Prompt neutrinos in the forward region at the LHC

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Hadronic production of heavy quarks

$$p + p \to \begin{cases} c & \to D^0, D^+, \boxed{D_s^+}, \Lambda_c^+ \\ \\ b & \to \boxed{B^0}, \boxed{B^+}, B_s^0, \Lambda_b^0 \end{cases}$$

$\to \nu_\tau, \nu_e \approx \nu_\mu$

$\to$ DIS CC $\nu + N \to l + X$ at detector

Heavy quark production at NLO pQCD

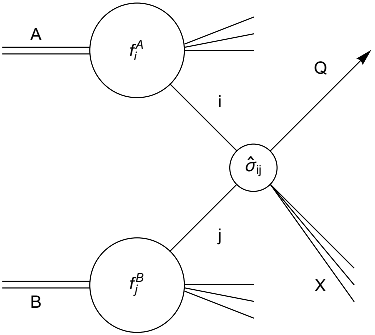
The inclusive differential cross section for the heavy quark for the process $A + B \to Q + X$ is

$$\left(E\frac{d^3\sigma}{d^3p}\right)_Q = \sum_{i,j=q,\bar{q},g} \int dx_1 dx_2 f_i^A(x_1,\mu_F^2) f_j^B(x_2,\mu_F^2) \left[E\frac{d^3\widehat{\sigma}_{ij}(x_1P_A, x_2P_B, p, m^2, \mu_F^2, \mu_R^2)}{d^3p}\right]$$

where

$$(\mu_F, \mu_R) = (\mathrm{NF}, \mathrm{NR}) * \sqrt{m_Q^2 + p_T^2}, \text{ and } q = u, d, s.$$

P. Nason et al., 1988, HVQ program is used.



$$q + \bar{q} \to Q + \bar{Q}, \quad \alpha_s^2, \alpha_s^3$$
$$q + \bar{q} \to Q + \bar{Q} + g, \quad \alpha_s^3$$

$$g + g \to Q + \bar{Q}, \quad \alpha_s^2, \alpha_s^3$$
$$g + g \to Q + \bar{Q} + g, \quad \alpha_s^3$$

$$g + q \to Q + \bar{Q} + q, \quad \alpha_s^3$$
$$g + \bar{q} \to Q + \bar{Q} + \bar{q}, \quad \alpha_s^3.$$

Same amount of Q and $\bar{Q}$ produced, same amount of ν as $\bar{\nu}$.

Intrinsic transverse momentum is important

Introduce the $\vec{k}_T$ smearing to the heavy quark production (J. F. Owens, 1987)

$$\left(E\frac{d^3\sigma}{d^3p}\right)_Q = \sum_{i,j=q,\bar{q},g} \int dx_1 dx_2 f_i^A(x_1,\mu_F^2) f_j^B(x_2,\mu_F^2) \left[E\frac{d^3\widehat{\sigma}_{ij}(x_1P_A, x_2P_B, p, m^2, \mu_F^2, \mu_R^2)}{d^3p}\right]$$

$$dx_1 f_i^A(x_1,\mu_F^2) \rightarrow dx_1 \boxed{d^2k_{T_1}\,\mathrm{f}(\vec{k}_{T_1})} f_i^A(x_1,\mu_F^2)$$

where the Gaussian form below is taken:

$$f(\vec{k}_T) = \frac{1}{\pi\left\langle k_T^2\right\rangle}\exp\left(-\frac{k_T^2}{\left\langle k_T^2\right\rangle}\right)$$

Heavy quark Fragmentation

From heavy quark to heavy hadron

$$\left(E\frac{d^3\sigma}{d^3p}\right)_H = \left(E\frac{d^3\sigma}{d^3p}\right)_Q \otimes D_Q^H(z) \text{ with } D_Q^H(z) = \frac{Nz(1-z)^2}{((1-z)^2+\epsilon z)^2}$$

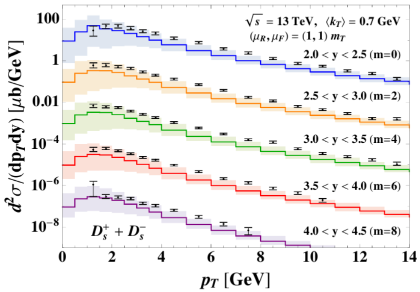
is the $Q \to H$ fragmentation function, where

$$\vec{p}_H = z\vec{p}_Q$$

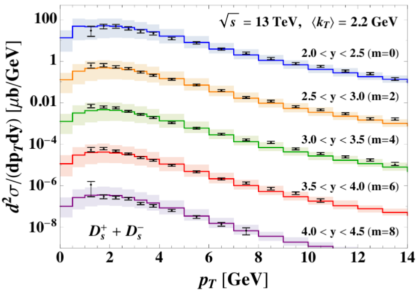
The parameter ϵ are different for different hadrons, e.g., (Belle Collaboration,2006)

Hadrons	D^-	D^0	D_s^-	Λ_c^+	B/B^0
ϵ	0.039	0.028	0.008	0.011	0.0033

Comparison with LHCb $D_s^\pm$ data



$(\mu_R, \mu_F) = (1, 1)\, m_T$



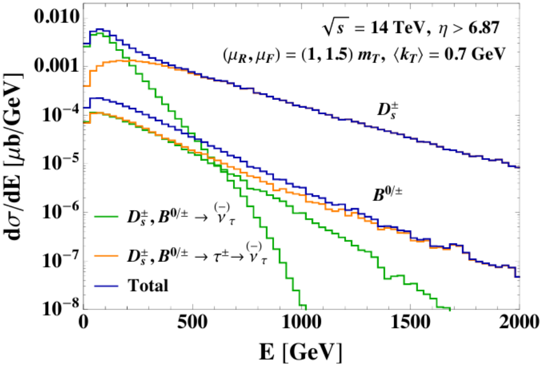
$(\mu_R, \mu_F) = (1, 1.5)\, m_T$

Heavy hadron decay to neutrinos

- ν_τ production: $\begin{cases} D_s \to \tau + \nu_\tau, \\ B/B^0 \to D + \tau + \nu_\tau, \end{cases}$

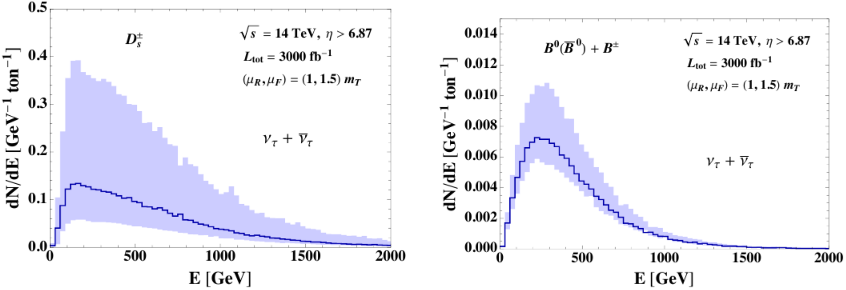
and the subsequent $\tau \to \nu_\tau + X$ with massive τ and $X = \mu\nu_\mu, e\nu_e, \pi, \rho, a_1$

- $\nu_e \approx \nu_\mu$ production: $c/b \to s/c + \mu + \nu_\mu$
- All at c/b hadron rest frame, then Lorentz transformed to the collider frame.



Number of events

- For an $r = 1$ m lead neutrino detector, located 480m down the stream of pp collision:



- The uncertainties from the perturbative QCD higher-order corrections are large.

$\nu_\tau + \bar{\nu}_\tau, \langle k_T^2 \rangle = 0.7$ GeV			
(μ_R, μ_F)	(1,1.5)	(0.5,1.5)	(1,0.75)
$D_s^\pm$	3642	11008	1716
$B^{\pm,0}$	142	214	115
Total	3784	11222	1831

Summary

- We evaluate the prompt $\nu_\mu + \bar{\nu}_\mu$ and $\nu_\tau + \bar{\nu}_\tau$ number of events from $D_s^\pm$ and $B^{\pm,0}$ decays in the far forward region at the LHC. Thousands of CC $\nu_\tau + \bar{\nu}_\tau$ events can be expected for a 1 m long lead neutrino detector located 480m down the stream for pp collision at $\sqrt{s} = 14$ TeV and $\mathcal{L}$ =3000 fb^{-1}.

- However, the uncertainties from the perturbative QCD higher-order corrections are large.

Thanks