Feasibility study for B_c meson and quarkonia studies at CMS

Aafke Kraan
INFN Pisa
On behalf of the CMS collaboration

International Workshop on Heavy Quarkonium 2007
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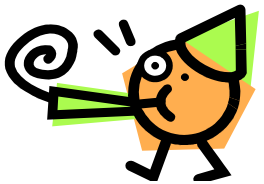
Outline

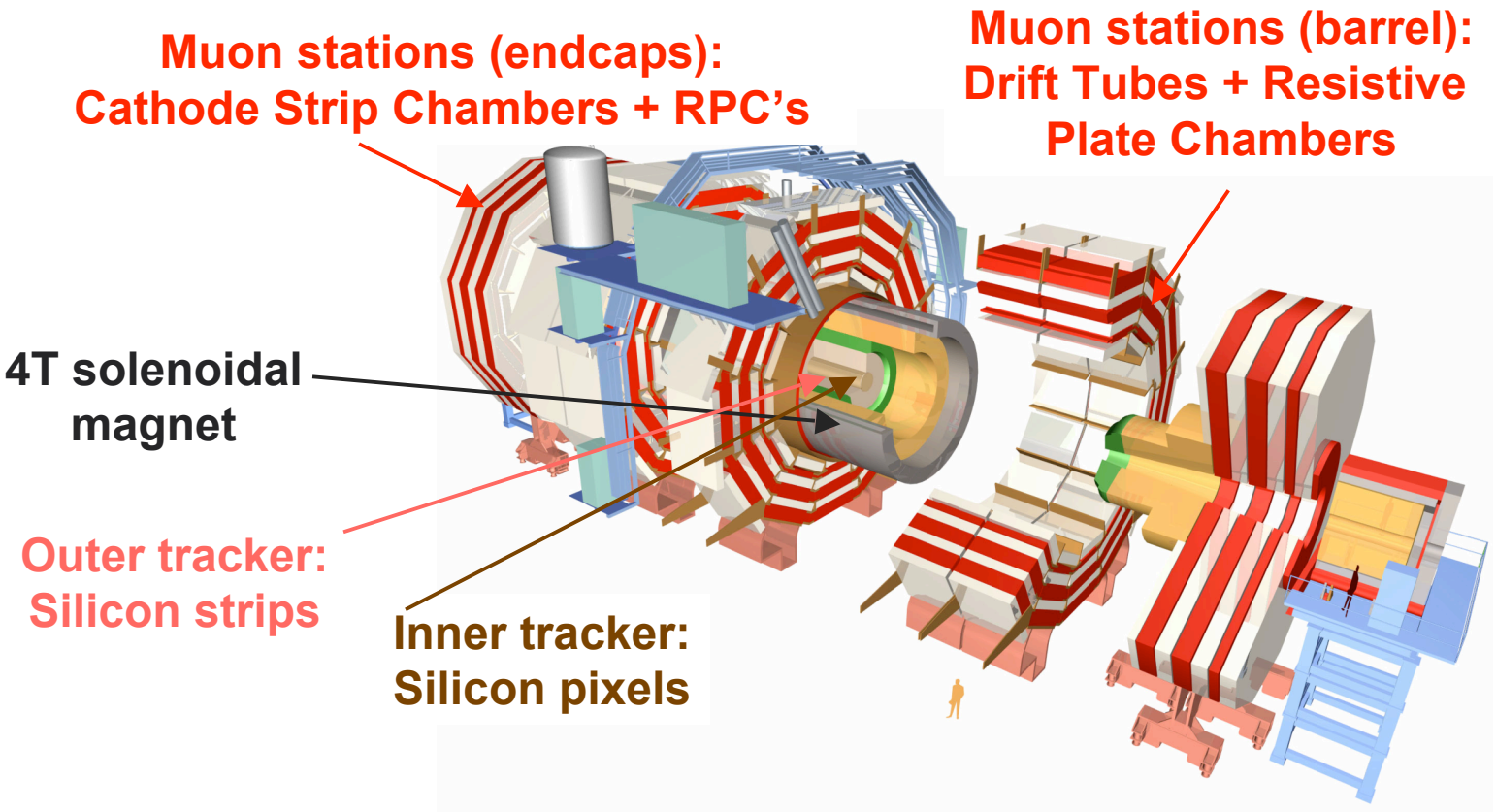
- Introduction
- Feasibility to study B_c-meson at CMS
  - Introduction
  - Event generation
  - Event selection
  - Systematic errors & results
- Quarkonia studies in CMS
  - Introduction & analysis overview
  - J/psi reconstruction & trigger studies
  - J/psi production mechanism studies
- Conclusions



Heavy flavour physics at CMS

- LHC:
  - p-p collisions at E_{CM} = 14.0 TeV,
  - Initial $\mathcal{L} \sim 2 \times 10^{32}$ cm^{-2} s^{-1}, nominal $\mathcal{L} \sim 1 \times 10^{34}$ cm^{-2} s^{-1}
- CMS:
  - Competition with ALICE, LHCb, (ATLAS)...
  - but...CMS has excellent muon system, tracker, large acceptance!
  - Most analyses here based on medium and high P^T muons

HI collisions in CMS see talk P. Ramalhede



The B_c meson

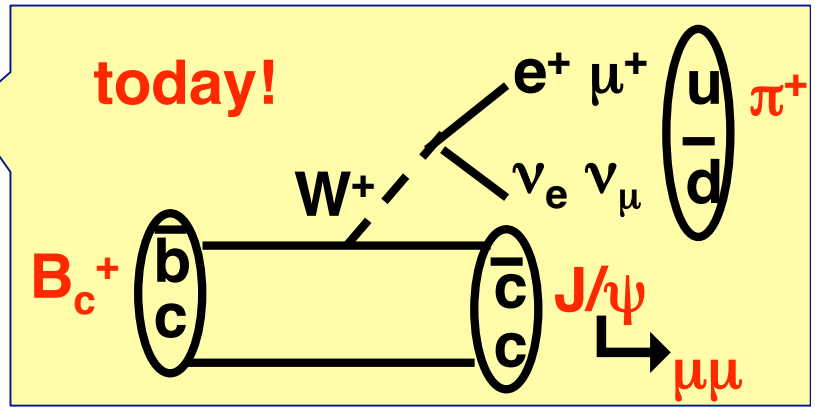
[See also talks by W.Wester, L. Welty-Rieger]

Goal: measure mass and lifetime of B_c-meson with CMS

↳ ground state of $\bar{b}c$ unique properties!!

Theory-predictions:

- B_c production in hadron collider: many theoretical uncertainties!
  $\sigma(B_c) \sim 10^{-3}\sigma$(other B-mesons) [E.g:Chang&Wu,EPJC38,267]
- B_c mass: M=6.24±0.05 GeV See e.g: [Kwong,Rosner, PRD44, 212] [Eichten, Quigg, PRD49, 5845]
- B_c decay (only weak!):
  - b-decay with c as spectator: 20-25%
  - c-decay with b as spectator: 64-72%
  - annihilation decays: 6.6-7.2%



Experiments:

- Tevatron: CDF: B_c mass: 6.2741±0.0032 (stat.)±0.0026(syst.)
  ↳ channel $B_c \to J/\psi\,\pi$
  D0: lifetime: $0.444^{+0.039}_{-0.036}$ (stat.)$^{+0.039}_{-0.034}$(syst.) ps
  ↳ channel $B_c \to J/\psi$ e ν

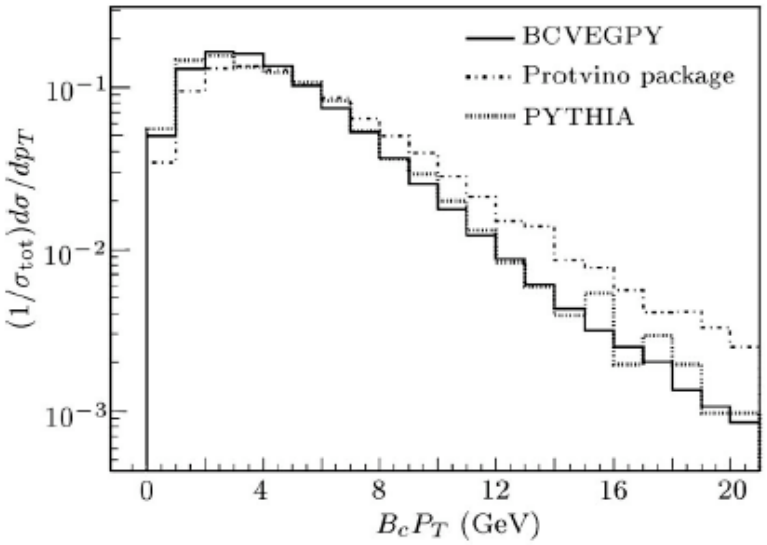
Event generation

[CMS note 2006/118 Meng,Tao, Chen]

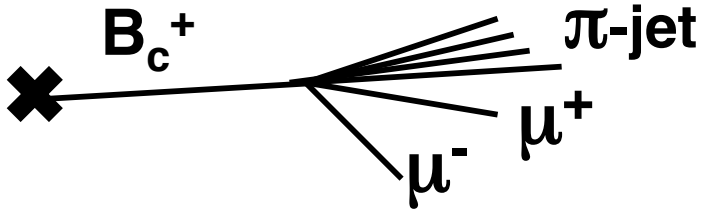
- **Signal: $B_c \rightarrow J/\psi\ \pi$, $J/\psi \rightarrow \mu\mu$ generated with BCVEGPY generator**
  [Chang&Wu, EPJC38:267,2004]
  - **Generator cuts (simulate L1 and HLT trigger):**

B_c pT≥10GeV |η|≤2.0
μ pT≥4GeV |η|≤2.2
π pT≥2GeV |η|≤2.4

Decay channel	σ(pb)	Generated~ 30 fb-1
Bc→J/ψπ, J/ψ→μμ	1.781	5.2082(·10⁴)

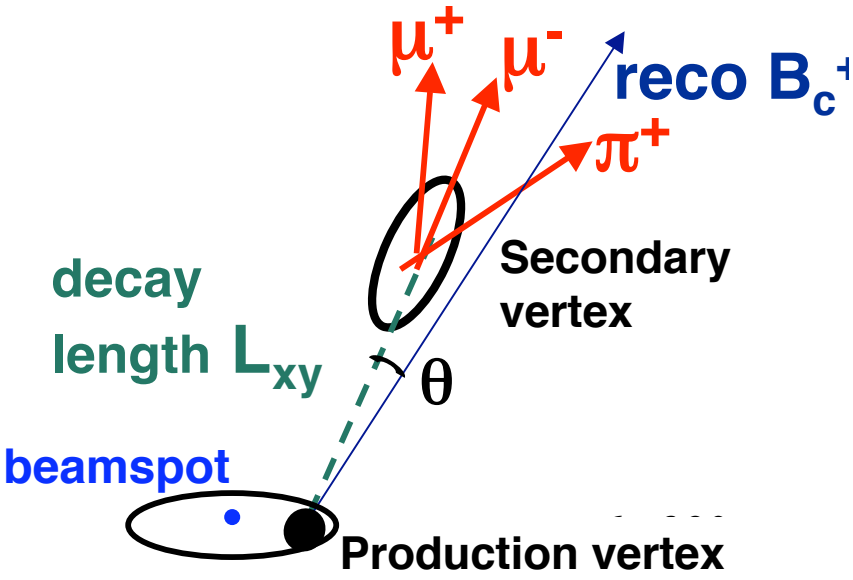


- **Backgrounds:**
  1) Other b hadrons' decay include J/ψ
  2) Prompt J/ψ
  3) cc, bb→μμx
  4) Generic QCD
  5) W+jets, Z+jets

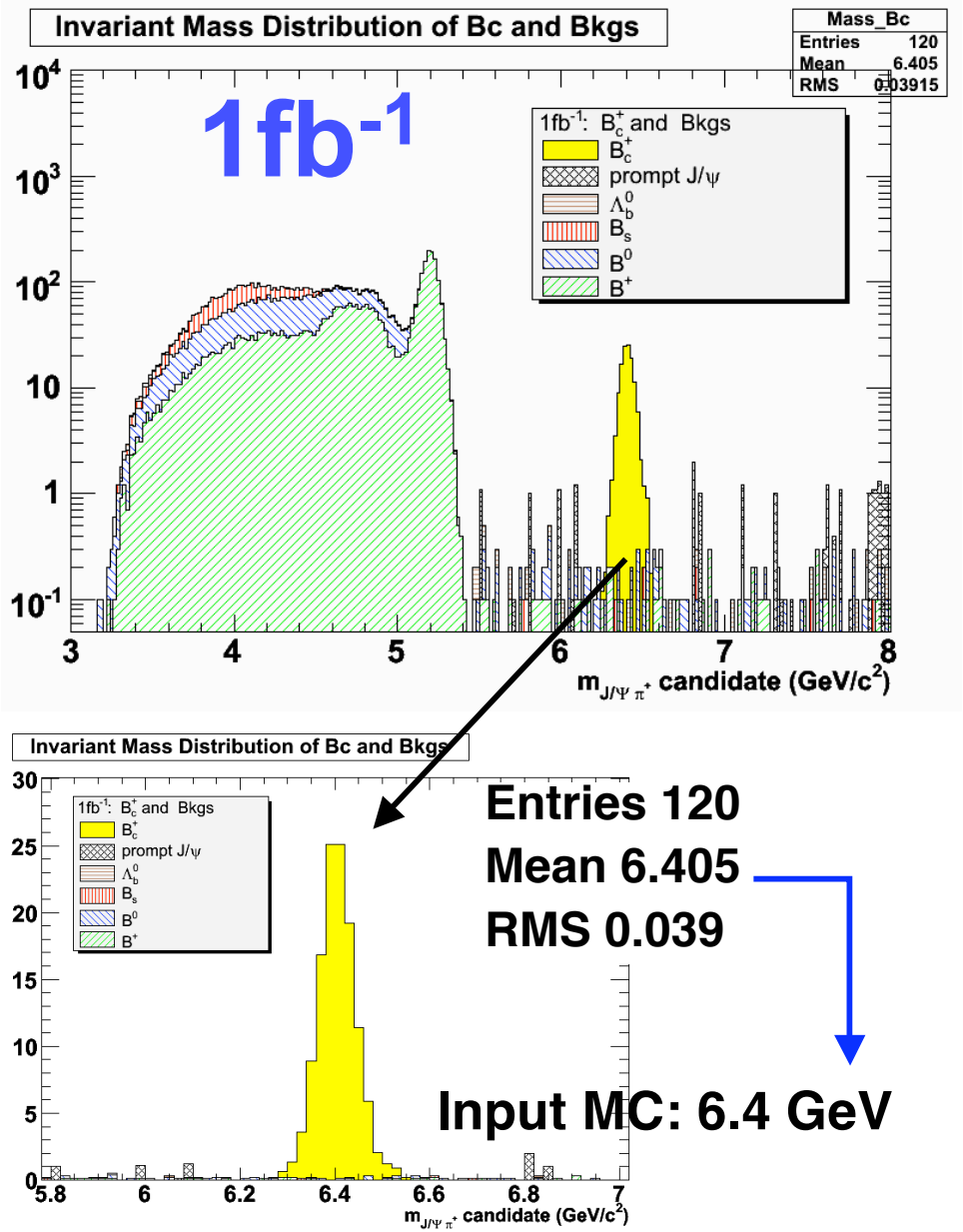


Event selection

- Step 0: trigger, not included in this study.
  - See slide 13!
- Step 1: J/psi candidates:
  - 2 muons (P_T>4 GeV, |η|<2.2), same vertex, different charge, M_{inv} (3.0,3.2) GeV
- Step 2: Pion candidates:
  - pT≥2 GeV ,|η|≤2.4, not identified as lepton, same vertex as muons
- Step 3: Suppress prompt J/psi background
  - Cut on proper decay length (L^{PDL}_{xy}) and significance (L^{PDL}_{xy}/σ_{xy})



Event selection

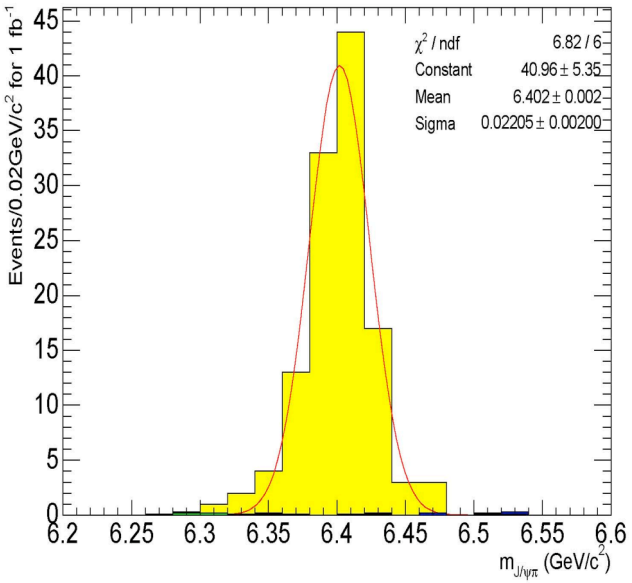


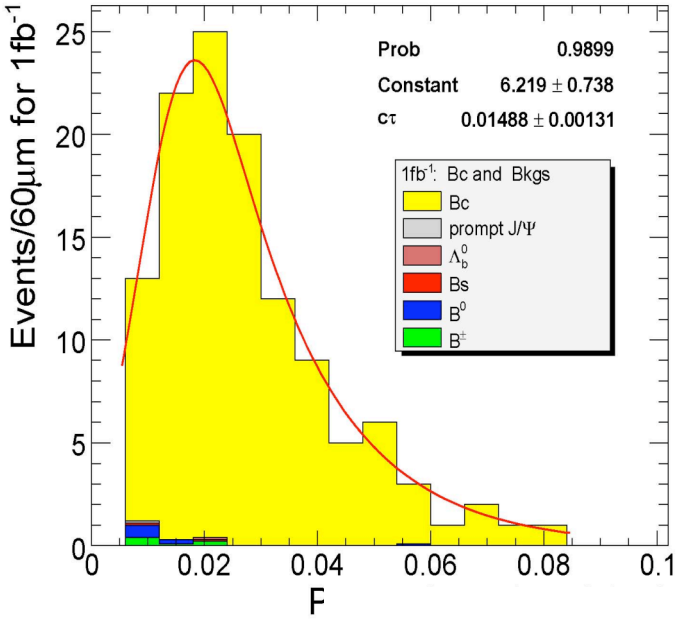
- Step 4: invariant mass window cut: $M_{J/\psi\pi} \in [6.25, 6.55]$ GeV
- Summary of selection for B_c-events (~1 fb^{-1}):

signal B_c	120±11
total bg	2.6±0.4
B^+	0.7±0.2
B_s	0.1
B^0	0.8±0.3
Prompt J/ψ	0.1
QCD	0.7±0.1
Λ_b	0.1
ccbar	0.01
bbar	0.01

Mass and lifetime fit

- **Kinematic fit Bc→J/ψπ, J/ψ→μμ: totally 3 tracks**
  - **2 muon tracks: J/ψ mass constraint $M_{\mu\mu}$=3.096 GeV**
  - **all 3 tracks: from same vertex**





$$\mu = N \cdot \epsilon(x) \cdot exp(-x/c\tau) \bigotimes G(x,\sigma)$$

M(B_c): 6402 ± 2 MeV
Input MC:6400 MeV
Masswidth: 22 MeV

cτ(B_c):148.8 ± 13.1 μm
Input MC 150 μm
τ(B_c)=0.0496 ± 0.044 ps

Systematic error and results

- Systematic error estimation ($1\ fb^{-1}$)
  NB pessimistic & conservative!
- When data come, control sample $B \rightarrow J/\psi\ K$ can be used to improve!

Source	B_c mass (MeV)	$B_c c\tau$ (μm)
momentum scale	11	0.2
momentum resolution	10	0.8
vertex resolution	-	2.4
sensitivity to cuts	0.1	0.2
MC statistics	-	0.1
Theoretical (pt-spectrum)	-	1.5
Total	14.9	3.0

Result:

CMS AN 2006/079
CMS NOTE 2006/118
X.W. MENG, J.Q. TAO, G.M. CHEN

	L (fb^{-1})	Signal events	Precision of mass value (MeV)	Precision of lifetime (ps)
CMS $B_c \rightarrow J/\psi\pi$	1	120 ±11	2.0(fit)±14.9(syst)	0.044(fit)±0.010(syst)

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Motivations & analysis overview

Motivations: More than 30 years after discovery of the J/psi production properties still not well understood...

- E.g.: NRQCD succcesful in explaining $P_T(J/\psi)$ spectrum at Tevatron (octet mechanism), but not in polarization prediction...

[See: CDF J/psi polarization, arXiv: 0704.0638,see talks yesterday!]

- At LHC: higher P_T values & luminosity allow for new studies!

CMS (p-p) studies concerning quarkonium:

- Determination of $J/\psi \rightarrow \mu\mu$ reconstruction efficiency
- Trigger studies
- Understanding underlying J/ψ production mechanism with complementary observables (in progress)
- Cross section measurement $J/\psi \rightarrow \mu\mu$ (in progress)
- J/ψ polarization measurement (in progress)
- Detector-studies: quarkonia for detector alignment and calibration

➡ Focus of CMS studies has been on J/psi's!

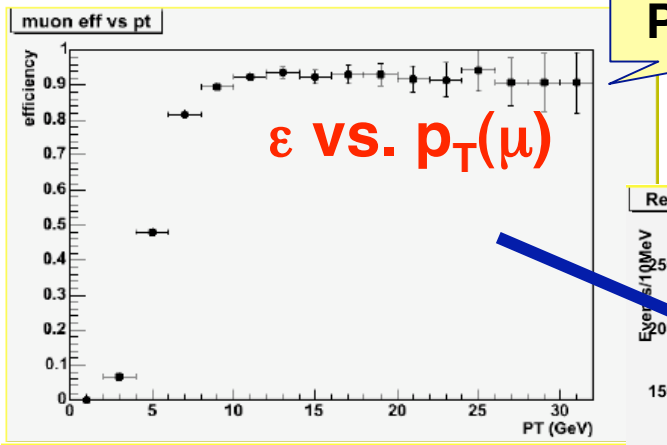
J/psi reconstruction

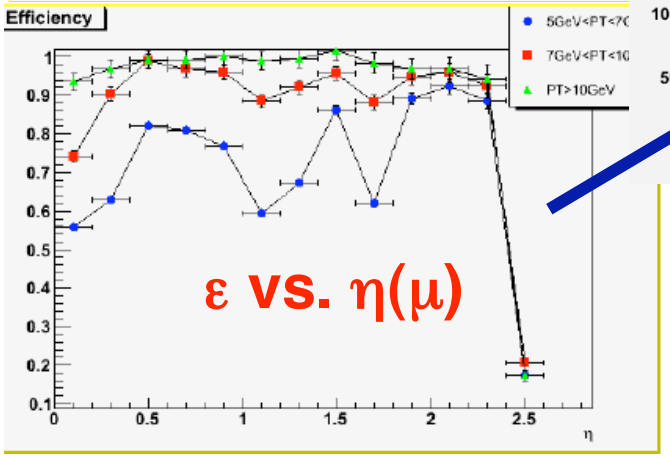
Z. Yang and S. Qian,
CMS-note 2006/094
CMS-note-2007/017

- Essential ingredient in many heavy flavour analysis: J/ψ→μμ
- J/psi reconstruction efficiency studies with B→J/ψ + φ (J/ψ→μμ) events
- ORCA results (2006). New results in CMSSW coming!

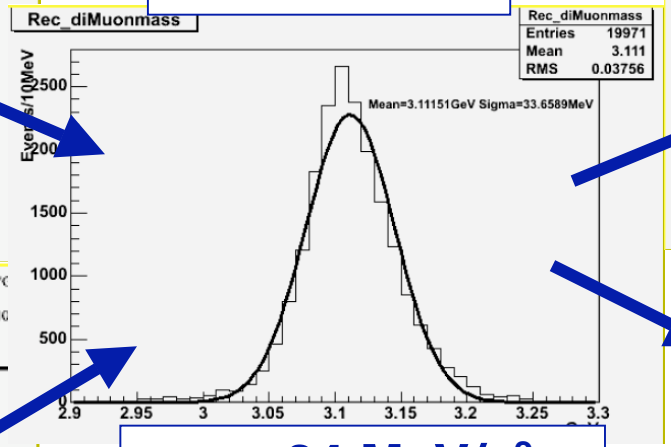
Single muon

ε~90% for P_T>7 GeV





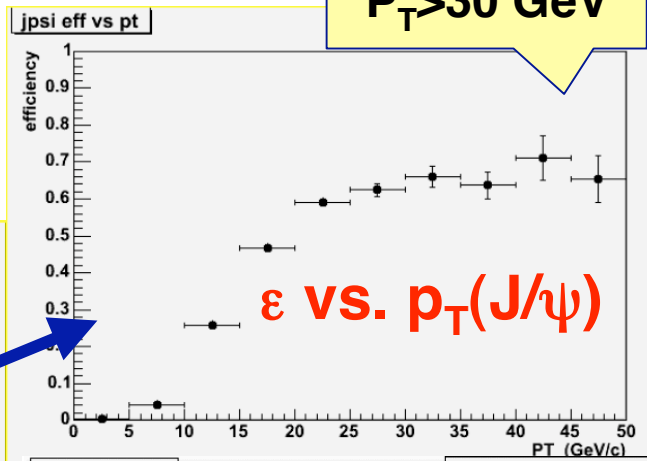
$\mu^-\mu^+$ mass

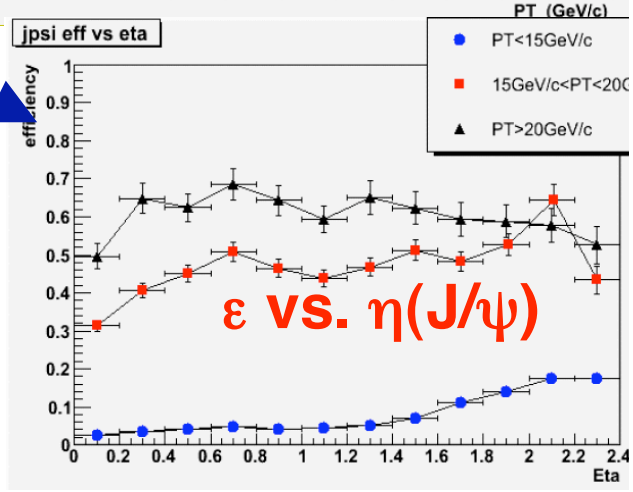


σ = 34 MeV/c^2

J/psi

ε~70% for P_T>30 GeV





J/ψ→μμ trigger

HLT report CERN/LHCC 2007-021, LHCC-G-134, July 2007

- CMS trigger study based on LHC startup conditions: $L=10^{32}cm^{-2}s^{-1}$
- For quarkonia: muon trigger [muon system:
  Drift Tubes, Cathode Strip Chambers, Resistive Plate Chambers]

LEVEL 1 muon trigger:
Single μ- trigger: P_T>7 GeV
Double μ-trigger: P_T>3 GeV

HIGH LEVEL muon trigger:
- More precise muon reconstruction including silicon tracker (L3)
- Optional: isolation criteria

Quarkonia: double μ trigger: P_T>3 GeV without isolation [Note! great performance for high Pt muons: Z→μμ: efficiency~90%)

Interaction rate: 10 MHz (startup)

L1 Output rate:
Single μ: 1kHz
Double μ: 200 Hz

HLT Output rate (total150 Hz):
J/ψ→μμ: 2.0 ± 0.8 Hz
Υ→μμ : 1.8 ± 0.5 Hz

- Also relevant (heavy flavour analyses like B_c)

HIGH LEVEL lifetime trigger: Displaced vertex trigger

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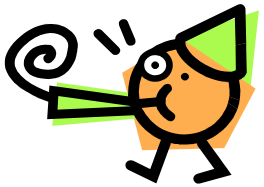


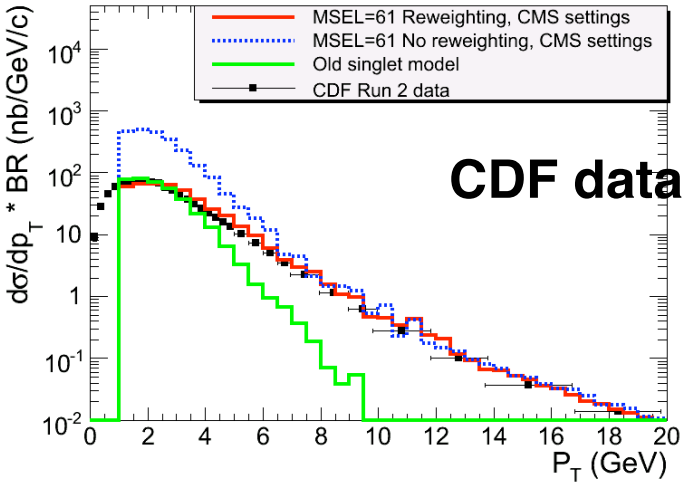
J/psi production studies: PYTHIA

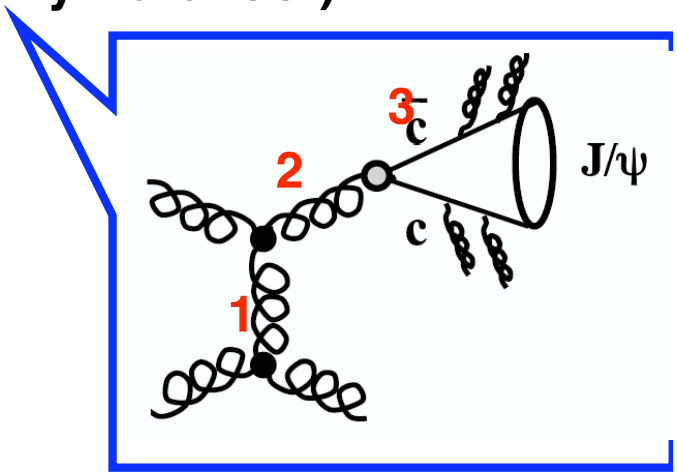
See also my talk yesterday

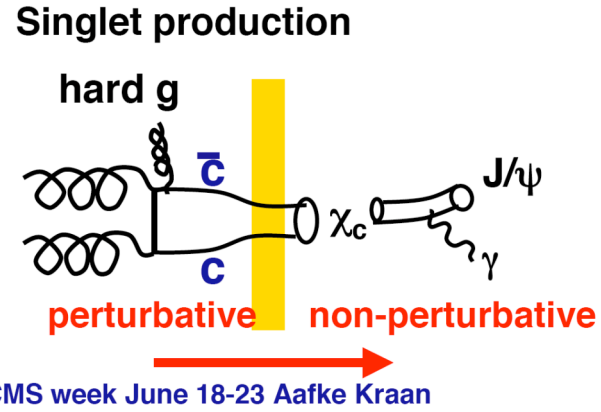
Quarkonium production: PYTHIA 6.409

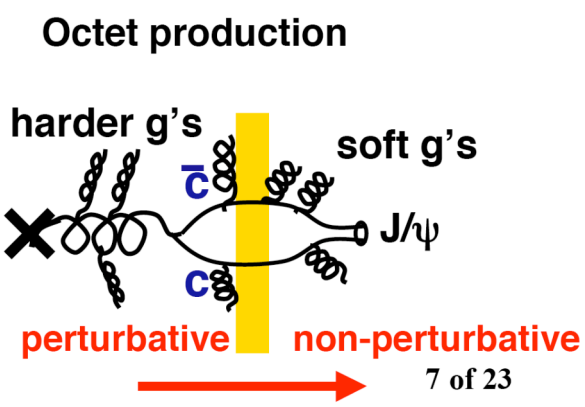
(Until May 2007: version 6.227)

- Original implementation by S. Wolf
- Singlet & octet mechanism
- Based on NRQCD matrix elements
  [See tuning: M.Bargiotti, CERN-LHCb-2007-042.
- Cross section regularization like gg→gg in underlying event formalism (applies naturally here too!)
  [T. Sjöstrand and M.v.Z, PRD 1987]
- Parton showers ➡Different options for radiation off octet cc: MSTP(149), MSTP(148)



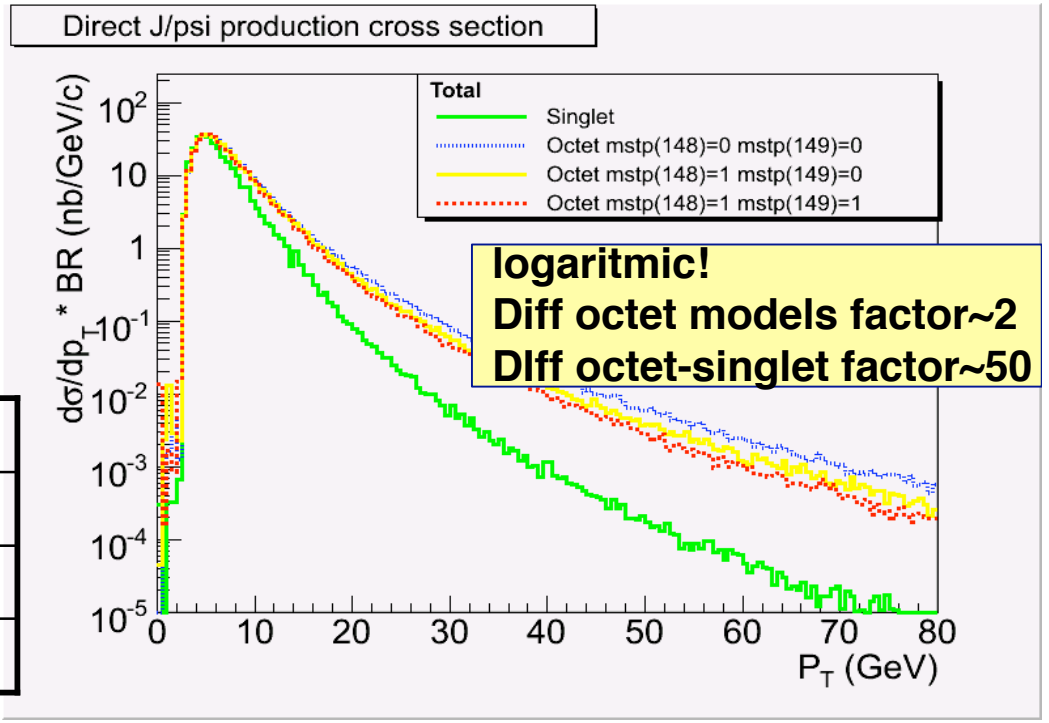






J/psi production studies: cross section

- CMS J/psi differential cross section for 4 production cases:
  - Singlet
  - 3 octet cases, different showering+fragmentation



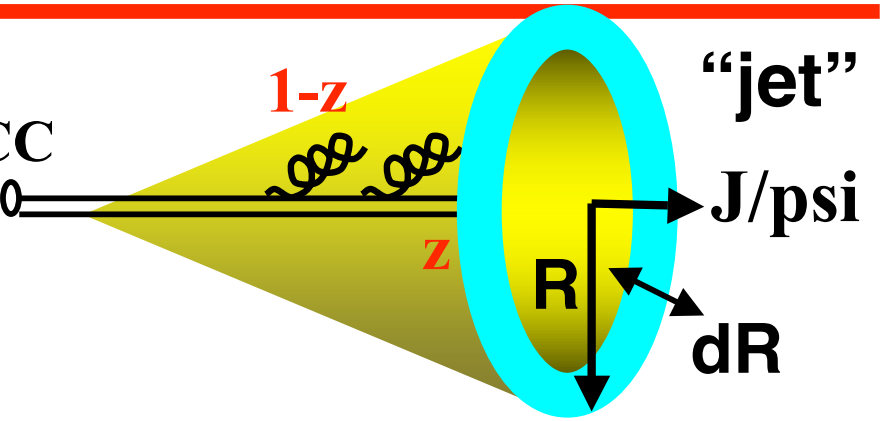
- In 100 pb-1 (singlet+octet):
  $\eta(mu)<2.5$ $P_T(mu)>2.5$

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

- Many parameters influence cross section shape (backup slide 22)!
  - ISR
  - FSR (e.g. see plot)
  - Mass of cc
  - Reweighting function
- Conclusion: measuring the cross section does not mean we understand producton! ➡ Need more observables [Idea with T. Sjöstrand]

J/psi production studies: new observables!

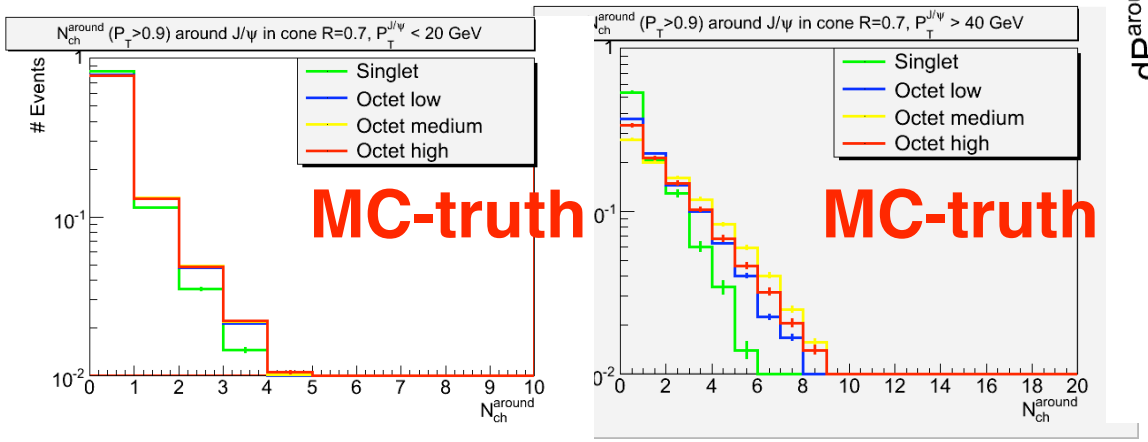
- Shower activity of 4 models is different ➔ natural observable=
  Nr charged particles (P_T>0.9, not μ's) around J/ψ in cone R (e.g. 0.7)

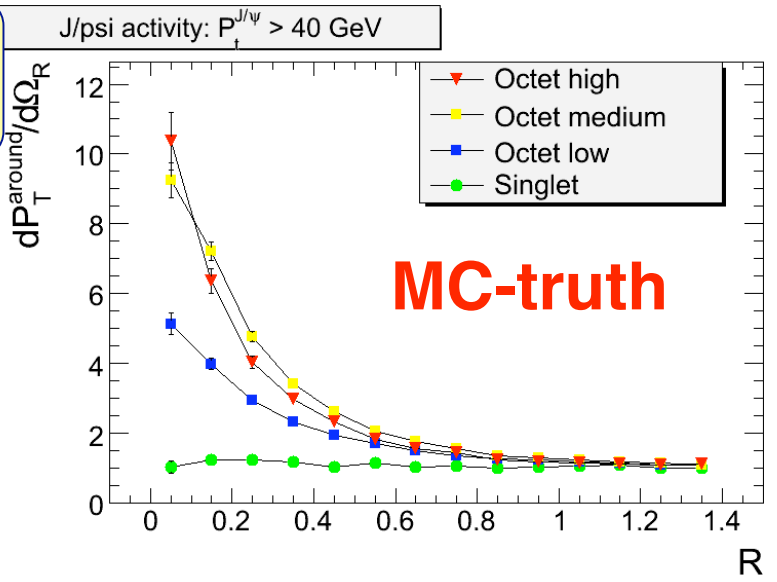


➔ Differences at high Pt jpsi!

- The particle or momentum density as function of cone size R
- Etcetera... many more variables could be useful...
  (suggestions welcome for new ones!)

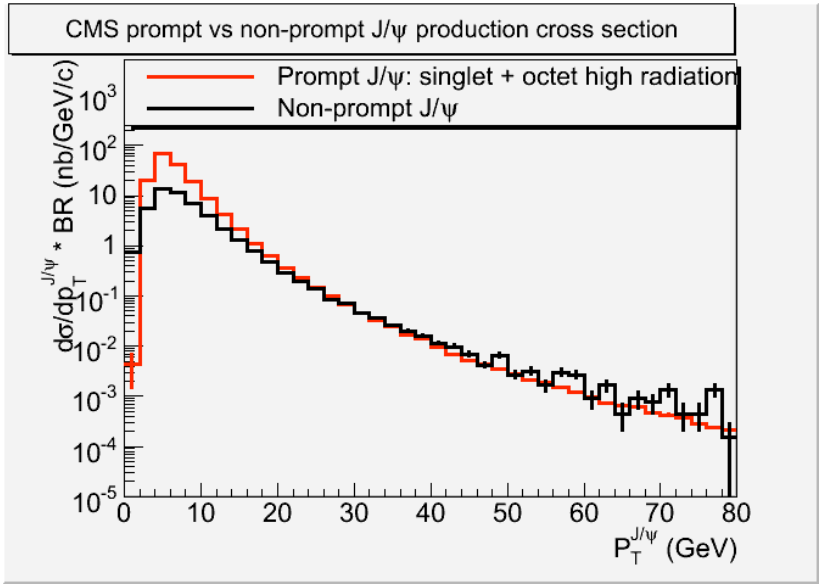
In combination with diff xs measurement, could help in understanding mechanism?!





J/psi production studies: challenges

- **Main challenges in this study:**
  - **Technical. Accumulating Monte Carlo statistics (so far no official production), solve by using fast simulation.**
  - **Background. Non-prompt J/psi background (high cross section at large P_T!!)**
  - **Theoretical. Activity in events can be influenced by many parameters...**



Given the generally large activity around non-prompt J/psi's, a wrong estimation of the non-prompt J/psi background could lead to a totally wrong conclusion!!

Plans

- J/psi production measurement proposal is in progress.
- J/psi polarization measurement is in progress.
- No Upsilons shown here! Production is currently going on, we hope to come with proposal for cross section measurement
- Excited states should be studied

Conclusions

- Feasibility to study B_c meson at CMS studied
  - With 1 fb-1 of data CMS can reconstruct 120 $B_c \rightarrow J/\psi\pi$ events
  - The precision on the mass (central value) is (conservative syst err!)
    2 (fit)±15(syst) MeV
  - The precision on the lifetime is (conservative syst err!)
    0.044(fit)±0.010(syst) ps

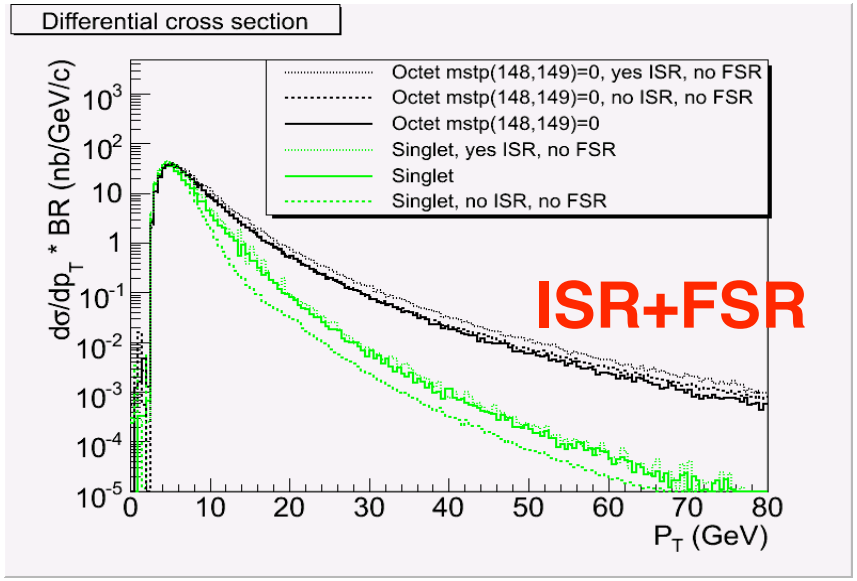
- Current quarkonia studies in CMS:
  - $J/\psi \rightarrow \mu\mu$ reconstruction efficiency: up to 70% at high $P_T(J/\psi)$
  - $J/\psi \rightarrow \mu\mu$ trigger
  - Understand the J/psi production mechanism with complementary observables next to cross section measurement.
  - Cross section measurement (in progress)
  - Detector related studies (in progress, not here)

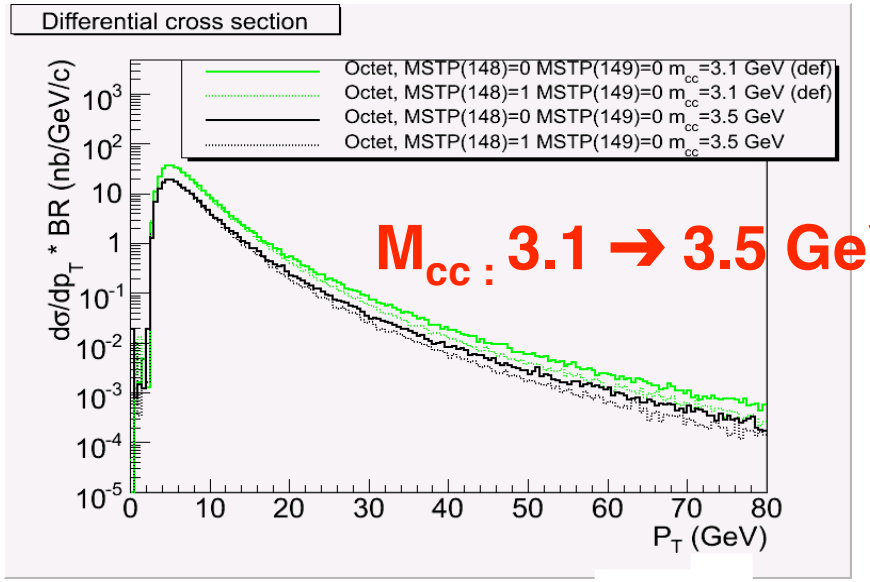
See also my talk yesterday

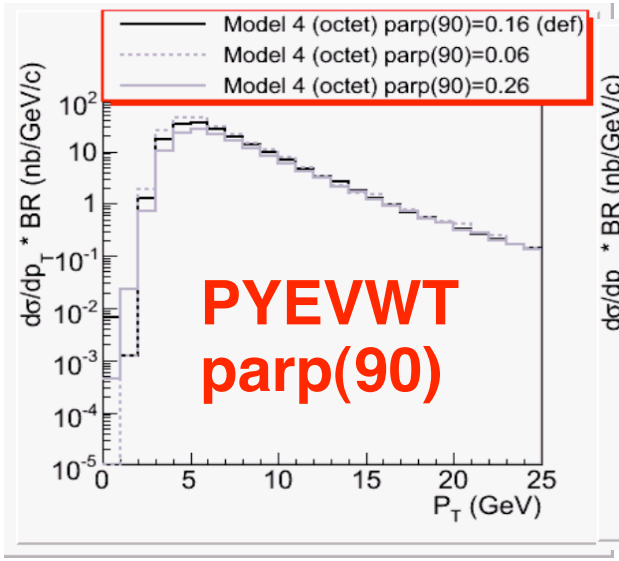
Backup slides

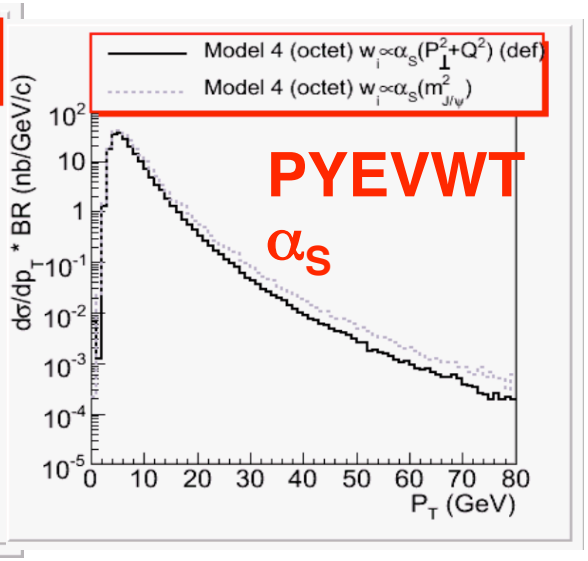
Prompt J/psi differential cross section

Examples of changes in the differential cross section:



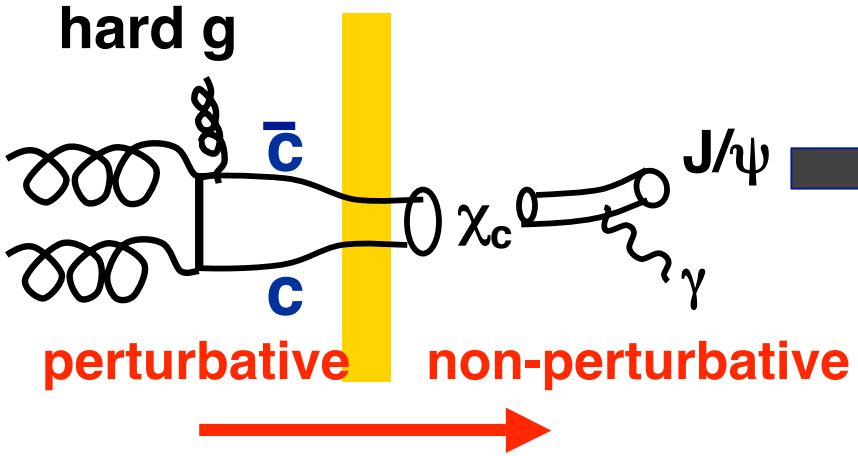




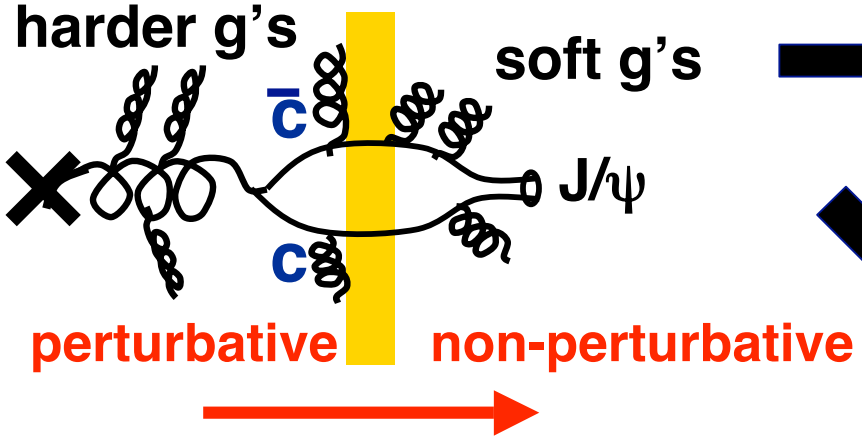


Models for study:

Singlet production



Octet production



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 2,3,4 all fit CDF data!