MC production of quarkonia in CMS

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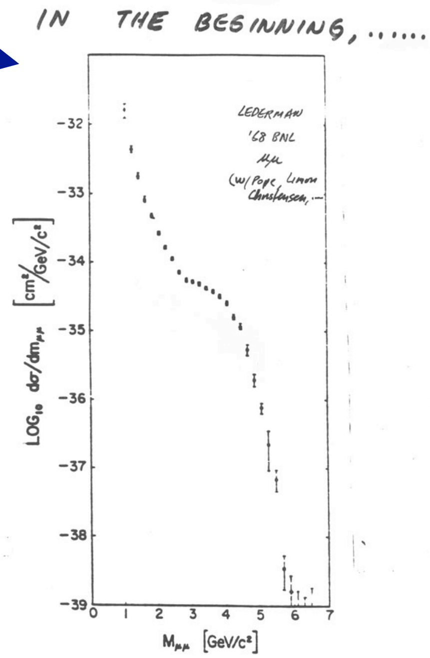
Outline

- Introduction and motivations
- Quarkonium production mechanisms: theory
- Quarkonia production in PYTHIA
- J/psi production at CMS
- Upsilon production at CMS
- Conclusions

Motivations

The J/psi has been discovered more than 30 years ago... and has since then been studied by many experiments like Tevatron, HERA, ...

$Q\bar{Q} = c\bar{c}, b\bar{b}$



Why still study quarkonia at the LHC??

- Still today quarkonium production properties not well understood!
  - Tevatron data not understood! NRQCD-formalism (see next slide) succcesful in explaining P_T(J/psi) spectrum, but not in polarization prediction...
  - Theoretically very recently lots of interesting progress made
  - At LHC: higher P_T values & luminosity allow for new studies
- These kind of analyses can begin in first months of data taking
- We know that they exist! (no exclusion spectra of new physics)

Quarkonia are still highly interesting!

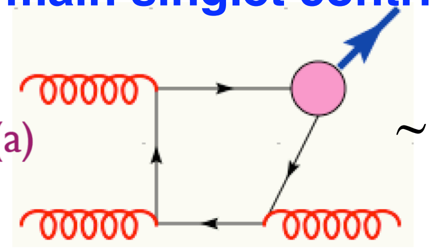
NB This talk is about prompt quarkonia only!

Quarkonium production: theory

Before CDF Run 1 data: J/psi's thought to be produced via singlet mechanism (=$c\bar{c}$ in colour singlet state in hard interaction)

main singlet contribution

(a)



$$\sim \alpha_S^3 \frac{(2m_c)^4}{P_T^8}$$

CDF data did not fit with this hypothesis, especially at high P_T factor 50 too low!

New approaches developed

1) 1995: Non-Relativistic QCD-formalism

- **Quarkonium state written as expansion in v in Fock-space:**
  (v = velocity of Q in bound state in CM)

$$|J/\psi\rangle = O(1)\left|Q\bar{Q}(^3S_1^{[1]})\right\rangle + O(v)\left|Q\bar{Q}(^3P_J^{[8]})g\right\rangle + O(v^2)\left|Q\bar{Q}(^1S_0^{[8]})g\right\rangle + O(v^2)\left|Q\bar{Q}(^3S_1^{[1,8]})gg\right\rangle + O(v^4)$$

- **Production cross section based on factorization method:**

$$\sigma[H] = \sum_n \sigma_n(\Lambda)\left\langle O_n^H(\Lambda)\right\rangle$$

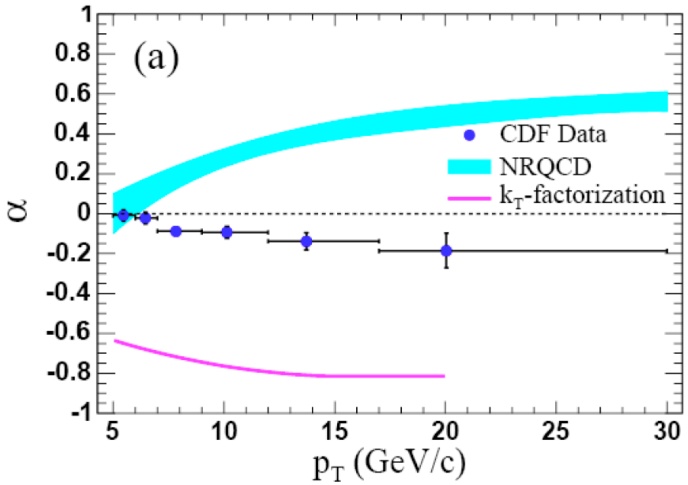
short distance: perturbative QQ- production

long-distance: non-perturbative QQ→colour singlet NRQCD matrix elements

Singlet+Octet mechanism!

Quarkonium production: theory

- Including octet: P_T(J/psi) spectrum at Tevatron explained (tuned)
- However, octet mechanism predicts transverse polarization, while recent polarization measurements favour no polarization! See: CDF coll, arXiv: 0704.0638,



Examples of other models available:

2) Very recent: in NRQCD framework:
singlet model calculations gg $\rightarrow {}^3S_1^{[1]}$ +X refreshed, including NLO, NNLO corrections See eg: Maltoni etal, PRL98:252002,2007 new
NB In this talk "singlet" refers to LO singlet only...

3) Very recent: K_T factorization approach: See talk by S. Baranov yesterday! new

4) Older: Soft-Colour-Interaction models , Colour-evaporation models

Nice overview see J.-P.Lansberg, Int.J.Mod.Phys.A21:3857-3916,2006

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Quarkonium production in PYTHIA

Original implementation

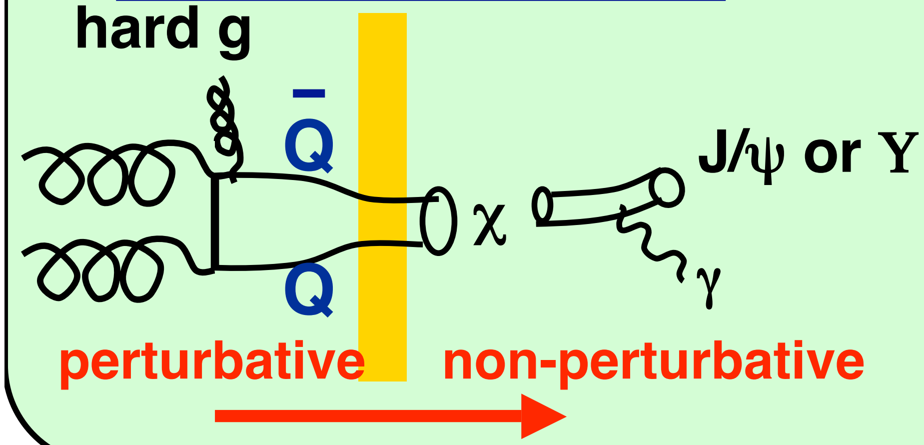
- Done by S. Wolf (2002), but never officially released
  [in all releases < 6.324 only singlet!]
- Based on NRQCD- approach
- Singlet and octet $Q\bar{Q}$ produced perturbatively, followed by shower
- Parton showers for radiation off octet cc ➡ slide 8, 9

Recent (2006, 2007) progress:

- Code integrated (Torbjörn Sjöstrand): PYTHIA ≥ 6.324
- NRQCD matrix elements implemented ➡ slide 10 [See CERN-LHCb-2007-042].
- Possibility to normalize cross section like in UE ➡ slide 11
- Possibility for polarization (with MSTP(195), MSTP(196))
- Generation of J/ψ(1S), Υ(1S) possible (MSEL=61, MSEL=62)
- Extension to ψ(2S), Υ(2S), Υ(3S) possible
- Update on shower switches MSTP(148), MSTP(149) in PYTHIA versions ≥ 6.412, see `http://projects.hepforge.org/pythia6/`

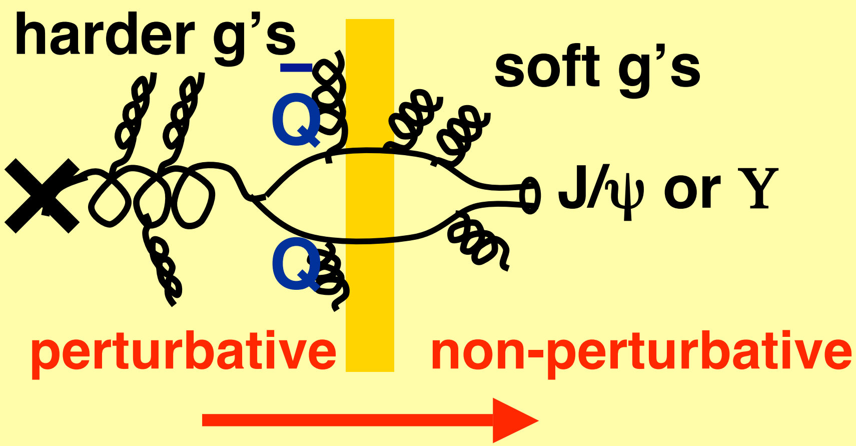
Parton showers

Singlet production



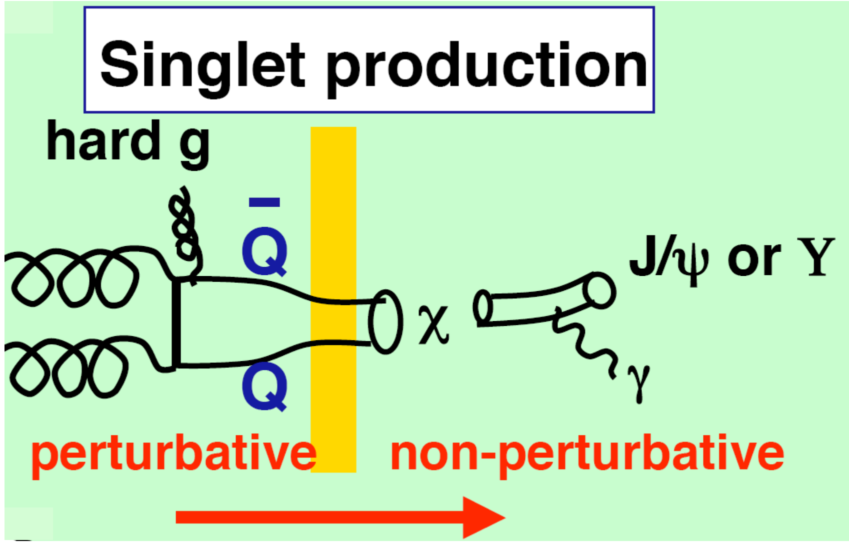
- Quarkonium produced direct or via χ
- QQ-state produced in colour singlet in hard interaction
- Color singlet➔ no g-radiation
- **J/psi produced in isolation!**

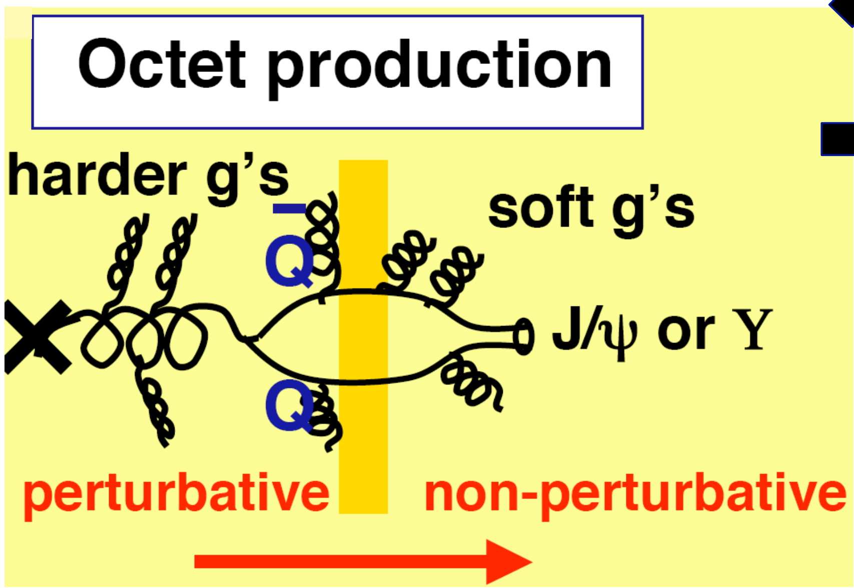
Octet production



- Quarkonium produced direct of via χ
- Physics-wise: shower expected from
  1) $gg \rightarrow ggg \rightarrow gggg$...
  2) $g \rightarrow QQ^{(8)}$
  3) $QQ^{(8)} \rightarrow$ J/psi or Υ
- Technically: cc-octet state produced in hard interaction
- Switches MSTP(148), MSTP(149)
- **J/psi produced in shower!**

Possibilities studied in CMS:





Case 1: Singlet

Case 2: octet low radiation

MSTP(148)=0 (MSTP(149) doesn't matter)
AP splitting function:q→qg

Case 3: octet med. radiation

MSTP(148)=1, MSTP(149)=0
A-P splitting function:
g→gg (but follow hardest)

Case 4: octet high radiation

MSTP(148)=1, MSTP(149)=1
A-P splitting function:
g→gg (symm. z=1/2)

NB: case (1+2),(1+3),(1+4)
all fit CDF data!

NRQCD matrix elements

[See M.Bargiotti, V. Vagnoni, CERN-LHCb-2007-042]

- Rates for all quarkonium processes given by NRQCD matrix elements

See also talk by M.Bargiotti at HERA-LHC workshop 2006

- Motivation of tuning: agreement MC⇔data
- NRQCD matrix elements from: hep-ph/0003142
  - CSM values extracted from potential models (hep-ph/9503356)
  - COM values from CDF data
- Quark masses: m_c= 1.5 GeV, m_b = 4.88 GeV

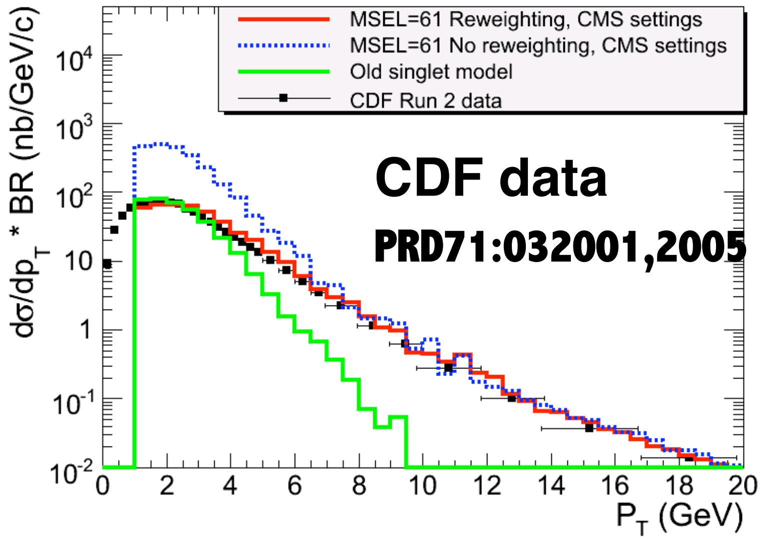
PARP(141)	$\langle O^{J/\psi}[^3S_1^{(1)}]\rangle$	1.16
PARP(142)	$\langle O^{J/\psi}[^3S_1^{(8)}]\rangle$	0.0119
PARP(143)	$\langle O^{J/\psi}[^1S_0^{(8)}]\rangle$	0.01
PARP(144)	$\langle O^{J/\psi}[^3P_0^{(8)}]\rangle / m_c^2$	0.01
PARP(145)	$\langle O^{\chi_{c0}}[^3P_0^{(1)}]\rangle / m_c^2$	0.05
PARP(146)	$\langle O^{\Upsilon}[^3S_1^{(1)}]\rangle$	9.28
PARP(147)	$\langle O^{\Upsilon}[^3S_1^{(8)}]\rangle$	0.15
PARP(148)	$\langle O^{\Upsilon}[^1S_0^{(8)}]\rangle$	0.02
PARP(149)	$\langle O^{\Upsilon}[^3P_0^{(8)}]\rangle / m_b^2$	0.02
PARP(150)	$\langle O^{\chi_{b0}}[^3P_0^{(1)}]\rangle / m_b^2$	0.085

Quarkonia in PYTHIA: PYEVWT.f

- **Problem:** even with octet, quarkonium cross section not right shape (too big at low Pt)
- **Solution:** PYEVWT.f: cross section dampened like gg→gg in underlying event formalism

T. Sjöstrand and M.v.Z, PRD 1987

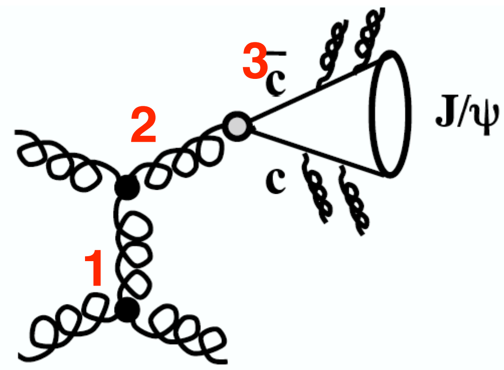
$$\frac{d\sigma}{dp_T^2} \propto \frac{[\alpha_S(p_T^2)]^2}{p_T^4} \implies \frac{[\alpha_S(p_{T_0}^2 + p_T^2)]^2}{(p_{T_0}^2 + p_T^2)^2}$$



- **Applies naturally here too!**

$$w_i = \frac{\sigma_{reweighted}}{\sigma_{not\ reweighted}} = \left(\frac{\hat{p}_T^2}{p_{T_0}^2 + \hat{p}_T^2}\right)^2 \left(\frac{\alpha_S(p_{T_0}^2 + Q^2)}{\alpha_S(Q^2)}\right)^3$$

- p_{T0} ~ scale below which g cannot resolve colours ⇒ coupling decreases ⇒ xs decreases!
- p_{T0} ~ 2 GeV at CDF, is assumed to grow with √s [x smaller ➔ denser packing of gluons ➔ more screening CMS: p_{T0} = 1.94(14 TeV/1.96 TeV)$^{0.16}$=2.66 GeV



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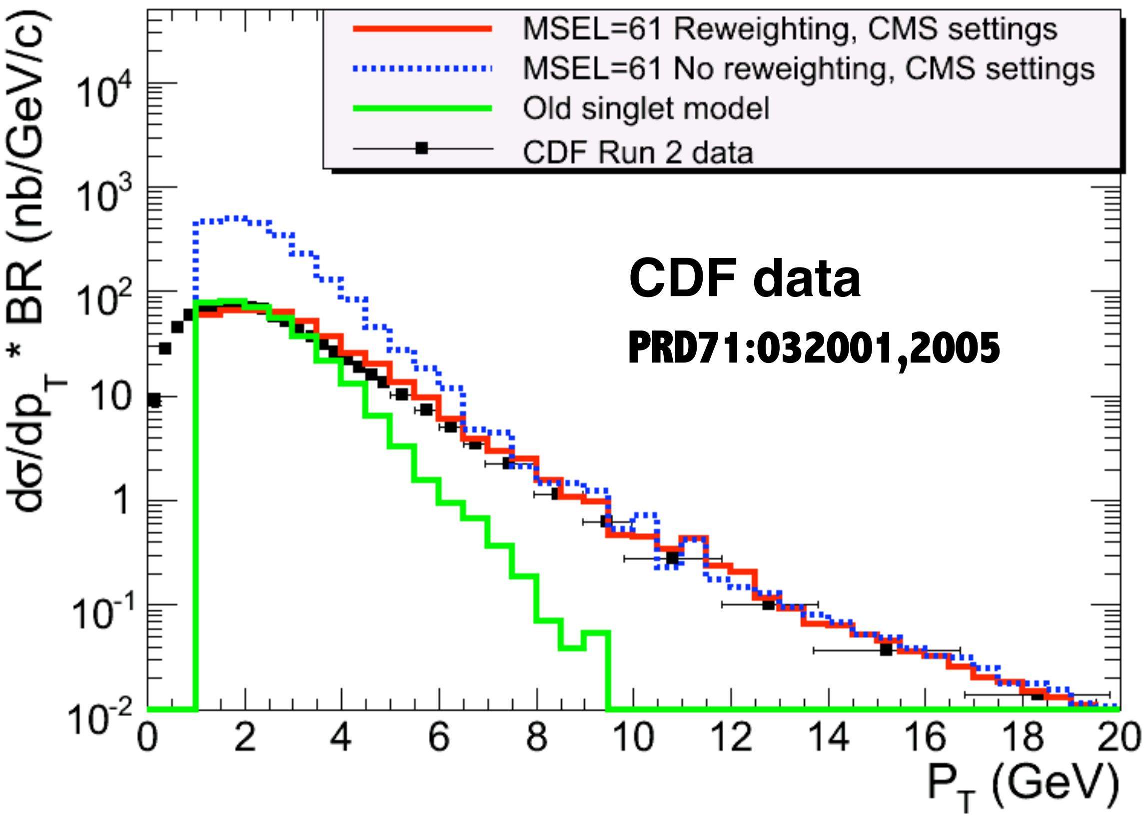
Validation of J/psi production

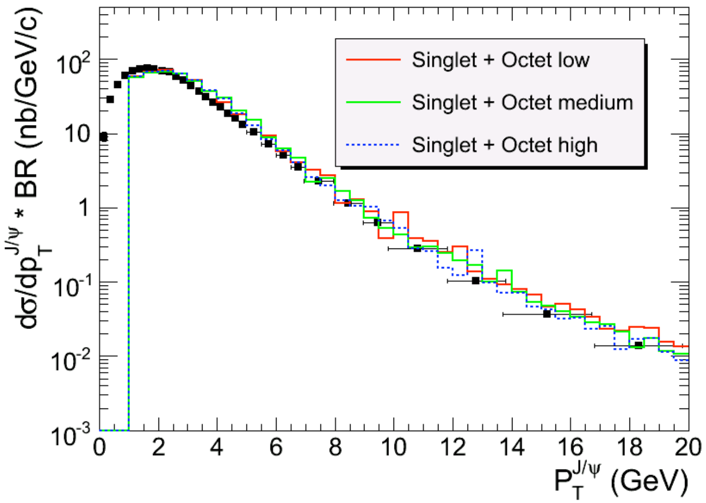
Validation of CMS settings by comparison with CDF data:

- **Collisions: pp √s= 1.96 TeV**
- **|y(J/psi)|<0.6 P_T(J/psi)>1 GeV**
- **PYEVWT.f used**

- **NRQCD matrix elements (slide 8)**
- **MSEL=61: singlet&octet production**
- **MSTP(148)=1, MSTP(149)=1 (high radiation case is default)**

NB: all radiation cases from slide 9 fit CDF data pretty well!



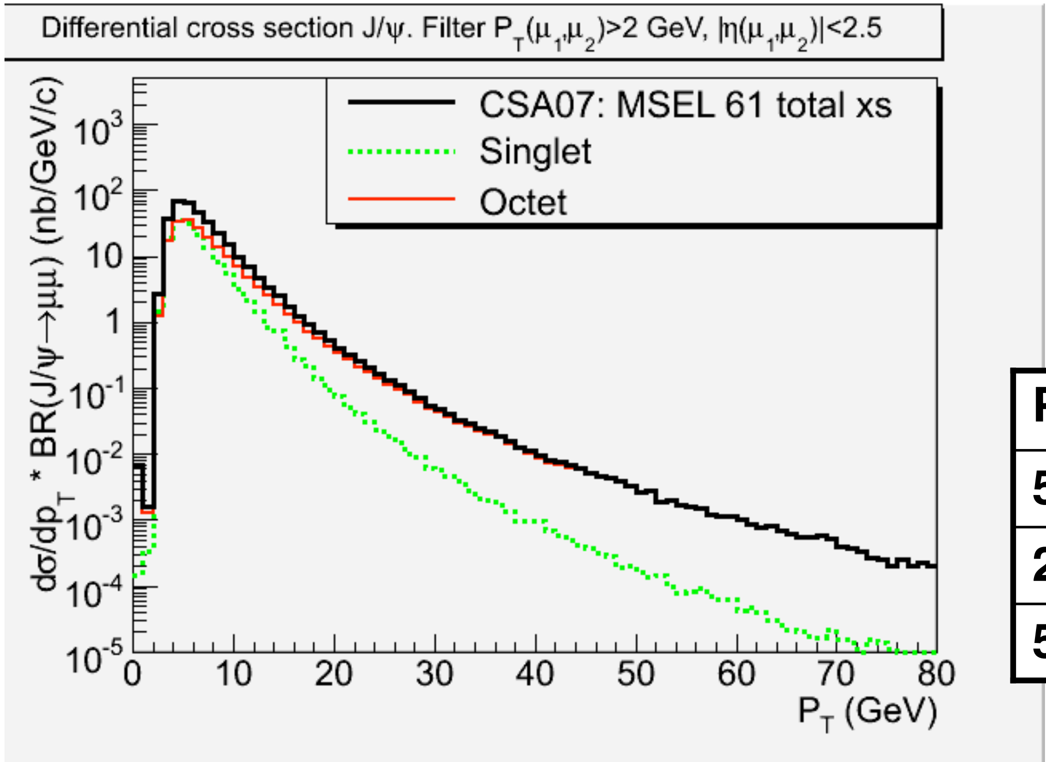


J/psi production cross section CMS

CMS settings:

- **Collisions: pp √s= 14 TeV**
- **2 muons |η|<2.5, Pt>2.5 GeV**
- **PYEVWT.f used**

- **NRQCD matrix elements (slide 8)**
- **MSEL=61: singlet&octet production**
- **MSTP(148)=1, MSTP(149)=1 (high radiation case is default)**



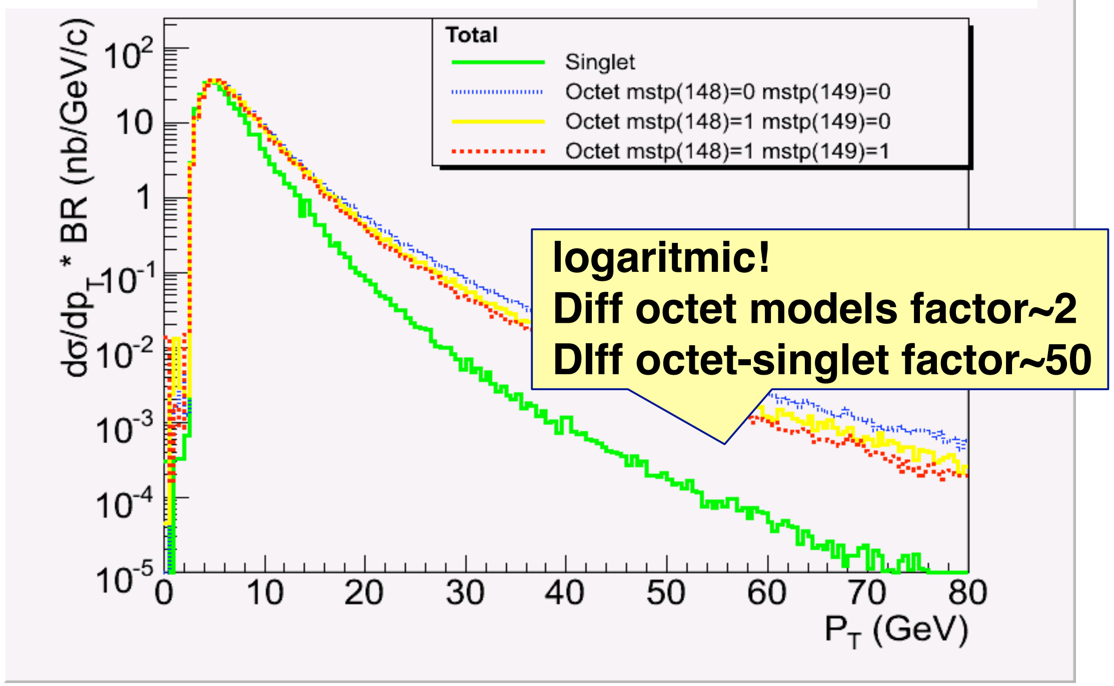
- **In 100 pb-1 (singlet+octet): η(mu)<2.5 P_T(mu)>2.5**

P_T (J/ψ)>	Produced	Reconstructed
5 GeV	~2*10^7	~5*10^6
20 GeV	~3*10^5	~2*10^5
50 GeV	~5*10^3	~3*10^3

J/psi production cross section CMS

- At CMS: enormous differences between singlet&octet models
  - ➡cross section measurement will clarify production via singlet (LO) or octet
- Also differences between different octet models visible at high PT!
  - ➡cross section measurement can help to understand details....

Prompt J/psi production cross section at CMS

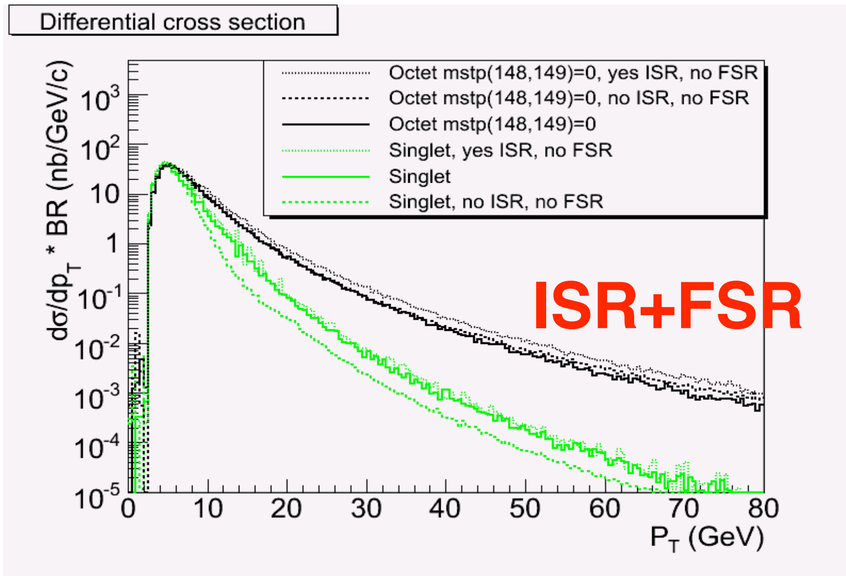


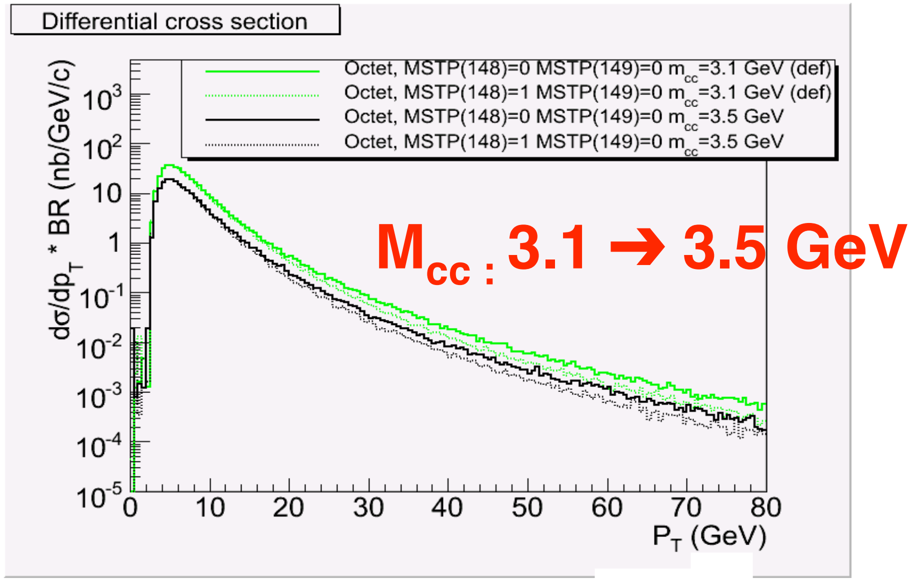
.... however, many parameters can influence cross section shape...

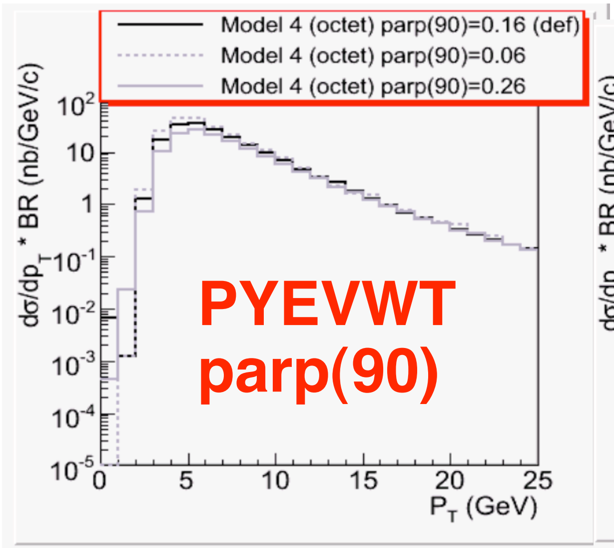
- ISR
- FSR
- Mass of cc-octet
- Reweighting function

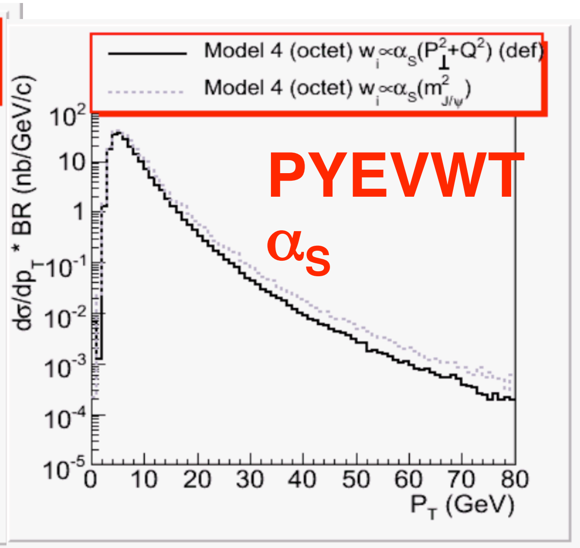
J/psi production cross section CMS

Examples of changes in the differential cross section:









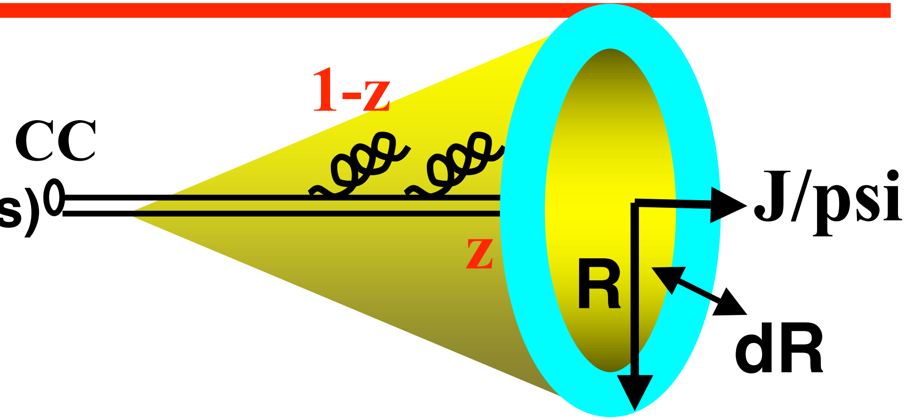
Conclusion:

- **Diff. xs is subject to uncertainties!**
- **Measuring the spectrum doesn't mean we understand production...**

J/psi production studies: new observables!

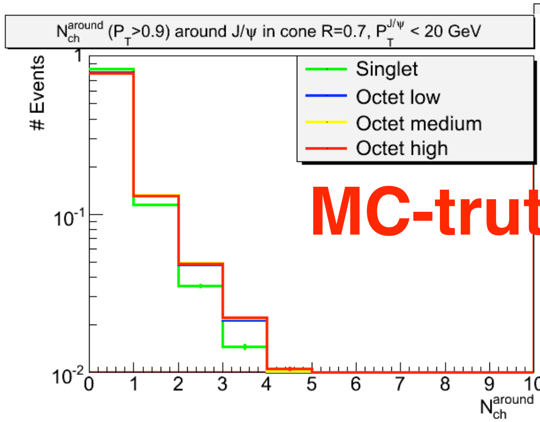
- Shower activity of 4 models is different ➔ natural observable= Nr charged particles (P_T>0.9, not μ's) around J/ψ in cone R (e.g. 0.7)

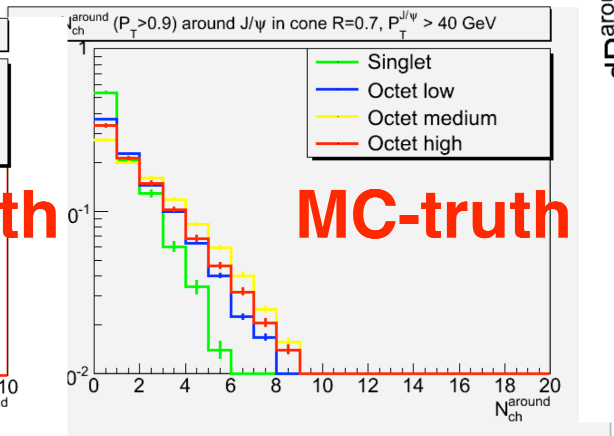
➡ **Differences at high Pt jpsi!**

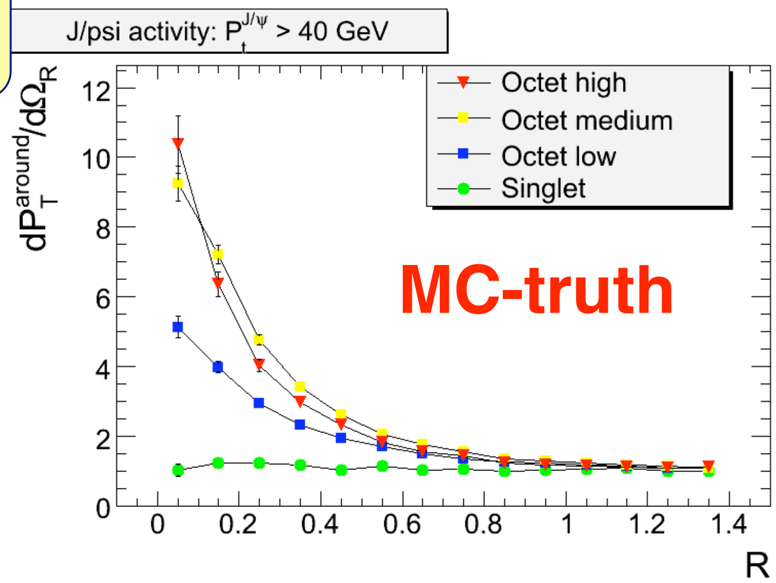


- The particle or momentum density as function of cone size R
- Etcetera... different variables studied in CMS (HERA advice welcome!)

In combination with diff xs measurement, could help in understanding mechanism?!







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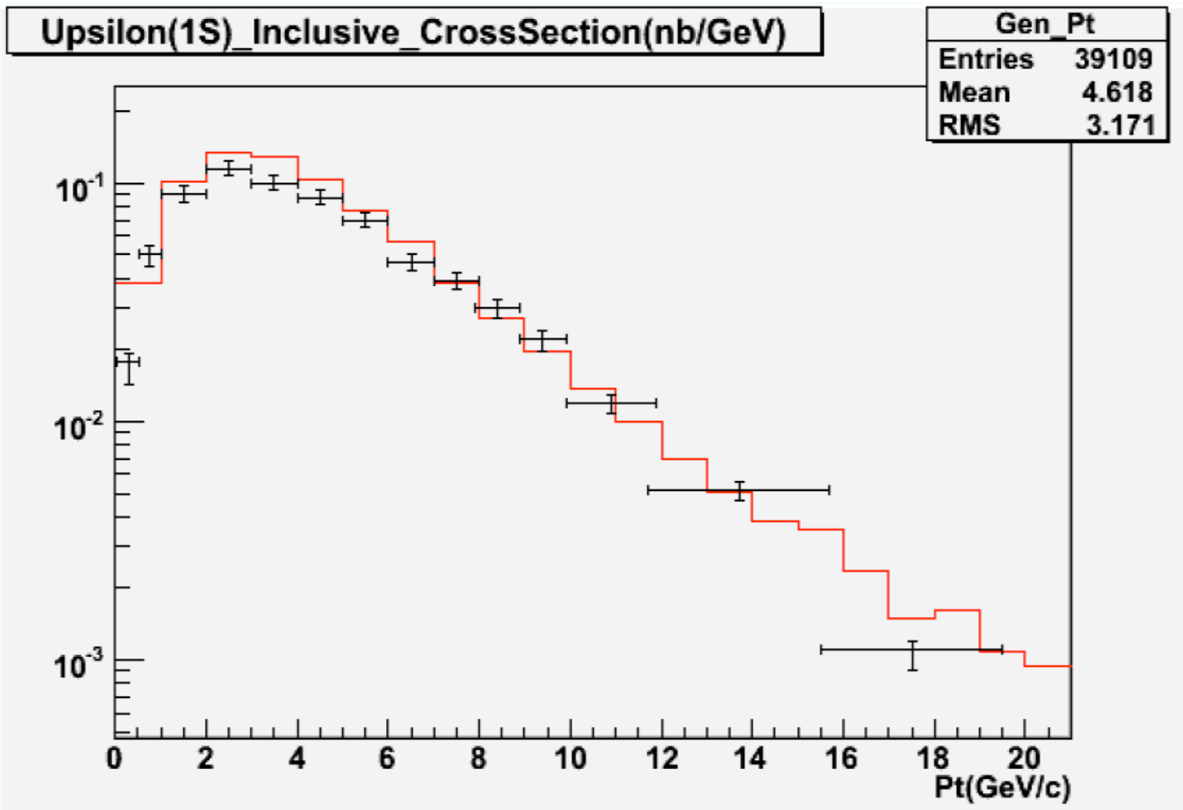
- Upsilon production in PYTHIA 6.409
- Future
- Conclusions

Validation of Υ production

Validation of CMS settings by comparison with CDF data:

- Collisions: pp $\sqrt{s}$= 1.96 TeV
- Rapidity(Υ)<0.6 P_T(Υ)>1
- PYEVWT.f used

- NRQCD matrix elements (slide 10)
- MSEL=62: singlet&octet production
- MSTP(148)=1, MSTP(149)=1

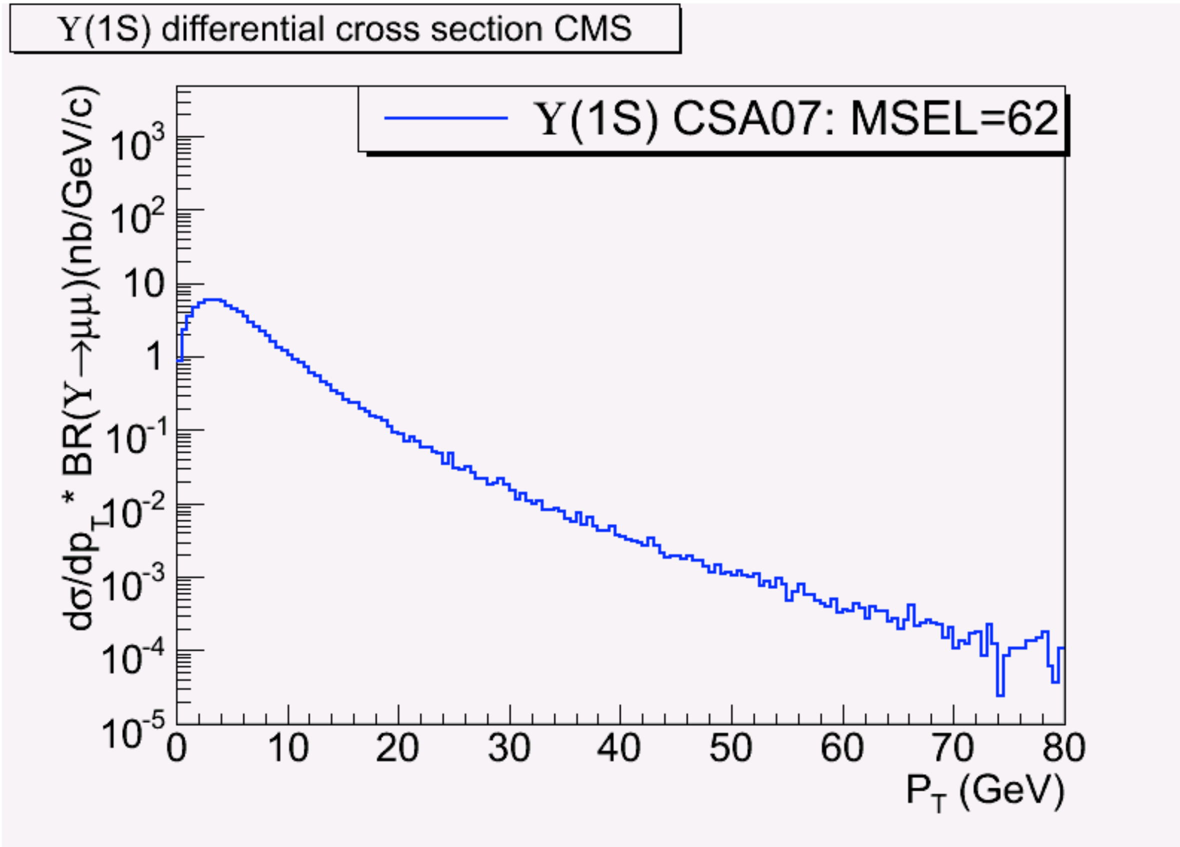


Υ production cross section CMS

CMS settings:

- **Collisions: pp √s= 14 TeV**
- **2 muons |η|<2.5, Pt>2.5 GeV**
- **PYEVWT.f used**

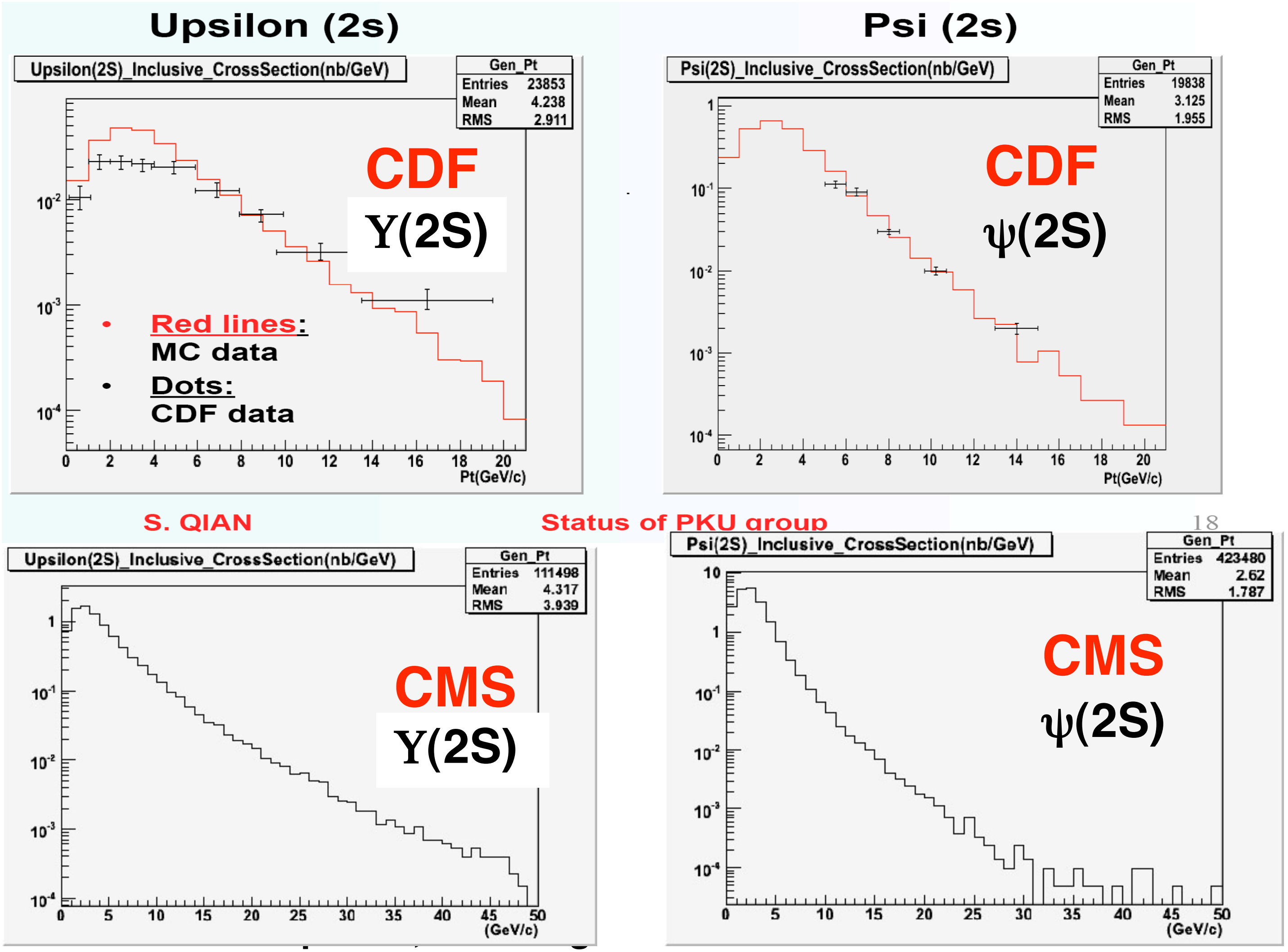
- **NRQCD matrix elements (slide 8)**
- **MSEL=62: singlet&octet production**
- **MSTP(148)=1, MSTP(149)=1**



Future: ψ(2S), Υ(2S), Υ(3S)

Next to 1S, code can be extended to ψ(2S), Υ(2S), Υ(3S)(not simultanaously!)

- **NRQCD matrix elements in hep-ph/0003142**
- **Take into account branching ratios and mass of ψ(2S), Υ(2S), Υ(3S)**



More studies on the way!

Conclusions

- Quarkonium production not understood: octet mechanism is not in agreement with polarization measurements
- LHC: higher P_T(J/psi) values and luminosities will allow for much more detailed studies than Tevatron!
- PYTHIA 6.409: quarkonia generation possible with singlet and octet mechanism
  - NRQCD matrix elements tuned
  - Cross section dampening at small P_T introduced
  - Different options for radiation off octet QQ-state
  - J/psi(1S) and Upsilon(1S) generation with MSEL=61, MSEL=62 resp.
  - Also extension to 2S (and 3S) generation possible
- In CMS quarkonia studies have started and lots of interesting results are on the way