Electroweak and BSM Searches in B Physics with ATLAS

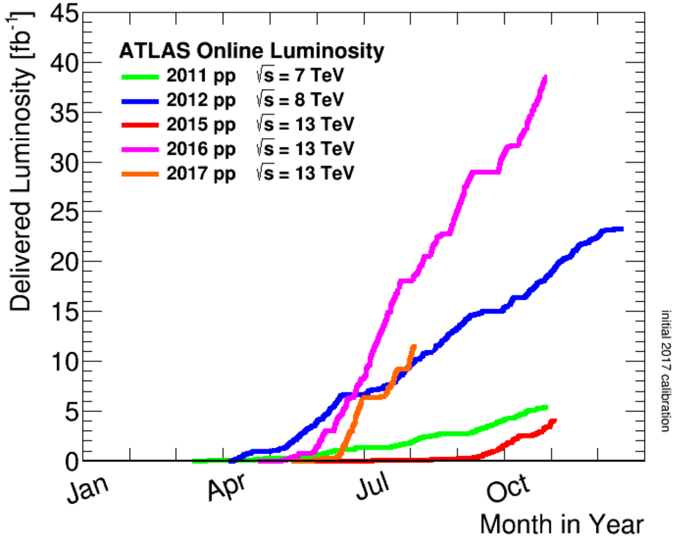
A. CERRI, FOR THE ATLAS COLLABORATION

Outline

- Introduction
- $\Delta\Gamma_d / \Gamma_d$
- $B^0 \to K^*\mu\mu$
- $B_s \to J/\psi\phi$, $B \to \mu\mu$ perspectives
- Conclusions

Introduction

- …I will not lecture you on detector performance, key detector elements, motivations, etc.
- General Purpose Experiments at the LHC are integrating large amounts of integrated luminosity
  - In 2016 alone, ATLAS integrated more than in all previous years combined



- GP Detectors are not fully tuned for flavour physics
  - No PID
  - High pile-up
  - Focus on central production
  - Other compromises (lepton ID threshold, momentum resolution etc.)
- There are however areas where advantage can be gained combining the strengths of the experiment

$\Delta\Gamma_d / \Gamma_d$

MEASUREMENT OF THE RELATIVE WIDTH DIFFERENCE OF THE B0-B0BAR SYSTEM WITH THE ATLAS DETECTOR
ATLAS COLLABORATION (MORAD AABOUD (OUJDA U.) *ET AL.*). MAY 24, 2016. 38 PP.
PUBLISHED IN **JHEP 1606 (2016) 081**

B_d Lifetime Difference

- Experimental sensitivity still below SM predictions

$$\frac{\Delta\Gamma_d}{\Gamma_d}(SM) = (0.42 \pm 0.08)\times 10^{-2} \qquad \frac{\Delta\Gamma_d}{\Gamma_d}(World\ avg.) = (0.1 \pm 1.0)\times 10^{-2}$$

  - New physics could still hide in $\Delta\boldsymbol{\Gamma}_d / \boldsymbol{\Gamma}_d$
  - Increased precision and complementing measurement methods important

- ATLAS measurement: $\mathcal{L} = 25.2\ \mathrm{fb}^{-1}, \sqrt{s} = 7, 8\ \mathrm{TeV}$
  - Decay rates difference for light/heavy eigenstates shows $\Delta\boldsymbol{\Gamma}_d / \boldsymbol{\Gamma}_d$ dependency
  - Measured through relative ratio of B_d decays to $J/\psi K_s$ vs $J/\psi K^*(892)$

Method

- Time dependence of B→f decay rate:

$$\Gamma[f,t] \propto e^{-\Gamma_q t}\left[\cosh\frac{\Delta\Gamma_q t}{2} + A_{\mathrm{P}}A_{\mathrm{CP}}^{\mathrm{dir}}\cos(\Delta m_q t) + A_{\Delta\Gamma}\sinh\frac{\Delta\Gamma_q t}{2} + A_{\mathrm{P}}A_{\mathrm{CP}}^{\mathrm{mix}}\sin(\Delta m_q t)\right]$$

A_{P} is the particle/anti-particle production asymmetry

$A_{\mathrm{CP}}^{\mathrm{dir}}$, $A_{\Delta\Gamma}$, and $A_{\mathrm{CP}}^{\mathrm{mix}}$ are well defined for CP/flavour eigenstates

- Base measurement on comparison of B_d→J/ψK_s vs B_d→ J/ψK*(892):
  - **J/ψK_s**: $A_{CP}^{dir} = 0,\ A_{\Delta\Gamma} = \cos 2\beta\,, A_{CP}^{mix} = -\sin 2\beta$ (CP-specific)
  - **J/ψK*(892)**: $A_{CP}^{dir} = 1,\ \ A_{\Delta\Gamma} = 0,\ \ A_{CP}^{mix} = 0$ (flavour-specific)

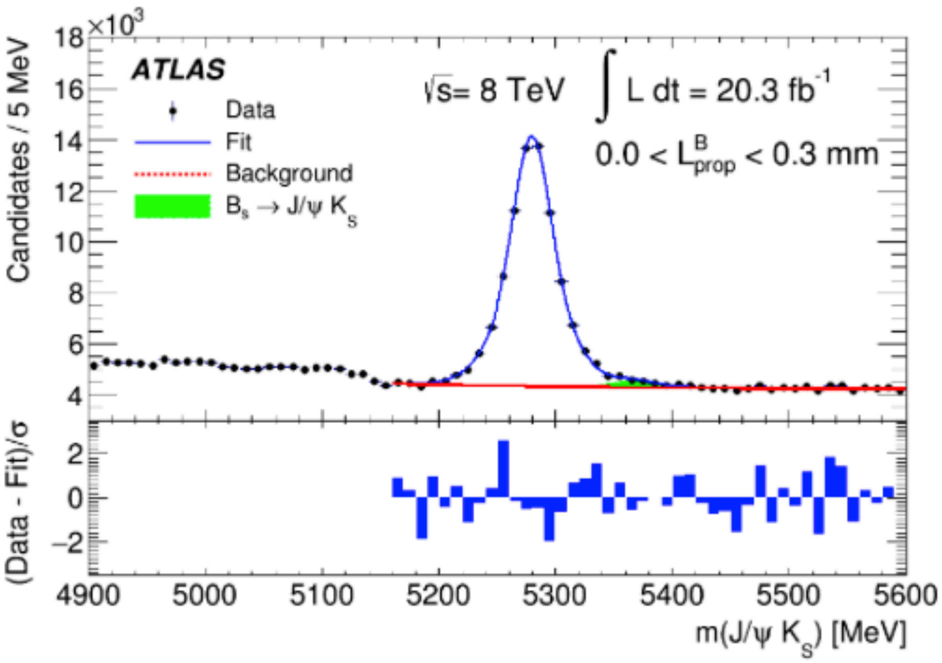
- Fit the ratio of CP/flavour eigenstates to determine ΔΓ:

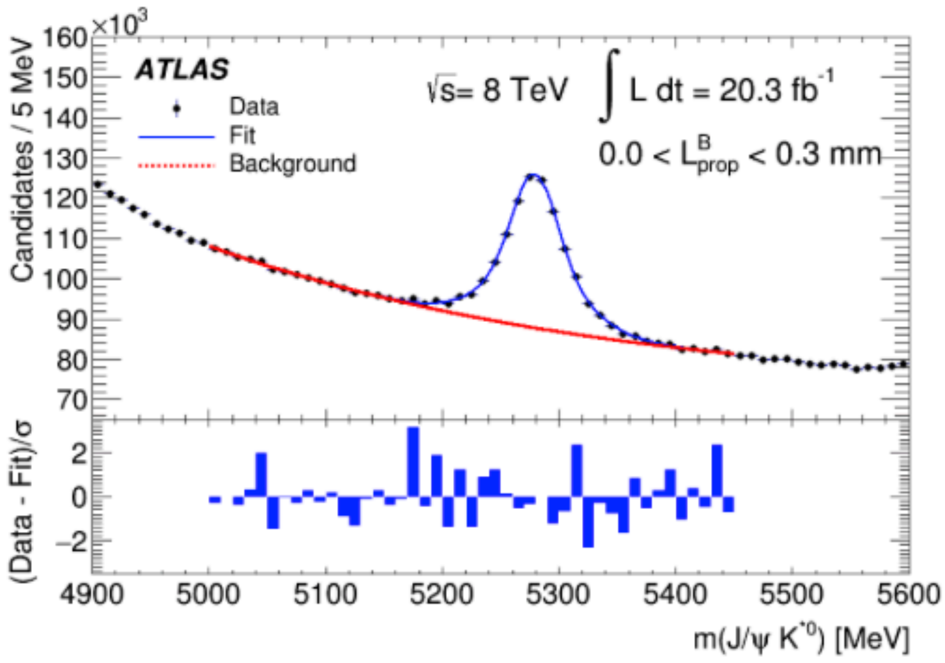
$$\frac{\Gamma[\psi K_s,t]}{\Gamma[\psi K^*,t]} = \frac{\cosh\frac{\Delta\Gamma_{\mathrm{d}}t}{2} + \cos 2\beta \sinh\frac{\Delta\Gamma_{\mathrm{d}}t}{2} - A_p \sin\Delta m_d t}{\cosh\frac{\Delta\Gamma_{\mathrm{d}}t}{2} + A_p\cos\Delta m_d t}$$

- Can determine $\Delta\Gamma_{\mathrm{d}}$ and A_p from data

Extracting Binned Signal Yields

- Signal counts are determined in bins of proper decay length
  - Use 10 bins between -0.3mm and 0.6mm
  - Yields determined through mass fits
  - Per-bin detector acceptance taken into account





Determination of A_p

- Production asymmetry derived from observed time-dependent asymmetry of $J/\psi K^*(892)$ candidates (omitting CP violating mixing terms):

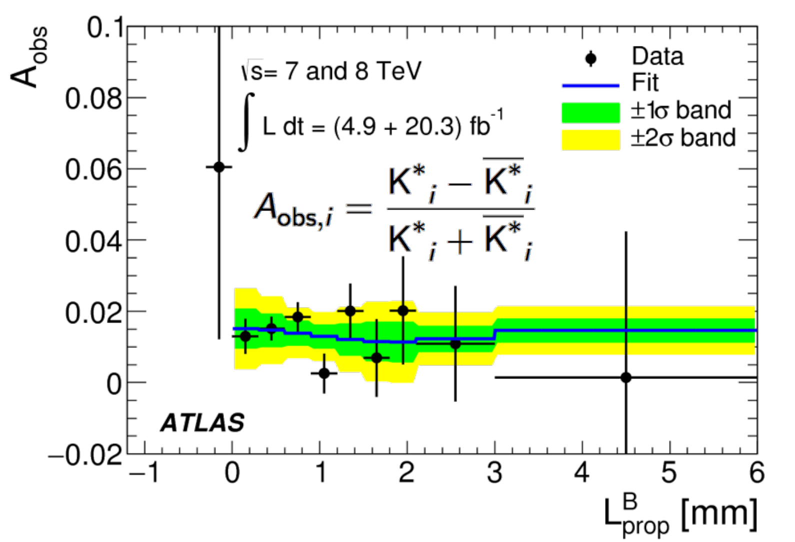
$$\Gamma[t, B/\bar{B} \to J\psi K^*] = e^{-\Gamma_d t}[\cosh \frac{\Delta\Gamma_d t}{2} \pm A_p \cos \Delta m t]$$

- ct bins are fitted with predicted A_{exp}, accounting for detector effects (mostly tracking asymmetry for charged K):

K-π mis-id
W~0.12

$$A_{\mathrm{exp},i} = (A_{\mathrm{det}} + A_{\mathrm{osc},i})(1 - 2W)$$

- $\chi^2 = 6.50$, d.o.f $= 7$
- $A_{det} = (1.33 \pm 0.24 \pm 0.30) \times 10^{-2}$
  - Checked against MC
- $A_p = (0.25 \pm 0.48 \pm 0.05) \times 10^{-2}$



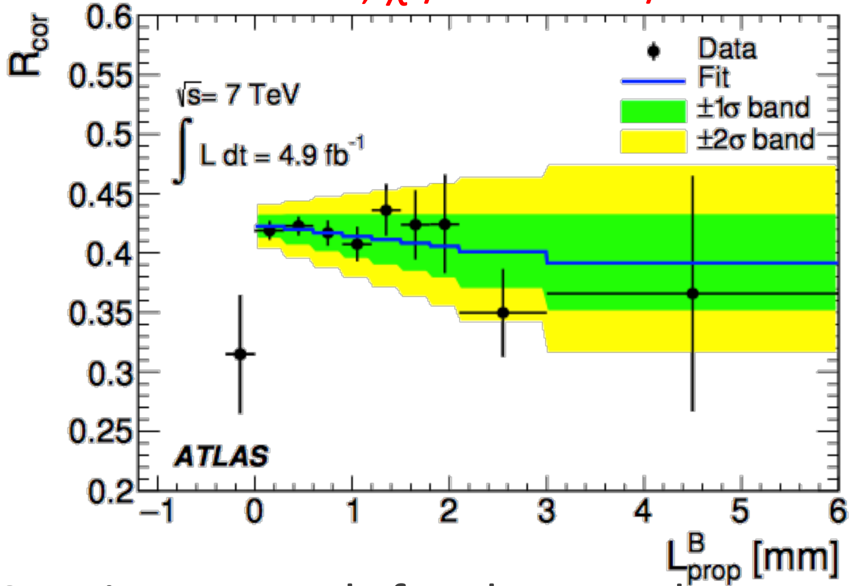
- Systematics driven by mis-tag fraction uncertainties and $|q/p|=1$ assumption
- Consistent with LHCb measurement

First LHC measurement of production asymmetry in central region

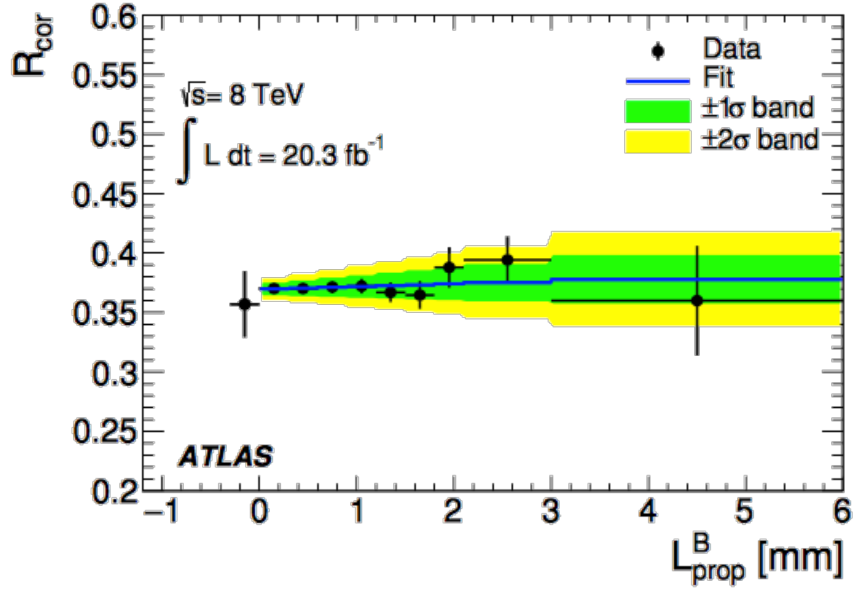
Determination of $\Delta\Gamma_d$

- Extract ct-dependent yields for K* and K_s decays
- Fit ct-dependency leaving $\Delta\Gamma_d/\Gamma_d$ as the only free parameter

2011 Data, χ^2/NDF=4.34/7



2012 Data, χ^2/NDF=2.81/7



- Consistent result for the two datasets

$$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1(\text{stat.}) \pm 0.9(\text{syst.})) \times 10^{-2}$$

- Currently the most precise single measurement available on the market!

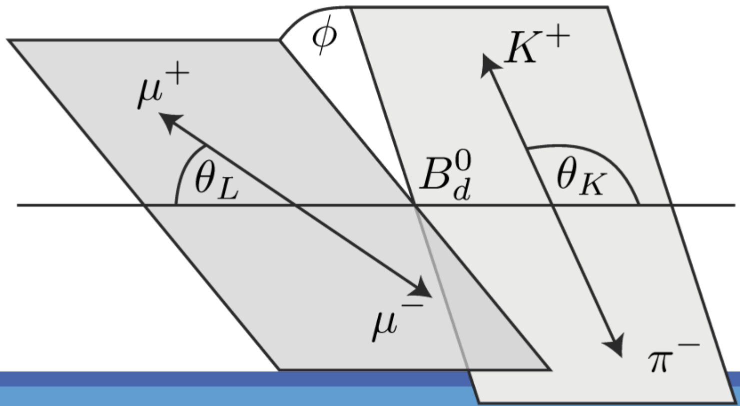
[LHCB: $\Delta\Gamma_d/\Gamma_d = (-4.4 \pm 2.5(\text{stat.}) \pm 1.1(\text{syst.})) \times 10^{-2}$]

$B^0 \rightarrow K^*\mu\mu$

NEW PRELIMINARY RESULT: ATLAS-CONF-2017-023

Motivation

- FCNC process, forbidden at LO
  - Box and penguin contributions dominate
  - NP processes may contribute to decay amplitudes
- Known tension between experiment and some theoretical models in P'5 (arXiv 1512.04442)
- New preliminary result from ATLAS
  - Data from 2012 collisions @8 TeV E_{CM}, analysing 20.3 fb^{-1} of 1,2,3-μ triggers
  - Measured 6 overlapping bins of q^2: [0.04,6] GeV^2
  - Differential decay amplitude analysis to extract coefficients sensitive to NP
  - Fit performed in three angles: θ_L, θ_K, Φ



Angular Analysis

- Differential decay amplitude:

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_L\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_\ell$$
$$-F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$
$$+S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big].$$

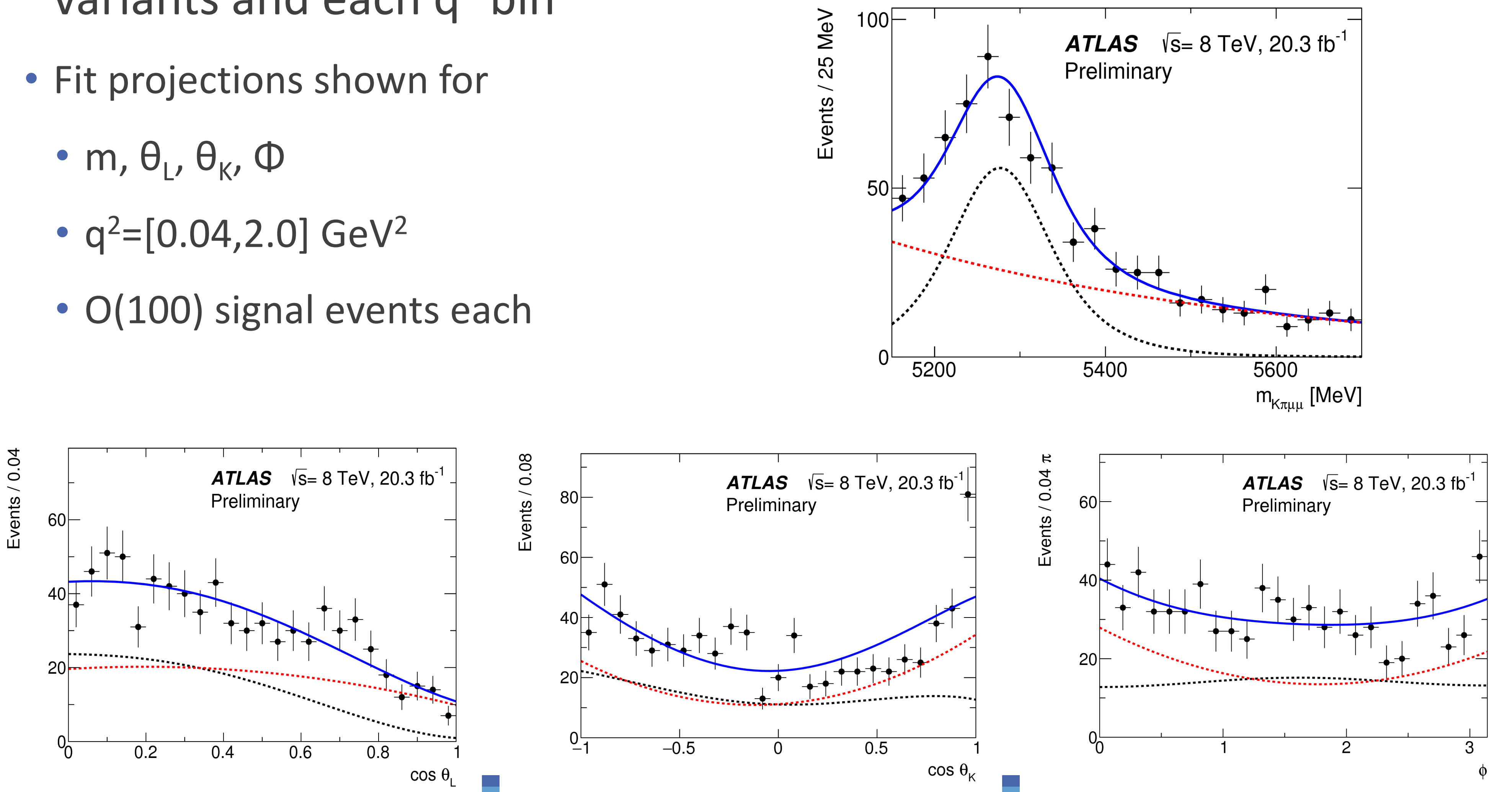
- Si suffers from significant theory uncertainties, cancelled at leading order through:

$$P_1 = \frac{2S_3}{1-F_L} \quad P_2 = \frac{2}{3}\frac{A_{FB}}{1-F_L} \quad P_3 = -\frac{S_9}{1-F_L} \quad P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}.$$

- Exploiting symmetries of trigonometric functions we reduce the parameters extraction to: **F_L, P_1, $P'_{4,5,6,8}$**

Angular Analysis: fits

- Extended un-binned maximum likelihood fits to each of the fit variants and each q^2 bin
- Fit projections shown for
  - m, θ_L, θ_K, Φ
  - q^2=[0.04,2.0] GeV^2
  - O(100) signal events each



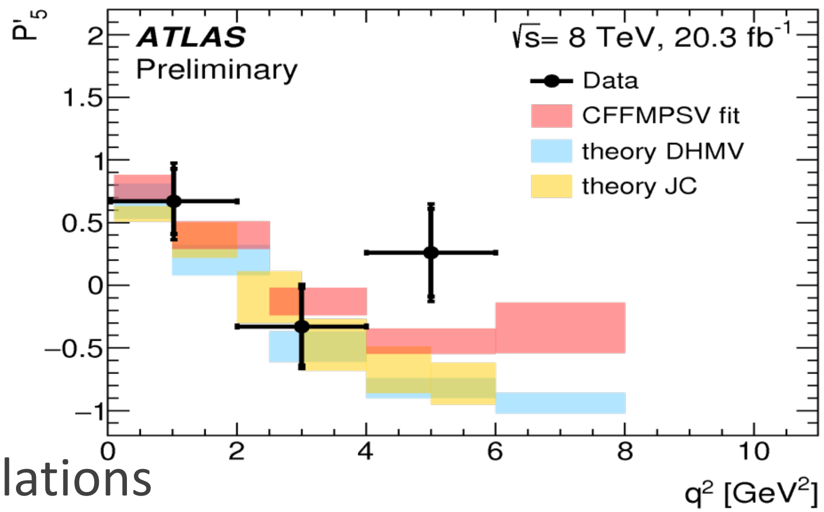
Uncertainties

- Results are statistics-limited
  - Control channels [J/ψK* and ψ(2s)K*] used to extract nuisance parameters for signal PDF (mass, per-candidate mass resolution…)
- Dominant sources of systematic uncertainties:
  - Fake (Kπ) backgrounds (e.g. at high cos θ_K~1 contributions from $B^+ \to K/\pi\mu\mu X$ and fake K*)
  - Partially reconstructed $B \to D \to X$ decays around |cos θ_L|~0.7
  - Other combinatorial and peaking background sources (e.g. Λ_b decays model added/removed in fit)
  - Alignment and B-field calibrations
  - Possible S-wave contributions (~5%, included as systematics)
  - Examples:
    - F_L larges systematics from cos θ_K and cos θ_L backgrounds: 0.11
    - S_i systematics also from background uncertainties: 0.01-0.13

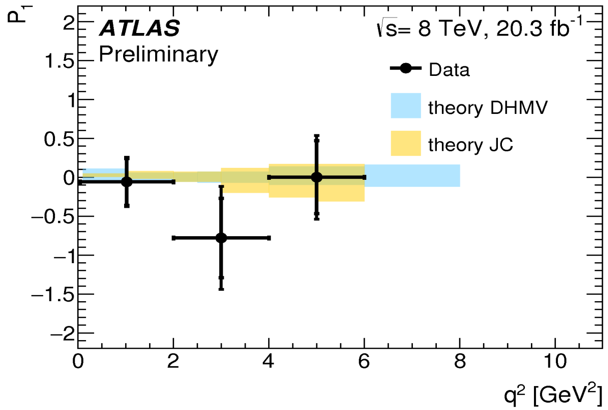
Comparison With Theory

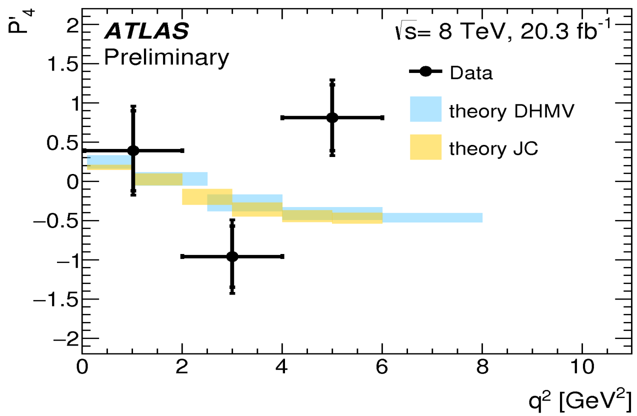
CFFMPSV: Ciuchini et al.; JHEP **06** (2016) 116; **arXiv:1611.04338.**
DMVH: Decotes-Genon et al.; JHEP **01** (2013) 048; JHEP **05** (2013) 137; JHEP **12** (2014) 125.
JC: Jäger-Camalich; JHEP **05** (2013) 043; Phys. Rev. **D93** (2016) 014028.

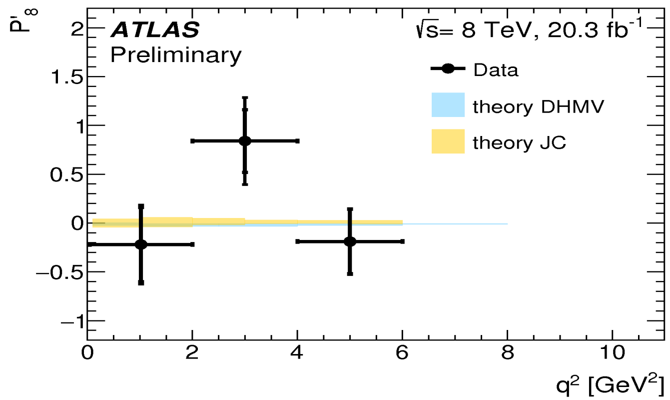
- OPE fits to LHCb data (CFFMPSV) (separate plots in back-up)
- Factorisation QCD computation (DHMV)
- Jäger-Camalich
- …more in back-up



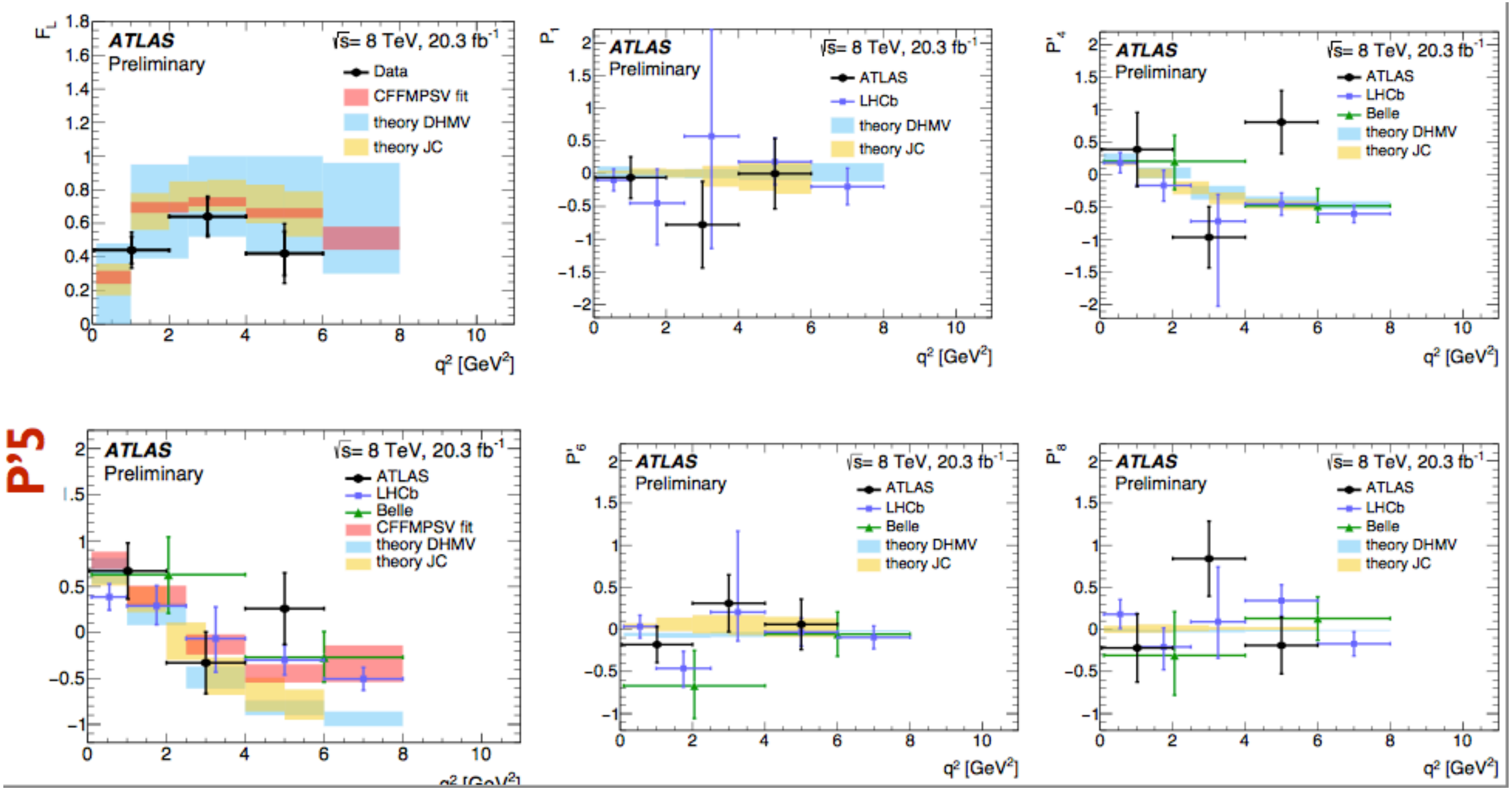
- Bottomline: compatible with theoretical calculations







Comparison With Other Experiments



All P' are in general compatible with theory and other experimental determinations

$B_s \rightarrow J/\psi\phi$, $B \rightarrow \mu\mu$ status & perspectives

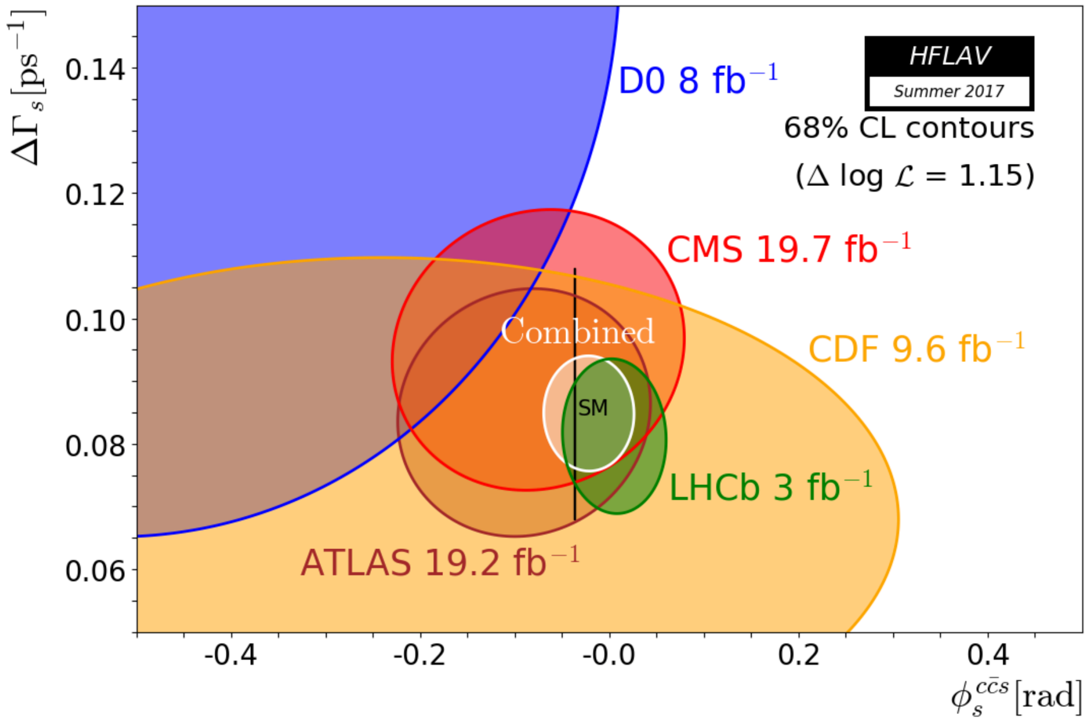
JHEP 1608 (2016) 147 AND EUR. PHYS. J. C 76 (2016) 513

J/ψϕ

Parameter	Value	Statistical uncertainty	Systematic uncertainty
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
$\lvert A_{\parallel}(0)\rvert^2$	0.227	0.004	0.006
$\lvert A_0(0)\rvert^2$	0.514	0.004	0.003
$\lvert A_S(0)\rvert^2$	0.071	0.007	0.017
$\delta_{\perp}$	4.13	0.33	0.16
$\delta_{\parallel}$	3.15	0.13	0.05
$\delta_{\perp} - \delta_S$	−0.08	0.04	0.01

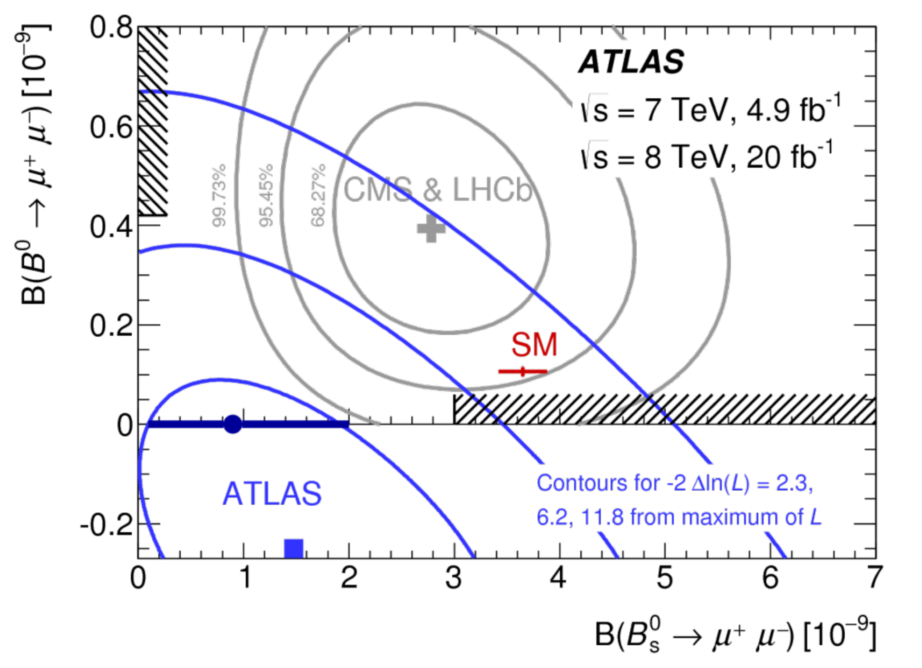
- Time-dependent angular analysis
  - BLUE method used to combine 2011/2012 results
  - Combination is statistically limited
  - Precision determined by ct resolution

- No new result approved yet
- Run 2 dataset collection continues with comparable efficiency
- Expect extrapolation to scale essentially with luminosity
- Ct resolution improvement from IBL in run 2 will improve effective tagging dilution by x4



μμ

- Latest result available based on full Run 1 statistics
- Projected uncertainties comparable to CMS
  - “under-flluctuation” on signal yield negatively affects contours/limits
  - Breakdown of differences in terms of mass resolution vs statistical methods well understood
  - Working in improved statistical extraction
- Analysis group plan:
  - First iteration of the analysis based on 2015 dataset
  - Second result will be based on full Run 2 dataset



- Result is statistically limited: expect sensitivity to essentially scale with statistics
- Topological triggers exploited in Run II to maintain signal data taking efficiency

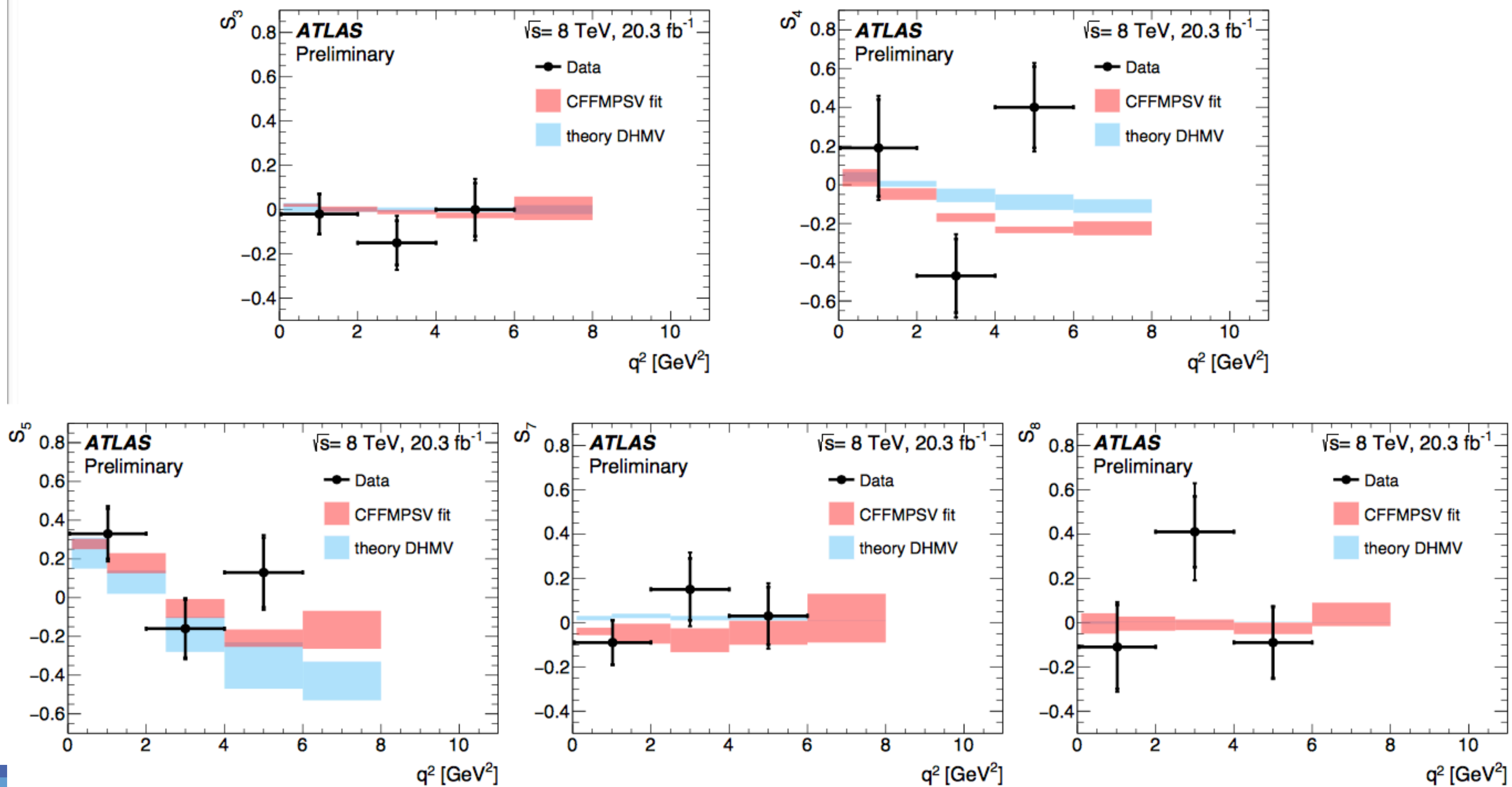
Conclusions

- Wide ranging programme of NP investigations with Beauty ATLAS
- Precision measurements of decay rate parameters $\Delta\Gamma_d$
  - Most precise single-experiment measurement available on the market
  - further constraining possibilities for NP
- Recently published results by ATLAS on the angular analysis of the $B_d \rightarrow K^*\mu\mu$
  - All P' parameters compatible with the theoretical predictions and the other experiments
  - Measurements are all statistically limited
- Most analyses now engaged with Run 2 datasets
- All results discussed are statistics-limited: very encouraging perspectives with Run 2 datasets
  - Crucial use of topological triggers and partial event building to maintain low trigger thresholds in the high pile-up regime

Backup

Comparison With Theory for K*μμ

- S_i coefficients compared to:
  - Operator Product Expansion (OPE) (fits to LHCb data) (CFFMPSV)
  - Factorisation QCD computation (DHMV)



Comparison With exp. for K*μμ

- Comparable to other experiments and theory, with ~3σ largest deviation in single bin.
  - w.r.t. DHMV; P'$_5$ shows similar trend to LHCb in [4,6] GeV^2, at ~2.7σ.

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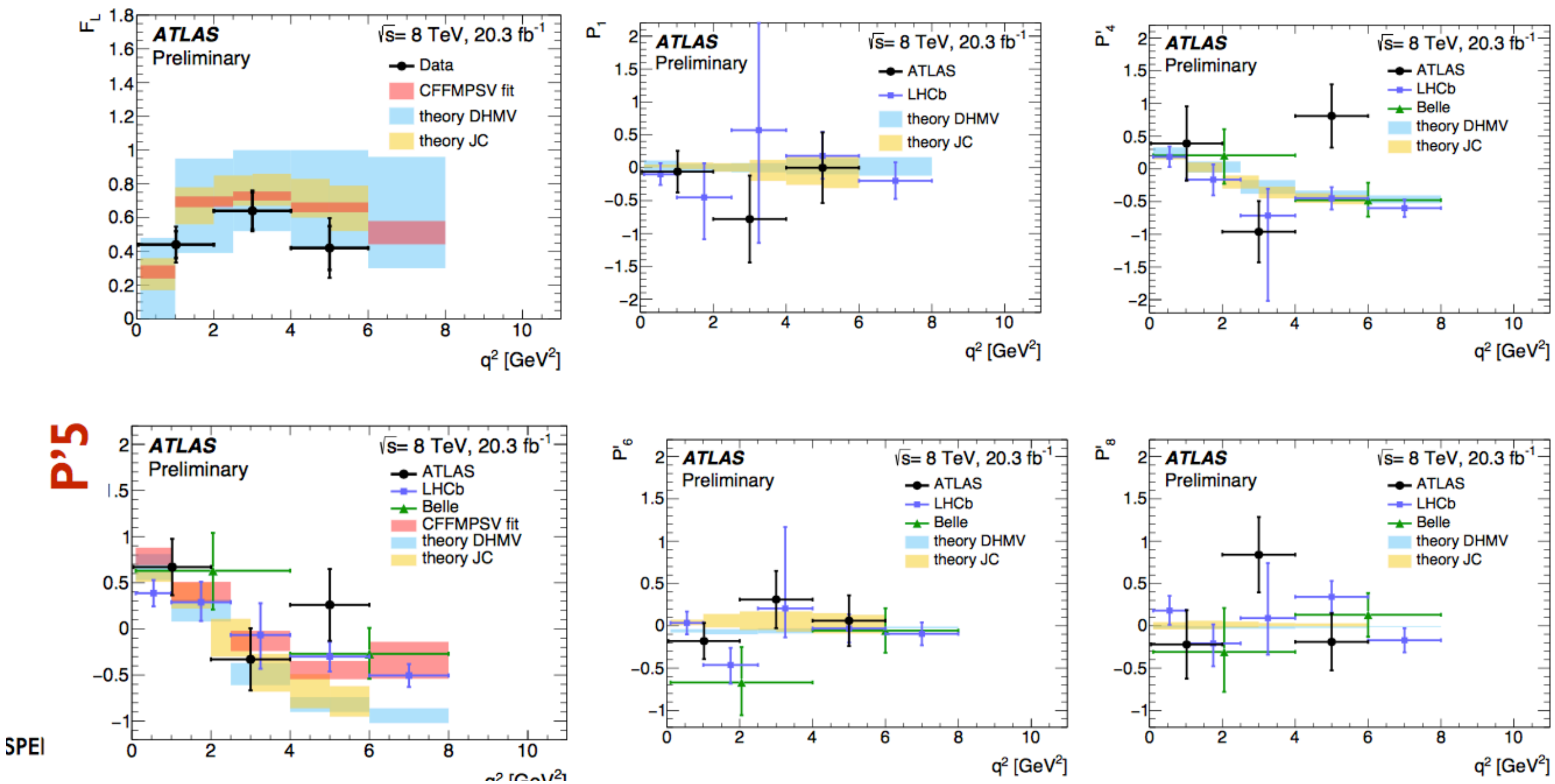

K*μμ Event Yields

q^2 [GeV^2]	n_{signal}	$n_{\text{background}}$
[0.04, 2.0]	128 ± 22	122 ± 22
[2.0, 4.0]	106 ± 23	113 ± 23
[4.0, 6.0]	114 ± 24	204 ± 26
[0.04, 4.0]	236 ± 31	233 ± 32
[1.1, 6.0]	275 ± 35	363 ± 36
[0.04, 6.0]	342 ± 39	445 ± 40