Measurement of inclusive b-quark production at $\sqrt{s}$ =7 TeV with the CMS experiment

DPF 2011

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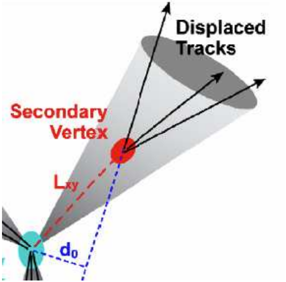
- Cross sections from:
  - Correlated $b\bar{b}$ with dimuons
  - Single muons
  - Inclusive b-jet
- $B\overline{B}$ angular correlations

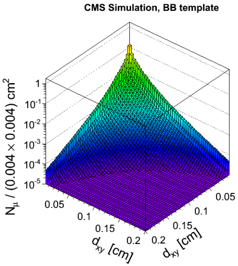
Correlated $b\overline{b}$ cross section with dimuons

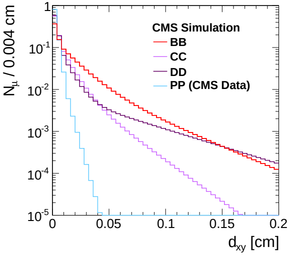
- Cross section for $b\overline{b}$ production from both b quarks decaying into muons
- $\mathcal{L} = 28\ pb^{-1}$ @ $\sqrt{s} = 7$ TeV
- Flavor composition of the dimuon sample in data $\rightarrow$ fit to the muon transverse impact parameters with respect to primary vertex (d_{xy})
- Both muons need to satisfy: $p_T^{\mu} > 4$ GeV and $|\eta^{\mu}| < 2.1$ and from same PV
- Cuts on $M_{\mu\mu}$ remove backgrounds from Z ($M_{\mu\mu} > 70$ GeV), Υ ($8.9 < M_{\mu\mu} < 10.6$ GeV), charmonium resonances and sequential decays ($M_{\mu\mu} < 5$ GeV)



Correlated $b\bar{b}$ cross section with dimuons

- Single muon events in MC are classified as:
  - **B**: $b \rightarrow \mu$
  - **C**: $c \rightarrow \mu$
  - **P**: prompt tracks or fakes
  - **D**: meson decay in flight
- Impact parameter distribution for **B**, **C** and **D** from simulation. Distribution for **P** extracted from data: $\Upsilon(1s)$ decays
- Dimuon templates (**BB**,**CC**,**PP**,**DD**) and combinations (**BD**, **BC**, **CD**...)
- Binned maximum likelihood fit using the 2D distributions





Correlated $b\bar{b}$ cross section with dimuons: **results**

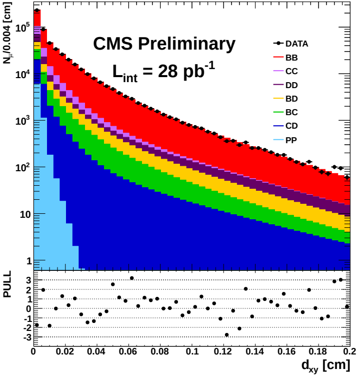
- CMS-PAS-BPH-10-015

$$\sigma(pp \to b\bar{b}X \to \mu\mu Y) = 26.18 \pm 0.14(\mathrm{stat.}) \pm 2.82(\mathrm{syst.}) \pm 1.05(\mathrm{lumi.})\ \mathrm{nb}$$

$$\sigma_{\mathrm{PYTHIA}} = 48.2\ \mathrm{nb}$$

$$\sigma_{\mathrm{MC@NLO}} = 19.95 \pm 0.46(\mathrm{stat.})\ ^{+4.68}_{-4.33}(\mathrm{scale{+}pdf{+}m}_b)\ \mathrm{nb}$$

- Fraction of **BB** from fit: 65%
- **BP**, **CP** and **PD** can be neglected
- Constraints: **BC/BB**, **BD/BB** and **CD/CC** from MC
- Largest systematic uncertainty from trigger efficiency ($\approx 8.3\%$)

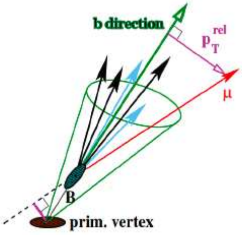


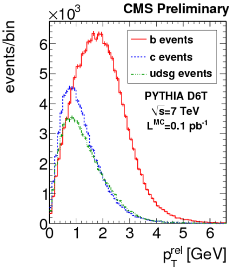
Open beauty production with muons

- $\mathcal{L} = 85\ \mathrm{nb}^{-1}$ @ $\sqrt{s} = 7$ TeV
- Signal events discriminated using muon transverse momentum relative to the jet direction p_T^{rel}:

$$p_T^{\mathrm{rel}} = \frac{|\vec{p}_\mu \times \vec{p}_{\mathrm{jet}}|}{|\vec{p}_{\mathrm{jet}}|}$$

- p_T^{rel} is harder in b-events than in background due to larger mass of b-quark
- Binned maximum likelihood fit to measure p_T^{rel} distribution based on templates

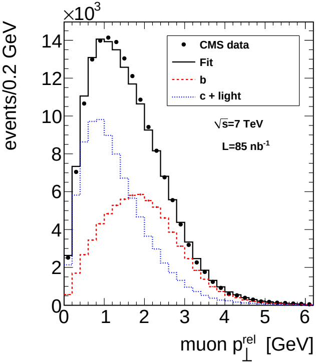




Open Beauty production with muons

- $p_T^{\mu} > 6$ GeV and $|\eta^{\mu}| < 2.1$
- μ IP requirement: $|d_0| < 2$ mm, $|d_z| < 1$ cm
- Track Jets:
  - Determine $\vec{p}_{\rm jet}/|\vec{p}_{\rm jet}|$
  - Tracks with $p_T > 300$ MeV, anti-k_T with $R = 0.5$, $E_T^{\rm jet} > 1$ GeV (without muon)

- Shape of the light quark/gluon component is evaluated from minimum bias data $\rightarrow$ misidentification probability for hadrons to be selected as muons
- Templates for c and light quark/gluon events are combined
- b fraction from the fit$= 46\%$



Open Beauty production with muons: **results**

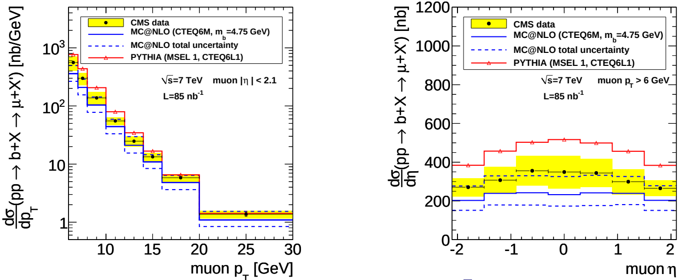
- JHEP 03 (2011) 090

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

$$\sigma_{\text{PYTHIA}} = 1.9\ \mu\text{b}$$

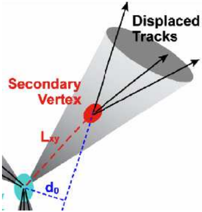
$$\sigma_{\text{MC@NLO}} = 0.95^{+0.41}_{-0.21}(\text{scale}) \pm 0.09(m_b) \pm 0.05(\text{pdf})\ \mu\text{b}$$

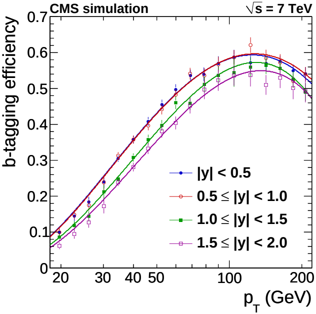
- Major systematic uncertainties are b p_T^{rel} shape uncertainty (21%) and luminosity (11%)
- Data and MC@NLO compatible within uncertainties



Inclusive b-jet production

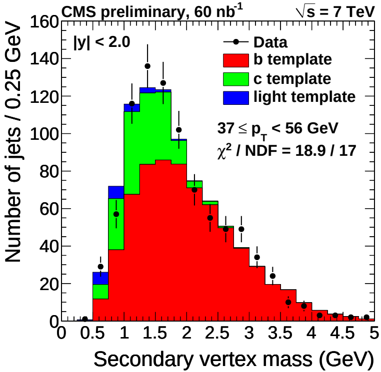
- $\mathcal{L} = 60\ \mathrm{nb}^{-1}$ @ $\sqrt{s} = 7$ TeV
- Minimum bias and jet triggers
- Particle flow jets. Jet reconstruction using anti-k_T algorithm, with $R = 0.5$
- Jet required to have: $18 < p_T^{\mathrm{jet}} < 300$ GeV and rapidity $|y| < 2$
- b jets identified using a secondary vertex tagger:
  - Secondary vertex fitted with at least 3 charged particle tracks
  - 3D decay length significance cut is applied

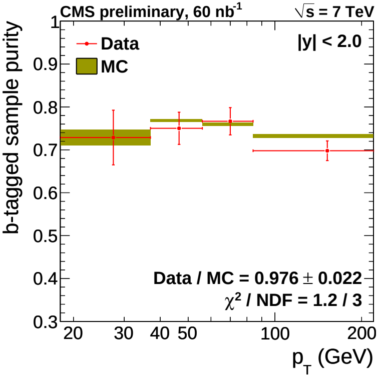




Inclusive b-jet production

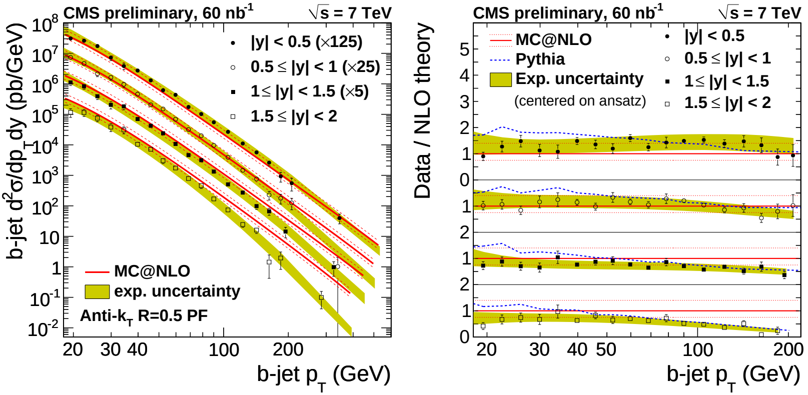
- b-tagging efficiency as a function of $p_T^{\rm jet}$ and $y^{\rm jet}$ is from MC $\rightarrow$ verified in a subsample using data/MC scale factors based on $p_T^{\rm rel}$
- b-content (purity) in selected jets is estimated in data by fitting the secondary vertex mass distribution after the selection





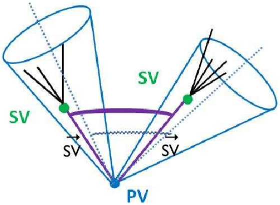
Inclusive *b*-jet production: **results**

- CMS-PAS-BPH-10-009
- MC@NLO describes well the overall fraction of *b*-jets, but shape differences in $p_T^{\rm jet}$ and $y^{\rm jet}$
- Main systematic uncertainties from *b*-tag efficiency (20%), jet energy scale (5%) and luminosity (11%)



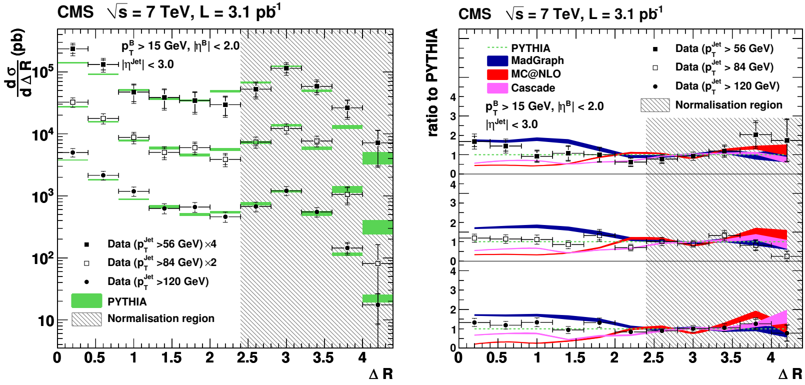
$B\overline{B}$ angular correlations

- $\mathcal{L} = 3.1\ \text{pb}^{-1}$ at $\sqrt{s} = 7$ TeV
- Use single jet triggers: jet only used to set the energy scale
- Measure $\Delta\phi$ and $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ between flight directions of the two B-hadrons
- Secondary vertices (SV) reconstructed using an inclusive vertex finder (jet independent): SV reconstructed even if the two B-hadrons are in the same jet



$B\overline{B}$ angular correlations: **results**

- JHEP03 (2011) 136
- Differential production cross section in bins of opening angle of $B\overline{B}$ pairs
- MC@NLO does not describe the data well, particularly at low ΔR, where large gluon splitting contribution is dominant



Conclusions

- Inclusive b-quark production at $\sqrt{s} = 7$ TeV has been measured:
  - Correlated $b\bar{b}$ production with dimuons
  - Open Beauty production with muons
  - Inclusive b-jet production
- Inclusive measurements are in overall agreement with MC@NLO
- MC@NLO does not describe data well at low $B\overline{B}$ opening angles (gluon splitting)

Backup slides

Correlated $b\overline{b}$ cross section with dimuons

- 2D symmetrized distributions populated according to:

$$T_{12,ij} = \frac{S_{1,i} \cdot S_{2,j} + S_{1,j} \cdot S_{2,i}}{2}$$

- Real data events fill the $T_{12,ij}$ distribution by assigning the muon inn random order

Correlated $b\overline{b}$ cross section with dimuons

- Efficiencies: $\varepsilon_i = \varepsilon_{i,MuSel} \cdot \varepsilon_{i\ ,EvSel} \cdot \varepsilon_{i,Trg}$
  - ε_i=44.3 $\pm$ 0.1%
  - $\varepsilon_{i,MuSel} = 64.8 \pm 0.1\%$
  - $\varepsilon_{i,EvSel} = 78.0 \pm 0.1\%$
  - $\varepsilon_{i,Trg} = 87.7 \pm 0.1\%$
- Scaling factors obtained by Tag-and-Probe (J/ψ)
  - $SF^{Global}_{TP,Data} = 1.082 \pm 0.082$
- $\varepsilon = \varepsilon_{MC} \cdot SF^{Global}_{TP,Data} = 47.9 \pm 0.1\%$

Correlated $b\overline{b}$ cross section with dimuons

- MC@NLO+Herwig
  - CTEQ6.6 PDF, $m_b = 4.75$ GeV
- PYTHIA 6.4
  - Z2 tune, CTEQ6L1 structure function
- Systematic error on MC@NLO: $m_b = [4.5, 5]$ GeV, PDF $\rightarrow$ MSTW2008, renormalization:
- Small error on the scale+pdf seems to come from requiring both the 2 muons with low p_T

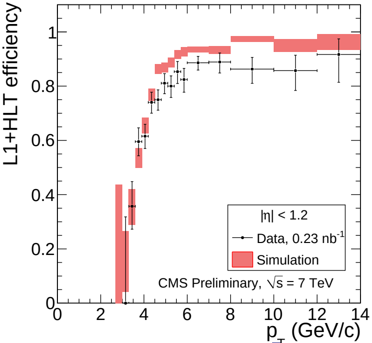
Correlated $b\overline{b}$ cross section with dimuons

- Systematic errors:
  - Template shapes 5.1%
  - Fit Method 4.7%
  - Efficiencies and normalization 8.3%
  - $\mathcal{L}$ 4%
  - Total 11.4%

Open Beauty production with muons: efficiency measurement ε

$$\varepsilon = \varepsilon_{\text{trigger}} \cdot \varepsilon_{\mu,\text{reco}} \cdot \varepsilon_{\mu,\text{jet}}$$

- $\varepsilon_{\text{trigger}} = (88 \pm 5)$ % from data
- $\varepsilon_{\mu,\text{reco}} = (94 \pm 3)$ % from MC
- $\varepsilon_{\mu,\text{jet}} = (77 \pm 8)$ % from MC

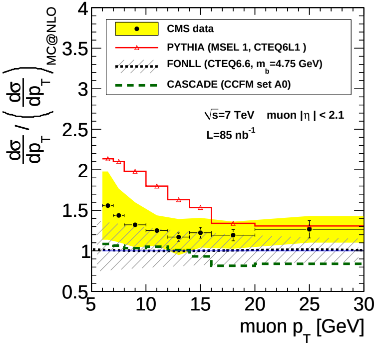


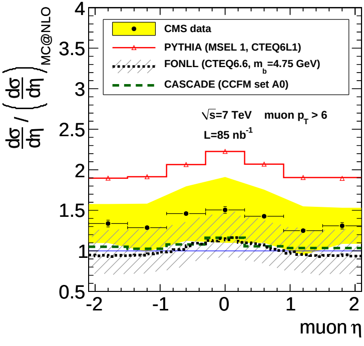
Open Beauty production with muons: efficiency measurement ε

- PYTHIA
  - CTEQ6L1 PDF
  - $m_b = 4.8$ GeV
  - Peterson et al fragmentation function ($\varepsilon_c = 0.05$ and $\varepsilon_b = 0.005$)
  - D6T tune (underlying events)
- MC@NLO +HERWIG
  - m_b=4.75 GeV
  - CTEQ6M PDF

Open Beauty production with muons: comparison with the theory

- Comparison with MC@NLO





Inclusive *b*-jet production

Unfolding

- Ansatz method to correct jet p_T back to particle level
- Phenomenological power law motivated by parton model (Feynman, Field, Fox), extended at the Tevatron and updated at CMS for low p_T and b-jets

$$f(p_T) = N_0 p_T^{-\alpha} \underbrace{\left(1 - \frac{2p_T \cosh(y_{\min})}{\sqrt{s}}\right)^{\beta}}_{\text{high } p_T} \underbrace{\exp(-\gamma/p_T)}_{\text{low } p_T \text{ and b-jets}}$$

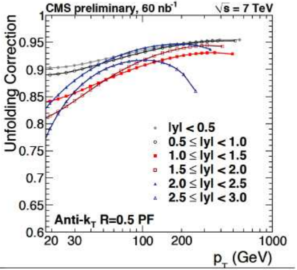
new

$f(p_T)$: Ansatz function to parametrize true jet p_T spectrum

$$F(p_T) = \int_0^\infty f(p'_T) R(p'_T - p_T; \sigma) dp'_T$$

$R(p'_T - p_T; \sigma)$: smearing function

$$C_{res} = f(p_T)/F(p_T)$$

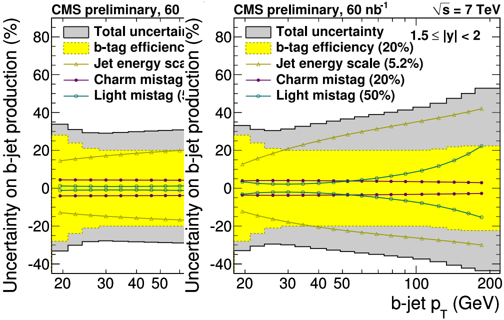


Inclusive b-jet production

- MC@NLO
  - CTEQ6M PDF
  - $m_b = 4.75$ GeV
  - $\mu_F = \mu_R = p_T$
- PYTHIA
  - D6T
- Systematics:
  - $\mu_R \rightarrow [0.5,2]$: $+40\%$,-25%
  - CTEQ PDF: $+10\%$, -6%
  - $m_b \rightarrow [4.5,5]$ GeV: $+17\%$,-14%

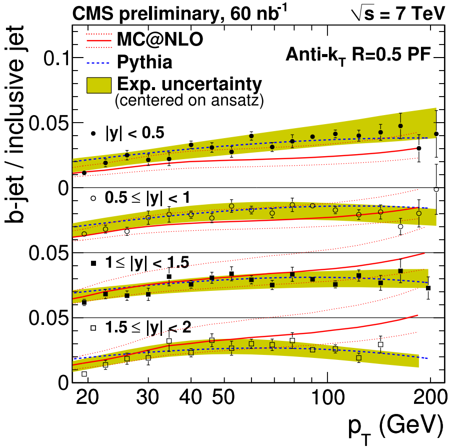
Inclusive *b*-jet production

- Systematics



Inclusive *b*-jet production

- Ratio to inclusive jets



Heavy Quark Production

- LO
  - Flavor creation (FCR): gg fusion (dominant) and $q\bar{q}$ annihilation
- Large NLO contributions
  - Flavor excitation (FEX): $b\bar{b}$ from the sea, only one b participates in hard scattering
  - Gluon splitting (GSP): g → $b\bar{b}$ in initial or final state
- Production mechanism not separated in analyses presented here