Two short comments on:

Lepton number violation searches at LHC

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$\mathcal{I}.$

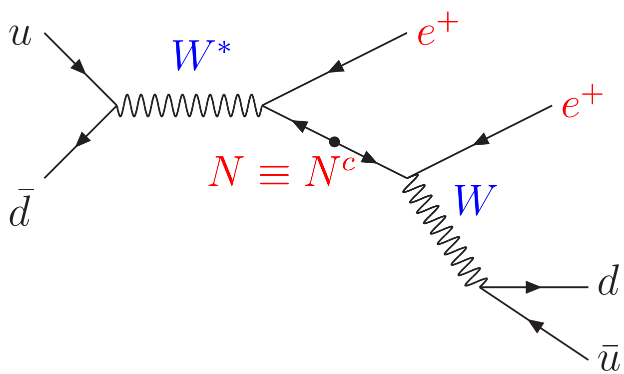
Quasi-Dirac neutrinos at the LHC

Anamiati, Hirsch & Nardi

JHEP1610 (2016) 010

LNV @ LHC

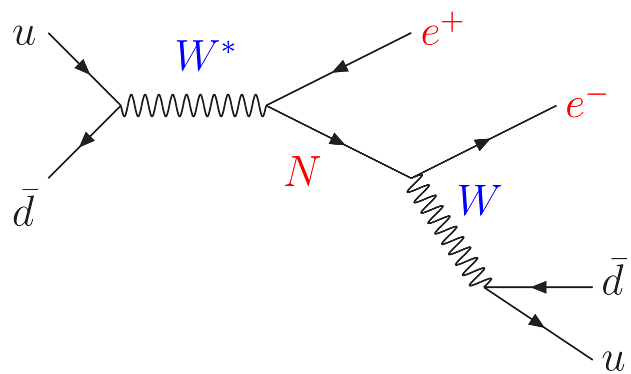
$pp \to l^+ l^+ + jj$



Majorana neutrino

$R_{ll} \equiv 1$

$pp \to l^+ l^- + jj$



Dirac neutrino

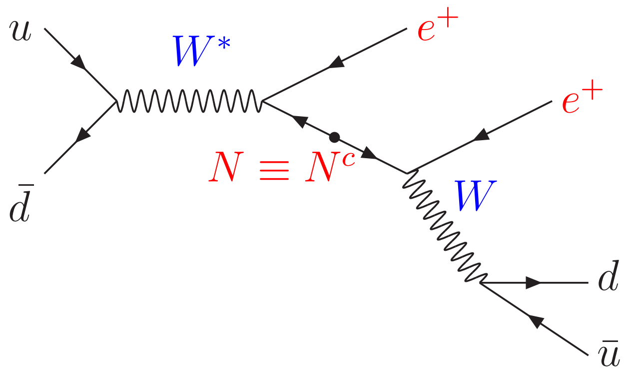
$R_{ll} \equiv 0$

where:

$$R_{ll} = \frac{\#(l^+ l^+ jj) + \#(l^- l^- jj)}{\#(l^+ l^- jj)}$$

LNV @ LHC

$pp \to l^+ l^+ + jj$



Majorana neutrino

$R_{ll} \equiv 1$

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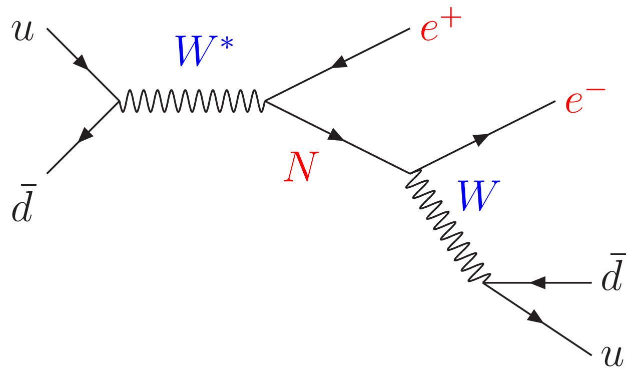

Dirac neutrino

$R_{ll} \equiv 0$

Can one have $R_{ll} = 1/2, 1/4 \ldots 1/13$?

Inverse seesaw

Inverse seesaw, basis (ν_L, N_R^c, S_R^c):

$$M_\nu = \begin{pmatrix} 0 & m_D^T & 0 \\ m_D & 0 & M_R \\ 0 & M_R^T & \mu \end{pmatrix}$$

Mohapatra & Valle, 1986

"Inverse" seesaw, because:

$$\begin{aligned} m_\nu &\Rightarrow 0 \\ M_\pm &\Rightarrow \pm\left(\hat{M}_R + \left\{m_D.m_D^T, \hat{M}_R^{-1}\right\}\right) \end{aligned}$$

IF: $\mu \Rightarrow 0$

In this limit:

$\Rightarrow$ Light neutrinos massless

$\Rightarrow$ Heavy neutrinos: Dirac pair

Smallness of m_ν due to nearly conserved L!

Inverse seesaw

Inverse seesaw, basis (ν_L, N_R^c, S_R^c):

$$M_\nu = \begin{pmatrix} 0 & m_D^T & 0 \\ m_D & 0 & M_R \\ 0 & M_R^T & \mu \end{pmatrix}$$

Mohapatra & Valle, 1986

For non-zero μ:

$$\begin{aligned} \hat{m}_\nu = V_L m_\nu V_L^T &= V_L m_D^T.(M_R^T)^{-1}.\mu.(M_R)^{-1}.m_D V_L^T \\ M_\pm &= \left(\hat{M}_R + \left\{m_D.m_D^T, \hat{M}_R^{-1}\right\}\right) \pm \frac{1}{2}\mu_V \end{aligned}$$

$\Rightarrow$ - 3 light eigenvalues: $\hat{m}_\nu$

$\Rightarrow$ - (3+3) heavy (nearly diagonal) eigenvalues : $\hat{M}_\pm = \hat{M}_R \pm \frac{1}{2}\mu_V$ Quasi-Dirac!

Quasi-Dirac ν oscillations

Write the state from $W^+_{L/R} \to \bar{\ell} N_\ell$ and its conjugate state from $W^-_{L/R} \to \ell N_{\bar{\ell}}$ in terms of the mass eigenstates as:

$$
\begin{aligned}
N_\ell &= \frac{1}{\sqrt{2}}(N_+ - iN_-)\,, \\
N_{\bar{\ell}} &= \frac{1}{\sqrt{2}}(N_+ + iN_-)\,.
\end{aligned}
$$

Let them evolve. After time t:

$$
\begin{aligned}
N_\ell(t) &= g_+(t) N_\ell + g_-(t) N_{\bar{\ell}}\,, \\
N_{\bar{\ell}}(t) &= g_-(t) N_\ell + g_+(t) N_{\bar{\ell}}\,,
\end{aligned}
$$

where the oscillating amplitudes read :

$$
\begin{aligned}
g_+(t) &= e^{-iMt} e^{-\frac{\Gamma}{2}t} \cos\left(\frac{\Delta M}{2} t\right)\,, \\
g_-(t) &= i\, e^{-iMt} e^{-\frac{\Gamma}{2}t} \sin\left(\frac{\Delta M}{2} t\right)\,.
\end{aligned}
$$

Quasi-Dirac ν oscillations

If $\Gamma \gtrsim 10^{-14}$ GeV (or so), decay length short. Integrate over time:

$$R_{ll} = \frac{\int_0^\infty |g_-|^2 \, dt}{\int_0^\infty |g_+|^2 \, dt} = \frac{\Delta M^2}{2\Gamma^2 + \Delta M^2} \, .$$

Quasi-Dirac ν oscillations

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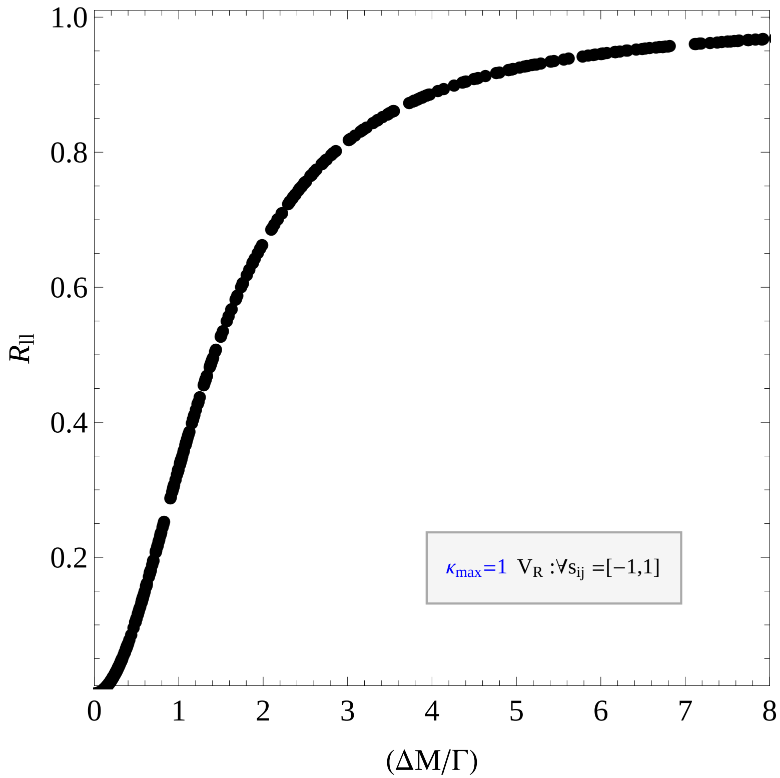


Physics interpretation:

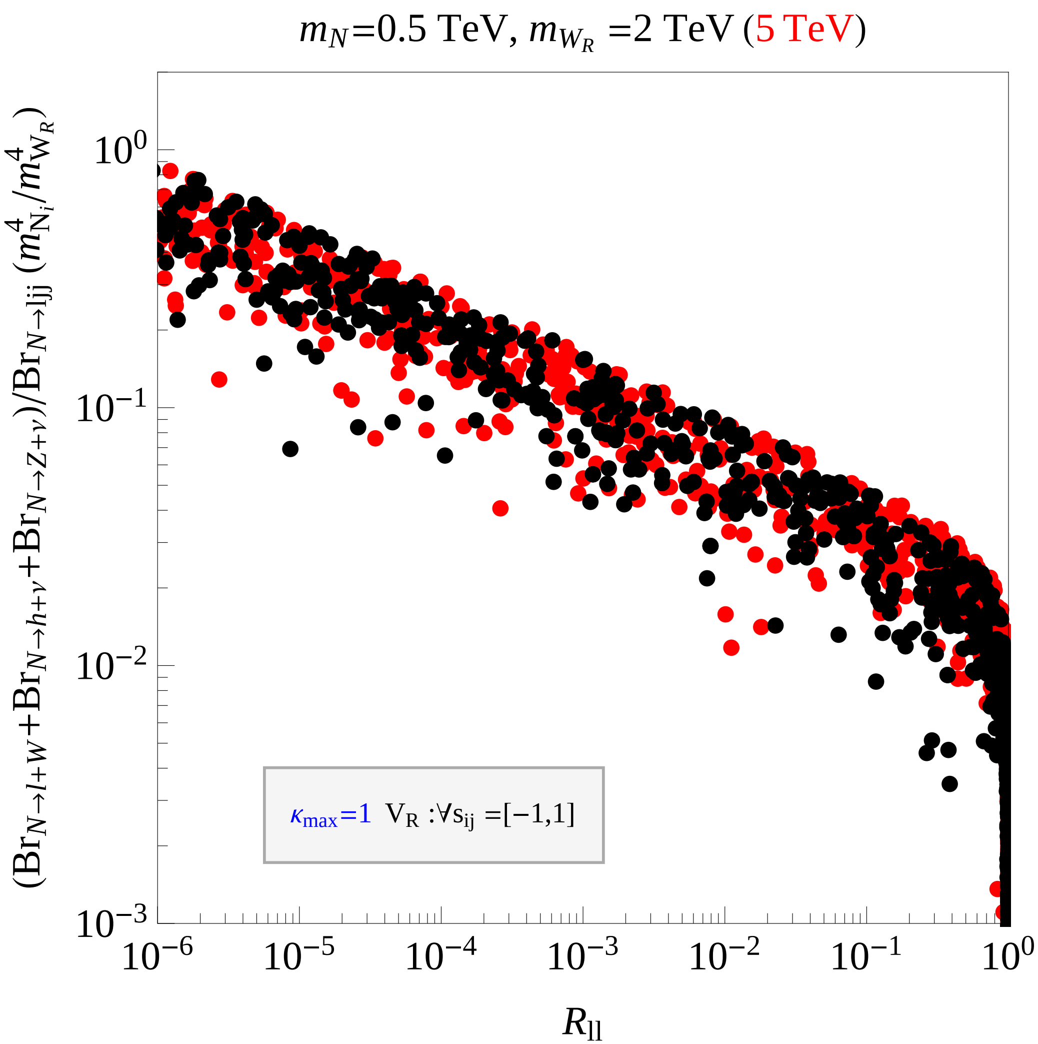
If $\Gamma \simeq \Delta M$

states can interfere!

R_{ll} any value in (0,1)

Is this observable at LHC?

Heavy neutrino decays



Plot for LR model
+ inverse seesaw

Decays to SM bosons
(anti-)correlate with R_{ll}!

$\mathcal{II}.$

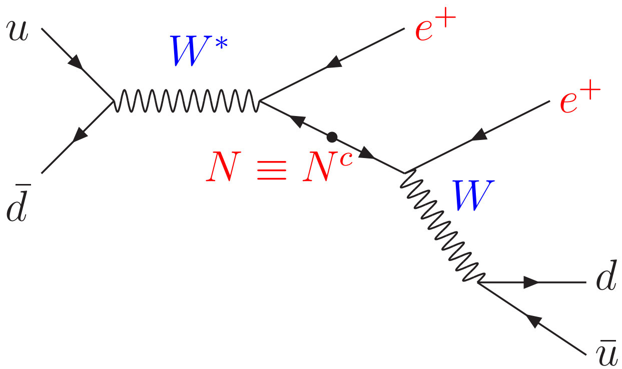
Dijet constraints on LNV searches

Helo & Hirsch

Phys.Rev. D92 (2015) 073017

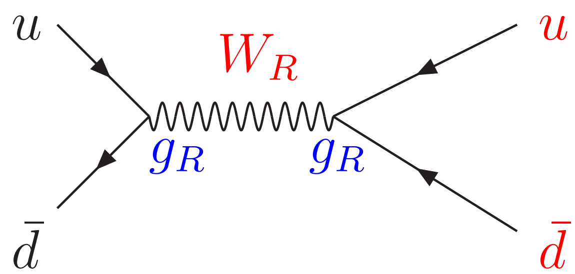
LNV and Di-jets @ LHC

$pp \rightarrow l^+ l^+ + jj$



Lepton number violation

$pp \rightarrow jj$

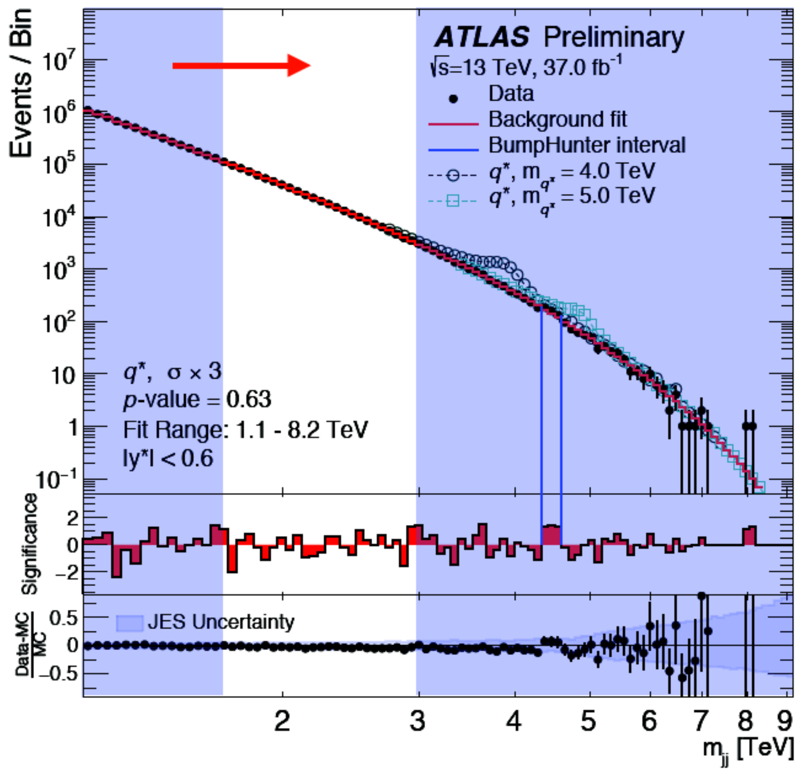


Lepton number conserved

$\Rightarrow$ production cross section proportional to g_R^2

$\Rightarrow$ Significant branching ratio to LNC state unavoidable

Dijets 2017



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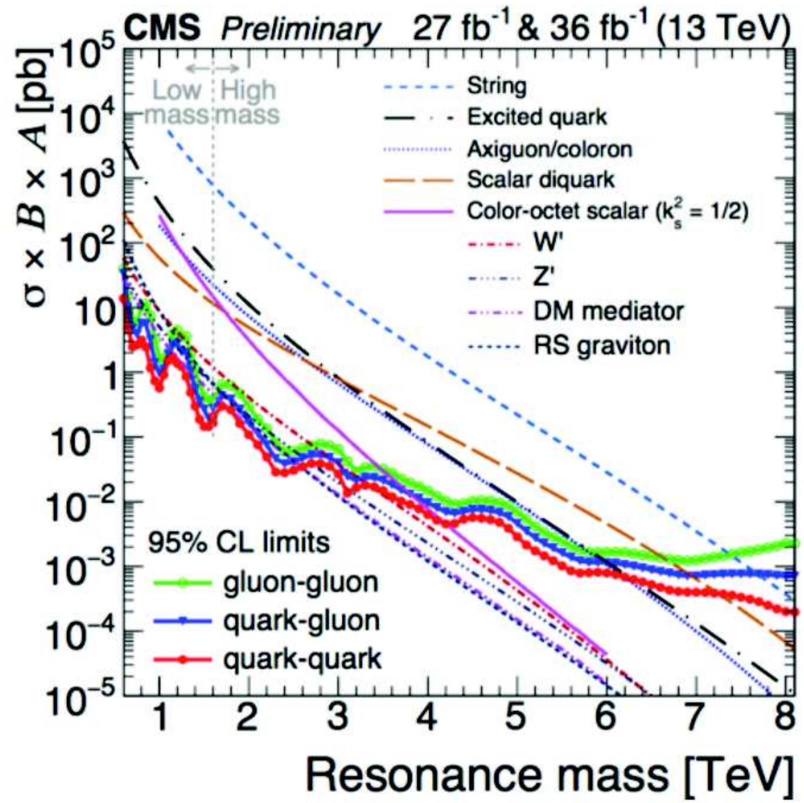
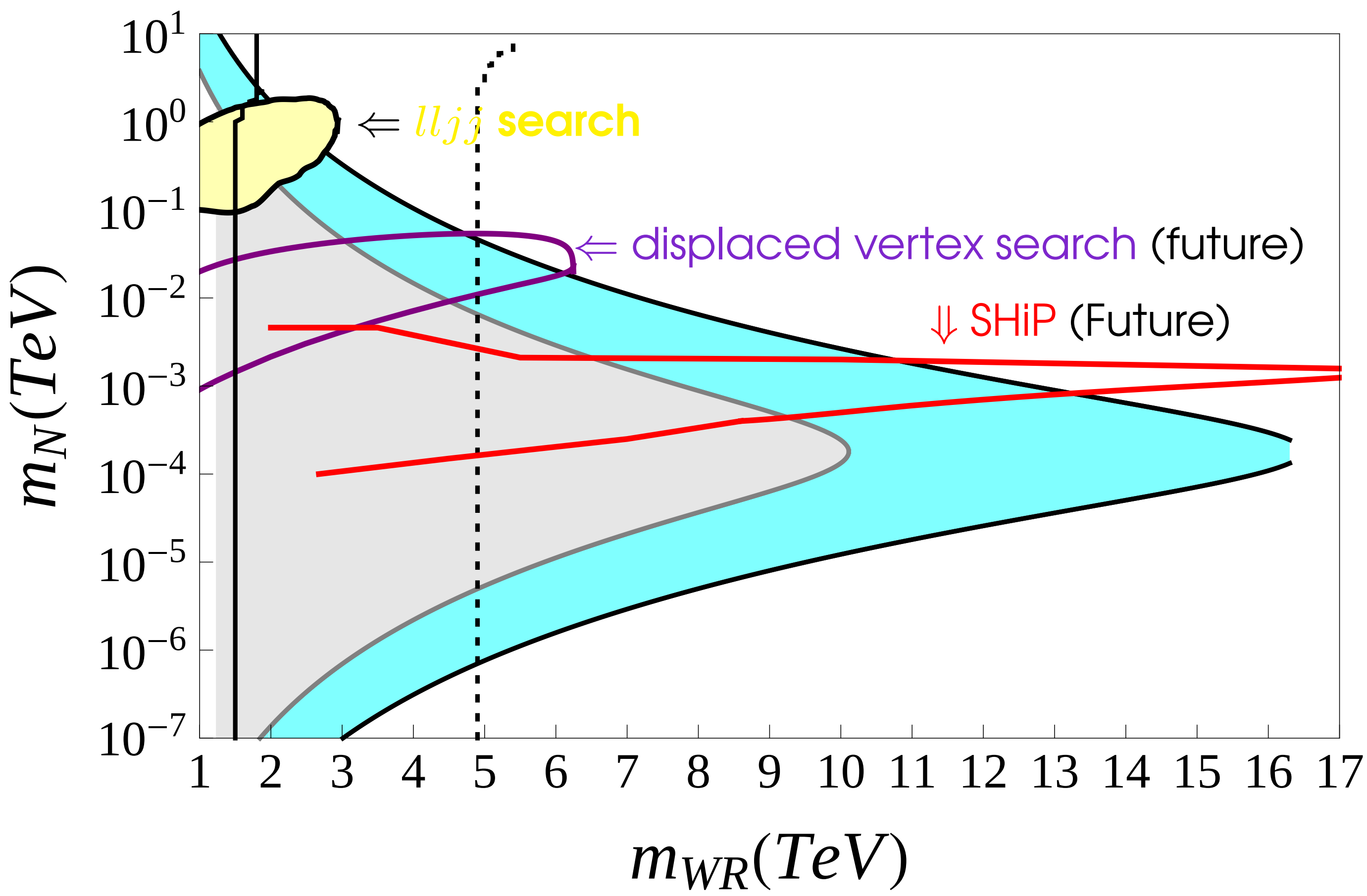


LEFT: ATLAS Dijet data

RIGHT: CMS Limits from dijet data

Dijet and $0\nu\beta\beta$ decay

Absence of $pp \to W_R \to jj$ gives limit on $0\nu\beta\beta$:



Helo & Hirsch PRD92 (2015)

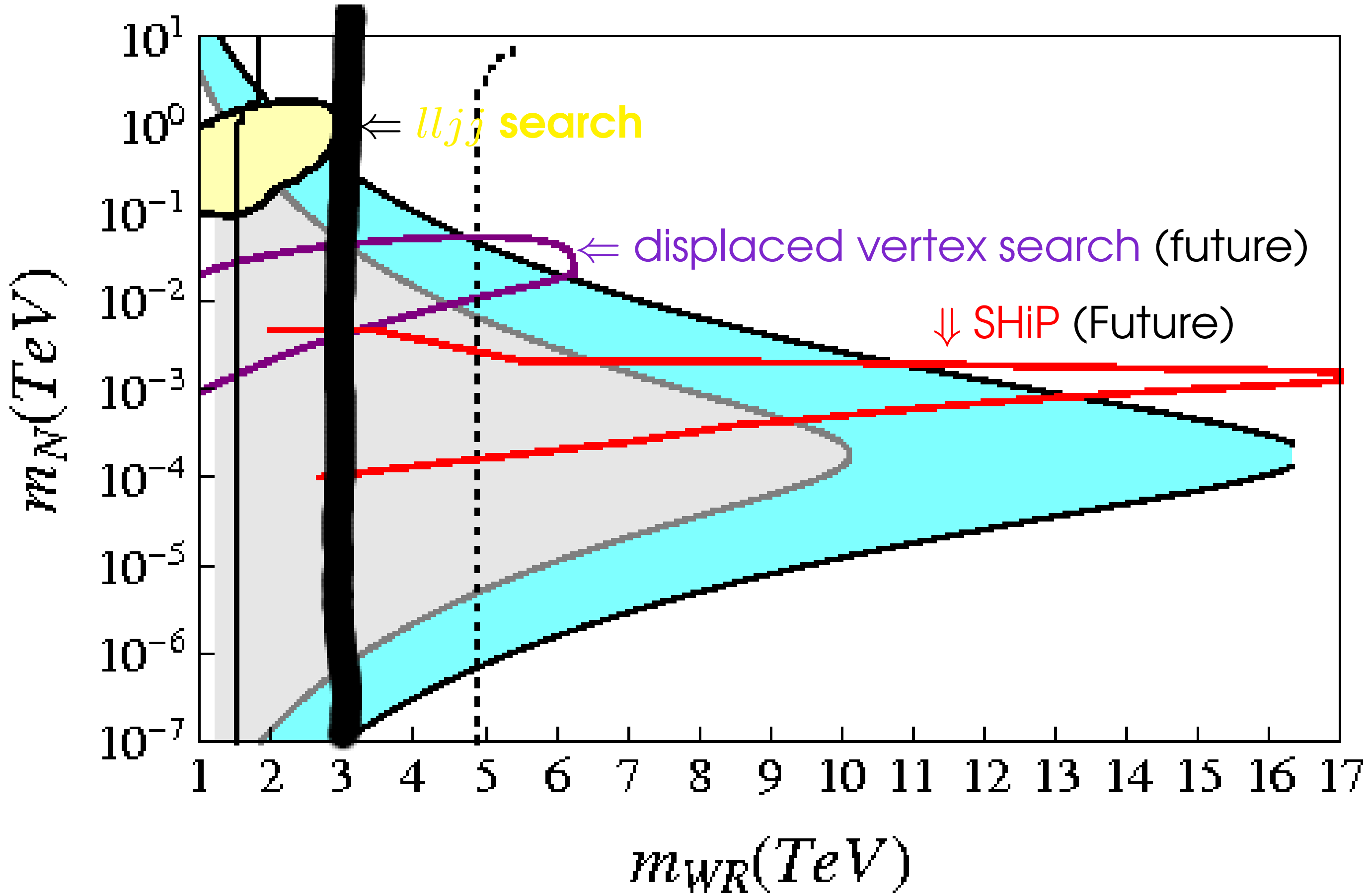
gray: $T^{0\nu\beta\beta}_{1/2} \gtrsim 10^{25}$ ys

cyan: $T^{0\nu\beta\beta}_{1/2} \gtrsim 10^{27}$ ys

⇒ **full (dashed) 8 TeV data limit**
(future sensitivity) for dijet data

Dijet and $0\nu\beta\beta$ decay

Absence of $pp \to W_R \to jj$ gives limit on $0\nu\beta\beta$:



Helo & Hirsch
PRD92 (2015)

gray: $T_{1/2}^{0\nu\beta\beta} \gtrsim 10^{25}$ **ys**

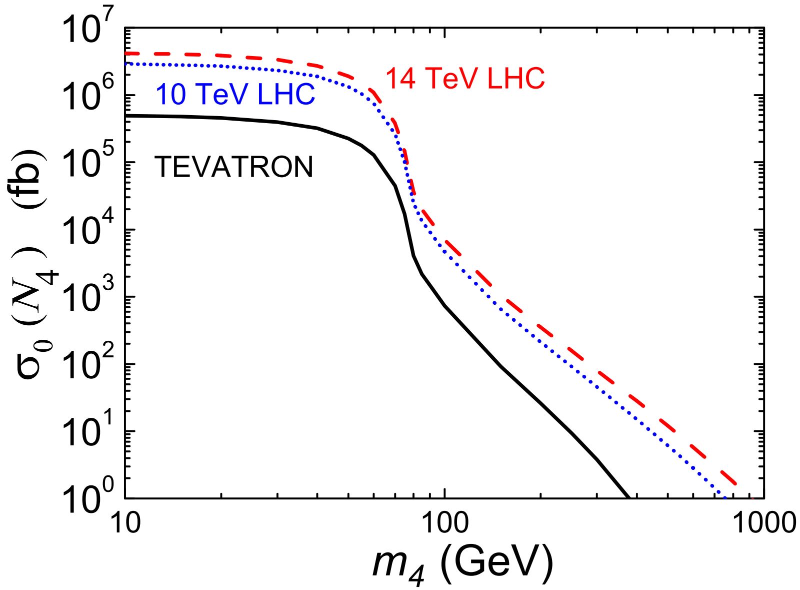
cyan: $T_{1/2}^{0\nu\beta\beta} \gtrsim 10^{27}$ ys

$\Rightarrow$ **thick full line: estimated limit from latest dijet data**

Thank you for your attention!

Backup slides

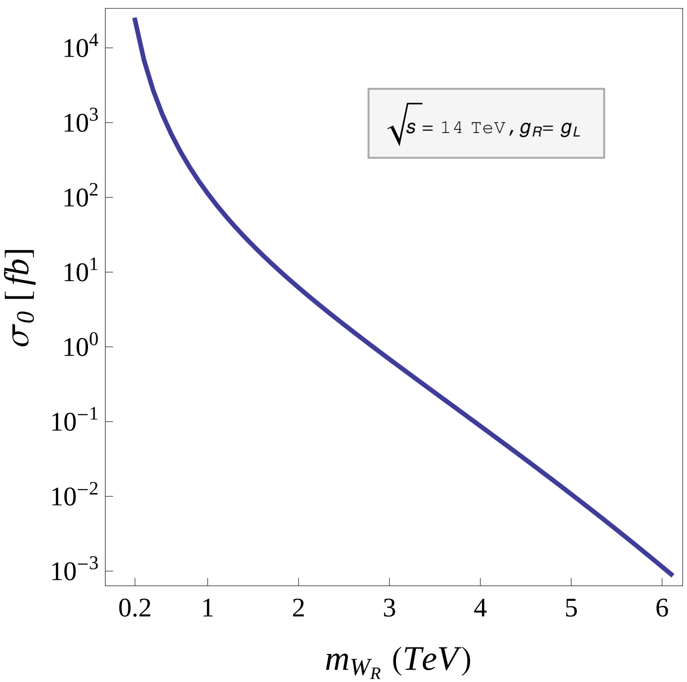
Cross sections



Heavy neutrino poduction in SM:

$$\sigma(pp \to W^* \to l_\alpha^\pm + N_k) \propto |U_{\alpha k}|^2 \sigma_0$$

this plot from:
Atre et al, JHEP 0905 (2009) 030



Heavy neutrino poduction in LR model:

$$\sigma(pp \to W_R) \times Br(W_R \to l_\alpha^\pm + N_k)$$

For $m_N \gtrsim 100$ GeV

(even for $|U_{\alpha k}|^2 \simeq \mathcal{O}(0.3)$)

$\sigma_{LR}/\sigma_{SM} \gtrsim 100$