Beauty and charm production with the CMS experiment

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On behalf of the CMS Collaboration

LHC Physics Day:
Charm and Beauty quark production at the LHC
3 December 2010
CERN, Geneva

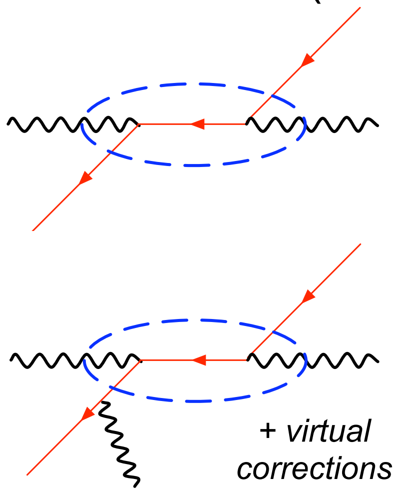
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

B-quark production at LHC

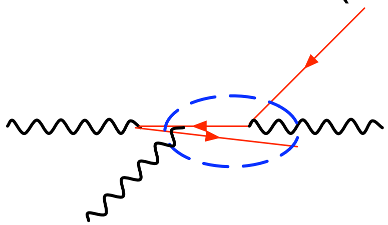
- **Excellent test bench for perturbative QCD and Monte Carlo models**
  - **Tensions between data and theory gradually resolved at hadron colliders with lower energy (Tevatron, HERA)**
  - **Early measurements at LHC can have smaller uncertainties than NLO QCD predictions currently available**
- **B-quark jets are a frequent background to searches for new physics**
  - **Rate and dynamics of b-quark production needs to be well measured and reproduced by MC tools**
- **CMS detector is well suited for b-quark cross section measurements, thanks to its excellent tracking and muon identification, combined with a flexible trigger system**

Production processes in p-p

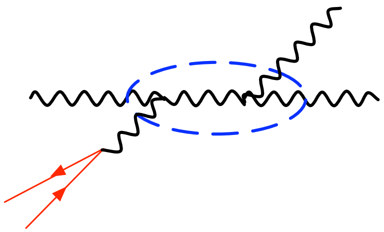
Flavour creation (FCR)



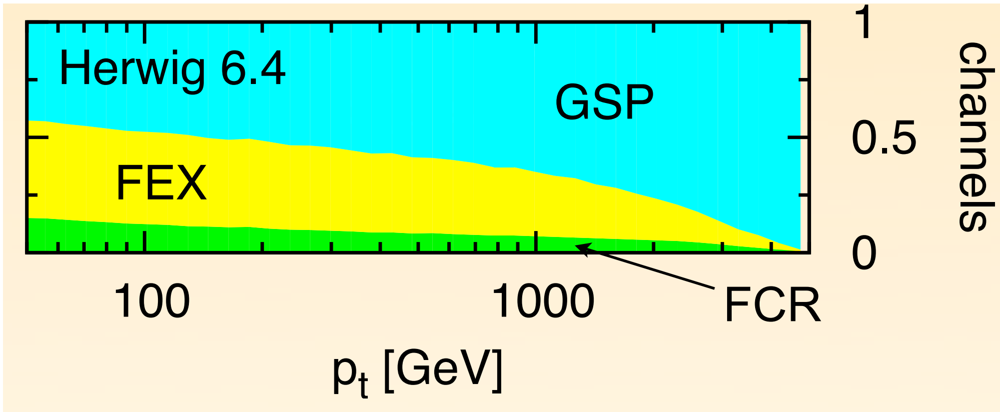
Flavour excitation (FEX)



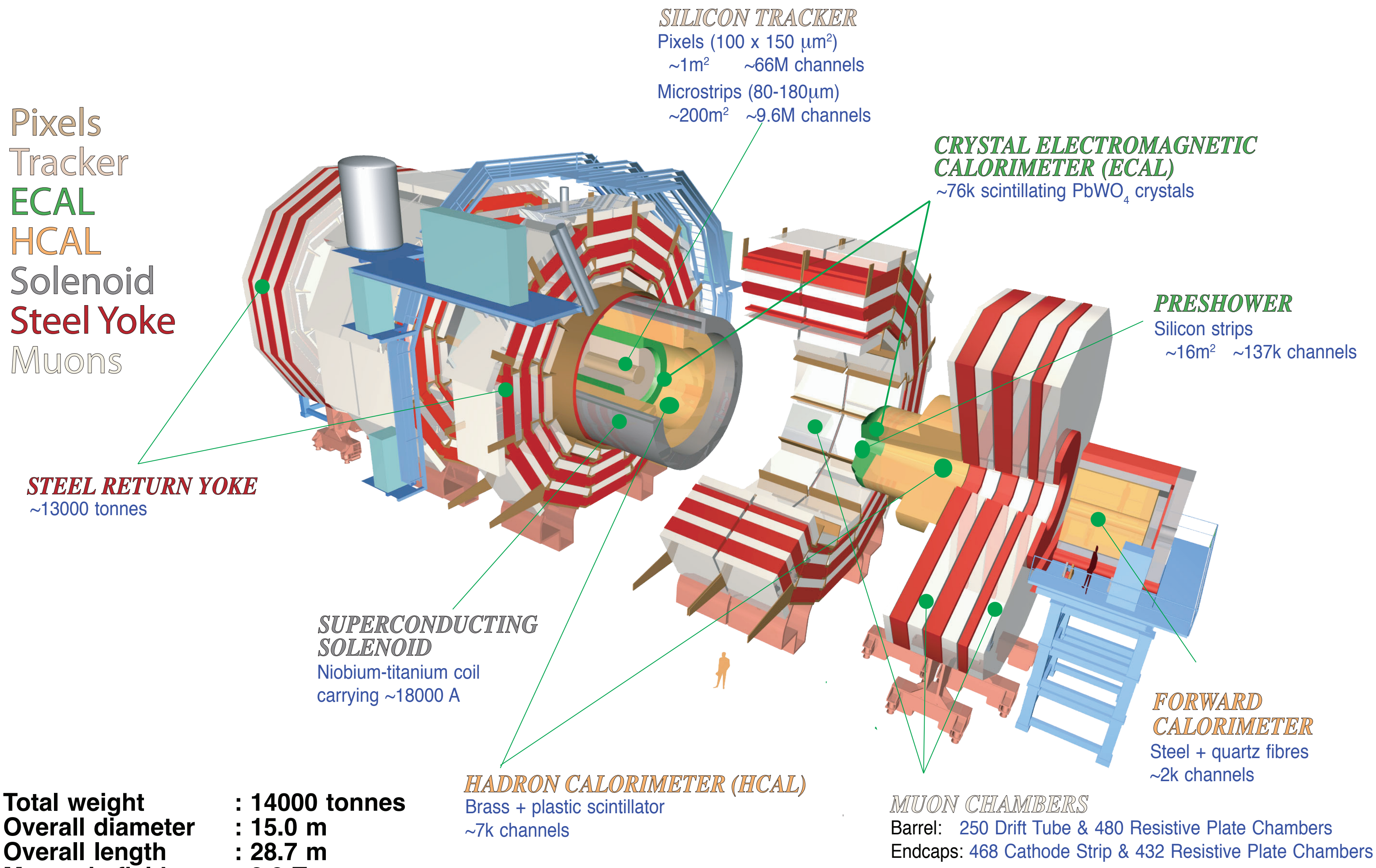
Gluon splitting (GSP)



- 2→2 processes:
  - Flavour creation: gluon fusion and qq annihilation
- 2→3 processes:
  - _Flavour Excitation_: bb from the proton sea, only one b participates to the hard scatter, asymmetric transverse momentum for the two b-quarks
  - _Gluon splitting_: g→ bb in initial or final state, b at low pT and close in the azimuthal angle (Δφ)
  - Real and virtual corrections to Flavour creation



2 to 3 processes dominant at the LHC!



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

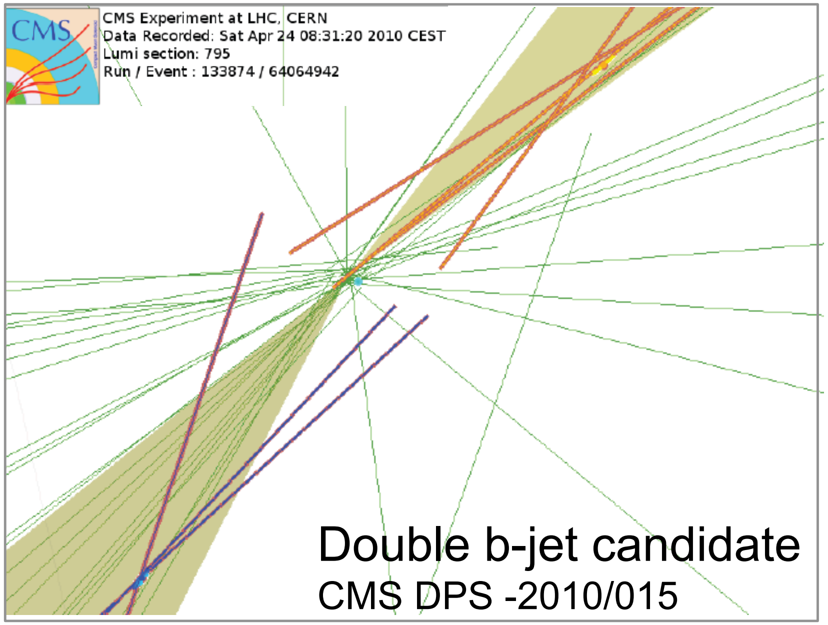
B-quark identification

- **Identification with semi-leptonic decay into muons**
  - Low momentum (3 GeV) single-muon trigger thresholds at CMS startup
  - Can probe inclusive beauty production at low momentum

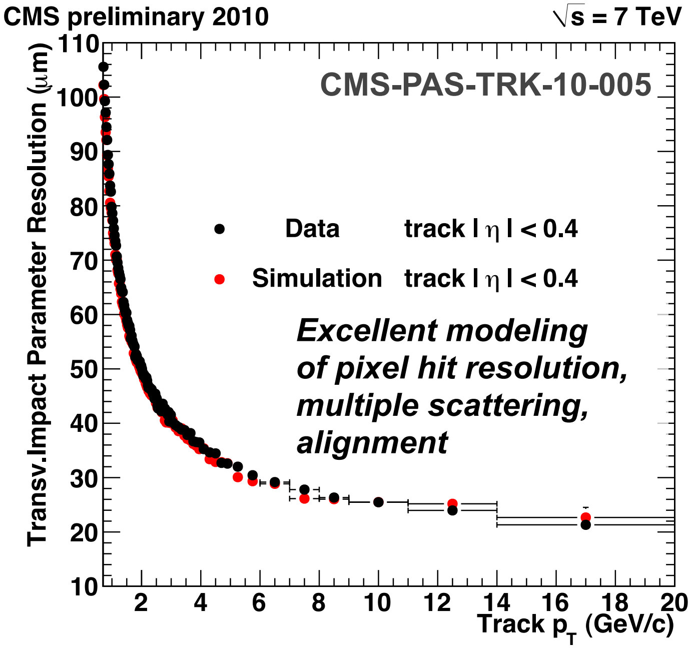
CMS-PAS-BPH-10-007

- **Secondary vertex identification**
  - Exploit high precision of pixel tracker and long B hadrons lifetimes
  - Efficient secondary vertex reconstruction for E_T^{jet}>20 GeV
  - Particle flow jet reconstruction for reliable jet energy resolution
  - Excellent for region at larger momenta

CMS-PAS-BPH-10-009



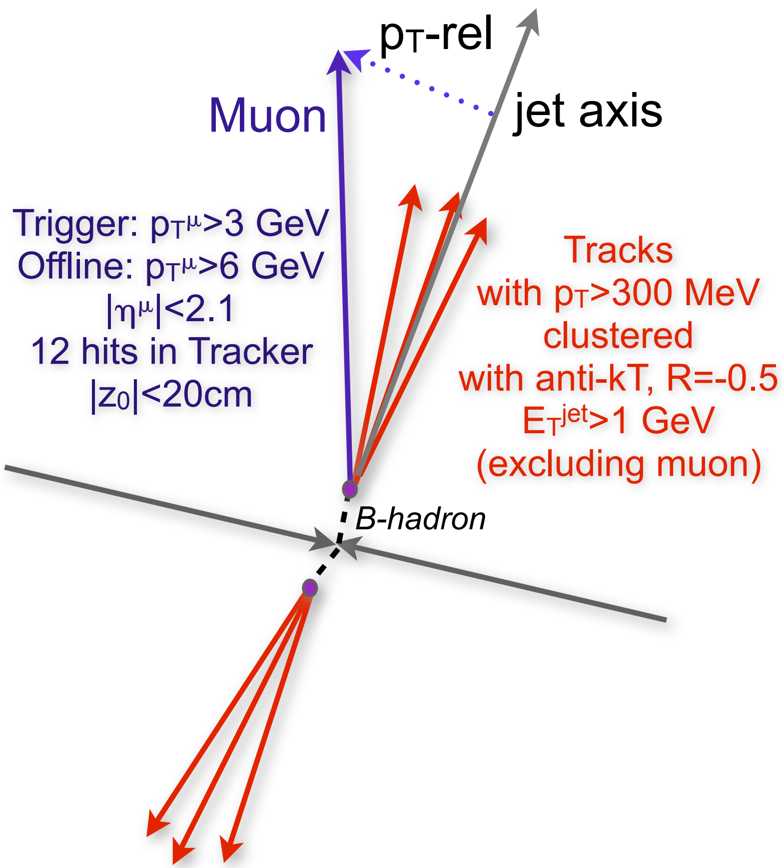
Double b-jet candidate
CMS DPS -2010/015

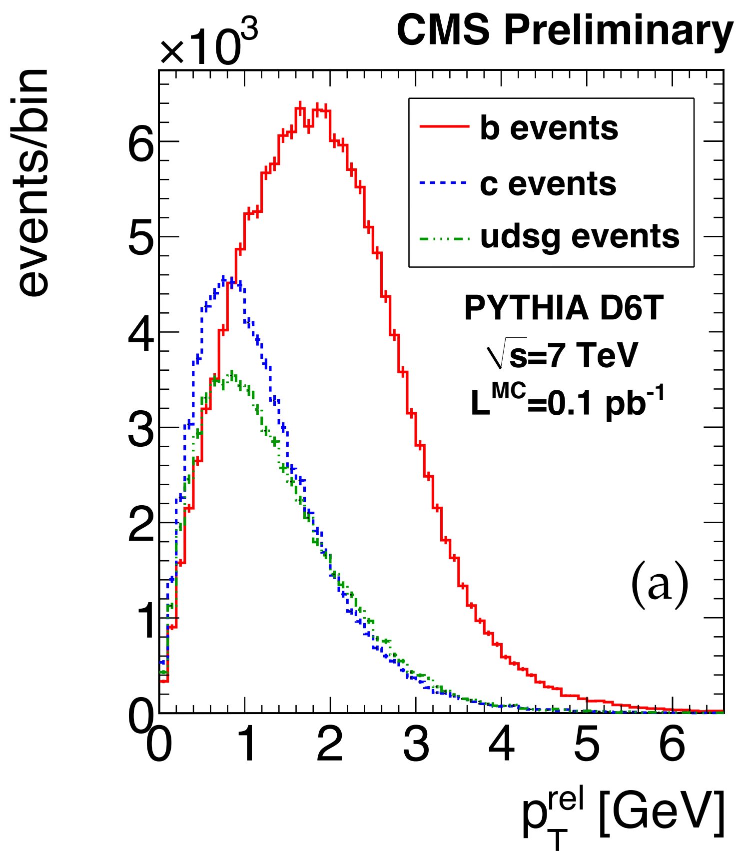


Measurement with semileptonic decays into muons

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

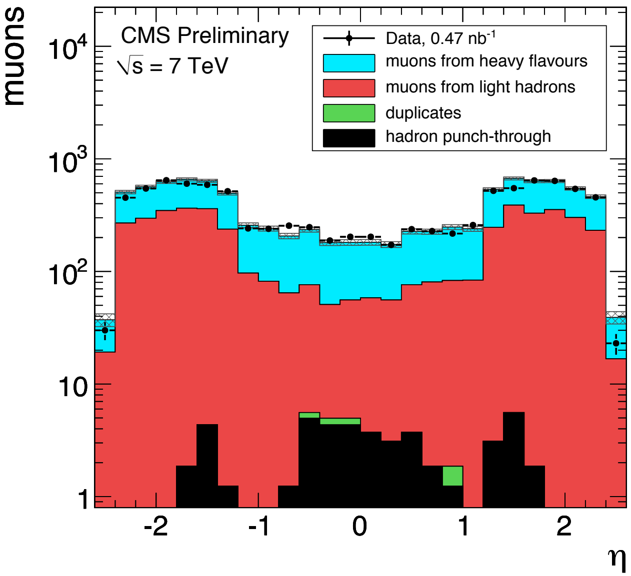


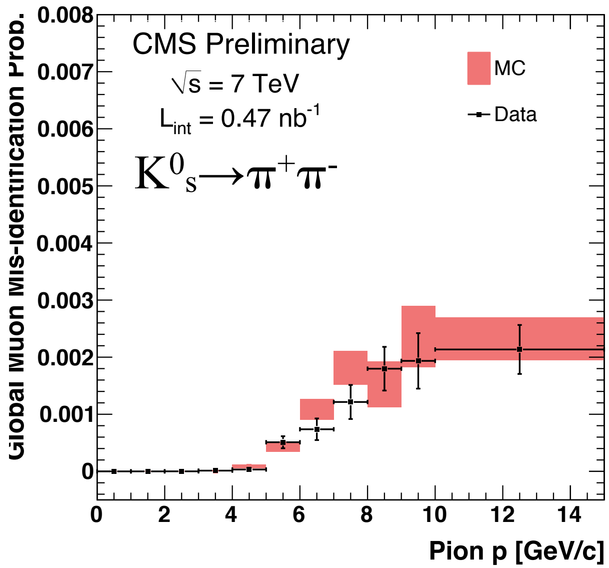


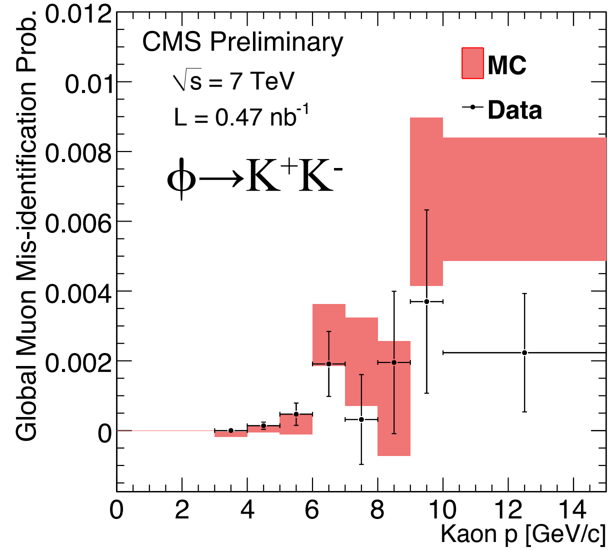
Muon ID performance

Min-bias dataset

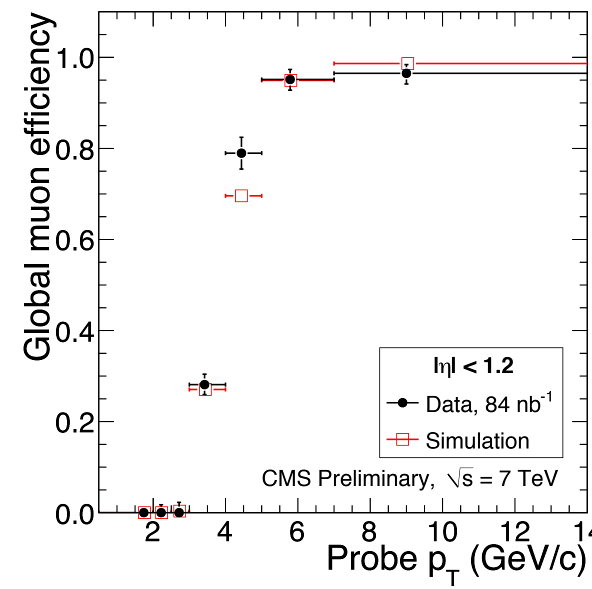
CMS-PAS-MUO-10-002



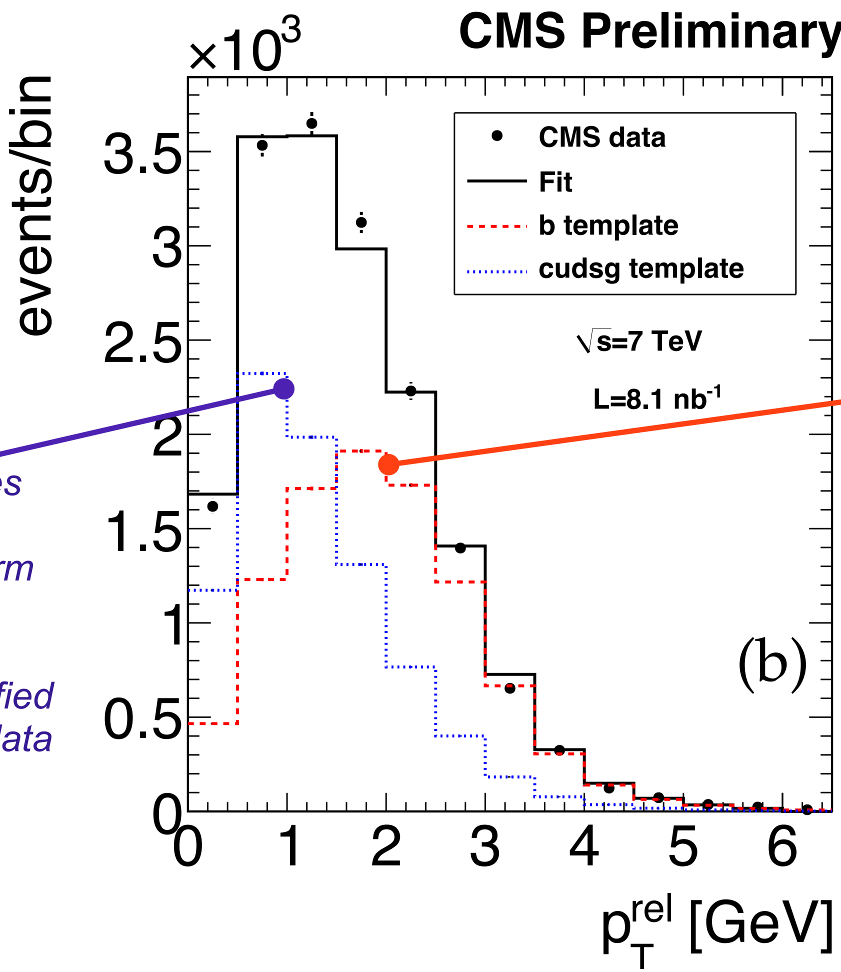




- Muon identification based on outside-in matching of muon segments with tracks in the inner tracks, "*Global muons*"
- Fraction of muons from Pions, Kaons and Protons verified with resonance decays
- Muon efficiency reconstruction verified with a "tag-and-probe" technique on J/ψ decays



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

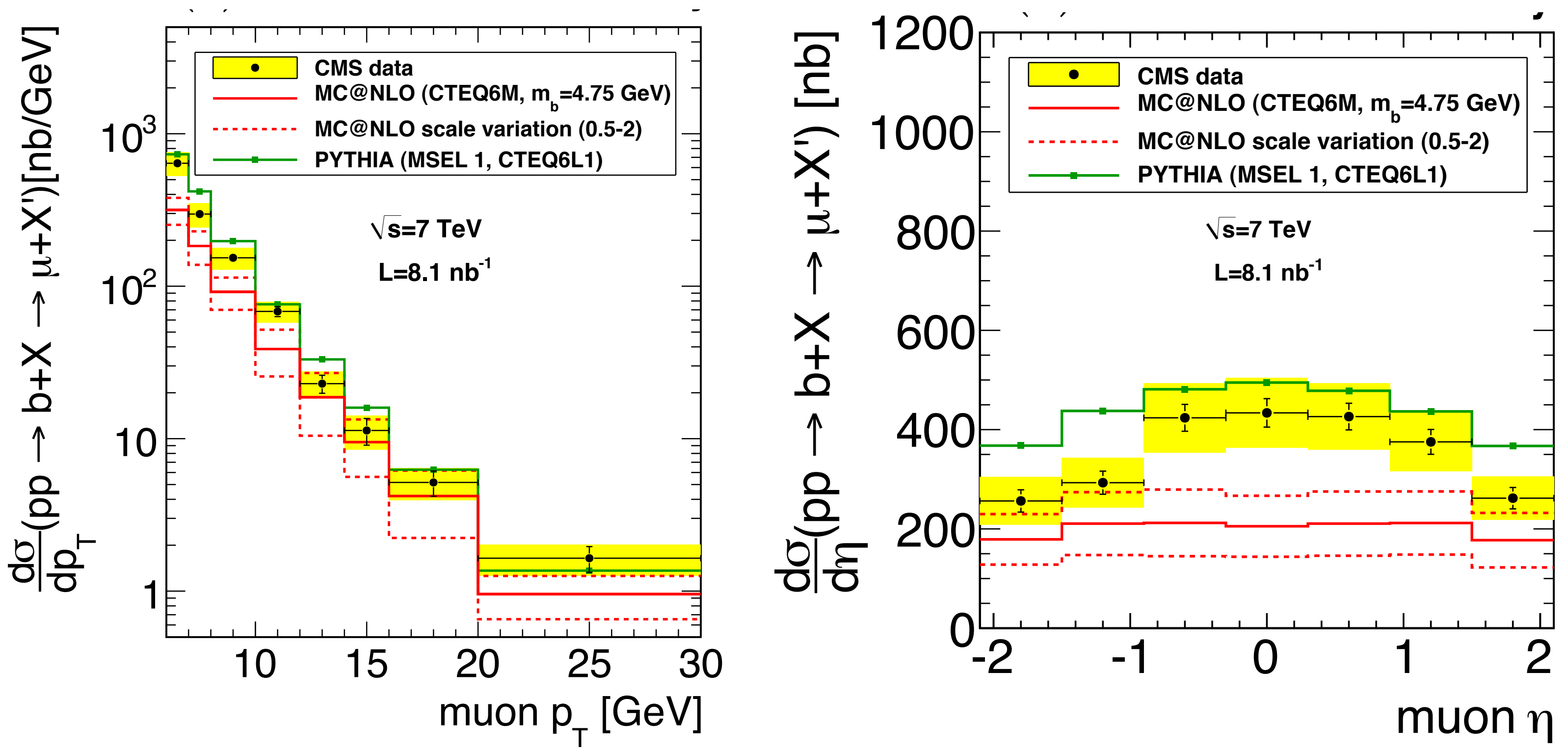
f_b from fit
(44±1)%

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

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

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

Differential cross sections



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

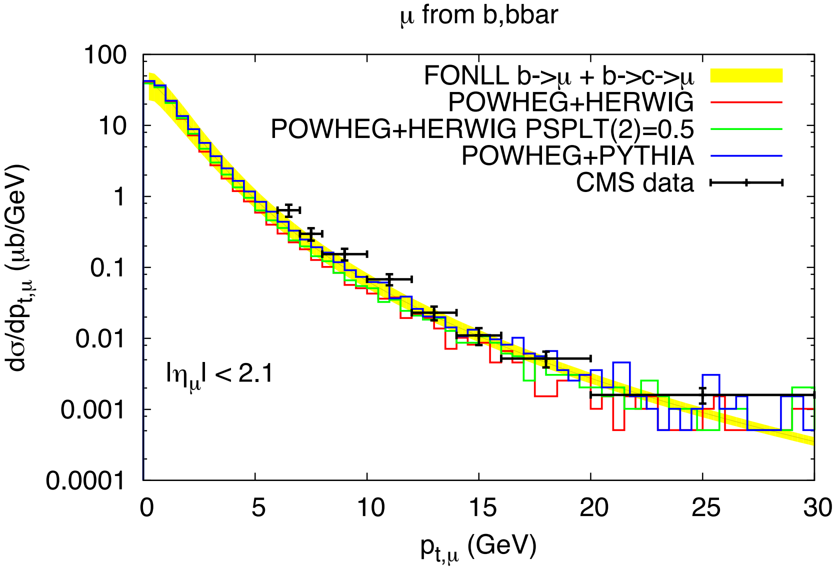
$$\sigma_{\mathrm{PYTHIA}} = 1.8\,\mu b$$

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

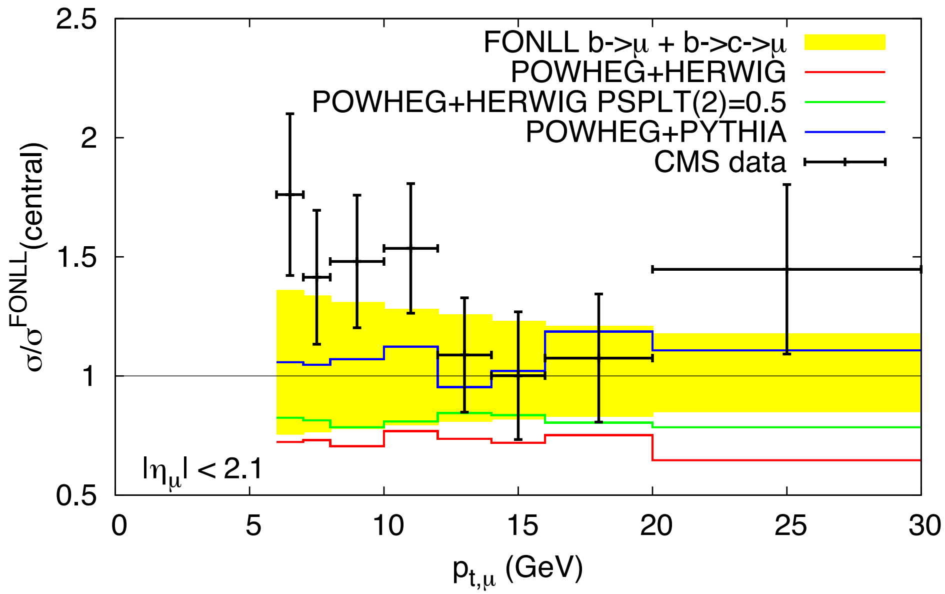
Experimental uncertainties (15-20%) dominated by modeling of fake muons and underlying event

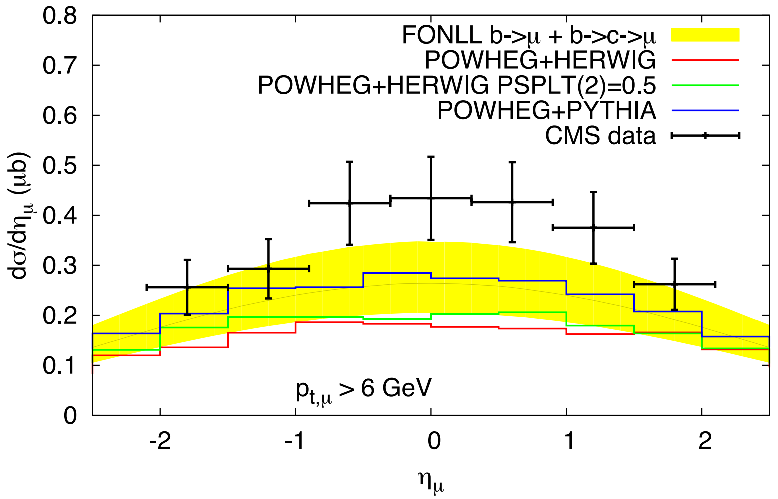
MC@NLO: larger discrepancies at low p_T^{μ} and central region

FONLL and POWHEG



M.Cacciari, P.Nason

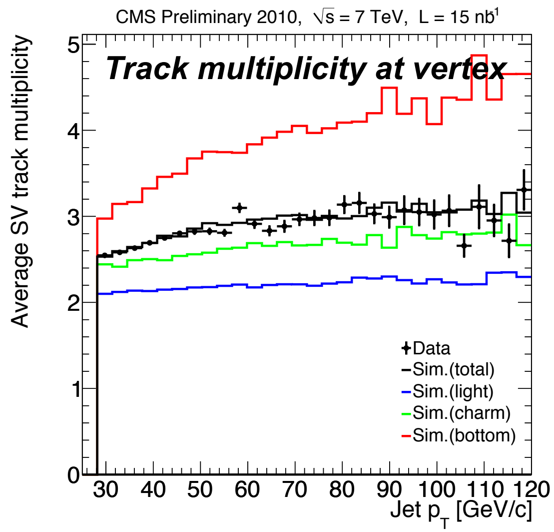


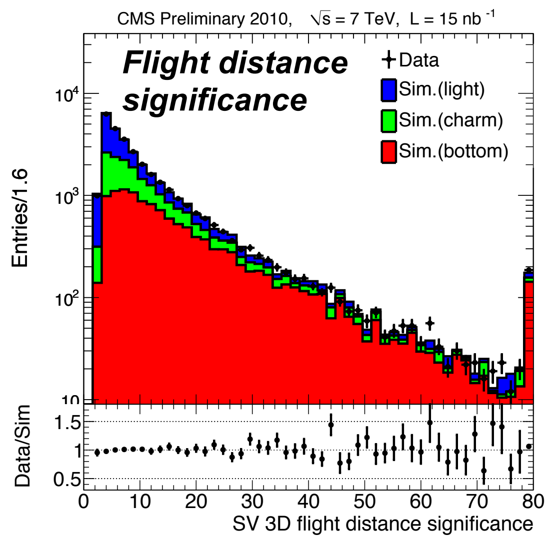


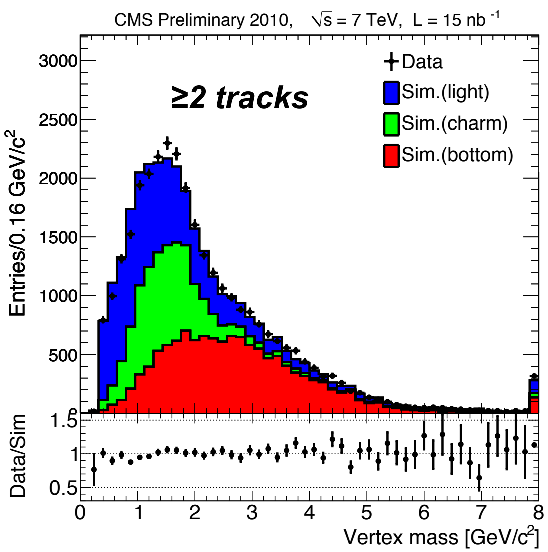
B-jets production with secondary vertex tagging

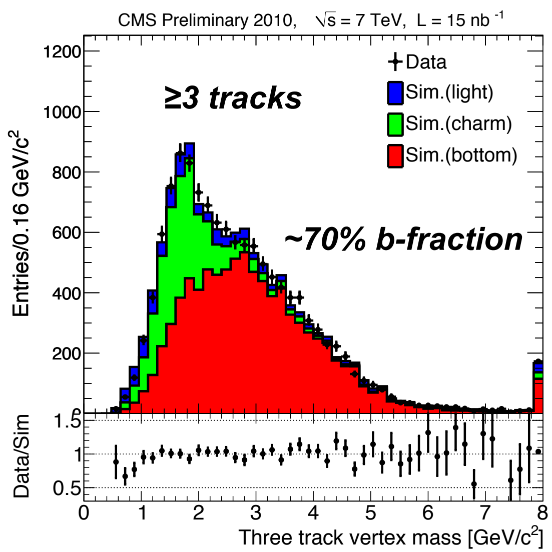
Secondary vertices

CMS-PAS-BTV-10-001





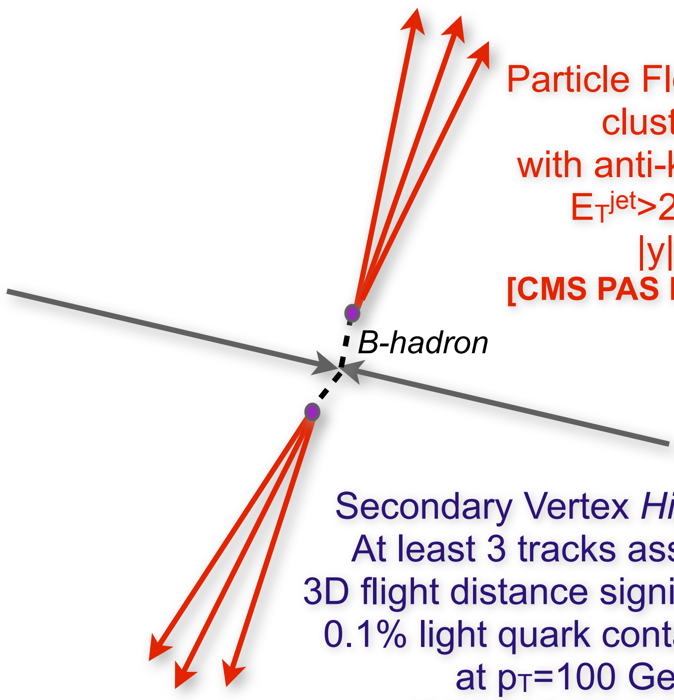




- Based on primary vertex finder tool applied to tracks in a jet
- Commissioning of secondary vertex reconstruction shows very good understanding of discrimination variables
  - **Track multiplicity**
  - **Flight distance significance**
- Invariant mass of tracks associated to the vertex is a useful tool to verify sample purity after tagging

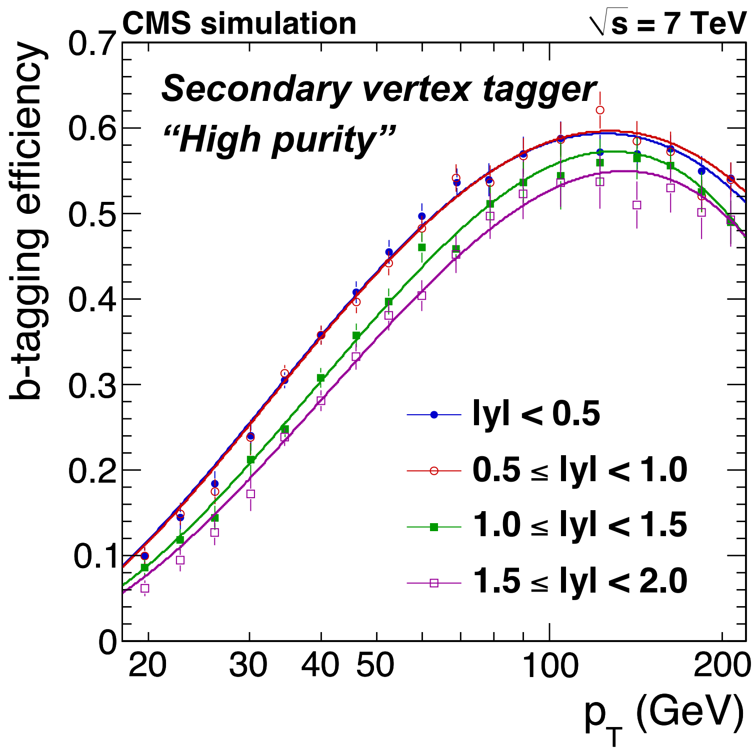
B jets cross section

- 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



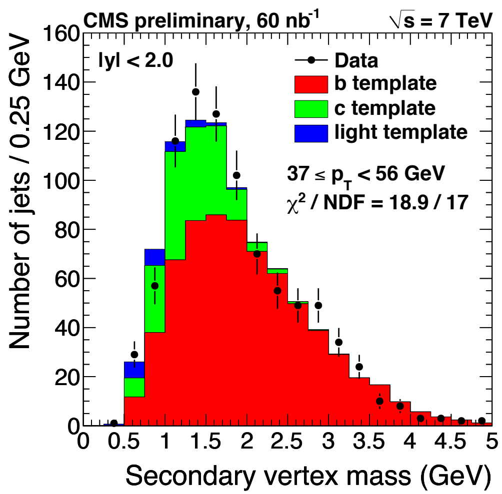
Particle Flow objects clustered with anti-kT, R=-0.5
E_T^{jet}>20 GeV
|y|<2
[CMS PAS PFT-09-001]

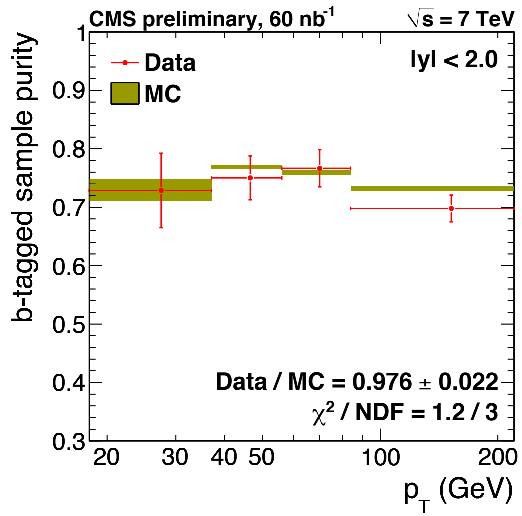
Secondary Vertex *High Purity*
At least 3 tracks associated
3D flight distance significance cut
0.1% light quark contamination at p_T=100 GeV
[CMS PAS BTV-10-001]

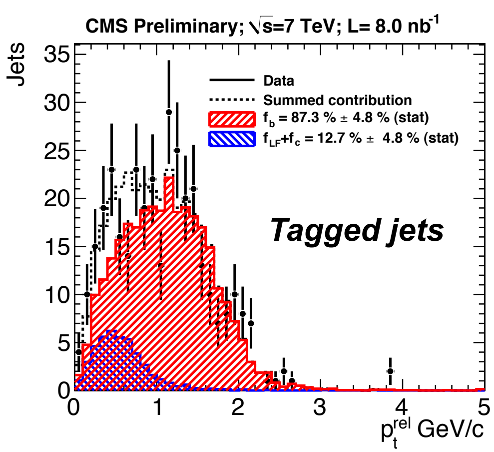


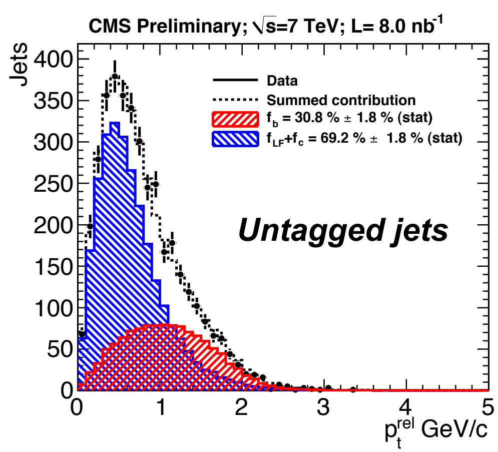
Cross section calculation

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









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

Tagging efficiency ϵ_b from MC validated with data-driven method

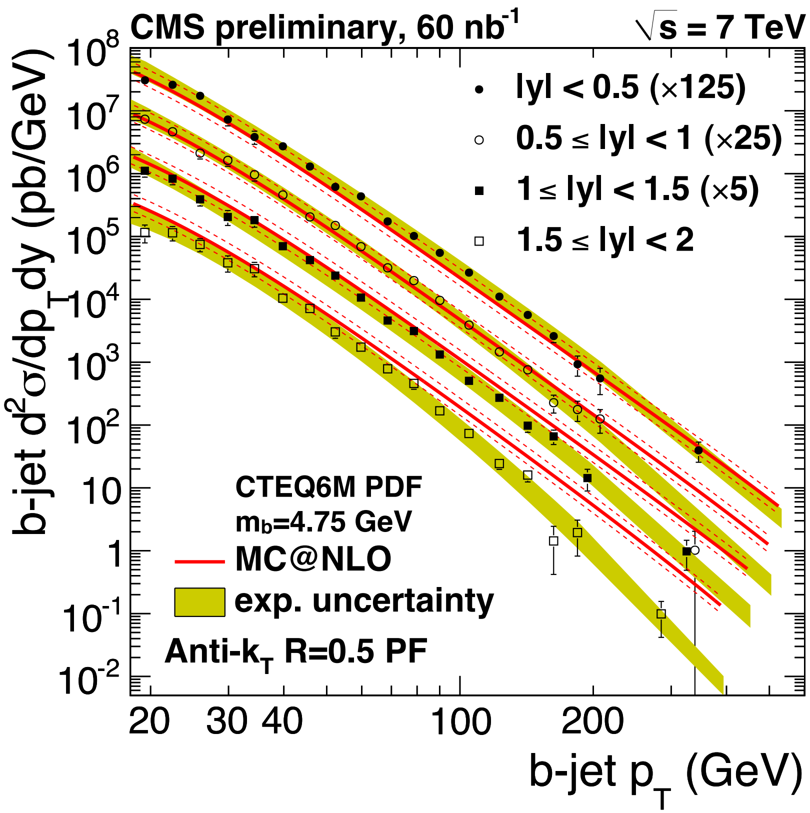
$\epsilon_{\mathrm{data}}/\epsilon_{\mathrm{MC}}$=0.98±0.08(stat)±0.18(syst)

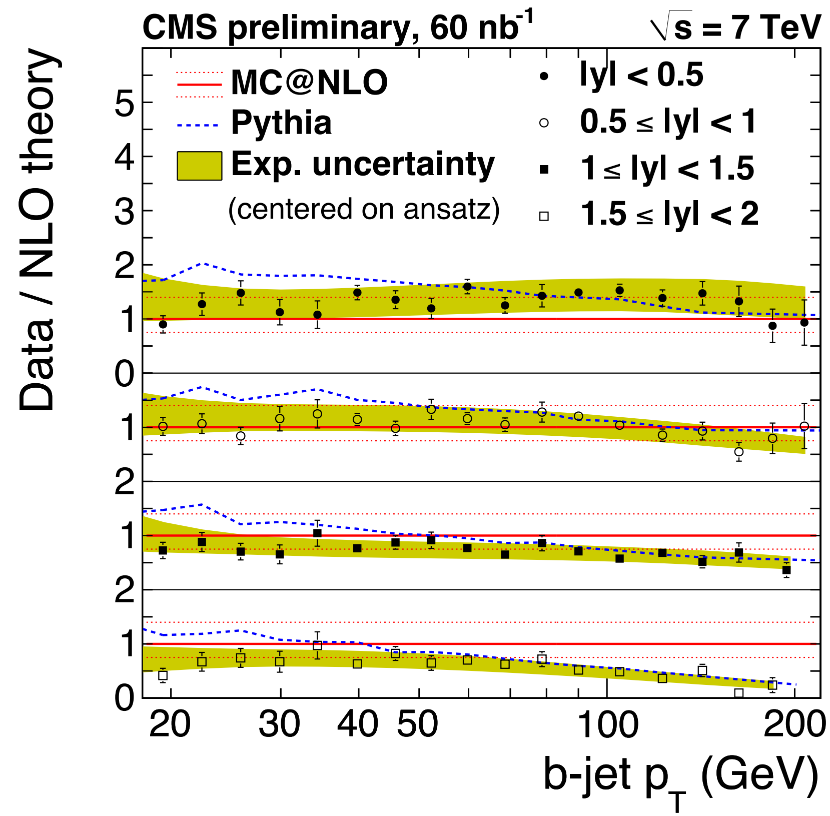
$$\epsilon_b^{\mathrm{data}} = \frac{f_b^{\mathrm{tag}} \cdot N_{\mathrm{data}}^{\mathrm{tag}}}{f_b^{\mathrm{tag}} \cdot N_{\mathrm{data}}^{\mathrm{tag}} + f_b^{\mathrm{untag}} \cdot N_{\mathrm{data}}^{\mathrm{untag}}}$$

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

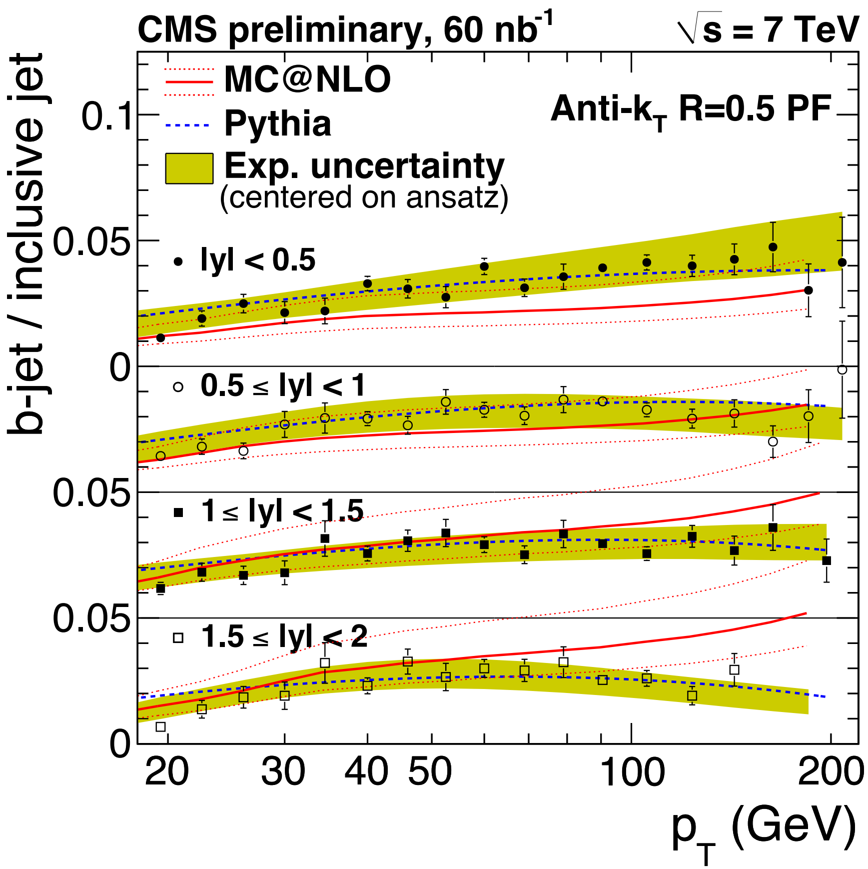
Luminosity ($\mathcal{L}$): 60 nb^{-1}

Results





- 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

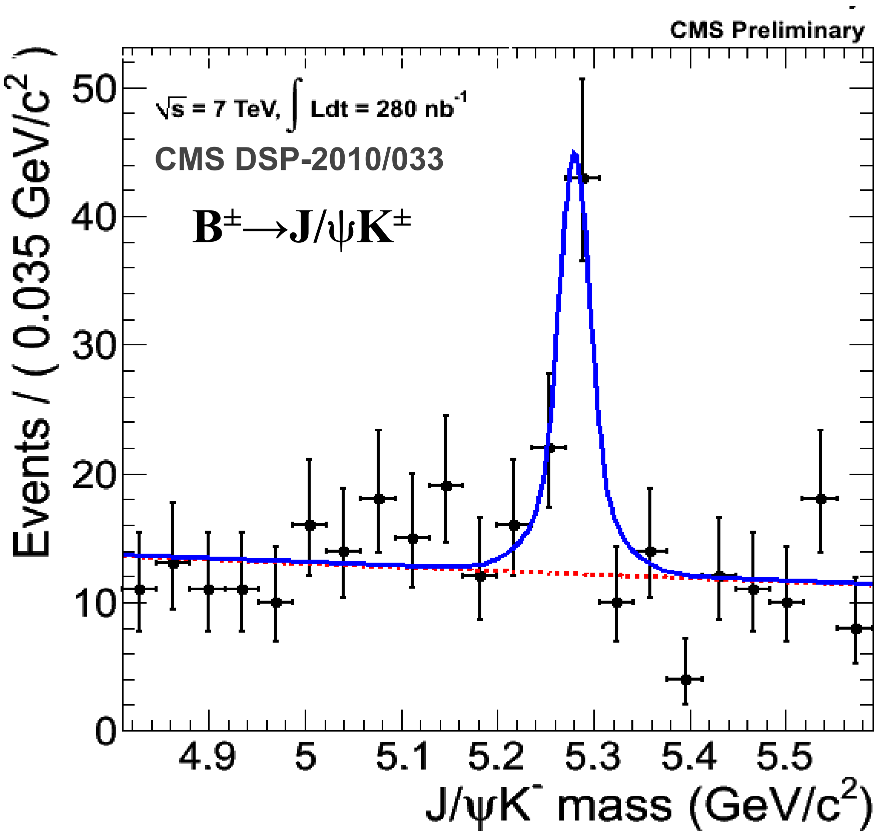


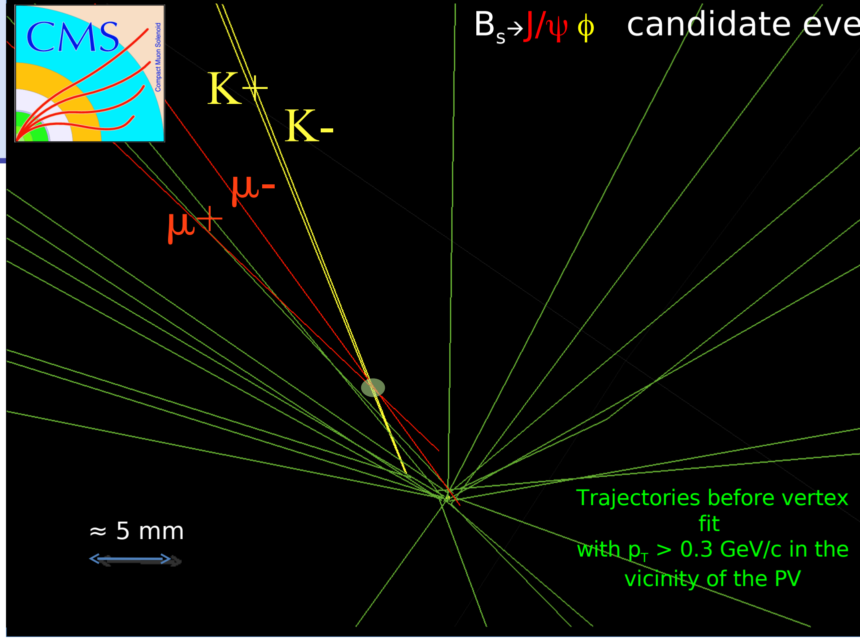
$$R = \frac{\text{B-jets cross section}}{\text{All jets cross section}} \sim 2\text{-}3\%$$

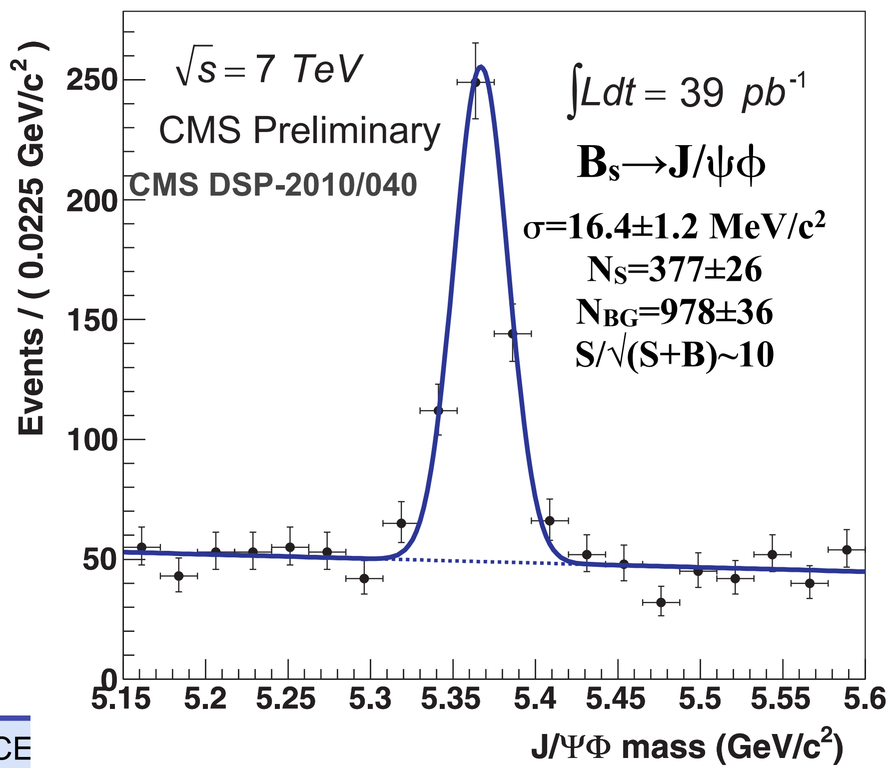
- Jet energy corrections and luminosity systematic uncertainties cancel out
- Pythia in agreement over the measured range
- Indicates shape discrepancies with NLOJet++/MC@NLO ratio

Inclusive jet measurement:
CMS PAS QCD-10-011

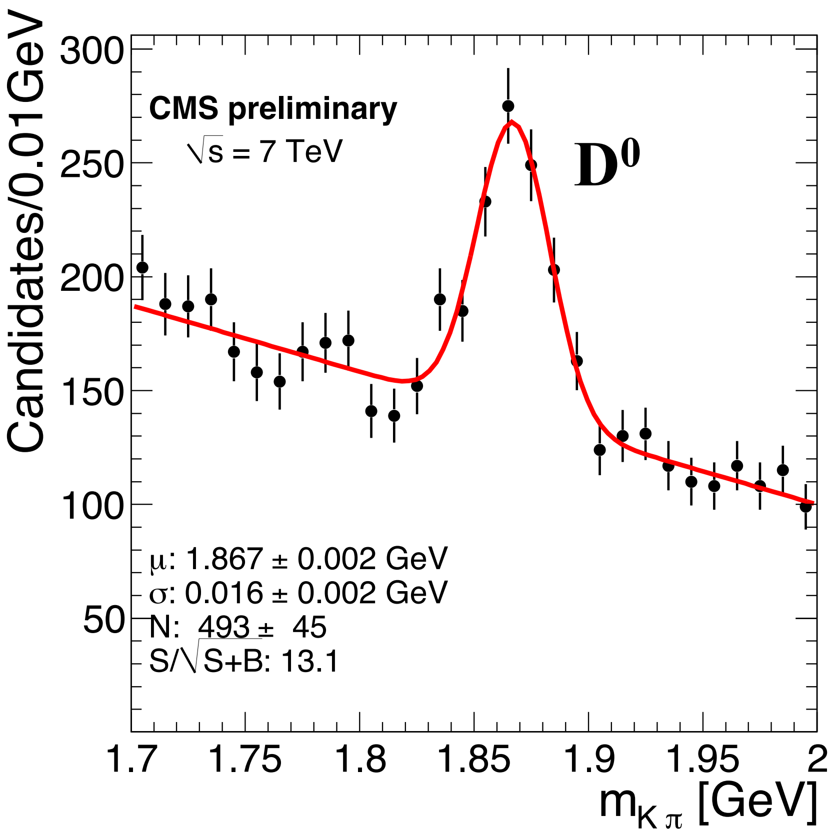
B-hadron decays

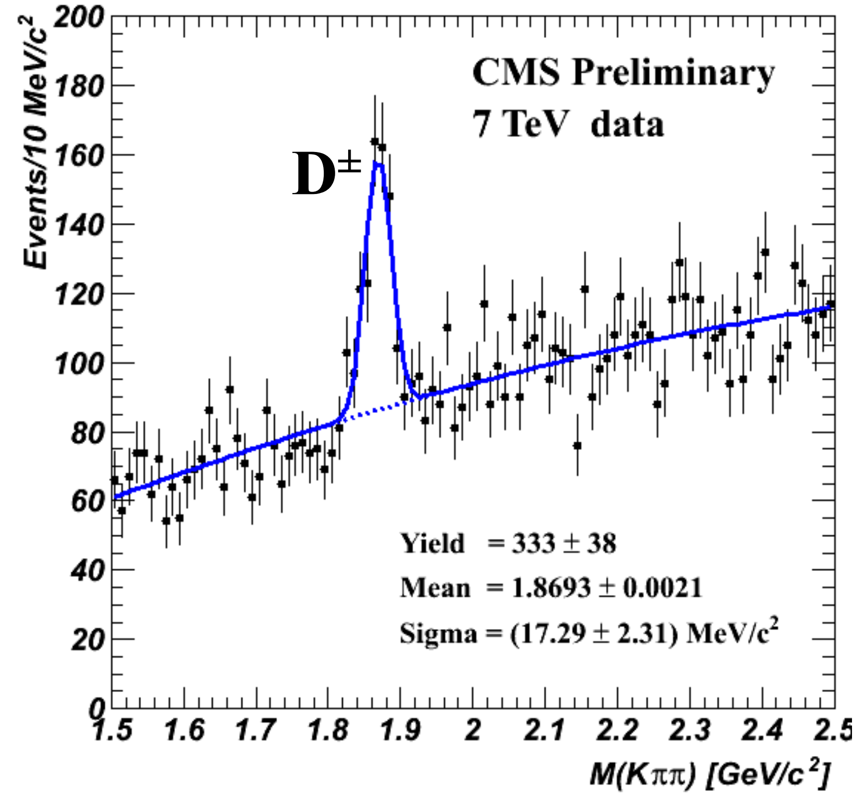






Charmed mesons





Conclusions

- **First measurements of b-quark production in central region for p-p collisions at $\sqrt{s}$=7 TeV available**
- **Significant uncertainties (up to 40%) on NLO QCD predictions**
- **Two different techniques adopted:**
  - **Semi-leptonic decays into muons:**
    - Sensitive to low momentum region $6<p_T^{\mu}<30$ GeV and $|\eta^{\mu}|<2.1$
    - 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**
    - Covers wider pt range 18<pT<300 GeV and |y|<2
    - Statistical error ~2% with 60 nb^{-1} and systematic ~20%
    - Good agreement with Pythia predictions
    - Reasonable agreement with MC@NLO but shape differences observed for p_T and y dependence
- **Outlook**:
  - Cross section measurements in exclusive decay channels (B^0, $B^{\pm}$, B_s, Λ_b, open *c*)
  - Measurements of B-hadron angular correlations: disentangle production process through final state topology

BACKUP

Muon cross section: systematics

source	uncertainty
Trigger	3–5 %
Muon reconstruction	3 %
Tracking efficiency	2 %
Background template shape uncertainty	1–10 %
Background composition	3–6 %
Production mechanism	2–5 %
Fragmentation	1–4 %
Decay	3 %
MC statistics	1–4 %
Underlying Event	10 %
Luminosity	11 %
total	16–20 %

B jets: systematic uncertainties