Test of proton intrinsic charm in $\gamma(Z)$+$c(b)$ production at LHC

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and

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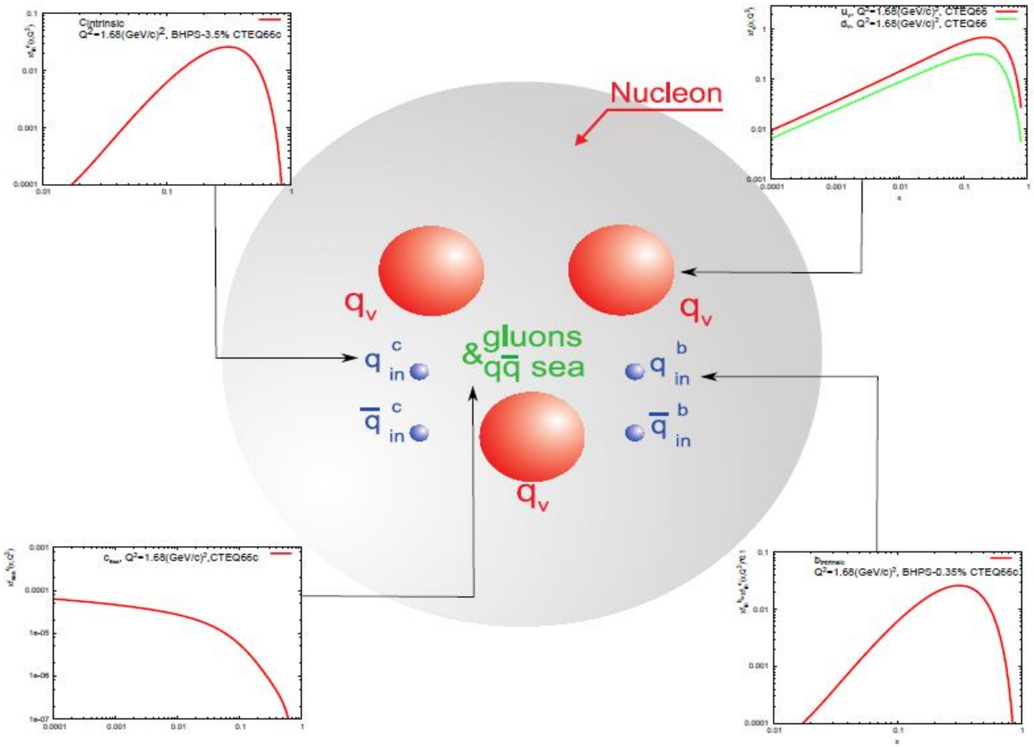
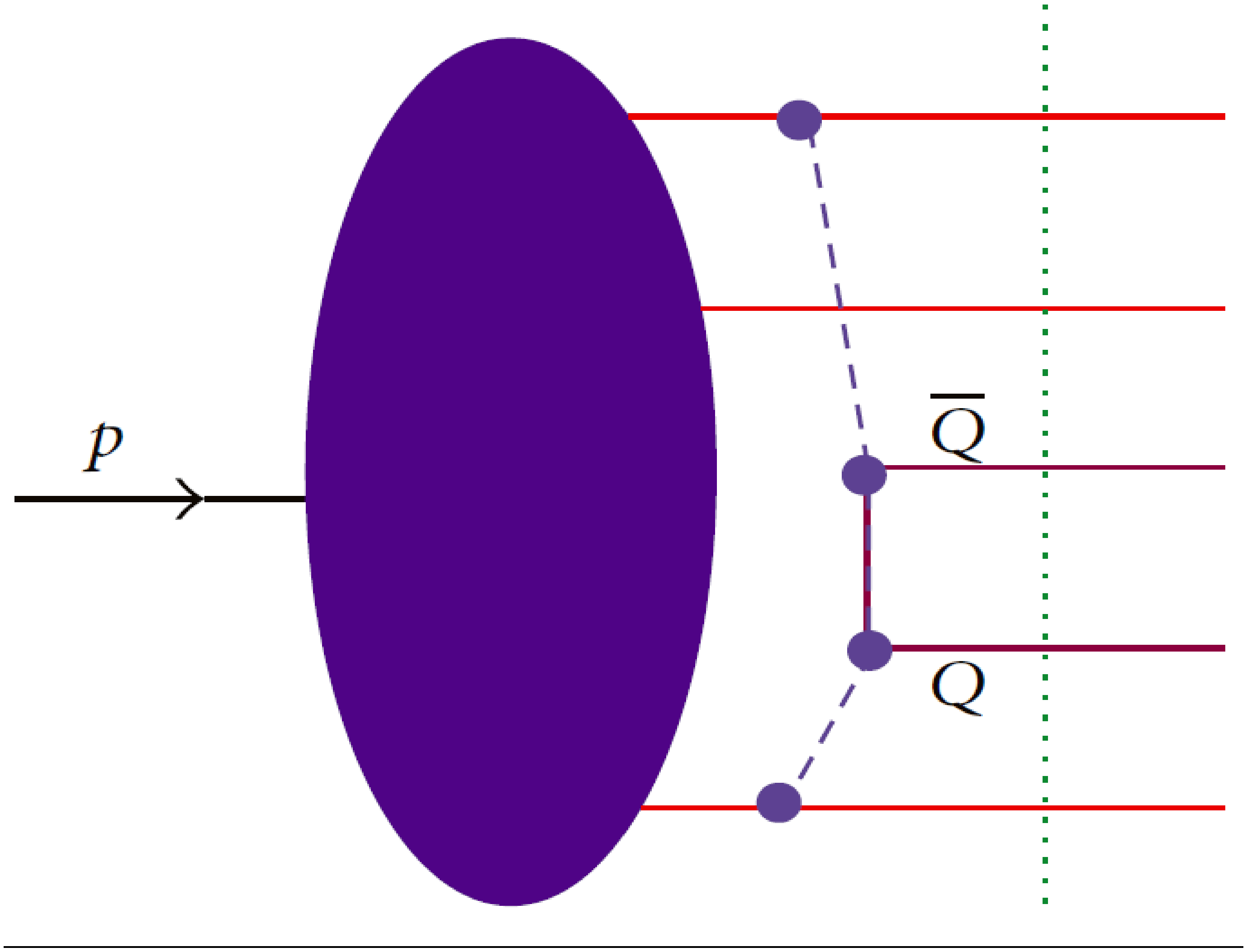
OUTLINE

1. **Intrinsic heavy flavours in proton**
2. **Main goal of our study**
3. **Search for intrinsic charm (*IC*) in p_T -spectra the $\gamma/Z/W+c(b)$ production in p-p collision**
4. **Ratio $\sigma(\gamma/Z/W+c)/\sigma(\gamma/Z/W+c)$ as a *significant* signal of the *IC contribution in proton***
5. **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

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

where

$$s=\sum^{5}\frac{p_{Tj}^2+m_j^2}{x_j}$$

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

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

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

and

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

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 $c\to 0$ leads to the BHPS result |

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

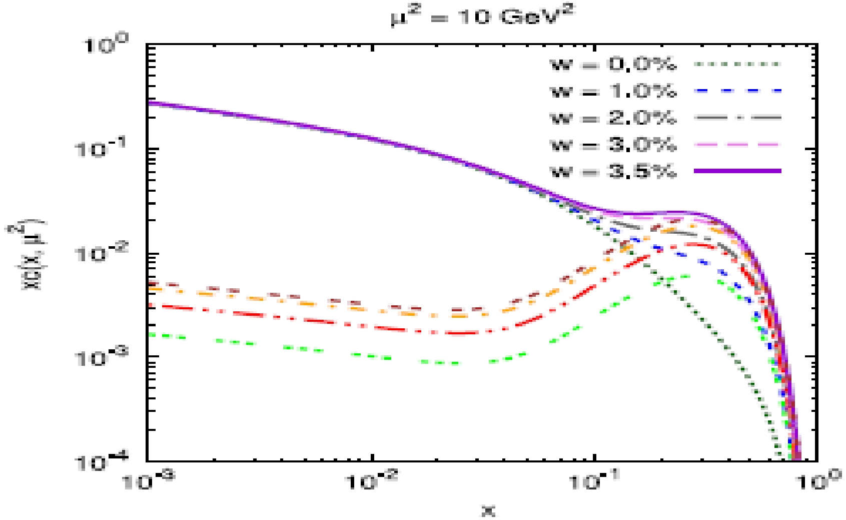
$$F^2=\exp\left(\frac{-(s-m_N^2)}{\Lambda^2}\right)$$

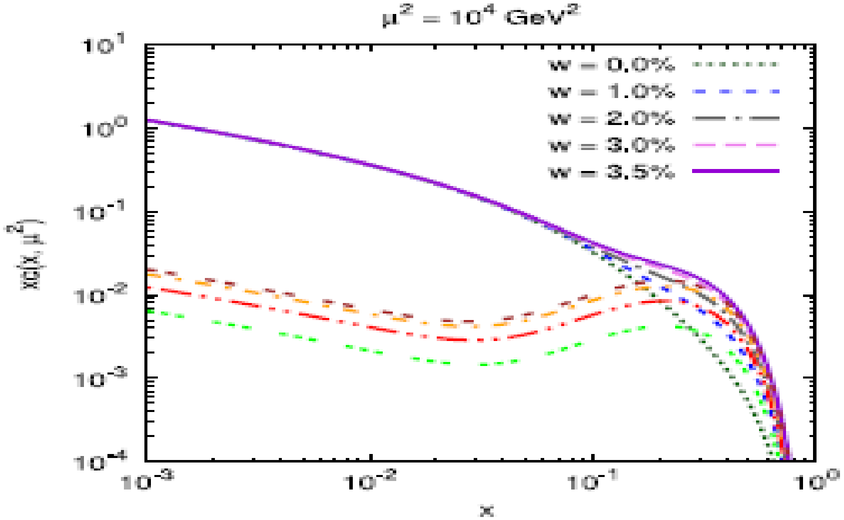
or the *power-low suppression* factor:

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

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

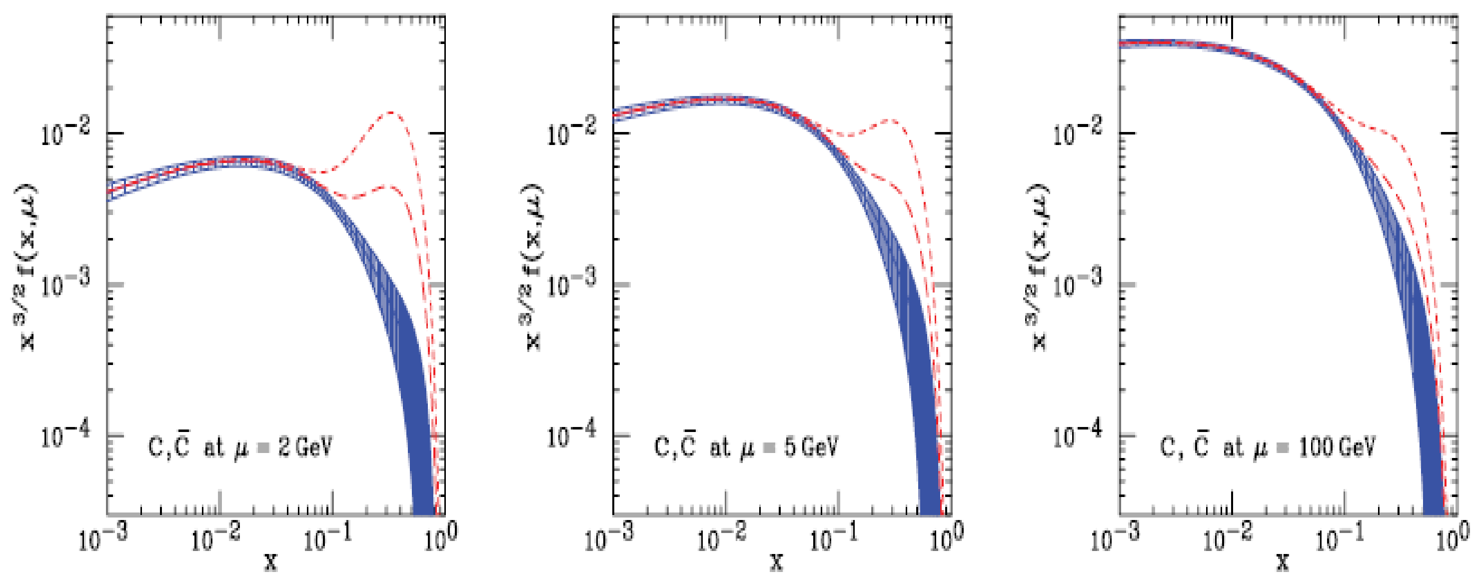
$$xc(x,\mu_0^2) = xc_{ex}(x,\mu_0^2) + xc_{in}(x,\mu_0^2).$$





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

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

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*

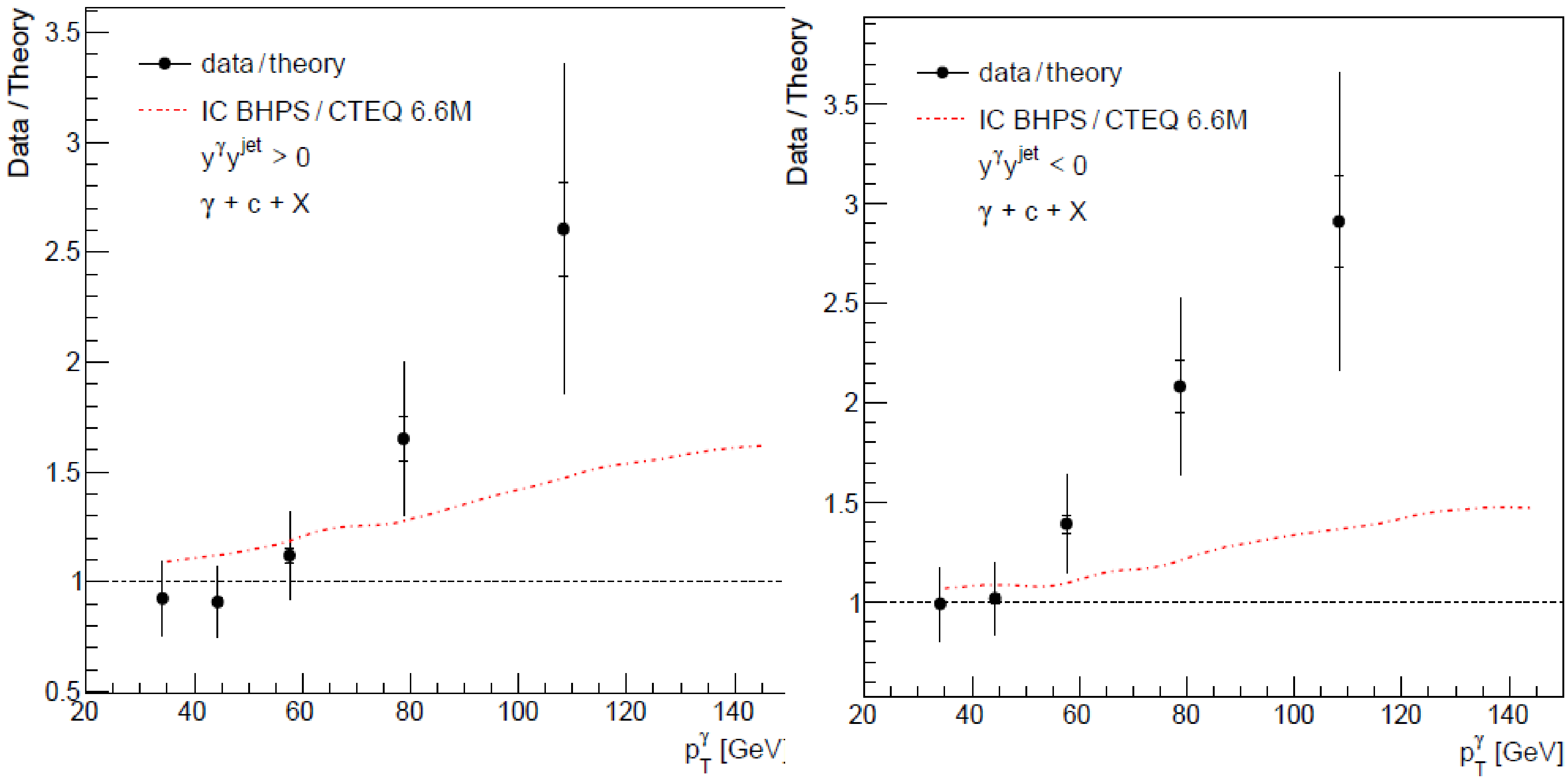
PP->γ + c +X : V.A.Bednyakov, M.A.Demichev,G.L.,T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (1914)

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

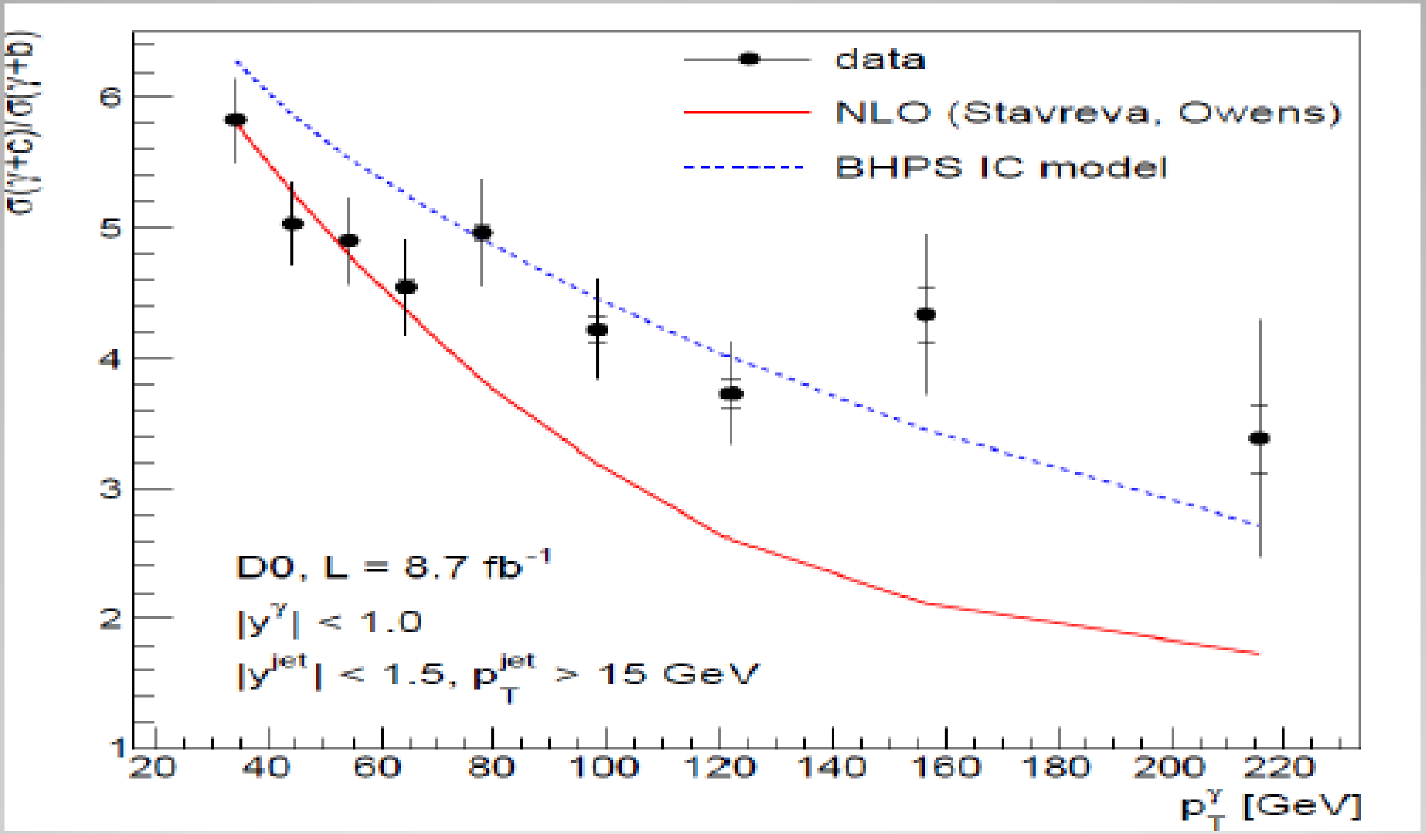
PP->γ/Z+ c(b)+X : A, Lipatov, GL, Yu. Stepanenko V.A.Bednyakov, Phys.Rev.D94, 05301 (2016)

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** $s^{1/2} = 1.96\, TeV$

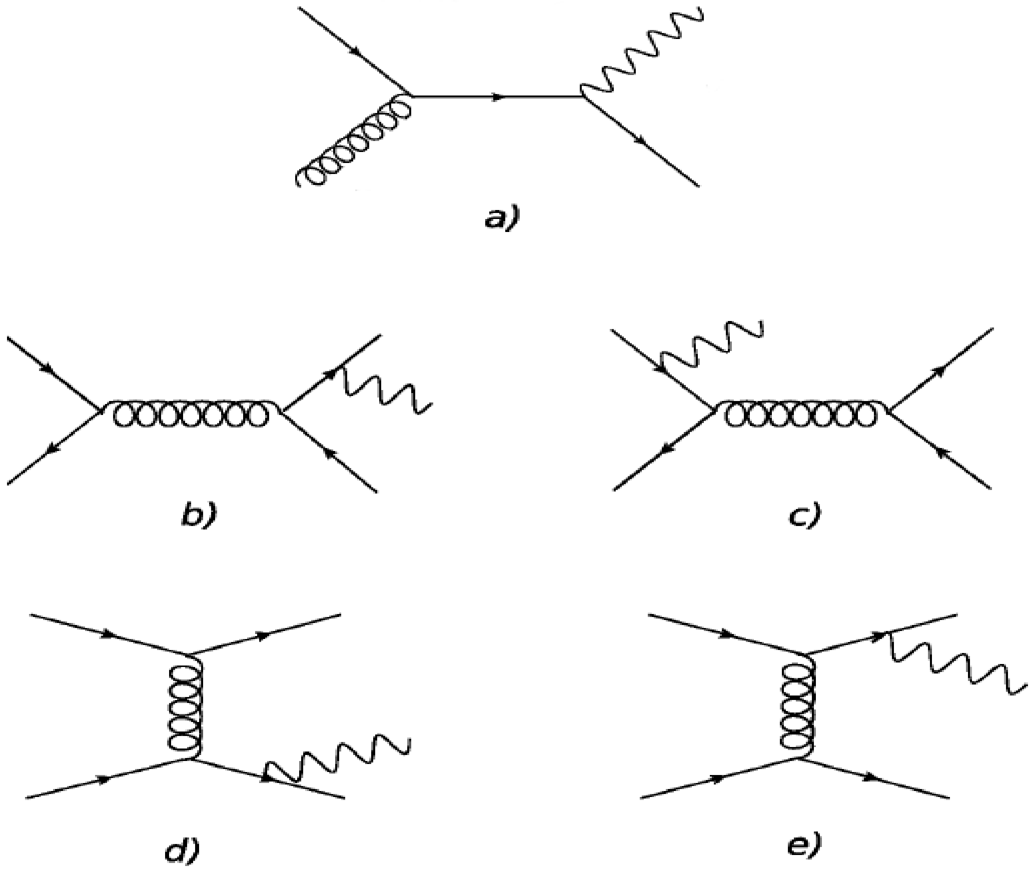


R=σ(γ + c)/σ(γ + b) for p bar{p} -> γ + Q at $s^{1/2}$ = 1.98 TeV



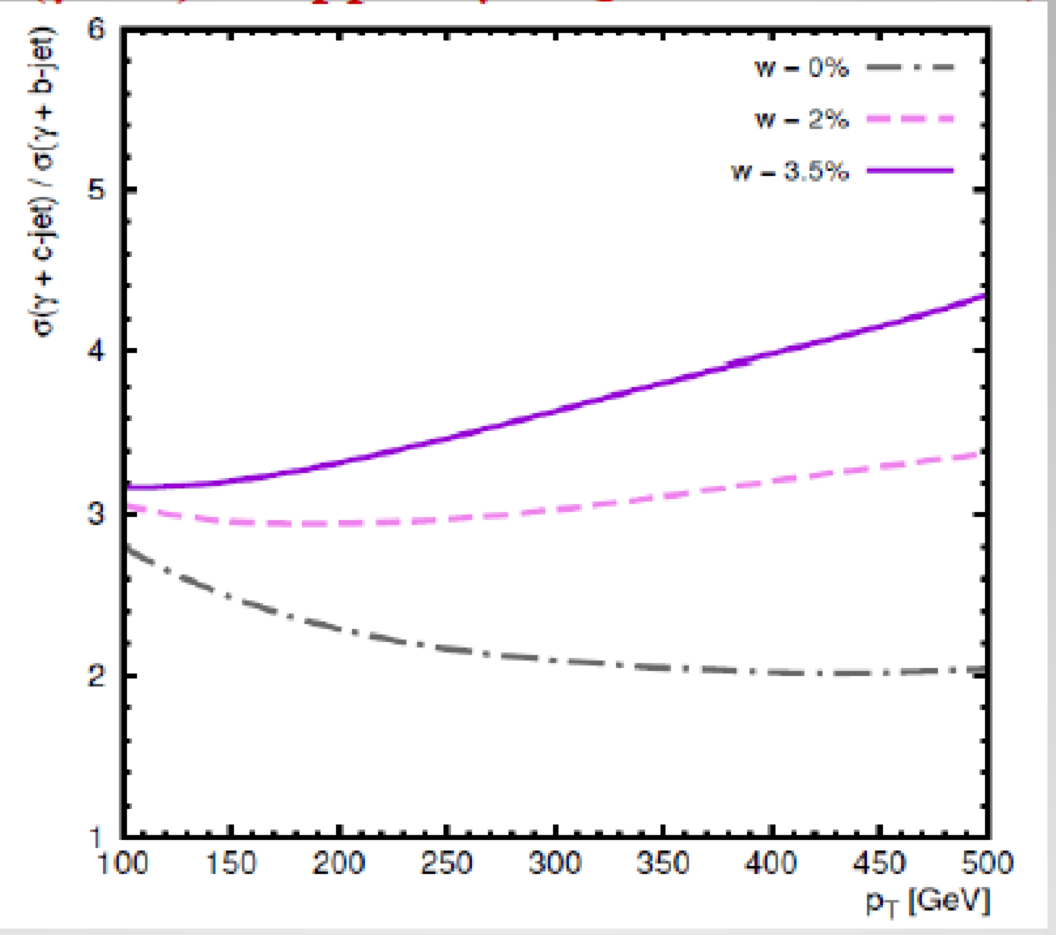
p_T –distribution of R, points are the D0 data; red solid line is NLO without *IC* ; short dash line is BHPS with *IC* probability about 1 %

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



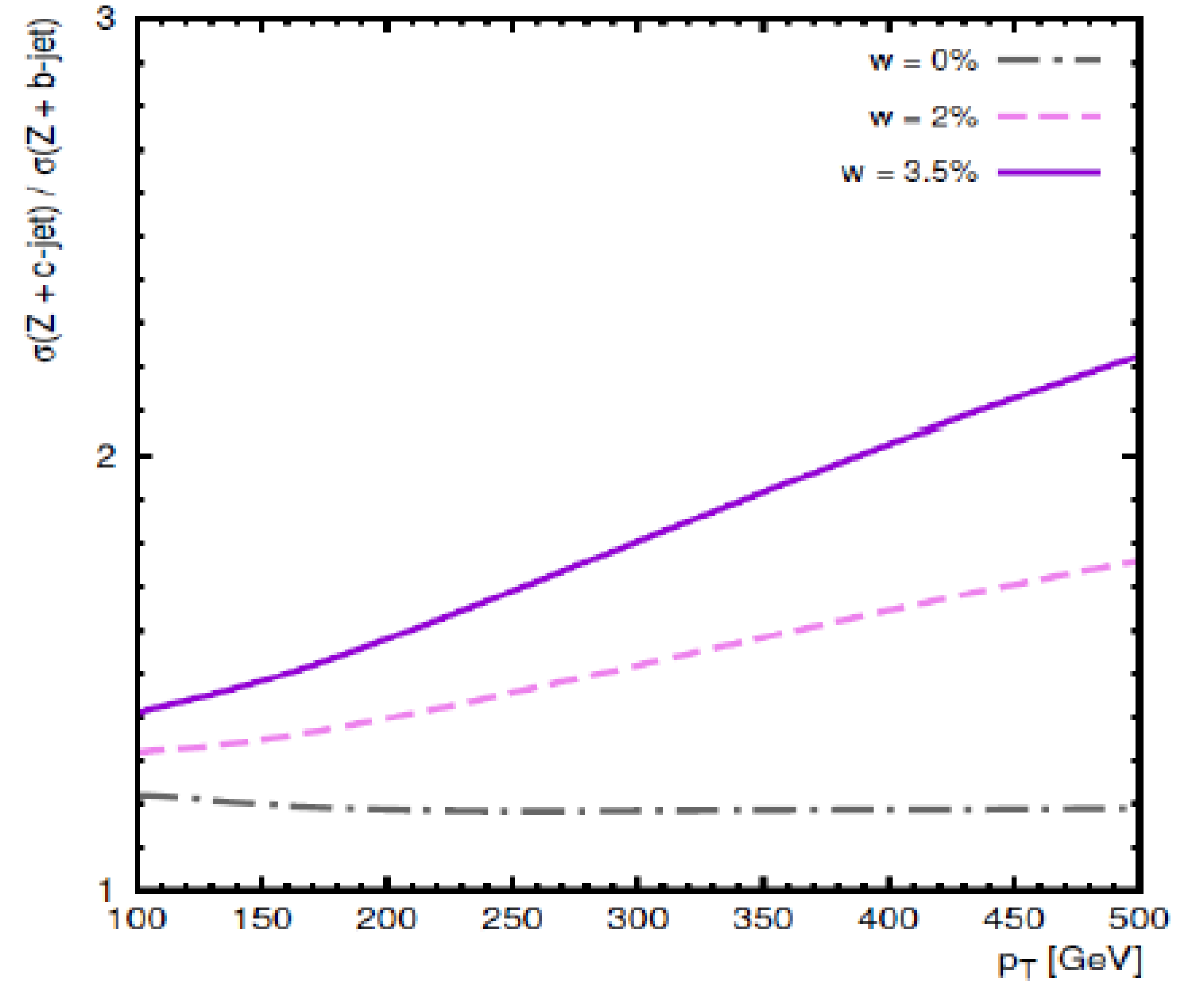
Feynman QCD diagrams: a): Q +g->γ +Q;
b-c): Q + barQ->Q + barQ + γ; d-e): Q(q)+q(Q)->Q(q)+q(Q)+γ

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



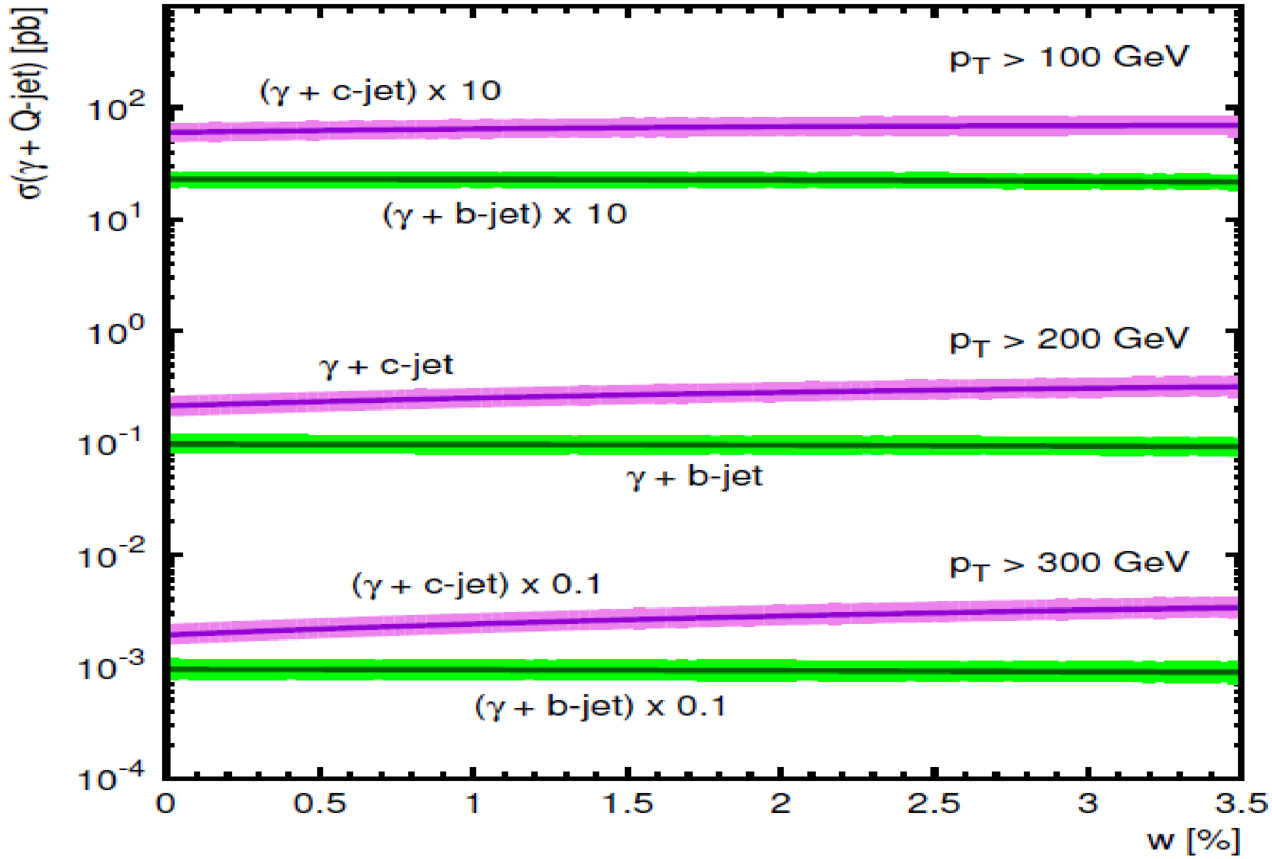
p_T –distribution of R at different IC probability w

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



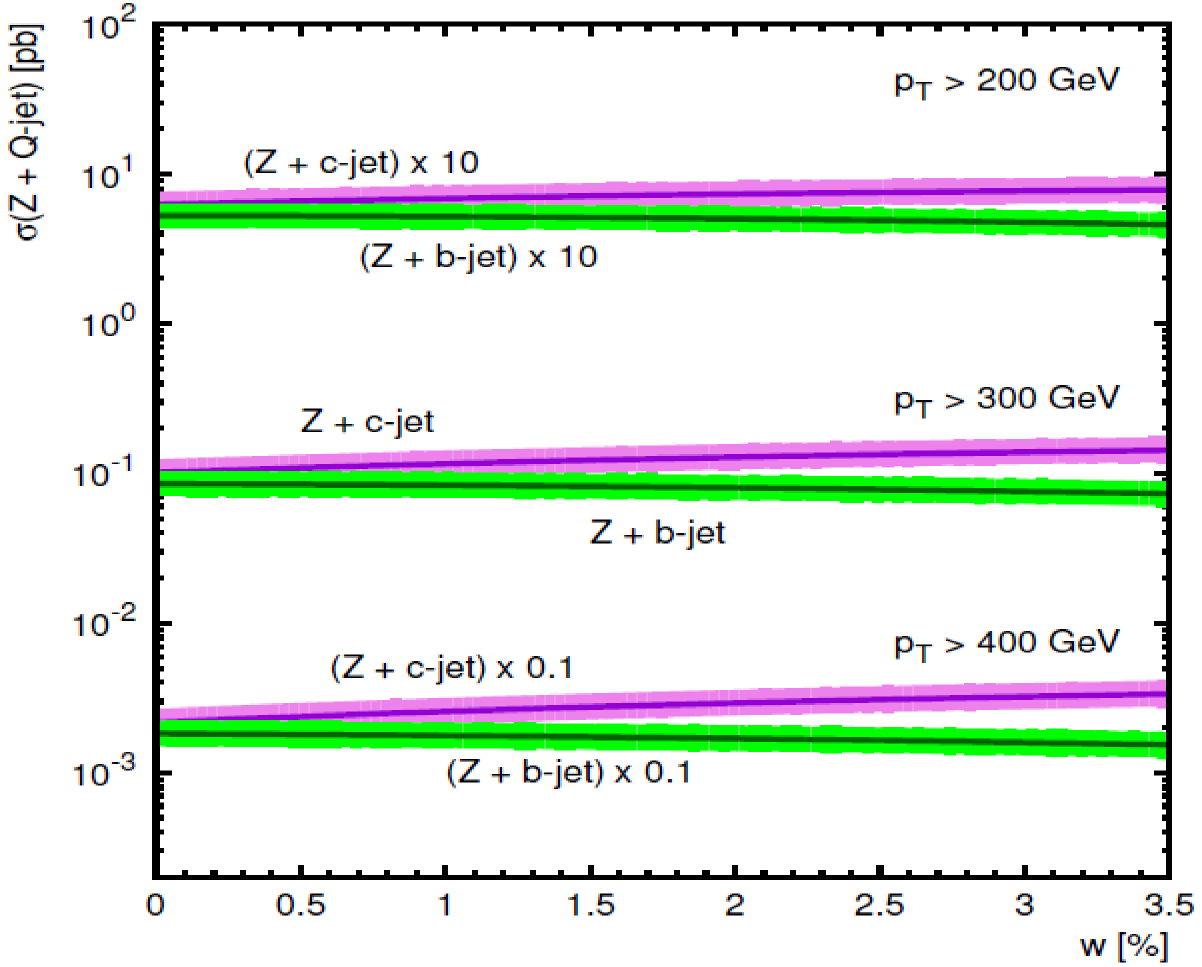
p_T –distribution of R at different IC probability w

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

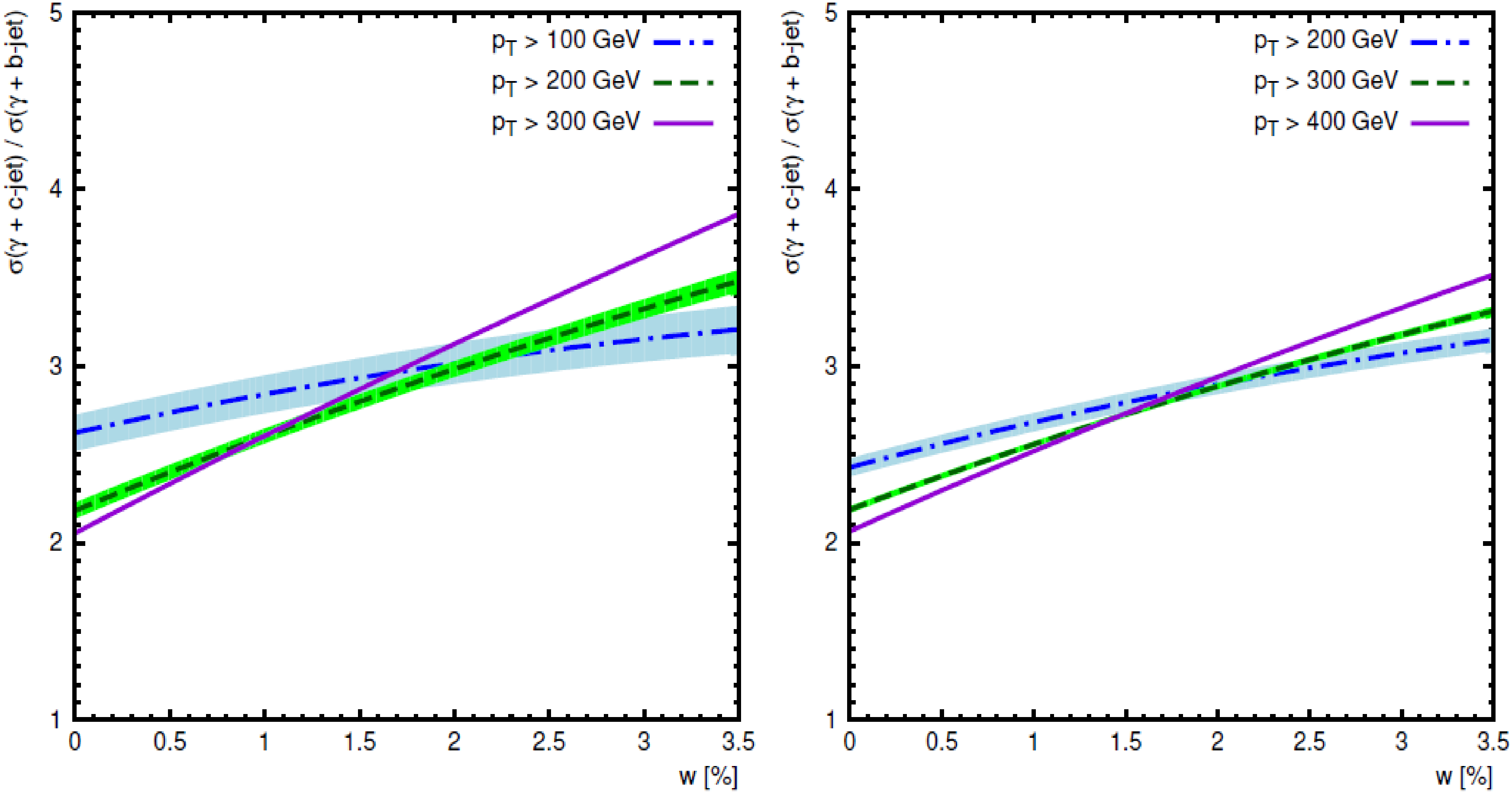


p_T^γ – spectrum integrated over p_T^γ , i.e., $\sigma(\gamma+c)$ and $\sigma(\gamma+b)$ at p_T^γ > 100 GeV or 200 GeV, or 300 GeV, vs. *IC* probability w

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

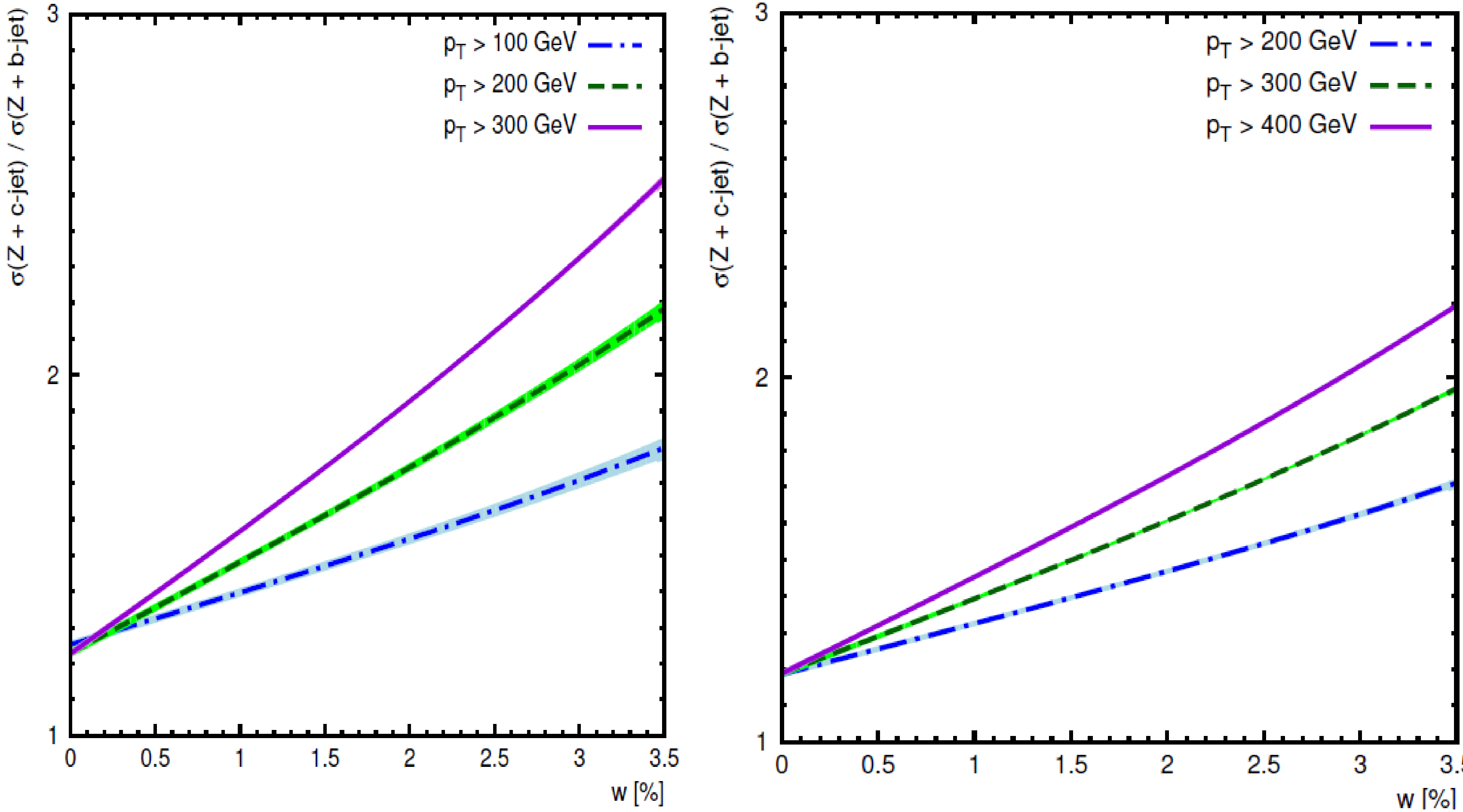


$s^{1/2} = 8$ TeV PP $\rightarrow \gamma + Q + X$, Q = c,b $s^{1/2} = 13$ TeV



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

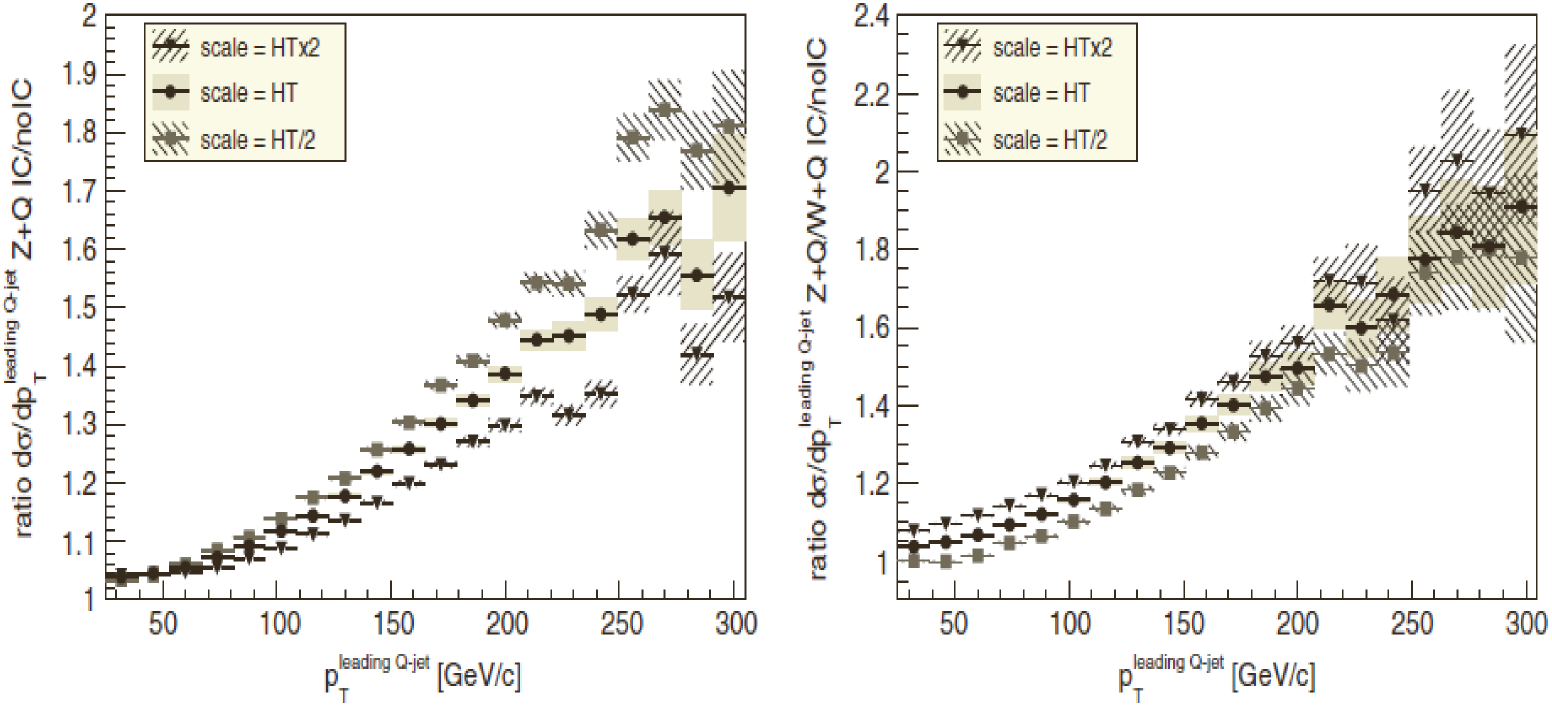
Ratio σ(Z+c)/σ(Z+b)
$S^{1/2}$ = 8 TeV (left) and $S^{1/2}$ = 13 TeV (right)



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)

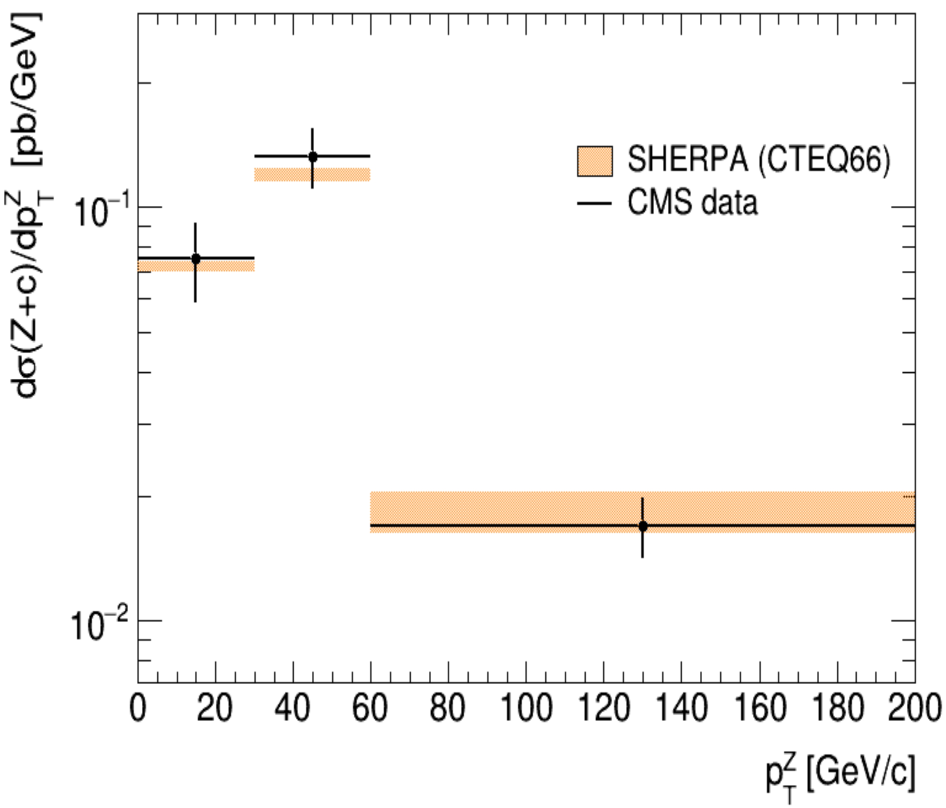
Scale uncertainty for Z+Q and Z+Q/W+Q

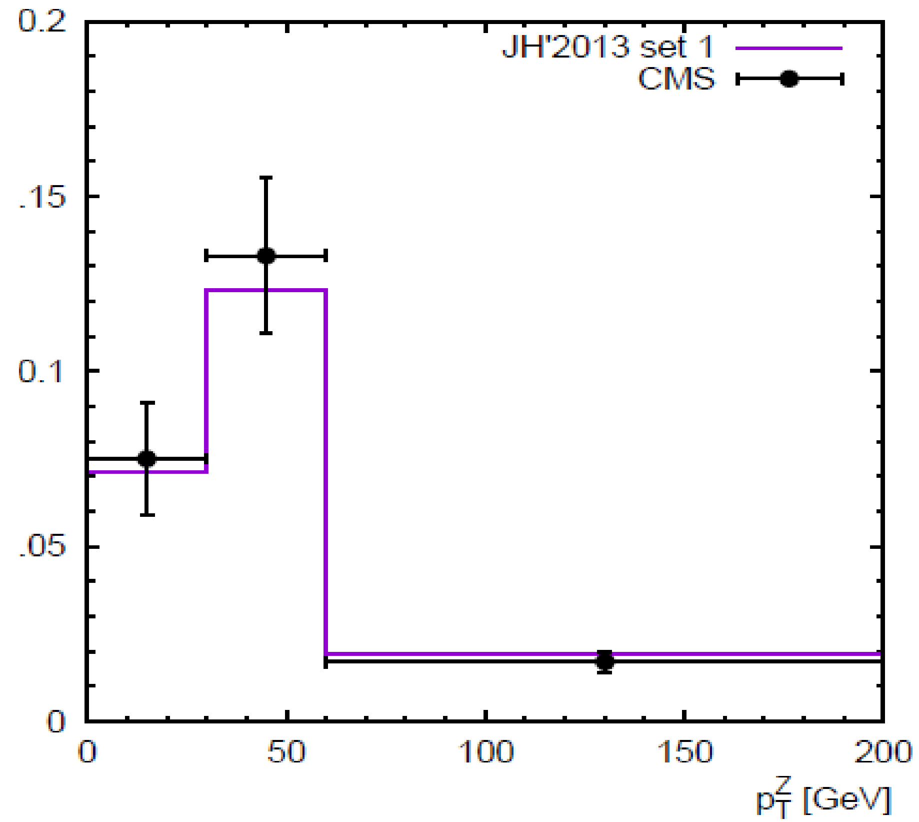


Left: Z+Q with IC and without IC at different scales
Right: Z+Q/W+Q with IC and without IC at different scales

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



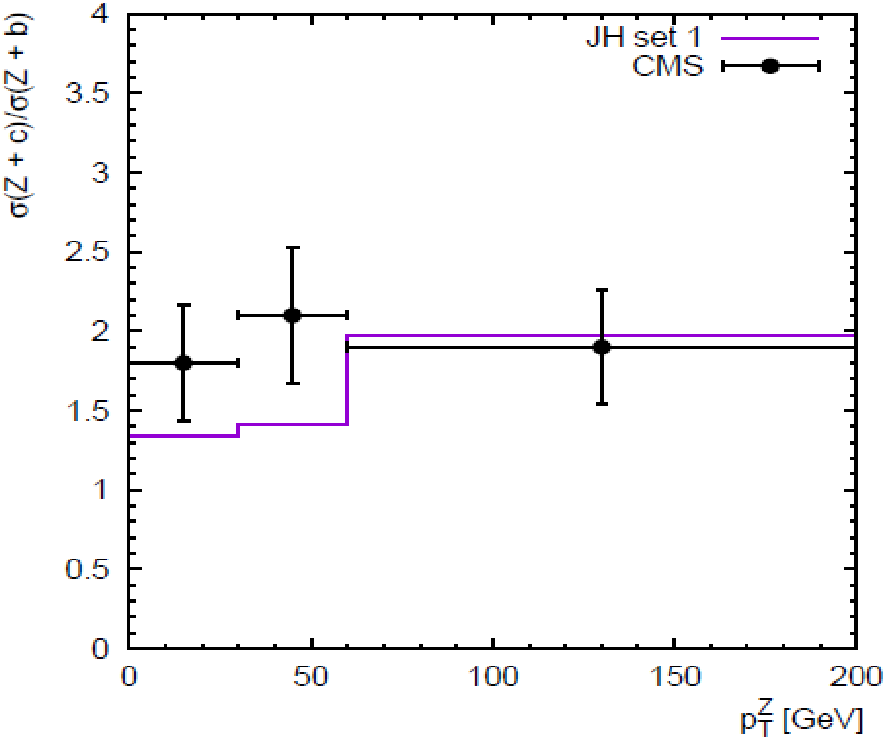


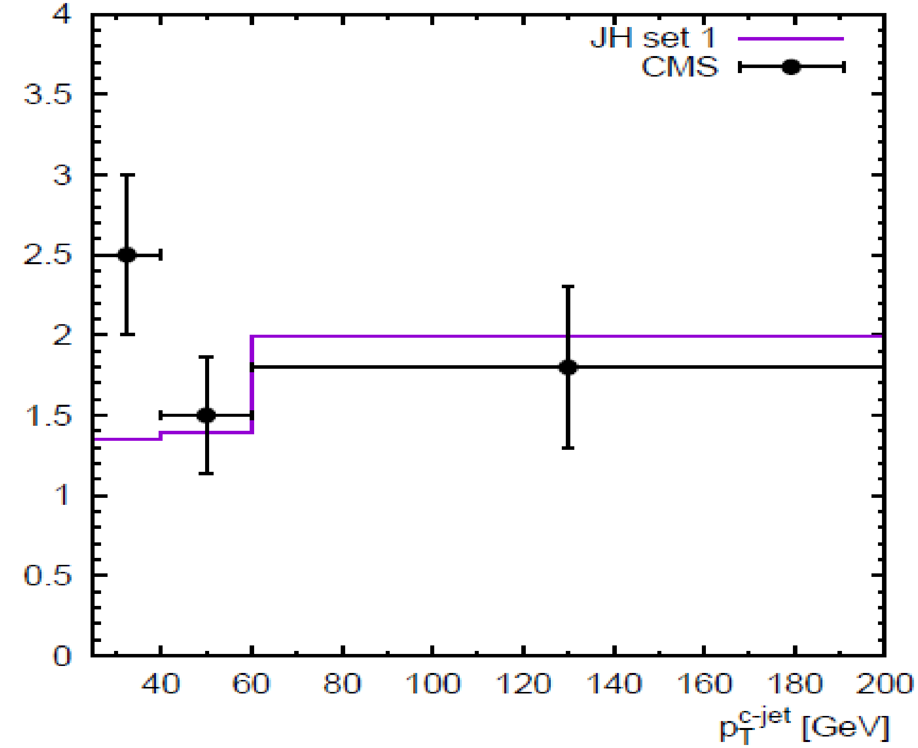
Left: SHERPA results

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.
6. The ratio between the cross sections of the *γ/Z +c* production and *γ/Z + b* one can give a significant *IC* signal.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP

PRODUCTION OF HEAVY FLAVOURS IN HARD P-P COLLISIONS

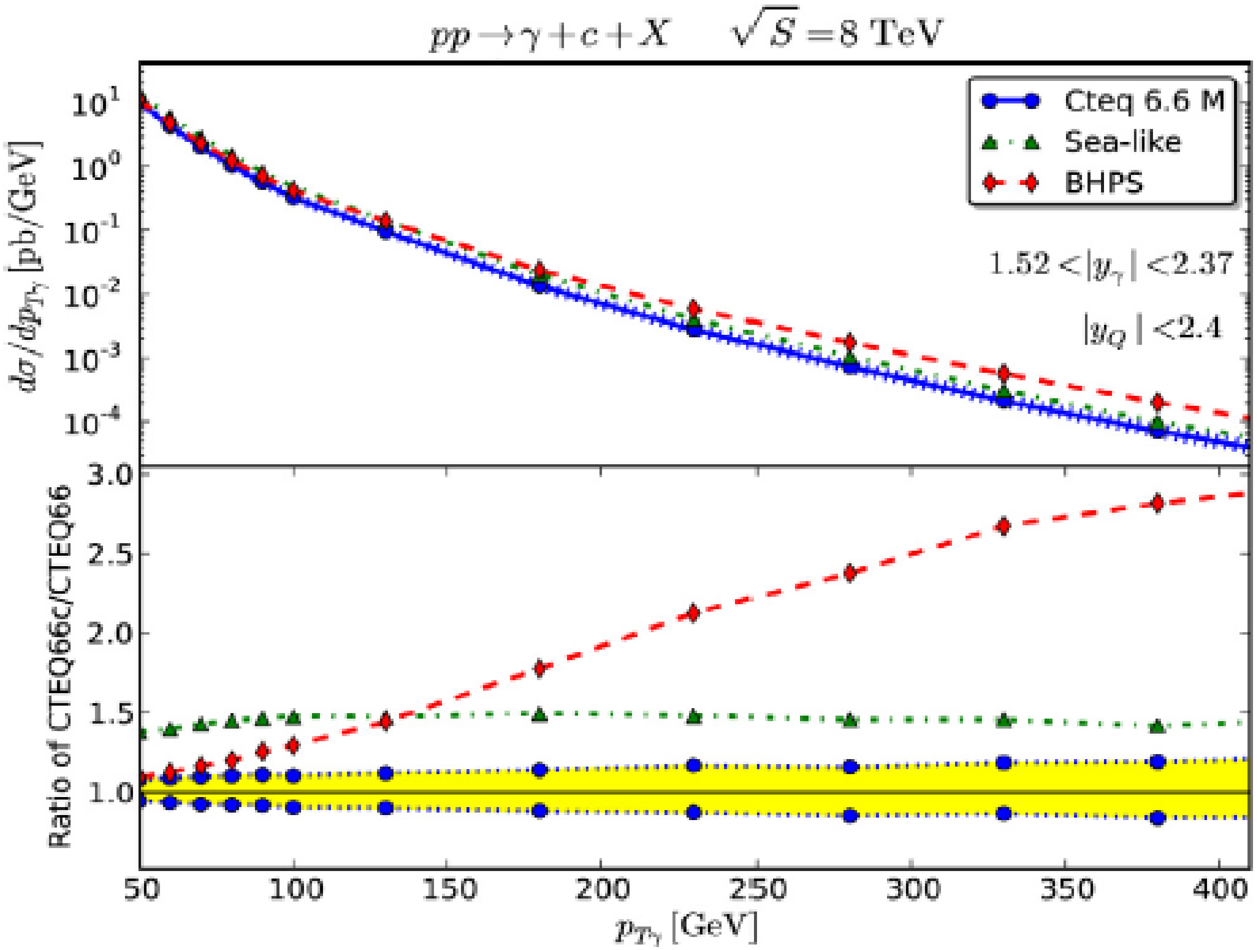
$$E\frac{d\sigma}{d^3p} = \sum_{i,j}\int d^2k_{iT}\int d^2k_{jT}\int_{x_i^{\min}}^1 dx_i\int_{x_j^{\min}}^1 dx_j f_i(x_i,k_{iT})f_j(x_j,k_{jT})\frac{d\sigma_{ij}(\hat{s},\hat{t})}{d\hat{t}}\frac{D_{i,j}^h(z_h)}{\pi z_h}$$

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

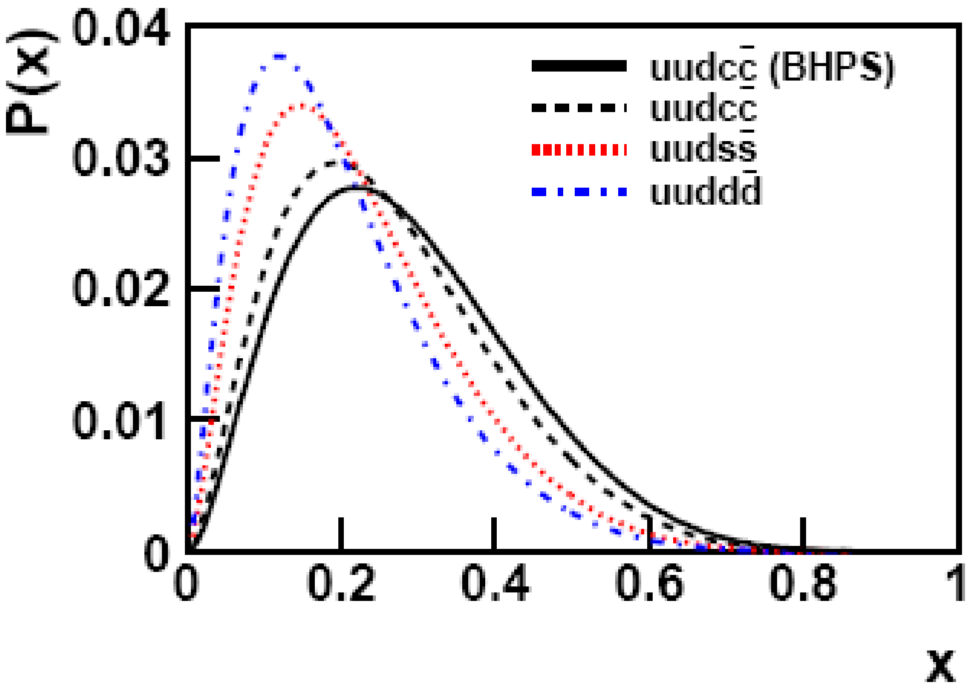
$$x_i^{min} = \frac{x_R + x_F}{2 - (x_R - x_F)} \qquad x_R = 2p/\sqrt{s}$$

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.

Predictions for ATLAS and SMC

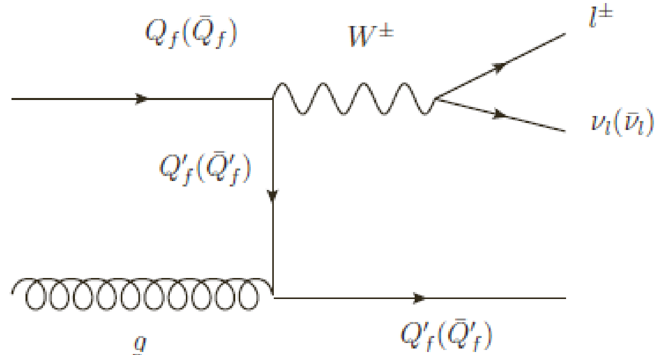


V.A. V.A.Bednyakov, M.A.Demichev, G.L.,T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (2014).

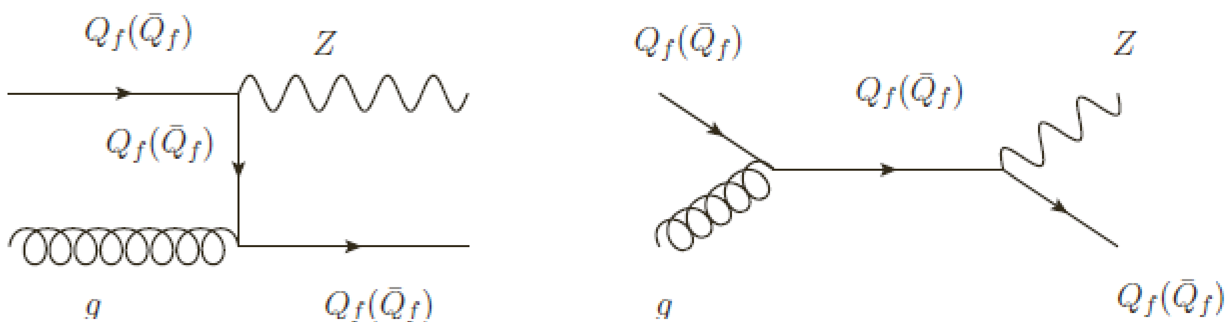


The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.

pp →W/Z+heavy flavour jets

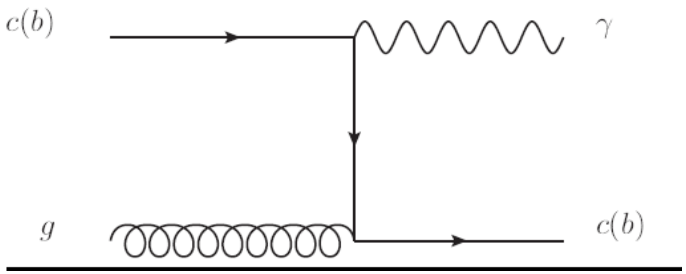


The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^{\pm}Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.



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

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



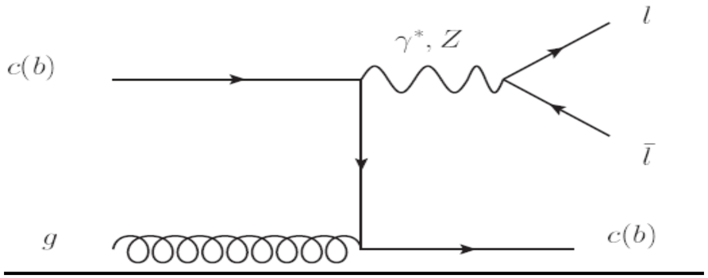


Fig.a. Feynman diagram for the process $c(b)+g\to\gamma+c(b)$

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

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

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

To observe the IC

for Fig.a

$$x_c\geq x_F>0.1$$

for Fig.b

$$x_{c(b)}=\frac{m^2_{l^+l^-}}{x_g s}+x^f_{c(b)}>0.$$