Stefano Gariazzo

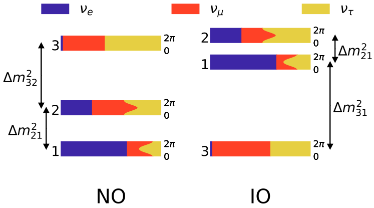
IFIC, Valencia (ES)
CSIC – Universitat de Valencia

gariazzo@ific.uv.es
http://ific.uv.es/~gariazzo/

Horizon 2020
European Union funding
for Research & Innovation

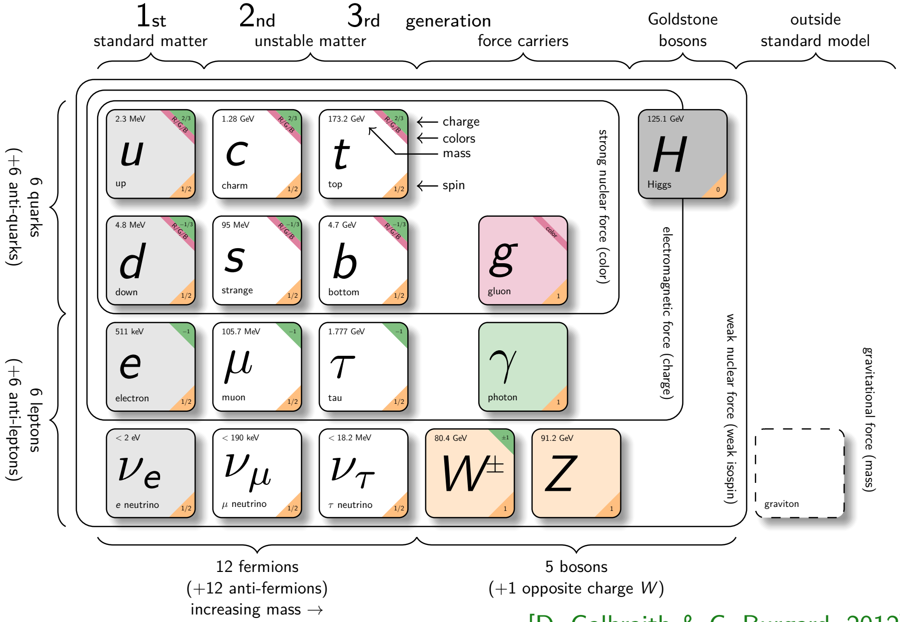
Theoretical introduction to neutrino masses

Tematic afternoon on neutrino masses, Sapienza Univ. (online), 8/07/2020



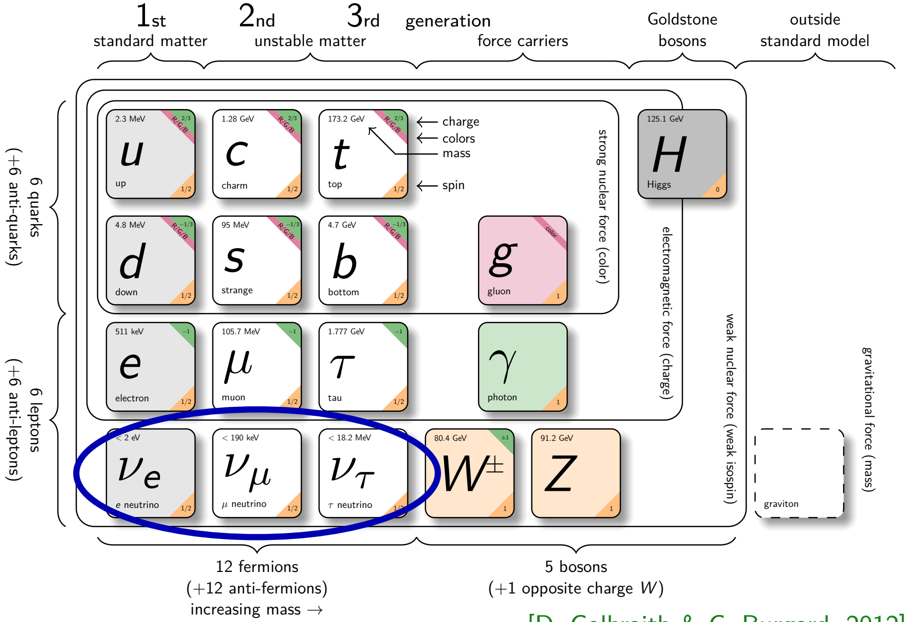
νe
νμ
ντ
3
2
1
Δm²32
Δm²21
Δm²31
2π
0
NO
IO

The Standard Model of Particle Physics



[D. Galbraith & C. Burgard, 2012]

The Standard Model of Particle Physics

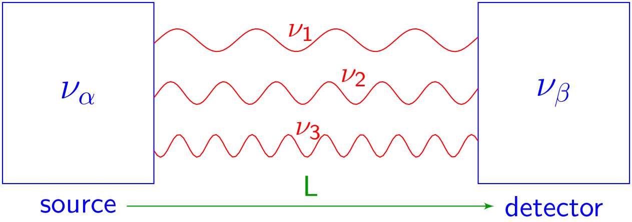


[D. Galbraith & C. Burgard, 2012]

Two neutrino bases

flavor neutrinos ν_α | $|\nu_\alpha\rangle = \sum_k U_{\alpha k}|\nu_k\rangle$ | massive neutrinos ν_k

$$|\nu(t=0)\rangle = |\nu_\alpha\rangle = U_{\alpha 1}|\nu_1\rangle + U_{\alpha 2}|\nu_2\rangle + U_{\alpha 3}|\nu_3\rangle$$



$$|\nu(t>0)\rangle = |\nu_\beta\rangle = U_{\alpha 1}\, e^{-iE_1 t}|\nu_1\rangle + U_{\alpha 2}\, e^{-iE_2 t}|\nu_2\rangle + U_{\alpha 3}\, e^{-iE_3 t}|\nu_3\rangle \neq |\nu_\alpha\rangle$$

$E_k^2 = p^2 + m_k^2 \longleftarrow$ define $\longrightarrow t = L$

$$P_{\nu_\alpha \to \nu_\beta}(L) = |\langle \nu_\alpha | \nu(L)\rangle|^2 = \sum_{k,j} U_{\beta k} U^*_{\alpha k} U^*_{\beta j} U_{\alpha j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E}\right)$$

$$\Delta m^2_{ij} = m_i^2 - m_j^2$$

Three Neutrino Oscillations

$$\nu_\alpha = \sum_{k=1}^{3} U_{\alpha k} \nu_k \quad (\alpha = e, \mu, \tau)$$

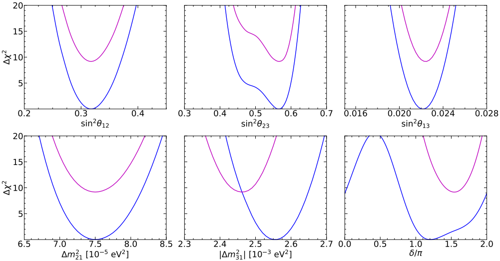
$U_{\alpha k}$ described by 3 mixing angles θ_{12}, θ_{13}, θ_{23} and one CP phase δ

Current knowledge of the 3 active ν mixing: [arxiv:2006.11237]

NO/NH: Normal Ordering/Hierarchy, $m_1 < m_2 < m_3$ IO/IH: Inverted O/H, $m_3 < m_1 < m_2$

$$\begin{aligned}
\Delta m^2_{21} &= (7.50^{+0.22}_{-0.20}) \cdot 10^{-5}\ \mathrm{eV}^2 \\
|\Delta m^2_{31}| &= (2.56^{+0.03}_{-0.04}) \cdot 10^{-3}\ \mathrm{eV}^2\ (\mathrm{NO}) \\
&= (2.46 \pm 0.03) \cdot 10^{-3}\ \mathrm{eV}^2\ (\mathrm{IO})
\end{aligned}$$

$$\begin{aligned}
10 \sin^2(\theta_{12}) &= 3.18 \pm 0.16 \\
10^2 \sin^2(\theta_{13}) &= 2.225^{+0.055}_{-0.078}\ (\mathrm{NO}) \\
&= 2.250^{+0.056}_{-0.076}\ (\mathrm{IO}) \\
10 \sin^2(\theta_{23}) &= 5.66^{+0.16}_{-0.22}\ (\mathrm{NO}) \\
&= 5.66^{+0.18}_{-0.23}\ (\mathrm{IO})
\end{aligned}$$



$$\begin{aligned}
\delta/\pi &= 1.20^{+0.23}_{-0.14}\ (\mathrm{NO}) \\
&= 1.54 \pm 0.13\ (\mathrm{IO})
\end{aligned}$$

see also: `http://globalfit.astroparticles.es`

Neutrinos and their masses

[de Salas+, Frontiers 5 (2018) 36]

Normal ordering (NO)

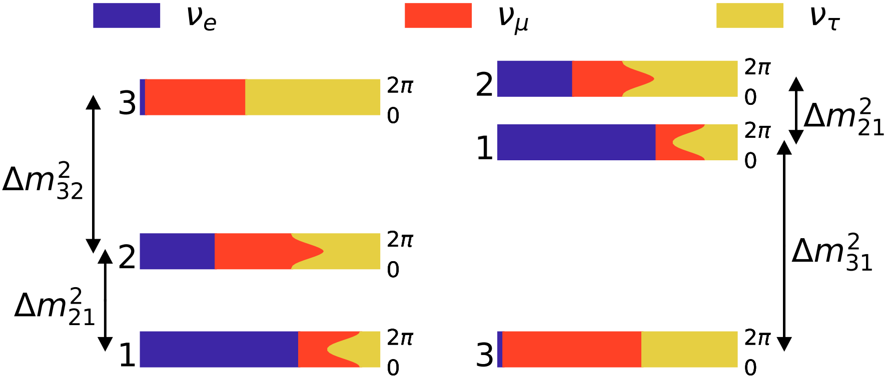
$m_1 < m_2 < m_3$

$\sum m_k \gtrsim 0.06$ eV

Inverted ordering (IO)

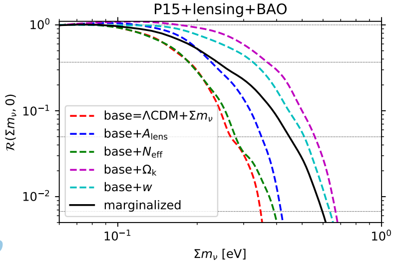
$m_3 < m_1 < m_2$

$\sum m_k \gtrsim 0.1$ eV



Absolute scale unknown!

Can we constrain the mass ordering using bounds on $\sum m_\nu$?

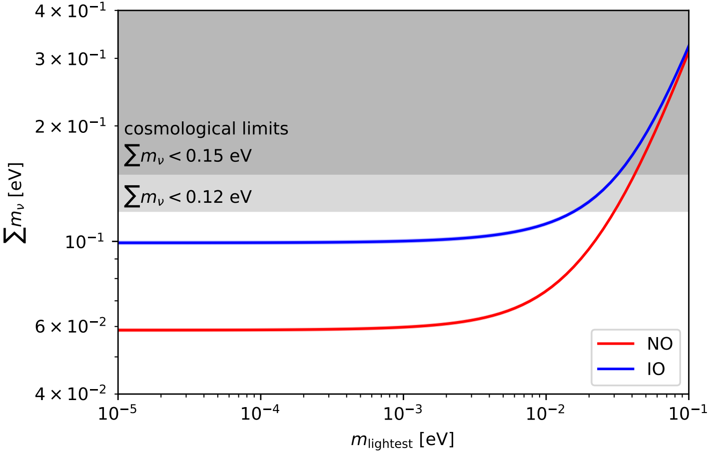

P15+lensing+BAO
$\mathcal{R}(\Sigma m_\nu, 0)$
Σm_ν [eV]
base=ΛCDM+Σm_ν
base+$A_{\rm lens}$
base+$N_{\rm eff}$
base+Ω_k
base+w
marginalized

From cosmology...

[de Salas+, Frontiers 5 (2018) 36]

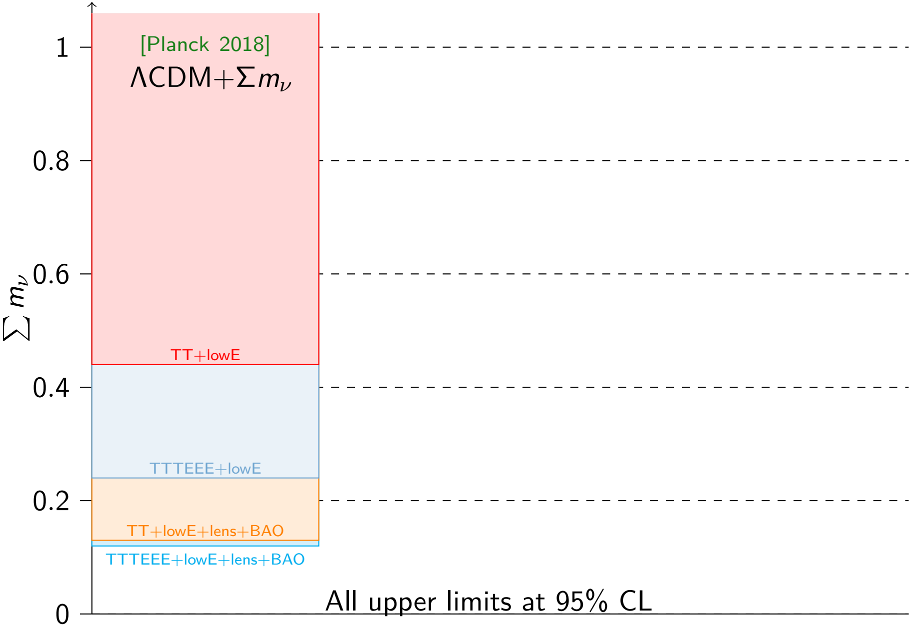
Warning: model dependent content!

How the limit change when considering extensions of the ΛCDM model?

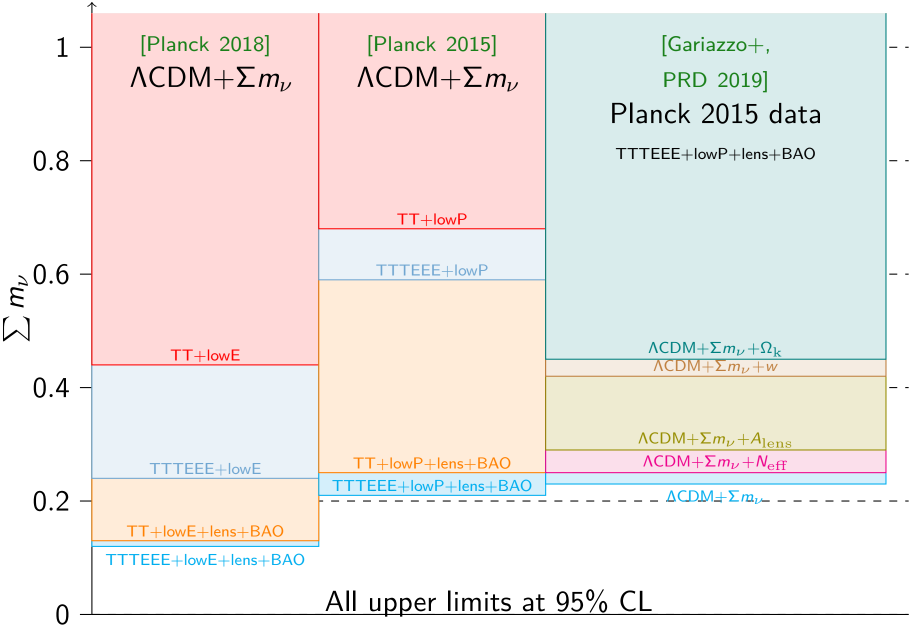


Warning: $\sum m_\nu \lesssim 0.1$ eV at 95% CL
does not mean IO disfavored at 95% CL!

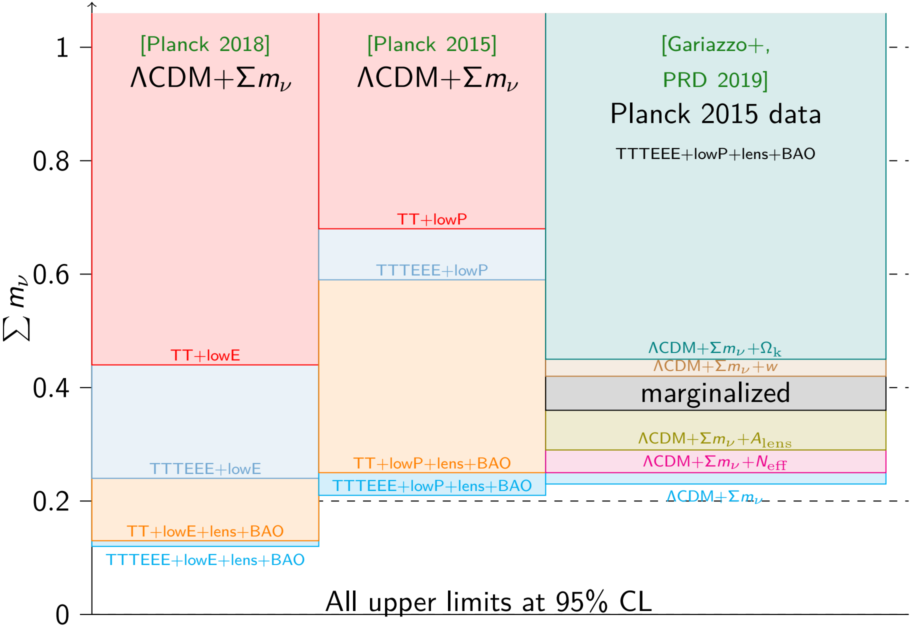
Cosmological neutrino mass bounds



Cosmological neutrino mass bounds



Cosmological neutrino mass bounds



Playing with priors

Bayes theorem:

$$p(\theta|d,\mathcal{M}) = \mathcal{L}(\theta)\frac{\pi(\theta|\mathcal{M})}{Z_{\mathcal{M}}}$$

posterior depends on prior!

parameters θ, model $\mathcal{M}$, data d $\pi(\theta|\mathcal{M})$ prior $p(\theta|d,\mathcal{M})$ posterior $\mathcal{L}(\theta)$ likelihood $Z_{\mathcal{M}}$ Bayesian evidence

Playing with priors

Bayes theorem:

$$p(\theta|d,\mathcal{M}) = \mathcal{L}(\theta)\frac{\pi(\theta|\mathcal{M})}{Z_\mathcal{M}}$$

posterior depends on prior!

[Planck 2018]: prior
$0 < \Sigma m_\nu < \mathcal{O}(1)$ eV

strongest upper limit (95%):
$\Sigma m_\nu < 113$ meV
(CMB+lens+BAO+SN)

corresponding to
$\Sigma m_\nu < 53.6$ meV (68%)

below minimum for NO!
does it make sense?

parameters θ, model $\mathcal{M}$, data d $\pi(\theta|\mathcal{M})$ prior $p(\theta|d,\mathcal{M})$ posterior $\mathcal{L}(\theta)$ likelihood $Z_\mathcal{M}$ Bayesian evidence

Playing with priors

Bayes theorem:

$$p(\theta|d,\mathcal{M}) = \mathcal{L}(\theta)\frac{\pi(\theta|\mathcal{M})}{Z_{\mathcal{M}}}$$

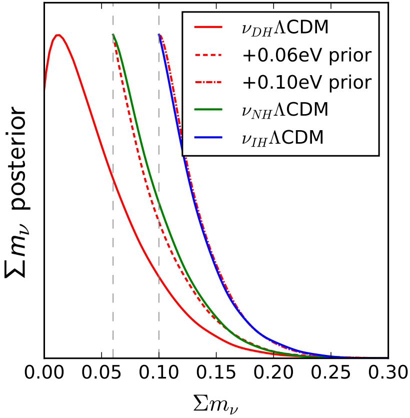
posterior depends on prior!

[Wang+, 2017]

degenerate (DH)
vs normal (NH)
vs inverted (IH) hierarchy

(i.e. change the prior lower bound)

Different limits if you consider simply $\Sigma m_\nu > 0$ or you take into account oscillation results...



parameters θ, model $\mathcal{M}$, data d $\pi(\theta|\mathcal{M})$ prior $p(\theta|d,\mathcal{M})$ posterior $\mathcal{L}(\theta)$ likelihood $Z_{\mathcal{M}}$ Bayesian evidence

An example with Planck 2018

[SG, EPJC 80 (2020)]

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Numerically easy to compute: fix $\pi(x)$, get $p(x|d)$ normally and divide

An example with Planck 2018

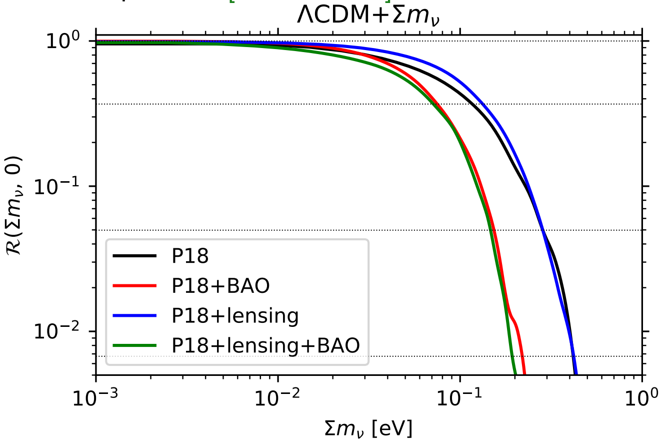
[SG, EPJC 80 (2020)]

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Numerically easy to compute: fix $\pi(x)$, get $p(x|d)$ normally and divide

Example with [Planck 2018] chains from PLA



An example with Planck 2018

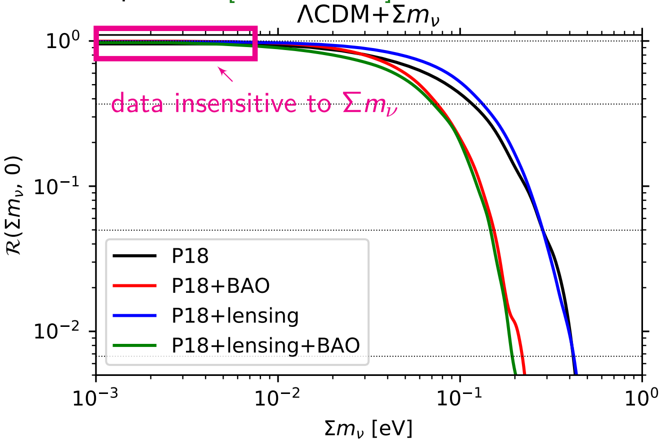
[SG, EPJC 80 (2020)]

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Numerically easy to compute: fix $\pi(x)$, get $p(x|d)$ normally and divide

Example with [Planck 2018] chains from PLA



An example with Planck 2018

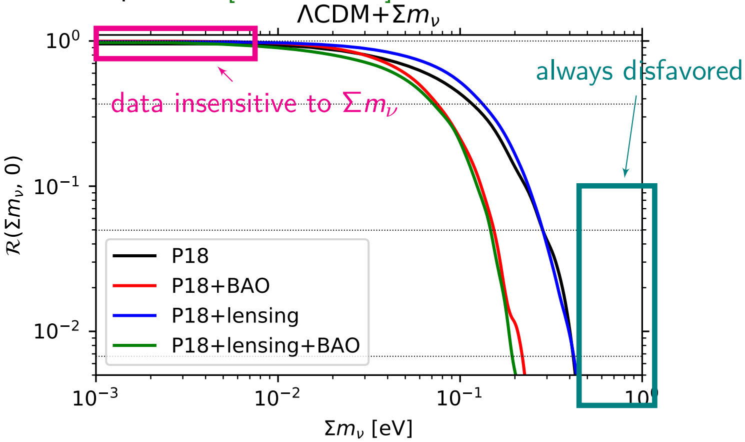
[SG, EPJC 80 (2020)]

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Numerically easy to compute: fix $\pi(x)$, get $p(x|d)$ normally and divide

Example with [Planck 2018] chains from PLA



An example with Planck 2018

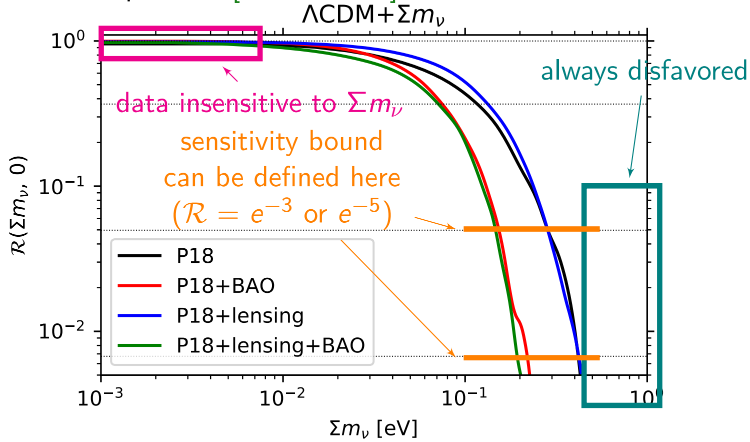
[SG, EPJC 80 (2020)]

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Numerically easy to compute: fix $\pi(x)$, get $p(x|d)$ normally and divide

Example with [Planck 2018] chains from PLA

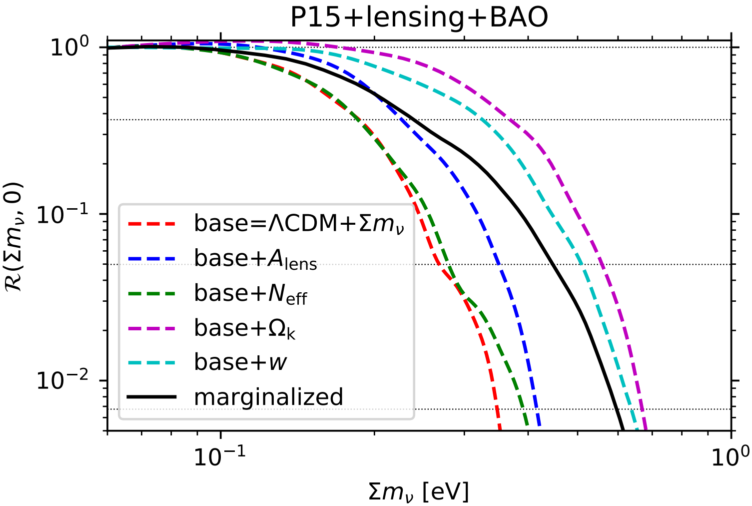


A model-marginalized example

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Example with [Planck 2015] chains from [SG+, PRD 99 (2019) 021301]

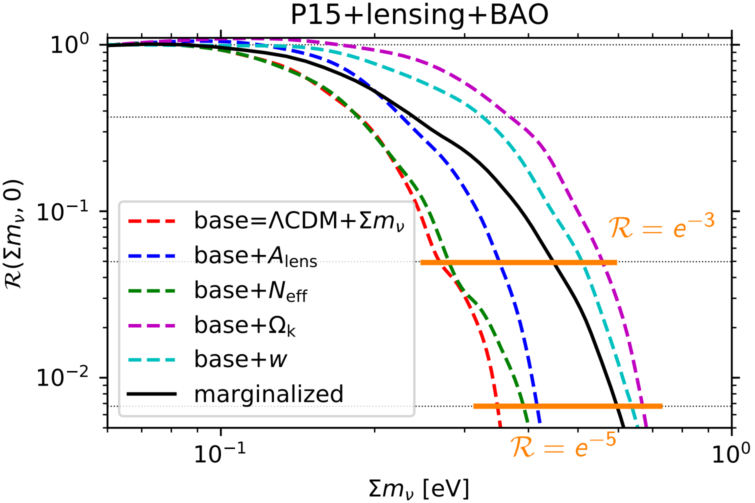


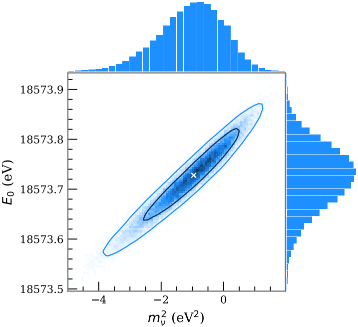
A model-marginalized example

relative belief updating ratio

$$\mathcal{R}(x, x_0|d) \equiv \frac{p(x|d)/\pi(x)}{p(x_0|d)/\pi(x_0)}$$

Example with [Planck 2015] chains from [SG+, PRD 99 (2019) 021301]




18573.9
18573.8
18573.7
18573.6
18573.5
E_0 (eV)
−4
−2
0
m_ν^2 (eV^2)

β decay

$$\beta \text{ decay: } \mathcal{N}(A,Z) \longrightarrow \mathcal{N}(A,Z+1) + e^- + \bar{\nu}_e$$

$$Q_\beta = M_i - M_f - m_e$$

total available energy

$$E_\nu = Q_\beta - T = Q_\beta - (E_e - m_e)$$

neutrino energy

notice that max electron energy is:

$$T_{\mathrm{max}} = Q_\beta - m_{\bar{\nu}_e}$$

β decay

β decay: $\mathcal{N}(A, Z) \longrightarrow \mathcal{N}(A, Z+1) + e^- + \bar{\nu}_e$

$$Q_\beta = M_i - M_f - m_e$$

total available energy

$$E_\nu = Q_\beta - T = Q_\beta - (E_e - m_e)$$

neutrino energy

notice that max electron energy is:

$$T_{\rm max} = Q_\beta - m_{\bar{\nu}_e}$$

Kurie function: (degenerate ν masses)

$$K(T) = \left[(Q_\beta - T)\sqrt{(Q_\beta - T)^2 - m^2_{\bar{\nu}_e}}\right]^{1/2}$$

Useful to describe the e^- spectrum near the endpoint

notice: flavor neutrinos have no definite mass!

β decay

$$\beta \text{ decay: } \mathcal{N}(A,Z) \longrightarrow \mathcal{N}(A,Z+1) + e^- + \bar{\nu}_e$$

$$Q_\beta = M_i - M_f - m_e$$

total available energy

$$E_\nu = Q_\beta - T = Q_\beta - (E_e - m_e)$$

neutrino energy

notice that max electron energy is:

$$T_{\rm max} = Q_\beta - m_{\bar{\nu}_e}$$

Kurie function: (degenerate ν masses)

$$K(T) = \left[(Q_\beta - T)\sqrt{(Q_\beta - T)^2 - m^2_{\bar{\nu}_e}}\right]^{1/2}$$

Useful to describe the e^- spectrum near the endpoint

notice: flavor neutrinos have no definite mass!

$$m^2_{\bar{\nu}_e} = \sum |U_{ei}|^2 m_i^2$$

Full expression:

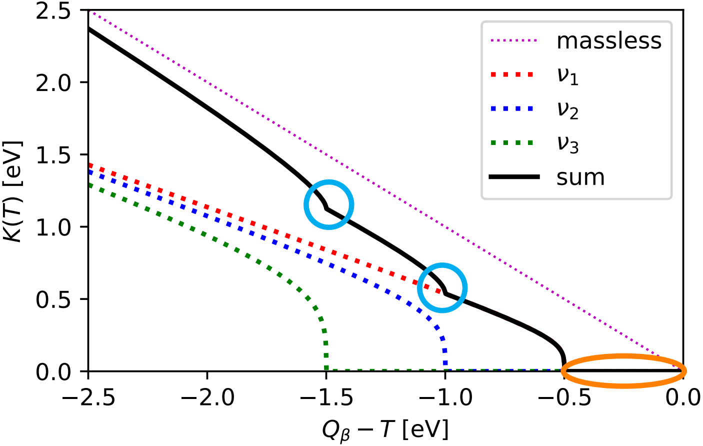
$$K(T) = \left[(Q_\beta - T)\sum_{i=1}^{N_\nu} |U_{ei}|^2 \sqrt{(Q_\beta - T)^2 - m_i^2}\right]^{1/2}$$

N_ν neutrinos with different masses m_i

mixing angles enter ($|U_{ei}|^2$)

β decay

$$K(T) = \left[(Q_\beta - T) \sum_{i=1}^{N_\nu} |U_{ei}|^2 \sqrt{(Q_\beta - T)^2 - m_i^2} \right]^{1/2}$$



Fake case:
3 neutrinos

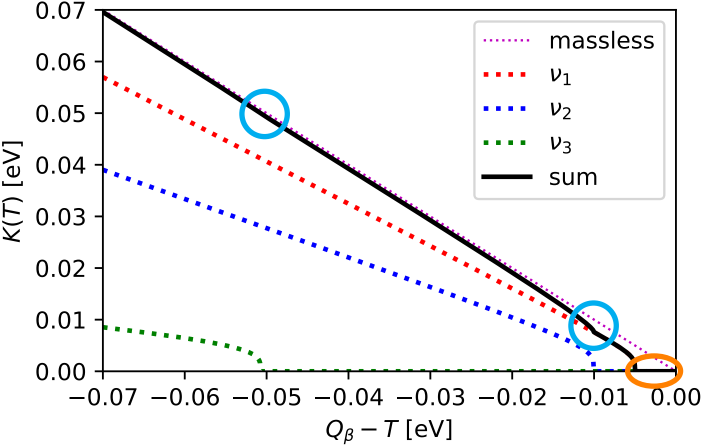
masses:
$m_i = i \cdot 0.5$ eV,

mixings:
$|U_{ei}|^2 = 1/3$

endpoint shifted + one kink for each mass eigenstate

β decay

$$K(T) = \left[(Q_\beta - T) \sum_{i=1}^{N_\nu} |U_{ei}|^2 \sqrt{(Q_\beta - T)^2 - m_i^2} \right]^{1/2}$$



Realistic case:
3 neutrinos, normal ordering

masses: $m_i = [5, 10, 51]$ meV,

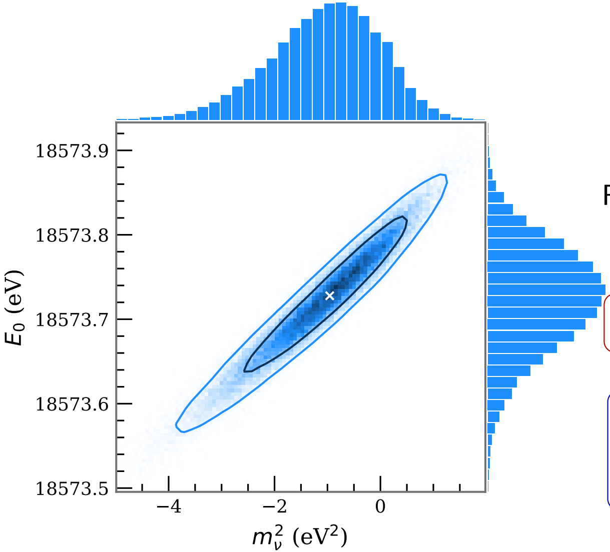
mixings: $|U_{ei}|^2 = [0.67, 0.31, 0.02]$

Much harder to see the endpoint shift and kinks!

KATRIN results

[KATRIN, PRL 123 (2019)]

strongest bound on $m_\nu (\equiv m_{\bar{\nu}_e})$ are from KATRIN



$m_\nu^2 = -1.0^{+0.9}_{-1.1}$ eV^2

Upper limit 90%:

$m_\nu < 1.1$ eV

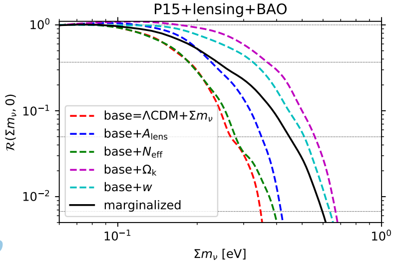
Feldman-Cousins 90%:

$m_\nu < 0.8$ eV

statistics dominated!

expected final sensitivity (90%):

$m_\nu \lesssim 0.2$ eV


P15+lensing+BAO
$\mathcal{R}(\Sigma m_\nu, 0)$
Σm_ν [eV]
base=ΛCDM+Σm_ν
base+A_{lens}
base+N_{eff}
base+Ω_k
base+w
marginalized

Neutrino masses from neutrinoless double β decay

(if neutrino is Majorana)

[Schechter&Valle, 1982]

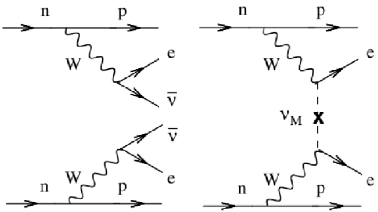
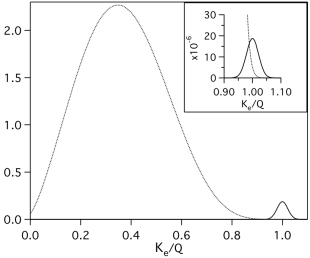
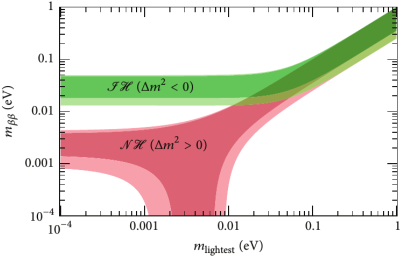


figure from [NEXT] webpage





[Dell'Oro et al., 2016]

Measure $T^{0\nu}_{1/2}$

m_e electron mass,
$G_{0\nu}$ phase space,
$\mathcal{M}'^{\nu}$ matrix element

convert into $m_{\beta\beta} = \dfrac{m_e}{\mathcal{M}'^{\nu}\sqrt{G_{0\nu}\,T^{0\nu}_{1/2}}}$

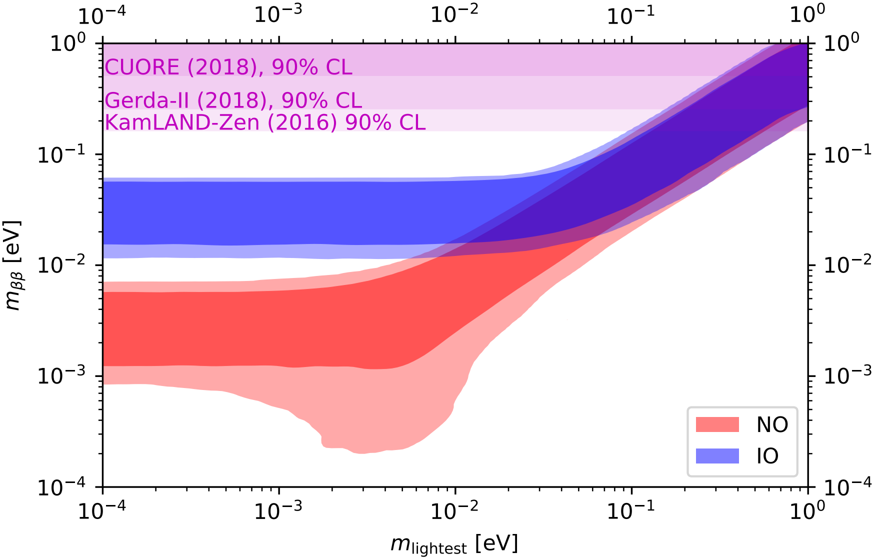
α_k Majorana phases

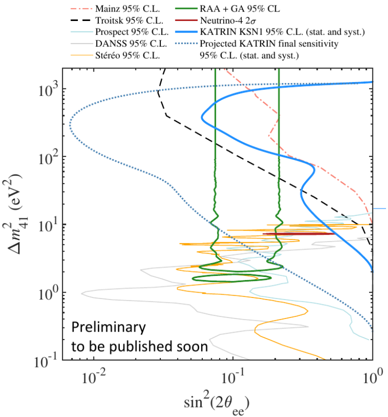
and then use $m_{\beta\beta} = \left|\sum_k e^{i\alpha_k}\,U^2_{ek}\,m_k\right|$

Constraints on $m_{\beta\beta}$

[de Salas+, Frontiers 5 (2018) 36]

$$m_{\beta\beta} = \left| \sum_k e^{i\alpha_k} U_{ek}^2 m_k \right|$$




Mainz 95% C.L.
Troitsk 95% C.L.
Prospect 95% C.L.
DANSS 95% C.L.
Stéréo 95% C.L.
RAA + GA 95% CL
Neutrino-4 2σ
KATRIN KSN1 95% C.L. (stat. and syst.)
Projected KATRIN final sensitivity 95% C.L. (stat. and syst.)
Preliminary
to be published soon
Δm²₄₁ (eV²)
sin²(2θee)

A large family

In principle, previous discussion is valid for N neutrinos

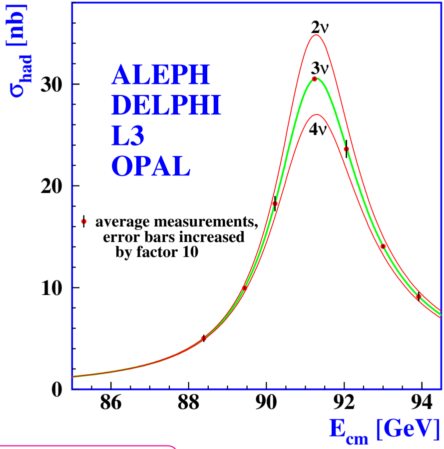
only constraint: there are exactly three flavor neutrinos in the SM

[LEP, Phys. Rept. 427 (2006) 257, arXiv:hep-ex/0509008]

$$N_\nu^{(Z)} = 2.9840 \pm 0.0082$$

through the measurement of the Z resonance

$$e^+e^- \longrightarrow Z \longrightarrow \sum_{a=e,\mu,\tau} \nu_a \bar{\nu}_a$$



neutrinos $\alpha > 3$ must be sterile

sterile neutrino = SM singlet: no couplings with other SM particles

A large family

In principle, previous discussion is valid for N neutrinos

$N \times N$ mixing matrix, N flavor neutrinos, N massive neutrinos

$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \\ |\nu_{s_1}\rangle \\ \ldots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & \vdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} & \\ \ldots & & & & \ddots \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \\ |\nu_4\rangle \\ \ldots \end{pmatrix}$$

A large family

In principle, previous discussion is valid for N neutrinos

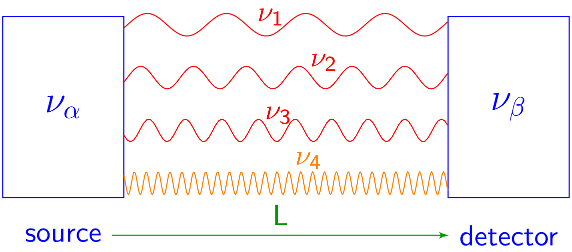
$N \times N$ mixing matrix, N flavor neutrinos, N massive neutrinos

$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \\ |\nu_{s_1}\rangle \\ \dots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & \vdots \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} & \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} & \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} & \\ \dots & & & & \ddots \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \\ |\nu_4\rangle \\ \dots \end{pmatrix}$$

Our case will be 3 (active)+1 (sterile), a perturbation of 3 neutrinos case

$m_4 \gg m_\ell$
$\ell = 1, 2, 3$

$\Delta m^2_{41} \simeq 1\ \mathrm{eV}^2 \simeq \Delta m^2_{42} \simeq \Delta m^2_{43}$



6 angles

3 Dirac CP phases

3 Majorana CP phases

3+1 Neutrino Model

new $\Delta m^2_{SBL} \Rightarrow$ 4 neutrinos!

$\downarrow$

ν_4 with $m_4 \simeq 1$ eV,
no weak interactions

$\downarrow$

light sterile neutrino (LSν)

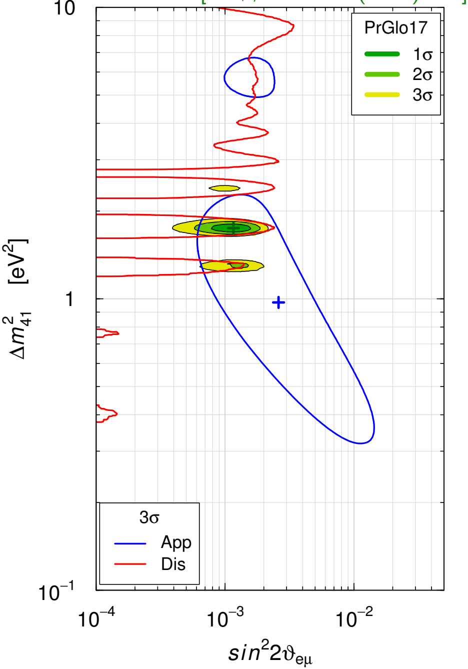
3 (active) + 1 (sterile) mixing:

$$\nu_\alpha = \sum_{k=1}^{3+1} U_{\alpha k}\nu_k \quad (\alpha = e, \mu, \tau, s)$$

ν_s is mainly ν_4:
$$m_s \simeq m_4 \simeq \sqrt{\Delta m^2_{41}} \simeq \sqrt{\Delta m^2_{SBL}}$$

assuming $m_4 \gg m_i$ $(i = 1, 2, 3)$

[SG+, JHEP 06 (2017) 135]



3+1 Neutrino Model

[SG+, work in progress]

new $\Delta m^2_{SBL} \Rightarrow$ 4 neutrinos!

↓

ν_4 with $m_4 \simeq 1$ eV,
no weak interactions

↓

light sterile neutrino (LSν)

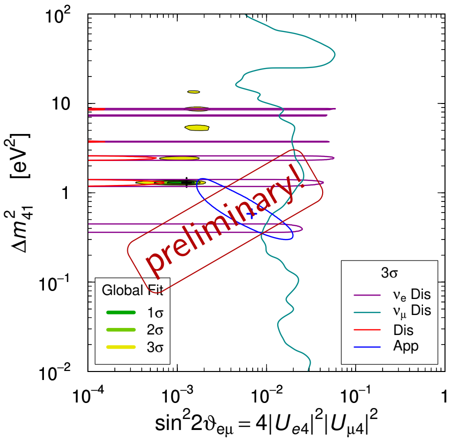
3 (active) + 1 (sterile) mixing:

$$\nu_\alpha = \sum_{k=1}^{3+1} U_{\alpha k}\nu_k \quad (\alpha = e, \mu, \tau, s)$$

ν_s is mainly ν_4:

$$m_s \simeq m_4 \simeq \sqrt{\Delta m^2_{41}} \simeq \sqrt{\Delta m^2_{SBL}}$$

assuming $m_4 \gg m_i$ $(i = 1, 2, 3)$



3+1 Neutrino Model

[SG+, work in progress]

new $\Delta m^2_{\rm SBL} \Rightarrow$ 4 neutrinos!

↓

ν_4 with $m_4 \simeq 1$ eV,
no weak interactions

↓

light sterile neutrino (LSν)

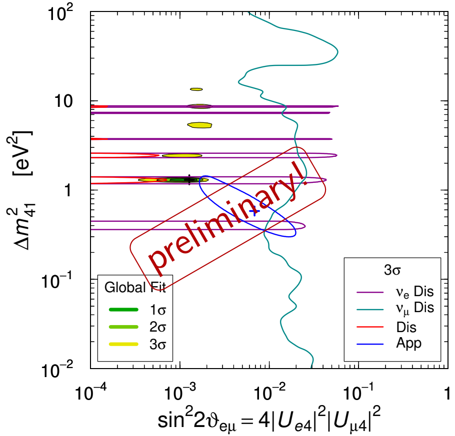
3 (active) + 1 (sterile) mixing:

$$\nu_\alpha = \sum_{k=1}^{3+1} U_{\alpha k}\nu_k \quad (\alpha = e, \mu, \tau, s)$$

ν_s is mainly ν_4:

$$m_s \simeq m_4 \simeq \sqrt{\Delta m^2_{41}} \simeq \sqrt{\Delta m^2_{\rm SBL}}$$

assuming $m_4 \gg m_i$ $(i = 1, 2, 3)$

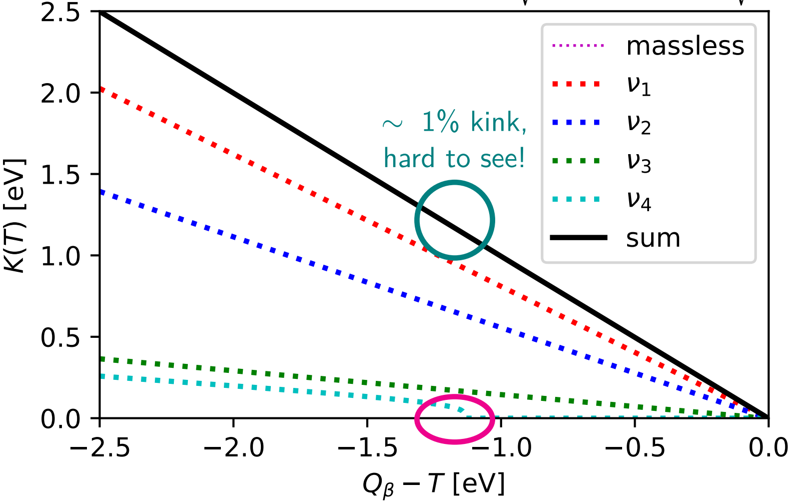


constraints from
mass measurements?

Sterile neutrino in β decay

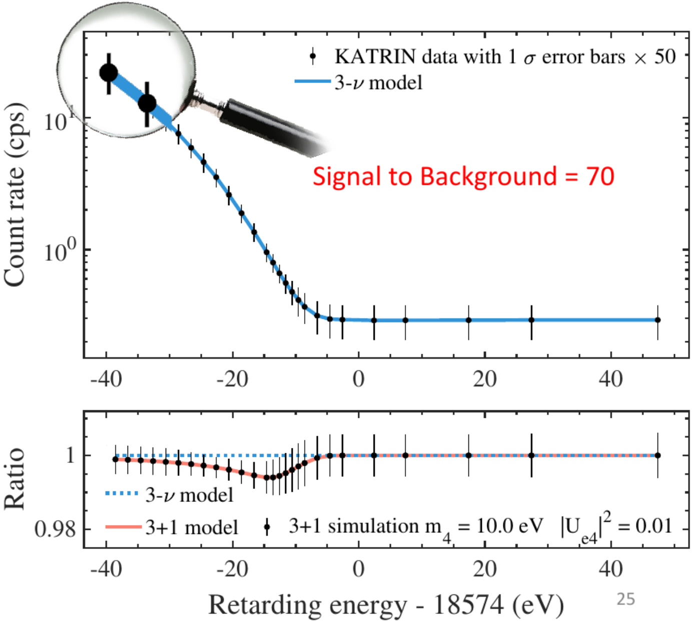
$$K(T) = \left[(Q_\beta - T) \sum_{i=1}^{N_\nu} |U_{ei}|^2 \sqrt{(Q_\beta - T)^2 - m_i^2} \right]^{1/2}$$

$|U_{e4}|^2 \sim 0.01$ $\quad$ $m_4 = \sqrt{m_1^2 + \Delta m_{41}^2} \sim \sqrt{\Delta m_{41}^2}$

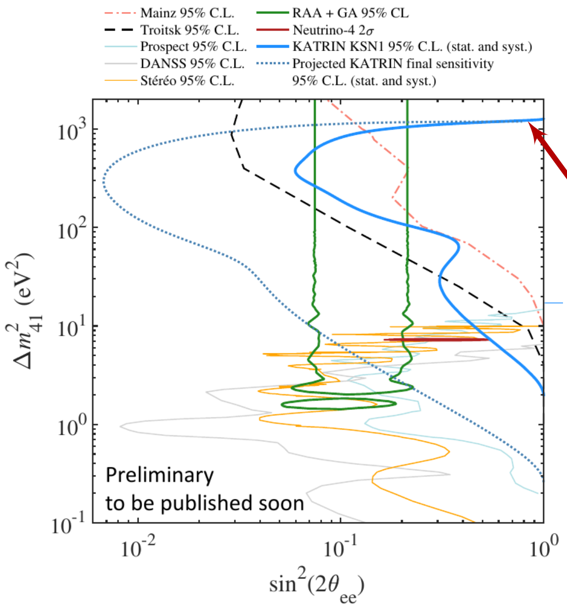


Sterile neutrino in β decay

[Mertens@Neutrino 2020]

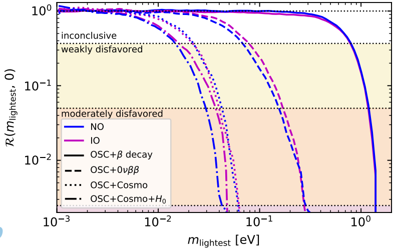


Sterile neutrino in β decay



final sensitivity will test several oscillation results!

search for keV states needs to measure the spectrum much further from the endpoint...


10^0
10^{-1}
10^{-2}
$\mathcal{R}(m_{\text{lightest}}, 0)$
inconclusive
weakly disfavored
moderately disfavored
NO
IO
OSC+β decay
OSC+$0\nu\beta\beta$
OSC+Cosmo
OSC+Cosmo+H_0
10^{-3}
10^{-2}
10^{-1}
10^0
m_{lightest} [eV]

Mass ordering in 2020

[arxiv:2006.11237]
http://globalfit.astroparticles.es/

Bayes theorem for models:

$$p(\mathcal{M}|d) \propto Z_{\mathcal{M}} \pi(\mathcal{M})$$

Bayesian evidence:

$$Z_{\mathcal{M}} = \int_{\Omega_{\mathcal{M}}} \mathcal{L}(\theta)\, \pi(\theta)\, d\theta$$

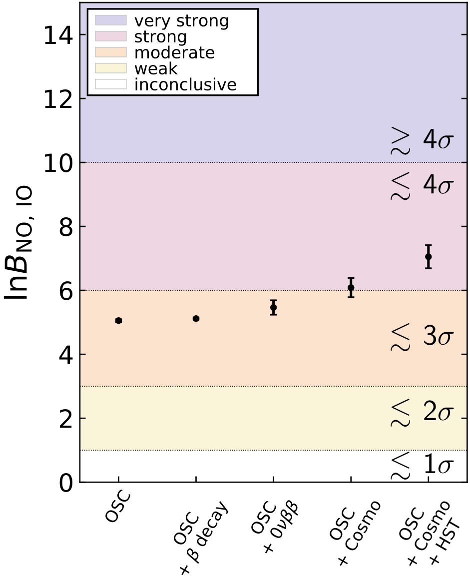
Bayes factor NO vs IO:

$$B_{\rm NO,IO} = Z_{\rm NO}/Z_{\rm IO}$$

Posterior probability:

$$P_{\rm NO} = B_{\rm NO,IO}/(B_{\rm NO,IO}+1)$$
$$P_{\rm IO} = 1/(B_{\rm NO,IO}+1)$$

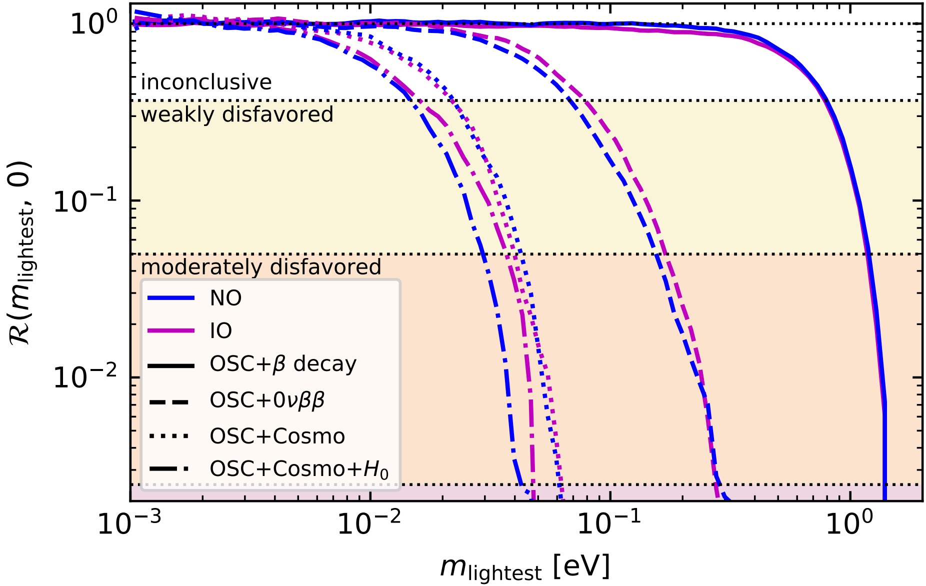
$N\sigma$ from $P_{\rm NO} = {\rm erf}(N/\sqrt{2})$



$\pi(\mathcal{M})$ model prior
$p(\mathcal{M}|d)$ model posterior
$\mathcal{L}(\theta)$ likelihood
$\Omega_{\mathcal{M}}$ parameter space, for parameters θ

Global bounds on the lightest neutrino mass

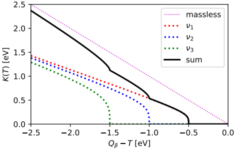
[arxiv:2006.11237]

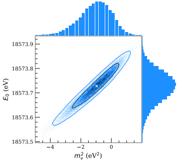


What do we learn on neutrino masses?

β

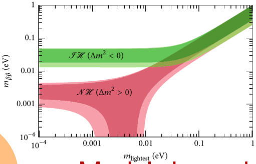
β decay

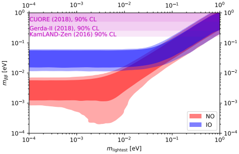




$\beta\beta$

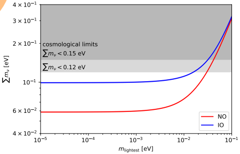
Majorana only: neutrinoless $\beta\beta$ decay

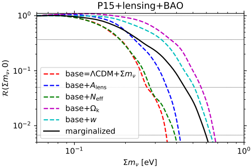




Cosmo

Model dependent: cosmology

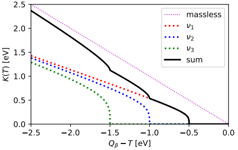


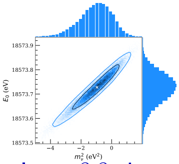


What do we learn on neutrino masses?

β

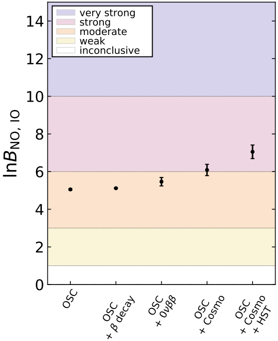
β decay





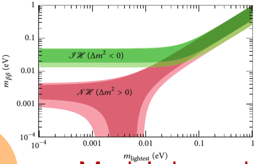
+

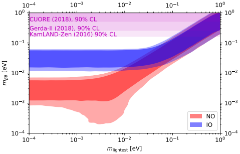
global fit



$\beta\beta$

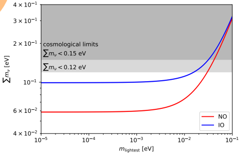
Majorana only: neutrinoless $\beta\beta$ decay

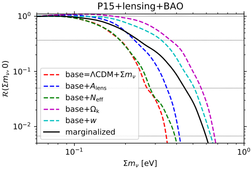


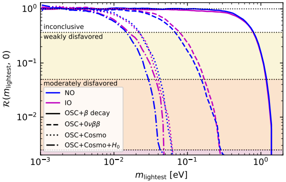


Cosmo

Model dependent: cosmology



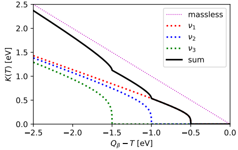


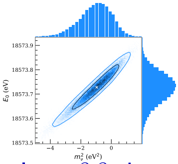


What do we learn on neutrino masses?

β

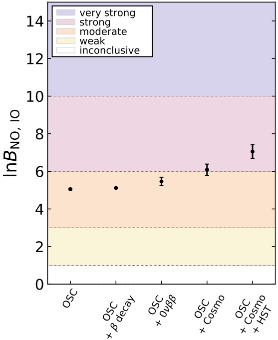
β decay





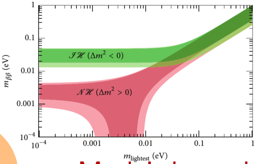
$+$

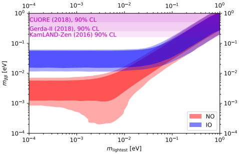
global fit



$\beta\beta$

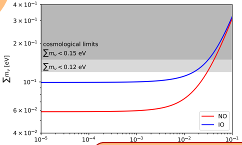
Majorana only: neutrinoless $\beta\beta$ decay

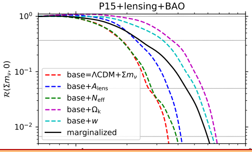


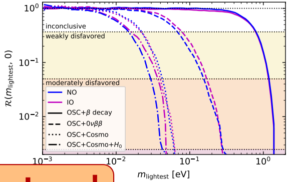


Cosmo

Model dependent: cosmology







Thanks for the attention!