BSM aspects of neutrino physics at the LHC

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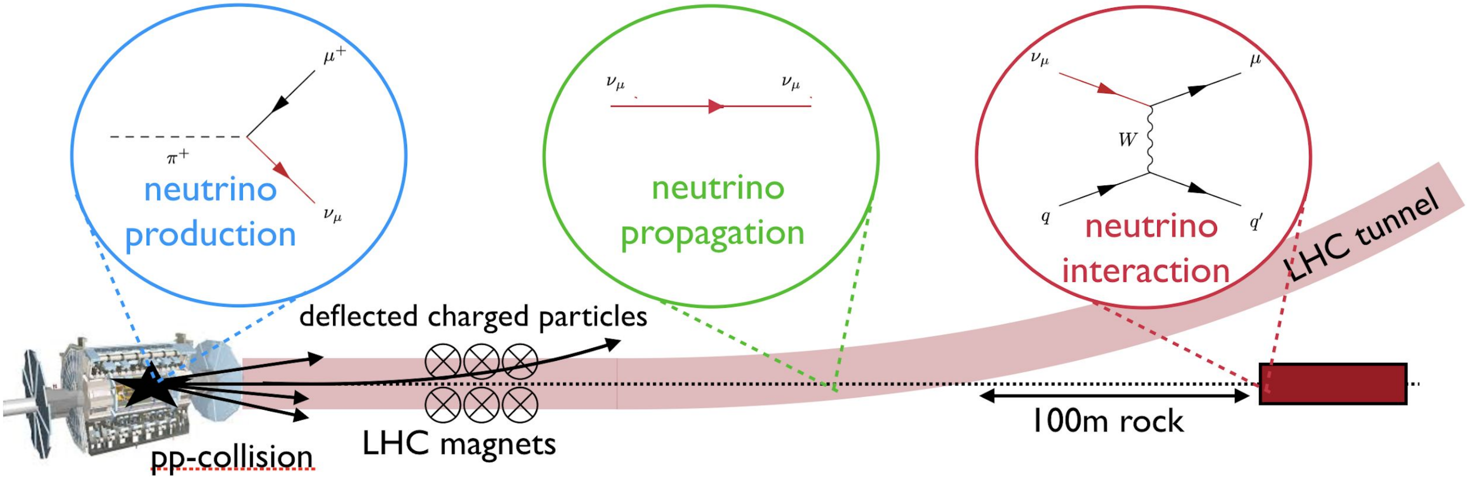
LHC Neutrino Physics Potential

What can we do learn from neutrinos at the LHC?



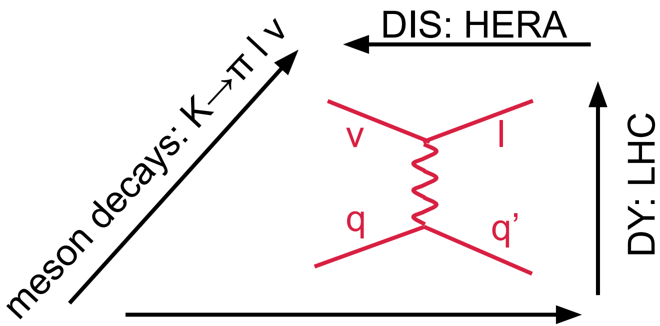
In the following, I will present some ideas.

At the end, I will comment on requirements on systematics.

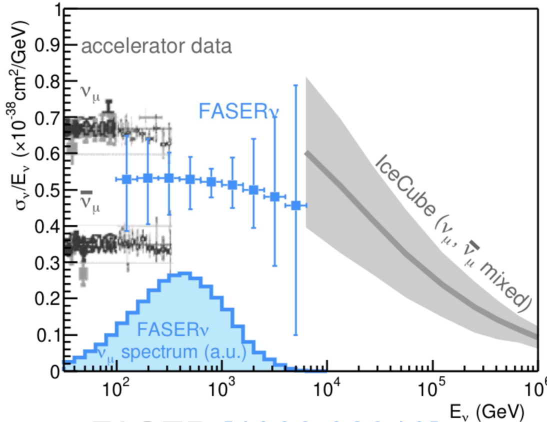
Neutrino Cross Sections

Neutrino experiments at the LHC will measure neutrino cross section at unexplored TeV energies for all three flavors.

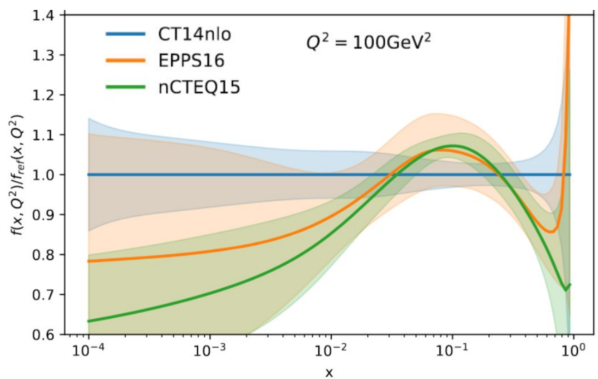
Many BSM physics models can affect the neutrino interaction rate. Existing measurements often put constraints on such models.



In addition to the hard scattering, neutrino interactions are also sensitive to hadronic physics (nuclear PDFs, hadronization, FSI).



FASER [1908.02310]



FASER [2001.03073]

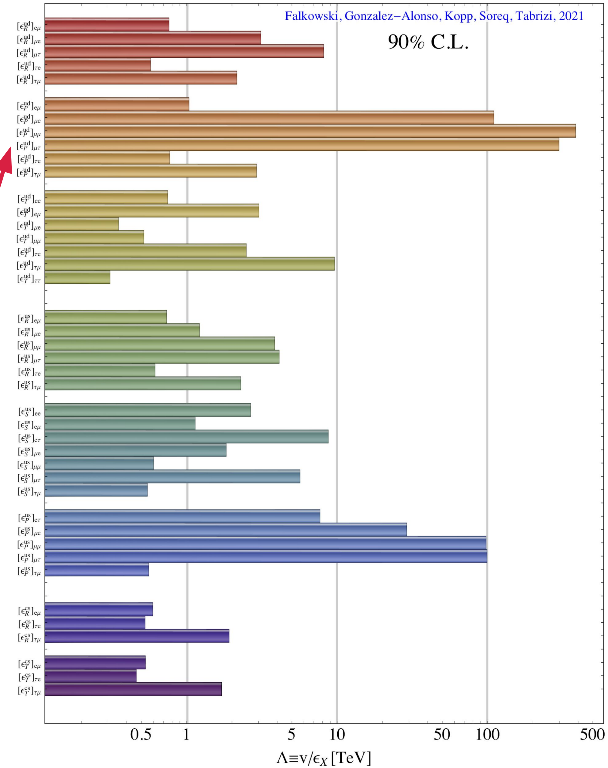
Effective Field Theories

The new physics effects can be parameterized using an effective field theory approach.

$$
\begin{aligned}
\mathcal{L} \supset -\frac{2V^{jk}}{v^2}\Big\{ & [\mathbf{1}+\epsilon_L]^{jk}_{\alpha\beta}\,(\bar{u}^j\gamma^\mu P_L d^k)(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta) \\
& + \frac{1}{2}[\epsilon_S]^{jk}_{\alpha\beta}(\bar{u}^j d^k)(\bar{\ell}_\alpha P_L\nu_\beta) - \frac{1}{2}[\epsilon_P]^{jk}_{\alpha\beta}(\bar{u}^j\gamma_5 d^k)(\bar{\ell}_\alpha P_L\nu_\beta) \\
& + \frac{1}{4}[\epsilon_T]^{jk}_{\alpha\beta}(\bar{u}^j\sigma^{\mu\nu}P_L d^k)(\bar{\ell}_\alpha\sigma_{\mu\nu}P_L\nu_\beta) + \text{h.c.}\Big\}\,. \\
& + [\epsilon_R]^{jk}_{\alpha\beta}(\bar{u}^j\gamma^\mu P_R d^k)(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta)
\end{aligned}
$$

These operators effect both neutrino production and interactions. This would modify the neutrino energy spectrum.

Good sensitivity to pseudoscalar operators.



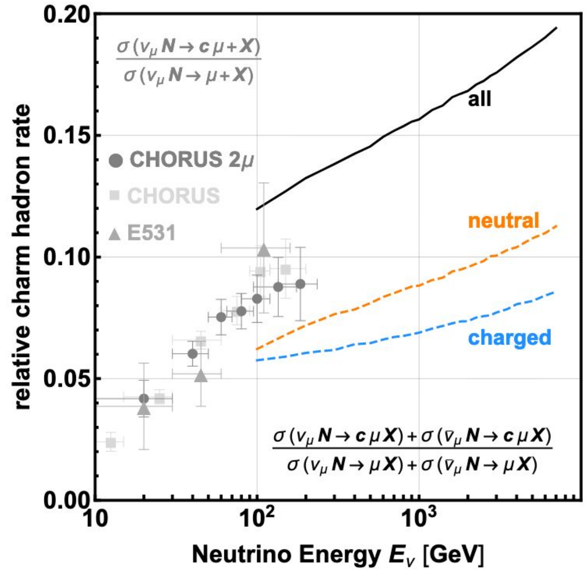
Falkowski, Gonzales-Alonso, Kopp, Soreq, Tabrizi (in progress)

Heavy Flavor Associated Interactions

We expect that O(10%) of the neutrino interactions to contain a charm hadron, and O(0.001%) to contain a beauty hadron.

Charm associated neutrino interactions will have large statistics. They could be used to probe the strange PDF: ν s → l c

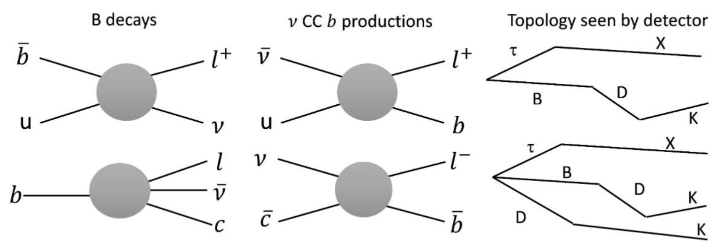
Neutrino interactions containing B-hadrons are very rare. They could be sensitive to BSM physics effects.



FASER [1908.02310]

B-physics anomalies for B →D τ ν could be probed via ντ c → b τ.

(but << 1 event expected during Run 3).

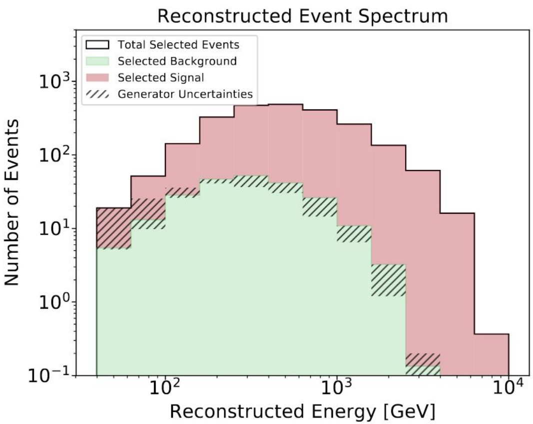


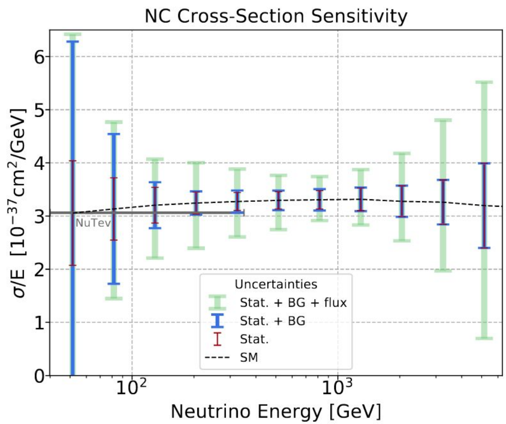
Neutral Currents and NSI

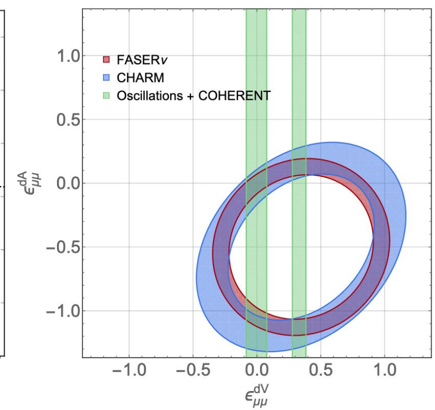
LHC neutrino experiments can also constrain the neutral current cross section.

This can be used to constrain neutrino non-standard interactions (NSI).

$$\mathcal{L} \supset -\sqrt{2}G_F \sum_{f,\alpha,\beta} [\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta][\epsilon^{f,V}_{\alpha\beta} \bar{f}\gamma_\mu f + \epsilon^{f,A}_{\alpha\beta} \bar{f}\gamma_\mu \gamma^5 f]$$





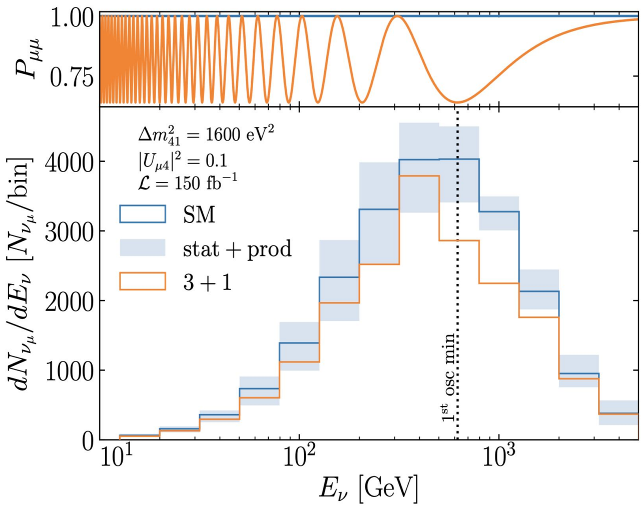


Abraham, Ismail, Kling [2012.10500]

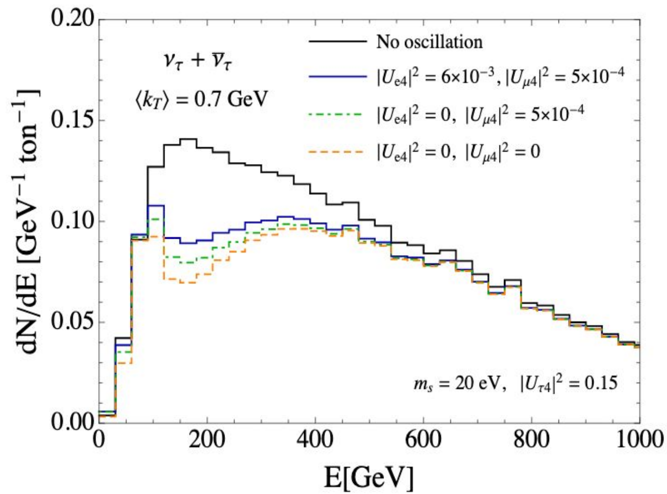
Neutrino Oscillations

SM neutrino oscillations are expected to be negligible at the LHC.

However, sterile neutrinos with mass ~40eV can cause oscillations. LHC neutrino detectors could act as a short-baseline neutrino experiment.



FASER collaboration
[1908.02310]



Bai, Diwan, Garzelli, Jeong, Reno
[2002.03012]

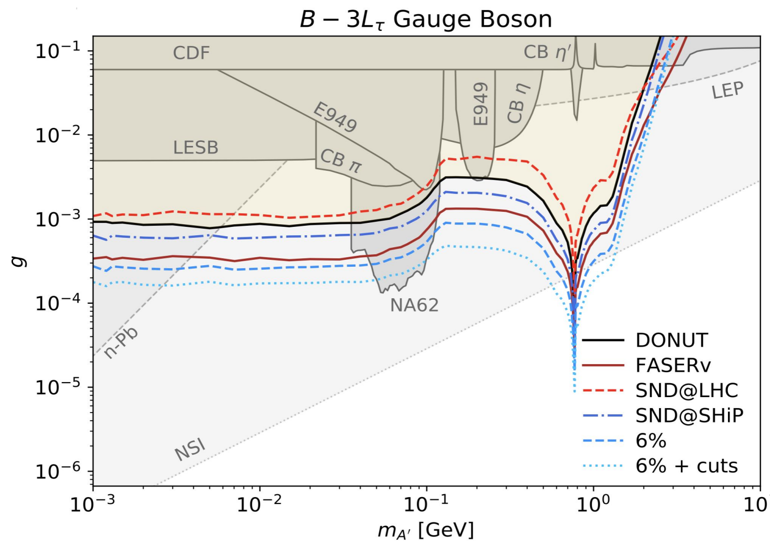
BSM contributions to tau neutrino flux

The tau neutrino flux small in SM. A new light weakly coupled gauge bosons decaying into tau neutrinos could significantly enhance the tau neutrino flux.

Example: B-3Lτ gauge boson
- anamonaly free gauge group
- abundantly produced at LHC
- decays mainly into ντ
- (relatively) poorly constrained
- search for excess in ντ flux

$$\pi^0 \to V\gamma, \quad V \to \nu_\tau \nu_\tau$$

Kling [2005.03594]

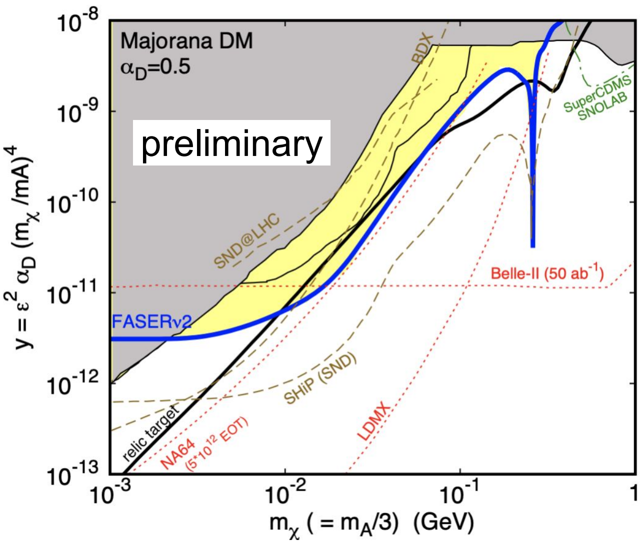


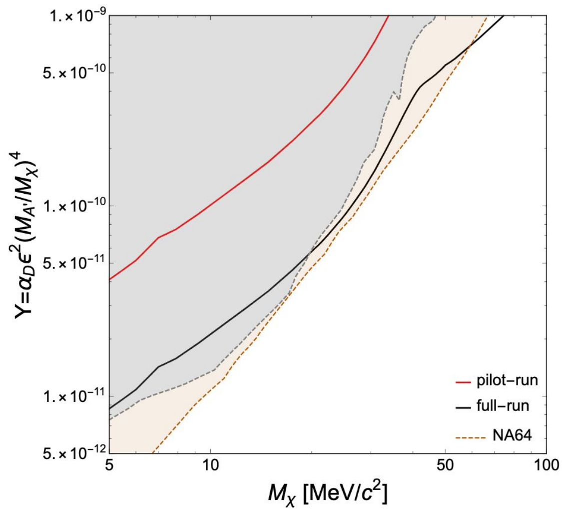
A separate study considered a similar scenario with a new light gauge boson that only couples to neutrinos: Bahraminasr, Pouya Bakhti, Meshkat Rajaee [2003.09985]

DM scattering

If DM is light, the LHC can produce an energetic and collimated DM beam in the forward direction. One simple example is the dark photon portal: π0 → A’ γ, A’ → X X

LHC neutrino experiments could search for DM scattering on electrons: X e → X e.





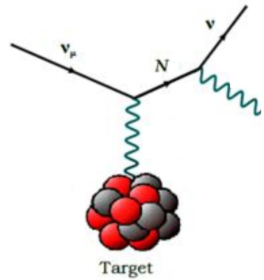
Batell, Feng, Trojanowski (in progress)

SND@LHC [2002.08722]

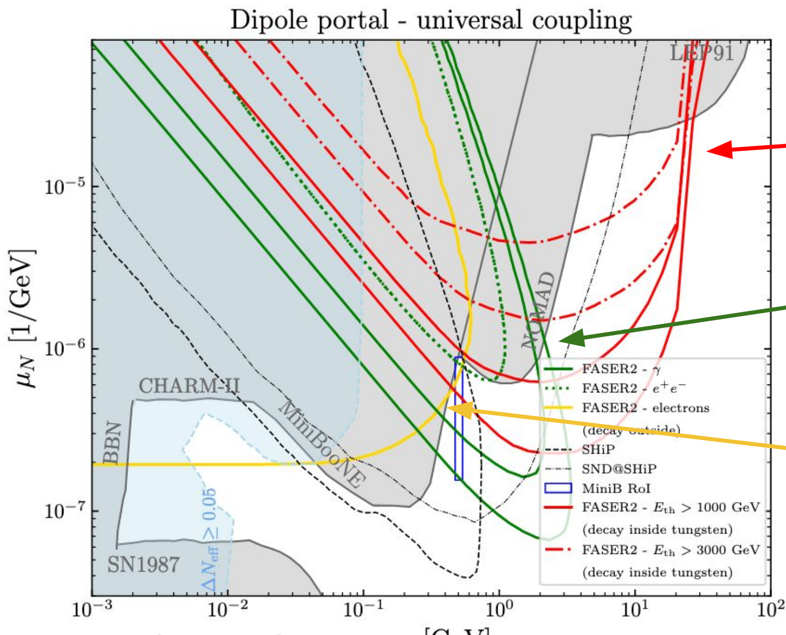
Neutrino dipole couplings to HNLs

The SM neutrinos could have dipole coupling to heavy sterile neutrinos N

$$\mathcal{L} \supset \mu_N \, \bar{\nu}_L \sigma_{\mu\nu} N_R F^{\mu\nu}$$



N could be produced in neutrino interactions, and would have macroscopic lifetimes.



limits for HL-LHC

N decays in FASERν: high energy photon

N decays in FASER decay volume

ν scatters on electrons, N escapes undetected

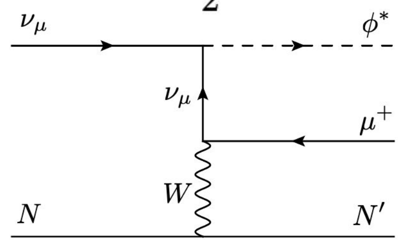
Jodlowski, Trojanowski [2011.04751]

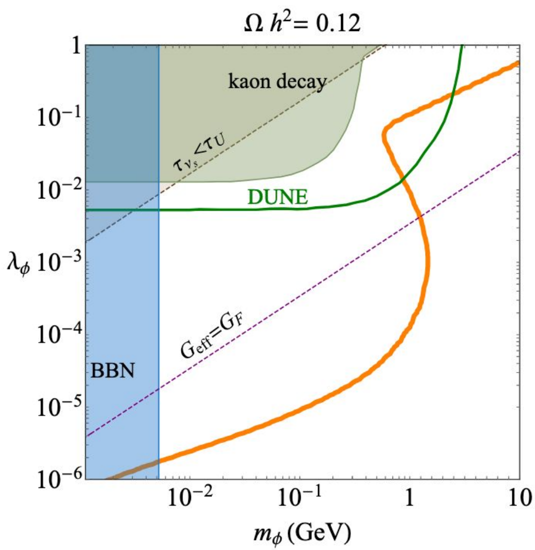
Neutrinophilic DM

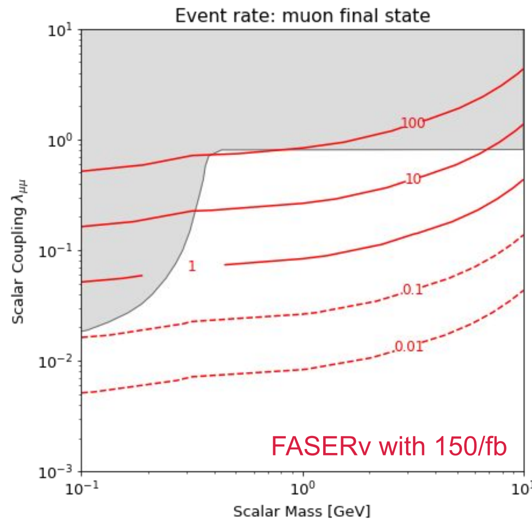
DM could be more elusive, and for example only talk to neutrinos. This scenario has been investigated in variety of studies: Kelly, Zhang [1901.01259], de Gouvea, Sen, Tangarife, Zhang [1910.04901]

At LHC neutrino experiments this would lead to charged current events with additional missing transverse momentum.

$$\mathcal{L} \supset \frac{\lambda_\phi}{2}\nu_a\nu_a\phi$$







Kelly, Kling, Tuckler, Zhang

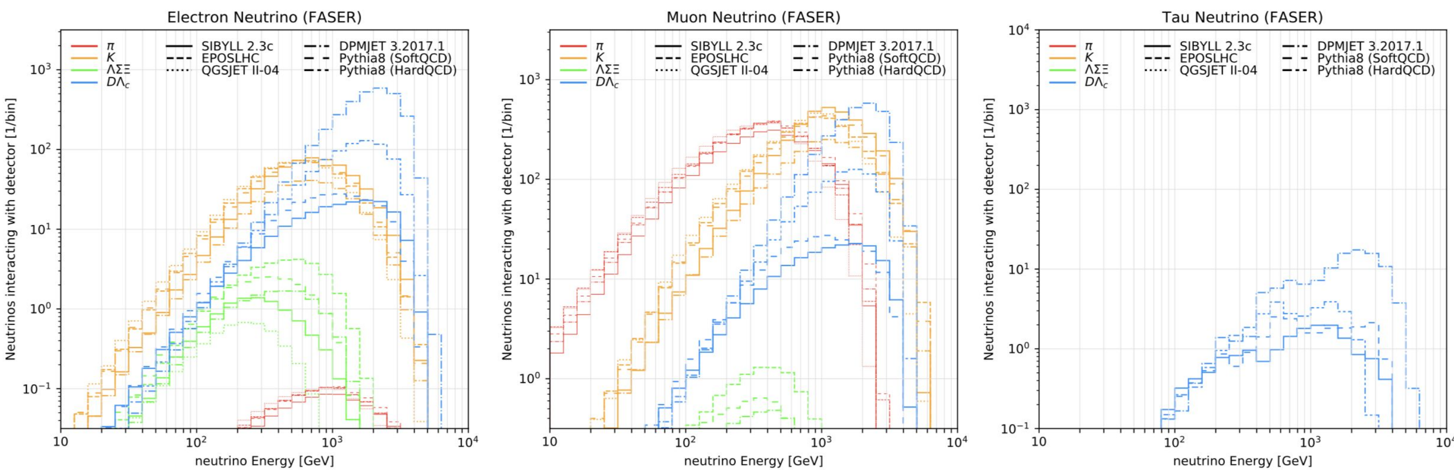
SM Requirements

In order to be able to search for subtle hints of new physics, one needs a precise predictions for the LHC's neutrino fluxes and neutrino interactions at TeV energies.

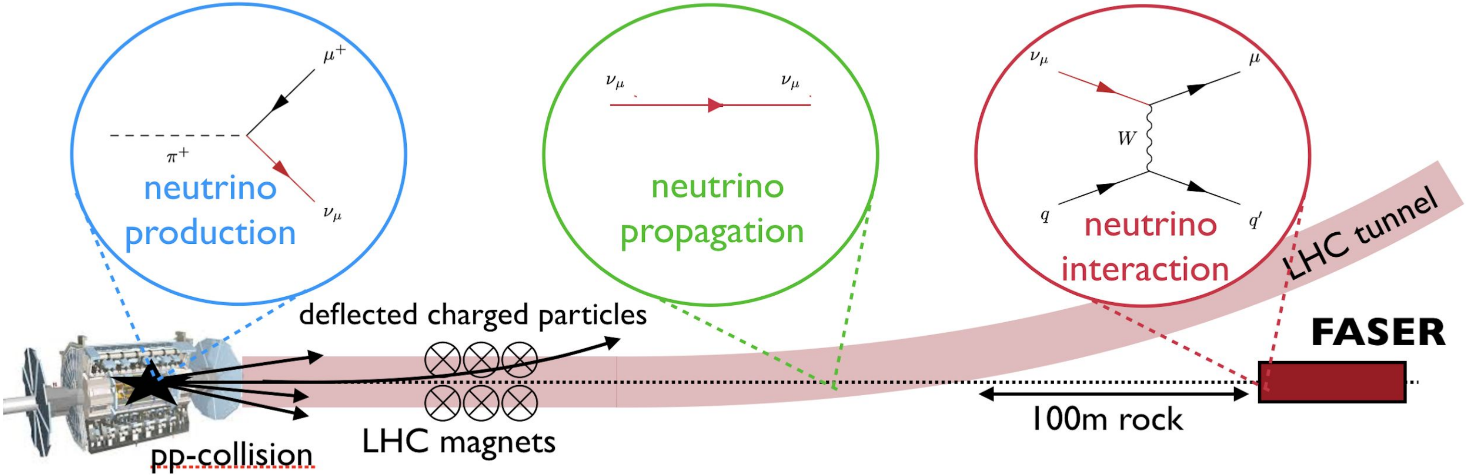
At the moment, there are large differences between different event generators. It is not clear how uncertainties should be defined.

	DPMJET	SIBYLL	Pythia8
ν_e , $\bar{\nu}_e$	3390 , 1024	800 , 452	826 , 477
ν_μ , $\bar{\nu}_\mu$	8270, 2391	6571 , 1653	7120 , 2178
ν_τ , $\bar{\nu}_\tau$	111 , 43	16 , 6	22 , 11

We need to quantify and reduce these uncertainties.



Summary



LHC neutrino experiments open up many new opportunities for neutrino physics, QCD measurements and BSM physics searches that can significantly extend the LHC's physics program.

A good understanding of systematic uncertainties is often crucial for such measurements.

Backup: all Fluxes