SEARCH FOR EXOTIC QUARK COMPONENTS IN PROTON AT HARD P-P COLLISIONS

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Baldin ISHEPP XXII, September 15-20, 2014

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. **Intrinsic strangeness (IS) in proton and open strangeness production at hard p-p collisions**

6. **Possible observation of IC signal in γ +c-jet production by p-p collisions at LHC**

7. **IC & IS signals in W+b (c)-jet production by p-p at LHC**

8. **Summary**

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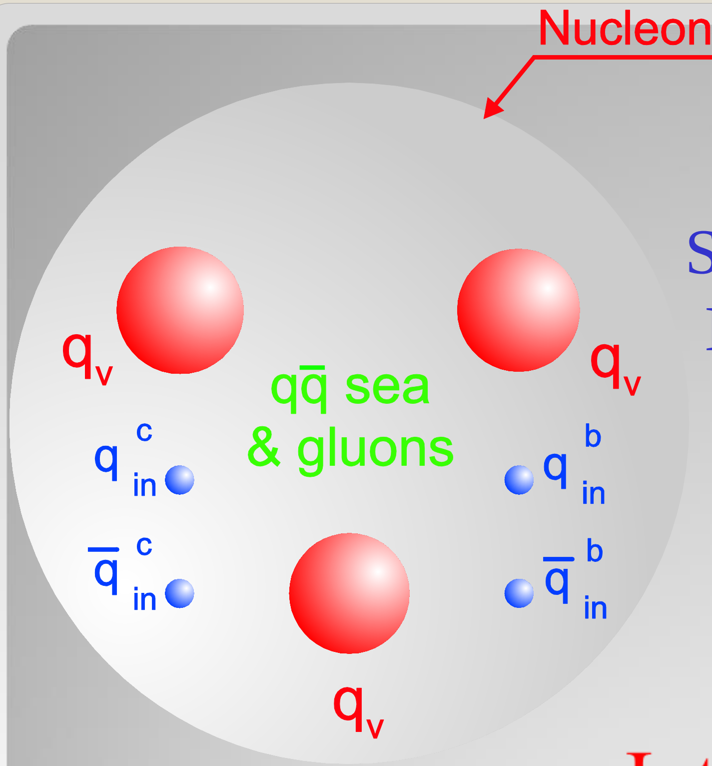


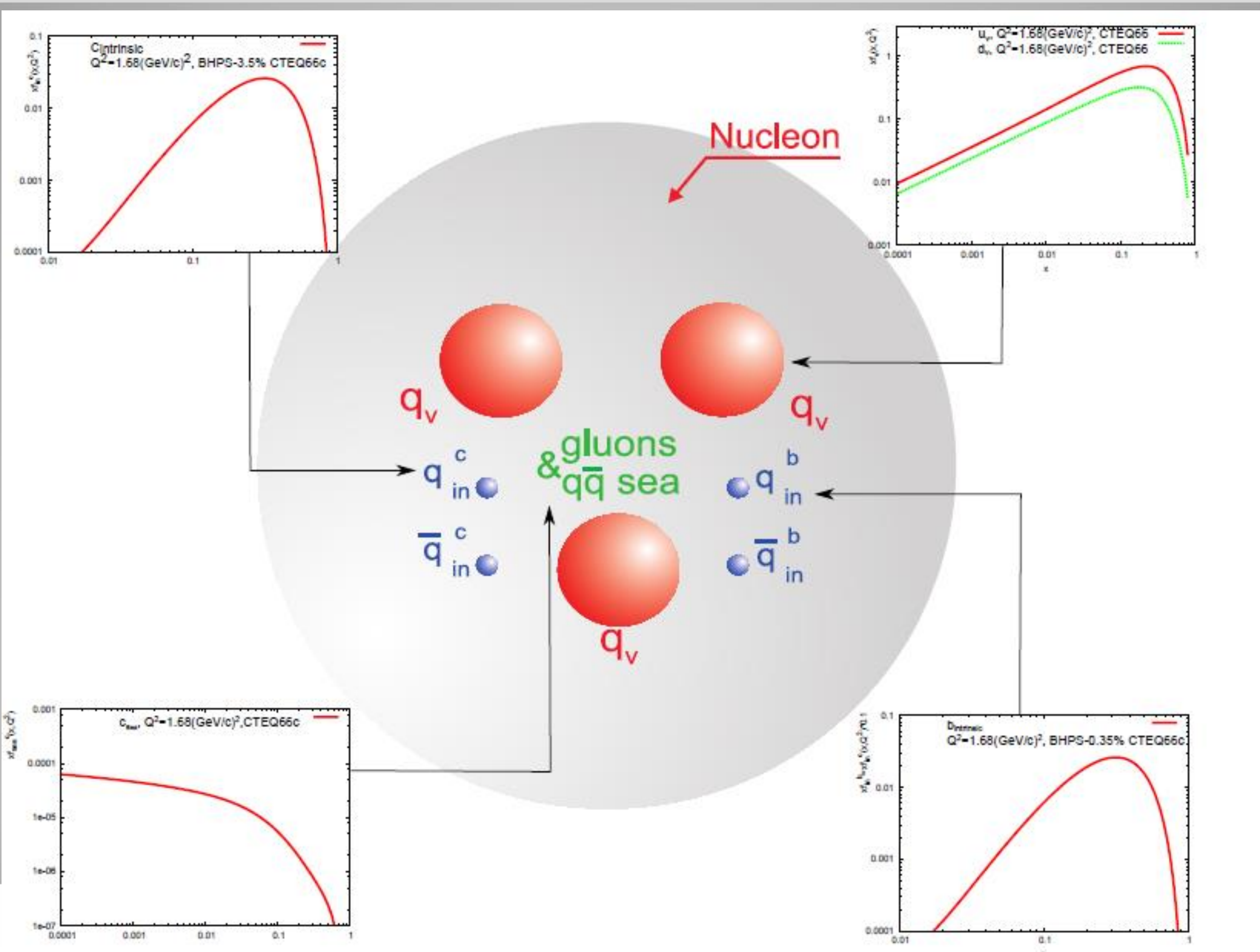
BHPS model

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



Cintrinsic
Q2=1.68(GeV/c)2, BHPS-3.5% CTEQ66c
uv, Q2=1.68(GeV/c)2, CTEQ66
dv, Q2=1.68(GeV/c)2, CTEQ66
Nucleon
qv
qv
qv
gluons
& qq̄ sea
q in c
q̄ in c
q in b
q̄ in b
csea, Q2=1.68(GeV/c)2,CTEQ66c
bintrinsic
Q2=1.68(GeV/c)2, BHPS-0.35% CTEQ66c

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

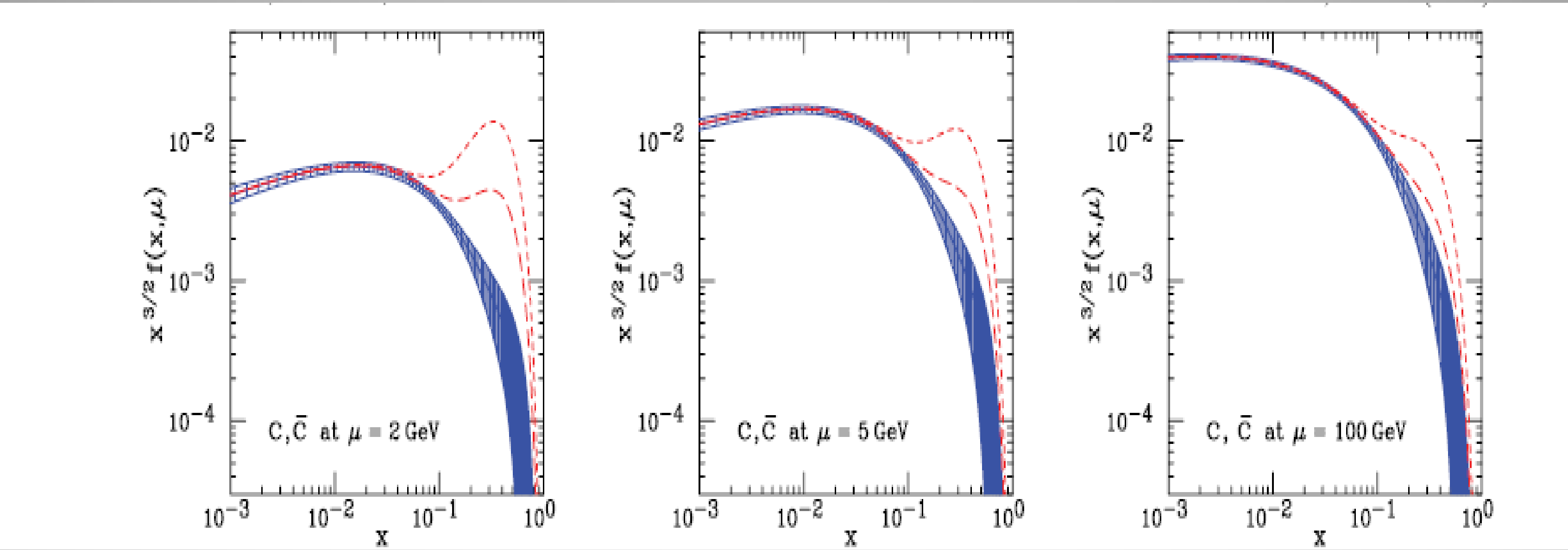
Integrating $P(x_1,\ldots,x_5)$ over $dx_1\ldots dx_4$ and neglecting of all quark masses except the charm quark mass we get

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

Where $\overline{N}_5 = N_5/m_{4,5}^4$ 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 $|uudQ\overline{Q}\rangle$ 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** $0 < x_5 < 1$

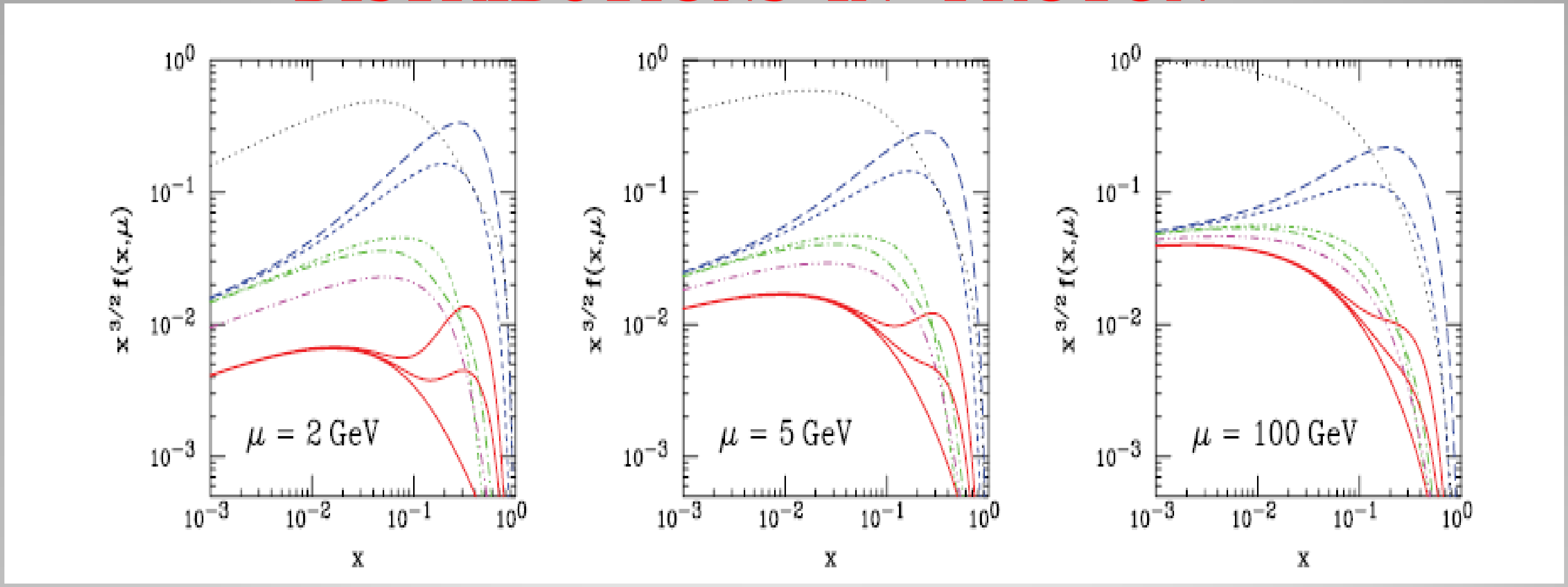
CHARM QUARK DISTRIBUTIONS IN PROTON



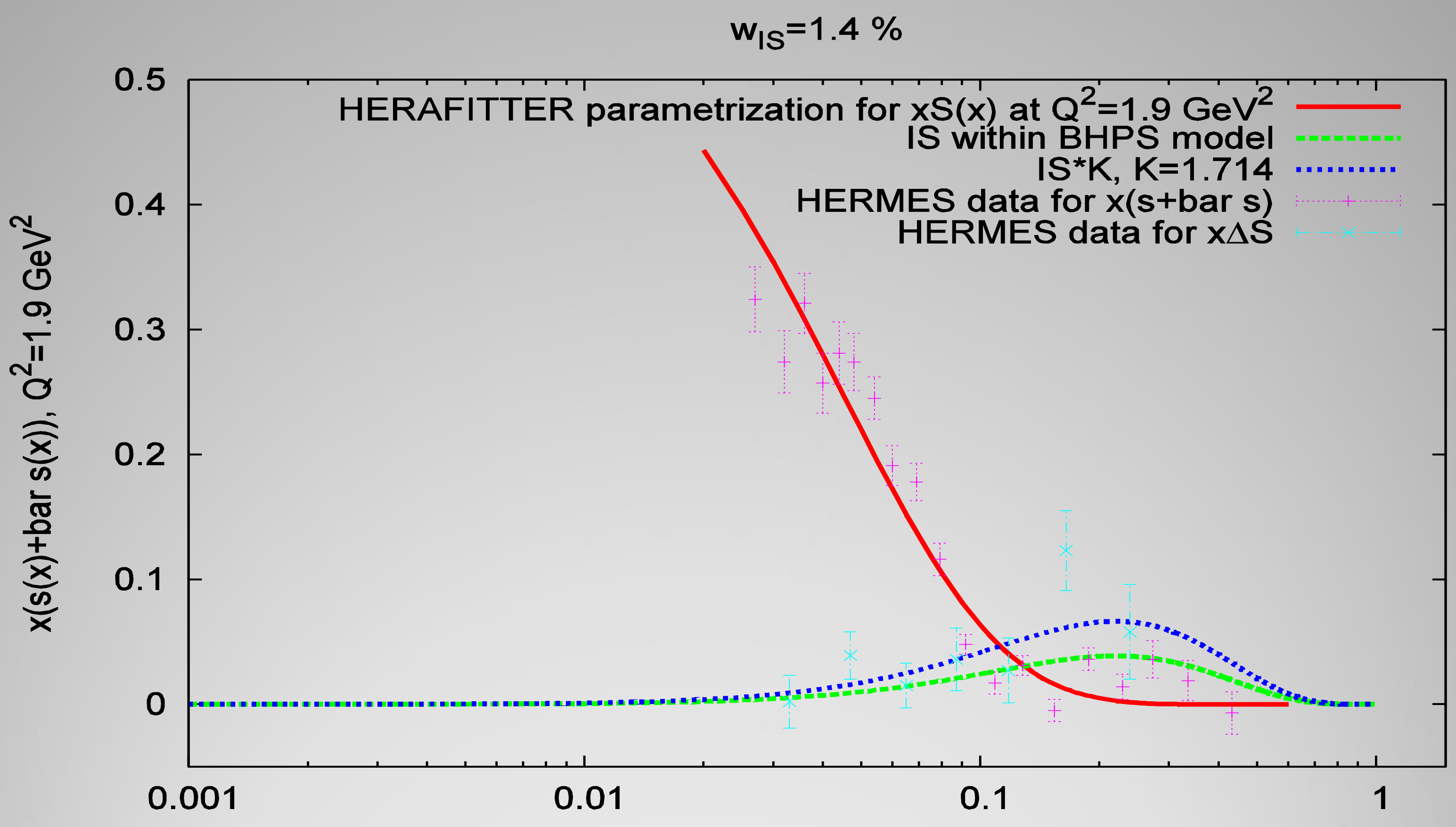
Charm quark distributions within the BHPS model. The three panels correspond to the renormalization scales $\mu = 2{,}5{,}100$ GeV respectively. The long-dashed and the short-dashed curves correspond to $\langle x_{c\bar{c}} \rangle = 0.57\%, 2.\%$ respectively using thn e PDF CTEQ66c. The solid curve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

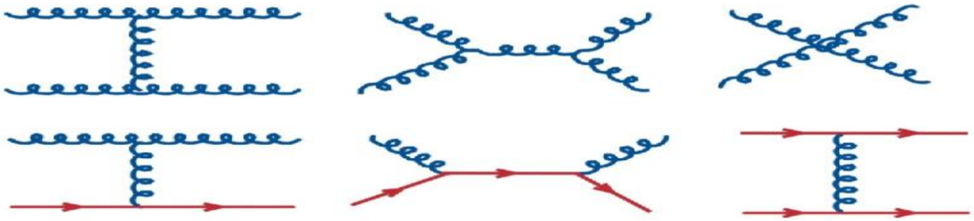


Comparison of the HERA data with calculation within the BHPS at Q^2 about 2.5 Gev^2, μ is the QCD scale. A.Airapetian, et al., Phys.Lett.B666 (2008) 446; J.Peng, W.Cheng, hep-ph/1207.2193.

THERE ARE NEW HERMES DATA ON S(X), WHICH SHOW A FLAT AT X>0.1

Hard processes

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

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

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

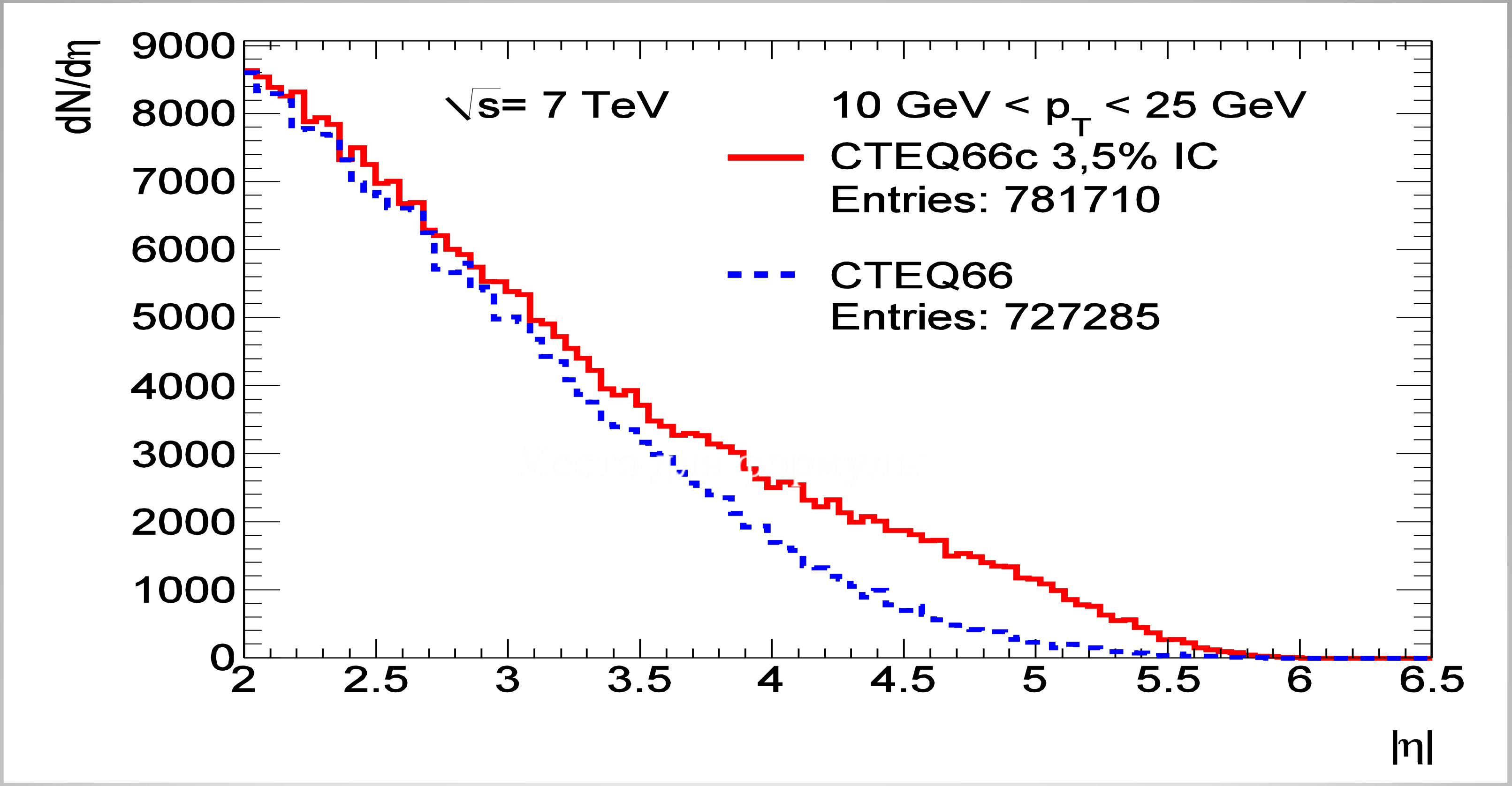
$$x_F \equiv \frac{2p_z}{\sqrt{s}} = \frac{2p_T}{\sqrt{s}}\frac{1}{\tan\theta} = \frac{2p_T}{\sqrt{s}}\sinh(\eta)$$

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

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

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.

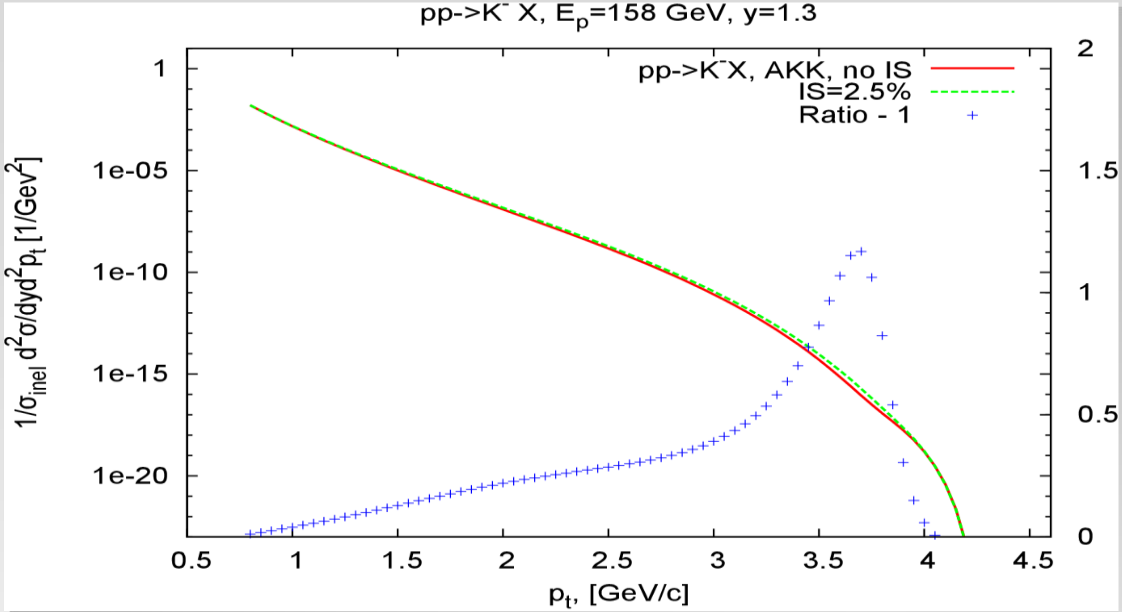
x_F is related to p_T and η . So, at certain values of these variables, in fact, there is no conventional sea heavy quark (extrinsic) contribution. And we can study the IQ contributions in hard processes at the certain kinematical region.

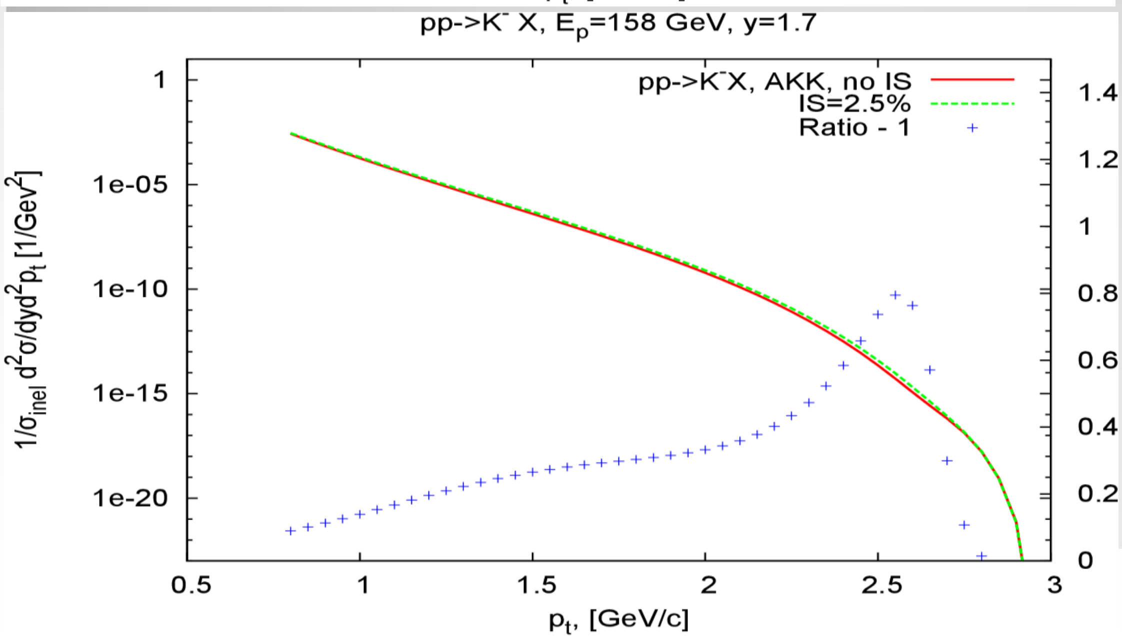


Single D^0 production in p-p at $s^{1/2} = 7$ TeV.

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

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





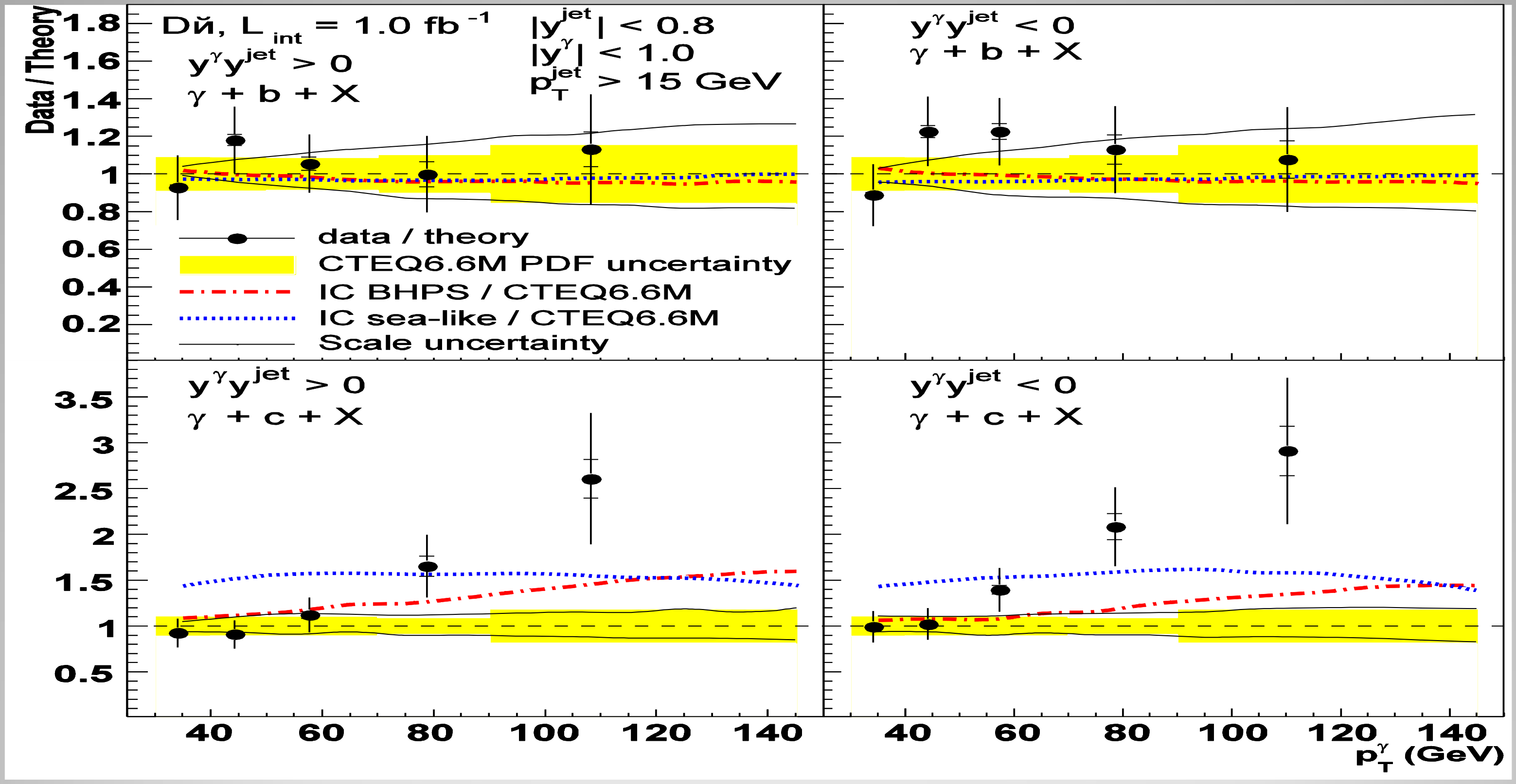
G.L., A.A.Grinyuk, I.V.Bednyakov, Proc. Baldin Conference, Dubna, Sept. 2012; C12-09-10.4; arXiv:1212.6381 [hep-ph].

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

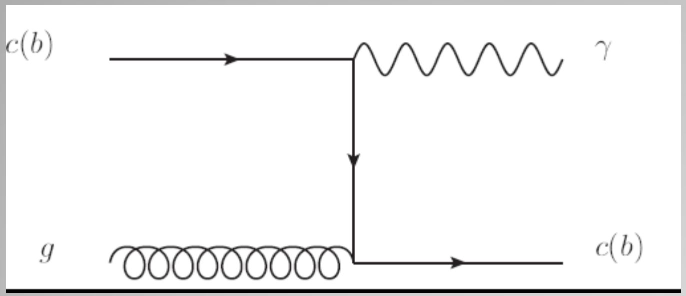


Fig.a. Feynman diagram for the process $c(b)+g\to\gamma+c(b)$

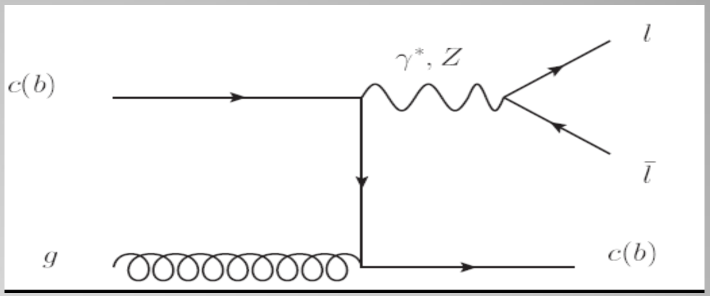


Fig.b. Feynman graph for the process $c(b)+g\to\gamma/Z^0+c(b)$

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

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

To observe the IC

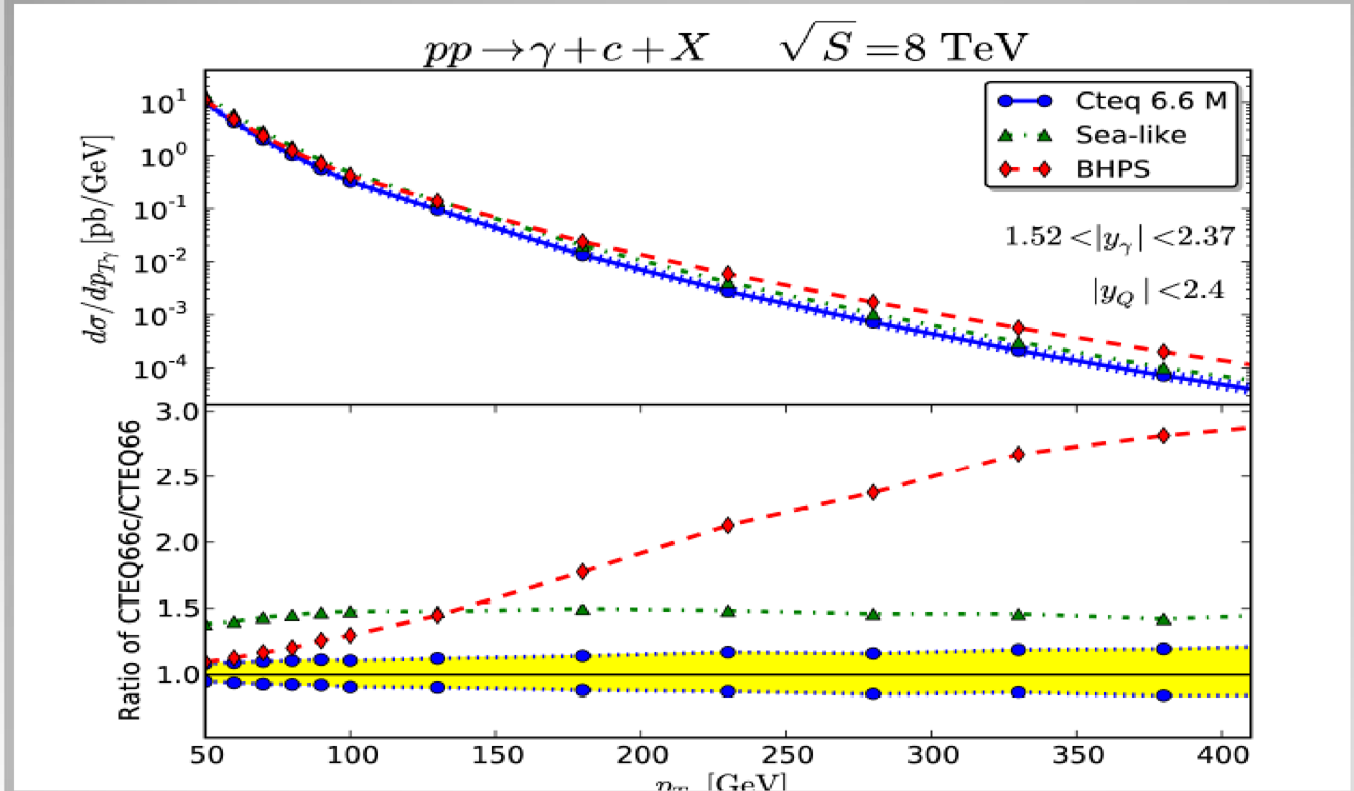
for Fig.a

$$x_c\geq x_F>0.1$$

for Fig.b

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

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.

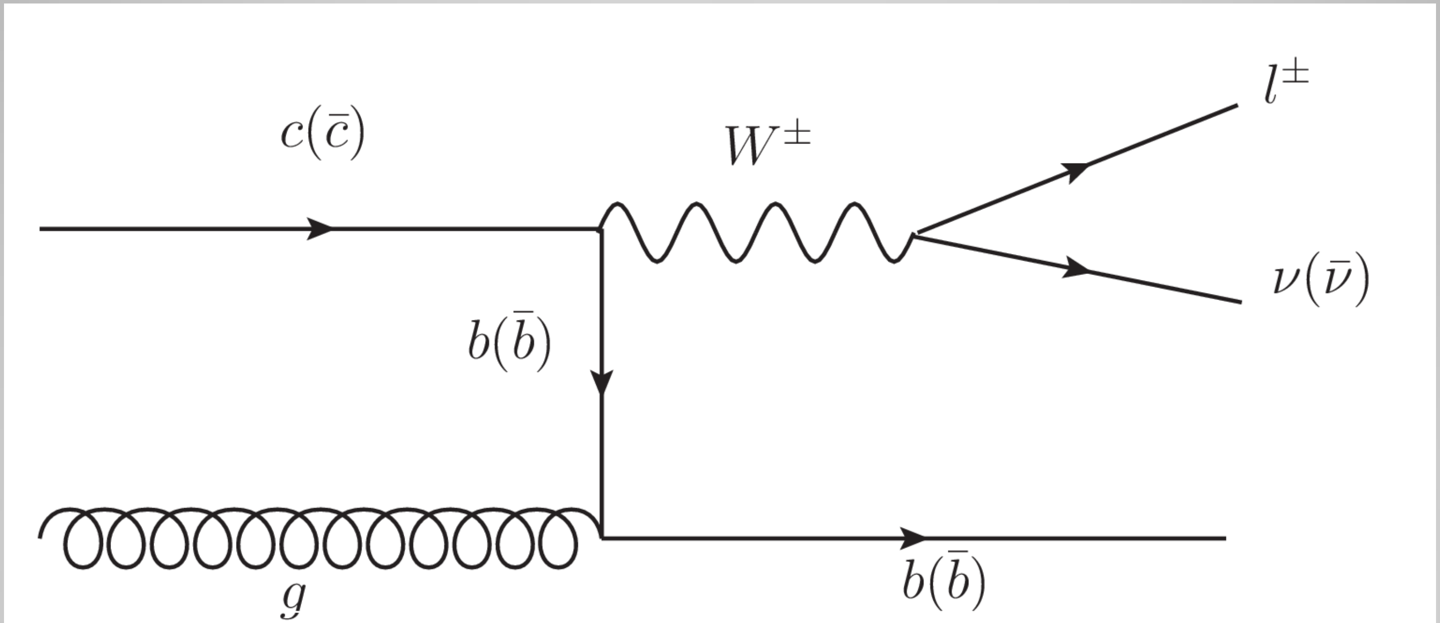
p_T – distribution of photons produced in $pp \to \gamma + c(jet) + X$

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

Production of vector bosons accompanied by heavy flavour jets

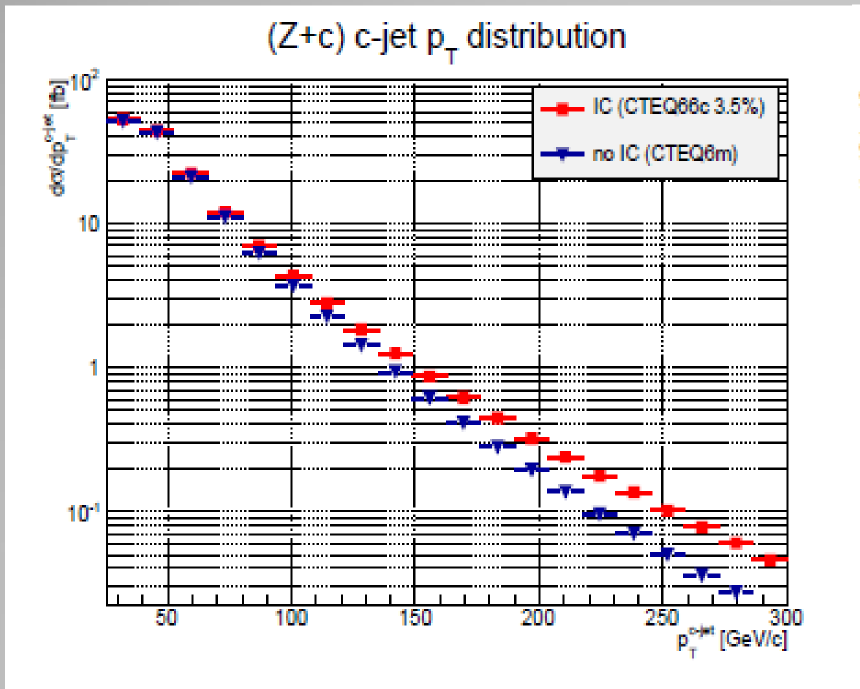
$$pp \rightarrow W + b\,(jet)$$

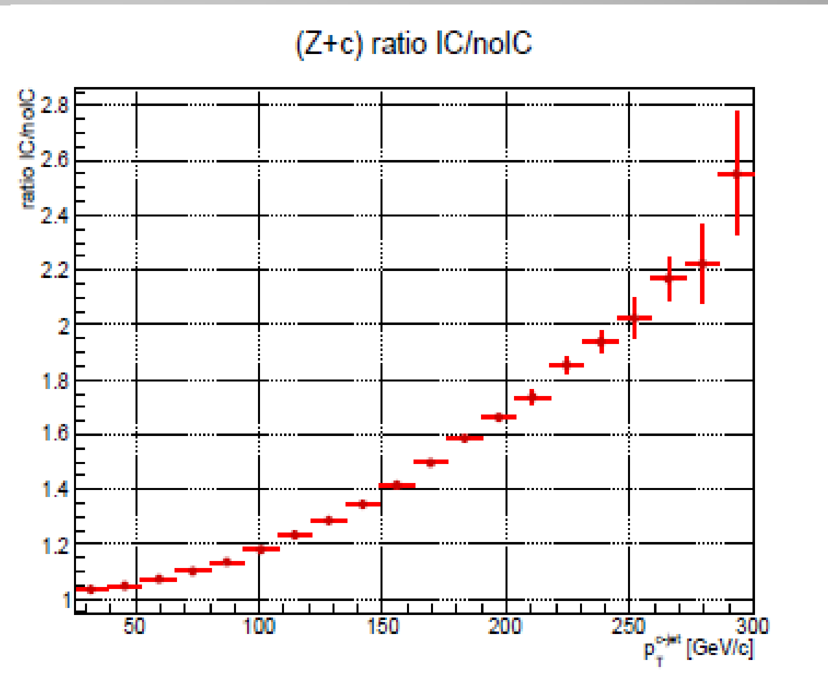
main subprocess $c(\bar{c}) + g \rightarrow W^{+/-} + b(\bar{b})$



Feynman diagram of the subprocess $c(\bar{c}) + g \rightarrow W^{+/-} + b(\bar{b})$

Production of Z-boson in p-p accompanied by c-jet at $s^{1/2}$ = 8 TeV, 1.52<y_Z <2.4

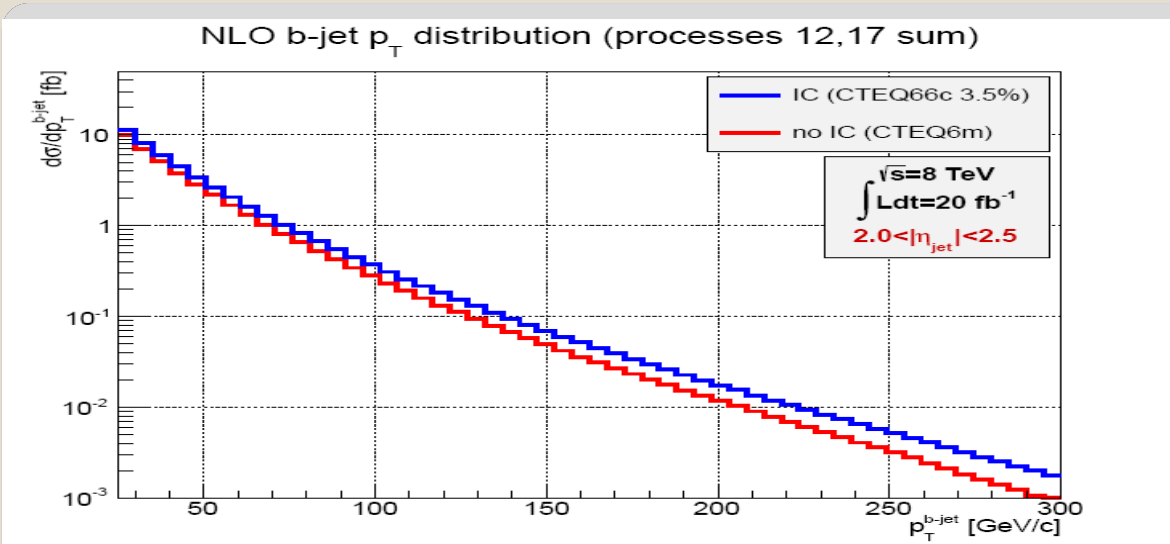




The p_T – spectrum of c-jet in the process $pp \to Z^0 + c - jet + X$

The ratio of p_T – spectra with IC (~3.5%) and without it

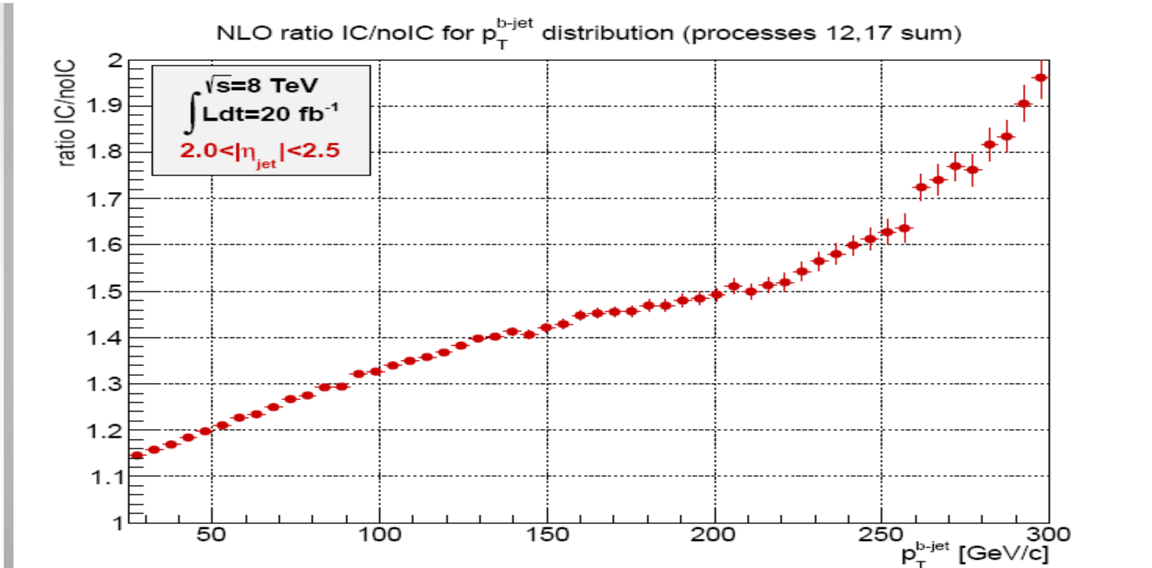
One can see that the inclusion of the IC (~3.5%) contribution in PDF increases the spectrum by a factor of 2 and more at p_T >200 GeV/c



P_T spectrum of b-jet in the process pp→W+b(jet)+X at $\sqrt{s} = 8TeV$, 2.0<|η|<2.5.

The read line is without **IC**,

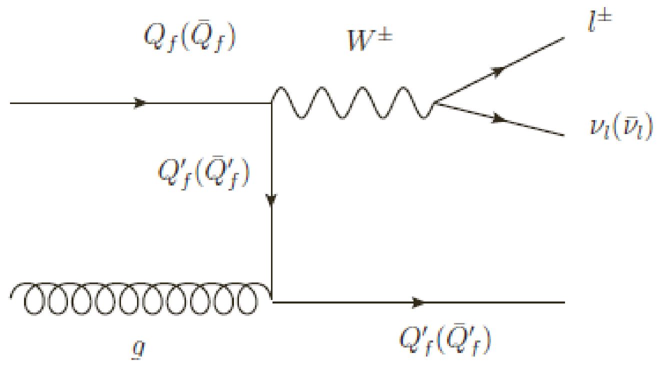
The blue curve is with the **IC,** its probability is about 3.5 %. Here W->e $^+$e$^-$', G.L., et. Al., Nucl.Phys.B [Proc.Suppl]245(2013),215



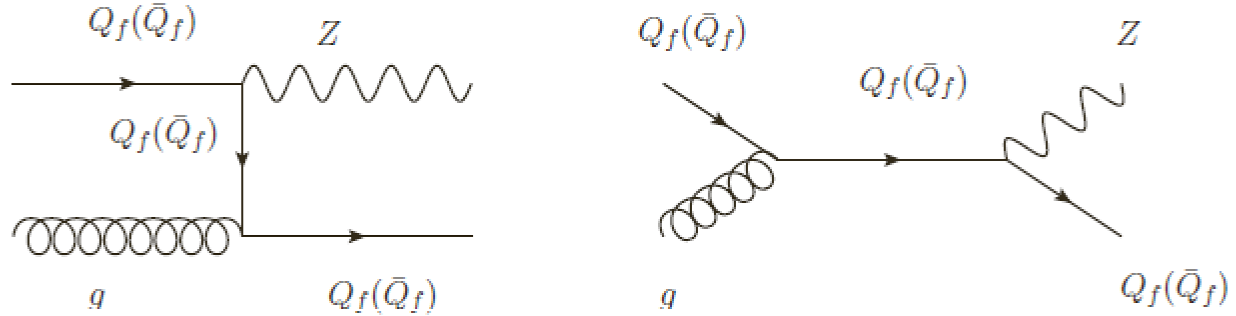
The ratio of P_T spectra with and without the **IC .**

The IC inclusion leads to the increase of the spectrum by a factor 1.4-1.5 at P_T ~150-200 GeV/c, where the number of the events is about 5-10 including both decays of W into e^+e^- and $\mu^+\mu^-$

pp →W/Z+heavy flavour jets

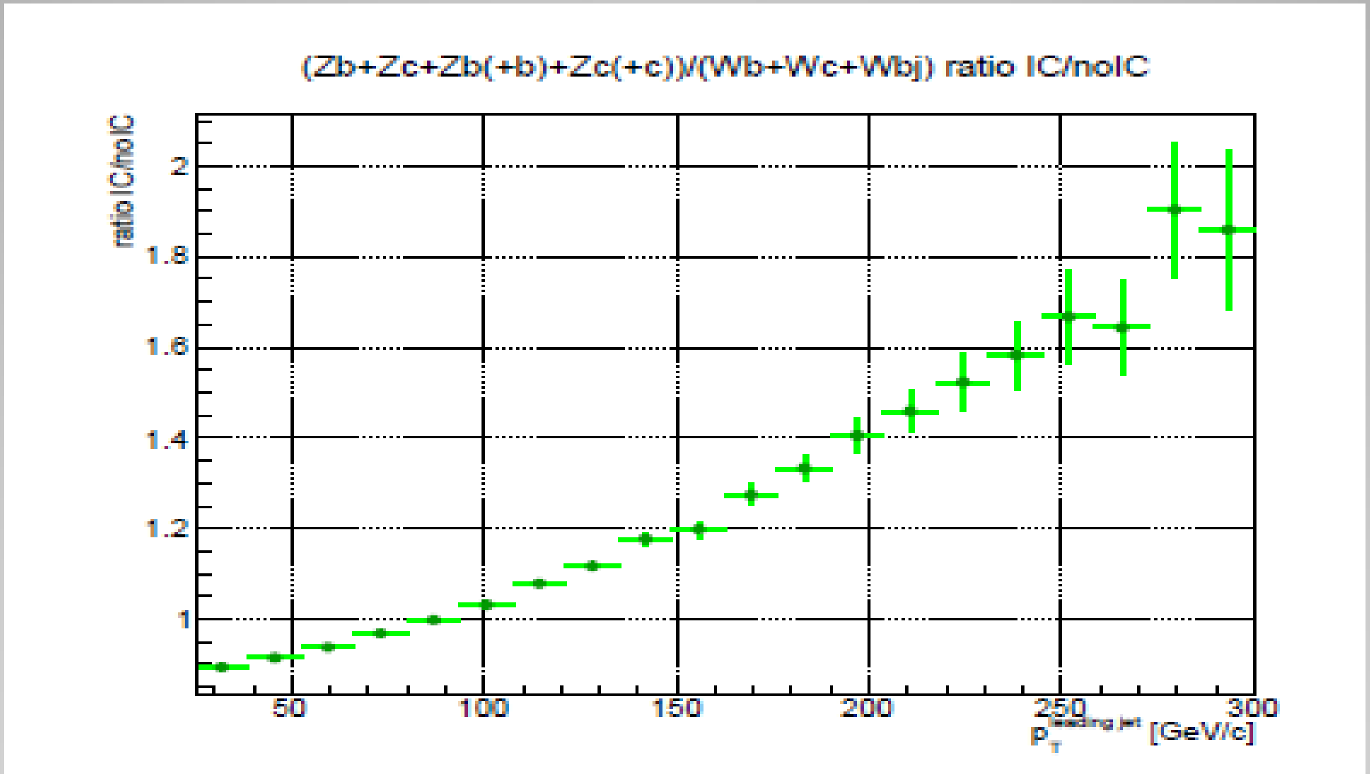


The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \rightarrow W^\pm Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.



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

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**

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 should depend on $p_T/s^{1/2}$ and does not depend on $s^{1/2}$.

In pA and AA collisions the IS signal can be more visible Because the yield of K-mesons is larger than in pp collisions

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

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

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

THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP

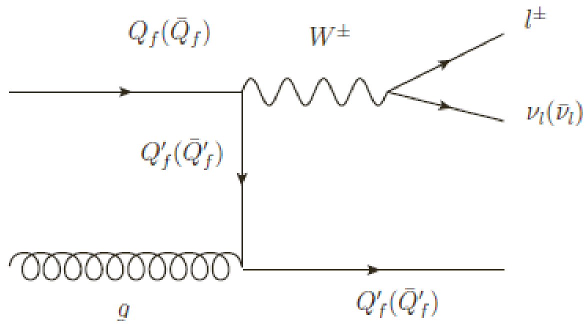


Figure 2: The LO Feynman diagrams for the process $Q_f(\bar{Q}_f)g \to W^{\pm}Q'_f(\bar{Q}'_f)$, where $Q_f = c.b$ and $Q'_f = b, c$ respectively.

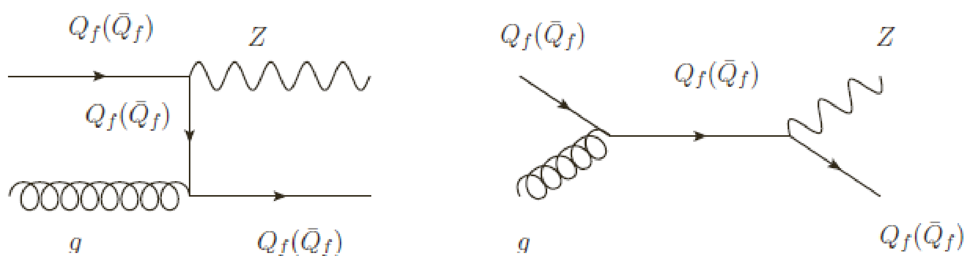
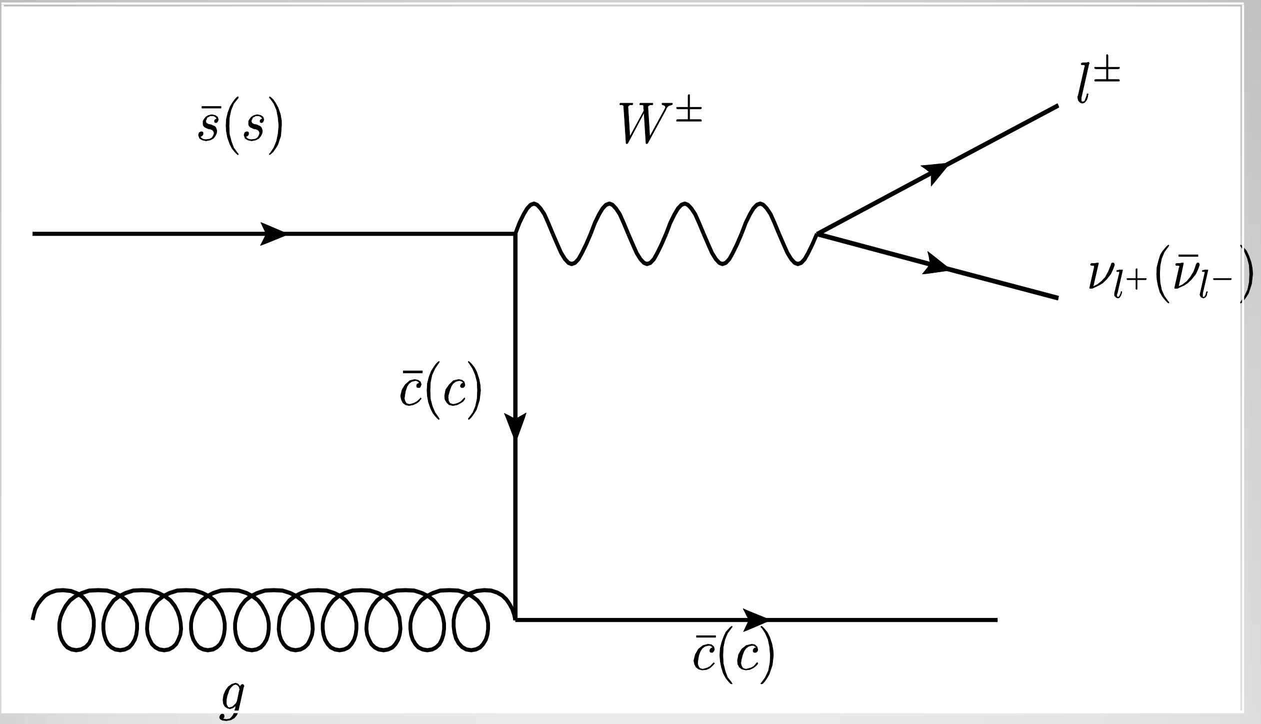
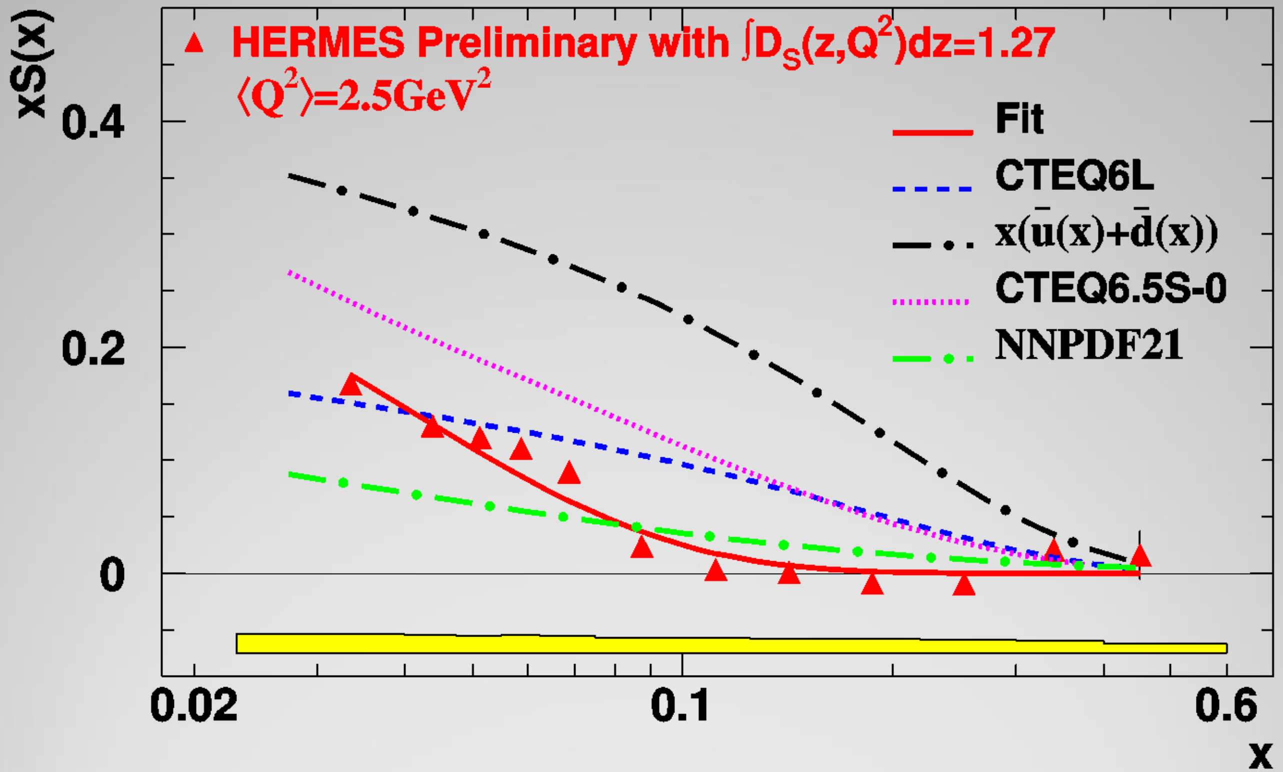


Figure 3: Feynman diagram for the process $Q_f(\bar{Q}_f)g \to ZQ_f(\bar{Q}_f)$

WHAT we are doing now ?

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





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

SEARCH FOR INTRINSIC STRANGENESS IN P-P

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

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

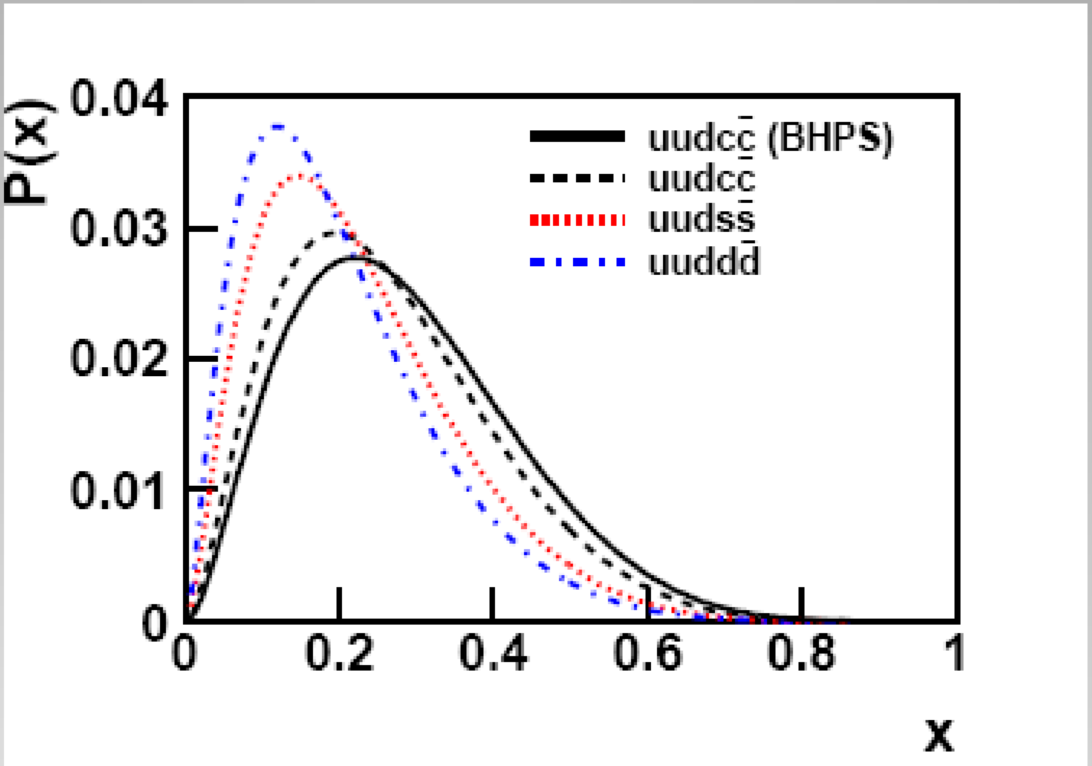
and does not depend on $\sqrt{s}$

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

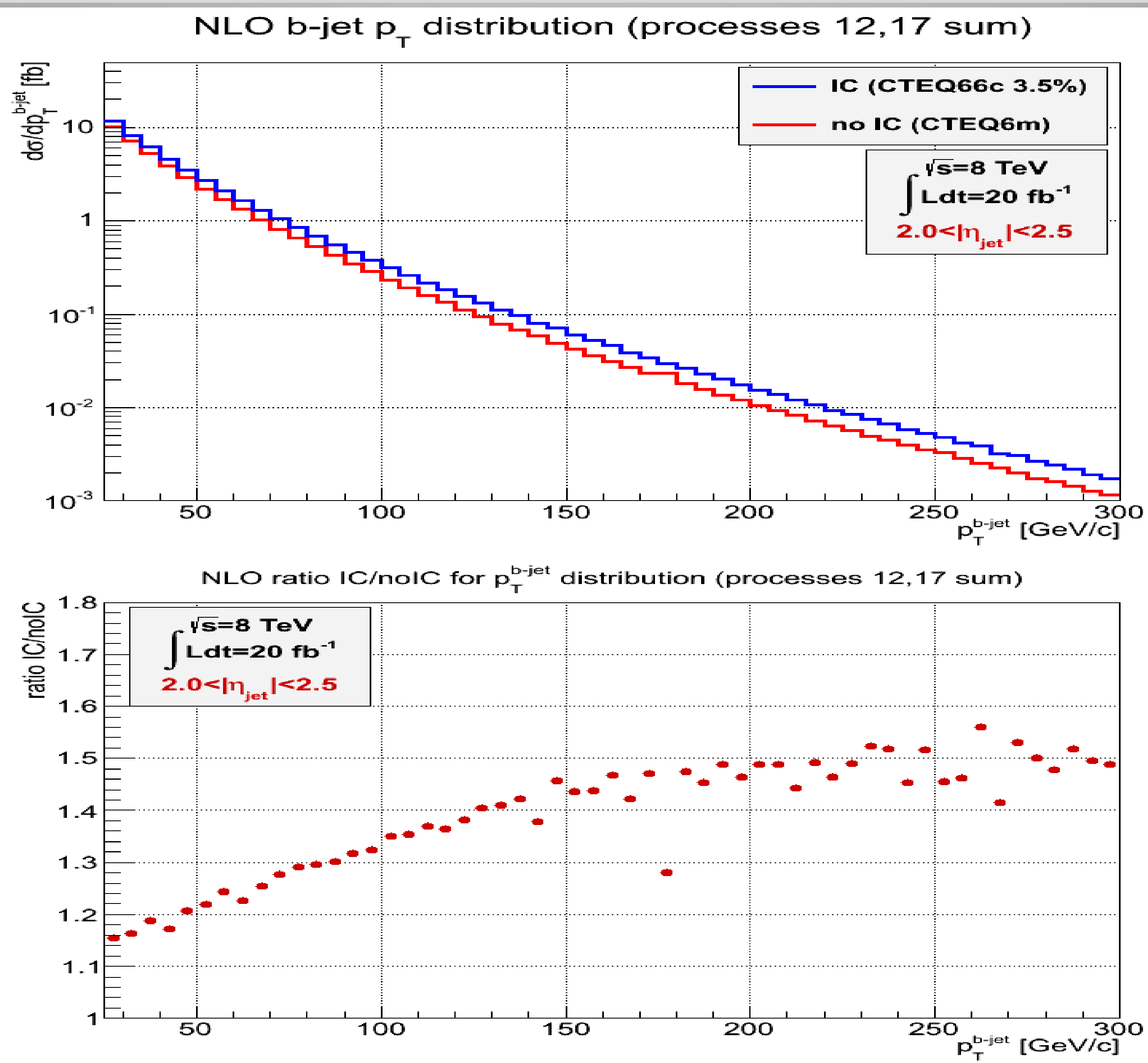
Therefore, it makes the certain sense to measure K^- mesons in p-p collisions at

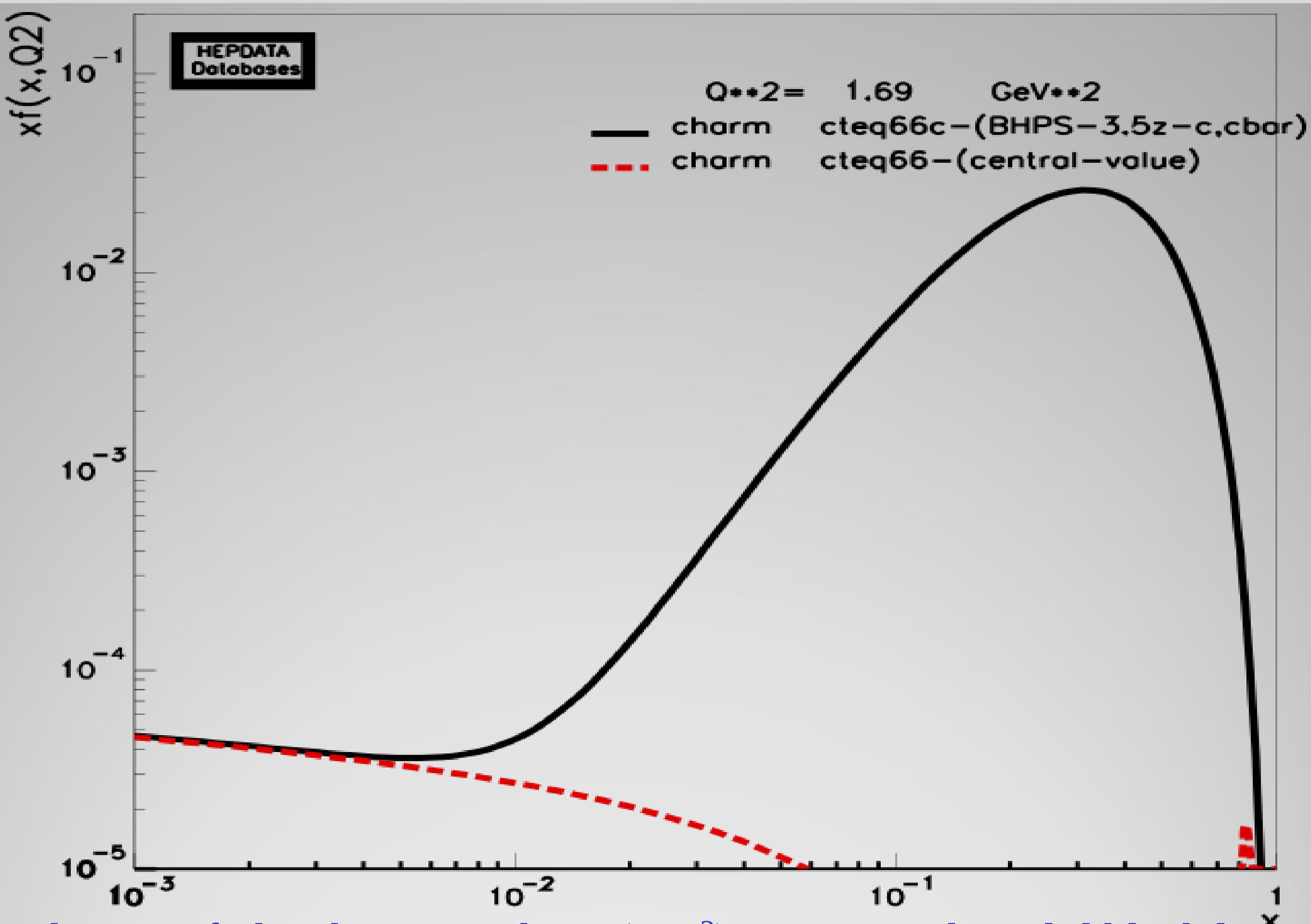
NA61, CBM & NICA

to observe a possible intrinsic strangeness in the proton

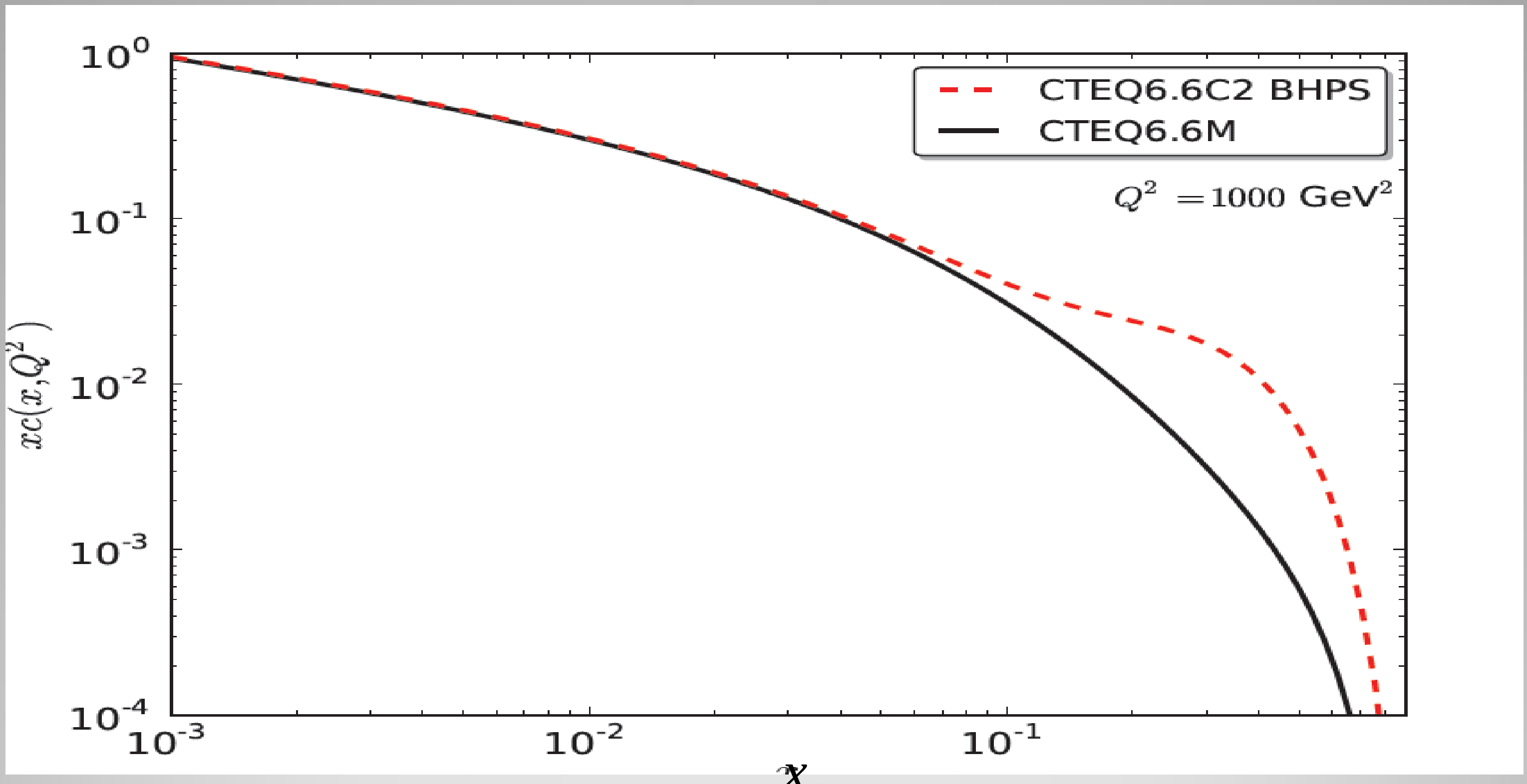


The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.


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]

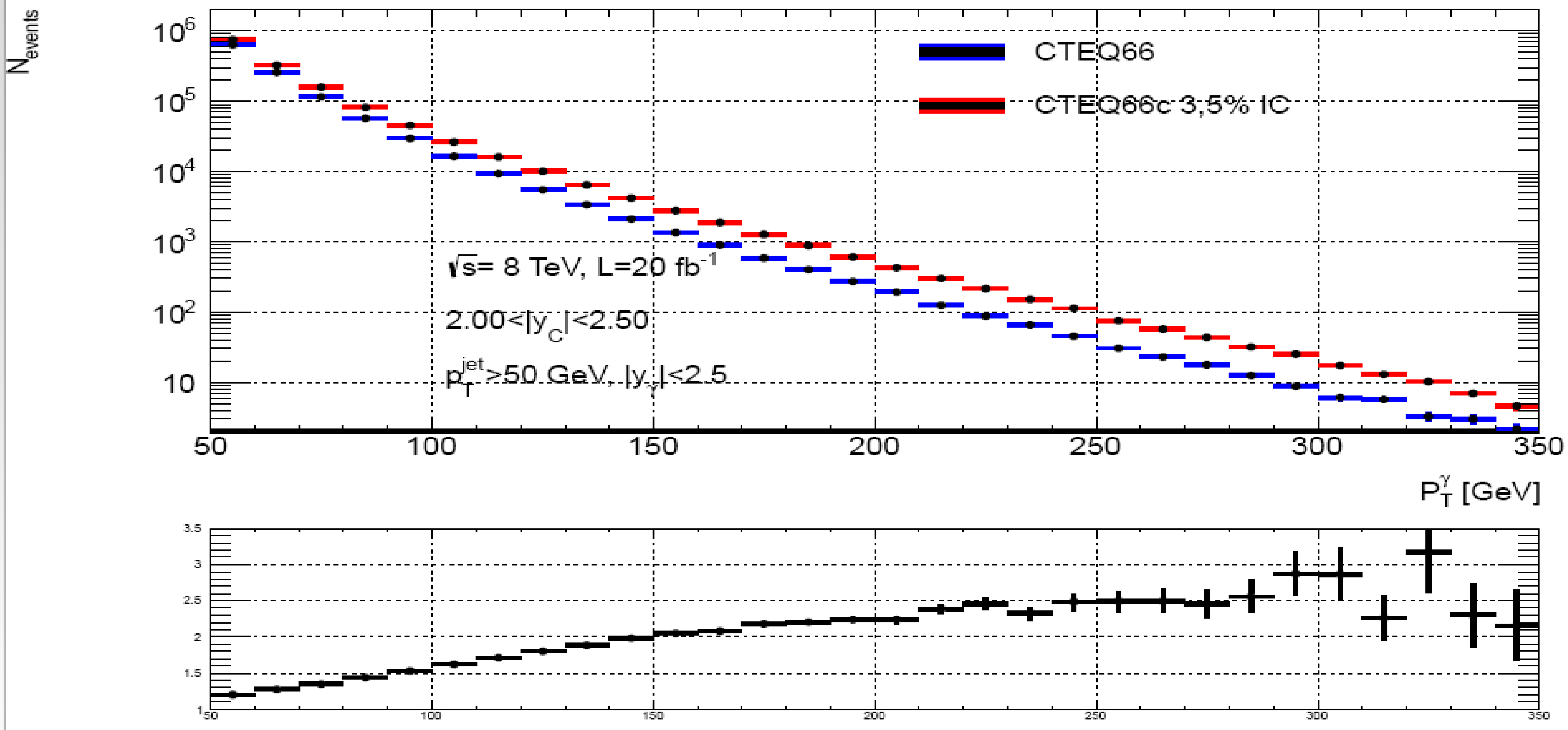


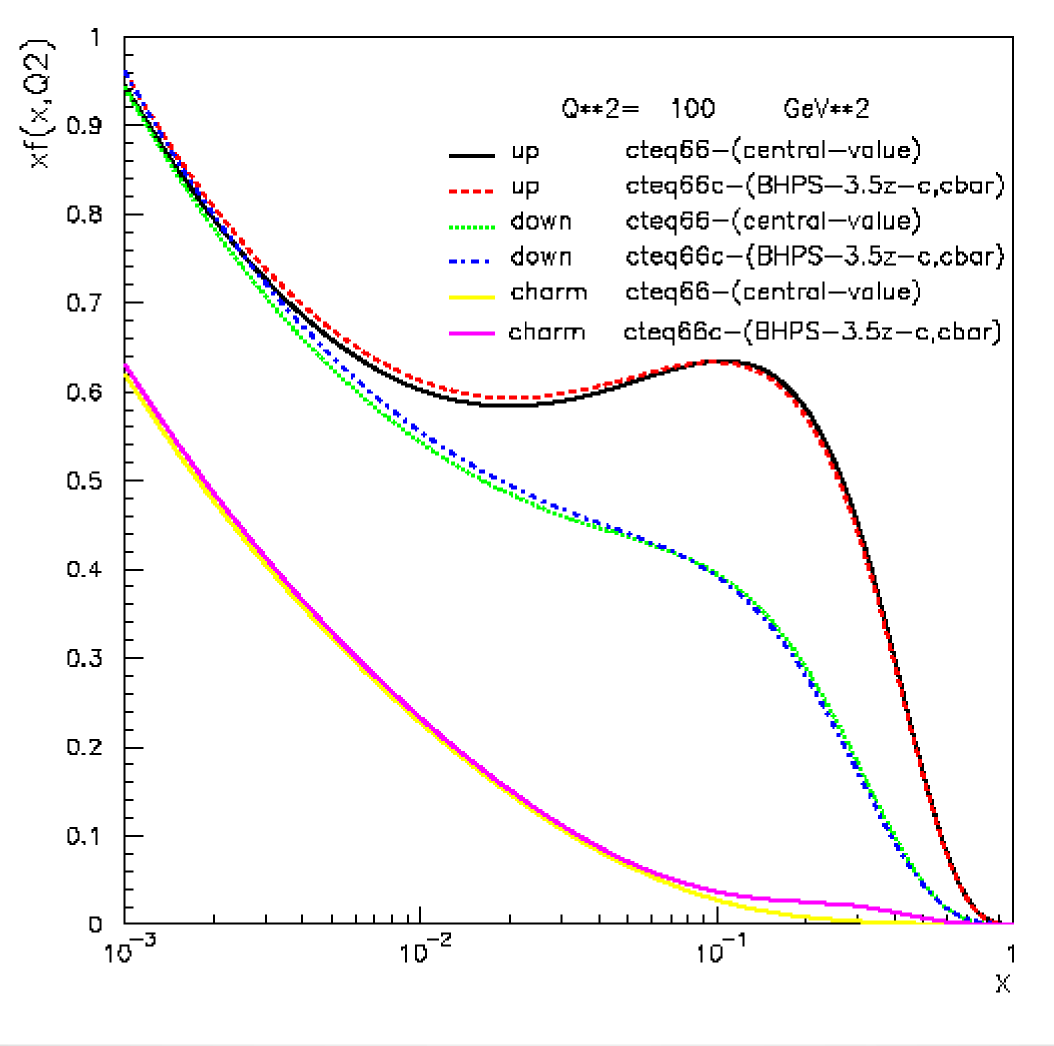
The x-distribution of the charm quarks $xc(x,Q^2)$ in proton; the solid black line is the IC contribution with its probability about 3.5 %, the dash green curve is the see charm quark contribution $xc_{sea}(x,Q^2)$ at Q^2=1.69 GeV^2. There is enhancement at x>0.1.



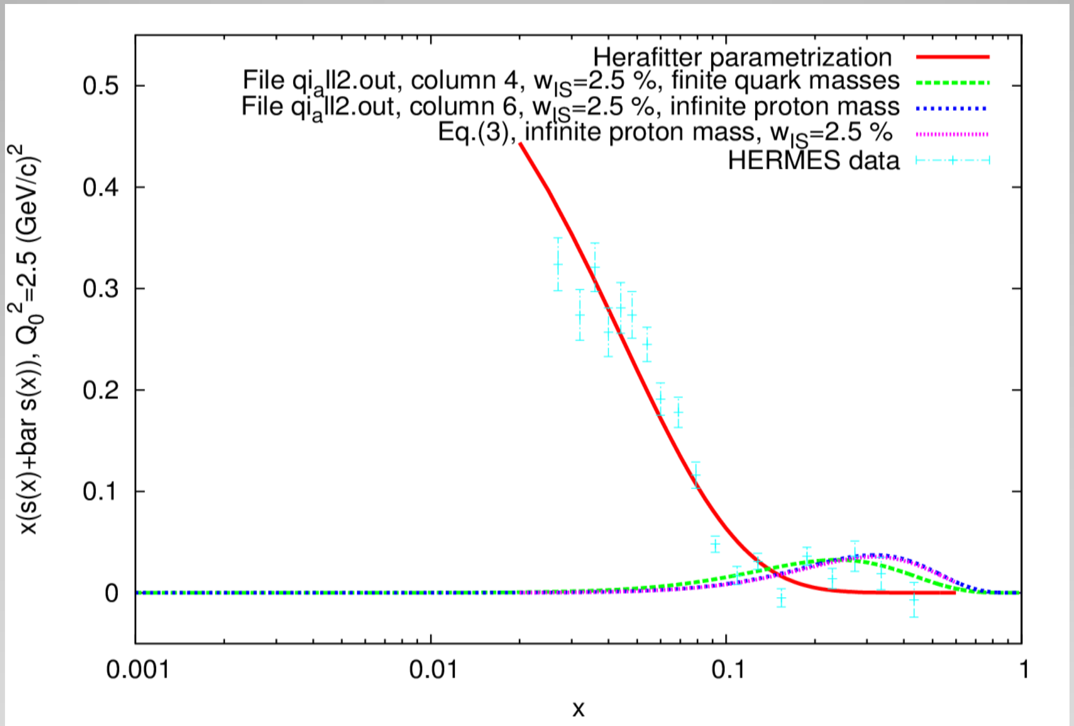
The x-distribution of the charm quarks $xc(x,Q^2)$ in the proton at Q^2=1000 GeV^2 ; the solid black line is the radiatively generated charm density $xc_{rg}(x,Q^2)$ distribution only , whereas the dashed curve is the sum of $xc_{rg}(x,Q^2)$ and the intrinsic charm density $xc_{in}(x,Q^2)$ with its probability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

MC PYTHIA8, LO QCD

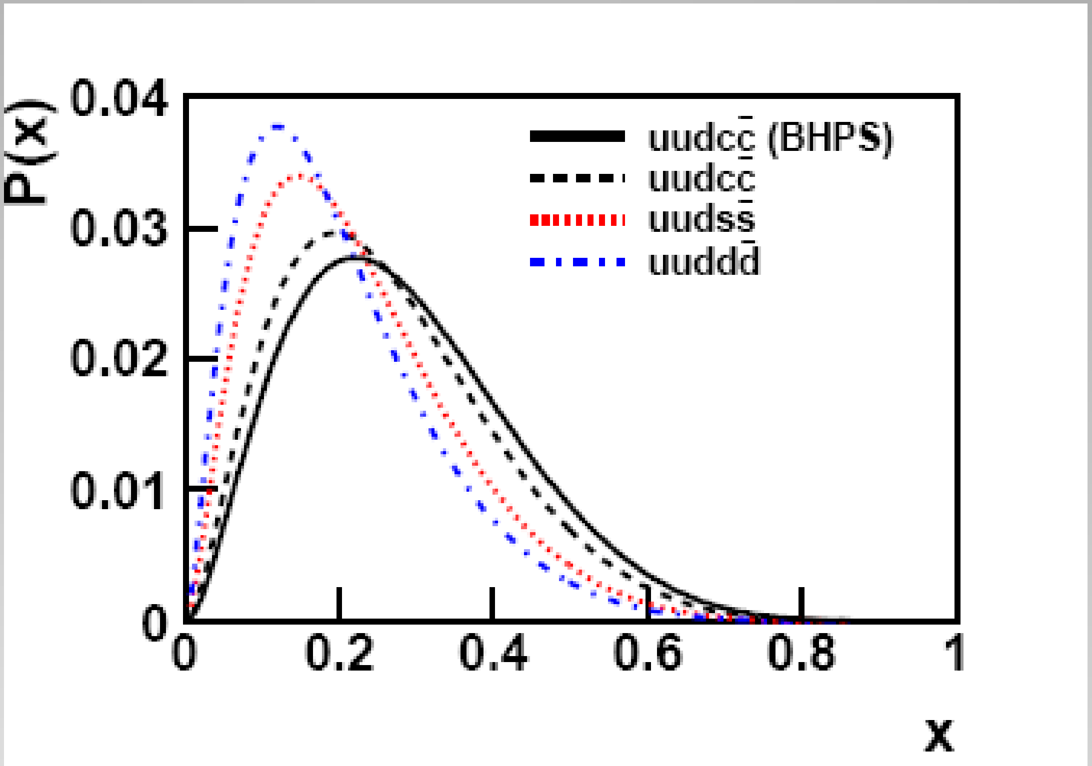




xf(x,Q2)
Q**2= 100 GeV**2
up cteq66-(central-value)
up cteq66c-(BHPS-3.5z-c,cbar)
down cteq66-(central-value)
down cteq66c-(BHPS-3.5z-c,cbar)
charm cteq66-(central-value)
charm cteq66c-(BHPS-3.5z-c,cbar)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^-3
10^-2
10^-1
1
X

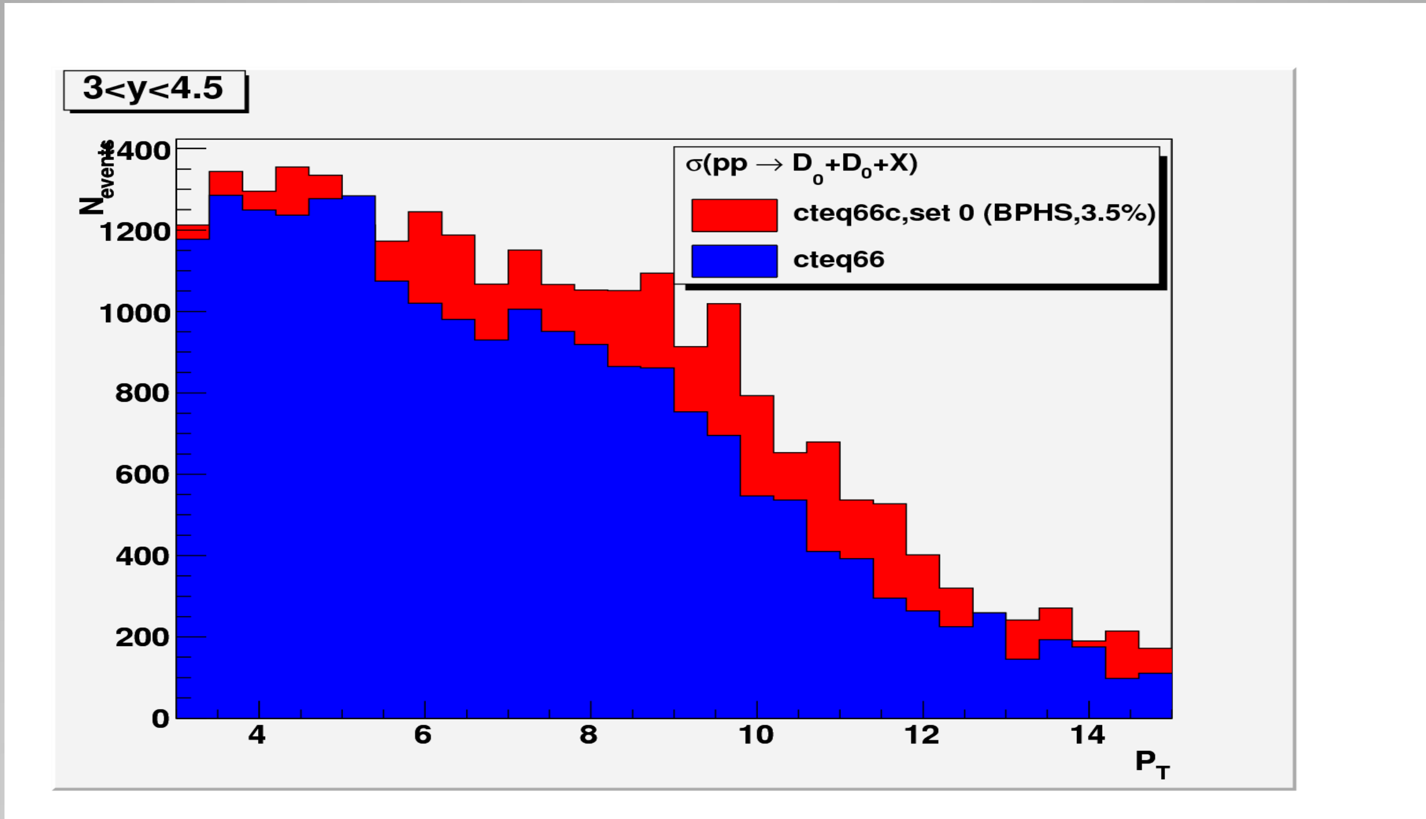


Comparison of the HERMES data with calculation within the BHPS at Q^2 about 2.5 Gev^2, μ is the QCD scale. A.Airapetian, et al., Phys.Lett.B666 (2008) 446; J.Peng, W.Cheng, hep-ph/1207.2193.



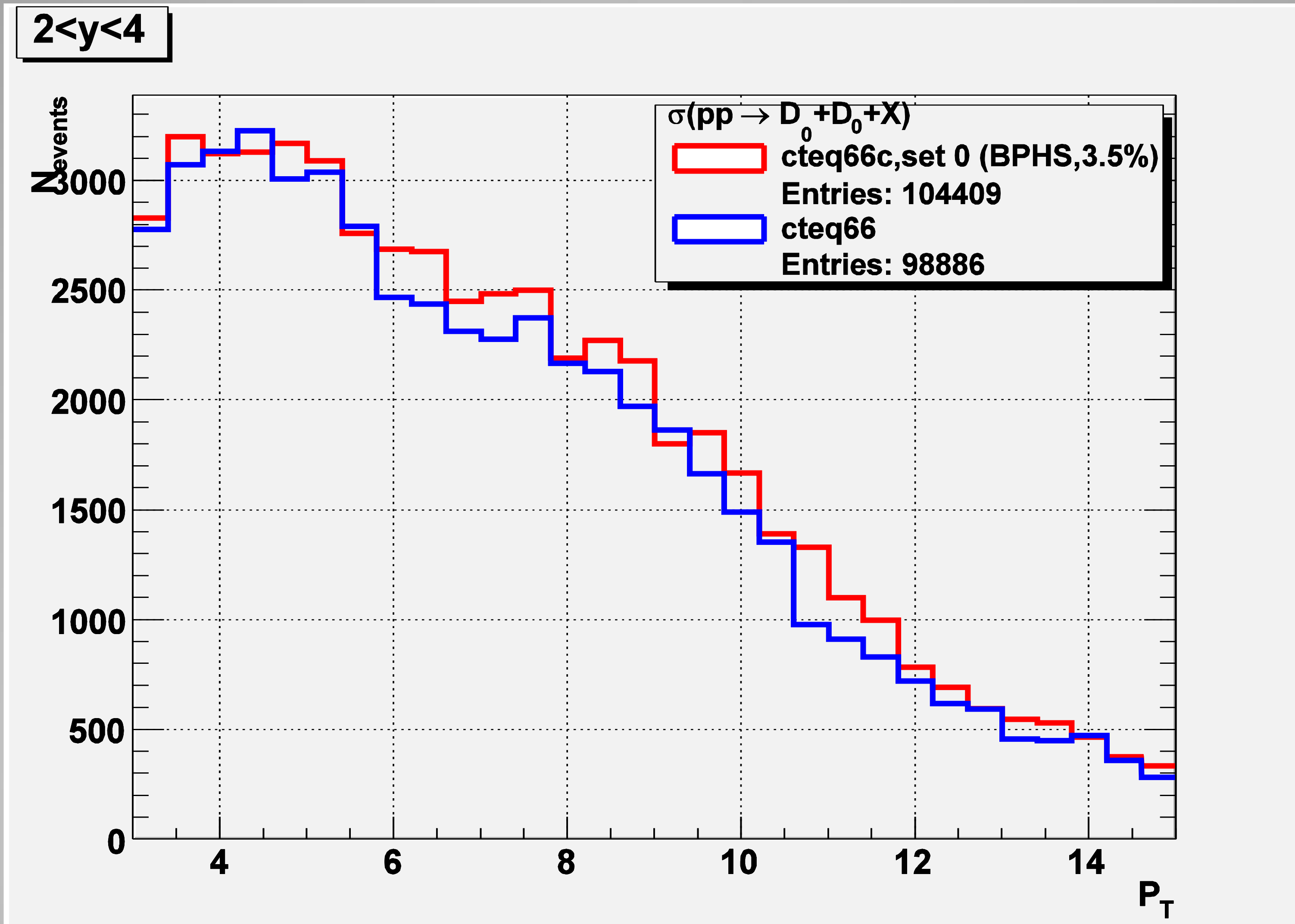
The x-distribution of the intrinsic **Q** calculated within the BHPS model. **There is an enhancement at x > 0.1**
Jen-Chieh Peng & We-Chen Chang, hep-ph/1207.2193.

Double D^0 production in pp at $\sqrt{s} = 7\,TeV$



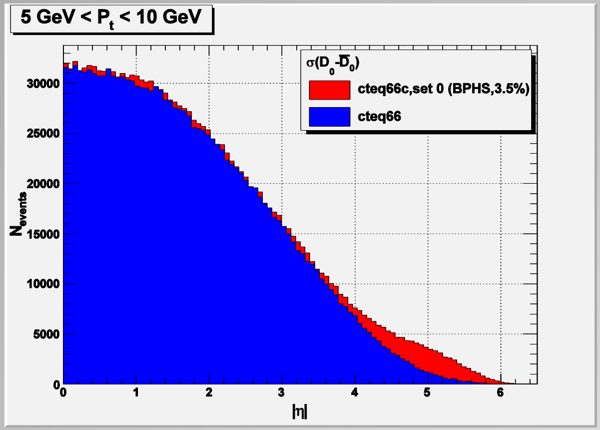
The number of D^0D^0 events in p-p as a function of the transverse momentum including the intrinsic charm in proton (red histogram) with the probability about 3.5%.

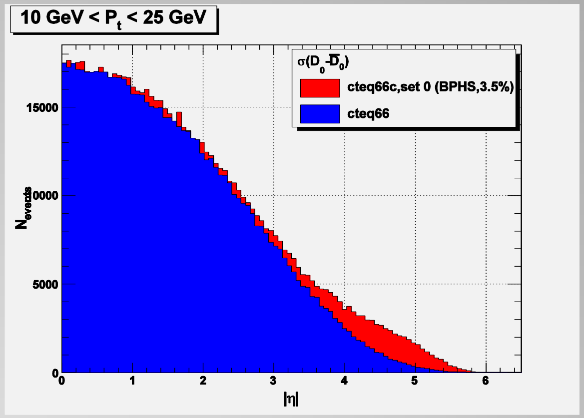
$\sigma^{theor}_{2D^0}\ 700\ nb$ including IC and $\sigma^{theor}_{2D^0}\ 630\ nb$ without IC. $\sigma^{exp}_{2D^0}\ 687 \pm 86\ nb$

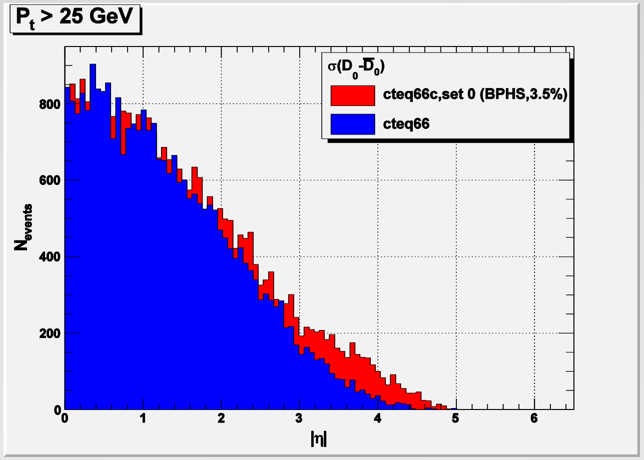


2<y<4
N_events
0
500
1000
1500
2000
2500
3000
4
6
8
10
12
14
P_T
σ(pp → D_0+D_0+X)
cteq66c,set 0 (BPHS,3.5%)
Entries: 104409
cteq66
Entries: 98886

Single D^0 production in p-p





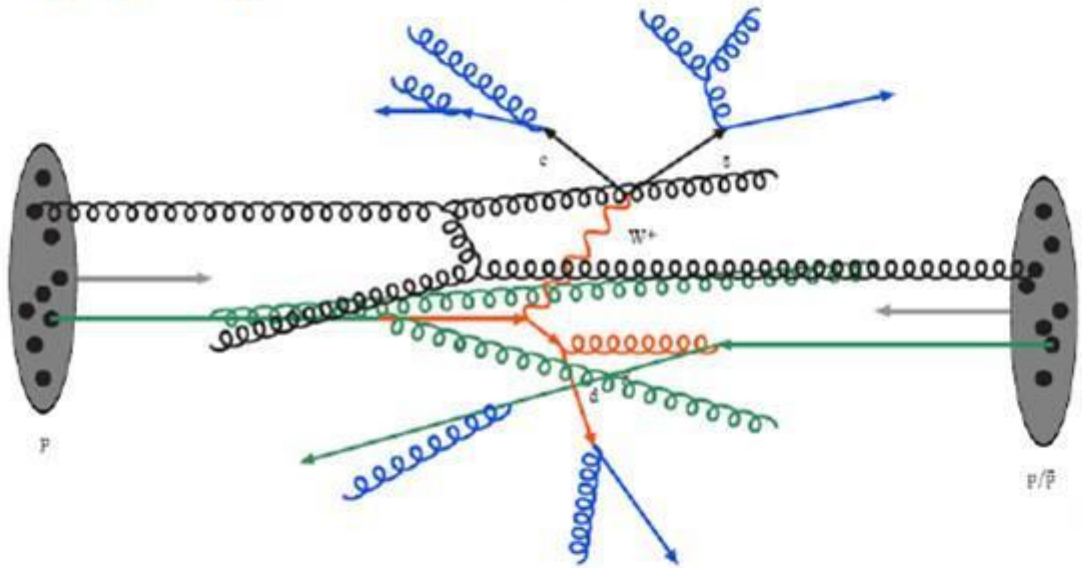


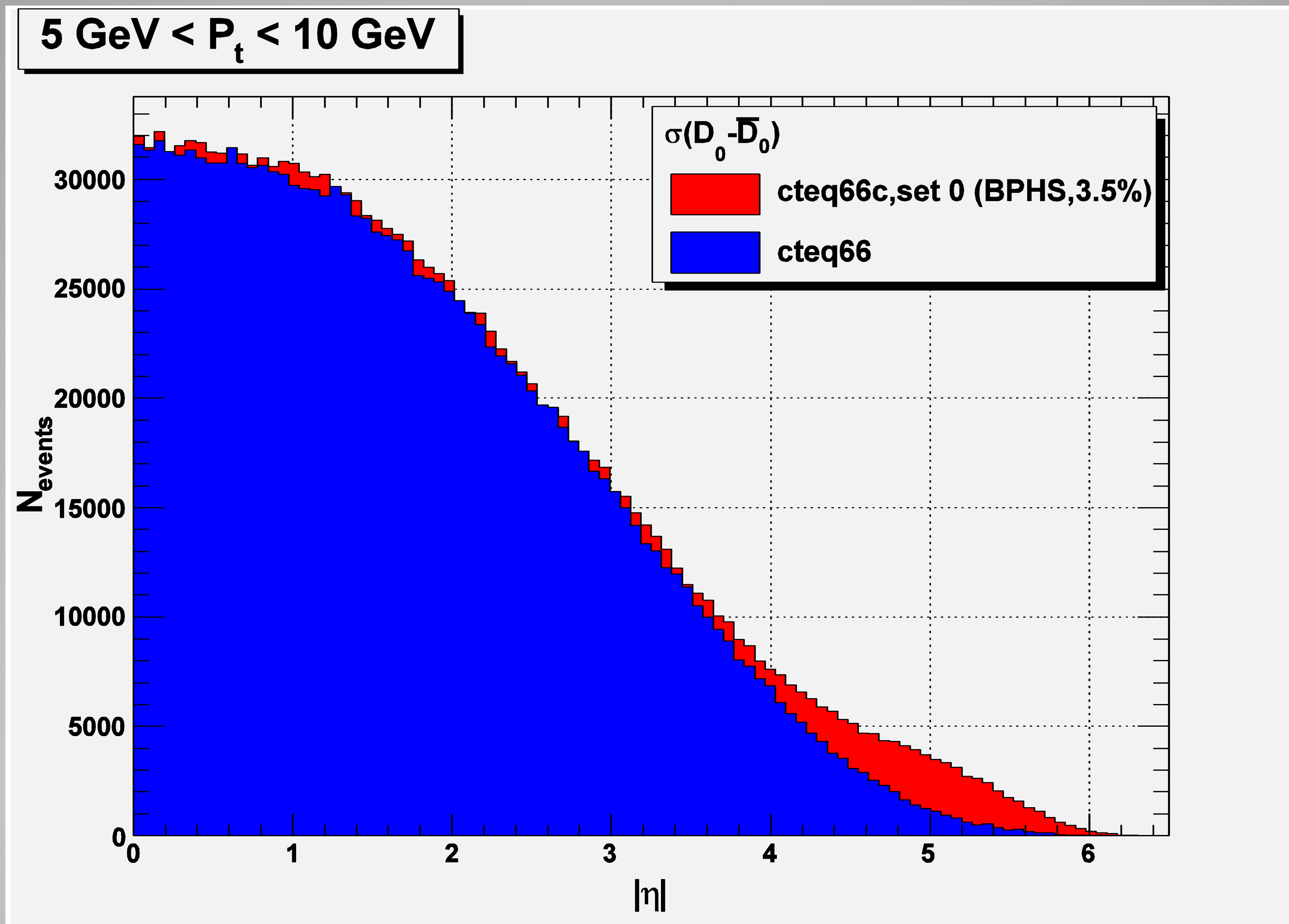
$\sqrt{s} = 7\,TeV$

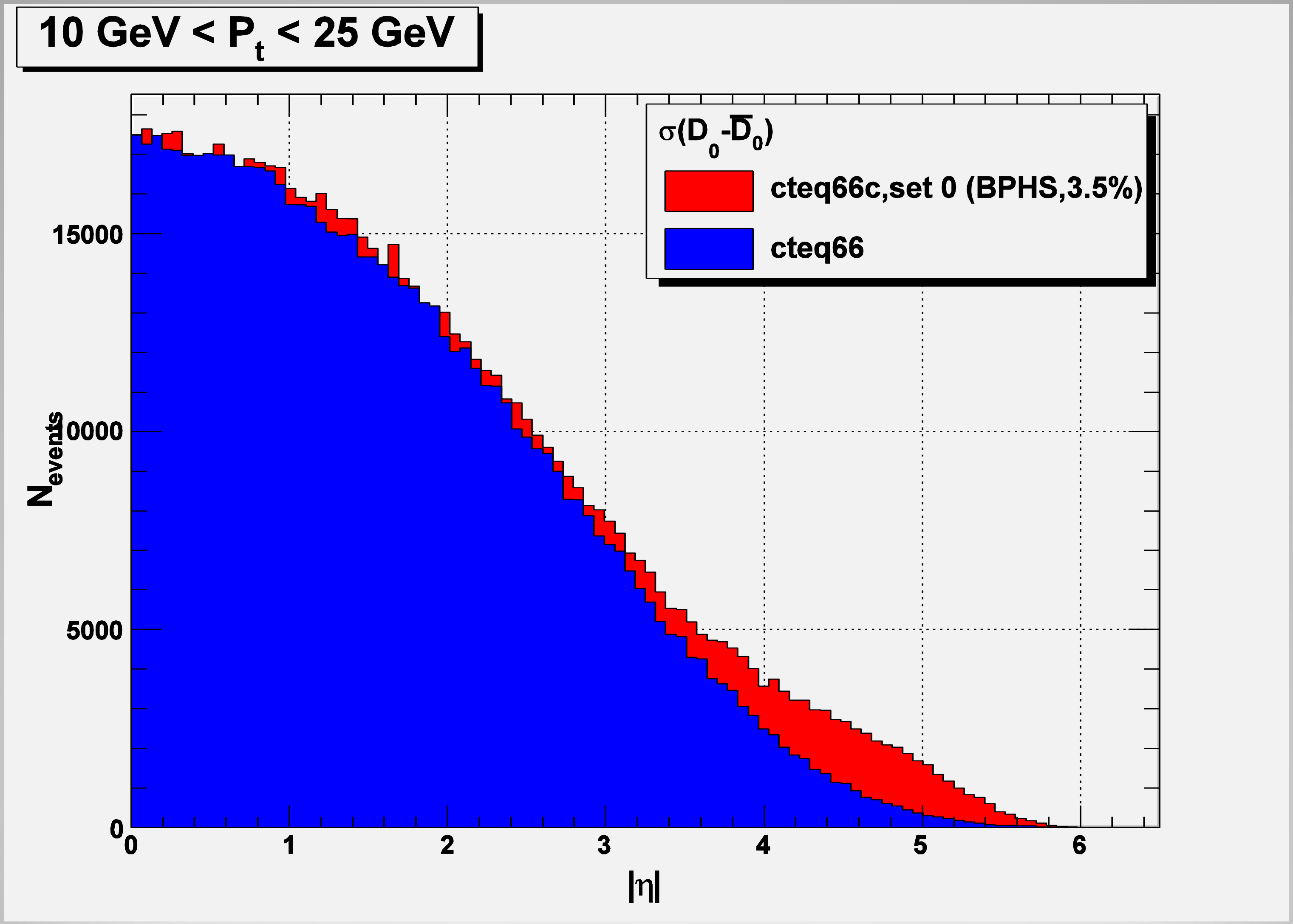
Pseudo-rapidity η distribution of $D^0 + \bar{D}^0$ produced in p-p

Structure of an event

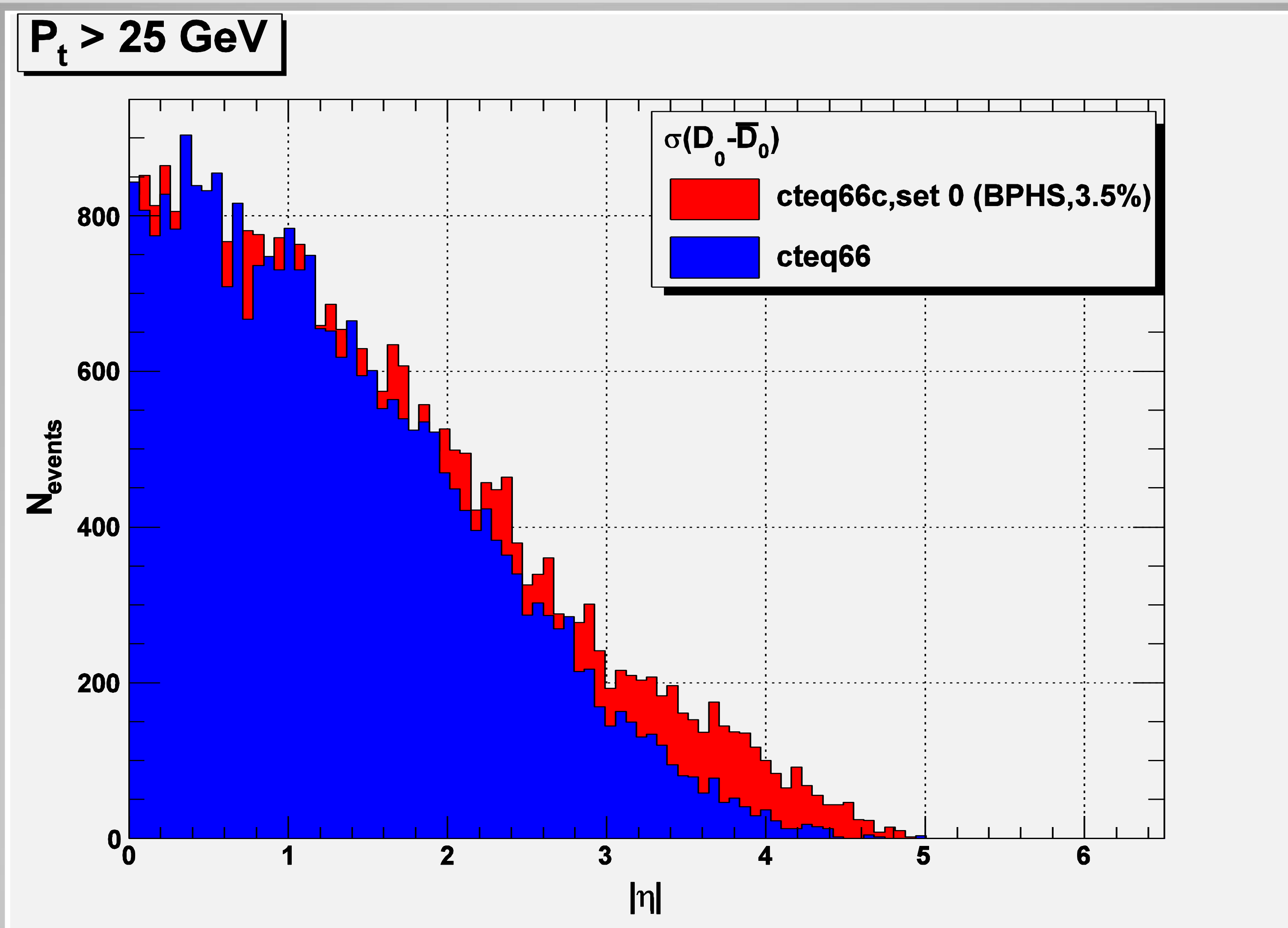
- Multiple parton-parton interactions




5 GeV < P_t < 10 GeV
$\sigma(D_0-\bar{D}_0)$
cteq66c,set 0 (BPHS,3.5%)
cteq66
N_{events}
30000
25000
20000
15000
10000
5000
0
0
1
2
3
4
5
6
$|\eta|$



10 GeV < P_t < 25 GeV
σ(D_0-D̄_0)
cteq66c,set 0 (BPHS,3.5%)
cteq66
N_events
|η|
0
5000
10000
15000
0
1
2
3
4
5
6



Pt > 25 GeV
σ(D0-D̄0)
cteq66c,set 0 (BPHS,3.5%)
cteq66
Nevents
|η|
0
200
400
600
800
0
1
2
3
4
5
6