ICHEP 2010

Measurement of the inclusive b production cross section in pp collisions at $\sqrt{s} = 7$ TeV

Lea Caminada
(ETH|PSI)
on behalf of the CMS collaboration

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ETH Institute for Particle Physics
CMS
PAUL SCHERRER INSTITUT
PSI

Heavy Quark Production

- Heavy Quark production is an important process for the study of QCD
- Previous measurements at other colliders (Tevatron, HERA, LEP, ...)

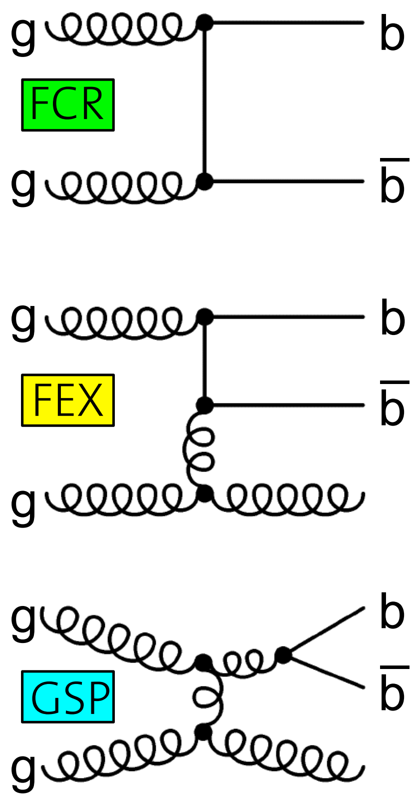
  - reasonable agreement with NLL/NLO QCD predictions
  - sizeable uncertainties

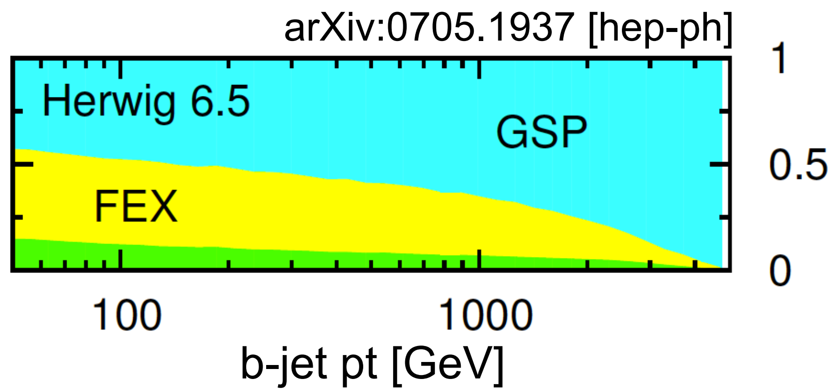
- Large $b\bar{b}$ production cross section in pp collisions at √s = 7 TeV at LHC

  - provides access to new regions in phase space
  - b events present important background to many searches

- b production at LHC

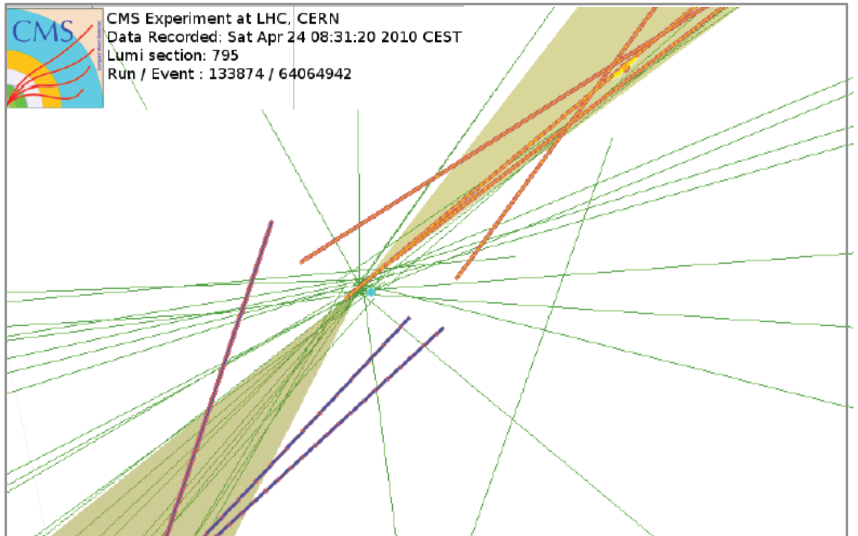
  - LO: Flavor creation (FCR)
  - Large NLO contributions: Flavor excitation (FEX) and Gluon splitting (GSP)



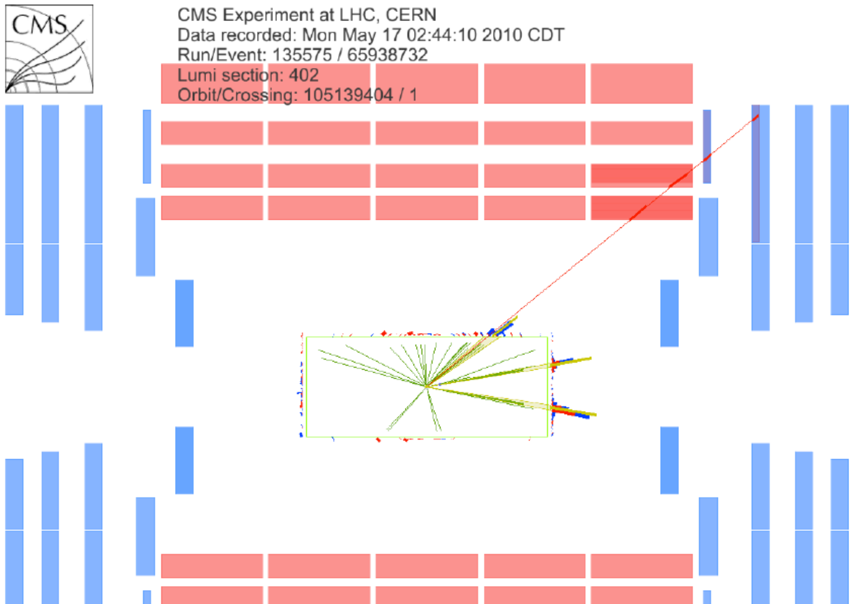


b Identification at CMS

- Use of distinct properties of b quarks
  - long lifetime, large mass, hard fragmentation
- Semi-leptonic and hadronic decays
- CMS very well suited for b physics due to excellent tracking and muon detectors
  - Pixel detector for precise reconstruction of secondary vertices
  - Muon system with ability to trigger on low p_T muons (p_T > 3 GeV)



Double b-jet candidate
CMS DPS -2010/015



Muon event
CMS PAS MUO-10-002

CMS Inclusive b Production Results

- Based on LHC data collected by the CMS experiment between March and July 2010

- CMS PAS BPH-10-007: Open beauty production cross section with muons in pp collisions at $\sqrt{s} = 7$ TeV

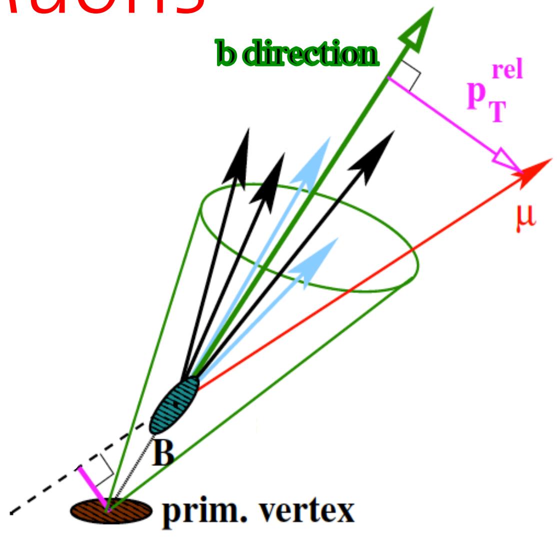
- CMS PAS BPH-10-009: Measurement of the inclusive b-jet production in pp collisions at $\sqrt{s} = 7$ TeV

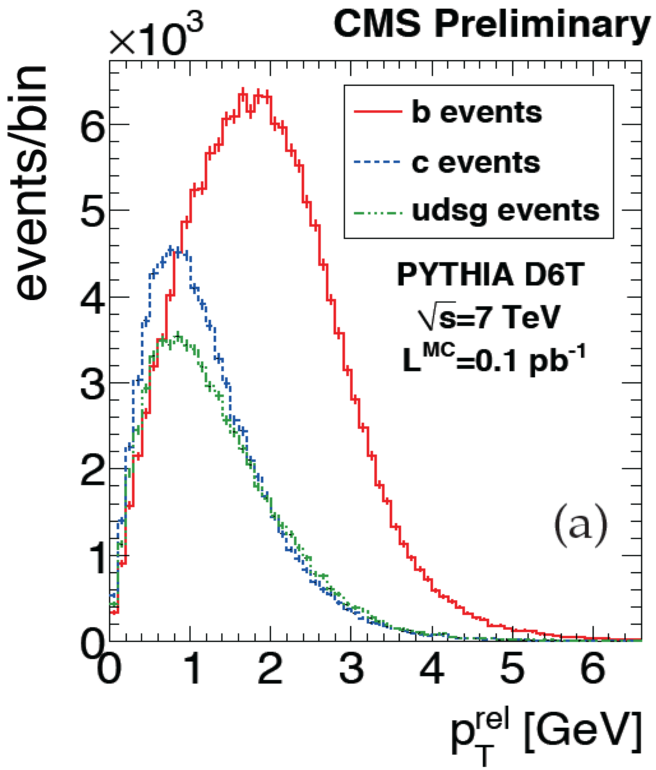
  → Poster by S. Honc:
  „Inclusive b-jet production measurement on early CMS data"

- Two independent measurements with their own systematic uncertainties and covering different regions in phase space

Open b Production with Muons

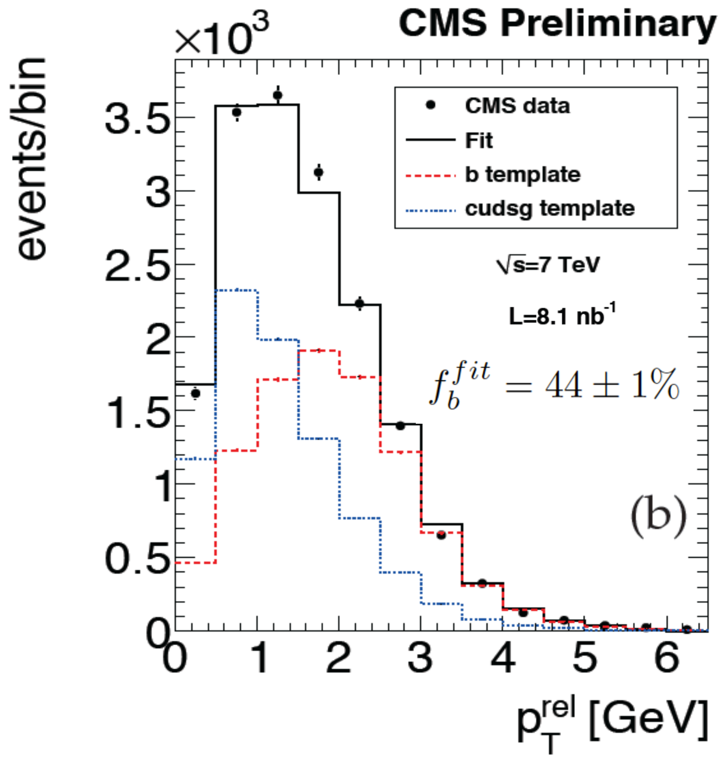
- Semi-leptonic b decays into muons
  - Single muon trigger ($p_T > 3$ GeV)
  - Muon $p_T > 6$ GeV, $|\eta| < 2.1$
    (Efficiency: trigger ~82%, reconstruction ~97%)
  - Signal events discriminated from background events based on muon p_T^{rel} (on average harder in b events due to larger b mass)
  - b direction reconstructed from tracks only
    → Tracks clustered by anti-k_T (R=0.5) algorithm
    → very good angular resolution (2-8%)
    → Efficiency of 74% to almost 100% depending on muon p_T
- Measurement of total cross section and differential cross section as a function of muon p_T and pseudo-rapidity with an integrated luminosity of L = 8.1 nb^{-1}





Cross Section Measurement

- Binned maximum likelihood fit to measured p_T^{rel} distribution
  - b and c templates from MC (signal validated in b-enriched data)
  - Data-driven template for muons from light quarks and gluons (measurement of in-flight decays)
  - Background combined in fit
  - Different templates for each bin in muon p_T and **η**



$$N_b^{data} = f_b^{fit} N^{data}$$

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

- N_b^{data} : number of b events in data
- ε : trigger and reconstruction efficiency
- $\mathcal{L}$: integrated luminosity

b Cross Section with Muons at √s = 7 TeV

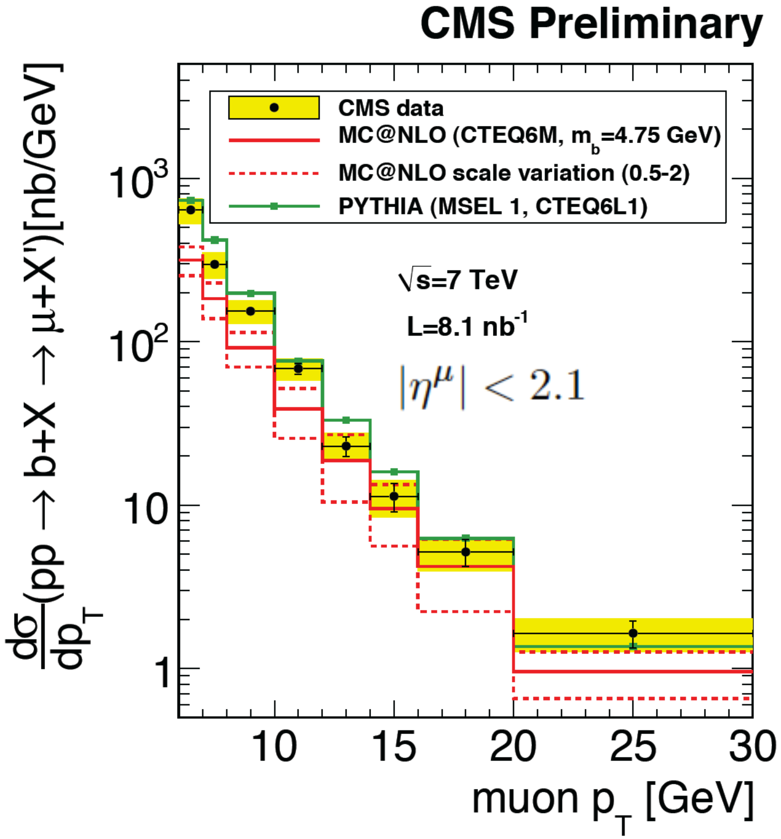
- Visible b cross section

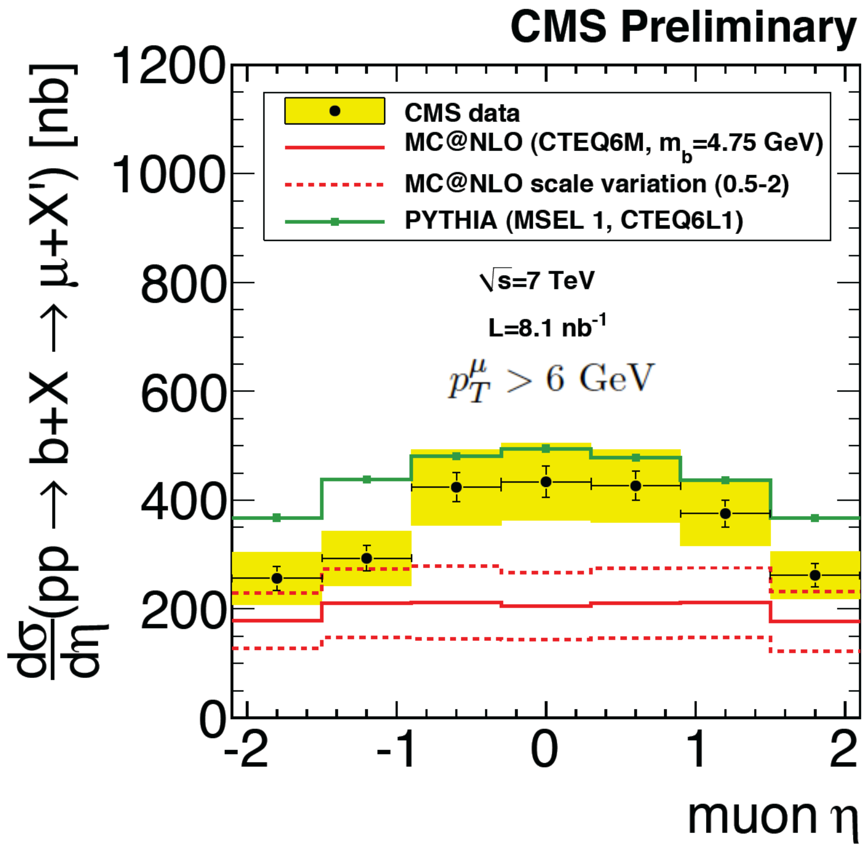
$$\sigma = (1.48 \pm 0.04_{\text{stat}} \pm 0.22_{\text{syst}} \pm 0.16_{\text{lumi}})\ \mu\text{b}$$

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

$$(\mu_F = \mu_R = p_T)$$

- Differential b cross section





- Measurement in agreement with MC@NLO for muon $p_T > 12$ GeV, while data is above the prediction in the central region at low p_T

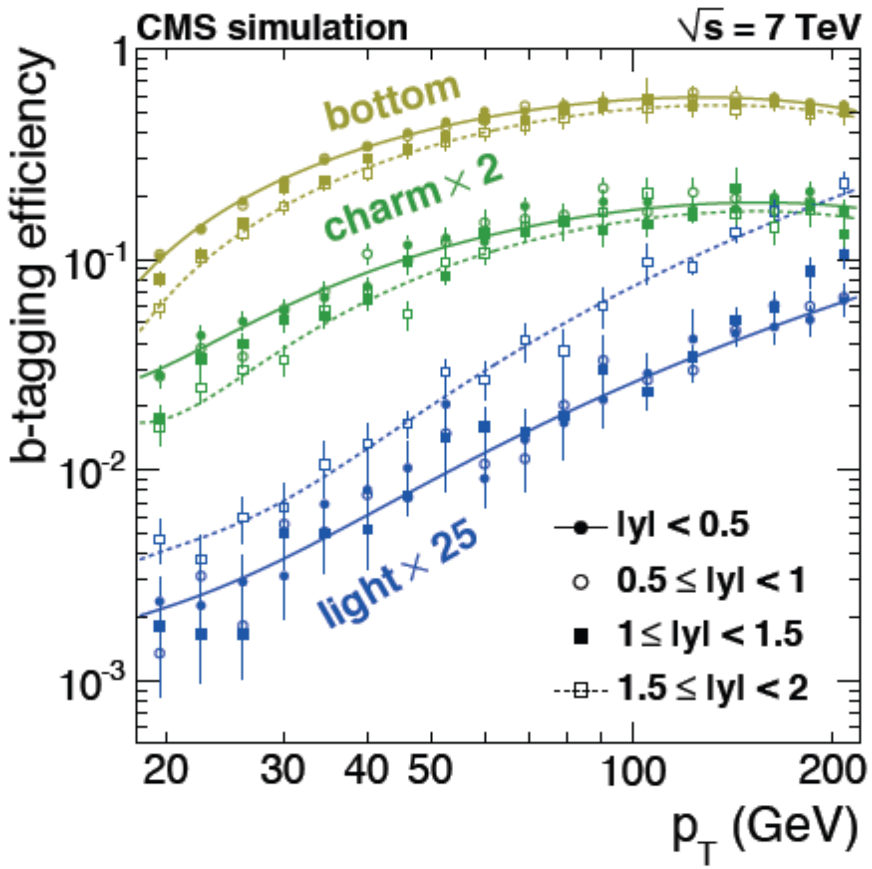
Systematic Uncertainties

- Systematic uncertainty dominated by the description of the light quark background template and the underlying event as well as the luminosity uncertainty
- Modelling of b production and decay are better understood and have less impact

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 %

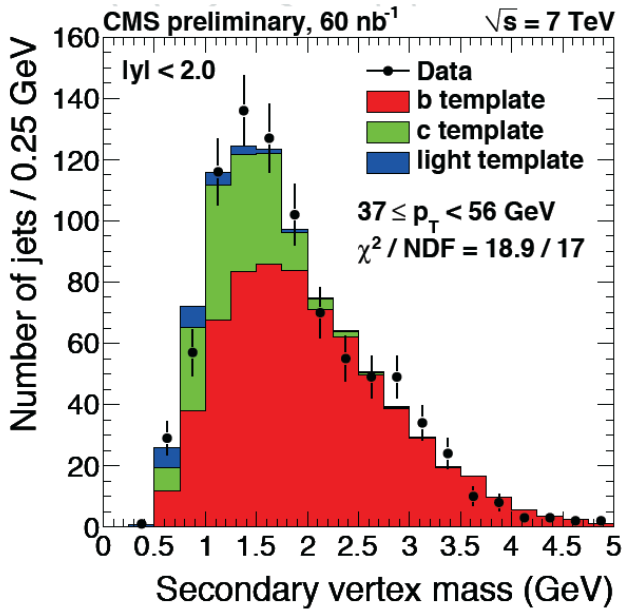
Inclusive b-jet Production

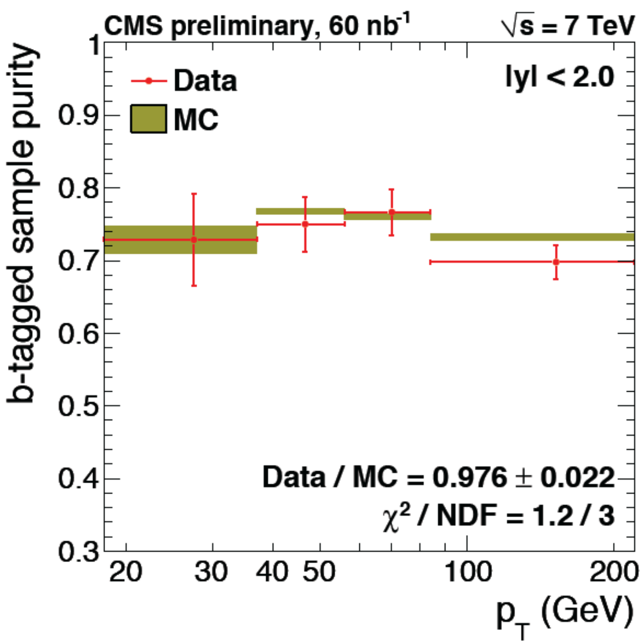
- Measurement of the inclusive b-jet cross section and ratio to the inclusive jet production with L = 60 nb^{-1}
- Events collected with a combination of minimum bias and jet triggers
- Jets ($18 < p_T < 300$ GeV, $|y| < 2$) reconstructed by anti-k_T algorithm (R=0.5) using tracker and calorimeter information (Particle Flow) [CMS PAS PFT-10-002]
- b-tagging based on secondary vertex reconstruction
  - Vertex with at least 3 tracks and large flight length significance
  - b-tagging efficiency from MC, verified in subsample by measurement of scale factor using p_T^{rel}
    $\epsilon_b^{Data}/\epsilon_b^{MC} = 0.98 \pm 0.08 \pm 0.18$
  - Mistag rate from MC, constrained by data-driven study using negative-tag discriminator

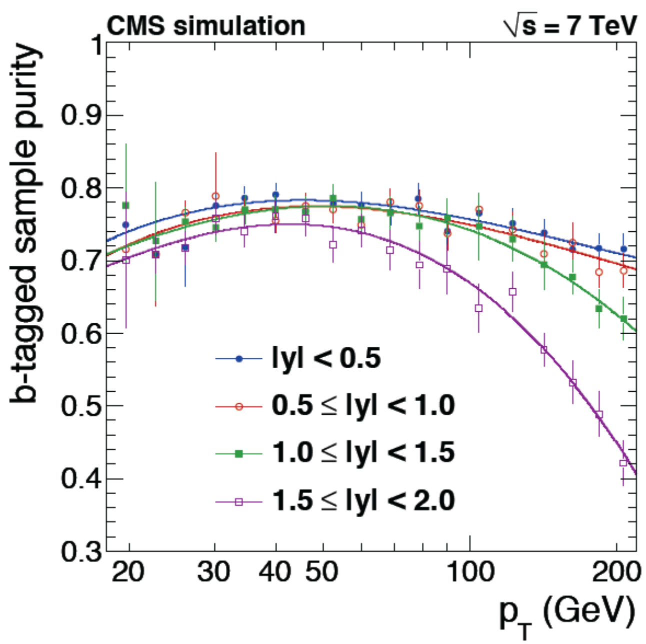


b-tagged Sample Purity

- Estimated using two complementary approaches
  1) Data-based: Fit to secondary vertex mass
  2) MC-based: $f_b = \dfrac{F_b \epsilon_b}{F_b \epsilon_b + F_c \epsilon_c + F_l \epsilon_l}$ (F: flavor fraction)
- Good agreement between data and MC: $Data/MC = 0.976 \pm 0.022$
- Central values taken from MC for proper treatment of p_T and y dependence



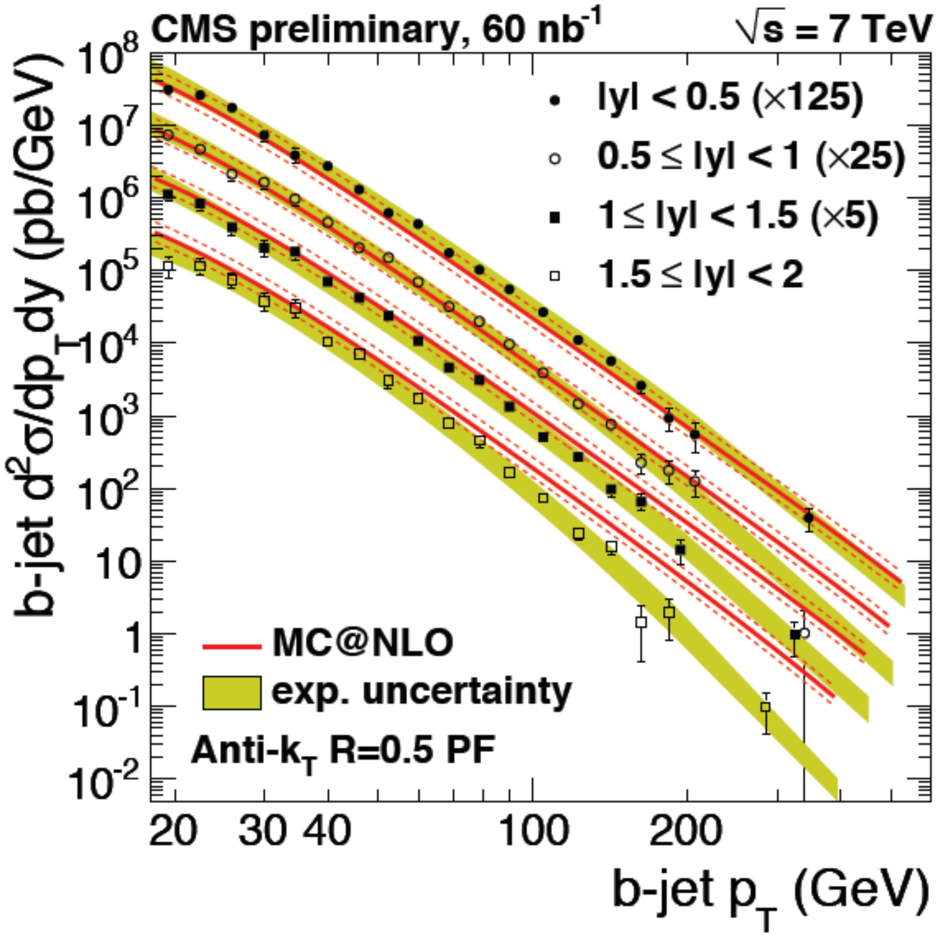


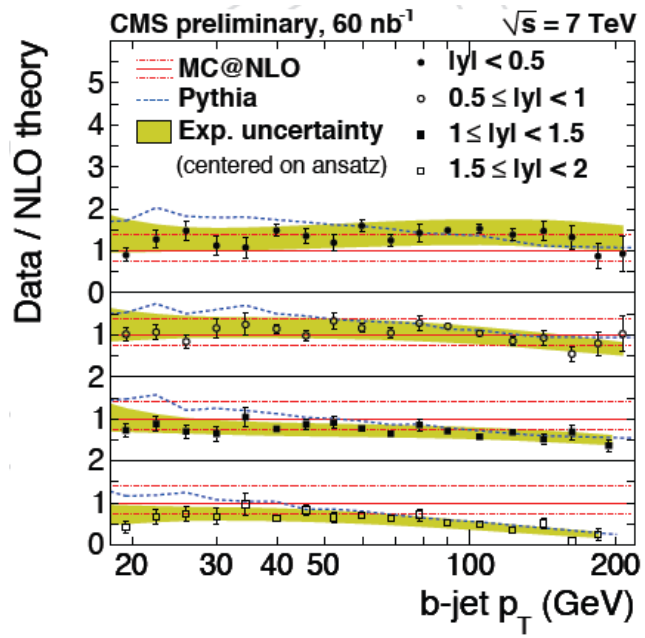


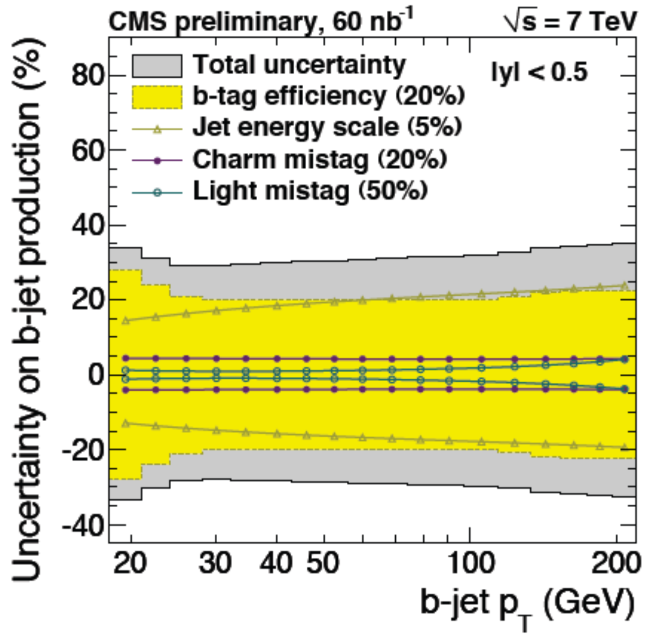
b-Jet Cross Section at √s = 7 TeV

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

with C_{smear} : unfolding correction
ϵ_{jet} : jet reconstruction efficiency
ϵ_b : b-tagging efficiency

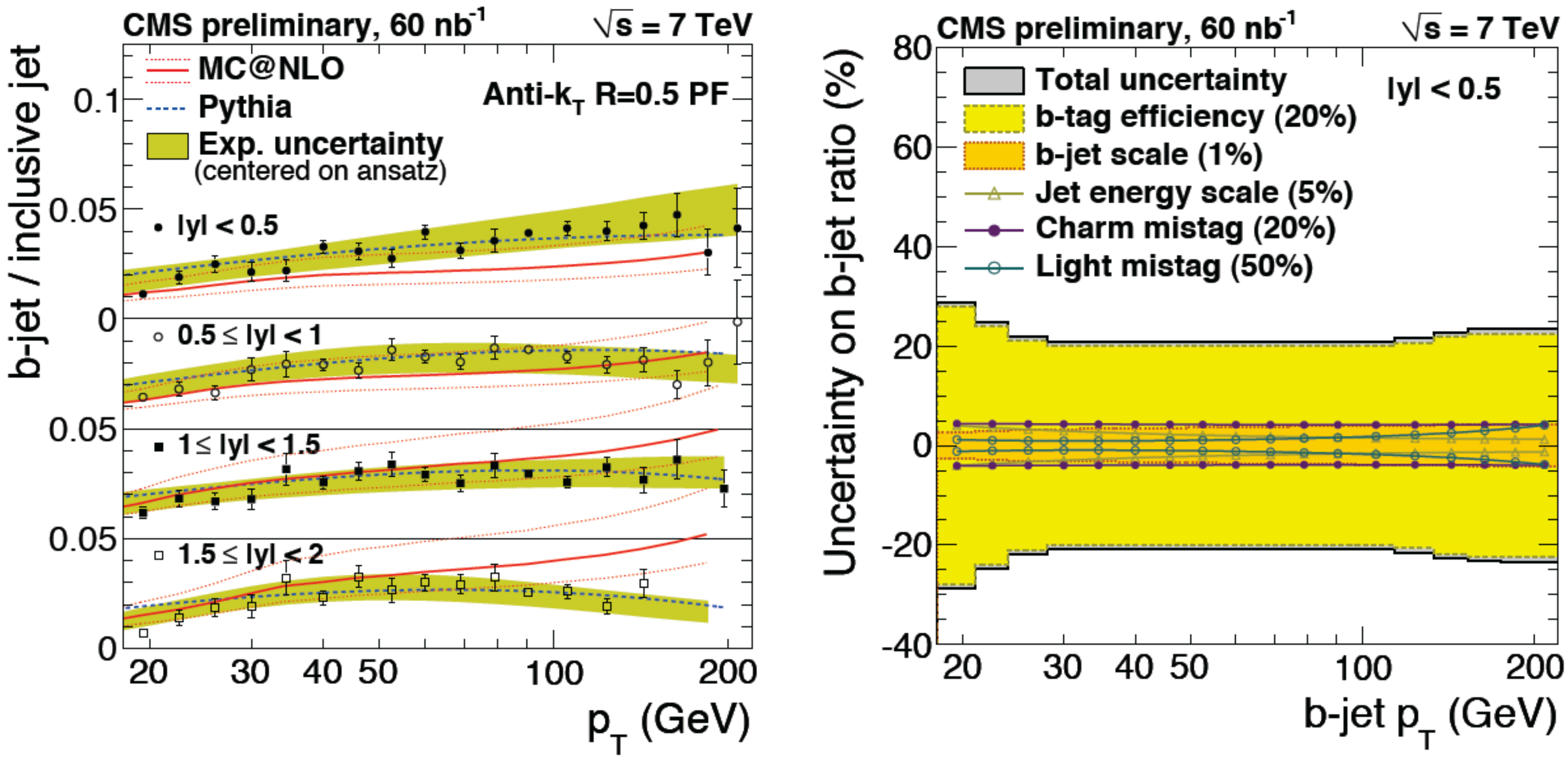






Ratio to Inclusive Jet Cross Section

- Inclusive jet cross section measurement → Talk by M. Voutilainen [CMS PAS QCD-10-011]
- Measurement of ratio reduces experimental uncertainty from jet energy reconstruction and luminosity
- Fit of measured ratio of data and PYTHIA for $30 < p_T < 150$ GeV and $|y| < 2$ yields scale factor of $0.99 \pm 0.02(\text{stat}) \pm 0.21(\text{syst})$

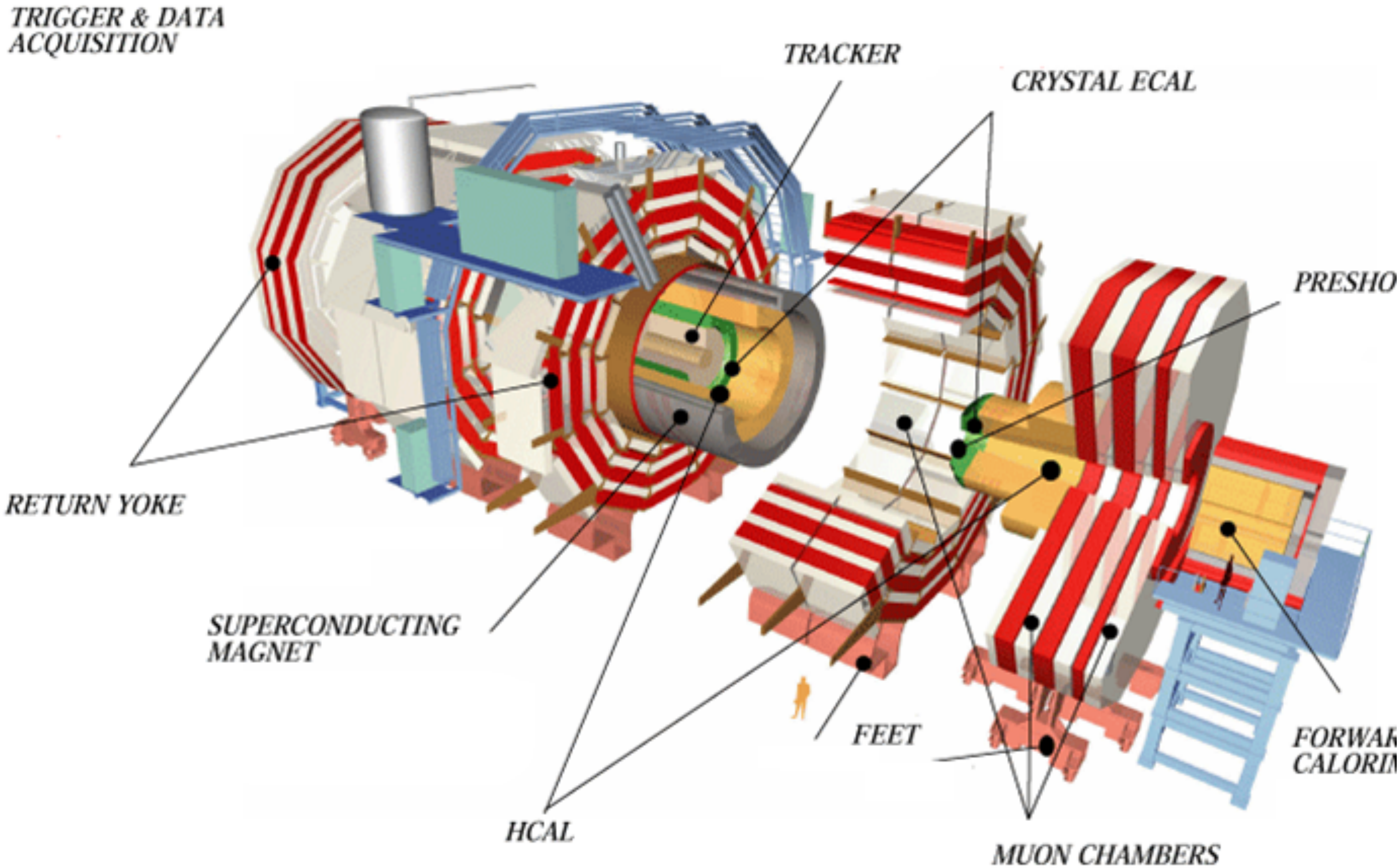


Conclusions

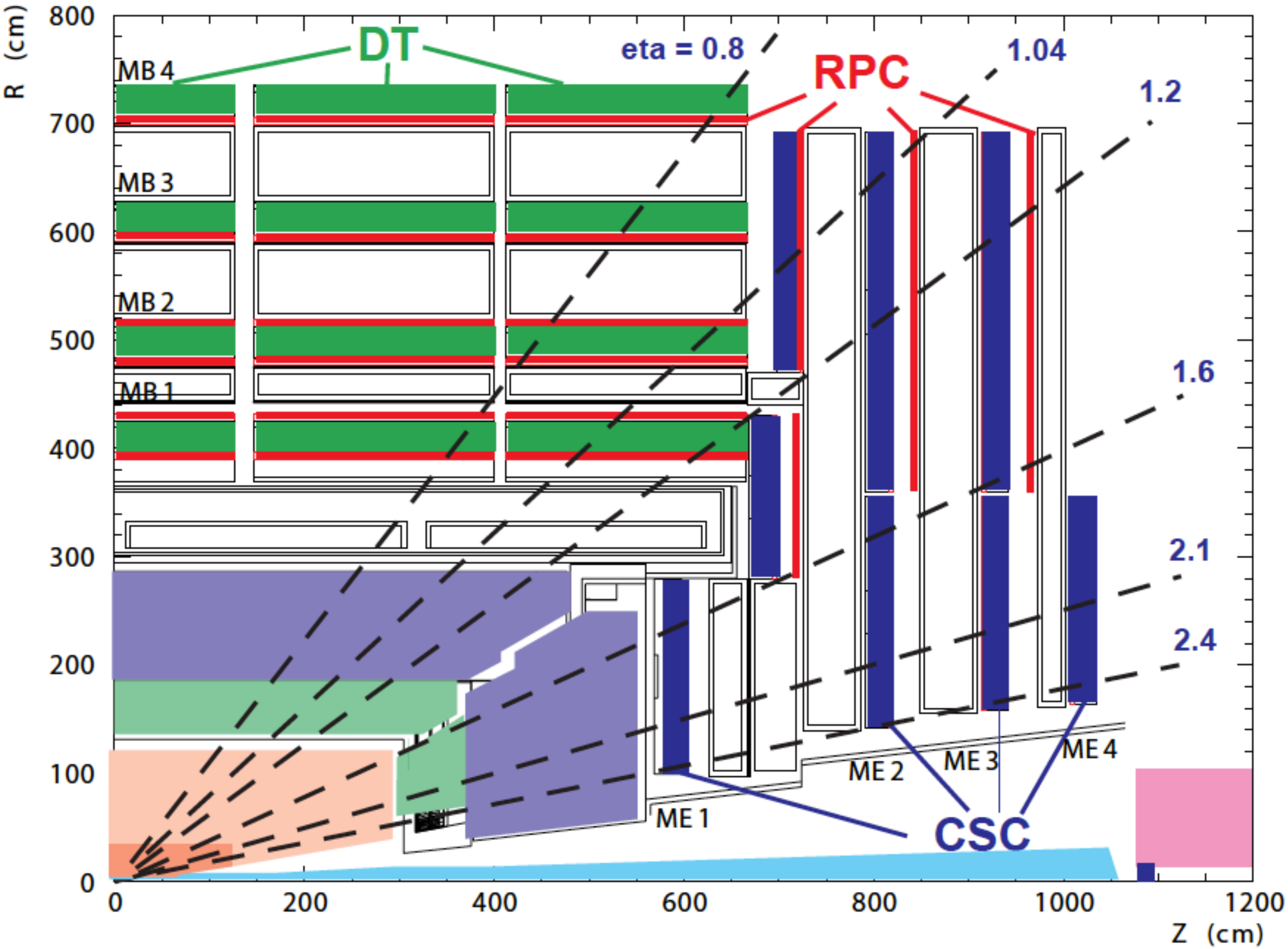
- Presented the first measurements of the inclusive b production at $\sqrt{s}$ = 7 TeV
- Open b production with muons:
  - Measurement for muon p_T = 6-30 GeV, $|\eta| < 2.1$ with statistical error of 5-20% and systematic uncertainty of 16-20%
  - Good agreement with MC@NLO at muon $p_T > 12$ GeV, while data are above the prediction in the central region at low p_T
- Inclusive b-jet production:
  - Measurement for jet p_T = 18-300 GeV, $|y| < 2$
  - Overall good agreement with PYTHIA within ~2% statistical and 21% systematic uncertainty
  - Reasonable agreement with MC@NLO for overall cross section, but shape differences in p_T and y

Backup

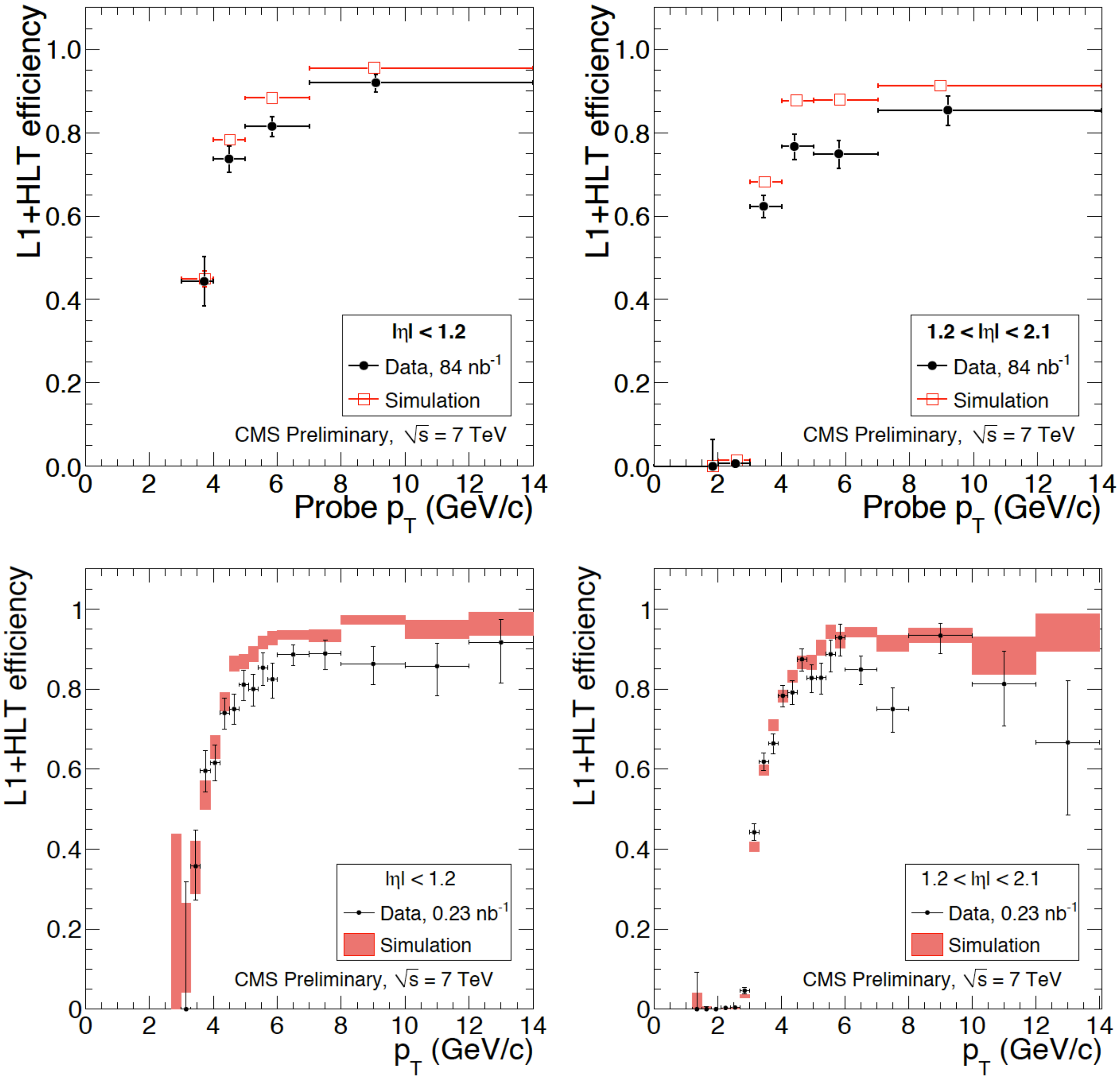
CMS Detector



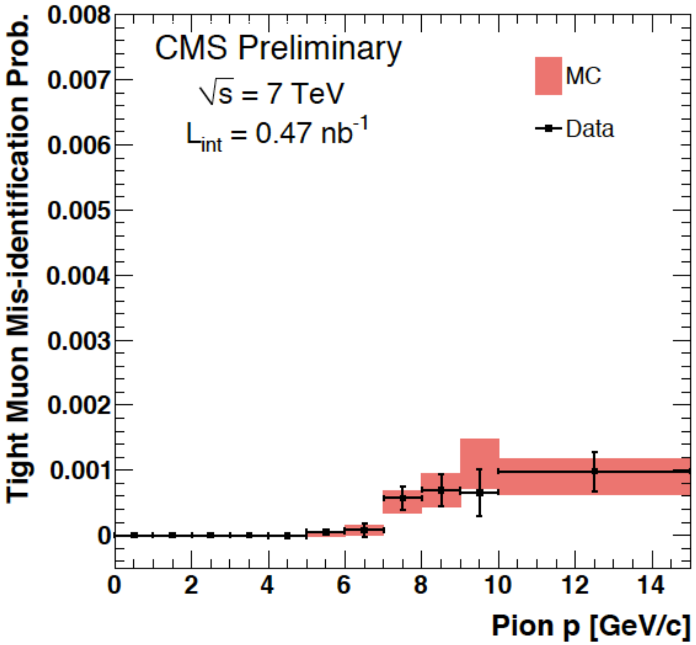
CMS Muon System

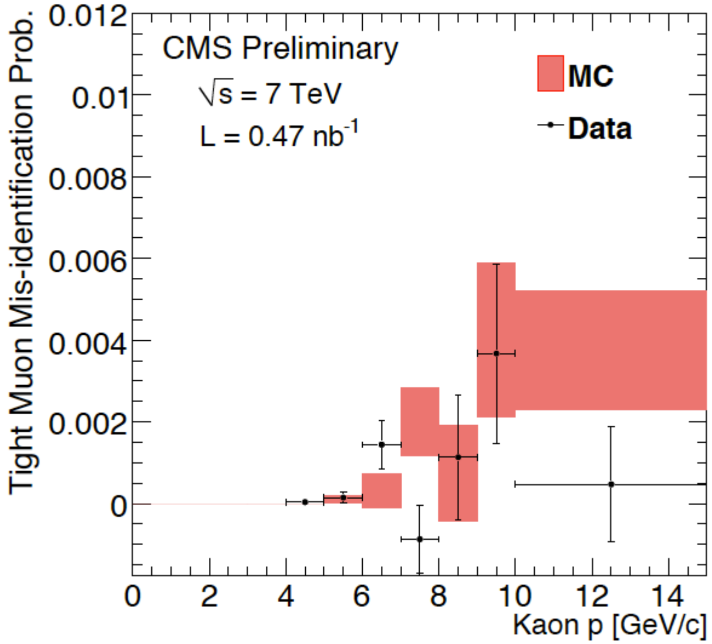


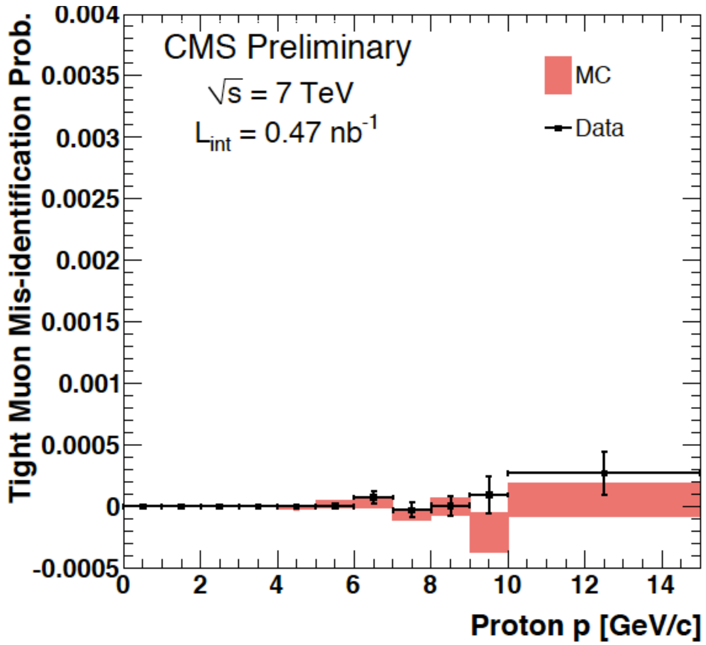
Muon Trigger Efficiency



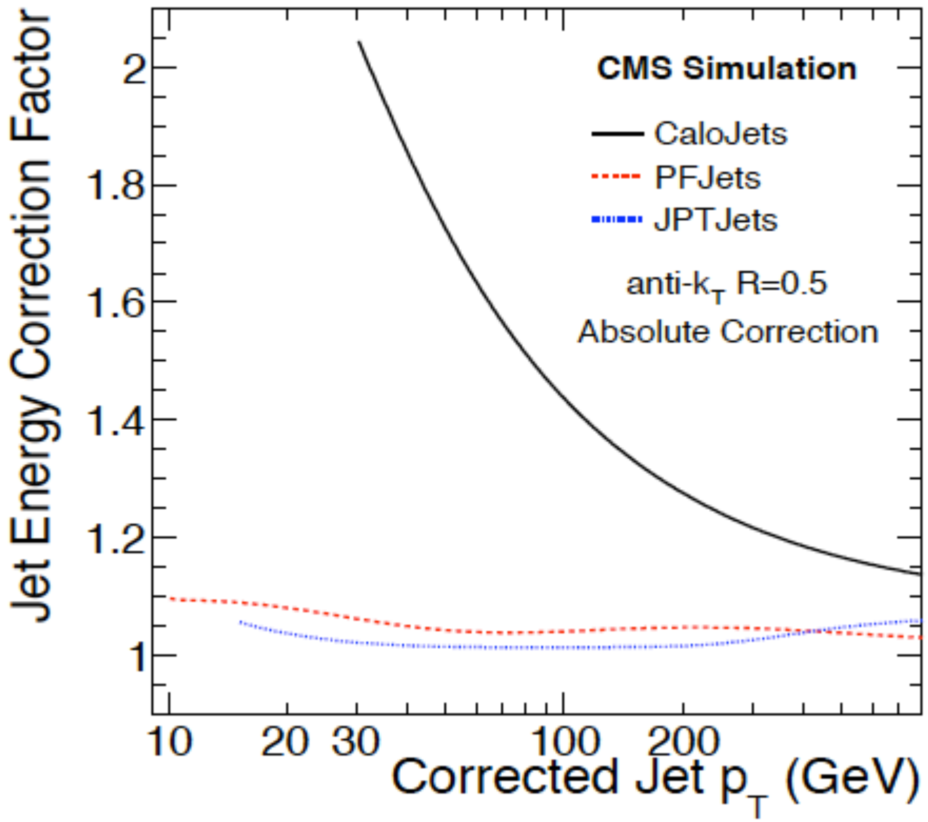
Fraction of pions, kaons and protons mis-identified as muons

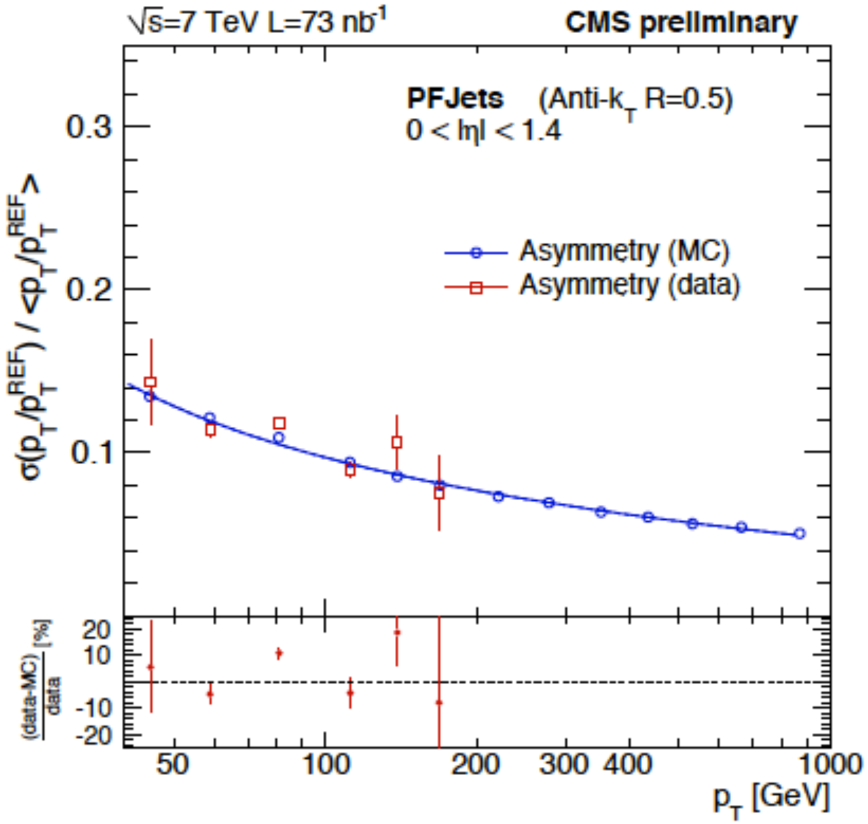






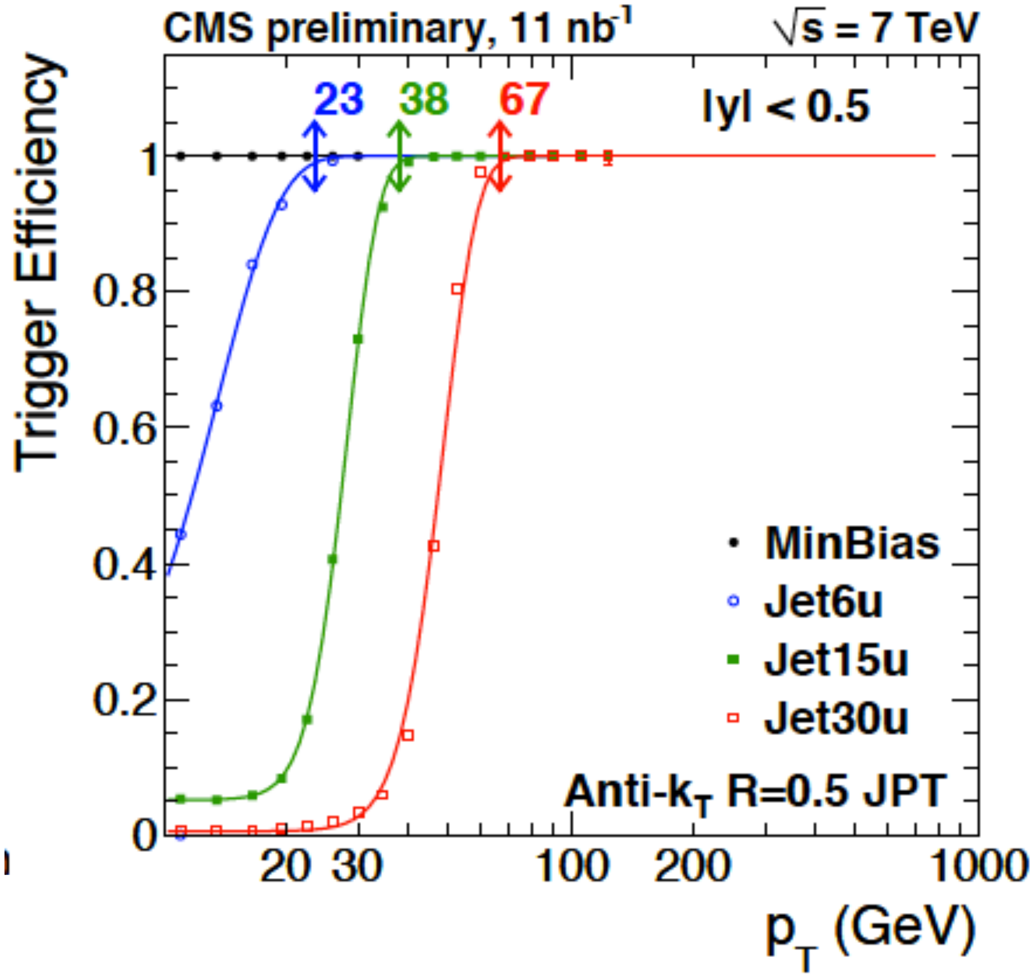
Jet Energy Correction and Jet Energy Resolution





Jet Trigger

- Minimum bias and single jet triggers p_T > 6, 15, 30 GeV
- Combined exclusively at ~99% turn-on



Unfolding → Talk by M. Voutilainen

- 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

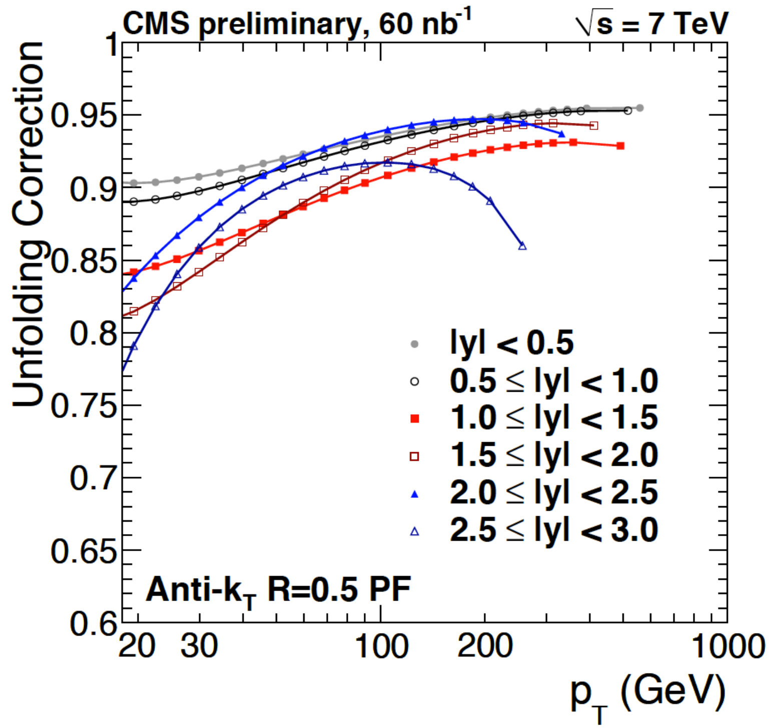
$$f(p_T) = \underbrace{N_0 p_T^{-\alpha}\left(1 - \frac{2p_T \cosh(y_{\min})}{\sqrt{s}}\right)^{\beta}}_{\text{high } p_T} \underbrace{\exp(-\gamma/p_T)}_{\text{low } p_T \text{ and b-jets}}$$

new

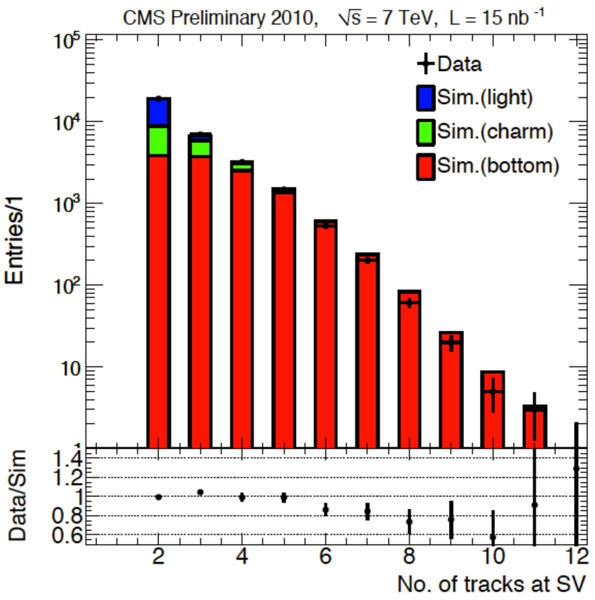
$$F(p_T) = \int_0^\infty f(p'_T) R(p'_T - p_T; \sigma) dp'_T$$

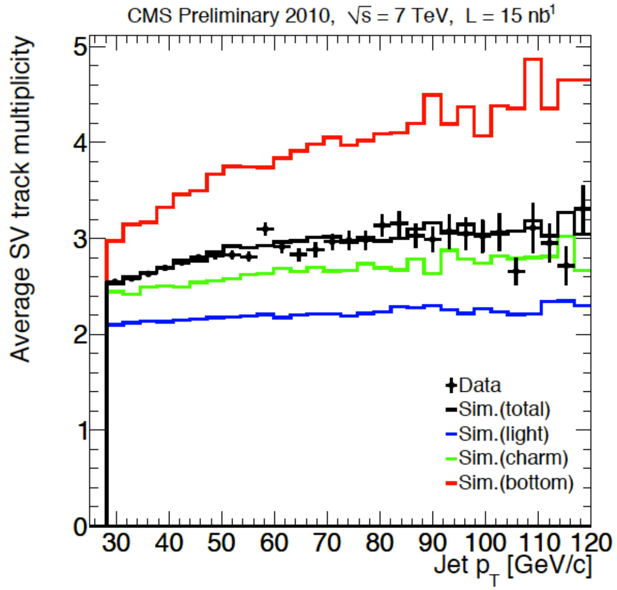
$R(p'_T - p_T; \sigma)$: smearing function

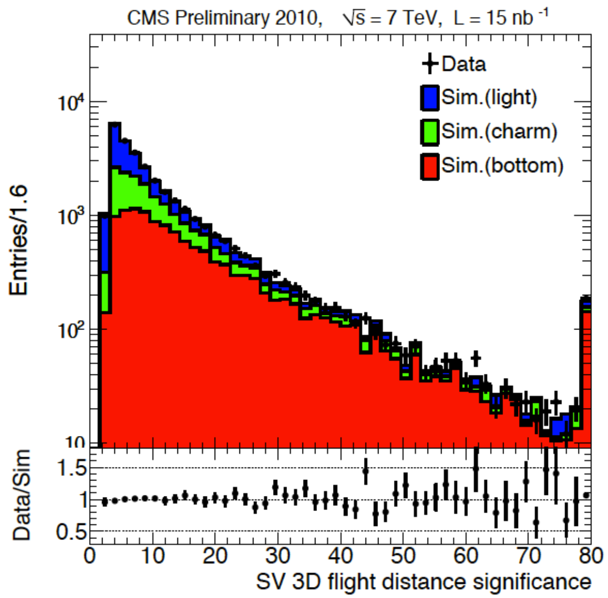
$$C_{res} = f(p_T)/F(p_T)$$

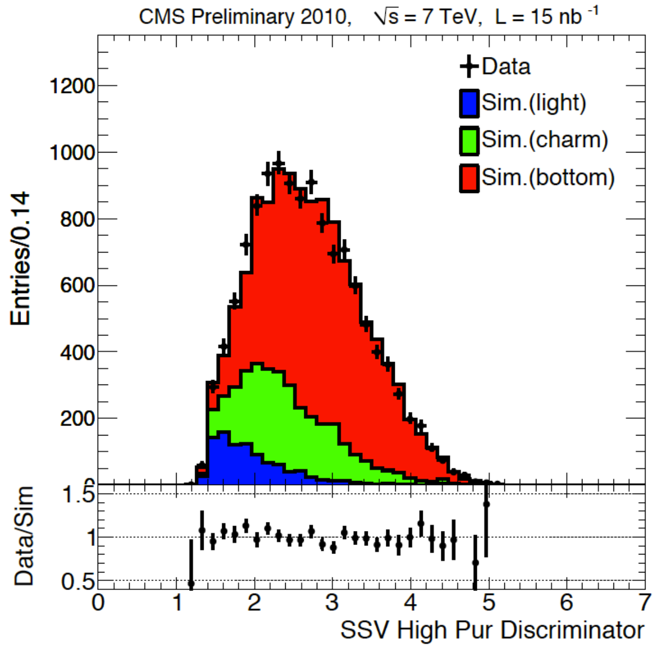


B tagging: Secondary Vertex Properties and Discriminator

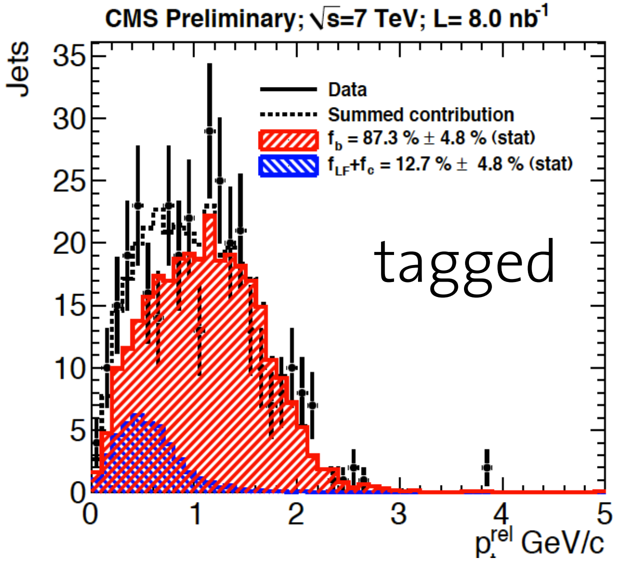


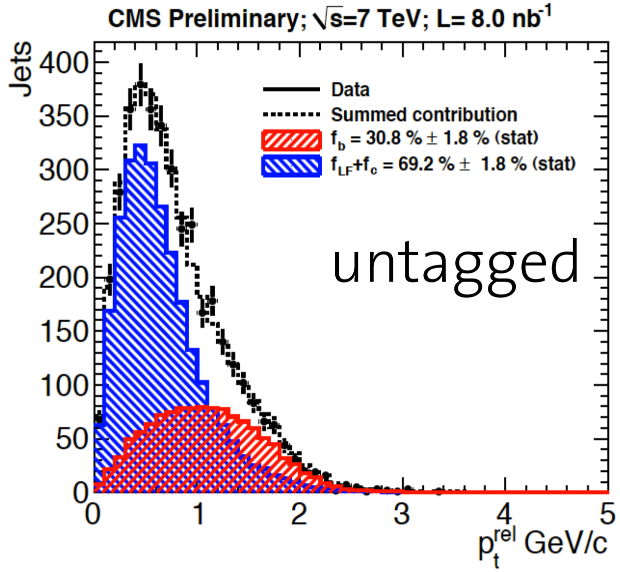






B tagging Efficiency





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

Tagger+Operating Point	ϵ_b^{data}	ϵ_b^{MC}	SF_b
SSVHPT	0.203 ± 0.015	0.207 ± 0.002	$0.98 \pm 0.08 \pm 0.18$

- 12% systematic uncertainty derived from study of jet p_T and η modelling (4-8%), muon selection (2-8%), jet flavor assignment (2%), pile-up (3%), shape of light quark background (3-5%)
- Additional systematic uncertainty of 15% to effects not yet studied(p_T^{rel} shape for b and non-b jets, fragmentation, effect of trigger, jet energy scale uncertainty)