Discussion theme:
Quarkonium production studies in pp: what do we aim to learn, and how?

Quarkonium production: Probing QCD at the LHC

Vienna, April 17-21 2011

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  - what more?

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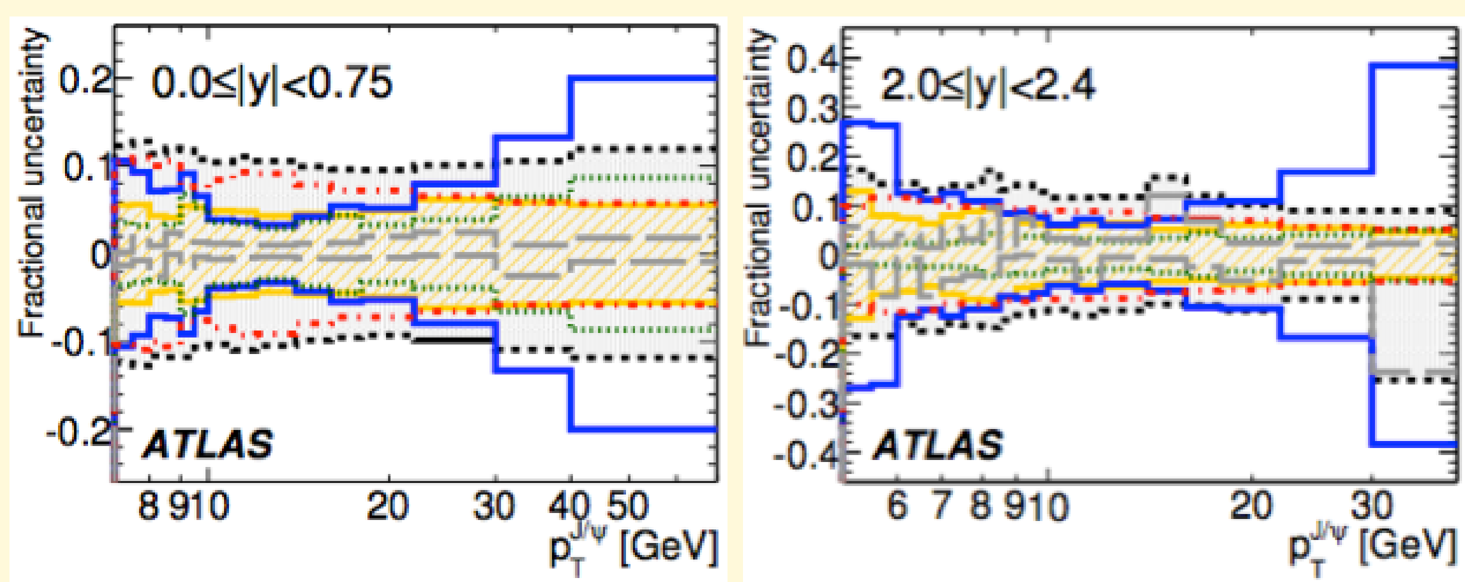
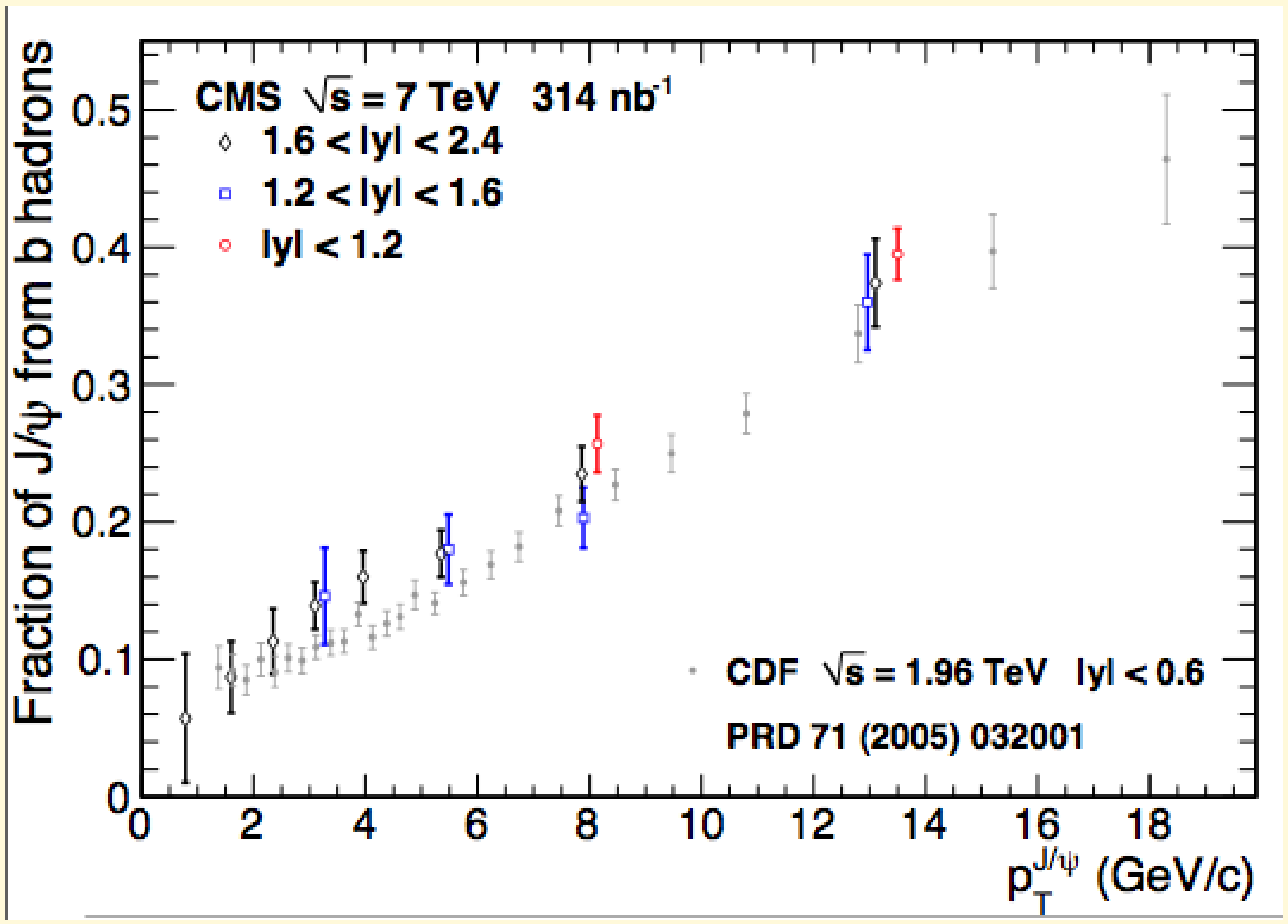
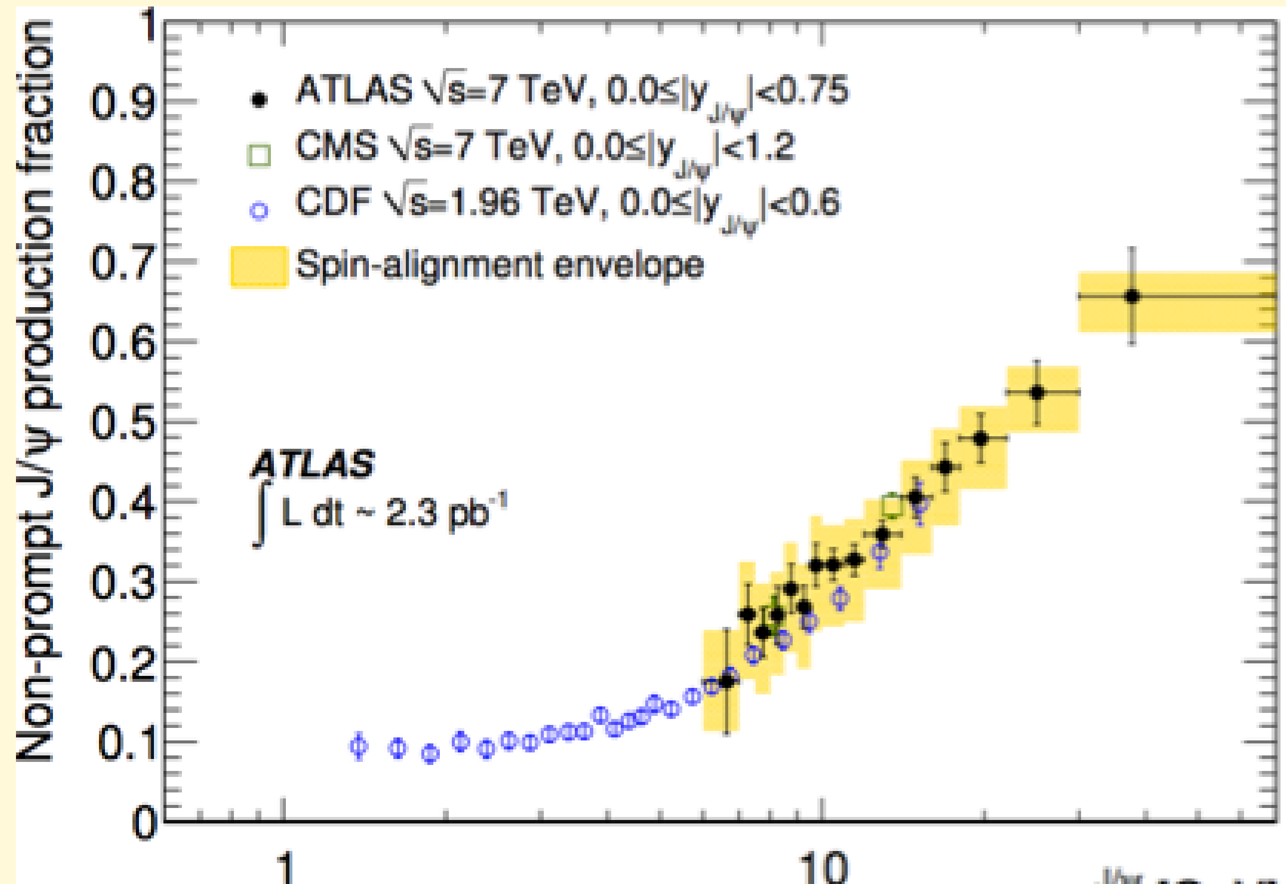


Note the amazing accuracy, 10%, that will soon be available up to the highest pt values

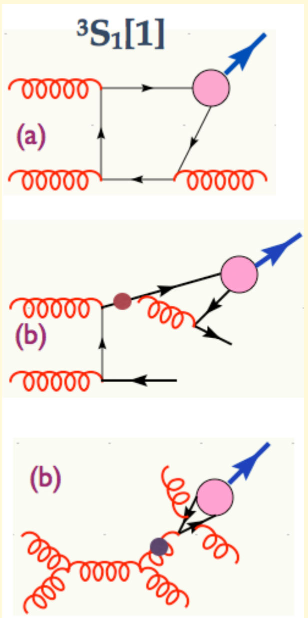
A starting point for reflection





arXiv:1104.3038

A qualitative picture of energy scaling



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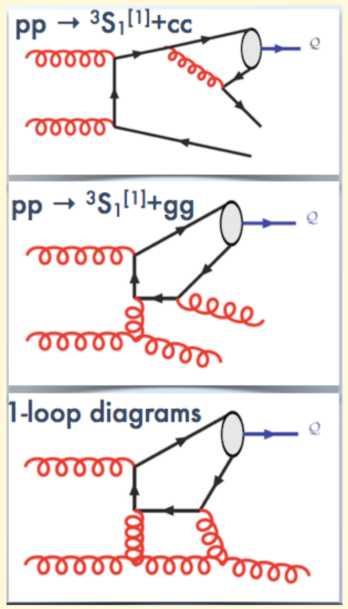

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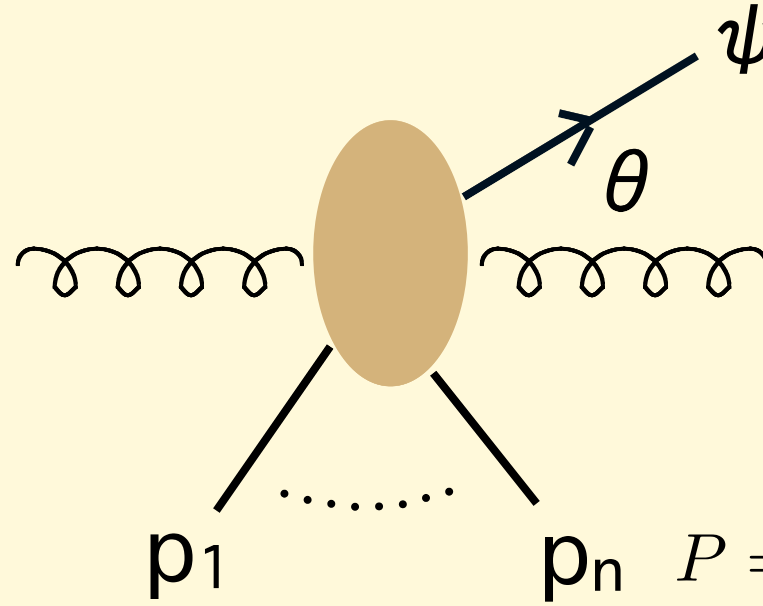


$$p_\psi \sim \frac{\hat{s} - M^2}{2\sqrt{\hat{s}}}$$

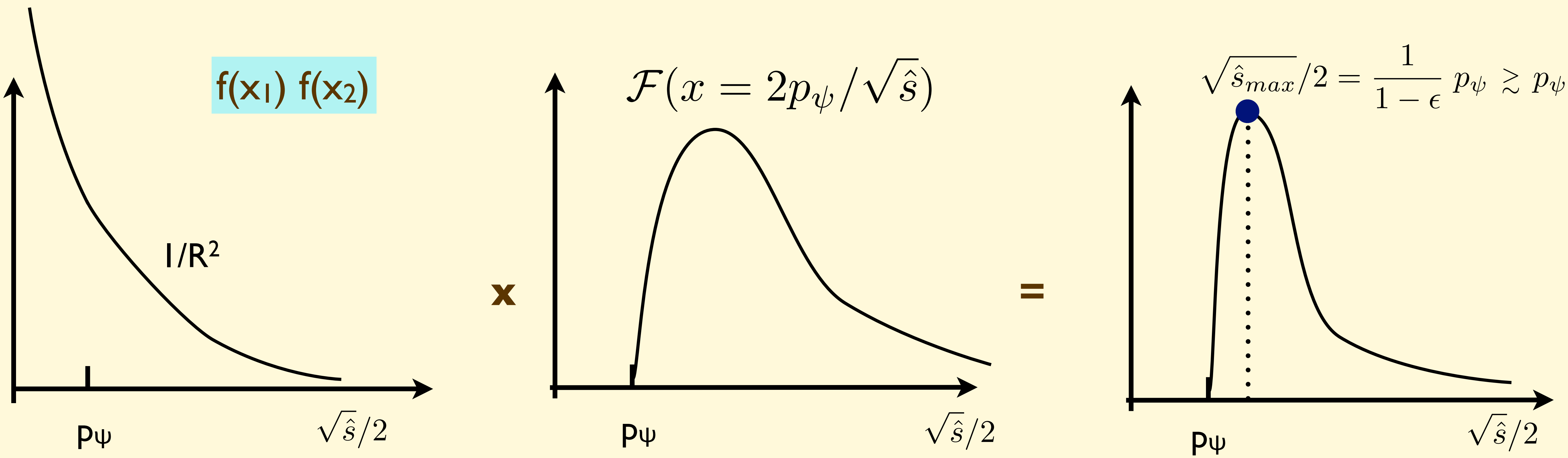
$$P = \sum_i p_i \quad , \quad P^2 = M^2$$

$$d\sigma = \int dx_1\, dx_2\, f_g(x_1) f_g(x_2)\, \frac{1}{2\hat{s}}\, \frac{d^3 p_\psi}{(2\pi)^3 2p^0_\psi}\, \frac{d^3 P}{(2\pi)^3 2P^0}\, \delta^4(P_{in} - P_{out}) \frac{dM^2}{2\pi} F(M, \hat{s}, \theta)$$

$$F(M, \hat{s}, \theta) = \int \prod_i^n \frac{d^3 p_i}{(2\pi)^3 2p^0_i} (2\pi)^4 \delta^4(P - \sum_i p_i)\, |A(p_\psi, \{p_i\}, \theta)|^2 \sim \frac{1}{\hat{s}} F(x, \theta)\,, \quad x = \frac{2p_\psi}{\sqrt{\hat{s}}} = 1 - \frac{M^2}{\hat{s}}$$

Neglecting for simplicity the θ dependence, (and for $p \gg m_\psi$)

$$\frac{d\sigma}{dy\, dp^2_\psi} = \int d\tau\, f(x_1) f(x_2) \frac{1}{\hat{s}^2} \mathcal{F}(x)\ , \quad \tau = \hat{s}/S_{had}\ , \quad x_{1,2} = \sqrt{\tau}\, e^{\pm y}$$



Here ϵ depends on the specific process, and on p_ψ, but not on S_{had}

Assuming **f(x) ~ 1 / x$^{1+\delta}$**

we get, in the saddle-point approximation:

$$\frac{d\sigma}{dy\, dp_\psi^2} \sim \frac{S_{had}^\delta}{(p_\psi^2)^{2+\delta}}\, \mathcal{F}(x = 1-\epsilon)$$

As a result:

(1) $$\frac{d\sigma(S)}{dy\,dp_\psi^2} \sim \left(\frac{S}{S_0}\right)^\delta \frac{d\sigma(S_0)}{dy\,dp_\psi^2}$$

$\sqrt{S}$ scaling of the cross section probes the behavior of gluon PDFs, not of the production process

This specific scaling prediction will break down at large p_ψ, since the $1/x^{1+\delta}$ behaviour of the gluon density is valid only over a limited x range

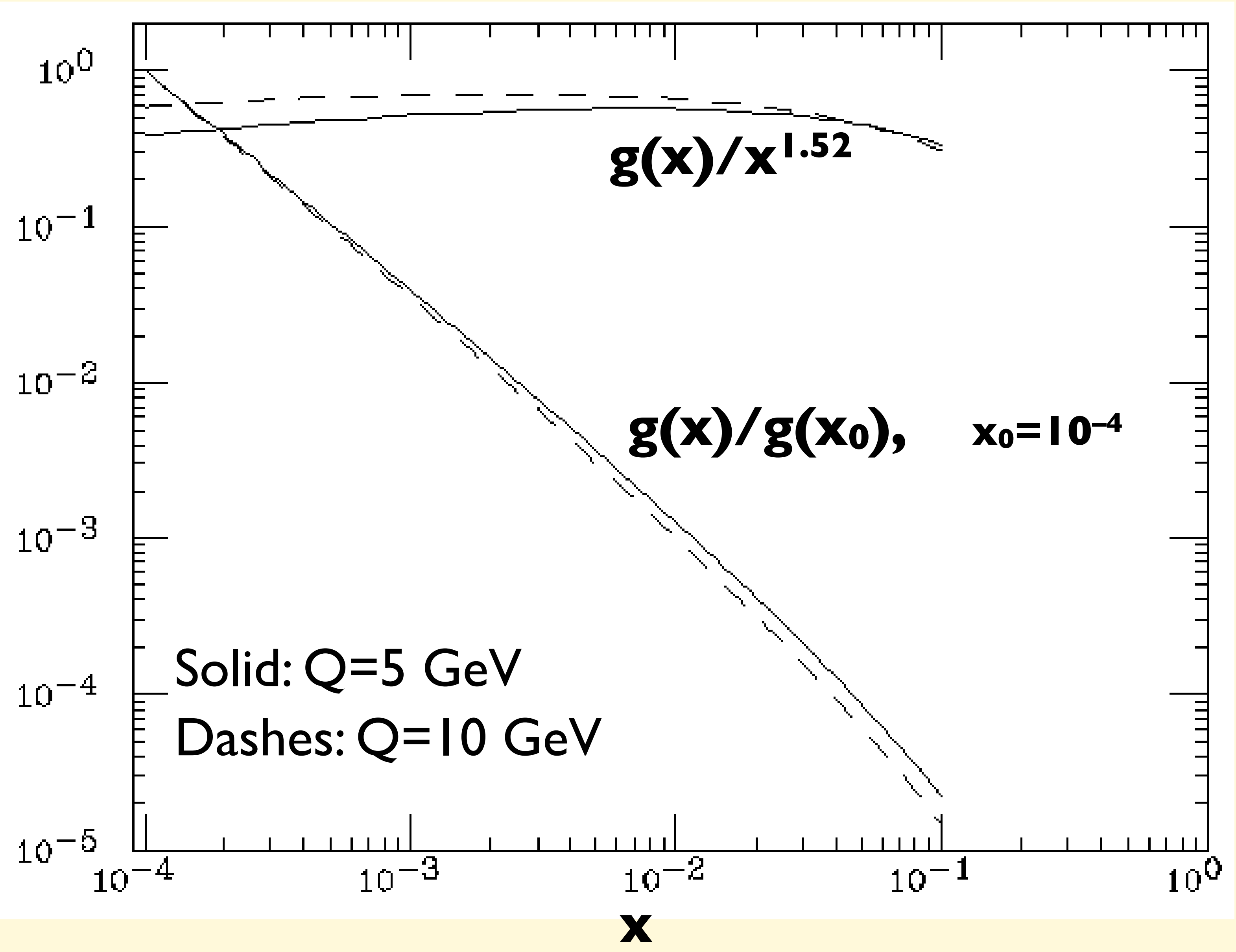
(2) $$\frac{\frac{d\sigma(b\to\psi)}{dy\,dp_\psi^2}}{\frac{d\sigma(\psi)}{dy\,dp_\psi^2}} \sim \frac{\mathcal{F}_{(b\to\psi)}(p_\psi)}{\mathcal{F}_{(\psi)}(p_\psi)}$$

The fraction of ψ from b decays depends on p_ψ , but is independent of $\sqrt{S}$. This prediciton is more robust against changes in the behaviour of the gluon density

The same holds for ratios of other subprocesses.

So the measurement of momentum spectra at the LHC **appears** to add little fundamental information on the underlying production processes, relative to the measurements at the Tevatron

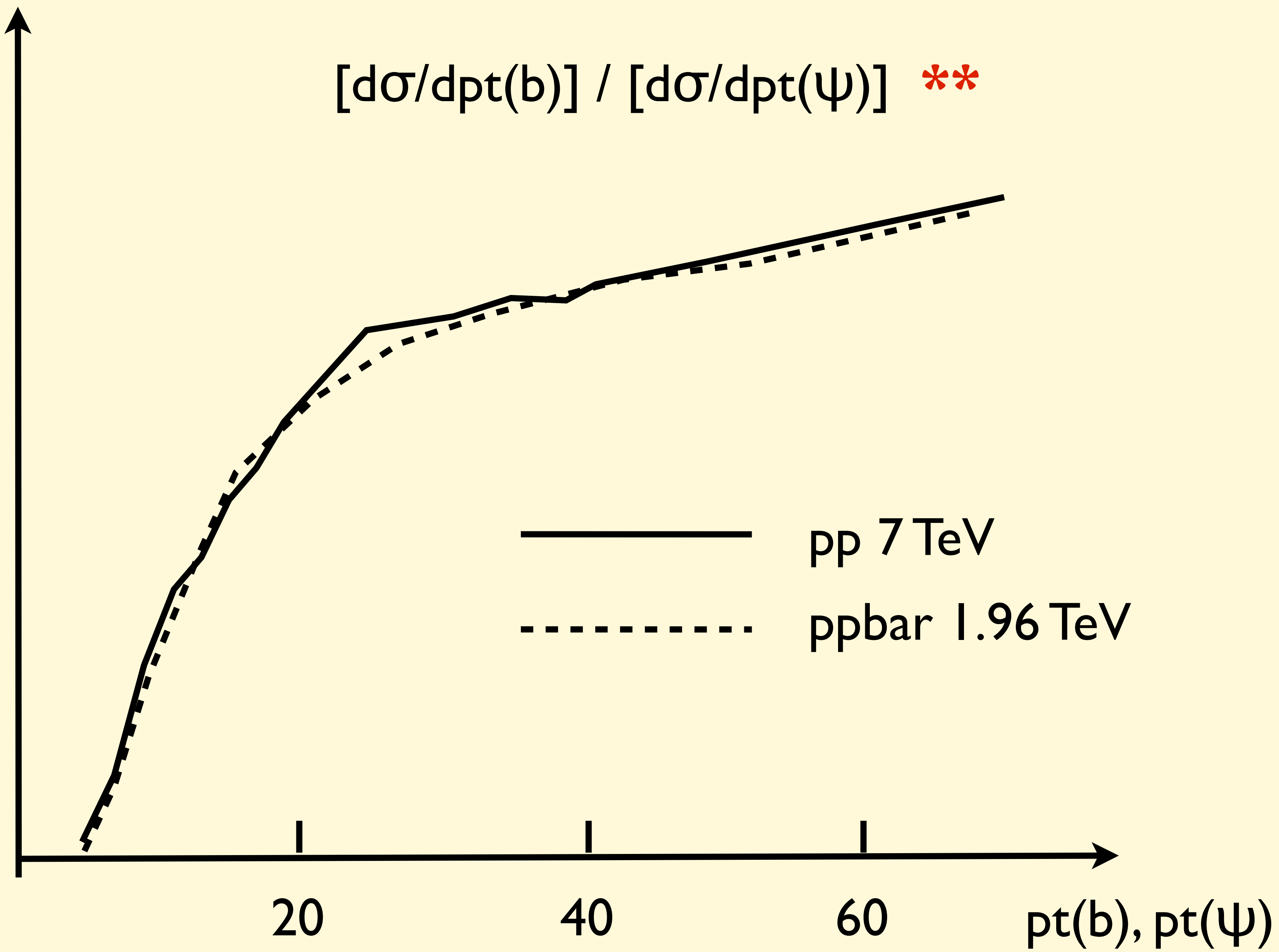
Example



$g(x)/x^{1.52} \Rightarrow \delta=0.52$

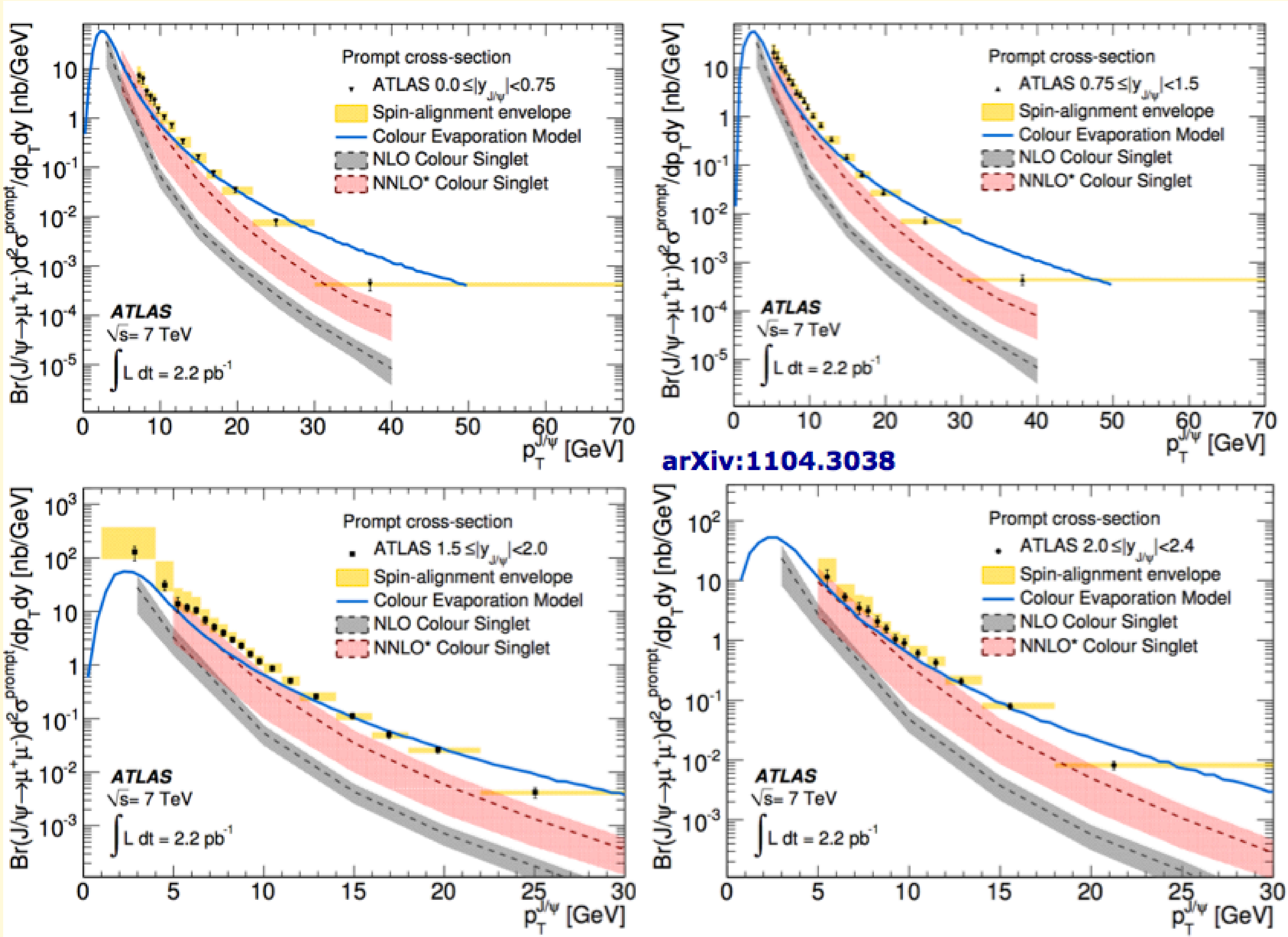
$\sigma_{LHC} / \sigma_{TEV} \sim (7\ \text{TeV} / 1.96\ \text{TeV})^{2\delta} \sim 3.5$

Example



** NB:

- ψ: color-evaporation model, namely all c-cbar pairs with m_{cc}<4 GeV
- this is **not** the ratio of pt spectra of ψ from b's over "direct" ψ's. It's the ratio of pt spectra of b's and "direct" ψ. It's for simplicity, and for illustration purposes

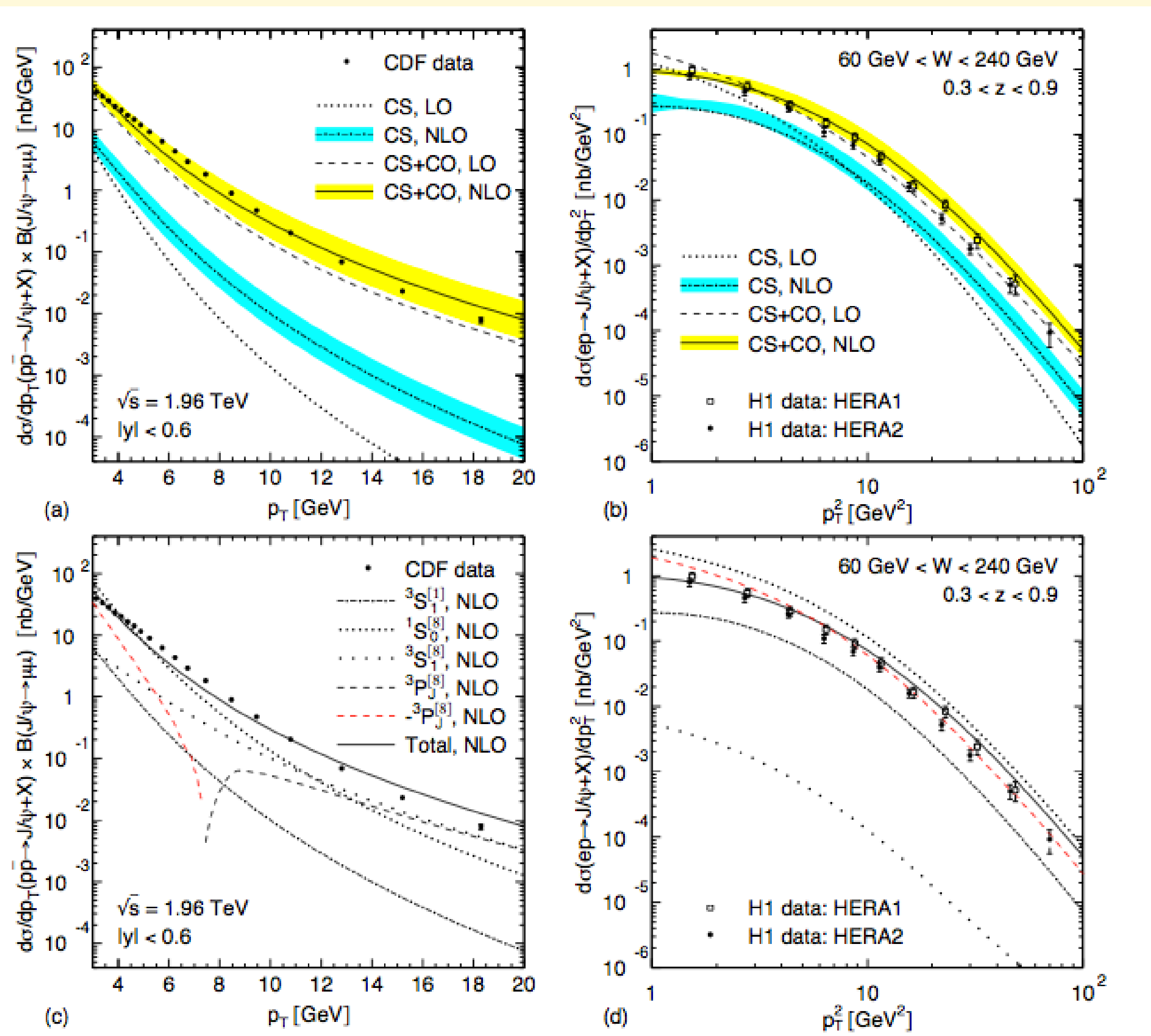


The previous considerations make the disagreement shown here between data and CEM (presumably "tuned" to Tevatron data) a bit puzzling ....

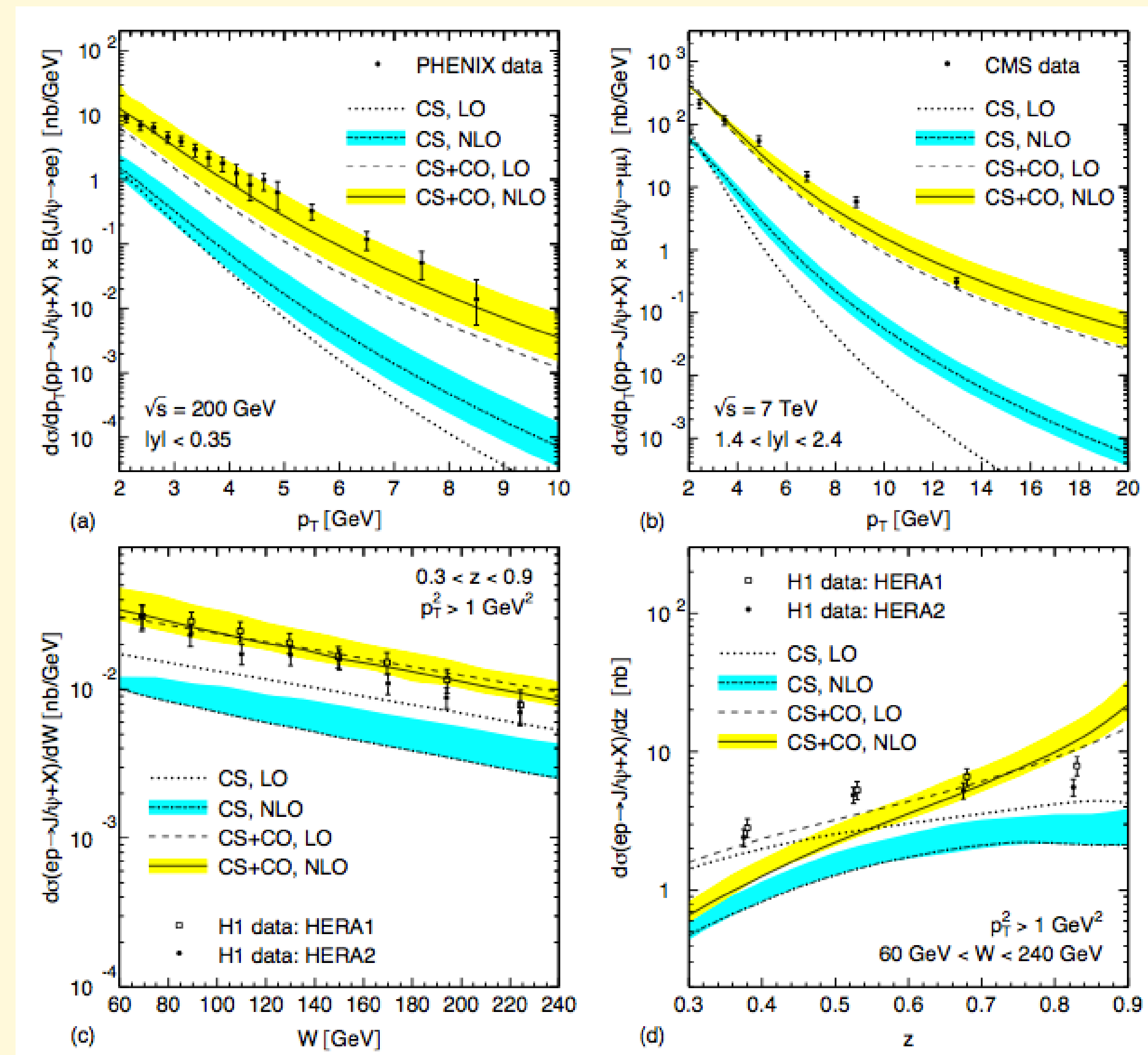
Reconciling J/ψ production at HERA, RHIC, Tevatron, and LHC with NRQCD factorization at next-to-leading order

Mathias Butenschön, Bernd A. Kniehl

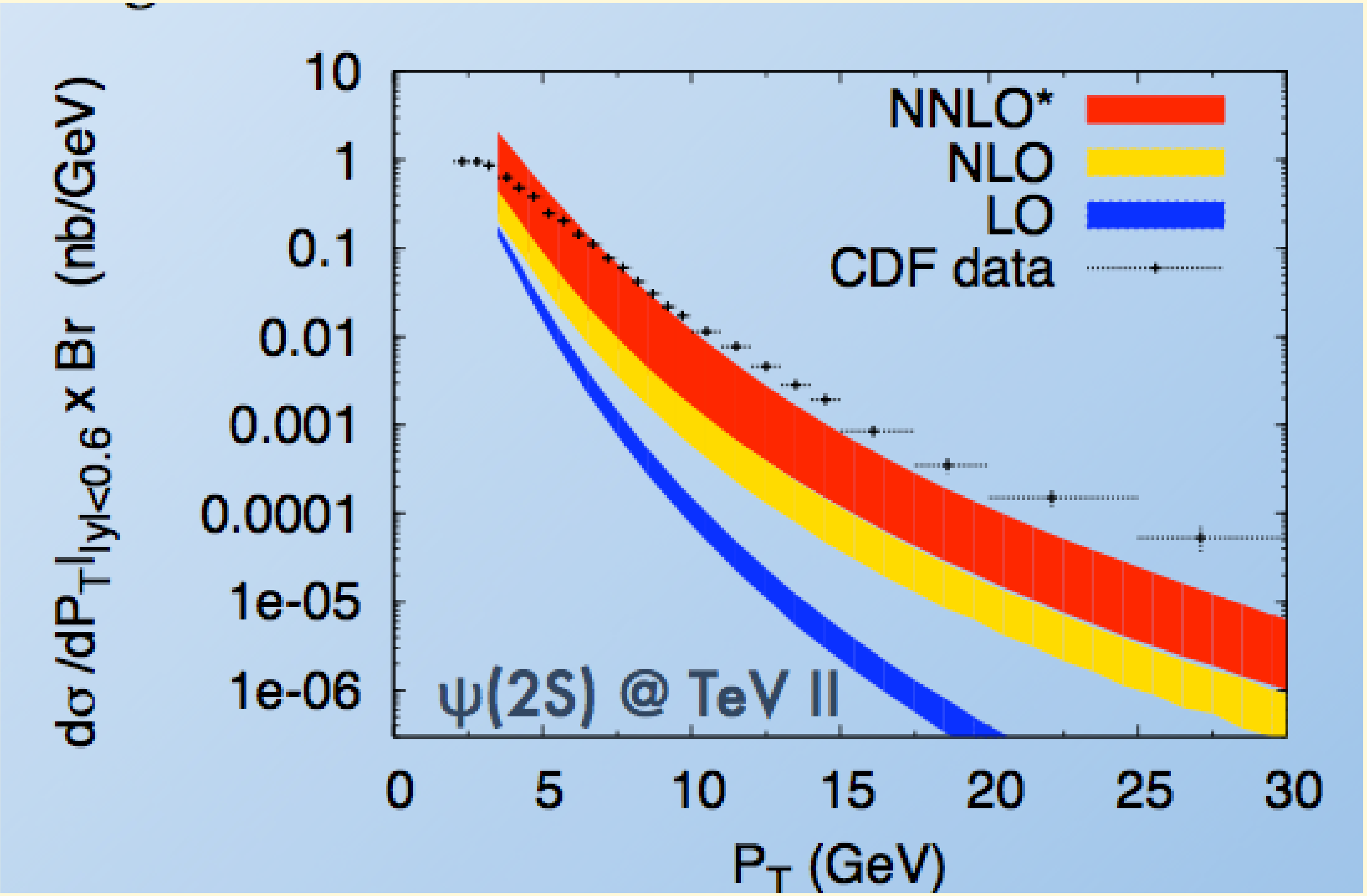
arXiv:1009.5662v1



Fit inputs

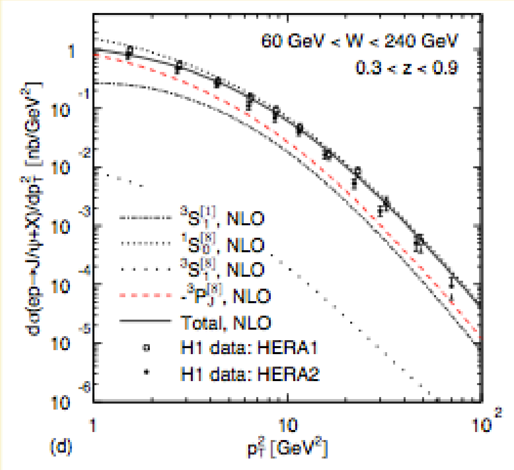


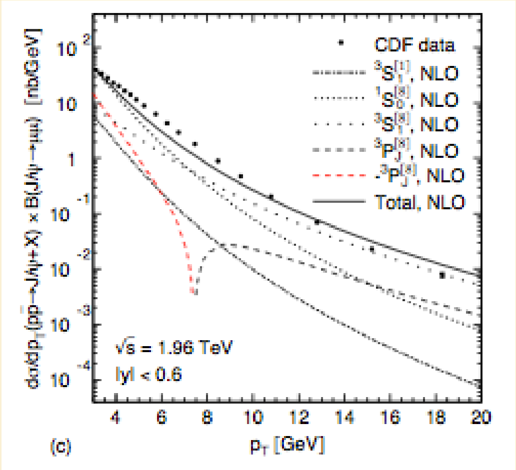
Predicctions



NNLO*
NLO
LO
CDF data
ψ(2S) @ TeV II
dσ /dP_T-|_|y|<0.6 x Br (nb/GeV)
P_T (GeV)
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
0
5
10
15
20
25
30

Fit to Tevatron $p_T > 7$ GeV and HERA data, excluding feed-down





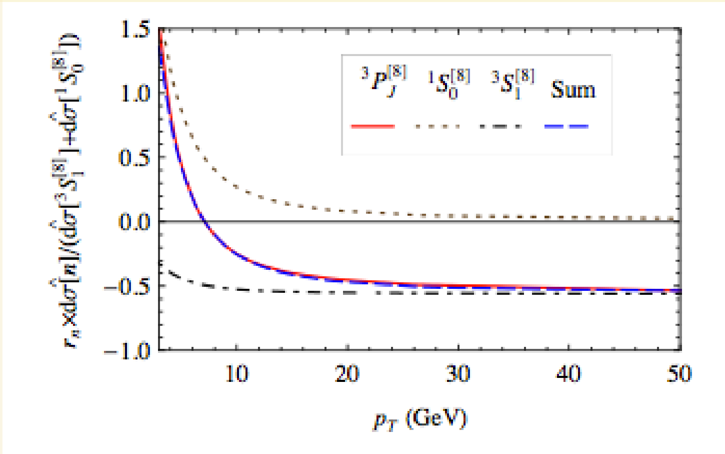
10^{-2} GeV^{3+2L}	BK default	Tevatron $p_T > 7$ GeV
$\langle \mathcal{O}(^1S_0^{[8]}) \rangle$	4.76 ± 0.71	2.9
$\langle \mathcal{O}(^3S_1^{[8]}) \rangle$	0.265 ± 0.091	0.4
$\langle \mathcal{O}(^3P_0^{[8]}) \rangle$	-1.32 ± 0.35	-0.58

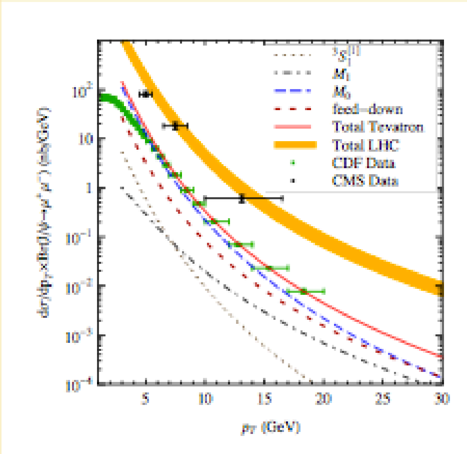
- Shift of p_T cut on Tevatron data from 3 GeV to 7 GeV less dramatic
- Thanks to stabilizing influence of HERA data

Butenschön, Kniehl

Phys. Rev. Lett. **104** (2010) 072001, arXiv:1009.5662

Fit only to Tevatron data with $p_T > 7$ GeV, including feed-down





Ma, Wang, Chao arXiv:1009.3655

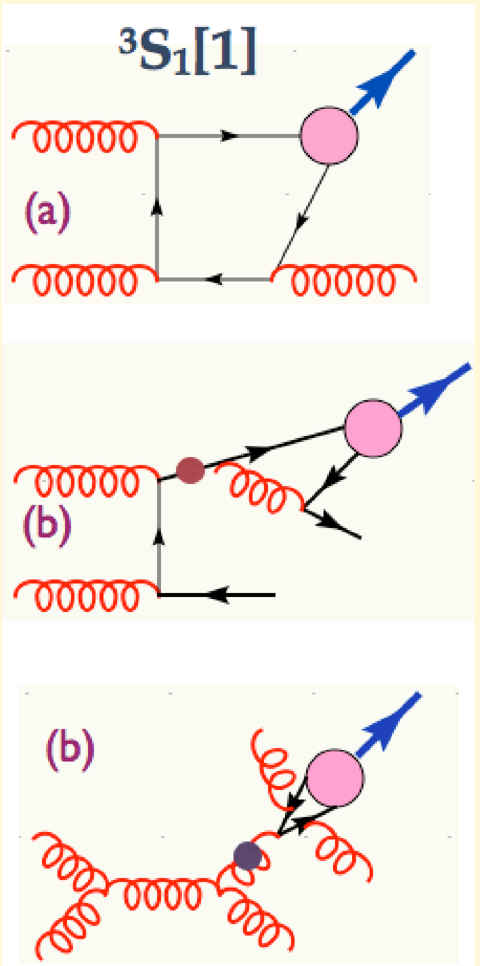
- Observe that $d\hat{\sigma}(^3P_J^{[8]}) \approx r_0 d\hat{\sigma}(^1S_0^{[8]}) + r_1 d\hat{\sigma}(^3S_1^{[8]})$ with $r_0 = 3.9$ and $r_1 = -0.56$
- Define $M_0 = \langle \mathcal{O}(^1S_0^{[8]}) \rangle + \frac{r_0}{m_c^2} \langle \mathcal{O}(^3P_0^{[8]}) \rangle$ and $M_1 = \langle \mathcal{O}(^3S_1^{[8]}) \rangle + \frac{r_1}{m_c^2} \langle \mathcal{O}(^3P_0^{[8]}) \rangle$
- Substitute $\langle \mathcal{O}(^1S_0^{[8]}) \rangle \to M_0$ and $\langle \mathcal{O}(^3S_1^{[8]}) \rangle \to M_1$ and discard $d\hat{\sigma}(^3P_J^{[8]})$.
- Fit yields $M_0 = (7.4 \pm 1.9) \times 10^{-2}$ GeV^3 and $M_1 = (0.05 \pm 0.02) \times 10^{-2}$ GeV^3 with $\chi^2/\text{d.o.f.} = 0.33$
- Cf. $M_0 = (2.47 \pm 0.93) \times 10^{-2}$ GeV^3 and $M_1 = (0.59 \pm 0.13) \times 10^{-2}$ GeV^3 from BK

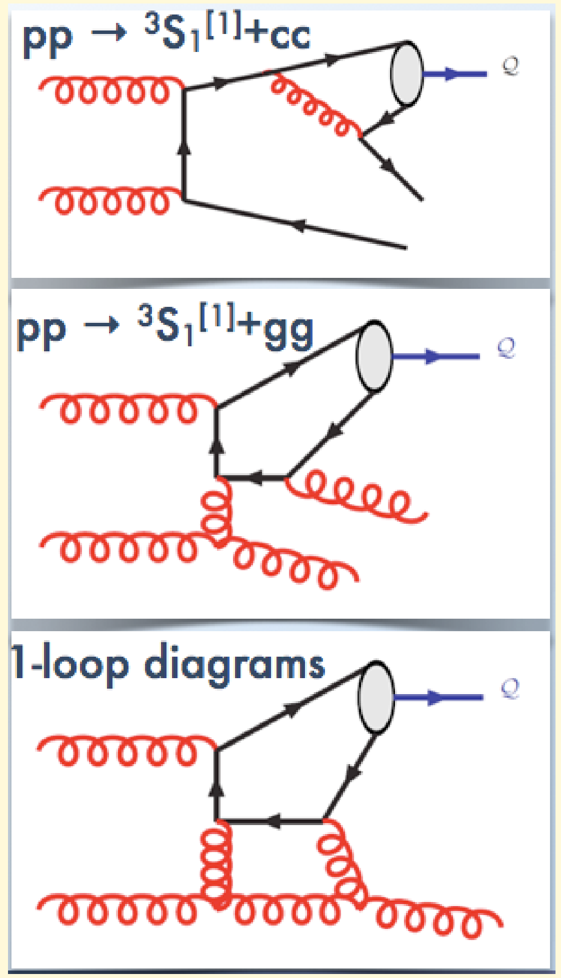
Summary of M_0 and M_1 in (10^{-2} GeV^3) from BK and MWC

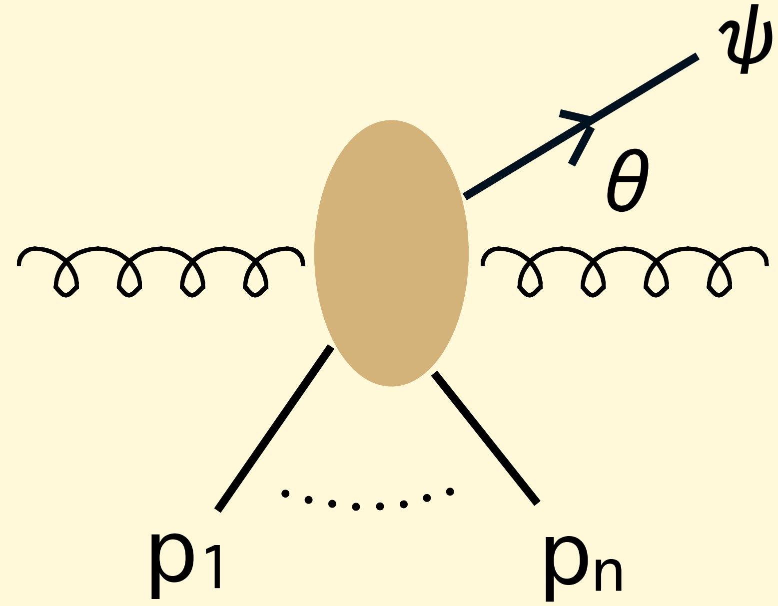
authors	data	feed-down	M_0	M_1
BK	default	—	2.5	0.59
BK	HERA $p_T > \sqrt{5}$ GeV	—	2.5	0.60
BK	Tevatron $p_T > 7$ GeV	—	1.9	0.54
BK	default	√	1.7	0.43
BK	only Tevatron	—	8.7	0.62
BK	only Tevatron $p_T > 7$ GeV	—	9.3	0.30
MWC	only Tevatron $p_T > 5$ GeV	√	5.2	0.16
MWC	only Tevatron $p_T > 7$ GeV	√	7.4	0.05

- Lower p_T cuts on HERA or Tevatron data marginal in joint fit
- Feed-fown corrections moderate ⇝ no qualitative change
- Exclusion of HERA data ⇝ fit greatly underconstrained

Remark: angular distributions



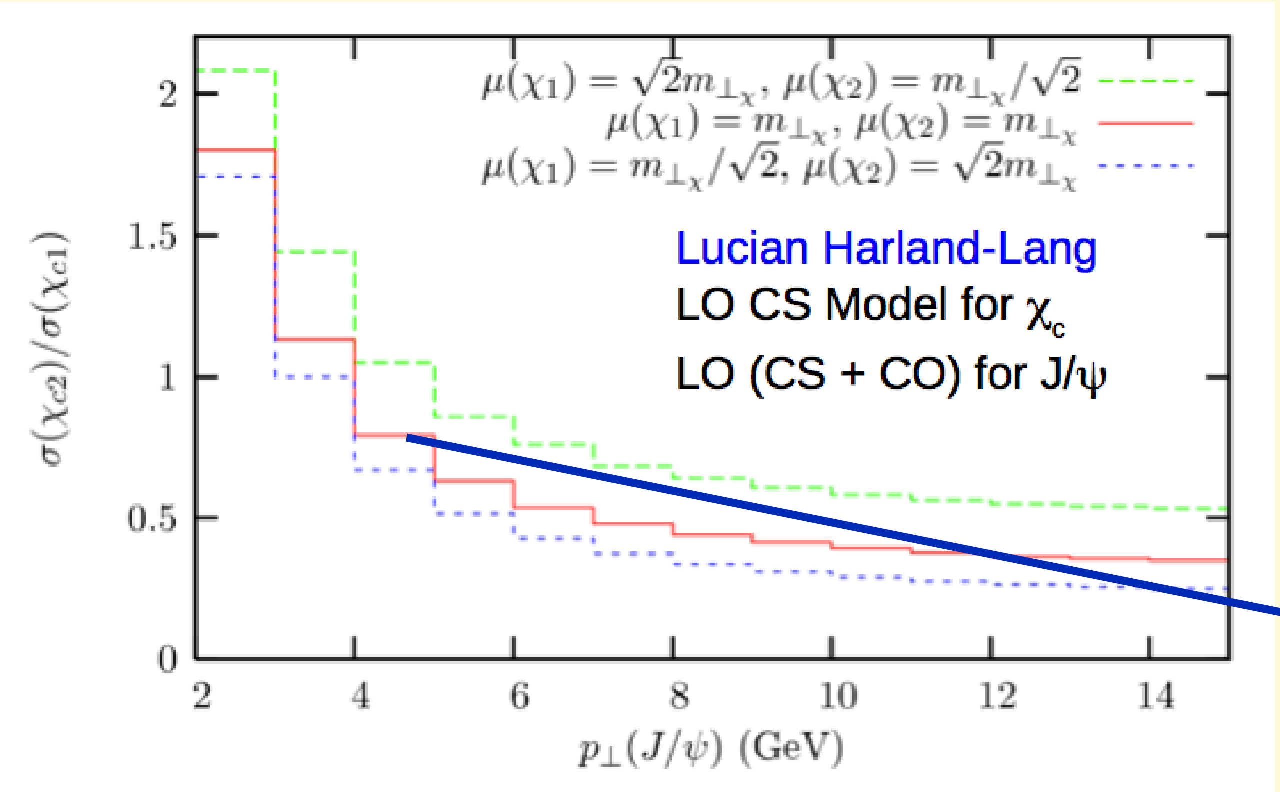


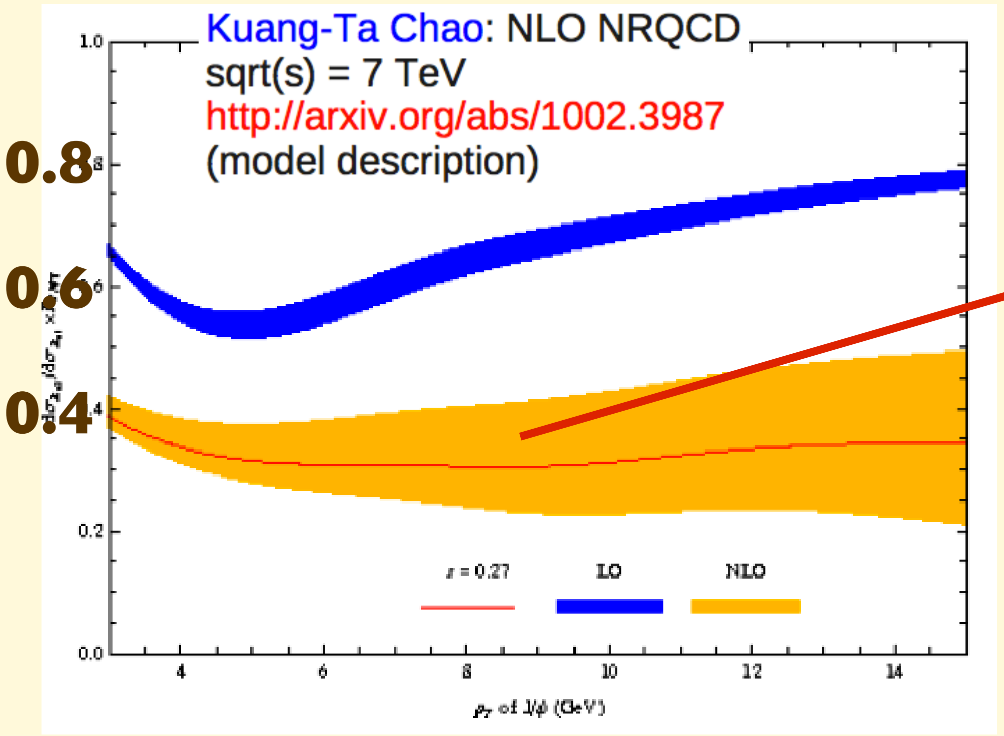


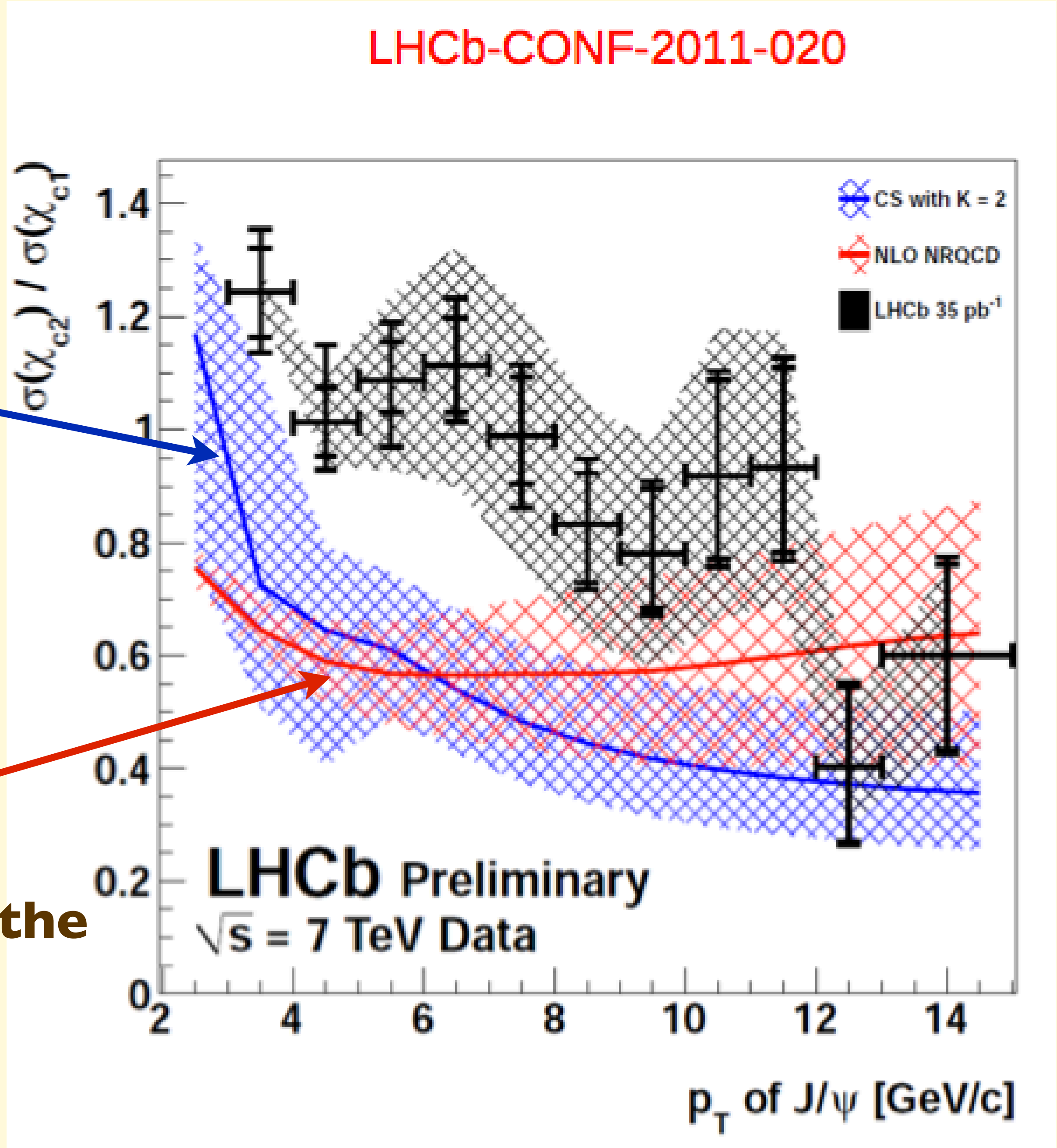
These subprocesses have rather different θ distributions, because of different t-channel structures.

The onium η spectra presumably contain a lot of crucial information on the various subprocesses. Since the process composition is expected to vary as a function of pt, η distributions for different pt slices seem like a good observable, never studied before (to my knowledge)

From the LHCb talk (L. Li Gioi)



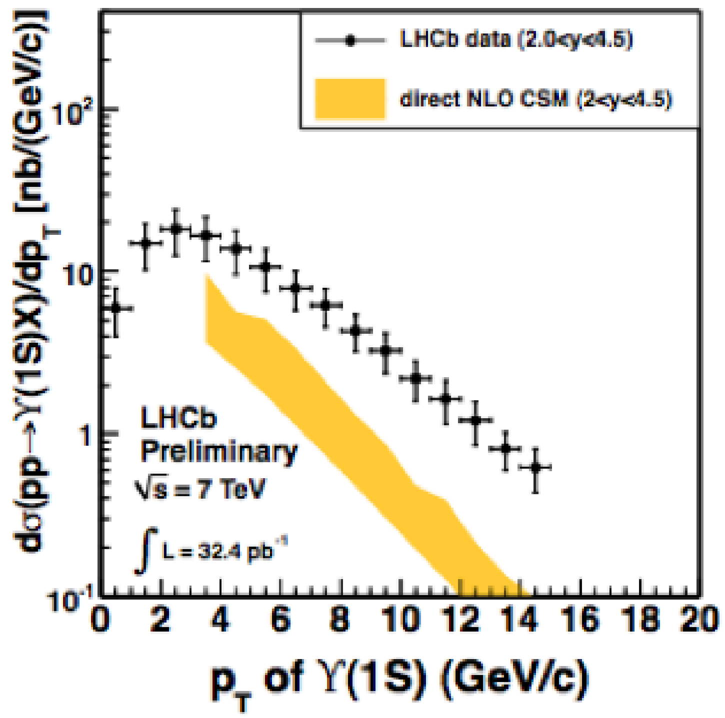




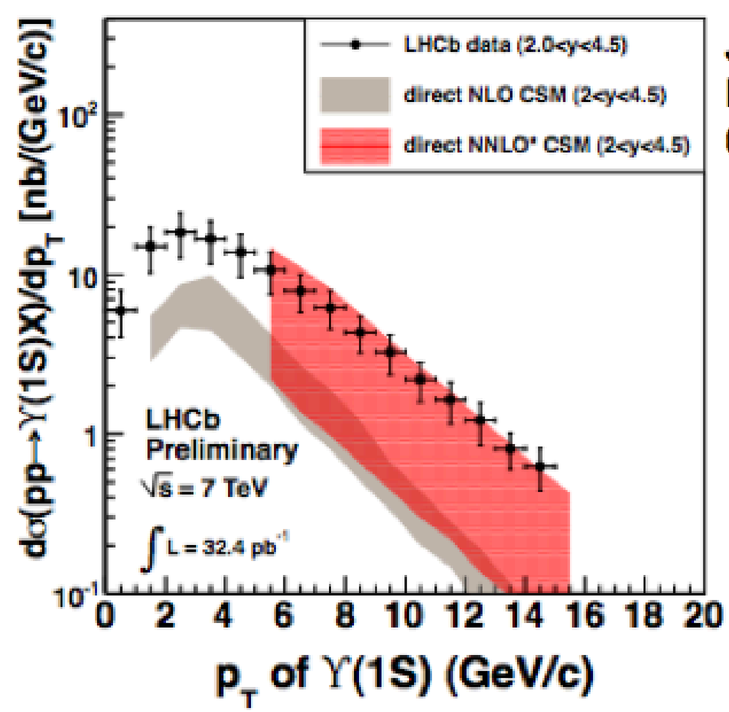
50% higher in the LHCb plot

Comparison with Theory

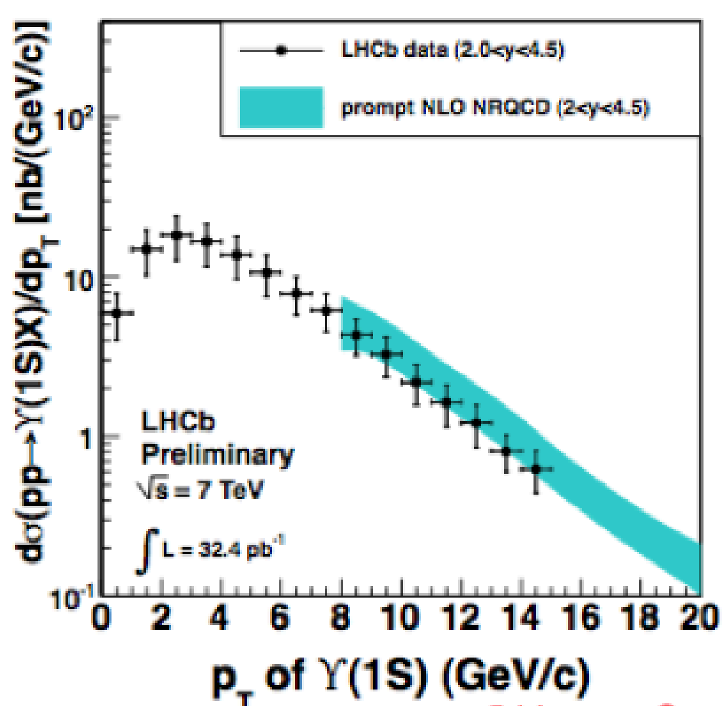
P. Artoisenet, PoS ICHEP 2010 (2010) 192.



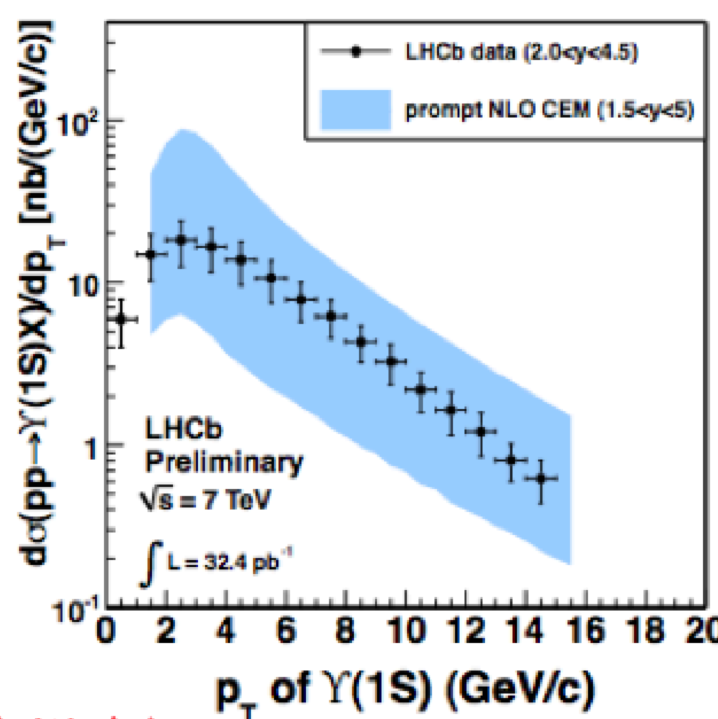
J.-P. Lansberg, Eur. Phys. J. C 61 (2009) 693



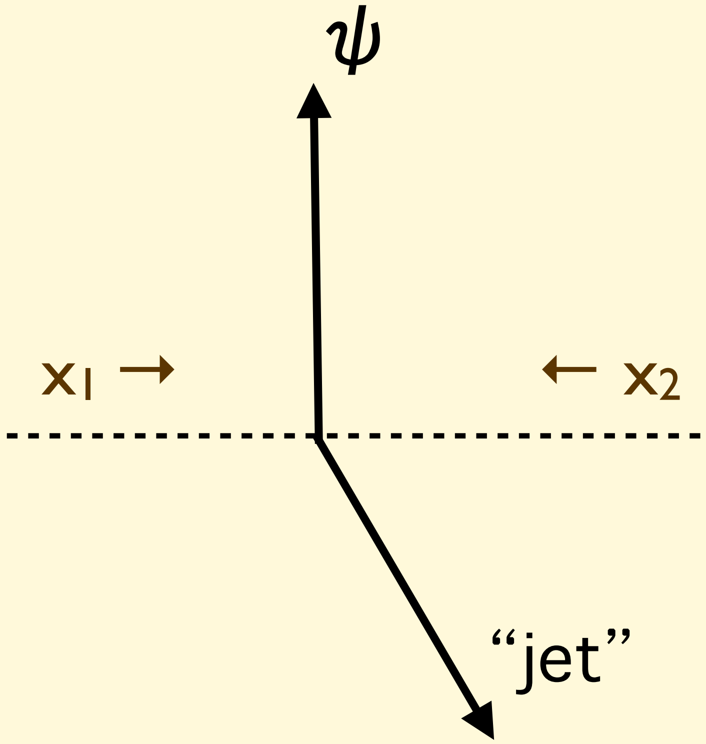
Y. Q. Ma, K. Wang and K. T. Chao, Phys. Rev. Lett. 106 (2011) 042002.



A. D. Frawley, T. Ullrich and R. Vogt, Phys. Rep. 462 (2008) 125.



Central kinematics

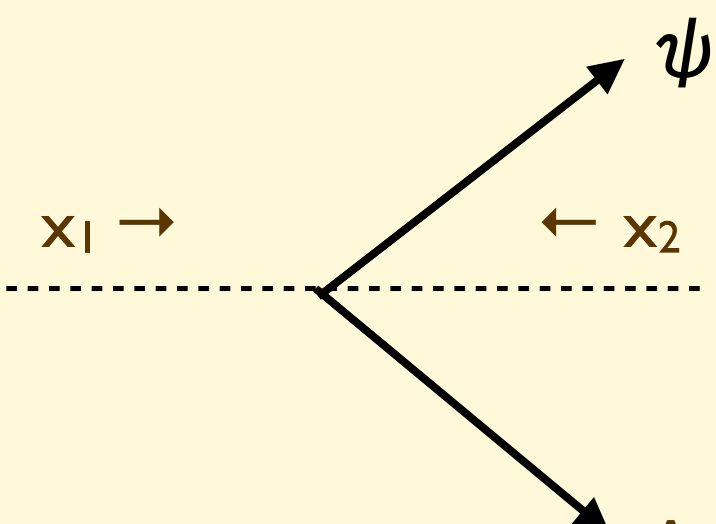


$\Delta y = y_\psi - y_{jet}$

Exploit the direction of the recoil to probe different values of the CoM scattering angle:

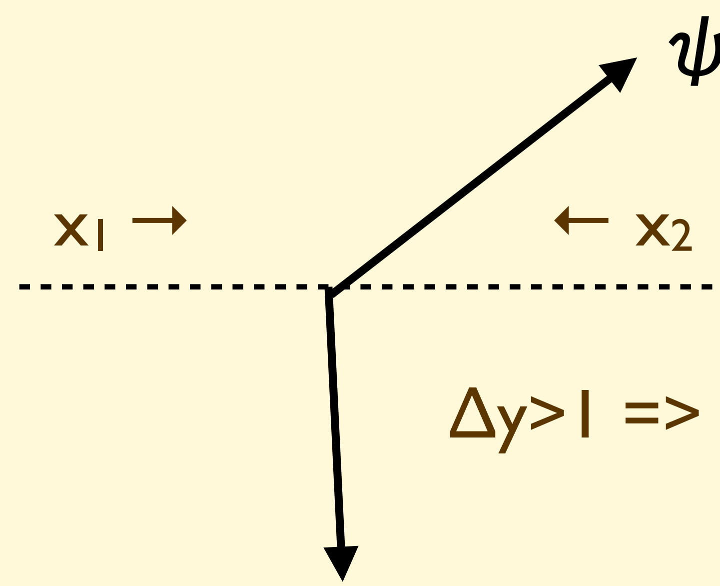
tag the recoil "jet", and plot $d\sigma/d\Delta y$

Forward kinematics



$\theta_{CM} \sim \pi/2$

$\Delta y \sim 0 \Rightarrow x1 >> x2$



$\theta_{CM} < \pi/2$

$\Delta y > 1 \Rightarrow x1 \sim x2$

Possible LHC probes, beyond Tevatron

1. Higher pt reach
   1.1. great, but doesn't help understanding the most critical part of the spectrum, in the pt range up to 15-20 GeV
2. Larger η coverage
   2.1. should be exploited to complement the pt spectrum information, to separate the various components.
   2.2. N.B. the interpretation of "polarization" measurements needs first sorting out which processes dominate at which pt
3. Greater control over the structure of final state:
   3.1. study the environment in which the onium is produced:
      3.1.1. is it inside a jet? => measure the psi fragmentation function
      3.1.2. is it isolated? => study nearby track/energy activity vs pt_ψ
      3.1.3. is there open charm nearby? how does the rate of open charm vary vs pt?
      3.1.4. what's the structure of the recoil system?
4. Bigger statistics for upsilons: repeat exercises in 2 and 3