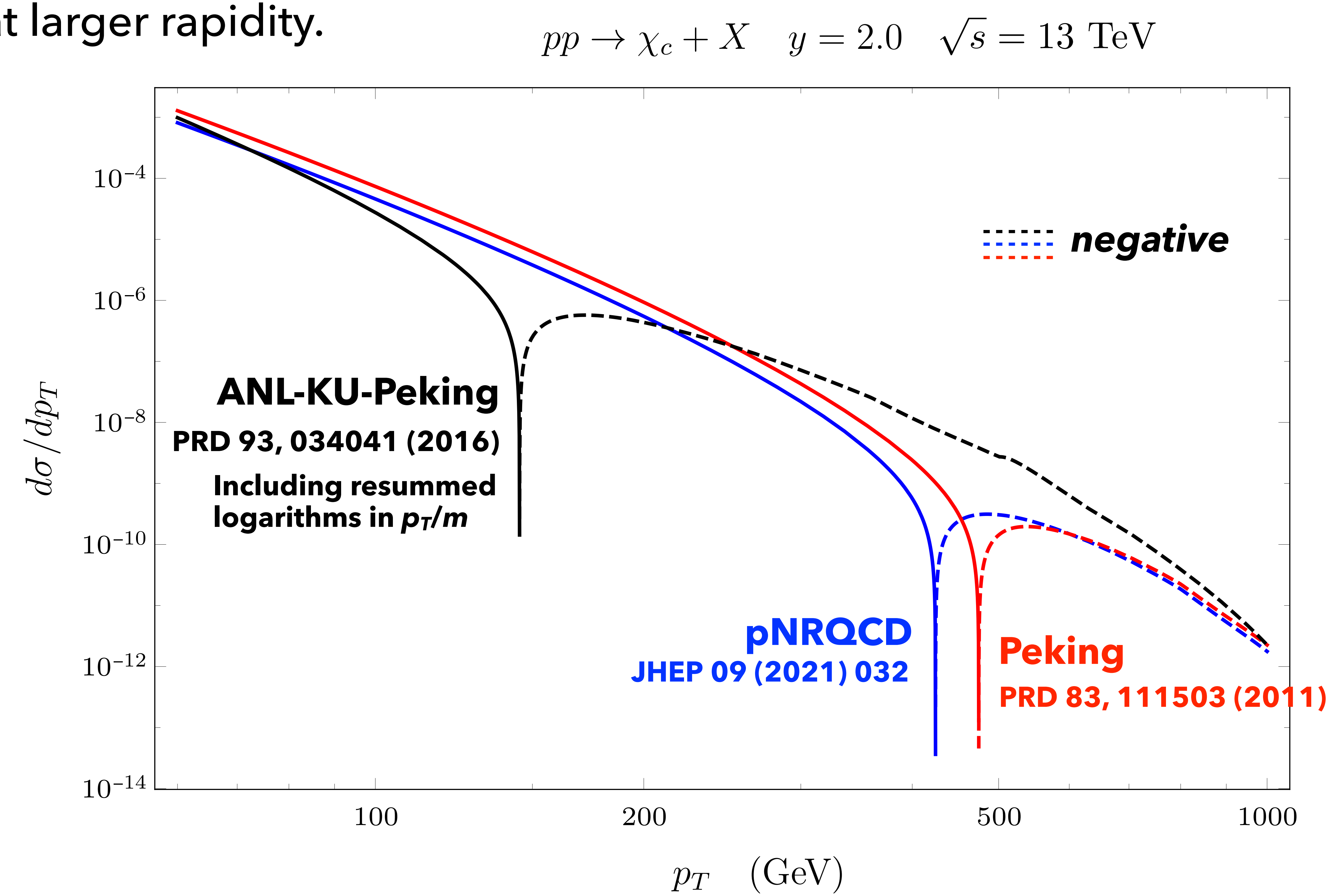
NEGATIVE P–WAVE PRODUCTION RATE AT LARGE P_T

- Problem : cross section turns negative at large p_T. This gets more severe at larger rapidity.



NEGATIVE P-WAVE PRODUCTION RATE AT LARGE P_T

- Why? ${}^3S_1^{[8]}$ and ${}^3P_J^{[1]}$ mix under renormalization. RGE:

$$\frac{d}{d\log\Lambda}\langle\mathcal{O}^{\chi_{QJ}}({}^3S_1^{[8]})\rangle = \frac{4C_F\alpha_s}{3N_c\pi m^2}\langle\mathcal{O}^{\chi_{QJ}}({}^3P_J^{[1]})\rangle$$

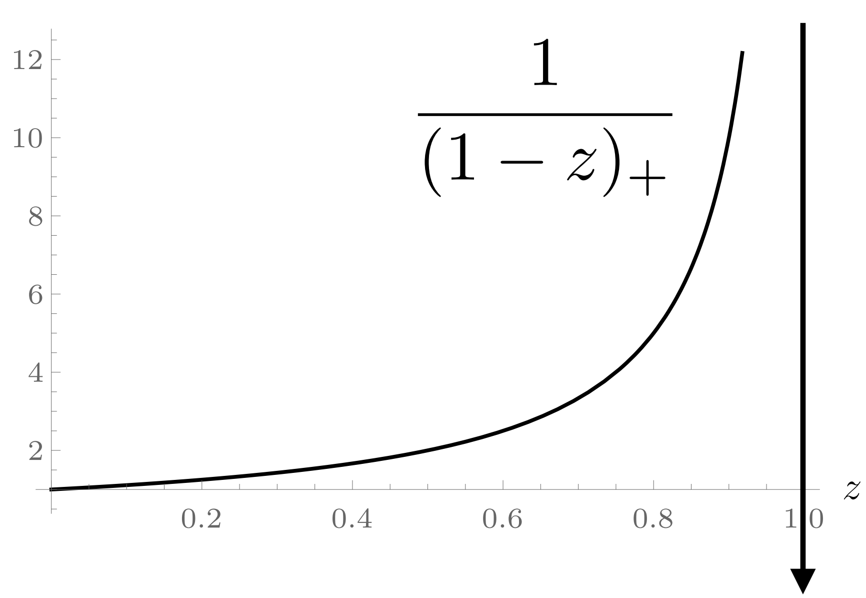
Negative

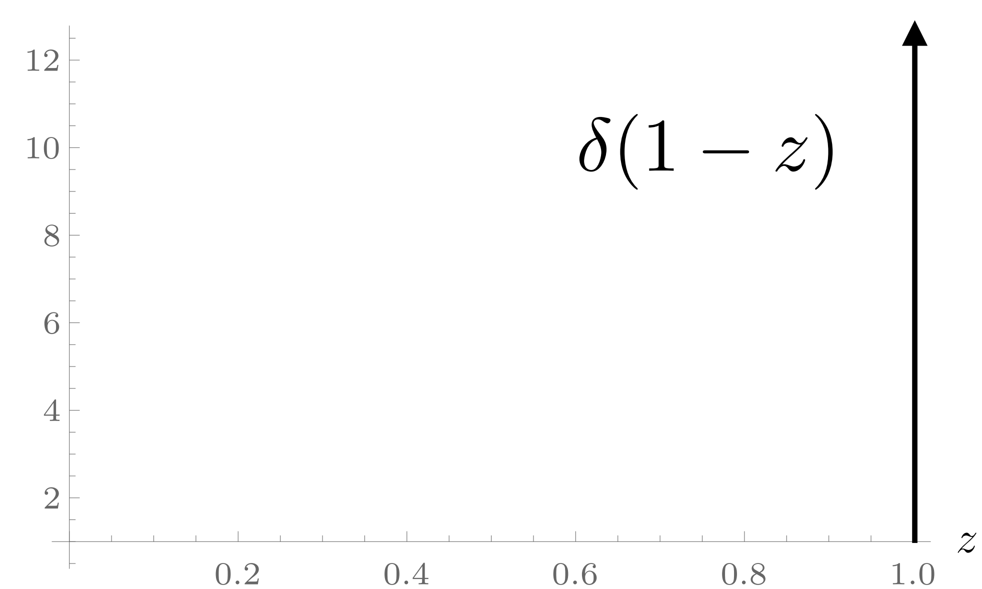
$$\sigma_{\chi_{QJ}+X} = \sigma_{Q\bar{Q}({}^3P_J^{[1]})}\langle\mathcal{O}^{\chi_{QJ}}({}^3P_J^{[1]})\rangle + \sigma_{Q\bar{Q}({}^3S_1^{[8]})}\langle\mathcal{O}^{\chi_{QJ}}({}^3S_1^{[8]})\rangle$$

Positive

$$\sigma_{Q\bar{Q}({}^3P_J^{[1]})} = \sigma_g \otimes \left\{0\times\alpha_s + \frac{2\alpha_s^2}{27N_c m_c^5}\left[\left(\frac{Q_J}{2J+1} - \log\frac{\Lambda}{2m_c}\right)\delta(1-z) + \frac{z}{(1-z)_+} + \frac{P_J(z)}{2J+1}\right]\right\}$$

$$\sigma_{Q\bar{Q}({}^3S_1^{[8]})} = \sigma_g \otimes \left\{\frac{\pi\alpha_s(Q)}{24m_c^3}\delta(1-z) + \text{NLO}\right\}$$





NEGATIVE P-WAVE PRODUCTION RATE AT LARGE P_T

- P-wave cross section is the remnant of the cancellation.

Negative → Positive

$$\sigma_{\chi_{QJ}+X} = \sigma_{Q\bar{Q}(^3P_J^{[1]})}\langle \mathcal{O}^{\chi_{QJ}}(^3P_J^{[1]})\rangle + \sigma_{Q\bar{Q}(^3S_1^{[8]})}\langle \mathcal{O}^{\chi_{QJ}}(^3S_1^{[8]})\rangle$$

$$\sigma_{Q\bar{Q}(^3P_J^{[1]})} = \sigma_g \otimes \left\{ 0\times\alpha_s + \frac{2\alpha_s^2}{27N_c m_c^5}\left[\left(\frac{Q_J}{2J+1} - \log\frac{\Lambda}{2m_c}\right)\delta(1-z) + \frac{z}{(1-z)_+} + \frac{P_J(z)}{2J+1}\right]\right\}$$

$$\sigma_{Q\bar{Q}(^3S_1^{[8]})} = \sigma_g \otimes \left\{ \frac{\pi\alpha_s(Q)}{24m_c^3}\delta(1-z) + \frac{\alpha_s^2(Q)}{24m_c^3}\left[A(Q)\delta(1-z) + \left(\log\frac{Q}{2m_c} - \frac{1}{2}\right)P_{gg}(z) + \frac{3(1-z)}{z} + 6(2-z+z^2)\log(1-z) - \frac{6}{z}\left(\frac{\log(1-z)}{1-z}\right)_+\right]\right\}$$

- Cancellation occurs order by order, so there's always leftover pieces : e.g. NLO piece of $^3S_1{}^{[8]}$.

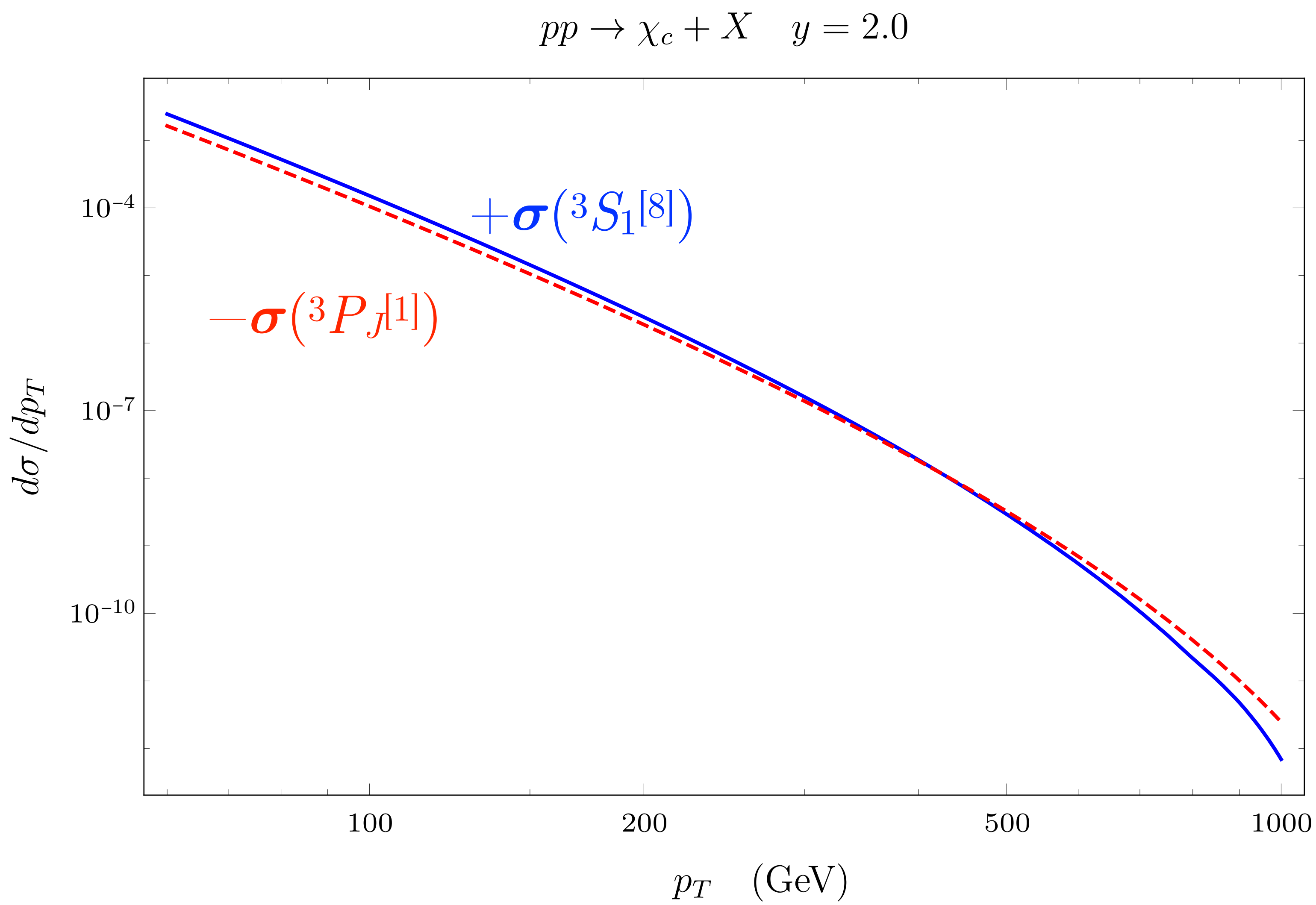
- Remnant of cancellation very sensitive to behavior at z=1 : cross section will depend strongly on $z\rightarrow 1$ behavior of σ_g

Negative P-wave Production Rate at Large p_T

- P-wave cross section is the remnant of the cancellation.

Negative ↘ Positive ↙

$$\sigma_{\chi_{QJ}+X} = \sigma_{Q\bar{Q}({}^3P_J^{[1]})} \langle \mathcal{O}^{\chi_{QJ}}({}^3P_J^{[1]}) \rangle + \sigma_{Q\bar{Q}({}^3S_1^{[8]})} \langle \mathcal{O}^{\chi_{QJ}}({}^3S_1^{[8]}) \rangle$$



- ${}^3P_J{}^{[8]}$ falls off slower than ${}^3S_1{}^{[8]}$, the sum turns negative at large p_T

NEGATIVE S-WAVE PRODUCTION RATE AT LARGE P_T

- Same issue with S-wave production in the ${}^3S_1^{[8]}$ + ${}^3P_J^{[8]}$ dominance case.

  Situation similar to P-wave : $\frac{d}{d\log\Lambda}\langle\mathcal{O}^V({}^3S_1^{[8]})\rangle = \frac{6(N_c^2-4)}{N_c m^2}\frac{\alpha_s}{\pi}\langle\mathcal{O}^V({}^3P_0^{[8]})\rangle$

$pp \to J/\psi + X \quad y = 0 \quad \sqrt{s} = 13$ TeV