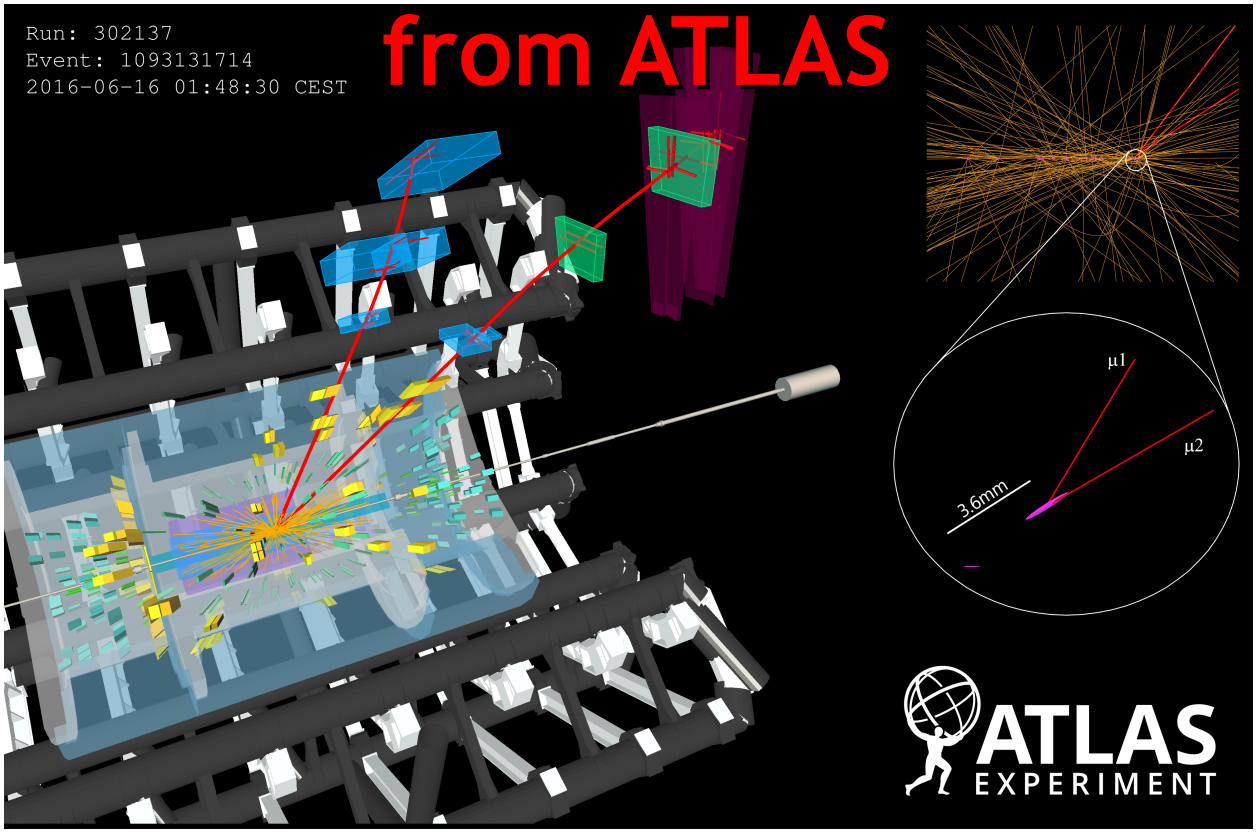
BEAUTY 2020
The 19th International Conference on B-Physics at Frontier Machines
21st - 24th September 2020
Kavli IPMU, University of Tokyo

Flavour highlights (and prospects) from ATLAS

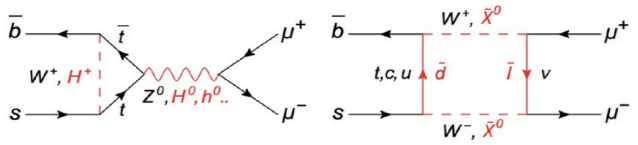


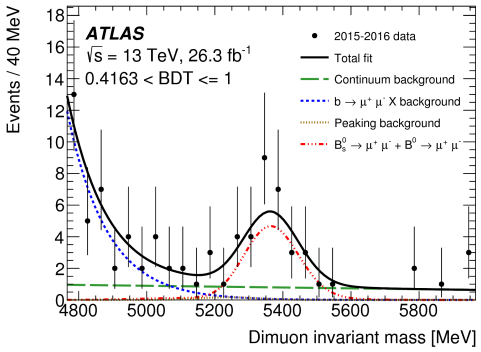
Pavel Řezníček
(Charles University, Prague)
on behalf of the ATLAS collaboration
pavel.reznicek@cern.ch

Rare b-hadron decays

- Search for deviations of (differential) branching ratio from the Standard Model predictions

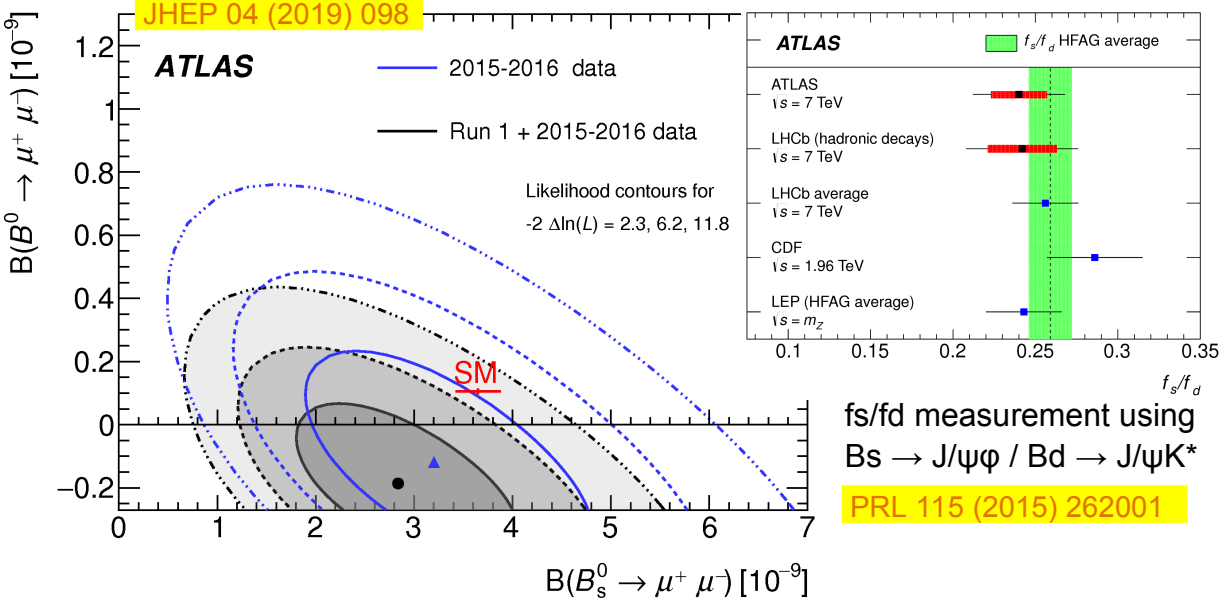
$B_{(s)} \to \mu\mu$





- Dimuon invariant mass fit projection in the BDT interval with most significant signal

JHEP 04 (2019) 098



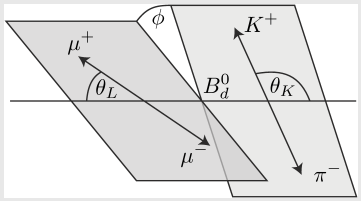
fs/fd measurement using Bs → J/ψφ / Bd → J/ψK*

PRL 115 (2015) 262001

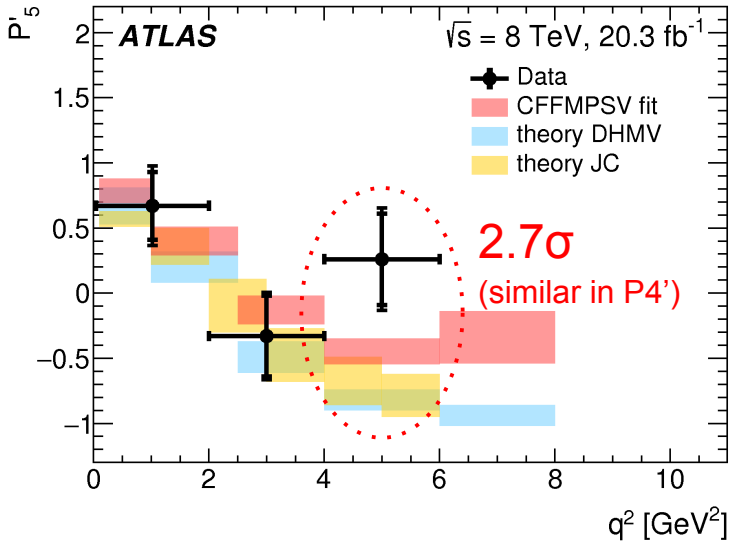
- $BR(B_s \to \mu\mu) = 3.2^{+1.1}_{-1.0} \times 10^{-9}$
- $BR(B_d \to \mu\mu) < 4.3 \times 10^{-10}$

$B_d \to K^*\mu\mu$

- Decay angles analysis in bins of di-muon invariant mass (q)



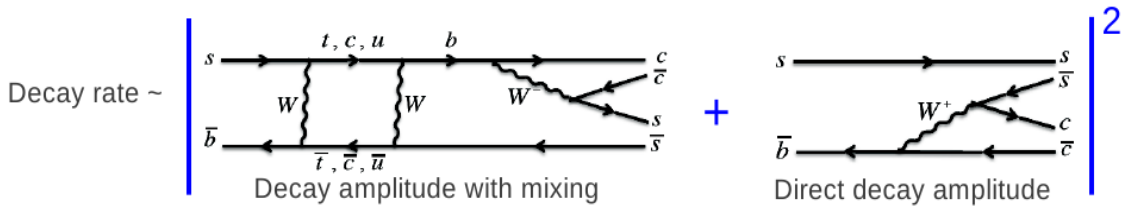
JHEP 10 (2018) 047

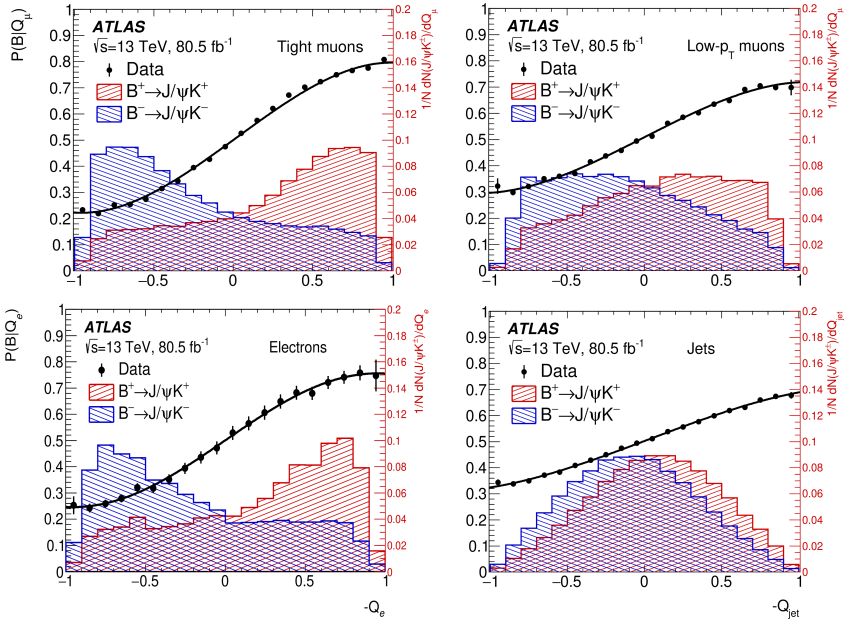


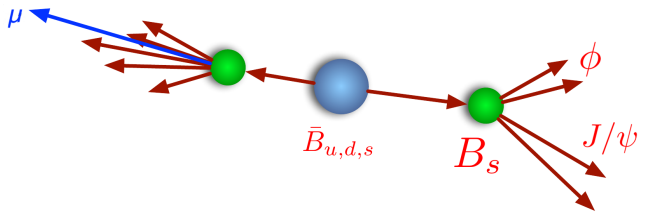
- P5' shift w.r.t. theory prediction in 3rd q^2 bin in similar direction as deviation at LHCb

CPV and oscillations

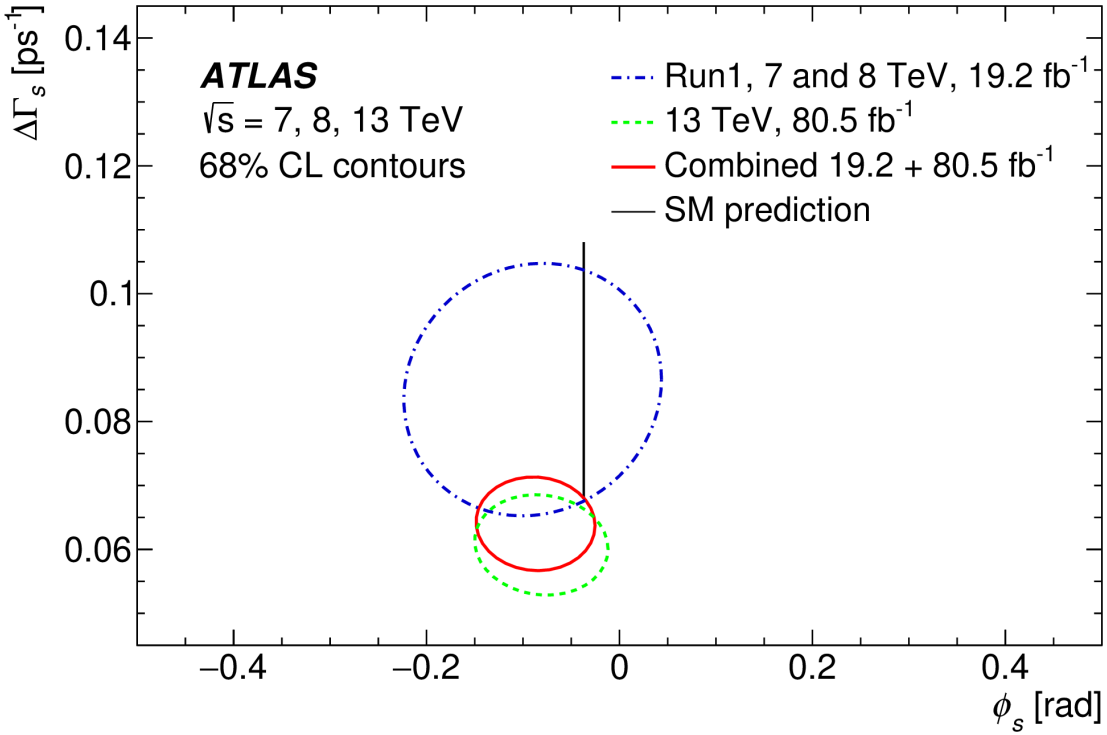
- Measurement of CPV in the interference of mixing and direct decay of $B_s \rightarrow J/\psi\varphi$
- Time-dependent flavour tagged angular analysis
- Unbinned max. likelihood fit with nine physics parameters including S-wave







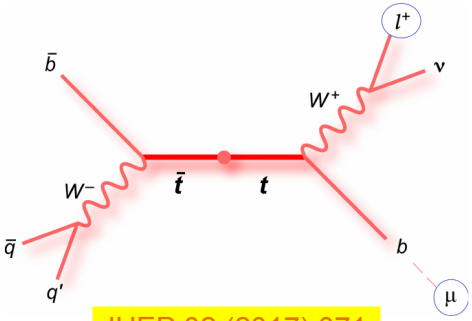
arXiv:2001.07115 submitted to EPJC



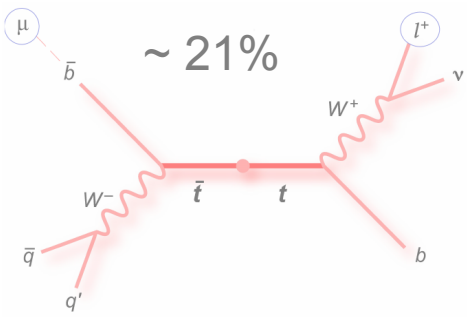
- Almost 500k signal candidates
- Improved precision with partial Run 2 data, consistent with SM

CPV and oscillations (2)

- CP asymmetries in b-hadrons from top
- Direct: $P(b \to l^+X) \neq P(b \to l^-X)$
  Mixing: $P(b \to \bar{b} \to l^+X) \neq P(\bar{b} \to b \to l^-X)$



JHEP 02 (2017) 071



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

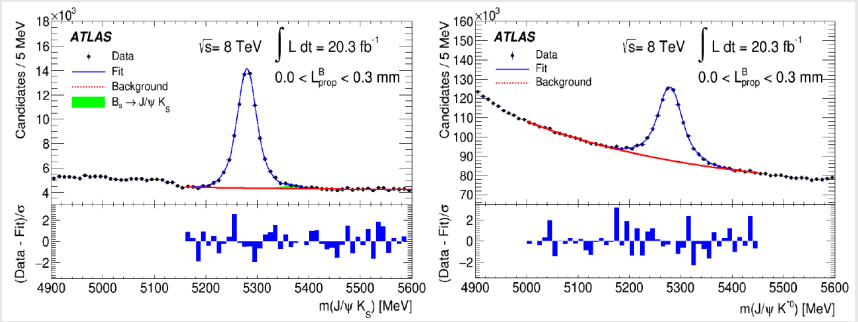
- CP asymmetries related to B-mixing and CPV in direct b- and c-decays

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

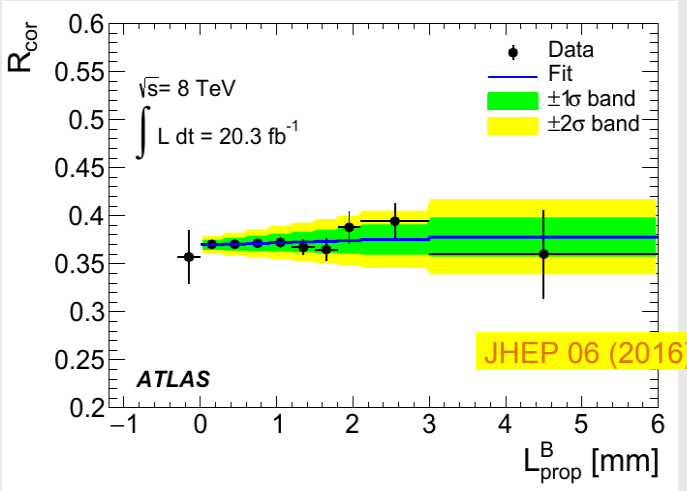
$$A^{\mathrm{os}} = \tilde{r}_b A^{b\ell}_{\mathrm{dir}} + \tilde{r}_c \left(A^{bc}_{\mathrm{mix}} + A^{c\ell}_{\mathrm{dir}}\right) + \tilde{r}_{c\bar{c}} A^{c\ell}_{\mathrm{dir}}$$

- Results consistent with zero (SM) with uncertainties at the level of 10^{-2}

- Novel technique in measurement of B^0_d decay with difference
- $\Delta\Gamma_d/\Gamma_d$ obtained from comparison of $B^0 \to J/\psi K_S$ and $B^0 \to J/\psi K^{*0}(892)$ decay time distributions (bins of L^b_{prop})



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



JHEP 06 (2016) 081

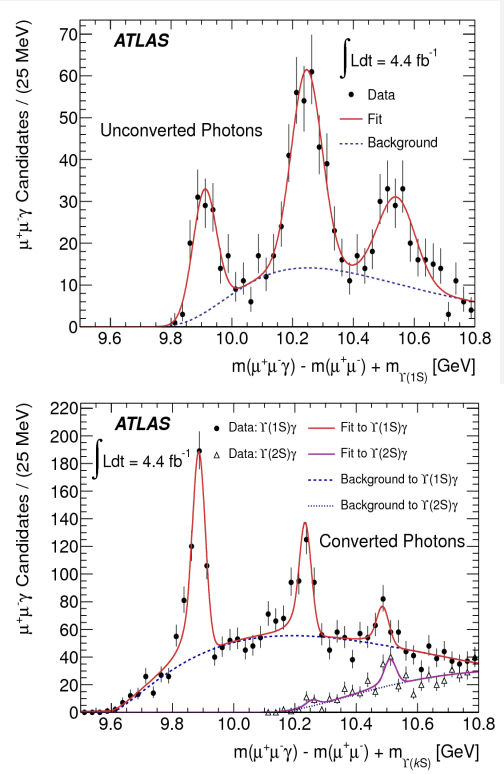
- Run 1 only, but most precise determination of $\Delta\Gamma_d/\Gamma_d$

Spectroscopy

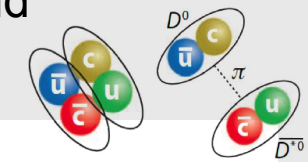
- Search for excited and exotic heavy flavor states

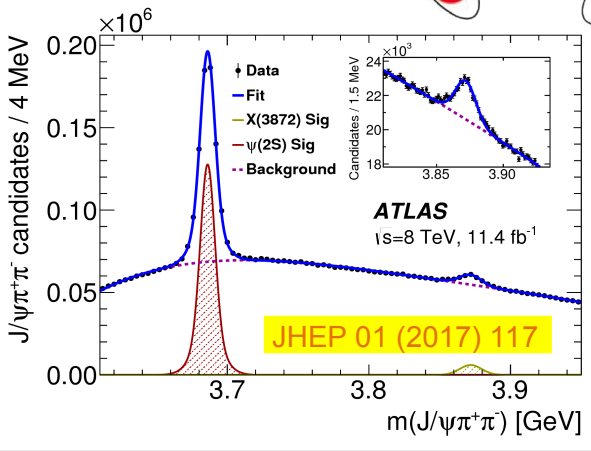
- First new particle seen by ATLAS:
  $\chi_b(3P) \rightarrow \Upsilon(1,2S)\gamma$

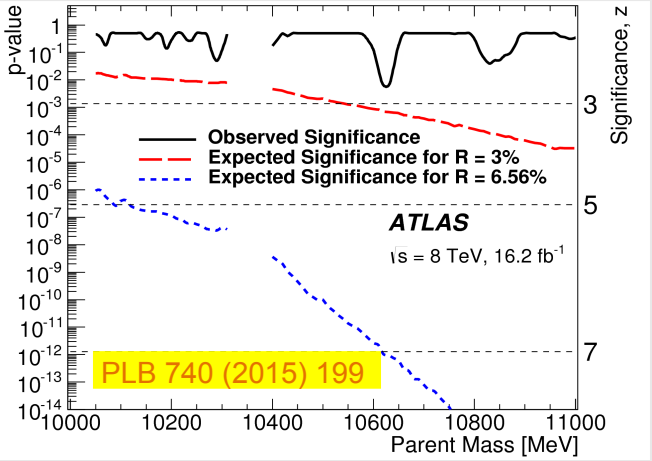
PLB 713 (2012) 387



- $X(3872) \rightarrow J/\psi\pi\pi$ production and $\pi\pi$ spectrum



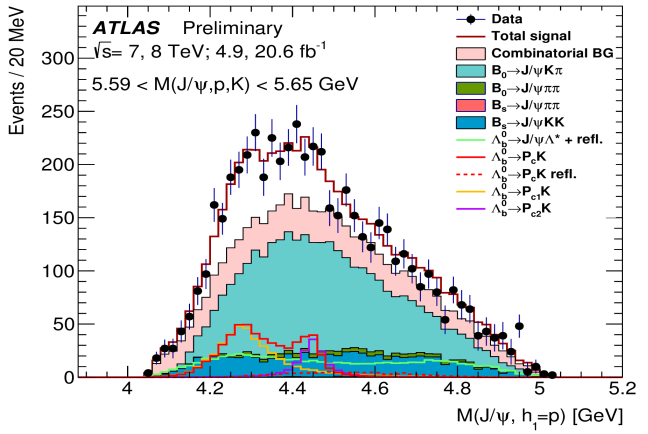


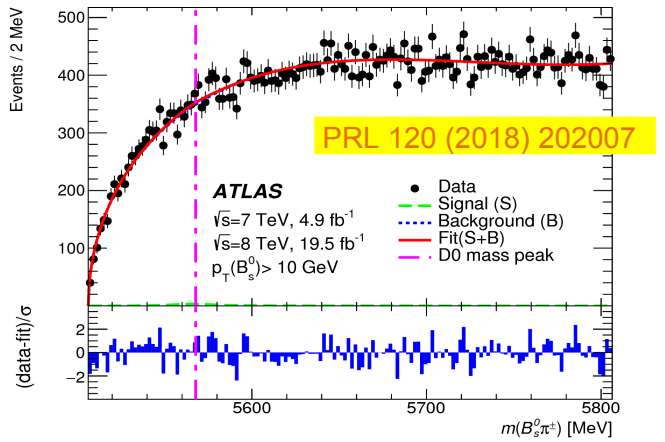


- Search for $X_b \rightarrow \Upsilon(1S)\pi\pi$ most stringent limits in range

- Pentaquark search in $\Lambda_b \rightarrow (J/\psi p)K$ decays
- Data best consistent with >= two pentaquark states (ala LHCb)

ATLAS-CONF-2019-048





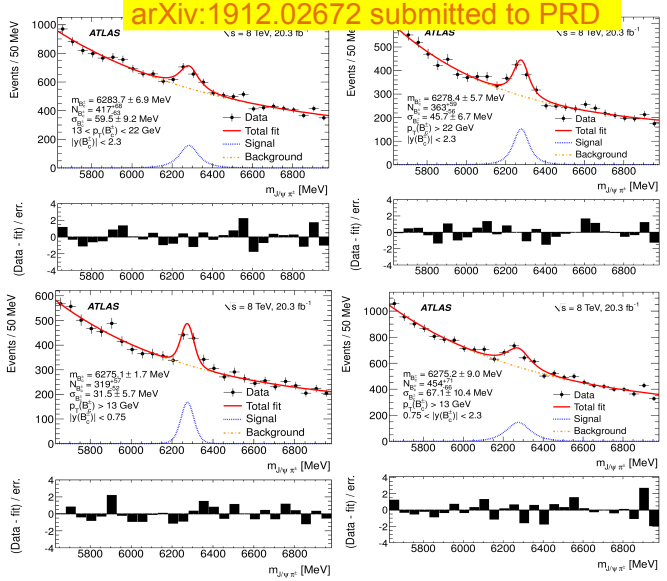
- Search for "DØ" tetraquark $X \rightarrow B_s\pi$, no evidence

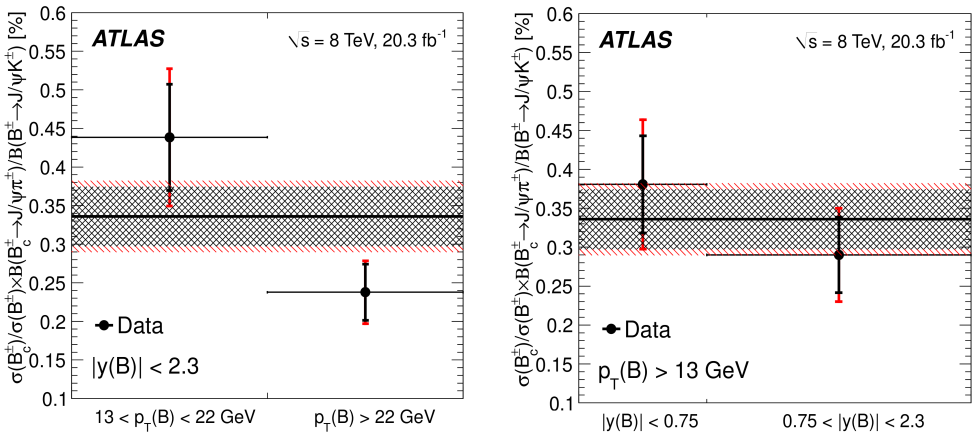
Spectroscopy (B_c)

- Analysis of double-heavy state ($\bar{b}c$) using $B_c \rightarrow J/\psi\pi^+$ decay

- Differential x-section measurement relatively to $B^+ \rightarrow J/\psi K^+$

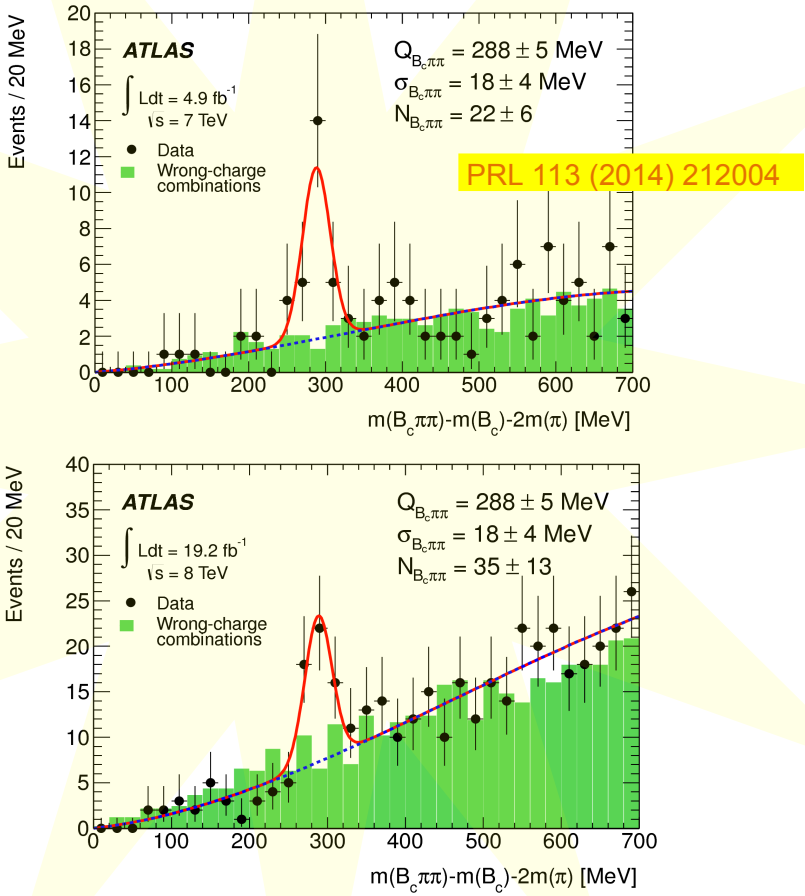
arXiv:1912.02672 submitted to PRD





Faster decrease with p_T

- First experiment observing $B_c(2S)$ state in the $B_c(2S) \rightarrow B_c\pi\pi$ decay



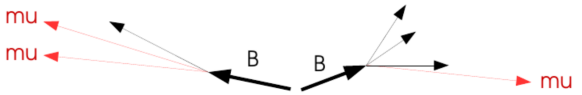
$$Q = m(B_c^{\pm}\pi^+\pi^-) - m(B_c^{\pm}) - 2m(\pi^{\pm})$$

$$Q = 288.3 \pm 3.5 \pm 4.1 \text{ MeV}$$

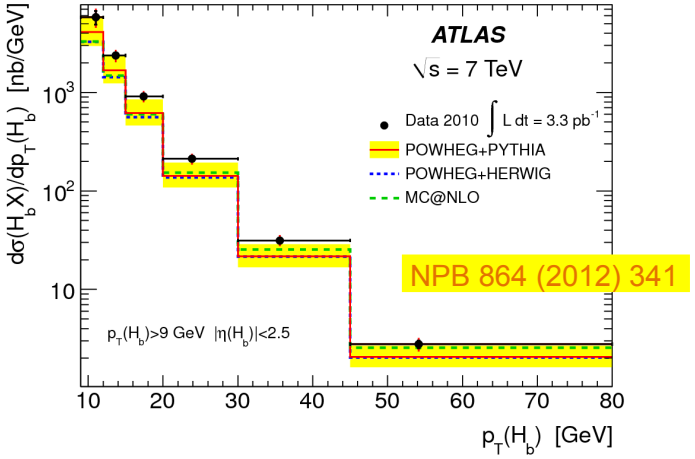
m(Bc(2S)) = 6842 ± 4 ± 5 MeV

Production of b and c hadrons

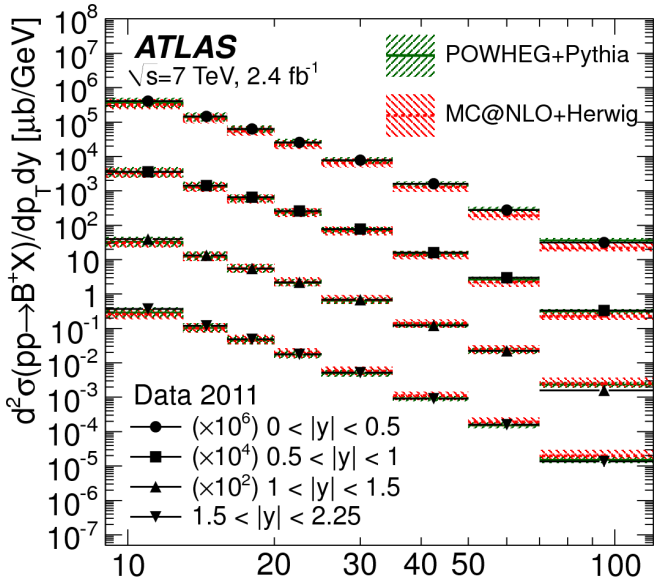
- Testing predictions of QCD and modeling in the MC generators



- b-hadron production using $H_b \rightarrow D^*\mu X$
  B^+ production using $B^+ \rightarrow J/\psi K^+$

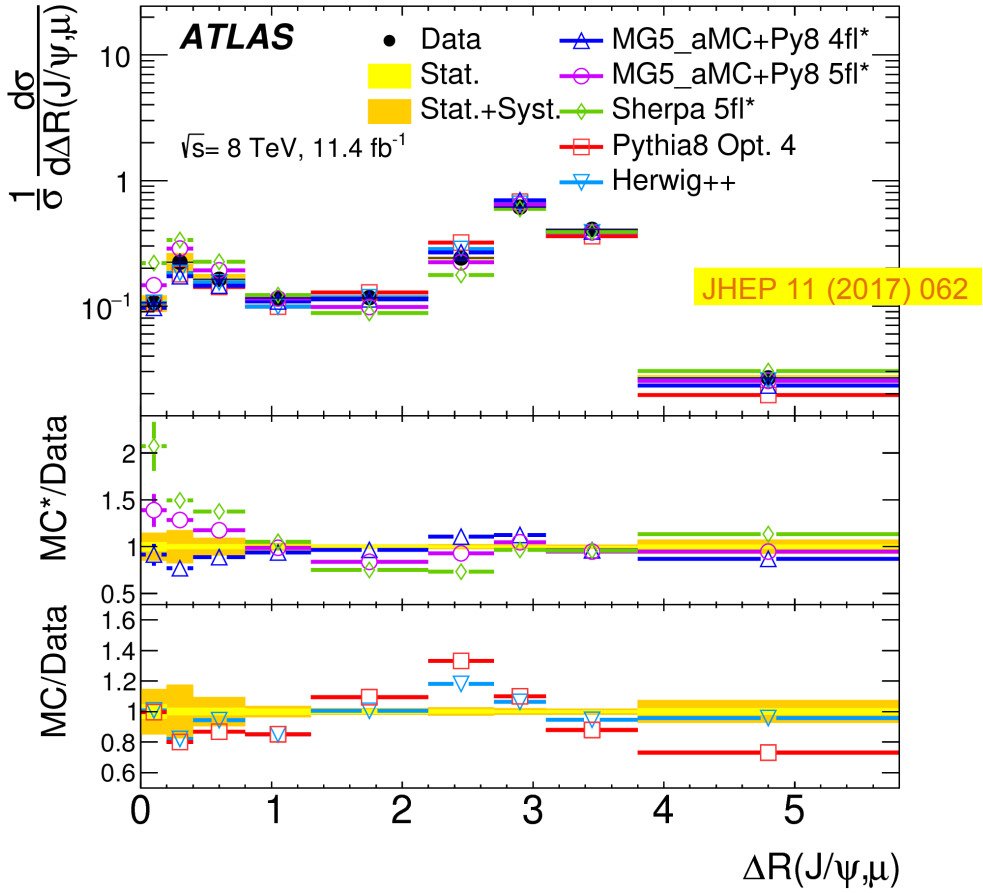


NPB 864 (2012) 341



JHEP 10 (2013) 042

- Production of b-hadron pairs using
  $H_b \rightarrow J/\psi X$ and $H_b \rightarrow \mu X$

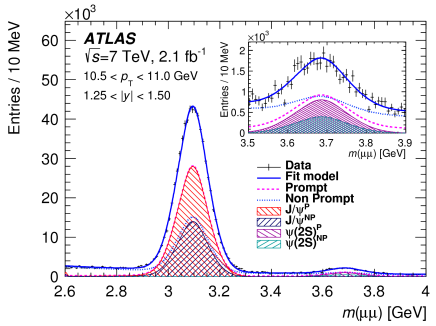


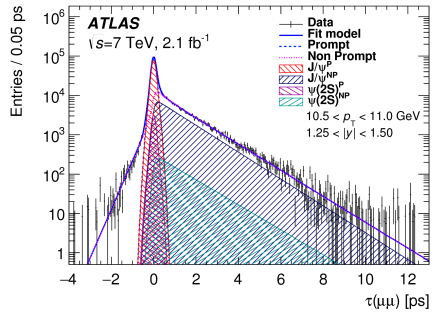
JHEP 11 (2017) 062

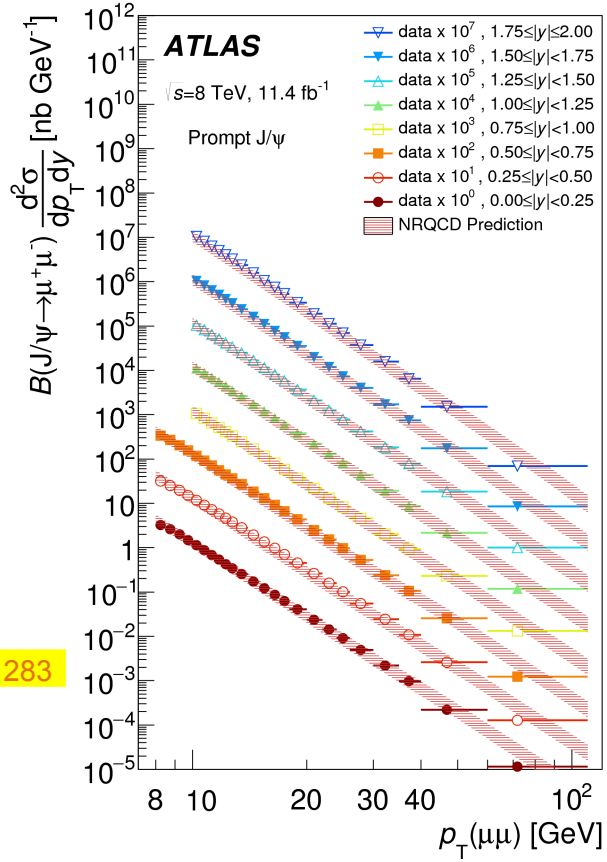
- Tested number of MC generators and Pythia8 $g \rightarrow b\bar{b}$ splitting functions
- 10 variables studied, provide input to MC

Production (quarkonia)

- Huge sample of J/ψ, ψ(2S) and Upsilon decays (→ μμ) allowing for thorough test of QCD calculation predictions in bins of η and p_T, and reaching very high p_T regions (→ 360 GeV)
- Prompt (NRQCD) and non-prompt (FONLL), directly or from feed-down
- Mass-pseudo-propertime fit, probing various spin-alignment

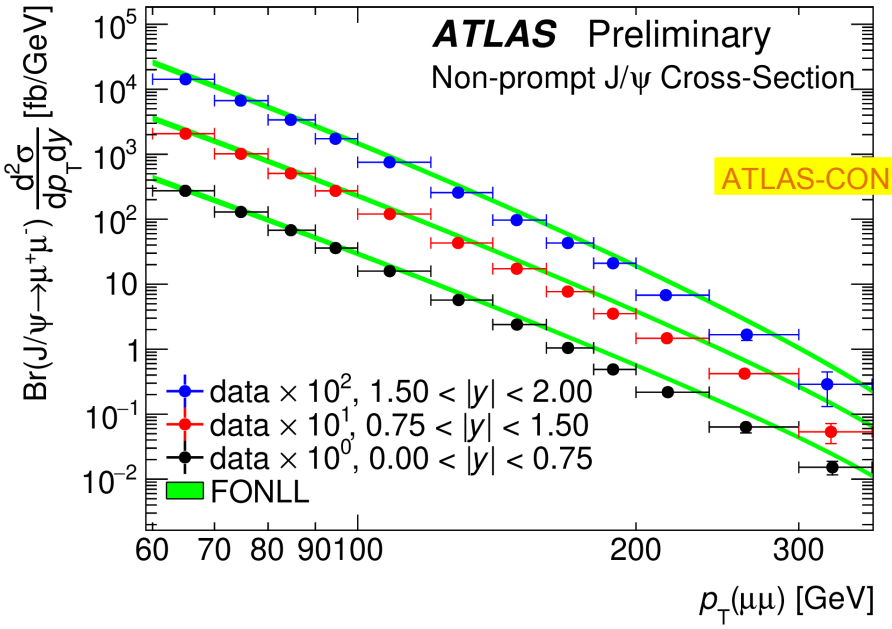






EPJC 76 (2016) 283

Run 1 and Run 2 (high-p_T) results

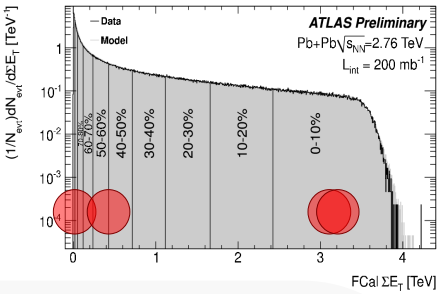


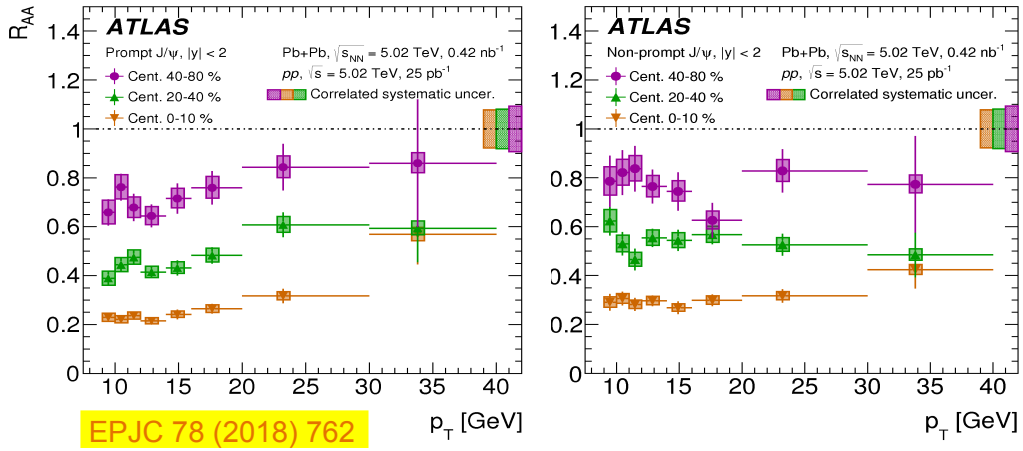
ATLAS-CONF-2019-047

Production (quarkonia in HI collisions)

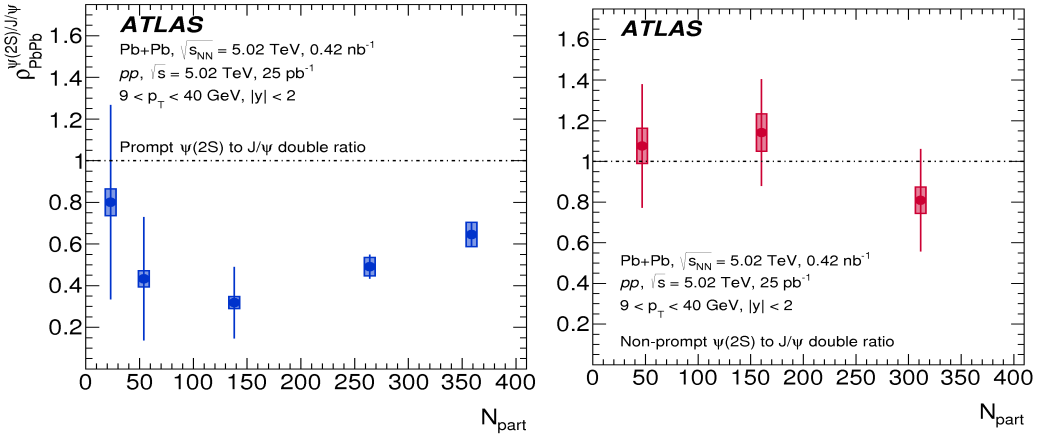
- Quarkonia production in A+A collisions probes deconfined quark/gluon plasma
  - suppression (degree of deconfinement) and enhancement ($c\bar{c}$ recombination) wrt. pp
  - suppression of higher degree states
  - non-prompt allows to study b-quark propagation through medium
  - p+A to disentangle cold nuclear matter effects
  - centrality dependence

Centrality characterized by E_T in forward calorimeter (FCAL)

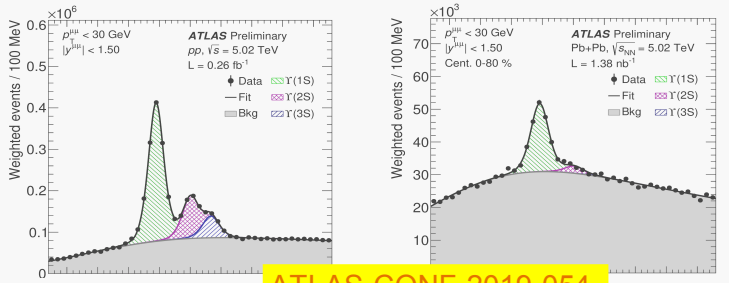




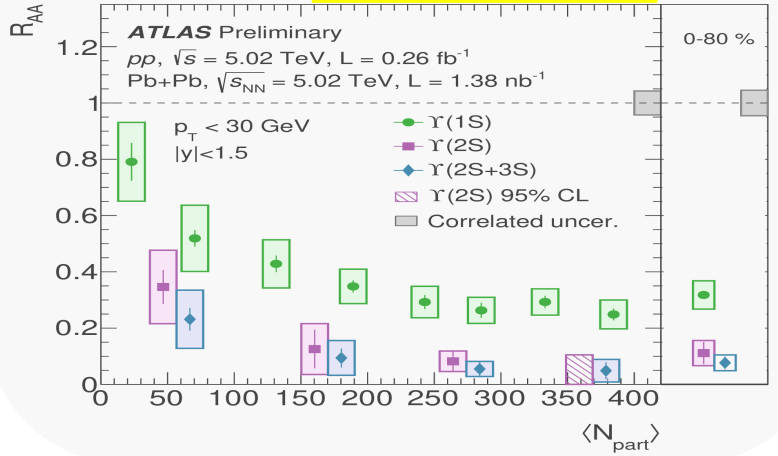
EPJC 78 (2018) 762



Upsilon suppression in HI



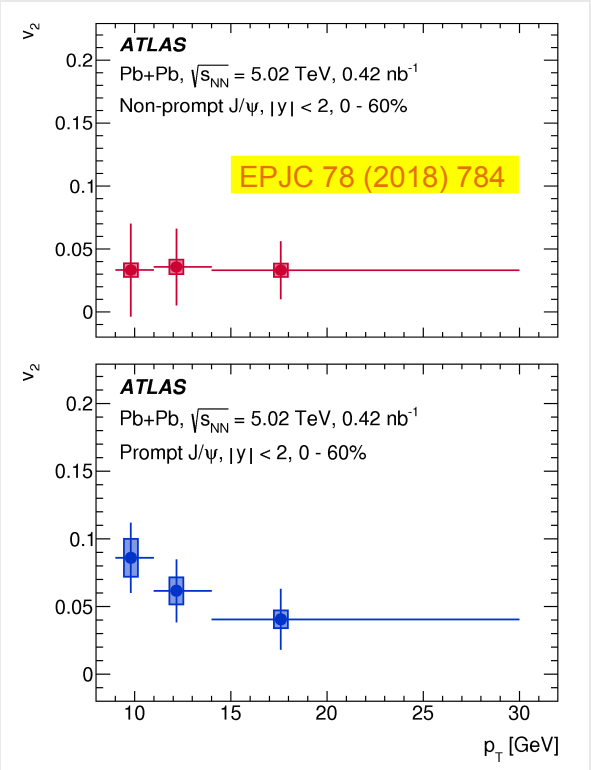
ATLAS-CONF-2019-054



Charm and beauty flow in HI collisions

- Azimuthal asymmetry in production provides another probe of the deconfinement
  - initial geometric inhomogeneities of QGP → momentum anisotropies
  - v_2 characterizes the deviation from the elliptic shape: $\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Psi_n)]$
  - HF quarks thermal production suppressed in QGP → produced at earliest times parton collisions → persist thorough the time evolution of QGP → probe the medium

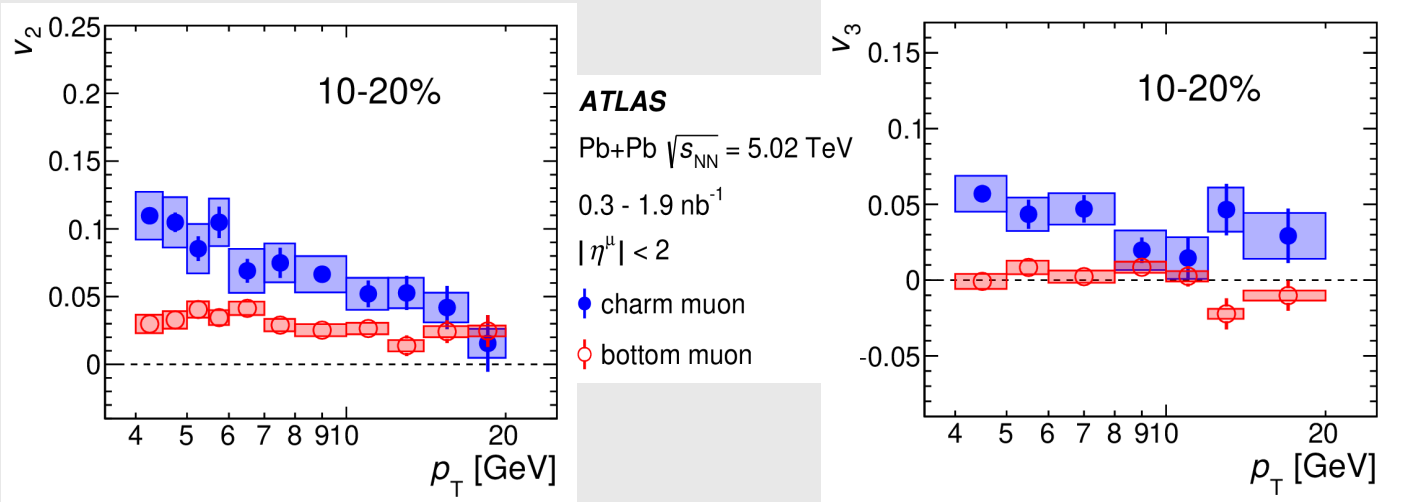
J/ψ flow observed, higher for prompt low-p_T



Elliptic flow for muons from HF decays:

- μ from charm: non-zero v_2 and v_3 up to ~20 GeV
- μ from beauty: non-zero v_2 up to ~20 GeV
- v_3 first measured for beauty (consistent with zero)

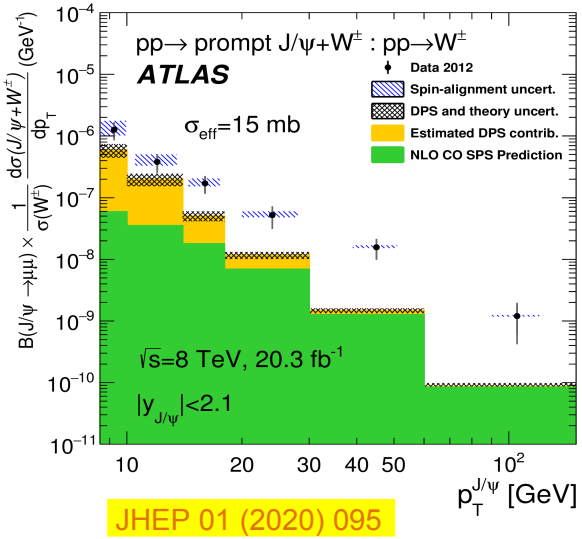
PLB 807 (2020) 135595



Associated production (quarkonia)

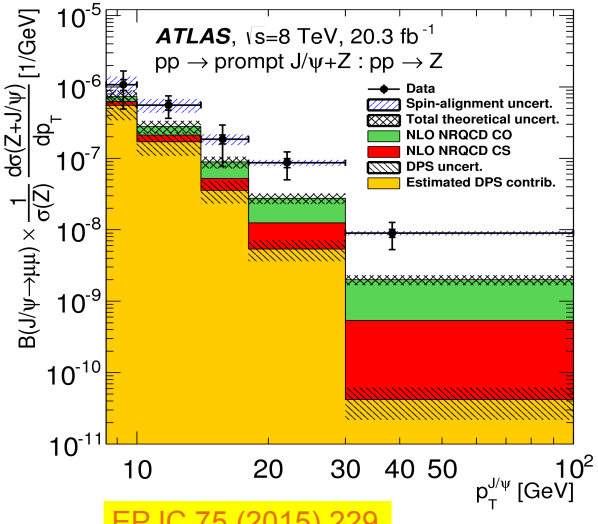
- Testing prediction of QCD, in particular color singlet/octet processes contributions

W + J/ψ



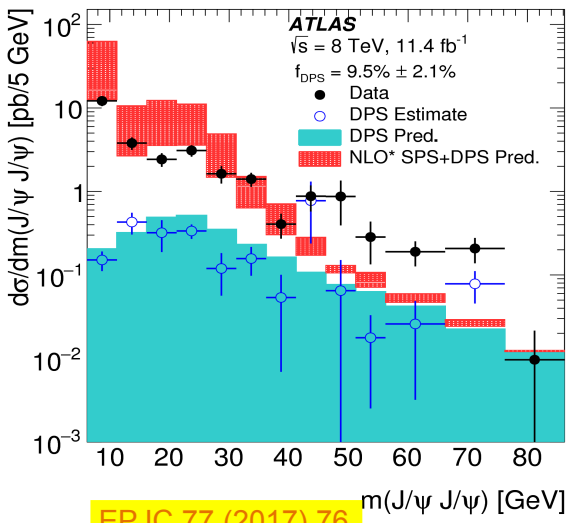
JHEP 01 (2020) 095

Z + J/ψ



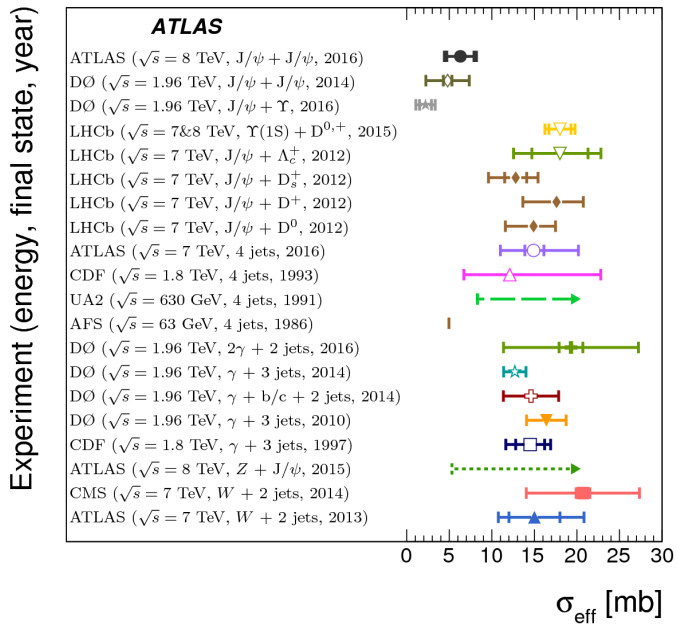
EPJC 75 (2015) 229

J/ψ + J/ψ



EPJC 77 (2017) 76

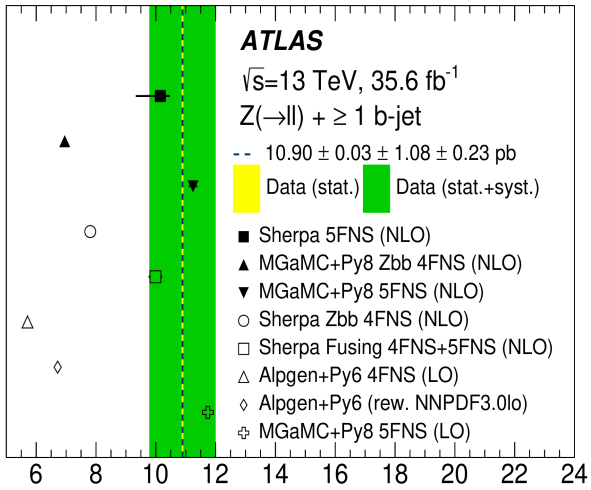
- W/Z+J/ψ: CO and CS models (and their sum) underestimates data. SPS excess or significant correlation in DPS that needs to be understood
- di-J/ψ: overestimate for high-p_T only
- Allow to extract DPS effective x-section (dominating in large Δφ regions)



Production (HF-jets)

- Testing prediction of QCD, benchmark for MC predictions of background to Higgs measurements, BSM searches etc., constraints on b/c-quark PDFs, test of QCD radiation

Z + b-jet(s)



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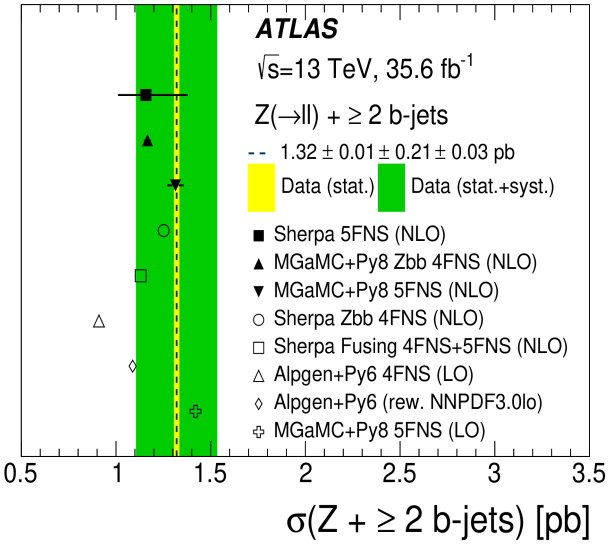
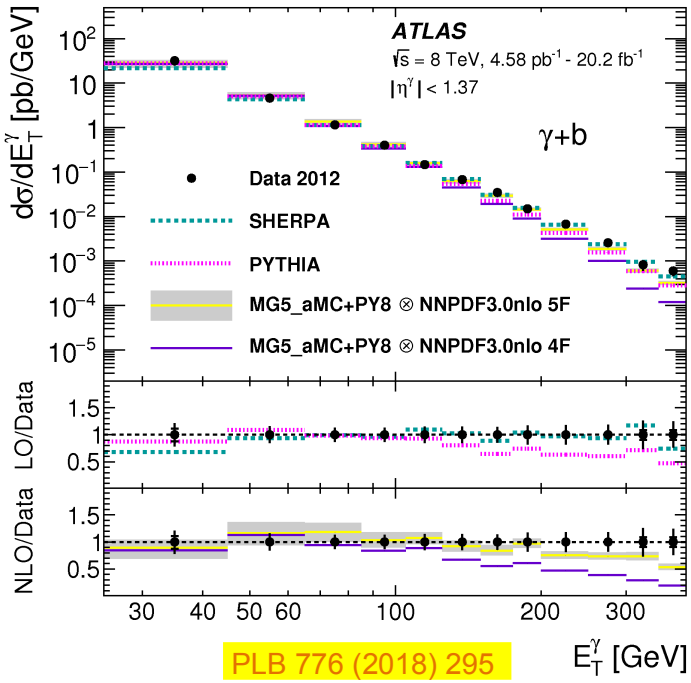


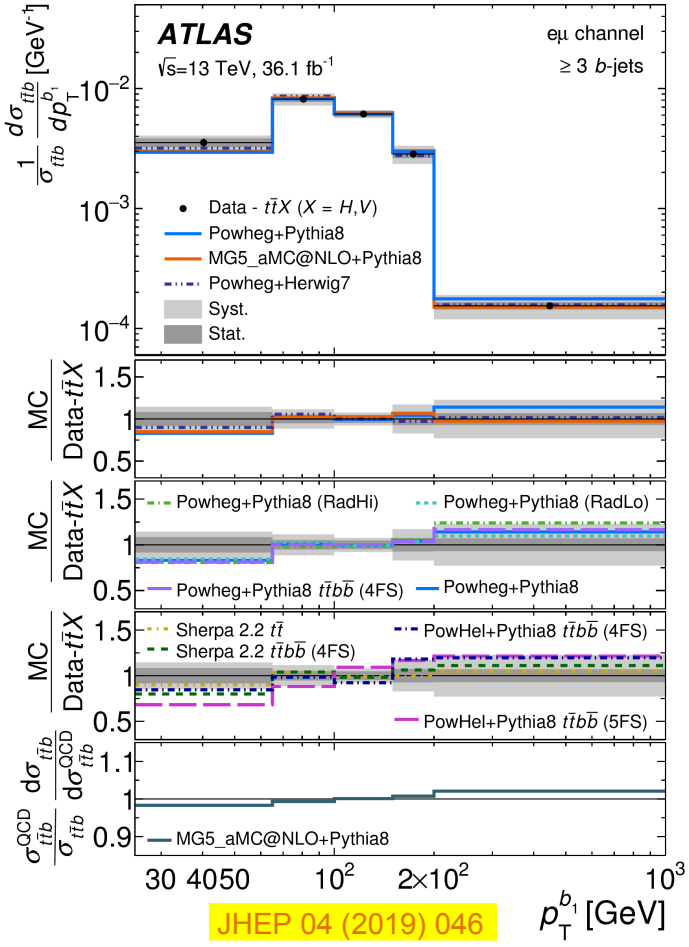
Isolated photon + b/c-jet(s)



PLB 776 (2018) 295

5-flavour scheme better describing data than 4-flavor

tt̄ + b-jet(s)

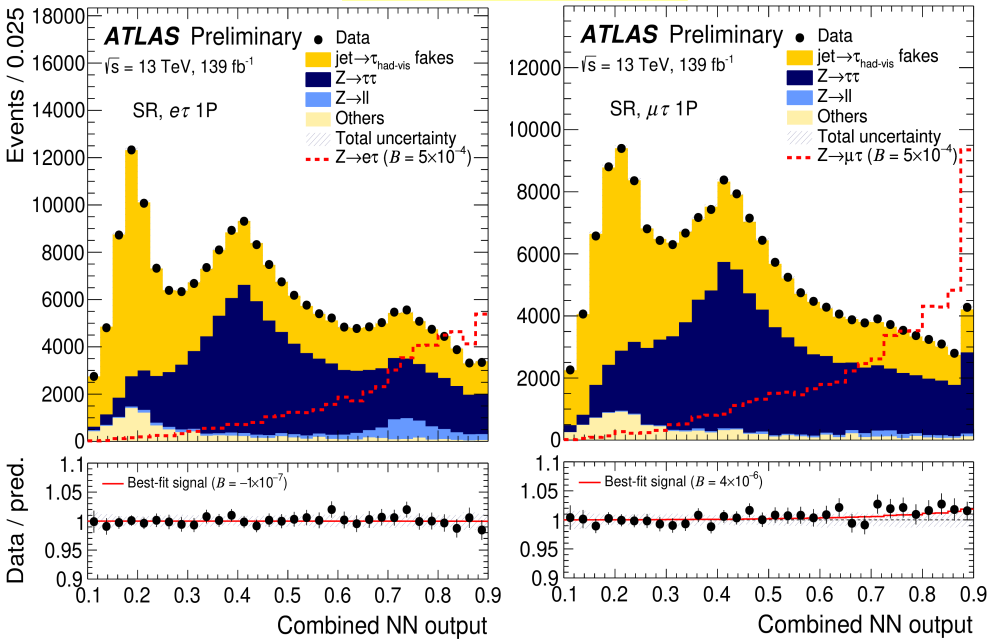


JHEP 04 (2019) 046

Lepton flavour violation & universality

- Large sample of Z-decays to look for $Z \rightarrow e\tau$ & $Z \rightarrow \mu\tau$ (τ hadronic decays)

ATLAS-CONF-2020-035

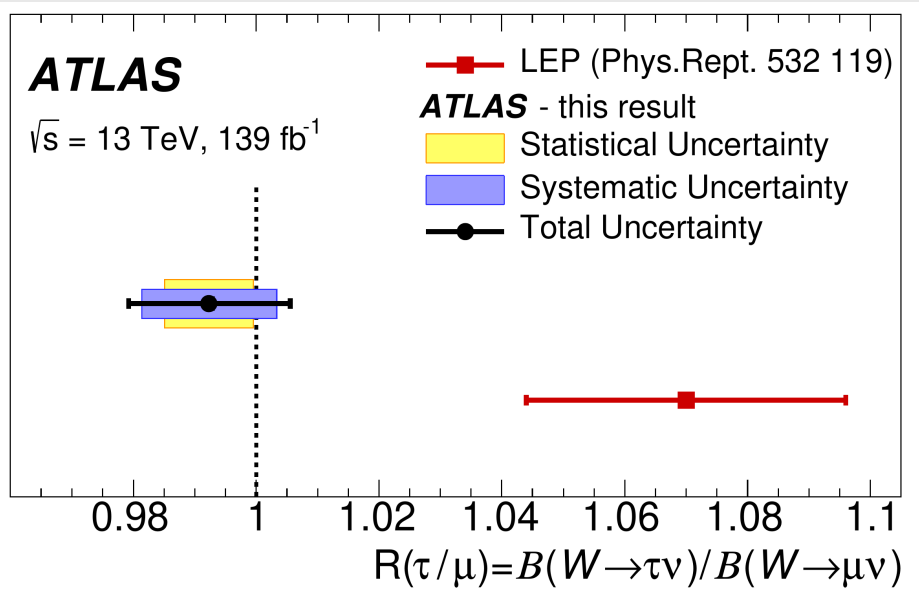


- Kinematic differences exploited using NN
- Best up to date limits:

$BR(Z \rightarrow e\tau) < 8.1 \times 10^{-6}$ (95% CL)

$BR(Z \rightarrow \mu\tau) < 9.5 \times 10^{-6}$ (95% CL)

- Large sample of W bosons from top decays to look for $W \rightarrow \tau\nu$ / $W \rightarrow \mu\nu$ (tau to muon decays)
- Also motivated by LEP result 1.070 ± 0.026

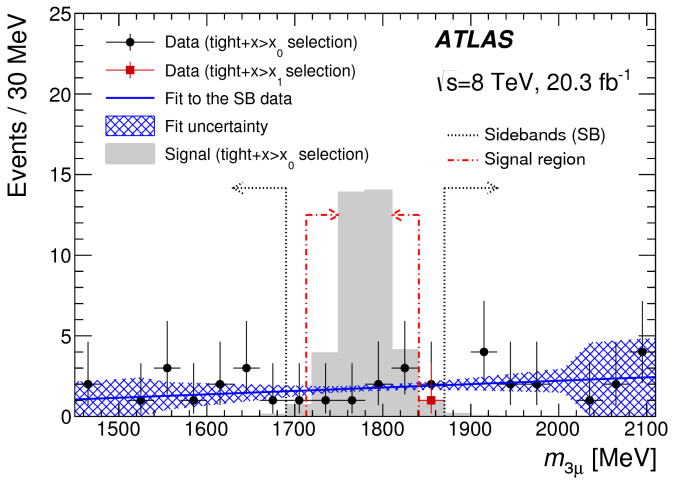


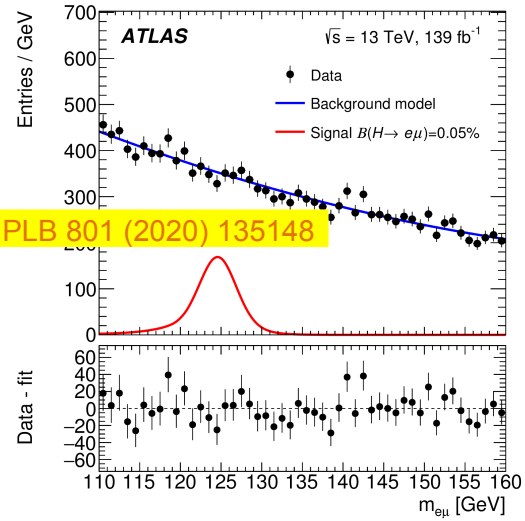
arXiv:2007.14040 submitted to Nature

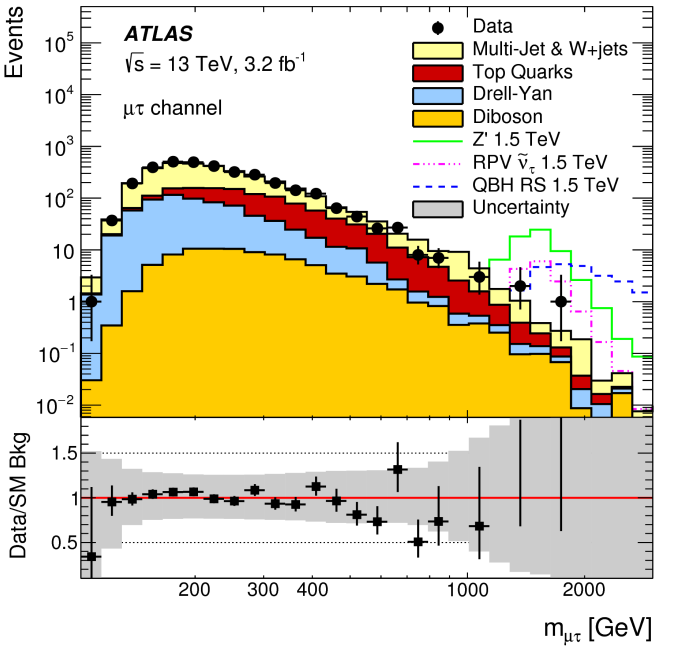
- R = 0.992 ± 0.013
- Consistent with unity
- Improves precision w.r.t. LEP measurement

Lepton flavour violation

- Search for LFV decay τ → μμμ EPJC (2016) 76:232
  - $BR_{90\%}(\tau \rightarrow \mu\mu\mu) < 3.76 \times 10^{-7}$
- Search for LFV in top decays t → ll'q ATLAS-CONF-2018-044
  - $BR_{95\%}(t \rightarrow ll'q) < 1.86 \times 10^{-5}$
  - $BR_{95\%}(t \rightarrow e\mu q) < 6.6 \times 10^{-6}$
- Search for LFV in Higgs decays:
  - $BR_{95\%}(H \rightarrow e\mu) < 6.1 \times 10^{-5}$ PLB 801 (2020) 135148
  - $BR_{95\%}(H \rightarrow \mu\tau) < 0.28\%$ PLB 800 (2020) 135069
  - $BR_{95\%}(H \rightarrow e\tau) < 0.47\%$
- Search for heavy particle decaying to eμ, eτ, μτ PRD 98 (2018) 092008
  - $Limits_{95\%}$ of 4.5, 3.7, 3.5 TeV on Z' mass
  - $Limits_{95\%}$ of 3.4, 2.9, 2.6 TeV on τ sneutrino with R-parity violating coupling
  - Limits on threshold mass for quantum black hole production





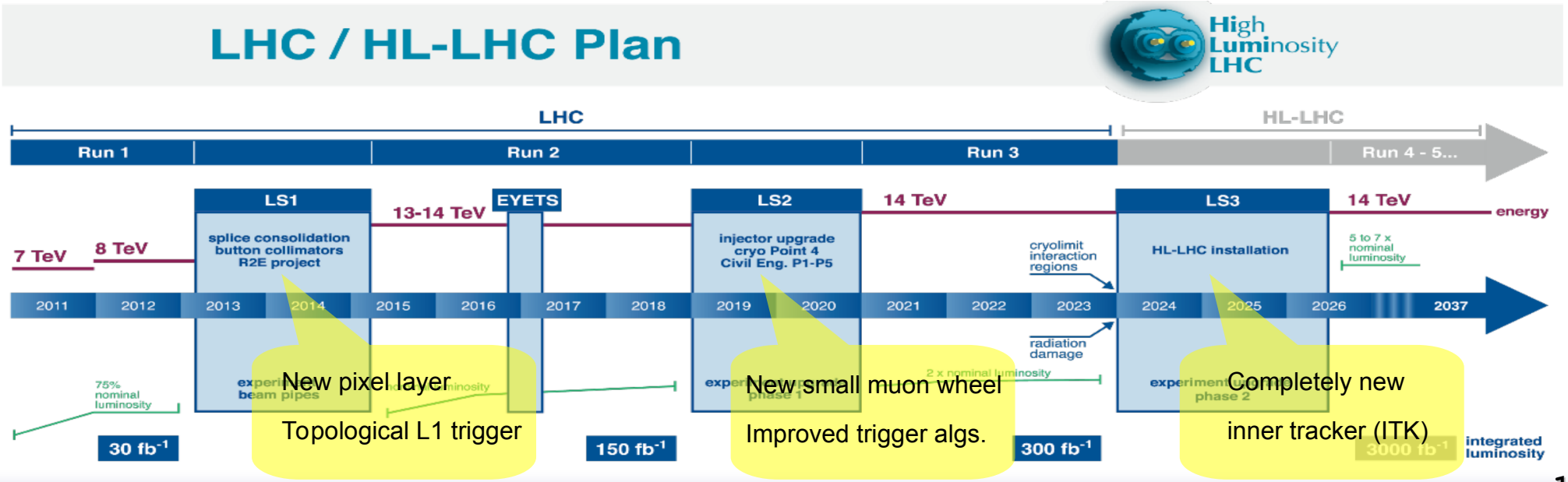


Summary and prospects for Run 2 & 3

- ATLAS has a rich heavy-flavour program involving:
  - Searches for NP in rare decays (precision test of SM) and LFV / LFU tests
  - Test of QCD predictions in b-quark / hadrons production and in spectroscopy
  - Probing QGP with heavy flavor

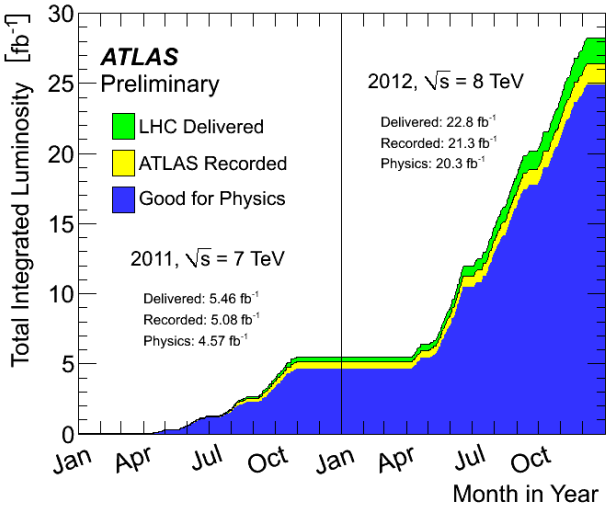
Number of analyses not covered by this talk !

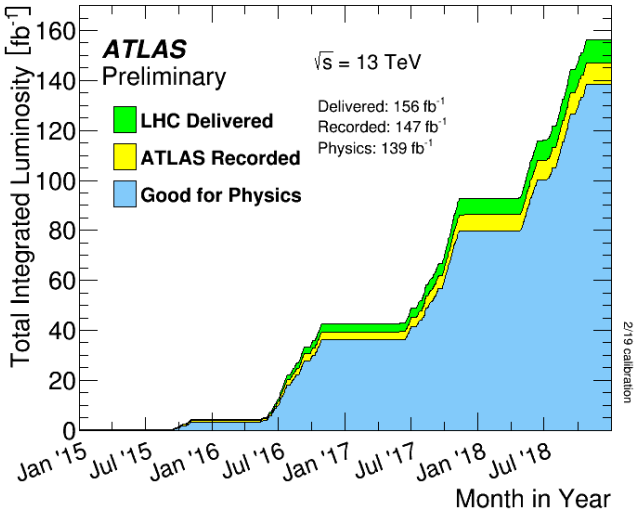
- Run 2 / 3 prospects:
  - Number of analyses still ongoing on Run 2 data (seldom using full dataset), gaining from IBL and L1-Topo
  - Majority of the current public results limited by statistics => will improve
  - New triggers allowing to probe B → eeX decays



Backup

Heavy flavour at ATLAS





- LHC $b\bar{b}$ production x-section ~ 500 μb
- ~ 10^{14} $b\bar{b}$ pairs produced !
- Aggressive trigger to fit storage rate (total ~1kHz)

- *Low*-p_T analyses searching for fully reconstructed b-hadron decays:
  - rare decays
  - b-hadron properties
  - CPV
  - b/c/quarkonia production
  - spectroscopy
- HF/quarkonia production in Heavy Ion collisions
- b-jets production
- LFV and LFU measurements