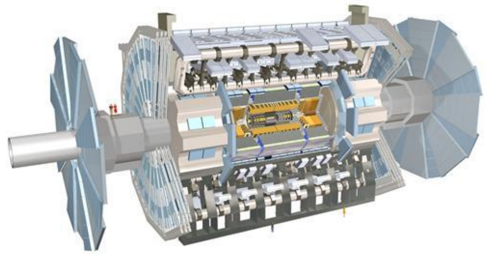
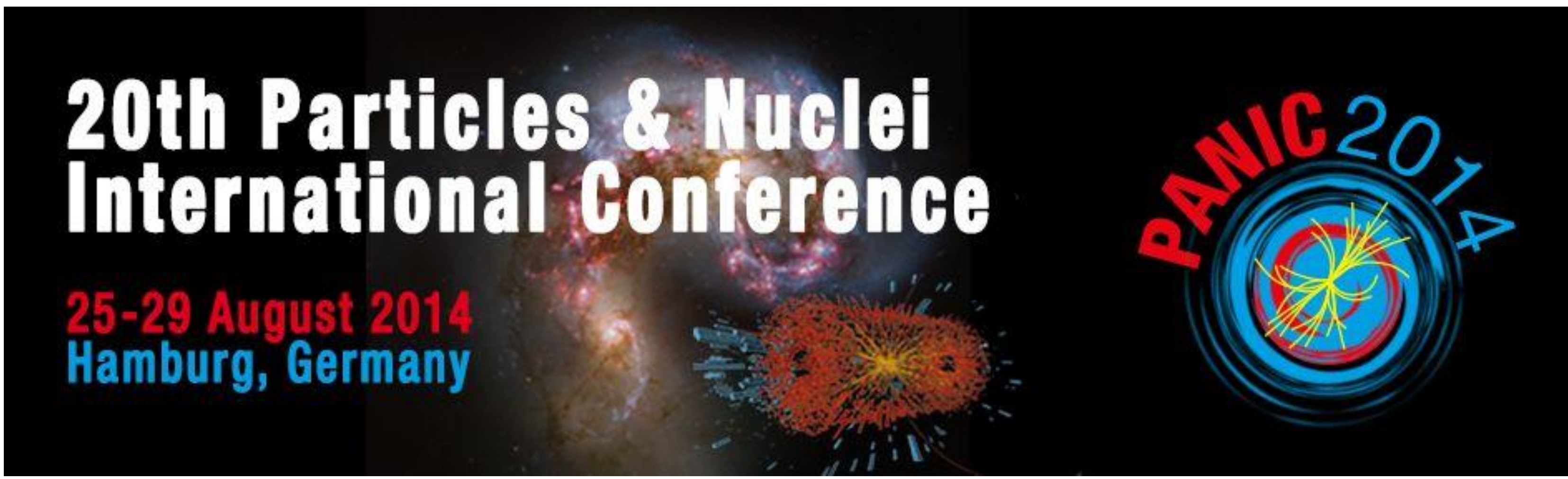


New physics searches with b-hadrons at the ATLAS experiment



Lidia Smirnova (Lomonosov Moscow SU)

on behalf of the ATLAS Collaboration

Outline :

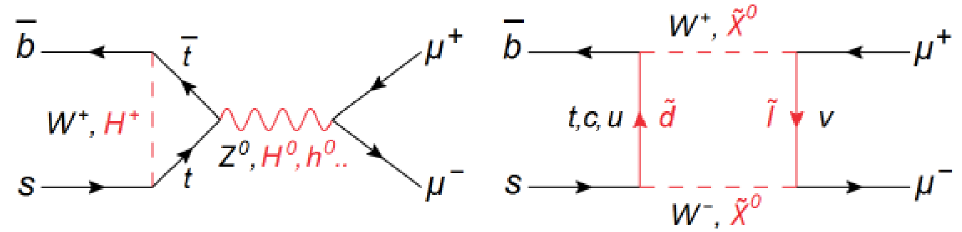
- Search for $B^0_s \to \mu^+\mu^-$ rare decay
- Updates for CP violation parameters from angular amplitudes of $B^0_s \to J/\psi(\mu^+\mu^-)\ \phi\ (K^+K^-)$ decay:
  1) CP-violating phase ϕ_s
  2) the average B_s meson lifetime $1/\Gamma_s$
  3) the decay width difference $\Delta\Gamma_s$

The searches with b-hadrons can present indirect evidence for New Physics and show the size of new effects. They are complementary to direct searches.

Search for $B^0_s \to \mu^+\mu^-$ rare decay

Motivation

- The decay is strongly suppressed in SM
- It realizes by FCNC
- Contributions of possibly existing new particles may increase or decrease decay branching ratio for $B^0_s \to \mu^+\mu^-$ and demonstrate presence of New Physics



$BR_{SM}(B^0_s \to \mu^+\mu^-) = (3.23 \pm 0.27) \cdot 10^{-9}$

Buras et al. , Eur.Phys.J. C72 (2012) 2172

CMS + LHCb common results show evidence for
$BR(B^0_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \cdot 10^{-9}$
with all RUN-1 collected data

LHCb: Phys. Rev. Lett. 111 (2013) 101805
CMS: Phys. Rev. Lett. 111 (2013) 101804
Combination: CMS-PAS-BPH-13-007

There is still room for New Physics and new results are welcome!

ATLAS search for $B^0_s \rightarrow \mu^+\mu^-$

Results with half data 2011 (2.4 fb^{-1}) analysis published in

PRL713 (2012) 387: BR ($B^0_s \rightarrow \mu^+\mu^-$) $< 2.2 \cdot 10^{-8}$ at 95% C.L.

Update with full 2011 data 4.9 fb^{-1} is presented

Analysis overview

ATLAS-CONF-2013-076

- *Unbiased relative BR measurements*
- *Blind analysis (signal region SR ± 300 MeV around B^0_s mass blinded)*
- *Use MC to model data*
- *Background data in two sidebands divided 50/50 to optimize selection cuts and to calculate bkg in signal region*
- *Multivariable analysis for Signal/Bkg discrimination (BDT with 13 var.)*
- *Signal extraction by event counting in SR and bkg estimation from sidebands*
- *Limit extraction by CL_s method*

$B^0_s \to \mu^+\mu^-$ analysis overview

Relative measurements : reference channel $B^+ \to J/\psi K^+$

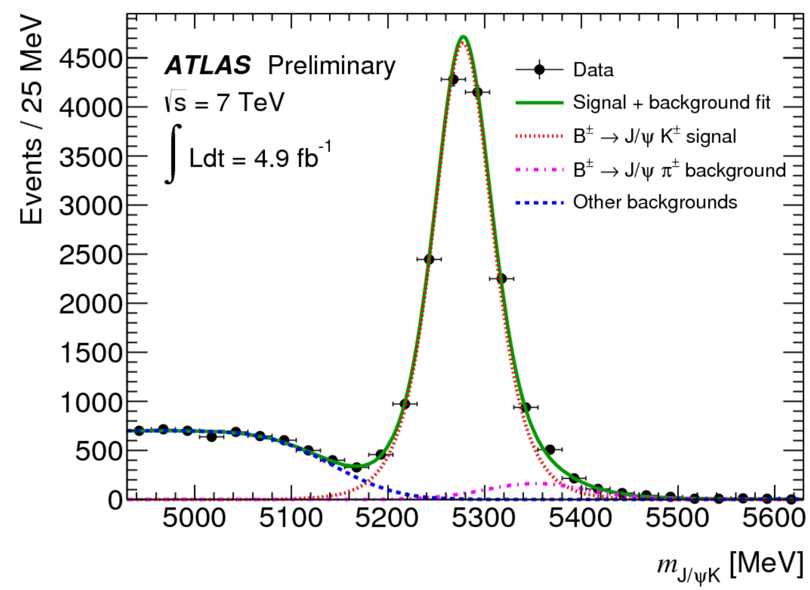
$$BR(B^0_s \to \mu^+\mu^-) = \boxed{BR(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm) \times \frac{f_u}{f_s}} \times \boxed{\frac{N_{\mu^+\mu^-}}{N_{J/\psi K^\pm}}} \times \boxed{\frac{A_{J/\psi K^\pm}}{A_{\mu^+\mu^-}} \frac{\epsilon_{J/\psi K^\pm}}{\epsilon_{\mu^+\mu^-}}} = N_{\mu^+\mu^-} \times \boxed{\mathrm{SES}}$$

From PDG

$N_{\mu^+\mu^-}$ is a number of observed signal events, $N_{J/\psi K^\pm}$ - is taken from the reference decay mode fit

$\frac{A_{J/\psi K^\pm}}{A_{\mu^+\mu^-}} \frac{\epsilon_{J/\psi K^\pm}}{\epsilon_{\mu^+\mu^-}}$ - obtained from data-driven corrected simulation

Same BDT selection applied for reference channel
Totally **15214** events with ±1.1% stat and ±2.4% syst were found



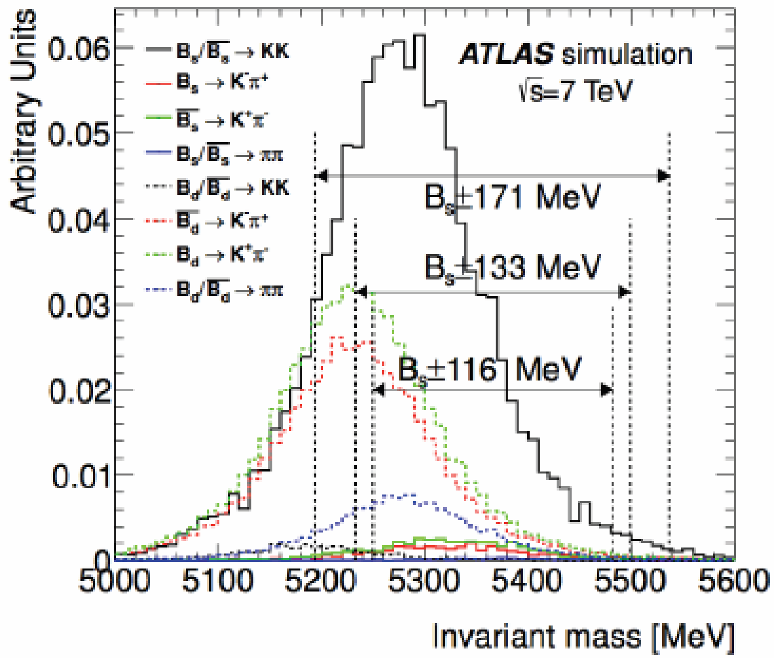
$B^0_s \rightarrow \mu^+\mu^-$: Background estimation

Two main sources of background:

1. Combinatorial background (continuum) :
- *Smooth mass spectrum*
- *BDT classifier is trained to suppress this bkg*
- $b\bar{b} \rightarrow \mu\mu X$ *provides a good description*
- *Estimated from sidebands to signal region*

2. Resonant background from B→ h⁺h'⁻, h = π or K
- *Irreducible background with π and K misidentified as muons*
- *Shown to be small w.r.t the continuum*
- *Estimated from MC*

B→hh reconstructed as μμ

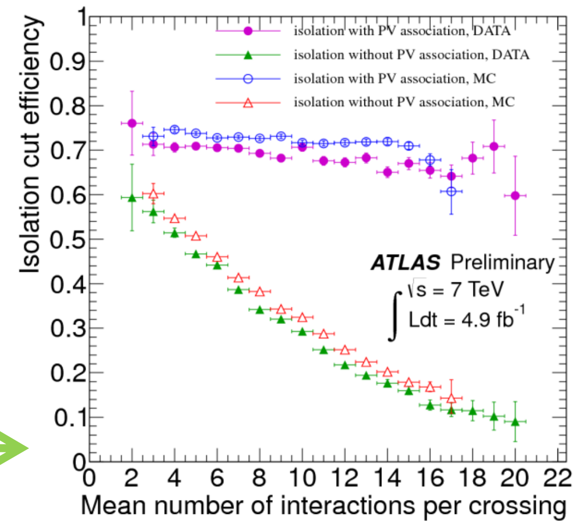


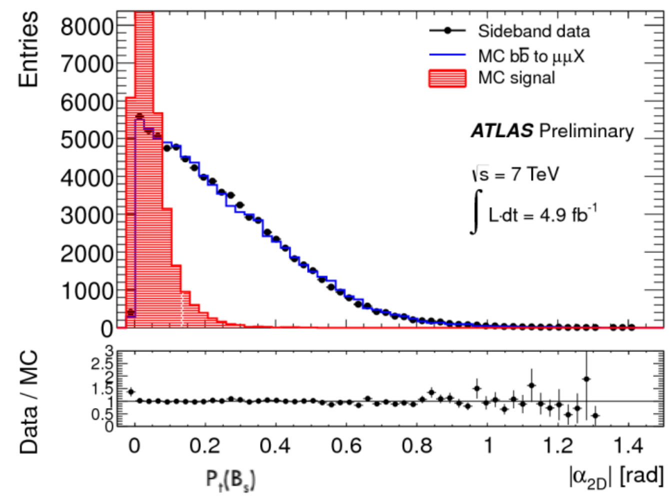
$B^0_s \to \mu^+\mu^-$: Signal/Bkg discrimination

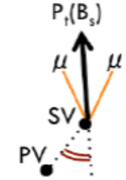
The Isolation variable is important for bkg suppression and it is stable with increased number of interaction vertices

Efficiency of the cut $I_{0.7}$>0.83

$$Iso = \frac{p_T(B)}{p_T(B) + \sum p_T^i(\Delta R_i < 0.7)}$$

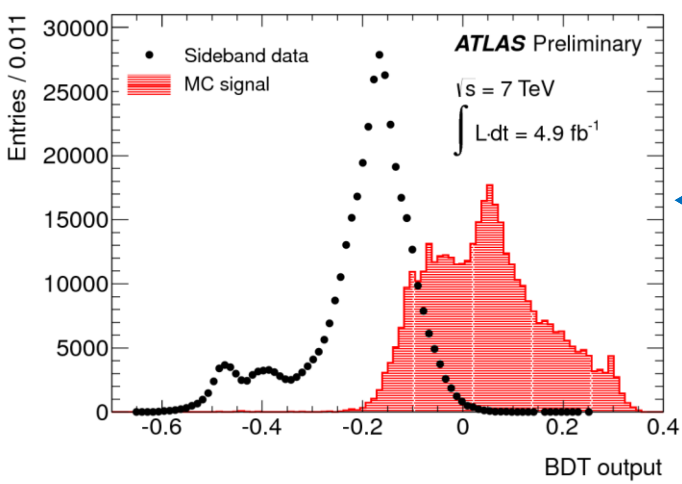






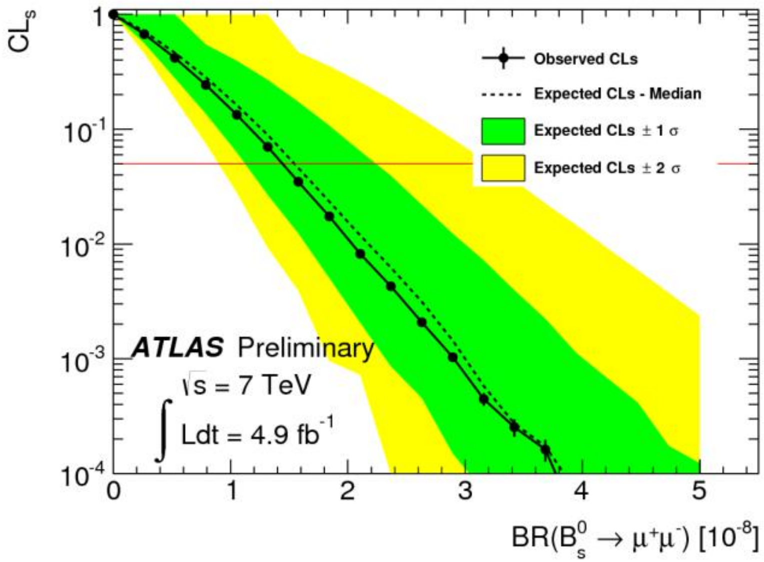
$|\alpha_{2D}|$ pointing angle

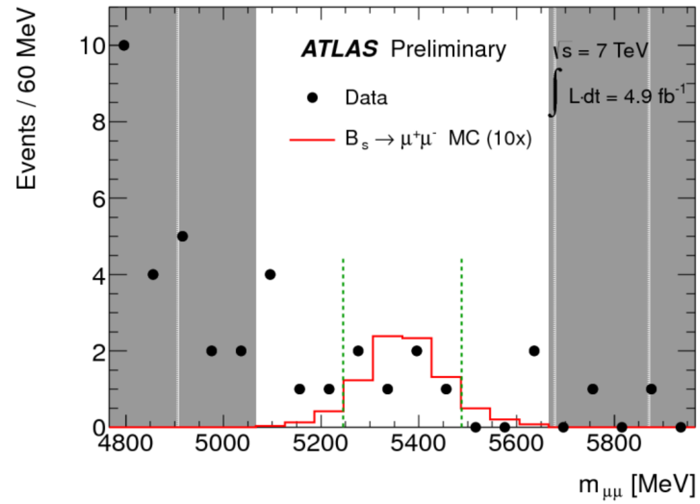
Comparisons between sideband data and data-reweighted $b\bar{b} \to \mu\mu X$ MC events for one of the most powerful separation variable $|\alpha_{2D}|$.



BDT output distribution for MC signal events and background events from sidebands (both normalized to bkg events number)

Result: Limit on 2011 BR($B^0_s \rightarrow \mu^+\mu^-$)





Observed CL_s vs BR($B^0_s \rightarrow \mu^+\mu^-$)

SES = (2.07 ± 26%(stat) ± 12.5%(syst))x10^{-9}

N_{bkg} expected in signal window = 6.75

N_{obs} in signal window = 6

BR $_{obs}$ ($B^0_s \rightarrow \mu^+\mu^-$) < 1.5 (1.2) $\cdot 10^{-8}$ at 95% (90%) C.L.

What is improved in the 2012 analysis

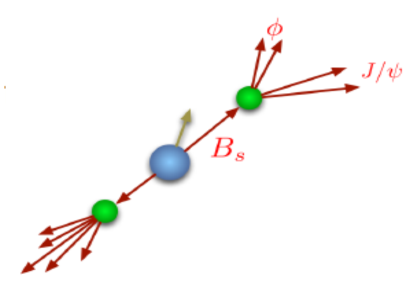
- Statistically significant MC background sample for detailed studies on the bkg composition;
- Improved fake-muon rejection;
- Improved multivariable analysis to discriminate the continuum;
- Maximum likelihood fit to extract the signal yield
- And more is ongoing work!

Results from analysis full data 2012 with 20 fb^{-1} will be published soon!

CP violation parameter φ_s and $\Delta\Gamma_s$ from angular amplitudes of $B^0_s \rightarrow J/\psi\ \phi$ decay

- *New phenomena beyond SM may alter CP violation in B-decays*
- *$B^0_s \rightarrow J/\psi\ \varphi$ is expected to be sensitive to NP contribution*
- *CP violation occurs due to interference between direct decays and B^0_s - antiB^0_s mixing, characterized by Δm_s of heavy B_H and light B_L mass eigenstates, and is measured by weak phase φ_s*
- *It is small in Standard Model: $\varphi_s = -\ 0.0368 \pm 0.0018$ rad*

  (PRL 97(2006)151803)
- *The width difference $\Delta\Gamma_s = \Gamma_H - \Gamma_L$ is not affected by NP and is useful for test*
- *The average decay width $\Gamma_s = (\Gamma_H + \Gamma_L)/2$*
- *φ_s, Γ_s and $\Delta\Gamma_s$ are measured from fully reconstructed decays $B^0_s \rightarrow J/\psi(\mu^+\mu^-)\ \varphi\ (K^+K^-)$ with only statistical CP states separation with 4.9 fb^{-1}* (JHEP12(2012)072)
- *the measurements are updated with flavour tagged time-dependent angular analysis* (arXiv:1407.1796, Accepted by PRD)



Flavour tagging for CPV measurement

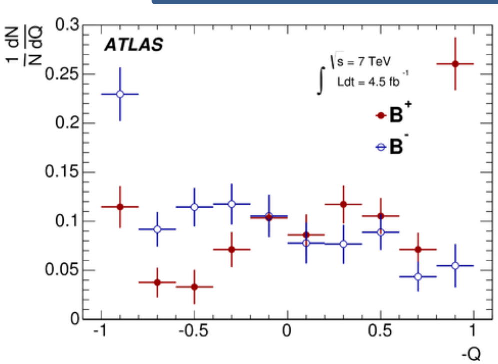
- The information of the initial flavour of B^0_s is produced from the other b-quark in the event (OST – opposite-side tagging)
- Method is calibrated with use of $B^{\pm} \rightarrow J/\psi K^{\pm}$ events
- It uses :
  1) An opposite ***muon cone charge*** with tracks in cone $\Delta R=0.5$ $\boldsymbol{Q_\mu}$ (k=1.1)
  2) If no muon, a ***jet charge*** $\boldsymbol{Q_{jet}}$

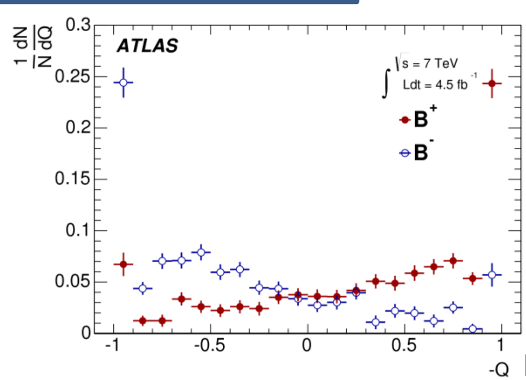
$$Q_{\text{jet}} = \frac{\sum_i^{N \text{ tracks}} q^i \cdot (p_T^i)^\kappa}{\sum_i^{N \text{ tracks}} (p_T^i)^\kappa}$$

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

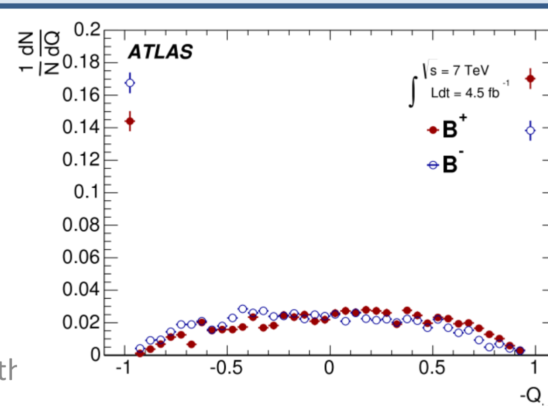
Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Segment Tagged muon	1.08 ± 0.02	36.7 ± 0.7	0.15 ± 0.02
Combined muon	3.37 ± 0.04	50.6 ± 0.5	0.86 ± 0.04
Jet charge	27.7 ± 0.1	12.68 ± 0.06	0.45 ± 0.03
Total	32.1 ± 0.1	21.3 ± 0.08	1.45 ± 0.05

Q_μ for muons with $B^{\pm}$



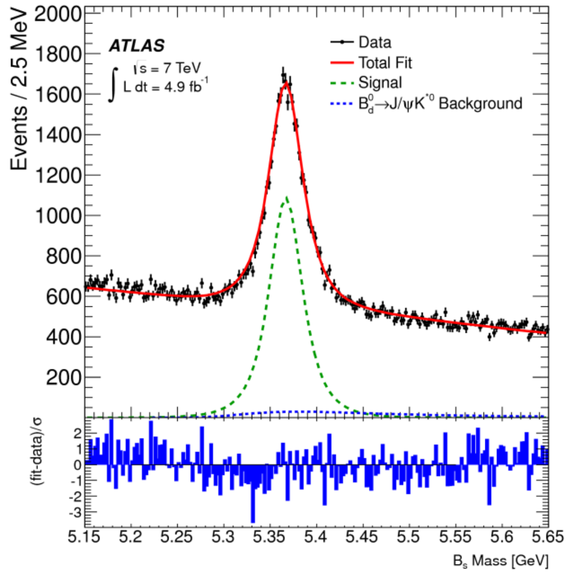


jet charge distribution for $B^{\pm}$

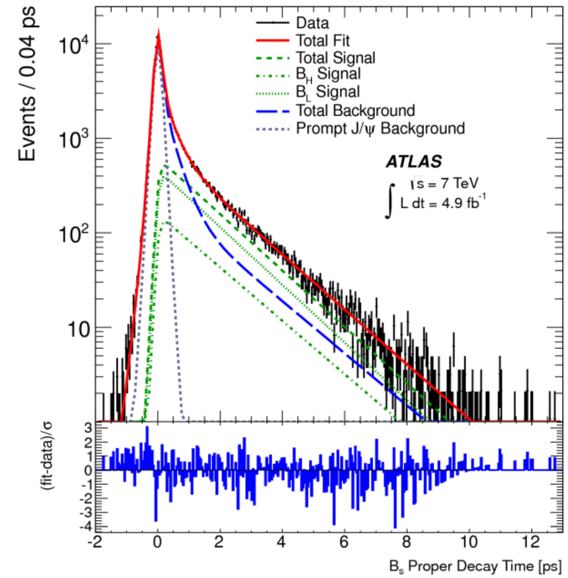


$B^0_s \rightarrow J/\psi(\mu\mu)\ \phi(KK)$ decay selection

- no displaced vertex or time cuts applied in trigger nor offline
- J/ψ mass window adapted to barrel and endcap
- ϕ mass window 22 MeV
- Kaons $p_T > 1$ GeV
- B-vertex χ^2/d.o.f. < 3
- In total 131k B^0_s candidates within 5.15 < $m(B^0_s)$ < 5.65 GeV used in the fit
- Number of signal B^0_s candidates extracted from the fit **22670 ± 150**



Mass fit projection for $B^0_s \rightarrow J/\psi\ \varphi$



Proper decay time t estimated by

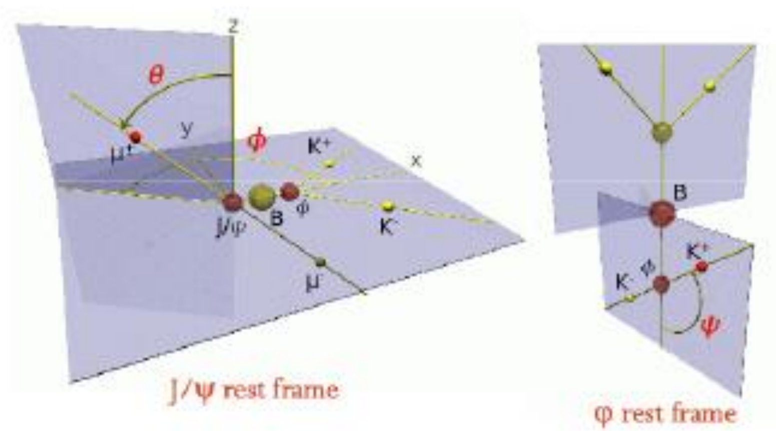
$$t = \frac{L_{xy}\, M_B}{pT_B}$$

$B^0_s \to J/\psi(\mu\mu)\ \phi(KK)$ decay analysis

- Parameters extracted from unbinned maximum likelihood fit;
- The likelihood function includes the signal and bkg probability density functions:
  (PDF)

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

- It uses reconstructed uncertainties, tag probability and transversity angels θ_T, ψ_T, φ_T for each $B^0_s \to J/\psi\phi$ candidate;
- θ_T, ψ_T, ϕ_T are defined in the J/ψ (θ_T, ϕ_T) and ϕ (ψ_T)rest frames:
- Signal PDF includes all measured quantities with uncertainties.



$B^0_s \to J/\psi\phi$ decay analysis

- Distribution for decay time *t* and transversity angles $\Omega(\theta_T, \psi_T, \phi_T)$ is given by the differential decay rate:

$$\frac{d^4\Gamma}{dt\ d\Omega} = \sum_{k=1}^{10} \mathcal{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \phi_T)$$, where $\mathcal{O}^{(k)}(t)$ and $g^{(k)}(\theta_T, \psi_T, \phi_T)$

are the time dependent amplitudes and the angular functions, they are obtained from the fit;
the time dependent amplitudes are the same for B^0_s and anti-B^0_s, but with sign reversal in term with Δm_s

Ten time-dependent amplitudes, extracted from the fit

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

9 physics variables to describe $B_s \rightarrow J/\psi\phi$ and S-wave component extracted from fit:

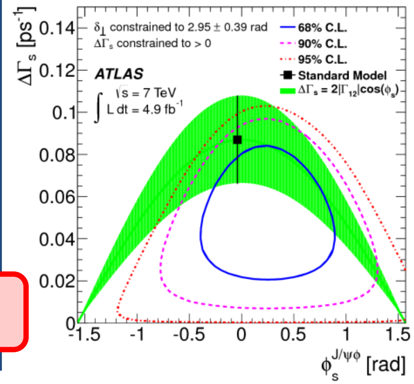
$\Delta\Gamma_s$, ϕ_s, Γ_s, $\vert A^0(0)\vert^2$, $\vert A_{\vert\vert}(0)\vert^2$, $\delta_{\vert\vert}$, $\vert A_S(0)\vert^2$, $\delta_{S\perp}$, $\delta_\perp$

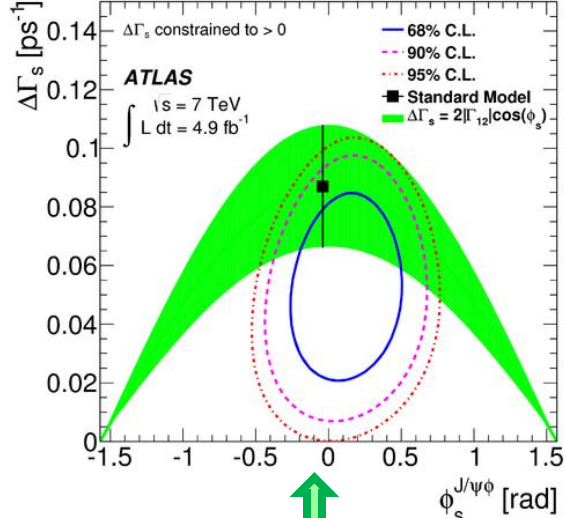
The result is :

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

NEW

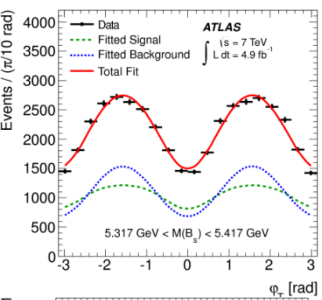
From untagged analysis

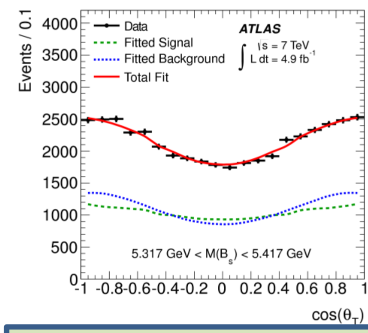


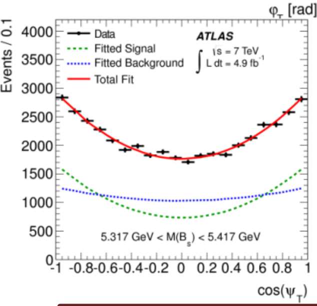


From Flavour tagged analysis

Likelihood contours in the $\varphi_s - \Delta\Gamma_s$ plane

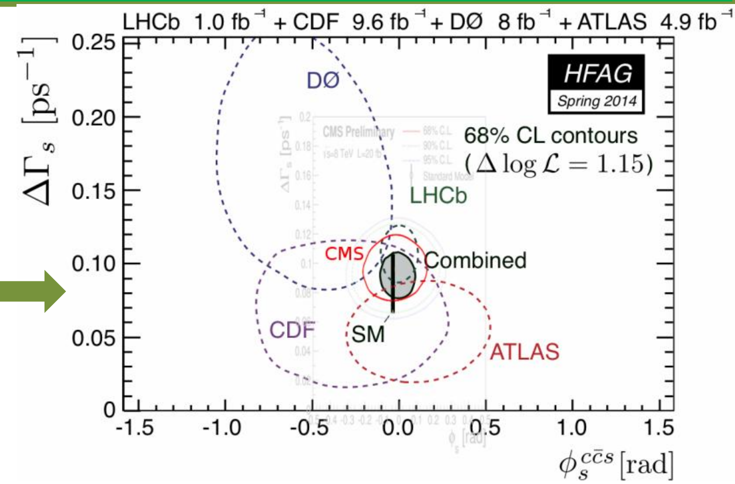






Fit projections for transversity angles φ_T, $\cos(\theta_T)$, $\cos(\psi_T)$

Comparison of ATLAS with other experiments



These results : 1) improve ϕ_s stat. error by 40% ; 2) gave sensitivity to $\delta_\perp$; 3) are consistent with other experiments and the values predicted by the Standard Model

Conclusions

- ***ATLAS results from full data 2011 for pp collisions at 7 TeV (4.9 fb^{-1}) are obtained for New Physics searches with rare decay $B^0_s \to \mu^+\mu^-$ selection and $B^0_s \to J/\psi\ \varphi$ decay parameters measurement***
- *Flavour tagged time dependent angular analysis is used for $B^0_s \to J/\psi\ \varphi$ with essential improvement of previous ATLAS measurement without tagging*
- ***All results are consistent with the predictions of the Standard Model***
- *Results with analysis of 20 fb^{-1} data 2012 at 8 TeV are coming soon!*