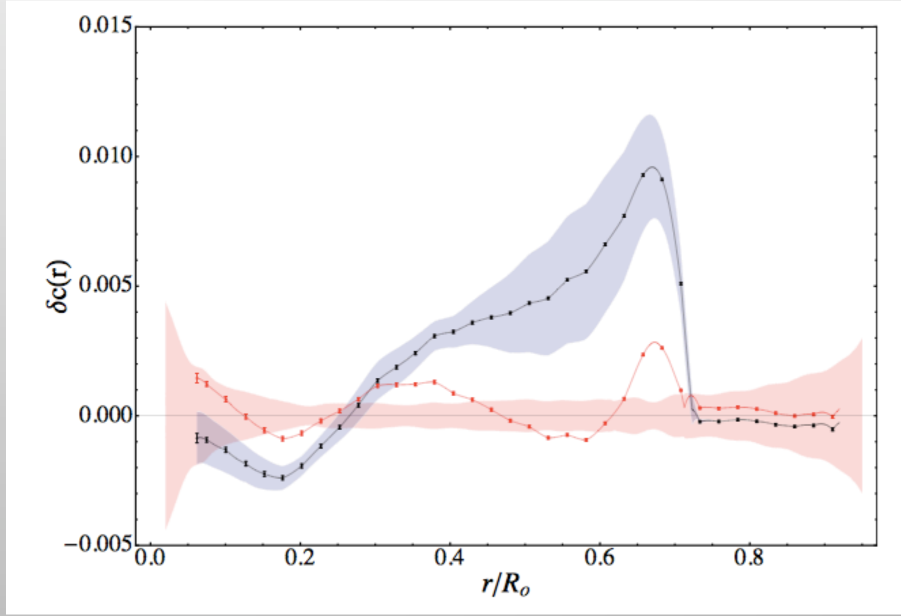
Ferrara: geo-neutrinos as probes of the Earth's crust and mantle



1412.3324 [physics.geo-ph] (JUNO)
1404.6692 [physics.geo-ph] (SNO+)

see also: world reactor background,
1411.6457 [physics.ins-det]

L'Aquila: solar neutrinos as probes of the Sun's interior



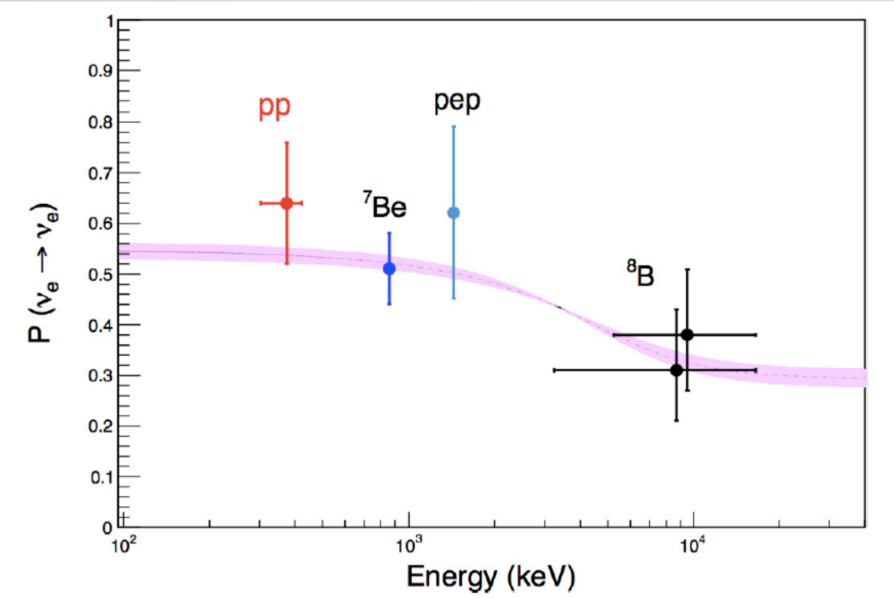
1312.3885 [astro-ph.SR]
1410.2796 [hep-ph] (eeCNO flux)

see also: solar axion bounds,
150101639 [astro-ph.SR]

Involvement in experimental projects & data analyses

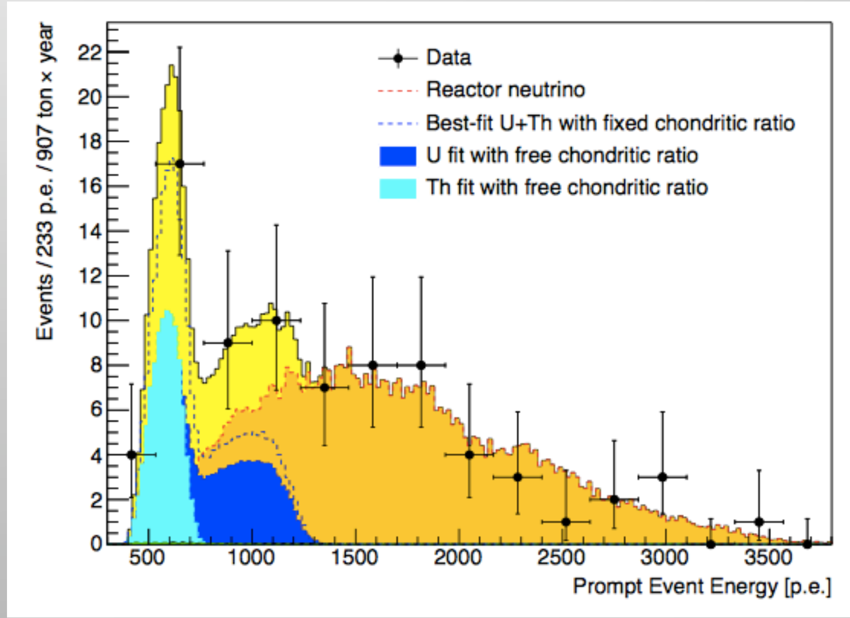
Ferrara: Borexino

2014 :1st direct solar pp ν observation



Nature 512 (2014) 7515

2015: >5σ geo-ν detection



1506.04610 [hep-ex]

Rome: Planck (dedicated talk later)

H.E.S.S.; Fermi, PTOLEMY R&D on CNB detection

Activity till today

- All topics of the initial proposal addressed;
- Multidisciplinary activity;
- Strong interactions with experimental activities;
- Many collaboration with external members/institutions ongoing;
- PRIN-INFN synergy.

Perspectives – hot/new topics ?

A personal choice of key issues

- ν mass scale, CPV, Majorana vs. Dirac;
- DM - ν relations;
- ν sources (and anomalies) – Cosmology;
- Strong link with experiments;
- Further promote internal node collaboration
  → meetings on specific topics (see What Next INFN strategy).