Inclusive and exclusive B production cross-sections at CMS

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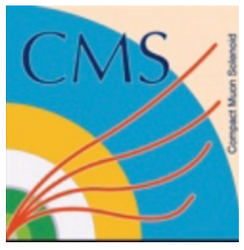
on behalf of the CMS collaboration



outline

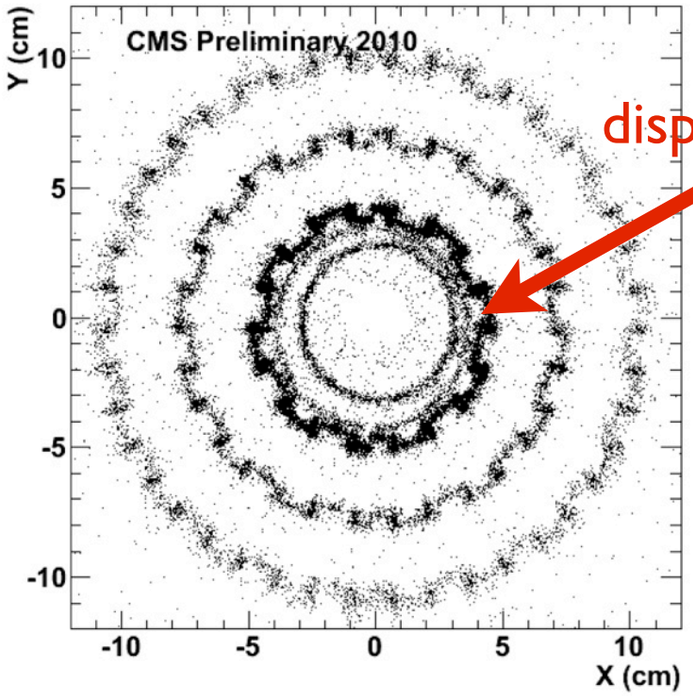
- the CMS detector:
  - ⋆ general overview (see K. Hoepfners talk yesterday)
  - ⋆ tracker performance

- ***inclusive*** B cross-sections:
  - ⋆ inclusive B production with muons (L=85nb^{-1})
  - ⋆ inclusive B -jet production with secondary vertices (L=60nb^{-1})

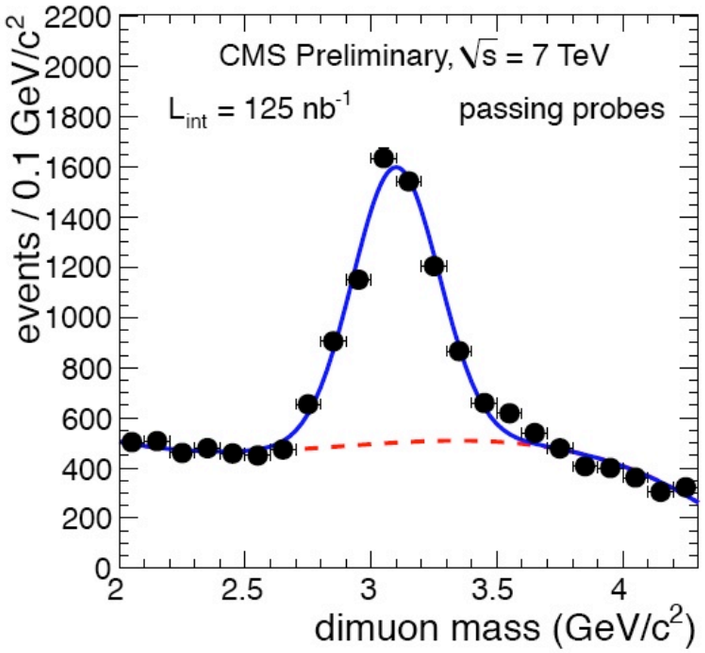
- ***exclusive*** B cross-sections:
  - ⋆ $B^+ \rightarrow J/\psi(\mu^+\mu^-)\ K^+$ (L=5.8pb^{-1})
  - ⋆ $B^0 \rightarrow J/\psi(\mu^+\mu^-)\ K_s(\pi^+\pi^-)$ (L=40pb^{-1})
  - ⋆ $B_s \rightarrow J/\psi(\mu^+\mu^-)\ \Phi(K^+\ K^-)$ (L=40pb^{-1})

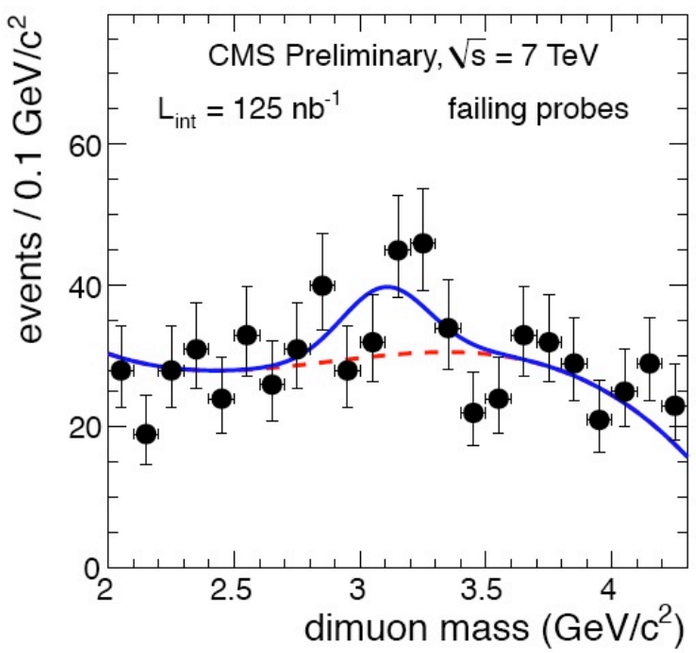
CMS tracker performance

pixel barrel detector radiography from conversions

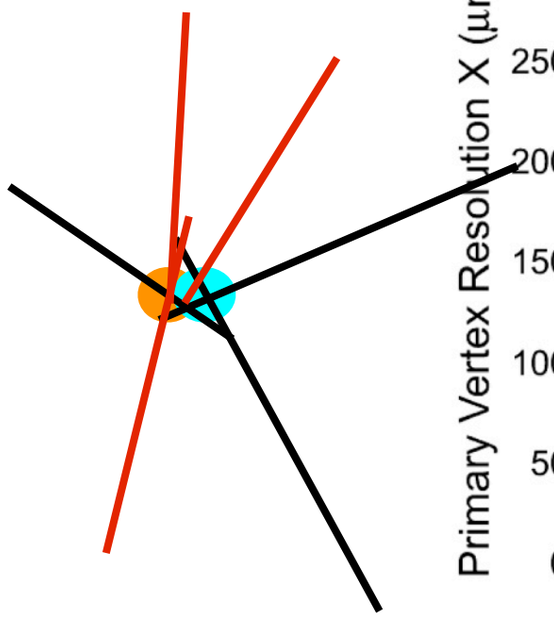


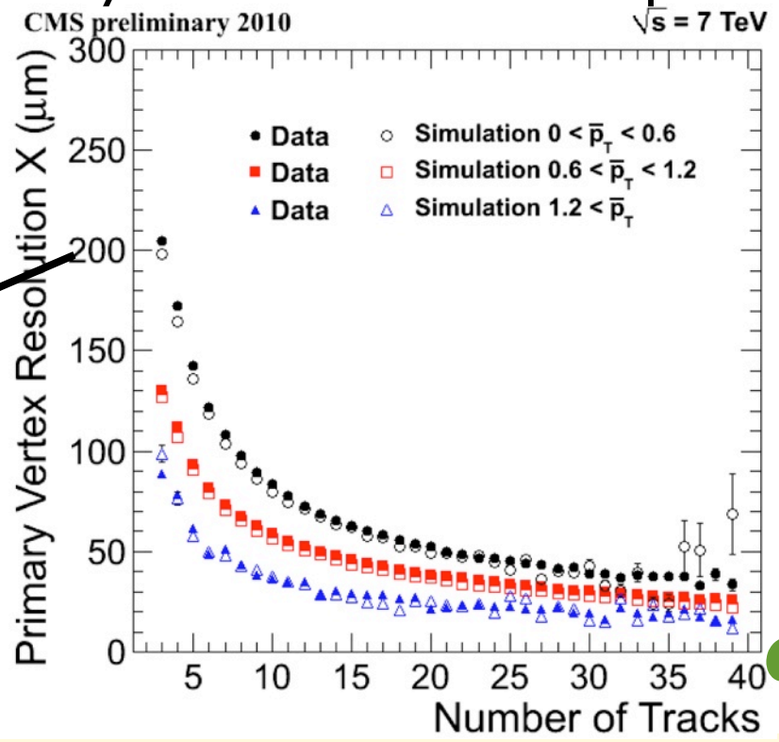
tracking efficiency from tag+probe method with di-muons from J/ψ



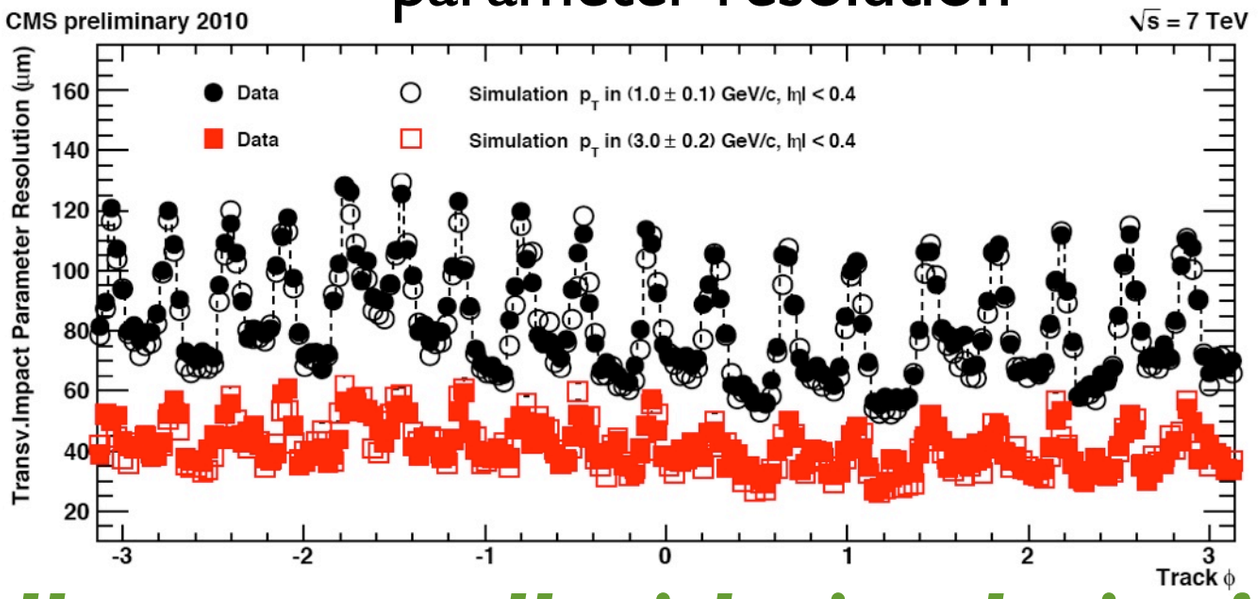


primary vertex efficiency and resolution from split method



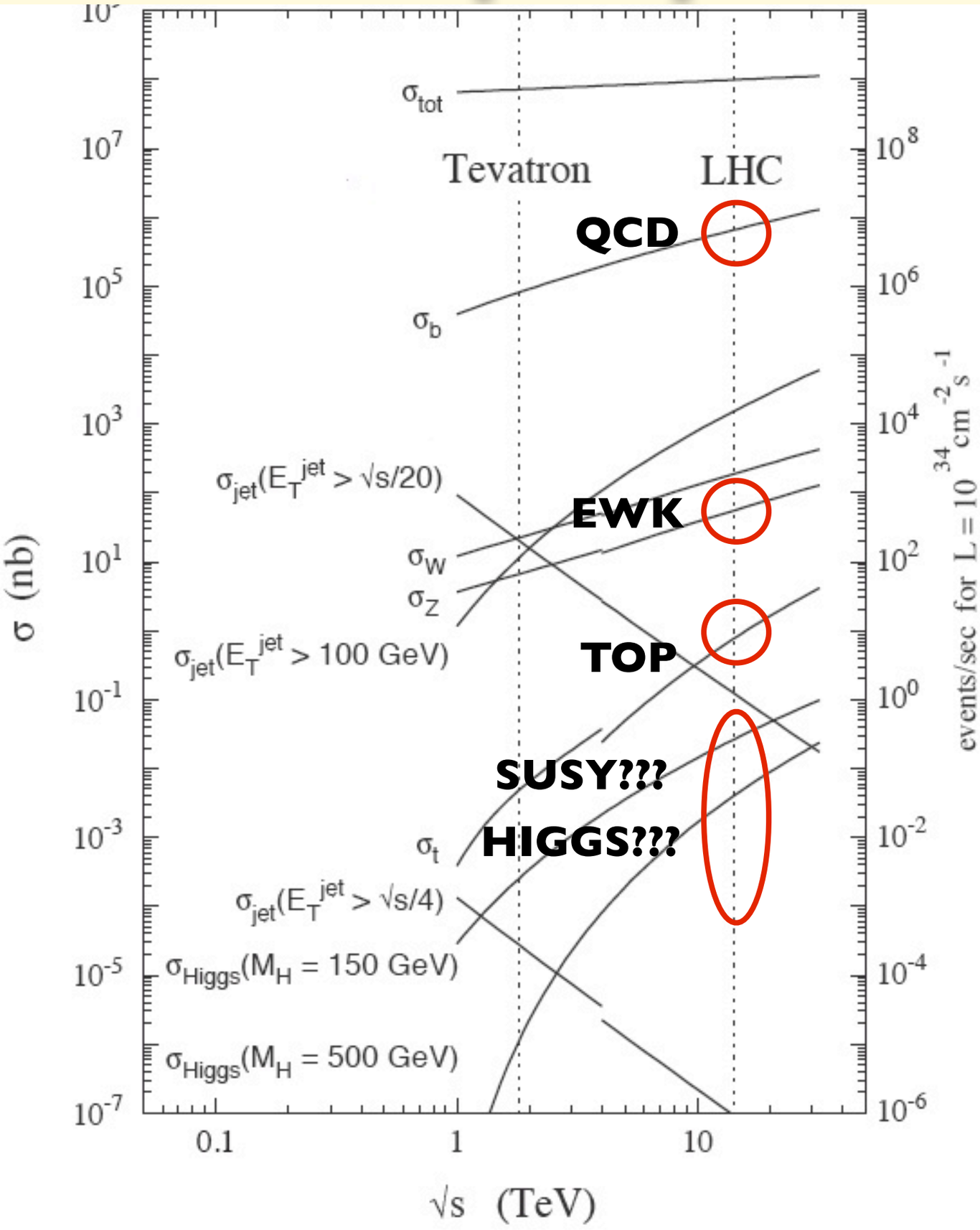


data-driven impact parameter resolution

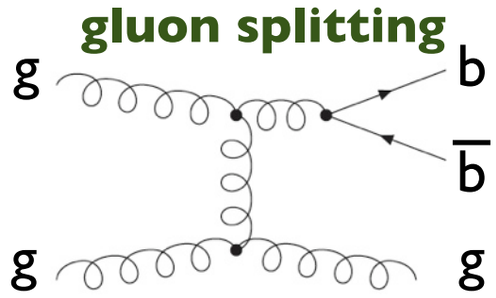


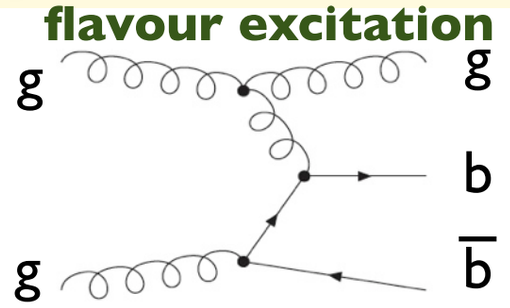
all agrees well with simulation!

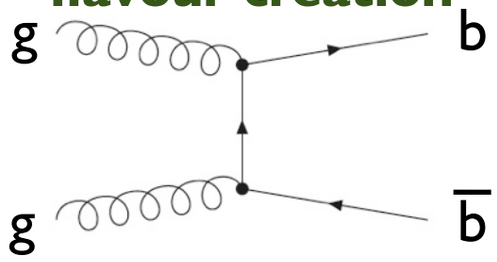
b quark production at the LHC



QCD:

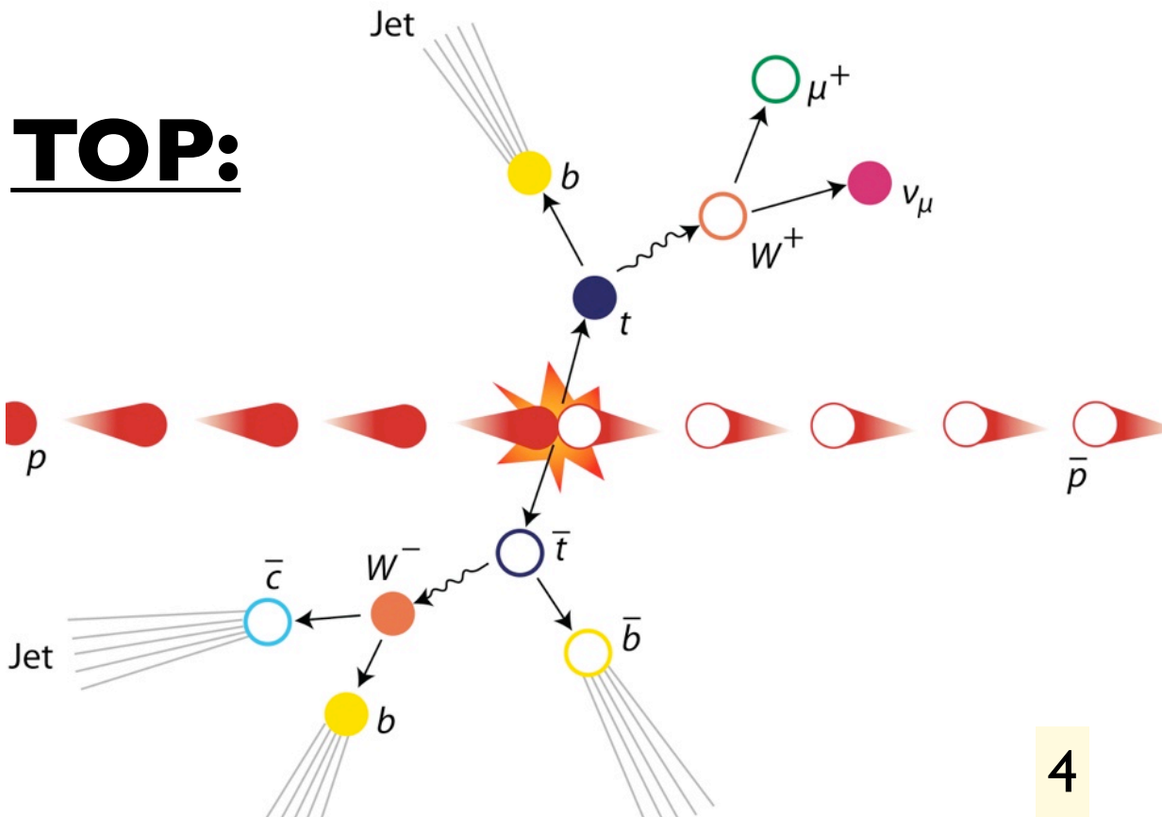






Electroweak: $Z \rightarrow b\bar{b}$

TOP:



b quark production at the LHC

test of perturbative QCD:

→measurements at LHC beyond theory uncertainties

good understanding of B production is mandatory for searches for new physics

→B is background in many searches

→dynamics and topology is relevant (see A. Rizzi's talk on bb correlations)

new physics may also show up in B decays!

→examples: CP violation in B_s → J/ψ Φ

branching fraction of B_s → $\mu^+\mu^-$

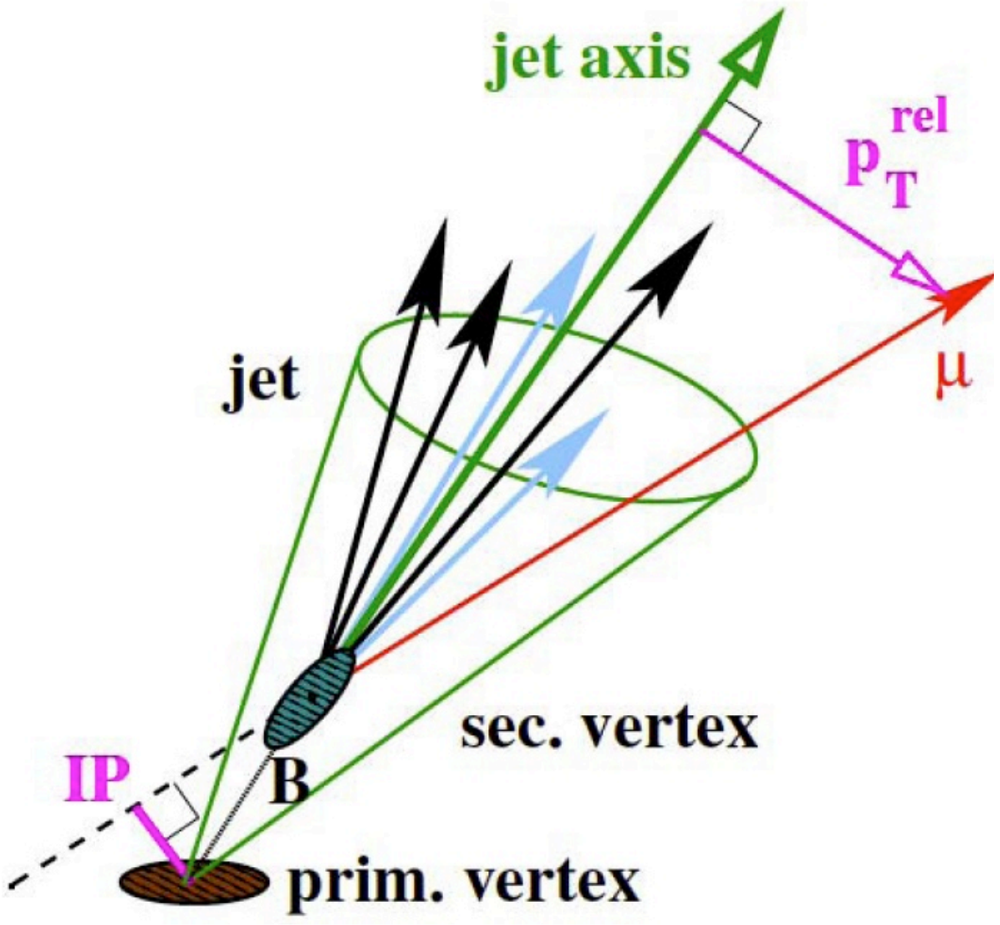
Inclusive B production with muons

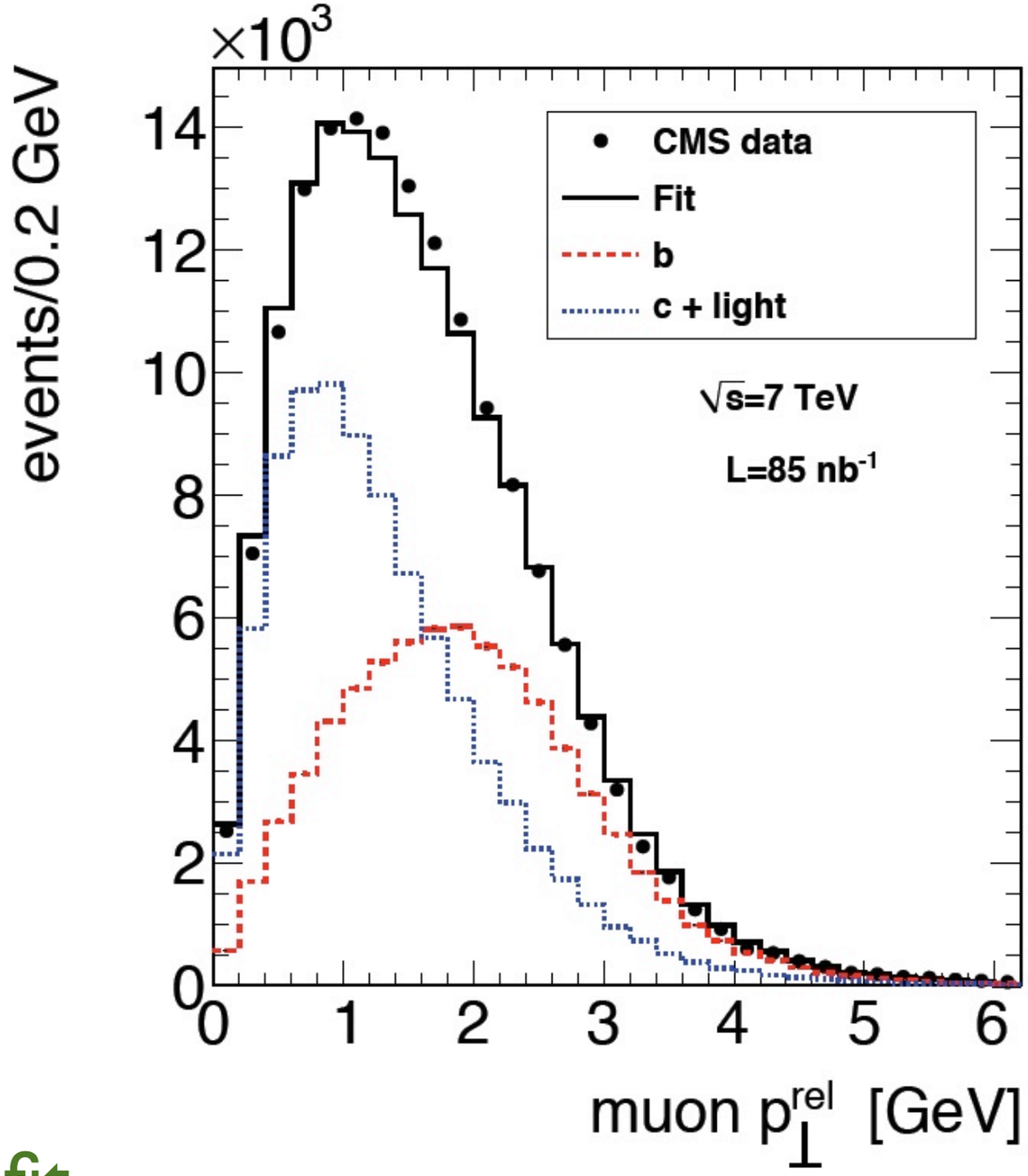
JHEP 1103:090,2011

muon p_t^{rel}

B mesons are heavy ($m=5GeV/c^2$)

➔decay products have large relative momenta





➡characteristic p_t^{rel} spectrum for muons from B decays

➡extract B fraction with template fit

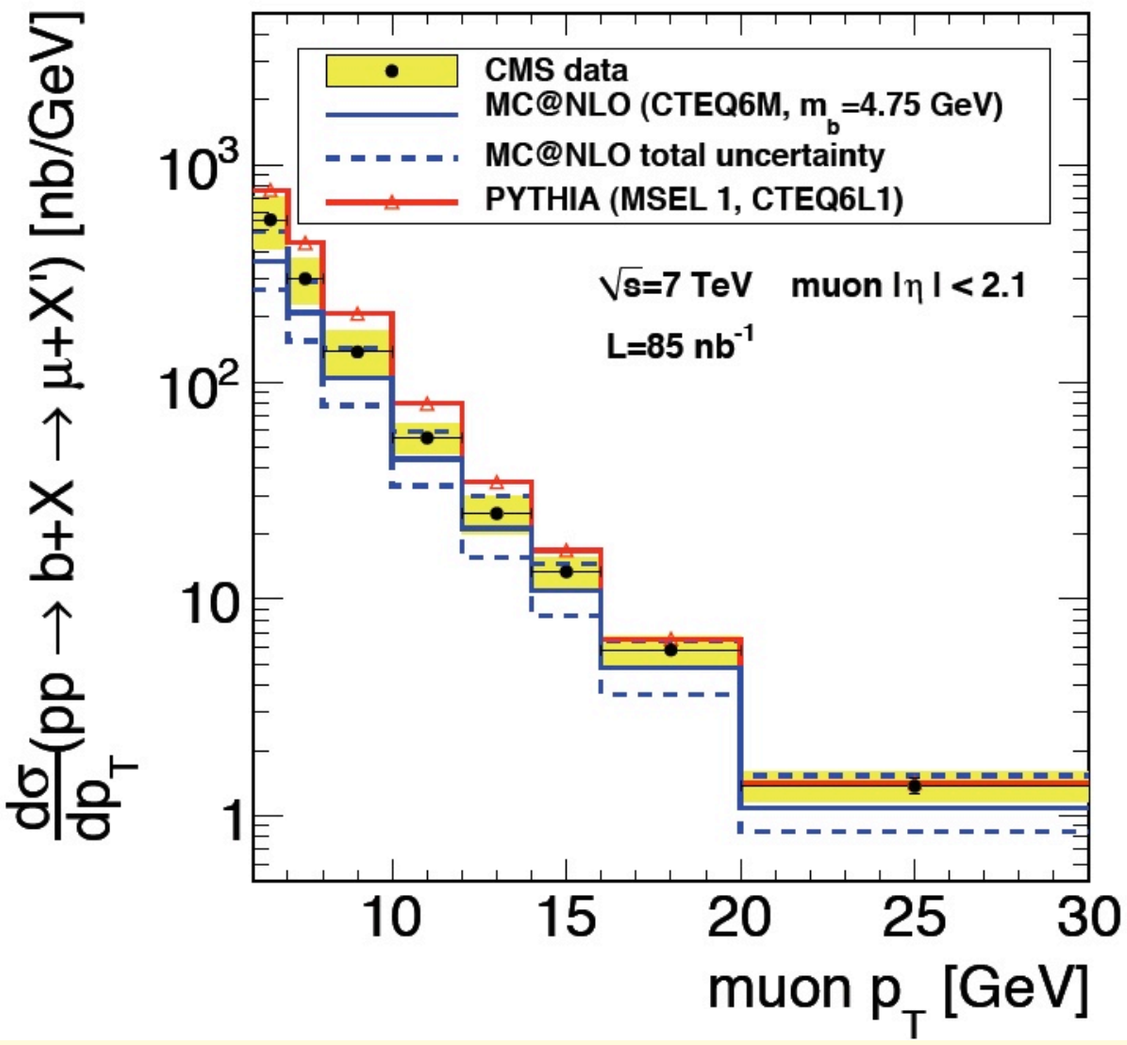
results

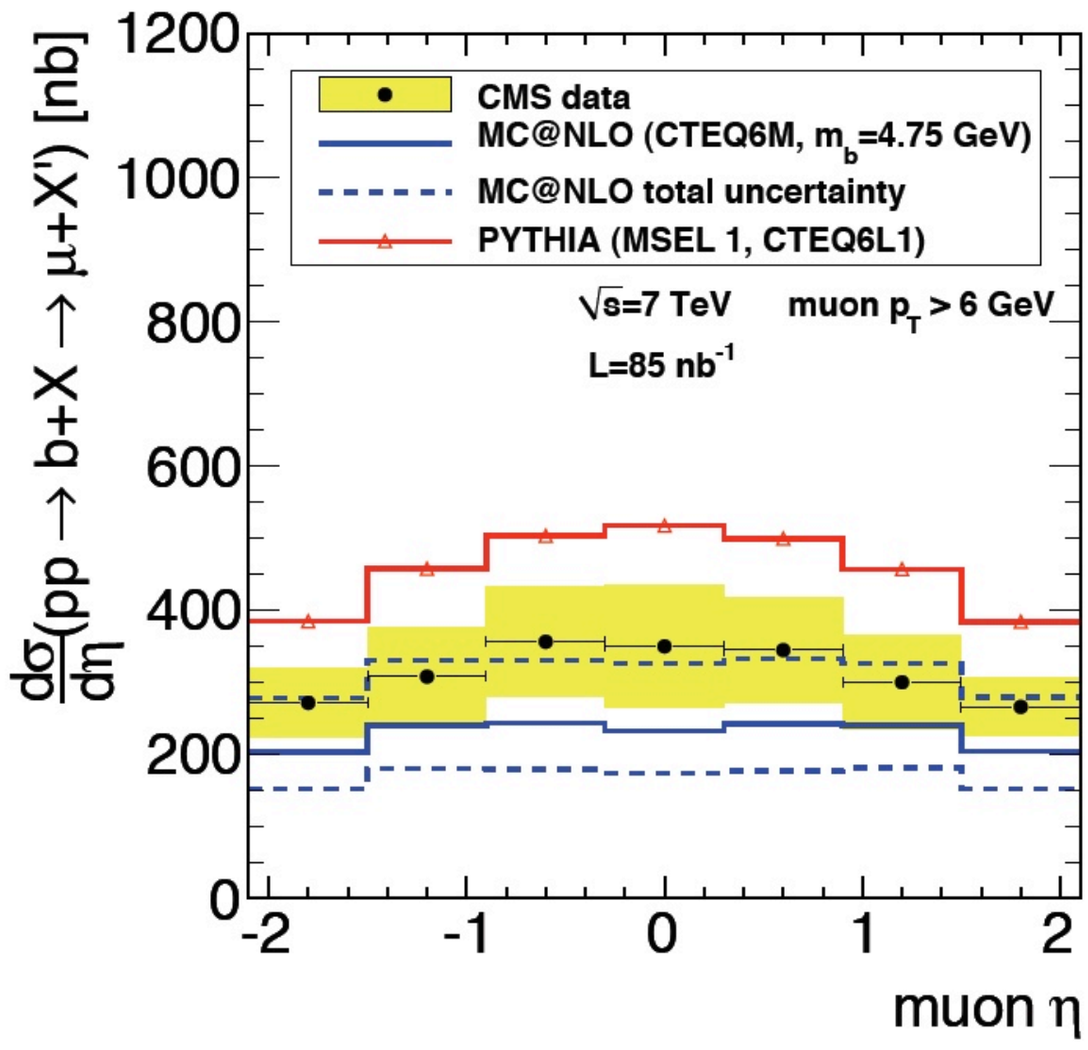
inclusive cross-section: $\sigma \equiv \sigma(\mathrm{pp} \to \mathrm{b} + X \to \mu + X') = \frac{N_\mathrm{b}}{\mathcal{L}\,\varepsilon}$

with N_b=observed events; $\mathcal{L}$=int. luminosity; ε=reco+trigger eff.

$$\sigma = 1.32 \pm 0.01(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.15(\mathrm{lumi})\ \mu\mathrm{b}$$

$\sigma_{MC@NLO} = 0.84^{+0.36}_{-0.19}(\mathrm{scale}) \pm 0.08(\mathrm{m_b}) \pm 0.04(\mathrm{pdf})\mu\mathrm{b}$ $\sigma_{PYTHIA} = 1.8\mu\mathrm{b}$





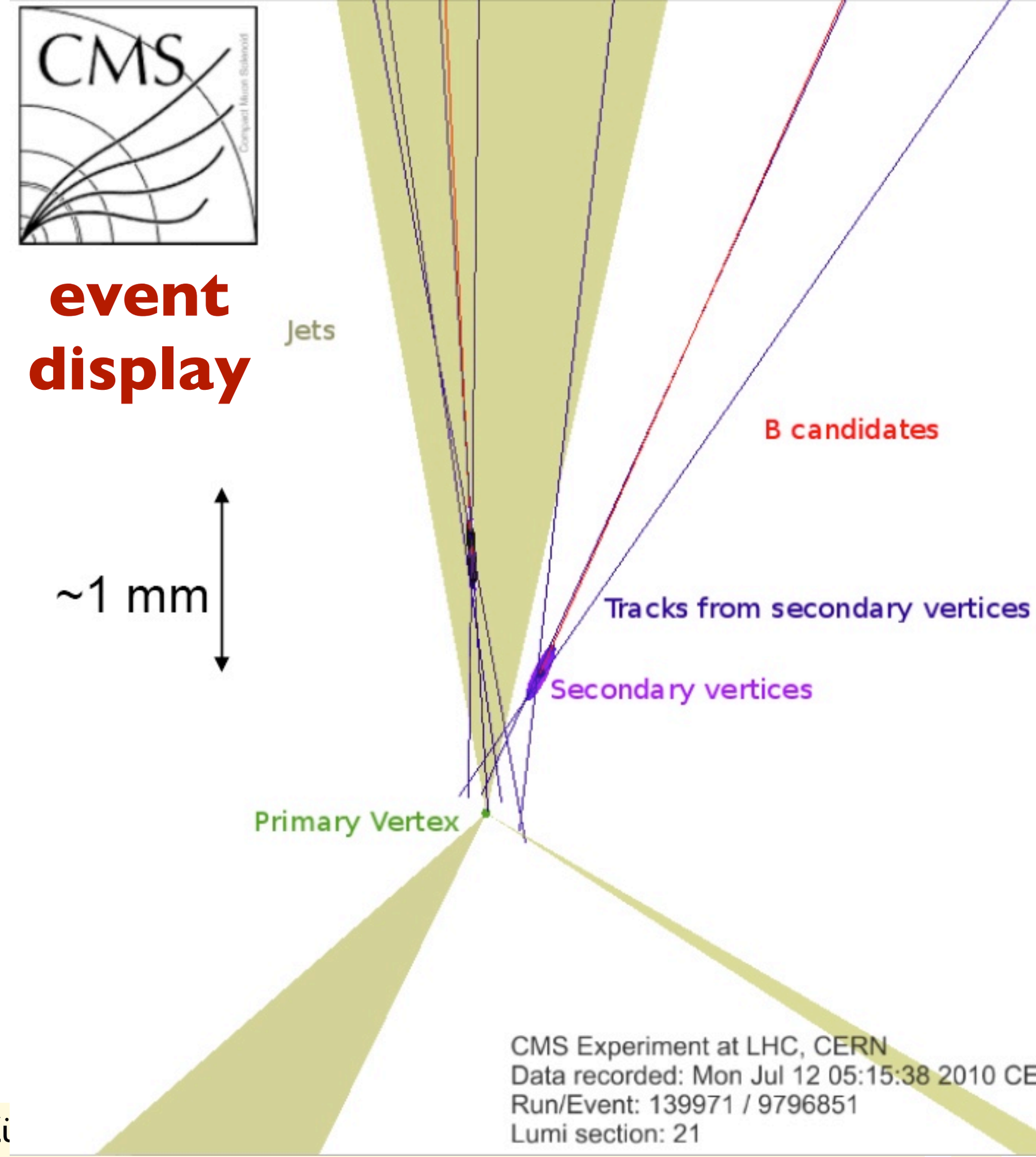
Inclusive B production using b-tagging with secondary vertices

CMS PAS BPH-10-009

secondary vertex b-tagging:

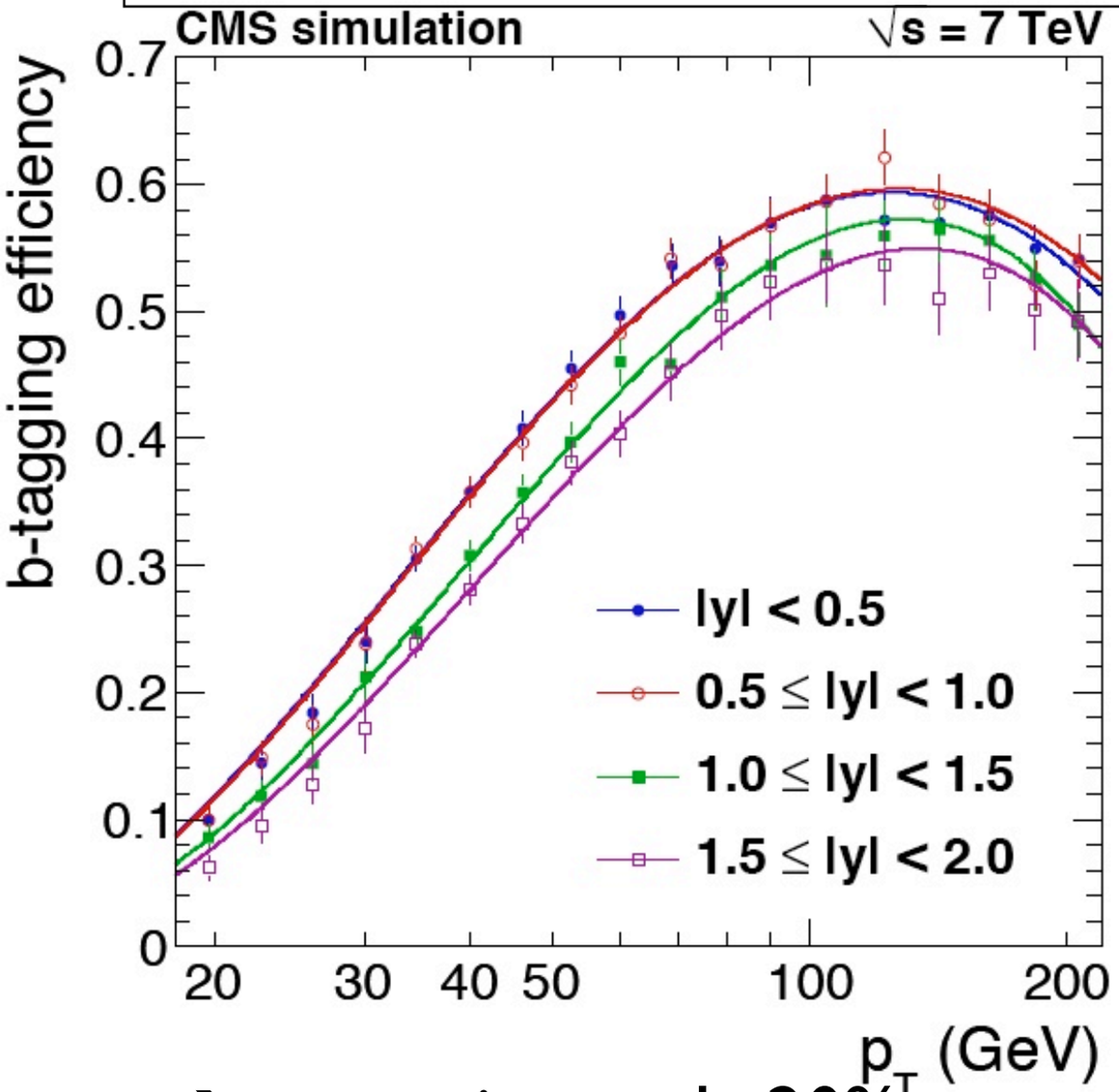
- define region around jet direction dR=0.5
- use tracks in this cone as input to vertex search
- separation between primary and secondary vertex is discriminator

event display



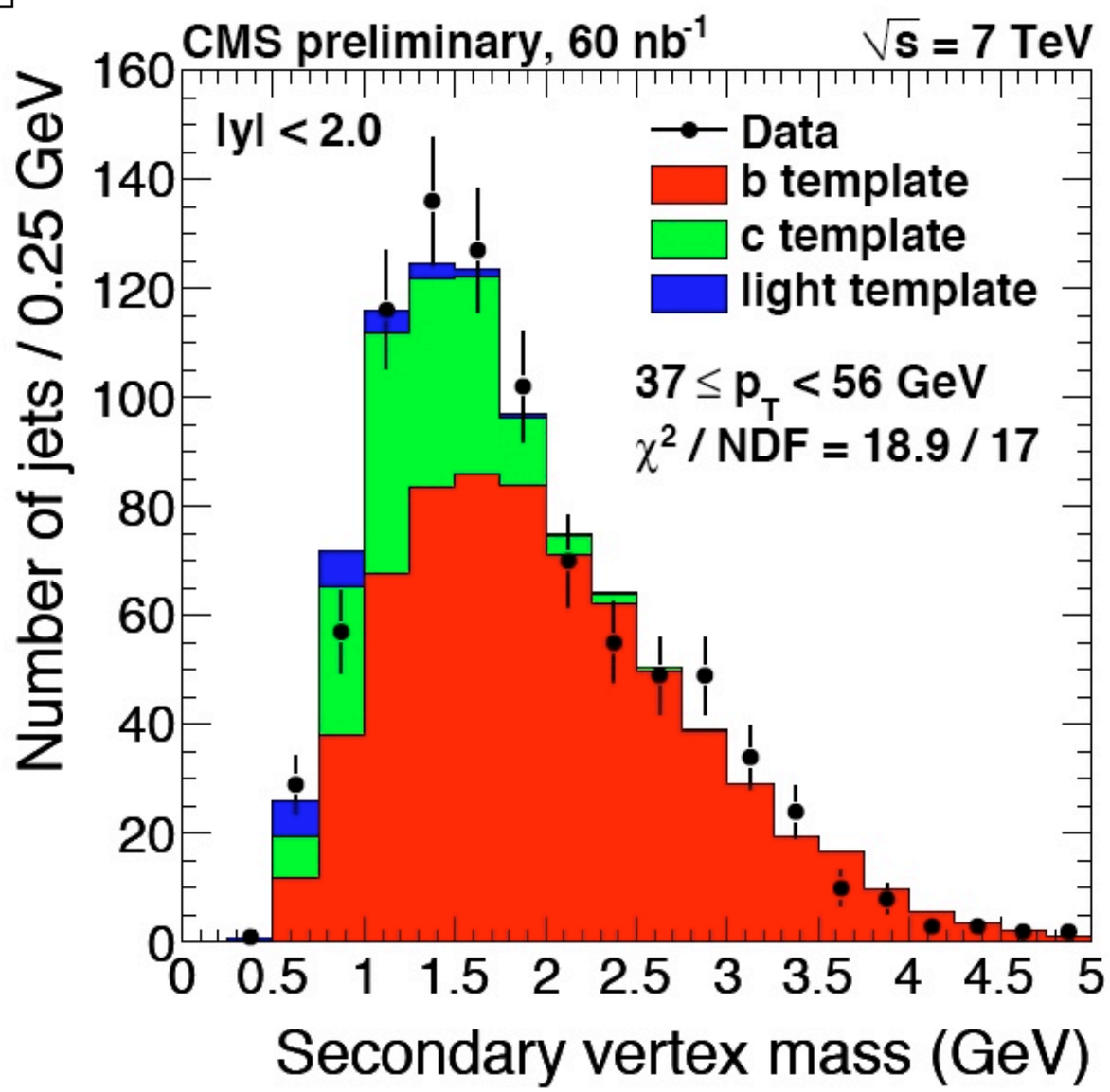
b-jet tagging

b-tag efficiency determined from simulation, validation with data-driven methods



→uncertainty only 20%
(right from the start)

b-tagged sample purity obtained from vertex mass fit



→purity f_b=75%

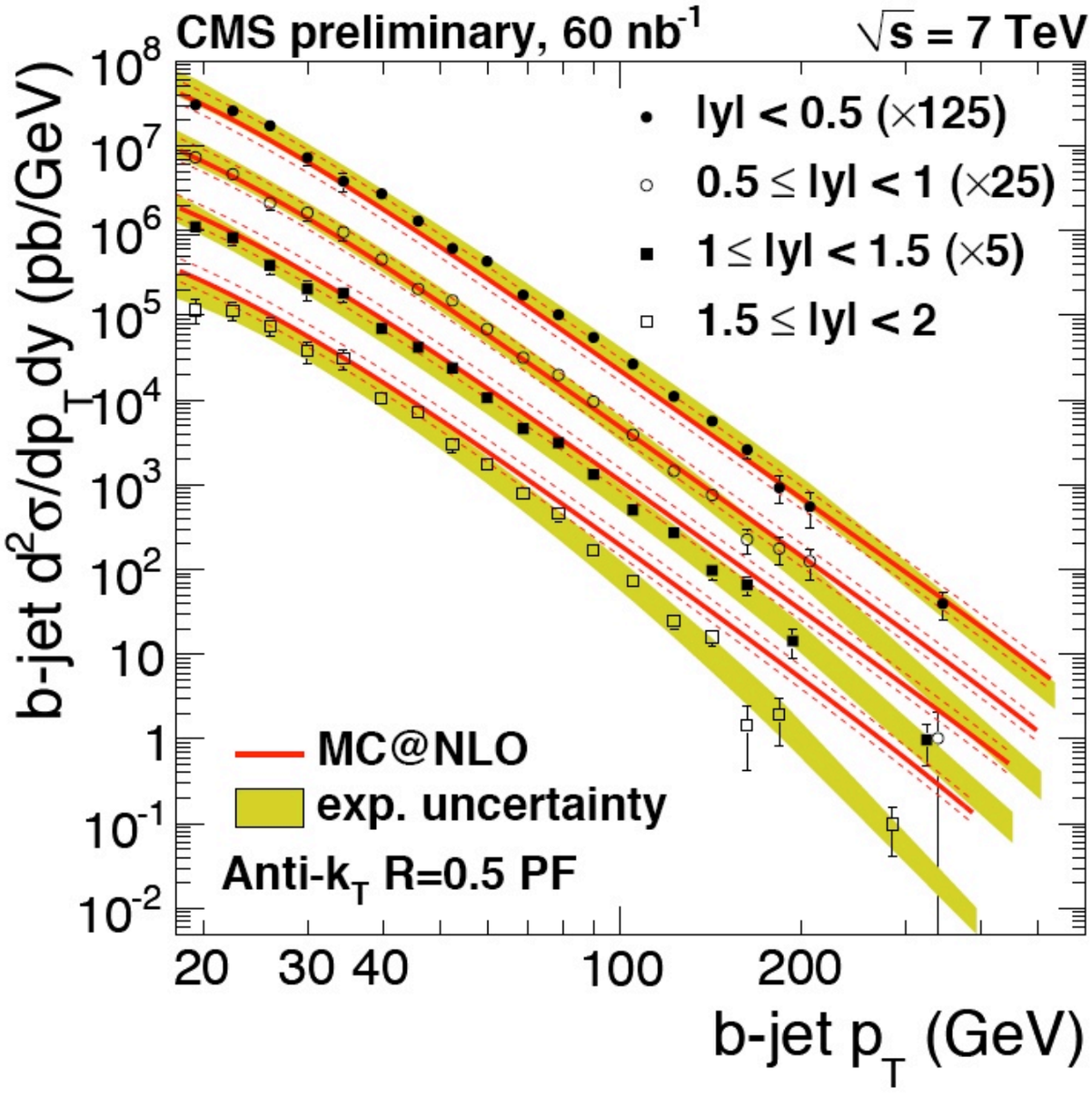
results

differential cross-section:

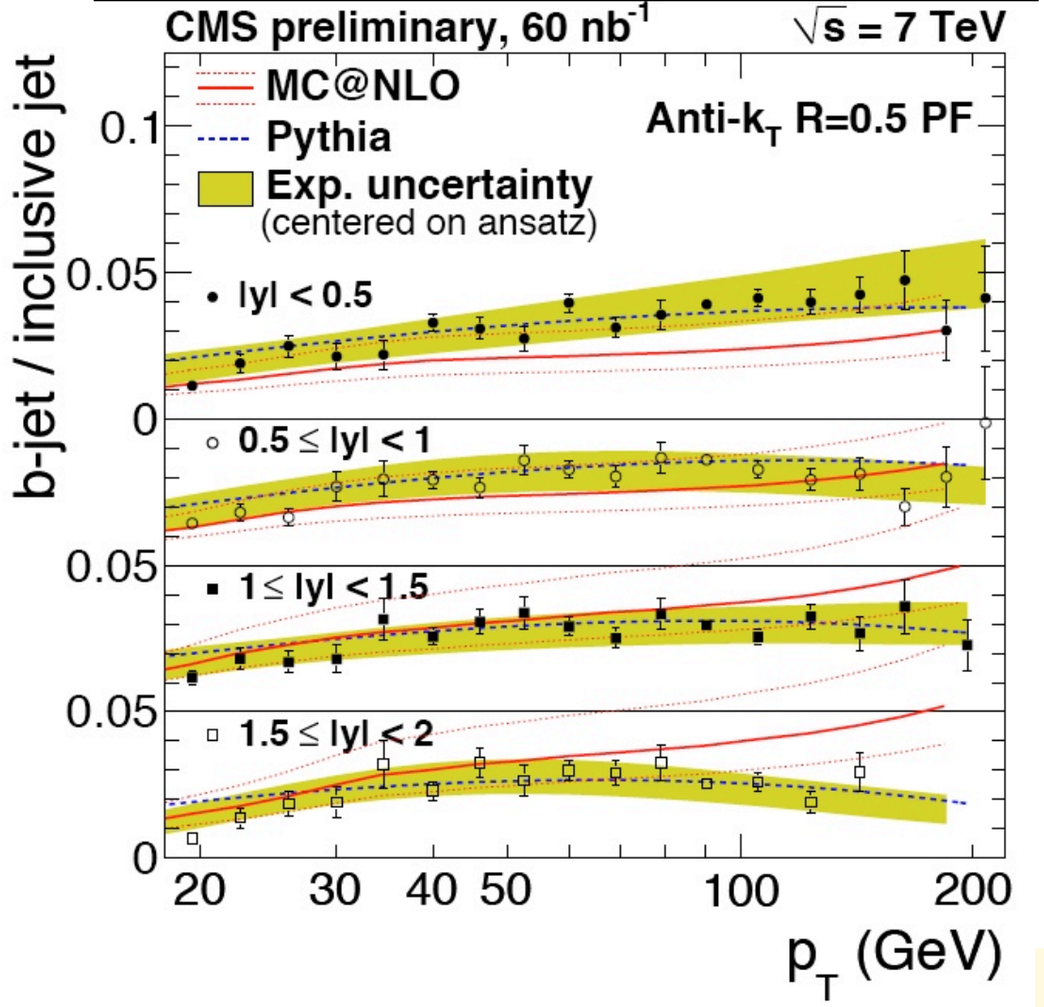
measured events — fitted purity — unfolding correction

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

jet reco. eff. — b-tag eff. — luminosity

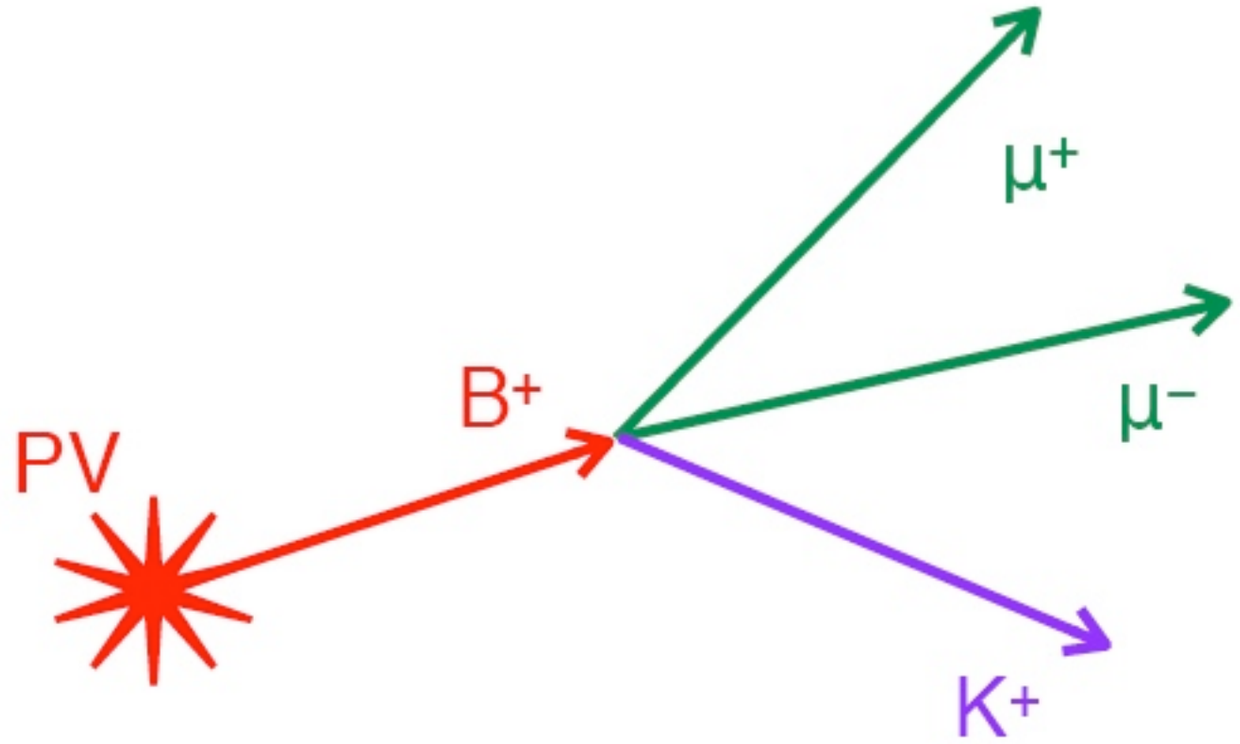


ratio to inclusive jets:



exclusive decay $B^+ \rightarrow J/\psi(\mu^+\mu^-)\ K^+$

PRL 106, 112001 (2011)



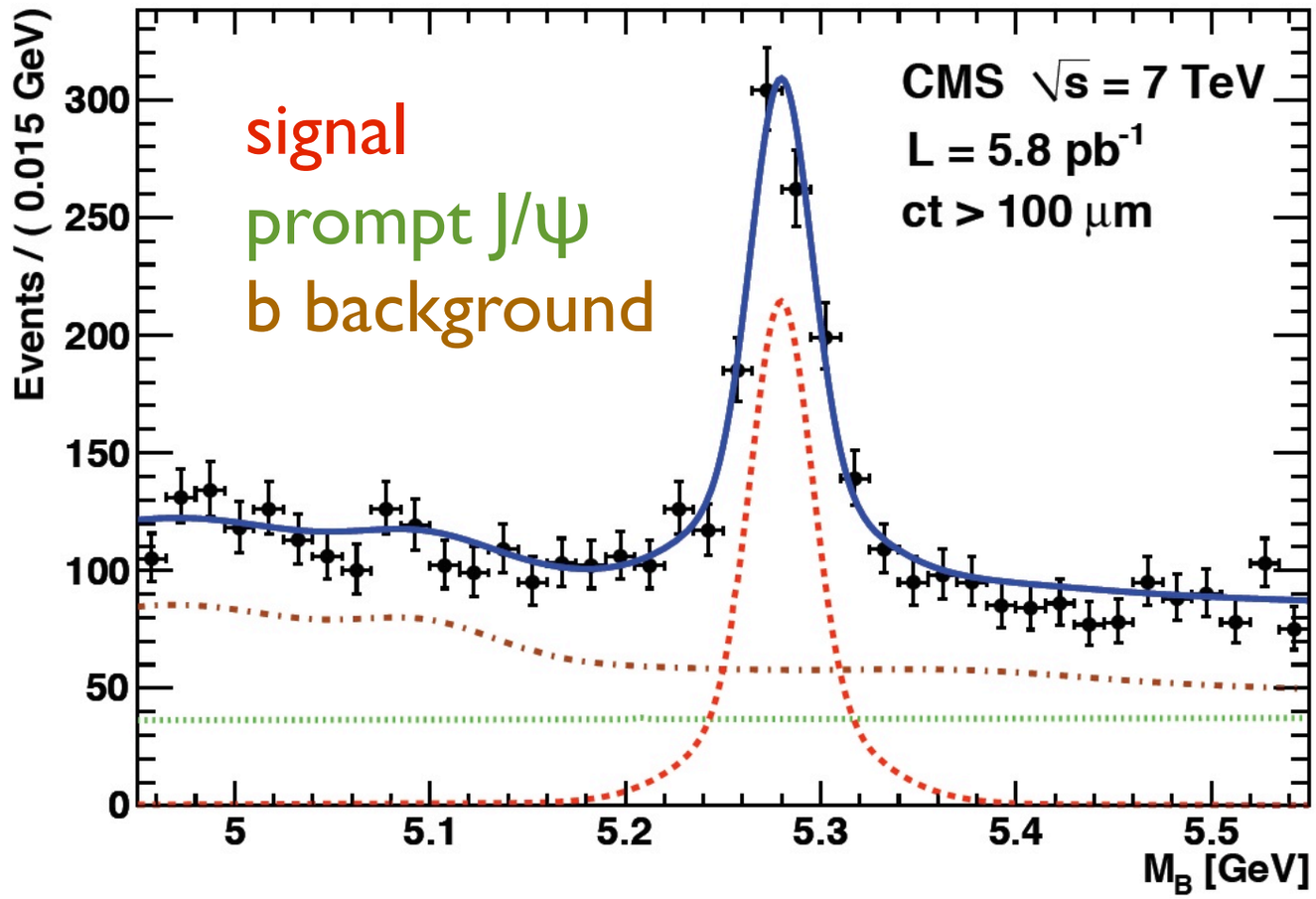
event reconstruction

- di-muon trigger (efficiency from tag + probe method)
- two opposite-sign muons within J/ψ mass window 150 MeV
- muon acceptance cuts:

$\|\eta\| < 1.3$	$p_T > 3.3$ GeV
$1.3 < \|\eta\| < 2.2$	$p > 2.9$ GeV
$2.2 < \|\eta\| < 2.4$	$p_T > 0.8$ GeV

- $p_t(K^+) > 0.9$ GeV
- kinematic constrained vertex fit with $\mu^+\mu^-$ and K^+
  (the J/ψ mass is constrained to the PDG value)
- three track vertex fit probability > 0.1%

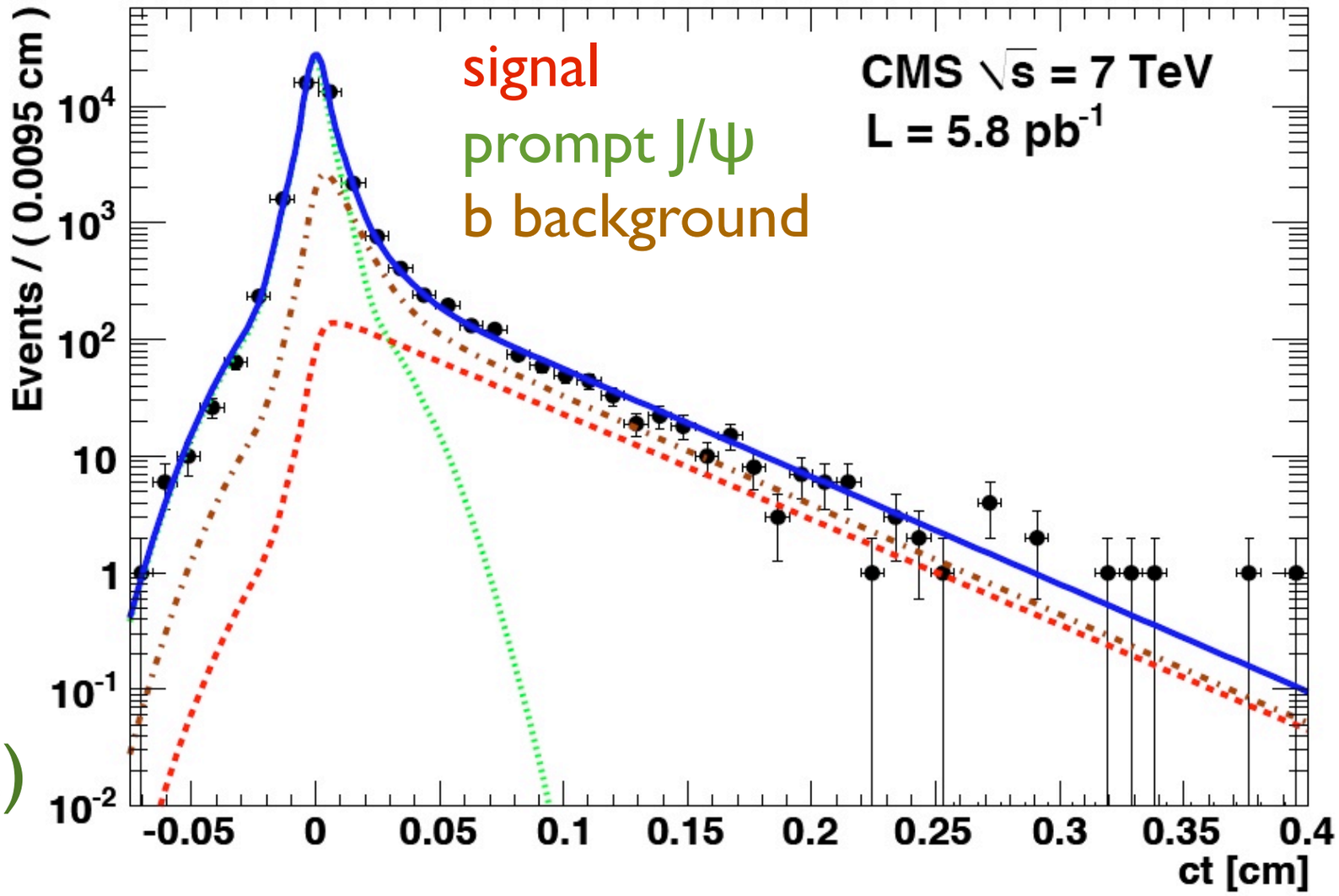
$\mu^+\mu^- K^+$ invariant mass



fit procedure

2D unbinned maximum likelihood fit to inv. mass ($\mu^+\mu^-$ K^+) and $c\tau$

- ➡extract number of signal events in p_t and $|\eta|$ bins
- ➡obtain background PDF parameters from sidebands
- ➡validated with toy MC
- ➡lifetime measured:
  $c\tau$ = 481± 22μm (stat.)
  $c\tau$(PDG)= 491± 9μm
- ➡fitted signal events: 912 ± 47



PDF uncertainties and fit bias:
2% - 5% systematic error

results

diff. cross-sections:

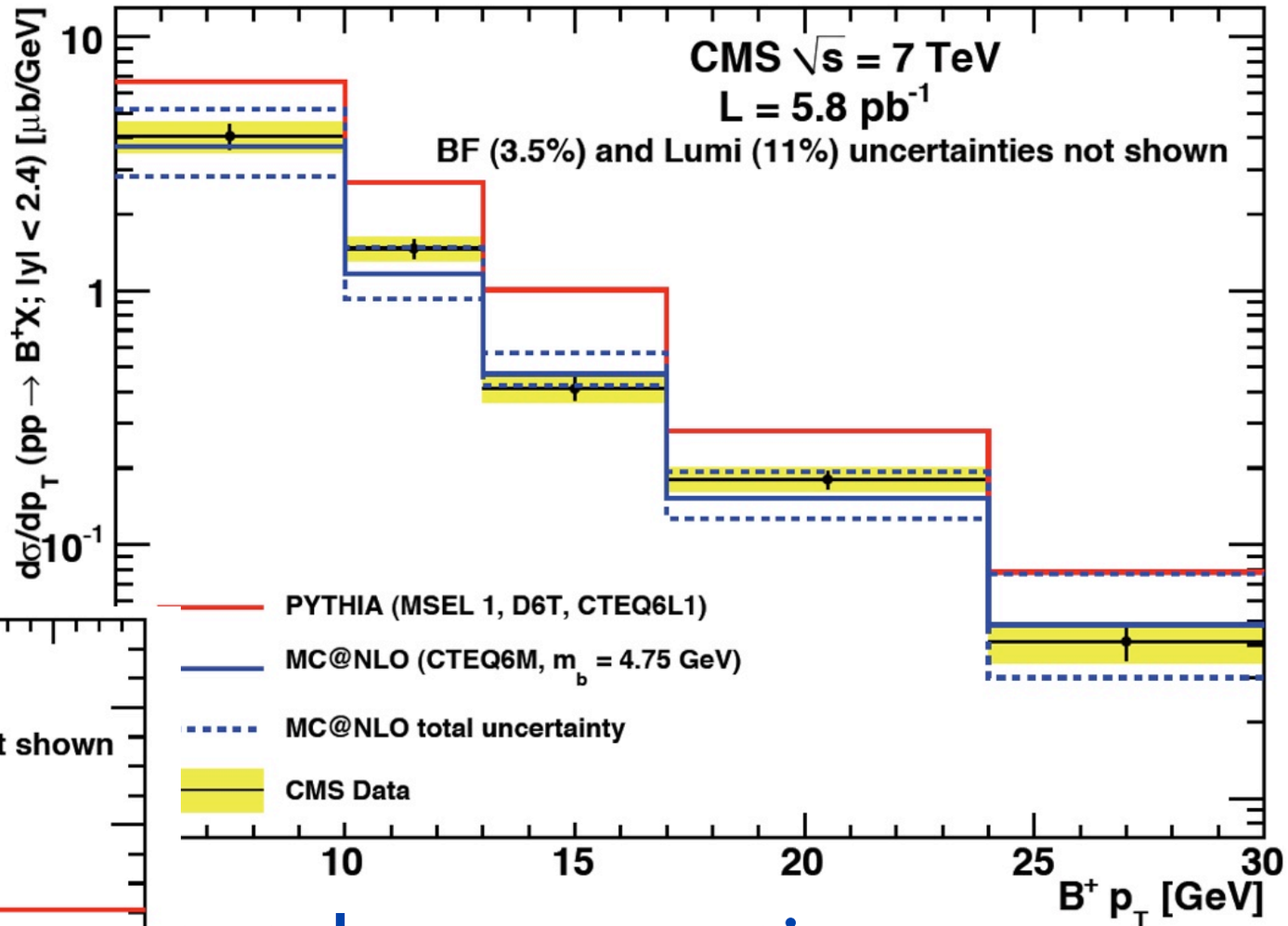
fitted yields

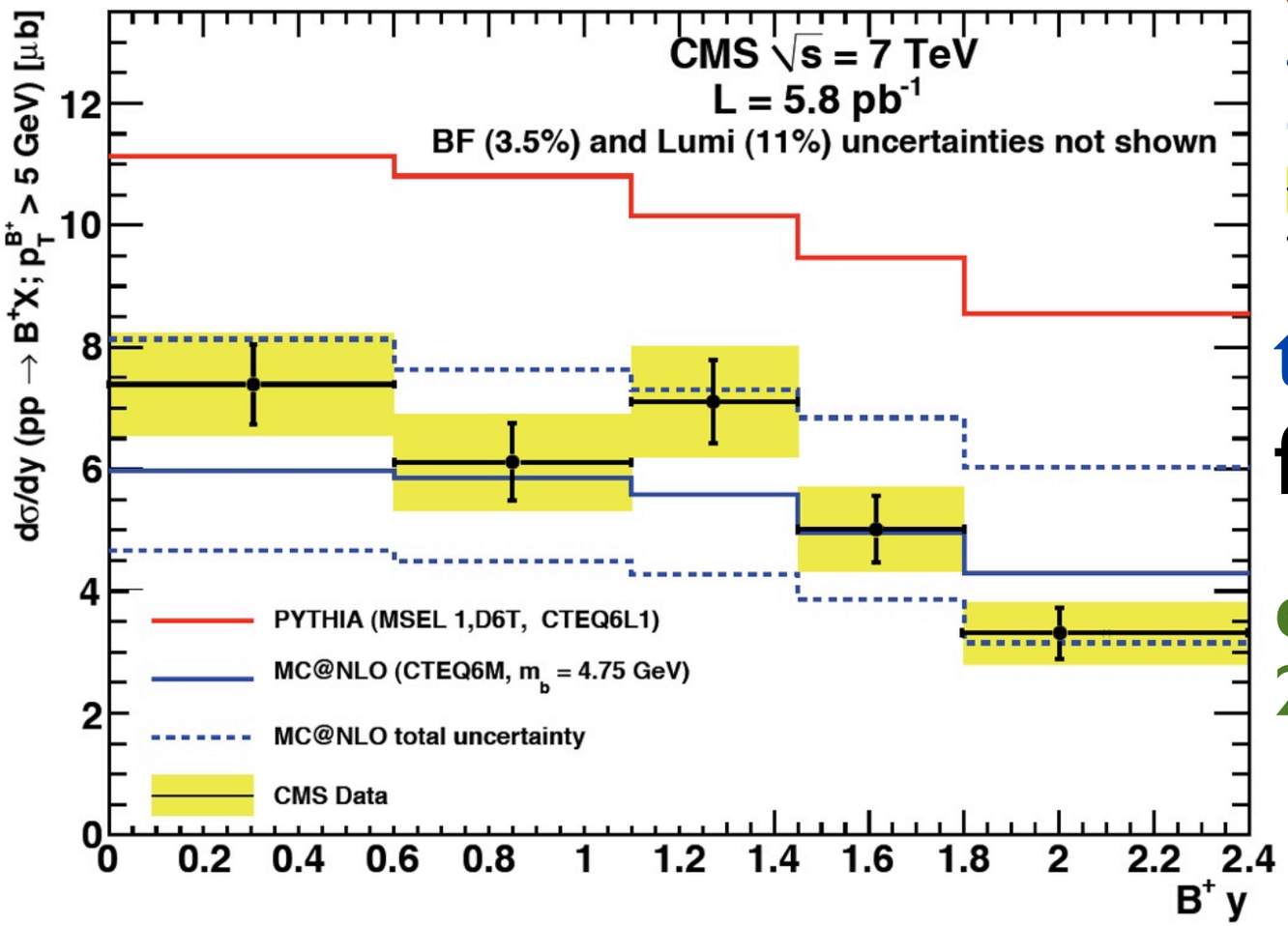
$$\frac{d\sigma(\mathrm{pp} \to \mathrm{B}^+X)}{dp_\mathrm{T}^\mathrm{B}} = \frac{n_\mathrm{sig}(p_\mathrm{T}^\mathrm{B})}{2\,\epsilon(p_\mathrm{T}^\mathrm{B})\,\mathcal{B}\,\mathcal{L}\,\Delta p_\mathrm{T}^\mathrm{B}{}'}$$

$$\frac{d\sigma(\mathrm{pp} \to \mathrm{B}^+X)}{dy^\mathrm{B}} = \frac{n_\mathrm{sig}(|y^\mathrm{B}|)}{2\,\epsilon(|y^\mathrm{B}|)\,\mathcal{B}\,\mathcal{L}\,\Delta y^\mathrm{B}{}'}$$

trigger+reco eff.

$\mathcal{B}$(B⁺ → J/ψK⁺) *B(J/ψ → μ⁺μ⁻)





total cross-section

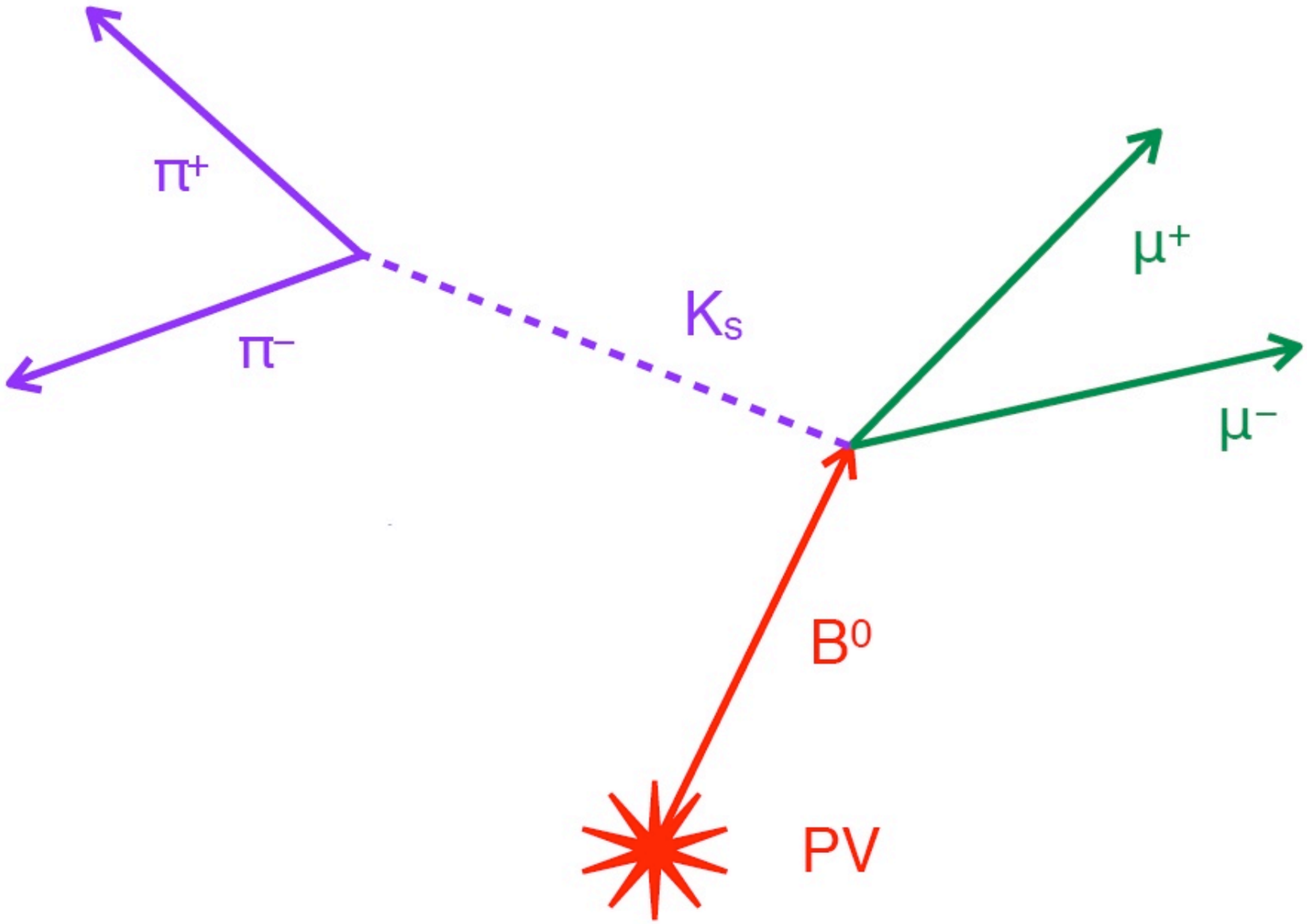
for p_t>5GeV and $|y^B|$<2.4:

σ(pp→B⁺+X)=

28.3±2.4(stat)±2.0(syst.)±1.1(lumi.) μb

$$\mathrm{MC@NLO} : 25.5^{+9.2}_{-5.7}\mu\mathrm{b}$$

exclusive decay $B^0 \rightarrow J/\psi(\mu^+\mu^-)\ K_s(\pi^+\pi^-)$



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$\|\eta\| < 1.3$	$p_T \geq 3.3$ GeV
$1.3 < \|\eta\| < 2.2$	$p > 2.9$ GeV
$2.2 < \|\eta\| < 2.4$	$p_T > 0.8$ GeV

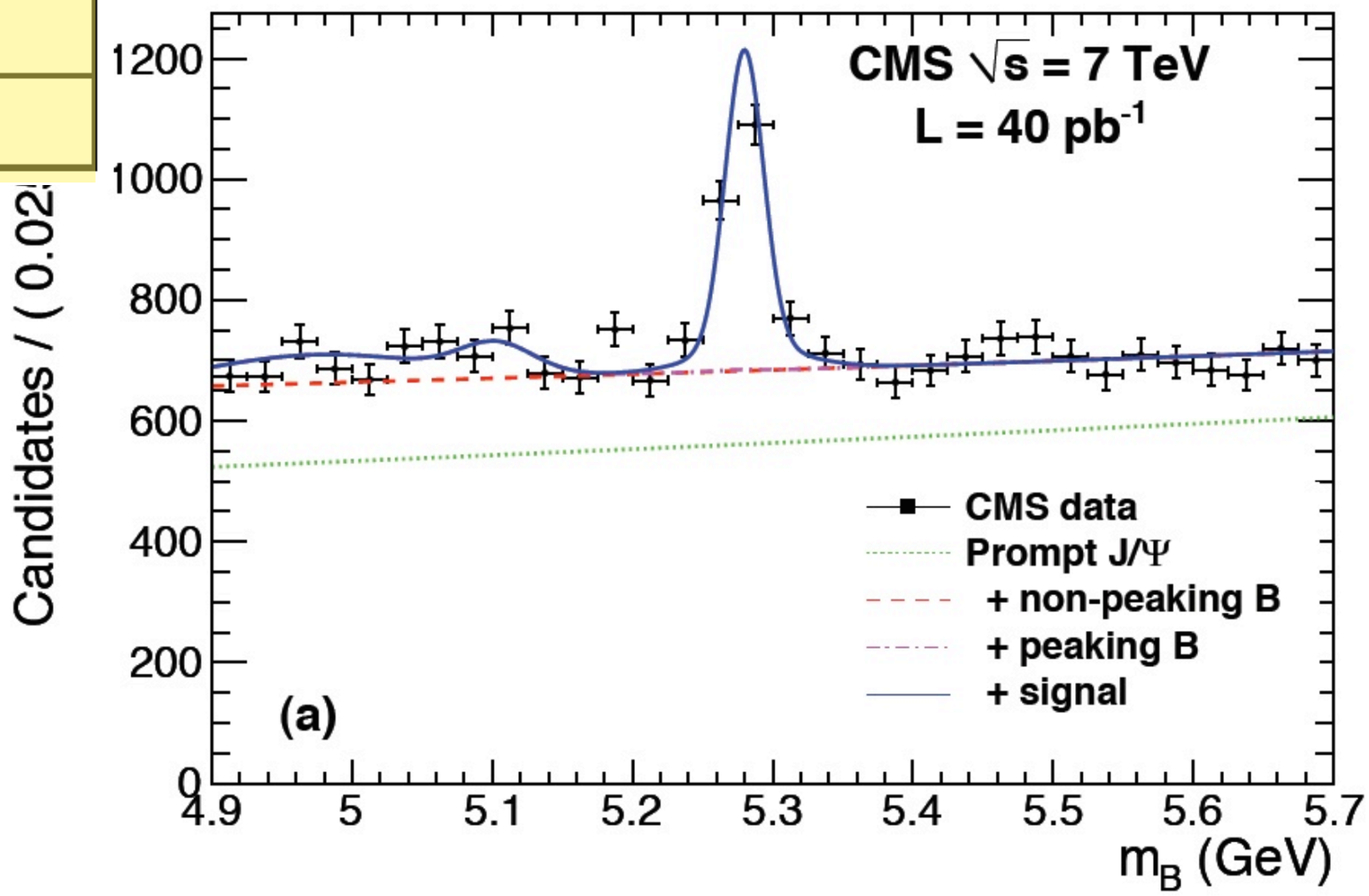
Same as in B^+ analysis

- additional difficulty:
  K_s reconstruction: find vtx.+ resonance using all displaced opposite-sign tracks

- kinematic fit with
  $\mu^+\mu^-$ and K_s candidates
  (the J/ψ mass **and K_s mass** are constrained to the PDG values)

- fit probability > 1%

$\mu^+\mu^-$ K_s invariant mass

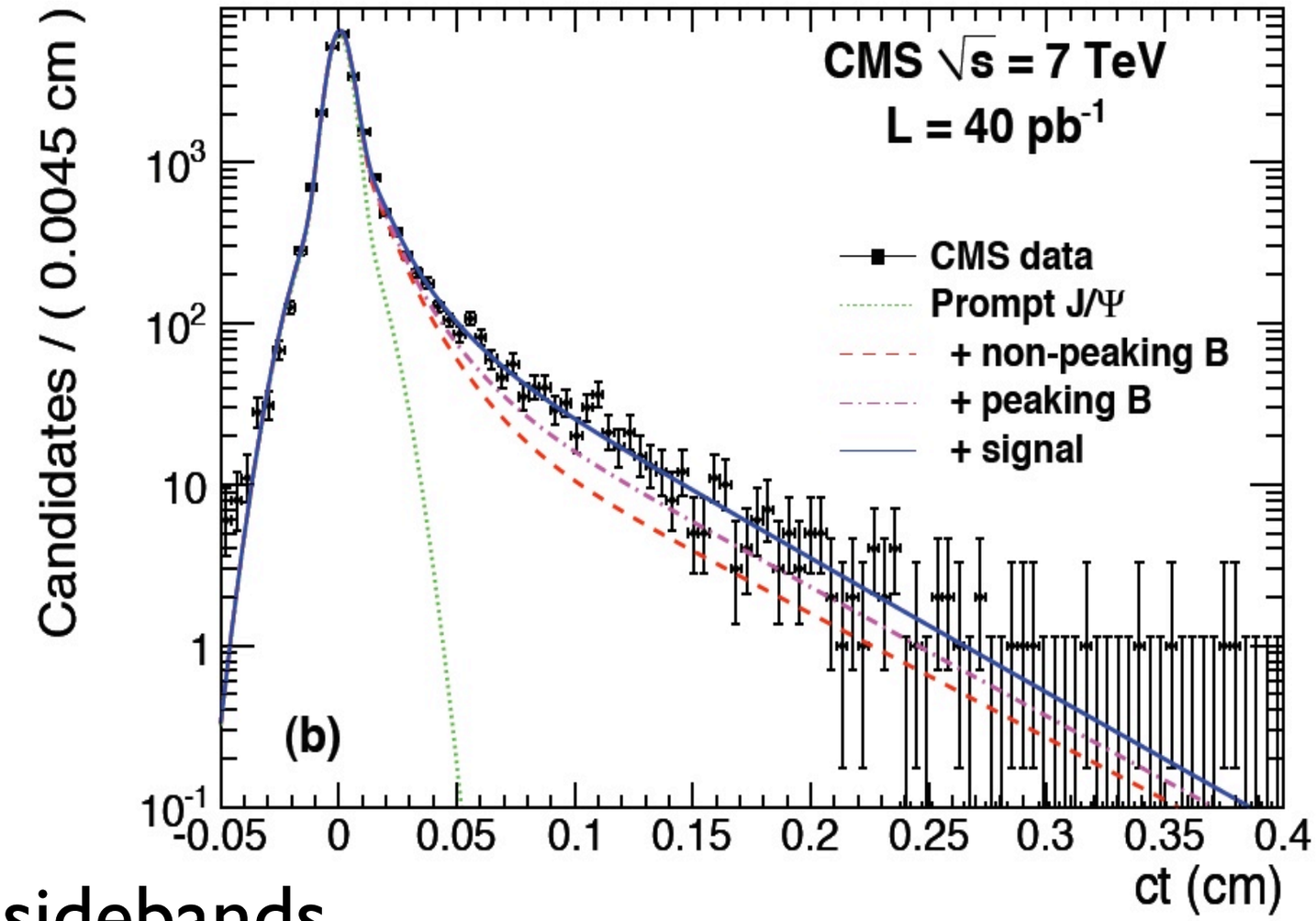


fit procedure

2D unbinned maximum likelihood fit to inv. mass ($\mu^+\mu^-$ K_s) and $c\tau$

➡extract number of signal events in p_t and $|\eta|$ bins

➡PDF functions:
mass: two gaussians for signal
polynomial for non-peaking background
lifetime: exponential decay convolved with resolution function (two gaussians) for signal
double exponential for B background,
pure resolution for prompt backgr.



➡background PDF parameters obtained from sidebands (except for peaking background)

➡fitted signal events: 809 ± 39

➡lifetime measured:
$c\tau$ = 479± 22μm (stat.)
$c\tau$(PDG)= 453 ±3μm

results

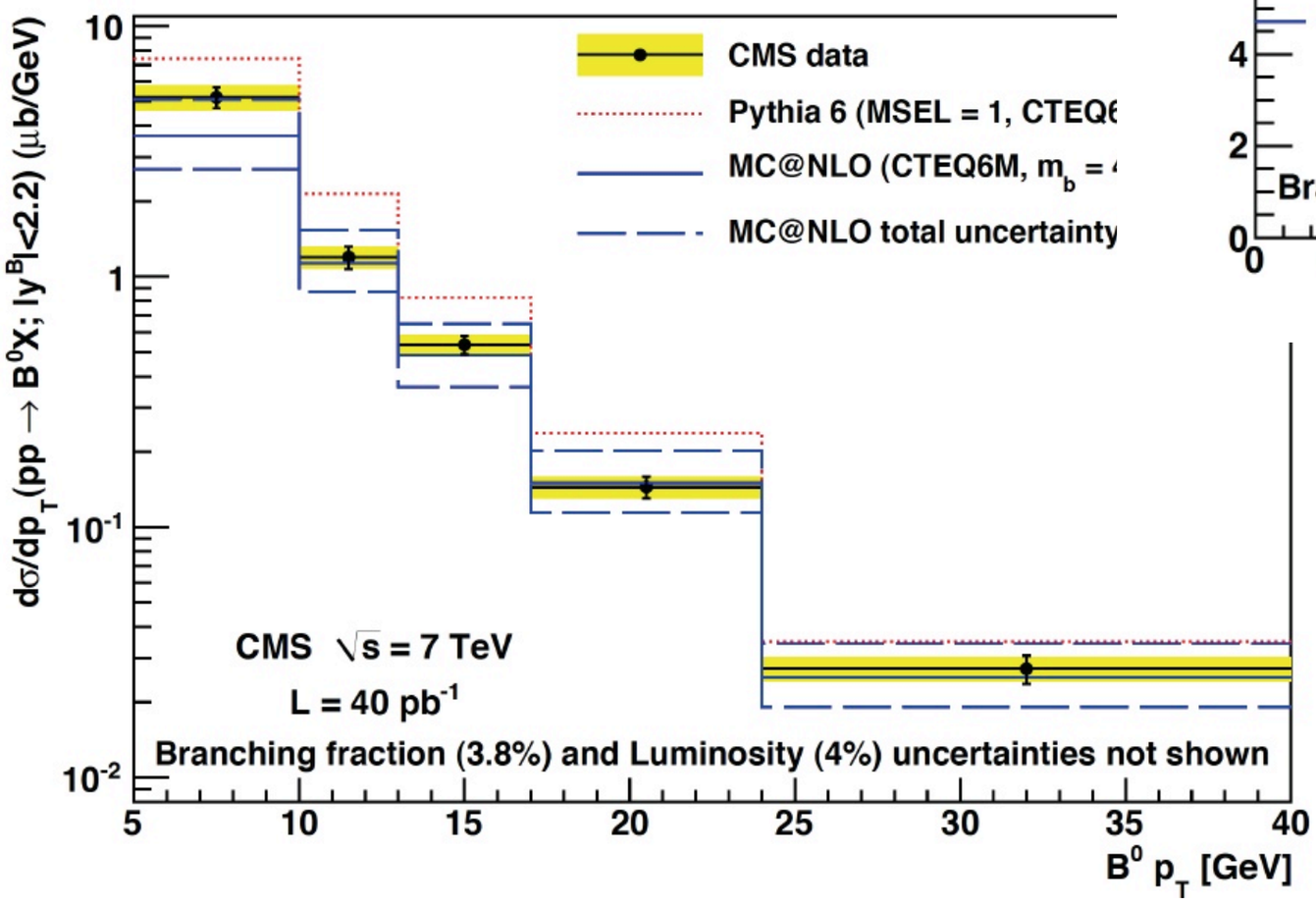
diff. cross-section:

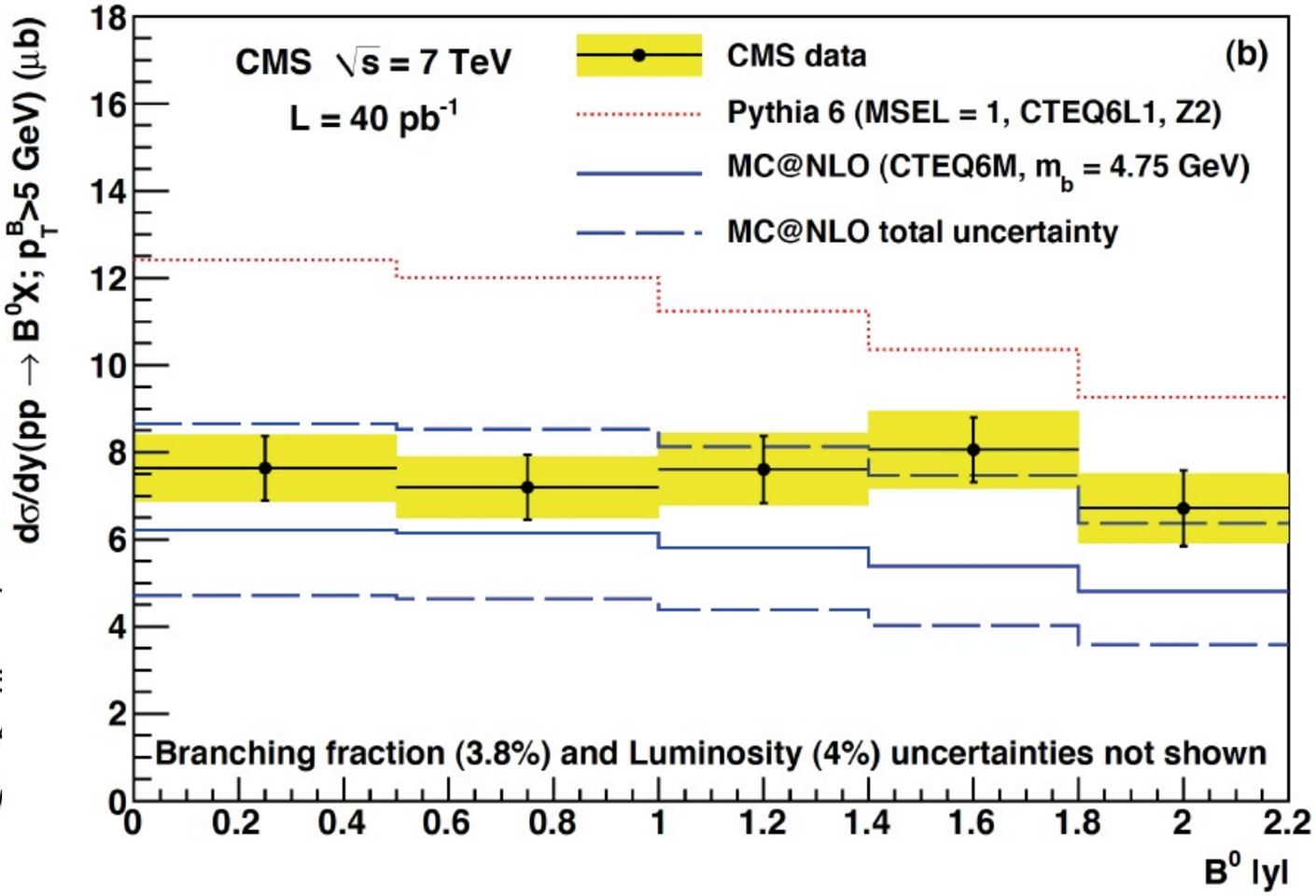
fitted yields

$$\frac{d\sigma(\mathrm{pp} \to \mathrm{B}^0 \mathrm{X})}{dp_{\mathrm{T}}^{\mathrm{B}}} = \frac{n_{\mathrm{sig}}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot L \cdot \Delta p_{\mathrm{T}}^{\mathrm{B}}}$$

trigger+reco eff.

$B(B^0 \to J/\psi K_s)$ $*B(J/\psi \to \mu^+\mu^-)$





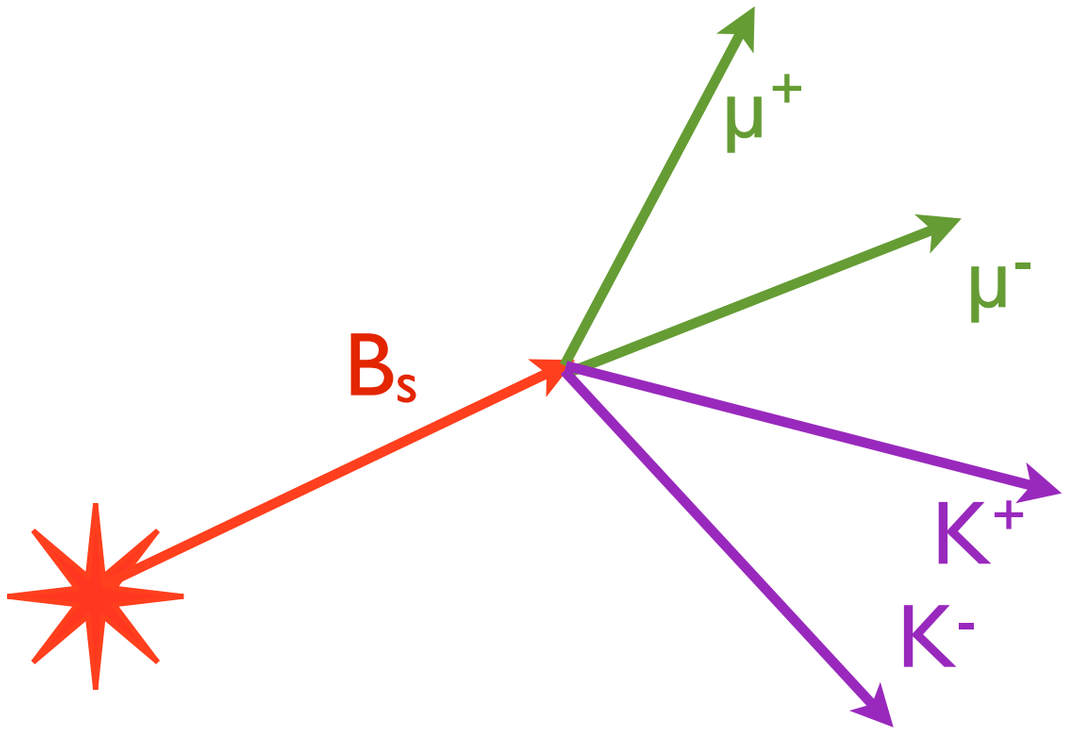
total cross-section for p_t>5GeV and $|y^B|$<2.2:

$\sigma(pp \to B^0+X)$=

33.2±2.5(stat)±3.1(syst.)±1.3(lumi.) μb

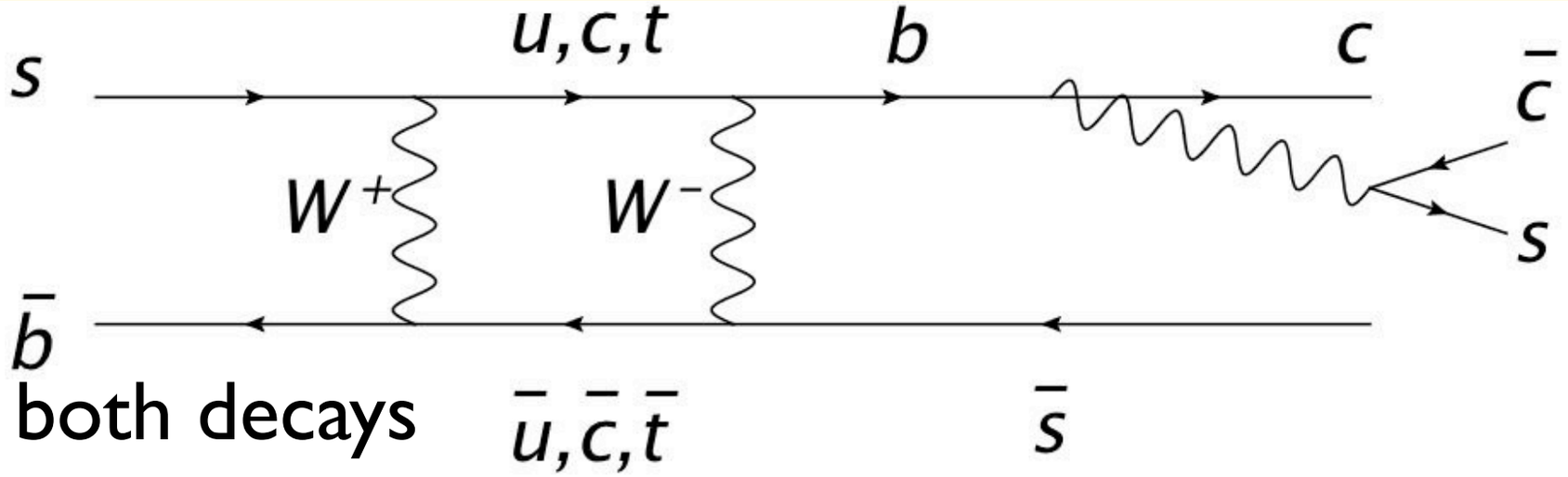
$$\mathrm{MC@NLO} = 25.5^{+9.6}_{-6.2}\mu\mathrm{b}$$

exclusive decay $B_s \rightarrow J/\psi(\mu^+\mu^-)\ \ \Phi(K^+\ K^-)$

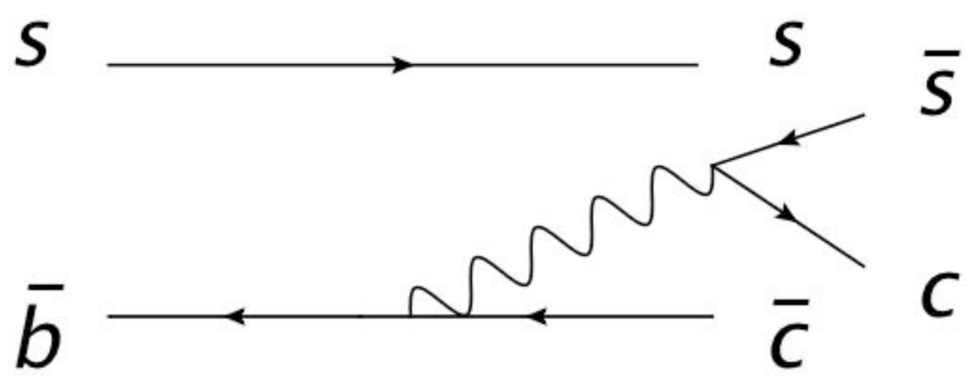


$B_s \rightarrow J/\psi\, \Phi$

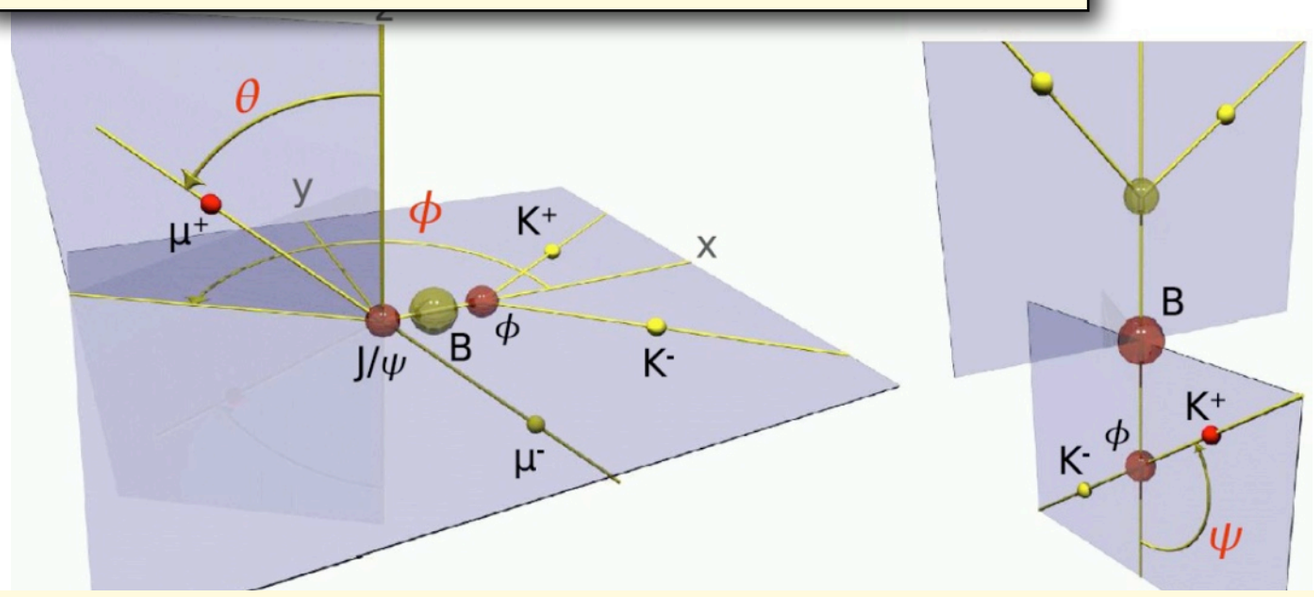
oscillation between particle and anti-particle states:



interference between both decays involves CP violating weak phase Φ_s which is predicted to be small in the SM



new physics (e.g. SUSY) can significantly enhance Φ_s !



roadmap:

~100pb^{-1}: CP even (odd) components (angular analysis)

~1fb^{-1}: CP violation: time dependent angular analysis with flavor tagging

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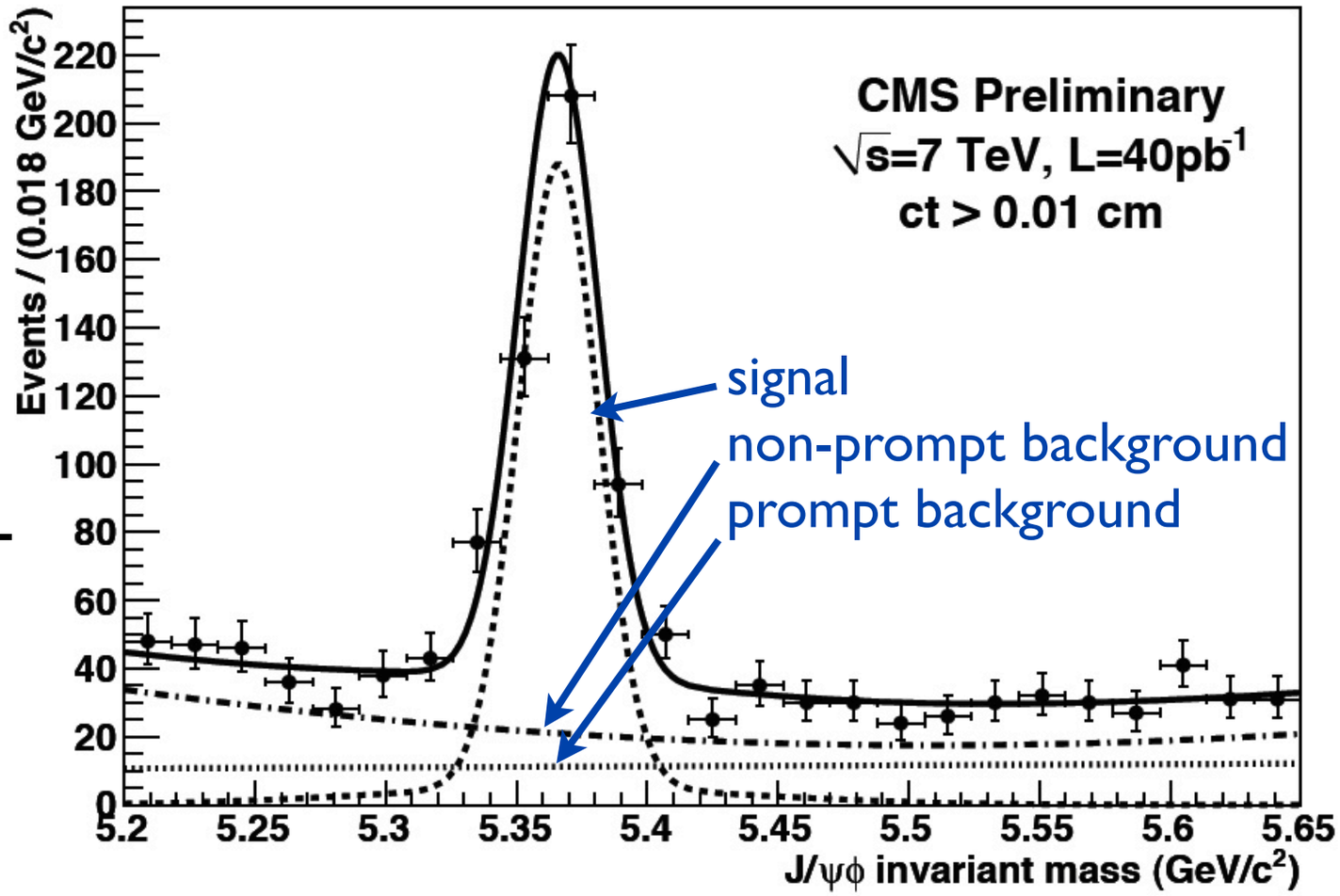
Same as in B^+ analysis

- $p_t(K^+, K^-) > 0.7$ GeV
- kinematic constrained vertex fit with $\mu^+\mu^-$ and $K^+ K^-$
  (the $\mu^+\mu^-$ mass is constrained to the PDG value)
- fit probability > 0.1%

$\mu^+\mu^- K^+ K^-$ invariant mass



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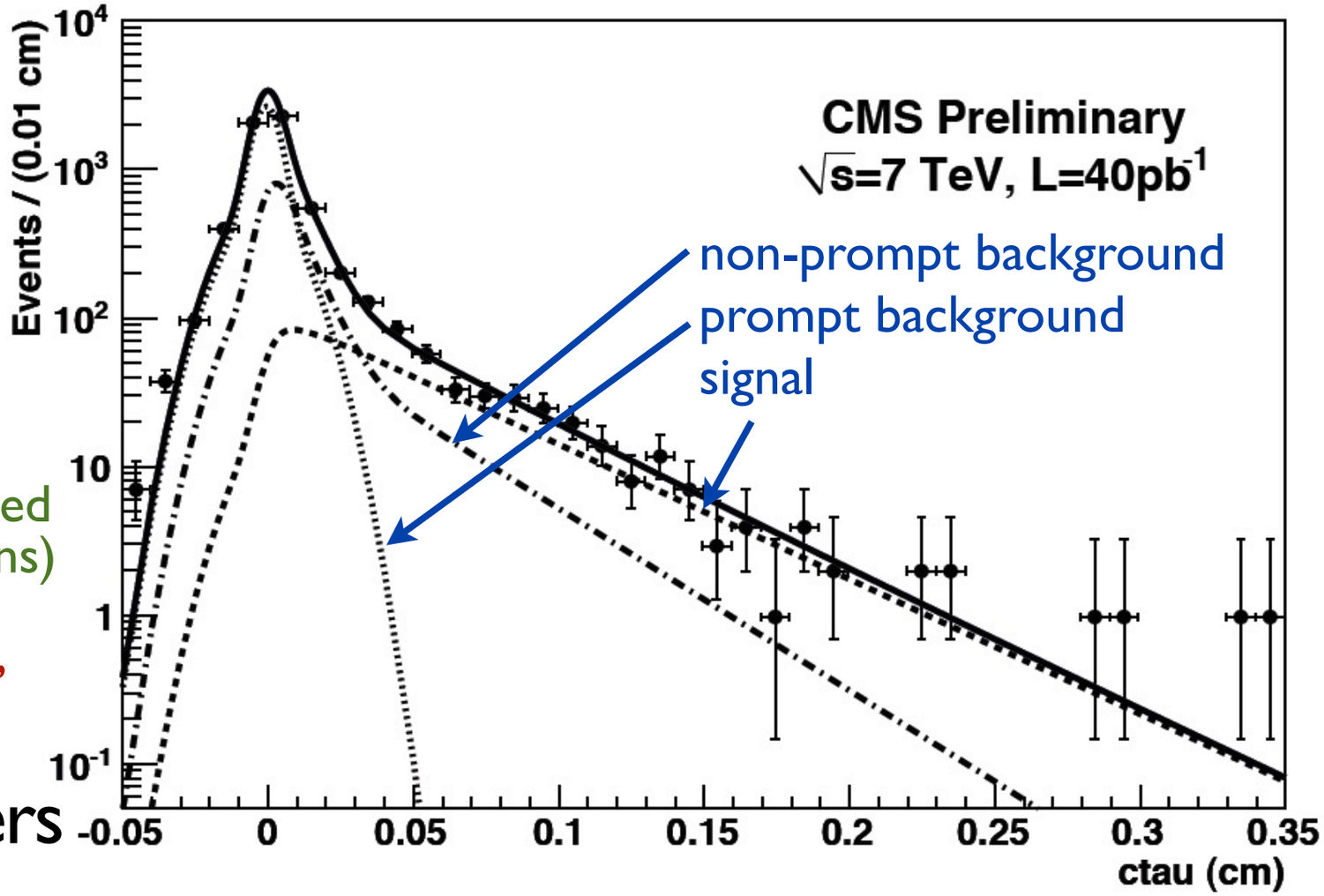
➡PDF functions:
mass: two gaussians for signal, polynomial for background
lifetime: exponential decay convolved with resolution function (two gaussians) for signal
double exponential for B background, pure resolution for prompt backgr.

➡background PDF parameters obtained from sidebands

➡fitted signal events: 549 ± 32



➡lifetime measured:
$c\tau$ = 478± 26μm (stat.)
$c\tau$(PDG)= 441μm

results

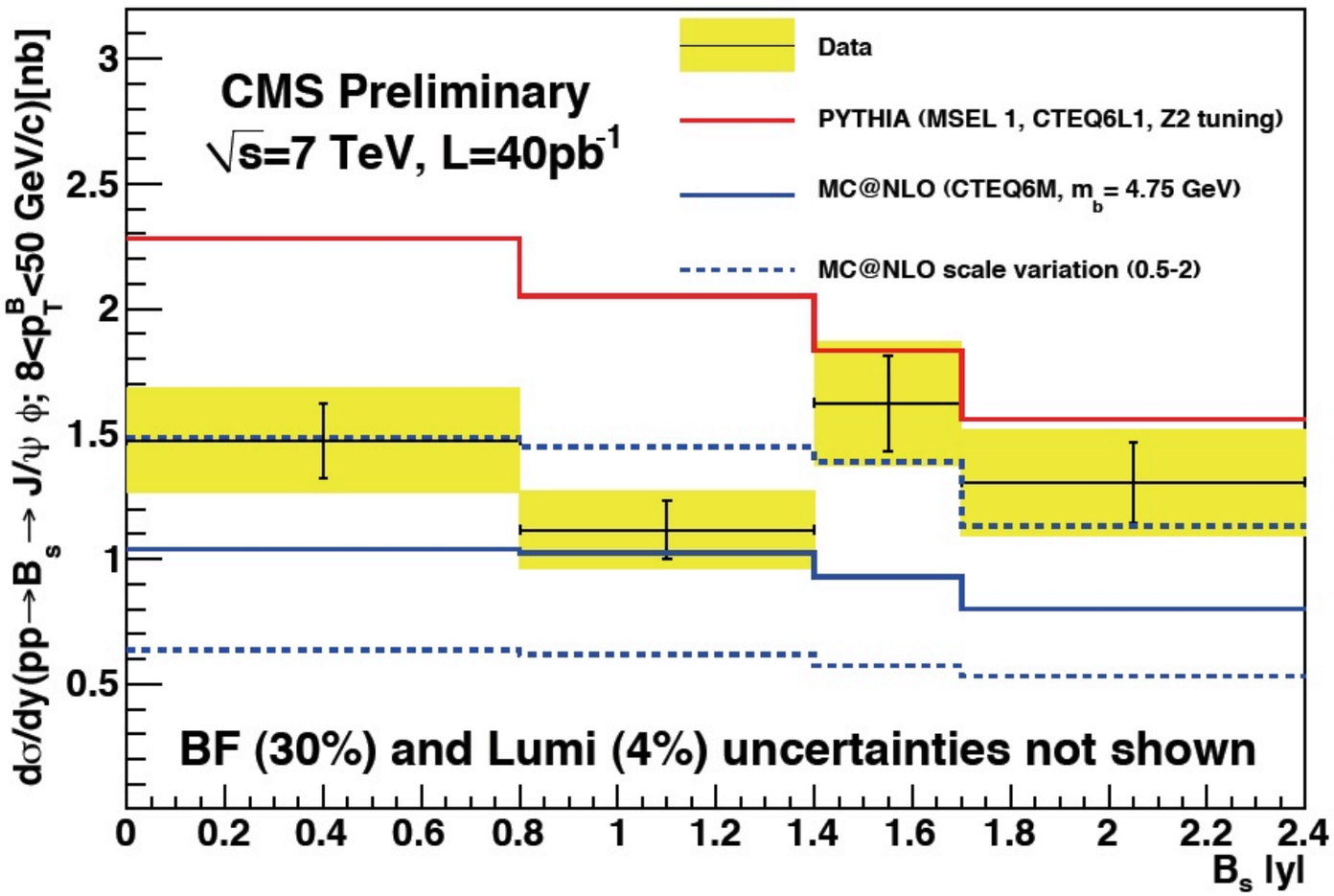
diff. cross-section:

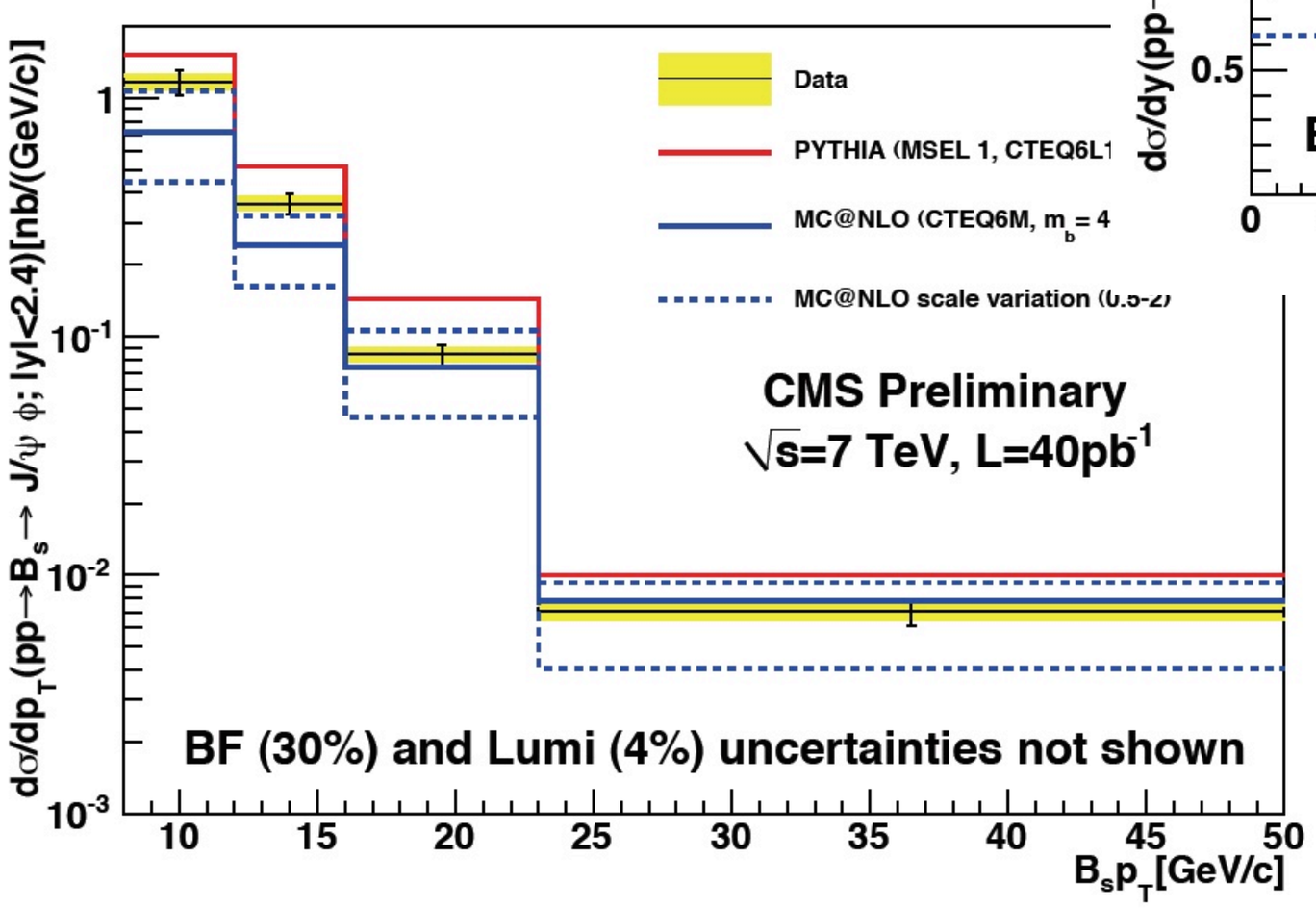
fitted yields

$$\frac{d\sigma(\mathrm{pp} \to B_s^0 \to J/\psi\phi)}{dx} = \frac{n_{\mathrm{sig}}}{2 \cdot \epsilon \cdot B \cdot L \cdot \Delta x}$$

trigger+reco eff.

B(Φ → K⁺ K⁻)
*B(J/ψ → μ⁺μ⁻)





total cross-section

for $8<p_t<50$ GeV and $|y^B|<2.4$:

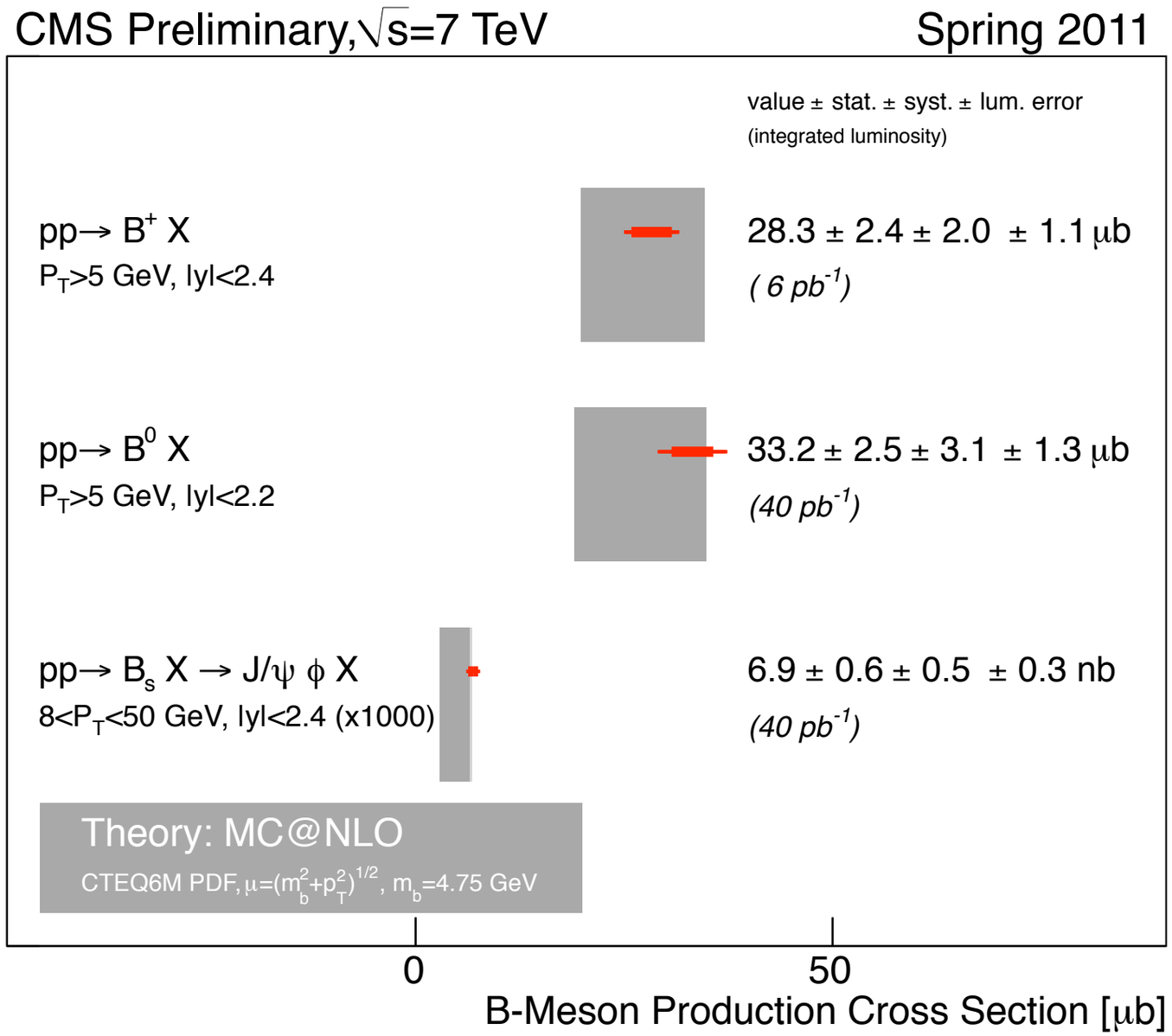
$\sigma(pp \to B_s \to J/\psi\,\Phi) =$

$6.9 \pm 0.6(\mathrm{stat}) \pm 0.5(\mathrm{syst.}) \pm 0.3(\mathrm{lumi.})$ nb

$$\mathrm{MC@NLO} = 4.57^{+1.93}_{-1.71} \pm 1.37\mathrm{nb}$$

conclusions

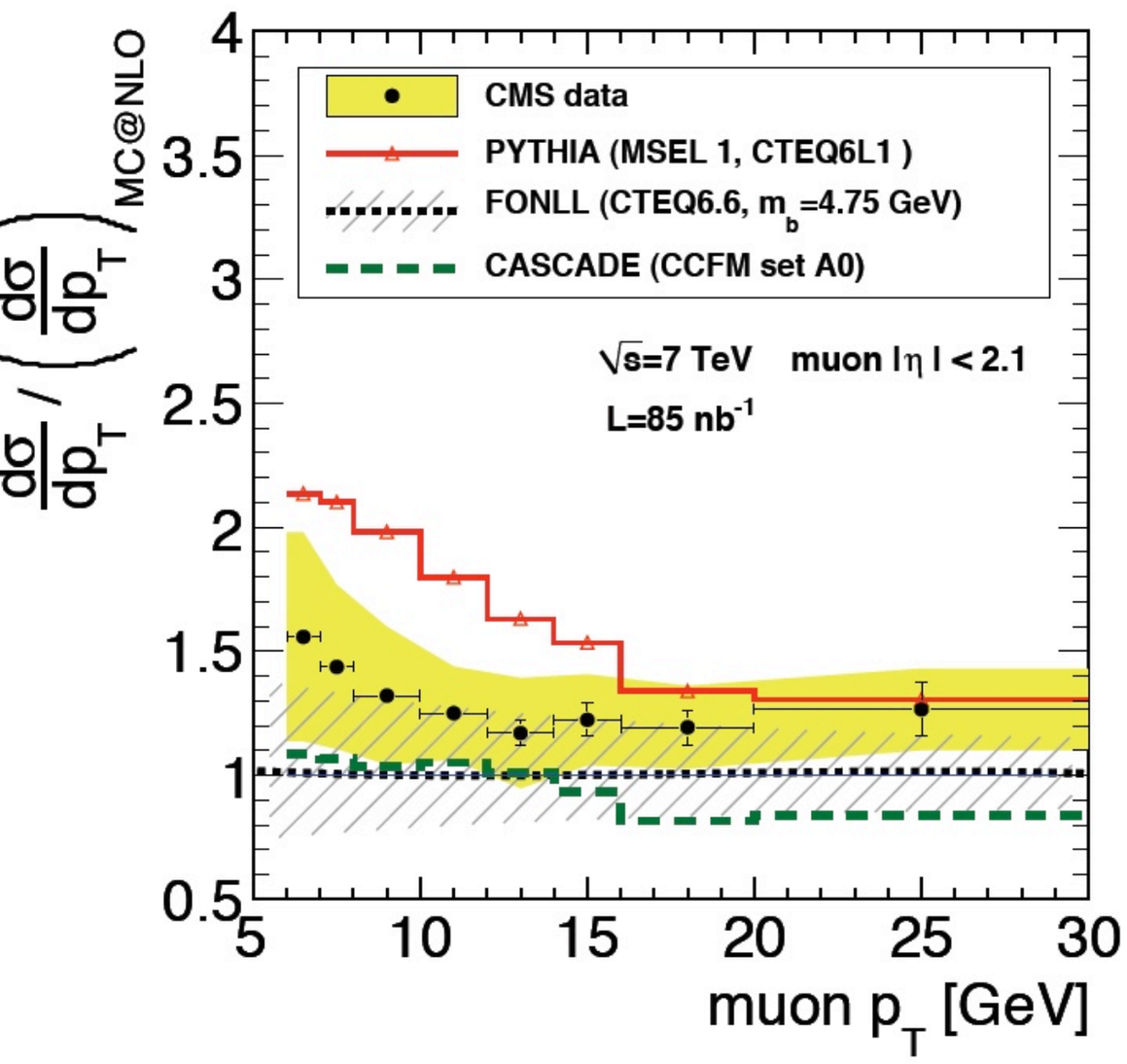
- CMS did precision measurements of b-production cross-sections right from the start
- demonstrates excellent detector performance and MC simulation
- in agreement with MC@NLO within uncertainties:
  - all results more precise than theory predictions: NLO errors dominated by scale uncertainties
  - MC@NLO tends to underestimate at low-p_t and overestimate at high-p_t and high-|y|
  - PYTHIA overestimates B x-section (both D6T and Z2 tunes)
- more results to come soon: Λ_B, B_c, ...

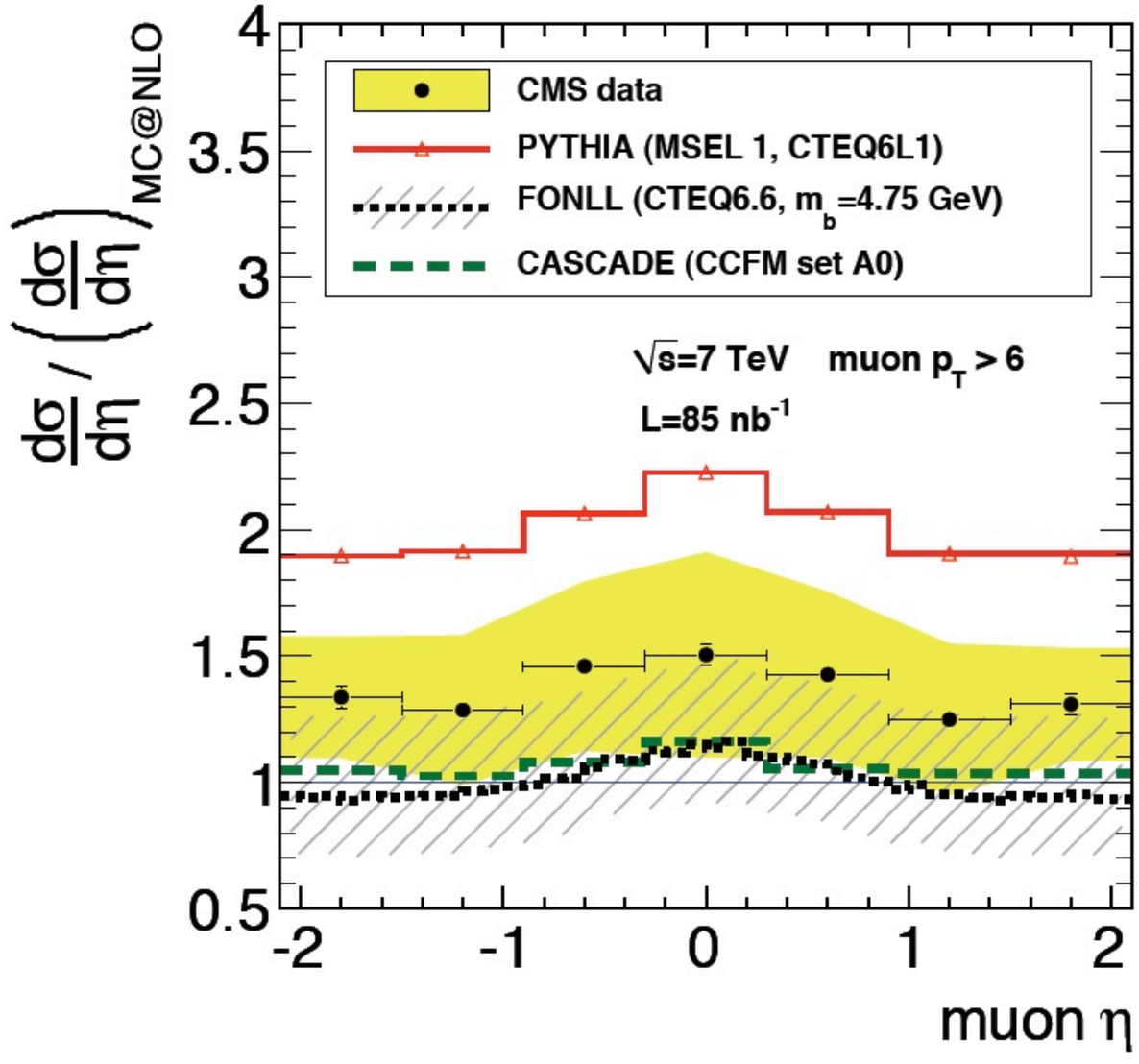


BACKUP SLIDES

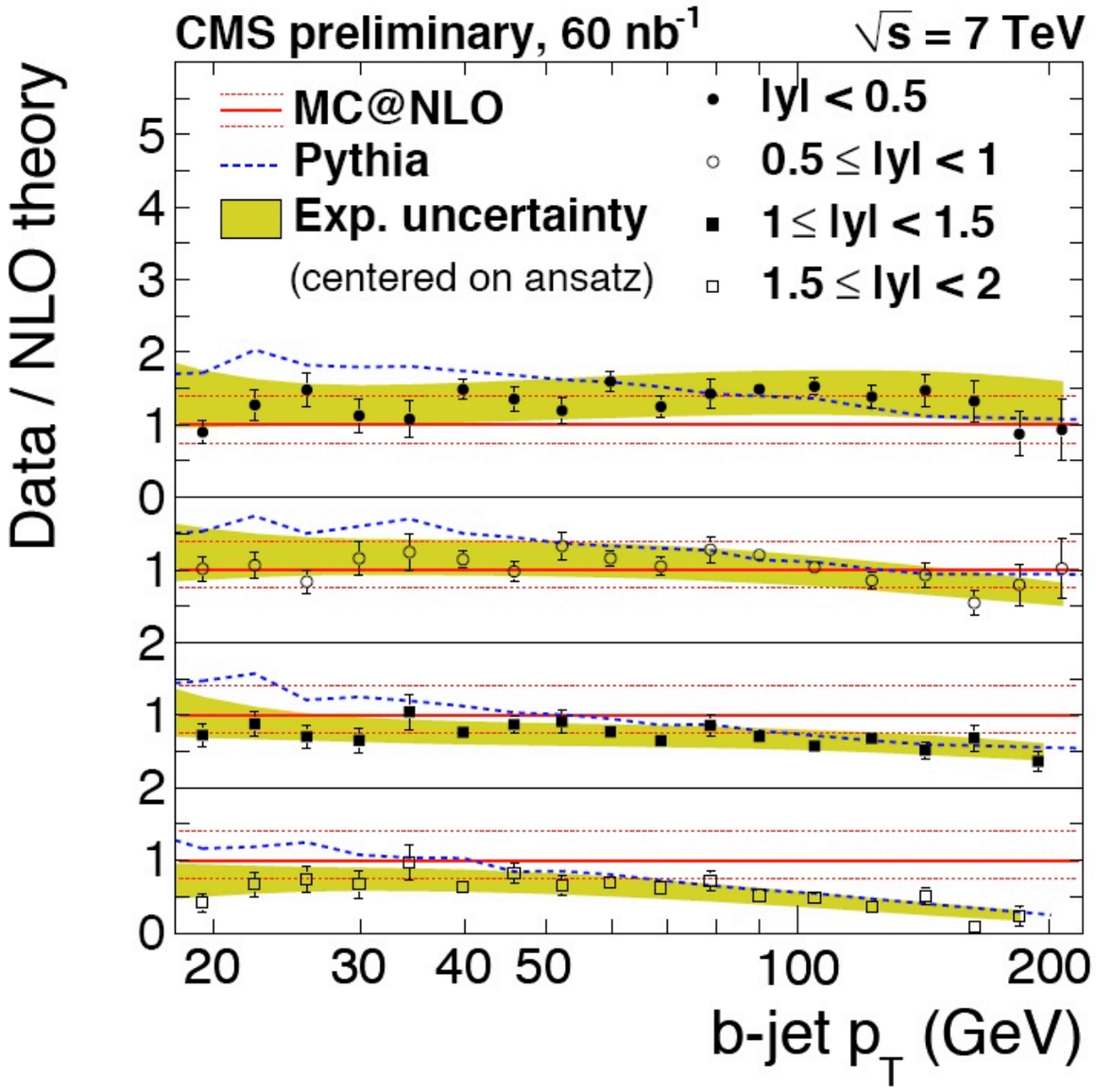
ratio to theory

Inclusive B production with muons: ratio to MC@NLO





ratio to theory



Inclusive B production using b-tagging with secondary vertices:

ratio to MC@NLO