Measurement of CP violation in $B_s \to J/\psi\ \varphi$ decay and prospects with ATLAS upgrade

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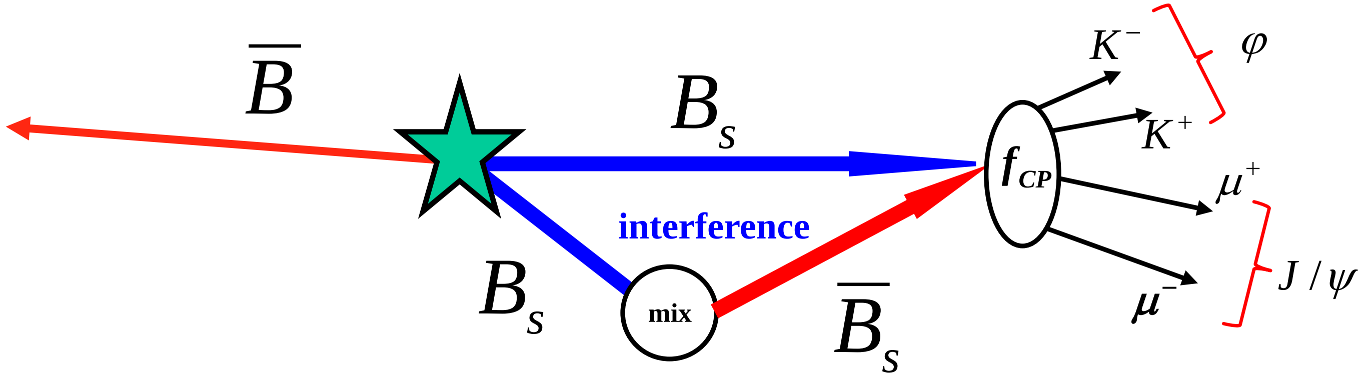
CKM-2014 Workshop

Vienna, 09 September 2014

CP-violation in $B_s \to J/\psi\ \varphi$ decay

- Interference of the B_s decays with and without mixing to the final state accessible to both B_s and $\overline{B}_s$ produces CP violation

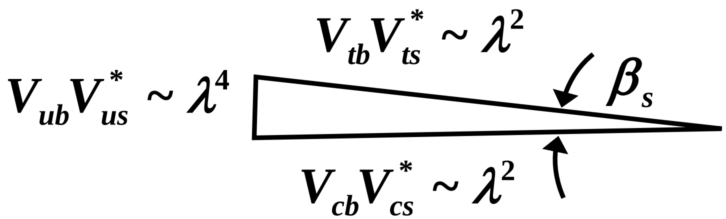


$$\Gamma(B_s(\to \overline{B}_s) \to f_{CP}) \neq \Gamma(\overline{B}_s(\to B_s) \to f_{CP})$$

CP violation in $B_s \to J/\psi\ \varphi$ decay

- CP asymmetry in $B_s \to J/\psi\varphi$ decay is described by the phase $\phi^{J/\psi\varphi}$
- Within the SM $\phi^{J/\psi\varphi}$ is related with the angle β_s of the (*bs*) unitarity triangle:

$$\phi^{J/\psi\varphi,SM} = -2\beta_s = 2\arg\left(-\frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*}\right) = -0.038 \pm 0.002$$



- $\phi^{J/\psi\varphi}$ can be significantly modified by the new physics:

$$\phi^{J/\psi\varphi} = \phi^{J/\psi\varphi,SM} + \phi_s^{NP}$$

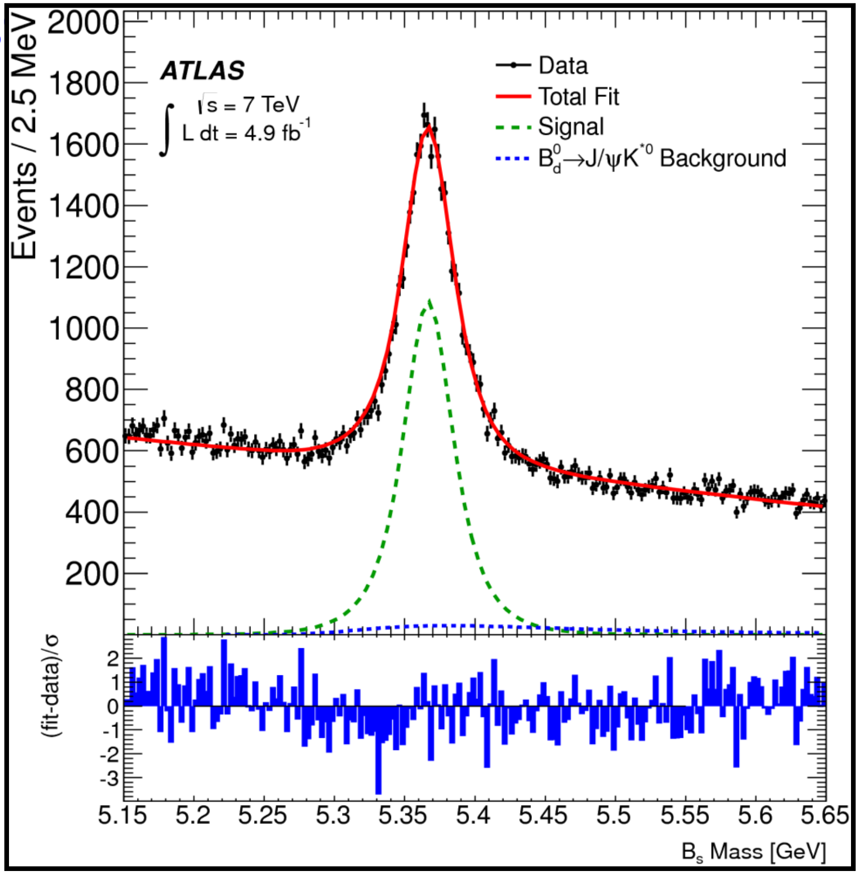
- This possibility explains elevated interest to this decay mode
  - Currently, the precise measurements of $\phi^{J/\psi\varphi}$ by the LHC experiments considerably reduced the possible amount of new physics contribution
- Still, the precise measurement of $\phi^{J/\psi\varphi}$ at the SM level is essential to test the SM and study the possible new physics extensions

Analysis of ATLAS data

Analysis of 2011 data is published: arXiv: 1407.1796

– Accepted by PRD

- Event are selected using dimuon trigg
  - Both muons with $p_T > 4$ GeV
  - Asymmetric triggers with p_T threshold for 2 muons 4 and 2 GeV
- Lifetime-unbiased reconstruction
- In total 130K event candidates are selected with $5.15 < m(J/\psi\varphi) < 5.65$ GeV
  - About 22K signal events
  - About 4 times more events expected in 2012

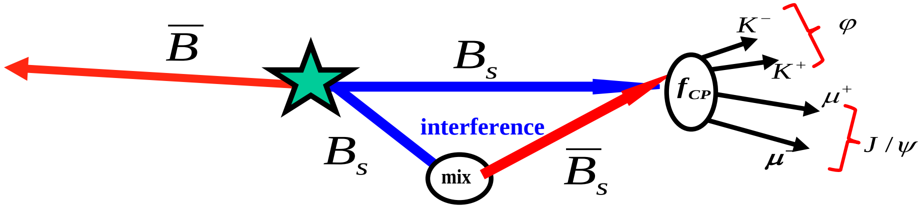


Initial state flavour tagging

- Tagging of the initial flavour (B_s or $\overline{B}_s$) is essential for CP violation study
  - We need to measure the difference between

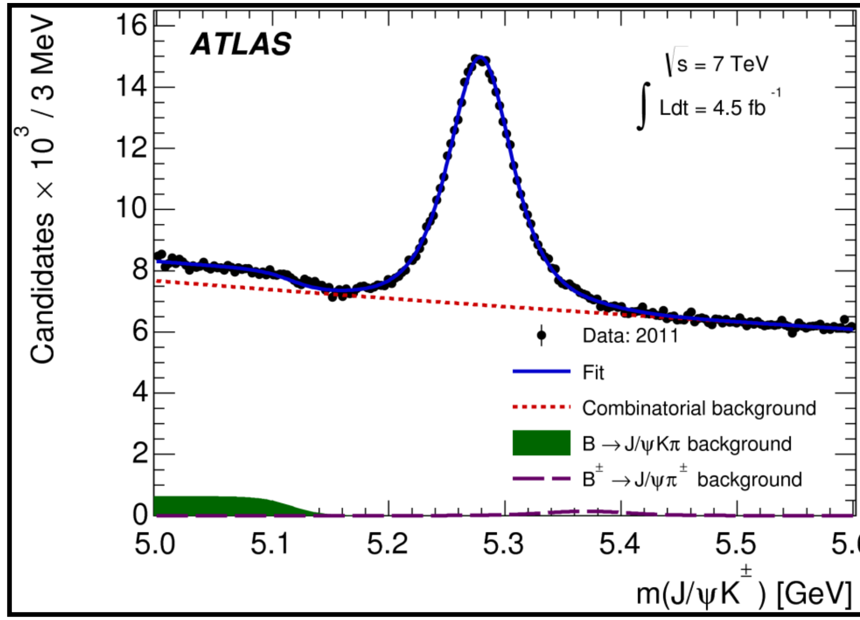
$$\Gamma(B_s(\rightarrow \overline{B}_s) \rightarrow f_{CP}) \text{ and } \Gamma(\overline{B}_s(\rightarrow B_s) \rightarrow f_{CP})$$

- In ATLAS the initial B_s flavour is determined by the flavour of the opposite B meson



- Several tagging methods are used
  - Muon from the opposite side
  - Jet charge of the jet with maximal btagging value
    - Tracks forming B_s candidate are excluded from the jet charge measuement
- Achieved tagging power is (1.45±0.05)%
  - Tagging power shows the effective fraction of statistics with 100% correct initial flavour measurement

Flavour tagging: details

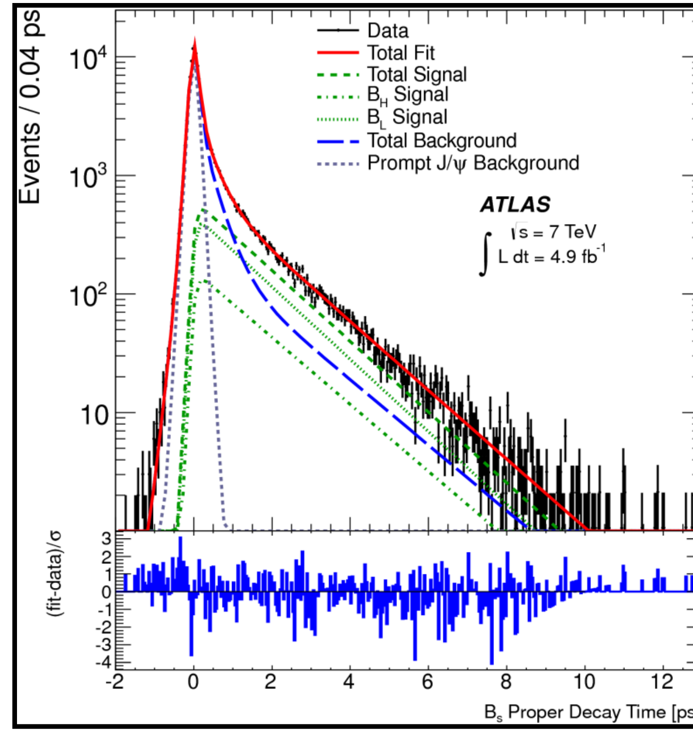


- Flavour tagging is calibrated using $B^{\pm} \to J/\psi\, K^{\pm}$ events
- Both for the muon charge and for the jet charge the tagger is computed as: $$Q = \frac{\sum_i q^i (p_T^i)^k}{\sum_i (p_T^i)^k}; \quad k = 1.1$$
  - For muon the sum is taken over tracks in $\Delta R<0.5$ cone around the muon
  - For jet the sum is taken over all tracks in the jet

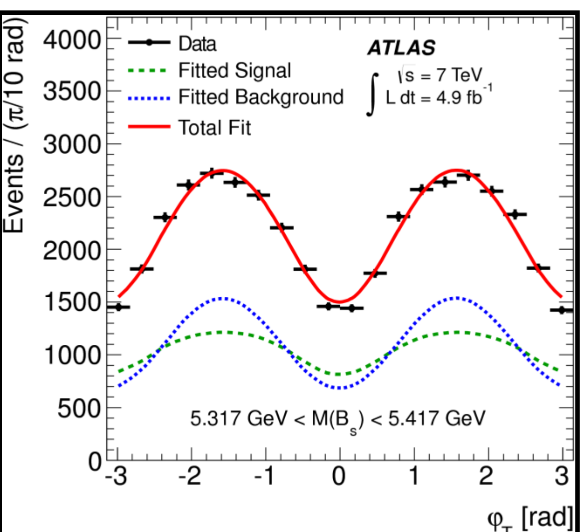
Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined μ	3.37 ± 0.04	50.6 ± 0.5	0.86 ± 0.04
Segment Tagged μ	1.08 ± 0.02	36.7 ± 0.7	0.15 ± 0.02
Jet charge	27.7 ± 0.1	12.68 ± 0.06	0.45 ± 0.03
Total	32.1 ± 0.1	21.3 ± 0.08	1.45 ± 0.05

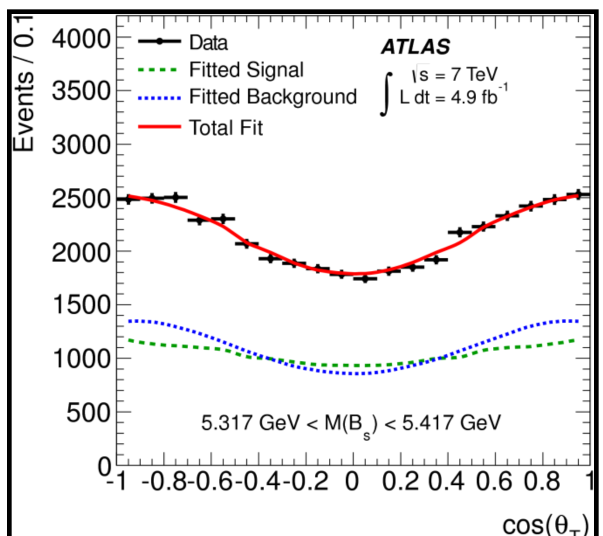
Unbinned maximum likelihood fit

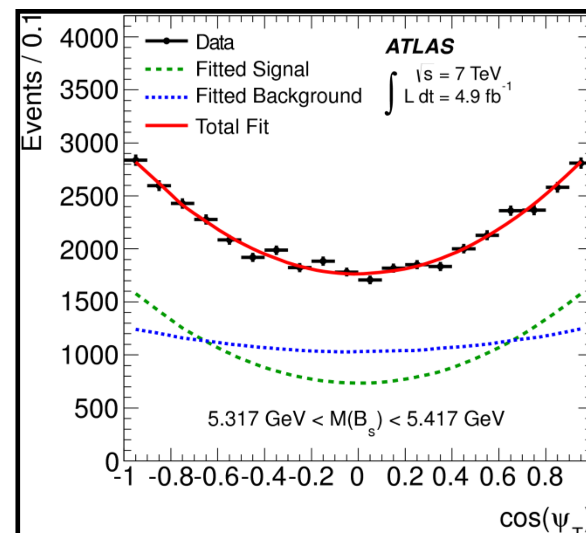
- The properties of $B_s \to J/\psi\varphi$ decay are obtained from the unbinned maximum likelihood fit which includes
  - Mass of $J/\psi\varphi$ system and its uncertainty
  - p_T of B_s candidate
  - Proper decay length and its uncertainty
  - Angles describing the kinematics of B_s decay
  - Flavour tagging



- Good quality of the fit is confirmed by the projection of the fit on all variables





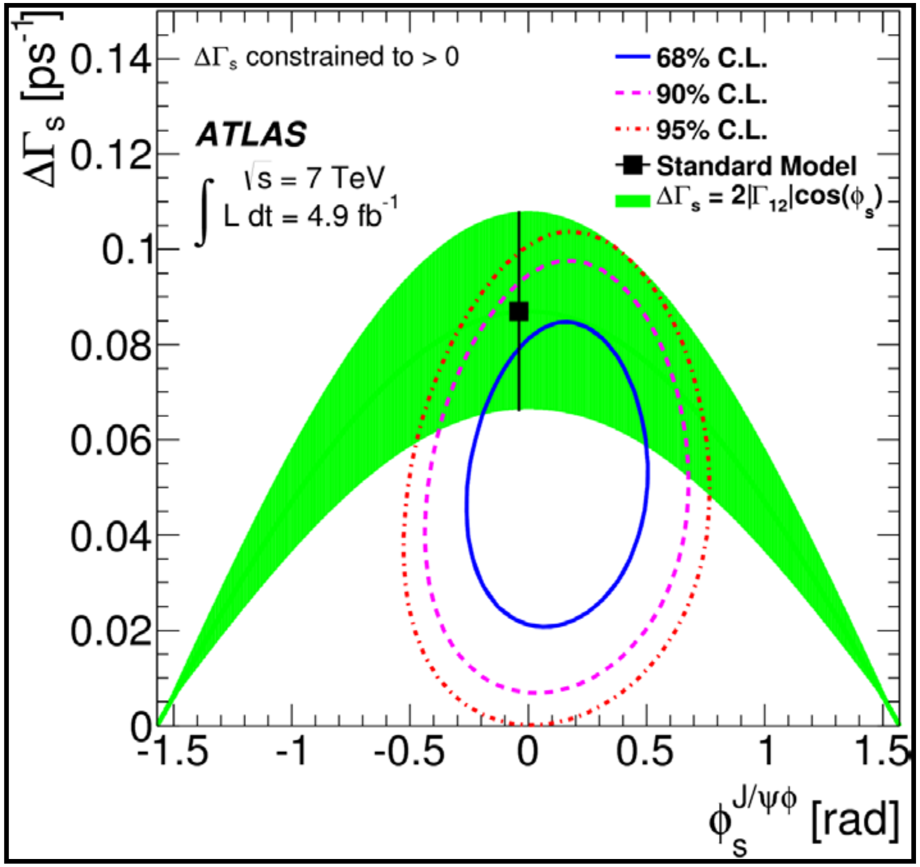


Results

- From the likelihood fit we obtain:

$$\phi^{J/\psi\varphi} = 0.12 \pm 0.25\,(\text{stat}) \pm 0.11\,(\text{syst})$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\,(\text{stat}) \pm 0.009\,(\text{syst})$$

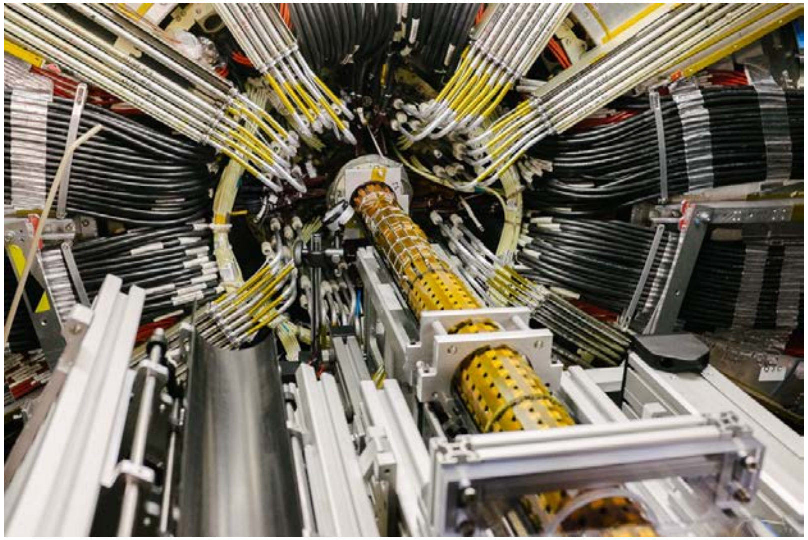
  - 40% improvement of the $\phi^{J/\psi\varphi}$ precision compared to our previous result
    - Because of adding flavour tagging in the analysis
- Result agrees well with the SM expectation
- Further improvements are expected after adding 2012 data and in the years following the upgrade of ATLAS detector



ATLAS upgrade

Upgrade of ATLAS detector will significantly improve its ability to work at high luminosity with better tracking precision

– Phase-0 Upgrade (2014-2015): Add new layer of silicon detector (IBL) at ~35 mm from beam pipe



Installation of IBL in ATLAS

– Phase-1 Upgrade (2018-2019): The main focus is on the Level-1 trigger to be capable to work at $\sim 2.2\times 10^{34}$ cm^{-2} s^{-1} and to collect 300-400 fb^{-1} integrated luminosity ("IBL layout")

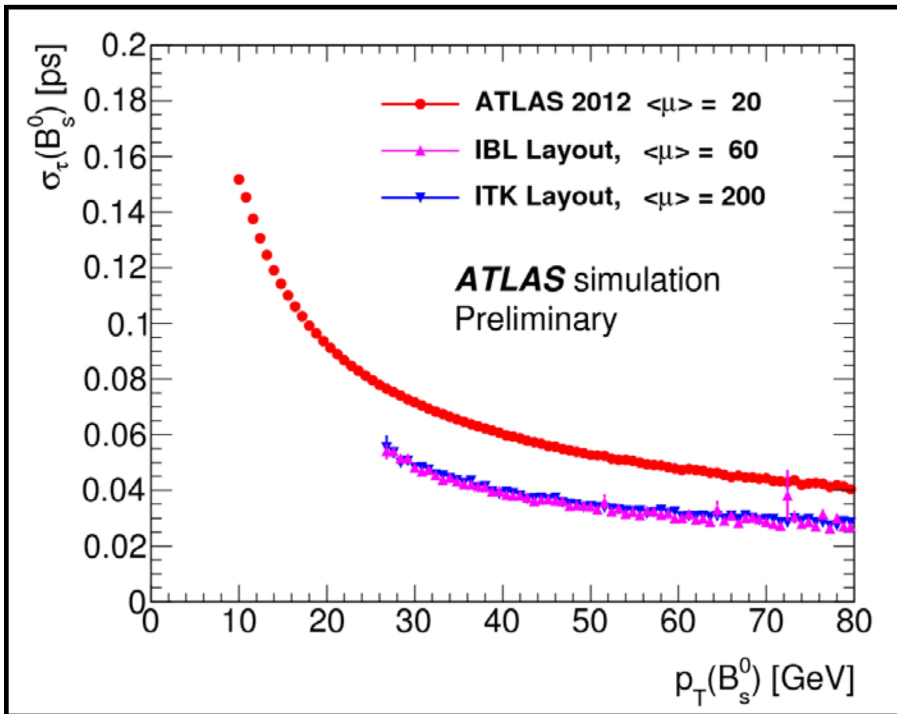
– Phase II Upgrade (HL-LHC) : New silicon tracker and upgrade of all other parts of the detector to be capable to work at $\sim 5\times 10^{34}$ cm^{-2} s^{-1} (corresponding to ~140 pile-up interactions per event) and to collect ~3000 fb^{-1} integrated luminosity ("ITK layout")

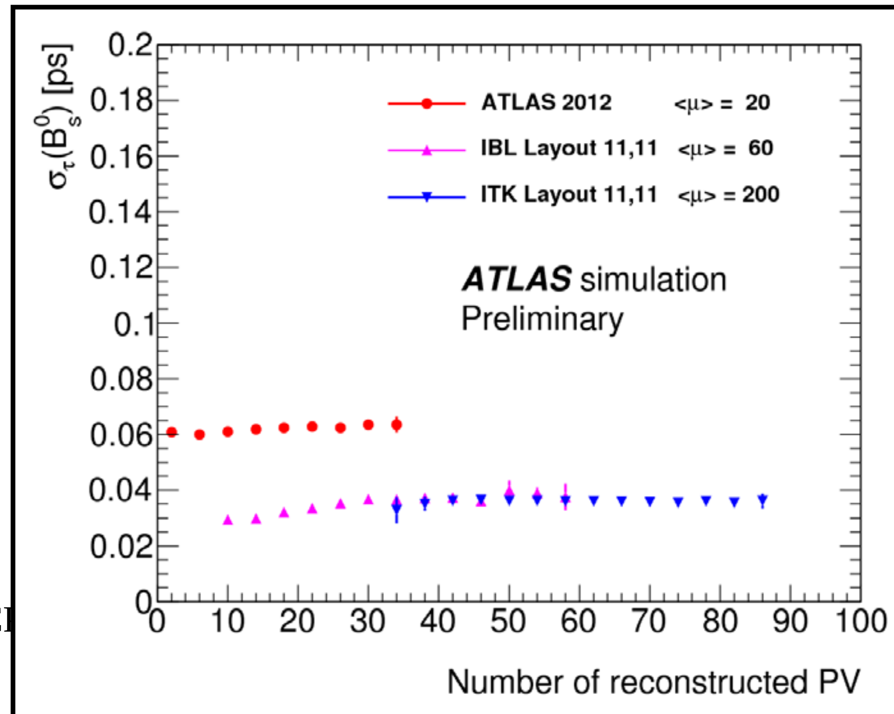
Increased signal statistics

- The statistics in $B_s \to J/\psi\varphi$ channel is expected to be much larger because of
  - Increased luminosity
  - Larger cross-section at $\sqrt{s}$=14 TeV
- However, the trigger threshold on the $p_T(\mu)$ will be increased to fit in the bandwidth available for B physics
  - In 2012: tag 2 muons with $p_T(\mu)$ 4 and 6 GeV
  - In 2015-2017 run increase the threshold to 6 GeV for both muons (and possibly to 11 GeV)
  - Starting from 2019 the threshold will be 11 GeV for both muons
    - These are current assumptions, they may evolve during preparation for data taking

Improved detector performance

- In addition to significantly increased statistics, the detector will have a much better lifetime resolution due to an improved tracking
- This resolution is especially important for a fast oscillating B_s meson
- No degradation of performance with the increase of luminosity





Expected precision

- Precision of $\phi^{J/\psi\varphi}$ measurement will improve significantly with time
- This year our precision is expected to be $\sigma(\phi^{J/\psi\varphi}) \approx 0.12$
- Our final precision $\sigma(\phi^{J/\psi\varphi}) = 0.022$ is expect to be at the level of the SM value ($\phi^{J/\psi\varphi,\,SM} = -0.038 \pm 0.002$)
  - Obtained from toy MC studies
  - More details can be found in: ATLAS-PHYS-PUB-2013-010

	2011	2012	2015-17		2019-21	2023-30+
Detector	current	current	IBL		IBL	ITK
Average interactions per BX $<\mu>$	6-12	21	60		60	200
Luminosity, fb^{-1}	4.9	20	100		250	3 000
Di-μ trigger p_T thresholds, GeV	4 - 4(6)	4 - 6	6 - 6	11 - 11	11 - 11	11 - 11
Signal events per fb^{-1}	4 400	4 320	3 280	460	460	330
Signal events	22 000	86 400	327 900	45 500	114 000	810 000
Total events in analysis	130 000	550 000	1 874 000	284 000	758 000	6 461 000
MC $\sigma(\phi_s)$ (stat.), rad	0.25	0.12	0.054	0.10	0.064	0.022

Conclusions

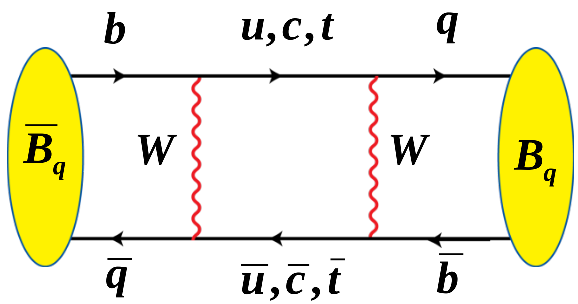
- Analysis of 2011 ATLAS data reveals no anomaly in $B_s \to J/\psi\varphi$ decay

$$\phi^{J/\psi\varphi} = 0.12 \pm 0.25 \pm 0.11$$
$$\Delta\Gamma_s = 0.053 \pm 0.021 \pm 0.009$$

- Initial flavour tagging is now included in the analysis; it improves considerably the precision of the $\phi^{J/\psi\varphi}$ measurement
- Significant increase in statistics is expected for the analysis of 2012 data, which will be available soon
- Upgraded ATLAS detector and increased luminosity will allow to test $\phi^{J/\psi\varphi}$ at the SM level
  - Precision of $\phi^{J/\psi\varphi}$ ~0.022 is expected by 2030

Backup slides

Neutral B_q system



- Dynamics of B_q meson ($q = d,s$) is described by 5 parameters:

$$m_q, \quad \Gamma_q, \quad \Delta m_q, \quad \Delta\Gamma_q, \quad \phi_q^{12}$$

- Δm_q and $\Delta\Gamma_q$ are the mass and width difference of two physical states B_q^H (heavy) and B_q^L (light)
  - With these definitions both Δm_q and $\Delta\Gamma_q$ positive in the SM
- m_q^{12} and Γ_q^{12} are non-diagonal elements of the **(m-*i*Γ/2)** matrix

$$\|\mathbf{m}_q\| = \begin{bmatrix} m_q & m_q^{12} \\ (m_q^{12})^* & m_q \end{bmatrix} - \frac{i}{2}\begin{bmatrix} \Gamma_q & \Gamma_q^{12} \\ (\Gamma_q^{12})^* & \Gamma_q \end{bmatrix}$$

$$\Delta m_q = m_{q,H} - m_{q,L} \approx 2\left|m_q^{12}\right|$$

$$\Delta\Gamma_q = \Gamma_{q,L} - \Gamma_{q,H} \approx 2\left|\Gamma_q^{12}\right|\cos\phi_q^{12}$$

$$\phi_q^{12} = \arg\left(-\frac{m_q^{12}}{\Gamma_q^{12}}\right)$$