b-physics with ATLAS and CMS

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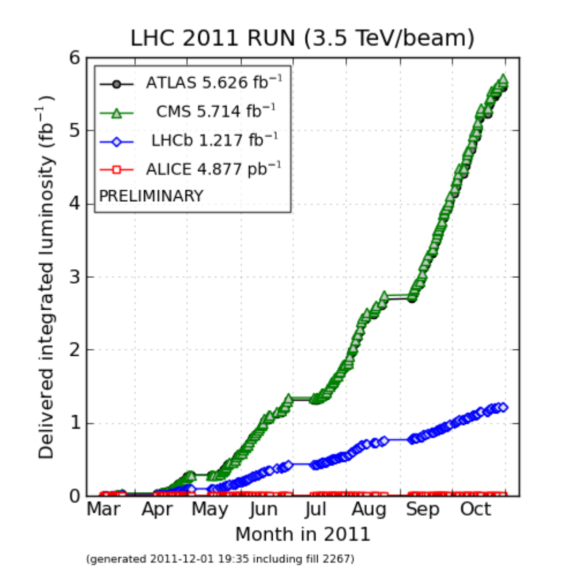
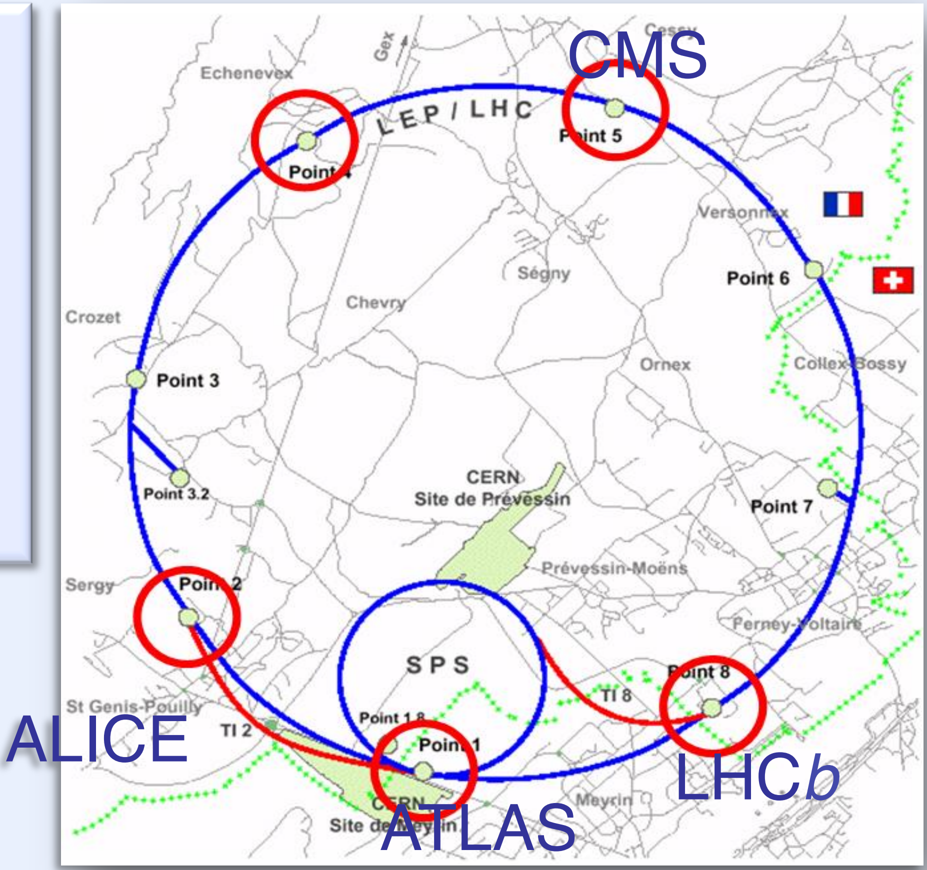
b-physics at the LHC

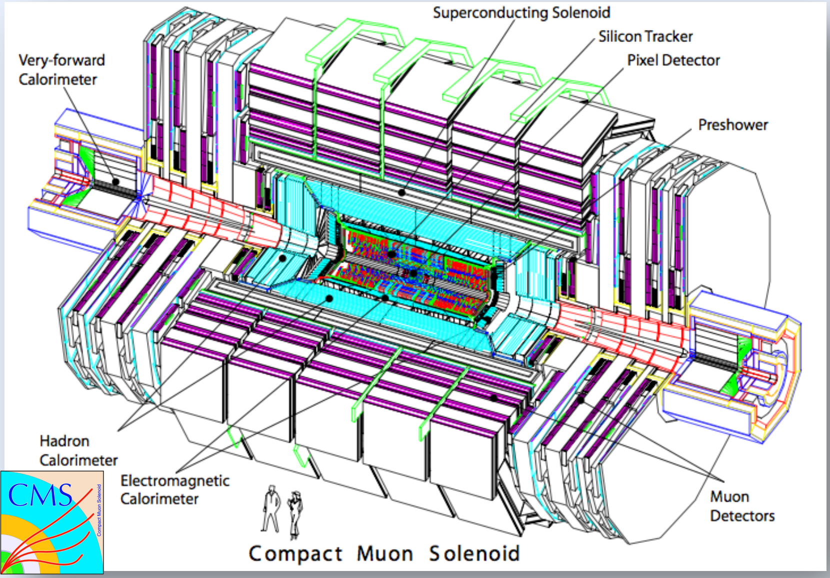
- World's highest energy and luminosity hadron collider
- pp collisions at 7 (8) TeV
- High *B* production cross sections
  - Collected largest hadron collision samples of *B* mesons in 2011
  - Overtaken Tevatron statistics for *B* meson samples



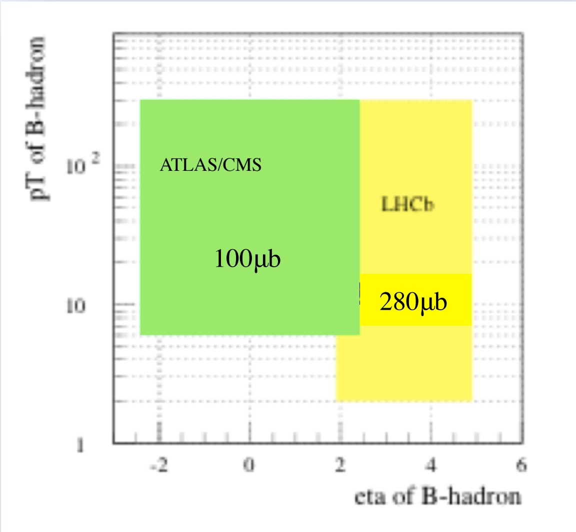


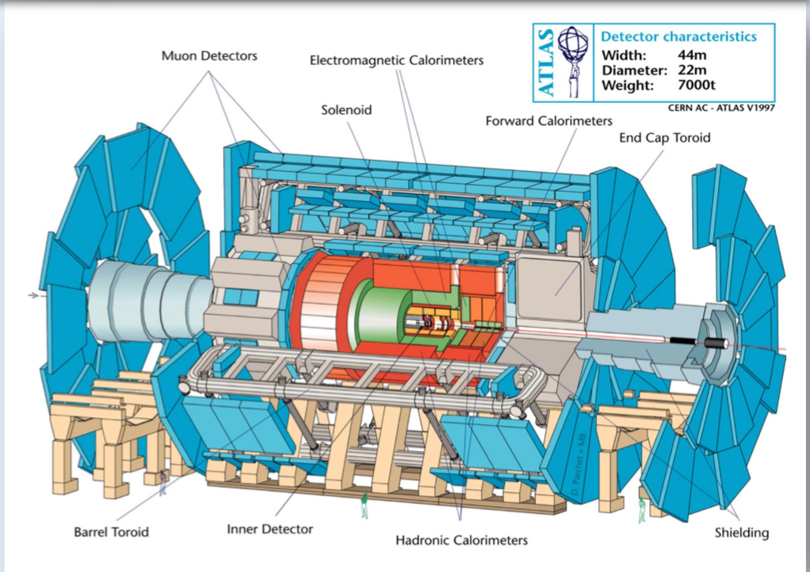
Delivered luminosity exceeded expectations for 2011 and continues to improve in 2012

ATLAS and CMS detectors



- General purpose detectors designed for high p_T studies
- Different p_T and eta range from LHC*b*
  - complementary *B* physics environments
- Rich *B* physics programmes at both experiments





Observations and lifetimes

- *B* lifetime measurements test the detector and reconstruction performance as well as preparing for CPV analyses

B meson observation and lifetimes

- With the 2010 data sample, ATLAS and CMS have demonstrated that *B* meson lifetimes can be accurately measured with the detector
- Very important component of the *CP* violation analysis in $B_s \to J/\psi\phi$

ATLAS-CONF-2011-092

$$m_{B_s} = (5363.7 \pm 1.2)\,\text{MeV}$$

$$\sigma_m = (24.8 \pm 1.2)\,\text{MeV}$$

$$\tau_{B_s} = (1.41 \pm 0.08 \pm 0.05)\,\text{ps}$$

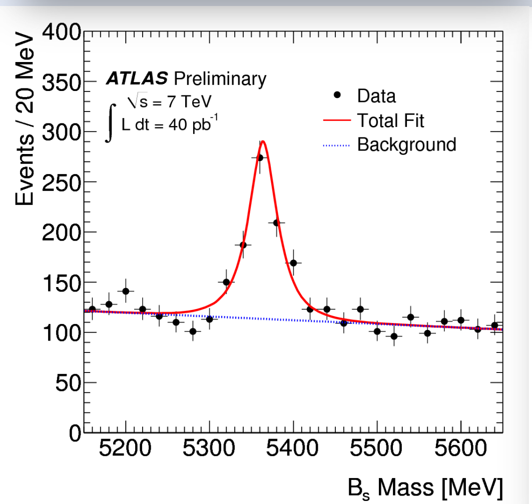
$$\tau_{PDG} = 1.472^{+0.024}_{-0.026}\ \text{ps}$$

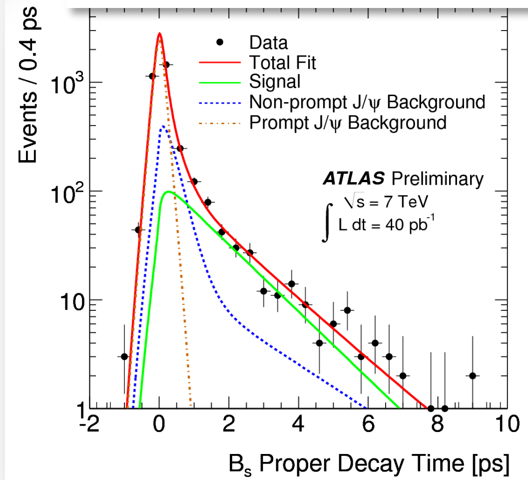
Phys.Rev.D 84, 052008 (2011)

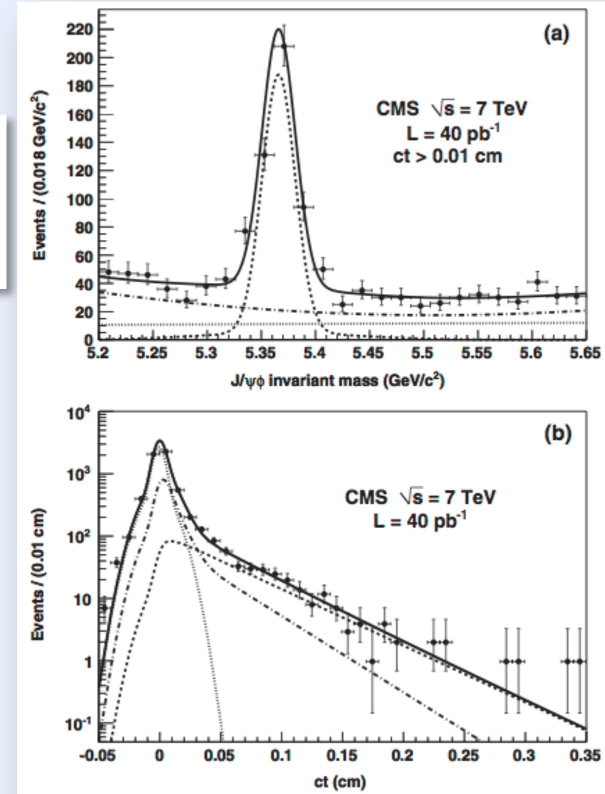
$\tau_{Bs} = 1.59 \pm 0.08$ ps (stat.)

$\mathcal{BR}(B_s \to J/\psi\phi)$ $6.9 \pm 0.6 \pm 0.6$ nb

($8 < p_T < 50$ GeV, $|y| < 2.4$)







- Parameterisations (e.g. backgrounds) tested in these analysis can be used directly in CP violation measurements

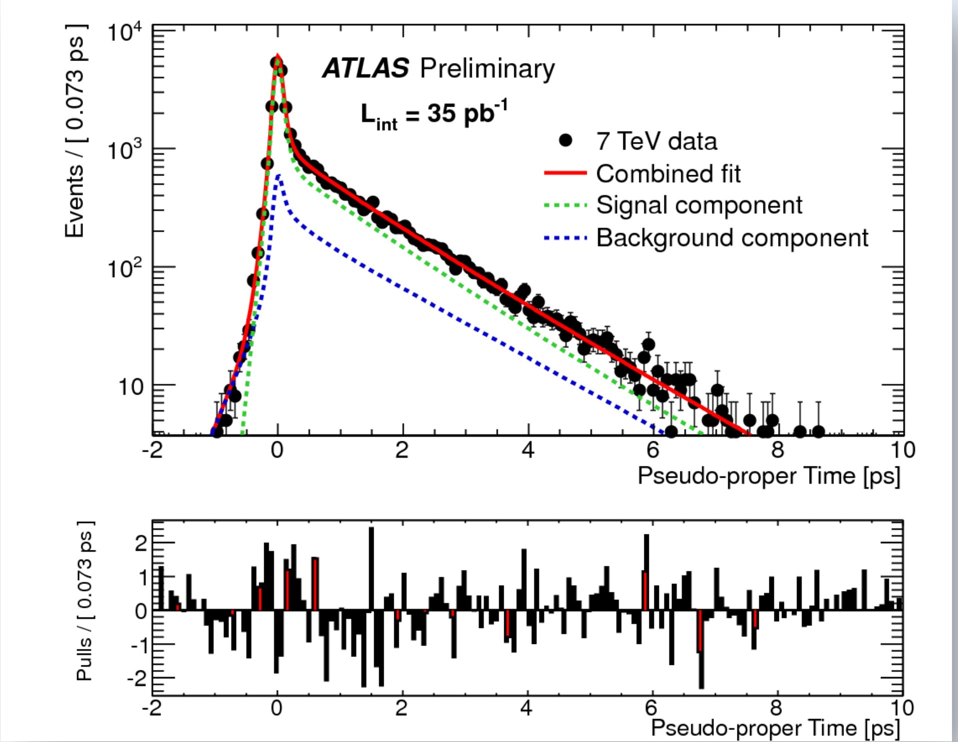
Inclusive B lifetimes ATLAS

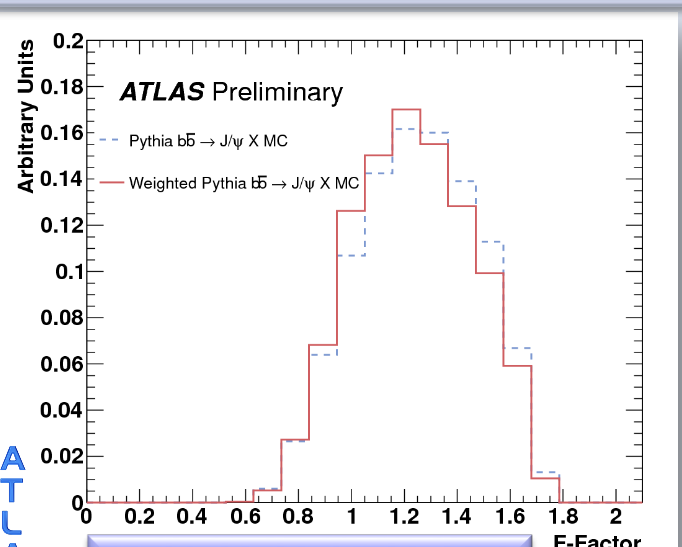
- Average *B* meson lifetime $\langle\tau_B\rangle$ measured in $B_x \rightarrow J/\psi X \rightarrow \mu^+\mu^- X$ decays

$\langle\tau_B\rangle$=1.489±0.016(stat.)±0.043(syst)ps

- Excellent test of detector calibration and performance
- c.f. CDF measurement:

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





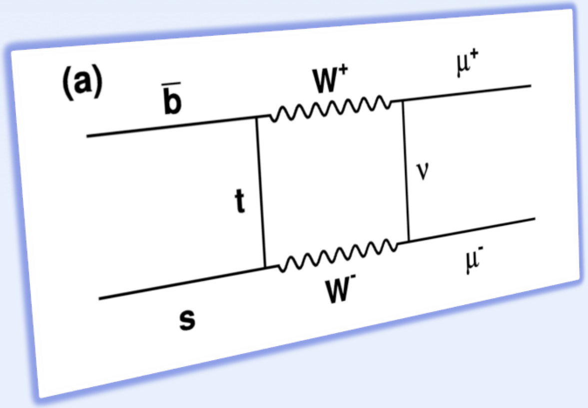
ATLAS-CONF-2011-145

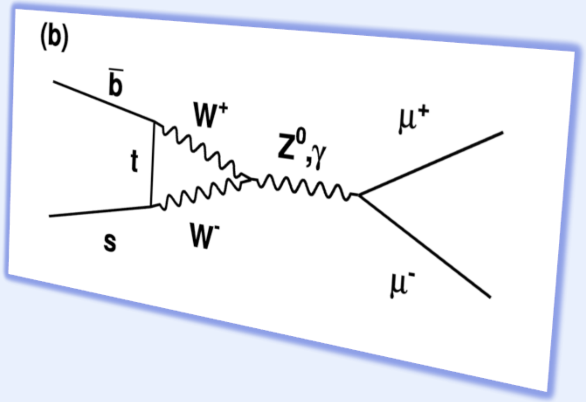
- Uses pseudo-proper decay time:

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

- F-factor is calculated from MC (weighted to BaBar data)

Rare decays: $B_{(s)} \to \mu\mu$





- CMS: arXiv:1203.3976 [hep-ex] (Accepted by JHEP)
- ATLAS: arXiv:1204.0735v2 [hep-ex] (Submitted to Phys.Lett.B)

$B_{(s)} \rightarrow \mu\mu$: Motivation

- Search for $B_s \rightarrow \mu\mu$ is an SM benchmark in flavour physics
- Can only occur through higher order FCNC diagrams (in SM)
- Good BSM probe:
  - small predicted SM cross section

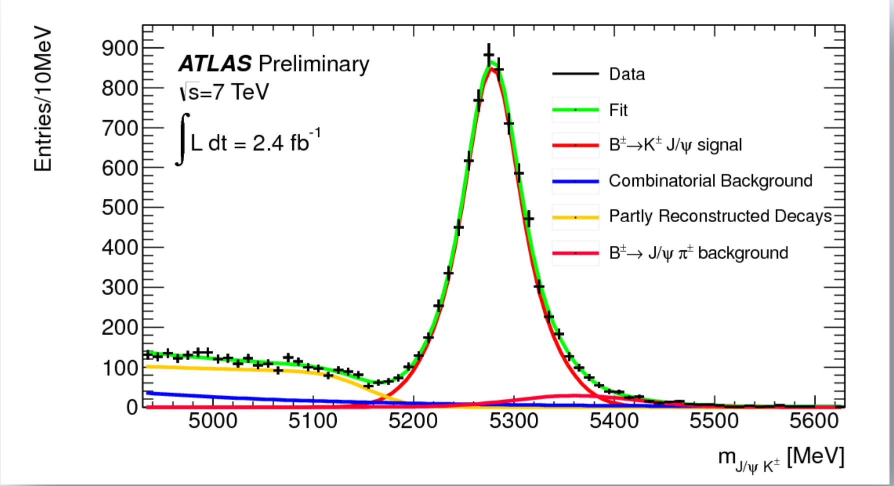
$$\mathcal{BR}(B_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

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

  - very low theoretical uncertainties
  - large class of BSM models predict large enhancements of $\mathcal{BR}(B_s \rightarrow \mu\mu)$
  - clean signature
  - ratio of $\mathcal{BR}(B_s \rightarrow \mu^+\mu^-)/\mathcal{BR}(B_d \rightarrow \mu^+\mu^-)$ can be used to discriminate between various BSM models

$B_{(s)} \rightarrow \mu\mu$: Searches

- Branching ratios measured relative to a high statistics reference channels
  - $B^+ \rightarrow J/\psi K^+$
  - $B_s \rightarrow J/\psi \phi$
- Main backgrounds are:
  - continuum μμ
    - estimated from mass sidebands
  - resonant backgrounds from misreconstructed decays
    - estimated using MC
- Differing event topology used to select signal like events with BDT or kinematic cuts



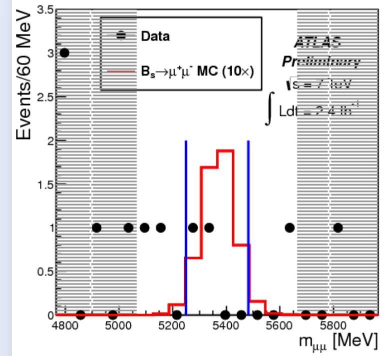
mass distribution of control sample

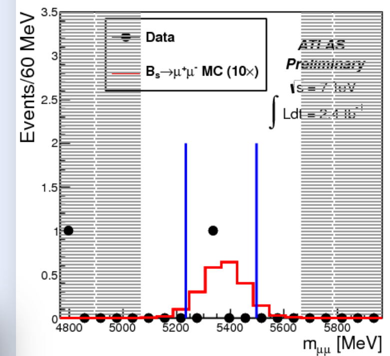
- High luminosity from the LHC important to this analysis

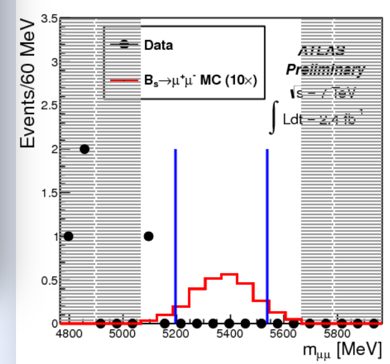
$B_{(s)} \to \mu\mu$: ATLAS results

- Signal selected by BDT combining kinematic and reconstruction variables
- BDT optimisation and background estimation using independent sample of sideband events to avoid bias on expected limit
- Measurement carried out in 3 η regions
- Plot show data passing selection cuts in signal regions
- 2.4 fb^{-1} data used in this analysis

$\lvert\eta\rvert_{\max}$ Range	0–1.0	1.0–1.5	1.5–2.5
SES$=(\epsilon\epsilon_i)^{-1}$ $[10^{-8}]$	0.71	1.6	1.4
$\epsilon=(f_s/f_u)/\mathrm{BR}(B^\pm\to J/\psi K^\pm\to\mu^+\mu^-K^\pm)$ $[10^3]$		4.45 ± 0.38	
$\epsilon_i=N_i^{B^\pm\to J/\psi K^\pm}/R^i_{A\epsilon}$ $[10^4]$	3.14 ± 0.17	1.40 ± 0.15	1.58 ± 0.26
bkg. scaling factor R_i^{bkg}	1.29	1.14	0.88
sideband count $N^{\mathrm{bkg}}_{\mathrm{obs},i}$ (even numbered events)	5	0	2
expected resonant bkg. $N_i^{B\to hh}$	0.10	0.06	0.08
search region count N_i^{obs}	2	1	0

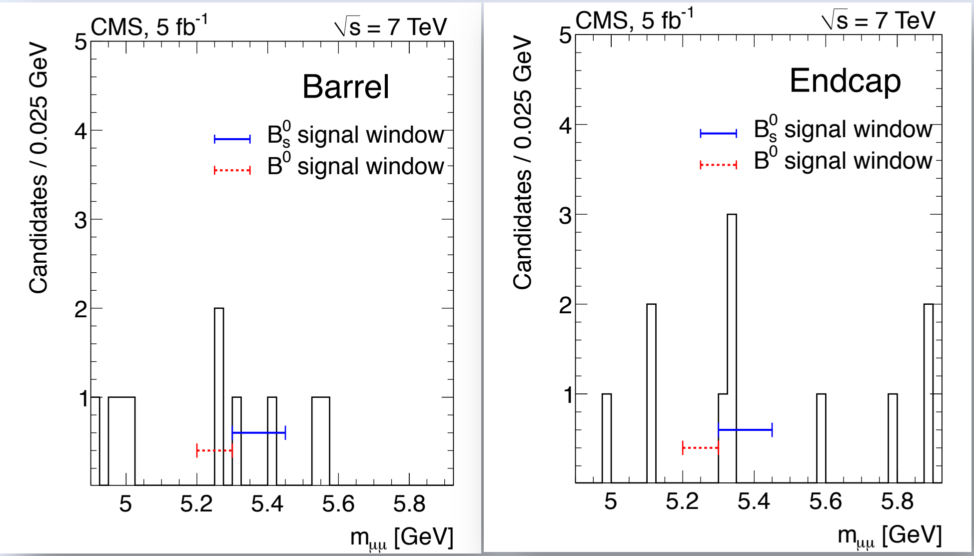






$B_{(s)} \rightarrow \mu\mu$: CMS results

- Signal selected by cuts on kinematic and reconstruction variables
- Measurement carried out in 2 detector regions then combined
- Plot shows data passing selection cuts in signal regions
- Full 2011 data sample of 5 fb^{-1}



Variable	$B^0 \to \mu^+\mu^-$ Barrel	$B^0_s \to \mu^+\mu^-$ Barrel	$B^0 \to \mu^+\mu^-$ Endcap	$B^0_s \to \mu^+\mu^-$ Endcap
ε_{tot}	0.0029 ± 0.0002	0.0029 ± 0.0002	0.0016 ± 0.0002	0.0016 ± 0.0002
N^{exp}_{signal}	0.24 ± 0.02	2.70 ± 0.41	0.10 ± 0.01	1.23 ± 0.18
N^{exp}_{peak}	0.33 ± 0.07	0.18 ± 0.06	0.15 ± 0.03	0.08 ± 0.02
N^{exp}_{comb}	0.40 ± 0.34	0.59 ± 0.50	0.76 ± 0.35	1.14 ± 0.53
N^{exp}_{total}	0.97 ± 0.35	3.47 ± 0.65	1.01 ± 0.35	2.45 ± 0.56
N_{obs}	2	2	0	4

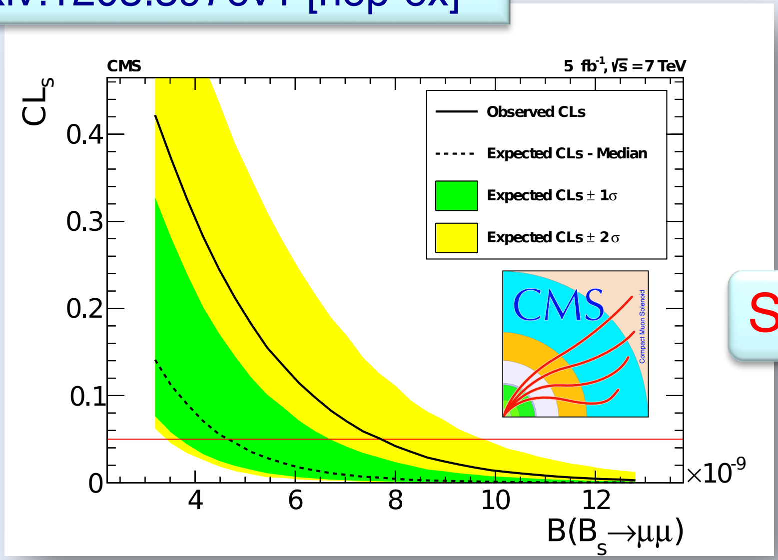
$B_{(s)} \to \mu\mu$: limits from ATLAS and CMS

- No evidence for anomalous signal
- Approaching SM sensitivity

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}

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

arXiv:1203.3976v1 [hep-ex]



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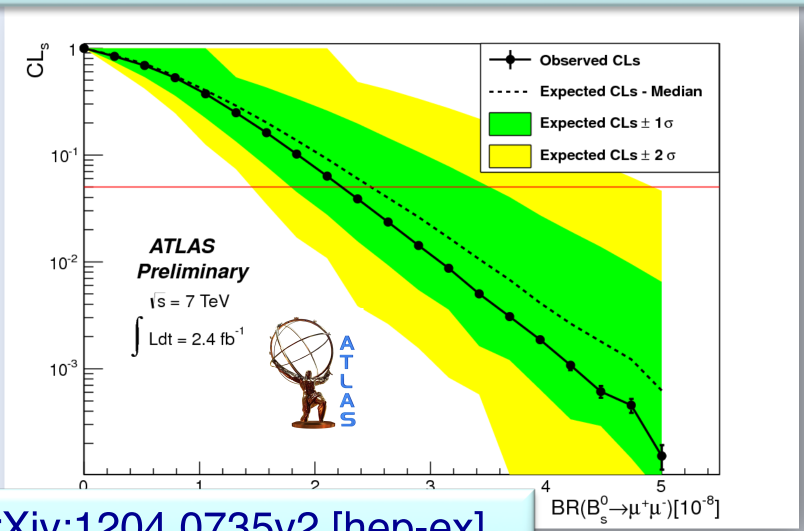
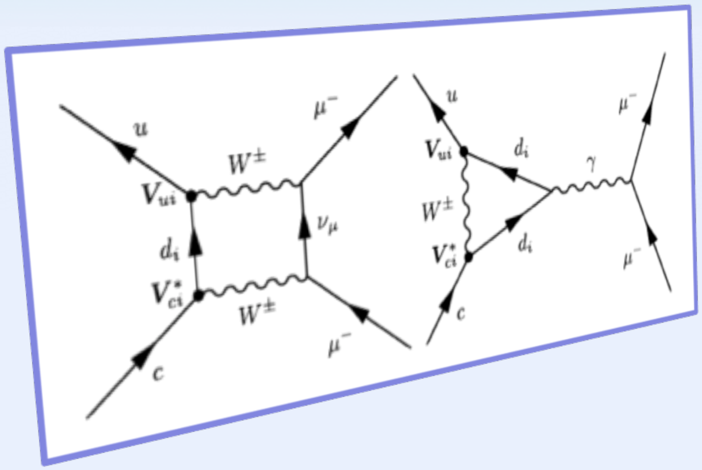
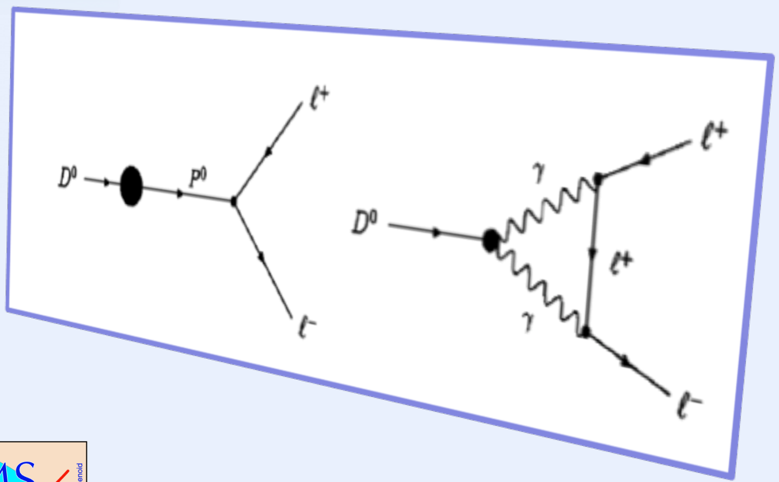


- CMS p-value for $B_s \to \mu^+\mu^-$ background only hypothesis: 6%
- CMS p-value for $B_s \to \mu^+\mu^-$ SM sig+bkg: 71%

Rare decay: $D^0 \rightarrow \mu^+\mu^-$



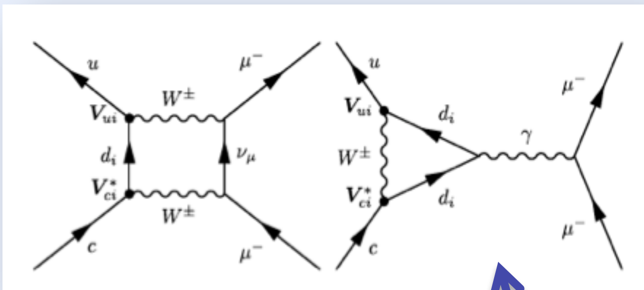


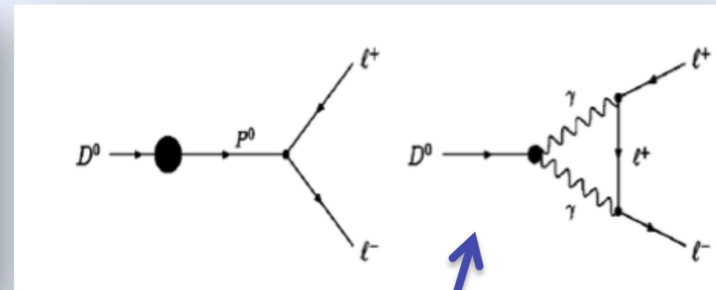
- New measurement from CMS
- First shown this month by Daniele Pedrini at Charm 2012:

http://www.phys.hawaii.edu/indico/getFile.py/access?contribId=10&sessionId=47&resId=0&materialId=slides&confId=338

Rare decay: $D^0 \rightarrow \mu\mu$

- Very rare FCNC process, heavily suppressed in the SM





$\mathcal{BR} \sim 10^{-18}$ (short distance) $\sim 10^{-13}$ (long distance)
[Burdnam et al.,Phys.Rev.D66:014009,2002]

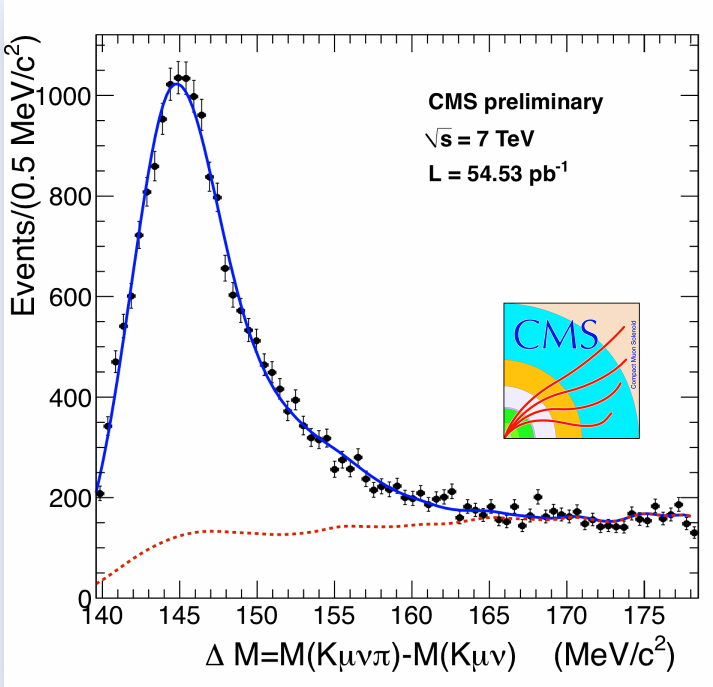
- NP models can enhance these fractions by orders of magnitude
- Search for FCNC in charm sector complementary to studies in *B* and *K* decays

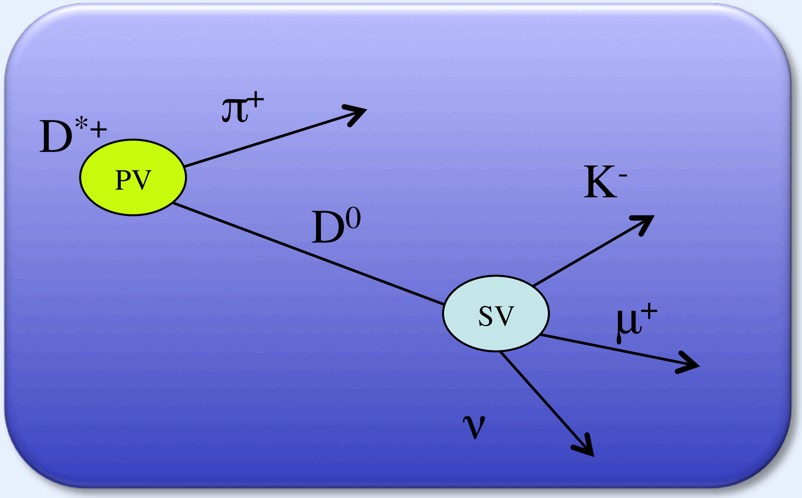
$D^0 \rightarrow \mu\mu$: Analysis method

- Branching fraction measured as a ratio with a kinematicly similar control mode:

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

- Many systematic uncertainties cancel
- Control channel yields 16458 ± 204 candidates
- 2010 and early 2011 data used

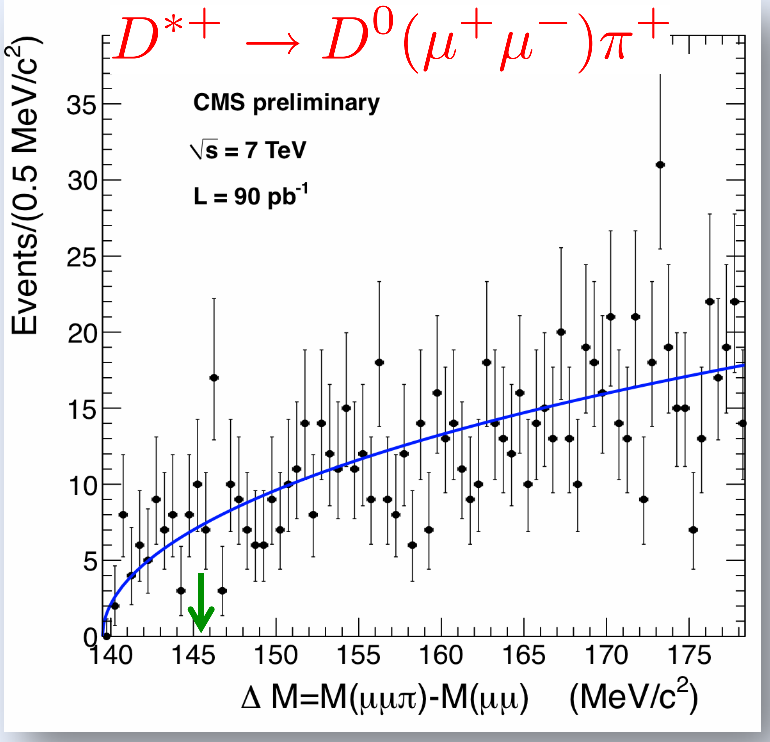


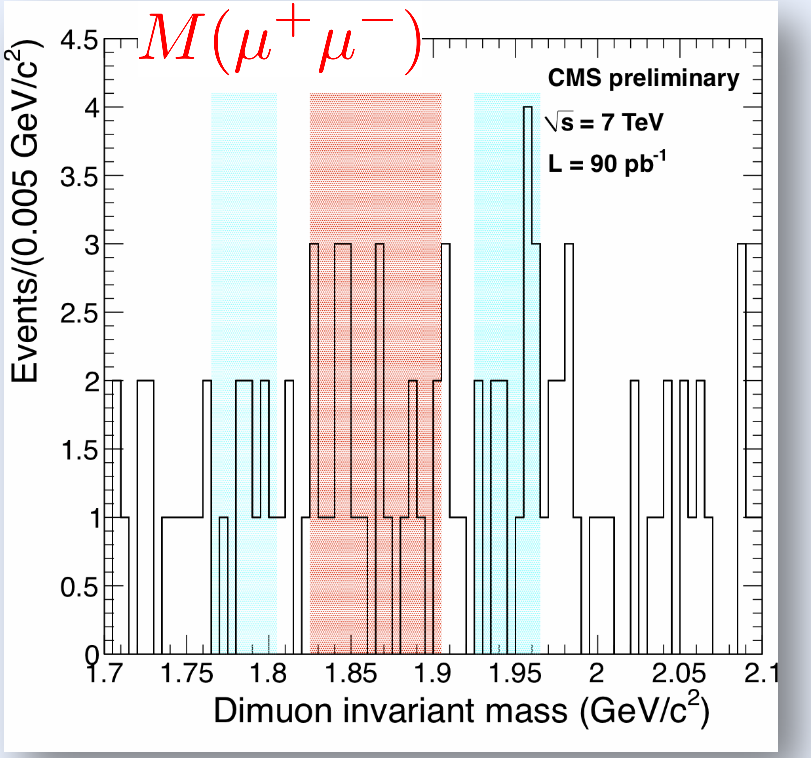


- Both decays reconstructed topologically
- Determine primary and secondary vertices
- D^0 candidate combined with one track from PV to form D^{*+}

$D^0 \to \mu\mu$: Results

- ΔM distribution shows no significant deviation from background
- PDG value marked with →





- $|\Delta M - \Delta M_{PDG}| < 3$ MeV required
- N_{obs} = 23 events (signal region)
- N_{bkg} = 23 events (sidebands)
- **No evidence of $D^0 \to \mu\mu$ from D^{*+}**

$D^0 \to \mu\mu$: Results

- No evidence for decay $D^0 \to \mu^+\mu^-$
- Upper limit set for branching ratio
- Contamination from peaking background $D^0 \to \pi^+\pi^-$ negligible due to very tight muon selection
- Background estimated from D^0 mass sidebands

$$\mathcal{BR}(\mathbf{D^0} \to \mu^+\mu^-) \leq$$
$$\mathcal{BR}(\mathbf{D^0} \to \mathbf{K}^-\mu^+\nu) \times \frac{\mathbf{N_{Data}}(\mu\mu)}{\mathbf{N_{Data}}(\mathbf{K}\mu\nu)}$$
$$\times \frac{\mathbf{a}(\mathbf{K}\mu\nu)}{\mathbf{a}(\mu\mu)} \times \frac{\epsilon_{\mathbf{trig}}(\mathbf{K}\mu\nu)}{\epsilon_{\mathbf{trig}}(\mu\mu)} \times \frac{\epsilon_{\mathbf{rec}}(\mathbf{K}\mu\nu)}{\epsilon_{\mathbf{rec}}(\mu\mu)}$$

- Taken from PDG
- Measured in CMS data
- Calculated from MC

- Using CL_s method, 90% CL is computed:

$$\mathcal{BR}(\mathbf{D^0} \to \mu^+\mu^-) \leq \mathbf{5.4 \times 10^{-7}}$$

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

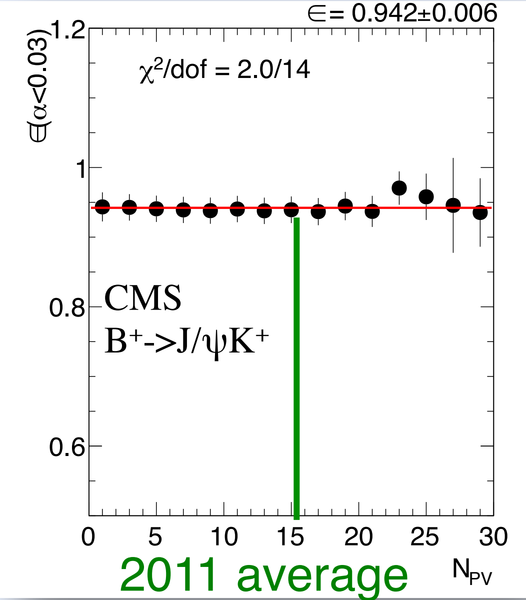
$$\mathcal{BR}(\mathbf{D^0} \to \mu^+\mu^-) \leq \mathbf{1.3 \times 10^{-8}}$$

Summary

- Wide ranging b-physics programmes on ATLAS and CMS
- High statistics and strong detector performance produce competitive results
- A few highlights shown in this talk
  - B lifetime measurements
  - Rare decays
    - $B \to \mu\mu$
    - $D^0 \to \mu\mu$
- Heavy flavour production covered in talk by S. Argiro in tomorrow's HF and QCD session
- See the b-physics public webpages for further results:
  - twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH
  - twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

Future:

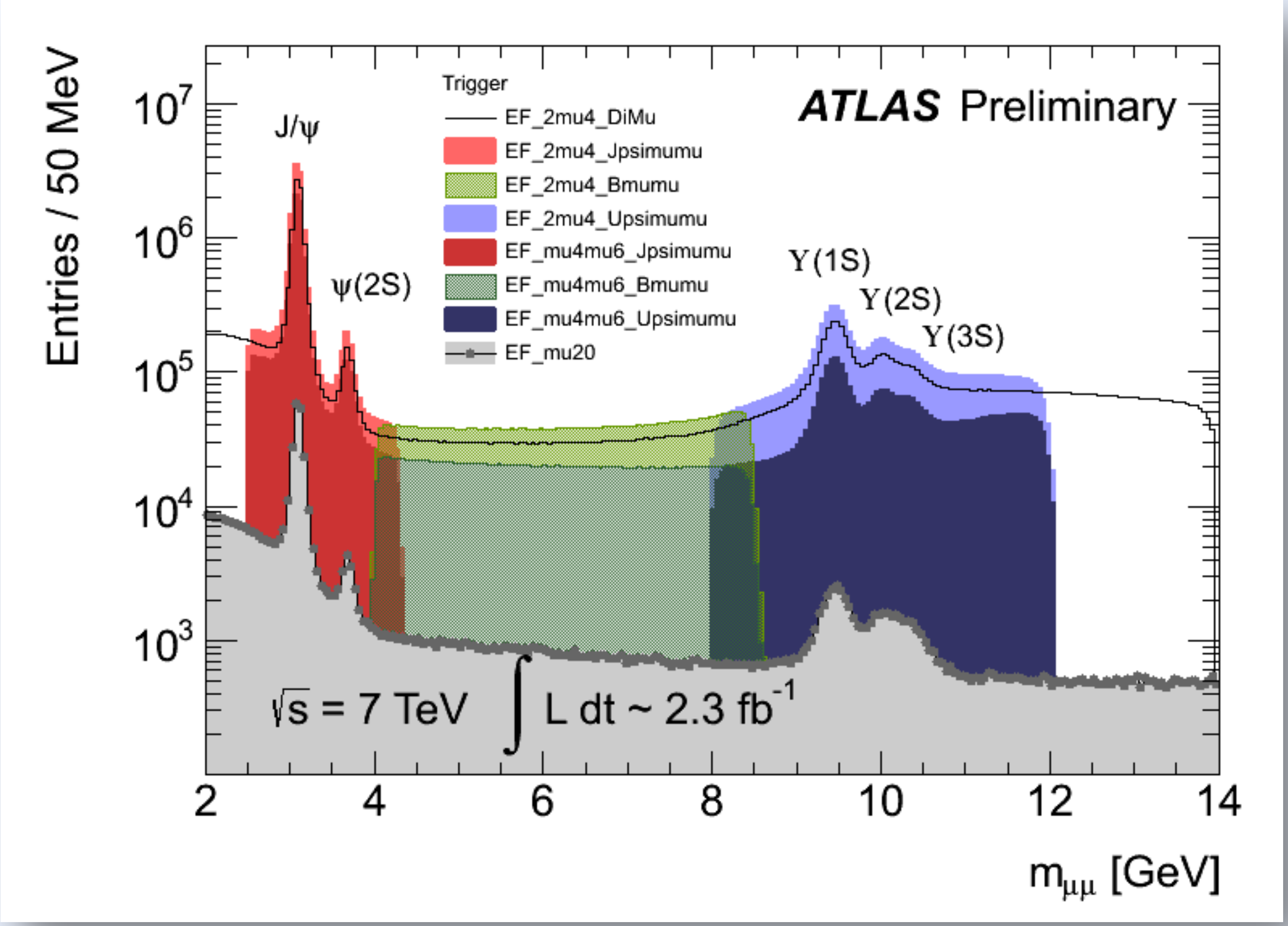
- Challenge for *B* physics is to use triggers efficiently
- Di-muon triggers will be prescaled
- Higher lumi -> greater pile-up, plot shows that selection efficiency is not affected for ≤ 20 primary vertices per event



Back up

Triggers

- Di-muon triggers provide clean selection of b-decays with two muons in final state
- Different triggers for specific di-muon resonances and continuum
- Rates adjusted with pre-scales or p_T thresholds



$B_{(s)} \to \mu\mu$: Analysis technique

- Major elements of the technique are the same for both experiments
- Differences discussed in later slides
- Rate of $B_s \to \mu\mu$ is measured relative to a control channel, $B^+ \to J/\psi K^+$, $J/\psi \to \mu\mu$ or $B_s \to J/\psi\phi$
- Many systematic uncertainties cancel when taking the ratio

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B+}} \frac{\epsilon^{trig}_{B+}}{\epsilon^{trig}_{B_s}} \frac{\epsilon^{reco}_{B+}}{\epsilon^{reco}_{B_s}} \frac{\alpha_{B+}}{\alpha_{B_s}} \frac{1}{\epsilon^{NN}_{B_s}} \frac{f_u}{f_s} \cdot \mathcal{BR}(B^+ \to J/\Psi K^+ \to \mu^+\mu^- K^+)$$

From Data, From MC, From PDG

$$N_{B+} \approx 2 \times 10^4$$

$$\frac{\epsilon^{trig}_{B+}}{\epsilon^{trig}_{B_s}} \approx 1$$

$$\frac{\epsilon^{reco}_{B+}}{\epsilon^{reco}_{B_s}} \approx 1$$

$$\frac{\alpha_{B+}}{\alpha_{B_s}} \approx 0.5$$

$$\frac{1}{\epsilon^{NN}_{B_s}} \approx 1$$

$$\frac{f_u}{f_s} \approx 3$$

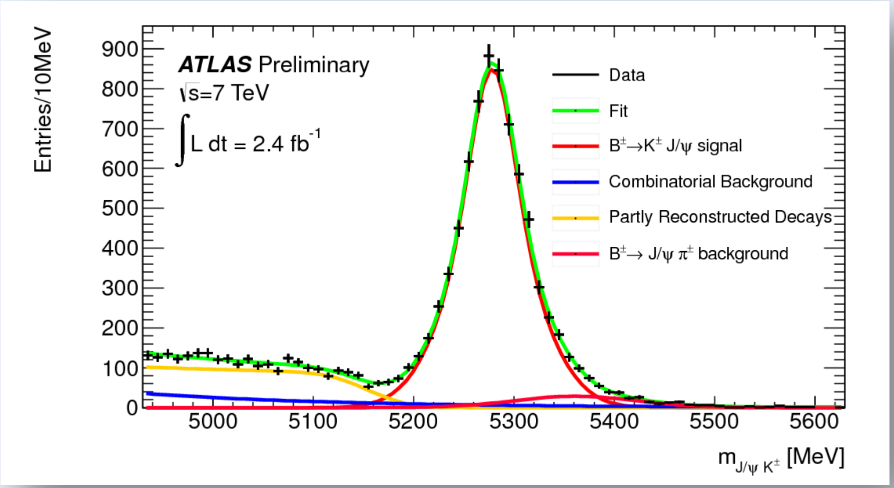
$$\mathcal{BR}(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+) \approx 5 \times 10^{-5}$$

$B_{(s)} \rightarrow \mu\mu$: Background rejection

Signal is fully reconstructed, long lived decay

Background can be made up of:

- Semi-leptonic decay:
  - $b \rightarrow c\mu^- X \rightarrow \mu^+\mu^- Y$
- Double semi-leptonic decay:
  - $bb \rightarrow \mu^+\mu^- X$
- μ+fake, fake + fake
- continuum $\mu^+\mu^-$
- $B \rightarrow$ hadrons (peaking in B mass signal region)



mass distribution of control sample

Background is generally softer, short lived, not fully reconstructed, more tracks