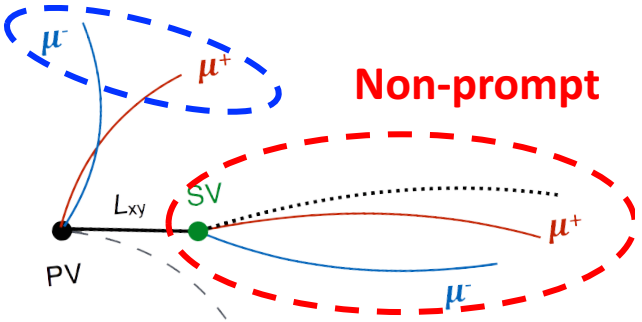
ATLAS 和 CMS 实验重味物理研究进展

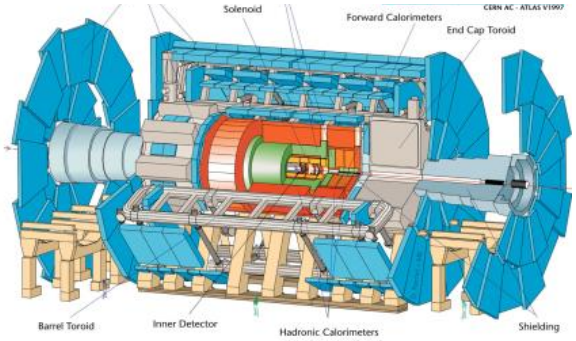
北京大学 王大勇

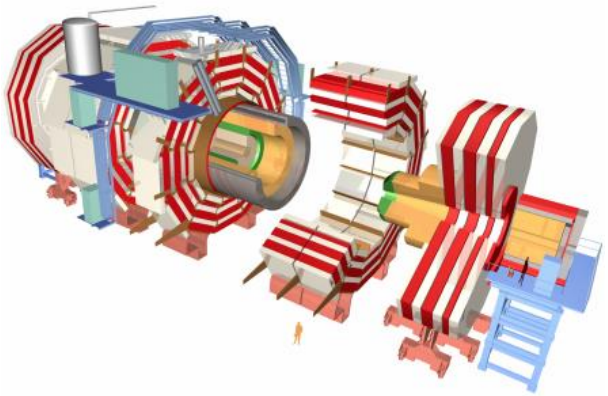
中国物理学会高能物理分会第十届全国粒子物理学术会议

上海 2018.6.22

ATLAS and CMS for HF studies







- Flexible triggers
- Large silicon tracker
- Strong magnetic field
- Broad acceptance
- Superb muon systems

(CMS parameters, ATLAS similar)

- Three different devices, coverage up to $|\eta|<2.4$
- Dimuon mass resolution ~0.6-1.5% (depending on $|y|$).
- Fake rate $\leq 0.1\%$ for pi,K; $\leq 0.05\%$ for proton, with very tight ID

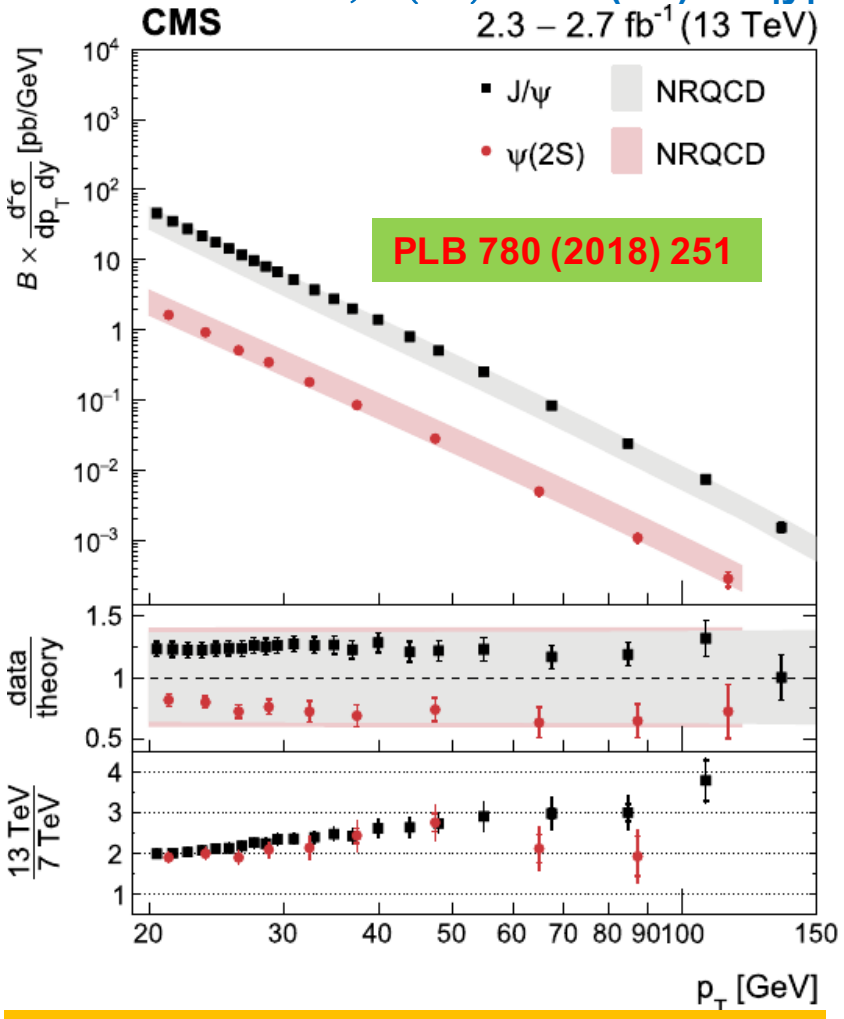
- Complementary to LHCb

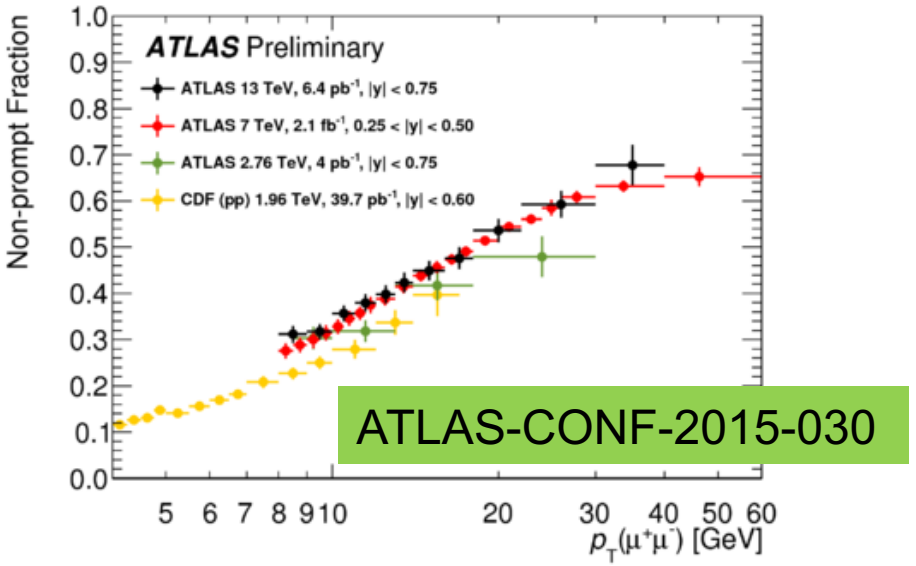
Recent results on selected topics

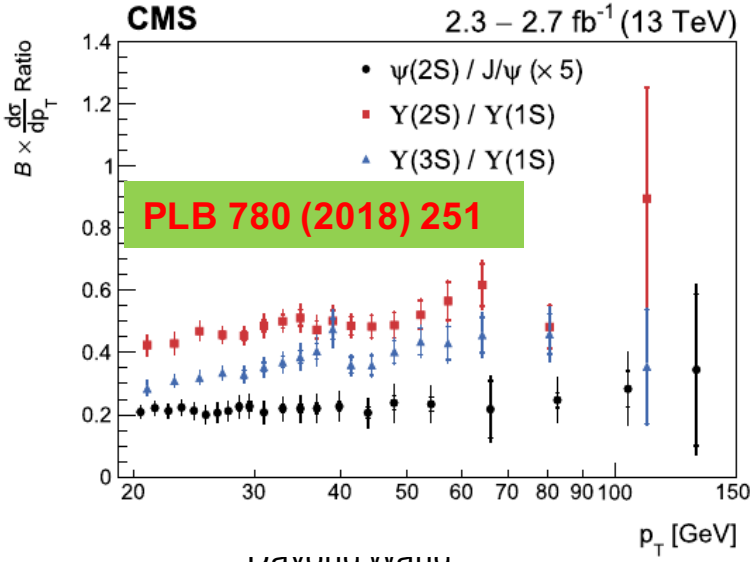
- Hadron production and polarization
- Spectroscopy and exotic states
- B decay property and angular analyses
- Disclaims
  - Not exclusive of all due to time limitation
  - No coverage of pA and AA results
  - Selections due to personal bias, esp the speaker is from CMS
  - More results from ATLAS and CMS can be found at:
    - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

Quarkonium production

Production of J/Ψ, Ψ(2S) and Υ(nS) for |y|<1.2 studied by CMS on 2.3-2.7 fb^{-1} of 13 TeV data

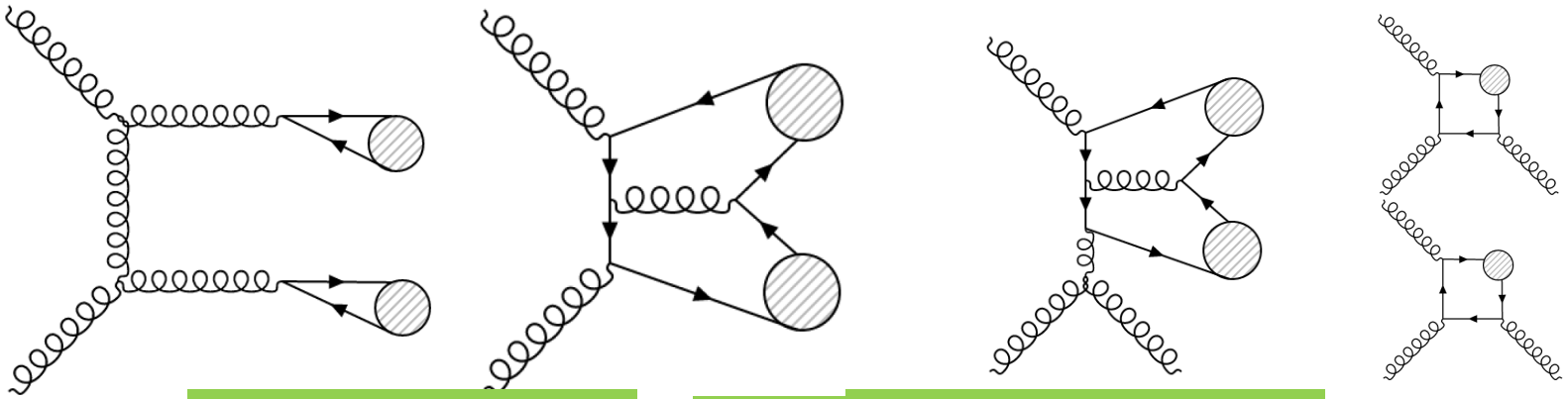






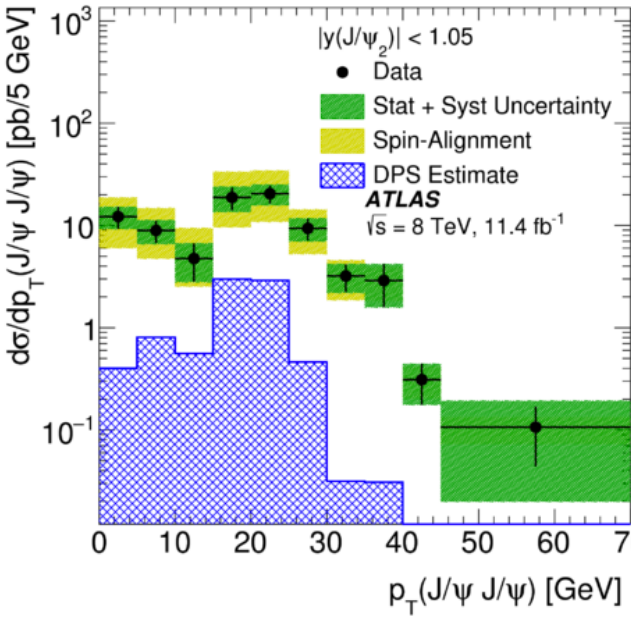
Results in reasonable agreement with NRQCD predictions

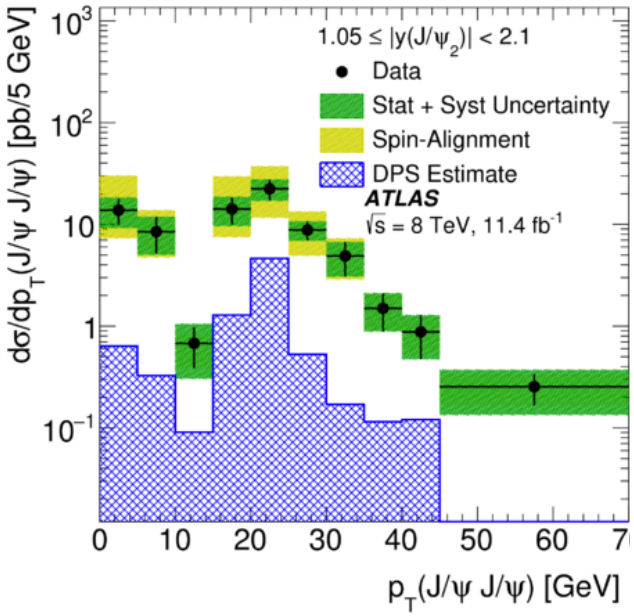
Prompt J/ψ pair production

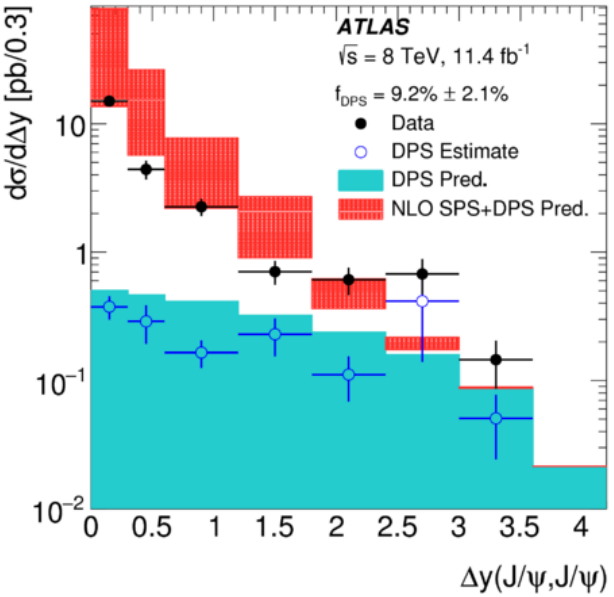


CMS:JHEP09(2014)094 **ATLAS: Eur.Phys.J. C77 (2017) 76**

J/ψ $p_T > 8.5$ GeV and rapidity $|y| < 2.1$

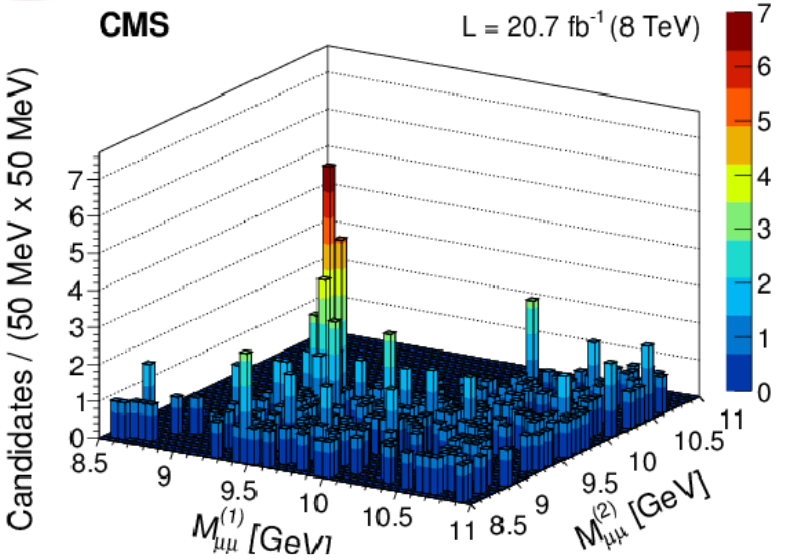






Y(1S) pair production@CMS

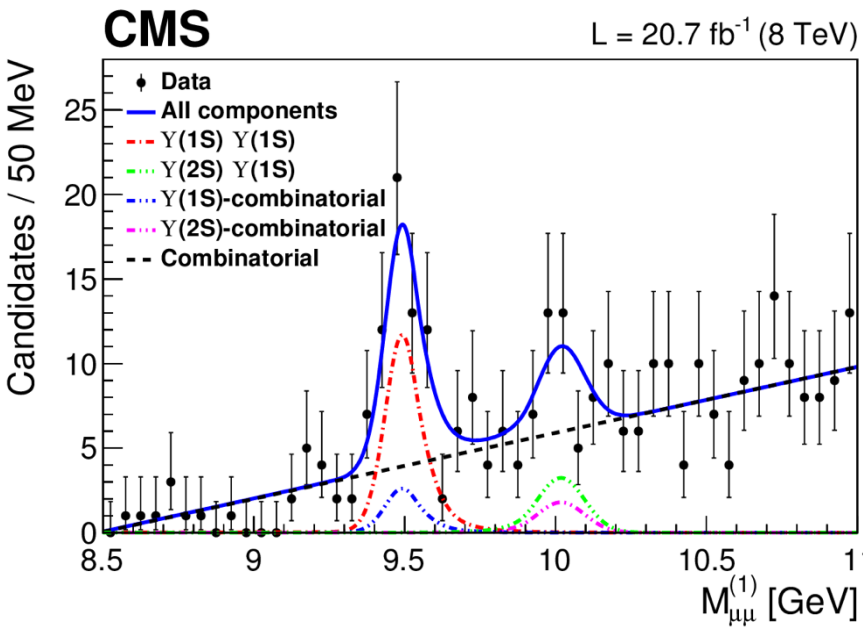
CMS: JHEP 05(2017) 013

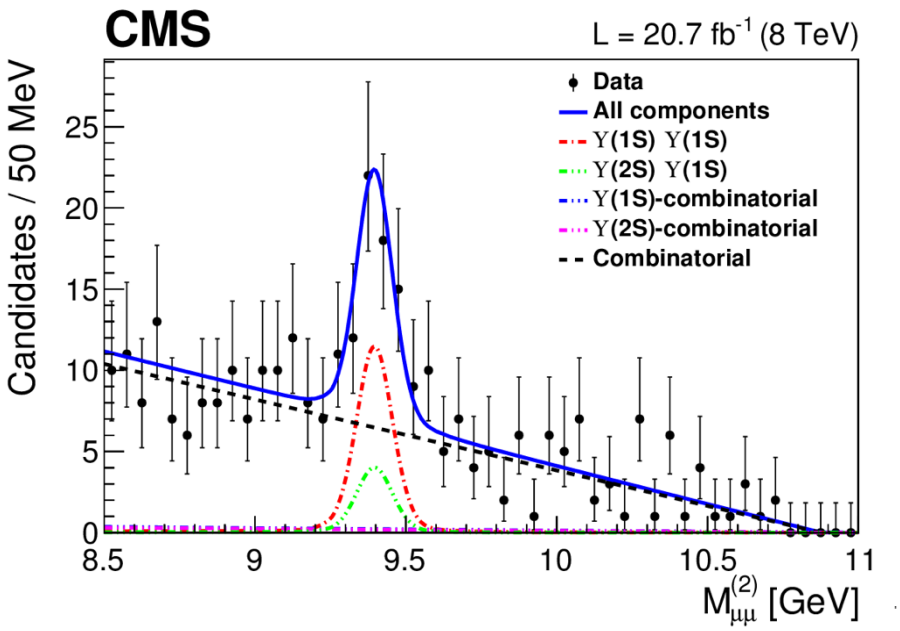


- Signal yield: 38+-7
- Significance > 5 σ, first observation
- The fiducial cross section with |y|<2.0:

$$\sigma_{\text{fid}} = 68.8 \pm 12.7\ (\text{stat}) \pm 7.4\ (\text{syst}) \pm 2.8\ (\mathcal{B})\ \text{pb}$$

- The effective cross section:consistent with the range of values from the heavy-quarkonium measurements





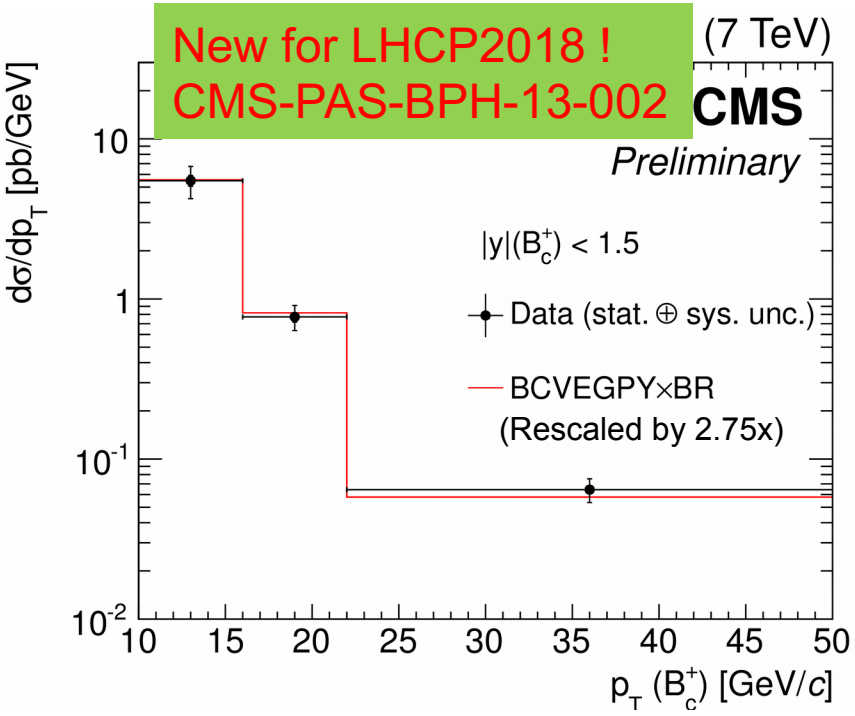
Measurement of B_c and B^+ cross sections

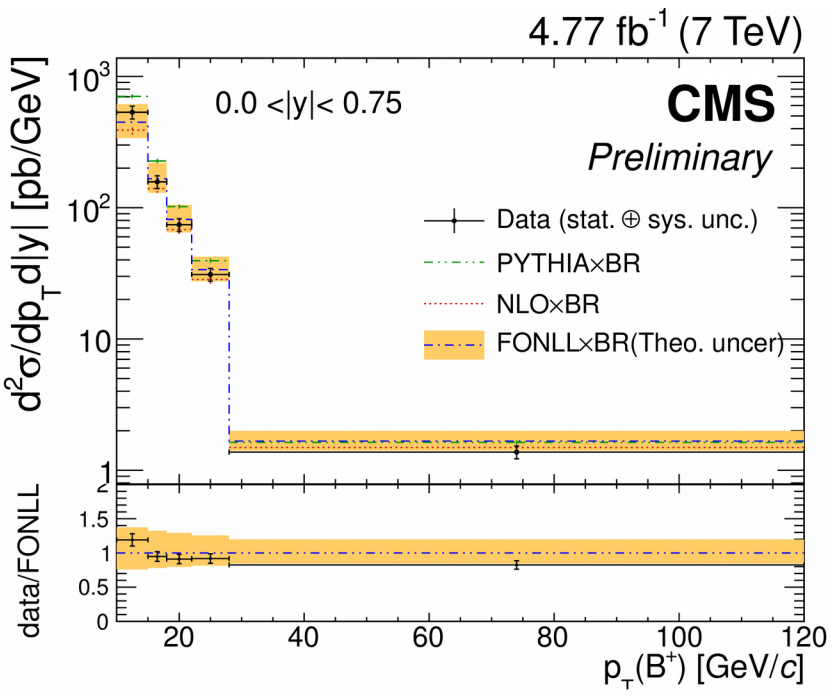
- **The integrated production cross sections times branching fraction**

$B_c^+ \to J/\psi\pi^+$: 40.8 ± 4.7 (stat) ± 2.8 (syst) pb [$p_T(B_c^+) > 10$ GeV and $|y|(B_c^+) < 1.5$]

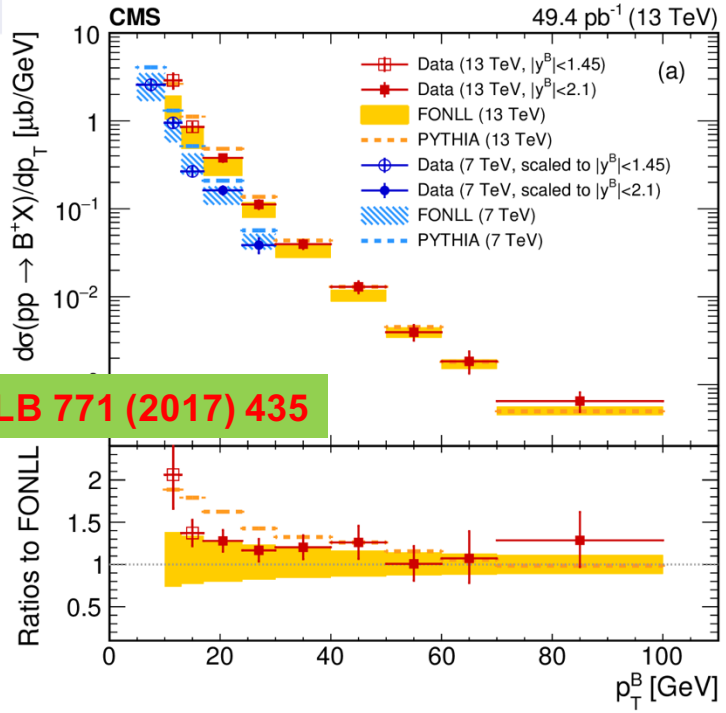
$B^+ \to J/\psi K^+$: 5851 ± 37 (stat) ± 446 (syst) pb [$p_T(B^+) > 10$ GeV and $|y|(B^+) < 1.5$]

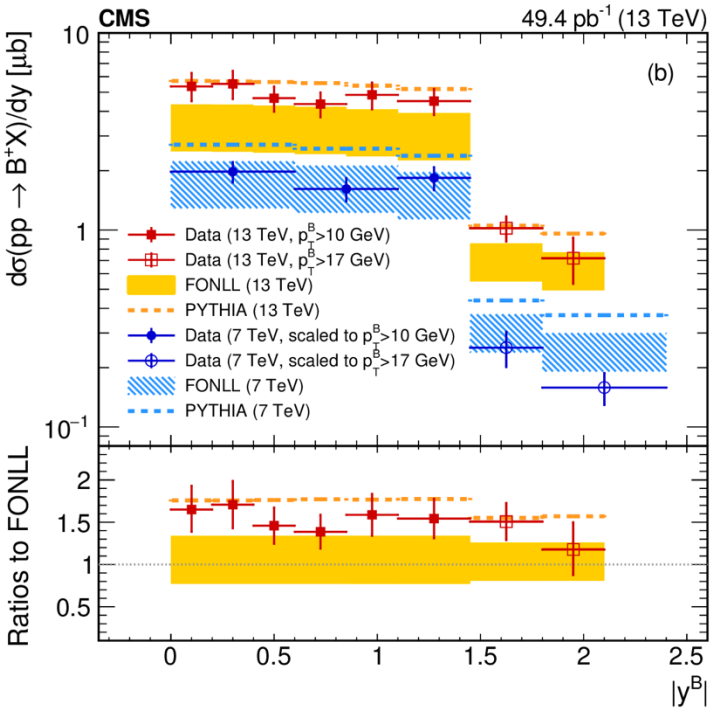
- **B_c shape in agreement with BCVEGPY, normalization off by ~2.75**
- **B^+ measurement consistent with PYTHIA, NLO, and FONLL predictions**



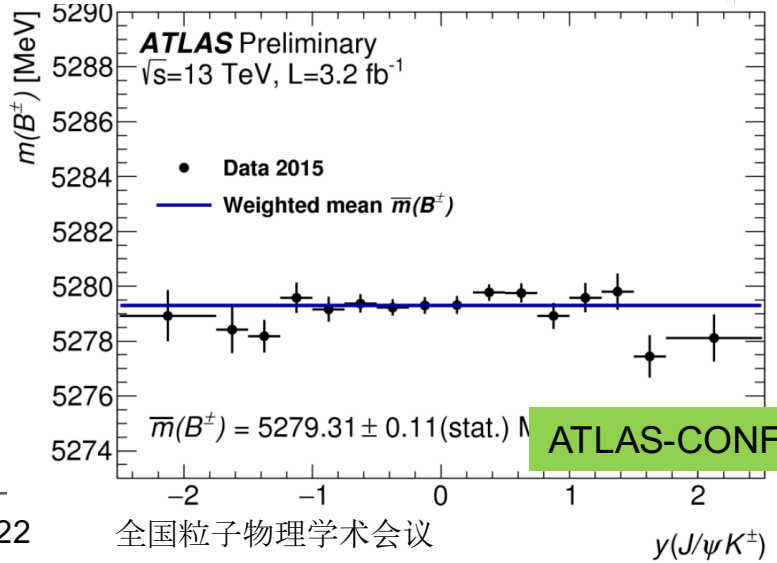


B+ production at 13 TeV





CMS: PLB 771 (2017) 435

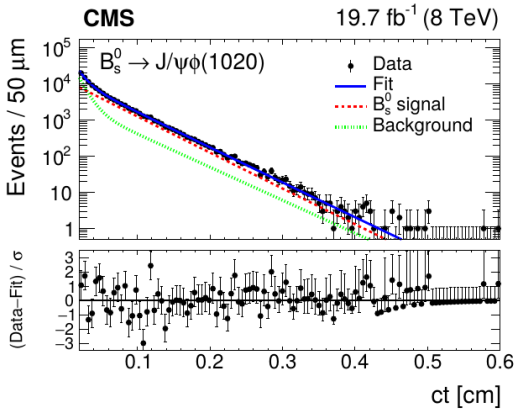


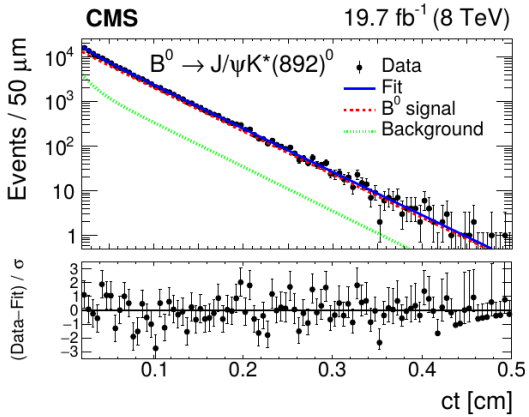
Source	Systematic Error [MeV]
y-Dependence	0.11
Signal Mass Model	0.09
Background Mass Model	0.17
Mass Fit Window	0.14
$B^\pm \to J/\psi\pi^\pm$ Background:	
Fraction	0.02
Line Shape	0.04
MC Reweighting	0.04
Total	0.25

ATLAS-CONF-2015-064

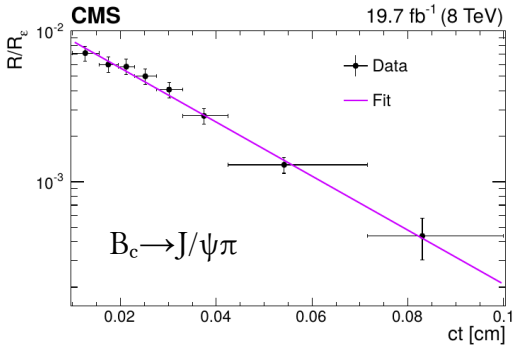
B hadron lifetime measurement

- B hadrons lifetimes measured by CMS on 8 TeV pp data
  - Decay modes used:
    - $B^0 \to J/\psi K^*(892)$ and $B^0 \to J/\psi K_s$
    - $\Lambda_b^0 \to J/\psi \Lambda^0$
    - $B_s^0 \to J/\psi \phi(1020)^0$ and $B_s^0 \to J/\psi \pi^+\pi^-$
    - $B_c^+ \to J/\psi \pi^+$





Channel	CMS result [μm]	PDG [μm]
$c\tau_{B^0}$	454.1 ± 1.4 (stat) ± 1.7 (syst)	455.7 ± 1.2
$c\tau_{B_s \to J/\psi\pi\pi}$	502.7 ± 10.2 (stat) ± 3.4 (syst)	482.4 ± 3.0
$c\tau_{B_s \to J/\psi\phi}$	443.9 ± 2.0 (stat) ± 1.5 (syst)	443.4 ± 3.6
$c\tau_{\Lambda_b}$	442.9 ± 8.2 (stat) ± 2.8 (syst)	440.7 ± 3.0
$c\tau_{B_c}$	162.3 ± 7.8 (stat) ± 4.2 (syst) ± 0.1 (B^+)	152.0 ± 2.7



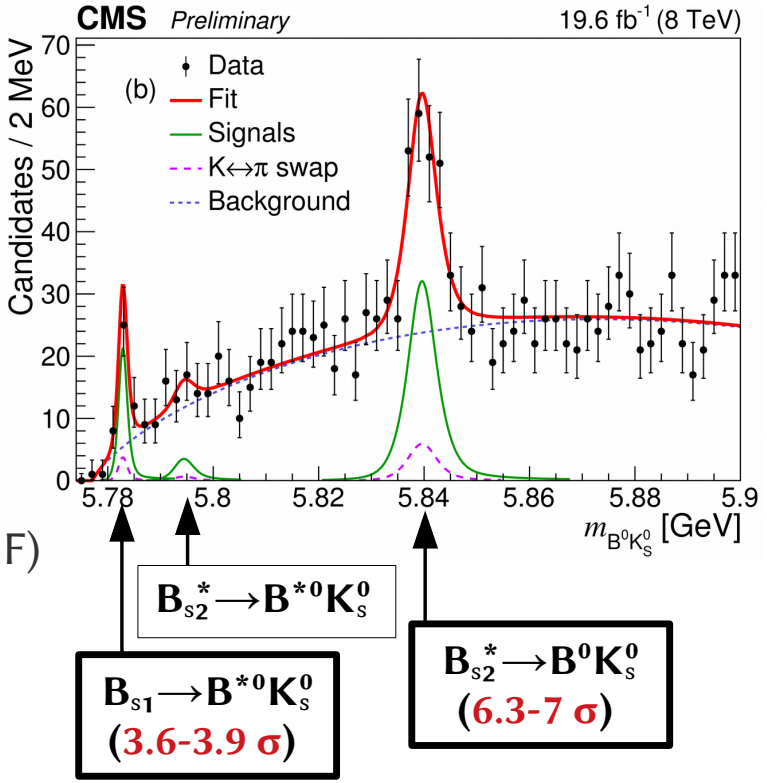
arXiv1710.08949
Accepted by EPJC

- Other observables found from the measured lifetimes:
  - Lifetime of the B_{sL} eigenstate $\mathbf{c\tau_L = 420.4 \pm 6.1\ (stat + syst)\ \mu m}$ (PDG: 423.6 ± 1.8 μm)
  - $\mathbf{\Delta\Gamma_d/\Gamma_d = 0.034 \pm 0.023\ (stat) \pm 0.024\ (syst)}$ (PDG: −0.002 ± 0.010)

Observation of a new B_{s2}^{*} decay

- Using 19.6 fb^{-1} of 8 TeV data, CMS studied the excited B_s states $B_{s1}(5830)^0$ and $B_{s2}^*(5840)^0$ in the B^+K^- and in the $B^0K_S^0$ decay modes
  - **First observation of the decay $B_{s2}^* \to B^0K_S^0$**
  - **First evidence of the decay $B_{s1} \to B^{*0}K_S^0$**
- Several related observables measured

New for LHCP2018 !
CMS-PAS-BPH-16-003



- **B_{s2}^* natural width** (consistent with LHCb and CDF)

$$\Gamma(B_{s2}^*) = 1.52 \pm 0.34\,(\text{stat}) \pm 0.30\,(\text{syst})\ \text{MeV}$$

- First measurement of **mass difference between B^{*0} and B^{*+} excited mesons**

$$m_{B^{*0}} - m_{B^{*+}} = 0.91 \pm 0.24\,(\text{stat}) \pm 0.09\,(\text{syst}) \pm 0.02\,(\text{PDG})\ \text{MeV}$$

- **Cross section times branching fraction ratios**

$$R_\sigma^{\pm} = \frac{\sigma(pp \to B_{s1}\ldots) \times \mathcal{B}(B_{s1} \to B^{*+}K^-)}{\sigma(pp \to B_{s2}^*\ldots) \times \mathcal{B}(B_{s2}^* \to B^+K^-)} = 0.233 \pm 0.019\,(\text{stat}) \pm 0.018\,(\text{syst})$$

Consistent with LHCb

$$R_\sigma^{0} = \frac{\sigma(pp \to B_{s1}\ldots) \times \mathcal{B}(B_{s1} \to B^{*0}K_S^0)}{\sigma(pp \to B_{s2}^*\ldots) \times \mathcal{B}(B_{s2}^* \to B^0K_S^0)} = 0.266 \pm 0.079\,(\text{stat}) \pm 0.063\,(\text{syst})$$

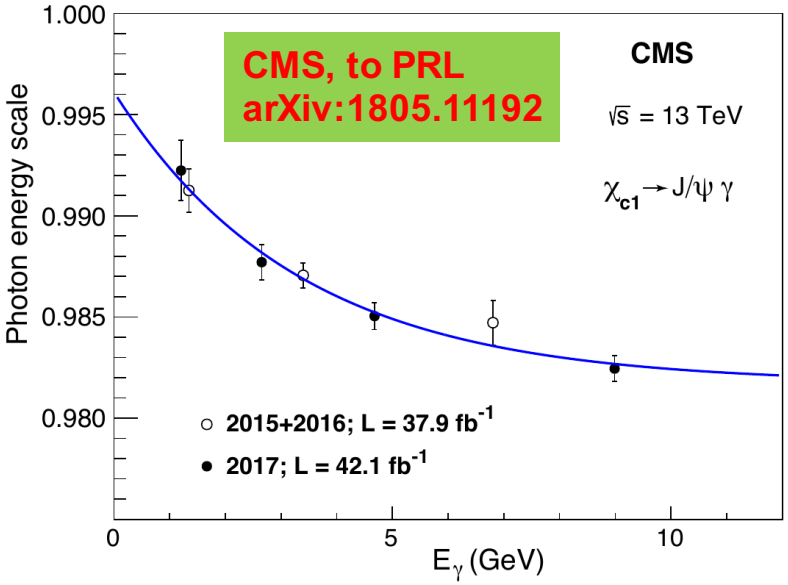
First measurement

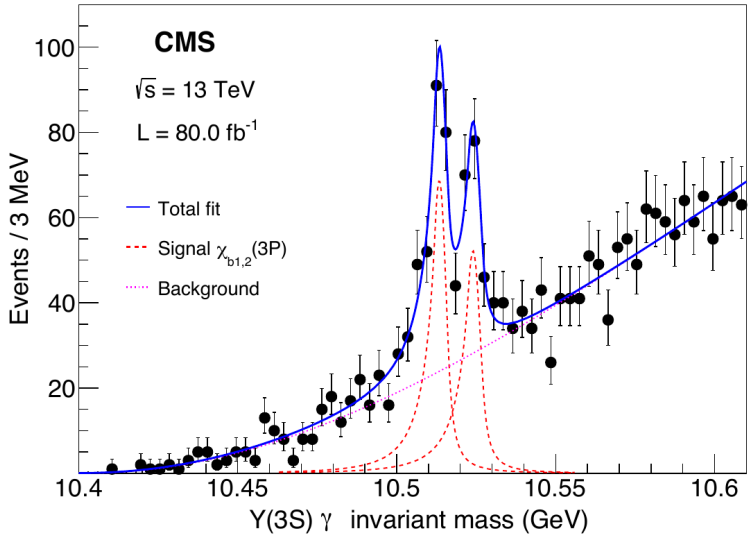
Observation of $\chi_{b1,2}(3P)$ mass split

- $\chi_b(3P)$ state first discovered by ATLAS (**PRL 108 (2012) 152001**), seen also by D0 and LHCb
- Analyzing the full LHC Run 2 dataset (**80 fb^{-1}**) CMS now observes for the first time **the split in the $\chi_{b1}(3P)$-$\chi_{b2}(3P)$ doublet** and measures the masses of the two states
- $\chi_b(3P)$ reconstructed in Υ(3S)+γ mode, with γ converting inside the CMS tracker
- Photon energy scale calibrated with high-yield $\chi_{c1} \rightarrow J/\psi+\gamma$ decays
- Results

  M_1 = 10513.42±0.41(stat)±0.18(syst) MeV
  M_2 = 10524.02±0.57(stat)±0.18(syst) MeV
  ΔM = 10.60±0.64(stat)±0.17(syst) MeV

- **Significantly constrains theoretical predictions**, which give mass splits in the range [−2, 18] GeV





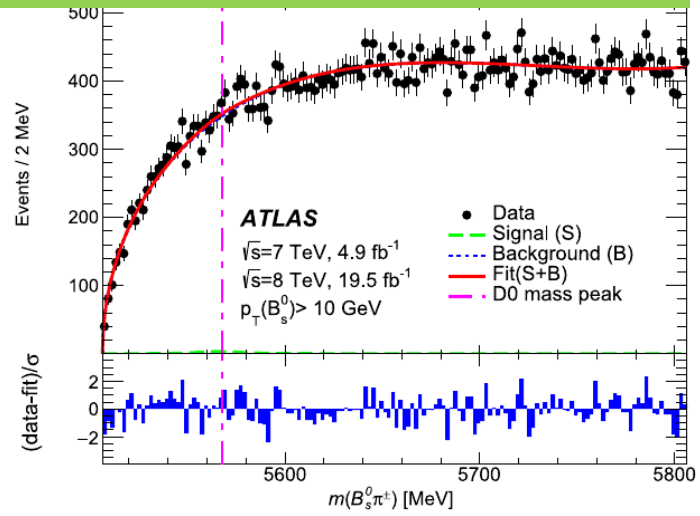
Search for $X^+(5568) \rightarrow B_s \pi^+$

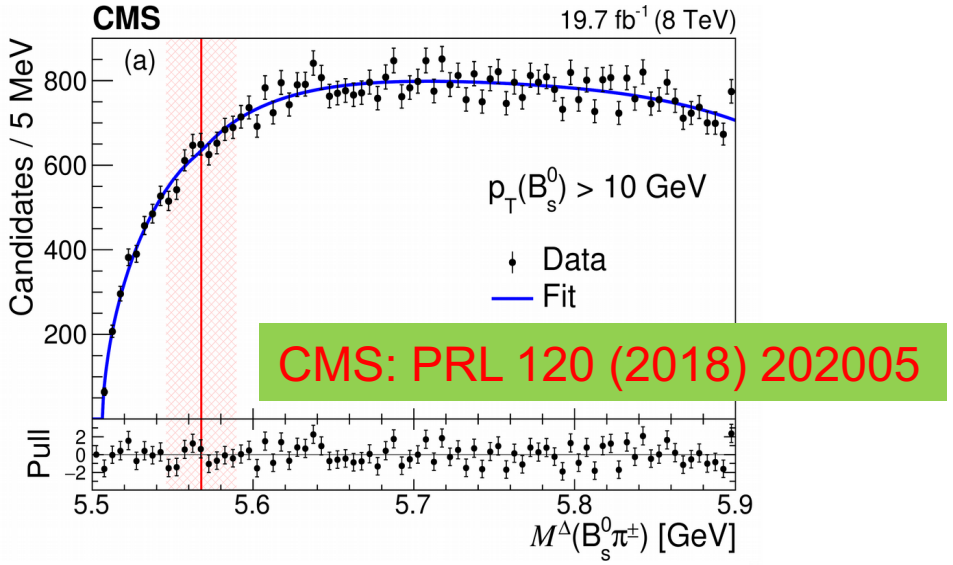
- **D0: a tetraquark candidate $X^+(5568) \rightarrow B_s\pi^+$**
  - **Phys. Rev. Lett. 117, 022003 (2016): 5.1sigma**
  - **DØ Note 6488-CONF: semi-leptonic channel**

$\rho_X = (8.6 \pm 1.9 \pm 1.4)\%$

- **LHCb/CDF reported non-confirmation results**
- **ATLAS/CMS: thousands of $B_s \rightarrow J/\psi\,\phi$ decays to search**

ATLAS: PRL 120 (2018) 202007





CMS: PRL 120 (2018) 202005

- **Stringent limits are set:**

ATLAS: $\rho_X < 1.5\%$ @ 95%CL

CMS: $\rho_X < 1.1\%$ @ 95%CL

$$\rho_X \equiv \frac{\sigma(pp \rightarrow X(5558) + anything) \times B(X(5558) \rightarrow B_s\pi^\pm)}{\sigma(pp \rightarrow B_s + anything)} = \frac{N_X}{N_{B_s}} \frac{\varepsilon_{B_s}}{\varepsilon_X}$$

Obersvation of excited B_c states

- Significance of the observed signal calculated with toy studies
  - 3.7 in 7TeV and 4.5 in 8TeV
  - Combined significance is 5.2
- Systematic dominated by fitting
- A new state observed at

Q = 288.3±3.5(stat.)±4.1(syst.) MeV

- Corresponds to a mass of

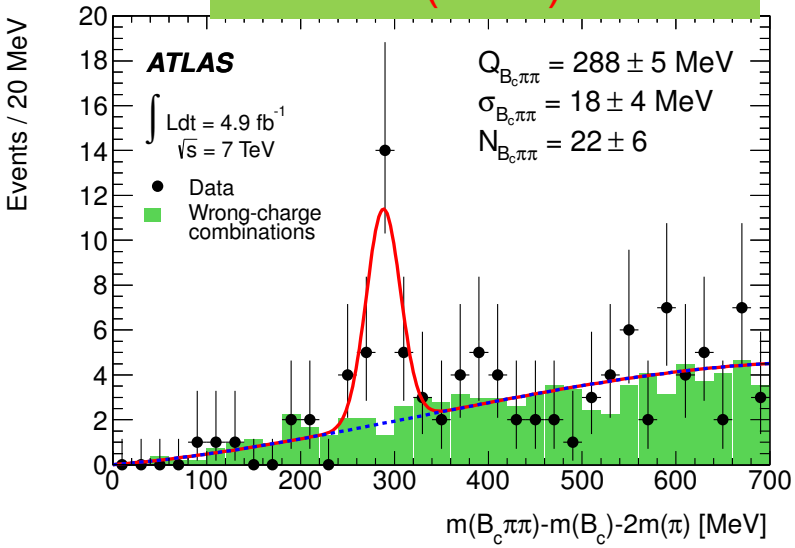
6842 ± 4(stat.) ± 5(syst.) MeV

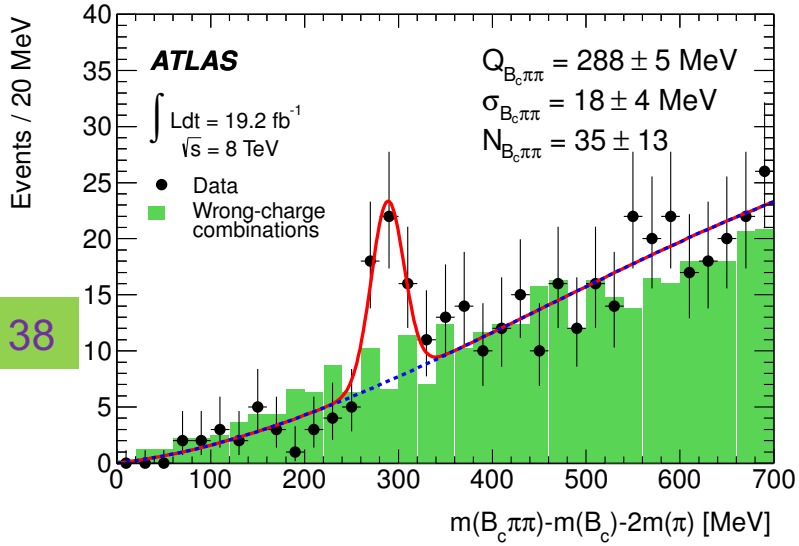
- LHCb: 2 fb^{-1} of 8 TeV data, no evidence for any resonance
- Ratio of $B_c(2S)$ to B_c cross section in the range [0.02, 0.14] @95%CL

JHEP (2018) 2018:138

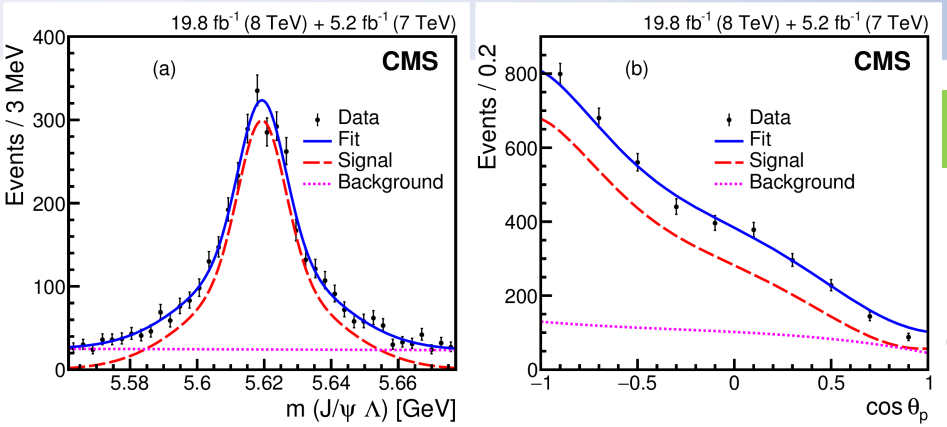
- ATLAS observation to be confirmed

PRL 113 (2014) 212004





Helicity study of $\Lambda_b \rightarrow J/\psi\,\Lambda$



Phys. Rev. D **97(2018)**, 072010

P=0.00 ± 0.06(stat) ± 0.06(syst)

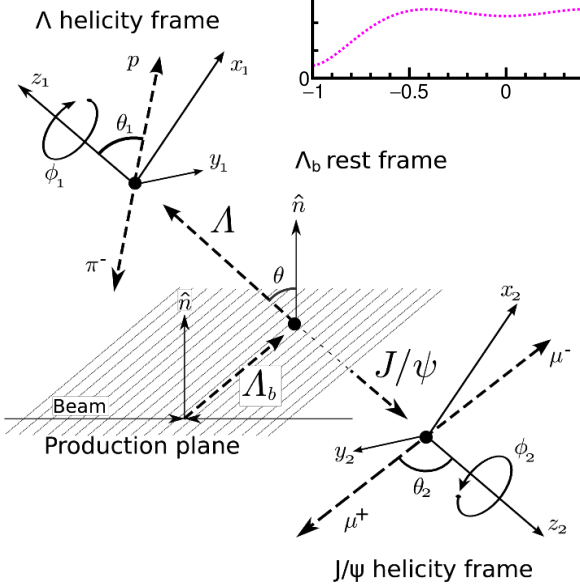
α_1=0.14 ± 0.14(stat) ± 0.10(syst)

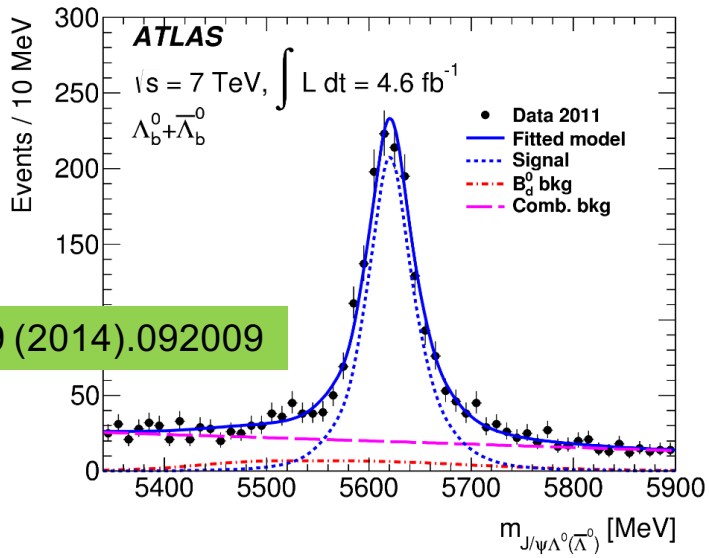
LHCb:

0.05 ± 0.17(stat) ± 0.07(syst)

ATLAS:

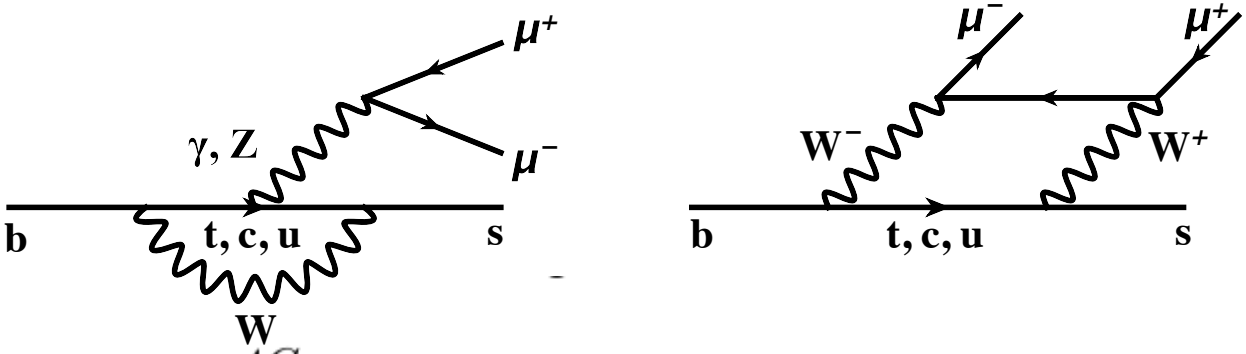
0.05 ± 0.16(stat) ± 0.06(syst)





Phys.Rev. D89 (2014).092009

FCNC processes $b \to s\mu^+\mu^-$: golden indirect probes of NP



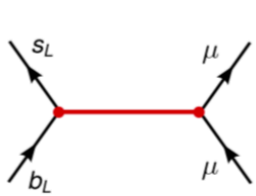
clean exp signature;
robust theory calc;
high sensitivity

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{tq}^* \sum_i \underbrace{C_i\mathcal{O}_i}_{\text{Left handed}} + \underbrace{C_i'\mathcal{O}_i'}_{\text{Right handed, } \frac{m_s}{m_b} \text{ suppressed}} + \sum \frac{c}{\Lambda_{\text{NP}}^2}\mathcal{O}_{\text{NP}}$$

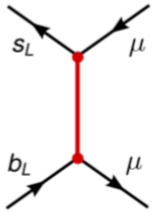
$i = 1, 2$	Tree
$i = 3 - 6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	EW penguin
$i = S, P$	(Pseudo)scalar penguin

Effective theory: Different processes are sensitive to different operators

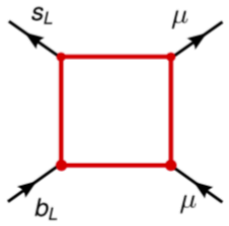
"B anomalies" => flood of NP models



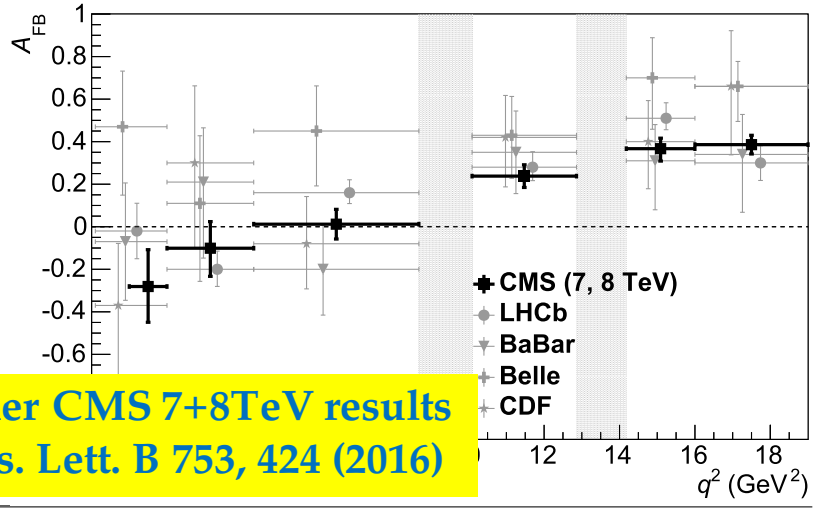
- Z'
- $SU(2)_L$ singlet or triplet



- Leptoquark
- Spin 0 or 1

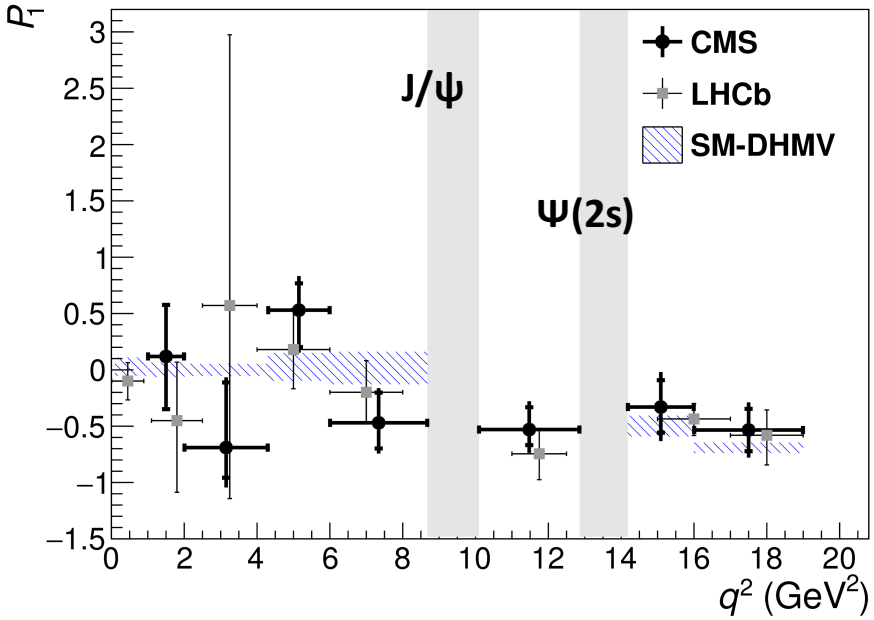


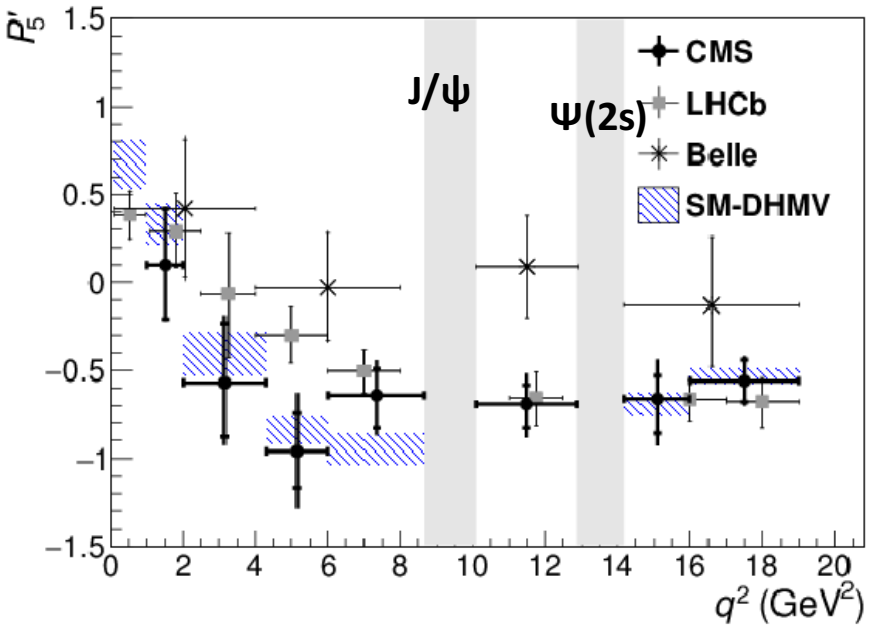
- New scalars/vectors also leptoquarks possible



Earlier CMS 7+8TeV results
Phys. Lett. B 753, 424 (2016)

$B^0 \to K^{*0}\,\mu^+\mu^-$: P_1 and P_5' results





- Fit in seven q^2 bins from 1 to 19 GeV^2, yielding 1397 signal and 1794 bkg evts
- CMS results are consistent with SM and previous measurements.

LHCb: *JHEP 02 (2016) 104*
Belle: *Phys. Rev. Lett. 118, 111801 (2017)*
SM-DHMV: *JHEP 01 (2013) 048, JHEP 05 (2013) 137*

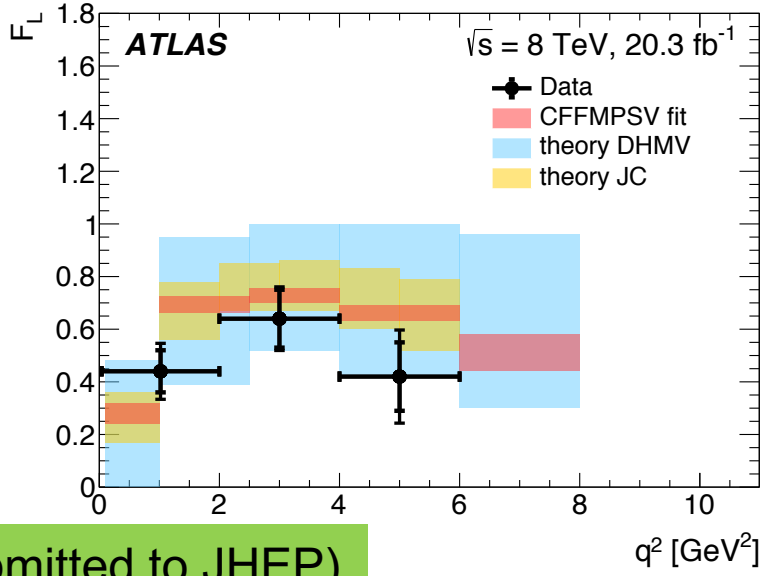
arxiv: 1710.02846
Phys. Lett. B 781 (2018) 517

Selected as the CMS "joker talk" at Moriond2017

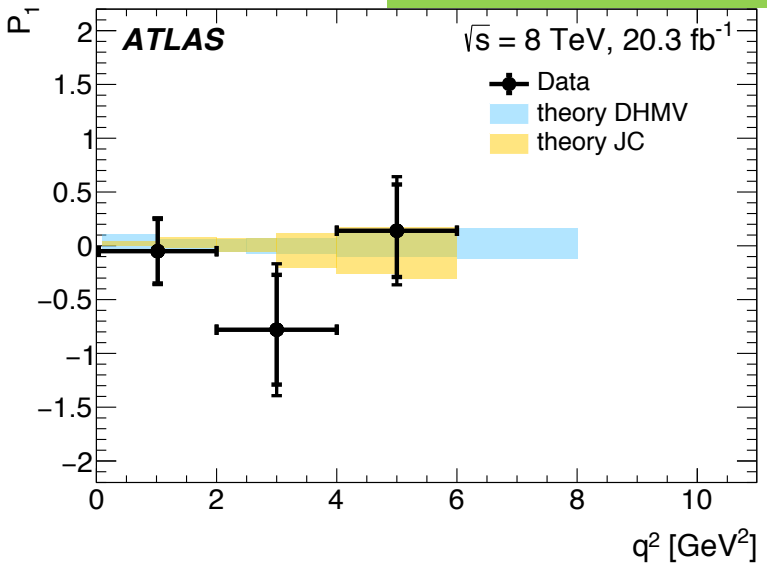
该分析由北大组与Milano, Padova合作完成
参与人：李林蔚/王大勇
李林蔚做Pre-Approval报告

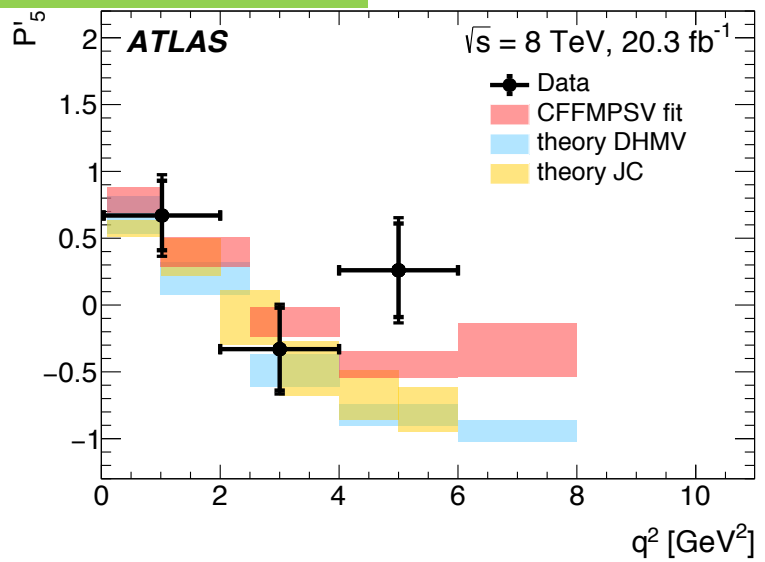
$B^0 \to K^{*0}\,\mu^+\mu^-$ angular analysis from ATLAS

- ✓ Second release of the results
- ✓ Based on 8TeV data, 20.3 fb^{-1}
- ✓ six different bins of q^2 in the range 0.04 to 6.0 GeV^2
- ✓ Much less yield: 348 signals, 439 bkg
- ✓ Compatible with the results of the LHCb, CMS and Belle

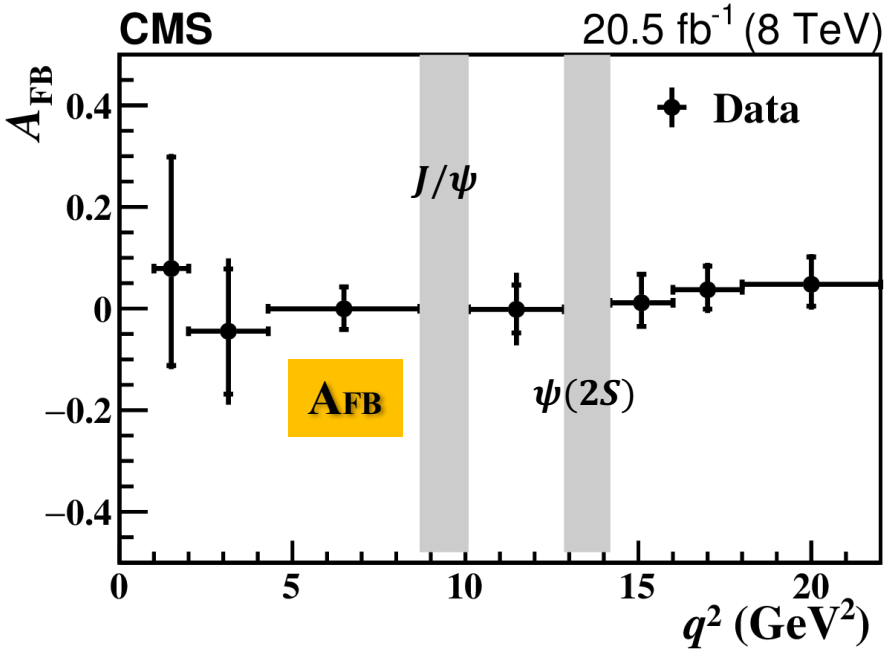


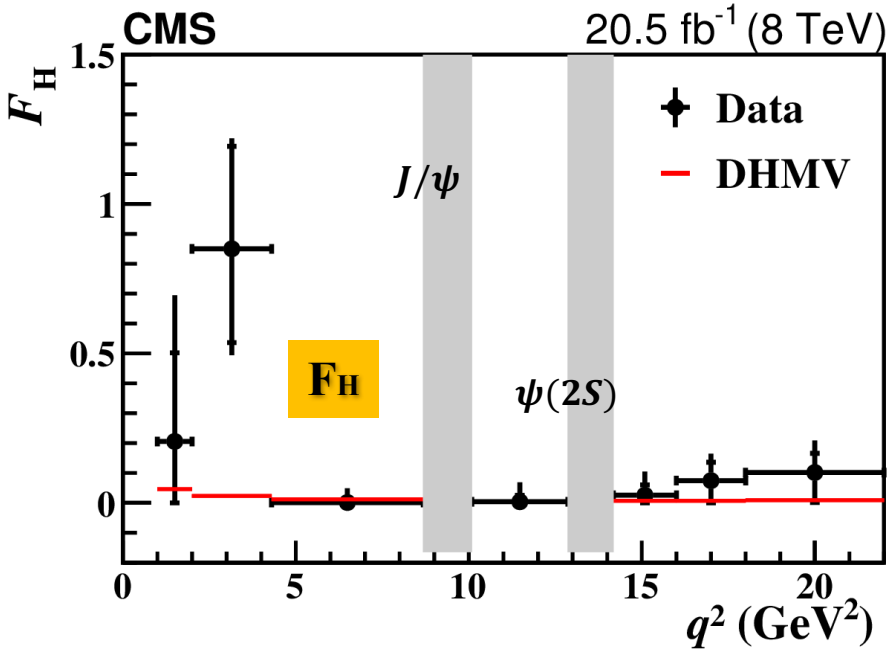
Arxiv: 1805.04000 (submitted to JHEP)





$B^+ \to K^+\mu^+\mu^-$ A_{FB} and F_H results





arxiv:1806.00636, submitted to Phys. Rev. D

The measured A_{FB} and F_H show good agreement with the SM predictions within the uncertainty.

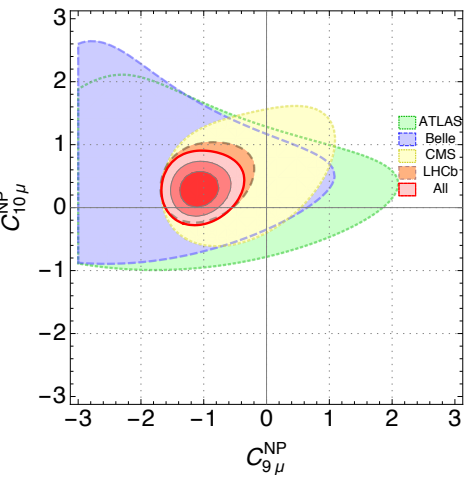
No clear indication of new physics beyond the SM could be drawn from present results.

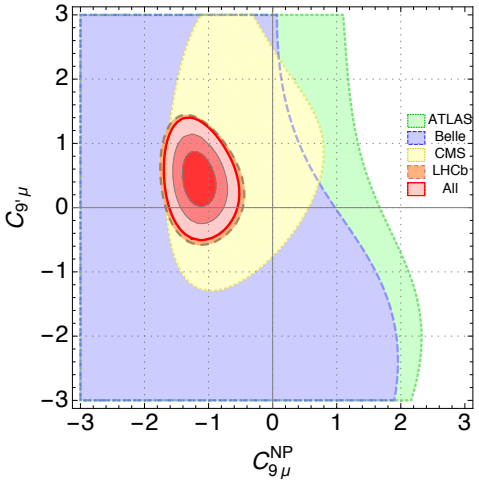
PAS was published for Moriond2018 conferences

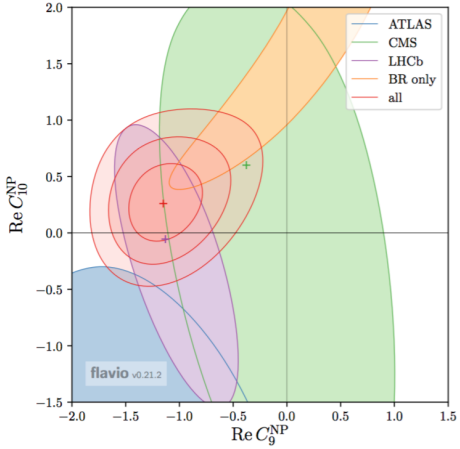
该分析由北大组提出并完成，担任联络人
参与人：陈耿/王大勇
王大勇做Pre-Approval报告
陈耿 做 Approval报告

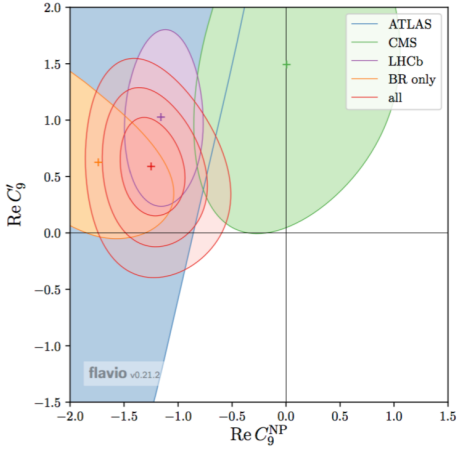
Global fits: try to be model-indep

$$\mathcal{C}_{9\mu}^{\mathrm{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\mathrm{NP}} = \mathcal{C}_{10'\mu}$$









"For the first time, the NP hypothesis is preferred over the SM by 5 σ in a general case when NP can enter SM-like operators and their chirally-flipped partners" [1]

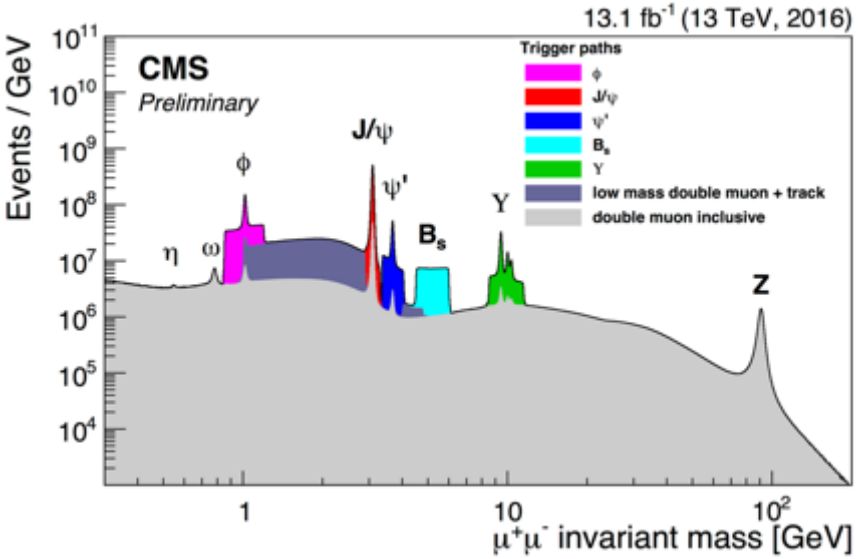
"we confirm the presence of a sizeable discrepancy between data and SM predictions…The data can be consistently described by new physics in the form of a four-fermion contact interaction…[2]

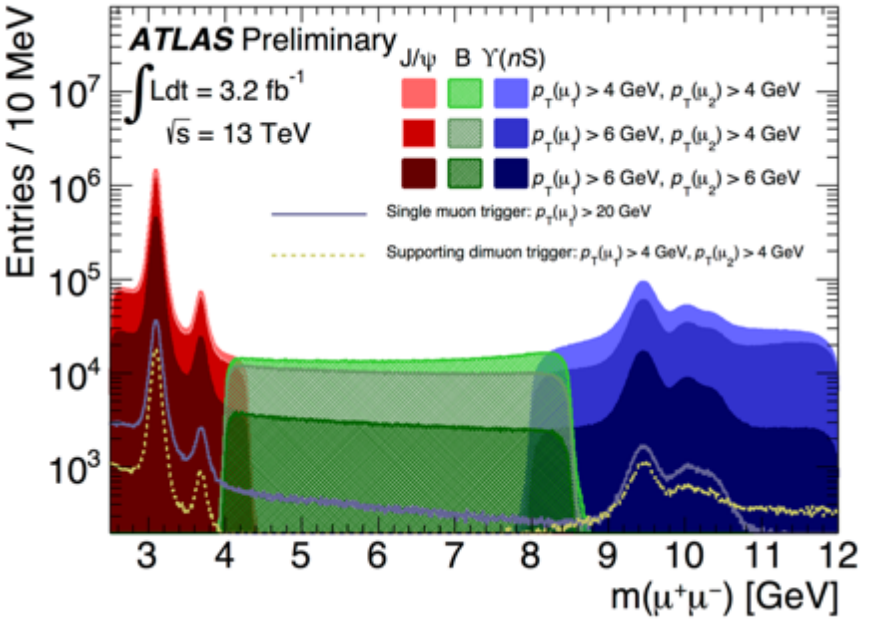
[1] J. High Energy Phys. **2018**, 93.
[2] Eur. Phys. J. C **77**, 377 (2017).

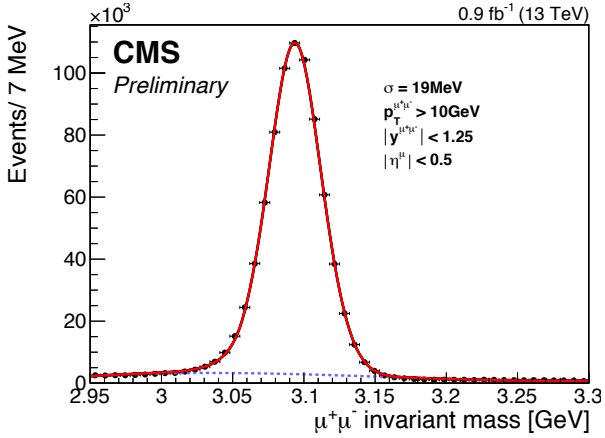
Summary

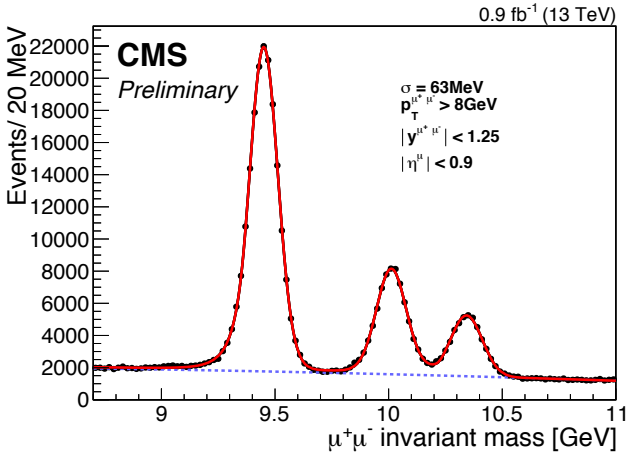
- **ATLAS and CMS are producing high quality HF physics results**
  - Hadron production and polarization
  - Spectroscopy and exotic states
  - B decay property and angular analyses
- **Many new HF results are released**
  - Excellent commissioning and performance
  - More to come from Run-II data
- **Chinese groups are actively contributing**
  - Welcome to join

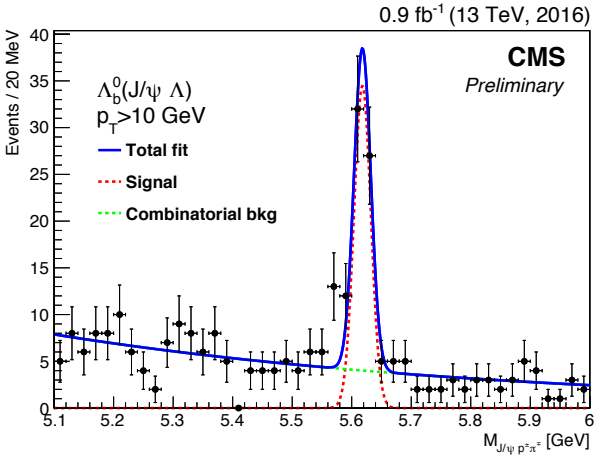
ATLAS/CMS: 13TeV HF performances



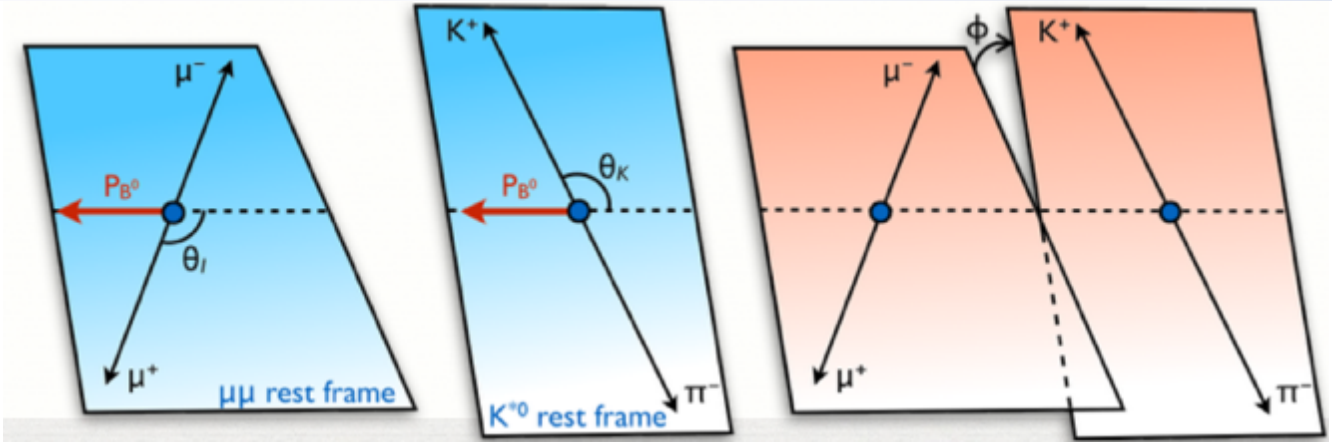








$B^0 \to K^{*0}\,\mu^+\mu^-$ Decay description

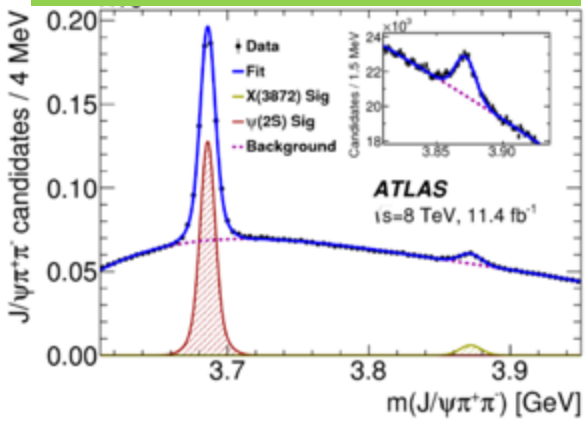


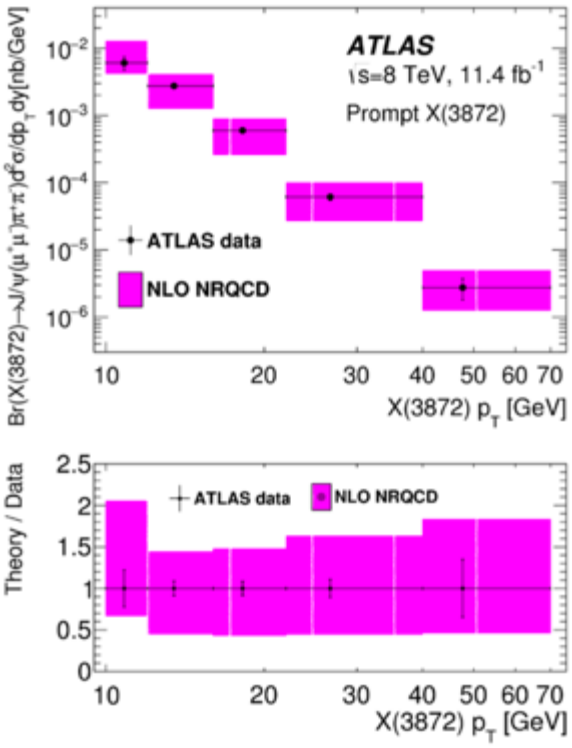
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{32\pi}\Big[S_1^s \sin^2\theta_K + S_1^c \cos^2\theta_K + S_2^s \sin^2\theta_K \cos 2\theta_\ell + S_2^c \cos^2\theta_K \cos 2\theta_\ell + S_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi + S_5 \sin 2\theta_K \sin\theta_\ell \cos\phi + S_6 \sin^2\theta_K \cos\theta_\ell + S_7 \sin 2\theta_K \sin\theta_\ell \sin\phi + S_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi + S_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi \Big] ,$$

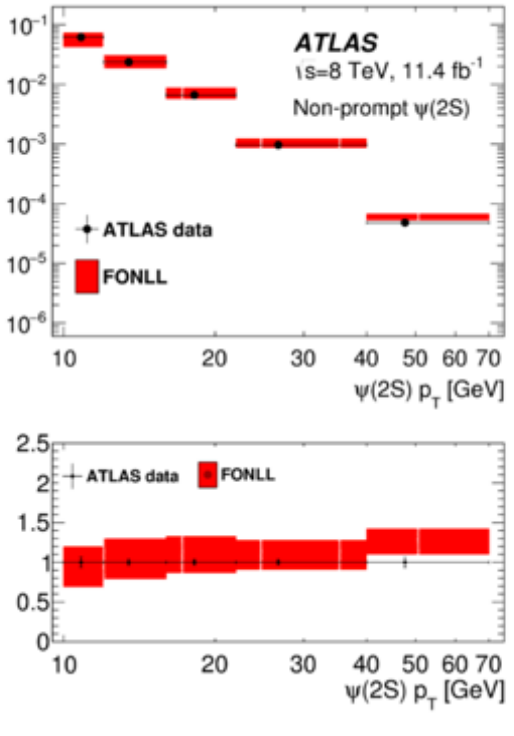
Complex fitting for precision measurement
With complex physics constraints

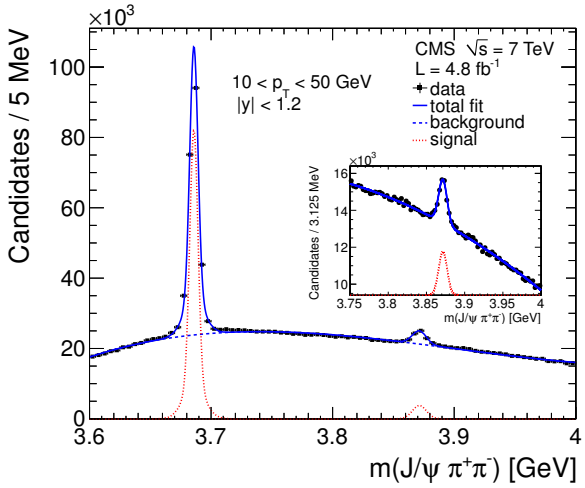
X(3872) production

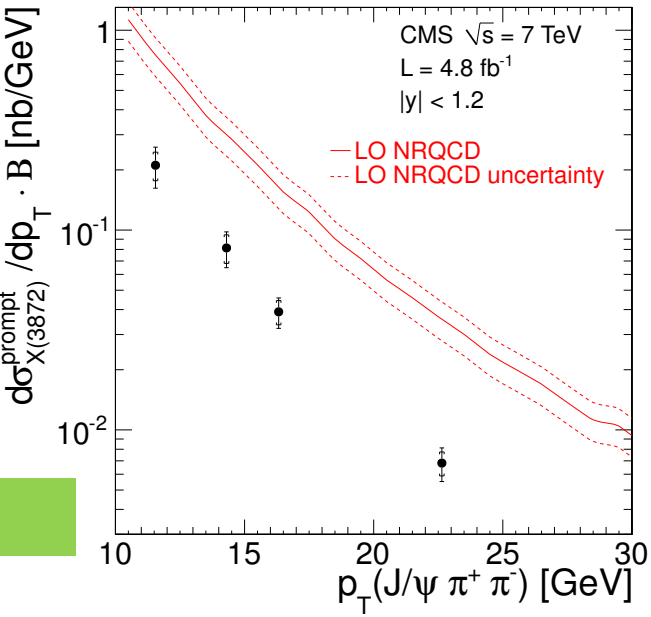
ATLAS:JHEP01(2017) 117

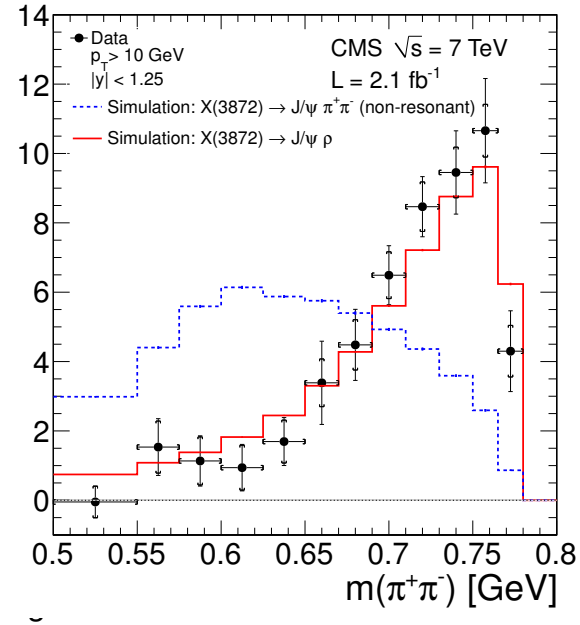












CMS: JHEP04 (2013) 154