COLLIDER TESTS OF INTRINSIC QUARK DISTRIBUTIONS IN PROTON

Gennady Lykasov[1]
in collaboration with

Vadim Bednyakov[1], *Stanly Brodsky*[2],
Hugo Beauchemin[3], *Artem Lipatov*[1,4],
Andrey Prokhorov[1], *Semen Turchikhin*[1],
Yuri Stepanenko[1]

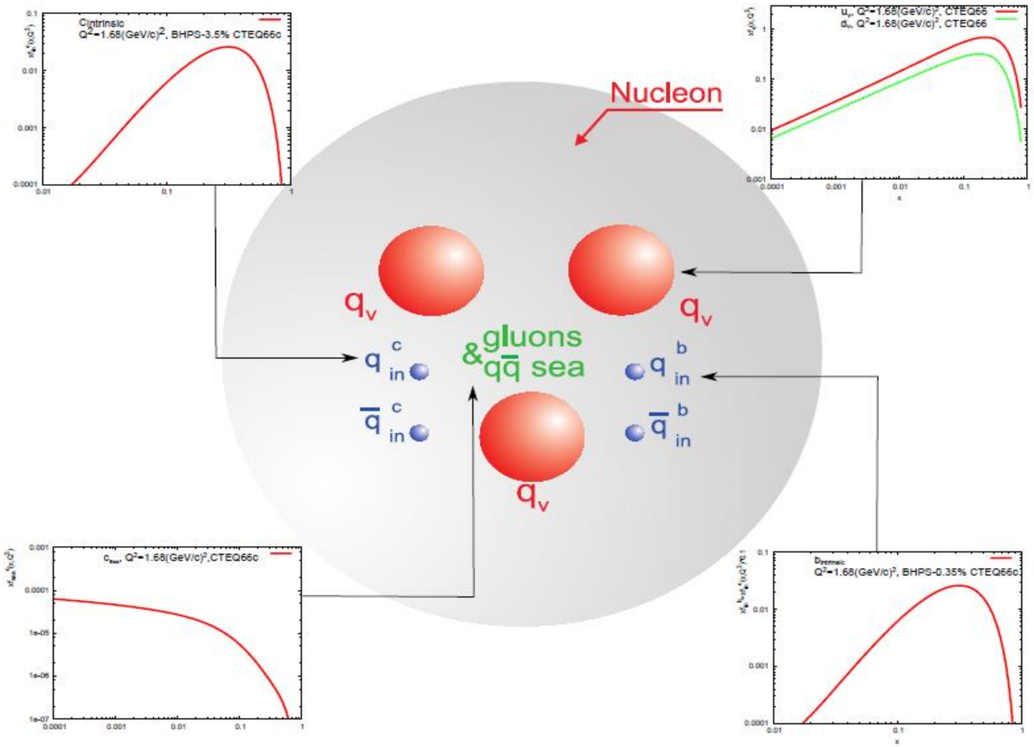
[1]*JINR, Dubna,*
[2]*SLAC, Stanford University,*
[3]*TUFS University, Medford, MA*
[4]*SINP, MSU, Moscow*

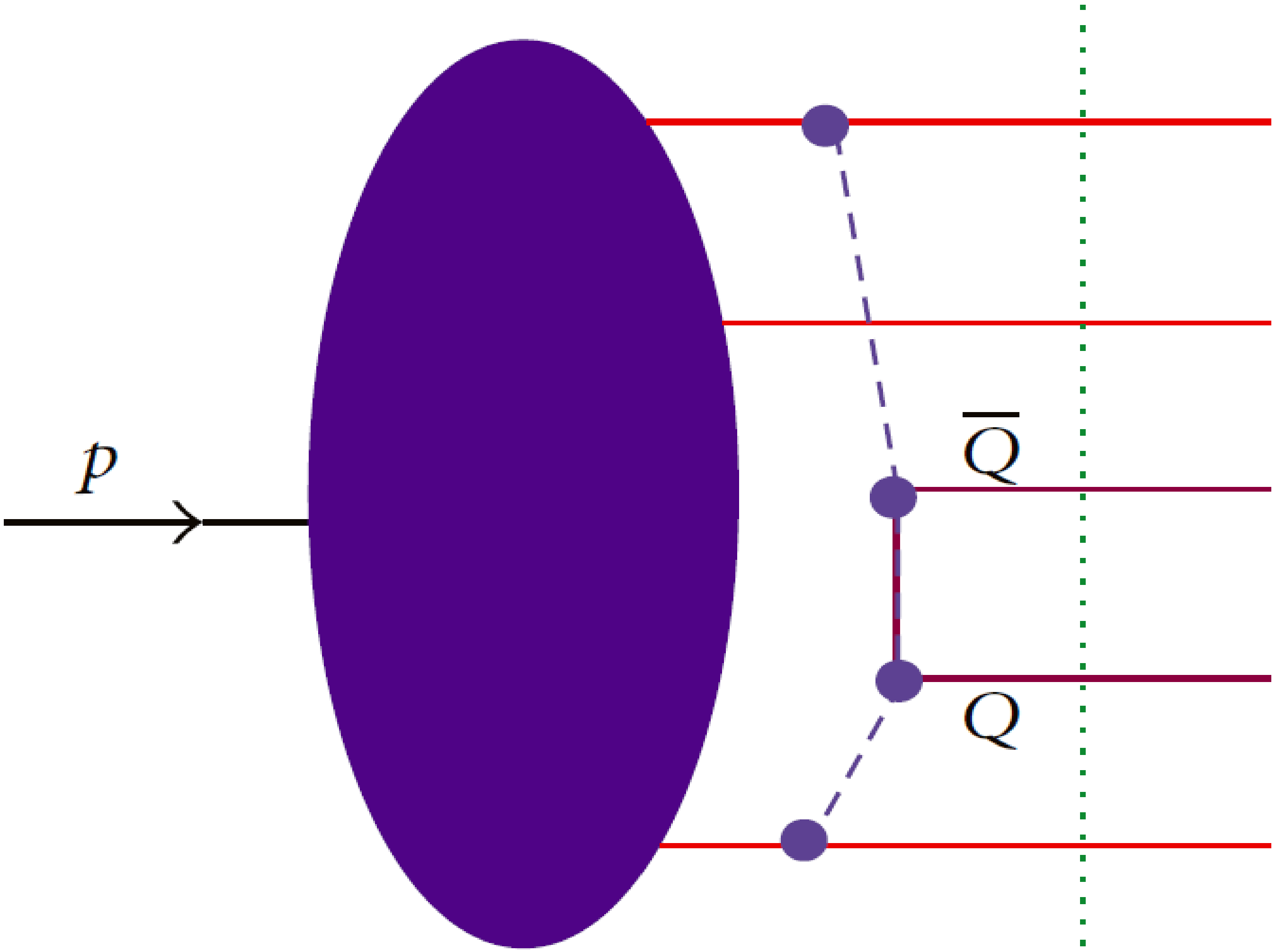
OUTLINE

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 γ+c and Z/W+c(b) production in
   p-p collision**
6. **Summaruy**

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->Q Qbar inserted into the proton self-energy

$$\mathrm{d}P = N \prod_{j=1}^{5} \frac{\mathrm{d}x_j}{x_j} \delta\left(1 - \sum_{j=1}^{5} x_j\right) \prod_{j=1}^{5} \mathrm{d}^2 p_{\mathrm{T}j} \delta^{(2)}\left(\sum_{j=1}^{5} p_{\mathrm{T}j}\right) \frac{F^2(s)}{(s - m_{\mathrm{N}}^2)^2},$$

where

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

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

where $x = x_5$, $c = m_{\mathrm{N}}^2 / m_{\mathrm{c}}^2$,

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

and

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

Here N is found from the normalization equation:

$$\int_0^1 P(x)\mathrm{d}x = w,$$

where w is the integral fraction of the intrinsic charm. Setting $c \to 0$ leads to the BHPS result |

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

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

or the *power-low suppression* factor:

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

PRODUCTION OF HEAVY FLAVOURS IN HARD P-P COLLISIONS

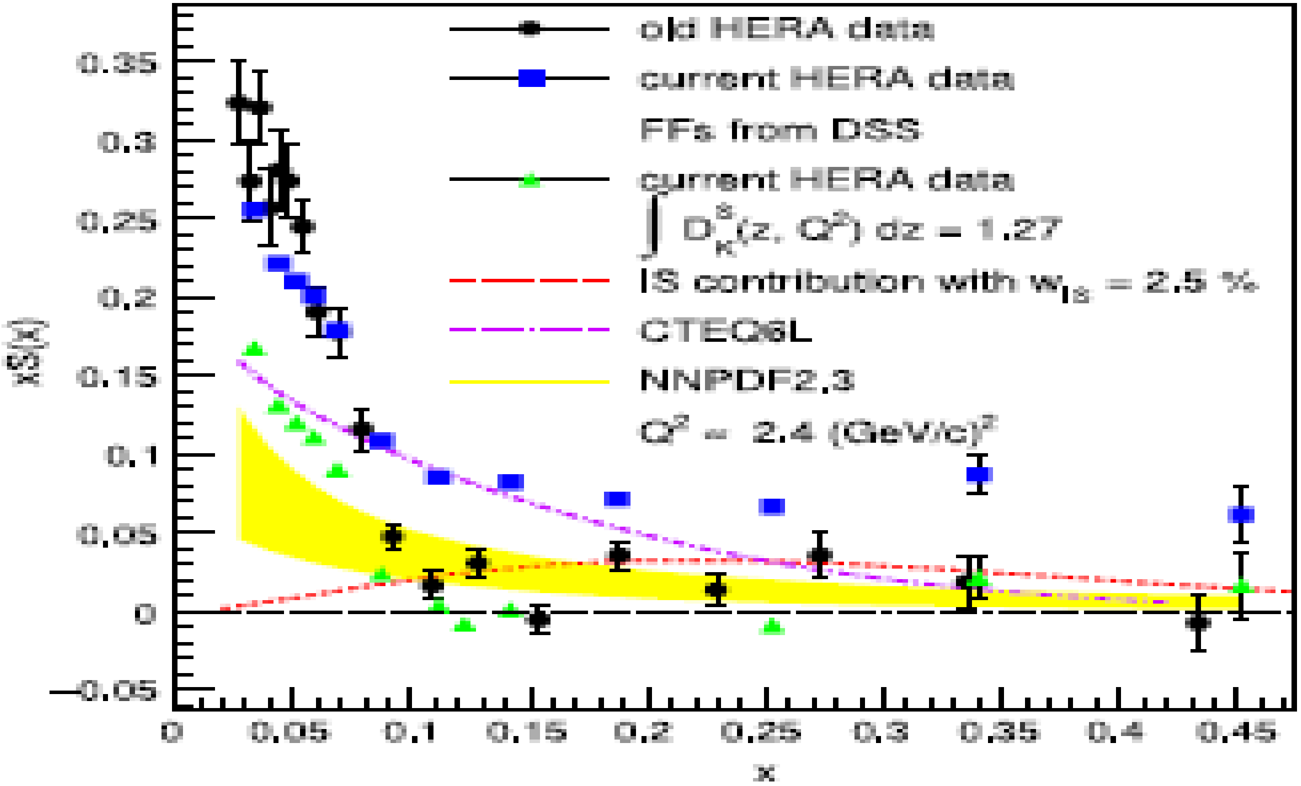
$$E\frac{d\sigma}{d^3p} = \sum_{i,j}\int d^2k_{iT}\int d^2k_{jT}\int_{x_i^{\min}}^1 dx_i\int_{x_j^{\min}}^1 dx_j f_i(x_i,k_{iT})f_j(x_j,k_{jT})\frac{d\sigma_{ij}(\hat{s},\hat{t})}{d\hat{t}}\frac{D_{i,j}^h(z_h)}{\pi z_h}$$

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

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

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.

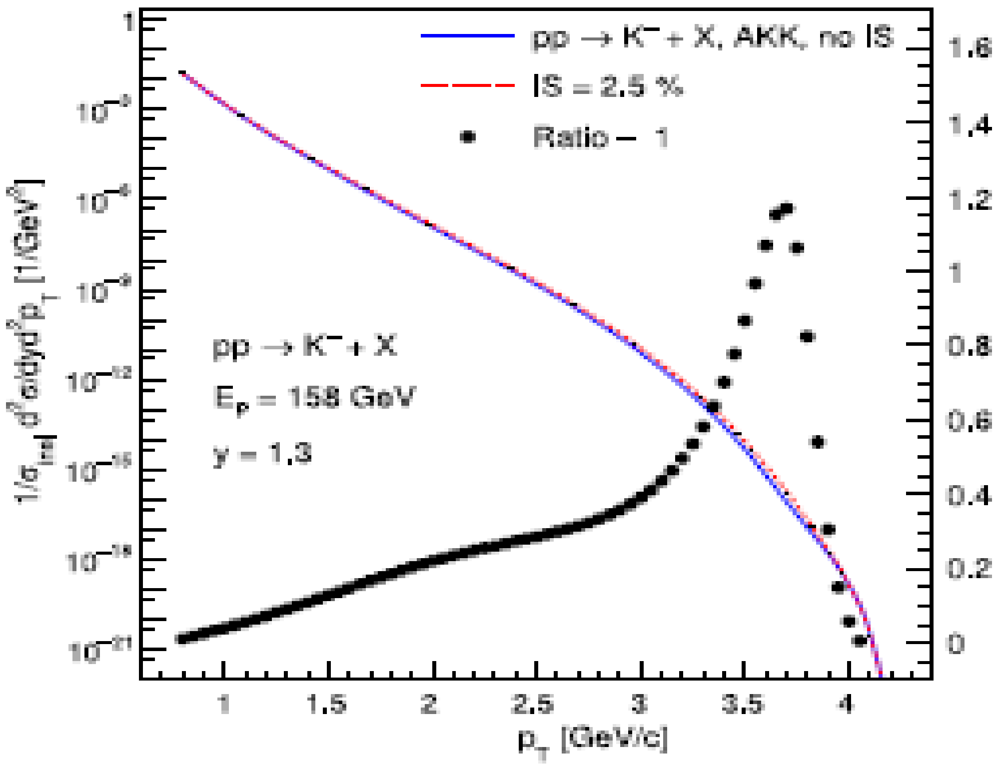
Intrinsic strangeness in proton



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

Predictions for NA61

pp --> K^- X at E_p = 158 GeV



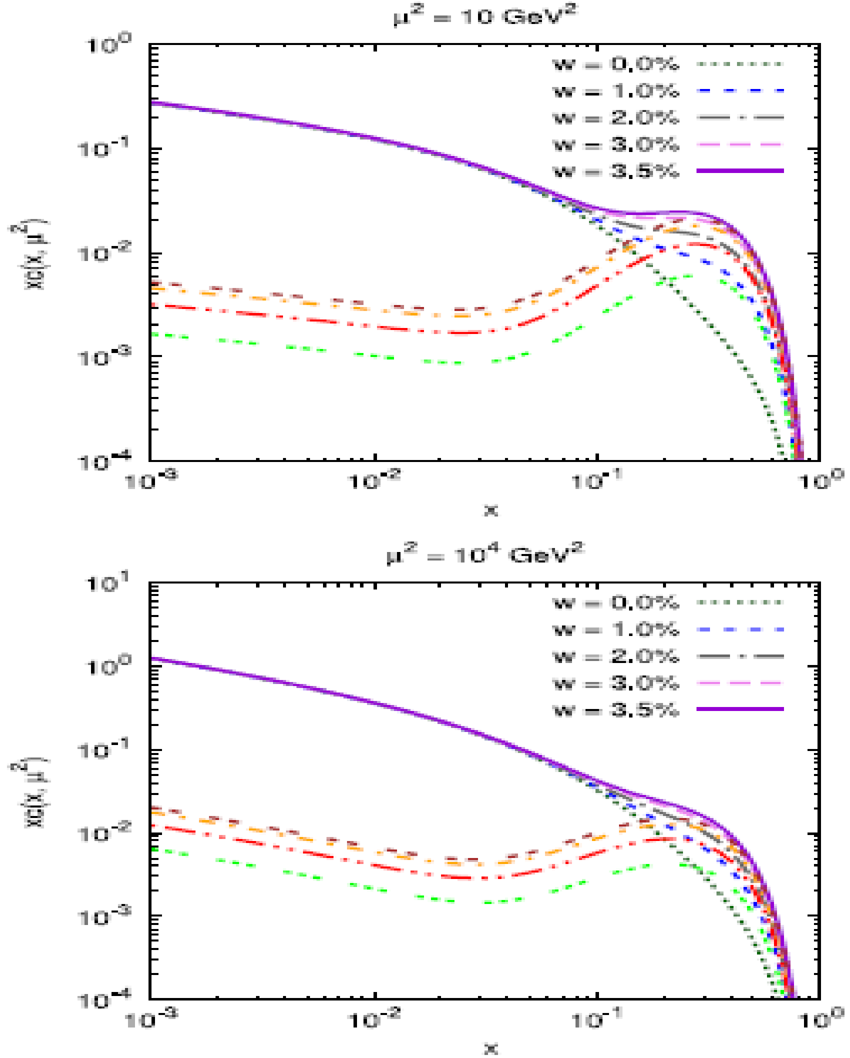
p_T – distribution of K^- at y=1.3

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

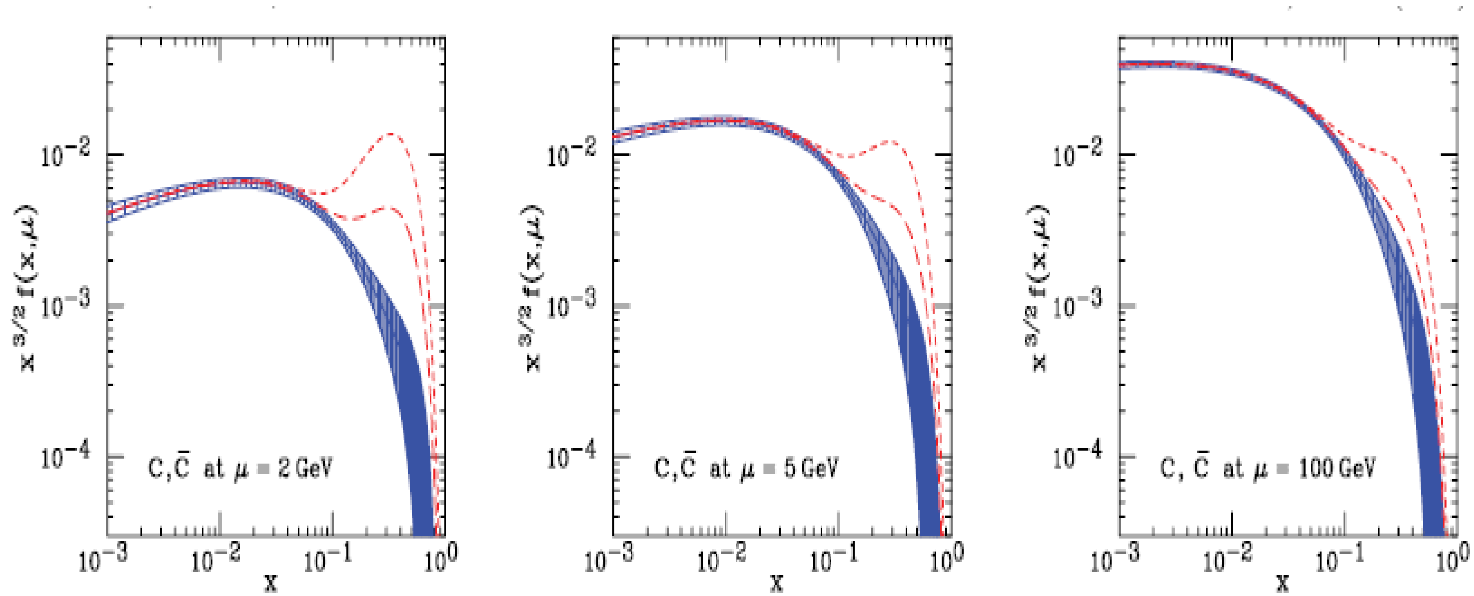
Intrinsic charm density in a proton as a function of IC probability w

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



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

CHARM QUARK DISTRIBUTIONS IN PROTON

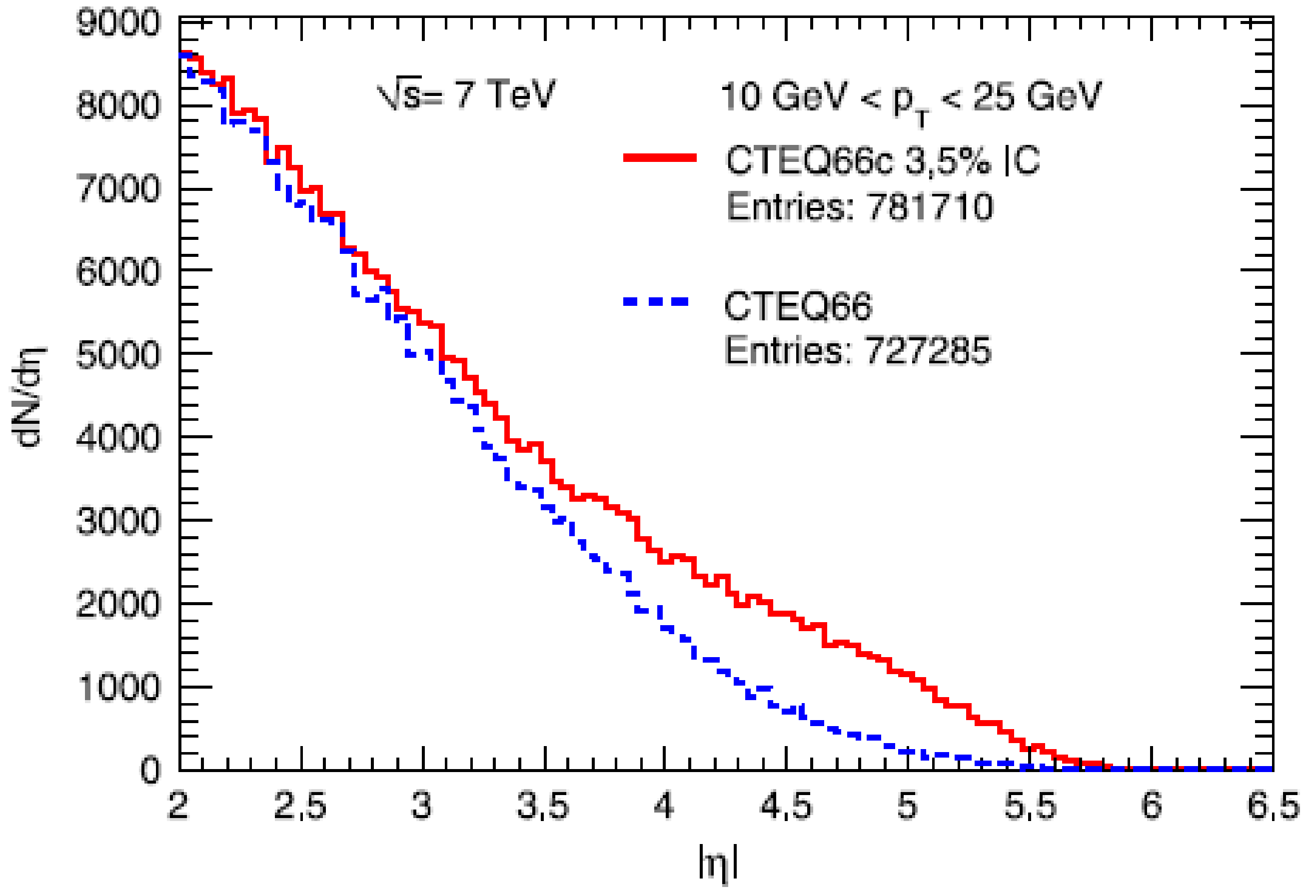


Charm quark distributions within the BHPS model. The three panels correspond to the renormalization scales $\mu = 2, 5, 100$ GeV respectively. The long-dashed and the short-dashed curves correspond to $\langle x_{c\bar{c}} \rangle = 0.57\%, 2.\%$ respectively using the PDF CTEQ66c. The solid curve and 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*

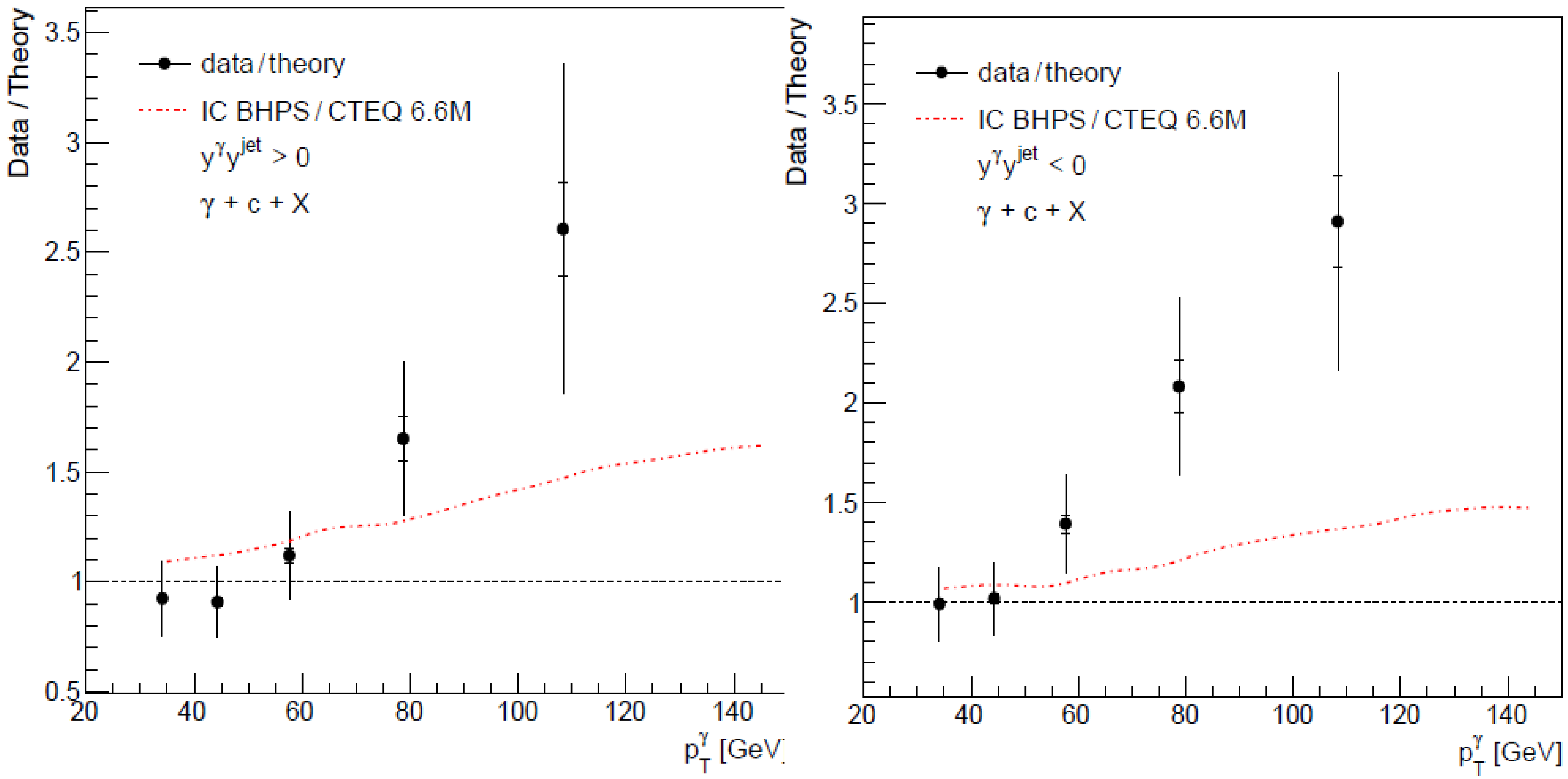
PP->γ + c +X : *V.A.Bednyakov, M.A.Demichev,G.L.,T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (1914)*

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

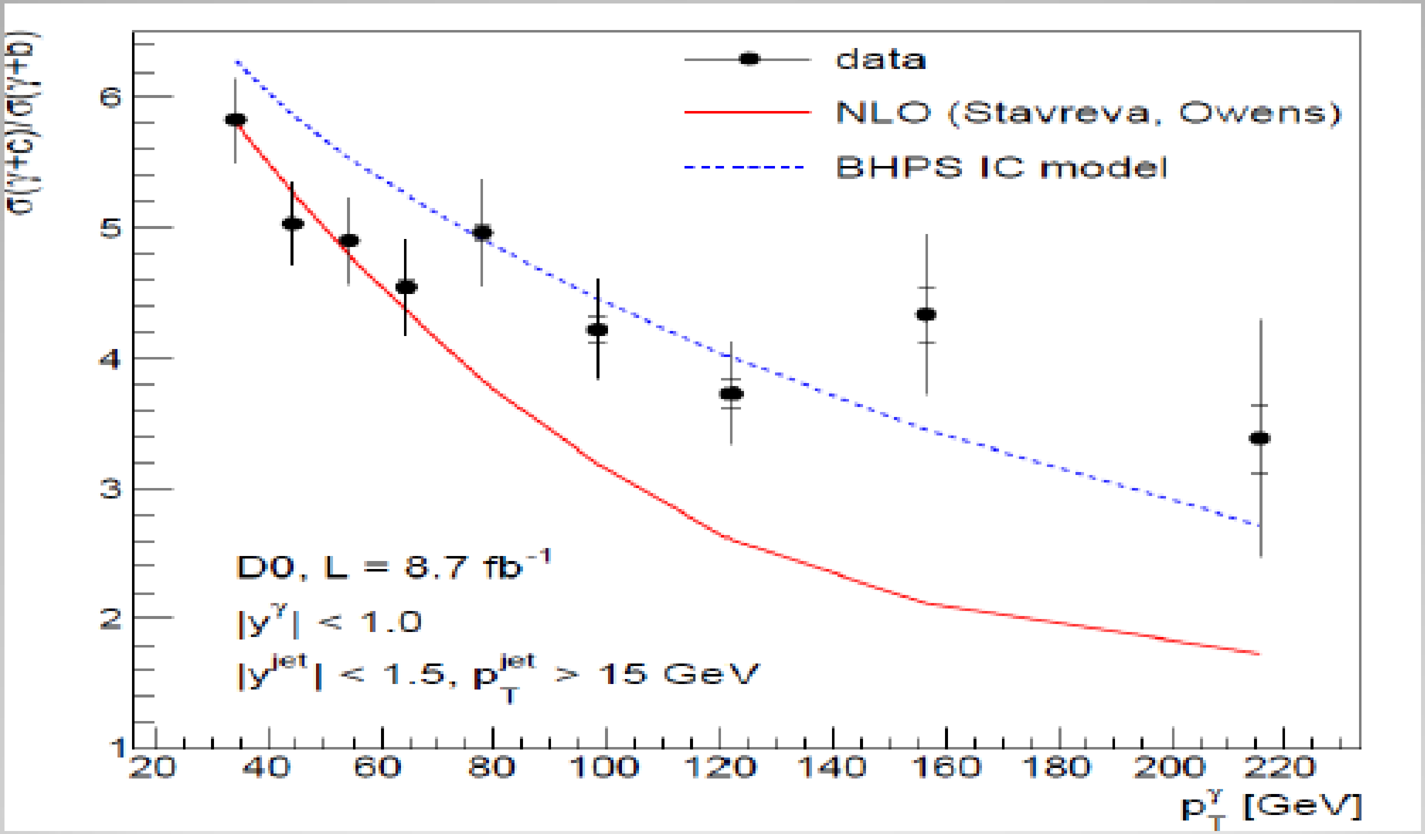
PP->γ/Z+ c(b)+X : *A, Lipatov, GL, Yu. Stepanenko V.A.Bednyakov, Phys.Rev.D94, 05301 (2016)*

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).*

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

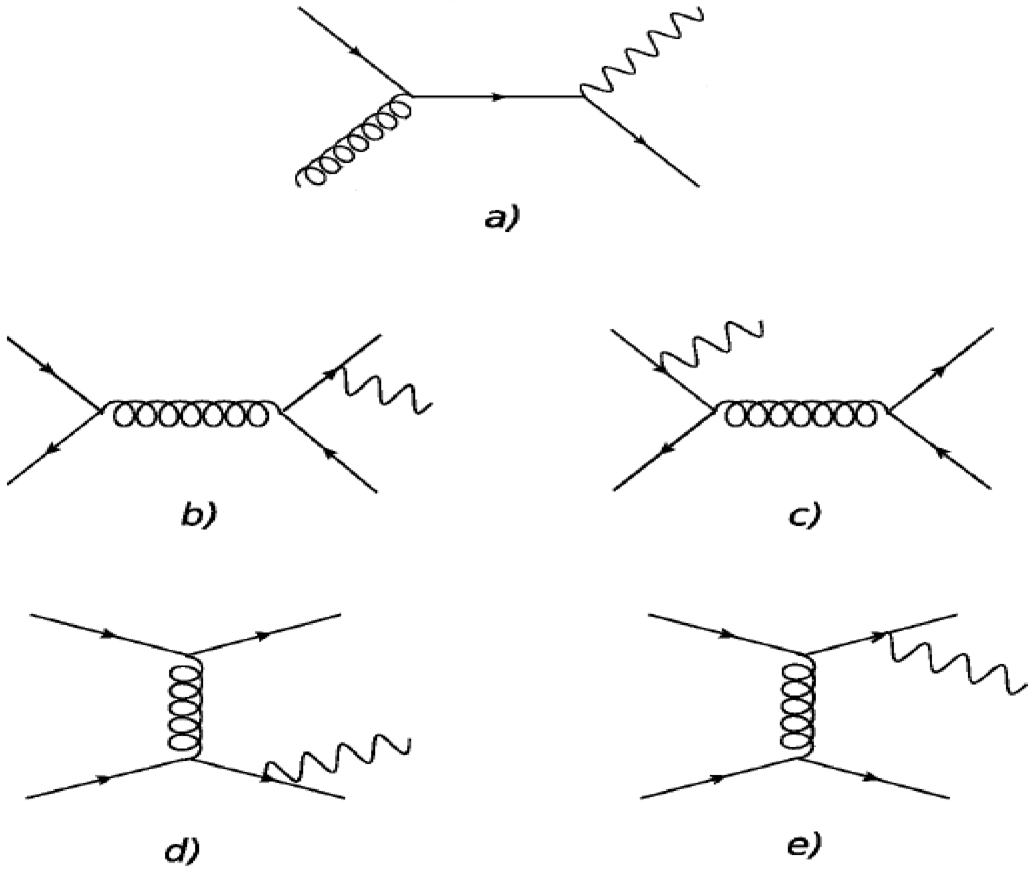


$R = \sigma(\gamma + c)/\sigma(\gamma + b)$ for p bar{p} -> γ + Q at $s^{1/2}$ = 1.98 TeV



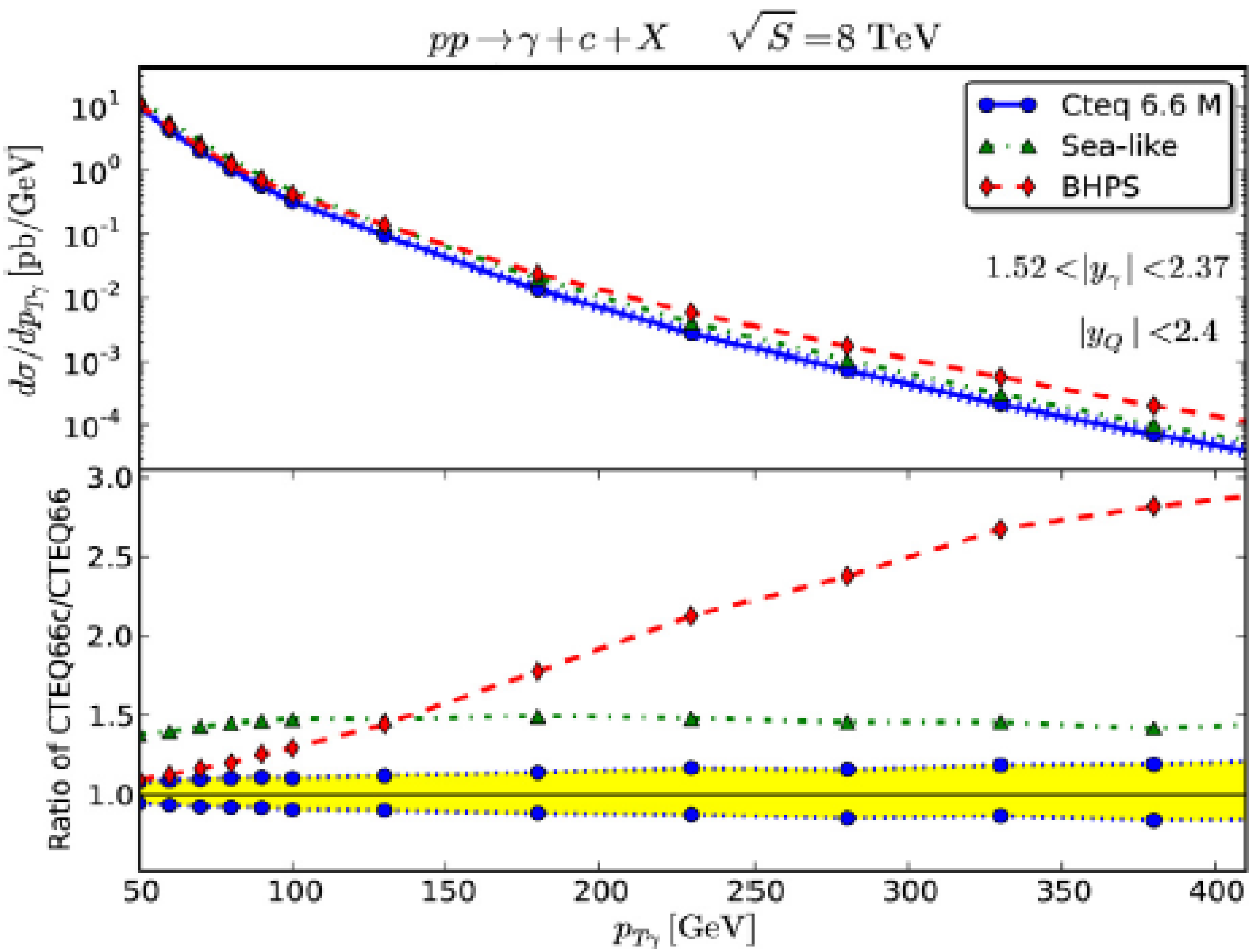
p_T –distribution of R, points are the D0 data; red solid line is NLO without *IC* ; short dash line is BHPS with *IC* probability about 1 %

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



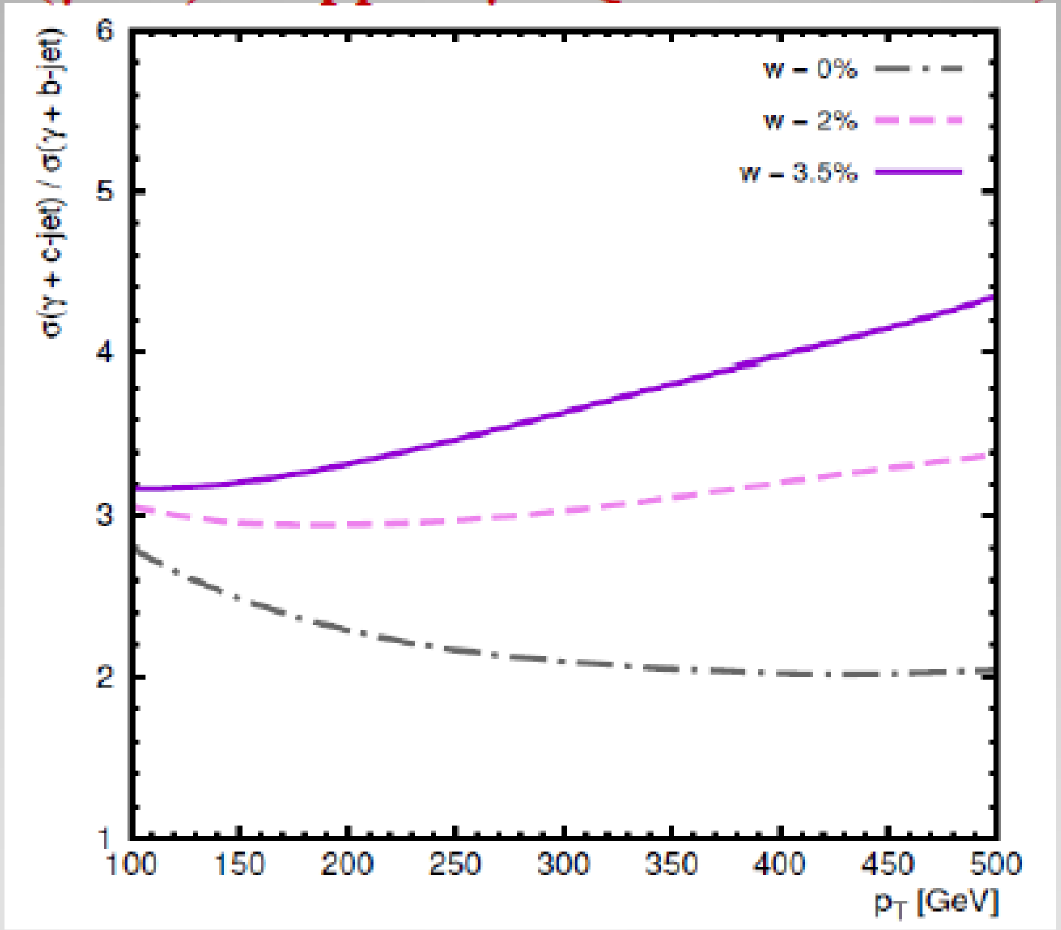
Feynman QCD diagrams: a): Q +g->γ +Q;
b-c): Q + barQ->Q + barQ + γ; d-e): Q(q)+q(Q)->Q(q)+q(Q)+γ

Predictions for ATLAS and SMC



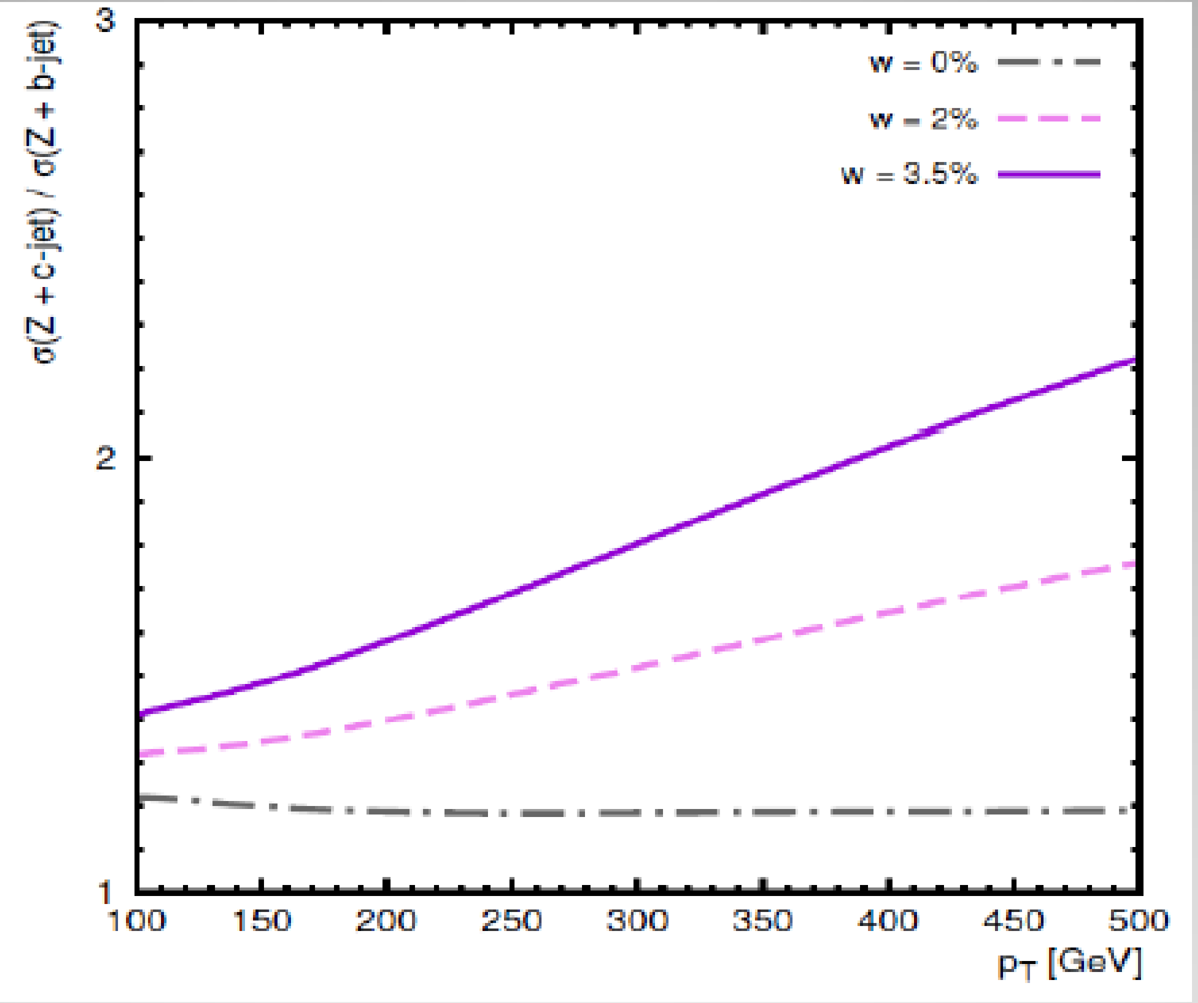
V.A. V.A.Bednyakov, M.A.Demichev, G.L.,T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (2014).

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



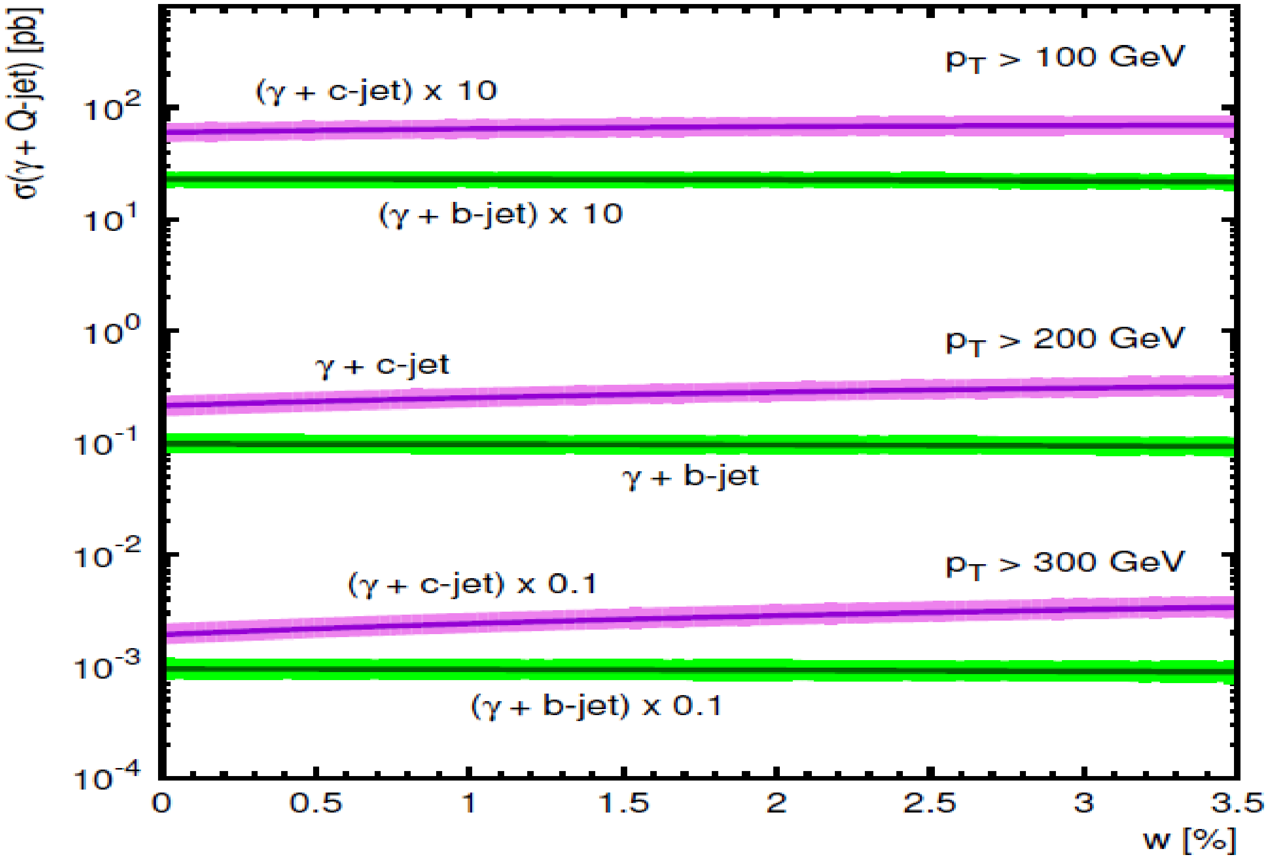
p_T –distribution of R at different IC probability w

R=σ(Z + c)/σ(Z + b) for pp -> Z+ Q at $s^{1/2}$ = 8 TeV ; 1.5< η< 2.4



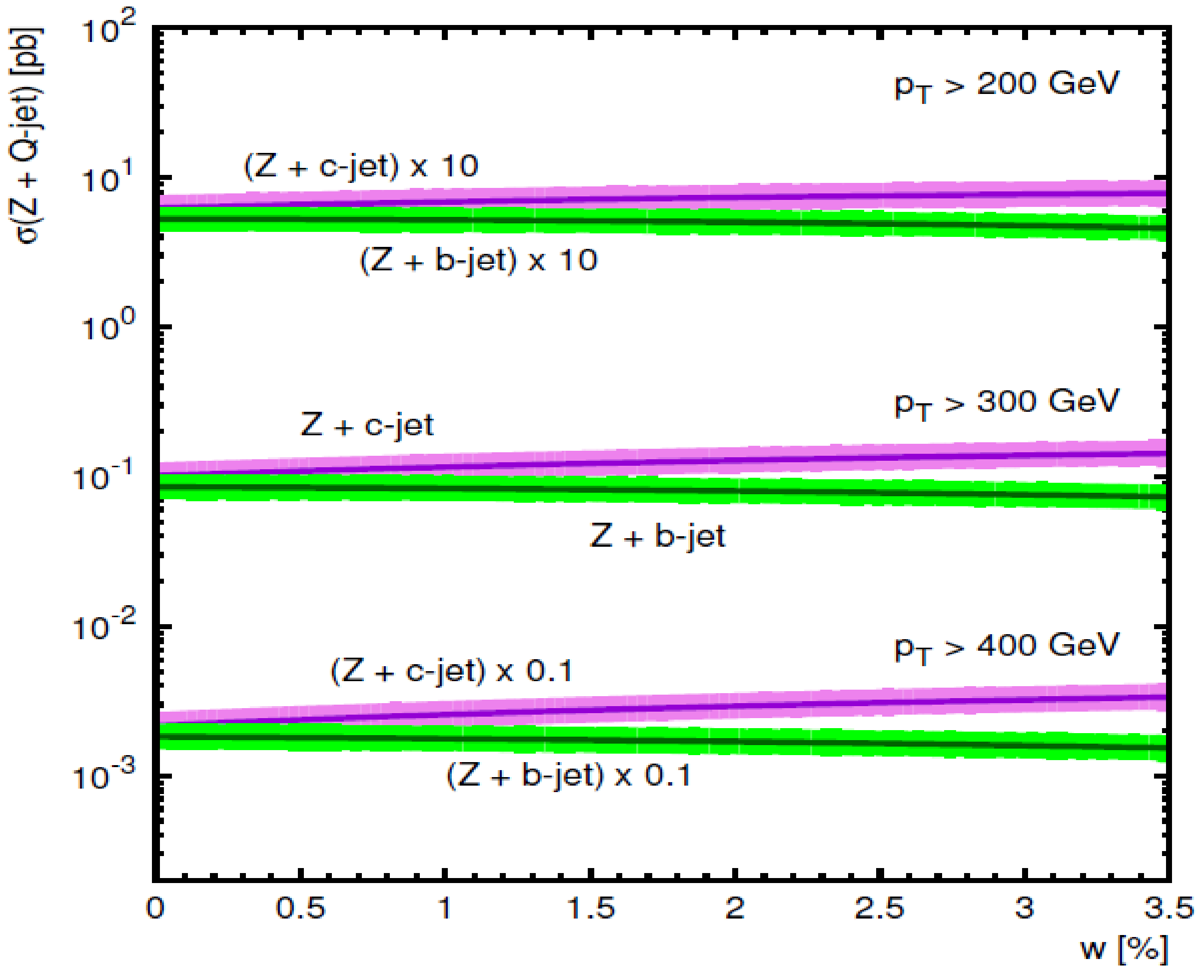
p_T –distribution of R at different IC probability w

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

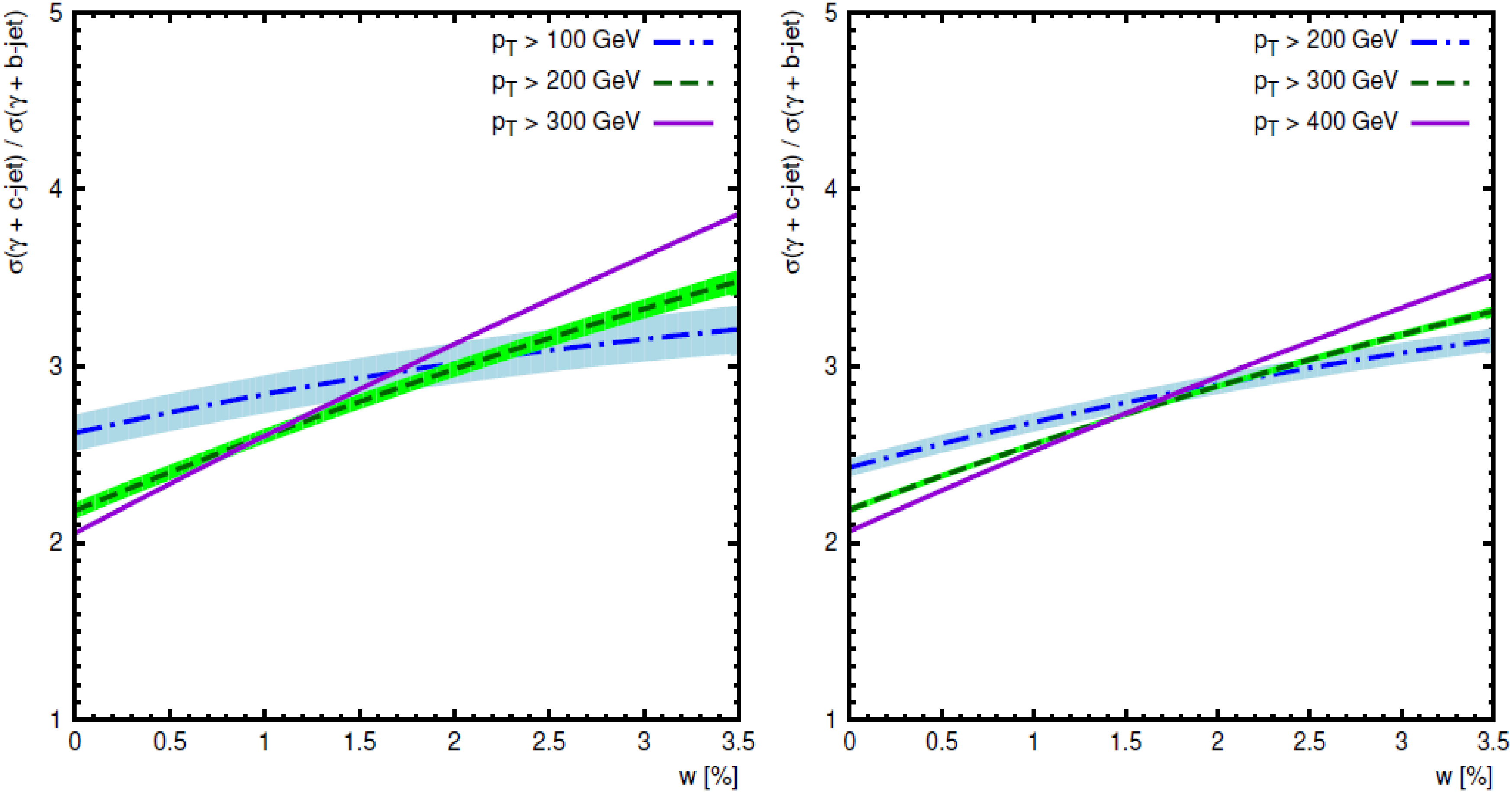


p_T^{γ} – spectrum integrated over p_T^{γ} , i.e., $\sigma(\gamma+c)$ and $\sigma(\gamma+b)$ at p_T^{γ} > 100 GeV or 200 GeV, or 300 GeV, vs. *IC* probability w

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

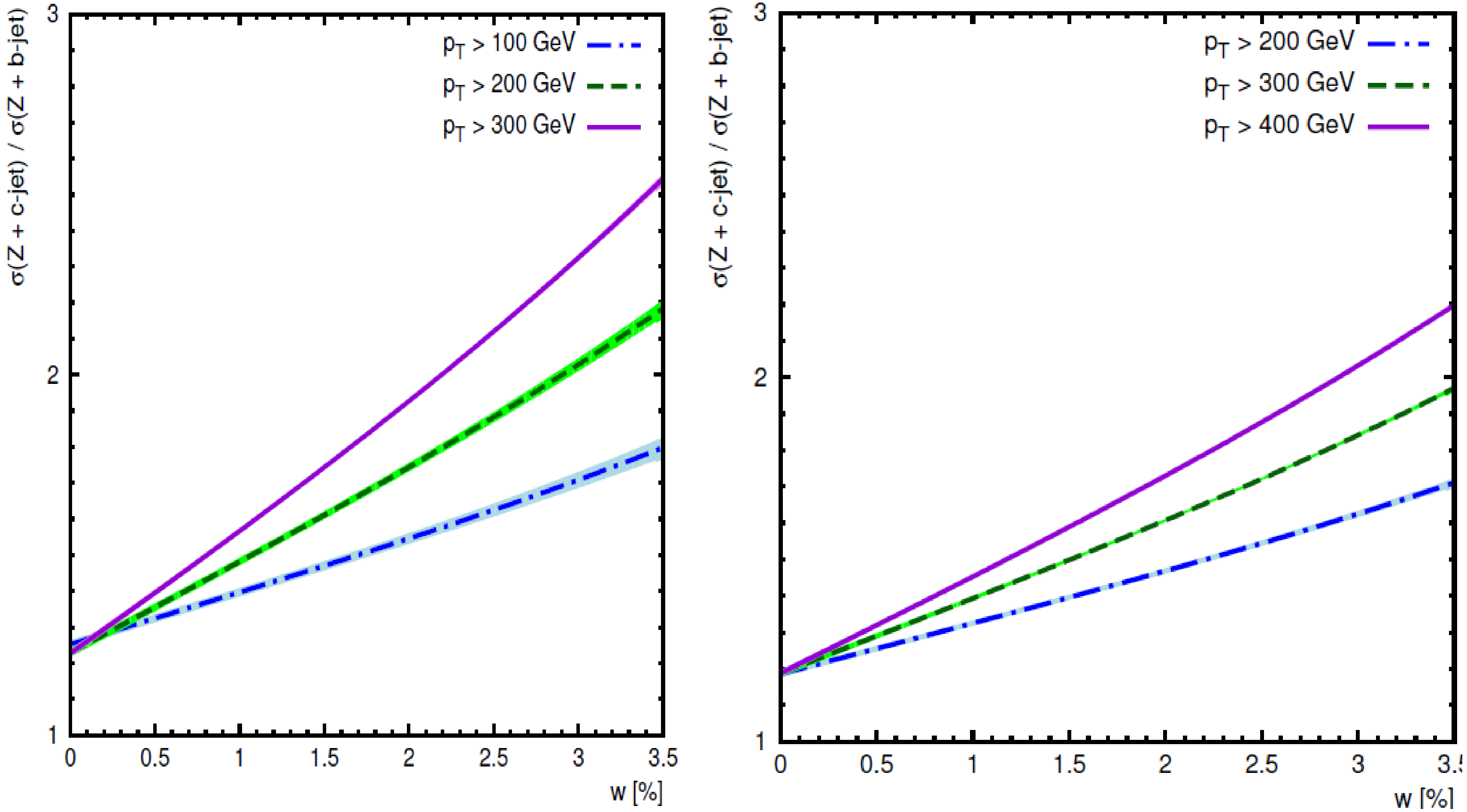


$s^{1/2}$ = 8 TeV PP → γ + Q +X , Q = c,b $s^{1/2}$ = 13 TeV



Ratio between the x-sections of γ +c and γ + b production integrated over $p_{T.}$ Bands mean the QCD scale uncertainty

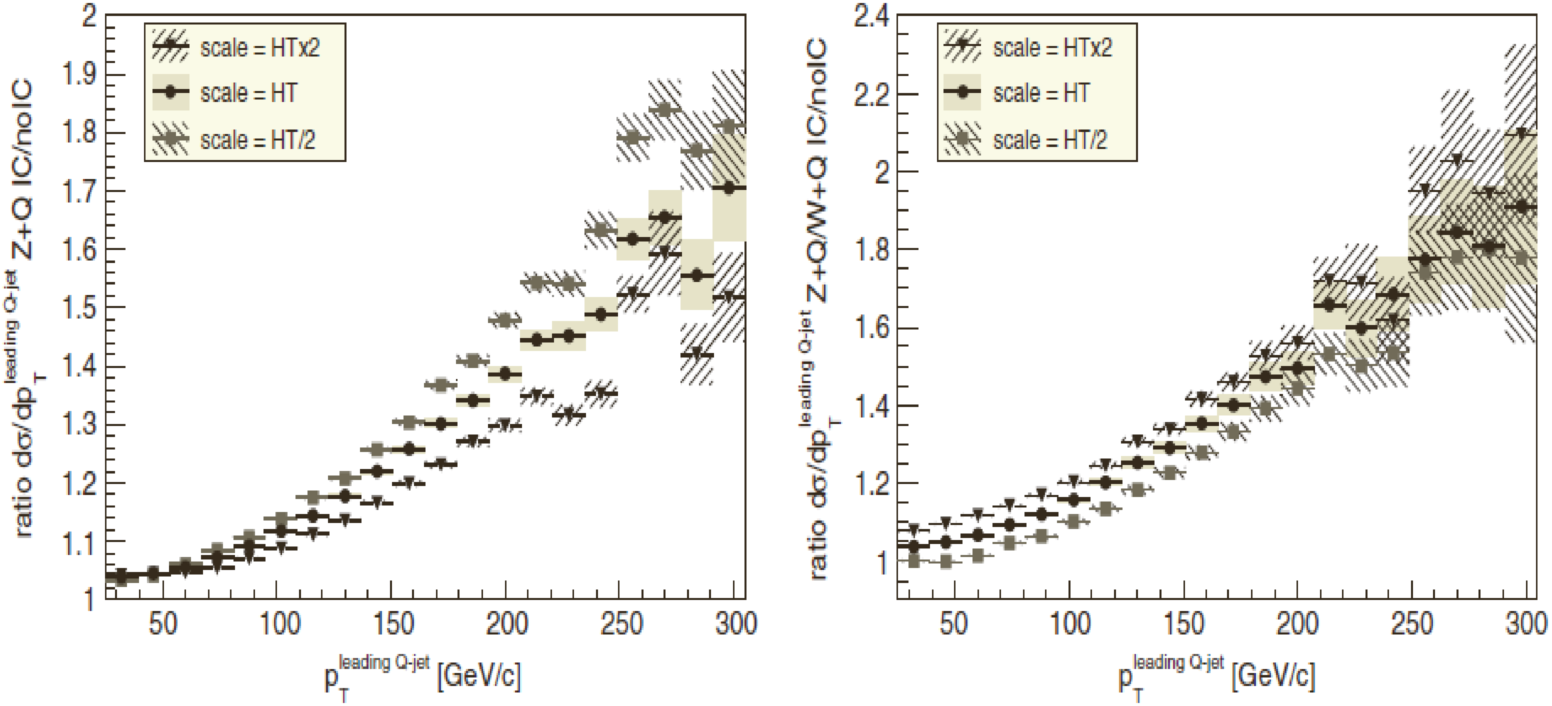
Ratio σ(Z+c)/σ(Z+b)
$S^{1/2}$ = 8 TeV (left) and $S^{1/2}$ = 13 TeV (right)



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

A.V.Lipatov, G.L., Yu.Yu.Stepanenko, V.A.Bednyakov, Phys.Rev. D94 , 053011 (2016) ;
S.J.Brodsky, V.A.Bednyakov, G.L., J.Smiesko, S.Tokar, arXiv:1612.01351 ,
Prog. Part.Nucl.Phys.,v. 93, p.108 (2017)

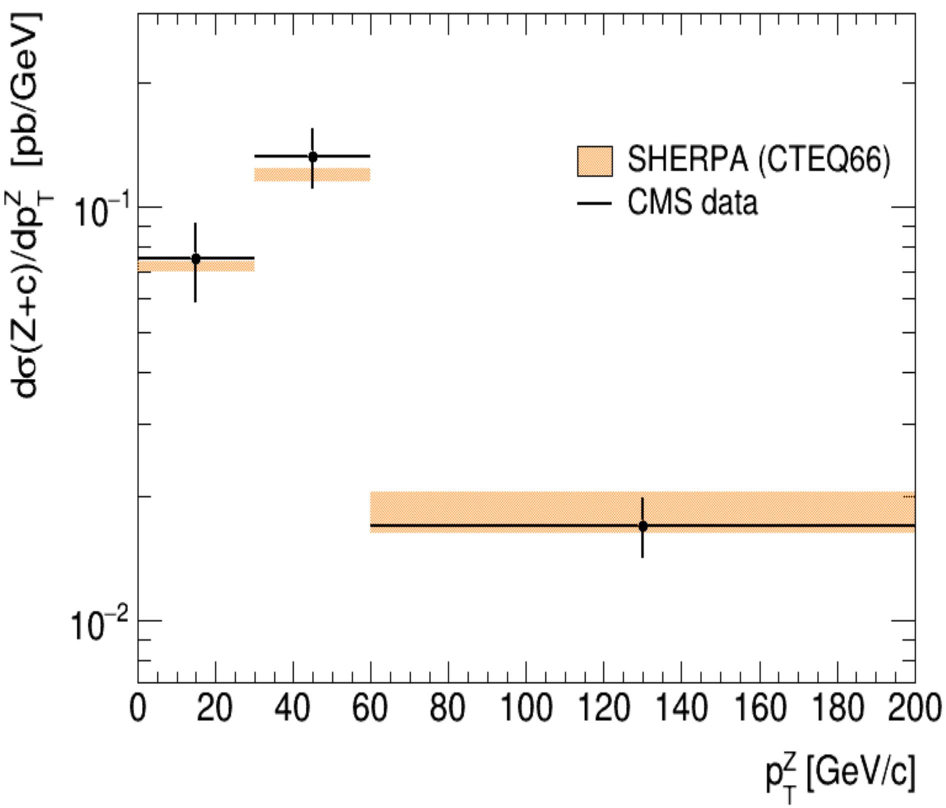
Scale uncertainty for Z+Q and Z+Q/W+Q

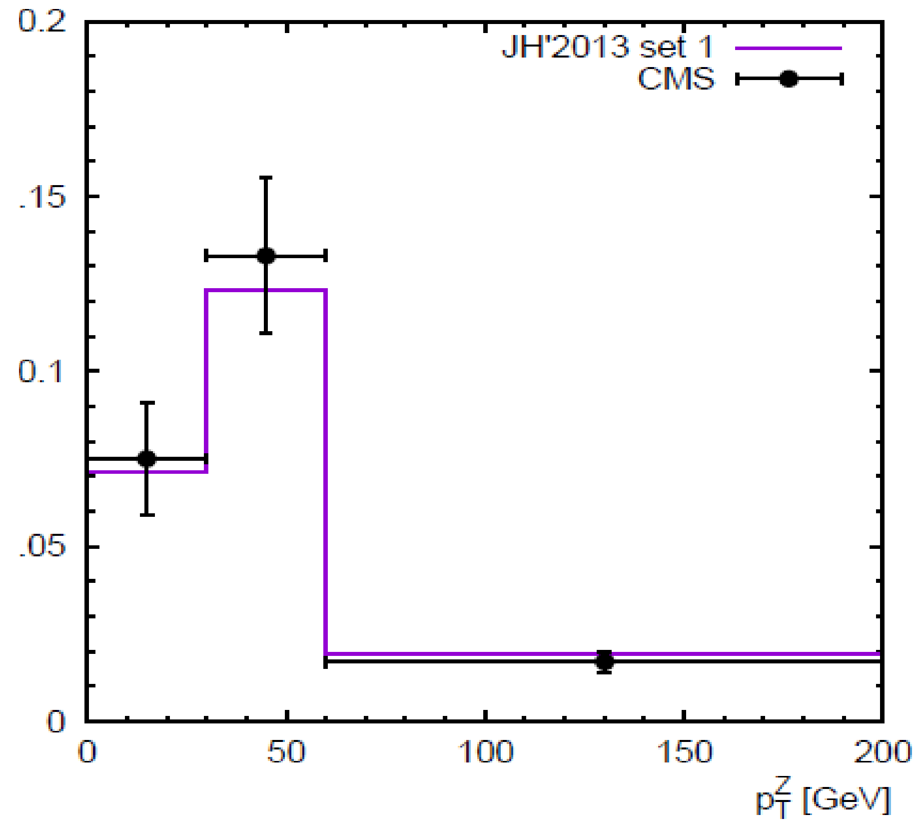


Left: Z+Q with IC and without IC at different scales
Right: Z+Q/W+Q with IC and without IC at different scales

P.A.Beauchemin, V.A.Bednyakov, G.L., Yu.Yu.Stepanenko, Phys.Rev.D92, 034014 (2015)

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





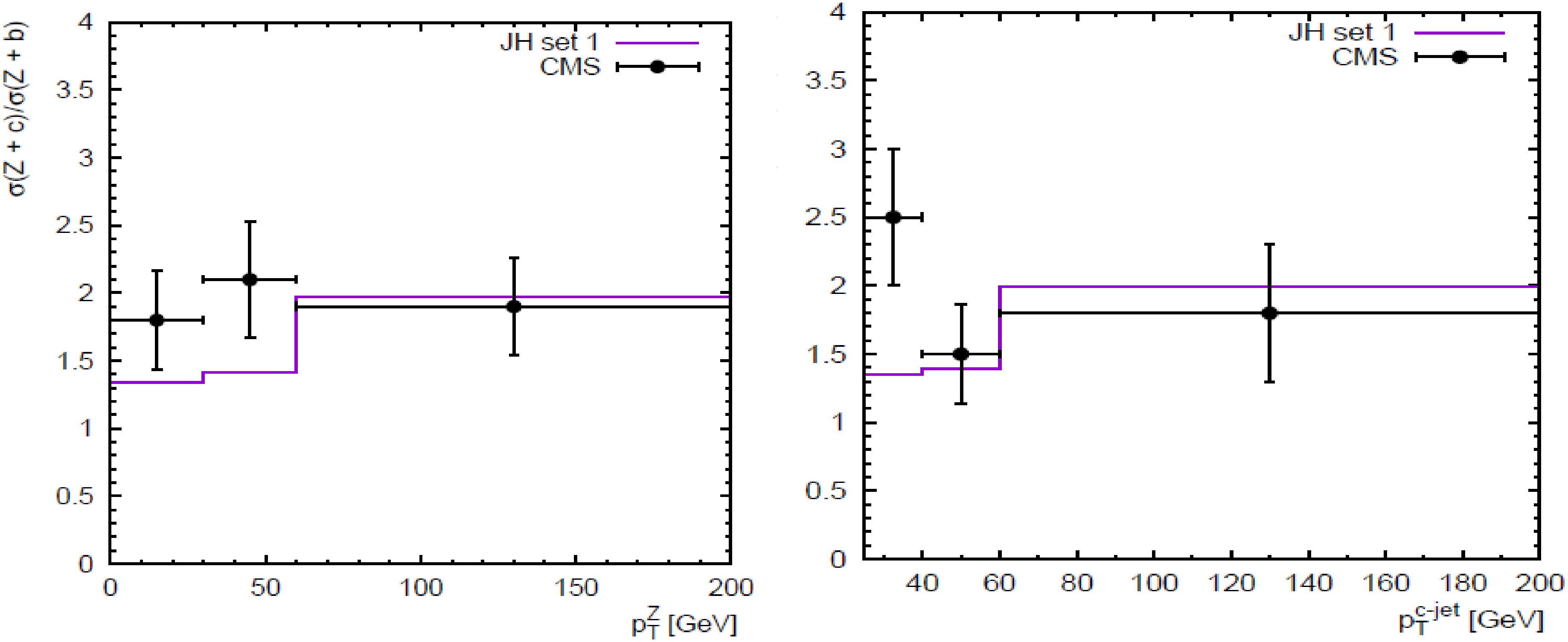
Left: SHERPA results

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 → Z+c(b)-jet +X at $s^{1/2}$ = 8 TeV

$p_T^{jet} > 25$ GeV/c; $|\eta^{jet}| < 2.5$



Ratio σ(Z+c)/σ(Z+b) as a function of p_T^Z

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

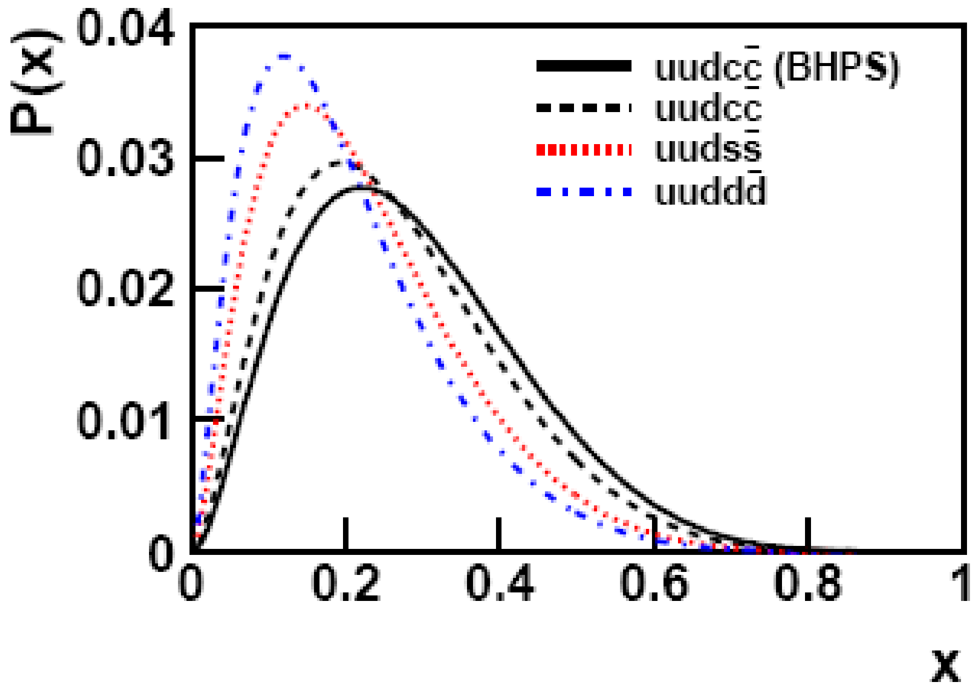
Experimental data are taken from CMS PAS SMP-15-009, CMS-SMP-14-10

SUMMARY

1. **QCD predicts two sources of heavy quarks: the standard small-x extrinsic contribution at from gluon splitting g → 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 *γ/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.**

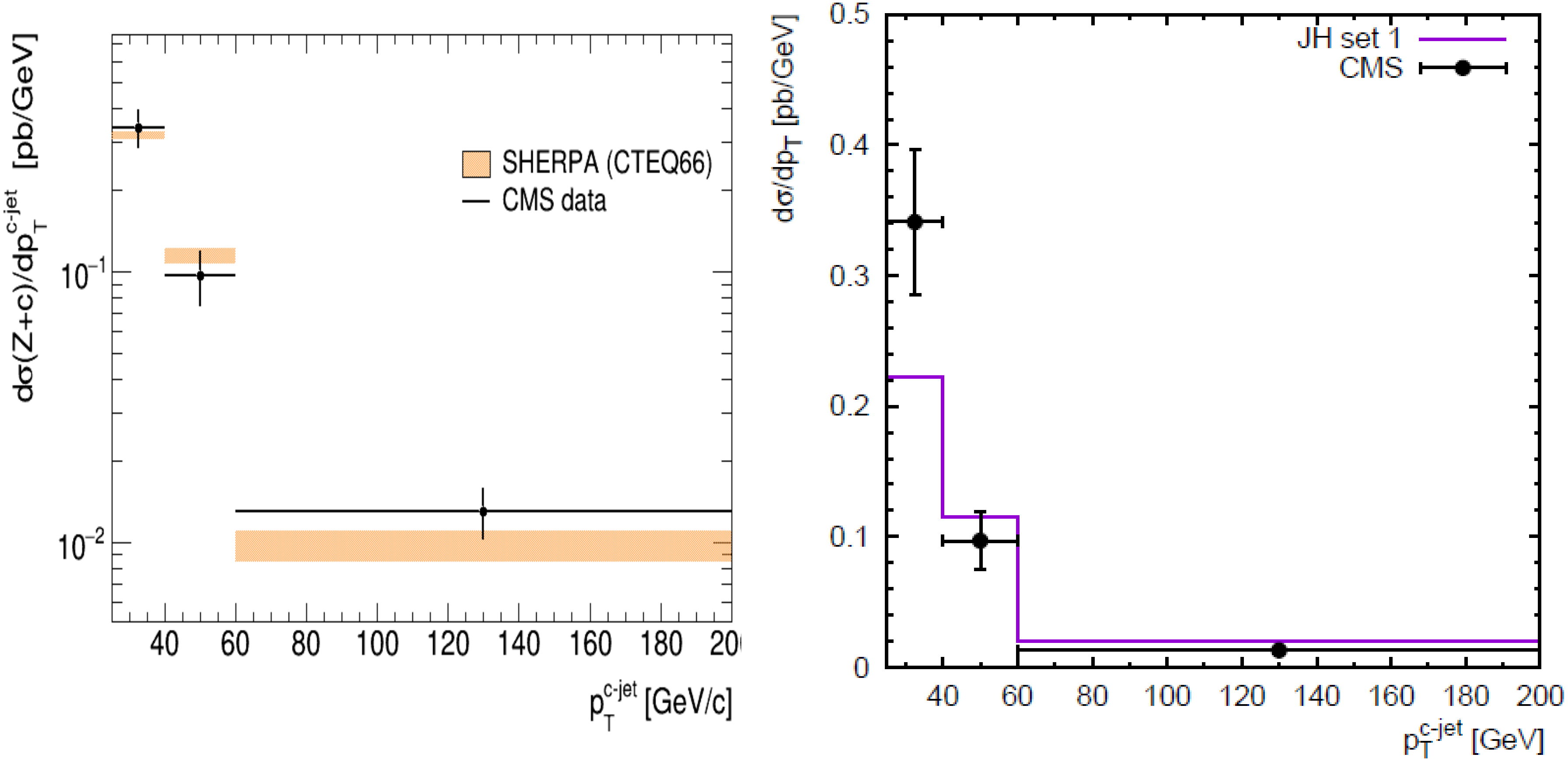
THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP



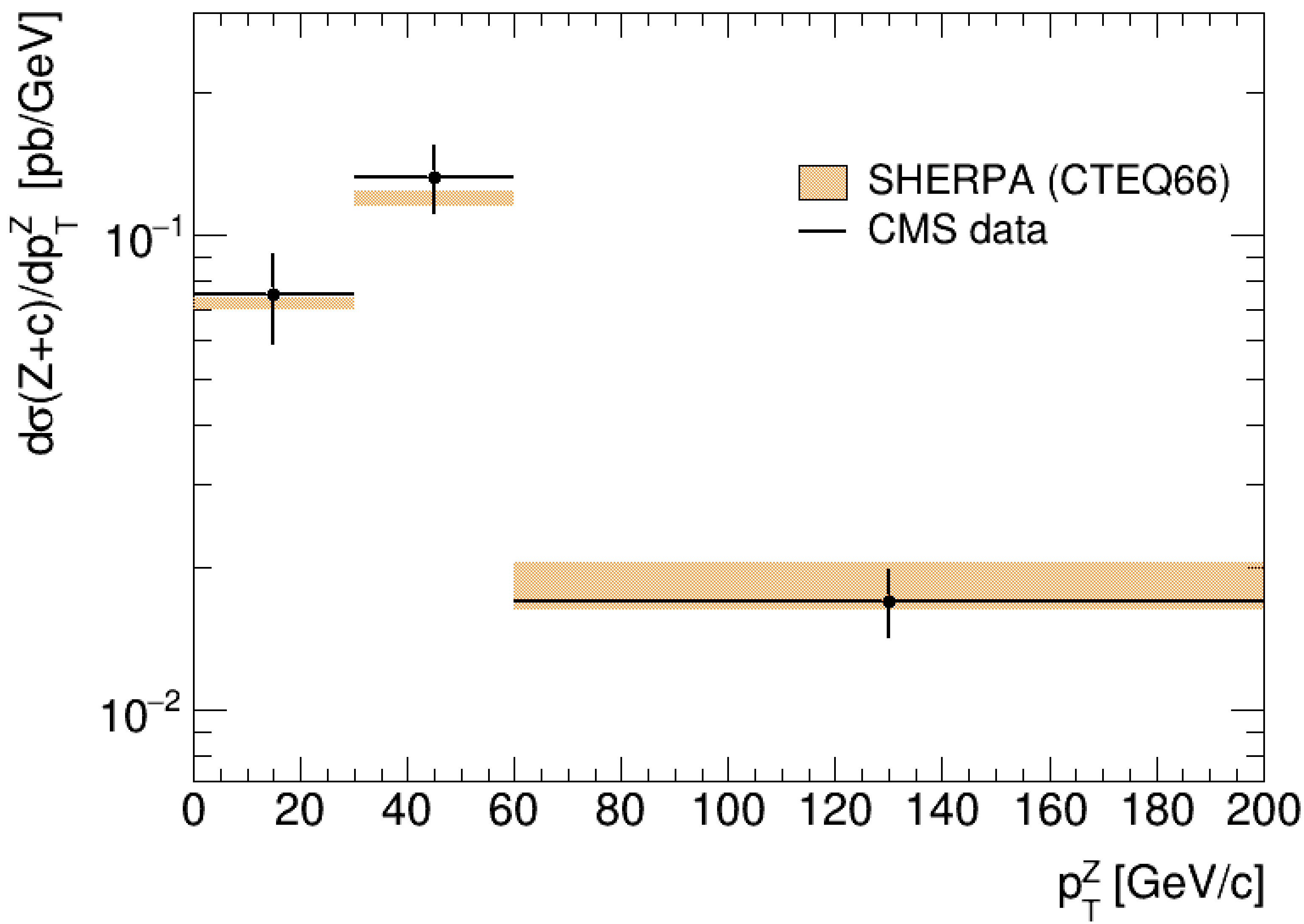
The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.

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

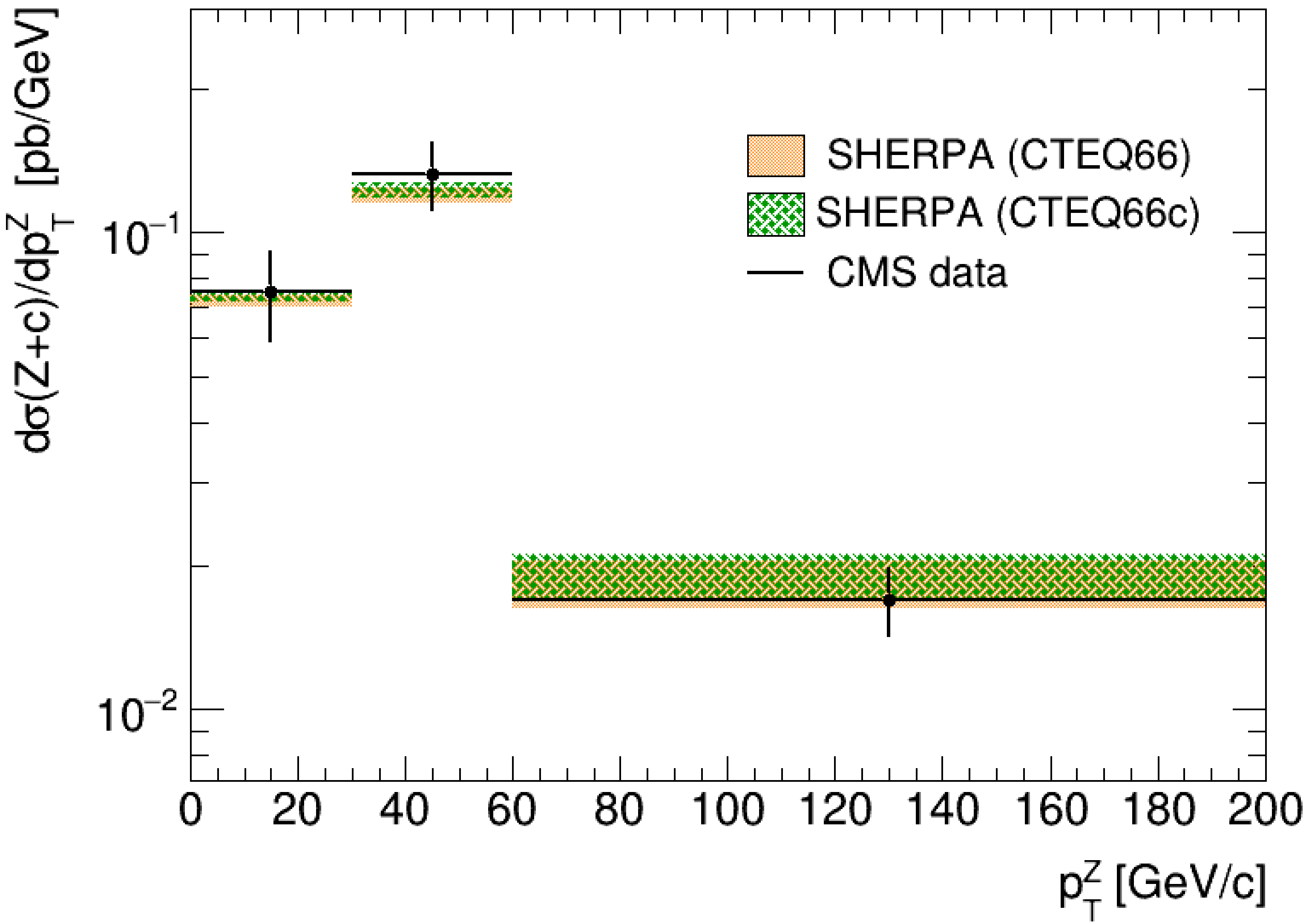


Left: **SHERPA results**

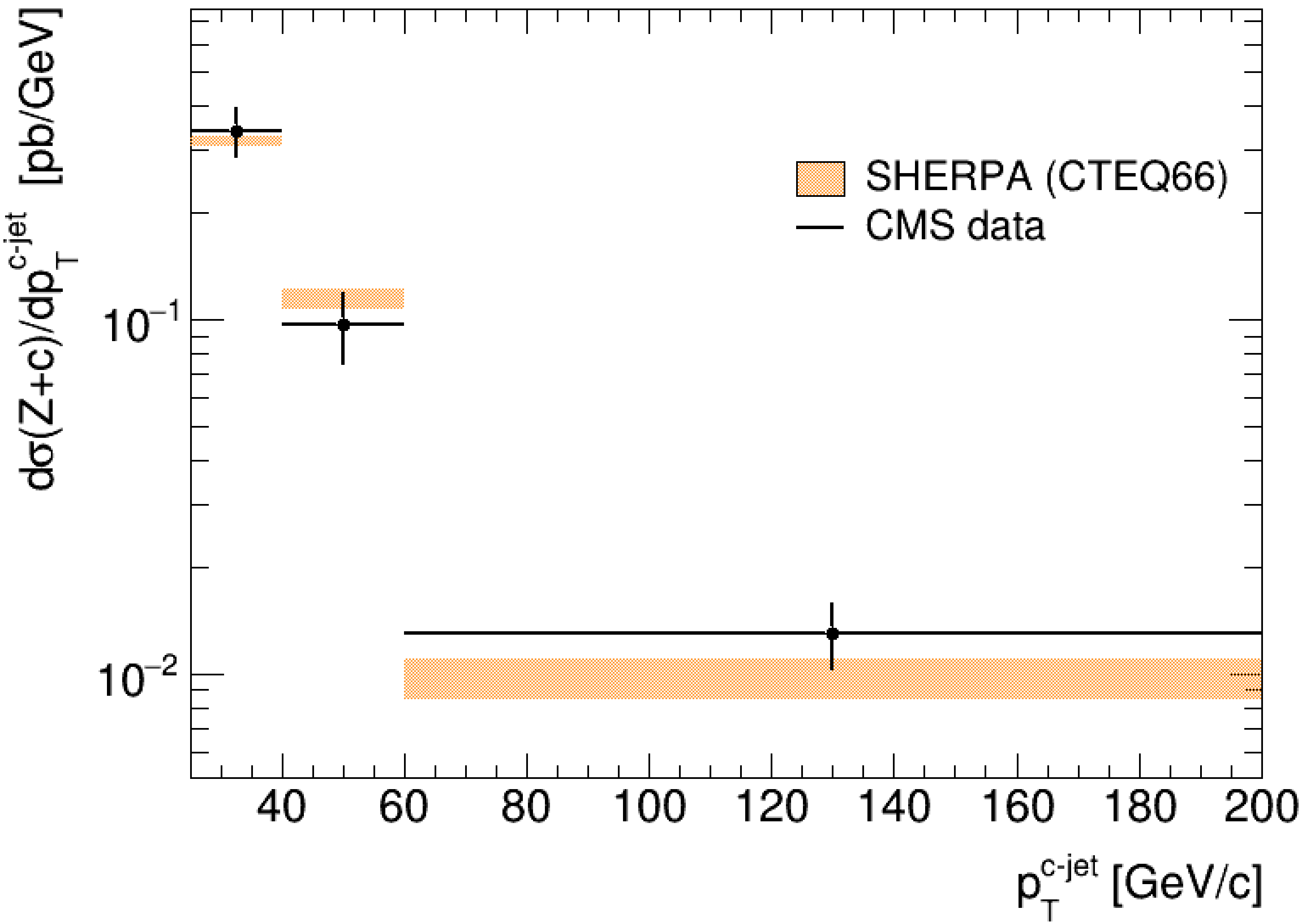
Right: **QCD calculation done by A.Lipatov, M.A.Malyshev, S.P. Malyshev**



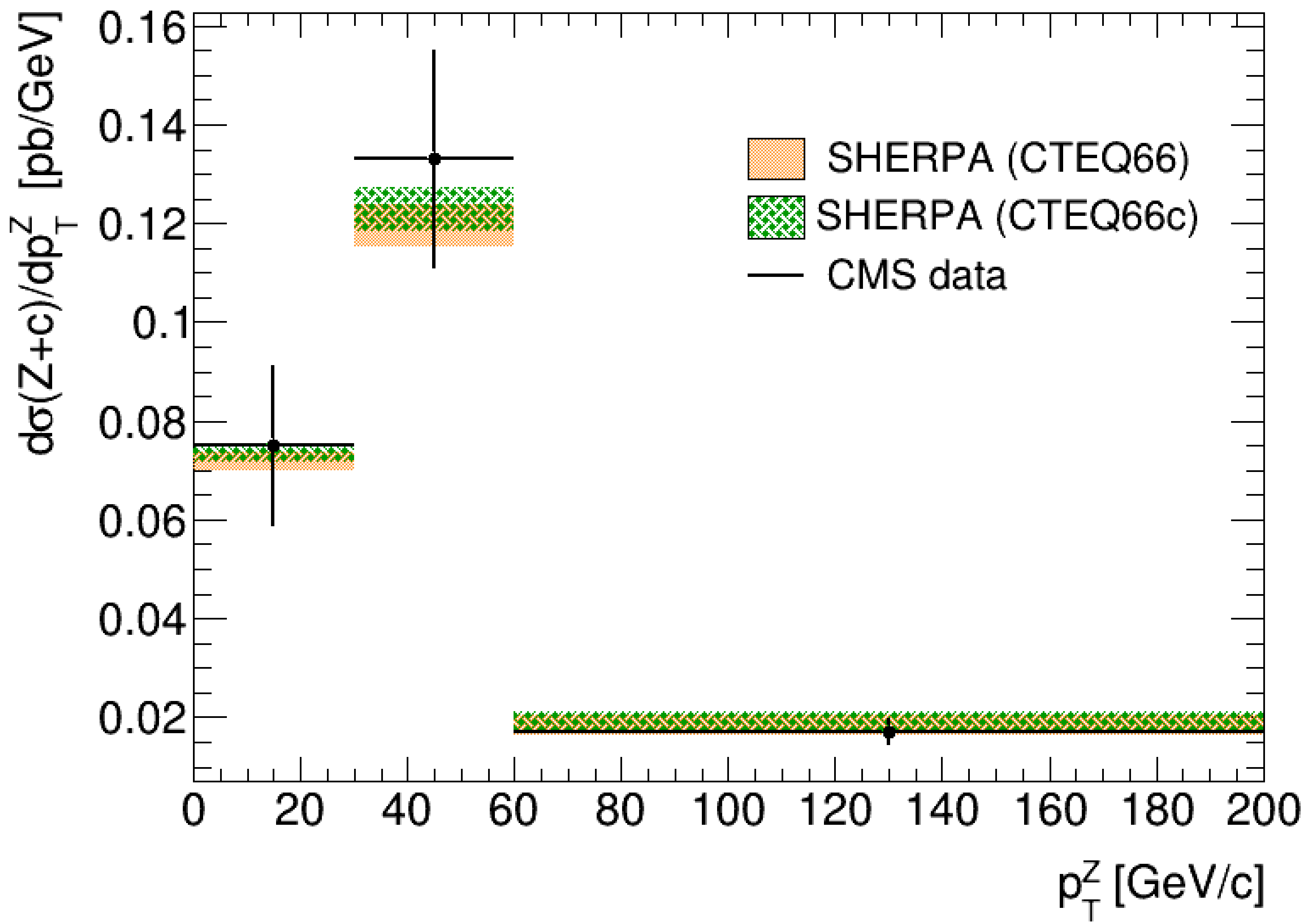
SHERPA (CTEQ66)
CMS data
dσ(Z+c)/dp$_T^Z$ [pb/GeV]
10^{-1}
10^{-2}
0
20
40
60
80
100
120
140
160
180
200
p$_T^Z$ [GeV/c]



SHERPA (CTEQ66)
SHERPA (CTEQ66c)
CMS data
dσ(Z+c)/dp$_T^Z$ [pb/GeV]
10^{-1}
10^{-2}
0
20
40
60
80
100
120
140
160
180
200
p$_T^Z$ [GeV/c]



SHERPA (CTEQ66)
CMS data
$d\sigma(Z+c)/dp_T^{c\text{-jet}}$ [pb/GeV]
10^{-1}
10^{-2}
40
60
80
100
120
140
160
180
200
$p_T^{c\text{-jet}}$ [GeV/c]



dσ(Z+c)/dp_T^Z [pb/GeV]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
20
40
60
80
100
120
140
160
180
200
p_T^Z [GeV/c]
SHERPA (CTEQ66)
SHERPA (CTEQ66c)
CMS data

INTRINSIC HEAVY QUARK STATES

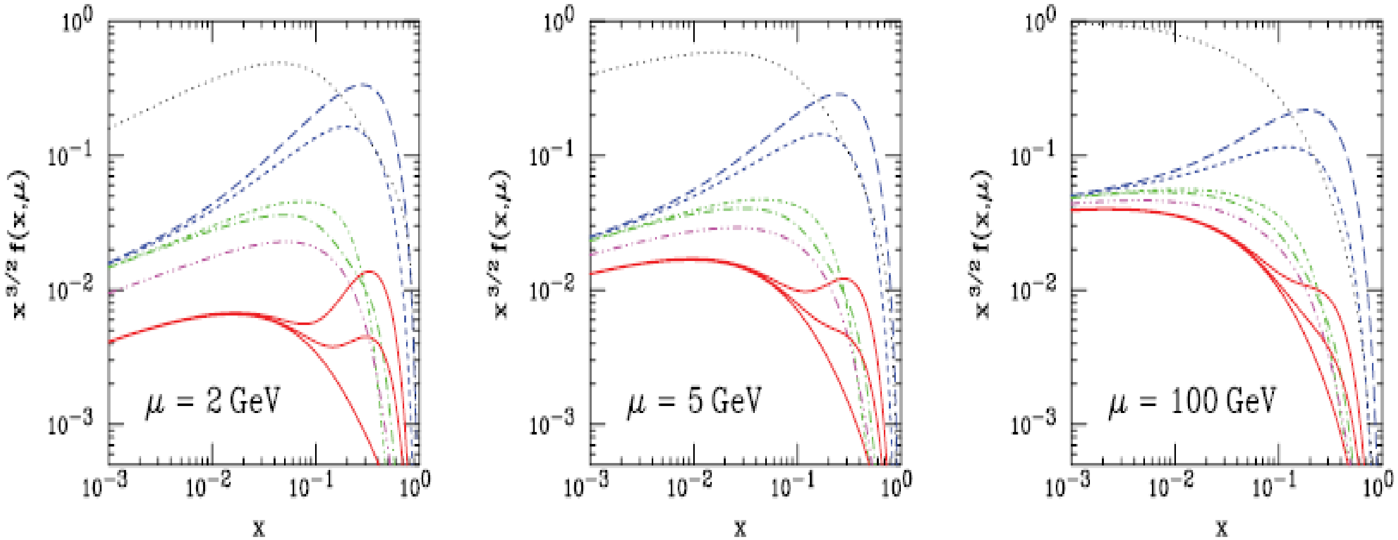
Two types of parton contributions

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.

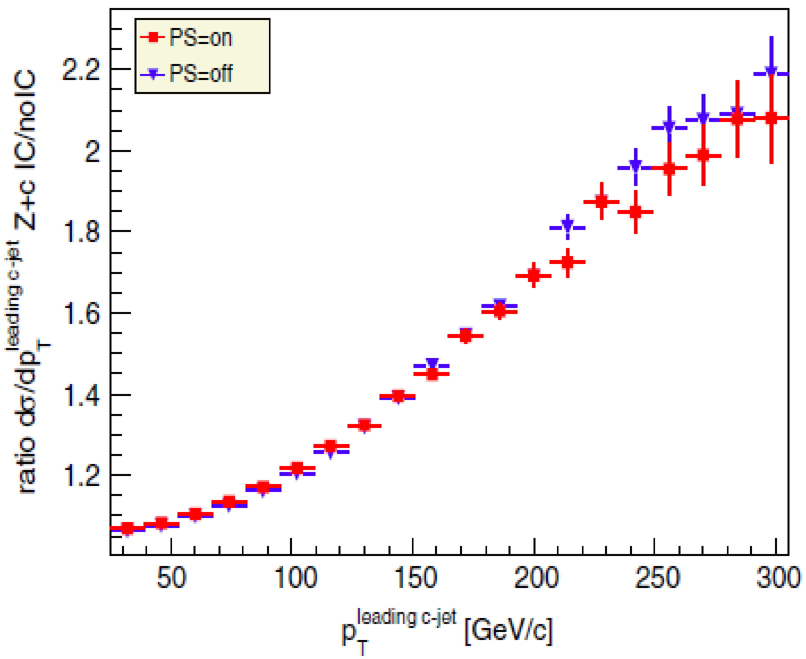
$$P(x_1,\ldots,x_5)=N_5\,\delta\left(1-\sum_{i=1}^{5}x_i\right)\left[M_p^2-\sum_{i=1}^{5}\frac{m_i^2}{x_i}\right]^{-2}$$

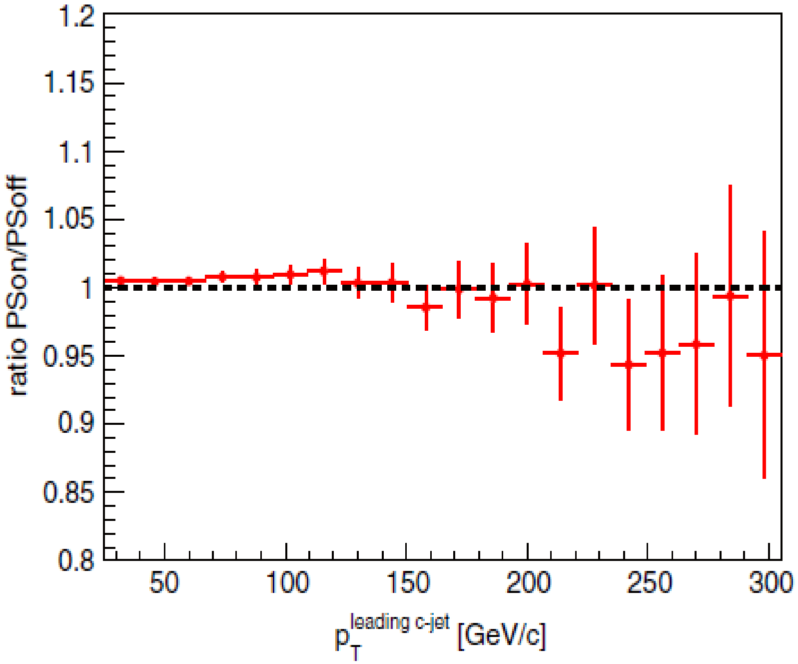
COMPARISON OF LIGHT AND HEAVY QUARK DISTRIBUTIONS IN PROTON



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 $\bar{u},\bar{d},\bar{s}$ at x>0.2

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

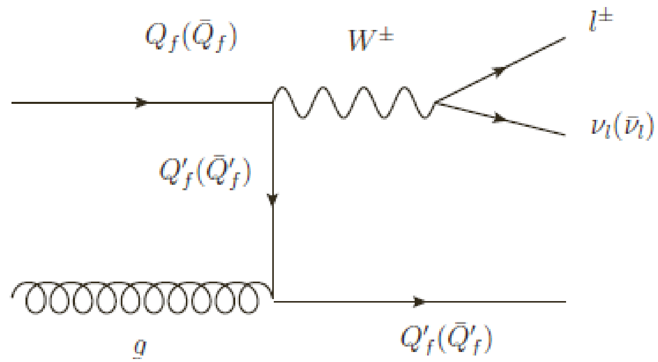




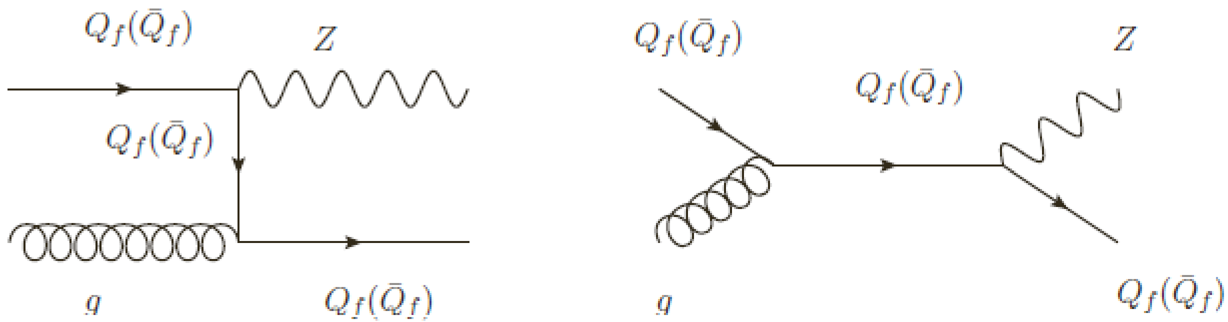
Left: p_T – spectra with parton shower (red points) and without it (blue points) using the PDF of type CTEQ66c (*3.5%* of *IC*)

Right: ratio of red points to blue points

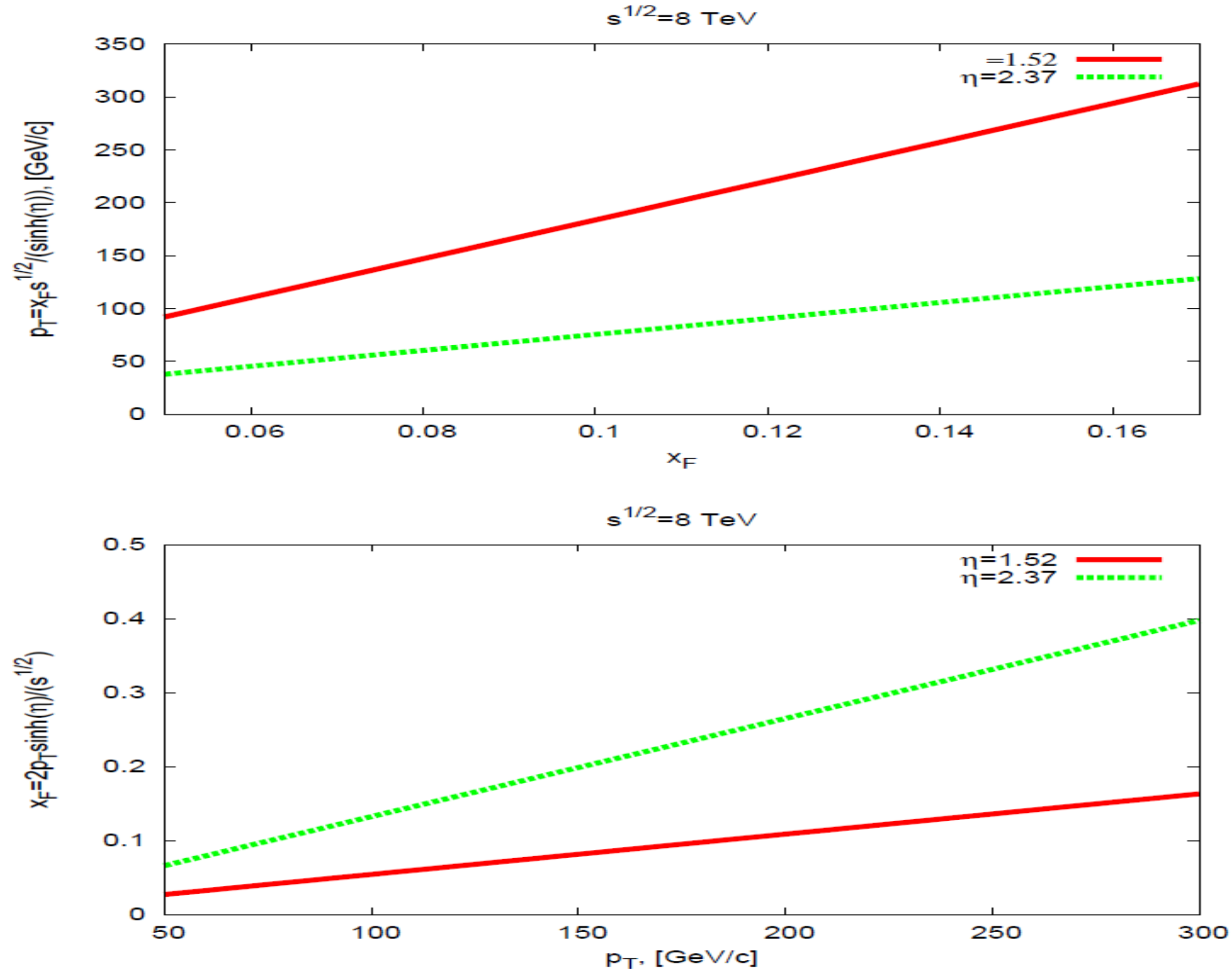
pp →W/Z+heavy flavour jets



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



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



s^1/2=8 TeV
=1.52
η=2.37
p_T=x_F s^1/2/(sinh(η)), [GeV/c]
x_F
0 50 100 150 200 250 300 350
0.06 0.08 0.1 0.12 0.14 0.16
s^1/2=8 TeV
η=1.52
η=2.37
x_F=2p_T sinh(η)/(s^1/2)
p_T, [GeV/c]
0 0.1 0.2 0.3 0.4 0.5
50 100 150 200 250 300

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

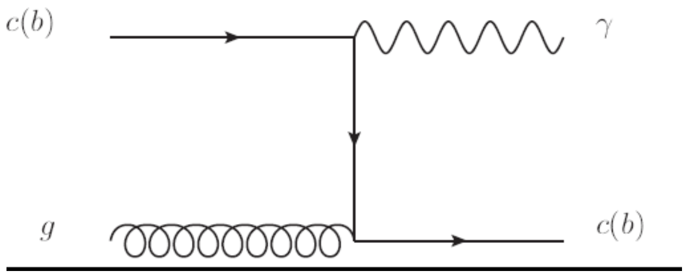


Fig.a. Feynman diagram for the process $c(b)+g\rightarrow\gamma+c(b)$

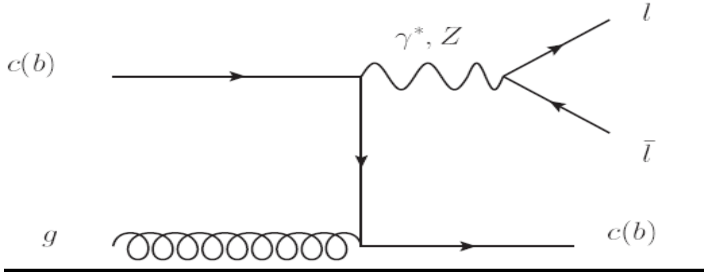


Fig.b. Feynman graph for the process $c(b)+g\rightarrow\gamma/Z^0+c(b)$

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

$$x_{c(b)}=\frac{m^2_{l^+l^-}}{x_g s}+x^f_{c(b)}$$

To observe the IC

for Fig.a

$$x_c\geq x_F>0.1$$

for Fig.b

$$x_{c(b)}=\frac{m^2_{l^+l^-}}{x_g s}+x^f_{c(b)}>0.1$$

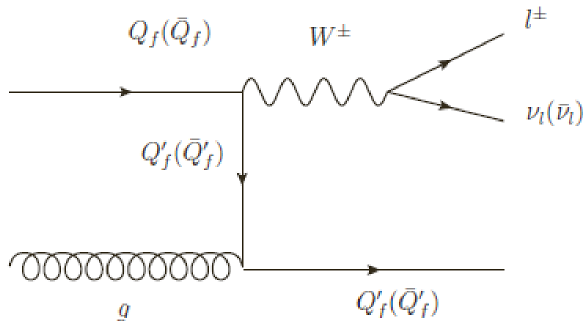


Figure 2: The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^{\pm}Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.

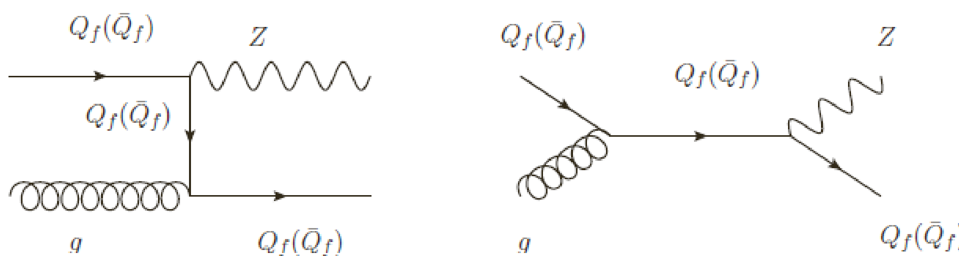
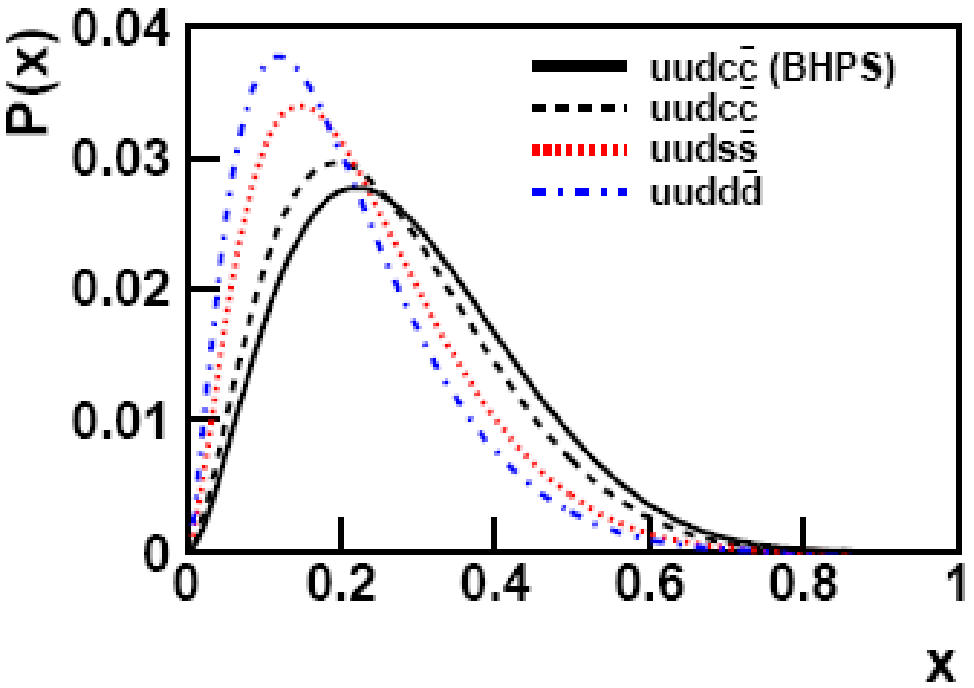


Figure 3: Feynman diagram for the process $Q_f(\bar{Q}_f)g \to ZQ_f(\bar{Q}_f)$



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.