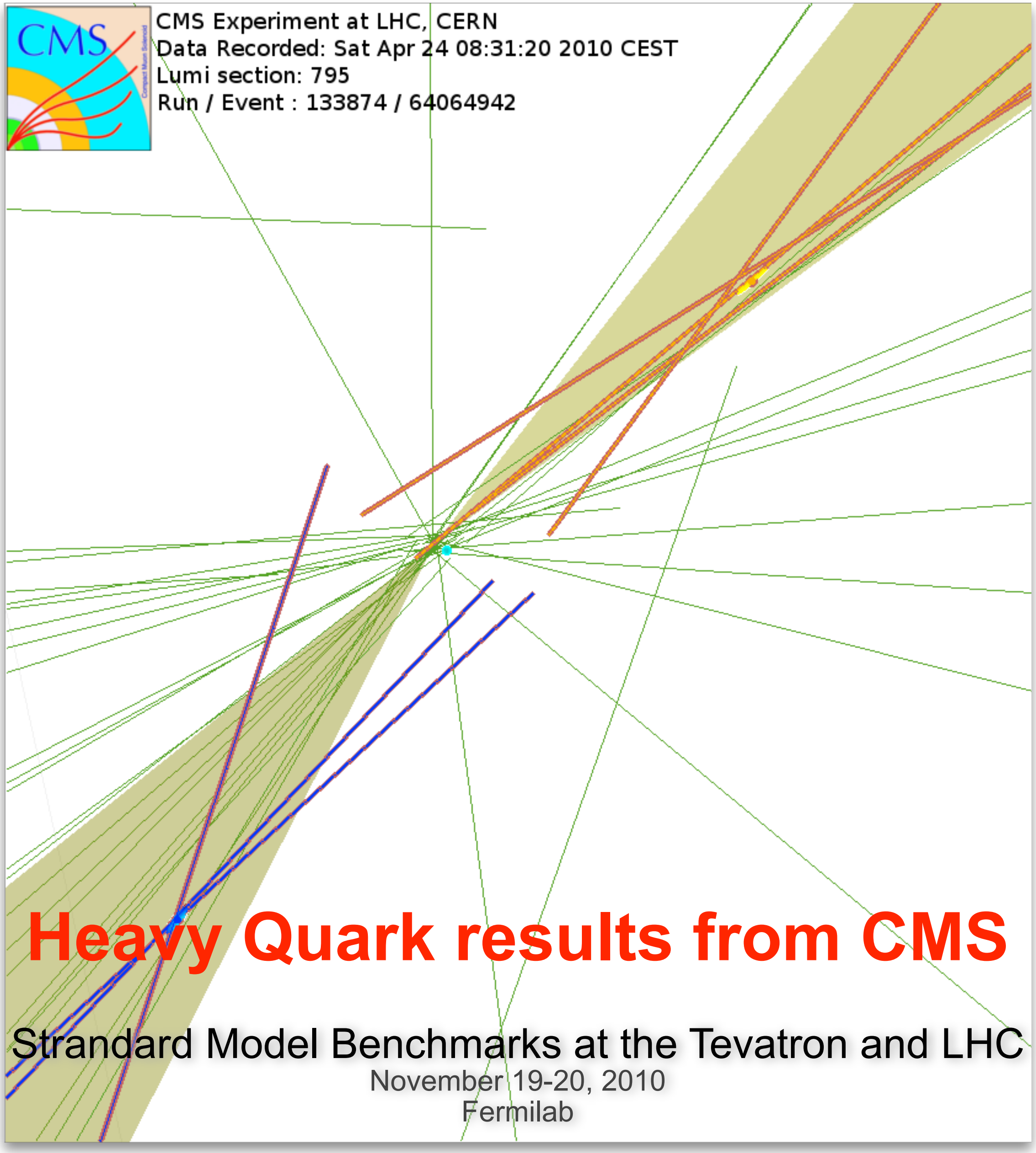


Heavy Quark results from CMS

Strandard Model Benchmarks at the Tevatron and LHC
November 19-20, 2010
Fermilab

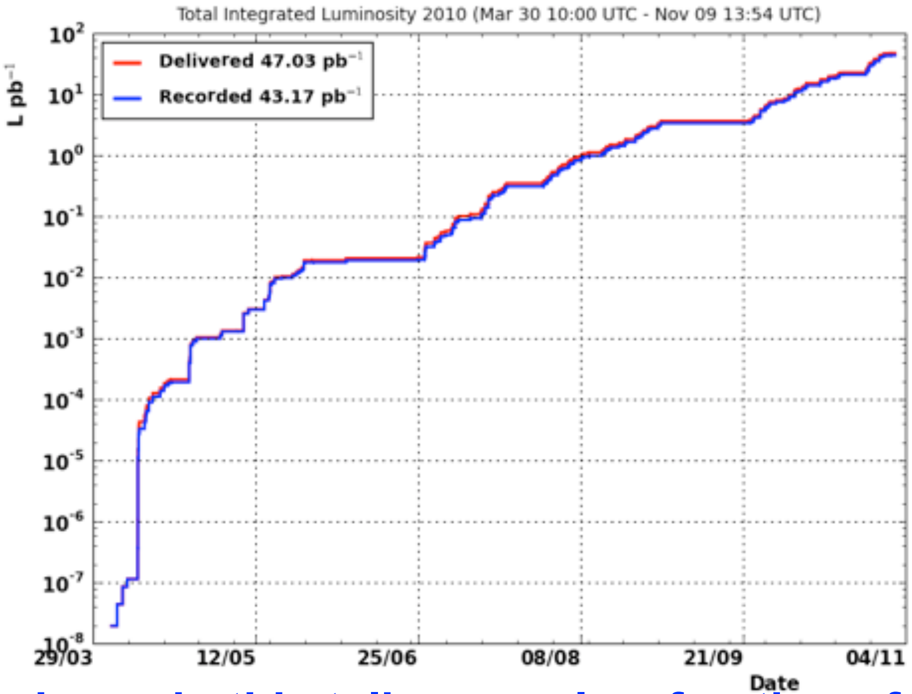
Fabrizio Palla
INFN - Pisa
on behalf of the CMS Collaboration

The LHC accelerator

- CMS integrated around 43 pb^{-1} by the end of the 2010 pp run with an overall data taking efficiency better than 90%

- LHC instantaneous pp luminosity already reached $2x10^{32}$ $cm^{-2}s^{-1}$
  → CMS trigger paths frequently upgraded, to keep a tolerable rate of stored events

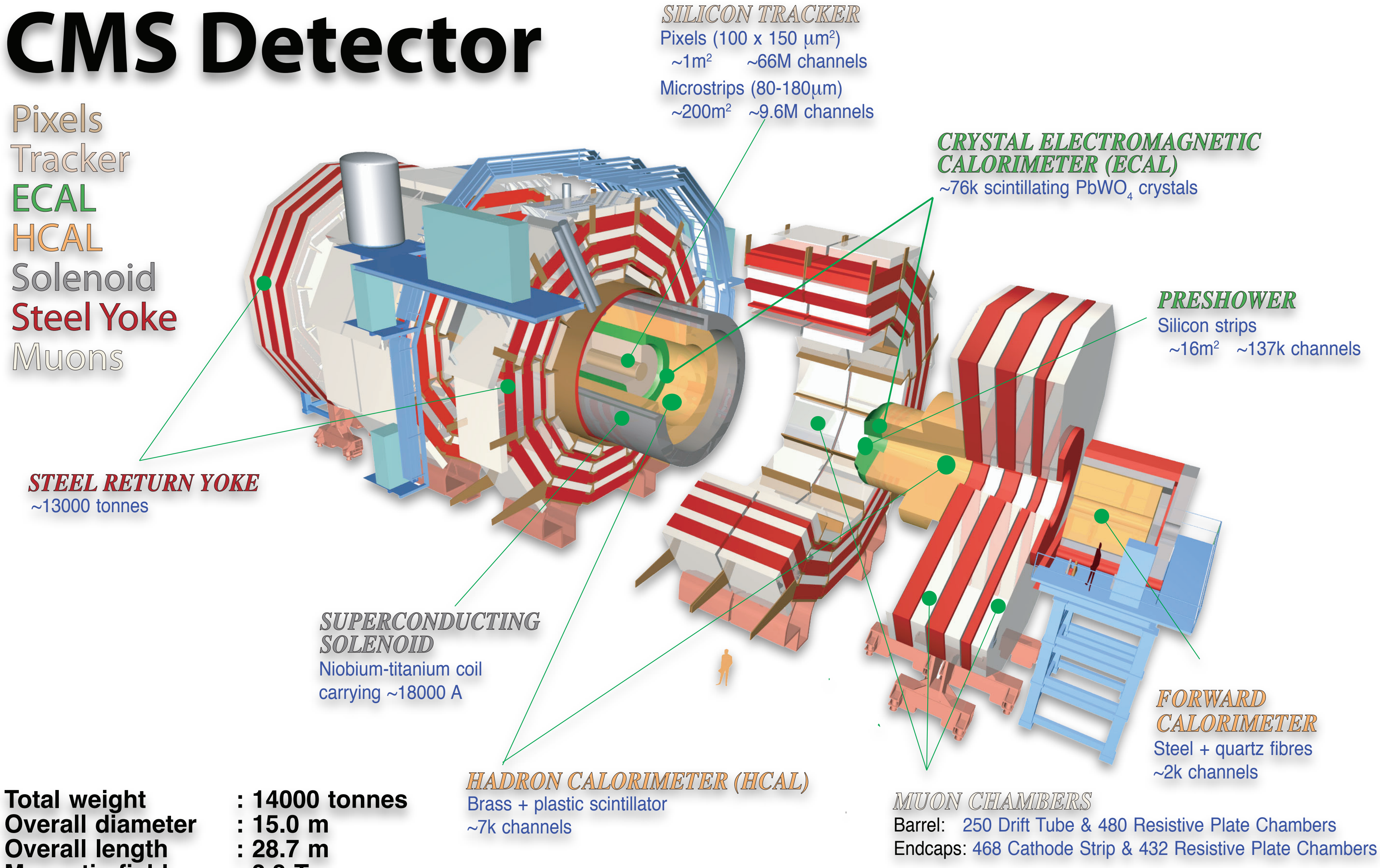
- **Low p_T dimuon triggers in 2010 optimized for J/ψ and Upsilon**



$\mathcal{L} \approx 2 \times 10^{32}$ $cm^{-2}s^{-1}$

Analyses shown in this talk use only a fraction of this delivered luminosity

CMS Detector



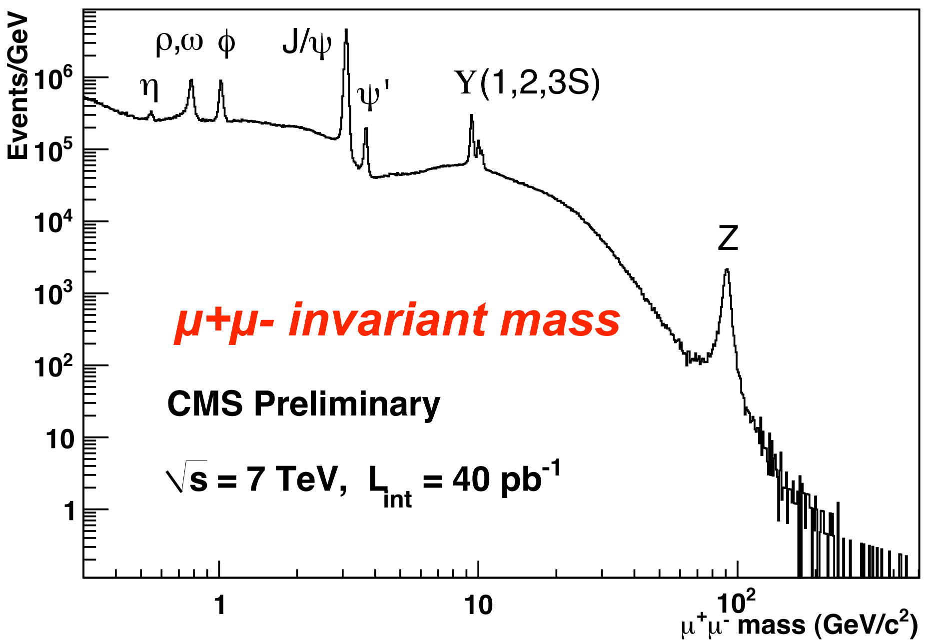
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

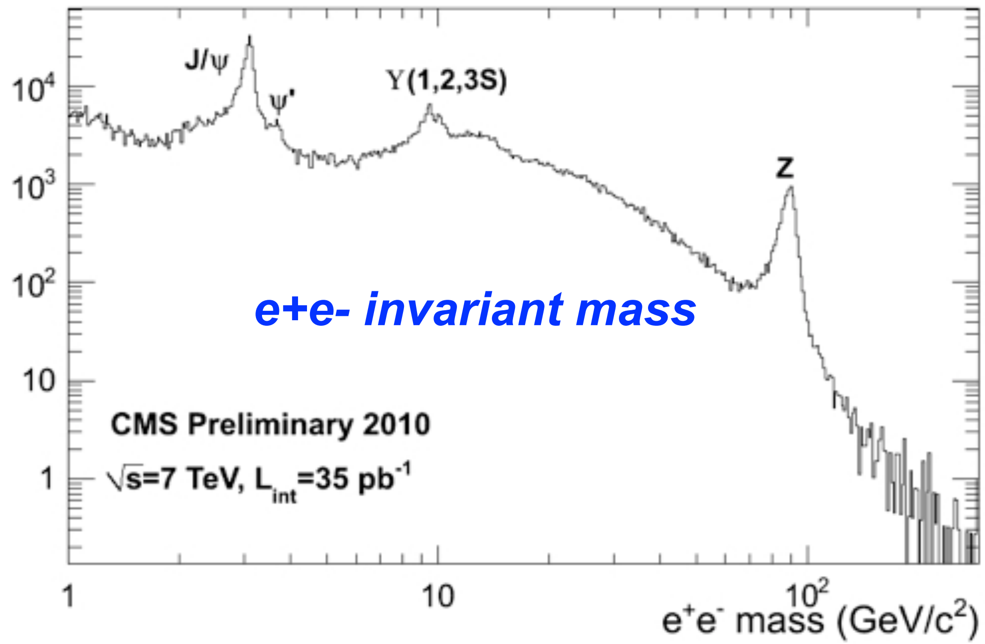
B-hadron reconstruction mainly exploits

- **Muon detectors for semileptonic decays, especially at low pT**
- **Silicon Tracker detector for long lifetime and large mass reconstruction**

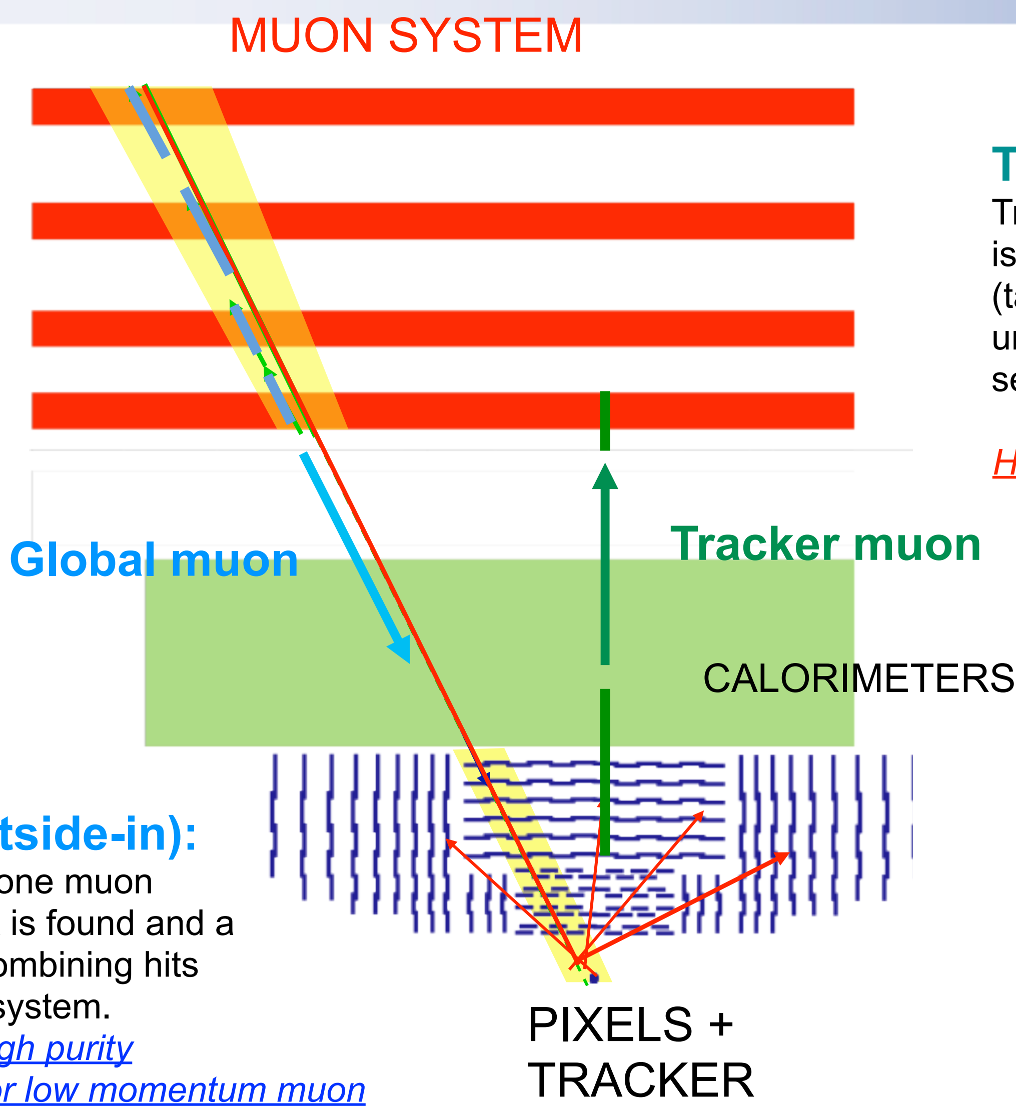
Di-lepton invariant mass

- Level-1 and HLT trigger capability and flexibility, allow to go down to rather low masses and p_T, especially for low p_T muon triggers, compatible with the (relatively) low instantaneous luminosities at LHC startup
  - Stricter triggers now in place to limit storage rates.





Muon identification



Tracker muon (inside-out):

Tracker track (pt>0.5 GeV,p>2.5 GeV) is extrapolated to the muon system (taking into account energy loss, MS uncertainty) at least one muon segment matches track in position.

Fake muon level high

Higher efficiency low momentum muon

Global muon (outside-in):

starting from a stand-alone muon a matching tracker track is found and a global fit is performed combining hits from tracker and muon system.

High purity

Low efficiency for low momentum muon

Muon Triggers

- Two **trigger levels**

L1: hardware
muon system and calorimeters only

↓

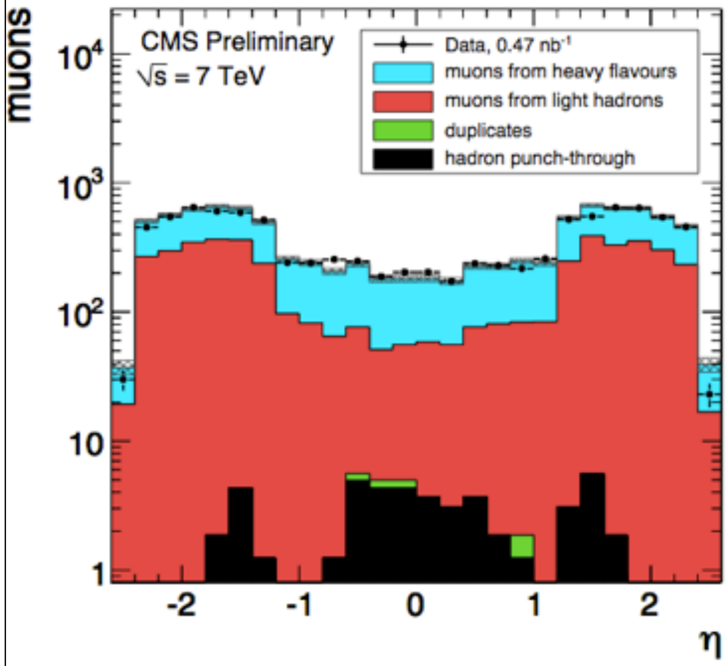
HLT: software
matching of different sub-detectors.
Fast local tracker reconstruction for muons

- Trigger requirements changing with increasing luminosity:
  - Single muons:
    - $p_T > 3$ GeV threshold at the startup
    - Gradually increasing ($p_T > 7$ GeV at L ~ 10^{31} cm^{-2} s^{-1})
  - Double muons:
    - L1 requirements only at the startup, no p_T threshold (not prescaled until 10^{31} Hz cm^{-2})

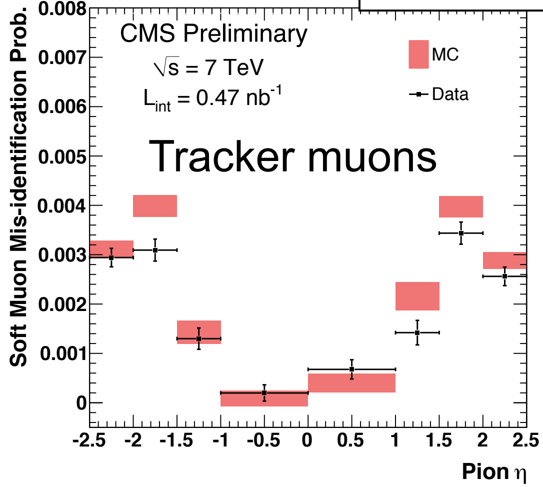
      allows to go down to 0 quarkonium p_T in the forward region
    - At L ~ 10^{31} cm^{-2} s^{-1} ad-hoc strategies adopted for quarkonia (combination of L1 and HLT muons, or HLT muon and track in specific invariant mass regions… etc.)

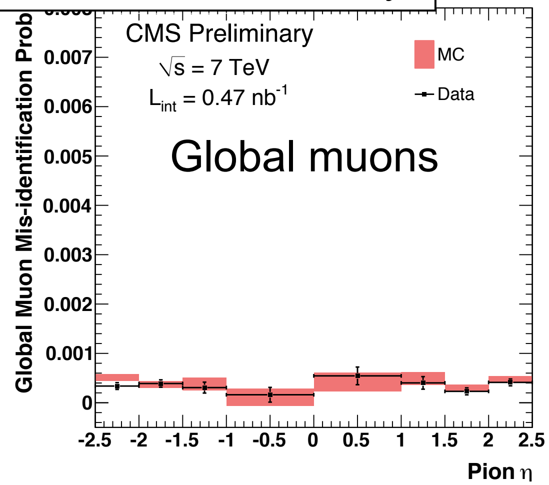
Muon reconstruction quality

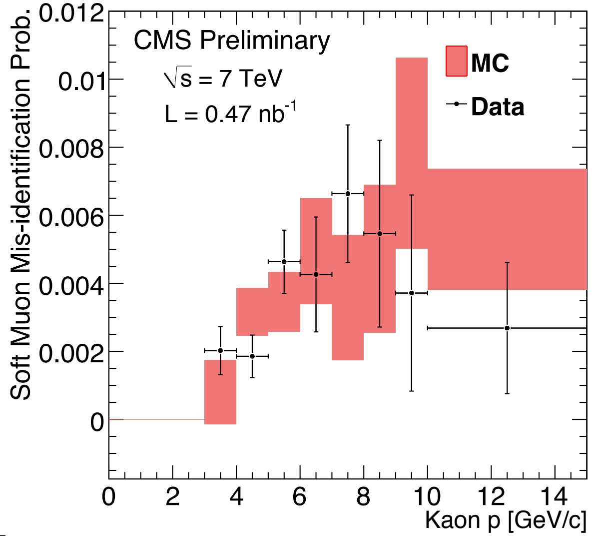
Muons in min-bias events
CMS-PAS-MUO-10-002



π misidentification from K_S decays



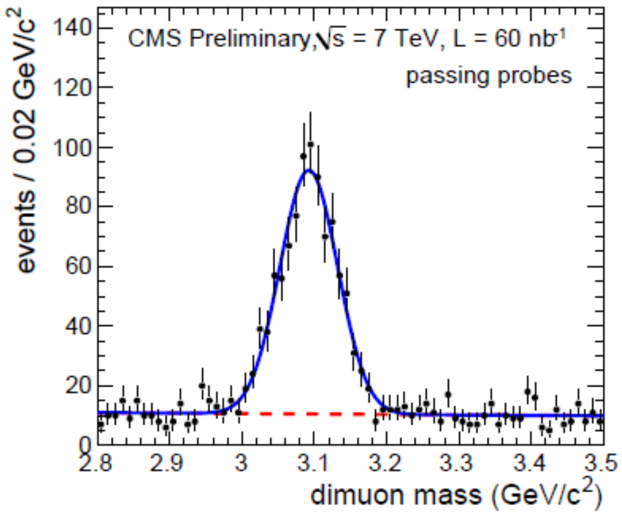


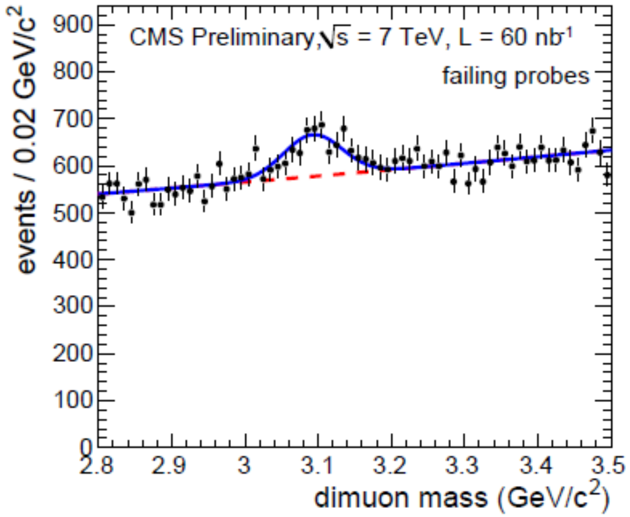


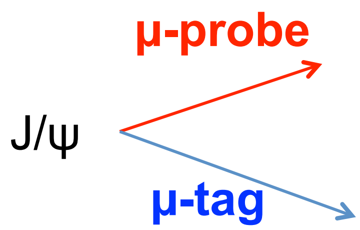
K misidentification from ϕ decays

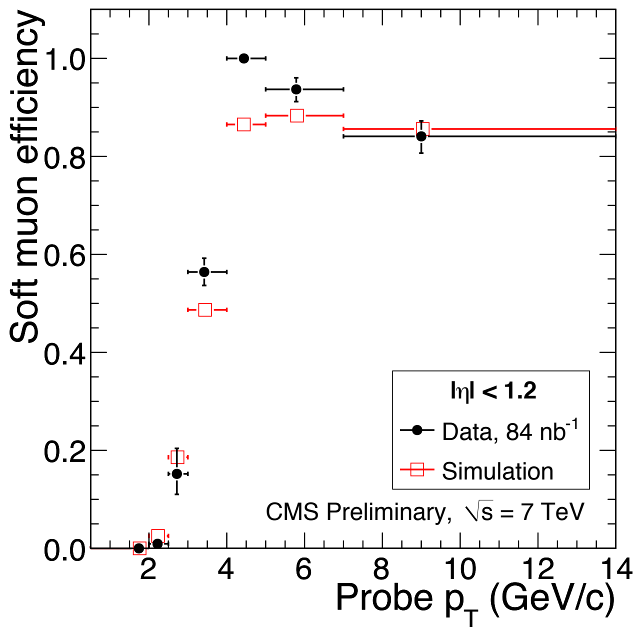
Excellent performance thanks to early detector commissioning using cosmic muons in 2008 and 2009.

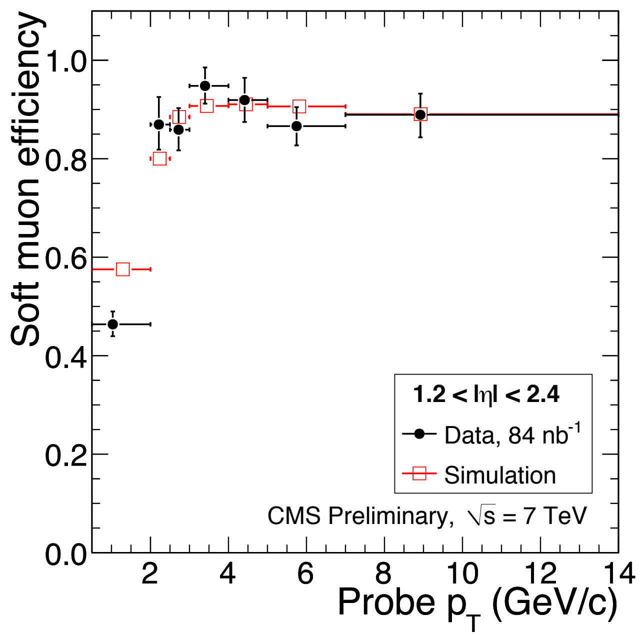
Muon efficiency using Tag&Probe









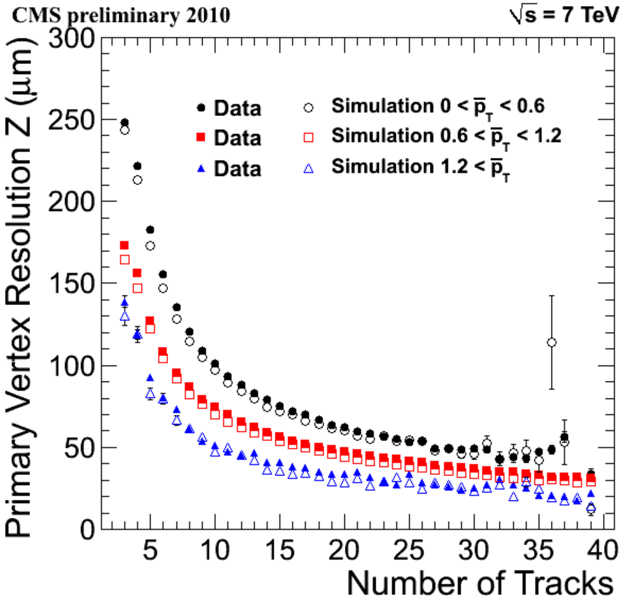


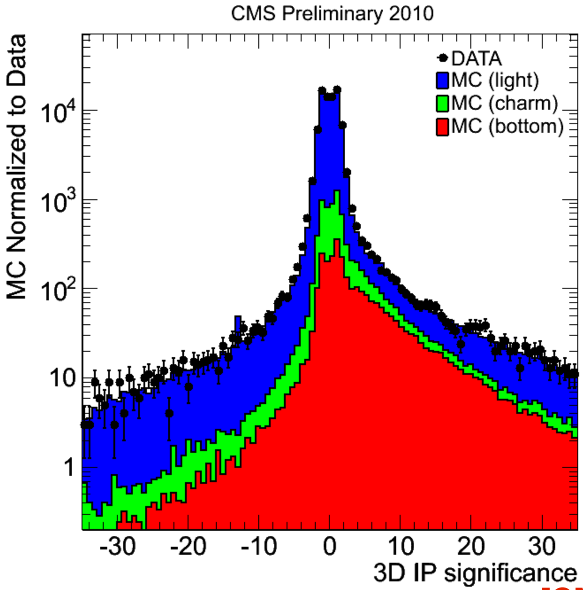
Tracker performance

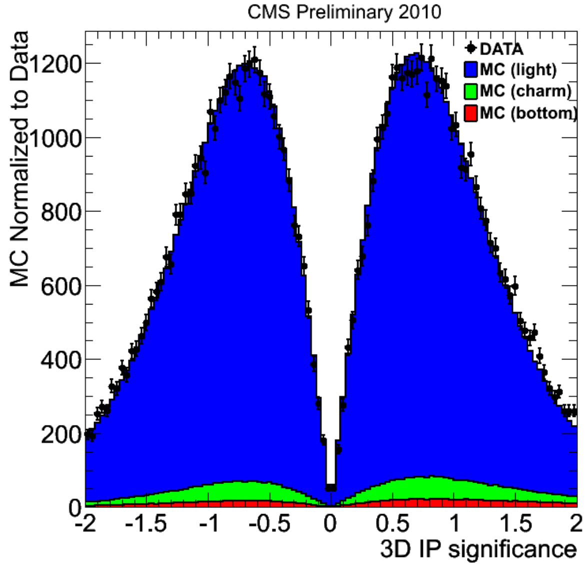
- Tracker performance well understood
  - Performance in agreement with the simulation
  - Excellent level of detector alignment

DMR	Data 7 TeV RMS [μm]	MC startup RMS [μm]	MC no misalignment RMS [μm]
BPIX (u')	1.6	3.1	0.9
BPIX (v')	5.5	8.9	1.8
FPIX (u')	5.7	10.7	2.5
FPIX (v')	7.3	14.4	6.1
TIB (u')	5.1	10.1	3.2
TOB (u')	7.5	11.1	7.5
TID (u')	4.0	10.4	2.4
TEC (u')	10.1	22.1	2.9

[CMS PAS TRK-10-001]





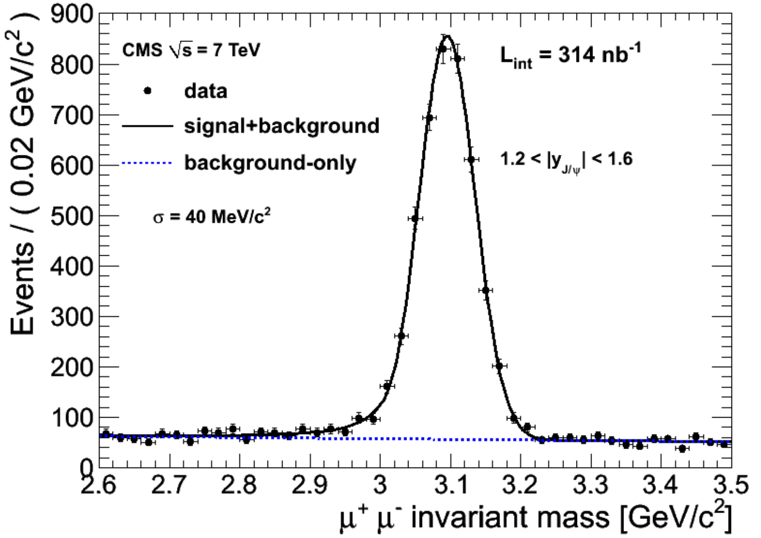


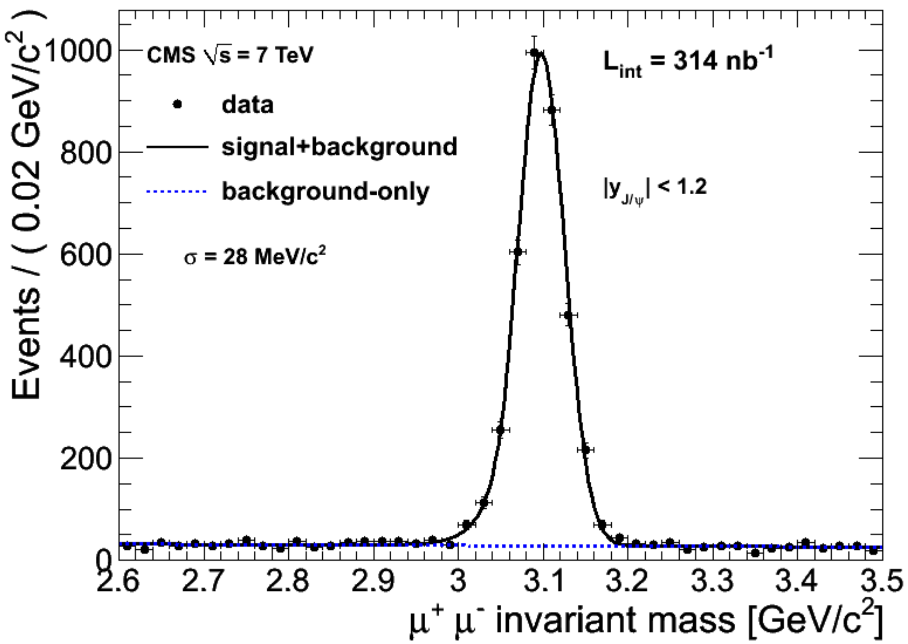
[CMS PAS BTV-10-001]

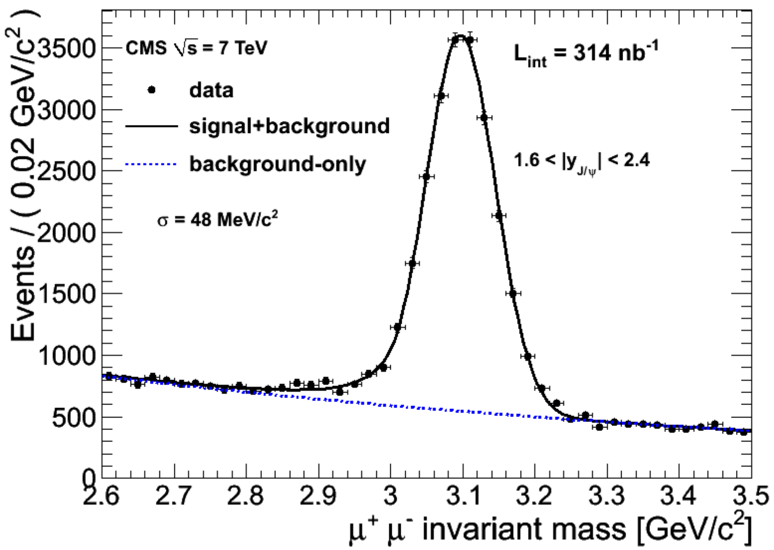
J/ψ cross section

- **Muons well within acceptance window**
- **Track quality:**
  - number of hits in full tracker
  - number of hits in pixel layers
  - track fit χ^2
- **Muon quality:**
  - fit χ^2
  - track-muon matching
- **Di-muon vertex quality**
- **~27000 events selected**

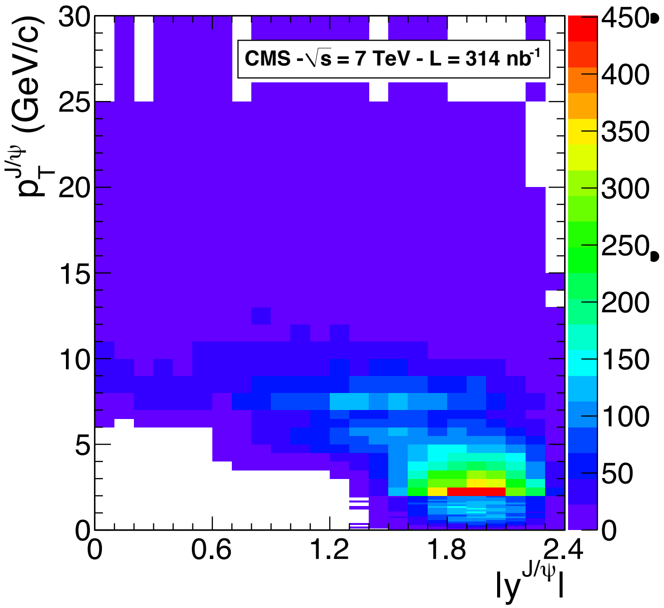
CERN-PH-EP/2010-046
18 Nov. 2010
Submitted to EPJC
arXiv:1011.4193







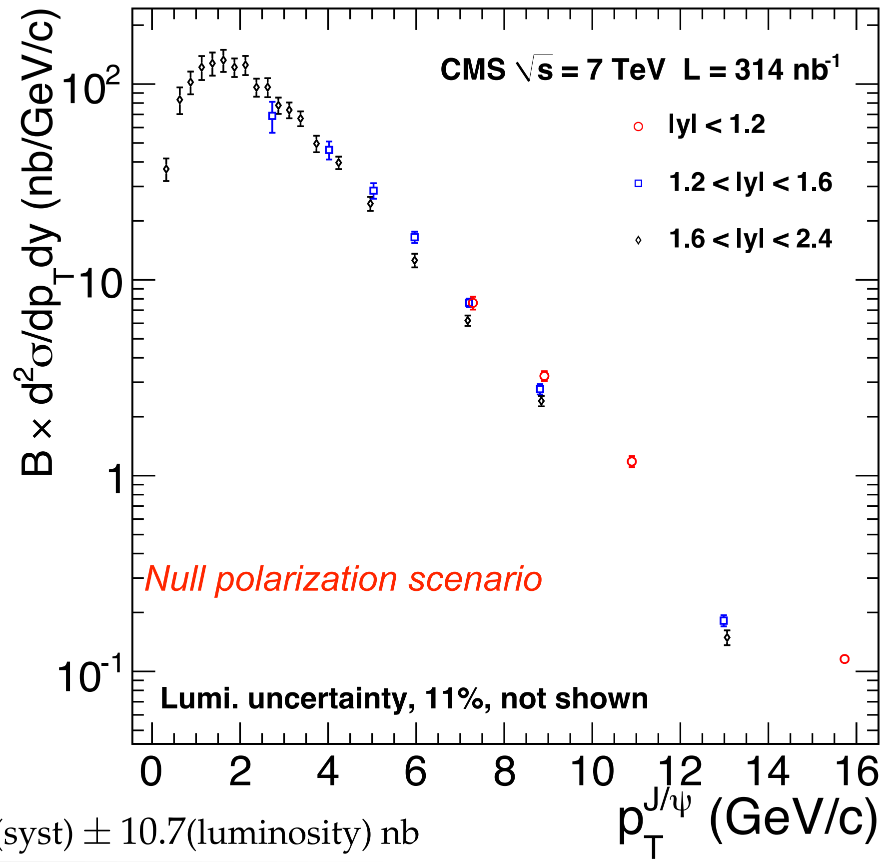
Inclusive J/ψ cross section



- **The acceptance is calculated by MC and depends on the assumed polarization scenario:**
  - **isotropic**
  - **extreme values of λ_θ (= ±1) in the helicity frame (along the Q momentum)**
  - **extreme values of λ_θ (= ±1) in the Collins-Soper frame (along the collision axis)**
- **The efficiency is determined from data using a T&P approach**

$$\frac{d^2\sigma}{dp_T dy} \times B(J/\psi \to \mu\mu) = \frac{N_{fit}\left\langle \frac{1}{A\cdot\varepsilon}\right\rangle}{\int Ldt\cdot \Delta p_T \cdot \Delta y}$$

Source	Relative error (%)		
	$\lvert y\rvert < 1.2$	$1.2 < \lvert y\rvert < 1.6$	$1.6 < \lvert y\rvert < 2.4$
FSR	0.8 – 2.5	0.3 – 1.6	0.0 – 0.9
p_T calibration and resolution	1.0 – 2.5	0.8 – 1.2	0.1 – 1.0
Kinematical distributions	0.3 – 0.8	0.6 – 2.6	0.9 – 3.1
b-hadron fraction and polarization	1.9 – 3.1	0.5 – 1.2	0.2 – 3.0
Muon efficiency	1.9 – 5.1	2.3 – 12.2	2.7 – 9.2
ρ factor	0.5 – 0.9	0.6 – 8.1	0.2 – 7.1
Fit function	0.6 – 1.1	0.4 – 5.3	0.3 – 8.8



$$\sigma(pp \to J/\psi + X)\cdot \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 97.5 \pm 1.5(\mathrm{stat}) \pm 3.4(\mathrm{syst}) \pm 10.7(\mathrm{luminosity})\ \mathrm{nb}$$

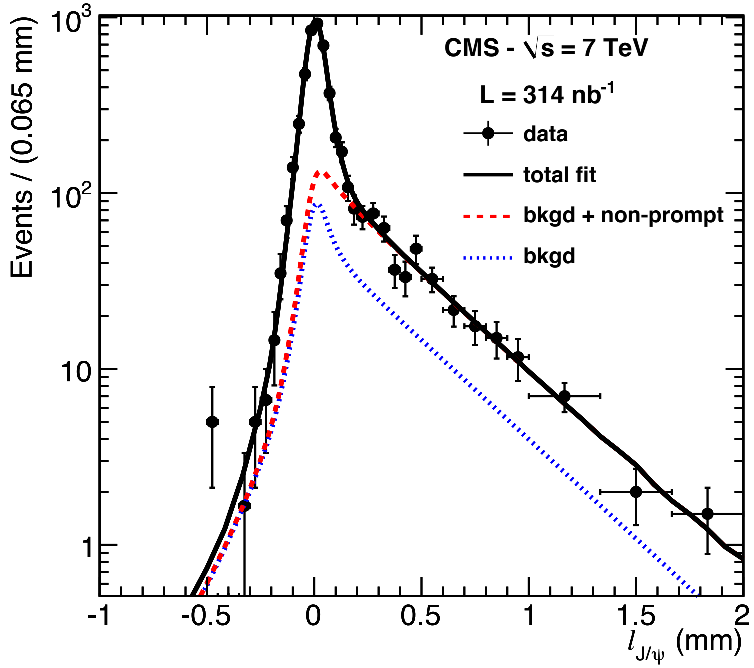
Non prompt J/ψ fraction

Pseudo proper decay length

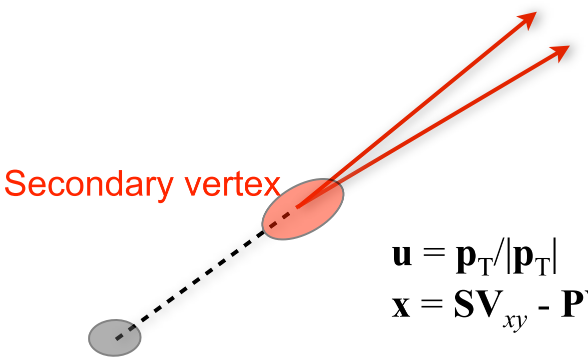
$$\ell_{J/\psi} = L_{xy} \cdot m_{J/\psi} / p_T \qquad L_{xy} = \frac{\mathbf{u}^T \sigma^{-1} \mathbf{x}}{\mathbf{u}^T \sigma^{-1} \mathbf{u}}$$

- Decay length parameterization :
  - Prompt : δ-function
  - Non-prompt : MC templates

all convoluted with a 3-Gaussian resolution



6.5<p_T<10 GeV/c, 1.6<|y|<2.4



$\mathbf{u} = \mathbf{p}_T / |\mathbf{p}_T|$

$\mathbf{x} = \mathbf{SV}_{xy} - \mathbf{PV}_{xy}$

Decay length l_{xy} resolutions depend on the p_T and mildly on the rapidity

p_T (J/Psi) 0-2 GeV/c ~250 μm

p_T (J/Psi) 10-30 GeV/c ~35 μm

relative error (in %)

	$\|y\| < 1.2$	$1.2 < \|y\| < 1.6$	$1.6 < \|y\| < 2.4$
Tracker misalignment	0.5 – 0.7	0.9 – 4.6	0.7 – 9.1
b-lifetime model	0.0 – 0.1	0.5 – 4.8	0.5 – 11.2
Vertex estimation	0.3	1.0 – 12.3	0.9 – 65.8
Background fit	0.1 – 4.7	0.5 – 9.5	0.2 – 14.8
Resolution model	0.8 – 2.8	1.3 – 13.0	0.4 – 30.2
Efficiency	0.1 – 1.1	0.3 – 1.3	0.2 – 2.4

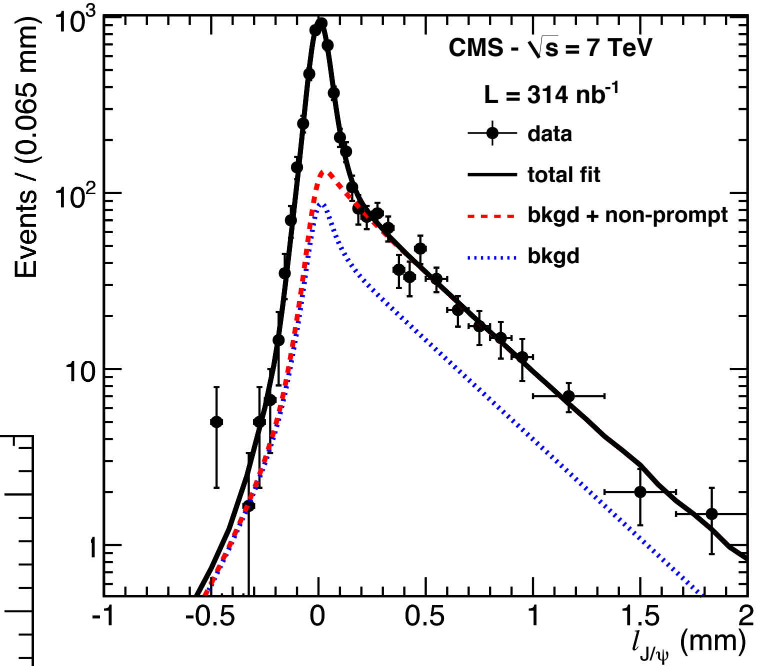
Non prompt J/ψ fraction

Pseudo proper decay length

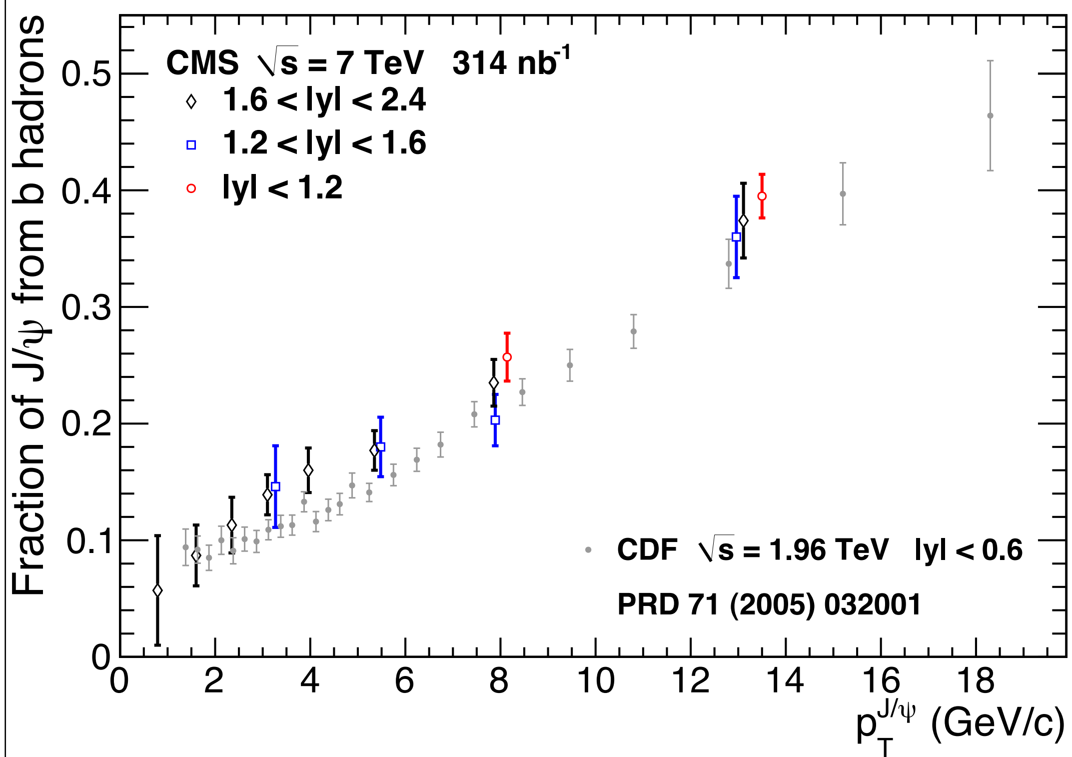
$$\ell_{J/\psi} = L_{xy} \cdot m_{J/\psi} / p_{\mathrm{T}} \qquad L_{xy} = \frac{\mathbf{u}^T \sigma^{-1} \mathbf{x}}{\mathbf{u}^T \sigma^{-1} \mathbf{u}}$$

- Decay length parameterization :
  - Prompt : δ-function
  - Non-prompt : MC templates

all convoluted with a 3-Gaussian resolution



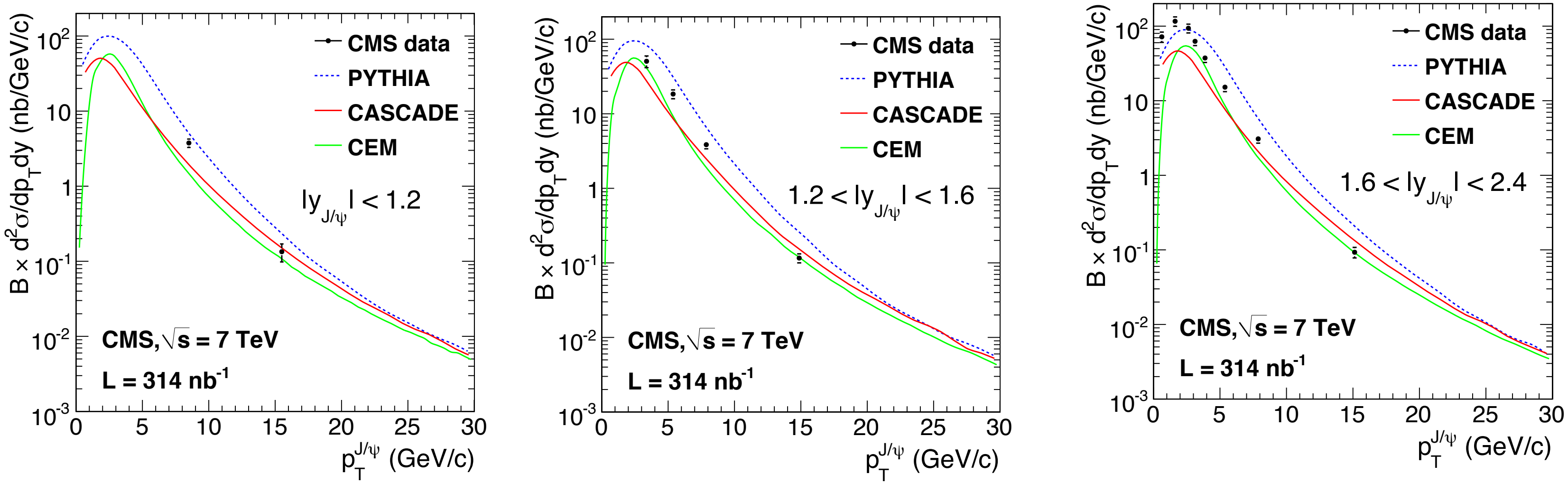
$6.5<p_T<10$ GeV/c, $1.6<|y|<2.4$



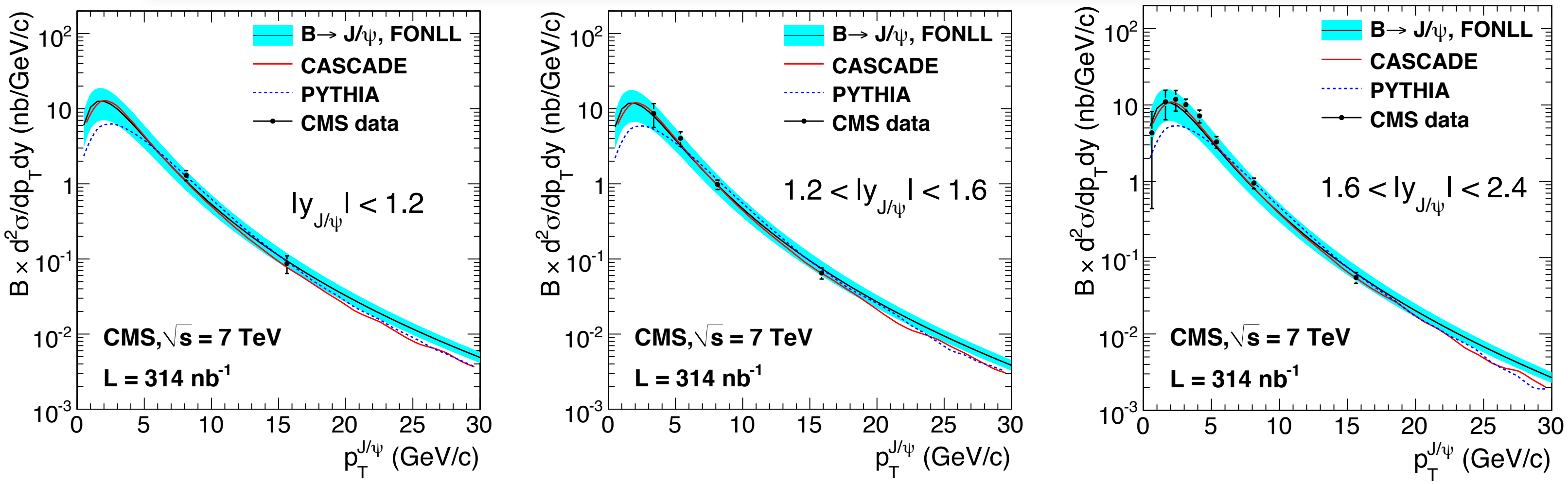
relative error (in %)

	$\|y\| < 1.2$	$1.2 < \|y\| < 1.6$	$1.6 < \|y\| < 2.4$
Tracker misalignment	0.5 – 0.7	0.9 – 4.6	0.7 – 9.1
b-lifetime model	0.0 – 0.1	0.5 – 4.8	0.5 – 11.2
Vertex estimation	0.3	1.0 – 12.3	0.9 – 65.8
Background fit	0.1 – 4.7	0.5 – 9.5	0.2 – 14.8
Resolution model	0.8 – 2.8	1.3 – 13.0	0.4 – 30.2
Efficiency	0.1 – 1.1	0.3 – 1.3	0.2 – 2.4

Comparison with theory



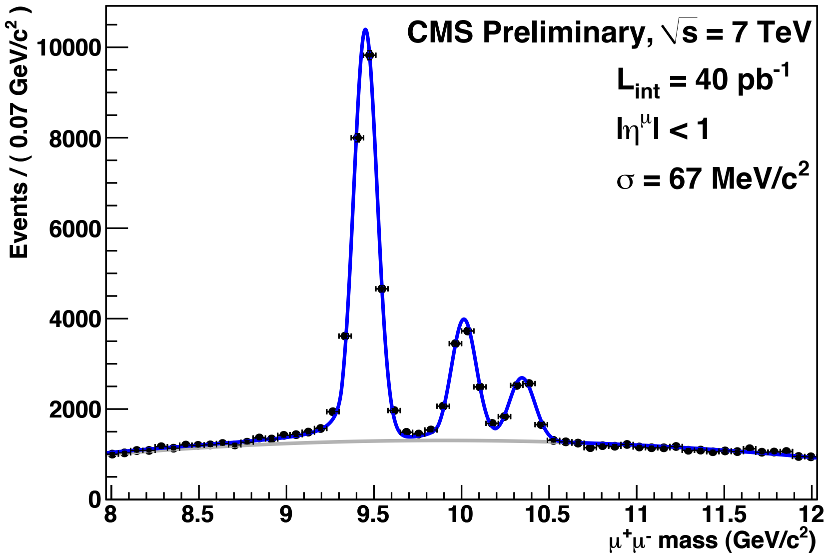
$$\sigma(pp \to J/\psi + X) \cdot BR(J/\psi \to \mu^+\mu^-) = 70.9 \pm 2.1(\text{stat}) \pm 3.0(\text{syst}) \pm 7.8(\text{luminosity})\ \text{nb}$$

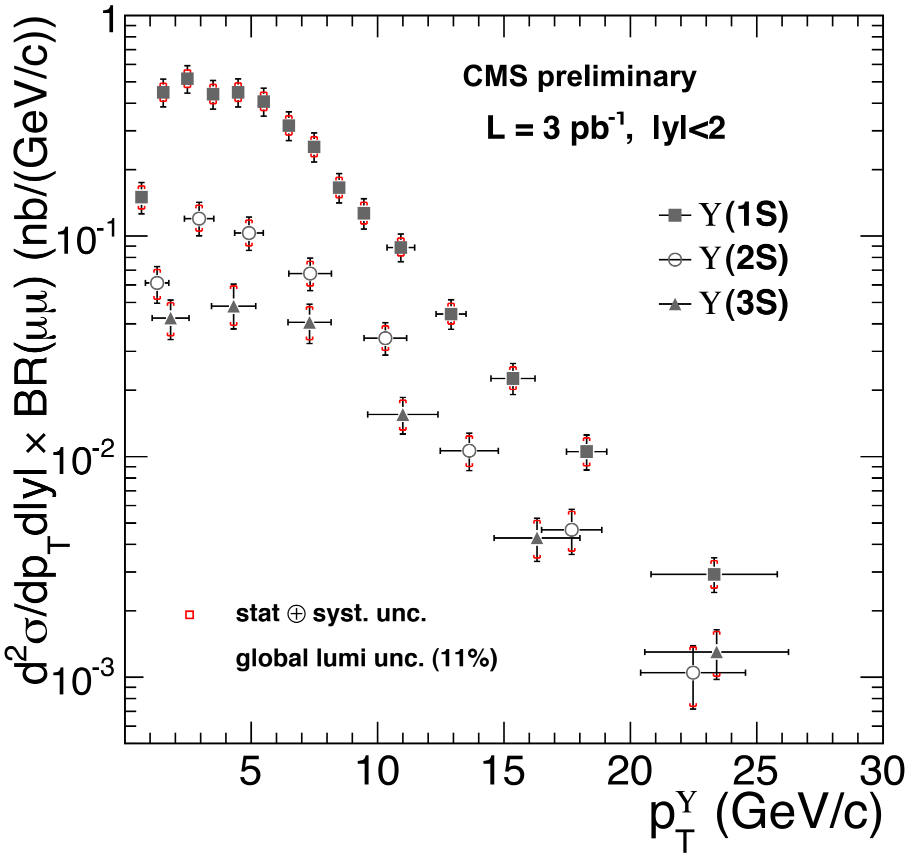


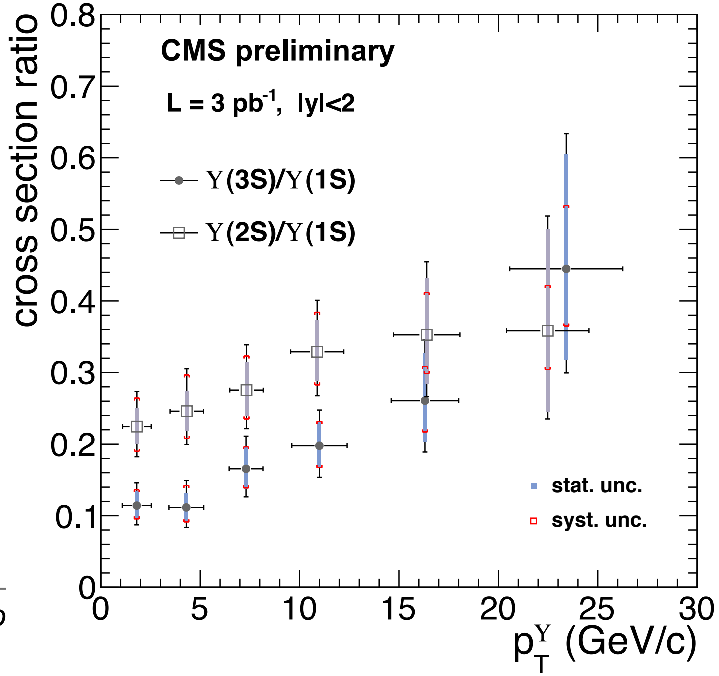
$$\sigma(pp \to bX \to J/\psi X) \cdot BR(J/\psi \to \mu^+\mu^-) = 26.0 \pm 1.4\ (\text{stat}) \pm 1.6\ (\text{syst}) \pm 2.9\ (\text{luminosity})\ \text{nb}$$

The Υ (nS) family

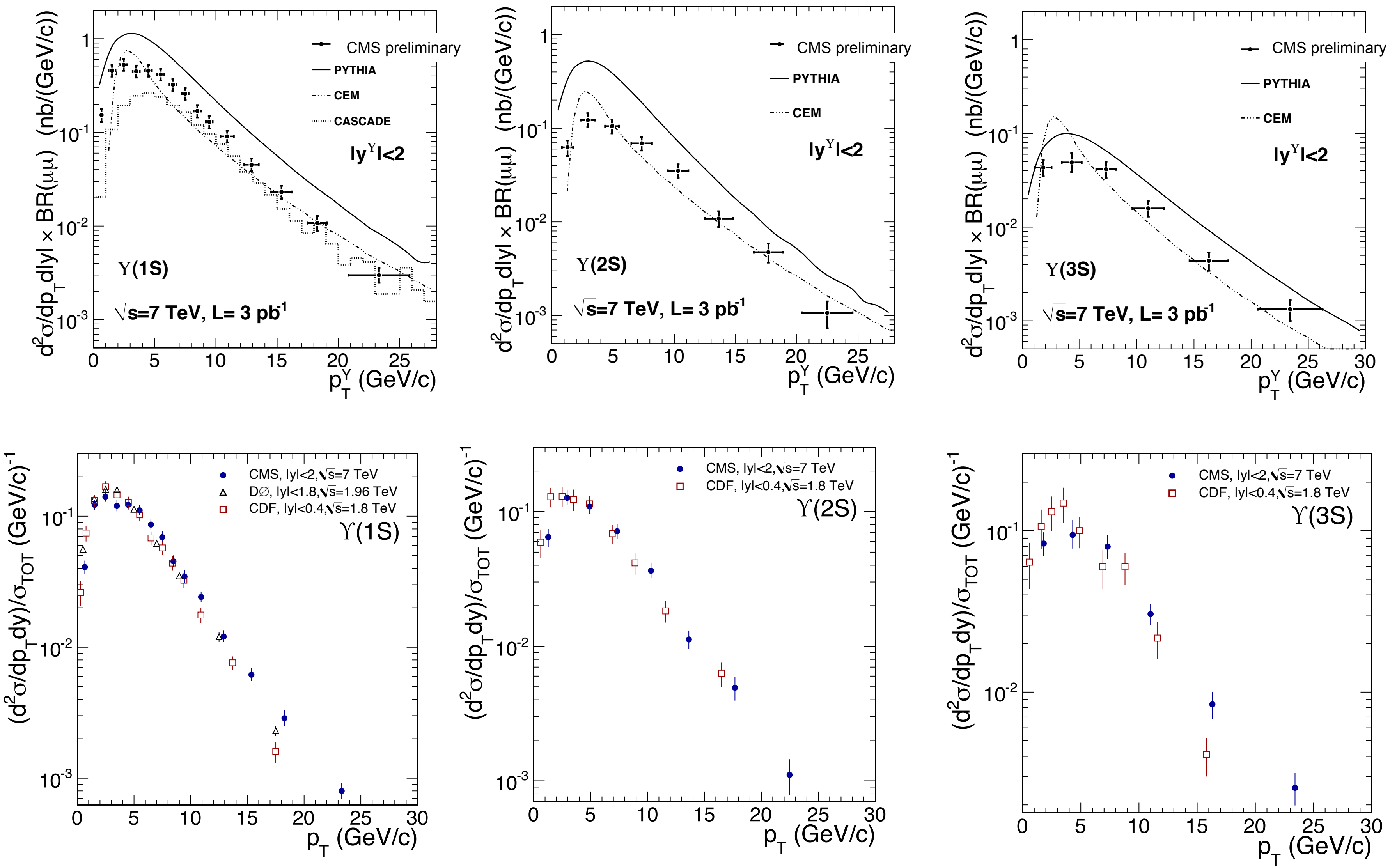
- Similar selection of J/psi
- Efficiencies from data (T&P)
- Yields: MLL fit (3CB+ Linear)
- Leading systematic from efficiency



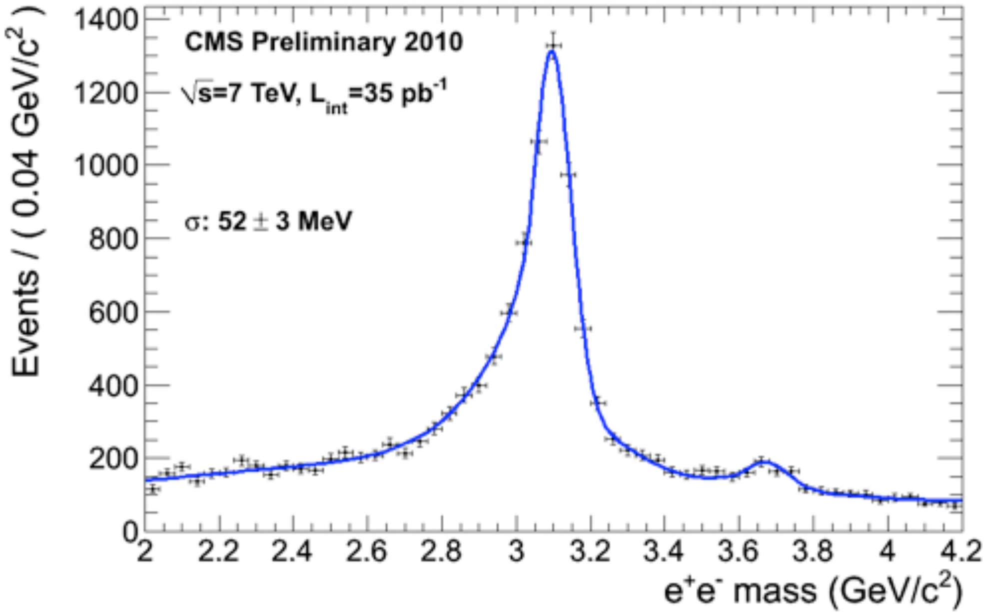


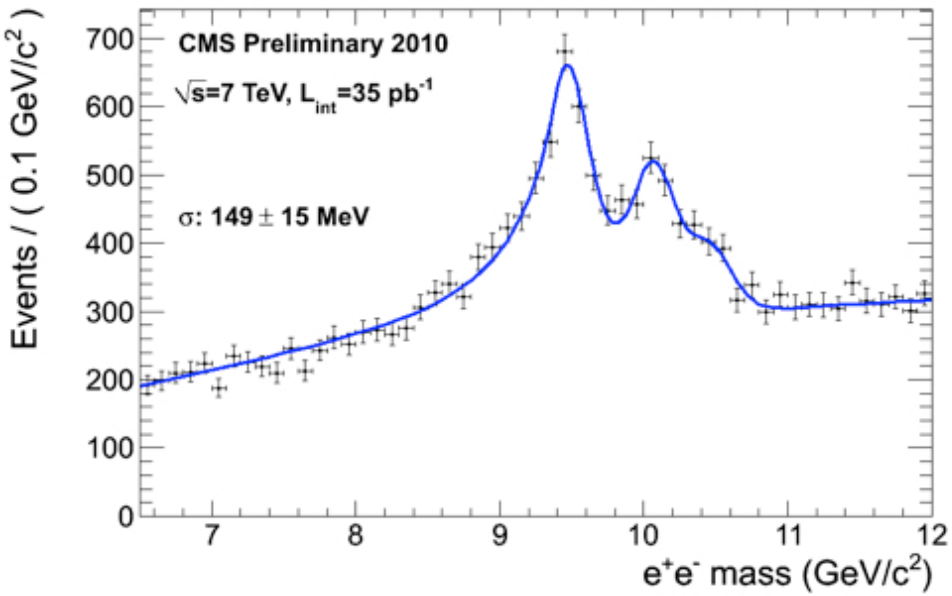


Comparison with theory and Tevatron



Quarkonia to electrons

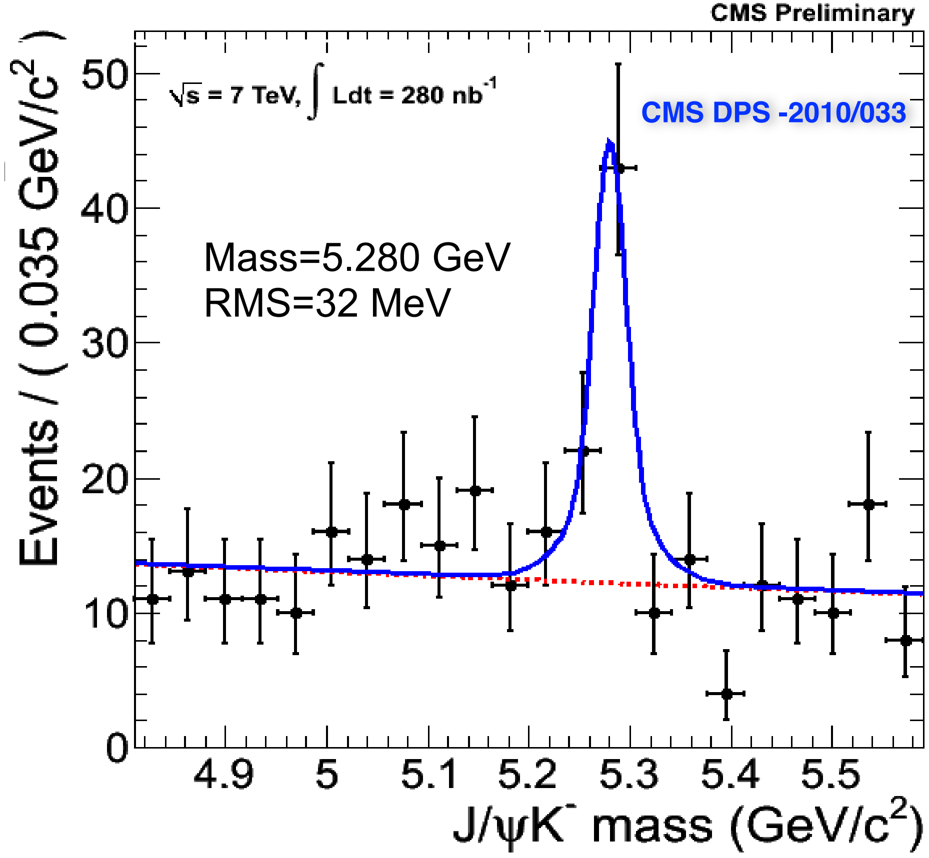




$B^{\pm}$ exclusive decays

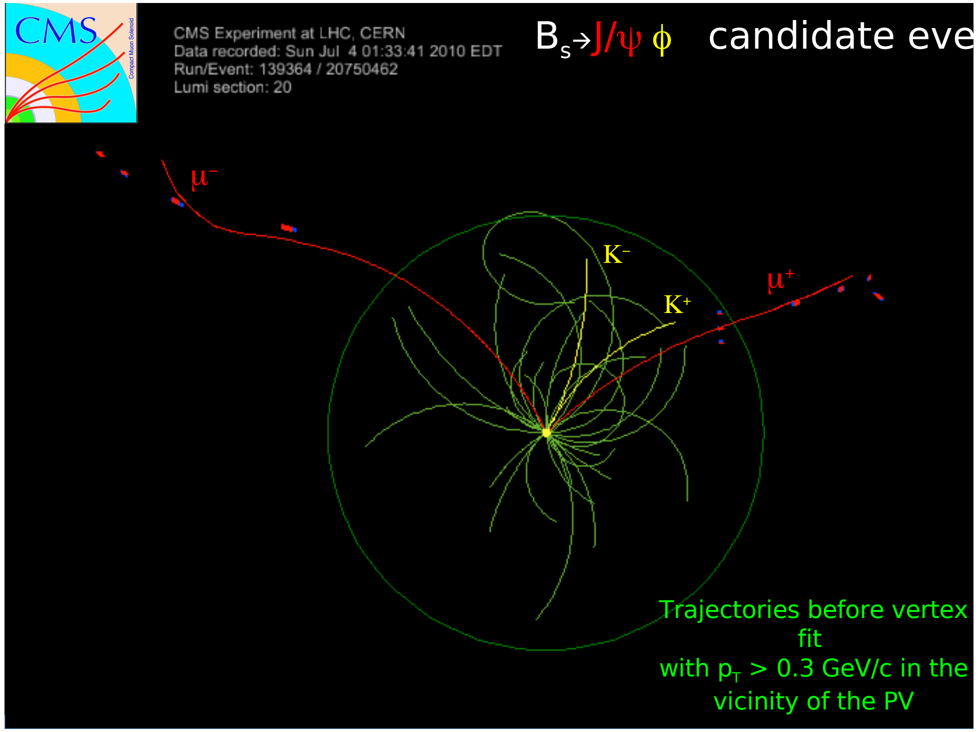
- $B^{\pm} \rightarrow J/\psi\, K^{\pm}$
  - Analysis will benefit of the huge statistics from the 2010 run

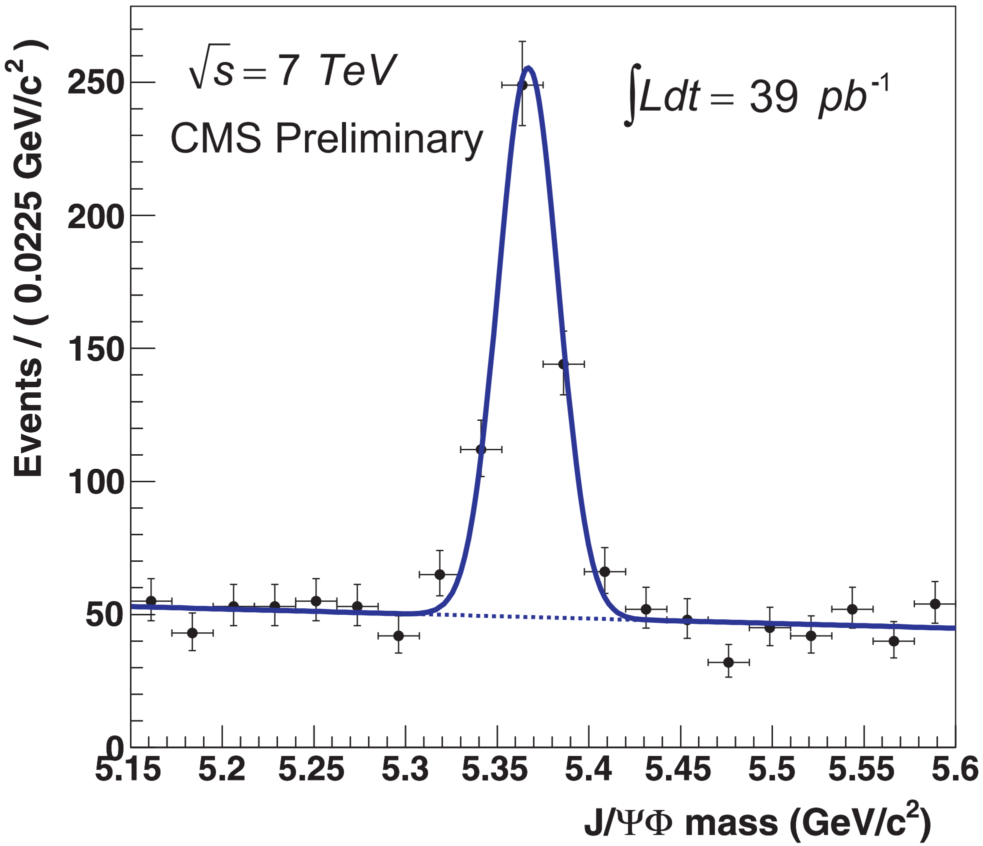
Fit using three signal Gaussians + exponential background



- Similar analysis for $B^0 \rightarrow J/\psi\, K^0_S$ and $J/\psi\, K^{*0}$ ongoing

$B_s \rightarrow J/\psi\ \phi$





Fit results:

μ_{gauss} = 5.3670 ± 1.2e-03 GeV/c^2

σ_{gauss} = 16.4 ± 1.2 MeV/c^2

N_{signal} = 377 ± 26

N_{BG} = 978 ± 36

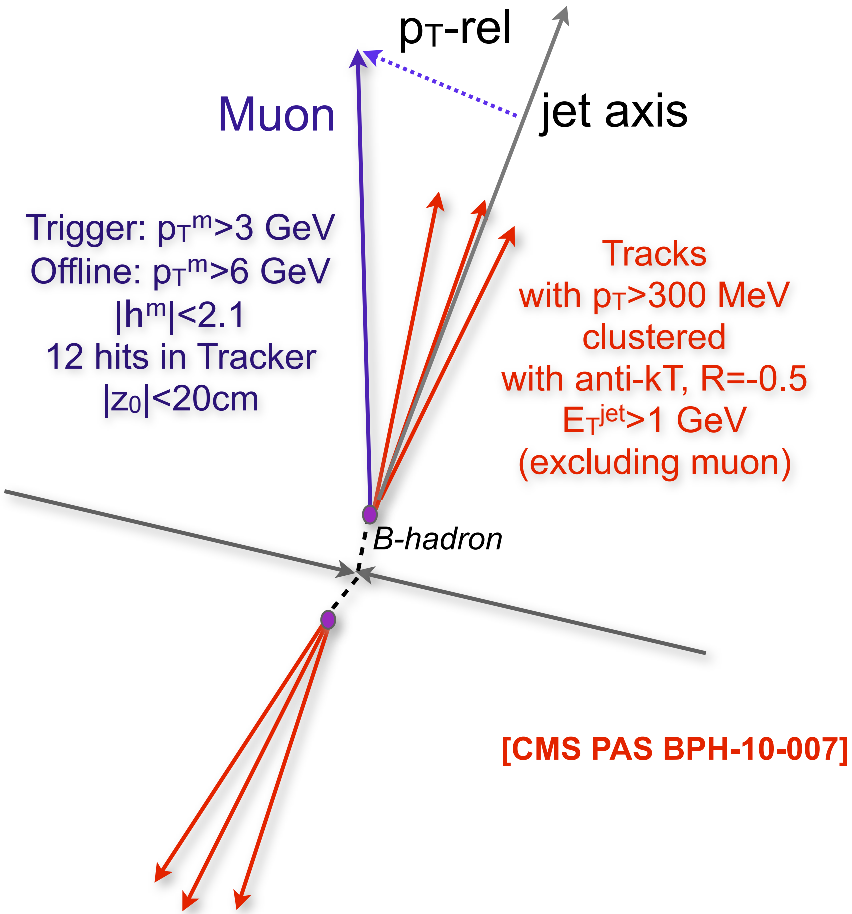
χ^2/ndof = 0.91

S/√(S+B) ≈ 10

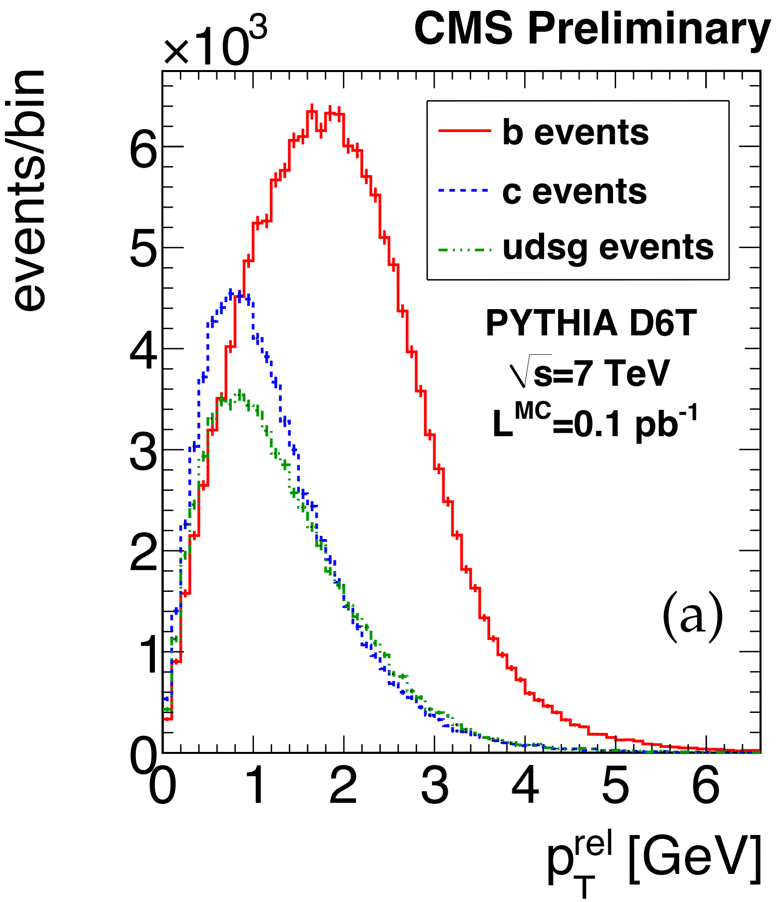
S/B ≈ 0.4

Semileptonic decays

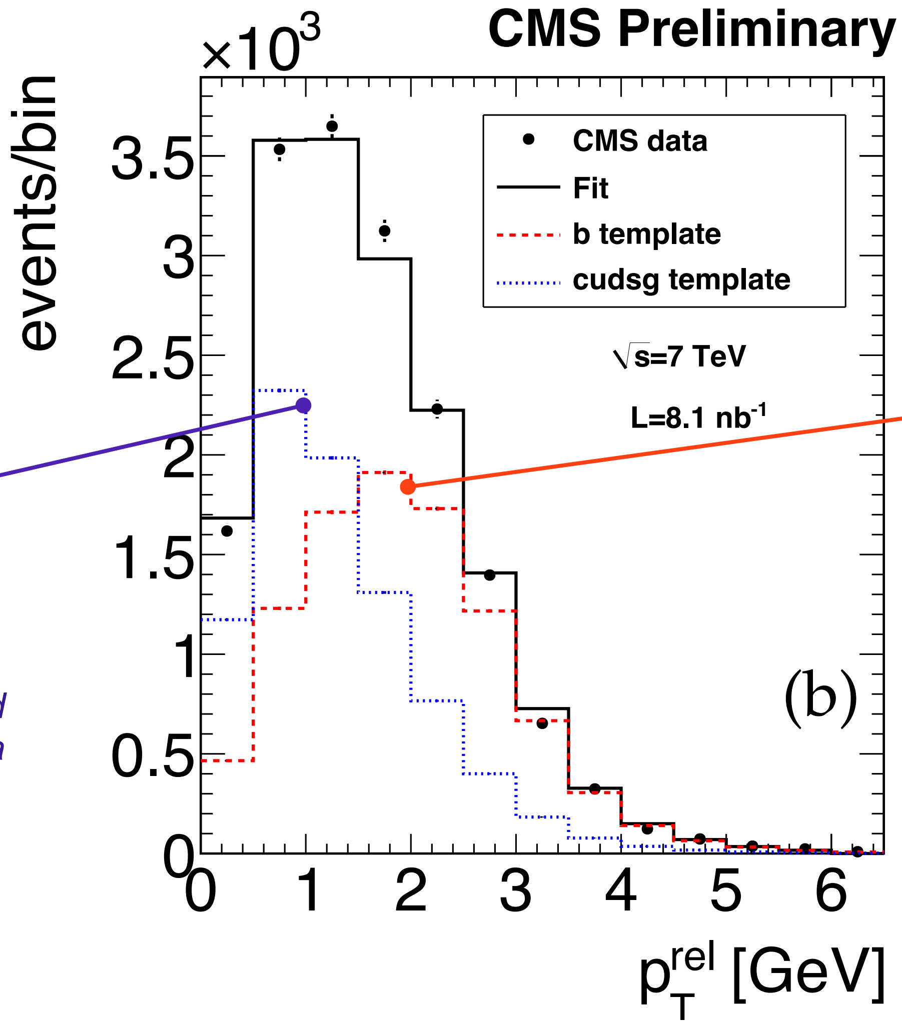
- Exploit kinematics of semi-leptonic decay due to heavy quark mass
  - Muon transverse momentum w.r.t. jet on average larger for b-quark
  - Fraction of events with b-decays extracted from a fit with simulated p_T^{rel} templates



[CMS PAS BPH-10-007]



Cross section calculation



Combination of templates from light quarks/gluons in-flight decays and charm decays.

Template from misidentified hadrons validated with data

b-quark templates from MC, validated with b-enriched data sample

f_b from fit
(44±1)%

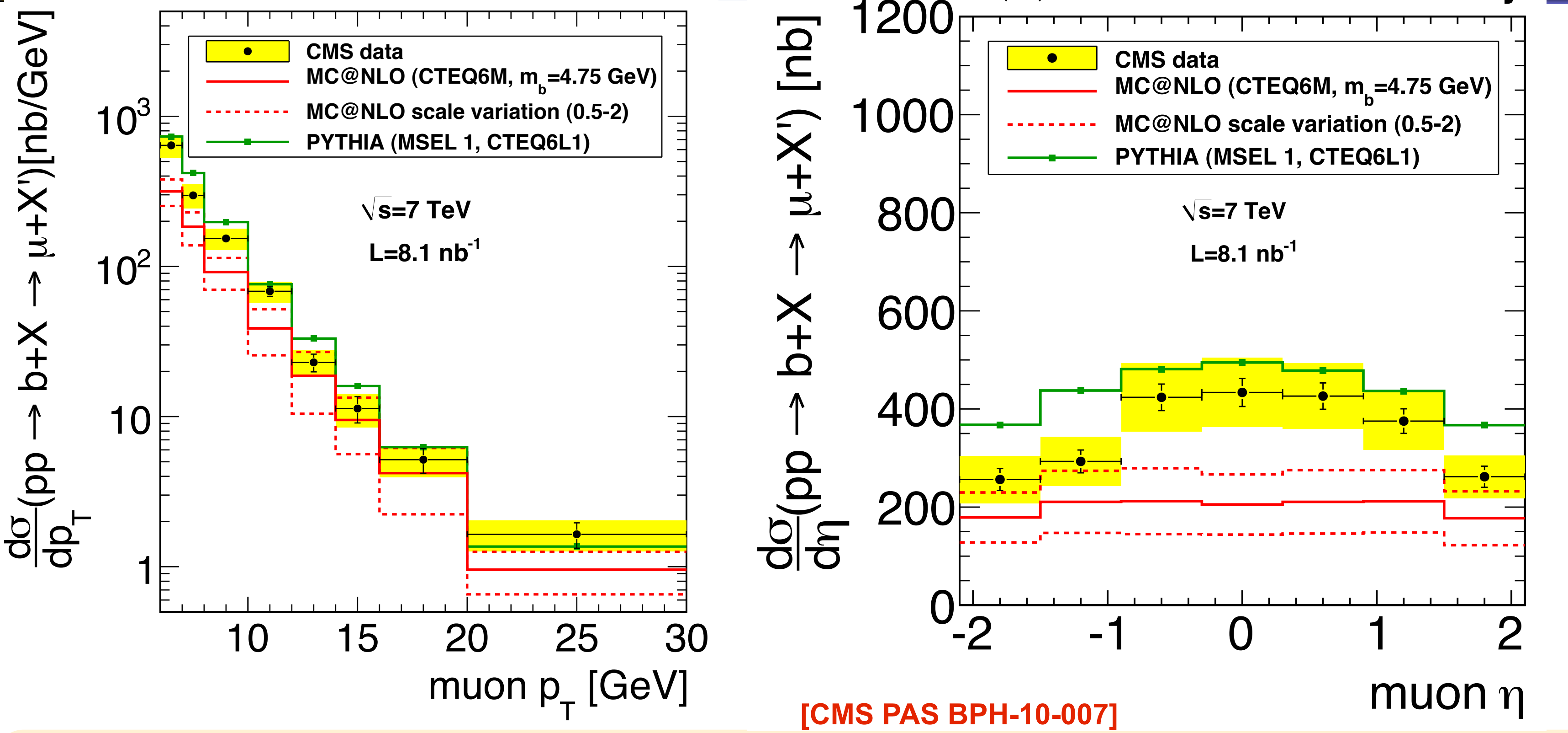
Efficiencies (e):
Muon trigger ~82% (Data)
Muon reconstruction ~97% (MC)
Muon-jet association ~77% (MC)

Luminosity ($\mathcal{L}$): 8.1 nb^{-1}

[CMS PAS BPH-10-007]

Cross section definition $\sigma \equiv \sigma(pp \to b + X \to \mu + X', p_\perp^\mu > 6\,\text{GeV}, |\eta^\mu| < 2.1) = \frac{N_b^{\text{data}}}{\mathcal{L}\,\varepsilon}$

Differential cross sections



[CMS PAS BPH-10-007]

$$\sigma = (1.48 \pm 0.04_{\rm stat} \pm 0.22_{\rm syst} \pm 0.16_{\rm lumi})\,\mu{\rm b}$$ **Measured visible cross section**

$$\sigma_{\rm PYTHIA} = 1.8\,\mu{\rm b}$$

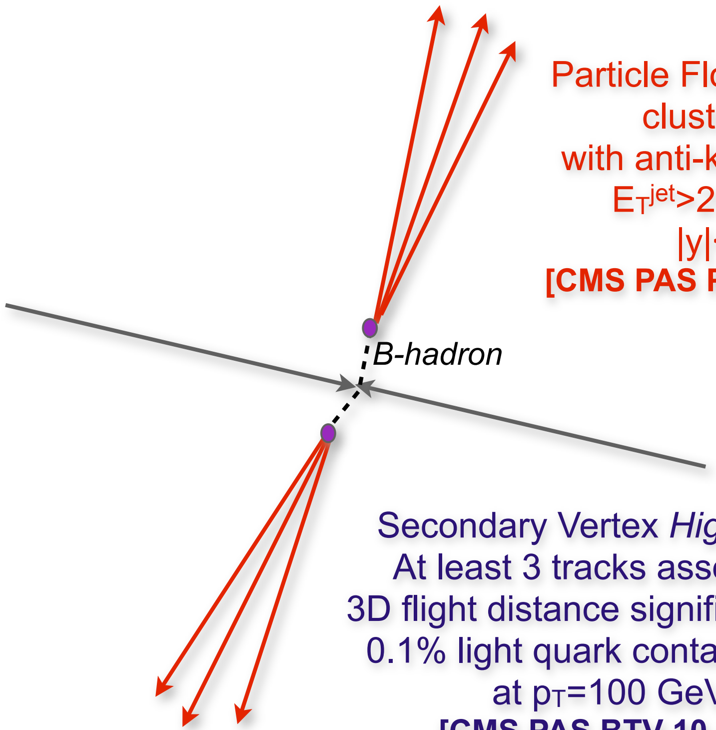
$$\sigma_{\rm MC@NLO} = [0.84^{+0.36}_{-0.19}({\rm scale}) \pm 0.08(m_b) \pm 0.04({\rm pdf})]\,\mu{\rm b}$$ (m_F=m_R=p_T)

Experimental uncertainties (15-20%) dominated by modeling of fake muons and underlying event

MC@NLO: larger discrepancies at low p_T^μ and central region

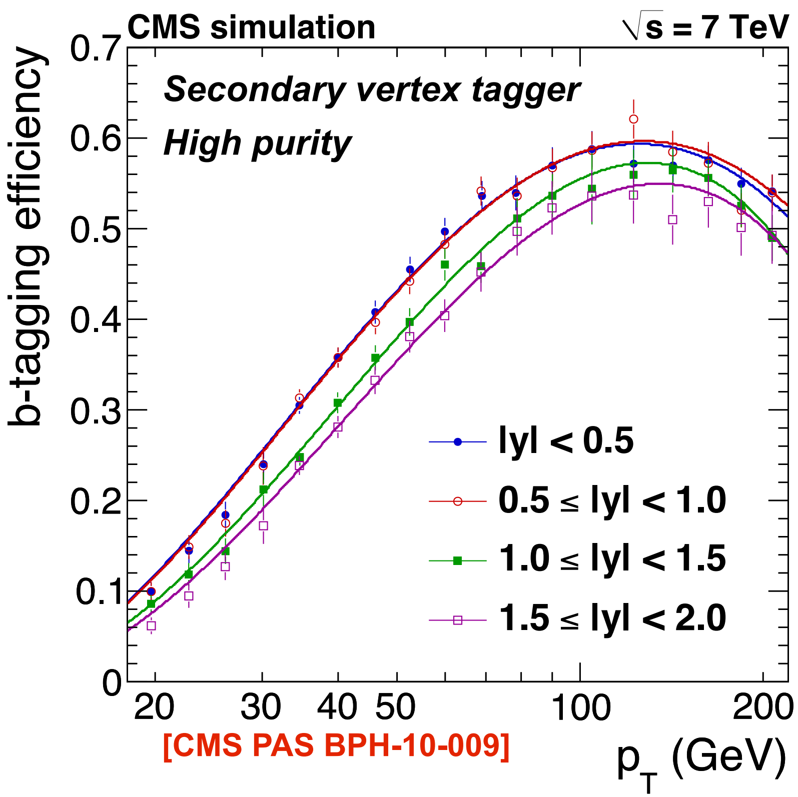
B jets cross section

- By tagging B jets we can extend the cross section measurement to large transverse momenta
  - Exploit secondary vertex reconstruction with silicon pixel detector
  - 50-60% tagging efficiency for p_T=100 GeV with 0.1% background contamination
- Different systematic uncertainties w.r.t. semi-leptonic decays



Particle Flow objects clustered
with anti-kT, R=-0.5
E_T^{jet}>20 GeV
|y|<2
[CMS PAS PFT-09-001]

Secondary Vertex *High Purity*
At least 3 tracks associated
3D flight distance significance cut
0.1% light quark contamination
at p_T=100 GeV
[CMS PAS BTV-10-001]



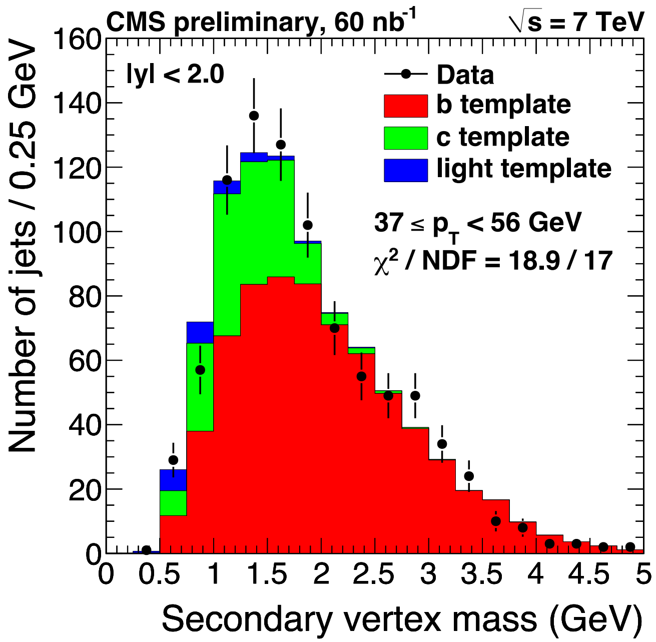
[CMS PAS BPH-10-009]

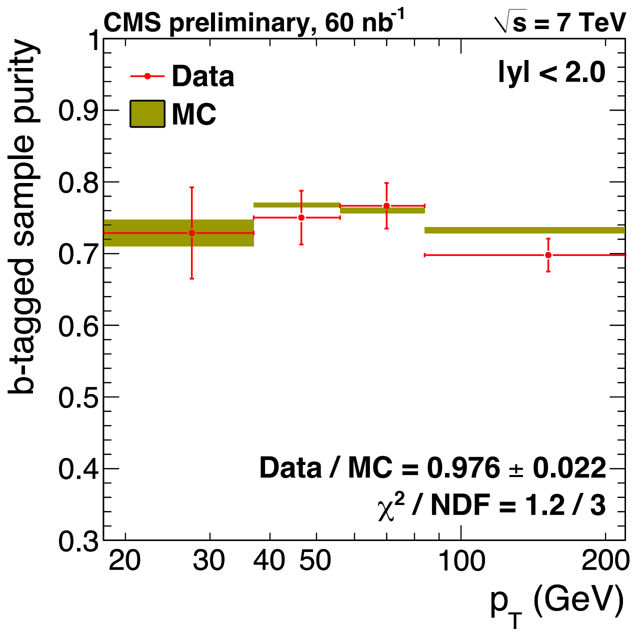
Cross section calculation

Cross section definition

[CMS PAS BPH-10-009]

$$\frac{d^2\sigma_{b-\mathrm{jets}}}{dp_T dy} = \frac{N_{\mathrm{tagged}} f_b C_{\mathrm{smear}}}{\epsilon_{\mathrm{jet}}\epsilon_b \Delta p_T \Delta y \mathcal{L}}$$





Tagged sample purity f_b from MC and fit to secondary vertex mass ~73%

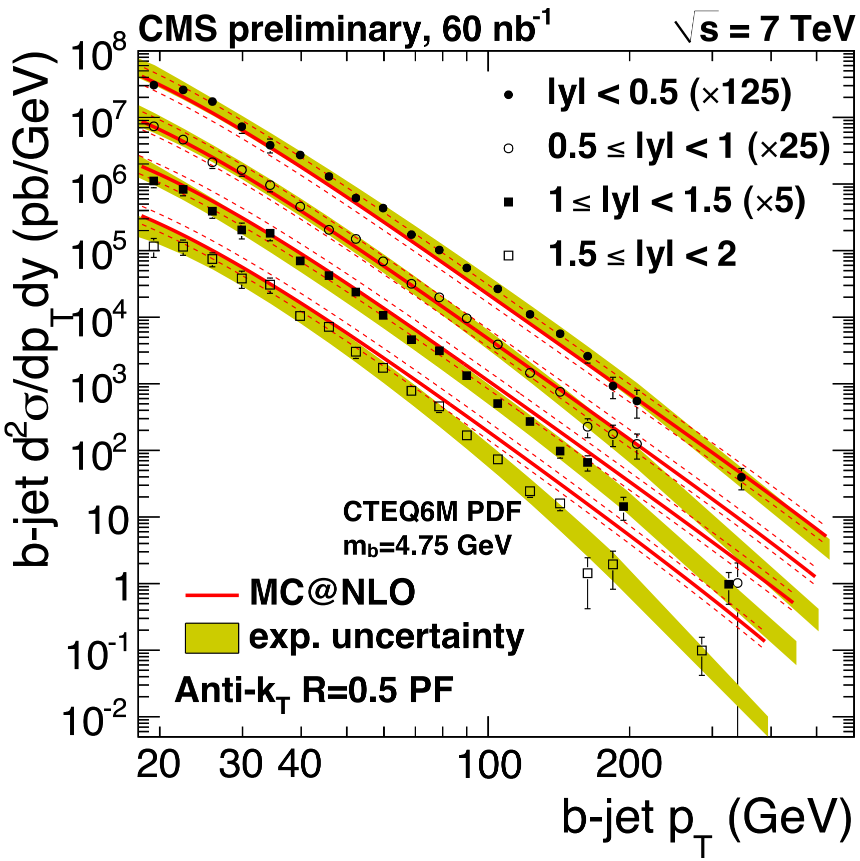
Tagging efficiency e_b validated with pt-rel

e_{data}/e_{MC}=0.98±0.08(stat)±0.18(syst)

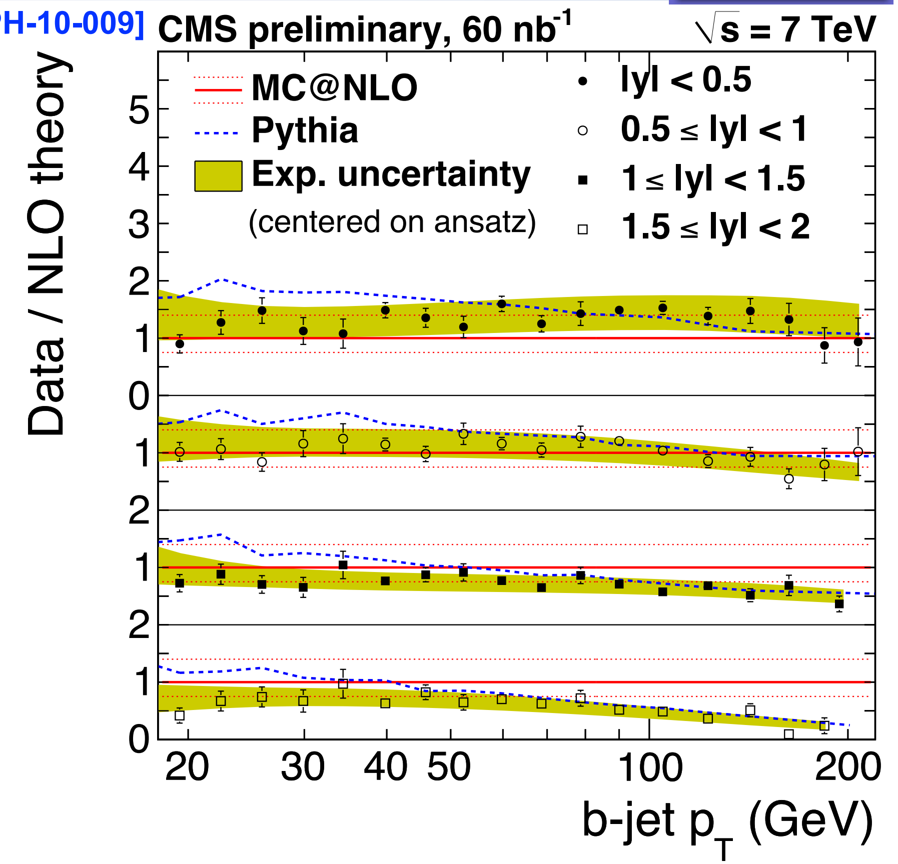
C_{smear} = unfolding correction
[CMS PAS QCD-10-011]

Luminosity ($\mathcal{L}$): 60 nb^{-1}

Results



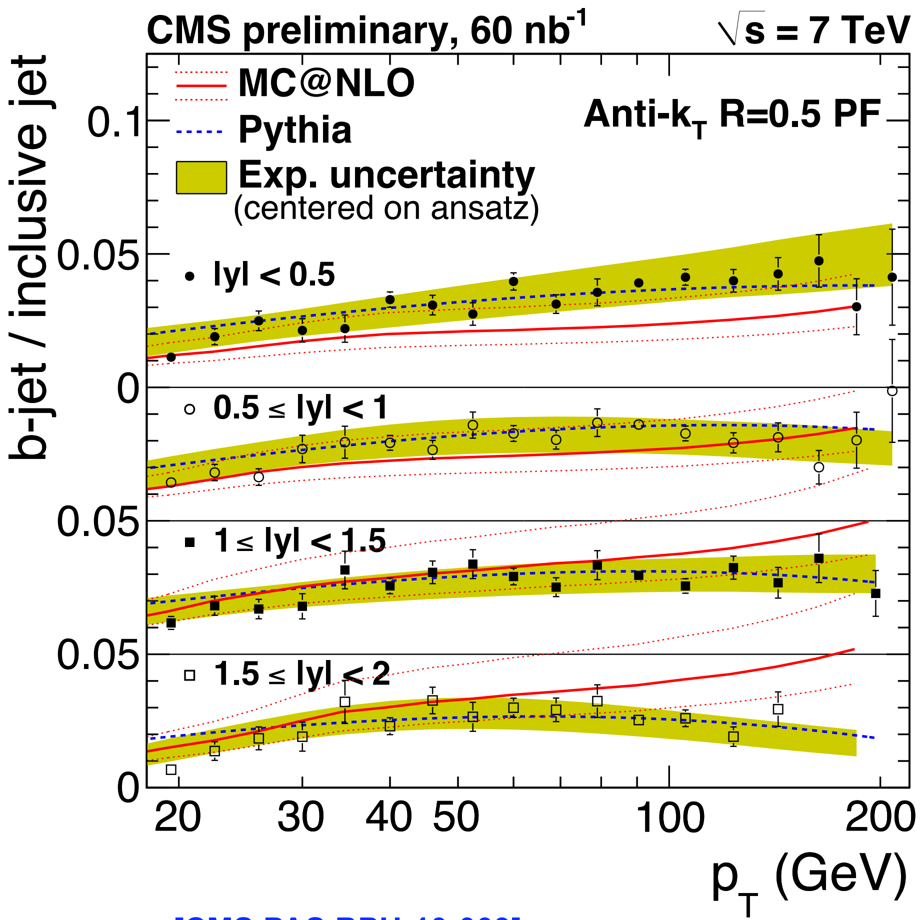
[CMS PAS BPH-10-009]



- Experimental uncertainties (~20%) dominated by b-tagging efficiency and jet energy scale
- MC@NLO uncertainties dominated by scale variations (+40%,-25%) and b-quark mass (+17%,-14%)

- Generally good agreement with Pythia above 40 GeV
- Shape differences with MC@NLO at large p_T and forward region

Ratio to inclusive jets



[CMS PAS BPH-10-009]

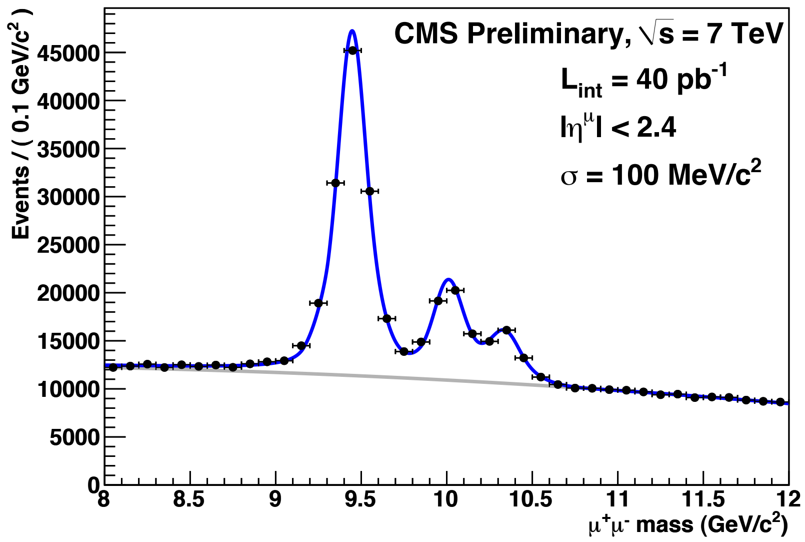
$$R = \frac{\text{B-jets cross section}}{\text{All jets cross section}} \sim 2\text{-}3\%$$

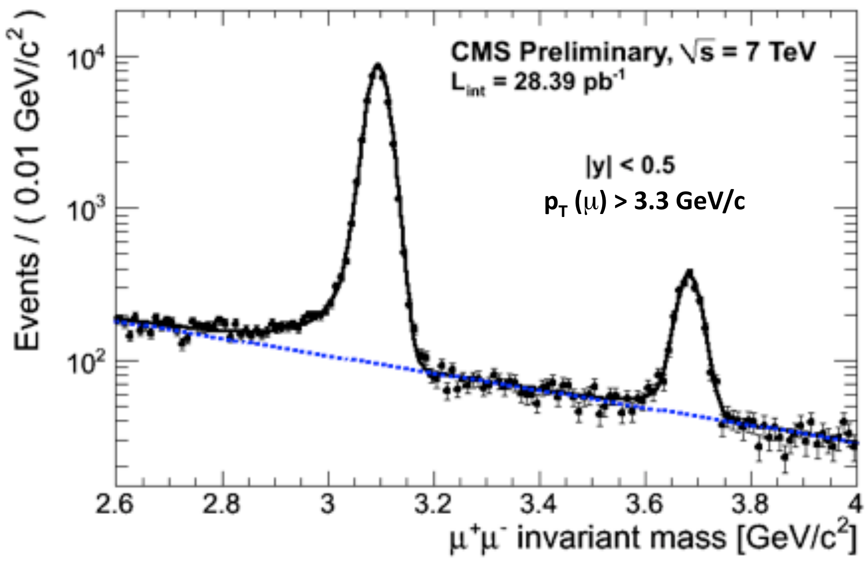
- **Jet energy corrections and luminosity systematic uncertainties cancel out**
- **Pythia in perfect agreement in measured range**
- **Indicates shape discrepancies with NLOJet++/MC@NLO ratio**

CMS Inclusive jet:
CMS PAS QCD-10-011

Prospects

- **Analysis of the entire 2010 data set on-going**
  - **many results expected:**
    - quarkonia production and polarizations in fine pt-y bins
    - χc and X(3872) production studies
    - b/bbar correlated production to study production mechanisms
    - B-hadron and B-meson production, like: $B^0 \to J/\psi K_S$, $\Lambda_b \to J/\psi \Lambda$, $B_c \to J/\psi \pi$





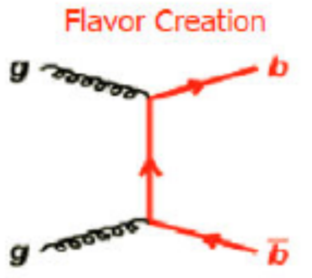
No. J/psi: 43957±217
Mean J/psi: 3.095 ± 0.0001 GeV
No. psi(2S): 1900±81
Mean psi(2S): 3.628 ± 0.0007 GeV

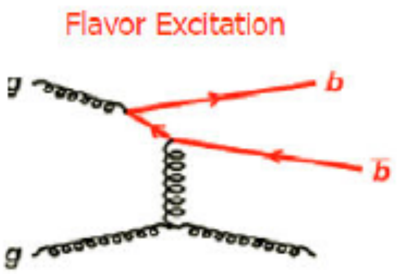
Conclusions

- Heavy flavour production at $\sqrt{s}$=7 TeV investigated with several techniques using data collected until Summer 2010 (up to 3 pb^{-1})
  - Quarkonia analyses allow first theory tests to be performed from 0 to ~30 GeV/c.
    - Statistical accuracy of ~2%, but systematics ~12% limited by luminosity. Good agreement with theory models for prompt J/ψ production; prompt J/ψ production not so well described by models we used.
  - Exclusive B-hadrons reconstructed in J/ψ decay modes:
    - $B_S \to J/\psi\phi$, $B^\pm \to J/\psi K^\pm$
  - Semi-leptonic decays into muons between 6 and 30 GeV/c:
    - Statistical error 5-20% with 8 nb^{-1} and systematic error ~15-20%
    - MC@NLO underestimates the cross section at low pt and central region
  - Jet cross section with secondary vertex b-tagging between 18 and 300 GeV
    - Statistical error ~2% with 60 nb^{-1} and systematic ~20%
    - Reasonable agreement with MC@NLO
- The proton LHC run has delivered ~43 pb-1 data, which amounts to >1 Million J/ψ and ~100,000 Υ(1S) decays to dimuons, more analyses in the pipeline

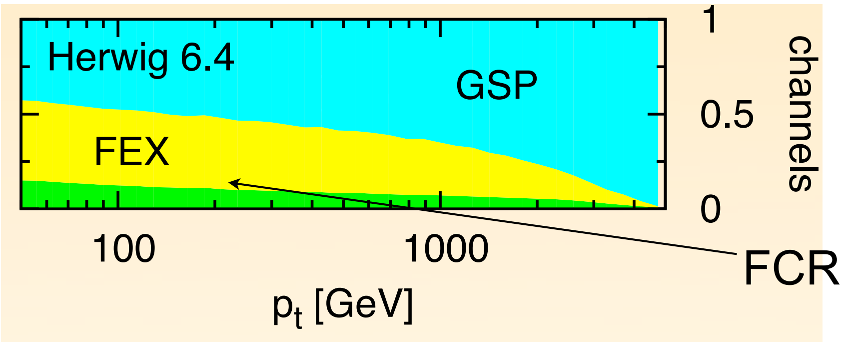
Backup slides

Production processes in p-p





- **LO:**
  - **Flavour creation**
- **Large NLO contributions:**
  - **Flavour Excitation**
  - **Gluon splitting**
- **Test benchmark for perturbative QCD, MC tools and detector performance**
  - **Long standing problems with lower energy data resolved**
  - **Measurements could have smaller errors than NLO QCD predictions currently available**



2 to 3 processes dominant at the LHC!

Inclusive J/Psi cross section

$p_T^{J/\psi}$ (GeV/c)	$\langle p_T^{J/\psi} \rangle$ (GeV/c)	$\frac{d^2\sigma}{dp_T dy} \cdot$ BR($J/\psi \to \mu^+\mu^-$) (nb/ GeV/c) $\lambda_\theta = 0$	$\lambda_\theta^{CS} = -1$	$\lambda_\theta^{CS} = +1$	$\lambda_\theta^{HX} = -1$	$\lambda_\theta^{HX} = +1$
			$\|y\| < 1.2$			
6.50 – 8.00	7.29	$7.63 \pm 0.30 \pm 0.97$	9.28 ± 1.20	6.99 ± 0.91	5.70 ± 0.74	9.14 ± 1.20
8.00 – 10.00	8.91	$3.23 \pm 0.11 \pm 0.38$	3.81 ± 0.47	3.00 ± 0.37	2.45 ± 0.30	3.85 ± 0.48
10.00 – 12.00	10.90	$1.18 \pm 0.05 \pm 0.14$	1.35 ± 0.17	1.10 ± 0.14	0.93 ± 0.12	1.37 ± 0.17
12.00 – 30.00	15.73	$0.116 \pm 0.005 \pm 0.013$	0.130 ± 0.016	0.110 ± 0.013	0.096 ± 0.012	0.129 ± 0.016
			$1.2 < \|y\| < 1.6$			
2.00 – 3.50	2.73	$68.8 \pm 6.3 \pm 13.0$	50.4 ± 9.9	84.6 ± 19.0	50.5 ± 9.9	84.5 ± 19.0
3.50 – 4.50	4.02	$46.1 \pm 2.7 \pm 6.5$	37.3 ± 5.7	52.8 ± 8.4	33.9 ± 5.2	56.4 ± 8.8
4.50 – 5.50	5.03	$28.6 \pm 1.3 \pm 3.9$	28.2 ± 4.1	28.7 ± 4.1	20.8 ± 3.0	35.0 ± 5.0
5.50 – 6.50	5.96	$16.5 \pm 0.8 \pm 2.0$	17.8 ± 2.3	16.0 ± 2.0	12.3 ± 1.6	20.1 ± 2.6
6.50 – 8.00	7.20	$7.64 \pm 0.30 \pm 0.87$	8.71 ± 1.10	7.19 ± 0.87	5.80 ± 0.71	9.19 ± 1.10
8.00 – 10.00	8.81	$2.76 \pm 0.14 \pm 0.32$	3.11 ± 0.39	2.62 ± 0.33	2.18 ± 0.27	3.24 ± 0.41
10.00 – 30.00	12.99	$0.182 \pm 0.010 \pm 0.021$	0.204 ± 0.026	0.173 ± 0.022	0.151 ± 0.019	0.202 ± 0.026
			$1.6 < \|y\| < 2.4$			
0.00 – 0.50	0.32	$36.8 \pm 2.2 \pm 6.0$	26.1 ± 4.5	46.5 ± 8.0	26.3 ± 4.5	45.6 ± 7.8
0.50 – 0.75	0.63	$83.2 \pm 4.5 \pm 15.3$	59.5 ± 11.3	105.1 ± 19.9	60.4 ± 11.6	103.2 ± 19.3
0.75 – 1.00	0.88	$102.3 \pm 5.0 \pm 16.9$	72.8 ± 13.3	128.9 ± 23.7	75.1 ± 13.4	125.0 ± 22.8
1.00 – 1.25	1.13	$121.9 \pm 5.3 \pm 21.1$	87.1 ± 14.8	152.4 ± 27.1	91.11 ± 18.2	146.2 ± 25.6
1.25 – 1.50	1.37	$127.7 \pm 5.6 \pm 21.6$	91.1 ± 15.6	160.1 ± 29.3	96.2 ± 17.7	152.9 ± 28.4
1.50 – 1.75	1.62	$132.5 \pm 5.3 \pm 21.9$	94.7 ± 15.8	165.9 ± 27.7	101.3 ± 16	157.8 ± 25.4
1.75 – 2.00	1.87	$121.9 \pm 6.2 \pm 17.9$	87.4 ± 13.6	152.1 ± 24.7	93.6 ± 14.9	143.9 ± 23.1
2.00 – 2.25	2.12	$125.2 \pm 6.1 \pm 18.7$	89.8 ± 13.9	156.3 ± 24.7	97.1 ± 14.9	147.3 ± 23.6
2.25 – 2.50	2.37	$96.3 \pm 4.2 \pm 14.1$	69.0 ± 10.2	120.5 ± 18.1	74.3 ± 11	114 ± 16.8
2.50 – 2.75	2.63	$96.4 \pm 7.7 \pm 13.0$	69.8 ± 11.1	119.3 ± 18.6	74.8 ± 11.8	113.2 ± 18.1
2.75 – 3.00	2.87	$77.9 \pm 3.7 \pm 10.7$	56.3 ± 8.0	96.4 ± 13.9	60.3 ± 8.5	91.6 ± 13.1
3.00 – 3.25	3.12	$73.7 \pm 3.5 \pm 10.0$	53.8 ± 7.7	91.2 ± 13.0	57.6 ± 8.3	86.5 ± 13.0
3.25 – 3.50	3.37	$66.7 \pm 3.2 \pm 8.8$	48.5 ± 6.9	82.8 ± 12.0	52.1 ± 7.3	78.3 ± 11.0
3.50 – 4.00	3.74	$49.6 \pm 1.7 \pm 7.1$	37.0 ± 5.5	60.6 ± 9.0	39.0 ± 5.8	58.3 ± 8.6
4.00 – 4.50	4.24	$39.7 \pm 1.4 \pm 5.0$	30.0 ± 4.0	47.3 ± 6.3	31.4 ± 4.2	46.0 ± 6.1
4.50 – 5.50	4.96	$24.5 \pm 0.7 \pm 3.3$	19.3 ± 2.6	28.7 ± 4.0	19.6 ± 2.7	28.2 ± 3.9
5.50 – 6.50	5.97	$12.6 \pm 0.4 \pm 1.7$	10.8 ± 1.4	14.0 ± 1.9	10.3 ± 1.4	14.3 ± 1.9
6.50 – 8.00	7.17	$6.20 \pm 0.24 \pm 0.74$	5.70 ± 0.72	6.61 ± 0.84	5.13 ± 0.65	6.94 ± 0.88
8.00 – 10.00	8.84	$2.41 \pm 0.11 \pm 0.28$	2.41 ± 0.31	2.44 ± 0.31	2.04 ± 0.26	2.64 ± 0.34
10.00 – 30.00	13.06	$0.149 \pm 0.008 \pm 0.019$	0.155 ± 0.021	0.148 ± 0.021	0.132 ± 0.019	0.161 ± 0.023

Prompt and non-prompt x-sec

p_T (GeV/c)	$BR(J/\psi \to \mu^+\mu^-) \cdot \frac{d^2\sigma_{prompt}}{dp_T dy}$ (nb/ GeV/c) $\lambda_\theta = 0$	$\lambda_\theta^{CS} = -1$	$\lambda_\theta^{CS} = +1$	$\lambda_\theta^{HX} = -1$	$\lambda_\theta^{HX} = +1$
	$\lvert y\rvert < 1.2$				
6.5 – 10.0	$3.76 \pm 0.13 \pm 0.47$	4.63 ± 0.60	3.45 ± 0.45	2.63 ± 0.34	4.79 ± 0.62
10.0 – 30.0	$0.134 \pm 0.033 \pm 0.016$	0.161 ± 0.044	0.123 ± 0.033	0.099 ± 0.026	0.164 ± 0.045
	$1.2 < \lvert y\rvert < 1.6$				
2.0 – 4.5	$50.6 \pm 3.6 \pm 8.4$	36.4 ± 6.5	63.6 ± 11.6	36.3 ± 6.5	63.1 ± 11.4
4.5 – 6.5	$18.4 \pm 0.7 \pm 2.4$	17.3 ± 2.3	19.1 ± 2.6	13.3 ± 1.8	22.7 ± 3.1
6.5 – 10.0	$3.85 \pm 0.15 \pm 0.44$	4.11 ± 0.49	3.74 ± 0.45	2.87 ± 0.34	4.67 ± 0.56
10.0 – 30.0	$0.116 \pm 0.009 \pm 0.014$	0.127 ± 0.018	0.111 ± 0.015	0.093 ± 0.013	0.133 ± 0.019
	$1.6 < \lvert y\rvert < 2.4$				
0.00 – 1.25	$71.9 \pm 2.4 \pm 11.2$	49.7 ± 7.9	92.5 ± 14.7	51.0 ± 8.1	90.3 ± 14.3
1.25 – 2.00	$116.2 \pm 3.5 \pm 16.8$	80.8 ± 11.9	149.1 ± 22.0	86.7 ± 12.8	140.7 ± 20.8
2.00 – 2.75	$93.7 \pm 3.4 \pm 12.4$	65.8 ± 9.1	118.8 ± 16.3	72.7 ± 10.0	110.3 ± 15.2
2.75 – 3.50	$62.6 \pm 2.0 \pm 7.9$	44.5 ± 5.7	78.8 ± 10.2	49.1 ± 6.4	72.7 ± 9.5
3.50 – 4.50	$37.4 \pm 1.1 \pm 4.9$	27.4 ± 3.7	45.7 ± 6.2	29.9 ± 4.1	42.8 ± 5.8
4.50 – 6.50	$15.2 \pm 0.4 \pm 2.0$	11.9 ± 1.6	18.0 ± 2.4	12.6 ± 1.7	17.1 ± 2.3
6.50 – 10.00	$3.08 \pm 0.11 \pm 0.37$	2.79 ± 0.35	3.36 ± 0.42	2.64 ± 0.33	3.37 ± 0.42
10.00 – 30.00	$0.093 \pm 0.007 \pm 0.012$	0.092 ± 0.014	0.096 ± 0.014	0.082 ± 0.012	0.100 ± 0.015

$p_T^{J/\psi}$ (GeV/c)	$BR(J/\psi \to \mu^+\mu^-) \cdot \frac{d^2\sigma_{non-prompt}}{dp_T dy}$ (nb/ GeV/c)
	$\lvert y\rvert < 1.2$
6.5 – 10.0	$1.30 \pm 0.08 \pm 0.19$
10.0 – 30.0	$0.087 \pm 0.024 \pm 0.010$
	$1.2 < \lvert y\rvert < 1.6$
2.0 – 4.5	$8.67 \pm 1.36 \pm 2.71$
4.5 – 6.5	$4.04 \pm 0.41 \pm 0.79$
6.5 – 10.0	$0.98 \pm 0.09 \pm 0.11$
10.0 – 30.0	$0.065 \pm 0.007 \pm 0.008$
	$1.6 < \lvert y\rvert < 2.4$
0.00 – 1.25	$4.31 \pm 1.59 \pm 3.54$
1.25 – 2.00	$11.0 \pm 1.8 \pm 4.2$
2.00 – 2.75	$11.9 \pm 1.4 \pm 3.4$
2.75 – 3.50	$10.1 \pm 1.1 \pm 1.6$
3.50 – 4.50	$7.19 \pm 0.65 \pm 1.25$
4.50 – 6.50	$3.28 \pm 0.24 \pm 0.53$
6.50 – 10.00	$0.95 \pm 0.07 \pm 0.13$
10.00 – 30.00	$0.055 \pm 0.005 \pm 0.007$