Informal Discussion: Neutrino Fluxes at the LHC

December 21st

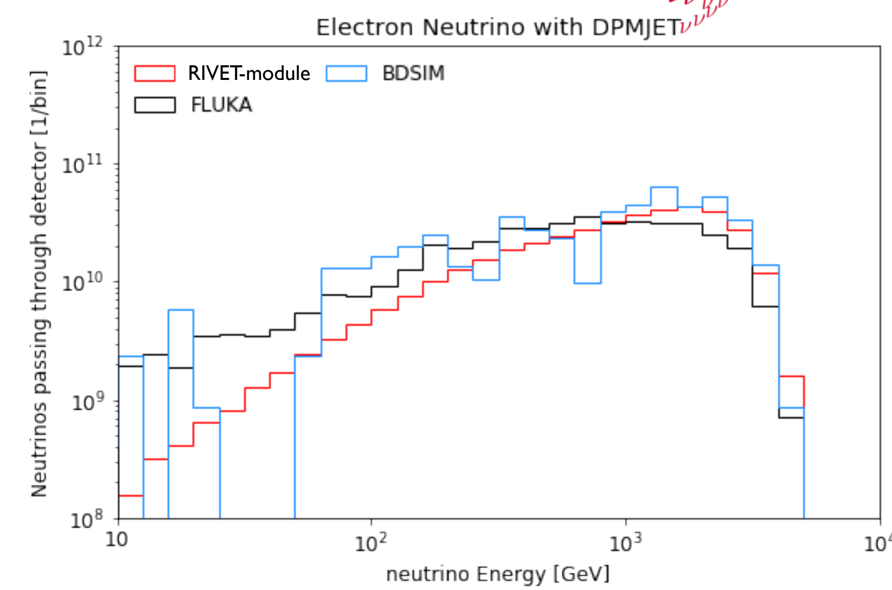
Felix Kling

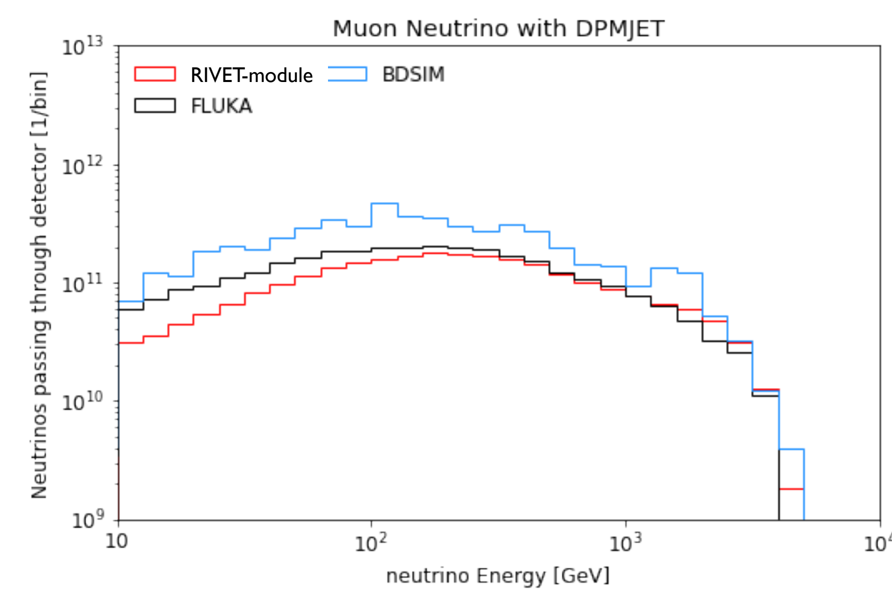
Previous Neutrino Flux Simulations

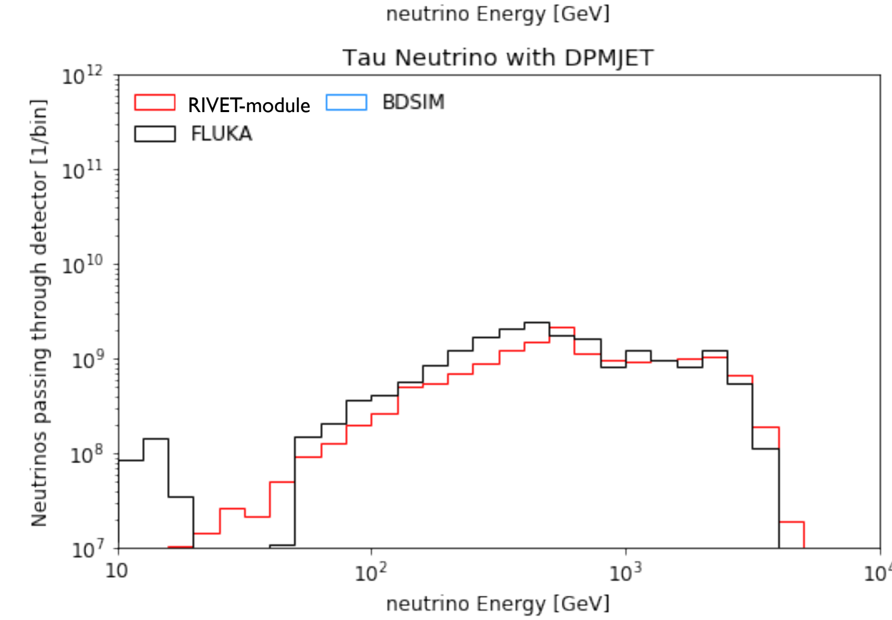
We compares three simulation (DPMJET)
- FLUKA (by CERN STI team)
  - v???, 13TeV?, 150urad vert. up corrected, decay?
- BDSIM (by Helena Lefebvre)
  - v???, 13TeV, no xing, DPMJET
- RIVET-Module (by me)
  - v3.2017.1, 14 TeV, no xing, Pythia8

Results seem generally consistent.

Possible Differences:
- generator; incl. version
- beam energy
- beam crossing angle
- decay BR / simulation
- T112 vs T118 ? Run2 vs Run3 setting ? … ?
- limited statistics







Simulations used here

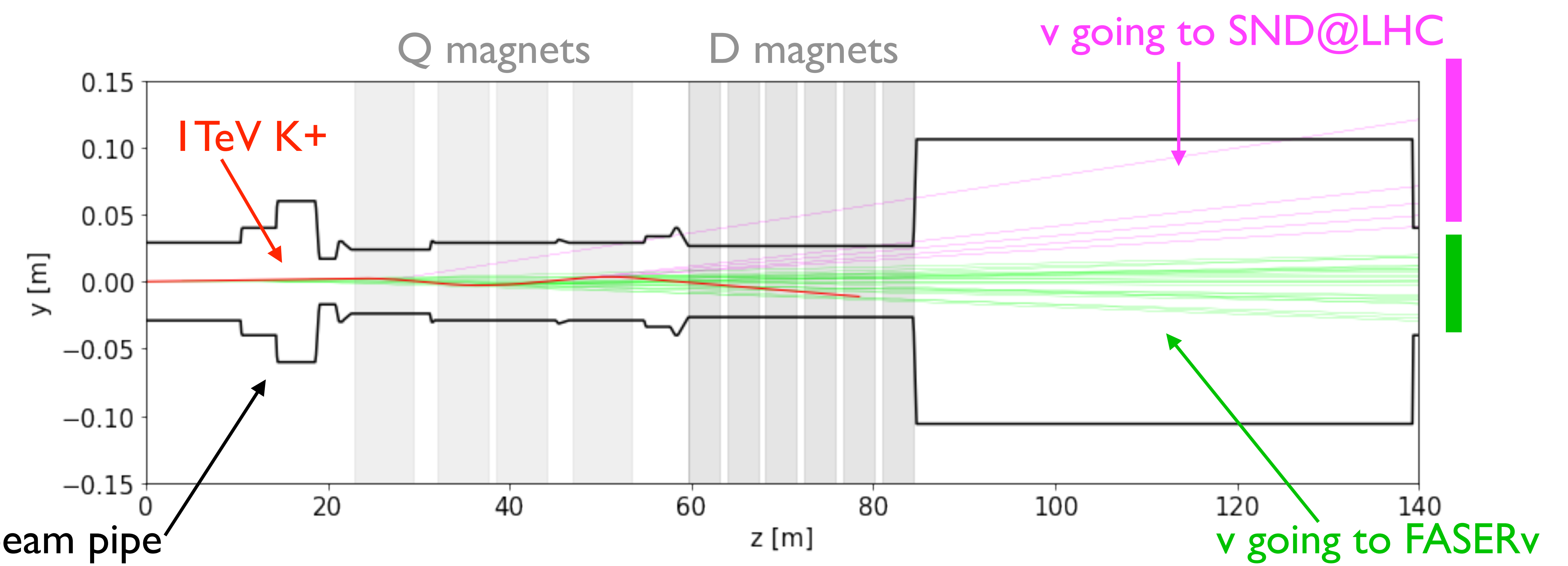
All these differences make it hard to understand the simulations. To <u>compare different event generators</u>, it's better to use a single simulation with fixed setting.

Solution used here: RIVET-module

- only ν's produced in beam pipe: νs from secondary interaction don't contribute (BDSIM)

- reads the forward hadron fluxes
- decays hadrons along trajectory
- propagates hadrons through pipe
- obtains neutrino fluxes histograms

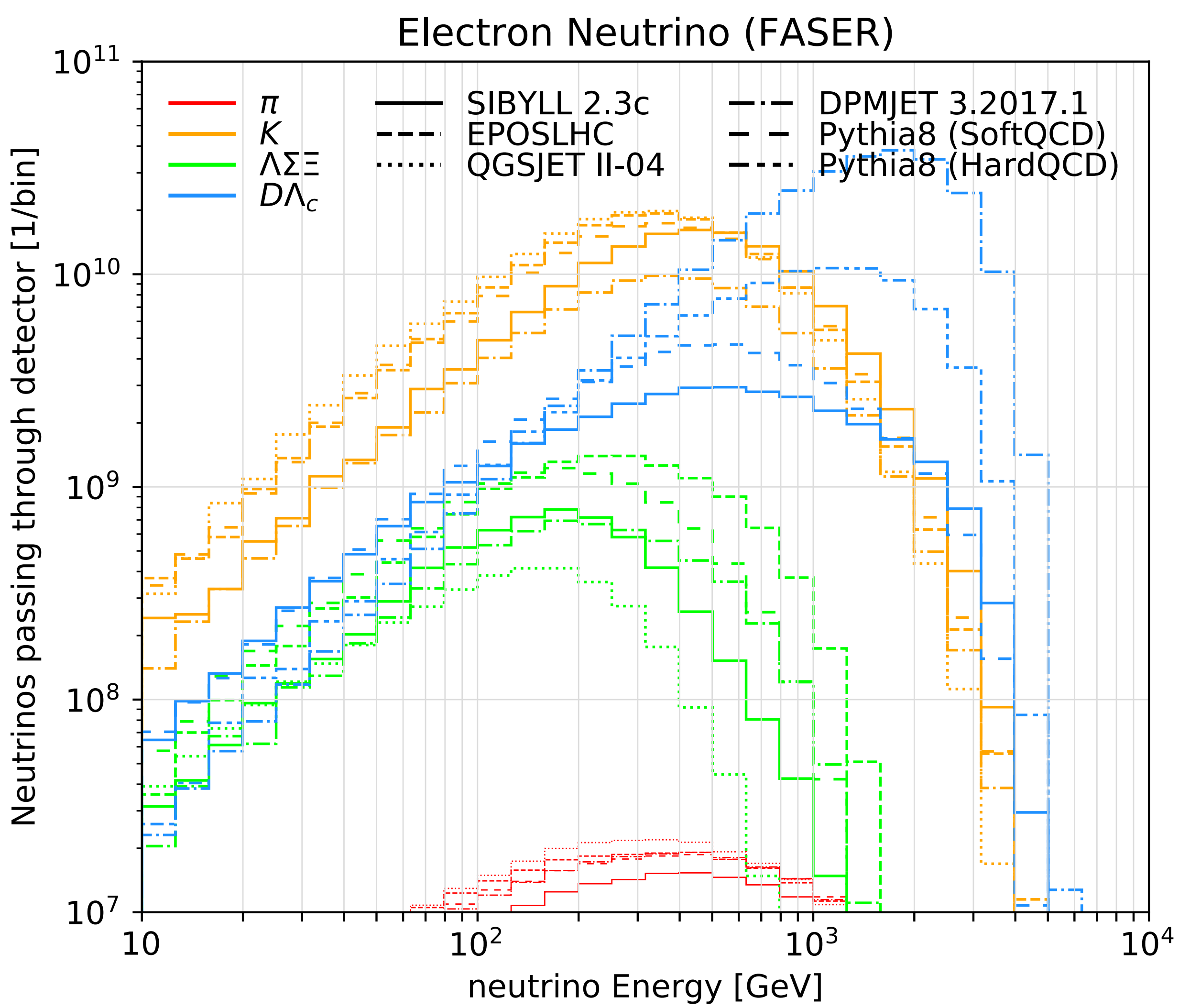
- based on BDSIM Run2 geometry
- very fast (similar to event generation)
- 14 TeV LHC with no crossing angle
- results for FASERν and SND@LHC

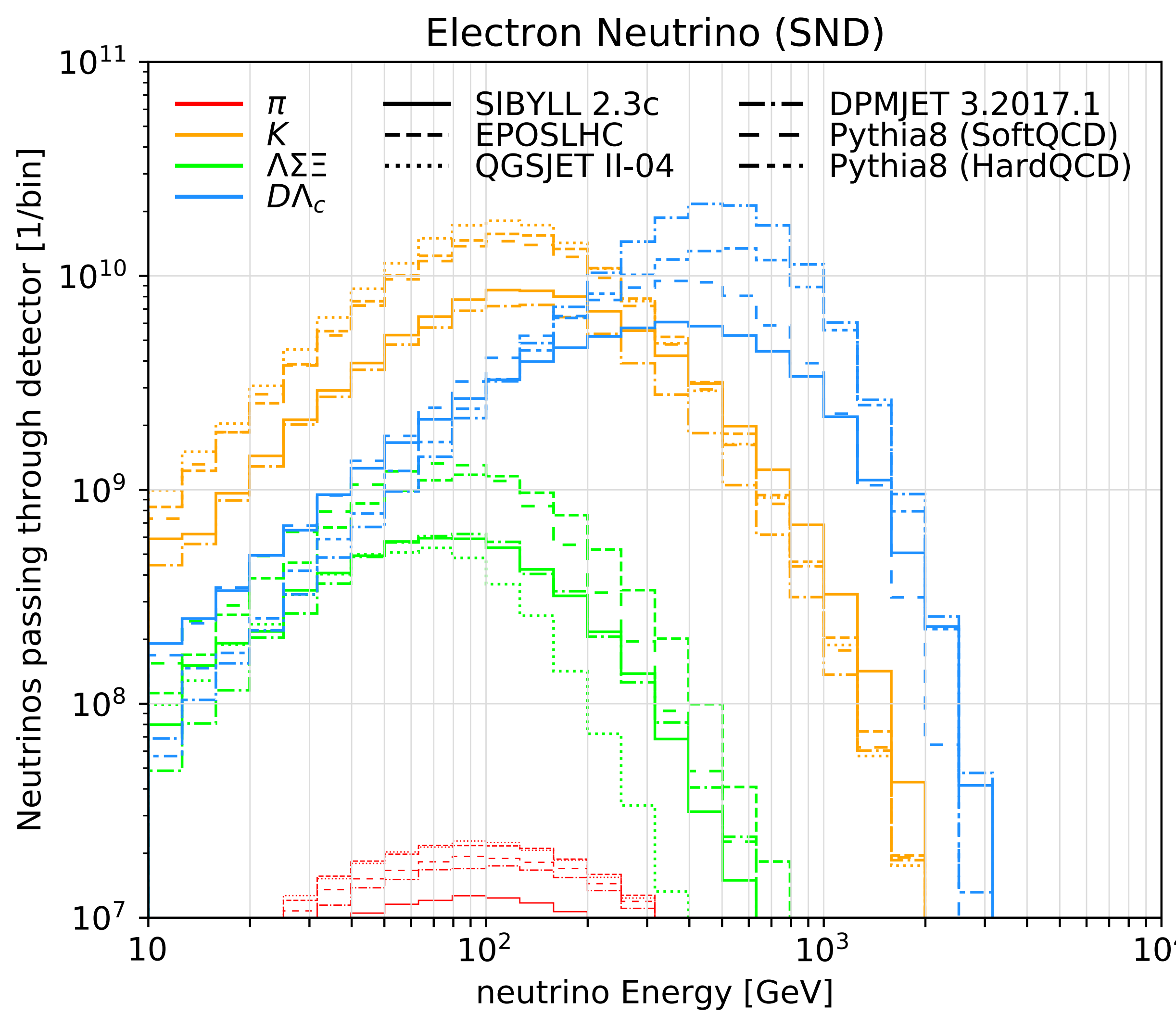


Energy Spectrum: nu_e

Neutrino flux for different generators (validated and unvalidated), split by parent hadron
- light hadrons decays: SIBYLL, EPOSLHC, QGSJET, Pythia8 and DPMJET
- charm decays: SIBYLL, Pythia8 (SoftQDC), Pythia8 (HardQCD) and DPMJET

Kaon decays dominate at low energy < few 100 GeV, charm decays at high energy



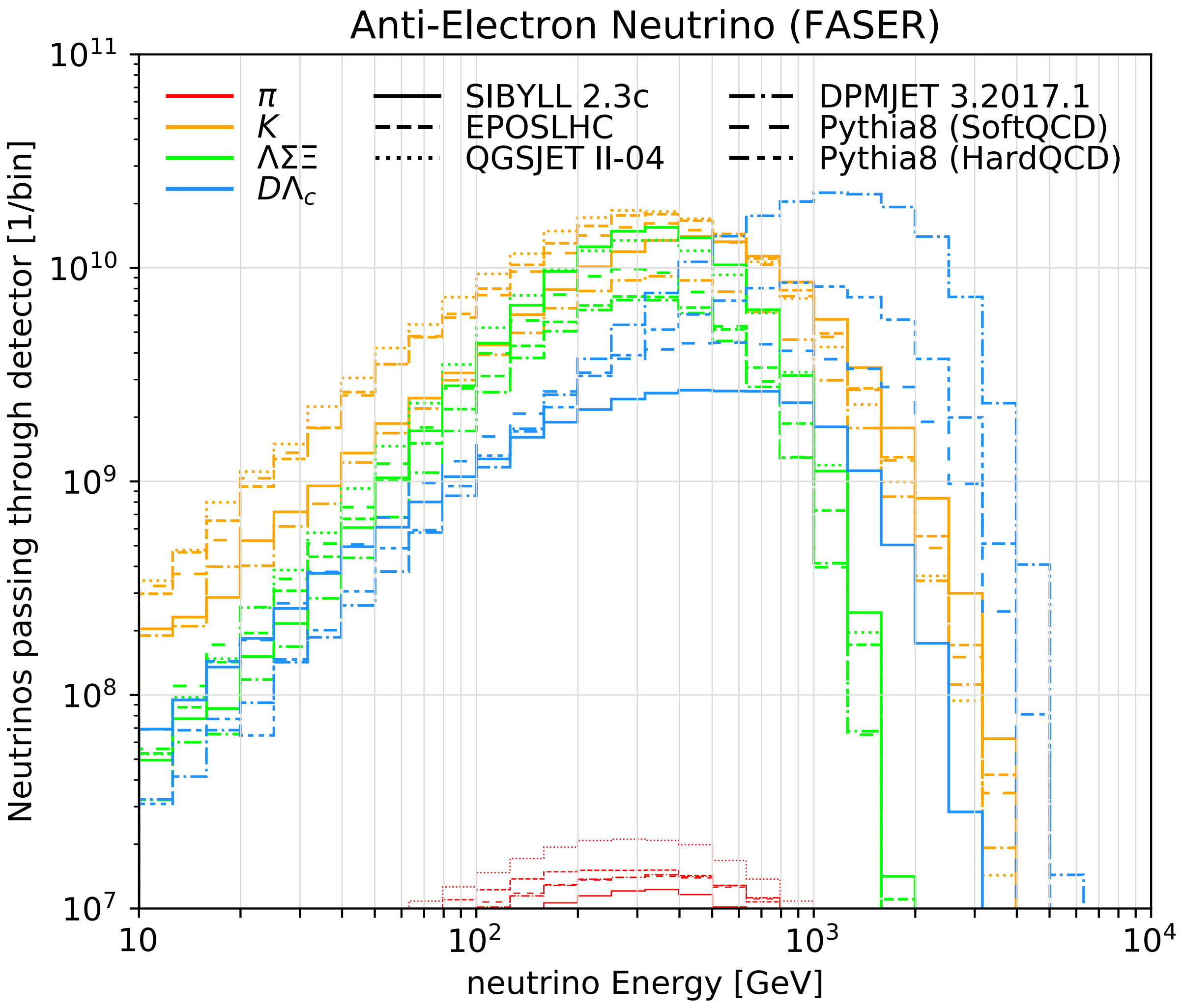


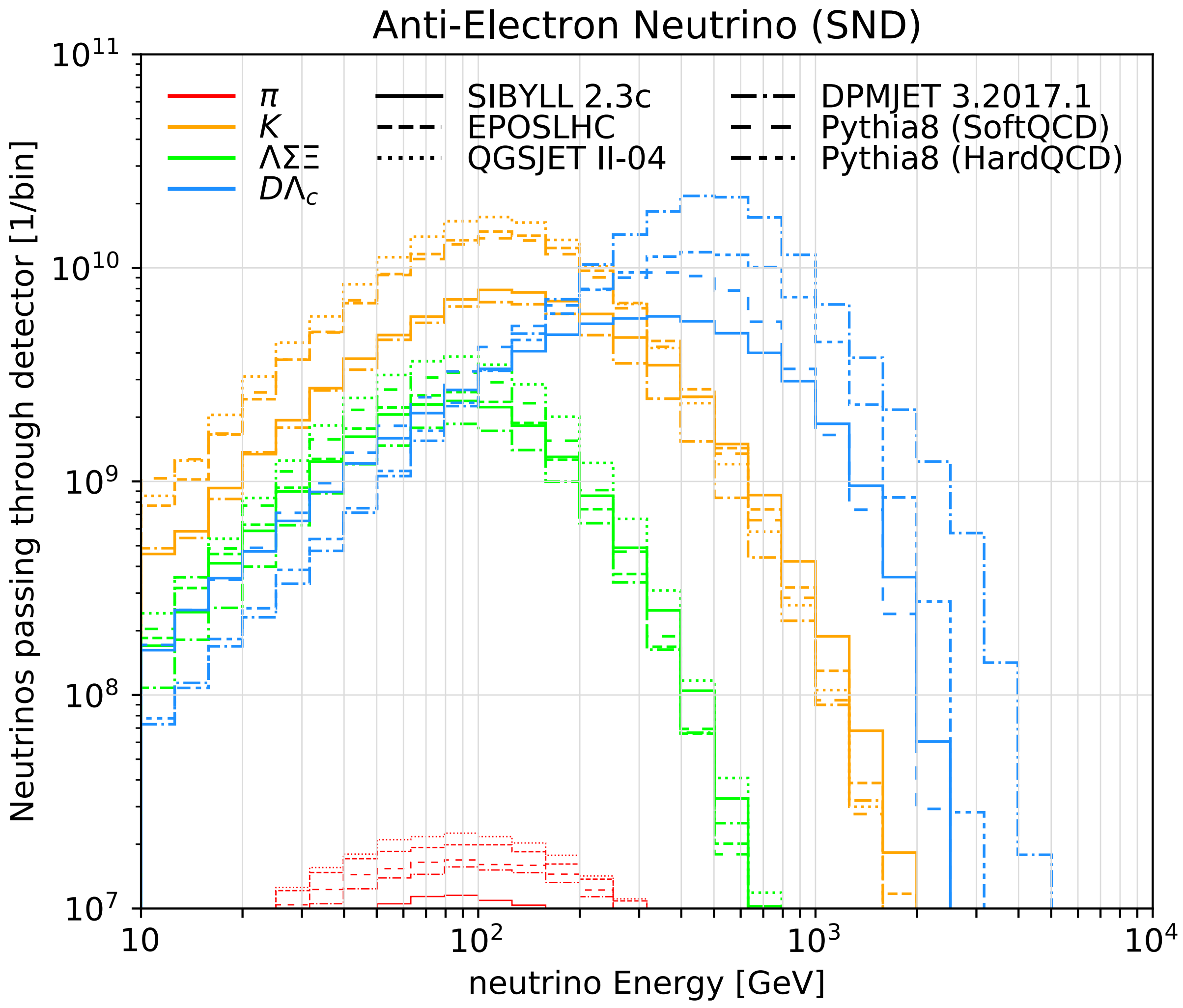
Anatoli Fedynitch (maintains DPMJET):

DPMJET-III is not validated at all for charm production and produces too hard spectra. It should not be used as an estimate, not even in a rough systematic comparison.

Energy Spectrum: nubar_e

Enhanced forward Λ production contributes significantly to anti-electron neutrino flux at FASERν

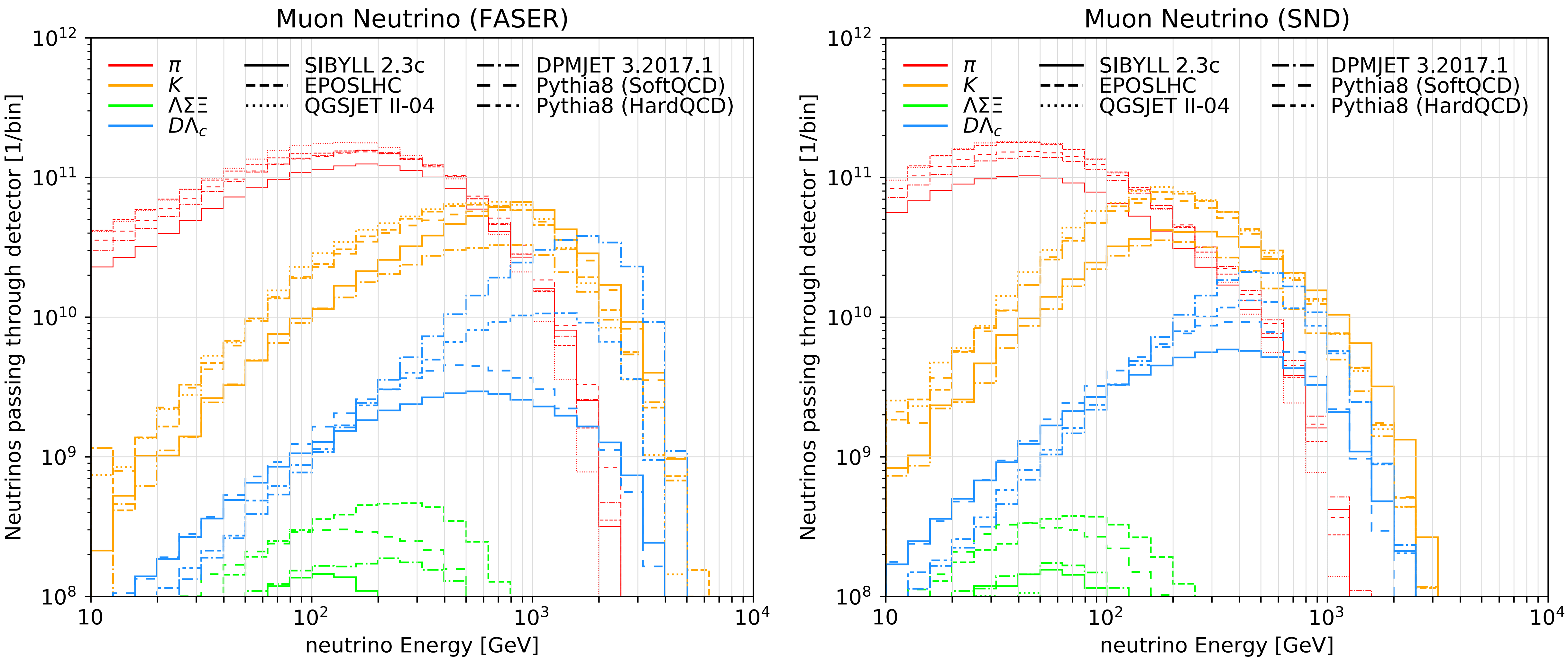




Energy Spectrum: nu_mu

Mostly from pion decays at low energy and kaon decays at high energy.

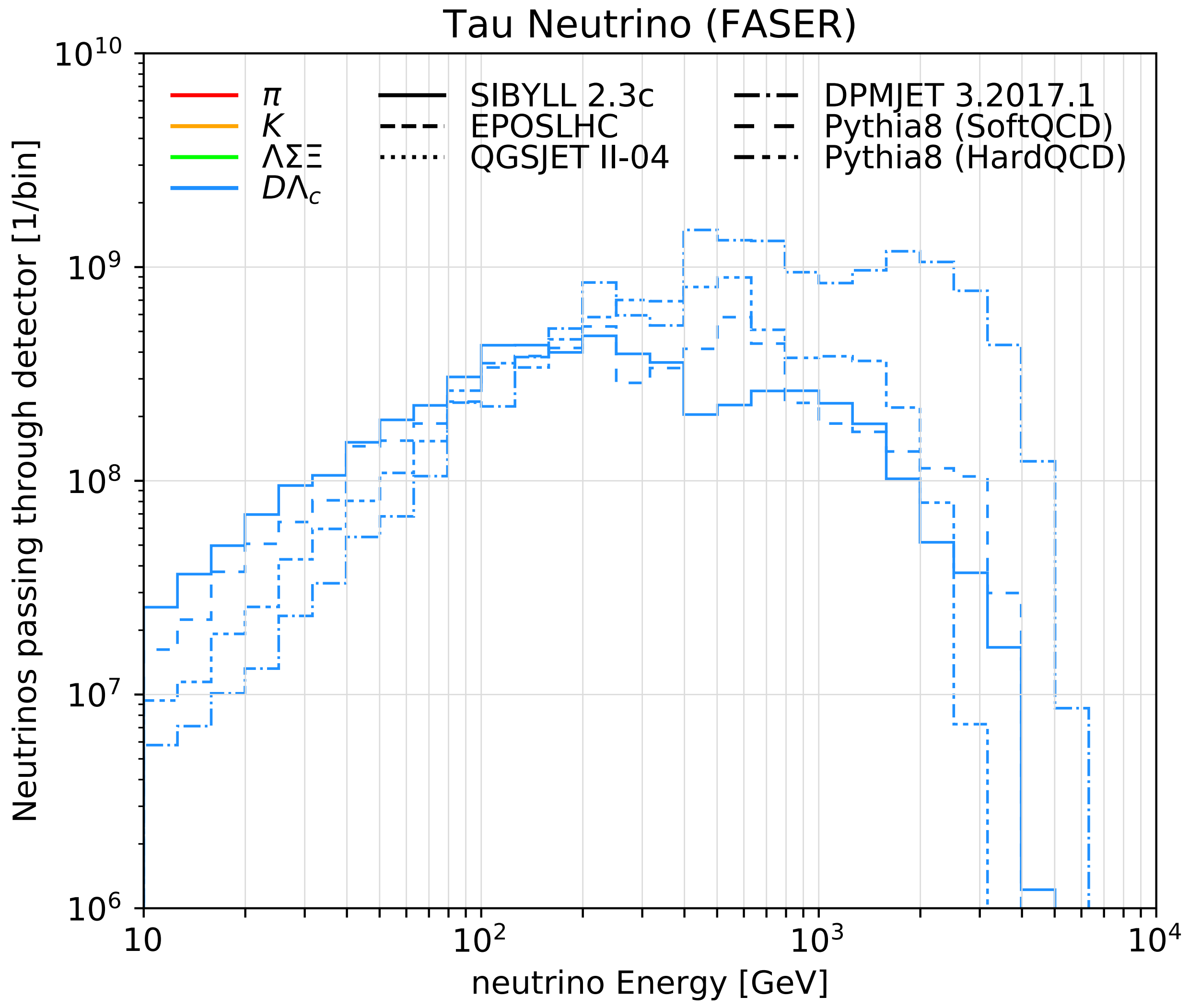
Importance of charm decay strongly depends on used event generator:
- DPMJET predicts enhanced charm production and suppressed kaon production
- SIBYLL predicts enhanced kaon production and suppressed charm production

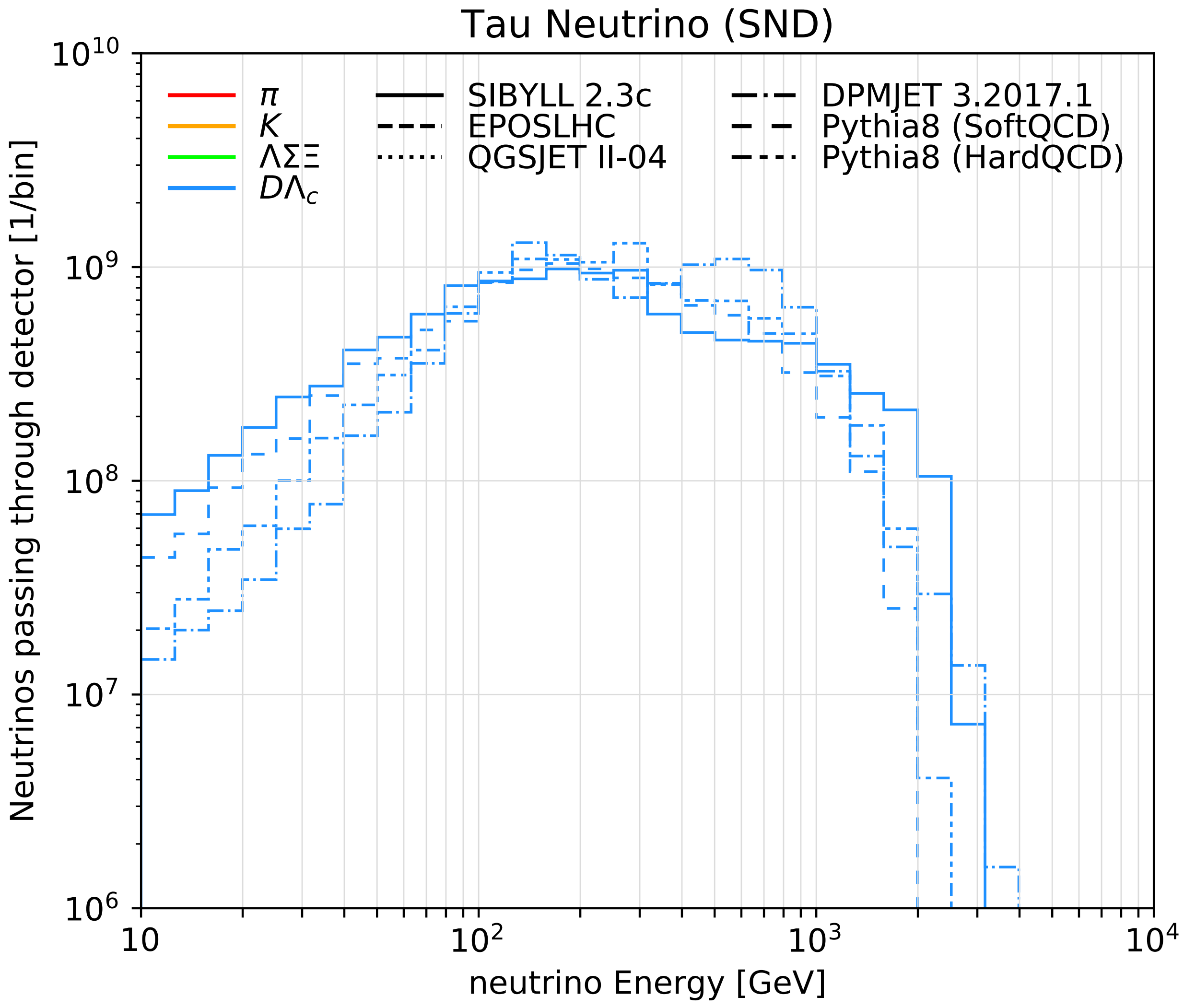


Energy Spectrum: nu_tau

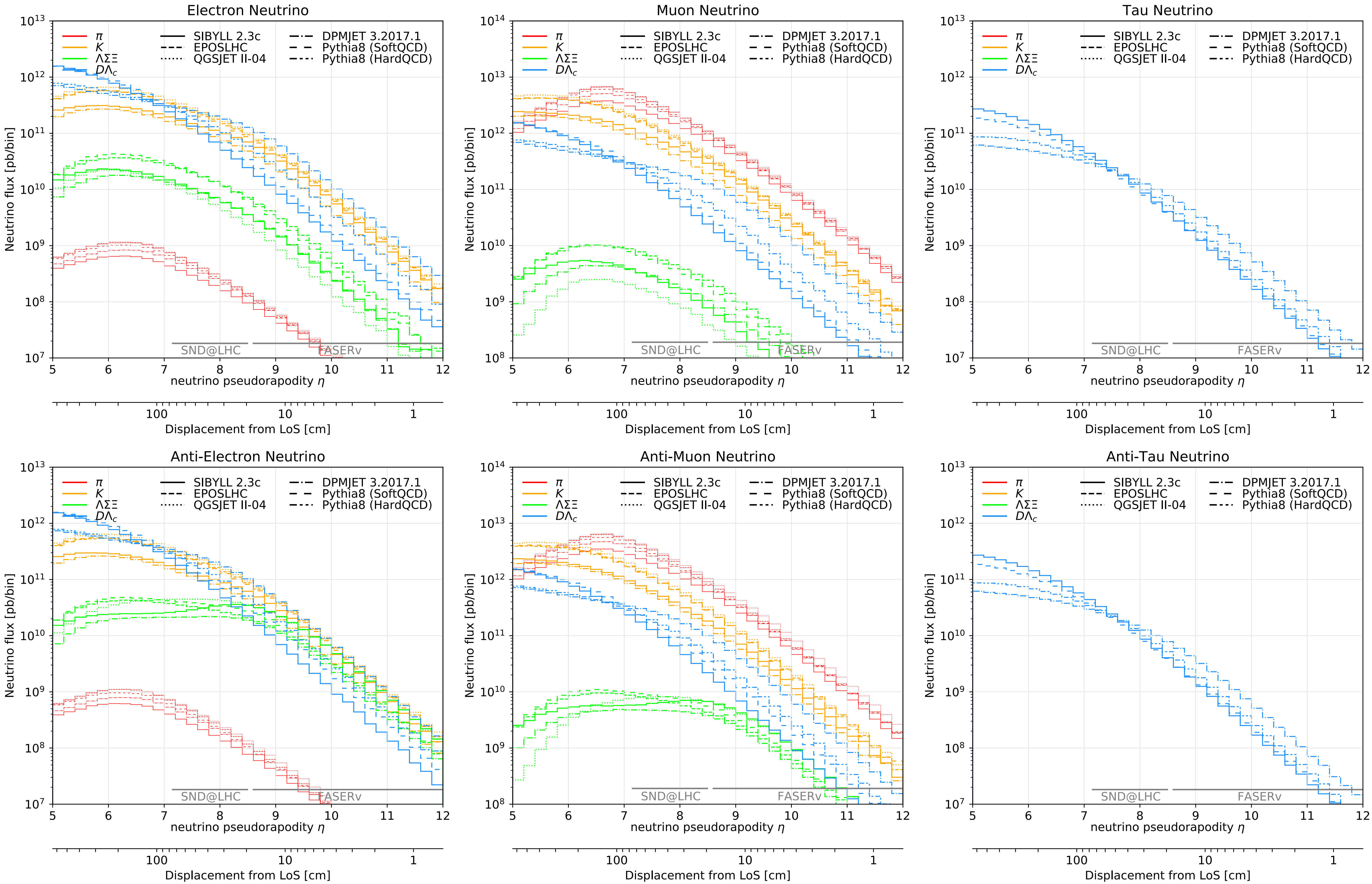
Mainly from Ds decay.

B decays contribute at O(10%) level, but are not shown here.

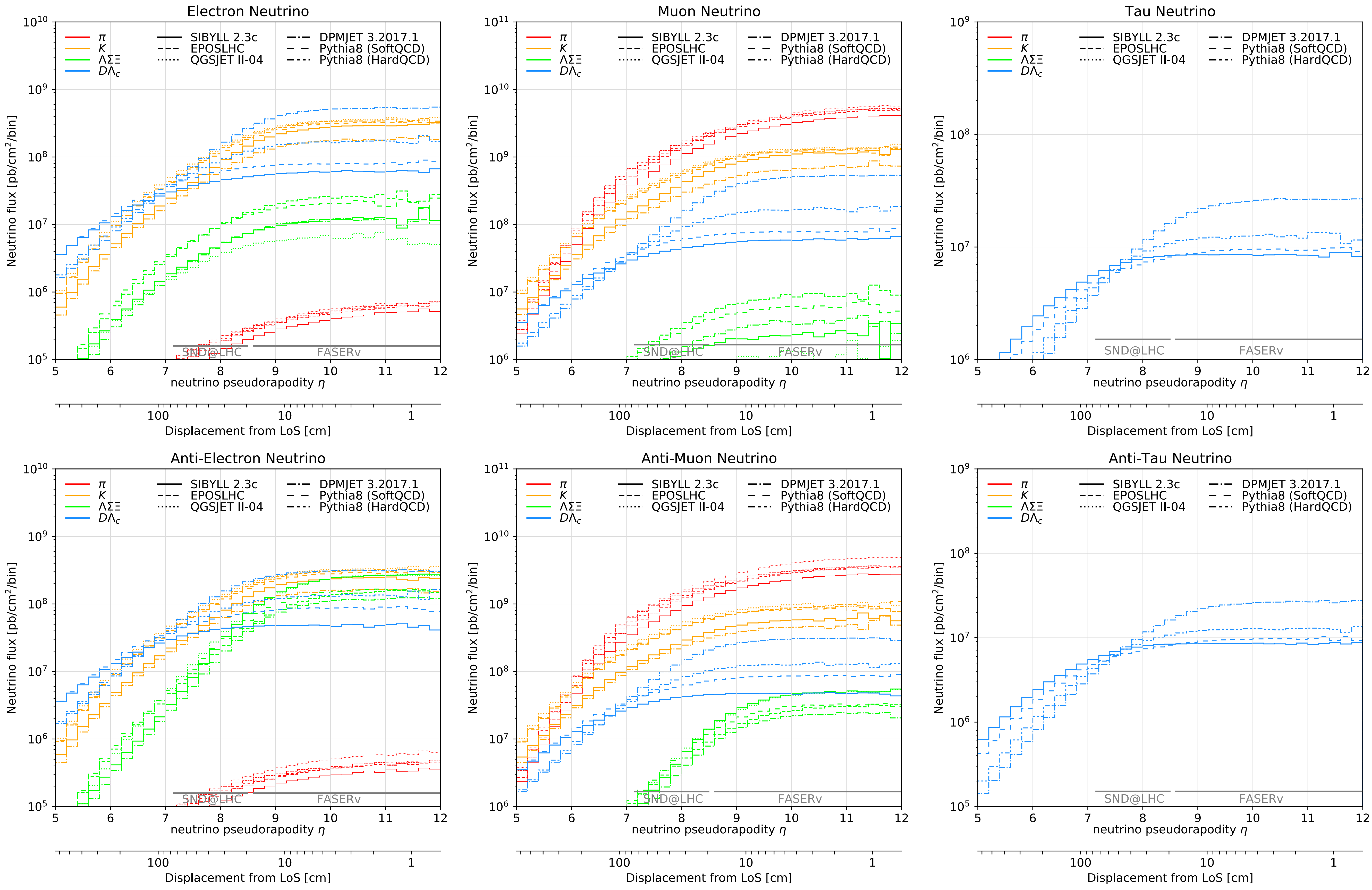




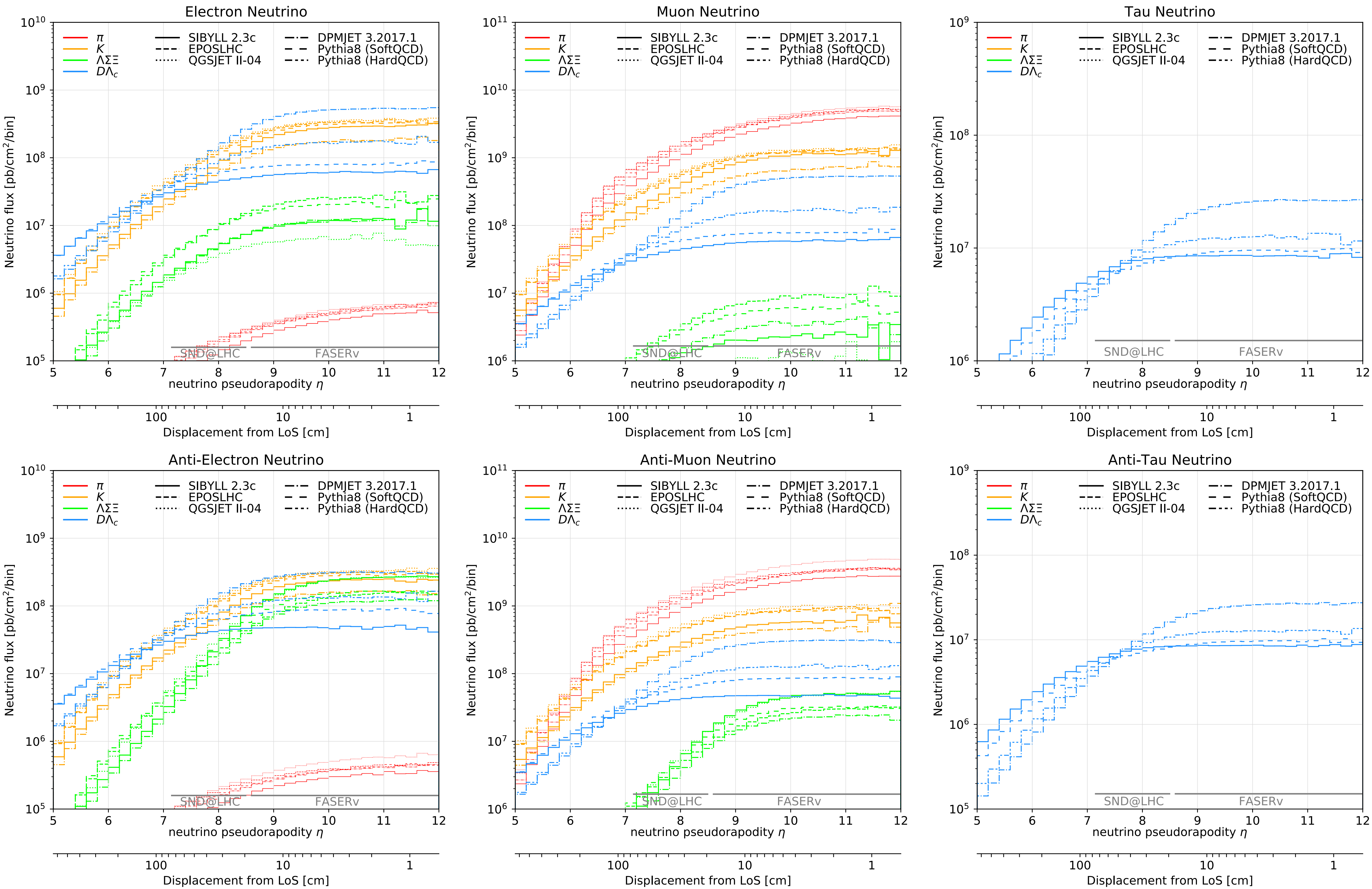
Radial Spectrum: eta distribution



Radial Spectrum: flux



Radial Spectrum: flux (linear scale)



Neutrino Flux Uncertainties:

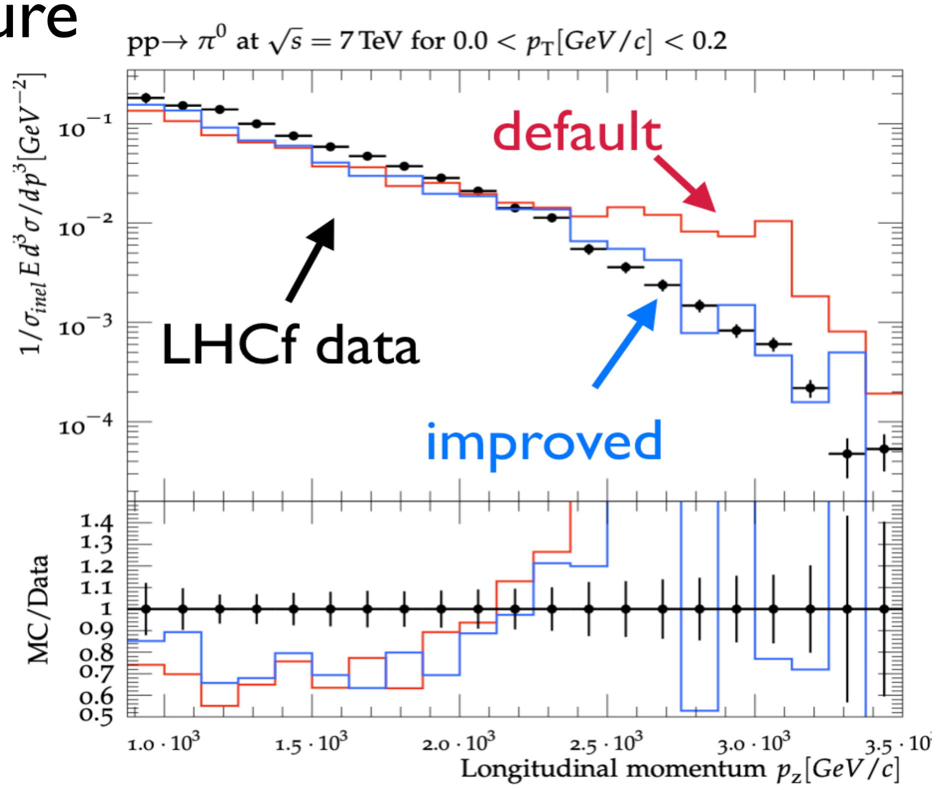
Uncertainties associated with forward hadron production are important
- includes sizable shape uncertainties, coming from relative size of different contributions

Dedicated Cosmic Ray Monte Carlos (CRMCs):
- sophisticated modeling of hadronic interaction
- tuned to data from fixed target, heavy ion, cosmic ray, HERA, LEP and LHC experiments

charm data used for SIBYLL 2.3c: 1806.04140

Name	$P_{\rm Lab}$ (GeV)	$\sqrt{s}$ (GeV)	x_F spectrum	x_F coverage	Beam config.	Ref.
E-769	250	22	yes	$-0.1 < x_F < 0.8$	p-Nuc	[52, 63]
EHS	400	27.4	yes	$0 < x_F < 0.6$	p-p	[53, 64]
MPS	800	39	yes	$-0.1 < x_F < 0.4$	p-p	[54]
HERA-B	920	42	no	$-0.1 < x_F < 0.05$	p-Nuc	[55]
STAR	21 TeV	200	no	$-0.03 < x_F < 0.03$	p-p	[57]
PHENIX	21 TeV	200	no	$-0.003 < x_F < 0.003$	p-p	[58]
ALICE	4 PeV	2.76 TeV	no	$-0.005 < x_F < 0.005$	p-p	[59]
	26 PeV	7 TeV	no	$-0.004 < x_F < 0.004$	p-p	[60]
LHCb	26 PeV	7 TeV	no	$0.002 < x_F < 0.1$	p-p	[61]
	90 PeV	13 TeV	no	$0.002 < x_F < 0.1$	p-p	[62]

Multipurpose generators
- "forward physics often overlooked" (Sherpa)
- "forward physics is extensively modeled ... but little tested" (Pythia)
- there seems a general interest in improving this in the future
- dedicated forward physics tune for Pythia8 in progress



Are there other effects besides forward particle production
- consistency of different simulation tools
- secondary neutrino production
- beam crossing angle has O(10%) effect at high energy

Neutrino Flux Uncertainties:

How should we quantify neutrino flux uncertainties?

Tuning Uncertainties:
- hadronic interaction models have many phenomenological parameters, tuned to data
- similar to PDFs, we can obtain additional eigentunes to characterize tuning uncertainties
- clear statistical interpretation of uncertainties
- efforts ongoing for Pythia, but currently little interest to add this feature to CRMC

Range of generator prediction ("Pythia vs Herwig"):
- similar to results shown earlier
- would capture uncertainties due to differences in underlying modeling
- result would often depend on the outlier / least accurate generator
- which generators are considered trustworthy enough to be included
- no clear statistical interpretation of uncertainties

Perturbative uncertainties for charm production
- seem to be quite large (see 2002.03012)
- more work needed before those can be used
- not clear which QCD formalism should be used
- proposal: combined white paper with different theory group to compare their charm production predictions