$k_\perp$-factorization and heavy quark production

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Based on C. Brenner Mariotto, M. B. Gay Ducati, M. Machado, hep-ph/0208155

Overview:

- Motivation
- Heavy quark photoproduction in $\boldsymbol{k}_{\perp}$-factorization approach
- Unintegrated gluon distributions
- Results
- Conclusions

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- Parton model (collinear approach)
  - NLO calculations
  - on-shell matrix elements, initial transverse momenta neglected

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- $\boldsymbol{k}_\perp$-factorization approach (semihard interactions)
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  - transverse momenta of incident partons included perturbatively
  - unintegrated parton distributions:

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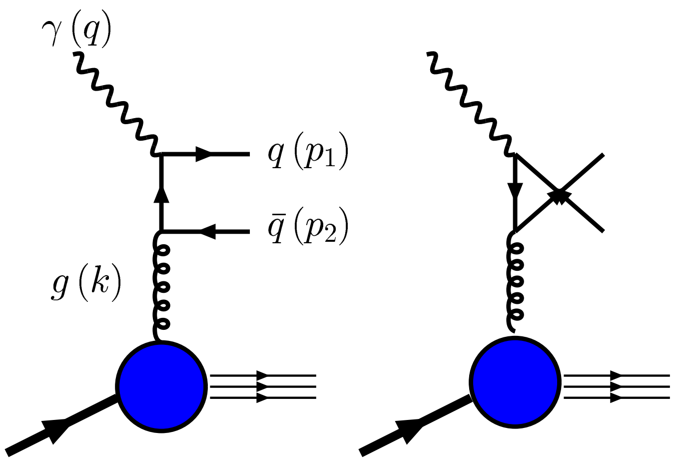
  - NLO and some NNLO contributions on collinear approach already included in LO matrix elements
  - infrared sector and saturation effects

Heavy quark photoproduction in $k_\perp$-factorization approach



$\mathcal{F}(x_2,\, k_\perp^2)$: unintegrated gluon distribution

- Using Sudakov variables

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\begin{aligned}
p_1 &= \alpha_1 P_1 + \beta_1 P_2 + \boldsymbol{p}_{1\perp} \\
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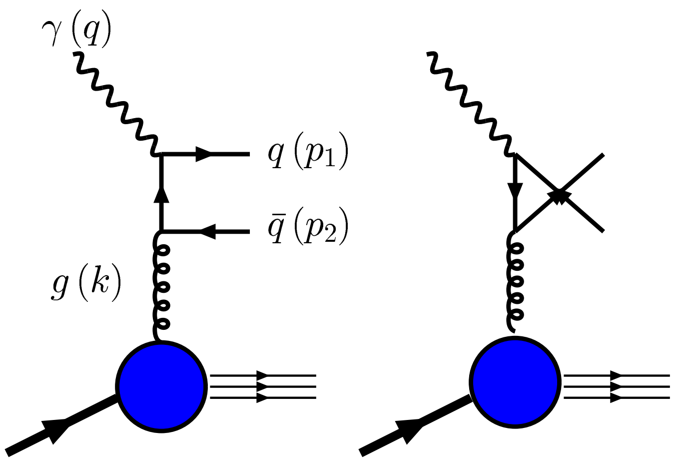

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- in terms of transverse masses $m_{1,2\,\perp}^2 = m_Q^2 + \boldsymbol{p}_{1,2\,\perp}^2$ and heavy-quark rapidities $y_{1,2}^*$,

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\alpha_2 = \frac{m_{2\perp}}{\sqrt{s}} \exp(y_2^*) \qquad \beta_2 = \frac{m_{2\perp}}{\sqrt{s}} \exp(-y_2^*) \qquad x_2 = \beta_1 + \beta_2
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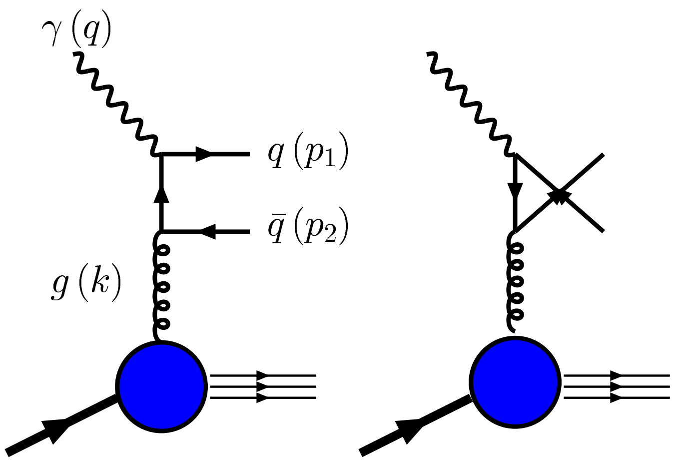

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- photoproduction: $q = P_1$, $x_1 = 1$, $\alpha_1 \equiv z$, $\alpha_2 \equiv 1 - z$
- z, $(1-z)$: longitudinal momentum fraction carried by the heavy-quark having $\boldsymbol{p}_{1\perp}$, $\boldsymbol{p}_{2\perp}$

Heavy quark photoproduction in $k_\perp$-factorization approach

- direct interaction: (resolved component not included)

$$\sigma_{tot}^{phot} = \frac{\alpha_{em}\, e_Q^2}{\pi} \int dz\; d^2\boldsymbol{p}_{1\perp}\, d^2\boldsymbol{k}_\perp$$

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$$\times \left\{ [z^2 + (1-z)^2] \left(\frac{\boldsymbol{p}_{1\perp}}{D_1} + \frac{(\boldsymbol{k}_\perp - \boldsymbol{p}_{1\perp})}{D_2} \right)^2 + m_Q^2 \left(\frac{1}{D_1} + \frac{1}{D_2} \right)^2 \right\}$$

where $D_1 \equiv \boldsymbol{p}_{1\perp}^2 + m_Q^2$ and $D_2 \equiv (\boldsymbol{k}_\perp - \boldsymbol{p}_{1\perp})^2 + m_Q^2$.

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- input: $\mathcal{F}(x_2, \boldsymbol{k}_\perp^2; \mu^2)$

Unintegrated gluon distributions

- **GBW** - Saturation Model

$$\mathcal{F}(x,\boldsymbol{k}_\perp^2) = \frac{3\,\sigma_0}{4\,\pi^2\alpha_s}\,R_0^2(x)\,\boldsymbol{k}_\perp^4\,\exp\left(-R_0^2(x)\,\boldsymbol{k}_\perp^2\right)$$

$\sigma_0 = 29.12$ mb, $\alpha_s = 0.2$, $R_0(x) = \frac{1}{Q_0}\left(\frac{x}{x_0}\right)^{\lambda/2}$, parameterization including charm: $Q_0 = 1$ GeV, $\lambda = 0.277$ and $x_0 = 0.41 \cdot 10^{-4}$

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- **Derivative of integrated gluon density** *(d-Gluon)*

$$\mathcal{G}(x,\boldsymbol{k}_\perp^2) =$$

$$+\frac{\partial\,[\,x\,G(x,\boldsymbol{k}_\perp^2)\,]}{\partial\,\ln\boldsymbol{k}_\perp^2}\,\Theta(\boldsymbol{k}_\perp^2 - Q_0^2) \qquad \text{(pQCD)}$$

$xG(x,\mu^2)$: GRV98 LO, $Q_0^2 = 0.8 GeV^2$

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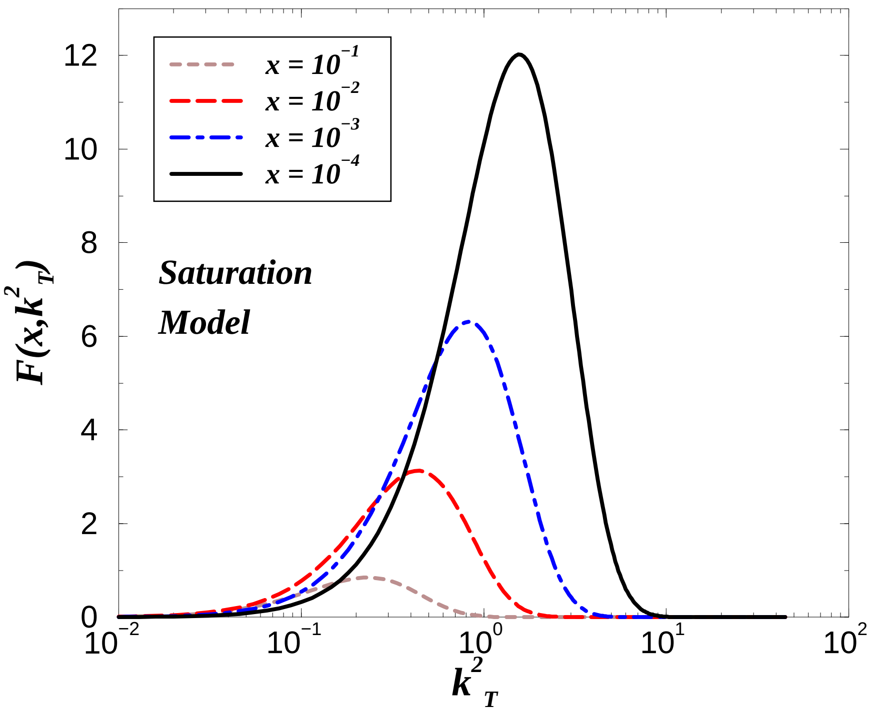
Unintegrated gluon distributions:



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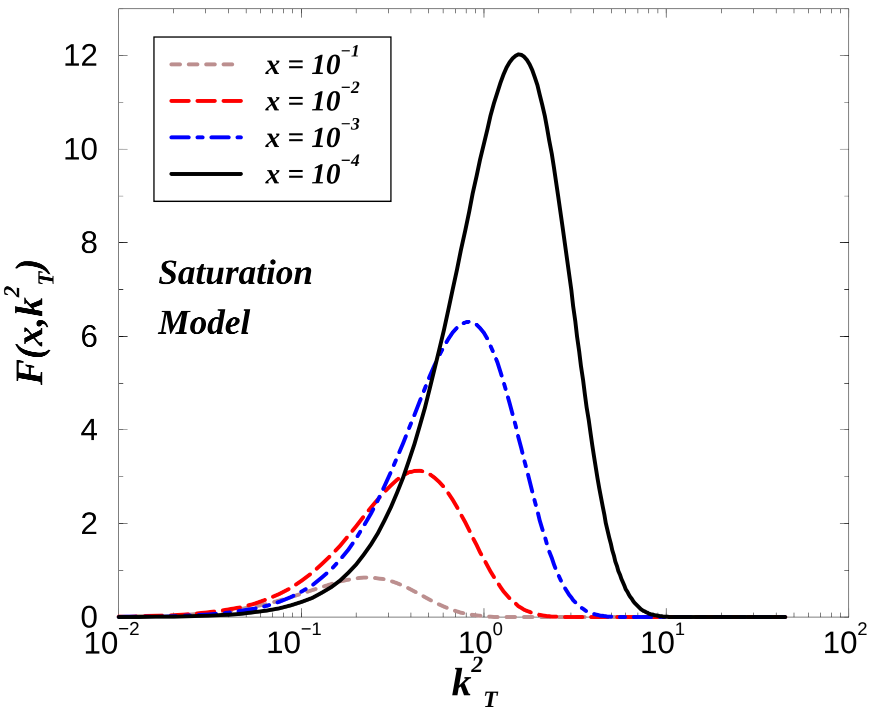
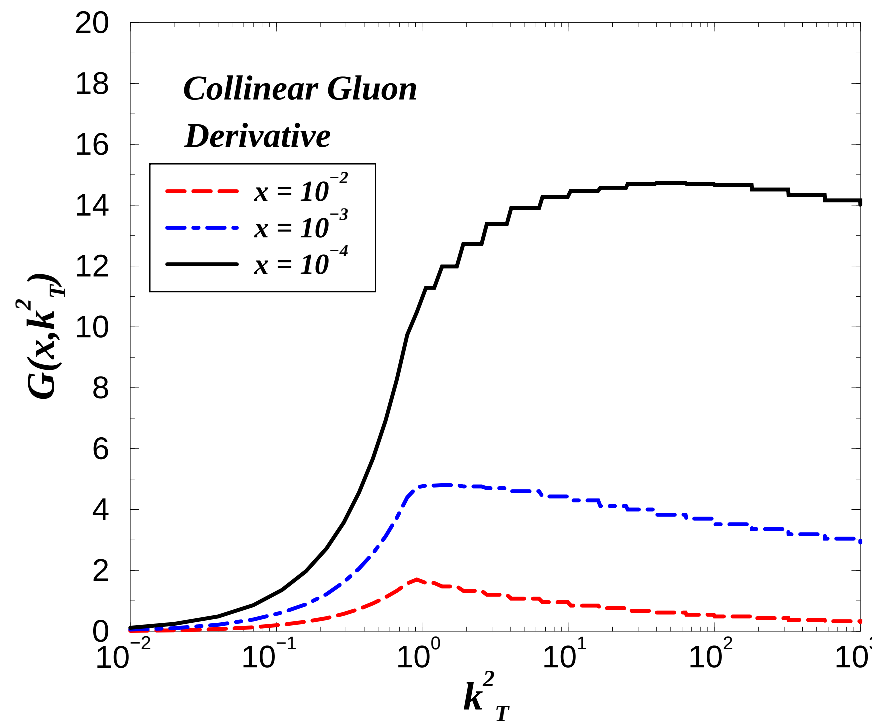


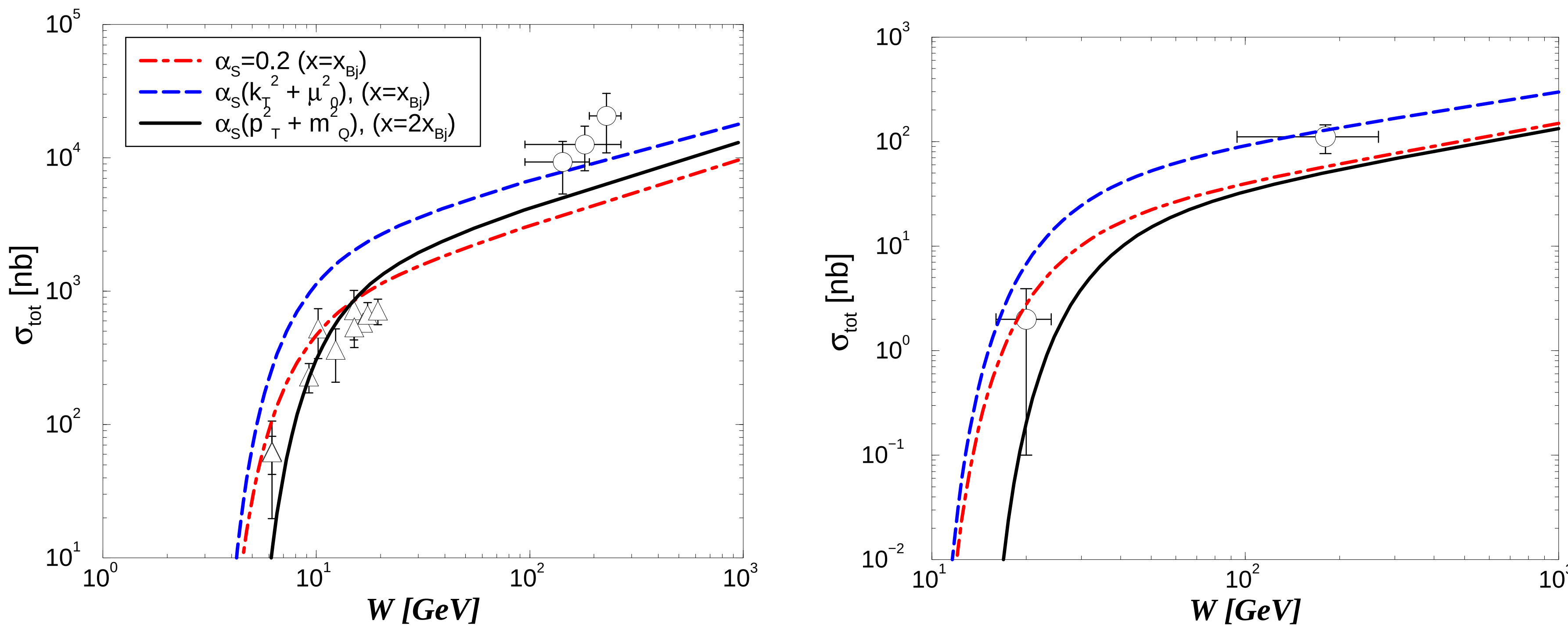


- GBW peaked at $\boldsymbol{k}_\perp^2 = 2\,Q_s^2(x)$
- d-Gluon broader in $k_\perp^2$

Total cross section, GBW

charm

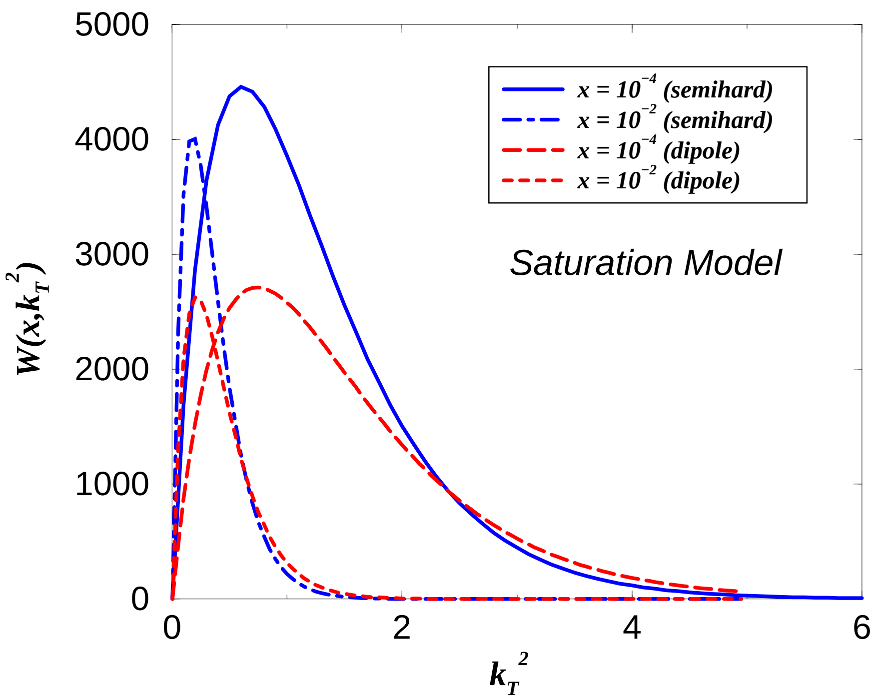
bottom



- Sensitivity to energy scale and gluon momentum fraction
  - $\alpha_s = 0.2$, $x_2 = x_{Bj}$ reproduces results of dipole approach (Szczurek)
  - More conservative choice $\mu^2 = \boldsymbol{p}_\perp^2 + m_Q^2$, $x_2 = 2\,x_{Bj}$

$W(x, \boldsymbol{k}_\perp^2) \rightarrow \boldsymbol{k}_\perp$ profile, charm

fixed target energies ($x = 10^{-2}$), high energies ($x = 10^{-4}$)



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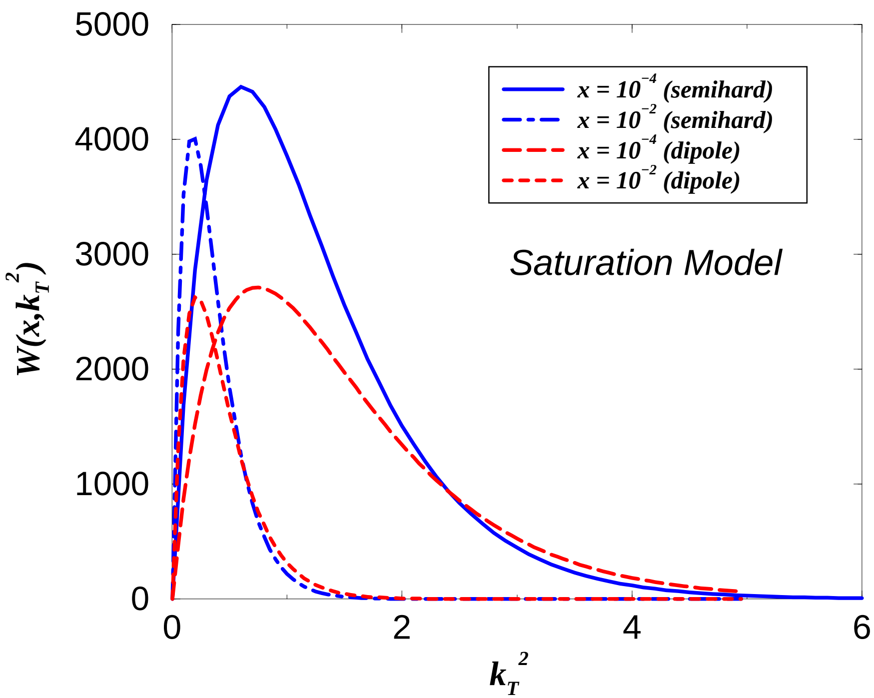

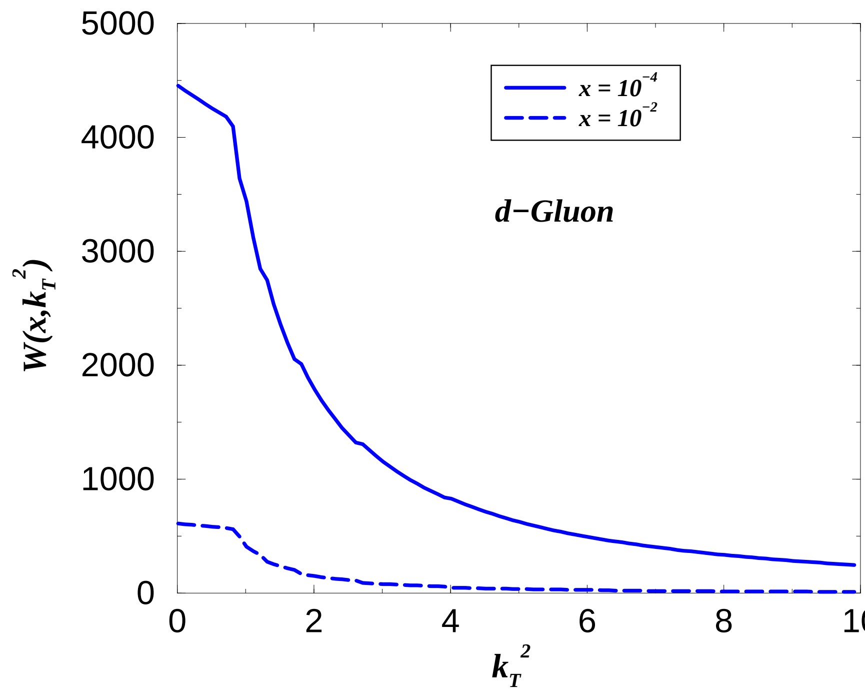

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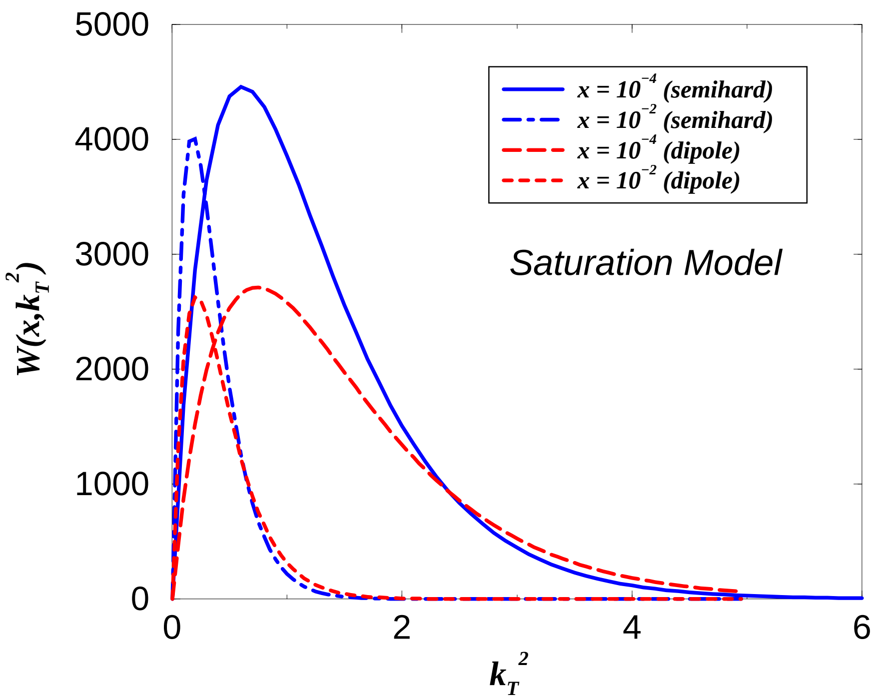

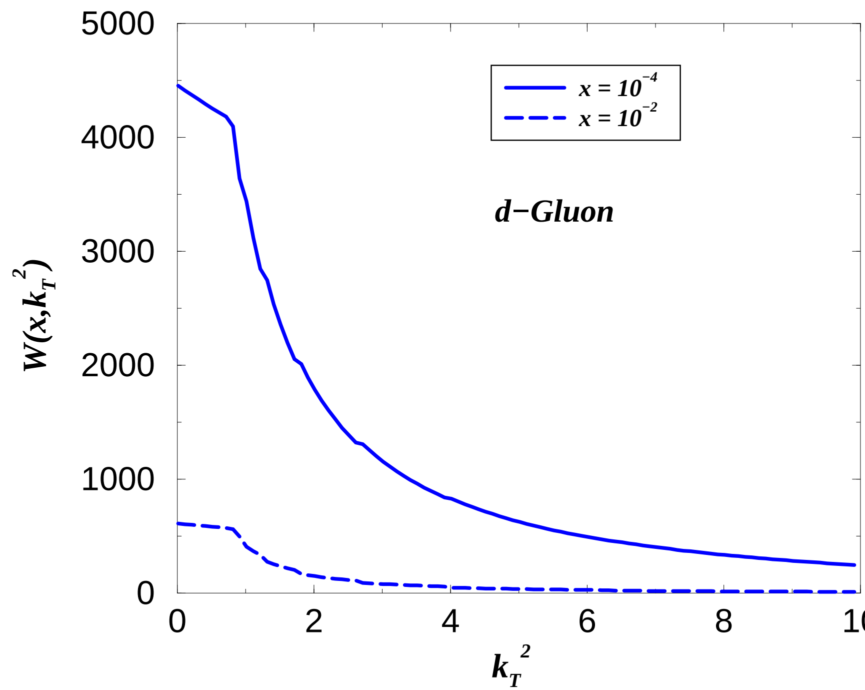

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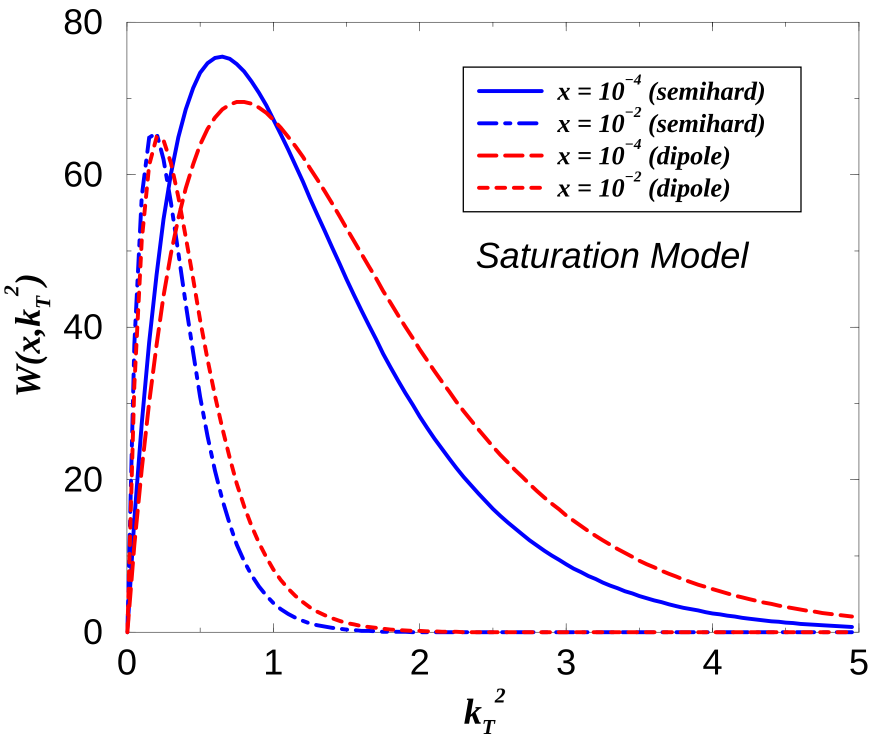
$W(x, \boldsymbol{k}_\perp^2) \to \boldsymbol{k}_\perp$ profile, bottom:



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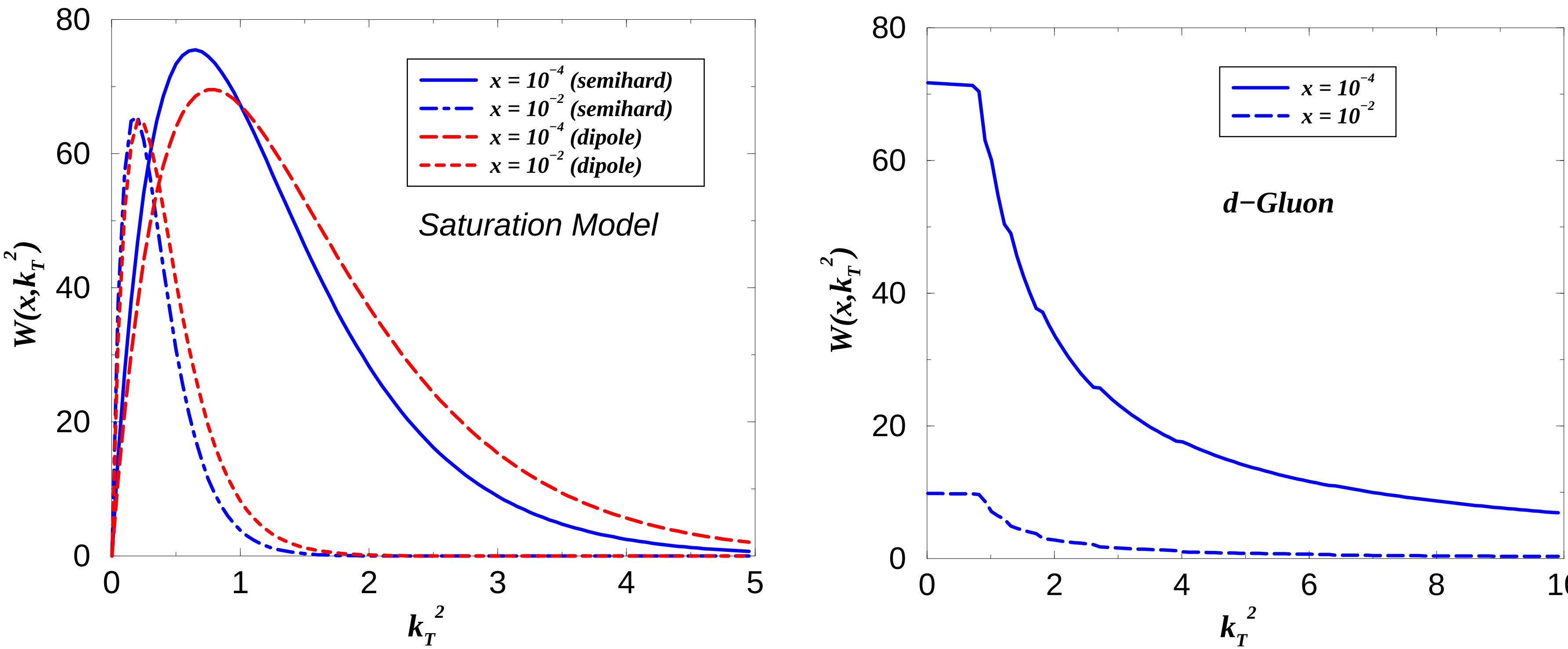
$W(x, \boldsymbol{k}_\perp^2) \rightarrow \boldsymbol{k}_\perp$ profile, bottom:



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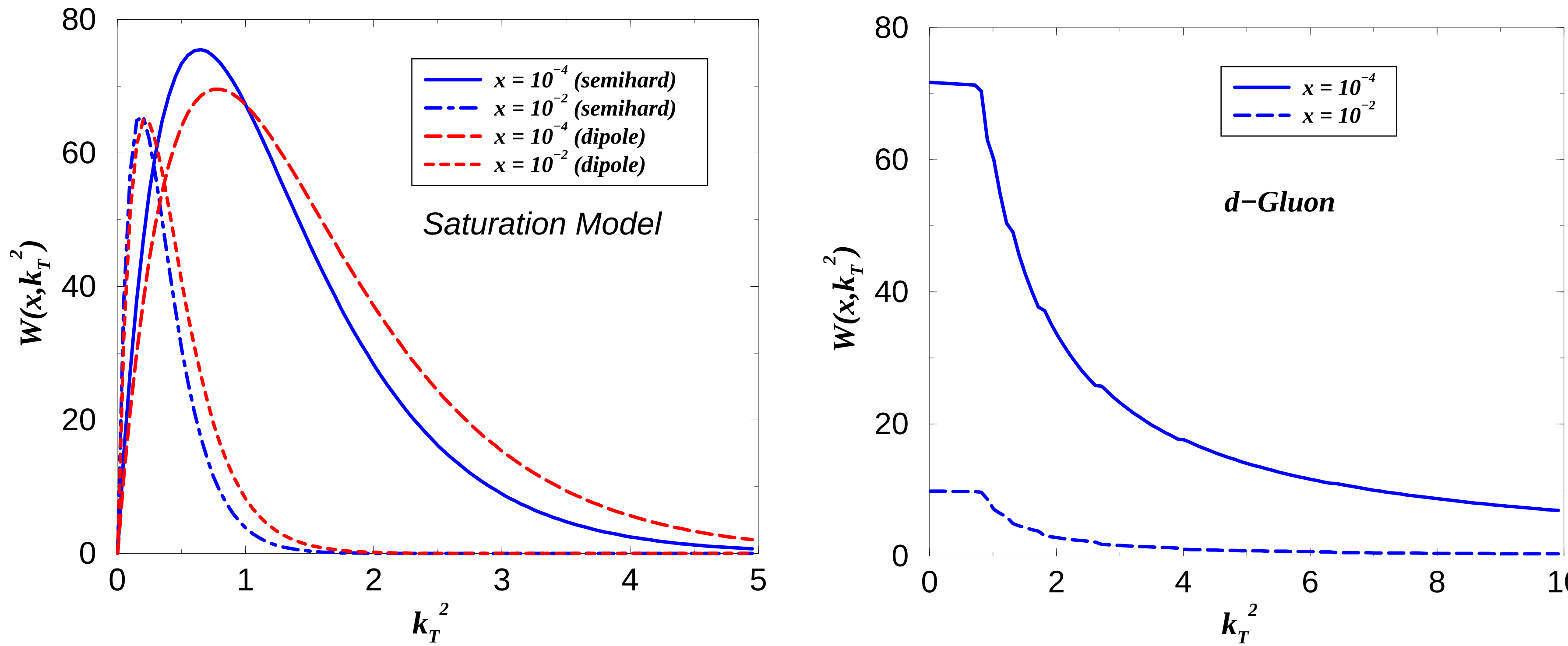

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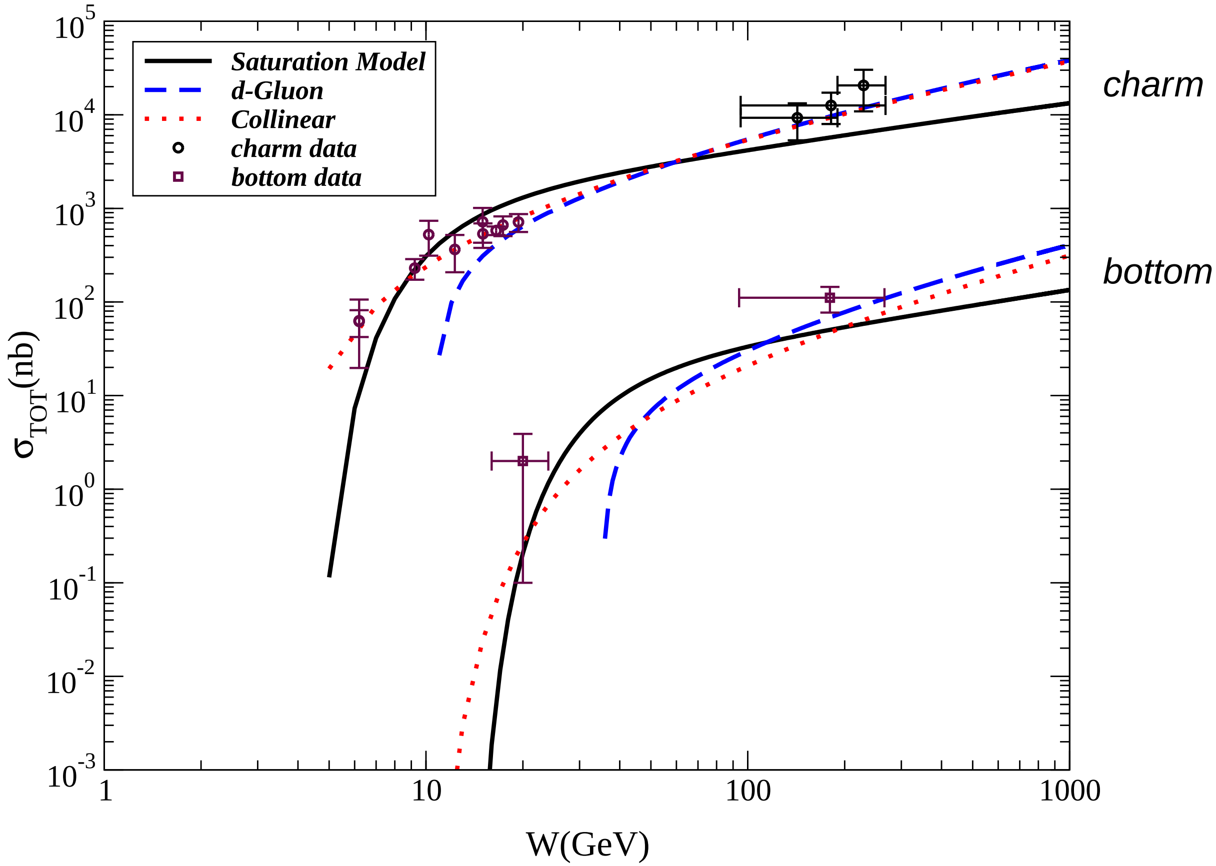
σ_{TOT}, Saturation Model x d-Gluon:

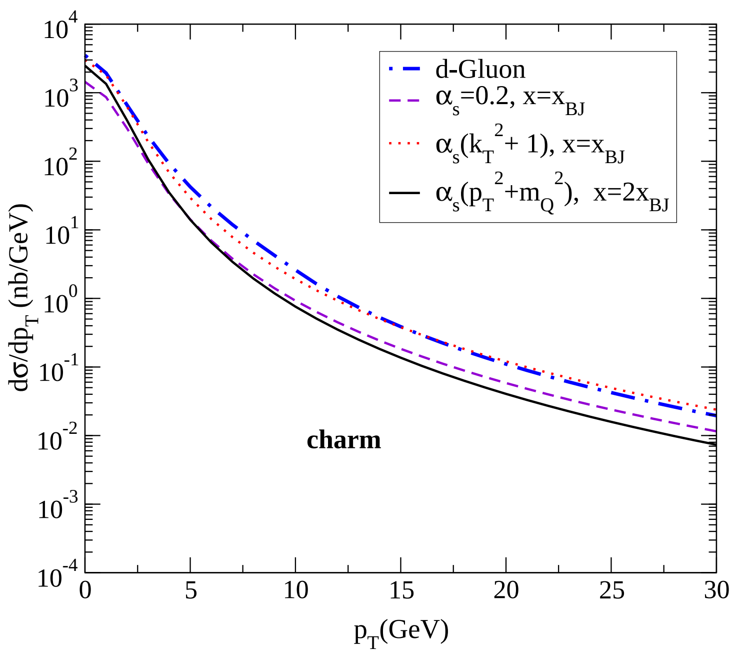


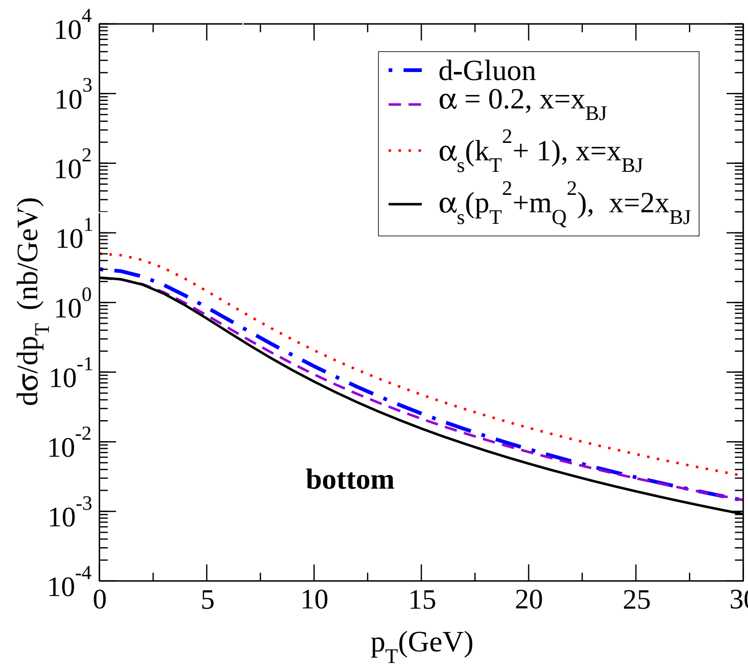
- Saturation Model: somewhat below high energy data (lack of QCD evolution)
- d-Gluon: better description of high energy data

  lower energies: lack of non-singlet (valence) content, $\rightarrow dG < 0$

p_T distributions

$W = 200\,GeV$, saturation model X d-Gluon





- usual fall off at large transverse momentum
- finite and well-controled behavior at $p_T = 0$

Conclusions

- k_T factorization: NLO and NNLO collinear diagrams in LO
- Several parameterizations for $\mathcal{F}$ in the market:
  Derivative of integrated gluon density: DGLAP
  GBW: consistent with small-x DIS and diffraction
- smooth connection between soft and hard regimes
- profile function: important below saturation scale
- fixed $\alpha_s = 0.2$ and $\bar{x} = x_{Bj}$ underestimates high energy data (consistent with dipole approach)
- more conservative choice $\alpha_s(p_T^2 + m_Q^2)$, $\bar{x} = 2x_{Bj}$ improves slightly the description
- p_T spectrum finite at $p_T \to 0$