Yields and polarisation of Ψ(1S,2S) in prompt production and in pair production at LHC

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Lunch Seminar @ TUHEP

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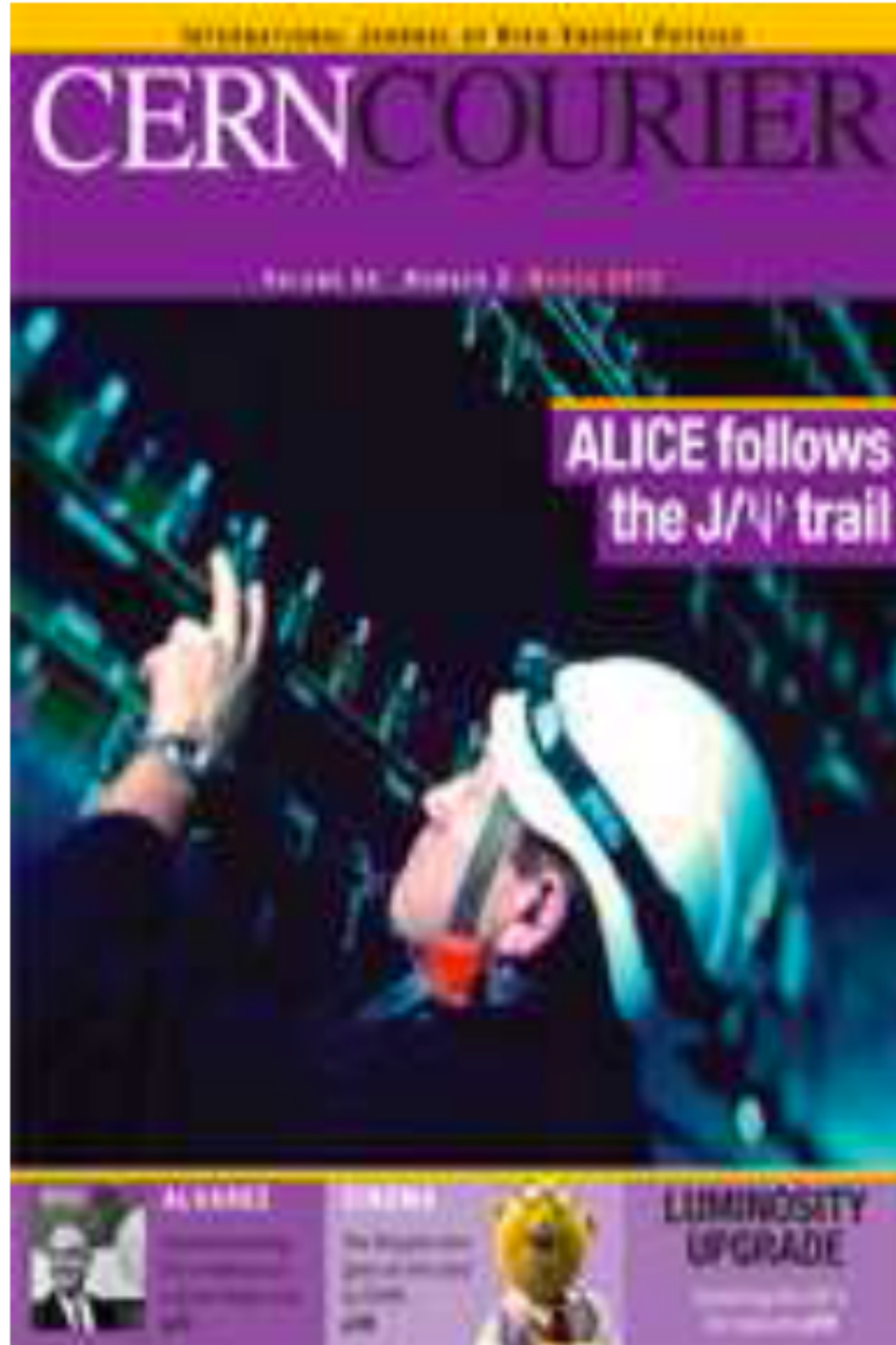
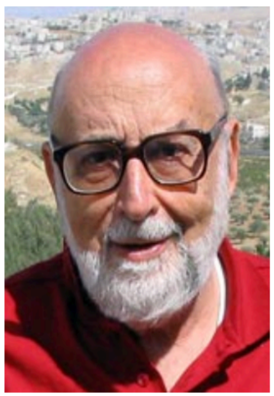
CERN COURIER
All eyes are on the Higgs
A BEAUTIFUL FUTURE


CERN COURIER
ALICE follows the J/ψ trail
LUMINOSITY UPGRADE

The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013



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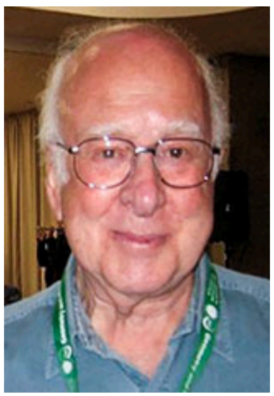
François Englert



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Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

The Nobel Prize in Physics 1976
Burton Richter, Samuel C.C. Ting

The Nobel Prize in Physics 1976

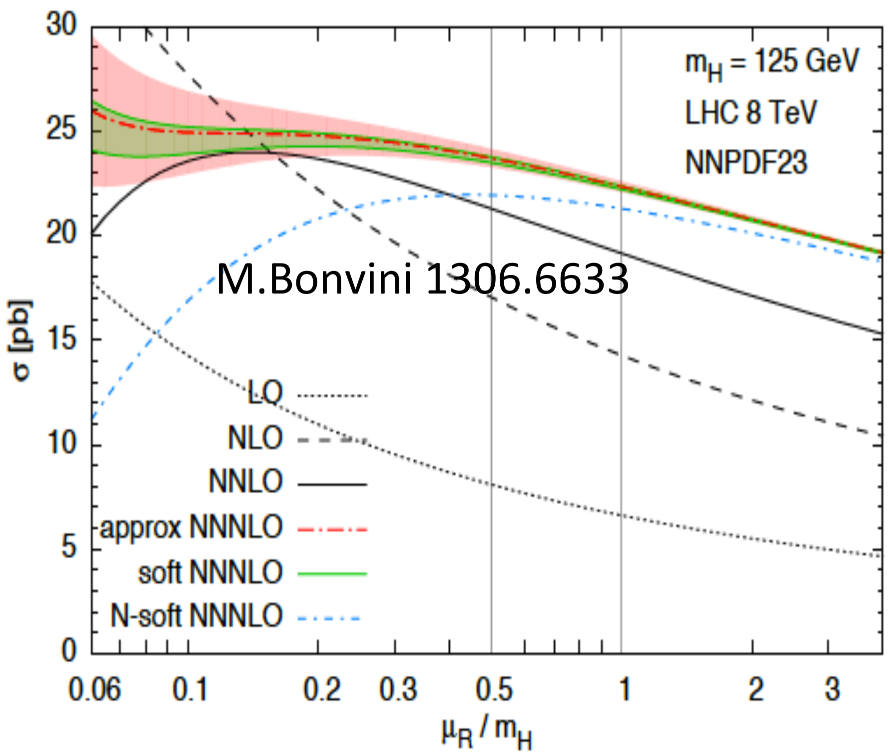
Burton Richter

Samuel Chao Chung Ting

The Nobel Prize in Physics 1976 was awarded jointly to Burton Richter and Samuel Chao Chung Ting *"for their pioneering work in the discovery of a heavy elementary particle of a new kind"*

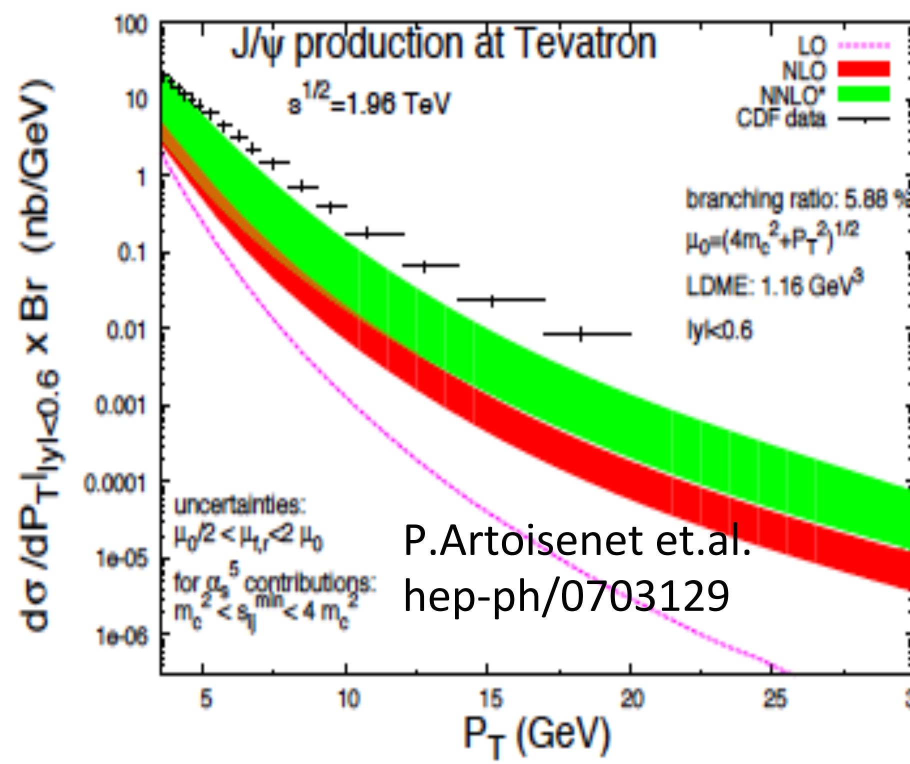
EW breaking Scale

- ❖ **Higgs** boson was discovered in 4 July 2012.
- ❖ Mass ~ 126 GeV. Narrow width resonance.
- ❖ Quantum number is JPC=0++.
- ❖ It is crucial in exploring the EW symmetry breaking mechanism and unveiling the underling new physics.
- ❖ Large high-order perturbative corrections at hadron-level cross section.

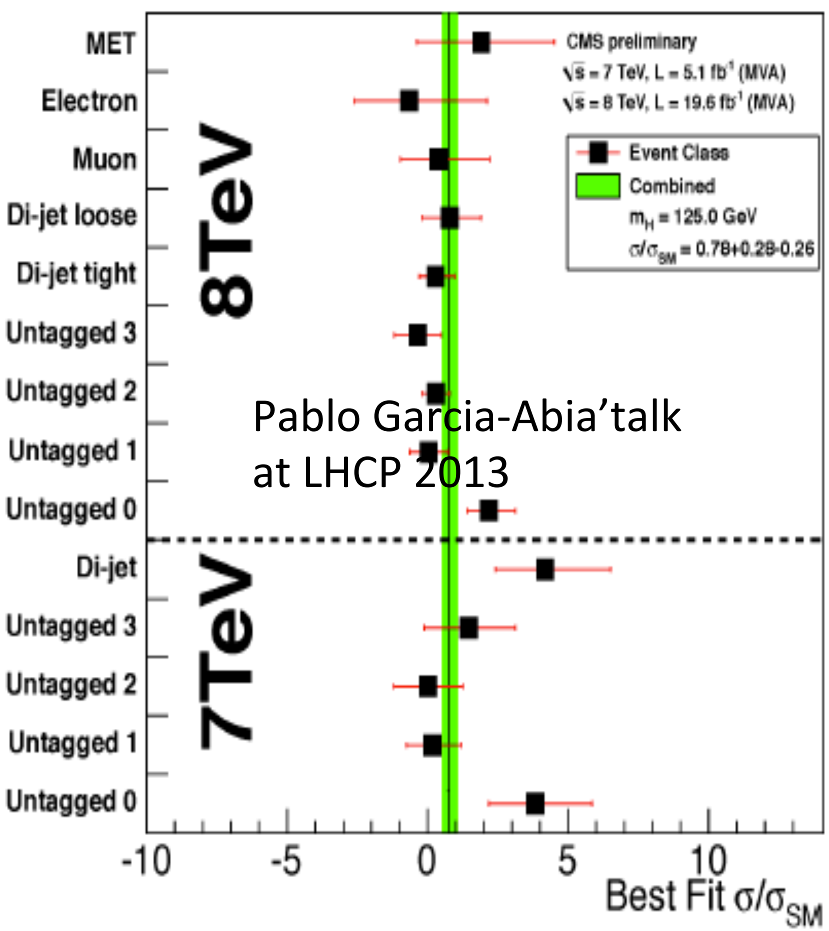


QCD perturbative Scale

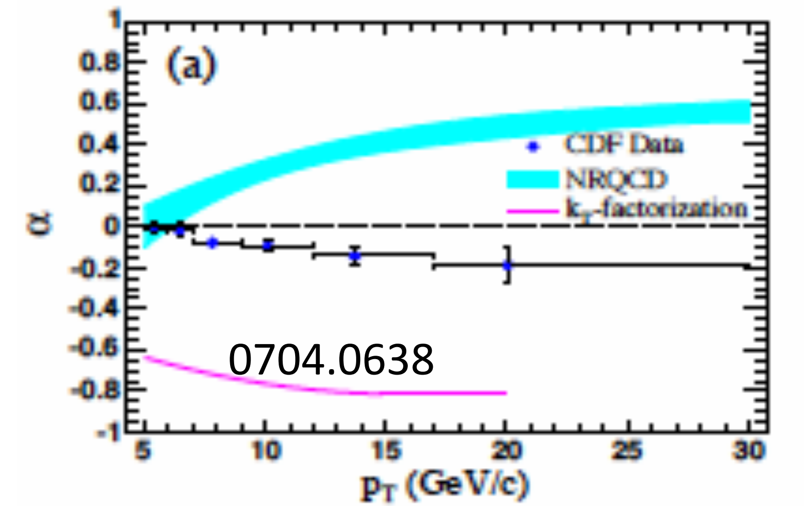
- ❖ **J/Ψ** boson was discovered in 11 Nov 1974.
- ❖ Mass ~ 3.1 GeV. Narrowwidth resonance.
- ❖ Quantum number is JPC=1--.
- ❖ It is a good candidate to explore the nature of strong force at subatomic level and tell us how QCD works at hadron level.
- ❖ Order enhancement in high-order perturbative corrections in pT spectrum.

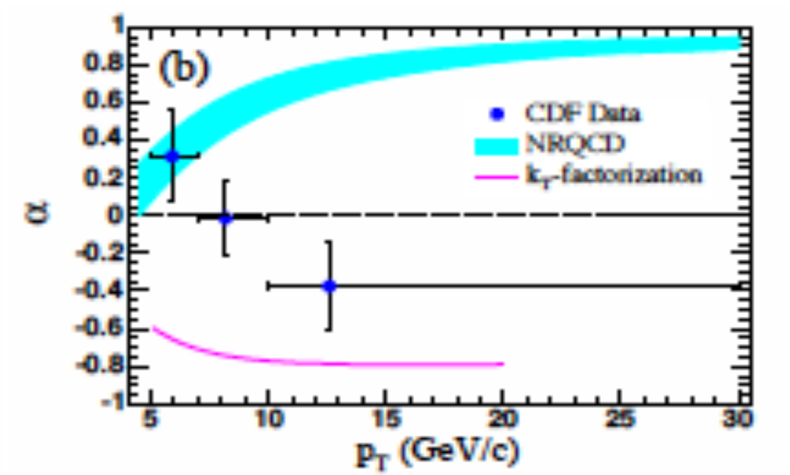


- Although **Higgs** boson was discovered in 4 July 2012, its properties (CP,spin, couplings) are measured well and it is close to the SM Higgs, which is a “bad” news to the new physics guys.



- Although **J/Ψ** boson was discovered in 11 Nov 1974, its polarisation at Tevatron and LHC is still a puzzle, which is also a “bad” news to the QCD guys.

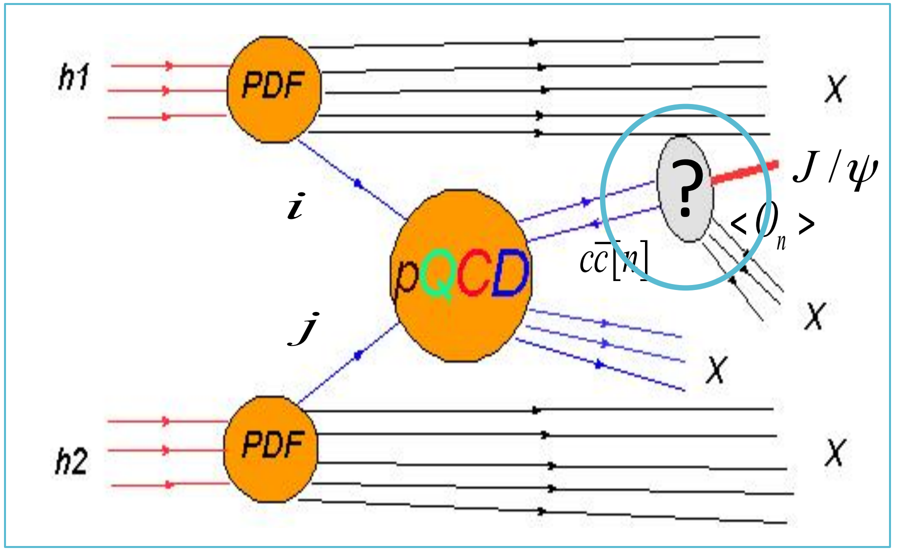




Do we know QCD well?

- It is apparent that people believe hadrons can be described by QCD (a theory to describe the strong force).
- We know its perturbative properties quite well (e.g. top quark production), but we know less in its non-perturbative regime. Especially, the mechanism of hadrons evolved from partons is still staying at empirical level.
- Ψ is a good lab to study its perturbative and non-perturbative behaviour simultaneously, since its mass is ~ 3 GeV and its bounding energy is ~ 300 MeV.
- How can people give a hadron level predictions, when there is a confinement ? Factorization !

factorization



- QCD factorization:

$$\sigma_{hadron} = f_{i/h1} \otimes f_{j/h2} \otimes \sigma^{ij}_{parton}$$

- NRQCD factorization *G. Bodwin et al. (1995)*:

$$\sigma^{ij}_{parton} = \sigma(ij \to c\bar{c}[n] + X) < O_n >$$

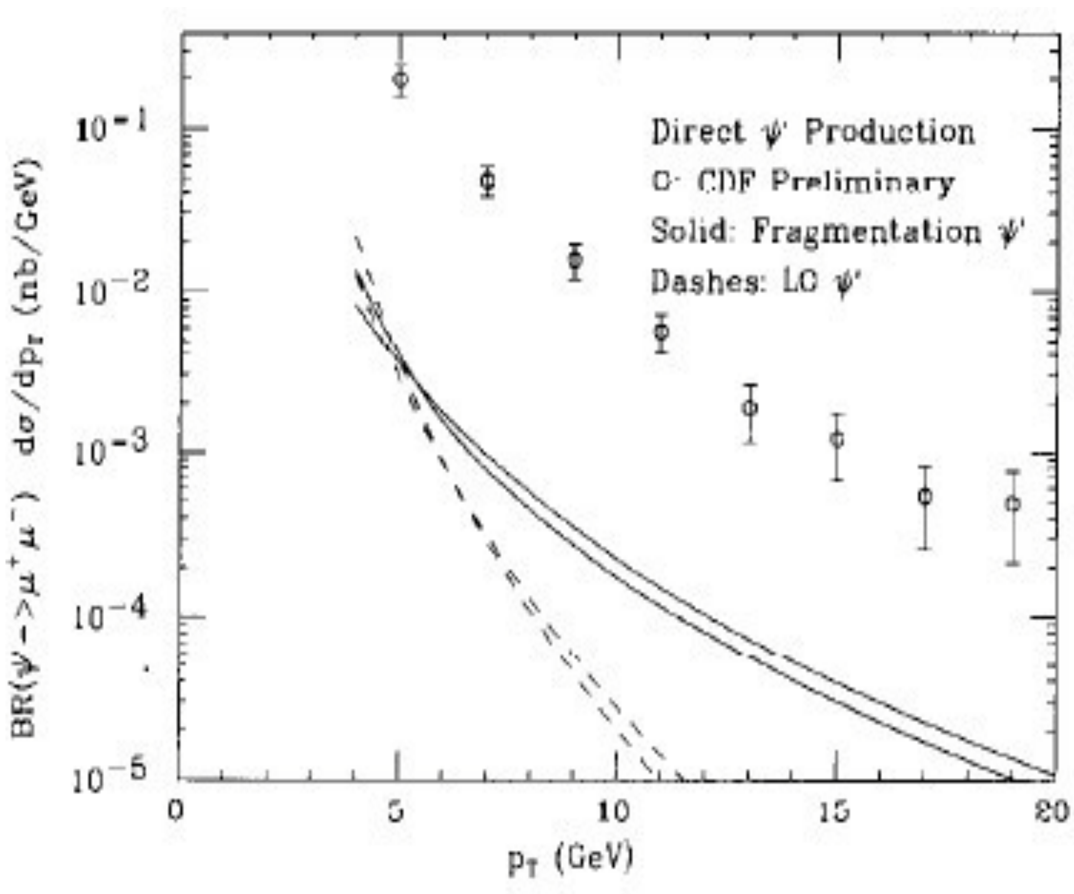
- The short distance parton level cross section is perturbative and process-dependent.
- The parton distribution functions and long distance matrix elements $< O_n >$ are non-perturbative but universal.
- The long distance matrix elements are matrix elements of four-fermion operators in NRQCD: $\langle O_n \rangle = \langle 0 | \chi^\dagger \kappa_n \psi (\sum_X | H + X \rangle \langle H + X |) \psi^\dagger \kappa_n' \chi | 0 \rangle$
- The long distance matrix elements are scaled by v: $v_c^2 \approx 0.23, v_b^2 \approx 0.08$

theoretical status

- CSM(see e.g. *M.B.Einhor et al. (1975)*): the heavy quark pair is produced in color-singlet states at short distance. P-wave is infrared-unsafe and incapable of interpreting heavy quarkonia production in high-pT region.
- CEM(see e.g. *H.Fritzsch et al. (1977)*): under the assumption of quark-hadron duality, the charm quark pair with its invariant mass between $2m_c$ and $2m_D$ evolves into charmonium. The fixed ratio of $\sigma_{J/\psi}:\sigma_{\chi_{cJ}}:\sigma_{\eta_c}:\ldots$ predicted by it is in contradiction with experimental measurements.
- NRQCD (see e.g. *G.T.Bodwin et al. (1995)*): in addition to the color-singlet intermediate states, there are also color-octet intermediate states produced at short distance. The infrared-divergences in the color-singlet P-wave are cancelled by the CO S-wave long distance matrix elements.

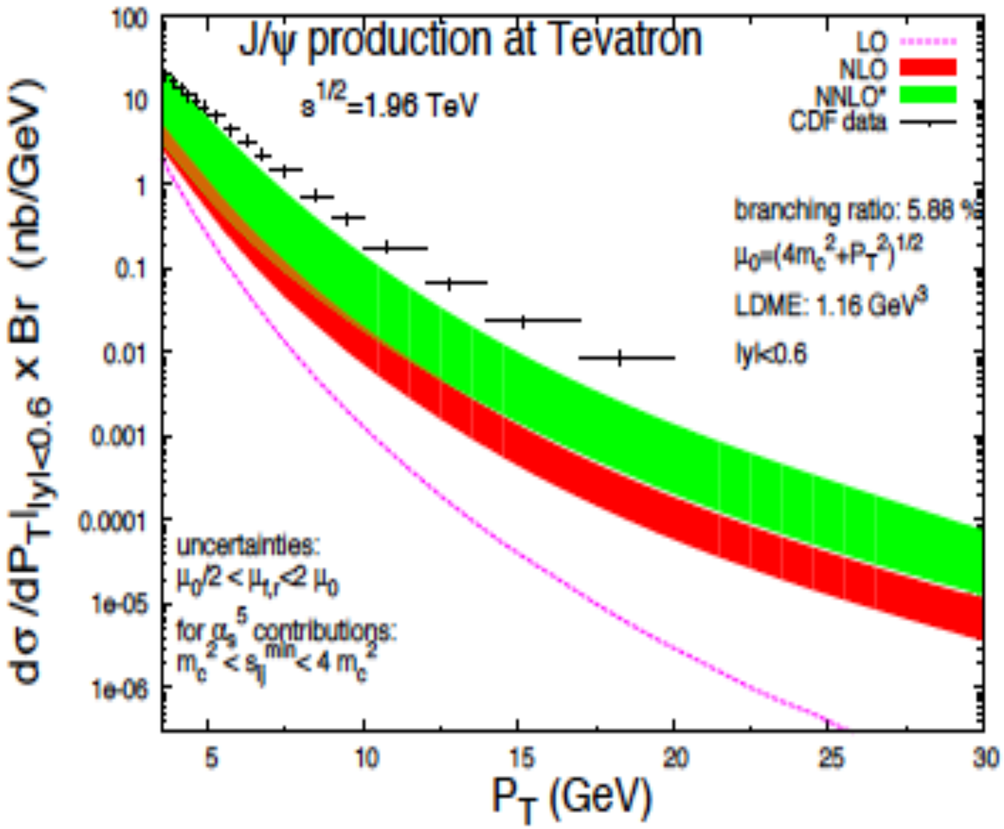
Prompt $\psi(1S,2S)$

Do we need CO?



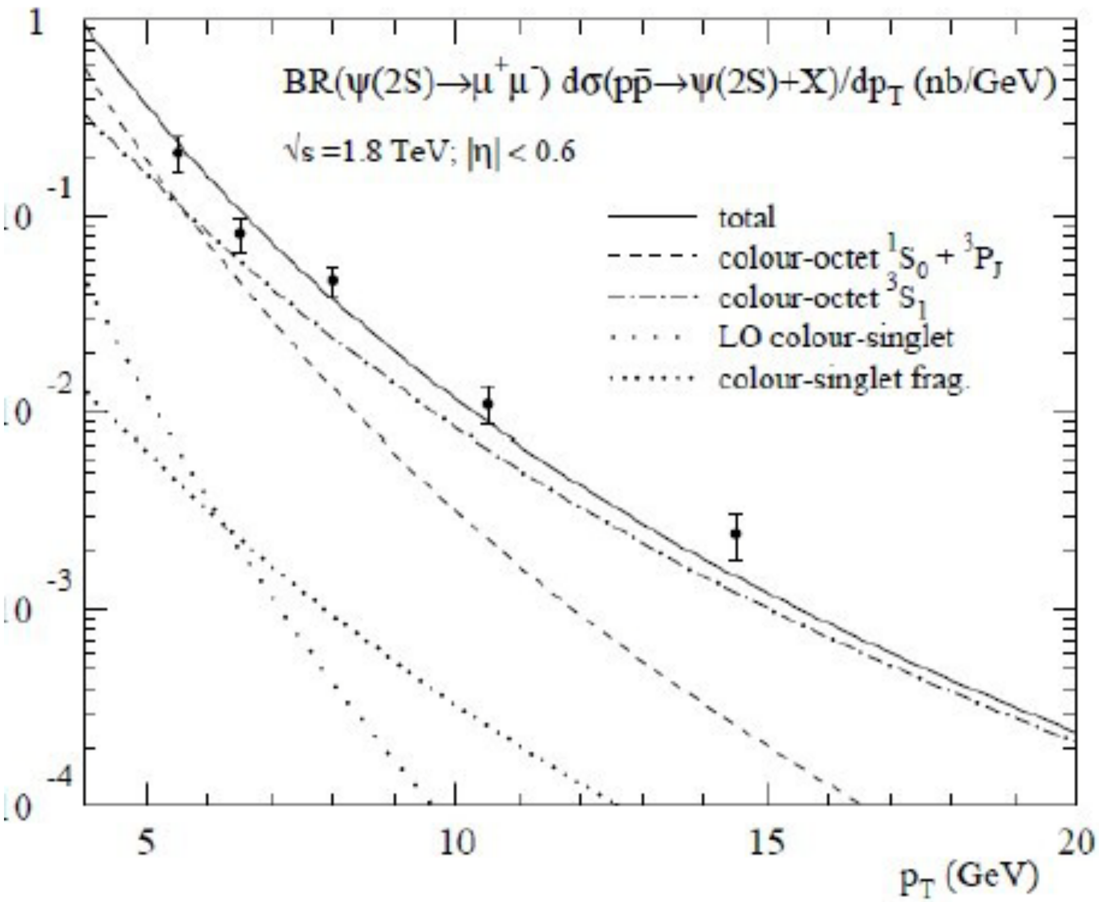
- Almost 20 years ago, CDF Collaboration found a large yields of ψ(2S) at pT > 5 GeV.
- The plot comes from Brateen et al. PLB (1994).
- The dashed is only for LO CS.
- The solid is for fragmentation contributions.

Do we need CO ?



- Higher order QCD corrections to CS are unexpected large (Campbell et al. 2007, Artoisenet et al. 2007). It is understood because of new low pT topologies appear at higher order.
- NNLO* only includes double real radiations.
- The data still seem to require another new contribution, though the shap is a little bit smilar.

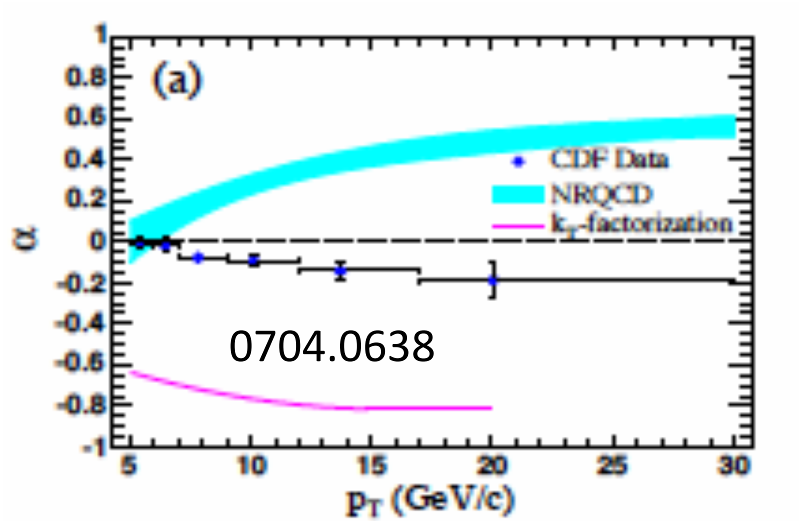
Do we need CO?

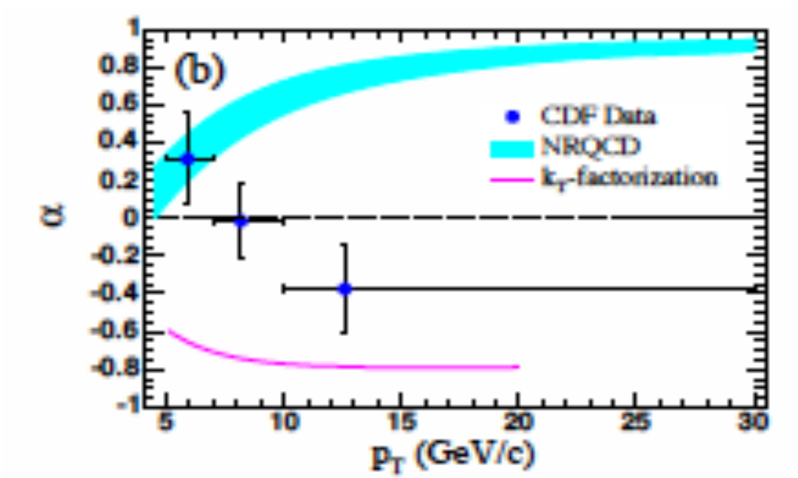


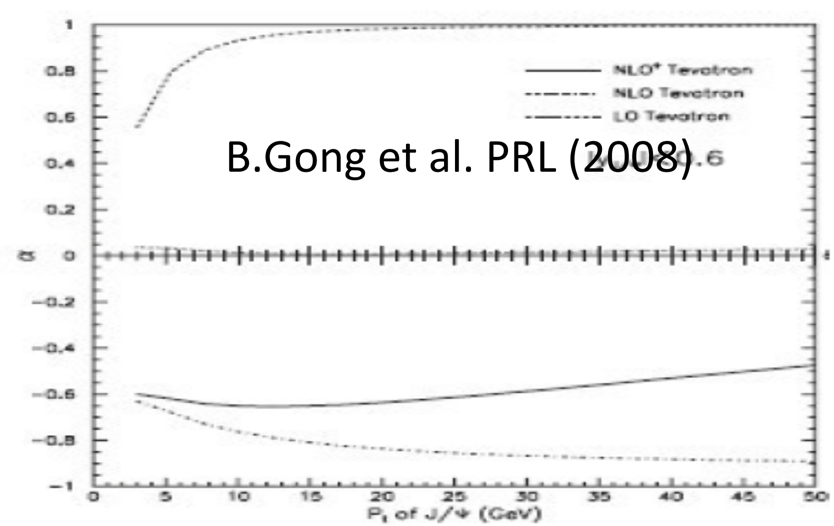
- At much earlier time, CO mechanism was proposed by Brateen et al. to fill the gap between LO CS and CDF data.
- Plot is taken from M.Kramer et al. hep-ph/0106120.
- A effective theory of QCD,nonrelativistic QCD, was proposed by Bodwin,Brateen,Lepage in 1995, though the factorization is still lacking of proof. It predicts a CO Fock state in nonrelativisitic expanasion.
- However, some people don't like it because it would be much unclear about the soft gluons in exclusive process.

Do we need CO?

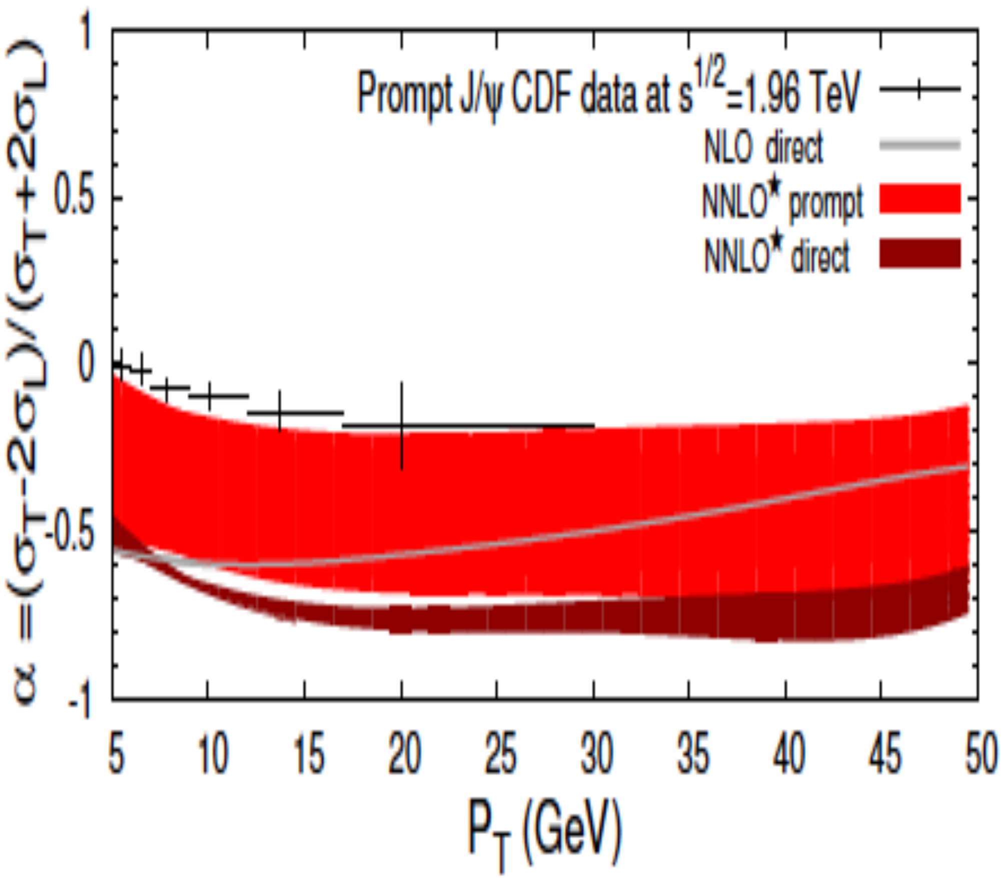
- Meanwhile, the polarisation based on LO NRQCD is completely in the opposite way compared with CDF data.
- The CDF data show unpolarized but a little longitudial α, while the LO NRQCD shows completely transverse one when pT >10 GeV.
- On the other side, NLO CS show a longitudial value but still a little too negative.







Do we need CO ?



- The NNLO* result shows the similar longitudial polarisation results. The error bar is a little bit large.
- It seems close to the CDF data but not to the LHC (CMS and LHCb) data.
- Plot is from Lansberg 1107.0292.

The NRQCD way

- It seems to be difficult to solve the yields as well as polarisation problem for CS only.
- On the other side, the CO is much easier (no HO essential) to solve the yields but in contrast with the polarisation (even worse than CS only).
- How about the NLO CO ? The challenging thing is we need P-wave NLO, which is expected to cancel the IR in S-wave at the same order.

Fock states

k	η_c, η_b	$J/\psi, \psi', \psi(3s)...$ $\Upsilon, \Upsilon(2s), \Upsilon(3s)...$	h_c, h_b	χ_{cJ}, χ_{bJ}
3	${}^1S_0^{(1)}$	${}^3S_1^{(1)}$	—	—
5	—	—	${}^1P_1^{(1)}, {}^1S_0^{(8)}$	${}^3P_J^{(1)}, {}^3S_1^{(8)}$
7	${}^1S_0^{(8)}, {}^3S_1^{(8)}, {}^1P_1^{(8)}$	${}^1S_0^{(8)}, {}^3S_1^{(8)}, {}^3P_J^{(8)}$	—	—

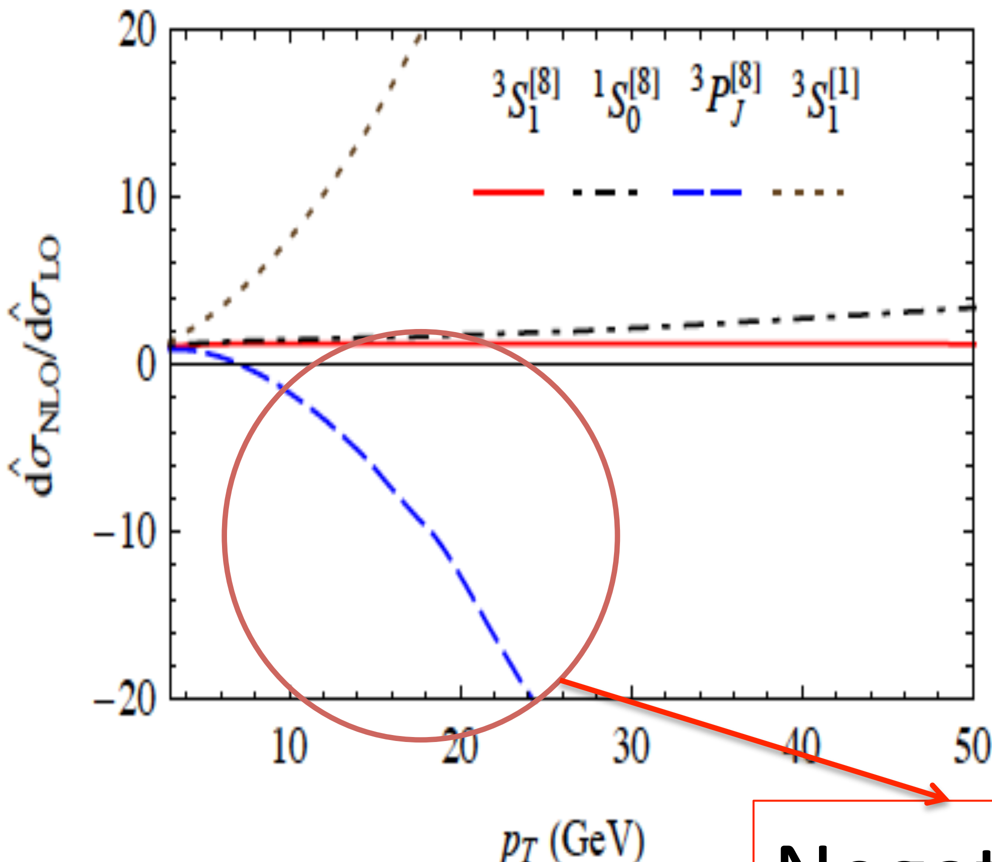
TABLE I: Values of k in the velocity-scaling rule $\langle \mathcal{O}^Q[n] \rangle \propto v^k$ for the leading $Q\bar{Q}$ Fock states n pertinent to Q.

Color-Octet LDME(s) should be determined from experimental input.

Challenges in P-wave !

K-factor in Fock states

Y.-Q.Ma et al. (2011)

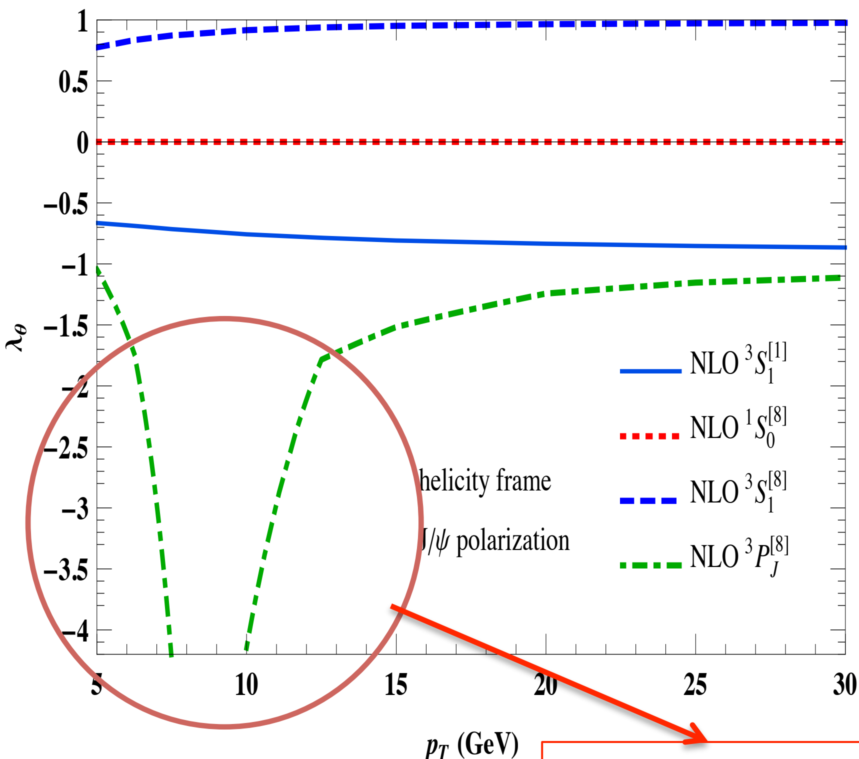


- There is no enhancement in higher-order corrections for 3S1[8], and mildly enhancement in 1S0[8].
- CS is enhanced a lot but can be negiligible compared with CO.
- CO P-wave is unexpected to be negative and large.

Negative !!!

Polarization in Fock states

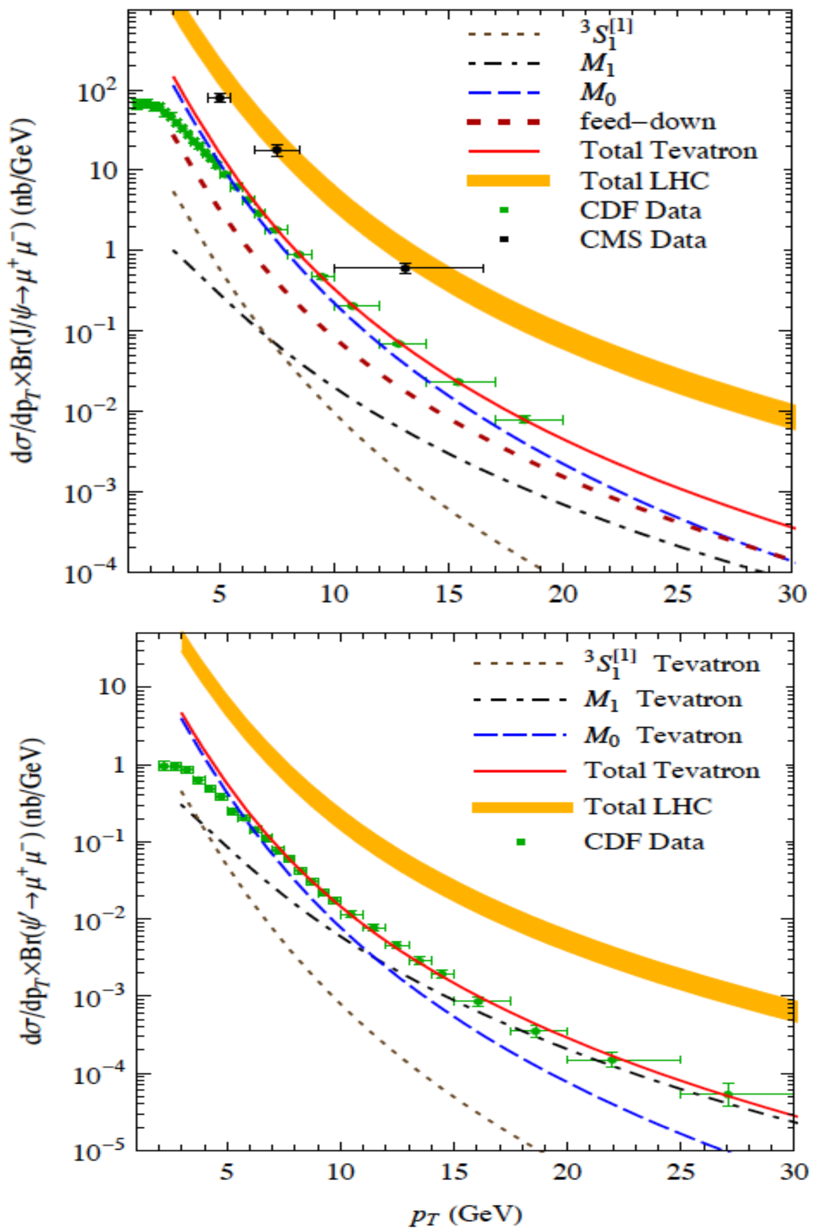
K.-T.Chao, Y.-Q.Ma, HSS, et al. (2012)



Negative !!!

- NLO CS is longitudial, but negaligible.
- 1S0[8] is unpolarized to all orders.
- NLO 3S1[8] is transverse, and it is easy to be dominant.
- NLO 3PJ[8] is again unexpected to be longitudial (because it is negative). It provides us the possibility to cancel the large transverse 3S1[8] contribution.

Yields

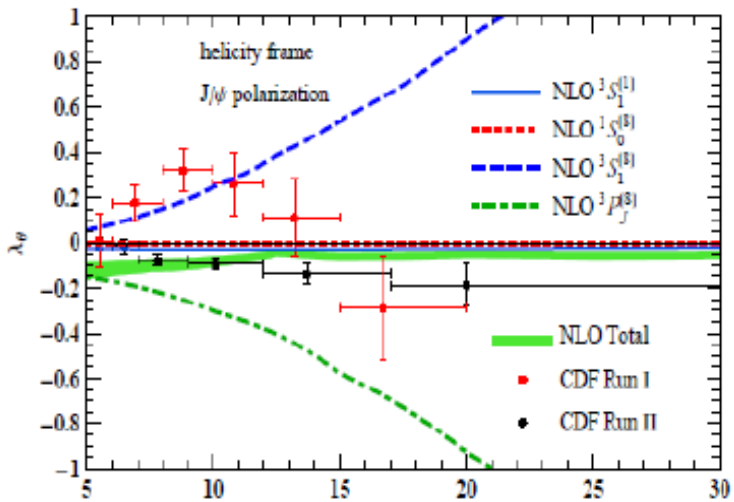


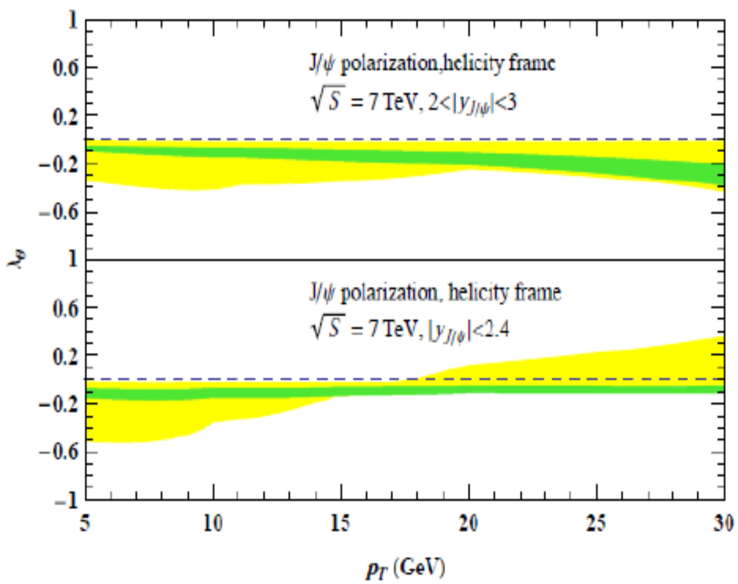
Y.-Q.Ma et al. (2011)

- Prompt ψ(1S,2S) at Tevatron and LHC.
- Prompt ψ(1S) includes the feeddown contributions from ψ(2S) and χcJ (J=0,1,2) decay.
- The CO LDMEs for χcJ (J=0,1,2) are fixed as spin symmetry and the Tevatron data of the yields of χc1/χc2.
- The CO LDMEs for ψ(1S,2S) are extracted from Tevatron data only.
- Only two linear combinations M0,M1 of three CO LDMEs can be determined ambuiguitesly.

Polarisation for direct ψ(1S)

K.-T.Chao, Y.-Q.Ma, HSS, et al. (2012)





- Direct ψ(1S) at Tevatron and LHC.
- Large cancellation seen in transverse 3S1[8] and longitudial 3PJ[8].
- The result can be unpolarized.
- Still only two linear combination of CO LDMEs M0 and M1 can be determined precisely.
- People might be worried about our missing feeddown contributions.

What we learn ?

- The short-distance coefficient of P-wave CO Fock state ${}^3P_J^{[8]}$ can be decomposed into a linear combination of the short-distance coefficients of ${}^1S_0^{[8]}$ and ${}^3S_1^{[8]}$,i.e.

$$d\hat{\sigma}({}^3P_J^{[8]}) = r_0 \frac{d\hat{\sigma}({}^1S_0^{[8]})}{m_c^2} + r_1 \frac{d\hat{\sigma}({}^3S_1^{[8]})}{m_c^2}. \tag{2.4}$$

r_0 and r_1 changes slightly with rapidity interval but almost not changes with the center-of-mass energy $\sqrt{S}$(see Table I in Ref.[10]). This makes it is difficult to extract three independent CO LDMEs by fitting unpolarized yields data at hadron colliders. Instead, one is restricted to be able to extract two linear combinations of three CO LDMEs within convincing precision. They are denoted as

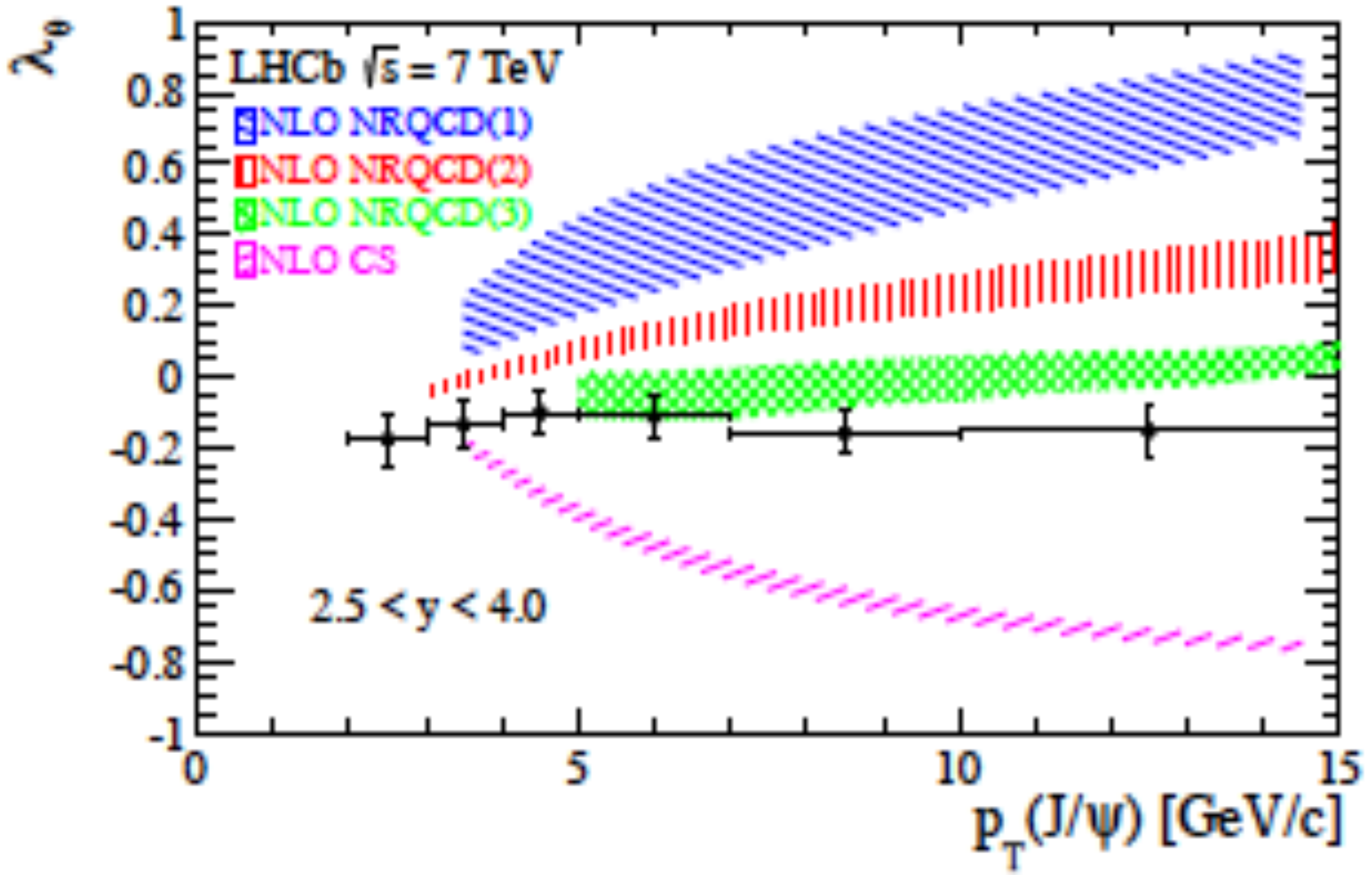
$$\begin{aligned}
M_{0,r_0}^{J/\psi(\psi(2S))} &\equiv \langle \mathcal{O}^{J/\psi(\psi(2S))}({}^1S_0^{[8]}) \rangle + r_0 \frac{\langle \mathcal{O}^{J/\psi(\psi(2S))}({}^3P_0^{[8]}) \rangle}{m_c^2} \\
M_{1,r_1}^{J/\psi(\psi(2S))} &\equiv \langle \mathcal{O}^{J/\psi(\psi(2S))}({}^3S_1^{[8]}) \rangle + r_1 \frac{\langle \mathcal{O}^{J/\psi(\psi(2S))}({}^3P_0^{[8]}) \rangle}{m_c^2}.
\end{aligned} \tag{2.5}$$

$M_{0,r_0}^{J/\psi(\psi(2S))}$,$M_{1,r_1}^{J/\psi(\psi(2S))}$ can be viewed as the coefficients of two different p_T curves.The second curve is much harder than the first one. From the Tevatron yields data [19, 20], they are extracted as $M_{0,r_0}^{J/\psi} = (7.4 \pm 1.9) \times 10^{-2}\mathrm{GeV}^3$, $\mathrm{M}_{1,r_1}^{J/\psi} = (0.05 \pm 0.02) \times 10^{-2}\mathrm{GeV}^3$, $M_{0,r_0}^{\psi(2S)} = (2.0 \pm 0.6) \times 10^{-2}\mathrm{GeV}^3$, $\mathrm{M}_{1,r_1}^{\psi(2S)} = (0.12 \pm 0.03) \times 10^{-2}\mathrm{GeV}^3$ with $r_0 = 3.9, r_1 = -0.56$.

What we learn ?

- The short-distance coefficient $d\hat{\sigma}_{11}({}^3P_J^{[8]})^4$ has the similar decomposition but into $d\hat{\sigma}_{11}({}^1S_0^{[8]})$ and $d\hat{\sigma}_{11}({}^3S_1^{[8]})$. The non-trivial thing is that r_1 in $d\hat{\sigma}_{11}({}^3P_J^{[8]})$ decomposition is quite close to that in $d\hat{\sigma}({}^3P_J^{[8]})$ decomposition [5]. Hence,it still doesn't help a lot to fix the three independent CO LDMEs by including polarisation data, which is emphasized in Ref.[5]. Moreover, the value of $M_{1,r_1}^{J/\psi(\psi(2S))}$ almost control the weight of transverse component. The unpolarized data really require a (very) small $M_{1,r_1}^{J/\psi(\psi(2S))}$.

- We assume that all of the CO LDMEs are positive [5], which is in contrast with that given in Refs.[4, 6].Since r_1 in forward rapidity interval is smaller than that in central rapidity interval, a positive $\langle\mathcal{O}^{J/\psi(\psi(2S))}({}^3P_0^{[8]})\rangle$ would guarantee the forward rapidity $\frac{d\sigma}{dp_T}$ and λ_θ is lower than the central rapidity $\frac{d\sigma}{dp_T}$ and λ_θ. Moreover, a $p_T > 7$ GeV cutoff is applied to get the best fit [9].

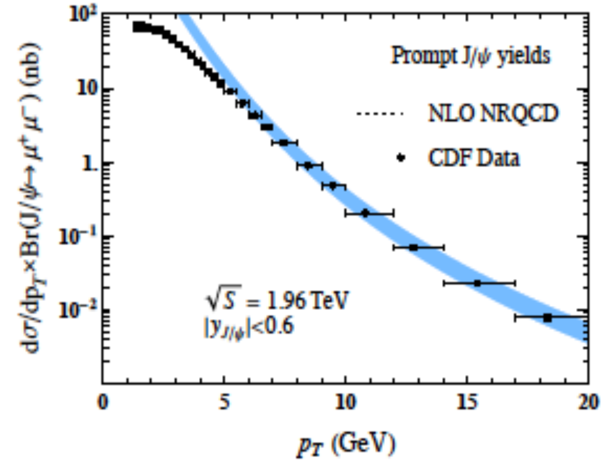


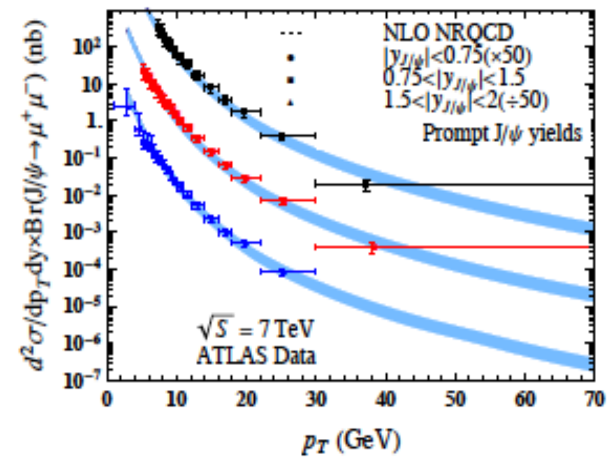
LHCb $\sqrt{s}$ = 7 TeV
NLO NRQCD(1)
NLO NRQCD(2)
NLO NRQCD(3)
NLO CS
2.5 < y < 4.0
λ_θ
$p_T(J/\psi)$ [GeV/c]

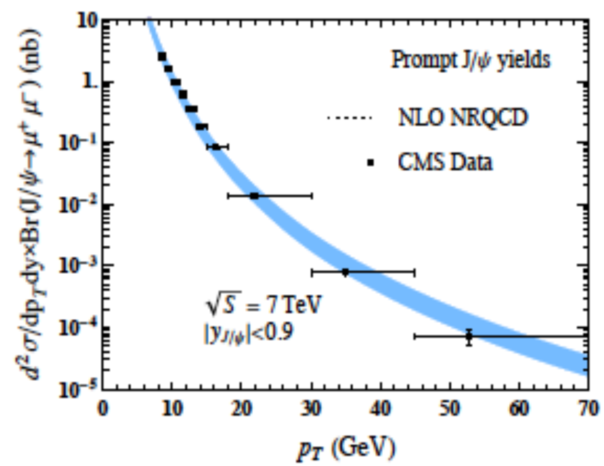
1307.6379

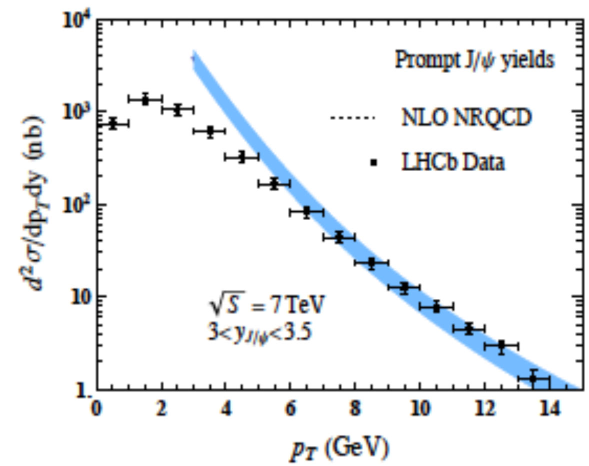
Yields for prompt ψ(1S)

In preparation



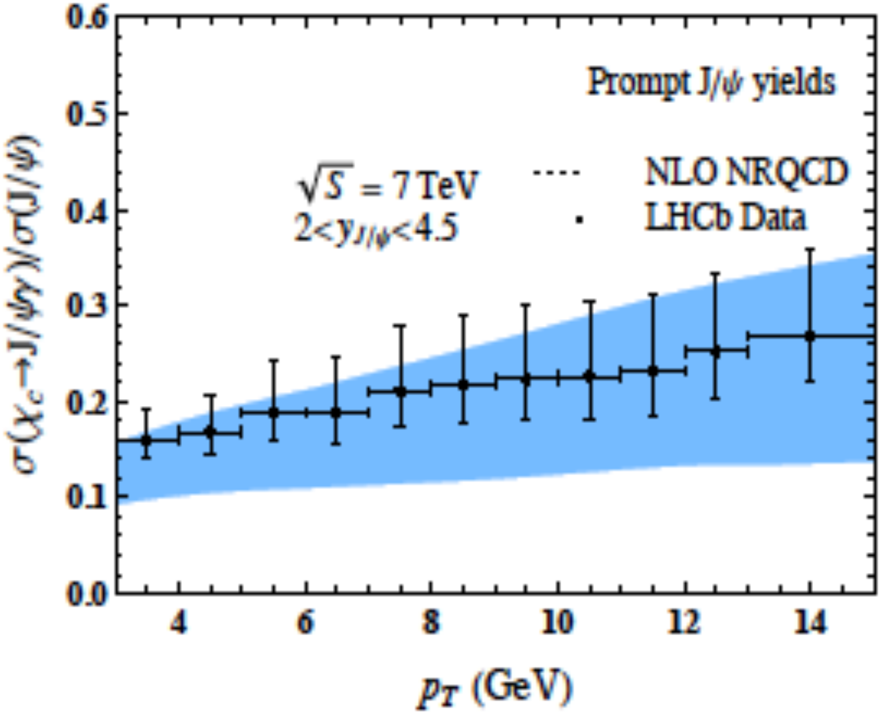


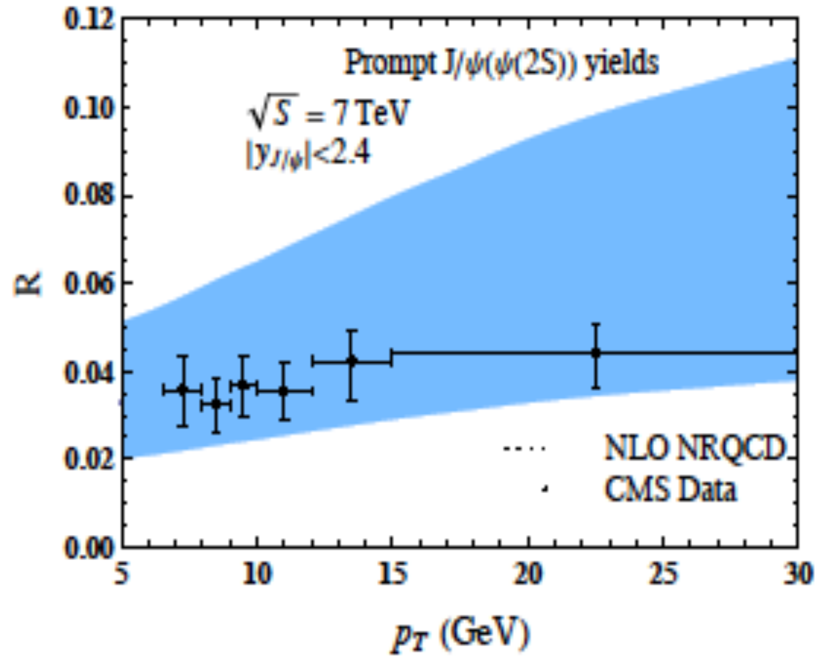




Feeddown in prompt ψ(1S)

In preparation

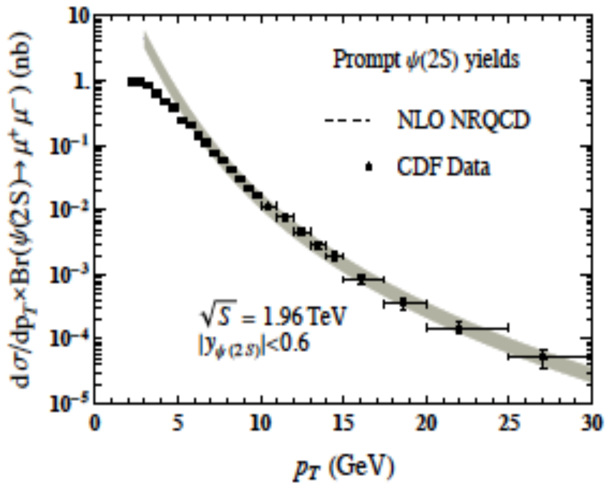


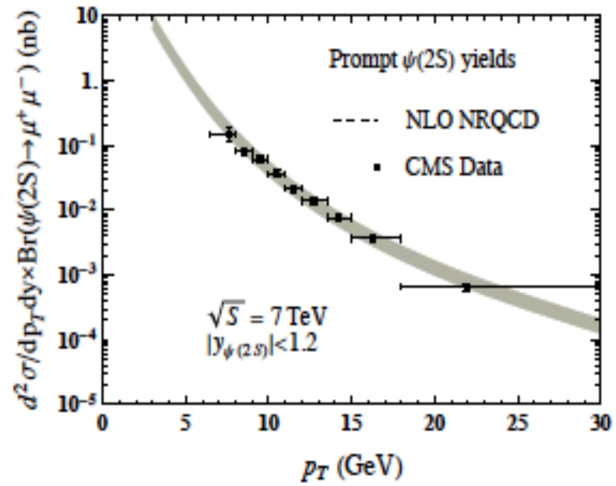


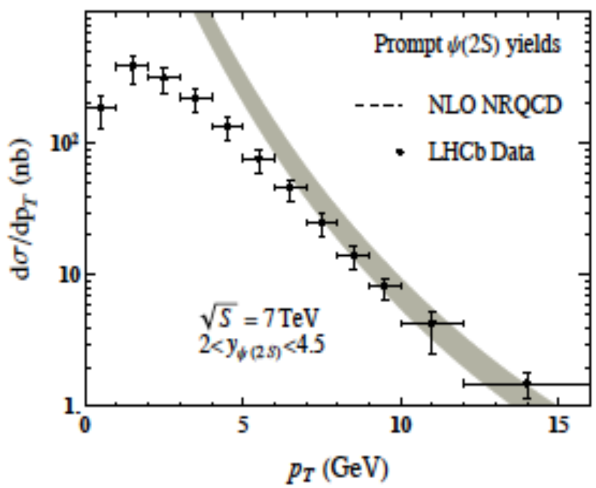
$$R \equiv \frac{\sigma(\psi(2S) \to \mu^+\mu^-)}{\sigma(J/\psi \to \mu^+\mu^-)},$$

Yields for prompt ψ(2S)

In preparation

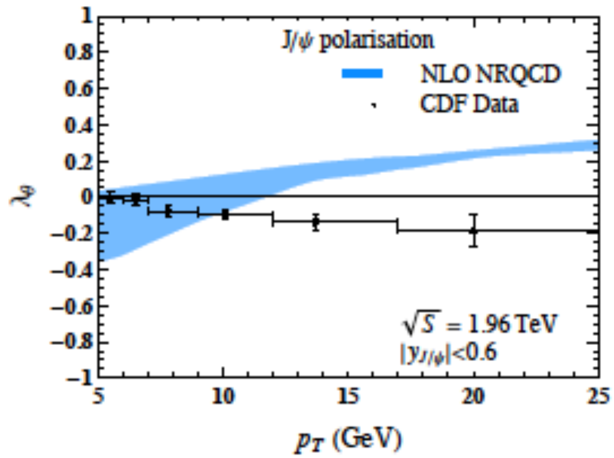


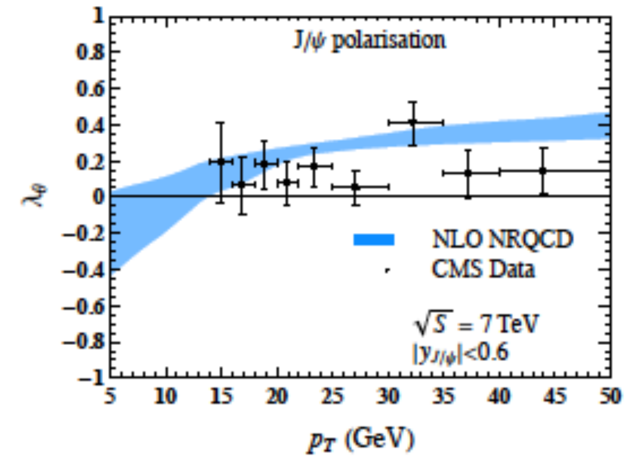


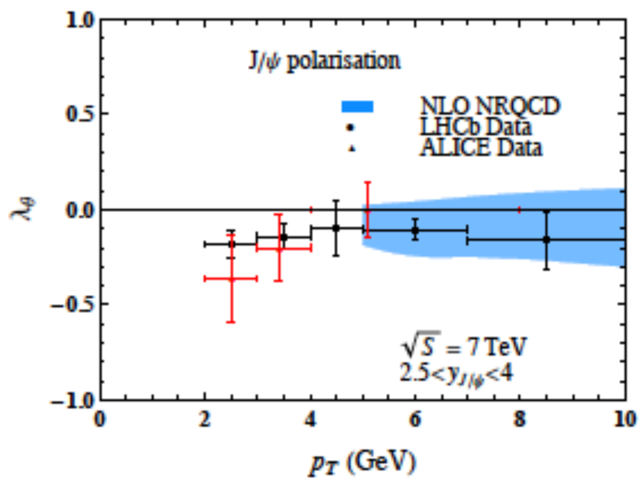


Polarisation for prompt ψ(1S)

In preparation

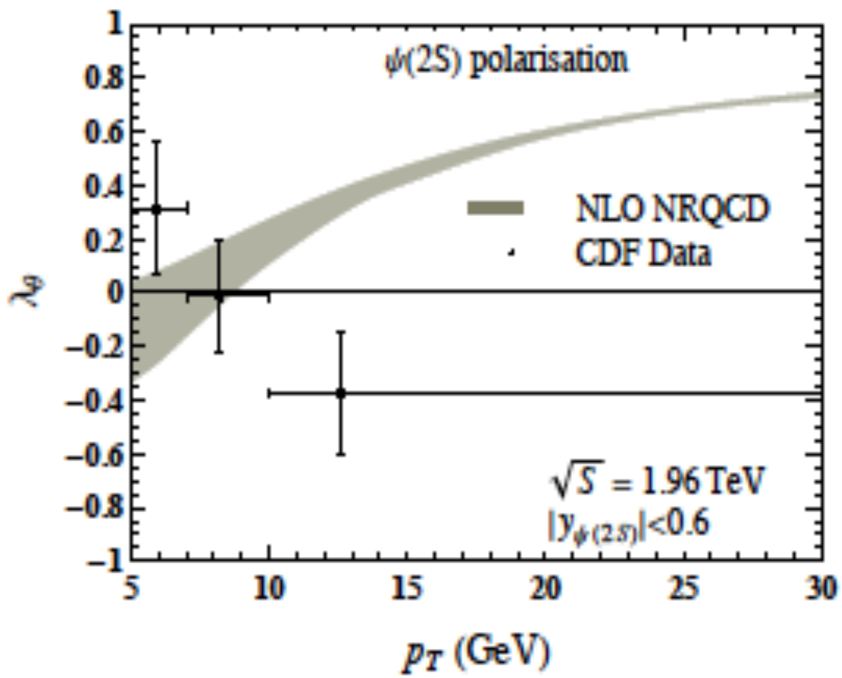


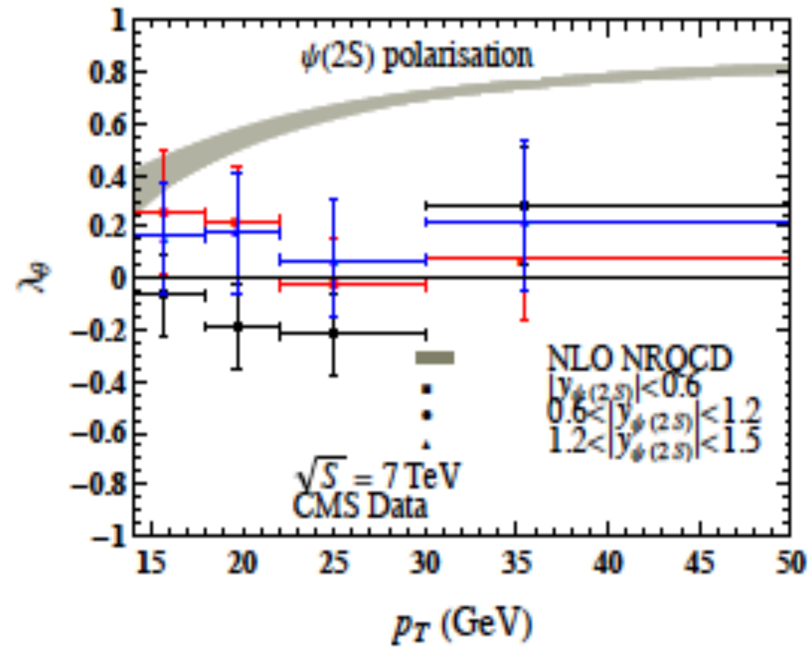




Polarisation for prompt ψ(2S)

In preparation





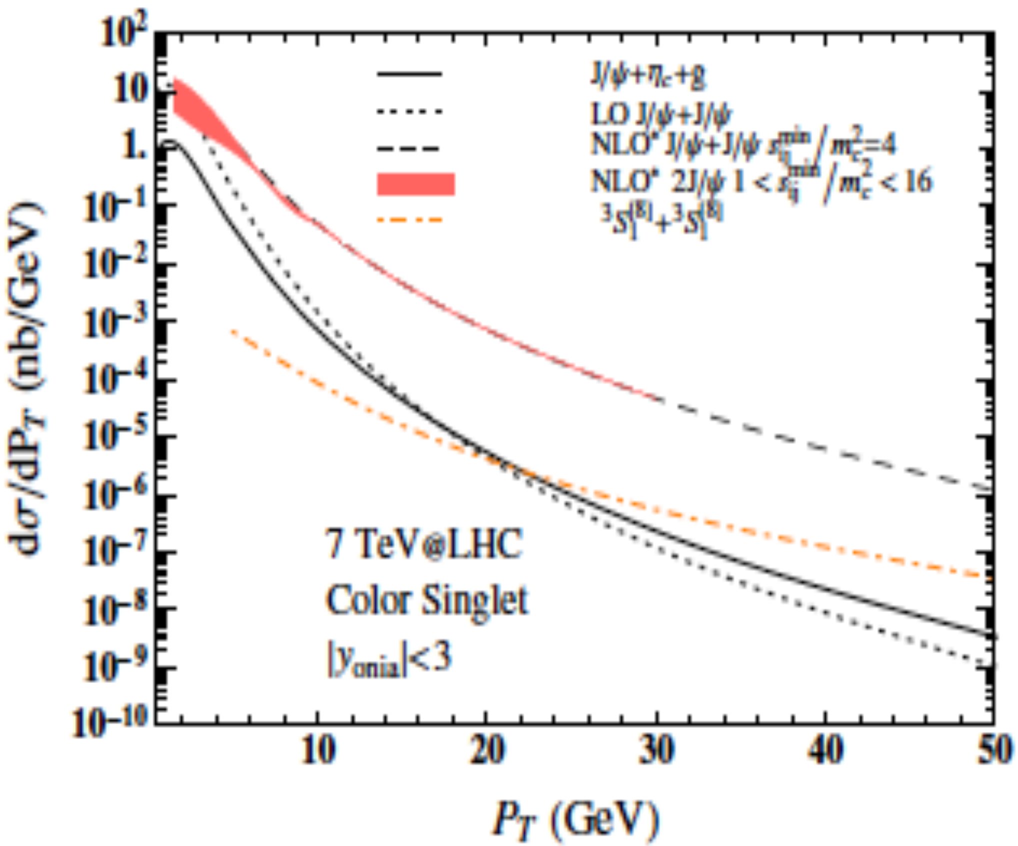
Pair Production

Motivation

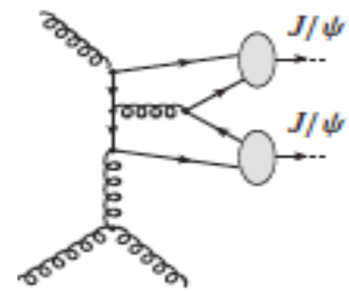
- Since it is still unclear whether we need CO, it is of course important to probe it in other production modes, where pair production is an possible way.
- Double parton scattering can be studied in pair production.
- Tetraquark might decay into double ψ.
- Since there is large enhancement of higher order corrections, people can doubt whether there is the similar behaviour in double ψ.

PT scaling

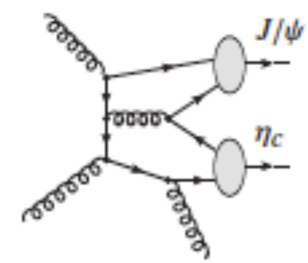
Lansberg, HSS, PRL (2013)



- LO ψ+ψ ~ PT^(-8)
- NLO ψ+ψ ~ PT^(-6)



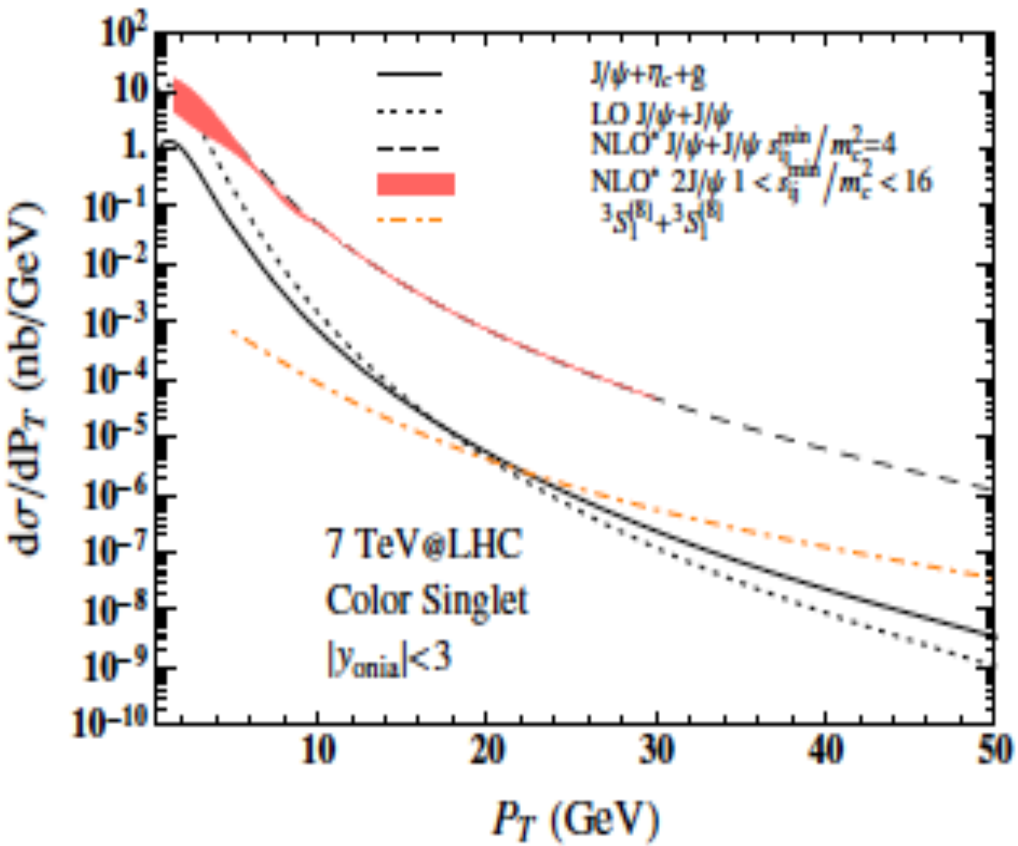
- LO ψ+ηc+g ~ PT^(-7)



- LO 3S1[8]+3S1[8] ~ PT^(-4)

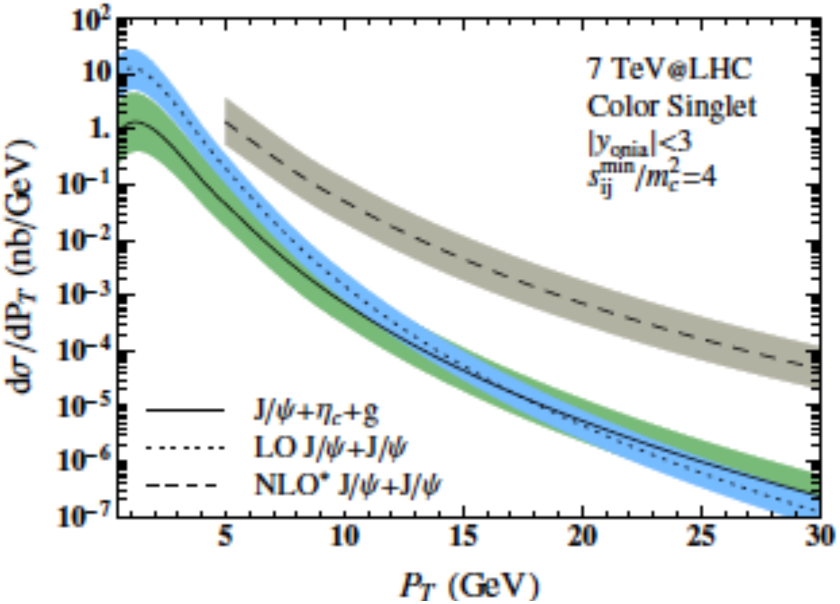
NLO*=NLO ?

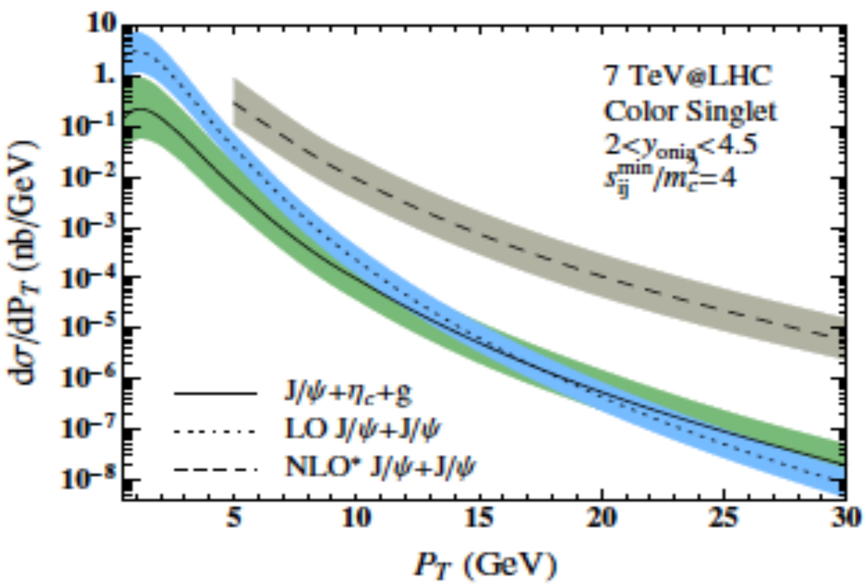
Lansberg, HSS, PRL (2013)



- It is missing of virtual, which is expected to be only PT^(-8). We call it NLO*. It can be calculated directly by MC generator HELAC-Onia and do simulation with PS program.
- The IR cut sentitivity is shown. We expect it will be (almost) exact the same with full NLO when pT > 5GeV. Recently, it has been checked with full NLO result. NLO and NLO* curves overlapped when pT > 5 GeV (thanks to L.P.Sun and Prof.Chao).
- CO is negiligble when PT < 50 GeV. Of course, it depends on the value of CO LDME.

Yields



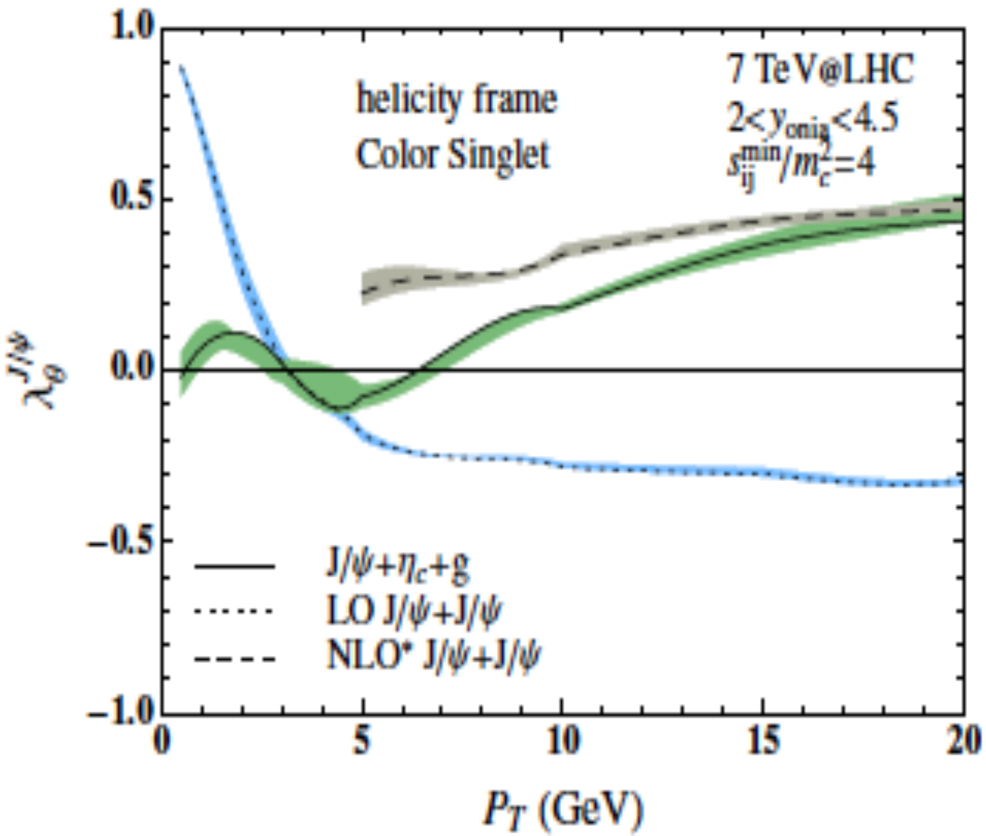


Lansberg, HSS, PRL (2013)

- Higher order corrections are really essential in double ψ production when PT > 5 GeV.
- ψ+ηc is not suppressed compared to LO double ψ, but it is compared to NLO double ψ.
- The behaviour of PT spectrum is understood.
- We are able to provide the NLO sample with HELAC-Onia.

Polarisation

Lansberg, HSS, PRL (2013)

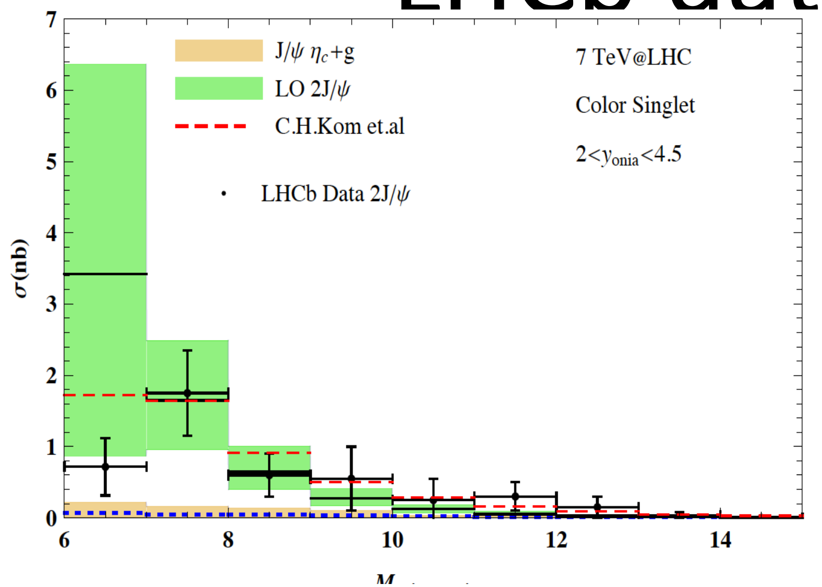


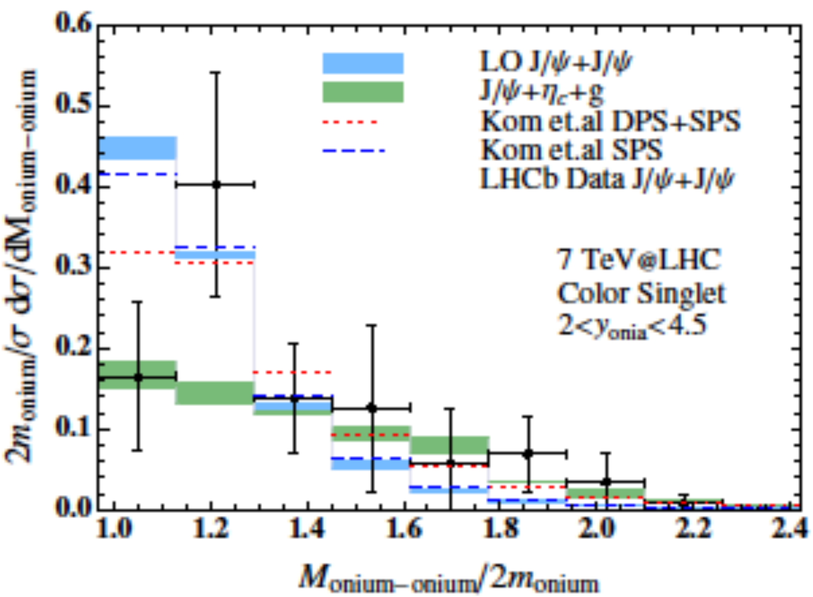
- Because of the new topology, the polarisation of ψ in LO ψ+ψ is completely different with NLO ψ+ψ.
- It is interesting to see that the polarisation of ψ in NLO ψ+ψ is close to that in ψ+ηc+g.
- It is also a good way to test the mechanisms at the LHC.

Comments on measurment

- ψ+ηc seems to be only possible to measure at LHCb, at which detector there is (anti)proton PID.It can be measured in ψ sample and then to find another ηc via two protons.
- The measurement of our “first” PT spectrum for ψ doesn’t require extra effort:
  - Measure two ψ’s PT.
  - If two ψ are in the same PT bin, count the number of events.
  - If they are NOT in the same PT bins, count the number of events in these two bins and then divide by 2.
  - For example, if you want to measure the yields in the bin of 5<PT<6 GeV, count the number of events when two ψ are both in 5<PT<6 GeV as Ns, and count the number of events when only one ψ is in 5<PT<6 GeV as Nos. Then the yields in the bin of 5<PT<6 GeV is just Ns+Nos/2.

LHCb data imply DPS ?



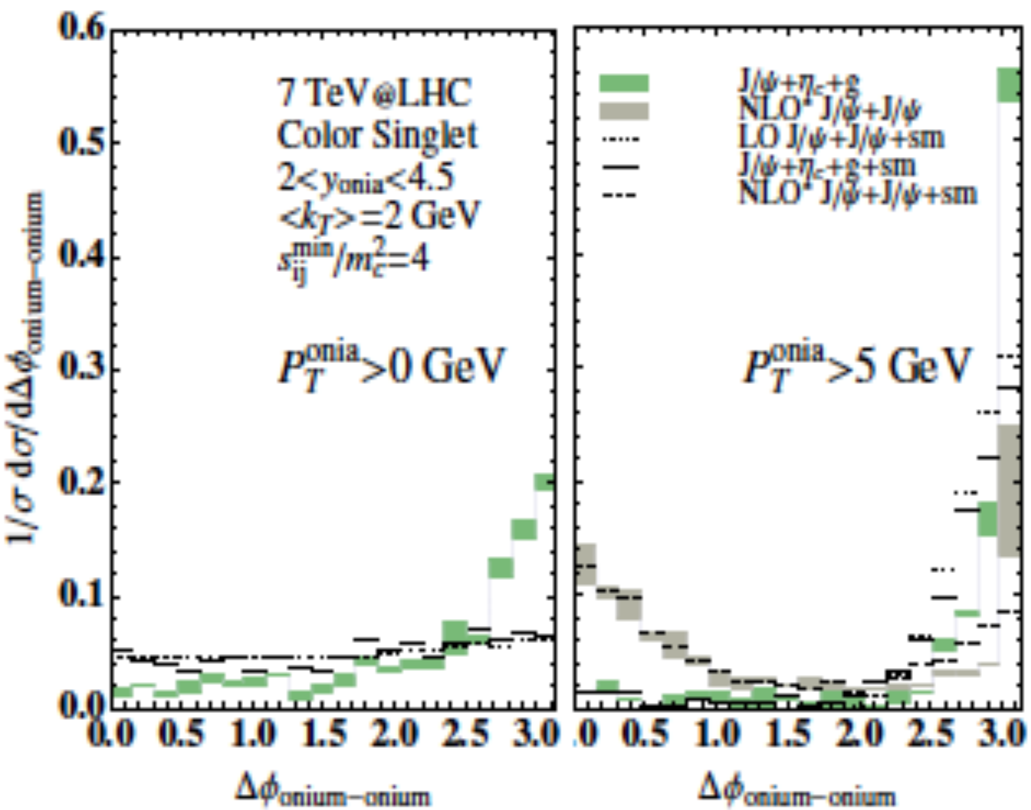


Lansberg, HSS, PRL (2013)

- The theoretical uncertainties are very large in invariant mass distribution, which are usually underestimated in literature.
- We use a normalization to cancel mass and scale uncertainties. The error is fantastic small. This treatment is first used in our paper.
- It is seen that the theory is in good agreement with LHCb data except the first bin, which we still cannot explain why even after including parton shower (ok, it doesn't change the distribution).
- In contrast to Kom et al, we think it is still hard to say whether there is siginificant DPS contribution or not in LHCb data.

Azimuthal correlation

Lansberg, HSS, PRL (2013)



- Azimuthal correlation is also an interesting observable to distinguish DPS and SPS, since in DPS, the azimuthal correlation is flat (uncorrelated).
- Without PT cuts, the intrinsic kT smearing effect is quite important and it will also make SPS azimuthal flat.
- If one impose a PT cutoff, the kT smearing will reduce as PT^(-1), it would be helpful.
- Again, the NLO correction will change the LO one a lot if PT> 5GeV.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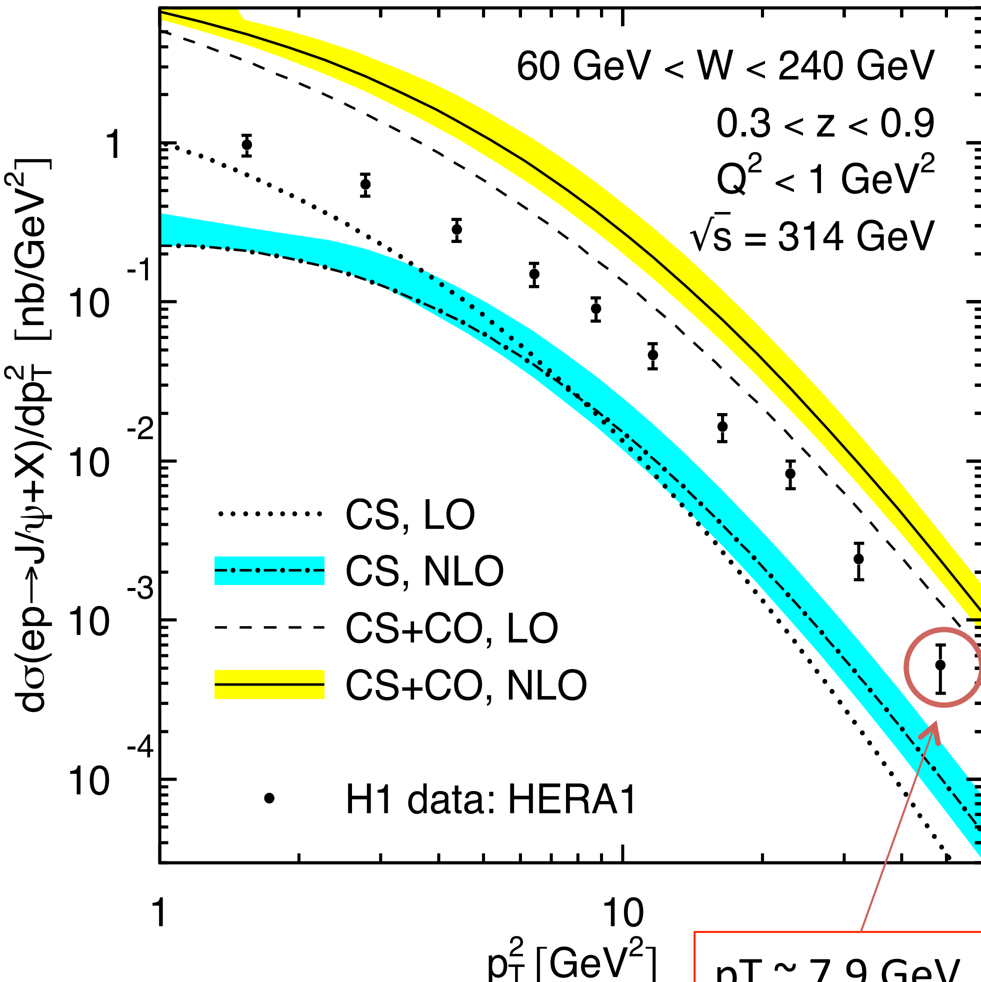
adavantages

- 1.The unpolarized predictions at hadron colliders (RHIC,Tevatron I,II and LHC) are quite good with data when pT > 7 GeV (cutoff in fit).
- 2.Positive P-wave CO LDME makes the polarization at hadron colliders near zero,i.e. unpolarized. It is quite close to CDF Run II data though it is lack of feeddown.

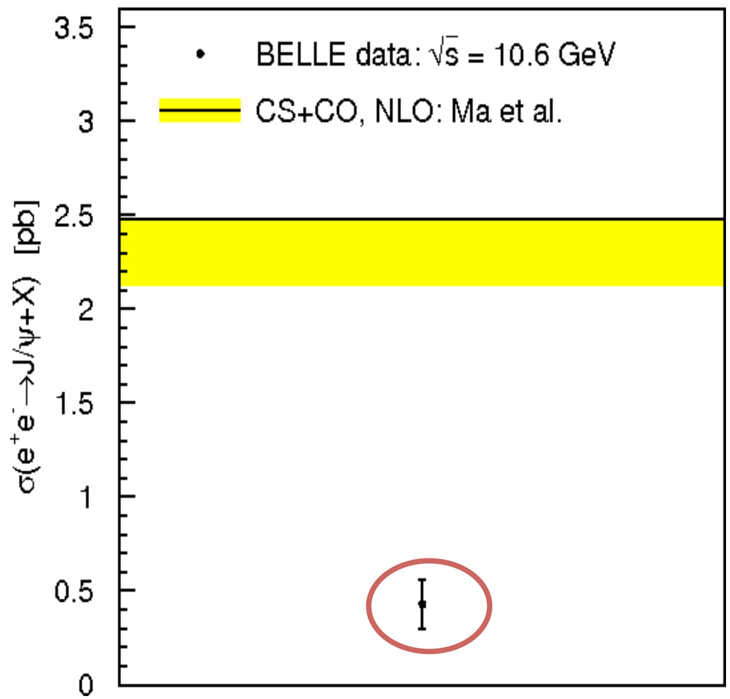
disadvantages

- 1.It cannot predict pT<7 GeV hadroproduction data, and it is also far from HERA data (pT is also small) and BELLE data. It might be debited to the failure of factorization of NRQCD in this small pT regime(?).
- 2. Resummation of large logarithm at large pT regime might make the good prediction worse.
- 3. It is still lacking of feeddown contribution in polarization. However, it might be not so important as long as P-wave CO LDME positive.

H1 data and BELLE data



pT ~ 7.9 GeV



Stole from M.Butenschon's talk

M.Butenschon and B.Kniehl's fit

M.Butenschon, B.Kniehl, (2011)

- 1.Use unpolarized data in pp (not include ATLAS and CMS large pT data), γp,γγ and e+e- collisions.
- 2. pT>1 GeV for γp,γγ data and pT>3 GeV for pp. There is only one data for e+e-.

$$\langle O^{J/\Psi}({}^1S_0^{[8]})\rangle = (4.97\pm0.44)\times10^{-2}GeV^3, \langle O^{J/\Psi}({}^3S_1^{[8]})\rangle = (2.24\pm0.59)\times10^{-3}GeV^3,$$

$$\langle O^{J/\Psi}({}^3P_0^{[8]})\rangle = (-1.61\pm0.20)\times10^{-2}GeV^5$$

- 3. After feeddown was included (pp:36%, γp: 15%, γγ: 9%, e+e-: 26%),

$$\langle O^{J/\Psi}({}^1S_0^{[8]})\rangle = (3.04\pm0.35)\times10^{-2}GeV^3, \langle O^{J/\Psi}({}^3S_1^{[8]})\rangle = (1.68\pm0.46)\times10^{-3}GeV^3,$$

$$\langle O^{J/\Psi}({}^3P_0^{[8]})\rangle = (-9.08\pm1.61)\times10^{-3}GeV^5$$

adavantages

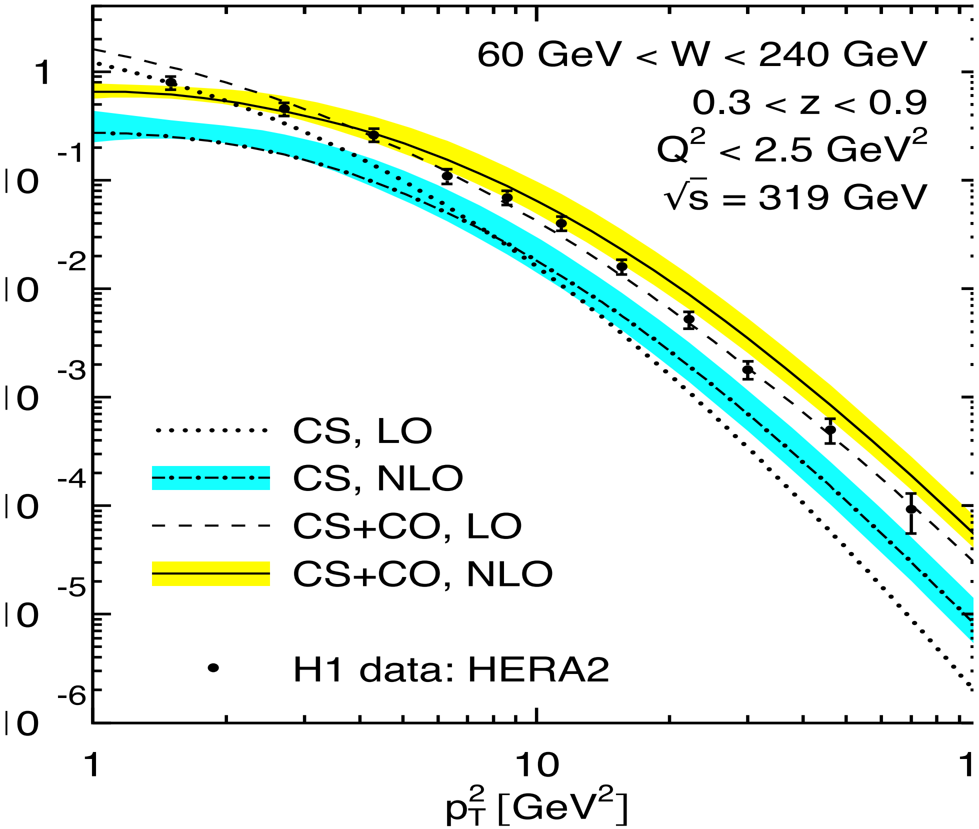
- 1. They include more small pT data in their fit (pT>3 GeV for hadroproduction and pT> 1 GeV for photoproduction and two-photon production). They can describe small pT hadroproduction data and HERA data better.
- 2. The discrepancy of e+e- data and NRQCD prediction is much smaller.

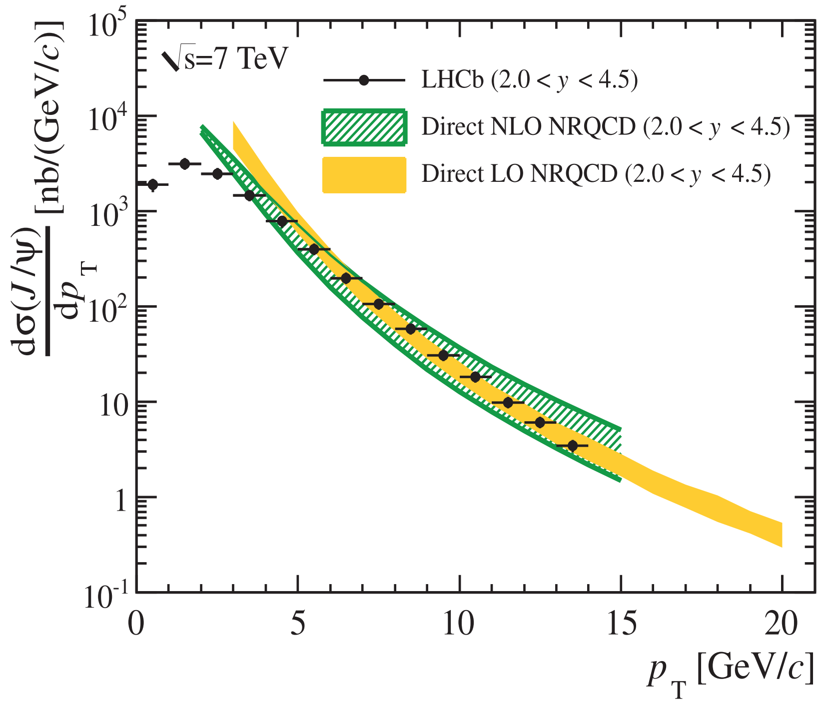
disadavantages

- 1. Some discrepancies like H1 data, LHCb data are still there with BK's global fit.
- 2. ATLAS and CMS's large pT data are not included. The prediction of unpolarized pT spectrum at large pT is above the experimental data (a factor of 3~4). It might be better after including resummation of logs of mc/pT. Can resummation change so much?
- 3. Because the value of P-wave CO LDME is negative, cancellation with S-wave CO cannot happen. It predicts transverse polarization at CDF Run II, which is in confliction (It is also lacking of feeddown in polarization).

H1 data and LHCb data

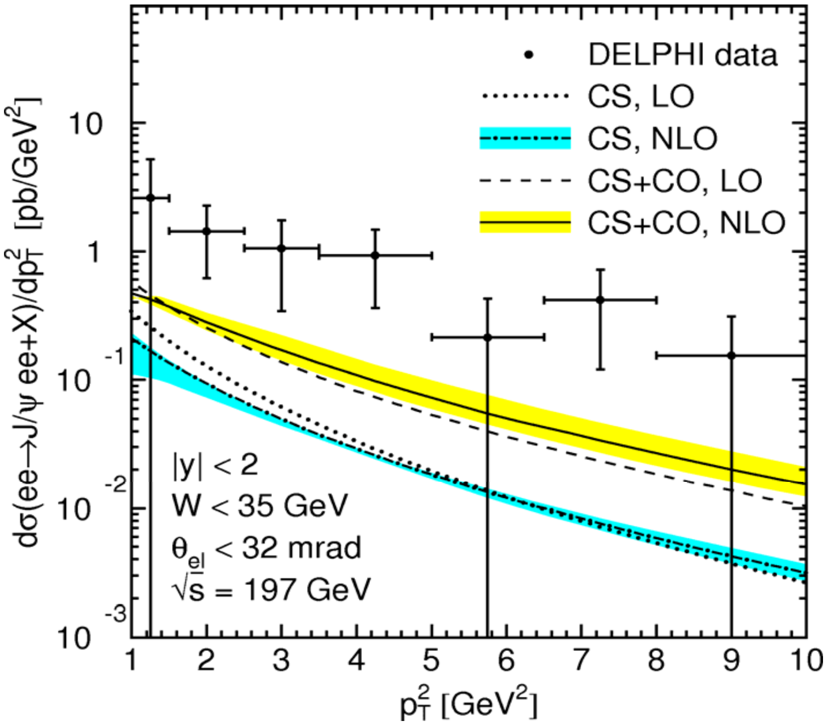
M.Butenschon, B.Kniehl, (2011)

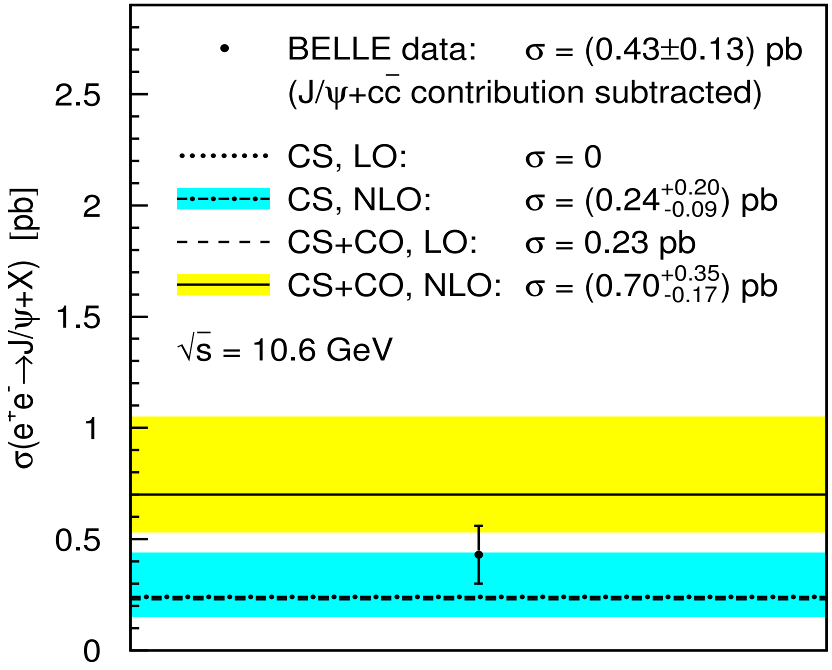




DELPHI data and BELLE data

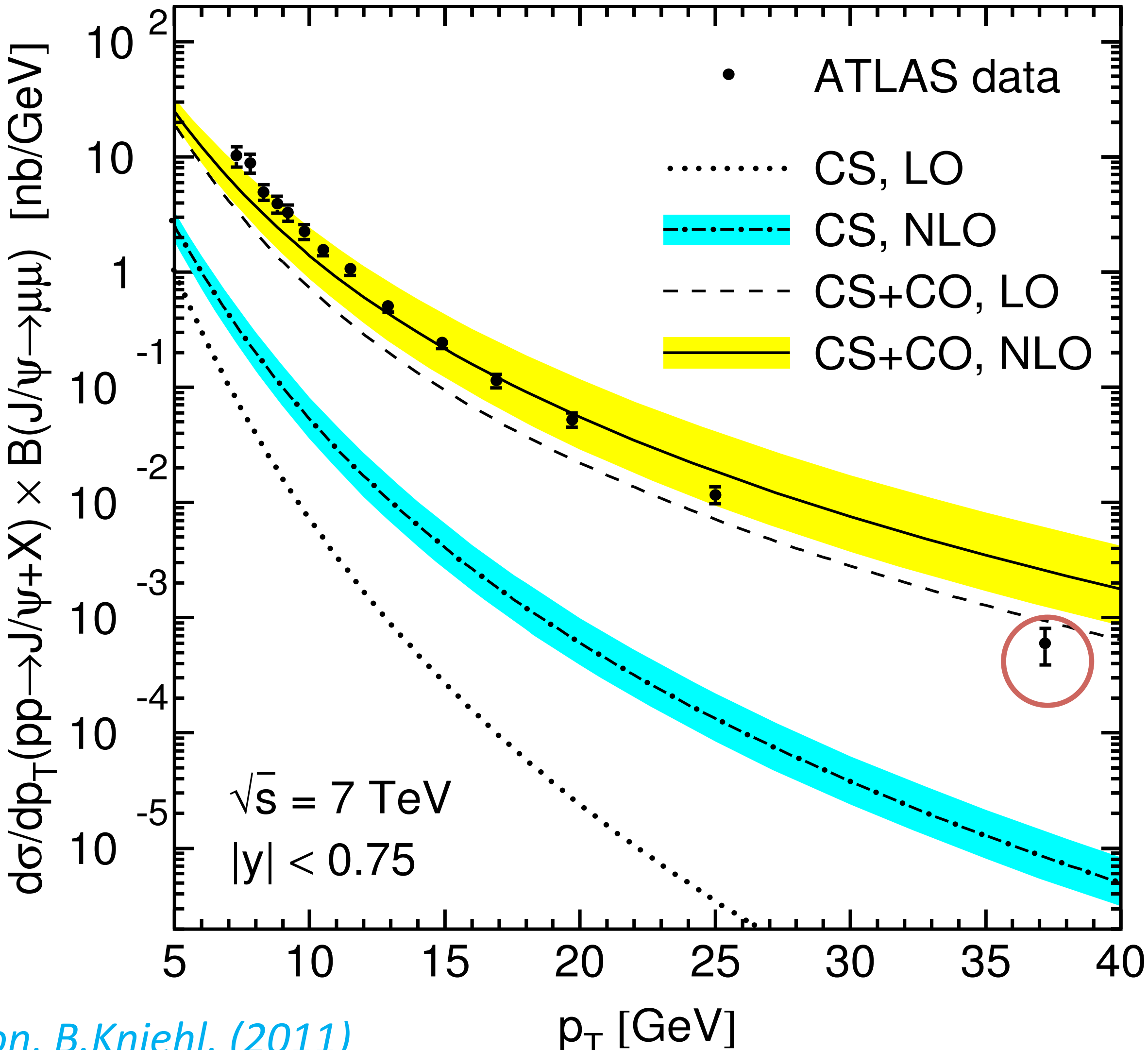
M.Butenschon, B.Kniehl, (2011,2012)





Factorization of NRQCD might be violated at such small pT ? !

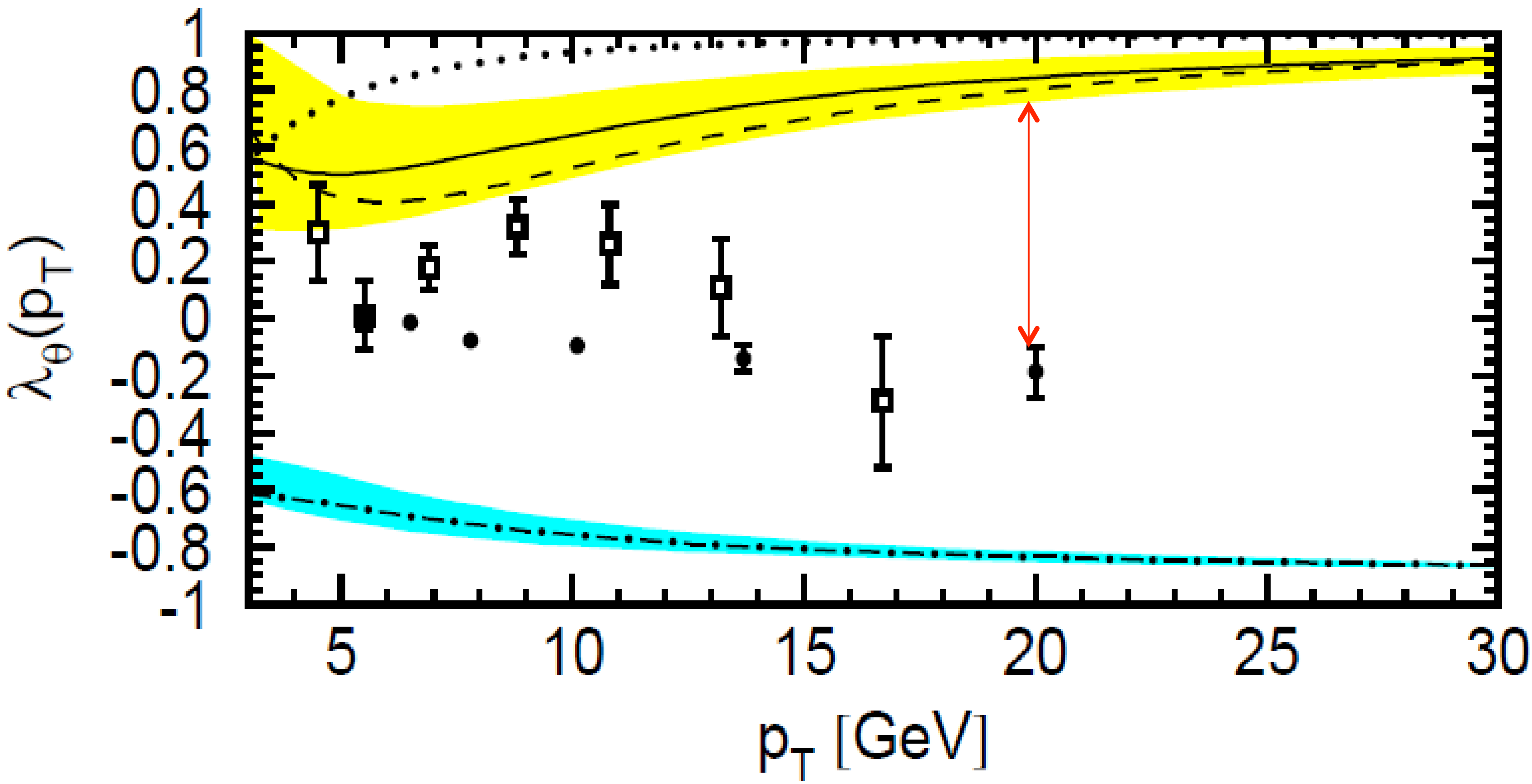
ATLAS data



M.Butenschon, B.Kniehl, (2011)

Polarization @CDF Run II

M.Butenschon, B.Kniehl, (2012)



fit by BWWZ group

B.Gong, L.-P.Wan, J.-X.Wang, H.-F.Zhang (2012)

- 1.Use unpolarized data and fit central region data by CDF Run II and forward region data by LHCb simultaneously (r0 and r1 in M0 and M1 are slightly different in these two regions!!!).
- 2.pT> 7 GeV.
- 3.Include feeddown from χc and Ψ(2S).

$$\langle O^{J/\Psi}({}^1S_0^{[8]})\rangle = 0.097 \pm 0.009 GeV^3, \langle O^{J/\Psi}({}^3S_1^{[8]})\rangle = (-0.46 \pm 0.13)\times 10^{-2} GeV^3,$$

$$\langle O^{J/\Psi}({}^3P_0^{[8]})\rangle = -0.0214 \pm 0.0056 GeV^5, \langle O^{\Psi'}({}^1S_0^{[8]})\rangle = (-0.012 \pm 0.869)\times 10^{-2} GeV^3,$$

$$\langle O^{\Psi'}({}^3S_1^{[8]})\rangle = (0.34 \pm 0.12)\times 10^{-2} GeV^3, \langle O^{\Psi'}({}^3P_0^{[8]})\rangle = (0.945 \pm 0.54)\times 10^{-2} GeV^5,$$

$$\langle O^{\chi c0}({}^3S_1^{[8]})\rangle = (0.22 \pm 0.012)\times 10^{-2} GeV^3$$

Cancellation is not sufficient to give an unpolarized prediction.

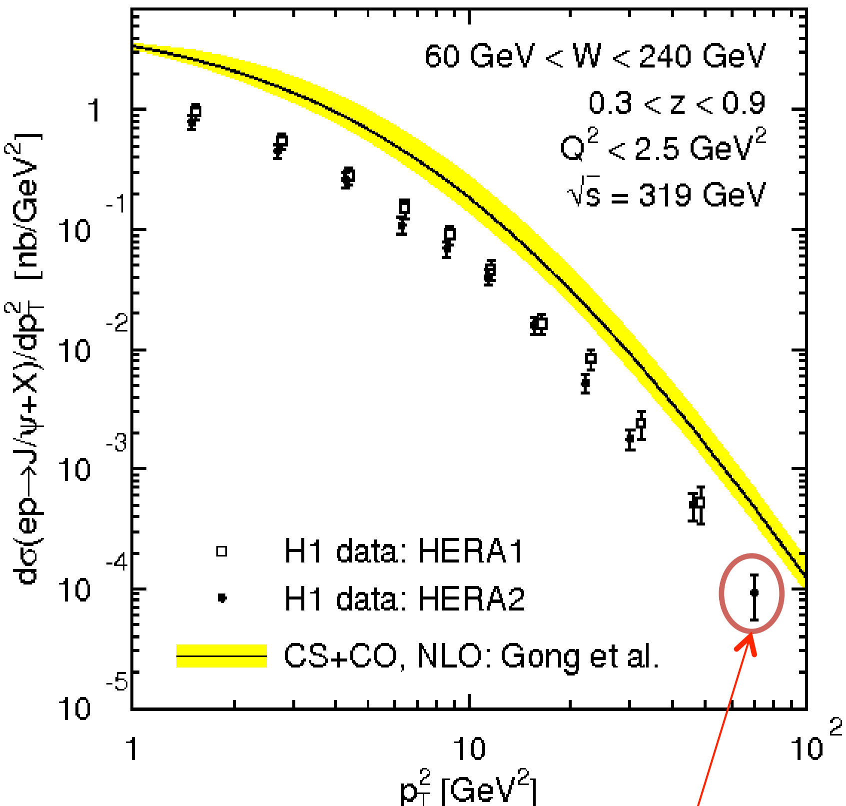
adavantages

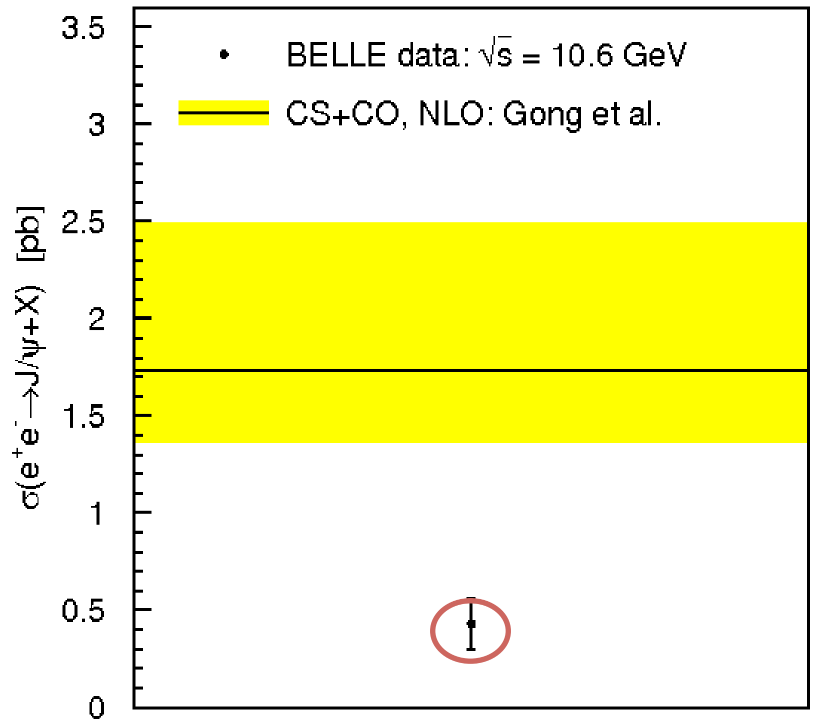
- 1.They fit J/Ψ CO LDMEs after substracting χc and Ψ(2S) feeddown for the first time.
- 2.They extract three CO LDMEs only from the hadroproduction data.
- 3. The cancellation of P-wave and S-wave makes the polarization prediction is better than BK's prediction at CDF Run II.

disadvantages

- 1. The main difference with CMSWZ and BK is from direct part (the feeddown contribution is not so important). It is a comprise set between CMSWZ and BK's sets. They are in disagreement with HERA and BELLE data.
- 2.There is a slight difference between their prediction and large pT data (CMS and ATLAS). Resummation ??
- 3.Because the cancellation is not sufficient, it is still predicting a transverse polarization, which is in contrast with CDF Run I and II data.

H1 data and BELLE data

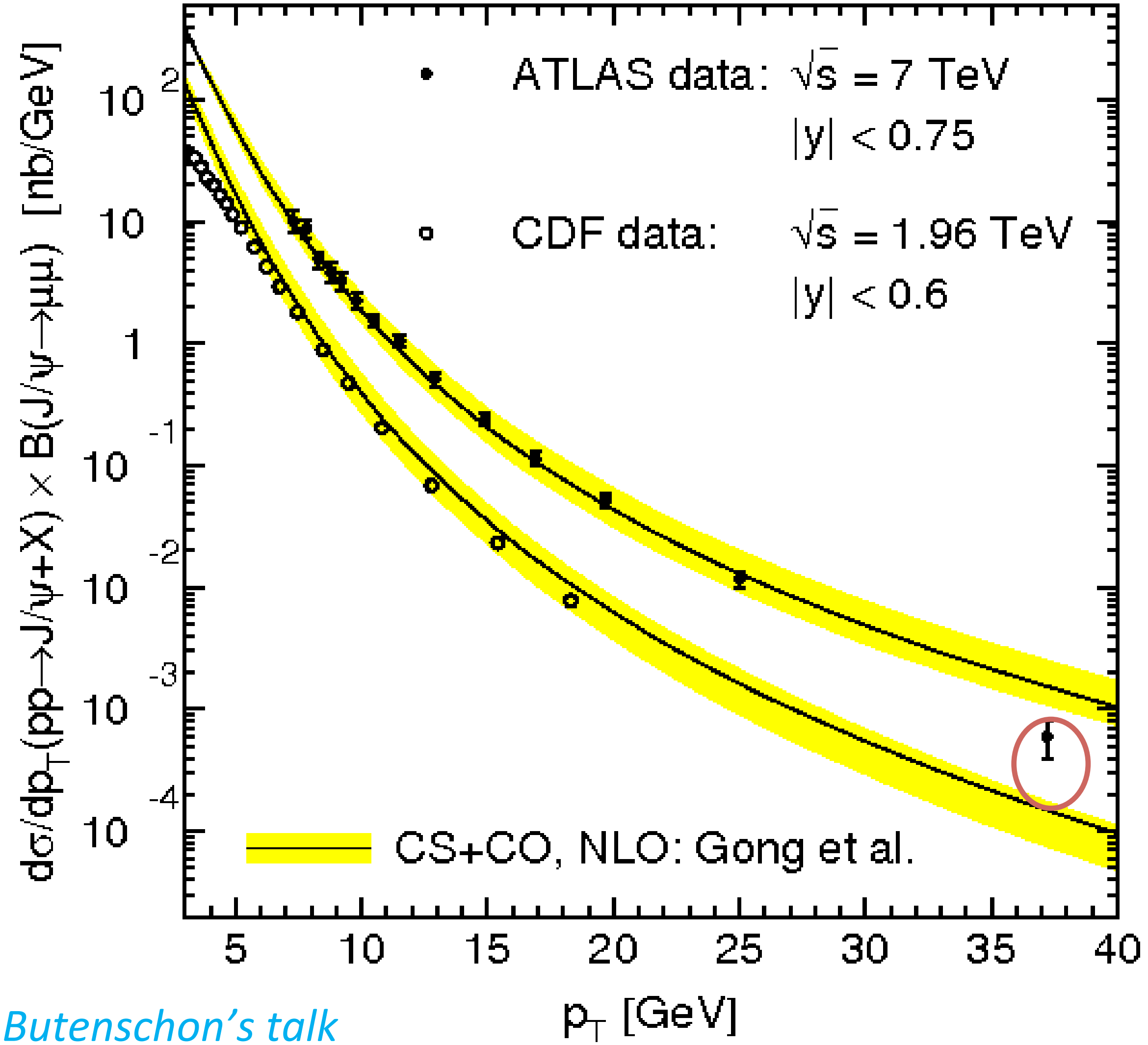




pT ~ 7.9 GeV

Stole from M.Butenschon's talk

ATLAS data



Stole from M.Butenschon's talk

polarization@CDF Run II