SEARCH FOR INTRINSIC CHARM IN HARD HADRON PROCESSES AT ATLAS: STATUS AND PERSPECTIVES

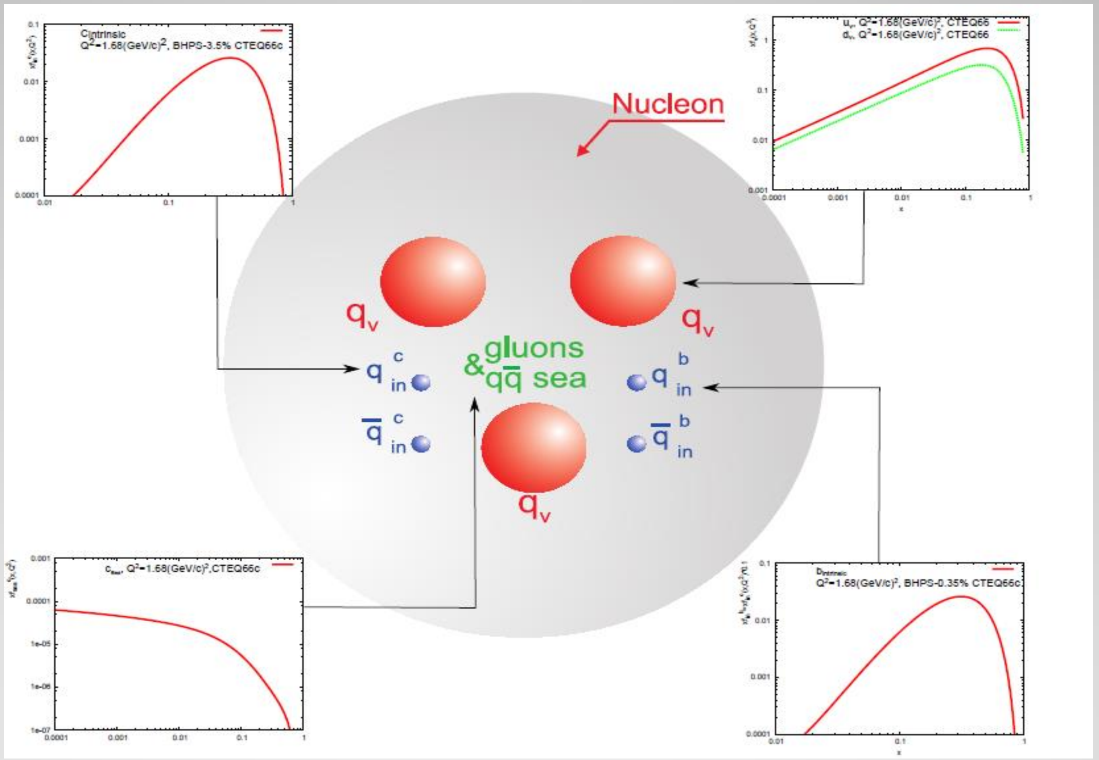
Gennady Lykasov
in collaboration with
Hugo Beauchemin[1],
Vadim Bednyakov[2],
Artem Lipatov[3],
Yuri Stepanenko[2]
[1]Tufs University, USA
[2]JINR, Dubna
[3]SINP, SMU, Moscow

OUTLINE

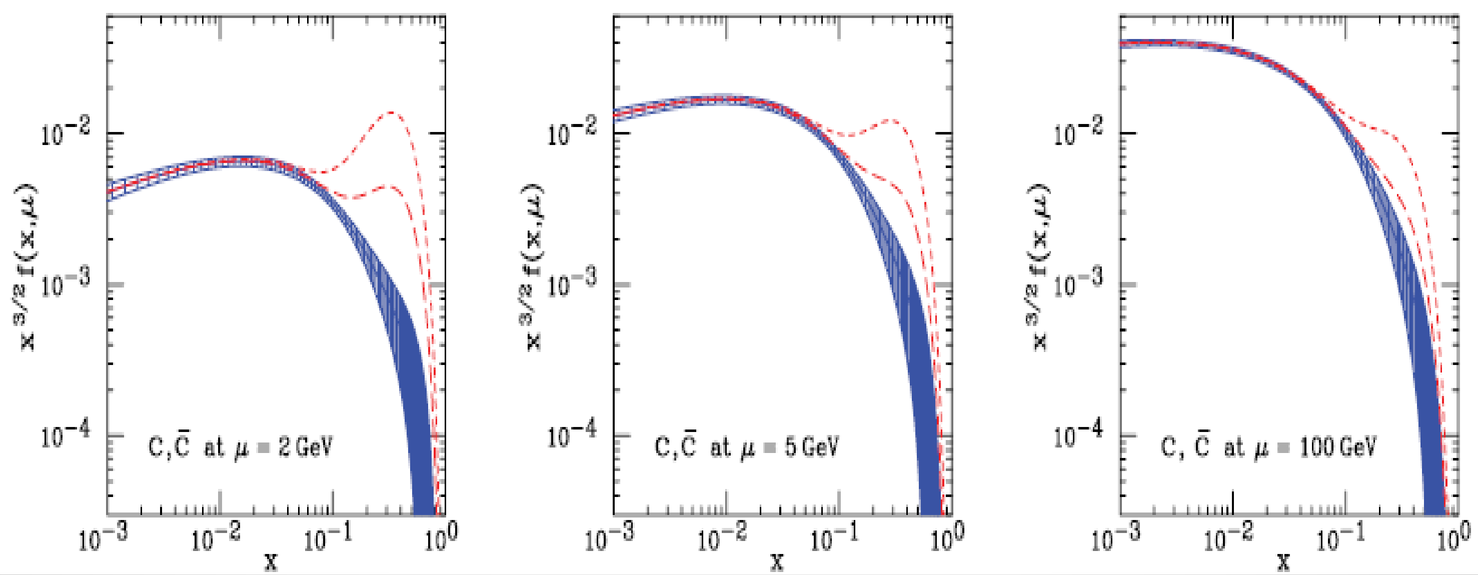
1. **Intrinsic heavy flavour in proton**
2. **Main goal of our study**
3. **New theoretical predictions on the search of intrinsic charm (*IC*) signal in production of γ + c(b) and Z/W+c(b) in p-p at $s^{1/2}$ =8,13 TeV**
4. **Status of ATLAS experiments on possible observation of *IC* signal in these hard processes**
5. **Perspectives of searching of the *IC* signal at ATLAS experiments**

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



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.

STATUS OF SEARCHING FOR INTRINSIC CHARM AT ATLAS EXPERIMENTS

I. **We have predictions on**

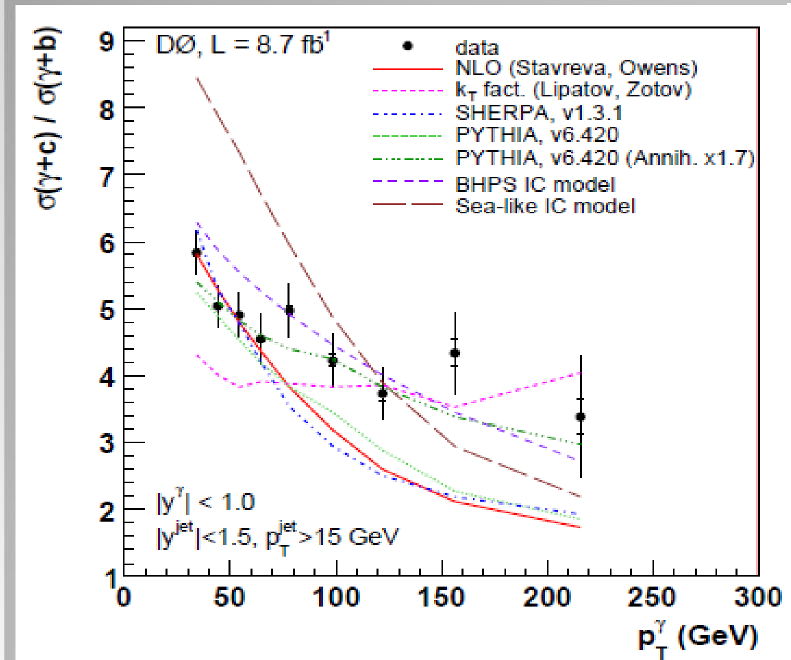
PP->γ + c +X *V.A.Bednyakov, M.A.Demichev,G.L.,T.Stavreva, M.Stockton, Phys.Lett. B728, 602 (1914)*

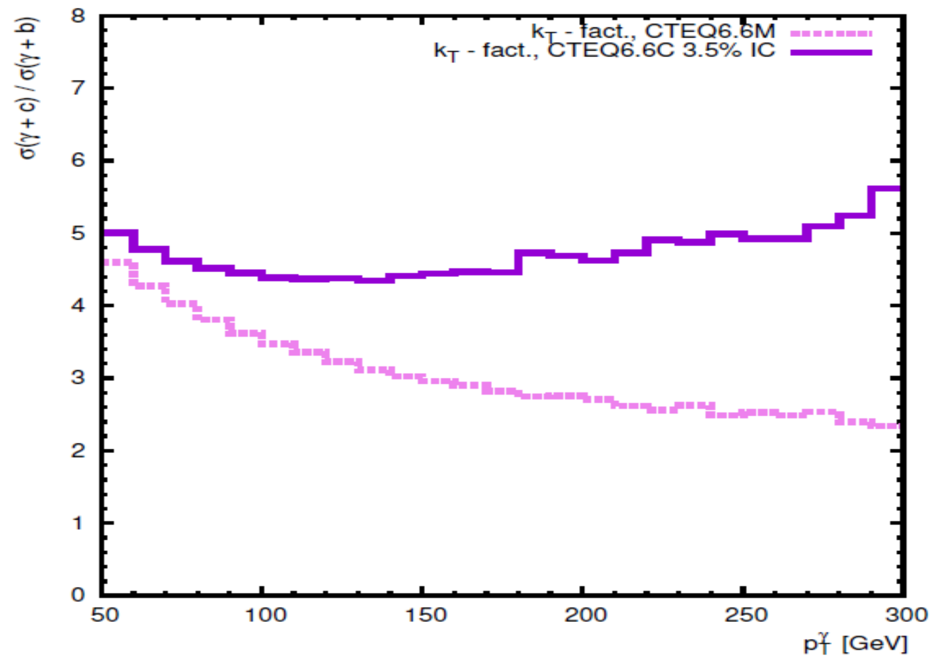
and ***PP->Z/W+ c(b)+X*** *H.Beauchemin, V.A.Bednyakov,G.L., Yu. Yu. Stepanenko, Phys.Rev.D92, 034014 (2015)*

Status of this research

II. **Data analysis on $\gamma + c$ production in p-p at $s^{1/2} = 8$ TeV is performed by many people, for example,**
Juraj Smiesko from Bratislava University
Robert Keys from McGill University, Canada
There are already very preliminary data which were presented at CRERN informal meetings.
III. **Data analysis on $\gamma + b$ produced in p-p at 8 TeV.**
IV. **Data analysis on *Z* and *W* bosons accompanied by heavy flavour jets *c* and *b* is started by**
Juri Stepanenko, Evelin Meoni (CERN), Hugo Beauchemin (Tifs University, USA)

New results on γ + c production in p-p





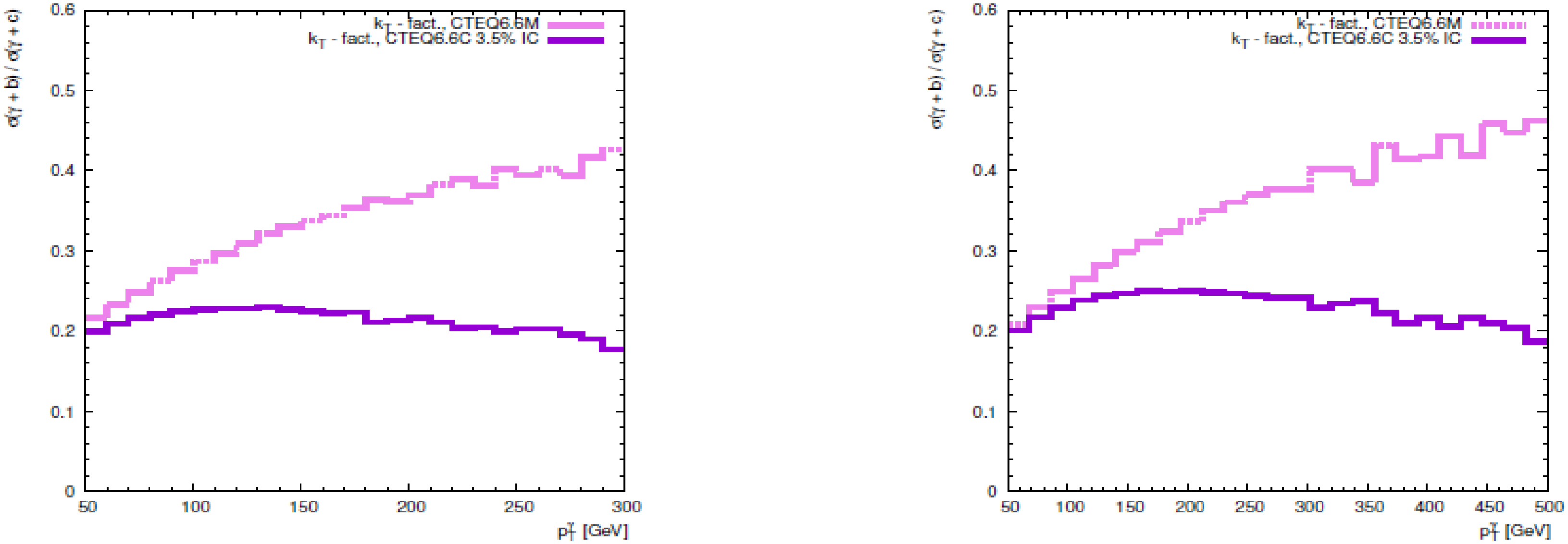
Ratio of differential cross sections of γ +c and γ +b productions as function of photon trancsverse momentum

Left : ***D0 data from TEVATRON and theoretical calculations***

D0 Collaboration, Phys. Lett. B **719**, 354 (2013); arXiv:1210.5033 [hep-ex].

Right: ***our latest predictions with the IC (top line) and without it (bottom line)***

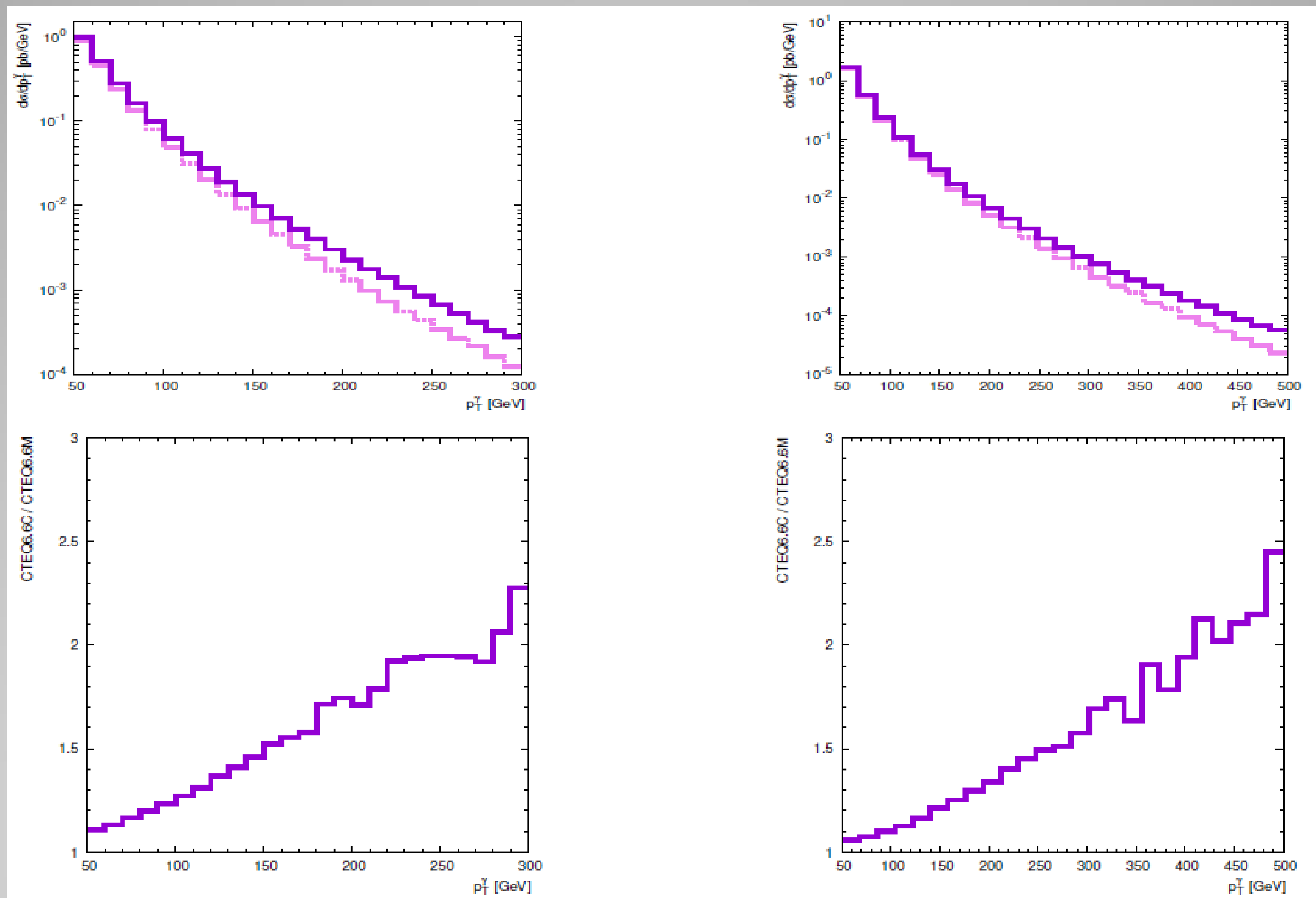
pp -> γ+c(b)+X



The ratio $\sigma(\gamma+b)/\sigma(\gamma+c)$ as a function of the photon transverse momentum at $1.5 < |y^\gamma| < 2.4$, $|y^{\rm jet}| < 2.4$, $p_T^{\rm jet} > 20$ GeV, $\sqrt{s} = 8$ TeV (left panel) and $\sqrt{s} = 13$ TeV (right panel)

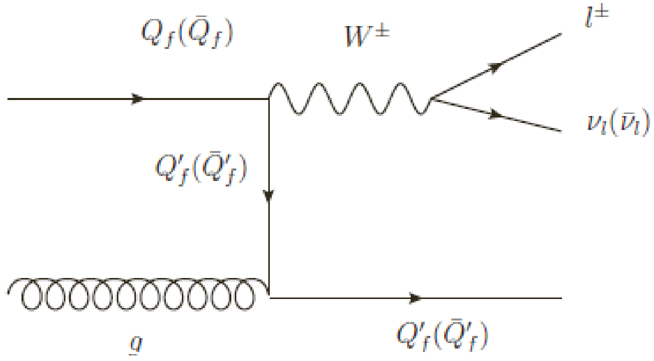
One can see a grow of this ratio by increasing of p_T^γ, when the intrinsic charm contribution (*IC*) in PDF is ignored. This ratio is approximately flat or slowly decreasing when the *IC* about 3.5 % is included. That is an additional *IC* signal, which could be measered at ATLAS.

pp ->γ+D +X*

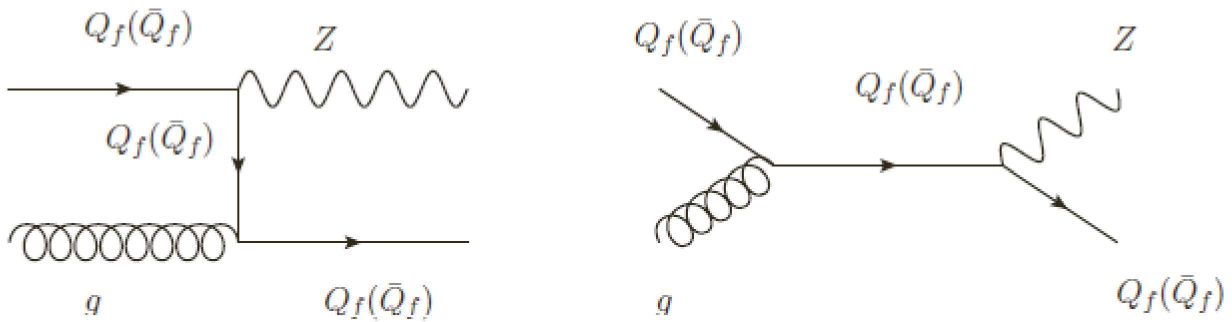


Top: p_T –spectra of a photon at $s^{1/2}$ =8 Tev (left) and 13 TeV(right)
Bottom: ratio of p_T –spectra with IC (3.5%) and without it at 8 TeV (left) and 13 TeV (right).

pp →Z/W + heavy flavour jets

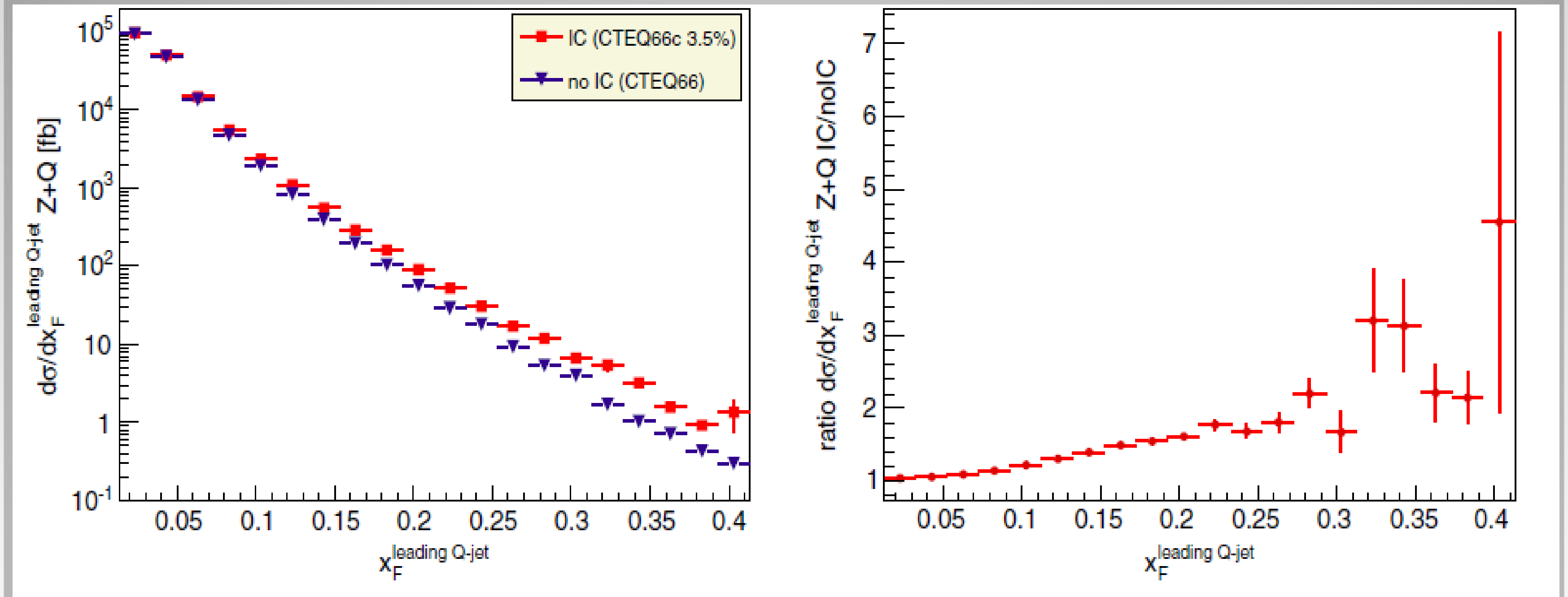


The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^\pm Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.



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

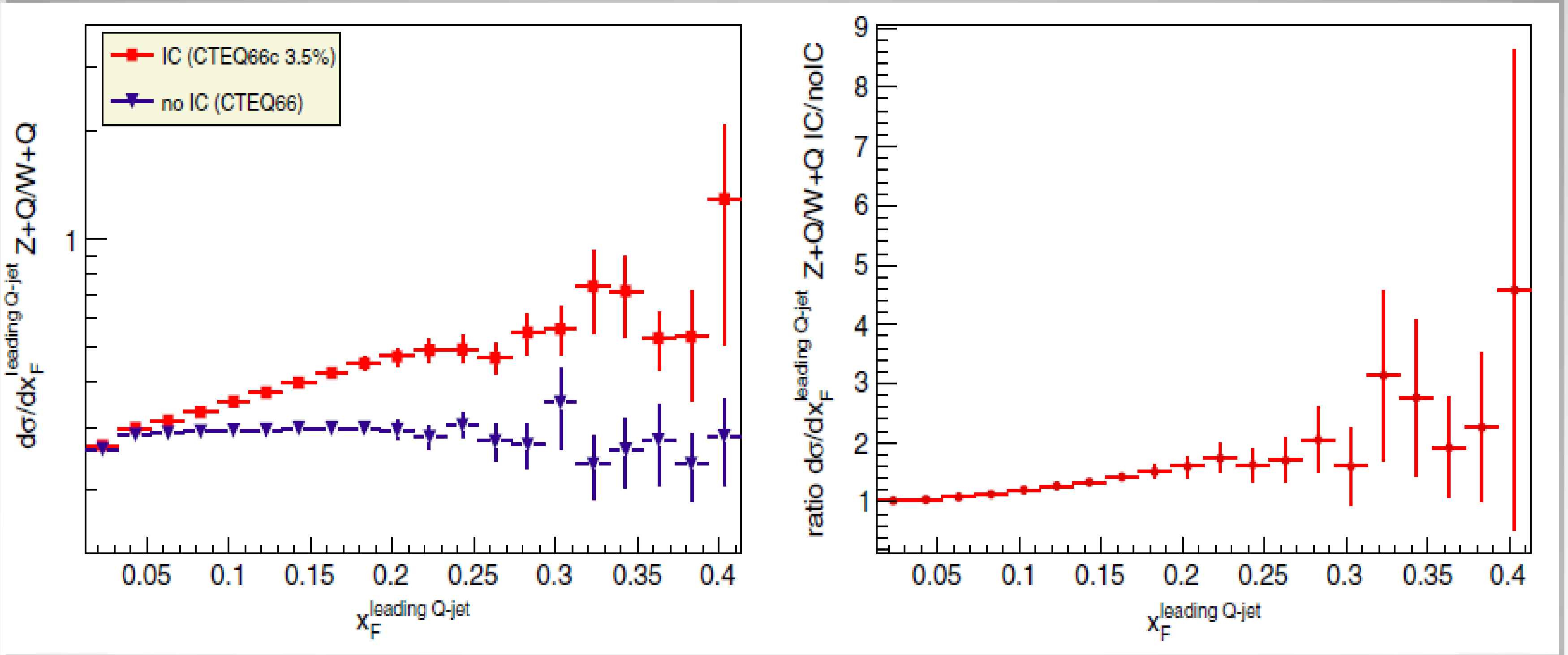
New results on Z+Q production in pp at $s^{1/2}$ =8 TeV (Q=c,b)



Left: x_F –spectra of leading *c* or *b* jet with the *IC* (red line) and without it (blue line).

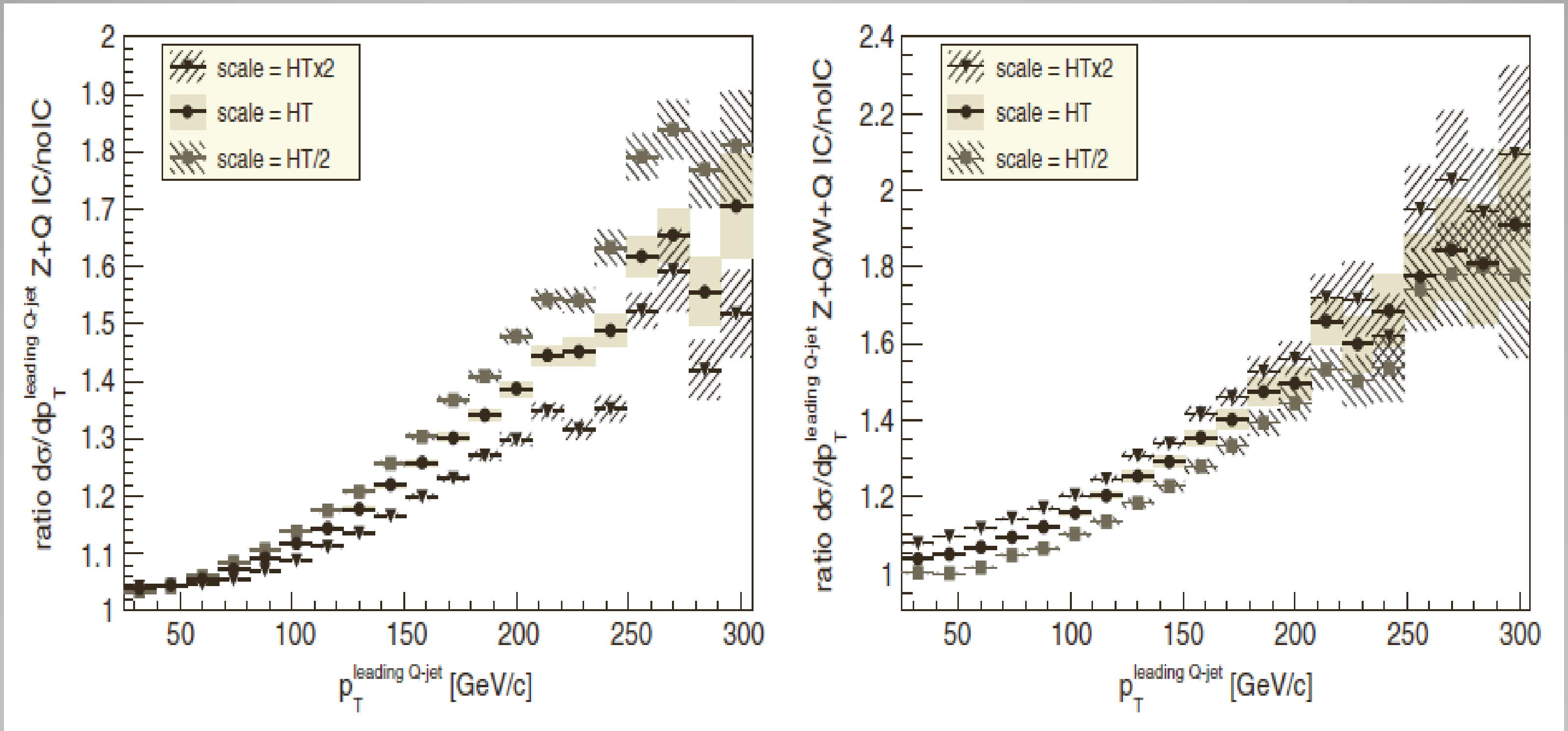
Right: ratio of *Z+Q* spectra with *IC* and without it as a function of x_F .

New results on Z+Q/W+Q at $s^{1/2}$ = 8 TeV



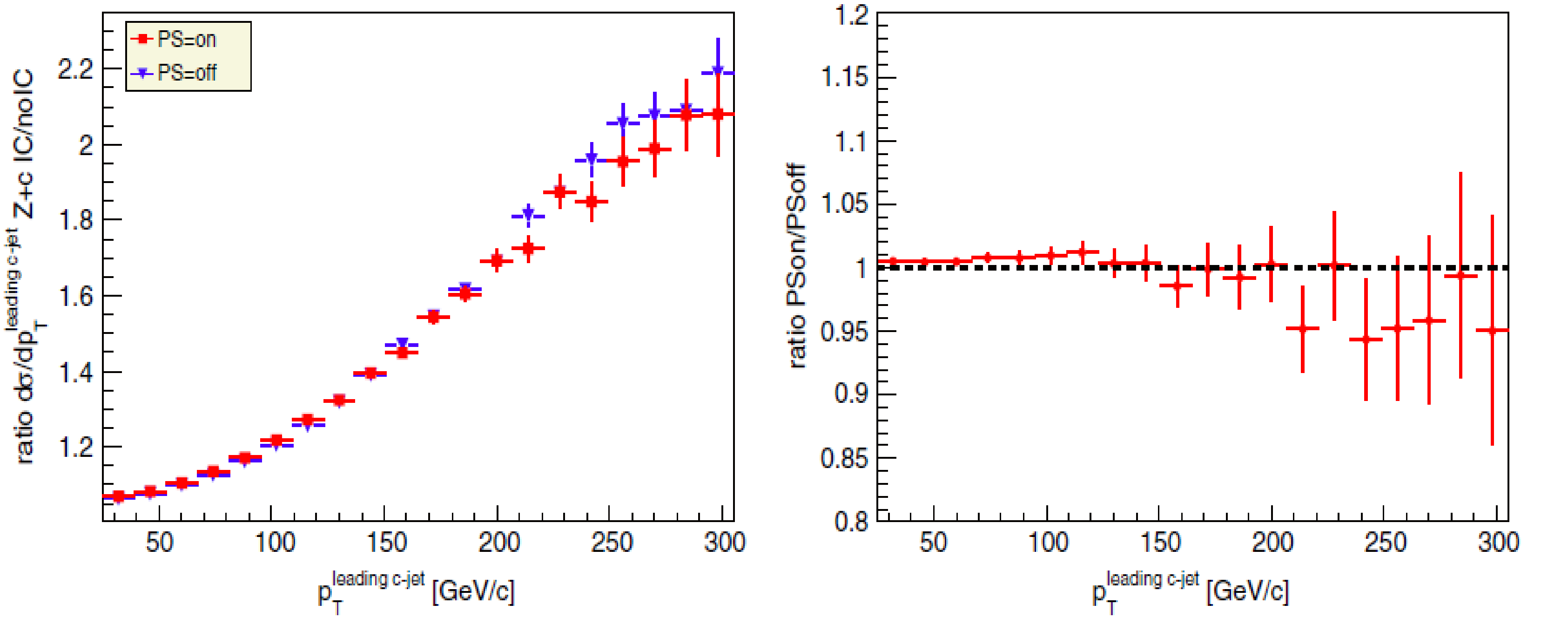
Left: ratio Z+Q/W+Q as a function of x_F of leading *c* or *b* jet with the *IC* (red line) and without it (blue line).
Right: double ratio of *Z+Q/W+Q* spectra with *IC* and without it as a function of x_F .

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

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*)

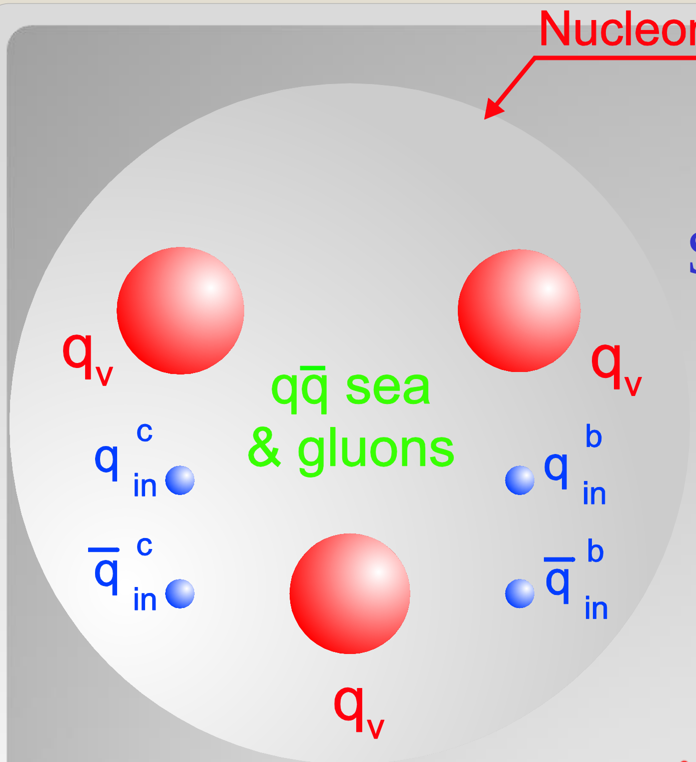
Right: ratio of red points to blue points

Perspectives of search for intrinsic charm at ATLAS

1. Informal photon group at ATLAS is going to finish the data analysis on $\gamma + c\ (b)$ production in p-p at 8 TeV and prepare a paper on it in the end of 2015 , and to do the similar analysis at 13 TeV in 2016.
2. We are doing the theoretical predictions on p_T – spectra of photons within different MC generators and QCD models including and ignoring the *IC* contributions with different values of the *IC* probability. Then, we will compare our calculations to data.
3. From this comparison we intend to extract the *IC* probability from the ATLAS data.
4. There is a plan to finish data analysis of *Z/W+c(b)* production in p-p at 8 TeV and prepare a paper in March 2016 , and turn to the similar analysis at 13 TeV.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP



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

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

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

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.

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

INTRINSIC HEAVY QUARK DISTRIBUTION IN PROTON

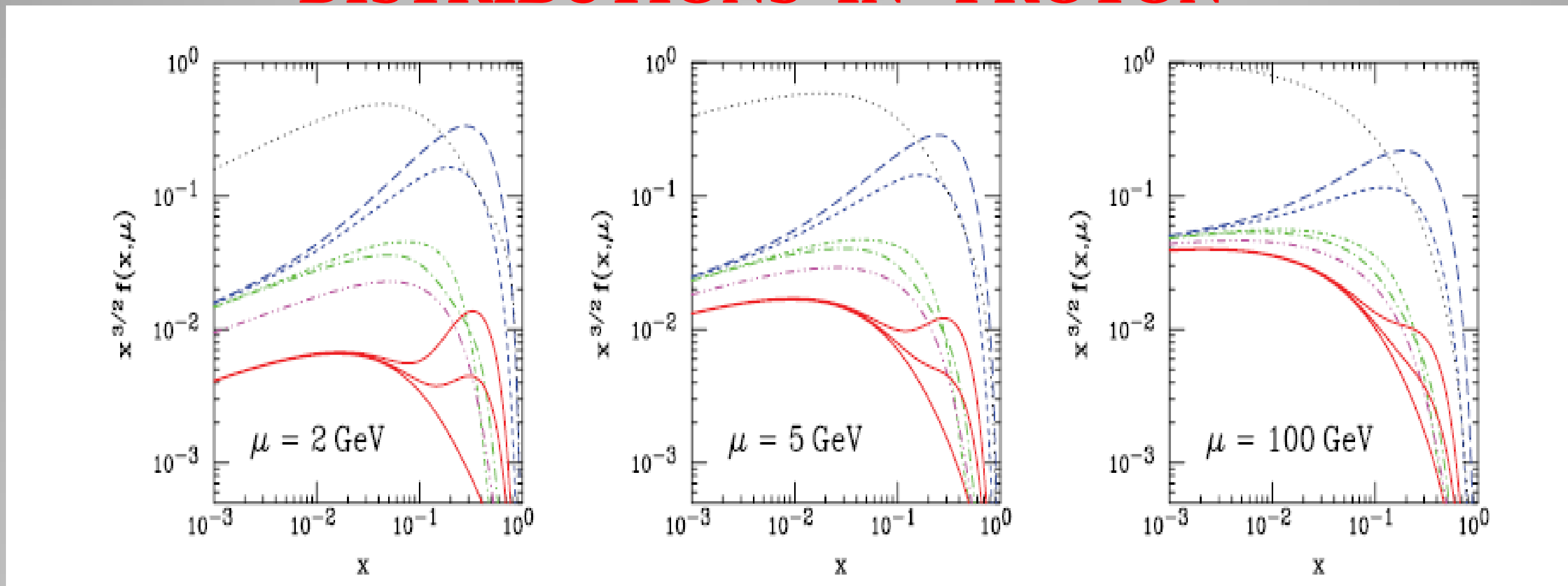
Integrating $P(x_1,\ldots,x_5)$ over $dx_1 \ldots dx_4$ and neglecting of all quark masses except the charm quark mass we get

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

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** $0 < x_5 < 1$

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

PRODUCTION OF HEAVY FLAVOURS IN HARD P-P COLLISIONS

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

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

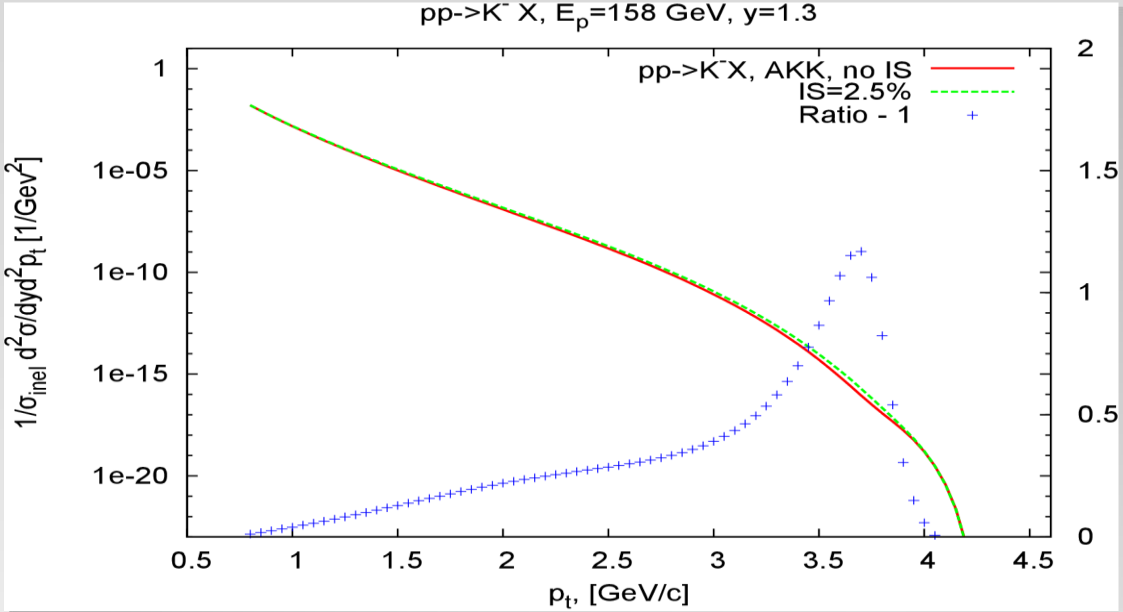
$$x_F\equiv\frac{2p_z}{\sqrt{s}}=\frac{2p_T}{\sqrt{s}}\frac{1}{\tan\theta}=\frac{2p_T}{\sqrt{s}}\sinh(\eta)$$

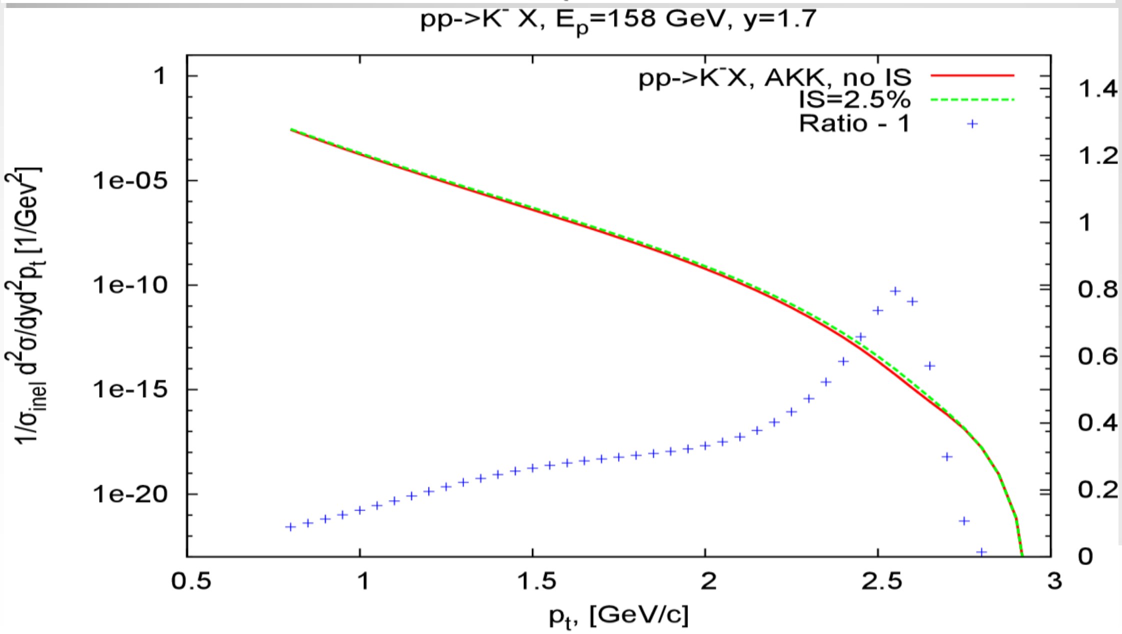
$$x_i^{min}=\frac{x_R+x_F}{2-(x_R-x_F)}$$

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

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.





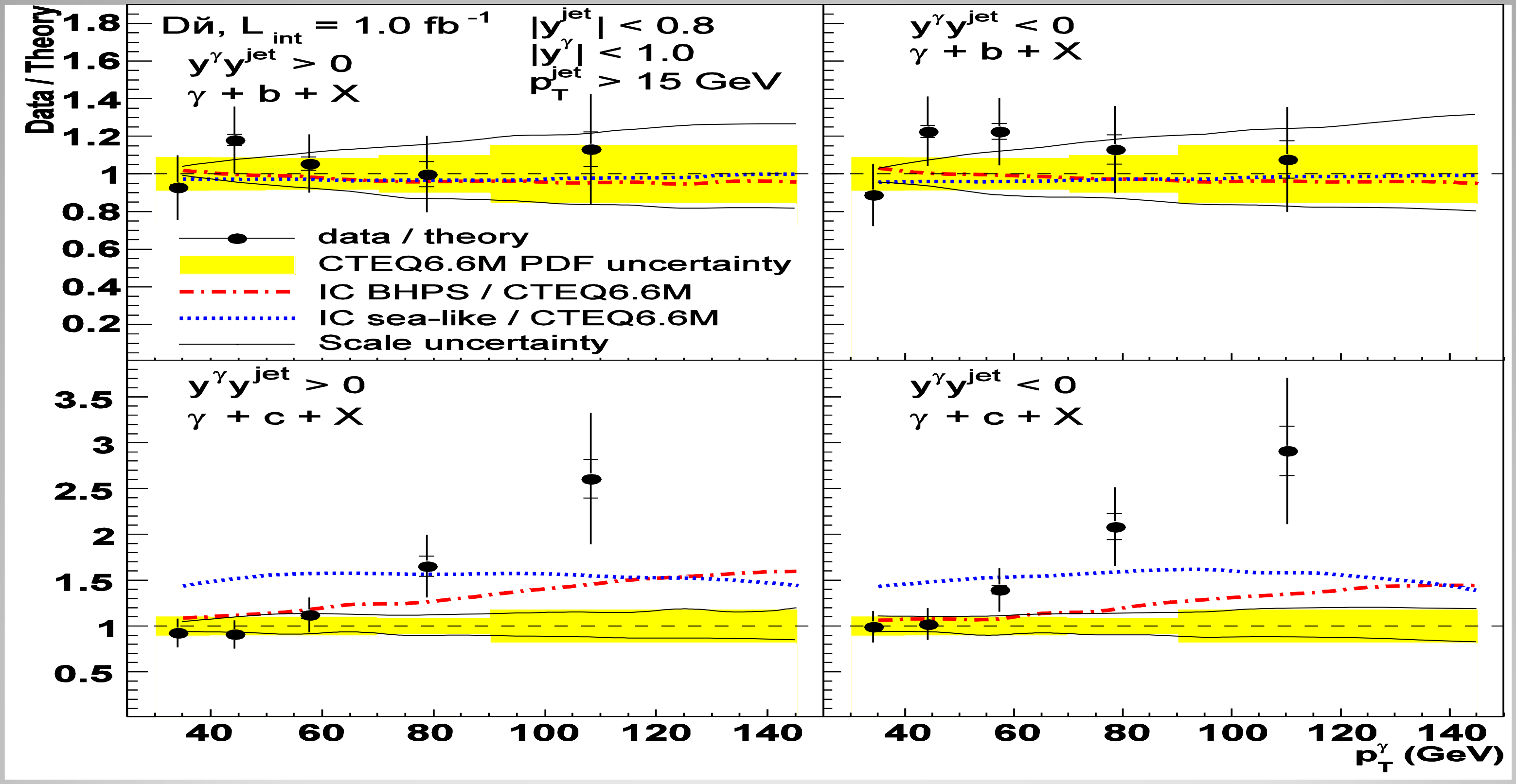
G.L., A.A.Grinyuk, I.V.Bednyakov, Proc. Baldin Conference, Dubna, Sept. 2012; C12-09-10.4; arXiv:1212.6381 [hep-ph].

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 coresponds to the ratio of the spectra with IC and without IC minus 1.

The IC signal is about 200 % at high transverse momenta

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



The data-to-theory ratio of cross sections as a function of p_T^γ for $p\bar{p} \to \gamma + c(b) + X$. There is the **three time excess** of the data above the theory for $\gamma + c$ at $p_T > 150 GeV/c$. **It stimulates us to study** $pp \to \gamma + c(b) + X$

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

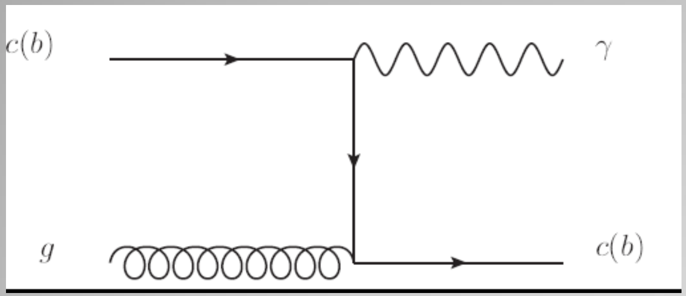


Fig.a. Feynman diagram for the process $c(b)+g\rightarrow\gamma+c(b)$

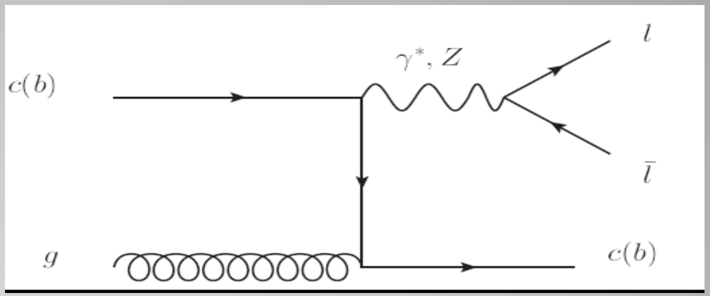


Fig.b. Feynman graph for the process $c(b)+g\rightarrow\gamma/Z^0+c(b)$

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

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

To observe the IC

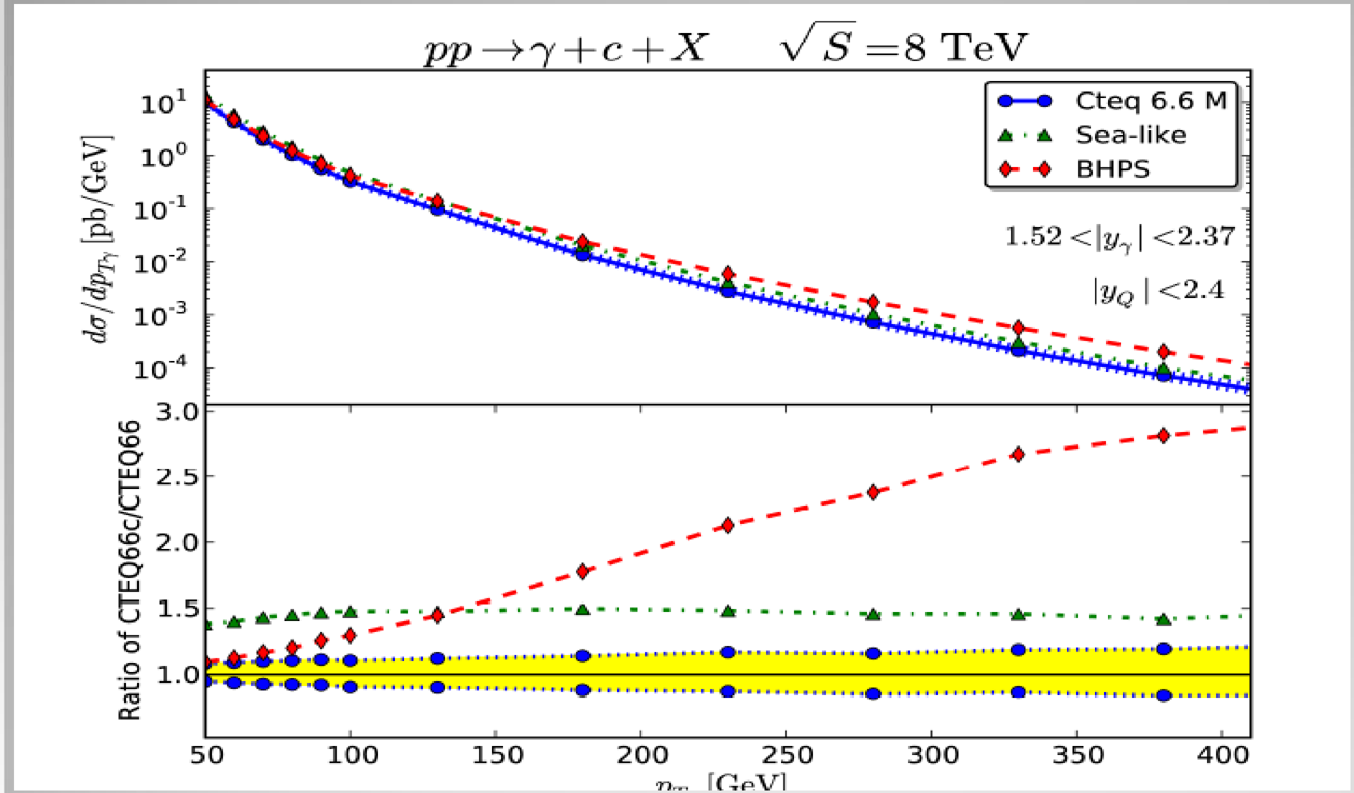
for Fig.a

$$x_c \geq x_F > 0.1$$

for Fig.b

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

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

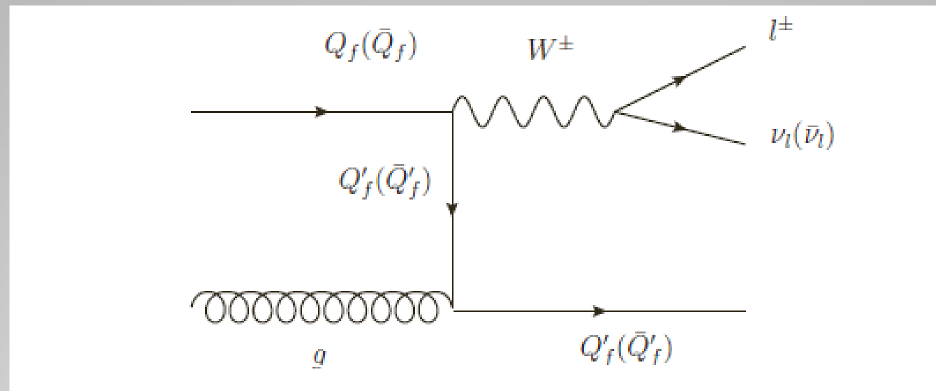
Phys.Lett. B728 (2014) 602.

p_T – distribution of photons produced in $pp \to \gamma + c(jet) + X$

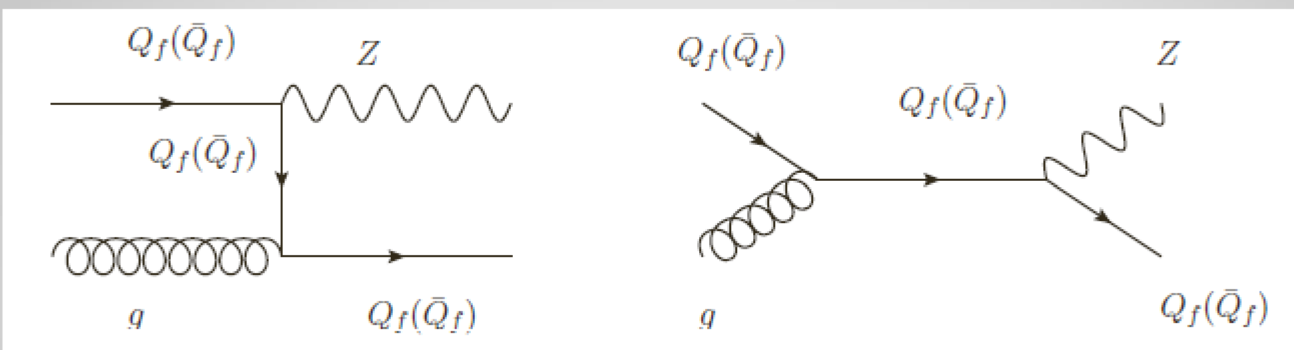
The blue line is calculation without the **IC.** The red curve includes the **IC,** its **probability is about 3.5 %** (top). The ratio of spectra with and without the **IC**

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

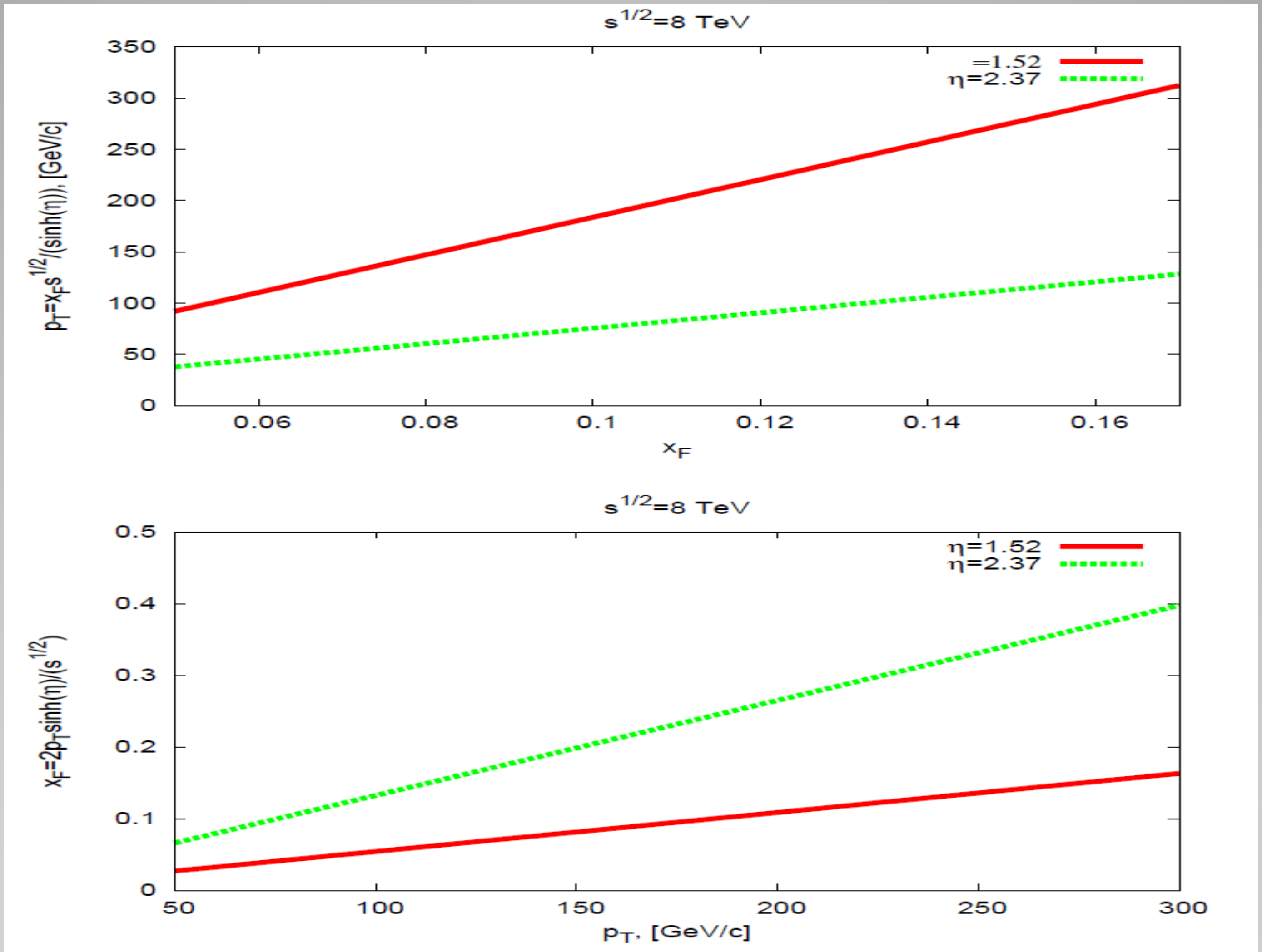
pp →W/Z+heavy flavour jets



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

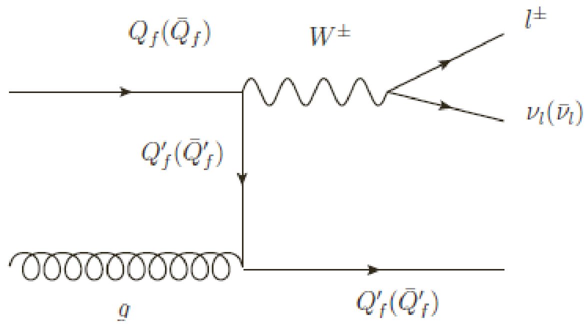


Figure 2: The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^{\pm}Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.

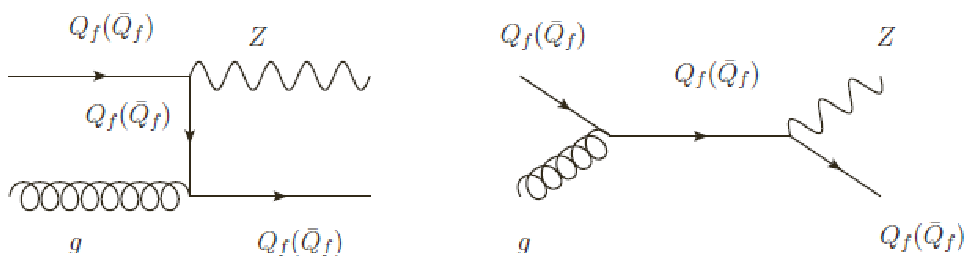
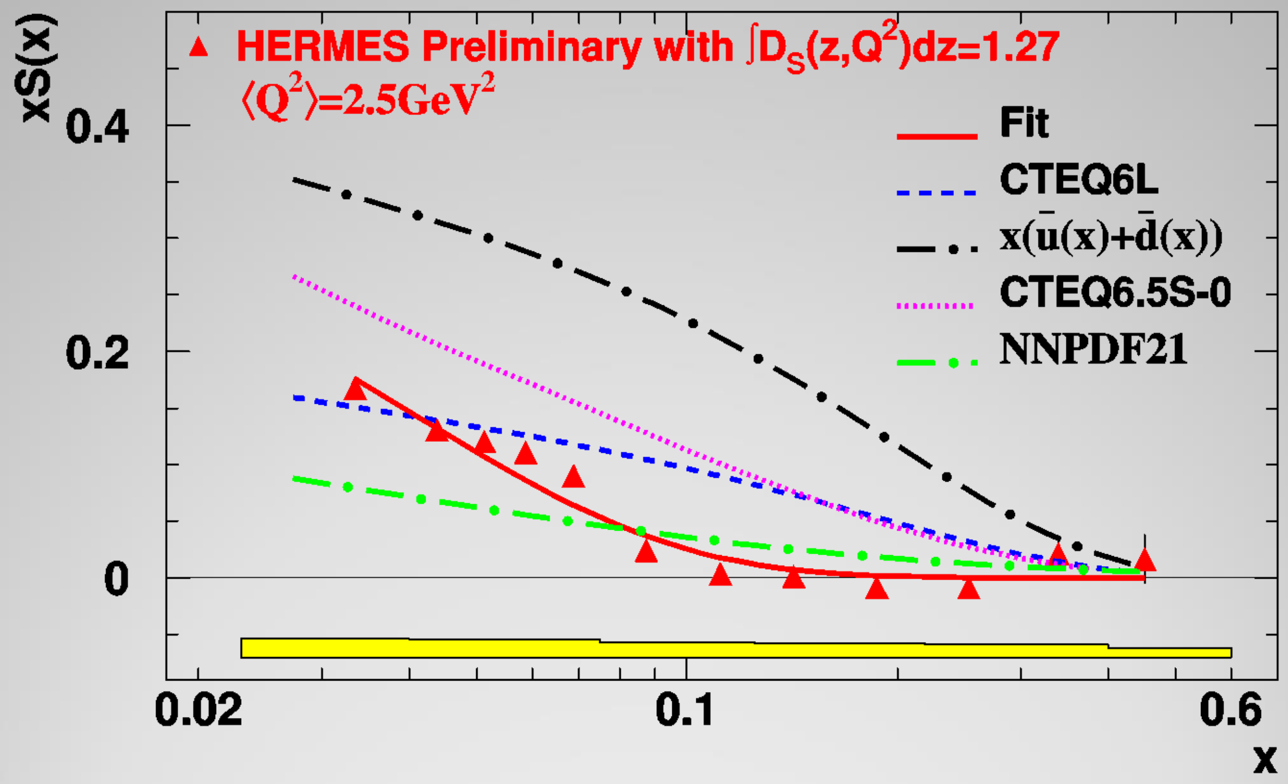


Figure 3: Feynman diagram for the process $Q_f(\bar{Q}_f)g \to ZQ_f(\bar{Q}_f)$

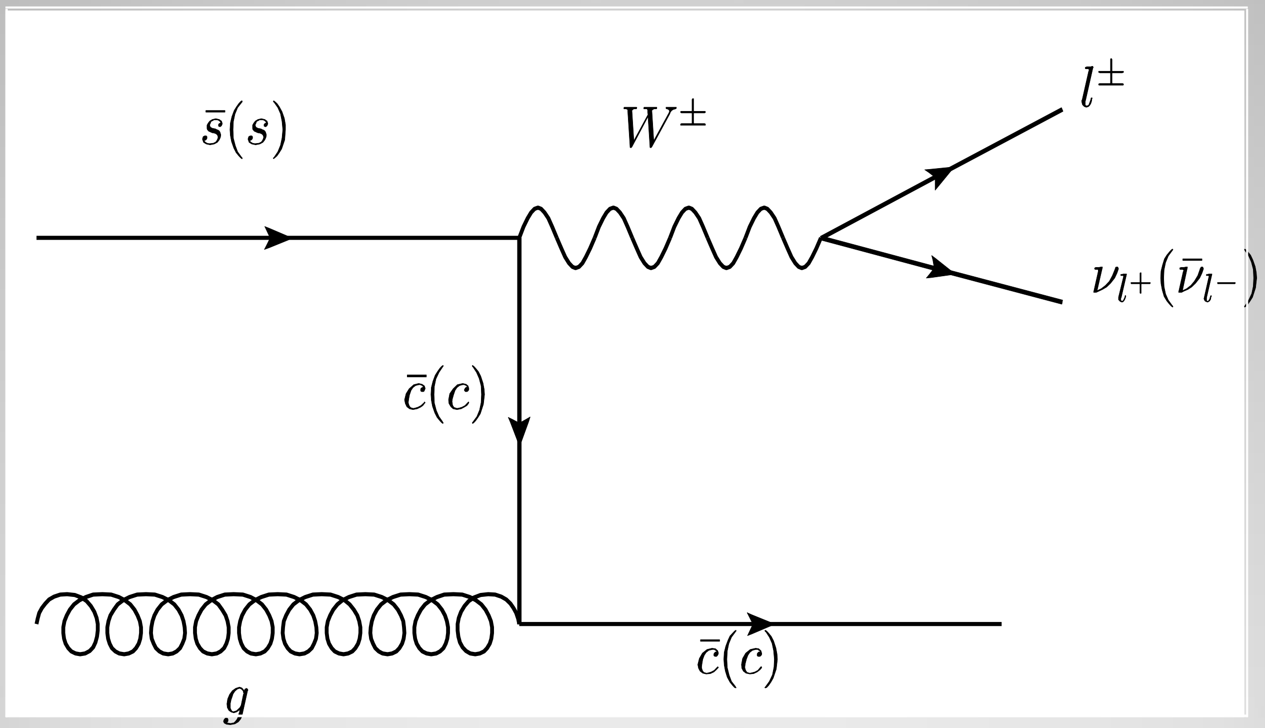
SUM MARY

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. It does not contribute to the heavy flavour production in p-p collisions at high energies.
2. The signal of the intrinsic charm (**IC**) and strangeness (**IS**) in proton can be studied in the inclusive open charm and open strangeness production in p-p at the LHC. The **IC** and **IS** 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** and **IS contributons** 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


HERMES Preliminary with ∫D_S(z,Q²)dz=1.27
⟨Q²⟩=2.5GeV²
Fit
CTEQ6L
x(ū(x)+d̄(x))
CTEQ6.5S-0
NNPDF21
xS(x)
0.4
0.2
0
0.02
0.1
0.6
x

WHAT we are doing now ?

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



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 $\frac{p_T}{\sqrt{s}}$

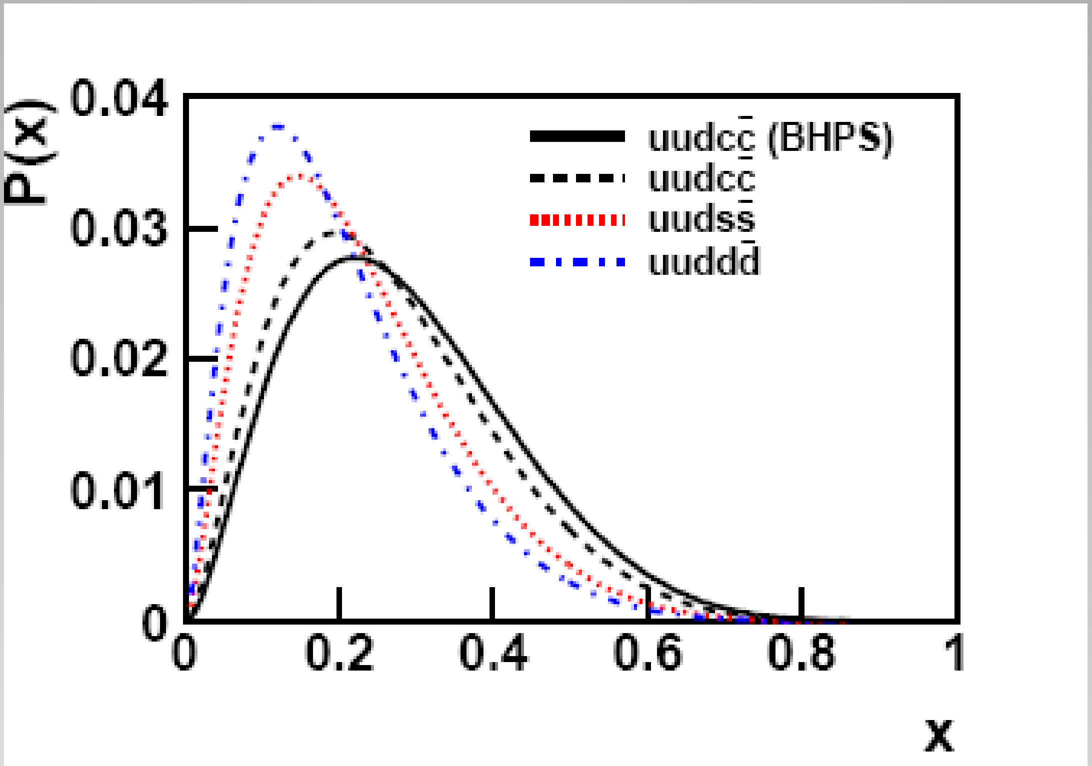
and does not depend on $\sqrt{s}$

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

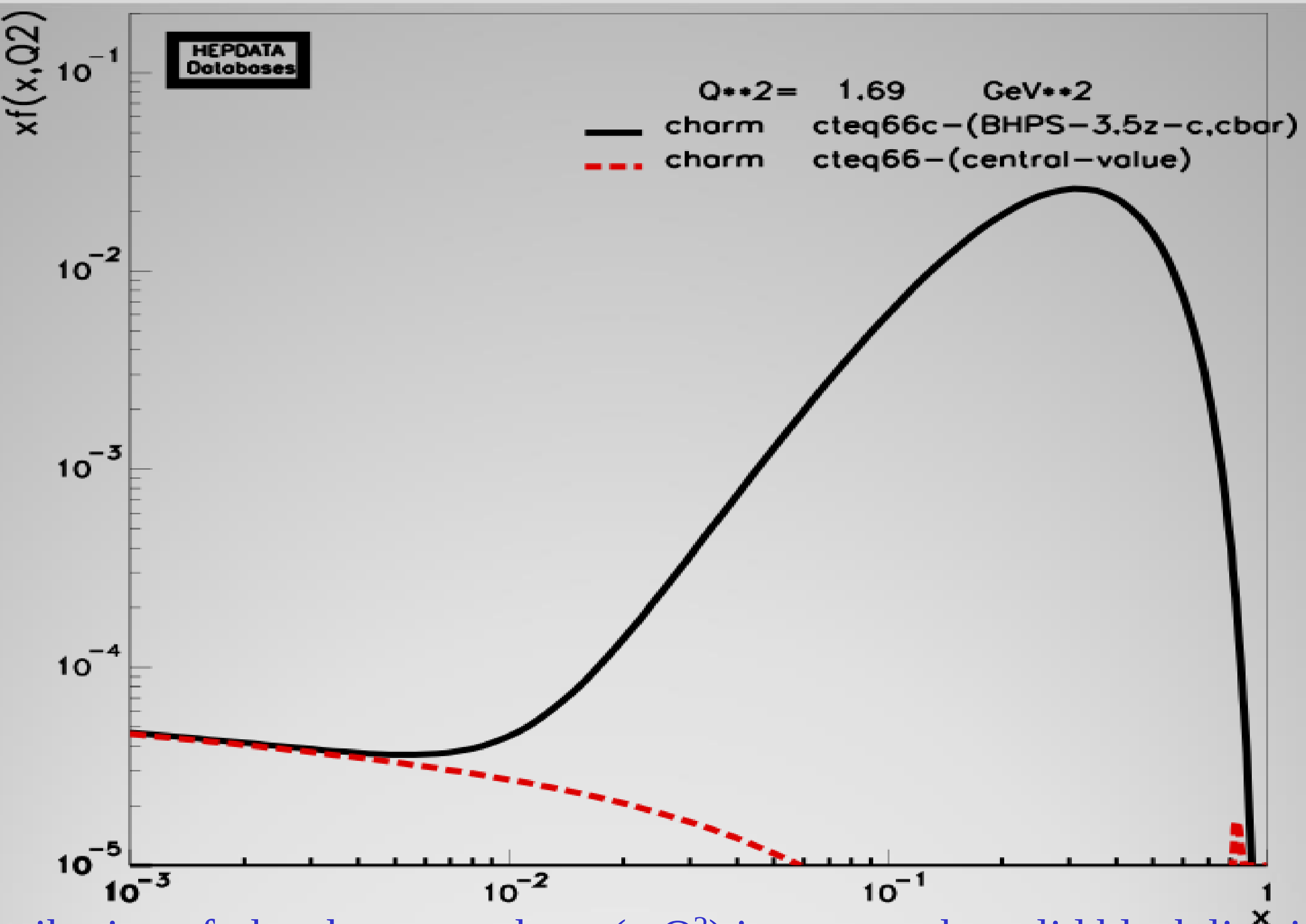
Therefore, it makes the certain sense to measure K^- mesons in p-p collisions at

NA61, CBM & NICA

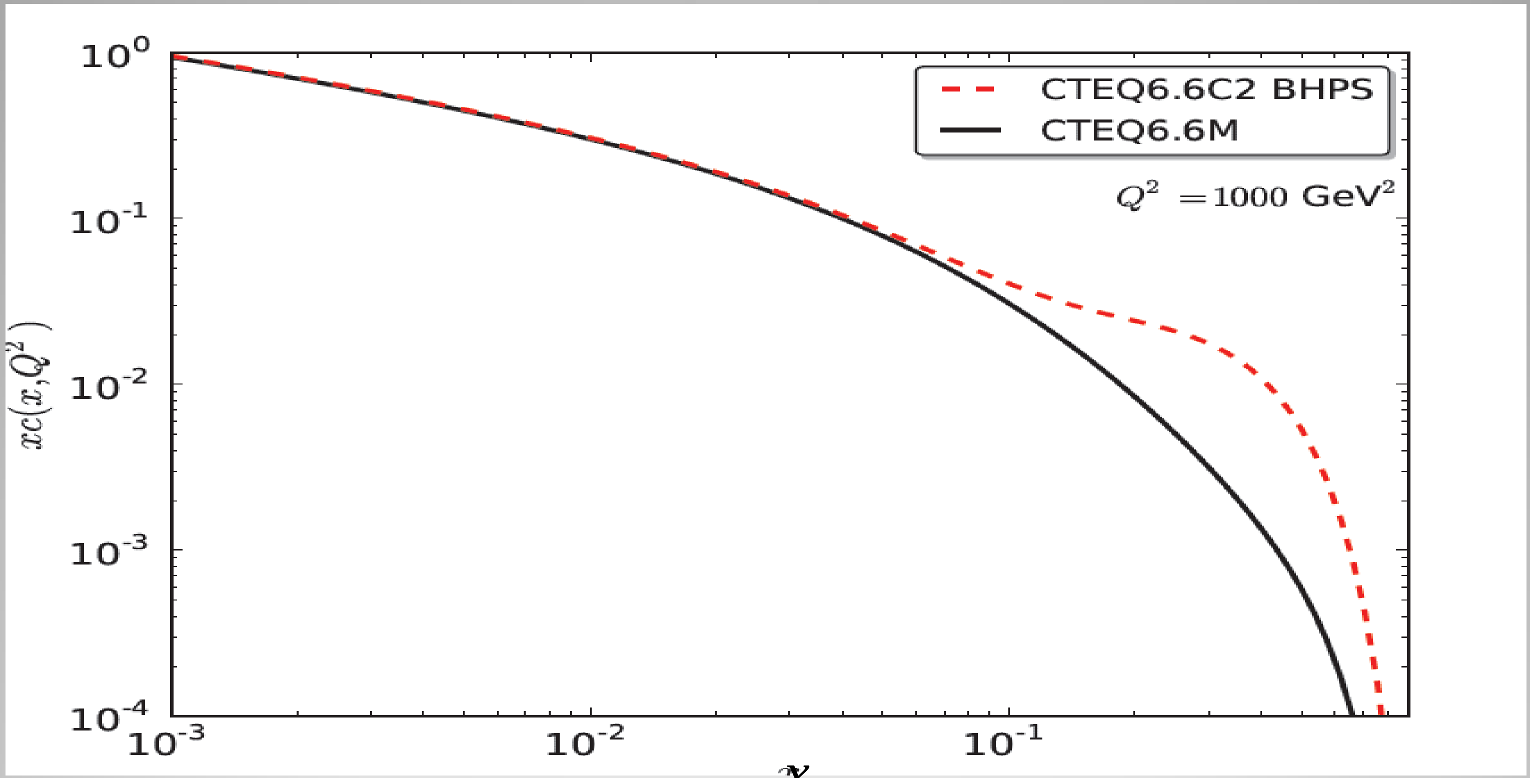
to observe a possible intrinsic strangeness in the proton



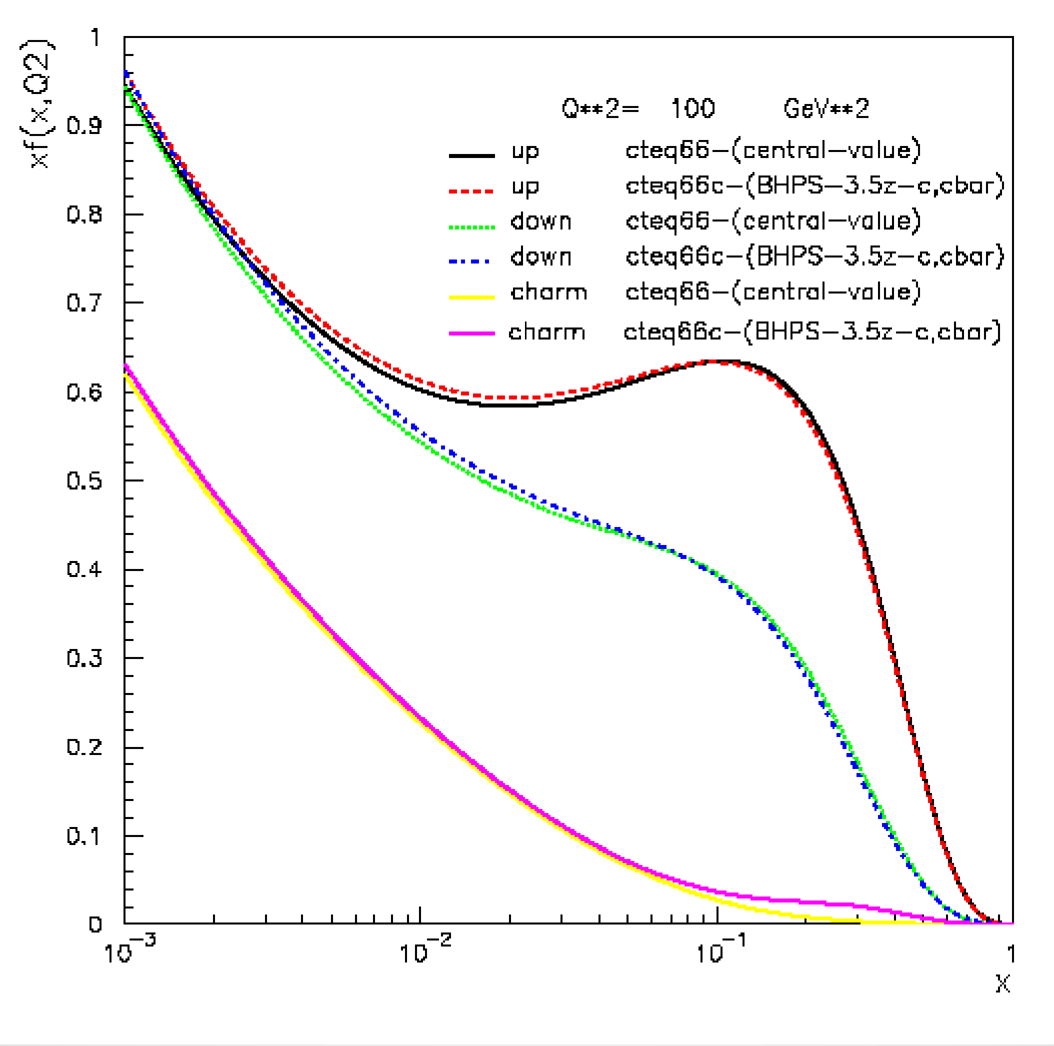
The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.



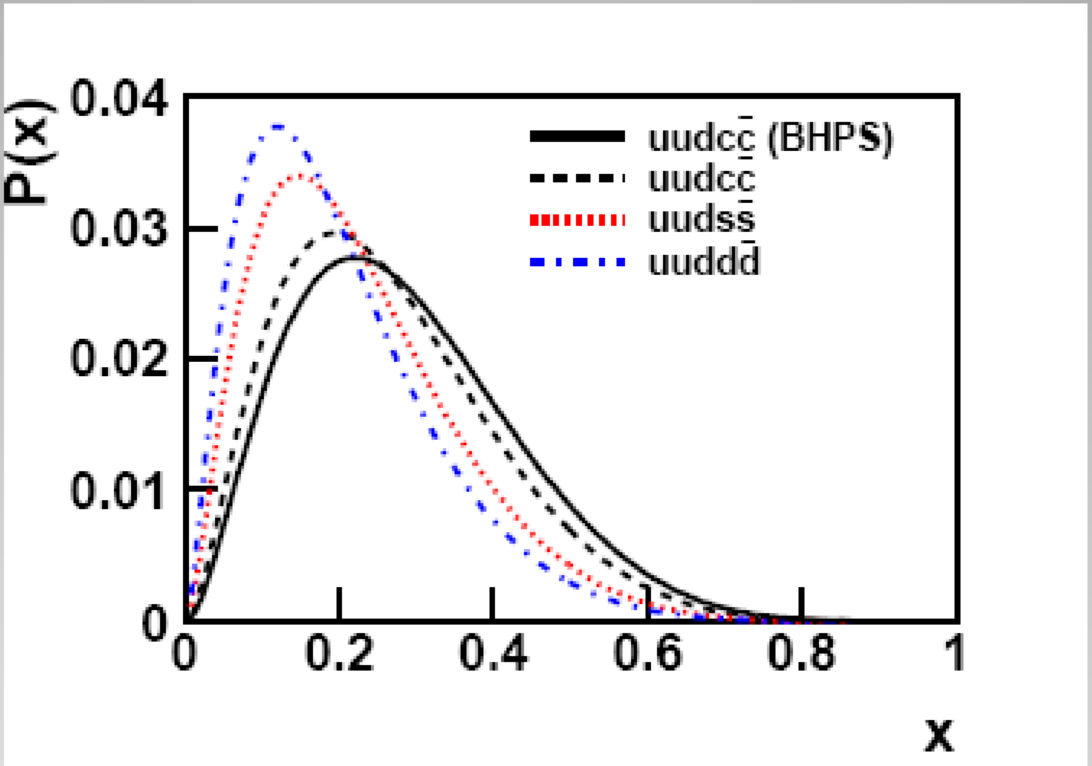
The x-distribution of the charm quarks $xc(x,Q^2)$ in proton; the solid black line is the IC contribution with its probability about 3.5 %, the dash green curve is the see charm quark contribution xc_{sea} (x,Q^2) at Q^2=1.69 GeV^2. There is enhancement at x>0.1.



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)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
10^-3 10^-2 10^-1 1
X



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.