New physics searches with heavy flavour with the ATLAS experiment

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ATLAS detector

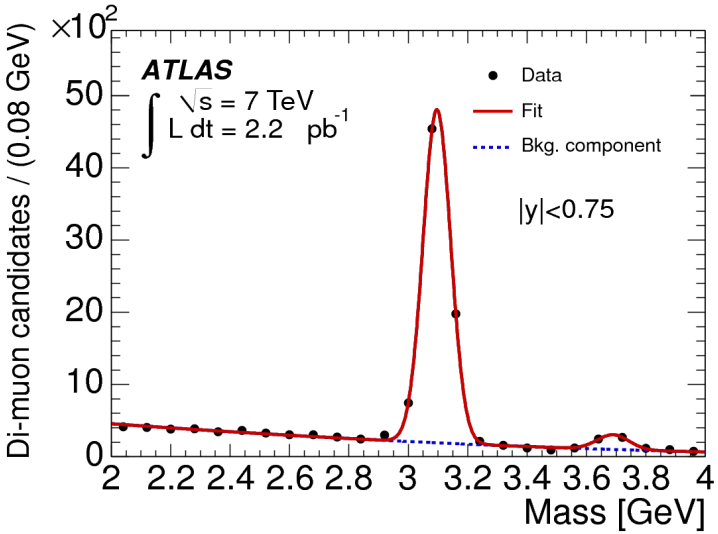
Inner Detector: tracking, momentum and vertex measurement

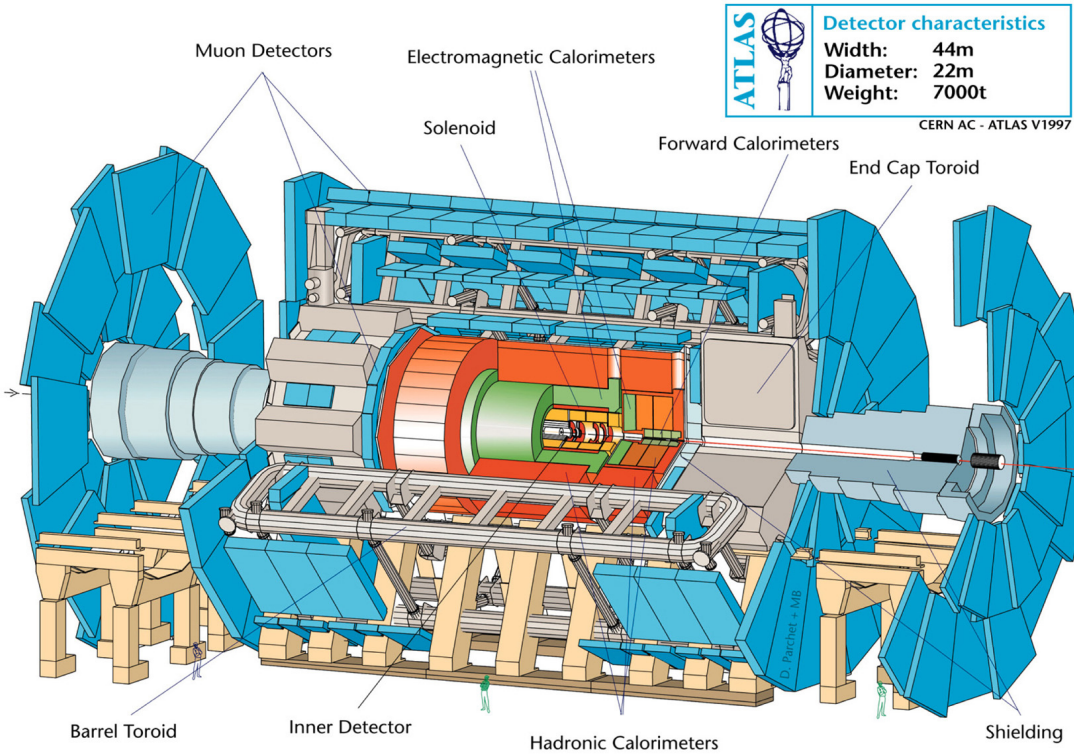
- $|\eta|$ <2.5, d_0 resolution $\sim$ 10 μm

Muon Spectrometer: trigger and muon identification

- $|\eta|$ <2.7, resolution $\sim$ 40 μm

Mass resolution $\sigma(m_{J/\psi})$ = 46$\pm$1 MeV

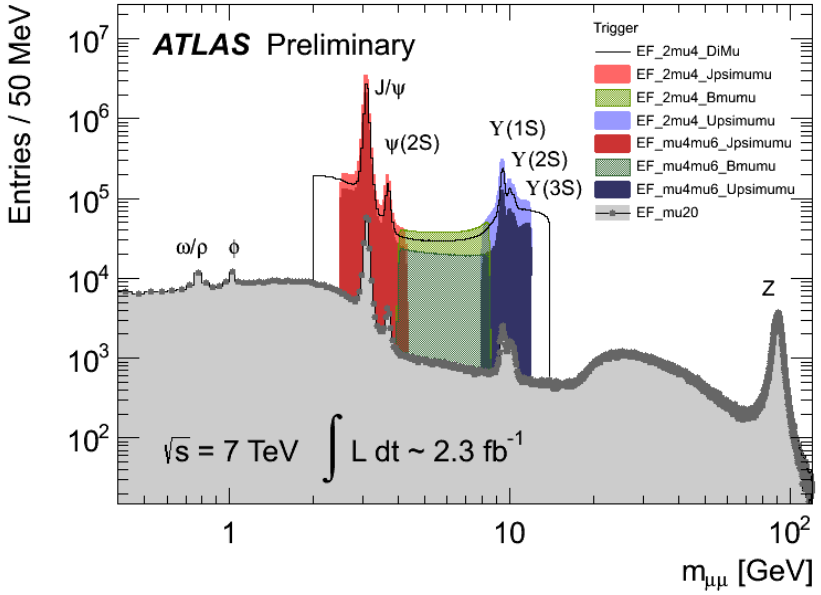




Trigger

B-physics trigger:

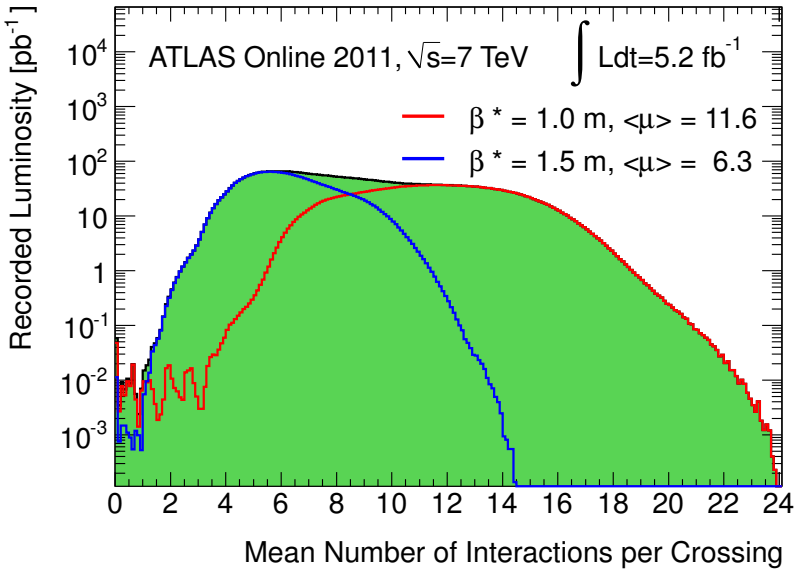
- muons and di-muon decays (J/ψ,Υ)
- L1: single and di-muon triggers (threshold from p_{T}= 4GeV)
- L2 and EF: muons from common vertex, opposite charge
- invariant mass window of J/ψ, B and Υ un-prescaled



Analyses shown here:

- 2011 dataset, $\int L \ = 4.9\mathrm{fb}^{-1}$
- all results and updates on

http://twiki.cern.ch/twiki/bin/view/AtlasPublic



$B_s^o \to J/\psi\ \phi$: measurement of ϕ_s and $\Delta\Gamma_s$

$B_s^o \to J/\psi\ \phi$

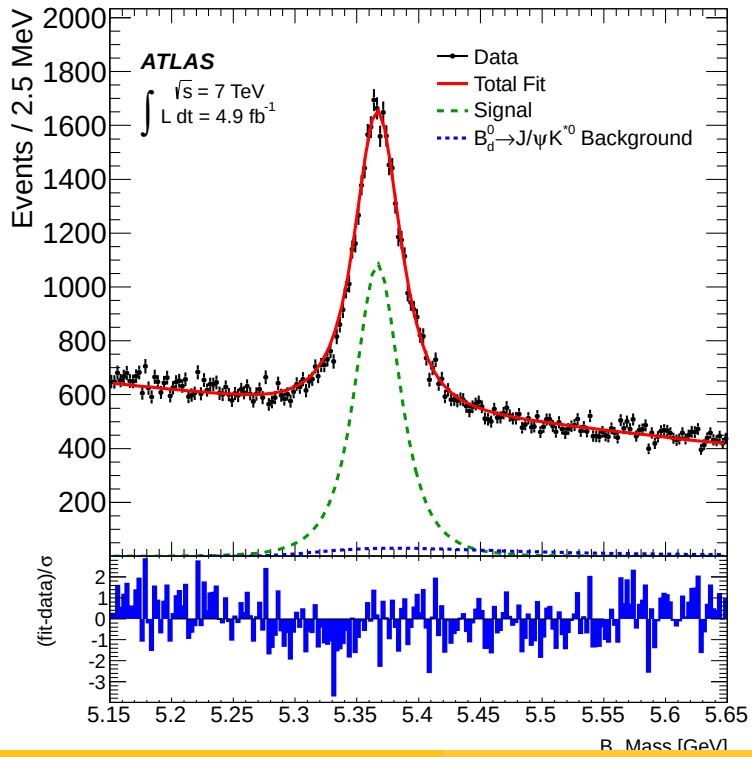
arXiv:1407.1796

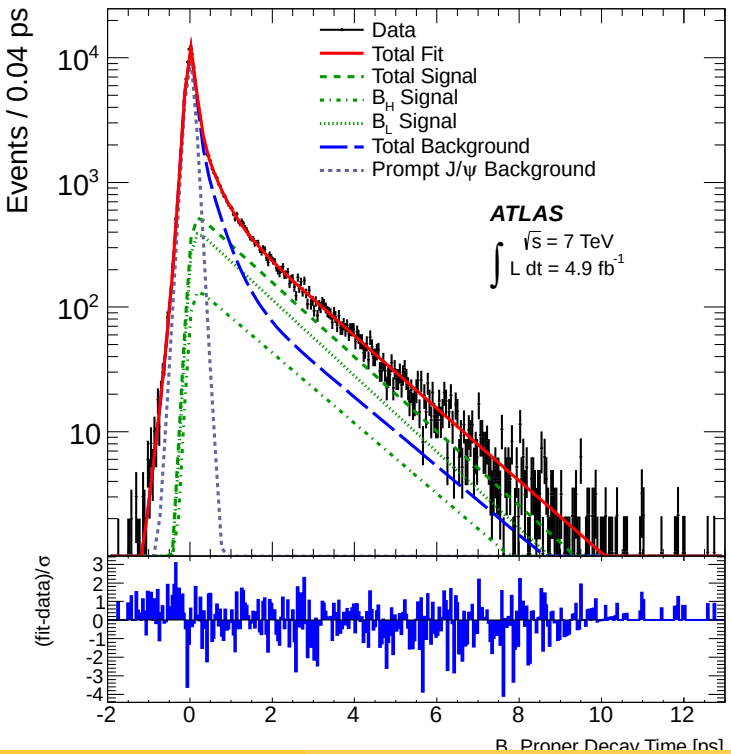
Standard Model predicts very small value for B_s mixing phase

$$\phi_s \simeq -2\beta_s = (-0.0368 \pm 0.0018)\ \mathrm{rad}$$

Event selection: J/ψ dimuon trigger, reconstruction of $B_s \to \mu^+\mu^-K^+K^-$
Measure mass and proper decay time $\tau = \frac{L_{xy} M_{B_s}}{p_{t_B}}$

- 22670 $\pm$ 150 candidates extracted from fit





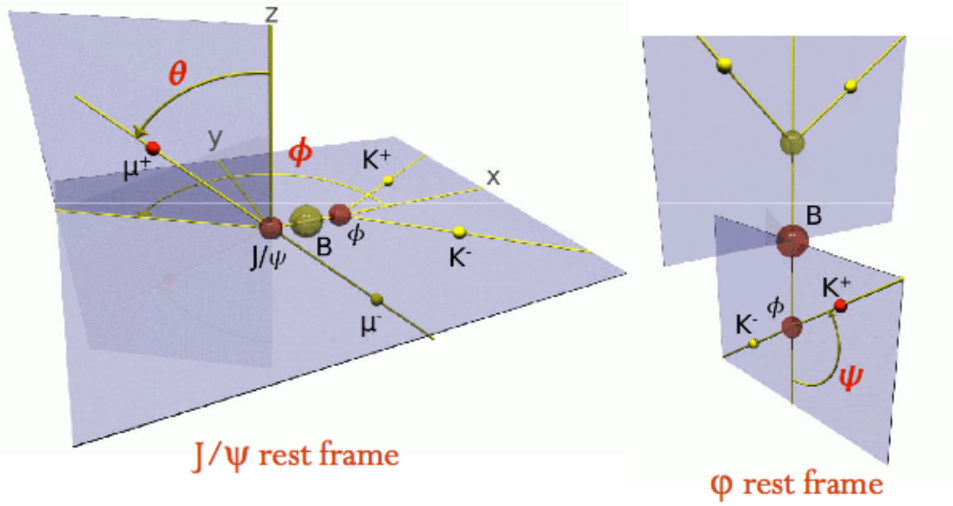
$B_s^o \to J/\psi\ \phi$: Analysis method

- per-candidate maximum likelihood fit

$$\ln\ \mathcal{L} = \sum_{i=1}^{N} \{\ln(w_i \cdot f_s \cdot \mathcal{F}_s(m_i, t_i, \Omega_i) + f_s \cdot f_{B^0} \cdot \mathcal{F}_{B^0}(m_i, t_i, \Omega_i) + (1 - f_s \cdot (1 + f_{B^0}))\mathcal{F}_{bkg}(m_i, t_i, \Omega_i))\}$$

- PDF with signal $\mathcal{F}_s$ and two background components $\mathcal{F}_{B^0}$ and $\mathcal{F}_{bkg}$

$$\mathcal{F}_s(m_i, t_i, \Omega_i, P(B|Q)) = P_s(m_i, \sigma_{m_i}) \cdot P_s(\sigma_{m_i}) \cdot P_s(\Omega_i, t_i, P(B|Q), \sigma_{t_i}) \cdot P_s(\sigma_{t_i}) \cdot P_s(P(B|Q)) \cdot A(\Omega_i, p_{Ti}) \cdot P_s(p_{Ti})$$



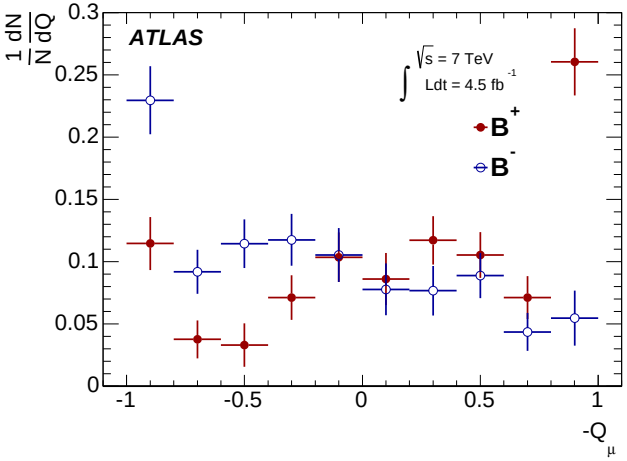
Measured variables:

- proper decay time t, mass m and their errors
- transversity angles Ω_i
- per-candidate probability that candidate was initially $B_s/\overline{B}_s$

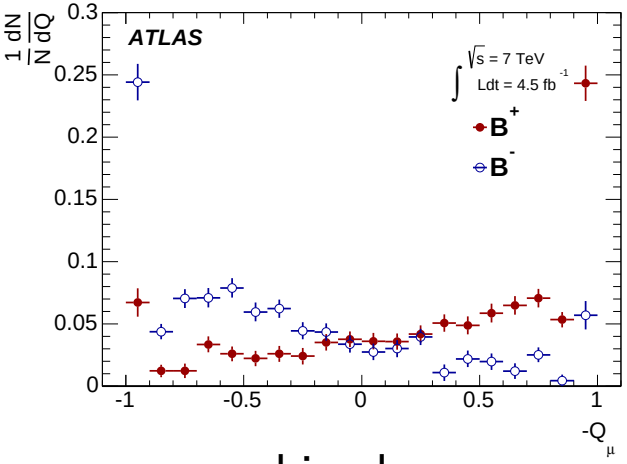
$B_s^o \to J/\psi\ \phi$: Flavour tagging

- using opposite side tagging, calibrated on $B^{\pm} \to J/\psi\ K^{\pm}$
- muon tagger - muon from semileptonic decay, cone charge Q_{μ}
- jet charge tagger - jet from the same primary vertex, jet charge Q_{jet}

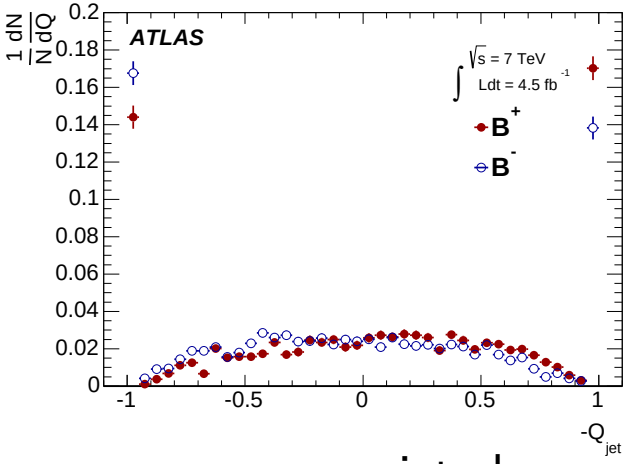
Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined muon	3.37 ± 0.04	50.6 ± 0.5	0.86 ± 0.04
Segment muon	1.08 ± 0.02	36.7 ± 0.7	0.15 ± 0.02
Jet charge	27.7 ± 0.1	12.68 ± 0.06	0.45 ± 0.03
Total	32.1 ± 0.1	21.3 ± 0.08	1.45 ± 0.05



segment muons



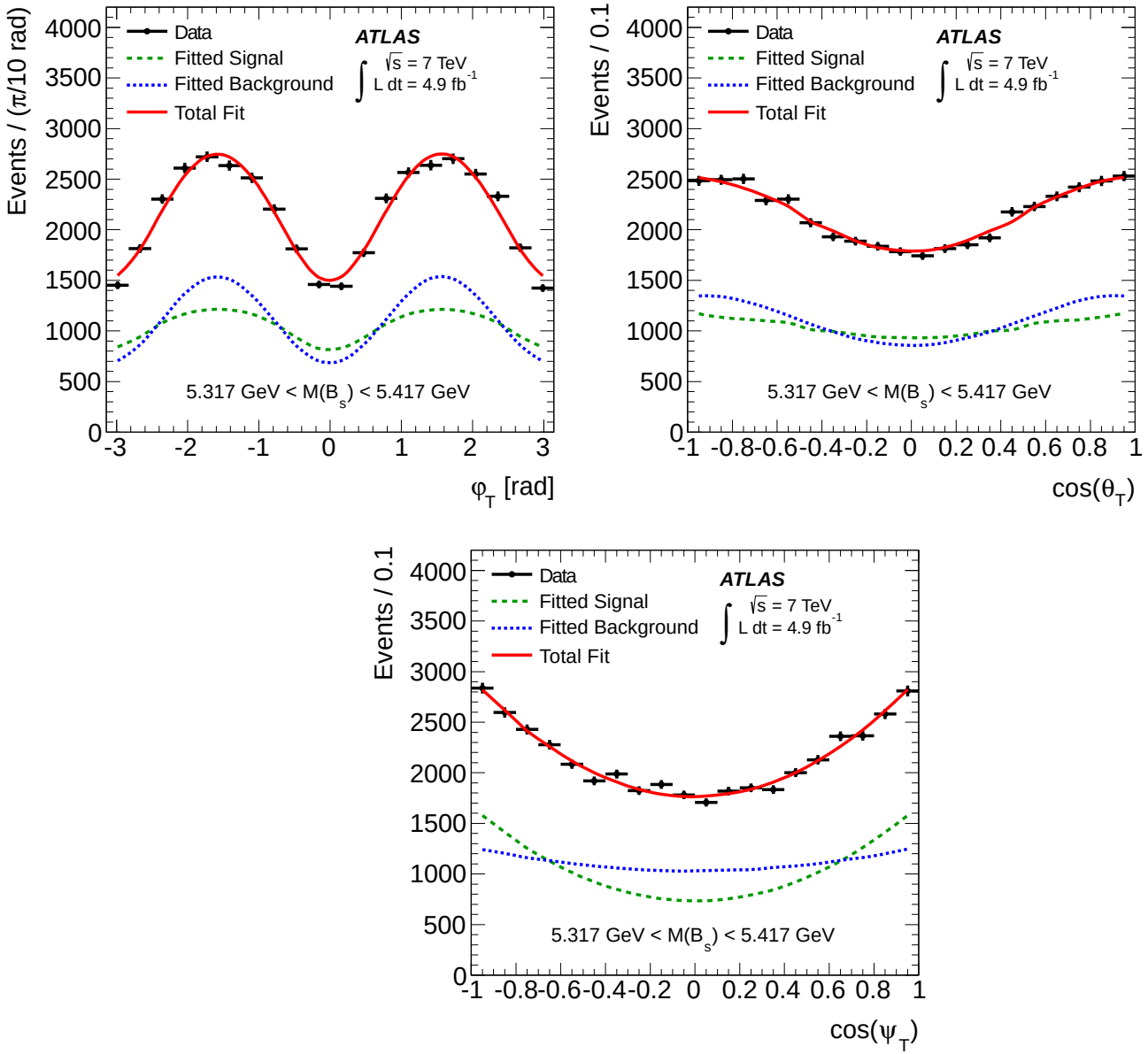
combined muons



jet charge

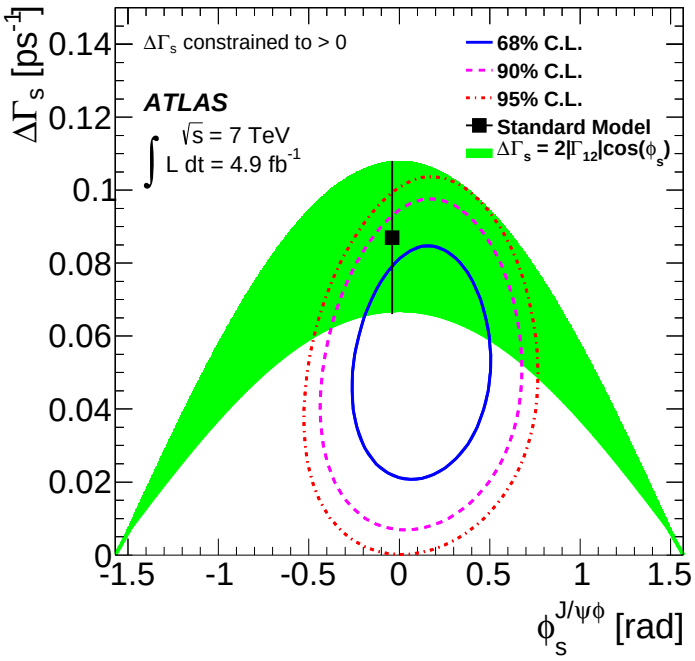
$B_s^o \to J/\psi\ \phi$: Results

Transversity angles in signal region:

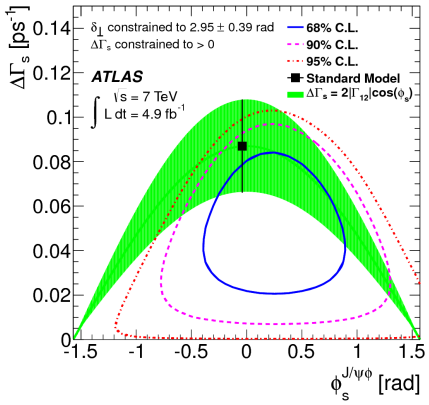


$B_s^o \to J/\psi\ \phi$: Results

$$\phi_s = 0.12 \pm 0.25\ (\text{stat.}) \pm 0.05\ (\text{syst.})\ \text{rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\ (\text{stat.}) \pm 0.010\ (\text{syst.})\ \text{ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1}$$
$$|A_0(0)|^2 = 0.529 \pm 0.006(\text{stat.}) \pm 0.012\ (\text{syst.})$$
$$|A_{\|}(0)|^2 = 0.220 \pm 0.008(\text{stat.}) \pm 0.009\ (\text{syst.})$$
$$|A_S(0)|^2 = 0.024 \pm 0.014(\text{stat.}) \pm 0.028\ (\text{syst.})$$
$$\delta_\perp = 3.89 \pm 0.47\ (\text{stat.}) \pm\ 0.11\ (\text{syst.})\ \text{rad}$$



- uncertainty of ϕ_s improved by 40% w.r.t. untagged analysis JHEP 12 (2012) 072
- gained sensitivity to $\delta_\perp$



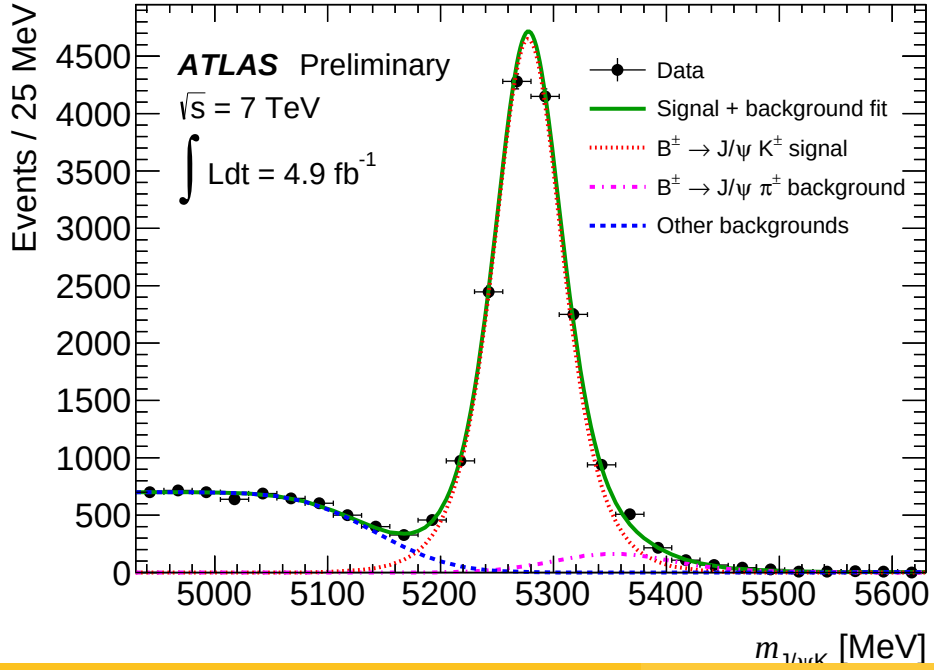
Search for $B_s^0 \to \mu^+\mu^-$

$B_s^0 \to \mu^+\mu^-$

ATLAS-CONF-2013-076

Analysis strategy:

- measure relative branching ratio with reference channel $B^\pm \to J/\psi K^\pm$
- blind analysis in signal region $m(B_s^0)\pm 300$MeV
- sidebands split in two: optimize selection cuts, measure background yield after cuts
- Boosted decision tree to suppress non-resonant background



- reference channel selected with the same BDT
- $N_{J/\psi K^\pm} = 15214 \pm 1.1\% \text{ (stat)} \pm 2.4\% \text{ (syst)}$

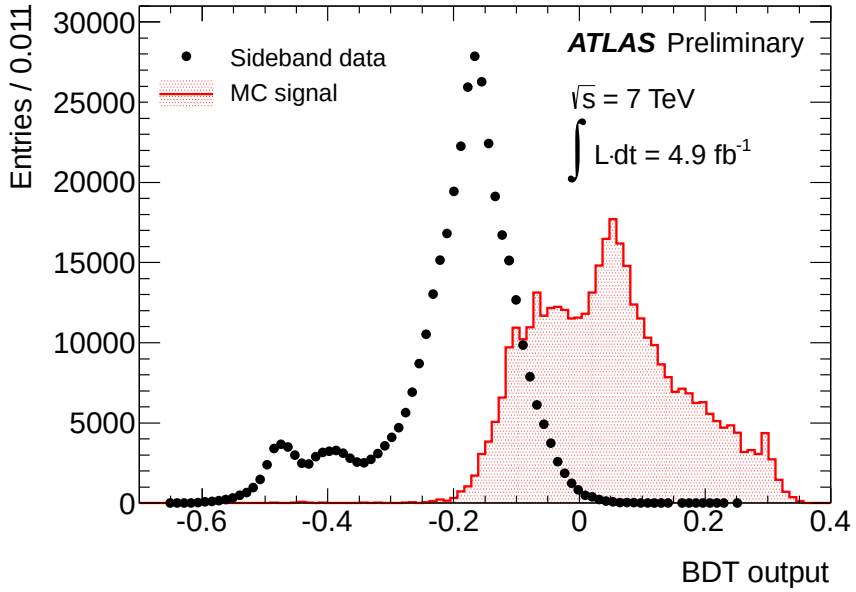
$B_s^0 \to \mu^+\mu^-$: Background discrimination

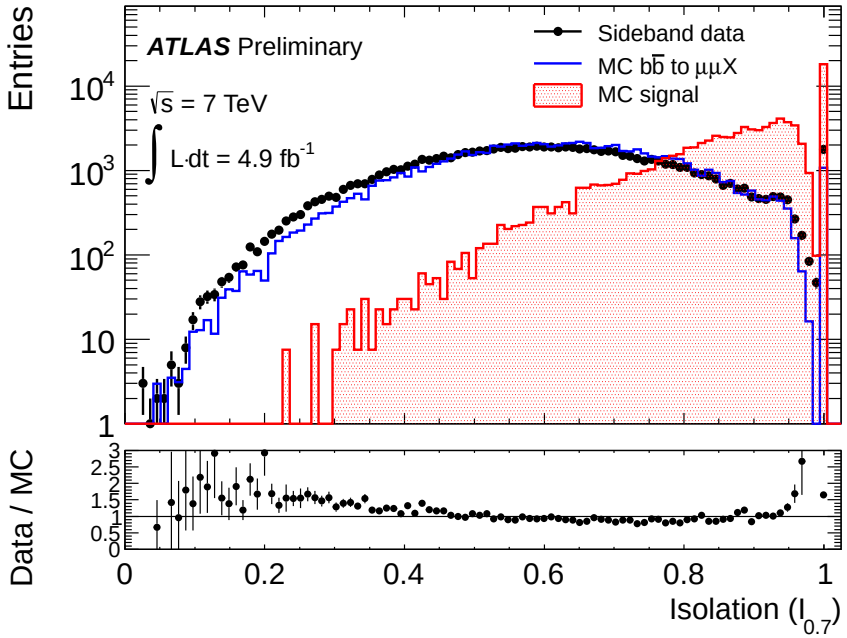
- continuum dominated by $b\bar{b} \to \mu^+\mu^- X$
- BDT with 13 discriminating variables
- trained on MC, optimized on sideband
- very good: isolation and pointing angle
- signal candidates selection optimized in $(\Delta m, t_{BDT})$ space as max of

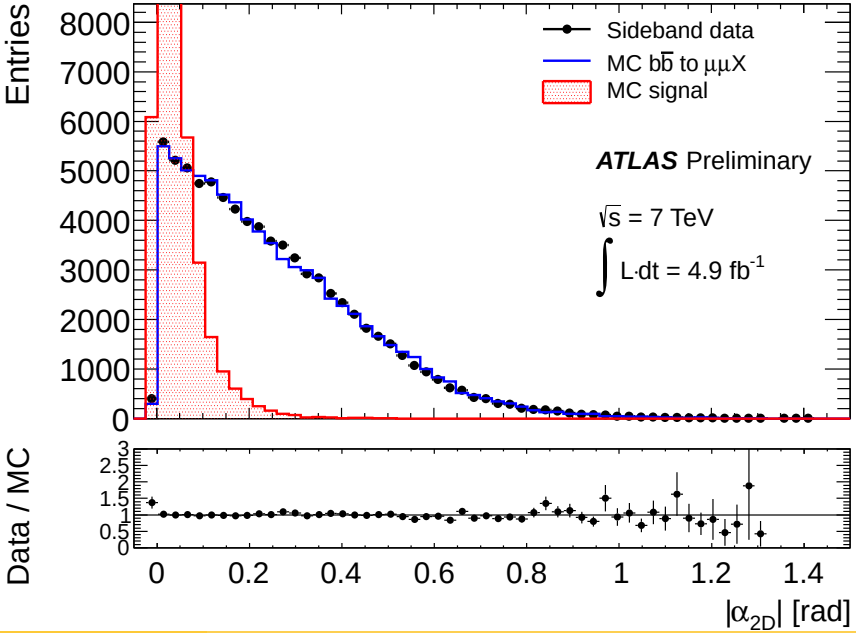
$$P(\Delta m, t_{BDT}) = \epsilon_{sig}/(1/\sqrt{N_{bkg}})$$

- working point:

$$t_{BDT} > 0.118, |\Delta m| < 121\text{MeV}$$



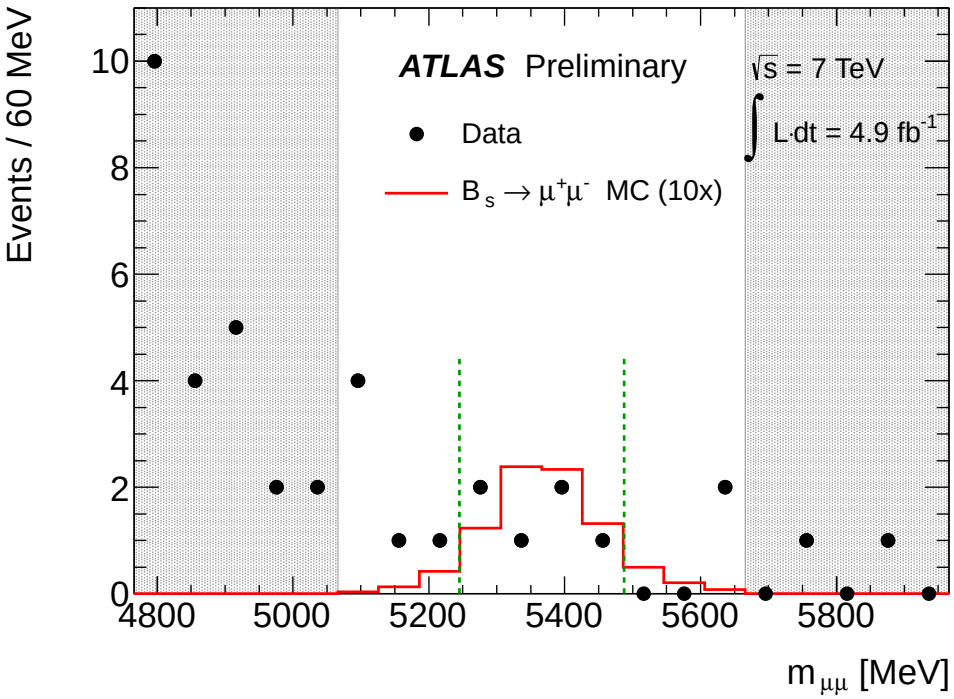


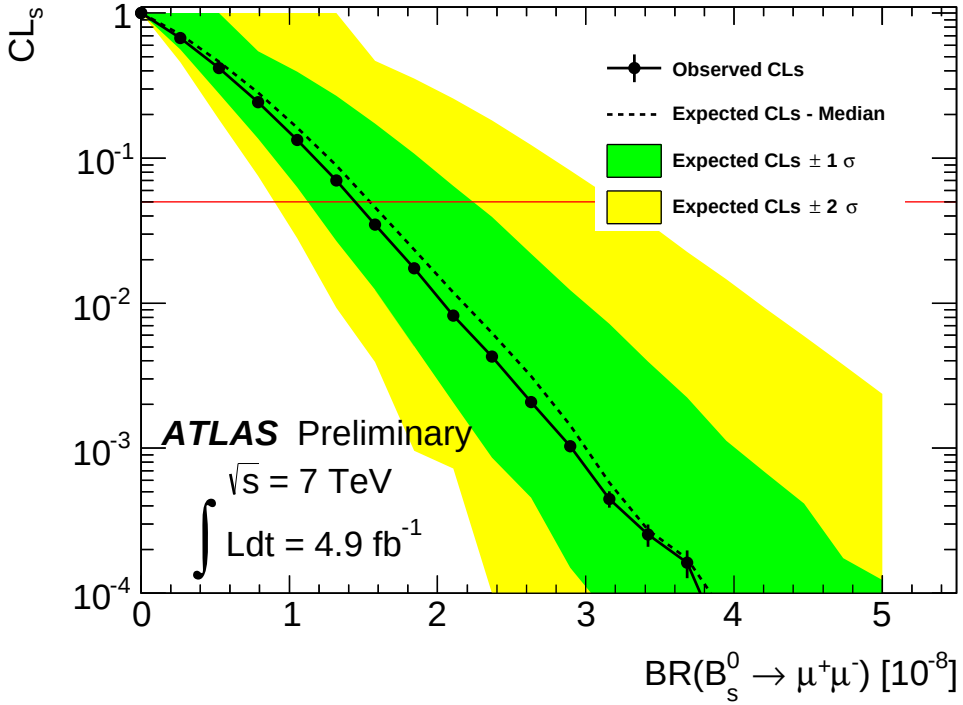


$B_s^0 \to \mu^+\mu^-$: Results

- single event sensitivity (2.07 ± 26% (stat) ± 12.5% (syst))x10^{-9}
- events expected in signal window $N_{bkg} = 6.75$
- events observed $N_{obs} = 6$
- upper limit extracted by CL method

$$BR(B_s^0 \to \mu^+\mu^-) < 1.5 \times 10^{-8} \text{ at } 95\% \text{ CL}$$





- new results with full Run1 dataset coming soon

Angular analysis of $B_d^0 \to K^{*0}(K^+\pi^-)\mu^+\mu^-$

$B_d^0 \to K^{*0}\mu^+\mu^-$

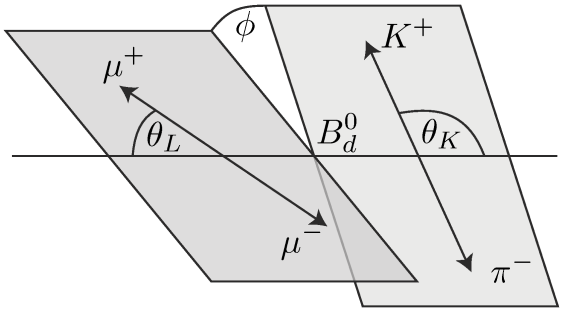
ATLAS-CONF-2013-038

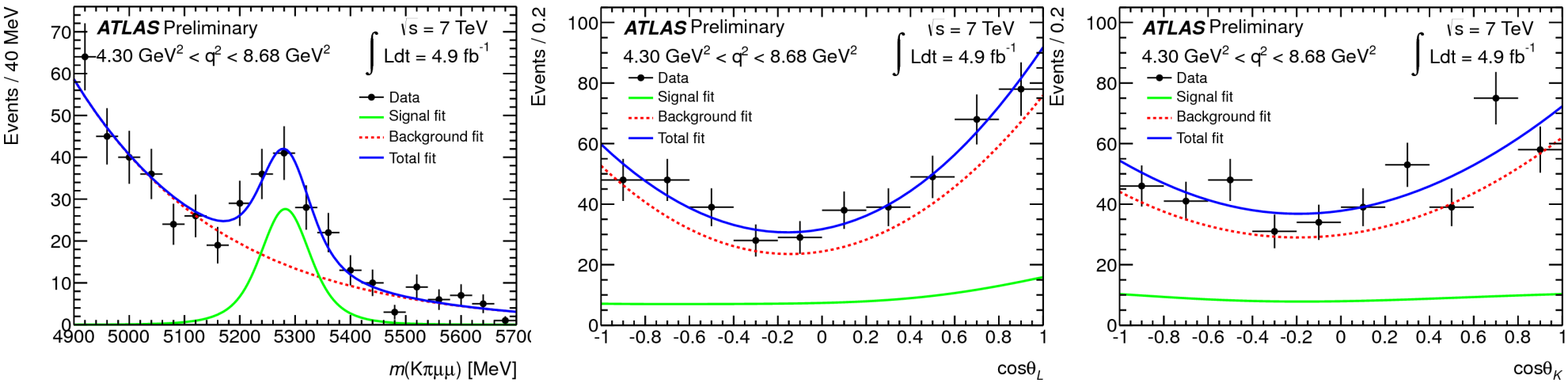
Event selection: based on $K\pi$ and $K\pi\mu\mu$ invariant mass

- excluded resonant J/ψ and $\psi(2S)$
- MC-optimized cuts for combinatorial and radiative decays background: eg. lifetime significance $\tau/\sigma_\tau > 12.75$, pointing angle $\cos\theta > 0.999$

Analysis:

- use unbinned maximum likelihood fit
- fit mass to separate signal from background
- $N_{sig} = 466 \pm 34$, $N_{bkg} = 1131 \pm 43$





$B_d^0 \to K^{*0}\mu^+\mu^-$

Forward-backward asymmetry and longitudinal polarization fraction measured from differential angular distribution (integrate out ϕ and θ)

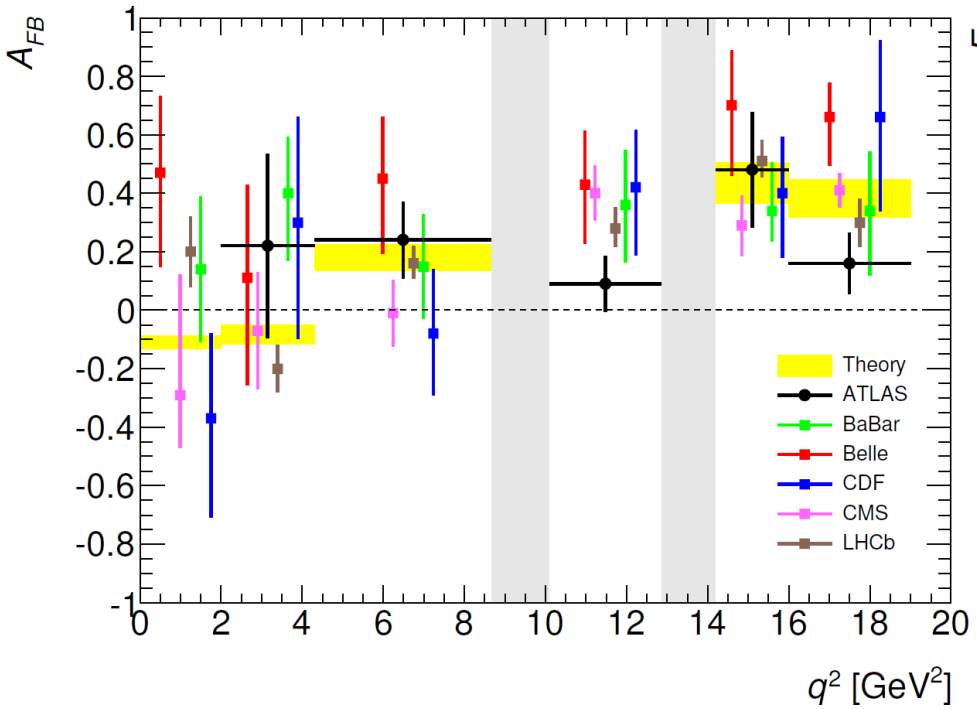
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}(1 - F_L(q^2))(1 - \cos^2\theta_K)$$

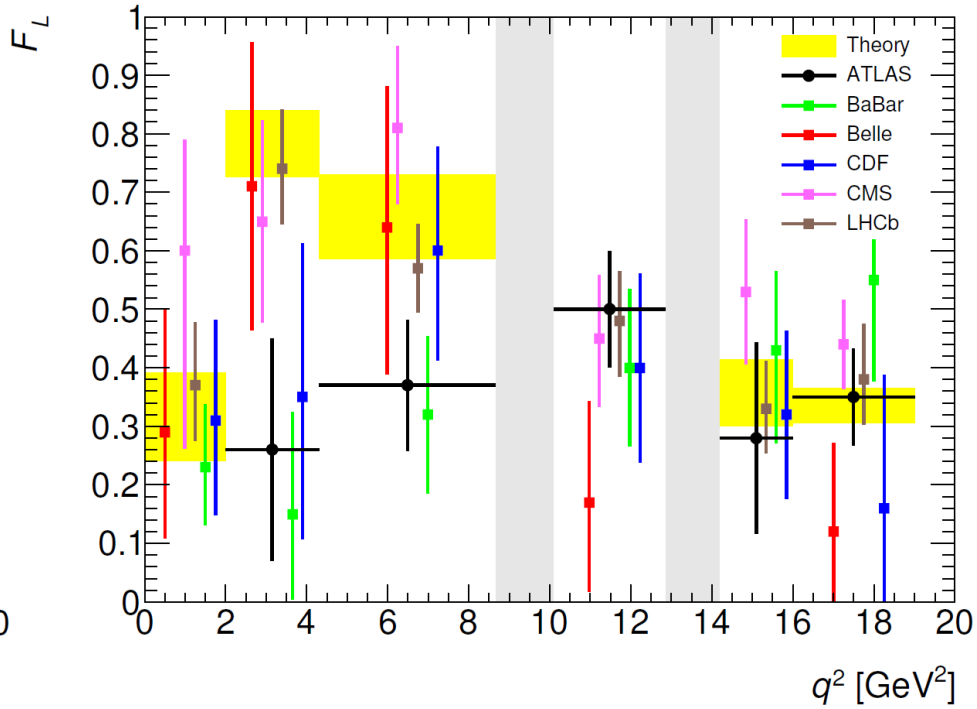
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_L} = \frac{3}{4}F_L(q^2)(1 - \cos^2\theta_L) + \frac{3}{8}(1 - F_L(q^2))(1 + \cos^2\theta_L) + A_{FB}(q^2)\cos\theta_L$$

q^2 range (GeV^2)	N_{sig}	A_{FB}	F_L
$2.00 < q^2 < 4.30$	19 ± 8	$0.22 \pm 0.28 \pm 0.14$	$0.26 \pm 0.18 \pm 0.06$
$4.30 < q^2 < 8.68$	88 ± 17	$0.24 \pm 0.13 \pm 0.01$	$0.37 \pm 0.11 \pm 0.02$
$10.09 < q^2 < 12.86$	138 ± 31	$0.09 \pm 0.09 \pm 0.03$	$0.50 \pm 0.09 \pm 0.04$
$14.18 < q^2 < 16.00$	32 ± 14	$0.48 \pm 0.19 \pm 0.05$	$0.28 \pm 0.16 \pm 0.03$
$16.00 < q^2 < 19.00$	149 ± 24	$0.16 \pm 0.10 \pm 0.03$	$0.35 \pm 0.08 \pm 0.02$
$1.00 < q^2 < 6.00$	42 ± 11	$0.07 \pm 0.20 \pm 0.07$	$0.18 \pm 0.15 \pm 0.03$

$B_d^0 \to K^{*0}\mu^+\mu^-$:Results

- measurement consistent with SM
- ATLAS result is competitive in high q^2 regions
- uncertainties statistically dominated (working on 2012 data)





Summary

The large amount of Heavy Flavour data collected by ATLAS is potentially sensitive to New Physics.
Presented analyses show no deviation from SM:

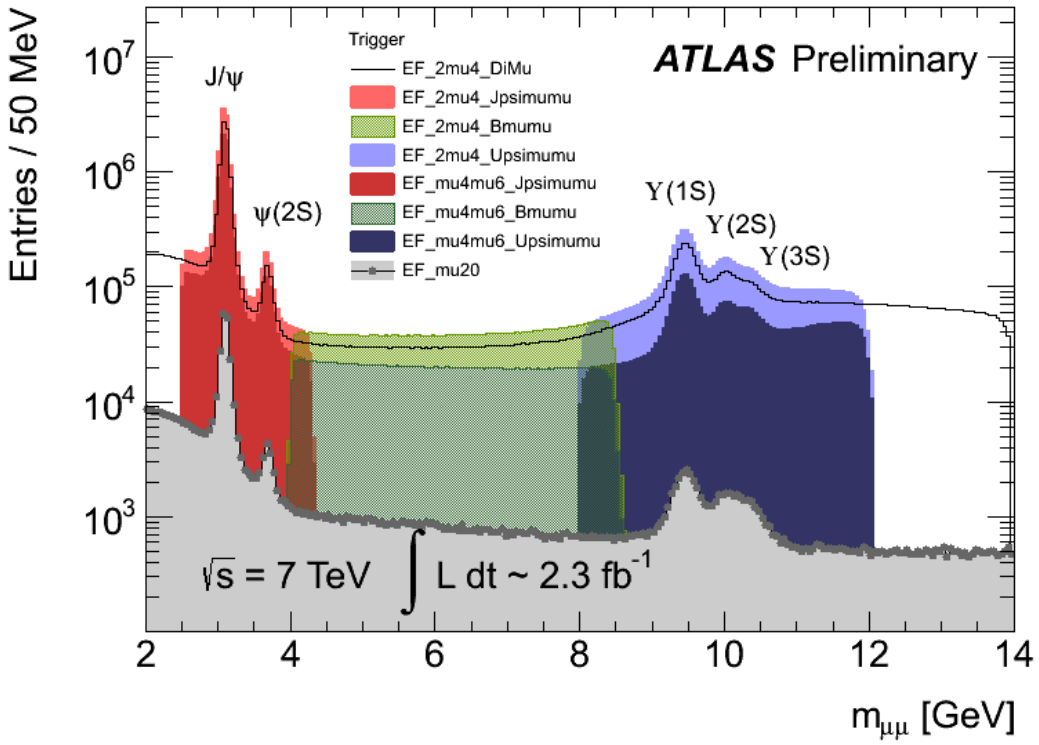
- $B_s^o \rightarrow J/\psi\ \phi$ (arXiv:1407.1796)
- $B_s^0 \rightarrow \mu^+\mu^-$ (ATLAS-CONF-2013-076)
- $B_d^0 \rightarrow K^{*0}\mu^+\mu^-$ (ATLAS-CONF-2013-038)

Measurements statistically limited, analyses for 2012 and full Run1 dataset (5+20 fb^{-1}) to be completed soon.

Thank you for your attention.

Backup

B physics triggers



- dimu - full range 1.5-14GeV
- Jpsimumu - 2.5-4.3GeV
- Bmumu - 4-8.5GeV
- Upsimumu - 8-12GeV

$B_s^o \to J/\psi\ \phi$ preselection

Trigger	dimuon 4+4GeV or 4+2GeV
Tracks	at least 1 PV from 4 ID tracks
	at least 2 oppositely charged muons
	min. 1 Pixel hit, 4 SCT hits
Muons	if $\|\eta\| < 1.05$ than $m_{\mu\mu}$ in (2.959,3.229)GeV
	if $1.05 < \|\eta\| < 2.5$ than $m_{\mu\mu}$ in (2.852,3.332)GeV
	combined $m_{\mu\mu}$ in (2.913,3.273)GeV
	muon vertex χ^2/N.D.F. < 10
K	$p_{\mathrm{T}} > 0.5$GeV, $\|\eta\| < 2.5$
Phi	$m(K^+K^-)$ in (1.0085,1.0305)GeV
	$p_{\mathrm{T}}(\mathrm{K}\pm) > 1$GeV
B_s	mass in (5.15,5.65)GeV
	χ^2/N.D.F. < 3

- extracted 131513 B_s candidates

$B_s^0 \to \mu^+\mu^-$ preselection

Triggers:	EF_2mu4_Bmumu
	EF_2mu4_Jpsimumu
General:	muons $p_T > 4$GeV, $\|\eta\| < 2.5$
	Kaons $p_T > 2.6$GeV, $\|\eta\| < 2.5$
	track hits: > 0 Pixel, > 5 SCT, > 8 TRT
J/ψ:	$m_{J/\psi}$ in (2.915,3.275)GeV
	vertex χ^2/N.D.F. < 10
$K^\pm$:	$\|d_0\|$ <1.5mm
	$\|z_0 sin\theta\| < 1.5$mm
B_s ($B^\pm$)	vertex χ^2/N.D.F. < 2 (6)
	$p_T > 8$, $\|\eta\| < 2.5$
	PV closest to B vertex in z

$B_s^0 \to \mu^+\mu^-$ BDT variables

Variable	Description
L_{xy}	Scalar product in the transverse plane of $(\Delta\vec{x} \cdot \vec{p}^B)/\lvert\vec{p}_T^B\rvert$
$I_{0.7}$ isolation	Ratio of $\lvert\vec{p}_T^B\rvert$ to the sum of $\lvert\vec{p}_T^B\rvert$ and the transverse momenta of all tracks with $p_T > 0.5$ GeV within a cone $\Delta R < 0.7$ from the B direction, excluding B decay products
$\lvert\alpha_{2D}\rvert$	Absolute value of the angle in the transverse plane between $\Delta\vec{x}$ and $\vec{p}^B$
p_L^{min}	Minimum momentum of the two muon candidates along the B direction
p_T^B	B transverse momentum
ct significance	Proper decay length $ct = L_{xy} \times m_B/p_T^B$ divided by its uncertainty
χ_z^2, χ_{xy}^2	Significance of the separation between production (PV) and decay vertex (SV) $\Delta\vec{x}^T \cdot \left(\sigma_{\Delta\vec{x}}^2\right)^{-1} \cdot \Delta\vec{x}$, in z and (x, y), respectively
$\lvert D_{xy}\rvert^{min}, \lvert D_z\rvert^{min}$	Absolute values of the minimum distance of closest approach in the xy plane or along z of tracks in the event to the B vertex
ΔR	Angle $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ between $\Delta\vec{x}$ and $\vec{p}^B$
$\lvert d_0\rvert^{max}, \lvert d_0\rvert^{min}$	Absolute values of the maximum and minimum impact parameter in the transverse plane of the B decay products relative to the primary vertex

$B_d^0 \to K^{*0}\mu^+\mu^-$ cuts

Baseline:	muon $p_T > 3.5$GeV
	tracks $\|\eta\| < 2.5$
	dimuon vertex χ^2/N.D.F. < 10
	K $p_T > 0.5$GeV
	π $p_T > 0.5$GeV
	m_{K^*} in (846,946)MeV
Selection cuts:	$\tau/\Delta\tau$(B)> 12.75
	cos(Θ) > 0.999
	χ^2/N.D.F. < 2
	K* $p_T > 3$GeV
	$\|(m_{B,rec} - m_{B,PDG}) - (m_{\mu\mu,rec} - m_{J/\psi),PDG})\| > 130$MeV
	(radiative J/ψ decays)