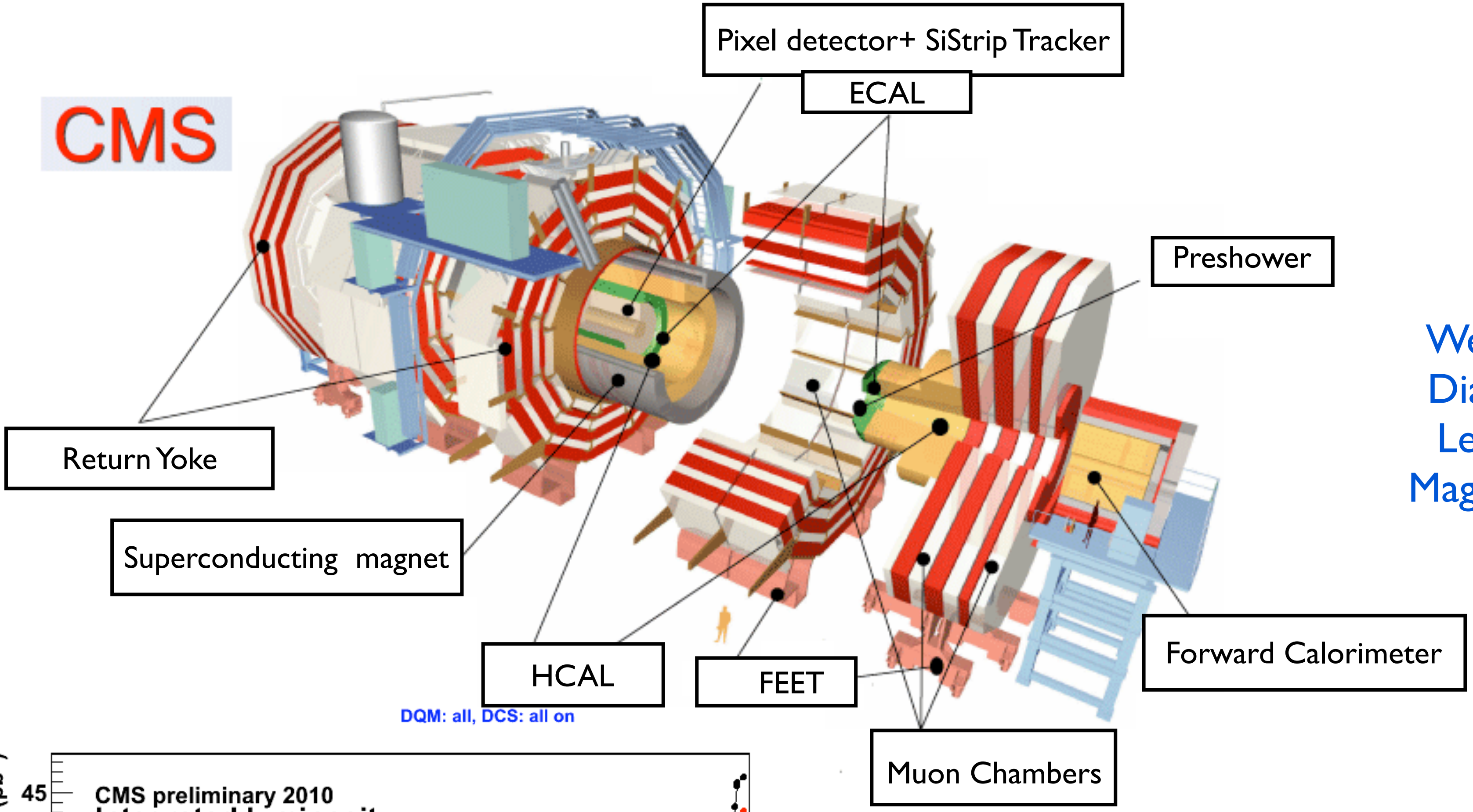
PLHC 2011 Perugia

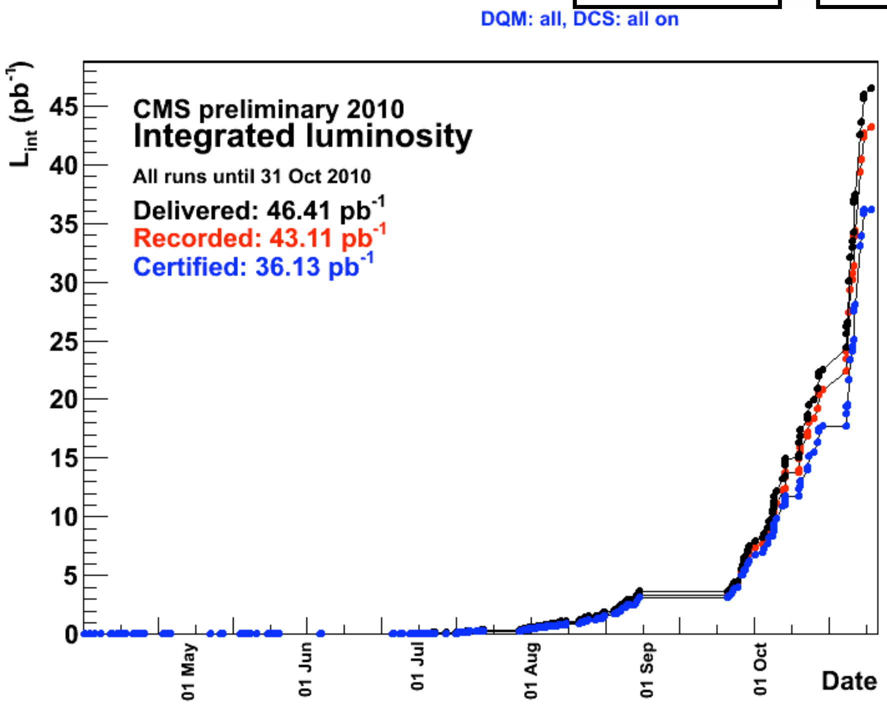
Measurements of B production with the CMS Experiment

Polina Otiougova (University of Zurich)
on behalf of CMS collaboration

09.06.2011



Weight: 12500 t
Diameter: 15 m
Length: 21.6 m
Magnetic field: 4 T



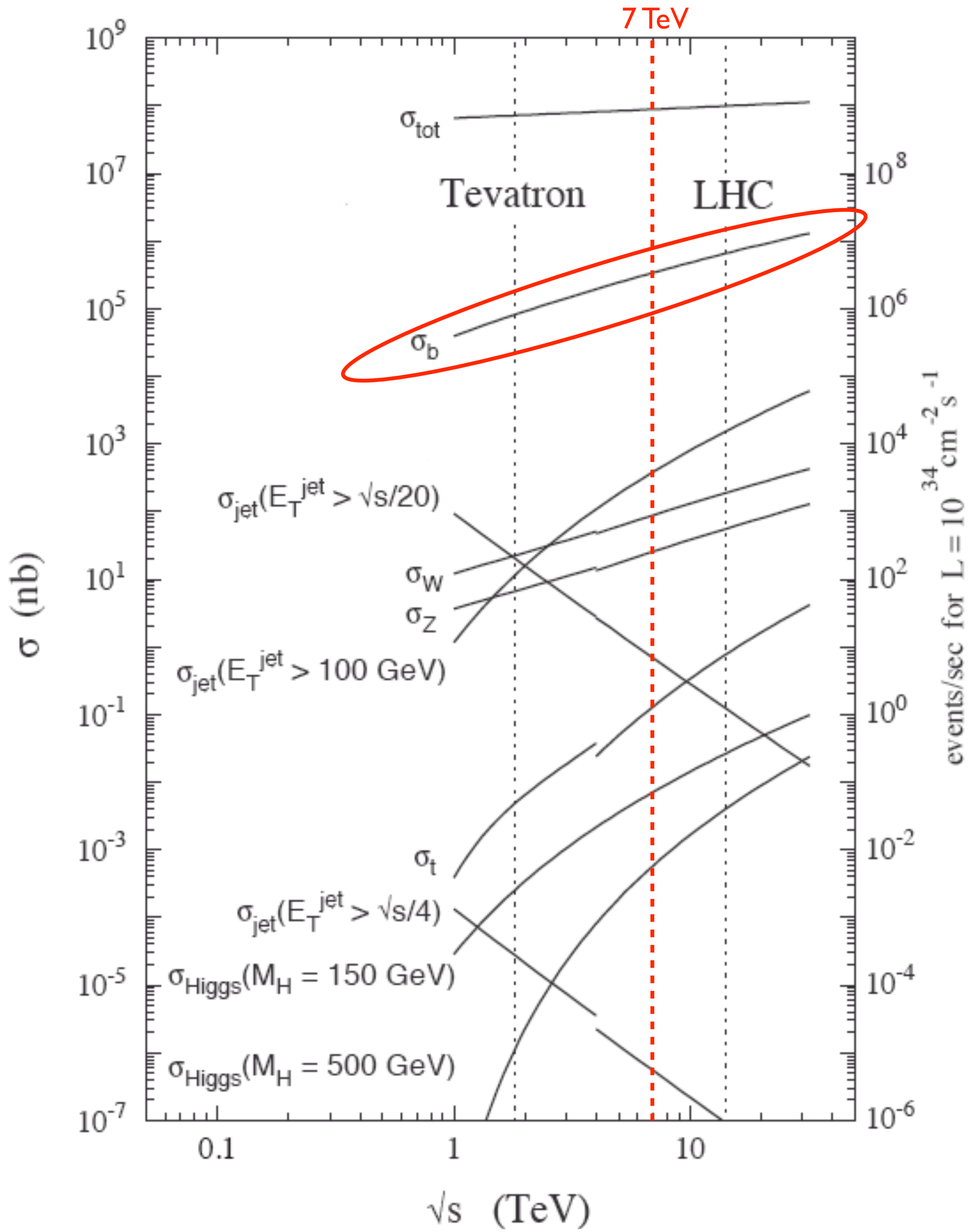
End of March 2010: first collisions at 7 TeV

Motivation for the measurements of B production

We perform the B measurements
at the new energy scale.

Comparison of
data and MC results.

Studies of the background
for Higgs,
SUSY and Top physics.



Outline

1. Exclusive B-meson production cross-section.
   1.1 $B^{+} \to J/\psi(\mu^{+}\mu^{-})K^{+}$ Phys.Rev.Lett.106:112001,2011
   1.2 $B^{0} \to J/\psi K_{s}^{0}$ arXiv:1104.2892, Accepted by Phys. Rev. Lett.
   1.3 $B_{s} \to J/\psi\phi$ CMS-BPH-1-013

2. Open beauty production cross section with muons.
   JHEP 1103 (2011) 090

3. Inclusive b-jet production. CMS-BPH-009

4. BB(bar) angular correlations. JHEP 1103 (2011) 136

Exclusive B-meson production cross-section

$B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$

The data correspond to the integrated luminocity 5.8 pb^{-1}

Selection: 2 opposite sign muons with invariant mass within 150MeV of the nominal J/ψ mass

Muon acceptance:

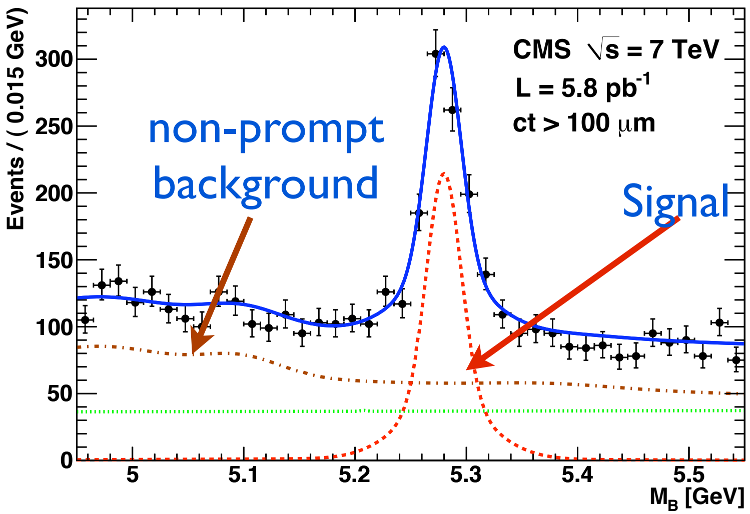
η <1.3	p_t >3.3 GeV
1.3< η <2.2	p >2.9 GeV
η <2.4	p_t >0.8 GeV

B^+ candidate:

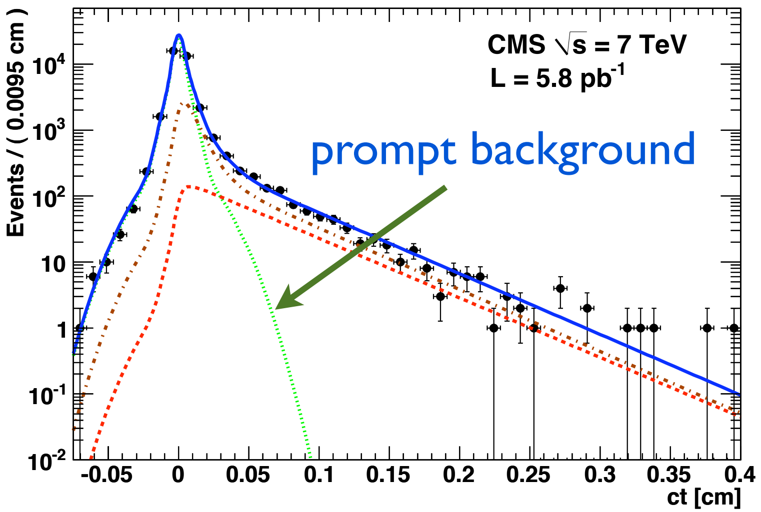
J/ψ candidate + K^+ track with p_t>0.9 GeV

Unbinned maximum likelihood fit to M_B and Ct

Invariant mass



Proper decay length



background shapes obtained from the data.

Main contributions: prompt and non prompt J/ψ

number of signal events in each p_t and |y| bin is obtained

n_{sig}=912$\pm$47

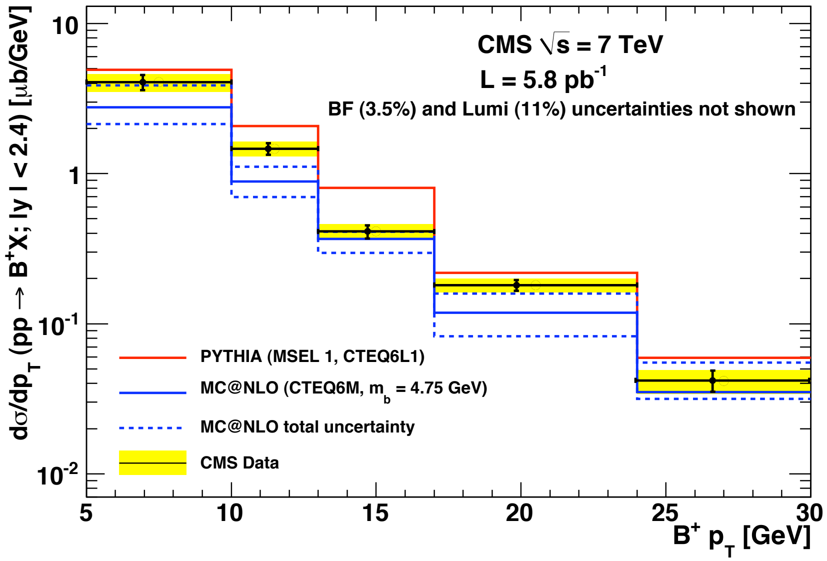
The result:

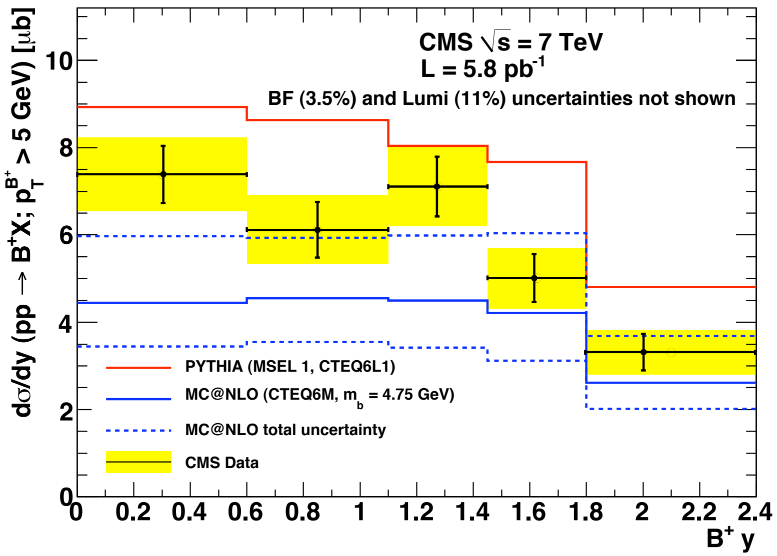
Ct=481$\pm$22μm

Ct_{PDG}=491$\pm$ 9 μm

Differential Cross section

Yellow bands- syst. and stat. uncertainties added in quadrature





$$\frac{d\sigma(\mathrm{pp}\to \mathrm{B}^+X)}{dp_{\mathrm{T}}^{\mathrm{B}}} = \frac{n_{\mathrm{sig}}(p_{\mathrm{T}}^{\mathrm{B}})}{2\,\epsilon(p_{\mathrm{T}}^{\mathrm{B}})\,\mathcal{B}\,\mathcal{L}\,\Delta p_{\mathrm{T}}^{\mathrm{B}}}, \quad \frac{d\sigma(\mathrm{pp}\to \mathrm{B}^+X)}{dy^{\mathrm{B}}} = \frac{n_{\mathrm{sig}}(|y^{\mathrm{B}}|)}{2\,\epsilon(|y^{\mathrm{B}}|)\,\mathcal{B}\,\mathcal{L}\,\Delta y^{\mathrm{B}}},$$

$n_{\mathrm{sig}}(p_{\mathrm{T}}^{\mathrm{B}})$ $n_{\mathrm{sig}}(|y^{\mathrm{B}}|)$ fitted signal yields in given bins

$\epsilon(|y^{\mathrm{B}}|)$ $\epsilon(p_{\mathrm{T}}^{\mathrm{B}})$ efficiency in each bin for for a B^+ meson to pass all the criteria

Δp Δy- bin sizes

Branching ratios:

$$\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\,\mathrm{K}^+) = (1.014 \pm 0.034) \times 10^{-3}$$

$$\mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-) = (5.93 \pm 0.06) \times 10^{-2}$$

The total integrated cross section for p_t>5 GeV and $|y^B|$<2.4:

$$\sigma = 28.1 \pm 2.4 \pm 2.0 \pm 3.1 \mu b$$

stat syst lumi

$$\mathrm{MC@NLO} : 25.5^{+9.2}_{-5.7} \mu\mathrm{b}$$

Agreement with MC@NLO within uncertainties!

$B^0 \to J/\psi K_s^0$

The data correspond to the integrated luminocity 40 pb^{-1}

Selection: 2 opposite sign muons with invariant mass within 150MeV of the nominal J/ψ mass

Muon acceptance:

η <1.3	p_t >3.3 GeV
1.3< η <2.2	p >2.9 GeV
η <2.4	p_t >0.8 GeV

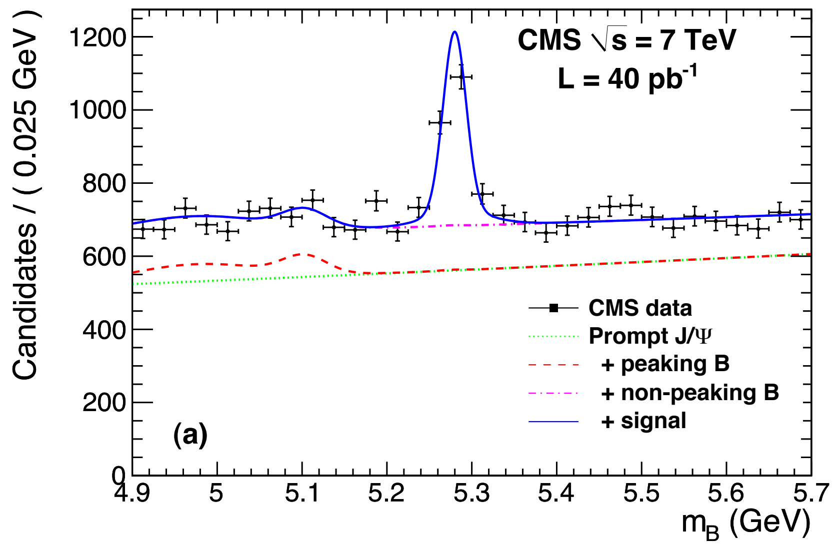
B^0 candidate:

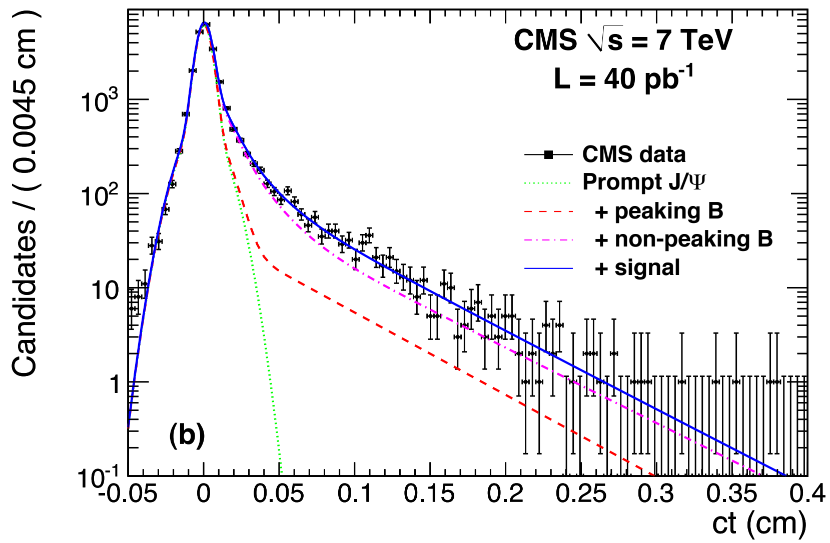
J/ψ candidate + K^0 formed by fitting oppositely charged tracks

The $\pi^+\pi^-$ invariant mass requires:

478 < m_{Ks}<518 MeV.

Unbinned maximum likelihood fit to M_B and Ct





background shapes obtained from the data.
Main contributions: prompt J/ψ and non-peaking component.

The result:

Ct=479±22 μm

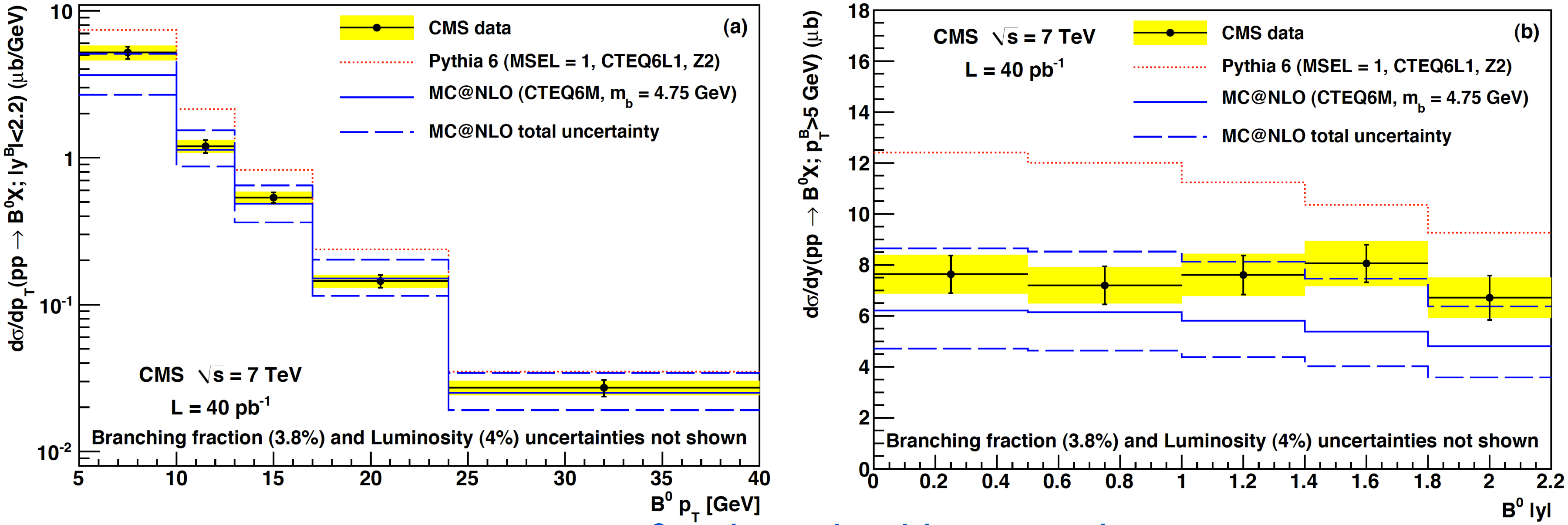
Ct_{PDG}=457±3 μm

number of signal events in each p_t and |y| bin is obtained

n_{sig}=809± 39

Differential Cross section

Yellow bands- syst. and stat. uncertainties added in quadrature



fitted signal yields in given bins

$$\frac{d\sigma(\mathrm{pp} \to \mathrm{B}^0\mathrm{X})}{dp_\mathrm{T}^\mathrm{B}} = \frac{n_\mathrm{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot L \cdot \Delta p_\mathrm{T}^\mathrm{B}},$$

efficiency lumi bin size

Branching ratio

$$B(K_s^0 \to \pi^+\pi^-) = 0.6920 \pm 0.0005$$

$$B(J/\psi \to \mu^+\mu^-) = (5.93 \pm 0.06) \bullet 10^{-2}$$

$$B(B^0 \to J/\psi K_s^0) = (4.36 \pm 0.16) \bullet 10^{-4}$$

similar for |y|

$$\mathrm{MC@NLO} = 25.5^{+9.6}_{-6.2} \mu b$$

The total integrated cross section for p_t>5 GeV and $|y^B|$<2.2:

$$\sigma = 33.2 \pm 2.5 \pm 3.5 \pm 1.3 \mu b$$

stat syst lumi

Agreement with MC@NLO within uncertainties!

$B_s \to J/\psi\phi$

The data correspond to the integrated luminocity 40 pb^{-1}

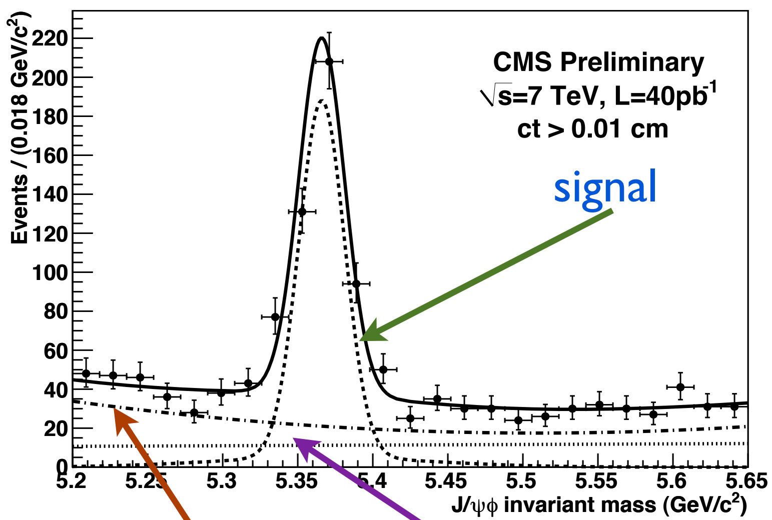
Selection: 2 opposite sign muons with invariant mass within 150MeV of the nominal J/ψ mass

Muon acceptance:

η <1.3	p_t >3.3 GeV
1.3< η <2.2	p >2.9 GeV
η <2.4	p_t >0.8 GeV

p_t (K^+,K^-)>0.7 GeV

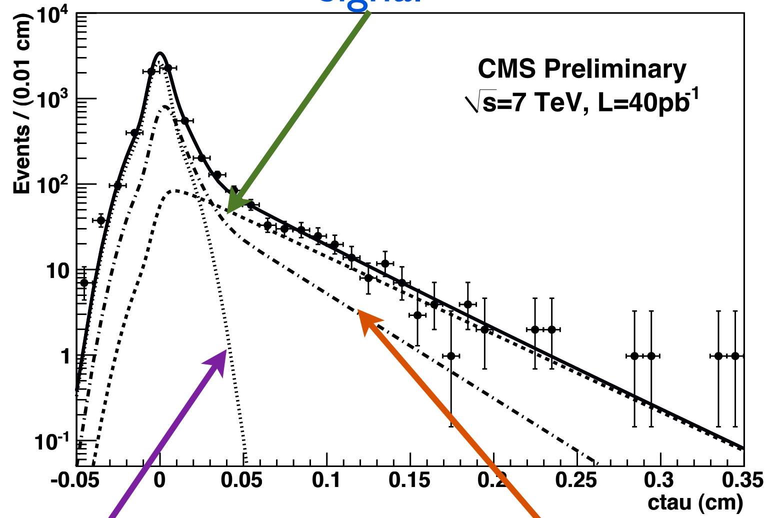
Unbinned maximum likelihood fit to M_B and Ct



non-prompt background

prompt background

signal



prompt background

non-prompt background

number of signal events in each p_t and |y| bin is obtained

n_{sig}=549 ± 32

The result:

Ct=478±26 μm

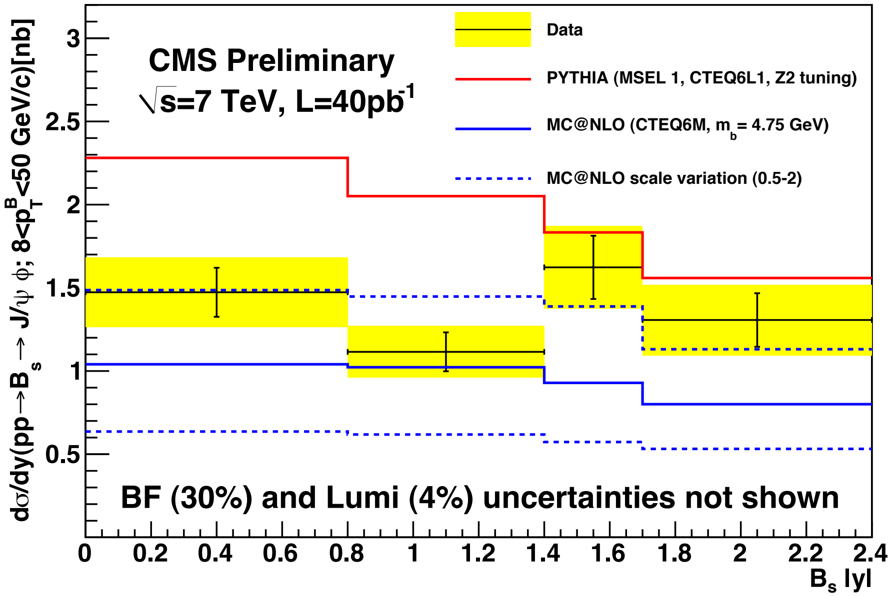
Ct_{PDG}=441 μm

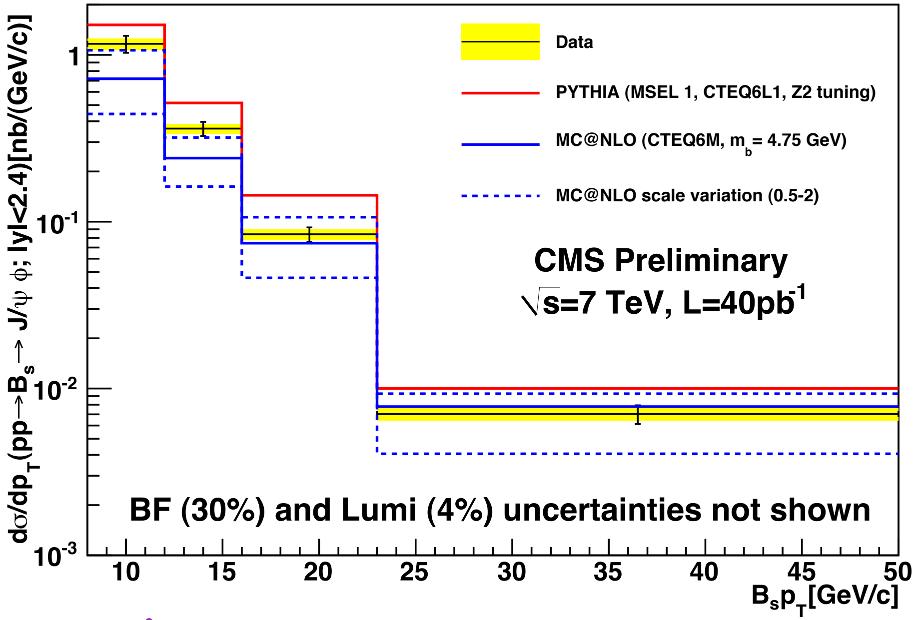
Differential cross section

fitted signal yields in given bins

$$\frac{d\sigma(pp \to B^0 X)}{dp_T^B} = \frac{n_{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot L \cdot \Delta p_T^B},$$

efficiency — Branching ratio — lumi — bin size





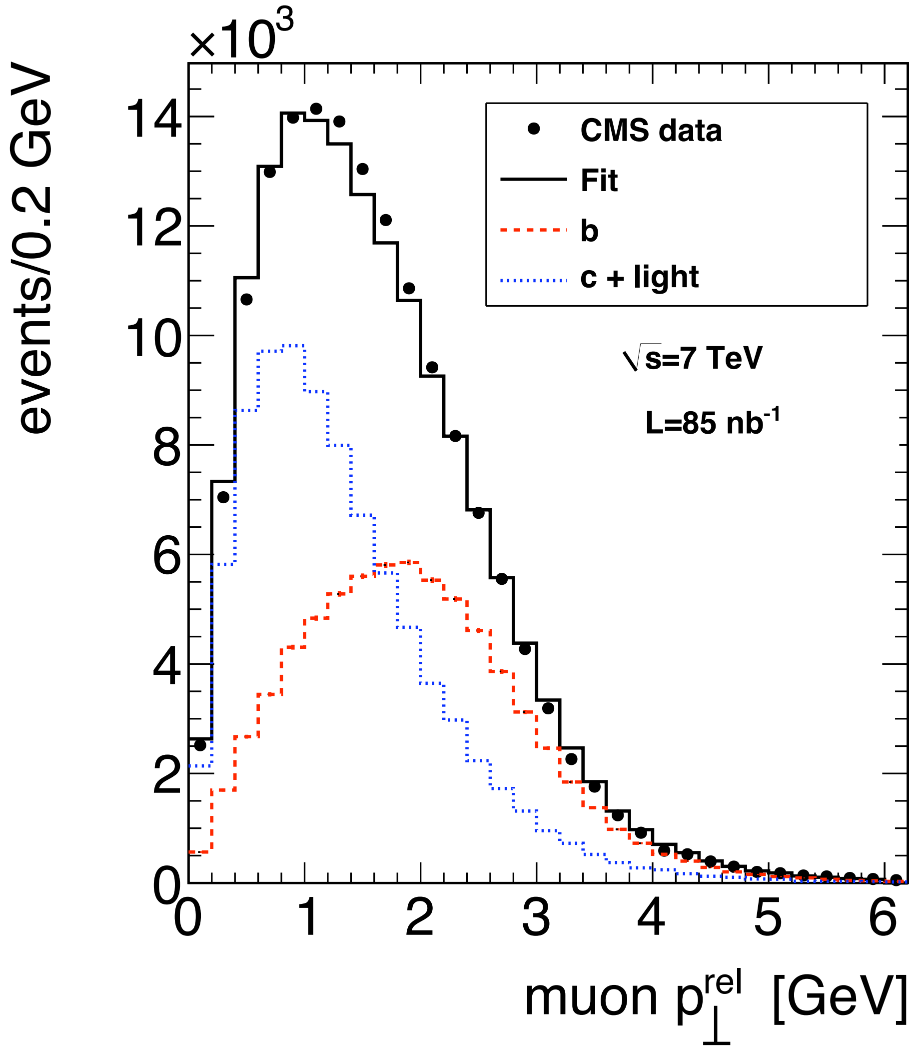
Total cross section

for 8<p_t<50 GeV and $|y^B|$ <2.4

$$\sigma = 6.9 \pm 0.6(stat) \pm 0.5(syst) \pm 0.3(lumi) \text{ nb}$$

$$MC@NLO = 4.57^{+1.93}_{-1.71} \pm 1.37 nb$$

Open beauty production cross section.



$$p_{\perp}^{\rm rel} = |\vec{p}_{\mu} \times \vec{p}_j| / |\vec{p}_j|$$

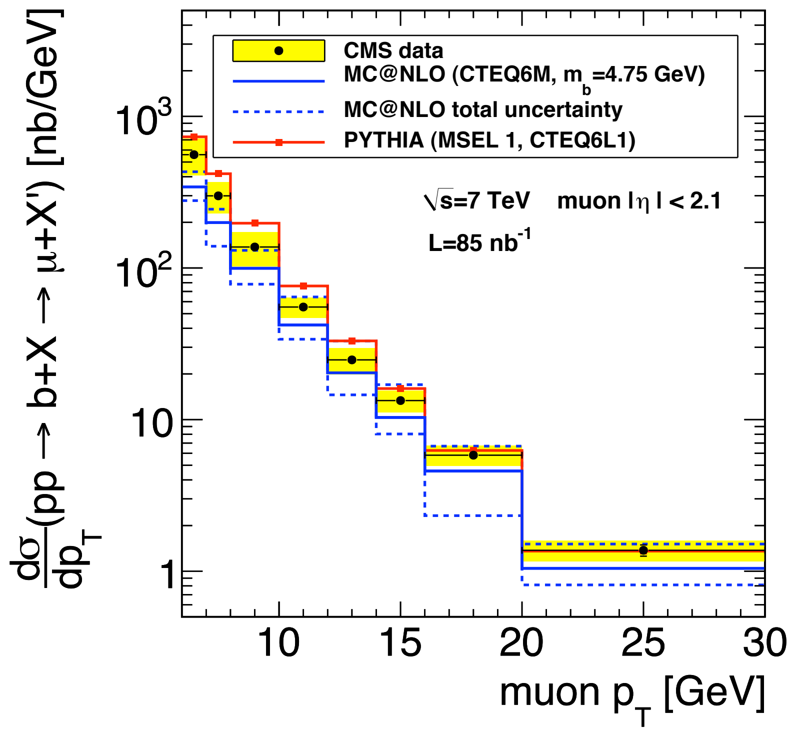
Global muon: combined fit of silicon and muon-chamber hits, belonging to the independent tracker and muon system.

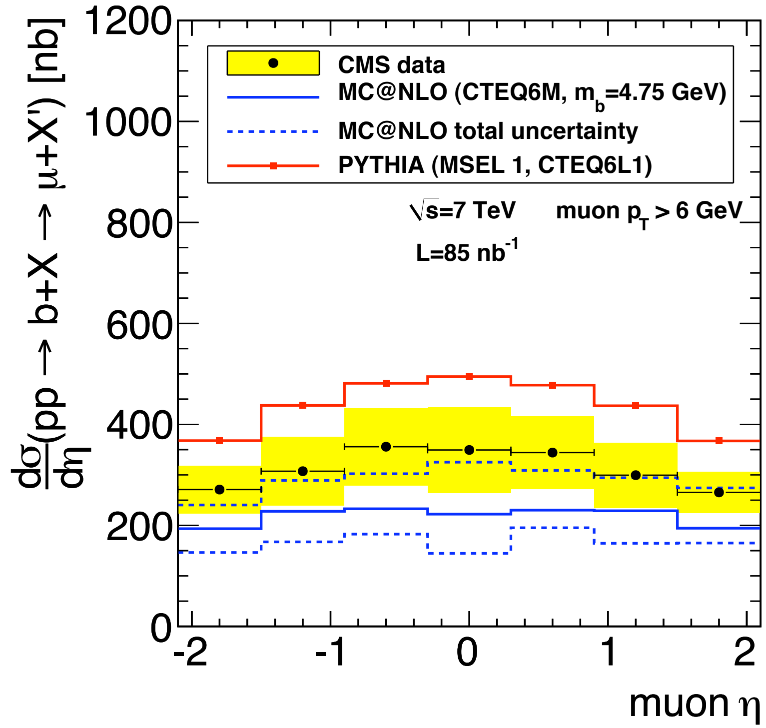
p_t>6 GeV/c

Distribution in data and results of the maximum likelihood fit.
The dashed red and blue lines: *b* and *cudsg*-templates

Differential Cross Section

Yellow bands- syst. and stat. uncertainties added in quadrature





$$\frac{d\sigma}{dp_\perp^\mu}(pp \rightarrow b+X \rightarrow \mu+X', |\eta^\mu| < 2.1) \qquad \frac{d\sigma}{d\eta^\mu}(pp \rightarrow b+X \rightarrow \mu+X', p_\perp^\mu > 6\,\mathrm{GeV})$$

Final Result:

$$\sigma(pp \rightarrow b+X \rightarrow \mu+X', p_\perp^\mu > 6\,\mathrm{GeV}, |\eta^\mu| < 2.1) = 1.32 \pm 0.01(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.15(\mathrm{lumi})\,\mu\mathrm{b}$$

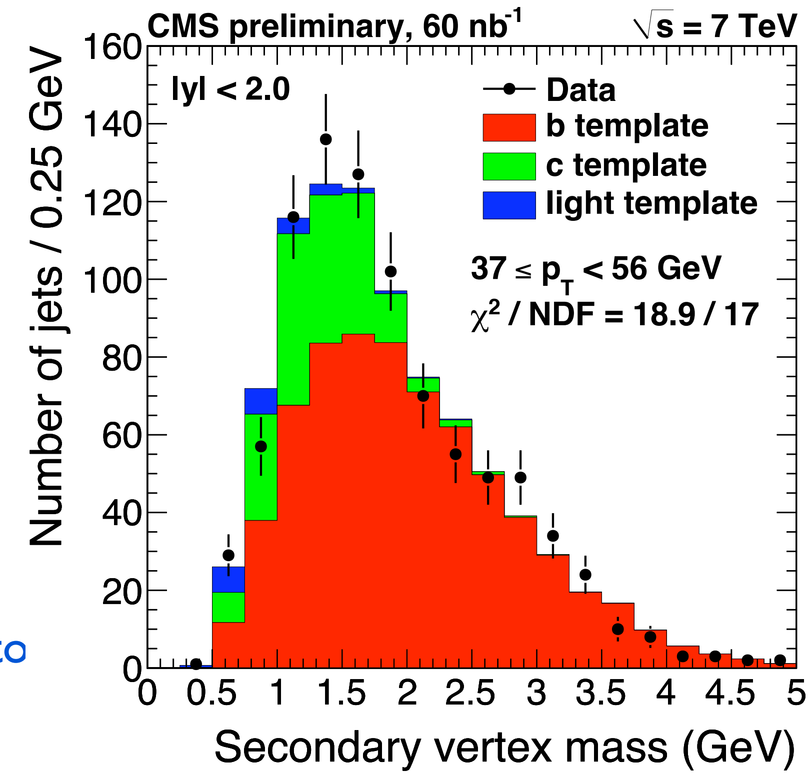
The observed shapes are reasonably well described by MC@NLO for muon p_t>12 GeV.

Low p_t- data is above the prediction.

Inclusive b-jet production in pp collisions at 7 TeV

b-tagging -
Based on secondary vertex (SV) reconstruction.
SV: has at least 3 tracks and a large flight length significance.
MC well reproduces the b-tagging observables.

b-tagged sample purity estimation



The production cross section:

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

N_{tagged} - number of tagged jets per bin;
Δp_t, ΔY bin widths;
f_b- fraction of tagged jets containing a b-hadron;
e_b- b-jet tagging efficiency;
e_{jet}-jet reconstruction efficiency;
C_{smear}-unfolding correction. Unfolds the measured p_t to particle level

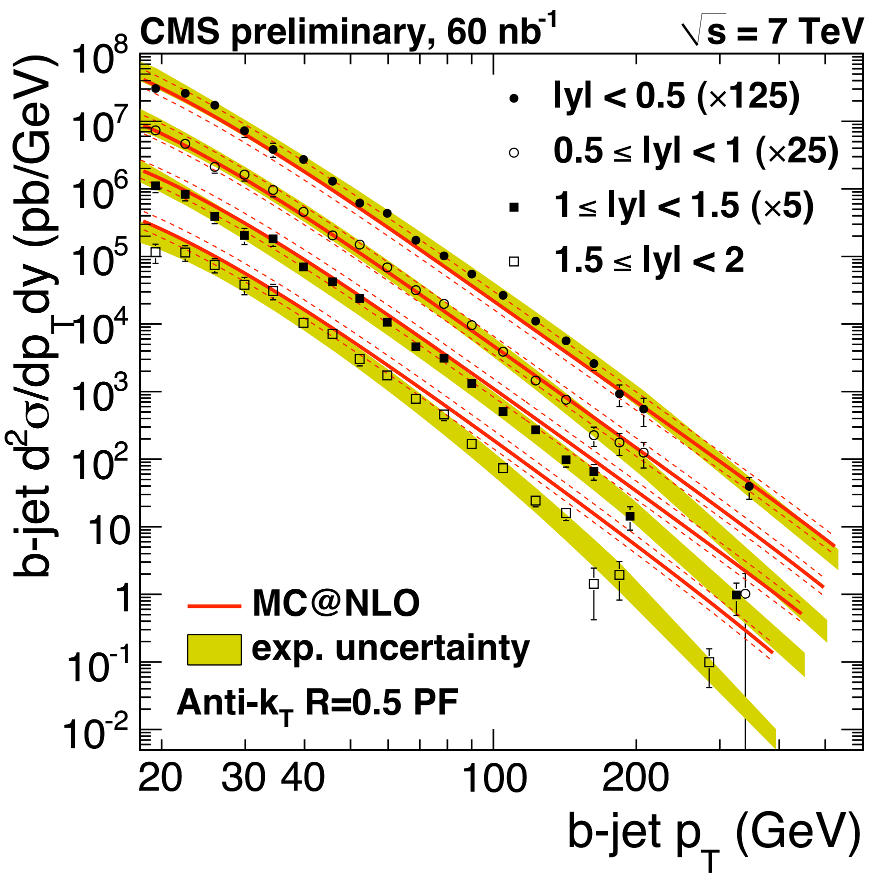
$$f_b = \frac{F_b\epsilon_b}{F_b\epsilon_b + F_c\epsilon_c + F_l\epsilon_l}$$

$e_{l,c}$- mistag rates for LF and Charm

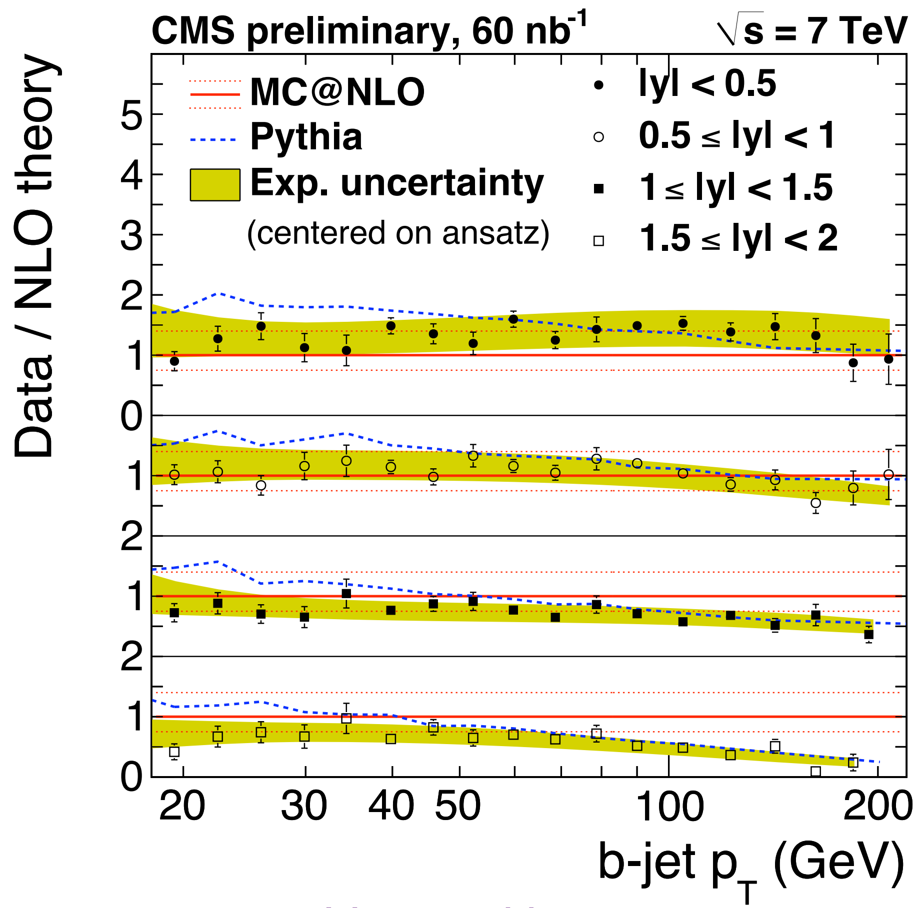
f_b=75%

F_b, F_c,F_l- relative fractions of jets

Results



Measured b-jet cross section compared to the MC@NLO (Overlayed)



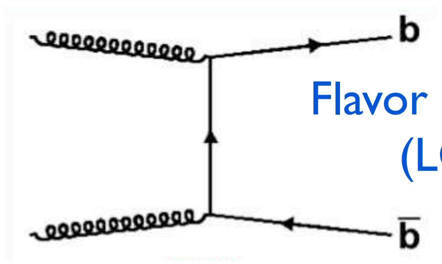
Measured b-jet cross section compared to the MC@NLO (As a ratio)

Good agreement between data and PYTHIA in the jet p_t-range $30<p_t<150$GeV, $|y|<2.0$, with 2% stat, 21% syst.

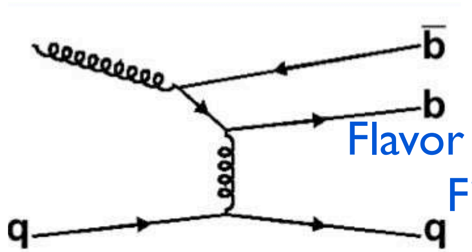
Reasonable agreement with MC@NLO calculation, and measured b-jet fraction, within 21% syst. Significant shape different in p_t and y.

BB(bar) angular correlations

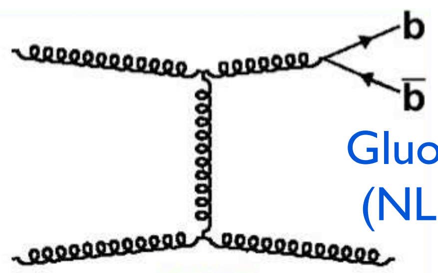
B-production:



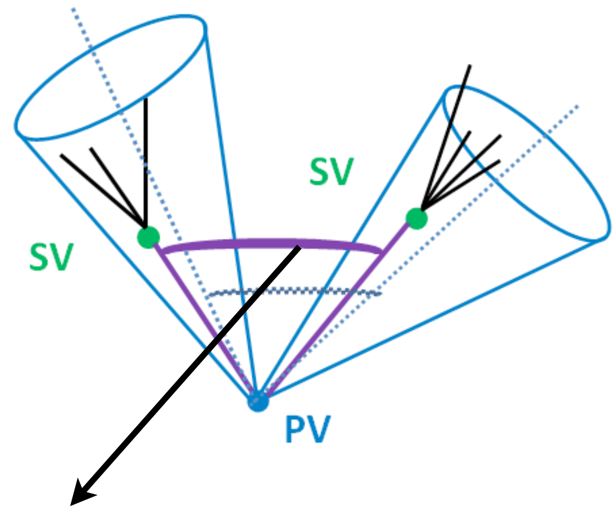
Flavor creation (FCR)
(LO process)



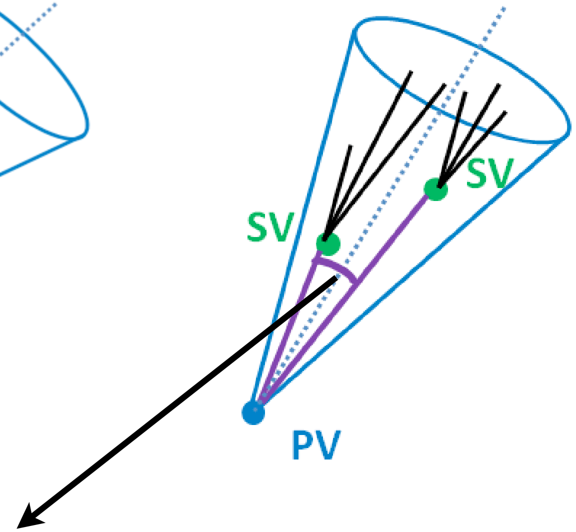
Flavor excitation (FEX)
First in NLO



Gluon splitting (GSP)
(NLO, small opening angles)



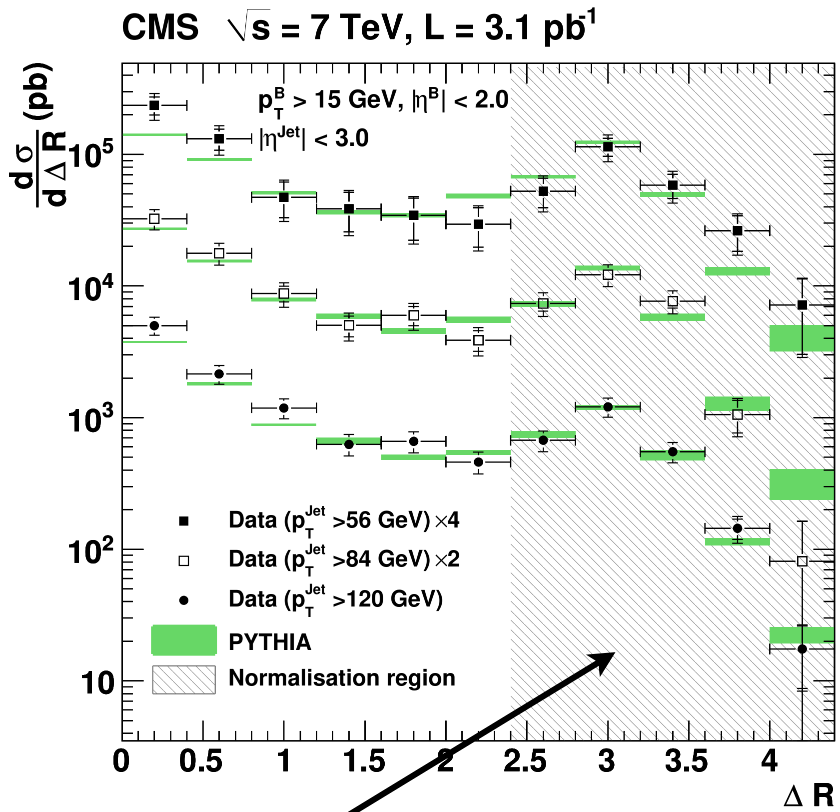
Large opening angle

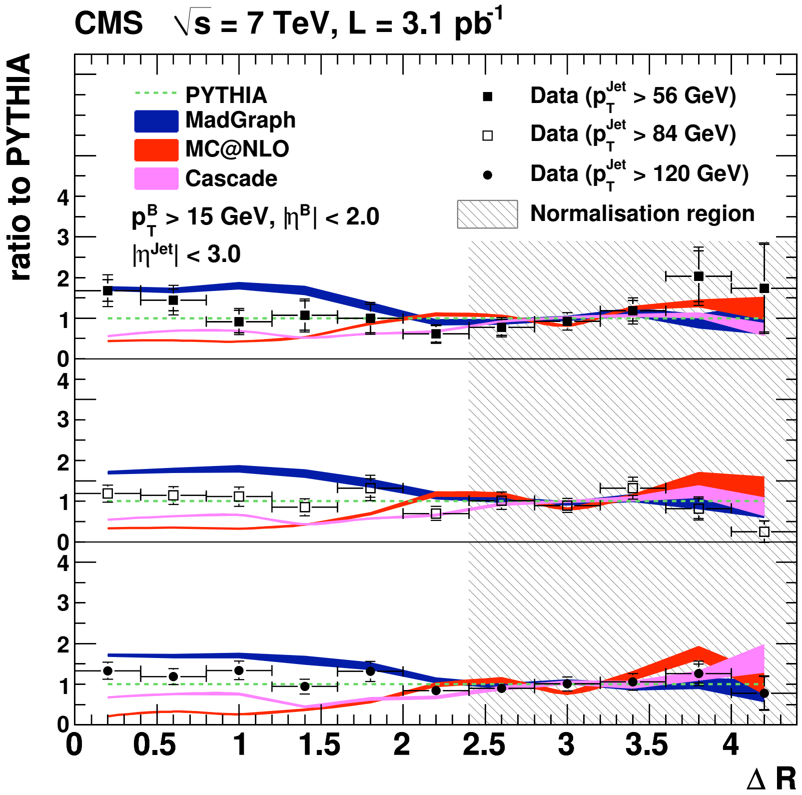


small opening angle
2B in one jet

Not possible to measure the small angles with jets;
using secondary vertices instead of jets

Differential cross section of BB(bar) pair production





Gluon splitting region

$\Delta R < 0.8$

Normalization region

$|\eta|<3$ for the leading jet

$p_t > 15$ for the leading jet

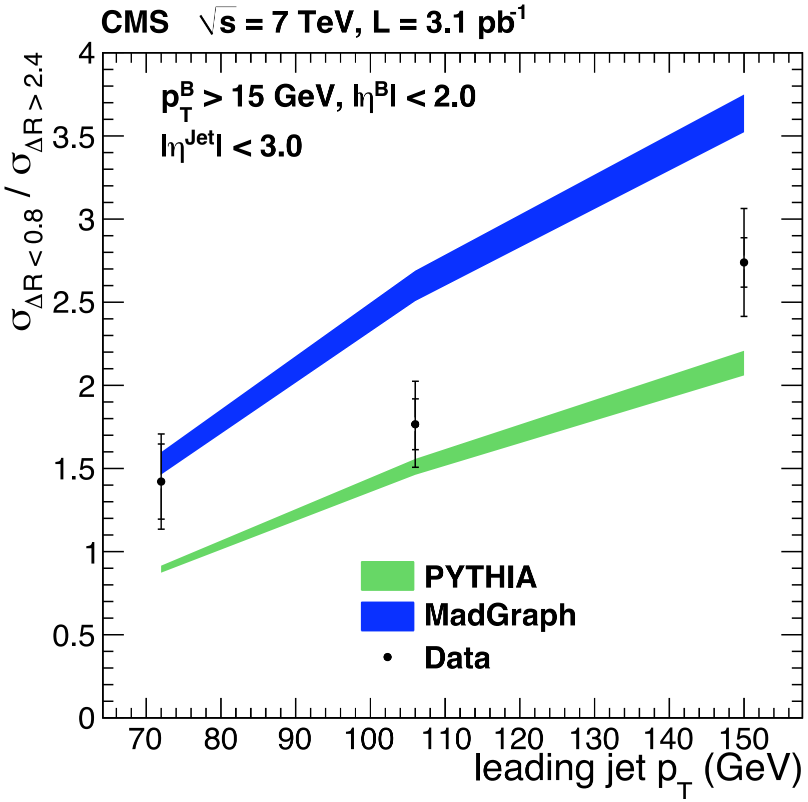
$|\eta| < 2$ for B hadrons

MC normalized to number of events with ΔR > 2.4 or $\Delta\varphi$ > 2.4 (FCR region)

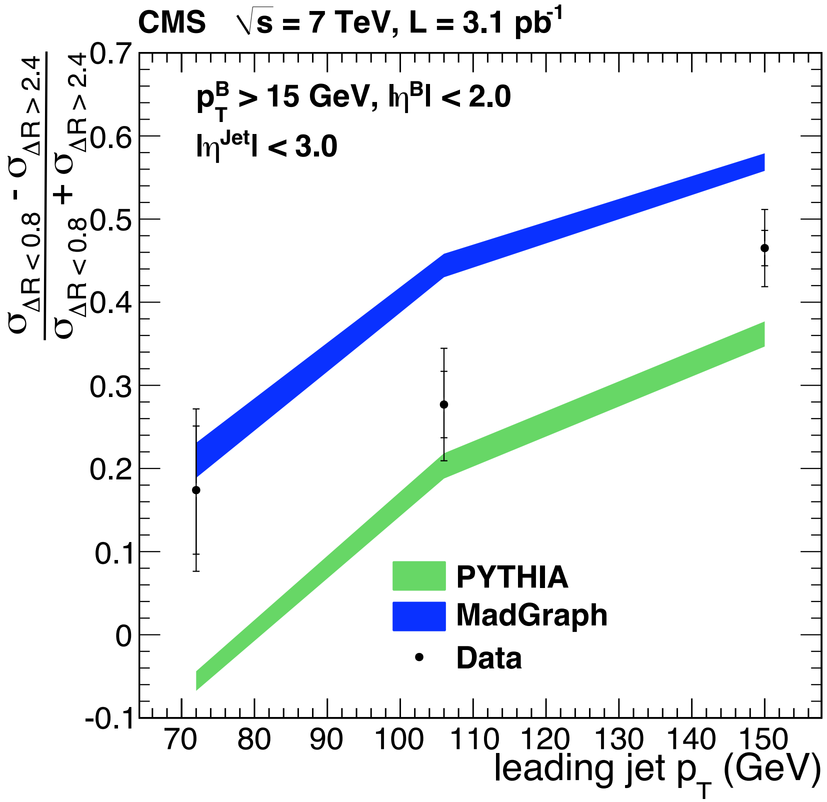
Comparison to perturbative QCD predictions at LO and NLO.

Results

Ratio GSP/FCR



Asymmetry

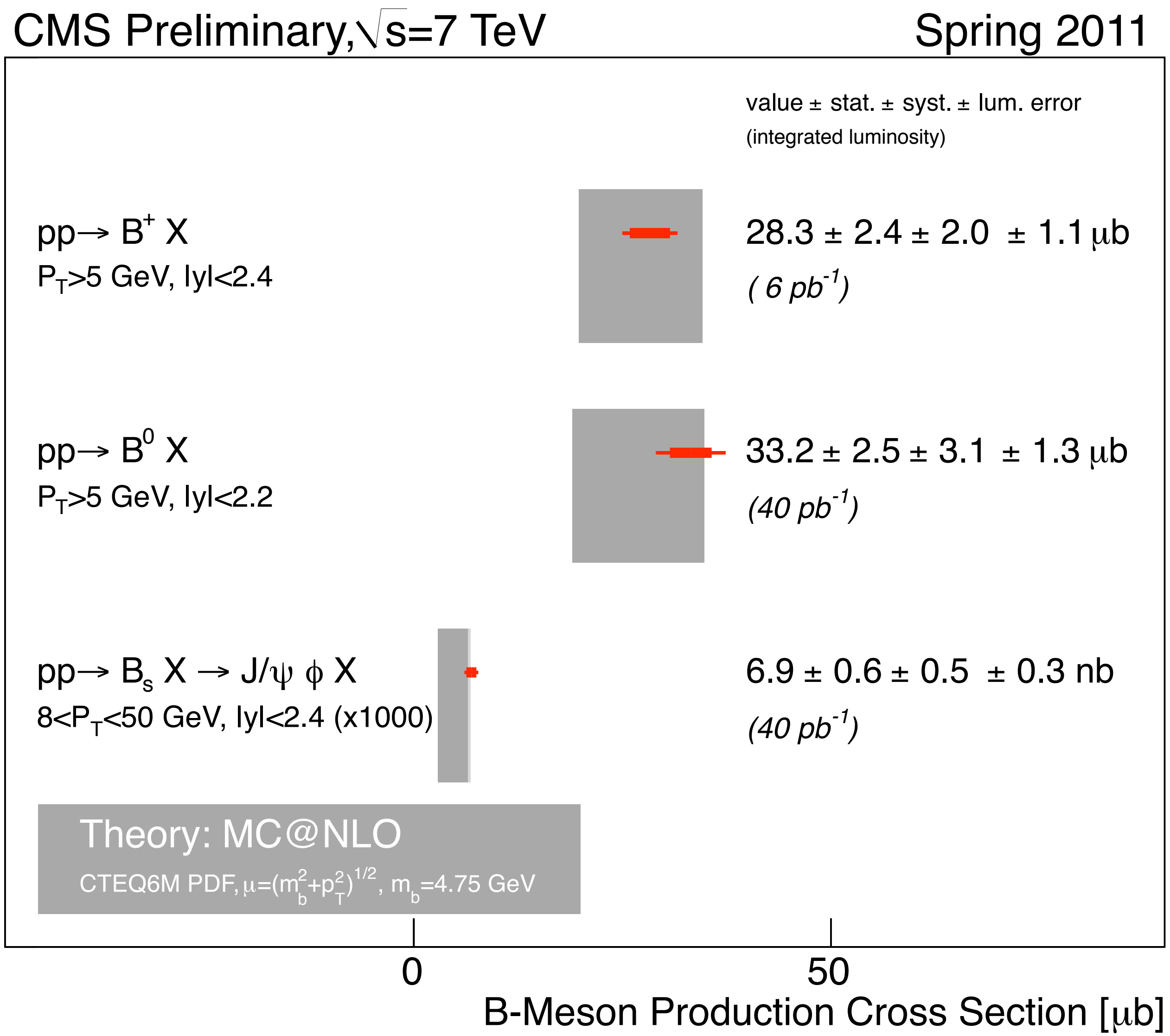


Comparison to PYTHIA and MadGraph results.

Fraction of collinear BB(bar) pairs increases with energy scale.

Conclusions (1)

1. B-Meson Production Cross Section



Conclusions (II)

2. Open beauty production:

$$\sigma(pp \to b + X \to \mu + X', p_\perp^\mu > 6\,\text{GeV}, |\eta^\mu| < 2.1) = (1.48 \pm 0.04_{\text{stat}} \pm 0.22_{\text{syst}} \pm 0.16_{\text{lumi}})\ \mu\text{b}$$

3. Inclusive b-jet production:

   Good agreement between data and PYTHIA in the jet p_t-range $30<p_t<150$GeV, $|y|<2.0$, with 2% stat, 21% syst.

   Reasonable agreement with MC@NLO calculation. and measured b-jet fraction, within 21% syst. Significant shape different in p_t and y.

4. BB(bar) angular correlations

   Usage of the new technique independent of the jet reconstruction.

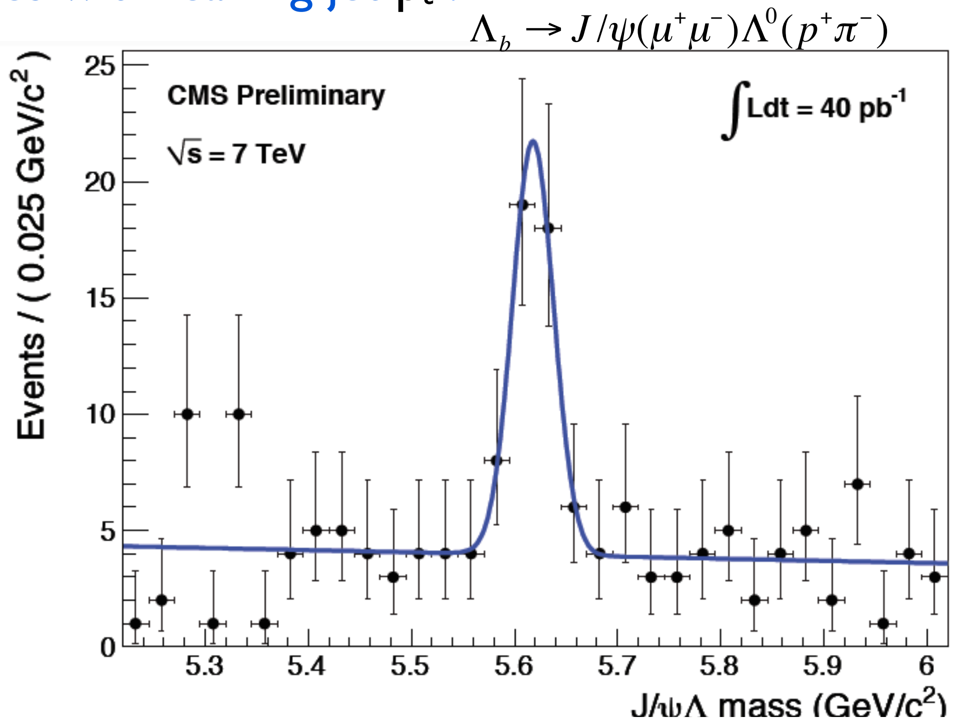
   Production of collinear BB(bar) increases with leading jet p_t .

5. Coming results:

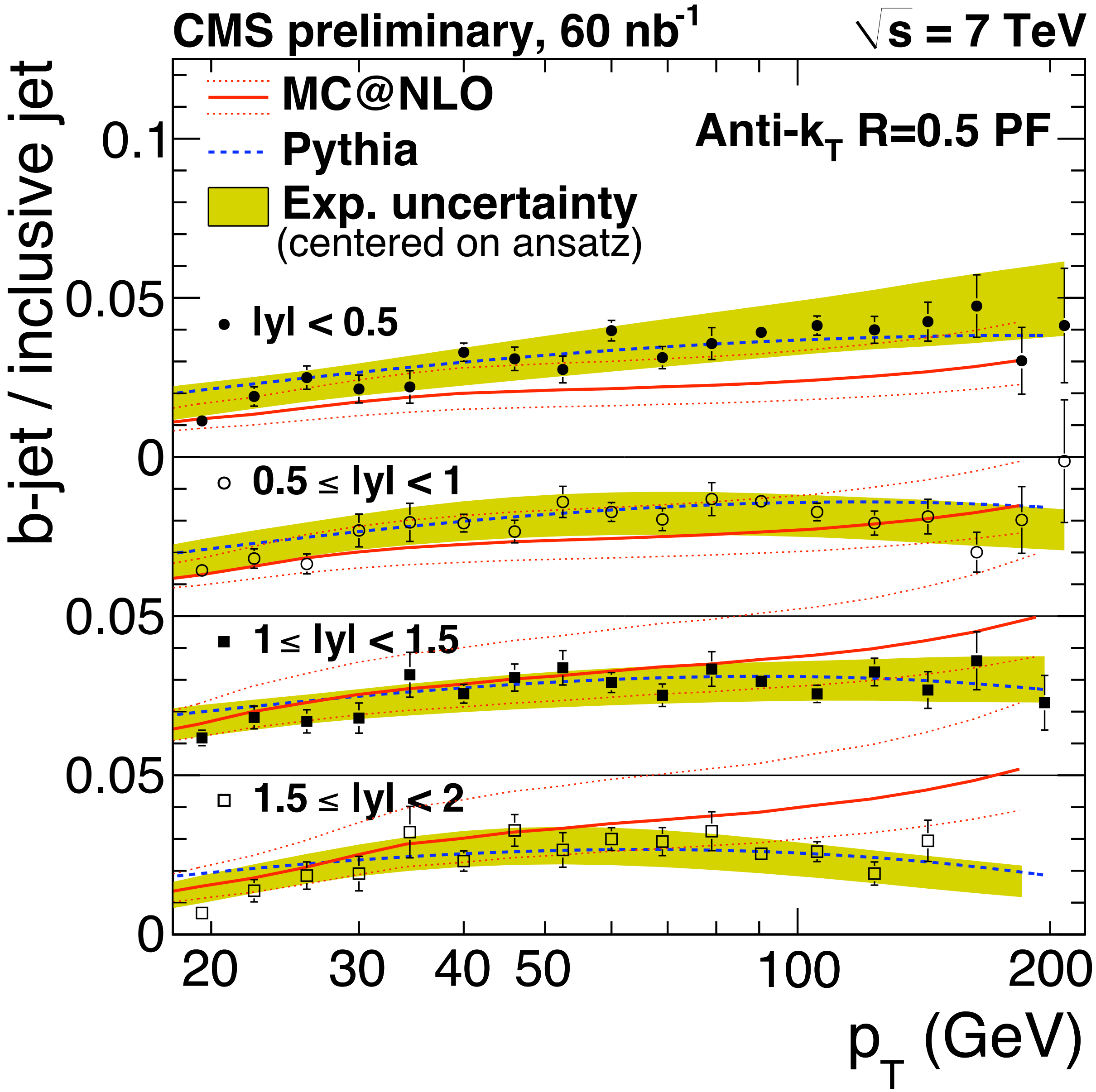
   Searches for $B_s \to \mu^+\mu^-$

   Λ_b production cross section

   more results on rare decays, CP violation and baryon cross sections in preparation.

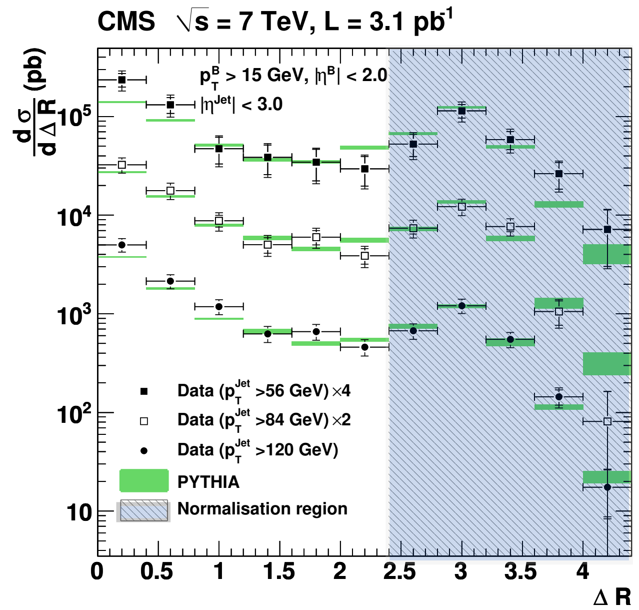


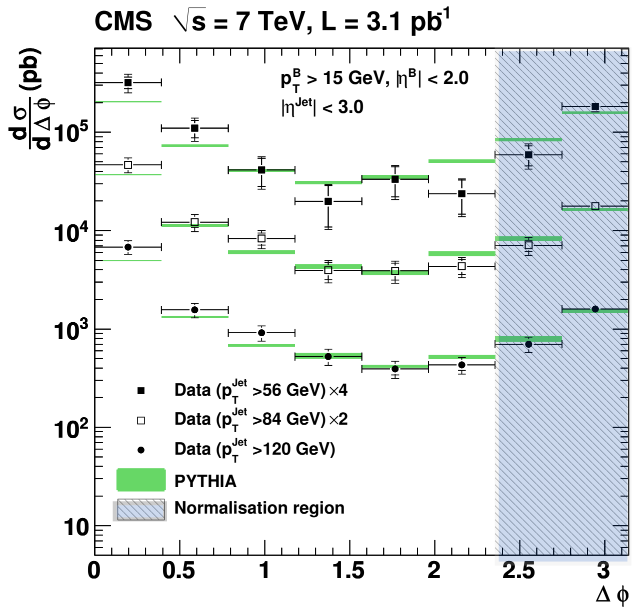
Backup SLIDES



Measured b-jet cross section
as a ratio to inclusive jet cross section.

Differential cross section of BB(bar) pair production





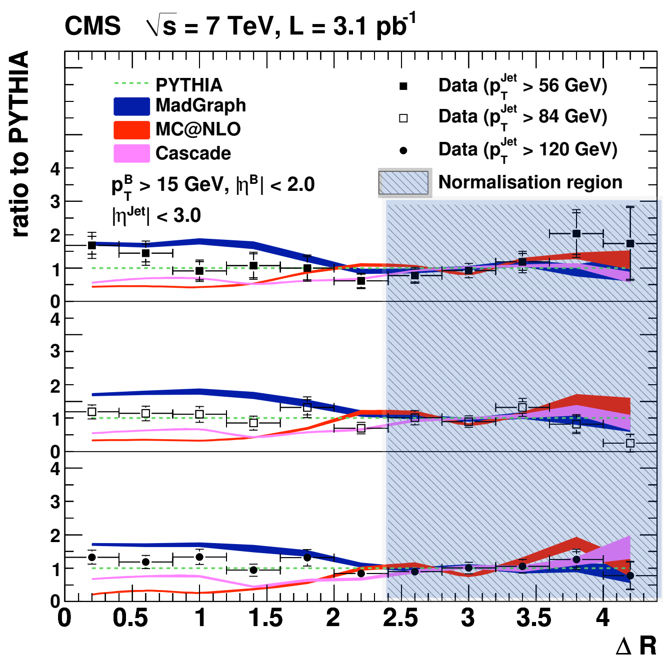
Gluon splitting region

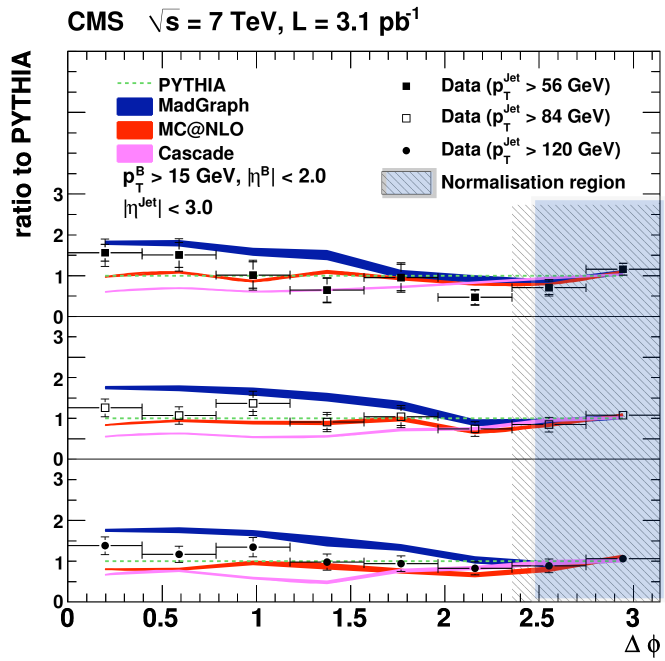
$\Delta R < 0.8$

Flavor creation region

$\Delta R > 2.4$

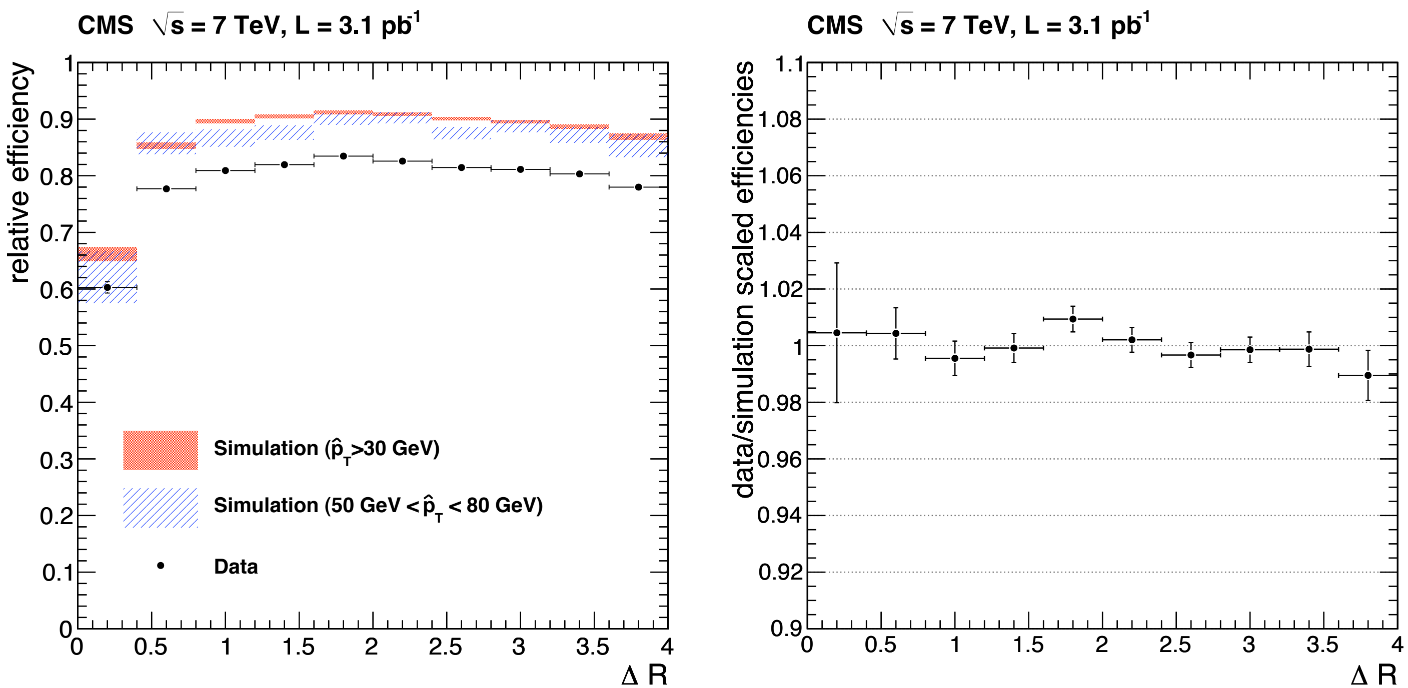
Data/MC ratio



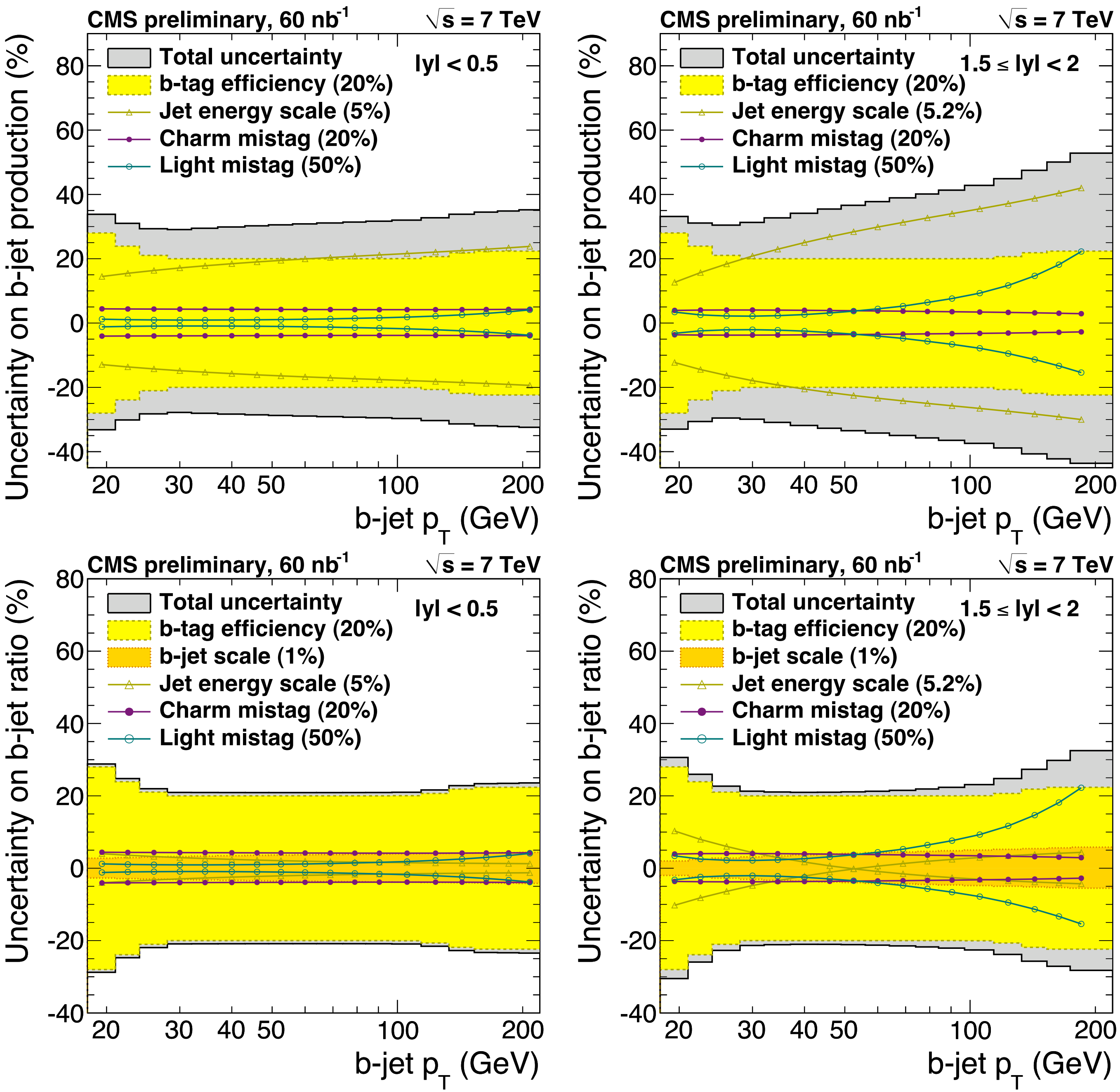


Systematic uncertainties

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



Leading sources of systematic uncertainties for b-jet cross section measurement.



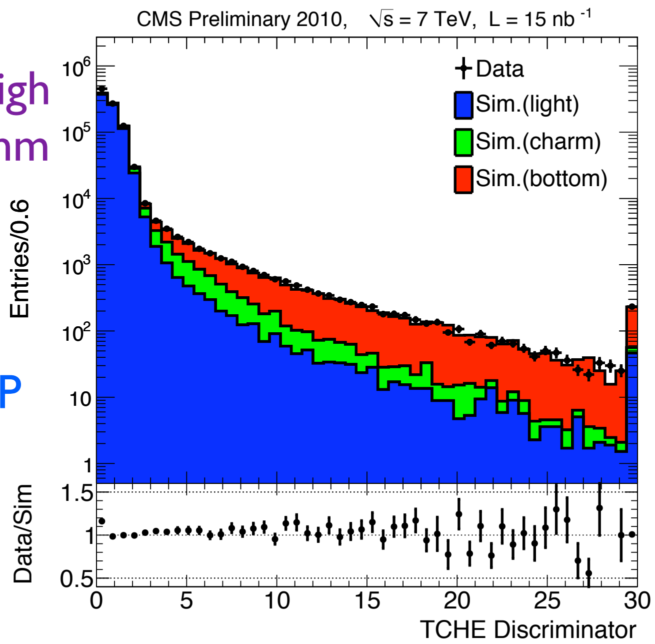
Commissioning of b-jet Identification at 7TeV.

(CMS PAS BTV-10-001)

Tagging discriminators. Comparing data and MC (I)

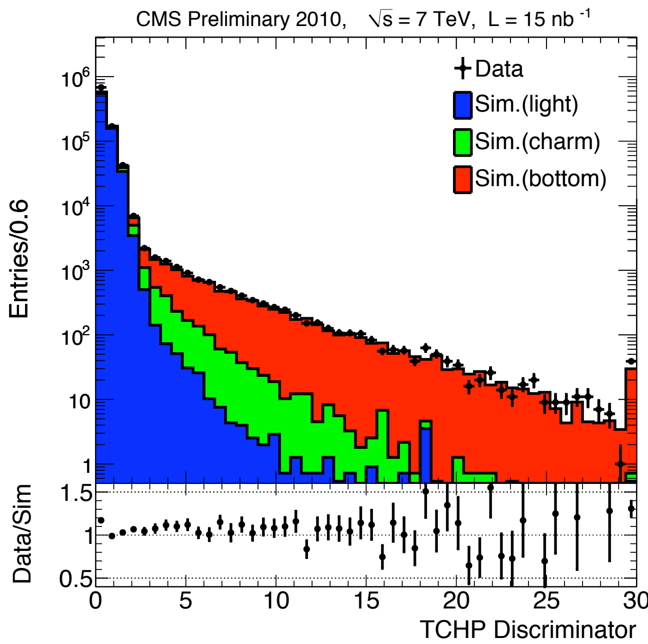
Track counting high efficiency algorithm

Using 2nd track IP significance



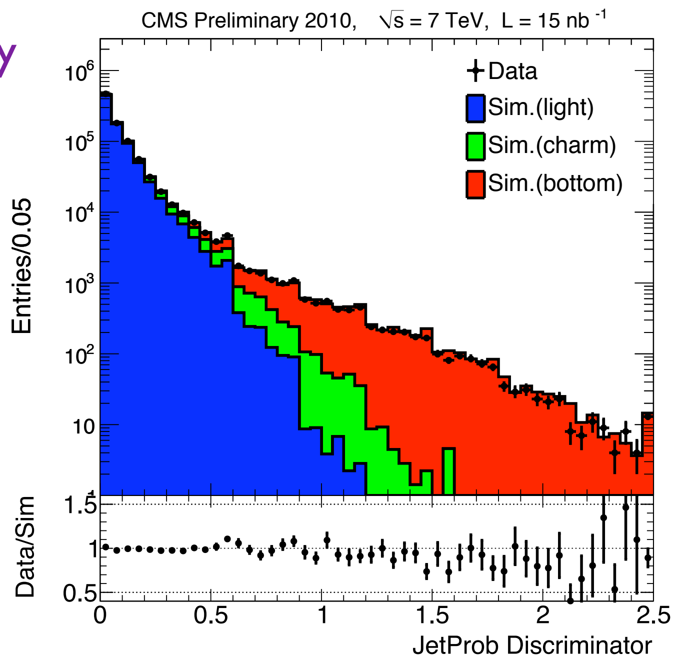
Track counting high purity algorithm

Using 3d track IP significance



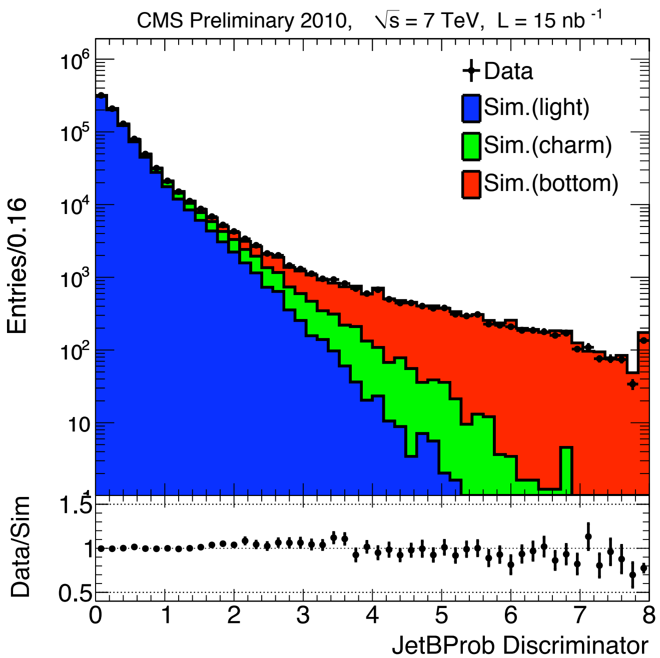
Jet probability

All tracks



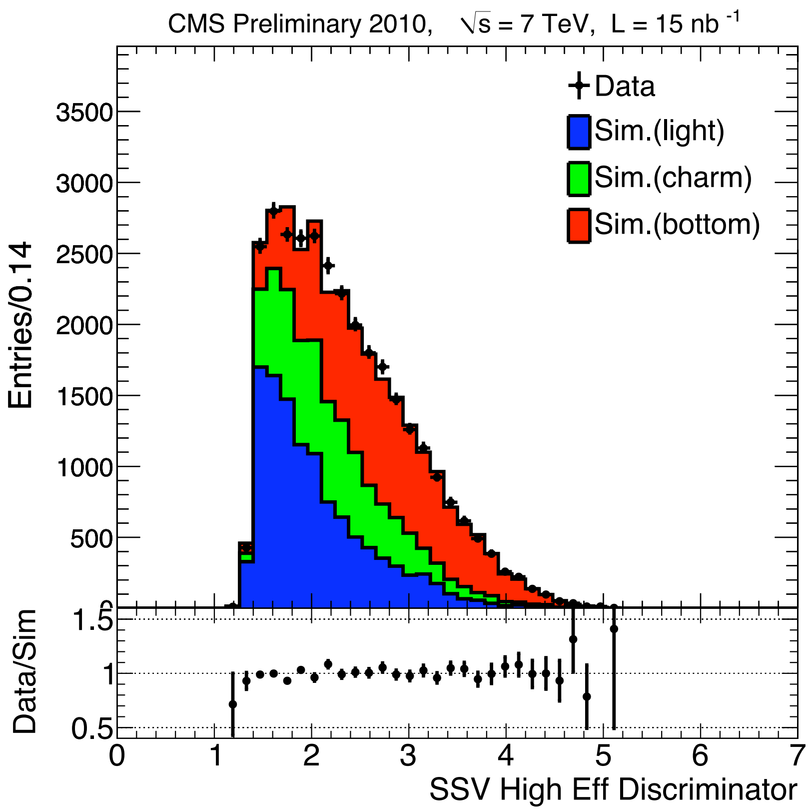
Jet B probability

Four most displaced tracks



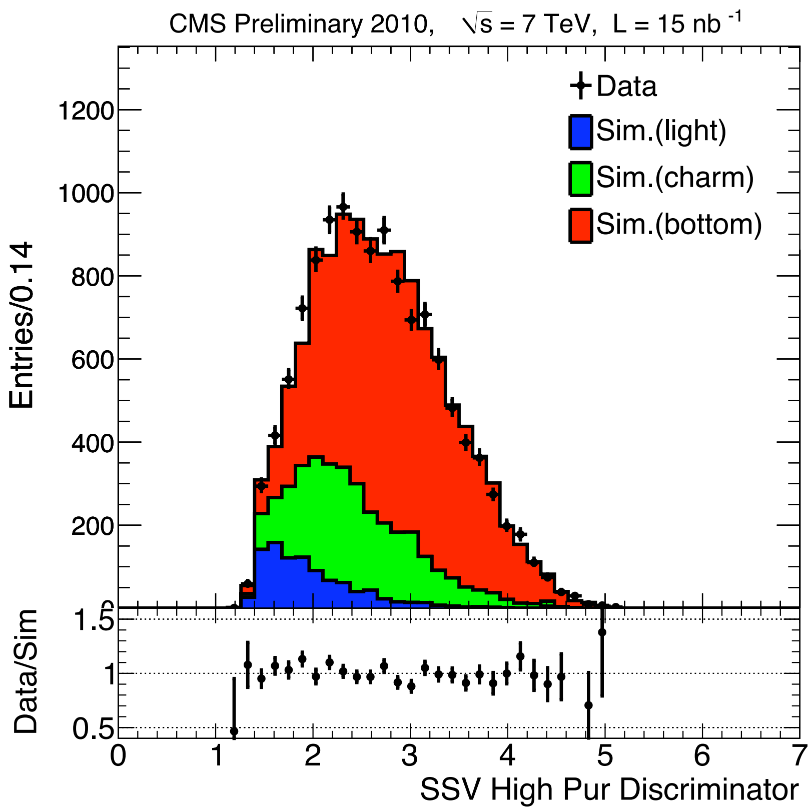
Tagging discriminators. Comparing data and MC (II)

Simple Secondary vertex high efficiency



Minimum number of tracks attached to the vertex $N_{trk} \geq 2$

Simple Secondary vertex high purity



Minimum number of tracks attached to the vertex $N_{trk} \geq 3$

Good agreement between data and MC for all the discriminators!

Estimation of the b-tagging efficiency (I)

Relative momentum of muon wrt. the jet (p_t^{rel}) is sensitive to B decays because of high B mass.

Use p_t^{rel} shape to fit fractions (f_b) of b and light+c jets in tagged and anti-tagged jets.

Efficiency calculation:

$$\epsilon_b^{\mathrm{data}} = \frac{f_b^{\mathrm{tag}} \cdot N_{data}^{\mathrm{tag}}}{f_b^{\mathrm{tag}} \cdot N_{data}^{\mathrm{tag}} + f_b^{\mathrm{untag}} \cdot N_{data}^{\mathrm{untag}}}$$

f_b^{tag}, f_b^{untag}-fractions of b jets in the data,
N_{data}^{tag} , N_{data}^{untag} - total yields of tagged and untagged jets.

Event Selection:

p_t> 20 GeV

Muon Selection:

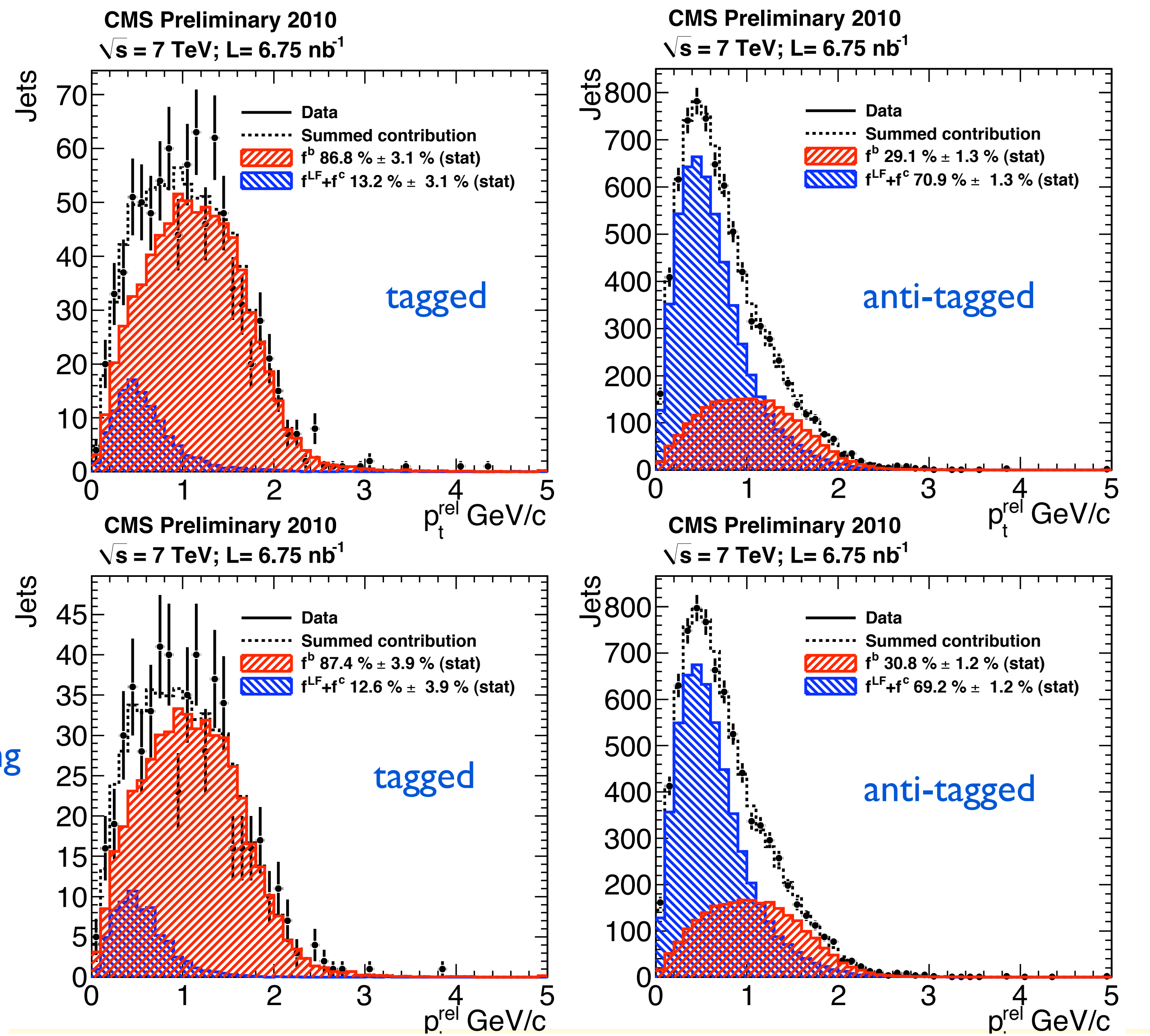
Global muon: combined fit of silicon and muon-chamber hits, belonging to the independent tracker and muon system.

p_t>5 GeV and | η |<2.4
$\chi^2 < 10$ for the global track
"high purity" track category
≥ 2 pixel hits and ≥ 12 total hits
expected tracker outer hits < 3

Estimation of the b-tagging efficiency (II)

TCHPM
M- medium
operating point

SSVHPT
T-tight operating
point



Algorithms for the b-jet identification:

1. The "track counting" (TC) approach. Jet is a b-jet if it contains at least N tracks with significance of impact parameter (IP) exceeding S. N=2- TC High Efficiency E; N=3-TC High Purity.
Discriminator: Value S for the Nth track.

2. SSV- based on the reconstruction of at least 1 SV. N_{trk}>=2-"high efficiency" SSVHE, N_{trk} >=3-"high purity" SSVHP.
Discriminator: A monotonic function of the three dimensional flight distance.

3. The jet probability algorithms. Each track is assigned a probability (P_{tr}) to originate at the PV.
Discriminator: built from the set of P_{tr} in the jet

4. Lepton-based tagging algorithms identify b hadrons via their semileptonic decay.
Discriminator: achieved on p_t of the lepton, the IP of the lepton or both.

operating points:

"loose" (L) contamination of light partons: 10%
"medium" (M) contamination of light partons: 1%
"tight" (T) contamination of light partons: 0.1%

Event Selection:

jet p_t > 30 GeV;
$|\eta|<2.4$;

Charged Particle Track quality requirements:

- number of pixel hits ≥ 2
- total number of silicon (pixel + strip) hits ≥ 8
- $\chi^2/ndof$ of the track fit < 5.0
- transverse momentum $p_T > 1.0\,\mathrm{GeV}/c$
- unsigned transverse impact parameter $d_{xy} < 0.2\,\mathrm{cm}$
- unsigned longitudinal impact parameter $d_z < 17\,\mathrm{cm}$
- distance of closest approach to the jet axis < 0.07 cm;
- decay length < 5 cm.