Production of prompt photons and Z-bosons accompanied by heavy flavour jets and constraints on the intrinsic charm content of the proton from recent LHC data

Gennady Lykasov

JINR, Dubna,

OUTLINE

1. Hard processes pp->γ/Z/W+b(c)+X, k_T - factorization of QCD and MC generators.
2. BHPS model on the intrinsic charm (IC) content in proton.
3. Constraints of the IC contribution from resent LHC data.
4. p_T –spectra of Z-bosons in pp->Z+b(c)+X at $s^{1/2}$ = 7 & 8 TeV and comparison to ATLAS and CMS data
5. Difference between results obtained within the QCD k_T – factorization and MC SHERPA.
6. Predictions on similar spectra at $s^{1/2}$ =13 TeV.
7. Summary

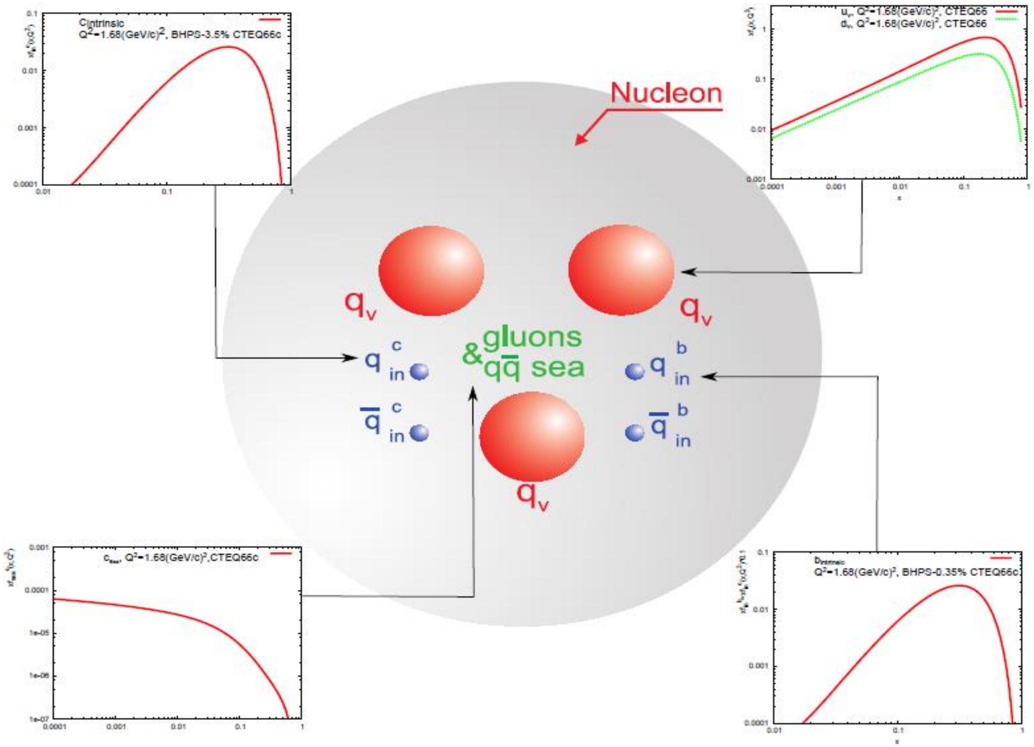
HARD PRODUCTION OF γ/Z/W ACCOMPANIED BY c/b JETS IN PP COLLISIONS AT LHC ENERGIES

At low x corresponded to the CMS and ATLAS kinematics

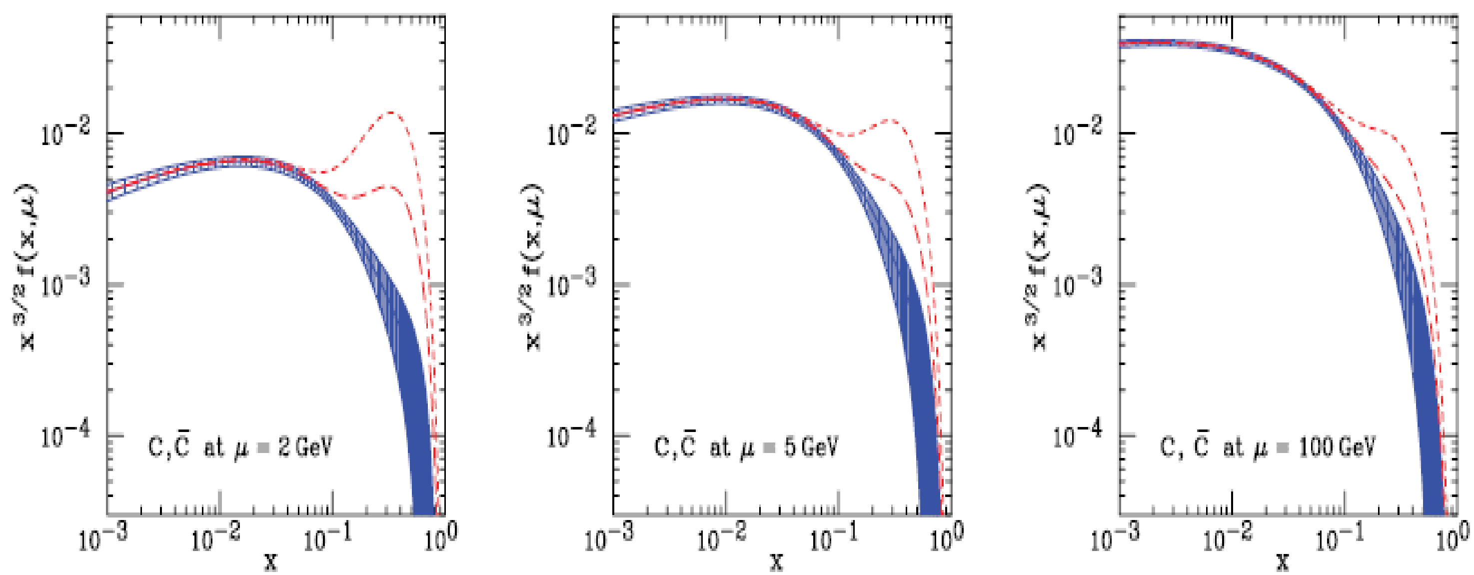
1. **The k_T – factorization of QCD using the unintegrated gluon distributions $g(x,k_T,\mu^2)$ & the MCFM μ^2 -evolution equations. The input $g(x,k_T,\mu_0^2)$ for this equation is very significant. We found it from calculation of the cut one-Pomeron exchange graph between the non perturbative gluons in colliding protons.**
2. **In the forward rapidity region of *the CMS and ATLAS* (|y|>1.5) and large p_T > 100 GeV/c, when x_F >0.1, the k_T – factorization can not be applied successfully. Therefore, the conventional collinear QCD approach with the mass shell gluons can be used .**
3. **For processes pp -> Z/W + c/b-jets the MC generator as a Sherpa can be used including NLO corrections.**
4. **Unfortunately for pp -> γ + c/b-jets there was only Sherpa (LO), version 2.2.1.**

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



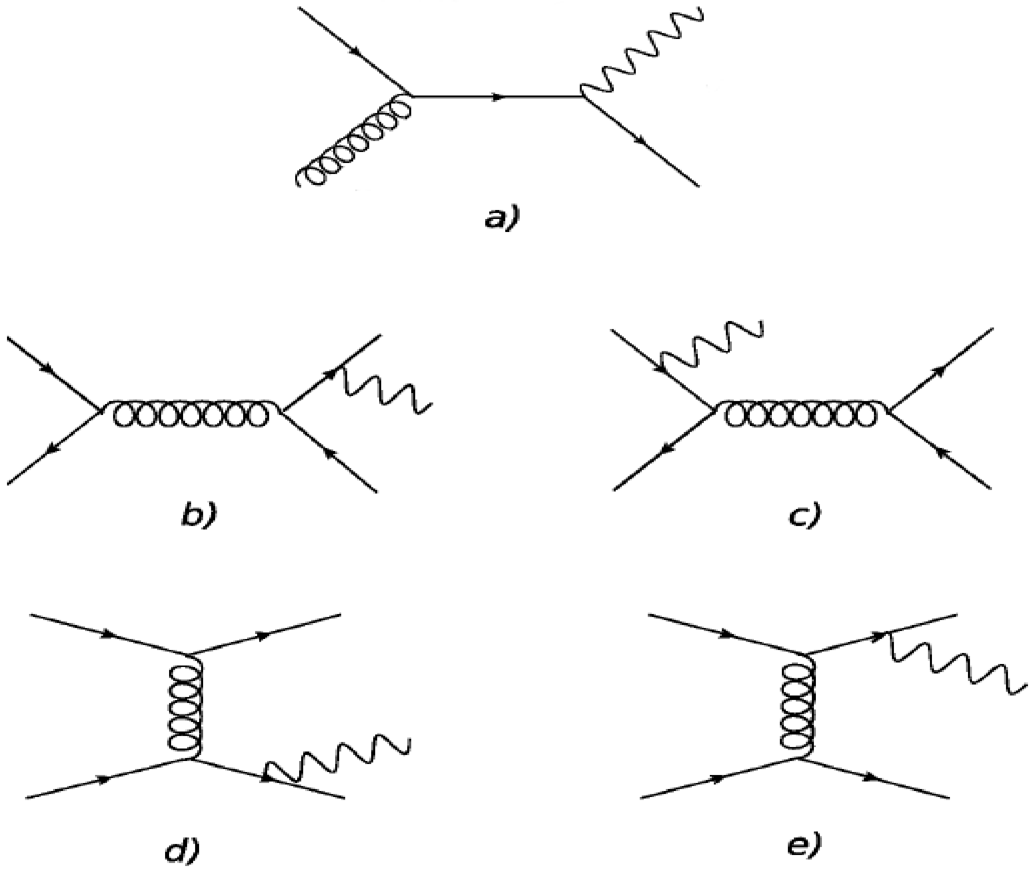
CHARM QUARK DISTRIBUTIONS IN PROTON



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, see J.Pumplin, Phys.Rev. D73, 114015 (2006) .

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



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

According to the BHPS model

$$xc(x,\mu_0^2) = xc_{extr}(x,\mu_0^2) + xc_{intr}(x,\mu_0^2)$$

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.

A simple linear interpolation over the IC probability *w*:

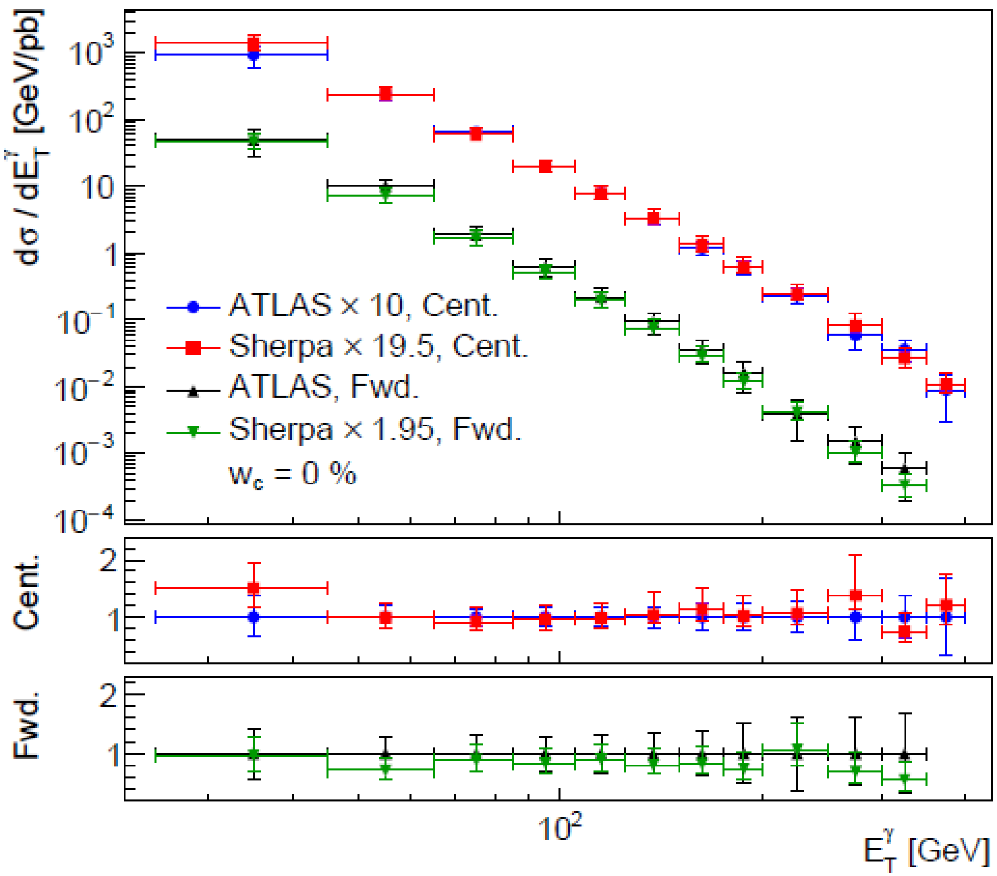
at *w* less or equal to w_{max}

$$xc_{intr}(w,x,\mu^2) = (w/w_{max})\, xc_{intr}(w_{max},x,\mu^2)$$

The quadratic *w* interpolation leads results differed from these no more than 0.5%, as is shown in

A.V.Lipatov, G.I.Lykasov, Yu.Yu.Stepanenko, V.A. Bednyakov, Phys.Rev. D94, 0653011 (2016)

ASSUMING THE BHPS MODEL
THE QUESTION ARISES TO CHECK IT FROM RECENT LHC DATA



TRANNSVERSE ENERGY SPECTRUM OF PHOTONS PRODUCED in P-P AT $S^{1/2}$ =8 TeV

Central: |η| <1.37; Forward: 1.56<|η|<2.37; w_c =0 is the IC probability

V.A.Bednyakov, S.J.Brodsky, A.V.Lipatov, G.I.Lykasov, M.A. Malyshev, J.Smiesko, S.Tokar; arXiv: 1712.09096 [hep-ph], December 2017

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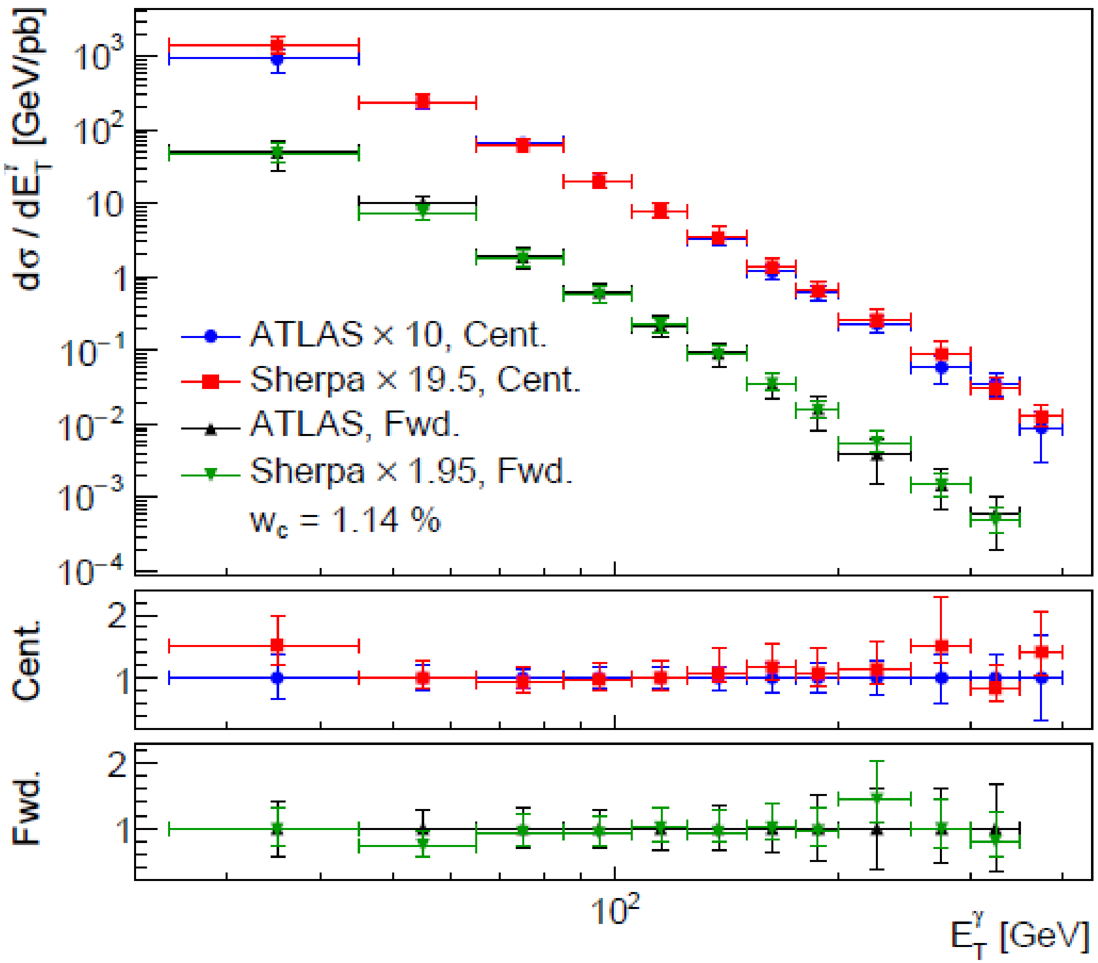

Central: |η| <1.37; Forward: 1.56<|η|<2.37; w_c = 1.14 % is the IC probability

V.A.Bednyakov, S.J.Brodsky, A.V.Lipatov, G.I.Lykasov, M.A. Malyshev, J.Smiesko, S.Tokar; arXiv: 1712.09096 [hep-ph], December 2017

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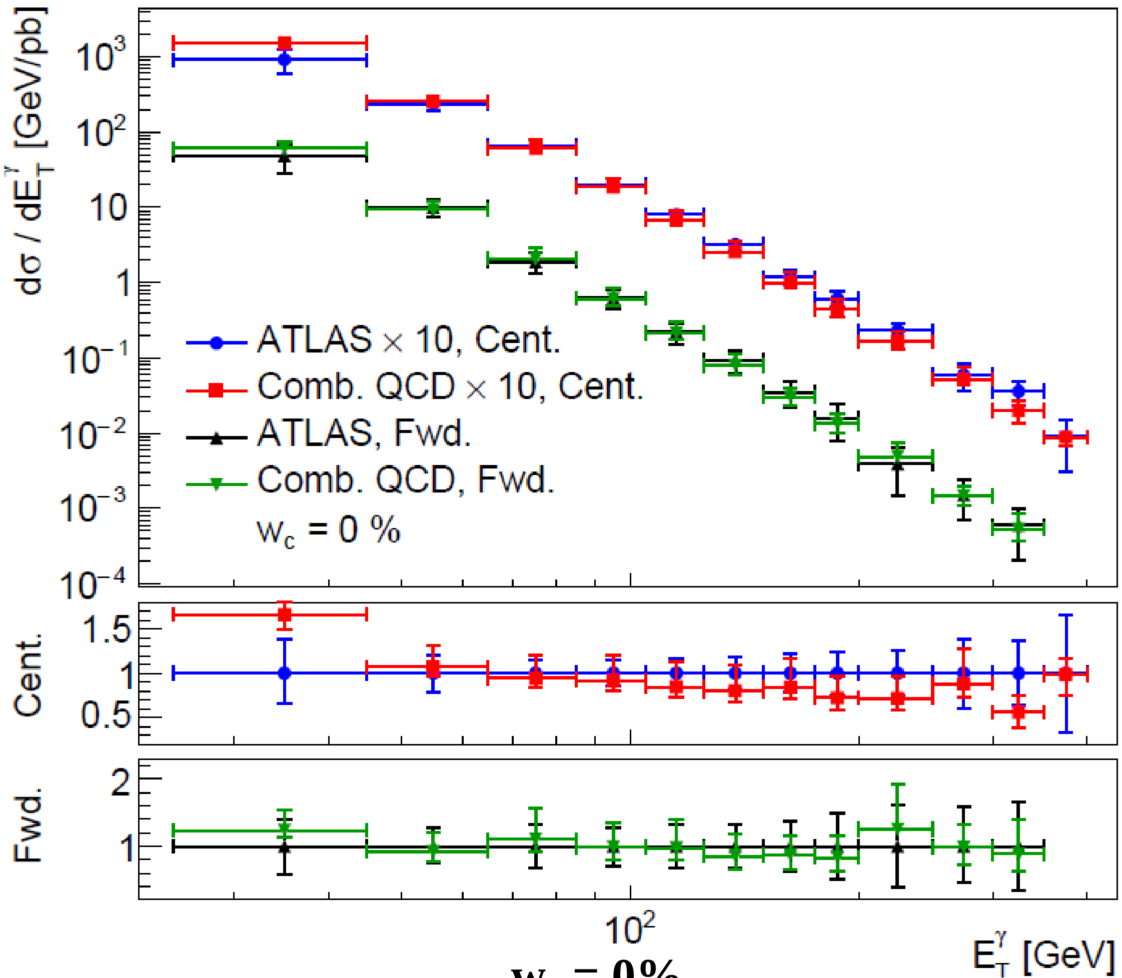
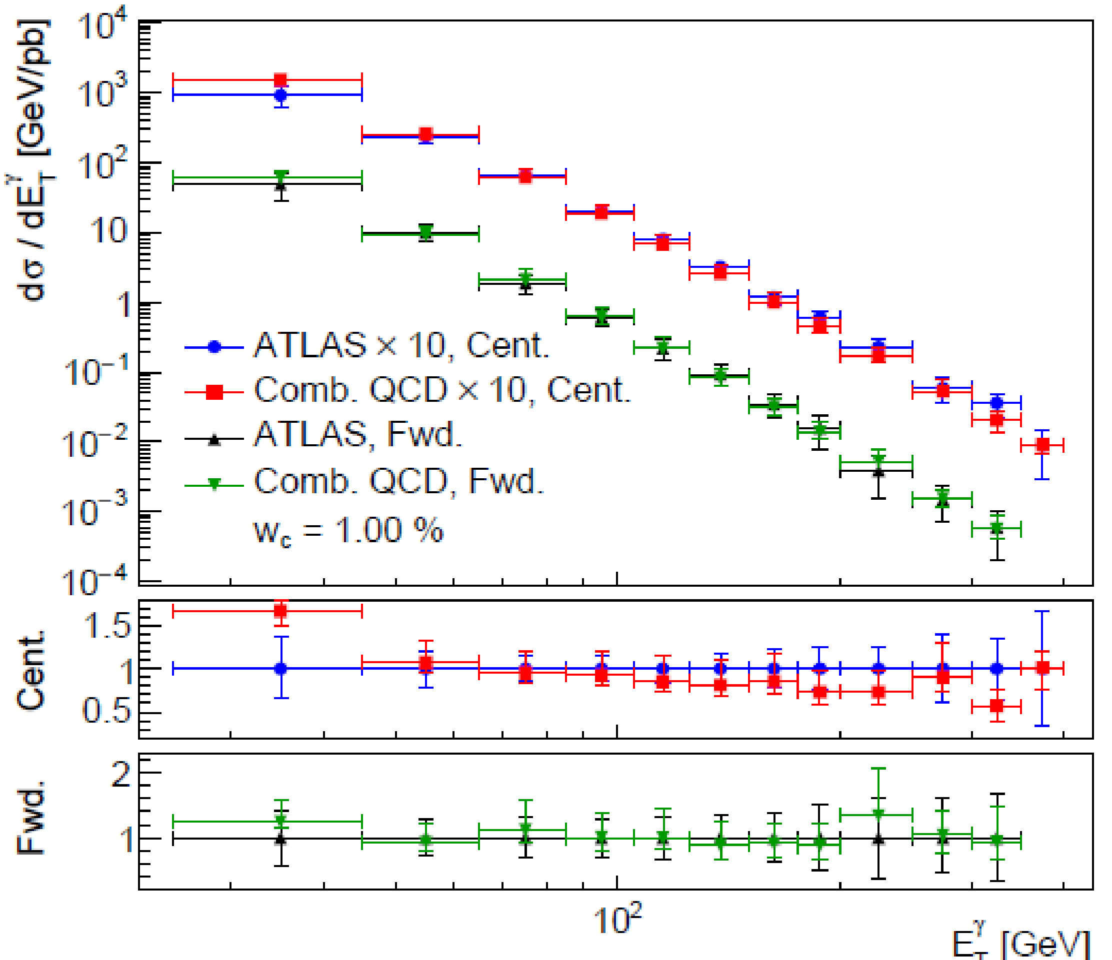


w_c = 0%

Combined QCD: k_T at low x (c g*-> γ c, g* g*->γ c bar{c})
and conventional collinear QCD for quarks and antiquarks graphs at large x

arXiv*: 1712.09096 [hep-ph], December 2017*

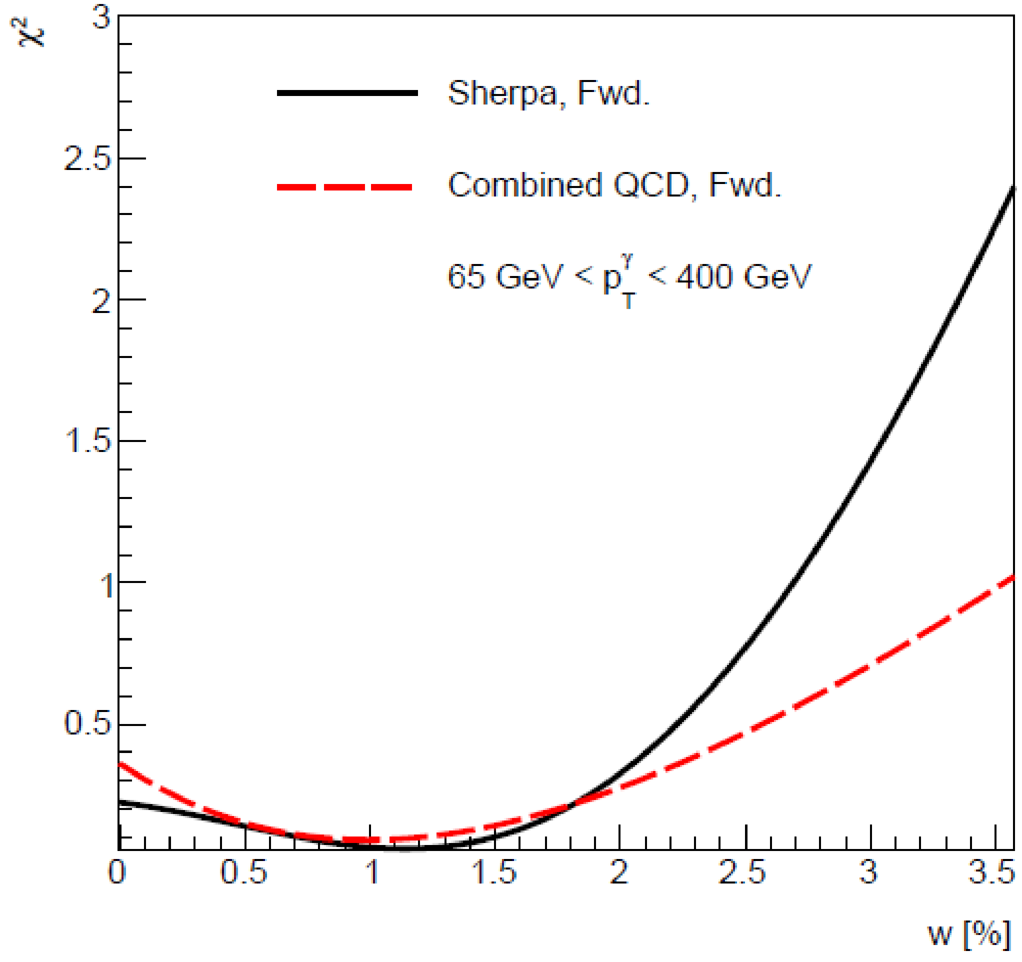
TRANNSVERSE ENERGY SPECTRUM OF PHOTONS PRODUCED in P-P AT $S^{1/2}$ =8 TeV



w_c = 1%

Combined QCD: k_T at low x (c g*-> γ c, g* g*->γ c bar{c})
and conventional collinear QCD for quarks and antiquarks graphs at large x

arXiv*: 1712.09096 [hep-ph], December 2017*



Solid line: χ^2 is a function of w at the forward rapidity region in SHERPA.
Dashed line: the similar χ^2 obtained by the combined QCD calculation.

	SHERPA [%]	Comb. QCD [%]
w_c	1.14	1.00
$w_{u.l.}$ (68% C.L.)	2.74	3.69
$w_{u.l.}$ (90% C.L.)	3.77	6.36
$w_{u.l.}$ (95% C.L.)	4.32	> 7.5

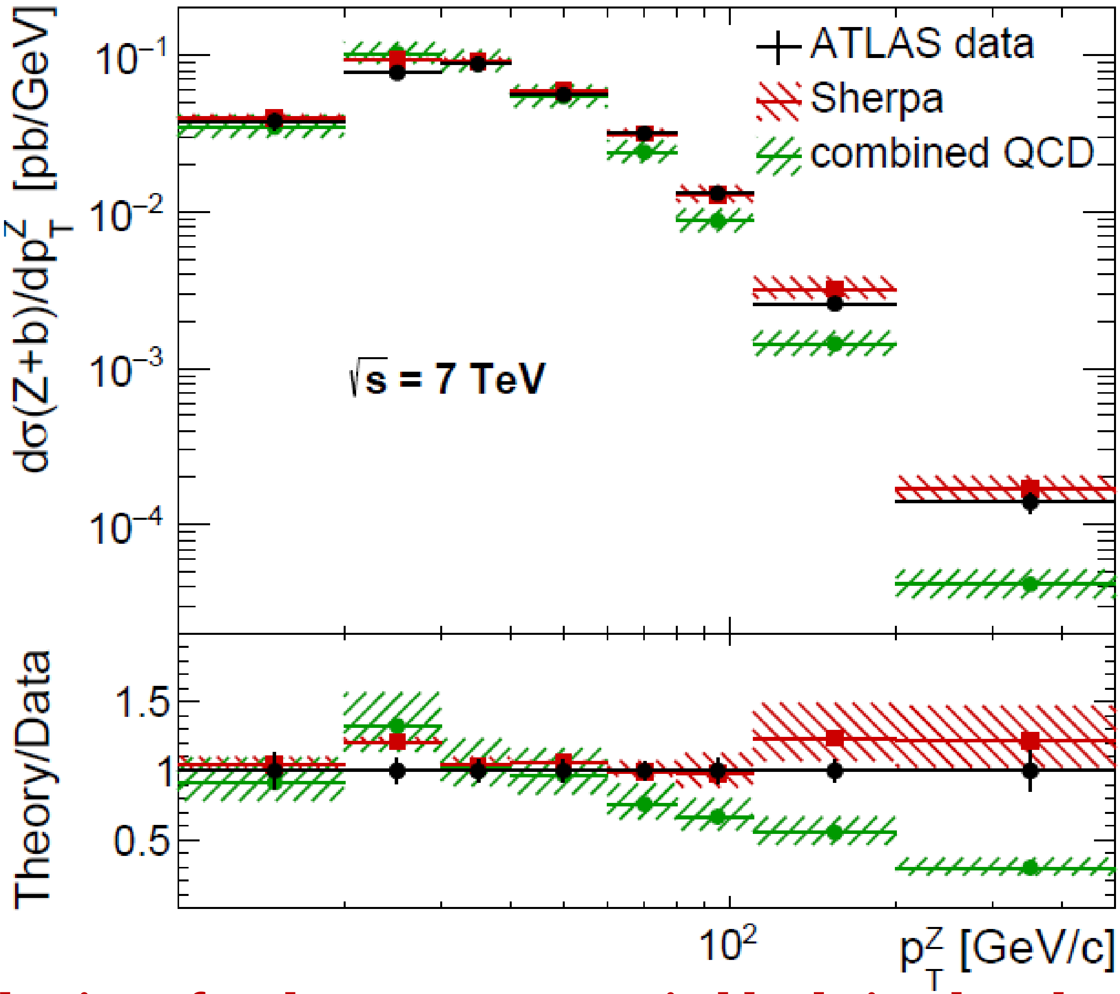
TABLE I. Central w_c value and upper limits $w_{u.l.}$ obtained within SHERPA and combined QCD calculations.

The first line corresponds to the central value w_c; the second (3rd, 4th) line is w_c plus one (two, three) standard deviation(s) σ, $w_{ul} = w_c + 1(2,3)\sigma$.

Even at a level of one standard deviation the w_c is comaparable to w=0, therefore it is reasonable to indicate only the upper limit w_{ul} .

Recently the global PDF analysis showed that the upper limit for the IC probability is about $w_{ul} = 5\%$.
(T.J. Hou et al., JHEP 02, 059 (2018); arXiv:1707.00657)

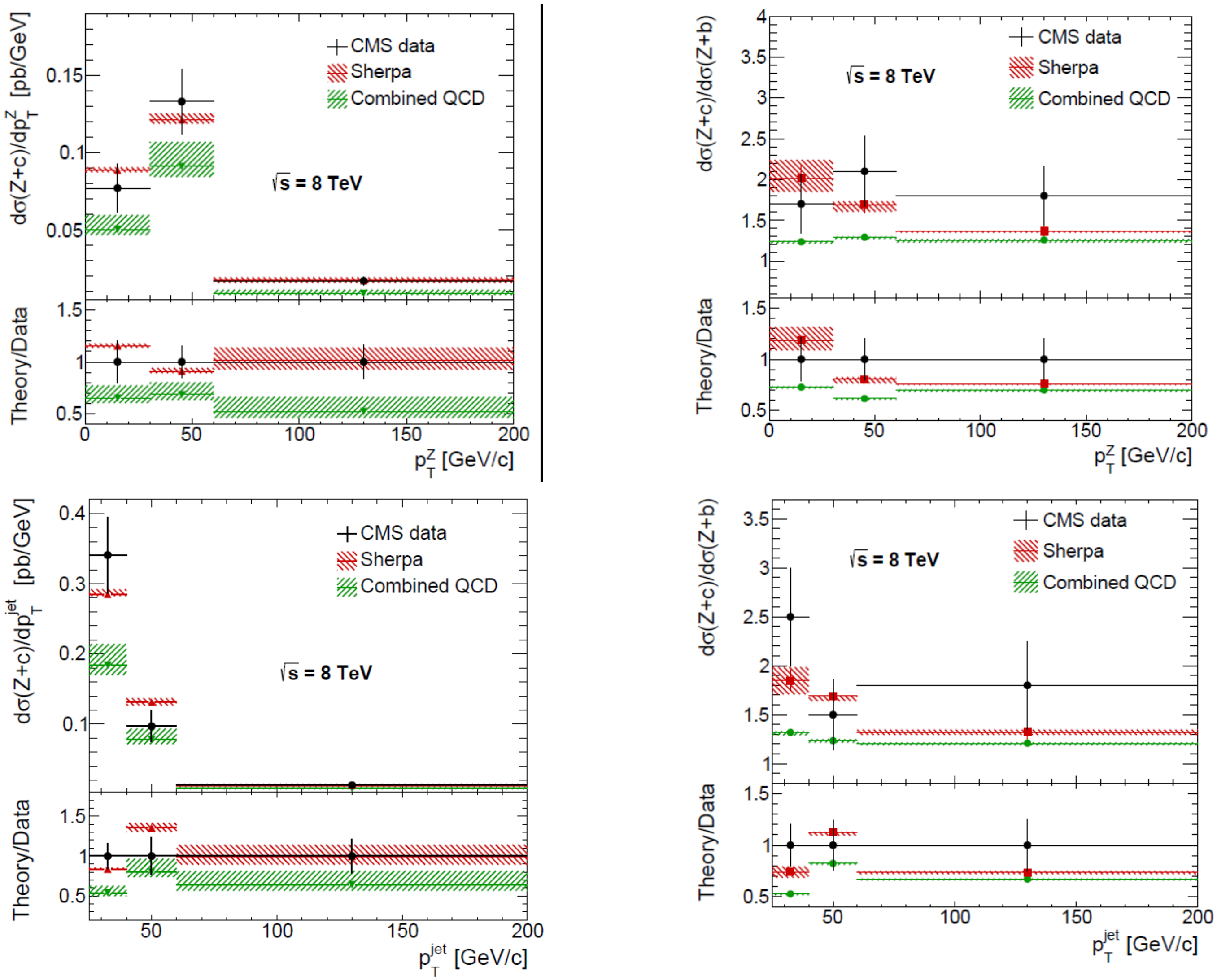
PP->Z+b+X, $s^{1/2}$ = 7 TeV



p_T^Z – distribution of Z-boson accompanied by b-jet; bands are the scale uncertainties.

A.V.Lipatov, G.I.Lykasov, M.A.Malyshev, A.A.Prokhorov, S.M.Turchikhin
arXiv: 1802.05082 [hep-ph]

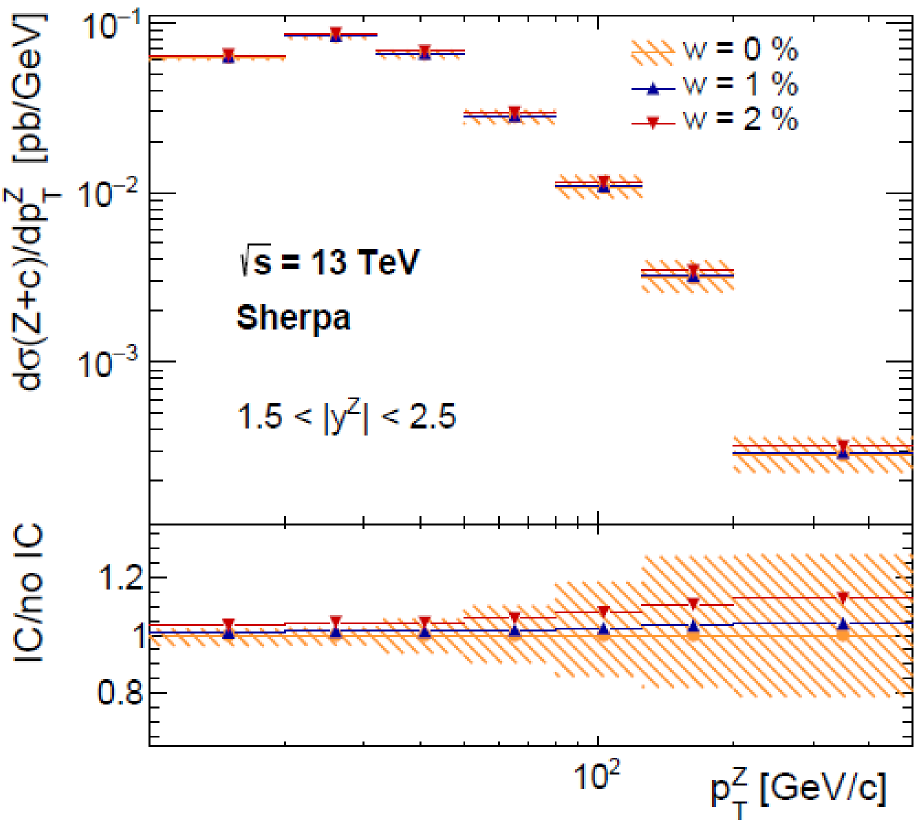
PP->Z+c(b)+X, $s^{1/2}$ = 8 TeV

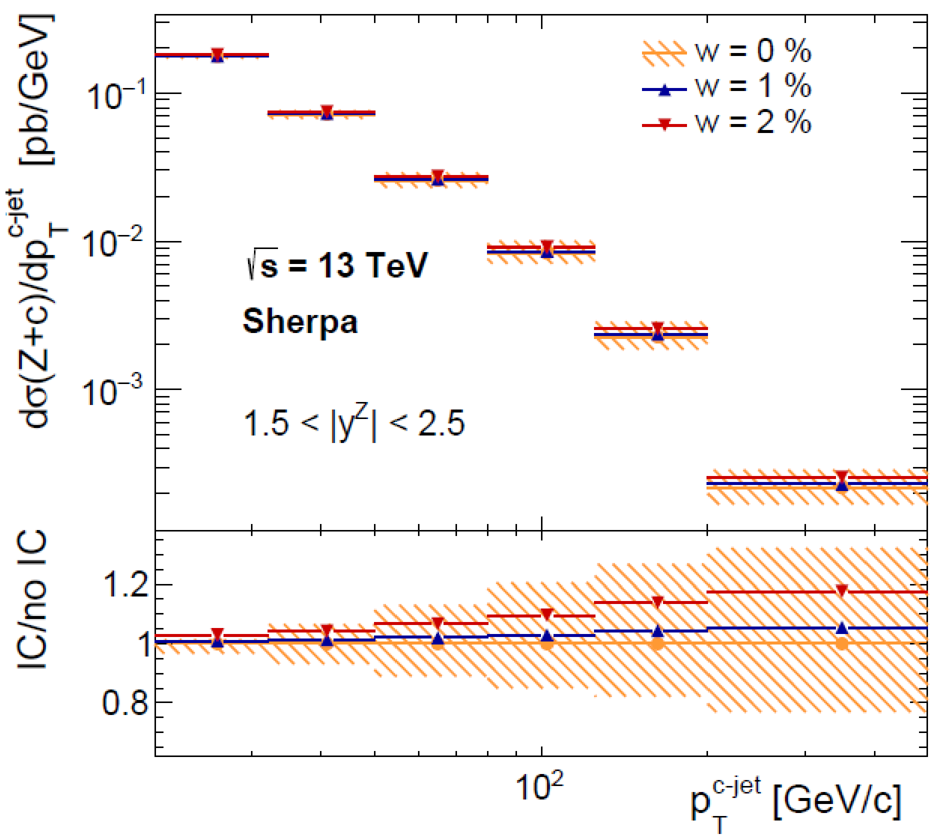


Top: p_T^Z – distribution in the Z+c production (left) and for the ratio σ(Z+c)/σ(Z+b)
Bottom: p_T^{jet} – distribution in the Z+c production (left) and for the ratio σ(Z+c)/σ(Z+b)

arXiv: 1802.05082 [hep-ph]

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

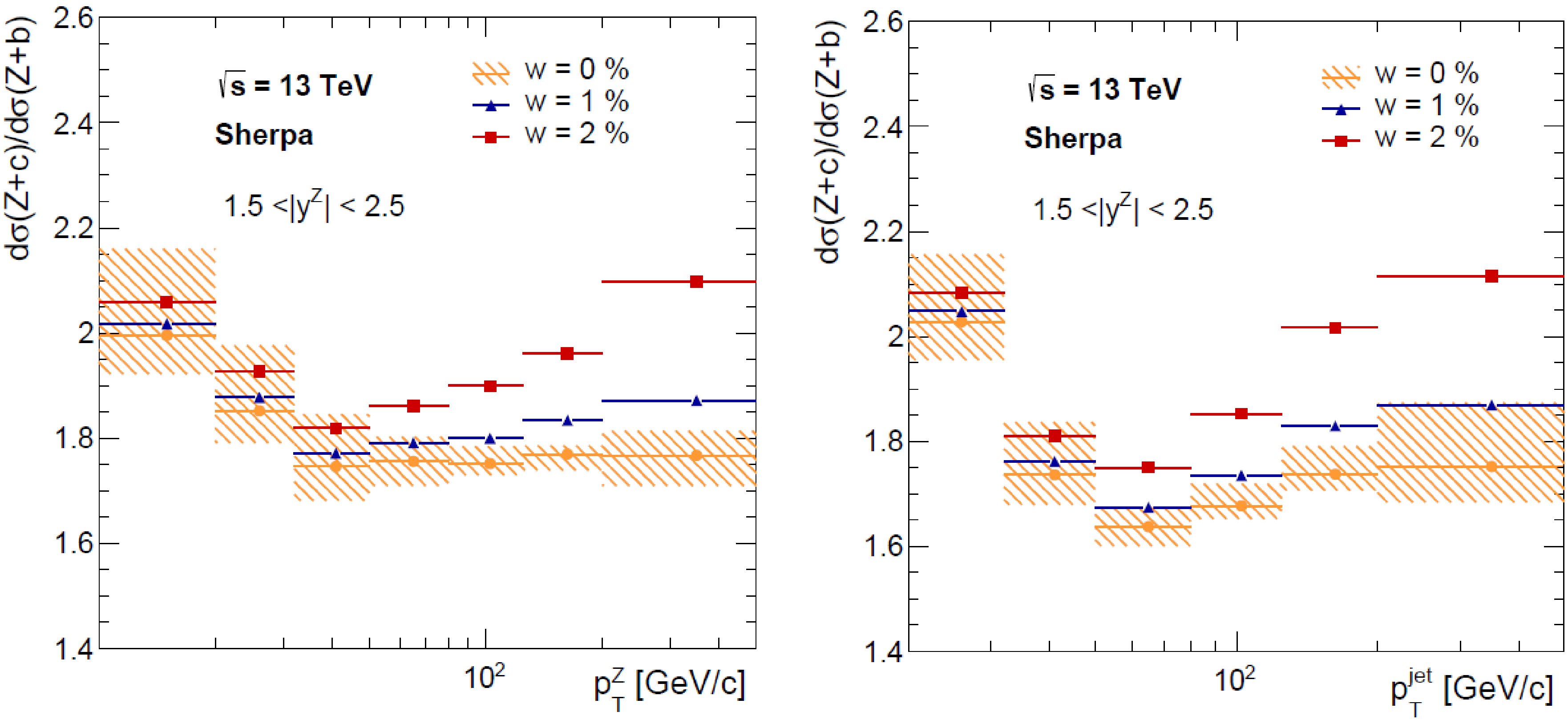




Predictions for spectra in the forward ATLAS region with different IC contribution in proton

arXiv: 1802.05082 [hep-ph]

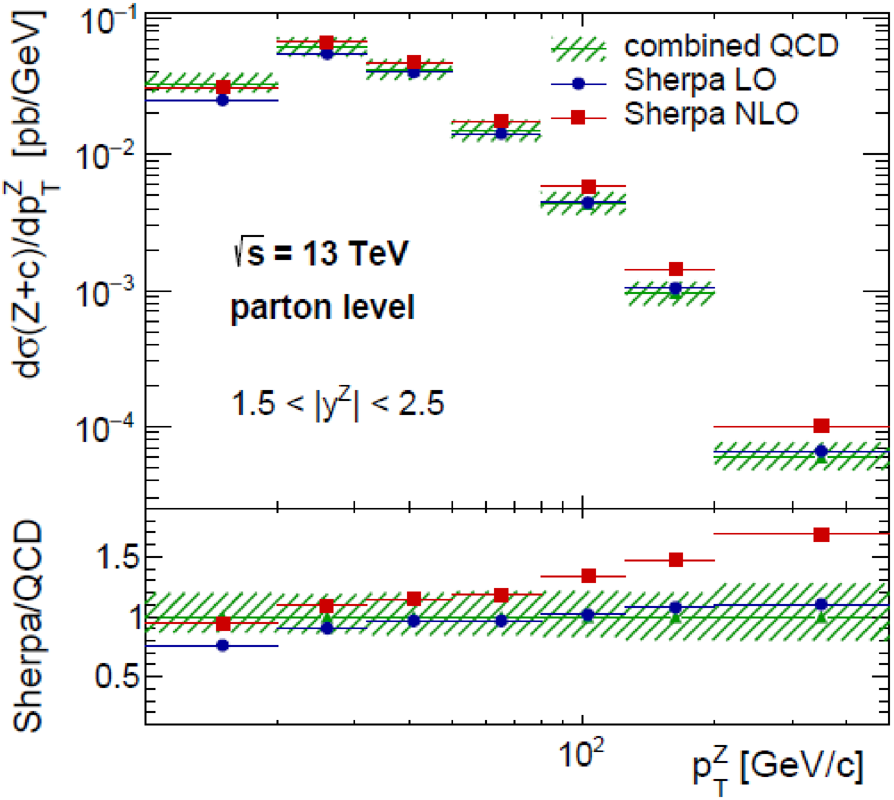
PP->Z+c+X, $s^{1/2}$ = 13 TeV

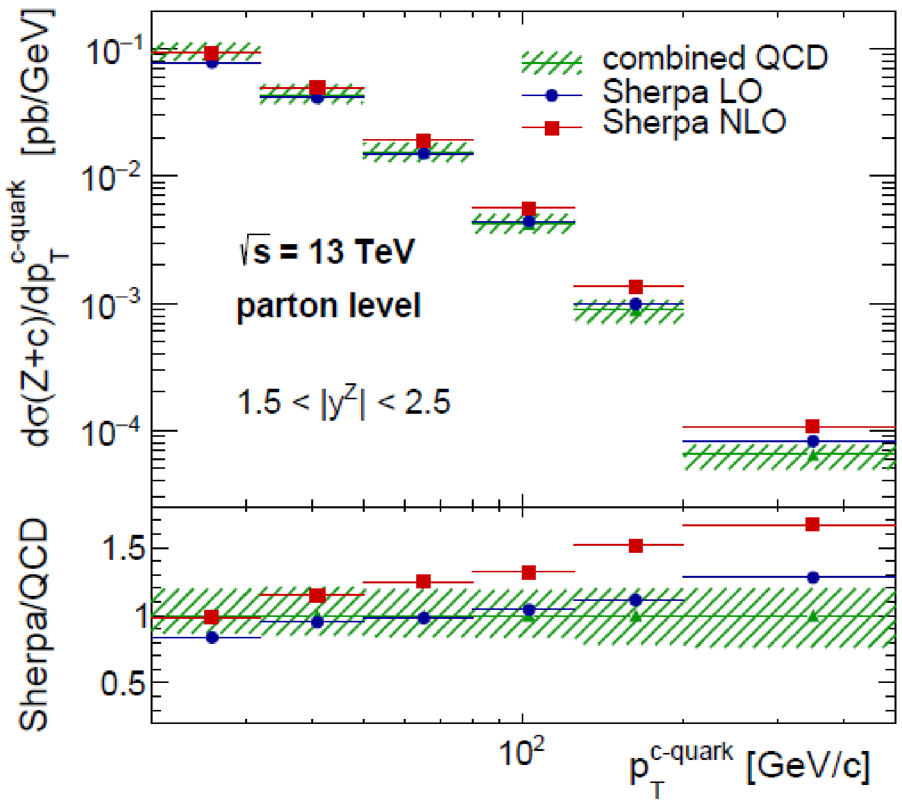


Predictions for the ratio σ(Z+c)/σ(Z+b) in the forward ATLAS region with different IC contribution in proton

arXiv: 1802.05082 [hep-ph]

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

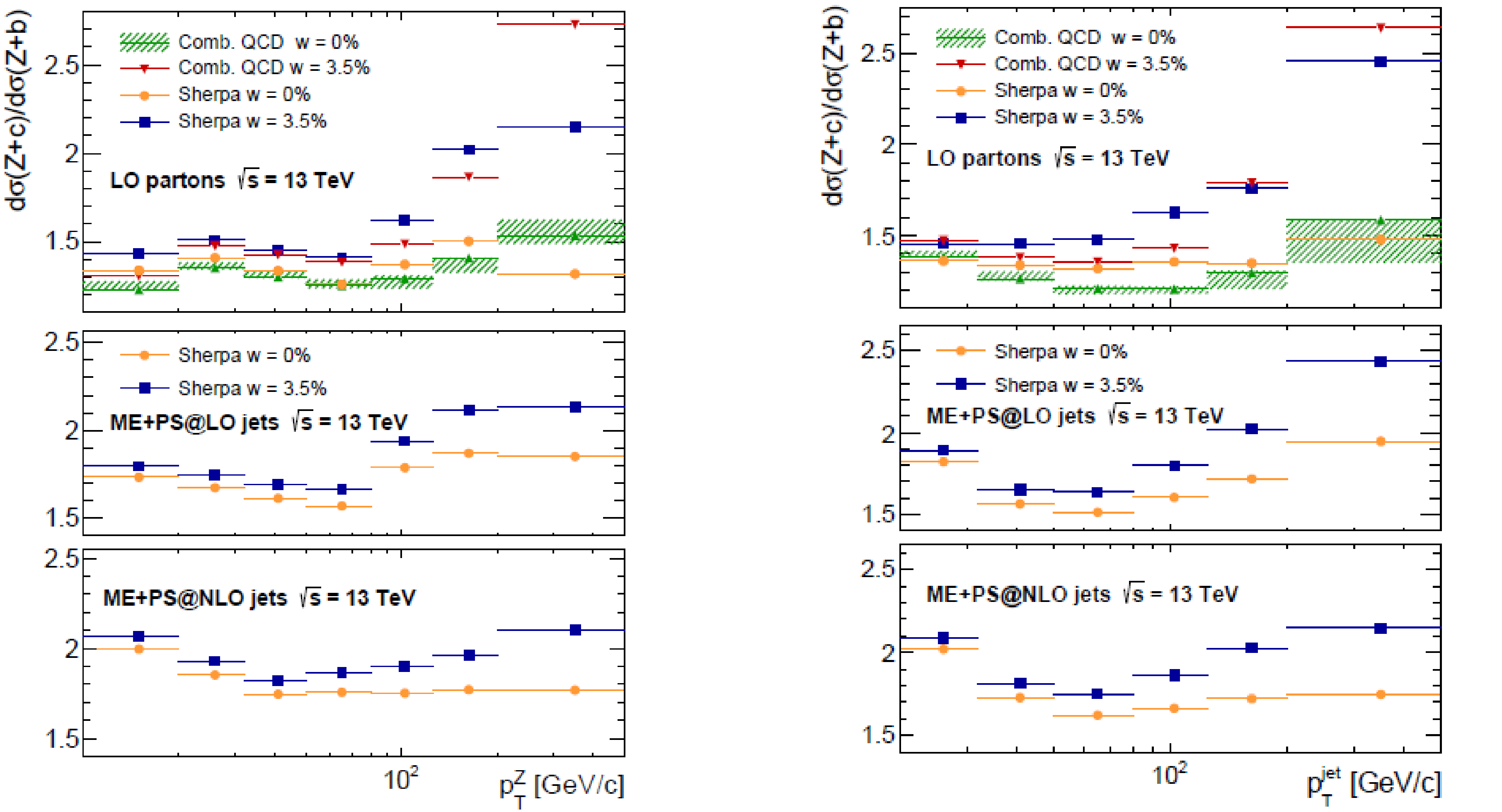




Parton level predictions for Z+c production in the forward ATLAS region within the Sherpa and combined QCD

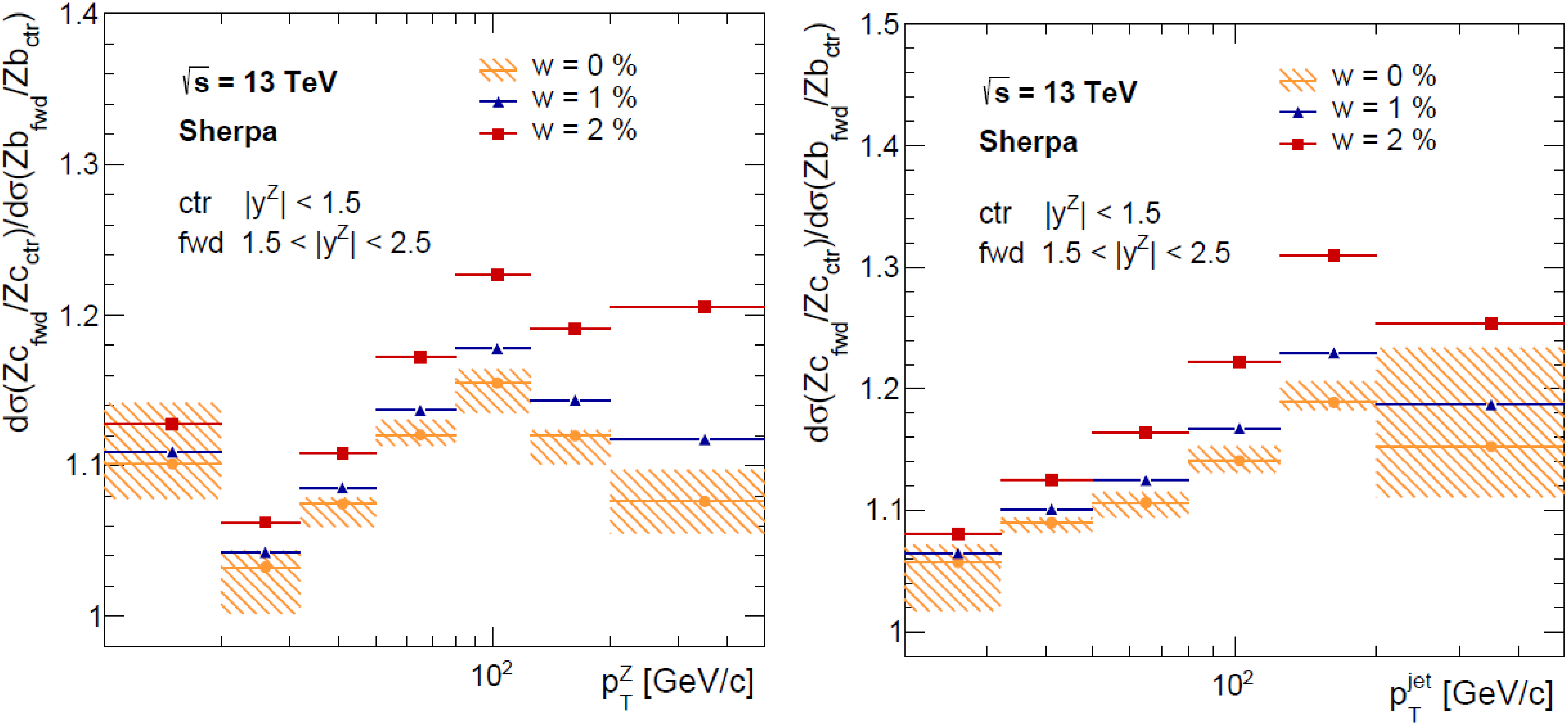
arXiv: 1802.05082 [hep-ph]

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



arXiv: 1802.05082 [hep-ph]

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



Double ratio as a function of p_T^Z (left) and p_T^{jet} (right)

arXiv: 1802.05082 [hep-ph]

SUMMARY

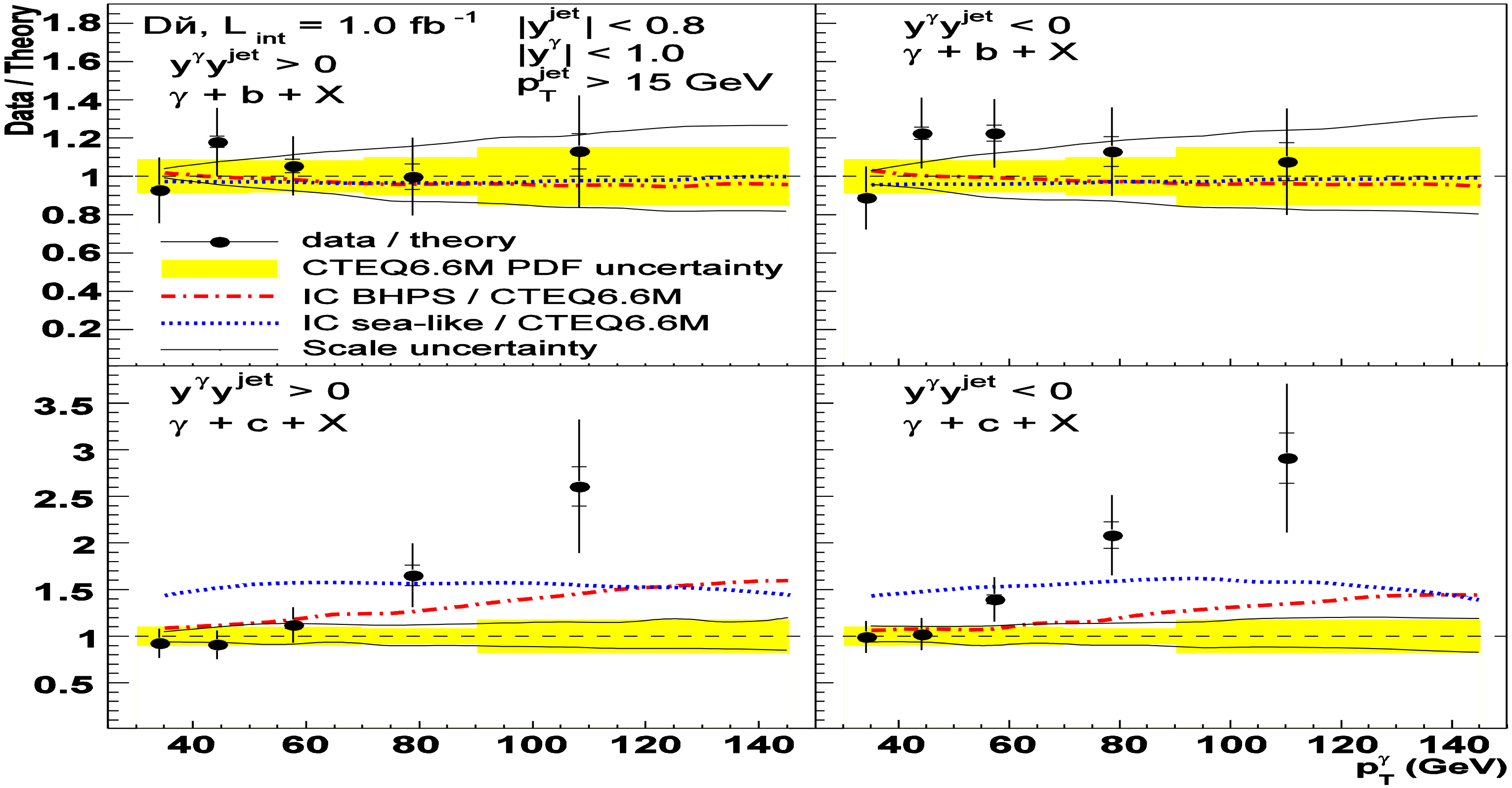
1. A first estimate of the intrinsic charm (IC) probabilityw in the proton has been carried out from the recent ATLAS data.
2. Big experimental_and theoretical uncertainties at allowed us to estimate only the upper limit w_{ul} = 2.74% at CL=68 % and w_{ul} =4.32% at CL=95%.
3. To obtain more accurate results on the IC contribution one needs additional data and at the same time reduced systematic uncertainty coming from light jet tagging.
4. One need s also the reduce the theoretical uncertainties related to the QCD scale.

5. We have the satisfactory description of ATLAS and CMS data on p_T –spectra of Z-bosons produced in pp->Z+b(c)+X at $s^{1/2}$ =7 and 8 TeV in the whole pseudo-rapidity region $|\eta^Z|$ <2.5
6. The results obtained within the k_T – factorization of QCD and MC generator SHERPA are closed each to other
7. The k_T -factorization predictions on similar spectra were done at $s^{1/2}$ =13 TeV both at central and forward rapidity regions.
8. For pp->Z+c+X we predict an enhancement in the p_T – spectrum of Z-boson at p_T >100 GeV/c due to the intrinsic charm (*IC*) contribution in the proton PDF.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

BACK UP

$p\bar{p} \to \gamma + c(b) + X$ **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** $pp \to \gamma + c(b) + X$

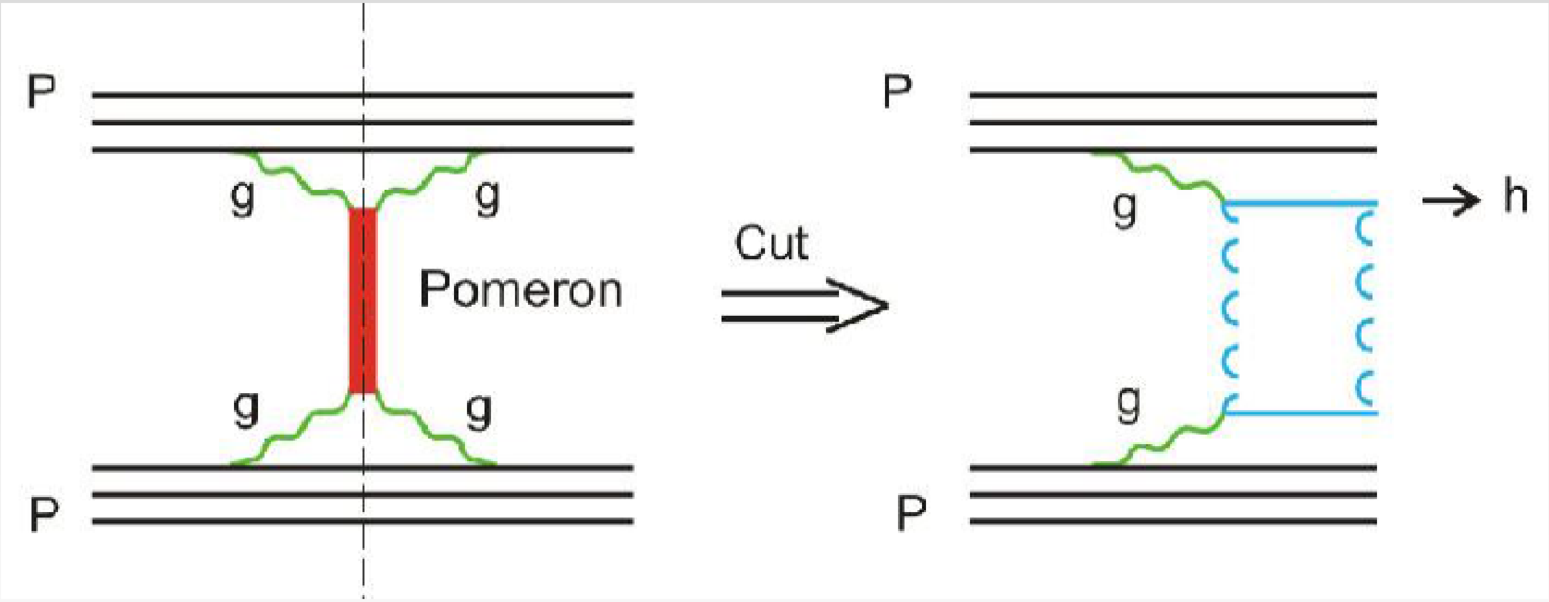
INTRINSIC HEAVY QUARK STATES

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.

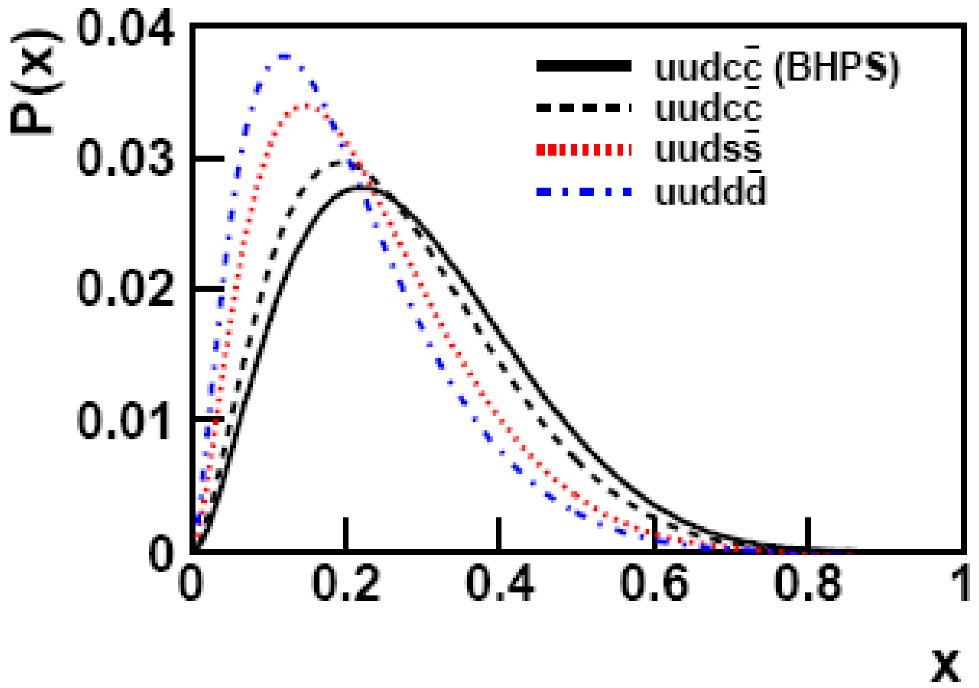
$$P(x_1, \ldots, x_5) = N_5\, \delta\left(1 - \sum_{i=1}^{5} x_i\right)\left[M_p^2 - \sum_{i=1}^{5} \frac{m_i^2}{x_i}\right]^{2}$$



One-Pomeron exchange (left) and the cut one-Pomeron exchange (right); P-proton, g-gluon, h-hadron produced in PP

In the light cone dynamics the proton has a general decomposition:

$|uud\rangle, |uudg\rangle, |uudq\bar{q}\rangle, \ldots$ S.J.Brodsky, C.Peterson, N.Sakai, Phys.Rev. D 23 (1981) 2745.



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.

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.