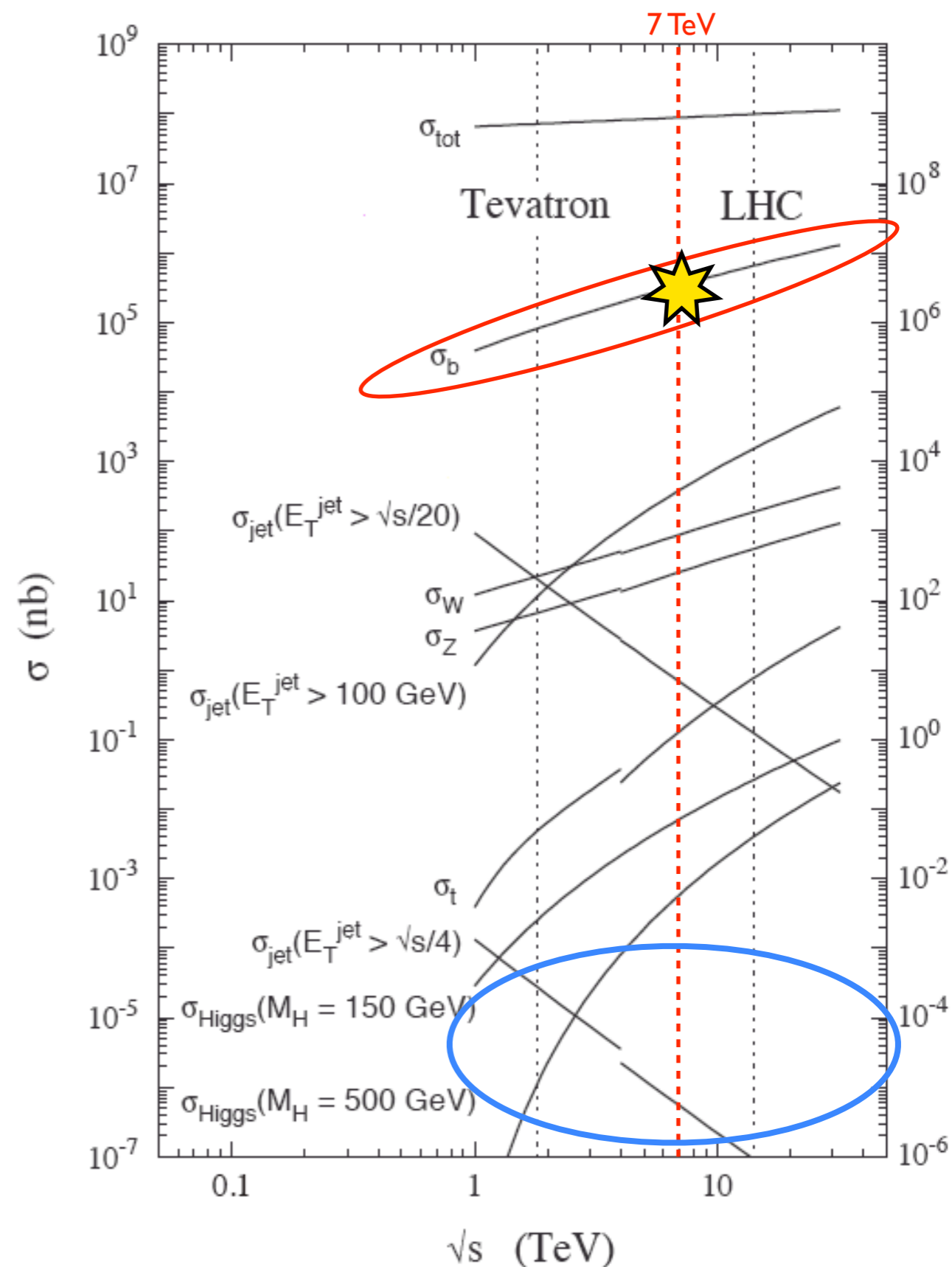


Recent heavy flavour results from the CMS experiment

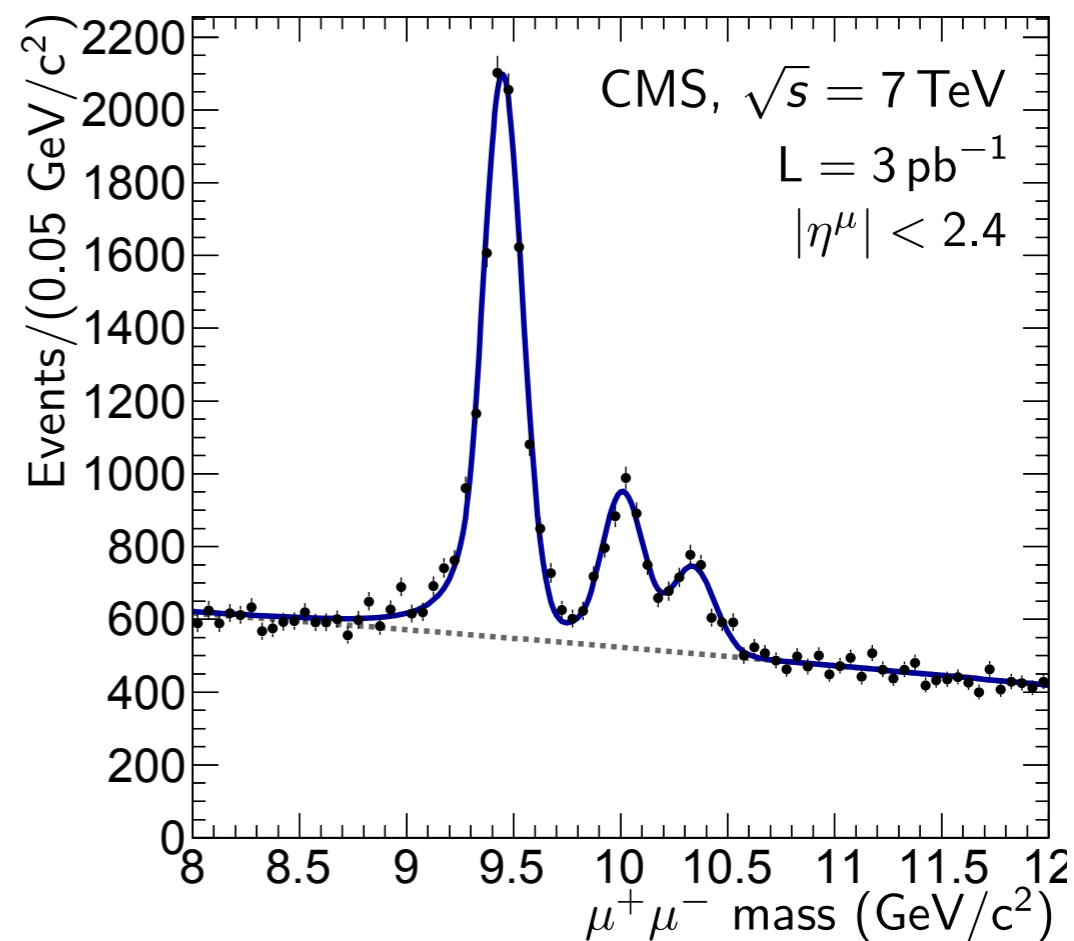
S. de Visscher - Universität Zürich

On behalf of the CMS collaboration

- Motivations to study HF production cross-sections at 7 TeV?
 - ◆ Large backgrounds for many SM and BSM analyses
 - ◆ Test of MC generators, (NR)QCD calculations
 - ◆ New physics
- HF physics is very rich but depends on triggers!
 - ◆ **muons**
 - benefit: validation of tracking and muon reconstruction
 - ◆ **jets**
 - ◆ **Exclusive ID: $\mu\mu+X$**
 - ◆ **Semi-leptonic decay: $B \rightarrow \mu+X$**
 - ◆ **Secondary vertex identification**



- Main motivation: test of (NR)QCD
- MC: Pythia 6 + photos (for FSR)
- Experimental conditions:
 - ◆ Lumi: 3.1/pb
 - ◆ Offline muon and Υ selection
 - $P_T(\mu) > 3.5$ GeV/c if $|\eta| < 1.6$
 - $P_T(\mu) > 2.5$ GeV/c if $1.6 < |\eta| < 2.4$
 - $8 \text{ GeV}/c < 2 < M_\Upsilon < 14 \text{ GeV}/c^2$ and $|\eta_\Upsilon| < 2$

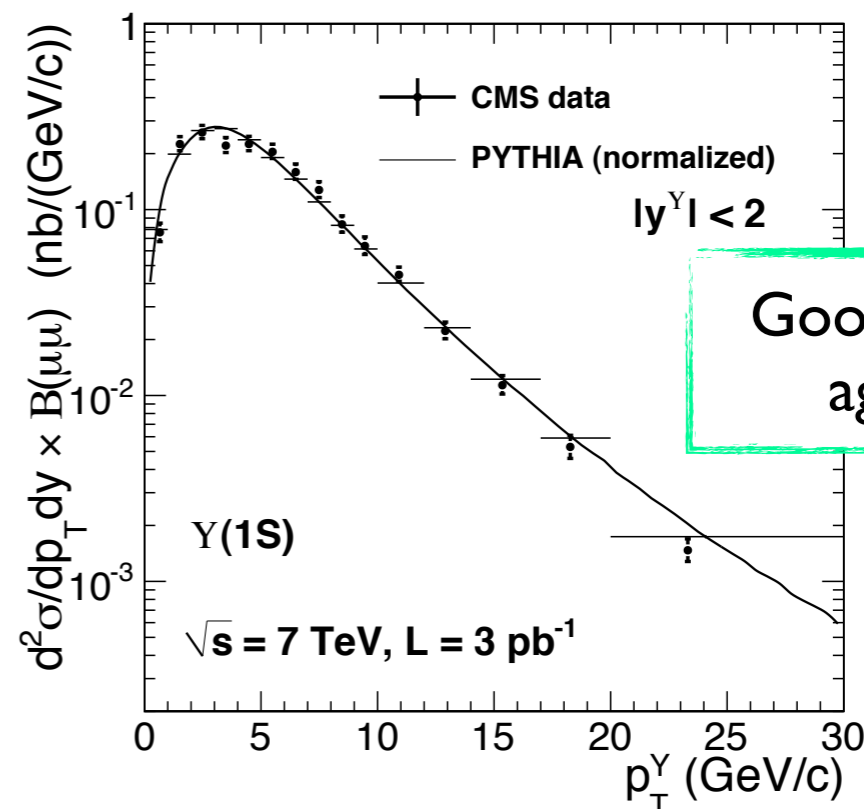


Acceptance, efficiency corrected
 $\sigma(pp \rightarrow \Upsilon(nS)X) * B(\Upsilon(nS) \rightarrow \mu\mu), |\eta| < 2$

$$7.37 \pm 0.13(\text{stat.})_{-0.42}^{+0.61}(\text{syst.}) \pm 0.81(\text{lumi.}) \text{ nb} \quad \mathbf{1S}$$

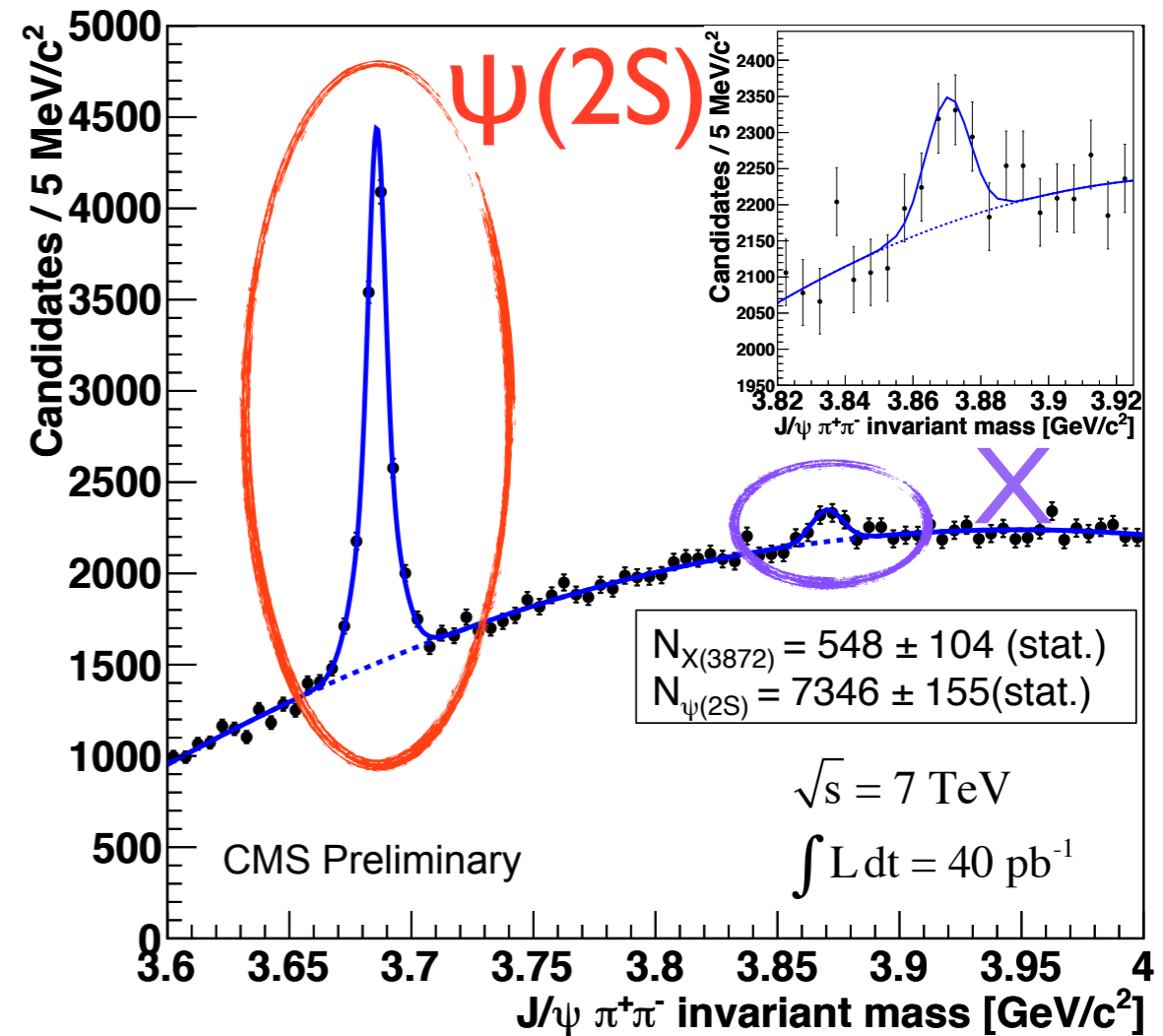
$$1.90 \pm 0.08(\text{stat.})_{-0.12}^{+0.18}(\text{syst.}) \pm 0.21(\text{lumi.}) \text{ nb} \quad \mathbf{2S}$$

$$1.02 \pm 0.07(\text{stat.})_{-0.08}^{+0.11}(\text{syst.}) \pm 0.11(\text{lumi.}) \text{ nb} \quad \mathbf{3S}$$



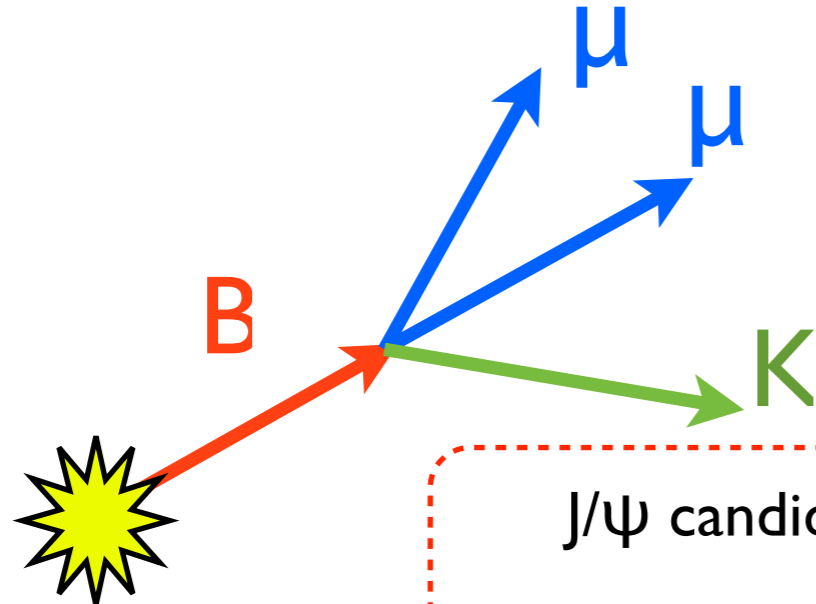
Good data/pythia
 agreement!

- $X(3872)$ discovered in 2003 (Belle), J^{PC} determined by CDF (in favor of 1^{++})
- Initiate the $X(3872)$ study with the full luminosity of 2010 run: $L=40/\text{pb}$
 - ◆ No absolute cross-section measured
 - ◆ Ratio of $\psi(2S)$ and $X(3872)$ xsec is measured instead with
 - $P_T(\mu\mu\pi\pi) > 8 \text{ GeV}/c$
 - $|\gamma(\mu\mu\pi\pi)| < 2.2$



$$R = \frac{\sigma(pp \rightarrow X(3872) + \text{anything}) \times BR(X(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\sigma(pp \rightarrow \psi(2S) + \text{anything}) \times BR(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} = 0.087 \pm 0.017(\text{stat.}) \pm 0.009(\text{syst.})$$

- **Charged:** $B^\pm \rightarrow (J/\psi \rightarrow \mu\mu)K^\pm$



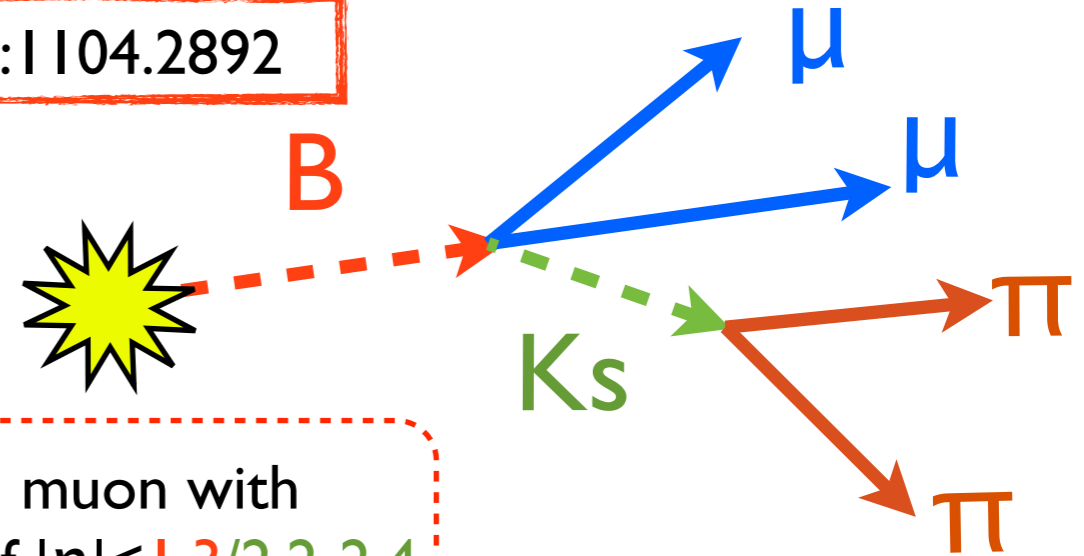
J/ψ candidate: 2 opposite sign muon with

- $P_t > 3.3/0.8$ GeV if $|\eta| < 1.3/2.2-2.4$
- $P > 2.9$ GeV if $1.3 < |\eta| < 2.2$

Invariant mass within 150 MeV to PDG value

- **Neutral:** $B^0 \rightarrow (J/\psi \rightarrow \mu\mu)K_s \rightarrow \pi\pi$

arxiv:1104.2892



- **B candidate**

- ◆ Combine J/ψ and tracks ($P_t > 0.9$ GeV)
- ◆ Kinematic fit with J/ψ mass + K track
- ◆ Choose combination with highest P_T

- **K_s candidate**

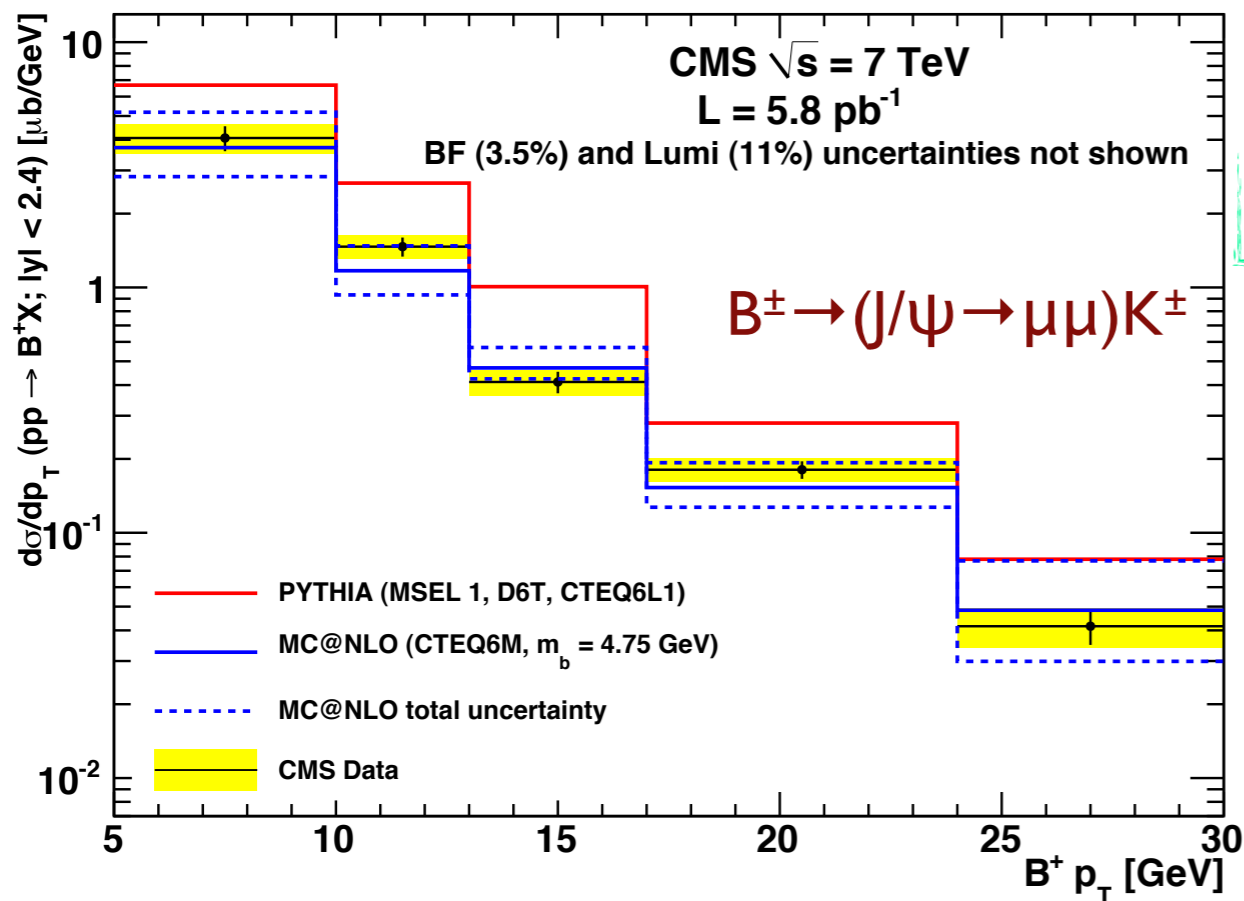
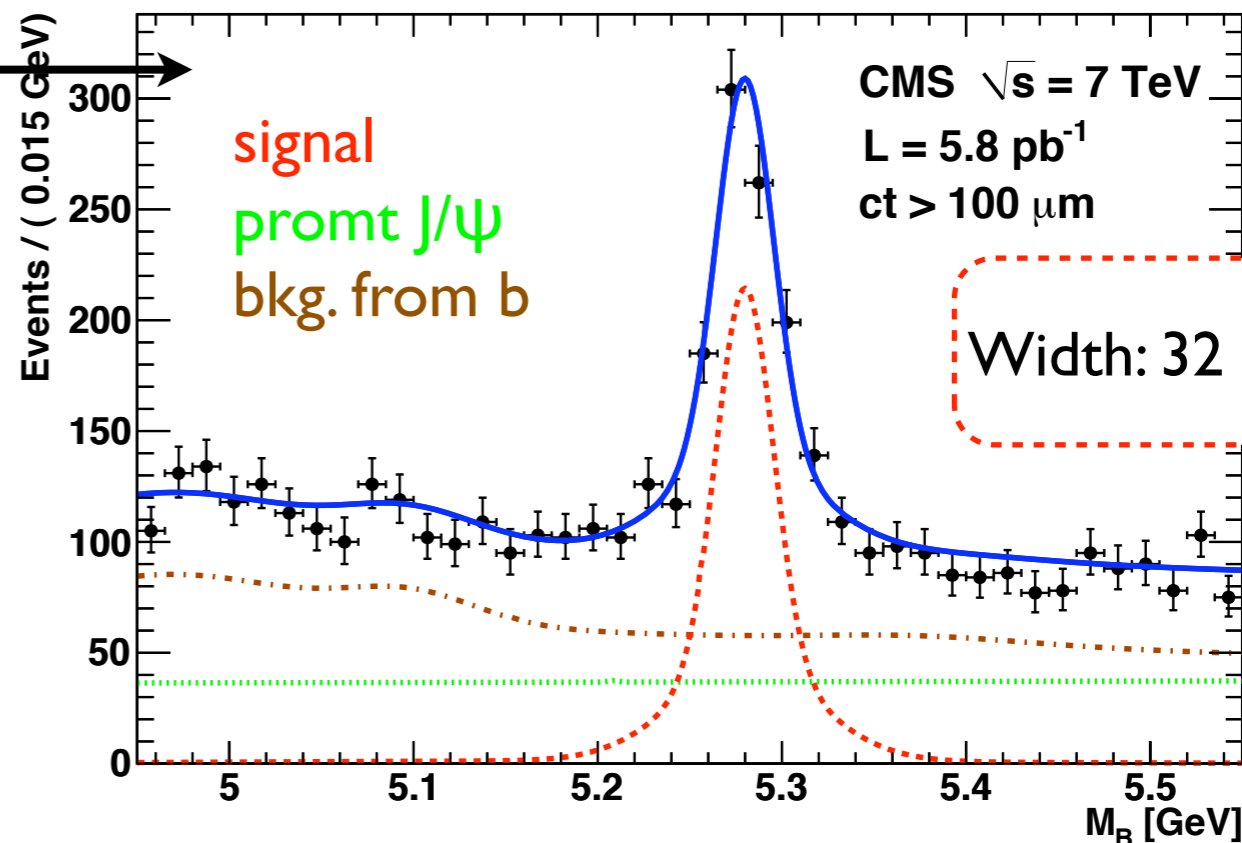
- ◆ combine 2 good quality tracks
- ◆ resulting vertex at 5σ from beam line
- ◆ Invariant mass in [478,518] MeV

- **B candidate**

- ◆ Kinematic fit with J/ψ and K_s masses constraints, $4.9 \text{ GeV} < M_B < 5.7 \text{ GeV}$
- ◆ Choose combination with highest B vertex probability

Phys.Rev.Lett. 106:112001,2011

- Fit over the mass and ct
- Extract the number of signal candidates
- Get total cross-section
- Get the differential cross-sections



$$\sigma(B^\pm \rightarrow (J/\psi \rightarrow \mu\mu)K^\pm) = 28.3 \pm 2.4 \pm 2.0 \pm 1.1 \mu\text{b}$$

$$\sigma(\text{MC@NLO}) \sim 25.5 \pm 3 \mu\text{b}$$

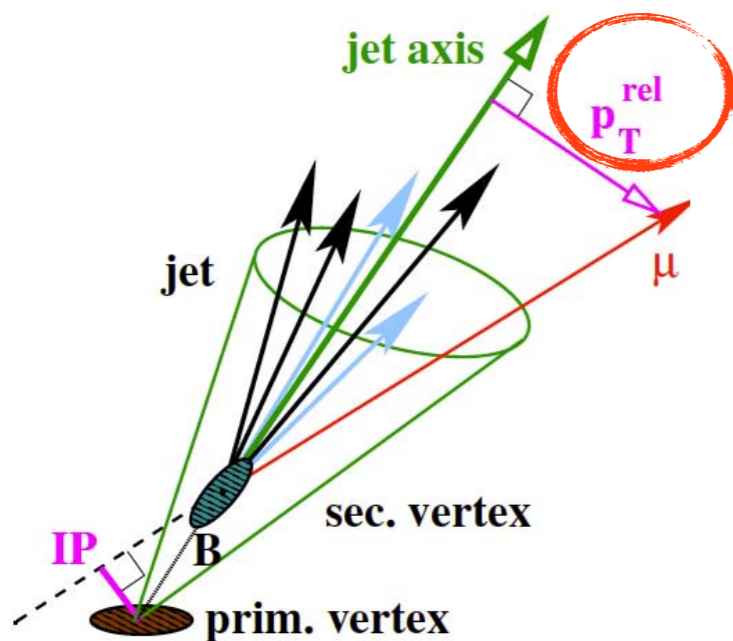
$$\sigma(\text{Pythia}) = 48.1 \mu\text{b}$$

$$\sigma(B^0 \rightarrow (J/\psi \rightarrow \mu\mu)(K_s \rightarrow \pi\pi)) = 33.2 \pm 2.5 \pm 3.1 \pm 1.3 \mu\text{b}$$

$$\sigma(\text{MC@NLO}) \sim 25.2 \pm 10 \mu\text{b}$$

$$\sigma(\text{Pythia}) = 49.1 \mu\text{b}$$

- Exploit muons from B mesons decays



- Muon selection

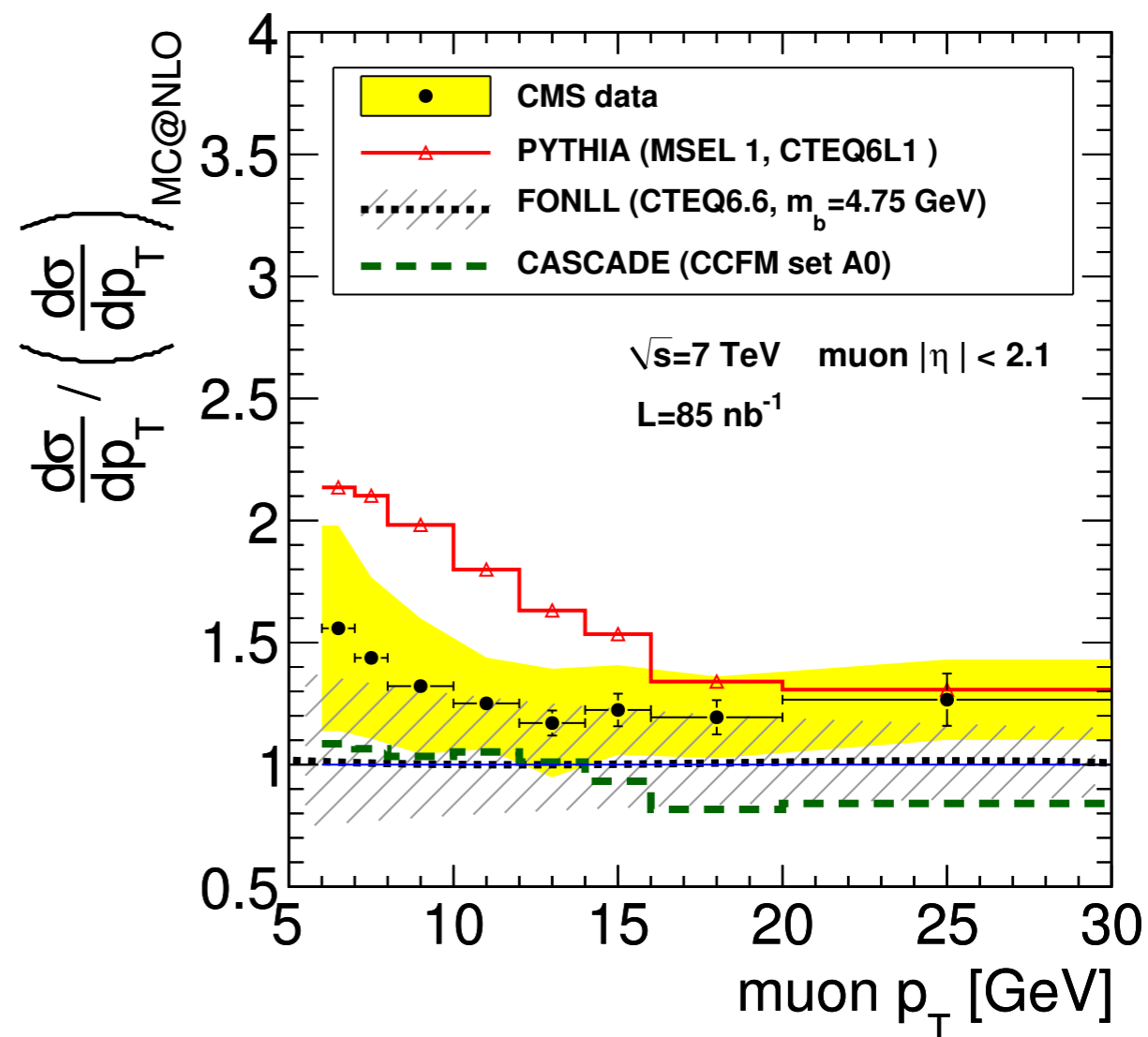
- ◆ $P_T(\mu) > 6 \text{ GeV}/c$, $|\eta| < 2.1$
- ◆ $|d_0| < 2.1 \text{ mm}$, $|d_z| < 1 \text{ cm}$

- (track-)jets selection

- ◆ $P_T(\text{tracks}) > 300 \text{ MeV}$, anti- $K_t(R=0.5)$
- ◆ $E_T(\text{without } \mu) > 1 \text{ GeV}$
- ◆ Using a fit on MC templates for $P_{T\text{Rel}}$, extract the fraction of b's

$$\sigma = 1.32 \pm 0.01(\text{stat}) \pm 0.30(\text{syst}) \pm 0.15(\text{lumi}) \mu\text{b}$$

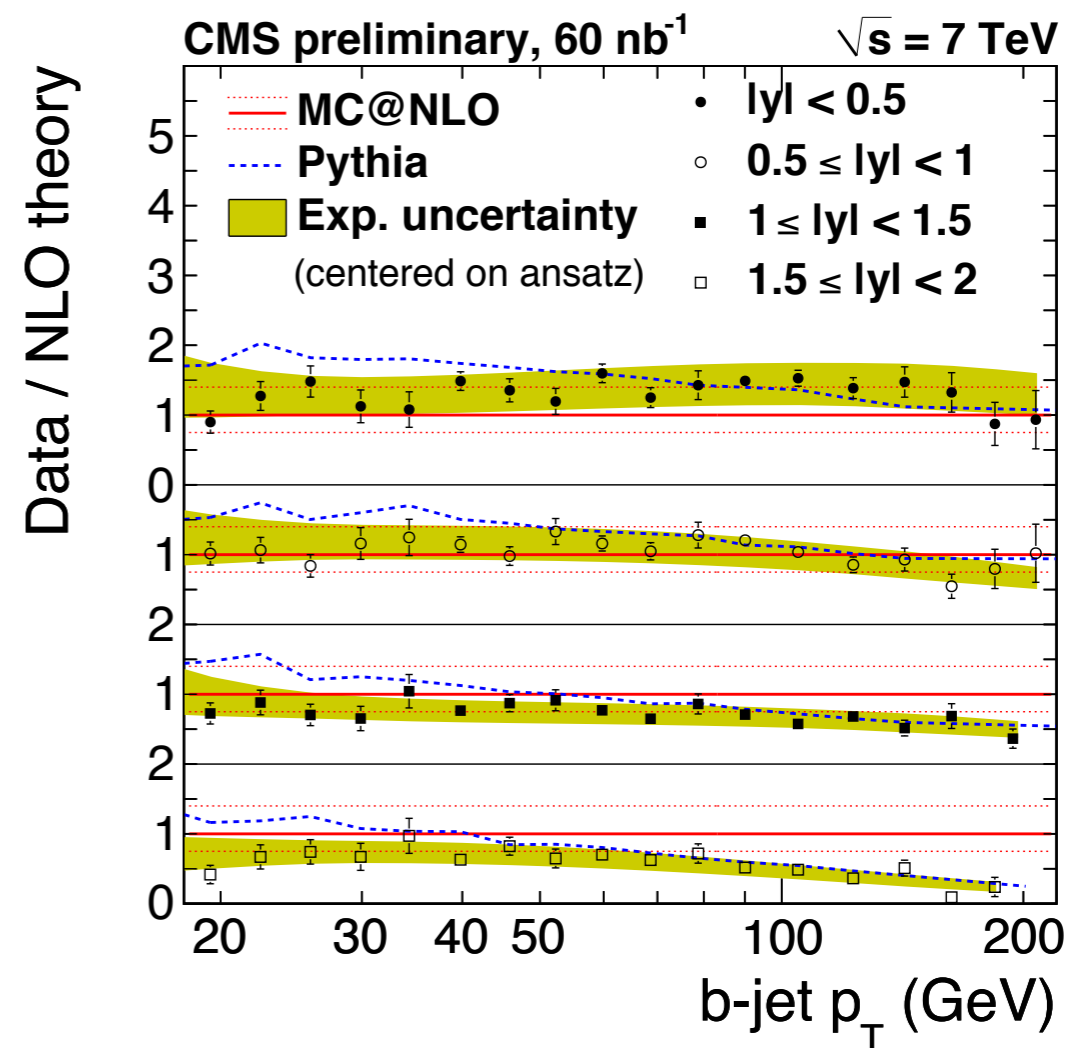
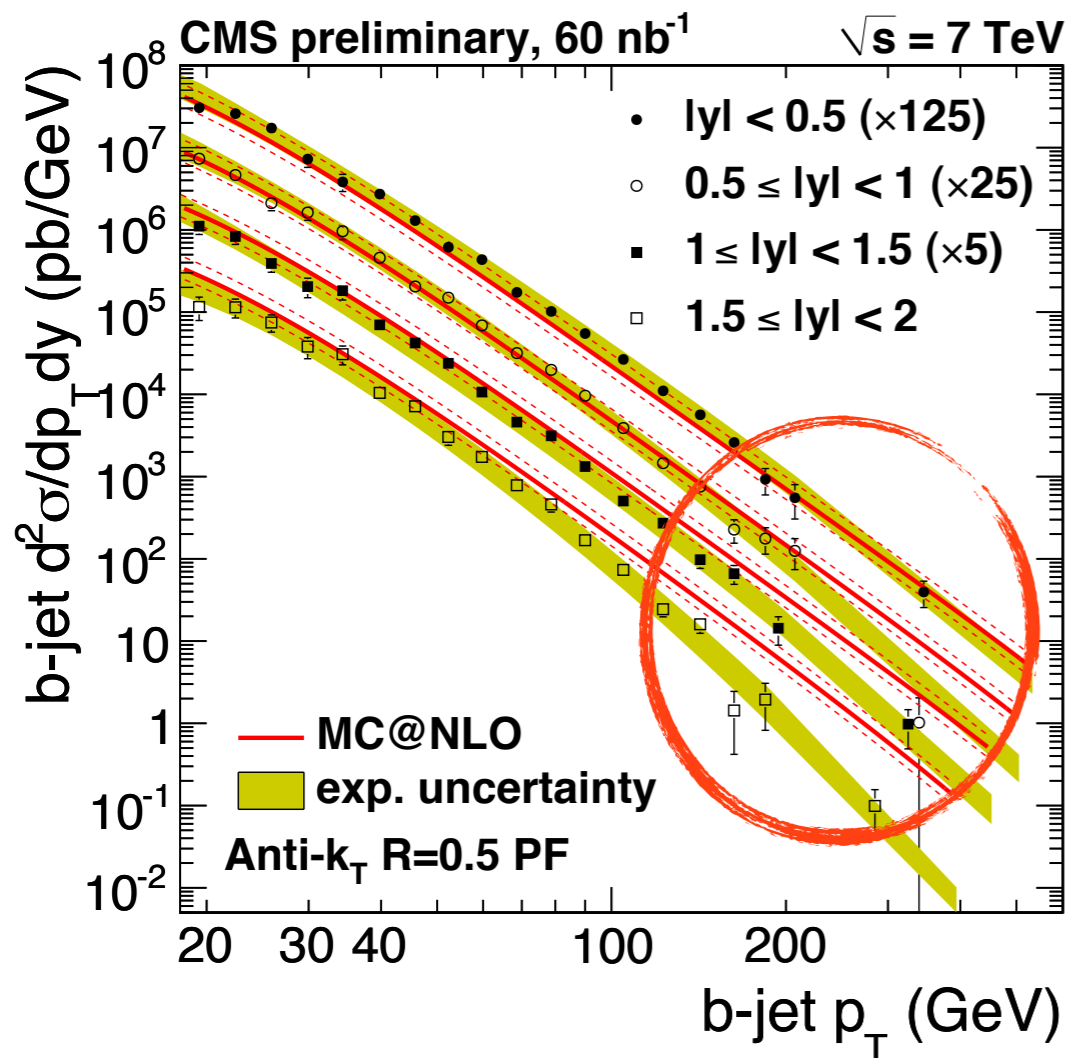
$$\sigma_{\text{MC@NLO}} = 0.95_{-0.21}^{+0.41}(\text{scale}) \pm 0.09(m_b) \pm 0.05(\text{pdf}) \mu\text{b}$$



Good data/MC agreement at high pt
Larger data/theory ratio in central region

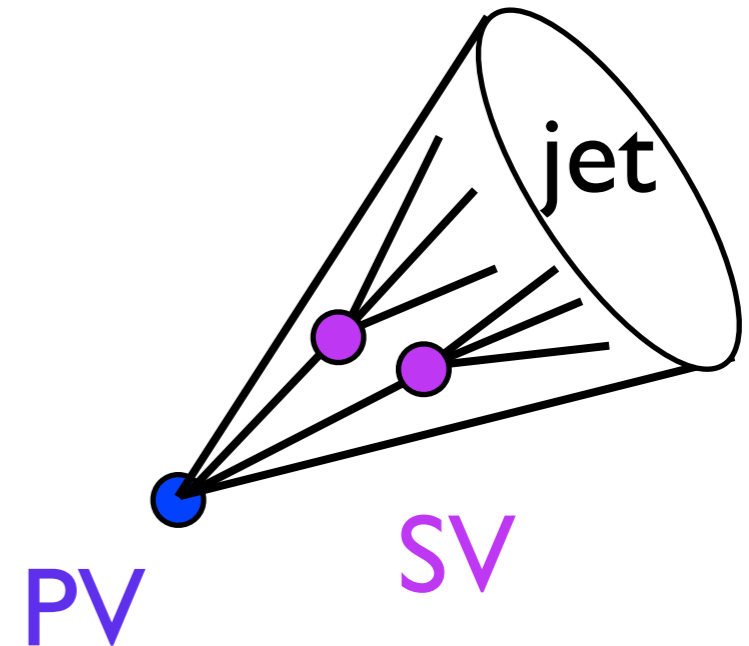


- Use jets and b-tagging with secondary vertex reconstruction
 - ◆ Lumi: 60/nb
 - ◆ Anti-Kt with R=0.5 (Particle Flow)
 - ◆ b-tagging efficiency from MC and data (cross-check with Pt-rel method)
 - ◆ b-tagging sample purity extracted from fit of secondary vertex mass



* data and pythia agree well at high Pt
 * Agreement with MC@NLO for overall cross-section, but fails in P_T and y

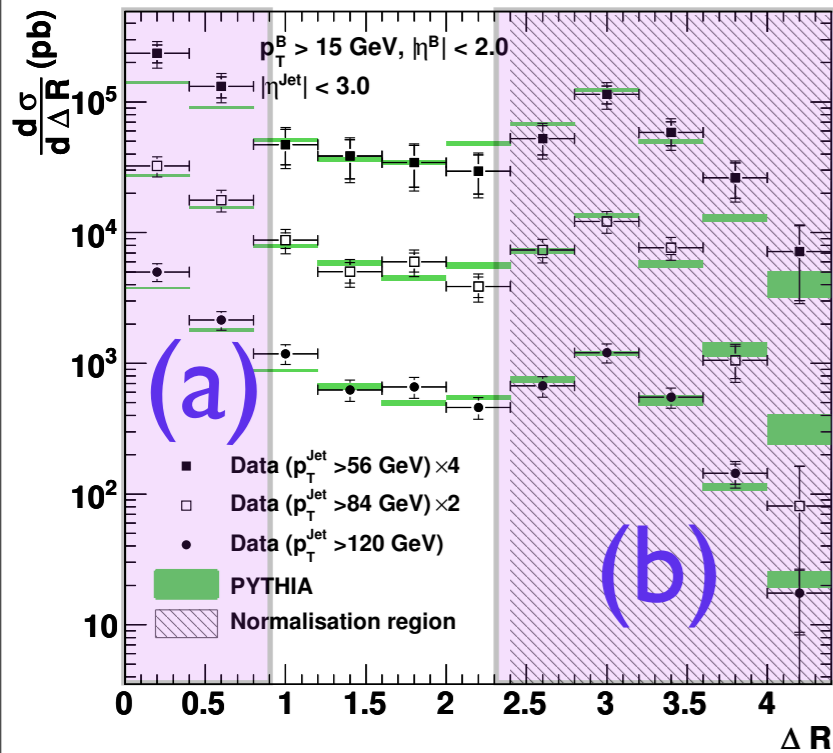
- Aim: measure the angular correlation of pairs of B mesons in QCD events: gluon splitting vs flavor creation/excitation
 - ◆ Luminosity: 3.1/pb
 - ◆ **No use of jets for B meson ID:** only secondary vertex finder \Rightarrow no ΔR restriction down to ~ 0.02 rad!
- Use the **Inclusive Vertex Finder**
 - ◆ **Seed** creation with tracks with large impact parameter
 - ◆ **Cluster** tracks compatible with seeds
 - ◆ **Fit** tracks to vertices
 - ◆ **Classify** the remaining tracks
- SV: $|\eta| < 2.0$, $P_t(B) < 15$ GeV
- Trigger on at least one calo jet
 - ◆ offline selection: $P_t > 56, 84, 120$ GeV (99% eff.)
 - ◆ anti-Kt with $R=0.5$



Secondary vertex ID: BB angular correlations

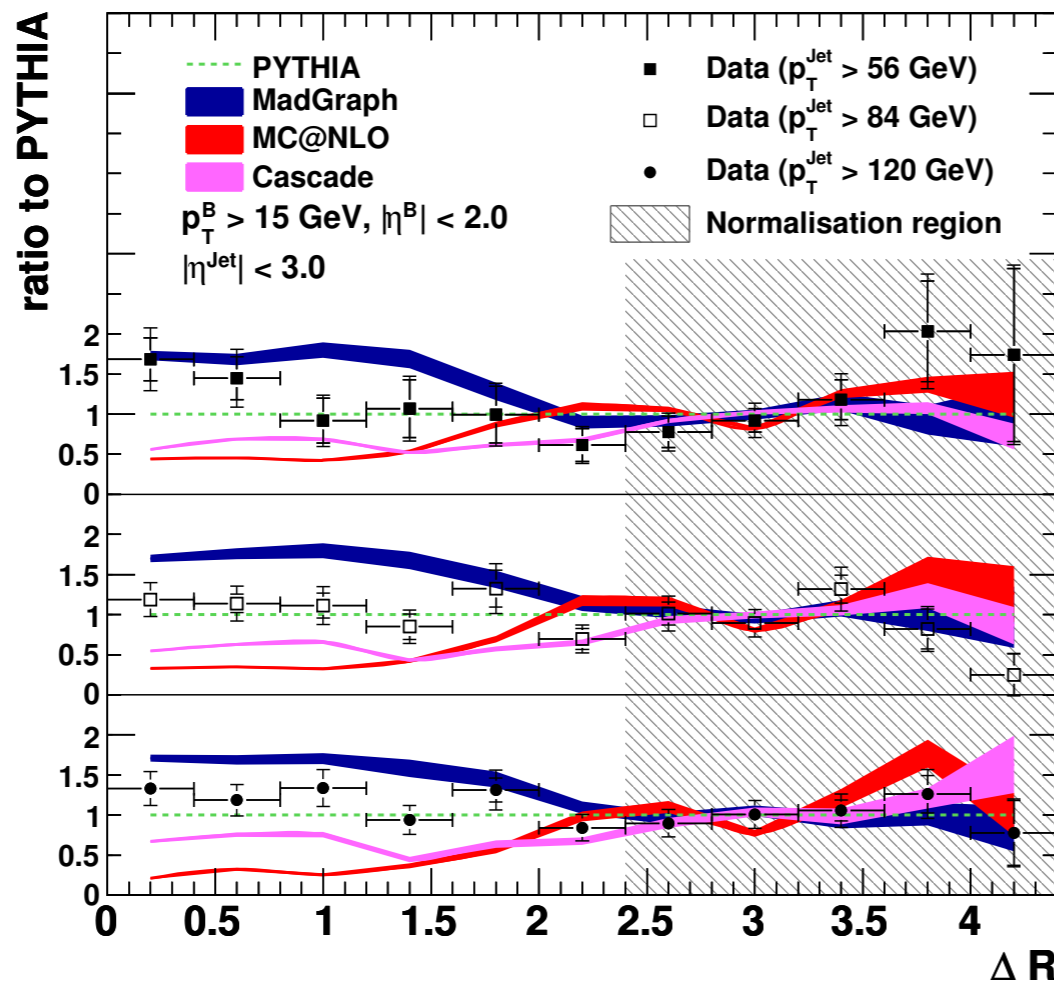


CMS $\sqrt{s} = 7 \text{ TeV}, L = 3.1 \text{ pb}^{-1}$

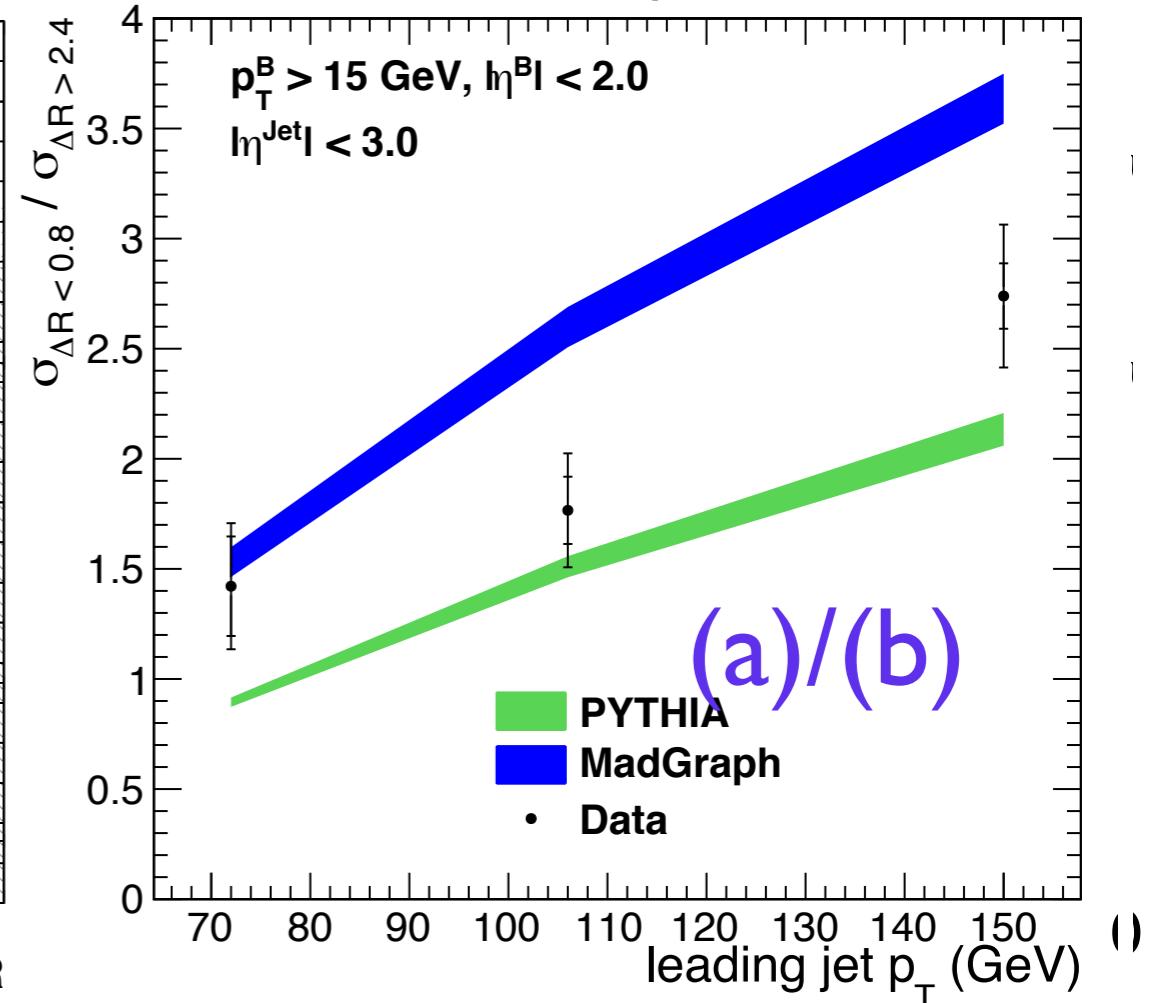


* First probe of the very small angle region, where gluon splitting dominates.
 * Reasonable agreement with Pythia and madgraph.

CMS $\sqrt{s} = 7 \text{ TeV}, L = 3.1 \text{ pb}^{-1}$



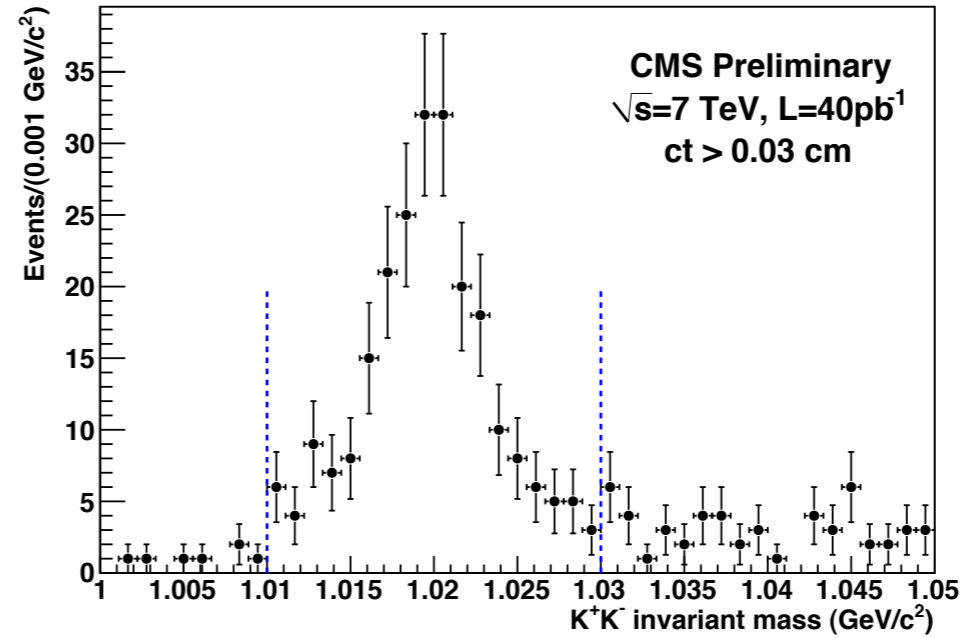
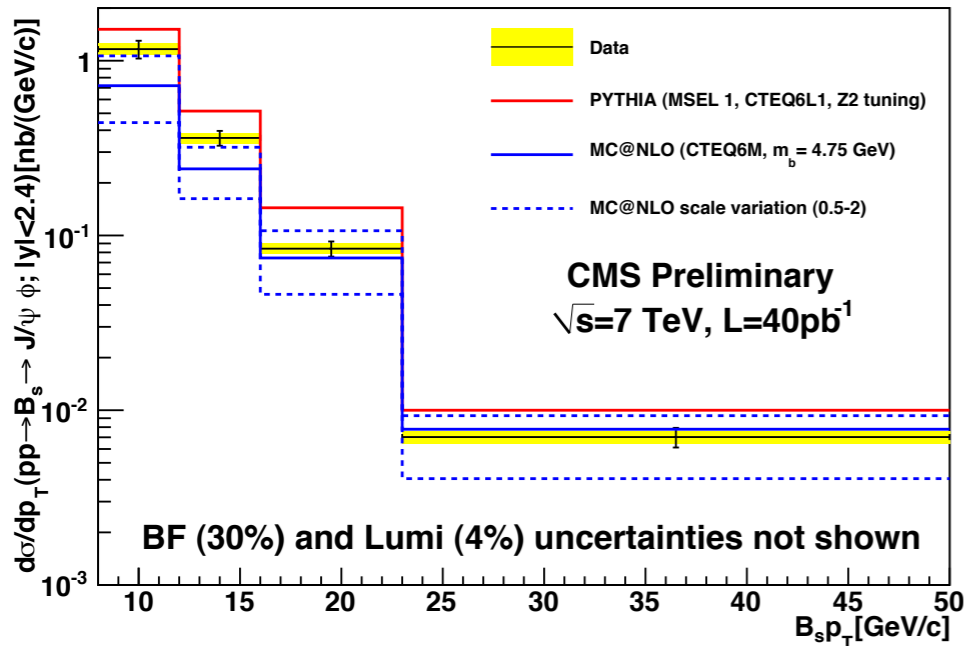
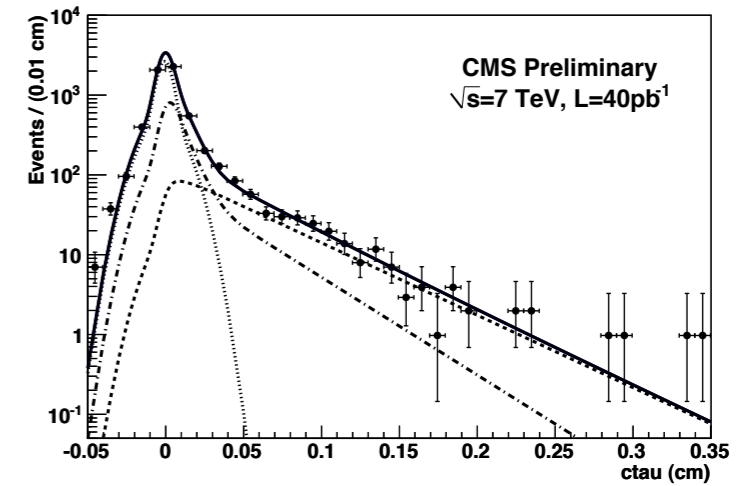
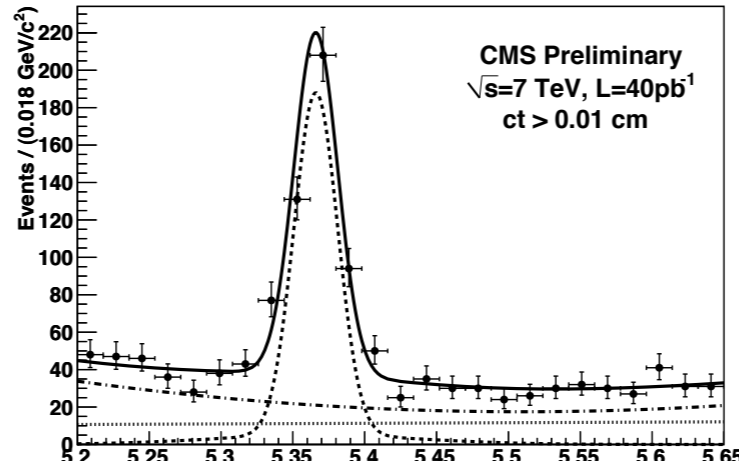
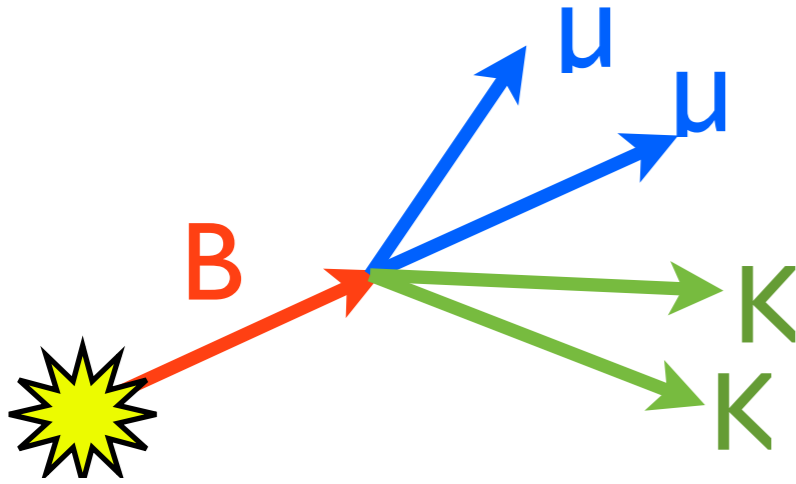
CMS $\sqrt{s} = 7 \text{ TeV}, L = 3.1 \text{ pb}^{-1}$



- Many new heavy flavor results from CMS
 - ◆ 6 publications, 3 preliminary results, several invariant mass plots,...
- $\Upsilon(nS)$:
 - ◆ good agreement with MC expectations
- Exclusive B meson production:
 - ◆ reasonable agreement with NLO in shape and normalization
 - ◆ Pythia: generally above data on Pt spectra
- Semi-leptonic decay of B's: inclusive b hadron production with muons
 - relatively good data/MC@NLO agreement for shapes in forward regions or high pt
 - Pythia overshoots the data at low Pt.
- Inclusive b-jet production
 - ◆ Pythia slightly overshoots data at low Pt, in all eta region
 - ◆ Overall cross-section agreement with MC@NLO (shape agreement at low Pt and low rapidity)
- BB correlation
 - ◆ First time that this measurement is done at very small angles
 - ◆ The data/MC agreement is quite good with Pythia and Madgraph: the proportion in collinear and back-to-back regions are quite well reproduced. MC@NLO, Cascade do not describe correctly the small angle region.

- CMS heavy flavor measurement
 - ◆ **Exclusive ID**
 - J/ψ
 - Υ
 - B_s
 - Λ_b
 - χ_{c1} and χ_{c2} states
 - $X(3872)$ vs $\psi(2S)$
 - Charged and neutral B mesons
 - ◆ **Semileptonic B decay ID**
 - b production with muons
 - ◆ **Secondary Vertex ID**
 - b-jet cross-section
 - B anti-B Angular correlation

Backup slides



. **Total cross section** (whole range $8 < p_B^T < 50$ and $|y^B| < 2.4$)

CMS experimental result: $\sigma(pp \rightarrow B_s^0 \rightarrow J/\psi \Phi) = (6.9 \pm 0.6 \text{ (stat)} \pm 0.5 \text{ (syst)} \pm 0.3 \text{ (lumi)})\text{nb}$

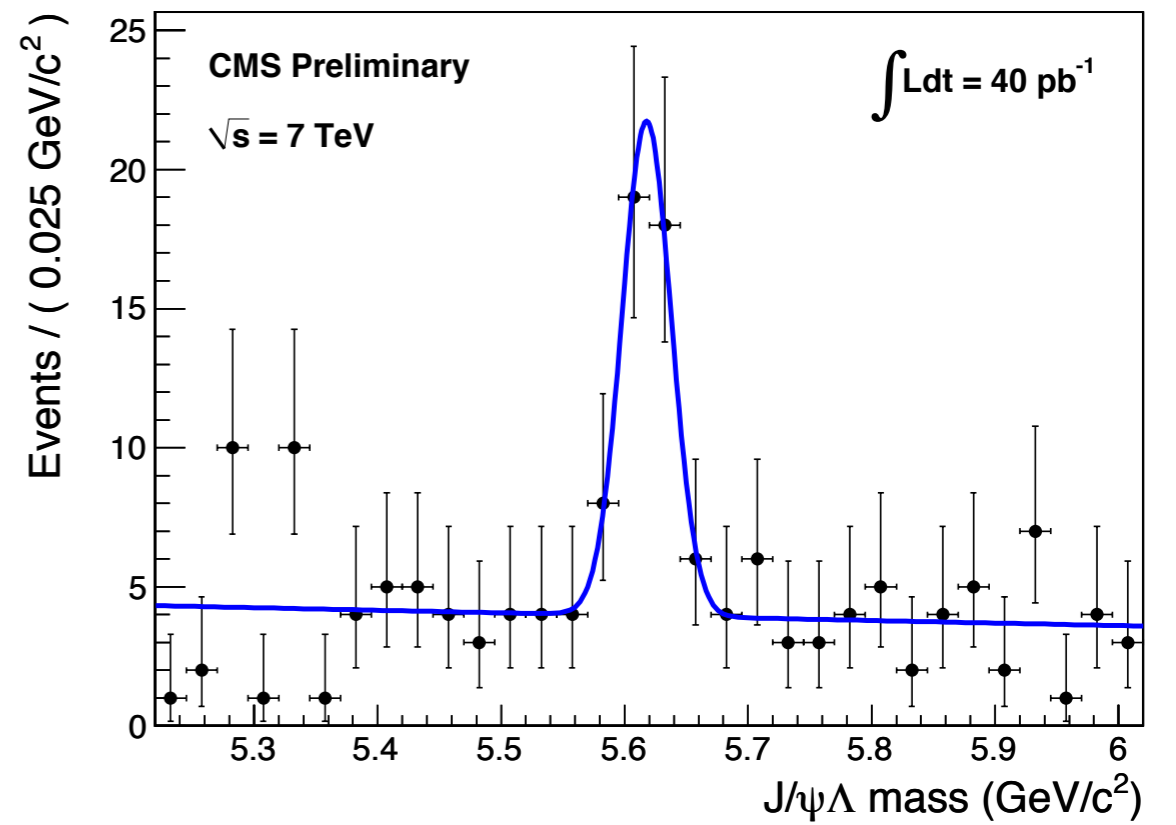
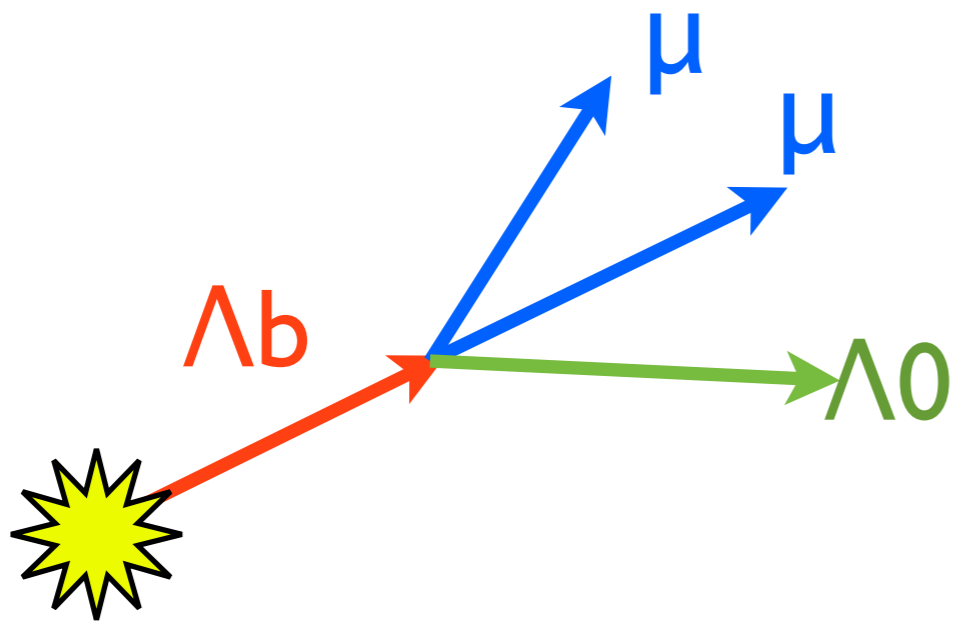
Theoretical predictions:

MC @ NLO: $\sigma(pp \rightarrow B_s^0 \rightarrow J/\psi \Phi) = (4.57^{+1.93}_{-1.71} \pm 1.37) \text{ nb}$

PYTHIA: $\sigma(pp \rightarrow B_s^0 \rightarrow J/\psi \Phi) = (9.39 \pm 2.82) \text{ nb}$

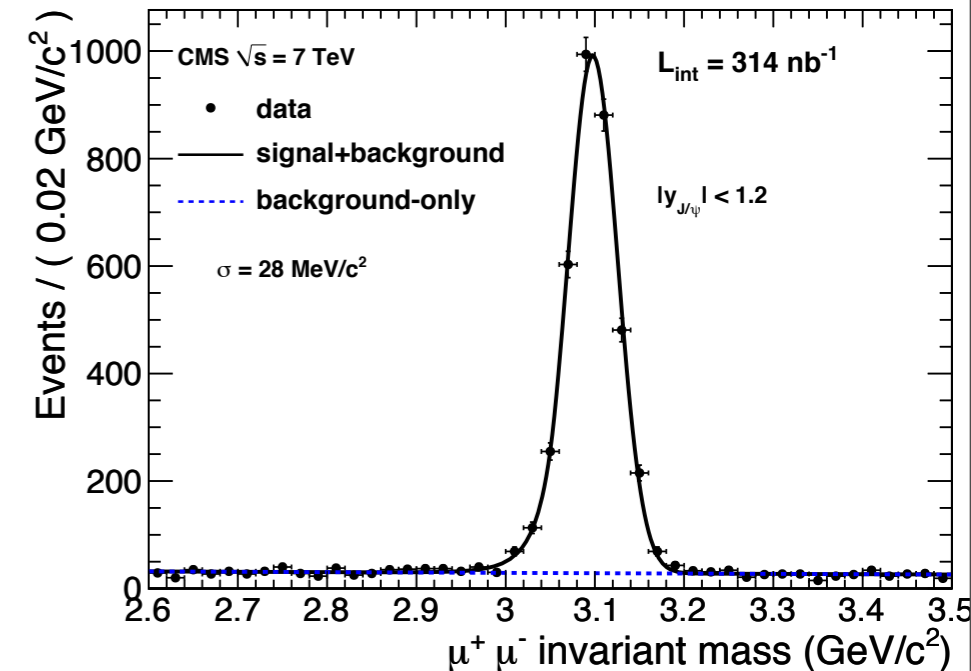
- . Summer 2011: $\sim 100/\text{pb}$ CP parameters
- End of 2011: $\sim 1/\text{fb}$ Φ s untagged analysis

From V.Azzolini talk @ Beauty II



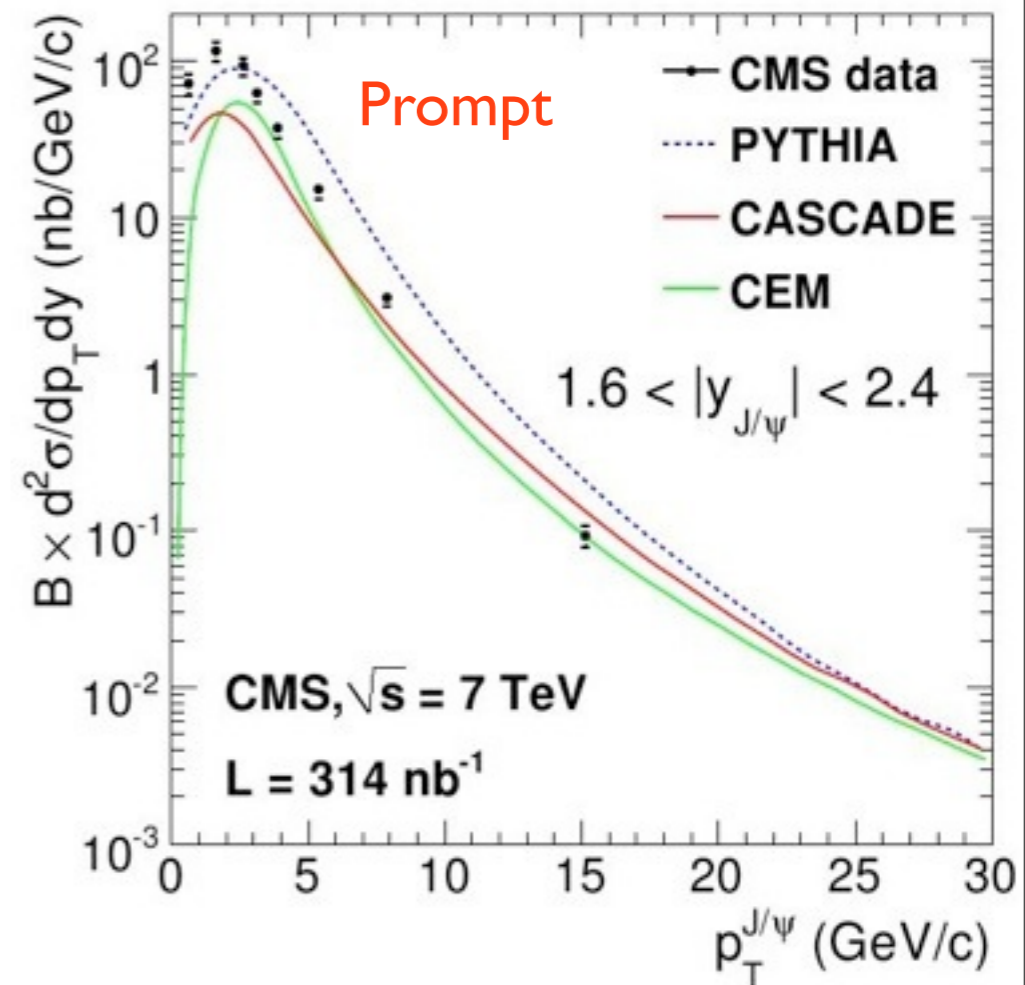
- Study of the J/ψ prompt and non prompt productions

- ◆ 27000 mesons reconstructed with $L=314/\text{nb}$, using opposite charge dimuons
- ◆ Different polarization scenario used
- ◆ Different systematics:
 - FSR
 - Spectra (Pythia, MC@NLO, Cascade, CEM)
 - b-had. fraction and polarization
 - Pt calibration and resolution

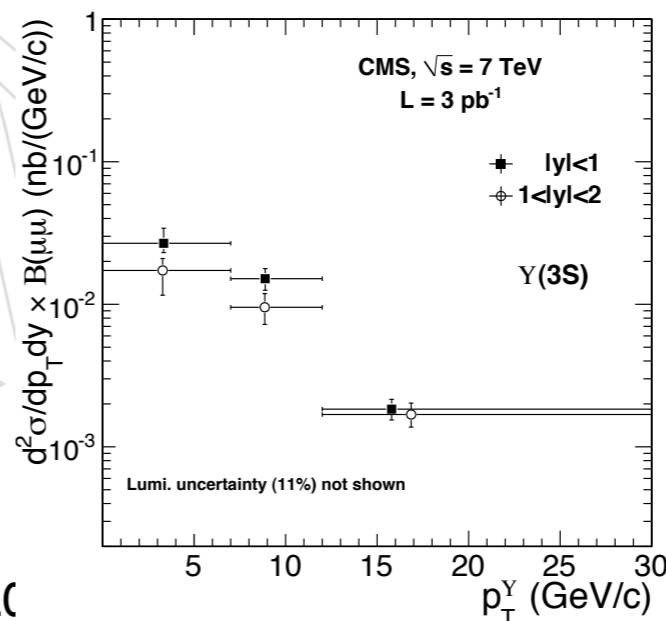
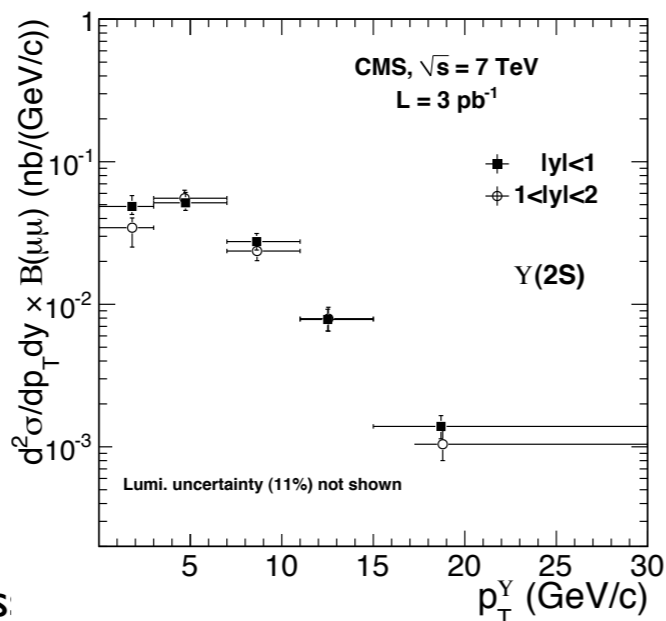
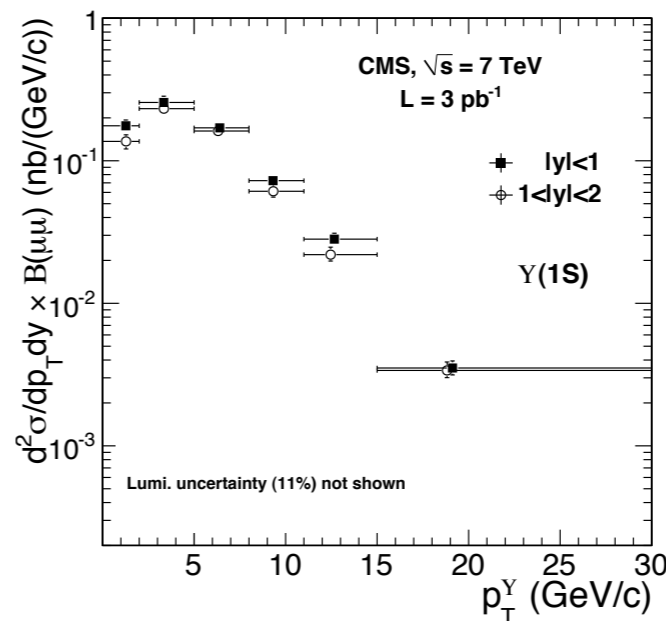
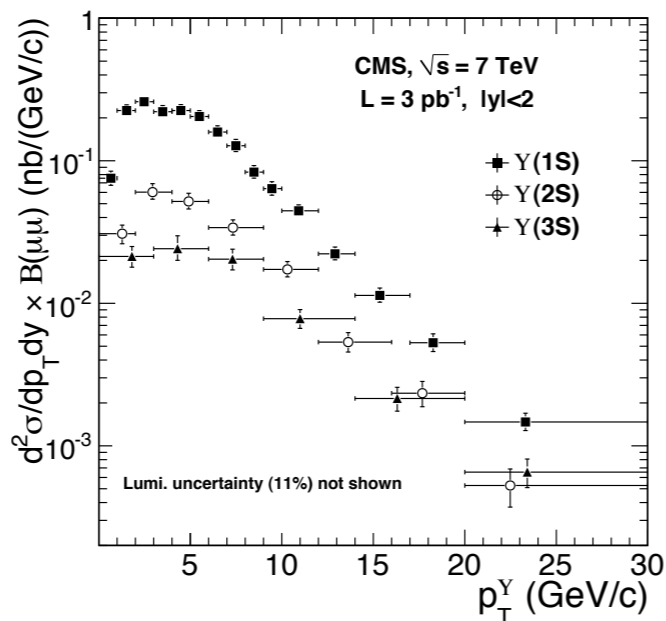
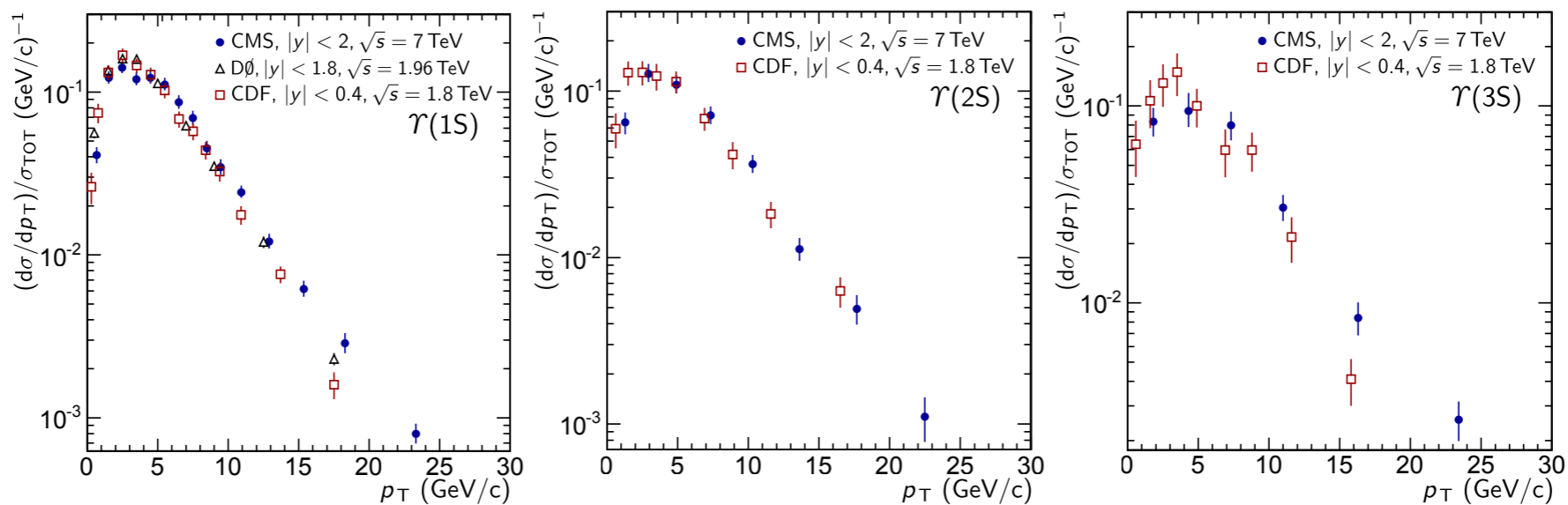


- For $6.5 < |p_T| < 30 \text{ GeV}/c$ and $|y| < 2.4$

- ◆ **Prompt:**
 - $70.9 \pm 2.1 \text{ (stat)} \pm 3.0 \text{ (syst)} \pm 7.8 \text{ (lum.) nb}$
- ◆ **Non prompt:**
 - $26.0 \pm 1.4 \text{ (stat)} \pm 1.6 \text{ (syst)} \pm 2.9 \text{ (lum.) nb}$



Exclusive ID: $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S) \rightarrow \mu\mu$



S. de Vis

2011

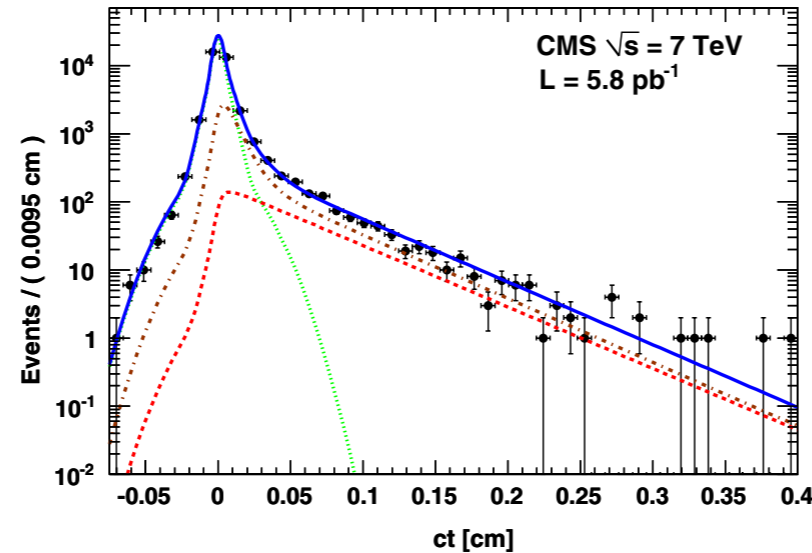
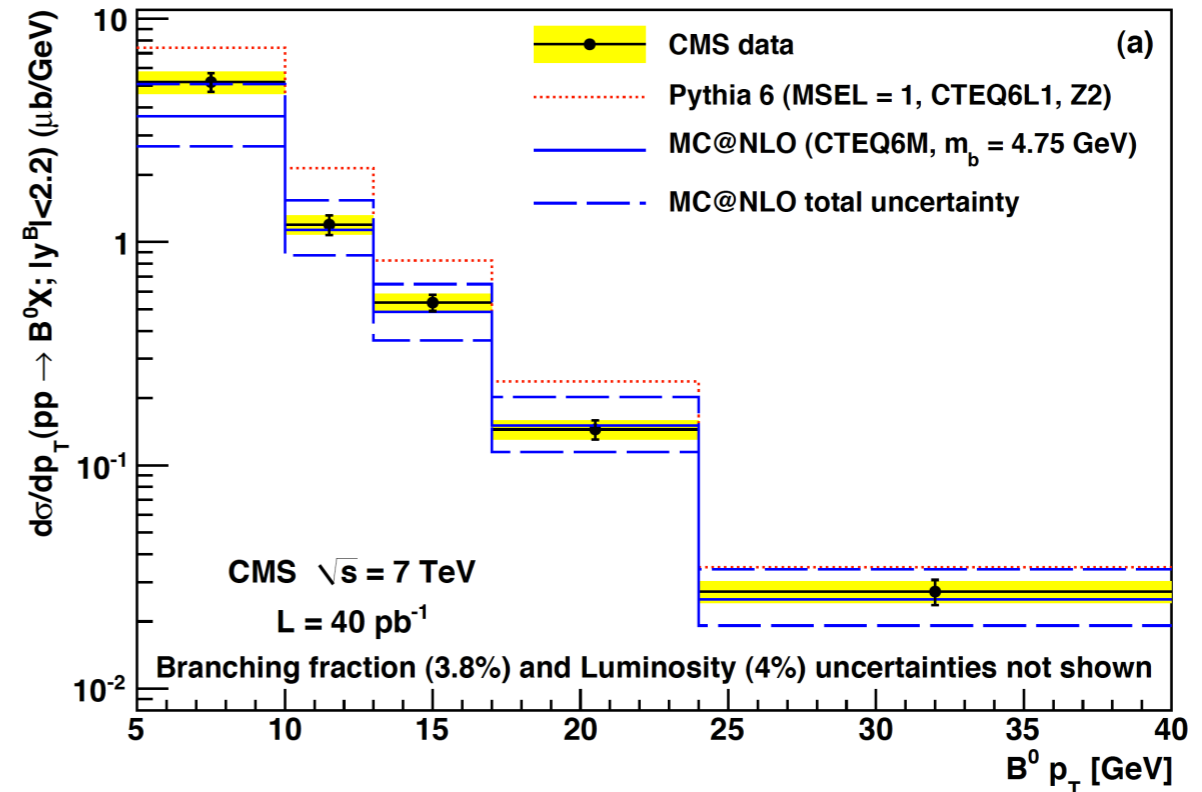
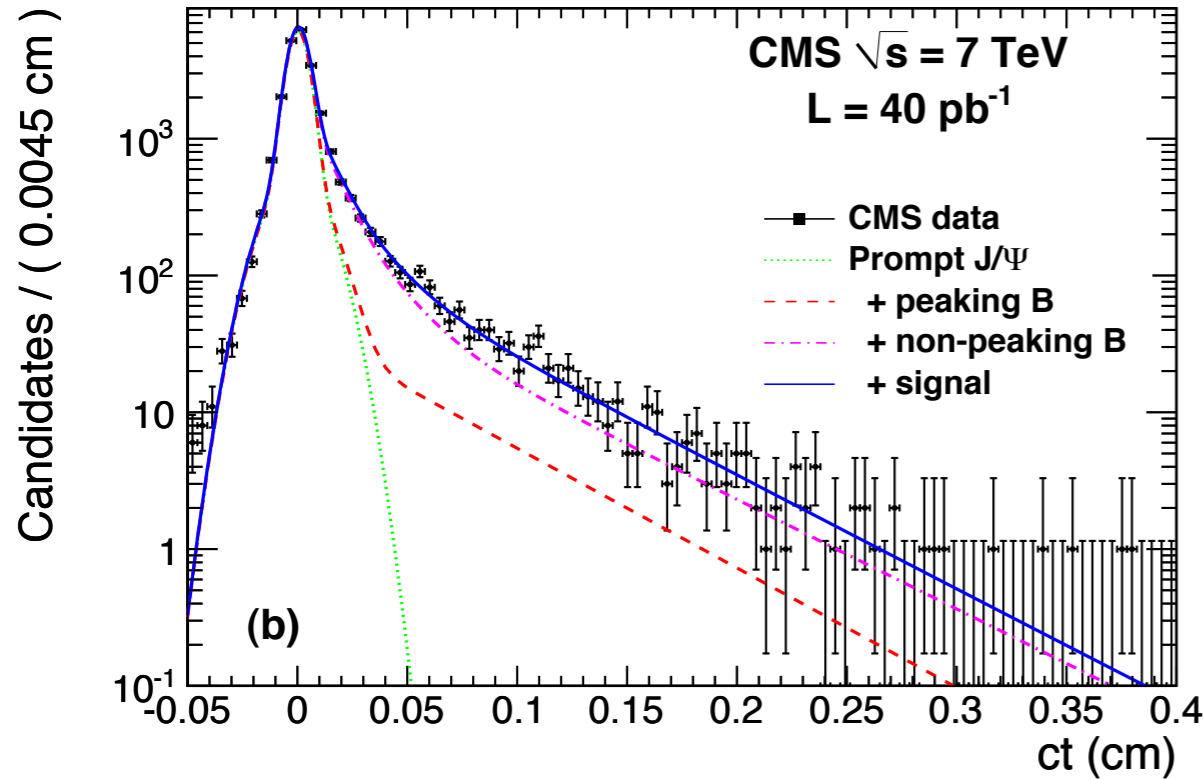


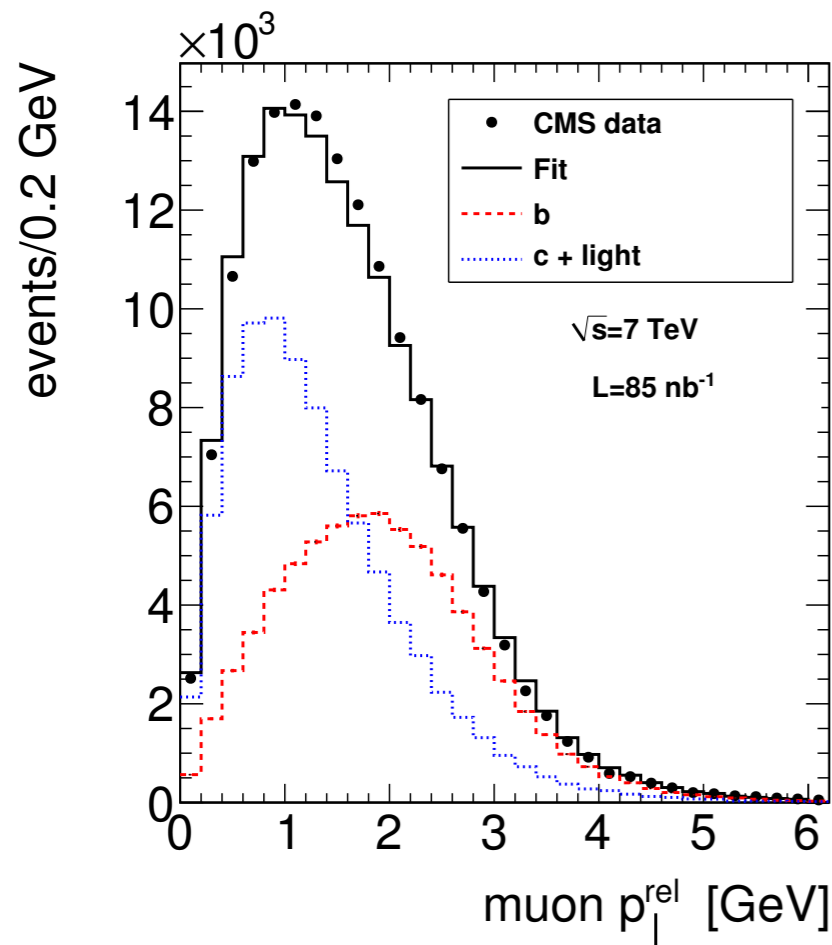
FIG. 1 (color online). Projections of the fit results in M_B (top) and ct (bottom) for $p_T^B > 5$ GeV and $|y^B| < 2.4$. The curves in each plot are the sum of all contributions (solid blue line); signal (dashed red); prompt J/ψ (dotted green); and the sum of non-prompt J/ψ , peaking $b\bar{b}$, and $J/\psi\pi^+$ (dot-dashed brown). For better visibility of the individual contributions, the M_B plot includes a requirement of $ct > 100 \mu\text{m}$.

TABLE I. Bin ranges for p_T^B and $|y^B|$, signal yields n_{sig} , efficiencies ϵ , and measured differential cross sections $d\sigma/dp_T^B$ and $d\sigma/dy^B$, compared to the MC@NLO [27] and PYTHIA predictions. The uncertainties in the measured cross sections are statistical and systematic, respectively, excluding the common branching fraction (3.5%) and luminosity (11%) uncertainties. The result for $p_T^B > 30$ GeV is quoted as an integrated cross section in μb .

p_T^B (GeV)	n_{sig}	ϵ (%)	$d\sigma/dp_T^B$ ($\mu\text{b}/\text{GeV}$)	MC@NLO	PYTHIA
5–10	223 ± 26	1.56 ± 0.02	$4.07 \pm 0.47 \pm 0.31$	$3.72^{+1.46}_{-0.89}$	6.68
10–13	236 ± 21	7.62 ± 0.11	$1.47 \pm 0.13 \pm 0.09$	$1.17^{+0.31}_{-0.24}$	2.66
13–17	169 ± 17	14.6 ± 0.2	$0.412 \pm 0.041 \pm 0.026$	$0.47^{+0.10}_{-0.05}$	1.01
17–240	207 ± 17	23.3 ± 0.6	$0.181 \pm 0.015 \pm 0.012$	$0.15^{+0.04}_{-0.03}$	0.28
24–30	56 ± 9	31.9 ± 1.5	$0.042 \pm 0.007 \pm 0.004$	$0.048^{+0.029}_{-0.018}$	0.08
>30	44 ± 8	33.4 ± 2.0	$0.188 \pm 0.034 \pm 0.018$	$0.20^{+0.11}_{-0.02}$	0.27
$ y^B $	n_{sig}	ϵ (%)	$d\sigma/dy^B$ (μb)	MC@NLO	PYTHIA
0.00–0.60	187 ± 17	3.01 ± 0.06	$7.39 \pm 0.65 \pm 0.53$	$5.98^{+2.2}_{-1.31}$	11.1
0.60–1.10	164 ± 17	3.81 ± 0.08	$6.11 \pm 0.64 \pm 0.47$	$5.85^{+1.78}_{-1.37}$	10.8
1.010–1.45	207 ± 20	5.92 ± 0.12	$7.11 \pm 0.69 \pm 0.59$	$5.59^{+1.71}_{-1.31}$	10.2
1.45–1.80	203 ± 22	8.24 ± 0.15	$5.01 \pm 0.55 \pm 0.42$	$4.96^{+1.88}_{-1.10}$	9.5
1.80–2.40	176 ± 22	6.31 ± 0.12	$3.31 \pm 0.42 \pm 0.28$	$4.29^{+1.73}_{-1.14}$	8.5



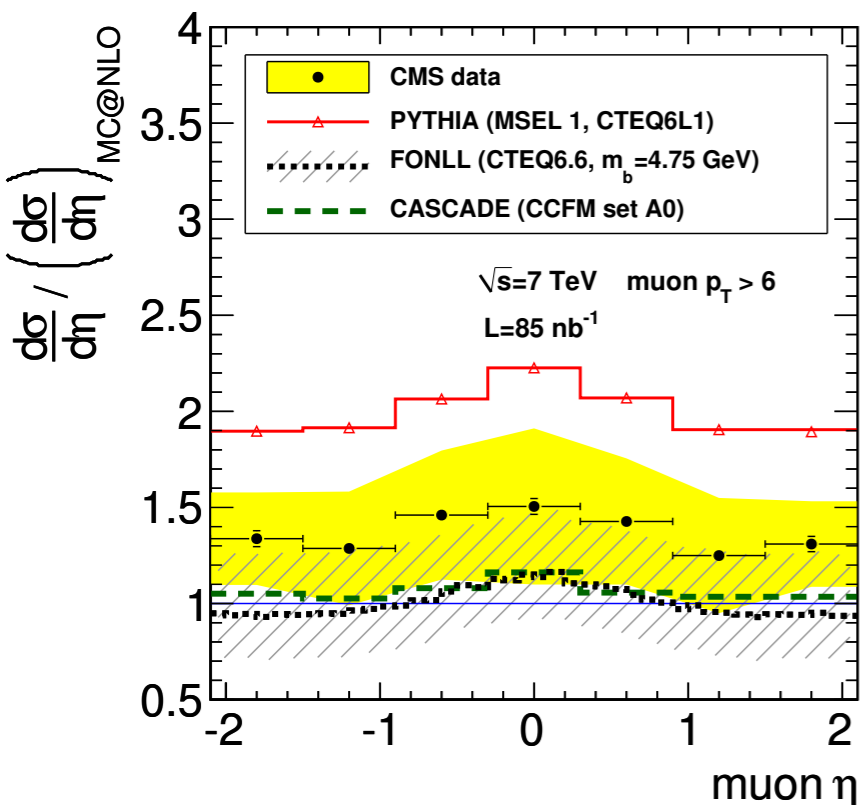
p_T^B (GeV)	n_{sig}	ϵ (%)	$d\sigma/dp_T^B$ ($\mu\text{b}/\text{GeV}$)	MC@NLO	PYTHIA
5 – 10	240 ± 23	0.65 ± 0.05	$5.20 \pm 0.50 \pm 0.59$	3.66	7.42
10 – 13	169 ± 17	3.32 ± 0.28	$1.196 \pm 0.121 \pm 0.117$	1.13	2.14
13 – 17	193 ± 16	6.37 ± 0.51	$0.535 \pm 0.045 \pm 0.051$	0.49	0.83
17 – 24	138 ± 13	9.60 ± 0.76	$0.145 \pm 0.014 \pm 0.014$	0.15	0.24
24 – 40	70 ± 9	11.40 ± 1.04	$0.027 \pm 0.003 \pm 0.003$	0.025	0.035
$ y^B $	n_{sig}	ϵ (%)	$d\sigma/dy^B$ (μb)	MC@NLO	PYTHIA
0.0 – 0.5	145 ± 14	1.34 ± 0.10	$7.63 \pm 0.74 \pm 0.76$	6.21	12.41
0.5 – 1.0	141 ± 15	1.38 ± 0.10	$7.20 \pm 0.75 \pm 0.71$	6.14	12.01
1.0 – 1.4	167 ± 17	1.93 ± 0.15	$7.61 \pm 0.77 \pm 0.83$	5.81	11.24
1.4 – 1.8	229 ± 21	2.51 ± 0.21	$8.06 \pm 0.74 \pm 0.89$	5.38	10.36
1.8 – 2.2	128 ± 17	1.69 ± 0.14	$6.71 \pm 0.87 \pm 0.80$	4.81	9.26



source	cross section uncertainty (%)
Trigger efficiency	5
Muon reconstruction efficiency	3
Hadron tracking efficiency	2
b p_{\perp}^{rel} shape uncertainty	≤ 21
Background p_{\perp}^{rel} shape uncertainty	2–14
Background composition	3–6
Production mechanism	2–5
Fragmentation	1–4
Decay	3
Underlying event	10
Luminosity	11

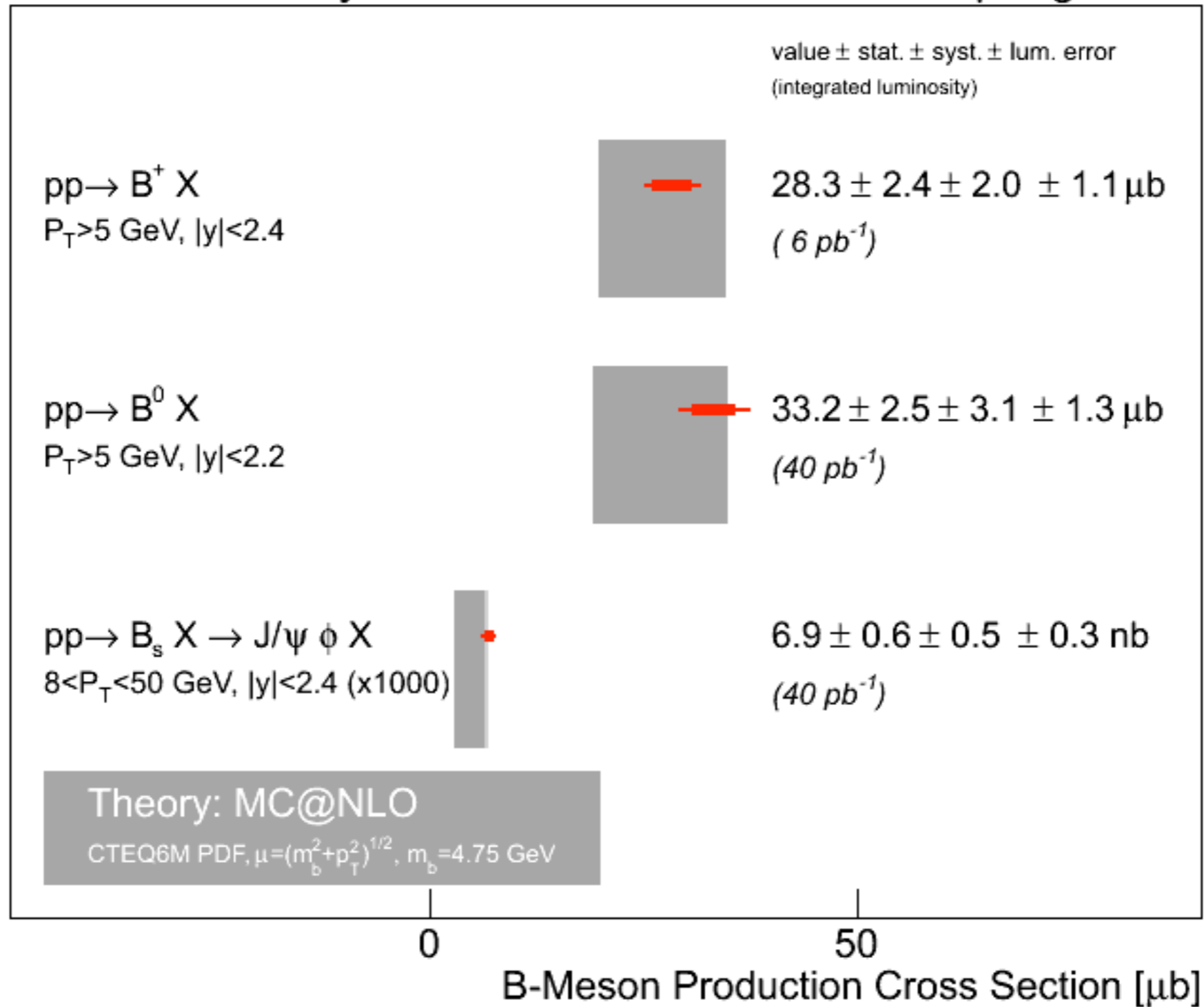
p_{T}^{μ} [GeV]	N_{b}	ϵ	$d\sigma/dp_{\text{T}}$ [nb/GeV]	stat (%)	syst (%)
6–7	26351 ± 523	0.55 ± 0.01	559	2	27
7–8	16016 ± 359	0.63 ± 0.01	299	2	23
8–10	16459 ± 332	0.70 ± 0.01	138	2	21
10–12	7136 ± 209	0.76 ± 0.02	55	3	15
12–14	3330 ± 146	0.79 ± 0.02	25	4	19
14–16	1871 ± 102	0.82 ± 0.04	13	5	15
16–20	1685 ± 99	0.85 ± 0.04	5.8	6	14
20–30	969 ± 82	0.83 ± 0.04	1.4	8	13
η^{μ}	N_{b}	ϵ	$d\sigma/d\eta$ [nb]	stat	syst
(-2.1,-1.5)	8452 ± 262	0.61 ± 0.02	271	3	18
(-1.5,-0.9)	9843 ± 276	0.63 ± 0.02	307	3	23
(-0.9,-0.3)	12476 ± 321	0.68 ± 0.02	356	3	23
(-0.3, 0.3)	11508 ± 315	0.64 ± 0.02	349	3	27
(0.3, 0.9)	11918 ± 312	0.68 ± 0.02	344	3	23
(0.9, 1.5)	9330 ± 272	0.61 ± 0.02	299	3	24
(1.5, 2.1)	8397 ± 255	0.62 ± 0.02	265	3	17

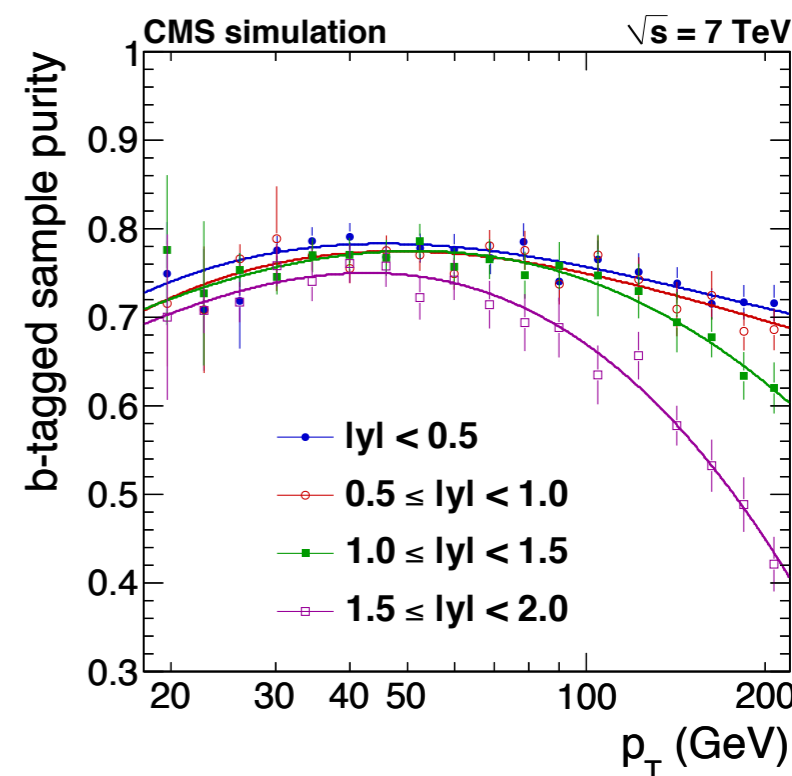
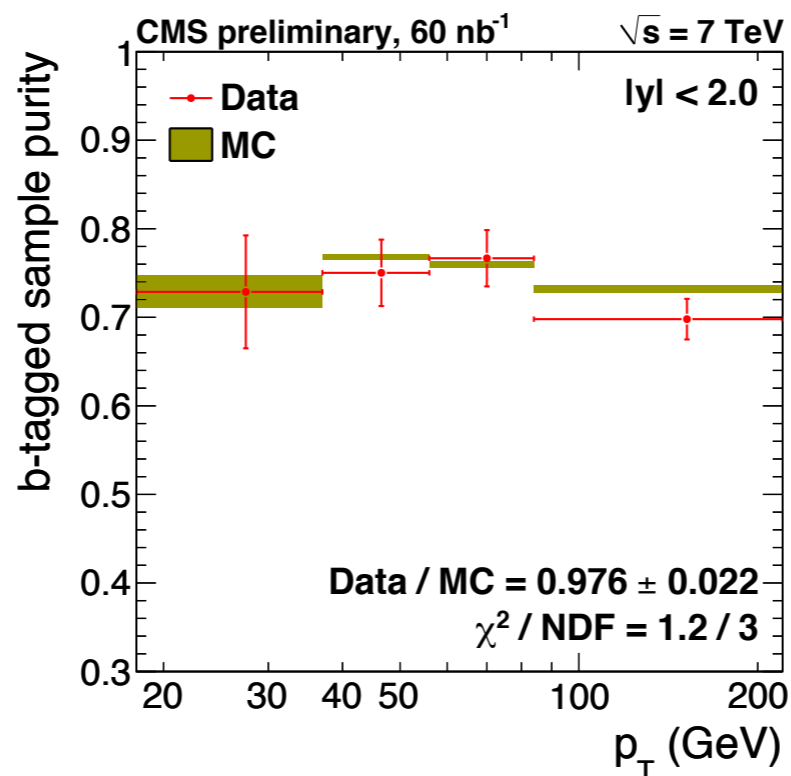
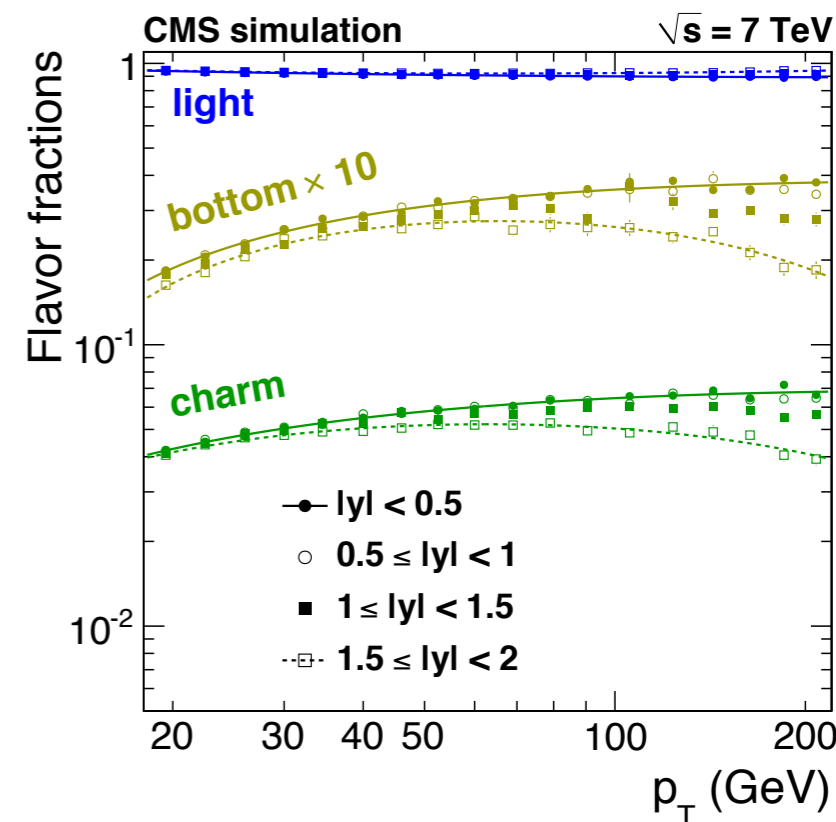
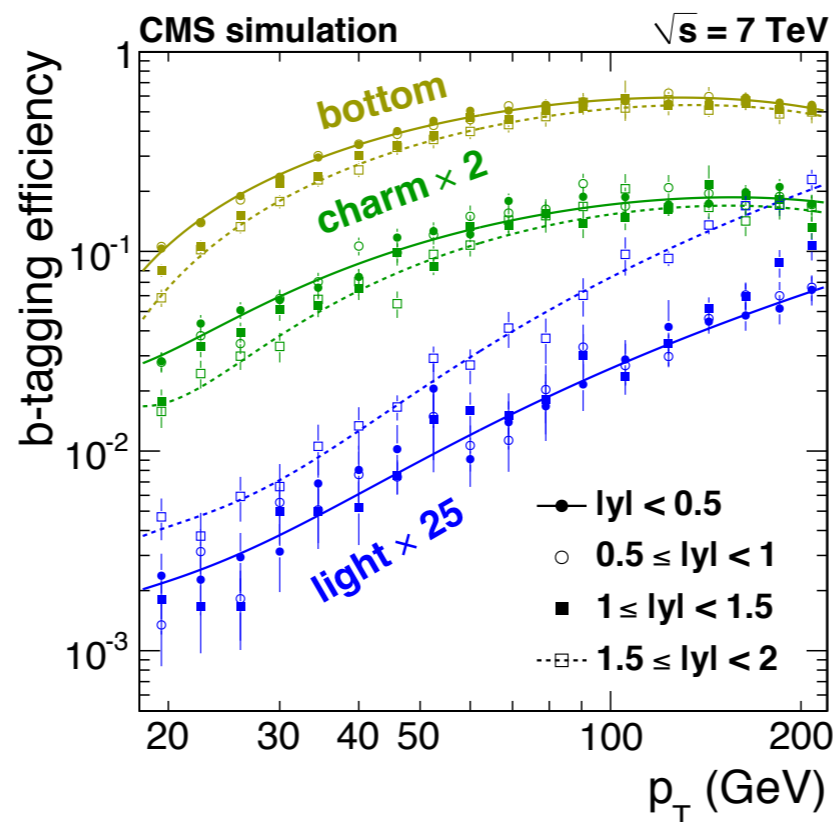
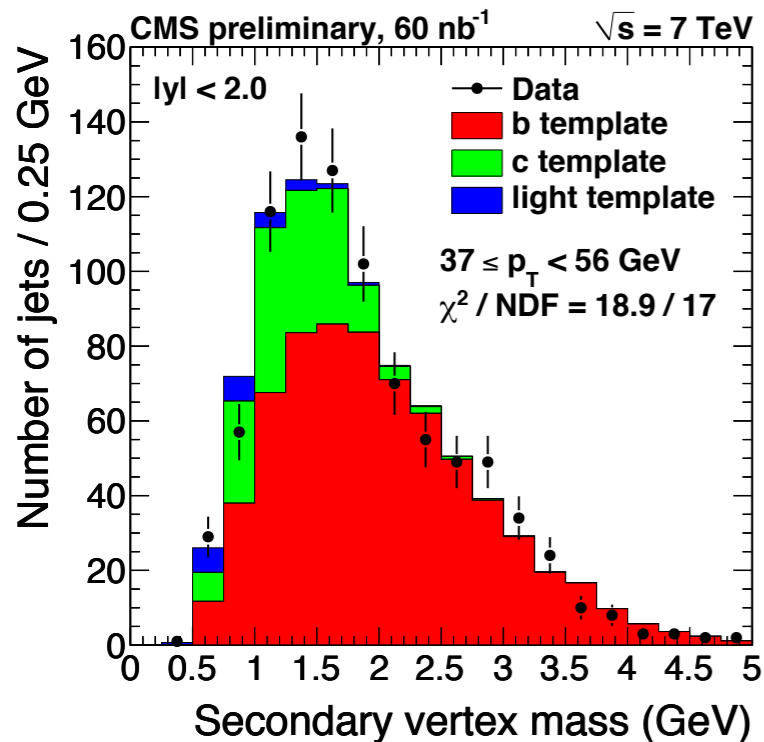
Table 2. Differential cross sections $d\sigma/dp_{\text{T}}^{\mu}$ for $|\eta^{\mu}| < 2.1$ in bins of muon transverse momentum and $d\sigma/d\eta^{\mu}$ for $p_{\text{T}}^{\mu} > 6$ GeV in bins of muon pseudorapidity. The number of b events (N_{b} , including $\bar{\text{b}}$ events) determined by the fit, the efficiency (ϵ) of the online and offline event selection, and the differential cross section, together with its relative statistical and systematic uncertainties, are given. A common uncertainty on the luminosity of 11% is not included.



CMS Preliminary, $\sqrt{s}=7$ TeV

Spring 2011





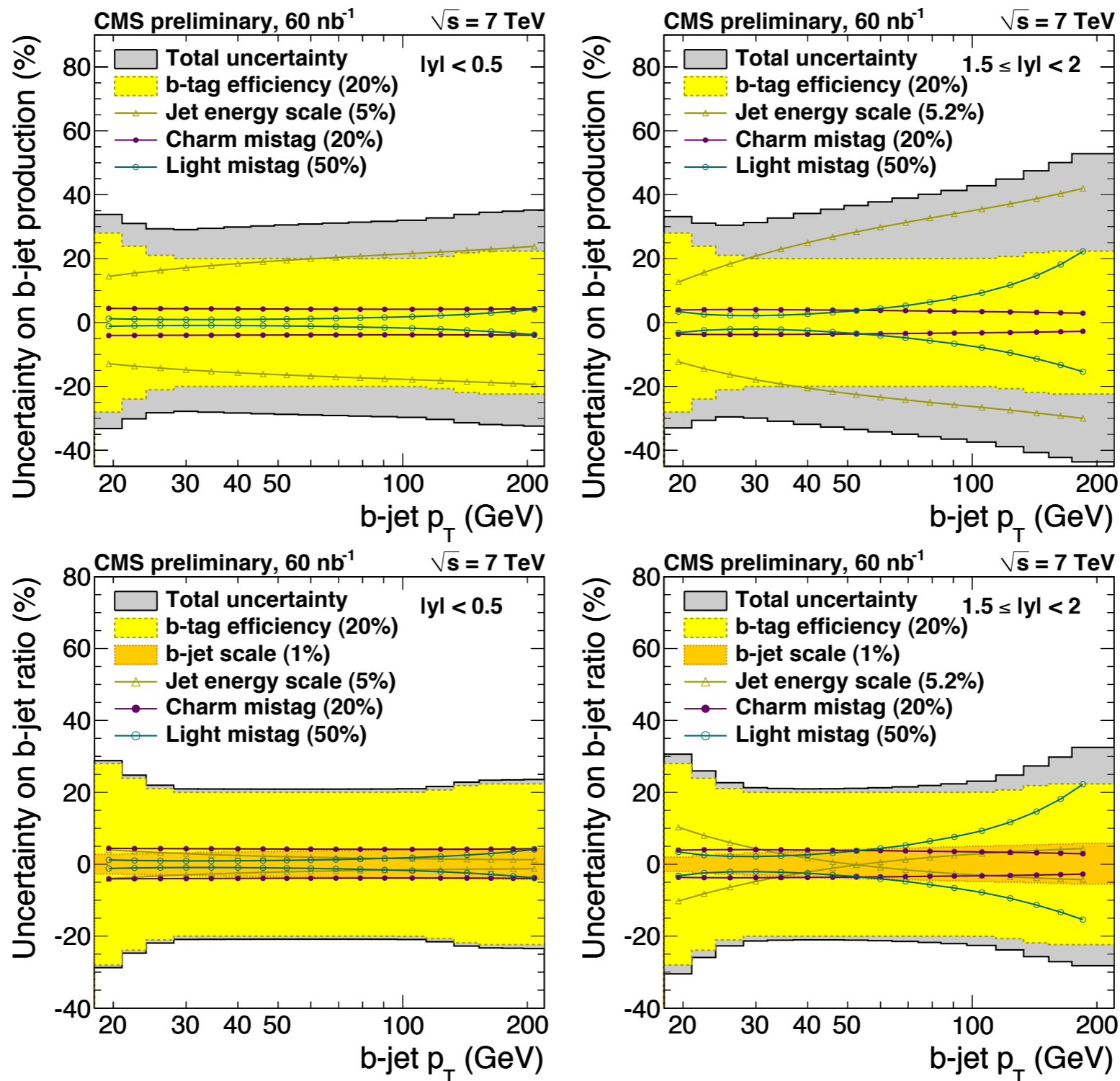
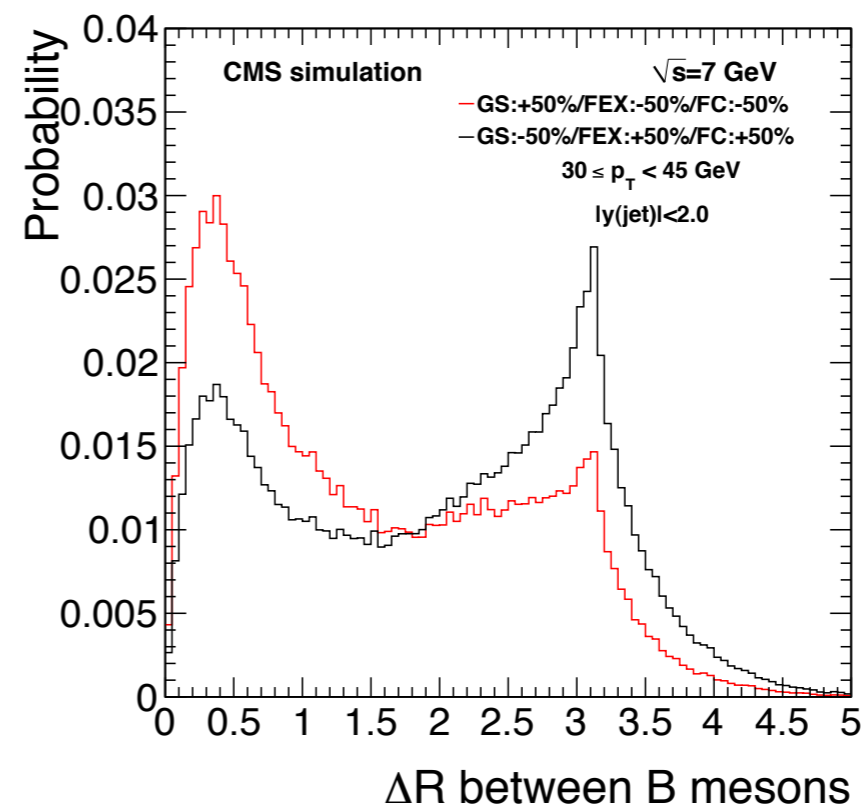
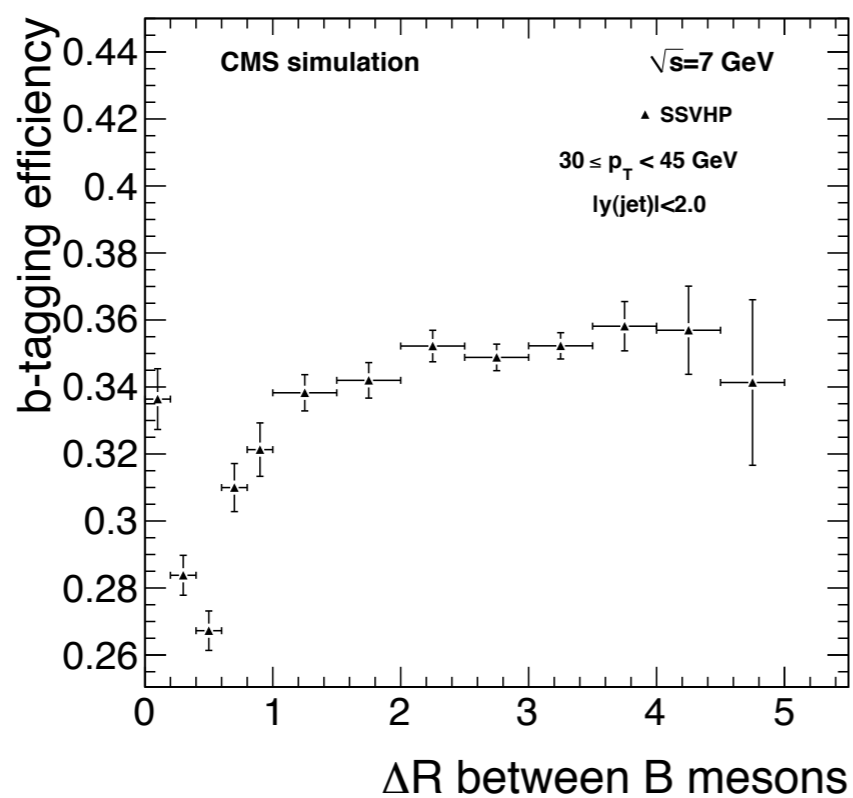


Figure 6: Leading sources of systematics uncertainty for the b-jet cross section measurement at $|y| < 0.5$ (top left) and at $1.5 \leq |y| < 2.0$ (top right), and for the ratio of b-jet and inclusive jet cross section measurements at $|y| < 0.5$ (bottom left), and $1.5 \leq |y| < 2.0$ (bottom right). The 11% luminosity uncertainty is not shown.

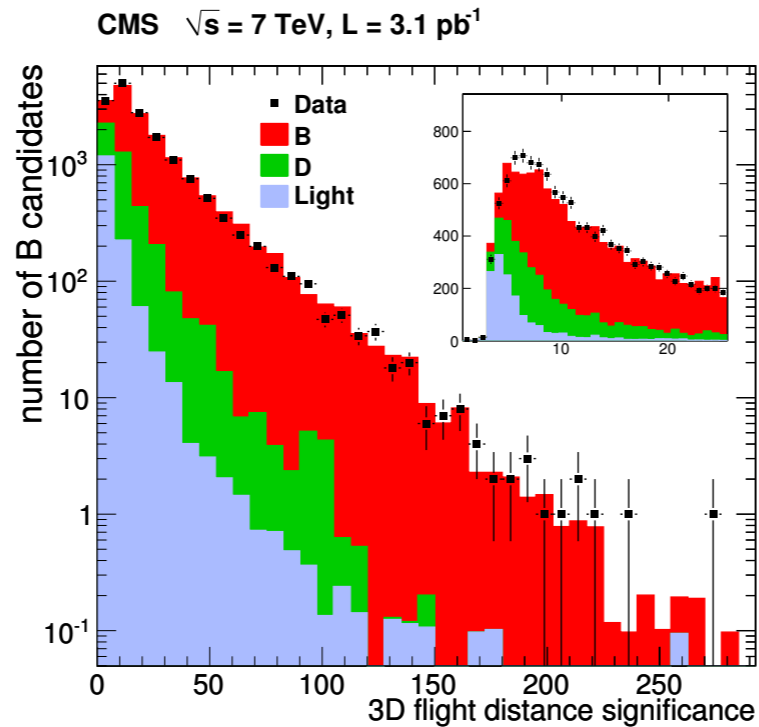
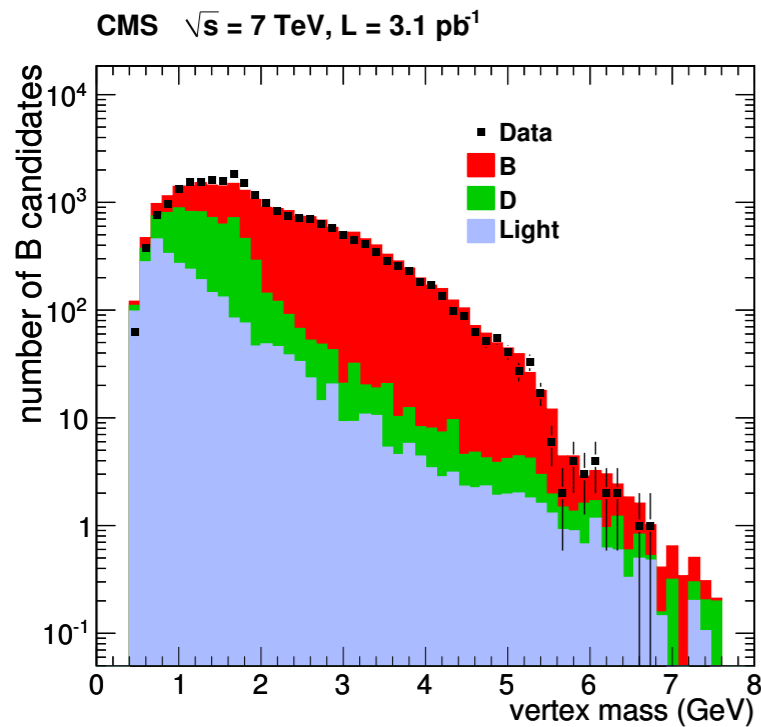
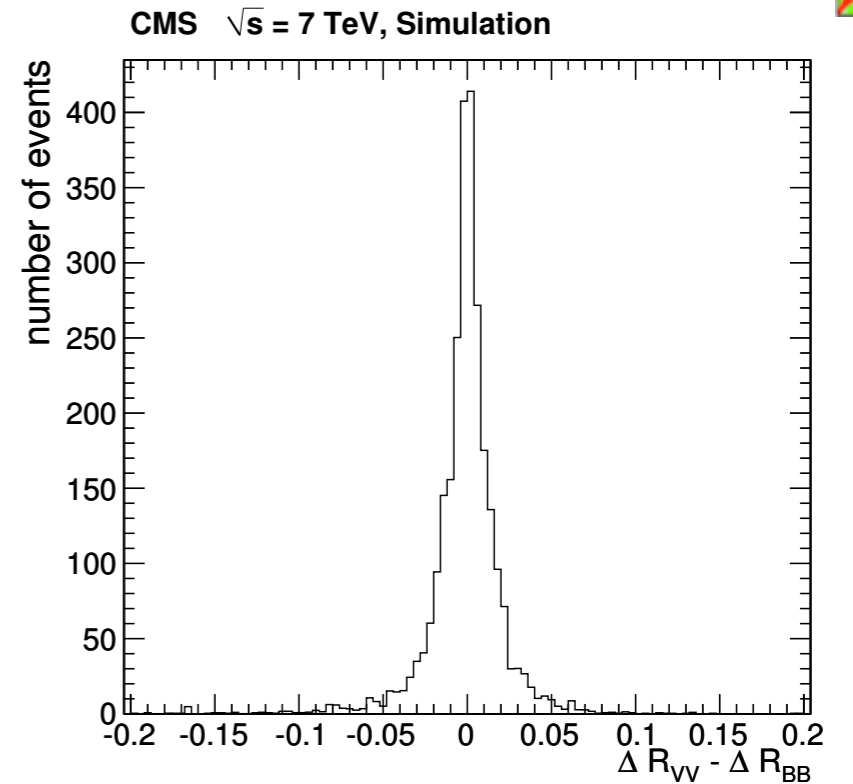
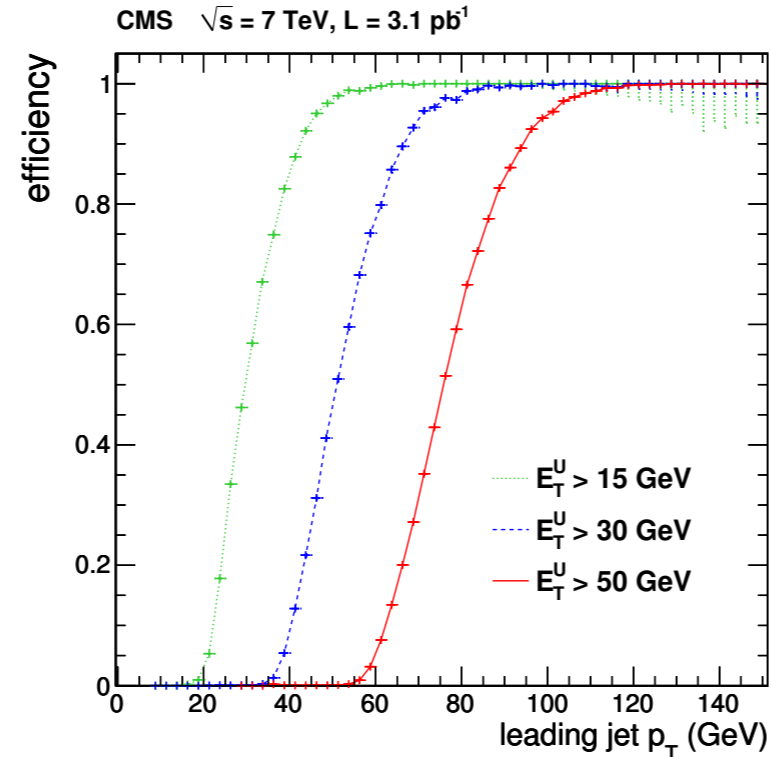
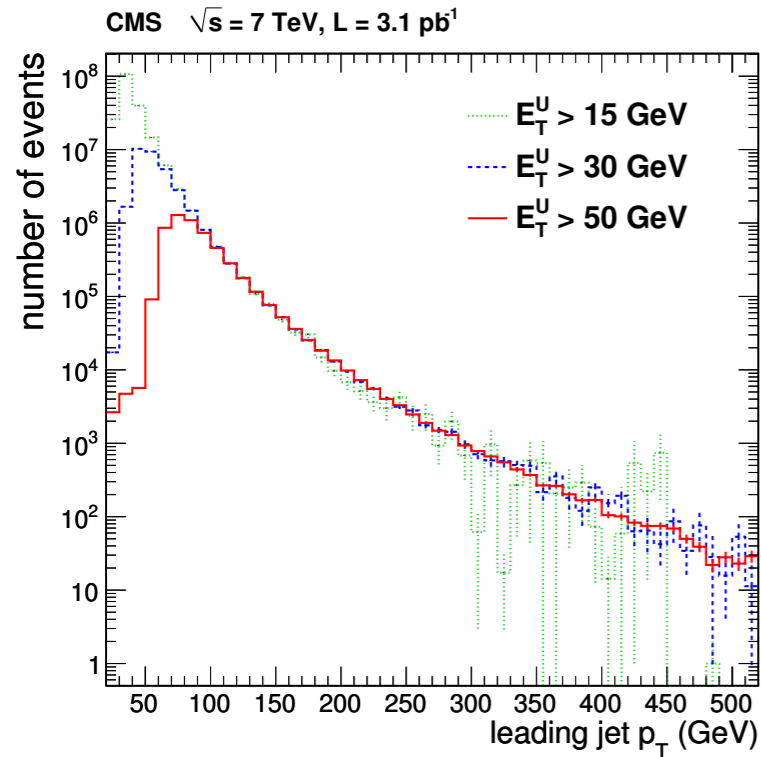


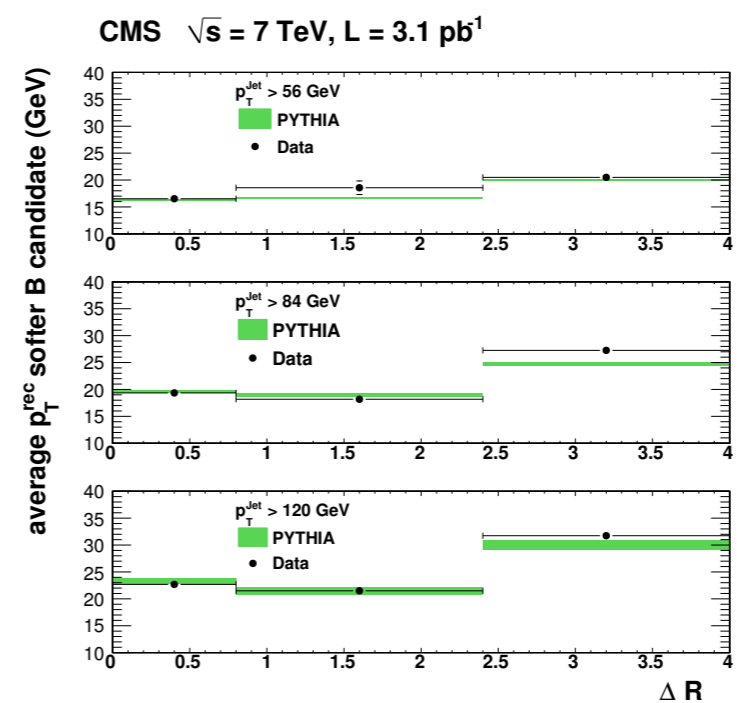
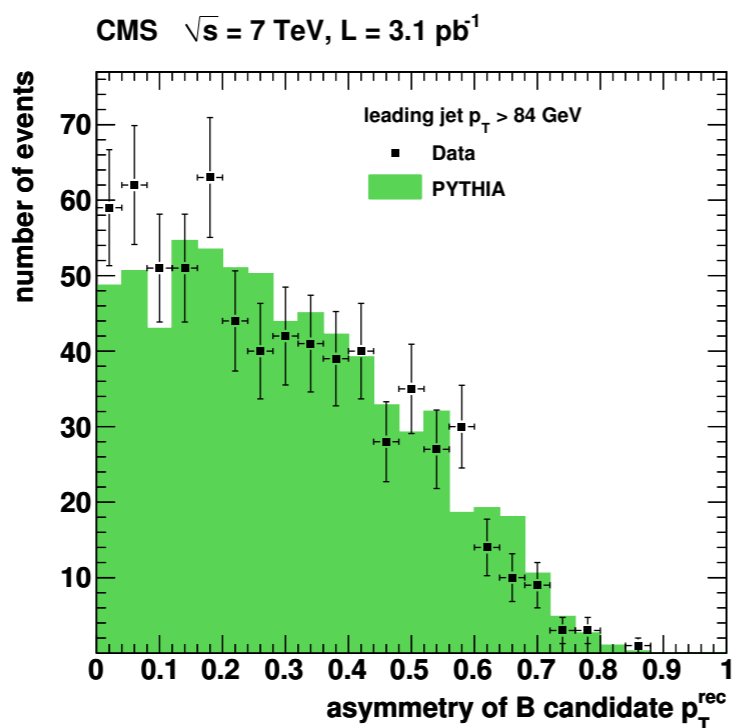
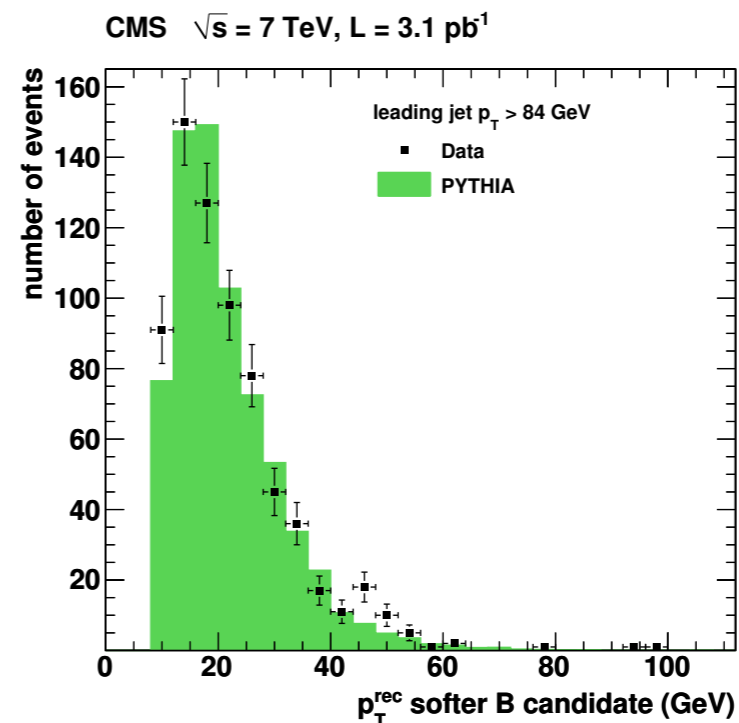
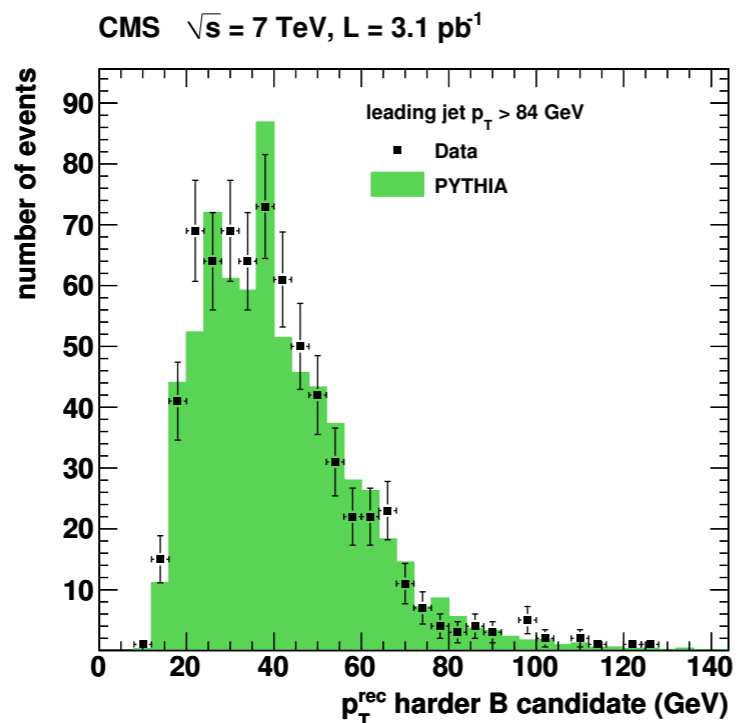
$$\frac{d^2\sigma_{b\text{-jets}}}{dp_T dy} = \frac{N_{\text{tagged}} f_b C_{\text{smear}}}{\epsilon_{\text{jet}} \epsilon_b \Delta p_T \Delta y \mathcal{L}}$$

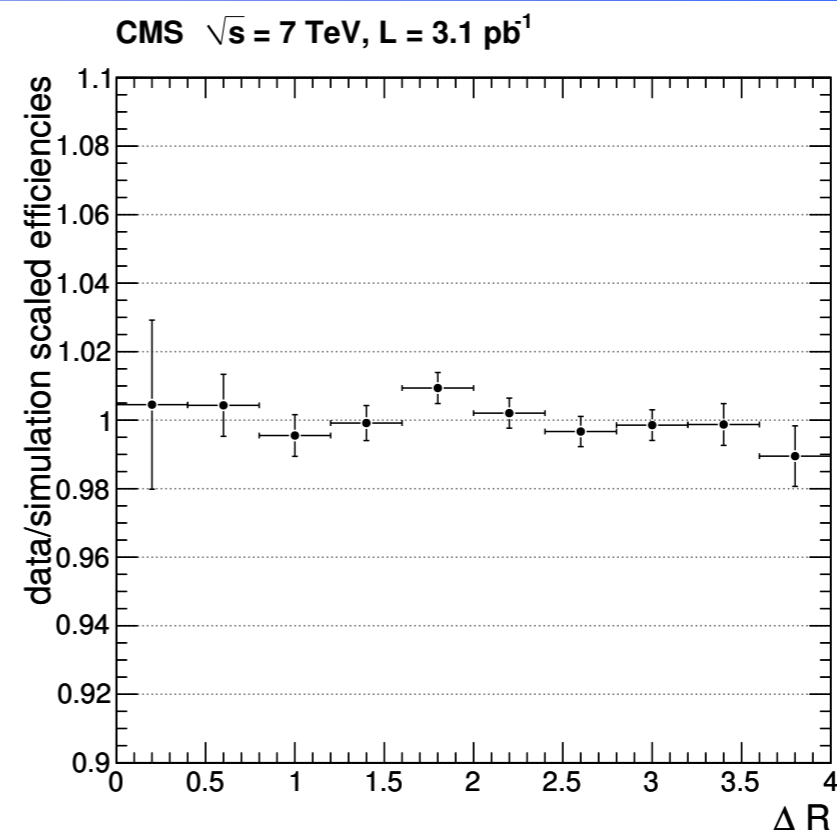
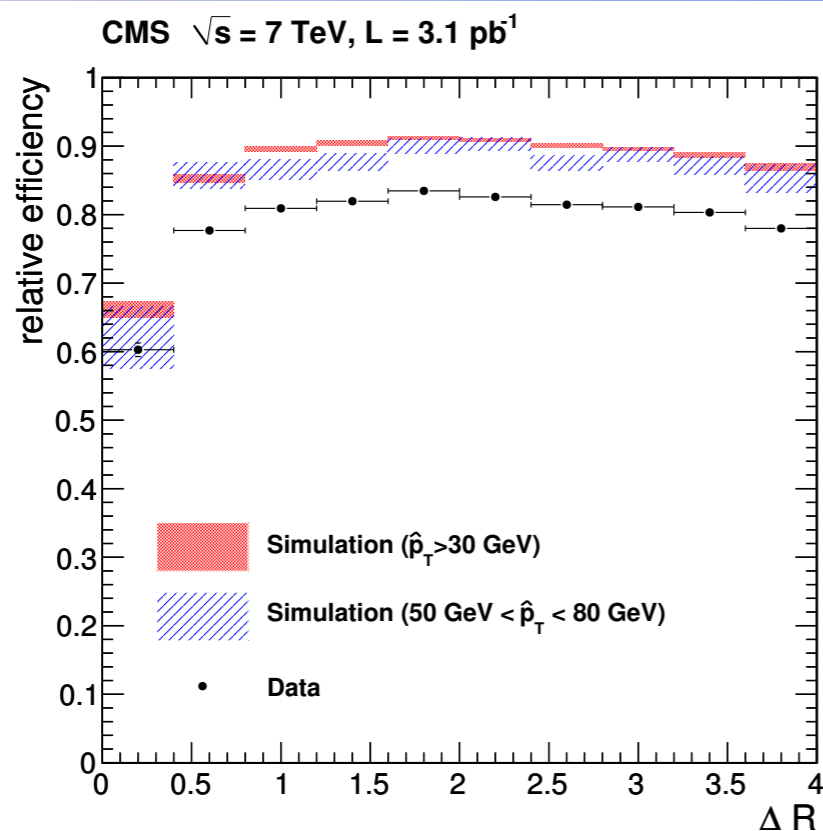
of tagged jets purity of tagged jets with a b inside Unfolding correction
Jet reco eff. Eff. to tag a b



Secondary vertex ID: BB angular correlations







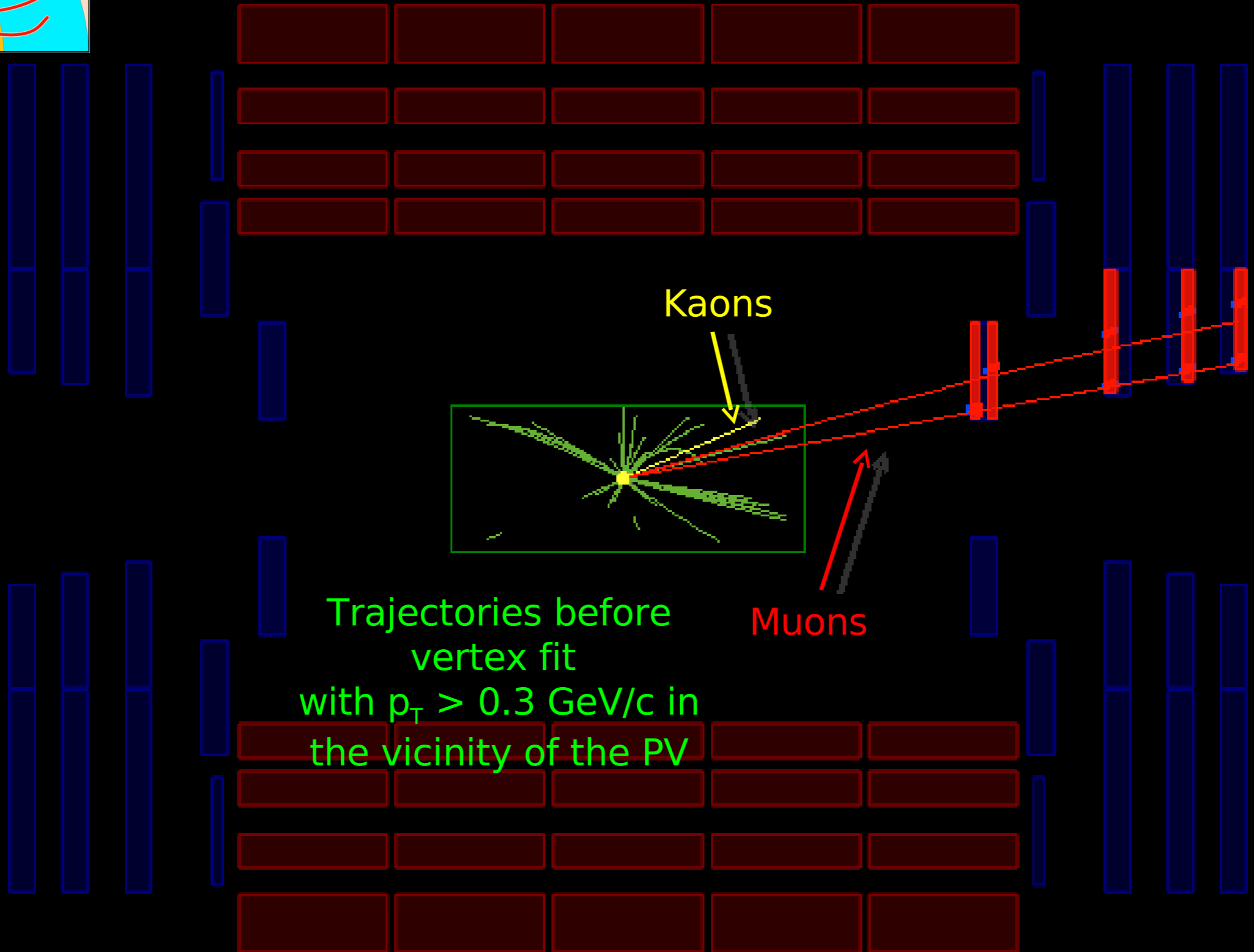
Source of uncertainty in shape	Change in $\rho_{\Delta R} = \sigma_{\Delta R < 0.8} / \sigma_{\Delta R > 2.4}$ (%)		
	Leading jet p_T bin (GeV)		
	> 56	> 84	> 120
Algorithmic effects (data mixing)	2.0	2.0	2.0
B hadron kinematics (p_T of softer B)	8.0	7.0	4.0
Jet energy scale	6.0	6.0	6.0
Phase space correction	2.8	2.8	2.8
Bin migration from resolution	0.6	1.3	2.1
Subtotal shape uncertainty	10.6	9.9	8.3
MC statistical uncertainty	13.0	13.0	13.0
Total shape uncertainty	16.8	16.4	15.4

Jet p_T						$\rho_{\Delta R} = \sigma_{\Delta R < 0.8} / \sigma_{\Delta R > 2.4}$		
Cut (GeV)	$\langle p_T \rangle$ (GeV)	$\sigma_{\Delta R < 0.8}$ (nb)	$\sigma_{\Delta R > 2.4}$ (nb)	$\langle \epsilon \rangle$ (%)	$\langle P \rangle$ (%)	Data (stat+sys)	PYTHIA (stat)	MADGRAPH (stat)
> 56	72	37 ± 18	26 ± 12	7.4	84.9	1.42 ± 0.29	0.89 ± 0.02	1.53 ± 0.07
> 84	106	10.0 ± 4.8	5.7 ± 2.7	9.3	84.6	1.77 ± 0.26	1.51 ± 0.05	2.60 ± 0.09
> 120	150	2.9 ± 1.4	1.0 ± 0.5	10.7	83.2	2.74 ± 0.32	2.13 ± 0.07	3.64 ± 0.11

Jet p_T						$\rho_{\Delta\phi} = \sigma_{\Delta\phi < \frac{1}{4}\pi} / \sigma_{\Delta\phi > \frac{3}{4}\pi}$		
Cut (GeV)	$\langle p_T \rangle$ (GeV)	$\sigma_{\Delta\phi < \frac{1}{4}\pi}$ (nb)	$\sigma_{\Delta\phi > \frac{3}{4}\pi}$ (nb)	$\langle \epsilon \rangle$ (%)	$\langle P \rangle$ (%)	Data (stat+sys)	PYTHIA (stat)	MADGRAPH (stat)
> 56	72	42 ± 20	24 ± 12	7.4	84.9	1.78 ± 0.36	1.15 ± 0.15	2.07 ± 0.10
> 84	106	11.5 ± 5.5	4.9 ± 2.3	9.3	84.6	2.37 ± 0.36	1.95 ± 0.25	3.41 ± 0.12
> 120	150	3.3 ± 1.6	0.9 ± 0.4	10.7	83.2	3.64 ± 0.46	2.73 ± 0.32	4.79 ± 0.15



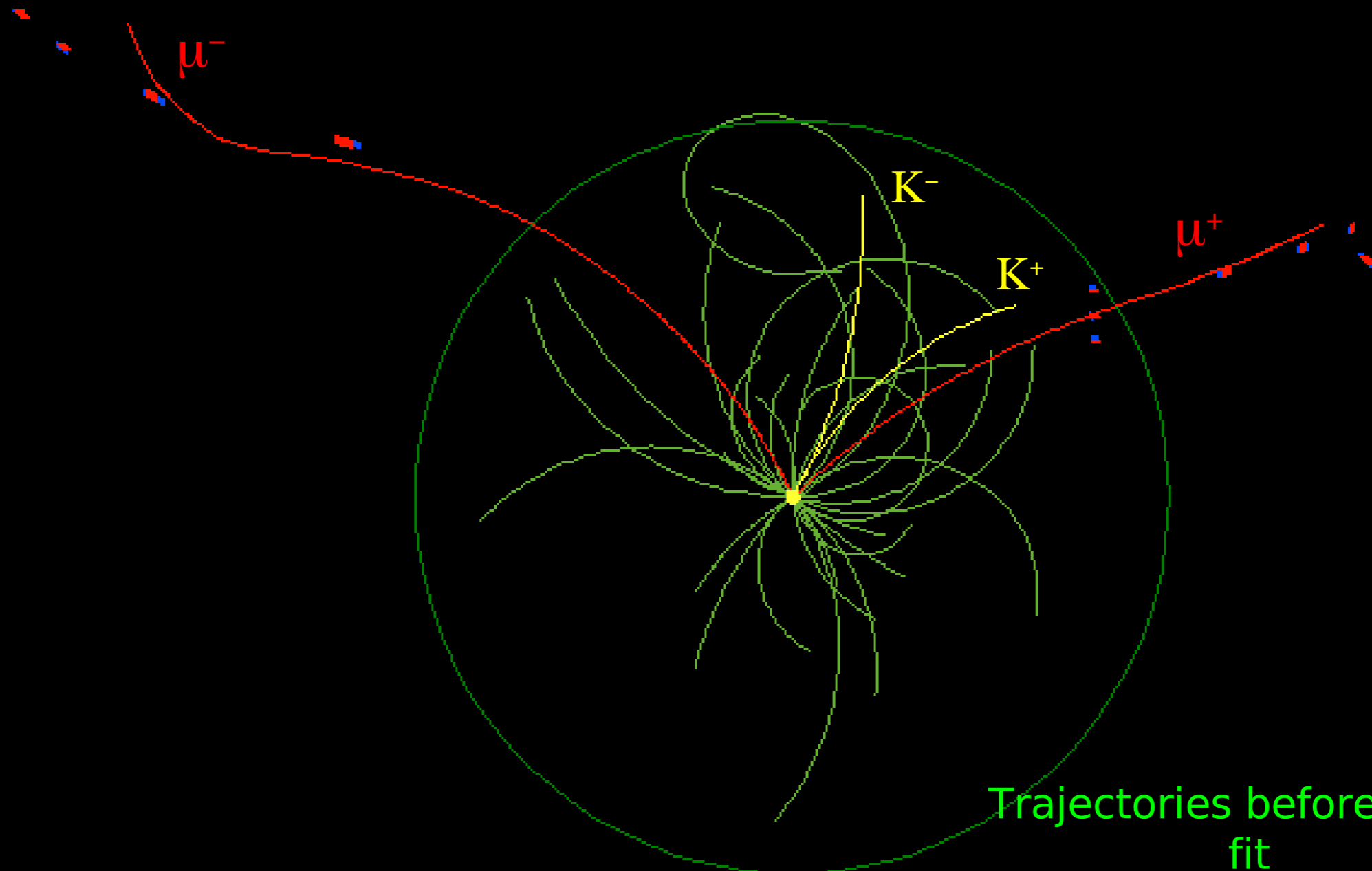
$B_s \rightarrow J/\psi \phi$ candidate event





CMS Experiment at LHC, CERN
 Data recorded: Sun Jul 4 01:33:41 2010 EDT
 Run/Event: 139364 / 20750462
 Lumi section: 20

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



Trajectories before vertex
 fit
 with $p_T > 0.3$ GeV/c in the
 vicinity of the PV



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

