Heavy Flavor Measurements **with ATLAS and CMS**

A. Salzburger, CERN

on behalf of the ATLAS and CMS Collaborations

QCD@LHC 2012, Michigan State University, 20-25th August 2012

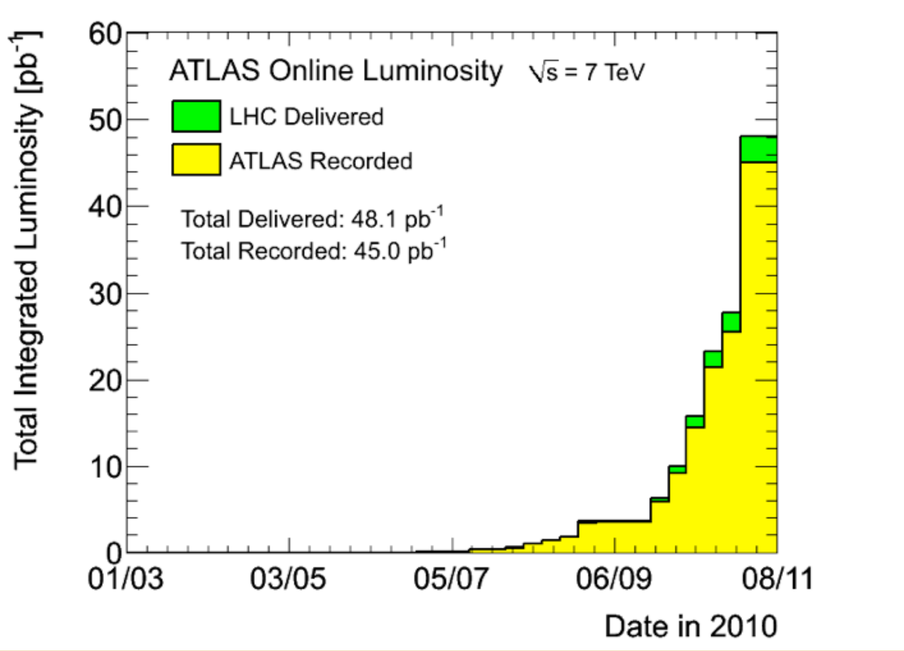
Introduction

- Heavy flavor measurements at LHC provide a stringent test of QCD
  - NLO contributions are large and can be checked
  - large theoretical uncertainties due to factorization and renormalization scale
  - test of extrapolations from previous measurements (SppS, Tevatron)
  - explore regimes unaccessible with B factories
- Rare decays accessible through high luminosity can open a door to physics beyond the SM
- importance for understanding of heavy flavor background to searches such as $\mathrm{H}^0 \rightarrow \mathrm{b}\bar{\mathrm{b}}$

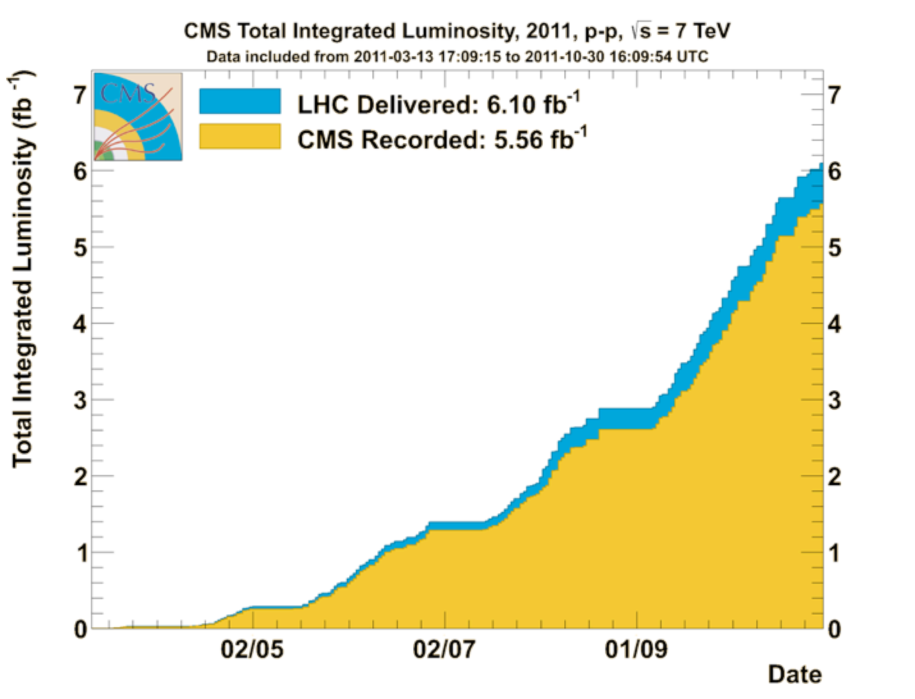
Overview

- Inclusive heavy flavor production
- Exclusive B-hadron production
- Mass and lifetime measurements
- Observations of new particle states
  - in both the quarkonium (ATLAS) and baryon (CMS) sector
- Rare decays & CP violation

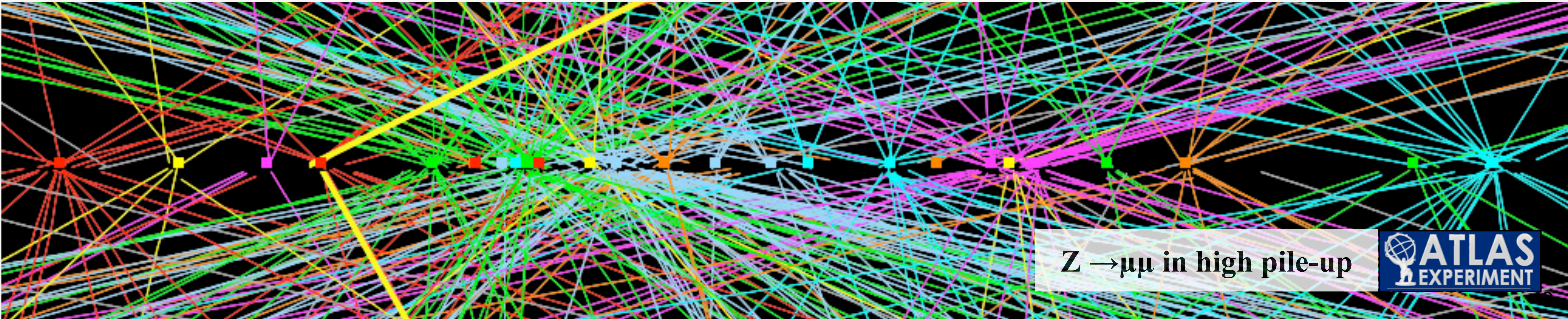
used data



2010
$\sqrt{s}$ = 7 Tev
negligible pile-up <μ>



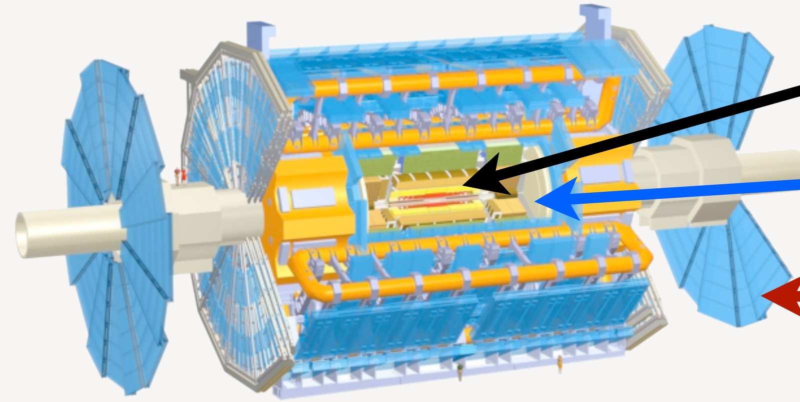
2011
$\sqrt{s}$ = 7 Tev
<μ> ~8-10

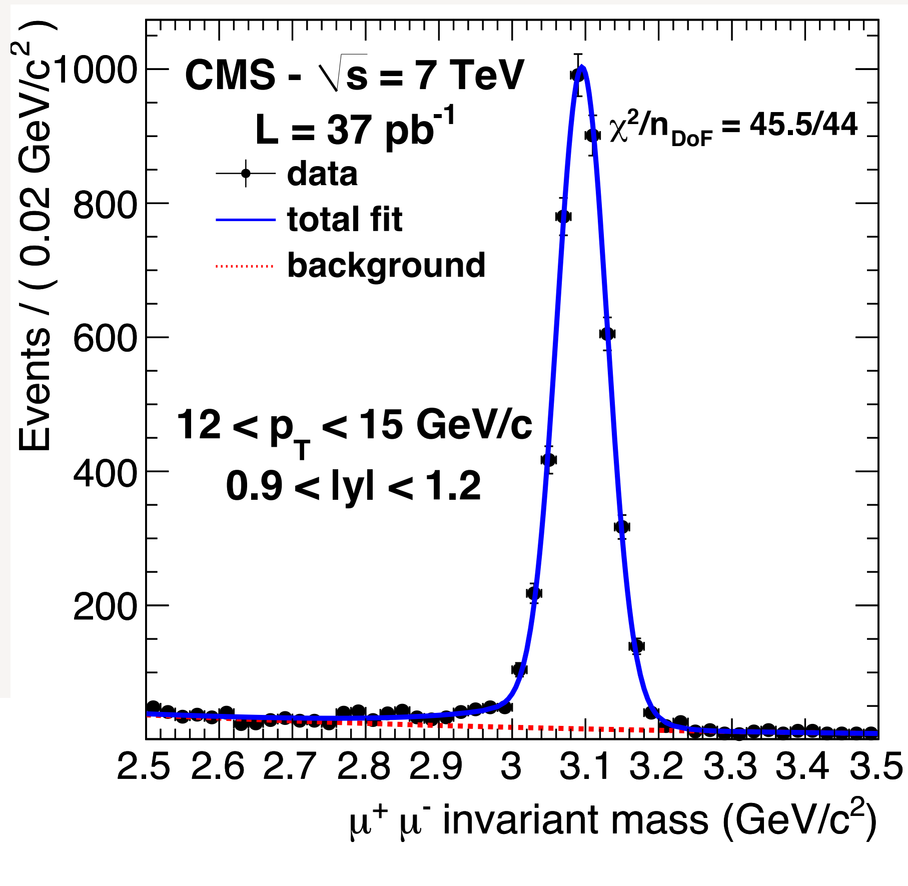


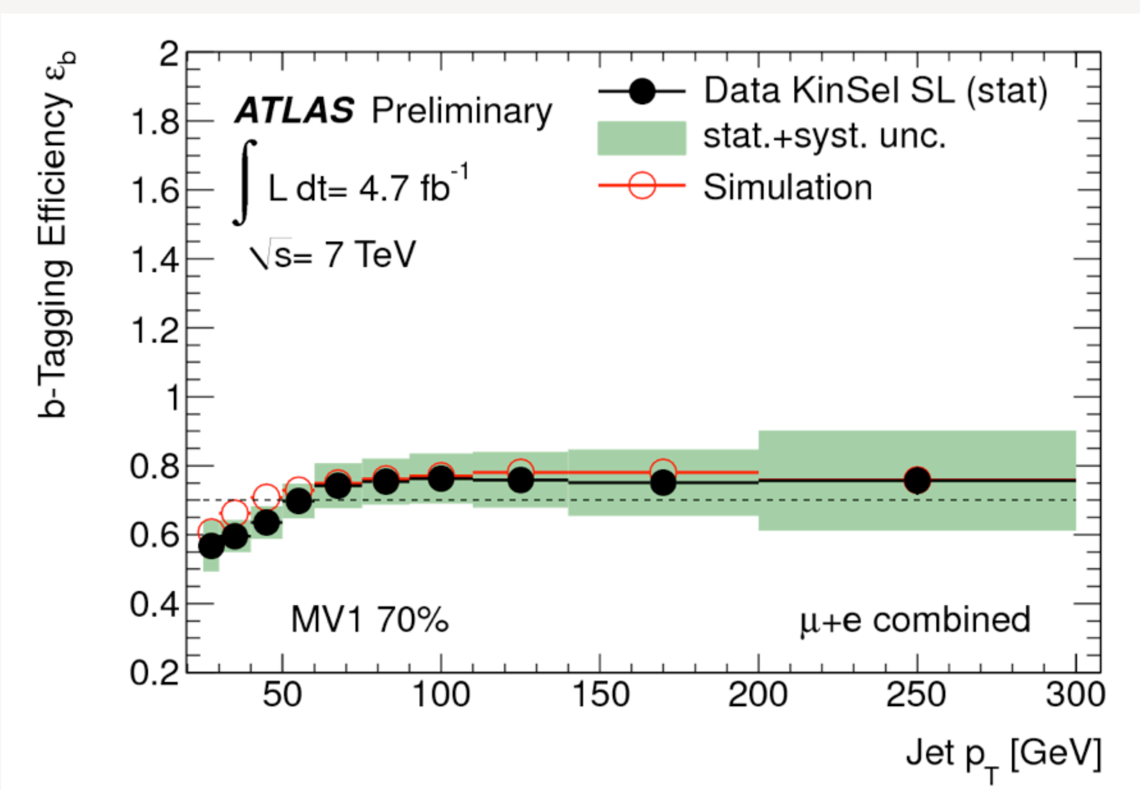
ATLAS and CMS

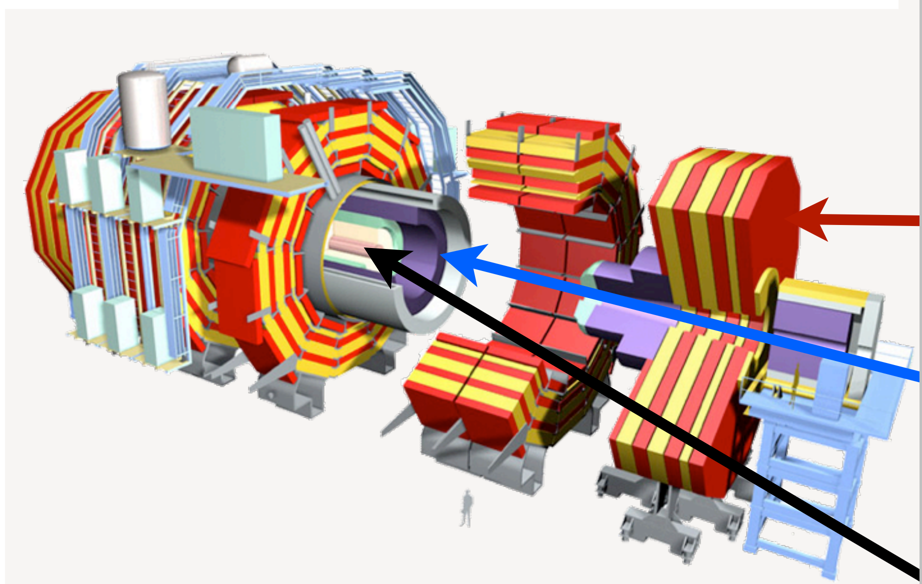
- general purpose detectors designed for high p_T studies
- rich heavy flavor physics programs

- access complementary phase space compared to LHCb ($|\eta| < 2.5$)
- excellent track & vertex reconstruction, mass resolution
- powerful b-tagging capabilities









Inner Detector:

ATLAS:
Silicon + straw detector in 2T solenoid

CMS :
pure Silicon detector in 3.8 T solenoid

Calorimeter:

ATLAS:
liquid argon EM/FC
iron tile HCAL

CMS :
lead-tungstate crystals EM,
steel-scintillator HCAL

Muon System:

ATLAS:
stand-alone tracker in toroidal magn. system (peak 5 T)

CMS :
muon chamber embedded in return choke of solenoid

Production cross sections, lifetime and mass measurements

Inclusive production

- 2010 data sample gave enough statistics to measure the inclusive and di-jet cross section of b-jets
- measured via semi-leptonic decay (μ) and b-tagged jets using secondary vertexing

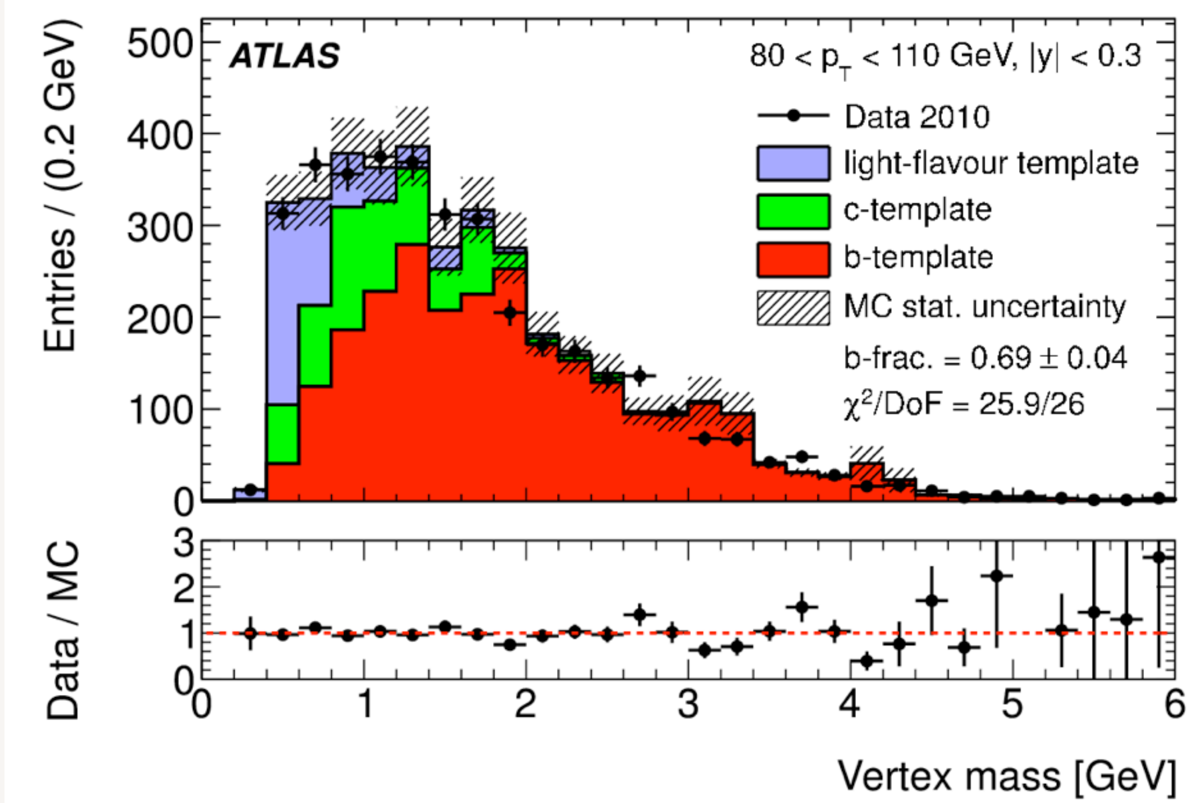
$$\frac{d\sigma}{dp_T^{b-jet}} = \frac{F_b N^{Jets}}{B \mathcal{L}_{int} \epsilon^{\mu J}} \frac{1}{\Delta p_T^{b-jet}}$$

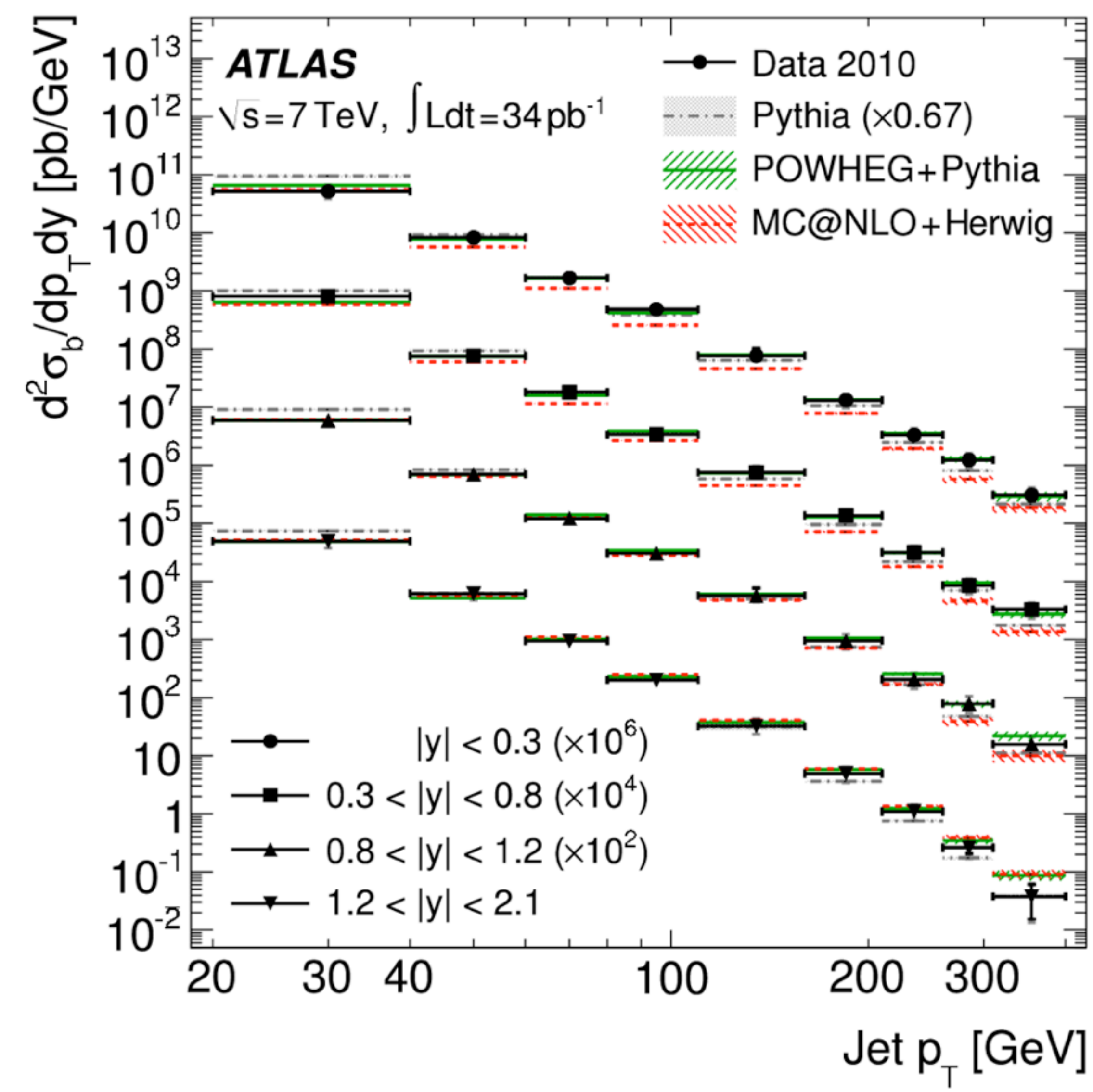
- bb di-jet cross section via template fits to the di-jet vertex mass
- already dominated by systematic error
  - jet energy scale, b-tagging efficiency

Good agreement with POWHEG+PYTHIA*, slight underestimation with MC@NLO+Herwig

(with MSTW 2008 NLO PDFs)

*only shape comparison when only using PYTHIA, LL PS not expected to get normalization correct





Eur.Phys.J.C 71 (2011) 1846, JHEP 04 (2012) 084

Inclusive production

- 2010 data sample gave enough statistics to measure the inclusive and di-jet cross section of b-jets
- measured via semi-leptonic decay (μ) and b-tagged jets using secondary vertexing

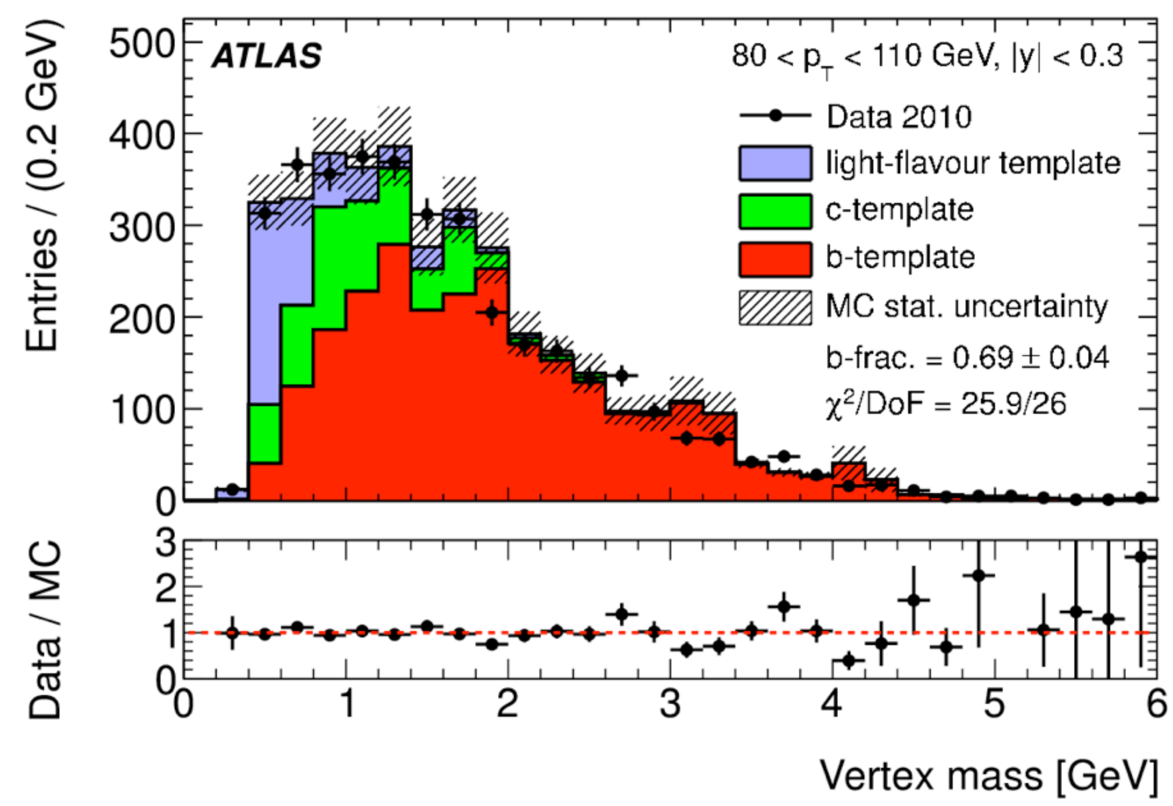
$$\frac{d\sigma}{dp_T^{b-jet}} = \frac{F_b N^{Jets}}{B\mathcal{L}_{int}\epsilon^{\mu J}} \frac{1}{\Delta p_T^{b-jet}}$$

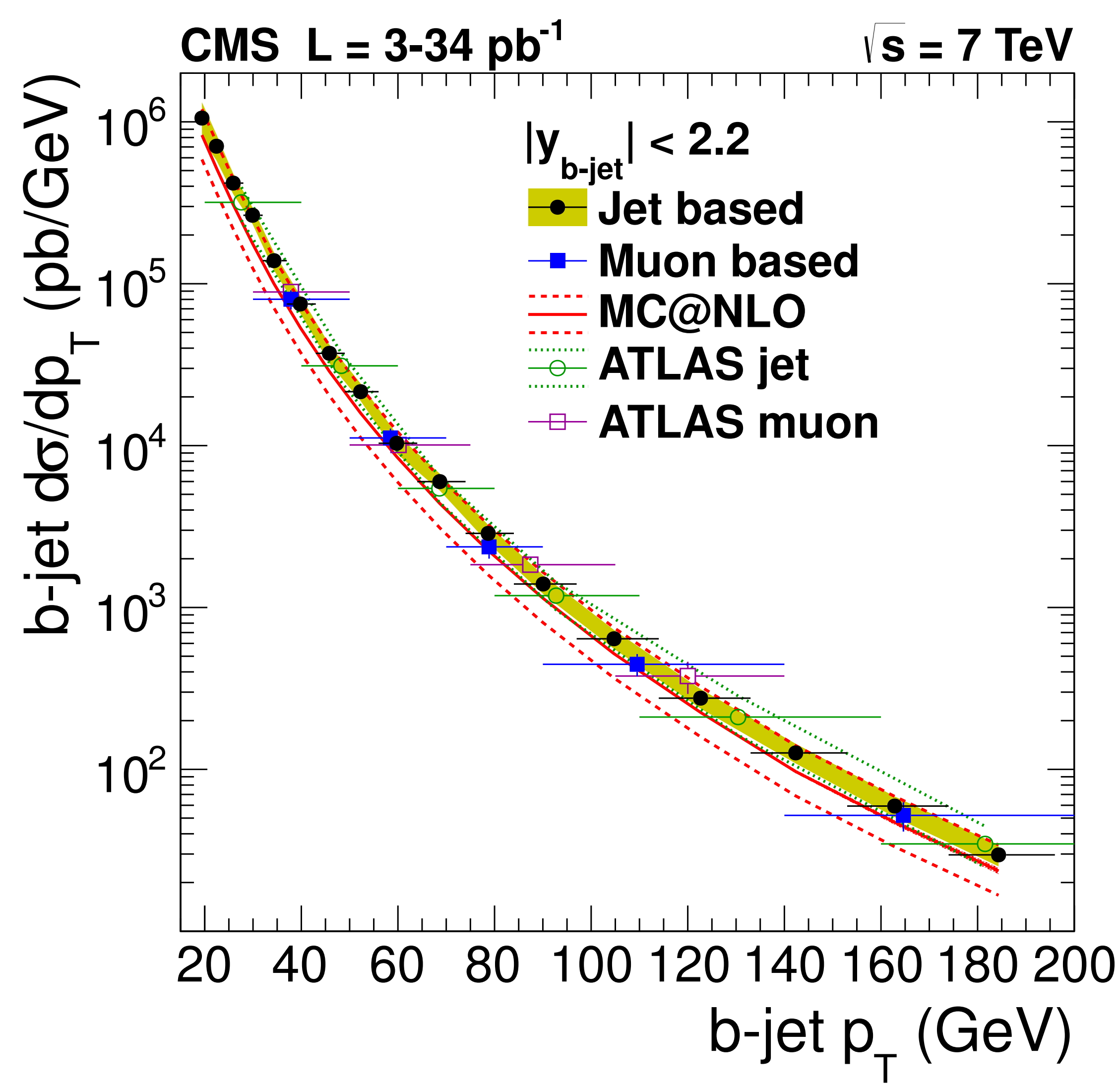
- bb di-jet cross section via template fits to the di-jet vertex mass
- already dominated by systematic error
  - jet energy scale, b-tagging efficiency

Good agreement with POWHEG+PYTHIA*, slight underestimation with MC@NLO+Herwig

(with MSTW 2008 NLO PDFs)

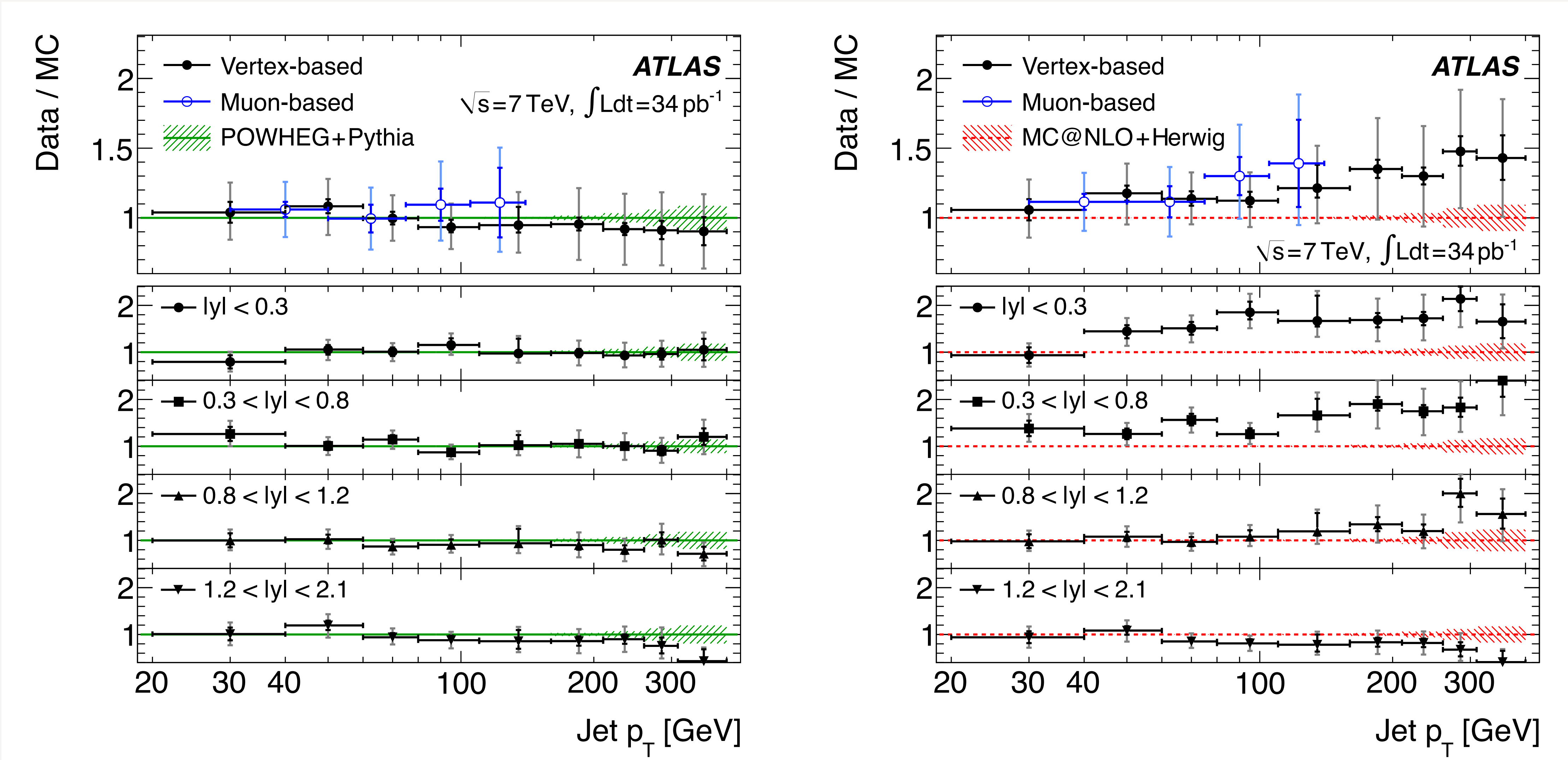
*only shape comparison when only using PYTHIA, LL PS not expected to get normalization correct





Eur.Phys.J.C 71 (2011) 1846, JHEP 04 (2012) 084

Inclusive production



(a) POWHEG

(b) MC@NLO

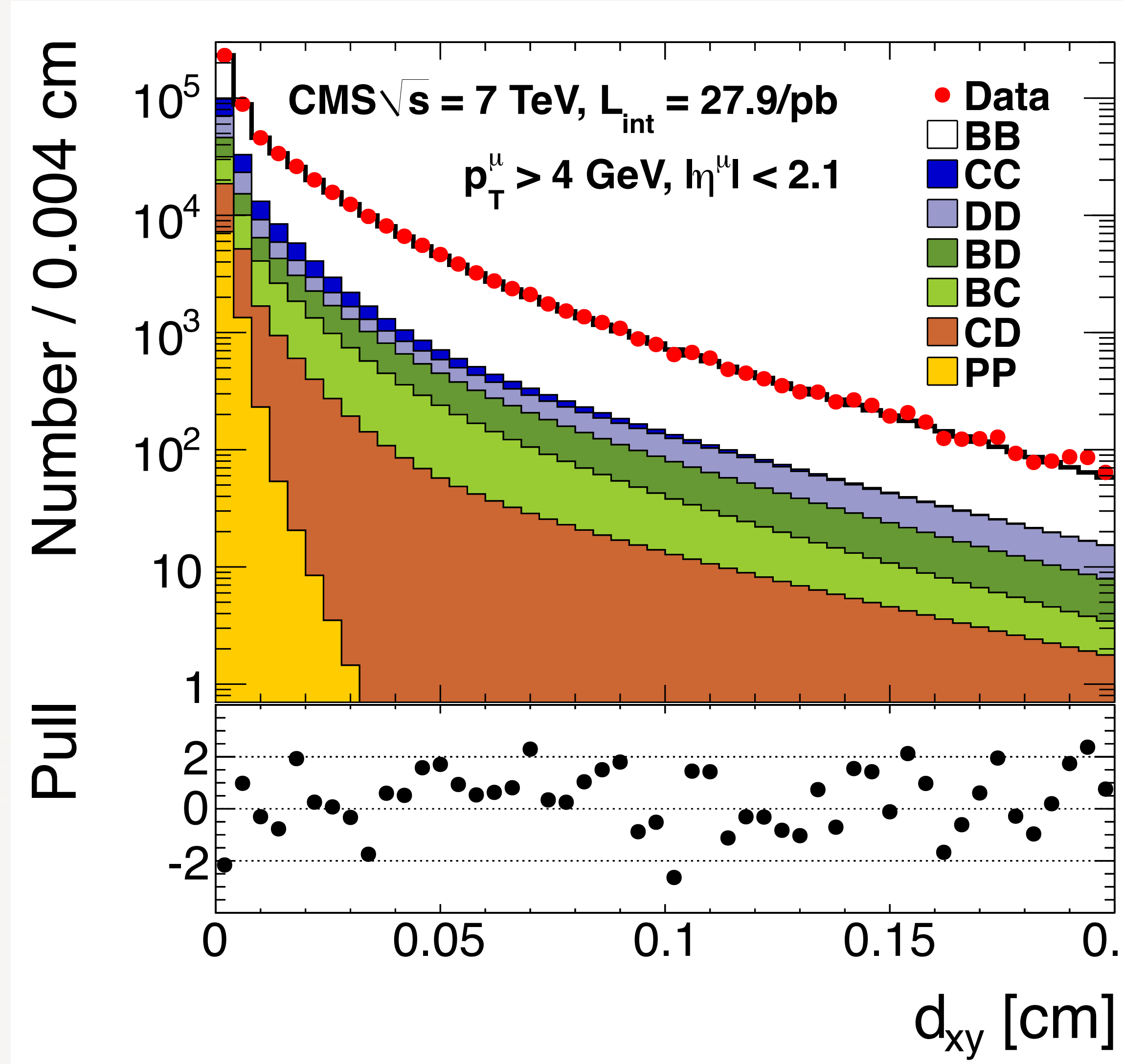
Eur.Phys.J.C 71 (2011) 1846, JHEP 04 (2012) 084

- POWHEG+Pythia shows good agreement in all rapidity regions
- MC@NLO predicts different behavior in double-differential cross section
- qualitative behavior remains the same when POWHEG is interfaced with Herwig instead of Pythia, rapidity dependence not from PS ?

Inclusive production $\sigma(\mathrm{pp} \to \mathrm{b\bar{b}X} \to \mu\mu\mathrm{X}')$

- suppressed gluon-splitting production
  - good for QCD comparison
- analysis strategy:
  - di-muon final state
  - rejection of Drell-Yan (DY) & decays of charmonium resonances through $M_{\mu\mu}$
  - classification into categories
    - **B:** B-hadron decays
    - **C:** charmed hadron decays
    - **P:** prompt tracks (DY, quarkonia, hadronic leakage)
    - **D:** in-flight decays
  - 2D templates to impact parameter d_{xy} distributions for yield extraction

Source	Uncertainty	
	$p_T > 4\,\mathrm{GeV}$	$p_T > 6\,\mathrm{GeV}$
Model dependency	5.5	5.1
Impact parameter resolution	2.7	4.0
Monte Carlo precision and fit method	2.2	2.7
Efficiencies and acceptance	6.1	6.2
Total	8.9	9.4



JHEP06 (2012) 110

$$\sigma(\mathrm{pp} \to \mathrm{b\bar{b}X} \to \mu\mu\mathrm{X}', p_T > 4\,\mathrm{GeV}, |\eta| < 2.1) = 26.4 \pm 0.1\,(\mathrm{stat.}) \pm 2.4\,(\mathrm{syst.}) \pm 1.1\,(\mathrm{lumi.})\ \mathrm{nb}$$

paper also includes $p_T > 6$ GeV

MC@NLO: $19.7 \pm 0.3\,(\mathrm{stat.})\ ^{+6.5}_{-4.1}\,(\mathrm{syst.})\ \mathrm{nb}$
interfaced to Herwig, and CTEQ6.6 PDF

Consistent with MC@NLO prediction

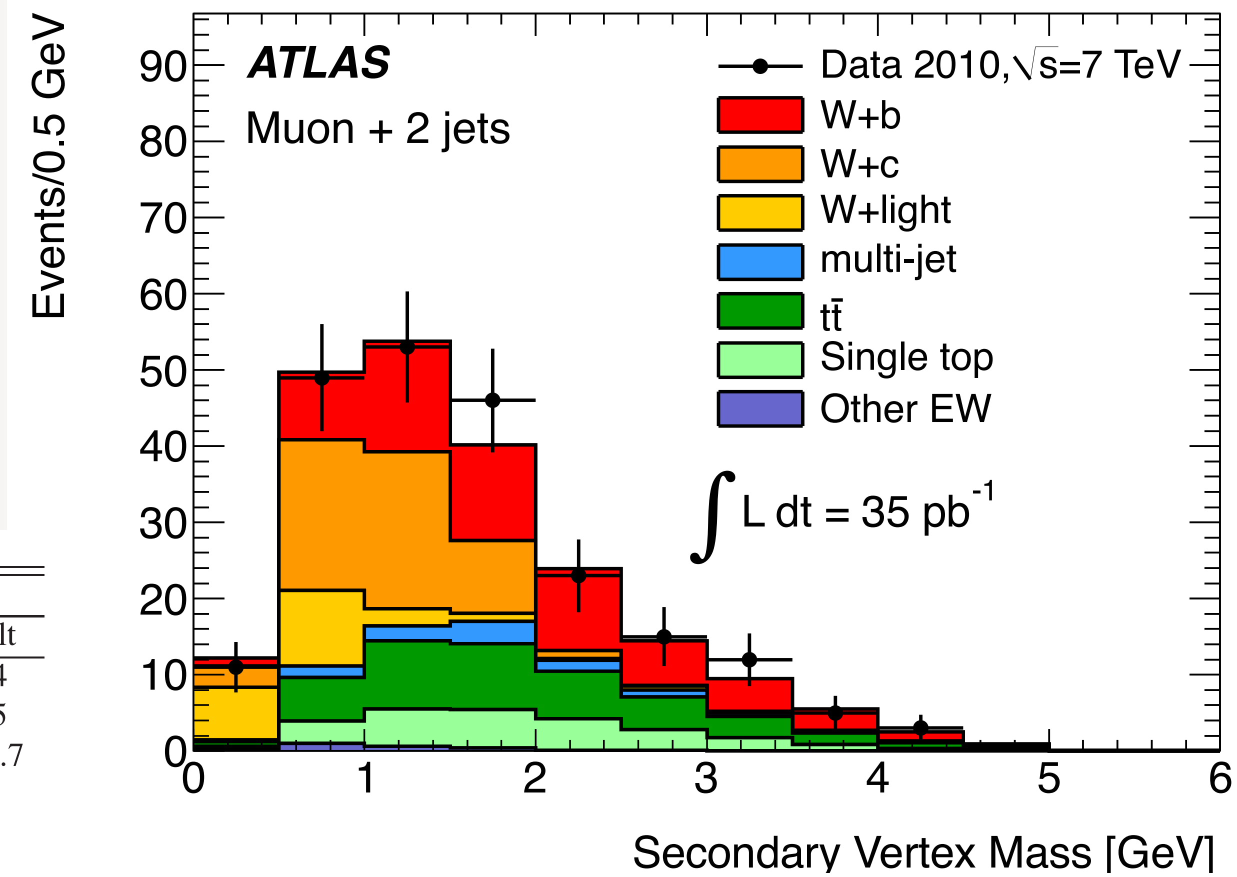
Associated W+b-jet production

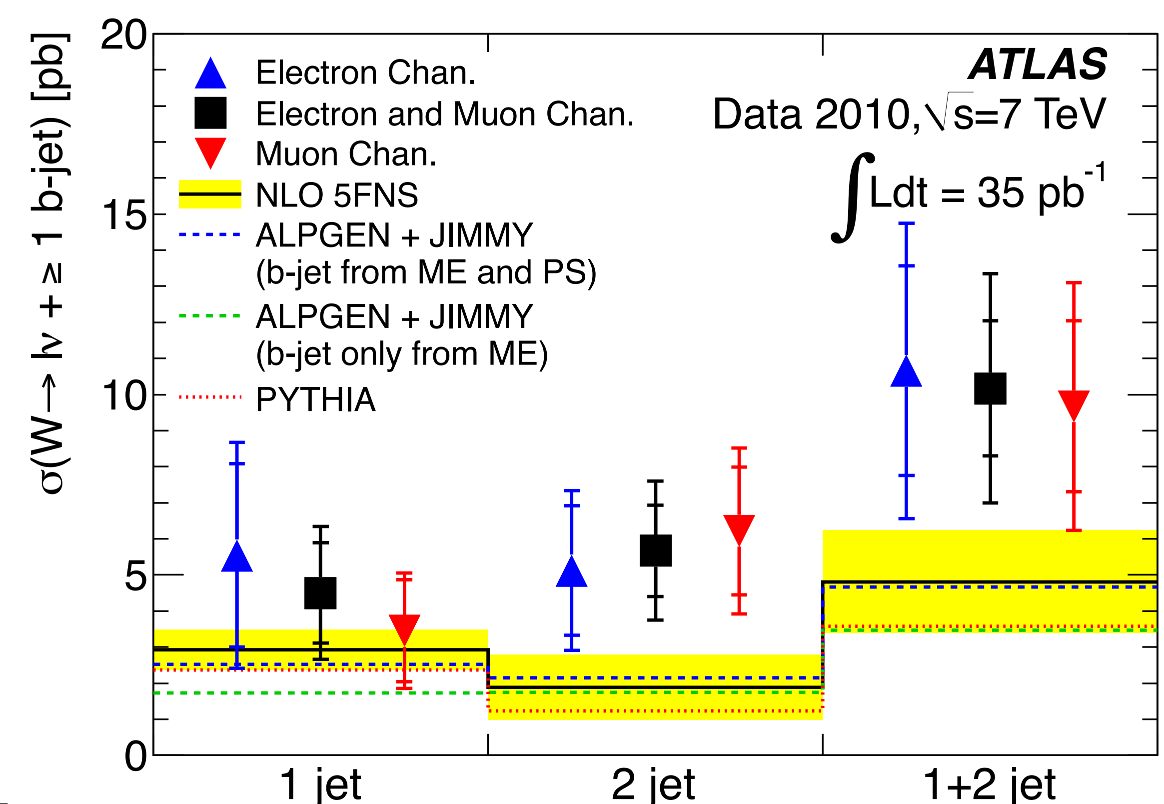
- measurement done using template fit to secondary vertex mass
- measurement carried out on 1,2 and 1+2 jet bin
- backgrounds well controlled

	$W \to \mu\nu$, 1-jet		$W \to \mu\nu$, 2-jet		$W \to e\nu$, 1-jet		$W \to e\nu$, 2-jet	
	Pred.	Fit result	Pred.	Fit result	Pred.	Fit result	Pred.	Fit result
$W+b$	25	28 ± 13	26	62 ± 18	18	33 ± 12	19	38 ± 14
$W+c$	108	170 ± 20	45	54 ± 19	84	105 ± 18	36	24 ± 15
W+light	38	21.2 ± 9.9	20	21 ± 10	30	22 ± 10	17	14.4 ± 7.7
Multi-jets	8	-	10	-	10	-	5.8	-
tt	11	-	44	-	8.1	-	33	-
Single top	17	-	23	-	14	-	18	-
Other backgrounds	3.9	-	2.5	-	1.9	-	2.1	-
Total Predicted	212	-	170	-	167	-	131	-
Data	261	-	217	-	194	-	136	-

- largest systematic uncertainties
- b-tagging efficiency (6-10 %)
- see talk of K. Mishra
  (CMS results, including Z+b-jet)

Tension with theory predictions @ 1.5 sigma





Phys.Lett. B707 (2012) 418-437

B hadron production cross section

using decays to $D^{*+}\mu^{-}X$ final states

- measurement concentrates on hadrons containing a b quark (H_b)

- via partial reconstruction of H_b final state $D^{*+}\mu^{-}X$ with $D^{*+} \to \pi^{+}D^{0}$, $D^{0} \to K^{-}\pi^{+}$

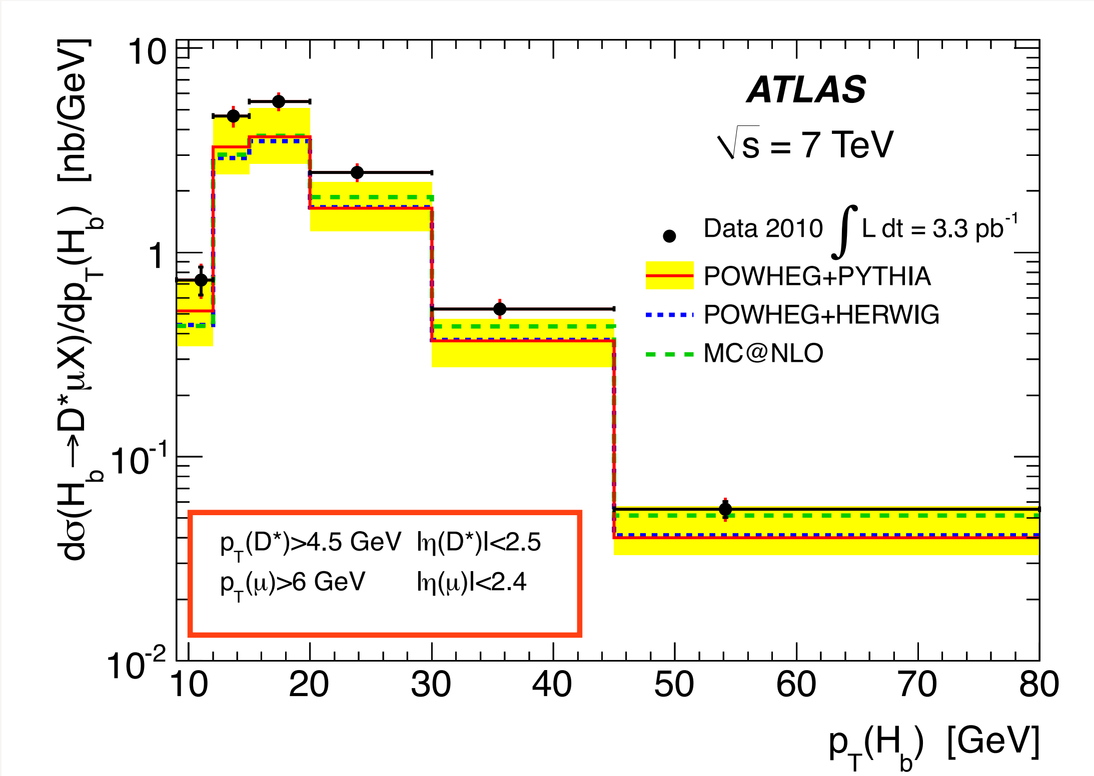
- counting experiment with corrections for trigger, reco. efficiency

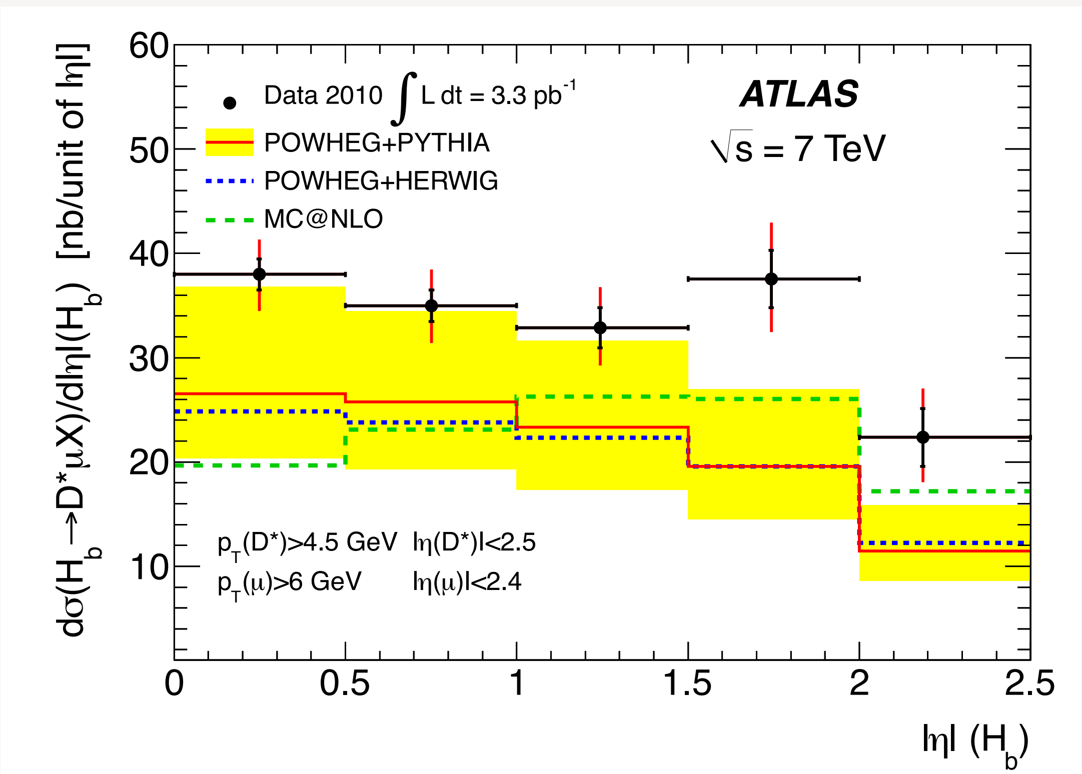
$$\boxed{\sigma(pp \to H_b X' \to D^{*+}\mu^{-}X) = 78.7 \pm 2.0\ (\mathrm{stat.}) \pm 7.3\ (\mathrm{syst.}) \pm 1.2(\mathscr{B}) \pm 2.7(\mathscr{L})\ \mathrm{nb}}$$

POWHEG+PYTHIA: $53\ ^{+18}_{-12}(\mathrm{scale})\ ^{+3}_{-3}(m_b)\ ^{+3}_{-3}(\mathrm{PDF})\ ^{+6}_{-5}(\mathrm{hadr.})\ \mathrm{nb}$

- derived B hadron differential cross section via branching ratio & acceptance

$$\frac{\mathrm{d}\sigma(H_b X)}{\mathrm{d}p_{\mathrm{T}}(\eta)} = \frac{1}{\alpha_{p_{\mathrm{T}}(\eta)}\mathscr{B}(b \to D^{*+}\mu^{-}X)} \frac{\mathrm{d}\sigma(pp \to H_b X' \to D^{*+}\mu^{-}X)}{\mathrm{d}p_{\mathrm{T}}(\eta)}$$





MC prediction in general lower than measurement, but (just) covered by systematics

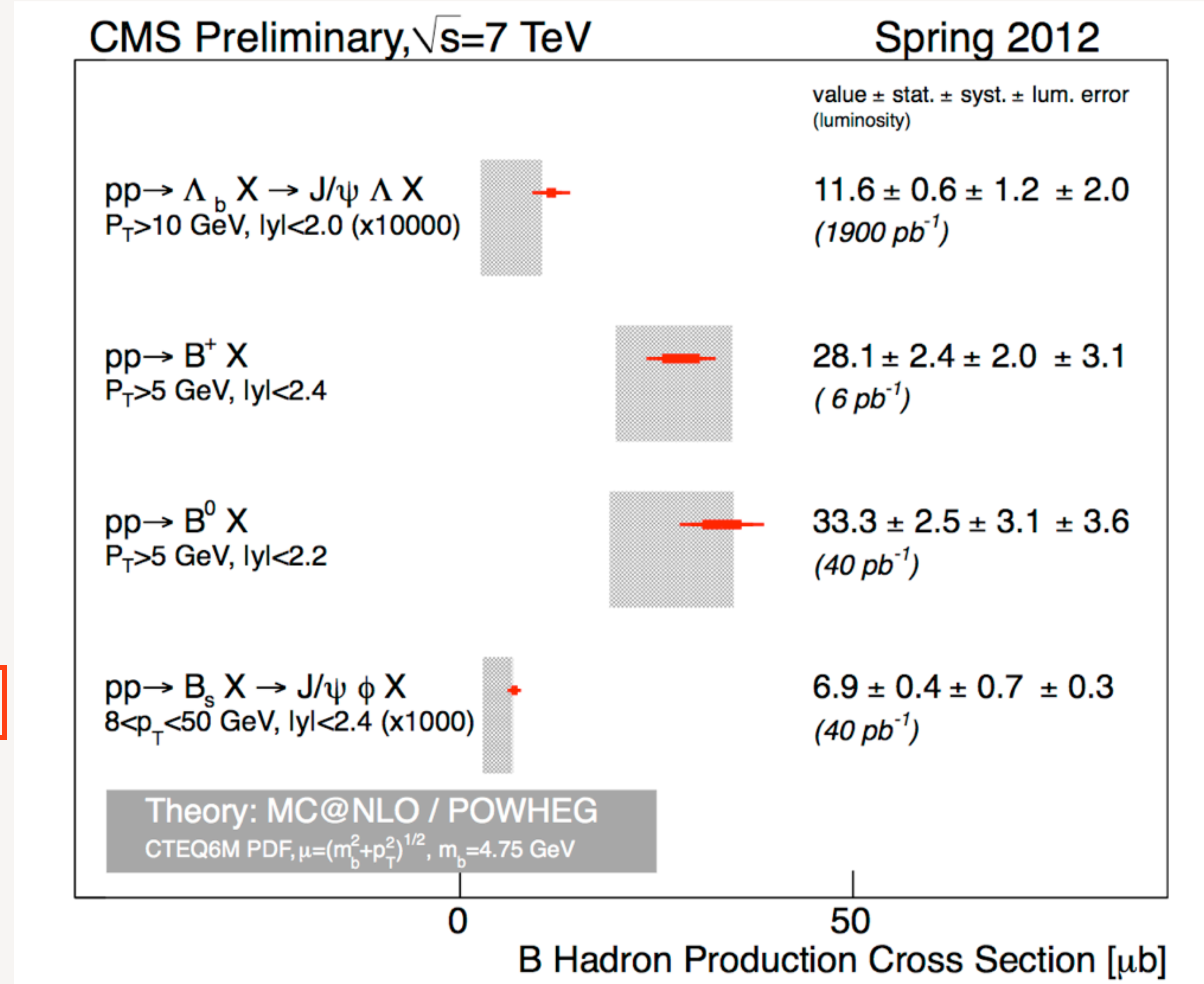
Nucl. Phys. B864 (2012) 341-381

Exclusive B hadron production

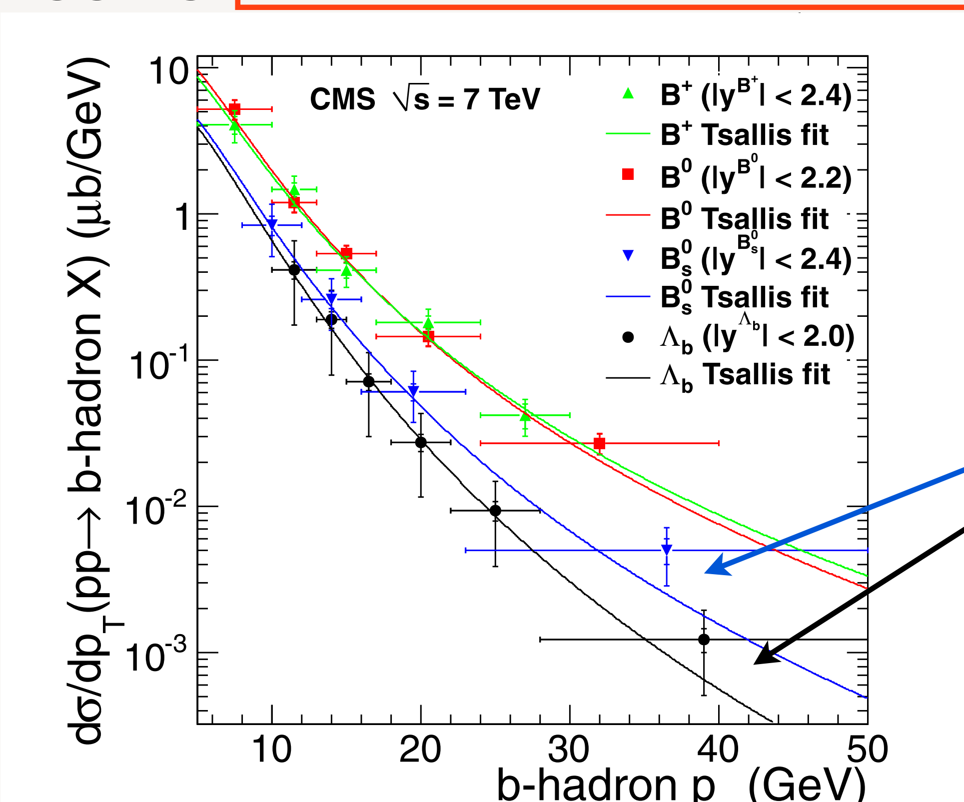
- baryon production relative to meson production at same initial momentum spectrum good to test differences in hadronization processes
- recently CMS has added the Λ_b cross section
- measurement via

$$\Lambda_b \to J/\psi\, \Lambda$$
$$\mu^+\mu^- \qquad\qquad p\,\pi$$

- charge conjugate state measured via anti-proton tagging $\boxed{\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b) = 1.02 \pm 0.07 \pm 0.09}$



Phys. Lett. B 714 (2012) 136-157



- systematic uncertainties dominated by poorly known branching fractions
  $\mathcal{B}(\Lambda_b \to J/\psi\,\Lambda)$ and $\mathcal{B}(B_s^0 \to J/\psi\,\phi)$
- cross section of Λ_b seems to fall faster with p_T

Good agreement with NLO predictions

Lifetime & mass measurements (1): Λ^0_b

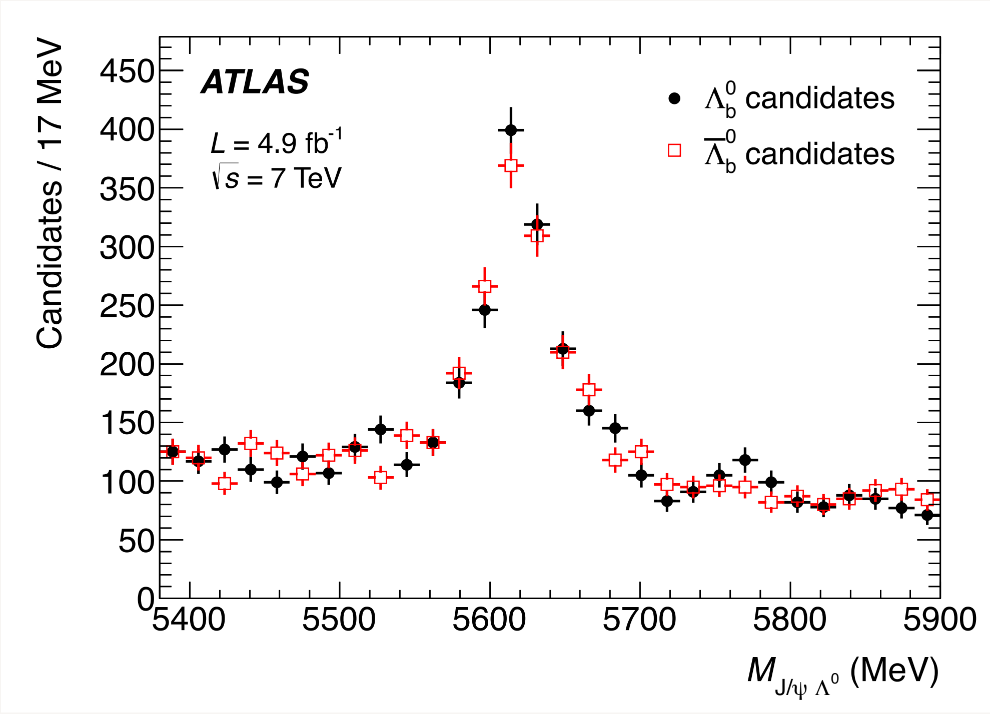
- Λ^0_b ($\overline{\Lambda}^0_b$) is the lightest baryon containing b ($\bar{b}$) quark
- not produced in B-factories, currently only accessible in hadron colliders
- ATLAS measurement carried out in

$$\boxed{\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)}$$

  - same event topology as

$$B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$$

  - theoretically, lifetime ratio $\tau_{\Lambda_b}/\tau_{B_d}$ can be predicted by HQET and pQCD
  - many systematic uncertainties cancel in ratio



Phys. Lett. B 714 (2012) 136-157

- Analysis strategy:
  - signal pre-selection via secondary (J/Ψ μμ) and tertiary (V^0) vertex with loose constraints to J/Ψ respectively Λ^0 mass
  - full decay topology fit required $\chi^2/\mathrm{ndf} < 3$
  - simultaneous fit of m_{Λ_b}, τ_{Λ_b}, number of signal events and event-by-event errors

Systematic uncertainty	$\sigma_\tau^{\mathrm{syst}}$ (fs)	σ_m^{syst} (MeV)
Selection/reco. bias	12	0.9
Background fit models	9	0.2
B_d^0 contamination	7	0.2
Residual misalignment	1	-
Extra material	3	0.2
Tracking p_T scale	-	0.5
Total systematic error	17	1.1

Lifetime & mass measurements (2): Λ^0_b

- Main systematic uncertainties
  - event selection and reconstruction bias (mainly from μ trigger and V^0 reconstruction)
  - background model fits
  - B^0_d contamination
  - residual misalignment / ID material
- Results

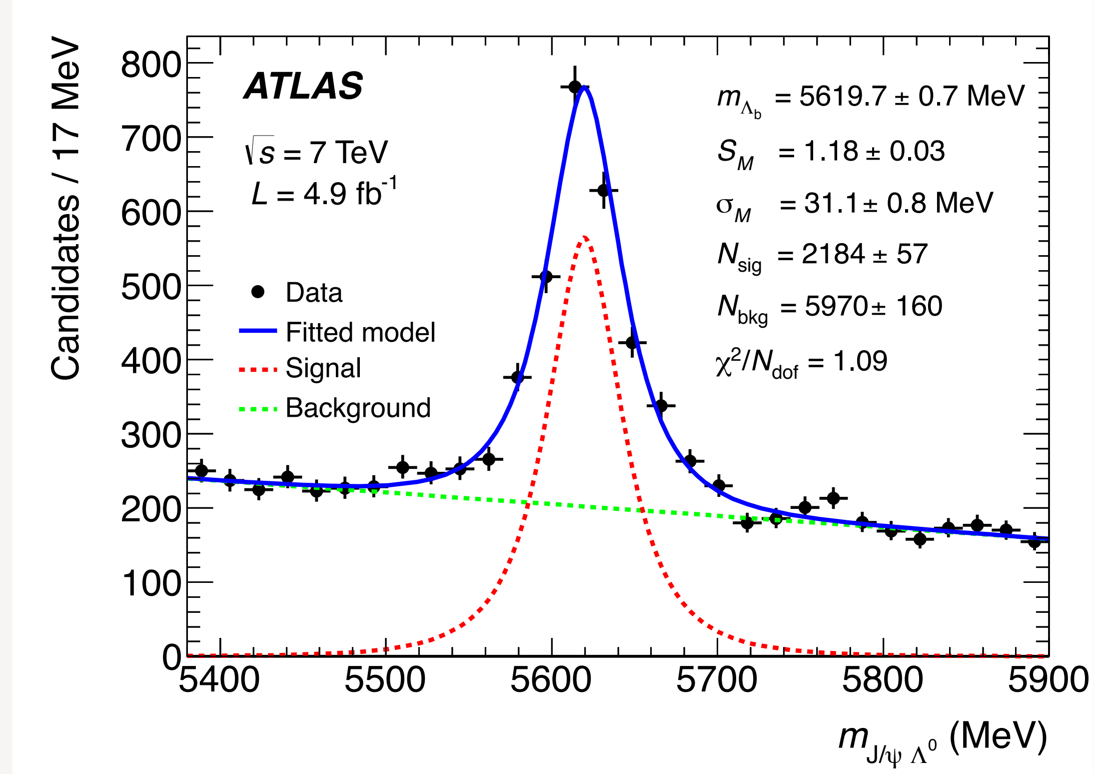
$$\boxed{\begin{aligned} \tau_{\Lambda_b} &= 1.449 \pm 0.036(\mathrm{stat}) \pm 0.017(\mathrm{syst})\ \mathrm{ps}, \\ m_{\Lambda_b} &= 5619.7 \pm 0.7(\mathrm{stat}) \pm 1.1(\mathrm{syst})\ \mathrm{MeV}. \end{aligned}}$$

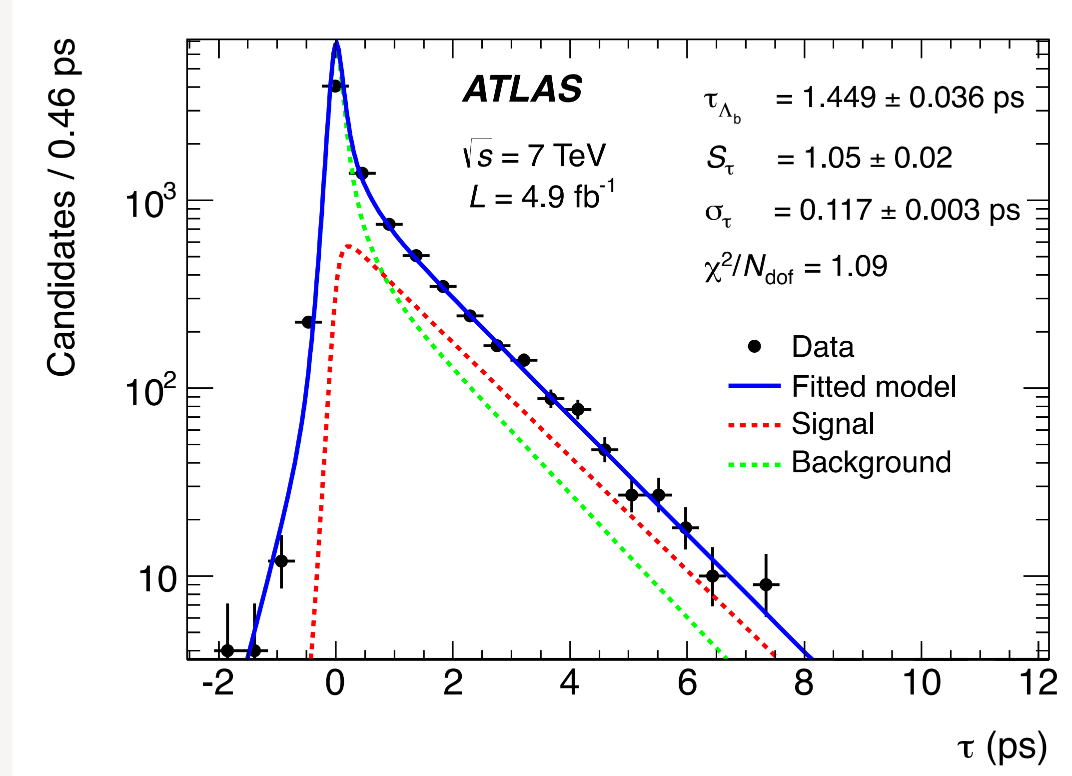
$$m_{\Lambda_b}^{\mathrm{LHCb}} = 5619.19 \pm 0.70(\mathrm{stat}) \pm 0.30(\mathrm{syst})\ \mathrm{MeV}$$

$$\tau_{\Lambda_b}^{\mathrm{PDG}} = 1.425 \pm 0.032\ \mathrm{ps} \quad m_{\Lambda_b}^{\mathrm{PDG}} = 5620.2 \pm 1.6\ \mathrm{MeV}$$

$$\boxed{R = \tau_{\Lambda_b}/\tau_{B_d} = 0.960 \pm 0.025(\mathrm{stat}) \pm 0.016(\mathrm{syst})}$$

$$R^{\mathrm{D\O}} = 0.864 \pm 0.052(\mathrm{stat}) \pm 0.033(\mathrm{syst})$$
$$R^{\mathrm{CDF}} = 1.020 \pm 0.030(\mathrm{stat}) \pm 0.008(\mathrm{syst})$$
$$R^{\mathrm{NLO}} = 0.88 \pm 0.05 \quad \text{(C. Tarantino, 2004)}$$





Phys. Lett. B 714 (2012) 136-157

Good agreement with previous measurements, compatible with NLO prediction

New Observations

Observations: χ_b (3P)

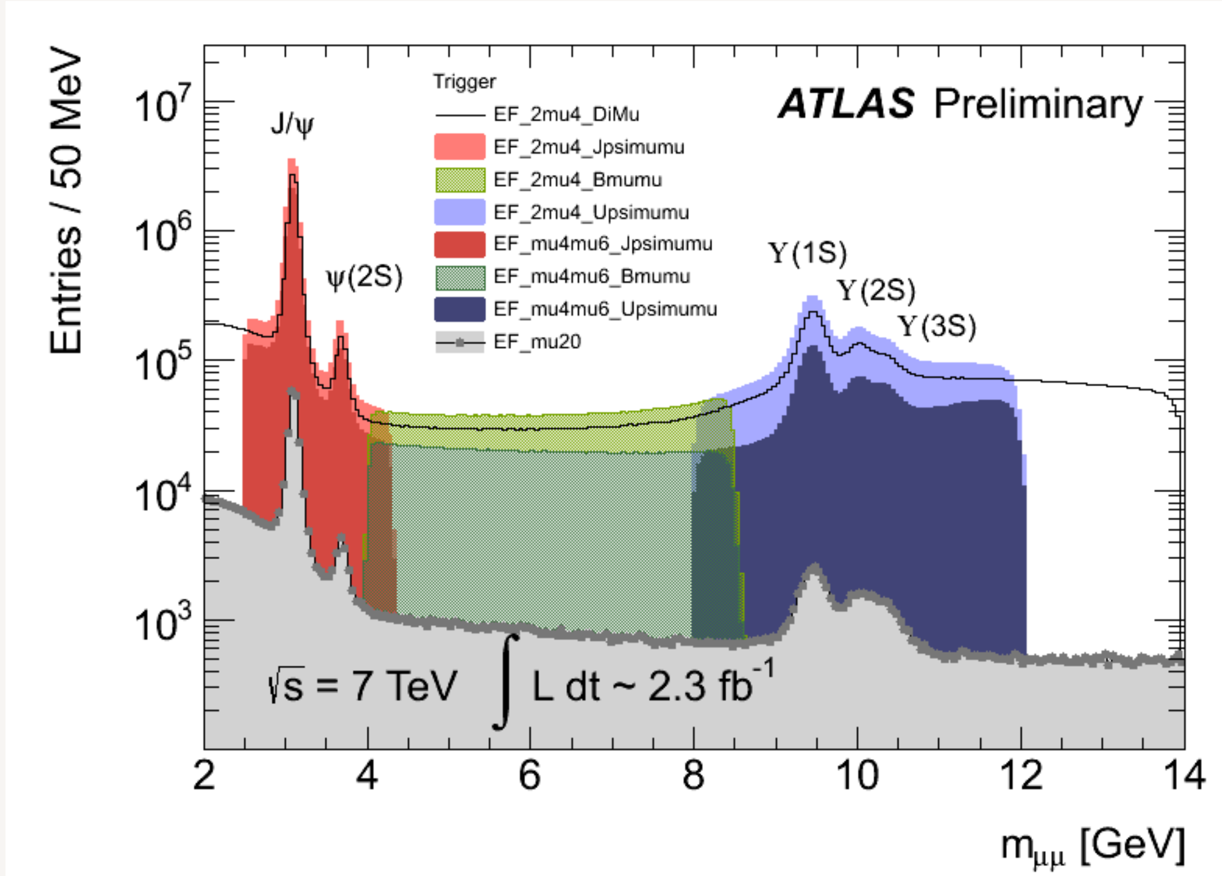
- $b\bar{b}$ quarkonia states with parallel spins
  - Υ (S-wave)
  - χ_b (P-wave)
- search for radiative decays of

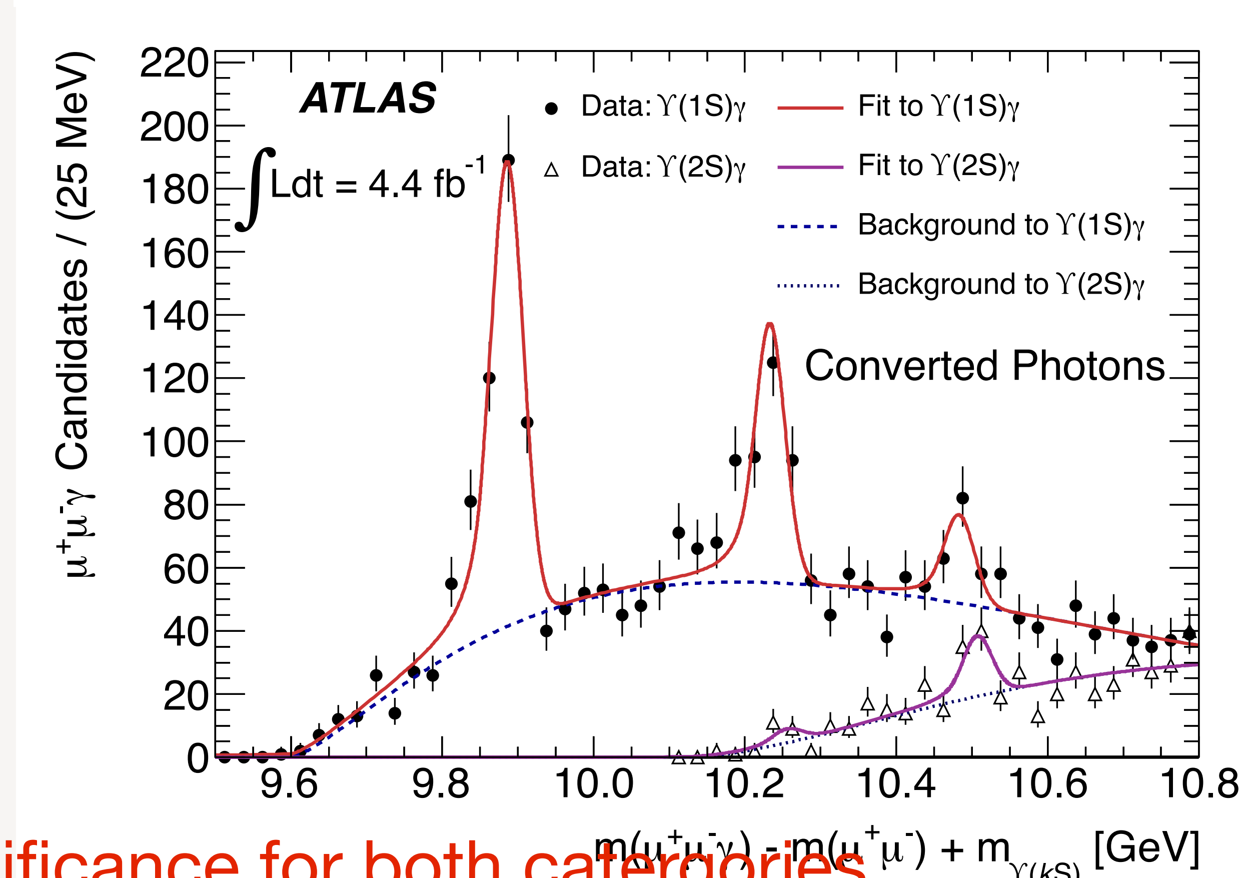
  $\chi_b\,(nP) \rightarrow \Upsilon(iS)\gamma$ with $i = 1{,}2$

  trigger $\mu^+\mu^-$

  final state, where γ can be converted /unconverted
- mass balance built as $m(\mu\mu\gamma)\text{-}m(\mu\mu)+m_{\Upsilon(iS)}$ and fitted
  - simultaneously for 1S/2S in case of converted photons
- higher thresholds prevent reconstruction of χ_b (2P) with photons
- mass measured as

$$\boxed{10.530 \pm 0.005\ \text{(stat)} \pm 0.009\ \text{(syst) GeV}}$$





PRL 108, 152001 (2012)

interpretation as 3P state of χ_b, 6 σ significance for both catergories

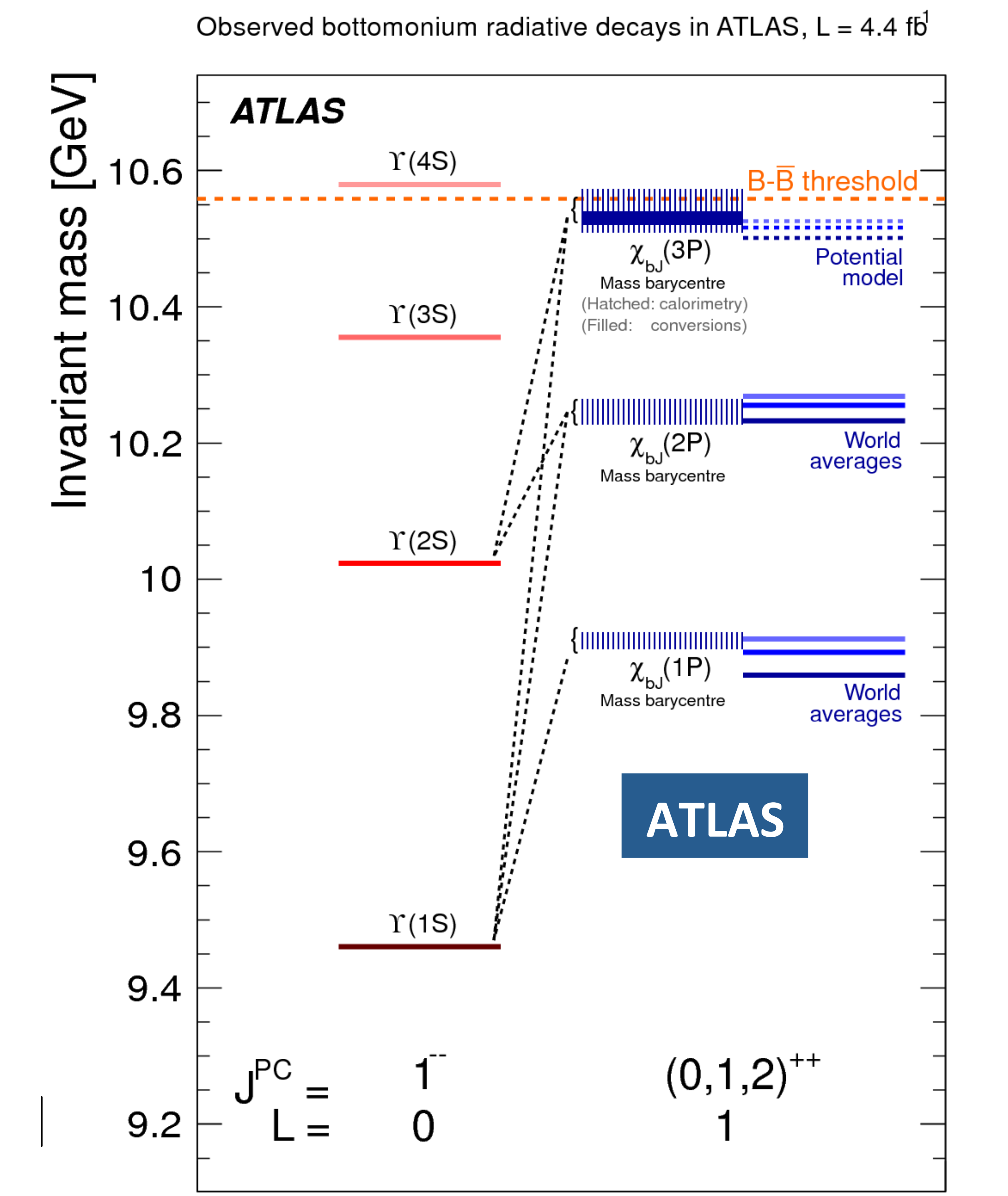
Observations: χ_b (3P)

- $b\bar{b}$ quarkonia states with parallel spins
  - Υ (S-wave)
  - χ_b (P-wave)
- search for radiative decays of
  $\chi_b(nP) \rightarrow \Upsilon(iS)\gamma$ with $i = 1,2$

trigger $\mu^+\mu^-$

final state, where γ can be converted /unconverted

- mass balance built as $m(\mu\mu\gamma)-m(\mu\mu)+m_{\Upsilon(iS)}$ and fitted
  - simultaneously for 1S/2S in case of converted photons
- higher thresholds prevent reconstruction of χ_b (2P) with photons
- mass measured as
  $\boxed{10.530 \pm 0.005\ (\mathrm{stat}) \pm 0.009\ (\mathrm{syst})\ \mathrm{GeV}}$

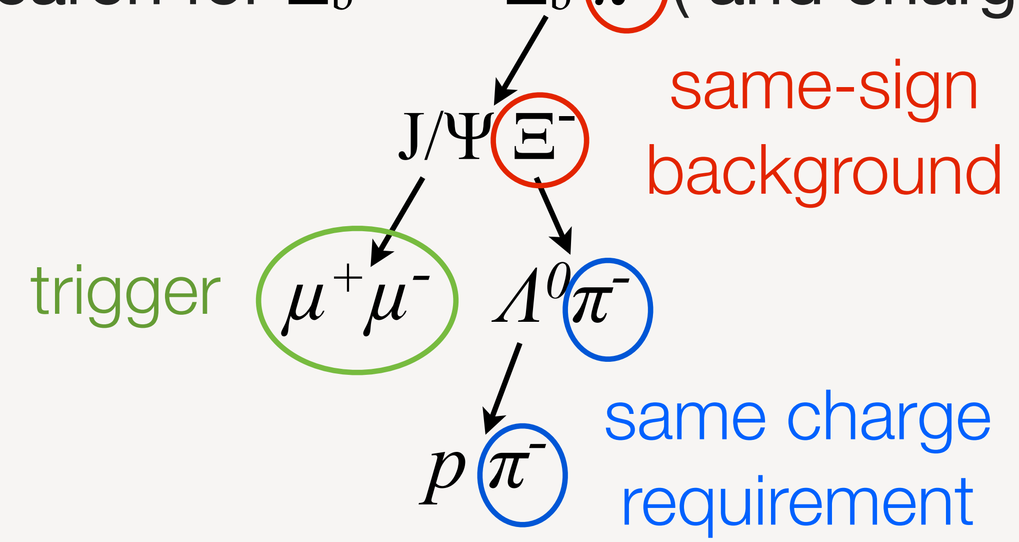


PRL 108, 152001 (2012)

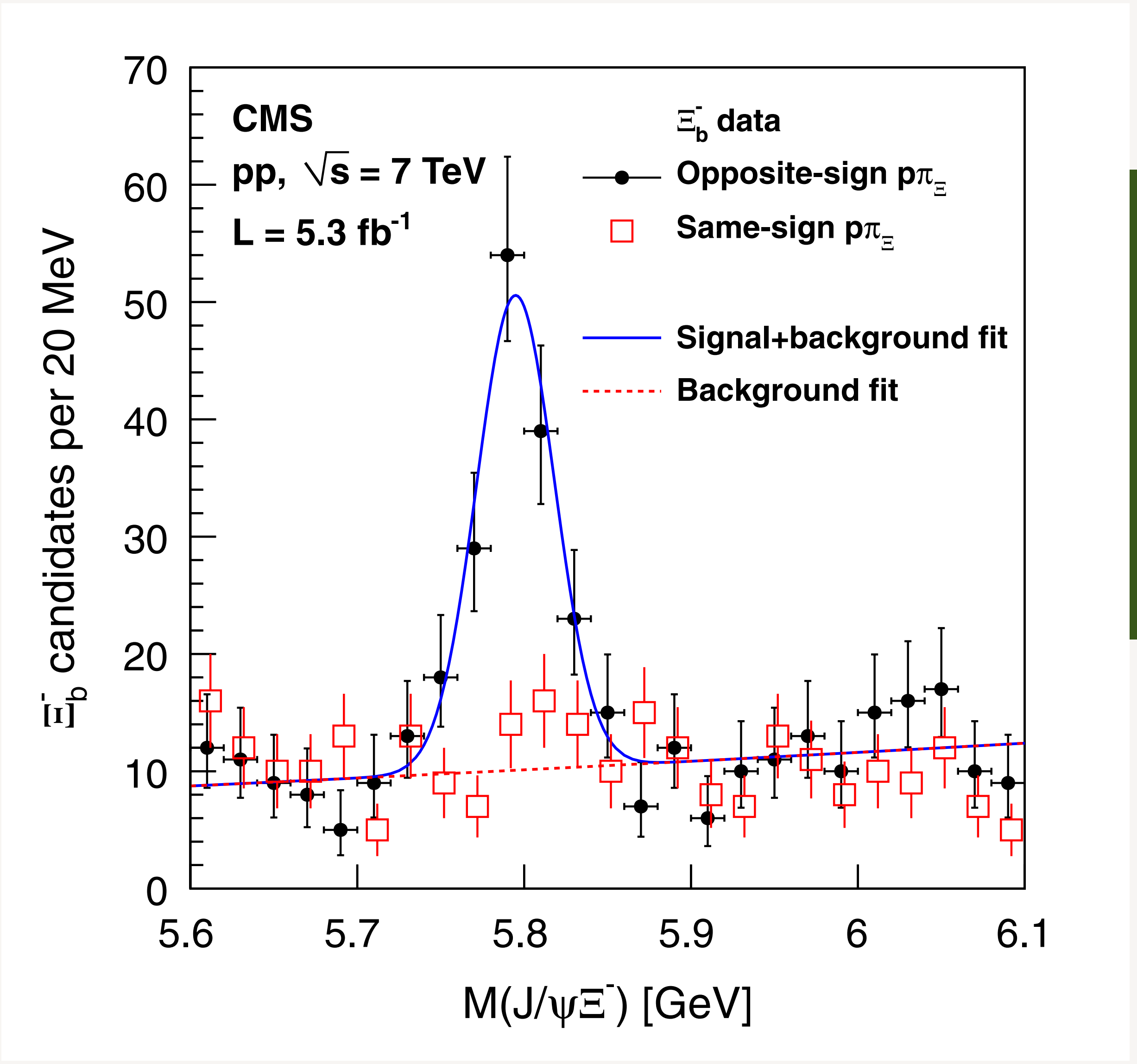
interpretation as 3P state of χ_b, 6 σ significance for both catergories

Observations: a new Ξ baryon

- mass difference of Ξ_b^* ($J^P = 3/2$ and $L = 0$) and ground state Ξ_b should be big enough to kinematically allow a strong decay
- search for $\Xi_b^{0*} \rightarrow \Xi_b^- \pi^+$ (and charge conjugate) in a full kinematic vertex fit



- prompt track suppression via impact parameter significance
- signal yield of 108 ± 14 events
- mass $\boxed{5795.0 \pm 3.1 \text{ (stat) MeV}}$ and mass resolution $\boxed{23.7 \pm 3.2 \text{ (stat) MeV}}$ in good agreement with full simulation

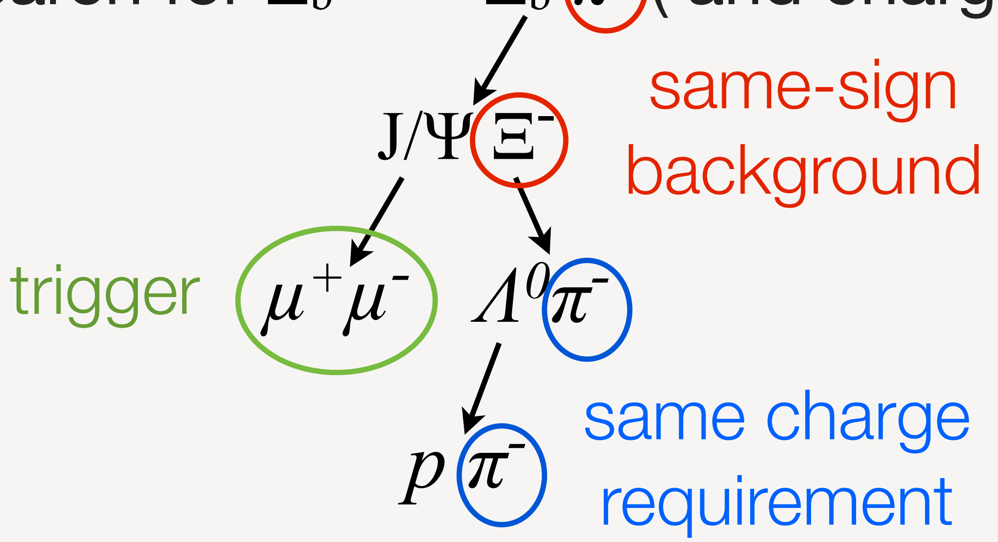


PRL 108, 252002 (2012)

Background fluctuation probability of 1.3×10^{-8}, corresponds to $5.7\ \sigma$

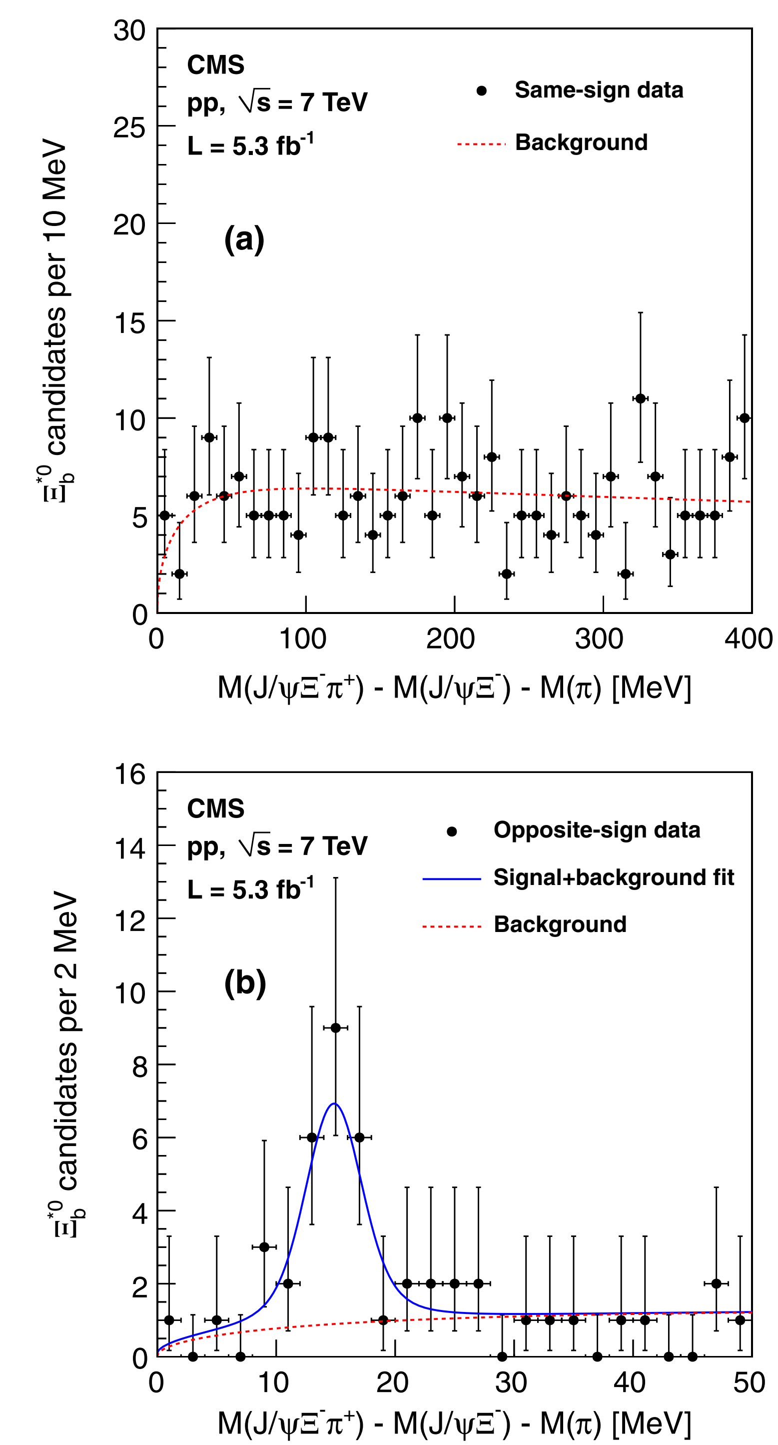
Observations: a new Ξ baryon

- mass difference of $\Xi_b{}^*$ ($J^P = 3/2$ and $L = 0$) and ground state Ξ_b should be big enough to kinematically allow a strong decay
- search for $\Xi_b{}^{0*} \rightarrow \Xi_b^- \pi^+$ (and charge conjugate) in a full kinematic vertex fit



- prompt track suppression via impact parameter significance
- signal yield of 108 ± 14 events
- mass $\boxed{5795.0 \pm 3.1\ (\mathrm{stat})\ \mathrm{MeV}}$ and mass resolution $\boxed{23.7 \pm 3.2\ (\mathrm{stat})\ \mathrm{MeV}}$ in good agreement with full simulation

Background fluctuation probability of 1.3 x 10^{-8}, corresponds to 5.7 σ



PRL 108, 252002 (2012)

Rare Decays

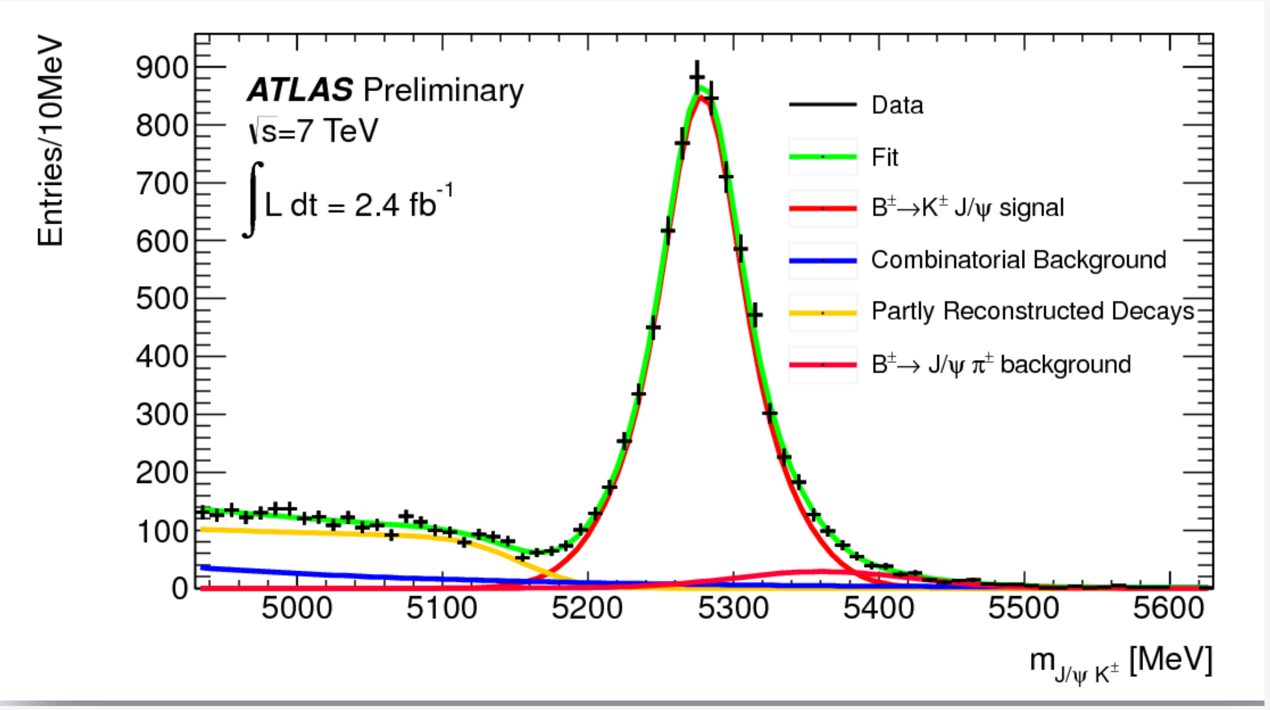
Rare decays: $B^0_{(s)} \to \mu^+\mu^-$ motivation

- Decay of $B^0_{(s)} \to \mu^+\mu^-$ is a SM benchmark process
  - can only occur through (highly suppressed) flavor changing neutral current
  - additionally helicity suppressed
- SM branching ratio (BR) extremely small, precise theoretical prediction

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

(Buras et al, JHEP 1009 (2010) 106)

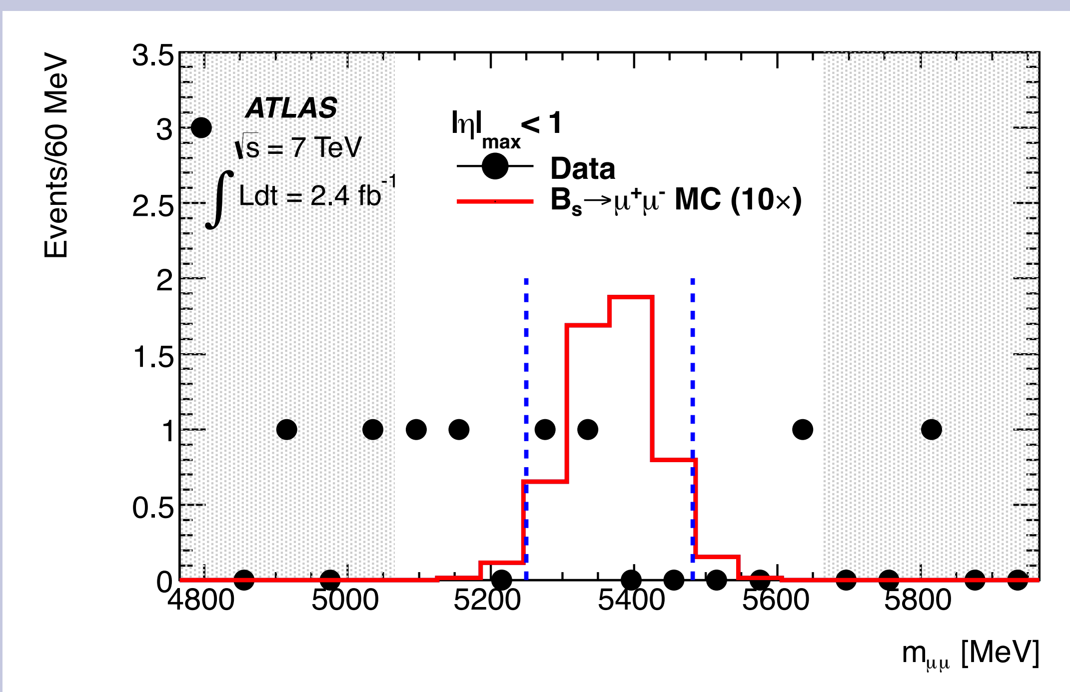
- BSM physics can enhance the branching ratio through loop contributions
- Clean event signature, controllable bkg
  - di-muon final state
  - mis-reconstructed resonances, $\mu^+\mu^-$ continuum
- BR measured w.r.t to reference channel
  - $B^+ \to J/\psi\, K^+$
  - $B_s \to J/\psi\, \phi$
- Both ATLAS & CMS perform a blind analysis



Rare decays: $B^0_{(s)} \rightarrow \mu^+\mu^-$ analyses

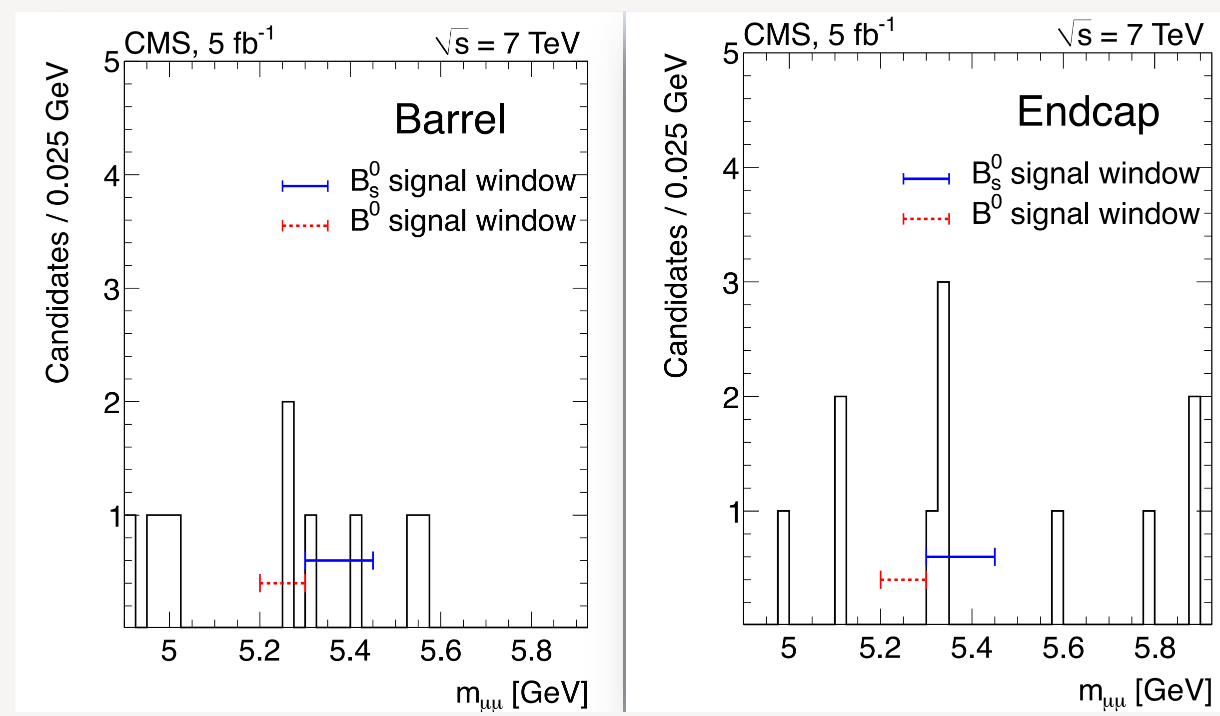
Phys. Lett. B713 (2012) 180-196

- 2.4 fb^{-1}data used
- measurement done in 3 η regions
- signal selection by BDT combining kinematic & reconstructed variables (cross-checked on ref.)
- BDT optimisation and background estimation done using independent sample of sideband events



JHEP 04 (2012) 033

- 5 fb^{-1}data used (2011 dataset)
- measurement done in 2 regions (barrel/endcap)
- cut analysis on kinematic & reconstructed variables (cross-check on reference sample)

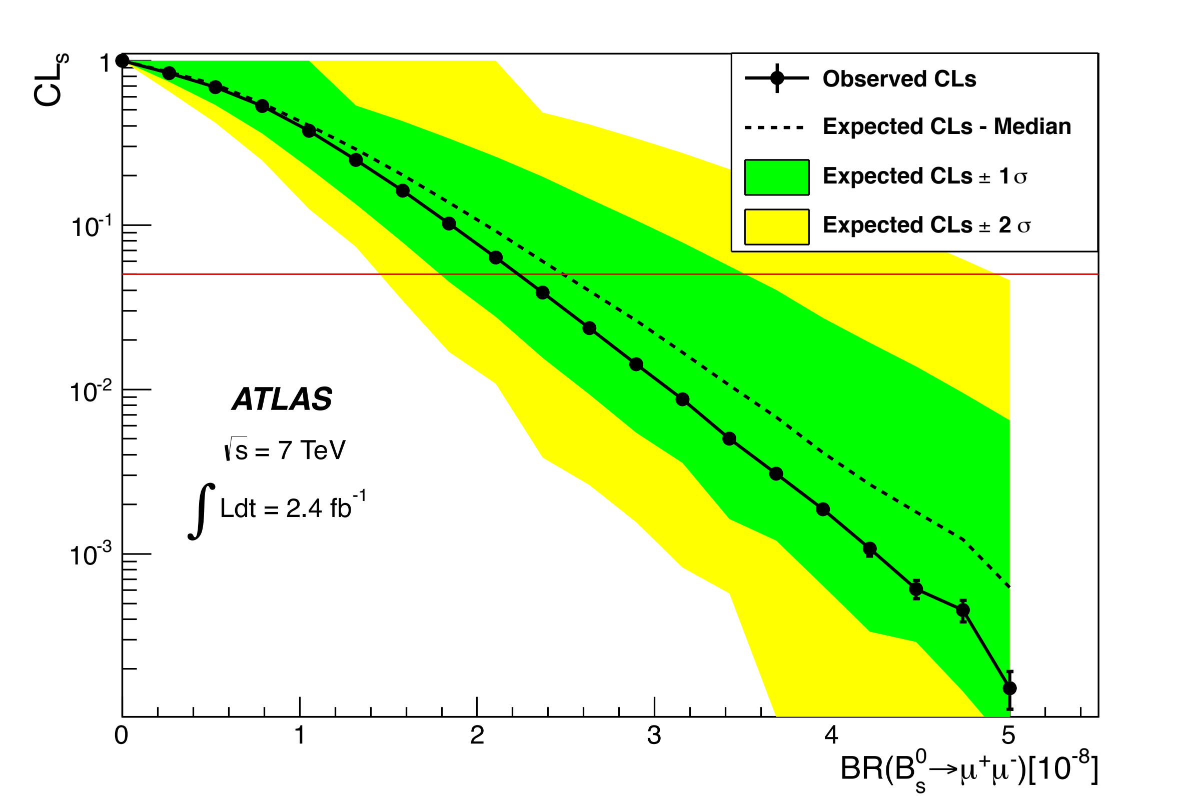


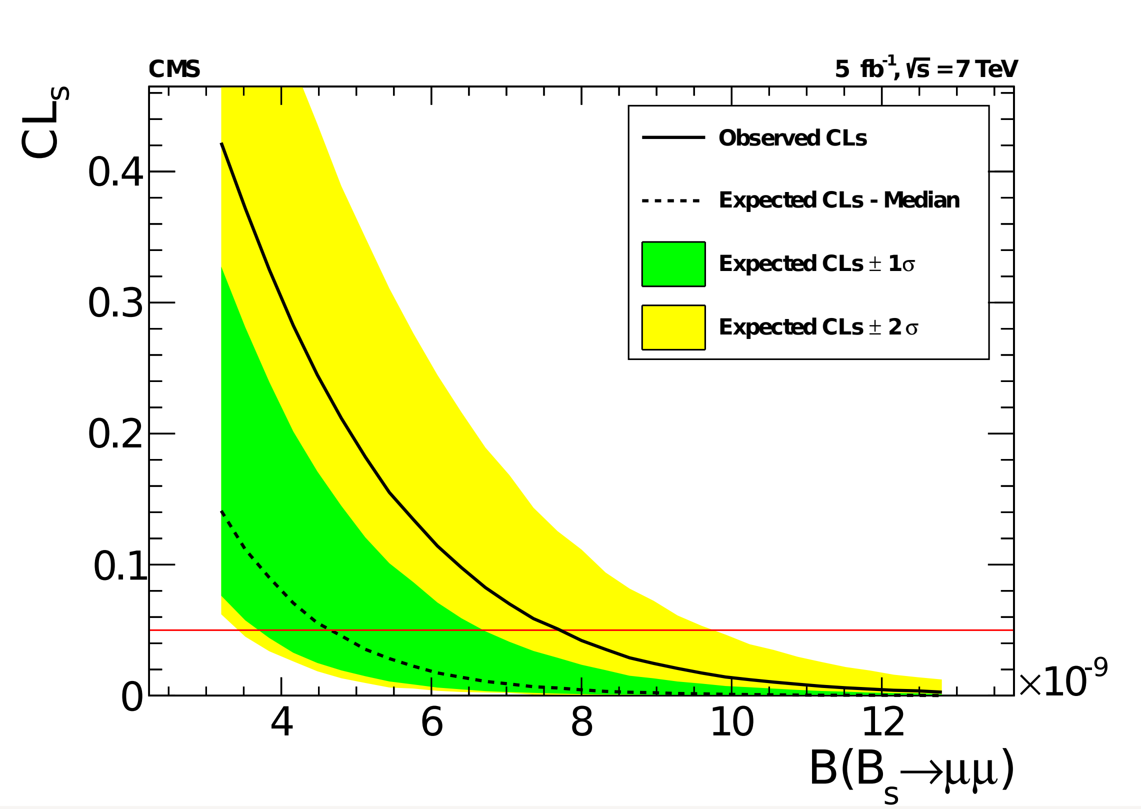
Rare decays: $B^0_{(s)} \rightarrow \mu^+\mu^-$ results

- No evidence for anomalous signal in ATLAS, CMS analyses
- Approaching SM sensitivity
  - ATLAS, CMS almost competitive with LHCb
  - cover different phase space than LHCb

Expt.	Channel	95% CL	Expected limit
LHC*b*	$B_s \rightarrow \mu^+\mu^-$	< 4.5 x 10^{-9}	7.2 x 10^{-9}
CMS	$B_s \rightarrow \mu^+\mu^-$	< 7.7 x 10^{-9}	8.4 x 10^{-9}
ATLAS	$B_s \rightarrow \mu^+\mu^-$	< 2.2 x 10^{-8}	2.3 x 10^{-8}
LHC*b*	$B_d \rightarrow \mu^+\mu^-$	< 1.03 x 10^{-9}	1.13 x 10^{-9}
CMS	$B_d \rightarrow \mu^+\mu^-$	< 1.7 x 10^{-9}	1.8 x 10^{-9}

$$\mathcal{BR}(B_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
(Buras et al, JHEP 1009 (2010) 106)





Rare decays: $B^0_{(s)} \to \mu^+\mu^-$ results

- No evidence for anomalous signal in ATLAS, CMS analyses
- Approaching SM sensitivity
  - ATLAS, CMS almost competitive with LHCb
  - cover different phase space than LHCb

Expt.	Channel	95% CL	Expected limit
LHC*b*	$B_s \to \mu^+\mu^-$	< 4.5 x 10^{-9}	7.2 x 10^{-9}
CMS	$B_s \to \mu^+\mu^-$	< 7.7 x 10^{-9}	8.4 x 10^{-9}
ATLAS	$B_s \to \mu^+\mu^-$	< 2.2 x 10^{-8}	2.3 x 10^{-8}
LHC*b*	$B_d \to \mu^+\mu^-$	< 1.03 x 10^{-9}	1.13 x 10^{-9}
CMS	$B_d \to \mu^+\mu^-$	< 1.7 x 10^{-9}	1.8 x 10^{-9}

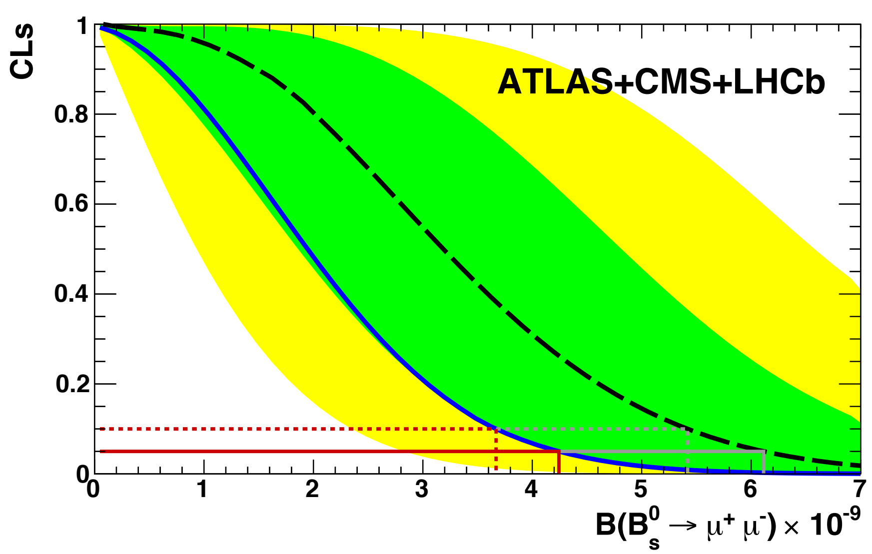
$$\mathcal{BR}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

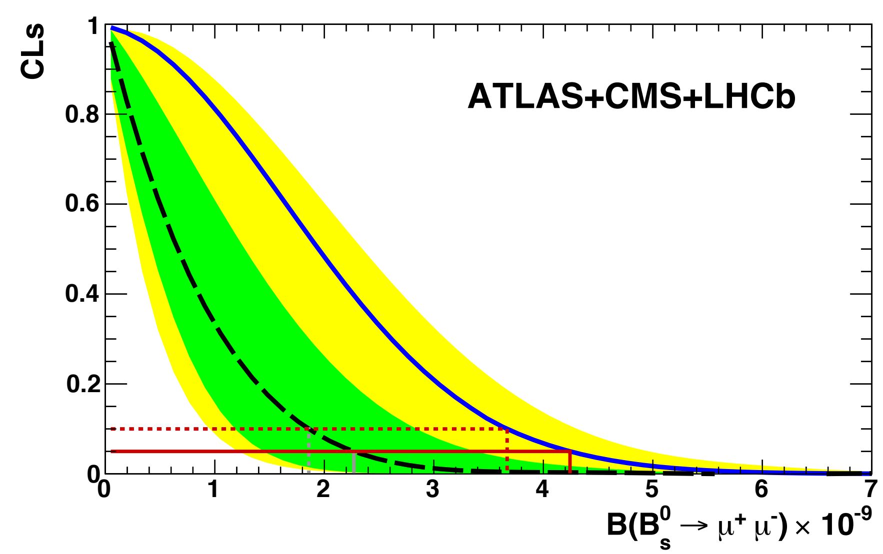
(Buras et al, JHEP 1009 (2010) 106)

- Recently combination of ATLAS+CMS+LHCb

C.L.	bkg only 90%	bkg only 95%	SM + bkg 90%	SM + bkg 95%	**Observed 90%**	**Observed 95%**
$\mathcal{B}(B^0_s \to \mu^+\mu^-)$ (10^{-9})	1.9	2.3	5.4	6.1	**3.7**	**4.2**

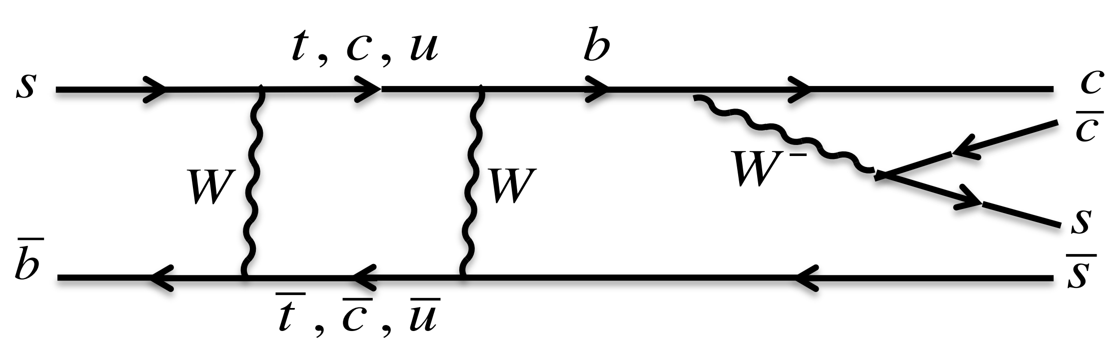
ATLAS-CONF-2012-061
CMS-PAS-BPH-12-009
LHCb-CONF-2012-017



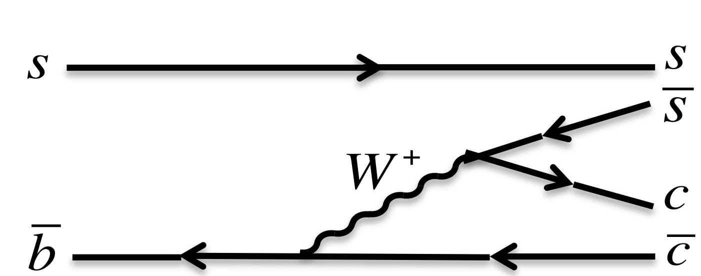


CP-violation in B sector: $\Delta\Gamma$ and φ_s from $B_s \to J/\psi\,\phi$

- Mixing in B sector creates time-dependent B_s states
- Time evolution of B_s and $\overline{B}_s$ are described by superposition of mass eigenstates B_H and B_L with masses $m_s \pm \Delta m_s/2$ and lifetimes $\Gamma_s \pm \Delta\Gamma_s/2$
  - these states deviate for pure CP = ±1 eigenstates through mixing phase $\Delta\varphi_s$
- NP could add significant contribution to $\Delta\varphi_s$ and alter $\Delta\Gamma_s$, Δm_s
- Access via fully reconstructed decay mode of $B_s \to J/\psi\,\phi \to \mu^+\mu^- K^+ K^-$
- Final states are composed of mixing amplitude, directs amplitude, interference terms and a non-resonant S-wave contribution for $K^+ K^-$



Decay amplitude with mixing (φ_s)



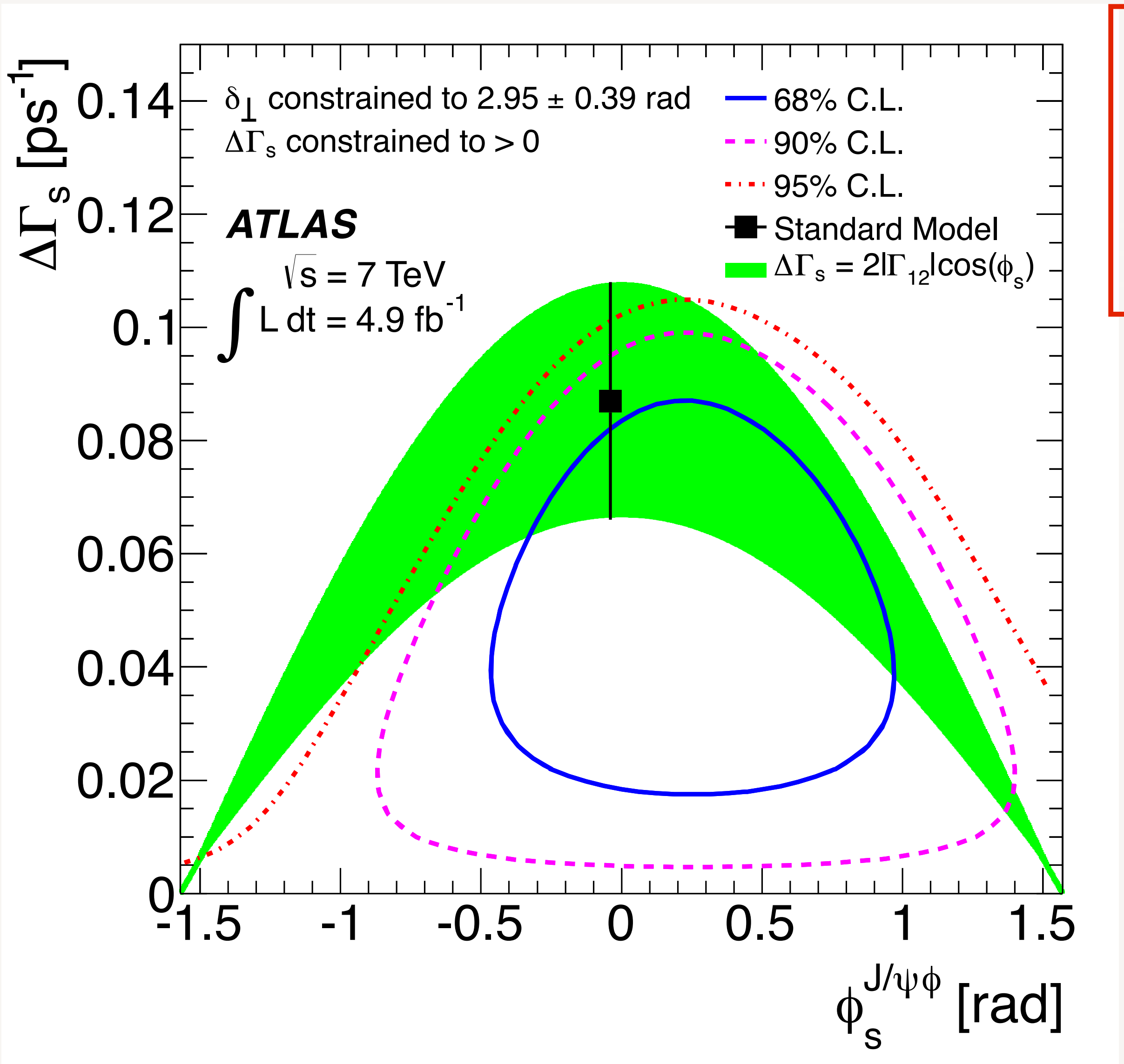
Amplitude with direct decay

- $B_s/\overline{B}_s$ flavor at production is not determined in this analysis
  - fast oscillation driven by Δm_s can not be measured, but interference terms give access to mixing phase
- Decay PDF can be parameterized in angular- and time-dependent amplitudes

http://arxiv.org/abs/1208.0572, submitted to JHEP

CP-violation in B sector: $\Delta\Gamma$ and φ_s from $B_s \to J/\psi\,\phi$

- Analysis strategy is a maximum likelihood fit to B_s mass and proper decay time
  - likelihood built from time- and angular dependent decay amplitudes, background contributions



$$\phi_s = 0.22 \pm 0.41\ (\text{stat.}) \pm 0.10\ (\text{syst.})\ \text{rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\ (\text{stat.}) \pm 0.008\ (\text{syst.})\ \text{ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1}$$

LHCb:

$$\phi_s = -0.001 \pm 0.101 \pm 0.027$$
$$\Delta\Gamma_s = 0.116 \pm 0.018 \pm 0.006$$
$$\Gamma_s = 0.6580 \pm 0.0054 \pm 0.0066$$

Measurement consistent with SM, competitive measurement for Γ and $\Delta\Gamma$

http://arxiv.org/abs/1208.0572, submitted to JHEP

Conclusions

- ATLAS and CMS serve a very rich heavy flavor physics program
  - this could never be a complete summary

- High statistics and excellent detector performances allow competitive measurements
  - inclusive and exclusive production cross sections
  - mass and lifetime measurements
  - observations of new states
  - test of BSM phenomena

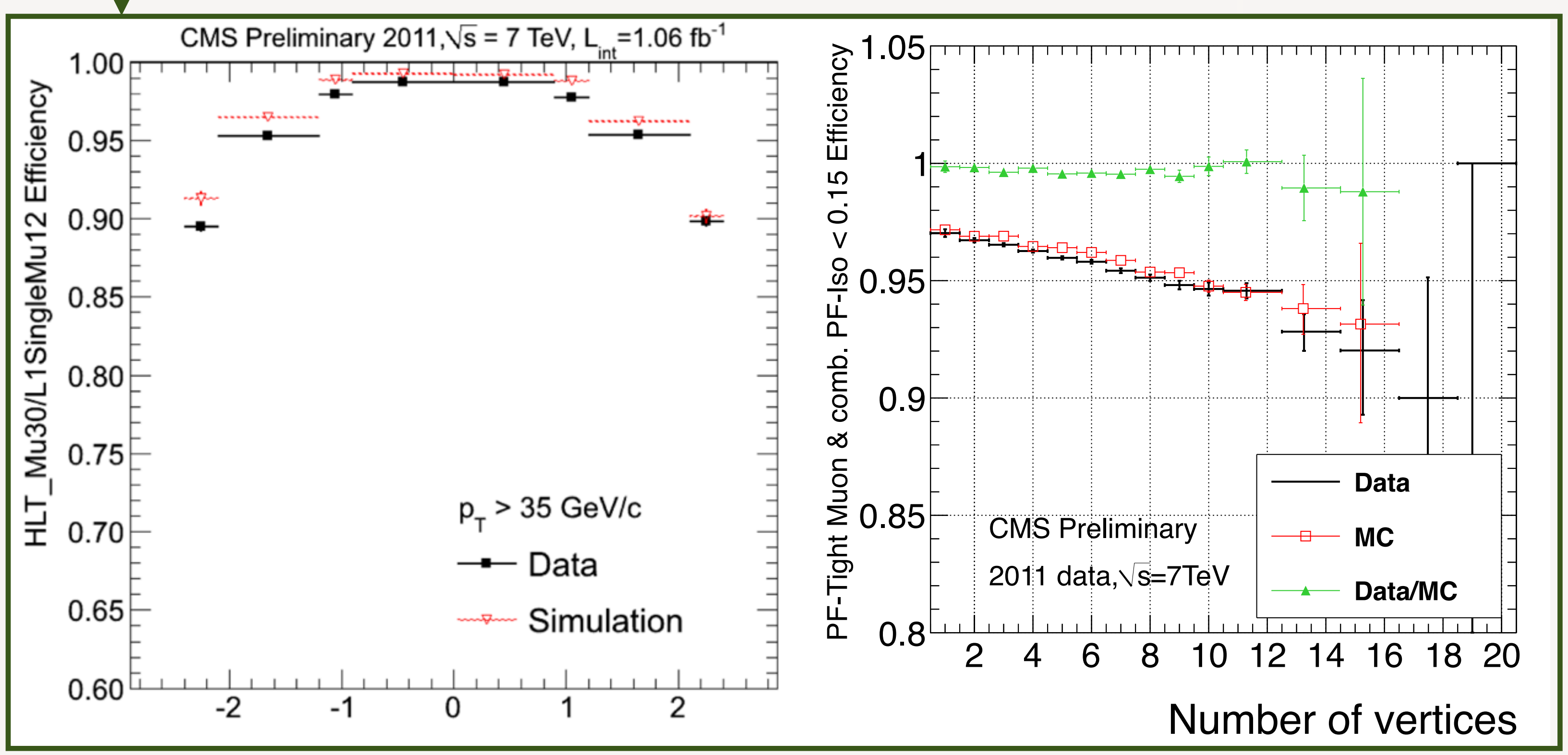
- In general, measurements are in good agreement with available pQCD/NLO predictions

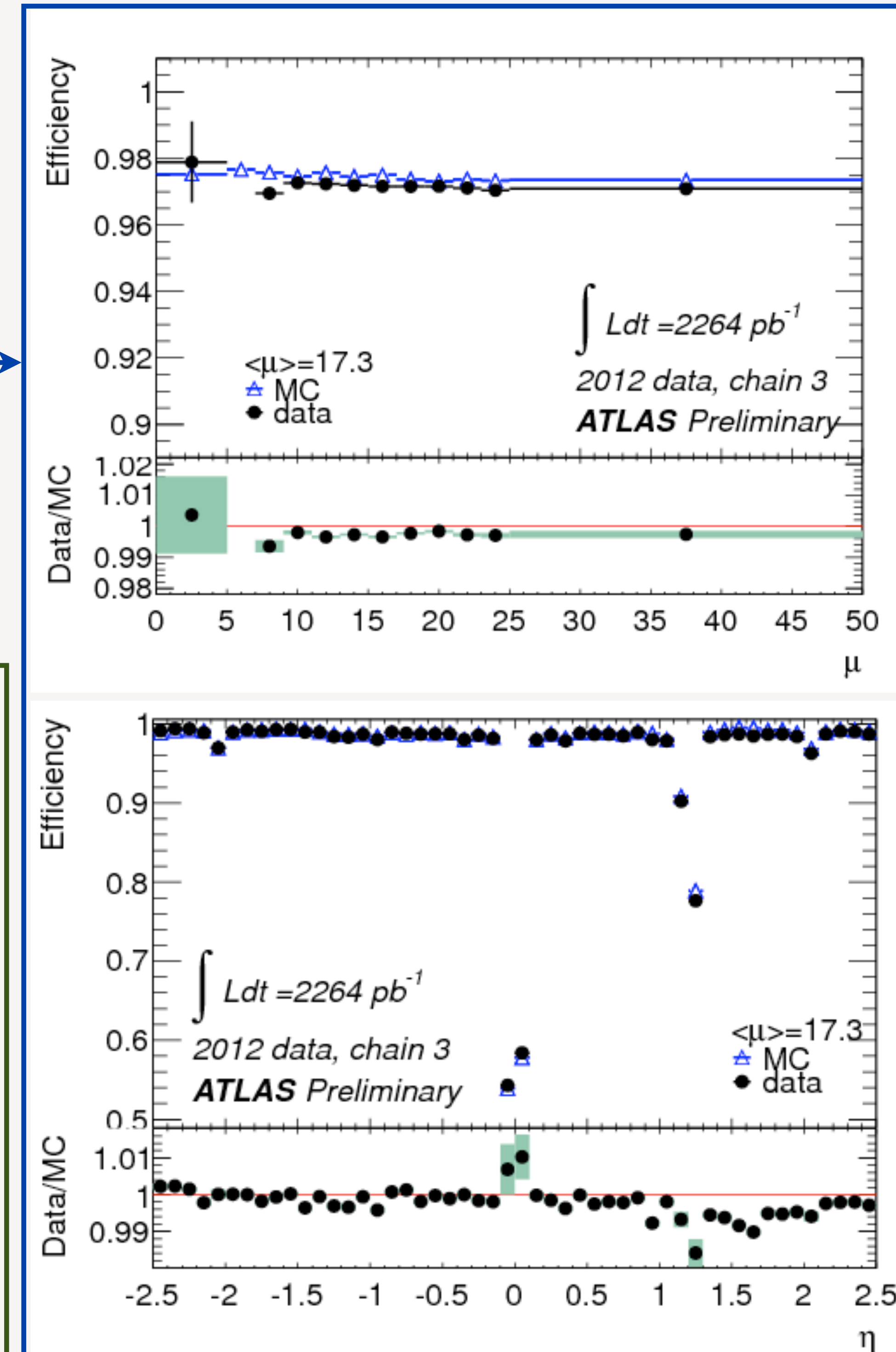
- No signs of evidence for BSM

Bonus Material

ATLAS and CMS - trigger & detector performance

- experiments run with > 95 % active channels
- MC simulation describes the data very well
- very robust reconstruction wrt pile-up, e.g. ATLAS μ combined reconstruction
- trigger systems & lepton isolation highly performing and well understood, e.g. CMS singly mu trigger & isolation wrt pile-up





Heavy flavor physics results rely on the full detector to work extremely well !

Inclusive B lifetime measurement

- Average B meson lifetime measurement with

$$B \rightarrow J/\psi\, X \rightarrow \mu^+\mu^-\, X$$

- excellent test of detector performance, and accurate reference measurements, e.g. CDF:

$$\tau_B = 1.526 \pm 0.034\ (\text{stat}) \pm 0.035\ (\text{syst})\ \text{ps}$$

- accessed through di-muon (partial) final state
- using pseudo-proper decay time

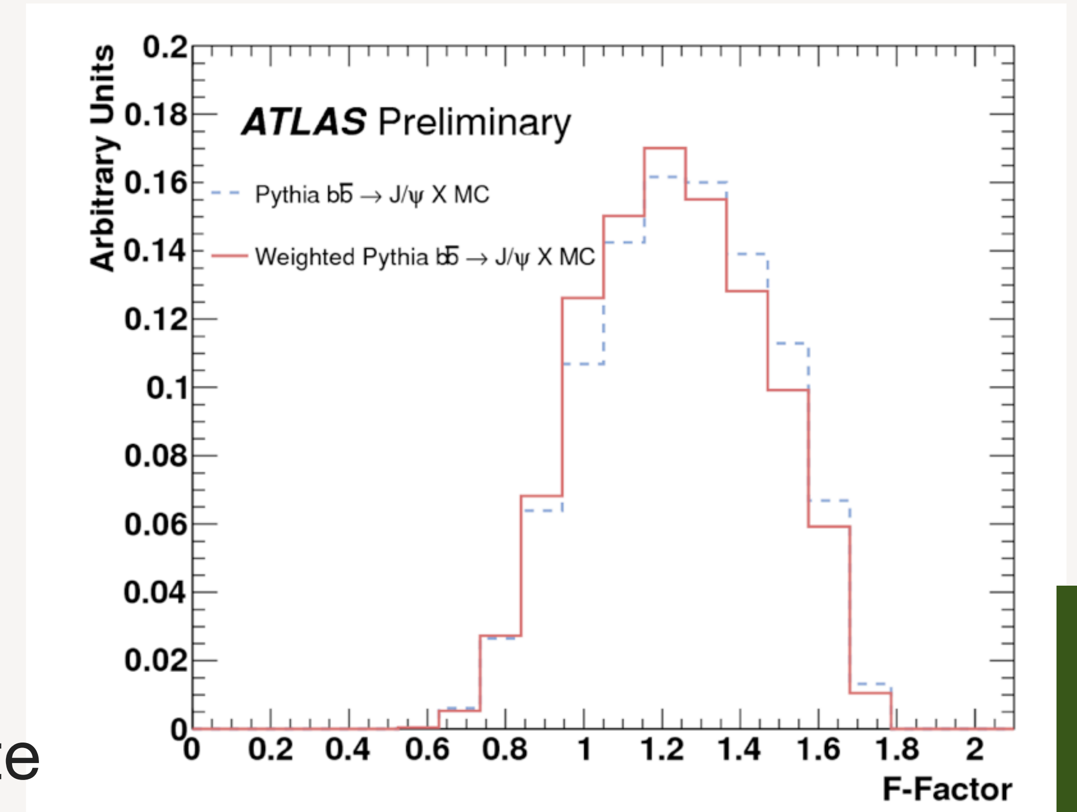
$$\tau_B = \frac{L_{xy} \cdot m_B^{PDG}}{p_T(B)} = \frac{L_{xy} \cdot m_{J/\psi}^{PDG}}{p_T(J/\psi)} \cdot F$$

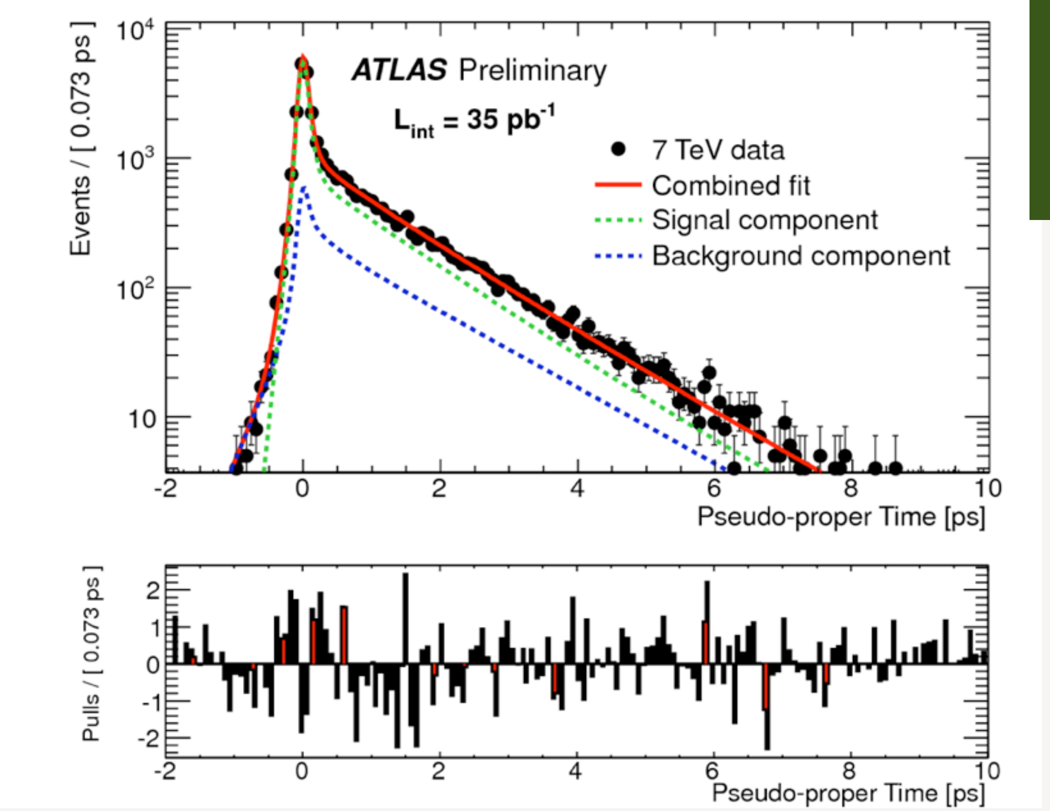
$$F = \frac{(\beta\gamma)_T^B}{(\beta\gamma)_T^{J/\psi}} = \frac{m_{PDG}^B \cdot p_T^{J/\psi}}{p_T^B \cdot m_{PDG}^{J/\psi}} \cdot \frac{1}{\cos\left(\Delta\phi(J/\psi - B)\right)}$$

taken from MC, weighted to BaBar data

$$\boxed{\tau_B = 1.489 \pm 0.016\ (\text{stat}) \pm 0.043\ (\text{syst})\ \text{ps}}$$

Good agreement with previous measurements

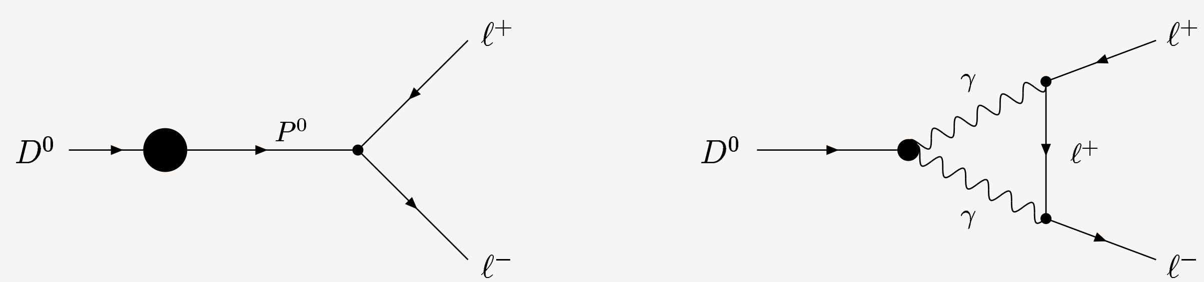




ATLAS-CONF-2011-145

Rare decays: $D^0 \rightarrow \mu^+\mu^-$ motivation & analysis

- Very rare FCNC process, extremely suppressed by SM



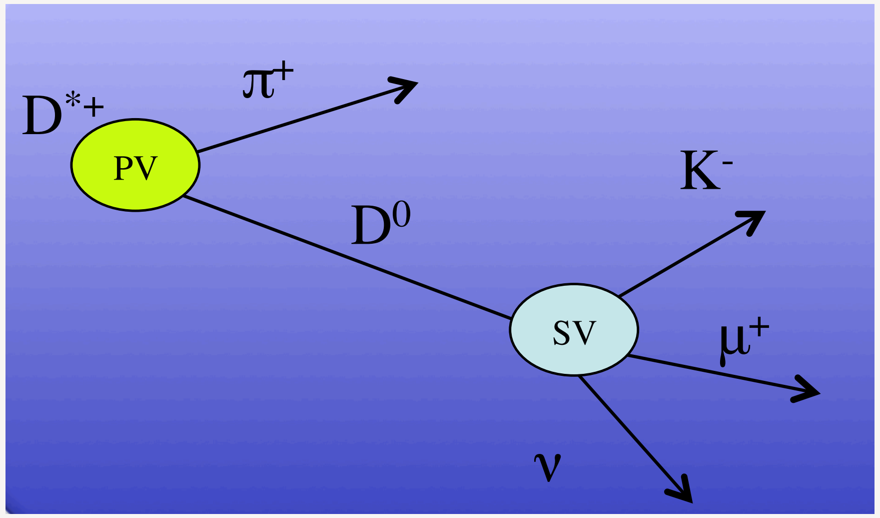
  - quoting Burdman et al (2008) when including long-range effects

generally, it scales as 2.7×10^{-5} times the branching ratio for $D^0 \rightarrow \gamma\gamma$. With the estimate $\mathcal{B}r_{D^0\rightarrow\gamma\gamma} \geq 10^{-8}$ arrived at in the previous section, we therefore anticipate a branching ratio for $D^0 \rightarrow \mu^+\mu^-$ of at least 3×10^{-13}.

- BR can be strongly enhanced when including NP phenomena
- Analysis strategy is the measurement of ratio

$$\frac{D^{*+}\rightarrow D^0(\mu^-\mu^+)\pi^+}{D^{*+}\rightarrow D^0(K^-\mu^+\nu)\pi^+}$$

- Many systematic uncertainties cancel in the ratio
- Both decays reconstructed topologically,
  for denominator D^0 direction needed to constrain **ν momentum** via PV pointing



CMS PAS BPH-11-017

Rare decays: $D^0 \rightarrow \mu^+\mu^-$ result

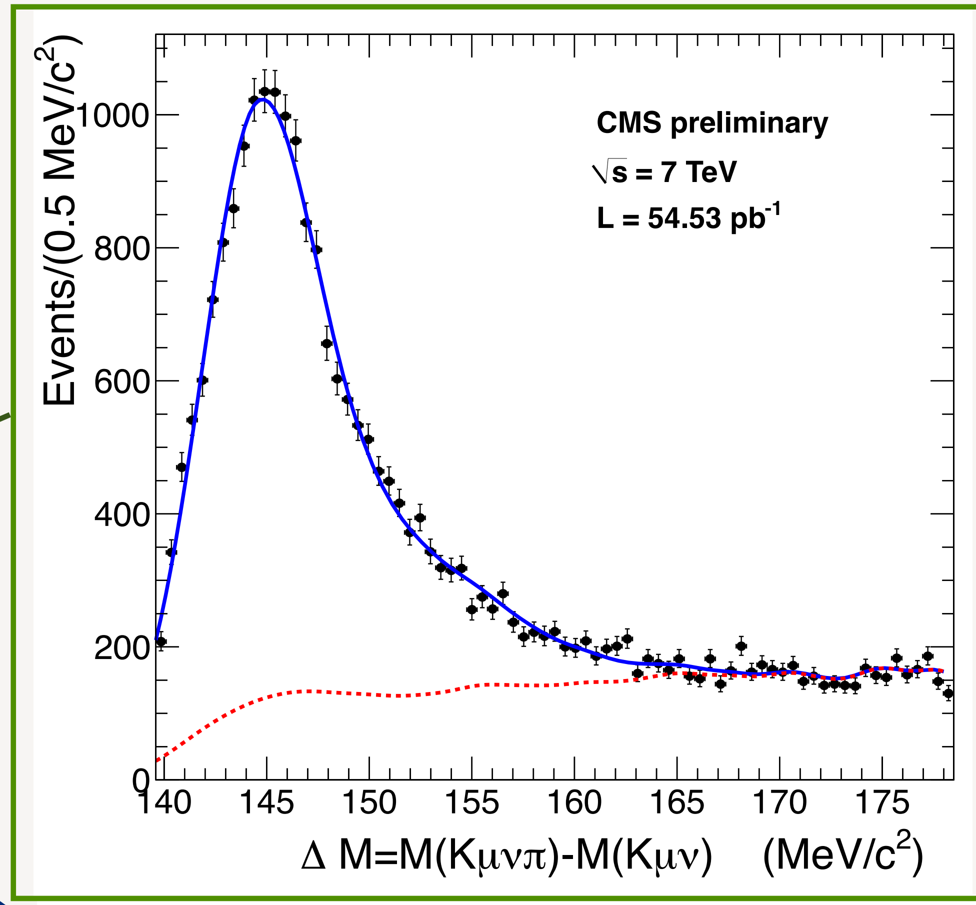
- building mass difference
  $\Delta M = M_{rec}(D^{*+}) - M_{rec}(D^0)$
- Signal window chosen with
  $|\Delta M - \Delta M_{PDG}| < 3$ MeV
  - N ($K\mu\nu\pi$) = 16458 ± 204 (from fit)
  - N ($\mu\mu$) = 23 (obs) / 23 (exp. background)

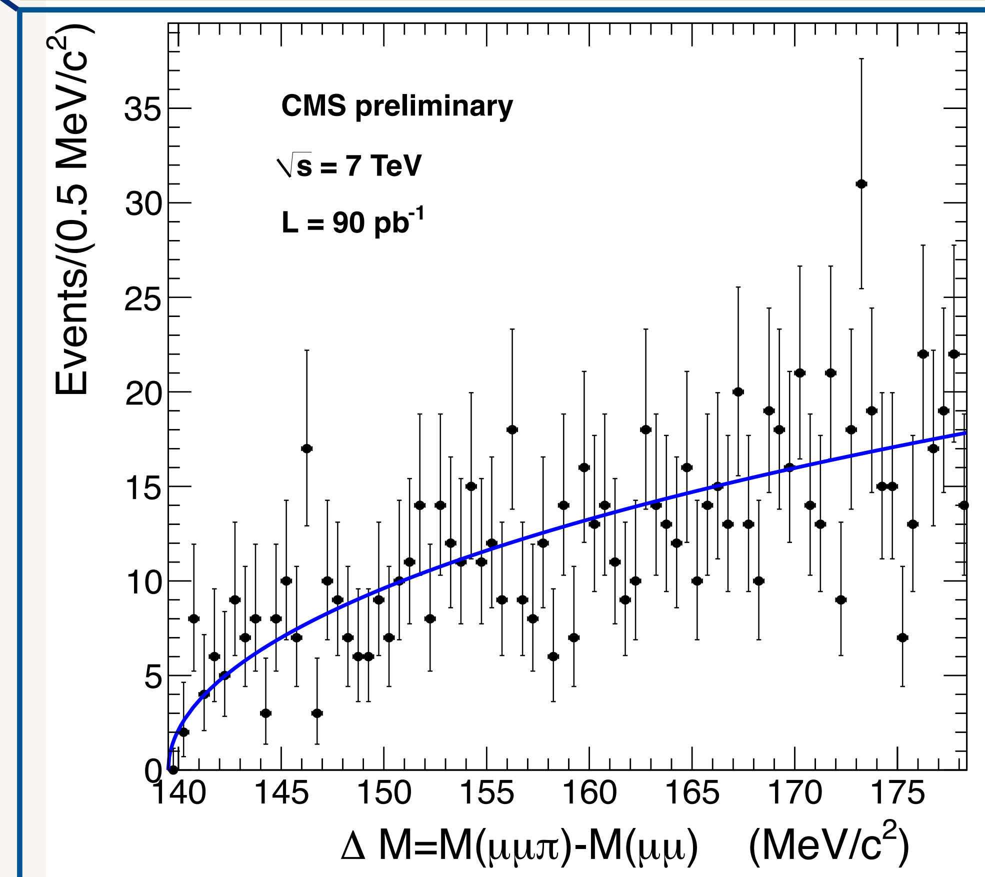
$$B(D^0 \to \mu^+\mu^-) \leq B(D^0 \to K^-\mu^+\nu) \times \frac{N(\mu\mu)}{N(K\mu\nu)} \times \frac{a(K\mu\nu)}{a(\mu\mu)} \times \frac{\epsilon_{\rm trig}(K\mu\nu)}{\epsilon_{\rm trig}(\mu\mu)} \times \frac{\epsilon_{\rm rec}(K\mu\nu)}{\epsilon_{\rm rec}(\mu\mu)}$$

Experiment	Upper limit at 90% CL
BABAR [13]	$< 1.3 \times 10^{-6}$
CDF [14]	$< 2.1 \times 10^{-7}$
BELLE [15]	$< 1.4 \times 10^{-7}$
this measurement	$< 5.4 \times 10^{-7}$

Best limit is from LHC*b*, at the 95% CL:

$$\mathcal{BR}(\mathbf{D^0} \to \mu^+\mu^-) \leq \mathbf{1.3 \times 10^{-8}}$$





CMS PAS BPH-11-017