Inclusive $b \to \mu X$ production at 7 TeV in CMS

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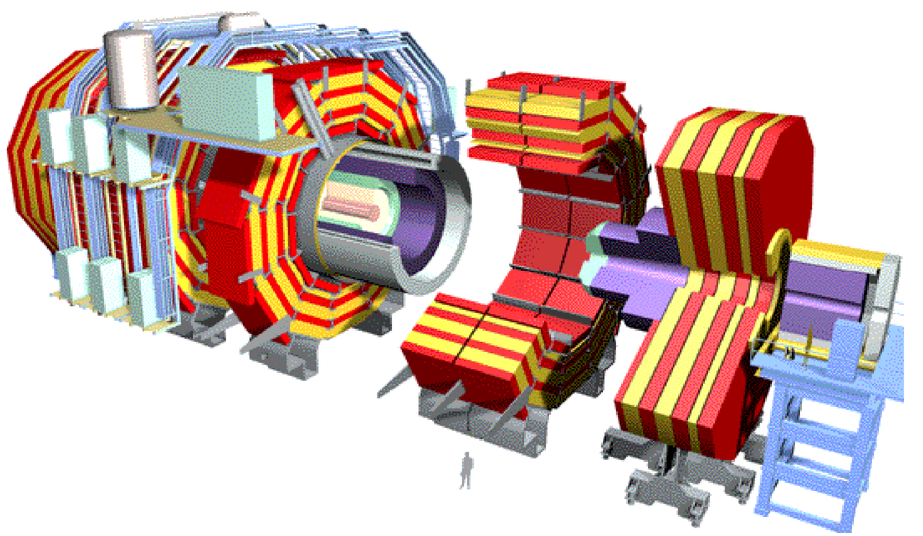
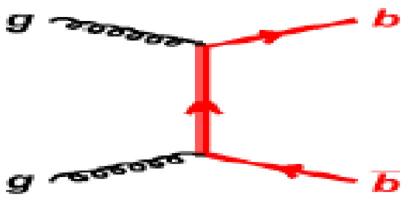


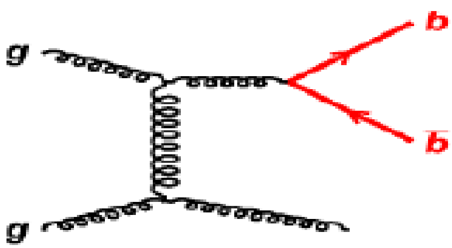
Inclusive b production at LHC

Three main processes:



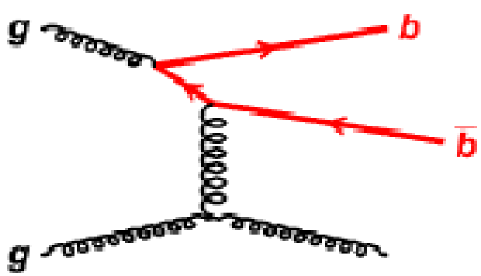
Flavor creation(FCR): 2→2 LO

gg or *qq* annihilation



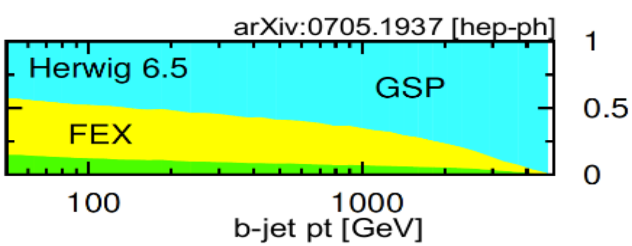
Gluon Splitting (GS): 2→3 LO+NLO

large contribution from soft *g* radiation



Flavor Excitation (FEX): 2→3 LO+NLO

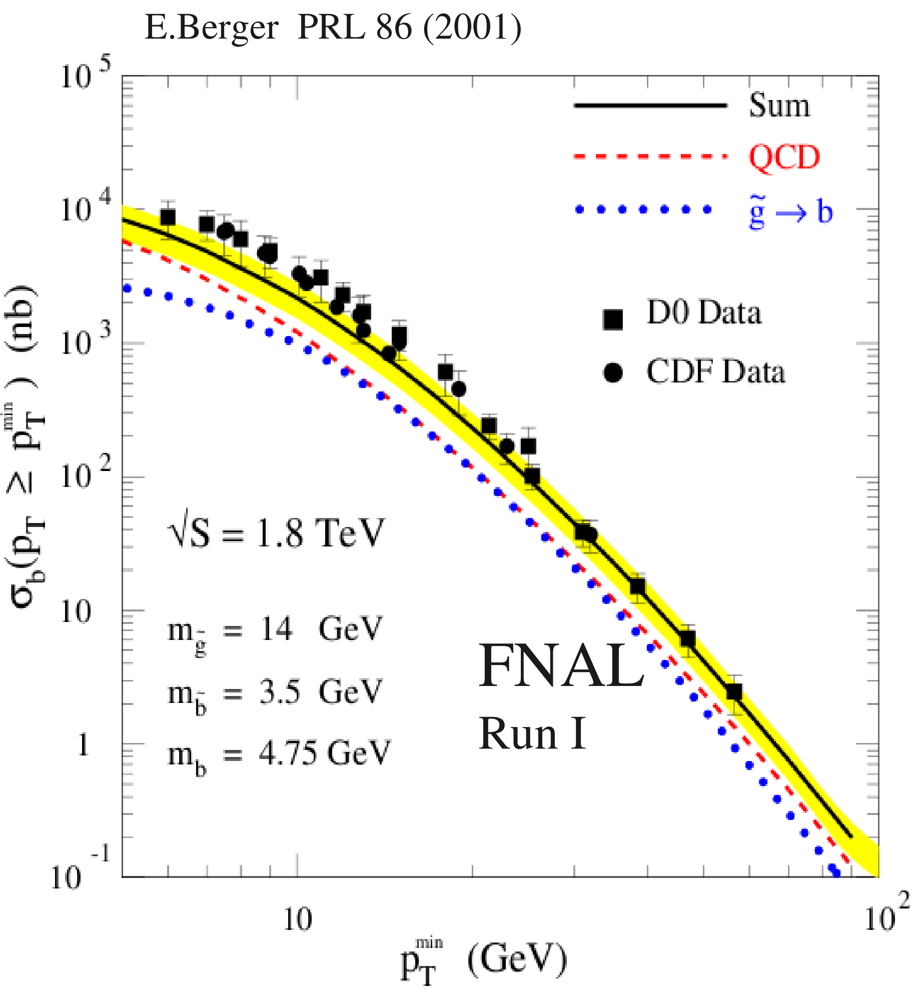
dominant for low p_T^b

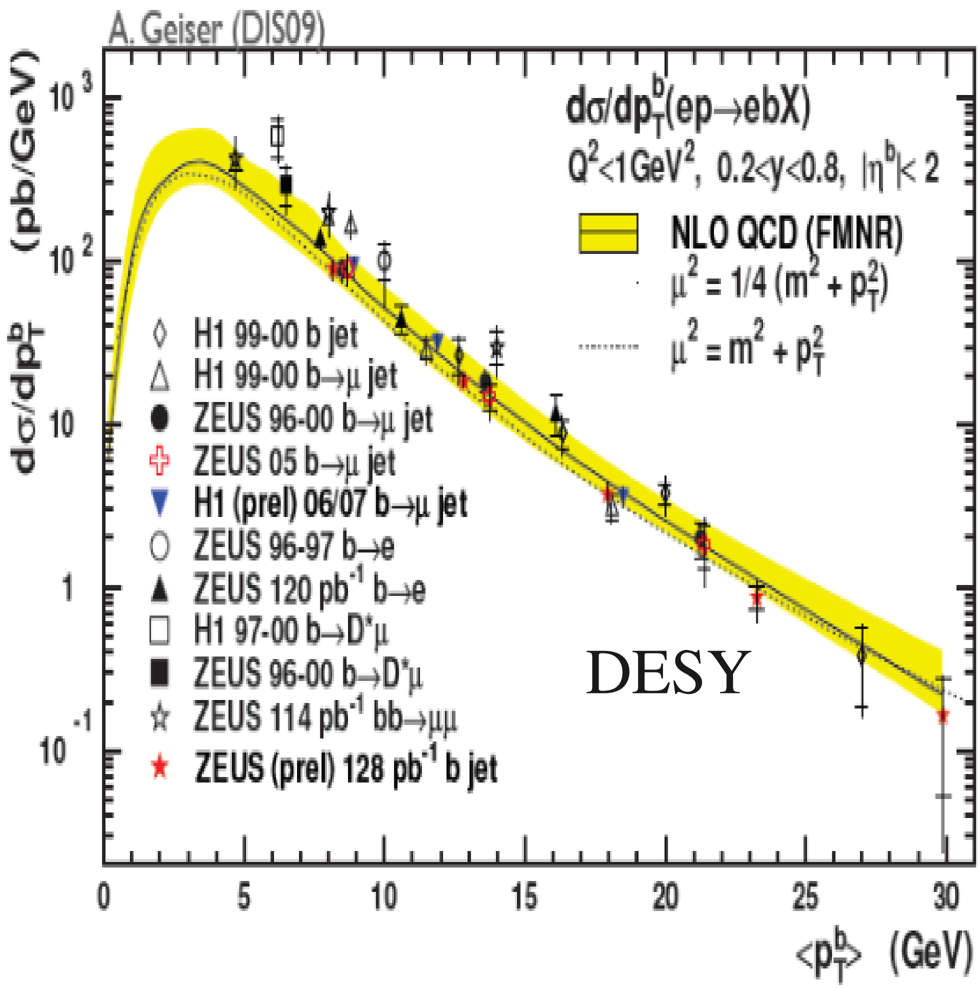


Depends upon:

- parton shower and fragmentation models
- factorization and renorm scales
- mass m_b

Experiments





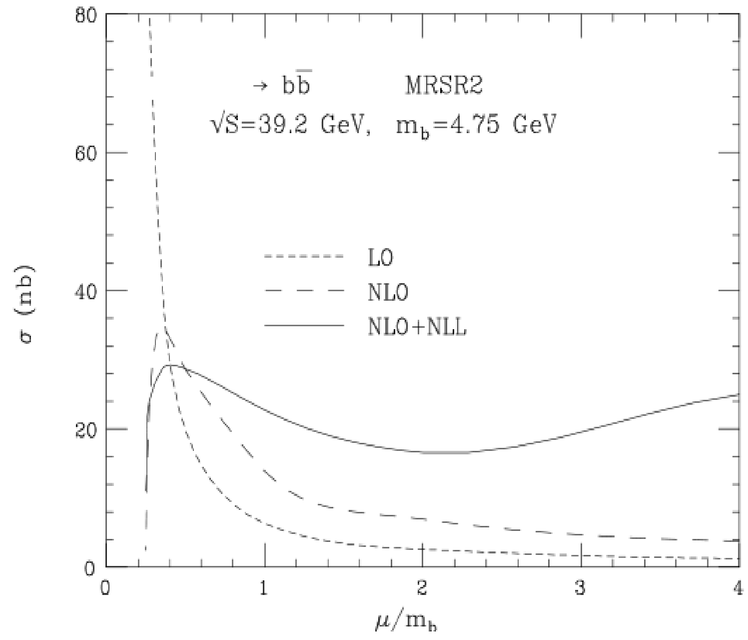
Data are systematically above fixed order (FO) NLO predictions (*bbX*)

Theory

$m_b >> \Lambda_{QCD}$ → perturbative calculations, but requires non perturbative fragmentation function, i.e scale dependency. FO NLO works then all scales are close to the scale of αs expansion, not the case for $p > m_b$

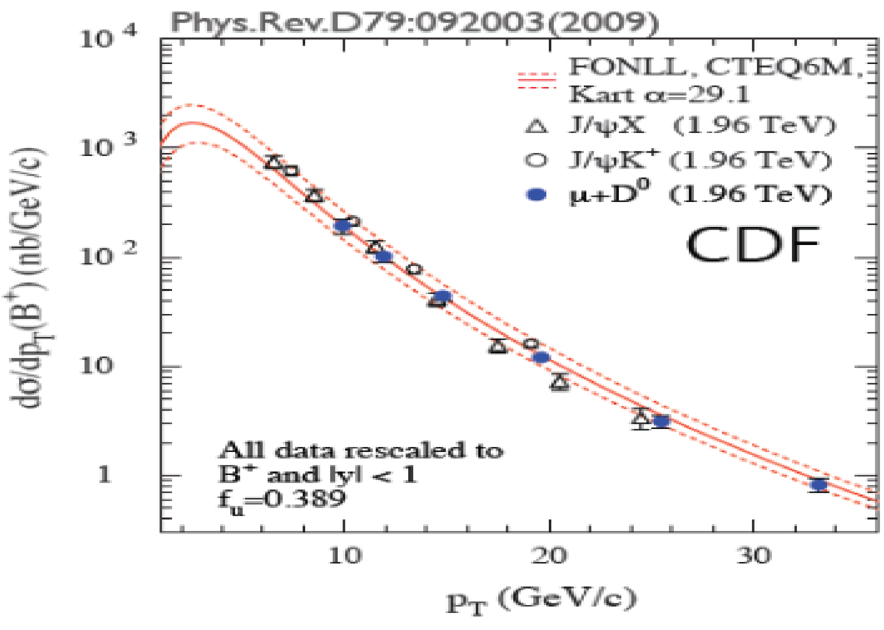
Extension of the FO NLO calculation → FO+NLL (NextLeadingLog)

P.Bonchiani Nucl.Phys B529, 424, 1998



Example of scale dependencies at HERAB energies

M.Cacciari, S. Frixione, P.Nason JHEP 0103 (2001)

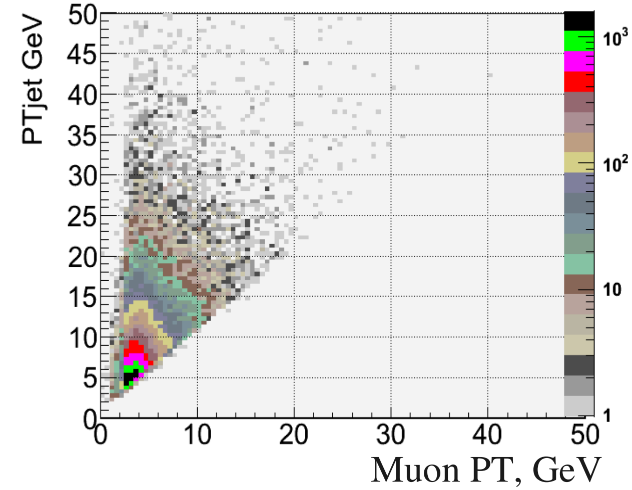


FONLL better describes Tevatron data

Will it work at LHC?

Inclusive b measurements at CMS

JetET vs muonPT (gen) b->μX



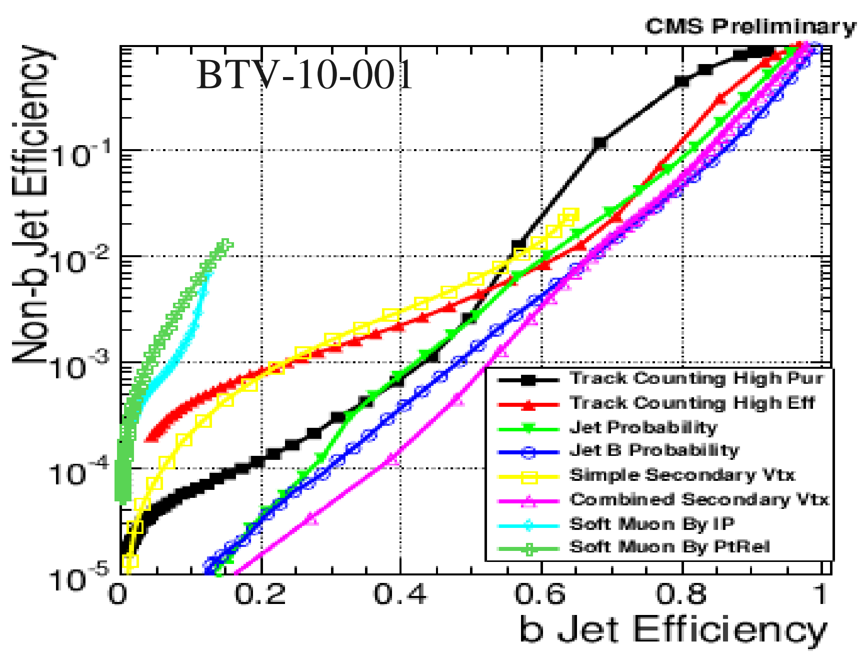
Two complimentary methods, depending on p_T^b

For high p_T^b jets b tagging, for low p_T^b use muons

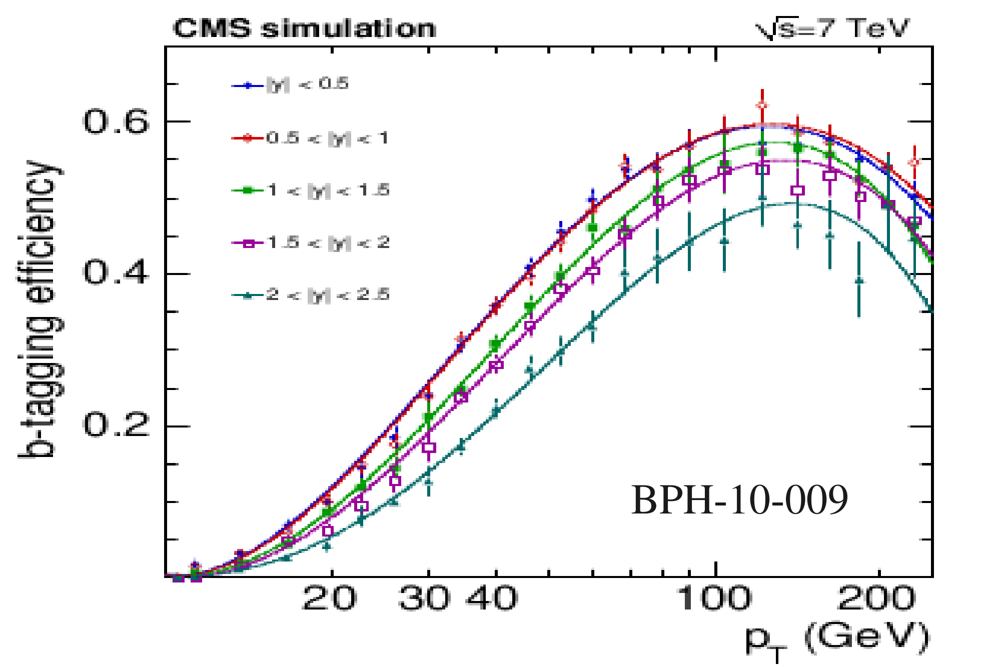
1. Using b-tagged jets

Different b-tagger available in CMS
eg. Simple Secondary Vertex (SSV) but all have small efficiency < 10% for p_T^b< 30 GeV

Performance of different Btag algorithms



B-tag(SSV) efficiency from MC vs jets p_T and y



b → μX production

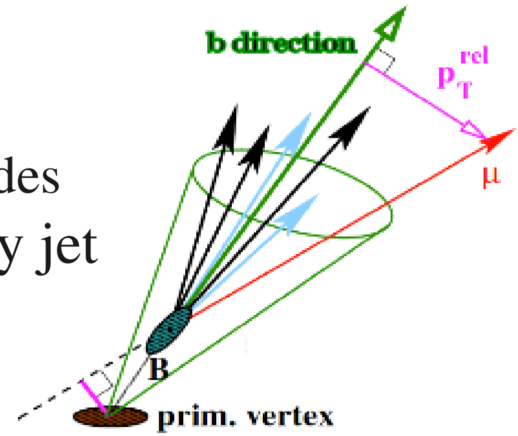
Main subject of this talks

For low $p_T^b \sim m_b$

2. Muons as a b-tag Br(bμ)=10.5%

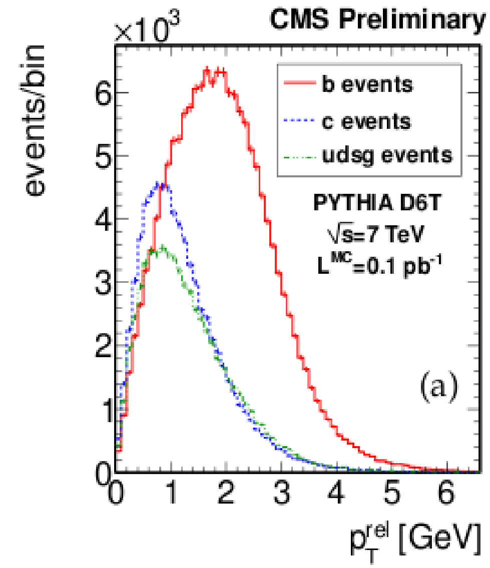
consider direct b → μX and b → c →μX cascades

Extract *b* fraction using p_T^{rel} to the nearby jet



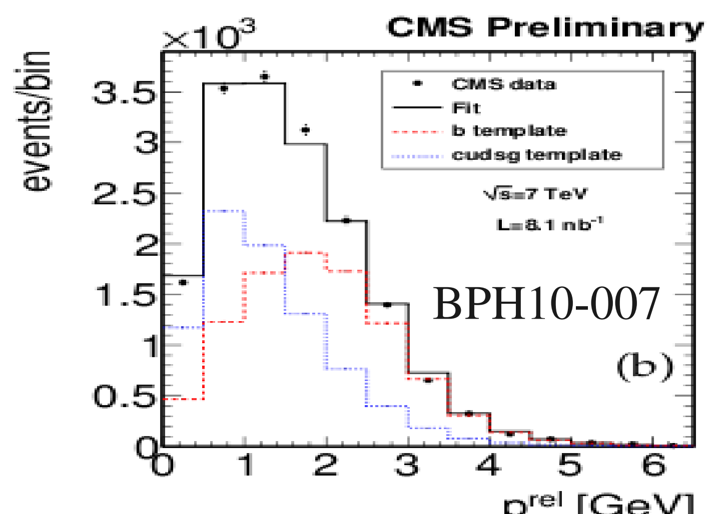
$$p_\perp^{rel} = \frac{|\vec{p}_\mu \times \vec{p}_{TrackJet}|}{|\vec{p}_{TrackJet}|},$$

PTrel distributions(MC) for muons from b,c, udsg



- Use two predefined p_T^{rel} templates:
  b and non *b* (*c*+*udsg*) since
  c and *udsg* are very similar at low p_T^b
- Validate *udsg* template with data using tracks and *b* template using muons with large impact parameter
- Perform two components binned likelihood fit to the data, extract *b*-fraction *fb*
- Calculate cross section:
  $\sigma = N_\mu f_b / \varepsilon \mathcal{L}$, where $\mathcal{L}$ -luminosity, f_b - b fraction,
  ε -efficiency = $\varepsilon_{trigger} * \varepsilon_{reco} * \varepsilon_{jet}$

PTrel two components template fit for muons PT=6-30 GeV



Event selection

- Data sample collected with single muon trigger $p_T^{\mu}>3$ GeV during first data taking $\mathcal{L}=8.1\ nb^{-1}$ (later the trigger threshold has been increased)
- Select good quality muons: $p_T^{\mu}>6$ GeV $|\eta^{\mu}|<2.1$

Tracker+Muon system fit (global) $\chi^2<10$
Tracker only fit(tracker) Nhits>10
impact parameter dxy<2mm

- Check if muon is a TrackJet constituent

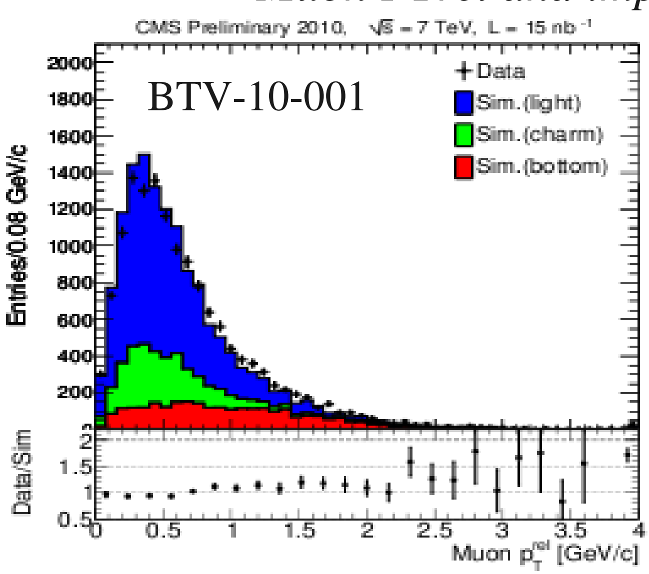
Subtract muon from the jet ($p_j - p_{\mu}$)

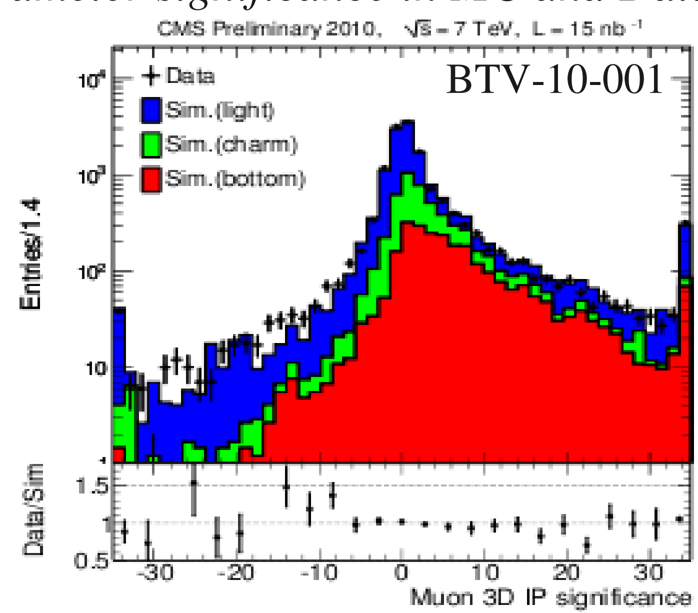
and select event if $p_T^{j}>1$ GeV

TrackJets uses only charged tracks $p_T>0.3$ GeV
Anti kt D=0.5 algorithm

Muon PTrel and impact parameter significance in MC and Data

Good agreement Data-MC (PYTHIA) for all muon's related observables





Efficiencies

Trigger efficiency

Measured in data:

- using dimuons from J/ψ
- using unbiased sample

Efficiency(>6 GeV) ε_{trig} ~ **85%**

Uncertainties $\Delta\varepsilon_{trig}$ ~ 5%

Muon selection efficiency

Obtained from MC truth

Efficiency for *b* muons ε_{trig} ~ **95%**

Uncertainties $\Delta\varepsilon_{reco}$ ~ 3%

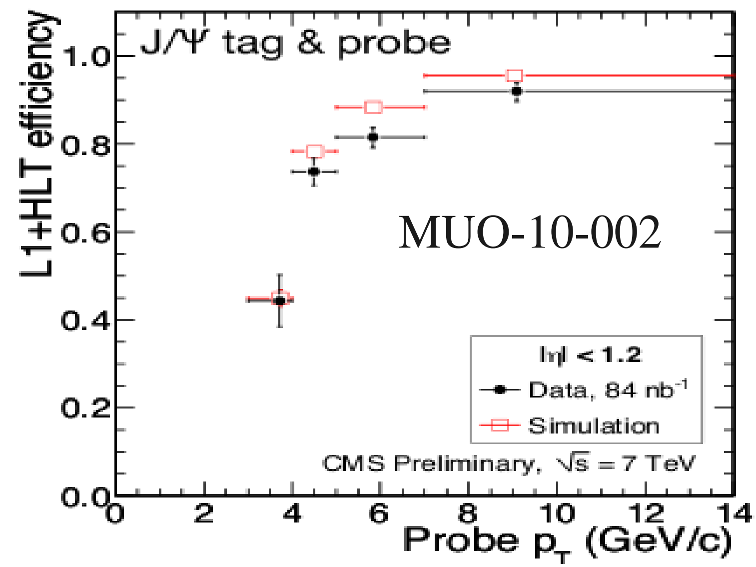
Jets association efficiency

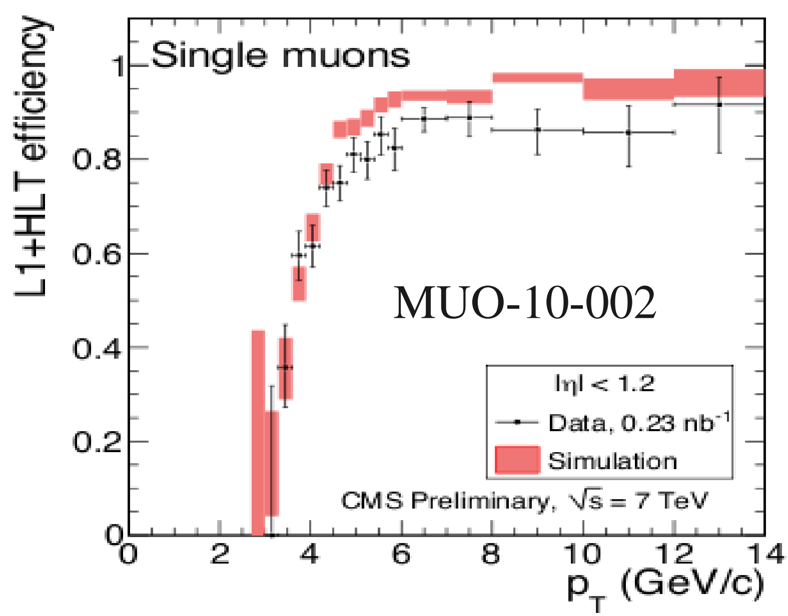
Obtained from MC, validated with data for all muons, depends upon muon PT and jets ET threshold

Efficiency for b muons(6-30 GeV) ε_{jets} = **65-95%**

Uncertainties $\Delta\varepsilon_{jets}$ < 10%

Trigger efficiency from data using dimuons(up) and unbiased sample(down)





Systematics

Main sources of systematics:
1. Luminosity measurements (~11%)
2. Instrumental: momentum resolution, muon and tracks efficiencies (<5%)
3. Theoretical:
production mechanism, fragmentation model, underlying events, decays

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 %

In particular:

Templates uncertainties

MC templates from different UE tunes: *PYTHIA6(D6T, A-tune, ProQ20, CW)*
Different showers and fragmentation models: *PYTHIA6, PYTHIA8, HERWIG*
Decays and NLO : *EvtGen, MCNLO*

Agreement within 20%
(largest deviation for Herwig)

Jets association efficiency

Using different jets type: TrackJets and Particle Flow Jets(with the calorimeter info)
Vary the jets ET threshold from 0.5 to 5 GeV

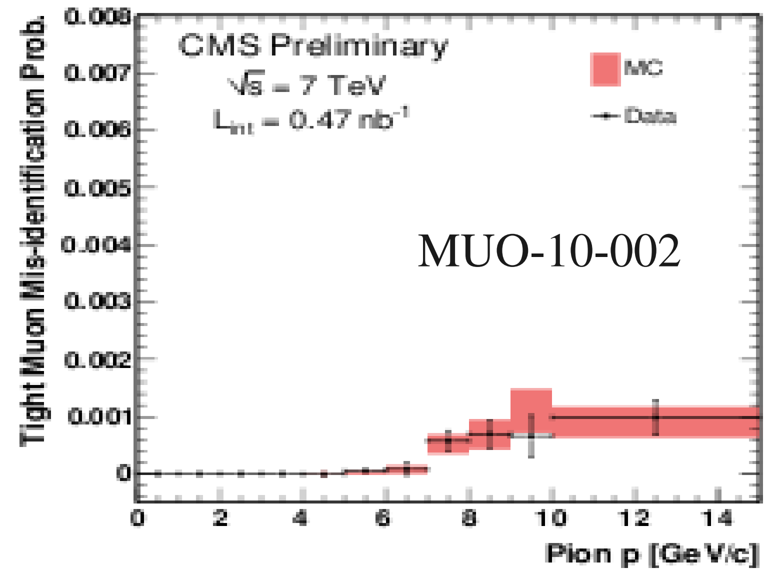
Agreement in ~10%

Templates validation with data

Muons fake rate from pions
Measured using K, Λ, Φ

Data driven(dd) *udsg* template

Use tracks in inclusive QCD jets instead of muons
Reweight tracks according to the muon 'fake' rate
(dd *udsg* template is slightly harder than MC)

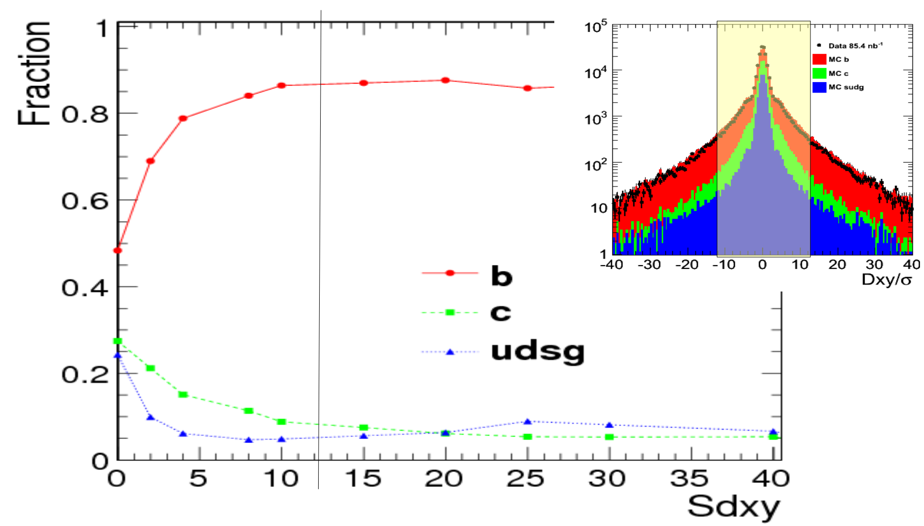


Add dd *udsg* template to c template from MC
Uncertainties in *c* fraction leads to ~ 6% in *fb*
Use of dd *udsg* template instead of MC
~10% change in *b* fraction

Fraction of b muons at different cut on Sdxy (gen level)

Data driven *b* templates

Select muons with large
impact parameter significance
For Sdxy=dxy/σ >12
~85% coming from *b* decays
The dd *b* template is close to the MC
prediction ~15% variations in cross section



Template fit with Impact Parameter

Independent check using
impact parameter related observables

- Similar to Ptrel fit use two templates: *b* and non *b* (udsg from tracks)

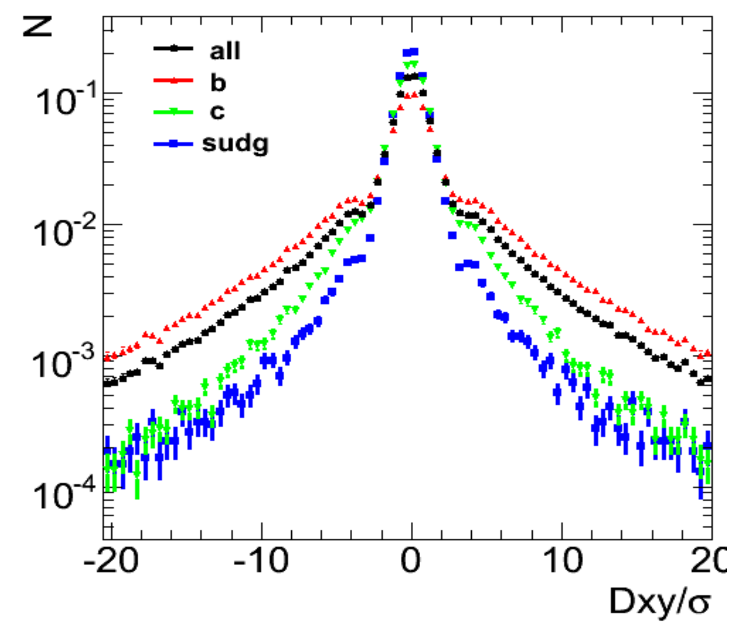
- *B* fraction with Impact parameter fit is ~10% below the Ptrel results.

- Cross section with the fit using muon without associated jet is ~16% below PTrel results

- Use different impact parameters definitions:

-in respect to primary vertex(PV)
-in respect to beam spot
-PV without muon
-signed IP to the jets direction
→ agree in ~10%

Impact parameter significance(Sdxy) distribution for muons from b,c,udsg (gen. level)



Agreement within 20% with the PTrel fit.
Consistent with the anticipated systematics.

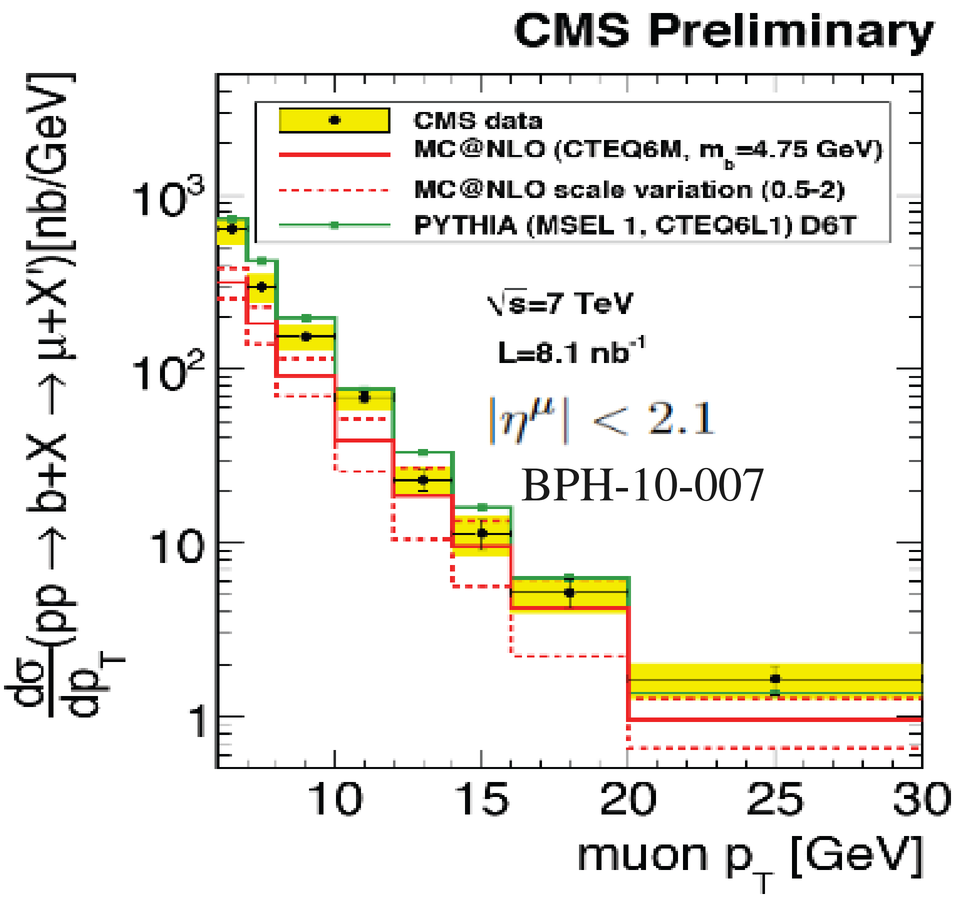
Template fit validation

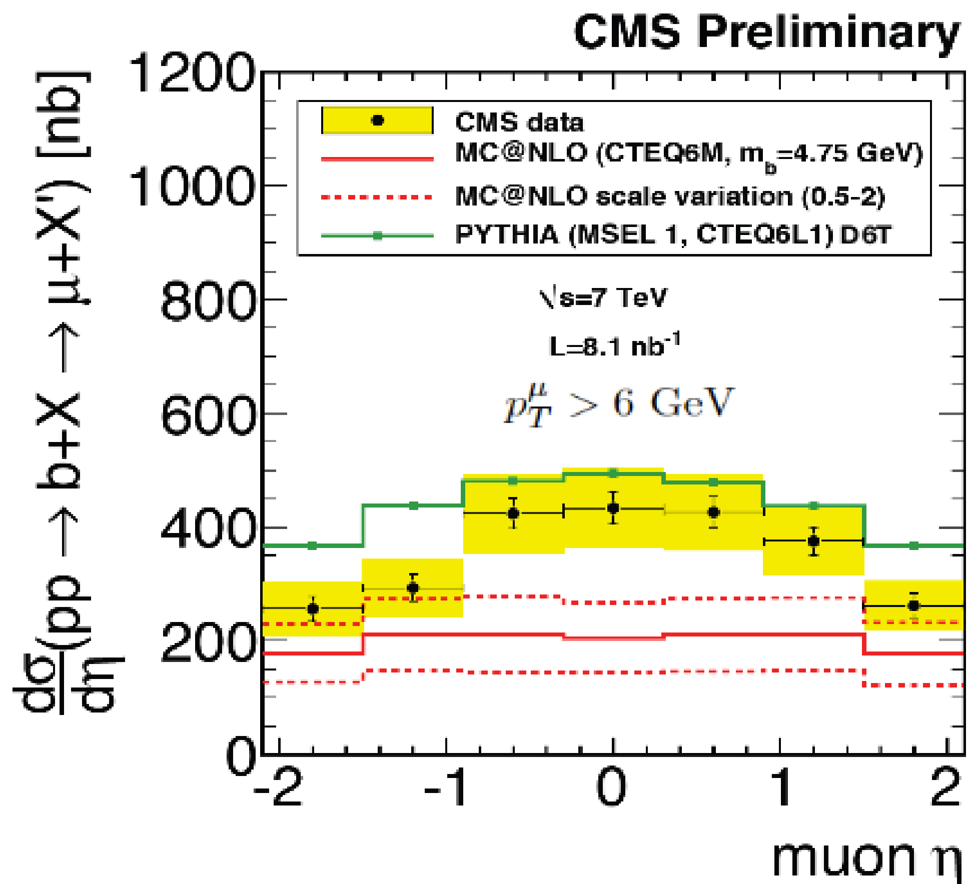
Stability checks

- rebining of templates used in fit : <2% effect
- artificially rescale PTrel *b* template up and down by fixed factor in order to get best fit χ^2 : ~15% variations in *b* fraction
- use three components fit with *b,c, udsg* templates :
  ~10% effect, fit is less stable, one of the fraction(c or udsg) tends to zero.
- vary selection for the tracks in dd light template: <10% changes
- use different jets type PFjets and jets thresholds ET_{thr} =0.5-5 GeV: <10% efffect
- check stability in different runs: agreement within statistical errors

Use PTrel fit with MC(PYTHIA) *B* template and dd *udsg* from tracks for final results
The systematics is ~20% at 6 GeV and decreasing to 10% for higher p_T^{μ}

B → μX cross section at 7 TeV





Total at $\mathcal{L}=8.1\ nb^{-1}$:

σ (pp→ b+X→ μ+X , p_T> 6 GeV, $|\eta_\mu|$< 2.1)= (**1.48 ± 0.04**$_{stat}$ **± 0.22**$_{syst}$ **± 0.16**$_{lumi}$) **μb**

- dominated by systematics
- reasonable agreement with theory (see next slide)

Comparison with theory

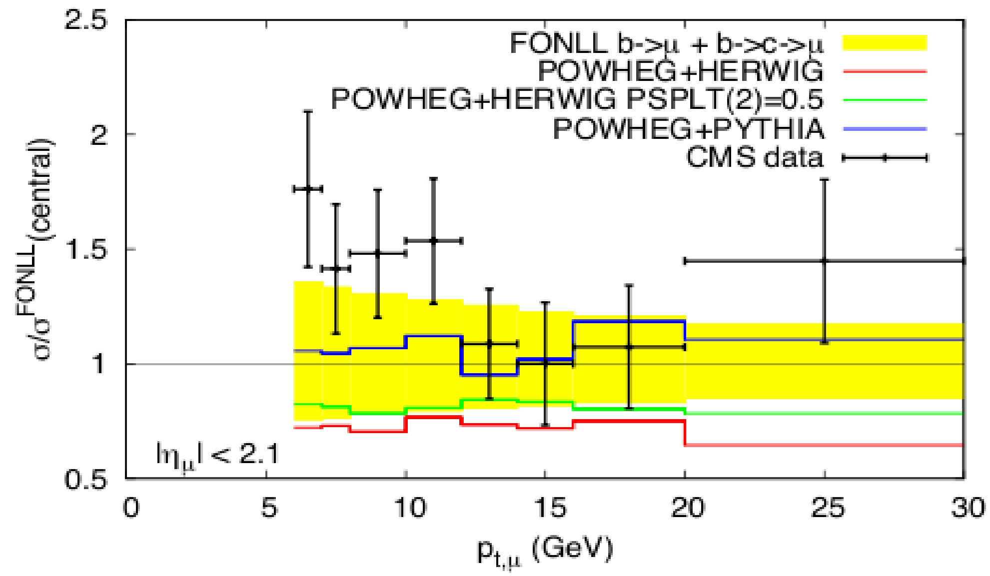
M.Cacciari, V.Chiochia

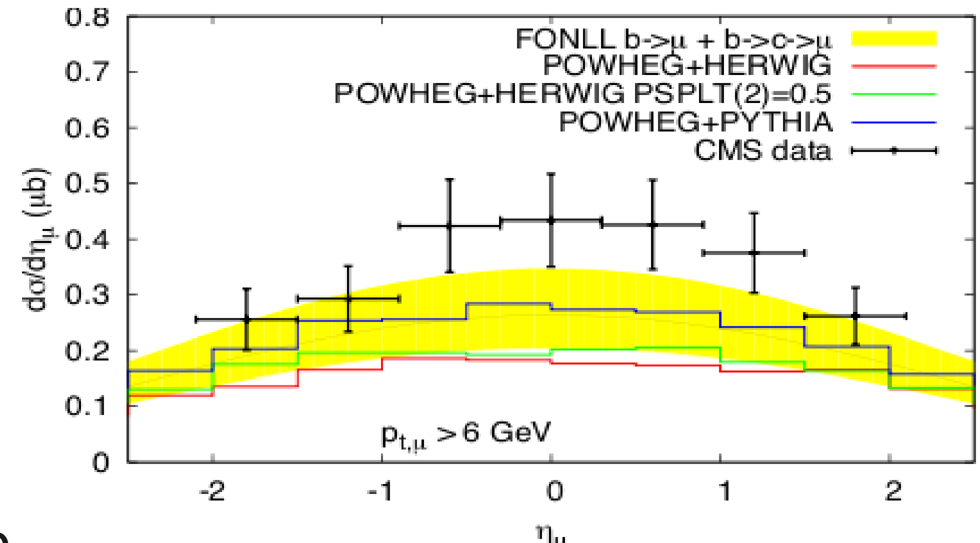
MCNLO3.4+HERWIG653
PDF CTEQ6M
σ = 0.84 μb
+0.36 -0.19 $m_{fragm}/m_{renorm}=0.5$-2
+/- 0.08 $m_b=4.5$-5 GeV
+/- 0.04 LHPDF

PYTHIA6(CTEQ6L):
σ = 1.8 μb

FONLL:
σ = 0.92 μb

- ~50% above FONLL (but in systematics range)
- ~20% below PYTHIA inclusive QCD (LO ME+PS) at low p_T





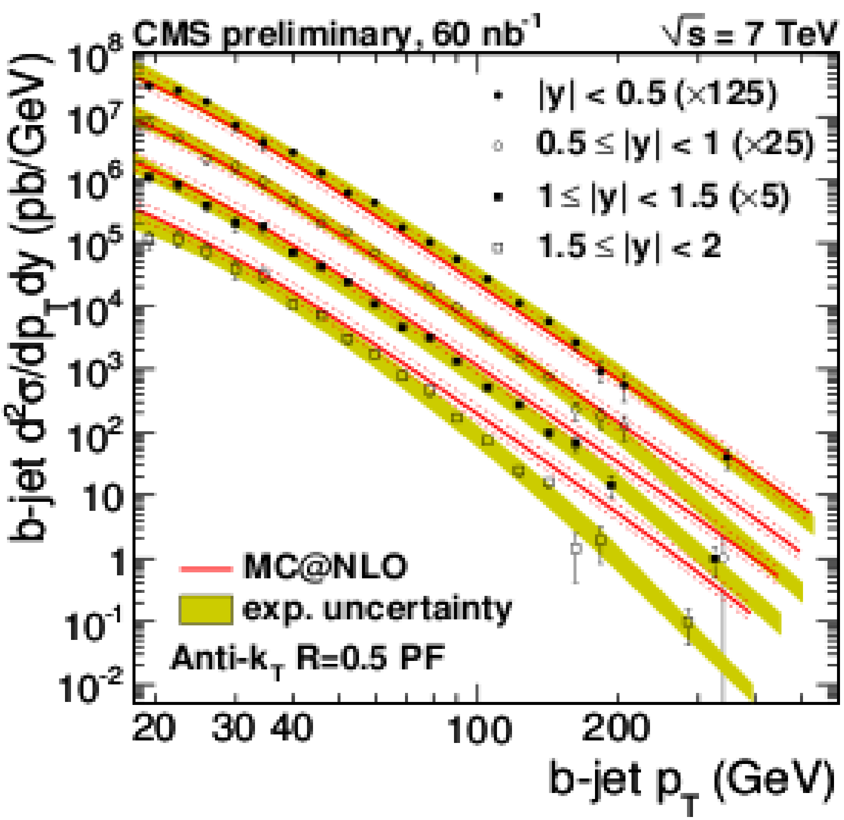
Normalized to FONLL predictions

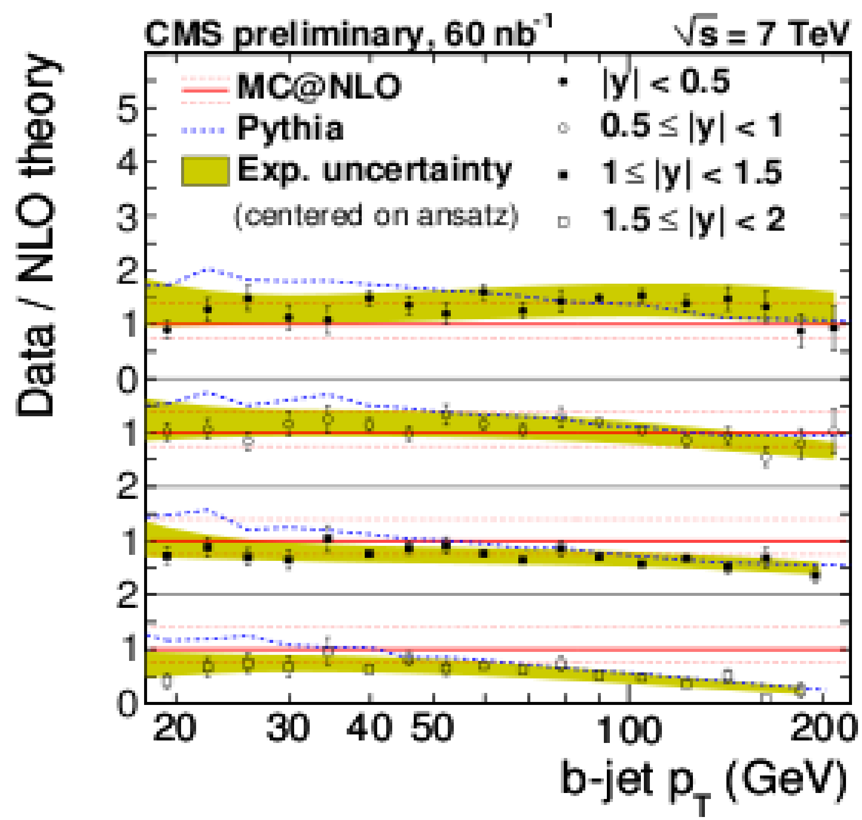
Inclusive *b*-jets

Using secondary vertex b-tagger(SSV)

$$\frac{d\sigma^2_{bjet}}{dp_T dy} = \frac{p_b N_{btagged} C_{smear}}{L\epsilon_b \epsilon_{jet} dp_T dy}$$

p_b - purity of b tagging($\sim 70\%$)
C_{smear} - smearing factor for jets energy resolution
ϵ_{jet} - jets reconstruction efficiency
ϵ_b - b tagging efficiency





Some overestimation of FO NLO at low p_T^b, consistent with $b \to \mu X$

Summary

- Excellent performance of the CMS detector

- Measurements of open b cross section in low $p_T^b < 30$ GeV range with muons $p_T^\mu > 6$ GeV $|\eta| < 2.1$ at $\mathcal{L} = 8.1\ nb^{-1}$ dominated by systematics (~20%) and is slightly above NLO predictions. Results do not change for higher accumulated luminosity.

- Measurements of cross section for $p_T^b > 20$ GeV with b-tagged jets $|y| < 2$ is dominated by systematics (~40%) and also above FO NLO predictions in central region at low $p_T^b < 30$ GeV