



# Inclusive quarkonium production: perspective for $\gamma\gamma$ collisions at the LHC

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Heidelberg U.

**Workshop on high energy photon collisions at the LHC**  
CERN

April 23, 2008

Thanks to P.Artoisenet, D.d'Enterria, A. Holzner, M.Klasen, F. Maltoni, ...

for materials and discussions



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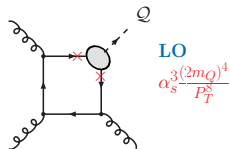
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But “theory” does not work in hadroproduction ...

# Hadroproduction : naive pQCD approach (CSM)

⇒ Perturbative creation of two quarks  $Q$  and  $\bar{Q}$  BUT

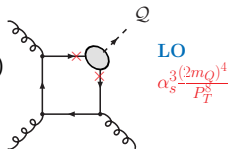




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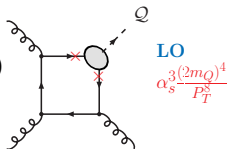
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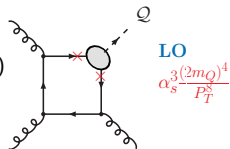
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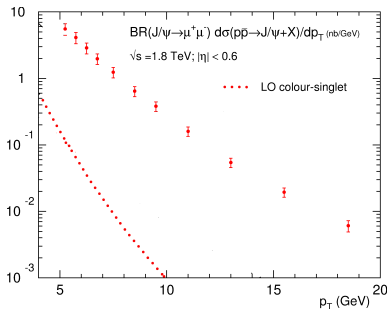
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# $J/\psi$ production in $\gamma\gamma$ collisions at LEP II

DELPHI, PLB 565 76, 2003

$$\sigma(e^+e^- \rightarrow e^+e^- J/\psi + X) = 45 \pm 9 \pm 17 \text{ pb}$$

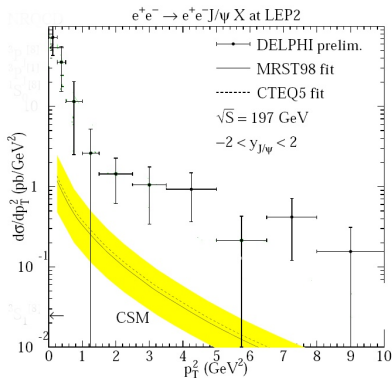
- $(74 \pm 22)\%$  from resolved  $\gamma$  by opposition to diffractive events (from PYTHIA)
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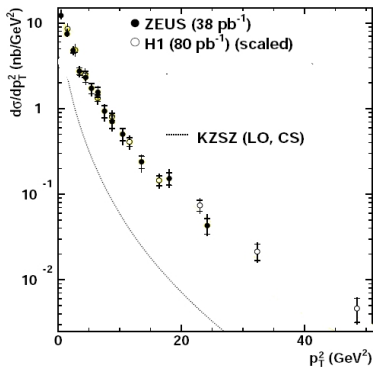
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# $J/\psi$ photoproduction at HERA

H1, EPJC 25, 2, 2002  
ZEUS, EPJC 27, 173, 2003

LO CSM also fails in photoproduction at HERA !



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Colour Octet Mechanism

→ Can't the quarks be produced off-shell? with relative momentum  $\neq 0$ ?

**s-channel cut contribution**

H. Habermann, J.P.L., PRL 100,032006,2008

No time to discuss it here, but surely matters at small  $P_T$

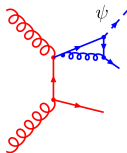
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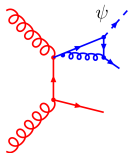
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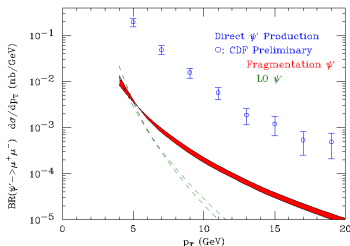
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→ Different  $p_T$  behaviour :  $P_T^{-4}$  vs.  $P_T^{-8}$ .

→ Illustration for the  $\psi'$

× Off by factor 30-100 for  $J/\psi$  and  $\psi'$

× Off by factor 10 for  $\Upsilon$ 's



# Fragmentation via Colour Octets

Many solutions were proposed to solve this problem :

For a recent review, see J.P.L. IJMPA 21 3857-3915 (2006)

the most used solution : the [Color Octet Mechanism \(NRQCD\)](#) :

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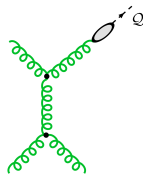
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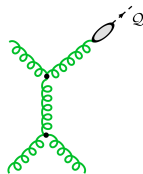
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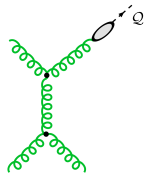
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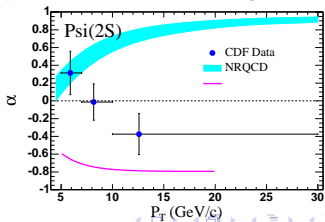
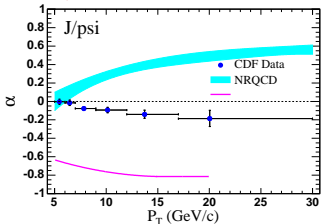
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- Experimentally, **this is totally contradicted !**



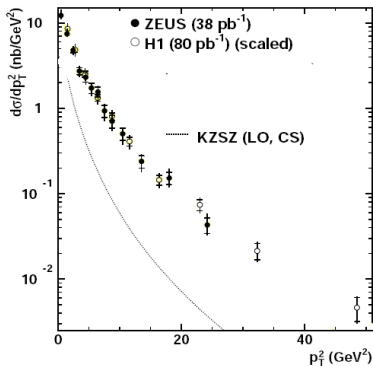
$\alpha = +1 \Leftrightarrow$  Transverse  $\alpha = 0 \Leftrightarrow$  Unpolarised  $\alpha = -1 \Leftrightarrow$  Longitudinal



# NLO QCD-corrections : $\alpha_S^4$

$J/\psi$  photoproduction at HERA

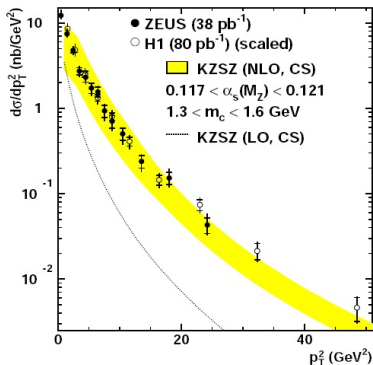
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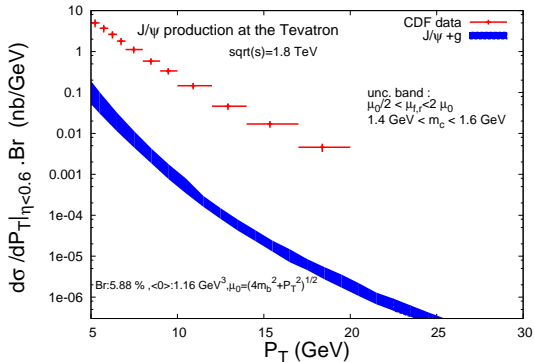
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- NLO corrections dominate at large  $P_T$  (expected from fragmentation channels)
- Same partonic process for **direct  $\gamma p$**  (large  $z$ ) as for **single resolved  $\gamma\gamma$**
- Same partonic process for **resolved  $\gamma p$**  as for **double resolved  $\gamma\gamma$**  and **hadroproduction**

# NLO QCD corrections for hadroproduction

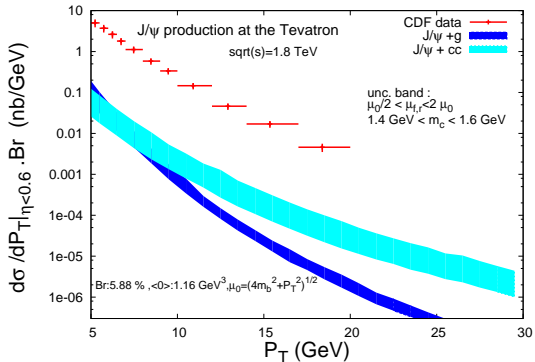
$J/\psi + c\bar{c}$  : P.Artoisenet, J.P.L, F.Maltoni, PLB 653 :60,2007  
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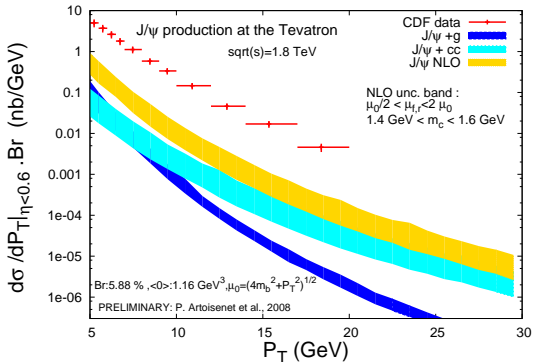
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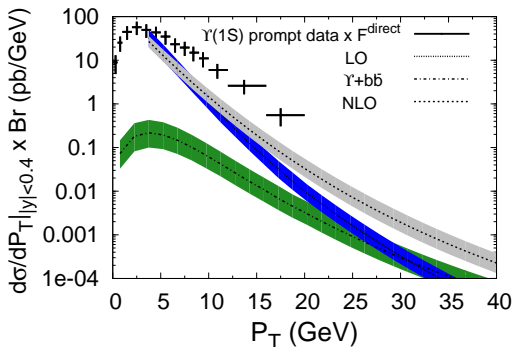


Significant improvement, but we need something more...

What about for the  $\Upsilon$ ?

# NLO QCD corrections for hadroproduction : $\Upsilon$

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Close to an agreement with data

Can we do better?

# $\alpha_s^5$ corrections : NNLO\*

MadOnia : P.Artoisenet, F. Maltoni, T. Stelzer, JHEP 0802 :102,2008.



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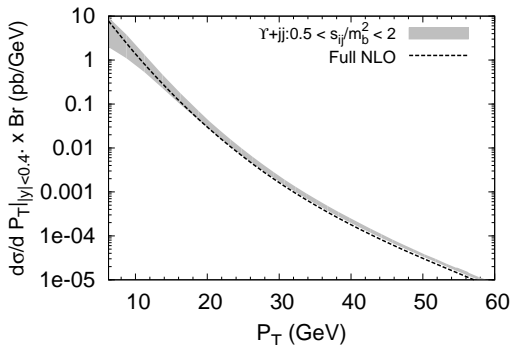
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Indeed, at  $\alpha_s^4$  :

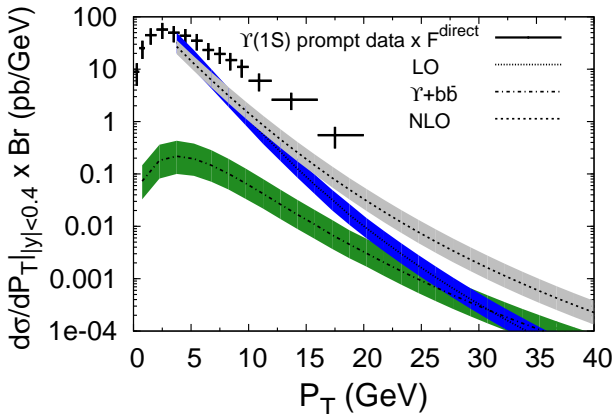


$p\bar{p} \rightarrow Qjjj$  ( $j = g, u, d, s, c$ ) with cuts :

first estimate of the impact of NNLO corrections ( $\alpha_s^5$ )

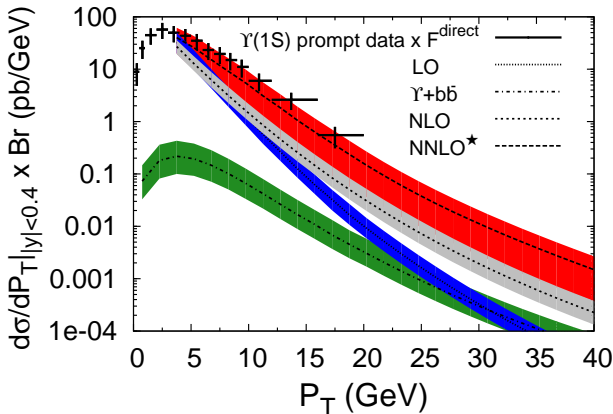
# $\alpha_s^5$ corrections : NNLO\* in hadroproduction

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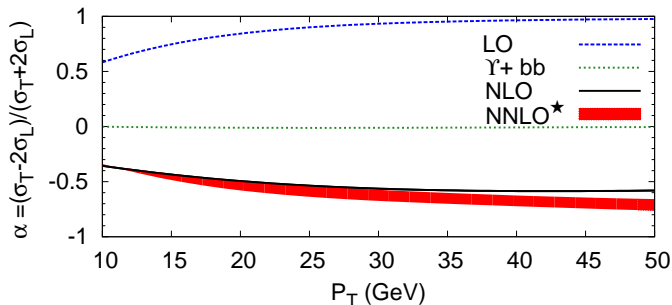
→ Exactly what is needed in normalisation and shape!

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- Polarisation ?

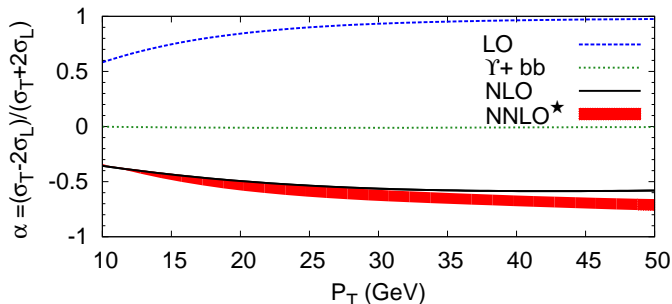
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- Comparison with prompt measurements ?
- Feed-down from  $\chi_b$  not known at NLO



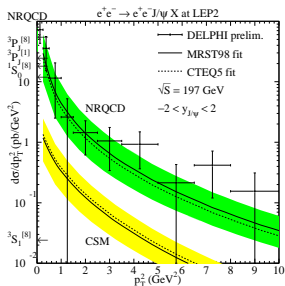
# Back to $\gamma\gamma$

LEP II data seem to favour Colour-Octet

M. Klasen *et al.*, PRL 89 :032001,2002.

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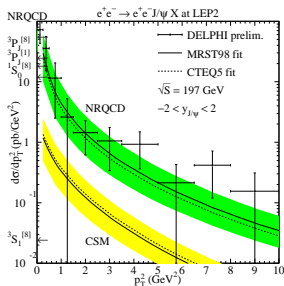
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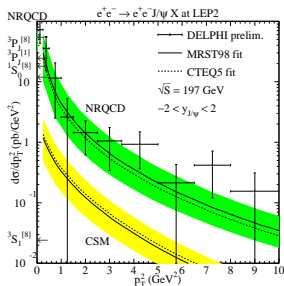


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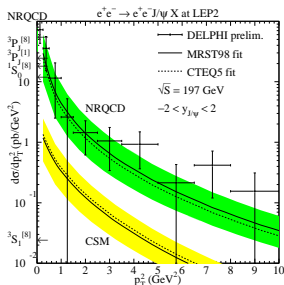
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→ Computed for direct  $\gamma\gamma$

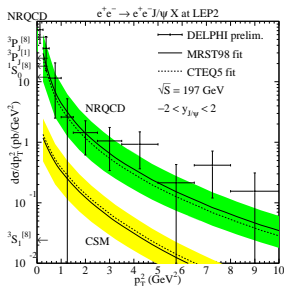
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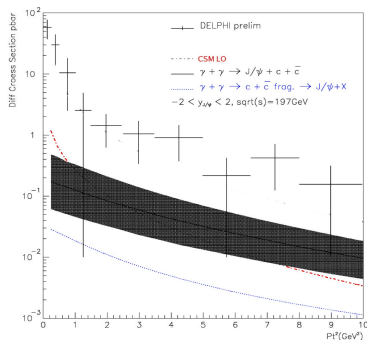
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Let's check the size of  $\gamma\gamma \rightarrow J/\psi c\bar{c}$  :

→ finite NLO contribution to direct  $\gamma\gamma$

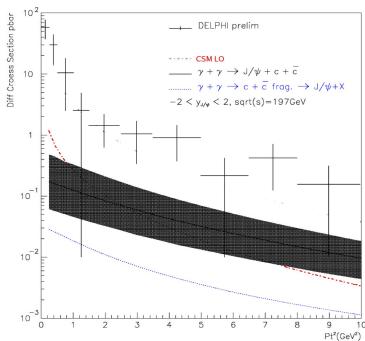
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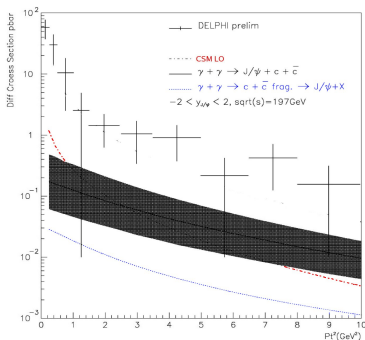


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- $\Rightarrow \gamma\gamma \rightarrow J/\psi + c\bar{c}$  larger than the CSM LO (mostly singled resolved  $J/\psi + g$ )
- $\Rightarrow$  not a real surprise : contains  $P_T^{-4}$  channel



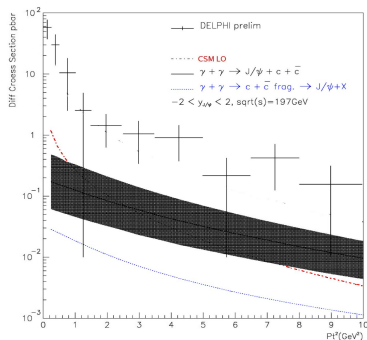
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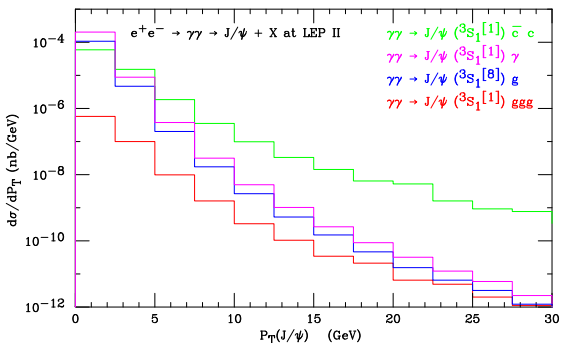
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- ⇒ therefore we can hope for other significant NLO corrections to CSM
- ⇒ quark-fragmentation approximation completely wrong (confirmed in  $pp$ )

P.Artoisenet, JPL, F. Maltoni, PLB 653 :60-66,2007.

$J/\psi + c\bar{c}$  as the dominant direct CSM contribution for  $P_T \gtrsim m_c$

## Confirmation with MadOnia

P.Artoisenet, F. Maltoni, T. Stelzer, JHEP 0802 :102,2008.



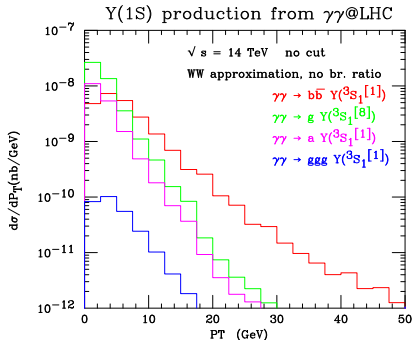
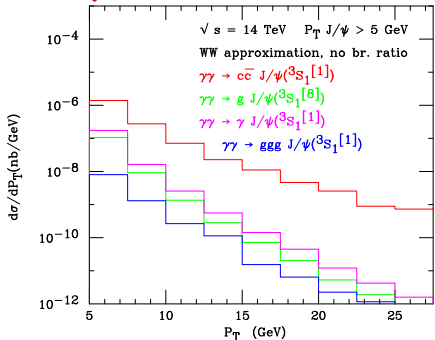
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## Preliminary results for the LHC



thanks to P.Artoisenet

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M.Kramer Nucl.Phys.B459 :3 1996

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- $\gamma\gamma$  measurements will be ideal compl(i/e)mentary ones to  $pp$  studies, **same (not understood) physics involved!**