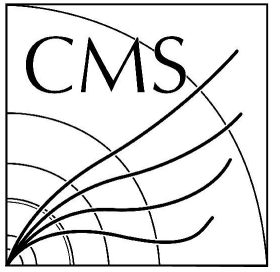


# Muon commissioning and Exclusive B production at CMS with the first LHC data

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INFN Milano Bicocca

On the behalf of the CMS collaboration

# Outline

- Introduction
  - CMS detector
  - Muon detection in CMS
- Cosmic Muons
- Muons in collisions
- Heavy flavour physics
  - $B \rightarrow J/\psi\ K$

# The CMS Detector

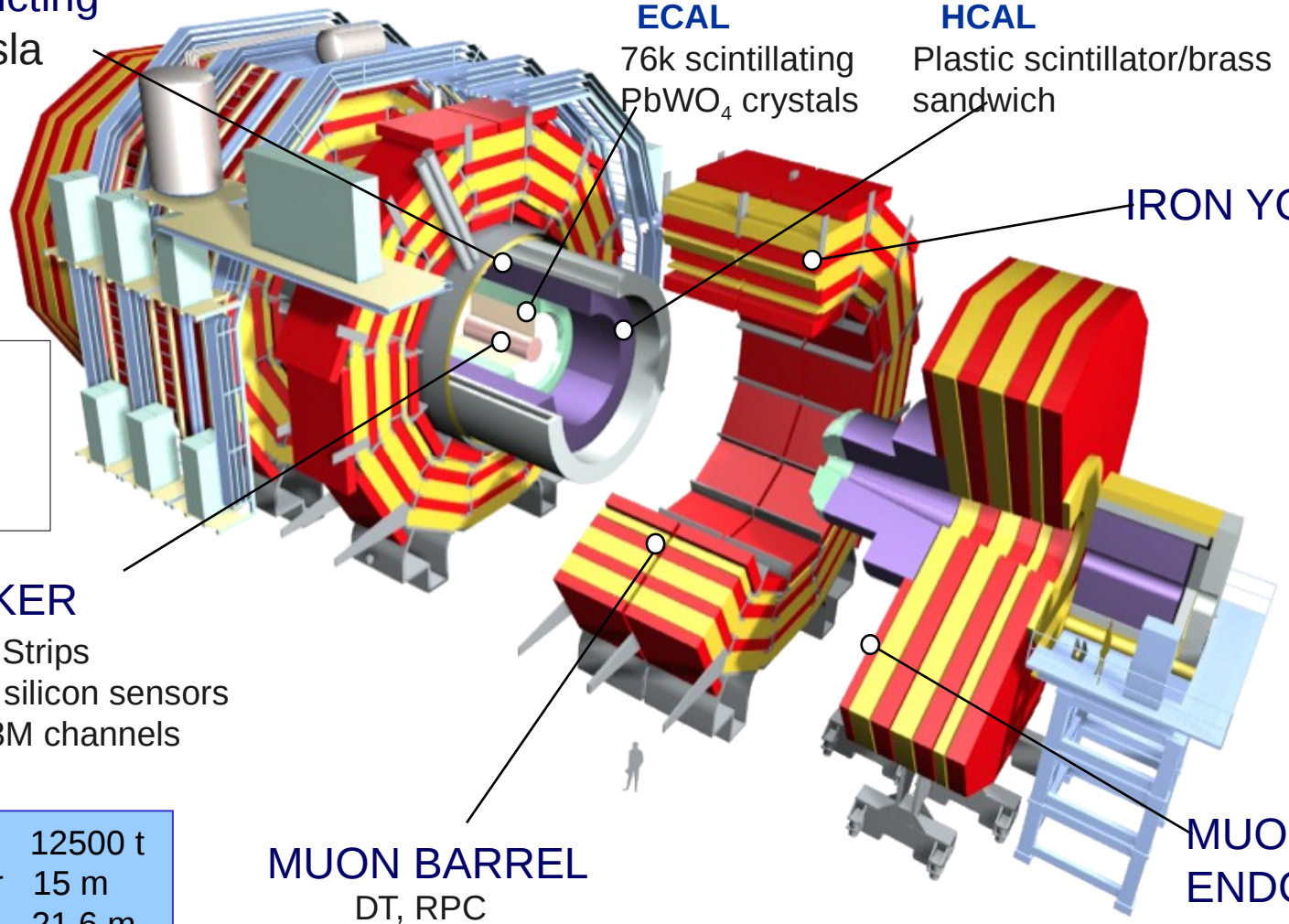
Superconducting Coil, 3.8 Tesla

CALORIMETERS

**ECAL**
76k scintillating $PbWO_4$ crystals

**HCAL**
Plastic scintillator/brass sandwich

IRON YOKE



38 Nations,
182 Institutions,
2900 scientists

TRACKER
Pixel and Strips
210 $m^2$ of silicon sensors
66M + 9.3M channels

| | |
|---|---|
| Total weight | 12500 t |
| Overall diameter | 15 m |
| Overall length | 21.6 m |

MUON BARREL
DT, RPC

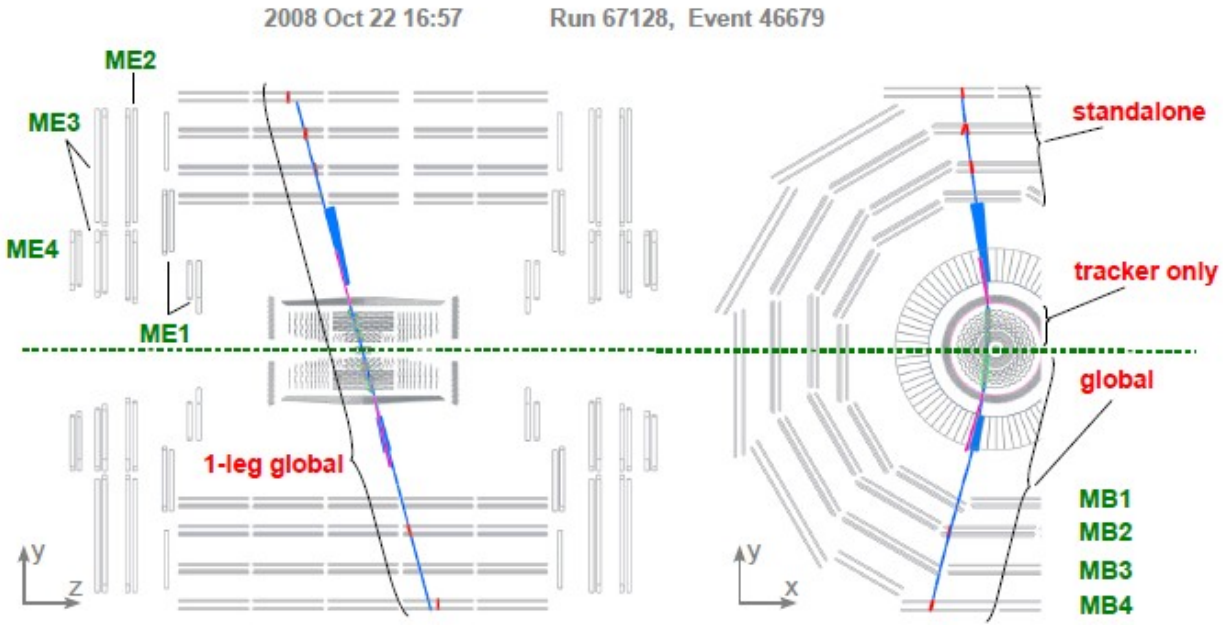
MUON ENDCAPS
CSC, RPC

# Muon reconstruction in CMS

- Redundant muon measurement
  - Muon system: DT and RPC (barrel) and CSC and RPC (endcap)
  - Inner tracker
- Large pseudorapidity coverage $|\eta| < 2.4$
- Excellent muon resolution:
  - Maching muon chamber – tracker information
  - High magnetic field

# Muon study with cosmic ray

- Muon reconstruction has been widely tested with the data sample of cosmic muons (CRAFT08 data)
  - Selections are applied to extract a collision-like sample
    - The distance between point of closest approach of the reference track to the beam line and the nominal interaction point has to be:

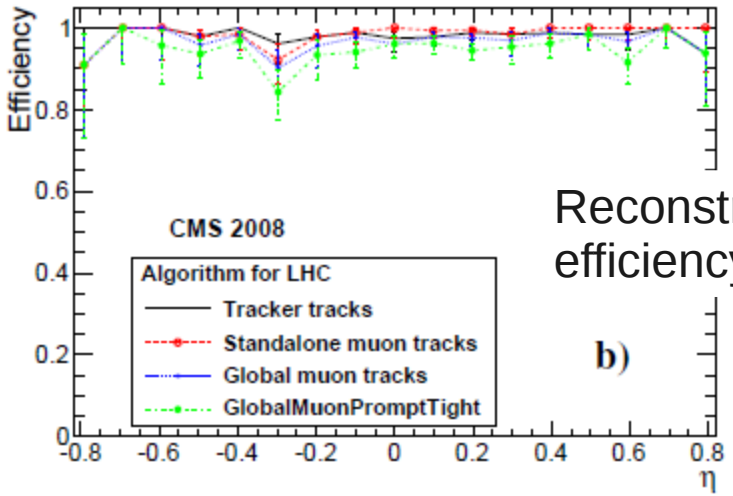



r < 4 cm in the transverse plane

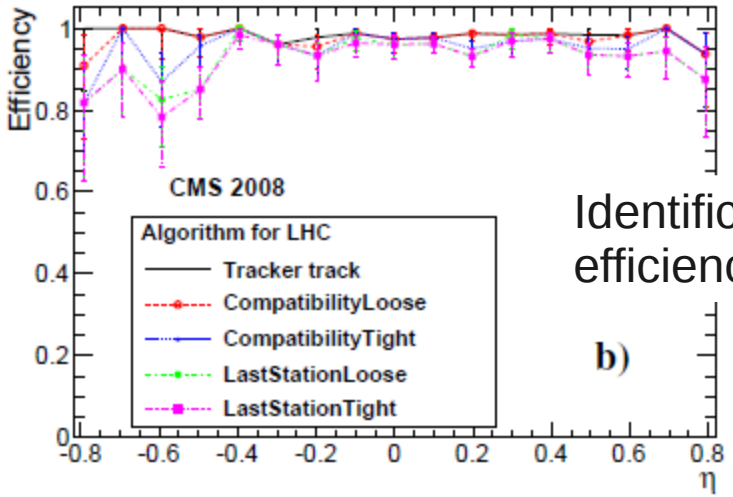
|z| < 10 cm along the beam line

# Efficient reconstruction and identification

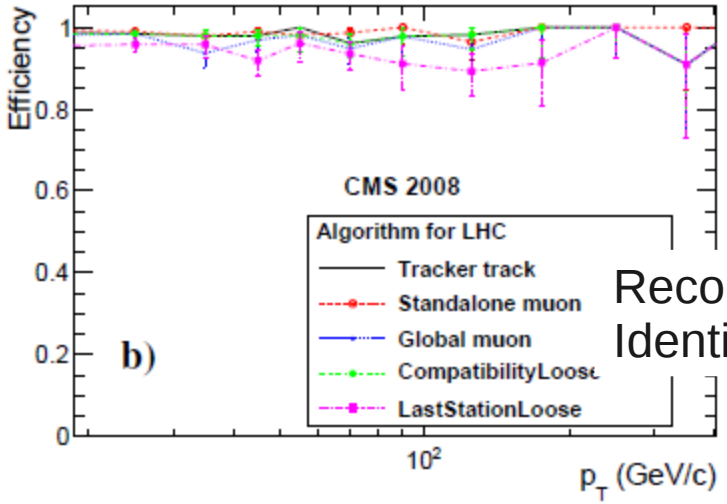
- No evidence of inefficiency in the barrel region ($|\eta|<0.8$) and in the whole $p_T$ spectrum




Reconstruction efficiency




Identification efficiency




Reconstruction and Identification efficiency

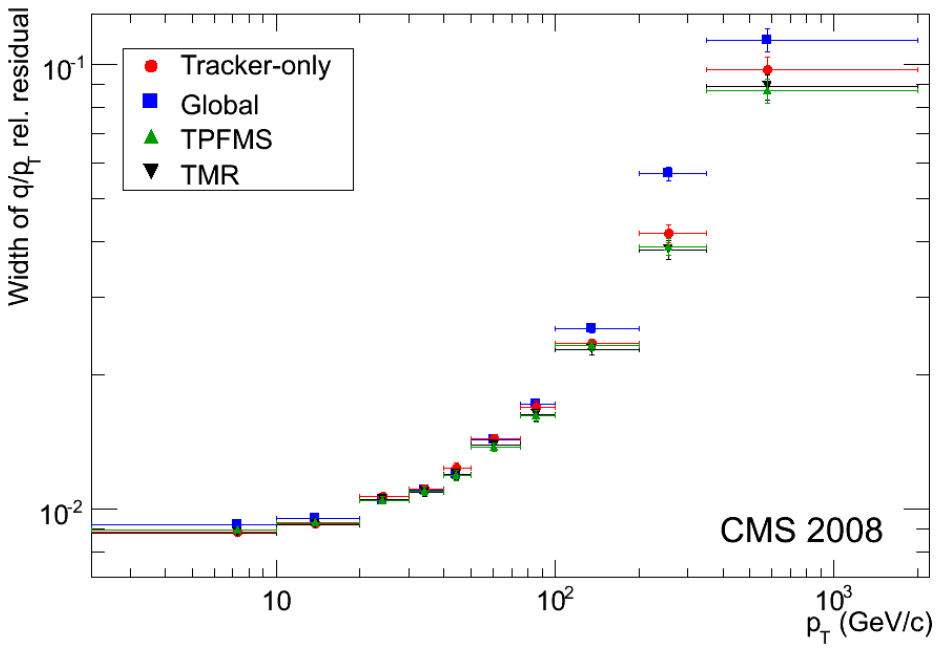
# $p_T$ resolution

- The transverse momentum resolution has been measured by the width of the distribution of the relative residuals:

$$R(q/p_T) = \frac{(q/p_T)^{upper} - (q/p_T)^{lower}}{\sqrt{2}(q/p_T)^{lower}}$$

where upper and lower stay for the upper and lower halves of the detector

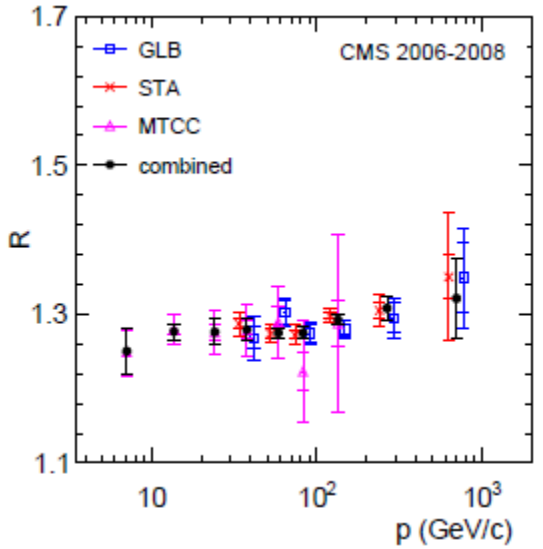
- In the region below 200GeV/c, the resolution is dominated by multiple scattering in the tracker. No improvement including muon hits.
- High $p_T$: currently global muons not as good as tracker tracks, but including, if necessary, the first muon station information (track by track choice) the resolution can be improved

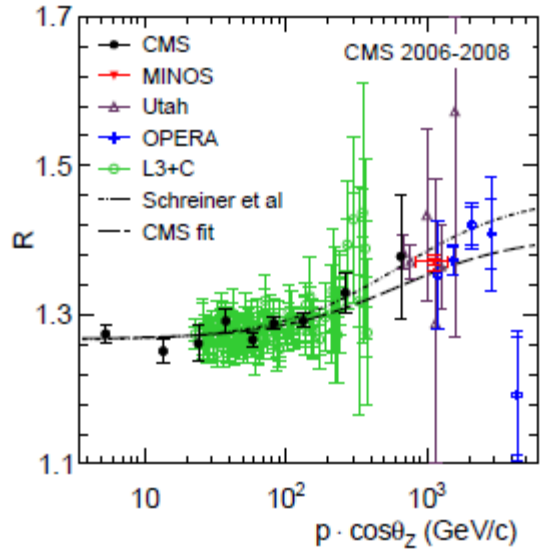


# Charge ratio of muons from cosmic rays

- CMS measured the ratio of positive to negative muon fluxes from cosmic rays
- Data acquisition at ground level (MTCC2006) and underground (CRAFT08)
- Muon momentum range 5GeV/c – 1 TeV/c
- CMS measurement is in agreement with models and previous measurements (last and most precise result before CMS is from MINOS)
- The ratio is indipendent from the muon momentum below 100 GeV/c

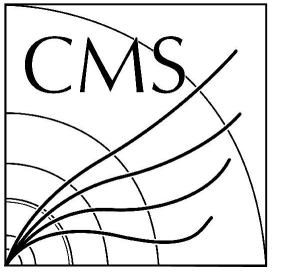
$$R\left(\frac{\mu^+}{\mu^-}\right) = 1.2766 \pm 0.0032\,(stat.) \pm 0.0032\,(syst.)$$




arXiv:1005.5332v1 submitted to Physics Letters B

# Muons in collisions: three classes of muons




- Muons from collisions are divided into 3 classes
  - **StandAlone Muons:** Their reconstruction only uses the muon stations
    - $p_{min}$~3 GeV/c (necessary to cross the whole half detector)
  - **Global Muons:** Their reconstruction starts from standalone muons; then, the muon track is matched with a track reconstructed in the silicon (pixel and strip) tracker.
  - **Tracker Muons:** Their reconstruction starts with tracks in the tracker which are then matched to segments in the muon stations (one or more).
    - The corresponding momentum cut-off is lower than for global muons (~1GeV/c), but these tracker muons are not most difficult to trigger on.

- Tracker muons are necessary to enhance the reconstruction efficiency of low momentum muons.

# Muons in collisions: trigger

- Different muon triggers for different LHC luminosity
  - Single muon trigger

$10^{29}$-$10^{30}$ $cm^{-2}s^{-1}$

  - Ad Hoc intermediate solutions:
    - Once a muon is triggered, another track in the tracker is selected and the compatibility with a resonance (J/$\psi$, $\Upsilon$) is checked
    - Single muon HLT but with a double muon Level-1 seed

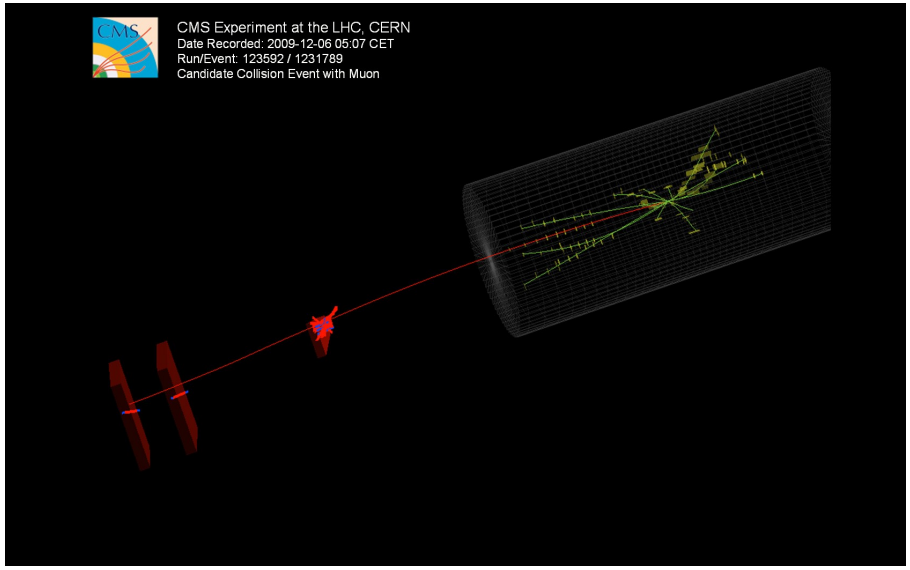
$10^{31}$ $cm^{-2}s^{-1}$

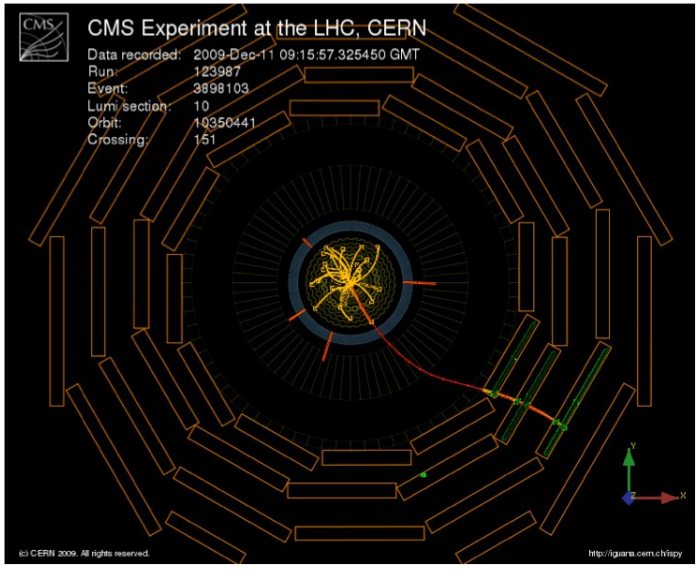
  - Single-high $p_T$ or double muon trigger

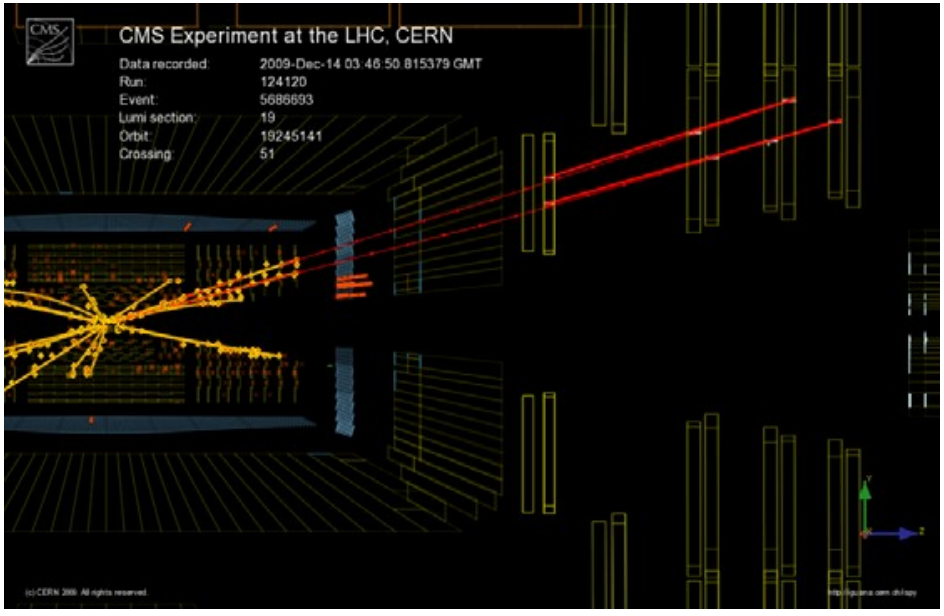
> ~ $10^{32}$ $cm^{-2}s^{-1}$

- During the first runs ($\mathscr{L}$<~$10^{28}$ $cm^{-2}s^{-1}$) a minimum bias trigger is used

# Muons in collisions: events at 0.9 and 2.36 TeV



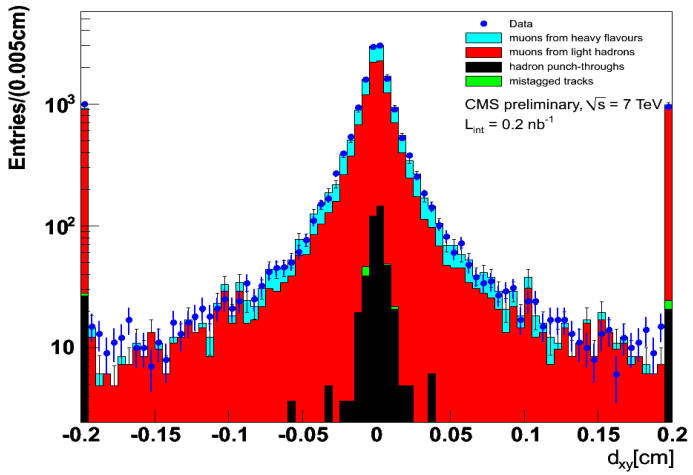



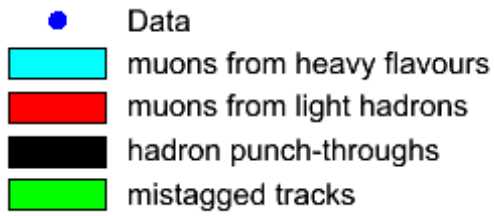

J/$\psi$ candidate in the endcap:

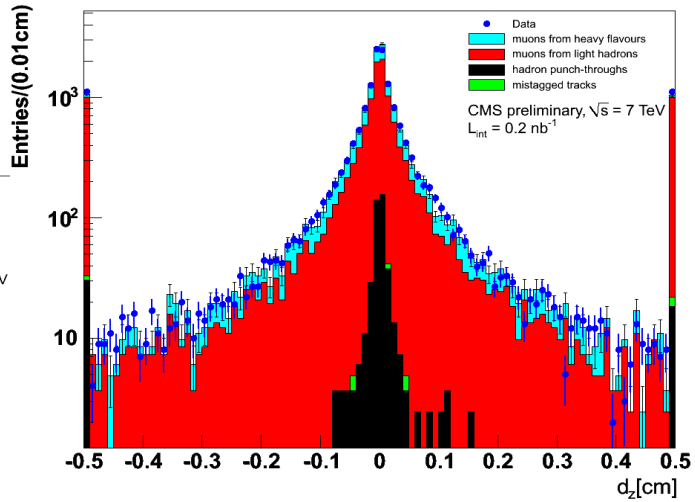
- $p_T(\mu_1)$ = 3.6 GeV/c
- $p_T(\mu_2)$ = 2.6 GeV/c
- M($\mu\mu$)= 3.03 GeV/$c^2$

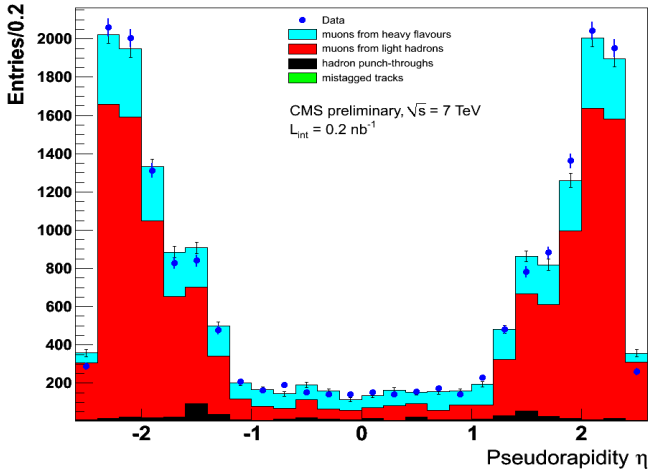
# Muons in collisions: 7 TeV

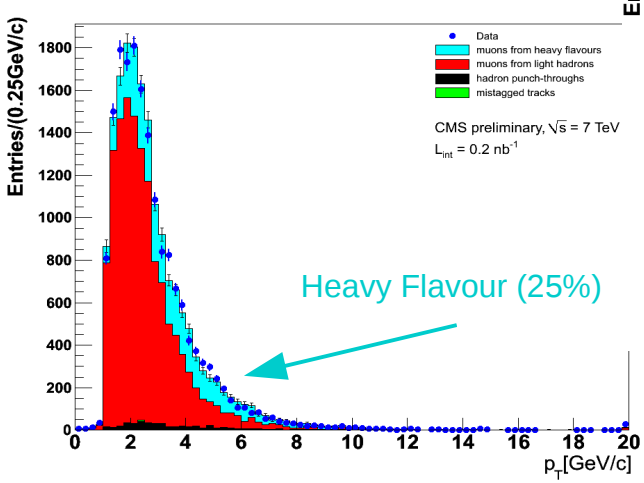
- Data-MC comparisons for a few basic kinematic distributions has been performed using minimum bias events at 7 TeV
- A good agreement results for both global and tracker muons



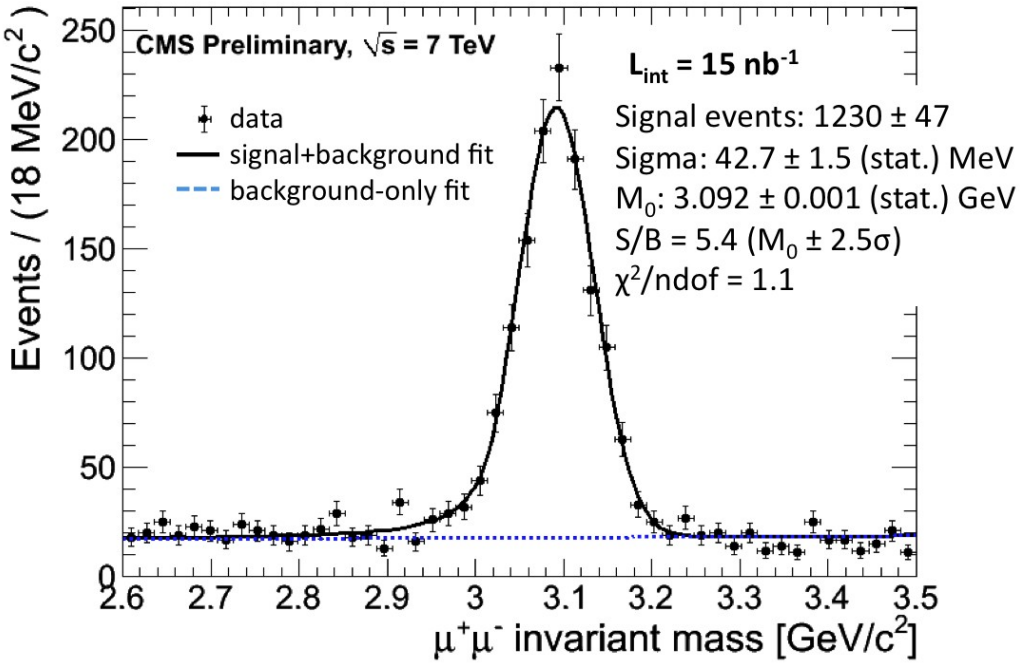



# Muons in collisions: J/$\psi \to \mu\mu$ at 7 TeV

**Selection:**

- dataset: 15 $nb^{-1}$
- acceptance of the muons: $|\eta| < 2.4$
  - $p_T > 3.3$ GeV if $|\eta| < 1.3$
  - $p > 2.9$ GeV if $1.3 < |\eta| < 2.2$
  - $pT > 0.8$ GeV if $|\eta| > 2.2$
- Tracker muons:
  - $\chi^2$/ndof < 4.0
  - $|d_0| < 3.0$ cm, $|dz| < 15.0$ cm
  - number of valid hits (pixel + strips) > 11
  - number of pixel layers with hits>= 2
- Global muons:
  - $\chi^2$/ndof (global fit)< 20.0
  - number of valid muon hits > 0
  - TM passing TMLastStationAngTight selector
- Secondary vertex P($\chi^2$) > 0.1%



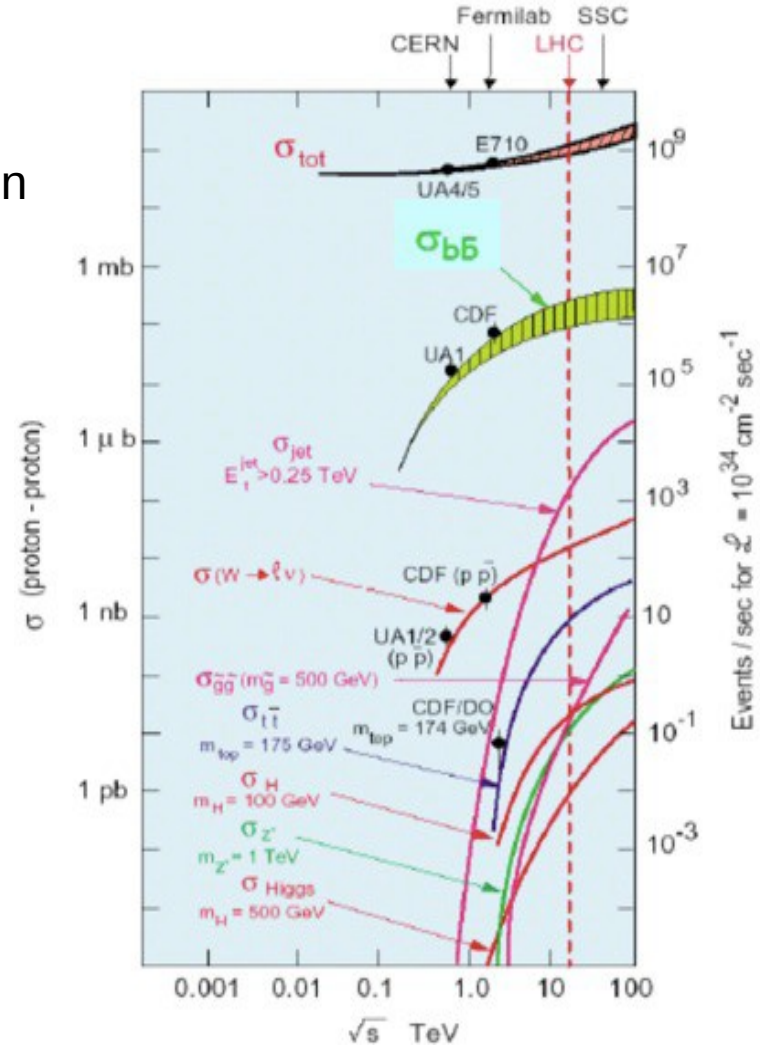

**Fit:**

- Extended ML fit with exponential for the background + a CrystalBall function for the signal (radiative tail)
- Shape parameter of the exponential fixed from a fit to the side bands
- All the parameters in the CrystalBall function are free

# Heavy flavour physics at CMS

- Heavy flavours will be abundantly produced at the LHC.
- At this starting phase, part of the CMS collaboration is investigating the heavy flavour sector.
  - Most of the analyses are driven by the J/$\psi \rightarrow \mu\mu$
- Interesting for physics
  - SM measurement
  - BSM searches

  and for commissioning
  - Detector
  - Trigger
- This study is also important for the background determination in other searches



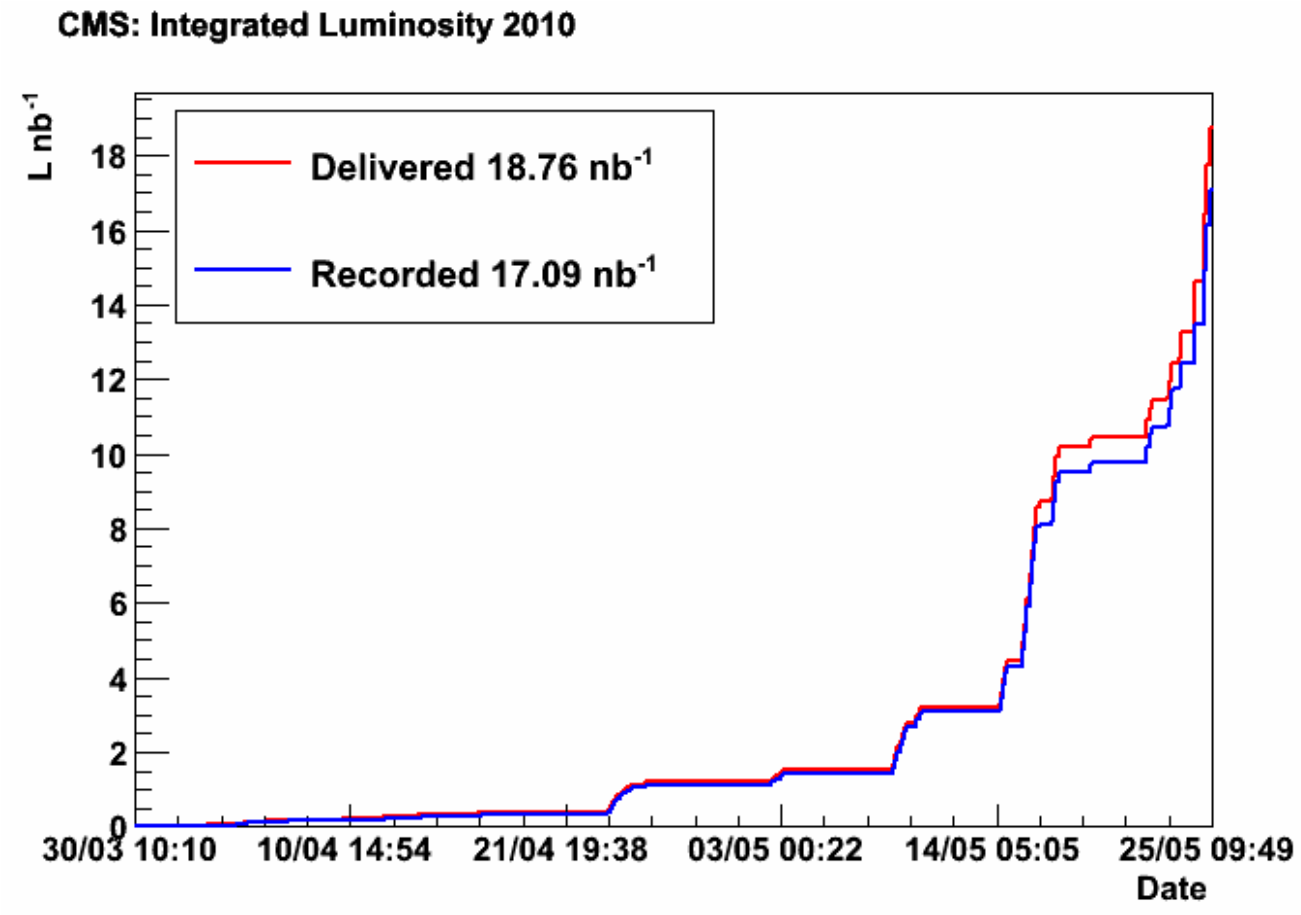
# Heavy flavour physics at CMS - II

- Rich program with few $pb^{-1}$ of integrated luminosity
  - *O*(0.1) $pb^{-1}$ Exclusive D signal
  - *O*(1) $pb^{-1}$ J/$\psi$ production cross section / polarization
    Inclusive b and $\Upsilon$(nS)
    - *O*(10) $pb^{-1}$ $b\bar{b}$ correlations, exclusive B
  - *O*(100)$pb^{-1}$ UL($B_s^0 \to \mu^- \mu^+$), exclusive $B_s^0$ decay

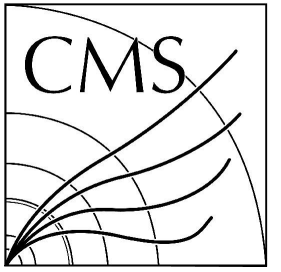
- Keep in mind the LHC plans for luminosity (continuously updating):
  - O(100)$pb^{-1}$ of integrated luminosity delivered at the end of the 2010
  - O(1)$fb^{-1}$ of integrated luminosity delivered at the end of the 2011 (end of the long run)

# Luminosity delivered up to now

- At the moment, tens of $nb^{-1}$ (7 TeV collisions) have been delivered by LHC and recorded by CMS



# Exclusive B: $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{0*}$




- CMS is going to measure the differential cross section and the lifetime ratio using the exclusive decays $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{0*}$, with $J/\psi \to \mu\mu$ and $K^{0*} \to K^+\pi^-$
  - BR $\sim 10^{-3}$ but systematics reduced w.r.t inclusive $B \to J/\psi X$
  - Background processes (inclusive b and prompt $J/\psi$) are easily identified using the invariant mass $M_B$ and the proper decay length of the reconstructed B candidate

- In addition, it is a test of the CMS detector performances because
  - Both decay modes are well known, deeply studied at the B-factories
  - BR for each mode known with a precision better than 5%

# $B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J/\psi K^{0*}$ MC study

- A MC study (at 10 TeV) has shown the feasibility.

- Selection:
  - Dimuon trigger ($p_T$>3GeV)
  - J/$\psi$ reconstruction from 2$\mu$
    - opposite charge
    - Vertexing
    - Tracker $\mu$
    - M($\mu\mu$)= M(J/$\psi$)$\pm$ 150 MeV/c$^2$
  - $K^{0*}$ reconstruction from 2 tracks
    - Opposite charge
    - $p_T$(track) > 0.5 GeV/c
    - Not muons
    - $N_{HIT}$ > 3
    - $\chi^2$/ndof < 5
    - The combination with the resulting mass closest to the K$\pi$ nominal value and within 120 GeV/c$^2$ from it, is chosen
  - K track:
    - $p_T$ > 0.8 GeV/c
    - $N_{HITS}$ >3
    - $\chi^2$/ndof < 5
    - Not a muon
- B candidate reconstruction:
  - Kinematic fit of J/$\psi$ + track(s)
    - M($\mu\mu$) constrained to the J/$\psi$ mass
    - M(K$\pi$) constrained to the $K^{*0}$ mass
  - 4.95 < M(B) < 5.55 GeV/c$^2$

# $B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J/\psi K^{0*}$ MC study - II

- ~1750 $B^+$ and ~900 $B^0$ events are reconstructed with 10 $pb^{-1}$ of integrated luminosity

- The lifetime is calculated from the proper decay length in the transverse plane

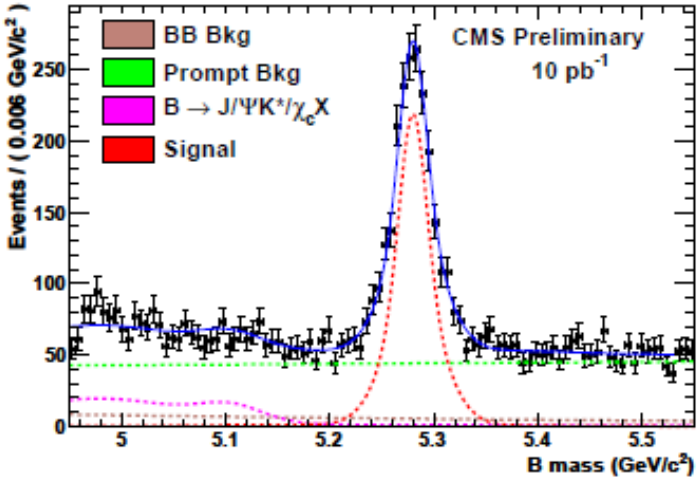
$$ct = \frac{M_B}{P_T^B} \cdot L_{xy}$$

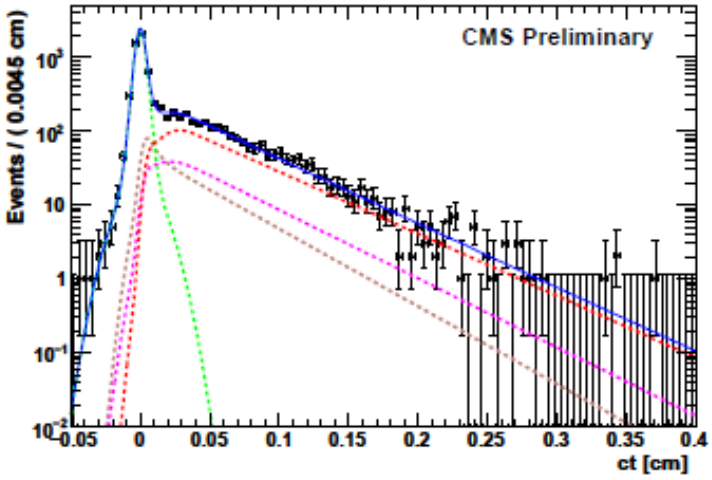
- Yield and lifetime: simultaneous fit to mass and proper decay length distributions for the whole sample with $p_T(B)>9GeV$
- Cross-section: yield fit for different $p_T$ bins, fixing the lifetime

# Yield and lifetime full $p_T$ spectrum (MC study)

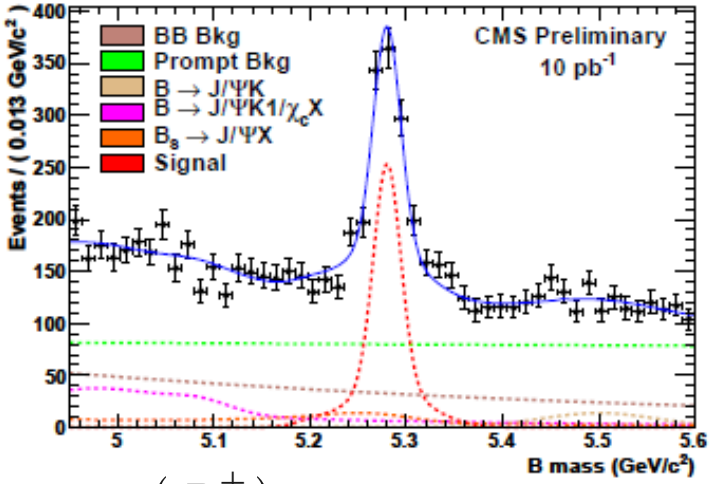
PAS BPH -09-001

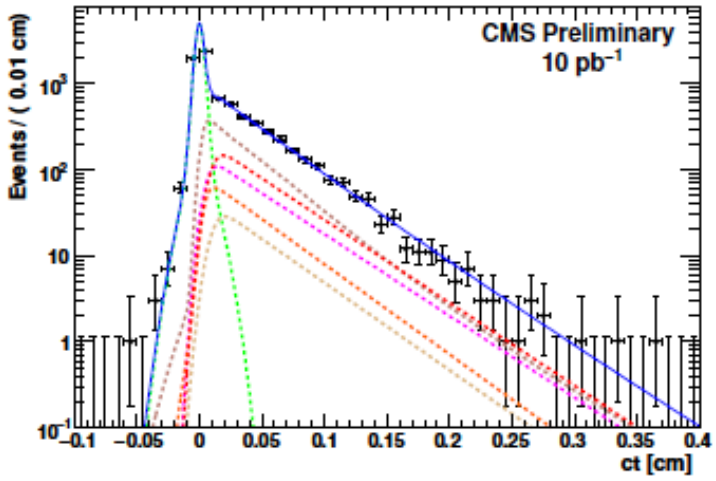
$B^+ \rightarrow J/\psi K^+$




$B^0 \rightarrow J/\psi K^{0*}$




Lifetime ratio $R_{+0} = \frac{\tau(B^+)}{\tau(B^0)} = 1.10 \pm 0.05 \pm 0.01$

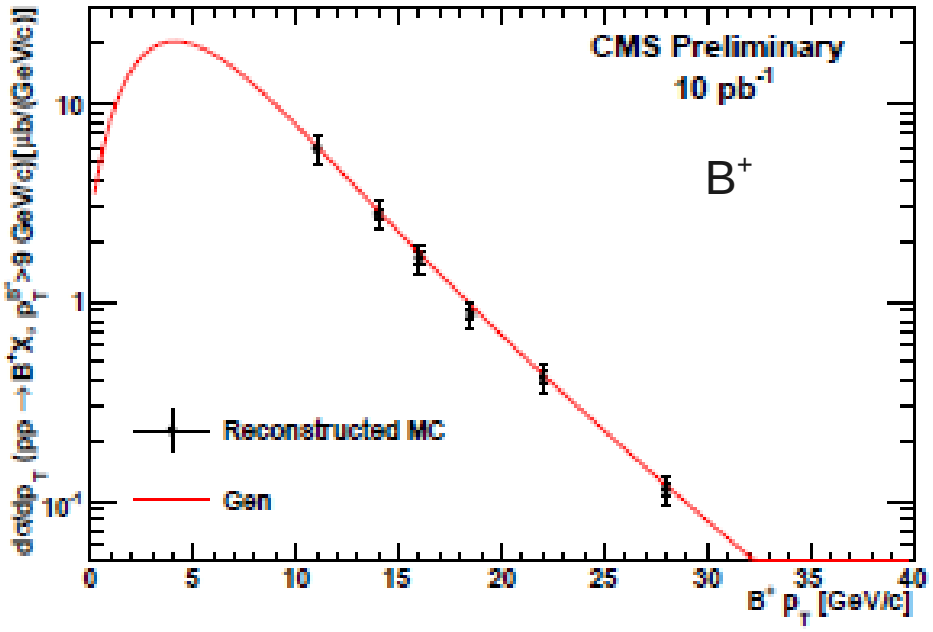
current PDG value $B^+/B^0 = 1.071 \pm 0.009$

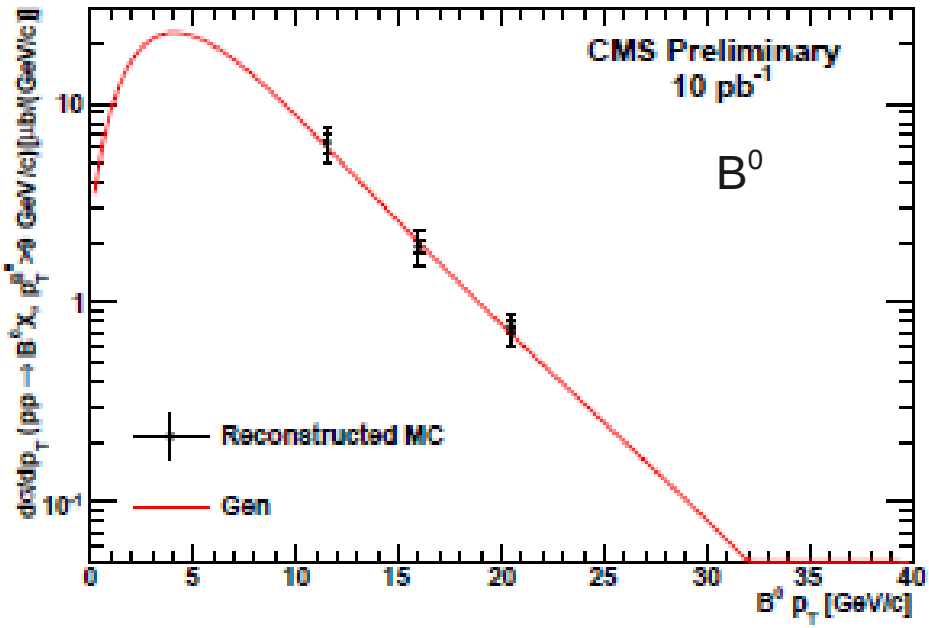
# Cross section (MC study)

- Cross-section: yield fit for $p_T$ bins, fixing the lifetime

$$\frac{d\sigma(pp \to BX)}{dp_T^B} = \frac{n_{sig} \cdot f_{bin}}{2 \cdot \epsilon_{trig} \cdot \epsilon_{reco} \cdot BR(B \to J/\psi K^{(*)}) \cdot BR(J/\psi \to \mu\mu) \cdot L \cdot \Delta p_T^B}$$

PAS BPH -09-001




- Statistical precision < 10%.
- Systematic dominated by the luminosity uncertainty (~10%)

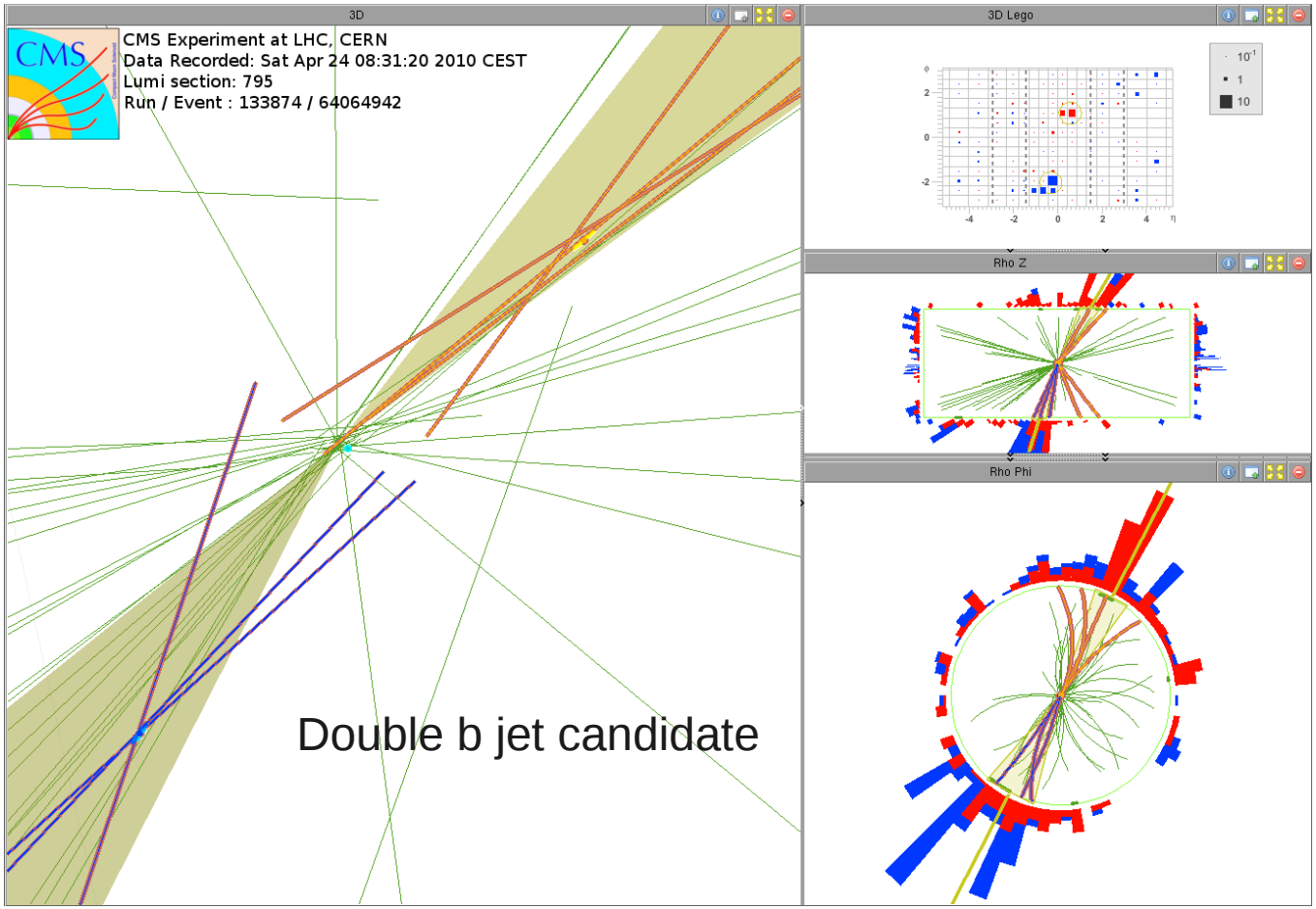
# Other B analyses

- Ongoing analysis:
  - Azimuthal correlation in $b\bar{b}$ production (PAS BPH-08-004)
    - Study performed with L= 50pb$^{-1}$, and $\sqrt{s}$ = 10 TeV.
  - B-hadron fraction in J/psi decays (PAS BPH-07-002)
    - Study performed with L=3pb$^{-1}$, and $\sqrt{s}$ =14 TeV.

- Lot of ideas (under study) for other exclusive B analyses:
  - $\Upsilon$(nS), $B_s \rightarrow J/\psi\phi$, UL $B_s \rightarrow \mu\mu$, $B^0 \rightarrow J/\psi K^0_s$, Open-beauty production cross section from $\mu$+jets, $B_c \rightarrow J/\psi\mu\nu$, $B_c \rightarrow J/\psi\pi$....

# B in 7 TeV collisions

- The statistics is too low to fit a mass peak but we are recording interesting events....



# Conclusions

- CMS is now taking data from collisions at 7 TeV
- It has a redundant muon system that efficiently identifies and reconstructs muons.
  - It was widely tested during the cosmic data taking and continuosly monitored using a well-know resonance (J/$\psi \rightarrow \mu\mu$)
- Thanks to its high performances with muons CMS can perform interesting measurements in the heavy flavour sector.
  - MC studies has shown the feasibility of these measurements with few $pb^{-1}$

... we are eager to analyse data