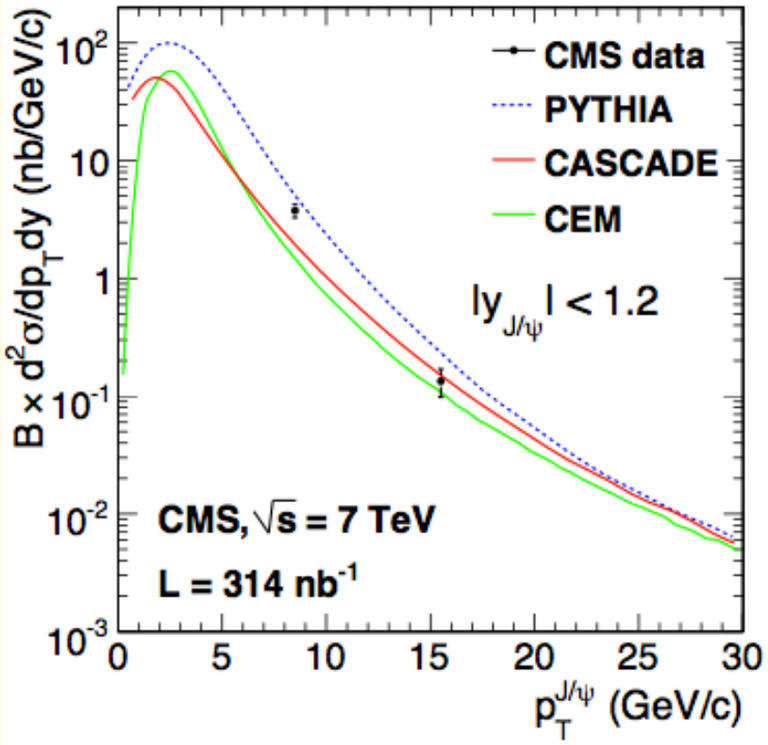
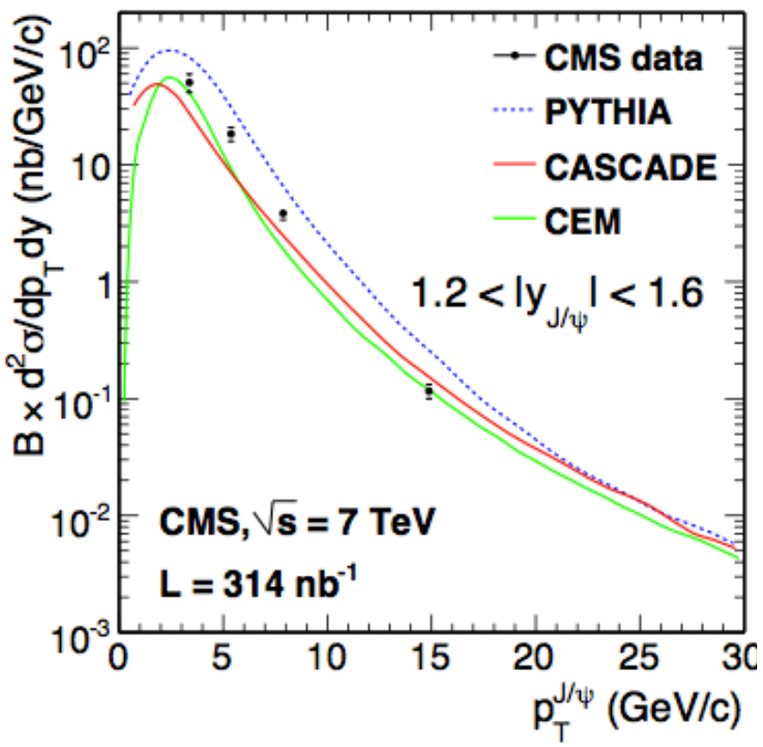
Heavy quark production, a first after-LHC assessment

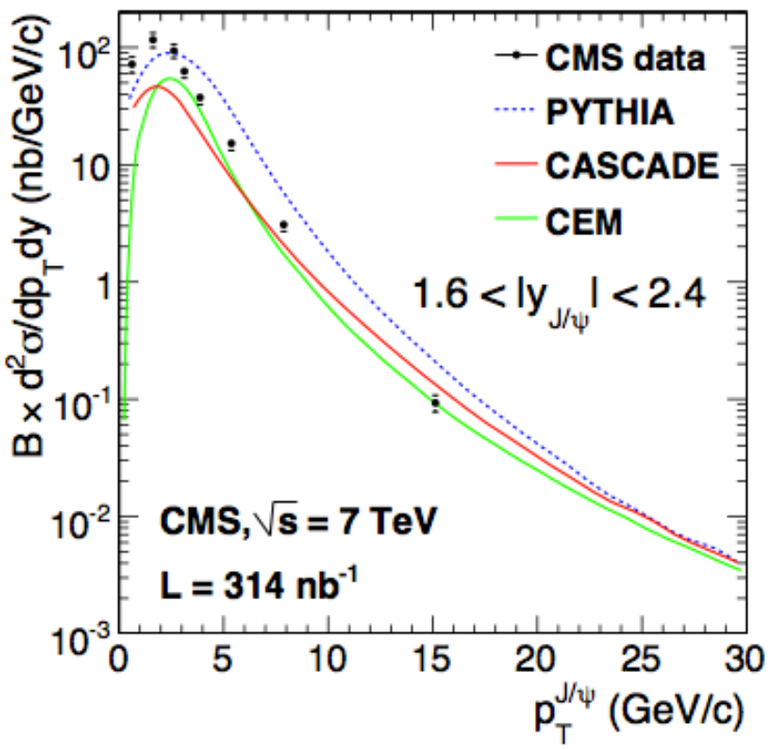
Standard Model benchamrks at the Tevatron and the LHC,
Fermilab, Nov 19-20 2010

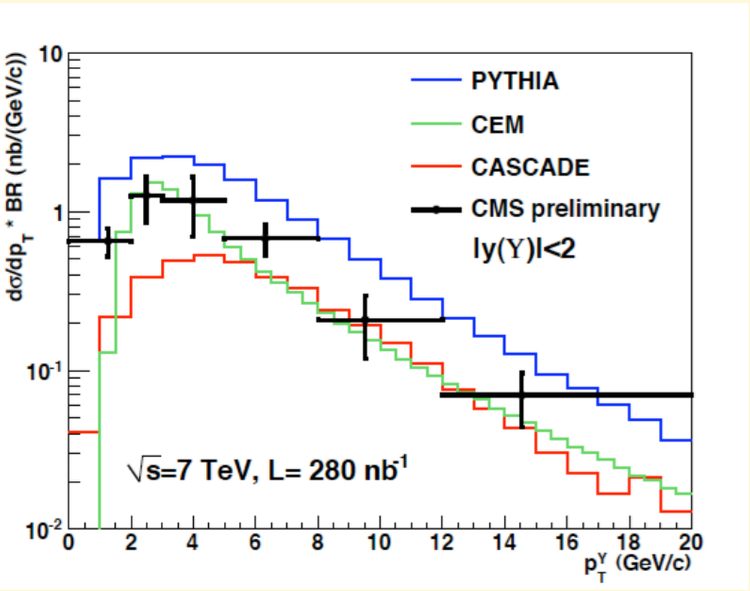
Michelangelo L. Mangano
CERN PH-TH

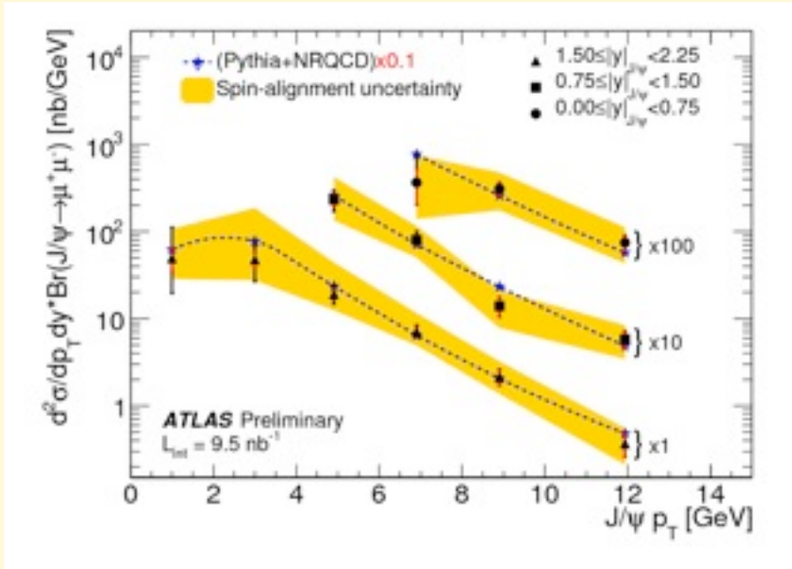
Few words about quarkonium

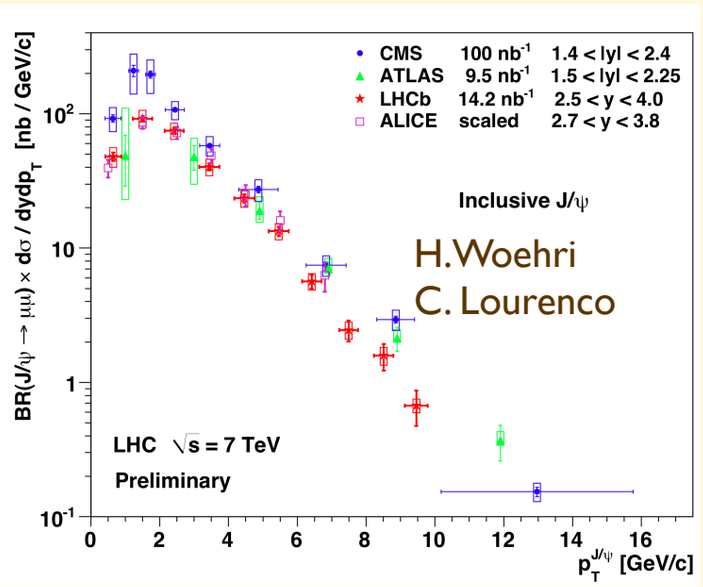












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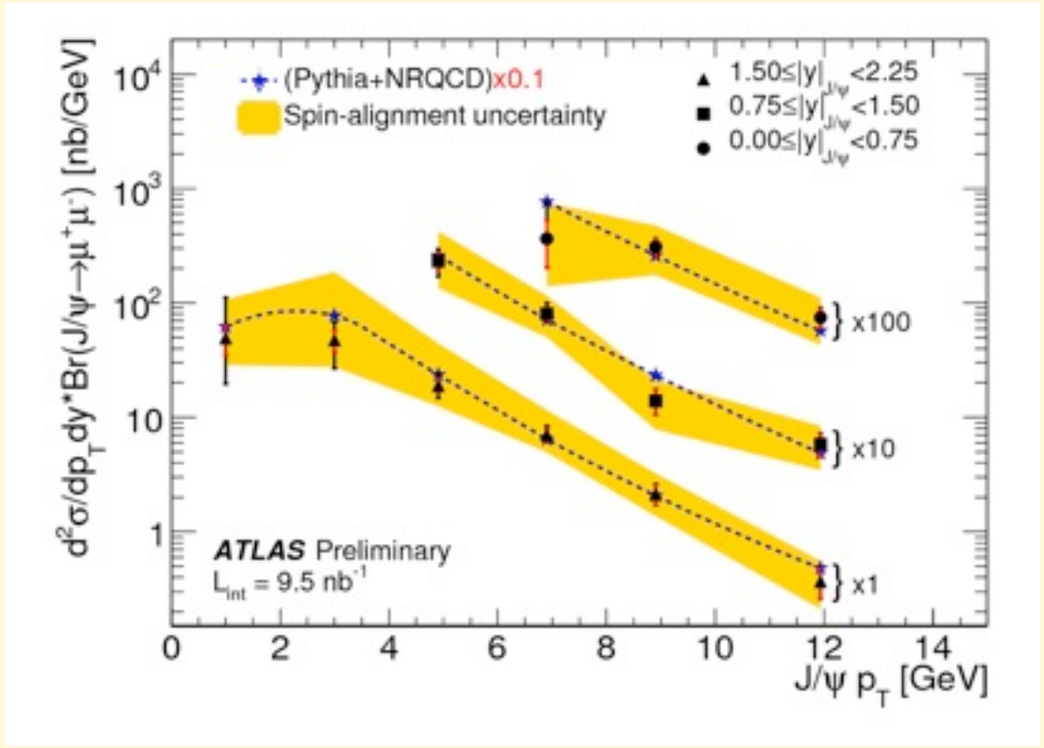
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Lint = 9.5 nb-1
d2σ/dpTdy*Br(J/ψ→μ+μ-) [nb/GeV]
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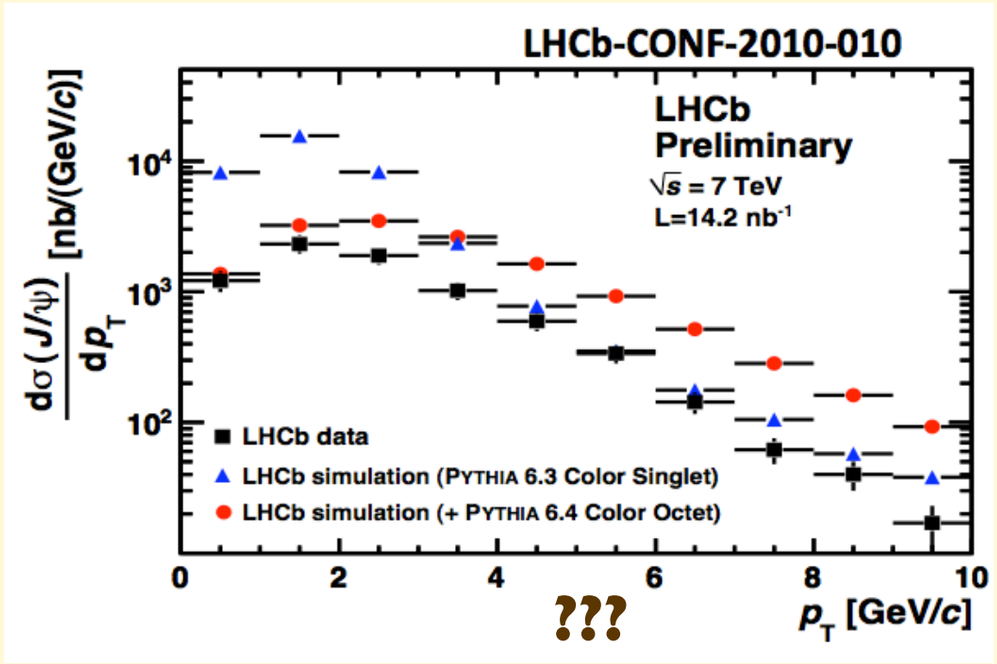
LHCb-CONF-2010-010
LHCb
Preliminary
√s = 7 TeV
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LHCb data
LHCb simulation (PYTHIA 6.3 Color Singlet)
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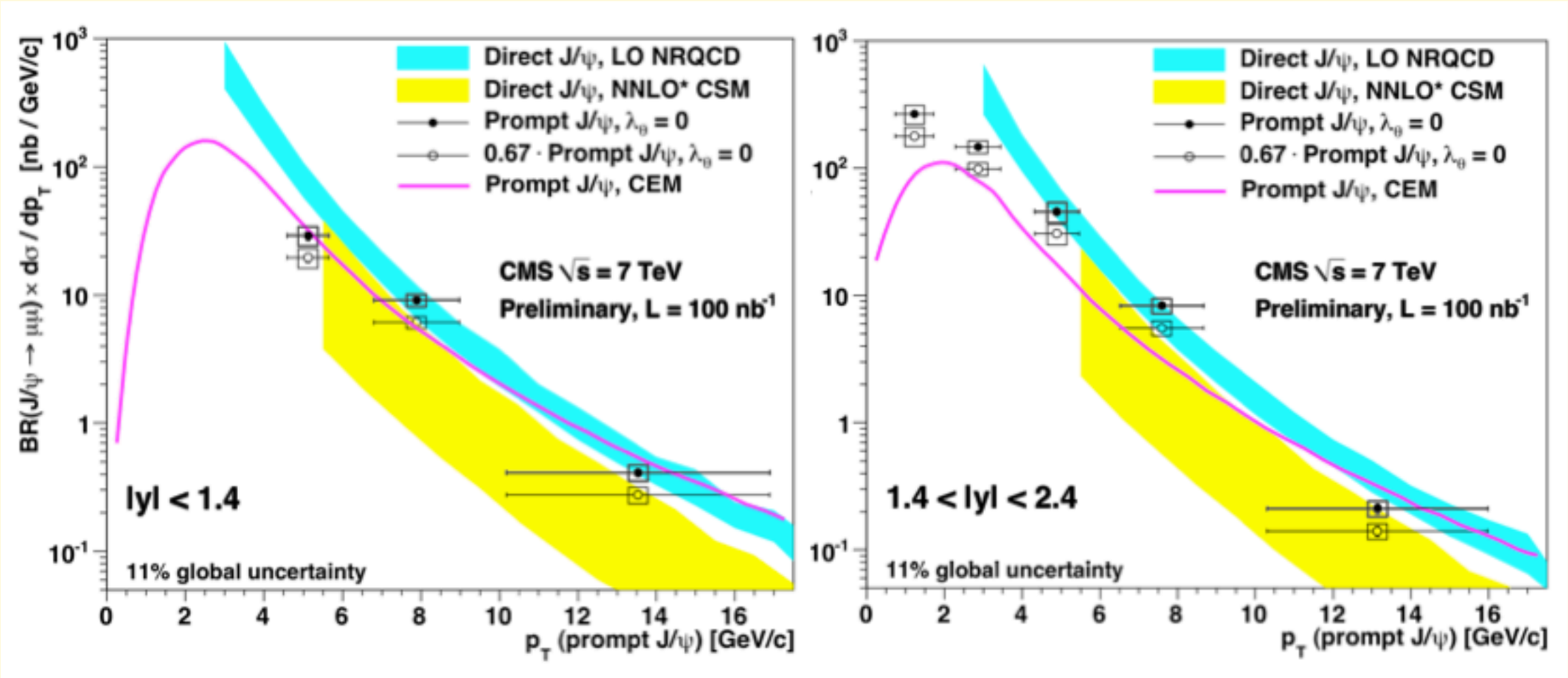
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Prompt J/ψ, CEM
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11% global uncertainty
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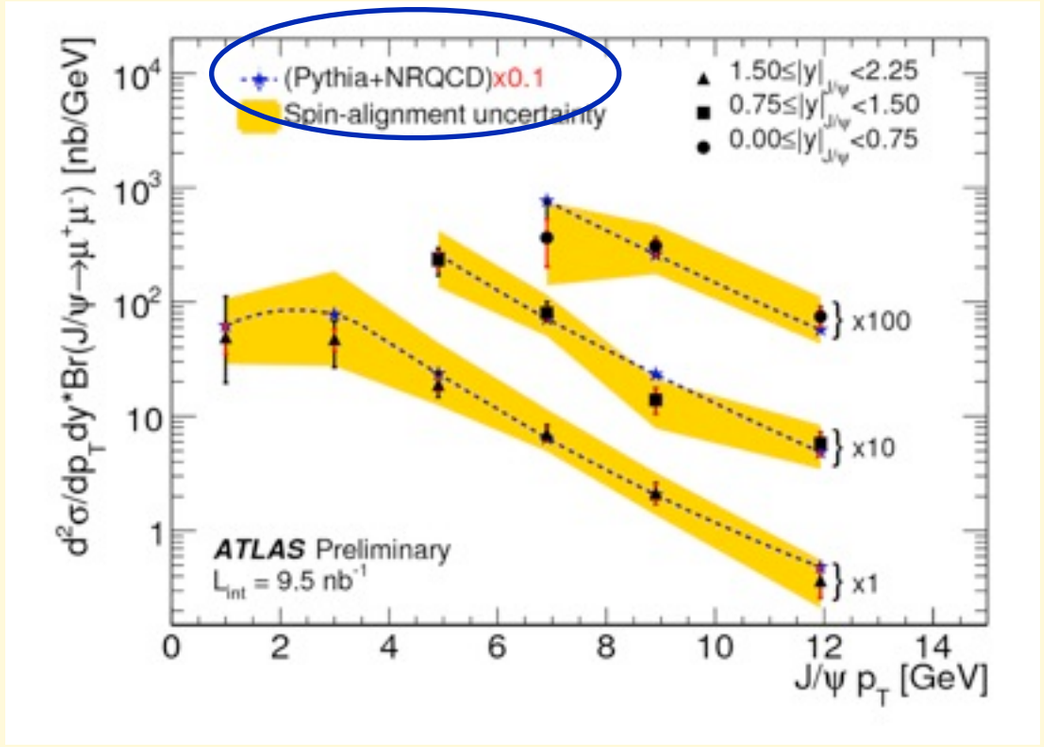
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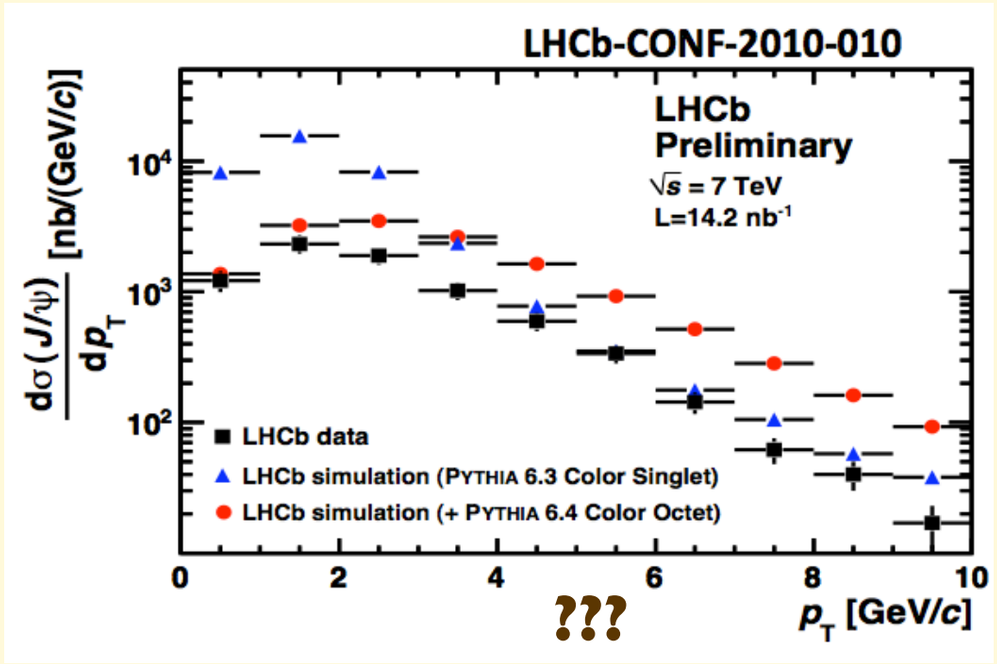
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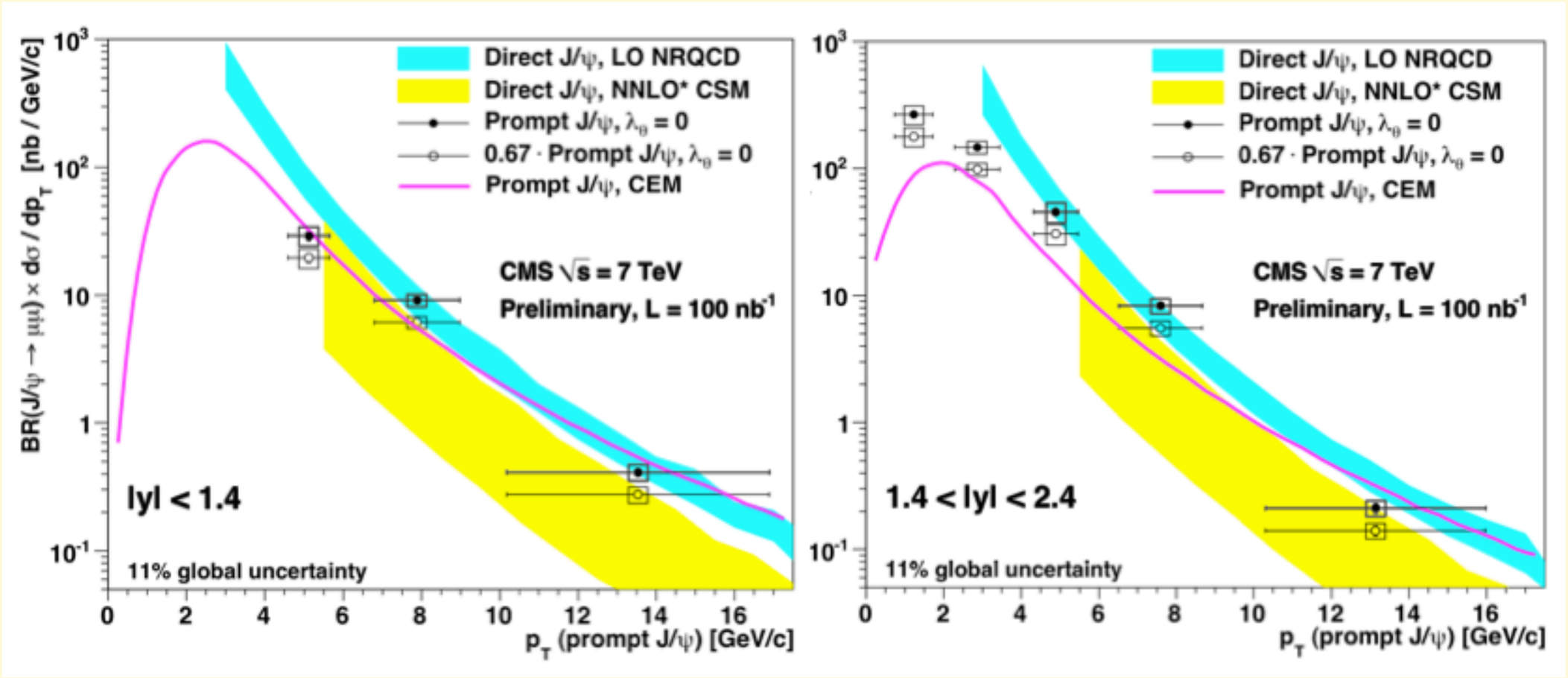
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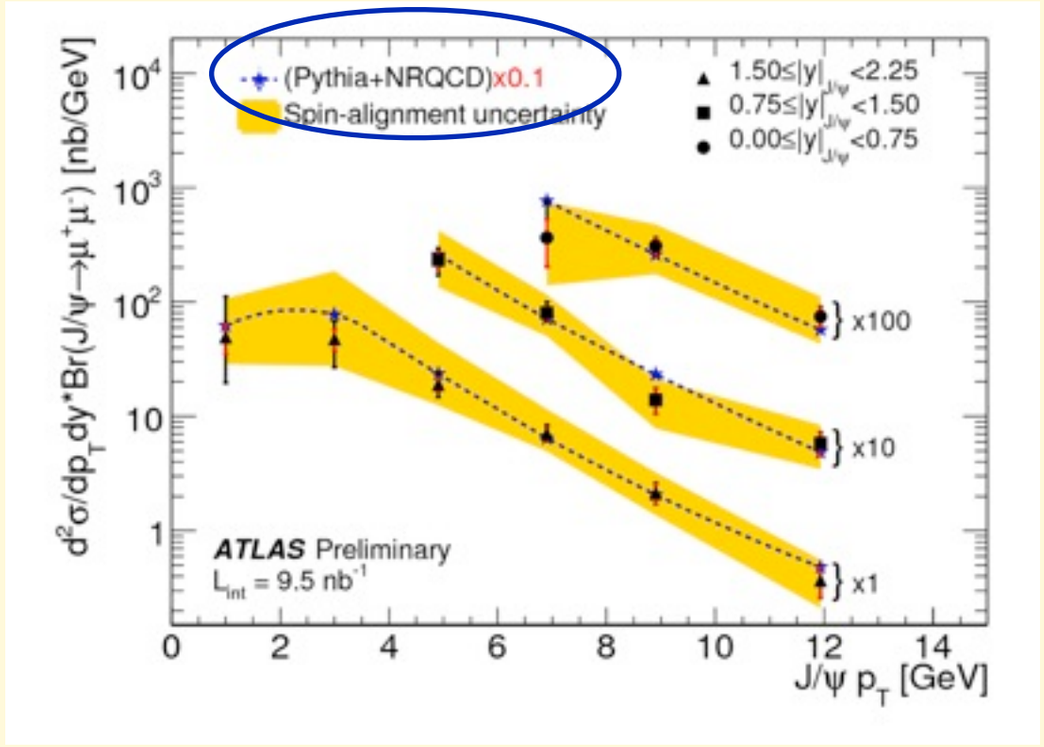
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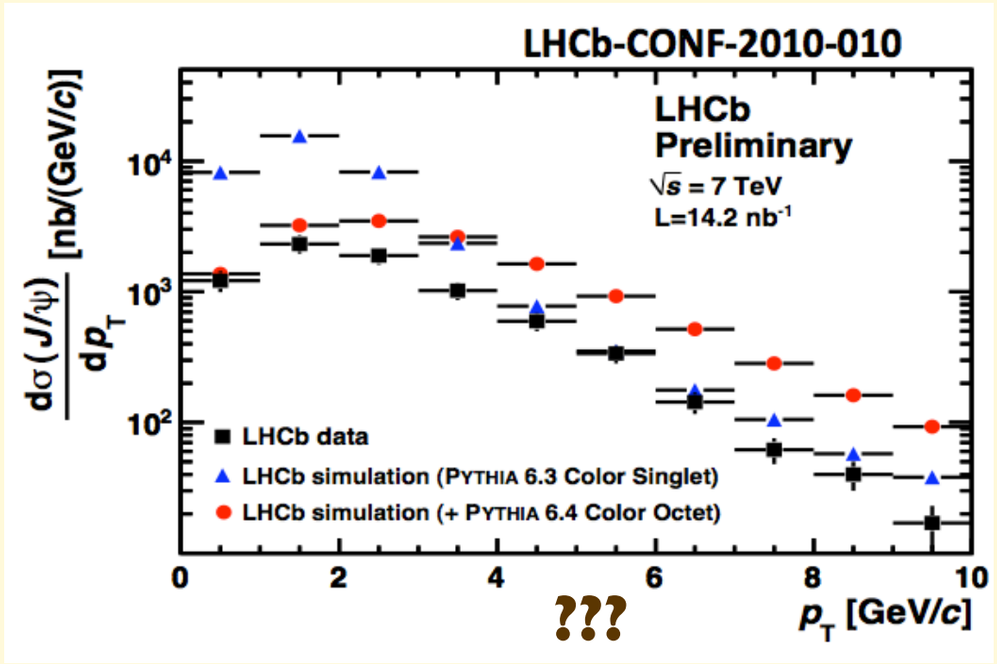
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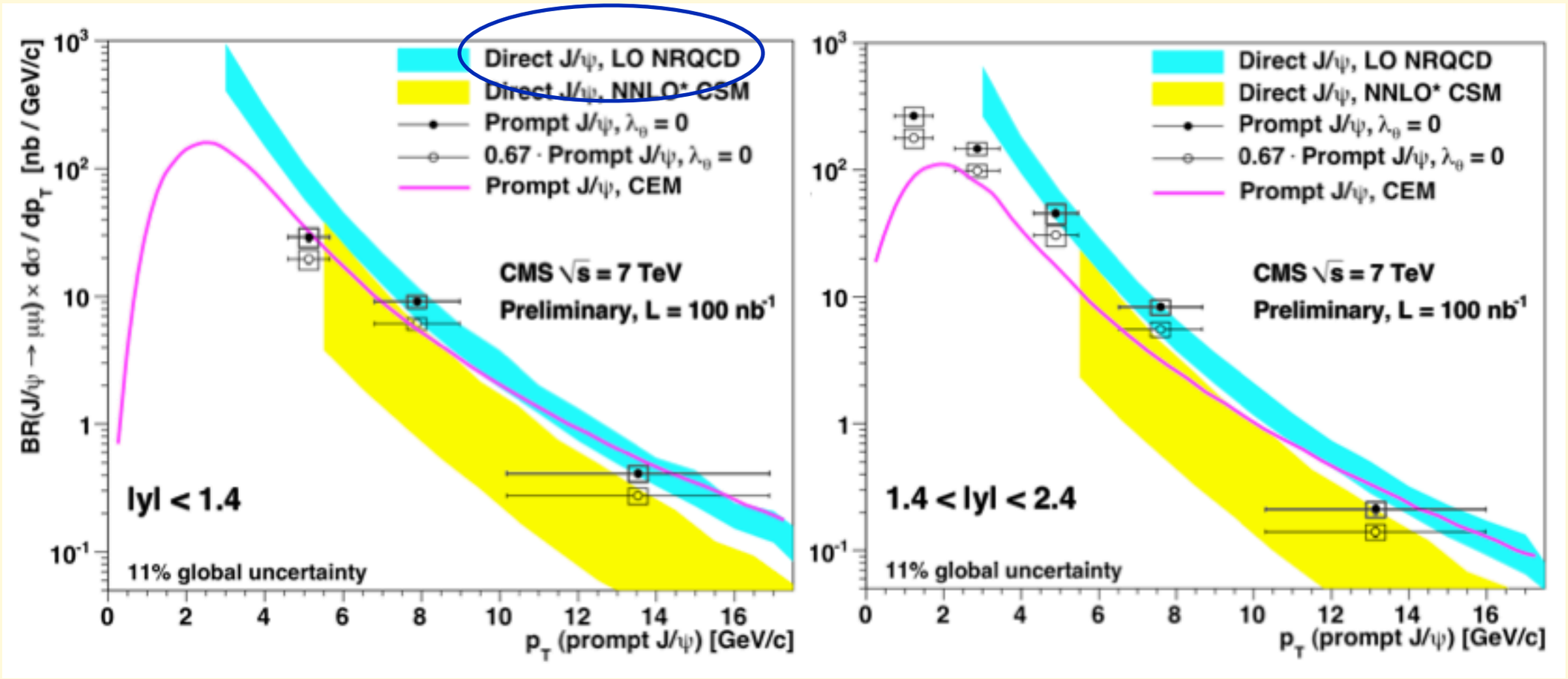
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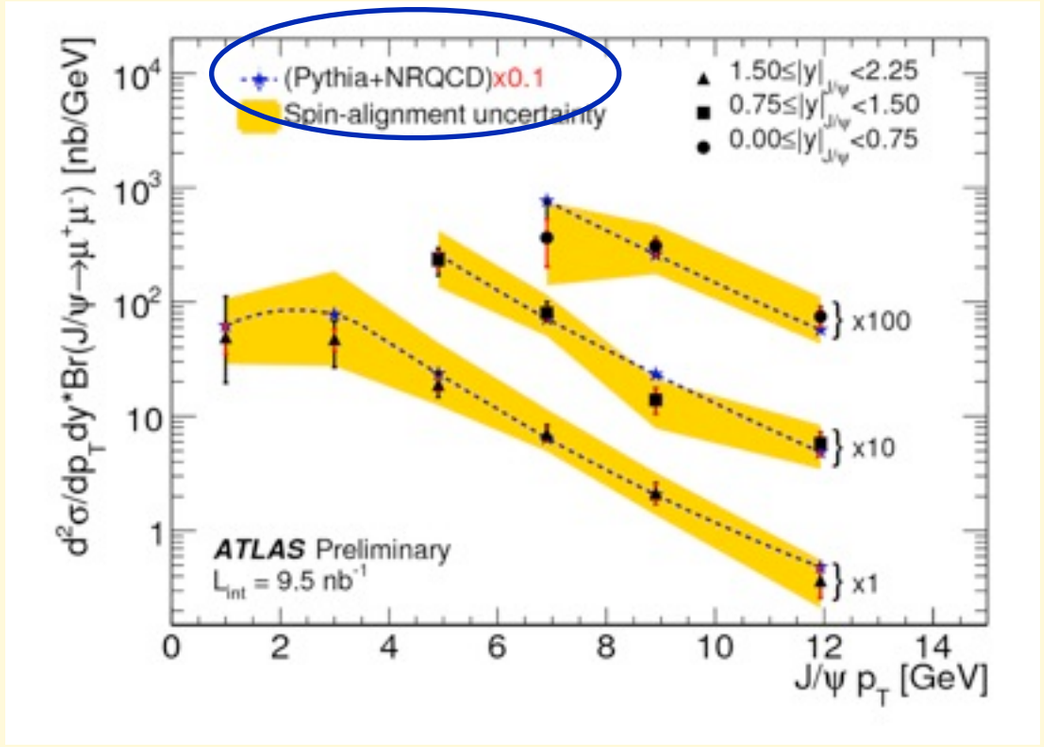
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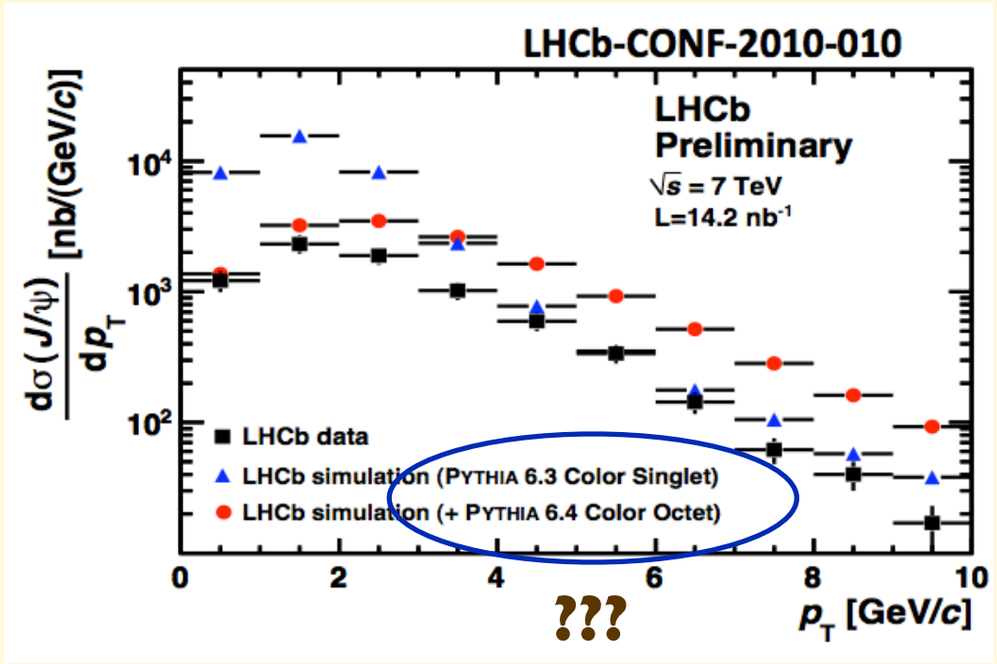
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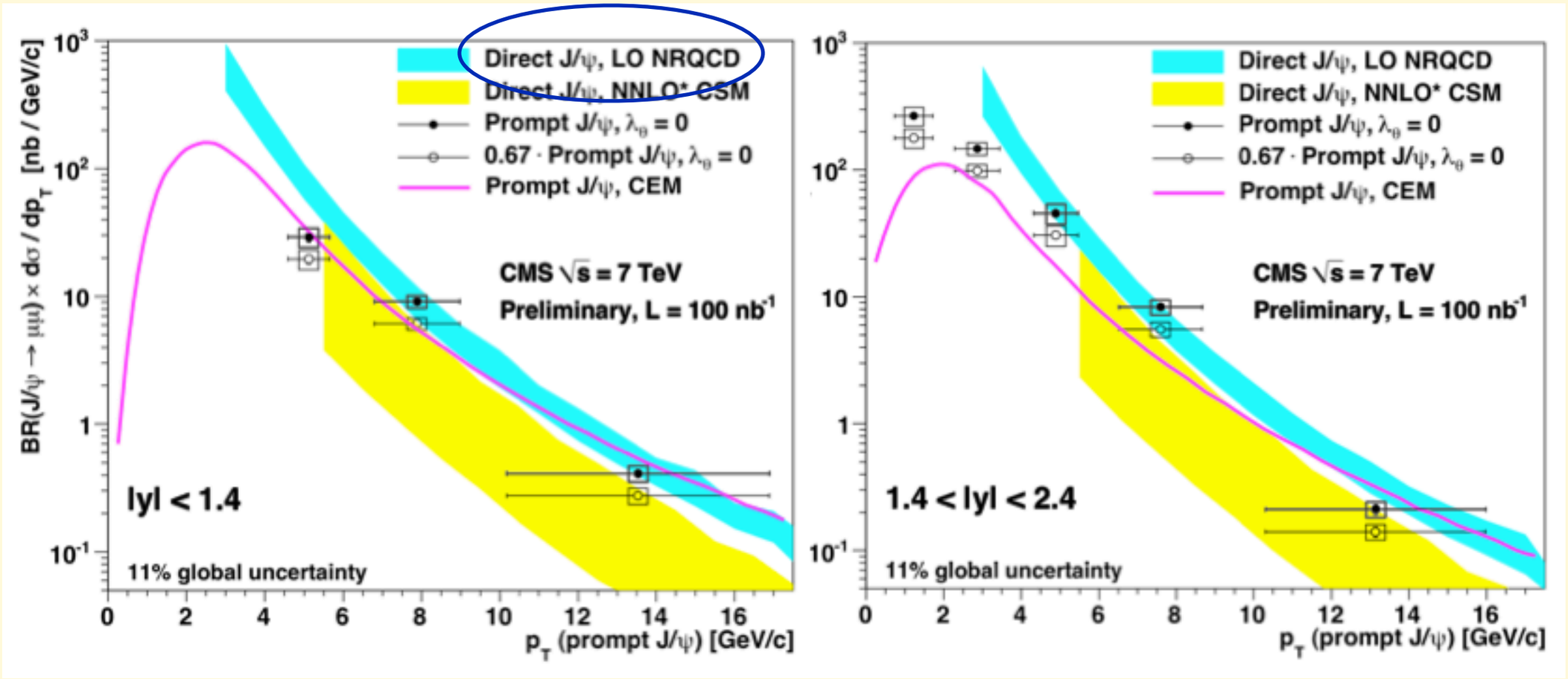
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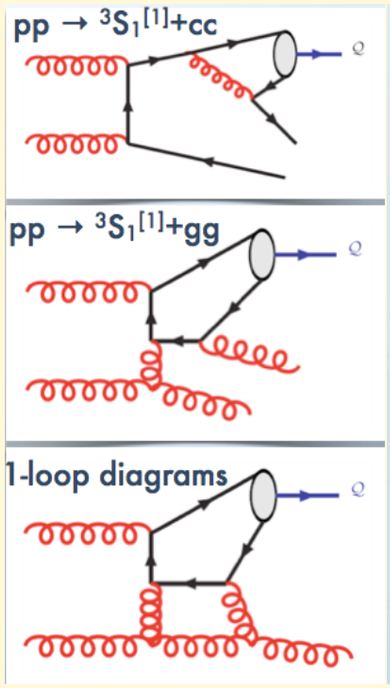
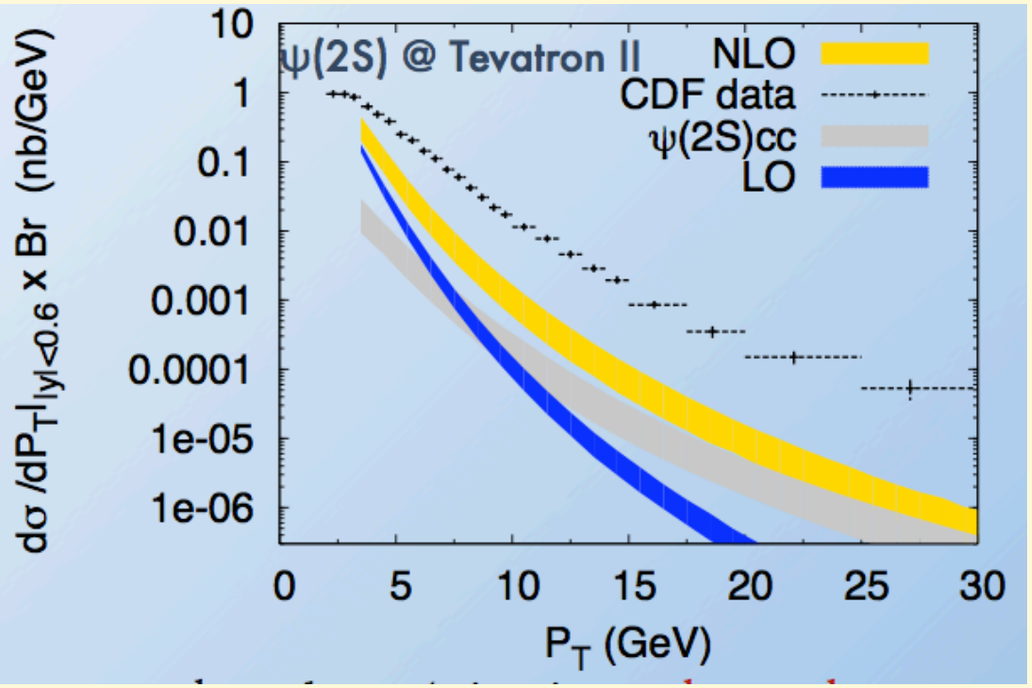
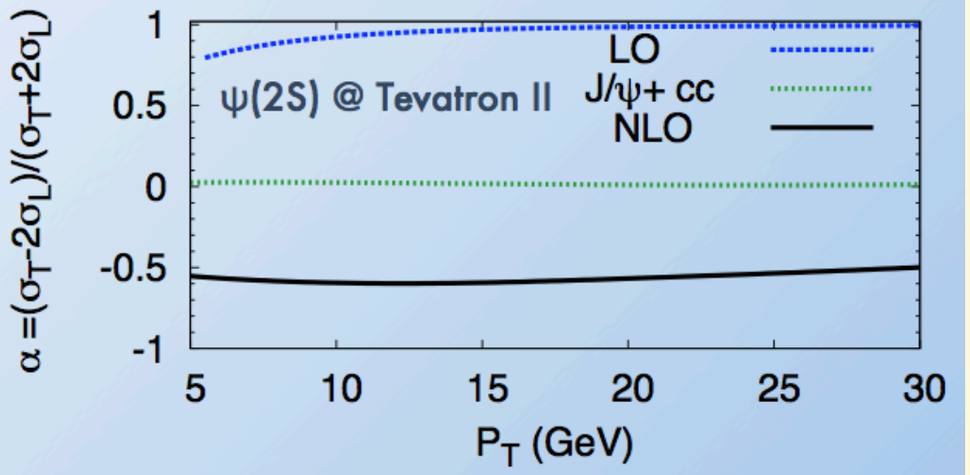
NLO Singlet contributions

Campbell, Maltoni, Tramontano





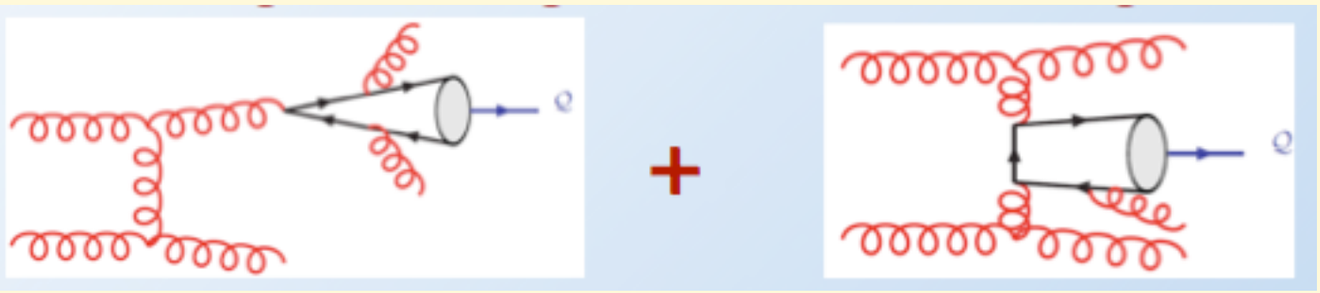
[Gong, Wang; 07]



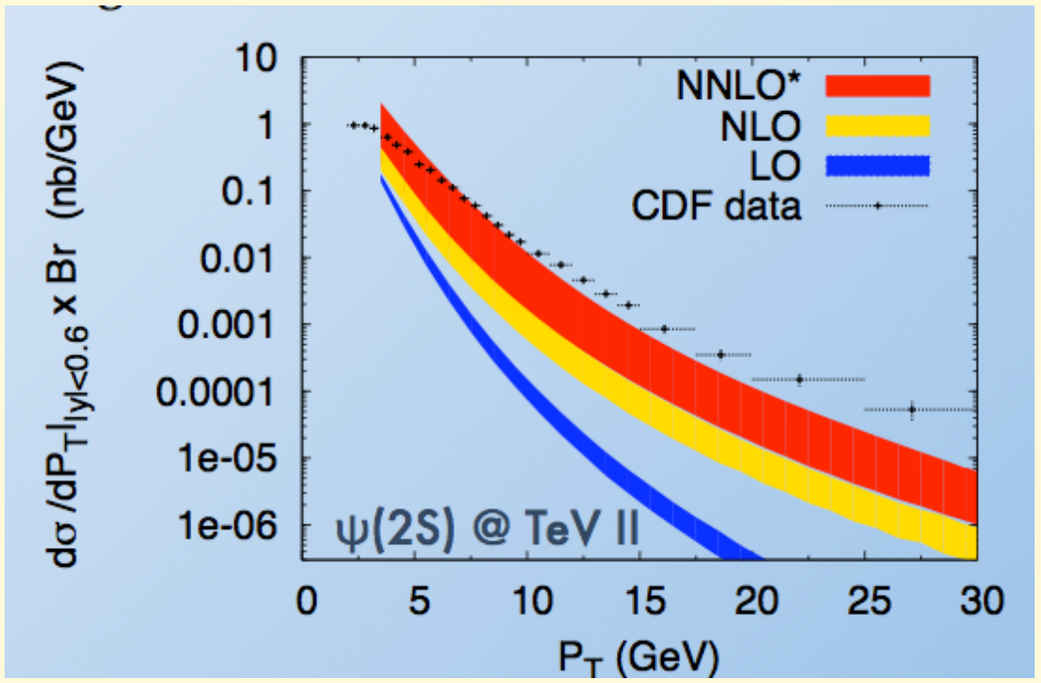
- New channels at α_s^4 strongly affect the polarization parameter α (polar asymmetry in the c.m. helicity frame)
- Polarization is longitudinal component at NLO
- Large correction may arise at order α_s^5 because new channels with a different p_T scaling open up at that order. One of them is the gluon fragmentation $g^* \to {}^3S_1^{[1]}$ ...

"NNLO" Singlet contributions

Artoisenet, Campbell, Lansberg, Maltoni, Tramontano



- IR cutoff logarithmic dependence expected to disappear at large p_T, but sizable at moderate p_T.
- This gives a large uncertainty on the normalization, the shape is rather stable though.

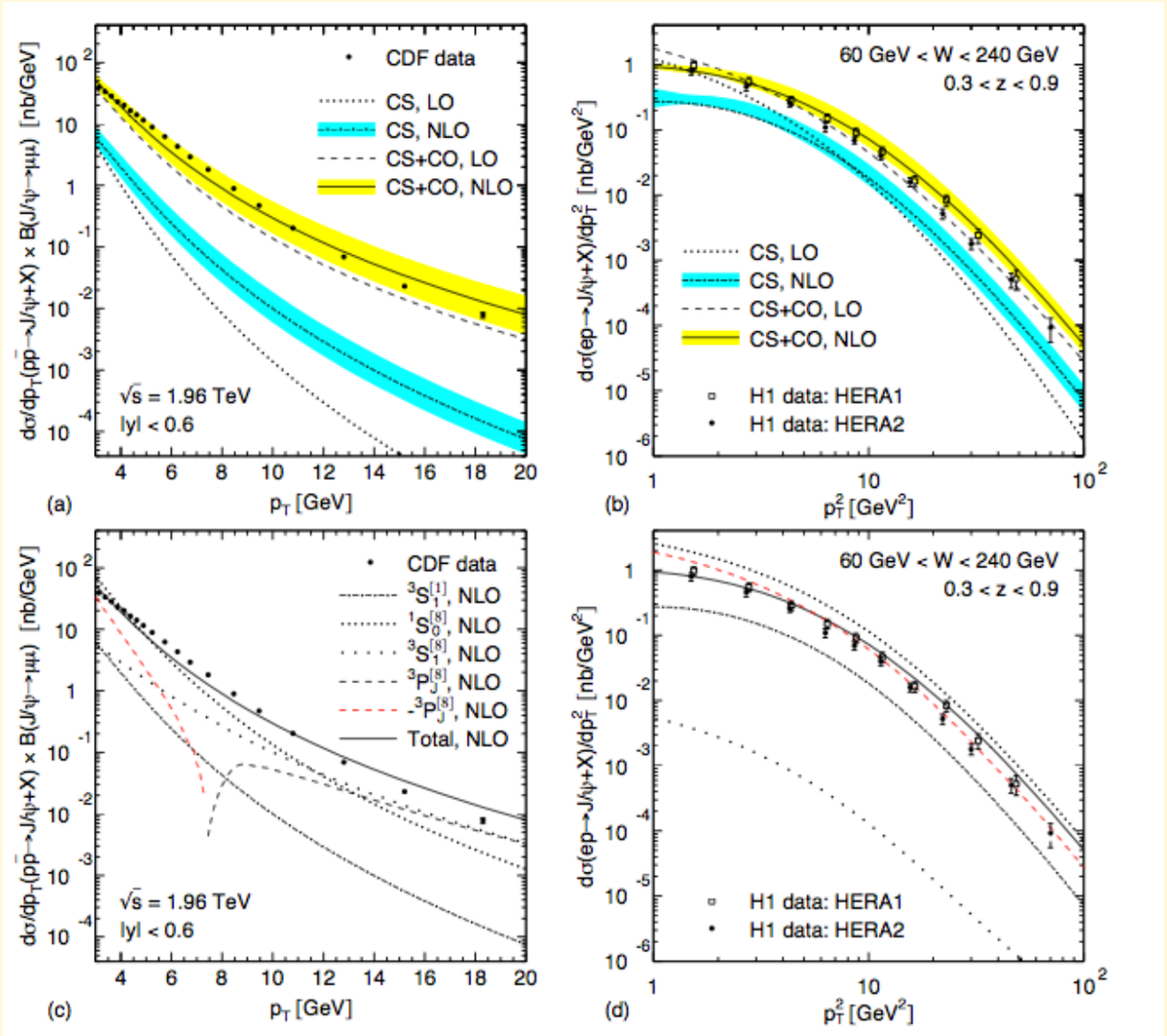


Material on this slide from Fabio Maltoni's talk at "Hard Probes 2010", Eilat

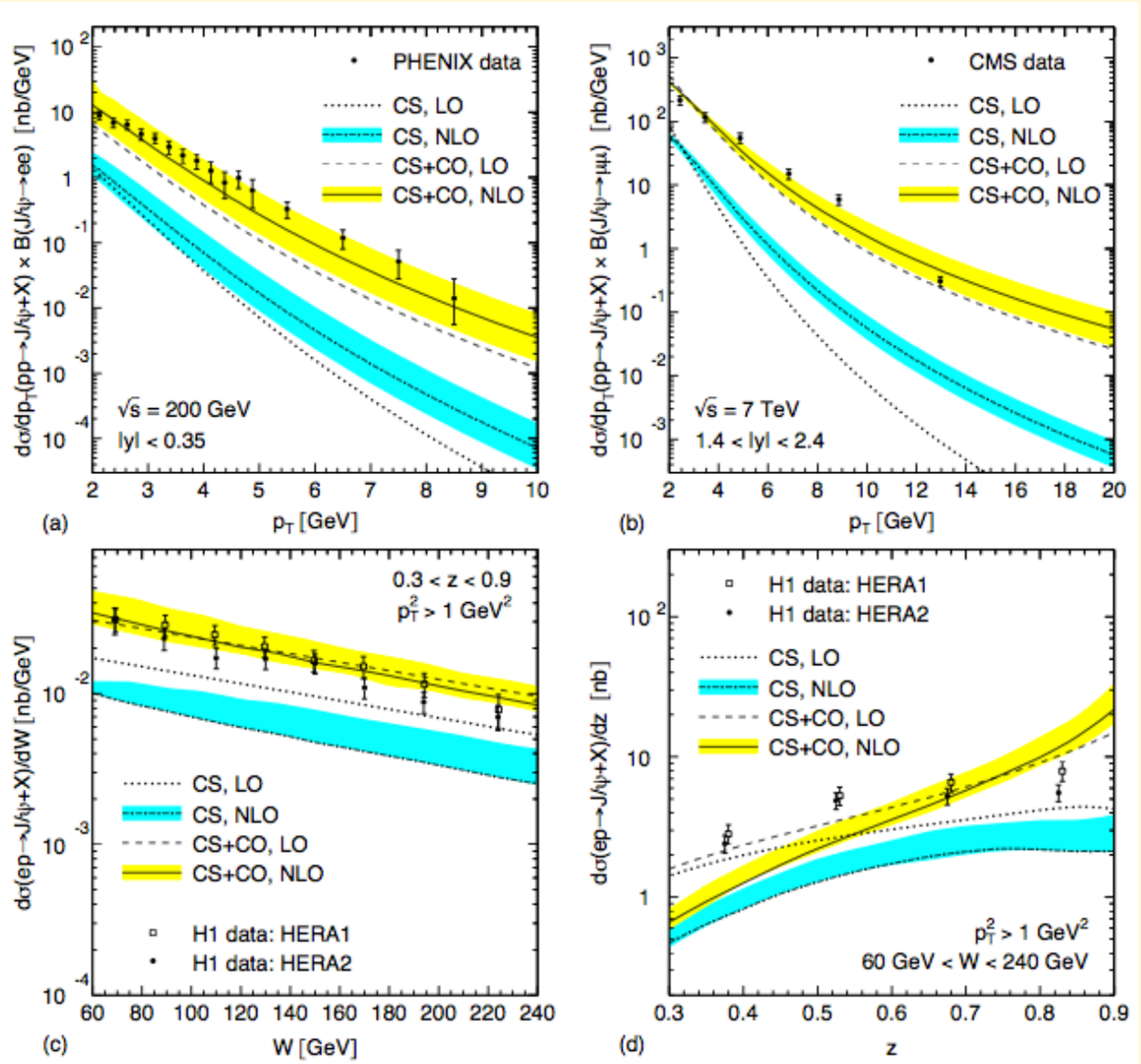
Reconciling J/ψ production at HERA, RHIC, Tevatron, and LHC with NRQCD factorization at next-to-leading order

Mathias Butenschön, Bernd A. Kniehl

arXiv:1009.5662v1



Fit inputs

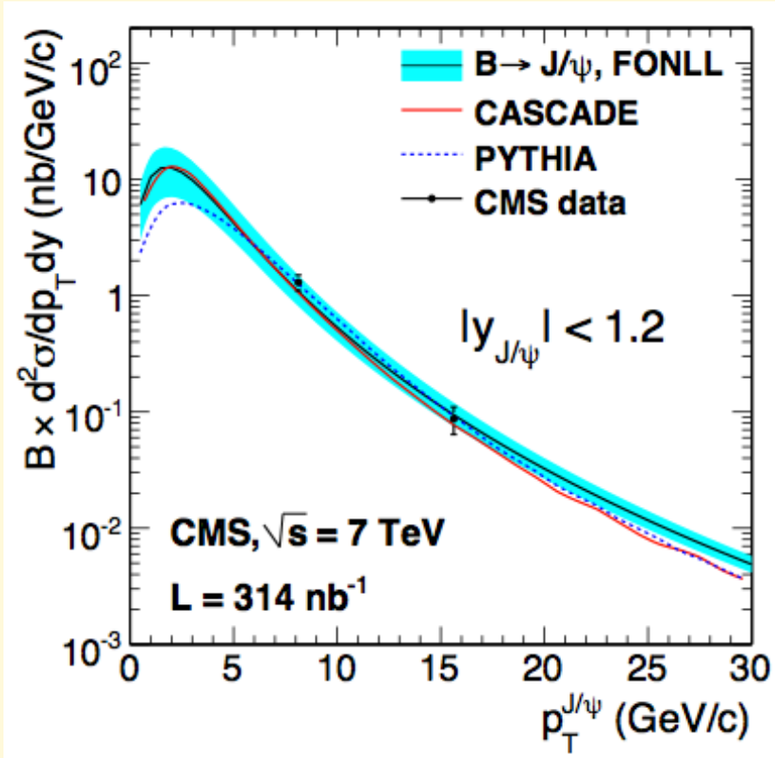


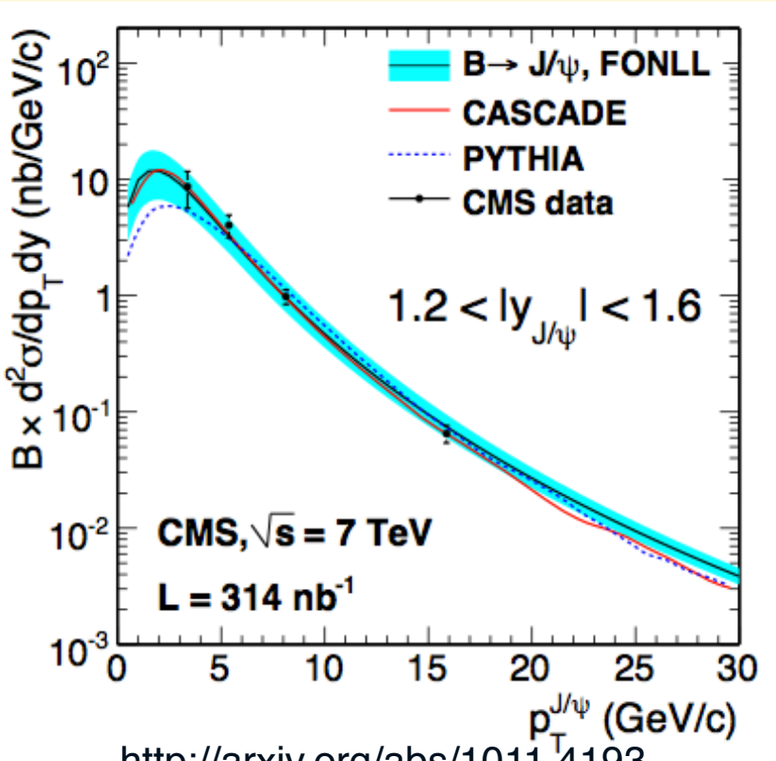
Predicctions

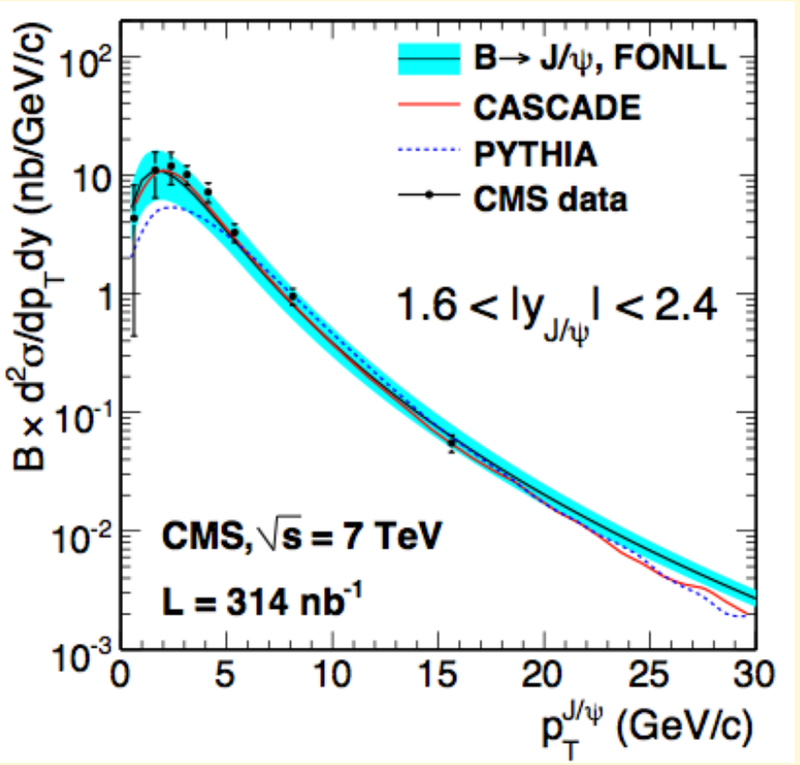
Conclusions

- Several are the mechanisms for quarkonium production in hadron collisions and not all understood at the same level of accuracy.
- In all cases, QCD (or effective theories matched onto QCD) are (or should be) used, so descriptions are first-principle based.
- A large and significant number of theoretical results have been published in the last 2-3 years which have brought NRQCD to the NLO level and more and allow global analyses.
- **In a nutshell, consensus has grown on the fact that higher order corrections in v (e.g. octets) and/or in α_S (e.g. NNLO*) are essential to give a consistent description of the present data.**
- Predictions and MC tools for the LHC are constantly improved and we are looking forward to detailed new studies...!

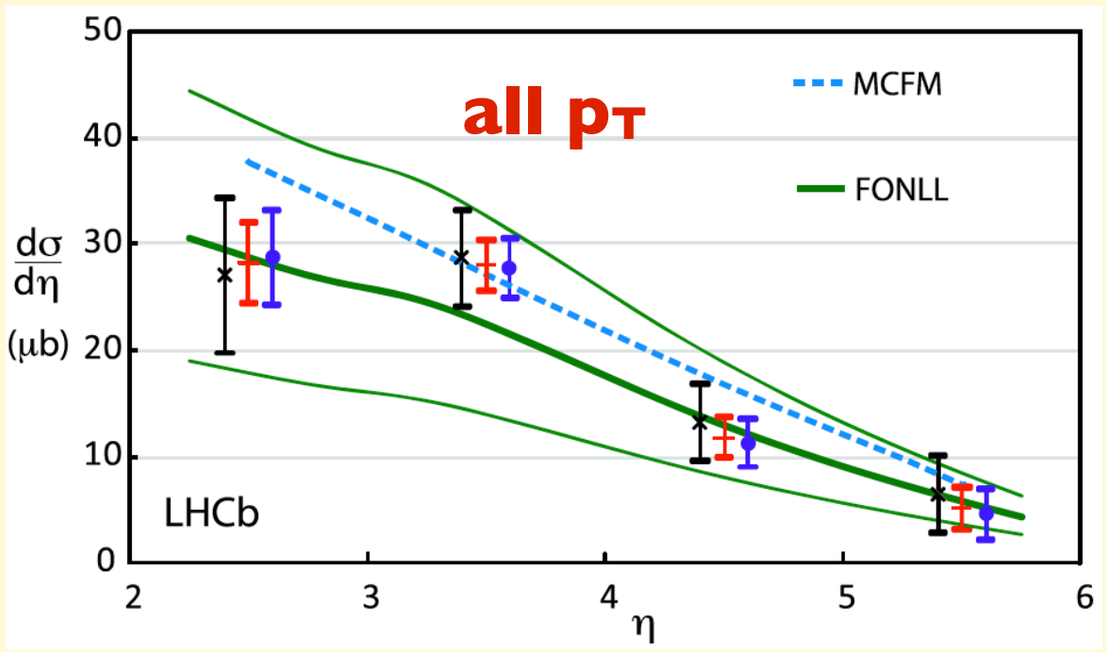
Open Q: by and large good agreement of data and NLO

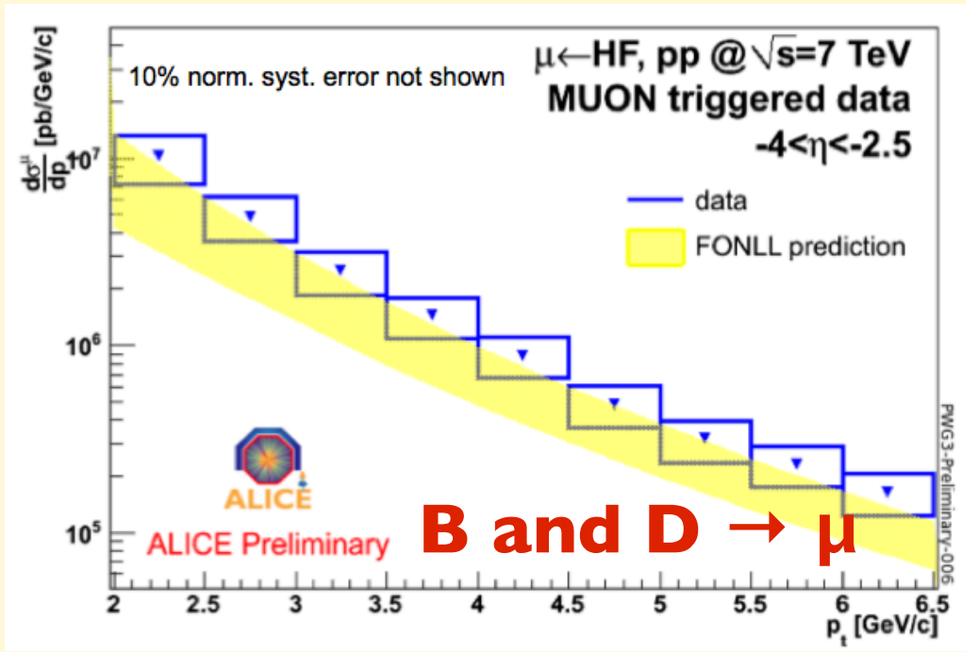






http://arxiv.org/abs/1011.4193



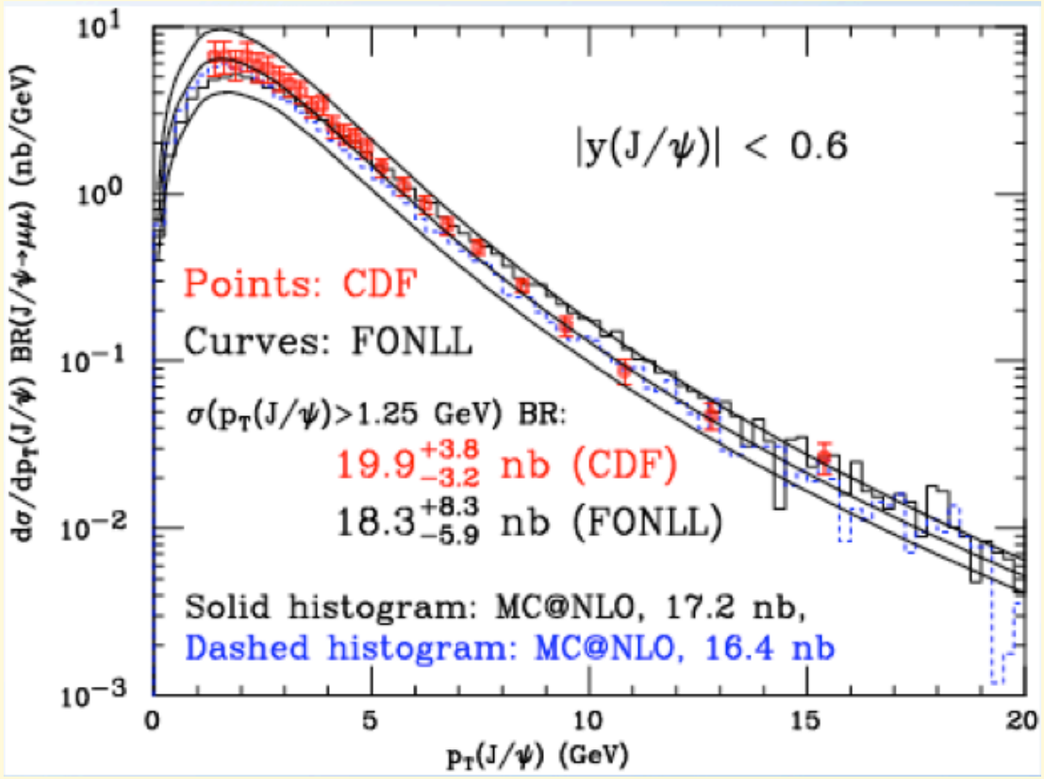


This agreement is one of the most significant results from LHC-2010

Why is it not trivial?

It took a while to establish consistency between Tevatron data and pQCD

hep-ph/0411020

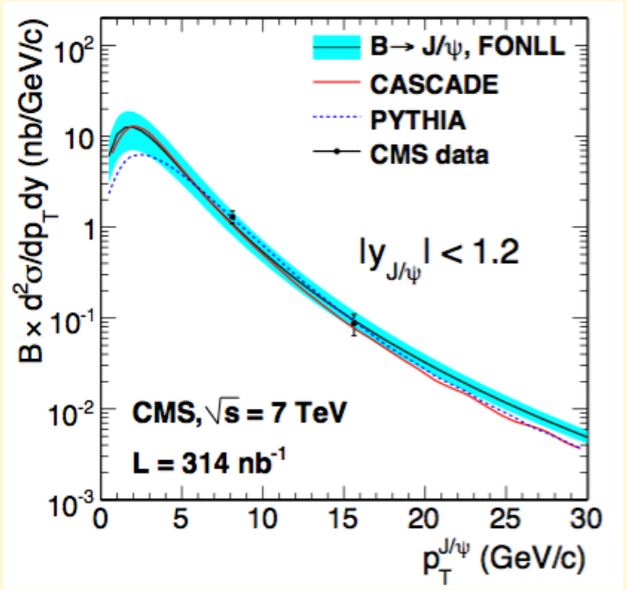


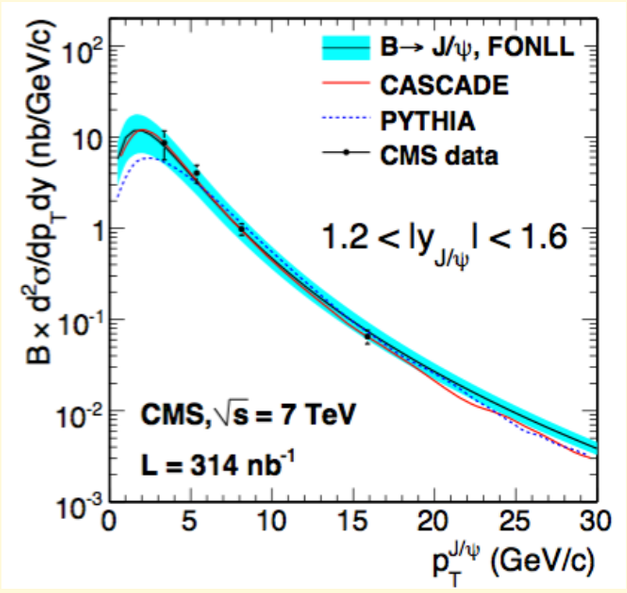
The dynamical regime of the LHC is theoretically more challenging

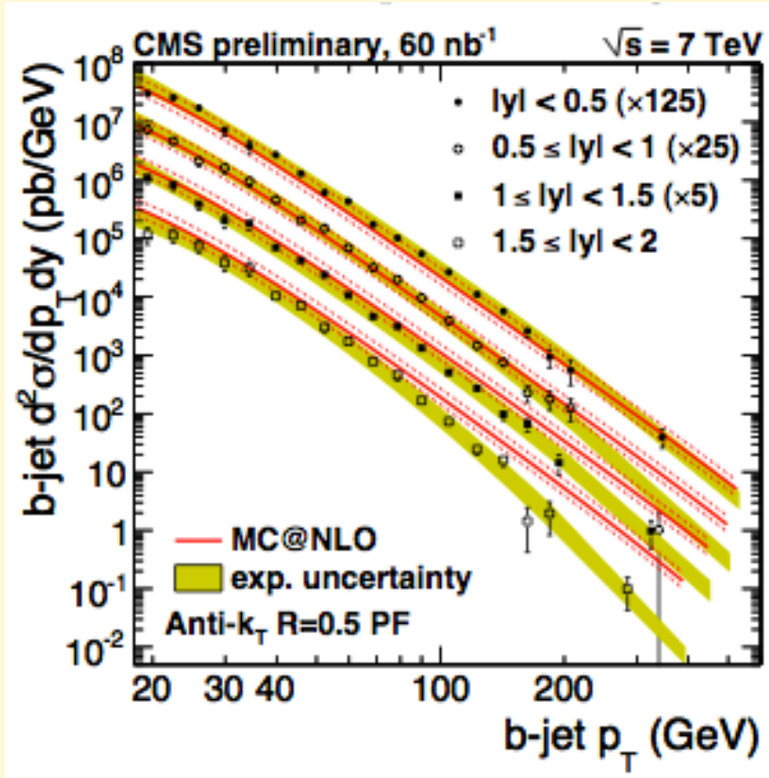
- large S => small x
- large rapidity (ALICE, LHCb)
  - o access to even smaller x
  - o small pt, sensitivity to higher-twist effects

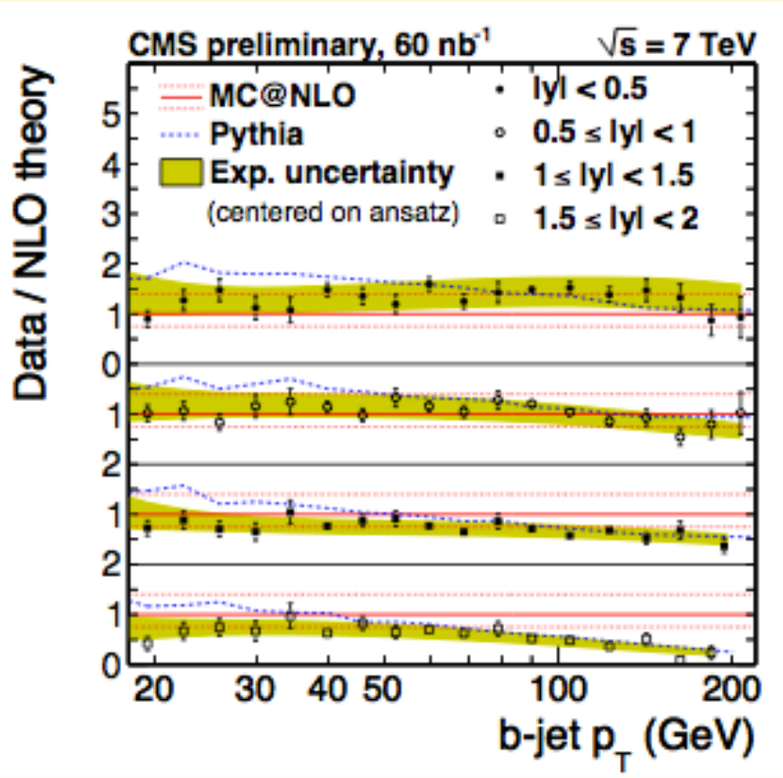
Nason, Dawson, Ellis
Collins, R.K.Ellis
Ball, Ellis
Catani Ciafaloni Hautmann
....

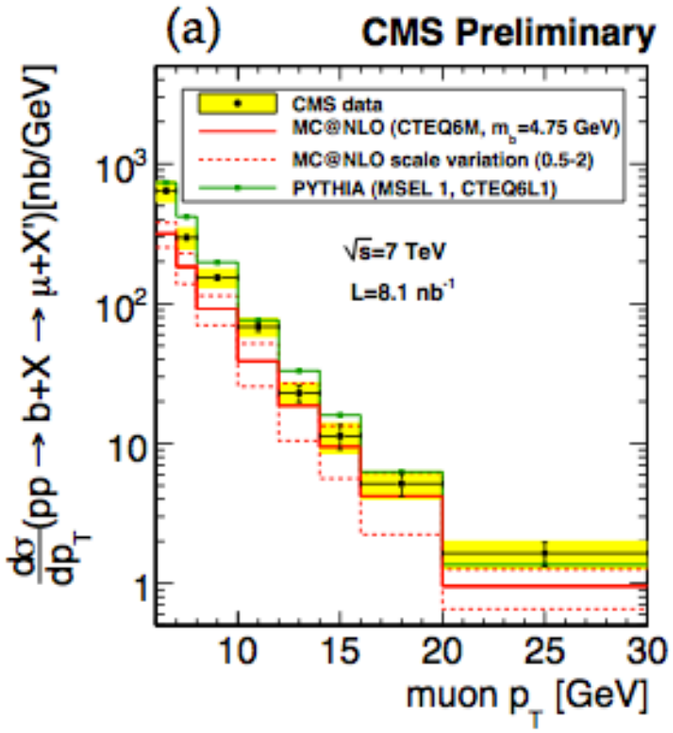
.... still, some inconsistency and disagreement needs to be sorted out

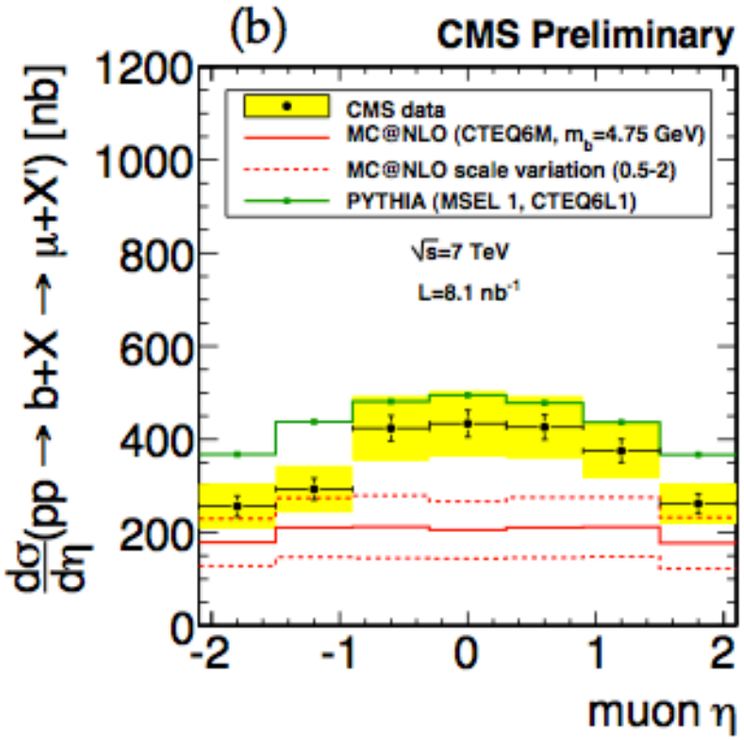












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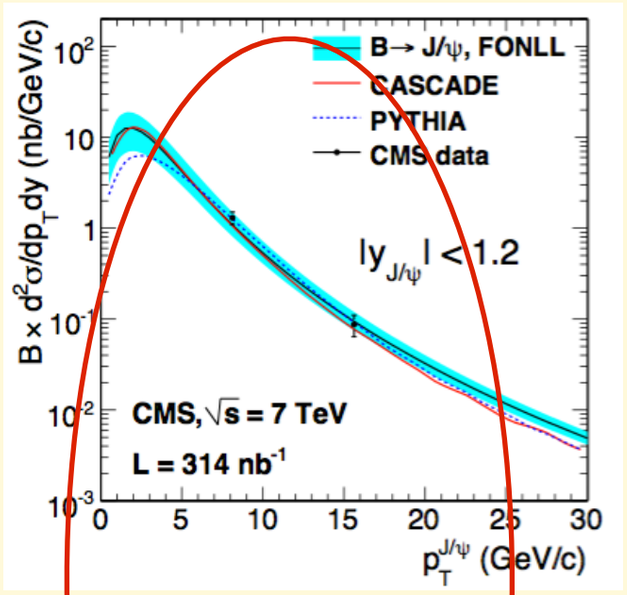

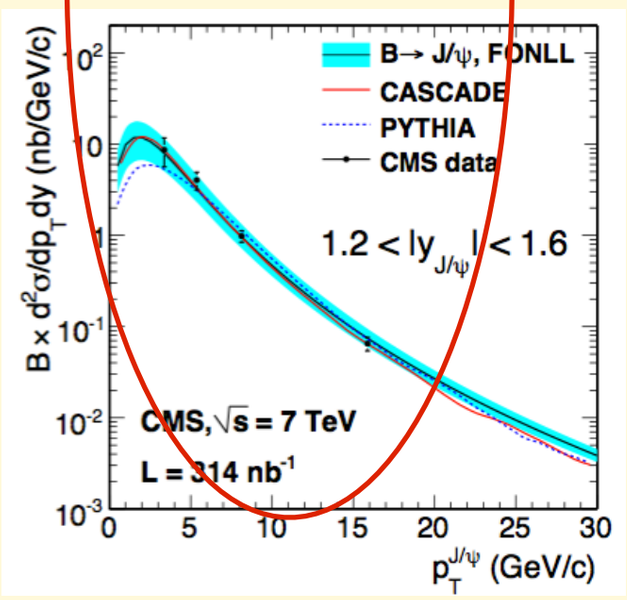

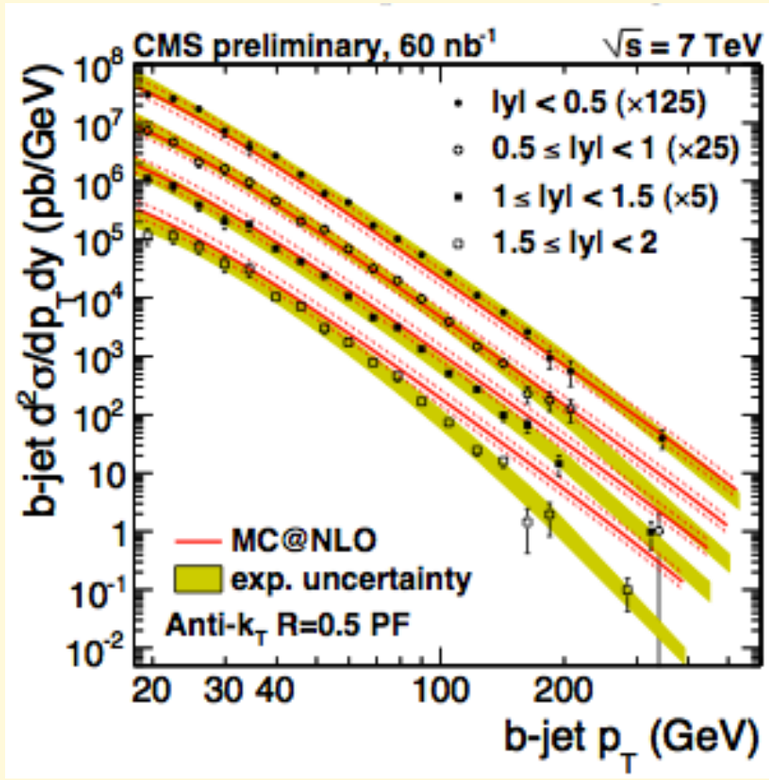

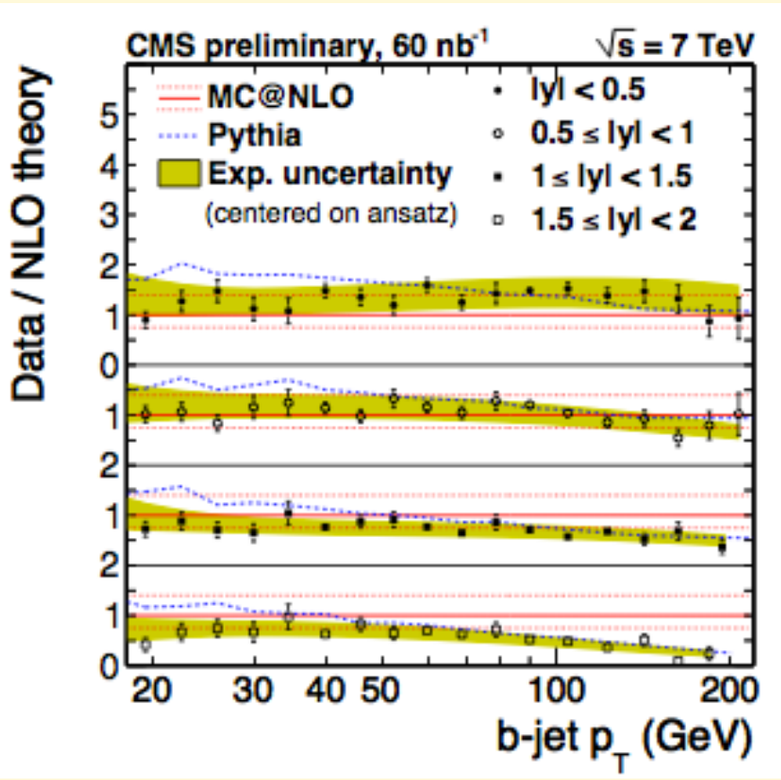

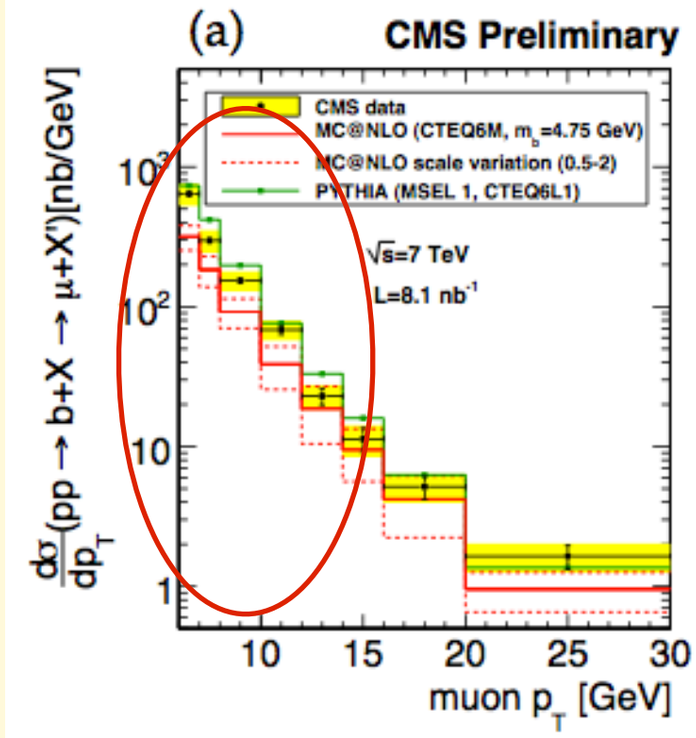

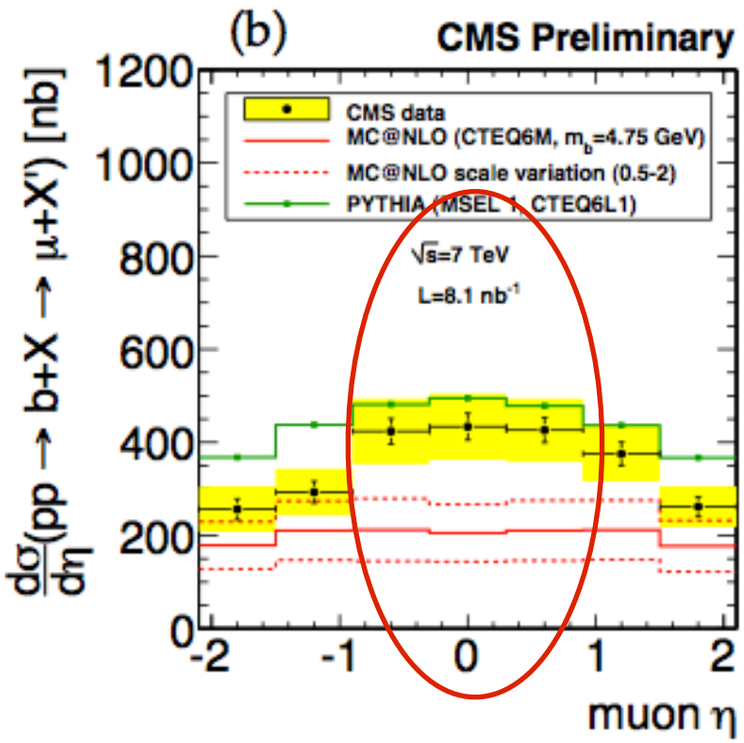

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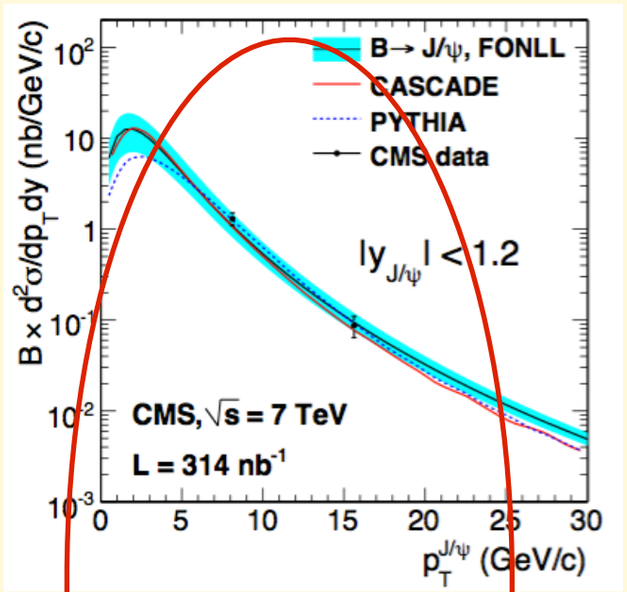
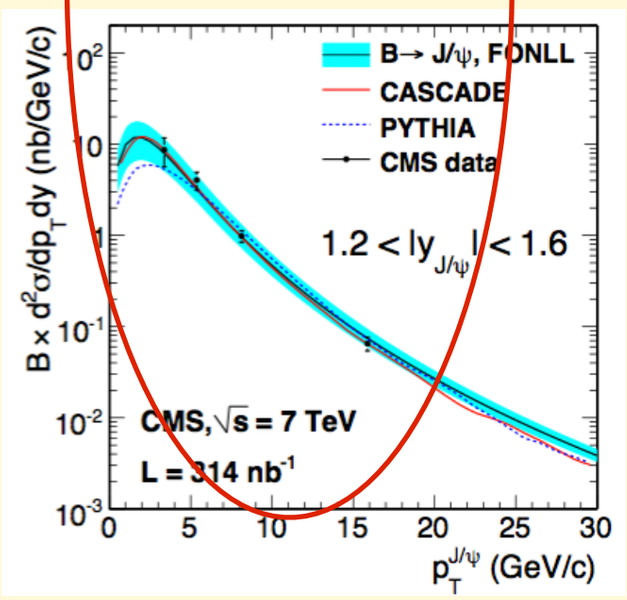
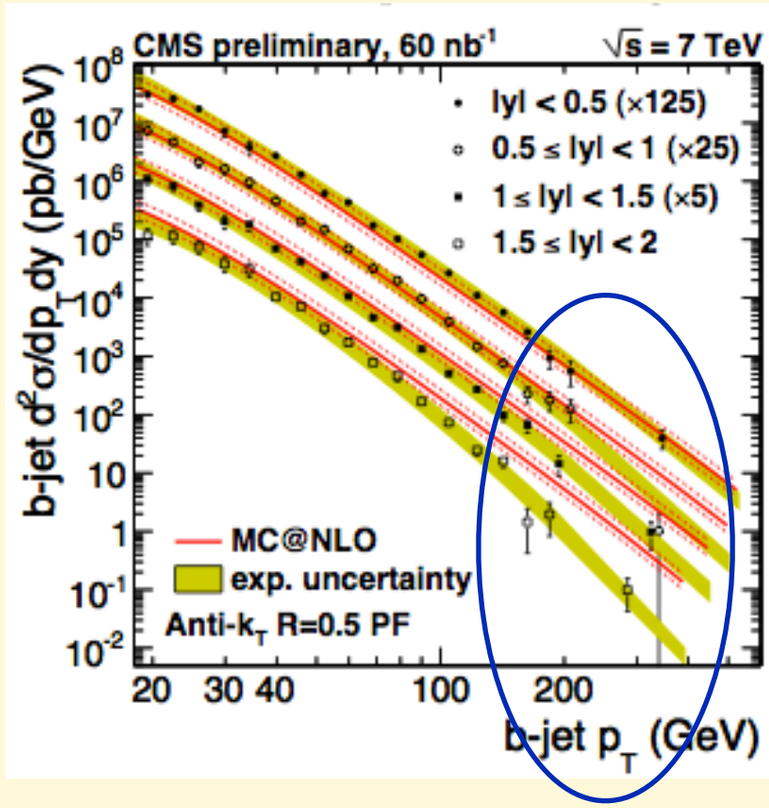
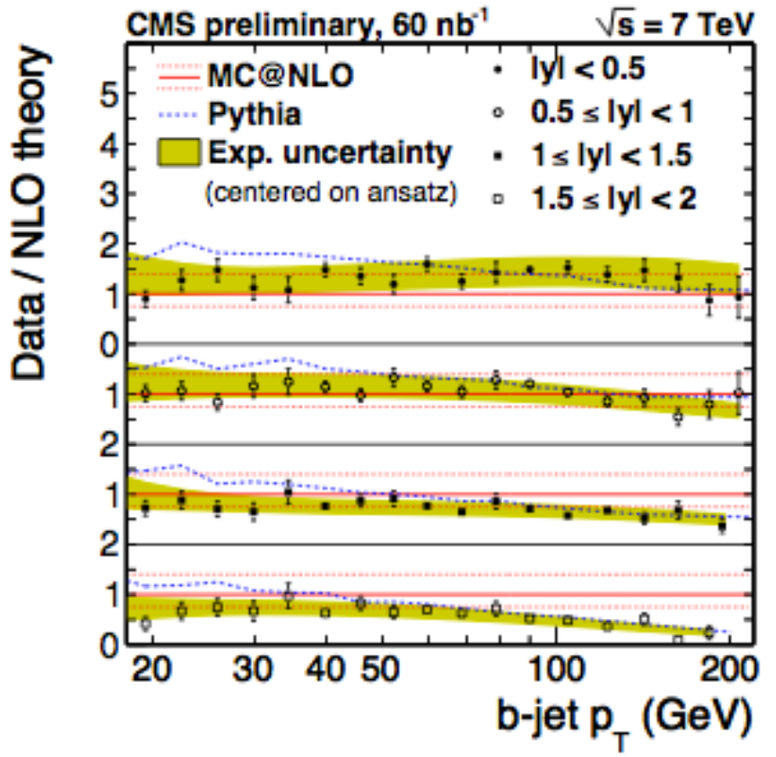
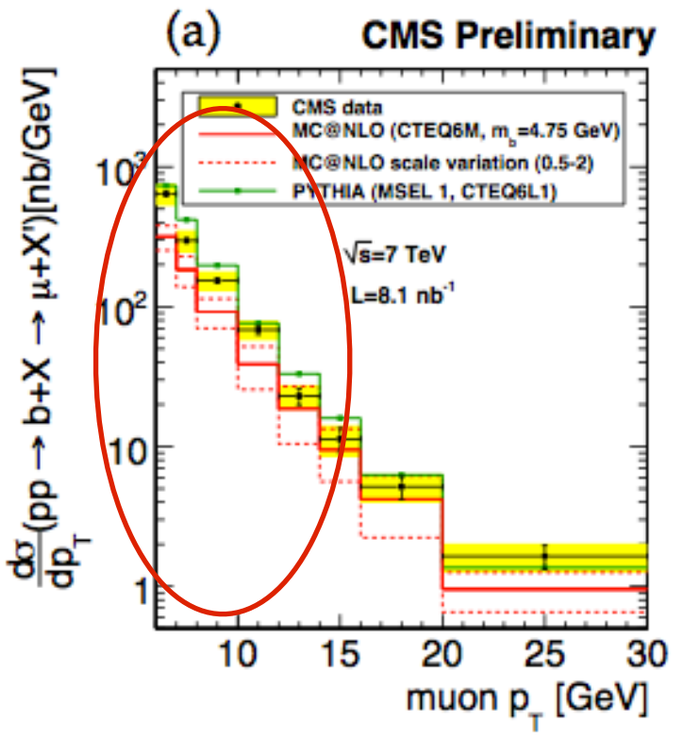
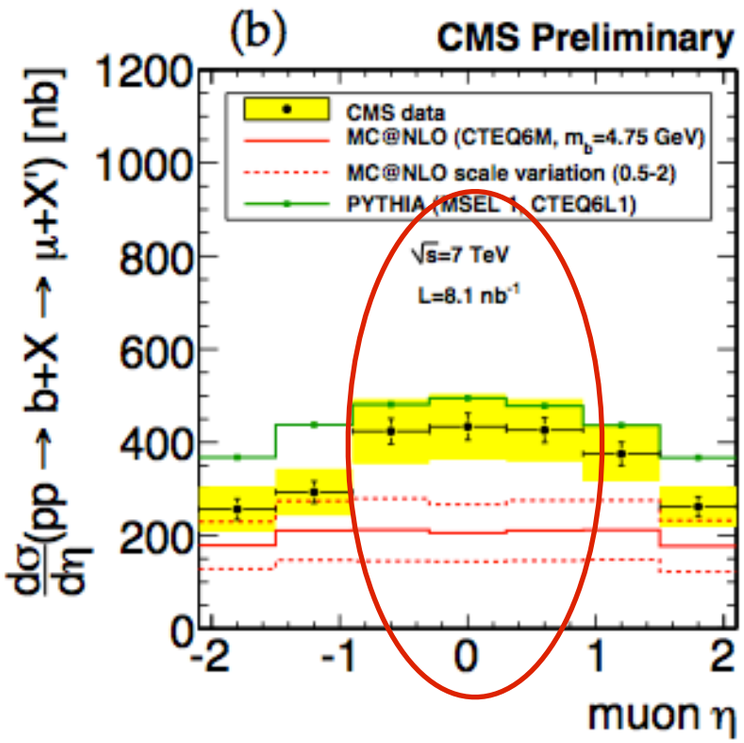




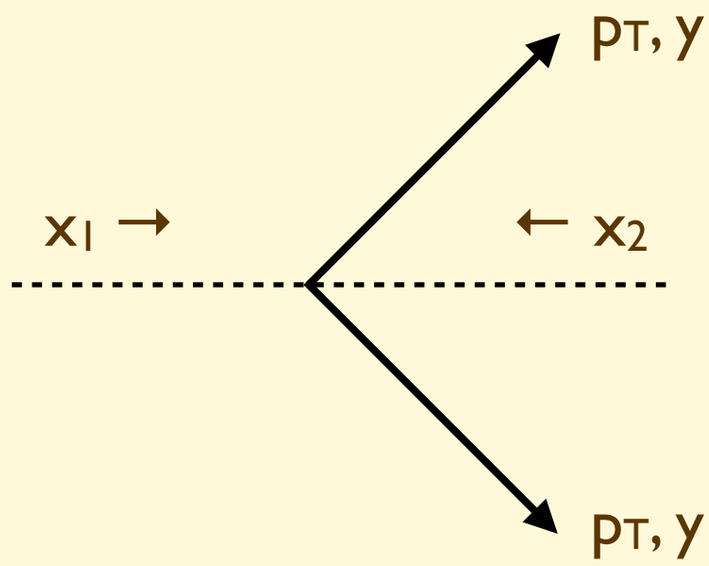




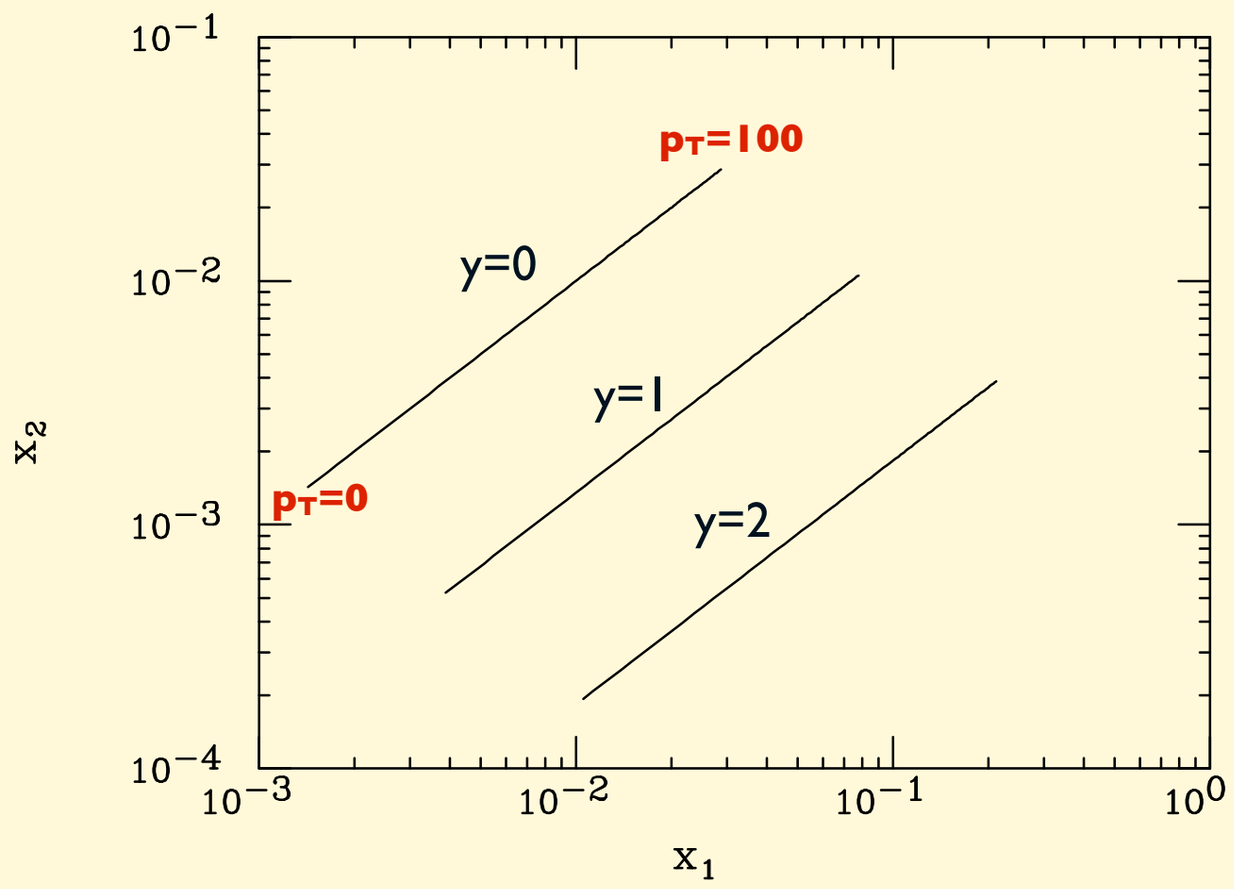


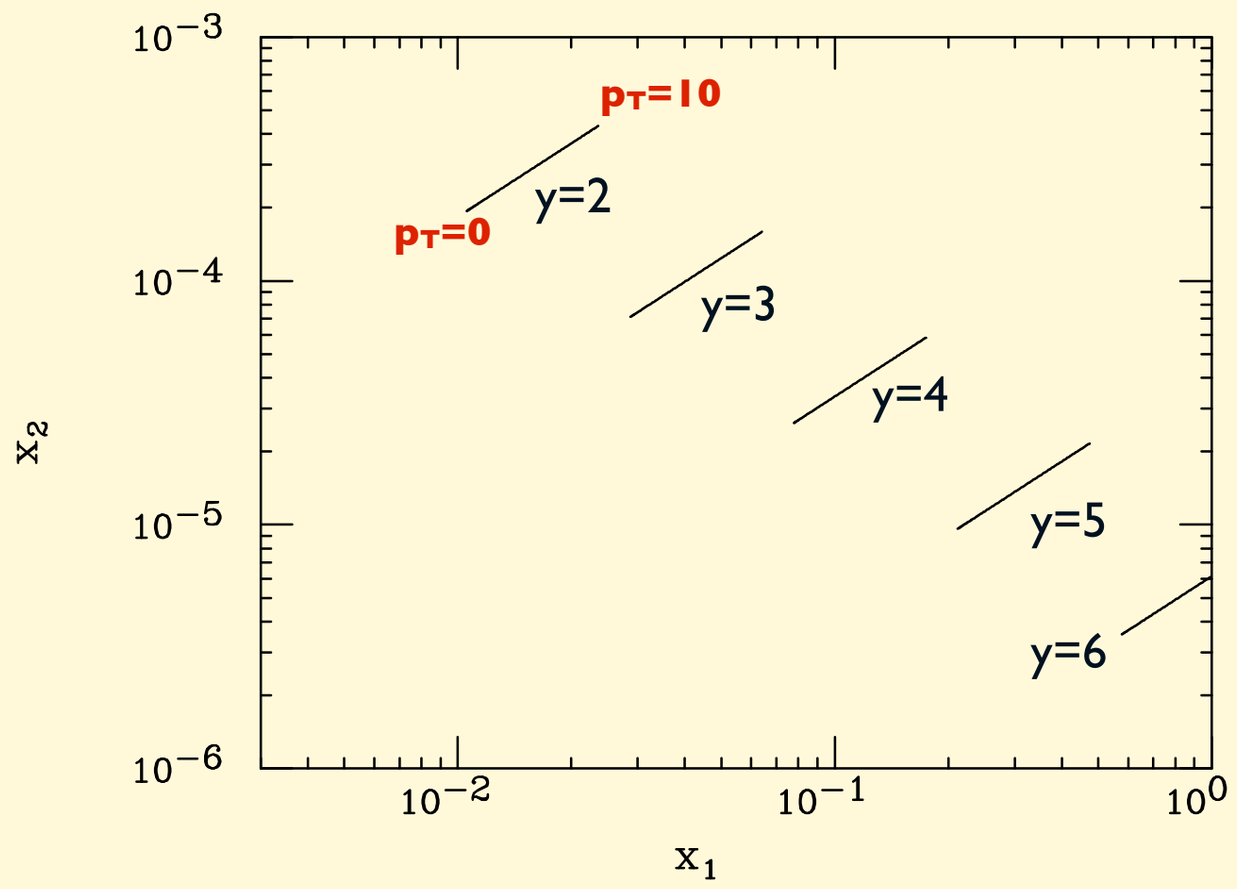


Kinematic reach

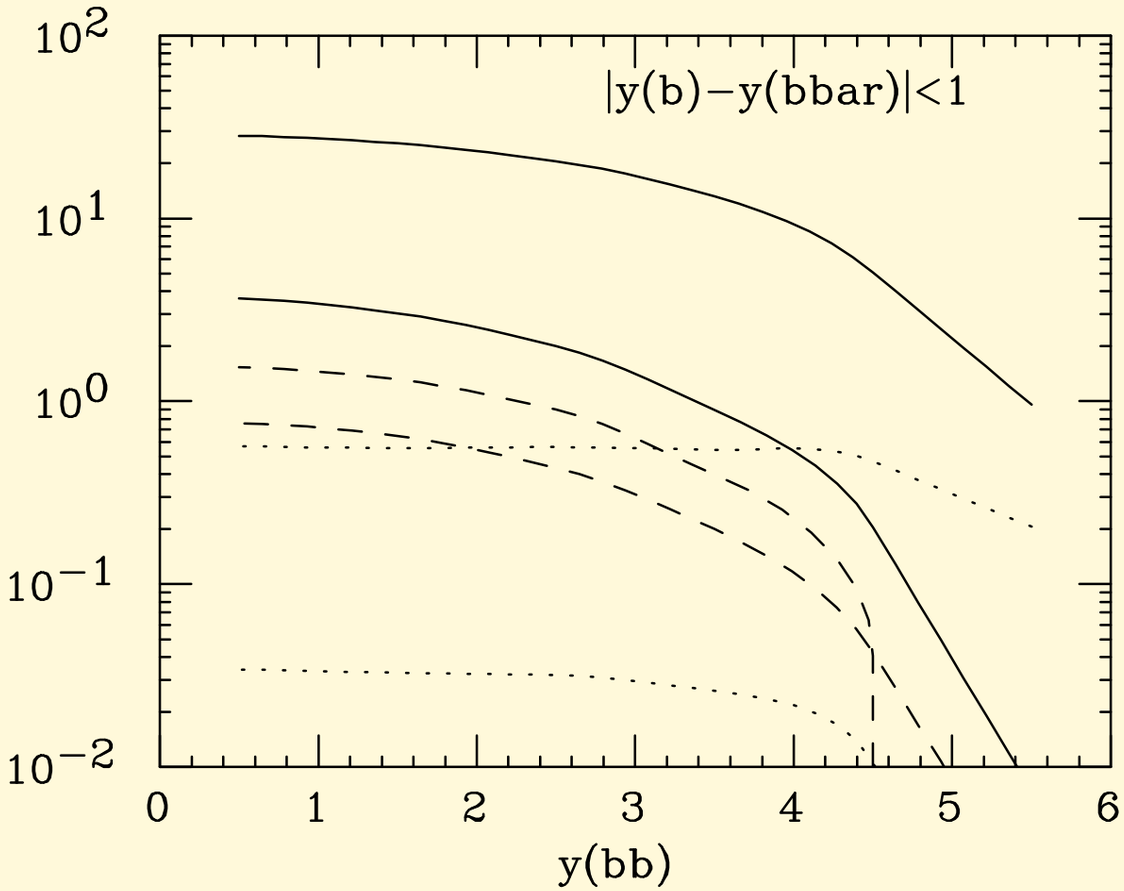


$$x_{1,2} = \frac{m_T}{E_b}\, e^{\pm y}$$





Initial state composition:



gg

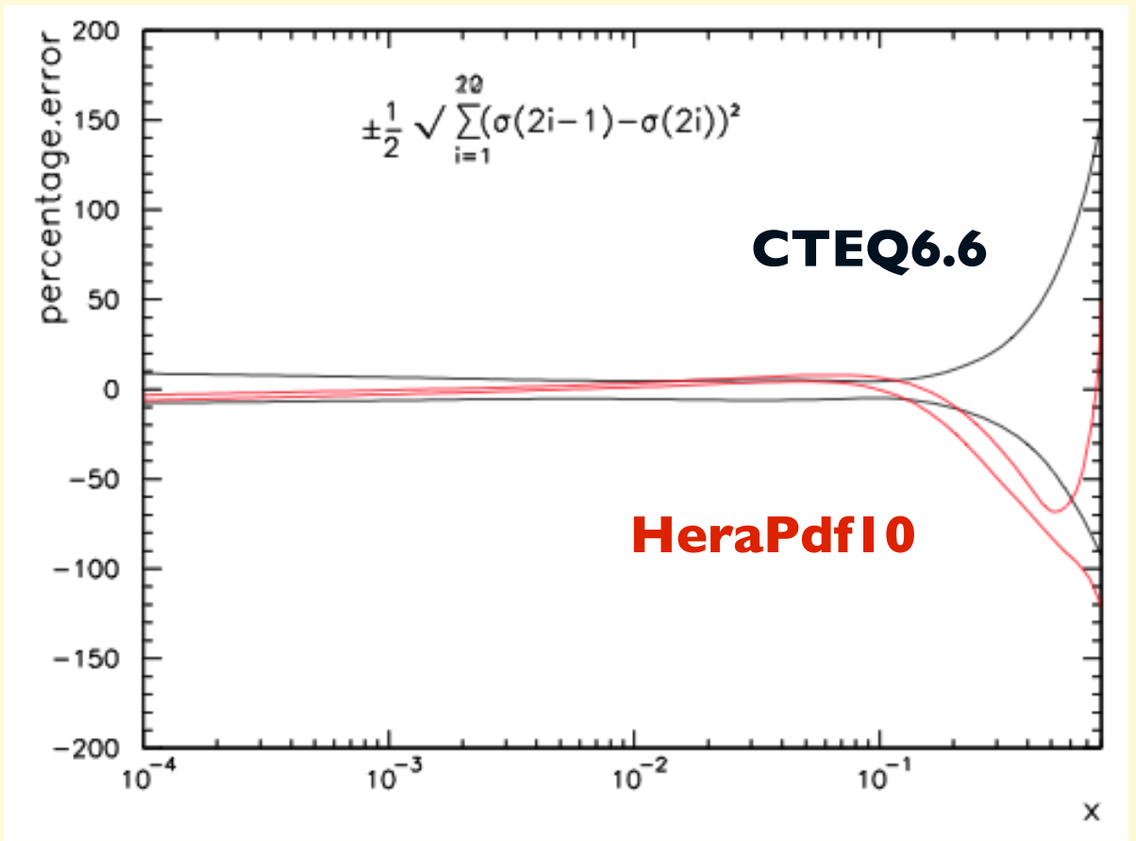
qg

qqbar

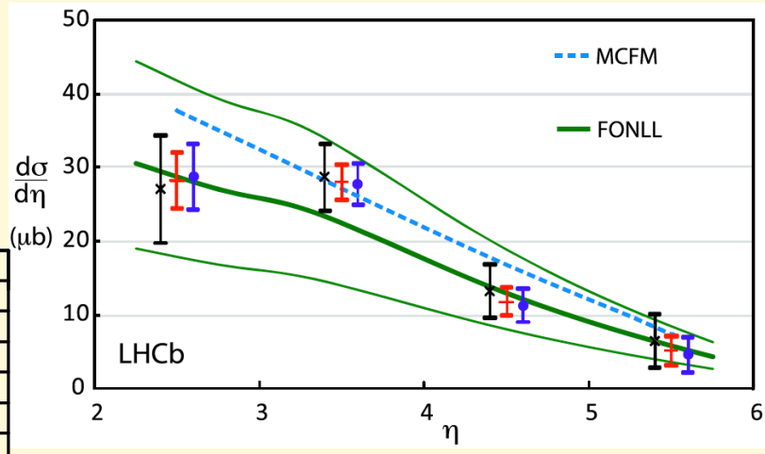
Upper curves: p_T>0

Lower curves: p_T>12 GeV

Dominated by gg initial state, possibly sensitive to gluon PDF



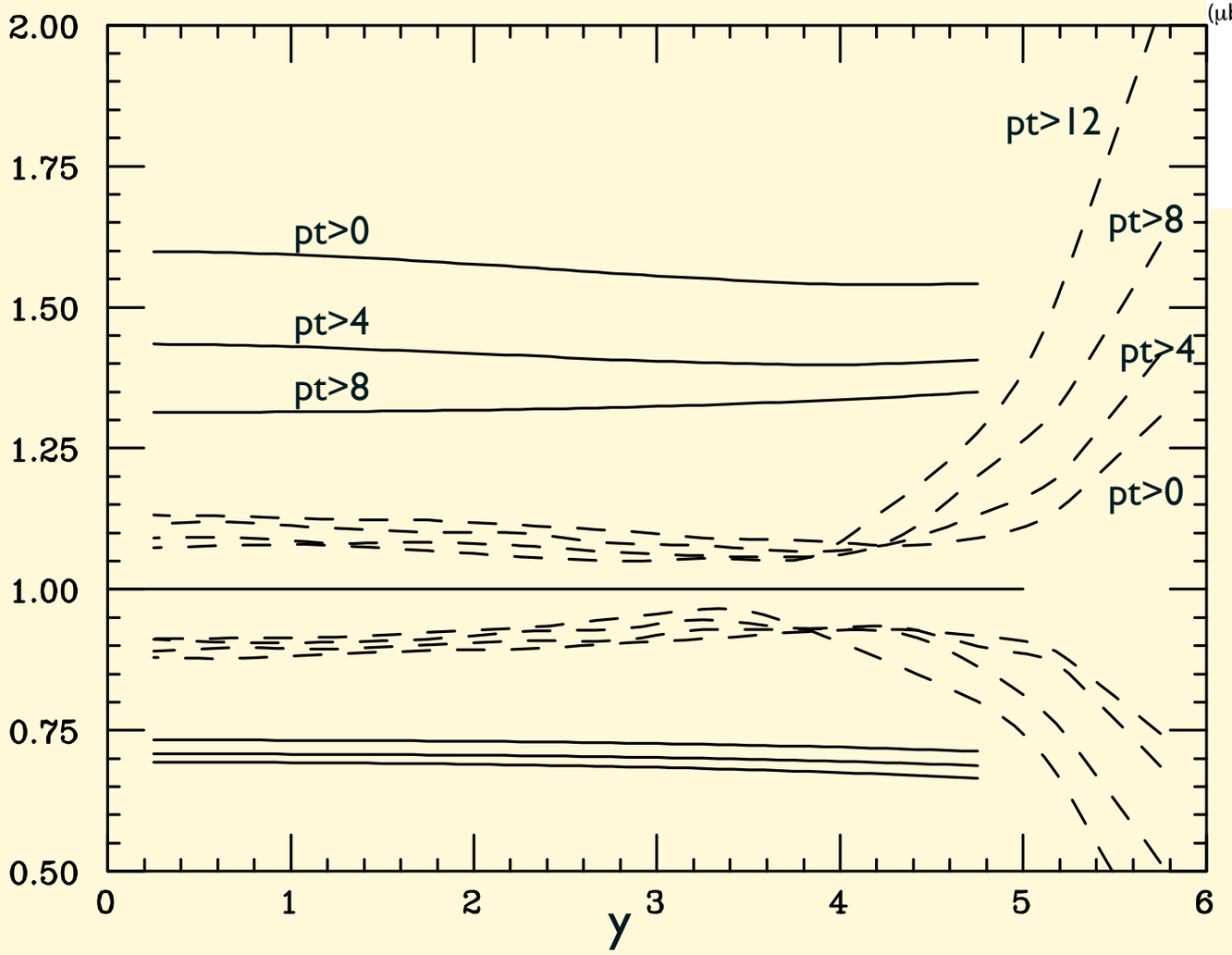
Scale vs PDF systematics



Solid lines: scale/mass systematics

$$\frac{\frac{d\sigma}{dy}(\mu_R^{max}, \mu_F^{max}, m_b^{max})}{\frac{d\sigma}{dy}(\mu_R^{0}, \mu_F^{0}, m_b^{0})}$$

$$\frac{\frac{d\sigma}{dy}(\mu_R^{min}, \mu_F^{min}, m_b^{min})}{\frac{d\sigma}{dy}(\mu_R^{0}, \mu_F^{0}, m_b^{0})}$$



Dashed lines: PDF systematics (CTEQ6.6)

$\mu_{\mathbf{F,R}}^{\mathbf{max,min,0}}, \mathbf{m_b^{max,min,0}}$ parameter values at **maximum, minimum and central** values of the cross-section

- great stability of the y distribution vs scale/mass variations
- scale systematics fully correlated in y, so **y shape is robust**
- scale dependence at the ±30% level dominates over mass-dependence for $p_T \gtrsim m_b$
- PDF systematics affects the shape of the y distribution well beyond the effects of scale variations, once y>4 => **PDF sensitivity**

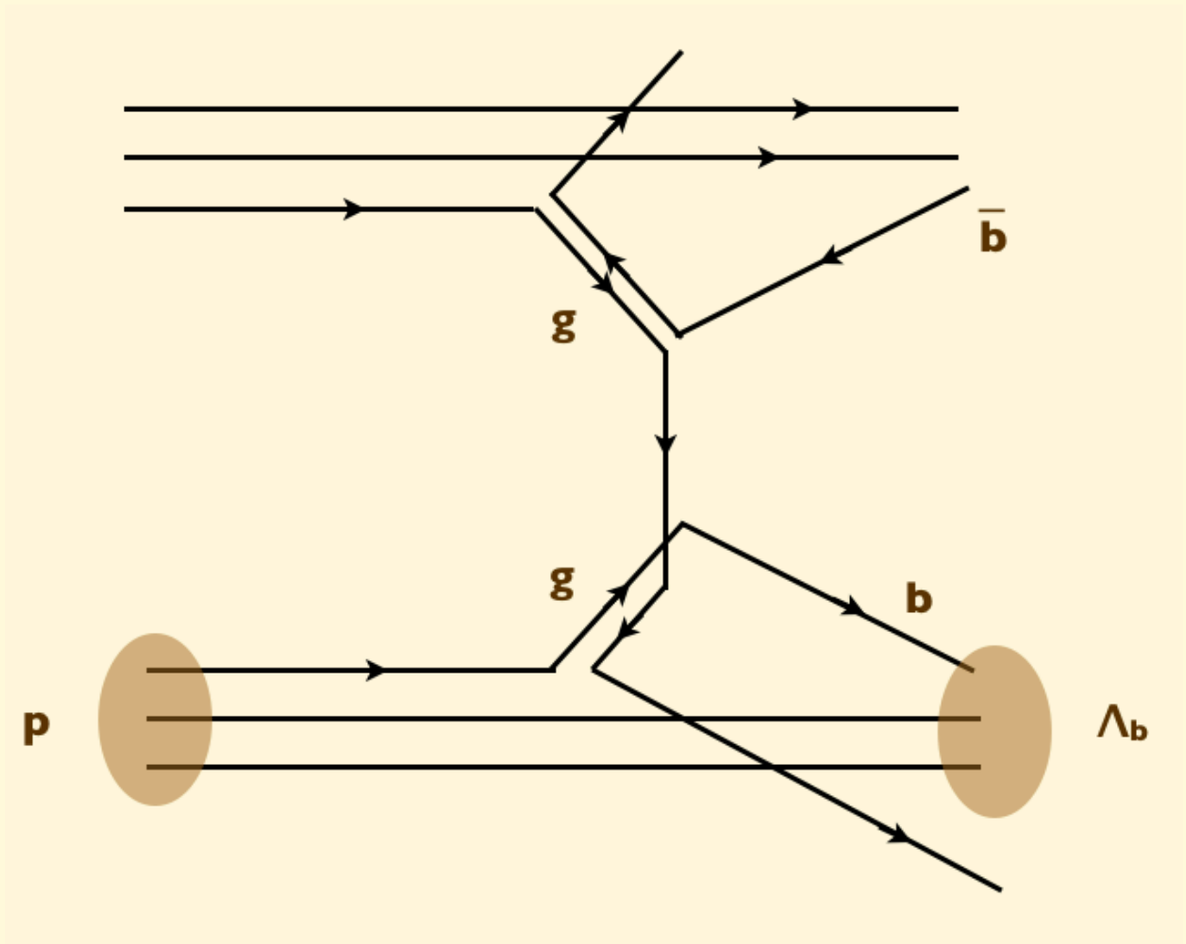
non-pQCD issues

$b \rightarrow H_b$ fragmentation fractions:

Species	Z^o fraction (%)	Tevatron fraction (%)
B^-	40.3±0.9	33.3±3.0
B^0	40.3±0.9	33.3±3.0
B_s	10.4±0.9	12.1±1.5
Λ_b	9.1±1.5	21.4±6.8

- **Needs clarification!**
- **To the least it points to — not unexpected — deviations from factorization**
- **In view of the CP non-invariance of the initial state, and of the forward kinematics of LHCb, each individual fraction will have to be measured very accurately**

Example



$$gg \rightarrow \overline{b}\,\Lambda_b$$

$$gg \not\rightarrow b\,\overline{\Lambda}_b$$

$$\frac{N(B^0)}{N(\bar{B}^0)} = \frac{1 - f(b \rightarrow \Lambda_b)}{1 - f(\bar{b} \rightarrow \bar{\Lambda}_b)}$$

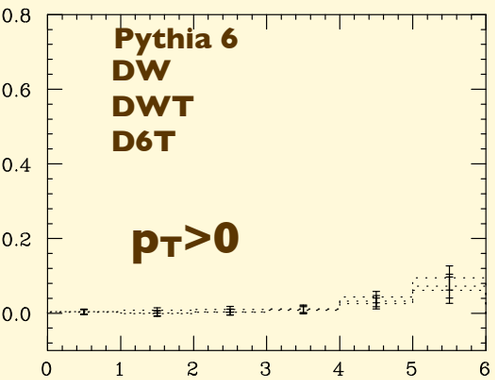
$$A(y) = \frac{dN(\Lambda_b)/dy - dN(\bar{\Lambda}_b)/dy}{dN(\Lambda_b)/dy + dN(\bar{\Lambda}_b)/dy}$$

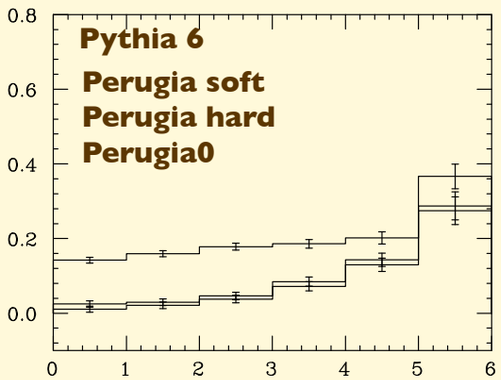
If A(y)≠0 ⇒ N(B)≠N(Bbar) ⇒ apparent CP violation!

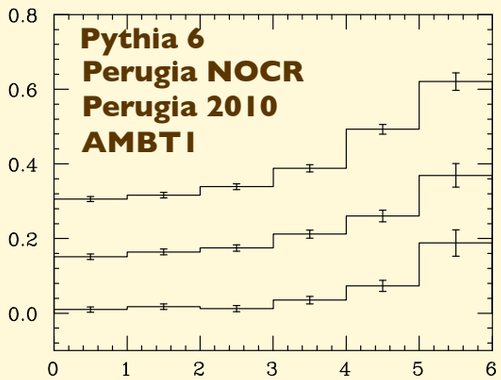
Modeling

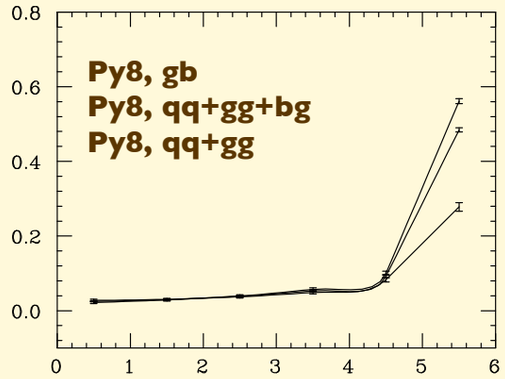
Thanks to P.Skands, T.Sjostrand, D.Grellsheid for providing these predictions

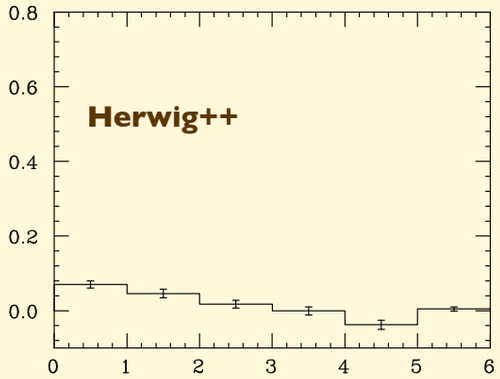
A(y) predictions from various MC codes and tunings:

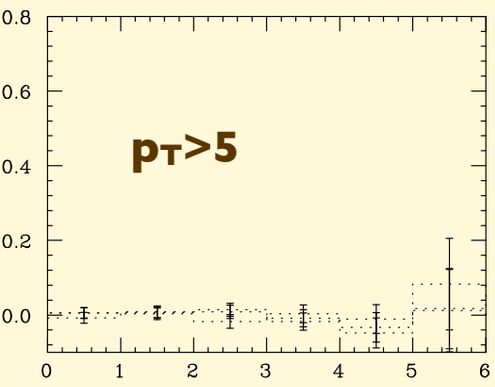


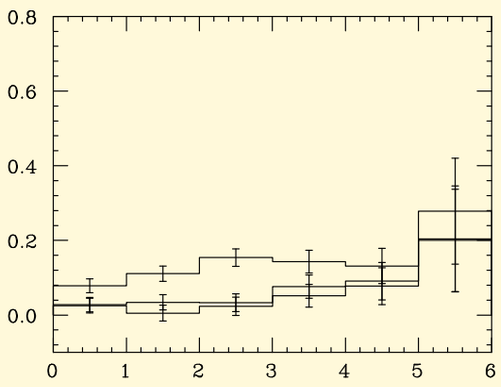


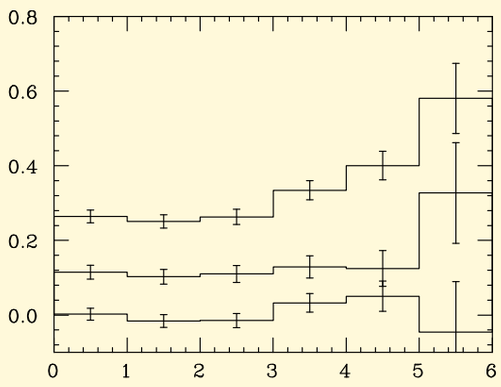


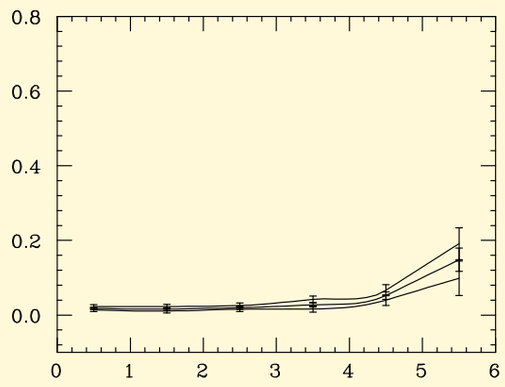


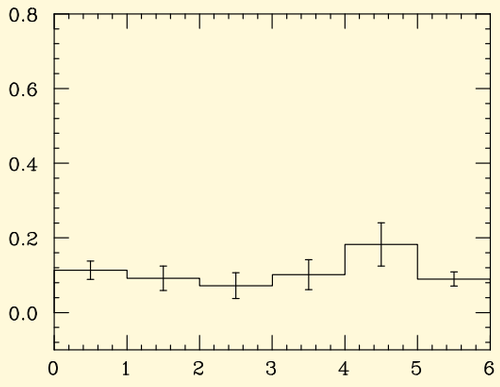




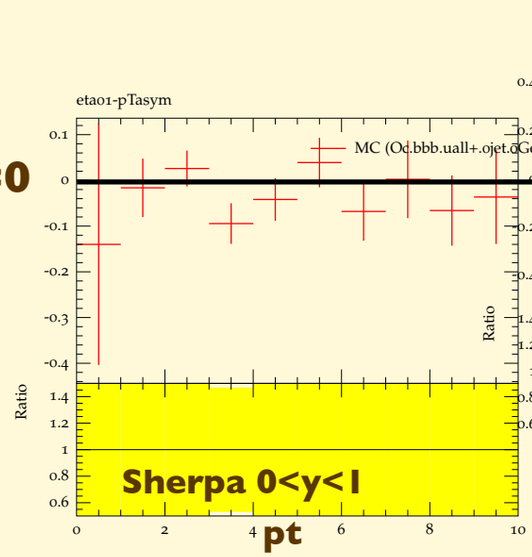


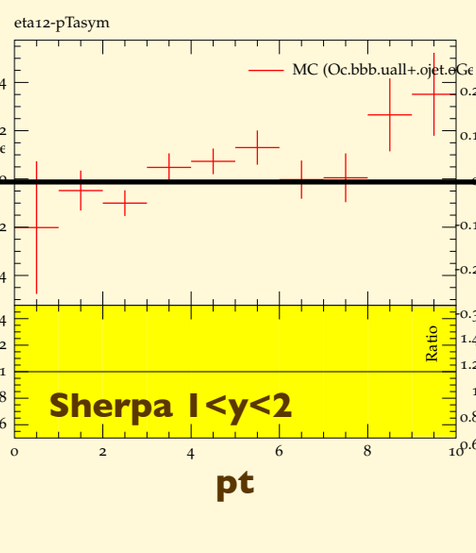


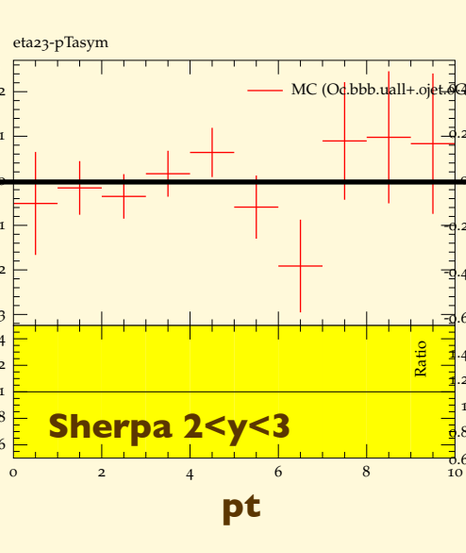


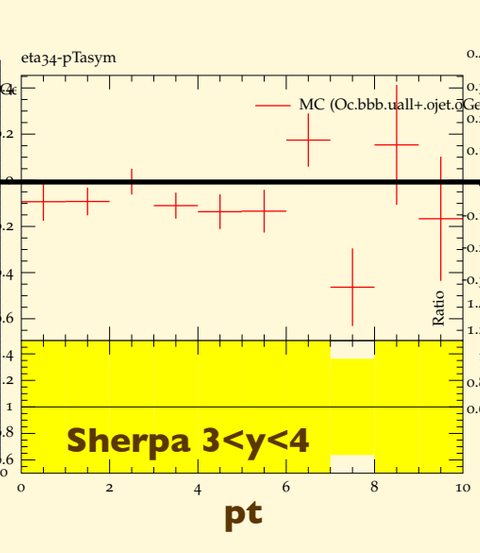


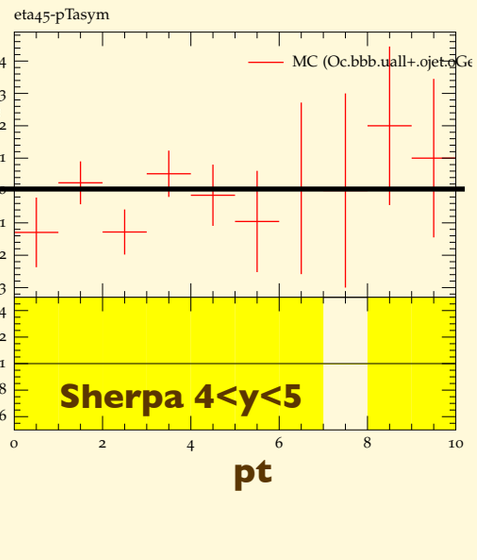
A=0











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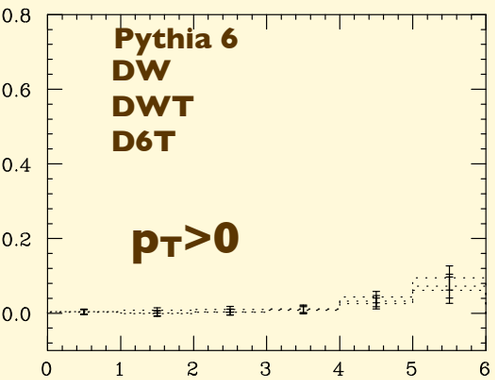

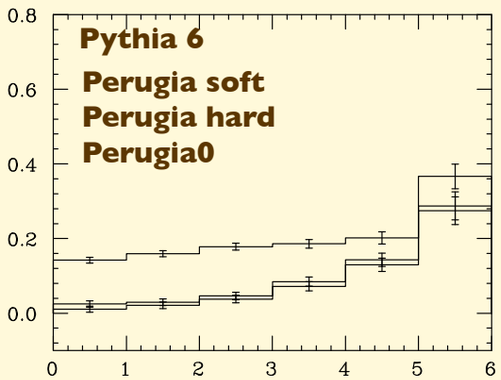

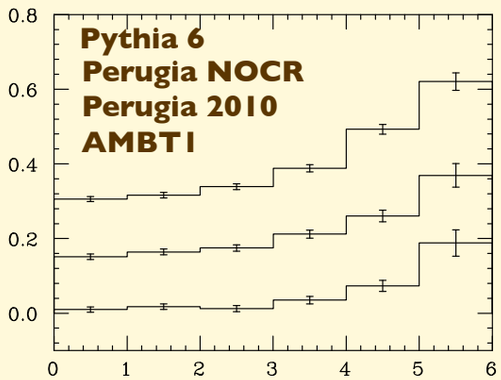

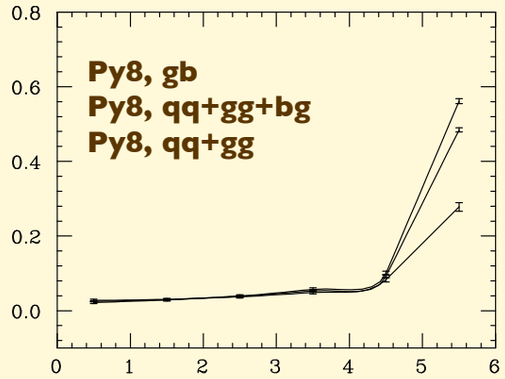

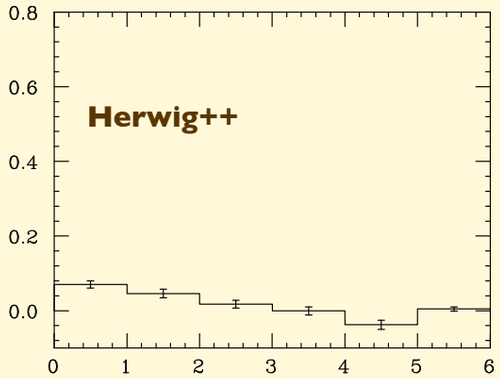

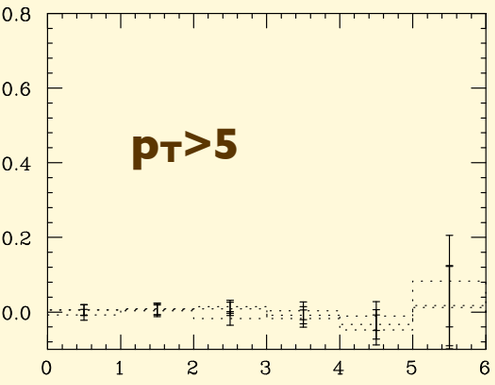

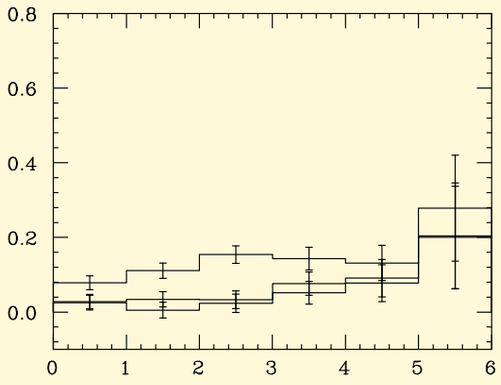

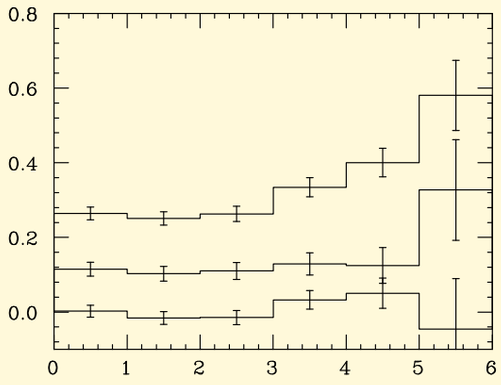

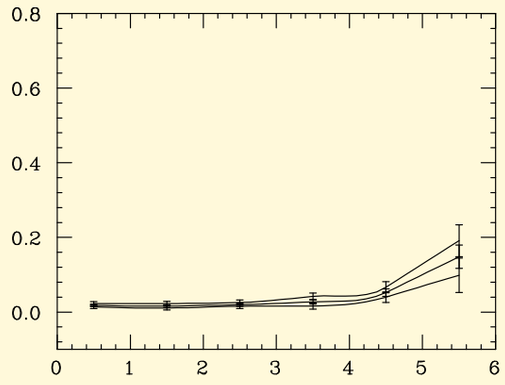

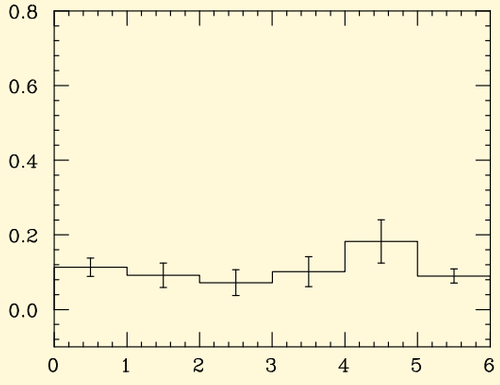

- **Very broad range of "predictions", no robust benchmark**
- **Strong dependence on modeling of perturbative part: more/less gluon radiation will reduce/increase the color-coupling of the b with the proton diquark fragment**
- **Expect correlation with the modeling of strange and charmed baryons**
- **Looking forward to LHCb data!**