LHC Monojet Constraints on Neutrino Interactions

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"A FIRST GLIMPSE OF THE TERA SCALE"

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Outline

- Non-Standard neutrino Interactions (NSI)
  - Motivations
  - Current Bounds
  - Examples
- Monojet constraints
  - Contact interaction limit
  - Light Mediators
- Distinguishing Neutrinos from Dark Matter at the LHC
- Conclusions

Non-Standard neutrino Interactions (NSI)

Wolfenstein '78

of the form:

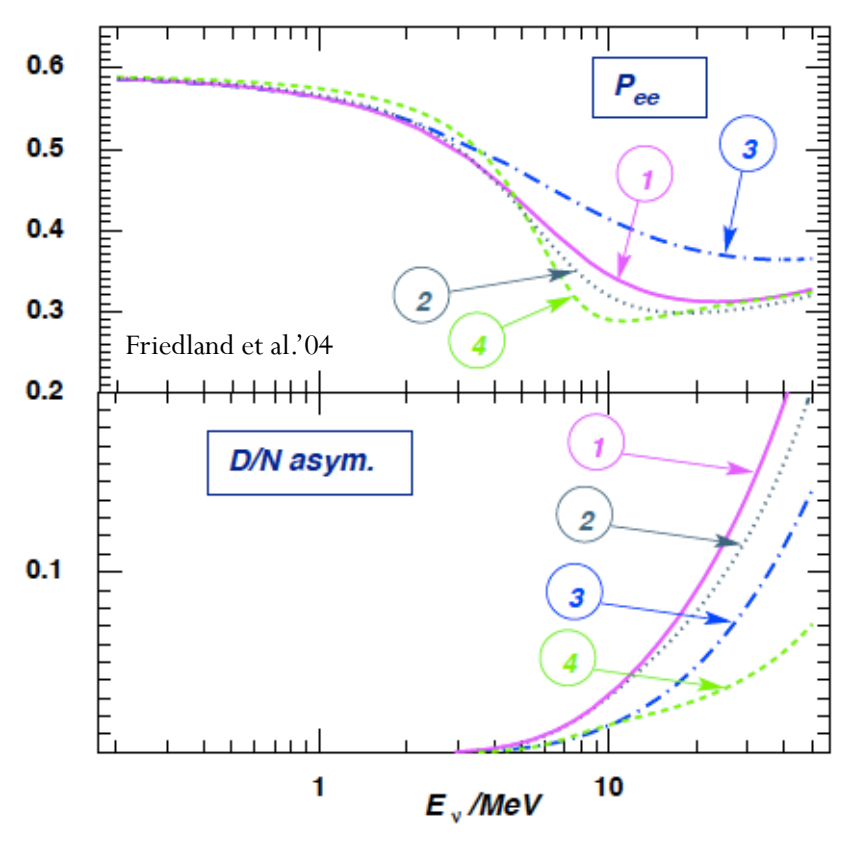
$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F\,\epsilon^{fP}_{\alpha\beta}(\overline{\nu}_\alpha\gamma^\rho\nu_\beta)(\overline{f}\gamma_\rho P f)$$

Neutrino Flavor

f =SM fermion
P=L,R

modify oscillation in matter,

AND ARE OFTEN PROPOSED AS SOLUTIONS TO THE CURRENT "... neutrino anomaly" (SOLAR, ATMOSPHERIC, REACTOR, ETC)



Palazzo '11 (Borexino+SK+SNO)

$$\epsilon^{dP}_{e\tau} \sim 0.2$$

Currently allowed !

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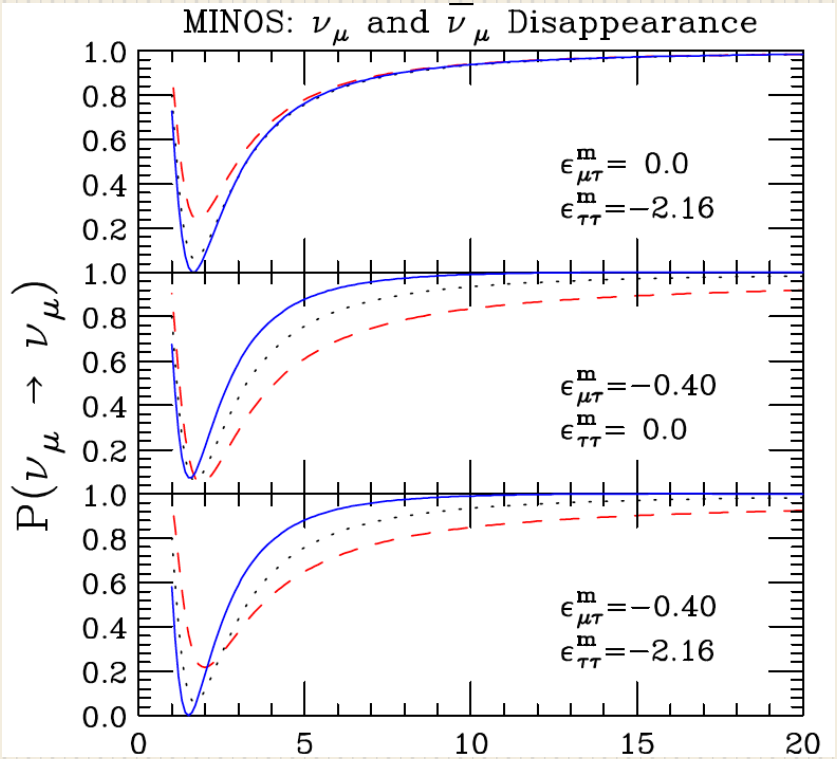
$$\epsilon^{qP}_{\tau\tau} \sim 2$$

Kopp et al. '11 (MINOS)



Current Bounds on neutral current NSI with quarks

$$q = u, d$$

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}\, G_F \epsilon^{qP}_{\alpha\beta} \left(\overline{\nu}_\alpha \gamma_\rho \nu_\beta\right) \left(\overline{q} \gamma^\rho P q\right)$$

- Muon neutrinos are very constrained (DIS) $\epsilon^{qP}_{\mu\alpha} \lesssim O(10^{-2})$
- **NSI for tau and electron neutrinos are poorly constrained** (LEP, DIS)

$$\epsilon^{qP}_{e\alpha\neq\mu} \lesssim 0.5 \qquad \epsilon^{qP}_{\tau\alpha\neq\mu} \lesssim 1$$

Is it phenomenologically viable to have NSI? What about $SU(2)_L$ invariance?!

To avoid the strong bounds on the charged lepton interactions one needs Higgs insertions [$SU(2)_L$ violation]...

Effectively: dimension-8 operators

$$\mathcal{L}_{\rm NSI}^{\rm dim-8} = -\frac{4\epsilon^{qP}_{\alpha\beta}}{v^4}(\overline{HL_\alpha}\gamma^\mu HL_\beta)(\bar{q}\gamma_\mu Pq)$$

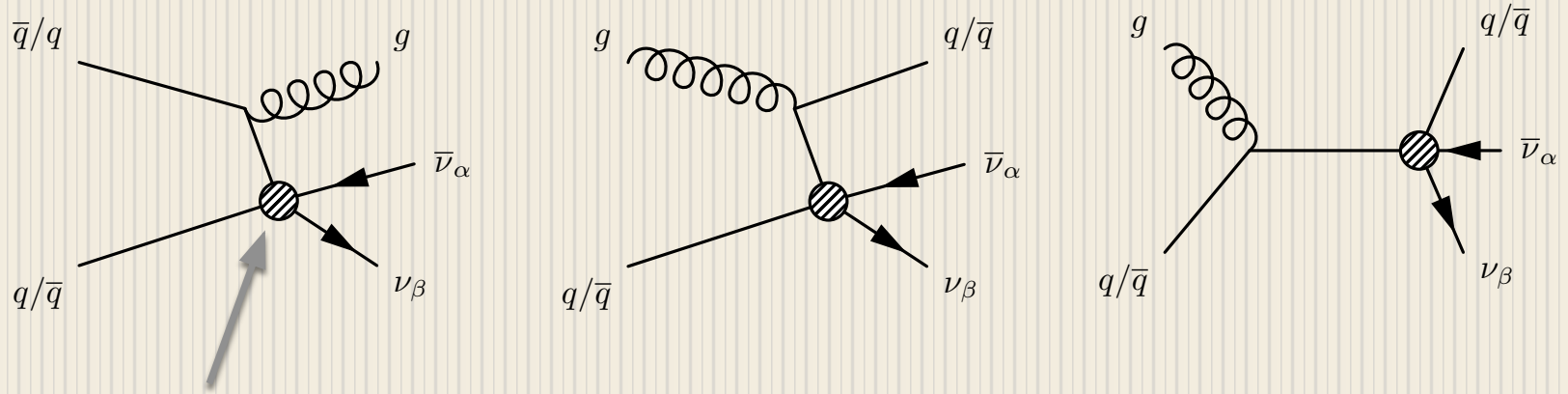
$$\to -2\sqrt{2}\,G_F\,\epsilon^{qP}_{\alpha\beta}\,(\bar{\nu}_\alpha\gamma^\mu\nu_\beta)\,(\bar{q}\gamma_\mu Pq)\left(1+\frac{h}{v}\right)^2$$

Examples of UV-completions: New non-sterile neutrinos (N) plus N-q mediators

What does the LHC say about NSI???

Monojet searches

At the LHC/Tevatron: $pp/p\bar{p} \to j\overline{\nu_\alpha}\nu_\beta$



NSI contact interaction

Mono-Photon by
Berezhiani & Rossi '11

CDF, ATLAS, and CMS $pp/p\bar{p} \to j+\mathrm{MET}$ **with 1 fb^{-1}**

SM background: $jZ \to j\nu\bar{\nu}$, $jW \to j\nu l$ and QCD multijets

DM monojets:
Birkedal et al. 04, Goodman et al. '10,
Bai et al. '10 Fox et al. '11

Missing ET could be any type of invisible stuff

(Neutrinos, Sterile Neutrinos, Dark Matter, ADD gravitons, unparticles, etc)

BUT

- Only Neutrinos interfere with the SM

$$\sigma(pp/p\bar{p} \to j + \mathrm{MET}) = \sigma_{\mathrm{SM}} + \epsilon\sigma_{\mathrm{int}} + \epsilon^2\sigma_{\mathrm{NSI}}$$

- Neutrinos have electroweak interactions

Monojet bounds on $\mathcal{L}_{\rm NSI} = -2\sqrt{2}\, G_F \epsilon^{qP}_{\alpha\beta} \left(\overline{\nu}_\alpha \gamma_\rho \nu_\beta\right) \left(\overline{q}\gamma^\rho P q\right)$

	$1\ \mathrm{fb}^{-1}$	CDF	LowPt	HighPt	veryHighPt
Diagonal	$\epsilon^{uP}_{\alpha\beta=\alpha}$	0.40	0.40	0.19	0.17
	$\epsilon^{dP}_{\alpha\beta=\alpha}$	1.00	0.54	0.28	0.26
Off diagonal	$\epsilon^{uP}_{\alpha\beta\neq\alpha}$	0.28	0.28	0.13	0.12
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One coefficient at a time

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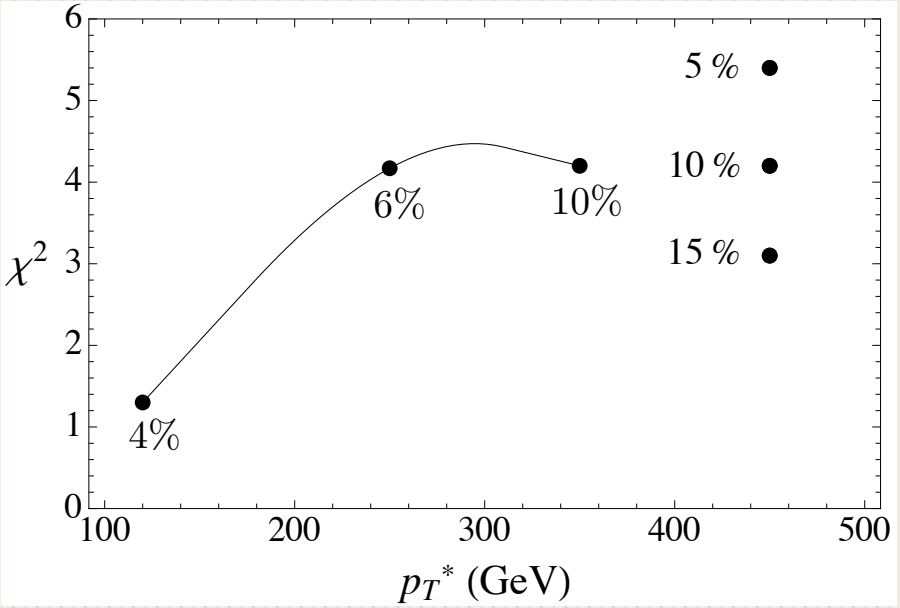
- **The interference is not relevant now, but it might be at 14 TeV**

Analysis is systematics dominated:

- there is a pT cut that maximizes the signal
- **the LHC is already more constraining!**
- a luminosity upgrade will **not** improve the bounds

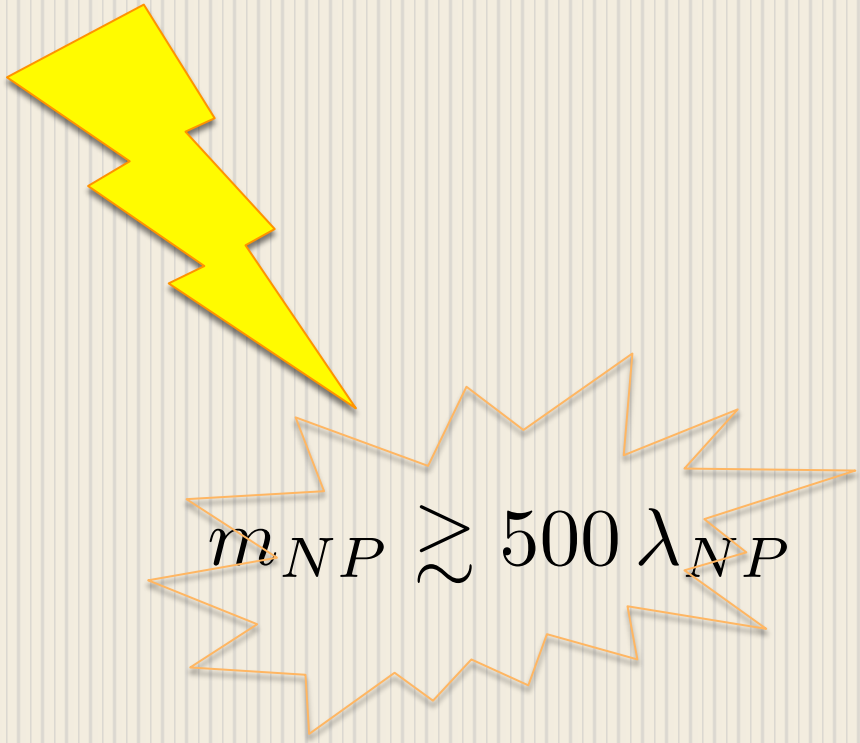


Current bounds will remain the world's best bounds for a while....

How accurate is the assumption of contact NSI?

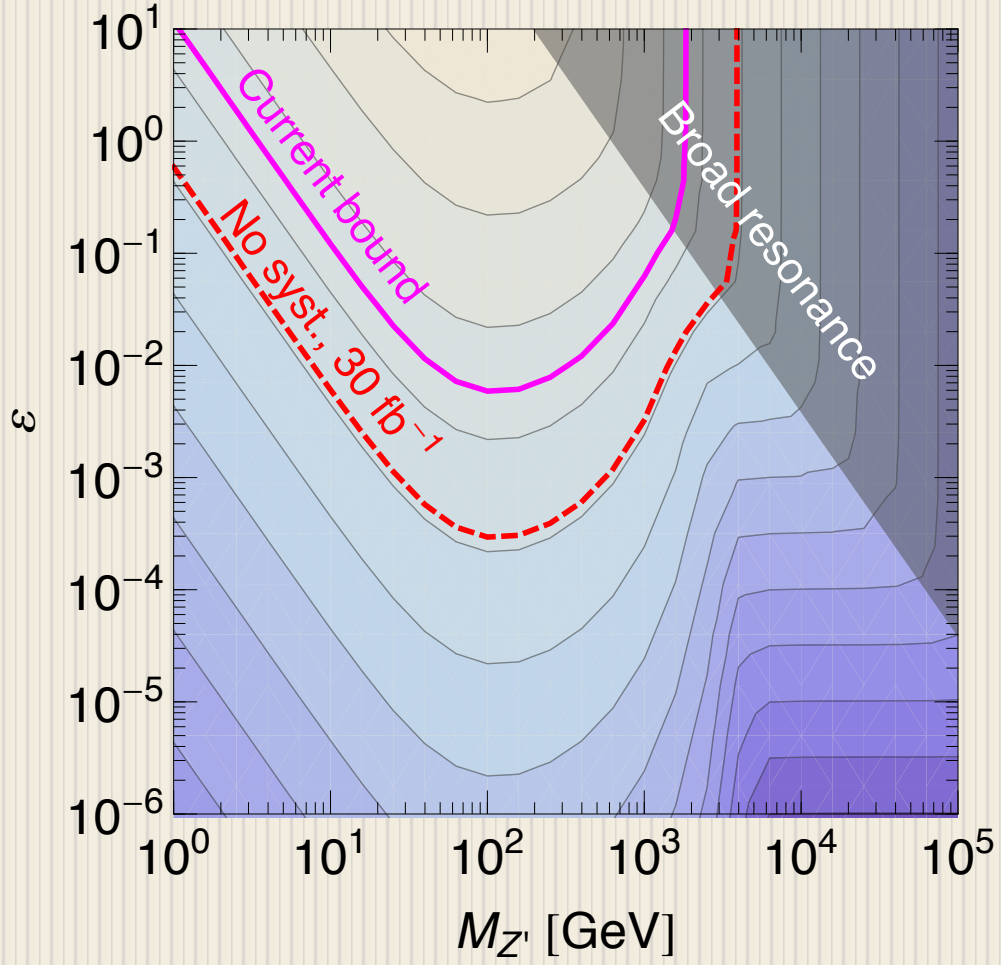
New Physics at tree-level:

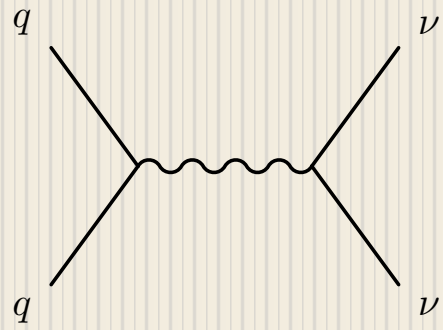
$$\epsilon = O(1)\left(\frac{\lambda_{NP} v}{m_{NP}}\right)^2 \lesssim 0.2$$



- LHC might have a chance to detect the mediator…
- New signatures (beyond monojets) might be present…

Monojets and Light mediators at the LHC…





Collider bounds strongly depend on the mediator's mass (here a Z'):

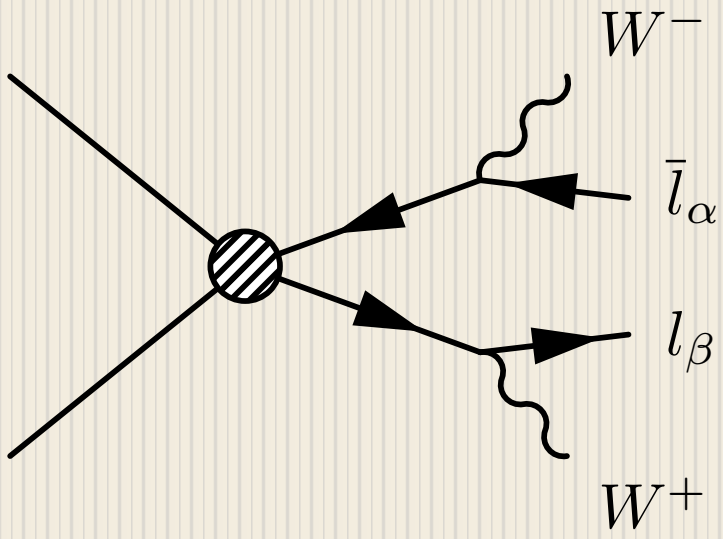
- Contact interaction limit applies if the mediator's mass is above 5-10 TeV.

IF NOT, THEN

- Bounds can be **much stronger** for masses of a few hundred GeV's
- Bounds become **weaker** for masses below 100 GeV, where $\varepsilon \sim (1/M_{Z'})^2$

How to discriminate neutrinos from other invisible stuff?

- ✓ **Neutrinos have electroweak charges**



See also Davidson & Sanz '11

$$pp \to W^+W^-\bar{l}_\alpha l_\beta$$

- Look for 3 or 4 charged leptons
- Background: $pp \to WWZ/WZ/W\gamma^*$ and $pp \to t\bar{t} \to W^-W^+b\bar{b}$

Berger & Sullivan

Cut in the ll invariant mass

pT cut on the leptons

- This process is potentially important, but **needs a high luminosity** (small rate…):

EX: requiring less than 10 events with pT>200 GeV we have

$$\epsilon^{dP} \lesssim 0.8\sqrt{\frac{\mathrm{fb}^{-1}}{\mathrm{L}}}$$

L=10 fb^{-1} is needed to compete with monojets, but the search might suffer less systematic uncertainty

Conclusions

- Neutrinos exist. Non-Standard neutrino Interactions are motivated extensions of the SM.

- With current data Monojet LHC searches provide the world's best model-independent bounds on electron and tau neutrinos
  - bounds are systematics dominated
  - bounds change for light mediators (model-dependent)

- **Both Dark Matter and neutrinos lead to Monojet signals**, but:
  I. Neutrino missing ET signals **interfere** with the SM
  II. Neutrinos have $SU(2)_L$ charges, and can be distinguished from invisible stuff looking for $W^+W^-l^+l^-$: **search required!**