Violación de CP a través de ATLAS y CMS

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on behalf of
ATLAS and CMS collaborations

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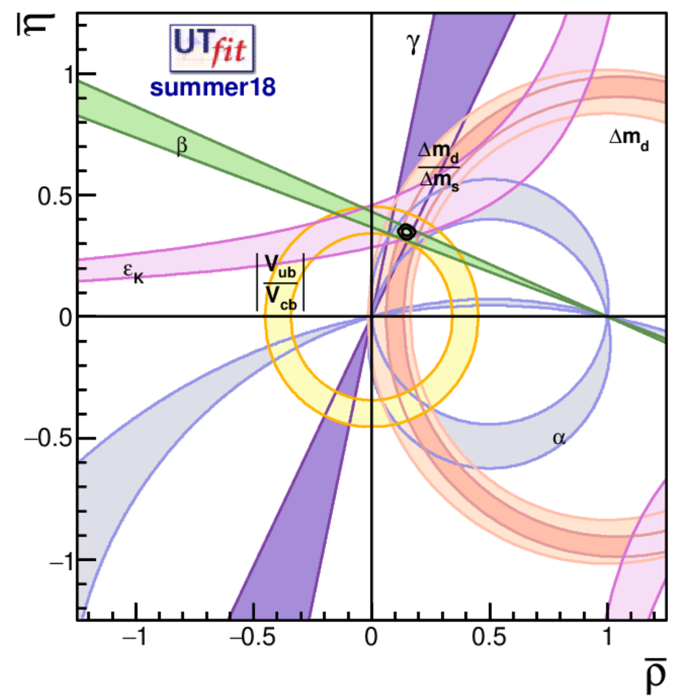
B physics in ATLAS and CMS

- I will concentrate on the latest (C)P parameter measurements:
  - **CMS**: Λ_b polarization and angular parameters in $\Lambda_b \to J/\psi\Lambda$ *[Phys. Rev. D 97 (2018) 072010]*
  - **ATLAS**: CP violating phase phis in $B_s^0 \to J/\psi\varphi$ angular analysis *[ATLAS-CONF-2019-009]*

- some recent (2018-2019) results *(not included here)*
  - **ATLAS**:
    - $B_{(s)}$ to μμ [JHEP 04 (2019) 098] NEW
    - B to K*μμ angular analysis *[JHEP 10 (2018) 047]*
    - $B_s\pi$ searches *[Phys. Rev. Lett. 120 (2018) 202007]*,
    - Quarkonia production *[Eur. Phys. J. C 78 (2018) 171]*
  - **CMS**:
    - $B_c^{(*)+}$(2S) observation / B_c^+(2S) mass *[PRL 122 (2019) 132001]*
    - $B_{s2}^*(5840)^0$ and $B_{s1}(5830)^0$ *[EPJC 78 (2018) 939]*
    - $Z \to \psi\ell^+\ell^-$ observation *[PRL 121 (2018) 141801]*
    - $B^+ \to K^+\mu\mu$ angular analysis *[PRD 98 (2018) 112011]*

CP violation in the SM and NP:

- $B_{(s)}$ systems are giving us a rather precise picture
  - However there is some space for NP
  - Could appear as new contributions in $\Delta F=2$ loop processes



The ratio of NP/SM amplitudes need to be:

< 18% @68% prob.

(30% @95%)

in B_d mixing

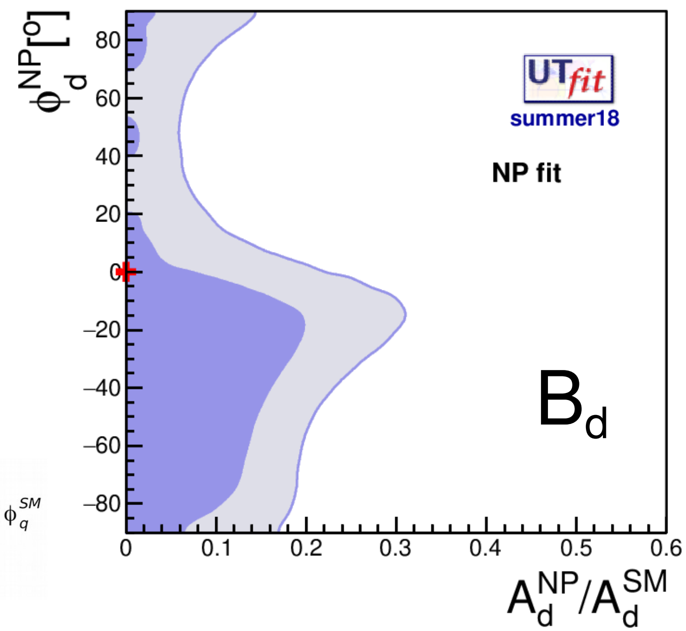
< 20% @68% prob.

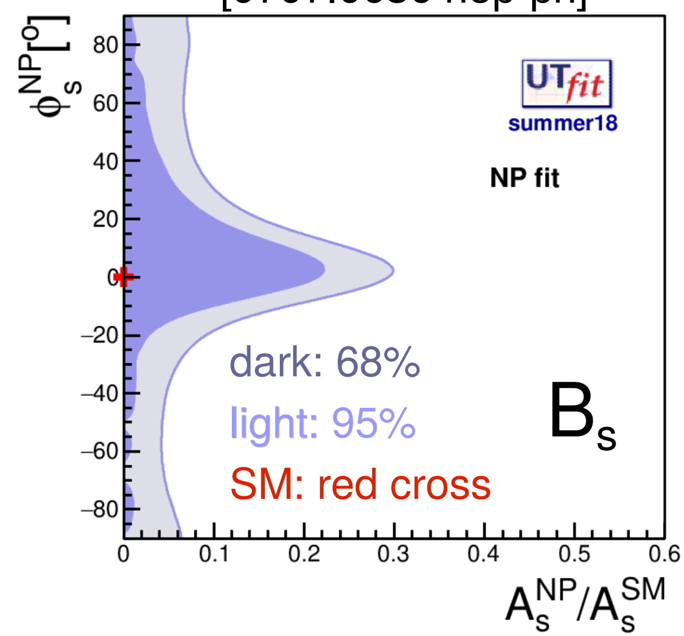
(30% @95%)

in B_s mixing

$$A_q = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

[0707.0636 hep-ph]





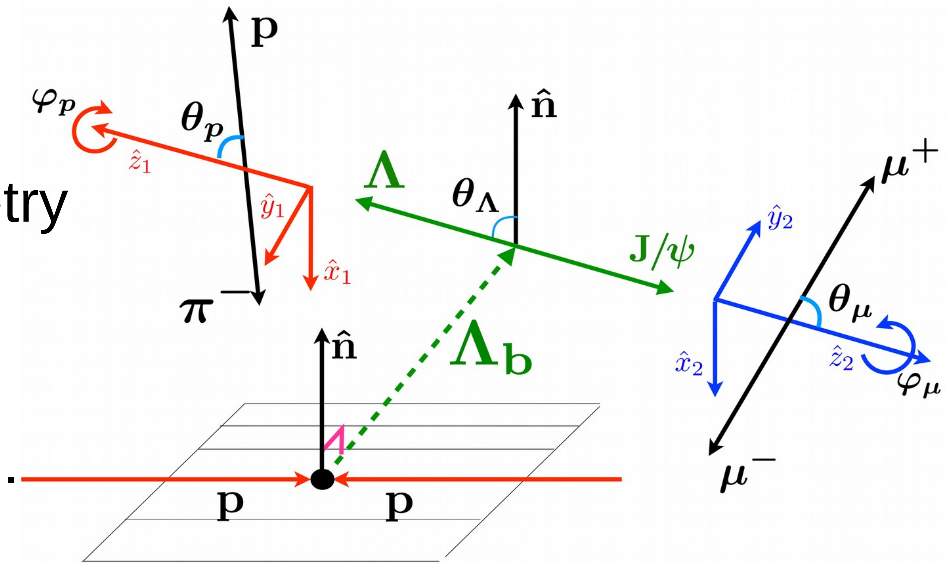
Measurement of the Λ_b polarization and angular parameters in $\Lambda_b \to J/\psi \Lambda$ decays at CMS

CMS result with 5.2 and 19.8 fb^{-1} of 7 and 8 TeV data (Run 1)
Phys. Rev. D 97 (2018) 072010, arXiv:1802.04867

Angular analysis in $\Lambda_b \to J/\psi\Lambda$ decays

Interesting parameters:

- the Λ_b polarisation P
- the parity-violating decay asymmetry α_1 of the Λ_b
- the Λ_b longitudinal polarisation α_2
- γ depends on the longitudinal and transverse polarisations of the J/ψ.



- Final state: $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi^-$
- Λ_b both from direct production and from decays of heavier b baryons

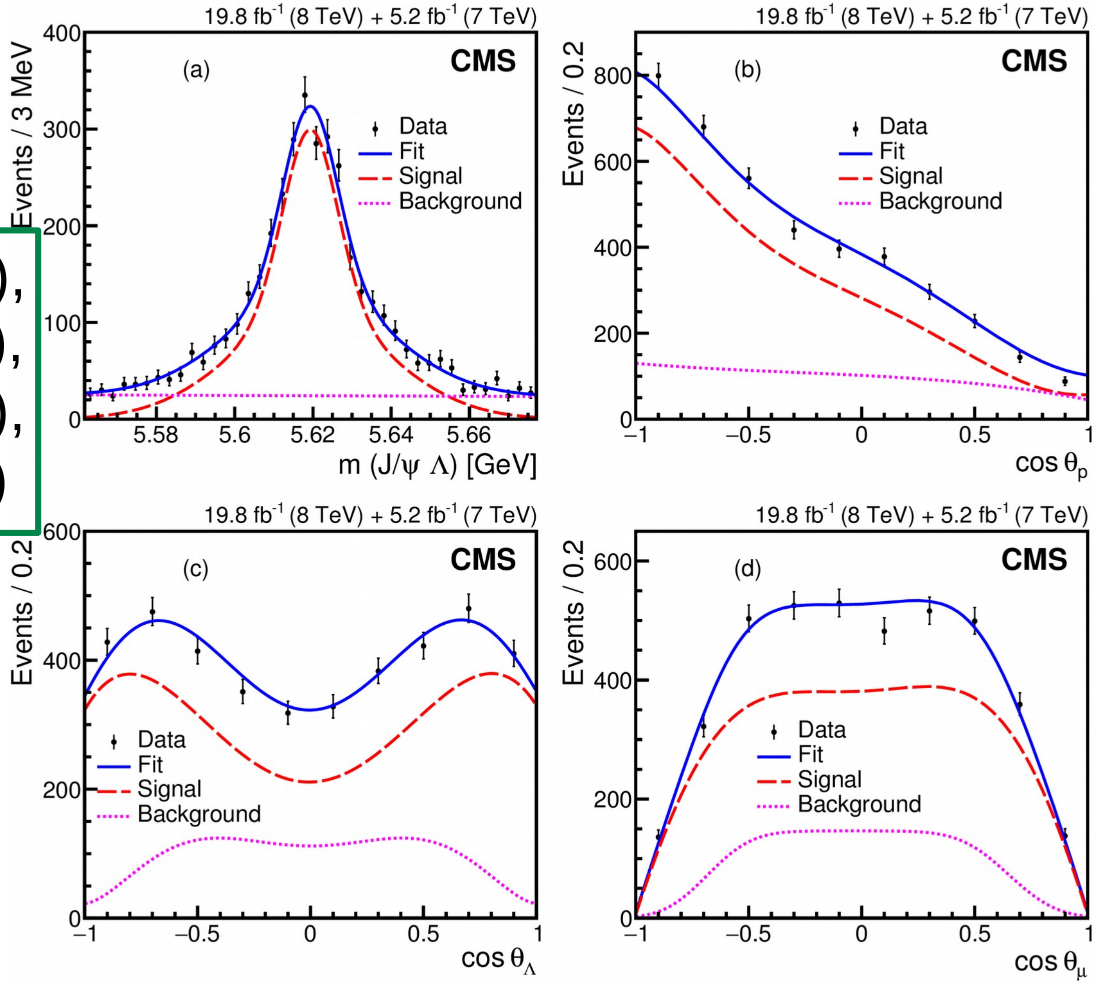
- angular distribution function of 5 decay angles (θ_Λ, θ_p, θ_μ, φ_p, φ_μ), but integrate over azimuthal angles.

- Unbinned maximum likelihood fit to $J/\psi\Lambda$ invariant mass and the 3 angular variables $\Theta_3 = (\cos\theta_\Lambda, \cos\theta_p, \cos\theta_\mu)$ to 4 datasets $\to$ Λ_b and $\bar{\Lambda}_b$ at 7 and 8 TeV (full Run 1)

Angular analysis in $\Lambda_b \to J/\psi \Lambda$ decays

Results:

$P = 0.00 \pm 0.06$ (stat) ± 0.06 (syst),
$\alpha_1 = 0.14 \pm 0.14$ (stat) ± 0.10 (syst),
$\alpha_2 = -1.11 \pm 0.04$ (stat) ± 0.05 (syst),
$\gamma_0 = -0.27 \pm 0.08$ (stat) ± 0.11 (syst)



- Λ_b polarization value P consistent with LHCb and theoretical predictions.
- α_1 PV value consistent with LHCb and ATLAS and with no parity violation at 1σ.
  - inconsistent at $\sim 5\sigma$ with the heavy-quark effective theory prediction, but consistent at $<1\sigma$ with other predictions (pQCD, quark model techniques..)

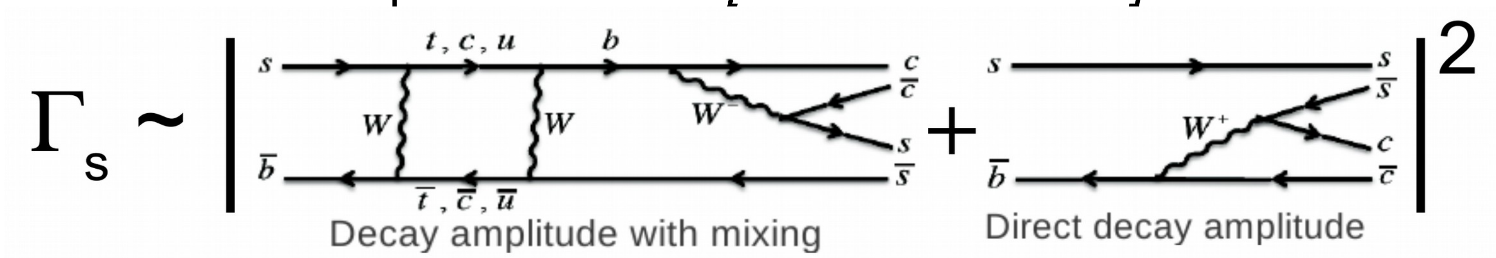
ATLAS EXPERIMENT

CP violation parameters from time-dependent angular analysis on $B_s \rightarrow J/\psi\phi$

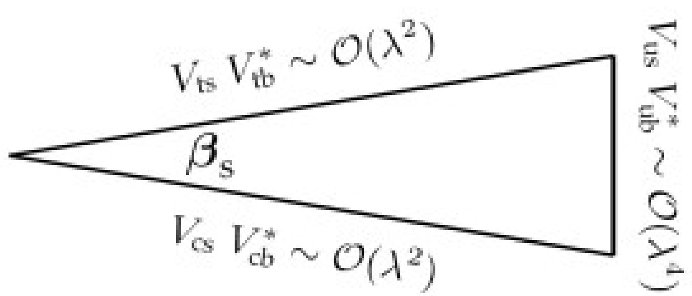
ATLAS result with 80.5/fb of 13 TeV data (Run 2, 2015-2017)
+ combination with 19.2/fb of 7-8 TeV data (Run 1)
ATLAS-CONF-2019-009 ***NEW***
+ JHEP 08 (2016) 147, arXiv:1601.03297

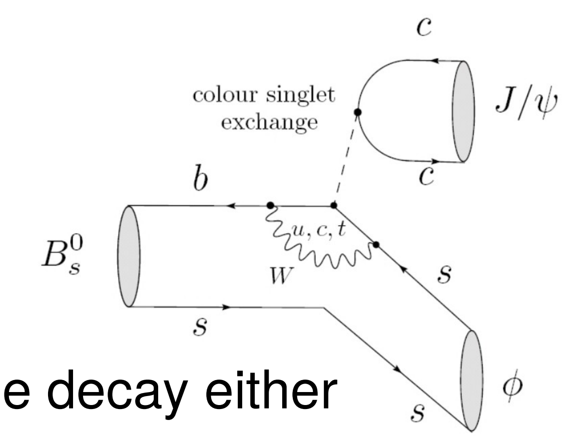
Time-dependent angular analysis of $B_s \to J/\psi\phi$

- Parameters of the B_s system:
  - Mixing → Decay width difference $\Delta\Gamma_s = \Gamma_L - \Gamma_S$
  - $\Delta\Gamma_s = 0.087 \pm 0.021\ \mathrm{ps}^{-1}$ in the SM *[arXiv:1102.4274]*



  - CPV phase φ_s → weak phase between mixing and b → ccs decay
  - $\varphi_s = -2\beta_s$ with $\beta_s = \arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$
  - SM: $-2\beta_s = -0.0363 \pm 0.0016$ *[arXiv:1106.4041],* 0.0370 ± 0.0010 *[UTfit18]*





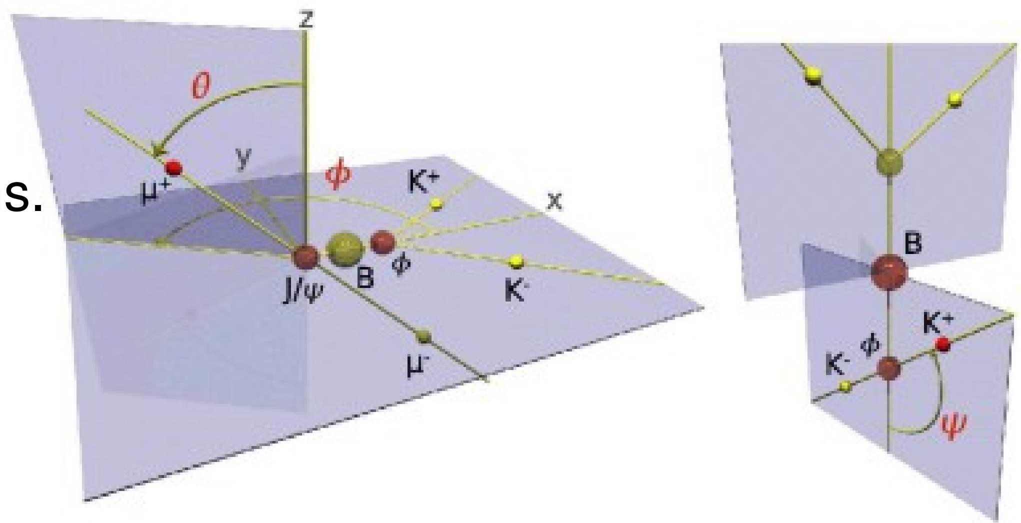
  - Golden mode: penguin diagrams can contribute to the decay either with the same weak phase (λ^2) or they are CKM suppressed (λ^4)

Time-dependent angular analysis of $B_s \rightarrow J/\psi\phi$

- Golden channel for measuring the B_s parameters
  - Pseudoscalar B0s to the vector–vector $J/\psi(\mu^+\mu^-)\varphi(K^+ K^-)$ final state → admixture of CP-odd and CP-even states (L = 0, 1 or 2).
  - L = 0 or 2 → CP-even states, while L = 1 → CP-odd state.
  - Same final state can also be K^+K^- pairs in S-wave → CP-odd.
  - CP states are separated statistically using an angular analysis
  - Differential decay rate:

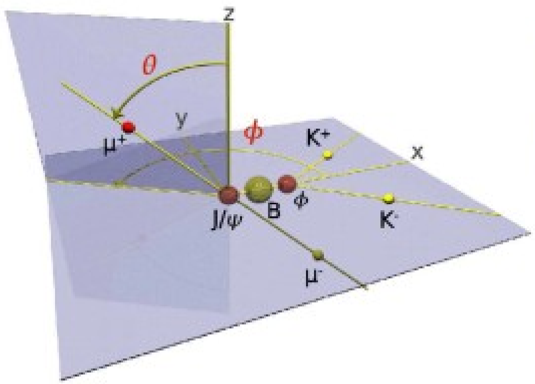
$$\frac{d^4\Gamma}{dt\, d\Omega} = \sum_{k=1}^{10} O^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \phi_T),$$

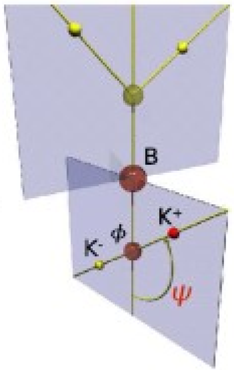
    with $O^{(k)}(t)$ time-dependent functions corresponding to the contributions of amplitudes (A_0, $A_{||}$, $A_\perp$, and A_S) (and interferences) and $g^{(k)}(\theta_T, \psi_T, \varphi_T)$ are angular functions.
  - Flavour tagging is used to distinguish between the initial B^0_s and $\bar{B}^0_s$ states.



Time-dependent angular analysis of $B_s \to J/\psi\phi$

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





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

TD angular analysis of $B_s \to J/\psi\phi$

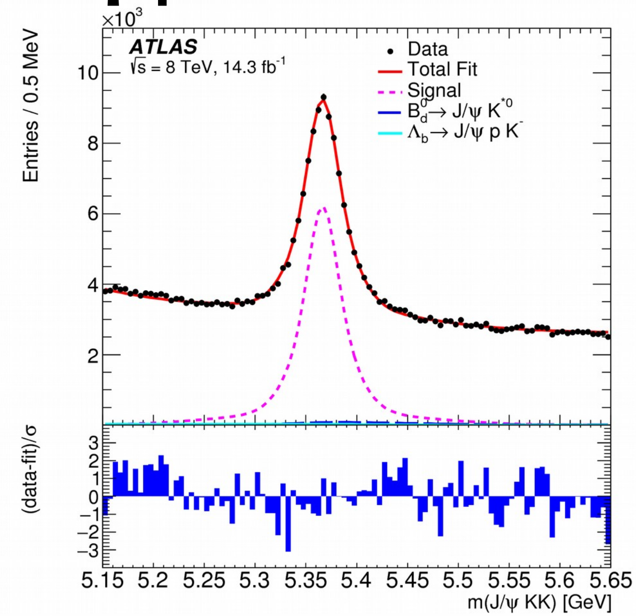
ATLAS Run-1 result:

- $14.3\ fb^{-1}$ of ATLAS data from 2012 at 8 TeV
- Results:

$$\phi_s = -0.090 \pm 0.078\ (stat) \pm 0.041\ (syst)\ rad$$

$$\Delta\Gamma_s = 0.085 \pm 0.011\ (stat) \pm 0.007\ (syst)\ ps^{-1}$$

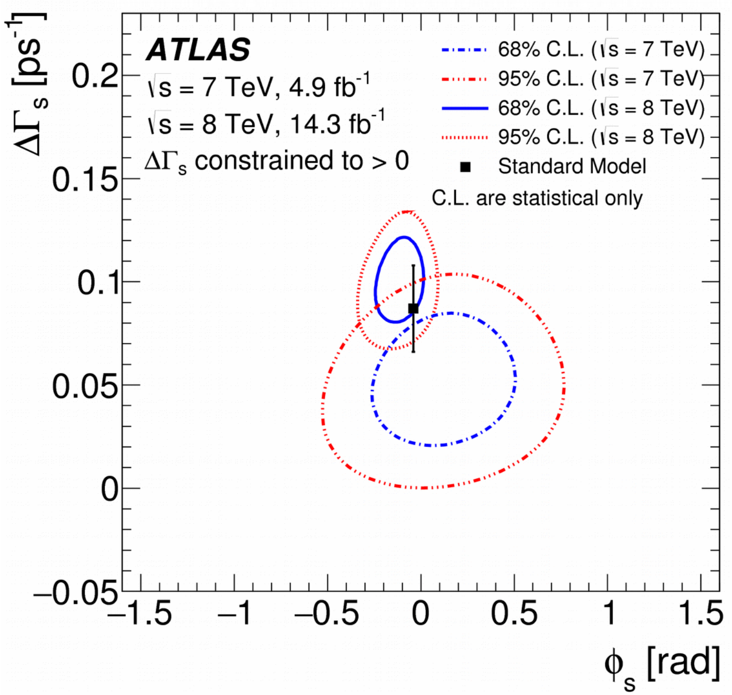
[JHEP 08 (2016) 147]



- Agrees with SM
- Consistent with other experiments
- Consistent with previous analysis, using 2011 data at 7 TeV

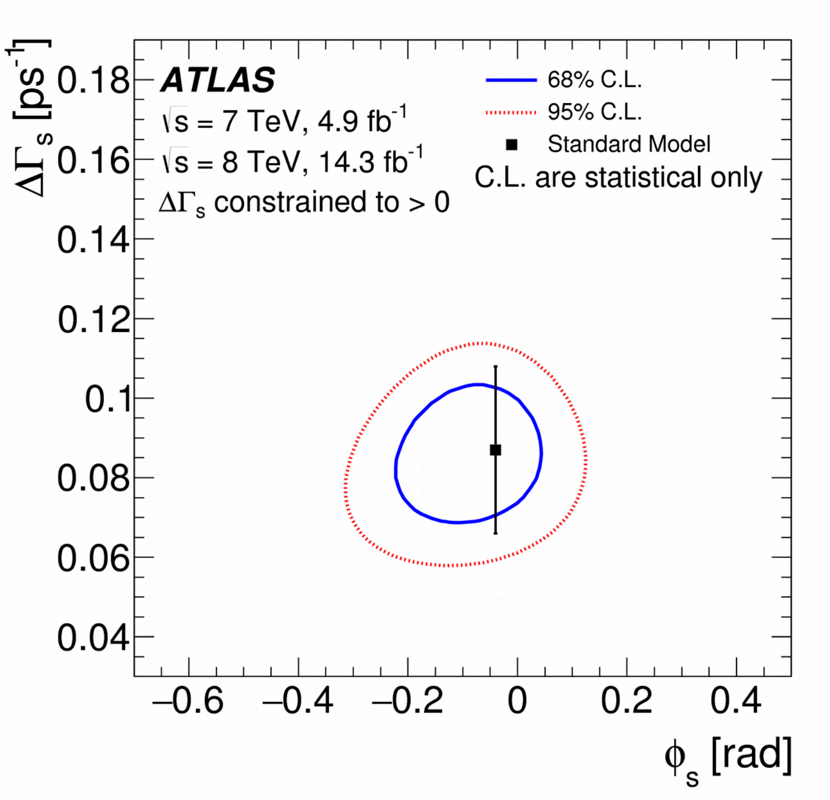
[Phys. Rev. D 90, 052007 (2014)]

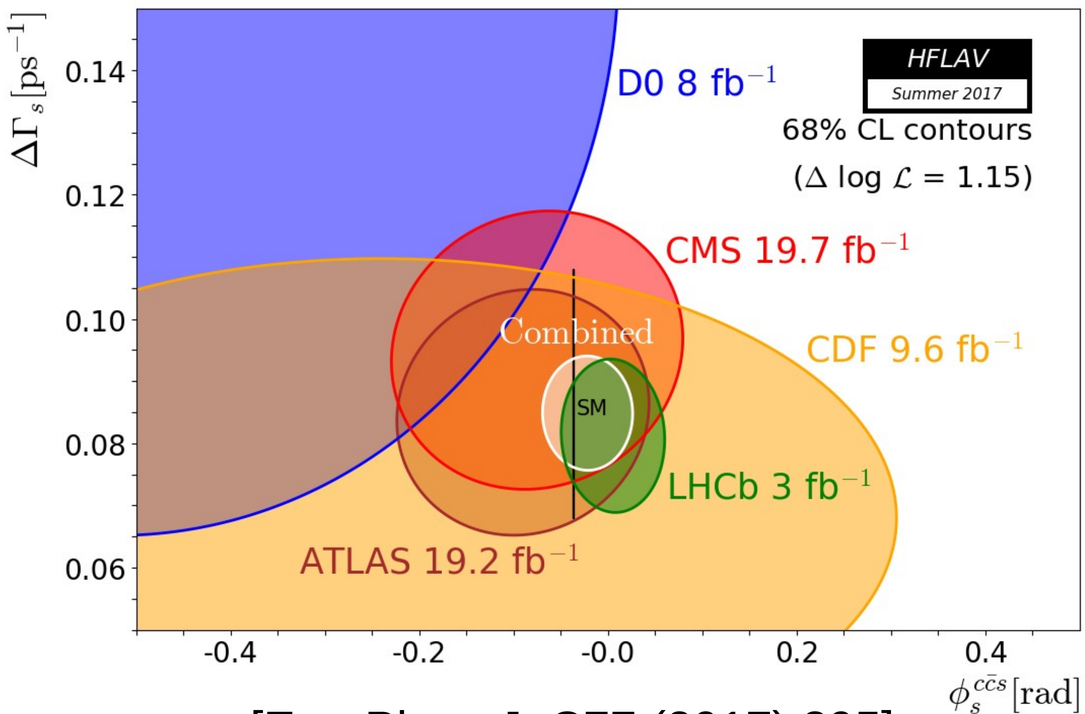
- A Best Linear Unbiased Estimate (BLUE) combination used to combine 7 and 8 TeV measurements



Time-dependent angular analysis of $B_s \to J/\psi\phi$

ATLAS combined Run-1 result:

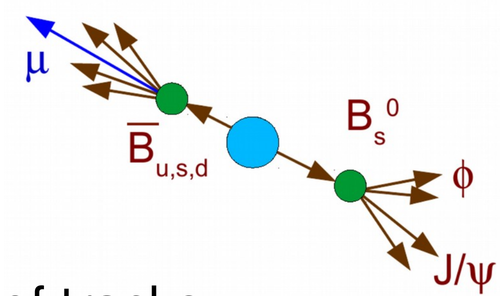




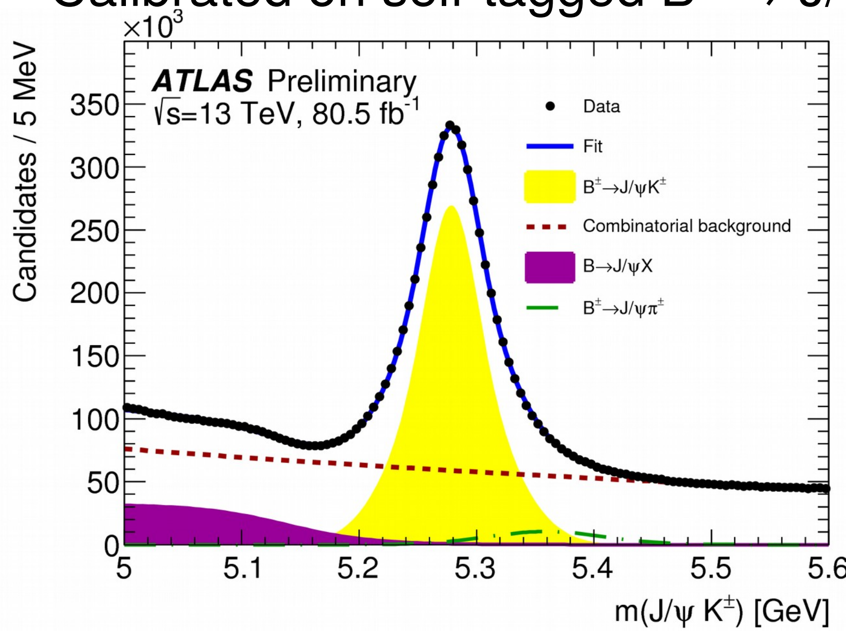
[Eur. Phys. J. C77 (2017) 895]

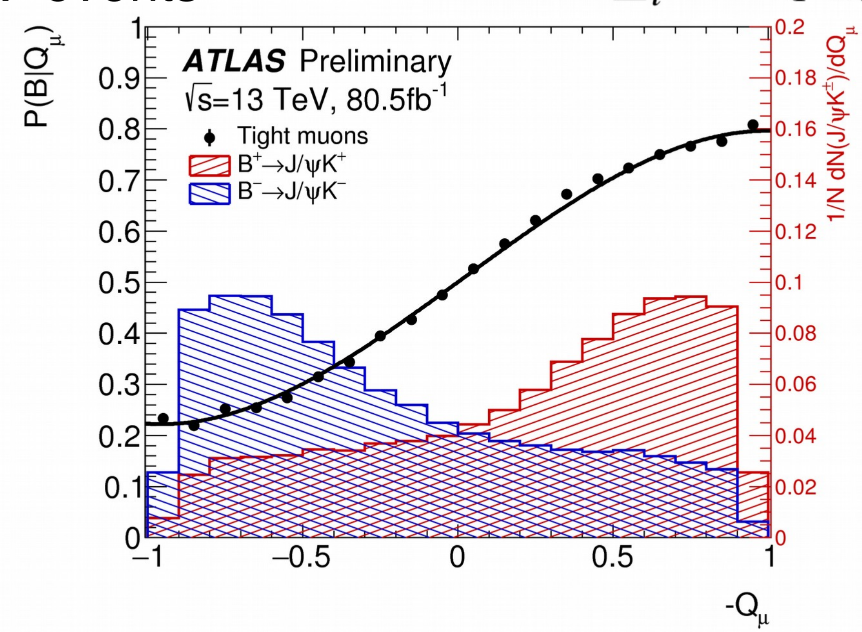
Time-dependent angular analysis of $B_s \to J/\psi\phi$

- ATLAS Run-2 result:
  - 80.5 fb^{-1} of 13 TeV data (Run 2, 2015-2017)
- Analysis strategy and experimental inputs:
  - J/ψ trigger with muon p_T of 4 or 6 GeV
  - Measurement of the proper decay time $t = L_{xy}\, m_B/p_T^B$
  - Flavour tagging to identify the flavour of the b quark:
    - opposite-side tagging (OST) using p_T-weighted charge of tracks in cone around muons / electrons / b jets
    - Calibrated on self-tagged $B^\pm \to J/\psi K^\pm$ events



$$Q_x = \frac{\sum_i^{N\ \text{tracks}} q_i \cdot (p_{\mathrm{T}i})^\kappa}{\sum_i^{N\ \text{tracks}} (p_{\mathrm{T}i})^\kappa}$$





Time-dependent angular analysis of $B_s \to J/\psi\phi$

- Analysis strategy and experimental inputs (cont):
  - Flavour tagging to identify the flavour of the b quark:
    - opposite-side tagging (OST) using p_T-weighted charge of tracks in cone around muons / electrons / b jets
    - Calibrated on self-tagged $B^\pm \to J/\psi K^\pm$ events

$$Q_x = \frac{\sum_i^{N\ \text{tracks}} q_i \cdot (p_{\mathrm{T}i})^\kappa}{\sum_i^{N\ \text{tracks}} (p_{\mathrm{T}i})^\kappa}$$

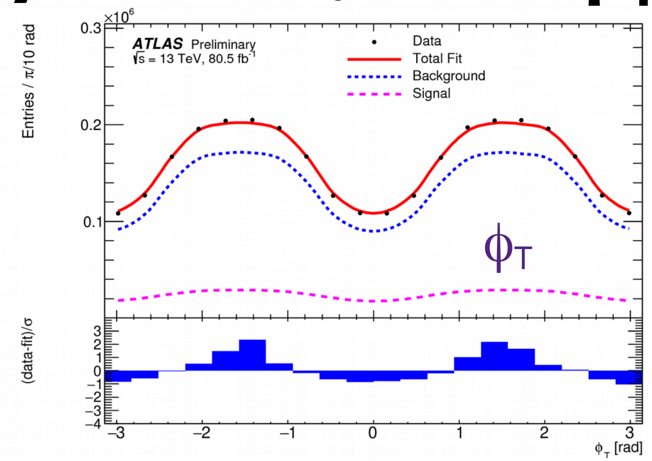
    - Dilution $D(Q_x)$ and tagging power T_x defined as:
    - Tag probabilities included in the B_s fit

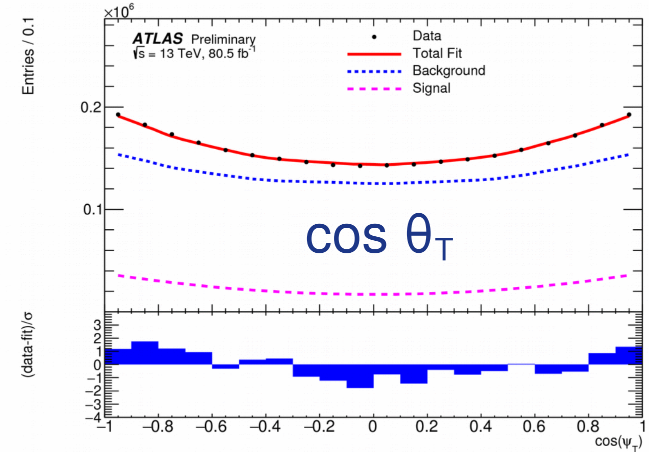
$$\mathcal{D}(Q_x) = 2P(B|Q_x) - 1$$
$$T_x = \sum_i \epsilon_{x\,i} \cdot (2P(B|Q_{x\,i}) - 1)^2$$

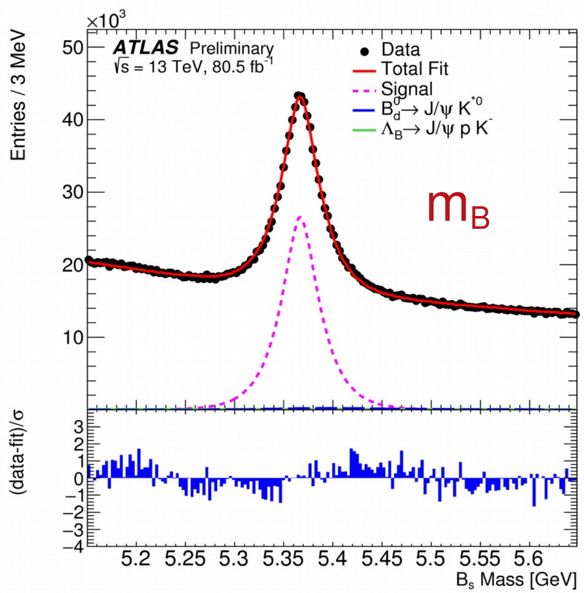
Tag method	Efficiency [%]	Effective Dilution [%]	Tagging Power [%]
Tight muon	4.50 ± 0.01	43.8 ± 0.2	0.862 ± 0.009
Electron	1.57 ± 0.01	41.8 ± 0.2	0.274 ± 0.004
Low-p_T muon	3.12 ± 0.01	29.9 ± 0.2	0.278 ± 0.006
Jet	5.54 ± 0.01	20.4 ± 0.1	0.231 ± 0.005
Total	14.74 ± 0.02	33.4 ± 0.1	1.65 ± 0.01

Time-dependent angular analysis of $B_s \to J/\psi\phi$

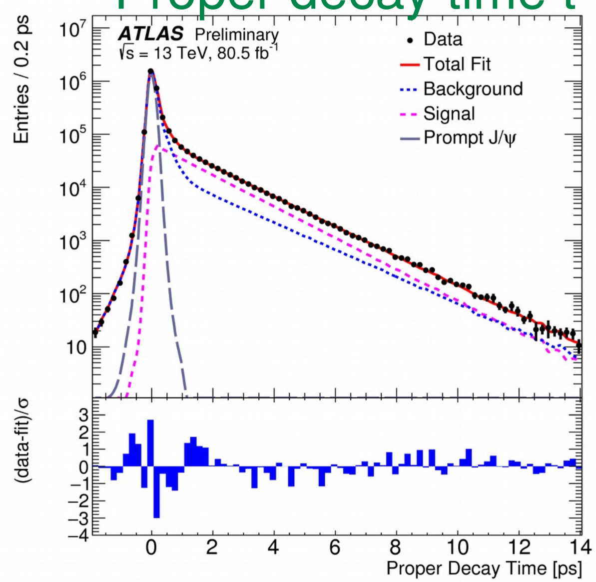
- Unbinned maximum-likelihood fit
  - *B_s properties*: reconstructed mass m_B, proper decay time t, proper decay time uncertainty σ_t, tagging probability $P(B|Q_x)$
  - *Transversity angles*: $\Omega(\theta_T, \psi_T, \phi_T)$ of each $B^0_s \to J/\psi\phi$ decay candidate
  - *Physical parameters*: **$\Delta\Gamma_s$, φ_s, Γ_s, $|A_0(0)|^2$, $|A_{||}(0)|^2$, $\delta_{||}$, $\delta_\perp$, $|A_s(0)|^2$ and δ_s**

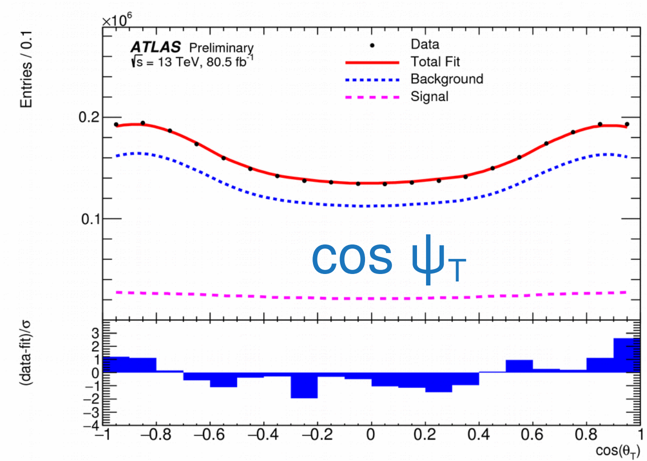






Proper decay time t





Time-dependent angular analysis of $B_s \to J/\psi\phi$

- Systematics:
  - *Lifetime model*: varying p_T bins and signal fraction
  - *Backgrounds*: B_d / Λ_b / angular models varied / p_T bins varied
  - *Tagging*: variation of the parameterisation / recalibration from MC samples / pile-up effects

	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	Γ_s [ps^{-1}]	$\vert A_\parallel(0)\vert^2$	$\vert A_0(0)\vert^2$	$\vert A_S(0)\vert^2$	$\delta_\perp$ [rad]	$\delta_\parallel$ [rad]	$\delta_\perp - \delta_S$ [rad]
Tagging	1.7×10^{-2}	0.4×10^{-3}	0.3×10^{-3}	0.2×10^{-3}	0.2×10^{-3}	2.3×10^{-3}	1.9×10^{-2}	2.2×10^{-2}	2.2×10^{-3}
Acceptance	0.7×10^{-3}	$<10^{-4}$	$<10^{-4}$	0.8×10^{-3}	0.7×10^{-3}	2.4×10^{-3}	3.3×10^{-2}	1.4×10^{-2}	2.6×10^{-3}
ID alignment	0.7×10^{-3}	0.1×10^{-3}	0.5×10^{-3}	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	1.0×10^{-2}	7.2×10^{-3}	$<10^{-4}$
S–wave phase	0.2×10^{-3}	$< 10^{-4}$	$<10^{-4}$	0.3×10^{-3}	$<10^{-4}$	0.3×10^{-3}	1.1×10^{-2}	2.1×10^{-2}	8.3×10^{-3}
Background angles model:									
Choice of fit function	1.8×10^{-3}	0.8×10^{-3}	$<10^{-4}$	1.4×10^{-3}	0.7×10^{-3}	0.2×10^{-3}	8.5×10^{-2}	1.9×10^{-1}	1.8×10^{-3}
Choice of p_T bins	1.3×10^{-3}	0.5×10^{-3}	$<10^{-4}$	0.4×10^{-3}	0.5×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	7.2×10^{-3}	1.0×10^{-3}
Choice of mass interval	0.4×10^{-3}	0.1×10^{-3}	0.1×10^{-3}	0.3×10^{-3}	0.3×10^{-3}	1.3×10^{-3}	4.4×10^{-3}	7.4×10^{-3}	2.3×10^{-3}
Dedicated backgrounds:									
B_d^0	2.3×10^{-3}	1.1×10^{-3}	$<10^{-4}$	0.2×10^{-3}	3.1×10^{-3}	1.4×10^{-3}	1.0×10^{-2}	2.3×10^{-2}	2.1×10^{-3}
Λ_b	1.6×10^{-3}	0.4×10^{-3}	0.2×10^{-3}	0.5×10^{-3}	1.2×10^{-3}	1.8×10^{-3}	1.4×10^{-2}	2.9×10^{-2}	0.8×10^{-3}
Fit model:									
Time res. sig frac	1.4×10^{-3}	1.1×10^{-3}	$<10^{-4}$	0.5×10^{-3}	0.6×10^{-3}	0.6×10^{-3}	1.2×10^{-2}	3.0×10^{-2}	0.4×10^{-3}
Time res. p_T bins	3.3×10^{-3}	1.4×10^{-3}	0.1×10^{-2}	$< 10^{-4}$	$< 10^{-4}$	0.5×10^{-3}	6.2×10^{-3}	5.2×10^{-3}	1.1×10^{-3}
Total	1.8×10^{-2}	0.2×10^{-2}	0.1×10^{-2}	0.2×10^{-2}	0.4×10^{-2}	0.4×10^{-2}	9.7×10^{-2}	2.0×10^{-1}	0.1×10^{-1}

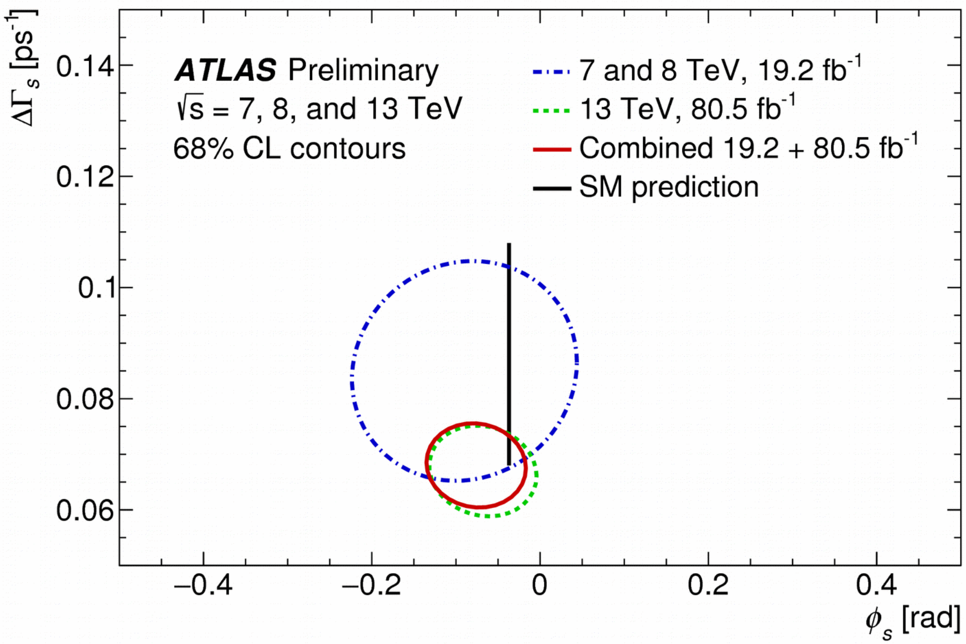
Time-dependent angular analysis of $B_s \to J/\psi\phi$

ATLAS Run-2 result on 80.5 fb^{-1} of 2015-2017 data

Run 2 only (80.5 fb^{-1}):

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	–0.068	0.038	0.018
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	0.067	0.005	0.002
$\Gamma_s[\mathrm{ps}^{-1}]$	0.669	0.001	0.001
$\lvert A_{\parallel}(0)\rvert^2$	0.219	0.002	0.002
$\lvert A_0(0)\rvert^2$	0.517	0.001	0.004
$\lvert A_S(0)\rvert^2$	0.046	0.003	0.004
$\delta_\perp$ [rad]	2.946	0.101	0.097
$\delta_{\parallel}$ [rad]	3.267	0.082	0.201
$\delta_\perp - \delta_S$ [rad]	–0.220	0.037	0.010

Run 1 (19.2 fb^{-1}) & Run 2 (80.5 fb^{-1}):

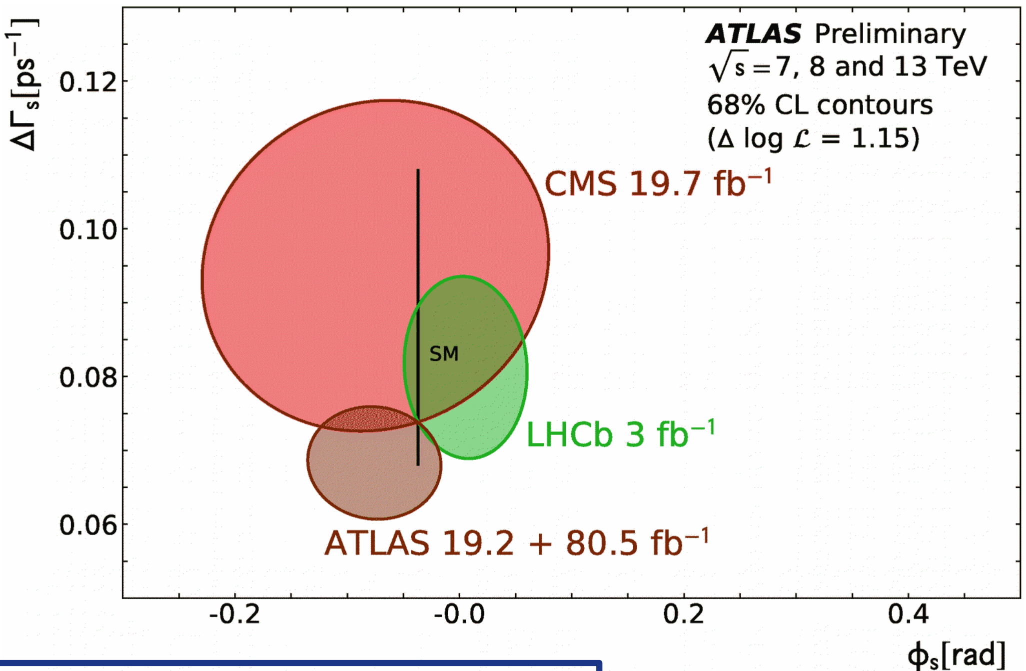


Time-dependent angular analysis of $B_s \to J/\psi\phi$

ATLAS Run 1 & Run 2 combined
(19.2 fb^{-1} + 80.5 fb^{-1})

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	–0.076	0.034	0.019
$\Delta\Gamma_s$[ps^{-1}]	0.068	0.004	0.003
Γ_s[ps^{-1}]	0.669	0.001	0.001
$\lvert A_{\parallel}(0)\rvert^2$	0.220	0.002	0.002
$\lvert A_0(0)\rvert^2$	0.517	0.001	0.004
$\lvert A_S\rvert^2$	0.043	0.004	0.004
$\delta_\perp$ [rad]	3.075	0.096	0.091
$\delta_\parallel$ [rad]	3.295	0.079	0.202
$\delta_\perp - \delta_S$ [rad]	–0.216	0.037	0.010

Comparison with CMS & LHCb:



$$\phi_s = -0.076 \pm 0.034\ (\text{stat}) \pm 0.019\ (\text{syst})\ \text{rad}$$
$$\Delta\Gamma_s = 0.068 \pm 0.004\ (\text{stat}) \pm 0.003\ (\text{syst})\ \text{ps}^{-1}$$

- Consistent with results from CMS, LHCb and Standard Model
- Stringent single measurement of ϕ_s, $\Delta\Gamma_s$, Γ_s and helicity function parameters
- Still to add 60 fb^{-1} of 2018 data

Time-dependent angular analysis of $B_s \to J/\psi\phi$

ATLAS Run 1 & Run 2 combined
($19.2\ fb^{-1} + 80.5\ fb^{-1}$)

Parameter	Value	Statistical uncertainty	Systematic uncertainty
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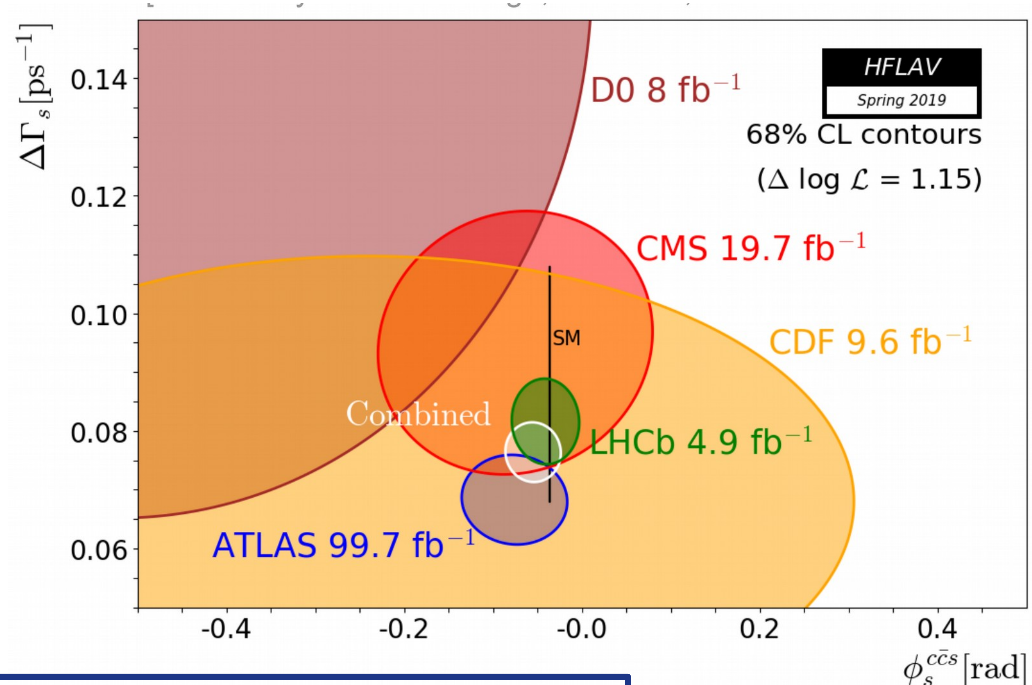
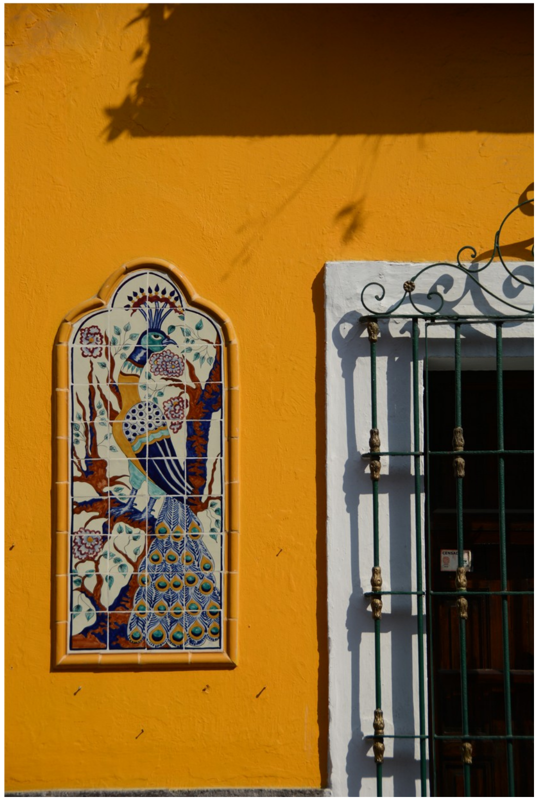


ϕ_s = -0.076 ± 0.034 (stat) ± 0.019 (syst) rad
$\Delta\Gamma_s$ = 0.068 ± 0.004 (stat) ± 0.003 (syst) ps^{-1}

Preliminary HFLAV average:
ϕ_s = -0.055 ± 0.021 rad
$\Delta\Gamma_s$ = 0.0764 ± 0.0034 ps^{-1}

Perspective of ATLAS & CMS for angular analysis of $B_s \to J/\psi\phi$

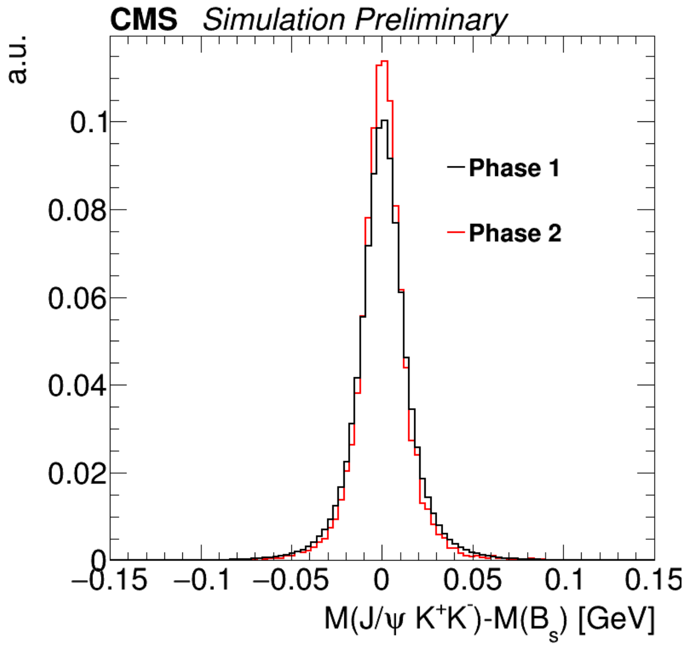


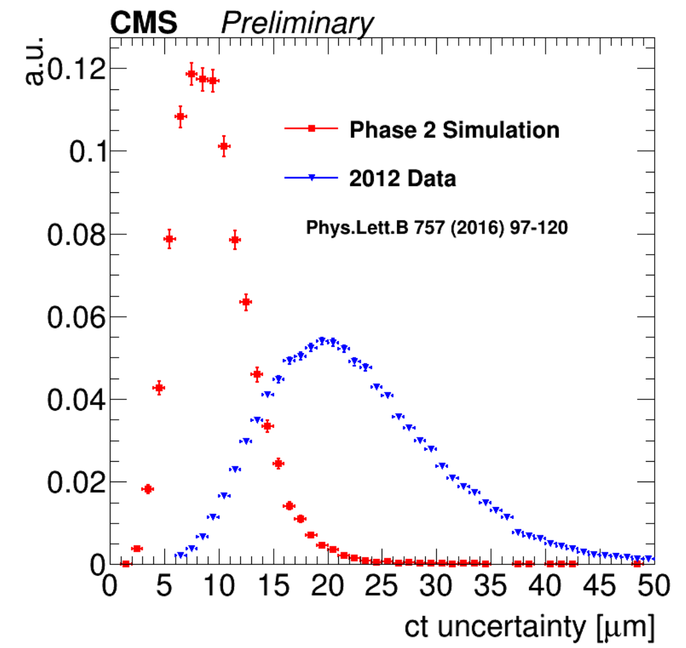
CMS: study for HL-LHC at 3 ab^{-1}
[CMS-PAS-FTR-18-041]
ATLAS: study for HL-LHC at 3 ab^{-1}
[ATL-PHYS-PUB-2018-041]

TD angular analysis of $B_s \to J/\psi\phi$

CMS-PAS-FTR-18-041

- Main upgrade: silicon tracker (with its L1 trigger capabilities).
- significant improvements in momentum and transverse impact parameter resolutions
    - improvements of the mass and lifetime resolutions
- L1 (hardware) and HLT (software) trigger expected comparable to Run 2
    - offline selections identical to 2012
    - no difference in S/B w.r.t. 2012





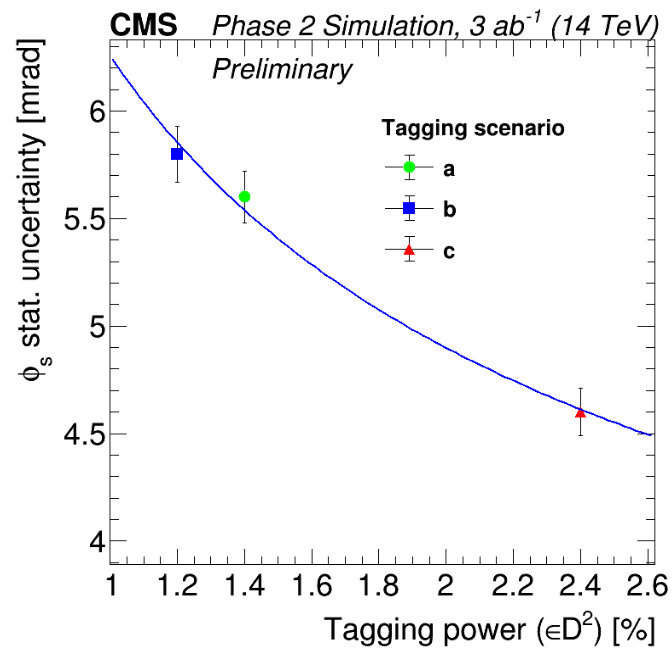
TD angular analysis of $B_s \to J/\psi\phi$

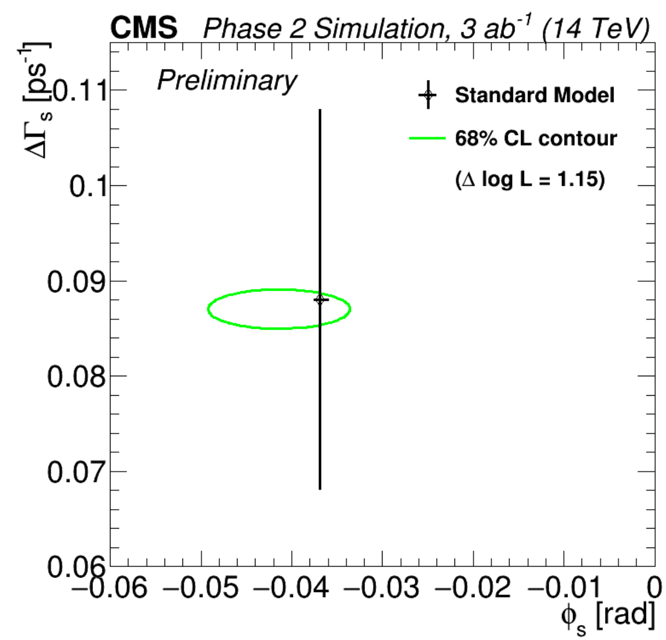
CMS-PAS-FTR-18-041

- Extrapolation to 3 ab^{-1}

Three tagging scenarios:
a/ tagging based on muons and jet–charge
b/ based on muon and electron (as 2012)
c/ well performing flavour tagging based on leptons, jet–charge, and same side jet–charge/kaon tagging.

Results:
- φ_s uncertainty in the range 5–6 mrad.
- uncertainty on φ_s dominated by statistics
- uncertainty on $\Delta\Gamma_s$ has comparable statistical and systematic contributions





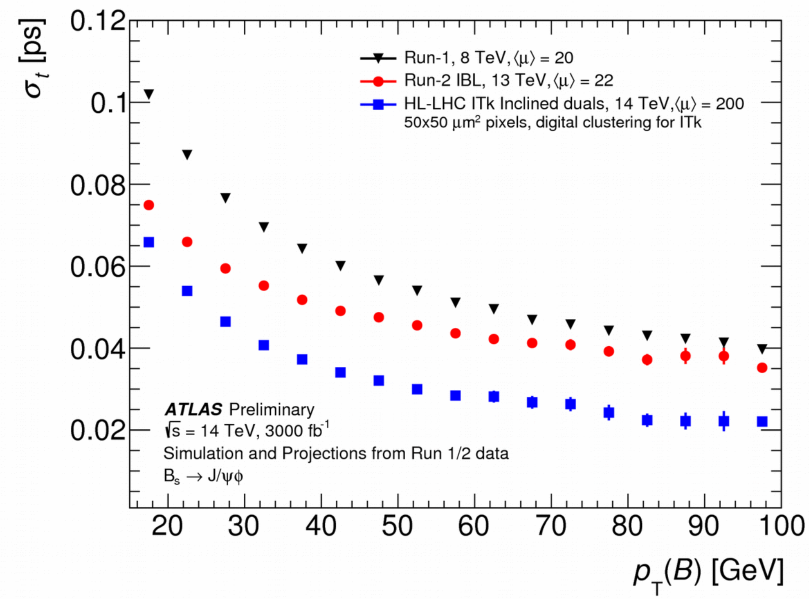
TD angular analysis of $B_s \rightarrow J/\psi\phi$

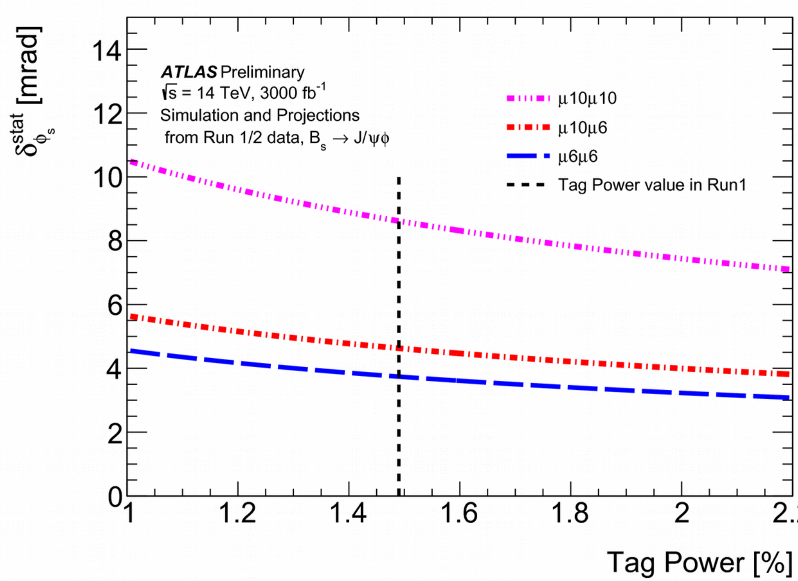
ATL-PHYS-PUB-2018-041

Updated tracking system (ITk):
- Proper decay time resolution improved by 21% w.r.t. Run 2
- B_s^0 mass resolution improved by 30%
  - not included for not linear effect on φ_s
- Stability in worse pile-up conditions

Three trigger scenarios for thresholds:
- (10, 10) GeV muon pT → x18 Run 1
- (6, 10) GeV muon pT → x60 Run 1
- (6, 6) GeV muon pT → x100 Run 1

Extrapolation:
- Yields scaled from Run 2
- Tagging power kept constant
- Main (most) systematics will also scale with the statistic of the sample





TD angular analysis of $B_s \rightarrow J/\psi\phi$

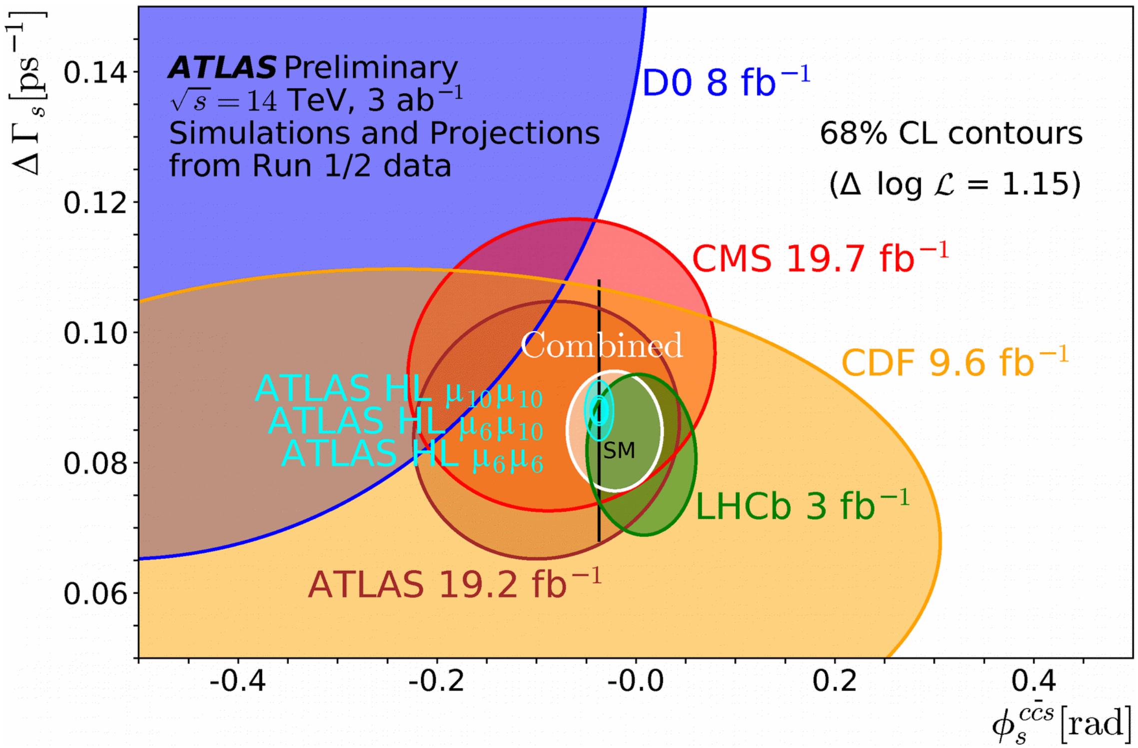
ATL-PHYS-PUB-2018-041

Systematics scaled with statistics w.r.t. Run 1

- except for detector aligment: Run-2 studies improve it of a factor 4
  - φ_s syst ~ 0.003 rad
  - $\Delta\Gamma_s$ syst ~ 0.0005 ps^{-1}

Improvements w.r.t. Run 1:

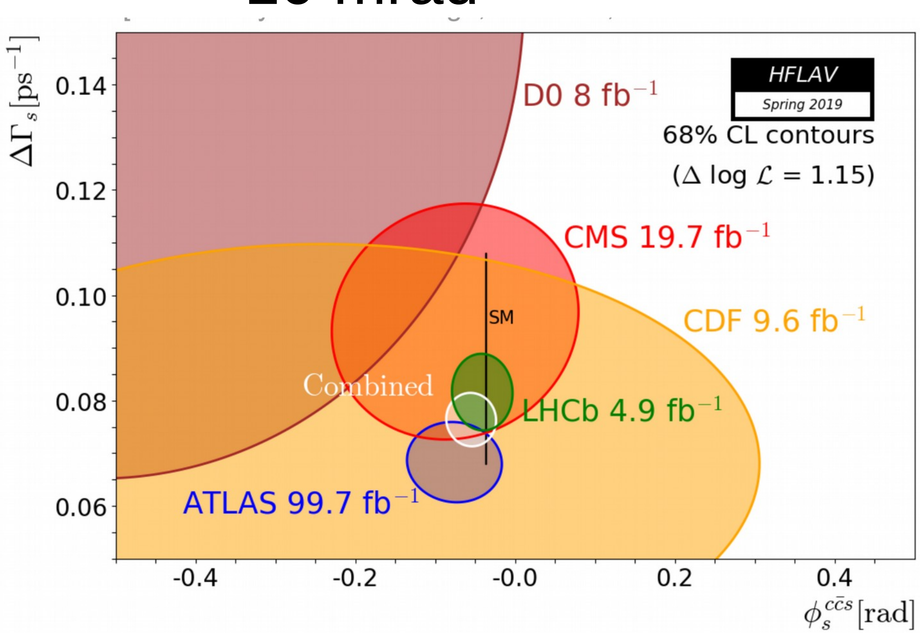
- φ_s stat:
  - better by a factor 9x to 20x
- $\Delta\Gamma_s$ stat:
  - better by a factor 4x to 10x
- With optimistic trigger, total uncertainty on φ_s
  - 8× larger than current theoretical uncertainty
  - 7× smaller than the predicted φ_s value from the SM

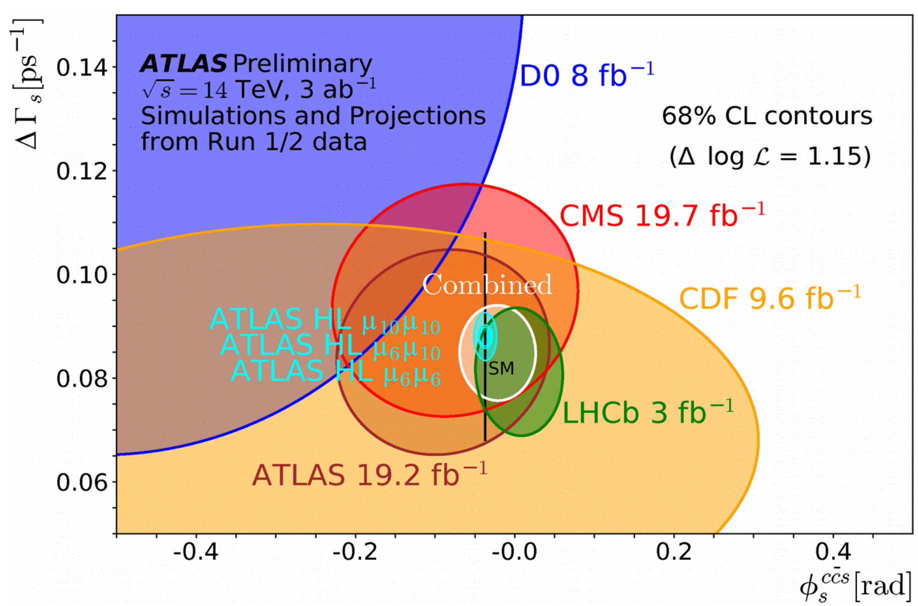


Conclusions

- ATLAS and CMS can be competitive in B physics with the dedicated LHCb experiment:
  - thanks to accumulate statistical samples
  - in conjuction with some detector performance (tracking)
  - perfect example the angular analysis of the golden mode $B_s \rightarrow J/\psi\phi$
    - however will need to consider penguin contribution soon
    - SU(3)-based data-driven estimate from $B_s \rightarrow J/\psi K^*$ ~10 mrad

[Dordei's talk, JHEP 11 (2015) 082]





A thought for our colleague Olga ‘Olya’ Igonkina who sadly passed away on Sunday.
Worked on Argus, Hera-B, BaBar and ATLAS (since 2006)

https://www.nikhef.nl/news/atlas-nikhef-physicist-prof-dr-olga-borisovna-igonkina-passes-away-at-45/

back-up slides

TD angular analysis of $B_s \rightarrow J/\psi\phi$

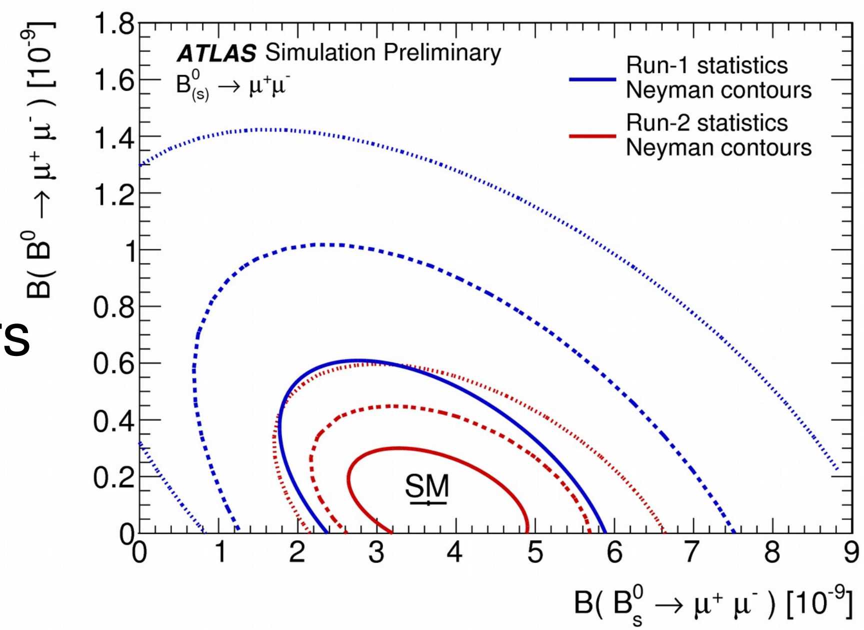
ATL-PHYS-PUB-2018-041

Period	L_{int} [fb^{-1}]	N_{sig}	f_{sig}	Tag Power [%]	$\sigma(\tau)$ [ps]	$\delta^{\text{stat}}_{\phi_s}$ [rad] measured (extrapolated)	$\delta^{\text{stat}}_{\Delta\Gamma_s}$ [ps^{-1}] measured (extrapolated)
2012	14.3	73693	0.20	1.49	0.091	0.082	0.013
2011	4.9	22690	0.17	1.45	0.100	0.25 (0.22)	0.021 (0.023)
						$\delta^{\text{stat}}_{\phi_s}$ [rad] extrapolated	
HL-LHC	3000						
Trigger $\mu6\mu6$		$9.72 \cdot 10^6$	0.17	1.49	0.048	0.004	0.0011
Trigger $\mu10\mu6$		$5.93 \cdot 10^6$	0.17	1.49	0.044	0.005	0.0014
Trigger $\mu10\mu10$		$1.75 \cdot 10^6$	0.15	1.49	0.038	0.009	0.003

Prospect on rare B decays $B_{(s)} \rightarrow \mu^+\mu^-$ at ATLAS

ATL-PHYS-PUB-2018-005

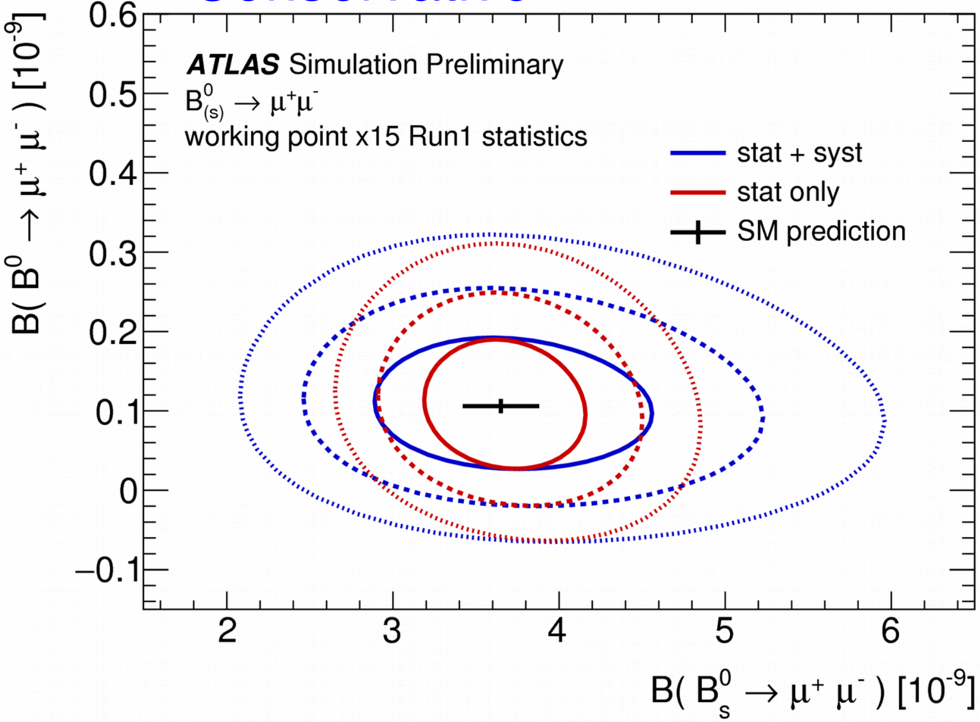
- Full Run 2:
  - assuming 130/fb
  - σ(bb): 8 TeV → 13/14 TeV → x1.7
  - 2MU6||MU6_MU4 topological triggers (6 GeV p_T thresholds)
  - Estimate N(Run 2) ~7 x N(Run 1)



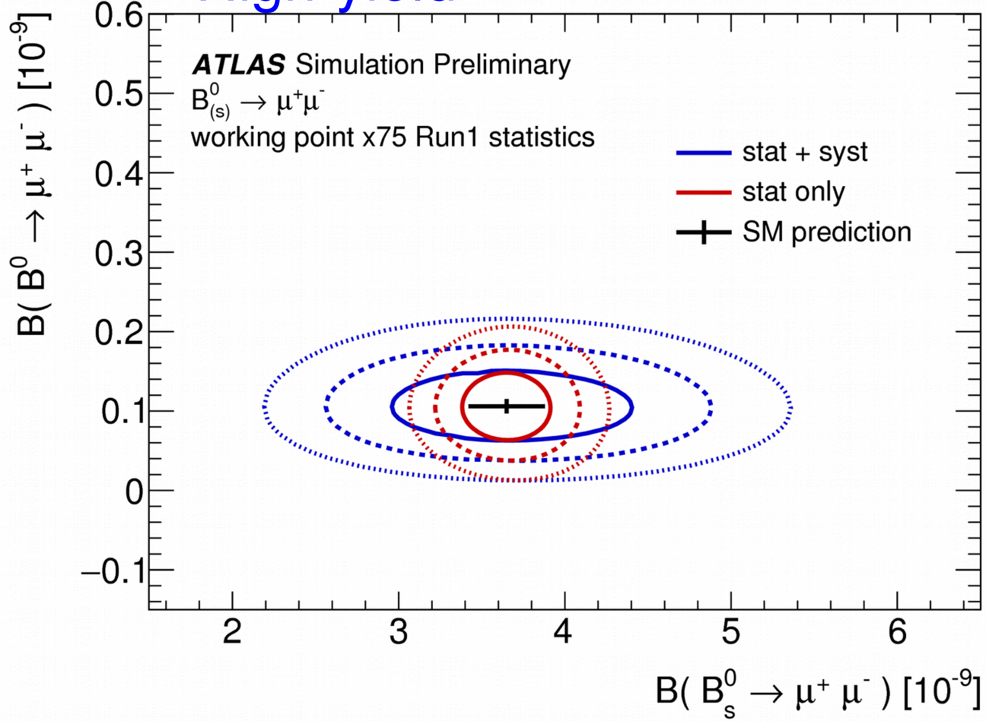
- HL-LHC → 3 trigger scenarios: dimuon transverse momentum thresholds ($p^{\mu 1}_T$, $p^{\mu 2}_T$):
  - Conservative: (10 GeV, 10 GeV) → ×15 Run 1 statistics;
  - Intermediate: (6 GeV, 10 GeV) → ×60 Run 1 statistics;
  - High-yield: (6 GeV, 6 GeV) → ×75 Run 1 statistics.

Prospect on rare B decays $B_{(s)} \to \mu^+\mu^-$ at ATLAS

Conservative



High-yield

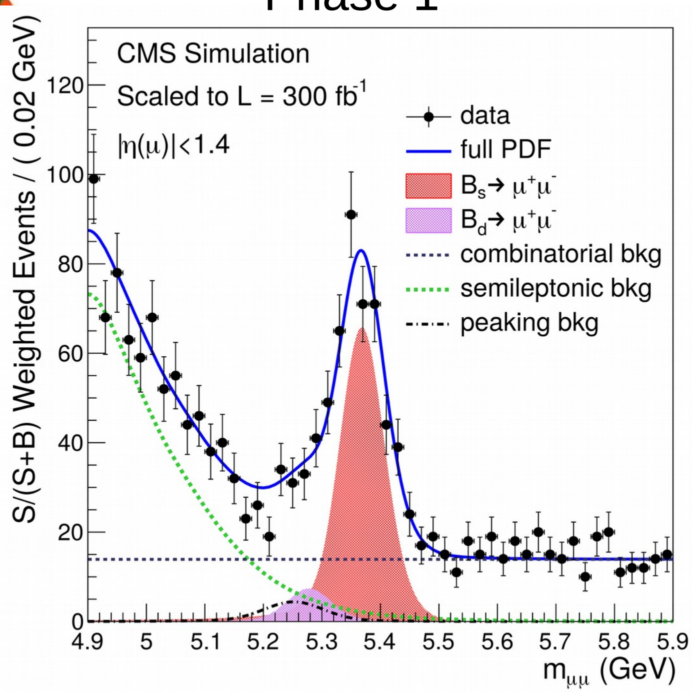


	$\mathcal{B}(B^0_s \to \mu^+\mu^-)$		$\mathcal{B}(B^0 \to \mu^+\mu^-)$	
	stat $[10^{-10}]$	stat + syst $[10^{-10}]$	stat $[10^{-10}]$	stat + syst $[10^{-10}]$
Run 2	7.0	8.3	1.42	1.43
HL-LHC: Conservative	3.2	5.5	0.53	0.54
HL-LHC: Intermediate	1.9	4.7	0.30	0.31
HL-LHC: High-yield	1.8	4.6	0.27	0.28

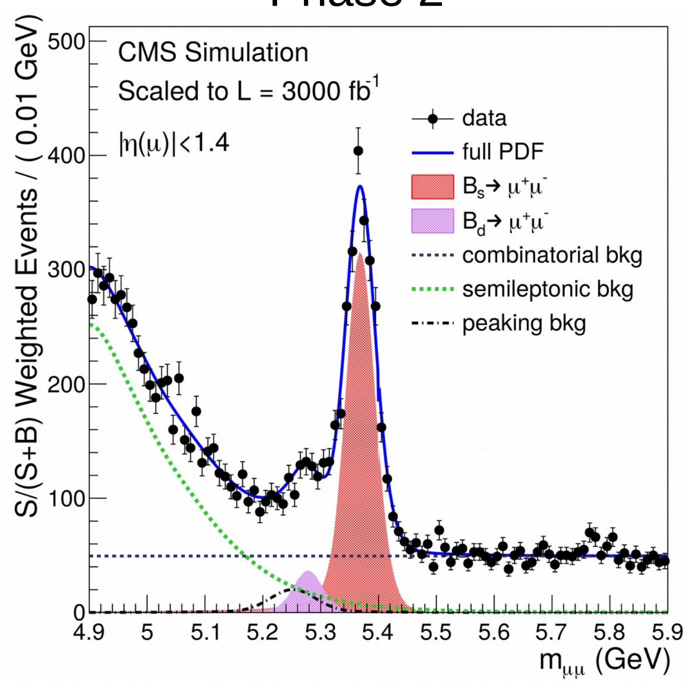
Prospect on rare B decays $B_{(s)} \rightarrow \mu^+\mu^-$ at CMS

FTR-14-015

Phase 1



Phase 2



Phase 2 with improved tracker:

- Improvement in the momentum resolution leads to about 40% gain in mass resolution for $|\eta| < 1.0$.
- about 25 % improvement in mass peak separation

Estimate of analysis sensitivity

$\mathcal{L}$ (fb^{-1})	$N(\mathrm{B}_s^0)$	$N(\mathrm{B}^0)$	$\delta\mathcal{B}(\mathrm{B}_s^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}(\mathrm{B}^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(\mathrm{B}^0\to\mu^+\mu^-)}{\mathcal{B}(\mathrm{B}_s^0\to\mu^+\mu^-)}$
20	18.2	2.2	35%	$>100\%$	$0.0 - 1.5\,\sigma$	$>100\%$
100	159	19	14%	63%	$0.6 - 2.5\,\sigma$	66%
300	478	57	12%	41%	$1.5 - 3.5\,\sigma$	43%
300 (barrel)	346	42	13%	48%	$1.2 - 3.3\,\sigma$	50%
3000 (barrel)	2250	271	11%	18%	$5.6 - 8.0\,\sigma$	21%

Future Prospect for ATLAS and CMS

- General purpose experiments can be competitive on favourable final states
- Dimuon is the quintessence of low-p_T experimental clean signature @LHC
- More statistics will allow to improve these results
- New trigger functionalities (e.g., tracking @L1) will allow to deal with 200 PU
- Detector limitation: experiments designed to do something else, namely cover 10-1000 GeV range
    - going below 10 GeV (e.g., with electrons and muons) requires effort
- Limited trigger bandwidth (general purpose vs. dedicated experiments)
- Needed customisation (reconstruction, trigger, etc.) vs working force (<50 people)
- Muons are the essential handle for flavour physics in ATLAS & CMS
- Electron reconstruction at ATLAS & CMS is about matching a track to >= 1
    - At low pT, the track might not even make it to the calorimeter and, in any case, deposits are very low energetic: difficult to disentangle them from noise, pileup, etc
- Clearly, growing interest in flavour (thanks to LHCb anomalies) is helping here.
- Still, there is much to do in view of HL-LHC

New ideas for data collection

Scouting

- Since 2010, CMS is taking special “scouting” streams:
  - Run reconstruction in trigger farm (muons, jets, ...)
  - Write object features (e.g., four momenta) rather than the full event
  - Few KB traded for 1 MB: can write thousands more
  - Same now by ATLAS (TLA), LHCb (TurboStream + upgrade) and ALICE

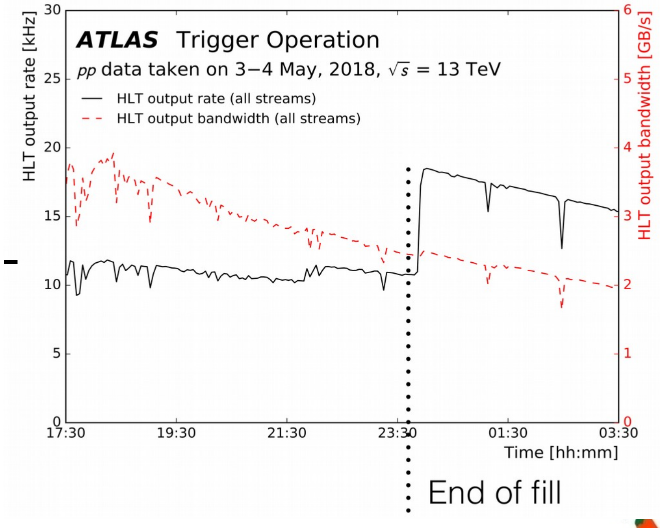
Parking

- Limitation to write 1000 evt/sec is not the trigger itself
- The problem is computing resources downstream → disk & CPU power
- In 2012, both ATLAS&CMS took more data, counting on shutdown computing pledges & opportunistic computing resources to process them
- Extra 300-350 Hz of “parked” data are collected to extend the physics program: standard model measurements and searches for new physics
- The triggers defining the parked datasets are either a looser version of the core physics triggers (for instance with reduced pT thresholds on the reconstructed objects) or brand-new triggers with small overlap with the rest

Data taking in 2018 for ATLAS and CMS

ATLAS data taking in 2018

- After few hours of collisions, L1 rate and HLT processing slots free up thanks to luminosity exponential decay
- High-rate and CPU-intensive triggers can be enabled within the data storage output limitation
- Strategy is used for the Trigger-level Analysis (ATL-DAQ-PUB-2017-003) → total HLT output is only marginally increased by these additional events
- End-of-fill strategy used for triggers for B-physics signals



CMS data taking in 2018

- Smooth running since May: only minor updates to the trigger implemented
- L1 trigger rate → 95 kHz at 2×10^{34} cm^{-2}s^{-1}
  - able to lower L1 thresholds for single Egamma, MET, di-tau to improve HLT turn-on curves
- HLT rate → 1.8 kHz at 2×10^{34} cm^{-2}s^{-1}
  - averages 1.1 kHz over 12h fill
- "parking" an unbiased sample of B mesons
  - so far recorded over 9B events