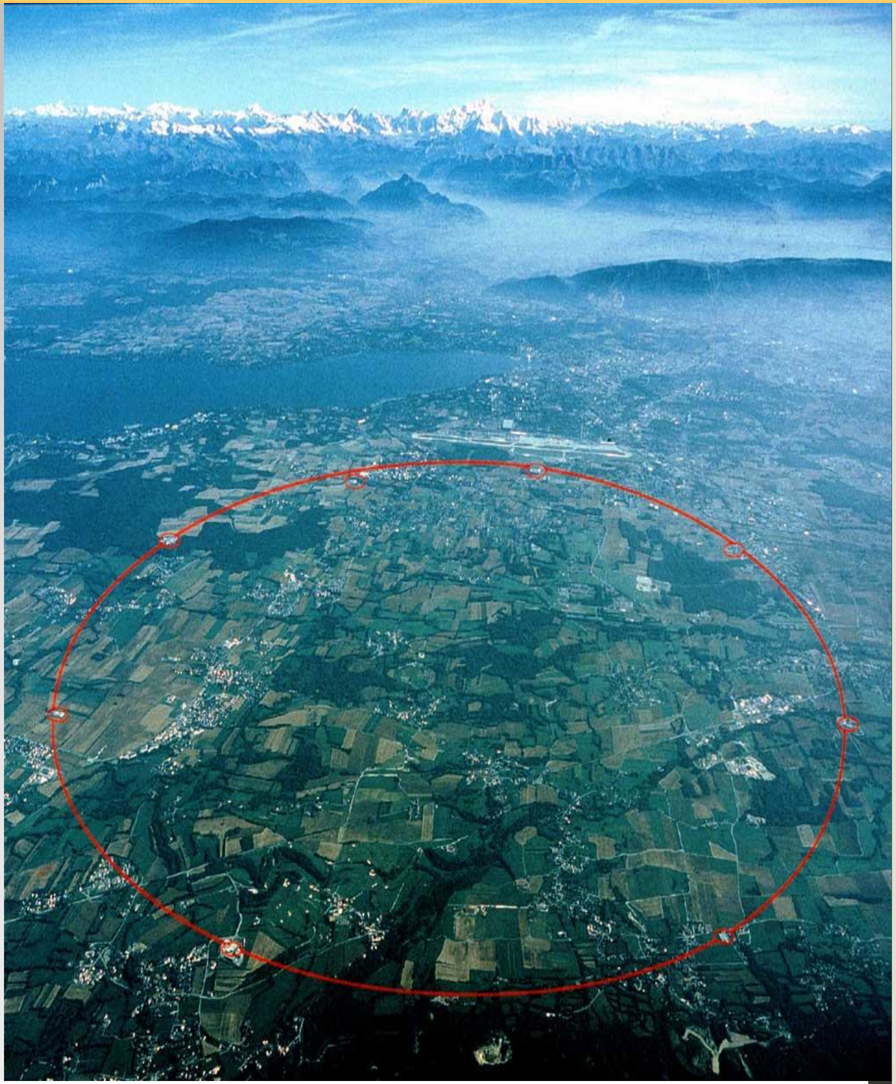
Physics of heavy quark distributions in proton: collider tests



Gennady Lykasov

JINR, Dubna

SF->HQ , Dubna, 18-30 July 2016

OUTLINE

1. Intrinsic flavour in proton

2. PDF including intrinsic heavy quark components

3. Hard parton-parton collisions and heavy flavour production

4. Intrinsic charm (IC) in proton and open charm production at hard p-p collisions

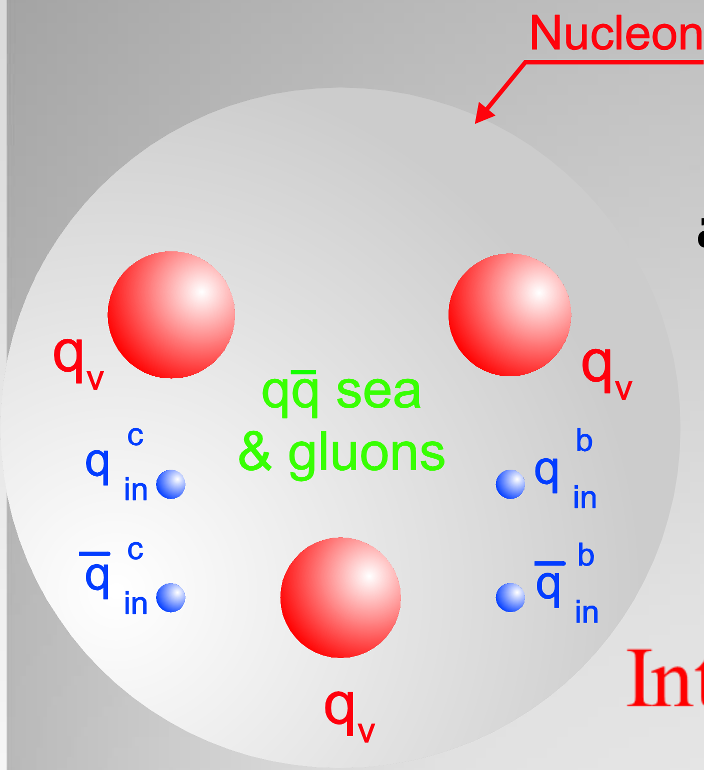
5. Possible observation of IC signal in γ(Z) +c-jet production by p-p collisions at LHC

6. Information on the IC probability in a nucleon from the LHC data

7. IC signal in W(Z)+b (c)-jet production by p-p at LHC

8. Summary

1. Intrinsic flavour in proton



BHPS model

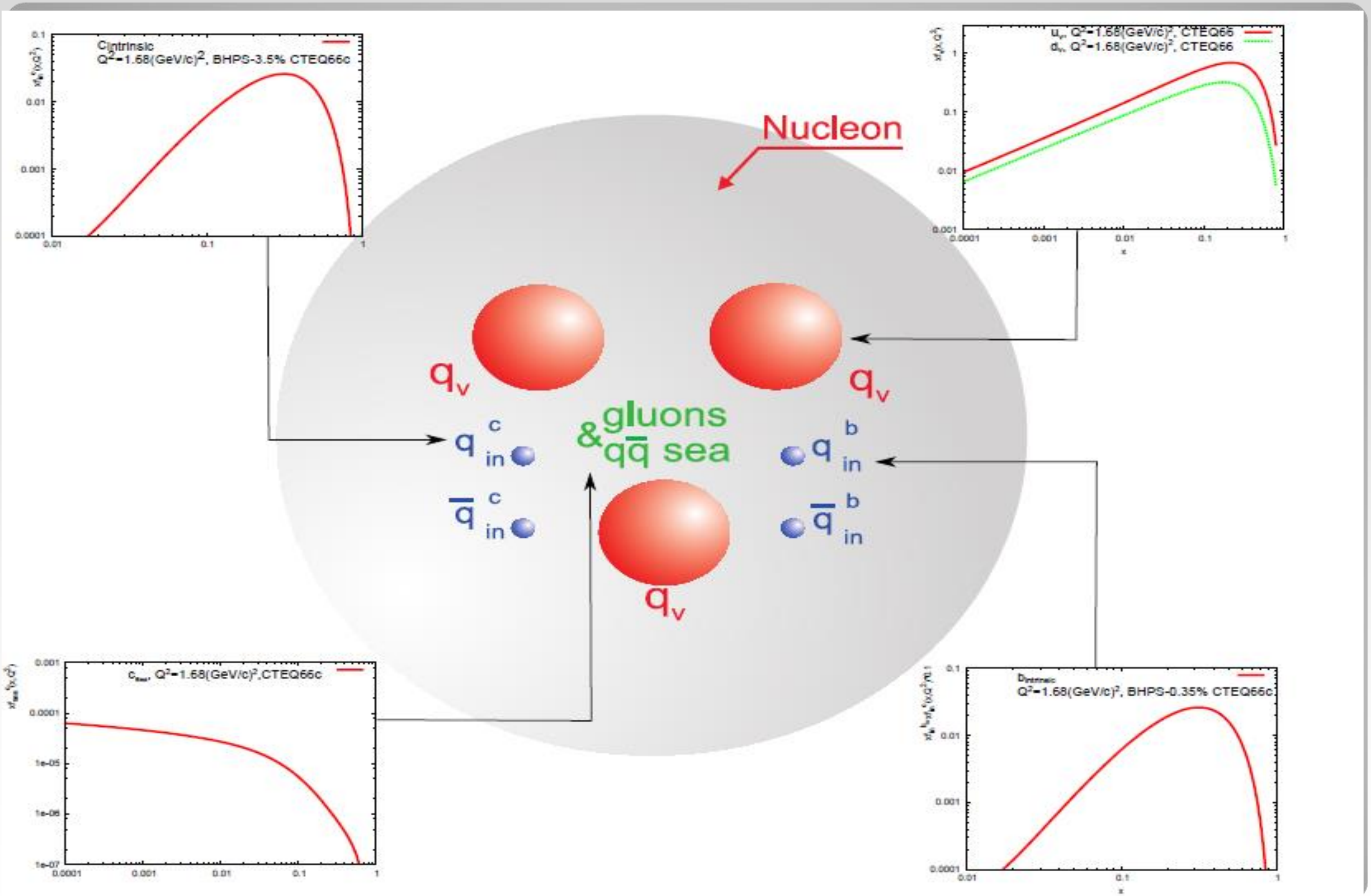
S.J. Brodsky,P. Hoyer, C. Peterson and N. Sakai, Phys.Lett. B93 (1980) 451;

S.J. Brodsky, S.J. Peterson and N. Sakai, Phys.Rev. D23 (1981) 2745.

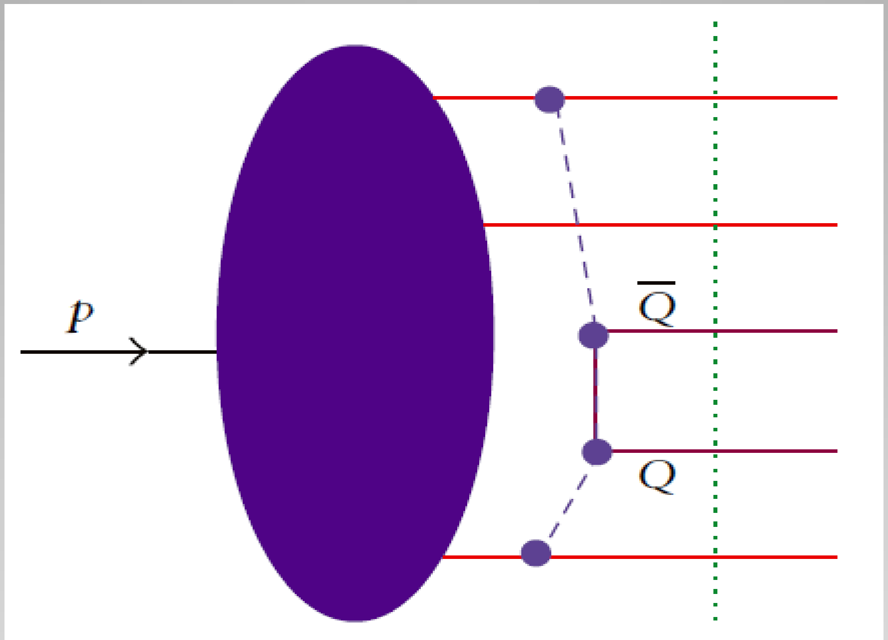
Intrinsic $Q\bar{Q}$ in proton

$$Q\bar{Q} = u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}, b\bar{b}, t\bar{t}$$

J.Pumplin, H.L. Lai and W.K.Tung, Phys.Rev.D75 (2007) 054029



SF->HQ , Dubna, 18-30 July 2016



Schematic graph of the $Q\bar{Q}$ pair creation in a nucleon.

If the gluon-gluon scattering box diagram, $gg \to Q\bar{Q} \to gg$ **,**
is inserted into the proton self-energy graph the cut of this amplitude generates the five-quark state of the proton $|uudQ\bar{Q}>$
This is analog of the cut diagram of the light-by-light scattering

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.

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

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

where

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

If F=1, then

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

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

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

and

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

Here N is found from the normalization equaton:

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

INTRINSIC HEAVY QUARK DISTRIBUTION IN PROTON

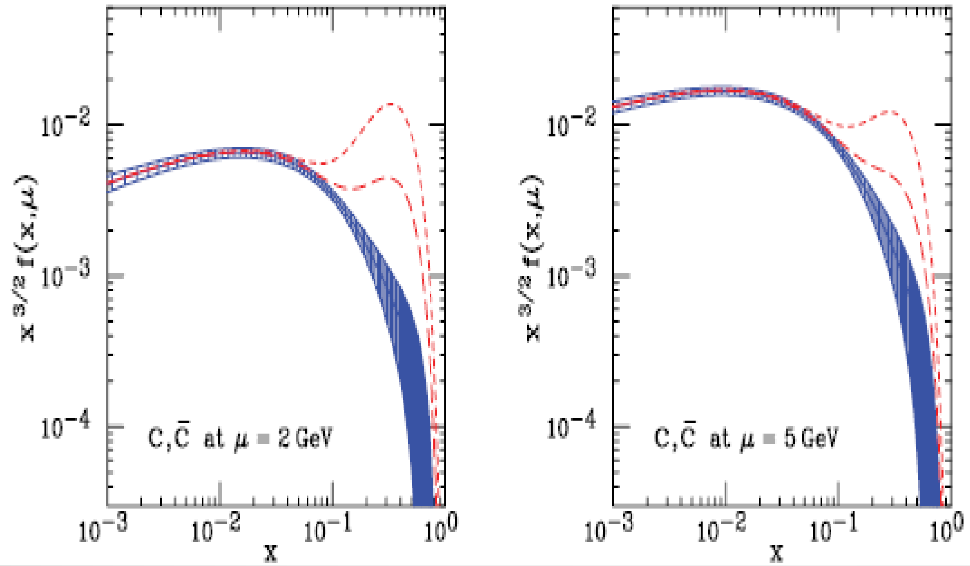
Integrating $P(x_1,\ldots,x_5)$ over $dx_1 \ldots dx_4$ and neglecting of all quark masses except the charm quark mass we get

$$P(x_5) = \frac{1}{2}\bar{N}_5 x_5^2 \left[\frac{1}{3}(1-x_5)(1+10x_5+x_5^2)+2x_5(1+x_5)\ln\left(1/x_5\right)\right]$$

Where $\bar{N}_5 = N_5 / m_{4,5}^4$ normalization constant . Here $m_4 = m_5 = m_c = m_{\bar{c}}$ is the bar mass of the charmed quark. N_5 determines some probability w_{IQ} to find the Fock state $|uudQ\bar{Q}\rangle$ in the proton.

One can see qualitatively that $P(x_5)$ vanishes at $x_5 \to 0$ and $x_5 \to 1$ and has an enhancement at $0 < x_5 < 1$

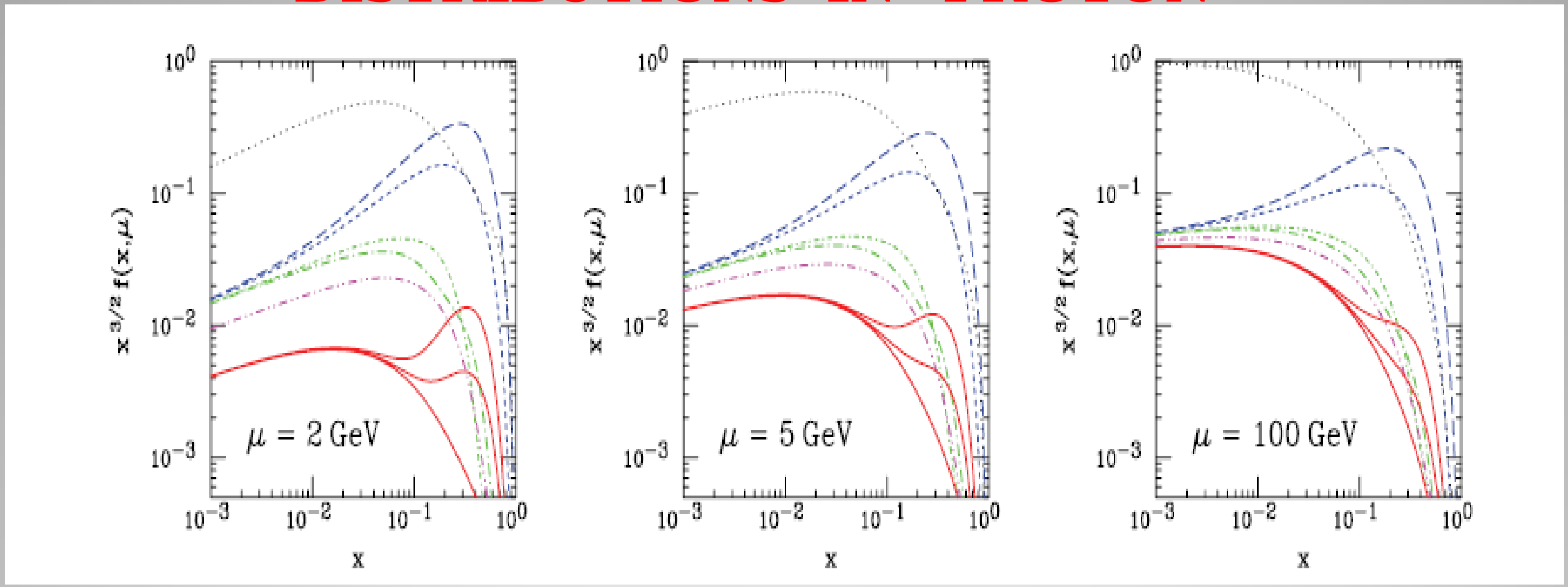
2. PDF including IQ **CHARM QUARK DISTRIBUTIONS IN PROTON**



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 e 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

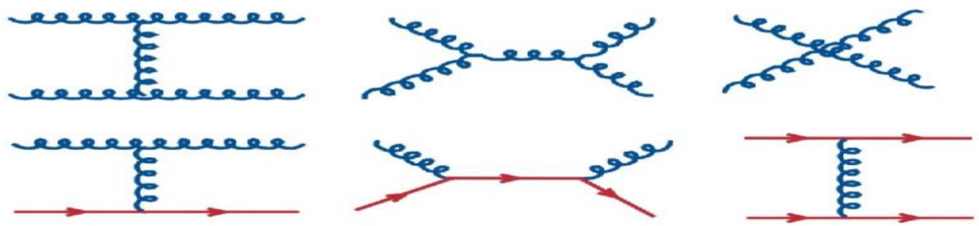
COMPARISON OF LIGHT AND HEAVY QUARK DISTRIBUTIONS IN PROTON



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

3.Hard processes and HF production

For example, leading order QCD.



Parton - parton interactions within LO QCD,
the wavy line is the gluon, the solid line is the quark.

$$\frac{d\sigma_{ij}}{d\hat{t}} = \frac{8\pi}{\hat{s}} A_1 \alpha_s^2 \frac{d\sigma_{ij}}{d\Phi_2}; \alpha_s(Q^2) = \frac{12\pi}{(33 - 2n_f)\ln(Q^2/\Lambda^2)};$$

Process	$\frac{d\hat{\sigma}}{d\Phi_2}$	Process	$\frac{d\hat{\sigma}}{d\Phi_2}$
$qq' \to qq'$	$\frac{1}{2\hat{s}}\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$	$q\bar{q} \to gg$	$\frac{1}{2}\frac{1}{2\hat{s}}\left[\frac{32}{27}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}} - \frac{8}{3}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right]$
$qq \to qq$	$\frac{1}{2}\frac{1}{2\hat{s}}\left[\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right) - \frac{8}{27}\frac{\hat{s}^2}{\hat{u}\hat{t}}\right]$	$gg \to q\bar{q}$	$\frac{1}{2\hat{s}}\left[\frac{1}{6}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}} - \frac{3}{8}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right]$
$q\bar{q} \to q'\bar{q}'$	$\frac{1}{2\hat{s}}\frac{4}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$	$gq \to gq$	$\frac{1}{2\hat{s}}\left[-\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{s}\hat{u}} + \frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}\right]$
$q\bar{q} \to q\bar{q}$	$\frac{1}{2\hat{s}}\left[\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right) - \frac{8}{27}\frac{\hat{u}^2}{\hat{s}\hat{t}}\right]$	$gg \to gg$	$\frac{1}{2}\frac{1}{2\hat{s}}\frac{9}{2}\left(3 - \frac{\hat{t}\hat{u}}{\hat{s}^2} - \frac{\hat{s}\hat{u}}{\hat{t}^2} - \frac{\hat{s}\hat{t}}{\hat{u}^2}\right)$

PRODUCTION OF HEAVY FLAVOURS IN HARD P-P COLLISIONS

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

$$x_i^{\min} = \frac{x_T \cot(\frac{\theta}{2})}{2 - x_T \tan(\frac{\theta}{2})}$$

$$x_F \equiv \frac{2p_z}{\sqrt{s}} = \frac{2p_T}{\sqrt{s}}\frac{1}{\tan\theta} = \frac{2p_T}{\sqrt{s}}\sinh(\eta)$$

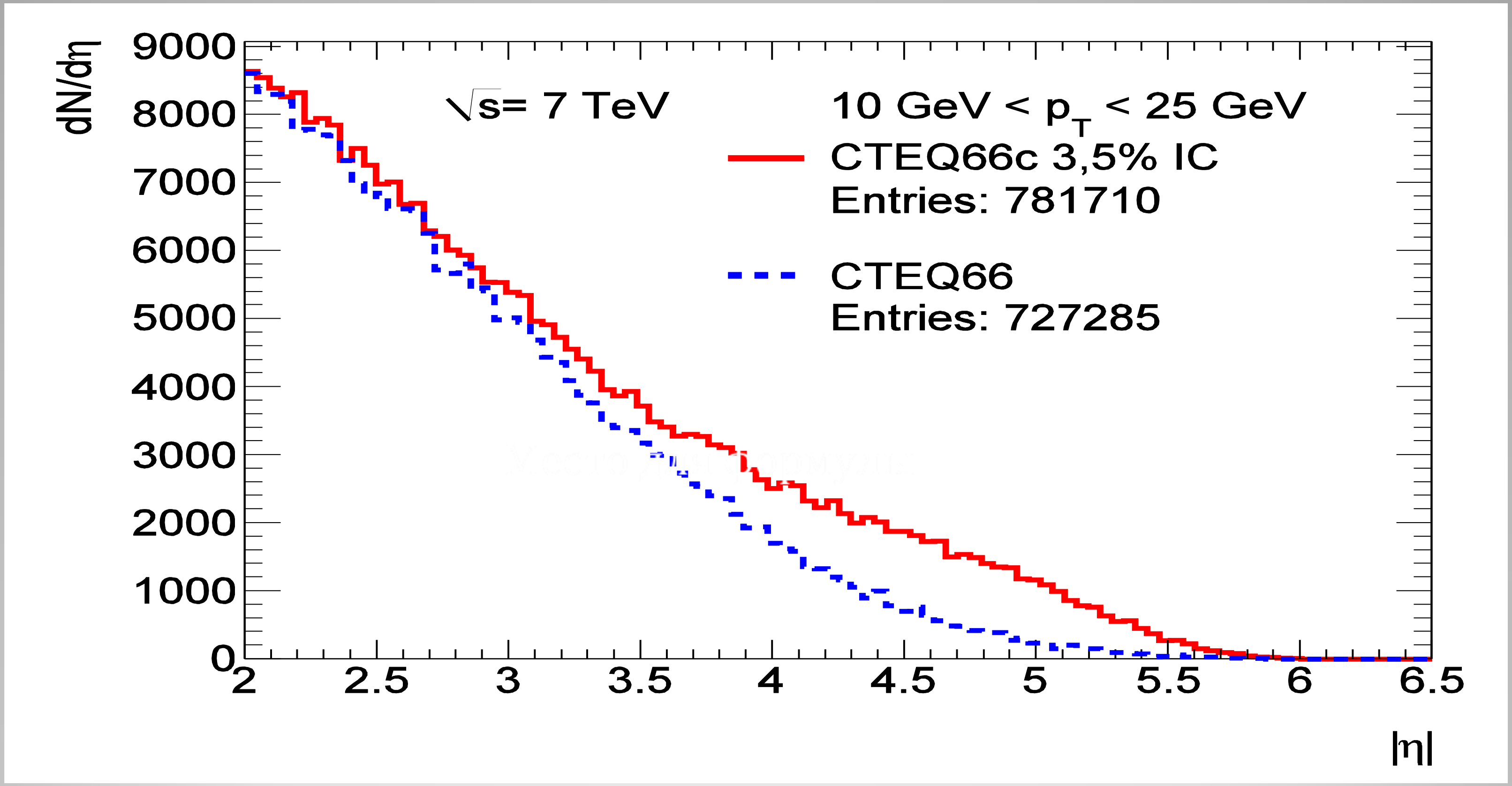
$$x_i^{min} = \frac{x_R + x_F}{2 - (x_R - x_F)}$$

$$x_R = 2p/\sqrt{s}$$

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.

4. IC in proton and open charm production

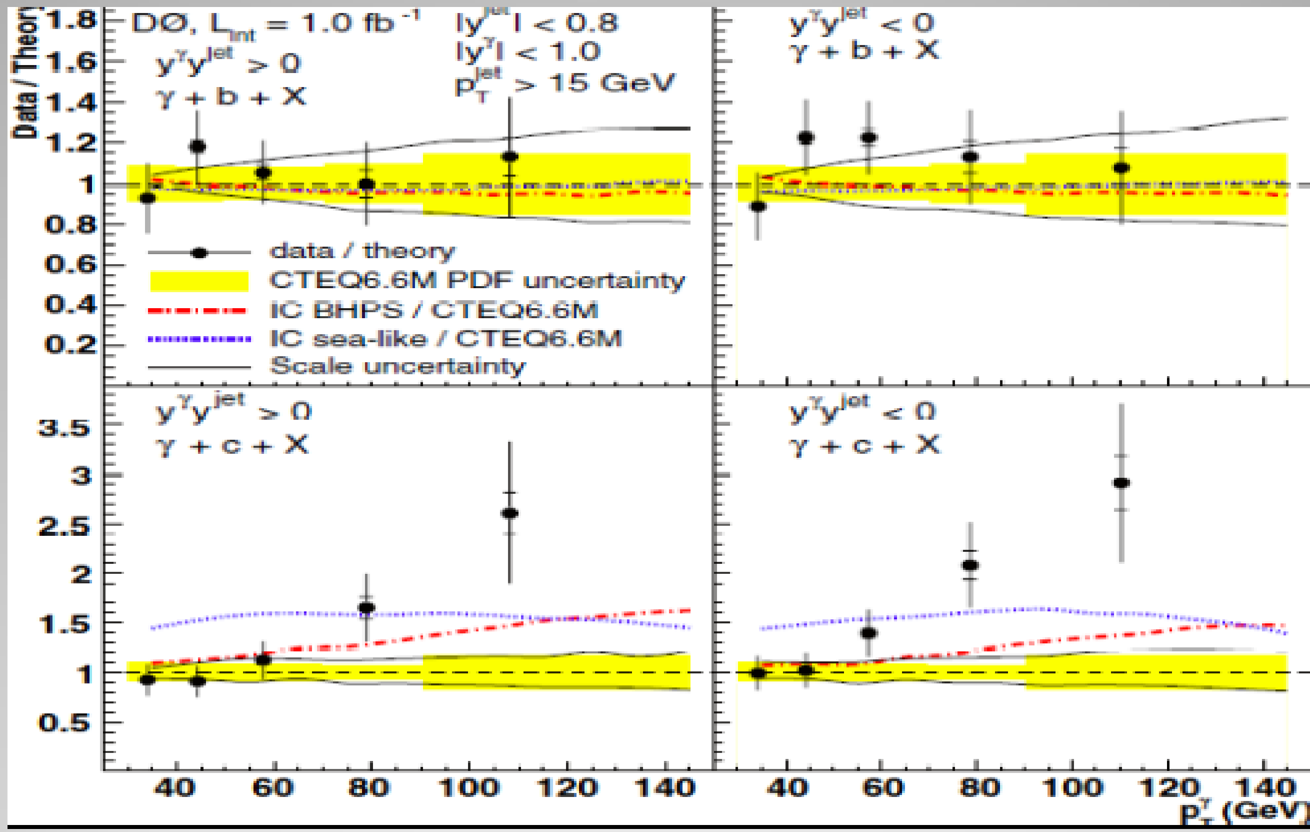


Single D^0 production in p-p at $s^{1/2}=7$ TeV.

$x_F = \frac{2p_t}{\sqrt{s}} \sinh(\eta) = x_t sinh(\eta)$; IC signal, when $x_F > 0.1$

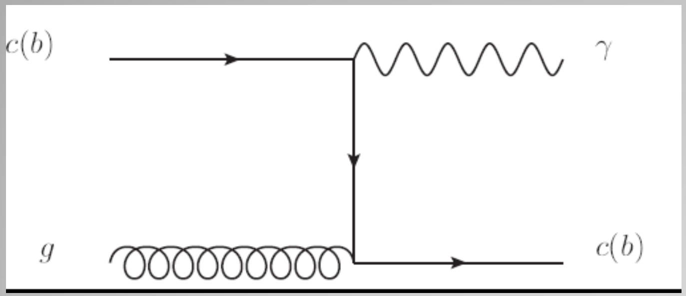
G.L., V.A.Bednyakov, A.F.Pikelner, N.P.Zimin, Eur.Phys.Lett. 96 (2012)21002

5. IC signal in γ(Z) +c-jet production



The data-to-theory ratio of cross sections as a function of p_T^{γ} for p+bar{p}->γ + Q+X, at $s^{1/2}$ = 1.98 TeV (Q=c,b). The points are D^0 data at Tevatron. There is the **three time excess** of the data above the theory at p_T^{γ} ~ 120 GeV if the ***IC*** is included (solid red lone) t the probability about 3.5 %. **It stimulates us to study a possible *IC* signal at LHC.**

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



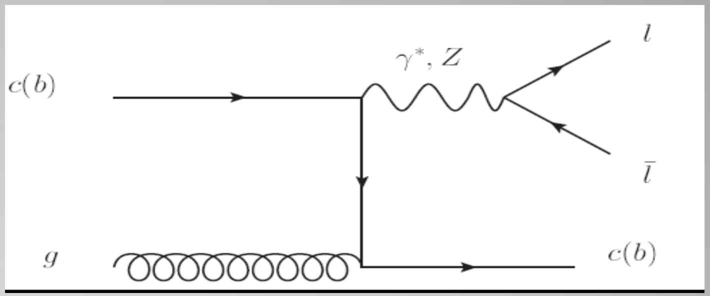


Fig.a. Feynman diagram for the process $c(b)+g\rightarrow\gamma+c(b)$

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

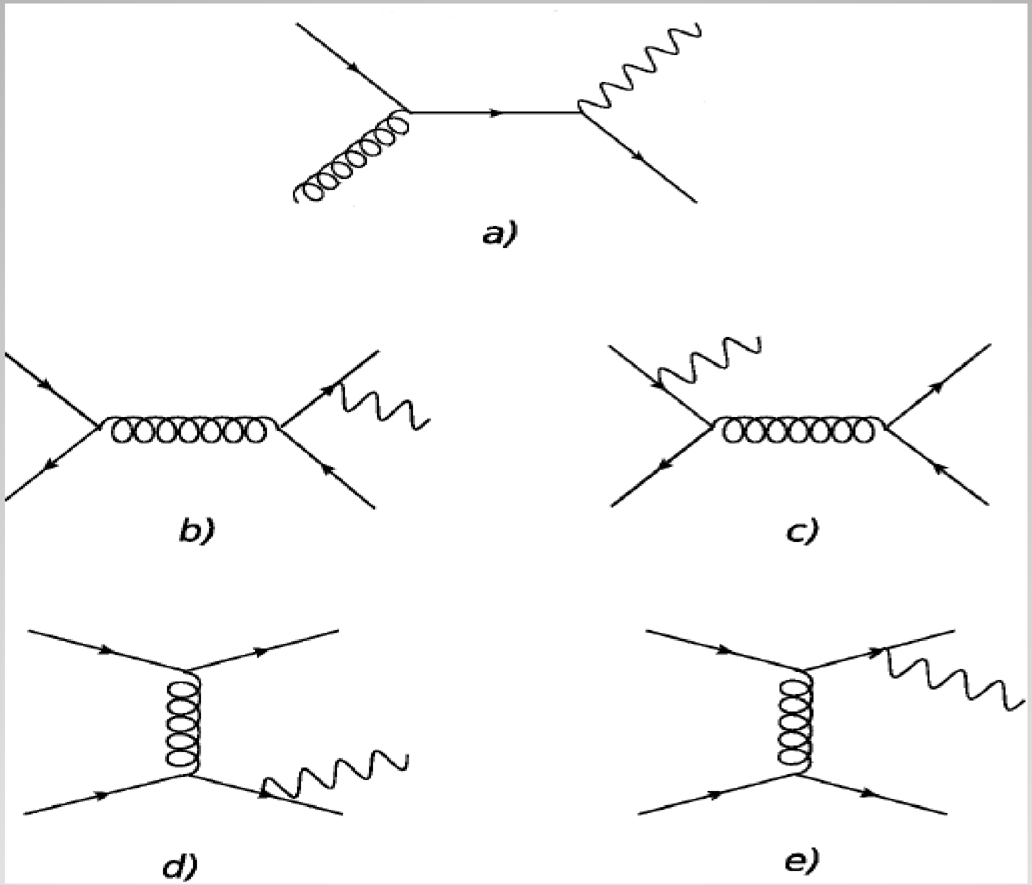
for Fig.a

$$x_c \geq x_F > 0.1$$

for Fig.b

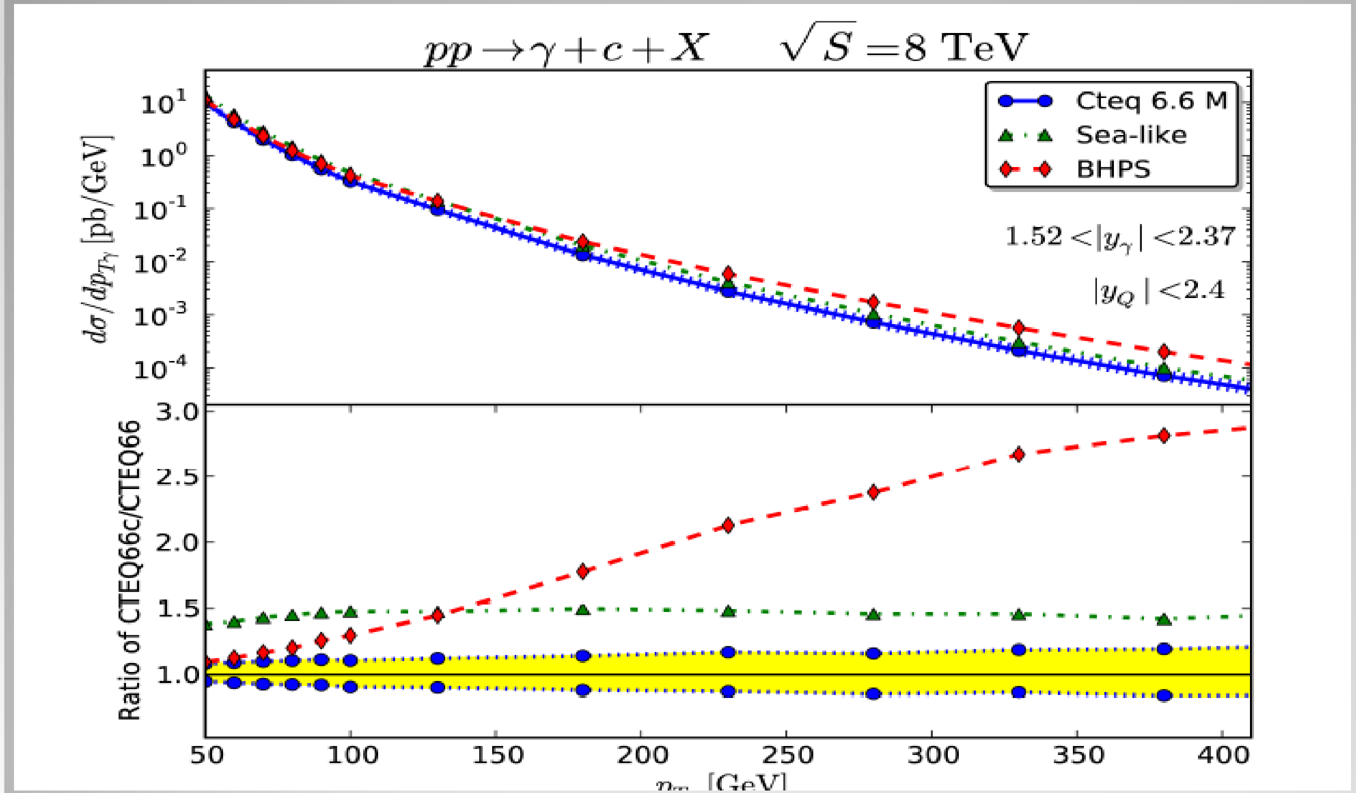
$$x_{c(b)} = \frac{m^2_{l^+l^-}}{x_g s} + x^f_{c(b)} > 0.1$$

pp → γ + 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

IC signal in $pp \to \gamma + c(jet) + X$



V.A.Bednyakov, M.A.Demichev, G.L., T.Stavreva, M.Stockton, hep-ph/1305.3548

Phys.Lett. B728 (2014) 602.

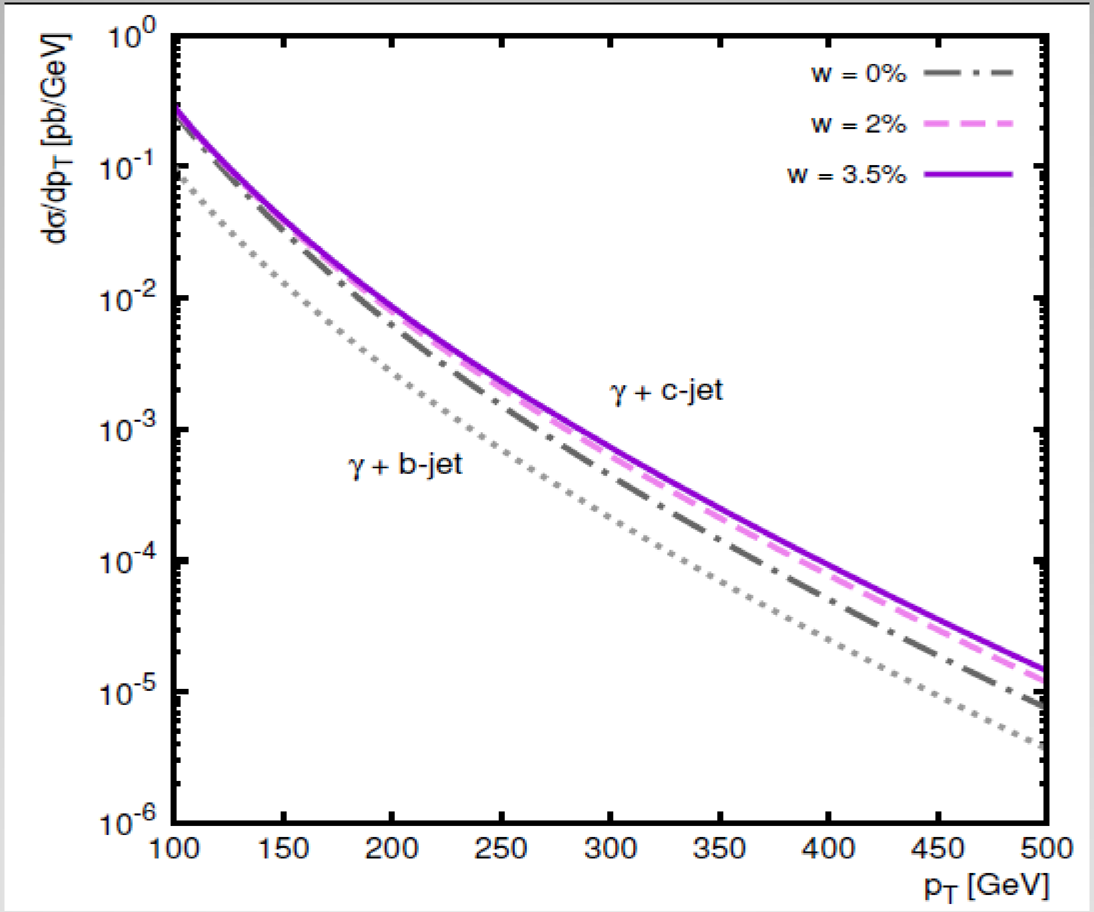
p_T - distribution of photons produced in pp->γ + c + X

The blue line is calculation without the *IC*. The red curve includes the *IC*, its probability is about 3.5 % (top). The ratio of spectra with and without the *IC*

The *IC* signal is about 200%-250% at $p_T \sim$ 150-200 GeV/c,

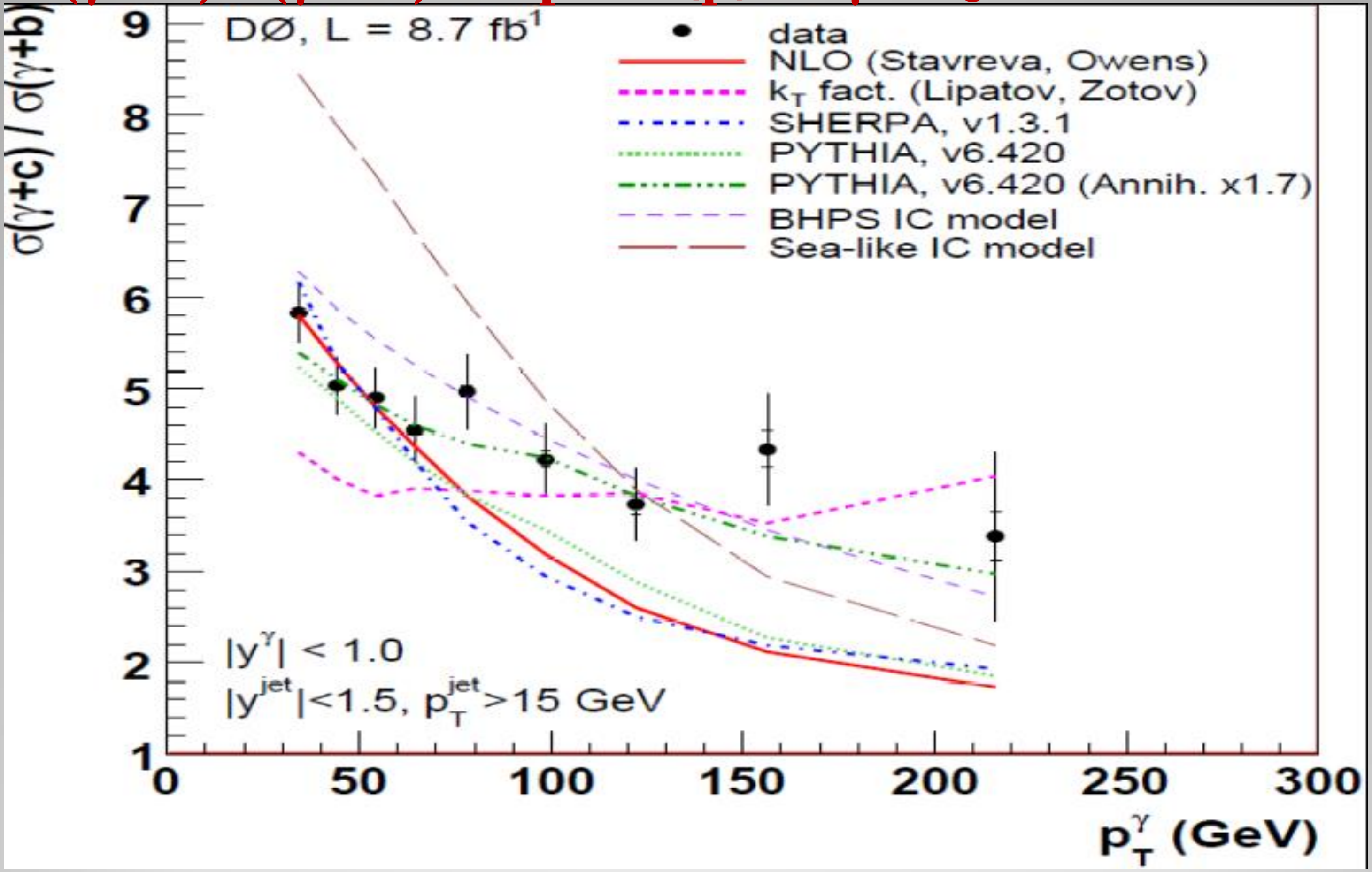
where the cross section is about 20-80 fb (400-3200 events) and can be measured

PP → γ + Q +X , $s^{1/2}$ = 8 TeV ; 1.5< η< 2.4; Q = c,b



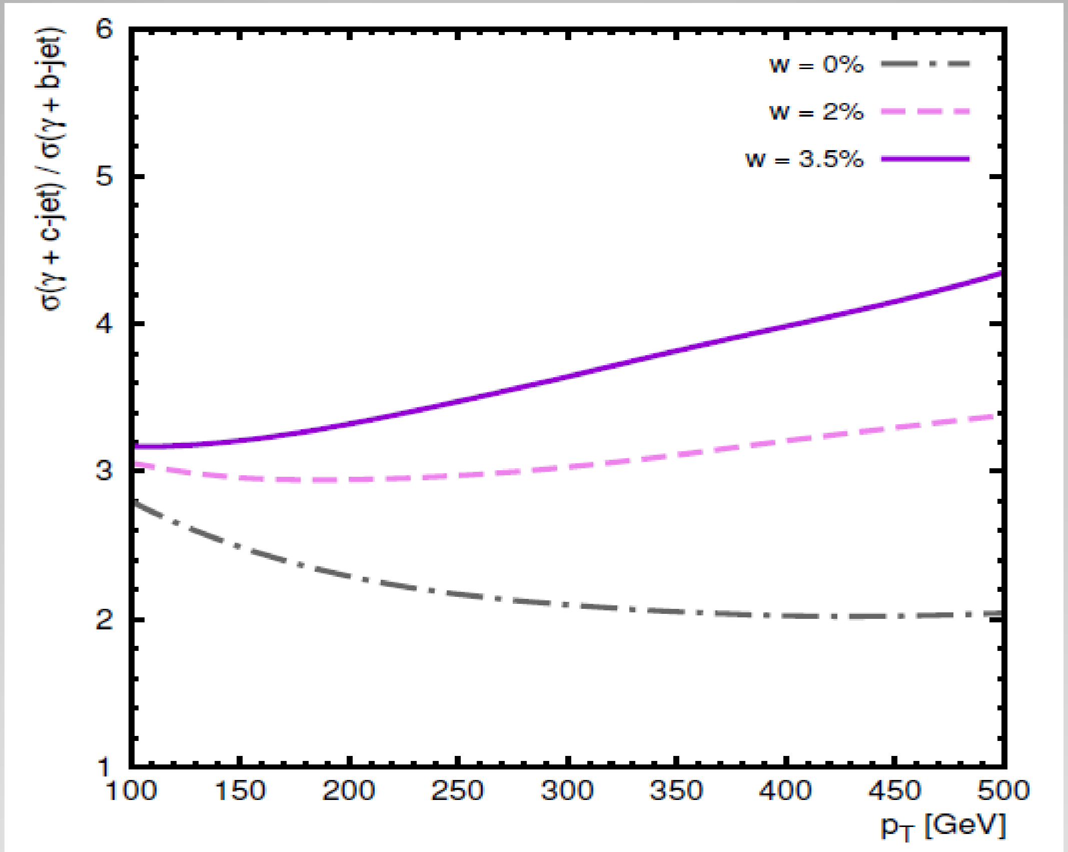
p_T –distribution within the k_T –factoriaztion of QCD

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 3.5 %

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



p_T –distribution of R at different IC probability w
A.V.Lipatov, G.L., Yu.Yu. Stepanenko , V.A.Bednyakov,
arXiv:1606.04882 [hep-ph] (2016)

6. IC probability in a nucleon from the LHC data

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

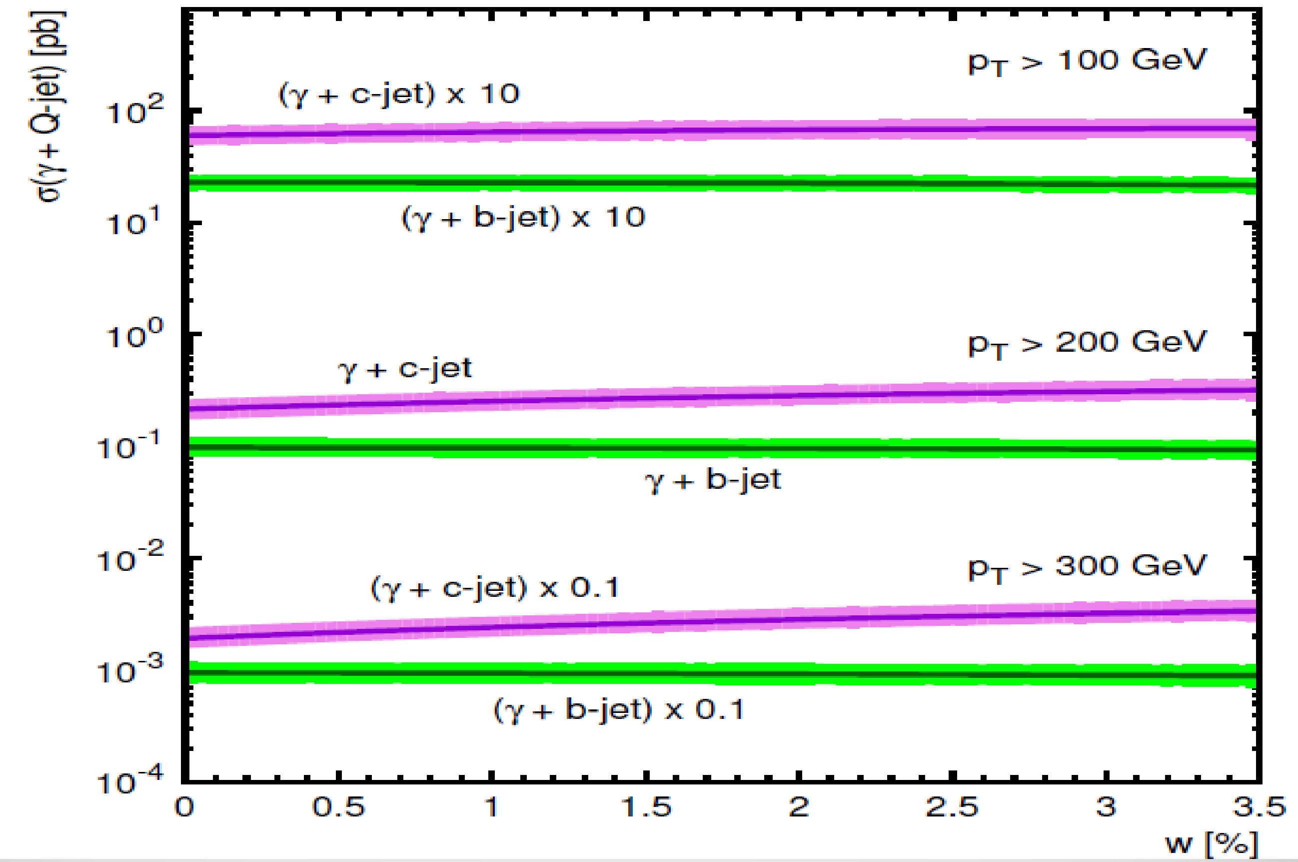
c(x) = $P(x) = 600wx^2\left[6x(1+x)\ln(x) + (1-x)(1+10x+x^2)\right]$

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

At any μ^2 the charm density xc(x) is calculated using the DGLAP within the CTEQ66c ($w = 1\%$ and $w = 3.5\%$) or CT14 ($w = 1\%$ and $w = 2\%$) sets. In general case , there is some mixing between $xc_{ext}(x, \mu^2)$ and $xc_{int}(x, \mu^2)$. However, such mixing, especially at large μ^2 and x is negligible. Therefore, one can apply DGLAP separately to the first part and the second one.

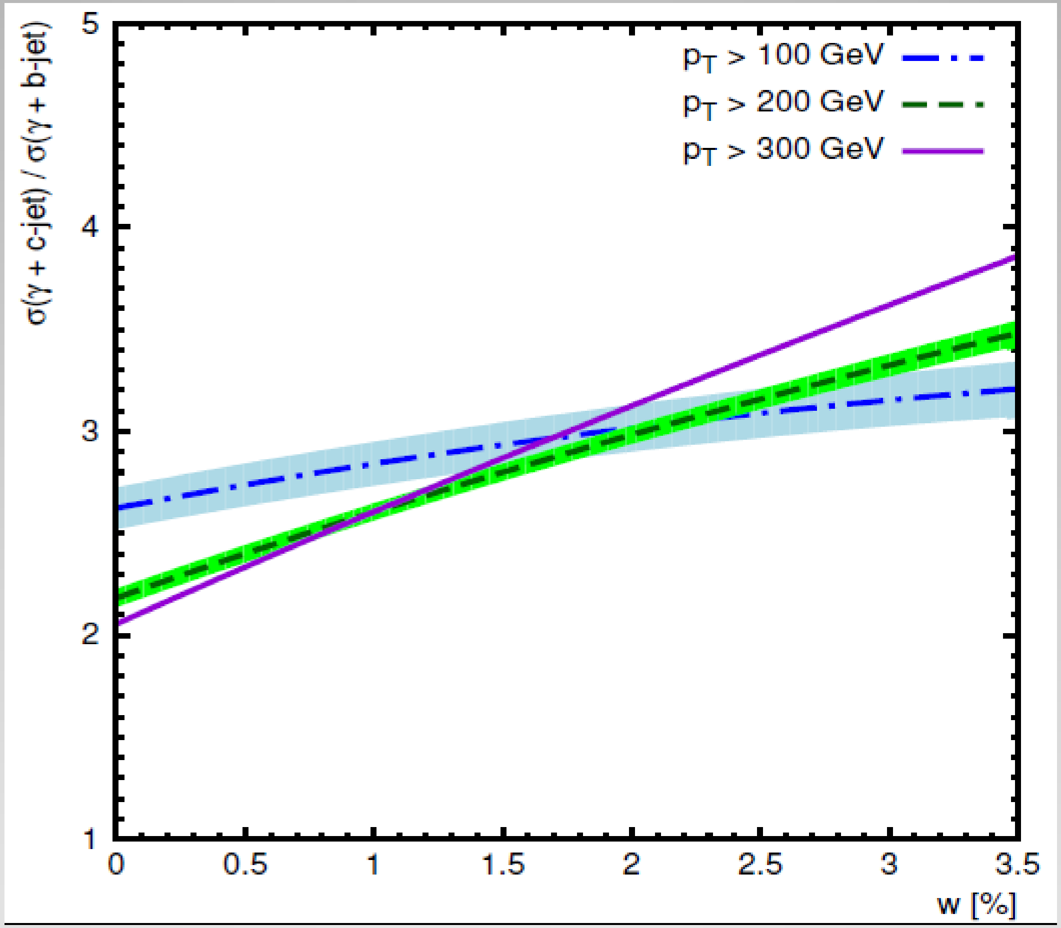
$$xc_{int}(x,\mu^2) = \frac{w}{w_{\max}} xc_{int}(x,\mu^2)|_{w=w_{\max}}$$

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



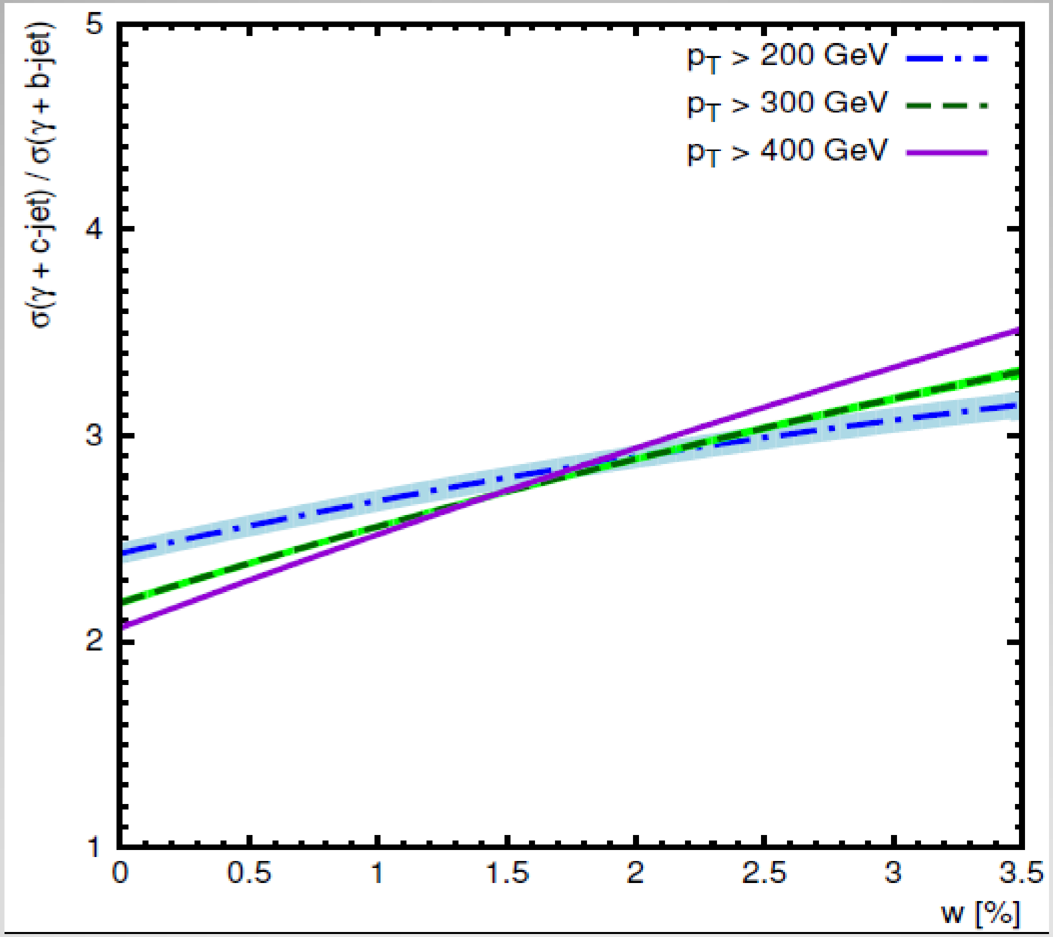
p_T^{γ} – spectrum integrated over p_T^{γ} , i.e., $\sigma(\gamma+c)$ and $\sigma(\gamma+b)$ at p_T^{γ} > 100 GeV or 200 GeV, or 300 GeV, vs. *IC* probability w

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



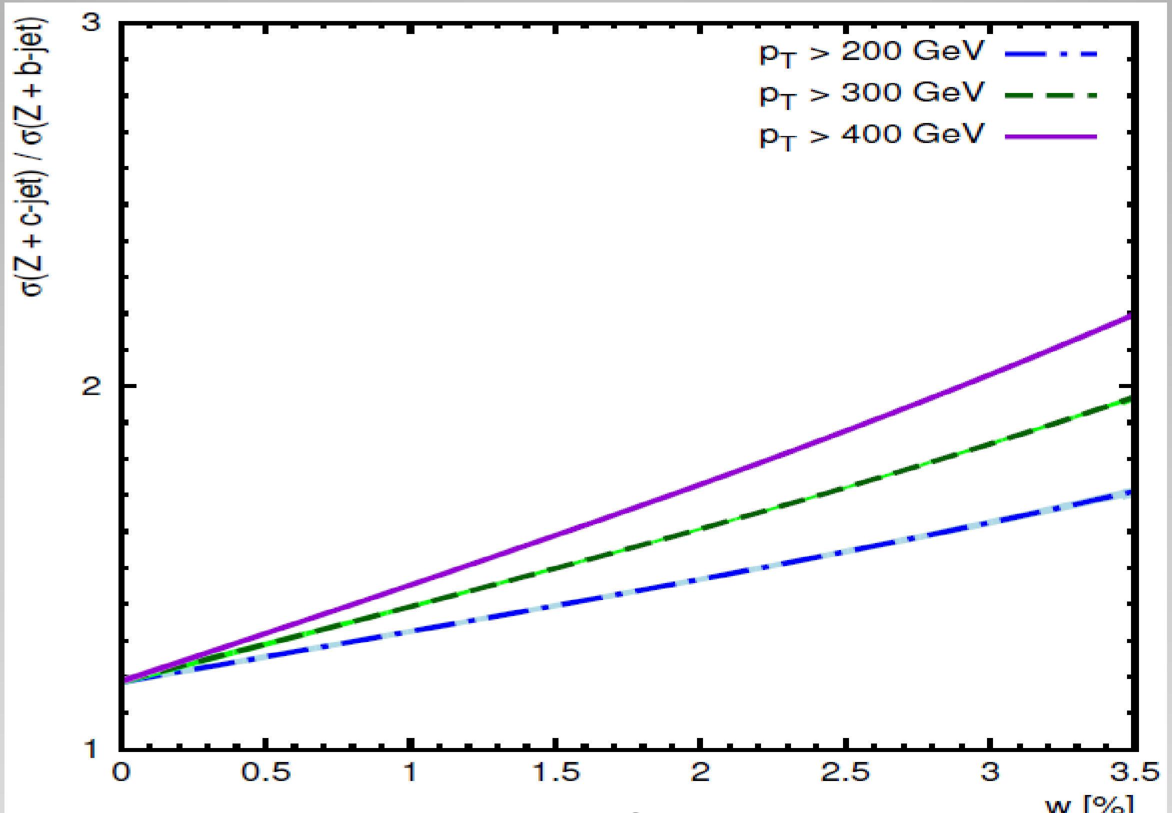
Ratio between the x-sections of γ +c and γ + b production integrated over p_T. Bands mean the QCD scale uncertainty

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



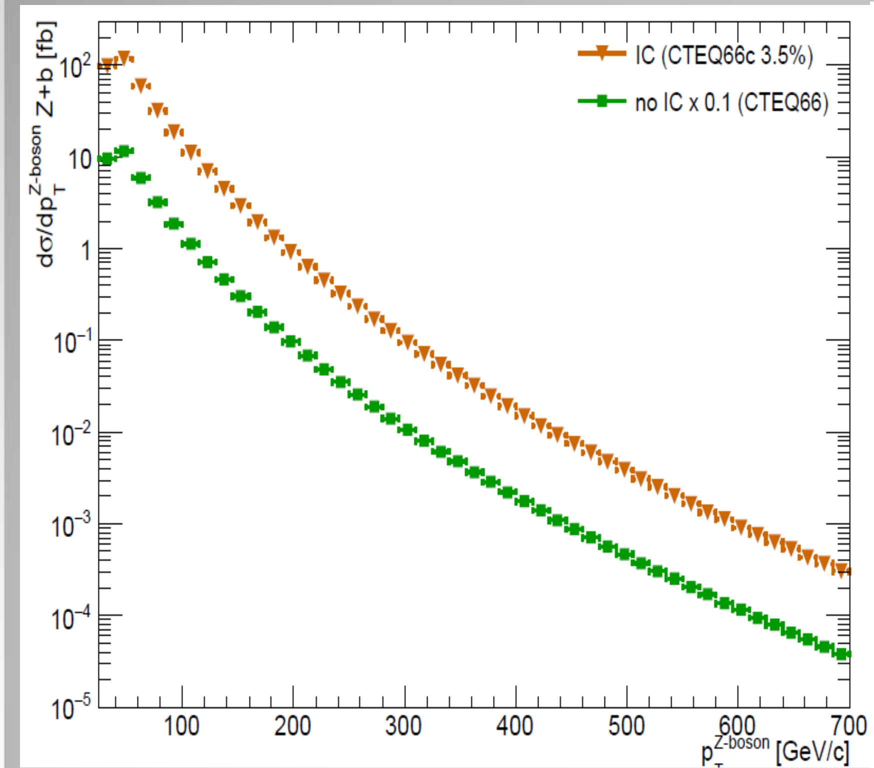
Ratio between the x-sections of γ +c and γ + b production integrated over p_T. Bands mean the QCD scale uncertainty

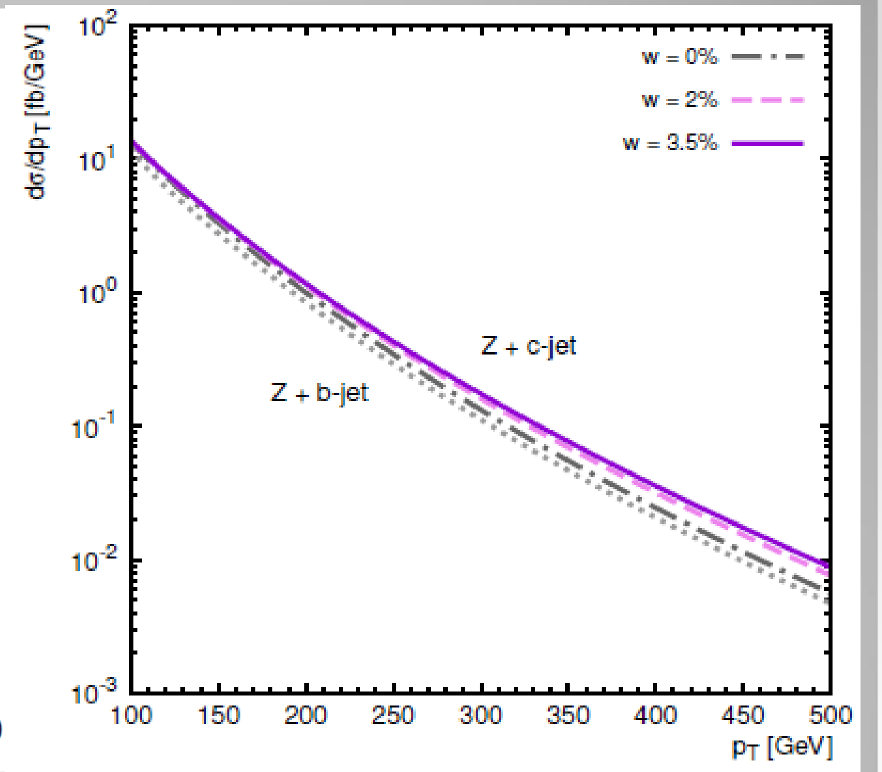
PP → Z + Q +X , $s^{1/2}$ = 13 TeV , Q = c,b



Ratio between the x-sections of Z +c and Z + b production integrated over $p_{T.}$ Bands mean the QCD scale uncertainty. A.V.Lipatov, G.L., Yu.Yu. Stepanenko , V.A.Bednyakov, arXiv:1606.04882 [hep-ph] (2016)

PP->Z+b+X at $s^{1/2}$ = 13 TeV

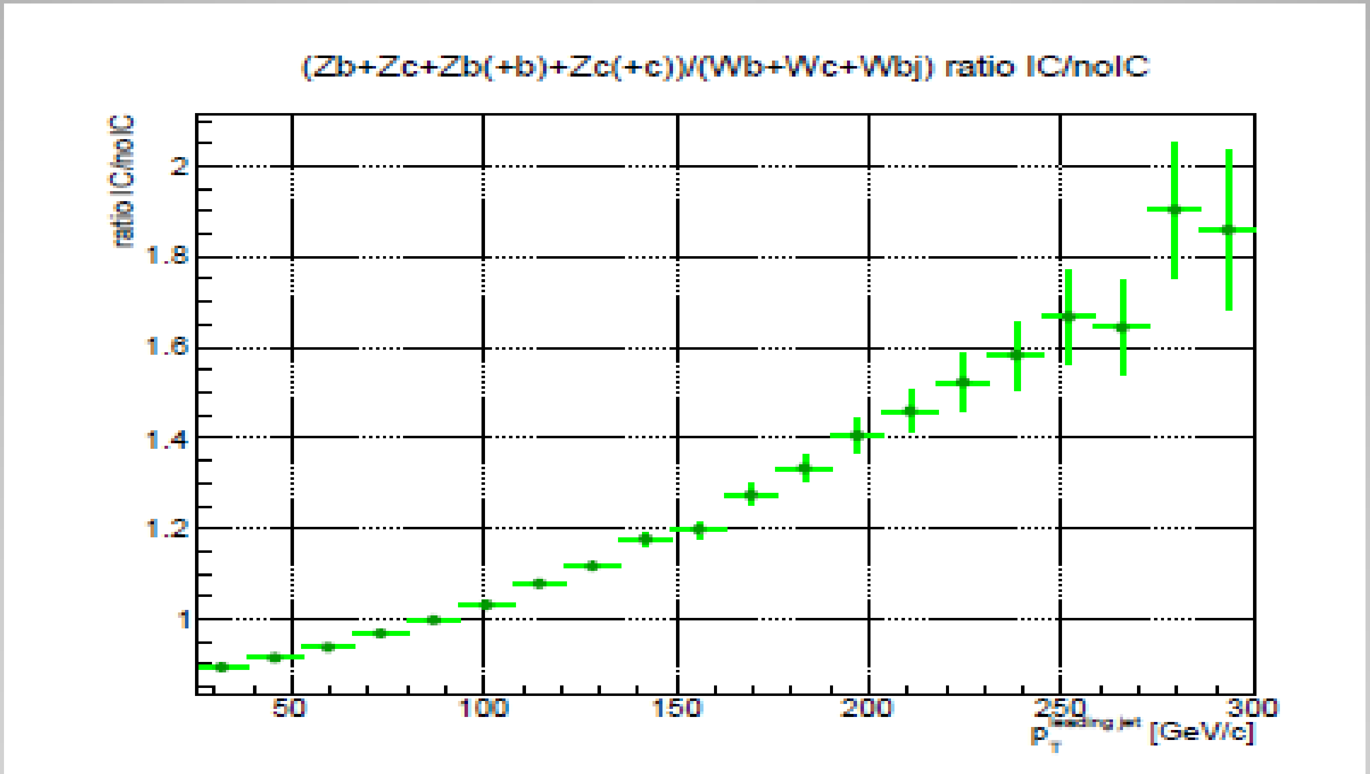




Left: distribution versus the leading jet transverse momentum Within the MCFM, NLO, $1.5<y_Z<2.0$; $1.5<y_{LJ}<2.0$

Right: Z-transverse momentum distribution within the k_T - factorization of QCD, $1.5<y_Z<2.4$.

7.IC signal in the production of W/Z accompanied by both c- an b-jets



The ratio for the processes $(Zb+Zc+Zb(+b)+Zc(+c))/(Wb+Wc+Wbj)$ **including the *IC* contribution and ignoring it (P.-H. Beauchmin, V.A.Bednyakov, G.L., Yu.Yu. Stepanenko, Phys.Rev. D92, 034014 (2015))**

8. SUMMARY

1. It is shown that at x_Q >0.1 the contribution of the conventional (**extrinsic**) sea heavy quark distributions is negligibly small in comparison to the **intrinsic** one.
2. The signal of **the intrinsic** charm (*IC*) in proton can be studied in the inclusive open charm production in p-p at the LHC. The *IC* signal can be about 200 % -300% at high y and p_t
3. These intrinsic heavy quark contributions to the PDF can be studied also in the hard SM processes of production of γ and W/Z associated with the heavy flavour c- and b-jets.
4. The *IC* can be about also 250%-300 % at certain values of rapidities and transverse momenta of photons or vector bosons. They can be measured at LHC.
5. The ratio $(\sigma(\gamma(Z)+c)/(\sigma(\gamma(Z)+b)$ is sensitive to the scale uncertainties much smaller than p_T – spectra. Therefore, this observable is more **promising** for search for the *IC* signal **in pp->γ(Z)+Q +X at LHC**.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP

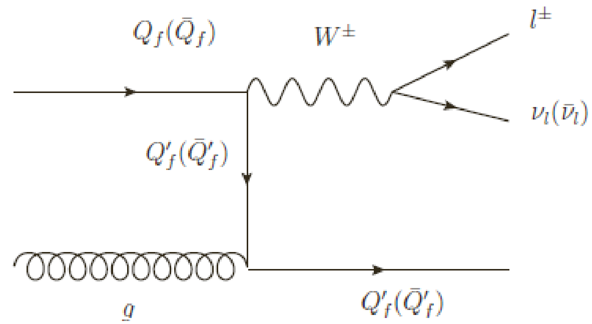


Figure 2: The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^\pm Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.

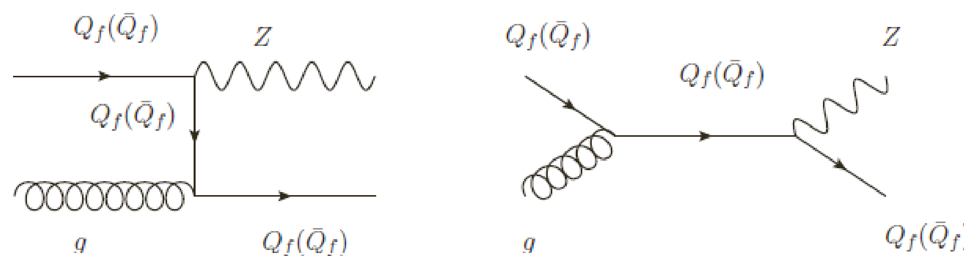
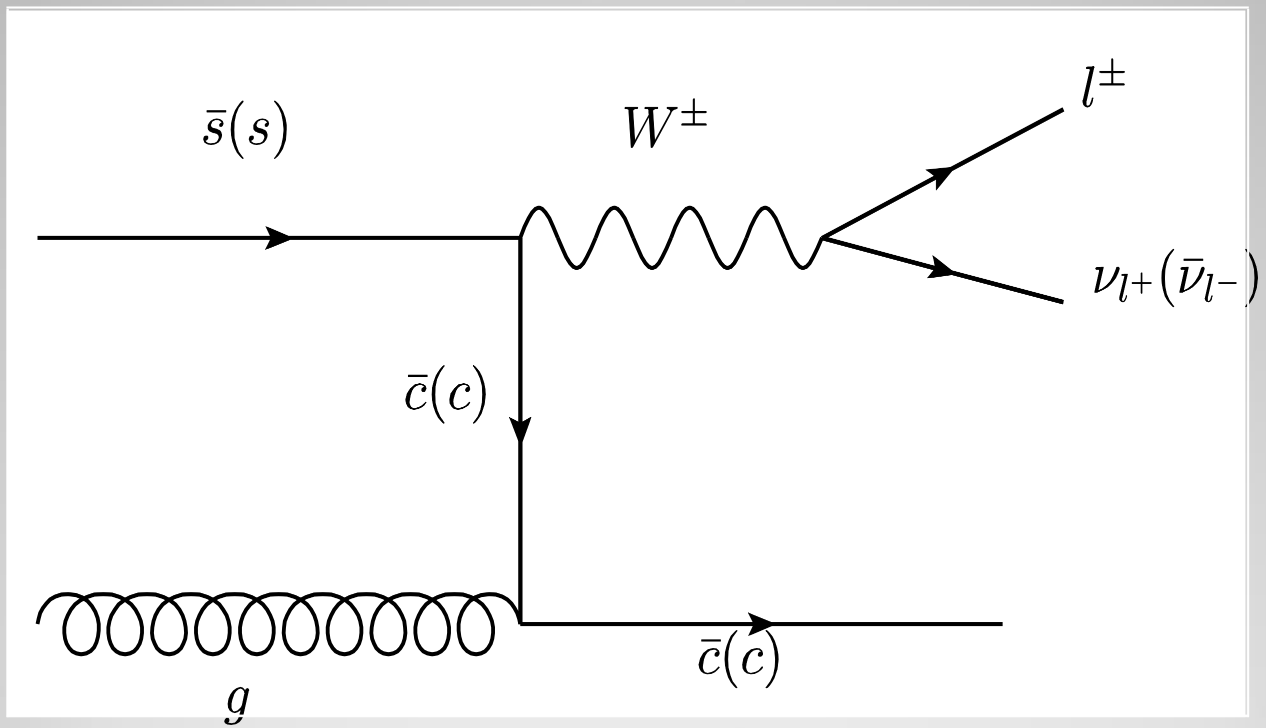
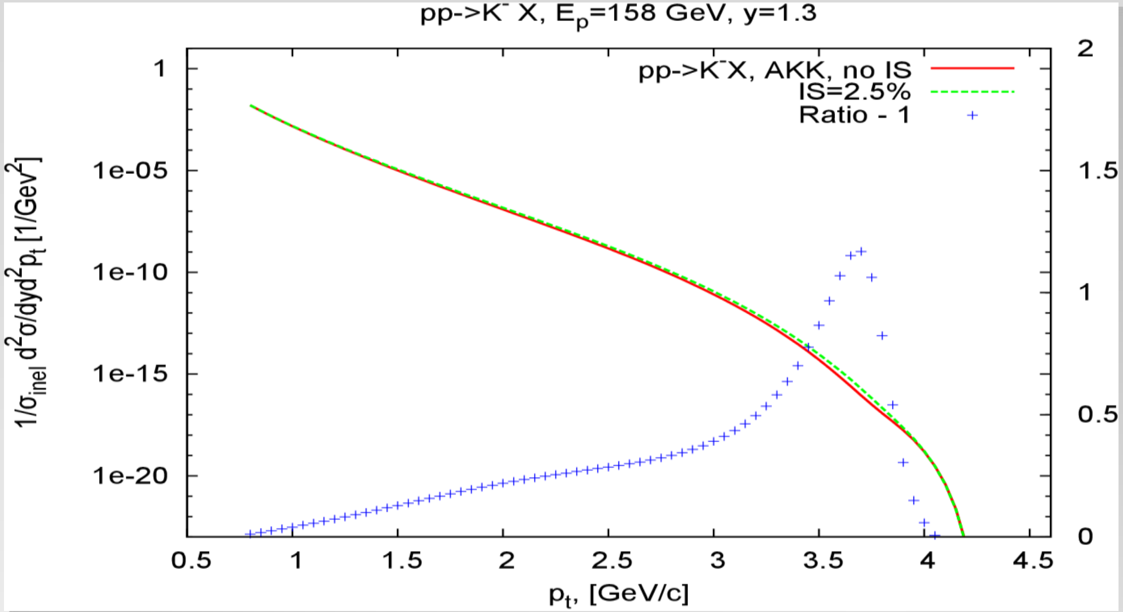


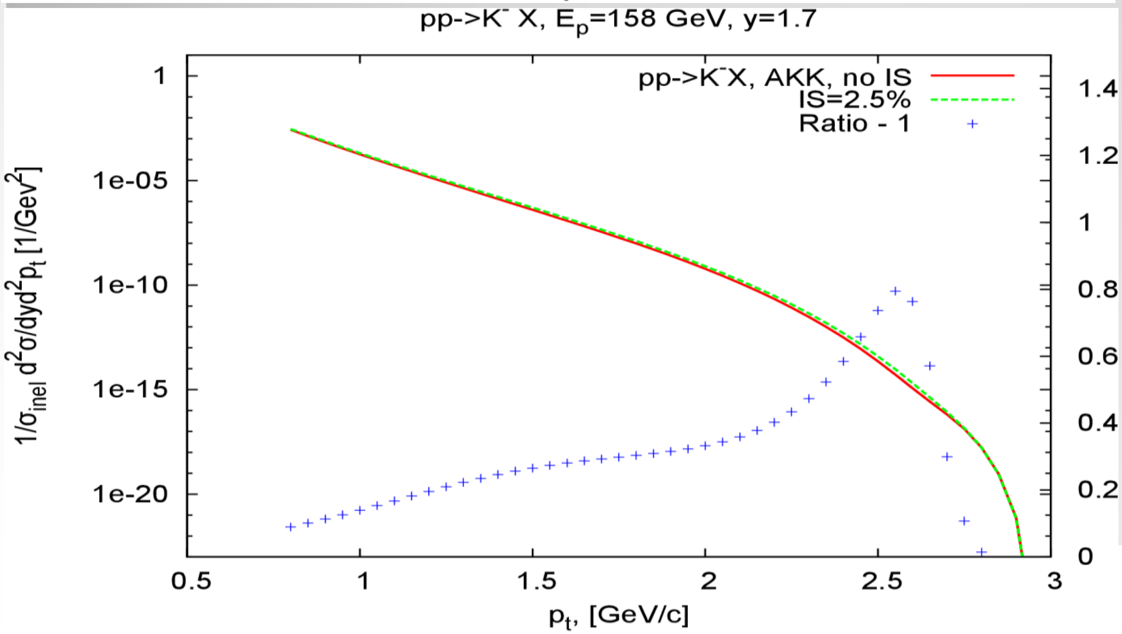
Figure 3: Feynman diagram for the process $Q_f(\bar{Q}_f)g \to ZQ_f(\bar{Q}_f)$

WHAT we are doing now ?

$$pp \rightarrow W + c - jet + X$$





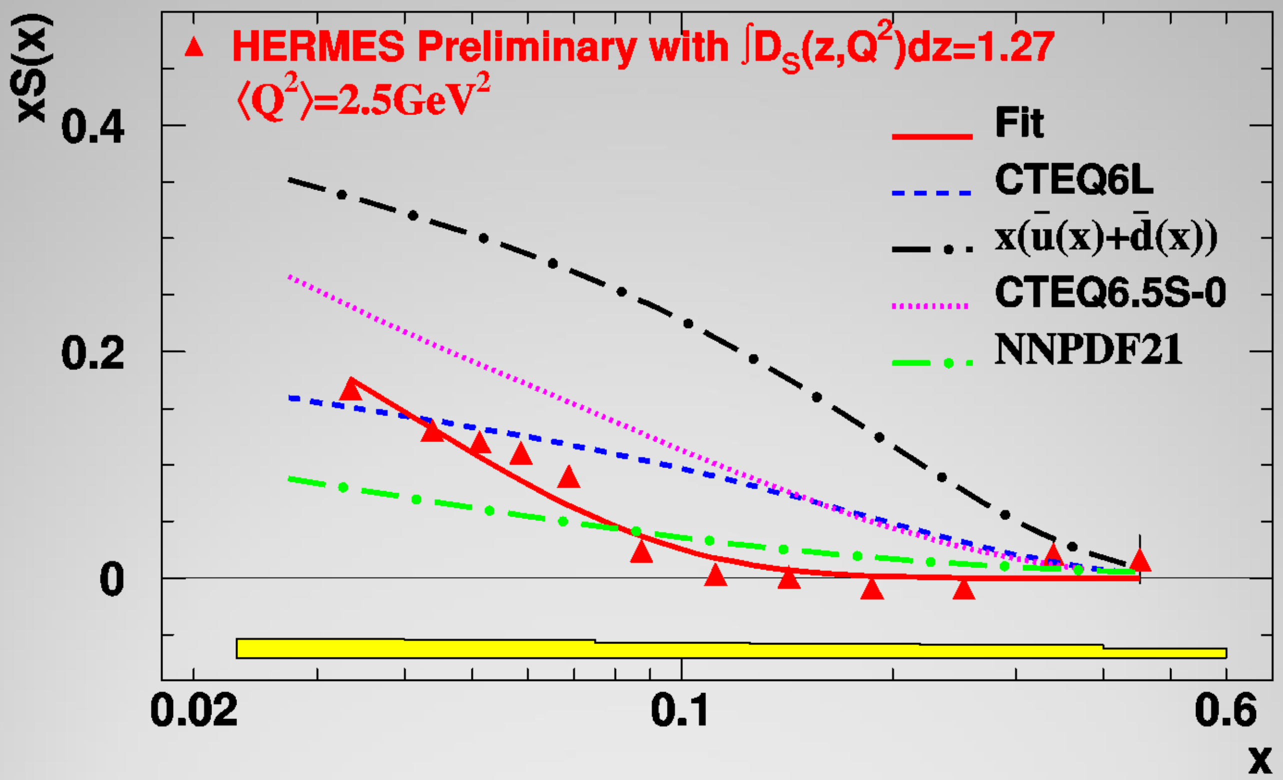


G.L., A.A.Grinyuk, I.V.Bednyakov, Proc. Baldin Conference, Dubna, Sept. 2012; C12-09-10.4; arXiv:1212.6381 [hep-ph].

The red line is the p_T- spectrum of K^- mesons produced in p-p at E_p =158 Gev, y=1.3 (top) and y=1.7 (bottom) without IC ; the green curve is the same as the red one but with the IC contribution, its probability is about 2.5 %.

The dotted line corresponds to the ratio of the spectra with IC and without IC minus 1.

The IC signal is about 200 % at high transverse momenta



HERMES Preliminary with $\int D_S(z,Q^2)dz=1.27$
$\langle Q^2\rangle=2.5GeV^2$
Fit
CTEQ6L
$x(\bar{u}(x)+\bar{d}(x))$
CTEQ6.5S-0
NNPDF21
xS(x)
0.4
0.2
0
0.02
0.1
0.6
x

SEARCH FOR INTRINSIC STRANGENESS IN P-P

$$pp \longrightarrow K^{+,-,0} X$$

At $x_F = \frac{2p_t}{\sqrt{s}} \sinh(\eta)$ above 0.1

there can be an enhancement due to the **IS.**

It means that the possible IS signal depend on $\frac{p_T}{\sqrt{s}}$

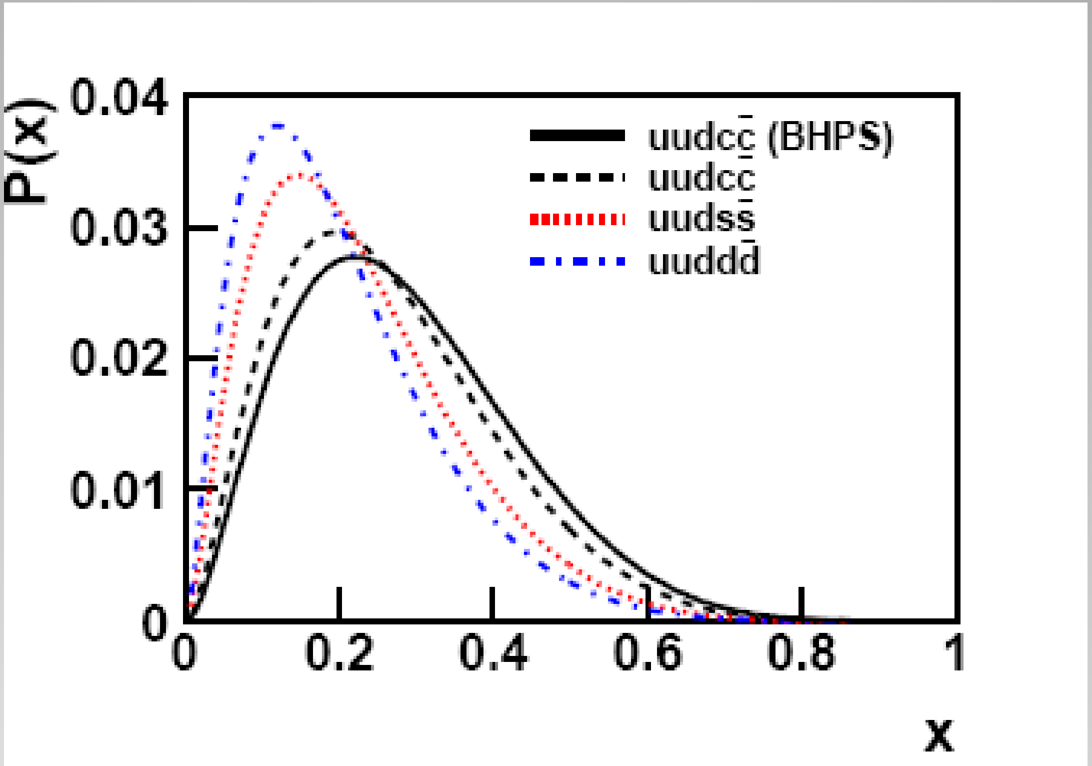
and does not depend on $\sqrt{s}$

$K^+(u\bar{s}); K^-(\bar{u}s)$

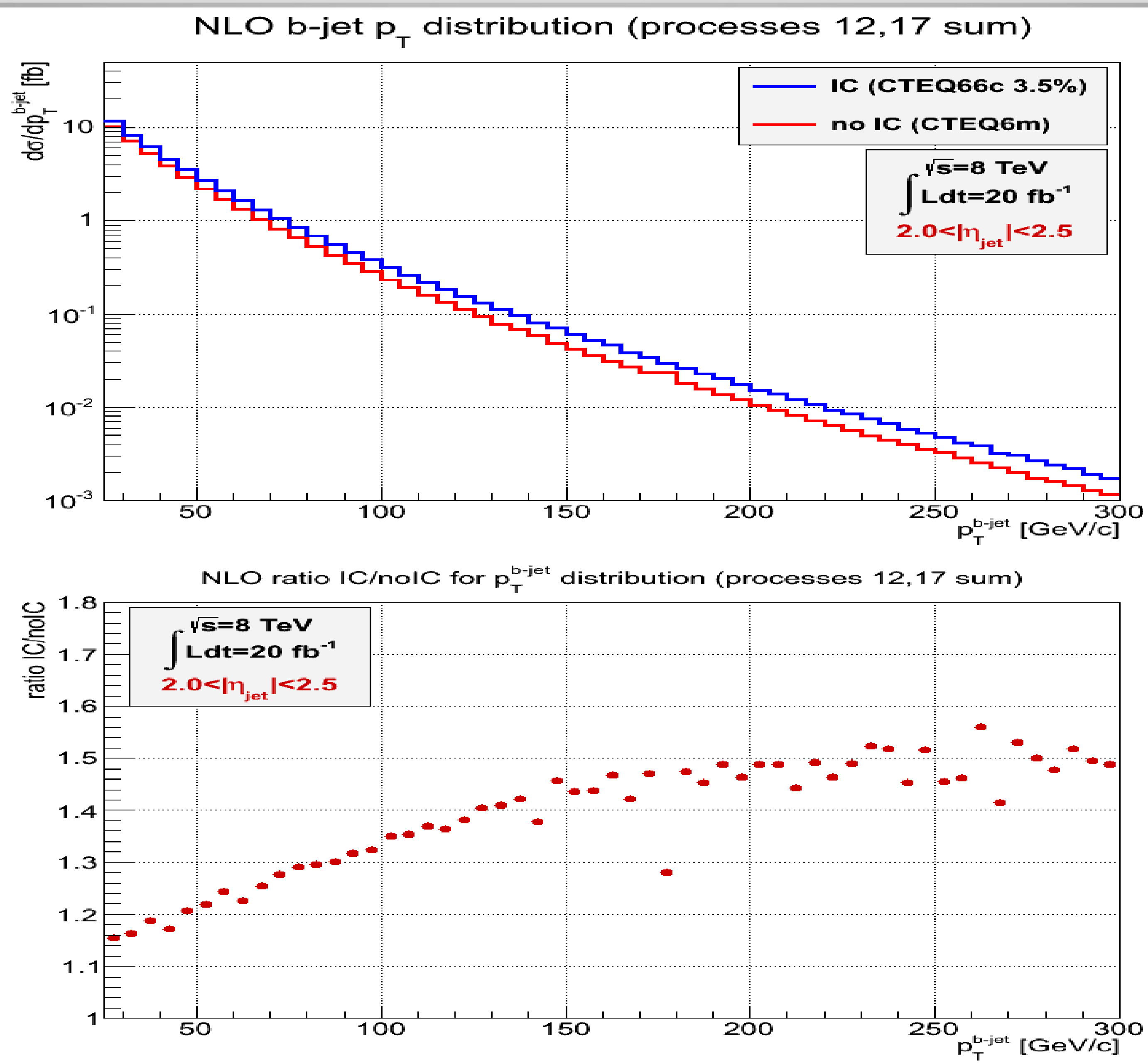
Therefore, it makes the certain sense to measure K^- mesons in p-p collisions at

NA61, CBM & NICA

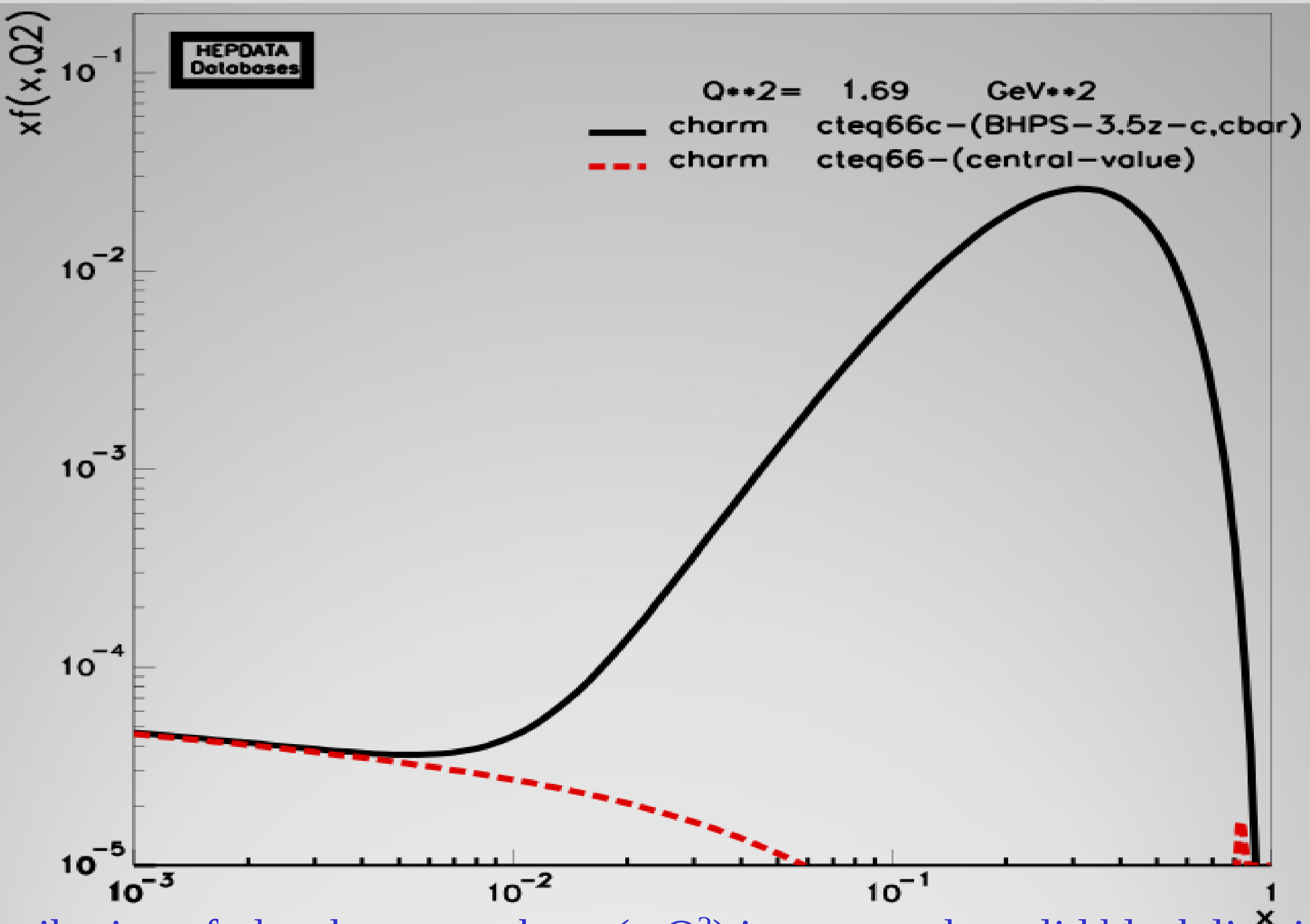
to observe a possible intrinsic strangeness in the proton



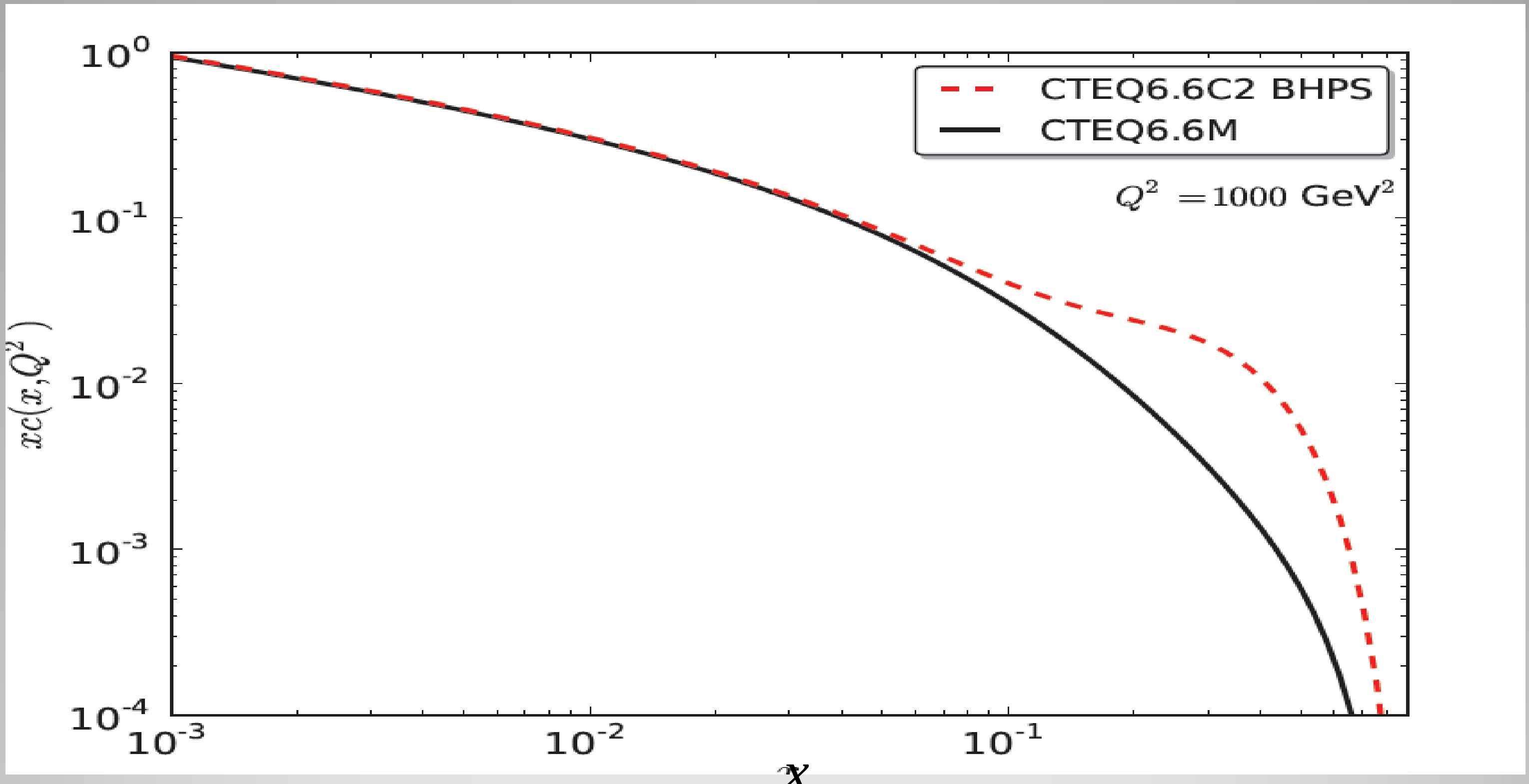
The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.



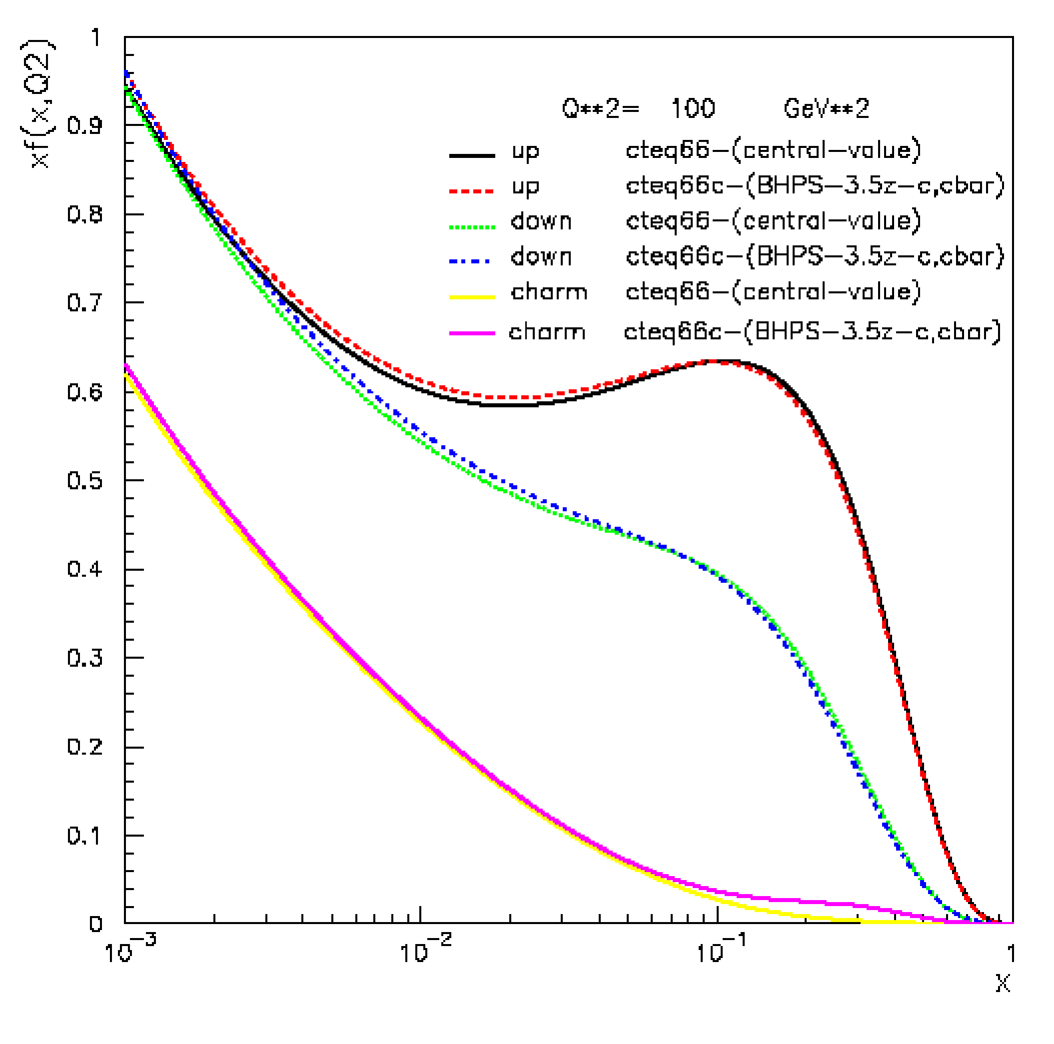
NLO b-jet p_T distribution (processes 12,17 sum)
$d\sigma/dp_T^{b\text{-}jet}$ [fb]
IC (CTEQ66c 3.5%)
no IC (CTEQ6m)
$\sqrt{s}$=8 TeV
$\int$Ldt=20 fb^{-1}
2.0<|η_{jet}|<2.5
$p_T^{b\text{-}jet}$ [GeV/c]
NLO ratio IC/noIC for $p_T^{b\text{-}jet}$ distribution (processes 12,17 sum)
ratio IC/noIC
$\sqrt{s}$=8 TeV
$\int$Ldt=20 fb^{-1}
2.0<|η_{jet}|<2.5
$p_T^{b\text{-}jet}$ [GeV/c]



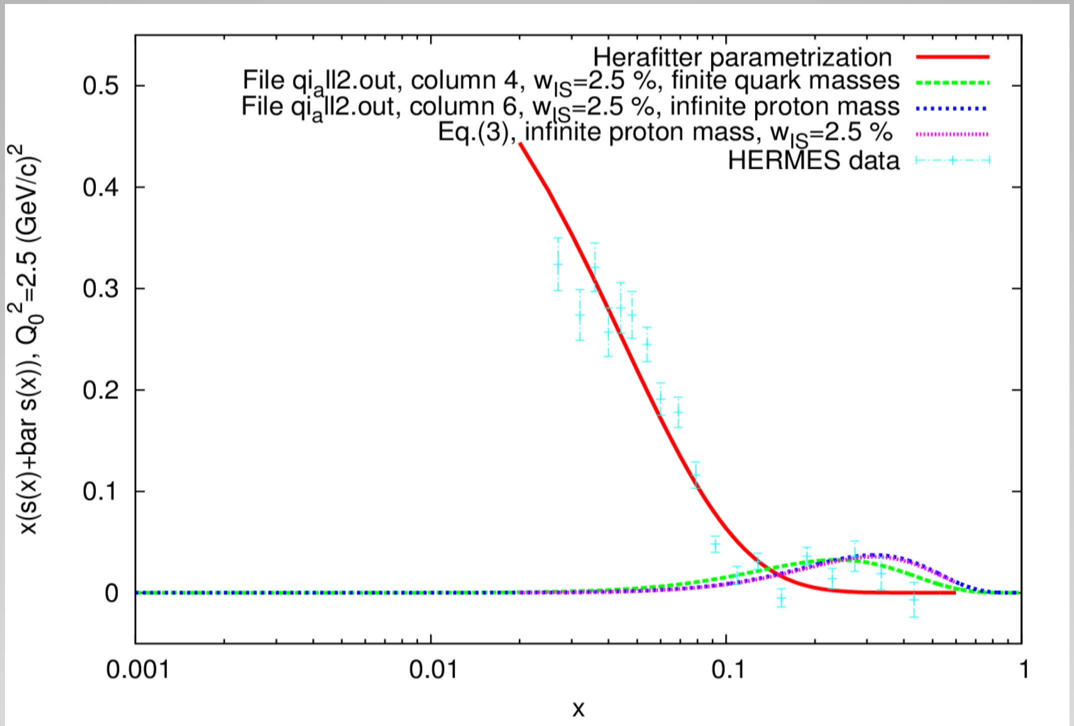
The x-distribution of the charm quarks $xc(x,Q^2)$ in proton; the solid black line is the IC contribution with its probability about 3.5 %, the dash green curve is the see charm quark contribution xc_{sea} (x,Q^2) at Q^2=1.69 GeV^2. There is enhancement at x>0.1.



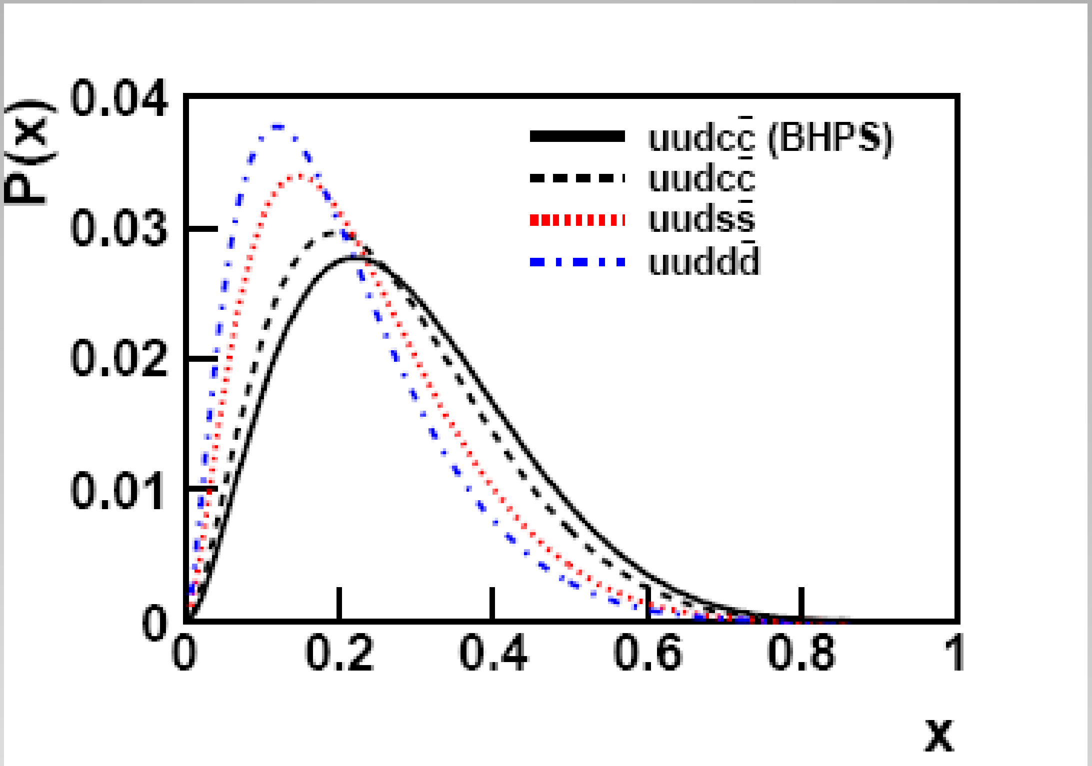
The x-distribution of the charm quarks $xc(x,Q^2)$ in the proton at Q^2=1000 GeV^2 ; the solid black line is the radiatively generated charm density $xc_{rg}(x,Q^2)$ distribution only , whereas the dashed curve is the sum of $xc_{rg}(x,Q^2)$ and the intrinsic charm density $xc_{in}(x,Q^2)$ with its probability about 3.5 %. **There is the sizable enhancement at x > 0.1**.



xf(x,Q2)
Q**2= 100 GeV**2
up cteq66-(central-value)
up cteq66c-(BHPS-3.5z-c,cbar)
down cteq66-(central-value)
down cteq66c-(BHPS-3.5z-c,cbar)
charm cteq66-(central-value)
charm cteq66c-(BHPS-3.5z-c,cbar)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^{-3}
10^{-2}
10^{-1}
1
X



Comparison of the HERMES data with calculation within the BHPS at Q^2 about 2.5 Gev^2, μ is the QCD scale. A.Airapetian, et al., Phys.Lett.B666 (2008) 446; J.Peng, W.Cheng, hep-ph/1207.2193.



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.