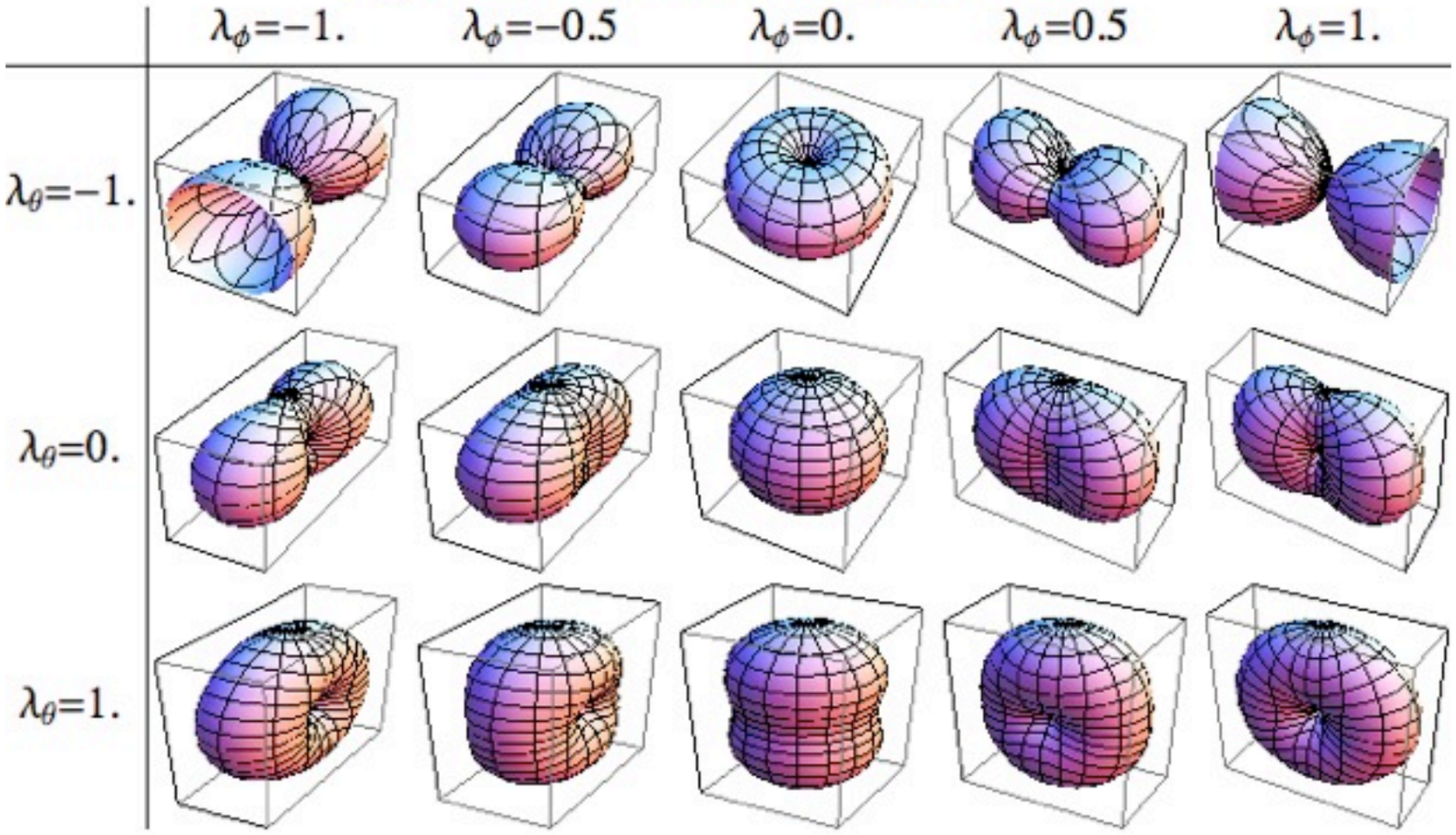
Quarkonium Polarisation



$\stackrel{?}{=}$

Hua-Sheng Shao

GDR QCD 2020, Orsay (Virtual)

16 December 2020

DISCLAIMER

- **Only quarkonium polarisations in pp**
  - Not talking heavy ion *(see Luca Micheletti's talk)* e.g. ALICE (2005.11128)
  - Not talking other collisions like e+e- and ep
- **Only pQCD and NRQCD in coll. factorisation**
  - No (I)CEM e.g. Cheung & Vogt (1808.02909)
  - No CGC e.g. Ma et al. (1809.03573)
  - No k_T factorisation e.g. Baranov & Lipatov (1906.07182)
- **Only single inclusive (prompt) quarkonium**
  - No polarisation of quarkonium in jets e.g. Kang et al. (1702.03287)
  - No polarisation of quarkonium in associated processes e.g. Lansberg & HSS (1308.0474)
  - No polarisation of charmonium from B decays
  - No polarisation of exclusive quarkonium production *(see Charlotte van Hulse's talk)*
- **Mainly J/psi and chic**
  - psi(2S) and bottomonia are analogous.

WHY WE ARE INTERESTED IN POLARISATION ?

LPTHE
LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

- **A colour-octet story starts from anomalously large yields**

Braaten et al. (hep-ph/9405407)

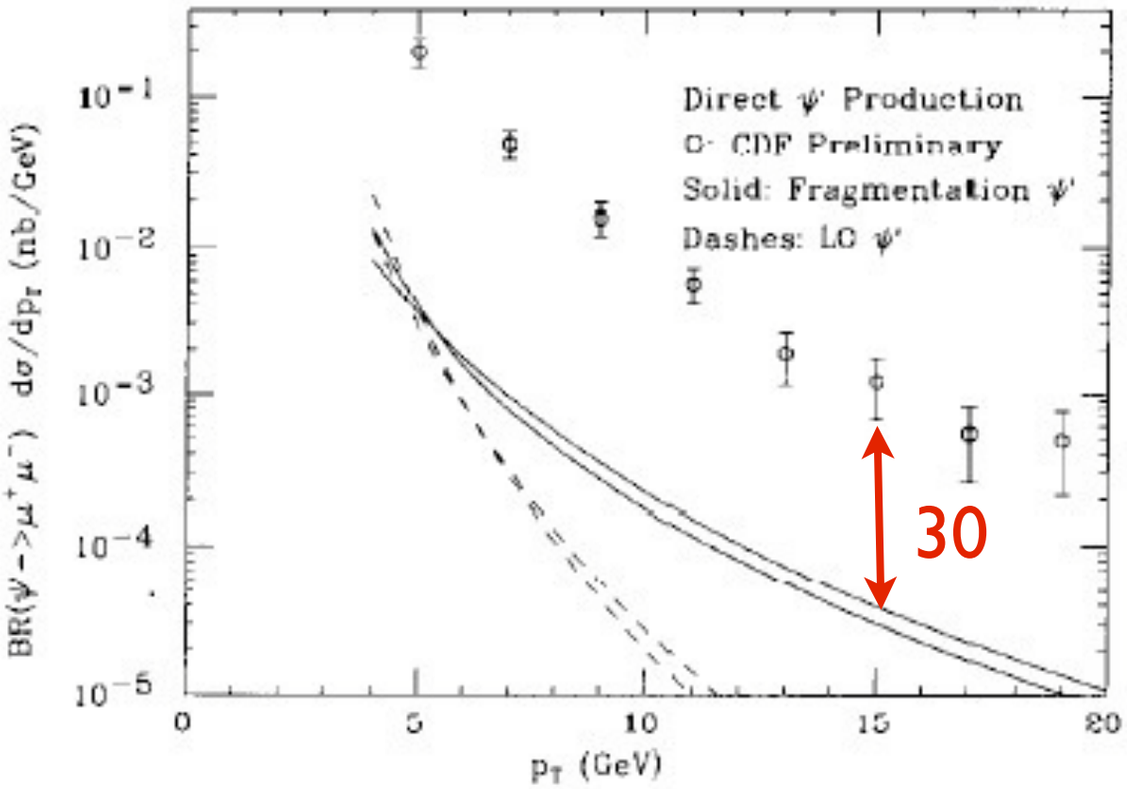


Fig. 4. Preliminary CDF data for prompt ψ' production (O) compared with theoretical predictions of the total fragmentation contribution (solid curves) and the total leading-order contribution (dashed curves).

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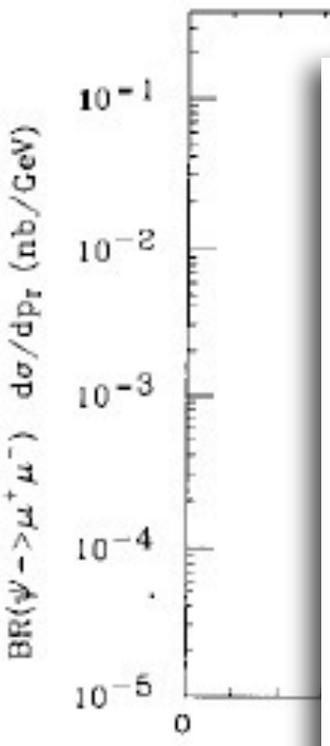

Fig. 4. Preliminar
compared with the
contribution (solid
(dashed curves).

Color-Octet Fragmentation and the ψ' Surplus at the Tevatron

Eric Braaten and Sean Fleming

Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208

hep-ph/9411365

Abstract

The production rate of prompt ψ''s at large transverse momentum at the Tevatron is larger than theoretical expectations by about a factor of 30. As a solution to this puzzle, we suggest that the dominant ψ' production mechanism is the fragmentation of a gluon into a $c\bar{c}$ pair in a pointlike color-octet S-wave state, which subsequently evolves nonperturbatively into a ψ' plus light hadrons. The contribution to the fragmentation

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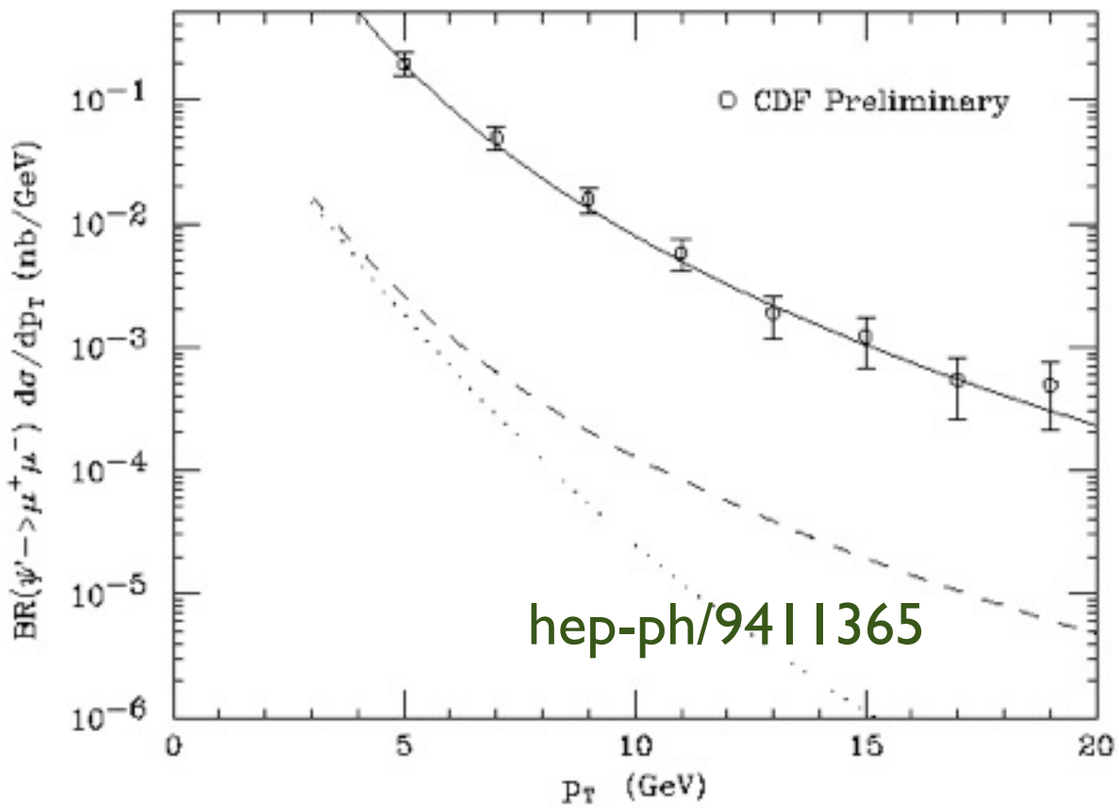

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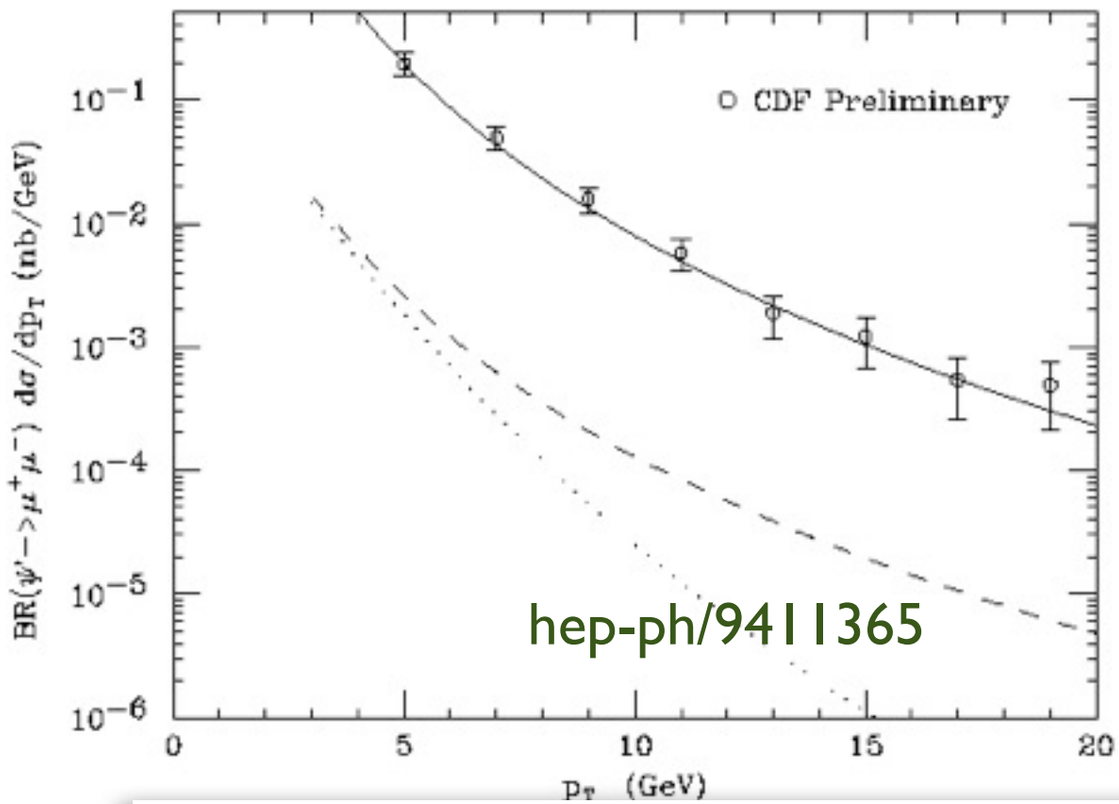

hep-ph/9411365

Fig. 4. compare contribu (dashed

)ctet Fragmentation

Surplus at the Tevatron

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Abstract

and in rapidity could provide evidence for this new production mechanism. It has recently been pointed out by Cho and Wise [14] that measurements of the spin alignment of the ψ''s, which is reflected in the angular distribution of their leptonic decays, might provide a clear signature for the color-octet fragmentation mechanism. This mechanism produces ψ''s that are 100% transversely polarized at leading order in α_s, while other mechanisms tend to produce unpolarized ψ''s.

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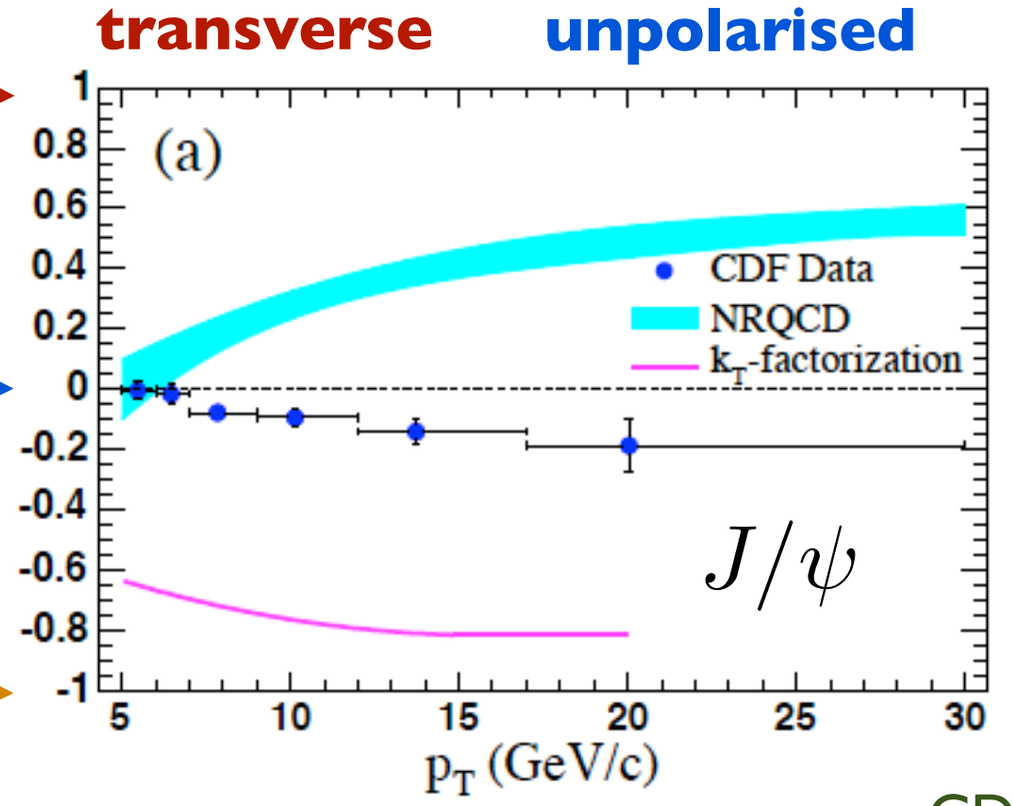

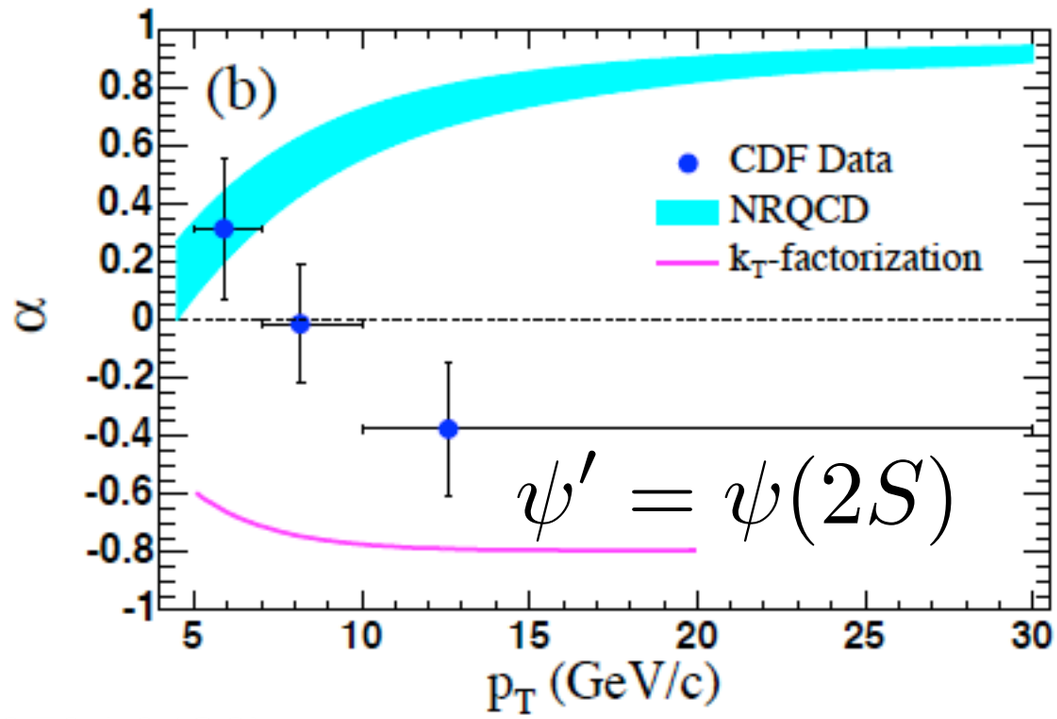

CDF (0704.0638)

FIG. 4: Prompt polarizations as functions of p_T: (a) J/ψ and (b) $\psi(2S)$. The band (line) is the prediction from NRQCD [4] (the k_T-factorization model [9]).

(dashed

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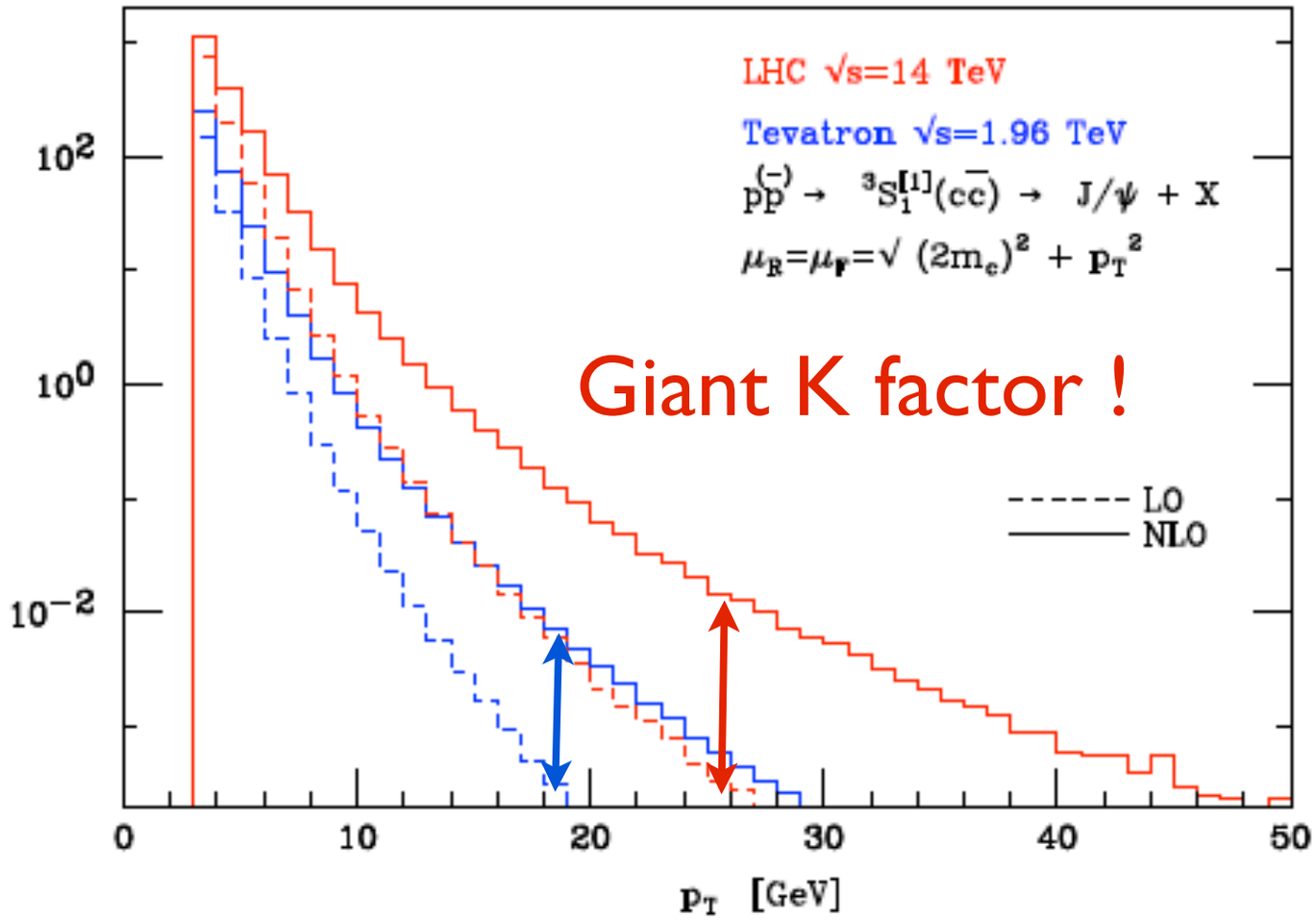
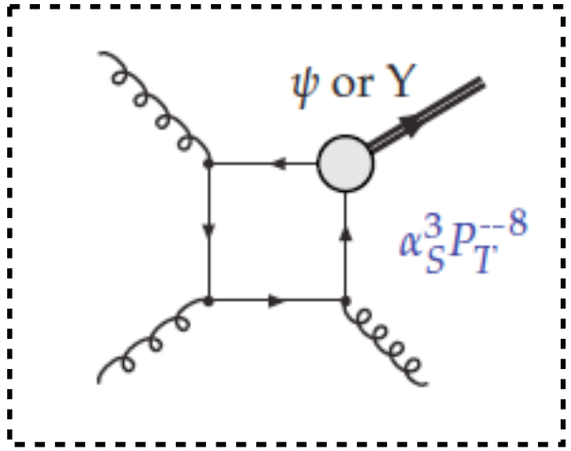
Campbell et al. (hep-ph/0703113)





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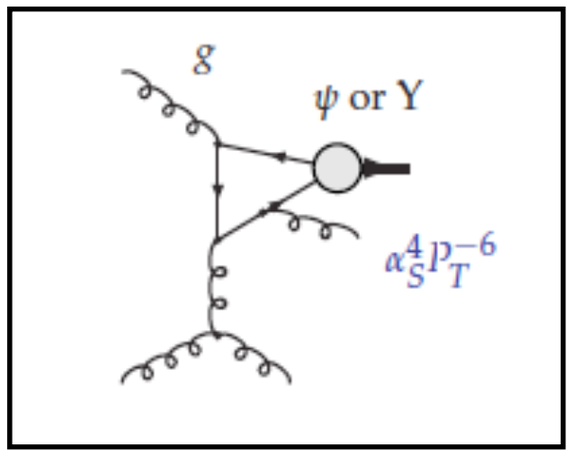

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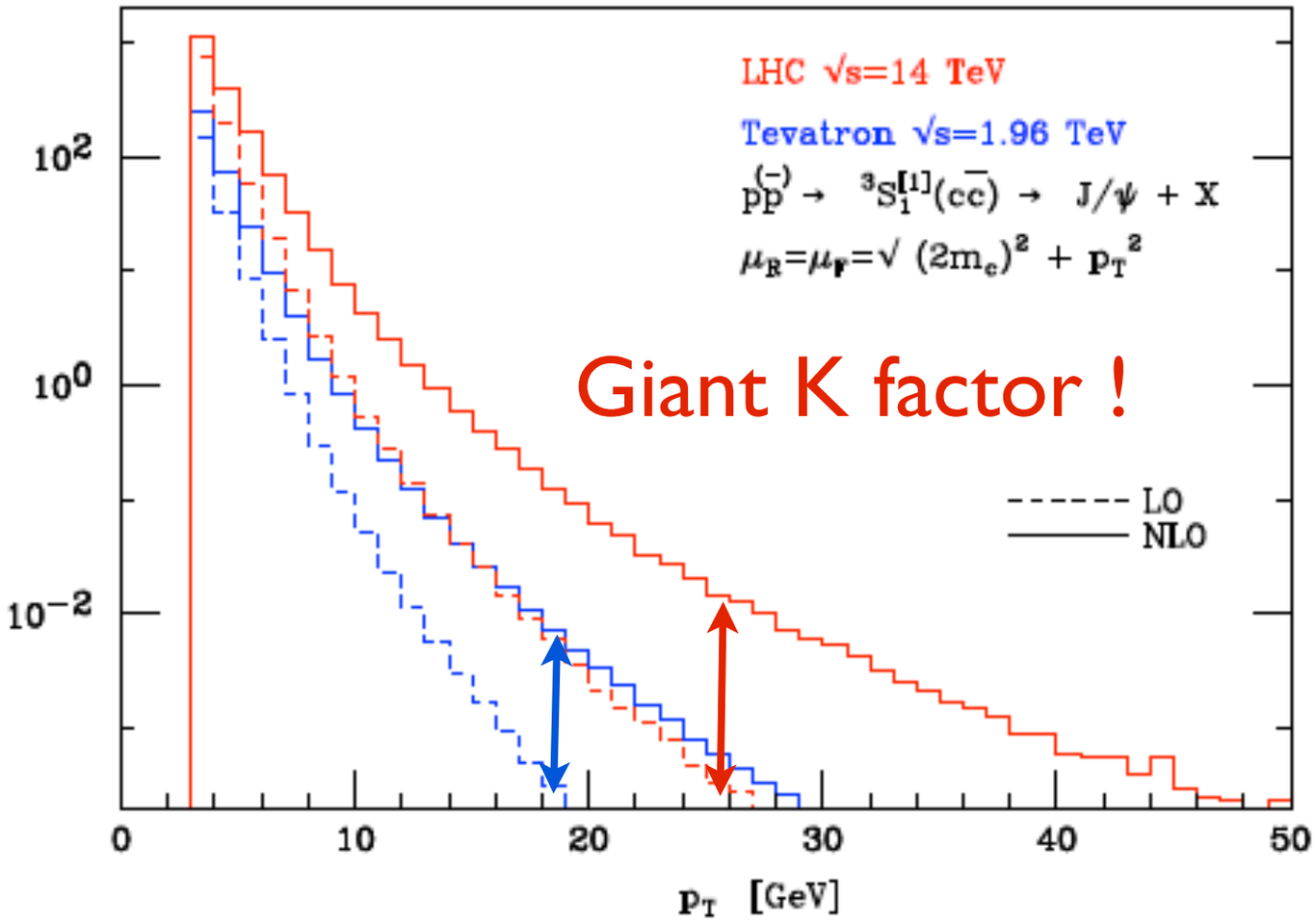

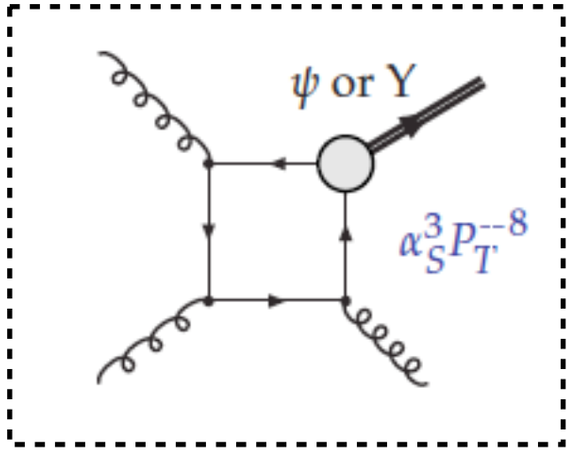

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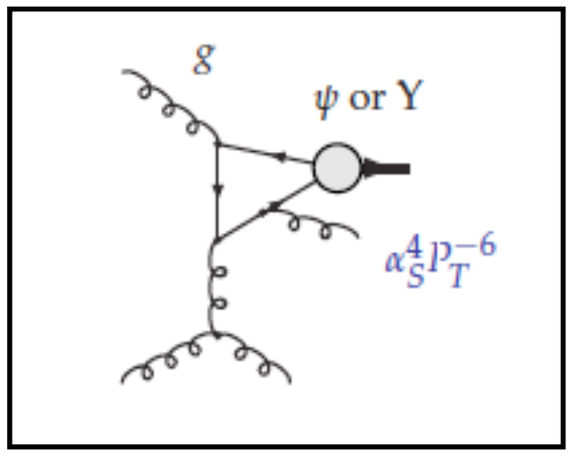

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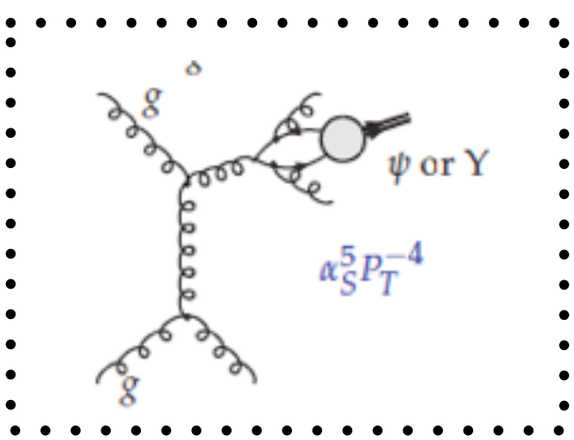

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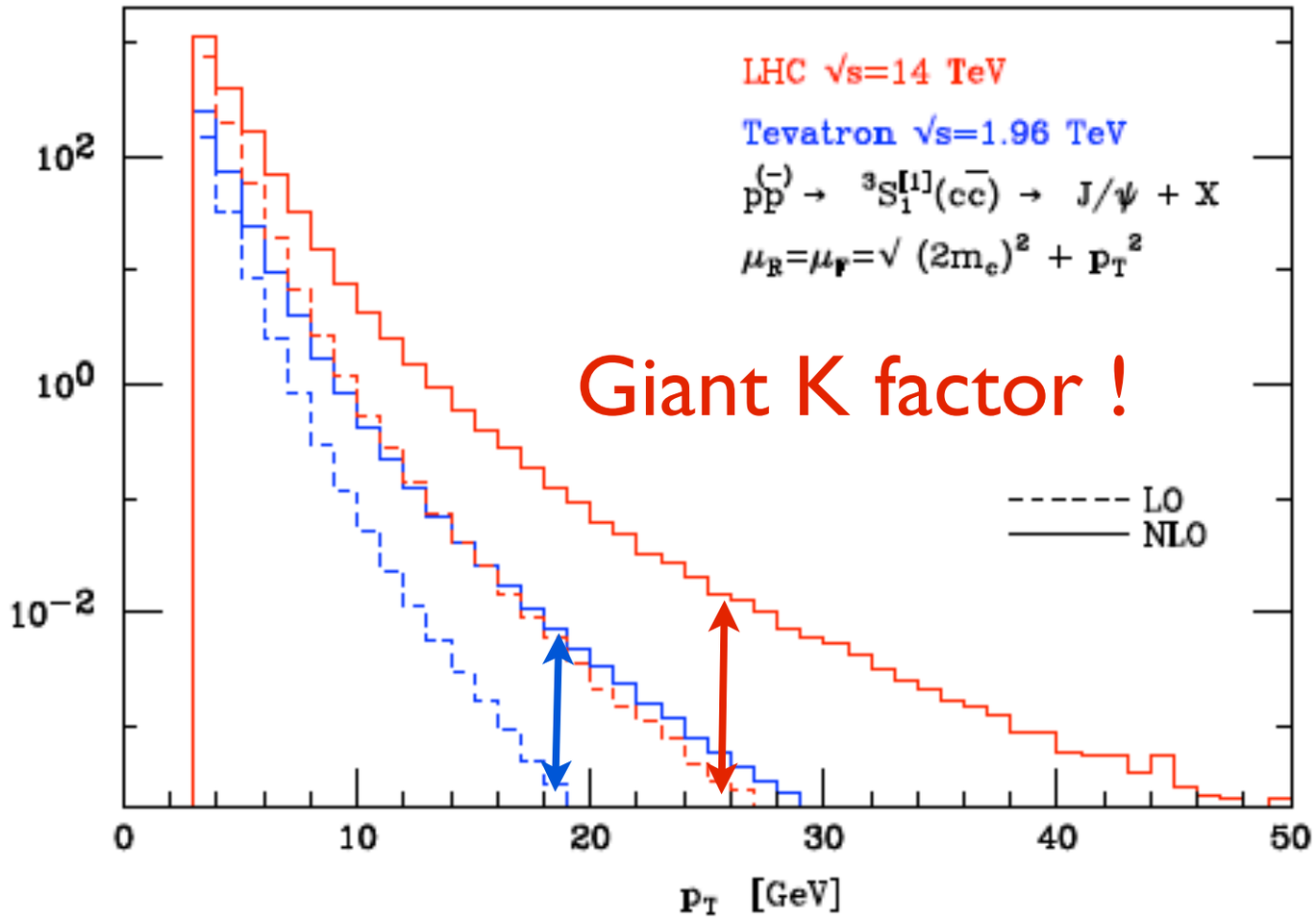

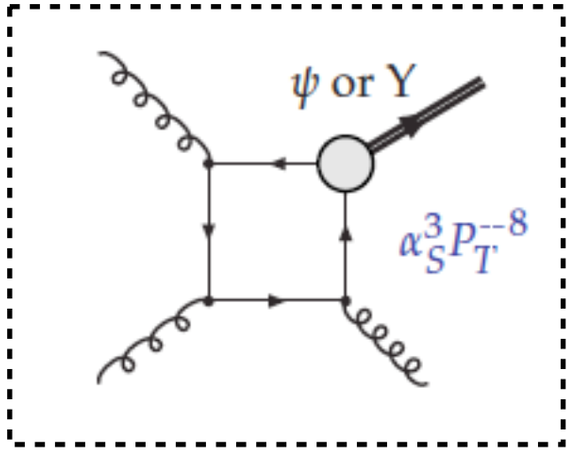

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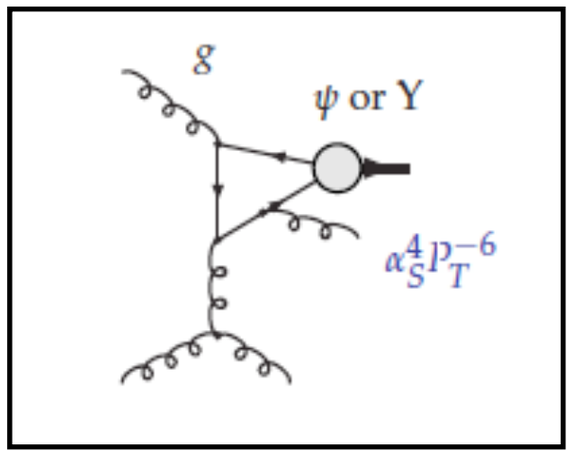

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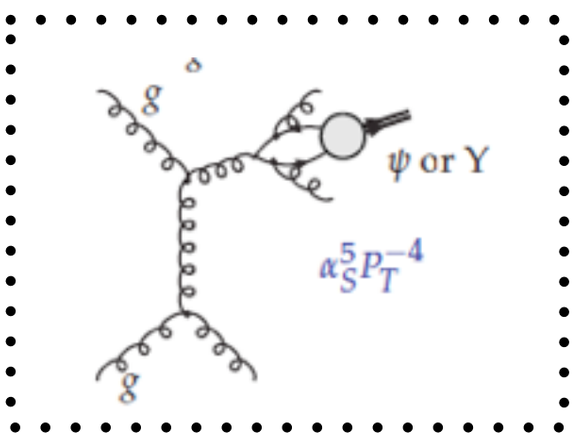


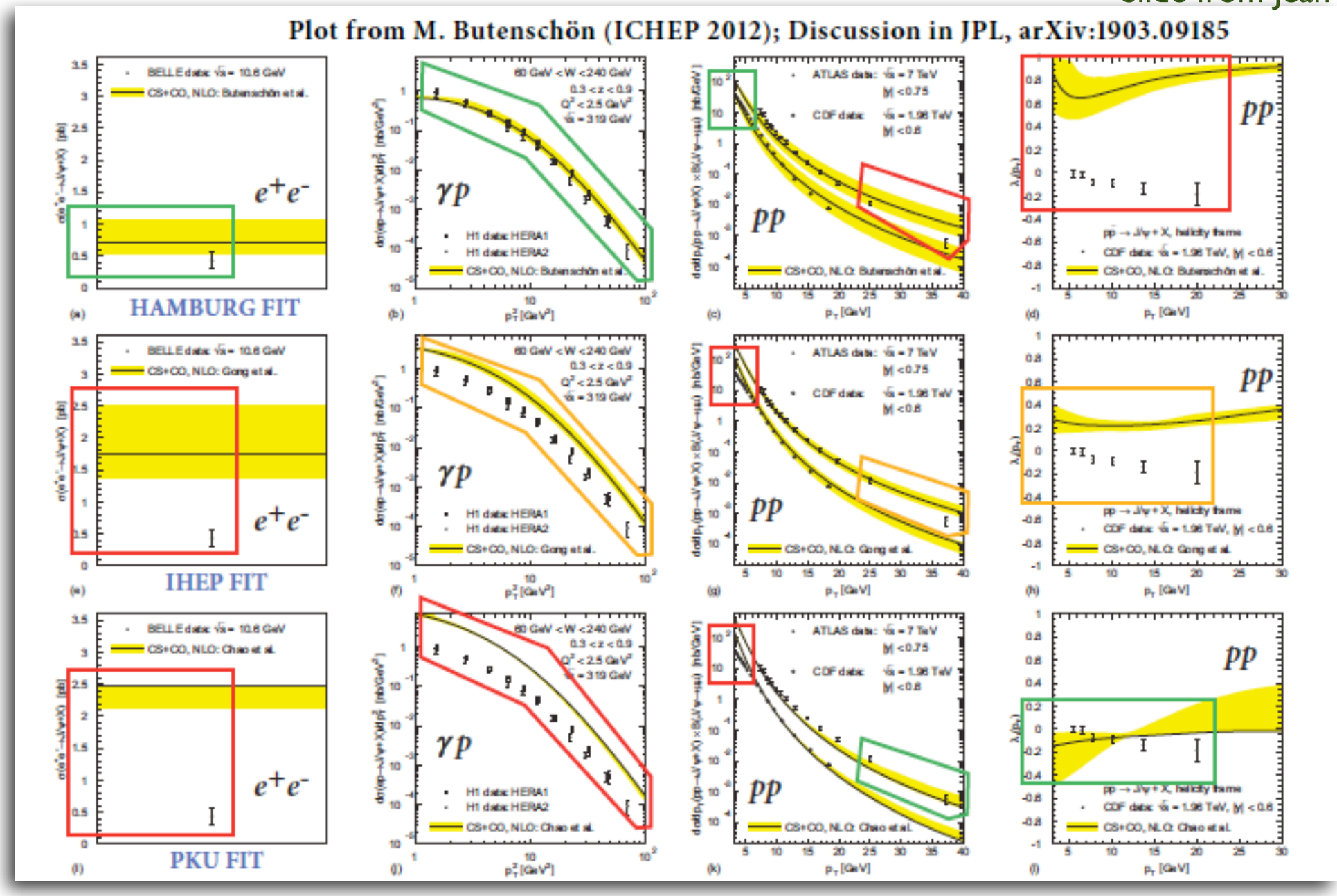
NNLO

Similar stories for other channels

DO WE HAVE A GLOBAL FIT ?

- The NLO era: physic picture was altered !

Slide from Jean-Philippe Lansberg



Clearly pointing we are lacking of a coherent picture !

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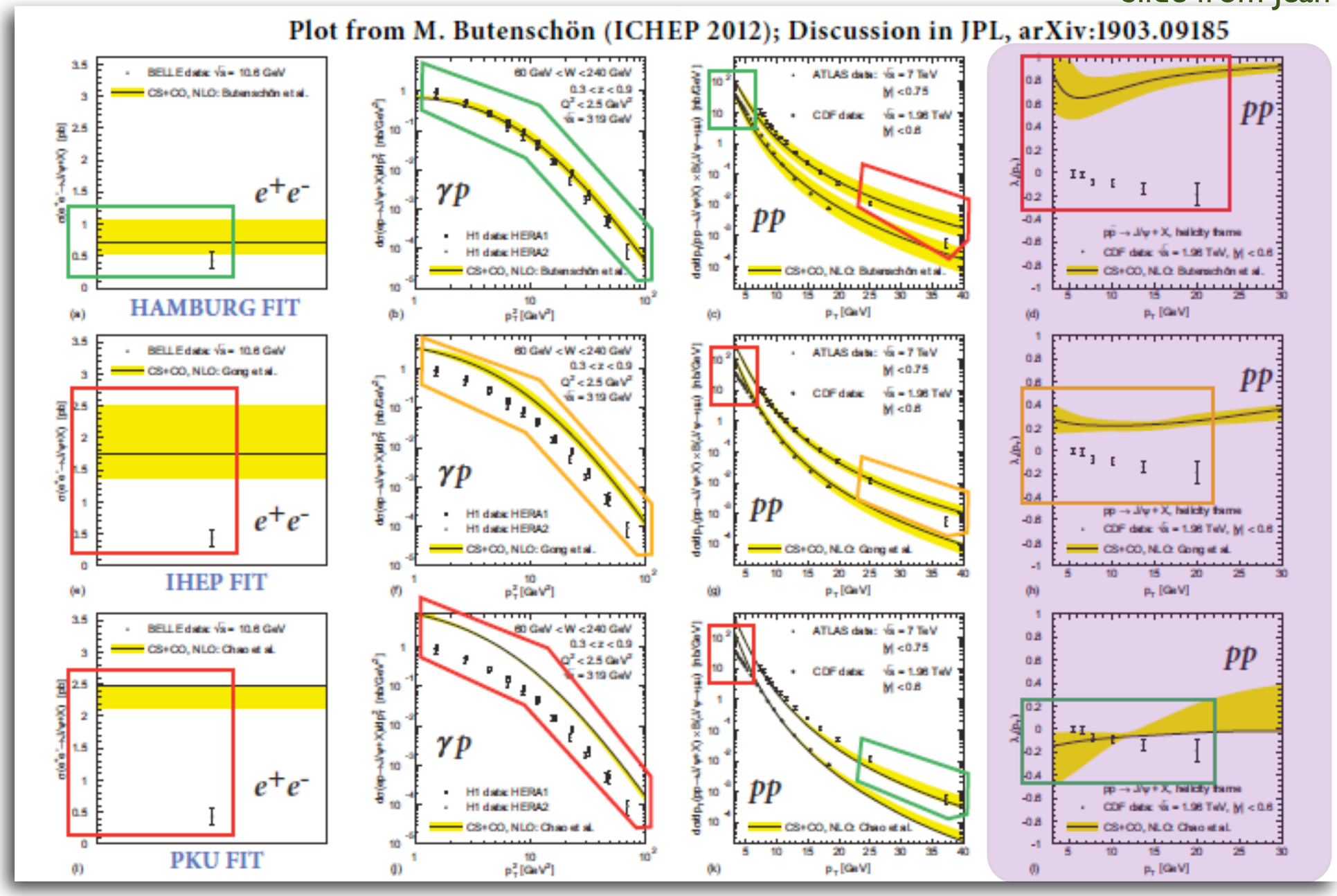

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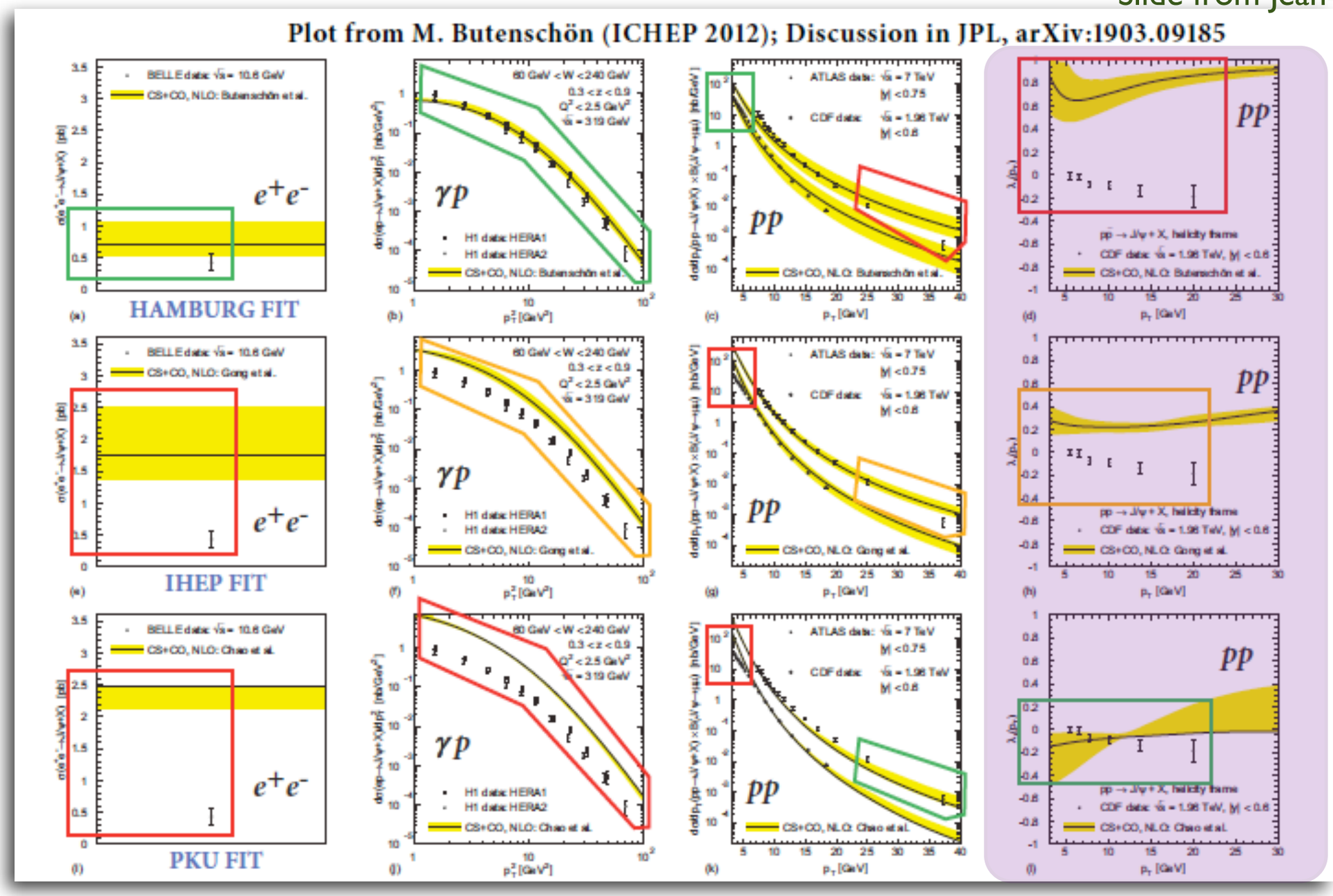

Clearly pointing we are lacking of a coherent picture !

... and more data came challenge theorists

η_c , quarkonium-jet profile etc

A BIT INTRODUCTION ON POLARISATION

LPTHE
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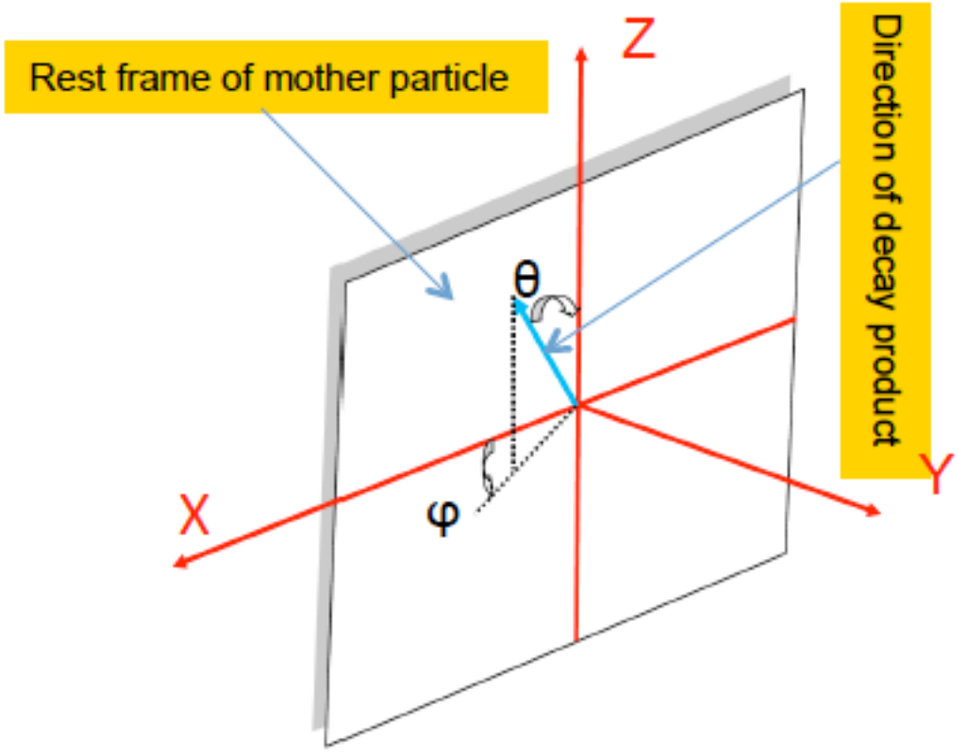
- **Angular distribution in a vector decay**

HSS et al. (1209.4610)

$$\begin{aligned}\mathcal{W}^V(\theta,\phi) \propto\ & 1+\lambda_\theta\cos^2\theta+\lambda_\phi\sin^2\theta\cos\phi \\ &+\lambda_{\theta\phi}\sin 2\theta\cos\phi+\lambda_\phi^\perp\sin^2\theta\sin 2\phi \\ &+\lambda_{\theta\phi}^\perp\sin 2\theta\sin\phi+2\eta_\theta\cos\theta \\ &+2\eta_{\theta\phi}\sin\theta\cos\phi+2\eta_{\theta\phi}^\perp\sin\theta\sin\phi,\end{aligned}$$



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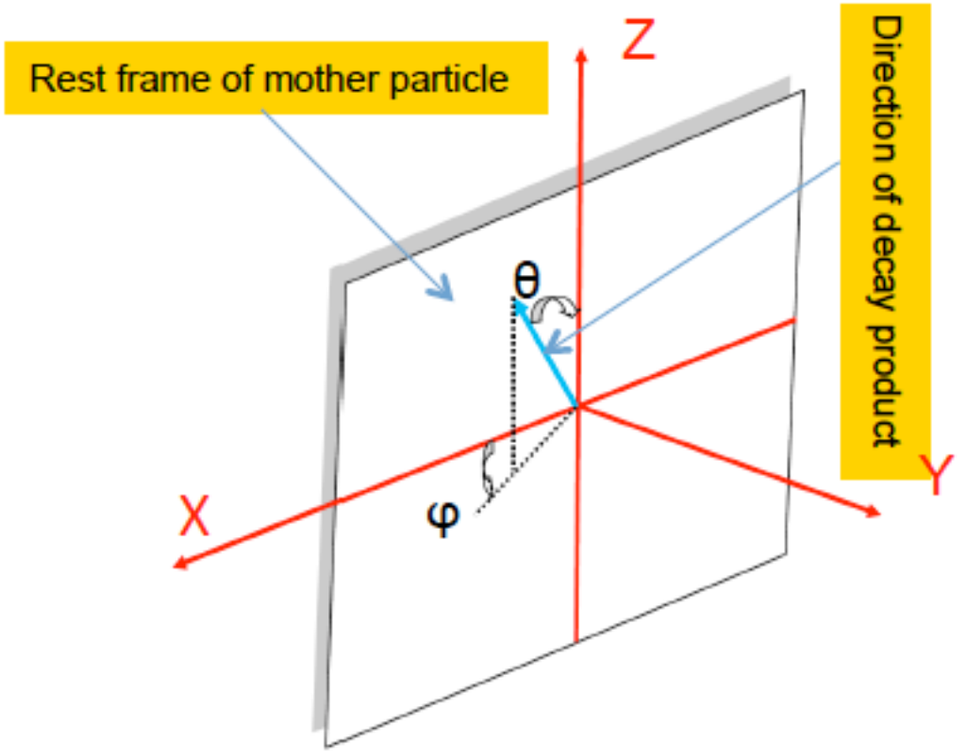
Parity invariance



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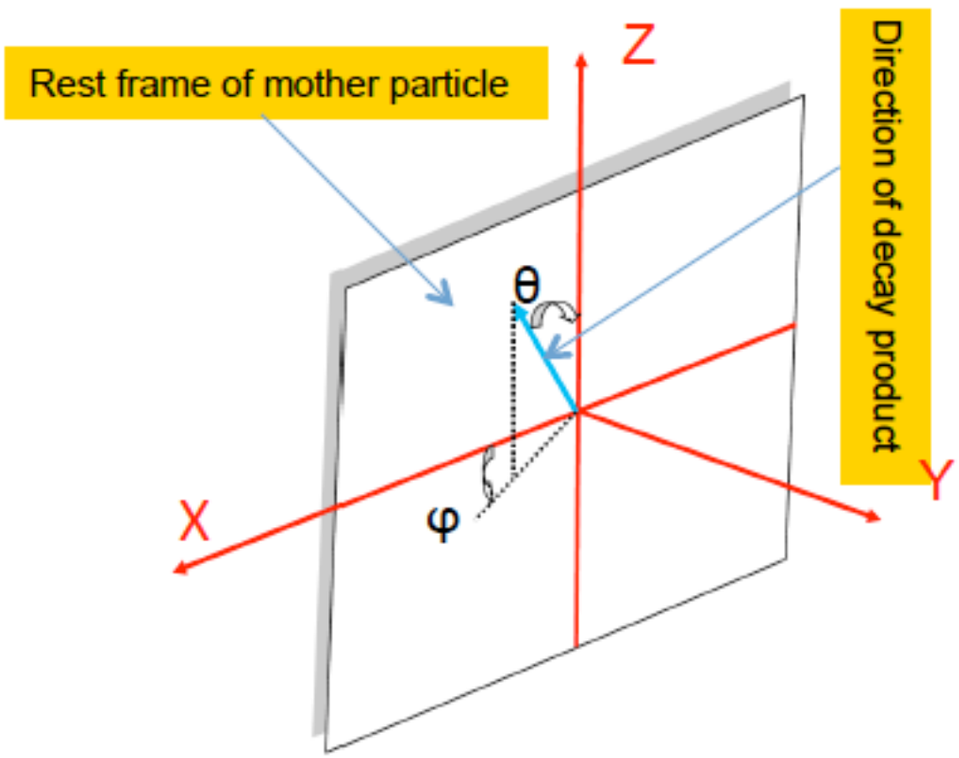
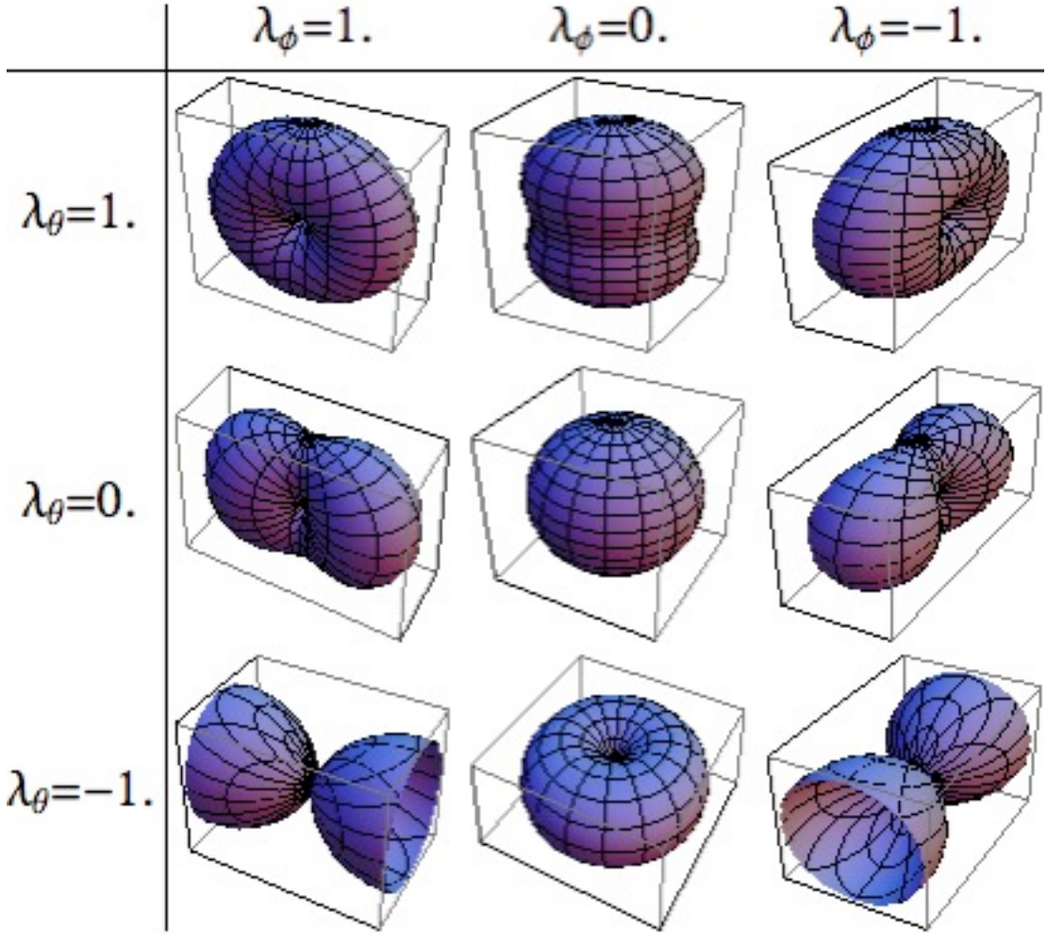


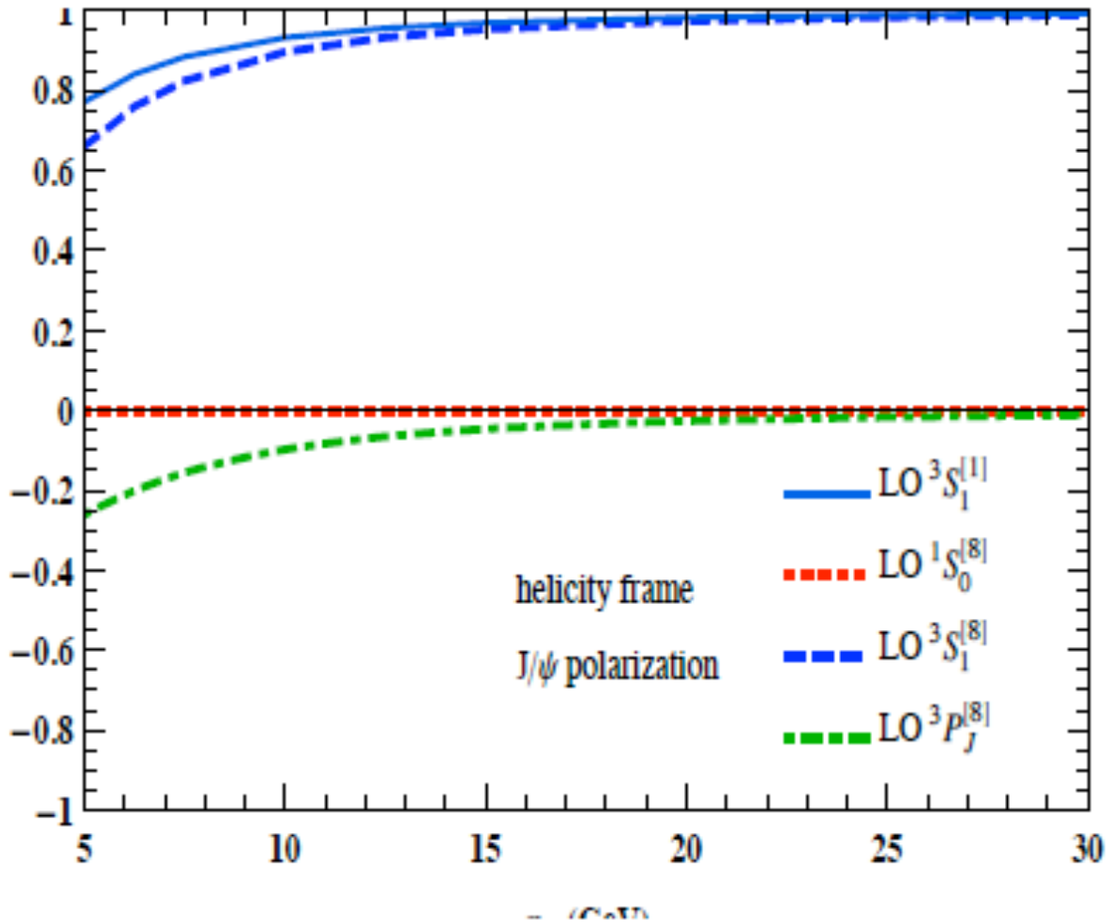
Most studies focus on

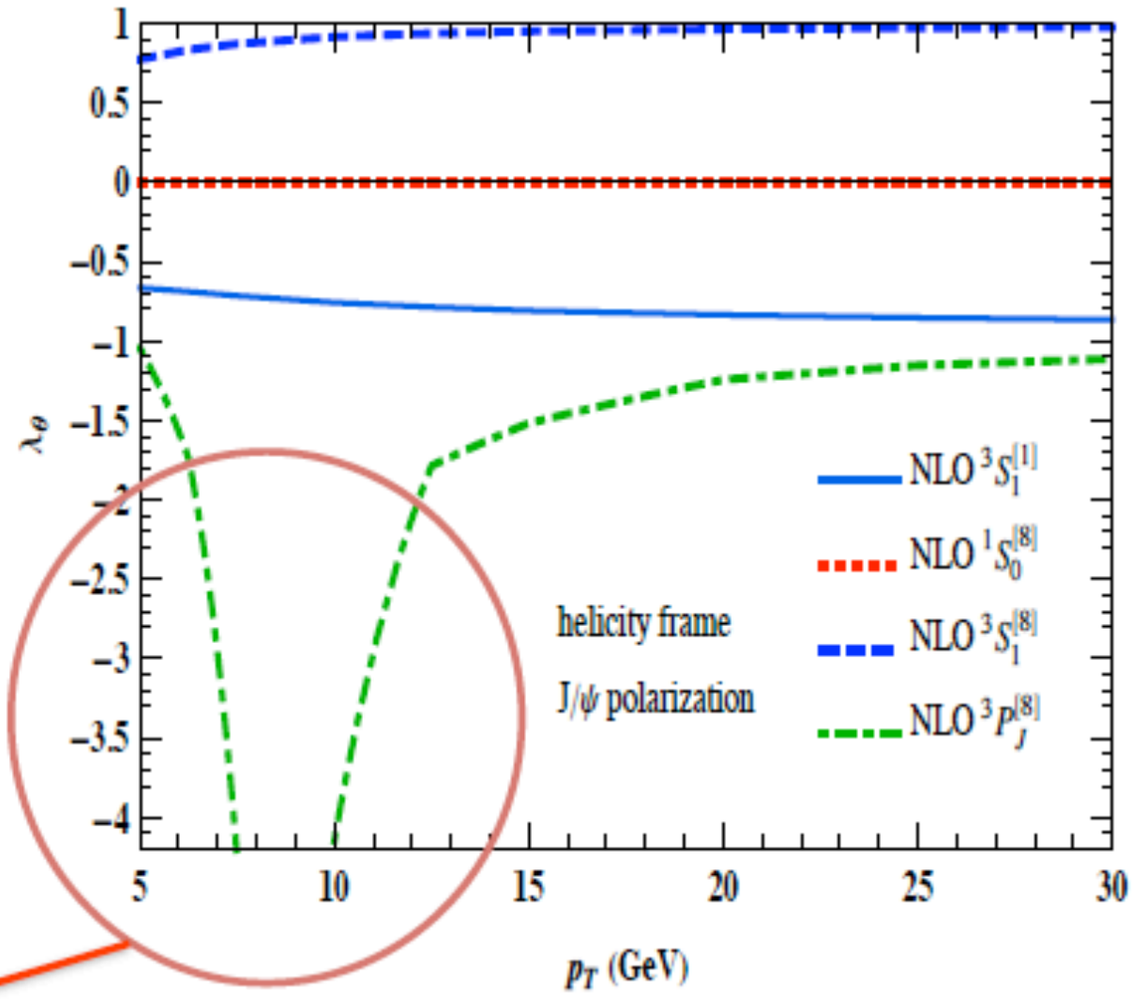


PSI POLARISATION

- **Negative P-wave due to over-subtraction !** See e.g. HSS (1809.02369)

Chao et al. (1201.2675)





Negative !!!

$$\mu_r = \mu_f = \sqrt{4m_c^2 + p_T^2}$$

$$\mu_\Lambda = m_c$$

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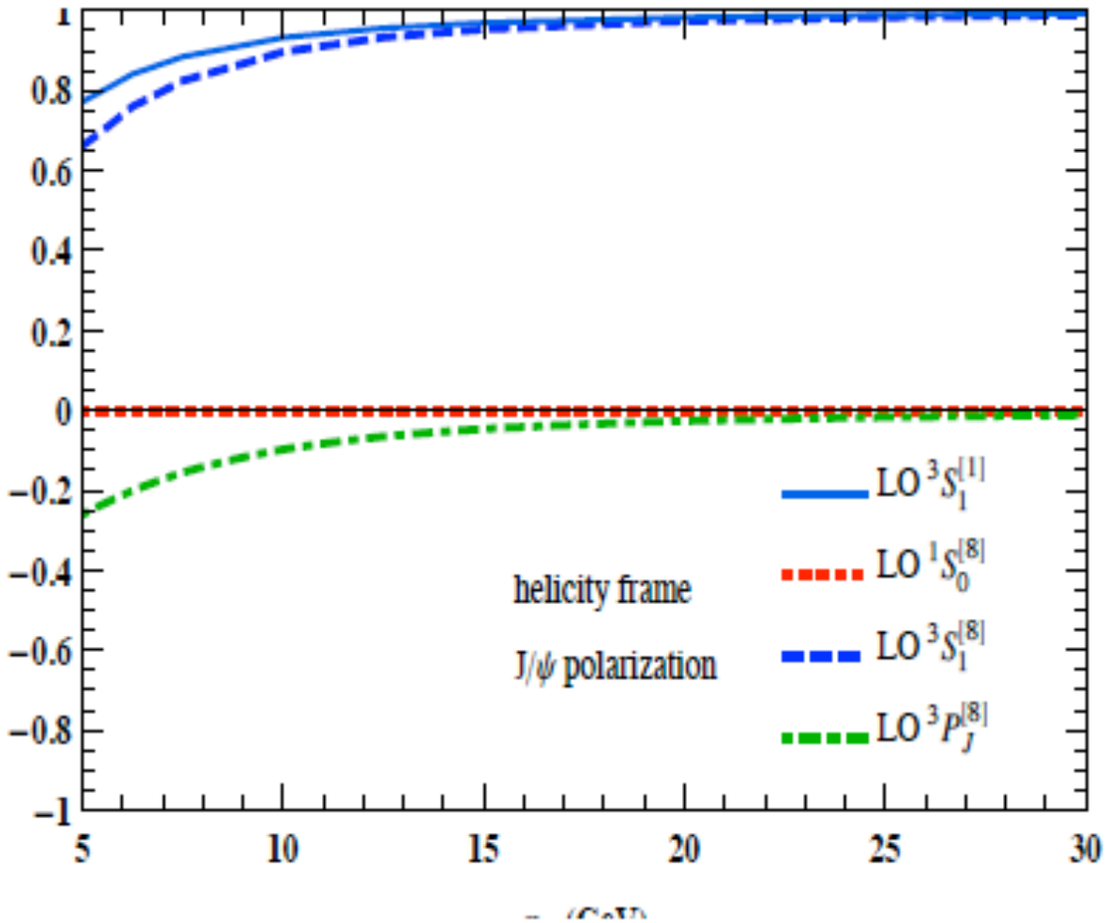
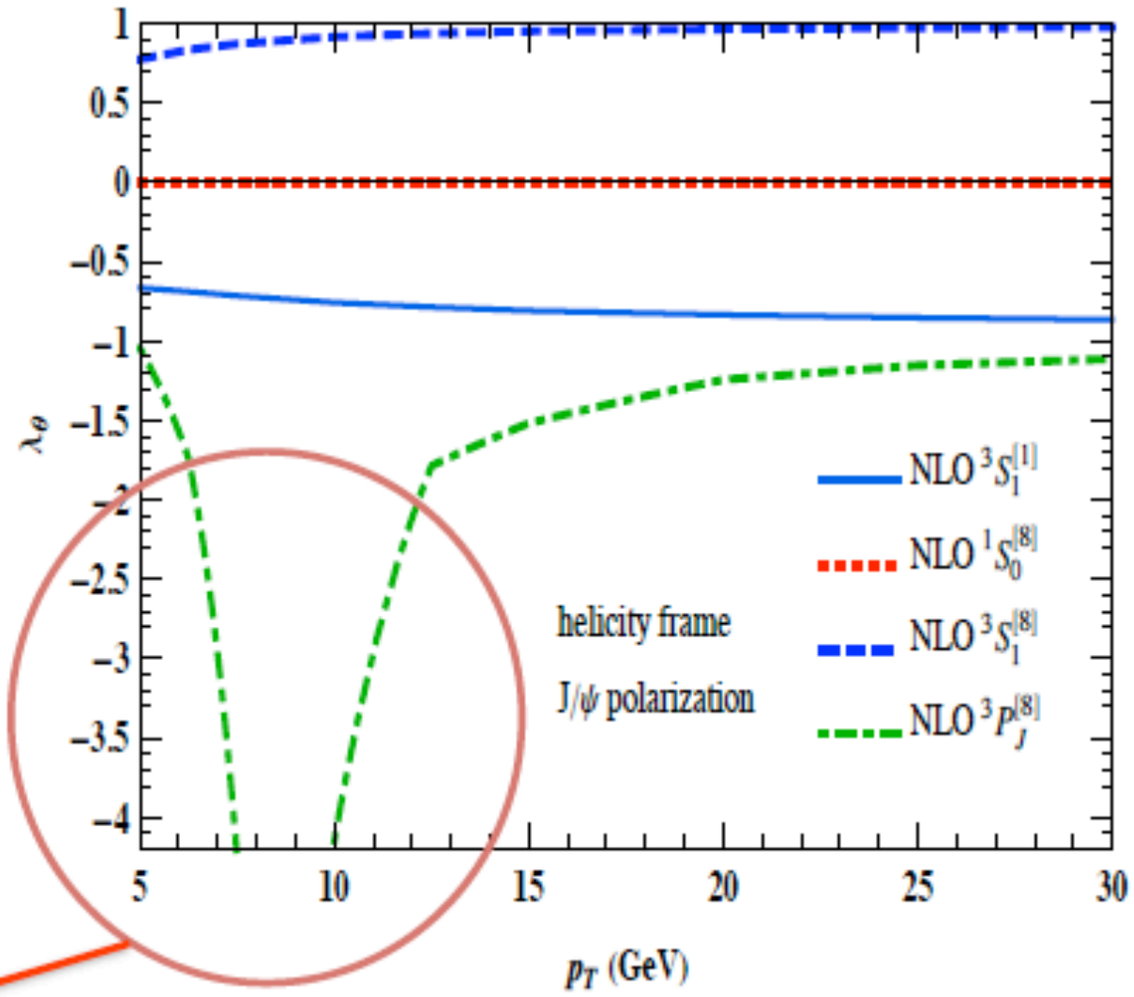
tricky in fit &
delicate cancellation

Chao et al. (1201.2675)





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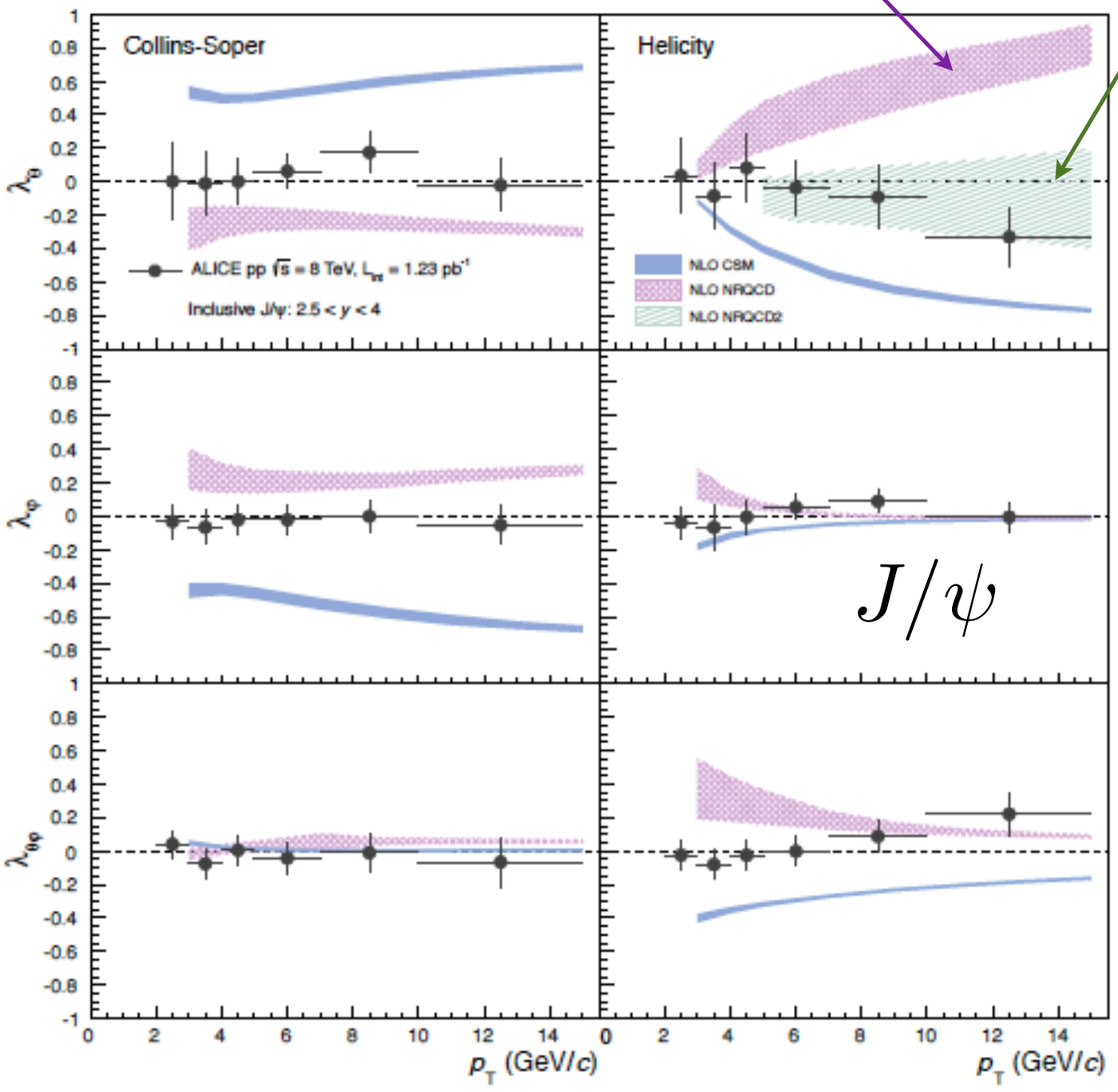
PSI POLARISATION

- **Two representative LHC results**

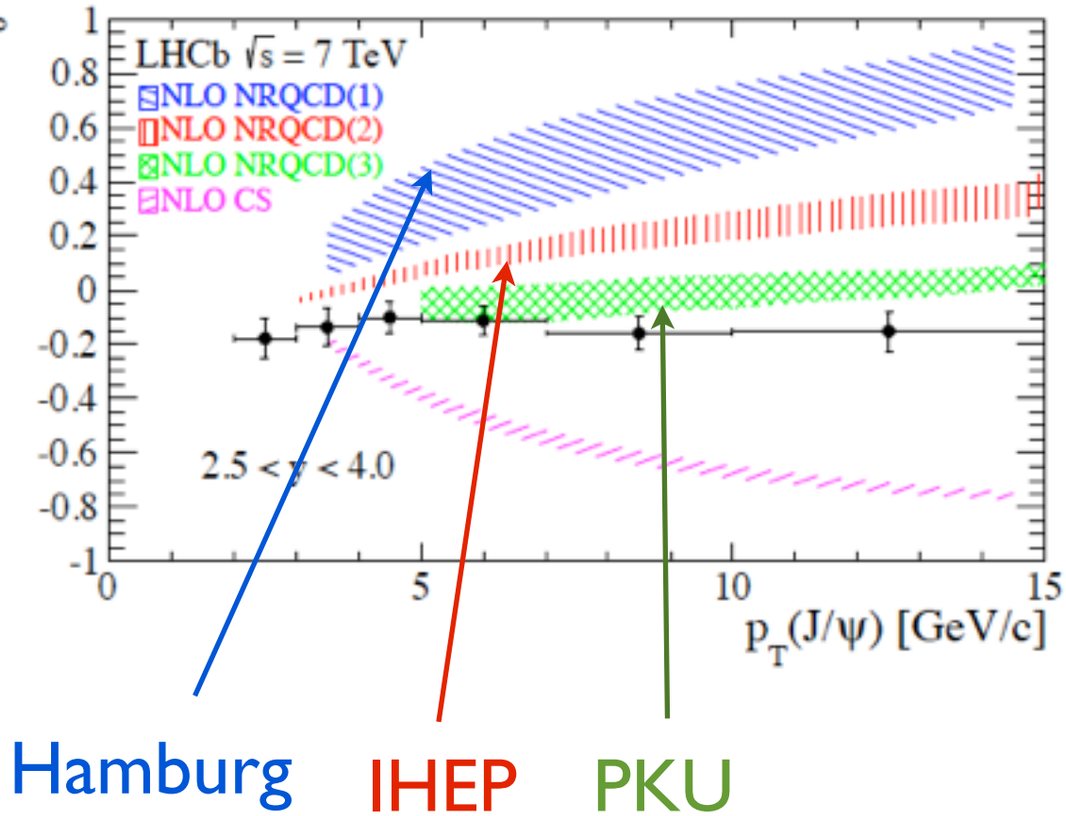
ALICE (1805.04374)

Hamburg

PKU



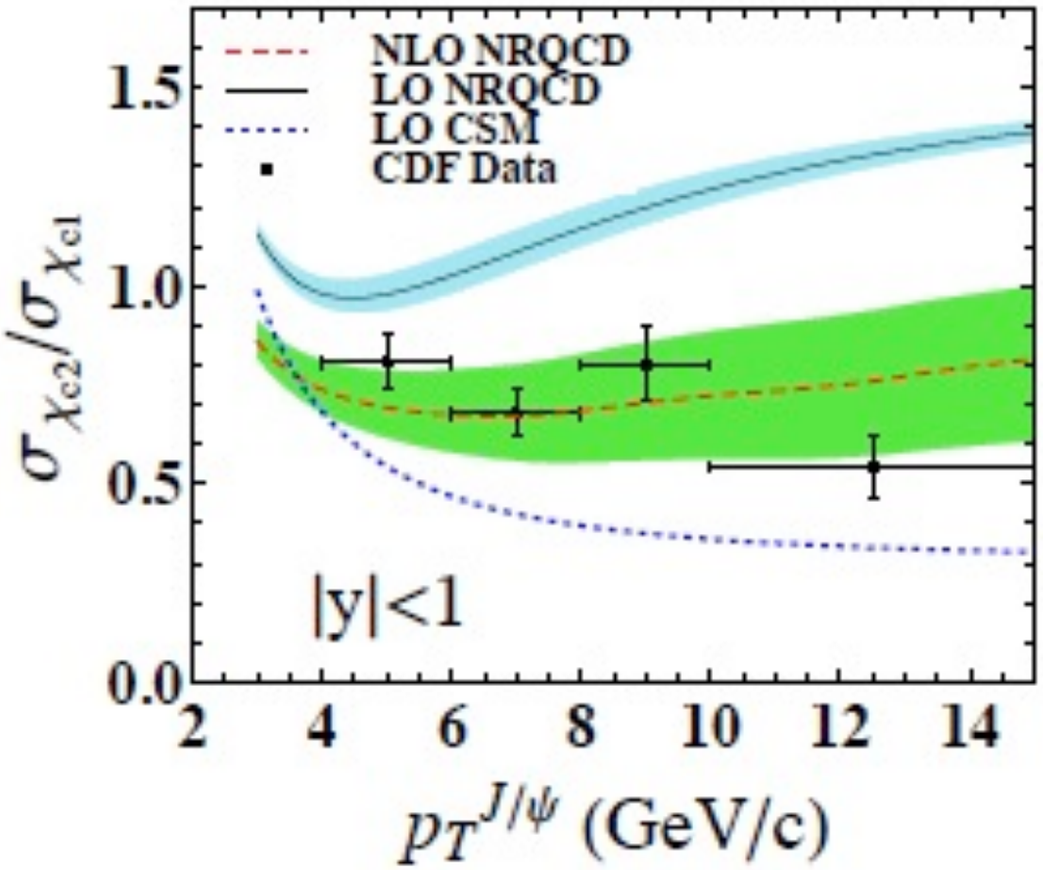
LHCb (1307.6379)

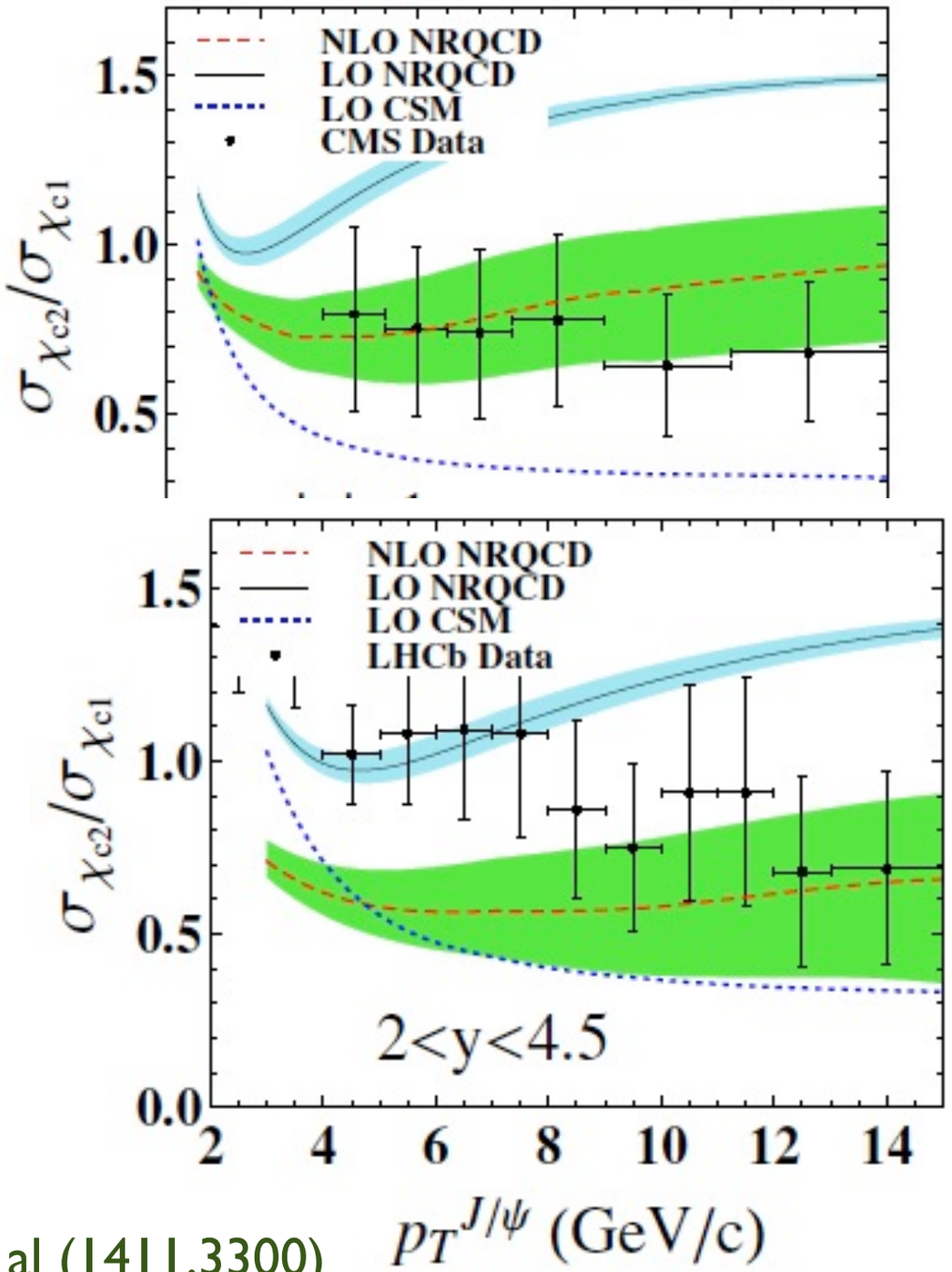


Hamburg IHEP PKU

WHY CHI$_c$ STATES ?

- Chi$_c$ has virtues of: 1) small feed-down; 2) one undetermined non-perturbative object (using HQSS)





HSS et. al (1411.3300)

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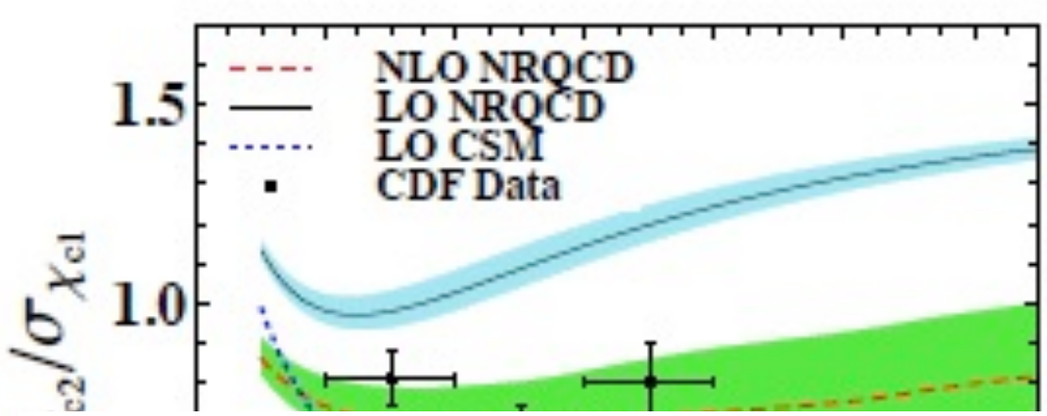

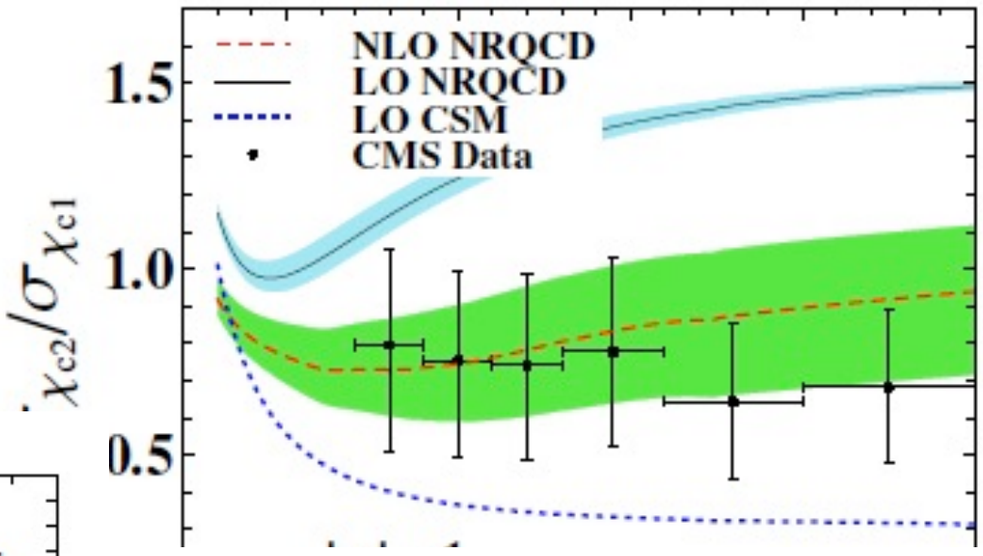

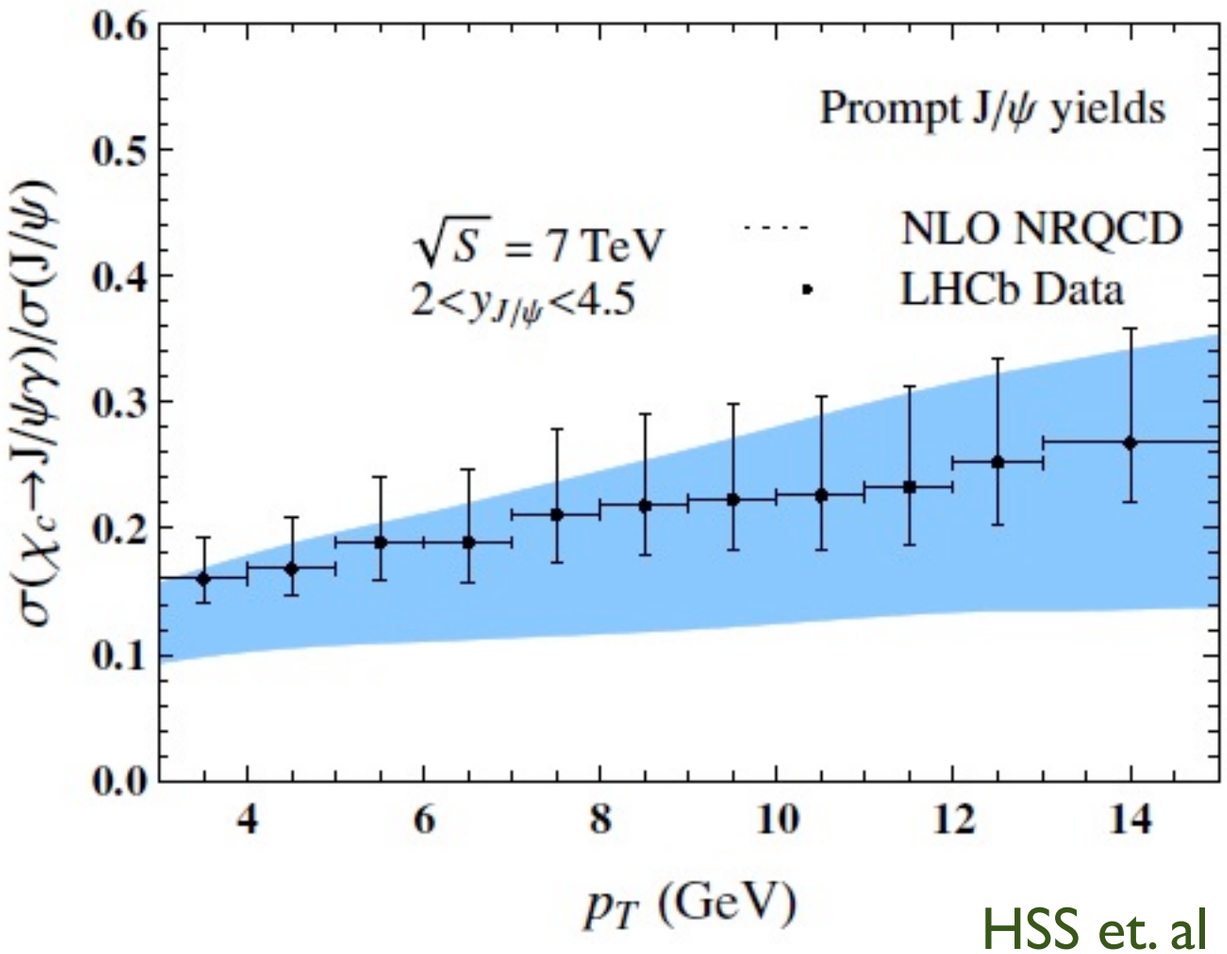

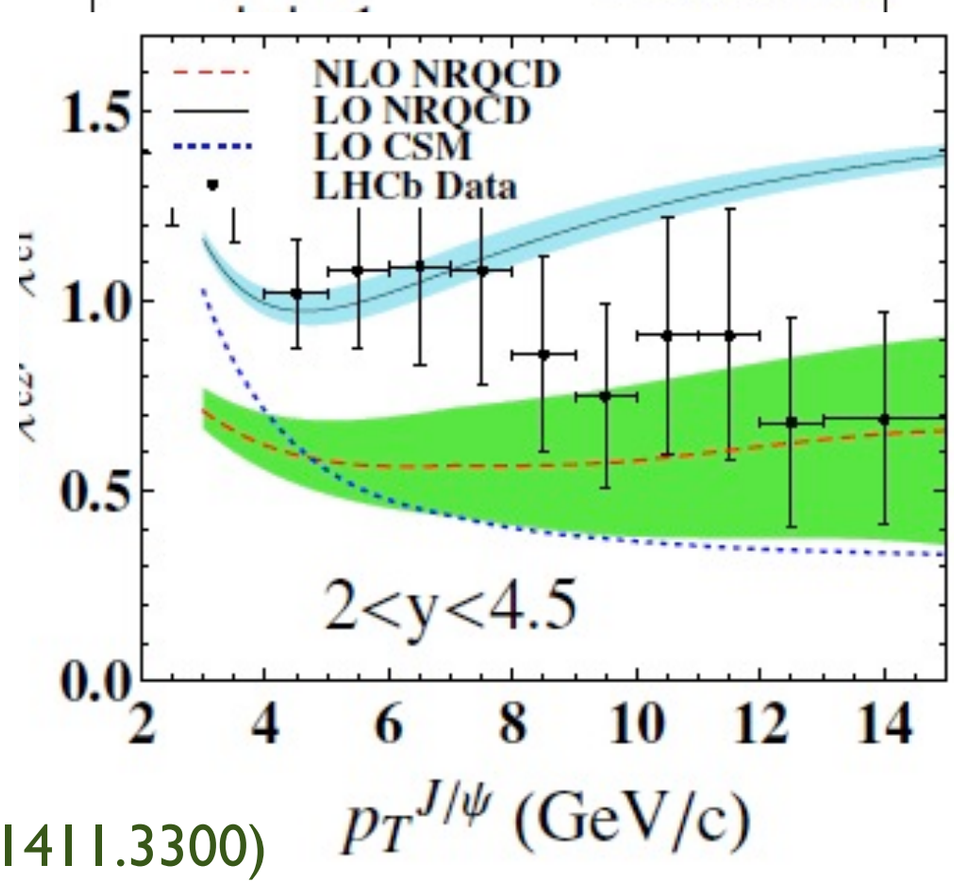

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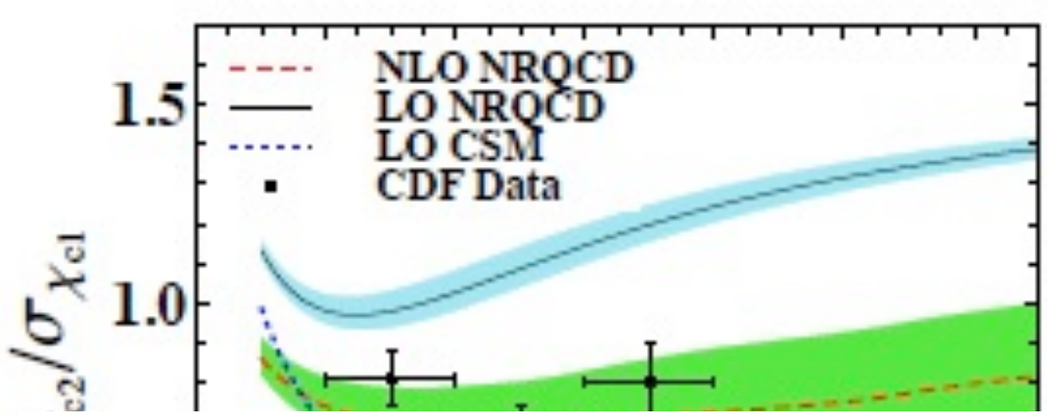
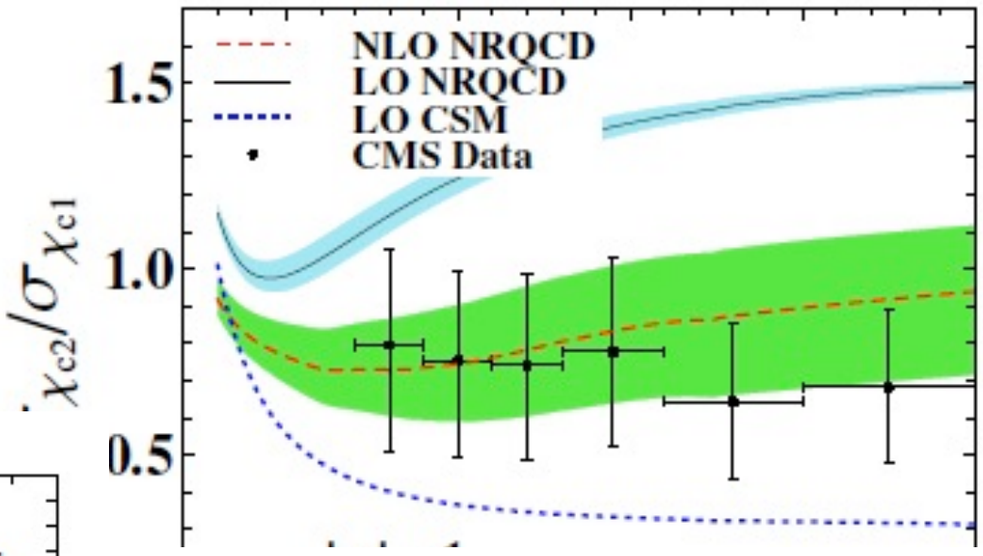
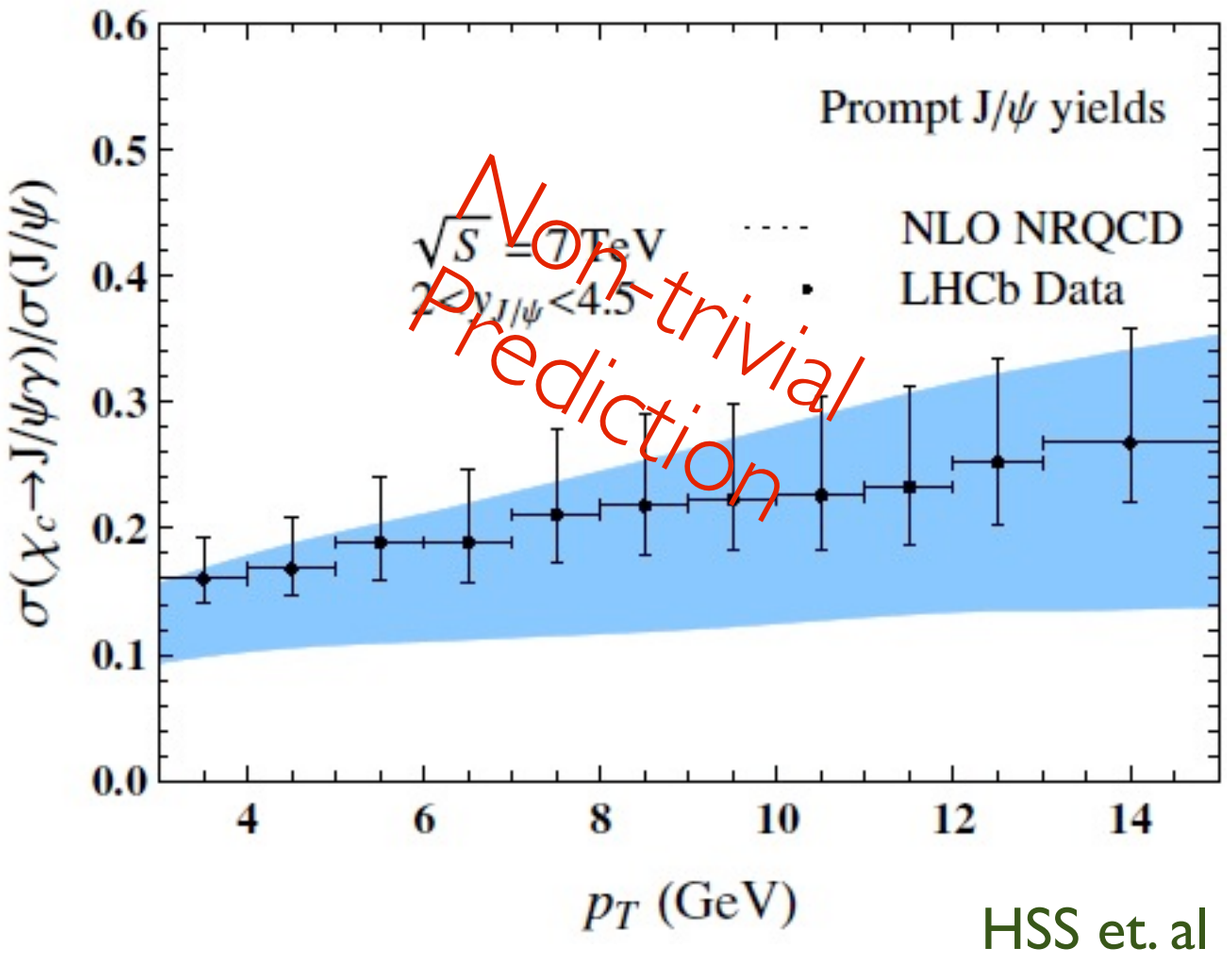
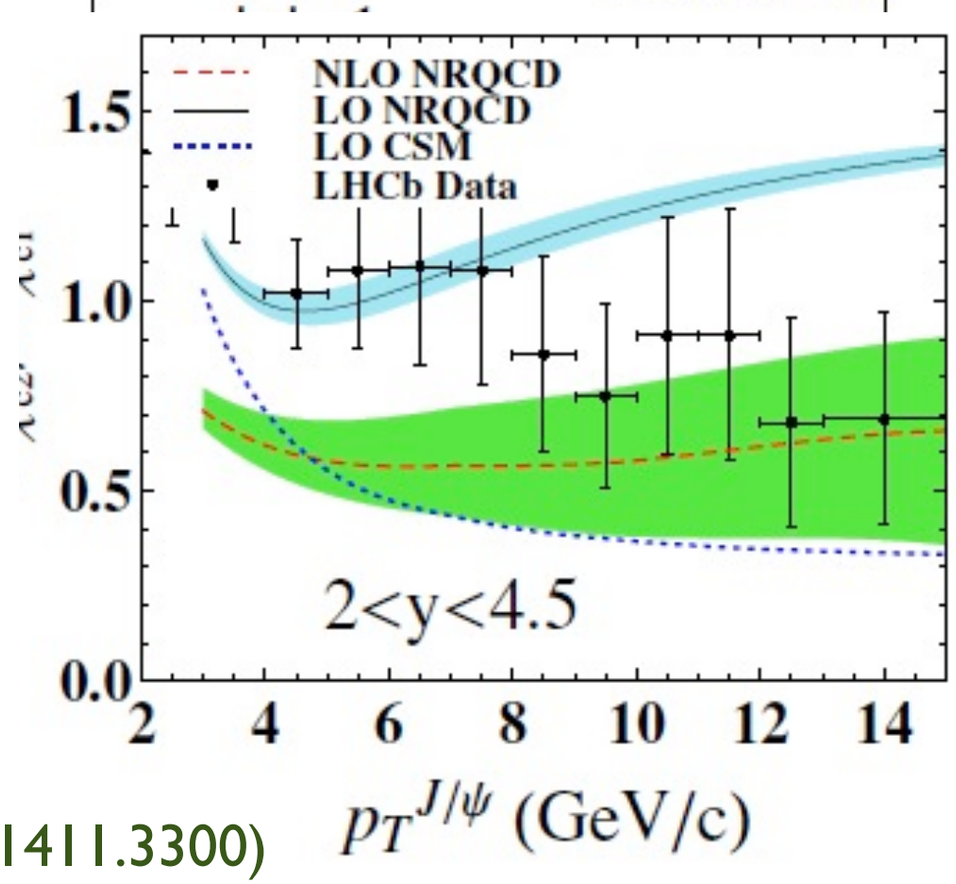








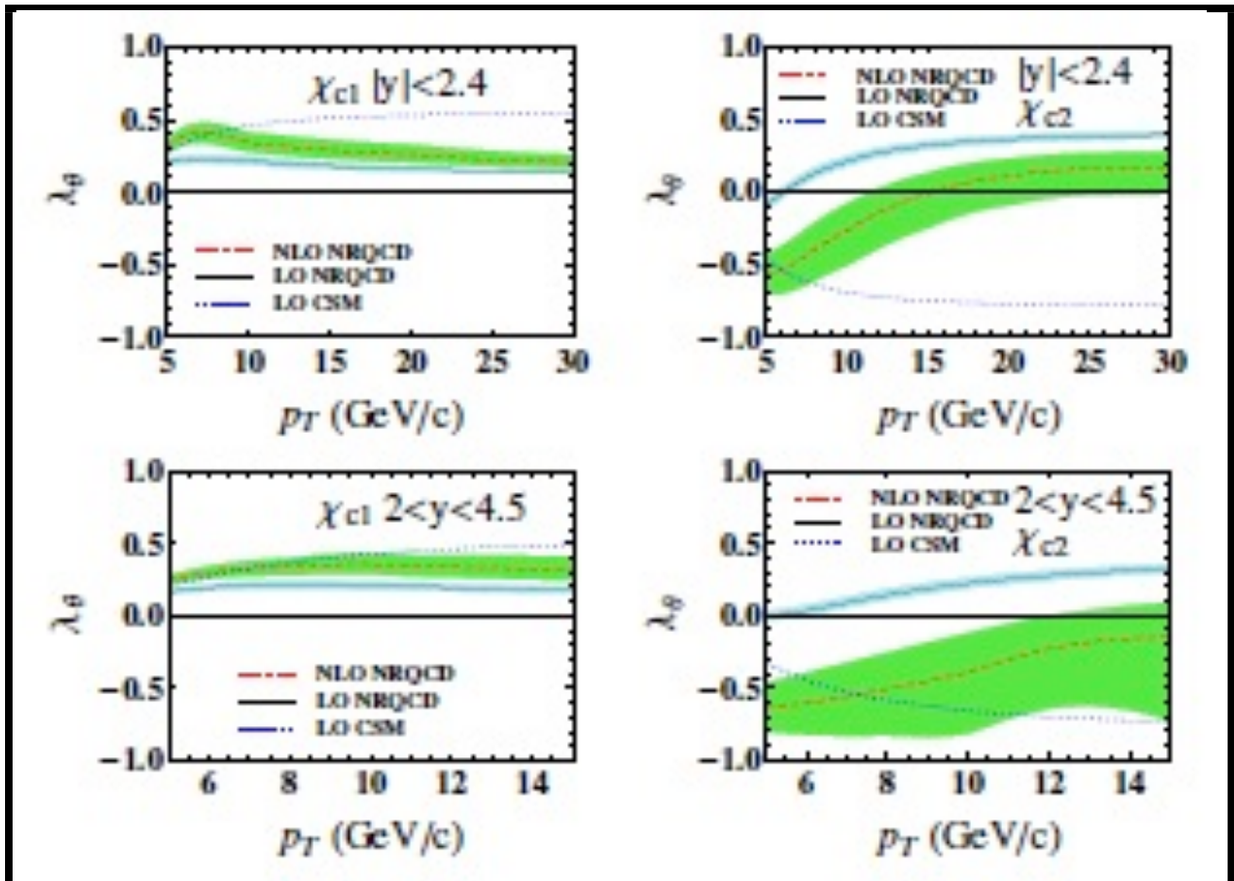
HSS et. al (1411.3300)

WHY CHIc STATES ?

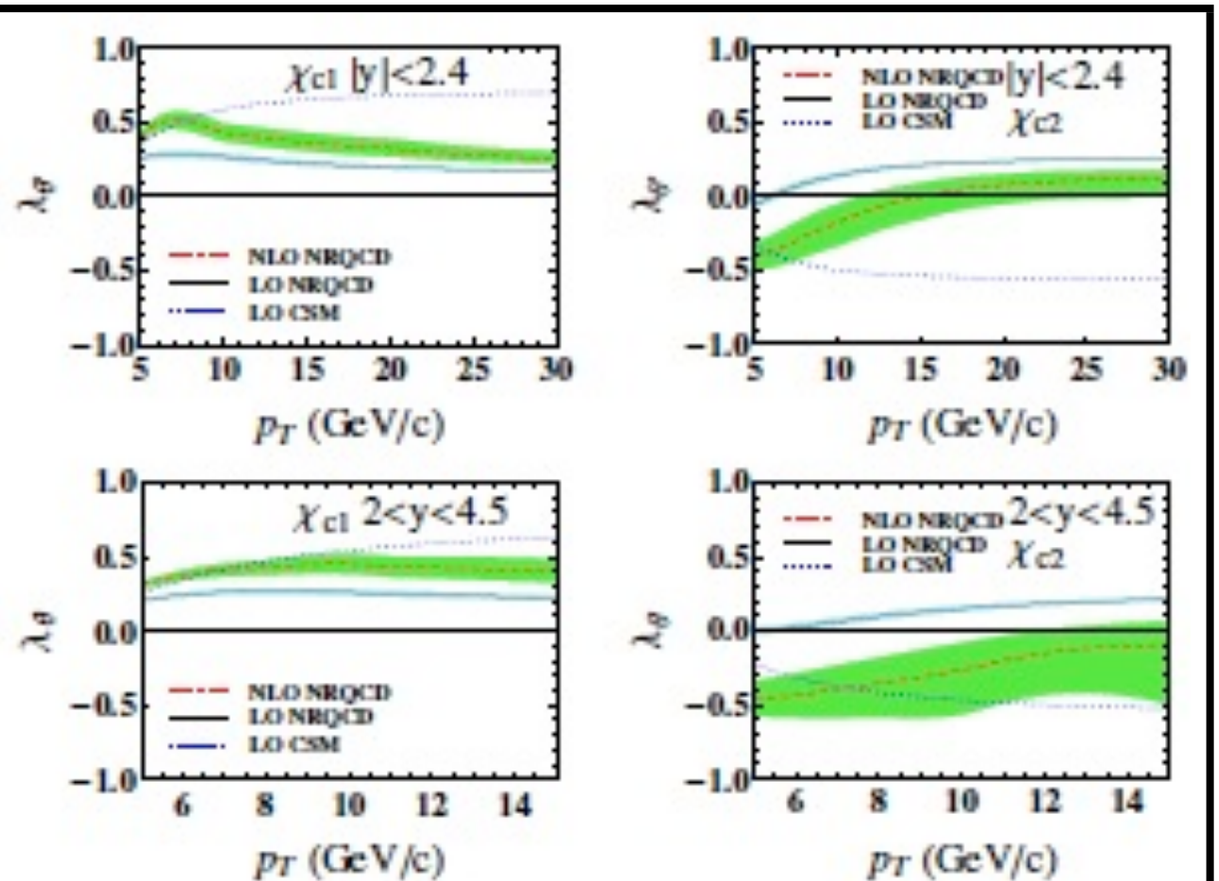
- **Chic polarisation is also very predictive albeit plagued with some theoretical uncertainties**

$$\chi_c \to J/\psi(\to \ell^+\ell^-) + \gamma$$

HSS et al. (1402.2913)



photon angular distribution coefficient

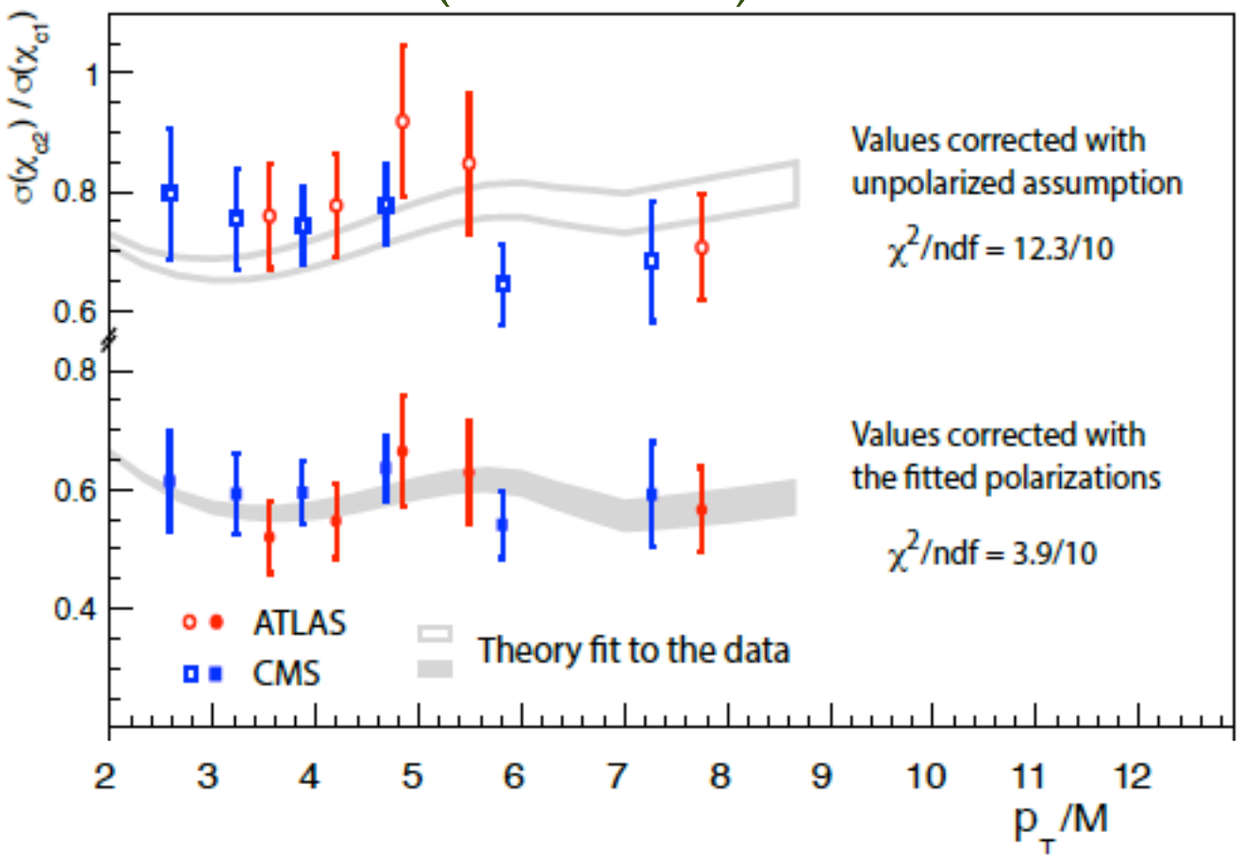


di-lepton angular distribution coefficient

WHY CHIc STATES ?

- **Chic polarisation:** important to coherent different measurements

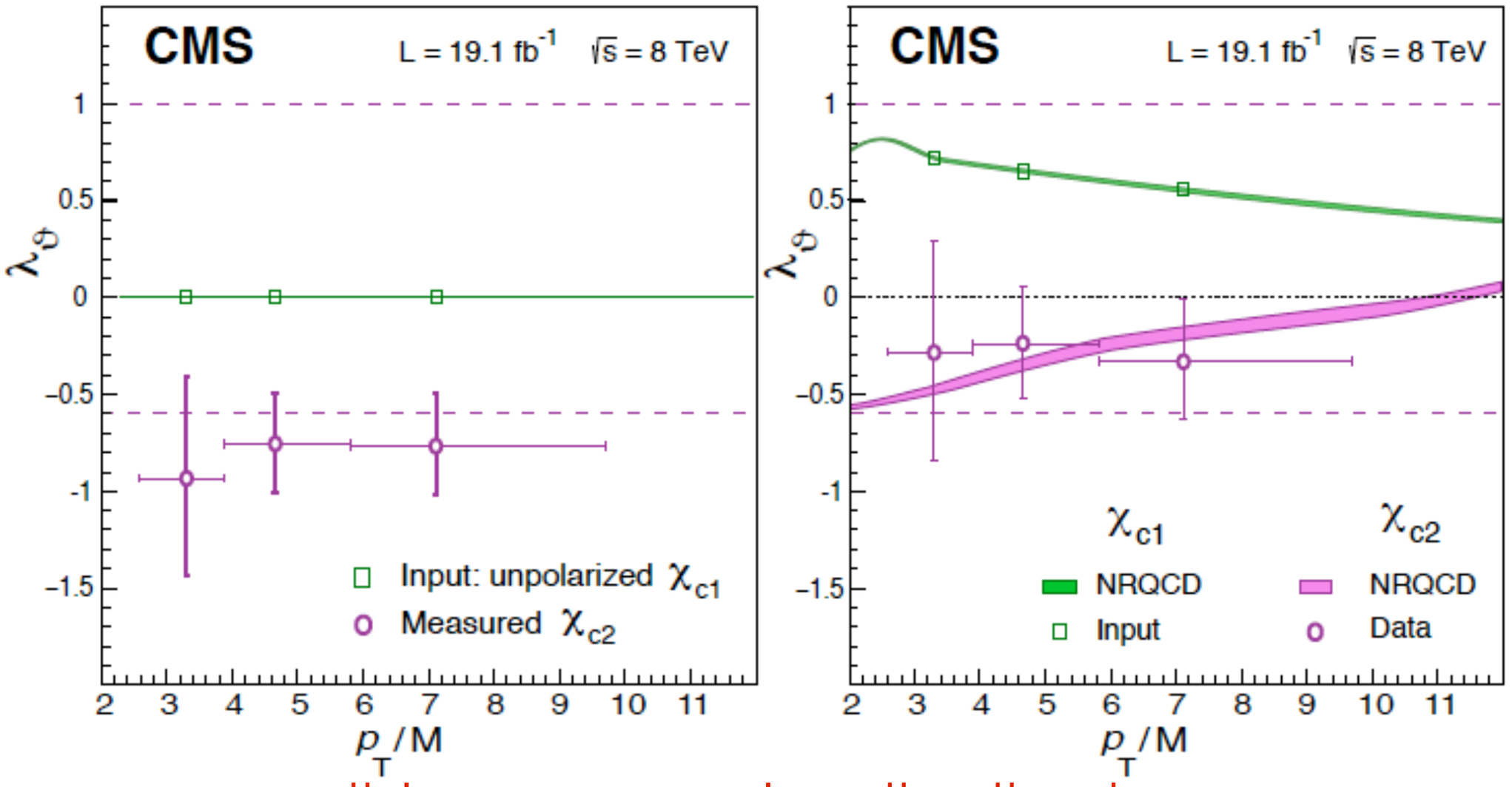
Faccioli et. al (1802.01106)



CHIc STATES

- **Chi$_c$ polarisation: the first measurement**
  - Only difference is known to cancel syst. errors from muon and photon efficiencies
  - Photon angular distribution is difficult due to the poorly known contributions of photon with large orbital angular momentum

CMS (1912.07706)



di-lepton angular distribution coefficient

TAKE HOME MESSAGE

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- The polarisation of psi, which was initially proposed to use as a smoking gun to the colour-octet mechanism, seems less plausible than before.
- Psi mesons (and also Y) are close to be unpolarised produced at the LHC.
- The first chi_c polarisation difference measurement seems being very encouraging but clearly more tests are necessary (e.g. to lift the limitation of the difference only)

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Thank you for your attention !