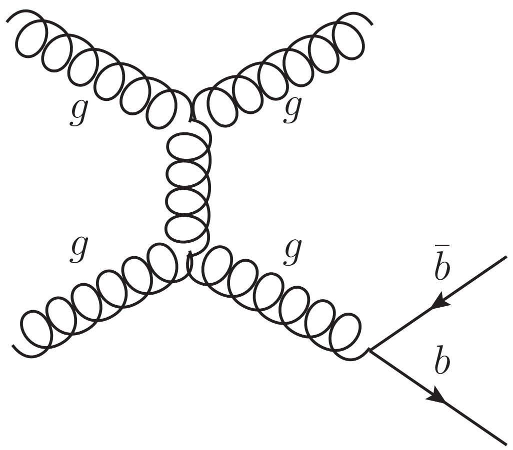
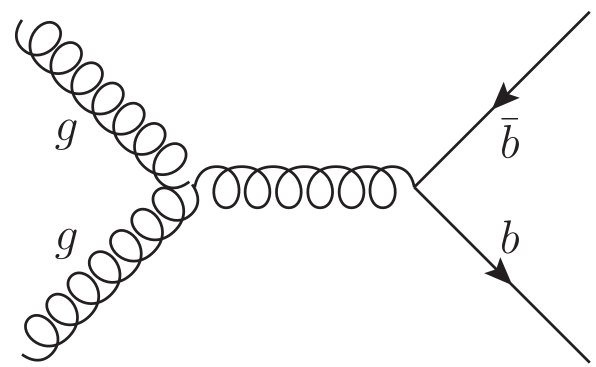
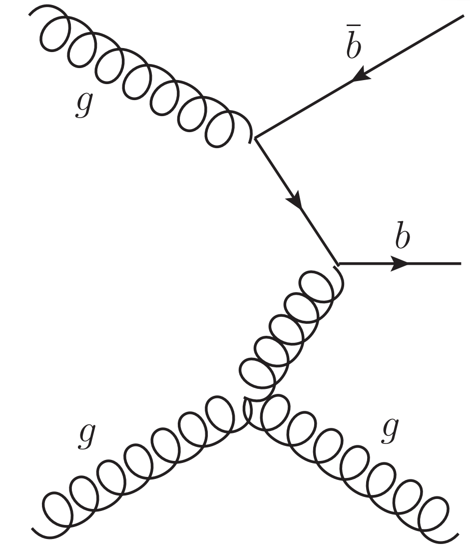






Measurements of b-quark production at 7 TeV with the CMS experiment:

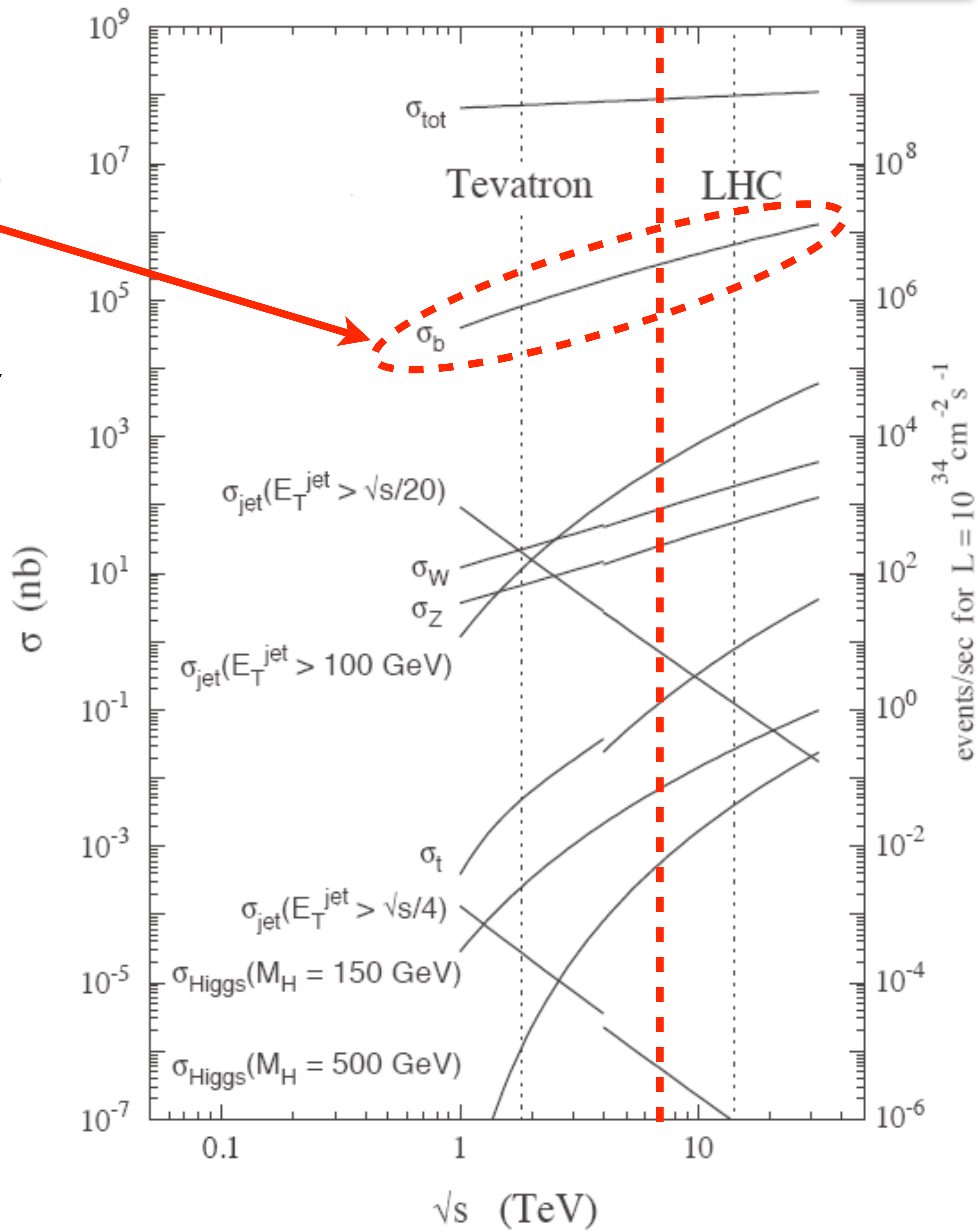
- Exclusive B-meson cross sections:
  - $B^0_d \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^0_s\ (\pi^+ \pi^-)$
  - $B^0_s \rightarrow J/\Psi\ (\mu^+ \mu^-)\ \phi\ (K^+ K^-)$
  - $B^+ \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^+$
- Inclusive b-hadron production cross sections:
  - with dimuons
  - b-b_{bar} angular correlation

Mauro Dinardo
University of Colorado - Boulder, USA
on behalf of the CMS collaboration

21/07/2011

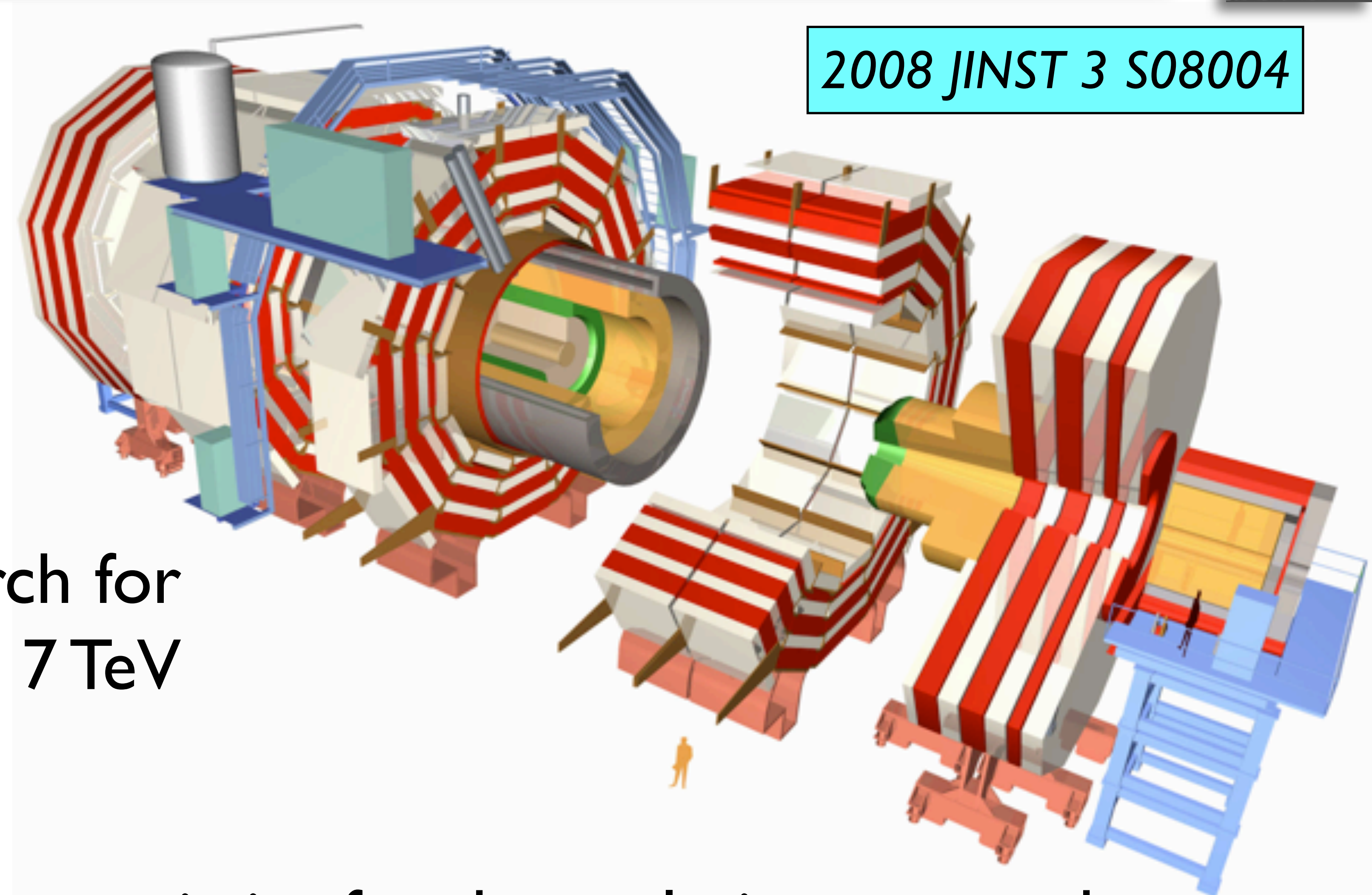
Introduction and motivation

- Early measurement possible due to large cross section (~250 μb)
- Measurement at new energy allows tests of perturbative QCD and Monte Carlo generators
- Improves understanding of b backgrounds for physics searches
- Improves understanding of the detector, especially tracking and muon reconstruction



The CMS experiment

2008 JINST 3 S08004



During 2010 and 2011, search for signals in pp collisions $\sqrt{s}$ = 7 TeV at the CERN LHC

Relevant CMS detector characteristics for the analysis presented

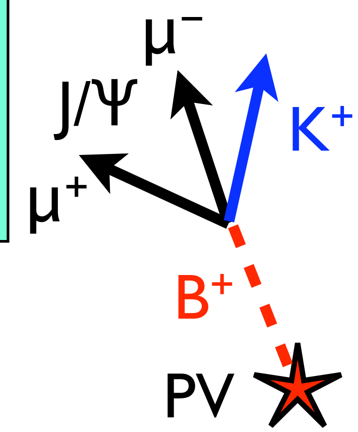
Silicon tracker

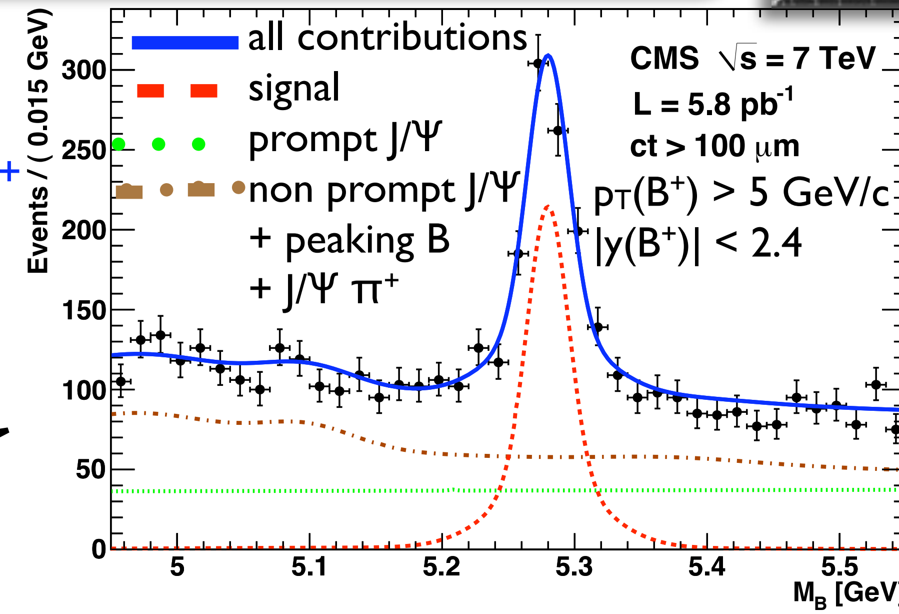
- solenoidal magnetic field of 3.8 T
- coverage $|\eta| < 2.5$
- impact parameter resolution ~15 μm (up to p_T 100 GeV/c)
- p_T resolution ~1.5% (up to p_T 100 GeV/c)

Muon detector coverage $|\eta| < 2.4$

Exclusive B-decays

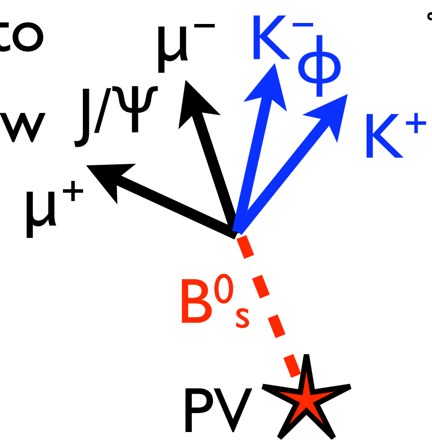
Differential production cross section in bins of p_T and y of the B^+, B^0_s and B^0_d mesons

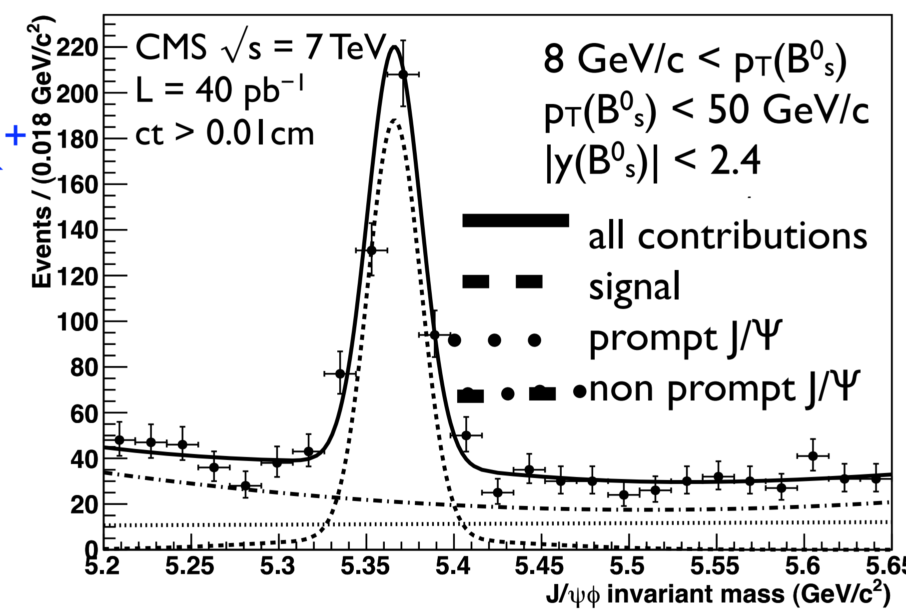




1.Build J/Ψ candidates from muons

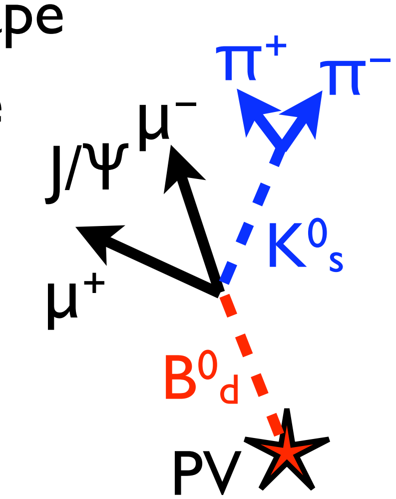
2.Combine with 1 (2) tracks from same vertex to form B^+ (B^0_s) candidates or with 2 tracks from new vertex consistent with K^0_s mass for B^0_d candidates

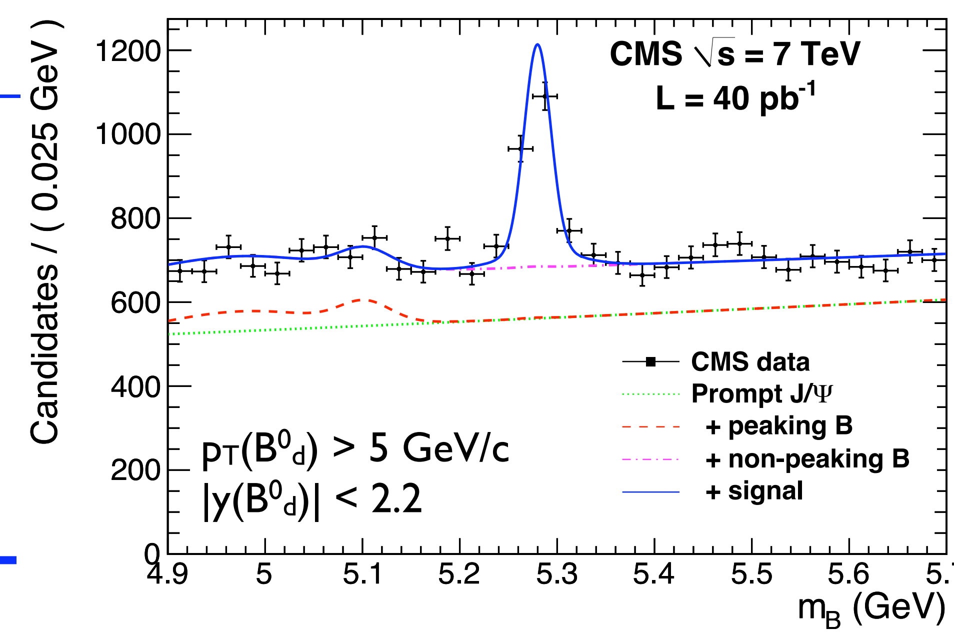




3.Kinematic fit with mass and vertex constraints

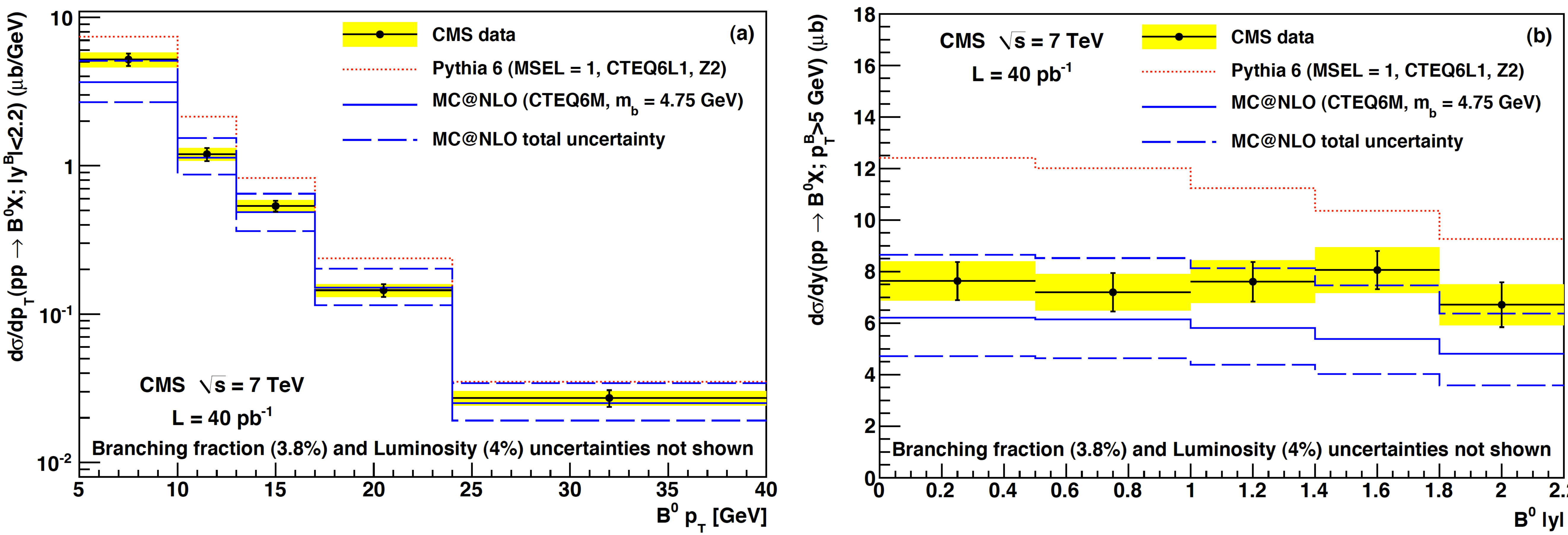
4.Extract signal yields from unbinned 2-dimensional likelihood fit in variables of $\mathbf{m_B}$ and $\mathbf{c\tau}$ with shape parameters determined from data as far as possible





Exclusive B-decays: $B^0_d \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^0_s\ (\pi^+ \pi^-)$

Phys. Rev. Lett. 106, 252001 (2011)



Total cross section for $p_T(B^0_d) > 5$ GeV/c and $|y(B^0_d)| < 2.2$

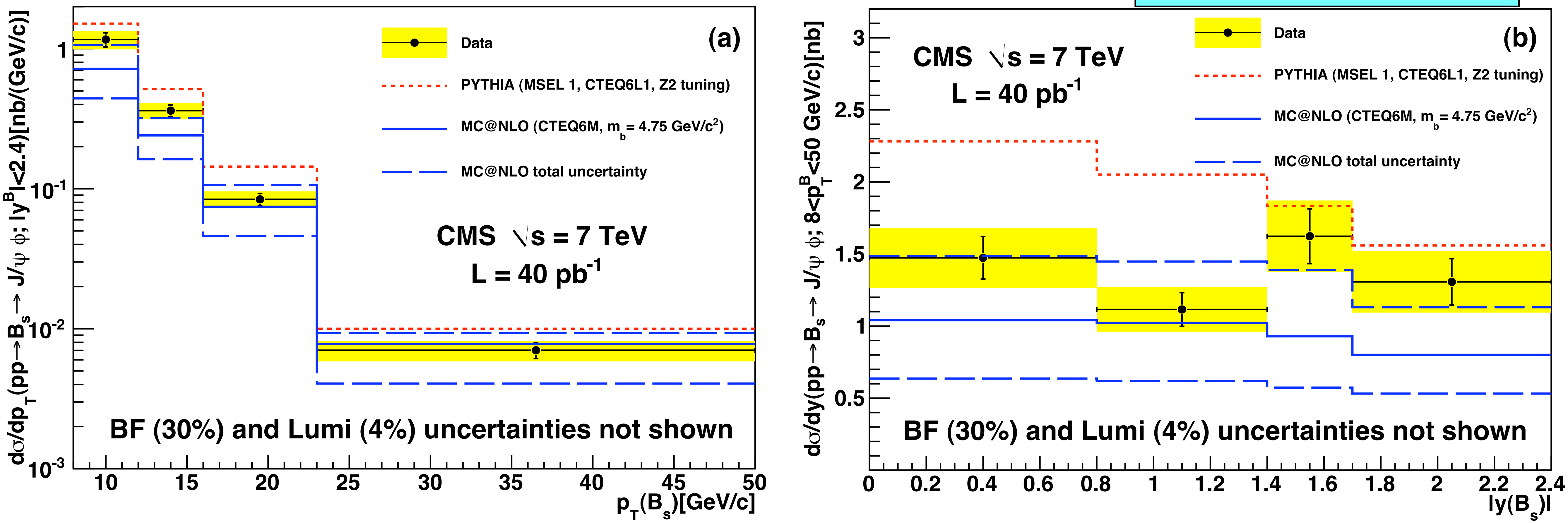
$\sigma(pp \rightarrow B^0_d X) = 33.2 \pm 2.5(\text{stat}) \pm 3.5(\text{syst})\ \mu b$

$\text{MC@NLO} = 25^{+9.6}_{-6.2}\ \mu b$

Good agreement with predictions from MC@NLO

Exclusive B-decays: $B^0_s \rightarrow J/\Psi\ (\mu^+ \mu^-)\ \phi\ (K^+ K^-)$

arXiv 1106, 4048 (2011)



Total cross section for 8 GeV/c < $p_T(B^0_s)$ < 50 GeV/c and $|y(B^0_s)| < 2.4$

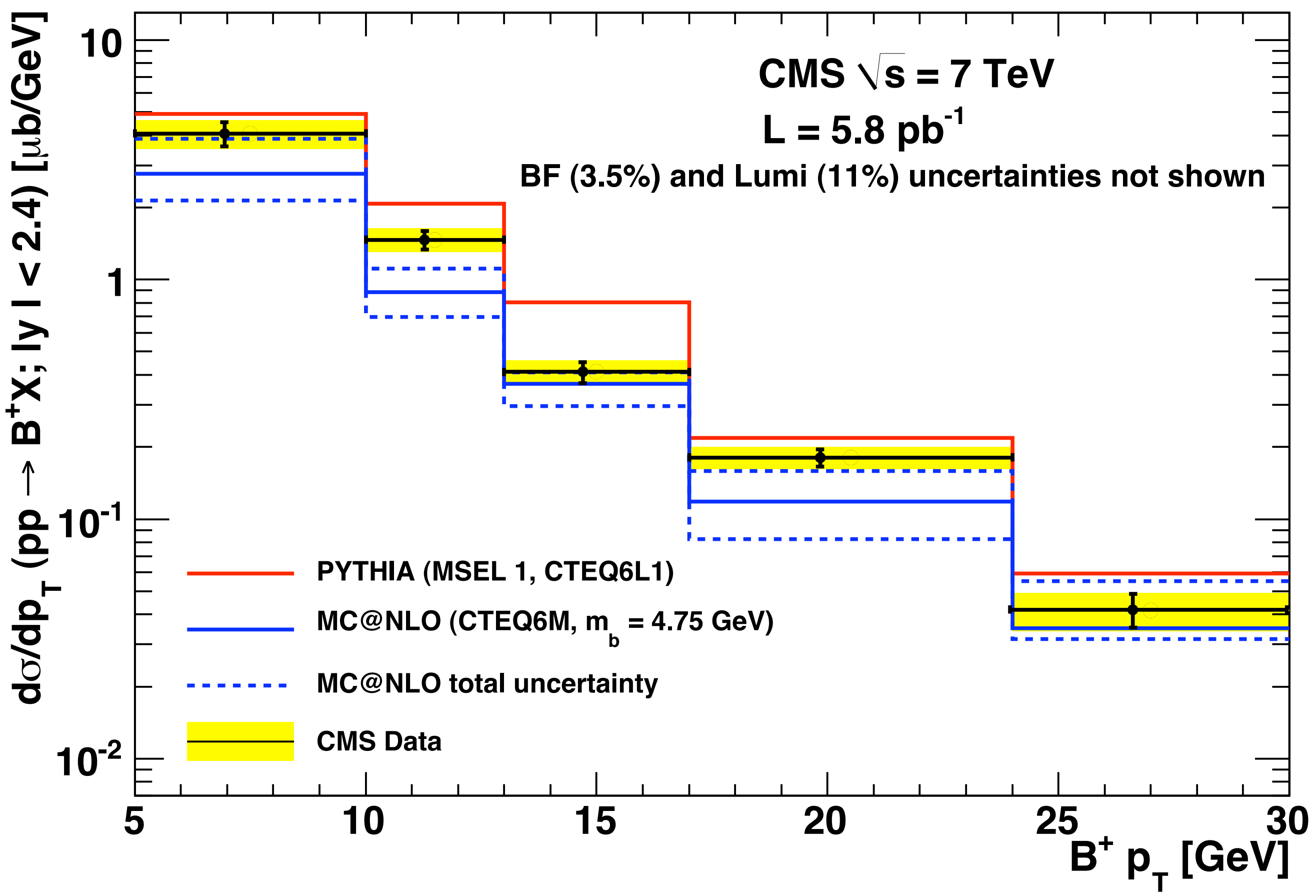
$\sigma(pp \rightarrow B^0_s X) \cdot BR(B^0_s \rightarrow J/\Psi\ \phi) = 6.9 \pm 0.6(stat) \pm 0.6(syst)$ nb

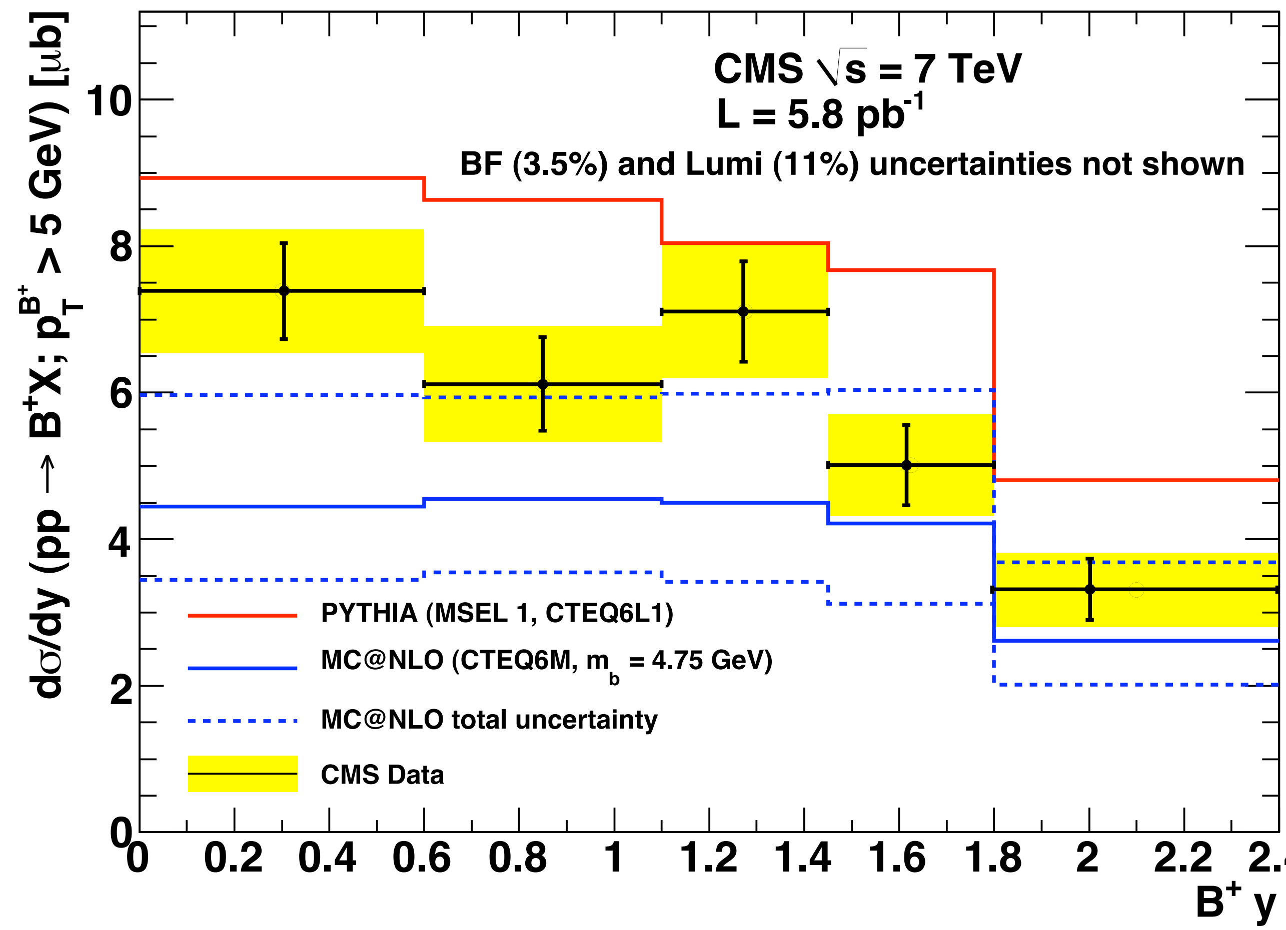
MC@NLO = $4.6^{+1.9}_{-1.7}$ nb

Good agreement with predictions from MC@NLO

Exclusive B-decays: $B^+ \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^+$

Phys.Rev.Lett. 106, 112001 (2011)





Total cross section for $p_T(B^+) > 5$ GeV/c and $|y(B^+)| < 2.4$

$\sigma(pp \rightarrow B^+ X) = 28.1 \pm 2.4(\text{stat}) \pm 2.0(\text{syst}) \pm 3.1(\text{lumi})\ \mu b$

$\text{MC@NLO} = 19.1^{+6.5}_{-1.4}\ \mu b$

Good agreement with predictions from MC@NLO

Measurement of correlated b-b_{bar} cross section with dimuons

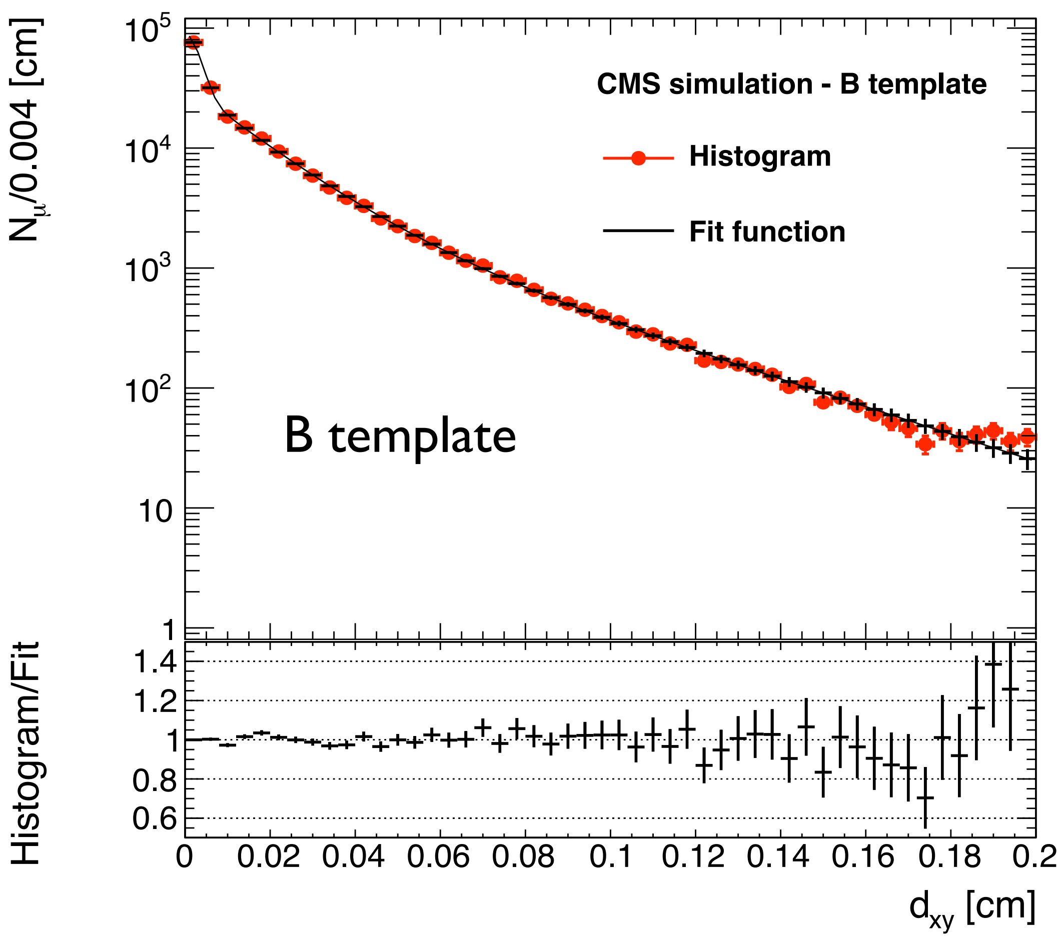
Cross section for b-b_{bar} production with both b quarks decaying into muons

CMS-PAS-BPH-10-015

Signal fraction extracted from template fit to dimuon impact parameter distribution (d_{xy})

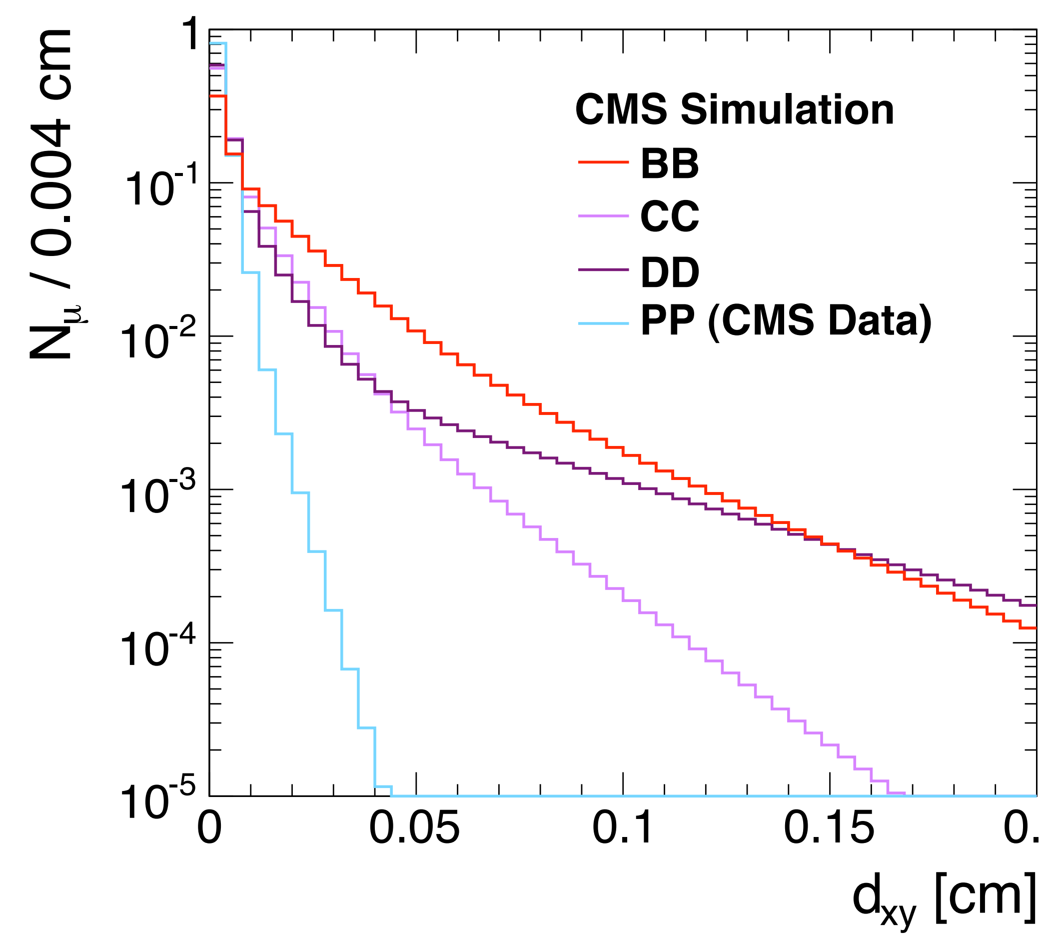
We consider the following classes of dimuon events in MC:

- **B**: b → μ (sequential b → c → μ are considered part of the signal)
- **C**: c → μ
- **P**: prompt muons (from primary vertex or hadron punch - through)
- **D**: decays in flight (π → μ, K → μ)



Dimuon templates (BB, CC, etc... and combinations) are obtained from single muon ones

Projections



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Sources of systematic uncertainties:

- Effects related the shape of the impact parameter distribution
- Effects related to the fit method
- Effects related to the measurement of the efficiency and overall normalization

Due to:
•detector resolution
•b,c hadrons fractions and lifetimes
•decays in flight sample

Source	Syst. Uncert. on $\sigma(pp \to b\bar{b}X \to \mu\mu Y)$ ($\pm\%$)
Template shapes	5.1
Fit method	4.7
Efficiencies and normalization	8.3
$\mathcal{L}$	4.0
Total systematic uncertainty	11.4

Due to fit constraints: fraction of mixed events (BC, BD ,CD) constrained using simulation

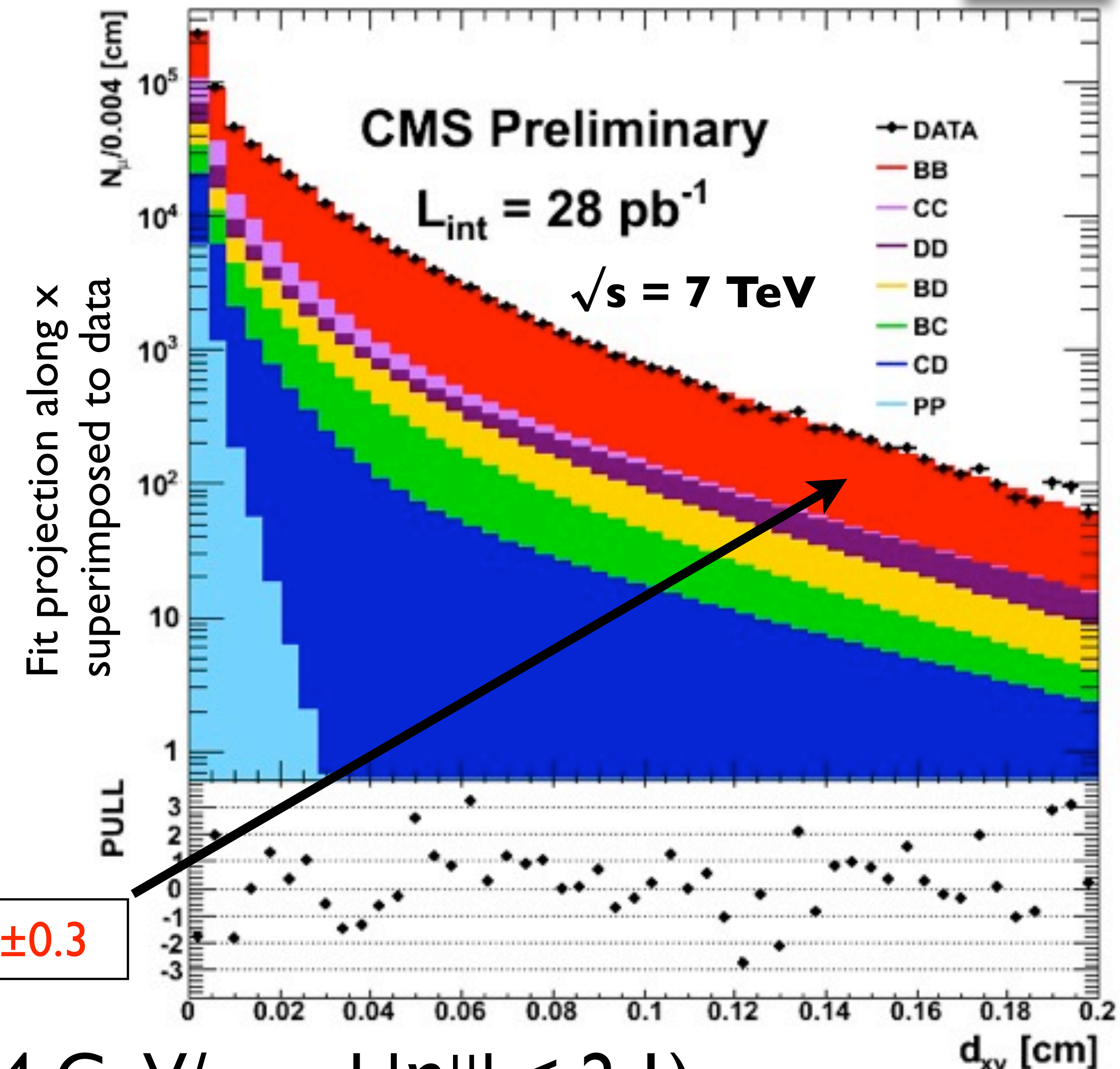
Due to statistical uncertainty of the Tag & Probe method

Measurement of correlated b-b_{bar} cross section with dimuons

• d_{xy} distributions for B, C and D are extracted from simulation

• d_{xy} distribution for P is extracted from data (from Υ(1S) decays)

• d_{xy} distribution <u>in data</u> is built by taking <u>d_{xy}</u> of the two selected muons <u>in random order</u>



BB fraction: 65.1%±0.3

Total cross section (p^{μ}_T > 4 GeV/c and $|\eta^{\mu}|$ < 2.1):

$\sigma(pp \rightarrow b b_{bar} X \rightarrow \mu\mu Y)$ = 26.18 ± 0.14(stat) ± 2.82(syst) ± 1.05(lumi) nb

MC@NLO = 19.95 ± 0.46(stat)$^{+4.68}_{-4.33}$(syst) nb

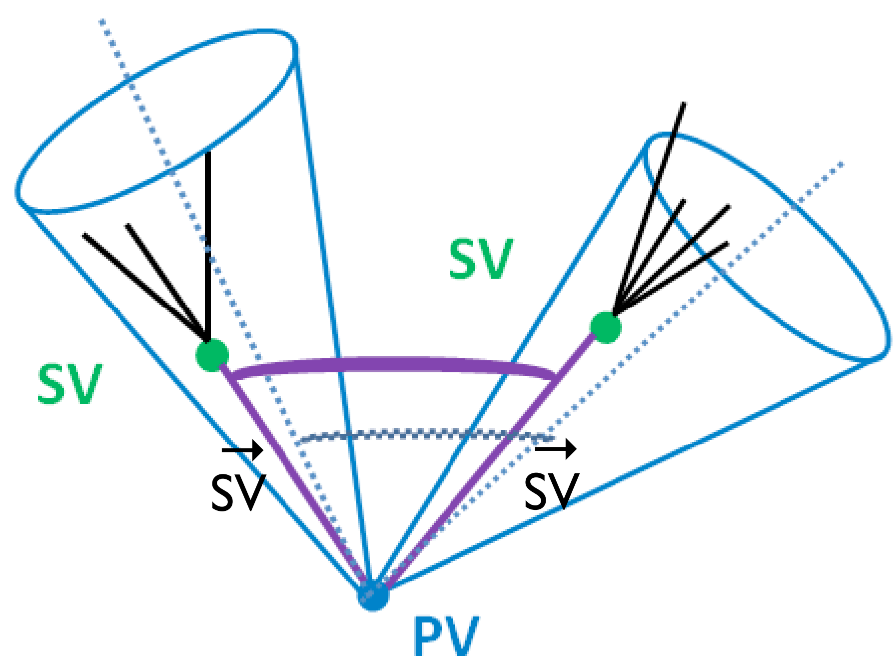
The result is consistent with the NLO QCD expectations

Differential production cross section in bins of opening angle of b-b_{bar} pairs

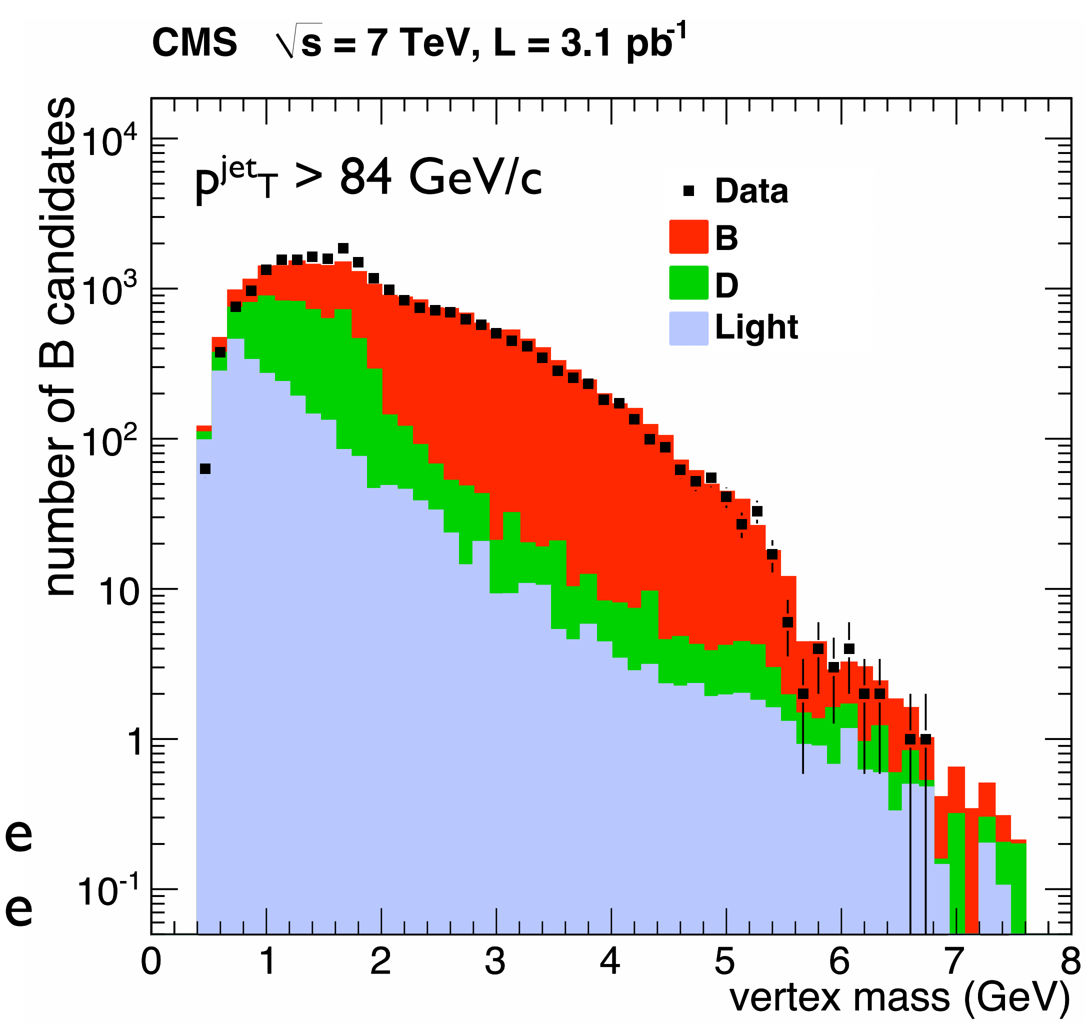
JHEP 1103 (2011) 136

1. Select events with at least <u>one</u> reconstructed <u>jet</u> with a minimum p_T, a reconstructed primary vertex and at least <u>two</u> reconstructed <u>secondary vertices</u> (SV) - <u>no need to be part of the jet</u>
2. b-hadron candidates are formed based on 3D flight distance significance, SV pseudorapidity, p_T, mass
3. Events are retained if they have exactly two b-hadron candidates with mass sum > 4.5 GeV/c^2
4. Differential cross section computed as a function of the b-hadron opening angles: azimuthal $\Delta\phi$, $\Delta R = \sqrt{(\Delta\eta^2+\Delta\phi^2)}$

Flight direction of the b-hadron is approximated by the vector $\vec{SV}$

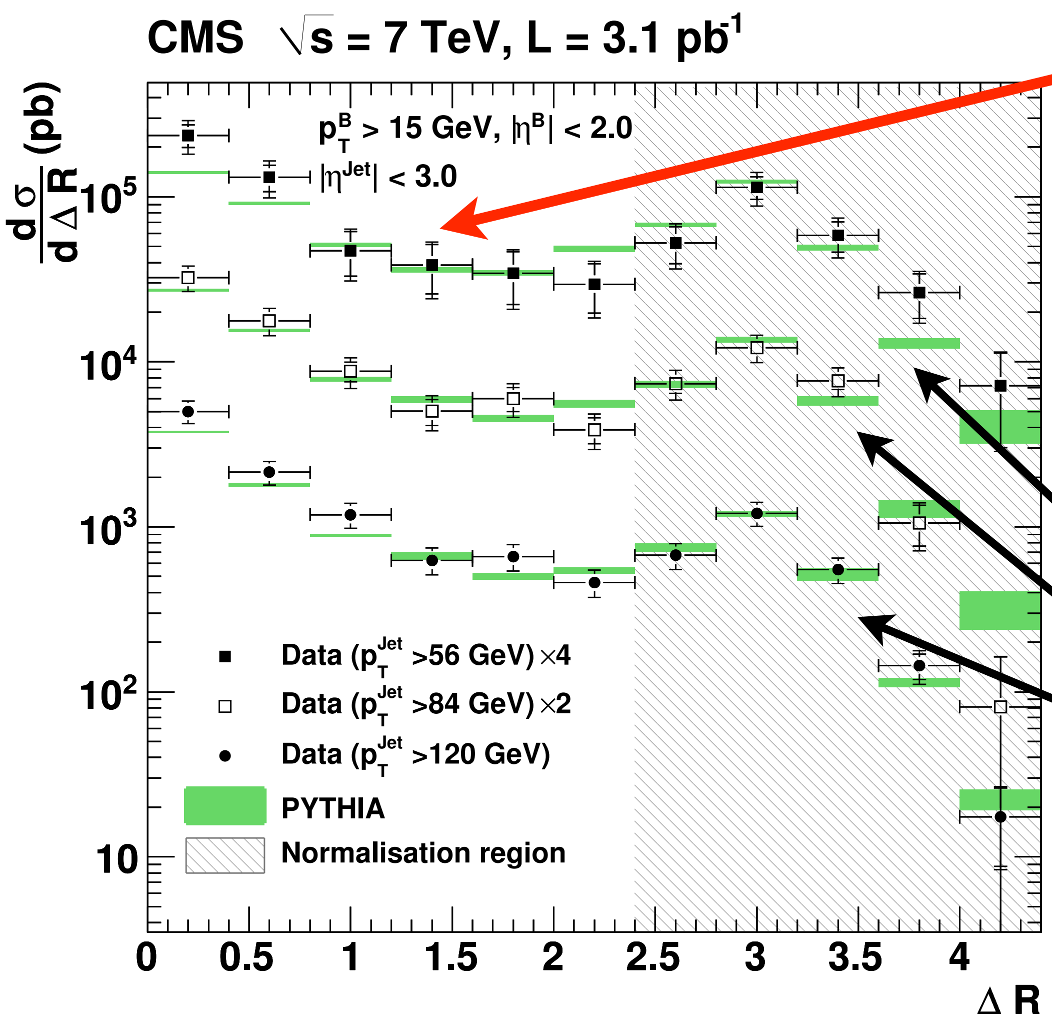


The quality of the B candidate reconstruction technique is illustrated: the simulation describes the data very well



Measurement of b-b_{bar} angular correlation based on secondary vertices

Differential cross section vs ΔR



Substantial enhancement at small angular separation

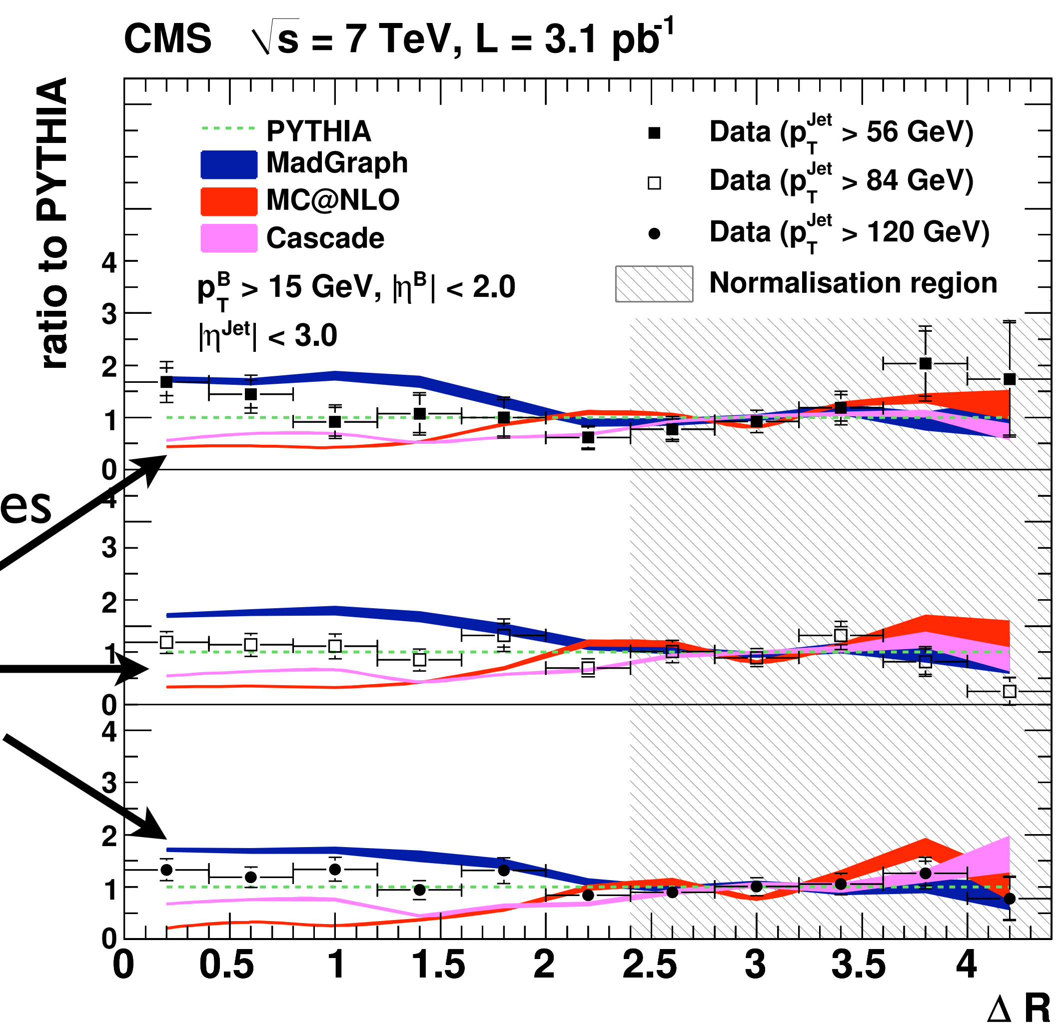
Three energy scales

p^{jet}_T > 56 GeV/c

p^{jet}_T > 84 GeV/c

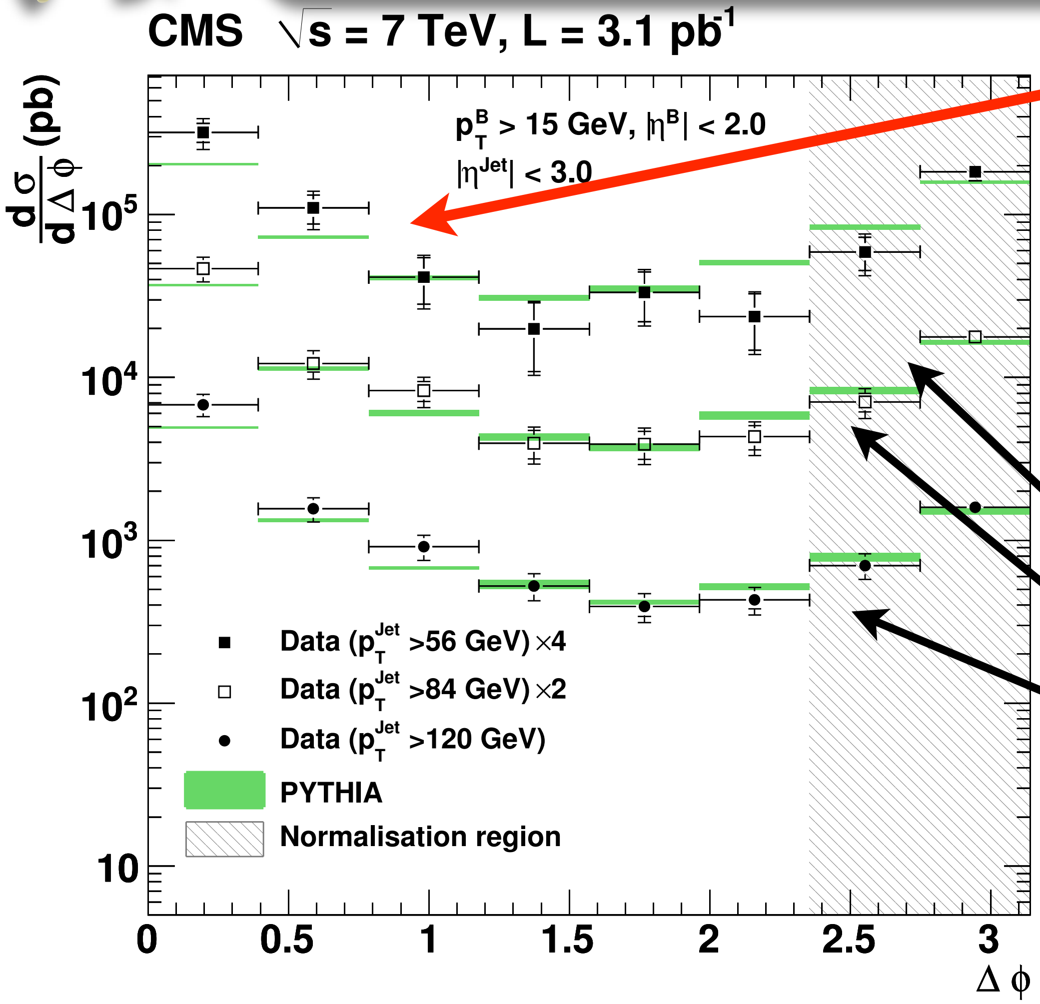
p^{jet}_T > 120 GeV/c

Comparison with PYTHIA



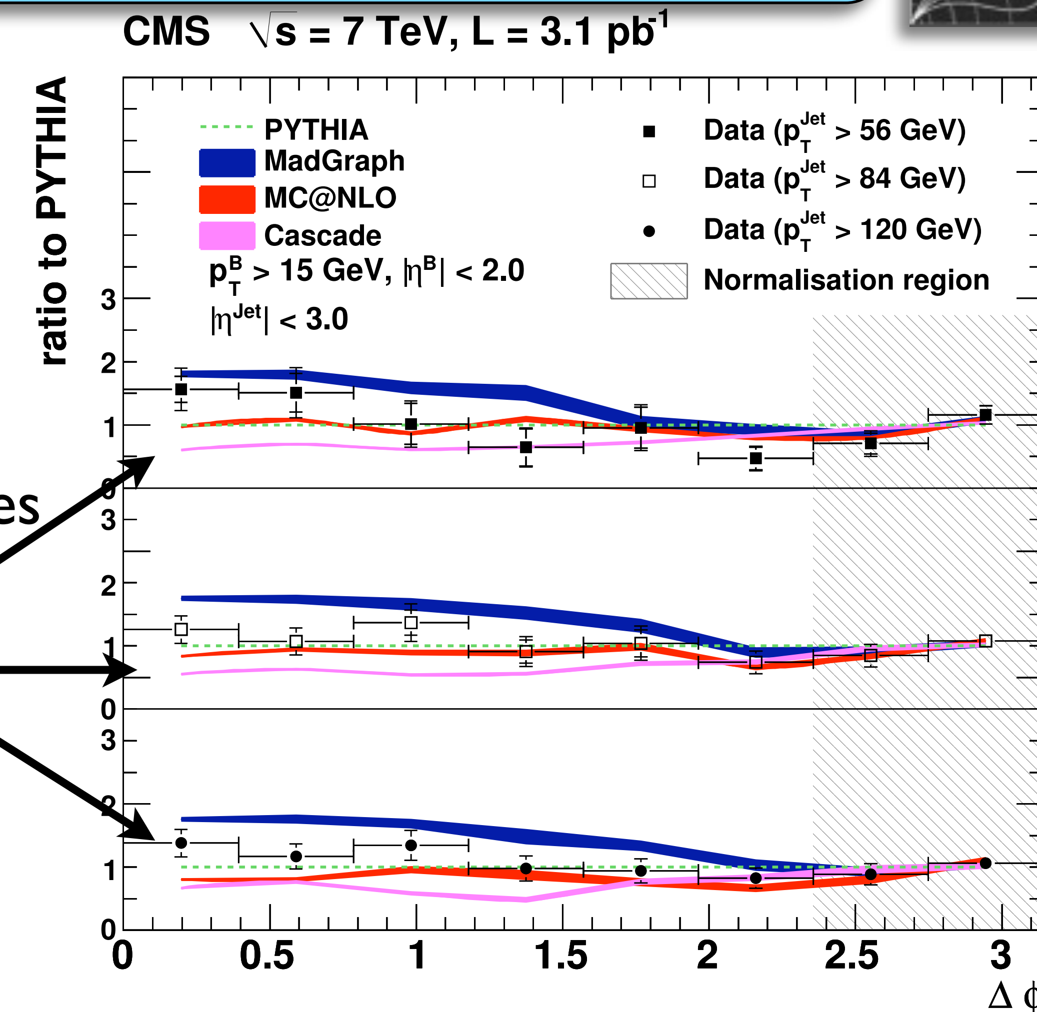
b-hadron kinematic region: p_T > 15 GeV/c $|\eta|$ < 2

Measurement of b-b_{bar} angular correlation based on secondary vertices



Substantial enhancement at small angular separation

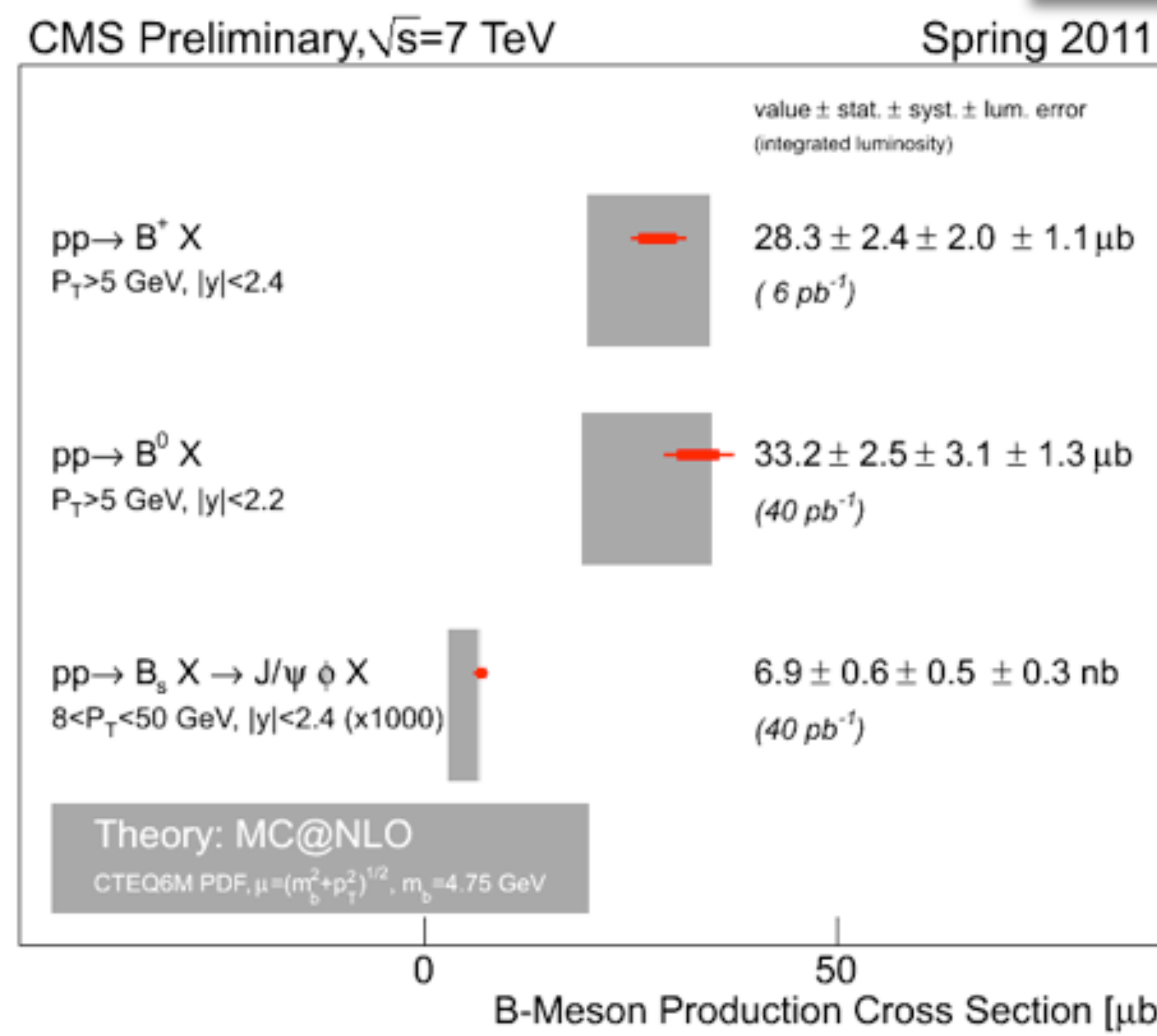
Three energy scales
p^{jet}_T > 56 GeV/c
p^{jet}_T > 84 GeV/c
p^{jet}_T > 120 GeV/c



b-hadron kinematic region: p_T > 15 GeV/c $|\eta|$ < 2

- Data lie between MADGRAPH and PYTHIA predictions
- Neither MC@NLO nor CASCADE calculations describe the shape of the ΔR distribution well, especially at small ΔR (gluon splitting processes expected to dominate and not well described)

Conclusions



Exclusive B-meson cross sections:

- Measurements of total and differential cross sections for B^+, B^0_d and B^0_s
- Good agreement with predictions from MC@NLO
- Results show the great performance of the CMS detector

Inclusive b-hadron production cross sections:

- with dimuons:
  - $\sigma(pp \rightarrow b b_{bar} X \rightarrow \mu\mu Y) = 26.18 \pm 0.14(\text{stat}) \pm 2.82(\text{syst}) \pm 1.05(\text{lumi})$ nb
- b-b_{bar} angular correlation based on secondary vertices

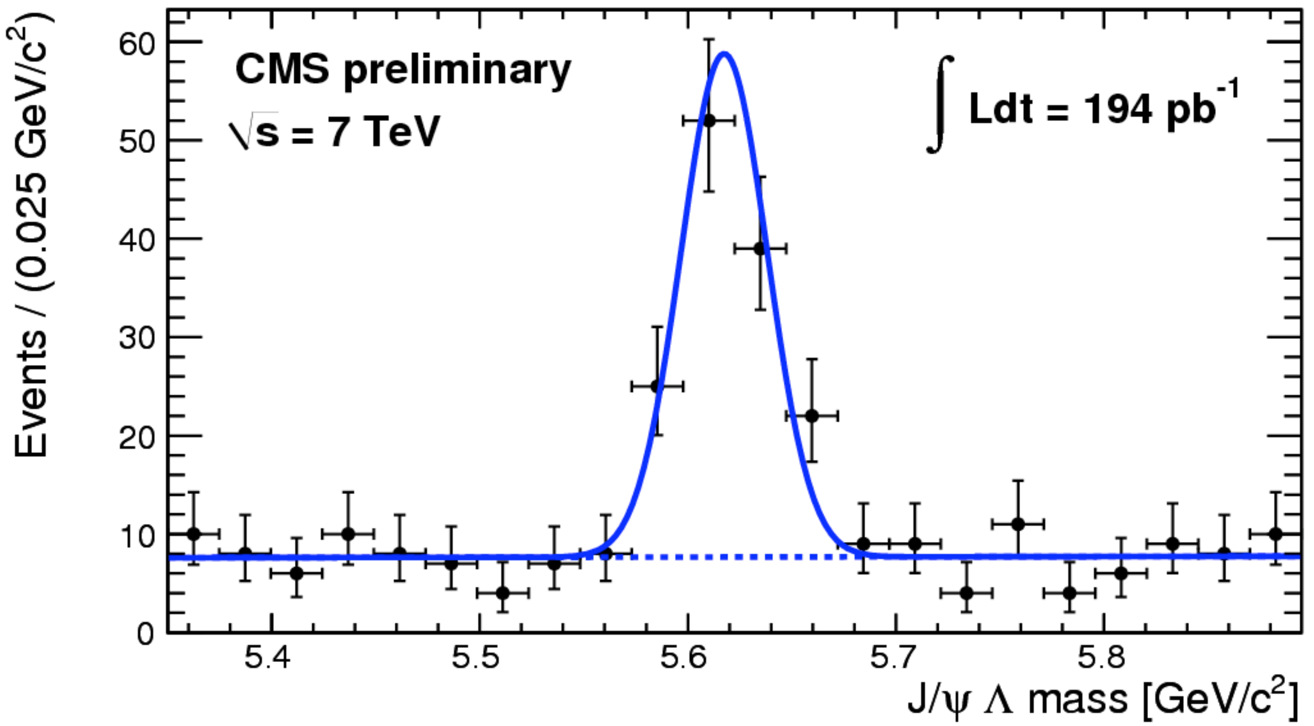
Found reasonable agreement between measurements and prediction from simulations (discrepancies in the b-b_{bar} angular correlation at small angular aperture)

Outlook

We are preparing the measurement of the Λ_b cross section through the exclusive decay: $\Lambda_b \rightarrow J/\Psi\ \Lambda^0(p\ \pi)$

- Proton selection using $p_T(p) > p_T(\pi)$
- Kinematic fit using
  - vertex constraint on all vertices
  - masses J/Ψ and Λ^0 constrained to PDG values
- Muons matched to trigger objects

$p_T(\Lambda_b) > 6$ GeV/c and $|y(\Lambda_b)| < 2.2$

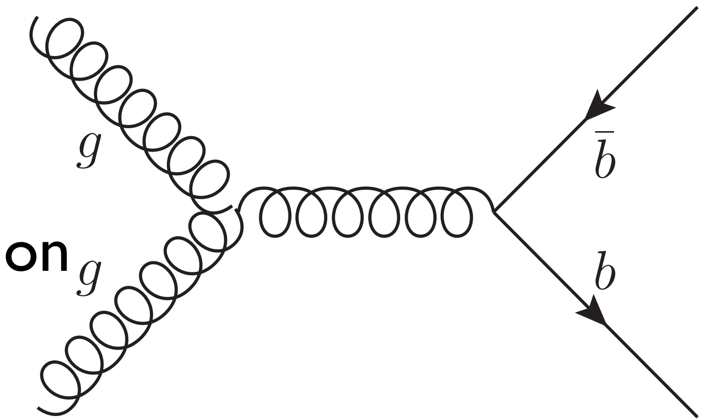


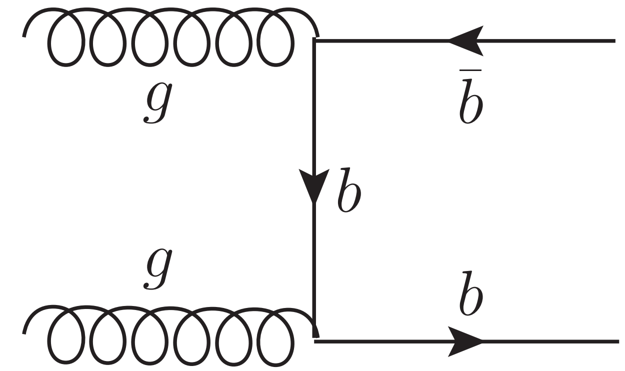
$\sigma_{Gauss} = 0.021$ GeV/c^2
$N_{signal} = 106 \pm 12$(stat)
$N_{background} = 32 \pm 3$

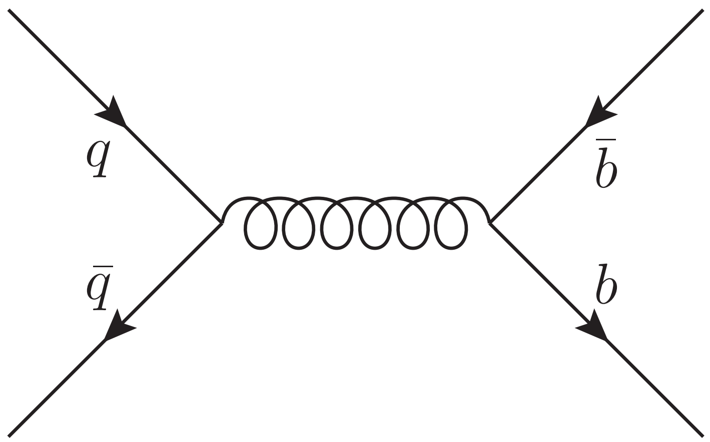
Backup

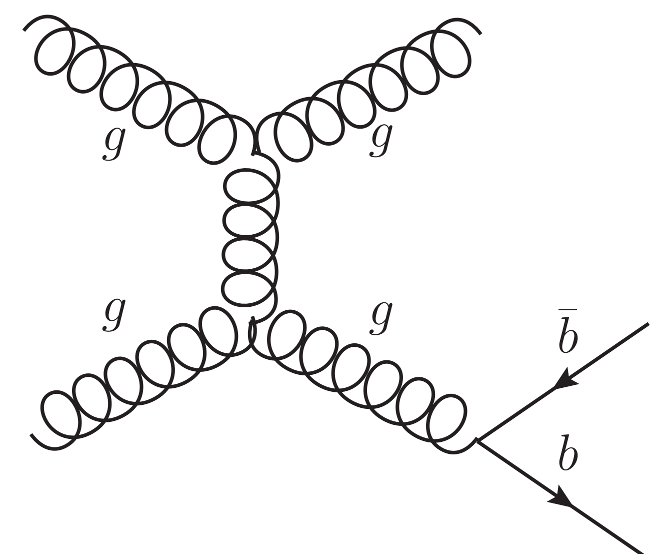
b-quark dominant production mechanisms at LHC

- **Flavor creation (50 μb):**
gluon fusion (dominant) and quark annihilation

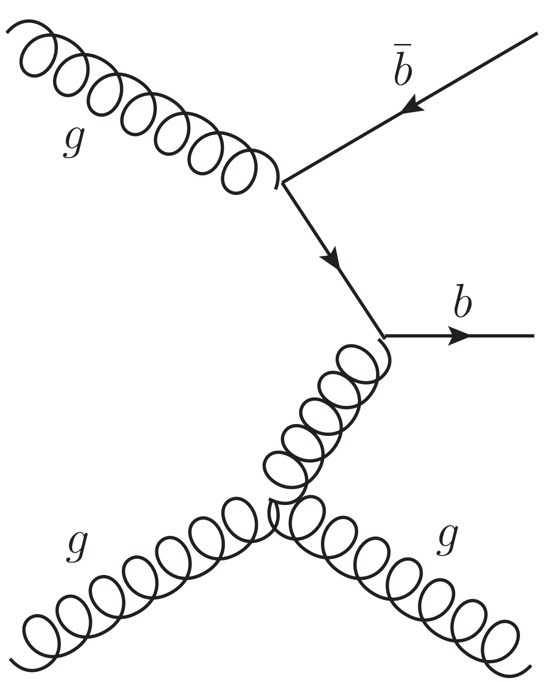








- **Gluon splitting (190 μb):**
b's at low p_T and close in the azimuthal angle ($\Delta\phi$)



- **Flavor excitation (220 μb):**
only one b participates to hard scatter, asymmetric p_T for the b's

CMS muon reconstruction

- **"Local reconstruction":**

combine DT, CSC and RPC hits in muon chambers into 3D segments

- **"Standalone reconstruction":**

backward Kalman filter to innermost muon station, followed by fit with vertex constraint

- **"Global reconstruction":**

1. extrapolate back to Silicon tracker surface
2. look for compatible tracks in region of interest
3. perform global fit and select candidates based on best χ^2

- **Alternative approach "inside-out":**

1. extrapolate every track outward
2. find compatible deposits in calorimeters and muon system
3. determine muon-compatibility
4. recover muon inefficiencies at muon chambers boundaries and low p_T

$$\varepsilon_{J/\Psi} = \varepsilon_{\mu 1} \bullet \varepsilon_{\mu 2} \bullet \mathbf{corr}$$

$\varepsilon_{\mu i}$ are the single muon efficiencies and **corr** is a correction factor for dimuon correlation effects, determined from simulation

The single muon efficiencies can be factorized as:

$$\varepsilon_{\mu i} = \varepsilon_{\mu i\ \mathrm{trigger}} \bullet \varepsilon_{\mu i\ \mathrm{ID}} \bullet \varepsilon_{\mu i\ \mathrm{tracking}}$$

each term is measured independently from data using T&P

Efficiency is determined for each bin of p_T and y of the corresponding B-signal meson

J/Ψ candidate
- Trigger on dimuon (no explicit p^{μ}_T cut)
- Oppositely charged muons fitted to common vertex
- Muons matched to trigger objects
- $|m_{\mu\mu} - m_{J/\Psi(PDG)}| < 150$ MeV/c^2

Muon selection	
$\|\eta\| < 1.3$	$p_T > 3.3$ GeV/c
$1.3 < \|\eta\| < 2.2$	$p > 2.9$ GeV/c
$2.2 < \|\eta\| < 2.4$	$p_T > 0.8$ GeV/c

Exclusive B-decays: $B^0_d \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^0_s\ (\pi^+ \pi^-)$

J/Ψ candidate

described before

K^0_s candidate

- oppositely charged tracks, #hits ≥ 6, χ^2/dof < 5, $d_0 > 0.5\sigma$
- Vertex fit, $\chi^2 < 7$, transverse distance to beamline $> 5\sigma$
- 478 MeV/c^2 < mK^0_s < 518 MeV/c^2

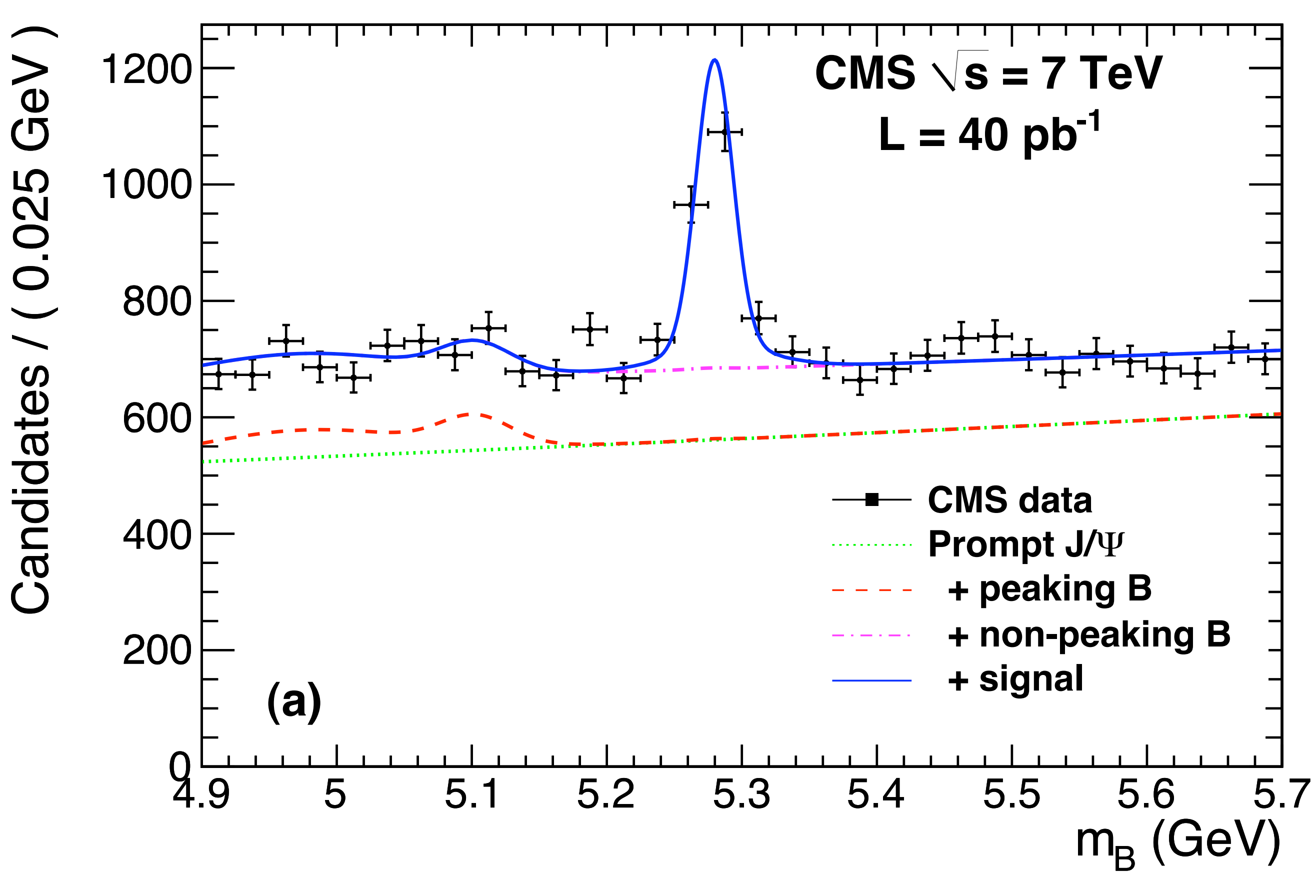
B^0_d candidate

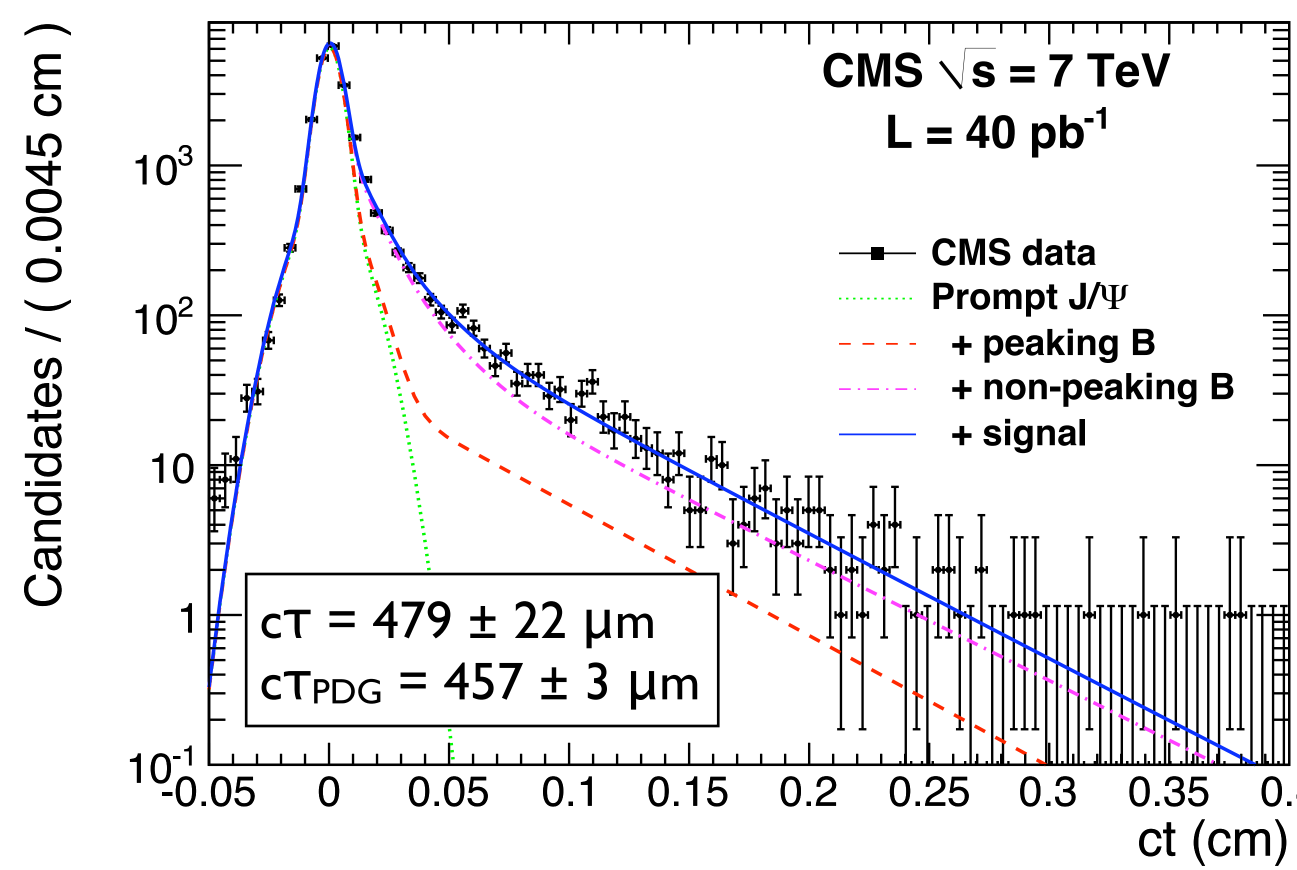
- Kinematic fit with constraints on mJ/Ψ and mK^0_s
- 4.9 GeV/c^2 < mB^0_d < 5.7 GeV/c^2
- B^0_d decay vertex probability > 1%

Background type

- prompt J/Ψ
- non-prompt J/Ψ (peaking and non-peaking B)

Projections in mB and $c\tau$ for $p_T(B^0_d)$ > 5 GeV/c and $|y(B^0_d)|$ < 2.2





Exclusive B-decays: $B^0_d \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^0_s\ (\pi^+ \pi^-)$

Total number of signal events: 809 ± 39(stat)

Total efficiency ranges from 0.7% for $p_T(B^0_d)$ ~5 GeV/c to 11.4% for $p_T(B^0_d)$ > 24 GeV/c

All shape parameters are extracted from data, except for the peaking background and the signal mB, which are taken from MC

Component	p.d.f. for mB	p.d.f. for cτ
Signal	Sum of 2 Gaussians	R⊗exponential
Peaking B Like $B^0_d \rightarrow J/\Psi\ K^{*0}$ (892)	Sum of 3 Gaussians	R⊗exponential
Prompt J/Ψ	Exponential	R
Non-peaking B	Exponential	R⊗(sum of 2 exponentials)

where R is a common resolution function = sum of two Gaussians

Data-driven fit procedure in 3 steps:

1. High mass side band fit in mB and cτ to determine lifetime of non-peaking background
2. Full range fit in mB and cτ to determine signal lifetime
3. Extract yields from fit in bins of $p_T(B^0_d)$ and $|y(B^0_d)|$ with lifetimes fixed from above

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Exclusive B-decays: $B^0_s \rightarrow J/\Psi\ (\mu^+ \mu^-)\ \phi\ (K^+ K^-)$

J/Ψ candidate

described before
with $p_T > 0.5$ GeV/c

ϕ candidate

- 2 oppositely charged tracks, #hits $\geq$ 5, χ^2/dof < 5, p_T > 0.7 GeV/c
- $|m\phi - m\phi_{PDG}| < 10$ MeV/c^2

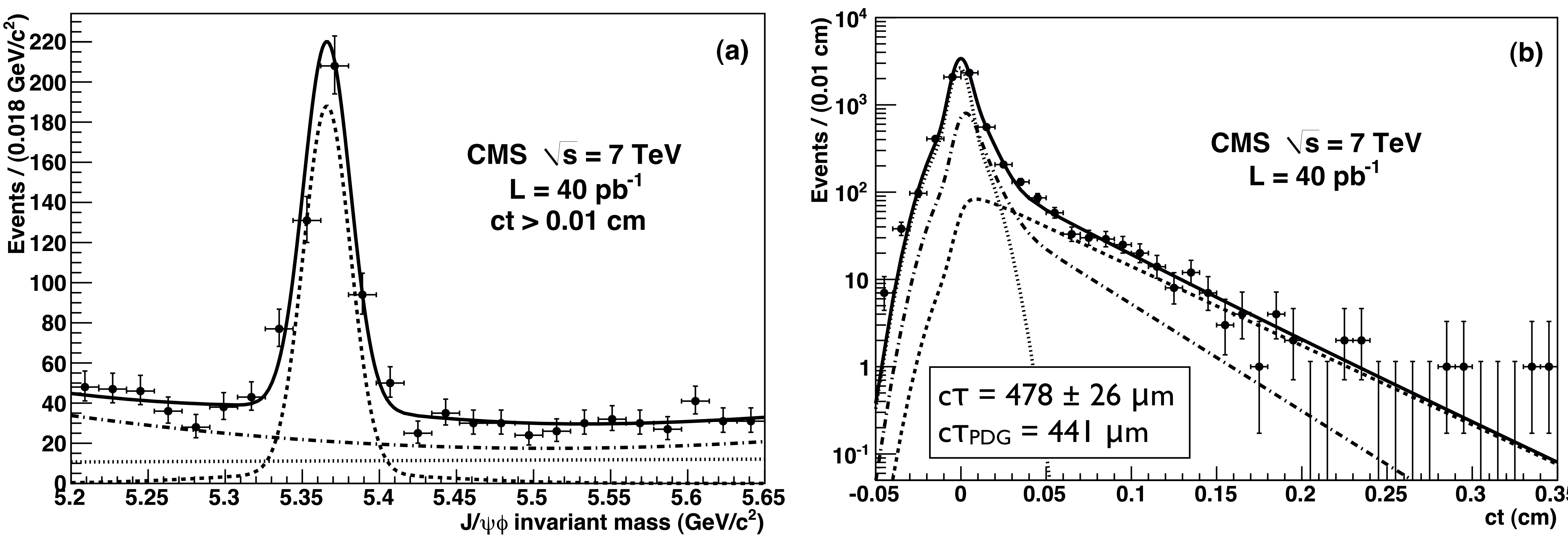
B^0_s candidate

- Kinematic fit with constraint on mJ/Ψ
- 5.20 GeV/c^2 < mB^0_s < 5.65 GeV/c^2
- B^0_s decay vertex probability > 2%

Background type

- prompt J/Ψ
- non-prompt J/Ψ

Projections in mB and cτ for 8 GeV/c < $p_T(B^0_s)$ < 50 GeV/c and $|y(B^0_s)|$ < 2.4



Exclusive B-decays: $B^0_s \rightarrow J/\Psi\ (\mu^+ \mu^-)\ \phi\ (K^+ K^-)$

Total number of signal events: 549 ± 32(stat)

Total efficiency ranges from 1.3% for $p_T(B^0_s)$ ~8 GeV/c to 19.6% for $p_T(B^0_s)$ > 23 GeV/c

All shape parameters are extracted from data, except for the signal mB, which is taken from MC

Component	p.d.f. for mB	p.d.f. for cτ
Signal	Sum of 2 Gaussians	R⊗exponential
Non-prompt J/Ψ	Second order polynomial	R⊗(sum of 2 exponentials)
Prompt J/Ψ	First order polynomial	R

where R is a common resolution function = sum of two Gaussians

Data-driven fit procedure in 4 steps:

1. Mass side band fit in cτ to determine lifetime of non-peaking background
2. Full range fit in mB and cτ to determine signal lifetime
3. Mass side band fit in bins of $p_T(B^0_s)$ and $|y(B^0_s)|$ with lifetimes fixed from above to determine resolution function
4. Extract yields from fit in bins of $p_T(B^0_s)$ and $|y(B^0_s)|$ with lifetimes and resolution function fixed from above

Exclusive B-decays: $B^+ \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^+$

J/Ψ candidate

described before

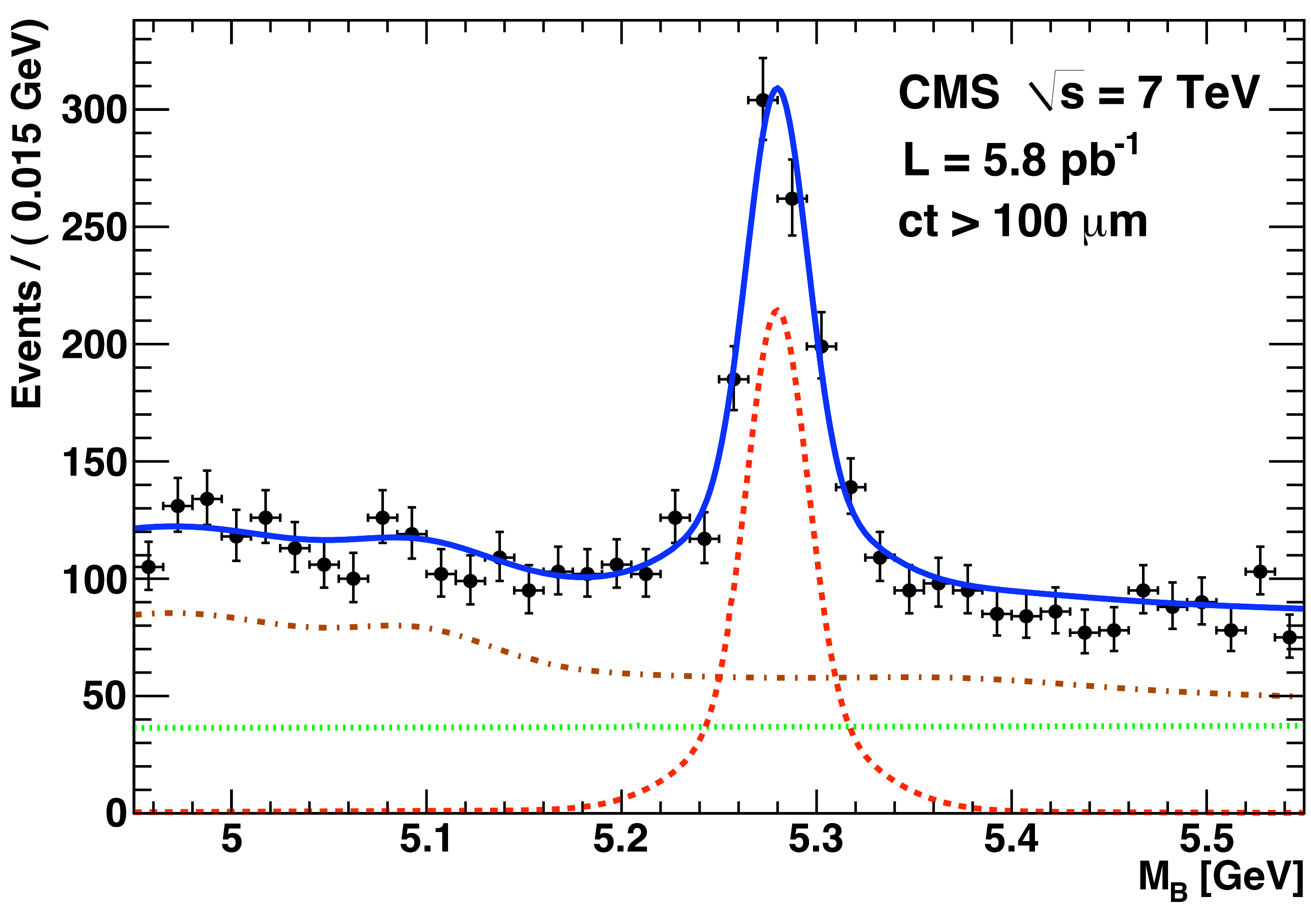
B^+ candidate

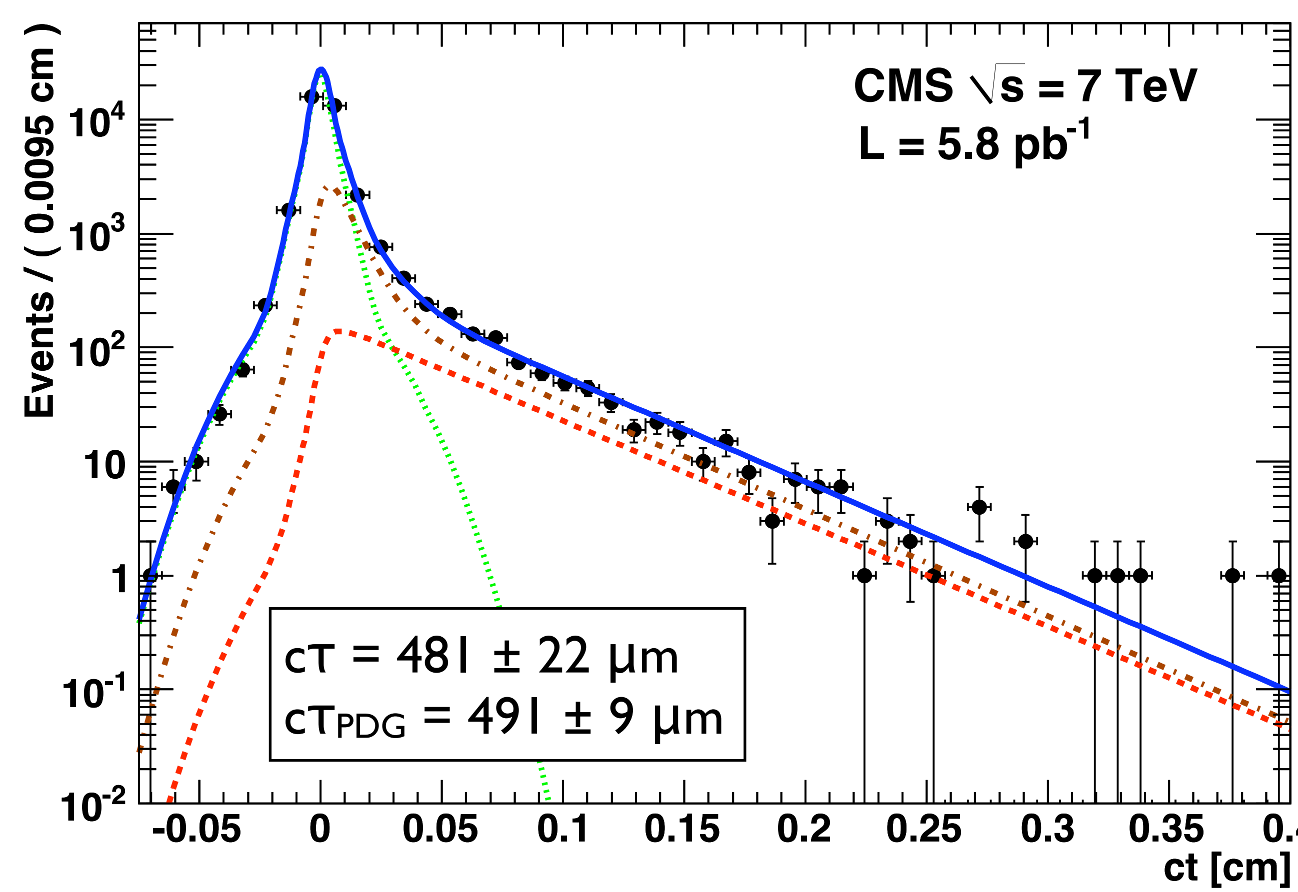
- Combine with track #hits ≥ 4, $\chi^2/dof < 5$, with kaon mass hypothesis and $p_T > 0.9$ GeV/c
- Kinematic fit with constraint on mJ/Ψ
- $4.95\ GeV/c^2 < mB^+ < 5.55\ GeV/c^2$
- B^+ decay vertex probability > 0.1%

Background type

- prompt J/Ψ
- peaking B
- non-peaking B
- $B^+ \rightarrow J/\Psi\ \pi^+$

Projection of the fit results in mB and $c\tau$ for $p_T(B^+) > 5$ GeV/c and $|y(B^+)| < 2.4$





Exclusive B-decays: $B^+ \rightarrow J/\Psi\ (\mu^+ \mu^-)\ K^+$

Total number of signal events: 912 ± 47(stat)

Total efficiency ranges from few % for $p_T(B^+)$ ~5 GeV/c to ~40% for $p_T(B^+)$ > 24 GeV/c

All shape parameters are extracted from data, except for the peaking background and the signal mB, which are taken from MC

Component	p.d.f. for mB	p.d.f. for cτ
Signal	Sum of 3 Gaussians	R⊗exponential
$B^+ \rightarrow J/\Psi\ \pi^+$	Sum of 2 Gaussians	R⊗exponential
Peaking B Like $B \rightarrow J/\Psi\ K^*$	Sum of 2 Gaussians + exponential	R⊗exponential
Prompt J/Ψ	Exponential	R
Non-peaking B	Exponential	R⊗(sum of 2 exponentials)

where R is a common resolution function = sum of two Gaussians

Data-driven fit procedure in 4 steps:

1. High mass side band fit in cτ to determine lifetime of non-prompt J/Ψ background
2. Full range fit in mB and cτ to determine signal lifetime
3. Fit in bins of $p_T(B^+)$ and $|y(B^+)|$ with lifetimes fixed from above to determine resolution function
4. Extract yields from fit in bins of $p_T(B^+)$ and $|y(B^+)|$ with lifetimes and resolution function fixed from above

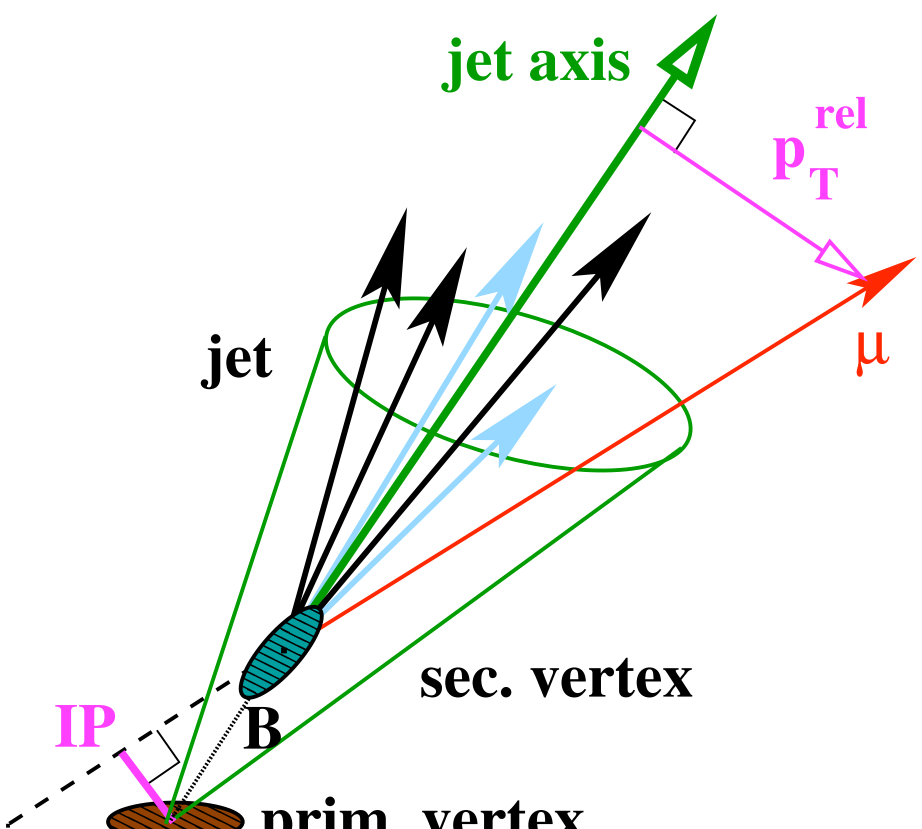
Differential production cross section of b-hadrons in bins of p_T and η of the daughter muon

JHEP 1103, 90 (2011)

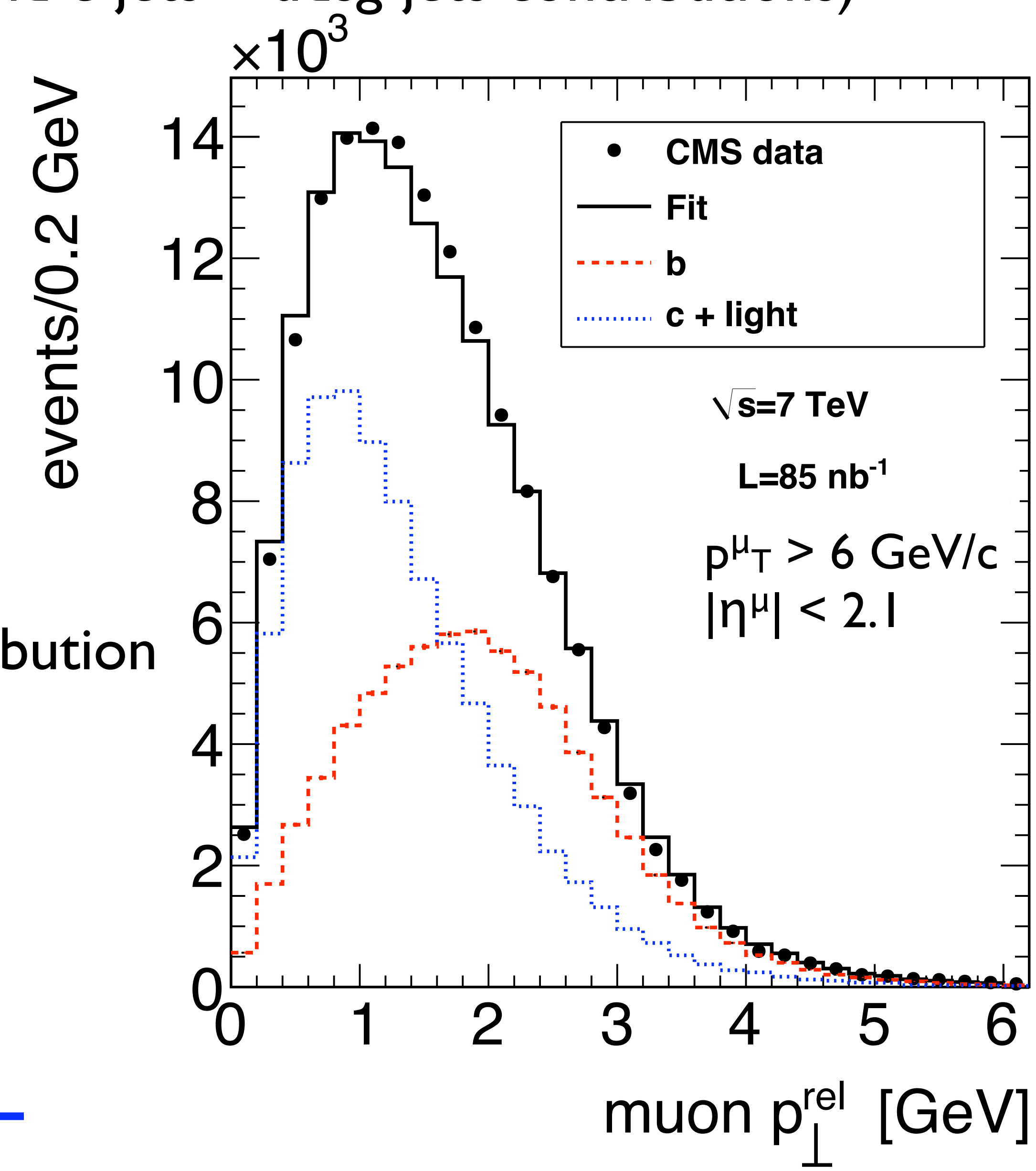
1. Select b-jets associated with a muon track
2. Compute the distribution of the muon transverse momentum relative to the jet axis (p^{rel}_T)
3. Extract signal yield from binned maximum likelihood fit to the p^{rel}_T distribution

<u>Fit function</u>: sum of two distributions (describing b-jets, and c-jets + udsg-jets contributions)

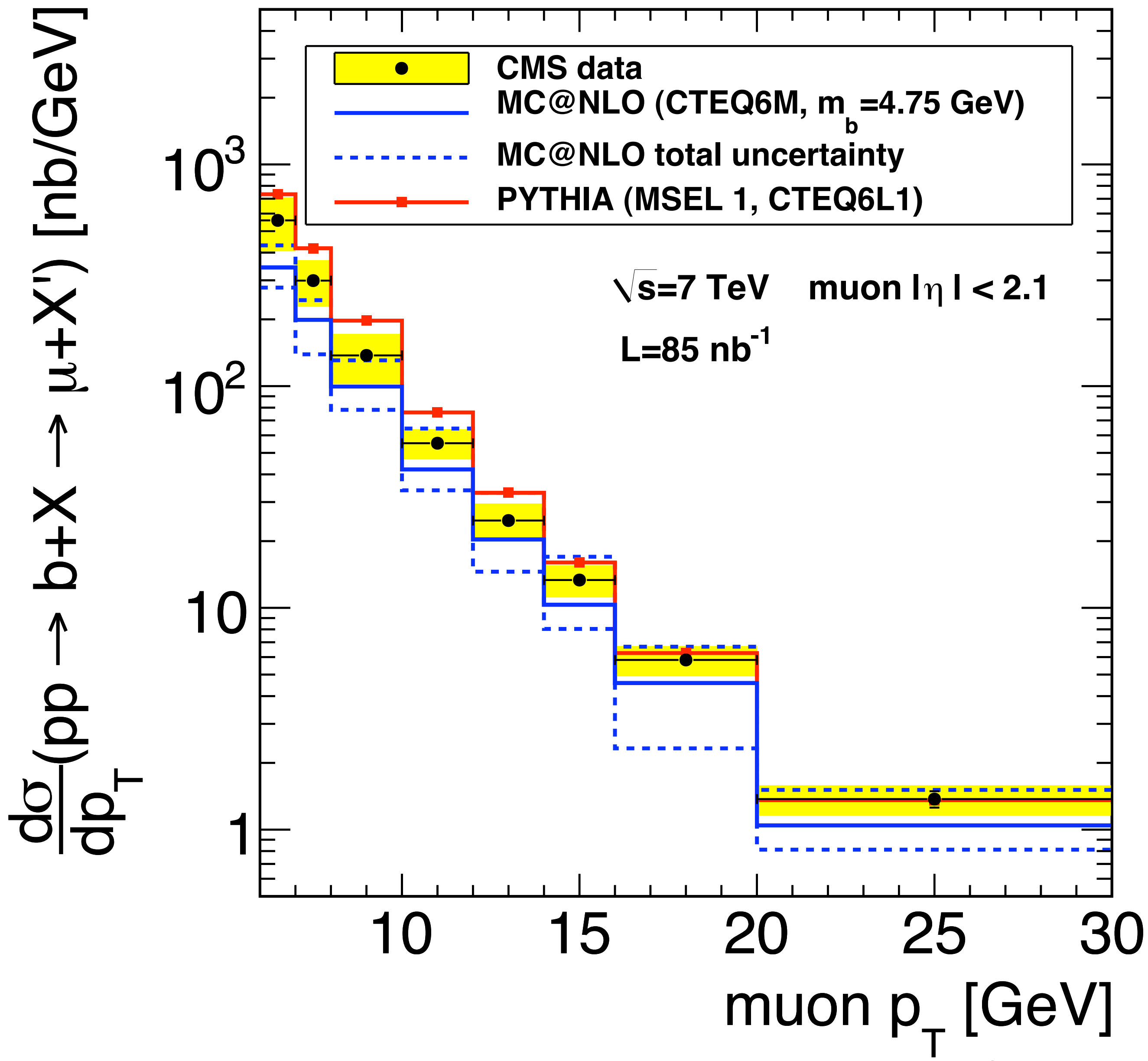
- *b-jet and c-jet shapes from MC*
- *udsg-jet (= light-jet) shapes from data (dominated by hadrons misidentified as muons - mainly in-flight decays)*

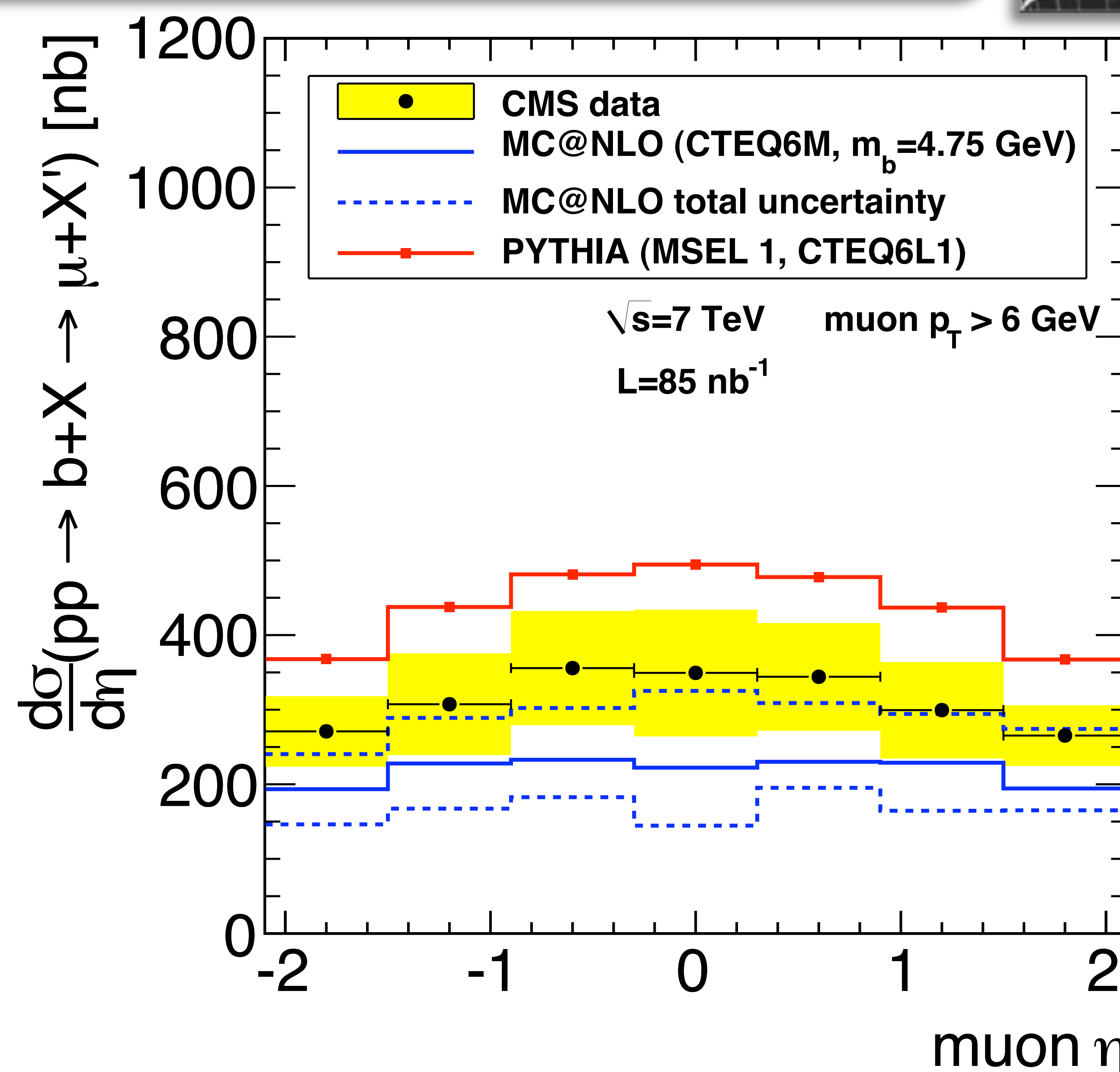


p^{rel}_T distribution



Inclusive b-hadron production cross section with muons





Total cross section for $p^{\mu}_T > 6$ GeV/c and $|\eta^{\mu}| < 2.1$

$\sigma(pp \rightarrow b\,X \rightarrow \mu\,X') = 1.32 \pm 0.01(\text{stat}) \pm 0.30(\text{syst}) \pm 0.15(\text{lumi})\ \mu b$

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

The observed shapes are reasonably well described by MC@NLO

The systematic uncertainties are dominated by the shape of the p^{rel}_T distributions ($\leq 21\%$)

Inclusive b-hadron production cross section with muons

Muon selection

$p^{\mu}_T > 6$ GeV/c, $|\eta^{\mu}| < 2.1$

$|d_0| < 2$ mm

$|d_z| < 1$ cm

#hits > 10, χ^2/dof < 10

Jet selection

$0.3 < p_T < 500$ GeV/c

$|z_0| < 2$ cm

tracks clustered with anti-kT algo,R=0.5

$E^{jet}_T > 1$ GeV/c^2

udsg-jet background dominated by hadrons misidentified as muons: hadrons satisfying all muon track criteria (without muon detector requirements) are weighted by the misidentification probability and used in the p^{rel}_T fit

Total number of events after selection: 157783

Total efficiency ranges from 74% for p^{μ}_T ~6 GeV/c to ~100% for $p^{\mu}_T > 20$ GeV/c

Total purity ranges from 93% for p^{μ}_T ~6 GeV/c to ~98% for $p^{\mu}_T > 20$ GeV/c

Sources of systematic uncertainties:

source	cross section uncertainty (%)
Trigger efficiency	5
Muon reconstruction efficiency	3
Hadron tracking efficiency	2
b $p_{\perp}^{\mathrm{rel}}$ shape uncertainty	≤ 21
Background $p_{\perp}^{\mathrm{rel}}$ shape uncertainty	2–14
Background composition	3–6
Production mechanism	2–5
Fragmentation	1–4
Decay	3
Underlying event	10
Luminosity	11

The **global efficiency** factor is obtained by event counting, applying the full set of cuts to the generated signal events: $\varepsilon_{TOT} = N_{SEL} / N_{GEN}$

We factorize ε_{TOT} in three terms: $\varepsilon_{TOT} = \varepsilon_{\mu SEL} \cdot \varepsilon_{EVT\text{-}SEL} \cdot \varepsilon_{TRIG}$

- $\varepsilon_{\mu SEL}$: efficiency to get signal events with at least two selected muons
- $\varepsilon_{EVT\text{-}SEL}$: efficiency of all other cuts (di-muon invariant mass, association with same vertex, etc...)
- ε_{TRIG}: trigger efficiency

All these efficiencies are extracted with a simple event counting on MC

We factorize $\varepsilon_{\mu SEL}$ and ε_{TRIG} in terms of the single-muon efficiencies (in bins of p^{μ}_{T} and η^{μ}) to use the data-driven results from T&P to find the correction factor MC ➜ data

We have 2 different single-μ efficiencies:

- Simple event counting from simulation of J/Ψ events
- T&P in real J/Ψ events

The ratio of these two efficiencies is the correction factor MC ➜ data

<u>Total correction factor 1.082, total corrected efficiency 47.92%</u>

Results of the fit using a BC, BD and CD constrained likelihood on data

Template	Fraction
BB	65.1%±0.30
CC	11.54%±0.60
BC	5.06%±0.10
PP	1.34%±0.30
DD	6.85%±1.17
BD	5.48%±0.10
CD	4.63%±0.83

$$\sigma(pp \to b\bar{b}X \to \mu\mu Y, p_T^{1,2} > 4\,\mathrm{GeV}, |\eta^{1,2}| < 2.1) = \frac{N_{\mu\mu} \cdot f_{BB}}{\varepsilon \cdot \mathcal{L}}$$

Event selection:

Good primary vertices (PV) are selected with the following criteria:

- |Z(PV) – Z(BeamSpot)| < 24 cm
- |R(PV) – R(BeamSpot)| < 1.8 cm
- # dof of the vertex fit > 4

Muons are associated to the nearest vertex in Z if

- $|d_z| < 1$ cm
- $d_{xy} < 0.2$ cm

Only consider vertices with exactly 2 muons associated

Check dimuon invariant mass outside the regions:

- $m_{\mu\mu} < 5$ GeV/c^2 (from charmonuim resonances and sequential semileptonic decays from b-quark)
- $8.9 < m_{\mu\mu} < 10.6$ GeV/c^2 (from Υ resonances)
- $m_{\mu\mu} > 70$ GeV/c^2 (from Z)

An event is selected if it contains exactly 1 vertex with a dimuon passing all criteria

Total number of events after selection: 537734

Measurement of b-b_{bar} angular correlation based on secondary vertices

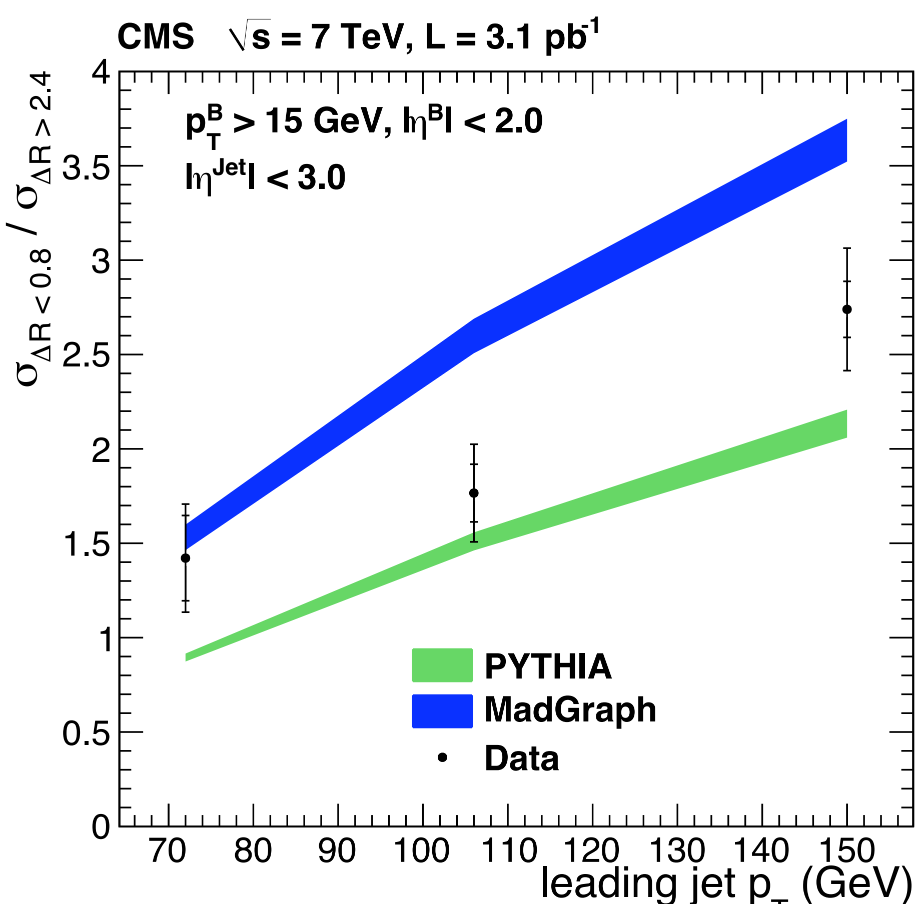
Total number of events after selection:

- 160 for p^{jet}_T > 56 GeV/c
- 380 for p^{jet}_T > 84 GeV/c
- 1038 for p^{jet}_T > 120 GeV/c

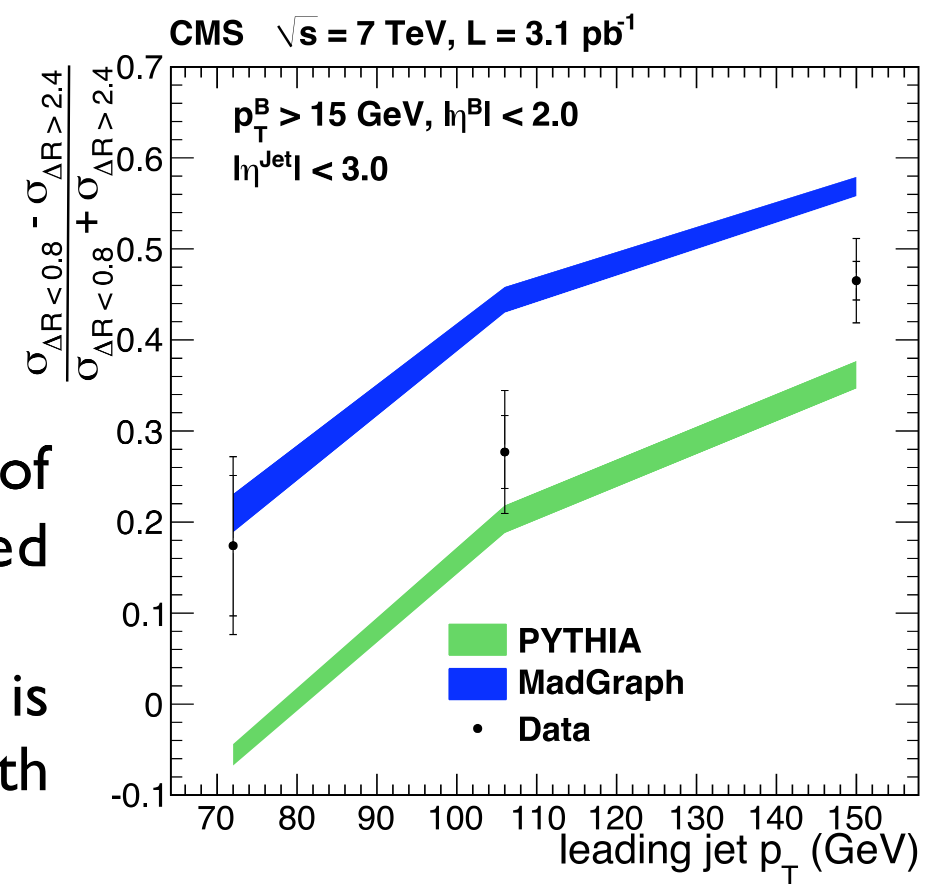
Ratio of cross sections:

$$\rho_{\Delta R} = \frac{\sigma(\Delta R < 0.8)}{\sigma(\Delta R > 2.4)}$$

$\rho_{\Delta R}$ increases with the energy scale because of more gluon radiation



The relative contributions of $\sigma_{\Delta R<0.8}$ significantly exceed those of of $\sigma_{\Delta R>2.4}$
The trend vs. energy scale is reproduced correctly by both MC but normalization is off



Mauro Dinardo, University of Colorado - Boulder

Systematic uncertainties

- Uncertainties affecting total cross sections (not relevant for the angular distribution) ~47% (mainly from b-hadron reconstruction efficiency ~44% (for two b-hadrons))
- Uncertainties affecting the shape of angular distributions (quantified in terms of variation in ratio between $\Delta R < 0.8$ and $\Delta R > 2.4$)

$\Delta R < 0.8$: gluon splitting dominates
$\Delta R > 2.4$: flavor creation dominates

Source of uncertainty in shape	Change in $\rho_{\Delta R} = \sigma_{\Delta R<0.8}/\sigma_{\Delta R>2.4}$ (%)		
	Leading jet p_T bin (GeV)		
	> 56	> 84	> 120
Algorithmic effects (data mixing)	2.0	2.0	2.0
B hadron kinematics (p_T of softer B)	8.0	7.0	4.0
Jet energy scale	6.0	6.0	6.0
Phase space correction	2.8	2.8	2.8
Bin migration from resolution	0.6	1.3	2.1
Subtotal shape uncertainty	10.6	9.9	8.3
MC statistical uncertainty	13.0	13.0	13.0
Total shape uncertainty	16.8	16.4	15.4

Efficiency check: event mixing technique

- Events are pre-selected containing at least one b-hadron candidate
- Pairs of events are mixed if their primary vertices are within the typical resolution (~20 μm)
- The mixed event is re-reconstructed, re-running tracking and secondary vertex reconstruction
- A relative efficiency is defined by counting the fraction of mixed events where the two b-hadron candidates, from the two original events, are re-reconstructed
- Overall efficiency to reconstruct both b-hadrons ~10% (from MC, checked on data with data mixing technique)
- Average b-b_{bar} purity ~84% (from MC)

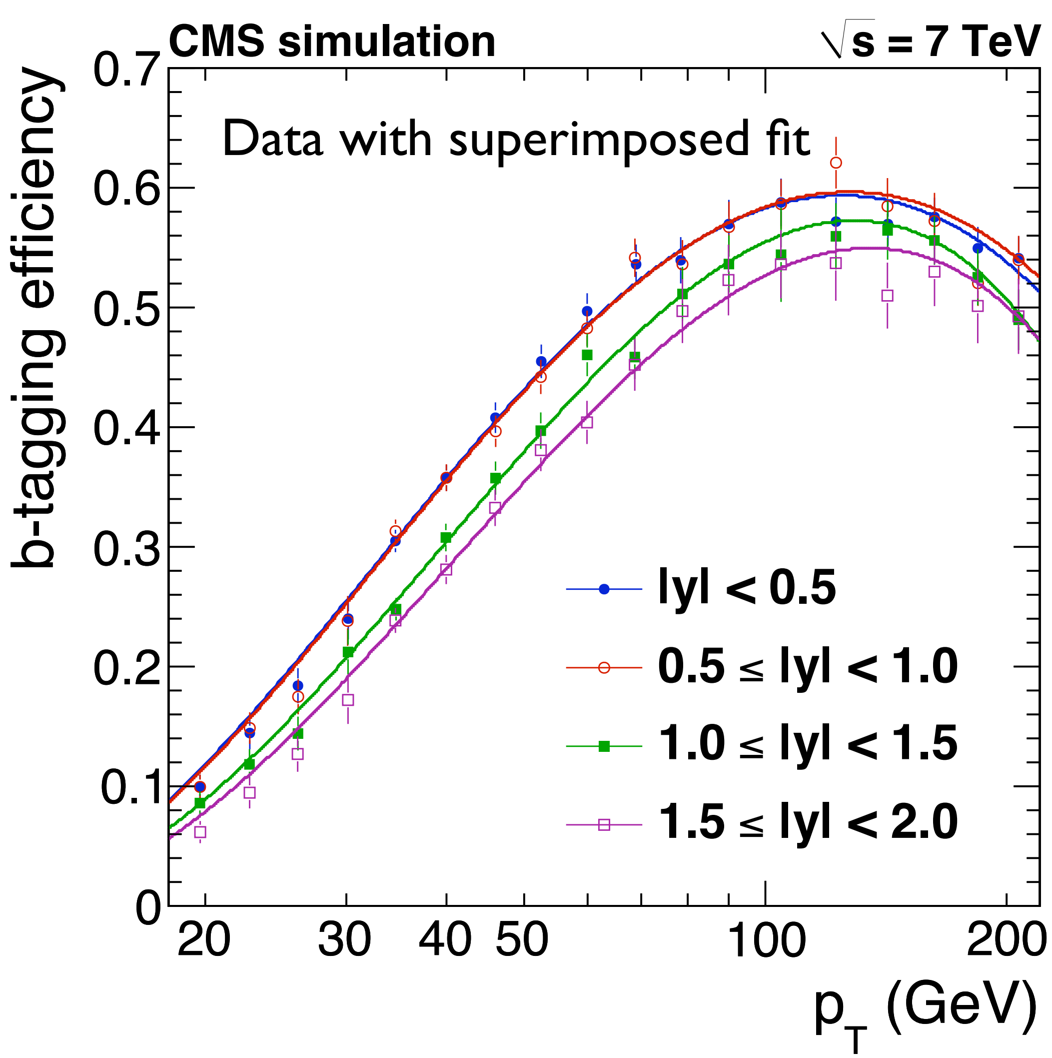
Inclusive b-jet production cross section

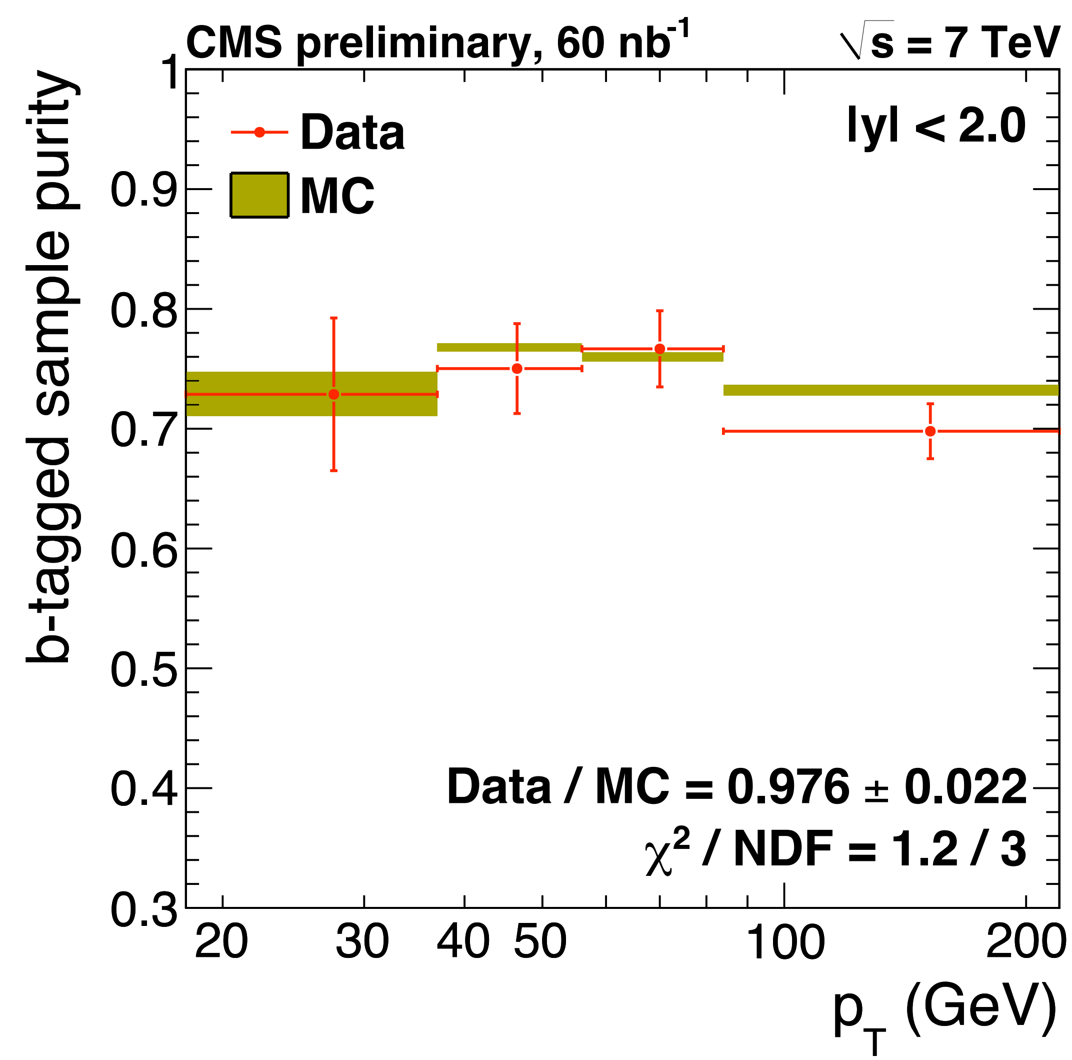
Differential production cross section in bins of p_T and y of the b-jets

CMS-PAS-BPH-10-009

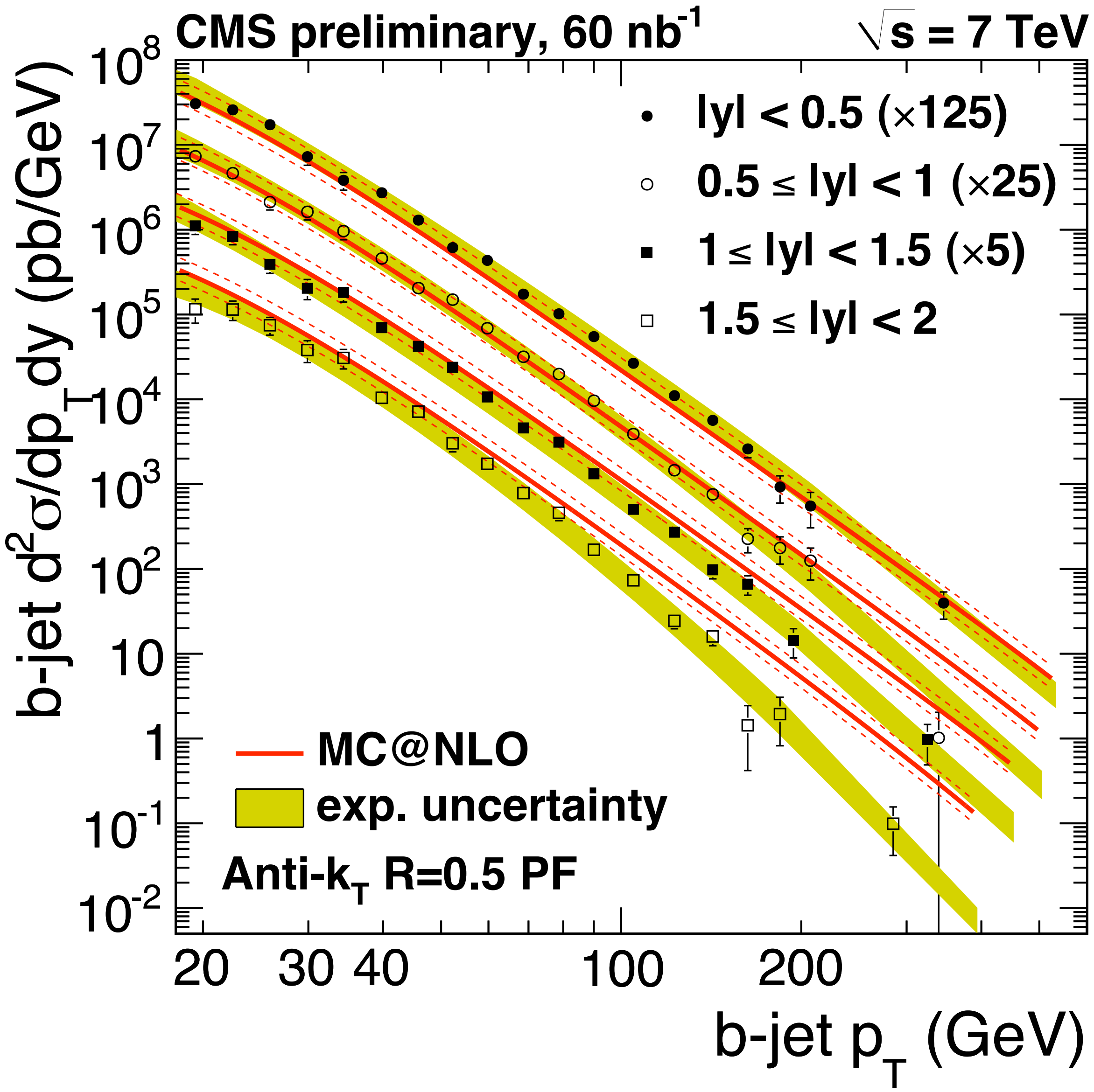
1. Select b-jets based on secondary vertex 3D decay length significance (N_{tagged})
2. Compute the b-jet efficiency (ε_b) and b-jet purity (f_b) to properly correct the number of b-jets ($N_{tagged} \cdot f_b / \varepsilon_b$)

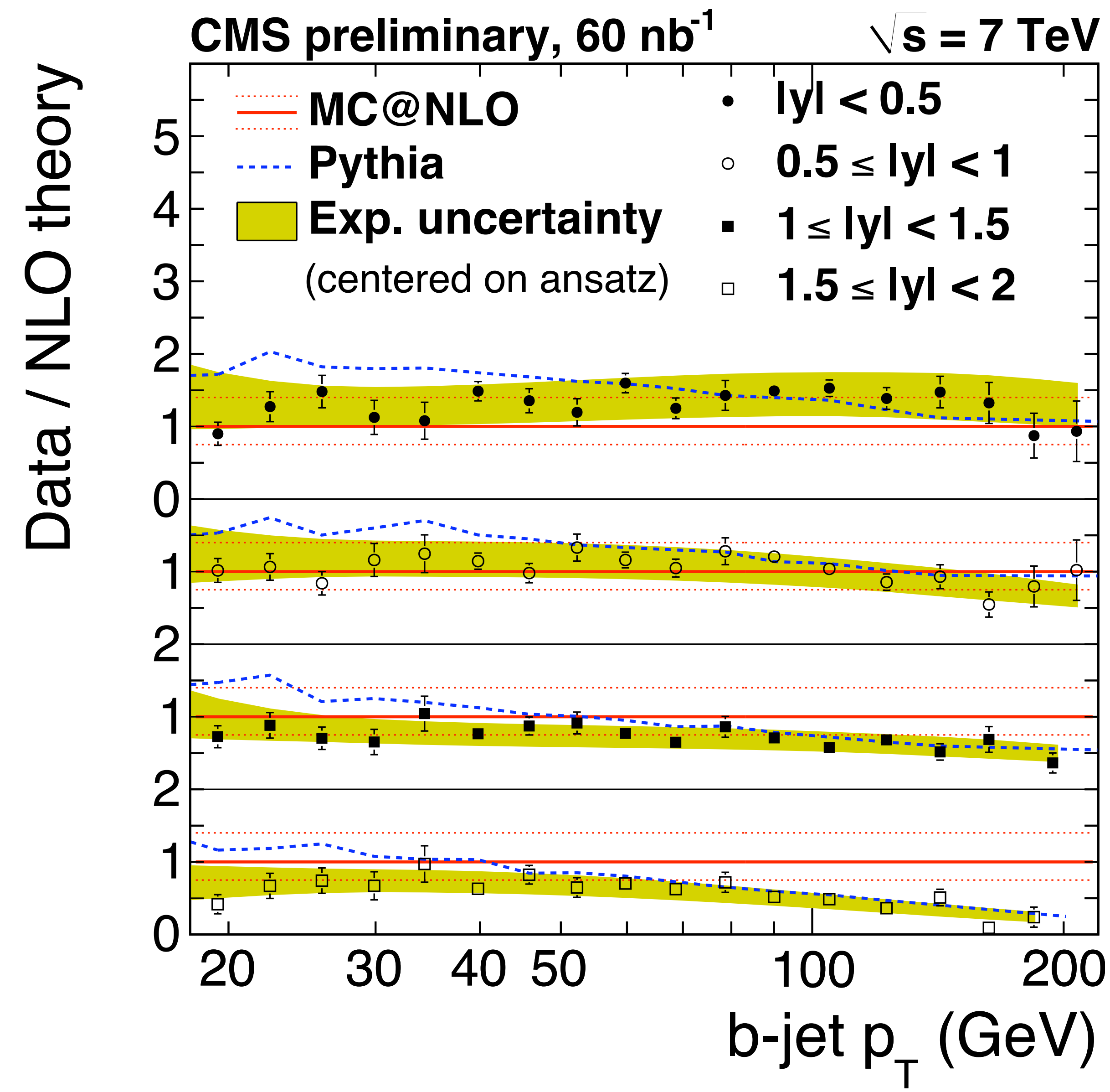
- ε_b is derived from the fit to the muon p^{rel}_T distribution in semi-leptonic b_{tagged} and non b_{tagged} jets
  ε_b = b-jet content in b_{tagged}-jets / (b-jet content in b_{tagged}-jets + b-jet content in non b_{tagged}-jets)
- f_b is derived from the fit to the secondary vertex invariant mass distribution





Inclusive b-jet production cross section



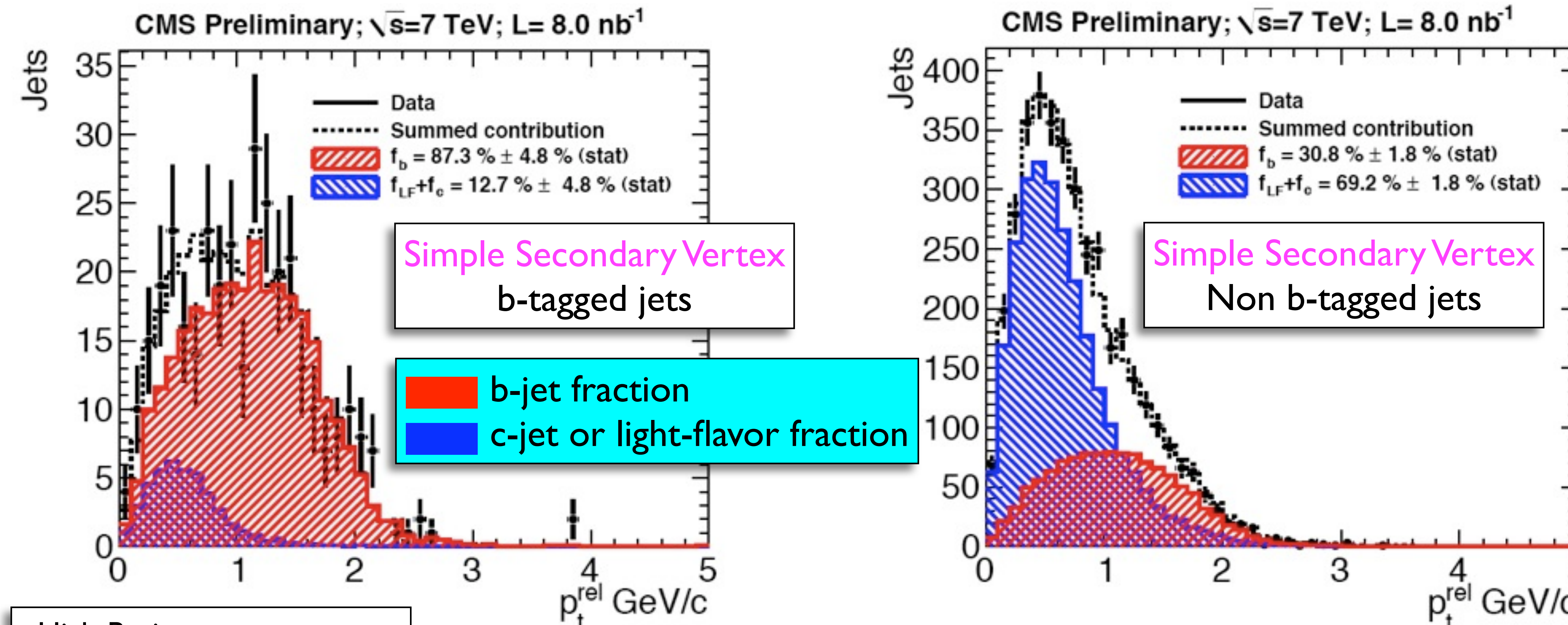


Overall good agreement between data and PYTHIA in the jet p_T-range $30 < p_T < 150$ GeV/c, $|y| < 2.0$, with 2% stat, 21% syst

Reasonable agreement between the MC@NLO calculation and the measured overall b-jet fraction, within 21% syst (dominated by uncertainty on b-tagging efficiency), but observed significant shape differences in p_T and y

Inclusive b-jet production cross section

- b-jet identification efficiency is estimated from data by fitting the p_T^{rel} (p_T with respect to the jet axes) distribution of muons in the semi-leptonic jets ($p_T > 20$ GeV/c; $|\eta| < 2.4$)
- b-jet fraction is extracted from the fit using distribution templates based on Monte Carlo



High-Purity + acceptance c and light-flavored jets ≤ 0.1%

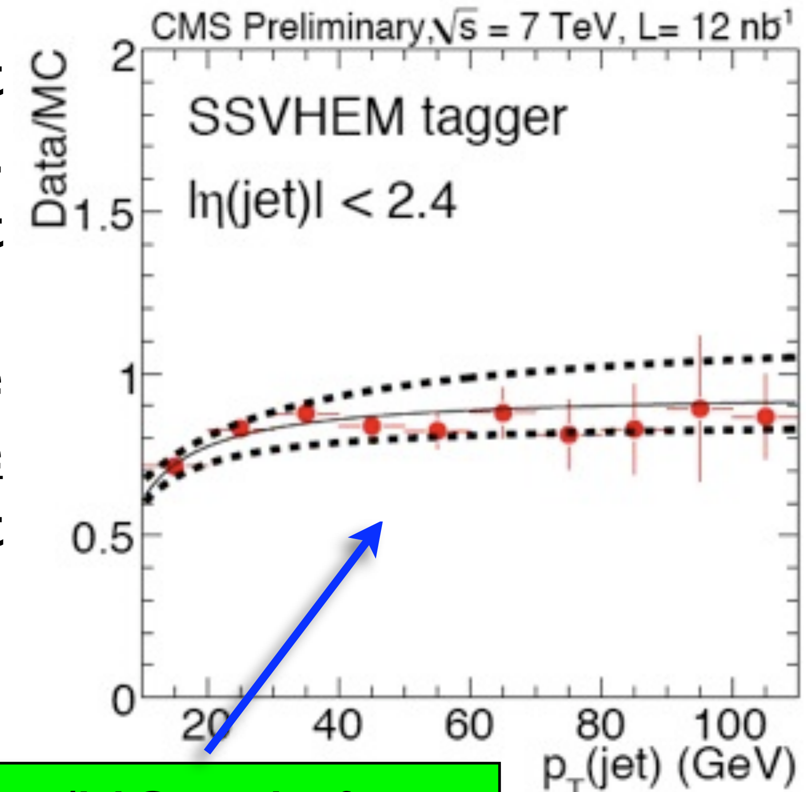
- $|\eta| \leq 2$
- $\langle p_T \rangle$ = 31GeV/c

Algorithm	ε_b(Data)	ε_b(MC)	ε_b(Data) / ε_b(MC)
Simple Secondary Vertex	0.203±0.015	0.207±0.002	0.98±0.08±0.18
Track Counting	0.233±0.014	0.244±0.002	0.95±0.06±0.19

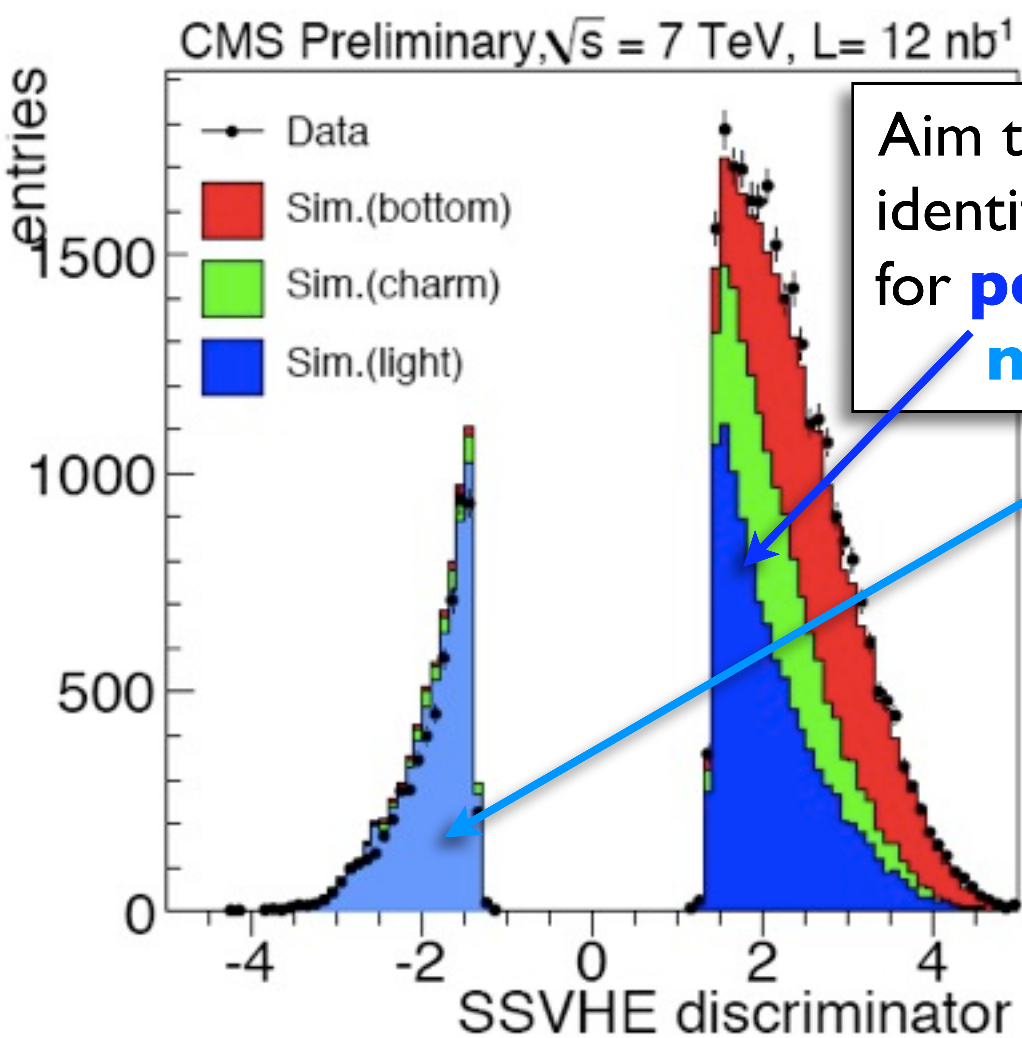
Inclusive b-jet production cross section

Track Counting algo.: requires 2 or 3 tracks with an impact parameter significance larger than a given cut. Negative tagging: the 2 or 3 tracks have a negative scalar product between the impact parameter and the jet axis

Simple Secondary Vertex algo.: requires a significance of the secondary vertex decay length larger than a given cut. Negative tagging: the secondary vertex is in the opposite direction with respect to the jet



Data/MC scale factor



Aim to estimate the mis-identification distribution for **positive tags** using **negative tags**

$$\varepsilon_{data}^{mistag} = \varepsilon_{data}^{-} \frac{\varepsilon_{MC}^{mistag}}{\varepsilon_{MC}^{-}}$$

Corrects for asymmetry between positive and negative tags