Neutrinos in the far-forward region at the LHC

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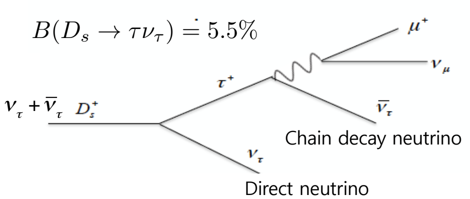
Weidong Bai (U Iowa), Milind Diwan (BNL), Maria Vittoria Garzelli (U degli Studi di Firenze & INFN, Firenze), Yu Seon Jeong (CERN), Mary Hall Reno (U Iowa)

Neutrinos & Heavy Flavor

Our new evaluation [1] of neutrino production in the far-forward region at the LHC is a topic of renewed interest with experiments under design or in preparation, e.g., Faser-nu [2], XSEN [3] and SND@LHC [4].

Production of D_s and B mesons, their prompt decays to ν_τ and τ, then decays of τ can produce a significant number of tau (anti-) neutrinos in the far-forward region.

The D_s production and decay is most important.



Direct ($D_s \to \nu_\tau$) and chain decay ($D_s \to \tau \to \nu_\tau$).

Our work [1]:

- NLO QCD + fragmentation functions to evaluate heavy flavor production at the LHC.
- Uncertainties associated with QCD renormalization and factorization scales.
- Non-perturbative transverse momentum smearing $\langle k_T \rangle$ uncertainties.

LHCb data [5] for D_s production in the rapidity range of $2.0 < y < 4.5$ guide parameter choices.

The NLO QCD evaluation is complemented by Peterson fragmentation functions and a phenomenological Gaussian smearing factor:

$$f(k_T^2) \sim \exp\left[-k_T^2 / \langle k_T^2 \rangle\right]$$

Factorization and renormalization scales here depend on transverse mass:

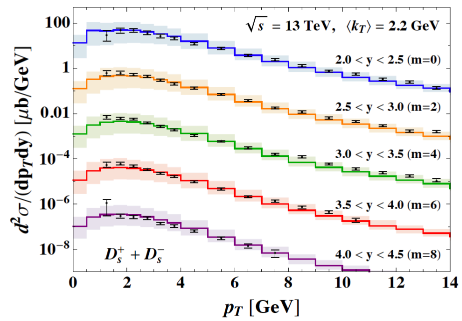
$$(\mu_R,\, \mu_F) = (N_R,\, N_F)\; m_T$$

LHCb data are well reproduced with

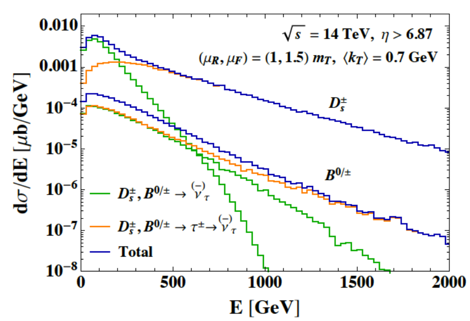
$$(N_R,\, N_F) \;=\; (1,\, 1.5)$$

$$\langle k_T \rangle = 2.2\ \text{GeV}\ \left(\langle k_T^2 \rangle = 6.2\ \text{GeV}^2\right)$$

An alternative choice would be $\langle k_T \rangle = 0.7$ GeV, more consistent with a Fermi motion interpretation.

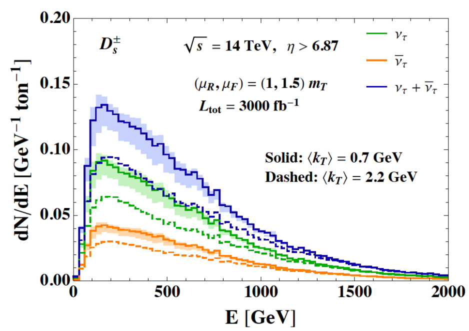


QCD predictions for D_s production with (N_R, N_F) = (1, 1.5), $\langle k_T \rangle$ = 2.2 GeV and LHCb data [5]. The shaded bands show the scale uncertainty bands.



The tau neutrino plus antineutrino energy distributions for $\eta > 6.87$ in pp collisions at $\sqrt{s}$ = 14 TeV from D_s and B.

Tau Neutrino Events



Tau neutrino and antineutrino events per ton of lead, from D_s production and decay, as a function of neutrino energy for $\eta > 6.87$, $\sqrt{s}$ = 14 TeV, and L_{tot} = 3 ab^{-1}. The shaded bands show the variation in the range of $\langle k_T \rangle$ = 0 - 1.4 GeV. The dashed histograms show results for $\langle k_T \rangle$ = 2.2 GeV.

QCD scale variations lead to large uncertainties in the absolute prediction of the number of events. Experiments that probe heavy flavor production in the forward region will help pin down uncertainties.

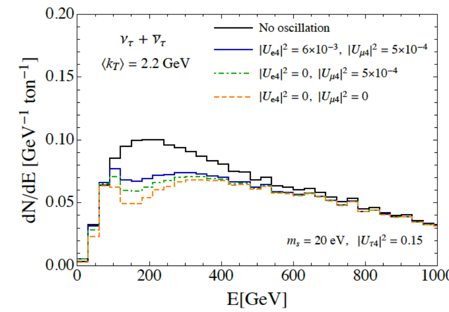
	ν_τ	$\bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$
$(\mu_R,\ \mu_F)$	$(1,\ 1.5)\ m_T$		
$\langle k_T \rangle$	0.7 GeV		
D_s	2451	1191	3642
$B^{\pm,0}$	96	46	142
Total	2547	1237	3784

	$\nu_\tau + \bar{\nu}_\tau$		
$(\mu_R,\ \mu_F)$	$(1,\ 1.5)\ m_T$		
$\langle k_T \rangle$	0 GeV	1.4 GeV	2.2 GeV
D_s	3799	3261	2735
$B^{\pm,0}$	144	137	127
Total	3943	3398	2862

Charged current event numbers for $\eta > 6.87$ and 1 m of lead, with integrated luminosity of L_{tot} = 3 ab^{-1}, for some scale choices.

The number of events from D_s dominate B contributions by more than a factor of 20.

BSM Physics: Sterile neutrino



Number of tau neutrinos plus antineutrinos per unit neutrino energy in four-flavor mixing scenarios with a 20 eV fourth generation neutrino, over a 480 m baseline.

Large numbers of tau neutrino events give the opportunity to constrain mixing with a fourth flavor of neutrino (sterile neutrino). The mixing element $|U_{\tau4}|$ is the least-constrained element.

Over a 480 m baseline, an oscillation dip occurs near the neutrino energy of ~200 GeV for a sterile neutrino mass of 20 eV.

References

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[2] H. Abreu et al., arXiv:2001.03073.
[3] N. Beni et al., arXiv:1910.11340.
[4] C. Ahdida et al., arXiv:2002.08722.
[5] R Aaij et al., JHEP 03 (2016) 159, erratum ibid 09 (2016) 13.

weidong-bai@uiowa.edu
diwan@bnl.gov
garzelli@mi.infn.it
yuseon.jeong@cern.ch
mary-hall-reno@uiowa.edu

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