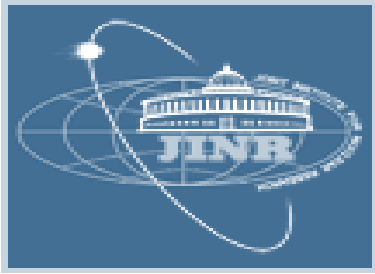


COLLIDER TESTS OF INTRINSIC QUARK DISTRIBUTIONS IN PROTON



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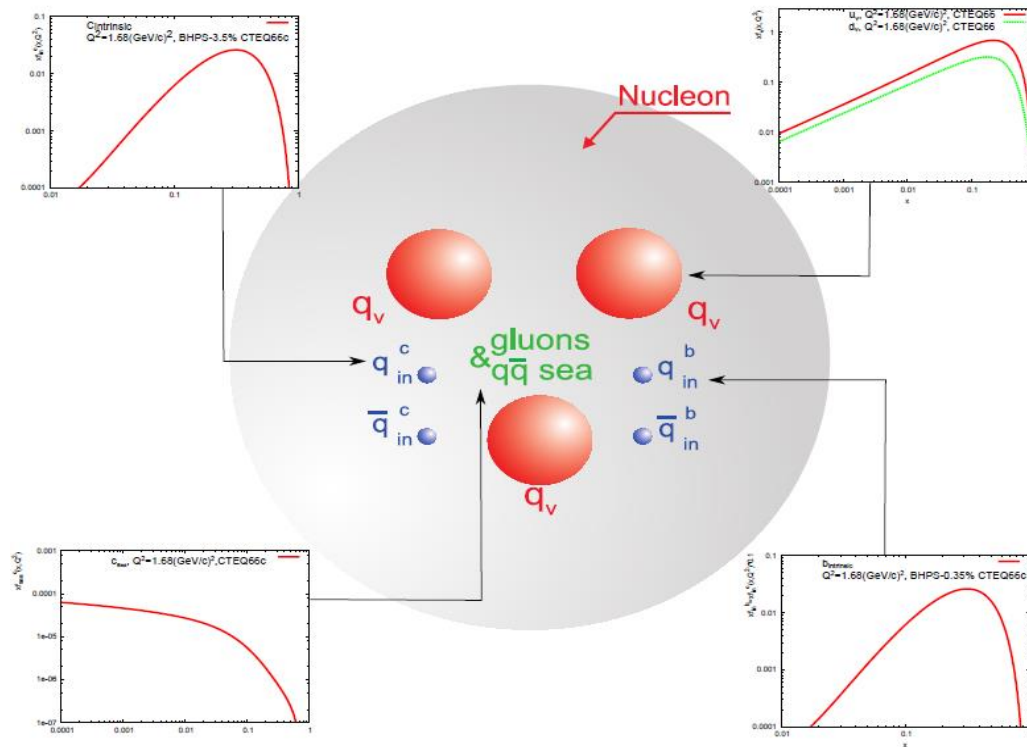


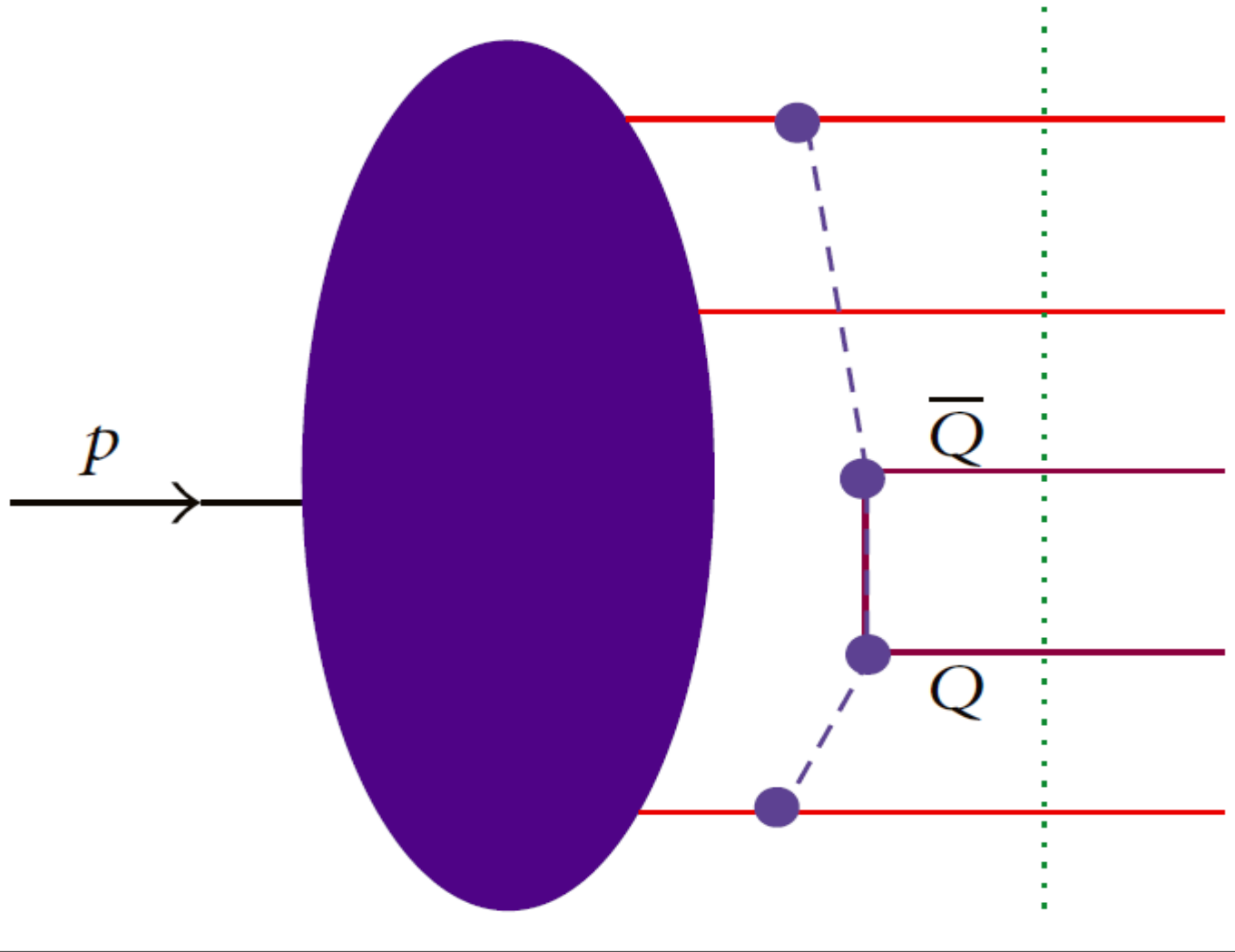
OUTLINE

1. Intrinsic heavy flavours in proton
2. Main goal of our study
3. Intrinsic strangeness
4. Search for intrinsic charm (*IC*)
in inclusive open charm production
5. Search for intrinsic charm
from $\gamma+c$ and $Z/W+c(b)$ production in
 $p-p$ collision
6. Summary

BHPS model: S.J. Brodsky, P. Hoyer, C. Peterson and N. Sakai, Phys.Lett.B9(1980) 451; S.J. Brodsky, S.J. Peterson and N. Sakai, Phys.Rev. D23 (1981) 2745.

Intrinsic $Q\bar{Q}$ in proton





Cut gluon-gluon scattering box diagram $gg \rightarrow Q \bar{Q}$ inserted into the proton self-energy

$$dP = N \prod_{j=1}^5 \frac{dx_j}{x_j} \delta \left(1 - \sum_{j=1}^5 x_j \right) \prod_{j=1}^5 d^2 p_{Tj} \delta^{(2)} \left(\sum_{j=1}^5 p_{Tj} \right) \frac{F^2(s)}{(s - m_N^2)^2},$$

where

$$s = \sum_{j=1}^5 \frac{p_{Tj}^2 + m_j^2}{x_j},$$

$$P(x) = \frac{Nx^2}{6(1-\alpha)^5} \left(\phi_1(x) + \phi_2(x) [\ln(x) - \ln[1 - c(1-x)x]] \right),$$

where $x = x_5$, $c = m_N^2/m_c^2$,

$$\phi_1(x) = (1-x)(1-\alpha) \left[1 + x \left[10 + x - c(1-x) \left(x(10 - c(1-x)) + 2 \right) \right] \right],$$

and

$$\phi_2(x) = 6x[1 + x(1 - c(1-x))][1 - c(1-x)x].$$

Here N is found from the normalization equation:

$$\int_0^1 P(x) dx = w,$$

where w is the integral fraction of the intrinsic charm. Setting $c \rightarrow 0$ leads to the BHPS result [10]

$$P(x) = 600wx^2 \left[6x(1+x) \ln x + (1-x)(1+10x+x^2) \right].$$

$$F^2 = \exp \left(\frac{-(s - m_N^2)}{\Lambda^2} \right)$$

or the *power-law suppression* factor:

$$F^2 = \frac{1}{(s + \Lambda^2)^n}.$$

PRODUCTION OF HEAVY FLAVOURS IN HARD P-P COLLISIONS

$$E \frac{d\sigma}{d^3p} = \sum_{i,j} \int d^2k_{iT} \int d^2k_{jT} \int_{x_i^{\min}}^1 dx_i \int_{x_j^{\min}}^1 dx_j f_i(x_i, k_{iT}) f_j(x_j, k_{jT}) \frac{d\sigma_{ij}(\hat{s}, \hat{t})}{d\hat{t}} \frac{D_{i,j}^h(z_h)}{\pi z_h}$$

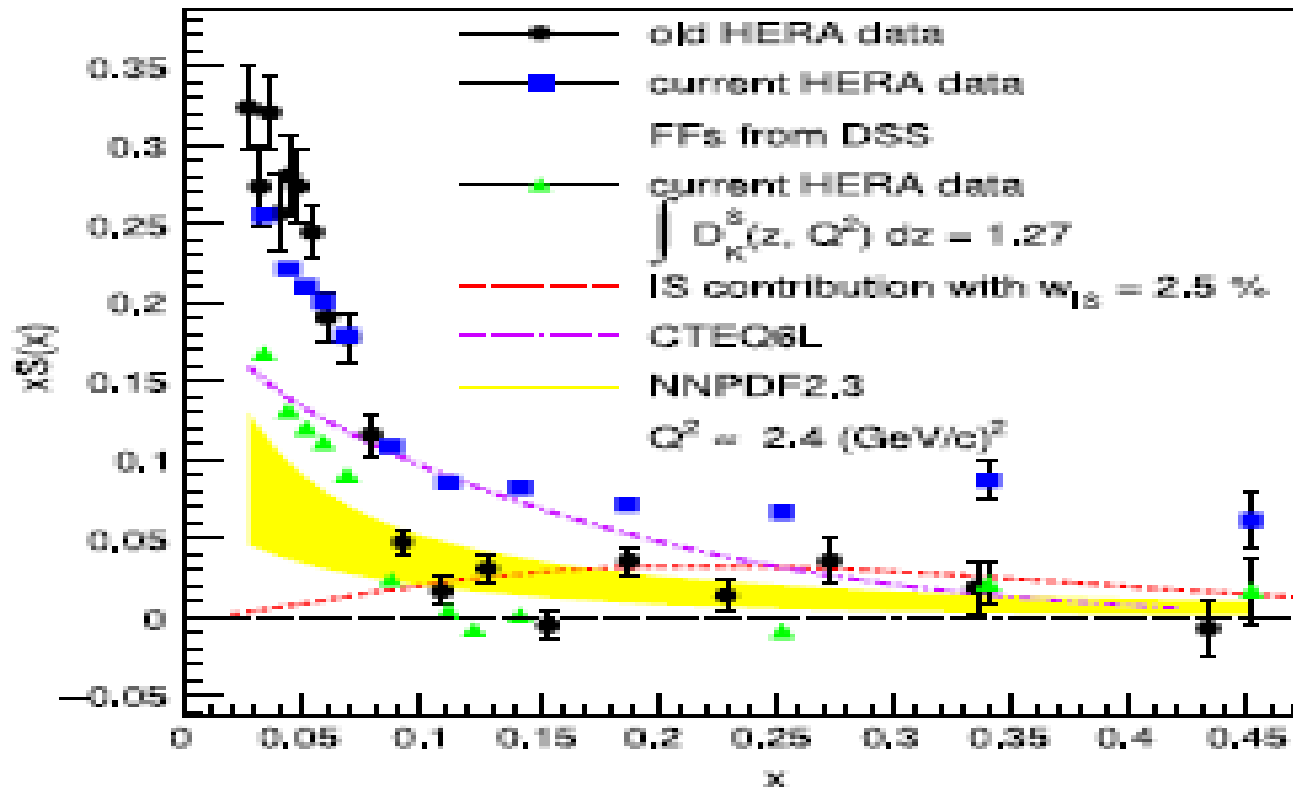
$$x_i^{\min} = \frac{x_T \cot(\frac{\theta}{2})}{2 - x_T \tan(\frac{\theta}{2})} \quad x_F \equiv \frac{2p_z}{\sqrt{s}} = \frac{2p_T}{\sqrt{s}} \frac{1}{\tan \theta} = \frac{2p_T}{\sqrt{s}} \sinh(\eta)$$

$$x_i^{\min} = \frac{x_R + x_F}{2 - (x_R - x_F)} \quad x_R = 2p/\sqrt{s}$$

One can see that $x_i \geq x_F$. If $x_F > 0.1$ then, $x_i > 0.1$ and the **conventional sea** heavy quark (extrinsic) contributions are suppressed in comparison to the **intrinsic** ones.

x_F is related to p_T and η . So, at certain values of these variables, in fact, there is **no conventional sea** heavy quark (**extrinsic**) contribution. And we can study the **IQ contributions** in hard processes at the **certain** kinematical region.

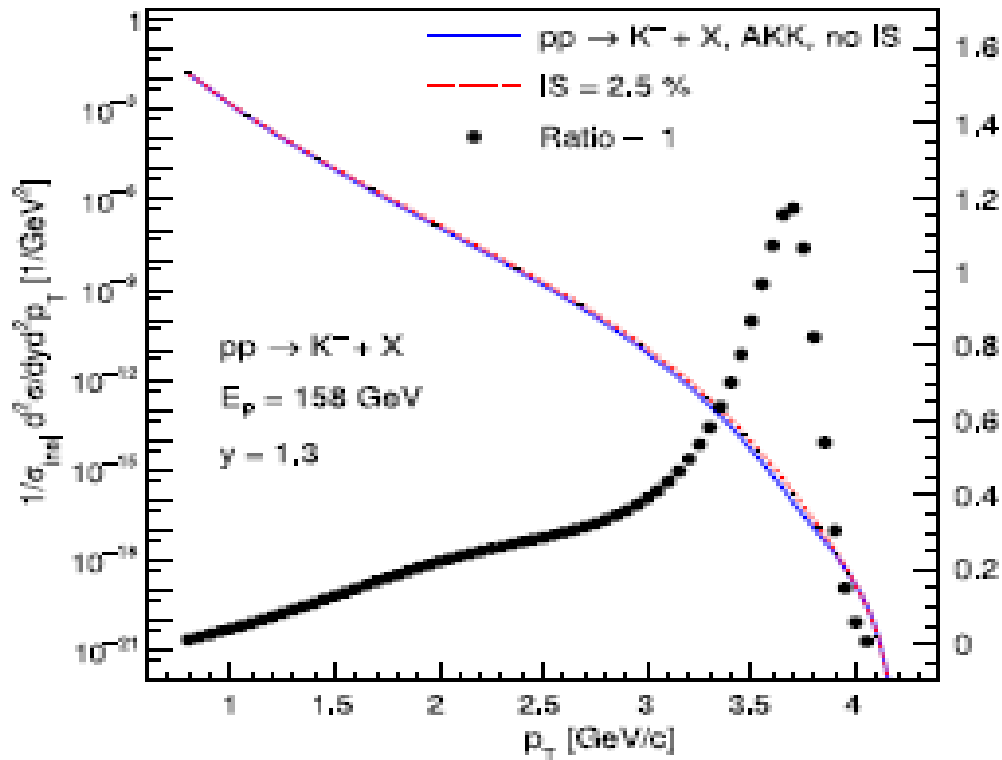
Intrinsic strangeness in proton



Strange quark density $xS(x)=x(s(x)+\bar{s}(x))$ as a function of x at $Q^2 = 2.4 \text{ (GeV/c)}^2$

Predictions for NA61

$pp \rightarrow K^- X$ at $E_p = 158$ GeV

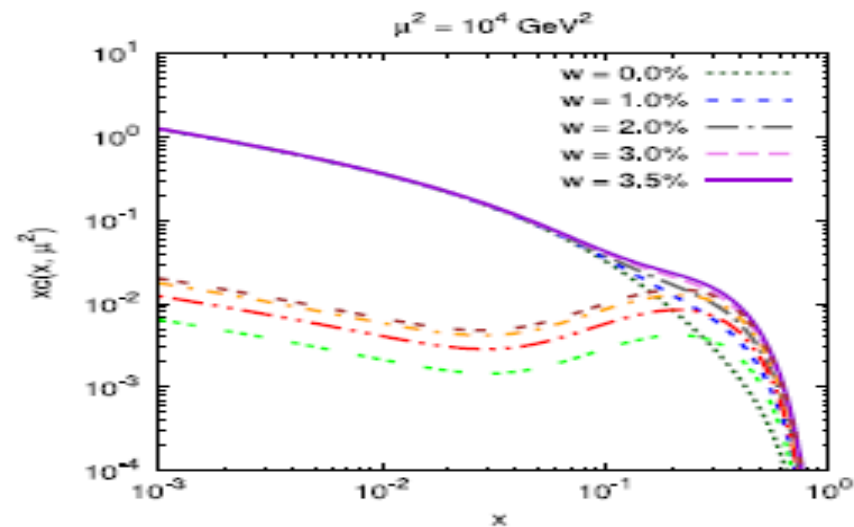
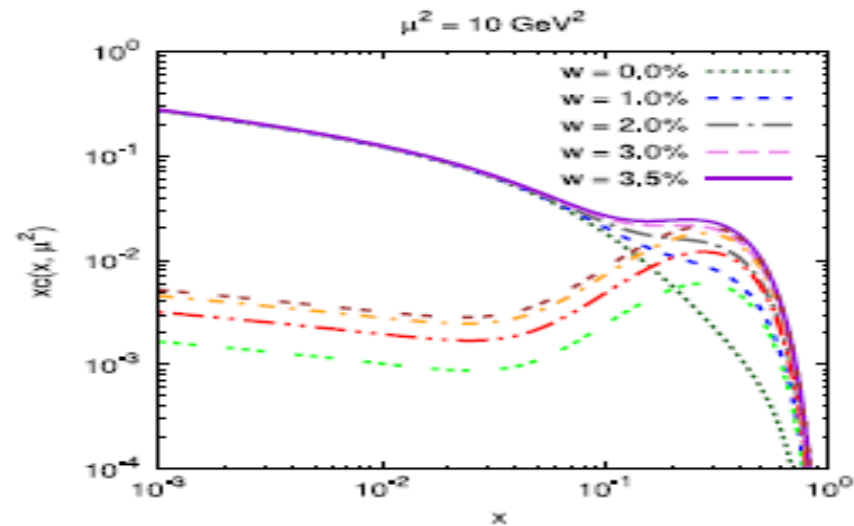


p_T – distribution of K^- at $y=1.3$
points correspond to ratio $IS/(no\ IS) - 1$

The inclusion of IS allows us to increase the p_T – spectrum by a factor about 2 at $p_T = 3.6-3.8$ GeV/c

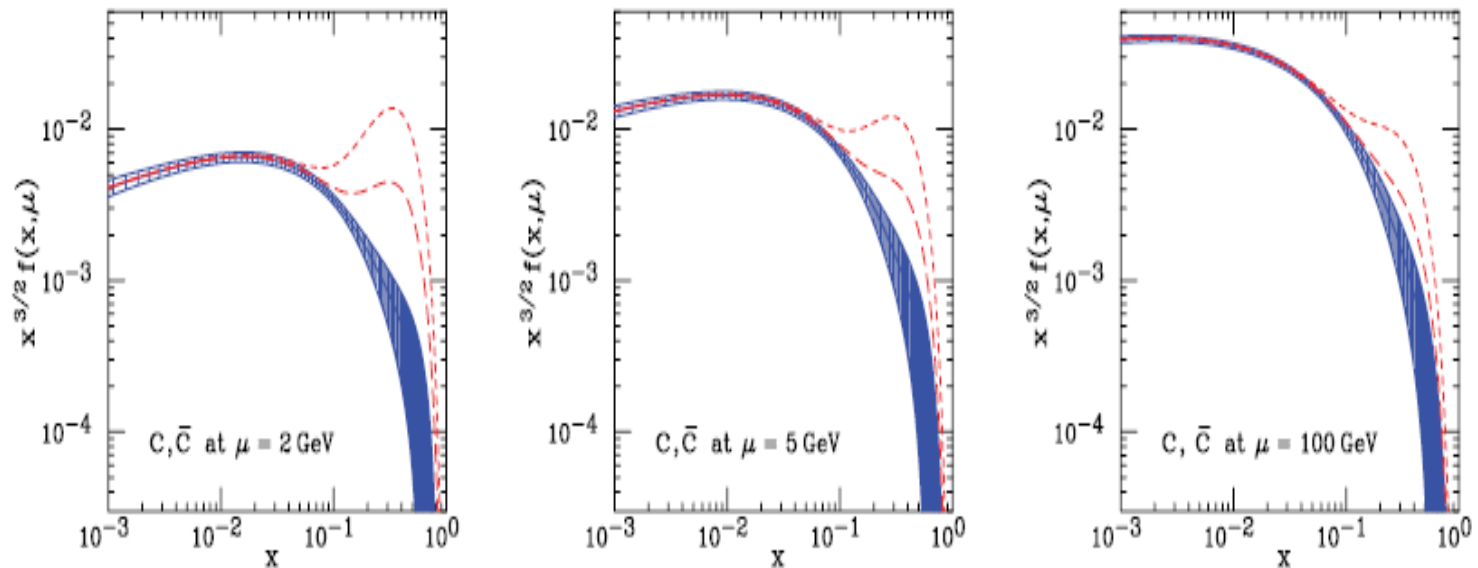
Intrinsic charm density in a proton as a function of IC probability w

$$xc(x, \mu_0^2) = xc_{\text{ex}}(x, \mu_0^2) + xc_{\text{in}}(x, \mu_0^2).$$



$$xc_{\text{in}}(x, \mu^2) = \frac{w}{w_{\text{max}}} xc_{\text{in}}(x, \mu^2) \Big|_{w=w_{\text{max}}}.$$

CHARM QUARK DISTRIBUTIONS IN PROTON

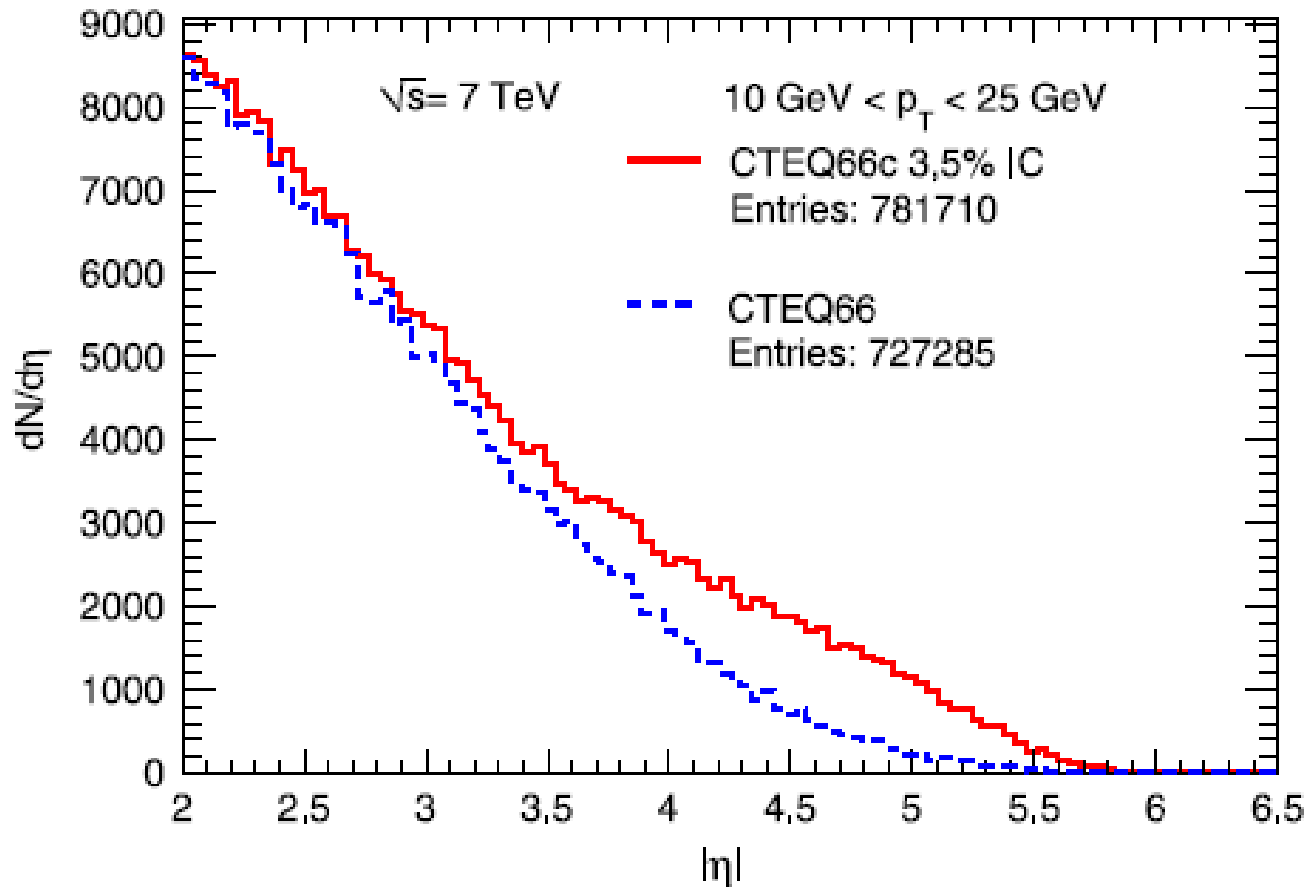


Charm quark distributions within the BHPS model. The three panels correspond to the renormalization scales $\mu = 2, 5, 100 \text{ GeV}$ respectively. The long-dashed and the short-dashed curves correspond to $\langle x_{c\bar{c}} \rangle = 0.57\%, 2.0\%$ respectively using the PDF CTEQ66c. The solid curve and shaded region show the central value and uncertainty from CTEQ6.5, which contains no **IC**.

There is an enhancement at $x > 0.1$ due to the IC contribution

Inclusive production of charmed meson

Predictions for LHCb



**G.L., V.A. , V.A.Bednyakov, A.F. Pikelner, N.I.Zimine,
Europhys.Lett. 99, 2102 (2012).**

Main goal: searching for the signal of the intrinsic charm (IC) contribution in proton from the analysis of the prompt photon or Z/W boson production in p-p collision accompanied by heavy c(b)-jet.

We have predictions on *IC*

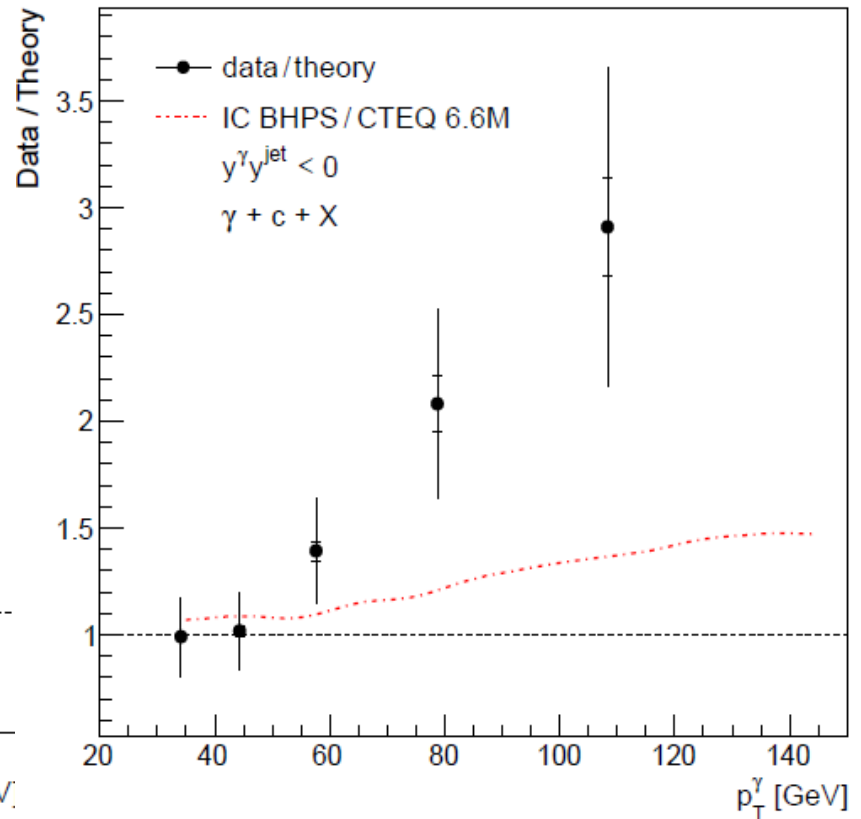
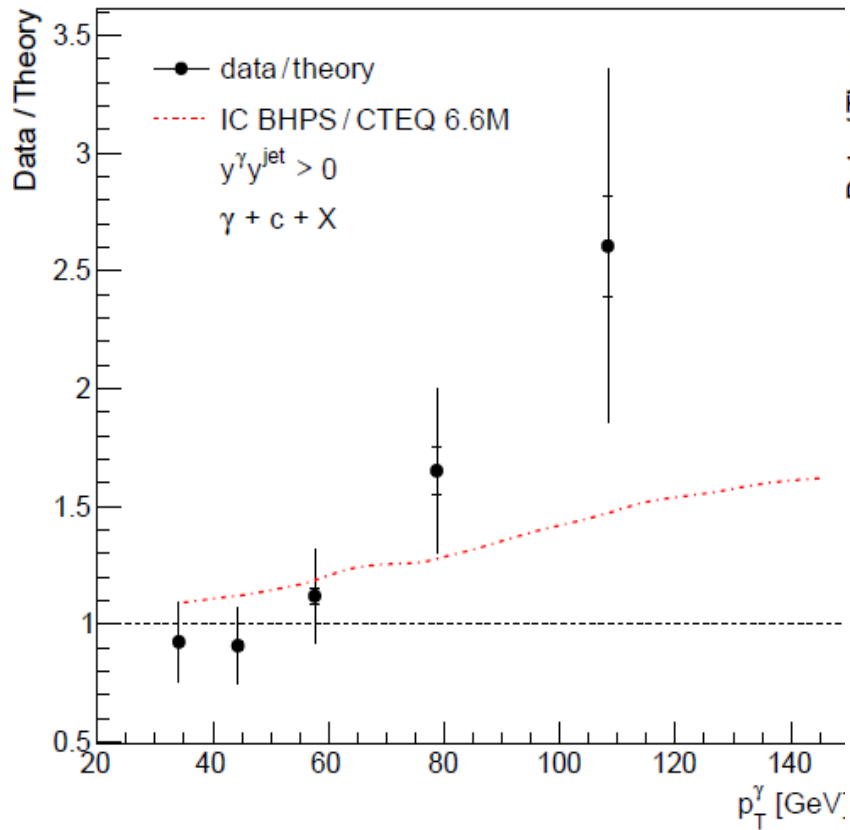
PP- $\rightarrow \gamma + c + X$: V.A.Bednyakov, M.A.Demichev, G.L., T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (1914)

PP- $\rightarrow Z/W + c(b) + X$: H.Beauchemin, V.A.Bednyakov, G.L., Yu. Yu. Stepanenko, Phys.Rev.D92, 034014 (2015)

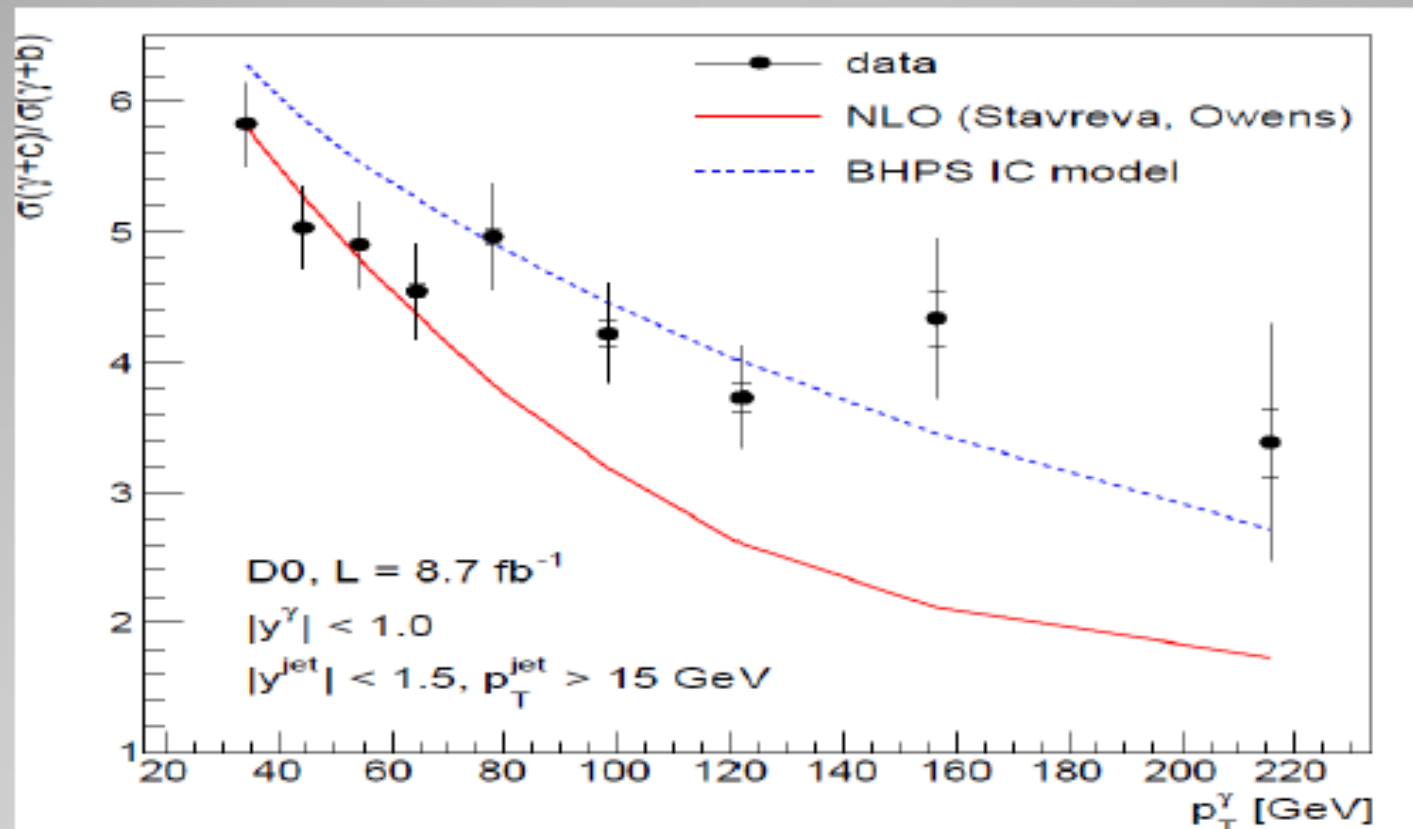
PP- $\rightarrow \gamma/Z + c(b) + X$: A. Lipatov, G.L., Yu. Stepanenko V.A.Bednyakov, Phys.Rev.D94, 05301 (2016)

Collider tests of heavy PDF: S.J.Brodsky, V.A.Bednyakov, G.L., S.Tokar, J.Smiesko, Prog. In Part. Nucl.Phys., 93, 108, (2017).

$p\bar{p} \rightarrow \gamma + c(b) + X$ **D0 experiment at Tevatron** $s^{1/2} = 1.96 \text{ TeV}$

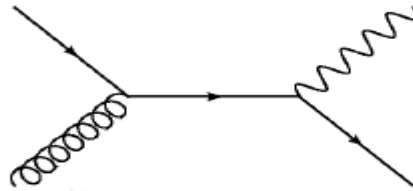


$R = \sigma(\gamma + c)/\sigma(\gamma + b)$ for $p \bar{p} \rightarrow \gamma + Q$ at $s^{1/2} = 1.98$ TeV

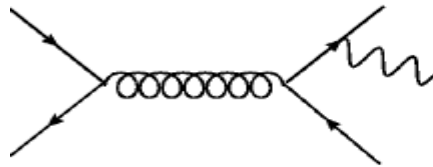


p_T -distribution of R , points are the D0 data; red solid line is NLO without *IC* ; short dash line is BHPS with *IC* probability about 1 %

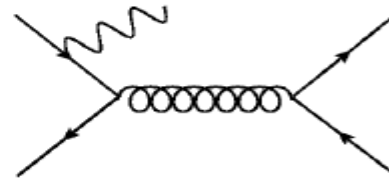
$$pp \rightarrow \gamma + Q + X, Q = c, b$$



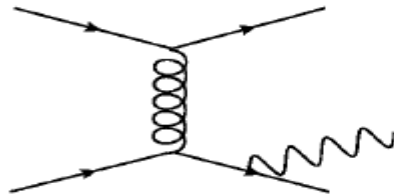
a)



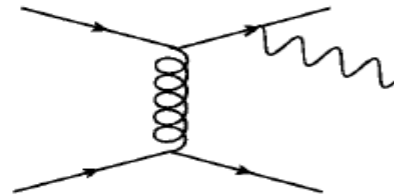
b)



c)



d)

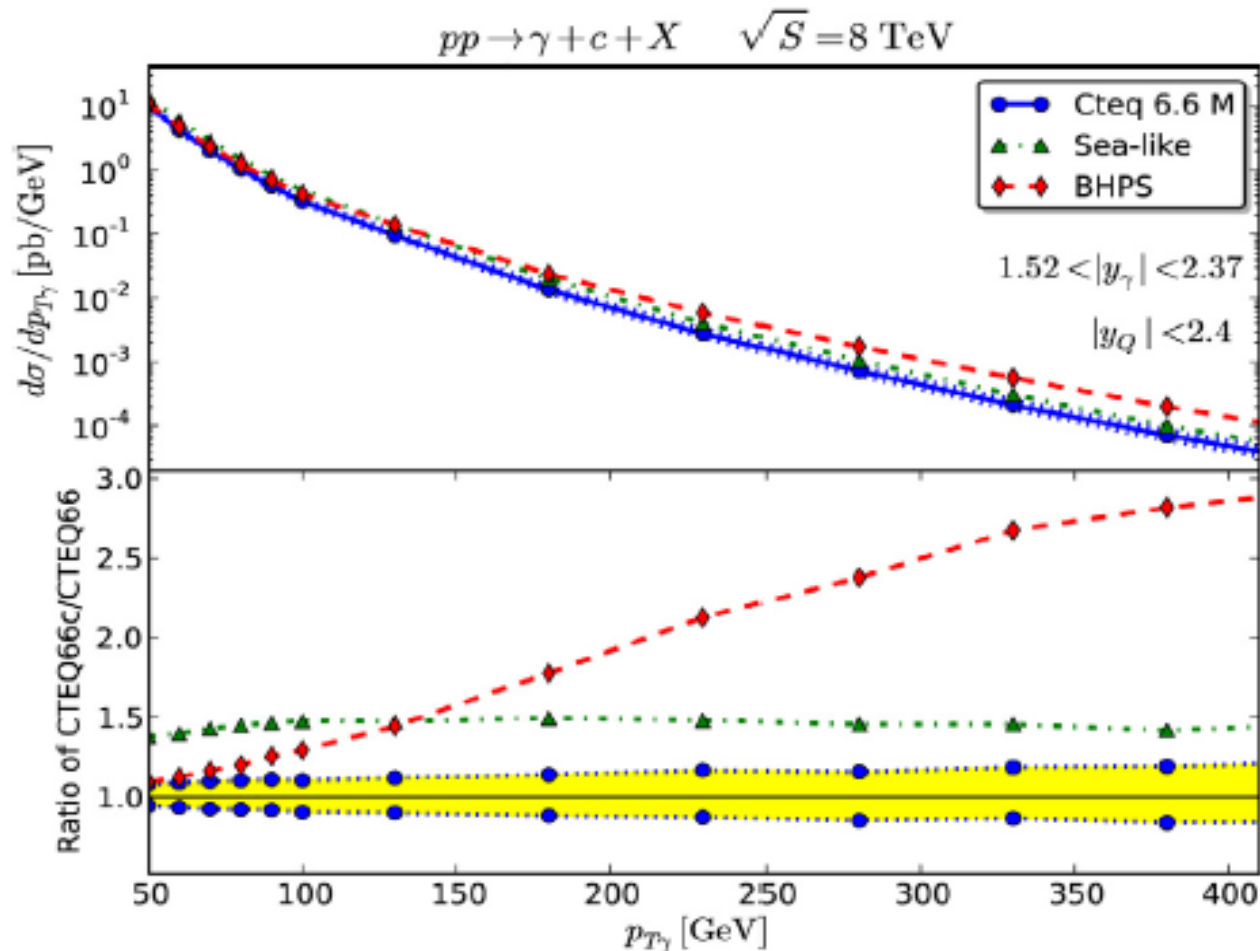


e)

Feynman QCD diagrams: a): $Q + g \rightarrow \gamma + Q$;

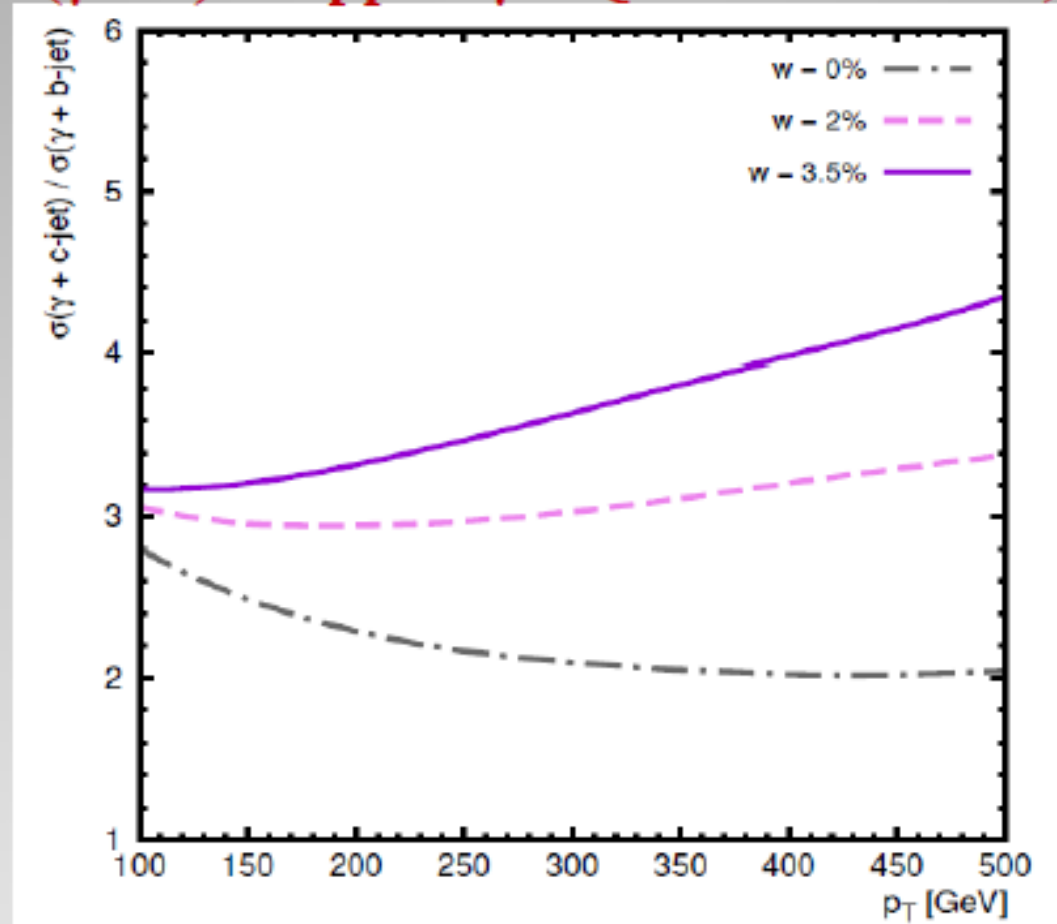
b-c): $Q + \bar{Q} \rightarrow Q + \bar{Q} + \gamma$; d-e): $Q(q) + q(Q) \rightarrow Q(q) + q(Q) + \gamma$

Predictions for ATLAS and SMC



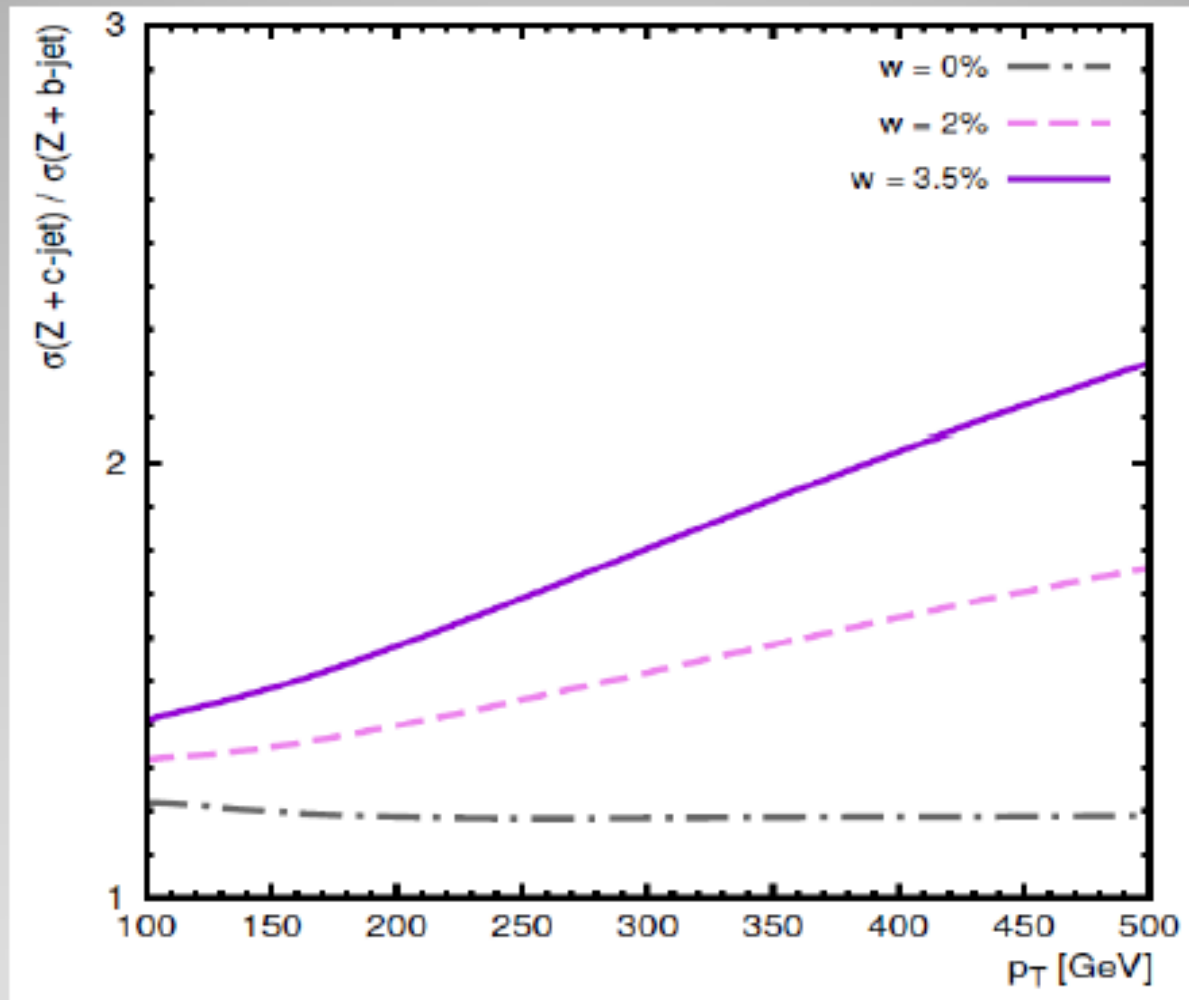
V.A. V.A.Bednyakov, M.A.Demichev, G.L.,T.Stavreva, M.Stockton,
Phys.Lett. B728, 602 (2014).

$R = \sigma(\gamma + c) / \sigma(\gamma + b)$ for $pp \rightarrow \gamma + Q$ at $s^{1/2} = 8 \text{ TeV}$; $1.5 < \eta < 2.4$



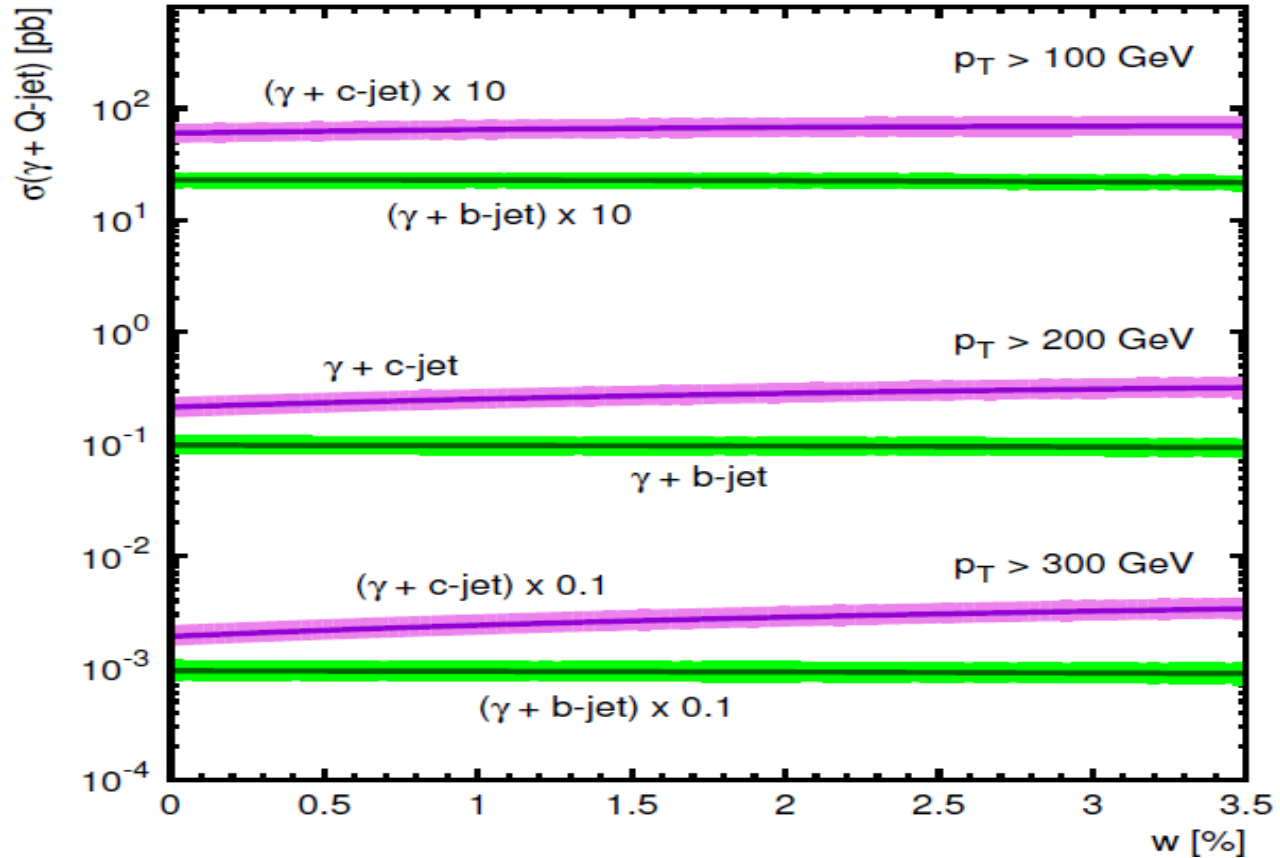
p_T -distribution of R at different IC probability w

$R = \sigma(Z + c) / \sigma(Z + b)$ for $pp \rightarrow Z + Q$ at $s^{1/2} = 8 \text{ TeV}$; $1.5 < \eta < 2.4$



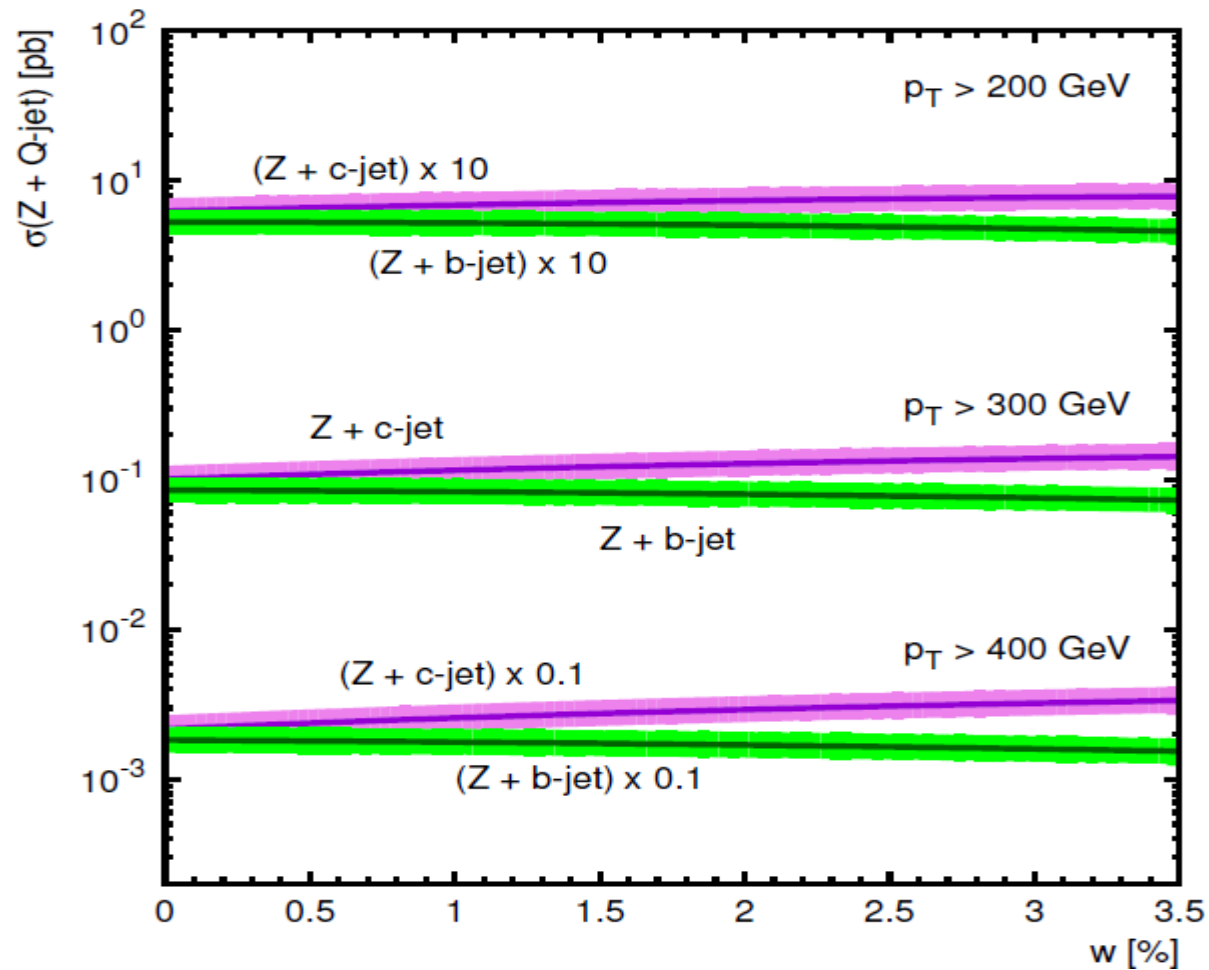
p_T –distribution of R at different IC probability w

$\sigma(\gamma + Q)$ at $s^{1/2} = 8 \text{ TeV}$; $1.5 < \eta < 2.4$; $Q = c, b$



p_T^γ – spectrum integrated over p_T^γ , i.e., $\sigma(\gamma+c)$ and $\sigma(\gamma+b)$
at $p_T^\gamma > 100 \text{ GeV}$ or 200 GeV , or 300 GeV , vs. **IC** probability w

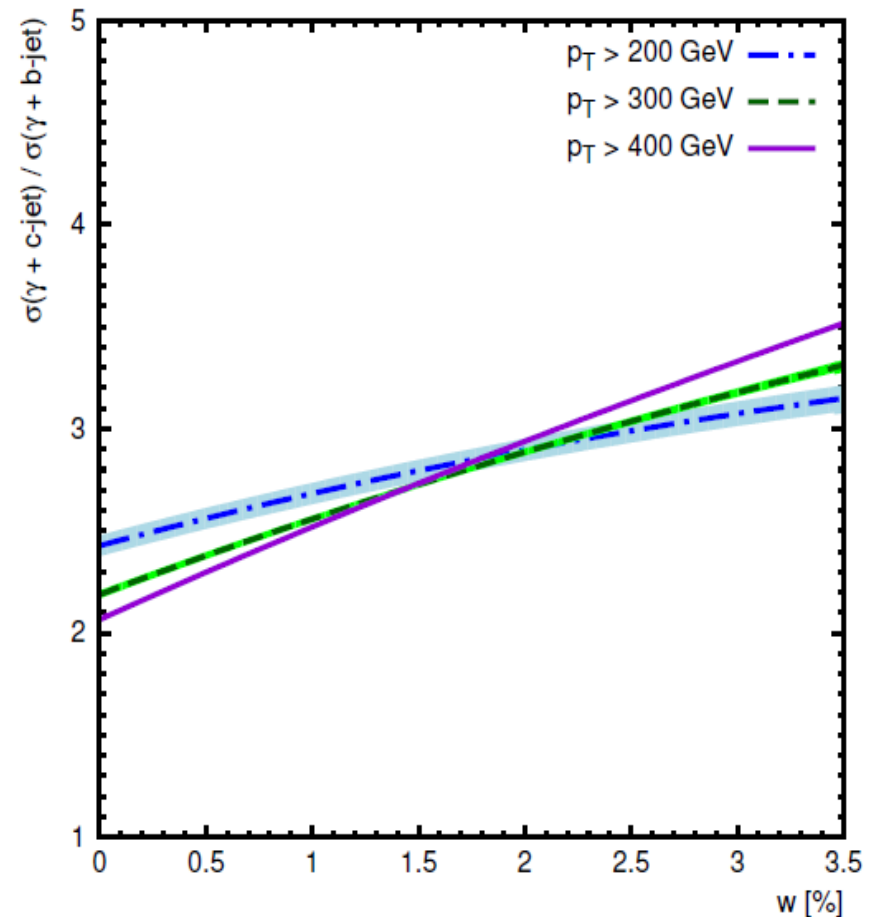
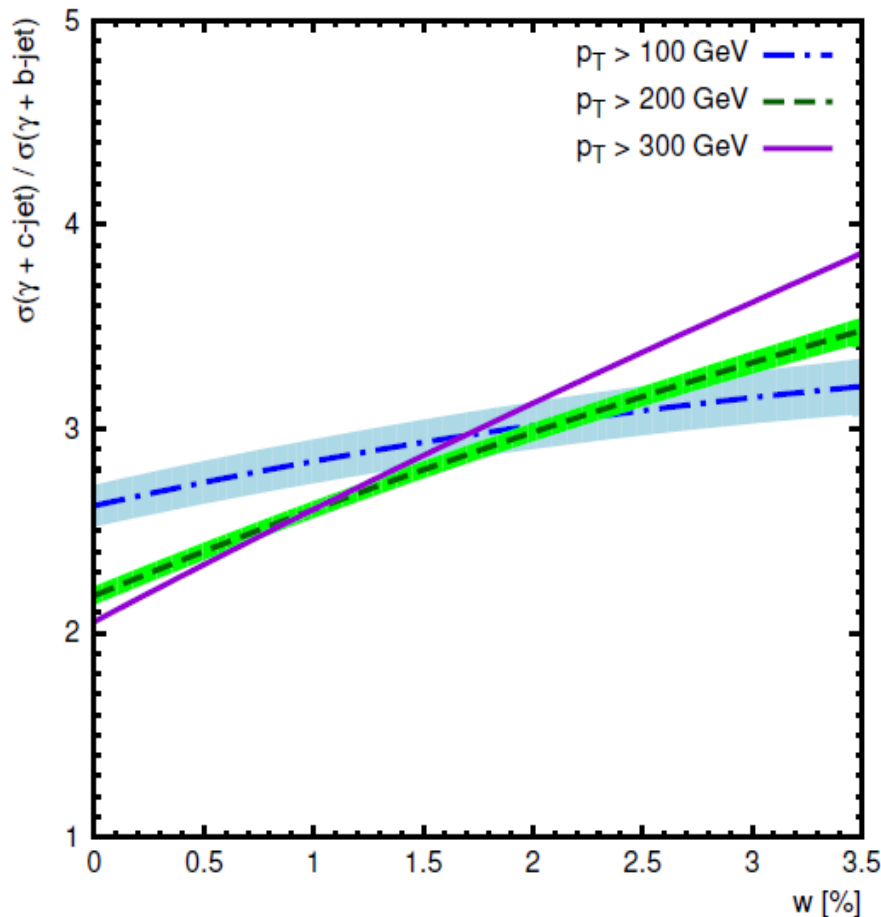
$\sigma(Z + Q)$ at $s^{1/2} = 13$ TeV ; $1.5 < \eta < 2.4$; $Q = c, b$



$s^{1/2} = 8 \text{ TeV}$

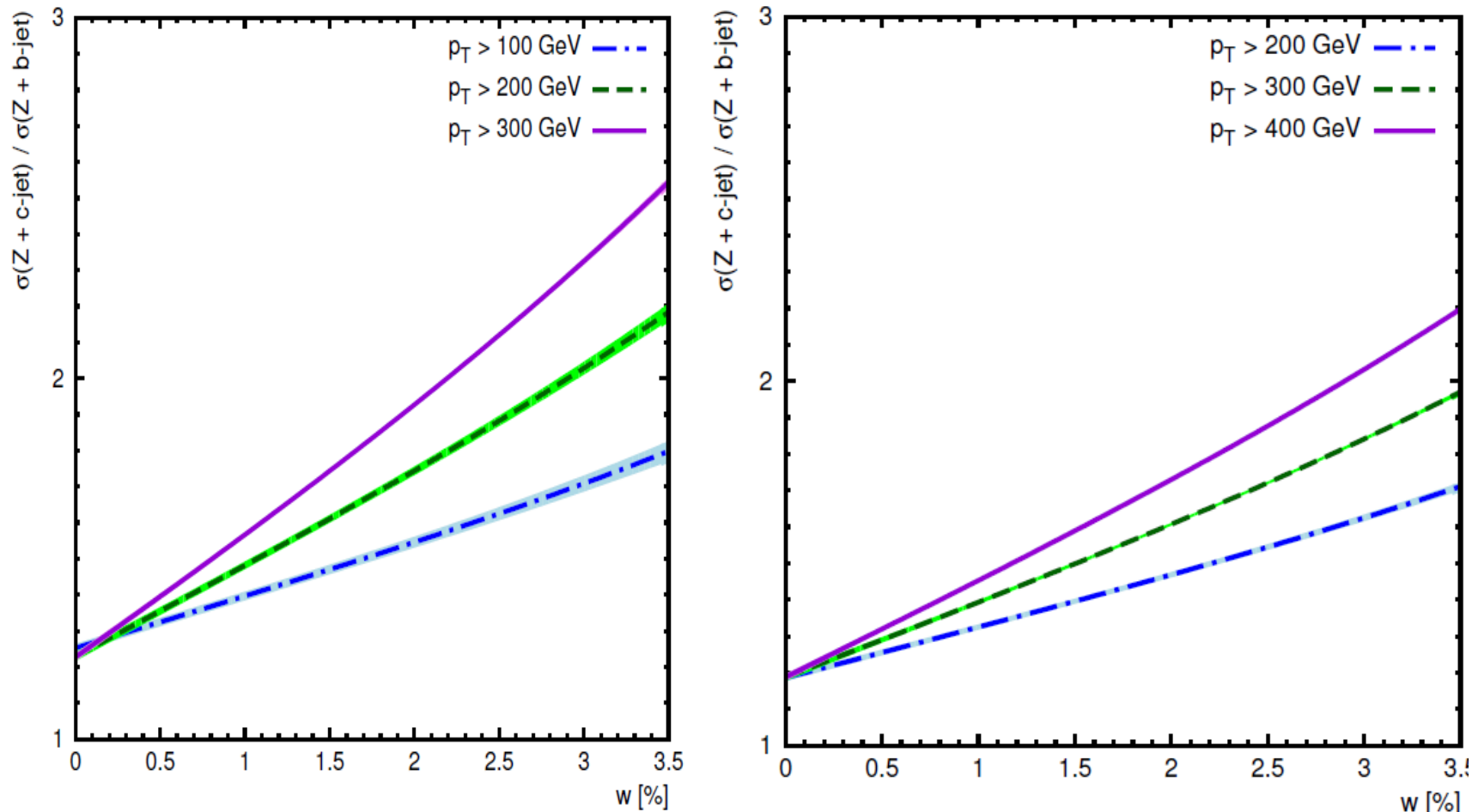
$PP \rightarrow \gamma + Q + X, Q = c, b$

$s^{1/2} = 13 \text{ TeV}$



Ratio between the x-sections of $\gamma + c$ and $\gamma + b$ production integrated over p_T . Bands mean the QCD scale uncertainty

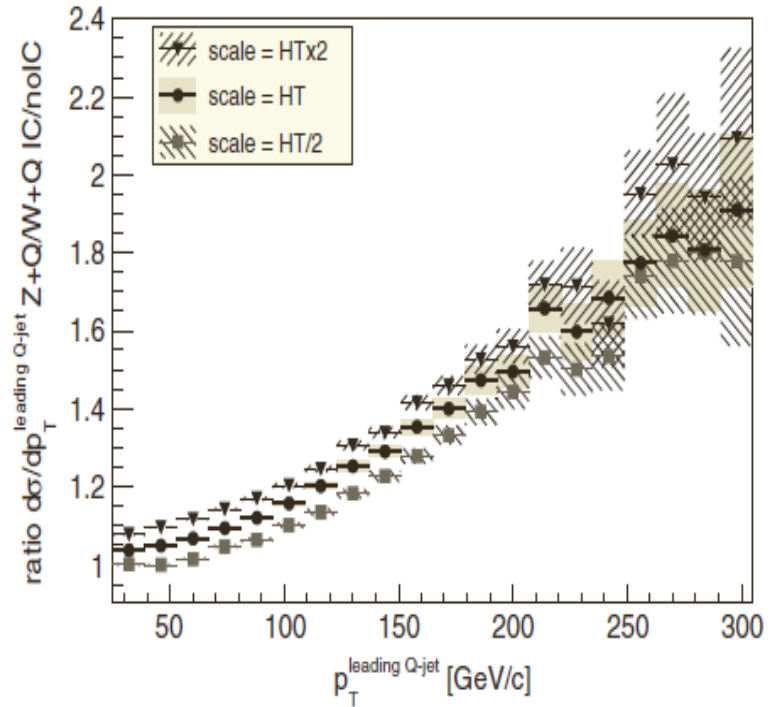
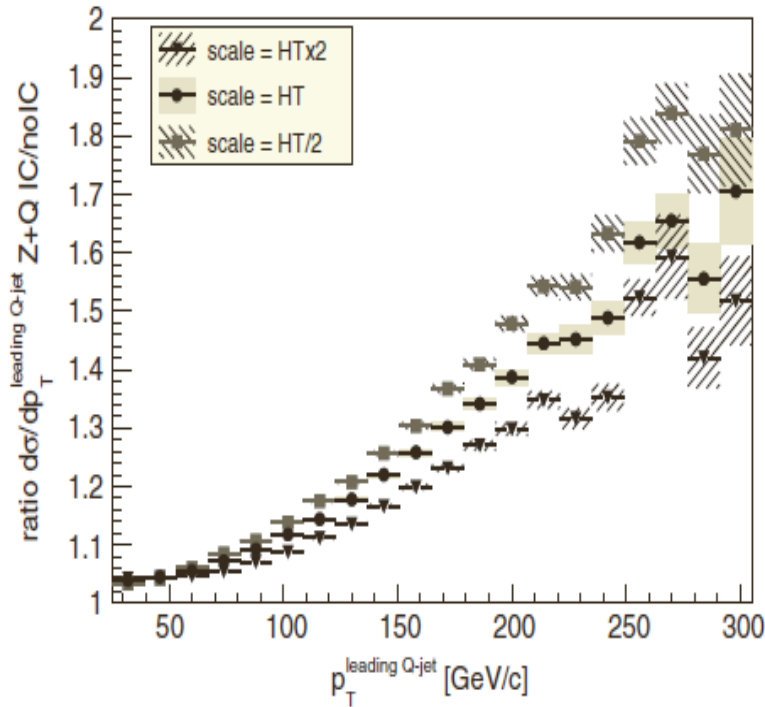
Ratio $\sigma(Z+c)/\sigma(Z+b)$
 $S^{1/2} = 8 \text{ TeV}$ (left) and $S^{1/2} = 13 \text{ TeV}$ (right)



**Ratio between the x-sections of $\gamma + c$ and $\gamma + b$ production
 integrated over p_T . Bands mean the QCD scale uncertainty**

**A.V.Lipatov, G.I.Lykasov, Yu.Yu.Stepanenko, V.A.Bednyakov, Phys.Rev. D94 , 053011 (2016) ;
 S.J.Brodsky, V.A.Bednyakov, G.I.Lykasov, J.Smiesko, S.Tokar, arXiv:1612.01351 , Prog.
 Part.Nucl.Phys. in press**

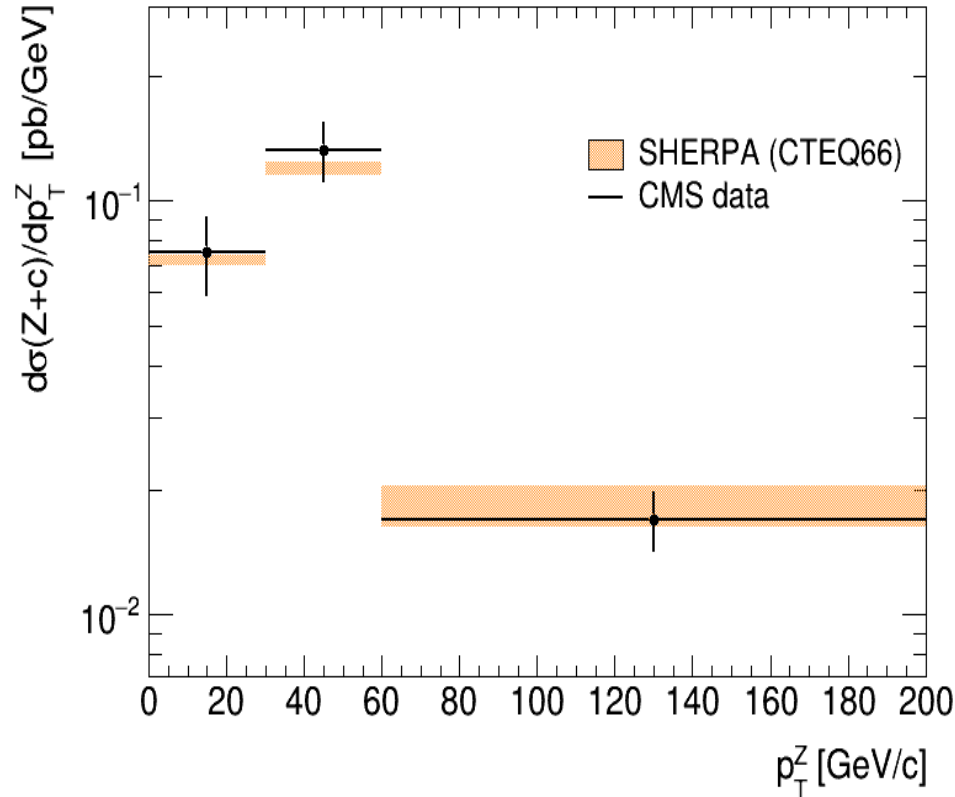
Scale uncertainty for Z+Q and Z+Q/W+Q



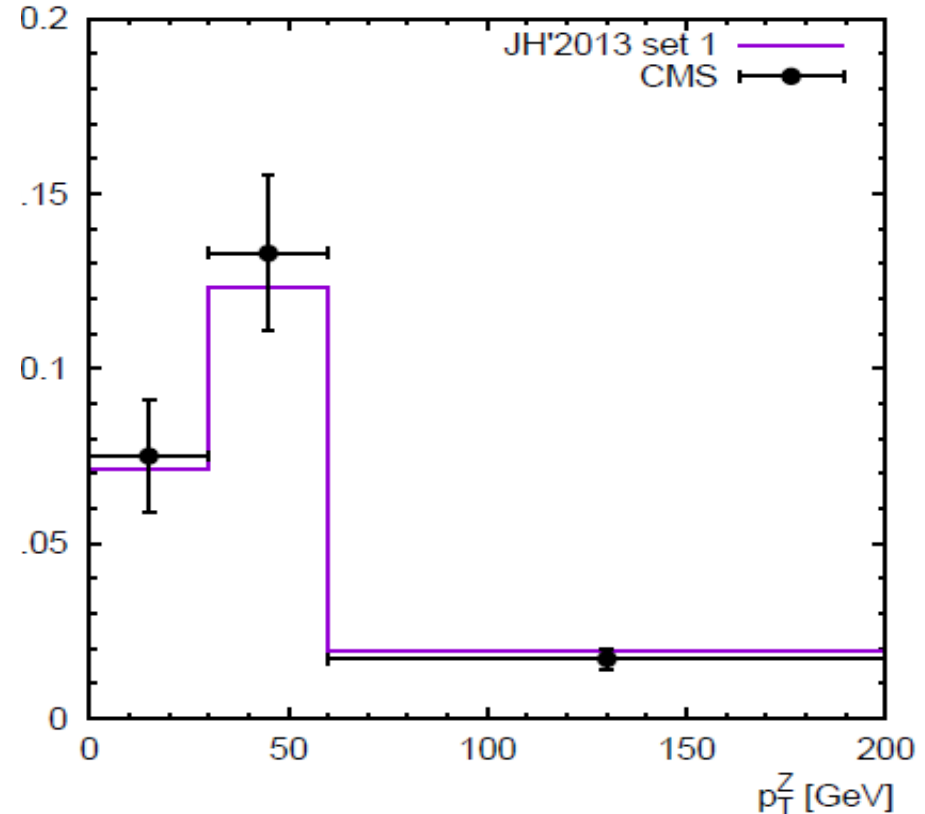
Left: Z+Q with IC and without IC at different scales

Right: Z+Q/W+Q with IC and without IC at different scales

$pp \rightarrow Z+c\text{-jet} + X$ at $s^{1/2} = 8$ TeV
 $p_T^{\text{jet}} > 25$ GeV/c; $|\eta^{\text{jet}}| < 2.5$



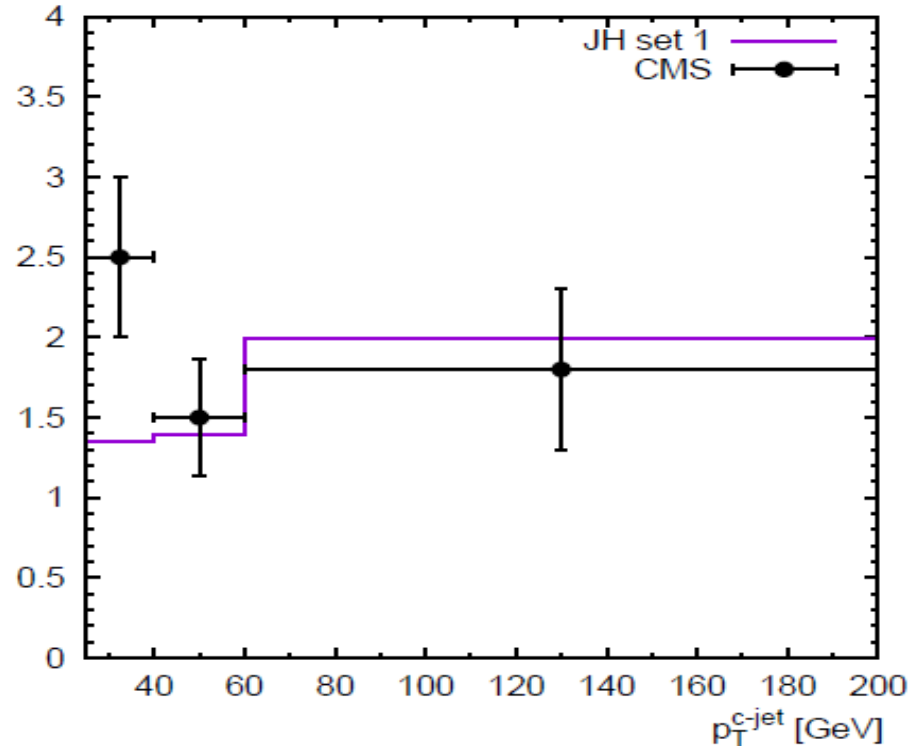
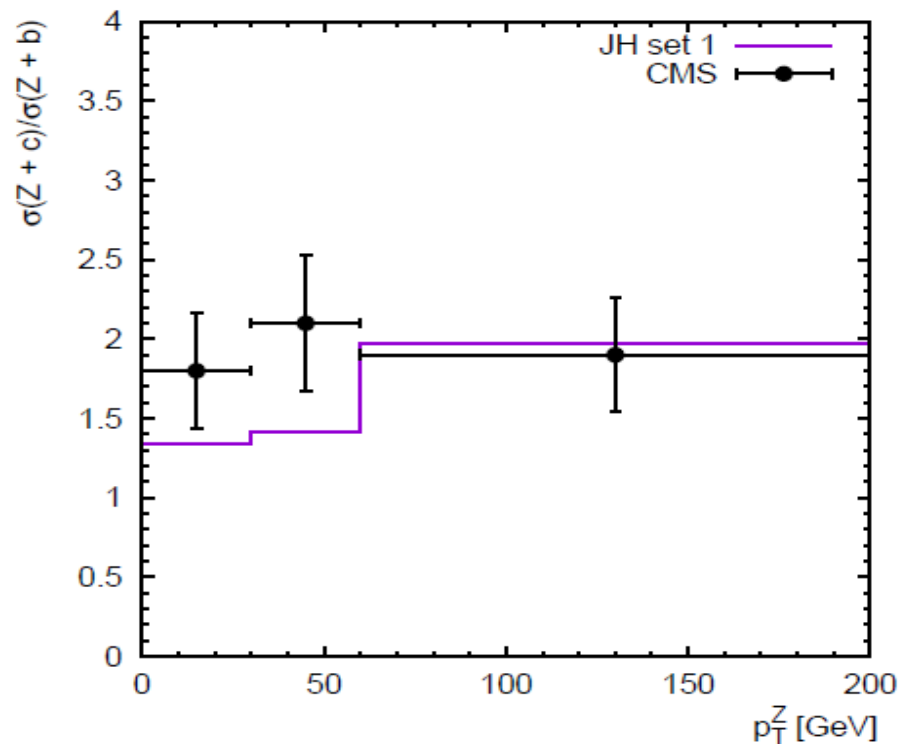
Left: SHERPA results



**Right: QCD calculation done
by A.V.Lipatov, M.A.Malyshev,
S.P. Baranov**

**Experimental data are taken from CMS PAS SMP-15-009,
CMS-SMP-14-10**

$pp \rightarrow Z+c(b)\text{-jet} + X$ at $s^{1/2} = 8$ TeV
 $p_T^{\text{jet}} > 25$ GeV/c; $|\eta^{\text{jet}}| < 2.5$



Ratio $\sigma(Z+c)/\sigma(Z+b)$ as a function of p_T^Z

QCD calculation done by A.Lipatov, S.Baranov, M.Malyshev

**Experimental data are taken from CMS PAS SMP-15-009,
 CMS-SMP-14-10**

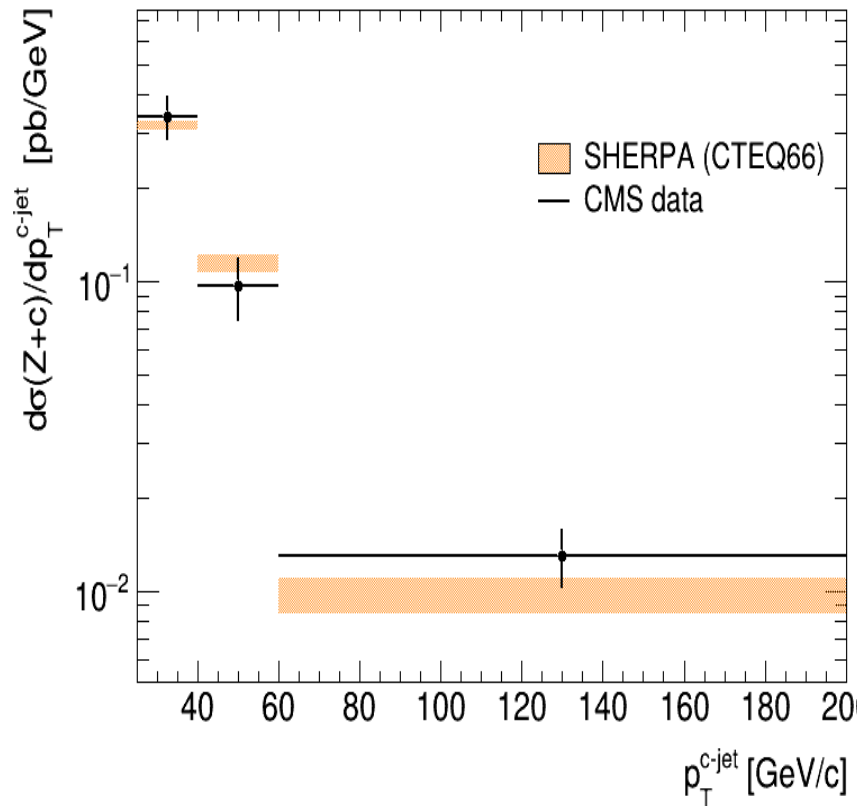
SUMMARY

1. QCD predicts two sources of heavy quarks: the standard small- x **extrinsic contribution at from gluon splitting $g \rightarrow Q \bar{Q}$** and **intrinsic contribution at large x** , which arises from the cut gluon-gluon scattering box.
2. The hypothesis of *intrinsic* quark components at large x was motivated by possible explanation of the large cross section for the forward open charm production in p-p at ISR.
3. However, the accuracy of such experimental data at large x does not provide precise constraints on the *IC* probability.
4. The production of prompt photons or gauge bosons accompanied by heavy jets (c,b) can provide an ideal method to verify the *IC* probability in proton.
5. The increase of p_T – spectrum of $\gamma/Z/W$ or *c/b*-jets produced at large p_T and the forward rapidity region of ATLAS or CMS due the the *IC* enhancement in the PDF is predicted.

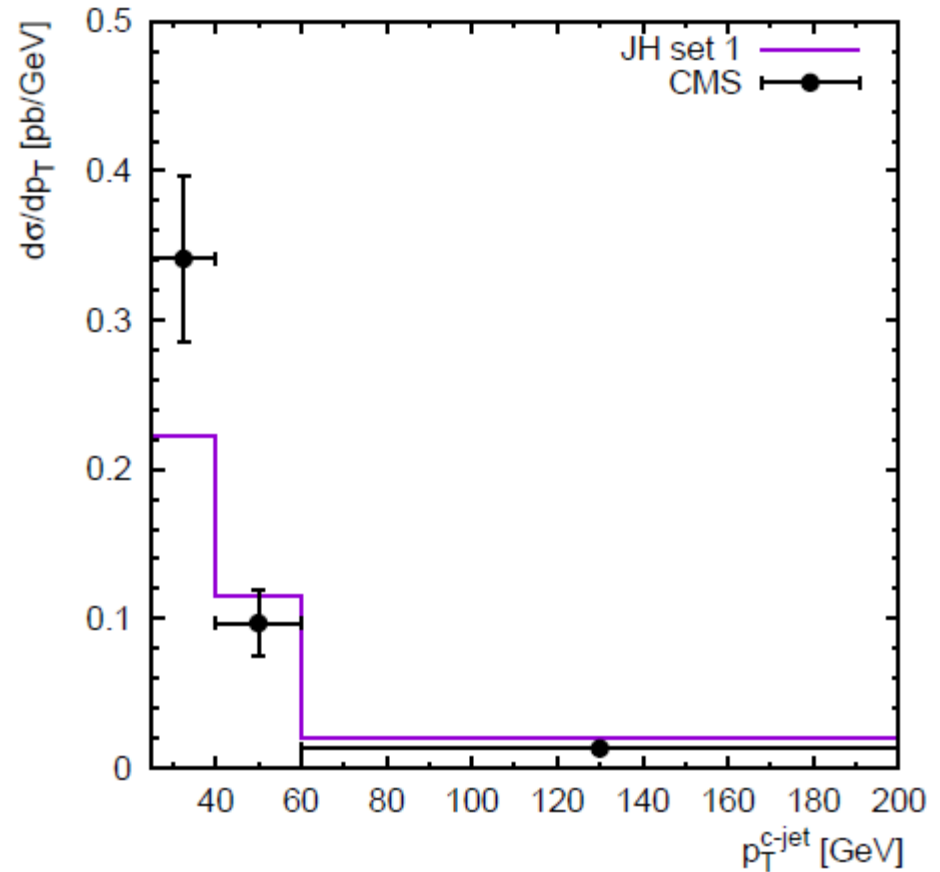
**THANK YOU VERY MUCH
FOR YOUR ATTENTION !**

BACK UP

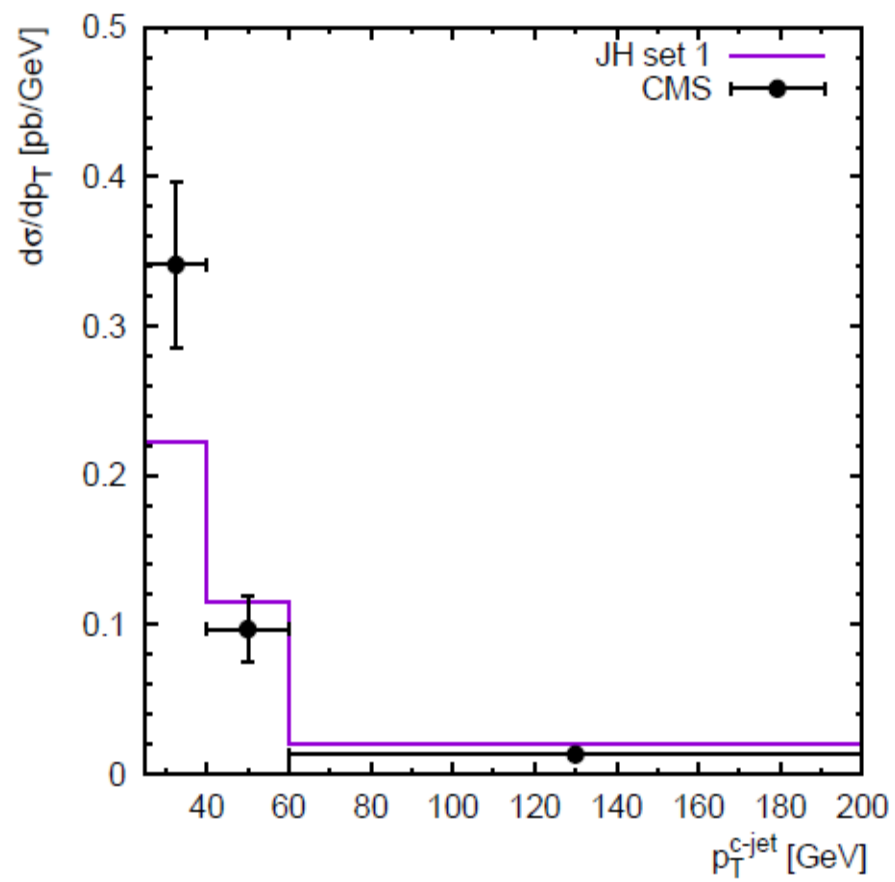
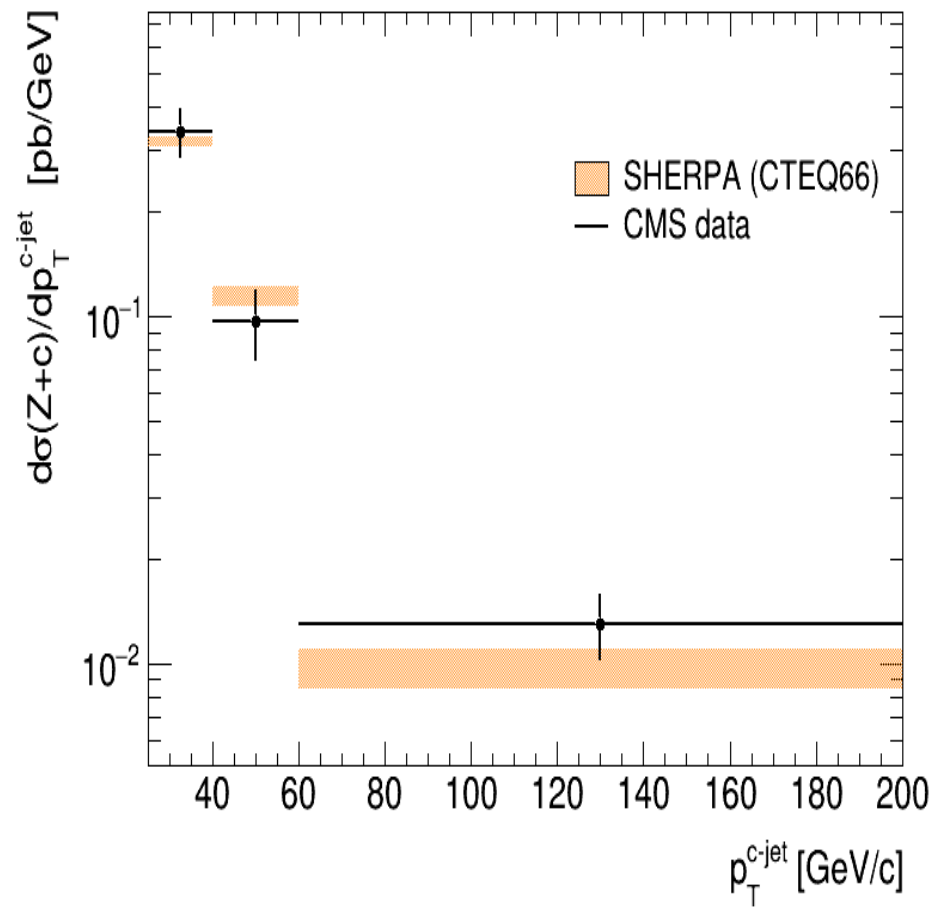
$pp \rightarrow Z+c\text{-jet} + X$ at $s^{1/2} = 8$ TeV
 $p_T^{\text{jet}} > 25$ GeV/c; $|\eta^{\text{jet}}| < 2.5$

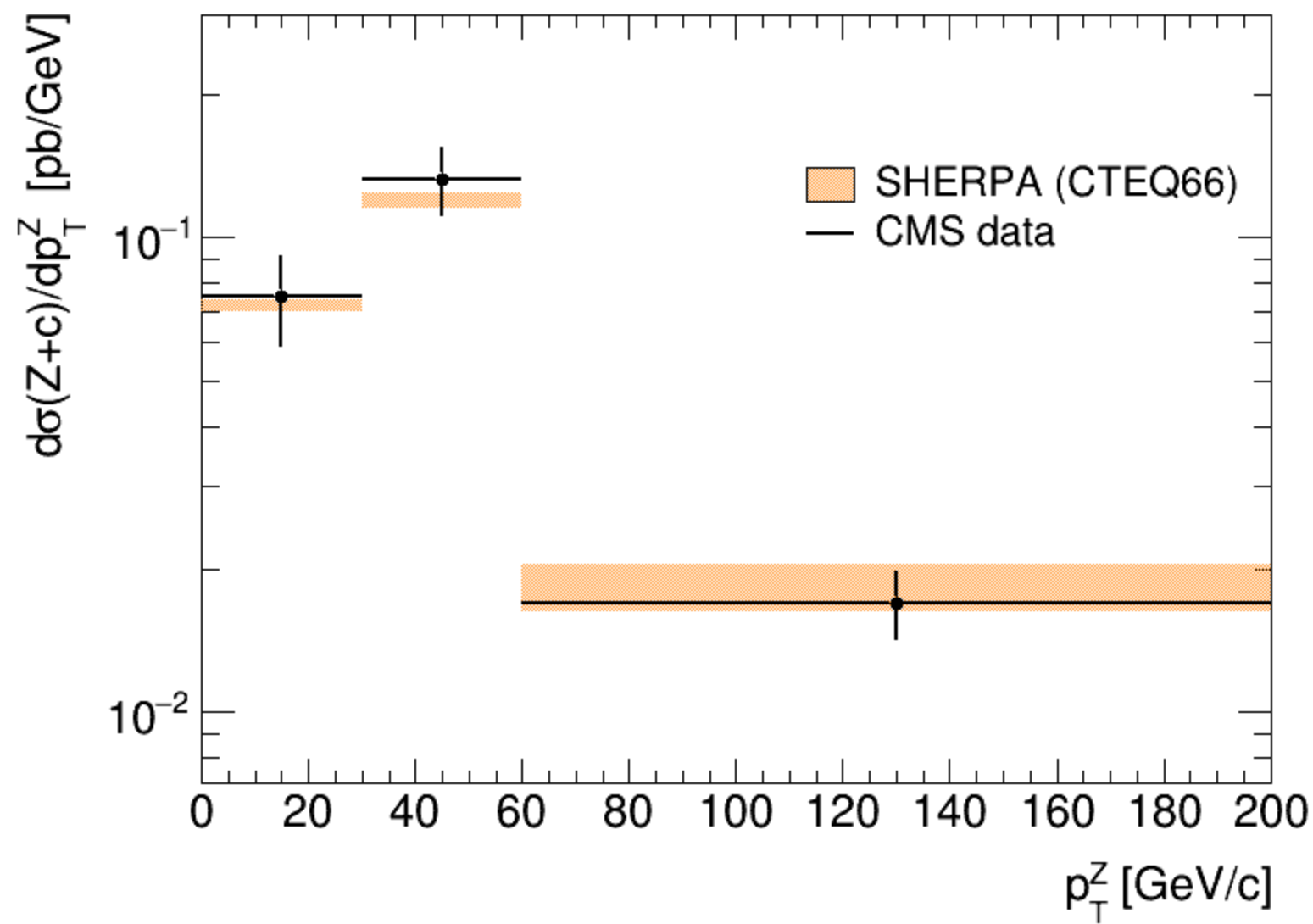


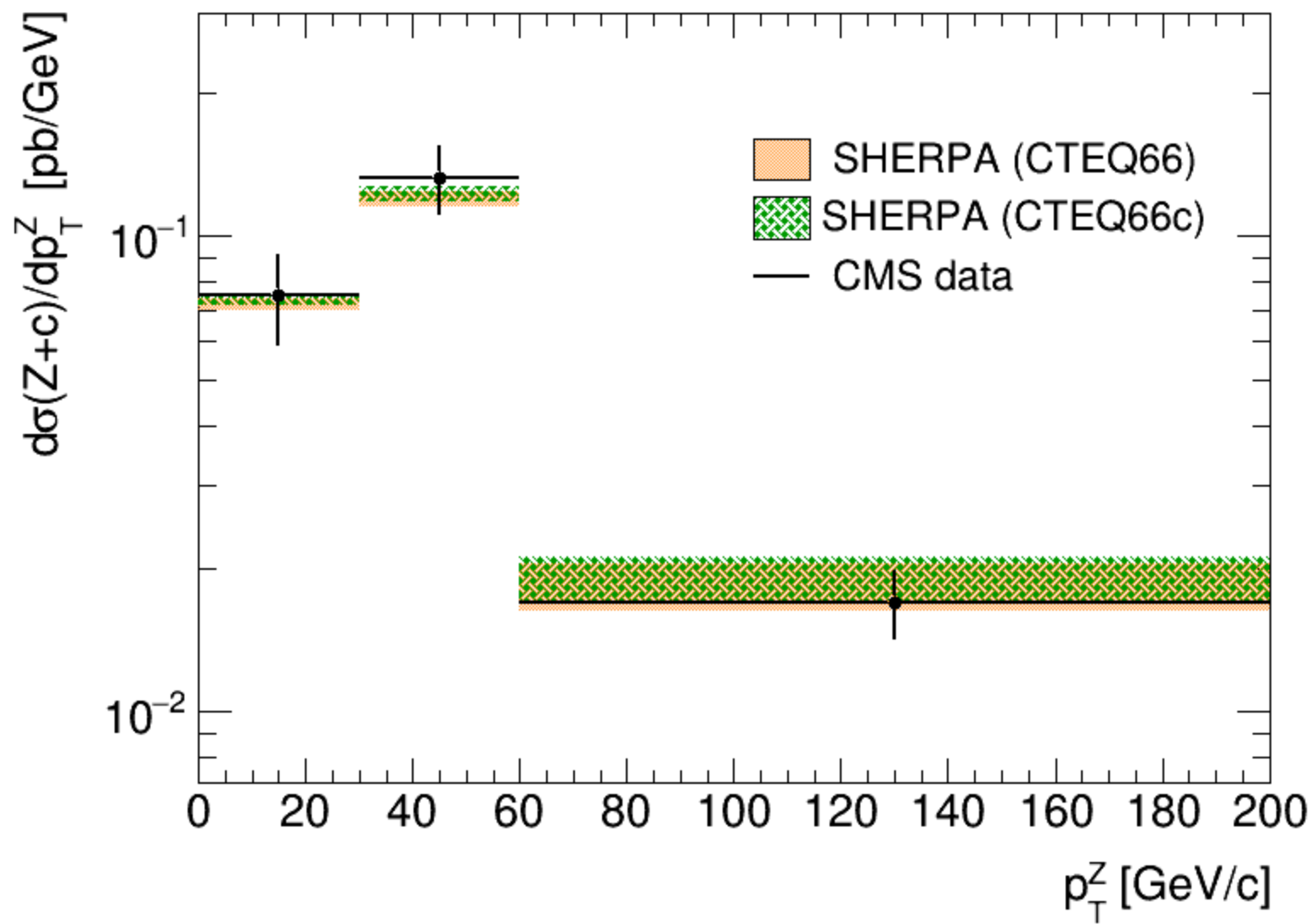
Left: SHERPA results

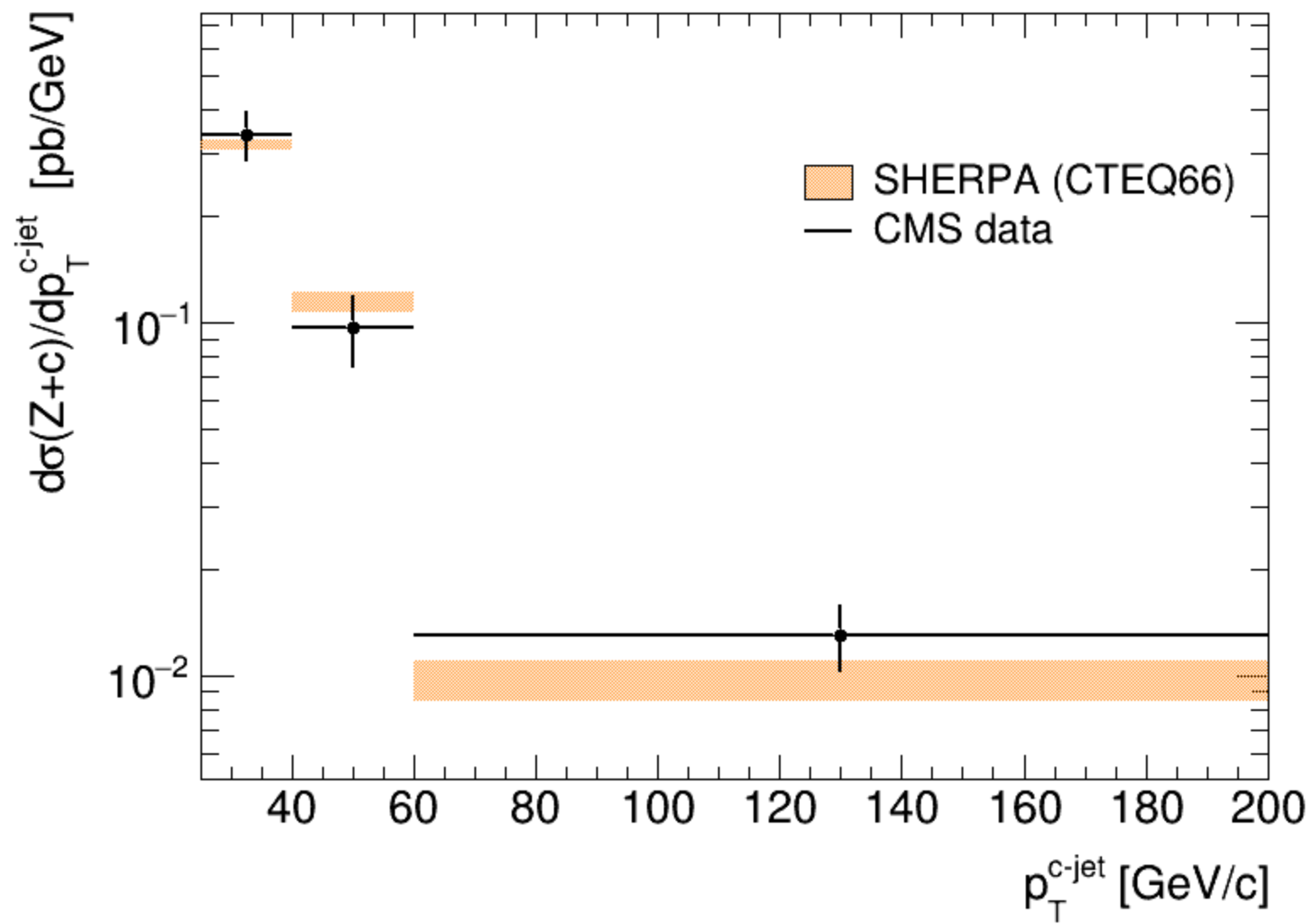


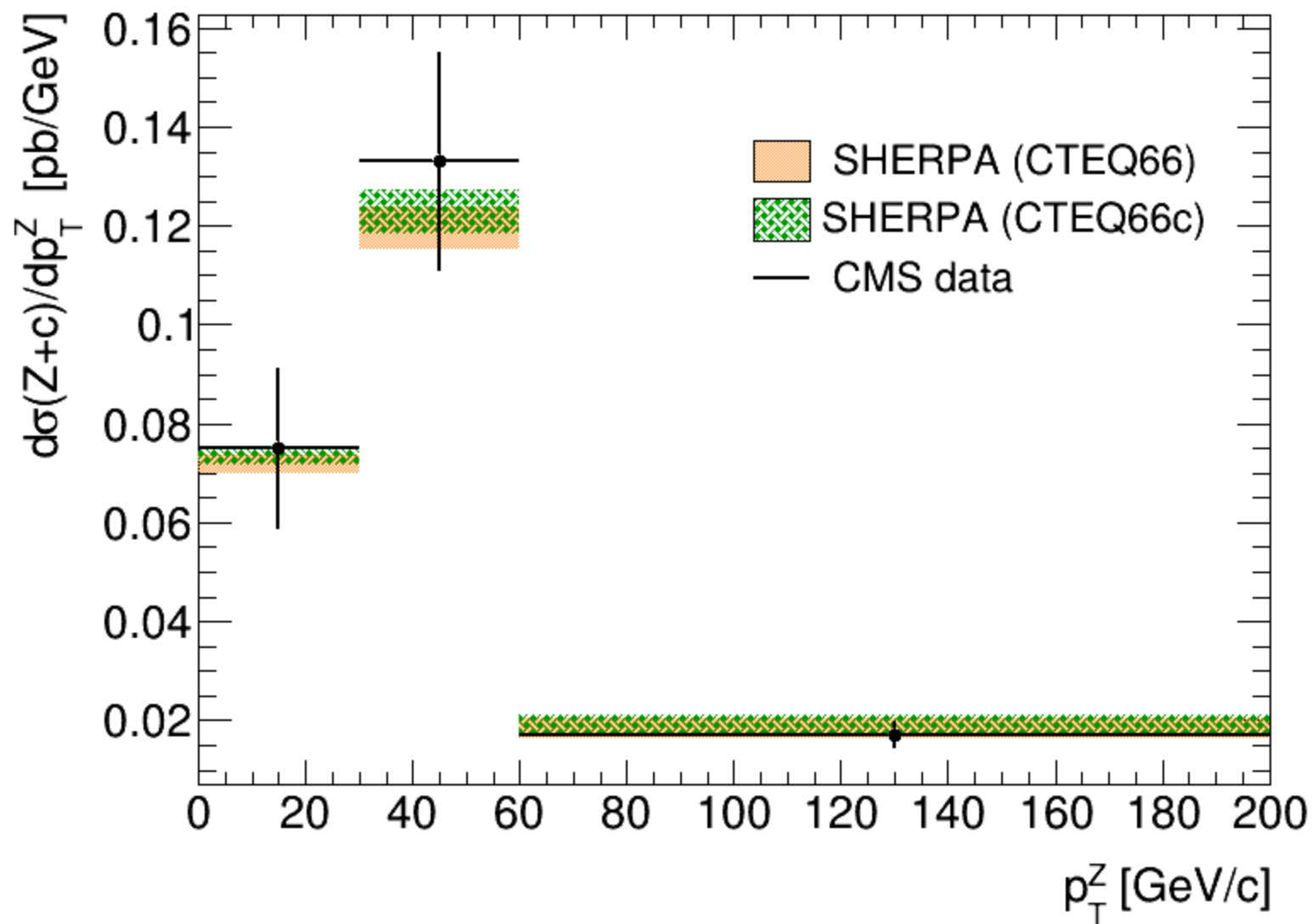
Right: QCD calculation done by A.Lipatov, M.A.Malyshev, S.P. Malyshev











INTRINSIC HEAVY QUARK STATES

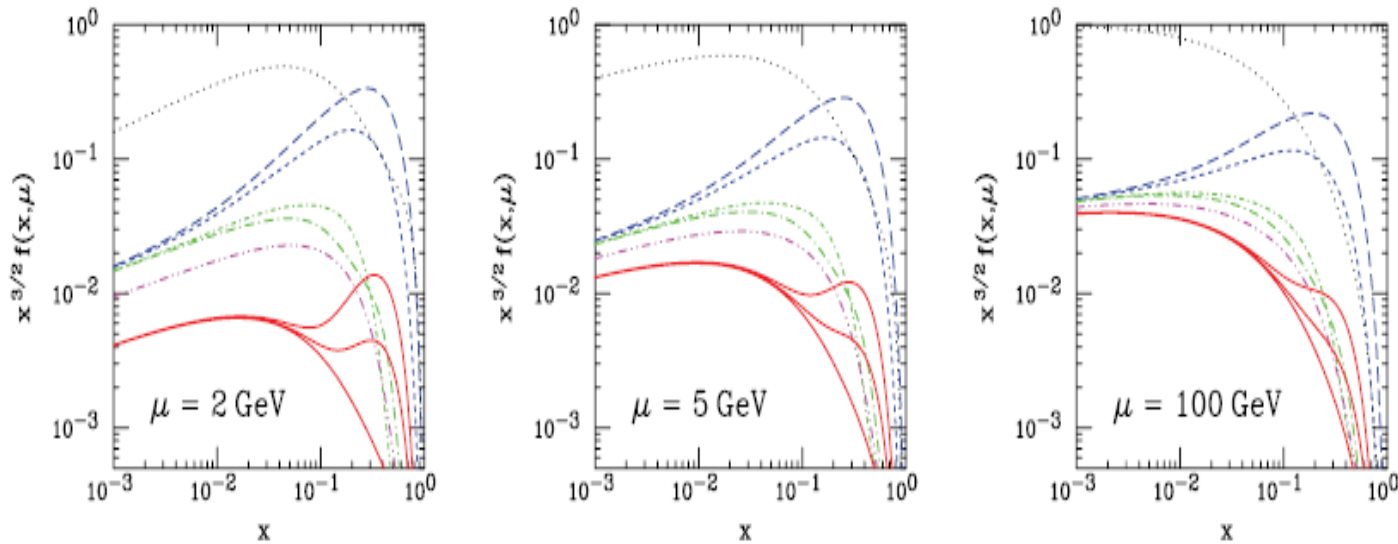
Two types of parton contributions

The extrinsic quarks and gluons are generated on a short time scale in association with a large transverse-momentum reaction.

The intrinsic quarks and gluons exist over a time scale independent of any probe momentum, they are associated with the bound state hadron dynamics.

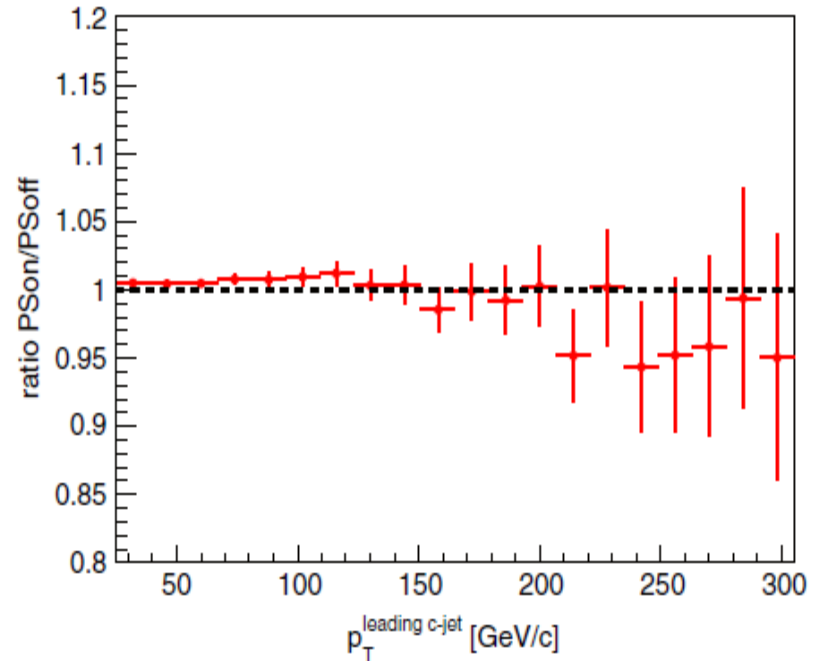
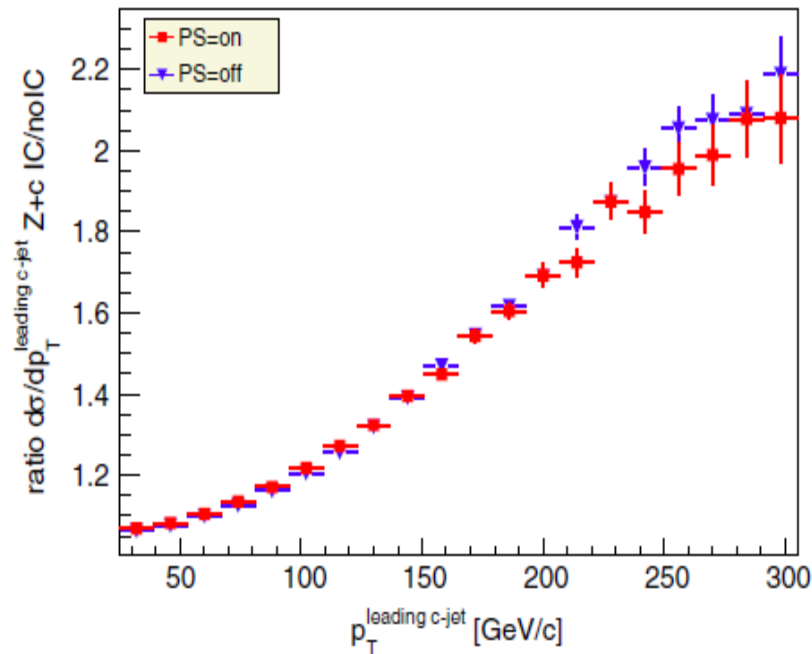
$$P(x_1, \dots, x_5) = N_5 \delta \left(1 - \sum_{i=1}^5 x_i \right) \left[M_p^2 - \sum_{i=1}^5 \frac{m_i^2}{x_i} \right]^2$$

COMPARISON OF LIGHT AND HEAVY QUARK DISTRIBUTIONS IN PROTON



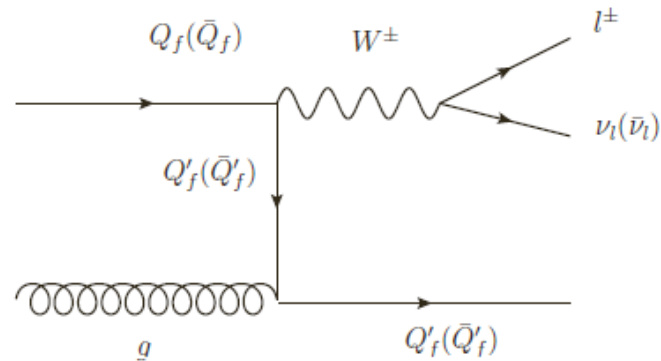
The dotted line is the gluon distribution, the blue long-dashed curve is the valence u -distribution, the blue short-dashed line is the valence d -distribution, the green long-dashed-dotted line is the **intrinsic** \bar{u} , the short dashed-dotted line is the **intrinsic** \bar{d} distribution, the dashed-dot-dotted is the **intrinsic** $s = \bar{s}$ and the solid curves are $c = \bar{c}$ with **no IC** (lowest) and with **IC**, $\langle x_{c\bar{c}} \rangle = 0.57\%, 2\%$ respectively. It is shown that **IC** contribution is larger than \bar{u}, \bar{d}, s at $x > 0.2$

Inclusion of parton shower by Z+Q production in pp at $s^{1/2} = 8$ TeV

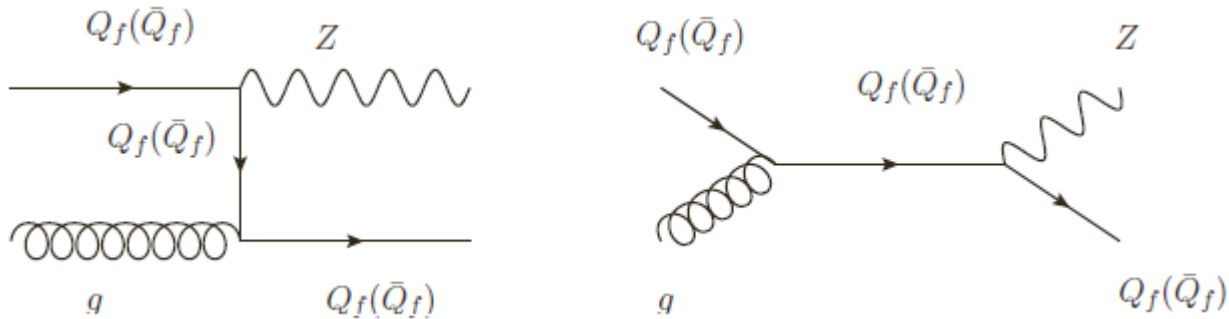


- Left:** p_T – spectra with parton shower (red points) and without it (blue points) using the PDF of type CTEQ66c (3.5% of *IC*)
- Right:** ratio of red points to blue points

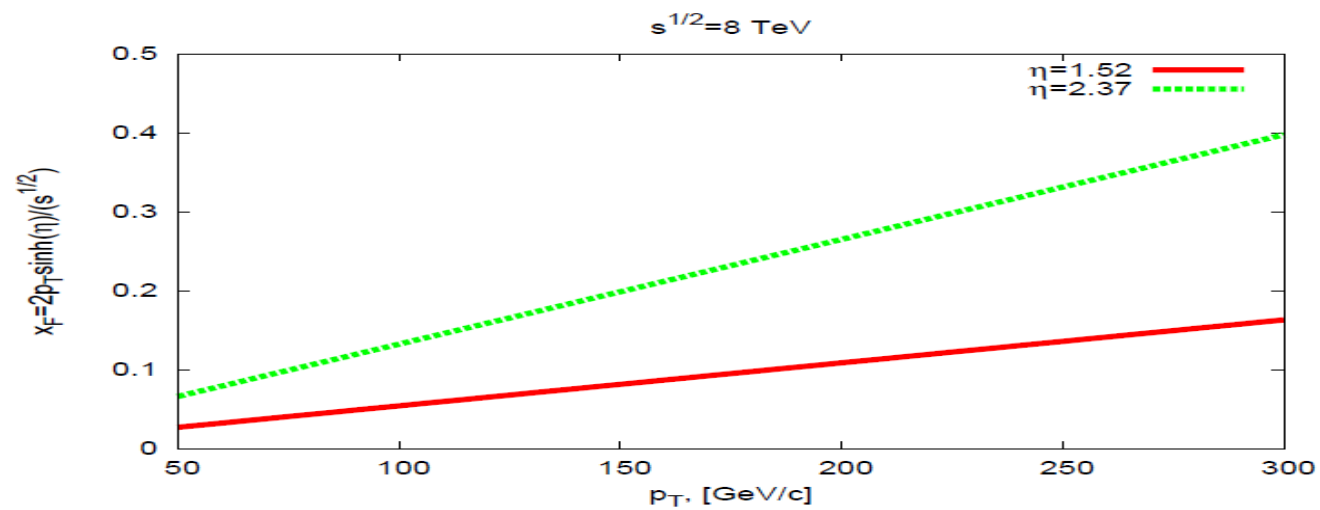
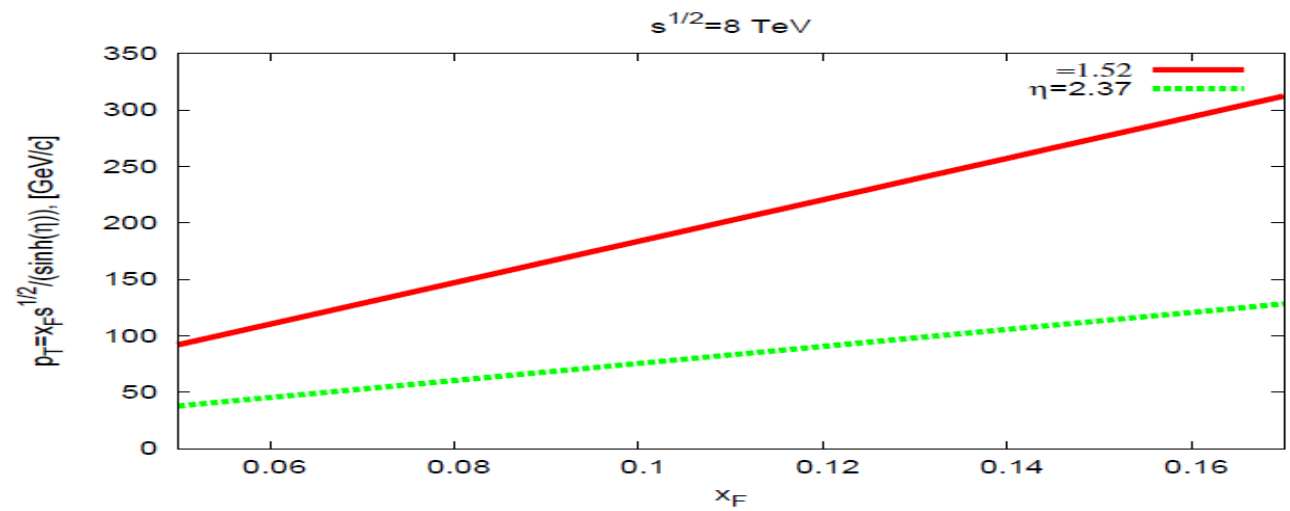
pp \rightarrow W/Z+heavy flavour jets



The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \rightarrow W^\pm Q'_f(\bar{Q}'_f)$, where $Q_f = c, b$ and $Q'_f = b, c$ respectively.



Feynman diagram for the process $Q_f(\bar{Q}_f)g \rightarrow Z Q_f(\bar{Q}_f)$



PHOTON (DI-LEPTON) AND c(b)-JETS PRODUCTION IN P-P

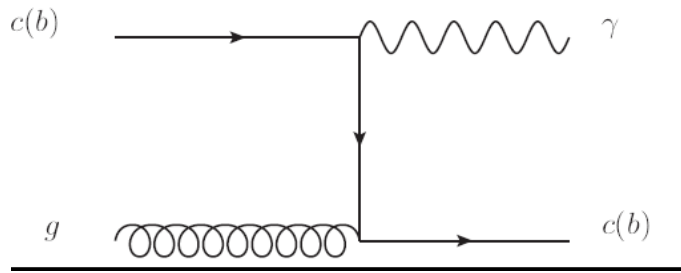


Fig.a. Feynman diagram
for the process $c(b) + g \rightarrow \gamma + c(b)$

$$x_F = \frac{2p_T}{s^{1/2}} sh(\eta); p_{T\gamma} = -p_{Tc}.$$

for Fig.a

$$x_c \geq x_F > 0.1$$

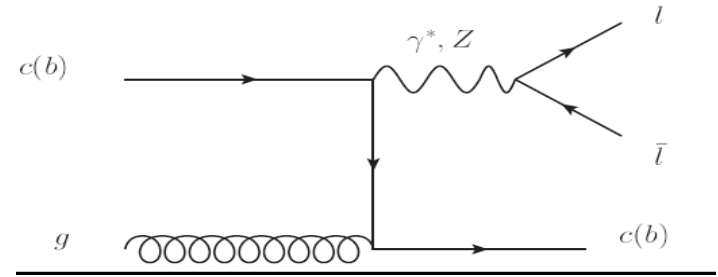


Fig.b. Feynman graph for
the process $c(b) + g \rightarrow \gamma/Z^0 + c(b)$

$$x_{c(b)} = \frac{m_{l^+l^-}^2}{x_g s} + x_{c(b)}^f$$

To observe the IC

for Fig.b

$$x_{c(b)} = \frac{m_{l^+l^-}^2}{x_g s} + x_{c(b)}^f > 0.1$$

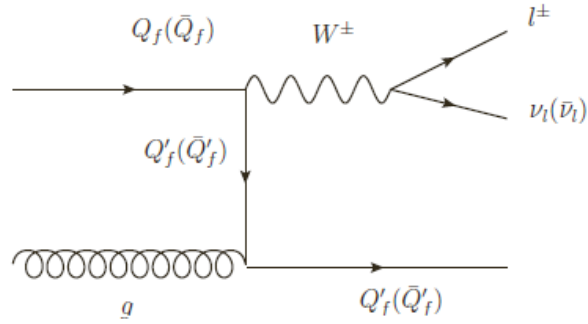


Figure 2: The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \rightarrow W^\pm Q'_f(\bar{Q}'_f)$, where $Q_f = c, b$ and $Q'_f = b, c$ respectively.

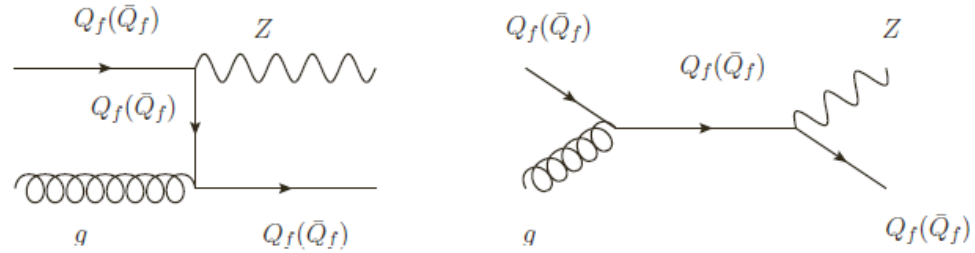
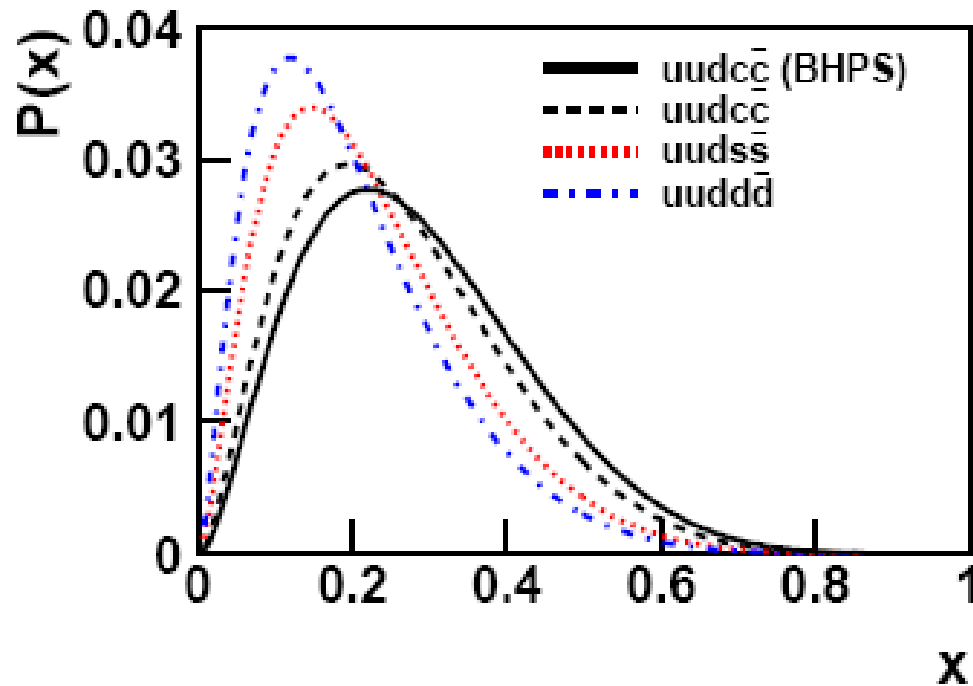
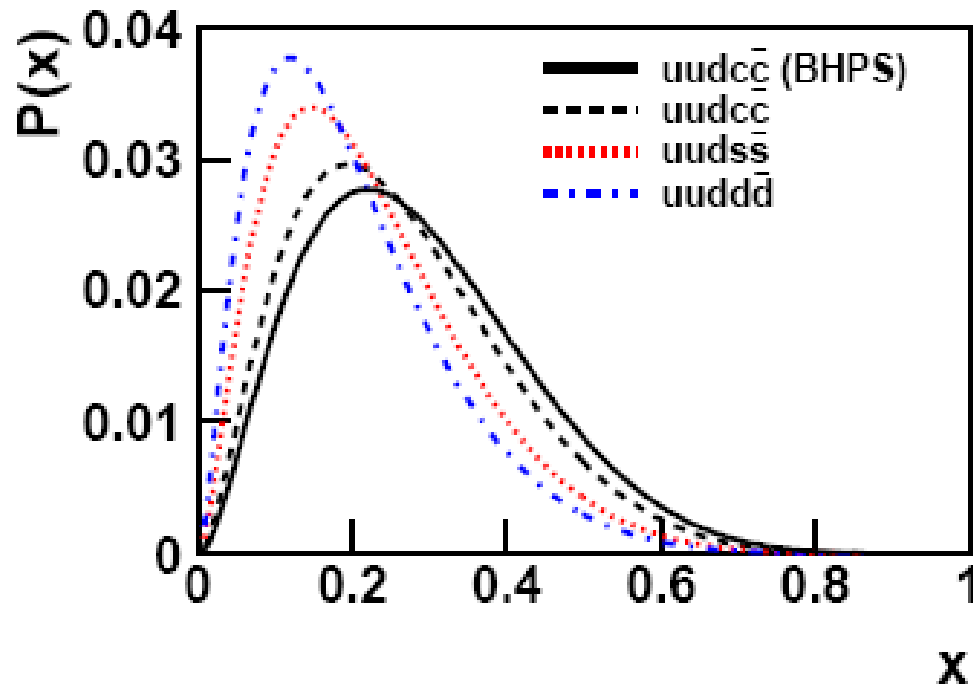


Figure 3: Feynman diagram for the process $Q_f(\bar{Q}_f)g \rightarrow Z Q_f(\bar{Q}_f)$



The x -distribution of the intrinsic Q calculated within the BHPS model. **There is an enhancement at $x > 0.1$**
 Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.



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