Recents Results from ATLAS in Beauty and Charm Physics

Lake Louise Winter Institute 24. 02. 2017

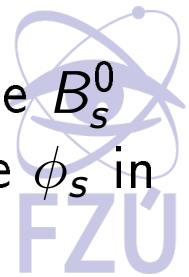
Tomas Jakoubek

on behalf of the ATLAS Collaboration

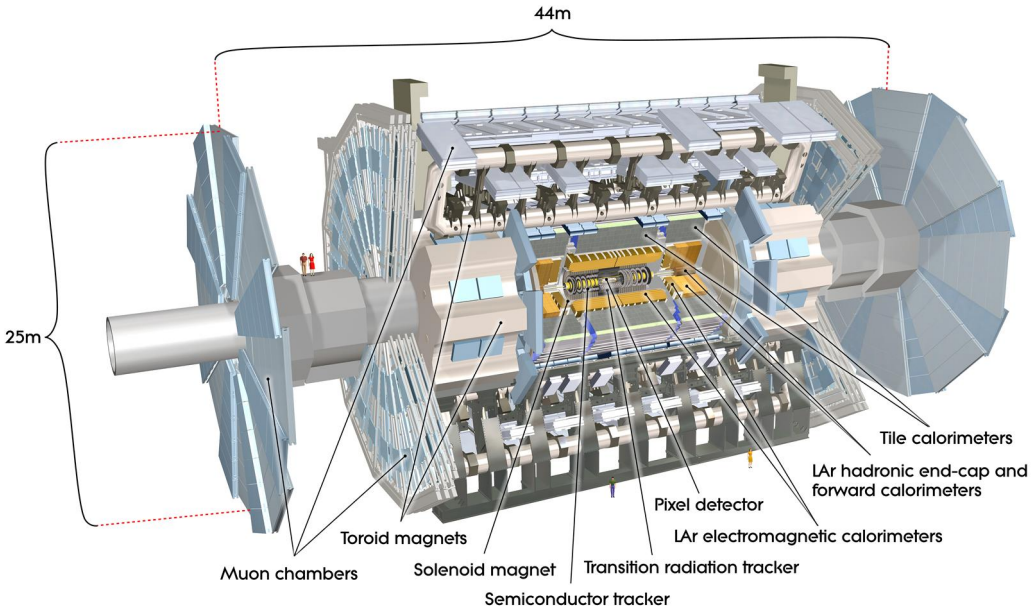
Czech Academy of Sciences | tomas.jakoubek@cern.ch

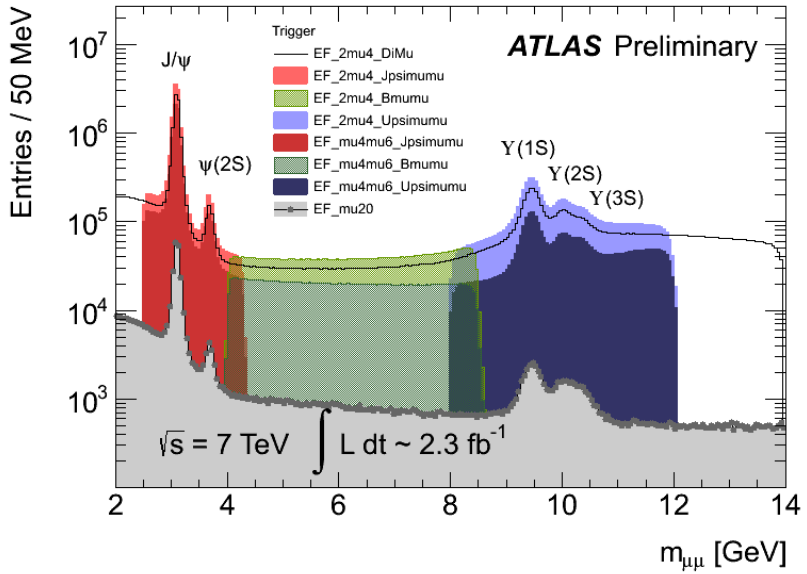
Outline

- **ATLAS** [1] has a wide program of studies in **heavy flavour** physics: from **QCD** tests performed on production cross section and properties of states containing heavy quarks, to searches for new physics in **EW** processes
- In this talk:
  - Differential production cross section of J/ψ pairs (separating associated production and multi-parton scattering) [2]
  - Differential production cross section for $X(3872)$, observed in the decay to $J/\psi\pi^+\pi^-$ [3]
  - Measurement of the width difference in the B^0-$\bar{B}^0$ system (via the comparison of the decay time distributions to CP and flavour eigenstates) [4]
  - Recent results and Run 2 expectations for FCNC process in the B_s^0 systems: rare decays to muon pairs [5] and CP violating phase ϕ_s in the decay to $J/\psi\phi$ [6]



The ATLAS Experiment





- **Muon Spectrometer:** triggering $|\eta| < 2.4$ and precision tracking $|\eta| < 2.7$
- **Inner Detector:** Silicon Pixels and Strips with Transition Radiation Tracker, $p_T > 0.4$ GeV and $|\eta| < 2.5$
  - **NEW for Run 2:** "Insertable B-Layer" (IBL) - additional inner-most pixel layer (r = 33 mm) and lower x/X_0 beam pipe
  - **Resolution in $m(\mu^+\mu^-)$:** Around 50 MeV at J/ψ, 150 MeV at $\Upsilon(nS)$
  - **Resolution in b-hadron proper decay time:** ~100 fs (30 % improvement with IBL)

Prompt J/ψ Pair Production Cross-section

- Test of non-perturbative QCD
- Di-J/ψ events can be produced from
  - single gg collision via Single Parton Scattering (**SPS**) or
  - two independent parton-parton scatters - Double Parton Scattering (**DPS**)
- 2012 pp data: 11.4 fb^{-1}, $\sqrt{s} = 8$ TeV [2]
- Differential cross-section as a function of the sub-leading J/ψ p_{T}, di-J/ψ p_{T}, and di-J/ψ mass
- Measured in two rapidity regions of the sub-leading J/ψ:

$$|y(J/\psi_2)| < 1.05 \quad \text{and} \quad 1.05 < |y(J/\psi_2)| < 2.1$$

- Assuming unpolarised J/ψ mesons

Prompt J/ψ Pair Production Cross-section

- Total cross-section over the full fiducial J/ψ rapidity:

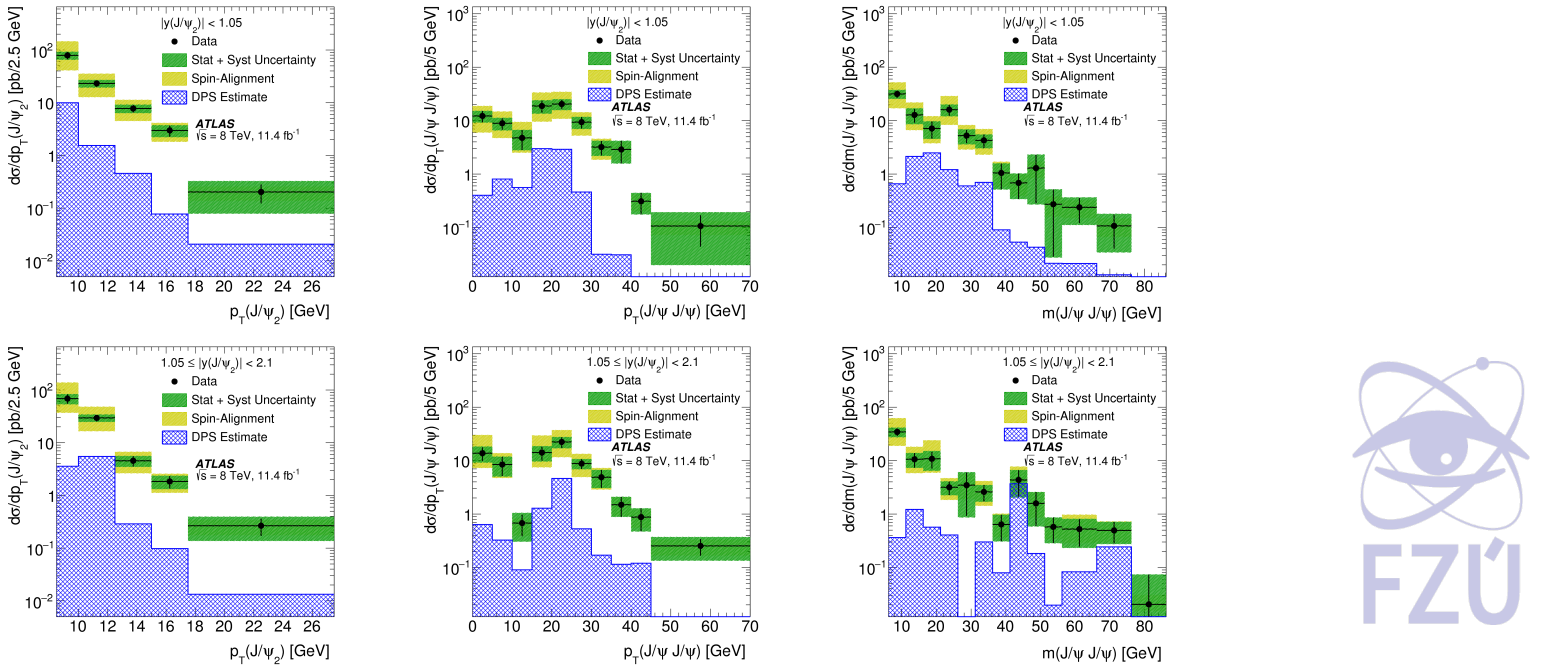
$$\sigma_{\text{total}}(pp \to J/\psi J/\psi + X) = 160 \pm 12\ (\text{stat}) \pm 14\ (\text{syst}) \pm 2\ (\text{BF}) \pm 3\ (\text{lumi})\ \text{pb}$$

- DPS/SPS weights as a function of $\Delta\phi$ and Δy:

$$f_{\text{DPS}} = 9.2 \pm 2.1\ (\text{stat}) \pm 0.5\ (\text{syst})\%$$

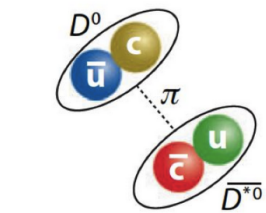
- Effective cross-section of DPS:

$$\sigma_{\text{eff}} = 6.3 \pm 1.6\ (\text{stat}) \pm 1.0\ (\text{syst}) \pm 0.1\ (\text{BF}) \pm 0.1\ (\text{lumi})\ \text{mb}$$



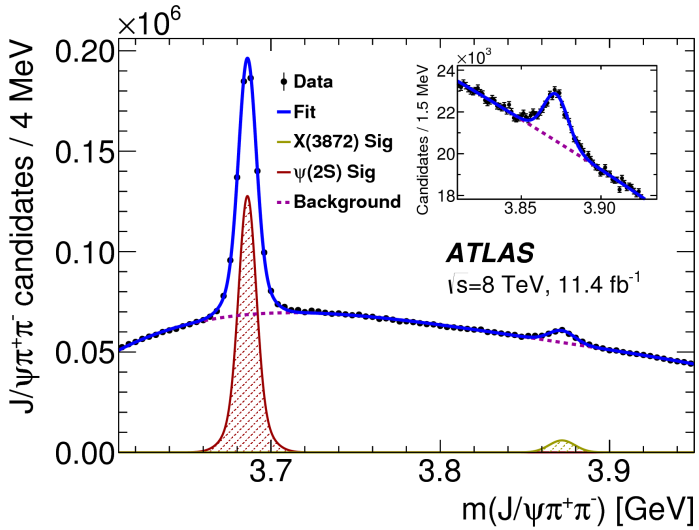
Production of $\psi(2S)$ and $X(3872)$ in the Decay to $J/\psi(\mu^+\mu^-)\pi^+\pi^-$

- $X(3872)$ first discovered by Belle 2003 in $B^\pm \to K^\pm J/\psi\pi^+\pi^-$, soon confirmed by other experiments
- Current world average (3871.69 ± 0.17) MeV [7] places $X(3872)$ mass very close to the $D^0\bar{D}^{*0}$ threshold
- The structure of the resonance remains unclear: tetraquark, molecular, and mixed models
- Measuring $X(3872)$ **and** the well-studied $\psi(2S)$ in the **same analysis** and in the **same final state** $J/\psi(\mu^+\mu^-)\pi^+\pi^-$ helps **reduce systematics** for various ratios and comparisons
- 2012 pp data: 11.4 fb^{-1}, $\sqrt{s} = 8$ TeV [3]
- $|y| < 0.75$, 10 GeV $< p_T <$ 70 GeV



D^0–$\bar{D}^{*0}$ "molecule"

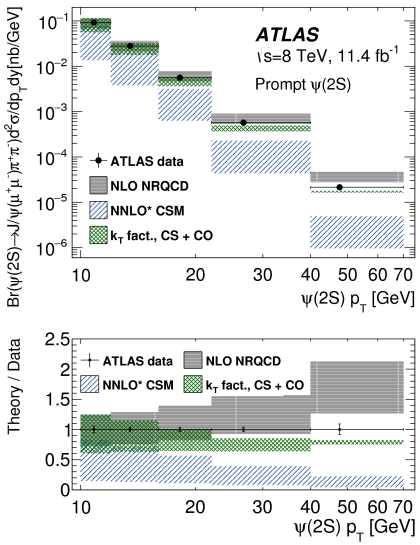
Diquark–diantiquark

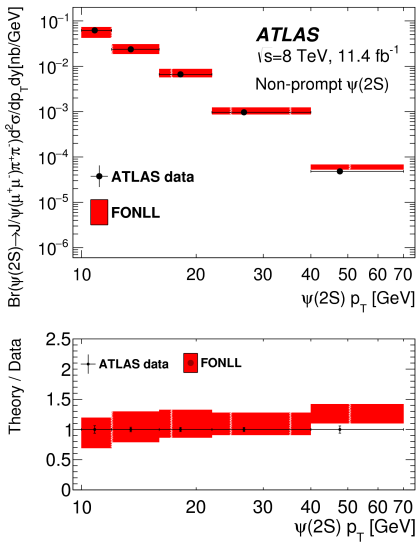


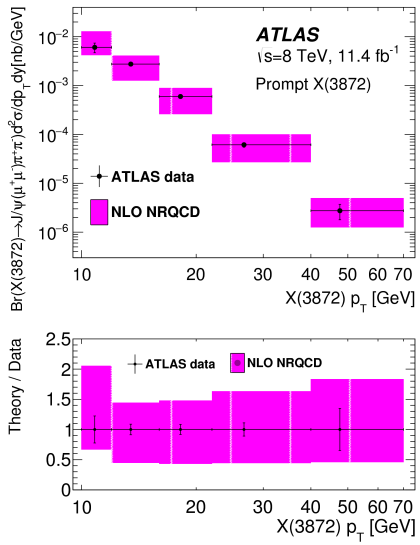
Production of $\psi(2S)$ and $X(3872)$ in the Decay to $J/\psi(\mu^+\mu^-)\pi^+\pi^-$

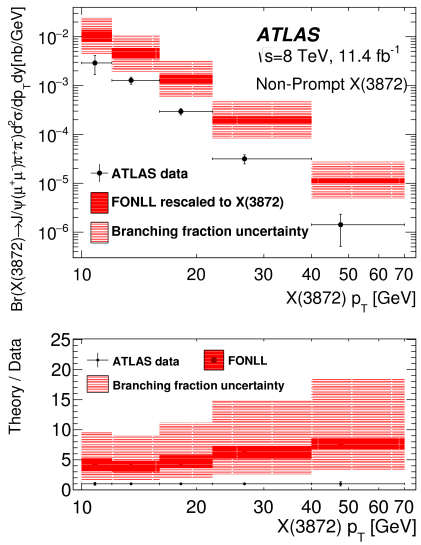
- The $\psi(2S)$ cross-section measurements: good consistency with **NLO NRQCD** for **prompt** and **FONLL** for **non-prompt** production
- **Prompt** $X(3872)$ cross-section measurement: good agreement with the **NLO NRQCD** model, which considers $X(3872)$ to be a mixture of $\chi_{c1}(2P)$ and a $D^0\bar{D}^{*0}$ molecular state, with production dominated by $\chi_{c1}(2P)$
- **FONLL** overestimate the **non-prompt** production of $X(3872)$, especially at large p_T
- Branching fraction ratios $R_B = \frac{\mathcal{B}(B\to X(3872)+\text{any})\mathcal{B}(X(3872\to J/\psi\pi^+\pi^-)}{\mathcal{B}(B\to\psi(2S)+\text{any})\mathcal{B}(\psi(2S)\to J/\psi\pi^+\pi^-)}$

$R_B^{1L} = (3.95 \pm 0.32(\text{stat}) \pm 0.08(\text{syst})) \times 10^{-2}$, $R_B^{2L} = (3.57 \pm 0.33(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-2}$









Relative Width Difference in $B^0 - \bar{B}^0$ System

- Value of $\frac{\Delta\Gamma_d}{\Gamma_d}$ is reliably predicted in the SM [8]: $(0.42 \pm 0.08) \times 10^{-2}$
- Relatively large variation of $\Delta\Gamma_d$ due to a possible **new physics** contribution would not contradict other existing SM results
- Current[1] experimental **uncertainty** on $\Delta\Gamma_d$ is much **larger** than the SM central value: $\frac{\Delta\Gamma_d}{\Gamma_d} = (0.1 \pm 1.0) \times 10^{-2}$ [9]
- 2011+2012 pp data: 4.9 fb^{-1}, $\sqrt{s} = 7$ TeV, 20.3 fb^{-1}, $\sqrt{s} = 8$ TeV [4]
- $\frac{\Delta\Gamma_d}{\Gamma_d}$ determined from ratio of proper decay time distributions of $B_d^0 \to J/\psi K_S^0$ and $B_d^0 \to J/\psi K^{*0}$
- B_d^0 production asymmetry A_P measured from a charge asymmetry A_{obs}, from a difference between $B_d^0 \to J/\psi K^{*0}$ and $\bar{B}_d^0 \to J/\psi \bar{K}^{*0}$ decays as a function proper decay lengths L_{prop}^B

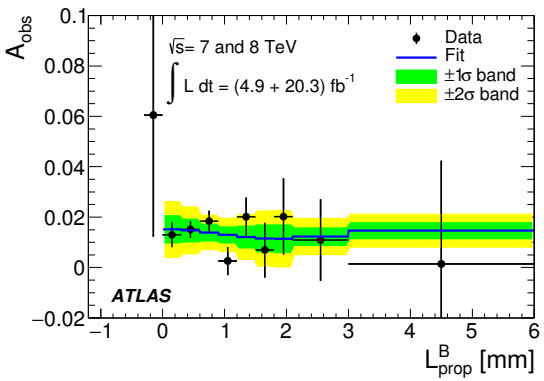
[1] Before the ATLAS measurement

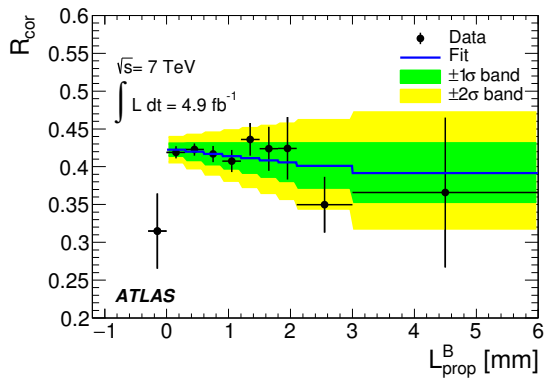
Relative Width Difference in $B^0 - \bar{B}^0$ System

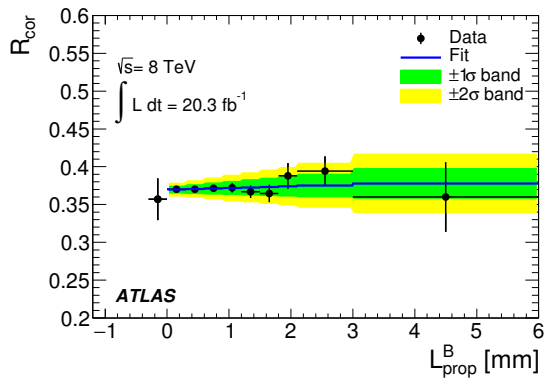
- ATLAS result is consistent with other measurements of $\frac{\Delta\Gamma_d}{\Gamma_d}$ and with the SM prediction
- Currently it is the most precise **single** measurement

ATLAS:	$(-0.1 \pm 1.1(\text{stat}) \pm 0.9(\text{syst})) \times 10^{-2}$
LHCb:	$(-4.4 \pm 2.5(\text{stat}) \pm 1.1(\text{syst})) \times 10^{-2}$
Belle:	$(1.7 \pm 1.8(\text{stat}) \pm 1.1(\text{syst})) \times 10^{-2}$
BaBar:	$(0.8 \pm 3.7(\text{stat}) \pm 1.8(\text{syst})) \times 10^{-2}$
SM:	$(0.42 \pm 0.08) \times 10^{-2}$

- $A_P = (0.25 \pm 0.48(\text{stat}) \pm 0.05(\text{syst})) \times 10^{-2}$ in agreement with expectations

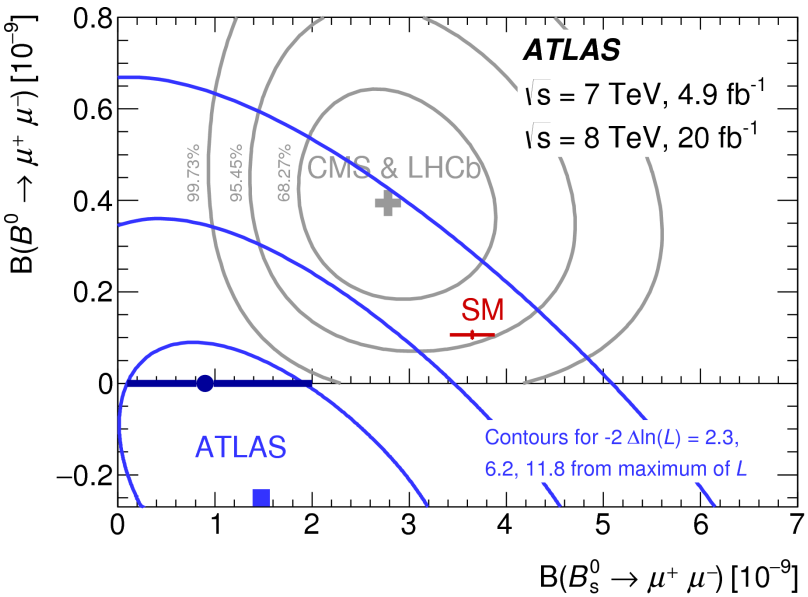






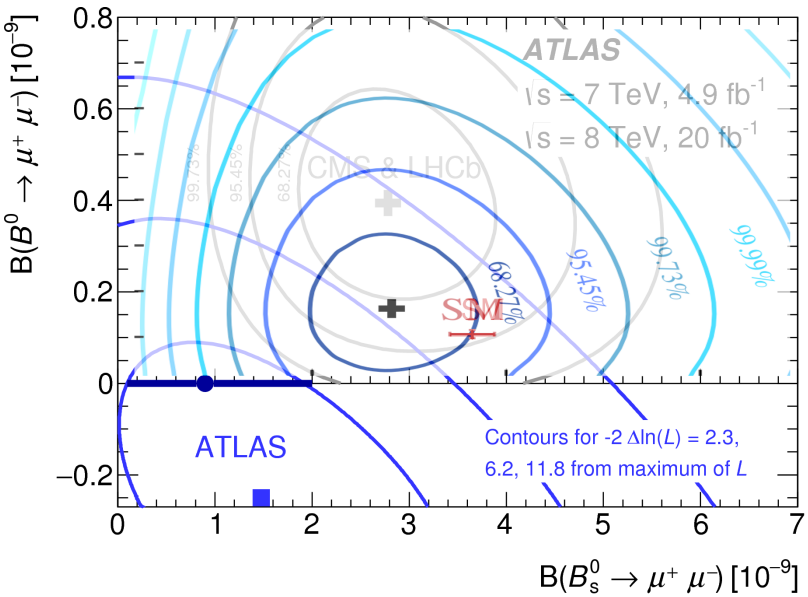
Rare Decays of B_s^0 and B_d^0 into Muon Pairs

- FCNC processes **highly suppressed** in the SM
- $B_{s,d}^0 \to \mu^+\mu^-$ additional **helicity suppression**
- Predicted in the SM [10]: $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$ and $\mathcal{B}(B_d^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$
- 2011+2012 pp data: 4.9 fb^{-1}, $\sqrt{s} = 7$ TeV, 20.0 fb^{-1}, $\sqrt{s} = 8$ TeV [5]
- $\mathcal{B}(B_d^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10}$ 95 % CL, compatible with SM and CMS+LHCb
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 3.0 \times 10^{-9}$ 95 % CL, **lower** than SM, in **better** agreement with CMS+LHCb
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$ errors include both the statistical and systematic uncertainties
- p-value of 4.8 % is found for the compatibility of the results with the SM



Rare Decays of B_s^0 and B_d^0 into Muon Pairs

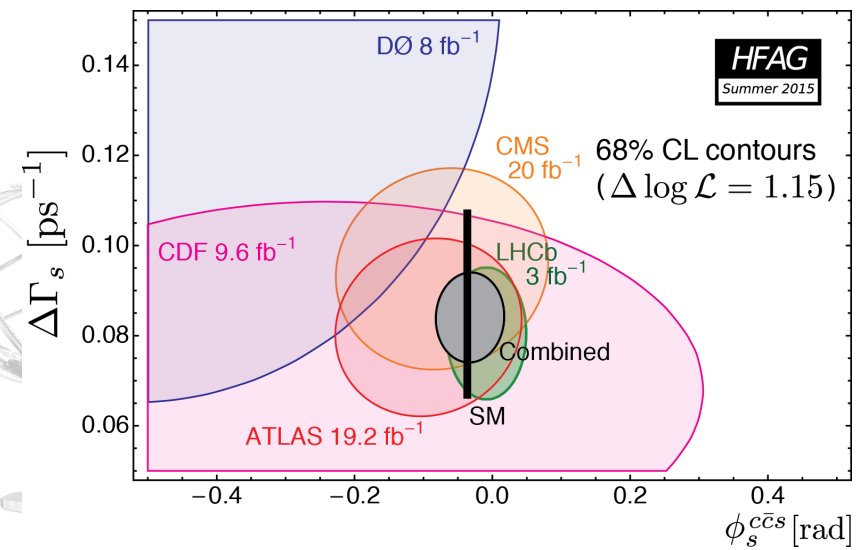
- FCNC processes **highly suppressed** in the SM
- $B_{s,d}^0 \to \mu^+\mu^-$ additional **helicity suppression**
- Predicted in the SM [10]: $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$ and $\mathcal{B}(B_d^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$
- 2011+2012 pp data: 4.9 fb^{-1}, $\sqrt{s} = 7$ TeV, 20.0 fb^{-1}, $\sqrt{s} = 8$ TeV [5]
- $\mathcal{B}(B_d^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10}$ 95 % CL, compatible with SM and CMS+LHCb
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 3.0 \times 10^{-9}$ 95 % CL, **lower** than SM, in **better** agreement with CMS+LHCb
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$ errors include both the statistical and systematic uncertainties
- p-value of 4.8 % is found for the compatibility of the results with the SM

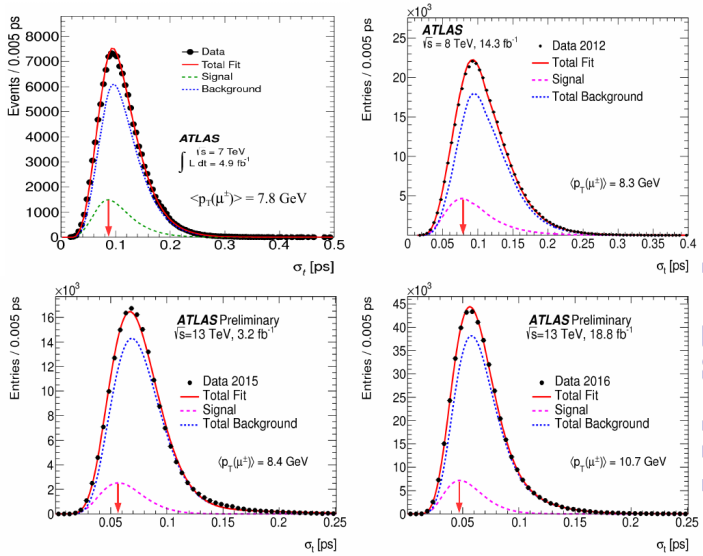


CP Violating Phase ϕ_s
in the decay $B_s^0 \to J/\psi\phi$ [6]

- *CP* violating phase ϕ_s is defined as the weak phase difference between the $B_s^0 - \bar{B}_s^0$ mixing amplitude and the $b \to c\bar{c}s$ decay amplitude
- **New physics** processes could introduce additional contributions to the box diagrams describing the B_s^0 mixing

	Lumi	ϕ_s [rad]
ATLAS RUN1	19.2 fb^{-1}	$-0.098 \pm 0.084 \pm 0.040$
LHCb RUN1	3.0 fb^{-1}	$-0.058 \pm 0.049 \pm 0.006$
CMS 2012	19.7 fb^{-1}	$-0.075 \pm 0.097 \pm 0.031$
Standard Model	-	-0.037 ± 0.002





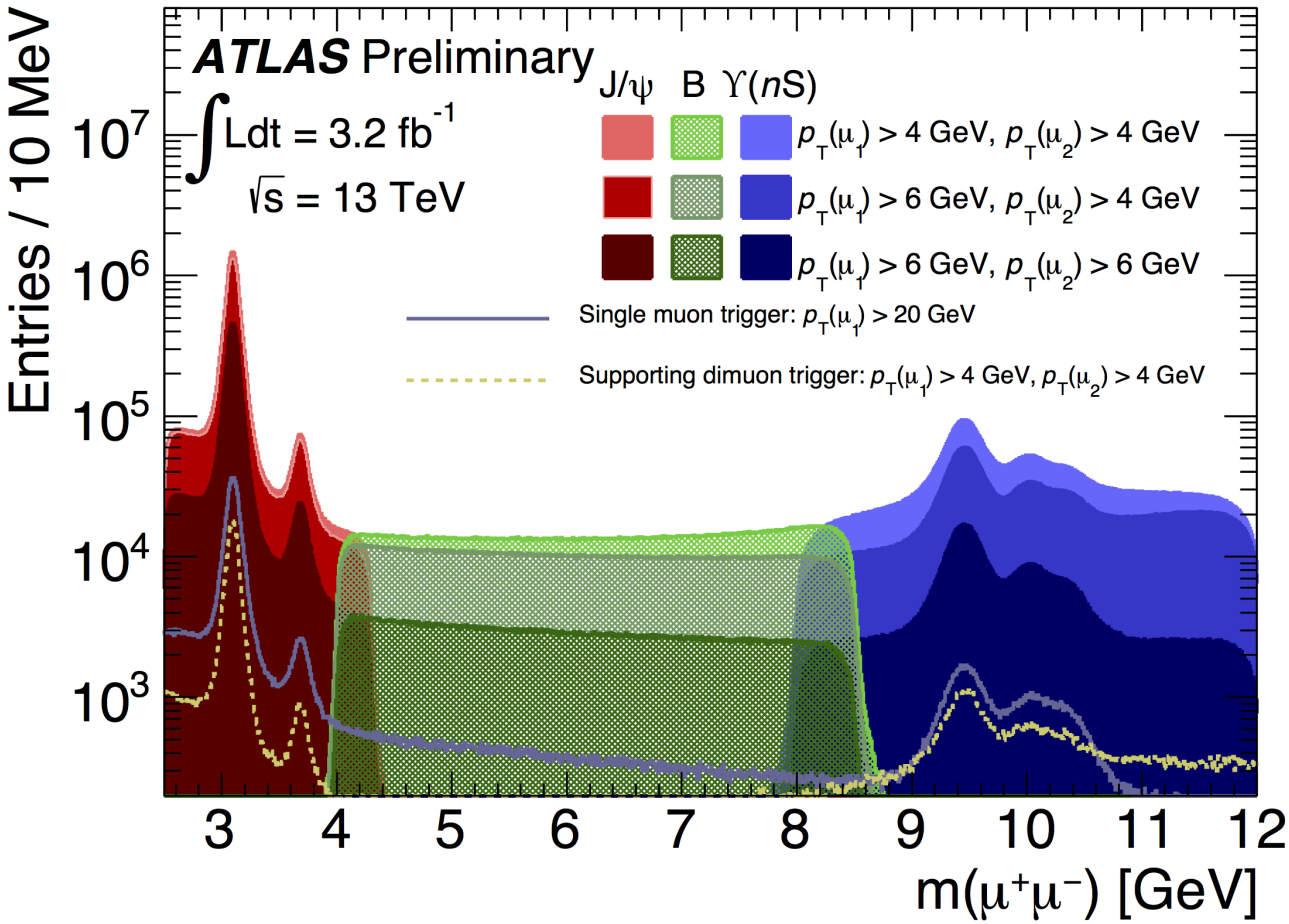
Summary

- **ATLAS** has produced **impressive** and **competitive** results in **beauty** and **charm** physics
- Presented today:
  - Differential production cross-section for $X(3872)$, observed in the decay to $J/\psi\pi^+\pi^-$
  - Currently the most precise **single** measurement of the B_d^0 width difference $\frac{\Delta\Gamma_d}{\Gamma_d}$
  - Differential production cross-section of J/ψ pairs
  - Rare decays of B_s^0 and B_d^0
  - Outlook for CP violation measurement in $B_s^0 \to J/\psi\phi$ in Run 2
- **More** public **results** on **ATLAS B-physics** TWiki page:
  `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults`

FZÚ

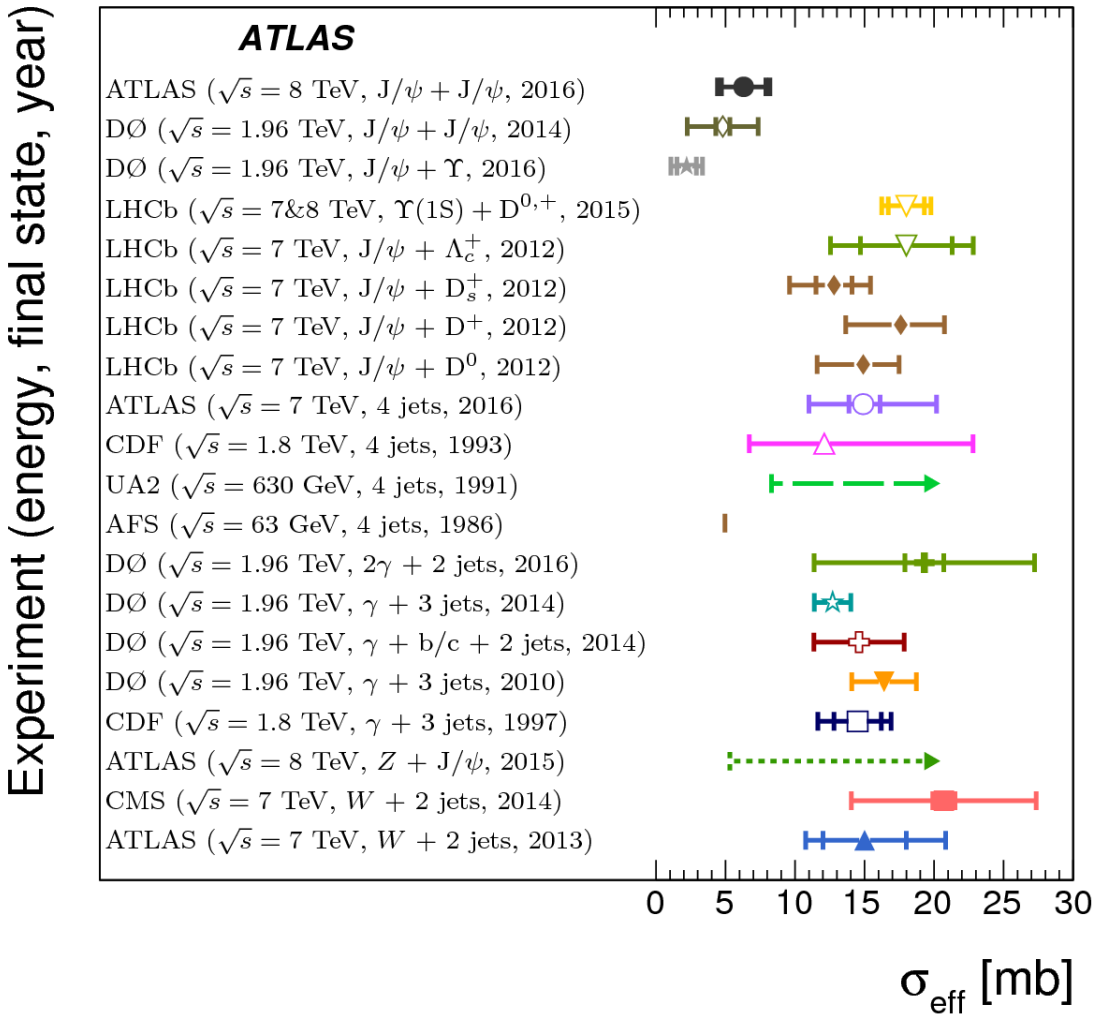
BACKUP

2015 Trigger yield



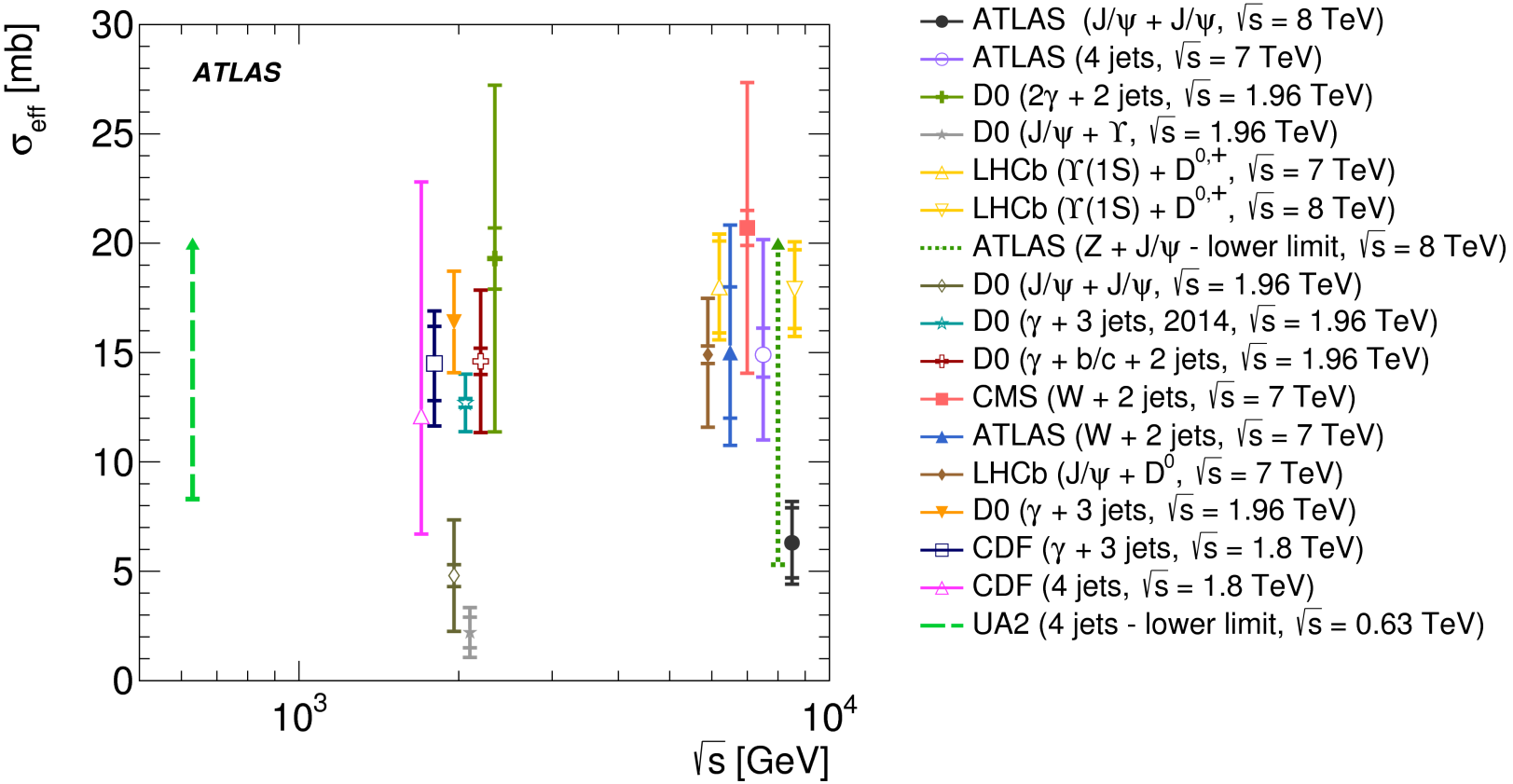
Prompt J/ψ Pair Production Cross-section

Eff. cross-section of DPS



Prompt J/ψ Pair Production Cross-section

Eff. cross-section of DPS as a function of $\sqrt{s}$



Rare Decays of B_s^0 and B_d^0
into Muon Pairs

$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-) = \frac{N_{d(s)}}{\epsilon_{\mu^+\mu^-}} \times [\mathcal{B}(B^+ \to J/\psi K^+) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)] \frac{\epsilon_{J/\psi K^+}}{N_{J/\psi K^+}} \times \frac{f_u}{f_{d(s)}} \quad (1)$$

References

[1] G. Aad *et al.*, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 (2008) S08003

[2] M. Aaboud *et al.*, *Measurement of the prompt J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, arXiv:1612.02950 [hep-ex], submited to EPJC

[3] M. Aaboud *et al.*, *Measurements of $\psi(2S)$ and $X(3872) \to J/\psi\pi^+\pi^-$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, JHEP 1701 (2017) 117

[4] M. Aaboud *et al.*, *Measurement of the relative width difference of the B^0-$\bar{B}^0$ system with the ATLAS detector*, JHEP 1606 (2016) 081

[5] M. Aaboud *et al.*, *Study of the rare decays of B_s^0 and B^0 into muon pairs from data collected during the LHC Run 1 with the ATLAS detector*, Eur. Phys. J. C 76 (2016) no.9, 513

[6] G. Aad *et al.*, *Measurement of the CP-violating phase ϕ_s and the B_s^0 meson decay width difference with $B_s^0 \to J/\psi\phi$ decays in ATLAS*, JHEP 1608 (2016) 147

[7] C. Patrignani *et al.*, *Review of Particle Physics*, Chin. Phys. C 40 (2016) no.10, 100001

[8] A. Lenz and U. Nierste, *Numerical Updates of Lifetimes and Mixing Parameters of B Mesons*, arXiv:1102.4274 [hep-ph]

[9] K. A. Olive *et al.*, *Review of Particle Physics*, Chin. Phys. C 38 (2014) 090001

[10] C. Bobeth, M. Gorbahn, T. Hermann, M. Misiak, E. Stamou and M. Steinhauser, *$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty*, Phys. Rev. Lett. 112 (2014) 101801

[11] Y. Amhis *et al.*, *Averages of b-hadron, c-hadron, and τ-lepton properties as of summer 2014*, arXiv:1412.7515 [hep-ex] and online update at `http://www.slac.stanford.edu/xorg/hfag`