Search for new physics phenomena with heavy flavour hadrons in ATLAS

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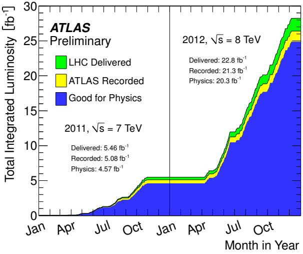
June 30, 2016

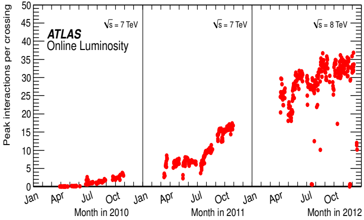
Layout of the talk

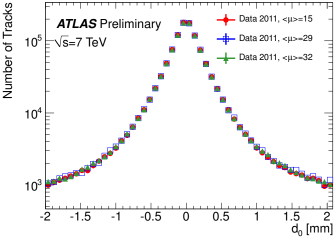
Precision measurements of B-hadrons decays in search for effects beyond Standard model (SM) in Run1 data ATLAS

- Performance at high luminosity of Run1
- CPV Phase ϕ_s in $B_s^0 \to J/\psi\phi$
- Width difference $\Delta\Gamma_d$ of B_d^0 meson, testing reliability of the SM
- Decay probabilities of $B_s^0/B_d^0 \to \mu^+\mu^-$ search for potential deviations from SM
- Summary

Run1 data, ATLAS performance







- Precise tracking essential for B-phys high-sensitivity searches for NP
- With increasing pileup, tracking, vertexing had to be improved to achieve stability
  - d0 resolution (the width of main peak) remaines stable
  - tails are potentially sensitive to fakes: no increase of the fake rate observed

Search for NP in precision measurement of the CPV Phase ϕ_s

Physics Motivation

- $B_s^0 \rightarrow J/\psi\phi$ expected to be sensitive to BSM physics
- CP-violation phase: ϕ_s
  - *CPV* due to interference between:
    - Direct decay
    - Flavour oscillation
- SM Predictions:
  - $\phi_s = -0.0364 \pm 0.0016$ [rads]
  - Indirect determination via global fits
  - SM precision much smaller than experimental
  - Experimental measurement a viable BSM search

Methodology - fit

Time-Dependent Angular Analysis

- Observables:
  - Mass, lifetime, p_T, transversity angles, initial flavour
  - Per-candidate errors
- UMLF $\rightarrow$ Physics parameters:
  - ϕ_s $\Delta\Gamma_s$ Γ_s
  - transversity amplitudes: $|A_0(0)|^2$, $|A_{\|}(0)|^2$, $|A_S(0)|^2$, $\delta_\perp$, $\delta_{\|}$, $\delta_\perp - \delta_S$

Methodology - tagging

OST Tagging

- Detect decay of pair-produced b
  - p_T weighted sum of charges from decay
- Per-event tagger/probability:
  - Muon, electron (2012), jet-charge
- Calibrated with $B^{\pm} \to J/\psi K^{\pm}$
- Tagging applied probabilistically in fit

Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined muon	4.12 ± 0.02	47.4 ± 0.2	0.92 ± 0.02
Electrons	1.19 ± 0.01	49.2 ± 0.3	0.29 ± 0.01
Segment Tagged muon	1.20 ± 0.01	28.6 ± 0.2	0.10 ± 0.01
Jet charge	13.15 ± 0.03	11.85 ± 0.03	0.19 ± 0.01
Total	19.7 ± 0.04	27.6 ± 0.06	1.49 ± 0.02

Dilution, Tagging power defined in Backup slide.

Mass/Lifetime Fits

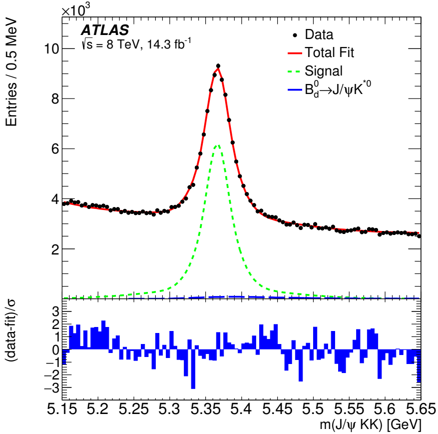


Figure: B_s^0 mass distribution (2012)

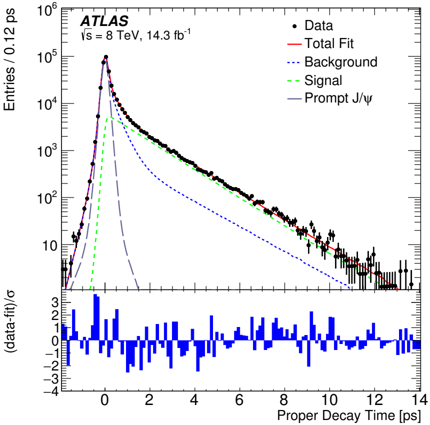


Figure: B_s^0 lifetime distribution (2012)

Angular Projection Fits

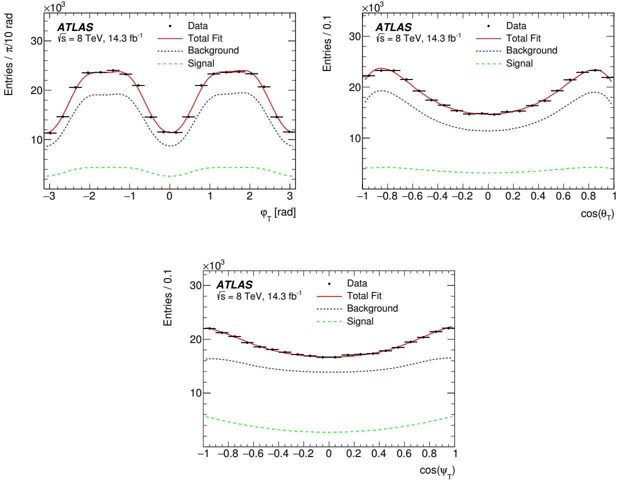


Figure: B_s^0 angular fit projections

2D Scans - ϕ_s v's $\Delta\Gamma_s$

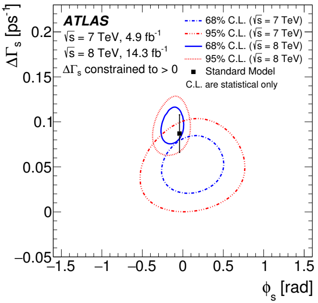


Figure: 2D scan (2011/2012)

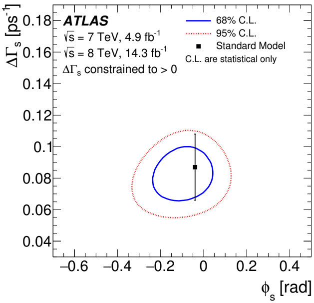


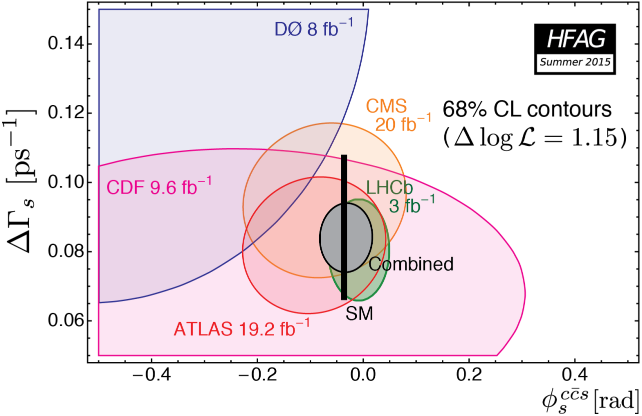
Figure: 2D scan (Run 1)

$B_s^0 \to J/\psi\phi$ Run 1 Results

Parameter	Value	Stat	Systematic
ϕ_s rad	- 0.098	0.084	0.040
$\Delta\Gamma_s$ [ps^{-1}]	0.083	0.011	0.007
Γ_s [ps^{-1}]	0.677	0.003	0.003
$\lvert A_0(0)\rvert^2$	0.514	0.004	0.003
$\lvert A_{\parallel}(0)\rvert^2$	0.227	0.004	0.006
$\lvert A_S(0)\rvert^2$	0.071	0.007	0.017
$\delta_{\perp}$ [rad]	4.13	0.33	0.16
$\delta_{\parallel}$ [rad]	3.15	0.13	0.05
$\delta_{\perp} - \delta_S$ [rad]	- 0.08	0.04	0.01

Table: Run 1 result

$B_s^0 \to J/\psi\phi$ Comparison, Conclusion



- All existing data consistent between each other and with the SM
  - HFAG used Preliminary ATLAS version, May 2015, ATLAS ArXive numbers - presented here - slightly differ
- Room for NP in CPV ϕ_s, need Run2 and LHC upgrade

Width difference of B_d^0

Physics motivation

- $\Delta\Gamma_d$ is one of the parameters describing the time evolution of the B_d^0 system
- It is reliably predicted in the Standard Model

$$\Delta\Gamma_d = (0.42 \pm 0.08) \cdot 10^{-2} (SM)$$

- Current experimental uncertainty still large to allow a comparison with the SM prediction

$$\Delta\Gamma_d = (0.1 \pm 1.0) \cdot 10^{-2} (Experiment\ World\ Average)$$

- Additional measurements are required to constrain this quantity and verify the SM prediction

$\Delta\Gamma_d$ measurement method

$\Delta\Gamma_d$ determined from ratio of proper decay time distributions of $B_d^0 \to J/\psi K_S^0$ and $B_d^0 \to J/\psi K^*$

- $B_d^0 \to J/\psi K_S^0$

$$\Gamma_d(t) \sim e^{-\Gamma t}(\cosh \frac{\Delta\Gamma_d}{2} t + \cos(2\beta)\sinh \frac{\Delta\Gamma_d}{2} t - A_p \sin(2\beta)\sin(\delta m t))$$

β CKM angle, A_p production asymmetry of B_d^0

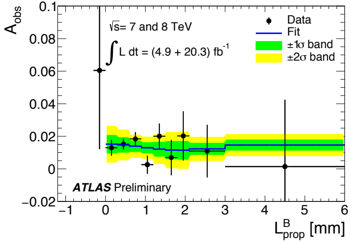
- $B_d^0 \to J/\psi K^*$ almost insensitive to $\Delta\Gamma_d$

$$\Gamma_d(t) \sim e^{-\Gamma t} \cosh \frac{\Delta\Gamma_d}{2} t$$

B_d^0 production asymmetry

- B_d^0 production asymmetry A_p measured from a charge asymmetry A_{obs}, from a difference between $B_d^0 \to J/\psi K^*$ and $\overline{B}_d^0 \to J/\psi \overline{K}^*$ decays as a function proper decay lengths L_{prop}^B
- Extracted A_{obs}, fig below, includes the asymmetry of K^+/ K^- reconstruction efficiency due to interactions in ID.

- ATLAS result $A_p = (0.25 \pm 0.48(stat) \pm 0.05(syst)) \cdot 10^{-2}$ agreement with expectations.



$\Delta\Gamma_d$ result

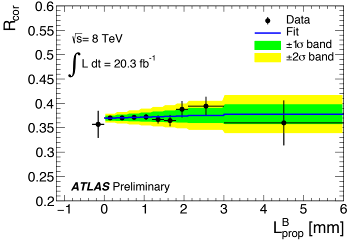


Figure: Ratio of L^B_{prop} distributions of $B_d^0 \to J/\psi K_S^0$ and $B_d^0 \to J/\psi K^*$, fitted to extract $\Delta\Gamma_d$

$\frac{\Delta\Gamma_d}{\Gamma_d}$ ATLAS Results

$$(-2.8 \pm 2.2(stat) \pm 1.7(syst)) \cdot 10^{-2} \text{ (7 TeV data)}$$

$$(0.8 \pm 1.3(stat) \pm 0.8(syst)) \cdot 10^{-2} \text{ (8 TeV data)}$$

$$(-0.1 \pm 1.1(stat) \pm 0.9(syst)) \cdot 10^{-2} \text{ (Combined)}$$

$\Delta\Gamma_d$ Comparison, Conclusions

$\frac{\Delta\Gamma_d}{\Gamma_d}$ Comparison

$$(-0.1 \pm 1.1(stat) \pm 0.9(syst)) \cdot 10^{-2} \text{ (ATLAS Run1)}$$

$$(-4.4 \pm 2.5(stat) \pm 1.1(syst)) \cdot 10^{-2} \text{ (LHCb)}$$

$$(1.7 \pm 1.8(stat) \pm 1.1(syst)) \cdot 10^{-2} \text{ (Belle)}$$

$$(0.8 \pm 3.7(stat) \pm 1.8(syst)) \cdot 10^{-2} \text{ (Belle)}$$

- ATLAS result is consistent with other measurements
- It is consistent with the SM prediction

$$(0.42 \pm 0.08) \cdot 10^{-2} \text{ (SM)}$$

$B_s^0/B_d^0 \to \mu^+\mu^-$ Physics motivation

Theory

- Flavour-changing neutral-current processes highly suppressed in SM
- $B_s^0/B_d^0 \to \mu^+\mu^-$ additional helicity suppression.
- SM prediction accurate:
  - Br ($B_s^0 \to \mu^+\mu^-$) $= (3.65 \pm 0.23) \times 10^{-9}$
  - Br ($B_d^0 \to \mu^+\mu^-$) $=(1.06 \pm 0.09) \times 10^{-10}$

Experiment

- Experimental measurement a viable BSM search
- CMS and LHCb observation of $B_s^0 \to \mu^+\mu^-$ and evidence of $B_d^0 \to \mu^+\mu^-$:
- Br ($B_s^0 \to \mu^+\mu^-$) $= (2.8^{+0.7}_{-0.6}) \times 10^{-9}$
- Br ($B_d^0 \to \mu^+\mu^-$) $= (3.9^{+1.6}_{-1.4}) \times 10^{-10}$

Method

Signal

- Select signal di-muon events from data.
- Extract yield using an un-binned maximum- likelihood fit to the data.
- Use control samples to understand background suppression BDT and other cross checks.

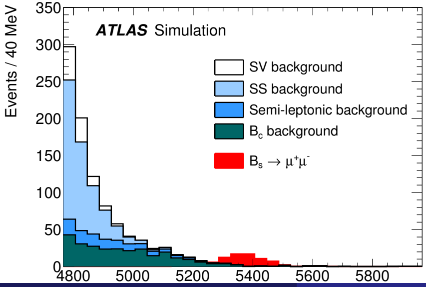
Normalise signal to $B^\mp \to J/\psi K^\pm$

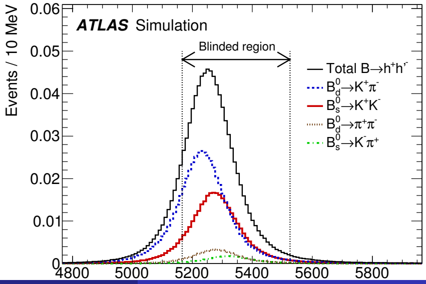
- Requires knowledge of hadronisation probabilities f_u/f_s and f_u/f_d
- Use the ATLAS result for $f_s/f_d = 0.240 \pm 0.020$. ATLAS Coll, PRL 11(2015) 262001(arXiv:1507.08925) and assuming isospin symmetry f_u/f_d=1.

Backgrounds

- Continuum Background - muons from b, $\bar{b}$, c, $\bar{c}$ quarks
- Partially Reconstructed Decays:
  - Same Vertex (SV): $b \to s\mu^+ qJ/\psi$
  - Same Side (SS) cascades; e.g. $b \to c\mu\nu_\mu \to s(d)\mu\mu\nu_\mu\bar{\nu}_\mu$
- Peaking 2-hadron decays, with both hadrons misidentified as muons

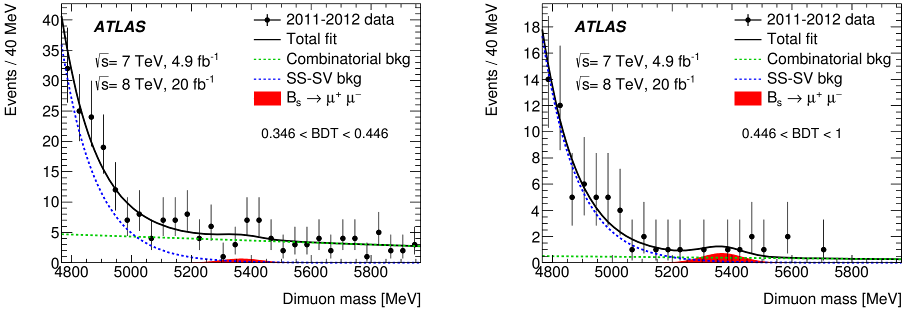
- Background suppression use a boosted decision tree (BDT) using signal and background variables. Two types: continuum-BDT and BDT against hadrons misidentified as muons.





Signal Fit result

Fitted signal yields are N $(B_s^0) = 16 \pm 12$, N $(B_d^0) = 11 \pm 9$ events



Result

Using 25 fb^{-1} of 7 TeV and 8 TeV proton–proton collision data ATLAS obtains:

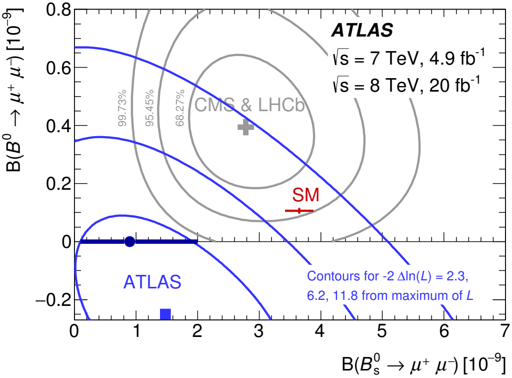
$$Br(B_d^0 \to \mu^+\mu^-) < 4.2 \cdot 10^{-10} \quad 95\% \; C.L.$$

$$Br(B_s^0 \to \mu^+\mu^-) < 3.0 \cdot 10^{-9} \quad 95\% C.L.$$

$$Br(B_s^0 \to \mu^+\mu^-) = (0.9^{+1.1}_{-0.8}) \cdot 10^{-9}$$

where the errors include both the statistical and systematic uncertainties.

Comparison, conclusion



- ATLAS is consistent with the LHCb and CMS
- ATLAS consistency with SM is 2.0 σ (computed from toy-experiments)
- Room for NP destructively interfering with the SM

Summary

- Using Run1 LHC data ATLAS made important contributions to CPV, mixing and rare decays of B-hadrons
- Results are consistent with other experiments
- Consistency with SM in all presented cases
- Room for New Physics opened
- Run2 data expected to increase precisions

Backup

Backup Slides

Tagging variables definitions

- efficiency of a tagging method - ϵ - is the ratio of events tagged by that method to the total number of candidates
- $P(B|Q)$ is a probability to tag a signal event correctly
- Dilution $\mathcal{D} = 2P(B|Q) - 1$
- Tagging power of a particular tagging method is defined as $T = \epsilon\mathcal{D}^2$.
- It is also possible to derive an effective average dilution, D, defined as $D = \sqrt{T/\epsilon}$, which removes the efficiency normalisation of the tagging power, and therefore allows the quality of different taggers to be compared.

Tagging: Cone-charge definition

Cone-charge definition:

$$Q_\mu = \frac{\sum_i^{N \text{ tracks}} q_i \cdot (p_{\mathrm{T}i})^\kappa}{\sum_i^{N \text{ tracks}} (p_{\mathrm{T}i})^\kappa}, \tag{1}$$

$$\epsilon^{\text{tag}} = \frac{N^{\text{tag}}}{N_B} \tag{2}$$

$$\epsilon^{\text{tag}} = \sum_i^{\text{bins}} \epsilon_i = \frac{1}{N_B} \sum_i^{\text{bins}} n_i^{\text{tag}}, \tag{3}$$