

Search for New Physics in Rare and Semi-Rare Decays of B- Mesons in ATLAS



Iskander Ibragimov



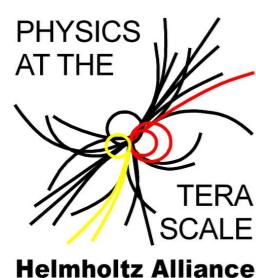
on behalf of the ATLAS Collaboration



SPONSORED BY THE



Federal Ministry
of Education
and Research



The 38th International Conference on High Energy Physics

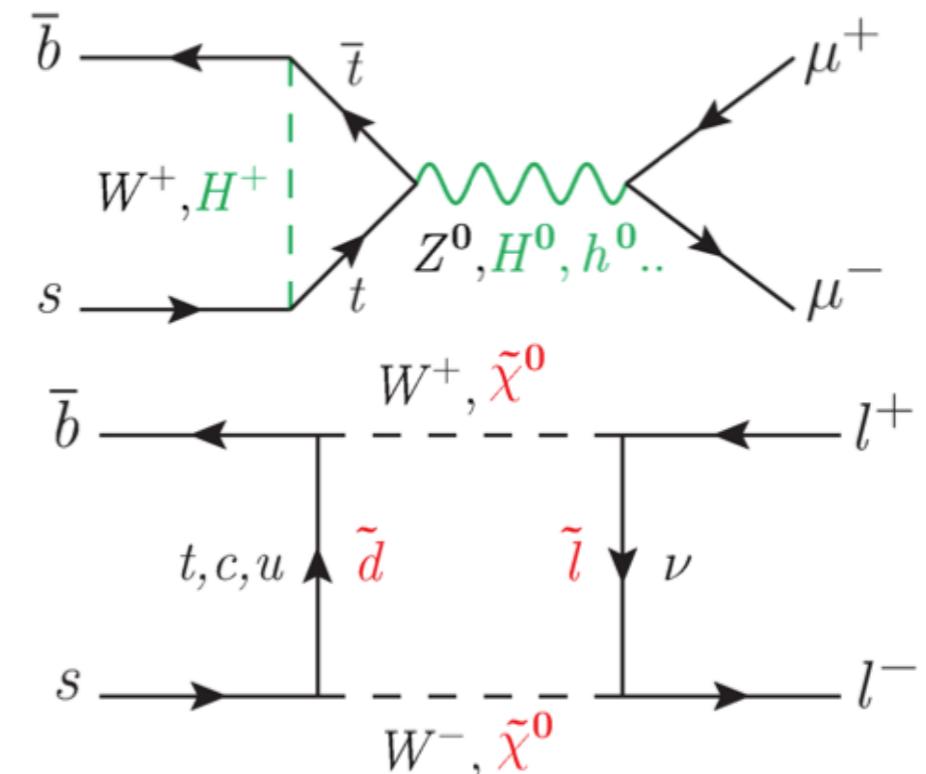
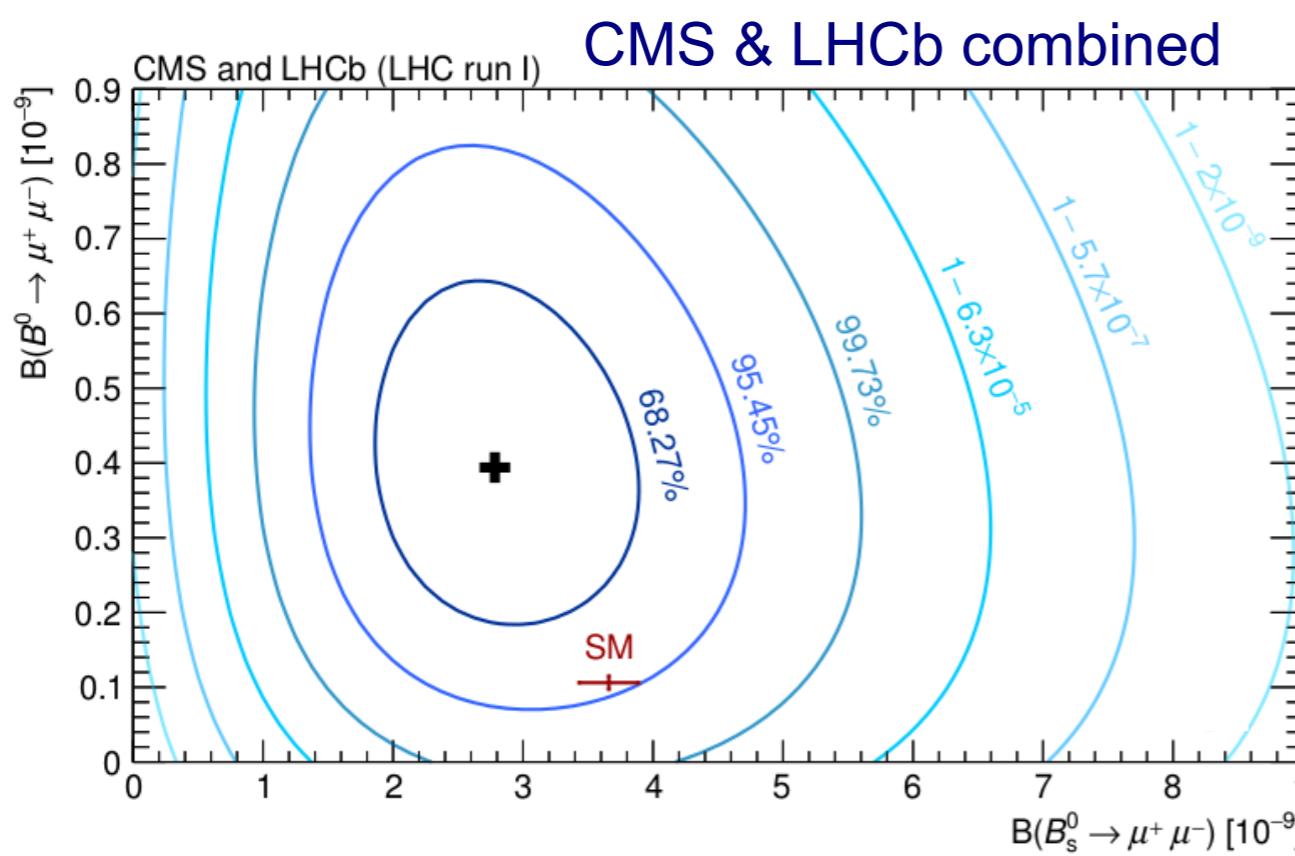
Sheraton Grand Chicago
August 03-10 2016, Chicago



$B^0_{s(d)} \rightarrow \mu^+ \mu^-$: Introduction

- ▶ strongly suppressed in the SM
 - flavor changing neutral current (FCNC) process
 - helicity suppression
- ▶ coupling to non-SM particles can affect BR
→ powerful indirect search for New Physics
- ▶ SM expectations accurately predicted:
 - $\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (3.65 \pm 0.23) \times 10^{-9}$
 - $\text{BR}(B^0 \rightarrow \mu^+ \mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

[C. Bobeth et al., PRL 112 (2014) 101801]

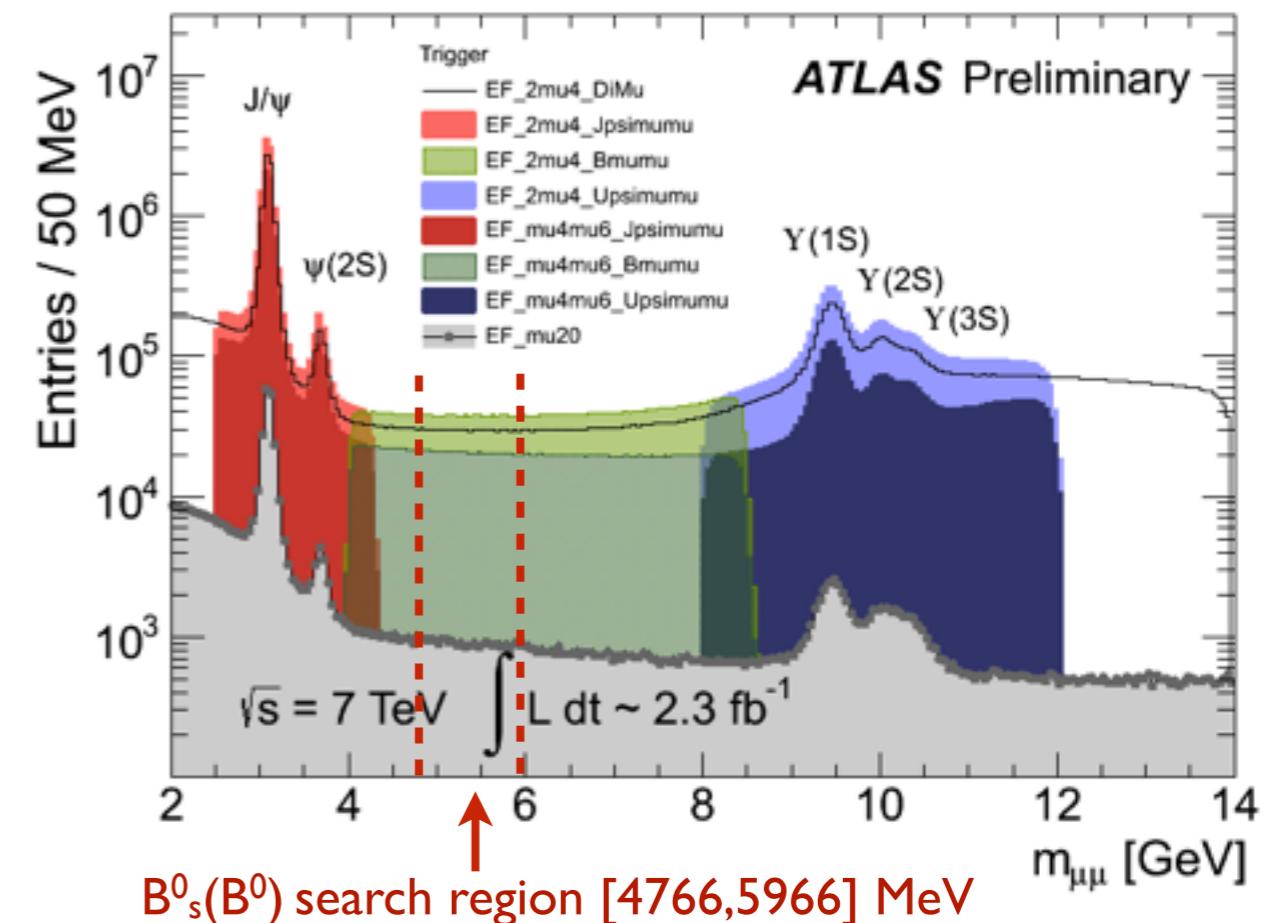


- ▶ Run I CMS & LHCb combination
 - $\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$
 - $\text{BR}(B^0 \rightarrow \mu^+ \mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$

[Nature 522 (2015) 68-72]

ATLAS $B^0_{s(d)} \rightarrow \mu^+\mu^-$ Run I Data

- ▶ excellent data taking efficiency and quality of data
- ▶ luminosity/number of reco'ed PV
 - in 2011 ($E_{CMS} = 7 \text{ TeV}$) 4.9 fb^{-1} / 6.2
 - in 2012 ($E_{CMS} = 8 \text{ TeV}$) 20 fb^{-1} / 11.4
- ▶ selection with di-muon triggers
 - ▶ at first trigger level:
 - 2011: two μ with $p_T(\mu) > 4 \text{ GeV}$
 - 2012: $p_T(\mu) > 4 \text{ GeV}$ and 6 GeV , one μ with $|\eta| < 1.05$ (barrel)
 - ▶ at higher trigger levels:
 - full track reconstruction and loose mass selection
- ▶ data split into four mutually exclusive data categories based on trigger and E_{CMS}



Analysis Strategy

- ▶ relative BR measurement (to $B^\pm \rightarrow J/\psi K^\pm$ reference channel)
 - partial cancelation of uncertainties (luminosity, cross-section, ...)

Analysis Strategy

► relative BR measurement (to $B^\pm \rightarrow J/\psi K^\pm$ reference channel)

- partial cancelation of uncertainties (luminosity, cross-section, ...)

[ATLAS: [PRL 115(2015)262001]]

$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \times [\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)] \times \frac{f_u}{f_{d(s)}} \times \frac{1}{\mathcal{D}_{\text{norm}}}$$

$N_{d(s)}$ is highlighted with a green box and has an arrow pointing to it from a box labeled $B_{(s)}^0$ yield from ML fit to $m_{\mu\mu}$ data.

$\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)$ is highlighted with a blue box and has an arrow pointing to it from a box labeled [world averages, PDG 2014].

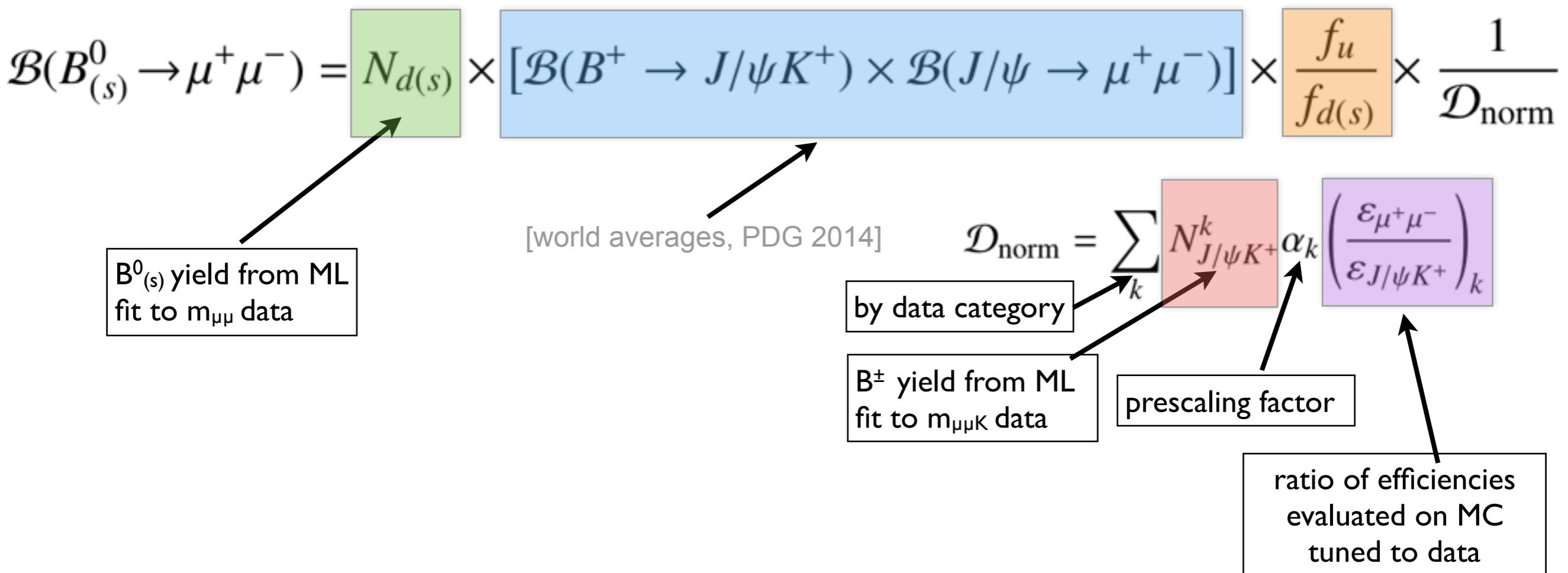
$\frac{f_u}{f_{d(s)}}$ is highlighted with an orange box and has an arrow pointing to it from the text [ATLAS: [PRL 115(2015)262001]].

Analysis Strategy

► relative BR measurement (to $B^\pm \rightarrow J/\psi K^\pm$ reference channel)

- partial cancelation of uncertainties (luminosity, cross-section, ...)

[ATLAS: [PRL 115(2015)262001]]



Analysis Strategy

- ▶ relative BR measurement (to $B^\pm \rightarrow J/\psi K^\pm$ reference channel)

- partial cancelation of uncertainties (luminosity, cross-section, ...)

[ATLAS: [PRL 115(2015)262001]]

$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \times [\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)] \times \frac{f_u}{f_{d(s)}} \times \frac{1}{\mathcal{D}_{\text{norm}}}$$

- ▶ enhance S/B ratio by using MVA technique (BDT)

- continuum-BDT (c-BDT) against combinatorial background
- fake muon-BDT (fm-BDT) against hadron misidentification

- ▶ keep S/B discrimination unbiased

- use independent dataset for c-BDT training (MC modelling of background)
- blind analysis - region **[5166,5526] MeV blinded**
- check Data/MC agreement on $B^\pm \rightarrow J/\psi K^\pm$ and $B_s^0 \rightarrow J/\psi \Phi, \Phi \rightarrow K^+ K^-$

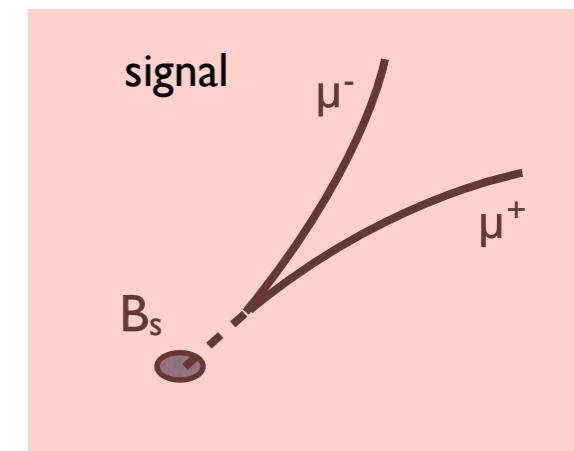
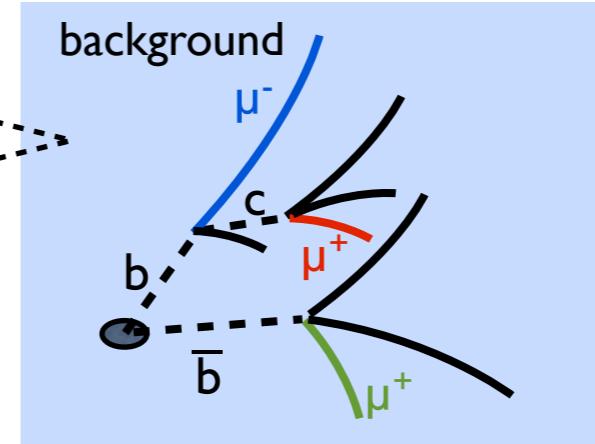
- ▶ signal extraction with ML fit over $m_{\mu\mu}$ in three intervals of c-BDT

Background Composition

combinatorics (from real muons)

- dominated by $b\bar{b} \rightarrow \mu^+\mu^-X$
- modelled with dedicated 1.4 G events MC
 - uncorrelated decays of b-(c-) (and c.c.) hadrons, forced into μ final states

small mass dependence over entire search region

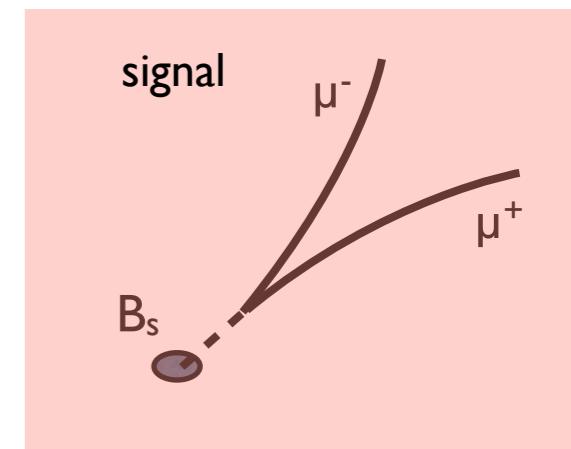
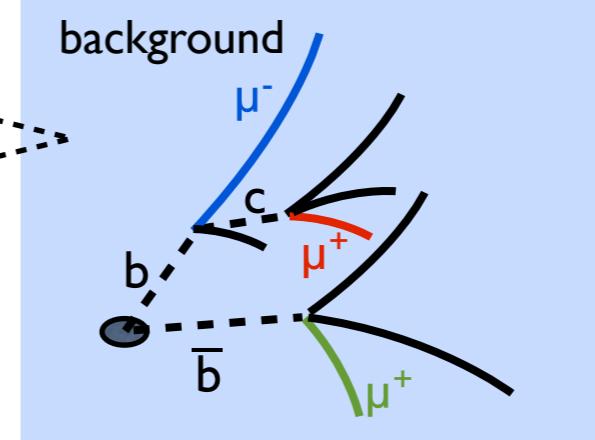


Background Composition

combinatorics (from real muons)

- dominated by $b\bar{b} \rightarrow \mu^+\mu^-X$
- modelled with dedicated 1.4 G events MC
 - uncorrelated decays of b-(c-) (and c.c.) hadrons, forced into μ final states

small mass dependence over entire search region

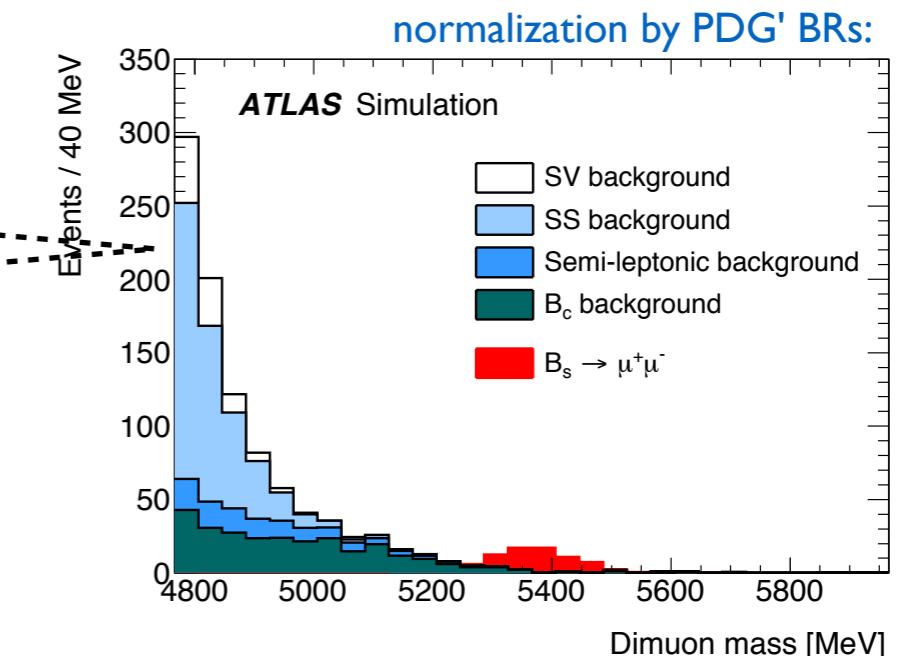


partially reconstructed $B \rightarrow \mu\mu X$ decays

- Same Vertex (SV), e.g. $B^0 \rightarrow K^*\mu\mu$
- Same Side (SS), semi-leptonic decay cascades
 - $b \rightarrow c\mu\nu \rightarrow s(d)\mu\mu\nu\nu$
- $B_c^\pm \rightarrow J/\psi\mu^\pm\nu \rightarrow \mu^\pm\mu^+\mu^-\nu$ decay

semi-leptonic $B_{(s)} \rightarrow \mu h\nu$

populate mainly left sideband

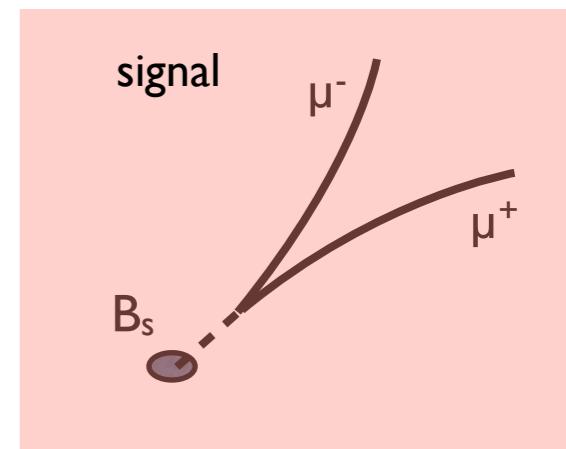
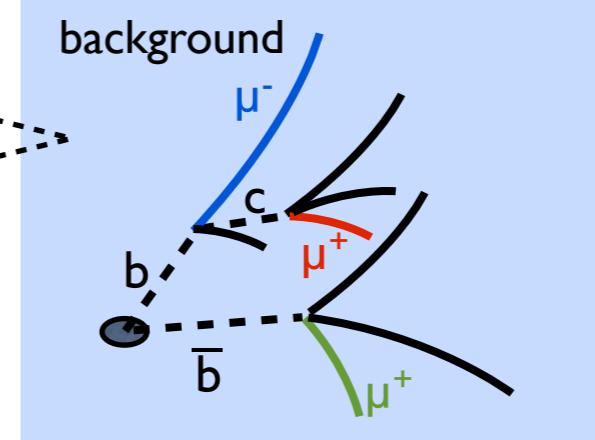


Background Composition

combinatorics (from real muons)

- dominated by $b\bar{b} \rightarrow \mu^+\mu^-X$
- modelled with dedicated 1.4 G events MC
 - uncorrelated decays of b-(c-) (and c.c.) hadrons, forced into μ final states

small mass dependence over entire search region



partially reconstructed $B \rightarrow \mu\mu X$ decays

- Same Vertex (SV), e.g. $B^0 \rightarrow K^*\mu\mu$
- Same Side (SS), semi-leptonic decay cascades
 $b \rightarrow c\mu\nu \rightarrow s(d)\mu\mu\nu\nu$
- $B_c^\pm \rightarrow J/\psi\mu^\pm\nu \rightarrow \mu^\pm\mu^+\mu^-\nu$ decay

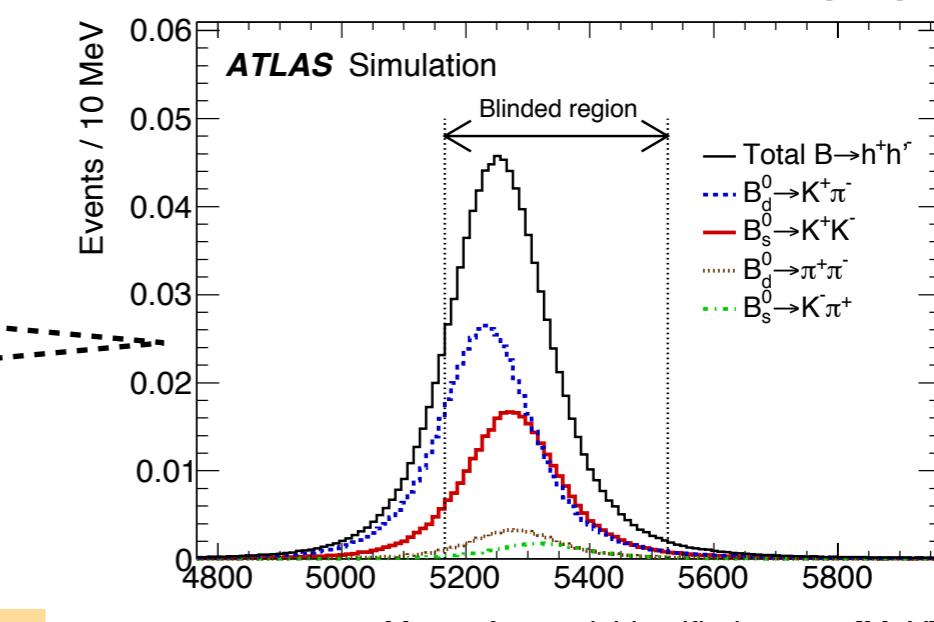
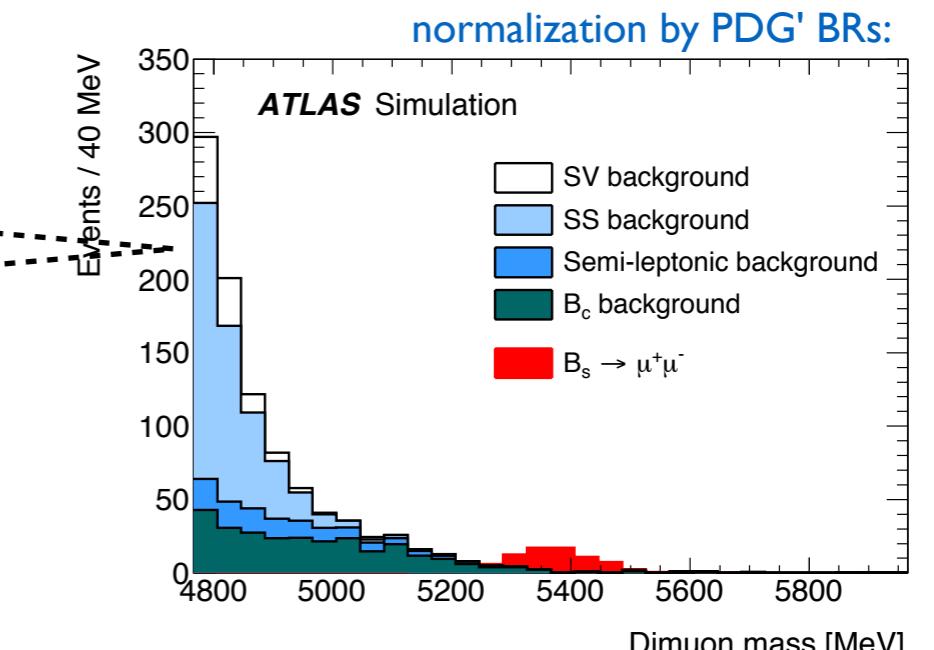
semi-leptonic $B_{(s)} \rightarrow \mu h\nu$

populate mainly left sideband

peaking $B \rightarrow hh'$ ("fake" + "fake")

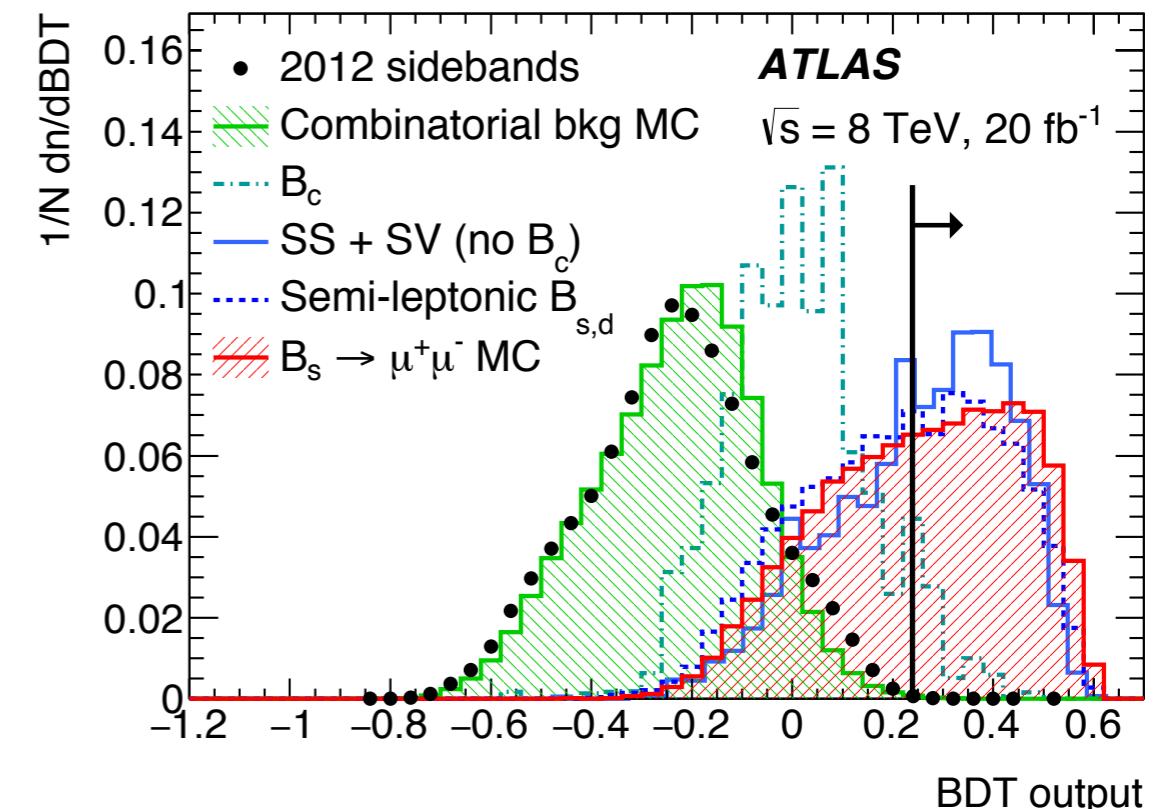
- mainly $B_s^0 \rightarrow K^+K^-$, $B^0 \rightarrow K^\pm\pi^\mp$, $B_s^0 \rightarrow \pi^+\pi^-$ decays
- signal-like topology

populate signal region



Continuum- and Fake Muon-BDTs

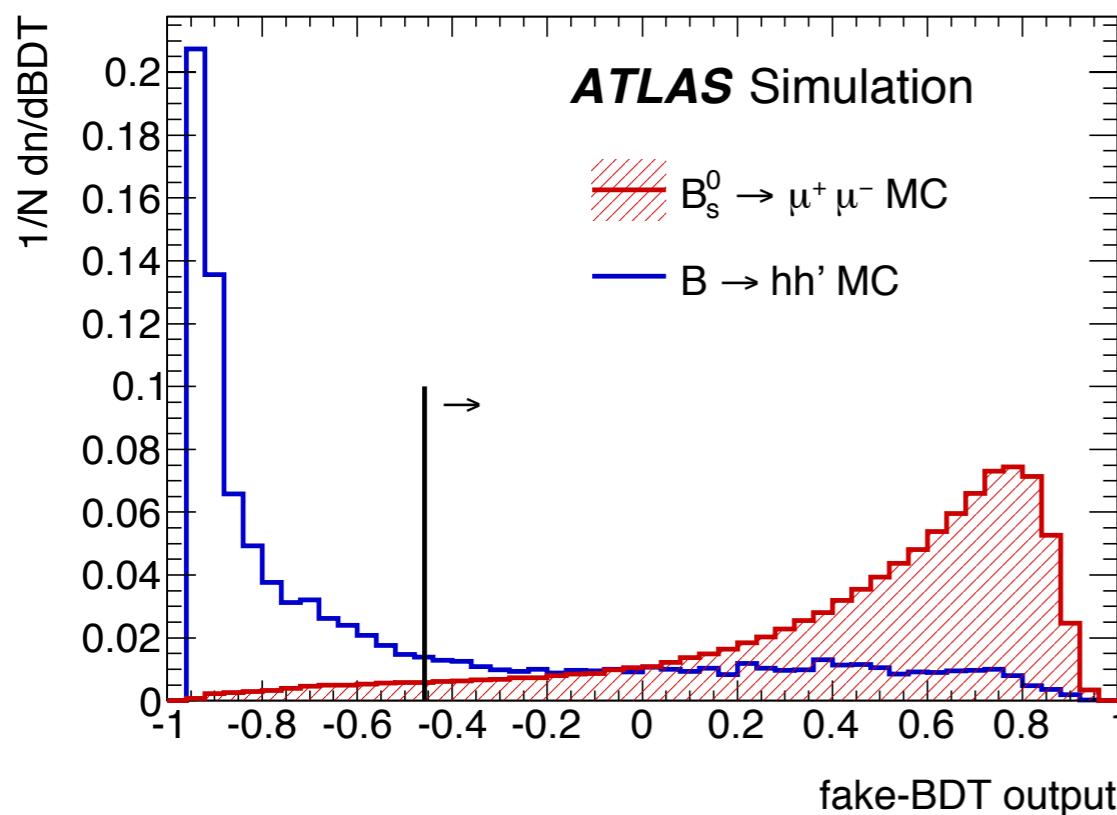
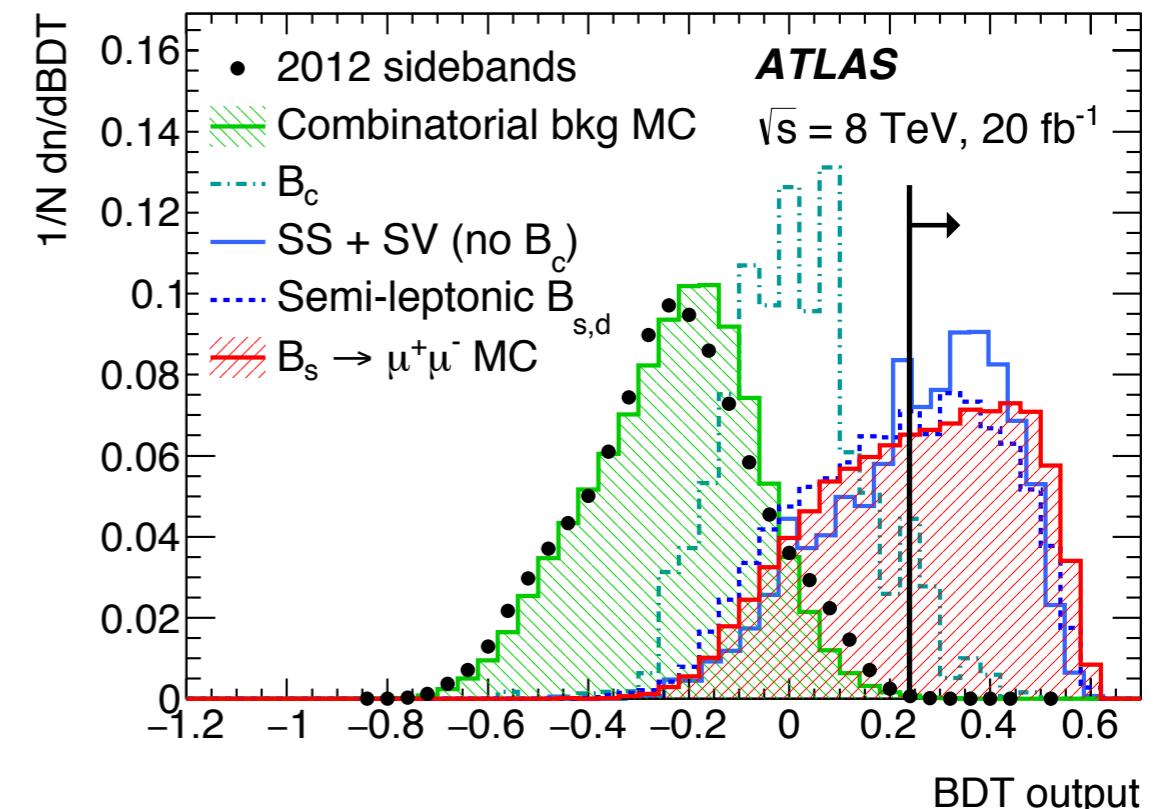
- ▶ continuum-BDT trained with 15 separation variables
 - B-decay topology, μ properties, other collision tracks, pile-up vertices
- ▶ final selection c-BDT>0.24
 - $\epsilon(B_s^0 \rightarrow \mu^+\mu^-) = 54\%$
 - bkg. suppression $\sim \times 1000$



Continuum- and Fake Muon-BDTs

- ▶ continuum-BDT trained with 15 separation variables
 - B-decay topology, μ properties, other collision tracks, pile-up vertices

- ▶ final selection c-BDT > 0.24
 - $\epsilon(B_s^0 \rightarrow \mu^+ \mu^-) = 54\%$
 - bkg. suppression $\sim \times 1000$



- ▶ hadron misidentification
 - h reco'ed as μ mainly due to decays in flight
 - low $P(\text{misID}) = 0.28\% (K^\pm), 0.12\% (\pi^\pm), <0.01\% (p)$

- ▶ fm-BDT trained with 8 separation variables
 - reduces fake rate by $\times 0.4$ with $\epsilon(\mu) = 95\%$

- ▶ normalized using $B^\pm \rightarrow J/\psi K^\pm$ yield and efficiency ratio
 - $N_{\text{peak-bkg}} = 1.0 \pm 0.4$ events

Reference Channel Yield

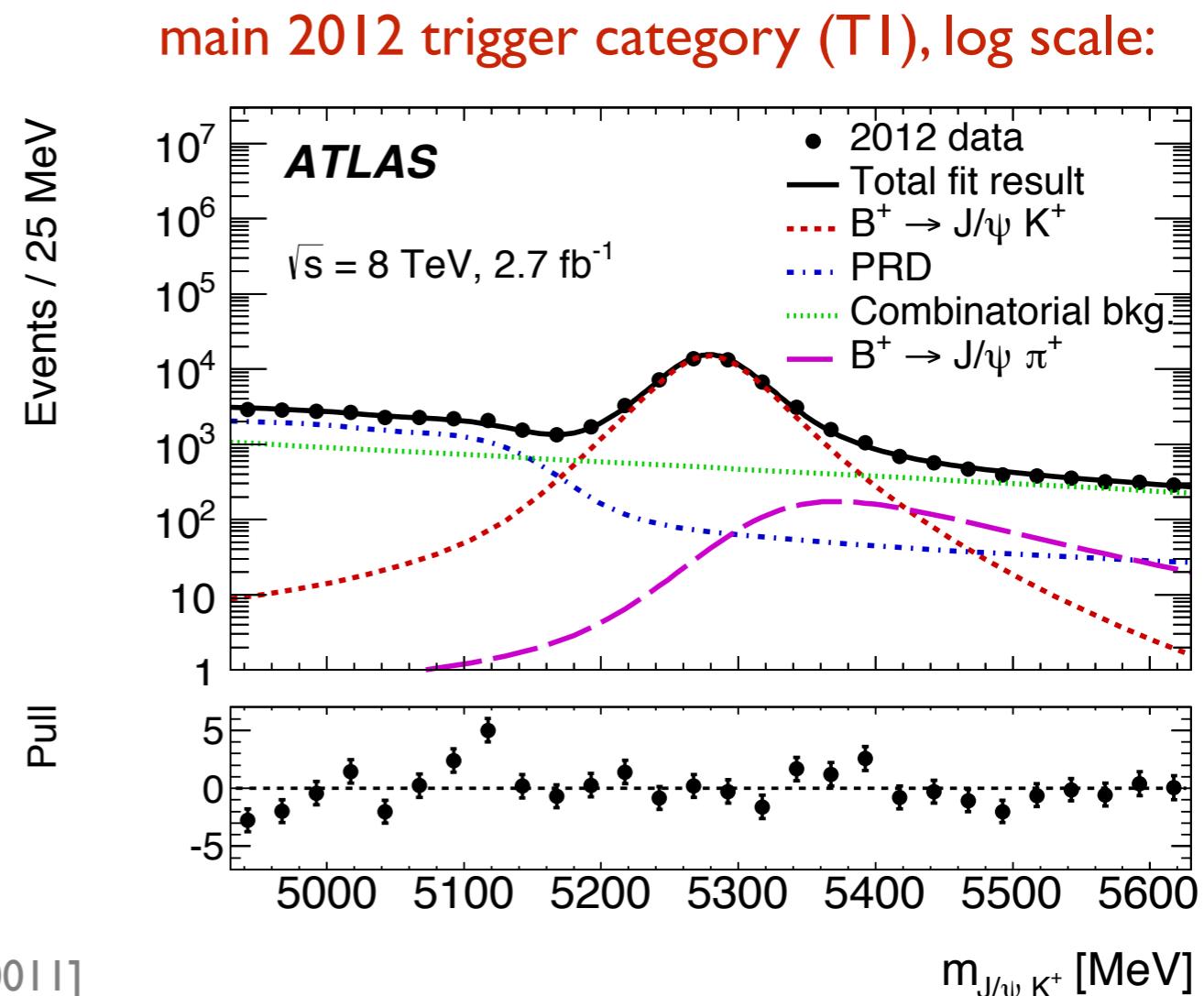
$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \times [\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)] \times \frac{f_u}{f_{d(s)}} \times \frac{1}{\mathcal{D}_{\text{norm}}}$$

$$\mathcal{D}_{\text{norm}} = \sum_k N_{J/\psi K^+}^k \alpha_k \left(\frac{\varepsilon_{\mu^+ \mu^-}}{\varepsilon_{J/\psi K^+}} \right)_k$$

- ▶ c- and fm-BDT selections applied
- ▶ unbinned ML fit of $m_{\mu\mu K}$ distributions
 - shape parameters from simultaneous fit to data and MC samples of sig. and bkg.
 - yields ($B^\pm \rightarrow J/\psi K^\pm$ and $B^\pm \rightarrow J/\psi \pi^\pm$) extracted from fit to data
 - contribution of systematic uncertainties to D_{norm} totals to only $\pm 0.9\%$
- ▶ π^\pm/K^\pm relative BR:

$$\text{BR}(B^\pm \rightarrow J/\psi \pi^\pm) / \text{BR}(B^\pm \rightarrow J/\psi K^\pm) = 0.035 \pm 0.003^{\text{stat}} \pm 0.012^{\text{syst}}$$

[LHCb: $0.0383 \pm 0.0011 \pm 0.0007$ BaBar: $0.0537 \pm 0.0045 \pm 0.0011$]



Signal Yield Extraction: Fit Model

$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \times [\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)] \times \frac{f_u}{f_{d(s)}} \times \frac{1}{\mathcal{D}_{\text{norm}}}$$

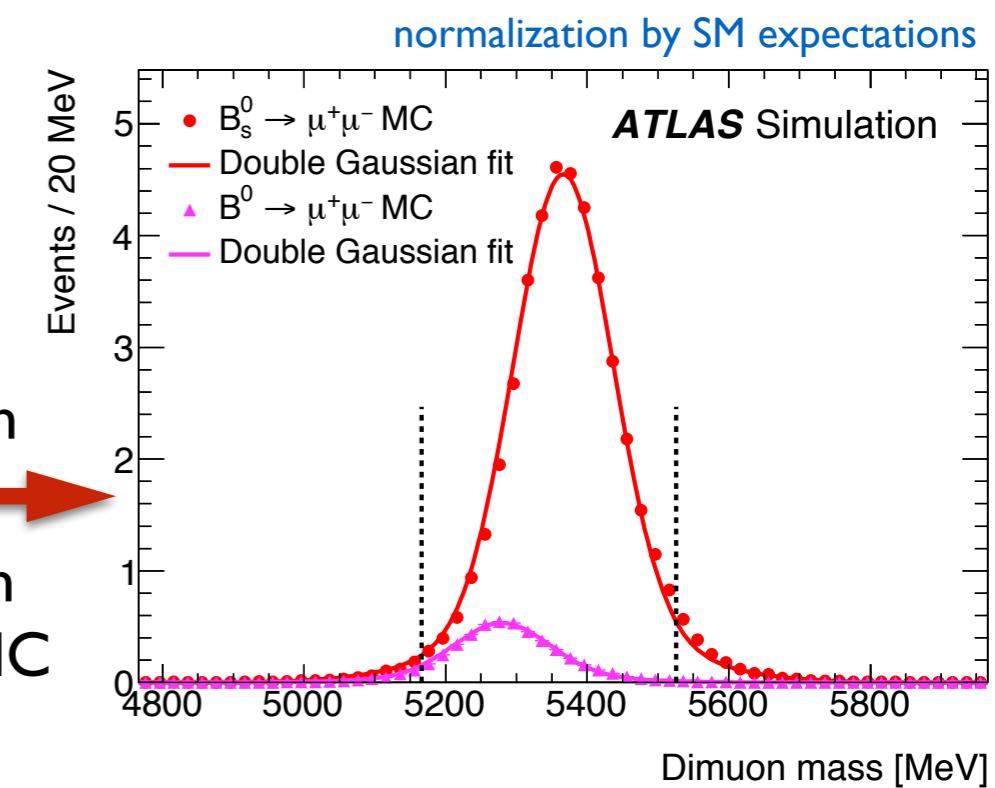
- $m_{\mu\mu}$ distributions split into 3 intervals (bins) in continuum-BDT (each with $\epsilon_{\text{sig}} = 18\%$)

- N_s and N_d extracted simultaneously in 3 bins with unbinned extended ML fit

- fit model

- signal: two Gaussians, avg. width 80 MeV, shape c-BDT-bin invariant
- continuum background: linear in $m_{\mu\mu}$, minimal correlation between $m_{\mu\mu}$ and c-BDT, sideband data consistent with MC
- SV+SS background: exponential in $m_{\mu\mu}$, determined from sideband data, c-BDT-bin invariant
- peaking background: two Gaussians, 1.0 ± 0.4 events total, equal shape and amplitude in c-BDT bins

- systematics of fit: $\sigma_{\text{syst}}(N_s) = \sqrt{2^2 + (0.06 \times N_s)^2}$ and $\sigma_{\text{syst}}(N_d) = 3$ events



Extraction of Signal Yield and BR($B^0_{(s)} \rightarrow \mu^+ \mu^-$)

► expected (SM) signal yields:

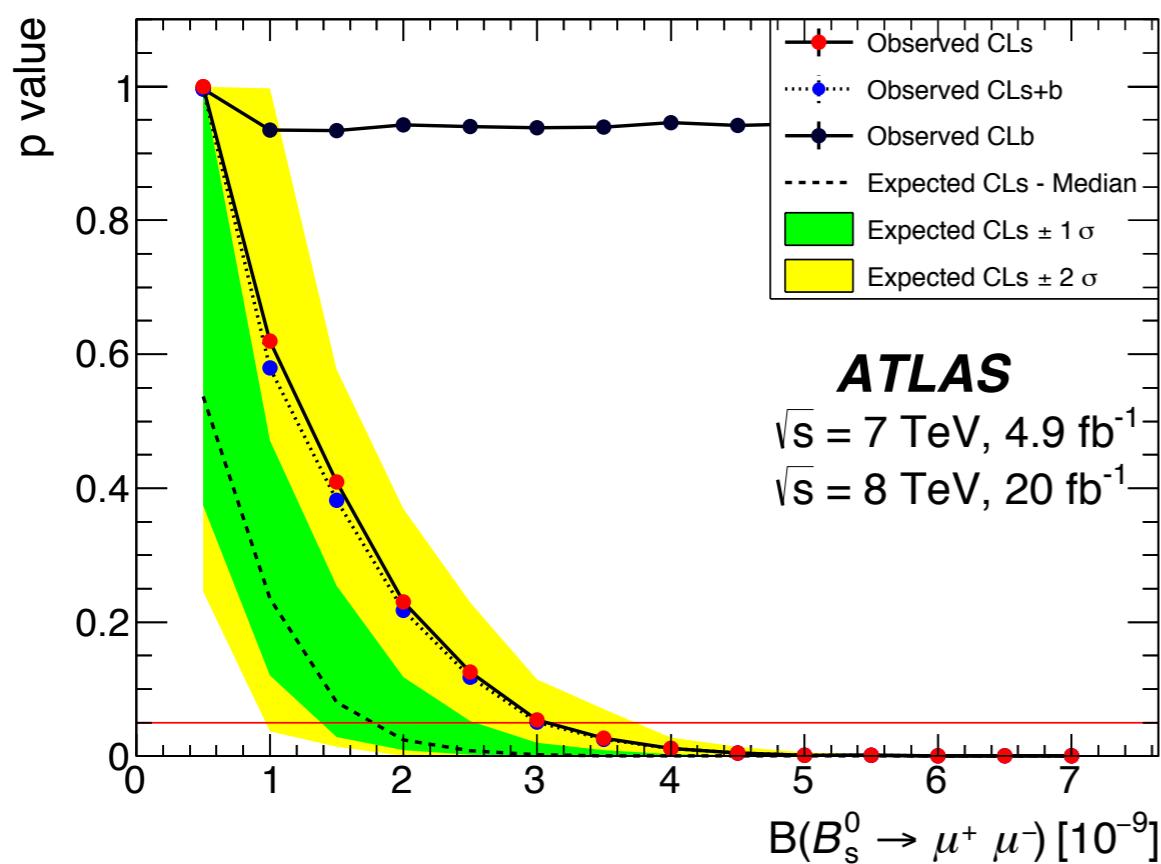
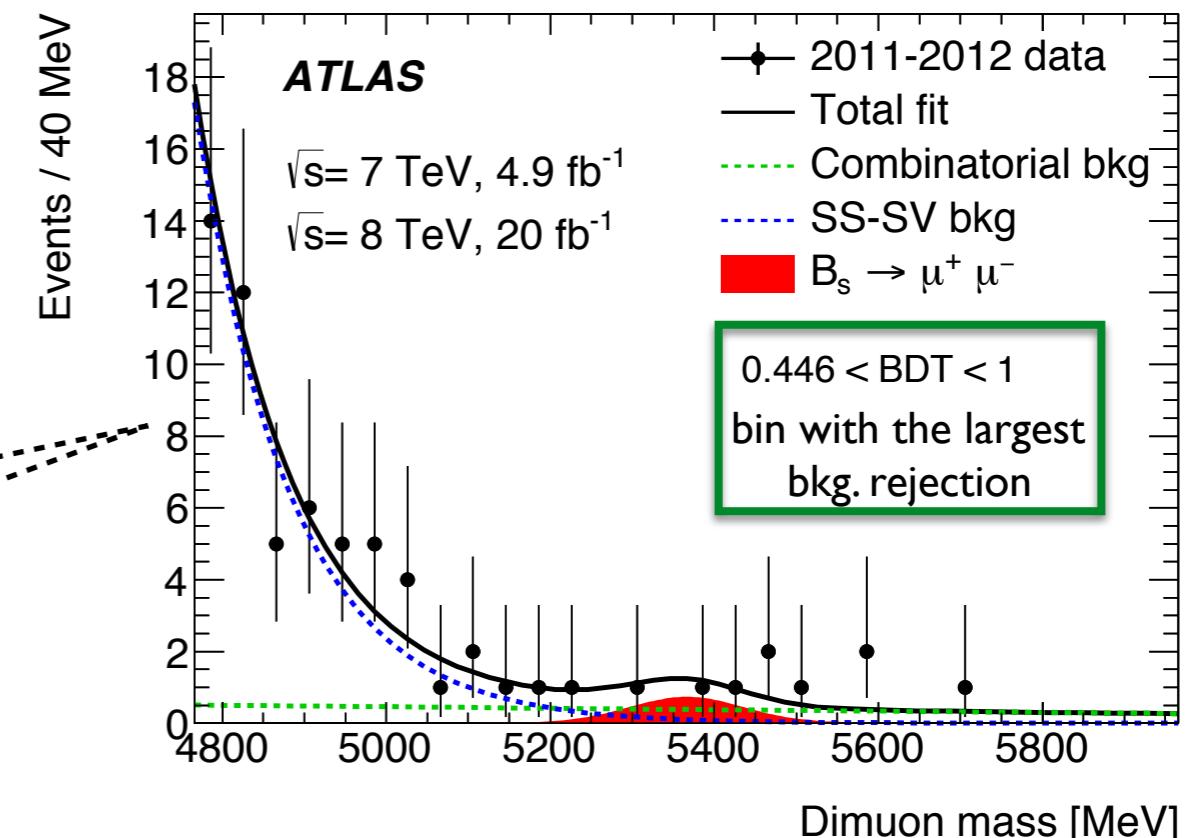
- $N_s = 41$ ($\sim 14/\text{bin}$) and $N_d = 5$ ($\sim 2/\text{bin}$)
→ significance 3.1σ (B^0_s) and 0.2σ (B^0)

► unconstrained signal yields:

- $N_s = 16 \pm 12$ and $N_d = -11 \pm 9$

► constrained (>0) signal yields:

- $N_s = 11$ and $N_d = 0$



$$\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$$

- obtained within boundary $\text{BRs} \geq 0$
- errors by frequentist belt using pseudo-MC experiments: $\sigma^{\text{syst}} = \pm 0.3 \times 10^{-9}$, σ^{stat} dominates

► upper limit (CLs method):

$$\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) < 3.0 \times 10^{-9} \text{ (at 95% CL)}$$

► observed significance 1.5σ

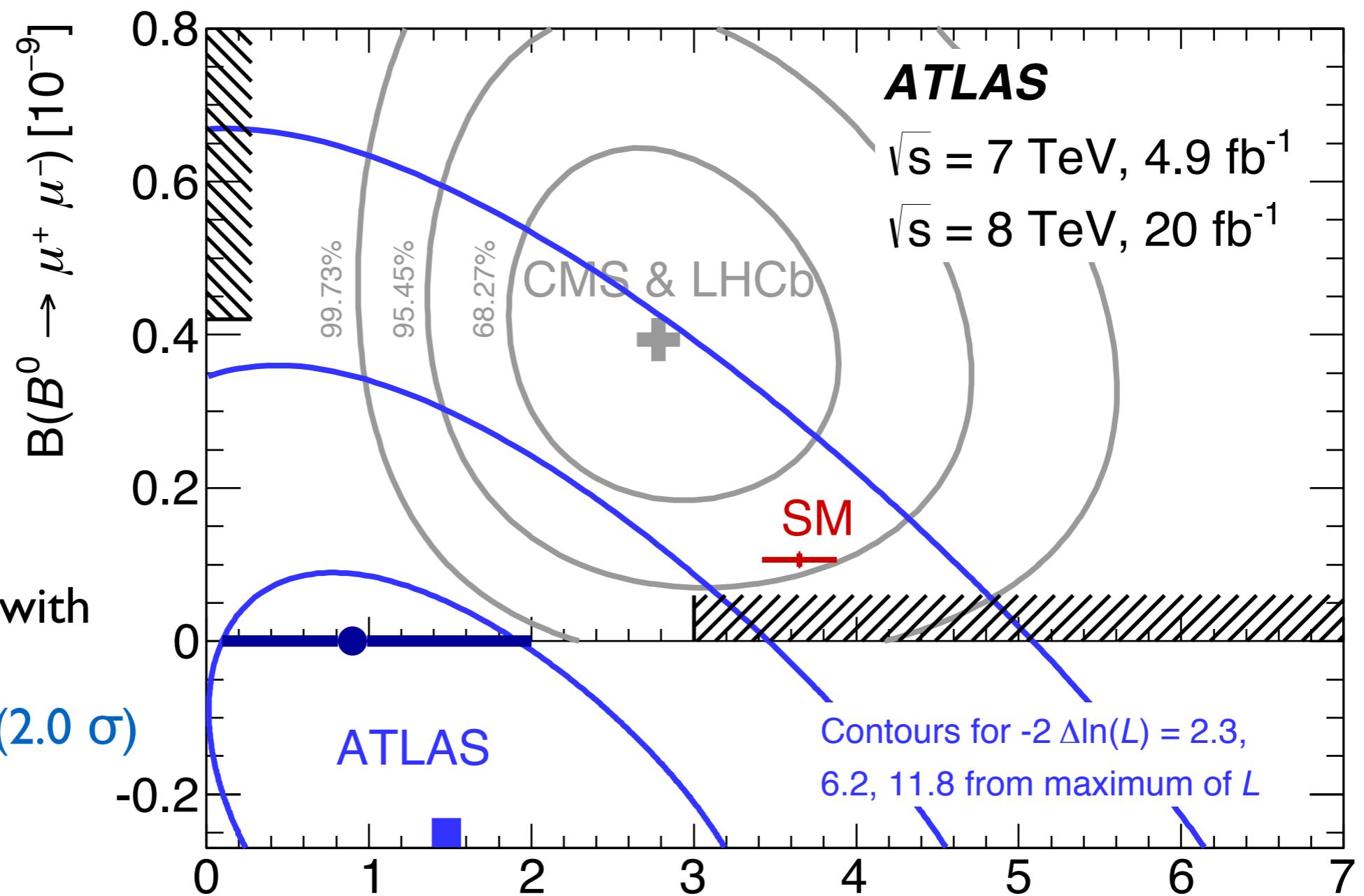
$$\text{BR}(B^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-10} \text{ (at 95% CL)}$$

Summary of LHC Run I Results

$\text{BR}(B^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-10}$ (at 95% CL)

CMS & LHCb contours from
[Nature 522 (2015) 68-72]
[ATLAS: arXiv: 1604.04263 [hep-ex]]

compatibility of
simultaneous fit with
SM prediction:
 $p\text{-value} = 0.048$ (2.0σ)



$\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$

$\text{BR}(B^0 \rightarrow \mu^+ \mu^-) [10^{-9}]$

Conclusions

[CERN-EP-2016-064, [arXiv:1604.04263](https://arxiv.org/abs/1604.04263), Submitted to EPJC]

- ▶ Results for $B^0_{(s)} \rightarrow \mu^+ \mu^-$ with full ATLAS Run-I data (25 fb^{-1})
 - ▶ $\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$
 $< 3.0 \times 10^{-9}$ (at 95% CL)
 - lower than SM prediction
 - lower than central value of CMS & LHCb combination
[$\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$]
 - precision is comparable
 - ▶ $\text{BR}(B^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-10}$ (at 95% CL)
 - covers SM prediction
 - reaches central value of CMS & LHCb combination
[$\text{BR}(B^0 \rightarrow \mu^+ \mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$]
- ▶ compatibility with SM for the simultaneous fit is 2.0σ
 - ▶ hint of destructive interference from NP ?
 - data of LHC Run 2 (100 fb^{-1} expected) will give an answer

Backup Slides

Branching Fraction Extraction, Ingredients

$$\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-) = N_{d(s)} \times [\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)] \times \frac{f_u}{f_{d(s)}} \times \frac{1}{\mathcal{D}_{\text{norm}}}$$

$$\mathcal{D}_{\text{norm}} = \sum_k N_{J/\psi K^+}^k \alpha_k \left(\frac{\mathcal{E}_{\mu^+ \mu^-}}{\mathcal{E}_{J/\psi K^+}} \right)_k$$

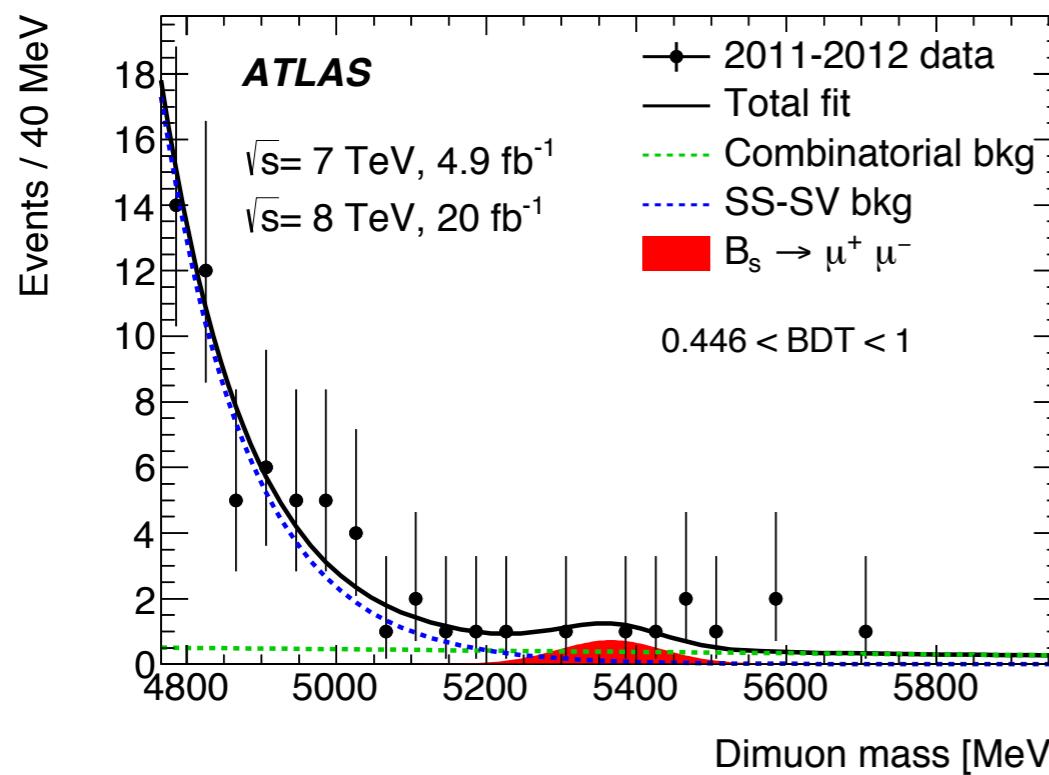
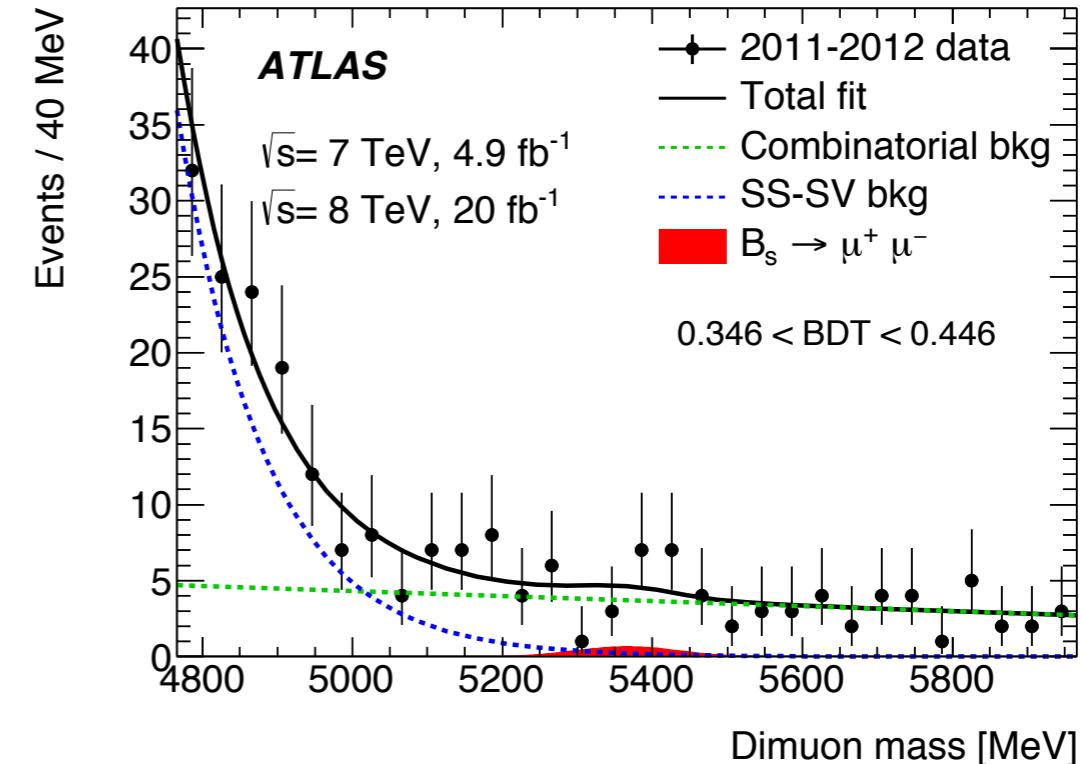
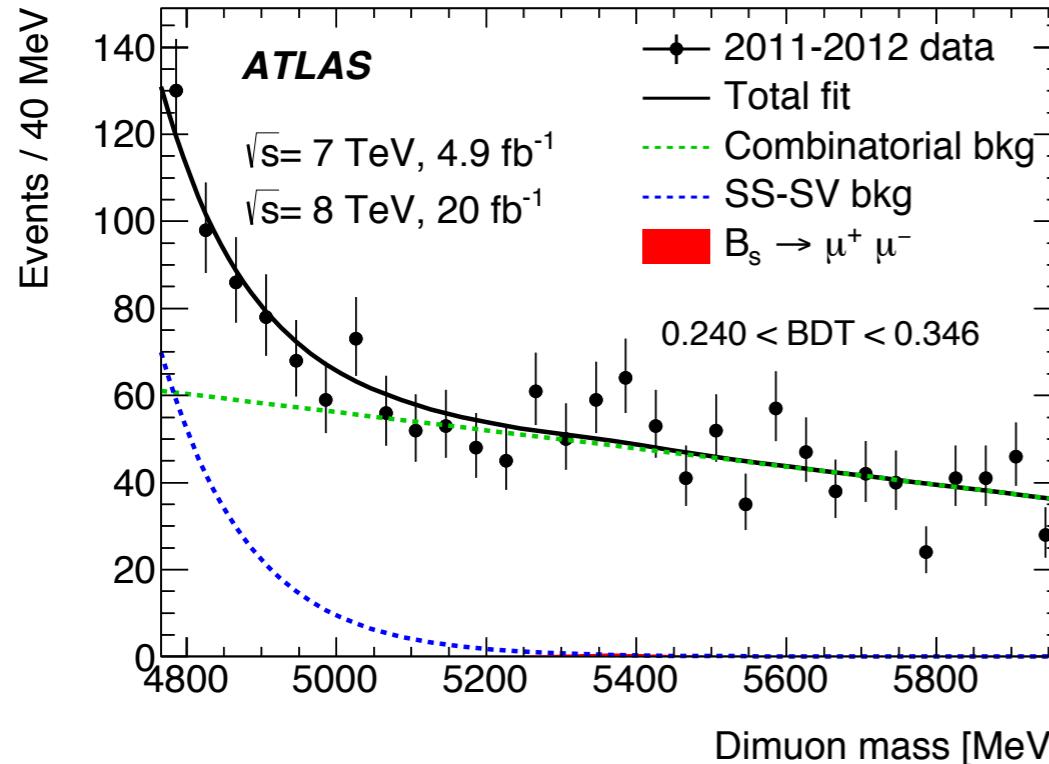
► efficiency ratio $B^+/B_{(s)}^0$

- p_T and η spectra tuned on reference channels
- trigger efficiencies extracted from tag&probe studies based on J/ψ and Υ
- systematic uncertainties:
 - data-MC discrepancies ($\pm 4.2\%$ dominant)
 - corrections due to tuning of isolation variable for B^\pm and $B_{(s)}^0$ (2012 only)
 - lifetime difference $\Delta\tau$ between B_s^0 mass eigenstates ($+4\%$ w.r.t. τ from SM prediction)
- total $\Delta D_{\text{norm}}^{\text{sys}} = \pm 5.9\%$

- $\text{BR}(B^\pm \rightarrow J/\psi K^\pm) \times \text{BR}(J/\psi \rightarrow \mu^+ \mu^-)$ from word-avg. [PDG 2014]
- f_u/f_s from ATLAS $f_s/f_d = 0.240 \pm 0.020$, assuming $f_u = f_d$, measured in the same p_T, η range [ATLAS: [PRL 115(2015)262001]]

- total normalization uncertainty:
 - $\pm 11\%$ for $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$
 - $\pm 7\%$ for $\text{BR}(B^0 \rightarrow \mu^+ \mu^-)$
- single event sensitivity:
 - $(8.9 \pm 1.0) \times 10^{-11}$ for B_s^0
 - $(2.21 \pm 0.15) \times 10^{-11}$ for B^0

Signal Yield Extraction: Results

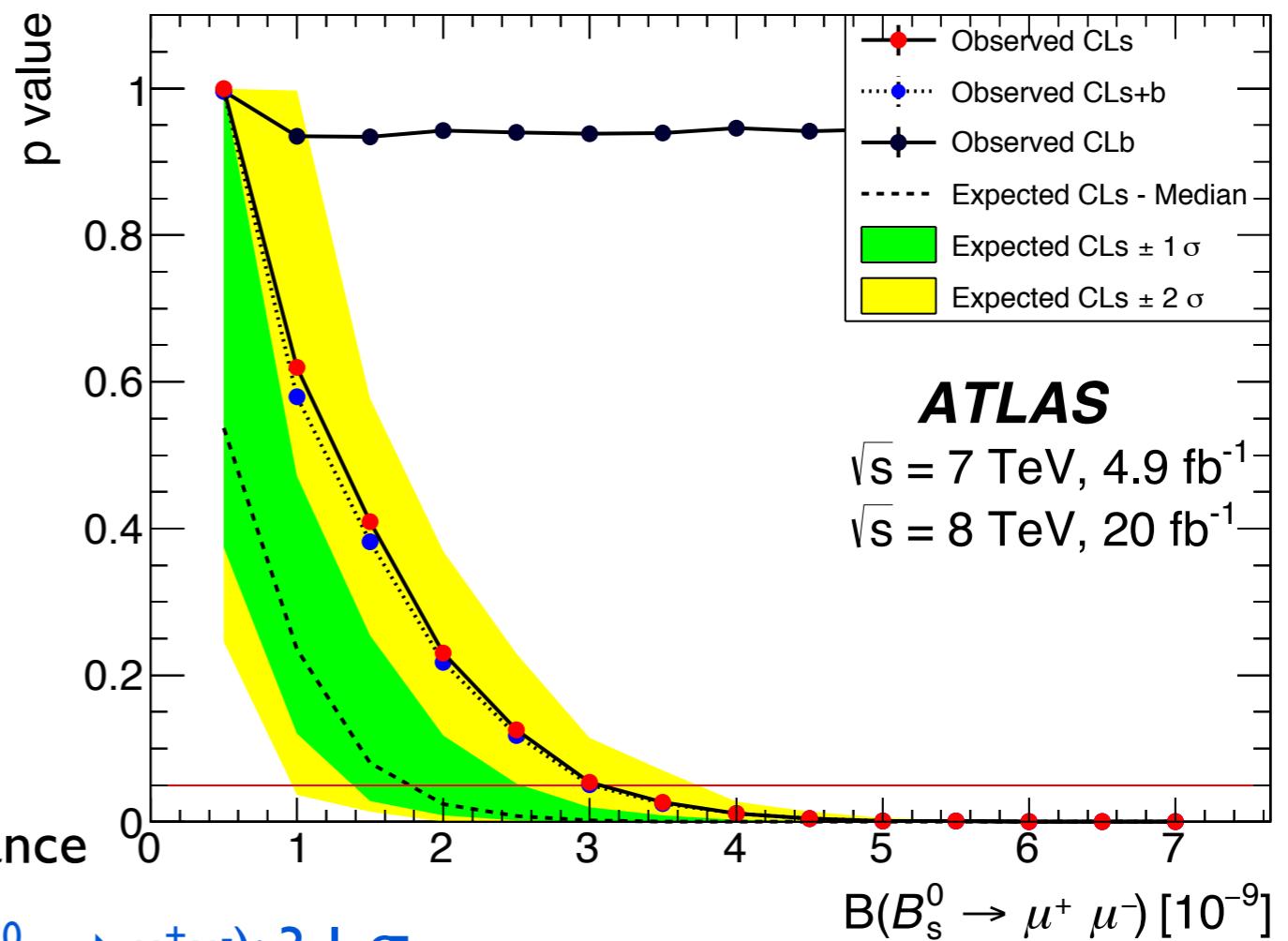


- ▶ **expected (SM):**
 - $N_s = 41$ and $N_d = 5$
- ▶ **unconstrained yields:**
 - $N_s = 16 \pm 12$ and $N_d = -11 \pm 9$
- ▶ **constrained (>0) yields:**
 - $N_s = 11$ and $N_d = 0$

$\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$

$$\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$$

- obtained within boundary of non-negative branching fractions
- errors by frequentist belt using pseudo-MC experiments: $\sigma^{\text{syst}} = \pm 0.3 \times 10^{-9}$, σ^{stat} dominates
- upper limit (CLs method)
 $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) < 3.0 \times 10^{-9}$ (at 95% CL)
- expected upper limit
 (no signal, $\text{BR}(B^0 \rightarrow \mu^+ \mu^-)$ free):
 $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) < (1.8^{+0.7}_{-0.4}) \times 10^{-9}$
- compatibility with null hypothesis
 (no signal, $\text{BR}(B^0 \rightarrow \mu^+ \mu^-)$ free):
 $p\text{-value} = 0.08$ (1.4σ) - observed significance
- expected significance assuming SM $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$: 3.1σ



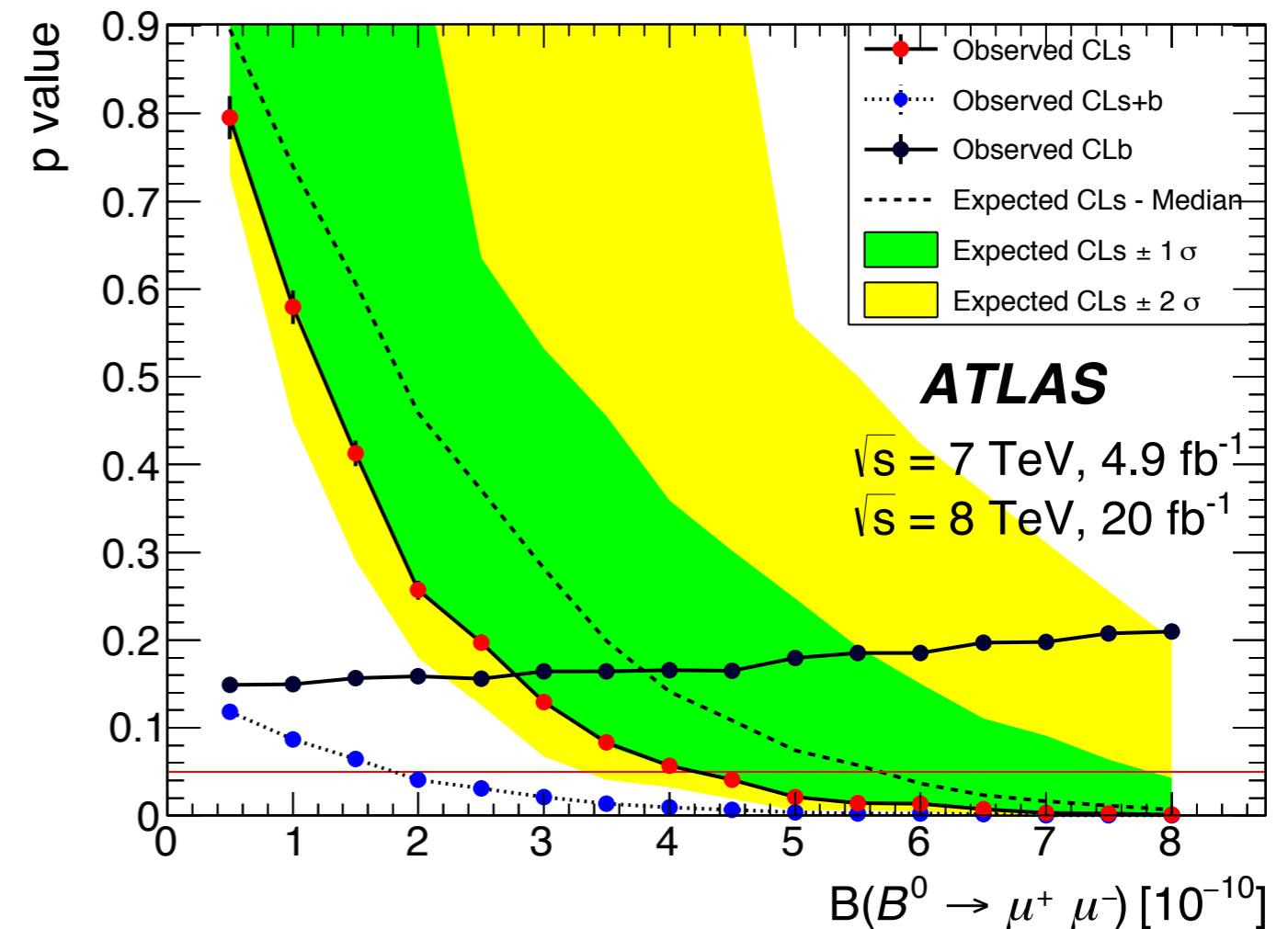
$\text{BR}(B^0 \rightarrow \mu^+ \mu^-)$

- ▶ upper limit (CLs method, no signal, $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$ free):
 $\text{BR}(B^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-10}$ (at 95% CL)

- ▶ $\text{CL}_b \approx 0.15$ for $\text{BR}(B^0 \rightarrow \mu^+ \mu^-)$ near 0:
 $\rightarrow (-1\sigma$ fluctuation of background)

- ▶ expected upper limit:
 $\text{BR}(B^0 \rightarrow \mu^+ \mu^-) < (5.7^{+2.1}_{-1.2}) \times 10^{-10}$
 larger than SM prediction:
 $\text{BR}(B^0 \rightarrow \mu^+ \mu^-)_{\text{SM}} = (1.06 \pm 0.09) \times 10^{-10}$

- ▶ expected significance assuming SM: 0.2σ



Systematics

of B^+ yield and efficiency ratio $B^+/B_{(s)}^0$, detailed:

Statistical uncertainty in simulation	0.5%
p_T, η reweighting and trigger efficiency	1.3%
Data to MC discrepancy in discriminating variables	4.2%
K^+ and B^+ reconstruction	3.6%
Residual trigger efficiency systematic uncertainty	1.5%
B^+ yield	0.8%
Total uncertainty	5.9%

of signal fit, detailed:

	$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$	$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$
Scale uncertainties		
$\mathcal{B}(B^+ \rightarrow J/\psi K^+) \times \mathcal{B}(J/\psi \rightarrow \mu\mu)$ branching fractions	3.1%	3.1%
$B_{(s)}^0/B^+$ production ratio	8.3%	0
B^+ yield and $B_{(s)}^0/B^+$ efficiency ratio	5.9%	5.9%
Relative efficiency of continuum-BDT intervals	9%	9%
Signal and background model	6%	0
Total scale uncertainty	16%	11%
Offset uncertainties		
Signal and background model	0.2×10^{-9}	0.7×10^{-10}

Systematics in ML Fits

B^+ yield fit:

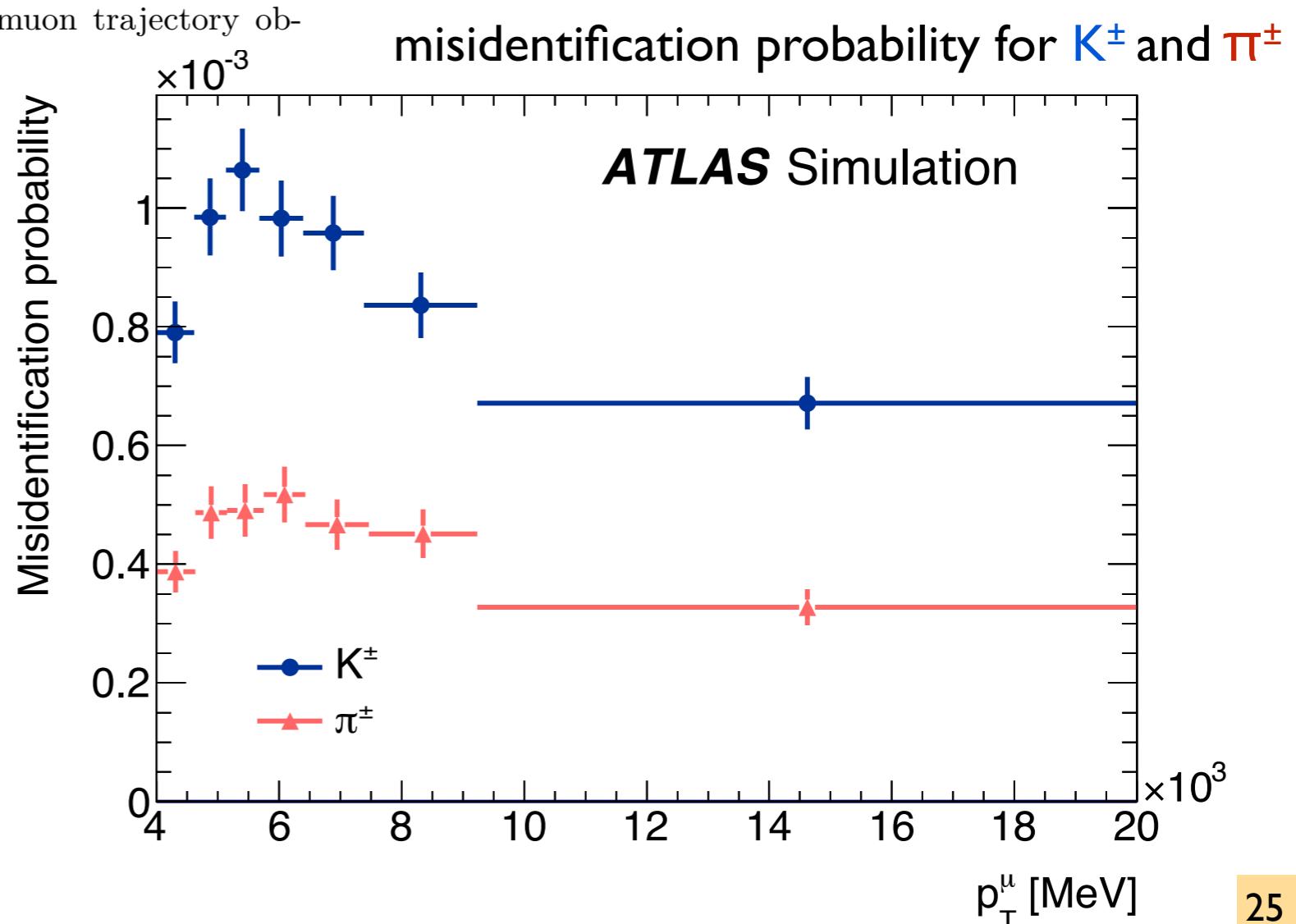
- ▶ systematic uncertainty accessed by:
 - varying background fit model
 - studying B^\pm reconstruction asymmetry
 - totals to $\pm 0.9\%$ to D_{norm}

Signal fit:

- ▶ dominant systematics assessed with toy MC studies:
 - alternative PDF for SS-SV
 - semileptonic background parameterised using MC templates (including $B_c^\pm \rightarrow J/\psi \mu^\pm \nu$ component)
 - alternative PDF for combinatorial background
 - mass scale and mass resolution uncertainties
 - combined fit uncertainty on $N_{d(s)}$:
$$\sigma_{\text{syst}}(N_d) = 3 \quad \sigma_{\text{syst}}(N_s) = (4 + (0.06 \times N_s)^2)^{1/2}$$
- ▶ additional systematics: uncertainty in the relative efficiencies of the 3 c-BDT bins (10-15%)
- ▶ all uncertainties fed into the likelihood as Gaussian constraints

f-BDT List of Separation Variables and misID prob.

1. Absolute value of the track rapidity measured in the ID.
2. Ratio q/p (charge over momentum) measured in the MS.
3. Scattering curvature significance: maximum variation of the track curvature between adjacent layers of the ID.
4. χ^2 of the track reconstruction in the MS.
5. Number of hits used to reconstruct the track in the MS.
6. Ratio of the values of q/p measured in the ID and in the MS, corrected for the average energy loss in the calorimeter.
7. χ^2 of the match between the tracks reconstructed in the ID and MS.
8. Energy deposited in the calorimeters along the muon trajectory obtained by combining ID and MS tracks.



c-BDT List of Separation Variables

Variable	Description
p_T^B	Magnitude of the B candidate transverse momentum \vec{p}_T^B .
$\chi_{\text{PV}, \text{DV } xy}^2$	Significance of the separation $\vec{\Delta x}$ between production (<i>i.e.</i> associated PV) and decay (DV) vertices in the transverse projection: $\vec{\Delta x}_T \cdot \Sigma_{\vec{\Delta x}_T}^{-1} \cdot \vec{\Delta x}_T$, where $\Sigma_{\vec{\Delta x}_T}$ is the covariance matrix.
ΔR	three-dimensional opening between \vec{p}_T^B and $\vec{\Delta x}$: $\sqrt{\alpha_{2D}^2 + \Delta\eta^2}$
$ \alpha_{2D} $	Absolute value of the angle between \vec{p}_T^B and $\vec{\Delta x}_T$ (transverse projection).
L_{xy}	Projection of $\vec{\Delta x}_T$ along the direction of \vec{p}_T^B : $(\vec{\Delta x}_T \cdot \vec{p}_T^B) / \vec{p}_T^B $.
IP_B^{3D}	three-dimensional impact parameter of the B candidate to the associated PV.
$\text{DOCA}_{\mu\mu}$	Distance of closest approach (DOCA) of the two tracks forming the B candidate (three-dimensional).
$\Delta\phi_{\mu\mu}$	Difference in azimuthal angle between the momenta of the two tracks forming the B candidate.
$ d_0 ^{\max\text{-sig.}}$	Significance of the larger absolute value of the impact parameters to the PV of the tracks forming the B candidate, in the transverse plane.
$ d_0 ^{\min\text{-sig.}}$	Significance of the smaller absolute value of the impact parameters to the PV of the tracks forming the B candidate, in the transverse plane.
P_L^{\min}	Value of the smaller projection of the momenta of the muon candidates along \vec{p}_T^B .
$I_{0.7}$	Isolation variable defined as ratio of $ \vec{p}_T^B $ to the sum of $ \vec{p}_T^B $ and of the transverse momenta of all additional tracks contained within a cone of size $\Delta R < 0.7$ around the B direction. Only tracks with $p_T > 0.5$ GeV and matched to the same PV as the B candidate are included in the sum.
$\text{DOCA}_{\text{xtrk}}$	DOCA of the closest additional track to the decay vertex of the B candidate. Tracks matched to a PV different from the B candidate are excluded.
$N_{\text{xtrk}}^{\text{close}}$	Number of additional tracks compatible with the decay vertex (DV) of the B candidate with $\ln(\chi_{\text{xtrk}, \text{DV}}^2) < 1$. The tracks matched to a PV different from the B candidate are excluded.
$\chi_{\mu, \text{xPV}}^2$	Minimum χ^2 for the compatibility of a muon in the B candidate with a PV different from the one associated with the B candidate.

ATLAS $B^0_{s(d)} \rightarrow \mu^+\mu^-$ Data

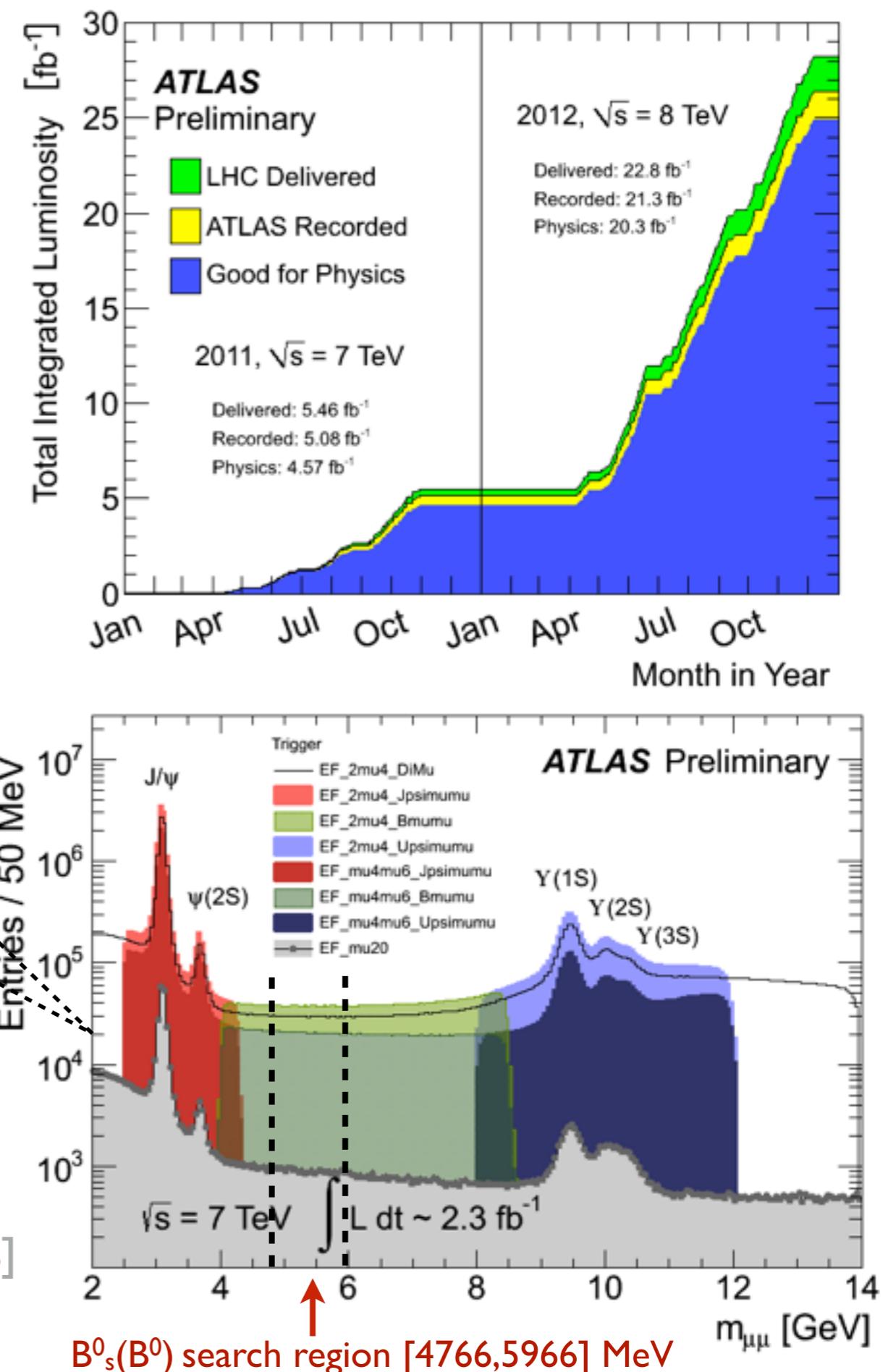
- excellent data taking efficiency and quality of data
- multiple interactions per bunch crossing ($\langle\mu\rangle$):
 - $> 5 \text{ fb}^{-1}$ recorded in 2011 (7 TeV)
 - $\langle\mu\rangle = 9$
 - $> 20 \text{ fb}^{-1}$ recorded in 2012 (8 TeV)
 - $\langle\mu\rangle = 20$

► selection with di-muon triggers

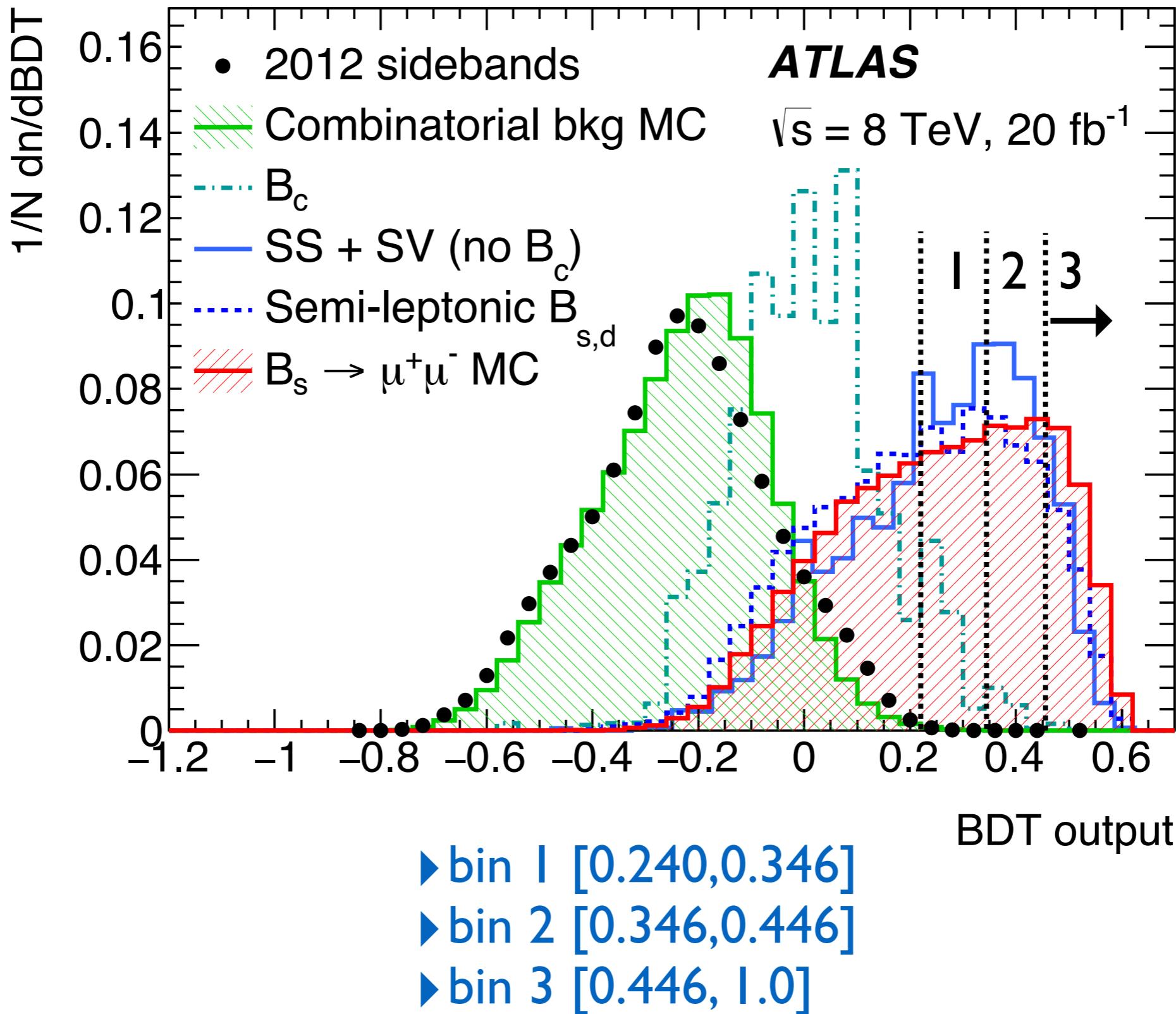
- at first trigger level:
 - 2011: two μ with $p_T(\mu) > 4 \text{ GeV}$
 - 2012: (prescales!) $p_T(\mu) > 4 \text{ GeV}$ and 6 GeV , one μ with $|\eta| < 1.05$ (barrel)
- at higher trigger levels:
 - full track reconstruction and loose mass selection

► four mutually exclusive data categories

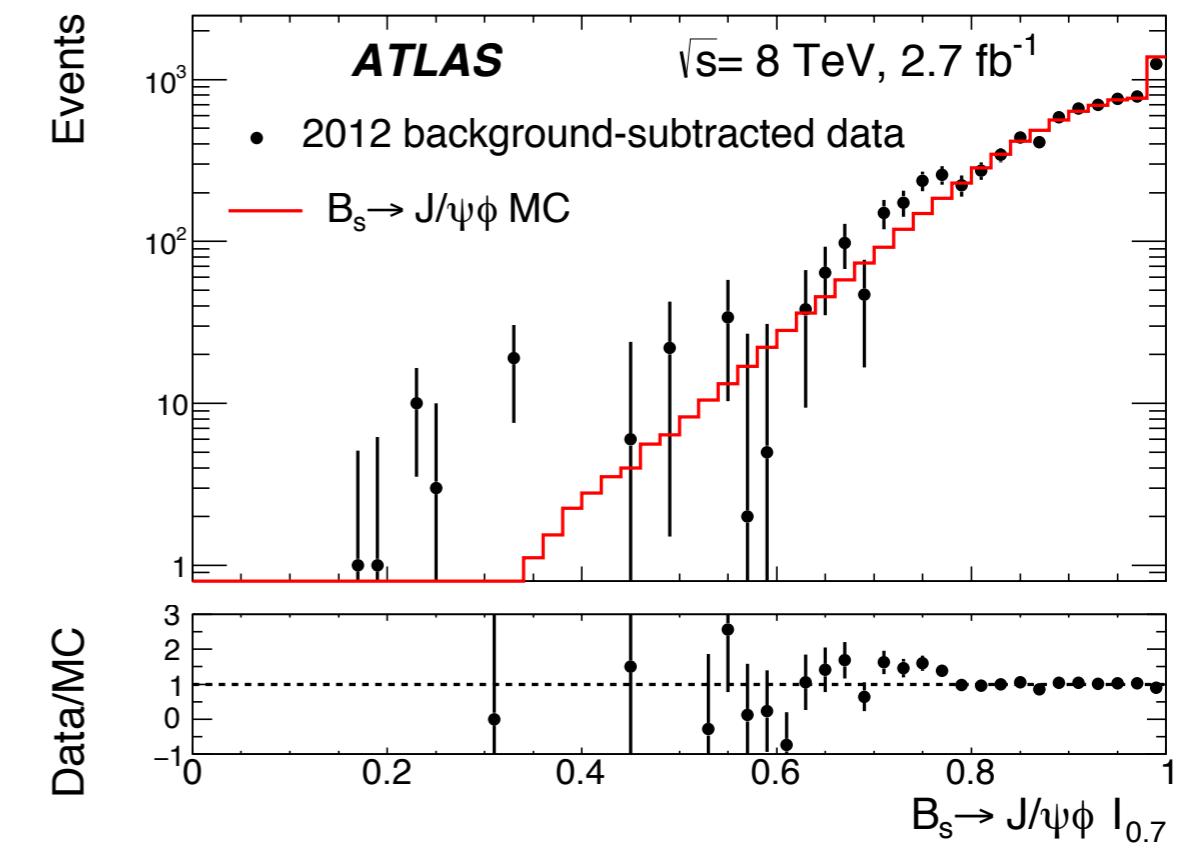
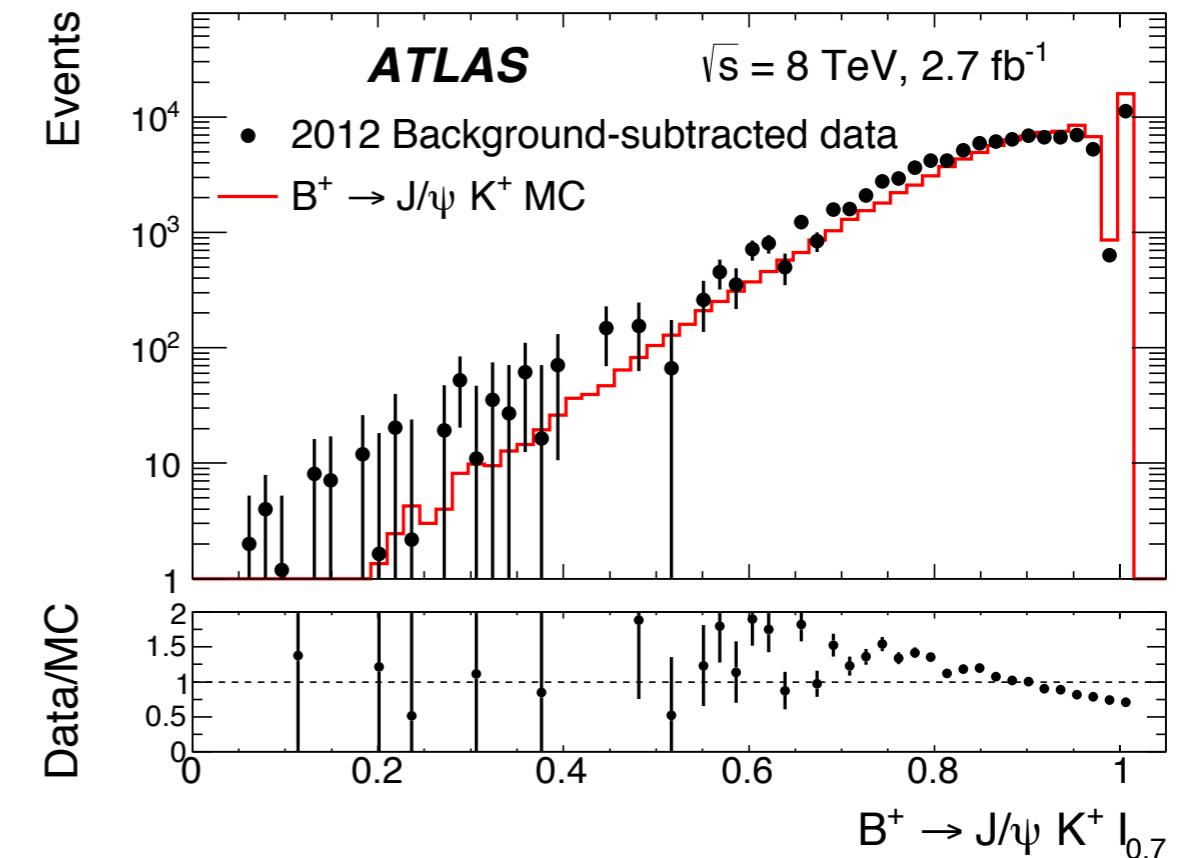
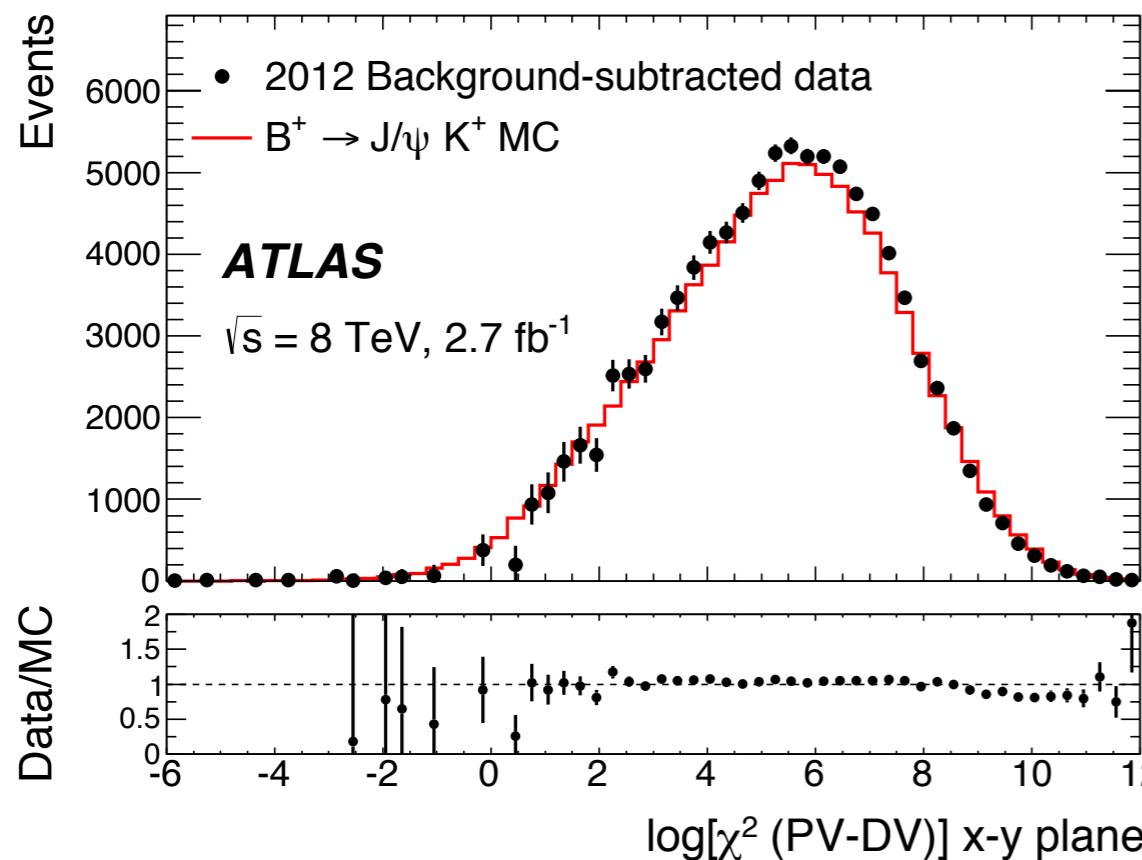
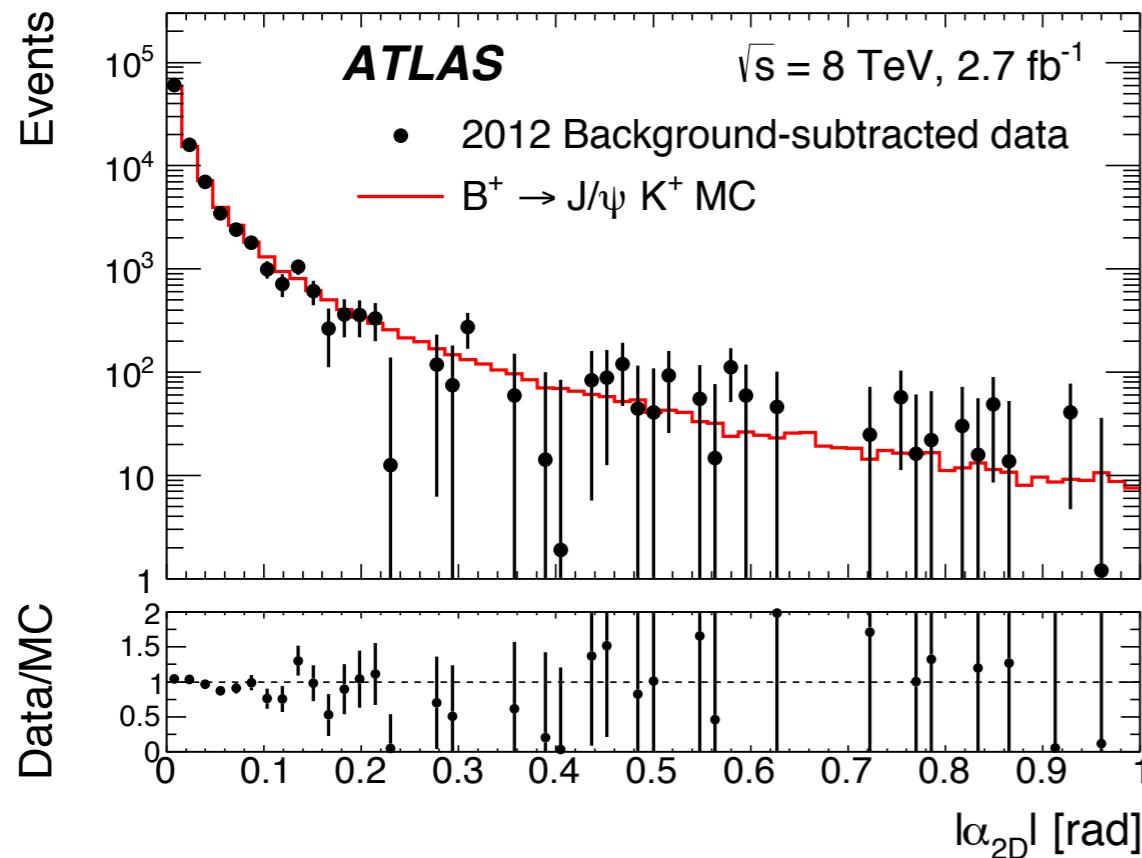
- 2011 data: $p_T(\mu_1, \mu_2) > 4 \text{ GeV}$ [22% of data]
- 2012 data:
 - T1: $p_T(\mu_1, \mu_2) > (4, 6) \text{ GeV}$ [68%]
 - T2: $(p_T(\mu) > 4 \text{ GeV}, |\eta|_{\mu_1 \text{ OR } \mu_2} < 1.05) \cap \overline{\text{T1}}$ [6%]
 - T3: $(p_T(\mu) > 4 \text{ GeV}) \cap (\overline{\text{T1}} \cup \text{T2})$ [4%]



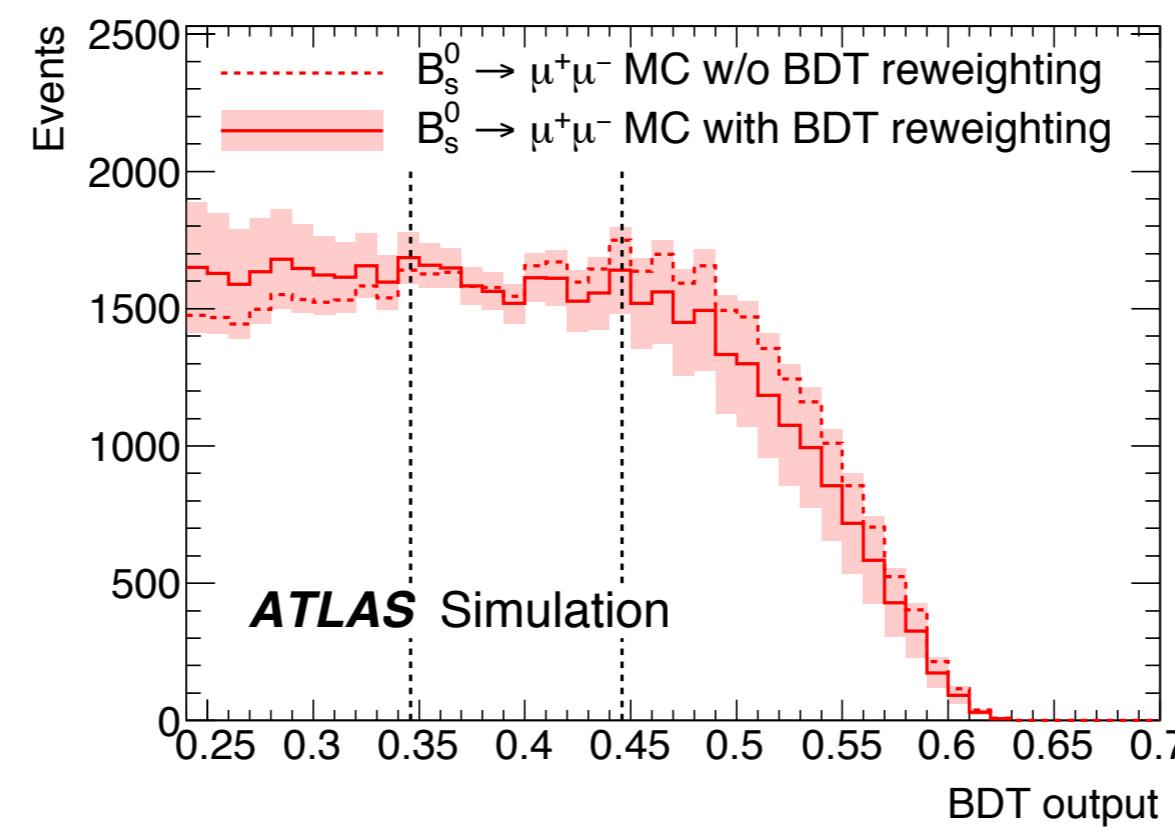
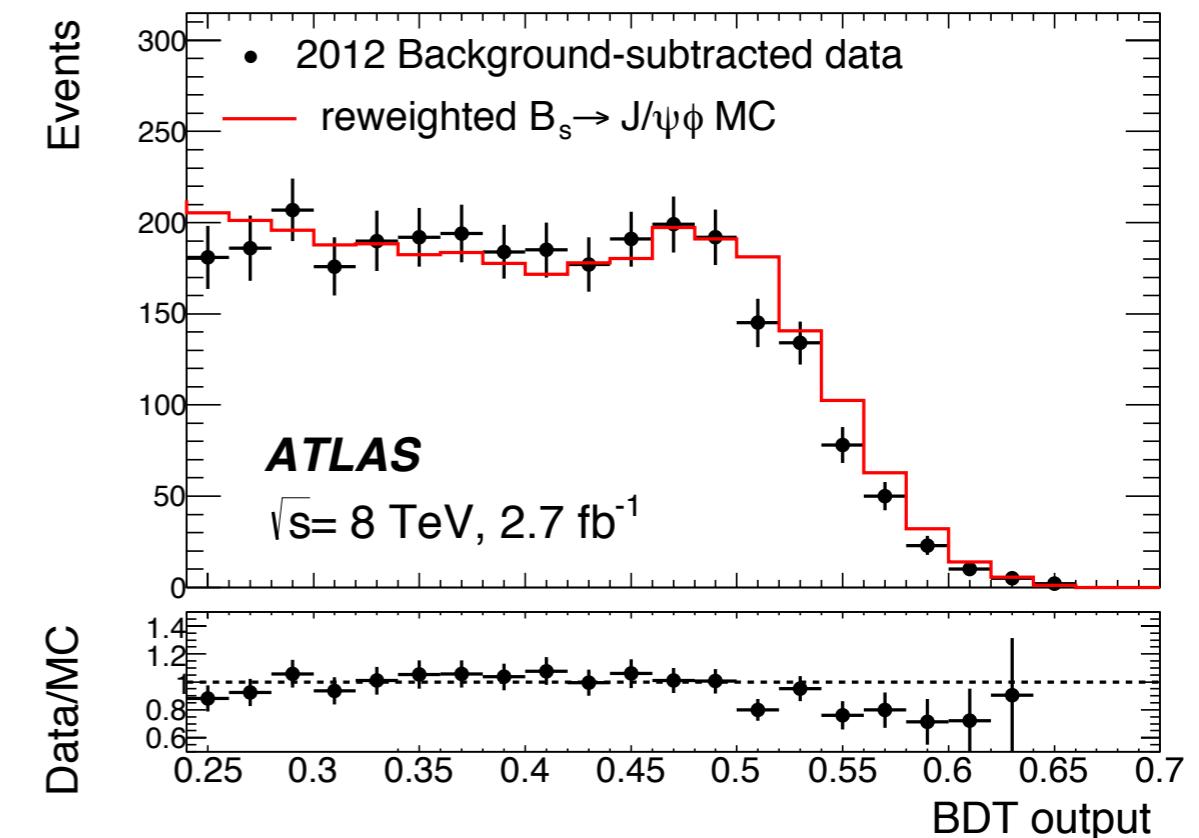
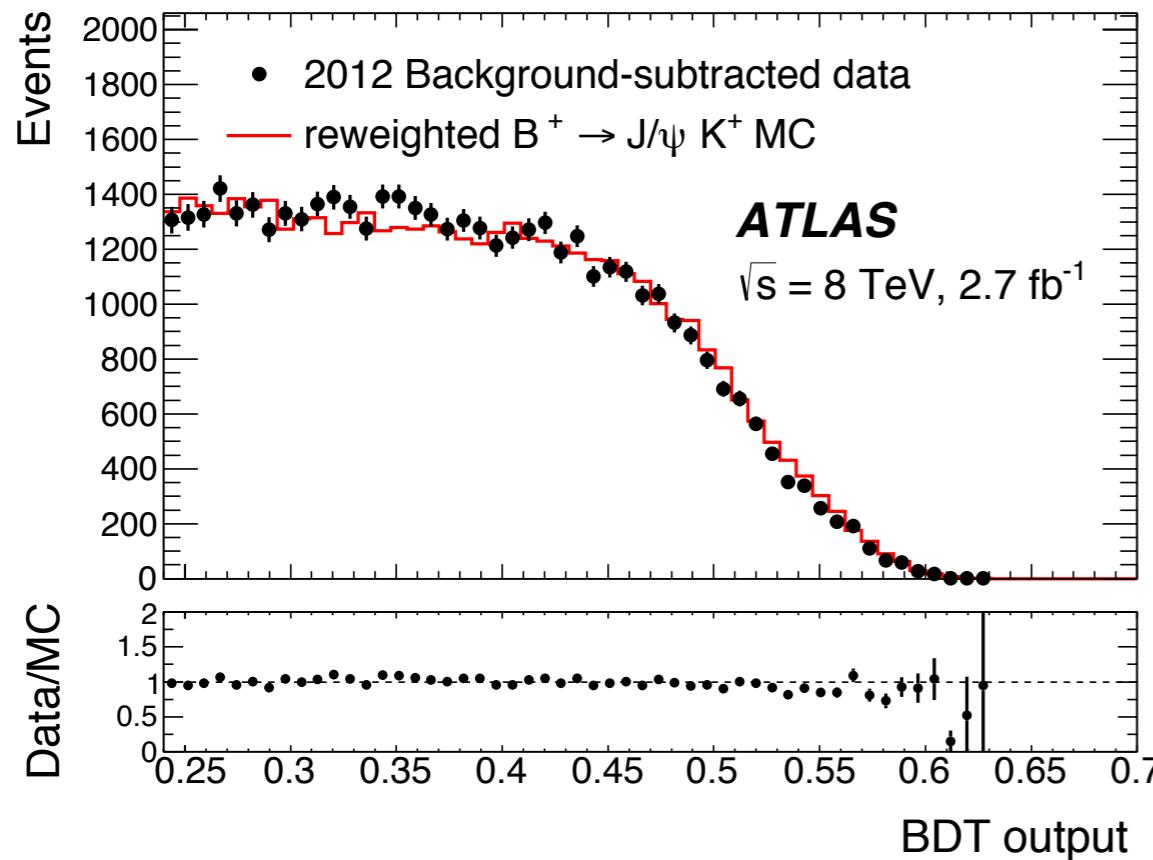
BDT Binning and Backgrounds



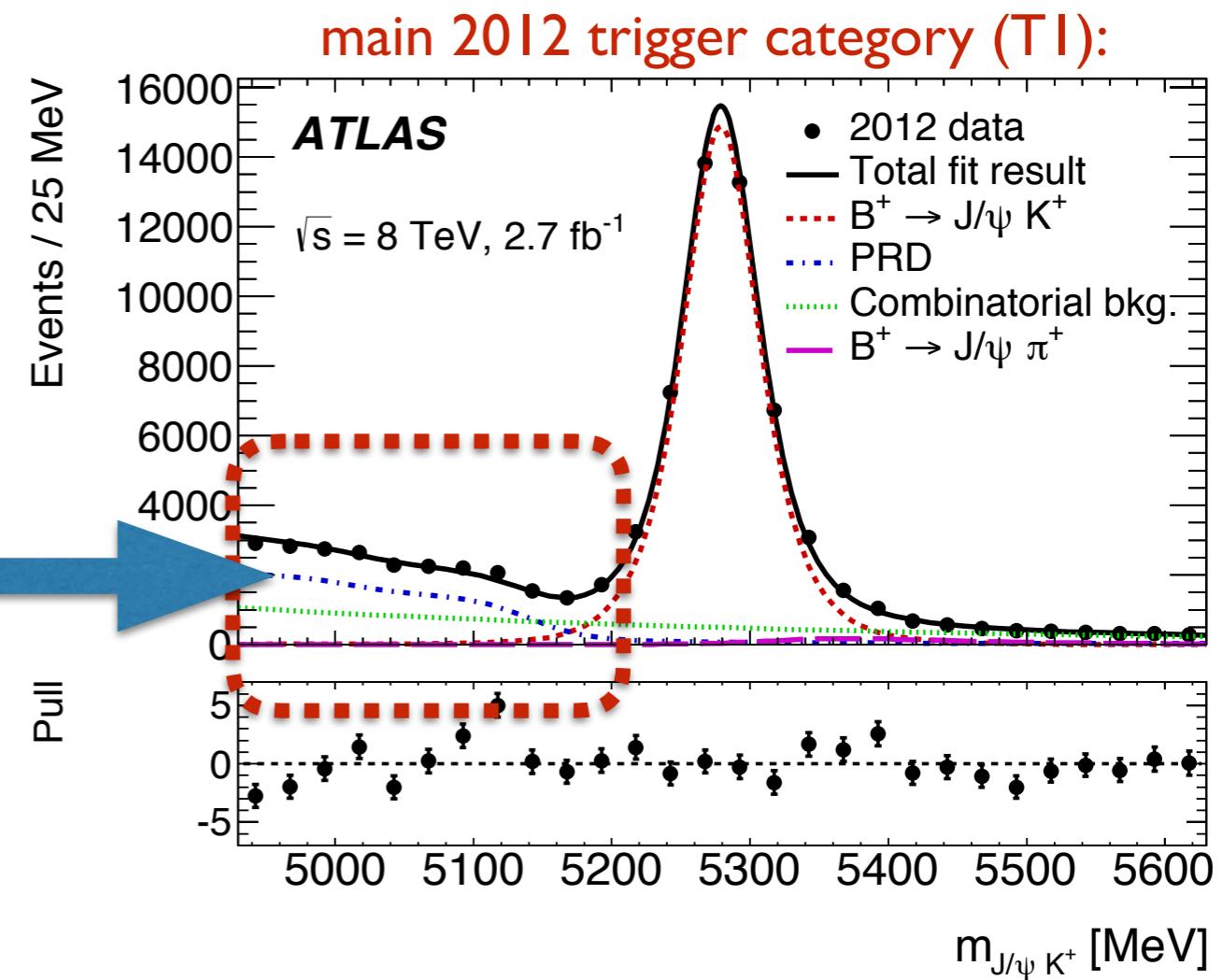
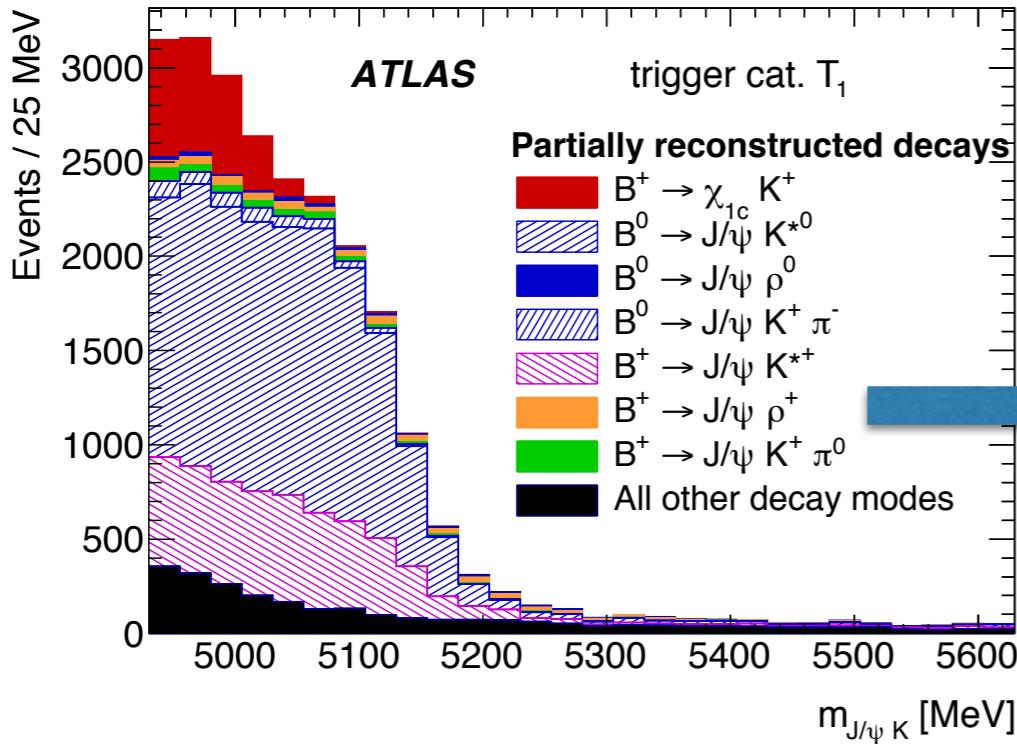
Data/MC Comparisons: Separation Variables



Data/MC Comparisons: Tails of BDT Distribution



$B^\pm \rightarrow J/\psi K^\pm$ and $B^\pm \rightarrow J/\psi \pi^\pm$ Fit



fit results:

Category	$N_{J/\psi K^+}$	$N_{J/\psi \pi^+}$
T_1	$46\,860 \pm 290 \pm 280$	$1\,420 \pm 230 \pm 440$
T_2	$5\,200 \pm 84 \pm 100$	$180 \pm 51 \pm 89$
T_3	$2\,512 \pm 91 \pm 42$	$85 \pm 77 \pm 30$
2011	$95\,900 \pm 420 \pm 1\,100$	$3\,000 \pm 340 \pm 1\,140$

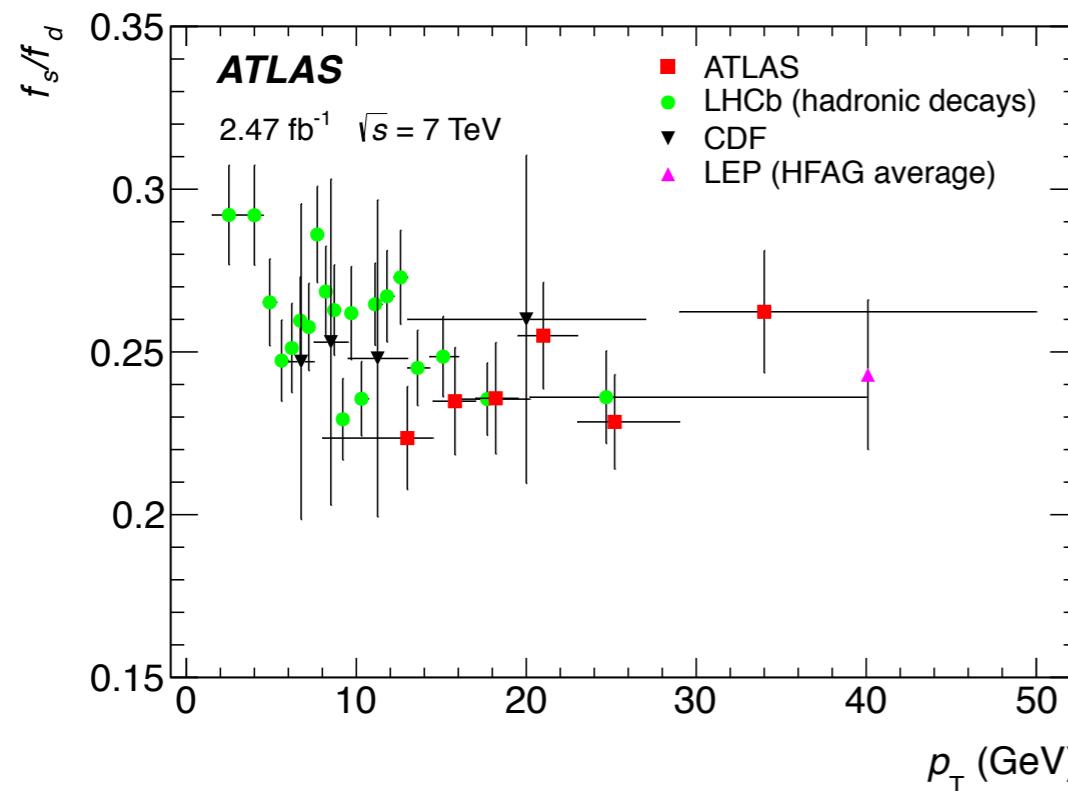
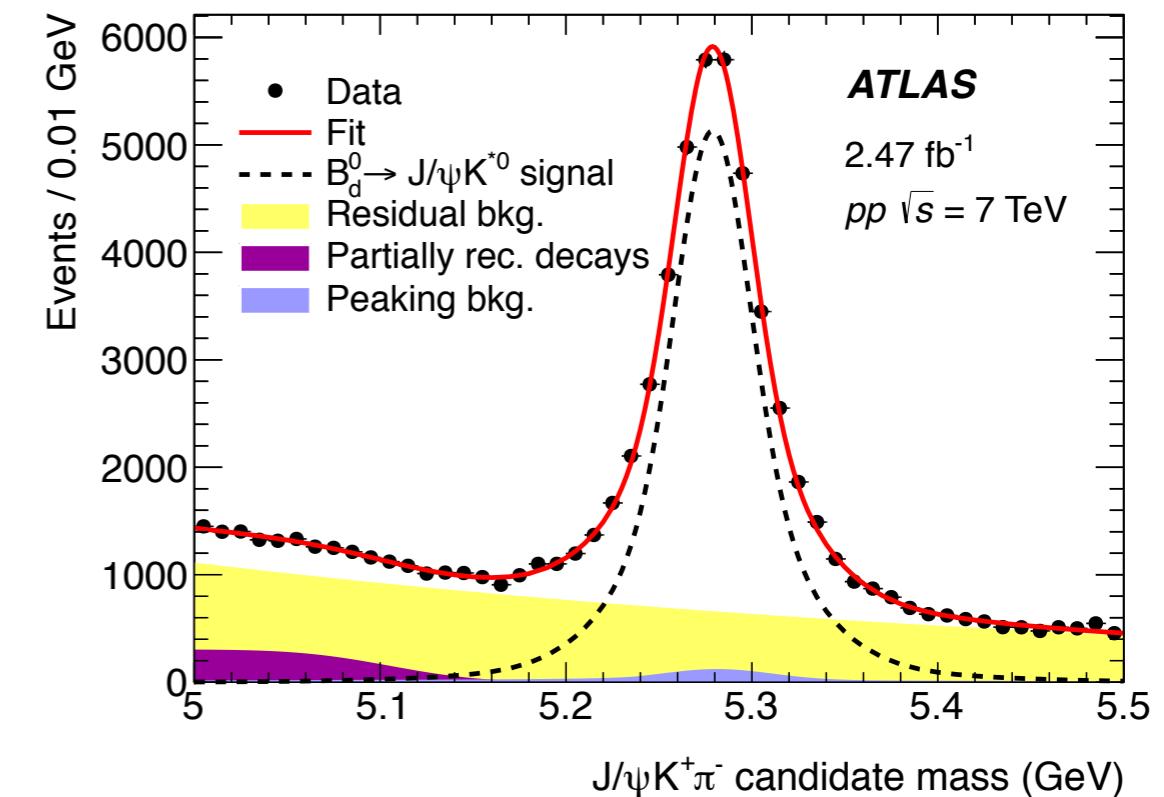
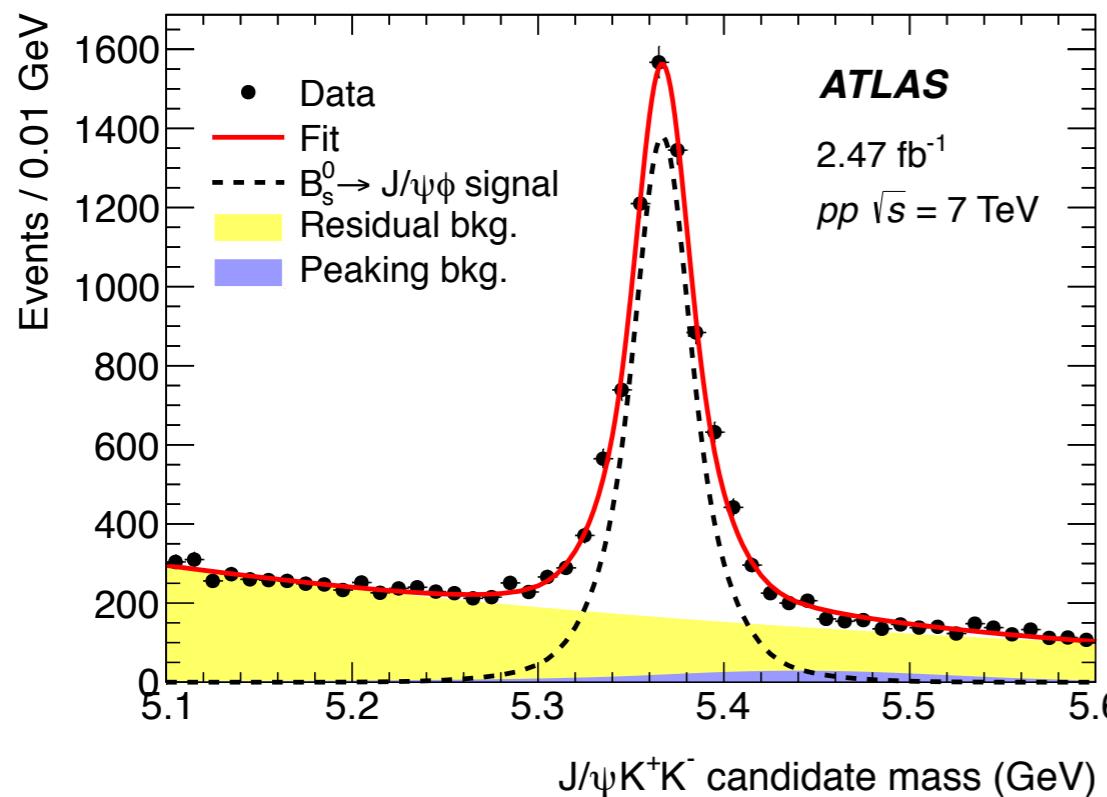
$$\text{BR}(B^\pm \rightarrow J/\psi \pi^\pm) / \text{BR}(B^\pm \rightarrow J/\psi K^\pm) = 0.035 \pm 0.003^{\text{stat}} \pm 0.012^{\text{syst}}$$

LHCb: $0.0383 \pm 0.0011 \pm 0.0007$

BaBar: $0.0537 \pm 0.0045 \pm 0.0011$

f_s/f_d Ratio

ATLAS Collaboration, PRL 115 (2015) 262001 (arXiv:1507.08925)



$$\frac{f_s}{f_d} = \frac{N_{B_s^0}}{N_{B_d^0}} \frac{\mathcal{B}(B_d^0 \rightarrow J/\psi K^{*0})}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)} \frac{\mathcal{B}(K^{*0} \rightarrow K^+ \pi^-)}{\mathcal{B}(\phi \rightarrow K^+ K^-)} \mathcal{R}_{\text{eff}},$$

► Results are in good agreement with other experiments:

$$f_s/f_d = 0.240 \pm 0.020$$

Upgrade: Topological L1 Trigger

Trigger menu optimized for all B physics channels, currently (mid 2016) under commissioning

