Overview of beauty production models

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Outline

- FFNS
- ZM-VFNS
- GM-VFNS
- FONLL
- NLO Monte Carlo generators
- [k_T factorization]
- [Double parton scattering]
- [Diffractive production]

Theoretical approaches:
Fixed Flavor Number Scheme (FFNS)

FFNS/Fixed Order

Factorization formula for inclusive heavy quark (Q) production:

PDFs

$$d\sigma^Q \simeq \sum_{a,b} f_a^A \otimes f_b^B \otimes d\tilde{\sigma}_{ab\to Q+X}$$

sum over all possible partonic subprocesses
NO heavy quark PDF

Calculable short distance cross section; log(pT/m) terms kept in **fixed order**

FFNS/Fixed Order

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Calculable short distance cross section; log(pT/m) terms kept in **fixed order**

Inclusive heavy-flavored hadron (H) production:

$$d\sigma^H = d\sigma^Q \otimes D_Q^H(z)$$

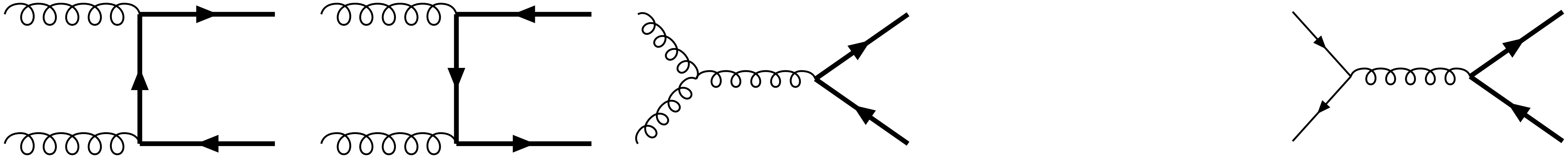
Convolution with a **scale-independent** FF

* non-perturbative
* describes hadronization
* not based on a fact. theorem

Leading Order (LO)

Leading order subprocesses:

1. $gg \to Q\bar{Q}$
2. $q\bar{q} \to Q\bar{Q} \quad (q = u, d, s)$



- The gg-channel is dominant at the LHC ($\sim 85\%$ at $\sqrt{S} = 14$ TeV).
- The total production cross section for heavy quarks is fi nite.
  The minimum virtuality of the t-channel propagator is m^2. Sets the scale in α_s.
  Perturbation theory should be reliable.
- Note: For $m^2 \to 0$ total cross section would diverge.

[See M. Mangano, hep-ph/9711337; Textbook by Ellis, Stirling and Webber]

Next-to-leading Order (NLO)

Next-to-leading order (NLO) subprocesses:

1. $gg \to Q\bar{Q}g$
2. $q\bar{q} \to Q\bar{Q}g \quad (q = u, d, s)$
3. $gq \to Q\bar{Q}q$, $g\bar{q} \to Q\bar{Q}\bar{q}$ [new at NLO]
4. Virtual corrections to $gg \to Q\bar{Q}$ and $q\bar{q} \to Q\bar{Q}$

NLO corrections for σ_{tot} and differential cross sections $d\sigma/dp_T dy$ known since long:

- Nason, Dawson, Ellis, NPB303(1988)607; Beenakker, Kuif, van Neerven, Smith, PRD40(1989)54 [σ_{tot}]
- NDE, NPB327(1989)49; (E)B335(1990)260; Beenakker *et al.*,NPB351(1991)507 [$d\sigma/dp_T dy$]

Well tested by recalculations and zero-mass limit:

- Bojak, Stratmann, PRD67(2003)034010 [$d\sigma/dp_T dy$ (un)polarized]
- Kniehl, Kramer, Spiesberger, IS, PRD71(2005)014018 [$m \to 0$ limit of diff. x-sec]
- Czakon, Mitov, NPB824(2010)111 [σ_{tot}, fully analytic]

Next-to-leading Order (NLO)

- Fixed order NLO calculation also useful to obtain predictions of heavy quark correlations!

  Mangano,Nason,Ridolfi ('92)

Next-to-next-to-leading Order (NNLO)

Channels: $q\bar{q}$, gg, qg

- Two-loop virtual most difficult $\quad M_2^{(0)} + M_2^{(1)} + M_2^{(2)}$
    - Analytic approach: Bonciani, Ferroglia, Gehrmann, Maitre, Studerus, von Manteuffel ('08-'10)
    - Numeric approach: Czakon, Mitov et al.
- Virtual + Real $\quad M_3^{(0)} + M_3^{(1)}$
  Dittmaier, Uwer, Weinzierl ('08)
- Subtraction method for IR singularities in double real $\quad M_4^{(0)}$
  Czakon ('10-'11)

Next-to-next-to-leading Order (NNLO)

- Available now for top pair production!
- Total cross section — Czakon, Mitov, PRL110(2013)252004
- Differential distributions — Czakon, Mitov, arXiv:1411.3007
- Analytic approach not yet complete

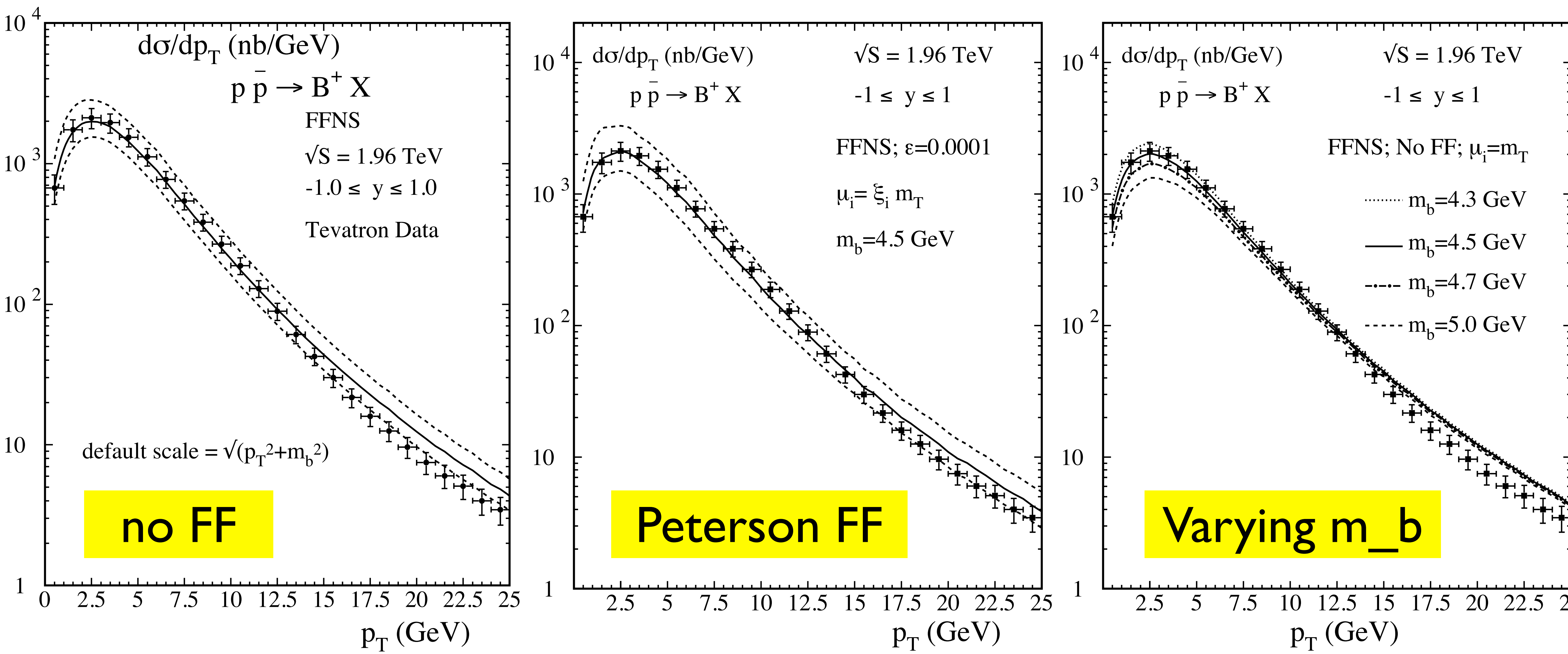
  [Bonciani et al.]

Very large scale uncertainties at NLO in c,b production

NNLO will be crucial to make progress!

Some NLO results for B-meson production

NLO FFNS works very well for pT up to roughly 5m



Remarks:

- Fixed order theory in reasonable agreement with Tevatron data up to $p_T \simeq 5m_b$
- At $p_T \lesssim m_b$ factorization less obvious. Depends on defi nition of convolution variable z: $p_B = zp_b$ or $p_T^B = zp_T^b$ or $p_B^+ = zp_b^+$ or $\vec{p}_B = z\vec{p}_b$
- Less hadronization effects than originally believed:
  ϵ-parameter small corresponding to a hard fragmentation function.
  Harder FF $\rightarrow$ harder p_T-spectrum
- Larger $\alpha_s(M_Z) \rightarrow$ harder p_T-spectrum
- Mass dependence imortant for $p_T \lesssim m$ (peak) $\rightarrow \sigma_{tot}$
- Only the 4th or 5th Mellin-moment of the FF is relevant for large p_T [M. Mangano]:
  $d\sigma^b/dp_T(b) \simeq A/p_T(b)^n$ with $n \simeq 4, \ldots, 5$

  $d\sigma^B/dp_T(B) = \int dz/z\, D(z)\, d\sigma^b/dp_T(b)[p_T(b) = p_T(B)/z] =$
  $A/p_T(B)^n \times \int dz\, z^{n-1}\, D(z)$

Theoretical approaches:
Zero Mass Variable Flavor Number Scheme (ZM-VFNS)

ZM-VFNS/RS

Factorization formula for inclusive heavy quark (Q) production:

$$d\sigma^{H+X} \simeq \sum_{a,b,c} \int_0^1 dx_a \int_0^1 dx_b \int_0^1 dz\ f_a^A(x_a,\mu_F) f_b^B(x_b,\mu_F) d\hat{\sigma}_{ab\to c+X} D_c^H(z,\mu_F') + \mathcal{O}(m^2/p_T^2)$$

- Same factorization formula as for inclusive production of pions and kaons
- Quark mass neglected in kinematics and the short distance cross section
- Allows to compute p_T spectrum for $p_T >> m$
- Needs **scale-dependent** FFs of quarks and gluons into the observed heavy-flavored hadron (H)

List of subprocesses in the ZM-VFNS

Massless NLO calculation: [Aversa,Chiappetta,Greco,Guillet,NPB327(1989)105]

1. $gg \to qX$
2. $gg \to gX$
3. $qg \to gX$
4. $qg \to qX$
5. $q\bar{q} \to gX$
6. $q\bar{q} \to qX$
7. $qg \to \bar{q}X$
8. $qg \to \bar{q}'X$
9. $qg \to q'X$
10. $qq \to gX$
11. $qq \to qX$
12. $q\bar{q} \to q'X$
13. $q\bar{q}' \to gX$
14. $q\bar{q}' \to qX$
15. $qq' \to gX$
16. $qq' \to qX$

$\oplus$ charge conjugated processes

Fragmentation functions

Approach I: Perturbative FFs (PFFs)

Caccciari, Greco, Nason, Oleari, ...

$$D_i^H(z,\mu_F') = D_i^Q(z,\mu_F') \otimes D_Q^H(z)$$

PFF evolved with DGLAP; short distance; boundary condition calculable

Non-pert., scale-independent FF describing hadronization of heavy quark Q into heavy hadron H

Mellin-moments of $D_Q^H(z)$ determined from e^+e^- data

Approach II: treat FFs into H in the same way as FFs into pions or kaons

Binnewies, Kniehl, Kramer, ...

Non-pert. boundary conditions $D_i^H(z,m)$ from fit to e^+e^- data; Determine FFs directly in x-space; evolved with DGLAP

PFF approach

Cacciari, Nason, PRL89(2002)122003

$$D_N \equiv \int D(z) z^N \frac{dz}{z}$$

$$\frac{d\sigma}{dp_T} = \int dz d\hat{p}_T\, D(z) \frac{A}{\hat{p}_T^n}\, \delta(p_T - z\hat{p}_T) = \frac{A}{p_T^n} D_n$$

n~3,4,5

Determine FF from N=2 moment in PFF approach; not from entire x-spectrum

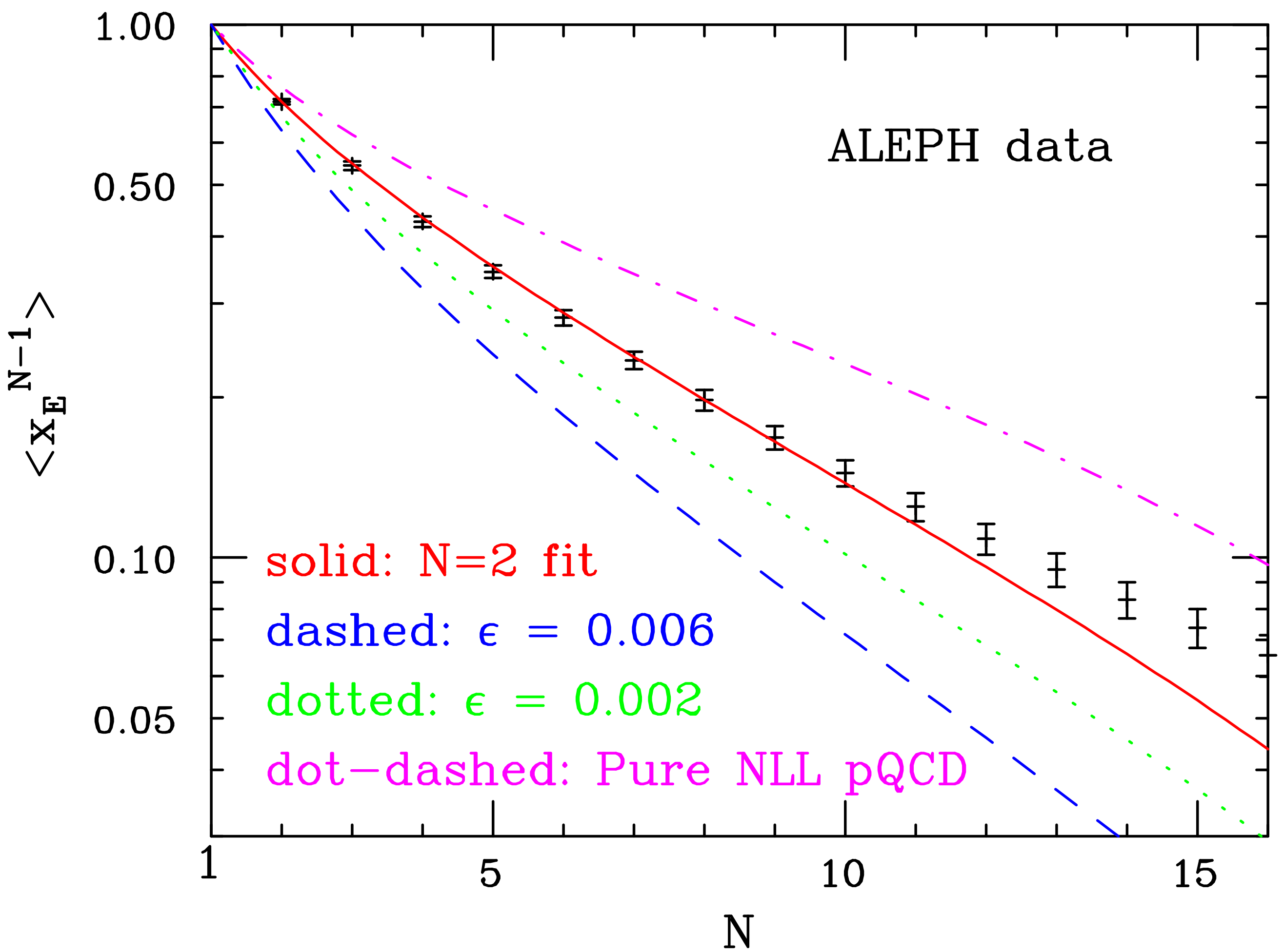
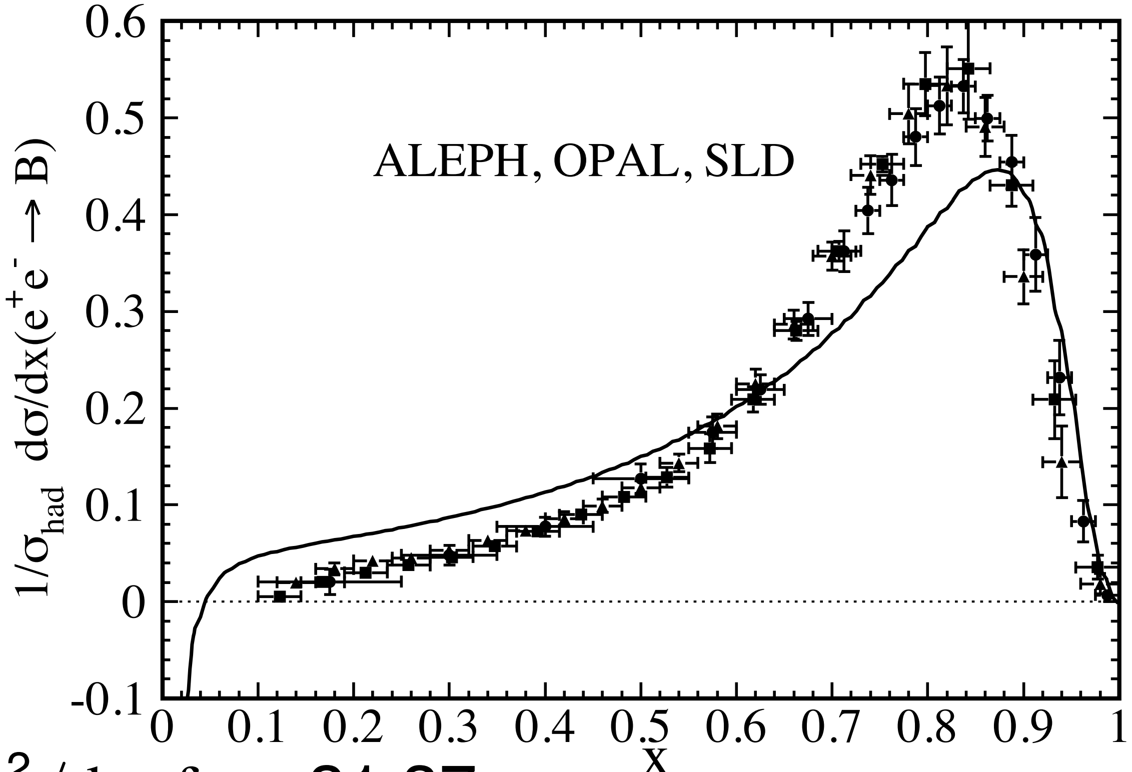


FIG. 1. Moments of the measured B meson fragmentation function, compared with the perturbative NLL calculation supplemented with different $D(z)$ non-perturbative fragmentation forms. The solid line is obtained using a one-parameter form fitted to the second moment.

FFs into B mesons [1] from LEP/SLC data [2]

Petersen

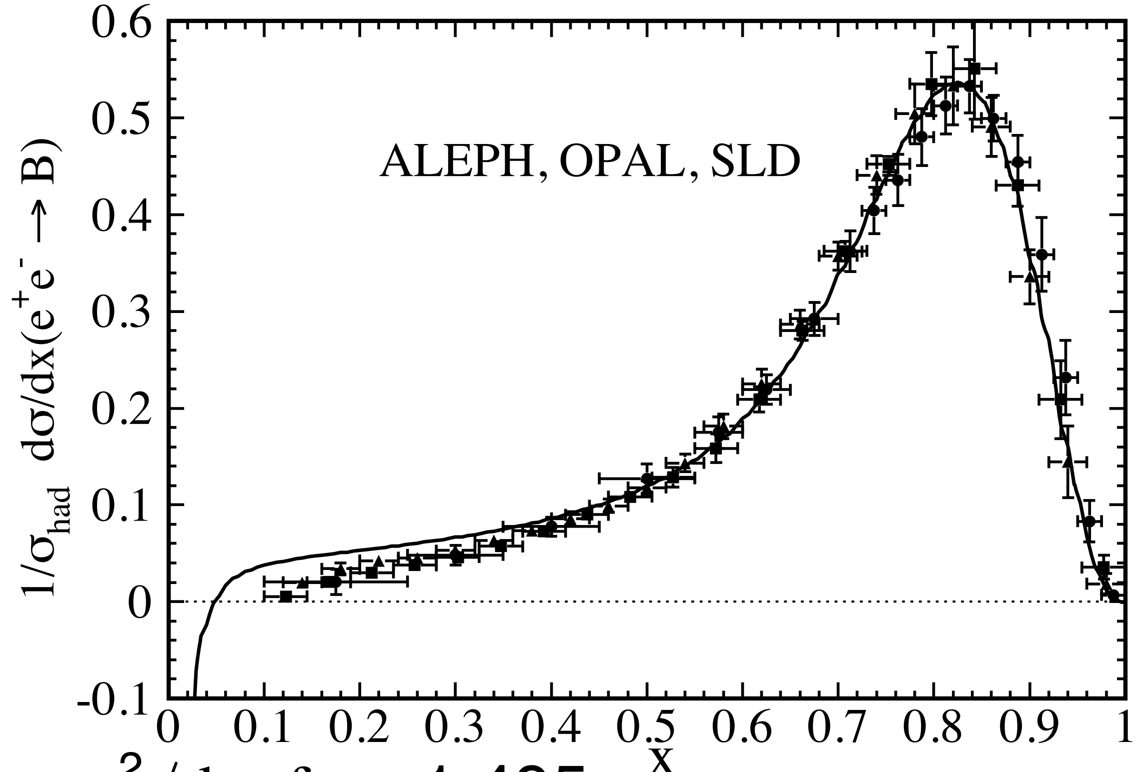
$$D(x,\mu_0^2) = N\frac{x(1-x)^2}{[(1-x)^2+\epsilon x]^2}$$



$\chi^2/\mathrm{d.o.f.} = 21.37$

Kartvelishvili-Likhoded

$$D(x,\mu_0^2) = Nx^{\alpha}(1-x)^{\beta}$$



$\chi^2/\mathrm{d.o.f.} = 1.495$

[1] Kniehl,Kramer,IS,Spiesberger,PRD77(2008)014011

[2] ALEPH, PLB512(2001)30; OPAL, EPJC29(2003)463; SLD, PRL84(2000)4300; PRD65(2002)092006

Theoretical approaches:

General Mass Variable Flavor Number Scheme (GM-VFNS)

GM-VFNS

Factorization Formula: [1]

$$d\sigma(p\bar{p} \to D^\star X) = \sum_{i,j,k} \int dx_1\, dx_2\, dz\, f_i^p(x_1)\, f_j^{\bar{p}}(x_2) \times$$
$$\mathrm{d}\hat{\sigma}(ij \to kX)\, D_k^{D^\star}(z) + \mathcal{O}(\alpha_s^{n+1}, (\tfrac{\Lambda}{Q})^p)$$

Q: hard scale, $p = 1, 2$

- $\mathrm{d}\hat{\sigma}(\mu_F, \mu'_F, \alpha_s(\mu_R), \frac{m_h}{p_T})$: hard scattering cross sections free of long-distance physics $\longrightarrow$ m_h kept
- PDFs $f_i^p(x_1, \mu_F)$, $f_j^{\bar{p}}(x_2, \mu_F)$: $i, j = g, q, c \quad [q = u, d, s]$
- FFs $D_k^{D^\star}(z, \mu'_F)$: $k = g, q, c$

$\Rightarrow$ need short distance coefficients including heavy quark masses

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[1] J. Collins, 'Hard-scattering factorization with heavy quarks: A general treatment', PRD58(1998)094002

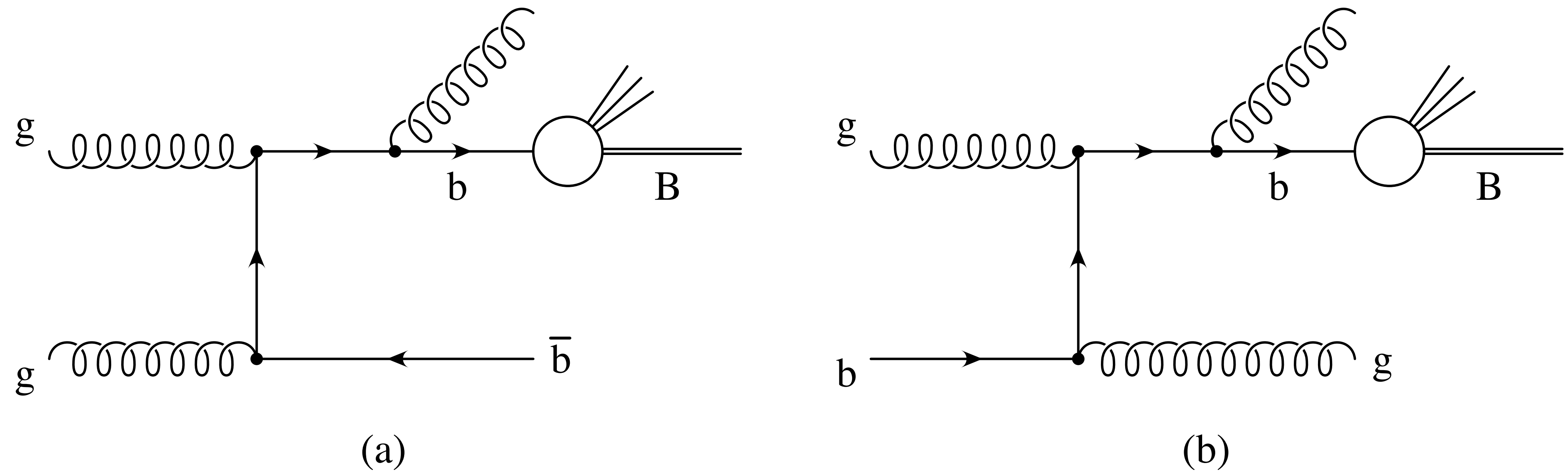
List of subprocesses in the GM-VFNS

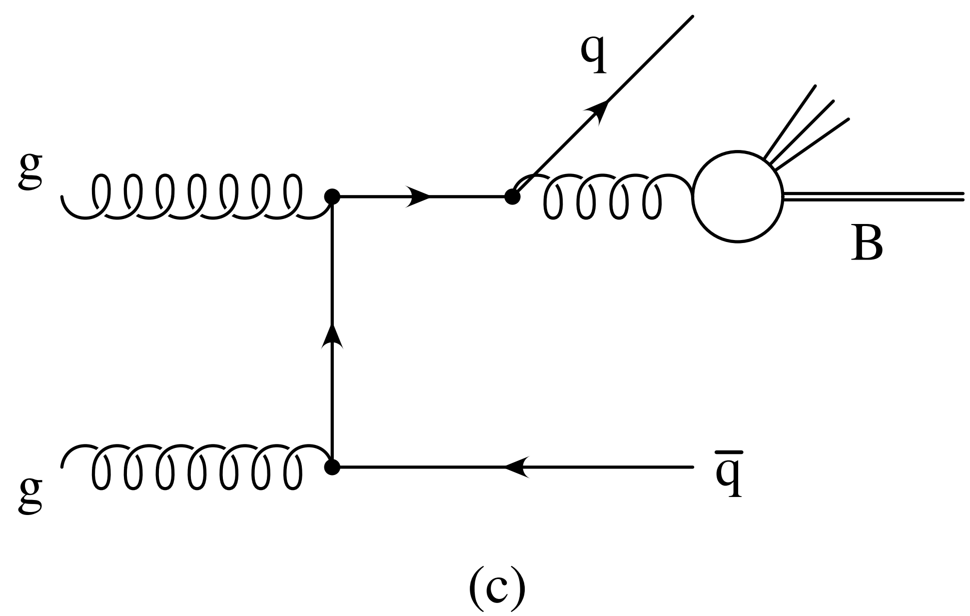
	Only light lines	Heavy quark initiated ($m_Q = 0$)	Mass effects: $m_Q \neq 0$
1	$gg \to qX$	-	$gg \to QX$
2	$gg \to gX$	-	-
3	$qg \to gX$	$Qg \to gX$	-
4	$qg \to qX$	$Qg \to QX$	-
5	$q\bar{q} \to gX$	$Q\bar{Q} \to gX$	-
6	$q\bar{q} \to qX$	$Q\bar{Q} \to QX$	-
7	$qg \to \bar{q}X$	$Qg \to \bar{Q}X$	-
8	$qg \to \bar{q}'X$	$Qg \to \bar{q}X$	$qg \to \bar{Q}X$
9	$qg \to q'X$	$Qg \to qX$	$qg \to QX$
10	$qq \to gX$	$QQ \to gX$	-
11	$qq \to qX$	$QQ \to QX$	-
12	$q\bar{q} \to q'X$	$Q\bar{Q} \to qX$	$q\bar{q} \to QX$
13	$q\bar{q}' \to gX$	$Q\bar{q} \to gX$, $q\bar{Q} \to gX$	-
14	$q\bar{q}' \to qX$	$Q\bar{q} \to QX$, $q\bar{Q} \to qX$	-
15	$qq' \to gX$	$Qq \to gX$, $qQ \to gX$	-
16	$qq' \to qX$	$Qq \to QX$, $qQ \to qX$	-

$\oplus$ charge conjugated processes

Example diagrams

m ≠ 0 | m = 0 (S-ACOT)





arXiv:0705.4392

Reaches 50% at Tevatron at small pT; decreases only mildly towards larger pT

FIG. 2: Examples of Feynman diagrams leading to contributions of (a) class (i), (b) class (ii), and (c) class (iii).

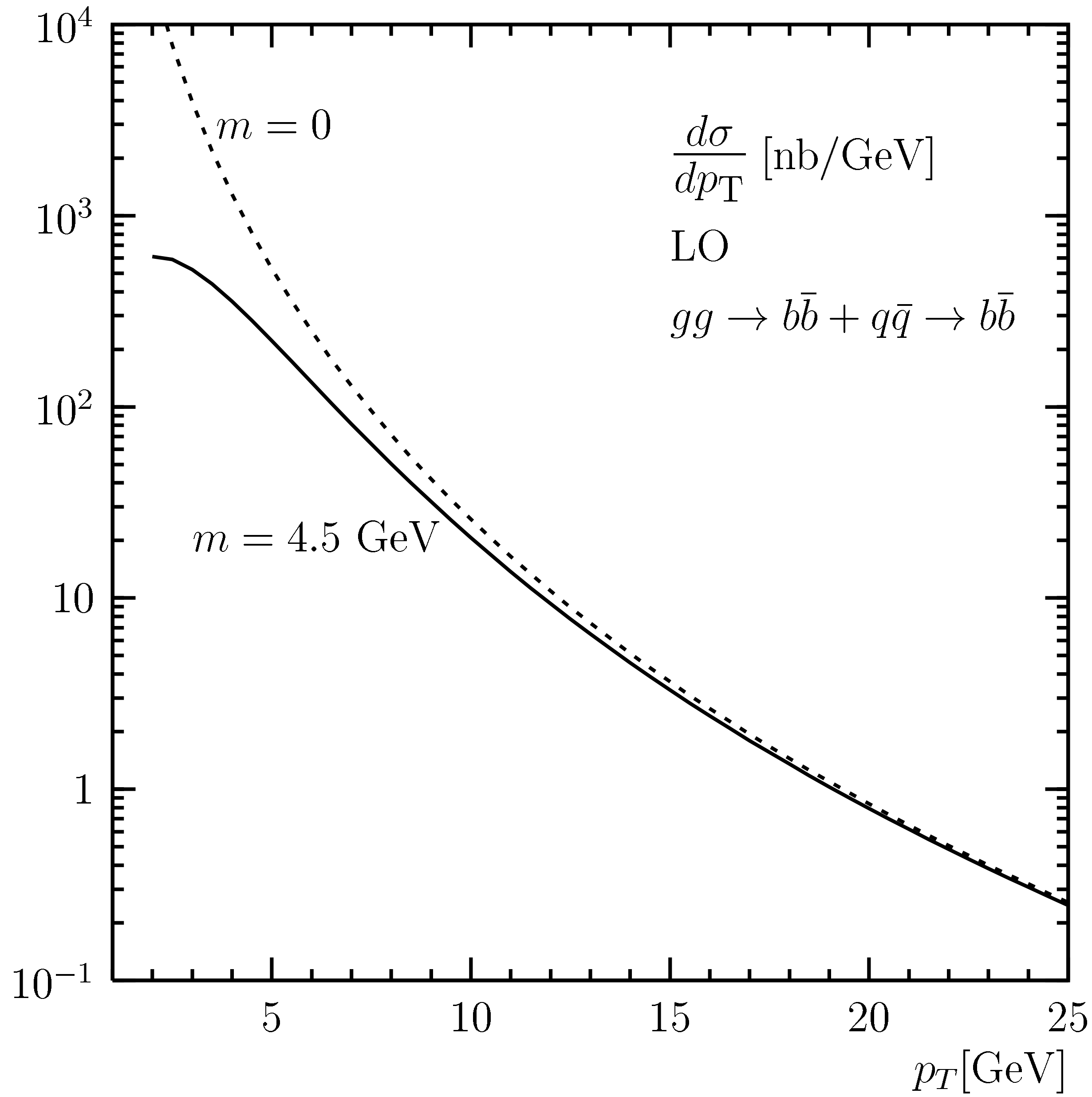
Limiting cases

- **GM-VFNS → ZM-VFNS for p_T >> m**
  (this is the case by construction)

- **GM-VFNS → FFNS for p_T ~ m**
  (formally this can be shown; numerically problematic in the S-ACOT scheme)

The GM-VFNS at low p_T

LO: m=0 case diverges at pT=0



Problem: current implementation in S-ACOT scheme
b+g channel with m=0 diverges at small p_T!

The GM-VFNS at low p_T

Problem can be solved by suitable scale choice

arXiv:1502.01001

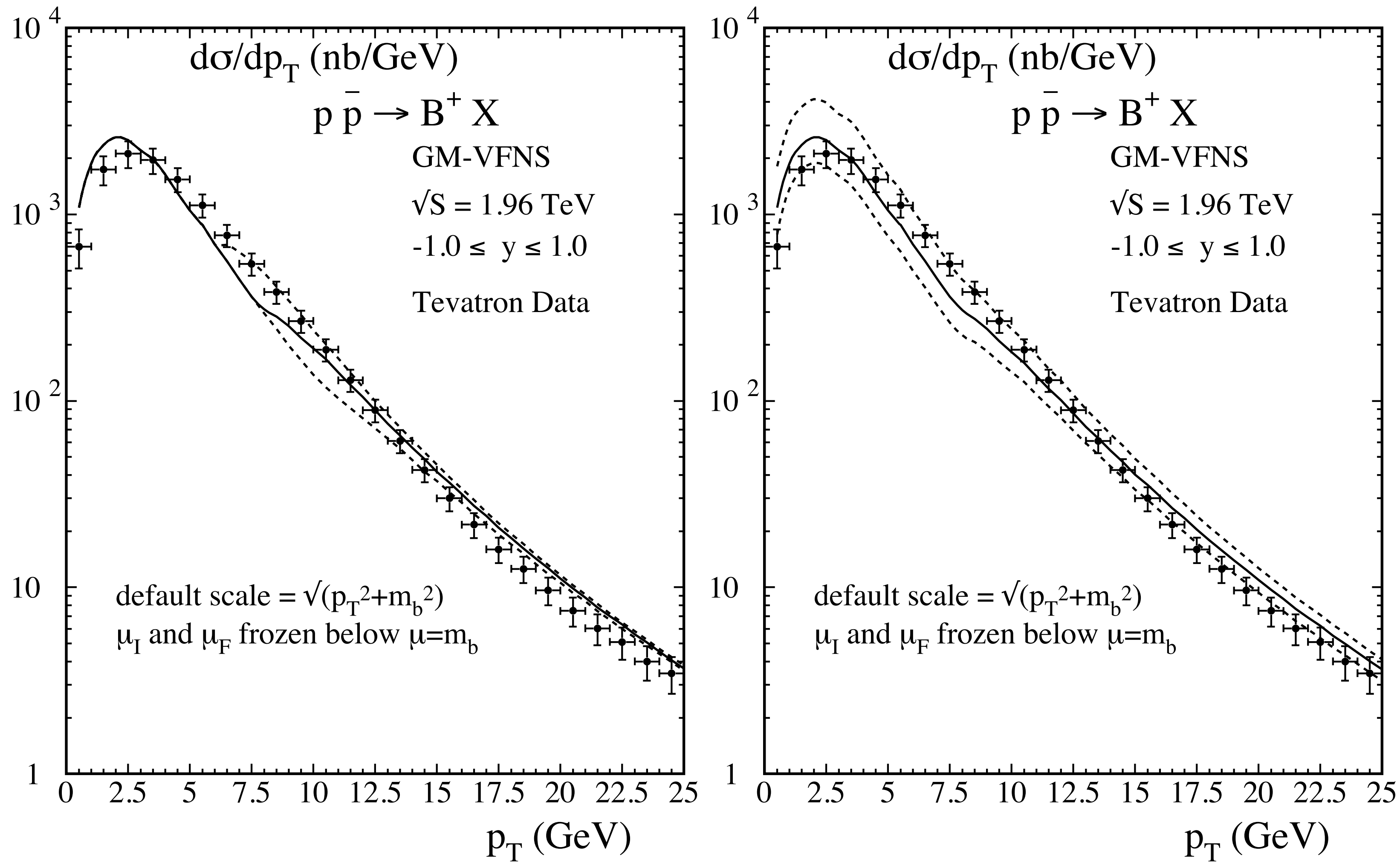


Figure 5: $d\sigma/dp_T$ for $p\bar{p} \to B^+ + X$ at $\sqrt{S} = 1.96$ TeV, $|y| < 1.0$, in the GM-VFNS (data from CDF [6]). Left panel: $\xi_R = 1$, $\xi_I = 0.5$ and $\xi_F = 0.5$ (full curve), $\xi_F = 0.6$ (upper dashed curve), $\xi_F = 0.4$ (lower dashed curve). Right panel: $\xi_i = (1, 0.5, 0.5)$ for the central curve; upper curve: $\xi_R = 0.5$, lower curve: $\xi_R = 2$.

The GM-VFNS at low p_T

Comparison with LHCb data

arXiv:1502.01001

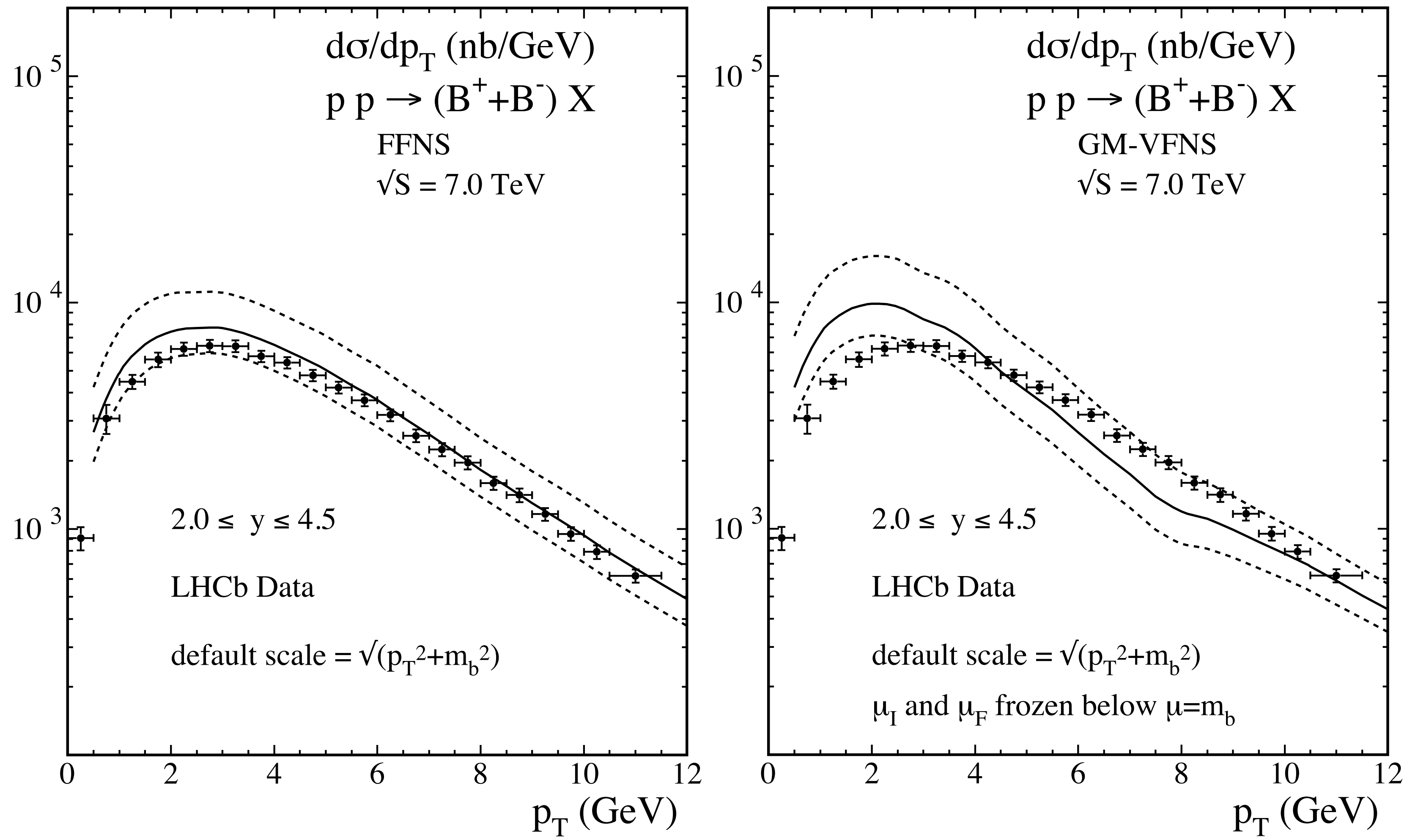


Figure 6: $d\sigma/dp_T$ for $pp \to B^+ + B^- + X$ at $\sqrt{S} = 7$ TeV with $2.0 < y < 4.5$, compared with results from the FFNS (left) and the GM-VFNS (right). $\xi_{R,I,F} = (1,\ 0.5,\ 0.5)$. The error band is obtained from variations by factors 2 up and down (maximum: $\xi_R = 0.5$, minimum: $\xi_R = 2$). The factorization scale parameters are frozen below $\mu_{I,F} = m_b$. Data points are taken from [15].

GM-VFNS: Comparison with ATLAS data

arXiv:1502.01001

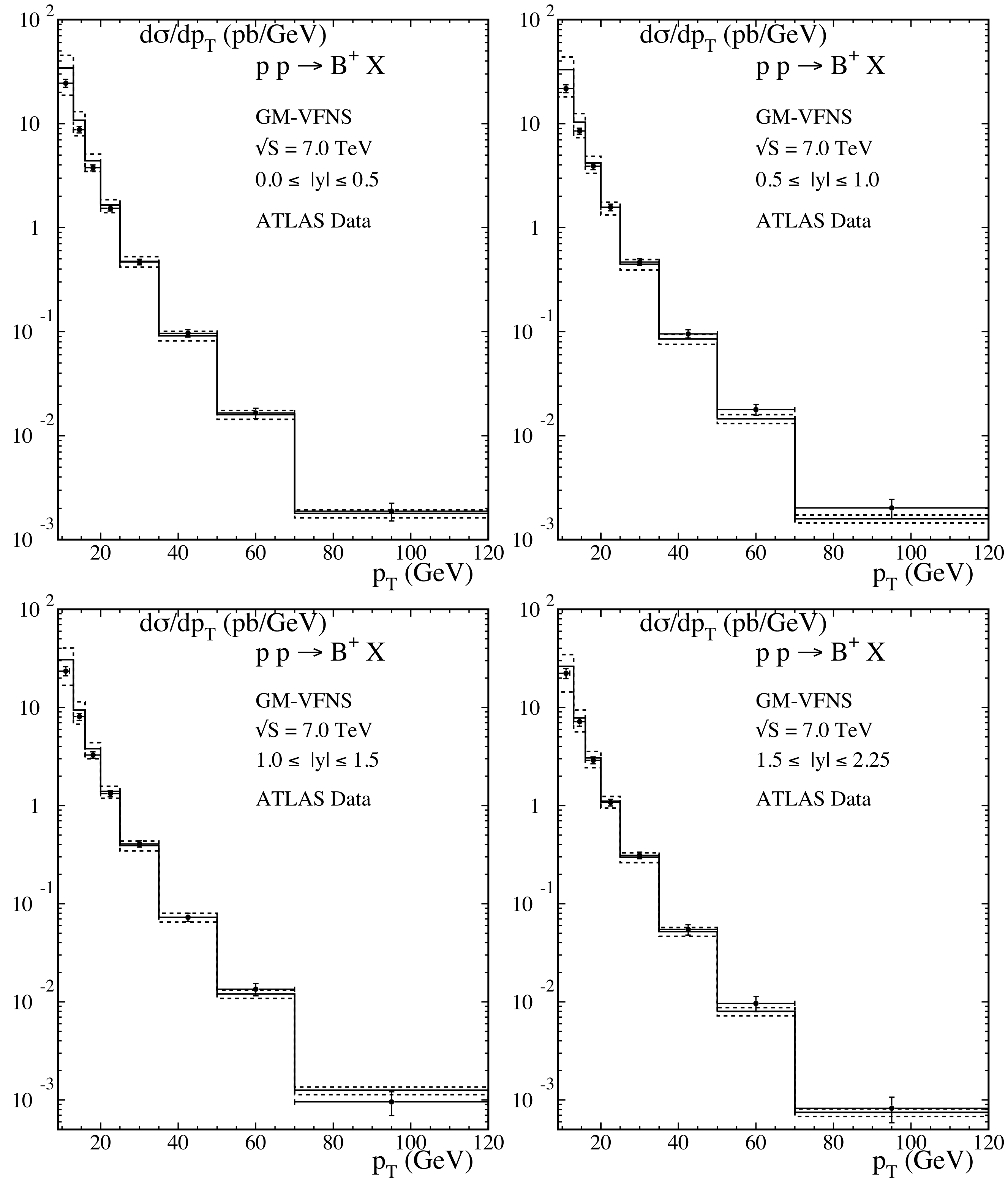


Figure 9: $pp \to B^+ + X$ at $\sqrt{S} = 7$ TeV in the GM-VFNS compared with data from ATLAS [13]. $\mu_{I,F}$ are frozen below m_b and $\xi_i = (1,\ 1,\ 1)$.

GM-VFNS

- FFs in x-space in the BKK approach

- Heavy-quark initiated contributions ($Q+g \rightarrow Q+X$, ...) get very large at small p_T in the massless case:

  (i) switch off heavy-quark PDF sufficiently quickly
  OR
  (ii) calculate these subprocesses with mass

- Error bands: μ_R , μ_F , μ_F' varied independently

- Predictions for D and B prod. at Tevatron, RHIC, LHC:
  arXiv:1502.01001, 1202.0439, 1109.2472, 0901.4130, 0705.4392, hep-ph/0508129, ph/0502194, ph/0410289

- Predictions including D-decay and B-decay:
  arXiv: 1310.2924, 1212.4356

Theoretical approaches:
Fixed Order plus Next-to-Leading Logarithms (FONLL)

FONLL=FO+NLL [1]

$$\mathrm{FONLL} = \mathrm{FO} + (\mathrm{RS} - \mathrm{FOM0})\,G(m, p_T)$$

FO: Fixed Order; FOM0: Massless limit of FO; RS: Resummed

$$G(m, p_T) = \frac{p_T^2}{p_T^2 + 25m^2} \simeq \begin{cases} 0.04 & : \quad p_T = m \\ 0.25 & : \quad p_T = 3m \\ 0.50 & : \quad p_T = 5m \\ 0.66 & : \quad p_T = 7m \\ 0.80 & : \quad p_T = 10m \end{cases}$$

$$\Rightarrow \mathrm{FONLL} = \begin{cases} \mathrm{FO} & : \quad p_T \lesssim 3m \\ \mathrm{RS} & : \quad p_T \gtrsim 10m \end{cases}$$

[1] Cacciari, Greco, Nason, JHEP05(1998)007

FONLL

- FFs in N-space in the PFF approach
- RS-FOM0 gets very large at small p_T:

  $G(m,p_T) = p_T^2/(p_T^2 + a^2\ m^2)$ with **a=5**

  needed to suppress this contribution sufficiently rapidly
- Central scale choice for FO, RS, FOM0: m_T
- Error bands: $\mu_F = \mu_F'$ (only two scales varied)
- Predictions for LHC7 in arXiv:1205.6344

Termes in the perturbation series

Termes in the perturbation series

$L = \ln(m/p_T)$
$a = \alpha_s/(2\pi)$

Resummed ↓

Fixed Order →

	LL	NLL	NNLL	...
LO	1			
NLO	aL	a		
NNLO	$(aL)^2$	$a(aL)$	a^2	
...	...	...	...	...

FFNS/Fixed Order NLO

Resummed ↓

Fixed Order→

	LL	NLL	NNLL	...
LO $m\neq0$	1			
NLO $m\neq0$	aL	a		
NNLO	$(aL)^2$	$a(aL)$	a^2	
...	...	...	...	...

ZM-VFNS/Resummed NLO

Resummed ↓

Fixed Order →

	LL m=0	NLL m=0	NNLL	...
LO	1			
NLO	aL	a		
NNLO	$(aL)^2$	a(aL)	a^2	
...	...	...	...	...

GM-VFNS/FONLL (NLO+NLL)

Resummed ↓

Fixed Order →

	LL	NLL	NNLL	...
LO	1 $m \neq 0$			
NLO	aL $m \neq 0$	a $m \neq 0$		
NNLO	$(aL)^2$ $m=0$	$a(aL)$ $m=0$	a^2	
...	... $m=0$	... $m=0$	...	...

NLO Monte Carlo generators:
MC@NLO and POWHEG

NLO MC generators

- MC@NLO, POWHEG: hep-ph/0305252, arXiv:0707.3088
  consistent matching of NLO matrix elements with parton showers (PS)

- Flexible simulation of hadronic final state
  (PS, hadronization, detector effects)

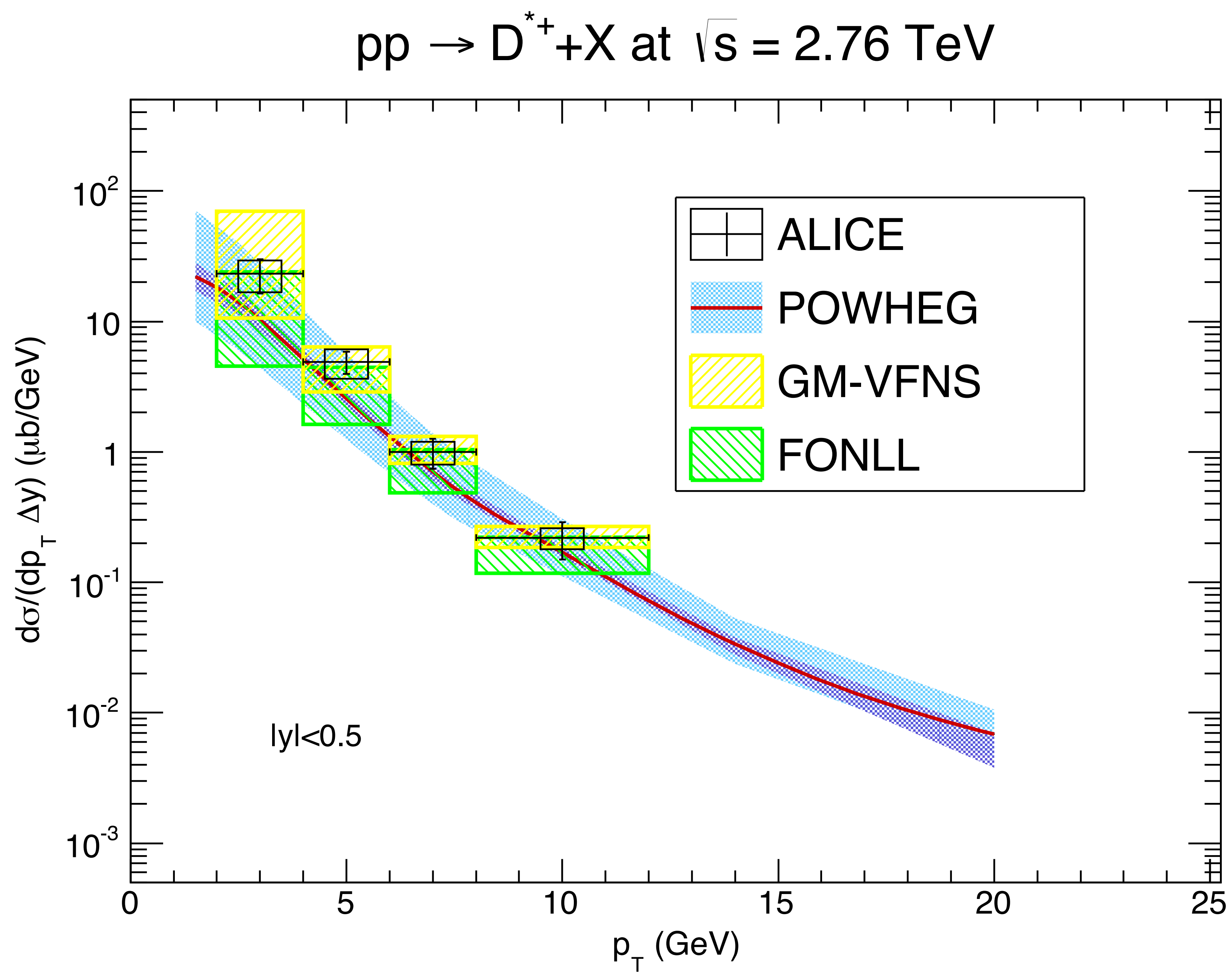
  Note: FONLL and GM-VFNS only one-particle inclusive observables

- High accuracy: NLO+LL*
  (FONLL and GM-VFNS have NLO+NLL accuracy)

- Simulation of hadronic final state involves tuning;
  NOT a pure theory prediction!

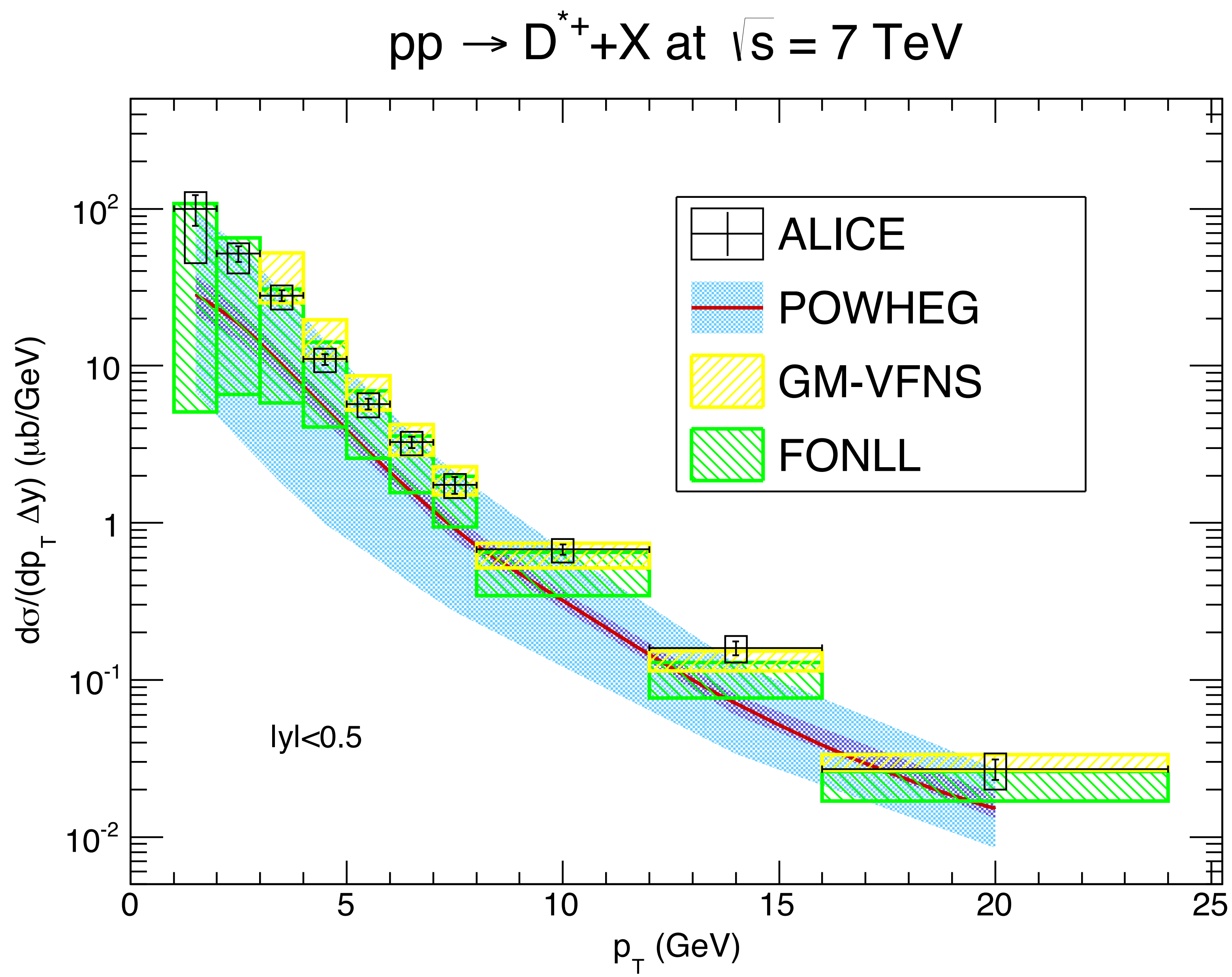
Comparison with ALICE data

arXiv:1405.3083



Comparison with ALICE data

arXiv:1405.3083



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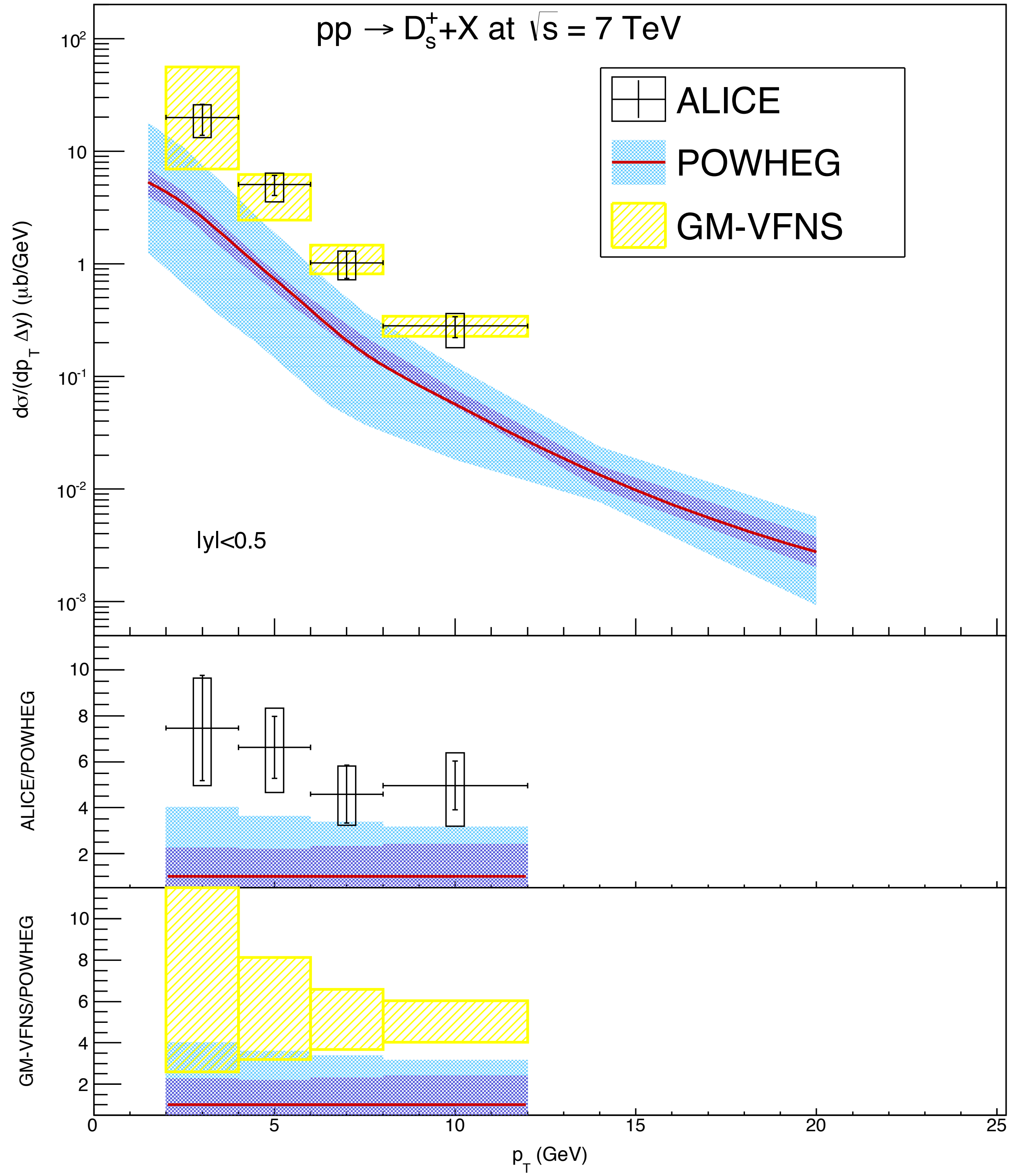
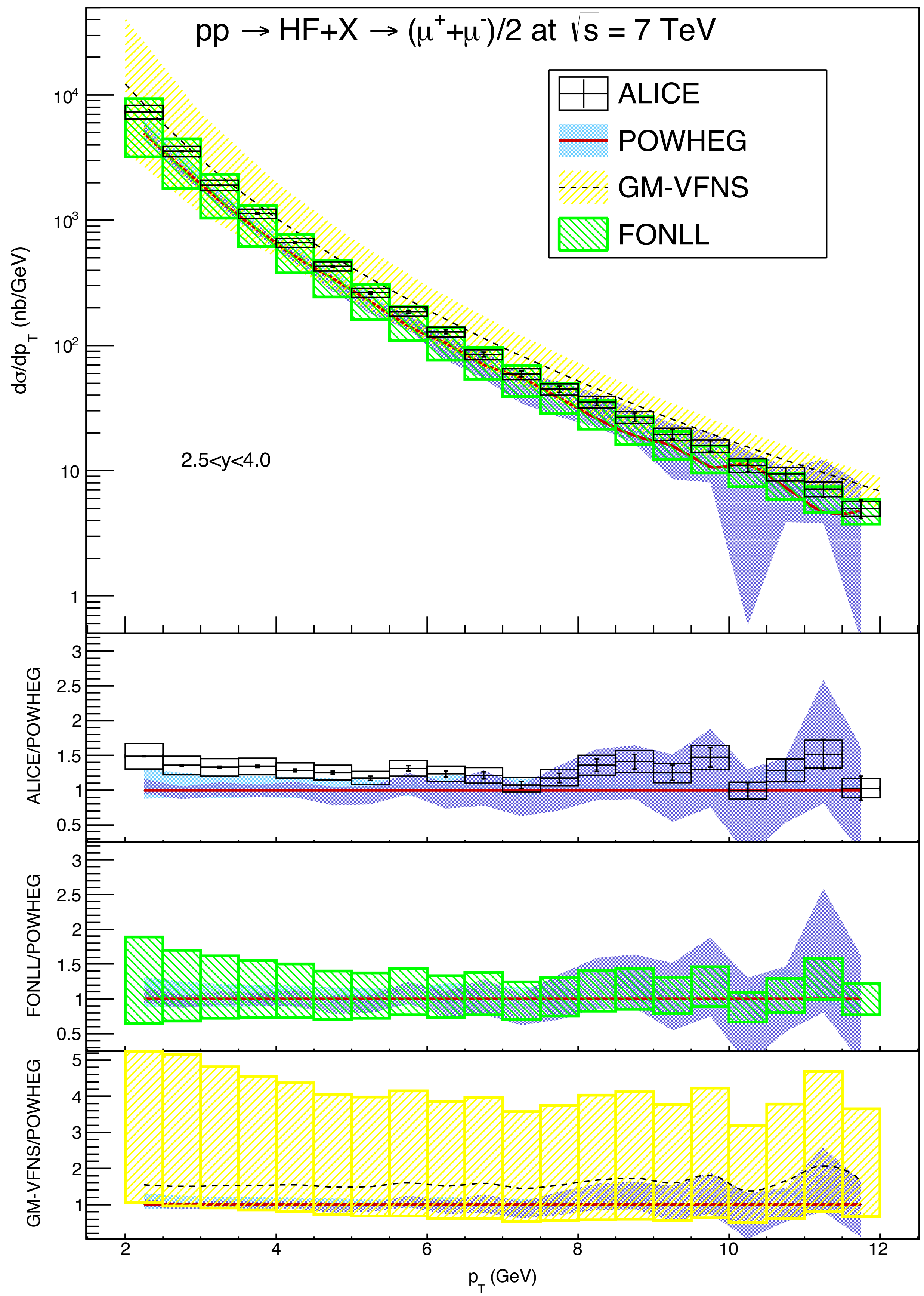


Comparison with ALICE data



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Comparison with ALICE data

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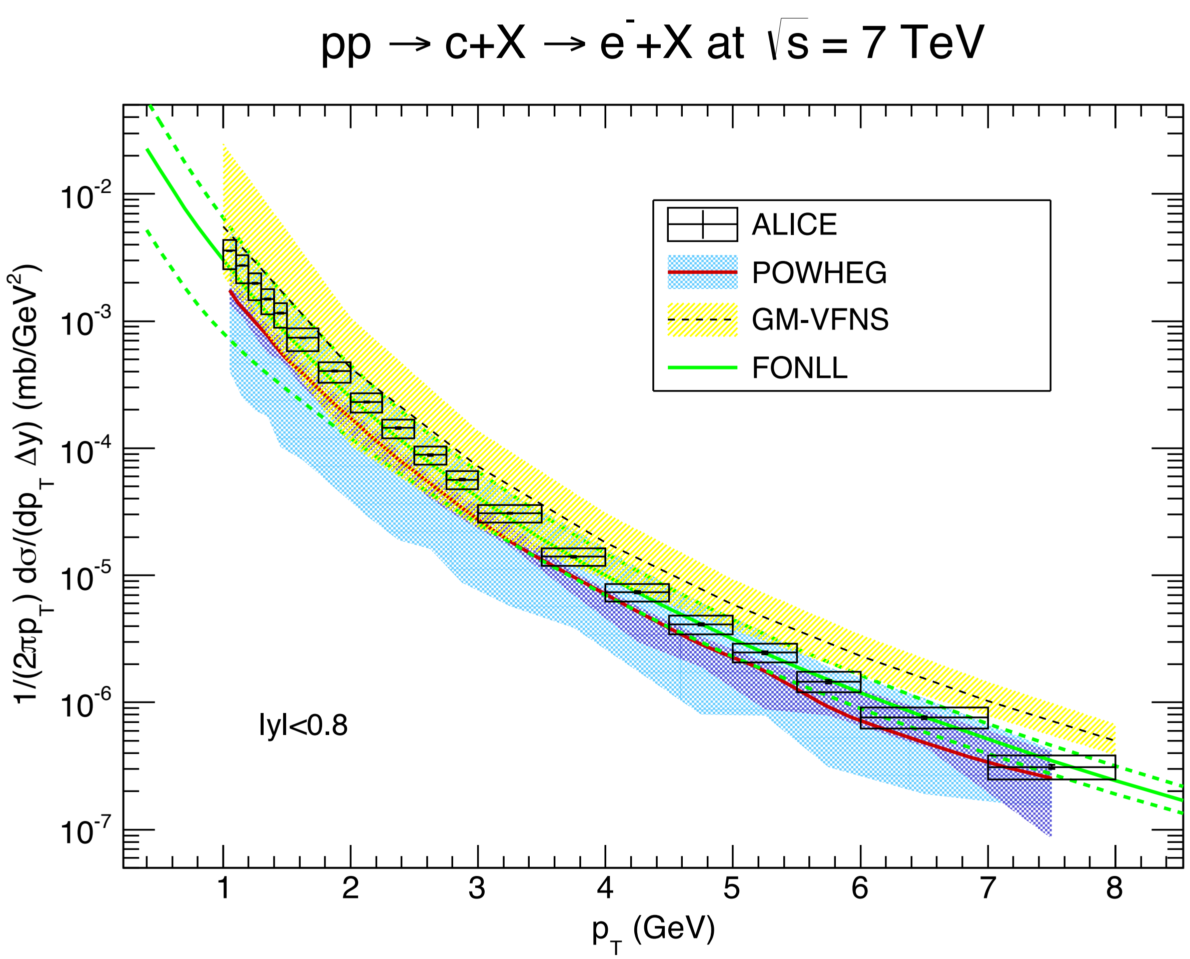
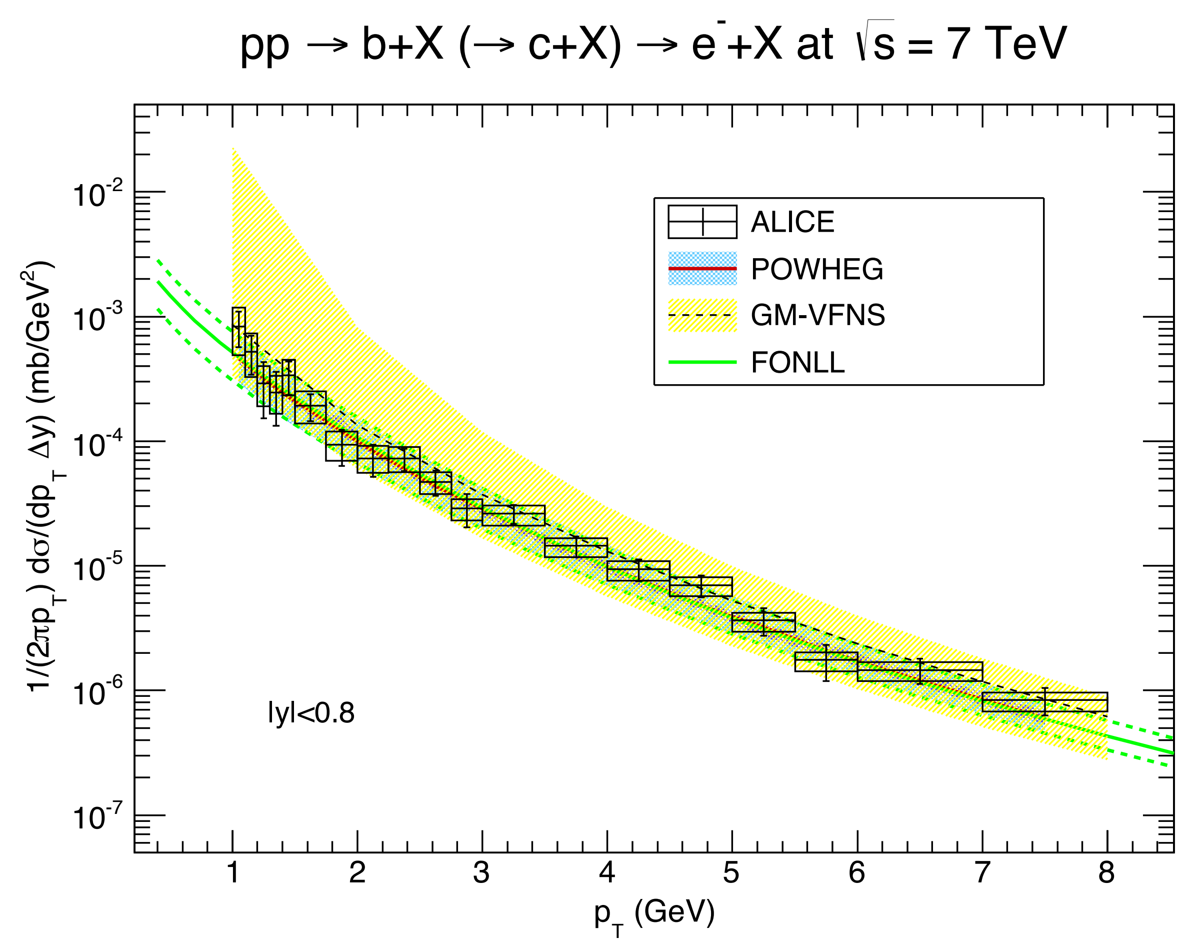




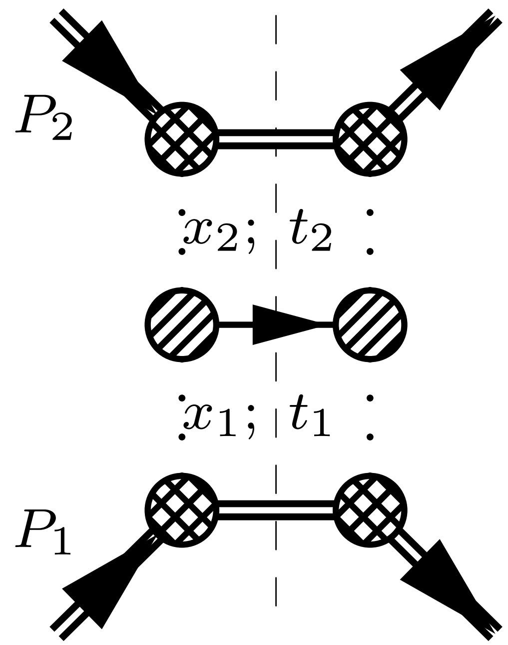
Theoretical approaches:
k_T factorization

k_T factorization

k_T factorization: Gribov et al. '83; Collins et al. '91; Catani et al. '91

Central production, small x~0.01 ... 0.001

Factorization:



Partonic cross-section:

$$d\hat{\sigma}_{PRA} = \frac{(2\pi)^4}{2x_1x_2S}\overline{|\mathcal{M}|^2}_{PRA}\delta^{(4)}(P_{[i]} - P_{[f]}) \times \times \prod_{j=[f]} \frac{d^3\mathbf{p}_j}{(2\pi)^3 2p_j^0},$$

Factorization formula:

$$d\sigma = \int \frac{d^2\mathbf{q}_{T1}}{\pi} \int \frac{dx_1}{x_1}\Phi(x_1, t_1, \mu_F) \times \times \int \frac{d^2\mathbf{q}_{T2}}{\pi} \int \frac{dx_2}{x_2}\Phi(x_2, t_2, \mu_F) d\hat{\sigma}_{PRA}$$

Where Φ - Unintegrated PDFs.

Normalization of the unPDF:

$$\int^{\mu^2} dt \Phi(x, t, \mu^2) = xf(x, \mu^2),$$

where $f(x, \mu^2)$ - collinear PDF, implies, that the *collinear limit* holds for the amplitude:

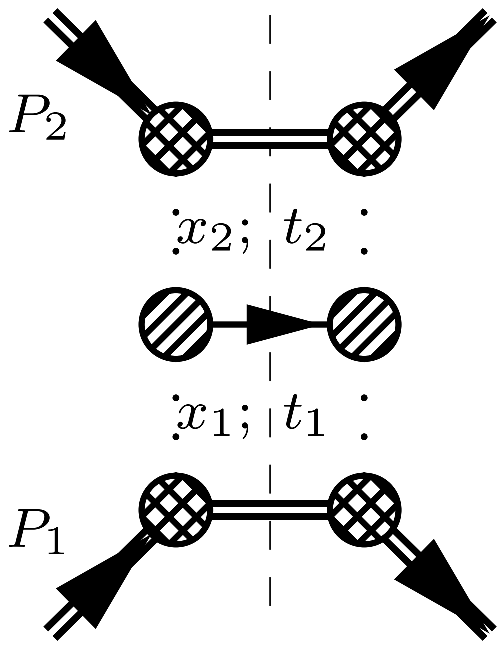
$$\int \frac{d\phi_1 d\phi_2}{(2\pi)^2} \lim_{t_{1,2}\to 0} \overline{|\mathcal{M}|^2}_{PRA} = \overline{|\mathcal{M}|^2}_{CPM}$$

Application to D and B meson production in Parton Reggeization Approach (RPA):
Karpishkov, Nefedov, Saleev, Shipilova, ...

k_T factorization

k_T factorization: Gribov et al. '83; Collins et al. '91; Catani et al. '91
Central production, small x~0.01 ... 0.001

Factorization:



Partonic cross-section:

$$d\hat{\sigma}_{PRA} = \frac{(2\pi)^4}{2x_1x_2S}\overline{|\mathcal{M}|^2}_{PRA}\delta^{(4)}(P_{[i]} - P_{[f]}) \times \times \prod_{j=[f]} \frac{d^3\mathbf{p}_j}{(2\pi)^3 2p_j^0},$$

Normalization of the unPDF:

$$\int^{\mu^2} dt\Phi(x,t,\mu^2) = xf(x,\mu^2),$$

Factorization formula:

$$d\sigma = \int \frac{d^2\mathbf{q}_{T1}}{\pi} \int \frac{dx_1}{x_1}\Phi(x_1,t_1,\mu_F) \times \times \int \frac{d^2\mathbf{q}_{T2}}{\pi} \int \frac{dx_2}{x_2}\Phi(x_2,t_2,\mu_F) d\hat{\sigma}_{PRA}$$

Where Φ - Unintegrated PDFs.

where $f(x,\mu^2)$ - collinear PDF, implies, that the *collinear limit* holds for the amplitude:

$$\int \frac{d\phi_1 d\phi_2}{(2\pi)^2} \lim_{t_{1,2}\to 0} \overline{|\mathcal{M}|^2}_{PRA} = \overline{|\mathcal{M}|^2}_{CPM}$$

Application to D and B meson production in Parton Reggeization Approach (RPA):
Karpishkov, Nefedov, Saleev, Shipilova, ...

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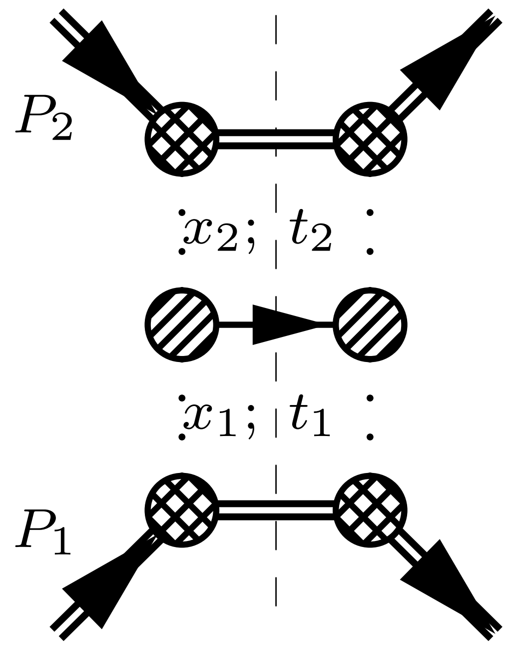

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$$d\sigma = \int \frac{d^2\mathbf{q}_{T1}}{\pi} \int \frac{dx_1}{x_1} \Phi(x_1, t_1, \mu_F) \times$$
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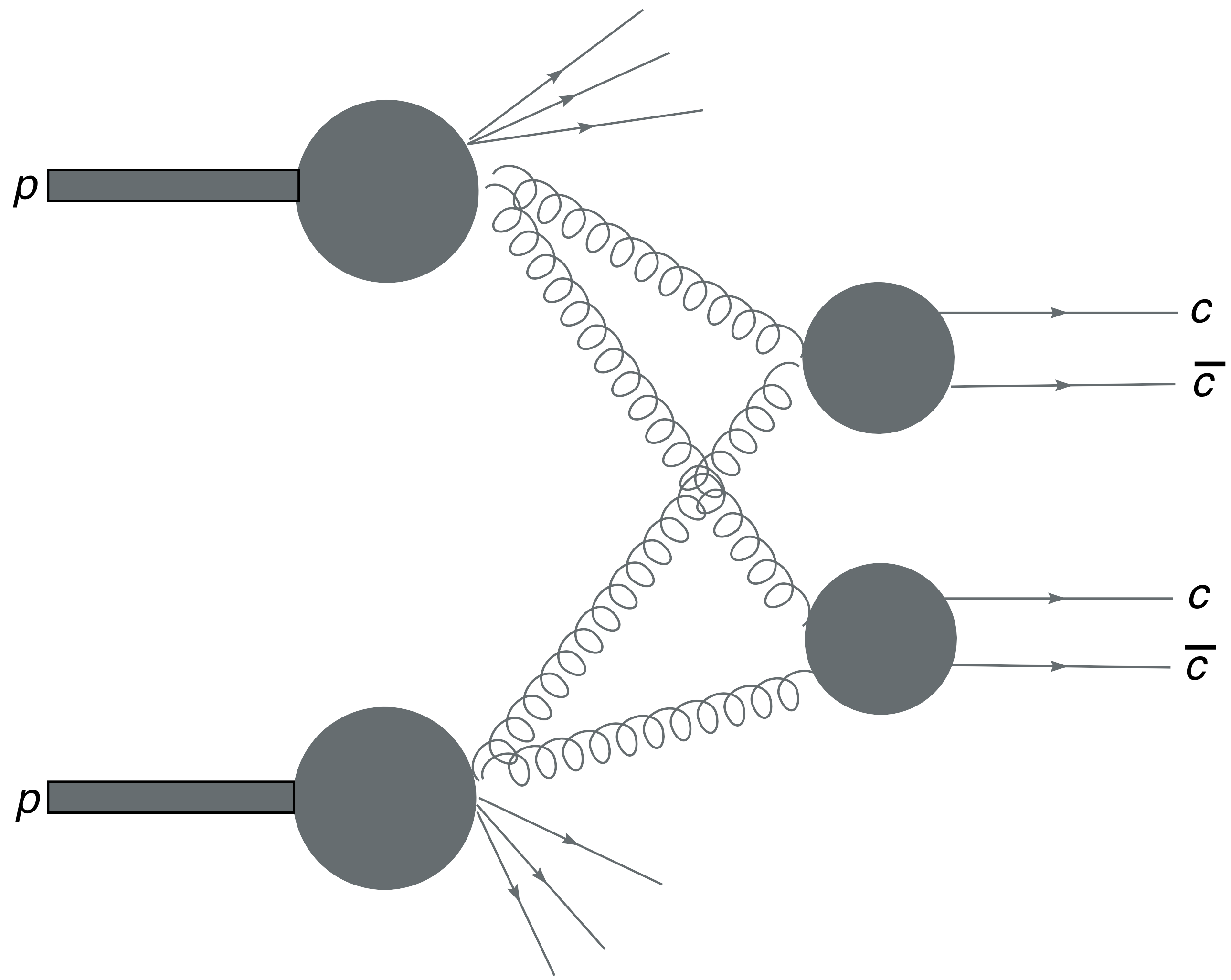
Application to D and B meson production in Parton Reggeization Approach (RPA):

Karpishkov, Nefedov, Saleev, Shipilova, ...

Theoretical approaches:
Double parton scattering

Production of two $c\bar{c}$ pairs in double-parton scattering

Consider two hard (parton) scatterings



Not consider so far in the literature

Luszczak, Maciula, Szczurek, arXiv:1111.3255

Factorization of double parton scattering?

arXiv:1410.6664

- Correlations between the two momentum fractions, the transverse separation of partons and/or flavor
- Spin correlations between the partons
- Color correlations between the partons
- Interferences in fermion number
- Interferences in flavor

Formalism

$$d\sigma^{DPS} = \frac{1}{2\sigma_{eff}} F_{gg}(x_1, x_2, \mu_1^2, \mu_2^2) F_{gg}(x_1' x_2', \mu_1^2, \mu_2^2)$$
$$d\sigma_{gg \to c\bar{c}}(x_1, x_1', \mu_1^2) d\sigma_{gg \to c\bar{c}}(x_2, x_2', \mu_2^2)\ dx_1 dx_2 dx_1' dx_2' \,.$$

$F_{gg}(x_1, x_2, \mu_1^2, \mu_2^2)$, $F_{gg}(x_1' x_2', \mu_1^2, \mu_2^2)$
are called double parton distributions

dPDF are subjected to special evoultion equations

single scale evolution: Snigireev

double scale evolution: Ceccopieri, Gaunt-Stirling

Formalism

Consider reaction: $pp \to c\bar{c}c\bar{c}X$

Modeling double-parton scattering

Factorized form:

If two hard scatterings are completely independent! (very rough!)

$$\sigma^{DPS}(pp \to c\bar{c}c\bar{c}X) = \frac{1}{2\sigma_{eff}} \sigma^{SPS}(pp \to c\bar{c}X_1) \cdot \sigma^{SPS}(pp \to c\bar{c}X_2).$$

The simple formula can be generalized to include differential distributions

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1t} dy_3 dy_4 d^2p_{2t}} = \frac{1}{2\sigma_{eff}} \cdot \frac{d\sigma}{dy_1 dy_2 d^2p_{1t}} \cdot \frac{d\sigma}{dy_3 dy_4 d^2p_{2t}} .$$

σ_{eff} is a model parameter (12-15 mb)

Theoretical approaches:
diffractive production

Diffractive production

Szczurek et al., arXiv:1412.3132

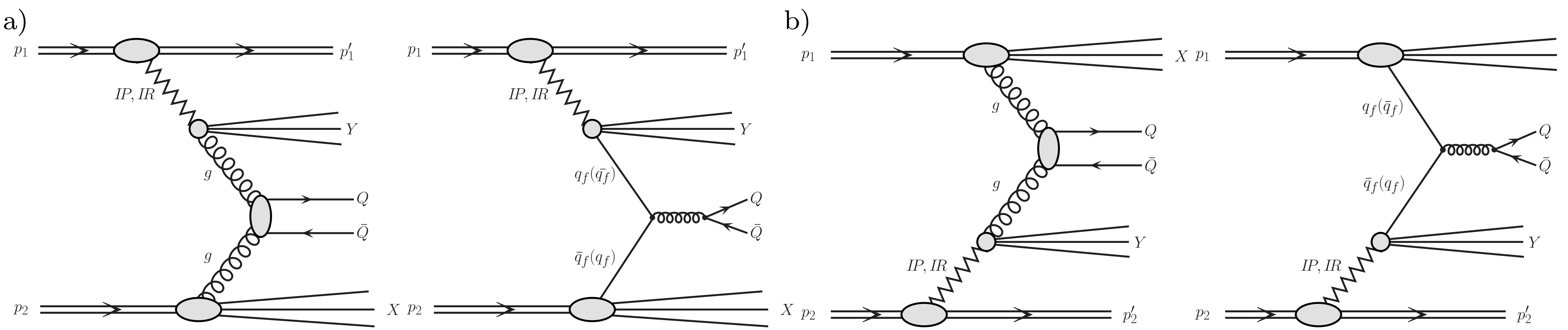


FIG. 1: The mechanisms of single-diffractive production of heavy quarks.

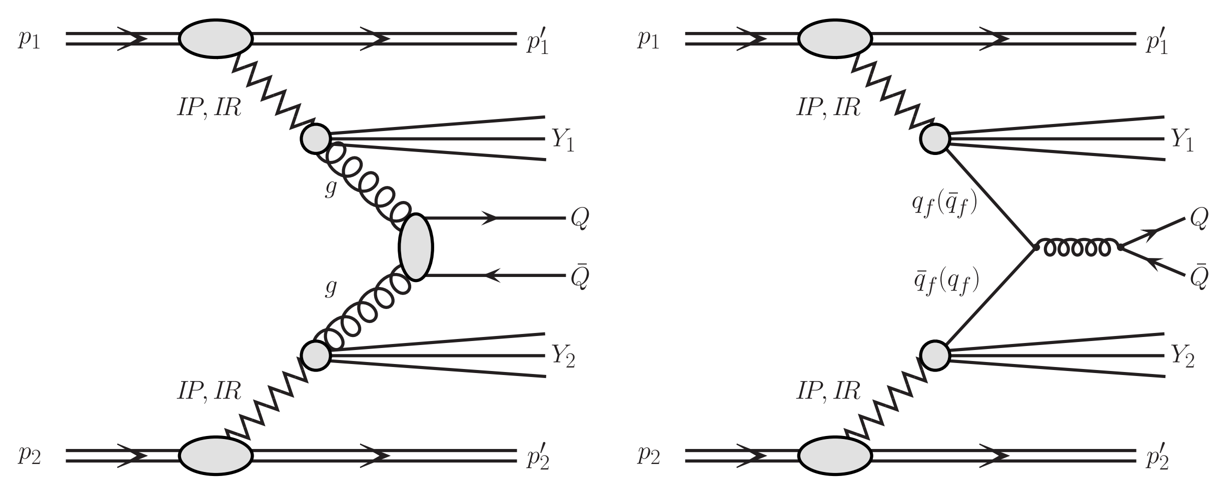


FIG. 2: The mechanisms of central-diffractive production of heavy quarks.

IV. SUMMARY

Summary

- Discussed different theoretical approaches to open heavy flavor hadroproduction
- GM-VFNS, FONLL, POWHEG in good agreement with data within large uncertainties!
- pA data for B meson production useful for constraining nuclear gluon PDF
- GM-VFNS at low p_T improved; more work