



Associated J/ψ production: $J/\psi + \gamma$, $J/\psi + c$,
 $J/\psi + c\bar{c}$, $J/\psi + J/\psi$, etc

J.P. Lansberg
Ecole Polytechnique – CPHT

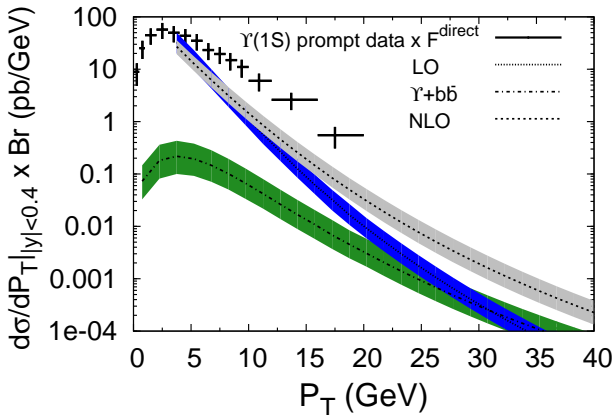
Quarkonium production at the LHC
CERN – February 19, 2010

Part I

Present theoretical uncertainties

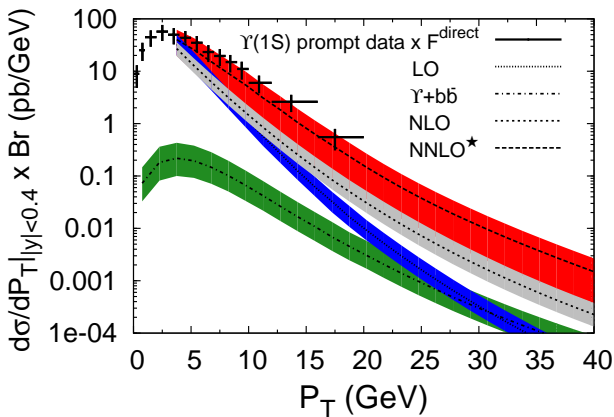
The best we can do for now : NNLO* contributions for Υ

P.Artoisenet, J.Campbell, JPL, F.Maltoni, F. Tramontano, Phys. Rev. Lett. 101, 152001 (2008)



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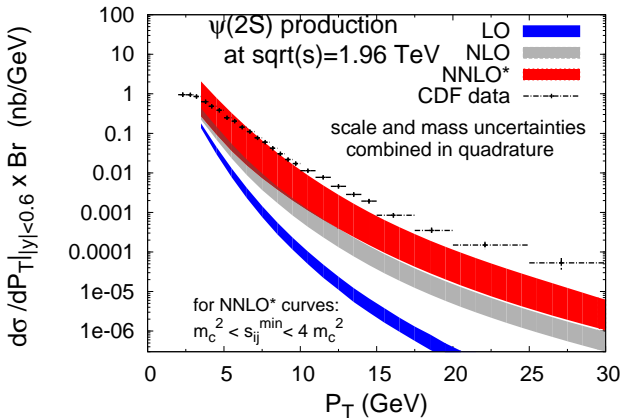


✗ Very large uncertainty attached to the choice of μ_r through $\alpha_s^5(\mu_r)$

This is indeed the Born order for the leading P_T graphs

NNLO* contributions for ψ

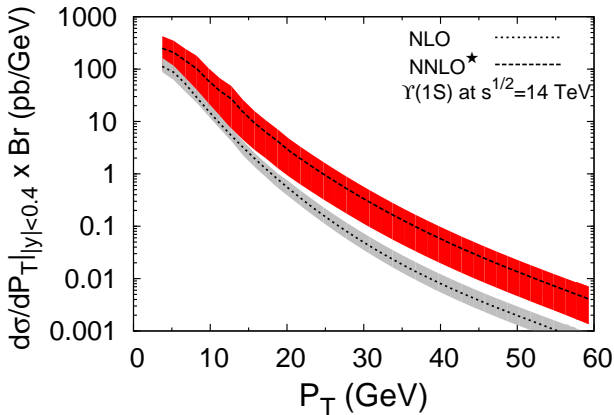
P.Artoisenet, AIP Proc. Conf 1038,55,2008.
JPL, EPJC 61:693,2009.



✗ Same large uncertainty attached to the choice of μ_r

Υ cross section at the LHC

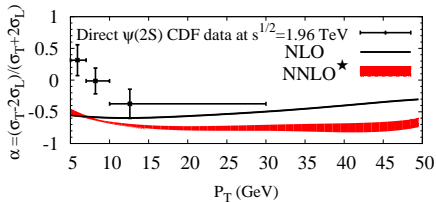
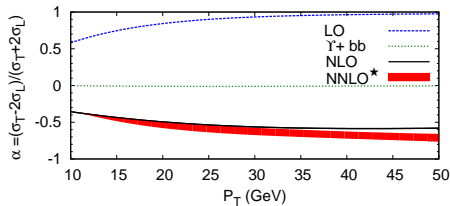
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X No surprise : same uncertainty band

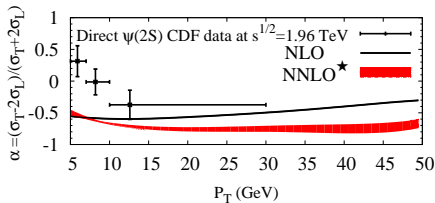
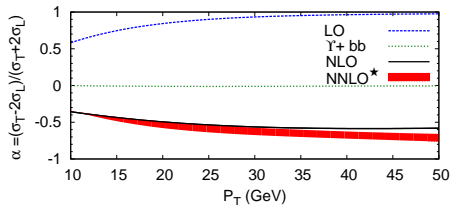
Υ and J/ψ polarisation in hadroproduction at $\mathcal{O}(\alpha_S^5)$

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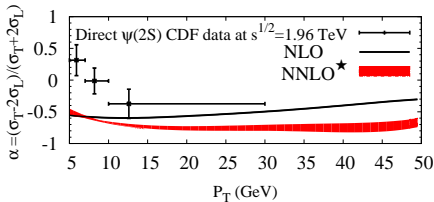
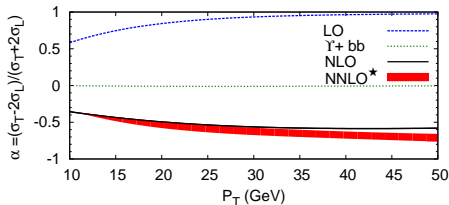
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✓ Most of the theoretical uncertainties vanish

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✗ For Υ and J/ψ , **comparisons with prompt measurements**
from CDF and $D\emptyset$ can be “dangerous”

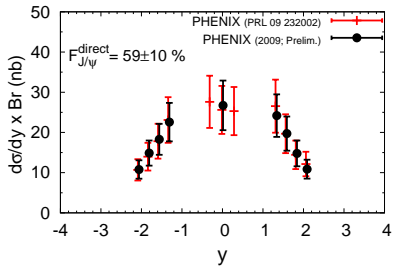
→ **Feed-down** from χ_c , χ_b **not known at NLO !!**

Part II

Grass greener somewhere else ? Low P_T ?

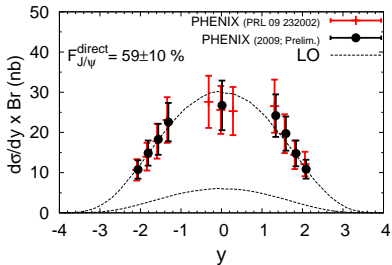
What about $\frac{d\sigma}{dy}$?

S. J. Brodsky and J. P. Lansberg, to appear in PRD Rapid. Com, 0908.0754 [hep-ph].



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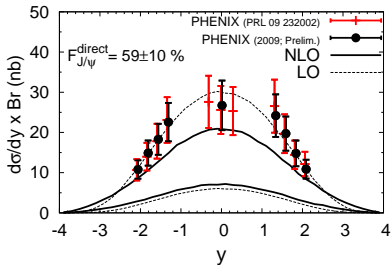


LO: $gg \rightarrow J/\psi g$: wrongly assumed to be negligible !

Large theoretical uncertainty

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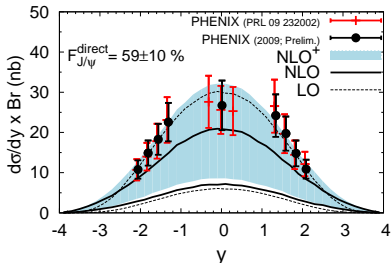
NLO: $gg \rightarrow J/\psi gg$, $gq \rightarrow J/\psi gq$, ...

using the matrix elements from J.Campbell, F. Maltoni, F. Tramontano, PRL 98:252002,2007

Theoretical uncertainty are somewhat reduced

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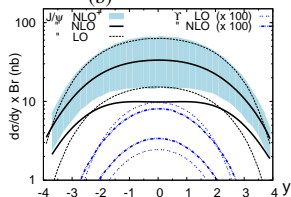
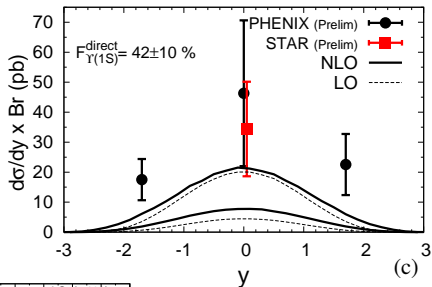
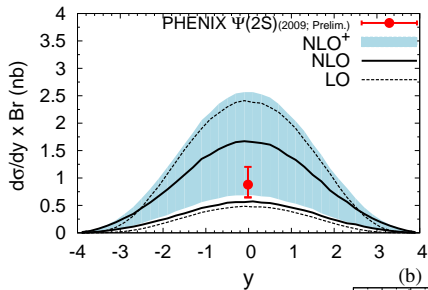
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Yet, one contribution at LO was overlooked: $cg \rightarrow J/\psi c$ (+ NLO = NLO⁺)

Introduce new uncertainties (attached to $c(x)$ mainly)

What about $\frac{d\sigma}{dy}$?

S. J. Brodsky and J. P. Lansberg, to appear in PRD Rapid. Com., 0908.0754 [hep-ph].



In all cases, somewhat large theoretical uncertainties

Part III

Need for more observables !

New observable: $Q + Q\bar{Q}$

- ⇒ Double charm/beauty HADRO-production should show large rates
let us see how it can be a new valuable observable

P.Artoisenet, J.P.L, F.Maltoni, PLB 653:60,2007; S.P. Baranov PRD73:074021,2006.

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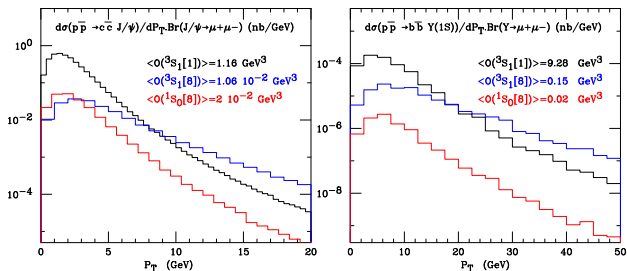
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- NRQCD factorisation ? Colour transfer mechanism ?

G.Nayak, J.W Qiu, G.Sterman,PRL99:212001,2007, PRD 77:034022,2008.

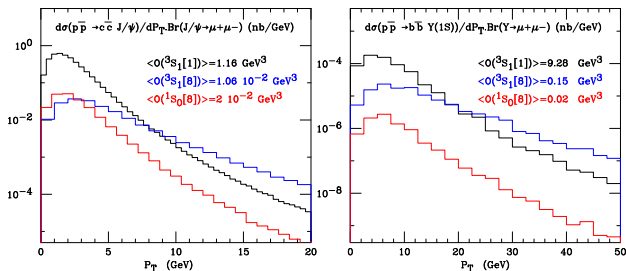
$Q + Q\bar{Q}$: CSM vs. COM (at the LHC)

P.Artoisenet, J.P.L, F.Maltoni, PLB 653:60,2007; P.Artoisenet, arXiv:0804.2975



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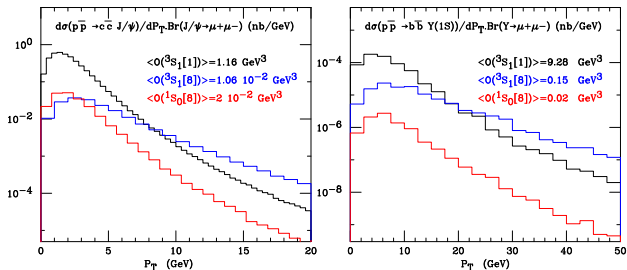
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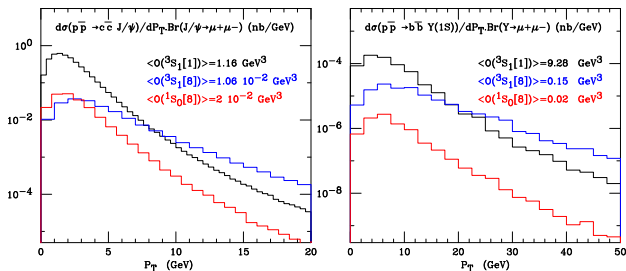


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B.Gong *et al.*, PRL 102:162003,2009; Y.Ma *et al.*, PRL102:162002,2009. Y. Zhang *et al.* arXiv:0911.2166

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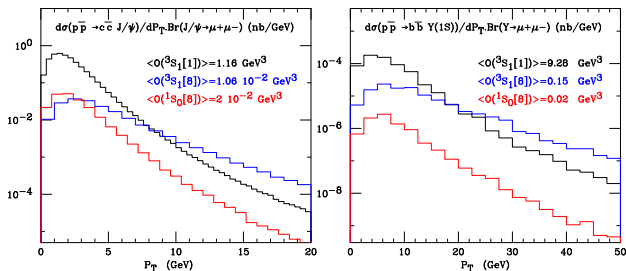
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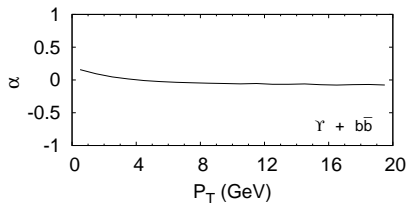
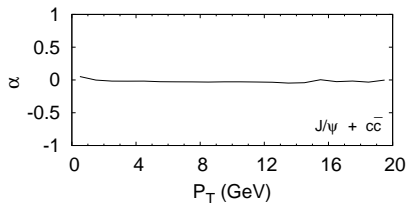
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- COM contributions (may) dominate from $P_T \geq 15 \text{ GeV}$

$Q + Q\bar{Q}$: polarisation

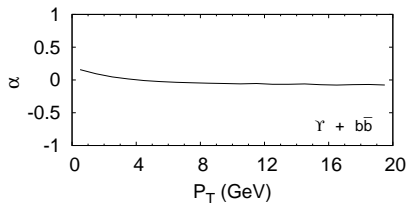
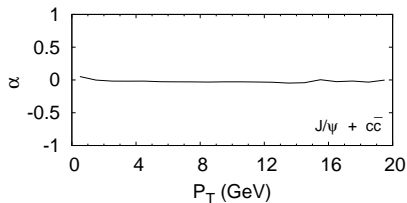
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Carlos' favourites !

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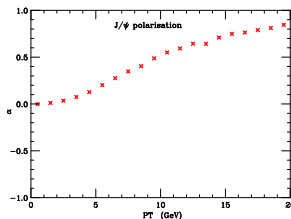
P.Artoisenet, J.P.L, F.Maltoni, PLB 653:60,2007



Carlos' favourites !

⇒ $J/\psi + c\bar{c}$: polarisation with COM ("old" CO matrix elements)

P.Artoisenet, private communication



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- ⇒ idem for the χ_c feed-down

Indeed, no kinematical enhancements here

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JPL, PLB 679:340,2009.

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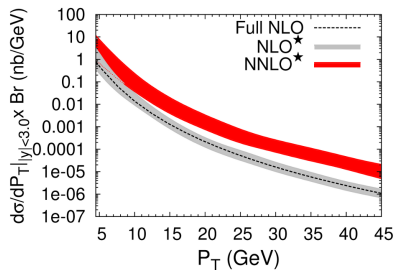
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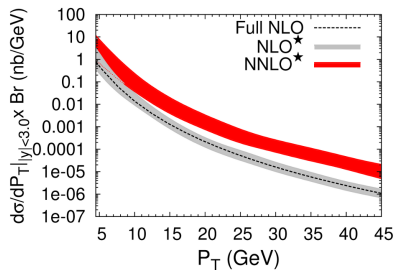
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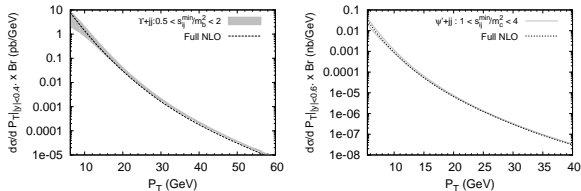
The yield will be dominated by the color singlet transitions !

Once more, no kinematical enhancements for CO

α_s^5 contributions \leftrightarrow NNLO*: validations

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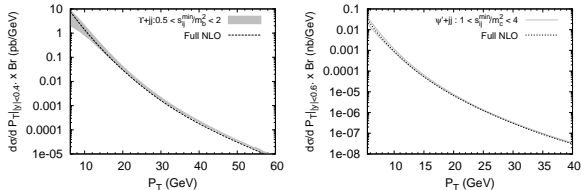
\rightarrow Validation at α_s^4 : the full NLO is amazingly well reproduced by $jj \rightarrow Qjj$



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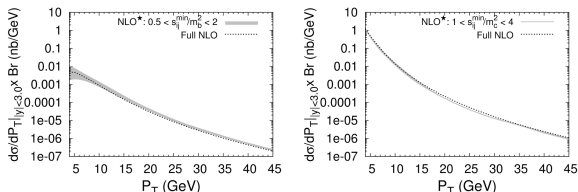
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\rightarrow Further validation with another process $Q + \gamma$: Full NLO vs $jj \rightarrow Q\gamma j$



Full NLO: R.Li and J.X. Wang, PLB 672:51,2009 – Comparison: JPL, PLB 679:340,2009.

New observable: $J/\psi + J/\psi$ (at the LHC)

⇒ Cross sections at $\sqrt{s} = 14$ TeV (times the branchings)

$\sigma(\text{events})$	$p_{T\text{cut}}=3$ GeV	$p_{T\text{cut}}=4$ GeV	$p_{T\text{cut}}=5$ GeV	$p_{T\text{cut}}=6$ GeV	$p_{T\text{cut}}=7$ GeV
$\perp\perp$	5.83pb(58324)	1.74pb(17425)	0.56pb(5607)	0.20pb(1981)	0.077pb(767)
$\parallel\parallel$	2.55pb(25543)	0.83pb(8262)	0.28pb(2786)	0.10pb(1014)	0.040pb(401)
$\parallel\perp$	3.95pb(39425)	0.94pb(9445)	0.24pb(2380)	0.066pb(660)	0.020pb(204)
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- ... and **QCD corrections** !?

New observable: $J/\psi + J/\psi$ (at the LHC)

⇒ Cross sections at $\sqrt{s} = 14$ TeV (times the branchings)

$\sigma(\text{events})$	$p_{T\text{cut}}=3$ GeV	$p_{T\text{cut}}=4$ GeV	$p_{T\text{cut}}=5$ GeV	$p_{T\text{cut}}=6$ GeV	$p_{T\text{cut}}=7$ GeV
$\perp\perp$	5.83pb(58324)	1.74pb(17425)	0.56pb(5607)	0.20pb(1981)	0.077pb(767)
$\parallel\parallel$	2.55pb(25543)	0.83pb(8262)	0.28pb(2786)	0.10pb(1014)	0.040pb(401)
$\parallel\perp$	3.95pb(39425)	0.94pb(9445)	0.24pb(2380)	0.066pb(660)	0.020pb(204)
<i>tot</i>	12.33pb(123319)	3.51pb(35131)	1.08pb(10773)	0.37pb(3656)	0.14pb(1372)
$\perp_8\perp_8$	2.90pb(29022)	1.82pb(18205)	1.15pb(11461)	0.74pb(7399)	0.49pb(4925)

C.F Qiao *et al.*, 0903.0954 [hep-ph]

- Usual complications: the **feed-downs** !
- ... and **QCD corrections** !?
- Maybe the data are not so out-of-reach:

Philip John Vint, Ph.D thesis: “Di- J/ψ Studies, Level 3 Tracking and the $D\emptyset$ Run IIb Upgrade”

(I have discovered it yesterday night, I haven't looked at it yet)

Part IV

Summary

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STAR, PRC 80, 041902(R) (2009), A. Kraan, AIP Conf.Proc.1038:45,2008.

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- Other proposals are welcome !
- Prepare yours for a 3 day workshop entirely devoted to Quarkonium production after ICHEP in Paris (29-31 July 2010)

www.cpht.polytechnique.fr/quarkonium

Part V

Backup slides

Colour Octet Dominance challenged at low/mid P_T in pp ?

- “Approximately taking into account the **higher-order effects** due to multiple-gluon initial-state radiation, [...] we find that the **matrix elements** [...] $^{2S+1}L_J = ^1S_0$ and 3P_J , are **significantly reduced**.”

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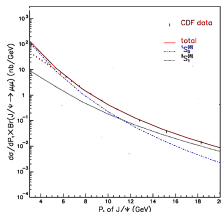
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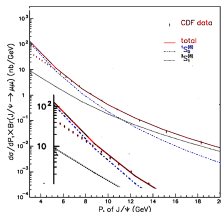
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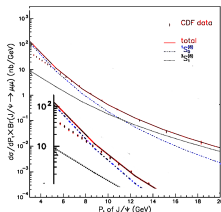
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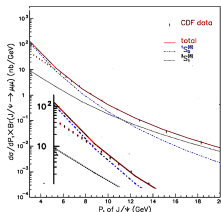


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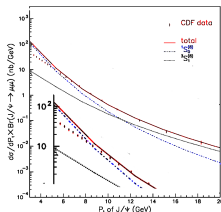
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Y. Zhang *et al.* arXiv:0911.2166