***Adrian Bevan**, on behalf of the ATLAS and CMS Collaborations*

This talk contains a selection of recent results from the general purpose detectors

Electroweak HF physics at ATLAS and CMS with 13 TeV data

Moriond
Electroweak 2017

ATLAS EXPERIMENT

Queen Mary
University of London

CMS
Compact Muon Solenoid

Outline

- Some recent highlights of the General Purpose Detector heavy flavour programme are shown here:
  - Angular analysis results on $B_d \rightarrow K^* \mu^+ \mu^-$ (from ATLAS*).
  - Total and differential $\sigma(B^+)$ at 13 TeV;
  - CP violation in b decays using top quark pairs;
  - Measurement of Λ_b polarisation for $\Lambda_b \rightarrow \Lambda(p\pi^-)J/\psi(\mu^+\mu^-)$.
- See the following pages for a comprehensive listing of results:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH#CMS_B_Physics_Results

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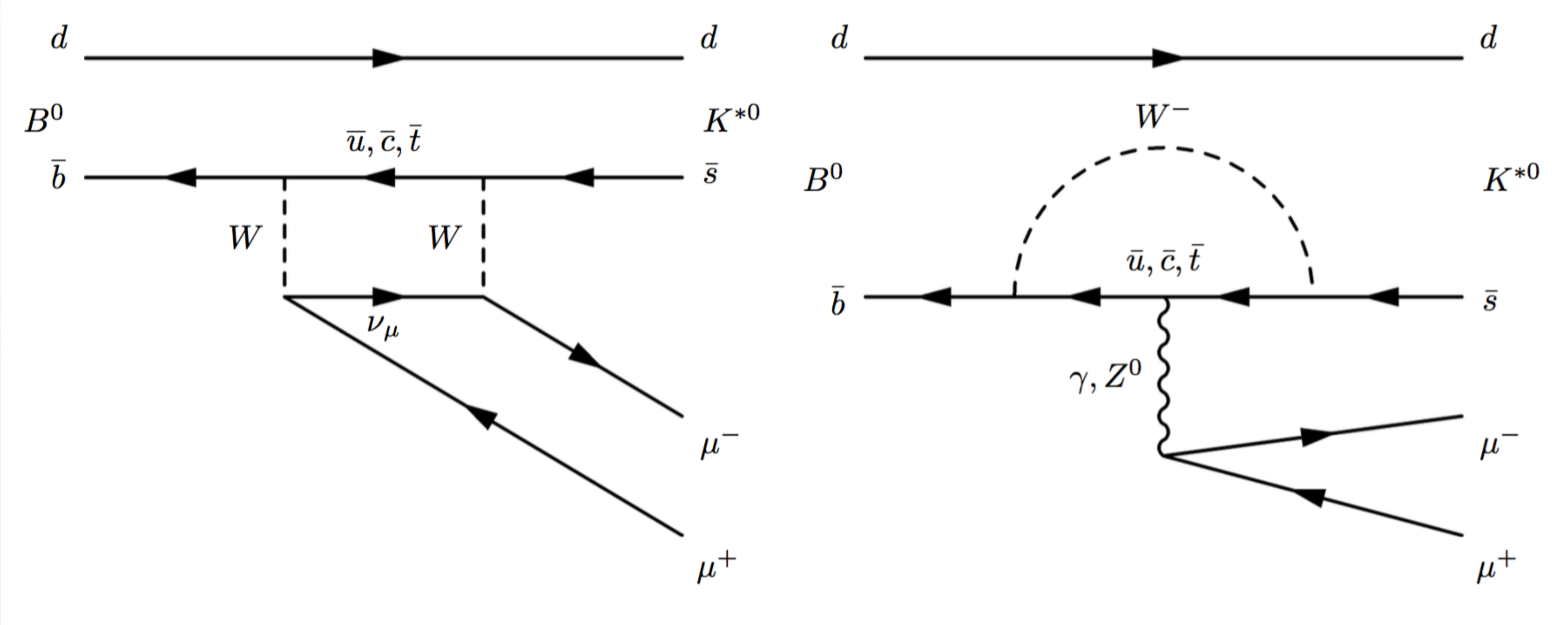
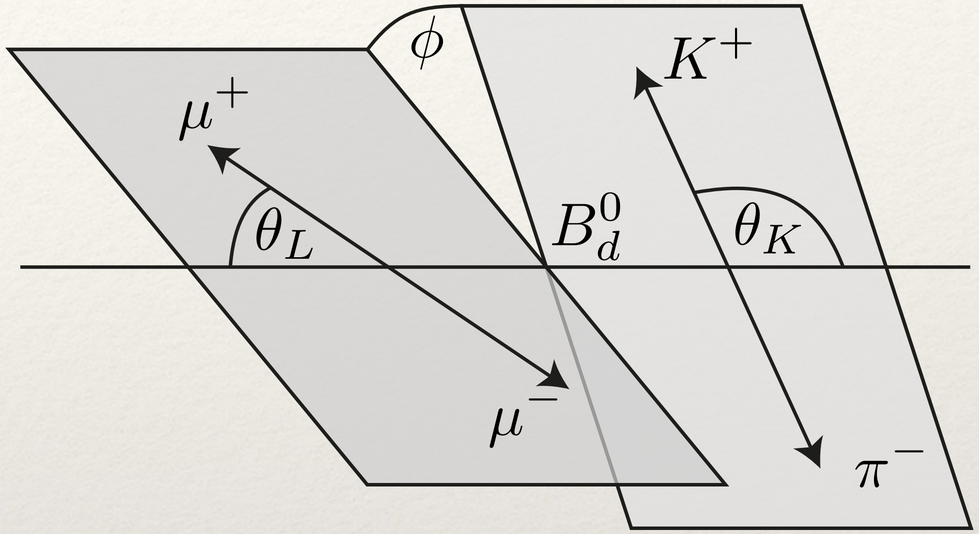
* See the next talk from CMS for the most recent update from that experiment and the backup slides for the CMS 2015 result.

Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Flavour Changing Neutral Current Decay: sensitive to New Physics.





- Several ways to represent the amplitudes of these decays;
  - CMS reported results using a “traditional” basis of parameters.
  - ATLAS report results using the “new” basis (a la Belle/LHCb).
  - Angular distribution is analysed in finite bins of the di-muon invariant mass squared (q^2) as a function of θ_L, θ_K and ϕ.
- LHCb report a 3.4σ deviation from the Standard Model (SM) in their paper.

Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- The angular distribution is given by:

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi}\Bigg[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_\ell$$

$$-F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$

$$+S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell$$

$$+S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi$$

$$+S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Bigg]. \qquad (4)$$

- ATLAS use trigonometric relations to reduce the problem into 4 sets of fits for three parameters (F_L, S_3 and S_i) for each q^2 bin.
- The S parameters are translated into $P^{(\prime)}$ parameter via

$$P_1 = \frac{2S_3}{1-F_L} \qquad P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

- The $P^{(\prime)}$s are theoretically cleaner parameters.

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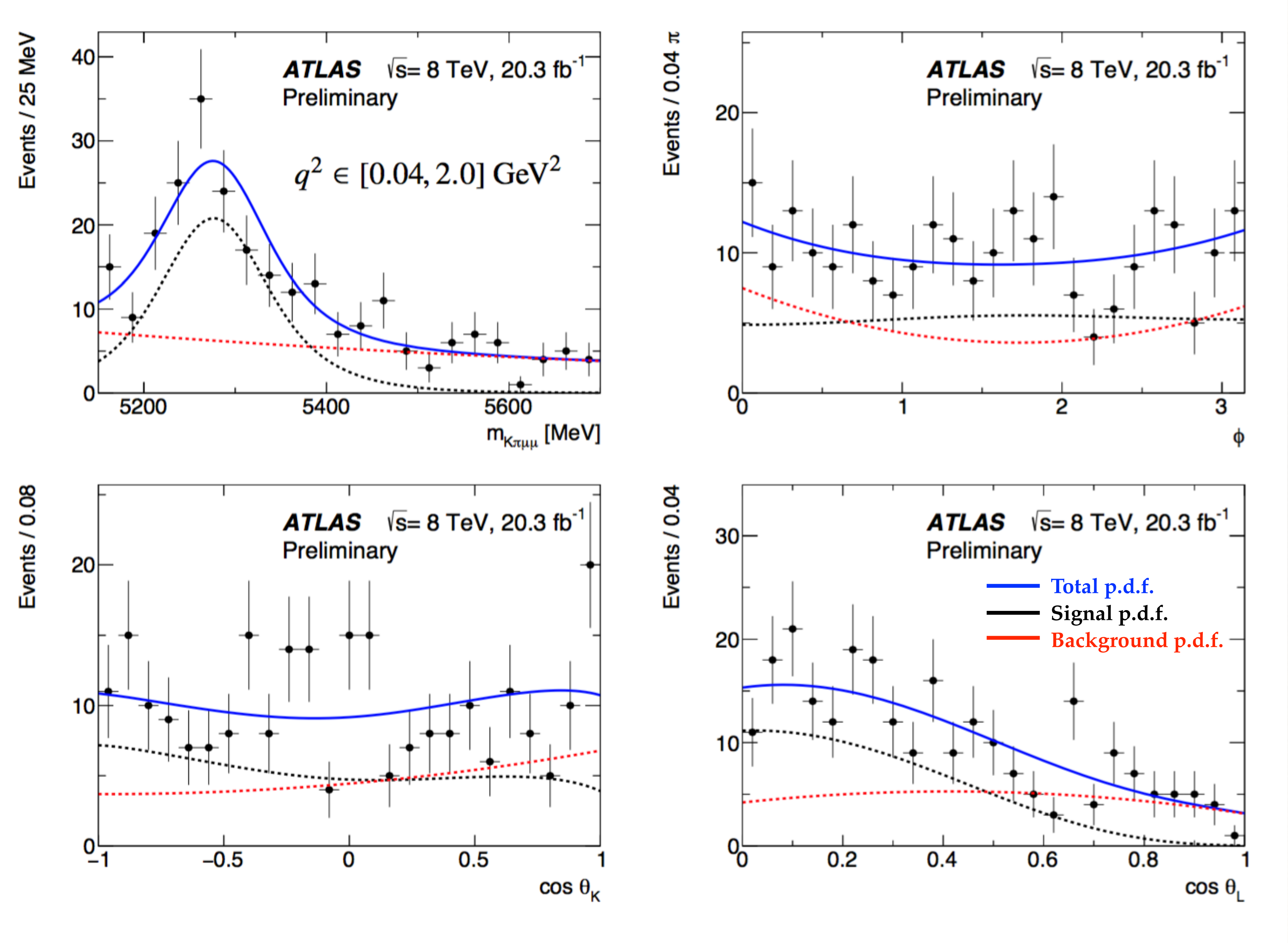
Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Fit $m_{K\pi\mu\mu}$, $\cos\theta_L$, $\cos\theta_K$ and ϕ to isolate signal and extract parameters of interest.

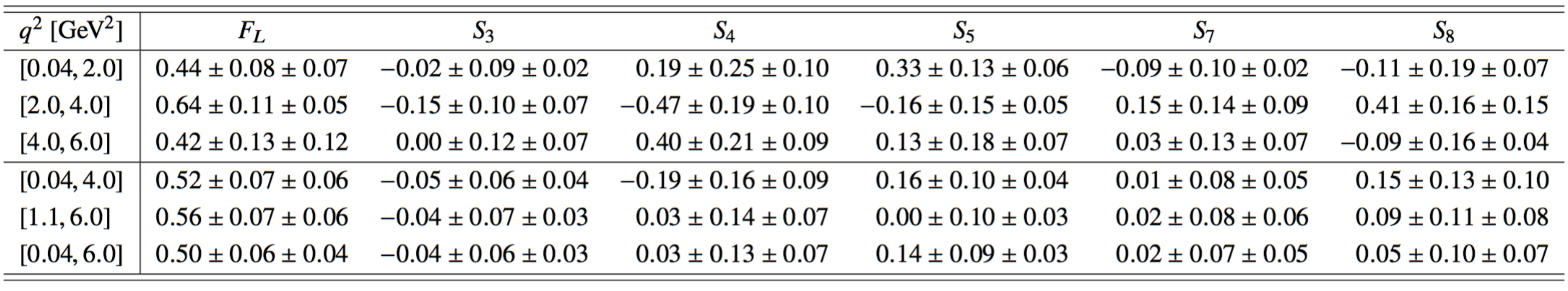


- 20.3 fb^{-1} of 8 TeV pp collision data.
- Analyse q^2 in [0.04, 6.0].
- Data shown for [0.04, 2.0] with fit projections for the S_4 fit.
- Approx 106-128 signal events / 2 GeV^2 q^2 bin.
- Similar results obtained for the other q^2 bins and other fit variants.

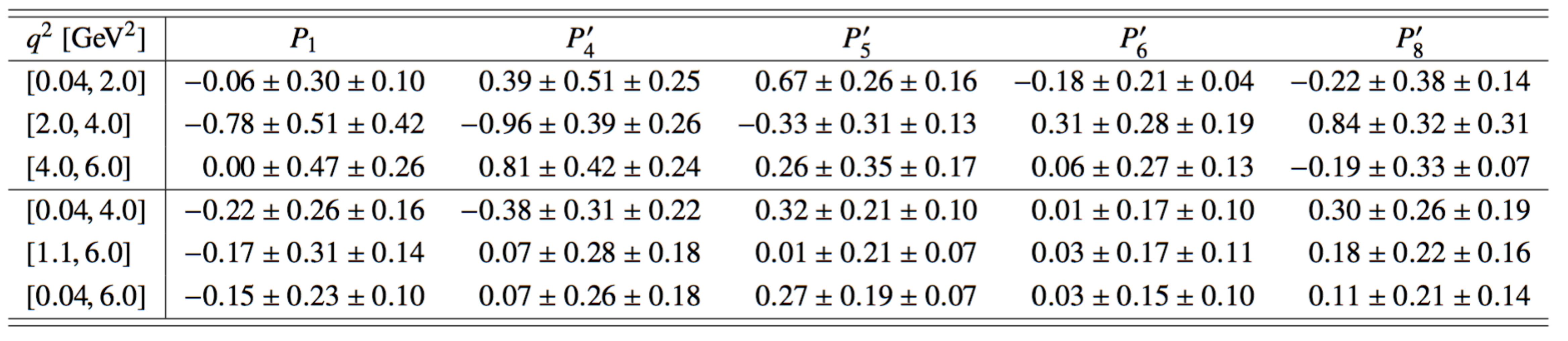
ATLAS-CONF-2017-023

Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Results obtained are generally statistics limited:



q^2 [GeV^2]	F_L	S_3	S_4	S_5	S_7	S_8
[0.04, 2.0]	$0.44 \pm 0.08 \pm 0.07$	$-0.02 \pm 0.09 \pm 0.02$	$0.19 \pm 0.25 \pm 0.10$	$0.33 \pm 0.13 \pm 0.06$	$-0.09 \pm 0.10 \pm 0.02$	$-0.11 \pm 0.19 \pm 0.07$
[2.0, 4.0]	$0.64 \pm 0.11 \pm 0.05$	$-0.15 \pm 0.10 \pm 0.07$	$-0.47 \pm 0.19 \pm 0.10$	$-0.16 \pm 0.15 \pm 0.05$	$0.15 \pm 0.14 \pm 0.09$	$0.41 \pm 0.16 \pm 0.15$
[4.0, 6.0]	$0.42 \pm 0.13 \pm 0.12$	$0.00 \pm 0.12 \pm 0.07$	$0.40 \pm 0.21 \pm 0.09$	$0.13 \pm 0.18 \pm 0.07$	$0.03 \pm 0.13 \pm 0.07$	$-0.09 \pm 0.16 \pm 0.04$
[0.04, 4.0]	$0.52 \pm 0.07 \pm 0.06$	$-0.05 \pm 0.06 \pm 0.04$	$-0.19 \pm 0.16 \pm 0.09$	$0.16 \pm 0.10 \pm 0.04$	$0.01 \pm 0.08 \pm 0.05$	$0.15 \pm 0.13 \pm 0.10$
[1.1, 6.0]	$0.56 \pm 0.07 \pm 0.06$	$-0.04 \pm 0.07 \pm 0.03$	$0.03 \pm 0.14 \pm 0.07$	$0.00 \pm 0.10 \pm 0.03$	$0.02 \pm 0.08 \pm 0.06$	$0.09 \pm 0.11 \pm 0.08$
[0.04, 6.0]	$0.50 \pm 0.06 \pm 0.04$	$-0.04 \pm 0.06 \pm 0.03$	$0.03 \pm 0.13 \pm 0.07$	$0.14 \pm 0.09 \pm 0.03$	$0.02 \pm 0.07 \pm 0.05$	$0.05 \pm 0.10 \pm 0.07$



q^2 [GeV^2]	P_1	P_4'	P_5'	P_6'	P_8'
[0.04, 2.0]	$-0.06 \pm 0.30 \pm 0.10$	$0.39 \pm 0.51 \pm 0.25$	$0.67 \pm 0.26 \pm 0.16$	$-0.18 \pm 0.21 \pm 0.04$	$-0.22 \pm 0.38 \pm 0.14$
[2.0, 4.0]	$-0.78 \pm 0.51 \pm 0.42$	$-0.96 \pm 0.39 \pm 0.26$	$-0.33 \pm 0.31 \pm 0.13$	$0.31 \pm 0.28 \pm 0.19$	$0.84 \pm 0.32 \pm 0.31$
[4.0, 6.0]	$0.00 \pm 0.47 \pm 0.26$	$0.81 \pm 0.42 \pm 0.24$	$0.26 \pm 0.35 \pm 0.17$	$0.06 \pm 0.27 \pm 0.13$	$-0.19 \pm 0.33 \pm 0.07$
[0.04, 4.0]	$-0.22 \pm 0.26 \pm 0.16$	$-0.38 \pm 0.31 \pm 0.22$	$0.32 \pm 0.21 \pm 0.10$	$0.01 \pm 0.17 \pm 0.10$	$0.30 \pm 0.26 \pm 0.19$
[1.1, 6.0]	$-0.17 \pm 0.31 \pm 0.14$	$0.07 \pm 0.28 \pm 0.18$	$0.01 \pm 0.21 \pm 0.07$	$0.03 \pm 0.17 \pm 0.11$	$0.18 \pm 0.22 \pm 0.16$
[0.04, 6.0]	$-0.15 \pm 0.23 \pm 0.10$	$0.07 \pm 0.26 \pm 0.18$	$0.27 \pm 0.19 \pm 0.07$	$0.03 \pm 0.15 \pm 0.10$	$0.11 \pm 0.21 \pm 0.14$

- Main systematic uncertainties come from treatment of backgrounds: partially reconstructed decays with charm and combinatoric $K\pi$ (fake K*).
- S-wave contributions result in a small systematic error.

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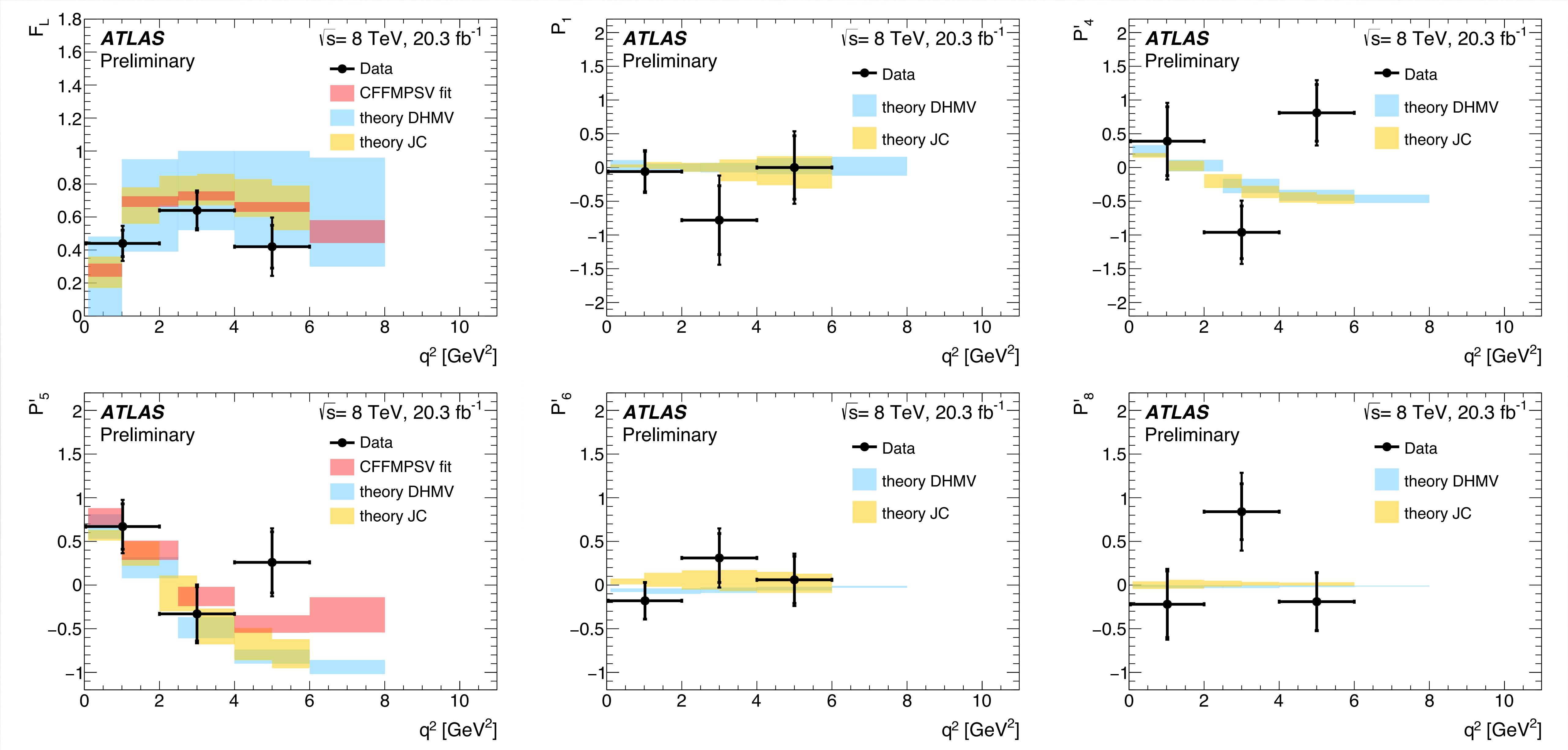
Angular analysis results on $B_d \rightarrow K^* \mu^+ \mu^-$

- Results are compatible with theoretical calculations & fits:



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.

ATLAS-CONF-2017-023

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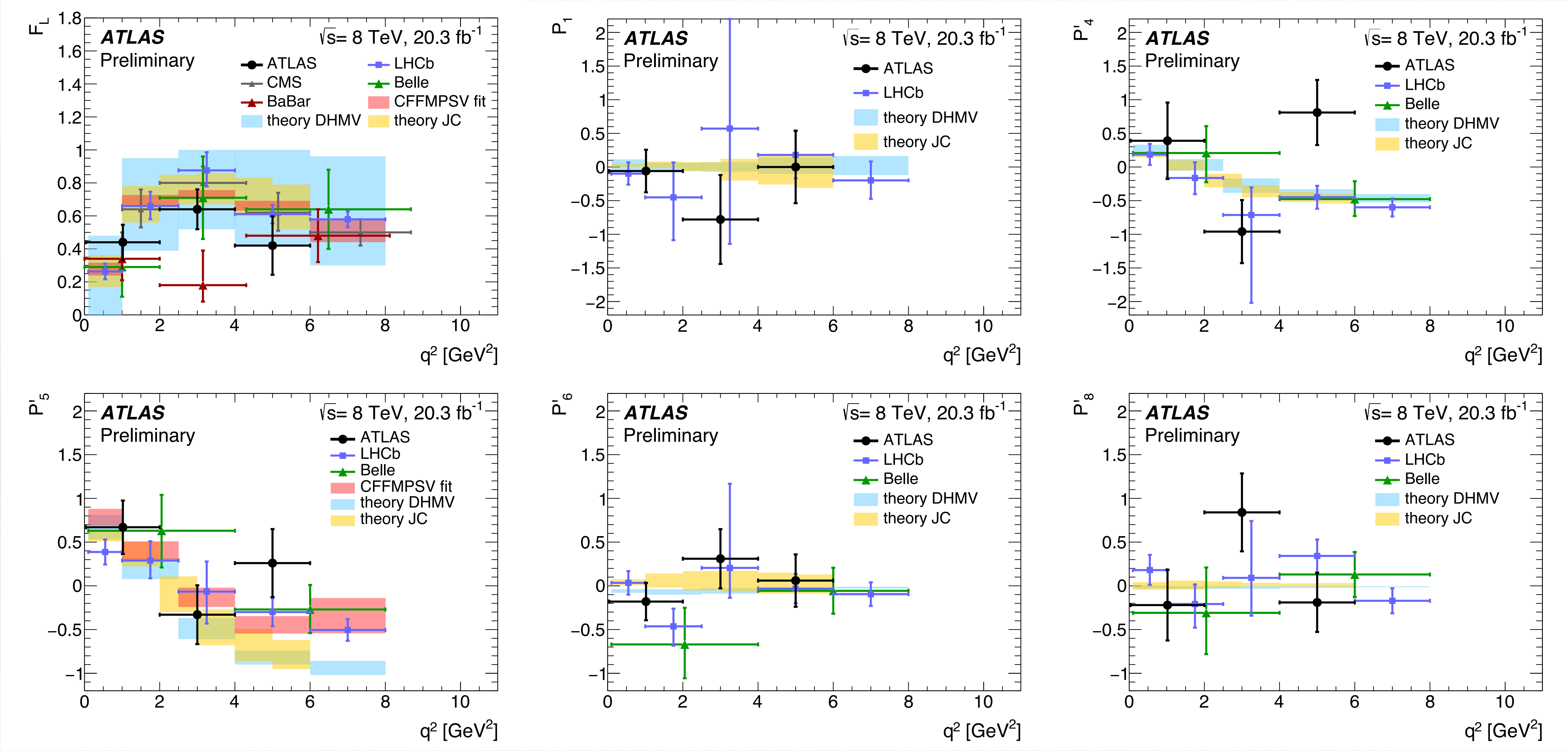

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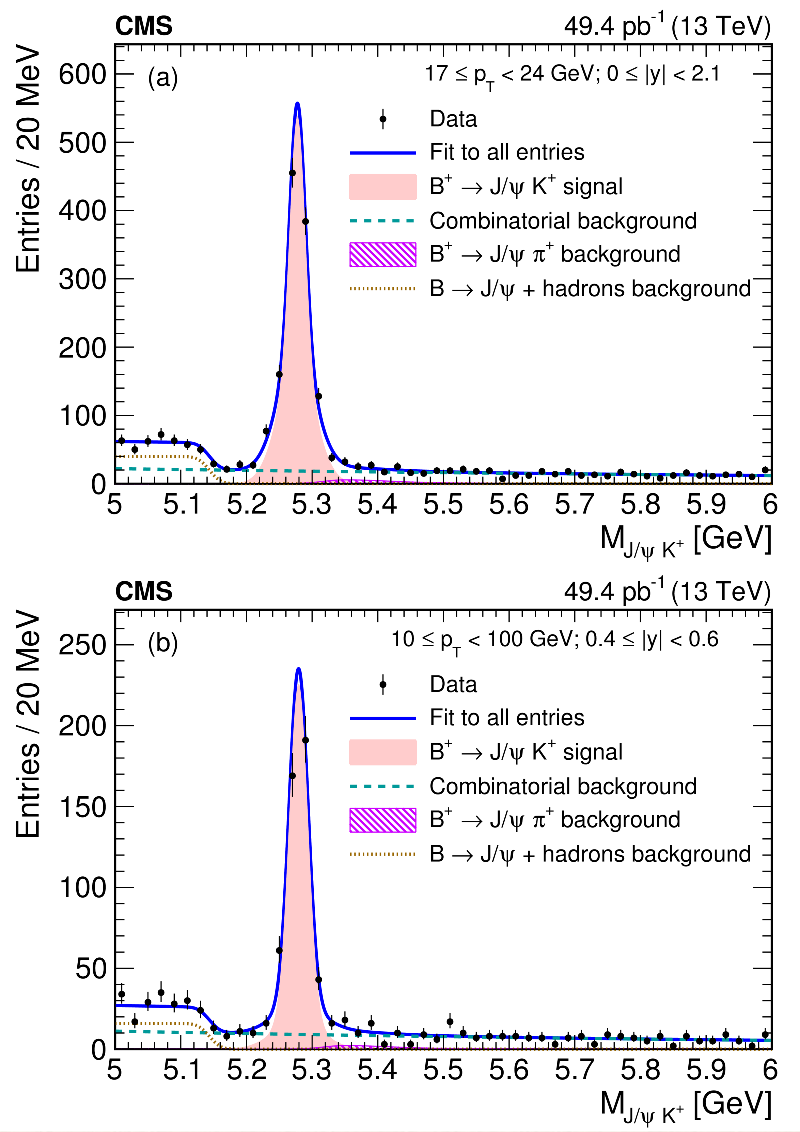
JC: Jäger-Camalich; JHEP **05** (2013) 043; Phys. Rev. **D93** (2016) 014028.

Total and differential σ(B^{+}) at 13 TeV

- Test of QCD; comparison with Pythia and FONLL calculations.
- Uses $49.4\,\mathrm{fb}^{-1}$ 13TeV pp collision data.
- Based on $pp \to B^{+}X \to J/\psi K^{+}X$, where $J/\psi \to \mu^{+}\mu^{-}$.



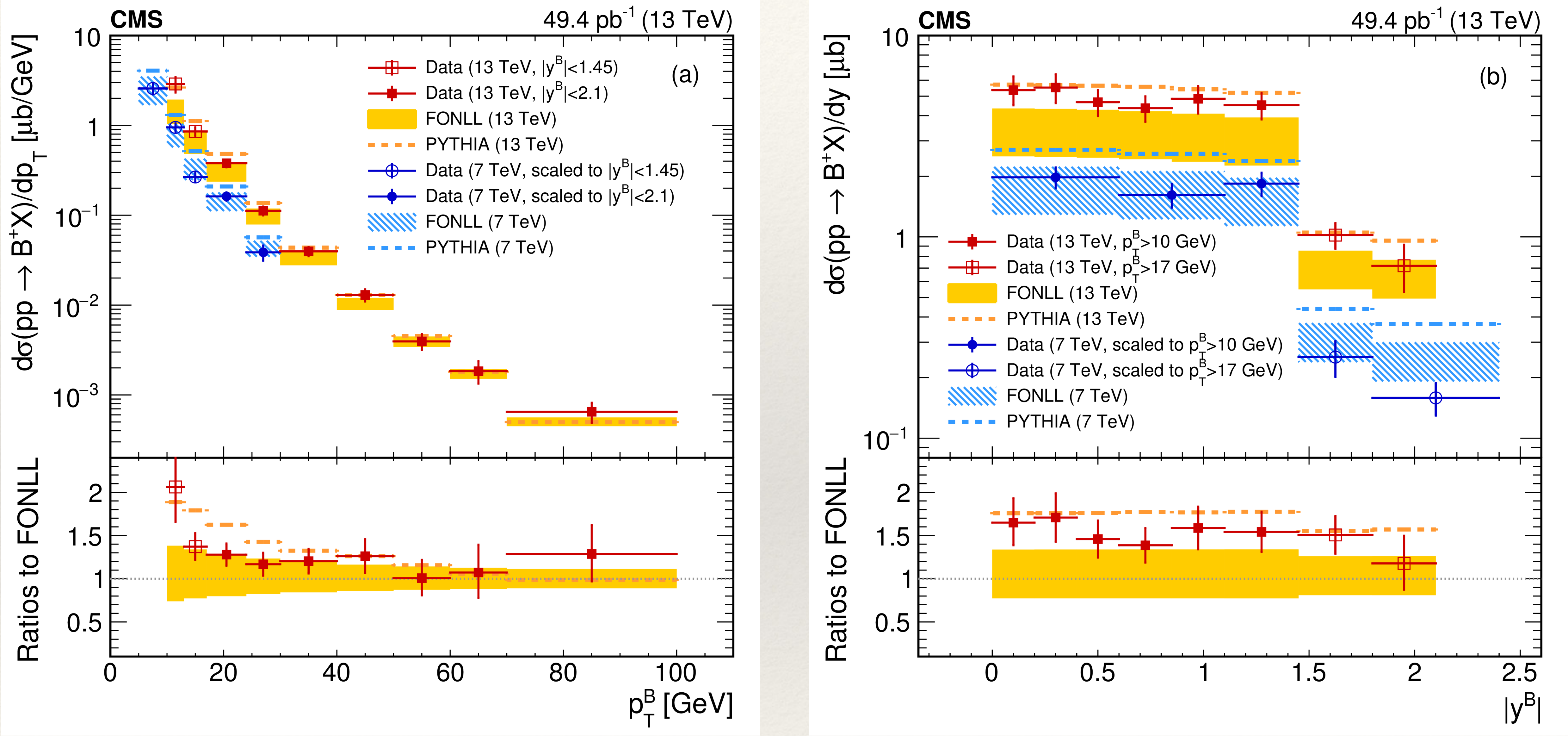
- Systematic uncertainties dominated by likelihood fit model, B^{+} kinematic distribution and estimation of μ identification and reconstruction.

Systematic sources	Relative uncertainties (%)
Muon trigger, identification, and reconstruction	6.0–13.7
Detector alignment	2.8
B^{+} vertex reconstruction	1.4
Size of simulated samples	0.5–3.9
Track reconstruction efficiency	3.9
$B^{+} \to J/\psi(\to \mu^{+}\mu^{-})K^{+}$ branching fraction	3.1
Model in likelihood fits	1.0–6.4
Bin-to-bin migration	0.4–3.7
B^{+} kinematic distributions	0.4–10.6
Parton distribution functions	0.1–0.7
B^{+} lifetime	0.3
Total (excluding the integrated luminosity)	9.1–15.6
Integrated luminosity	2.7

arXiv:1609.00873 (submitted to PLB)

Total and differential $\sigma(B^{+})$ at 13 TeV

- Agreement between data and Pythia / FONNL Monte Carlo.



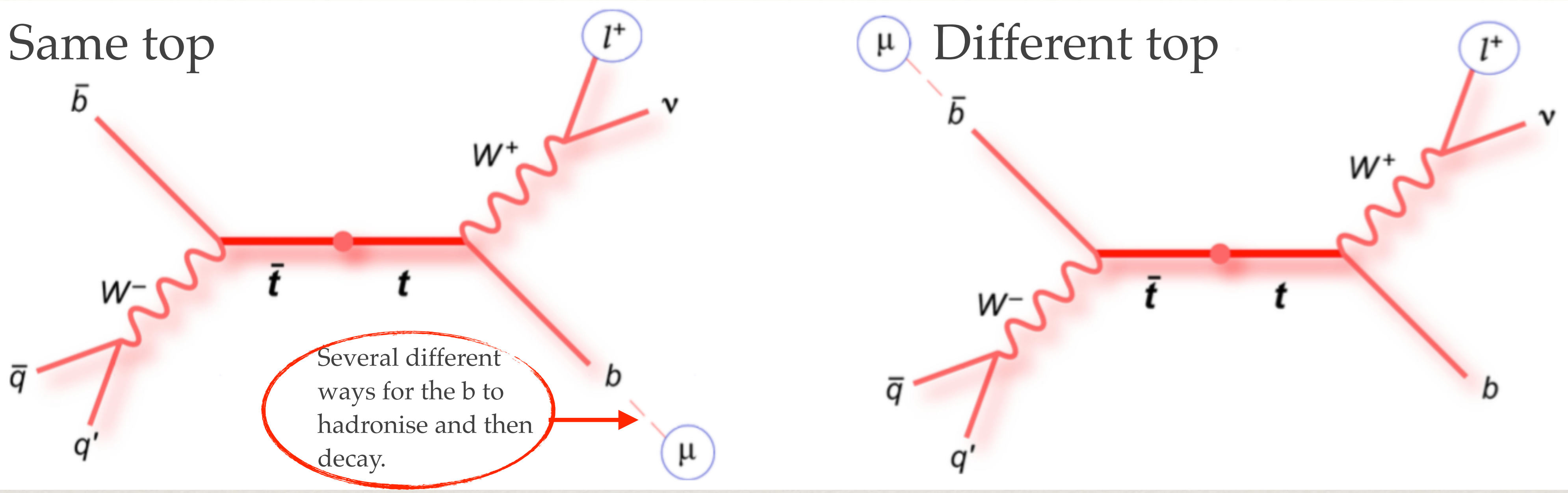
- Inclusive result: $\sigma = (14.9 \pm 0.4[\text{stat.}] \pm 0.2[\text{syst.}] \pm 0.4[\text{lumi.}])\mu\text{b}$
- c.f. FONLL: $\sigma = (9.9^{+3.3}_{-2.2})\mu\text{b}$ and Pythia: $\sigma = 17.2\mu\text{b}$.

arXiv:1609.00873 (submitted to PLB)

Analysis follows the procedure outlined by O. Gedalia et al., Phys. Rev. Lett. 110 (2013) 232002.

CP violation in *b* decays using top quark pairs

- 20.3 fb^{-1} of 8TeV data (*pp* collisions)



Several different ways for the b to hadronise and then decay.

- Measure same and opposite sign lepton pairs to compute mixing and direct CP asymmetries from observed N^{++}, N^{--}, N^{+-} and N^{-+} rates:

$$N^{ij} = N^{q_\mu q_W}$$

- Mistag probability is 21%:

	N_j^{++}	N_j^{--}	N_j^{+-}	N_j^{-+}
N_i^{++}	0.79	0.00	0.00	0.21
N_i^{--}	0.00	0.79	0.21	0.00
N_i^{+-}	0.00	0.21	0.79	0.00
N_i^{-+}	0.21	0.00	0.00	0.79

$$A_{\text{mix}}^{b\ell} = \frac{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) - \Gamma\left(\bar{b} \to b \to \ell^- X\right)}{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) + \Gamma\left(\bar{b} \to b \to \ell^- X\right)},$$

$$A_{\text{mix}}^{bc} = \frac{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) - \Gamma\left(\bar{b} \to b \to c X\right)}{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) + \Gamma\left(\bar{b} \to b \to c X\right)},$$

$$A_{\text{dir}}^{b\ell} = \frac{\Gamma\left(b \to \ell^- X\right) - \Gamma\left(\bar{b} \to \ell^+ X\right)}{\Gamma\left(b \to \ell^- X\right) + \Gamma\left(\bar{b} \to \ell^+ X\right)},$$

$$A_{\text{dir}}^{c\ell} = \frac{\Gamma\left(\bar{c} \to \ell^- X_L\right) - \Gamma\left(c \to \ell^+ X_L\right)}{\Gamma\left(\bar{c} \to \ell^- X_L\right) + \Gamma\left(c \to \ell^+ X_L\right)},$$

$$A_{\text{dir}}^{bc} = \frac{\Gamma\left(b \to c X_L\right) - \Gamma\left(\bar{b} \to \bar{c} X_L\right)}{\Gamma\left(b \to c X_L\right) + \Gamma\left(\bar{b} \to \bar{c} X_L\right)},$$

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CP violation in *b* decays using top quark pairs

- Hard lepton from W-boson tags *b* quark via $t \to bW^+ \to b\ell^+\nu$
- Soft muon (SMT algorithm*) from $b \to X\mu\nu$ probes the decay chain.
- Require 2 leptons in an event:

Same sign leptons:

$$
\begin{aligned}
&t \to \ell^+\nu\ (b \to \bar{b}) \to \ell^+\,\ell^+\,X\,,\\
&t \to \ell^+\nu\ (b \to c) \to \ell^+\,\ell^+\,X\,,\\
&t \to \ell^+\nu\ (b \to \bar{b} \to c\,\bar{c}) \to \ell^+\,\ell^+\,X\,,
\end{aligned}
$$

Opposite sign leptons:

$$
\begin{aligned}
&t \to \ell^+\nu\, b \to \ell^+\,\ell^-\,X\,,\\
&t \to \ell^+\nu\ (b \to \bar{b} \to \bar{c}) \to \ell^+\,\ell^-\,X\,,\\
&t \to \ell^+\nu\ (b \to c\,\bar{c}) \to \ell^+\,\ell^-\,X\,,
\end{aligned}
$$

- Use standard top reconstruction for a $t\bar{t}\quad \ell + jets$ event.
- Require a displaced vertex (*b* candidate) tagged with SMT algorithm.
- Fully reconstruct $t\bar{t}$ candidate with KLFitter#.

$$
\begin{aligned}
P(b \to \ell^+) &= \frac{N(b \to \ell^+)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{++}}{N^{+-} + N^{++}} = \frac{N^{++}}{N^{+}},\\
P(\bar{b} \to \ell^-) &= \frac{N(\bar{b} \to \ell^-)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{--}}{N^{--} + N^{-+}} = \frac{N^{--}}{N^{-}},\\
P(b \to \ell^-) &= \frac{N(b \to \ell^-)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{+-}}{N^{+-} + N^{++}} = \frac{N^{+-}}{N^{+}},\\
P(\bar{b} \to \ell^+) &= \frac{N(\bar{b} \to \ell^+)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{-+}}{N^{--} + N^{-+}} = \frac{N^{-+}}{N^{-}},
\end{aligned}
$$

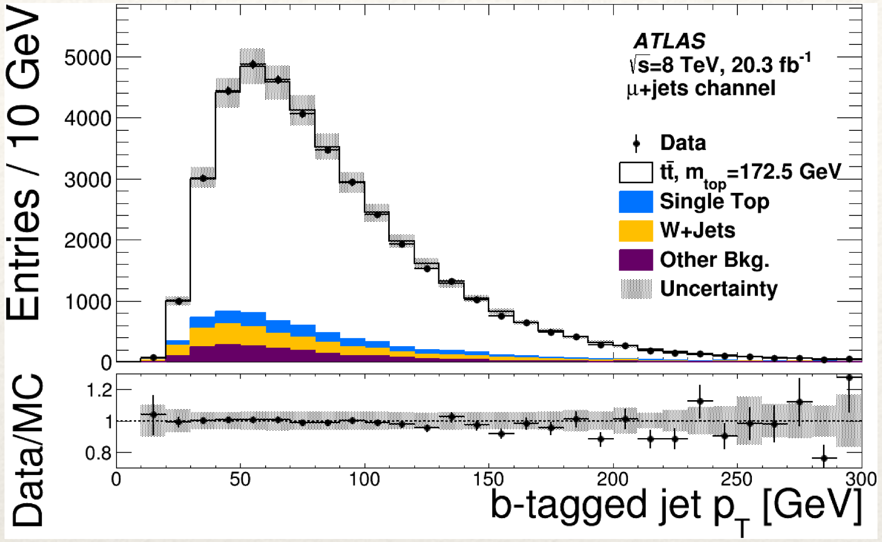
$$
A^{\mathrm{ss}} = \frac{P(b \to \ell^+) - P(\bar{b} \to \ell^-)}{P(b \to \ell^+) + P(\bar{b} \to \ell^-)}, \qquad A^{\mathrm{os}} = \frac{P(b \to \ell^-) - P(\bar{b} \to \ell^+)}{P(b \to \ell^-) + P(\bar{b} \to \ell^+)},
$$

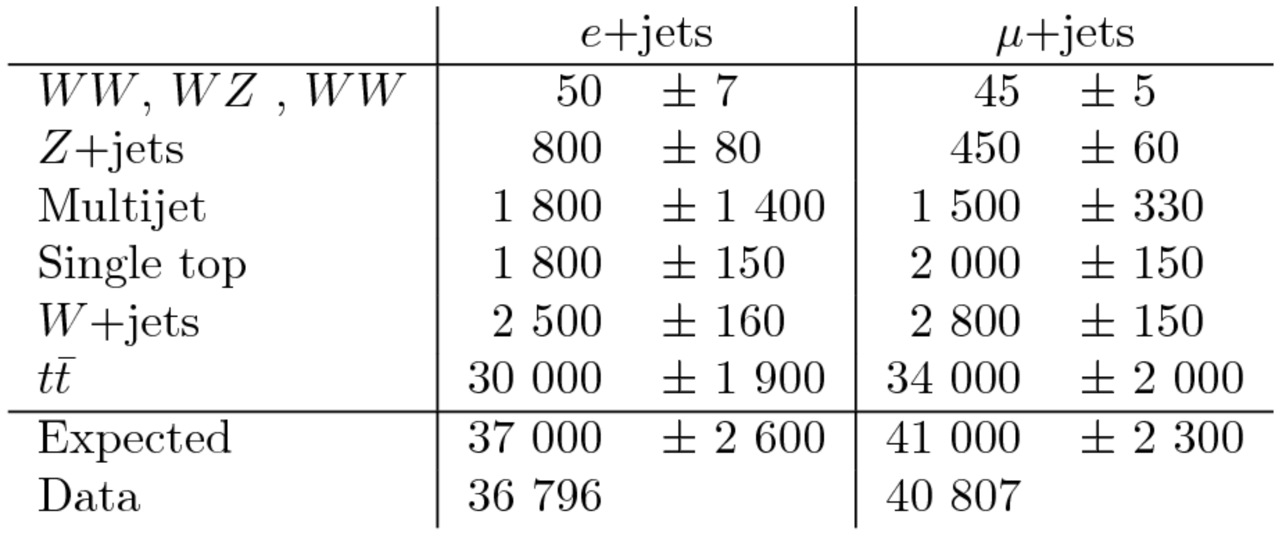
$$
\begin{aligned}
A^{\mathrm{ss}} &= r_b A^{b\ell}_{\mathrm{mix}} + r_c\left(A^{bc}_{\mathrm{dir}} - A^{c\ell}_{\mathrm{dir}}\right) + r_{c\bar{c}}\left(A^{bc}_{\mathrm{mix}} - A^{c\ell}_{\mathrm{dir}}\right)\\
A^{\mathrm{os}} &= \widetilde{r}_b A^{b\ell}_{\mathrm{dir}} + \widetilde{r}_c\left(A^{bc}_{\mathrm{mix}} + A^{c\ell}_{\mathrm{dir}}\right) + \widetilde{r}_{c\bar{c}} A^{c\ell}_{\mathrm{dir}}
\end{aligned}
$$

- The r ′s are decay rate fractions in fiducial region

J. High Energ. Phys. (2017) 2017: 7; *see JINST 11 (2016) P04008 for details of the SMT algorithm; #see Nucl. Instrum. Meth. A 748 (2014) 18–25 for the Kinematic Likelihood fitter description.

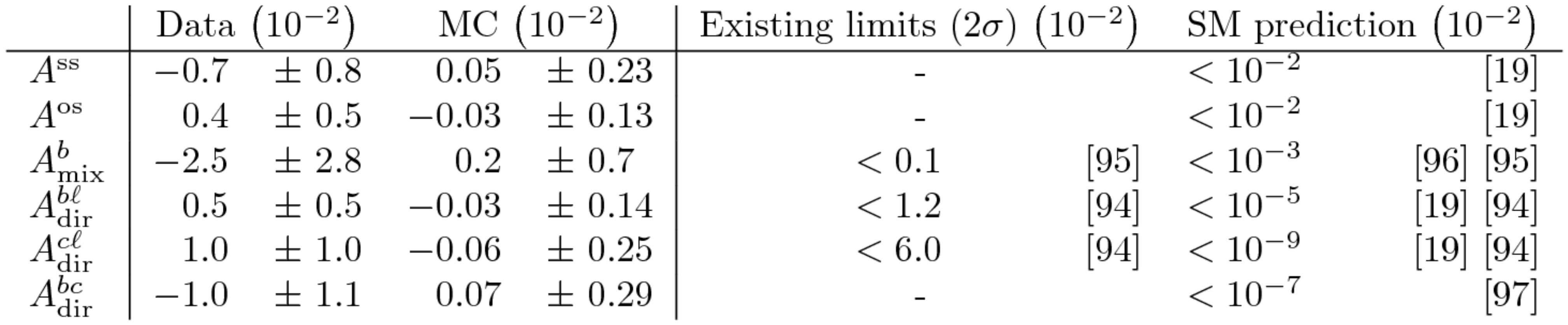
CP violation in *b* decays using top quark pairs





	e+jets		μ+jets	
WW, WZ , WW	50	± 7	45	± 5
Z+jets	800	± 80	450	± 60
Multijet	1 800	± 1 400	1 500	± 330
Single top	1 800	± 150	2 000	± 150
W+jets	2 500	± 160	2 800	± 150
$t\bar{t}$	30 000	± 1 900	34 000	± 2 000
Expected	37 000	± 2 600	41 000	± 2 300
Data	36 796		40 807	

- Good agreement between observed and expected yields.



	Data (10^{-2})		MC (10^{-2})		Existing limits (2σ) (10^{-2})		SM prediction (10^{-2})	
A^{ss}	-0.7	$\pm$ 0.8	0.05	$\pm$ 0.23	-		$< 10^{-2}$	[19]
A^{os}	0.4	$\pm$ 0.5	-0.03	$\pm$ 0.13	-		$< 10^{-2}$	[19]
A^{b}_{mix}	-2.5	$\pm$ 2.8	0.2	$\pm$ 0.7	< 0.1	[95]	$< 10^{-3}$	[96] [95]
$A^{b\ell}_{\mathrm{dir}}$	0.5	$\pm$ 0.5	-0.03	$\pm$ 0.14	< 1.2	[94]	$< 10^{-5}$	[19] [94]
$A^{c\ell}_{\mathrm{dir}}$	1.0	$\pm$ 1.0	-0.06	$\pm$ 0.25	< 6.0	[94]	$< 10^{-9}$	[19] [94]
A^{bc}_{dir}	-1.0	$\pm$ 1.1	0.07	$\pm$ 0.29	-		$< 10^{-7}$	[97]

- Competitive results (σ~%-level) obtained for mixing and direct CP asymmetries through this measurement
- Also measured A^{bc}_{dir}.

Existing constraints/SM predictions from:
[19] O. Gedalia et al., Phys. Rev. Lett. **110** (2013) 232002,
[94] Decotes-Genon et al., Phys. Rev. D **87** (2015).
[95] HFAG, arXiv:1412.7515.
[97] S. Bar-Shalom et al., Phys. Lett. B **694** (2011) 374–379

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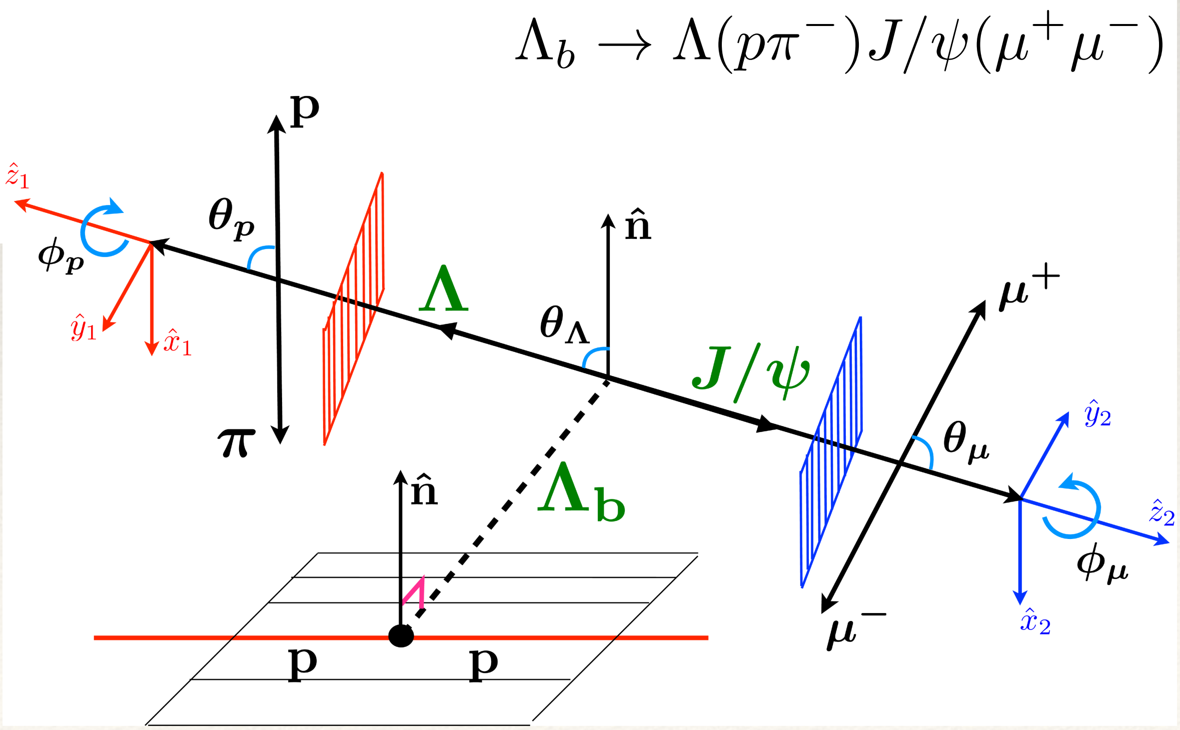
Measurement of Λ_b polarisation

- Provide a test of QCD relating to the underlying parity violation and polarisation determination for the decay $\Lambda_b \to \Lambda(p\pi^-)J/\psi(\mu^+\mu^-)$.
  - HQET: large part of transverse *b* quark polarisation retained after hadronisation to a Λ_b.
  - At the LHC we have production via hadronisation from pp collision and via decay of heavier particles.

$$\frac{d\Gamma}{d\Omega_3}(\theta_\Lambda,\theta_p,\theta_\mu) = \int_{-\pi}^{\pi}\int_{-\pi}^{\pi}\frac{d\Gamma}{d\Omega_5}(\theta_\Lambda,\theta_p,\theta_\mu,\phi_p,\phi_\mu)\,d\phi_p d\phi_\mu$$
$$\sim \sum_{i=1}^{8}\eta_i\left(|T_{++}|^2,|T_{+0}|^2,|T_{-0}|^2,|T_{--}|^2\right)c_i(P,\alpha_\Lambda)\,f_i(\theta_\Lambda,\theta_p,\theta_\mu)$$



The $T_{\lambda\lambda'}$ are helicity amplitudes, indices refer to the Λ and J/ψ, respectively.

α_1: Parity violating asymmetry for the Λ_b decay.
α_2: Longitudinal polarisation of Λ
γ_0: the longitudinal/transverse composition of the J/ψ.

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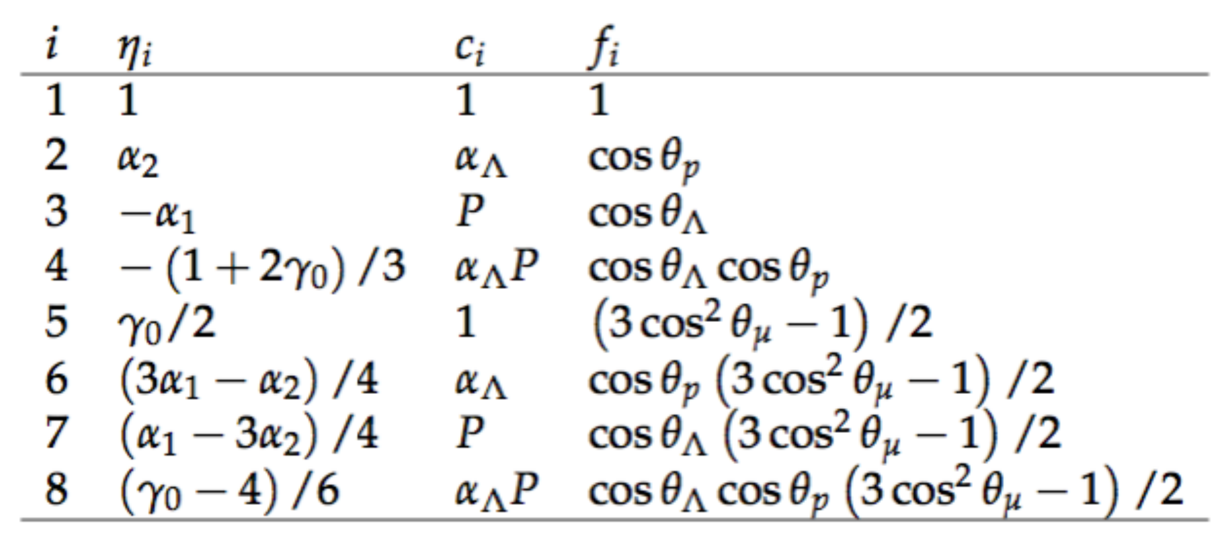
$$\sim \sum_{i=1}^{8}\eta_i\left(|T_{++}|^2,|T_{+0}|^2,|T_{-0}|^2,|T_{--}|^2\right)c_i\left(P,\alpha_\Lambda\right)f_i\left(\theta_\Lambda,\theta_p,\theta_\mu\right)$$



i	η_i	c_i	f_i
1	1	1	1
2	α_2	α_Λ	$\cos\theta_p$
3	$-\alpha_1$	P	$\cos\theta_\Lambda$
4	$-(1+2\gamma_0)/3$	$\alpha_\Lambda P$	$\cos\theta_\Lambda\cos\theta_p$
5	$\gamma_0/2$	1	$(3\cos^2\theta_\mu-1)/2$
6	$(3\alpha_1-\alpha_2)/4$	α_Λ	$\cos\theta_p(3\cos^2\theta_\mu-1)/2$
7	$(\alpha_1-3\alpha_2)/4$	P	$\cos\theta_\Lambda(3\cos^2\theta_\mu-1)/2$
8	$(\gamma_0-4)/6$	$\alpha_\Lambda P$	$\cos\theta_\Lambda\cos\theta_p(3\cos^2\theta_\mu-1)/2$

The $T_{\lambda\lambda'}$ are helicity amplitudes, indices refer to the Λ and J/ψ, respectively.

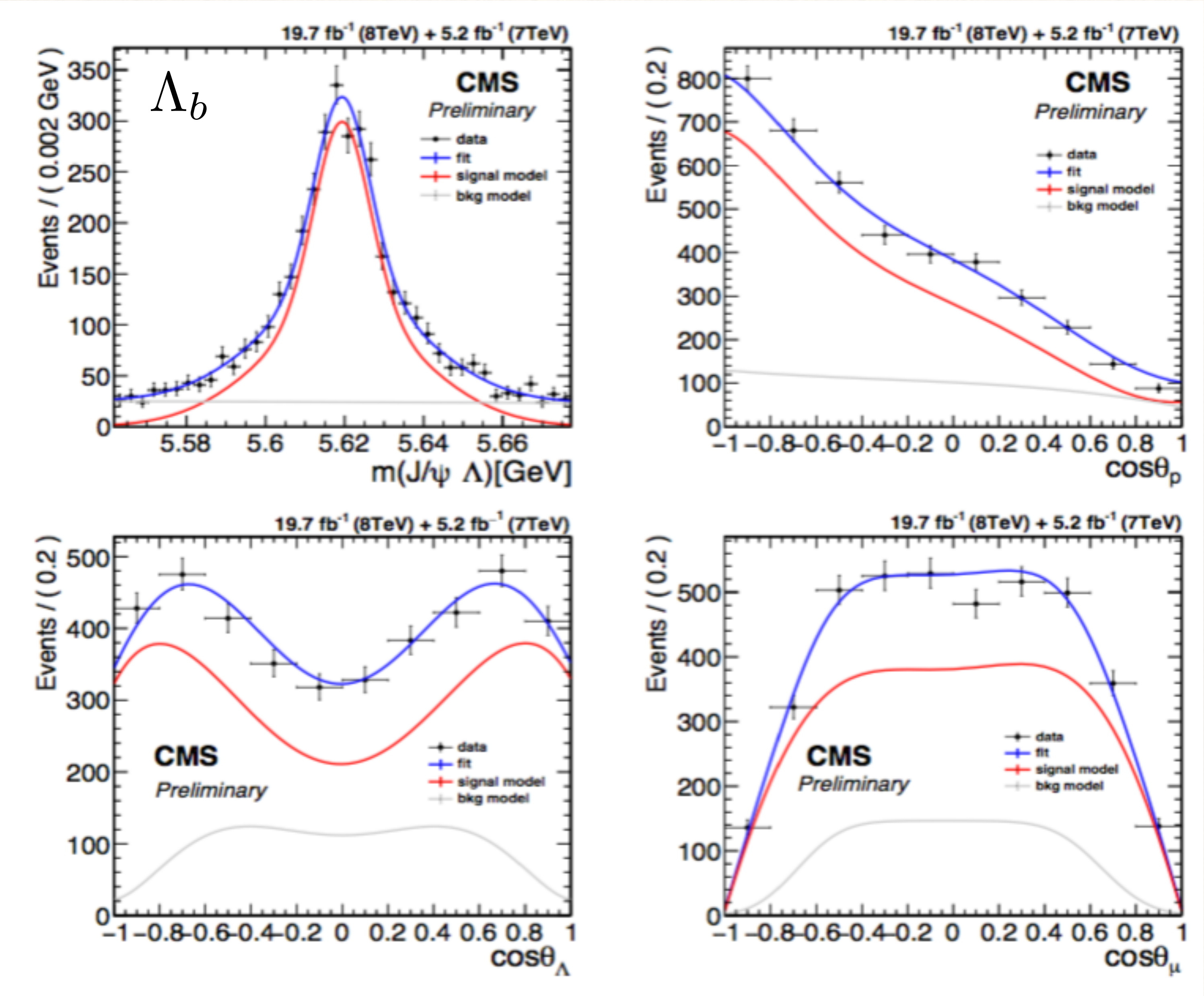
α_1: Parity violating asymmetry for the Λ_b decay.
α_2: Longitudinal polarisation of Λ
γ_0: the longitudinal/transverse composition of the J/ψ.

α_Λ: Parity violating asymmetry for the Λ decay.
P: Polarisation

CMS PAS BPH-15-002

Measurement of Λ_b polarisation

- Similar plots obtained for $\overline{\Lambda}_b$.



$$P = 0.00 \pm 0.06(stat) \pm 0.02(syst),$$
$$\alpha_1 = 0.12 \pm 0.13(stat) \pm 0.06(syst),$$
$$\alpha_2 = -0.93 \pm 0.04(stat) \pm 0.04(syst),$$
$$\gamma_0 = -0.46 \pm 0.07(stat) \pm 0.04(syst),$$

- Consistent with no polarisation.
- No evidence for P violation in the Λ_b decay.

$$|T_{-0}|^2 = 0.51 \pm 0.03(stat) \pm 0.02(syst),$$
$$|T_{+0}|^2 = -0.02 \pm 0.03(stat) \pm 0.02(syst),$$
$$|T_{--}|^2 = 0.46 \pm 0.02(stat) \pm 0.02(syst),$$
$$|T_{++}|^2 = 0.05 \pm 0.04(stat) \pm 0.02(syst).$$

- Results obtained are compatible with the P~10% expectation from pQCD calculations of Gutsche et. al., Phys. Rev. D **88** (2013) 114018.

- HQET computation of Ajaltouni et al., Phys. Lett. B**614** (2005) 165–173 has an expectation of P~20%; Disfavoured by this result.

Summary

- ATLAS and CMS continue to produce interesting results on heavy flavour physics.
  - Latest result on $B_d \to K^* \mu^+ \mu^-$ from ATLAS shown; no evidence for New Physics.
  - Total and differential production $\sigma(B^+)$ at 13 TeV from CMS in agreement with QCD calculation.
  - Competitive results obtained for direct and mixing CP violation in b decay, using top pairs as a source of HF published by ATLAS.
  - Measurement of Λ_b polarisation from CMS presented; data consistent with no polarisation.
- More to come from the Run 2 data.

Event Selection: $B_d \to K^* \mu^+ \mu^-$

- Tracks:
  - $P_T\ (\mu/h) > 3500\ /\ 500$ MeV; where $h = K, \pi$.
  - $|\eta| < 2.5$.
- Di-muon system:
  - Use muons constructed from ID and MC CP information.
  - $\chi^2 < 10$ for the $\mu\mu$ vertex.
- $K\pi$ system:
  - $m_{K\pi} = [846, 946]$.
  - $P_T(K^*) > 3000$ MeV.
- Event level selection:
  - Primary Vertex chosen as that which minimises z distance relative to the B_d 3-vector when extrapolated back to the beam axis.

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Event Selection: $B_d \to K^* \mu^+ \mu^-$

- B system:
  - $\chi^2 < 2$ for the B_d vertex.
  - $m_{K\pi\mu\mu}$ = [5150, 5700].
  - $\tau/\Delta\tau$ >12.75.
  - $\cos\theta > 0.999$ (flight direction cut on the 3D pointing angle between reconstructed B direction of flight and its momentum vector).
  - $|m(B_{\mathrm{rec}})-m(B_{\mathrm{PDG}})+m(\mu\mu_{\mathrm{rec}})-m(J/\psi_{\mathrm{PDG}})|<130$ MeV to suppress radiative charmonium decays.
- Candidates for fitting: 15% of selected events have more than one candidate per event:
  - The lack of a hadronic charged particle ID system means that $K^+\pi^-$ and $K^-\pi^+$ combinations can pass the selection (in addition to combinatoric mis-reconstructed signal).
  - Two stage candidate selection:
    - Select candidate with the lowest $\chi^2(B_d)$ [4% of events].
    - Select the candidate with the best K^* mass significance for $m_{K\pi}$ [96% of events].

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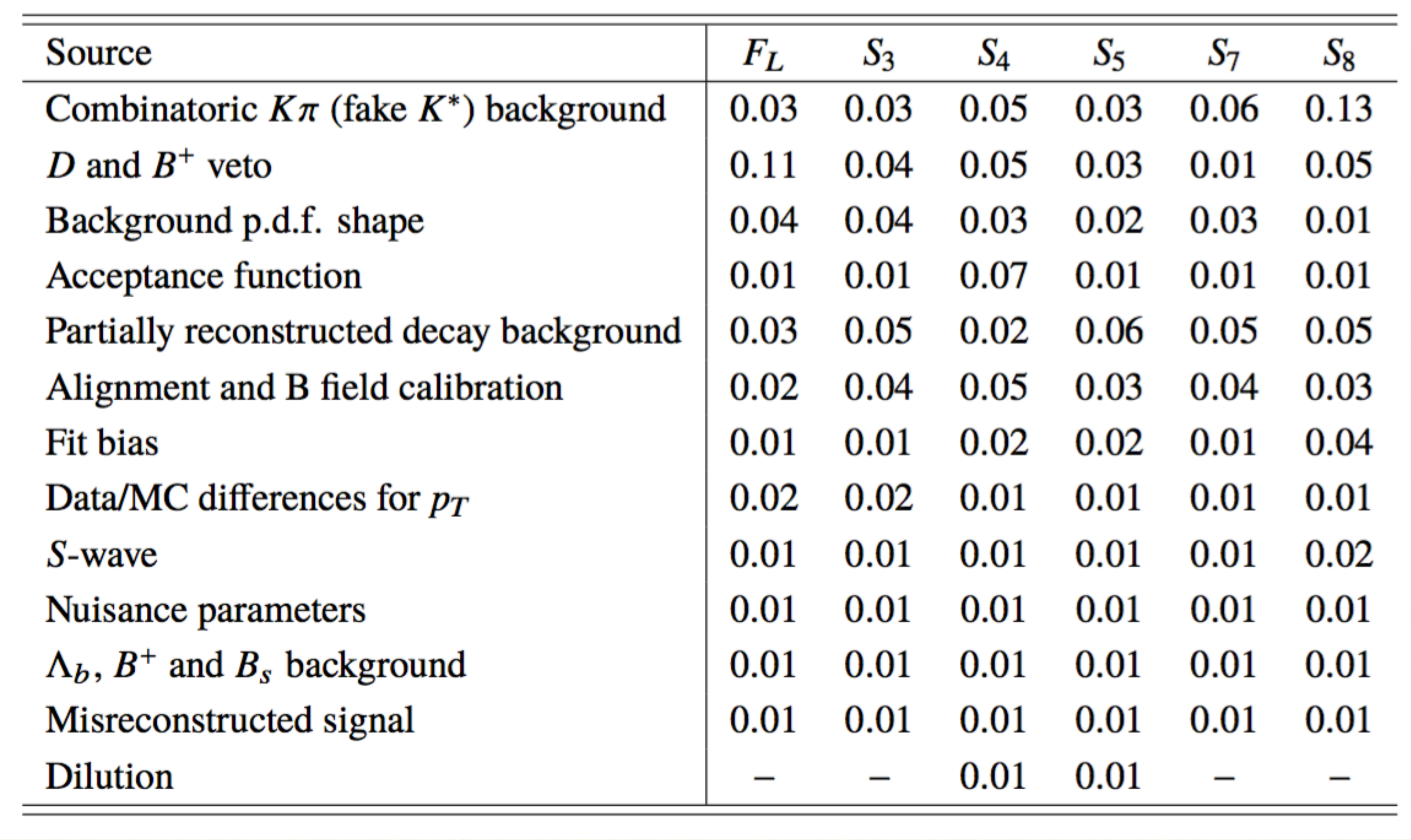
Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Dominant systematic uncertainties come from background content (partially reconstructed decays with D mesons and combinatoric $K\pi$ events) and p.d.f. shape.
- S-wave is a small contribution.



Source	F_L	S_3	S_4	S_5	S_7	S_8
Combinatoric $K\pi$ (fake K^*) background	0.03	0.03	0.05	0.03	0.06	0.13
D and B^+ veto	0.11	0.04	0.05	0.03	0.01	0.05
Background p.d.f. shape	0.04	0.04	0.03	0.02	0.03	0.01
Acceptance function	0.01	0.01	0.07	0.01	0.01	0.01
Partially reconstructed decay background	0.03	0.05	0.02	0.06	0.05	0.05
Alignment and B field calibration	0.02	0.04	0.05	0.03	0.04	0.03
Fit bias	0.01	0.01	0.02	0.02	0.01	0.04
Data/MC differences for p_T	0.02	0.02	0.01	0.01	0.01	0.01
S-wave	0.01	0.01	0.01	0.01	0.01	0.02
Nuisance parameters	0.01	0.01	0.01	0.01	0.01	0.01
Λ_b, B^+ and B_s background	0.01	0.01	0.01	0.01	0.01	0.01
Misreconstructed signal	0.01	0.01	0.01	0.01	0.01	0.01
Dilution	–	–	0.01	0.01	–	–

Systematic uncertainties are translated from S to P parameters using:

$$P_1 = \frac{2S_3}{1 - F_L}$$

$$P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1 - F_L)}}$$

See CMS talk (after this one) for an update on this channel.

Angular analysis results on $B_d \to K^*\mu^+\mu^-$

- The angular distribution is given by:

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2} = \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\}.$$

Signal parameters:

F_L: Fraction of longitudinally polarised events.

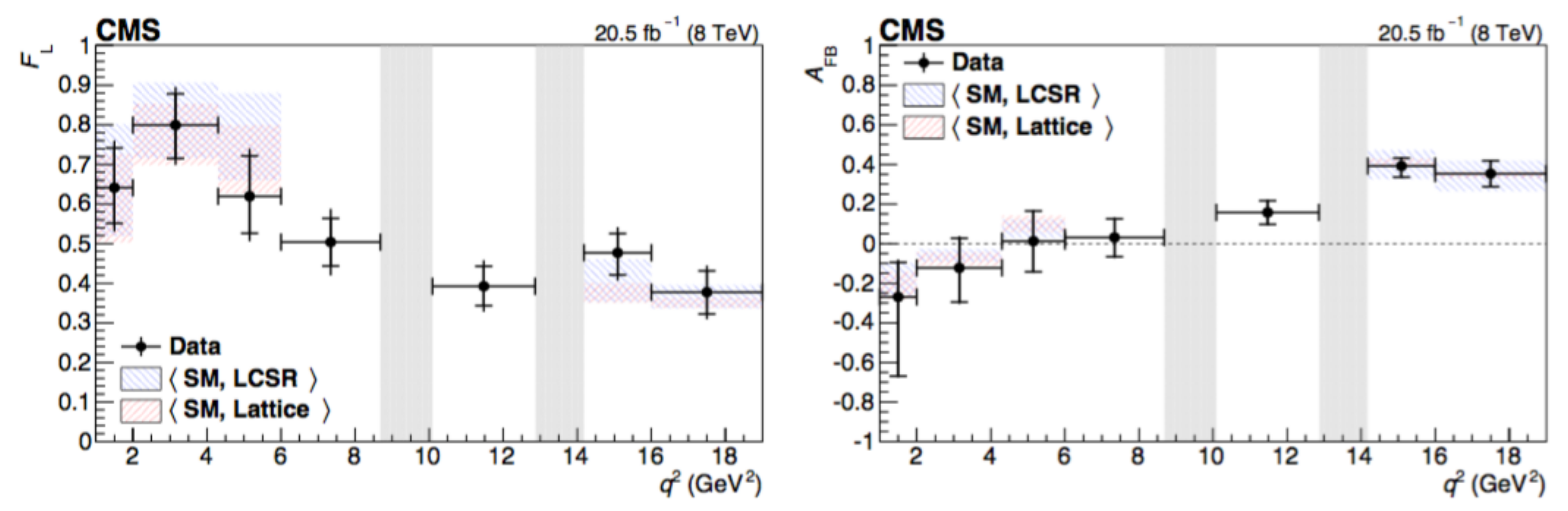
A_{FB}: Forward-backward asymmetry.

Scalar $K\pi\mu\mu$ parameters:

F_S: Fraction of Scalar (S-wave) (<0.03).

A_S: Interference amplitude between S and P wave [-0.3, 0.3].

- Results compatible with theory calculations.

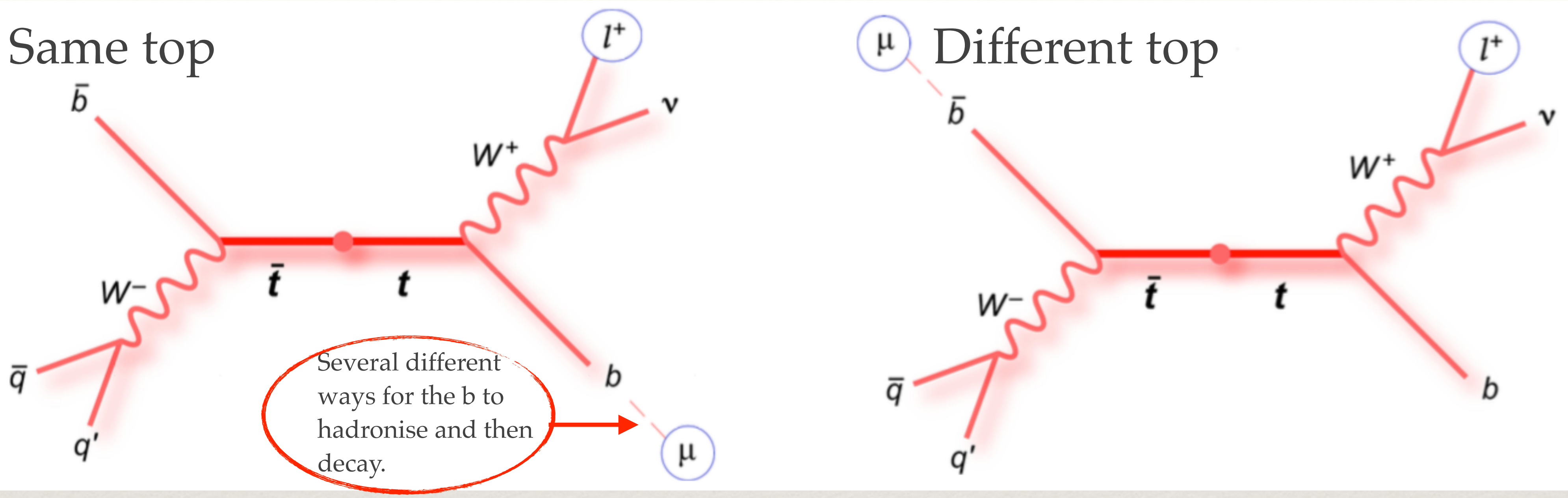


Phys. Lett. B 753 (2016) 424

Analysis follows the procedure outlined by O. Gedalia et al., Phys. Rev. Lett. 110 (2013) 232002.

CP violation in *b* decays using top quark pairs

- 20.3 fb^{-1} of 8TeV data (*pp* collisions)



Several different ways for the b to hadronise and then decay.

- Same top:
  - $W^+ \rightarrow \ell^+\nu$ tags the b quark as a b at the point of the top decay.
  - $W^- \rightarrow \ell^-\nu$ tags the b quark as a $\bar{b}$ at the point of the anti-top decay.
- Different top:
  - $W^+ \rightarrow \ell^+\nu$ tags the b quark as a $\bar{b}$ at the point of the anti-top decay.
  - $W^- \rightarrow \ell^-\nu$ tags the b quark as a b at the point of the top decay.

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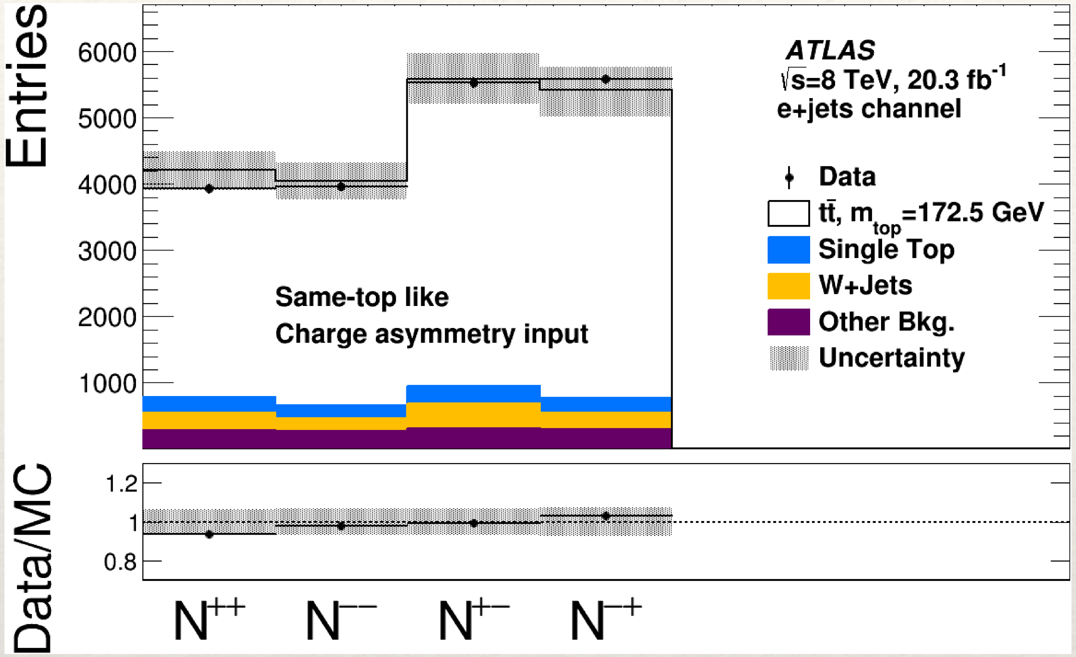
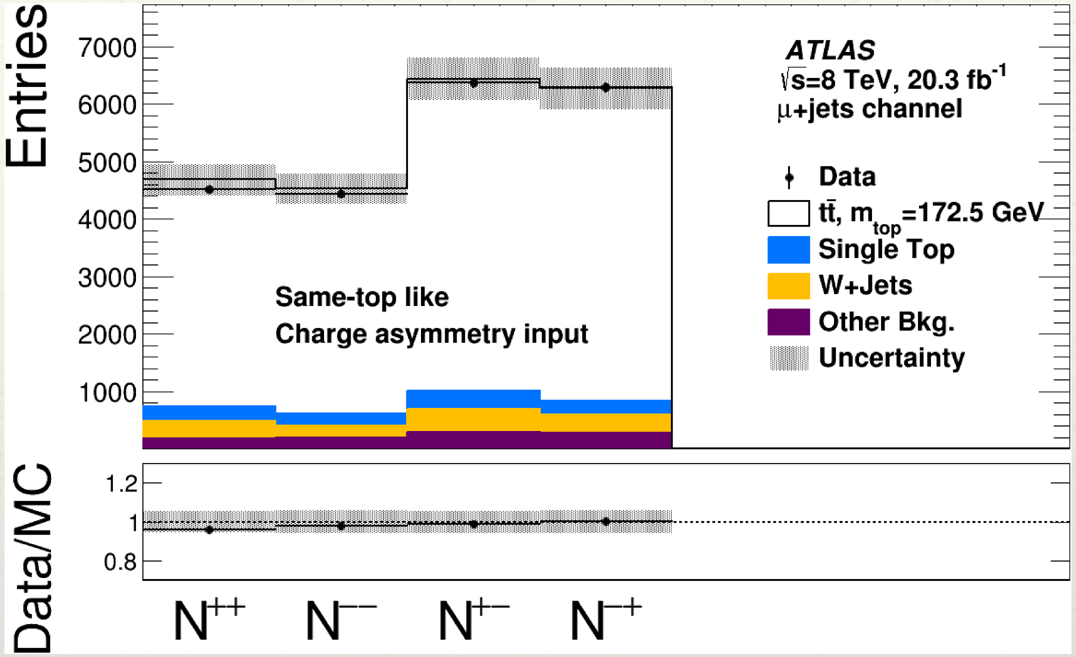
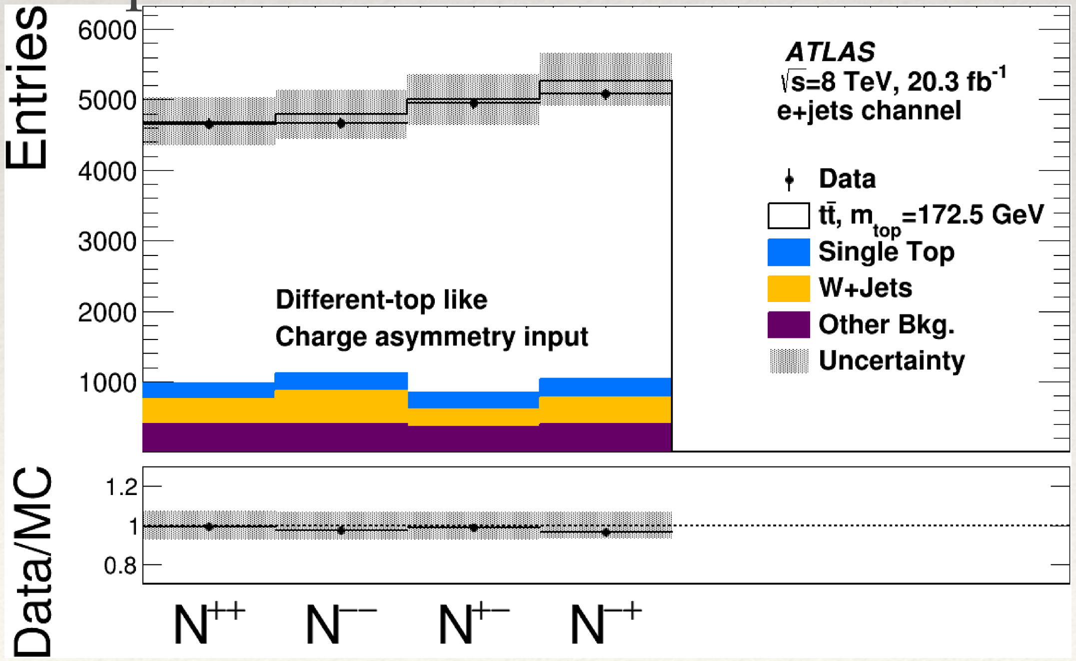
CP violation in *b* decays using top quark pairs

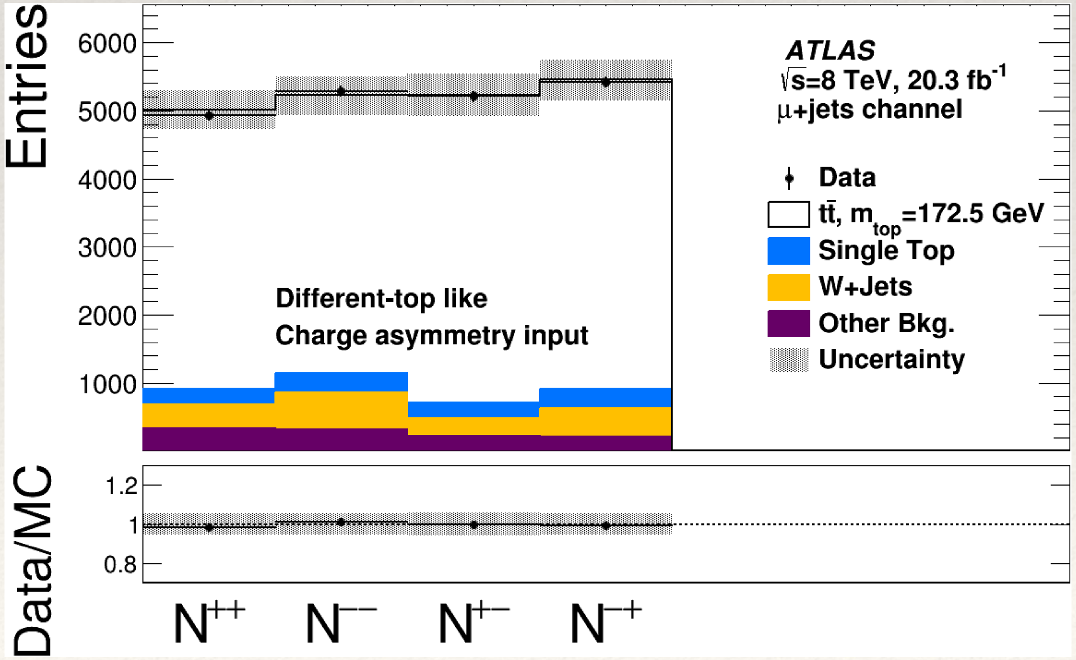
Same top data: e+jets μ+jets





Different top data





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CP violation in *b* decays using top quark pairs

- Measure yields for N^{ij}, where i, j = +, -.
- Relation between quark decay and observed events is:

$$A^{ss} = \frac{P(b \to \ell^+) - P(\bar{b} \to \ell^-)}{P(b \to \ell^+) + P(\bar{b} \to \ell^-)}, \qquad A^{os} = \frac{P(b \to \ell^-) - P(\bar{b} \to \ell^+)}{P(b \to \ell^-) + P(\bar{b} \to \ell^+)},$$

$$A^{ss} = \frac{\left(\frac{N^{++}}{N^+} - \frac{N^{--}}{N^-}\right)}{\left(\frac{N^{++}}{N^+} + \frac{N^{--}}{N^-}\right)}, \qquad A^{os} = \frac{\left(\frac{N^{+-}}{N^+} - \frac{N^{-+}}{N^-}\right)}{\left(\frac{N^{+-}}{N^+} + \frac{N^{-+}}{N^-}\right)}.$$

$$P(b \to \ell^+) = \frac{N(b \to \ell^+)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{++}}{N^{+-} + N^{++}} = \frac{N^{++}}{N^+},$$

$$P(\bar{b} \to \ell^-) = \frac{N(\bar{b} \to \ell^-)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{--}}{N^{--} + N^{-+}} = \frac{N^{--}}{N^-},$$

$$P(b \to \ell^-) = \frac{N(b \to \ell^-)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{+-}}{N^{+-} + N^{++}} = \frac{N^{+-}}{N^+},$$

$$P(\bar{b} \to \ell^+) = \frac{N(\bar{b} \to \ell^+)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{-+}}{N^{--} + N^{-+}} = \frac{N^{-+}}{N^-},$$

$$A^{ss} = r_b A^{b\ell}_{\text{mix}} + r_c\left(A^{bc}_{\text{dir}} - A^{c\ell}_{\text{dir}}\right) + r_{c\bar{c}}\left(A^{bc}_{\text{mix}} - A^{c\ell}_{\text{dir}}\right)$$

$$A^{os} = \widetilde{r}_b A^{b\ell}_{\text{dir}} + \widetilde{r}_c\left(A^{bc}_{\text{mix}} + A^{c\ell}_{\text{dir}}\right) + \widetilde{r}_{c\bar{c}} A^{c\ell}_{\text{dir}}$$

$$A^{b\ell}_{\text{mix}} = \frac{\Gamma(b \to \bar{b} \to \ell^+ X) - \Gamma(\bar{b} \to b \to \ell^- X)}{\Gamma(b \to \bar{b} \to \ell^+ X) + \Gamma(\bar{b} \to b \to \ell^- X)},$$

$$A^{bc}_{\text{mix}} = \frac{\Gamma(b \to \bar{b} \to \bar{c} X) - \Gamma(\bar{b} \to b \to c X)}{\Gamma(b \to \bar{b} \to \bar{c} X) + \Gamma(\bar{b} \to b \to c X)},$$

$$A^{b\ell}_{\text{dir}} = \frac{\Gamma(b \to \ell^- X) - \Gamma(\bar{b} \to \ell^+ X)}{\Gamma(b \to \ell^- X) + \Gamma(\bar{b} \to \ell^+ X)},$$

$$A^{c\ell}_{\text{dir}} = \frac{\Gamma(\bar{c} \to \ell^- X_L) - \Gamma(c \to \ell^+ X_L)}{\Gamma(\bar{c} \to \ell^- X_L) + \Gamma(c \to \ell^+ X_L)},$$

$$A^{bc}_{\text{dir}} = \frac{\Gamma(b \to c X_L) - \Gamma(\bar{b} \to \bar{c} X_L)}{\Gamma(b \to c X_L) + \Gamma(\bar{b} \to \bar{c} X_L)},$$

- r ’s are decay rate fractions in fiducial region.

$$r_b = \frac{N_{r_b}}{N_{r_b} + N_{r_c} + N_{r_{c\bar{c}}}}, \qquad \widetilde{r}_b = \frac{N_{\widetilde{r}_b}}{N_{\widetilde{r}_b} + N_{\widetilde{r}_c} + N_{\widetilde{r}_{c\bar{c}}}},$$

$$r_c = \frac{N_{r_c}}{N_{r_b} + N_{r_c} + N_{r_{c\bar{c}}}}, \qquad \widetilde{r}_c = \frac{N_{\widetilde{r}_c}}{N_{\widetilde{r}_b} + N_{\widetilde{r}_c} + N_{\widetilde{r}_{c\bar{c}}}},$$

$$r_{c\bar{c}} = \frac{N_{r_{c\bar{c}}}}{N_{r_b} + N_{r_c} + N_{r_{c\bar{c}}}}, \qquad \widetilde{r}_{c\bar{c}} = \frac{N_{\widetilde{r}_{c\bar{c}}}}{N_{\widetilde{r}_b} + N_{\widetilde{r}_c} + N_{\widetilde{r}_{c\bar{c}}}}.$$

CP violation in *b* decays using top quark pairs

- Systematic uncertainty contributions not dominant:

	A^{b}_{mix} (10^{-2})		$A^{b\ell}_{\text{dir}}$ (10^{-2})		$A^{c\ell}_{\text{dir}}$ (10^{-2})		A^{bc}_{dir} (10^{-2})	
Measured value	-2.5		0.5		0.9		-1.0	
Statistical uncertainty	$\pm$ 2.1		$\pm$ 0.4		$\pm$ 0.7		$\pm$ 0.8	
Sources of experimental uncertainty								
Lepton charge misidentification	+0.008	-0.007	+0.001	-0.002	+0.002	-0.003	+0.003	-0.003
Lepton energy resolution	+0.33	-0.39	+0.07	-0.06	+0.14	-0.12	+0.13	-0.15
Lepton trigger, reco, identification	+0.016	-0.015	+0.003	-0.003	+0.005	-0.006	+0.006	-0.006
Jet energy scale	+0.4	-0.5	+0.09	-0.07	+0.17	-0.13	+0.15	-0.19
Jet energy resolution	+0.07	-0.07	+0.011	-0.011	+0.024	-0.024	+0.027	-0.027
Jet reco efficiency	+0.034	-0.034	+0.006	-0.006	+0.012	-0.012	+0.014	-0.014
Jet vertex fraction	+0.33	-0.33	+0.06	-0.06	+0.12	-0.12	+0.13	-0.13
Fake lepton estimate	+0.18	-0.19	+0.029	-0.029	+0.07	-0.07	+0.07	-0.08
Background normalisation	+0.008	-0.009	+0.001	-0.001	+0.003	-0.003	+0.003	-0.003
W+jets estimate (statistical)	+0.009	-0.008	+0.002	-0.002	+0.003	-0.003	+0.004	-0.003
Single-top production asymmetry	+0.06	-0.01	+0.002	-0.011	+0.002	-0.020	+0.022	-0.003
b-tagging efficiency	+0.028	-0.028	+0.005	-0.005	+0.010	-0.010	+0.011	-0.011
c-jet mistag rate	+0.07	-0.07	+0.015	-0.015	+0.025	-0.026	+0.029	-0.027
Light-jet mistag rate	+0.08	-0.08	+0.014	-0.014	+0.028	-0.028	+0.031	-0.032
SMT reco identification	+0.013	-0.012	+0.004	-0.004	+0.004	-0.005	+0.005	-0.005
SMT momentum imbalance	+0.21	-0.22	+0.04	-0.04	+0.08	-0.08	+0.09	-0.09
SMT light-jet mistag rate	+0.035	-0.031	+0.005	-0.006	+0.011	-0.012	+0.014	-0.012
Sources of modelling uncertainty								
Hadron-to-muon branching ratio	+0.25	-0.36	+0.023	-0.020	+0.06	-0.05	+0.04	-0.04
b-hadron production fractions	+0.031	-0.021	+0.004	-0.010	+0.013	-0.020	+0.022	-0.015
Additional radiation	$\pm$1.4		$\pm$0.26		$\pm$0.6		$\pm$0.6	
MC generator	$\pm$0.17		$\pm$0.029		$\pm$0.07		$\pm$0.08	
Parton shower	$\pm$0.08		$\pm$0.021		$\pm$0.06		$\pm$0.07	
Parton distribution function	$\pm$0.8		$\pm$0.15		$\pm$0.29		$\pm$0.32	
Total experimental uncertainty	+0.7	-0.8	+0.14	-0.12	+0.27	-0.24	+0.27	-0.31
Total modelling uncertainty	+1.6	-1.7	+0.30	-0.30	+0.6	-0.6	+0.7	-0.7
Total systematic uncertainty	+1.8	-1.8	+0.34	-0.33	+0.7	-0.6	+0.7	-0.7

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Λ_b polarisation measurement

- Polarisation is the mean value of the spin along $\hat{n} = \frac{(\vec{p}_{beam} \times \vec{p}_{\Lambda_b})}{|\vec{p}_{beam} \times \vec{p}_{\Lambda_b}|}$ where the bean vector is in the counterclockwise direction