PDF uncertainties in theoretical predictions for far-forward tau neutrinos at the LHC

MH Reno for

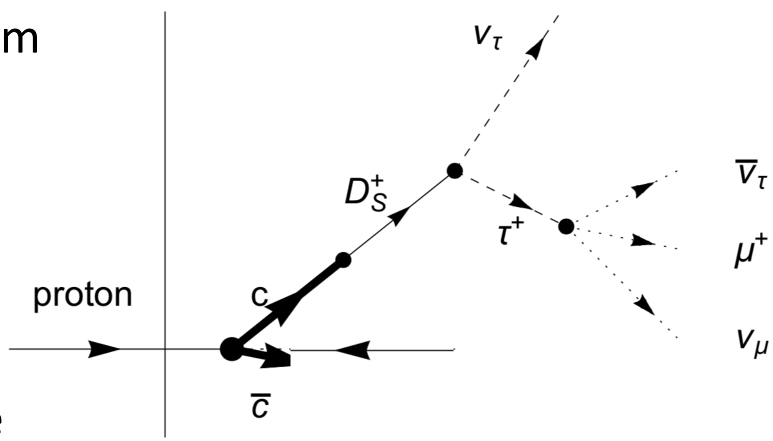
Weidong Bai, Milind Diwan, Maria Vittoria Garzelli, Yu Seon Jeong, Fnu Karan Kumar, MHR

preprint in preparation &
JHEP 06 (2020) 032 [2002.03012]

Work supported in part by the US DOE.

$\nu_\tau + \bar{\nu}_\tau$

- D_S is the lowest mass charm hadron to decay into $\bar{\nu}_\tau \tau$
- Pion-like decay: prompt
  $D_s^- \to \bar{\nu}_\tau \tau \to \bar{\nu}_\tau \nu_\tau X$
  Tau decay also prompt.
- Charm is dominant source of $\nu_\tau + \bar{\nu}_\tau$ - a factor of more than 10 larger than from b-quarks.



Forward production, $\eta_\nu > 6.9$

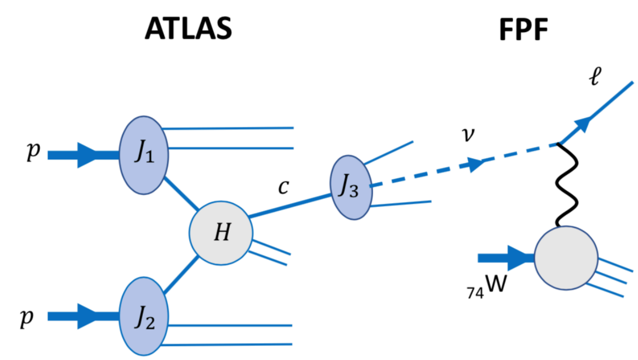
NLO pQCD evaluation of charm pair production.

- PROSA PDFs with scale & PDF uncertainties.
- Transverse momentum smearing.
- Other PDFs.

$$B(D_s \to \bar{\nu}_\tau \tau) = 5.48 \pm 0.23\%$$

Charm pair production

- PROSA 2019 fit to heavy flavor production including LHCb. Zenaiev et al, JHEP 04 (2020) 118.
  Fits include LHCb and HERA charm production cross sections.
  3 flavor PDFs.
- We use LHCb D_S data to (in part) anchor our FPF calculation.
- D_S rapidity correlated with ν_τ rapidity.



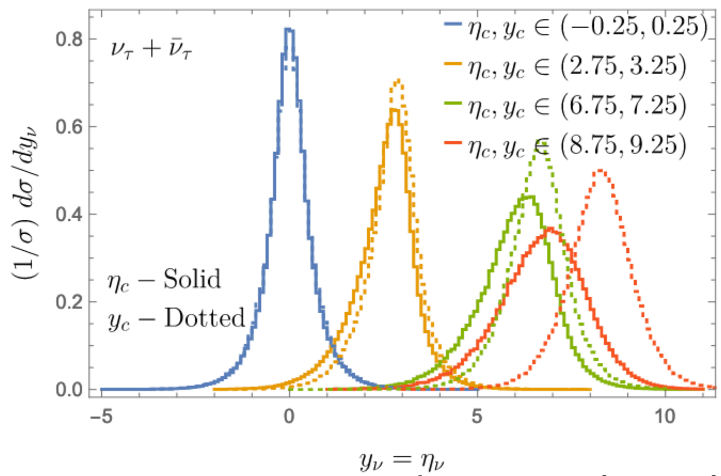
Short white paper 2109.10905

- PDFs, small *x* and large *x*
- Intrinsic k_T/ k_T smearing (mimicking higher order effects?)
- Renormalization, factorization scale effects
- ~~Intrinsic charm~~
- ~~Fragmentation, spectator effects~~

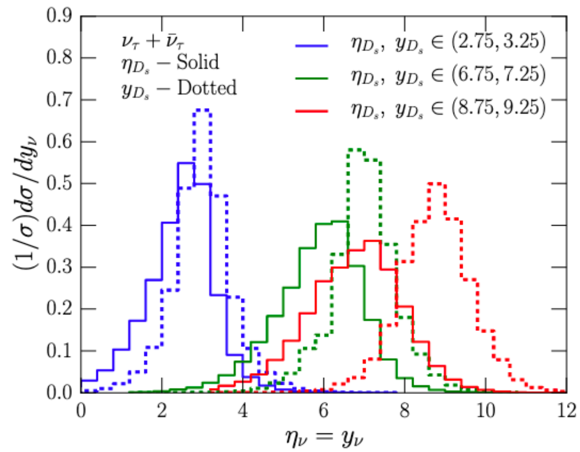
Rapidity/pseudorapidity

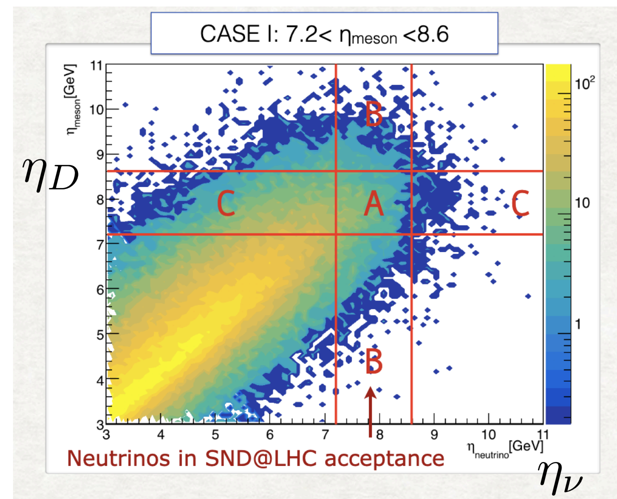
spread of neutrino rapidity for restricted charm or meson rapidity/pseudorapidity

charm quark and ν_τ



D_S and ν_τ





A. Di Crescenzo for SND@LHC, 3rd FPF Meeting

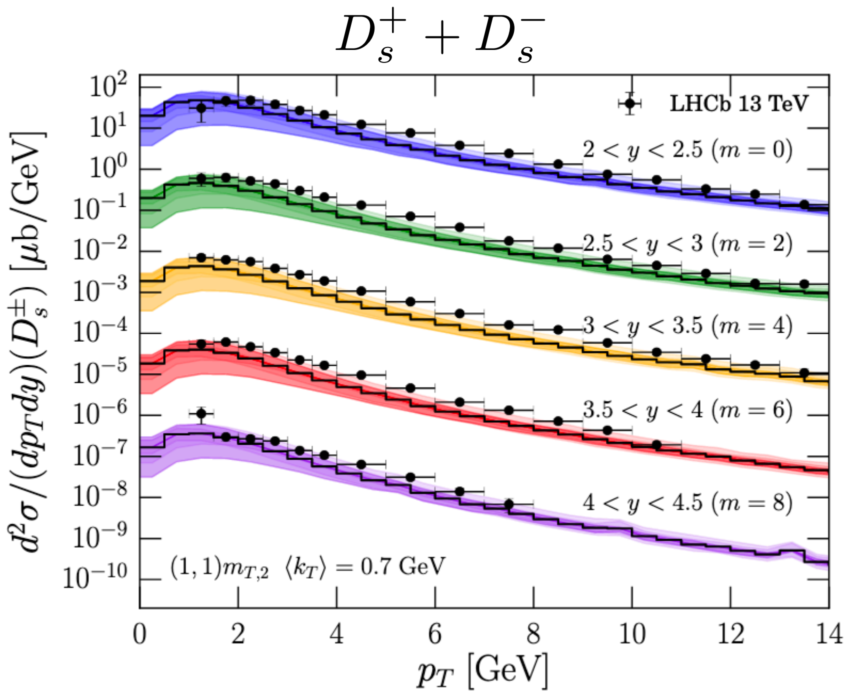
Neutrino rapidity correlates better with charm rapidity than with charm pseudorapidity in the forward region.

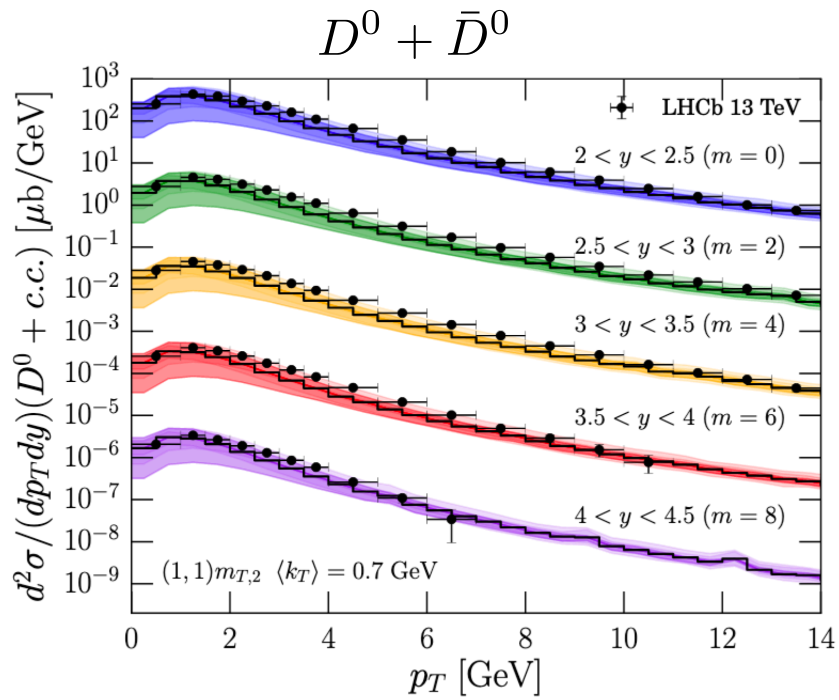
D's at LHCb

Gaussian smearing with:

$\langle k_T \rangle = 0.7$ GeV

similar to POWHEG
+ PYTHIA results





PROSA PDF fits done with $m_{T,2} \equiv \sqrt{(2m_c)^2 + p_T^2}$ also used here. Scale uncertainty band.

D's at LHCb 13 TeV

Default (1,1)

Blue solid lines:

$$m_{T,2} \equiv \sqrt{(2m_c)^2 + p_T^2}$$

$$\langle k_T \rangle = 0.7 \text{ GeV}$$

Red dashed lines:

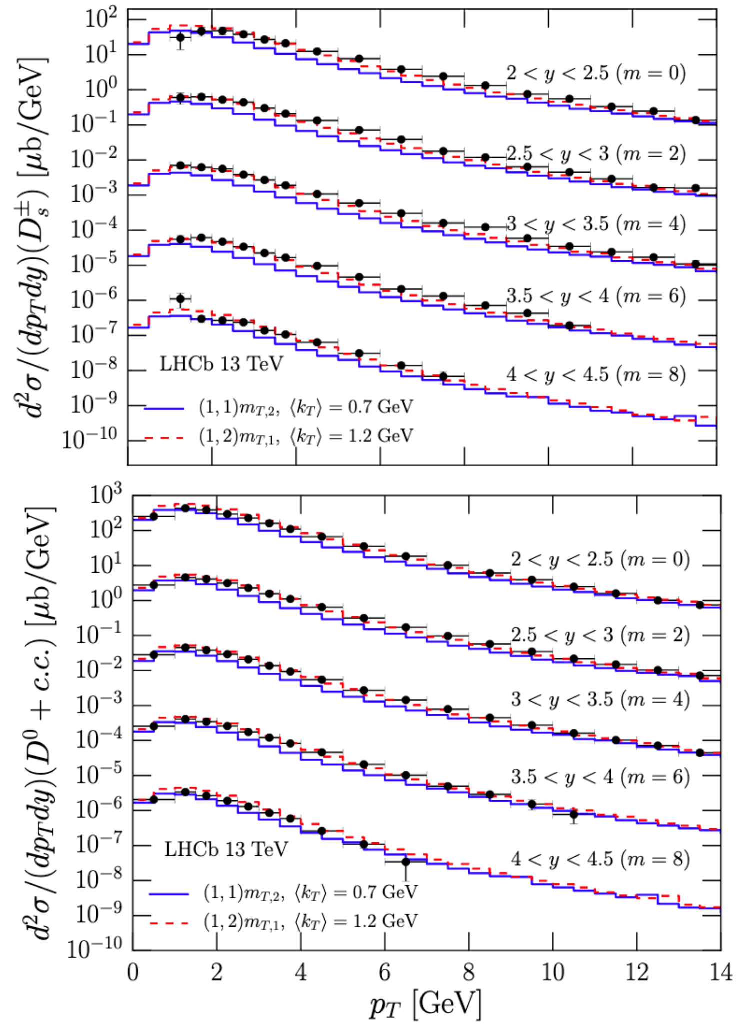
$$m_{T,1} \equiv \sqrt{(m_c)^2 + p_T^2}$$

$$\langle k_T \rangle = 1.2 \text{ GeV}$$

(1,2) factor
for (R,F) scale

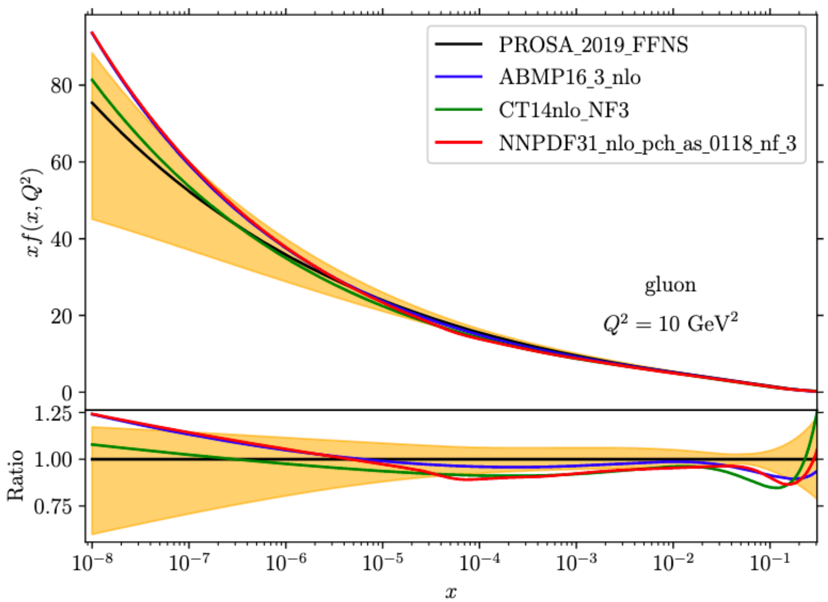
$D_s^+ + D_s^-$

$D^0 + \bar{D}^0$

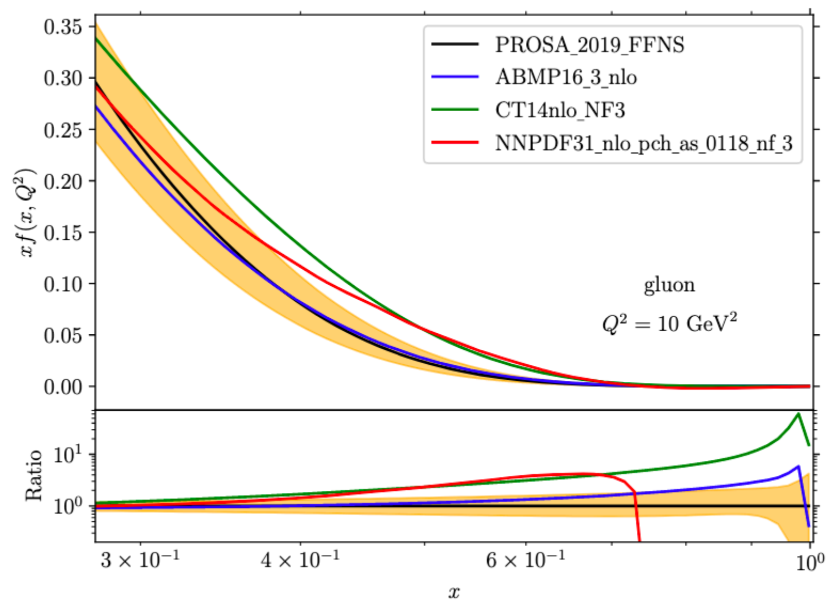


Forward physics: small *x* and large *x* PDFs

xg(x,Q)

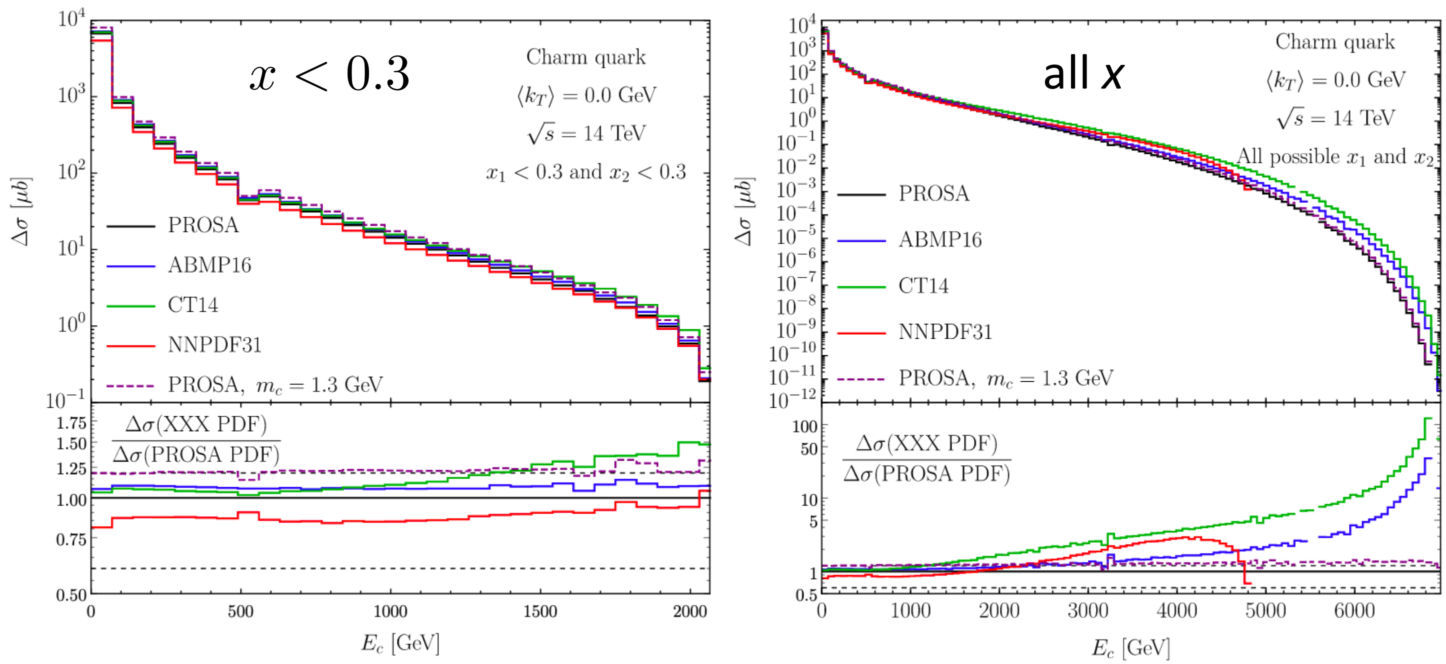


$x < 0.3$



$x > 0.3$

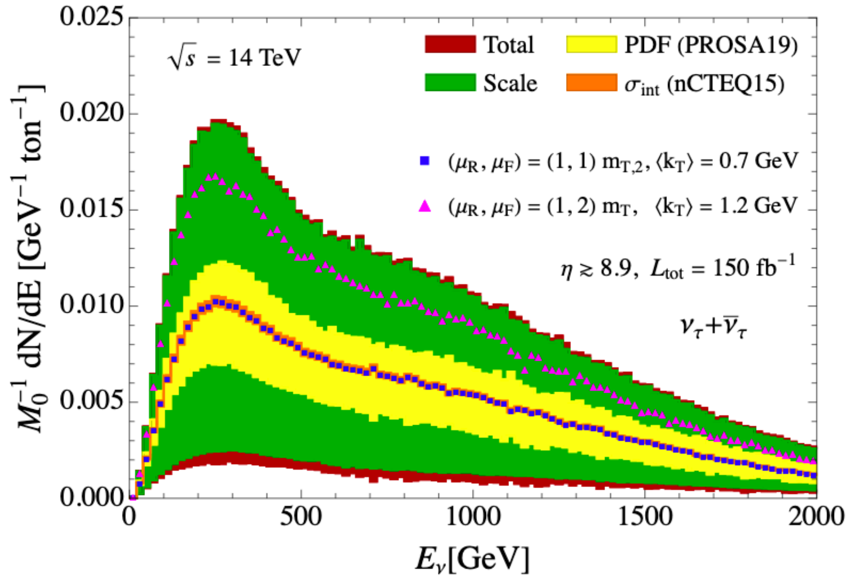
Forward physics: small x and large x PDFs



charm quark energy distribution

Results FASERν

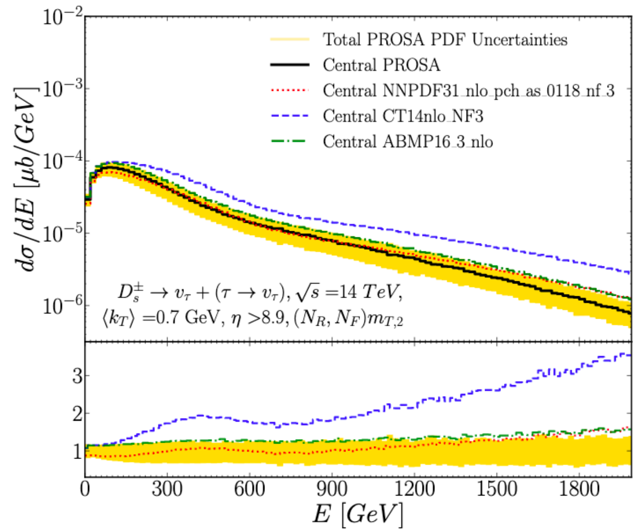
Events per GeV per ton



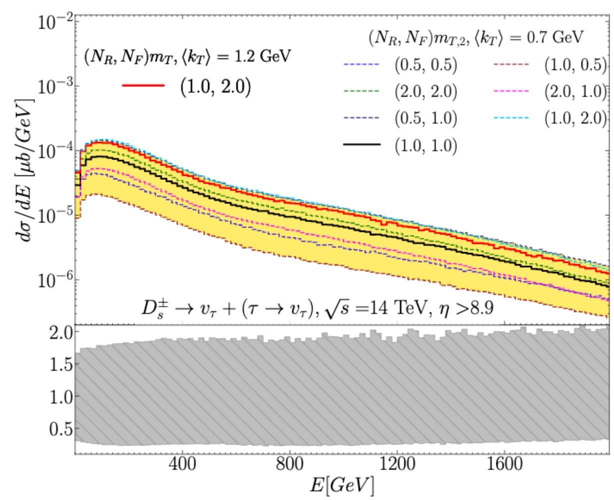
$$M_0 = 1 \text{ ton}$$

40 PROSA PDFs

CT14 is outlier

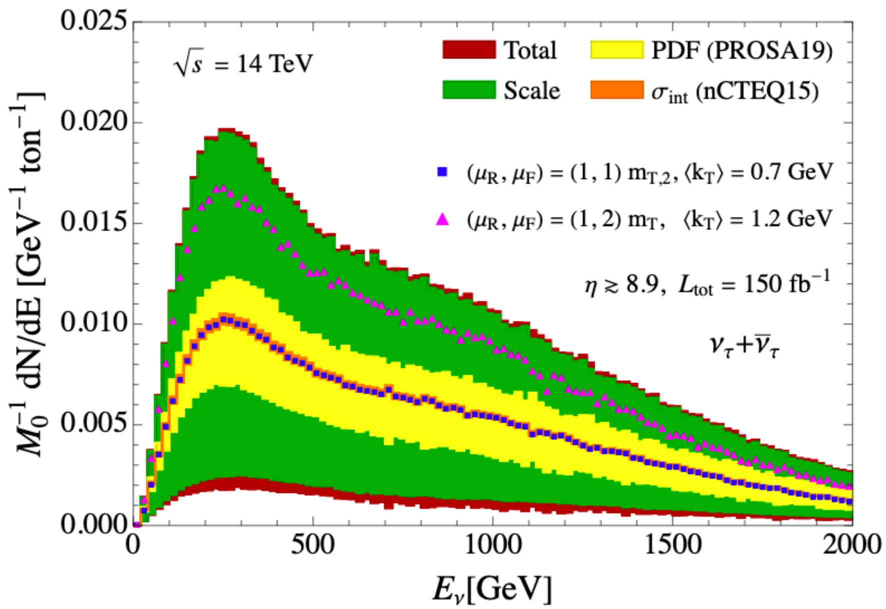


7-point scale variation

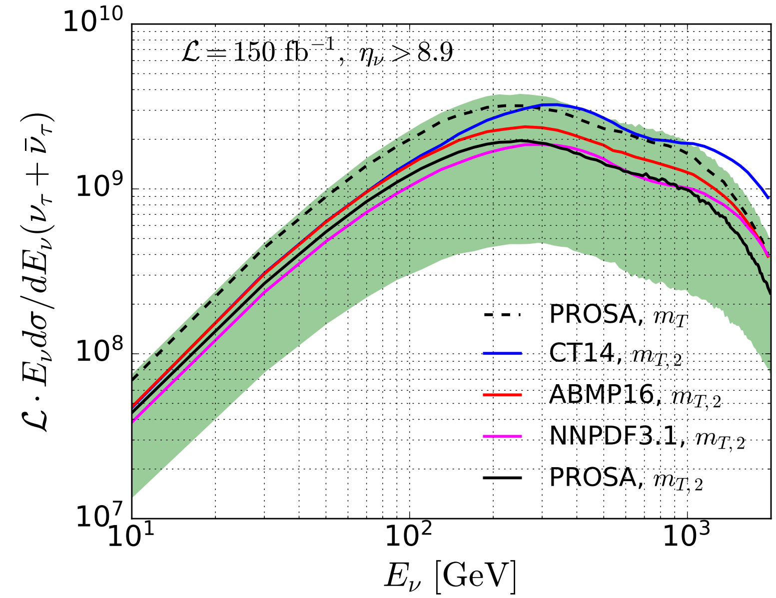


Results FASERν

Events per GeV per ton

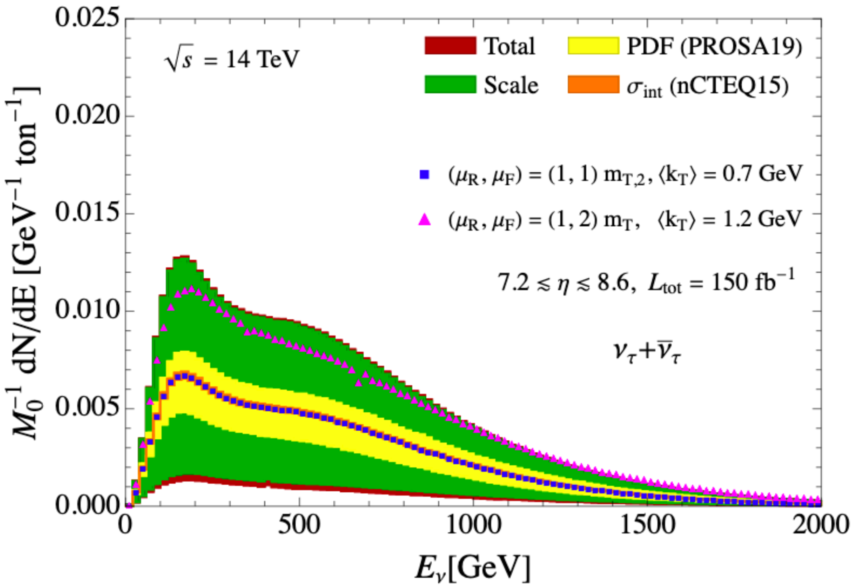


$\sigma_\nu \sim E_\nu$



Results SND@LHC

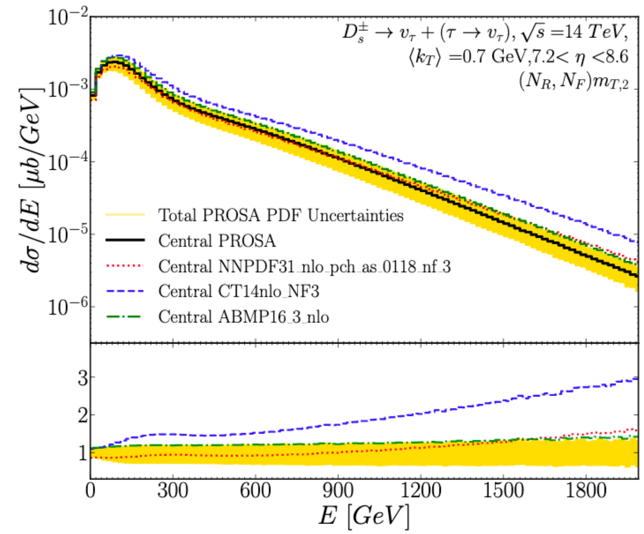
Events per GeV per ton



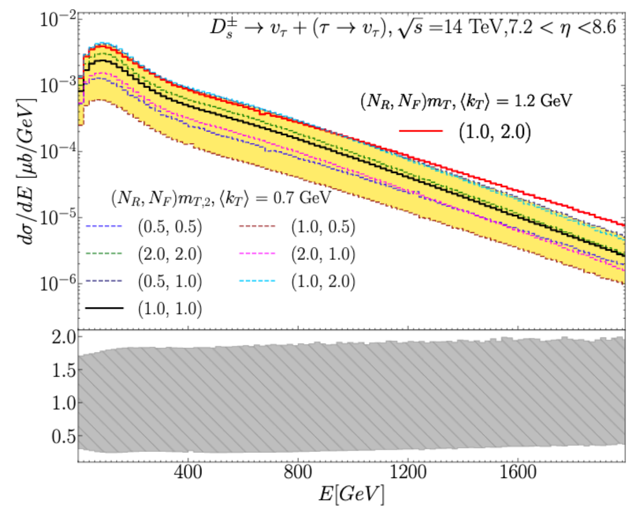
$M_0 = 1$ ton

40 PROSA PDFs

CT14 is outlier

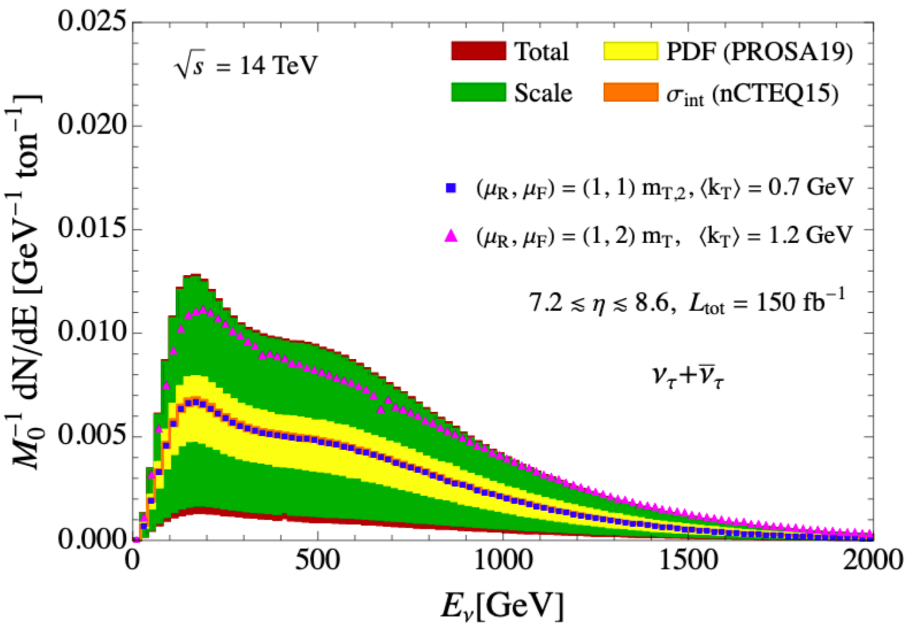


7-point scale variation

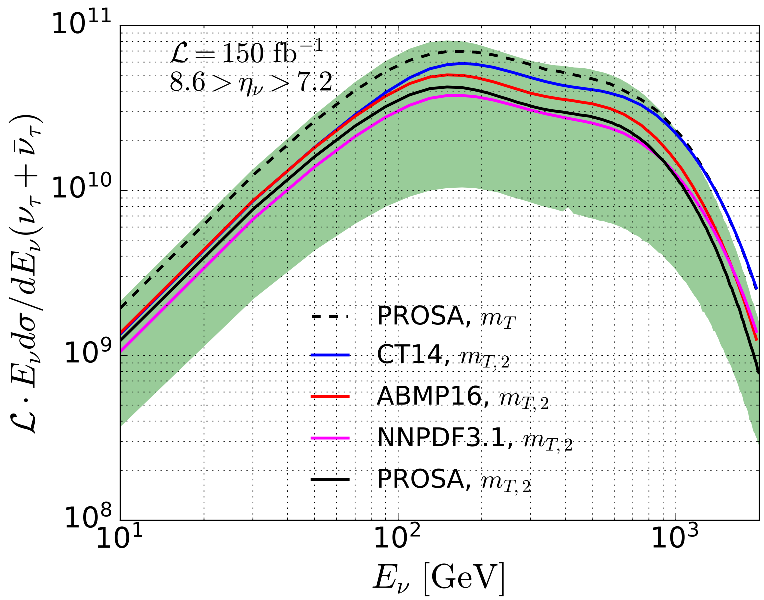


Results SND@LHC

Events per GeV per ton



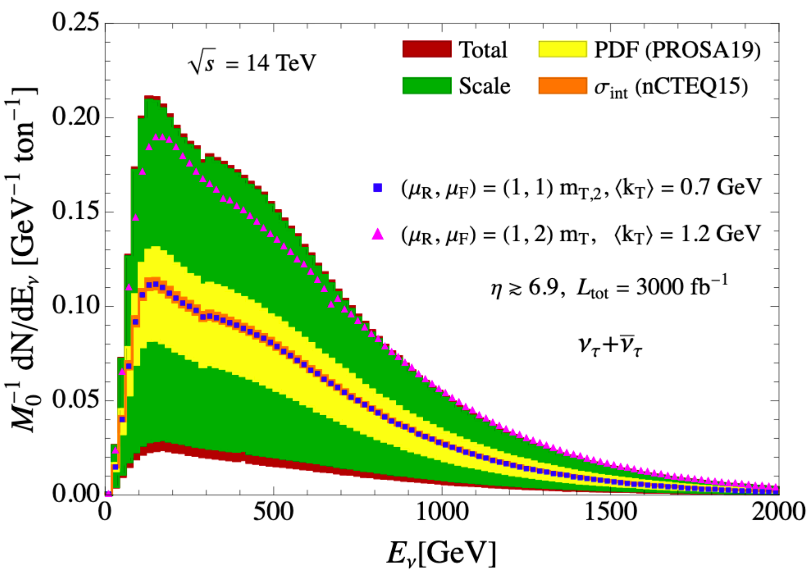
$\sigma_\nu \sim E_\nu$



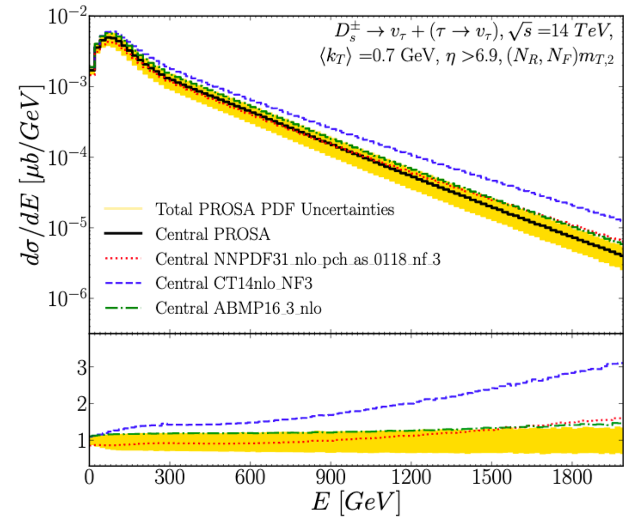
FPF $\eta > 6.9$

40 PROSA PDFs

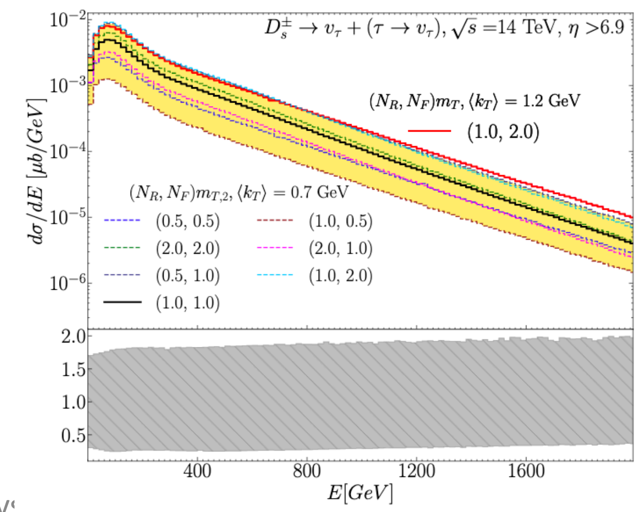
Events per GeV per ton



CT14 is outlier



7-point scale variation

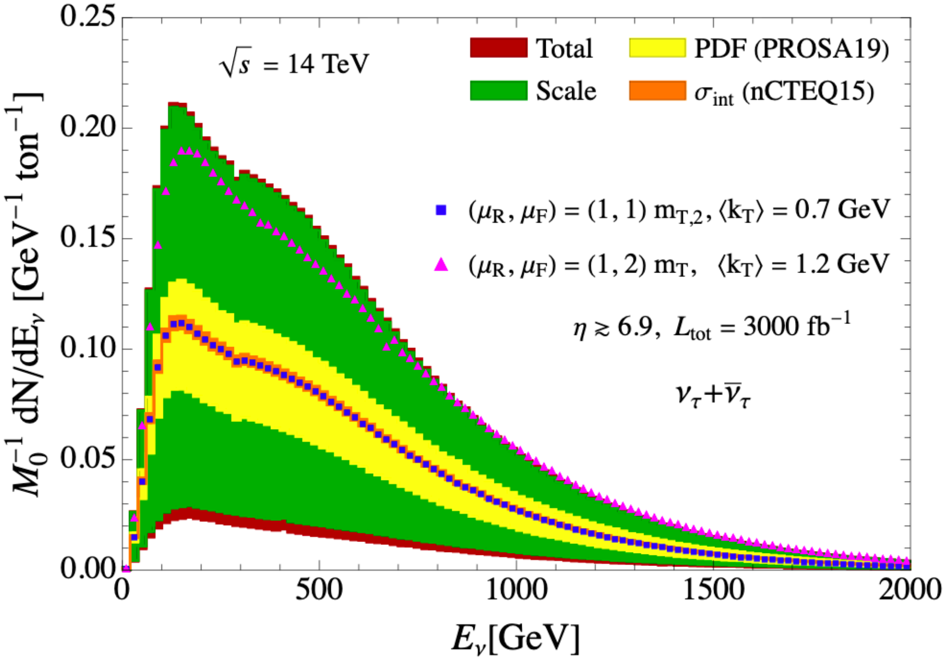


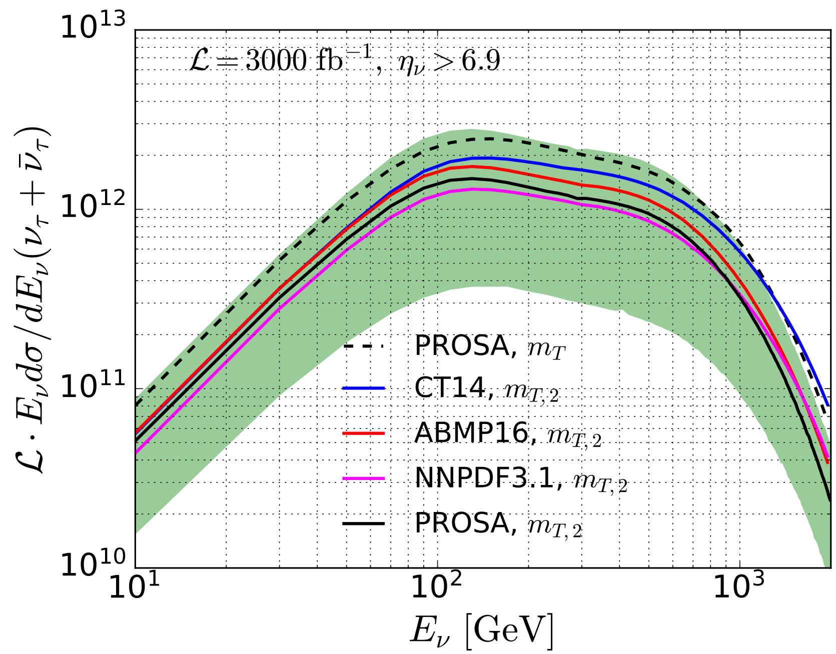
$M_0 = 1$ ton

FPF $\eta > 6.9$

Events per GeV per ton

$\sigma_\nu \sim E_\nu$





$\nu_\tau + \bar{\nu}_\tau$ Events Run 3

$\mathcal{L} = 150\ \text{fb}^{-1}$	ν_τ	$\bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$		
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	$(1,\ 1)\ m_{T,2}$, 0.7 GeV					
				scale(u/l)	PDF(u/l)	σ_{int}
SND@LHC $7.2 < \eta_\nu < 8.6$, 830 kg	2.8	1.3	$4.2^{+3.8}_{-3.3}$	+3.7/-3.1	+0.8/-1.2	± 0.1
FASERν $\eta_\nu > 8.9$, 1.2 ton	8.2	3.9	$12.1^{+11.6}_{-9.8}$	+11.3/-9.0	+2.8/-3.9	± 0.3
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	$(1,\ 2)\ m_T$, 1.2 GeV			$(1,\ 1)\ m_{T,2}$, 0.7 GeV		
PDF	PROSA FFNS			NNPDF3.1	CT14	ABMP16
SND@LHC $7.2 < \eta_\nu < 8.6$, 830 kg	5.1	2.4	7.5	4.0	6.6	5.0
FASERν $\eta_\nu > 8.9$, 1.2 ton	13.5	6.4	19.9	12.8	23.5	15.6

$\nu_\tau + \bar{\nu}_\tau$ Events HL

$\mathcal{L} = 3000\ \mathrm{fb}^{-1}$, 1 m	ν_τ	$\bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$		
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	(1, 1) $m_{T,2}$, 0.7 GeV					
				scale (u/l)	PDF (u/l)	σ_{int}
$\eta \gtrsim 6.9$	3260	1515	4775^{+4307}_{-3763}	+4205/-3494	+926/-1391	± 112
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	(1, 2) m_T, 1.2 GeV			(1, 1) $m_{T,2}$, 0.7 GeV		
PDF	PROSA FFNS			NNPDF3.1	CT14	ABMP16
$\eta \gtrsim 6.9$	5877	2739	8616	4545	7304	5735

1 m tungsten, namely 60.63 ton