Measurements of Inclusive B-quark Production at 7 TeV with the CMS Experiment

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on behalf of the

CMS Collaboration

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Summary

- LHC and CMS at Glance
- b-hadron Physics:
  Main Features and Reasons of Interest
- b-tagging with CMS Detector
- Inclusive b-hadron Production with Muons
- b-hadron Measurements with Secondary Vertexing
- Conclusions and Outlook

The LHC accelerator

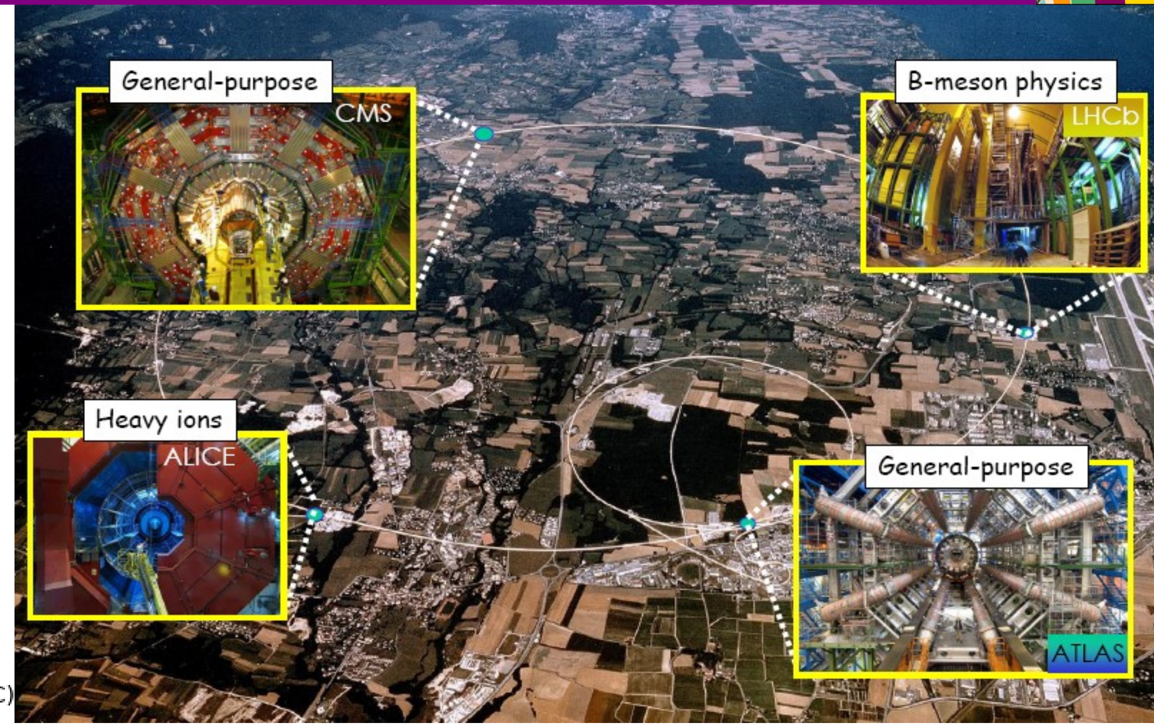
Excellent performances of the machine running smoothly @ 7 TeV since 2010

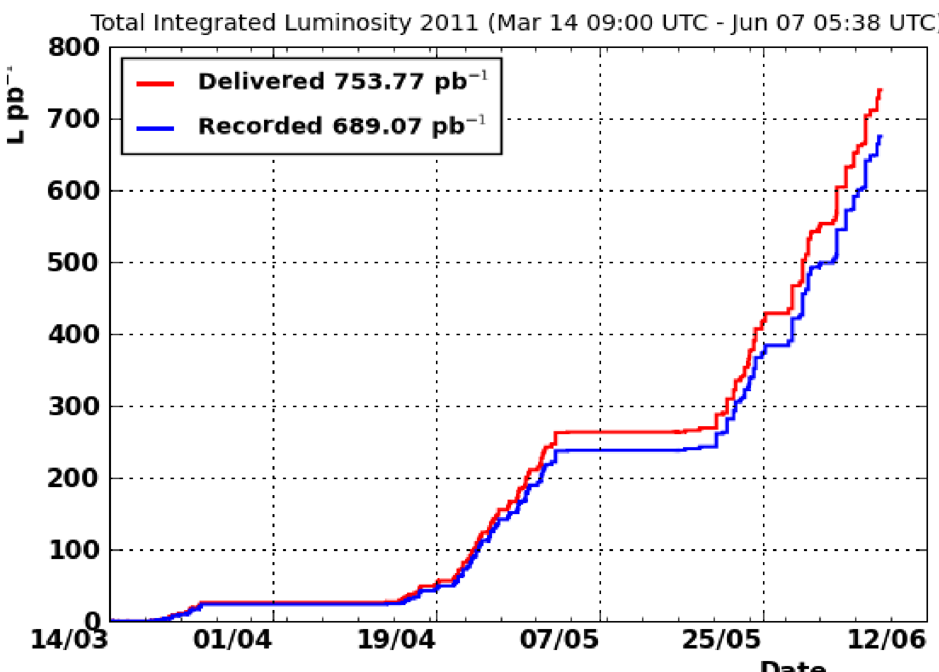
Current records:

Instantaneous luminosity already reached 1.27×10^{33} cm^{-2}s^{-1}

1092 proton bunches circulating,

up to with $1.7 \cdot 10^{11}$ protons/bunch , time spacing 50 ns.





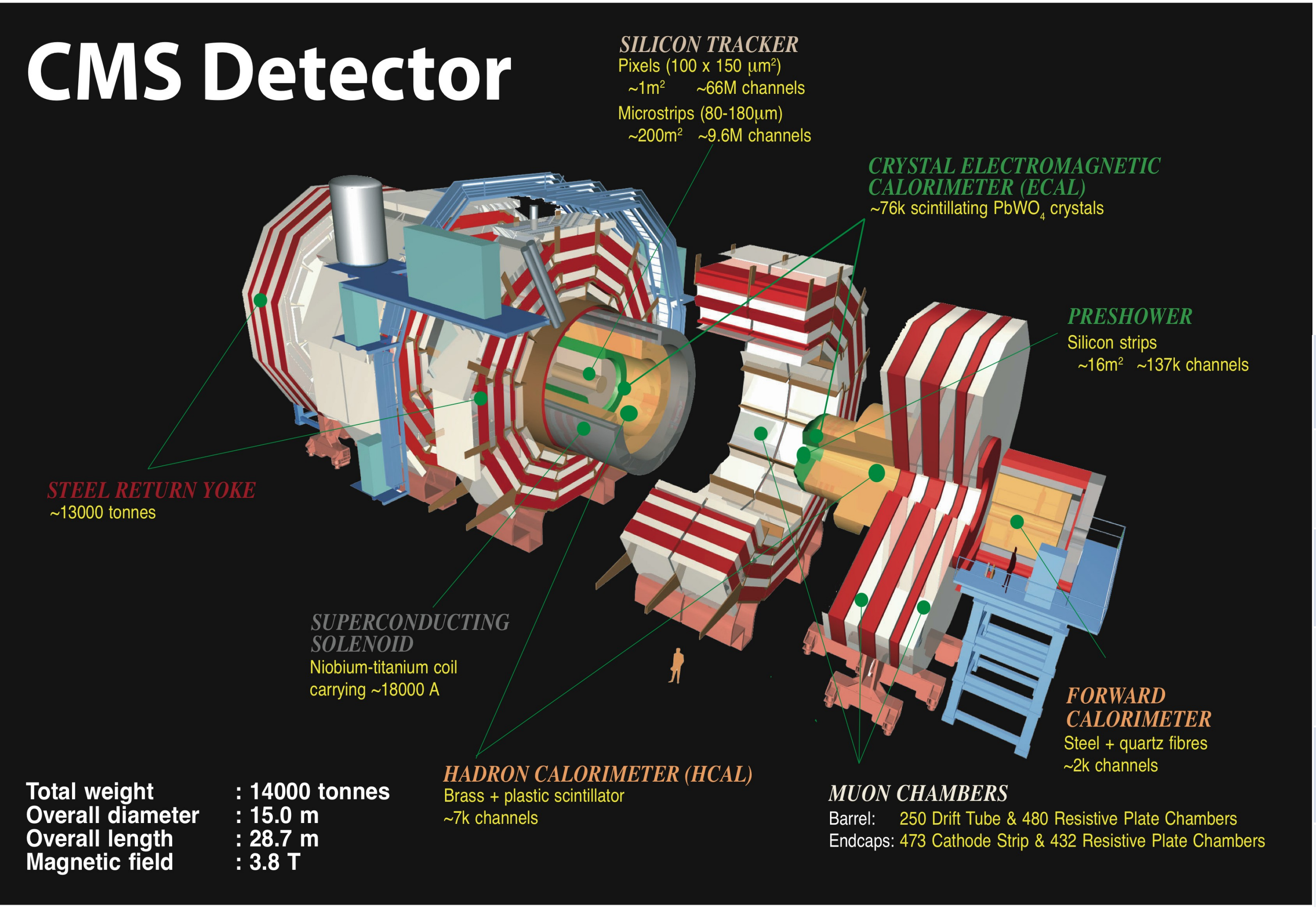
47 pb^{-1} delivered to CMS by the end of the 2010 pp run;

In 2011, ~750 pb^{-1} up to beginning of June;

Overall CMS data taking efficiency > 90%;

The CMS Collaboration

3170 Physicist and engeneers, 169 institutes from 39 countries



- Highly redundant muon system, triggering and recording muons with p_T > 1-3 GeV and $|\eta|$ <2.4
- Tracking efficiency > 99% for central muons

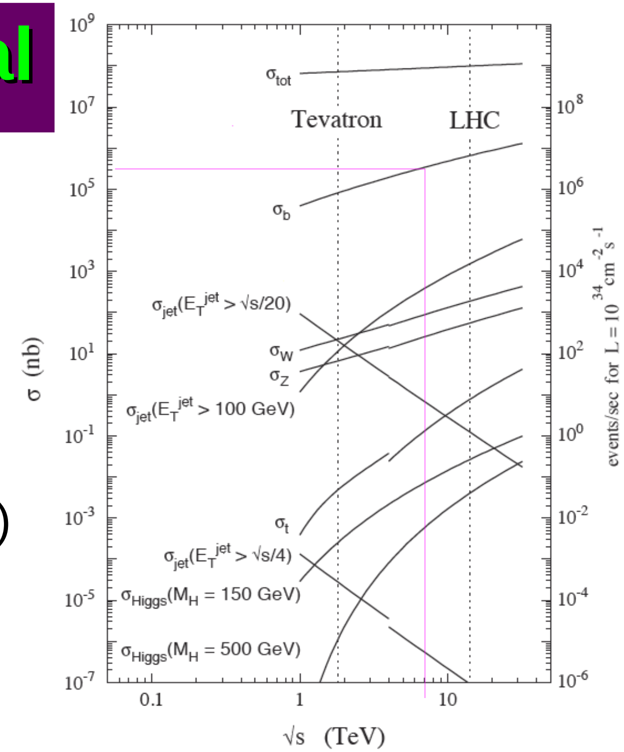
4 T solenoid + return yoke
Si pixels, strips $\sigma/p_T \approx 1.5\times10^{-4} p_T + 0.005$
PbWO4 crystals $\sigma/E \approx 3\%/\sqrt{E} + 0.003$
Brass+scintillator (7 λ + catcher) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV
$\sigma/p_T \approx 1\%$ @ 50GeV to 10% @ 1TeV (DT/CSC+Tracker)
L1+HLT (L2 + L3)

All silicon inner tracker allowing good resolution on p_T and impact parameter measurements

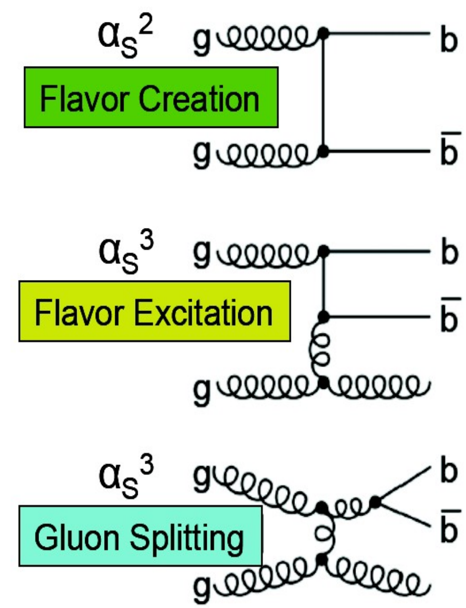
B-physics mainly relaying on:

- Muon detectors, for muon ID in semi-leptonic decays;
- Silicon Tracker detector, for b-tagging, lifetime measurements and inv. mass reconstruction.

b-handrons and b-jets: what's the deal



- Large beauty production cross section @ LHC at 7 TeV, new kinematical region accessible
- Cross section computed at NLO, essential at the LHC energy; in the past, tension between experimental and theoretical results
- Typical multi-scale process ($\sqrt{s}$, m_b, factorization, renormalization) large theoretical uncertainties
- B-hadron p_T spectra depending on the non-perturbative part (parametriz of fragm. function)
- Large scale dependence symptom of possibly large relevance of high order term
  @ low-p_T: small-x effects ($x = m_b / \sqrt{s}$);
  @ high-p_T: large log terms due to multiple gluon radiation.



b-jets

- Enclosing most of the radiation emitted by the b-quark
- High performance of tracking capabilities required, fully exploiting the detector potentialities
- b-jets essential in many searches of New Physics
- Measurements complementary to b-hadrons.

Jets and b-tagging

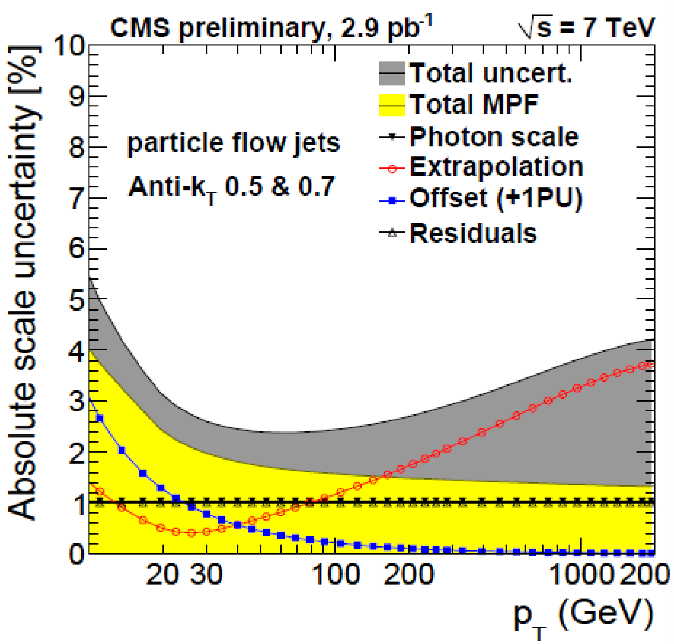
- The following results obtained using jets reconstructed with anti-kT algorithm with DR=0.5 with particle-flow techniques or 'track jets';
- Typical values:
  - ∗ jet resolution 10-15%;
  - ∗ scale uncertainty < 3%;

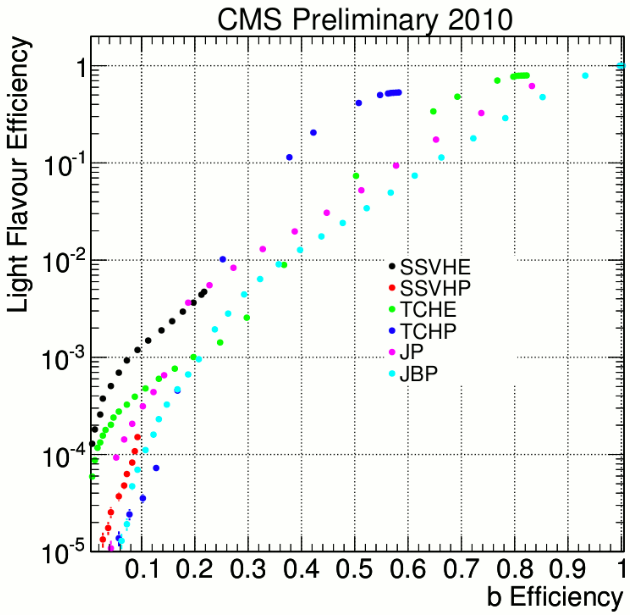
Good tracker performance and alignment → high b-tagging efficiency;

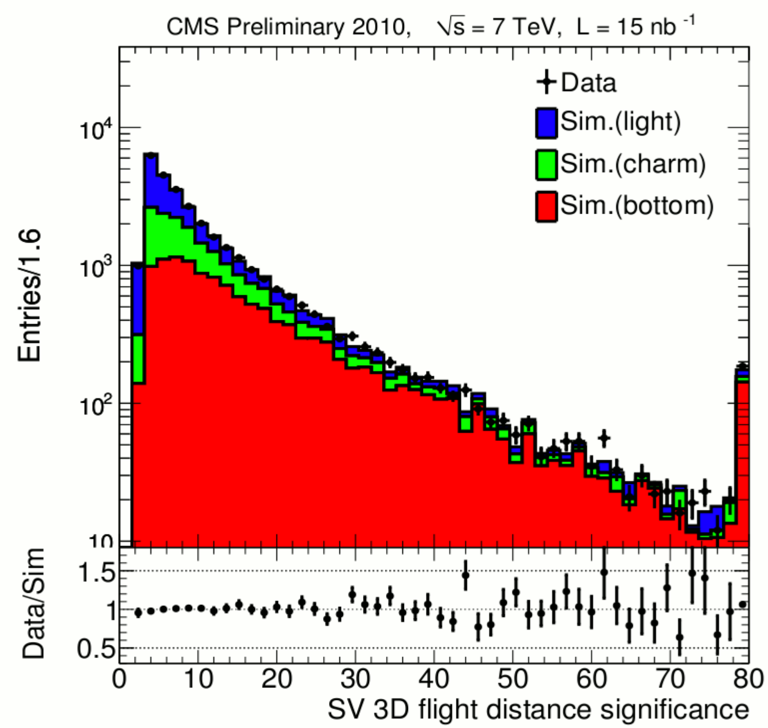
Data well reproduced by MC

Different algorithms:

- * Track counting (based on Impact Parameter significance)
- * Secondary Vertex tagging (decay length significance)
- * Combined

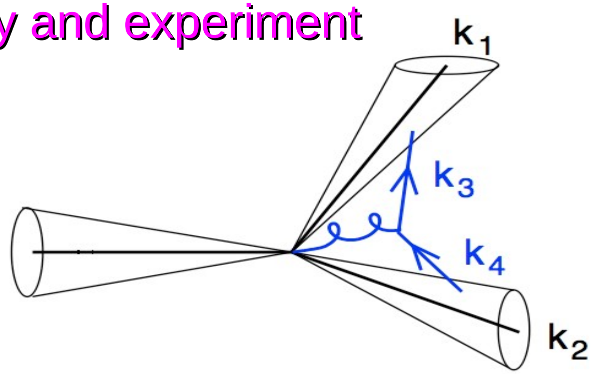






b-jet cross section measurement

Highly non-trivial measurements
Sizeable uncertainties from both theory and experiment



MEMO: standard jet definitions for flavoured jets are infrared-unsafe: soft gluons splitting into a qq pair can change the flavour of the jet

- **Theoretical Uncertainties** (~ in order of importance):
  - PDF Uncertainty
  - pQCD (Scale) Uncertainty
  - Non-perturbative Corrections
  - PDF Parameterization
  - Knowledge of $\alpha_s(M_Z)$
  - •••

- **Experimental Uncertainties** (~ in order of importance):
  - Jet Energy Scale (JES)
    - Noise Treatment
    - Pile-Up Treatment
  - Luminosity
  - Jet Energy Resolution (JER)
  - Trigger Efficiencies
  - Resolution in Rapidity
  - Resolution in Azimuth
  - Non-Collision Background
  - •••

Jet Algorithms used by CMS

- Iterative Cone
- SISCone
- (anti-)k_T

Main ingredients of the measurements:

- Number of tagged jets N_{tagged}
- b-tagging efficiency f_b: fit from MC, data/MC scale with muon p_T^{rel}
- b-tag purity ε_b: fit from MC, data/MC scale from SV mass templates

Master formula:

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

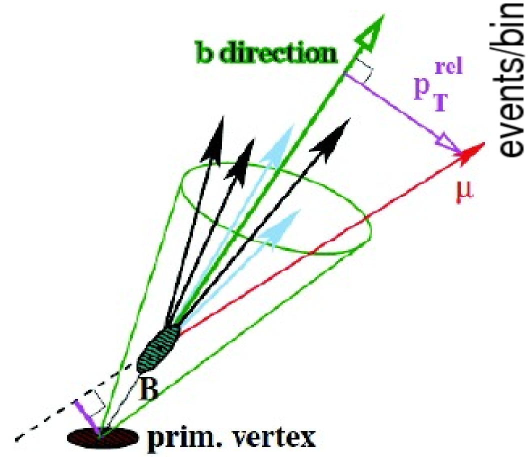
Other corrections:

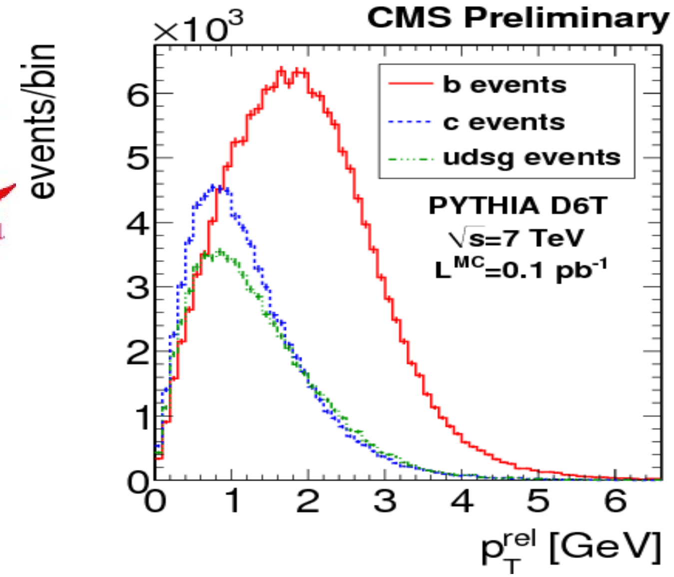
- Unfolding correction C_{smear} to move the measured p_T back to particle level using the ansatz method (need jet energy resolutions)
- b-jet JEC: same as inclusive jets (Pythia predicts residual difference below ~1%)

Inclusive beauty production

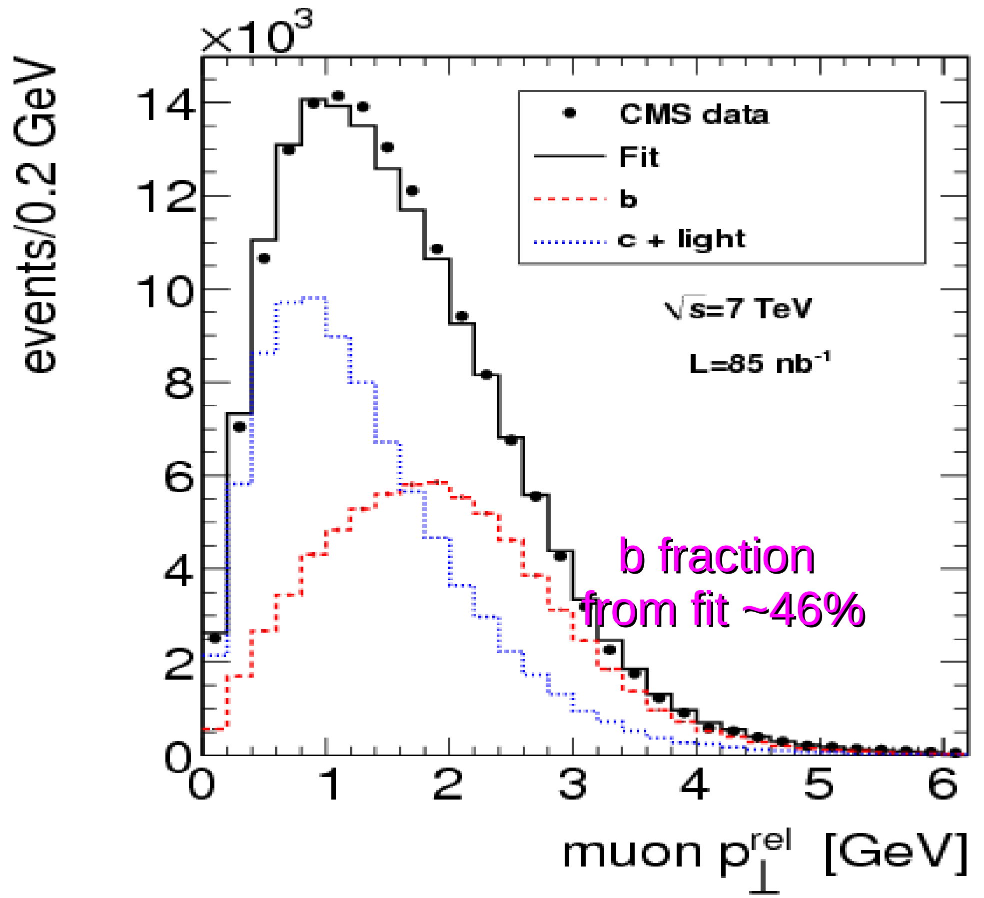
JHEP **1103** (2011) 090

Semi-leptonic decays used to separate b-jets from *udscg* jets: distance from jet axis of muon from b decays on average larger than for light quarks





- Triggering on muon p_T > 3 GeV; (p_T > 6 GeV, |η|< 2.1 offline)
- "Track jets": tracks with 0.3 < p_T < 500 GeV clustered with anti-k_T (R = 0.5); E_T^{jet} > 1 GeV
- p_T^{rel} spectrum fitted with distribution obtained from simulation (signal, c) and data (other backgr.); binned log-likelihood technique
- Signal validated in a b-enriched sample
- c and udsg templates combined in the fit
- Background dominated by hadrons misidentified as muons (mainly decay-in-flight), weighted by the misidentification rate from data; other sources neglected (< 3% from W @ high p_T)



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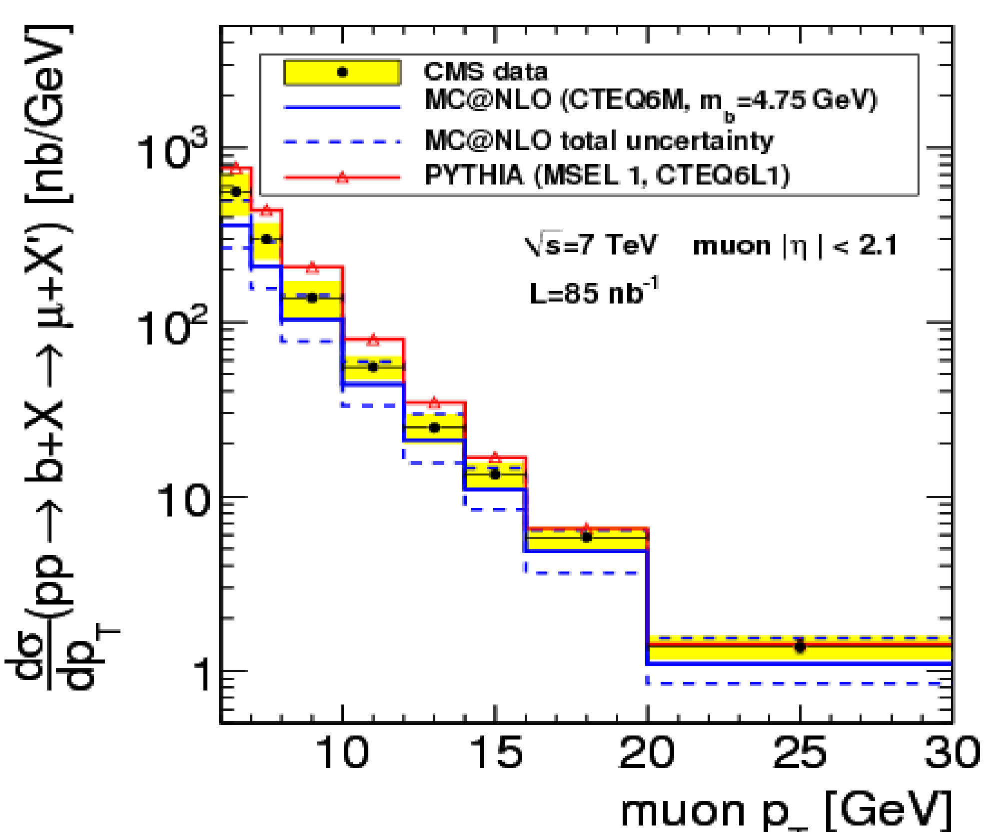
Inclusive beauty cross section

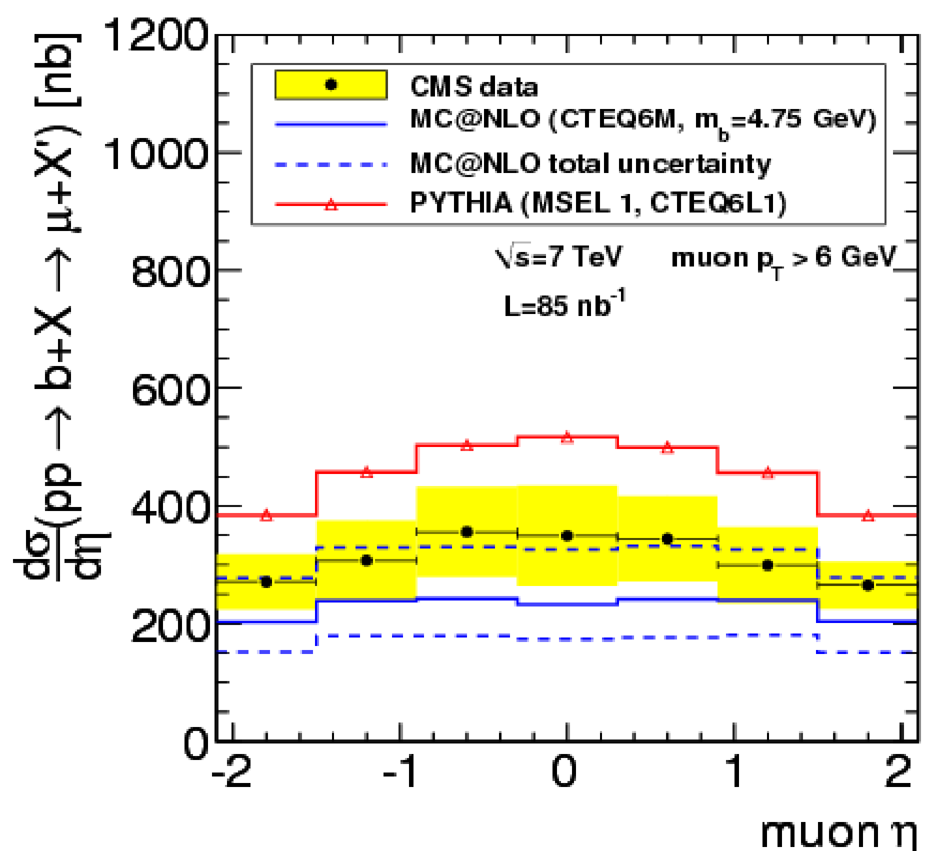
Measured visible cross section: $p_T(\mu) > 6$ GeV, $|\eta(\mu)| < 2.1$;

$$\sigma(pp \to b\,X \to \mu X) = (1.32 \pm 0.01(stat.) \pm 0.30(syst.) \pm 0.15\ (lumi.))\ \mu b$$

$\sigma_{MC@NLO} = (0.95^{+0.41}_{-0.21}\,(scale) \pm 0.09(m_b) \pm 0.05(pdf))\ \mu b$; $\sigma_{PYTHIA} = 1.9\ \mu b$

Results including efficiency of trigger (88±5)%, muon rec. (94±3)% and μ -jet association (77±8)%



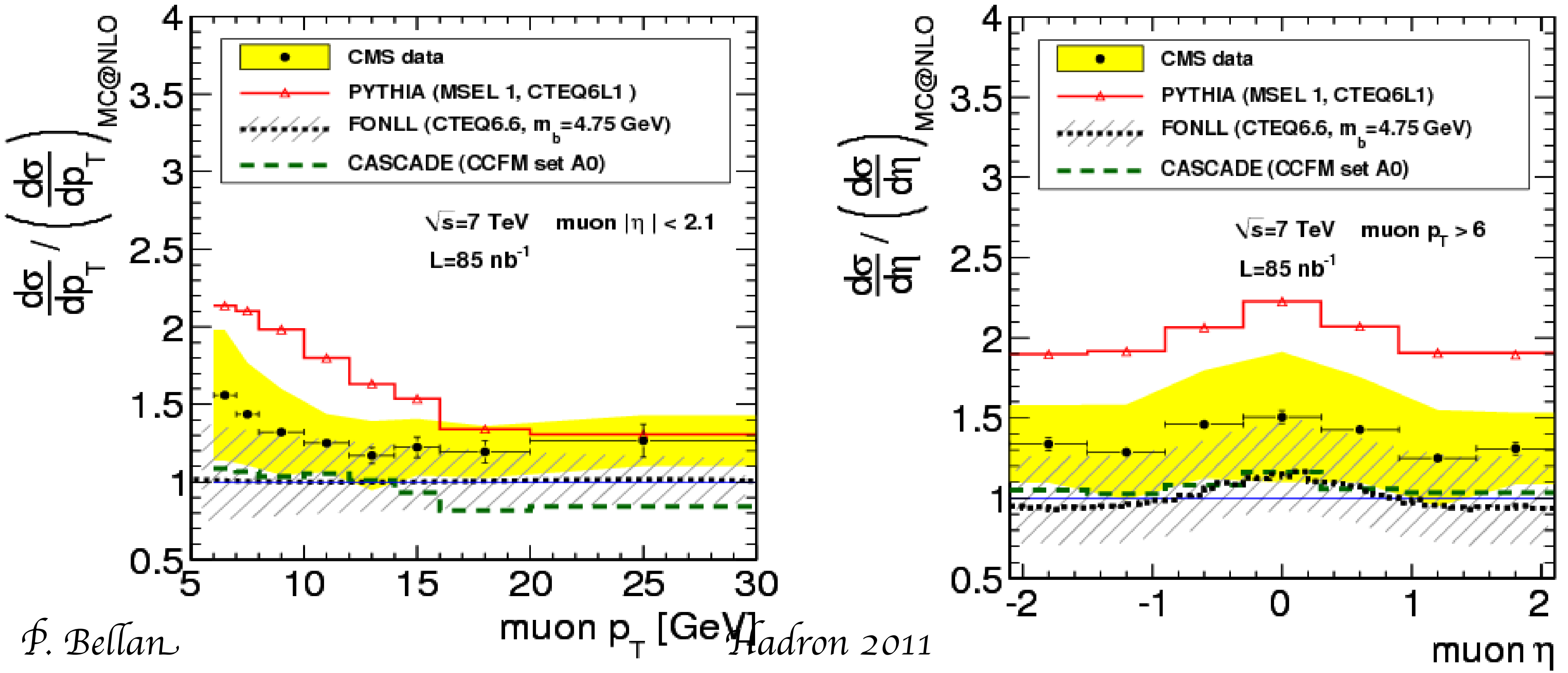


Inclusive beauty cross section

Shapes reasonably well described by NLO QCD;
Shape confirmed by the findings from b production using fully reconstructed B^+ mesons
Uncertainty dominated by signal and background p_T^{rel} shapes

SYSTEMATICS

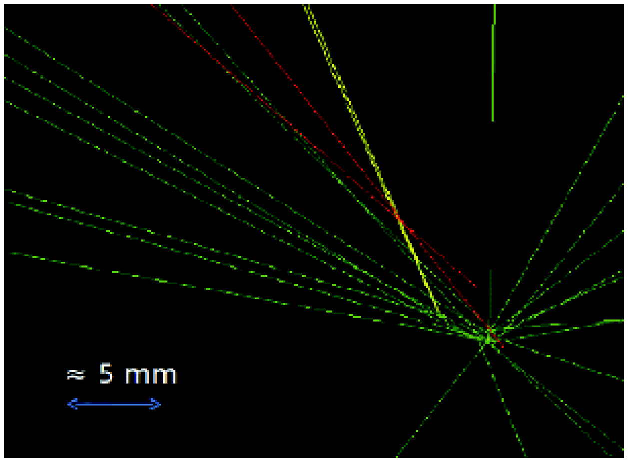
Trigger efficiency	5 %	Background composition	3-6 %
Muon reconstruction efficiency	3 %	Production mechanism	2-5 %
Hadron tracking efficiency	2 %	Fragmentation	1-4 %
b p_T^{rel} shape	≤ 21 %	Decay	3 %
Background p_T^{rel}shape	2-14 %	Underlying event	10 %
		Luminosity	11 %



CMS-PAS-BPH-10-009

Inclusive b from jet tagging with SV

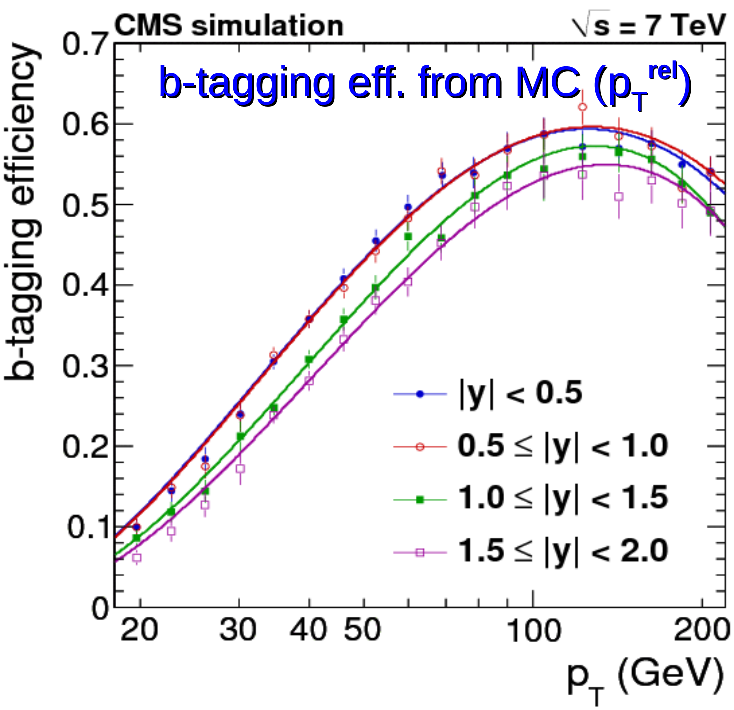
Identification of b-jets performed through the Secondary Vertex (SV) tagging

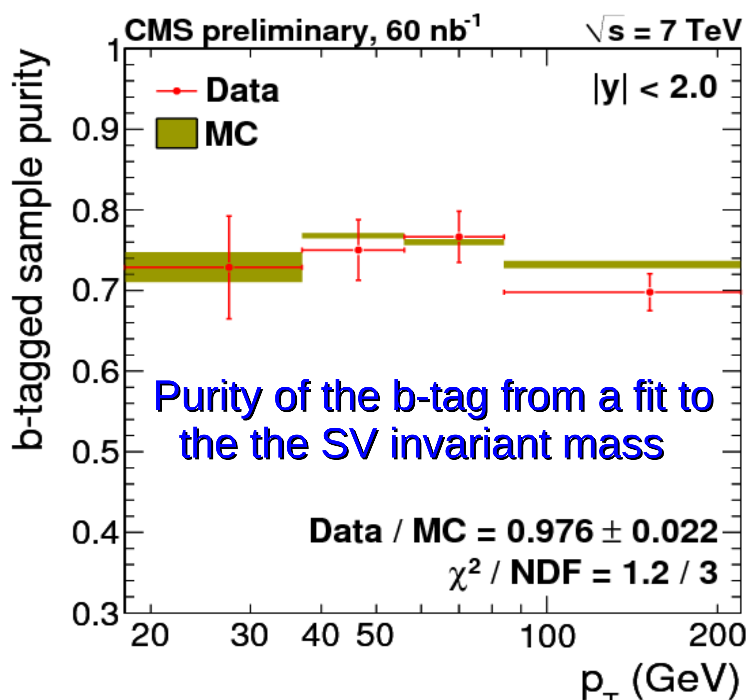


Displaced vertices with ≥ 3 tracks selected to identify b events; b-jets tagged using a high-purity SV tagger.

Discriminator: monotonic function of the 3D decay length; requirement on its significance corresponding to: tagging effic. = 60% @ p_T^{jet} = 100 GeV, ~0.1% contamination

Inclusive jet sample (anti-k_T R =0.5 with ParticleFlow) collected with minimum bias and single jet triggers combined;





b-tagging efficiency and mistag rates from c-jet and light jet taken from the MC and constrained by a data/MC scale factor from data

Analysis fot the b-jet tagging with SV

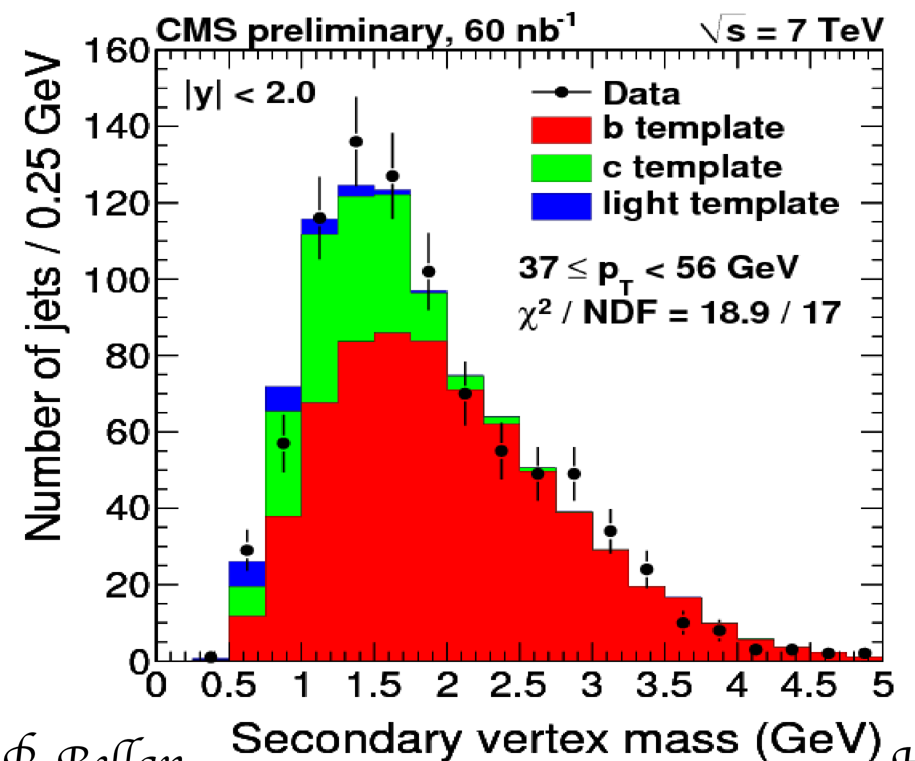
Jet energies correction:
for the rapidity dependence →from DATA
for absolute scale and p_T dependence →from MC

Uncertainty of JEC estimated using γ+jet or with dijet p_T balance technique (barrel/endcaps)

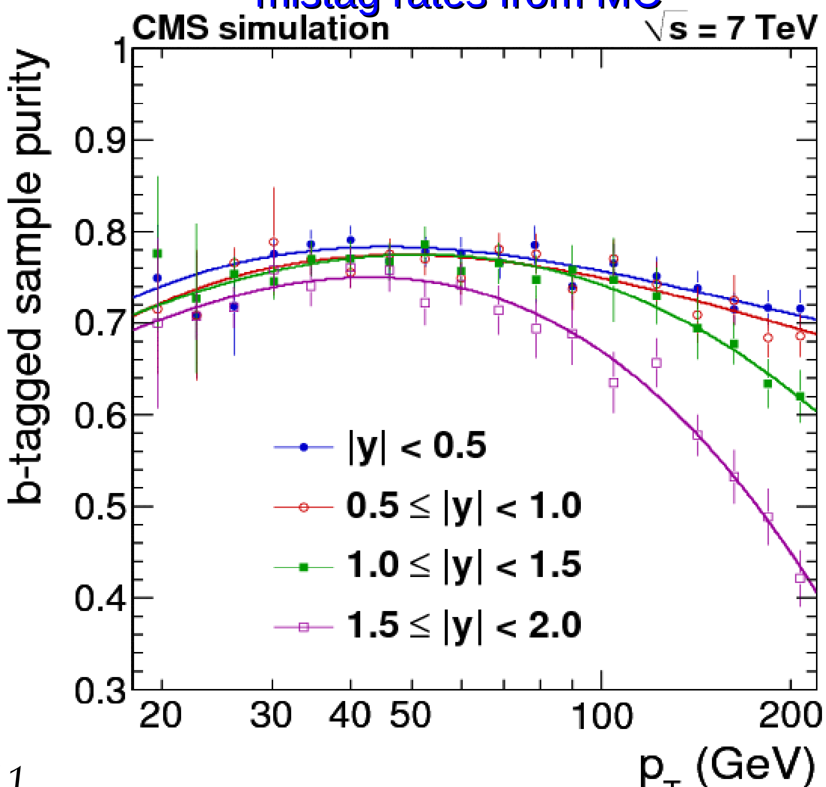
Fit to the SV mass distribution: shapes from MC, relative normalisations for c and b jets let free, (small) contribution from light fixed to the MC expectation ("template fit")

Results cross-check with alternative method MC based;

Example of fit to SV mass

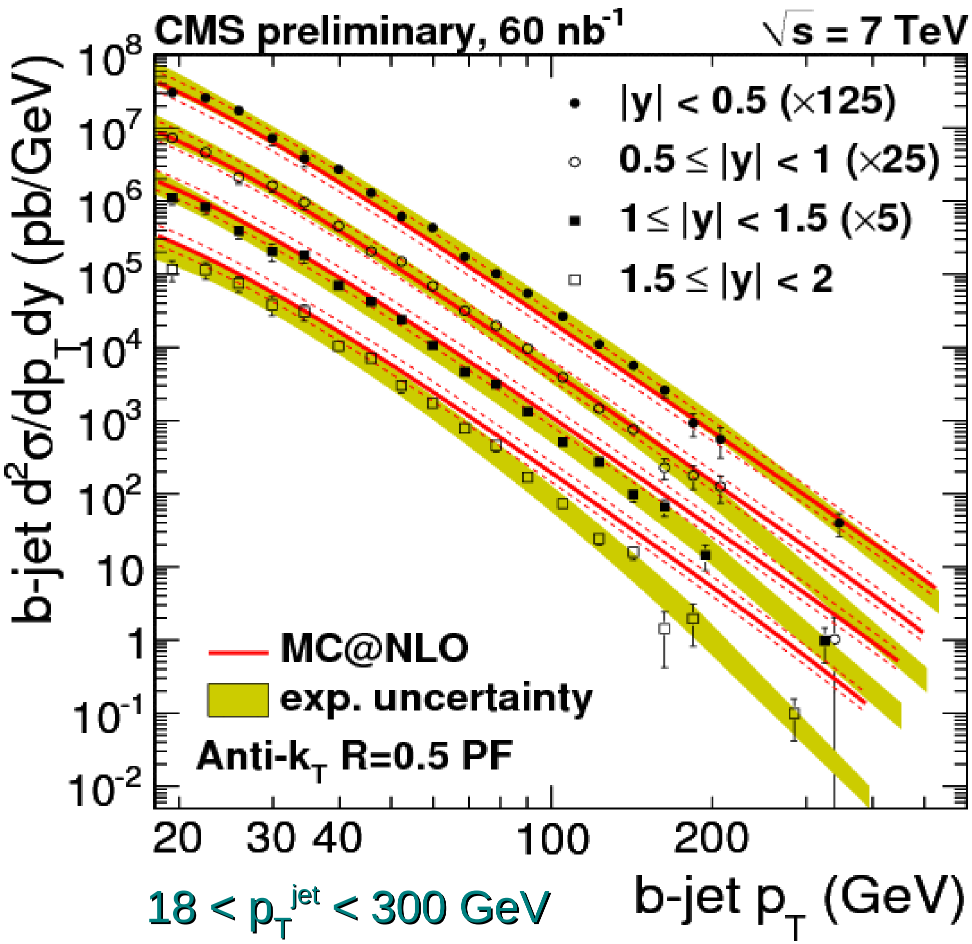


Purity using b-tagging efficiency and mistag rates from MC

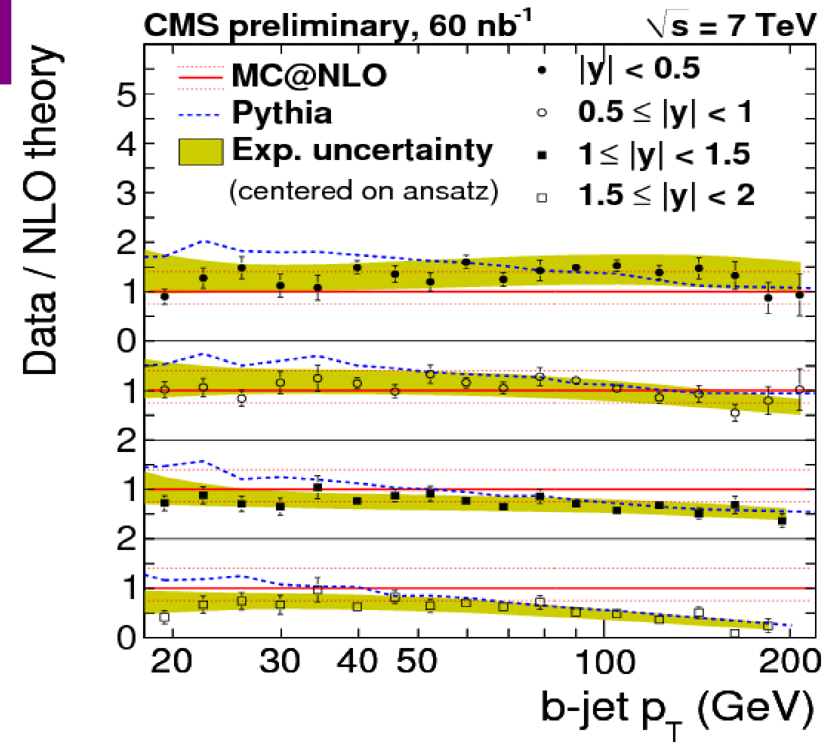


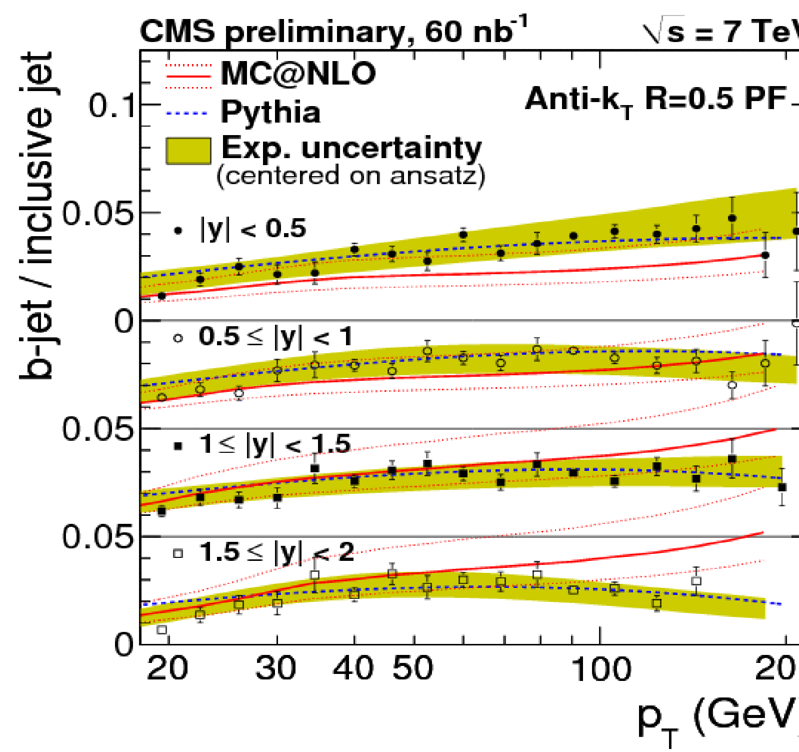
b-jet cross-section results

Reasonable agreement with Pythia and MC@NLO
Significant difference in shape though.



$18 < p_T^{jet} < 300$ GeV





Leading systematic uncertainties @ p_T > 30 GeV:

- b JES relative to inclusive jets (4–5%),
- data-based constraints on b-tagging efficiency (20%)
- mistag rate for charm (3–4%) and for light jets (1–10%).

Conclusions and outlook

- Successful B physics results with 2010 data, very significant results obtained with early data;
- CMS able to perform inclusive measurements of b-hadron production with high precision;
- Heavy flavour production measurements performed with different techniques;
- Wealth of new data going to be used to refine theoretical models and improve MC simulation.

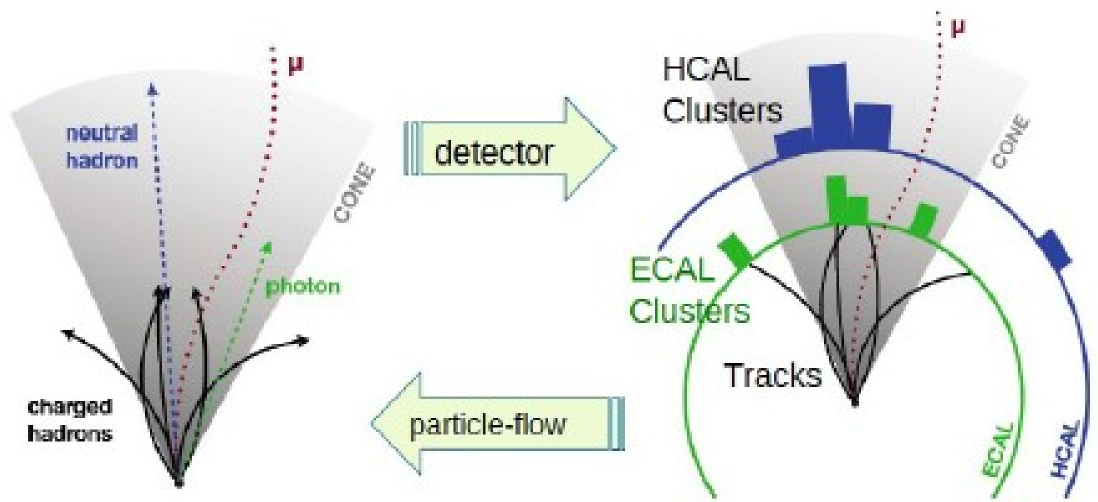
Thanks for your attention!

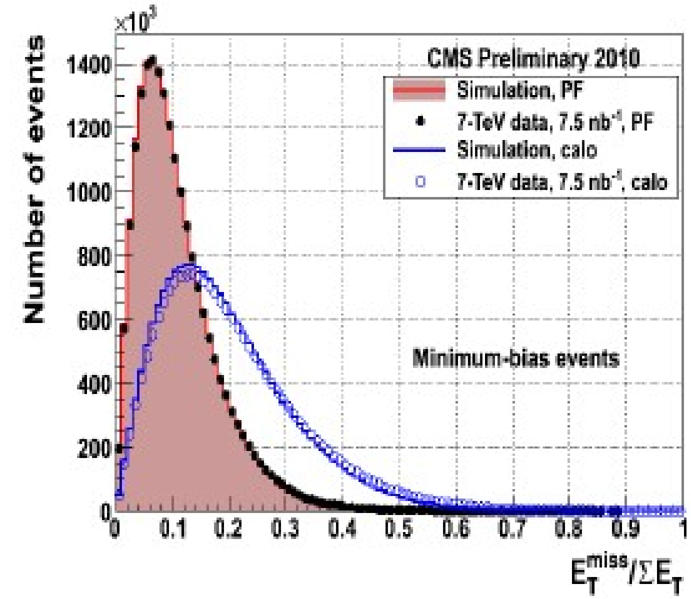
BACK UP SPLIDES

References

Topic	arXiv	Article	Luminosity (nb^{-1})
Inclusive b-hadron production	1101.3512	JHEP 1103 (2011) 090	85
Inclusive b-jet with SV (ICHEP2010)		CMS-PAS-BPH-10-009	60

Particle Flow Technique in CMS





- In CMS, charged particles get well separated due to the huge tracker volume and the high magnetic field (3.8 T)
- CMS has an excellent tracking resolution, able to go to down to very low momenta (~few hundred MeV)
- CMS has also an excellent electromagnetic calorimeter with good granularity
- In multijet events, only 10% of energy corresponds to neutral (stable) hadrons

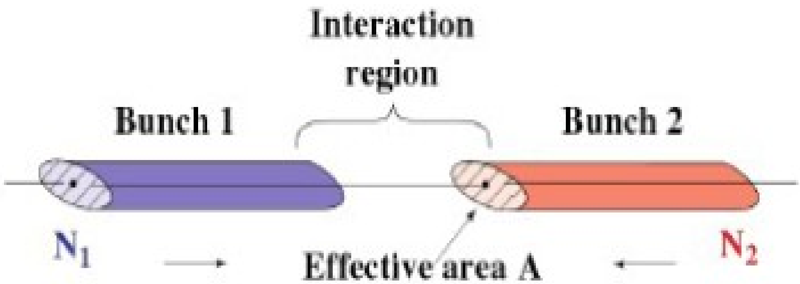
Big improvement in energy resolution and tau identification using particle-flow techniques

Luminosity Measurements

$$\mathcal{L} = N_1 N_2 f n_b \int \rho_1(x,y)\rho_2(x,y)\,dx\,dy$$

$$\mathcal{L} = \frac{N_1 N_2 f n_b}{A_{eff}}$$

$$A_{eff} = 2\pi\sigma_x\sigma_y$$



- Intensities $N_{1,2}$ measured by LHC beam current transformers
- Shape and size of the interaction region, A_{eff}, measured via Van der Meer scans: relative variations or rate as a function of the transverse separation between beams
- Rates measured in CMS using fraction of zero counts of HF and vertexing

Systematic	Error (%)
Effective Area Determination	2.7
Beam Intensity	2.9
Sample Dependence	0.7
Total	**4.0**

Uncertainty: 4%

Luminosity correction wrt initial estimates: -0.7%

Some technical details

The MC event generator PYTHIA 6.422 used
to compute efficiencies and kinematic distributions.
CTEQ6L1 PDF, m_b = 4.8 GeV, and Peterson fragm. funct. for c and quarks
(ε_c = 0.05 , ε_b = 0.005)
Underlying event simulated with the 'D6T tune' setting.

Pileup events not included (negligible impact)
Cross check sample with Evtgen for the b hadrons decay.

The MC@NLO package (NLO ME interfaced to herwig parton
Shower): m_b = 4.75 GeV ; CTEQ6M.
The CASCADE generator o-shell LO ME, kT factorization with CCFM low-x
evolution.
The unintegrated CCFM parton distribution set A0 and m_b = 4.75 GeV

Events generated with mc@nlo and CASCADE not passed through the detailed
detector simulation (studied only at the generator level)

Simulated events were reweighted to reproduce
the branching ratio $B(b \to \mu\ \nu_\mu\ X)$ = 10.95%

Results compared with the analytical FONLL calculation
(CTEQ6.6 PDF set, m_b = 4.75 GeV, Kartvelishvili fragm. function with α = 24.2)