Research of the background from

$B_d \to J/\psi K^*$ in $B_s \to J\psi\phi$

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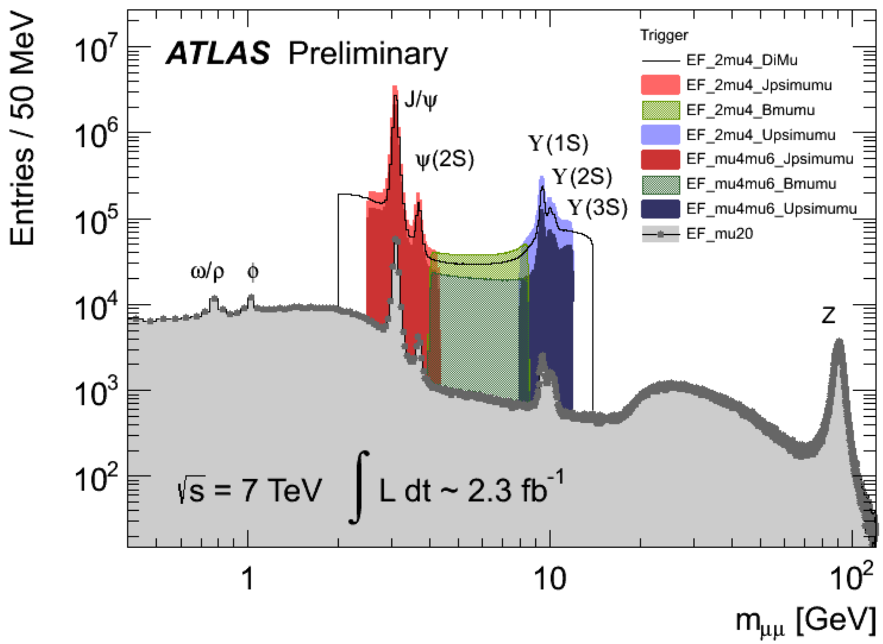
Outlook

- Introduction
- Measurement of CP-violation parameters in $B_s \rightarrow J/\psi\varphi$ decay

  $\Delta\Gamma_s$ and φ_s from Flavour-tagged time-dependent analysis
- Analysis of 2012 data. Combination of results from data at 7 and 8 TeV
- Vertex fit and reconstruction of B_d using data from run №00283270 (CERN november-december, 2016), Period C (CERN July, 2016) and Period C + Period B(September, Protvino, 2016)
- Summary

Introduction

- B-physics results are based on statistics acquired mainly with di-muon triggers.
- Requirements on muons p_t mostly 4 GeV/c (for small fraction of events with high instantaneous luminosity) increased to 6 GeV/c)
- No preference for di-muon mass close to B_s(5366) mass was applied.



B_s time evolution parameters

- Like the K^0 meson, B_s meson can be produced in CP-even or CP-odd state with different lifetimes. **$\Delta\Gamma_s$** is a difference between inverse lifetimes. CP-odd state has a longer lifetime than the CP-even one, the relative difference is ~13-17%.
- Observed $(\boldsymbol{b}\ \bar{\boldsymbol{s}}) \leftrightarrow (\bar{\boldsymbol{b}}\ \boldsymbol{s})$ **oscillations via box diagrams with intermediate u, c, t $q\bar{q}$ pairs in t-channel and possibly New Physics.** The mass difference between heavy (B^H) and light (B^L) CP-eigenstates leads to measured oscillation frequency Δm_s - $17.77\ ps^{-1}$.
- CP-violating phase **ϕ_s** manifests itself in interference terms between mixing and decay amplitudes

B_s time evolution and $B_s \rightarrow J/\psi\varphi$ decay

- In SM, phase $\varphi_s \approx -2\beta_s$, where β_s is angle in Kobayashi-Maskawa triangle,

$$\beta_s = \arg \frac{-V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}$$

NOT β angle in other unitary triangle,
with d instead of s quark, see PDG!

- SM predictions: $\Delta\Gamma$ = 0.087±0.021 ps

  $\varphi_s = -0.0363^{+16}_{-15}$ rad Phys. Rev. D, 84 (2011), p. 033005

- Measurements of φ_s and $\Delta\Gamma$ test SM predictions.
- The analysis of data at 8 TeV is similar for published analysis of 7 TeV data (Phys.Rev. D90 (2014) 052007) . The number of signal events at 8 TeV is greater by a factor of 3. Due to high statistics, more detailed study of acceptance, signal shape and background was performed. Also Electron tagging was applied. Finally, results at 8 and 7 TeV were statistically combined.

Partial waves in $J/\psi\varphi$ analysis

- $B_s \to J/\psi\varphi \to (\mu^+ \mu^-)(K^+ K^-)$ without Kaon identification
- $B_s \to J/\psi\varphi$ - pseudo-scalar to vector-vector decay, waves :
- CP-even (L=0,2) and CP-odd (L=1) final states,
- added 4th wave with (KK) in S-wave, $J/\psi KK$
- Distinguishable through time-dependent angular analysis
- Used 3 angles between final-state particles in Transversity basis

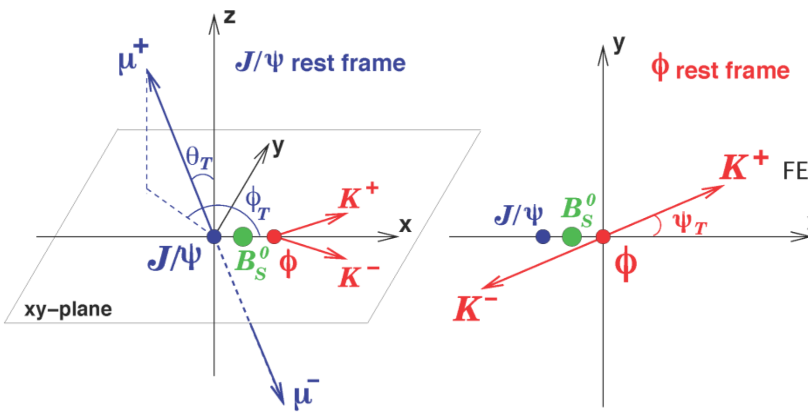
  - Multi-dimensional fit to the data; three amplitudes and strong phases extracted.

A_0 – longitudinal CP-even final state

$A_\parallel$ – transverse CP-even

$A_\perp$ – transverse CP-odd

$$\delta_0 = 0$$
$$\delta_\parallel = \arg[A_\parallel(0)A_0^*(0)]$$
$$\delta_\perp = \arg[A_\perp(0)A_0^*(0)]$$



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- 3 amplitudes and strong phases extracted alongside with φ_s and $\Delta\Gamma_s$
- 4-th amplitude A_s and phase δ_s for $J/\psi KK$ (CP-odd) also determined from the fit.

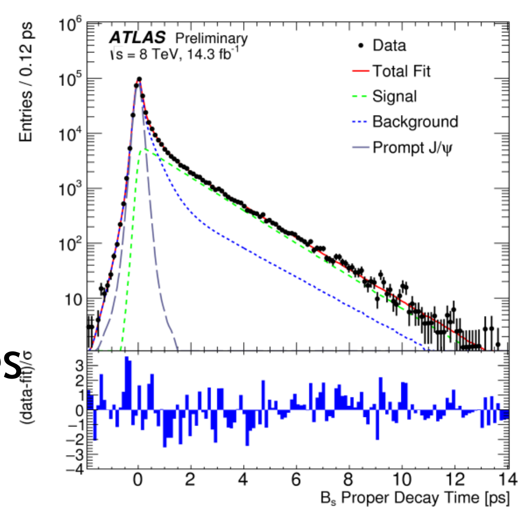
Event selection in 2012 data analysis

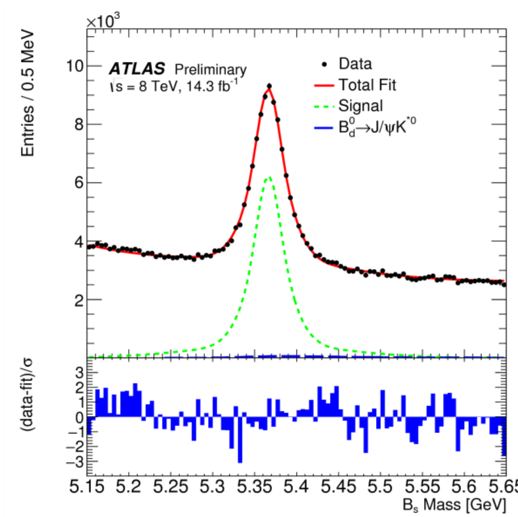
- Events selected from $\mu^+ \mu^-$ pairs using 14.3 fb $^{-1}$ data acquired at $\sqrt{s}$ = 8 TeV.
- 2 other opposite sign tracks with p_t > 1 GeV/c and $|\eta|$<2.5 taken with Kaon mass.
- Retain pairs consistent with φ : 1008.5 < m($K^+ K^-$)< 1030.5 MeV.
- 4-track Vertex Fit, using J/ψ mass constraint, χ^2 /NDF < 3.
- Primary vertex selected with smallest 3D-impact parameter.
- Proper decay time:

$$t = \frac{L_{xy} M_B}{p_{T_B}}$$ with B_s World Average mass M_B

- 376 K B_s candidates in range: 5.150 – 5.650 GeV
- 75100 ± 400 B_s signal candidates extracted from the fit

22670 ± 150 in 2011 data



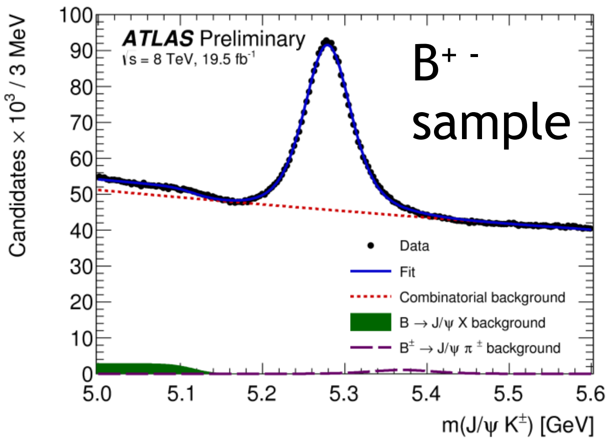


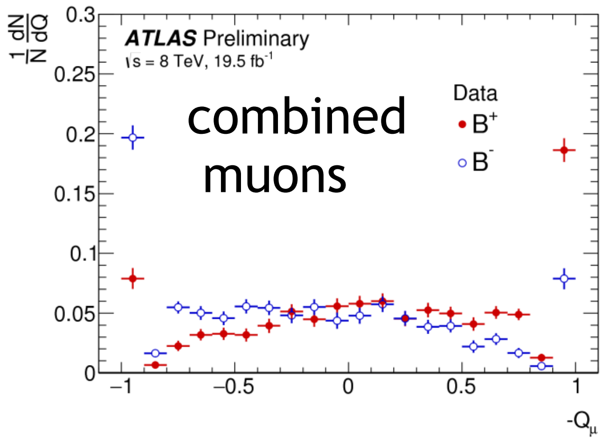
No decay time cut applied in analysis

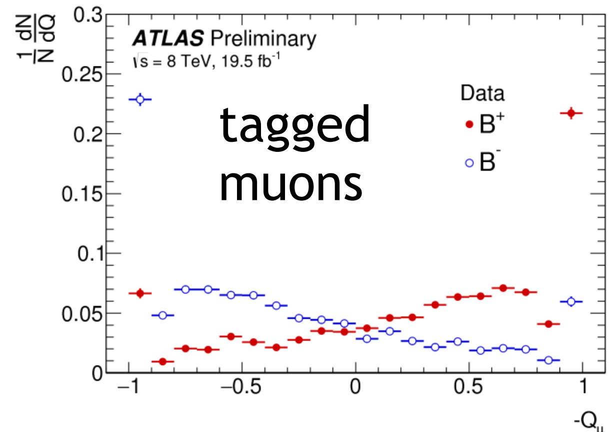
b-quark charge tagging

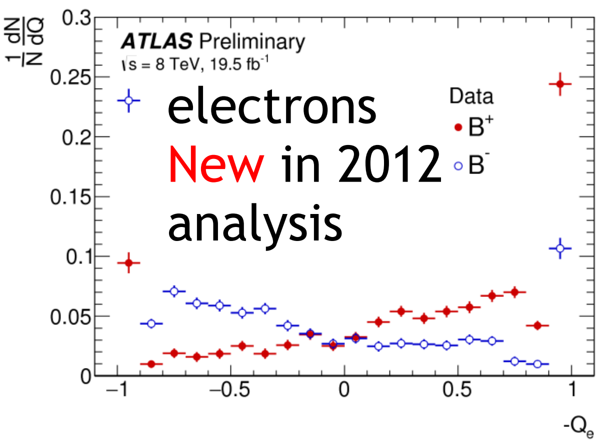
- Identification of b or anti-b quark in B_s at the production time improves precision of φ_s measurement and helps with sign ambiguities
- Information from opposite side tagging used, i.e. leptons and/or jet charge from decay of 2nd B-hadron in the event
- Methods were calibrated on B^{+-} candidates in data

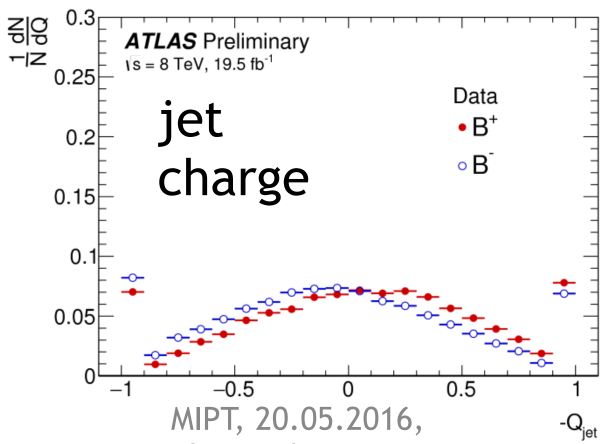
B^{+-} sample











Tagger	Tagging power [%]
Combined muon	0.92±0.02
Electron	0.29±0.01
Tagged muon	0.10±0.01
Jet charge	0.19±0.01
Total	1.49±0.02

Time and angular functions for $B_s \to J/\psi\varphi$

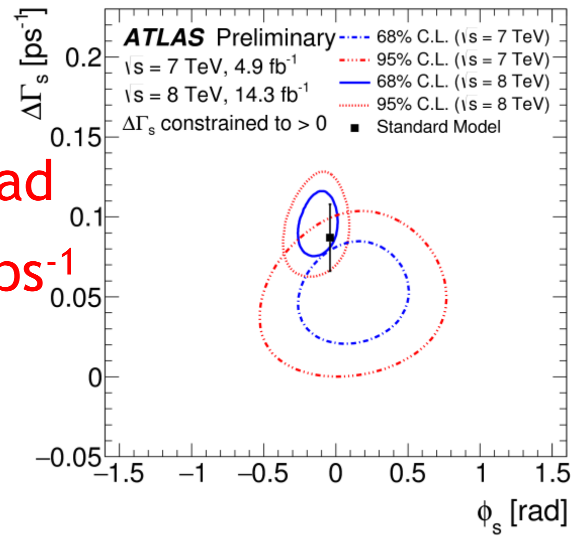
k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \phi_T)$
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T\sin^2\theta_T$
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_{\parallel}$ $\left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$
5	$\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin(\delta_\perp-\delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp-\delta_\parallel)\cos\phi_s\sin(\Delta m_s t))]$	$-\sin^2\psi_T\sin 2\theta_T\sin\phi_T$
6	$\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\cos\delta_\perp\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin\delta_\perp\cos(\Delta m_s t) - \cos\delta_\perp\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\phi_T$
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\phi_T\right)$
8	$\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\sin(\delta_\parallel-\delta_S)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos(\delta_\parallel-\delta_S)\cos(\Delta m_s t) - \sin(\delta_\parallel-\delta_S)\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$
9	$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert\sin(\delta_\perp-\delta_S)$ $\left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$
10	$\lvert A_0(0)\rvert\lvert A_S(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t})\sin\delta_S\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos\delta_S\cos(\Delta m_s t) + \sin\delta_S\cos\phi_s\sin(\Delta m_s t))]$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\phi_T\right)$

Systematic uncertainties in physics parameters

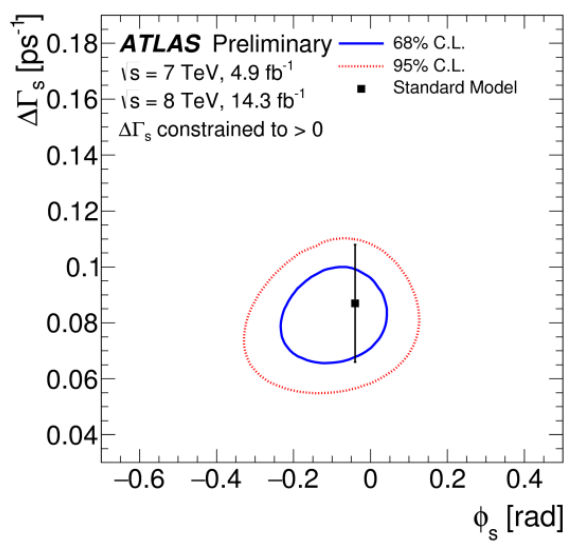
	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	Γ_s [ps^{-1}]	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$	$\delta_\perp$ [rad]	$\delta_\parallel$ [rad]	$\delta_\perp - \delta_S$ [rad]
Tagging	0.026	0.003	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.001	0.238	0.014	0.004
Acceptance	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.003	$<10^{-3}$	0.001	0.004	0.008	$<10^{-3}$
Background angles model:									
Choice of p_T bins	0.02	0.006	0.003	0.003	$<10^{-3}$	0.008	0.004	0.006	0.008
Choice of mass interval	0.008	0.001	0.001	$<10^{-3}$	$<10^{-3}$	0.002	0.021	0.005	0.003
B_d^0 background model	0.008	$<10^{-3}$	$<10^{-3}$	0.001	$<10^{-3}$	0.008	0.007	$<10^{-3}$	0.005
Fit model:									
Default fit	0.001	0.002	$<10^{-3}$	0.002	$<10^{-3}$	0.002	0.025	0.015	0.002
Mass Signal model	0.004	$<10^{-3}$	$<10^{-3}$	0.002	$<10^{-3}$	0.001	0.015	0.017	$<10^{-3}$
Mass Background model	$<10^{-3}$	0.002	$<10^{-3}$	0.002	$<10^{-3}$	0.002	0.027	0.038	$<10^{-3}$
Time Resolution model	0.003	$<10^{-3}$	0.001	0.002	$<10^{-3}$	0.002	0.057	0.011	0.001
Total	0.036	0.007	0.003	0.006	0.001	0.013	0.25	0.05	0.01

Results at 8 TeV and Combination

- Results from 8 TeV measurement:
  - φ_s = -0.119 ± 0.088 (stat.) ± 0.036 (syst.) rad
  - $\Delta\Gamma_s$ = 0.096 ± 0.013 (stat.) ± 0.007 (syst.) ps^{-1}
  - Correlation (φ_s , $\Delta\Gamma_s$) = 0.110



- Combination of results:
  - Statistical combination
  - Best Linear Unbiased Estimate (BLUE) of 7 TeV and 8 TeV results
  - Minimizes the variance in the estimators



$B_s \rightarrow J/\psi\varphi$ combined results

- Preliminary measurement of the time-dependent flavoured-tagged CP asymmetry parameters in decays $B_s \rightarrow J/\psi\varphi$

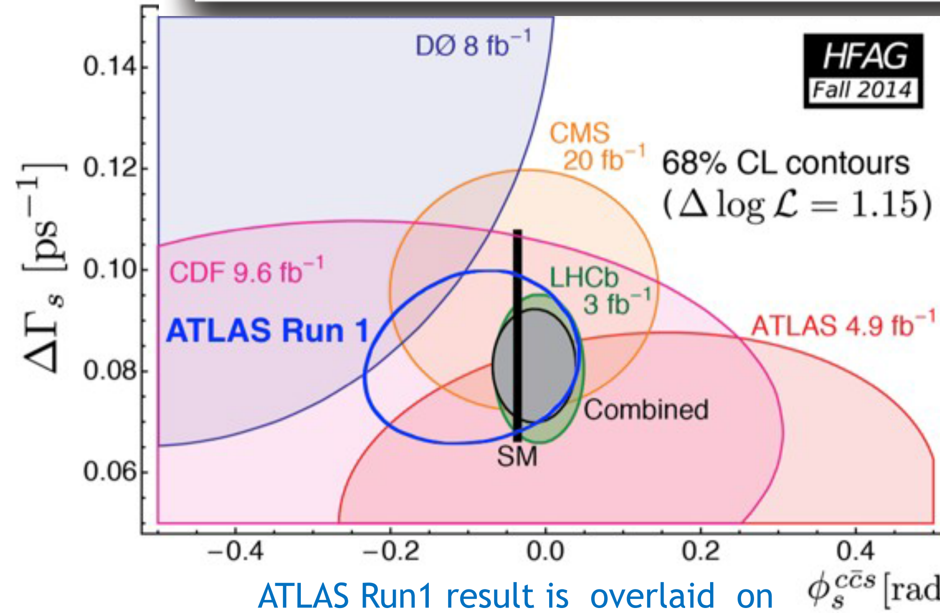
  - 14.3 fb $^{-1}$ from 8 TeV
    - statistically combined with previous result at 7 TeV 4.9 fb $^{-1}$
      Phys.Rev. D90 (2014) 052007

  - CP-violating phase, φ_s ,
    - consistent with other experiments and SM predictions

$\varphi_s = -0.0363\ ^{+16}_{-15}$ rad

$\Delta\Gamma_s^{(SM)} = 0.087 \pm 0.0021$ ps $^{-1}$

Parameter	Value	Stat.	Syst.	
Φ_s	-0.094	0.083	0.033	rad
$\Delta\Gamma_s$	0.082	0.011	0.007	ps $^{-1}$
Γ_s	0.677	0.003	0.003	ps $^{-1}$
$\lvert A_{\parallel}(0)\rvert^2$	0.227	0.004	0.006	
$\lvert A_0(0)\rvert^2$	0.515	0.004	0.002	
$\lvert A_s(0)\rvert^2$	0.086	0.007	0.012	
$\delta_\perp$	4.13	0.34	0.15	rad
$\delta_\parallel$	3.16	0.13	0.05	rad
$\delta_\perp - \delta_s$	-0.08	0.03	0.01	rad

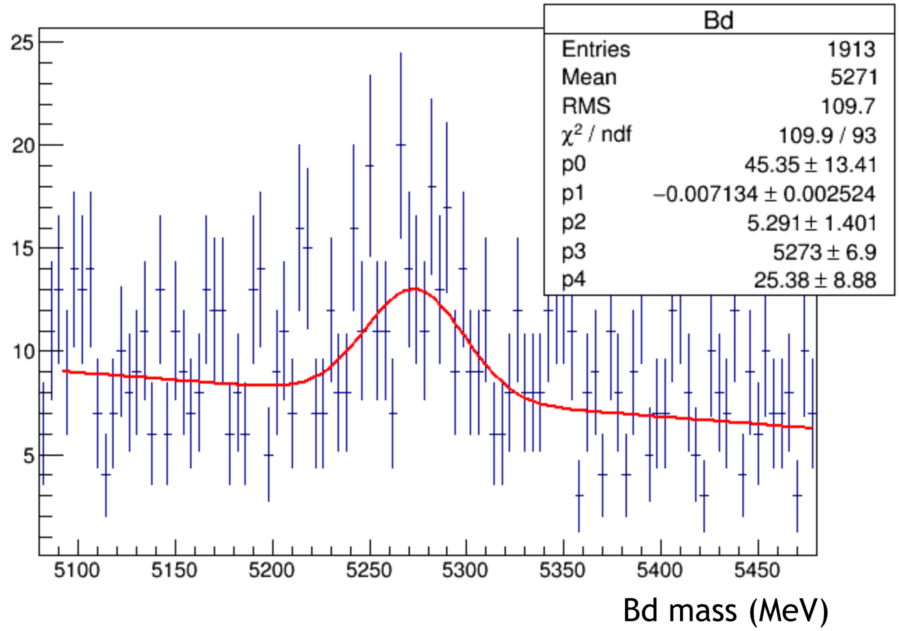


ATLAS Run1 result is overlaid on combination of other measurements

Vertex fit and reconstruction of Bd

- Vertex fit for 4 tracks had been done and the mass of Bd had been reconstructed.
- Only data from the Run-2 (13 Tev) had been used.
- The result (taking statistical and systematical errors into account) is consistent with PDG (see the next slide)

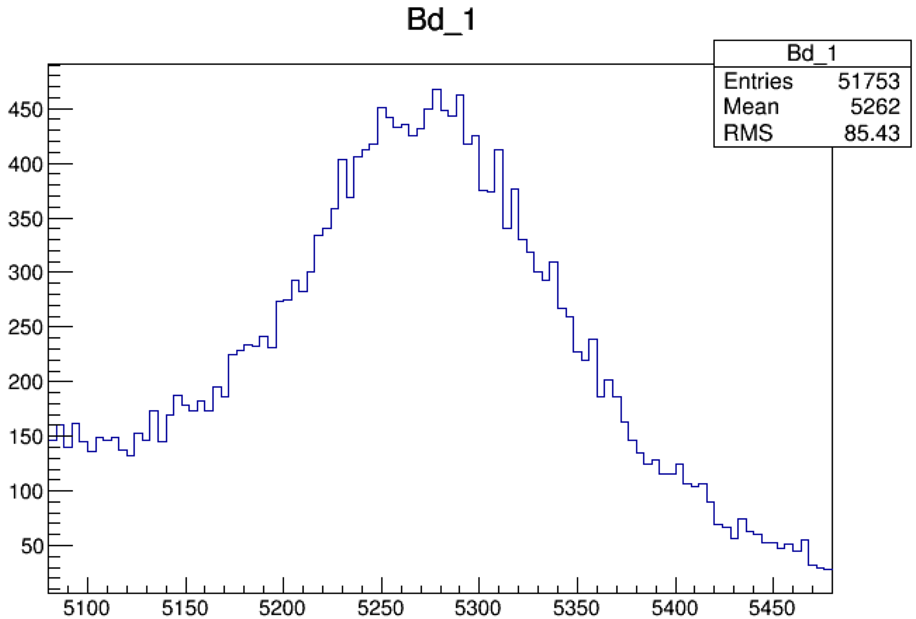
Reconstruction of Bd using data from run №00283270 (CERN, November-December 2016)

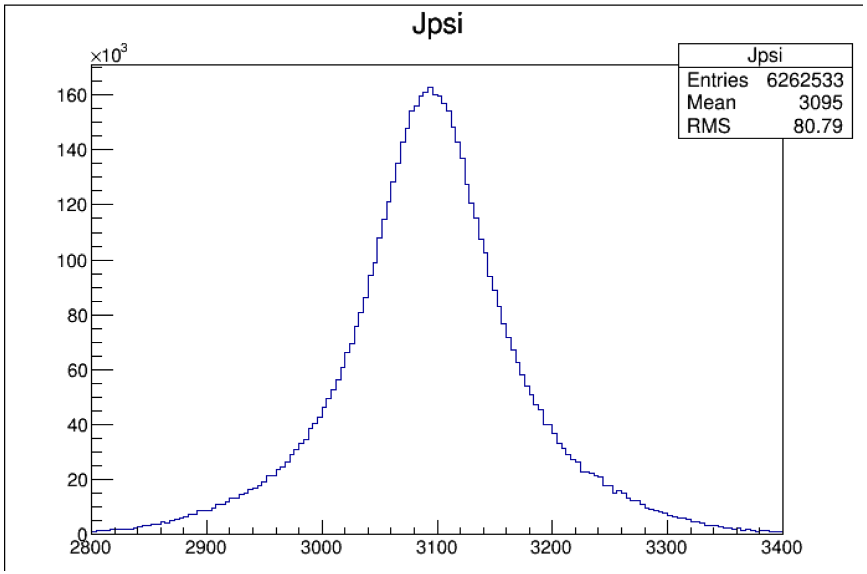


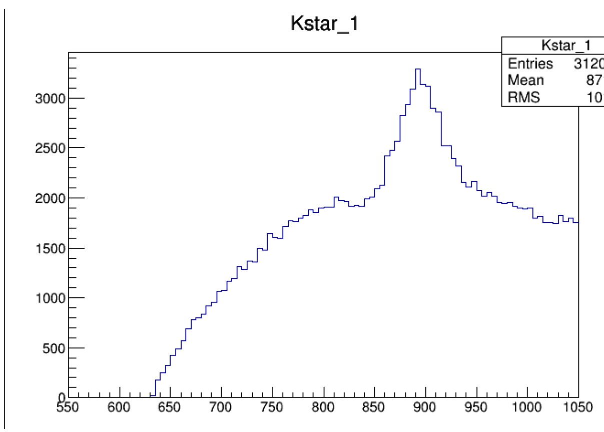
pic2: Linear+gaus fit. Parameters 0 and 1 stand for polynom and the rest stand for gaus distribution.

- From the fit the mass of reconstructed Bd can be obtained. As can be seen we have $M_{B_d} = 5273 \pm 6.9$
- PDG value is $M_{B_d} = 5279 \pm 0.26$
- This work was done during science trip to CERN in November-December 2016.

Reconstruction of Bd using data from Period C (CERN, July 2016)

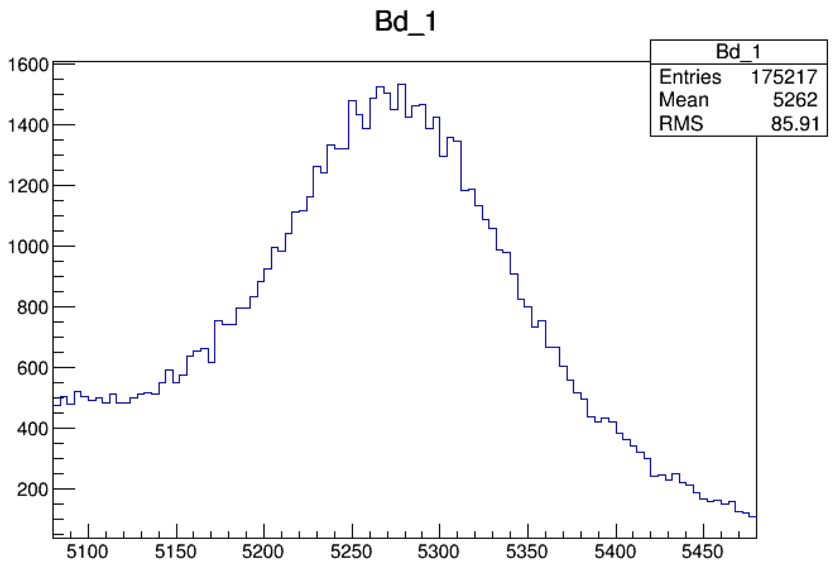


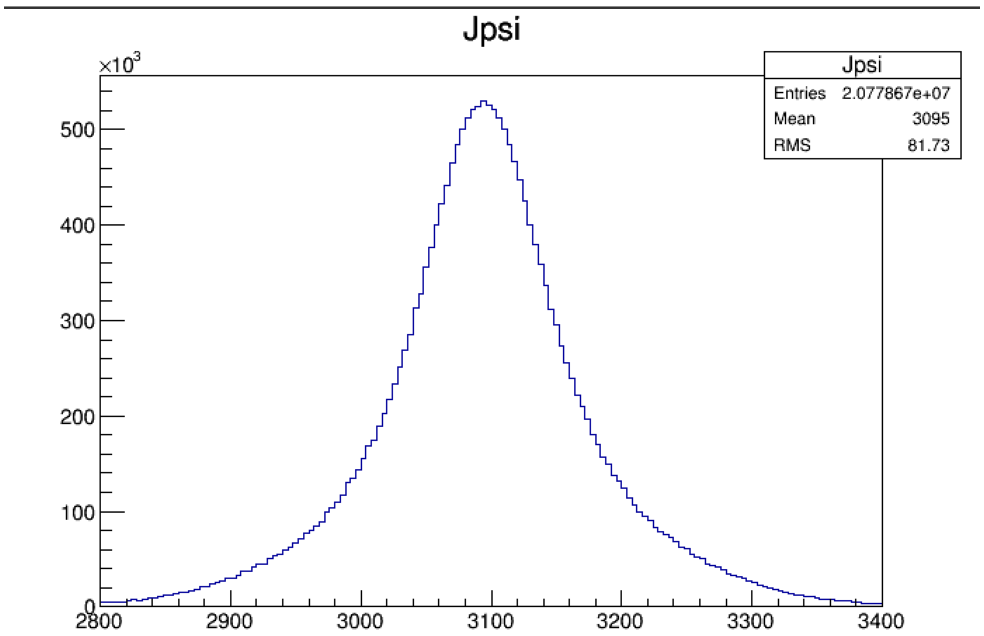


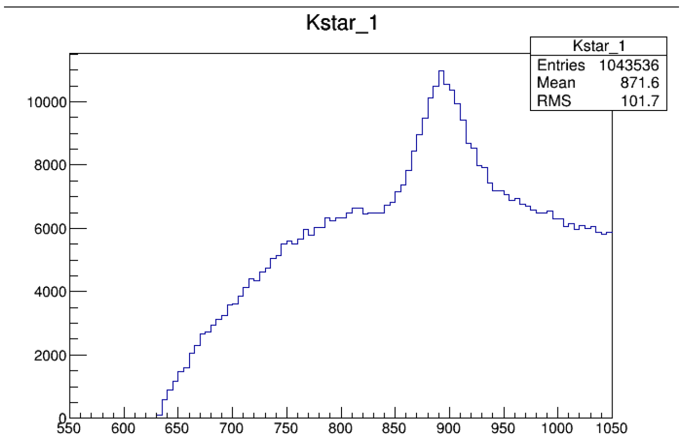


- As can be seen on the previous slide statistics raised dramatically after adding the whole period C. Furthermore, the histograms for $J/\psi\varphi$ and K^* were gained. Besides, the resonances are in their right places. This work was done during the science trip to CERN in July in 2016.

Reconstruction of Bd using data from Period C+PeriodB (Protvino, September 2016)







Summary

- - ATLAS can provide precise measurements in B-decays, which are relevant for searches of effects beyond SM
- - CP-violating phase φ_s and decay width difference $\Delta\Gamma$

  - analyzed 2012 data

  - statistical combination 2011+2012 (4.6+14.3 fb^{-1})

  $$\boldsymbol{\varphi_s = -0.094 \pm 0.083(\text{stat.}) \pm 0.033(\text{syst.})\ \text{rad}}$$

  $$\boldsymbol{\Delta\Gamma = 0.082 \pm 0.011 \pm 0.007\ ps^{-1}}$$

  - consistent with SM predictions and other experiments
- The Bd in $B_d \rightarrow J/\psi K^*$ channel was reconstructed and the mass of Bd was found. The result is consistent with PDG.
- Statistical errors dominate in measurements, we expect better precision from Run 2 due to modifications in ATLAS (IBL) and significantly more statistics.
- We also intend to gain more data, to have richer statistics and improve the results. After that we will be able to estimate the background in from $B_d \rightarrow J/\psi K^*$ to $B_s \rightarrow J/\psi \phi$ using data from Run 2.

References

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  Phys. Rev. D90 (2015) 5, 052007, arXiv:1407.1796
- Limit on $B^0_s \to \mu^+\mu^-$ branching fraction based on 4.9 fb^{-1} of integrated luminosity, ATLAS-CONF-2013-076

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- Precision measurement of CP violation in $B_s \to J/\psi K^+K^-$ decays,
- Phys.Rev. Lett. 114 (2015) 041801, arXiv:1411.3104

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- LHCb & CMS:
- Observation of the rare $B^0_s \rightarrow \mu^+\mu^-$ decay from combined analysis of CMS and LHCb data, Nature 522 (2015) 68, and ref. therein
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- Measurement of the CP-violating weak phase φ_s and the decay width difference $\Delta\Gamma$using the $B_s \rightarrow J/\psi\varphi(1020)$ decay channel, Tech.Rep. CMS-PAS-BPH-13-012, CERN, Geneva, 2014
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