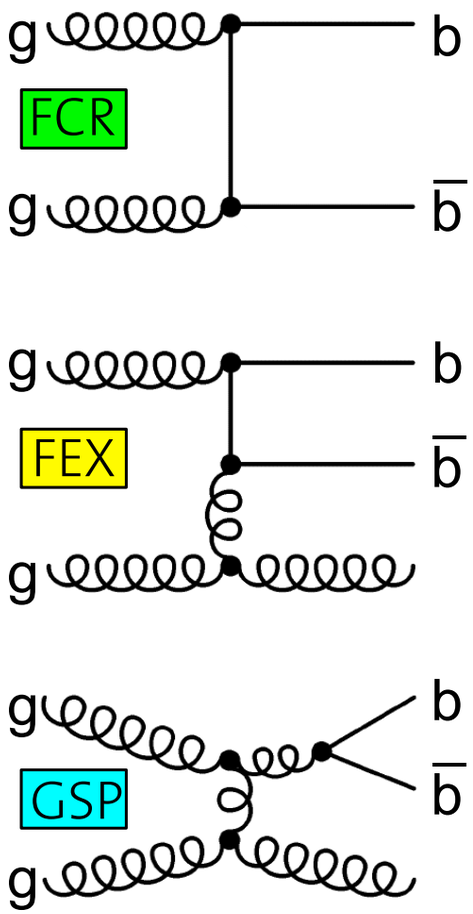
# Latest results on open heavy flavour from CMS

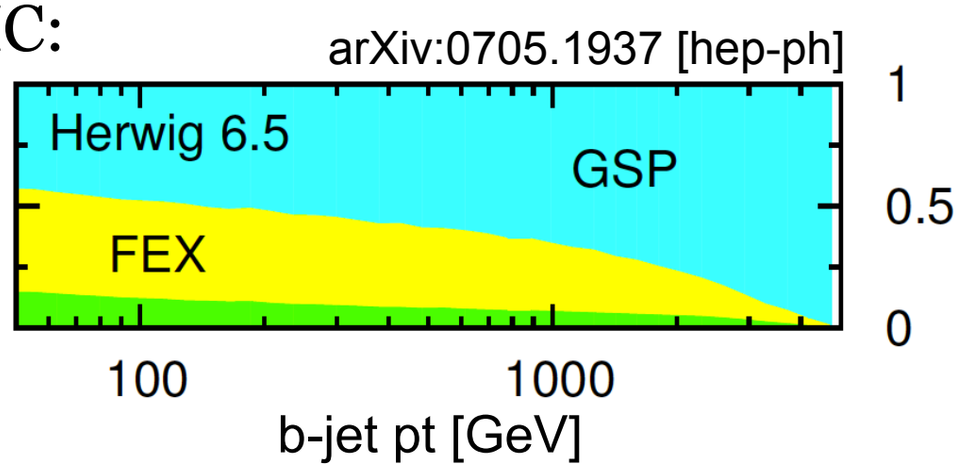
– Torsten Dahms –
(on behalf of CMS)
CERN / LLR - École Polytechnique

First ReteQuarkonii Workshop, Nantes
October 28th, 2010

# Introduction

- Open heavy flavour in p+p
  - Test of QCD
  - b-quark production important background for new physics searches
  - Reference for heavy ions
- Open heavy flavour in heavy ions
  - Hard probe of the medium
  - Sensitive to same initial state conditions as closed heavy flavour
  - Interesting results (disagreements) seen at RHIC:
    - Charm suppressed at high $p_T$ as light quarks
    - Charm flows
    - Role of bottom still unclear (as suppressed as charm?)

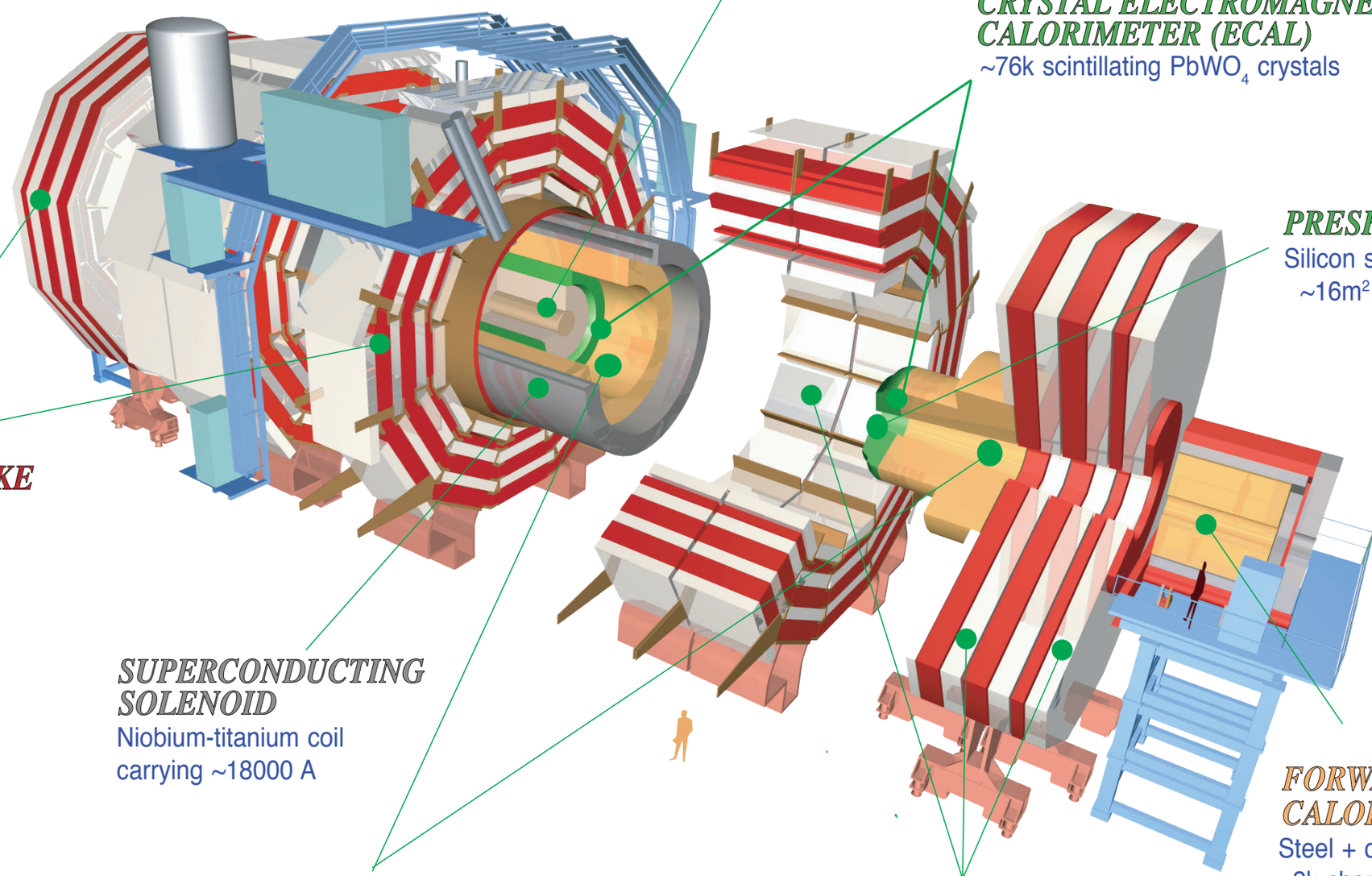


# The Compact Muon Solenoid

## CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



**SILICON TRACKER**
Pixels (100 x 150 $\mu m^2$)
~1$m^2$ ~66M channels
Microstrips (80-180$\mu m$)
~200$m^2$ ~9.6M channels

**CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)**
~76k scintillating $PbWO_4$ crystals

**PRESHOWER**
Silicon strips
~16$m^2$ ~137k channels

**STEEL RETURN YOKE**
~13000 tonnes

**SUPERCONDUCTING SOLENOID**
Niobium-titanium coil
carrying ~18000 A

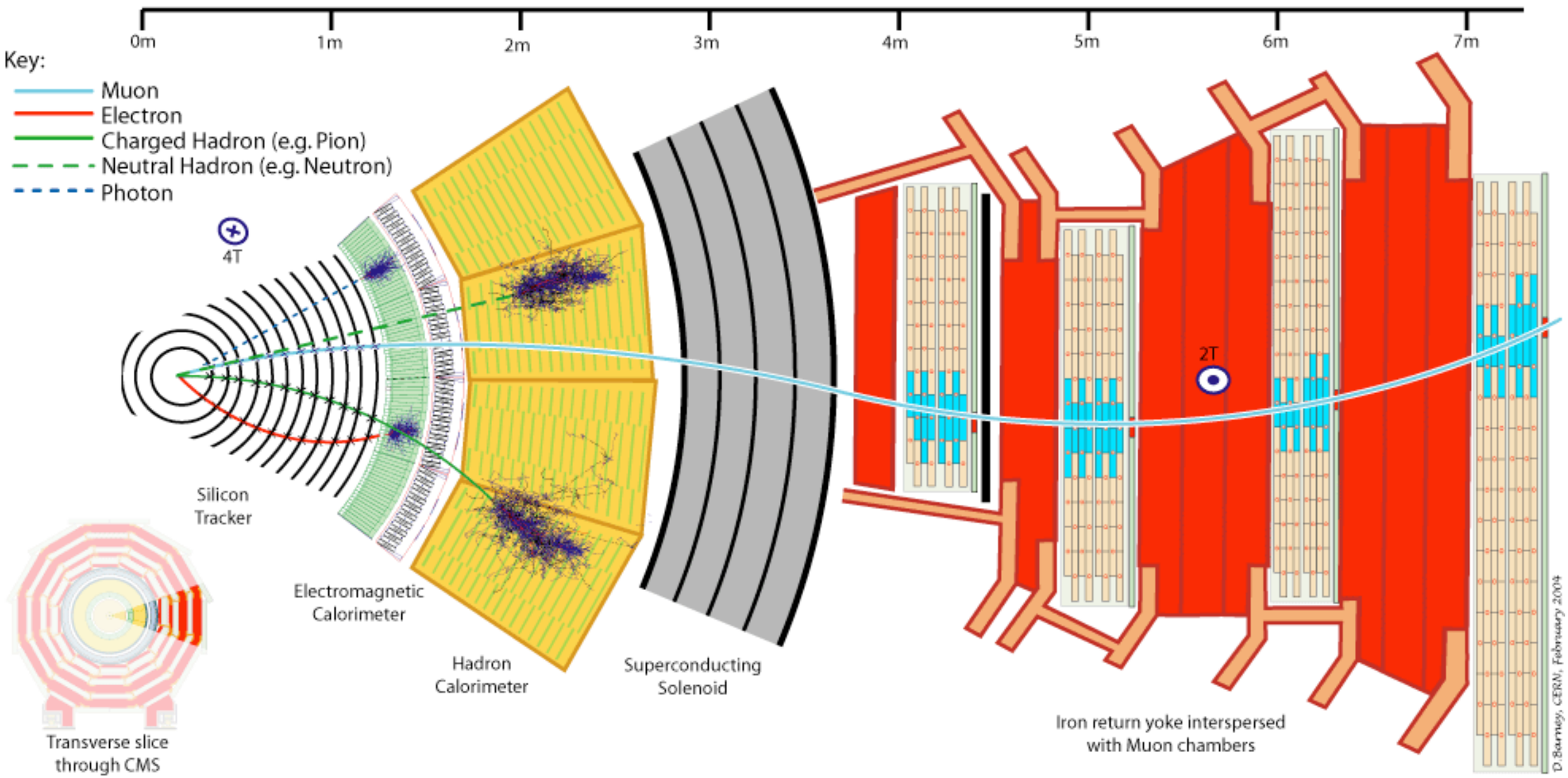
**FORWARD CALORIMETER**
Steel + quartz fibres
~2k channels

**HADRON CALORIMETER (HCAL)**
Brass + plastic scintillator
~7k channels

**MUON CHAMBERS**
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

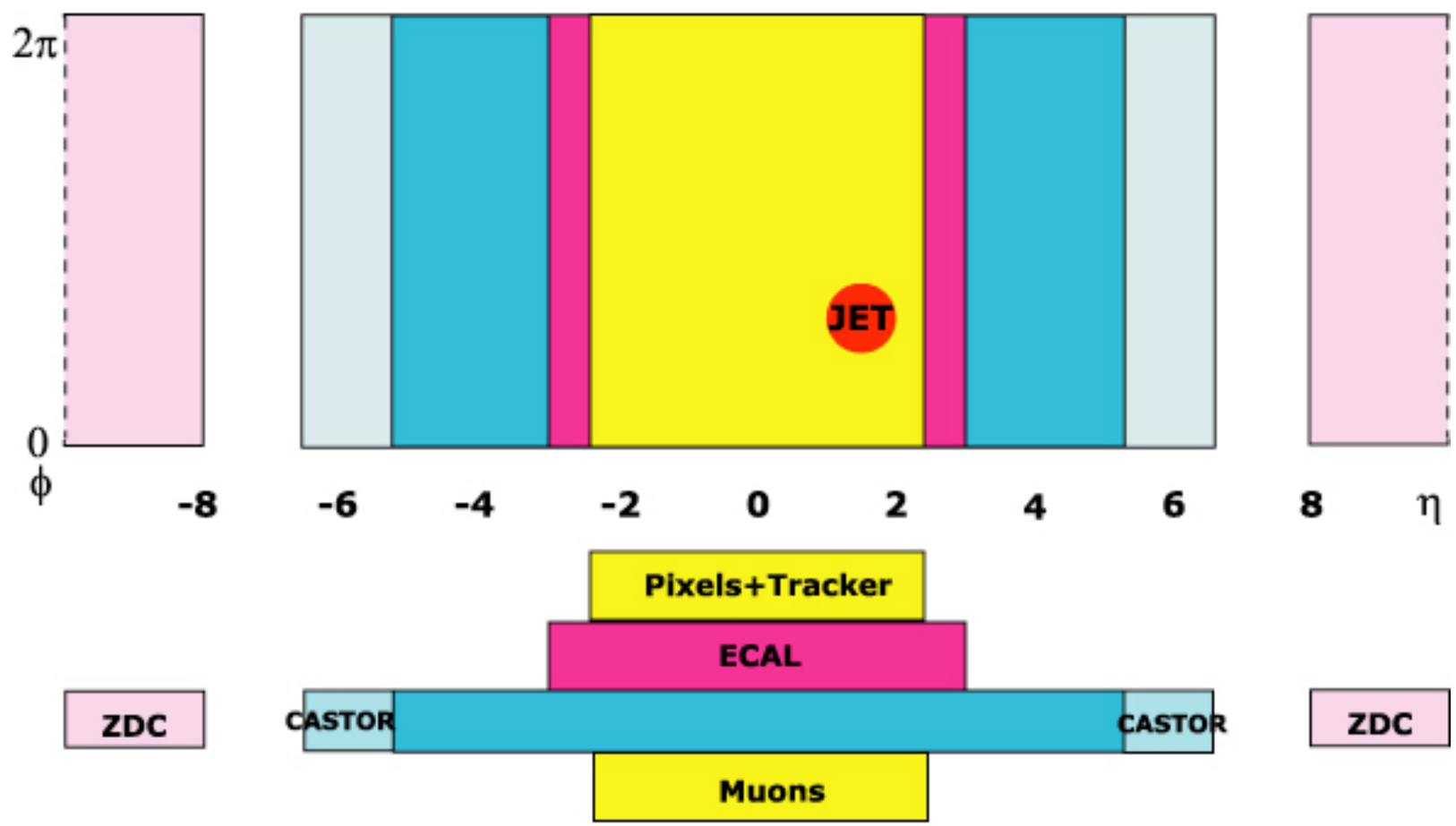
| | |
|---|---|
| **Total weight** | **: 14000 tonnes** |
| **Overall diameter** | **: 15.0 m** |
| **Overall length** | **: 28.7 m** |
| **Magnetic field** | **: 3.8 T** |

# The Compact Muon Solenoid



# CMS Phase Space Coverage

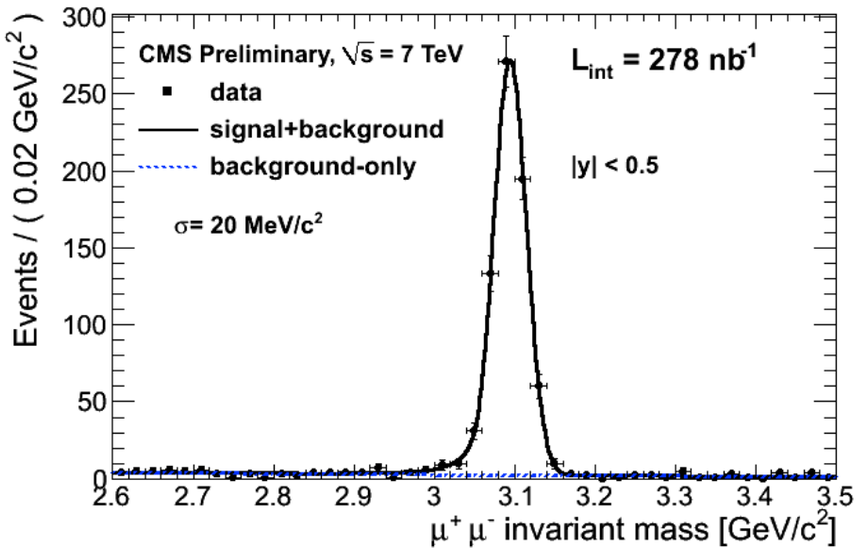
- CMS: full φ and almost full η acceptance at the LHC
- Charged tracks and muons: $|\eta| < 2.4$
- Electrons and photons: $|\eta| < 3$
- Jets: $|\eta| < 6.7$
  (plus $|\eta| > 8.3$ for neutrals, with the ZDC)

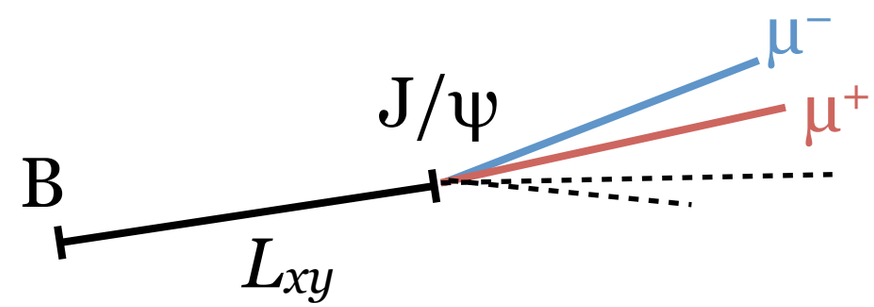


# Identifying B mesons with CMS

- Heavier and longer life time than light mesons ($B^{\pm}$ $c\tau = 491.1 \pm 3.2$ μm, $B^{0}$ $c\tau = 457.2 \pm 2.7$ μm)
- Semi-leptonic and hadronic decays
- CMS is very well suited for *b* physics due to excellent tracking and muon detectors:
  - reconstruct secondary vertex with inner tracker
  - trigger and reconstruct muons with muon detectors down to low $p_T$
- Three results:
  - CMS BPH-10-002 PAS: *"J/ψ prompt and non-prompt cross sections in pp collisions at √s = 7 TeV"*
    the reconstructed dimuon vertex is used to identify non-prompt J/ψ from B decays
  - CMS PAS BPH-10-007: *"Open beauty production cross section with muons in pp collisions at √s = 7 TeV"*
    uses the relative muon $p_T$ with respect to the jet direction
  - CMS PAS BPH-10-009: *"Measurement of the inclusive b-jet production in pp collisions at √s = 7 TeV"*
    tags jets with secondary vertex

# Lifetime fit of prompt J/ψ and B → J/ψ



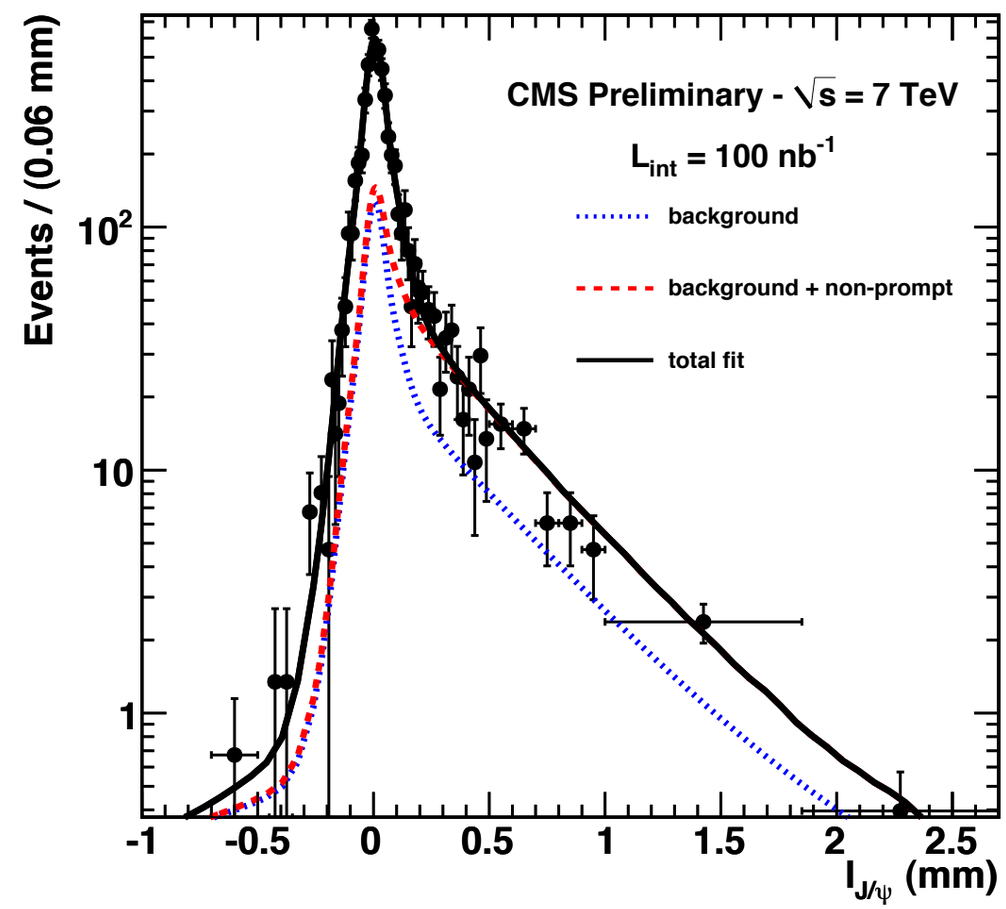




- Separate prompt and non-prompt contributions with a 2d unbinned max. likelihood fit to invariant mass and pseudo proper decay length:

$$\ell_{J/\psi} = L_{xy}\frac{m_{J/\psi}}{p_T}$$

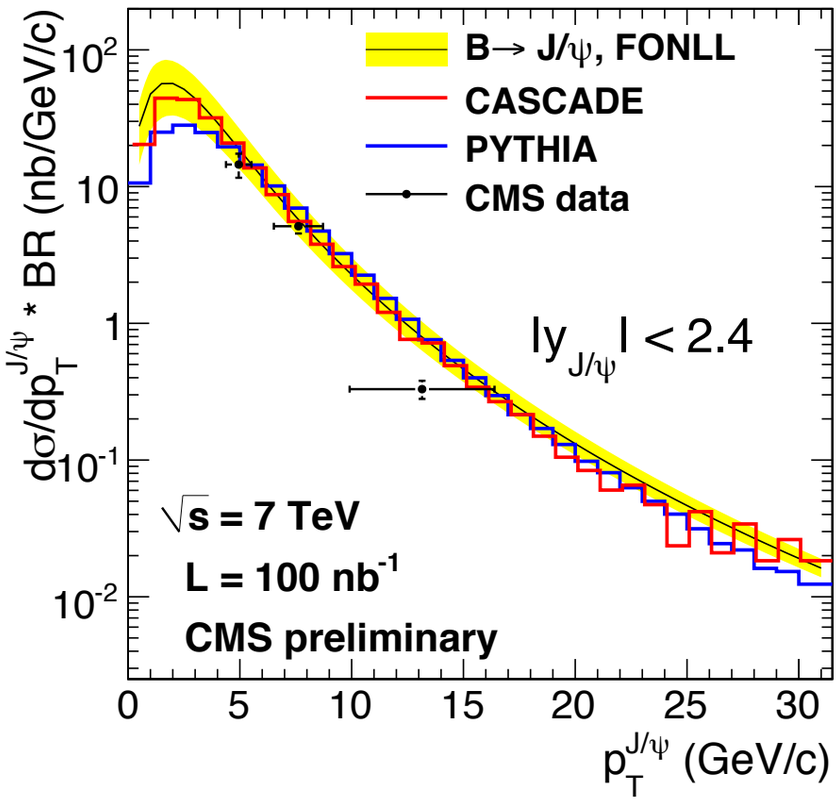
- Prompt contribution: pure resolution function (triple-Gaussian)

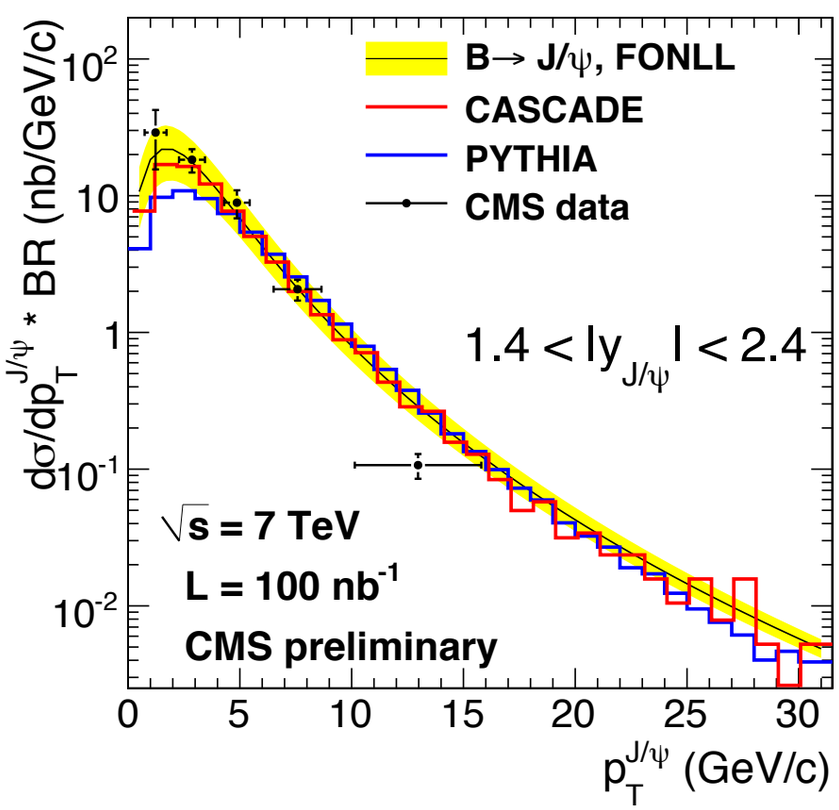
- Non-prompt contribution: exponential convolved with resolution function

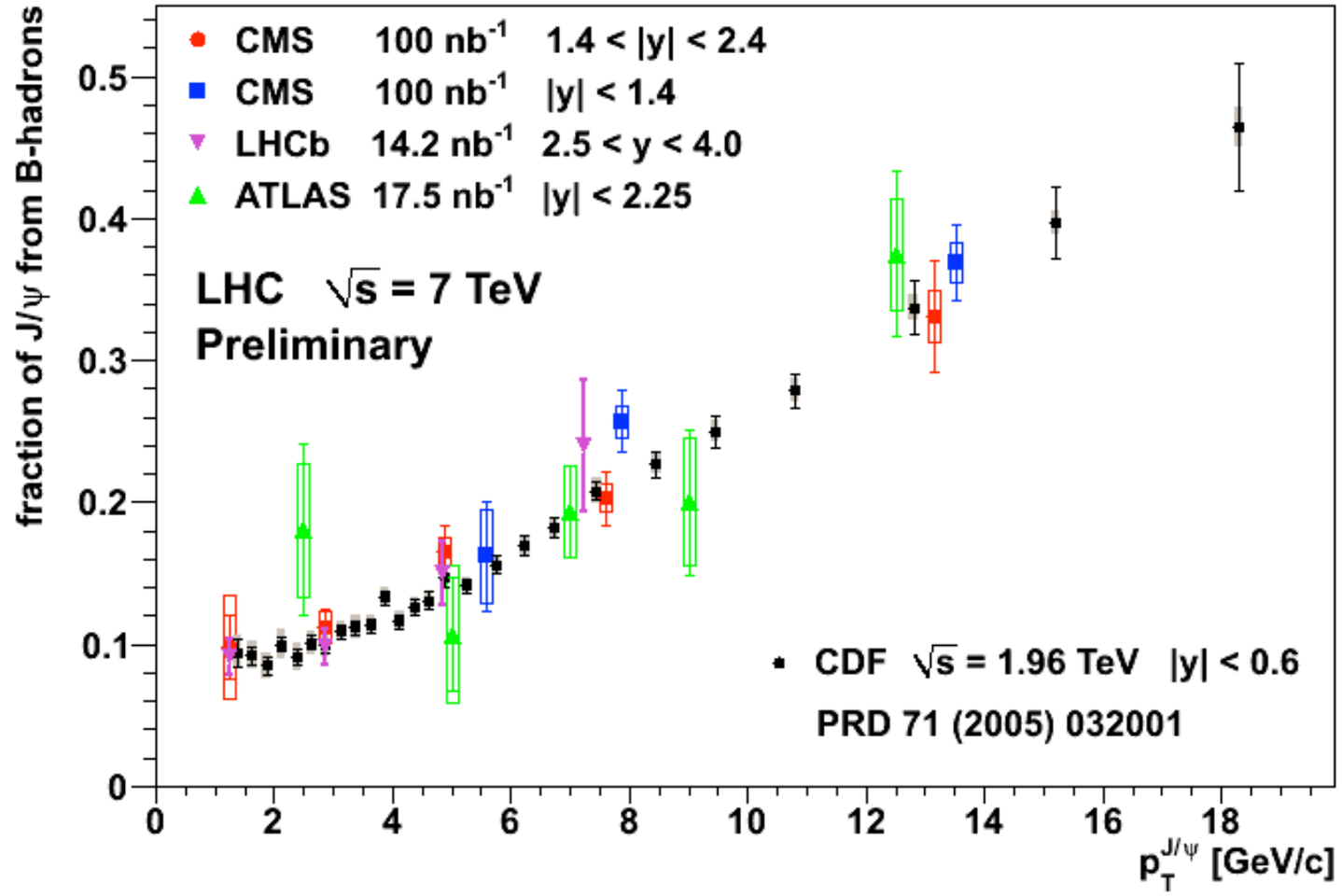



$$\sigma\left(pp \to bX \to J/\psi X'\right) \times \mathcal{B}\left(J/\psi \to \mu^+\mu^-\right) = 56.1 \pm 5.5(\text{stat}) \pm 7.2(\text{syst})\ \text{nb}$$

# B → J/ψ in p+p at √s=7 TeV



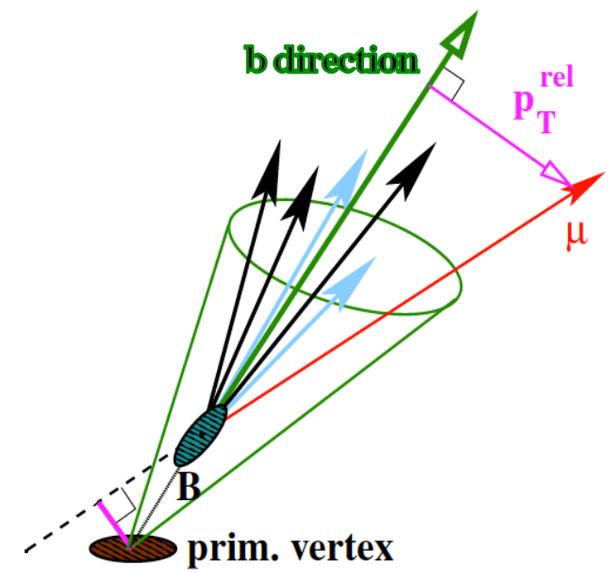



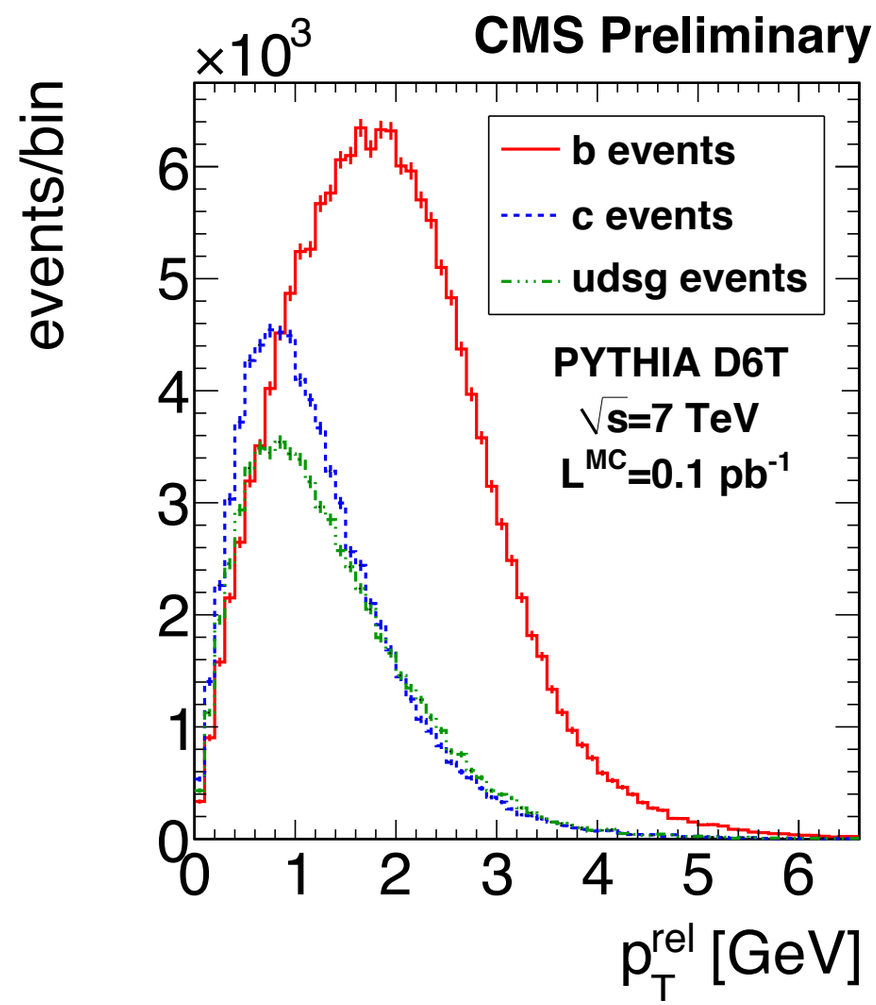




- Good agreement with other LHC experiments and CDF
- There seems to be no strong η or √s dependence
- (ATLAS points were converted from "B/prompt" to "B/inclusive")

# Semi-leptonic *b* decays

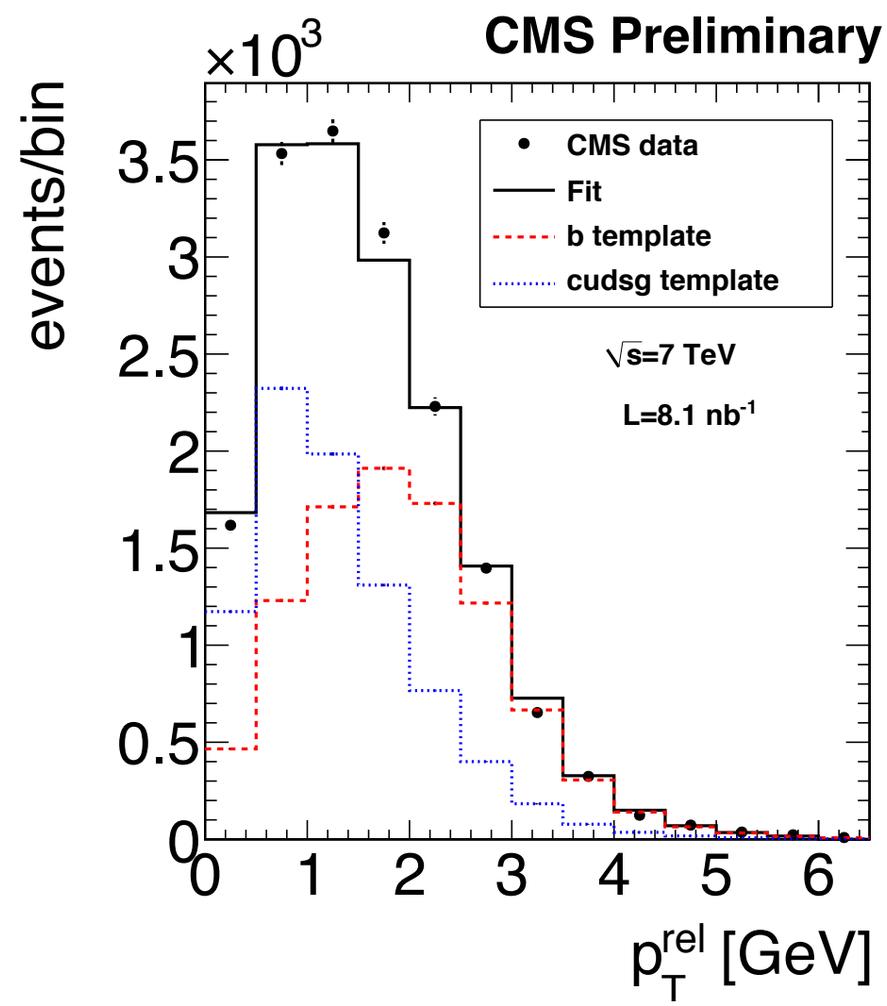
- Trigger on single μ ($p_T$ > 3 GeV/c)
- Require offline reconstructed μ with $p_T$ > 6 GeV/c and |η| < 2.1
- Cluster all tracks into jets using anti-$k_T$ algorithm (R=0.5)
  - Jet finding efficiency from 74% to almost 100% depending on μ $p_T$
  - Very good angular resolution (2–8%)
- Due to large B mass, muons from B decays have larger $p_T^{rel}$ ($p_T$ of μ relative to jet axis) than muons from *c* or light jets (*udsg*)
- Measurement of total cross section and differential cross section as a function of μ-$p_T$ and η with $L_{int}$ = 8.1 $nb^{-1}$



# Inclusive *b* cross section at $\sqrt{s}$ = 7 TeV

- Binned maximum likelihood fit of $p_T^{rel}$ distribution
- MC templates for *b* and *c* (signal template validated by *b* enriched data)
- Data driven template for *udsg* contribution (mostly from in-flight decays)
- Combined template for *c* and *udsg* contribution
- Templates for each μ-$p_T$ and η bin



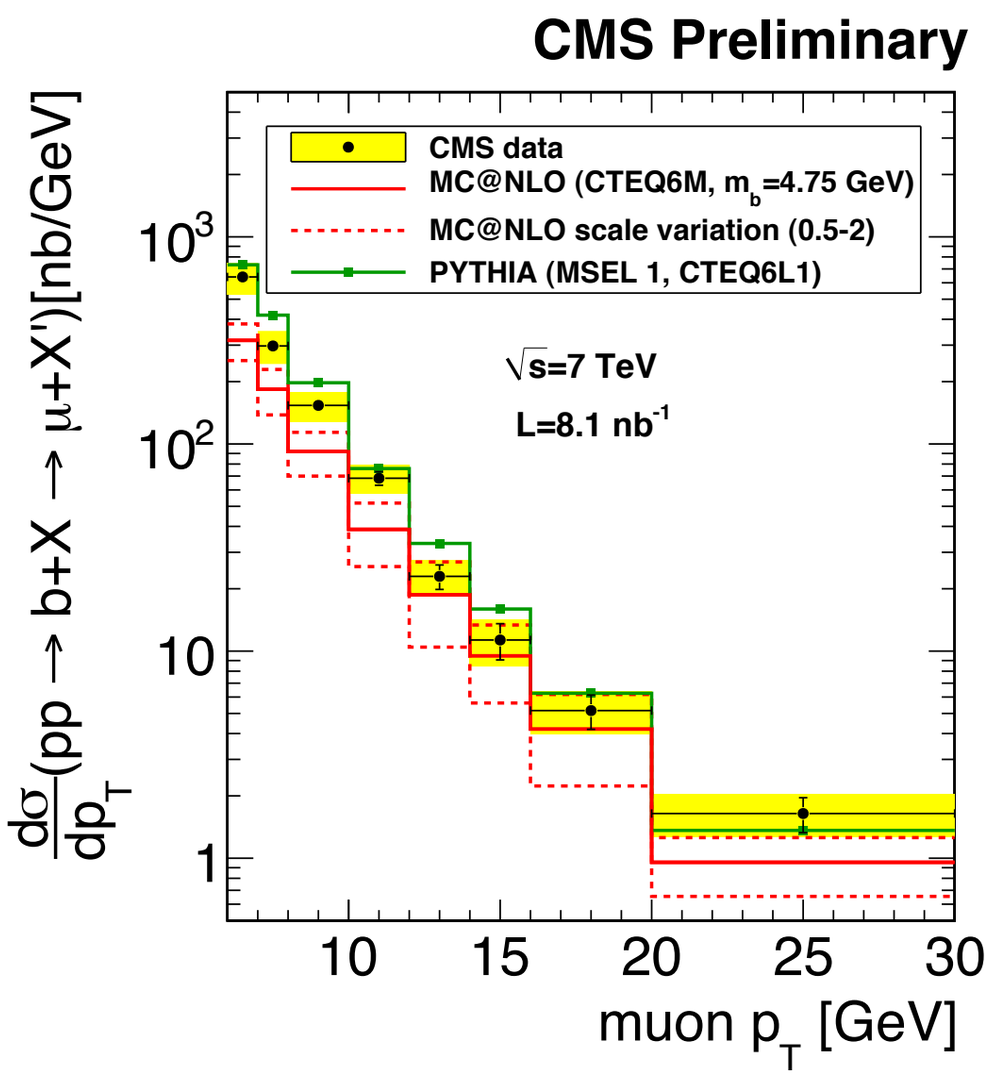

- Inclusive *b* cross section in kinematic range:

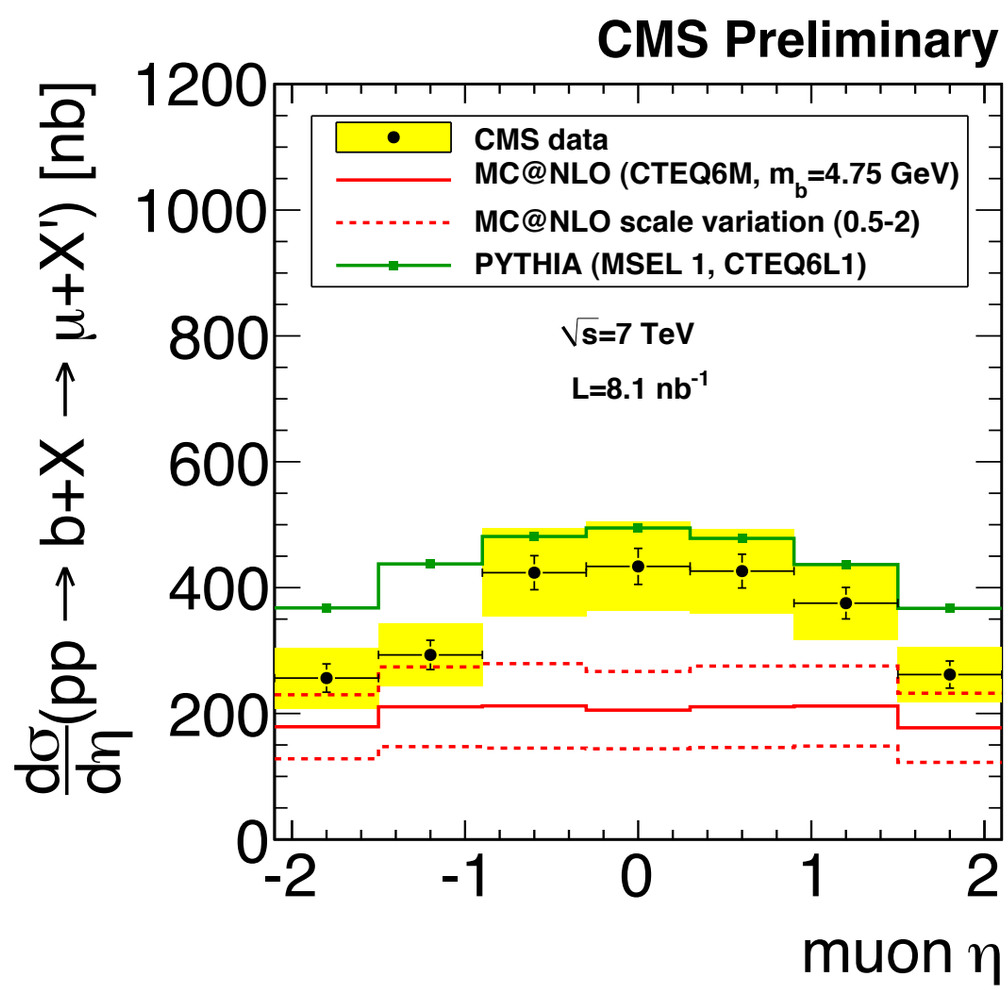
$$\sigma(pp \to b\bar{b} + X \to \mu + X', p_T^{\mu} > 6 \text{ GeV}, |\eta^{\mu}| < 2.1)$$
$$= 1.48 \pm 0.04(\text{stat.}) \pm 0.22(\text{syst.}) \pm 0.16(\text{lumi.})\ \mu\text{b}$$

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

# Differential *b* cross sections

- Measurement in agreement with MC@NLO for $p_T > 12$ GeV/c integrated over η
- Above MC@NLO at mid-rapidity at low $p_T$



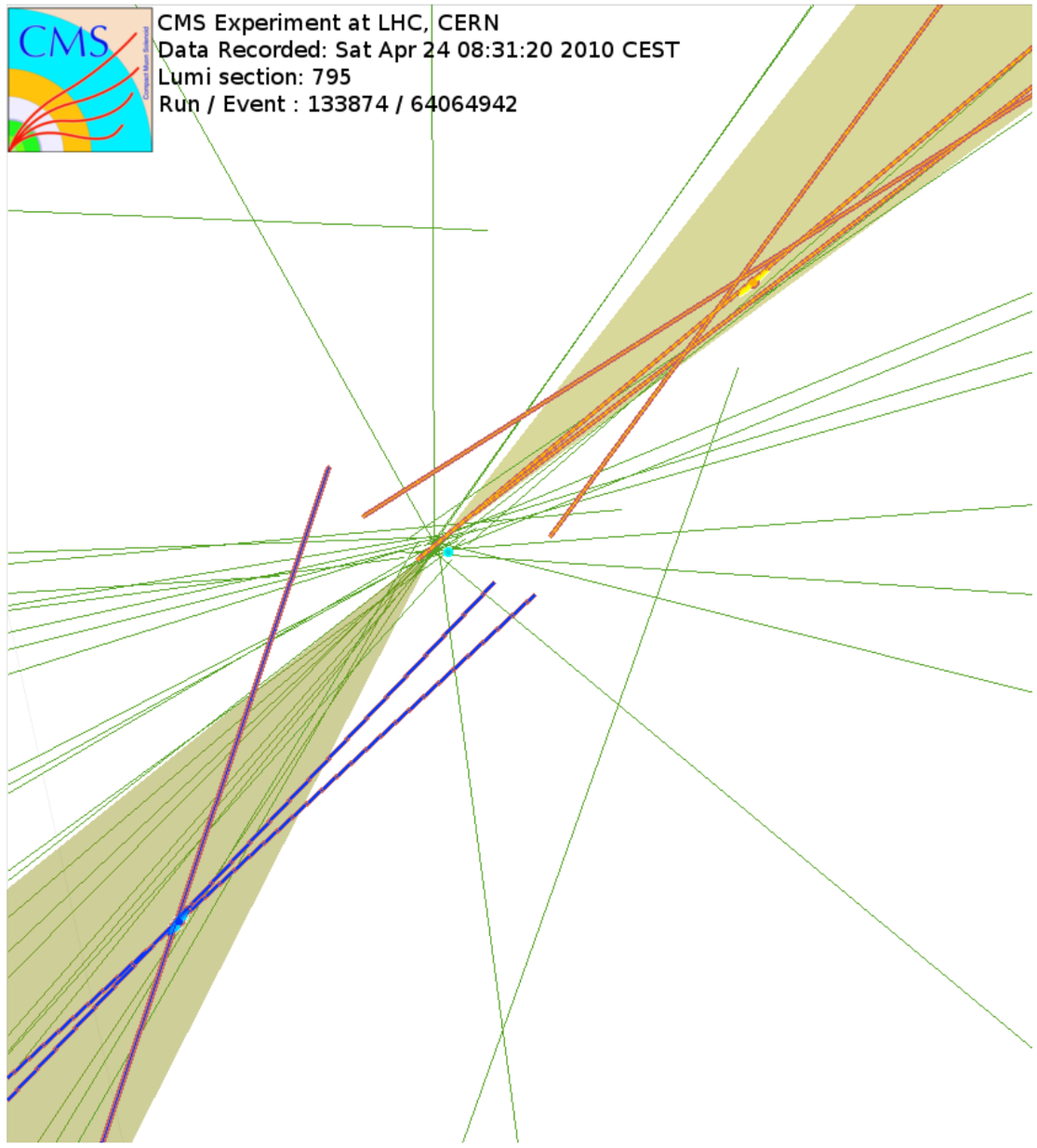
# Inclusive *b*-jet production

- Events collected with minimum bias and jet trigger
- Jets with $18 < p_T < 300$ GeV/c and $|y| < 2$ reconstructed with anti-$k_T$ algorithm (R=0.5) using calorimeter and tracker information (Particle Flow)
- *b*-tagging based on secondary vertex reconstruction
  - Require secondary vertex with at least 3 tracks
  - *b*-tagging efficiency from MC, verified in subsample by measurement of scale factor using $p_T^{rel}$

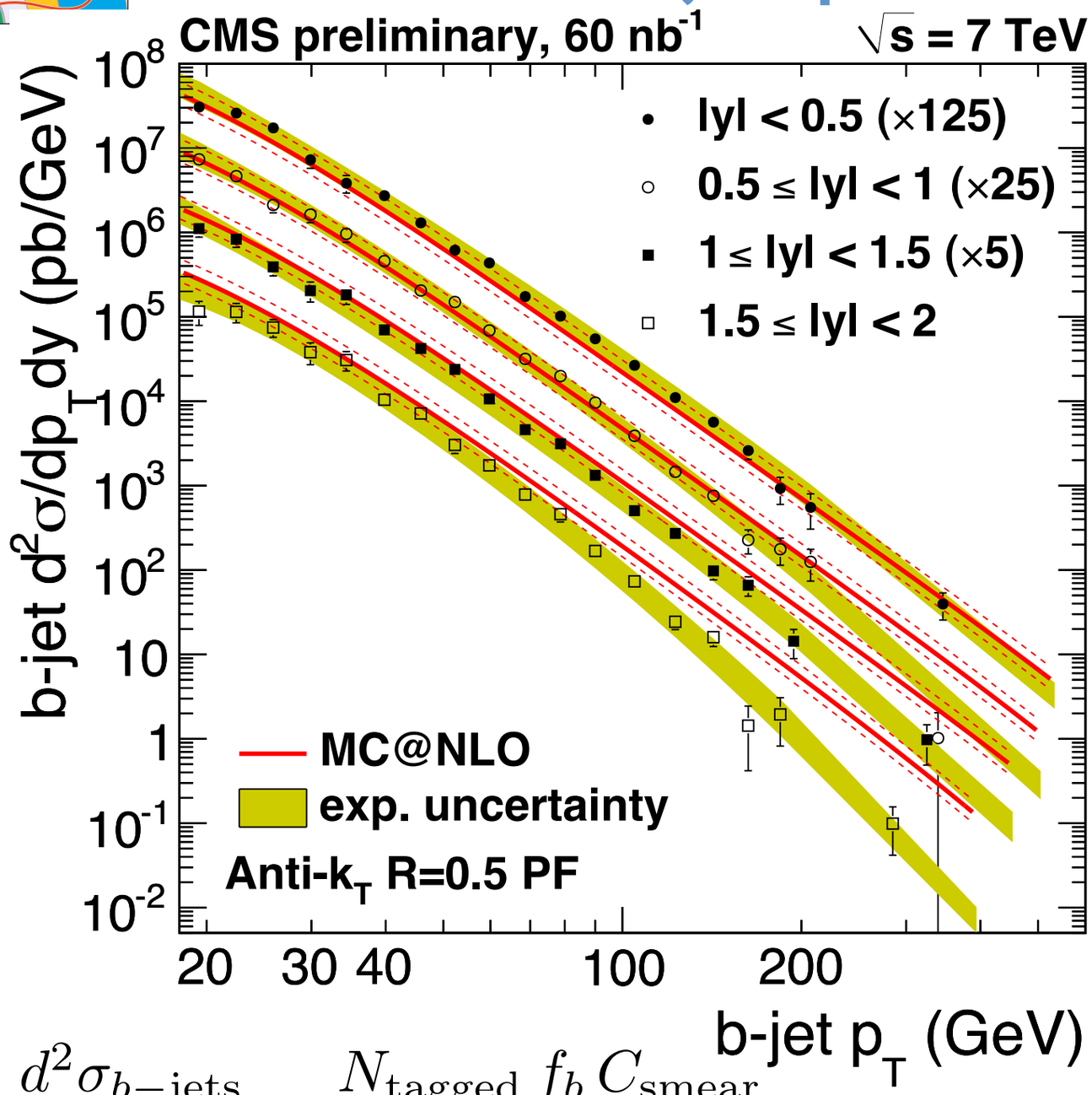
$$\varepsilon_b^{\mathrm{Data}}/\varepsilon_b^{\mathrm{MC}} = 0.98 \pm 0.08 \pm 0.18$$

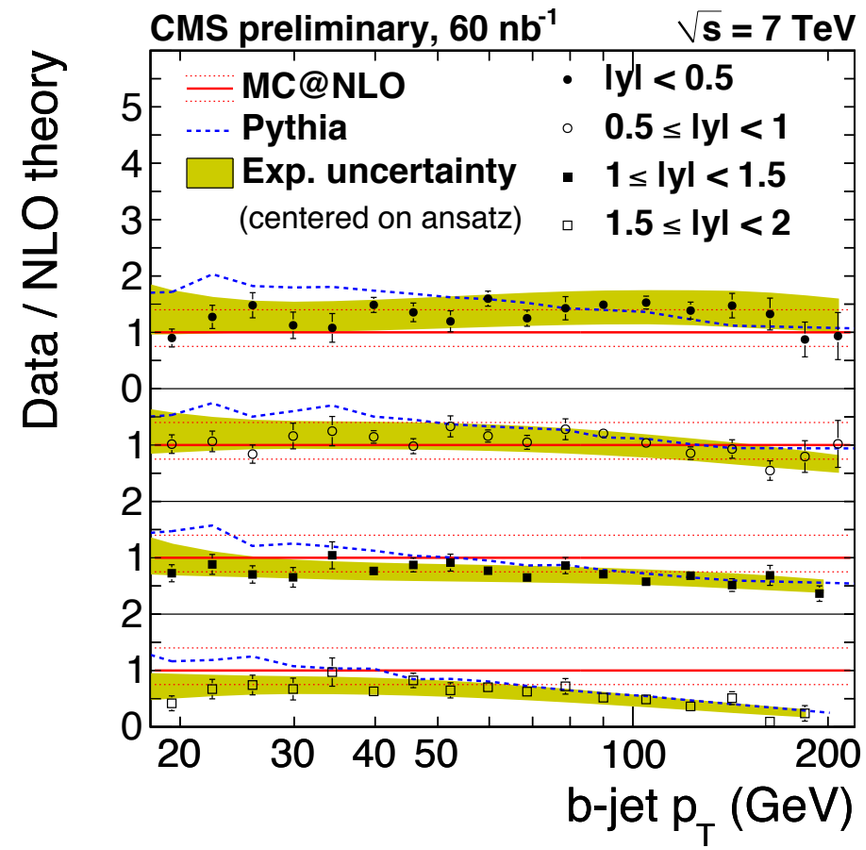
  - Mistag rate from MC, constrained by data-driven negative tag discriminator

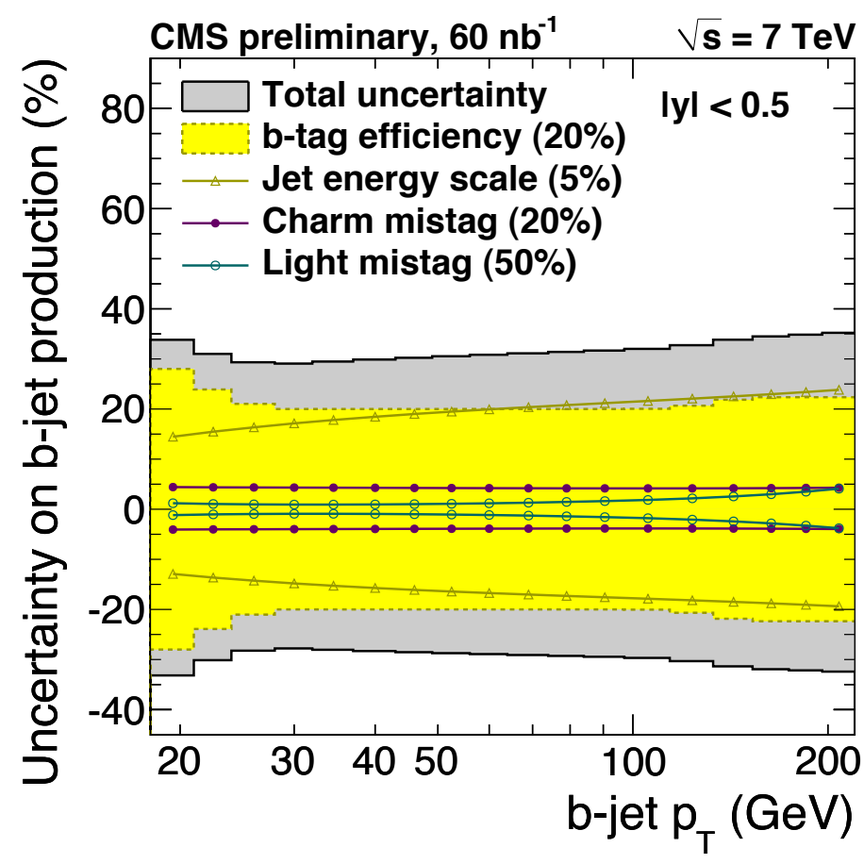
Double *b*-jet candidate (CMS DPS-2010/015)



# Inclusive *b*-jet production at $\sqrt{s}$ = 7 TeV




$$\frac{d^2\sigma_{b-\text{jets}}}{dp_T\,dy} = \frac{N_{\text{tagged}}\, f_b\, C_{\text{smear}}}{\varepsilon_{\text{jet}}\, \varepsilon_b\, \Delta p_T\, \Delta y\, \mathcal{L}}$$

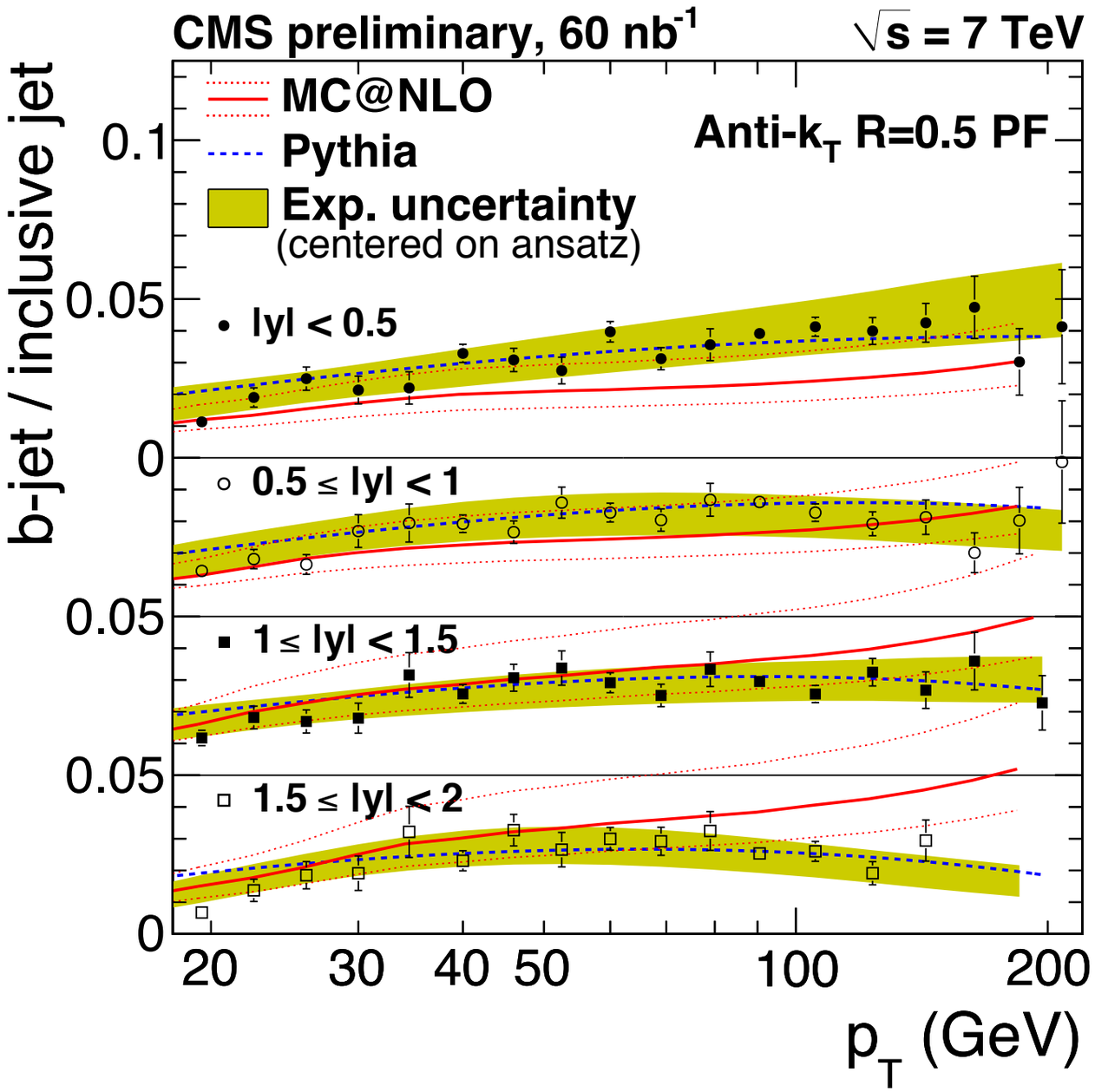
$C_{\text{smear}}$: unfolding correction

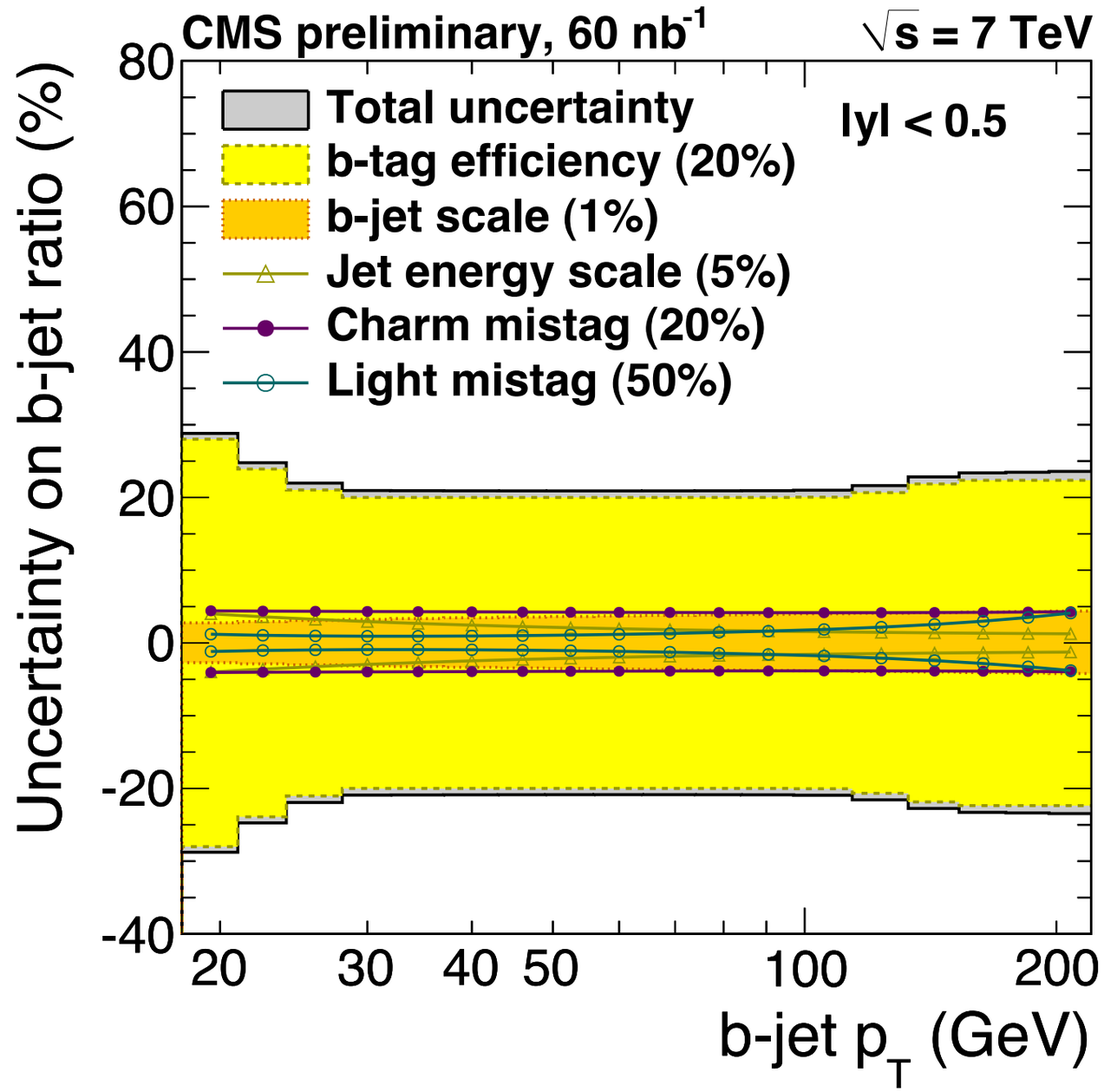
$f_b$: jet fraction containing $b$-hadrons

$\varepsilon_{\text{jet}}$: jet reconstruction efficiency

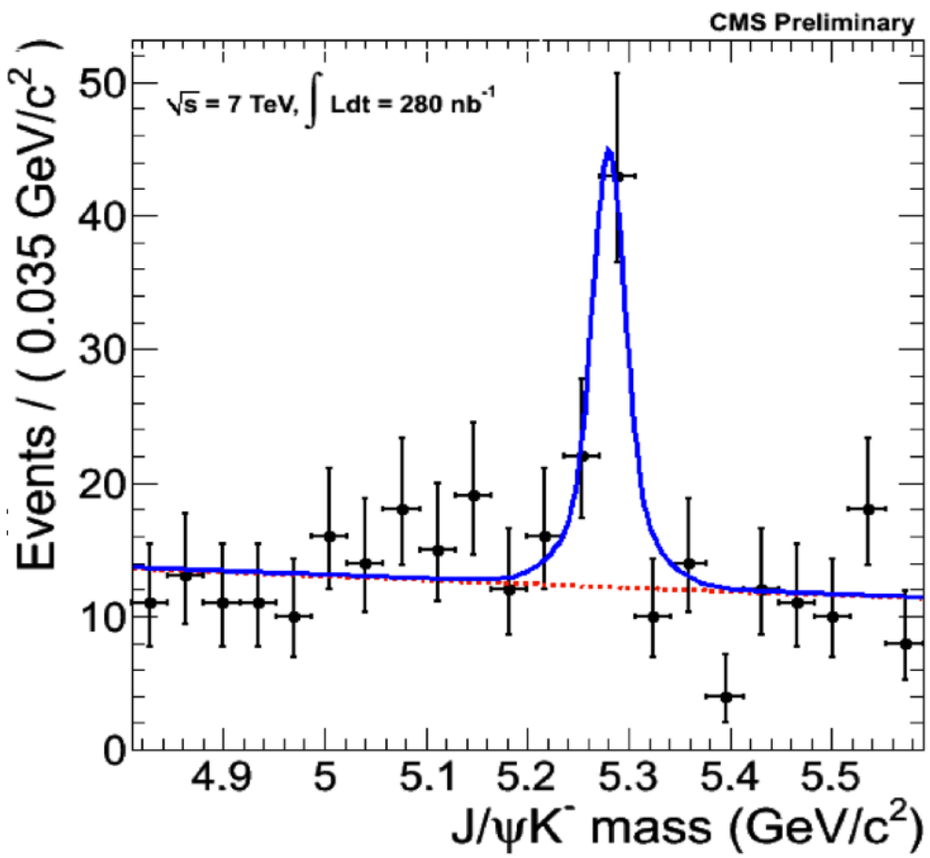
$\varepsilon_b$: b-tagging efficiency

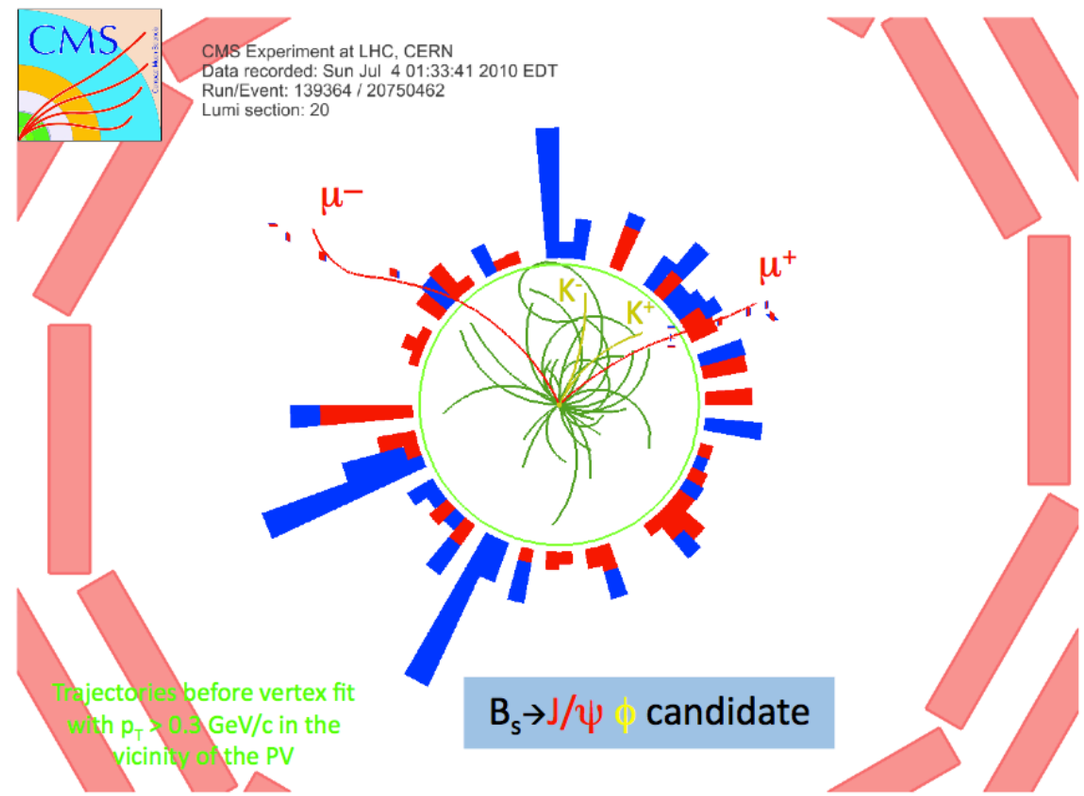
# b-jet/inclusive jet ratio

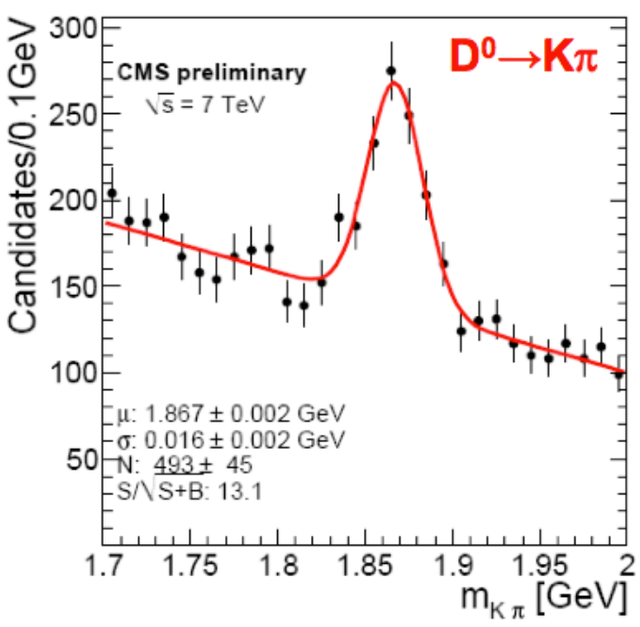


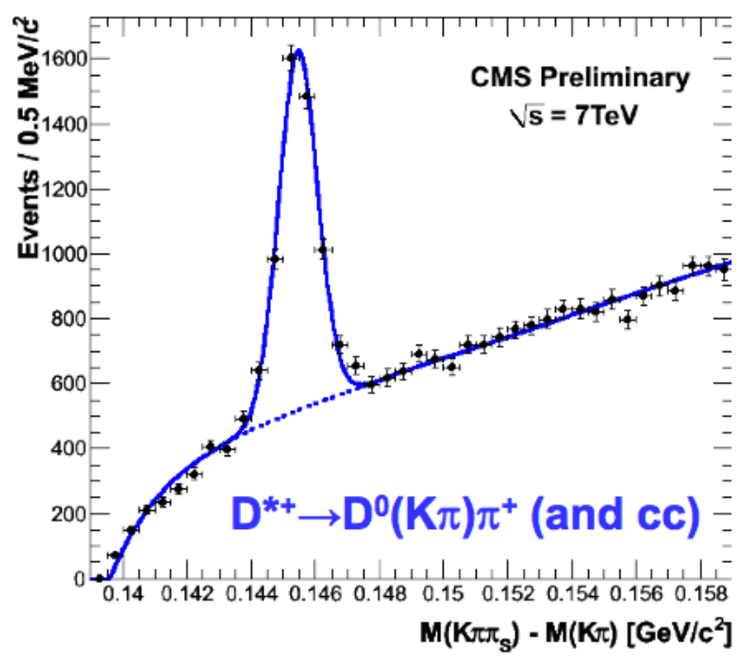



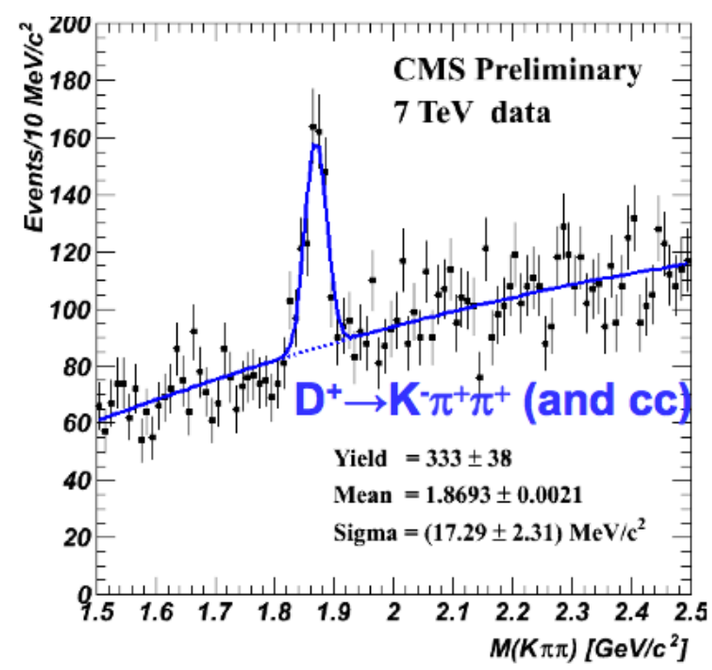
# Full B and D meson reconstruction



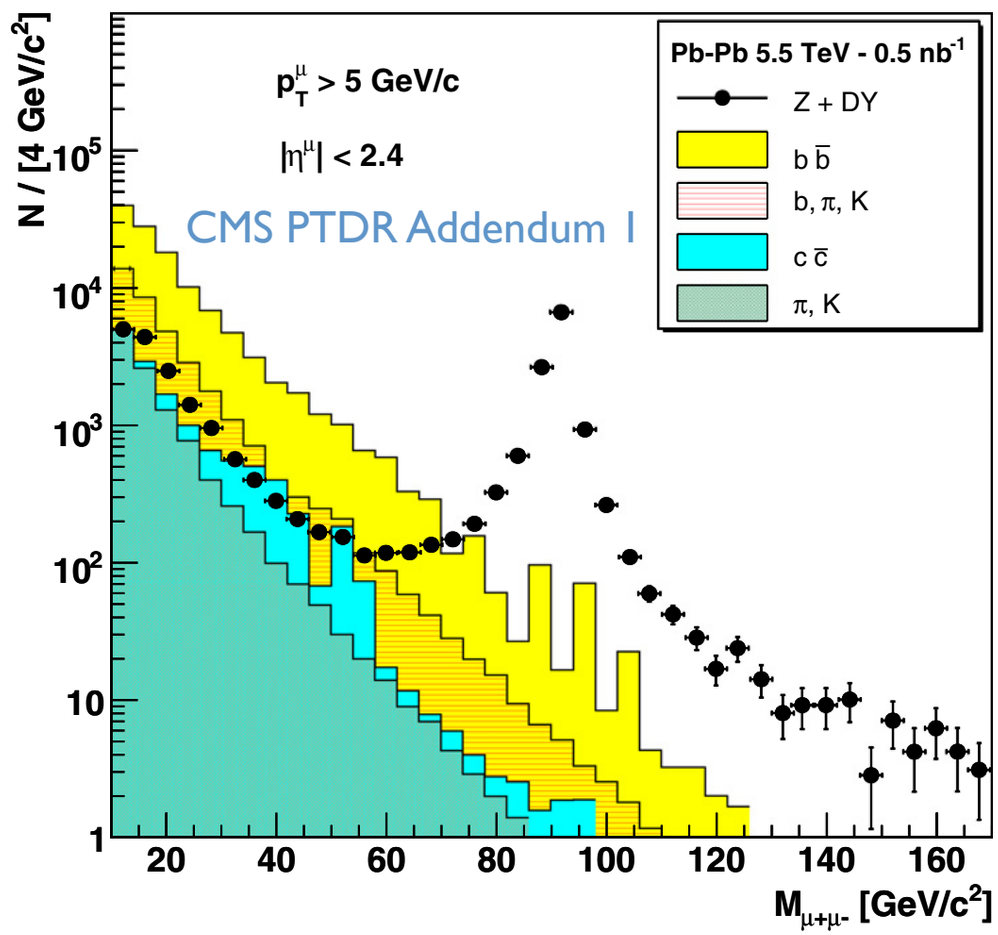



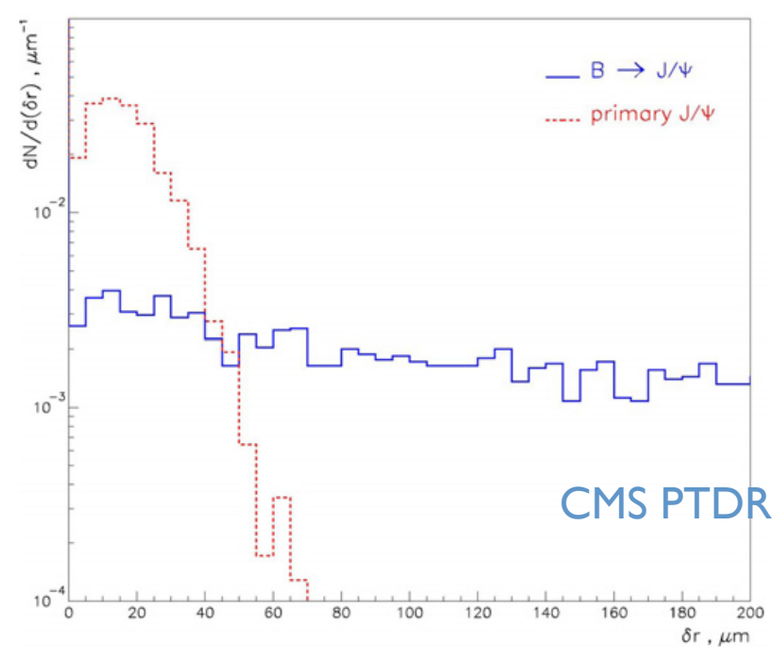



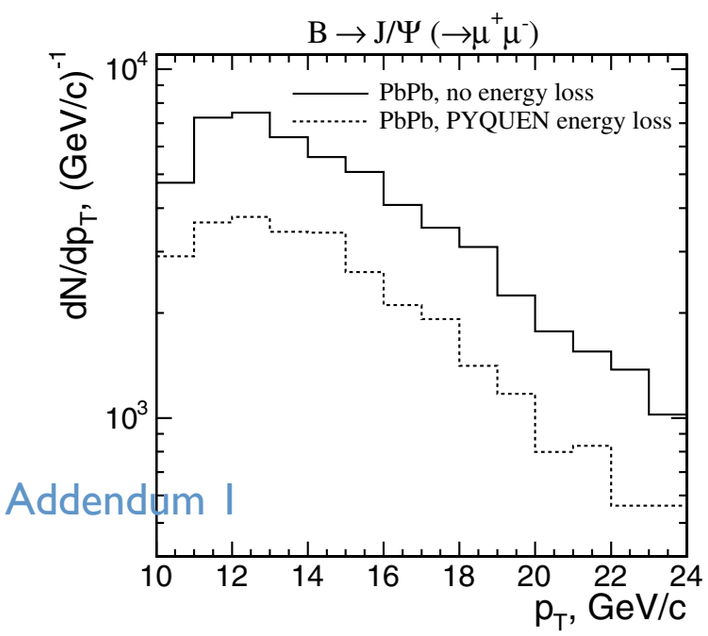



# Open heavy flavour in heavy ion collisions

- High-mass $\mu^+\mu^-$ continuum dominated by correlated semi-leptonic *b* decays
- Non-prompt J/ψ are very sensitive to *b*-quark energy loss
- *b*-tagged jets may provide another observable
- Challenge for the latter two lies in the secondary vertex reconstruction in the high multiplicity environment



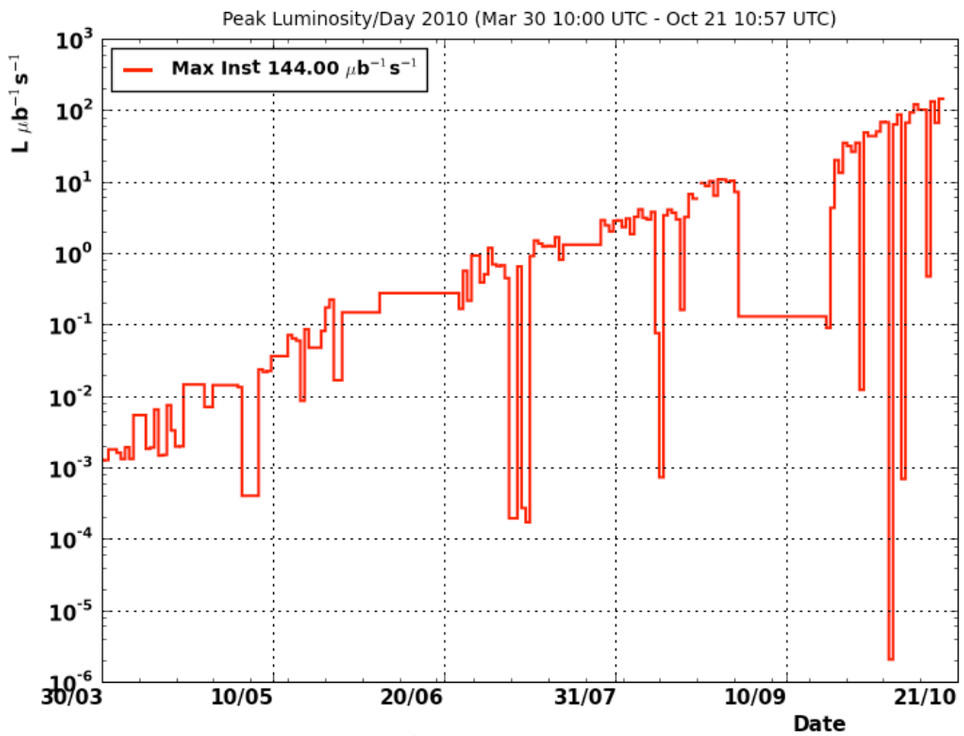



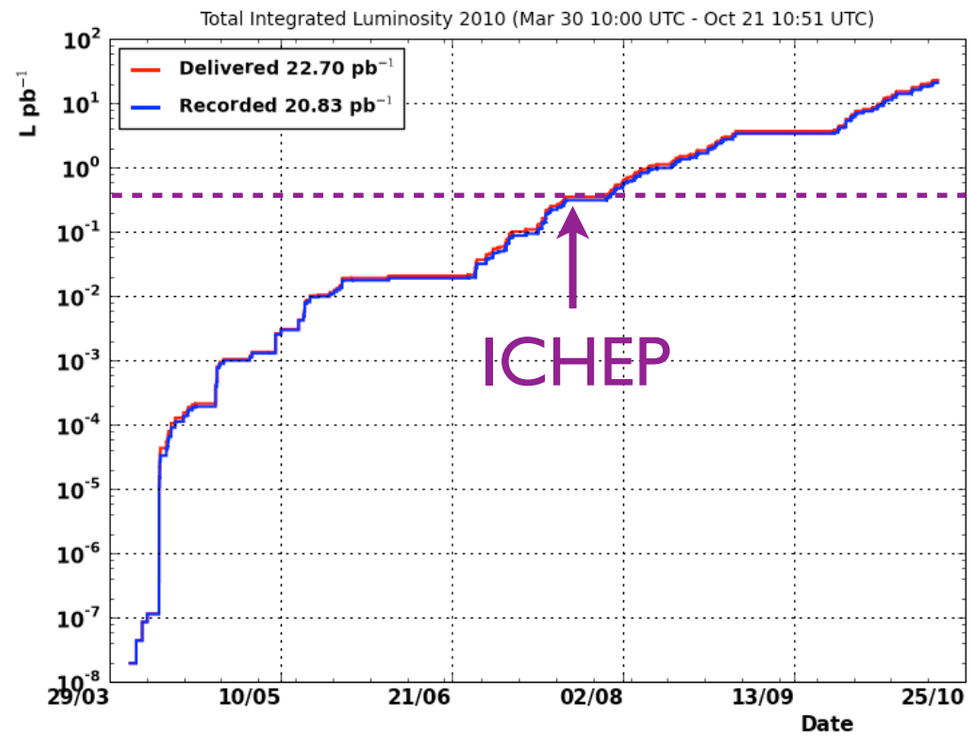
# Summary

- Very good tracking and muon detector performance allow rich quarkonia and B-Physics program at CMS.
- Very good *b*-tagging performance from early stage already! Measurement of inclusive *b*-production cross section has been possible with this method
- First measurements of the *b* cross section in p+p collisions at $\sqrt{s}$ = 7 TeV
  - with non-prompt J/ψ:
    - good agreement with other LHC experiments and CDF: no strong $\sqrt{s}$ and η dependence of non-prompt J/ψ fraction
  - from $p_T^{rel}$ measurement with muons:
    - Measurement for muon $p_T$ = 6–30 GeV/c, $|\eta| < 2.1$ with stat. error of 5–20% and syst. uncertainty of 16–20%
    - Good agreement with MC@NLO at muon $p_T$ > 12 GeV/c, while data are above the prediction in the central rapidity at low $p_T$
  - *b*-tagging of jets:
    - Measurement for jet $p_T$ = 18–300 GeV/c, $|y| < 2$
    - Overall good agreement with PYTHIA within ~2% stat. and 21% syst. uncertainty
    - Reasonable agreement with MC@NLO for overall cross section, but shape differences in $p_T$ and y
- Looking forward to the heavy ion run

# Backup

# LHC & CMS Performance



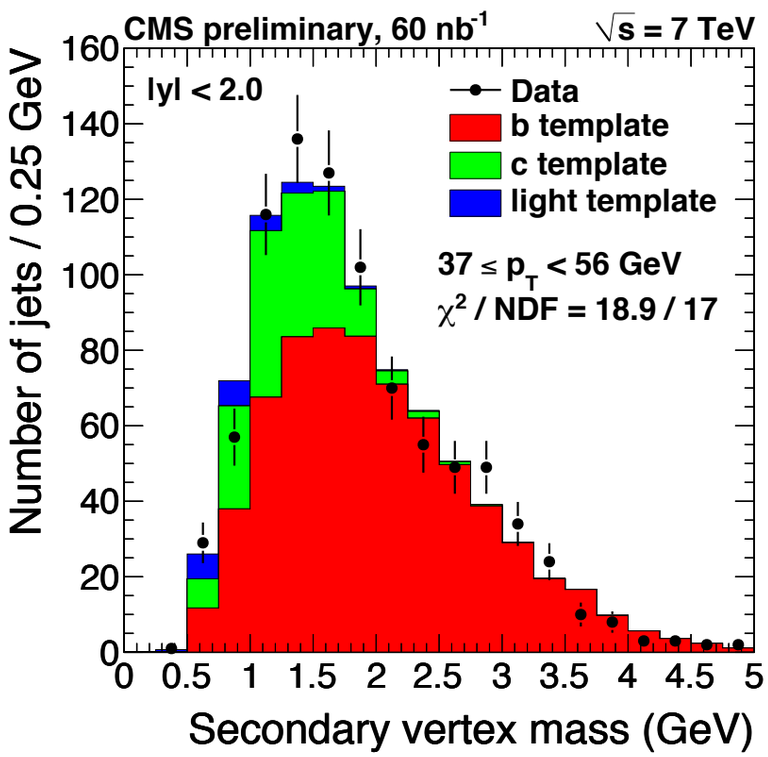

- March 30th, 2010: First p+p collisions at $\sqrt{s}$ = 7 TeV
- Since then:
  - LHC delivered integrated luminosity of $L_{int}$ = 22.7 $pb^{-1}$
  - CMS recorded $L_{int}$ = 20.83 $pb^{-1}$
  - Maximum instantaneous luminosity:
    $L_{inst}$ = 144 $\mu b^{-1}\ s^{-1}$ = 1.4 $10^{32}\ cm^{-2}\ s^{-1}$ (→ goal for 2010 achieved)
- Results shown today were approved for ICHEP 2010:
  $L_{int}$ ~ 10 – 300 $nb^{-1}$
- Current plan foresees:
  - p+p: deliver integrated luminosity of $L_{int}$ = 1 $fb^{-1}$ at $\sqrt{s}$ = 7 TeV with $L_{inst}$ up to few $10^{32}\ cm^{-2}\ s^{-1}$
  - Pb+Pb: 4 weeks in November/December at $\sqrt{s_{NN}}$ = 2.8 TeV≥ 2013
  - p+p at $\sqrt{s}$ = 14 TeV: only after longer shutdown (≥ 2013?)

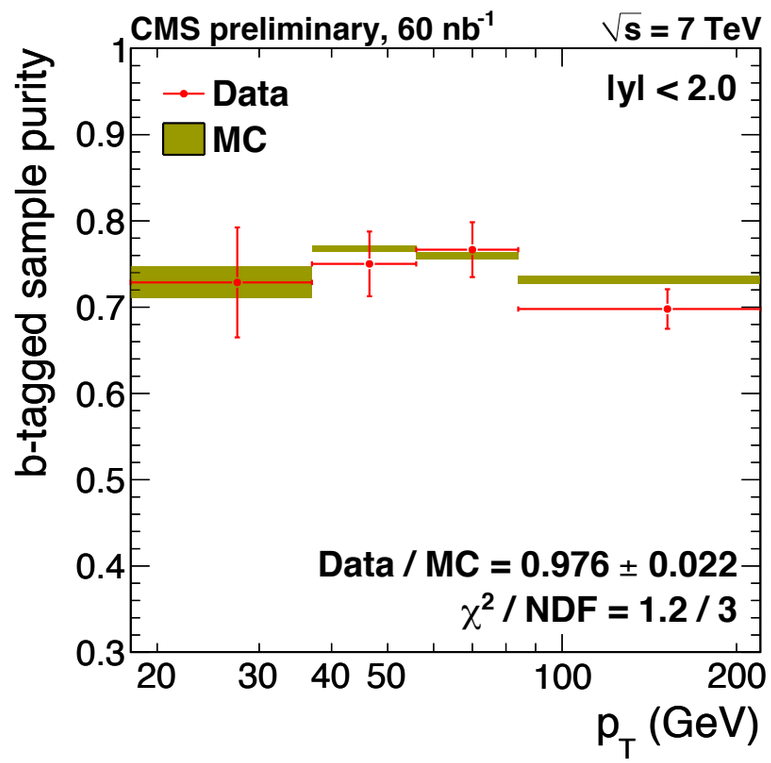
# Estimating the *b*-tagging purity

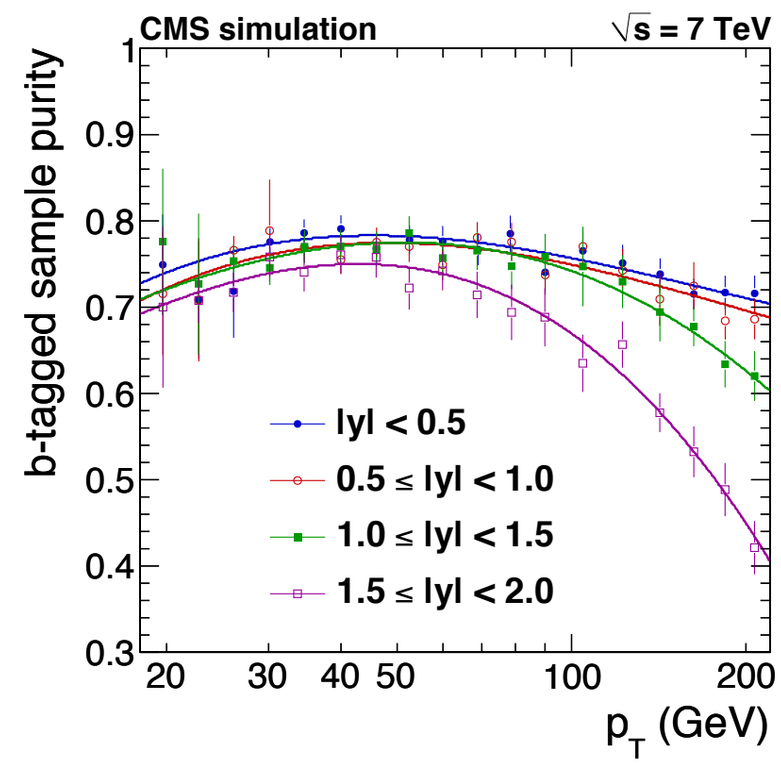
Data driven
Fit to secondary vertex mass

MC based
Fit of the flavour fractions

$$f_b = \frac{F_b \varepsilon_b}{F_b \varepsilon_b + F_c \varepsilon_c + F_l \varepsilon_l}$$

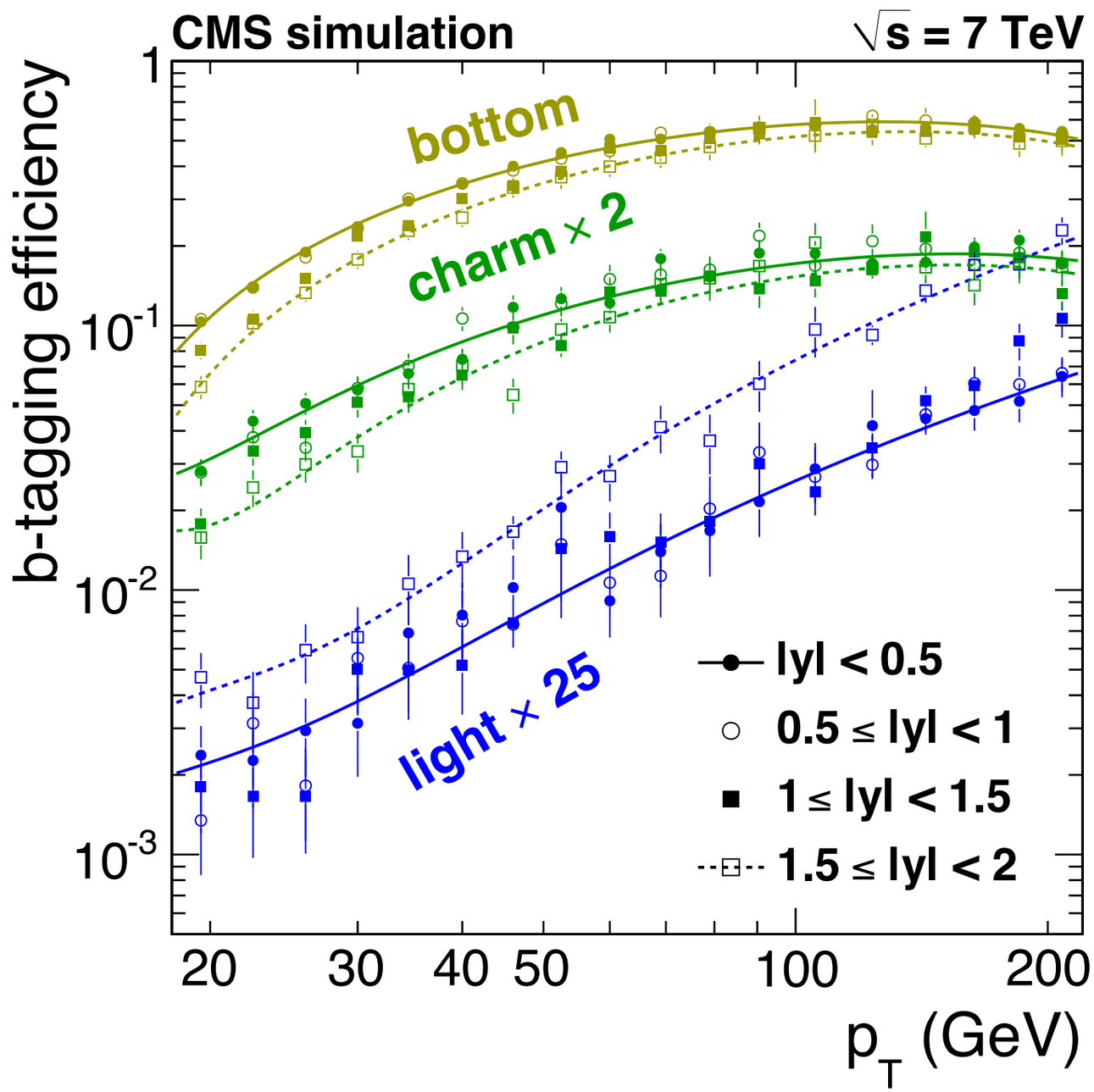



- Good agreement between data and MC: data/MC = 0.976 ± 0.022
- Central values taken from MC to properly take into account $p_T$ and y dependence

# *b*-tagging efficiency



# Muon momentum resolution

- Excellent momentum resolution ≤1% for |η|≤0.7; ≤3% for |η|≤2.5