ATLAS: Spectroscopy and exotic states

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on behalf on the ATLAS collaboration

BEAUTY2018

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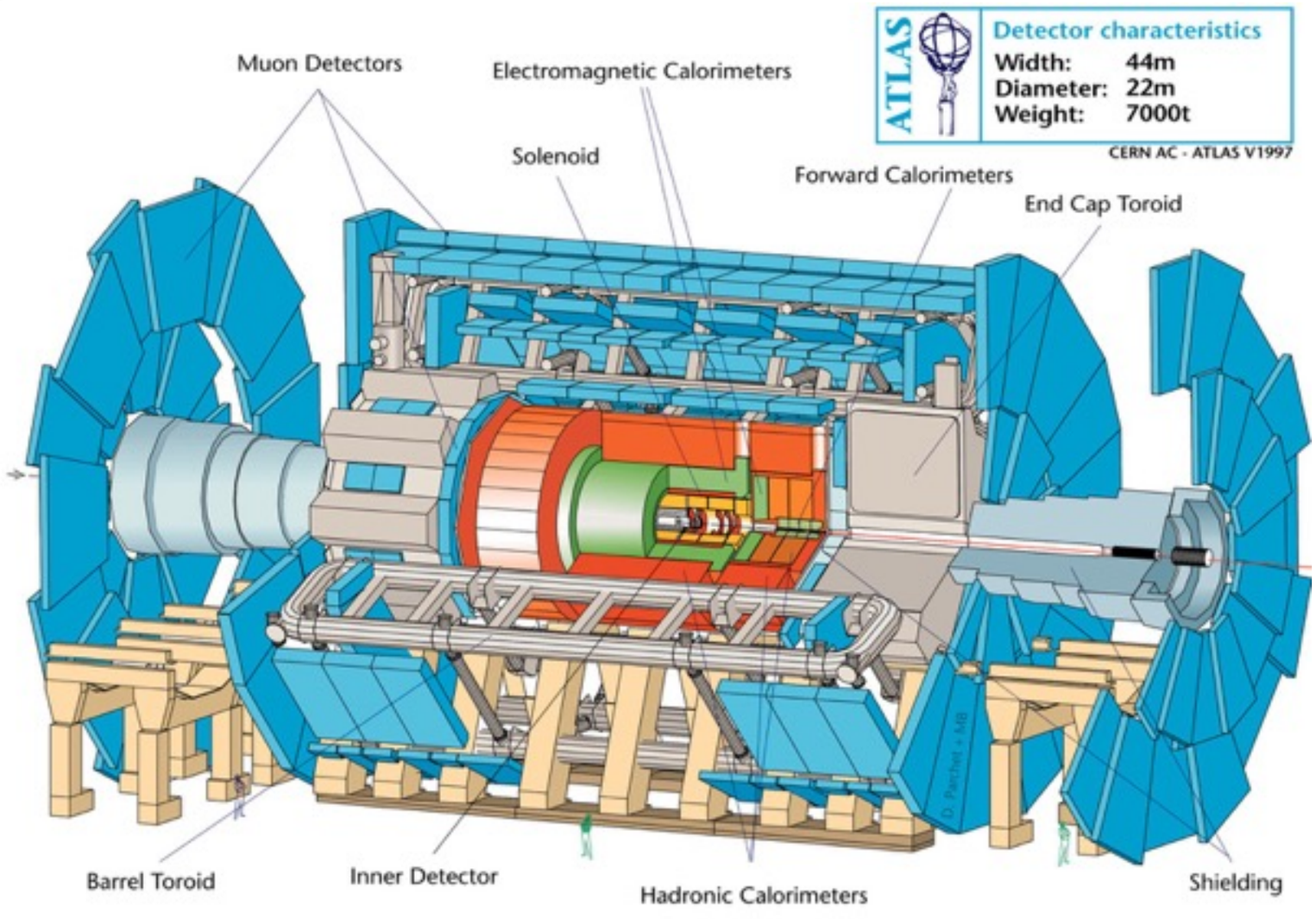
Outline

- The ATLAS detector
- $B_c(2S)$ observation
- Search for tetraquarks in B^0_s decays
- conclusion

The ATLAS detector

- Important subsystems for B-physics:
  - Inner Detector (ID)
    - tracking, momentum measurement and vertexing
  - Muon spectrometers
    - trigger and muon identification



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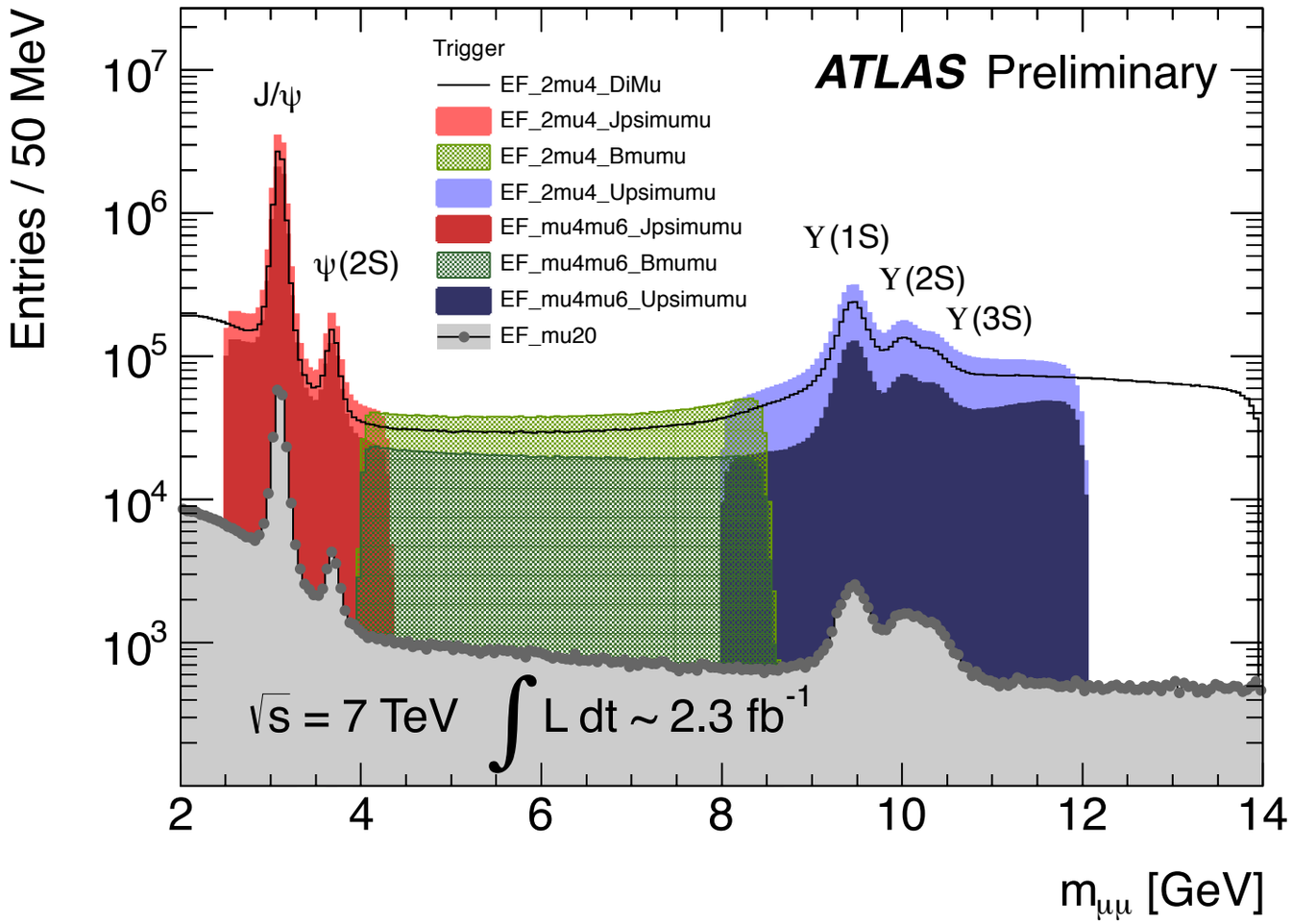
Datasets and triggers

- Datasets:
  - 4.9 fb^{-1} @ 7 TeV
  - 20.6 fb^{-1} @ 8 TeV

  } Run1 dataset

- ATLAS B-physics analyses based on (di-)muon triggers
  - different thresholds available



- relevant di-muon triggers for this talk:
  - $p_T(\mu_1) > 4$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 6$ GeV

- final states containing J/Ψ
  - M(μμ) in [2.5,4.3] GeV
  - common vertex

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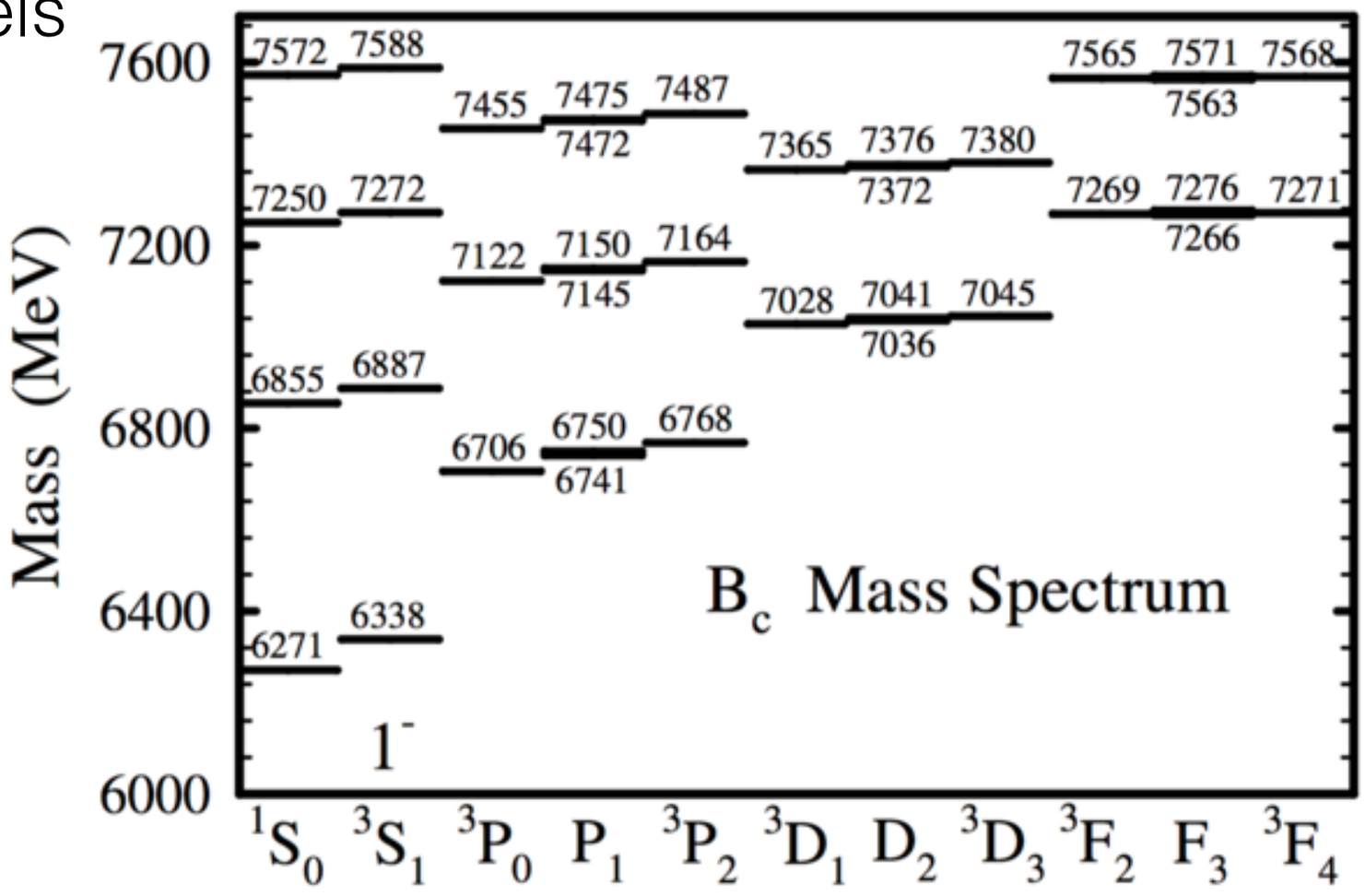
$B_c(2S)$ theoretical predictions

- B_c is a unique system
  - composed of two distinct heavy quarks
  - valuable inputs to lattice and perturbative QCD models

Phys.Rev.D70:054017,2004



- several theoretical predictions on B_c production and excited states

- a search for and excited B_c state was performed in ATLAS

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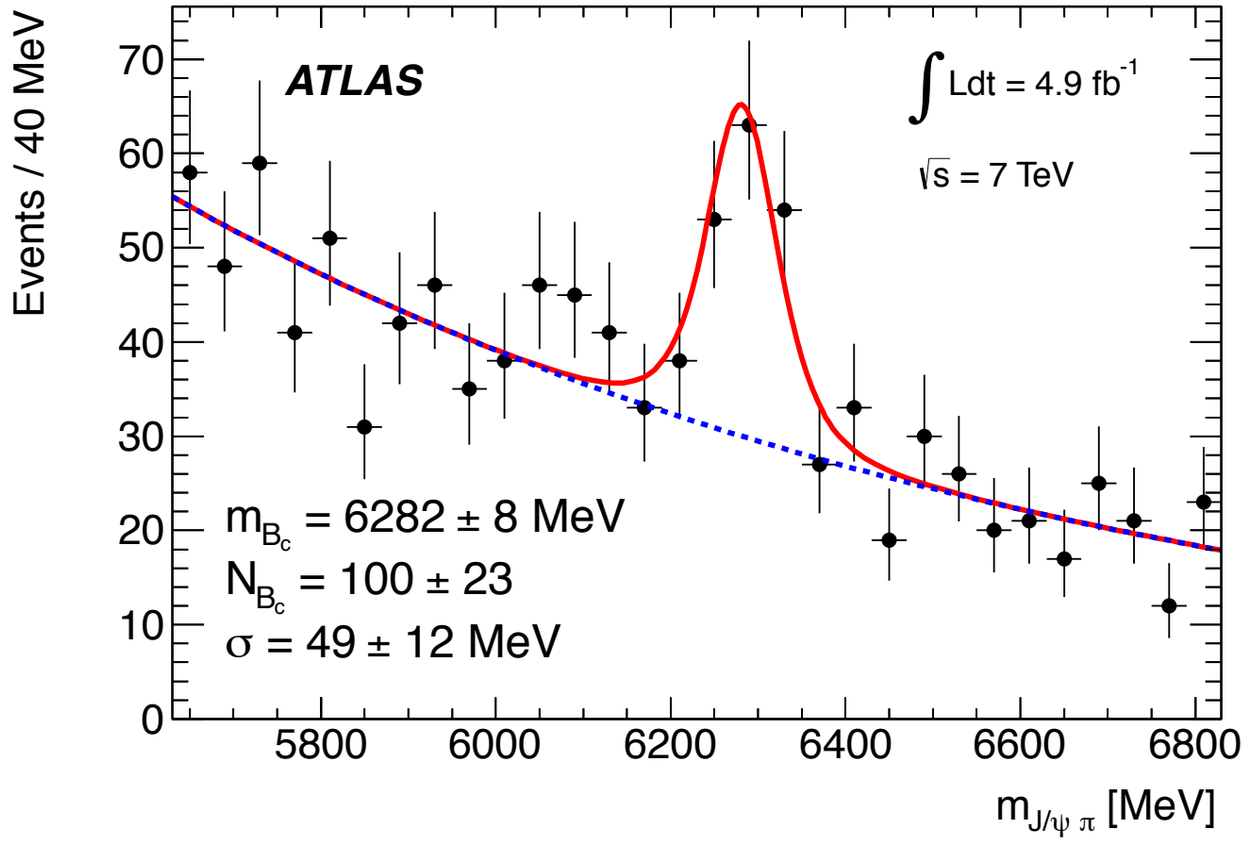
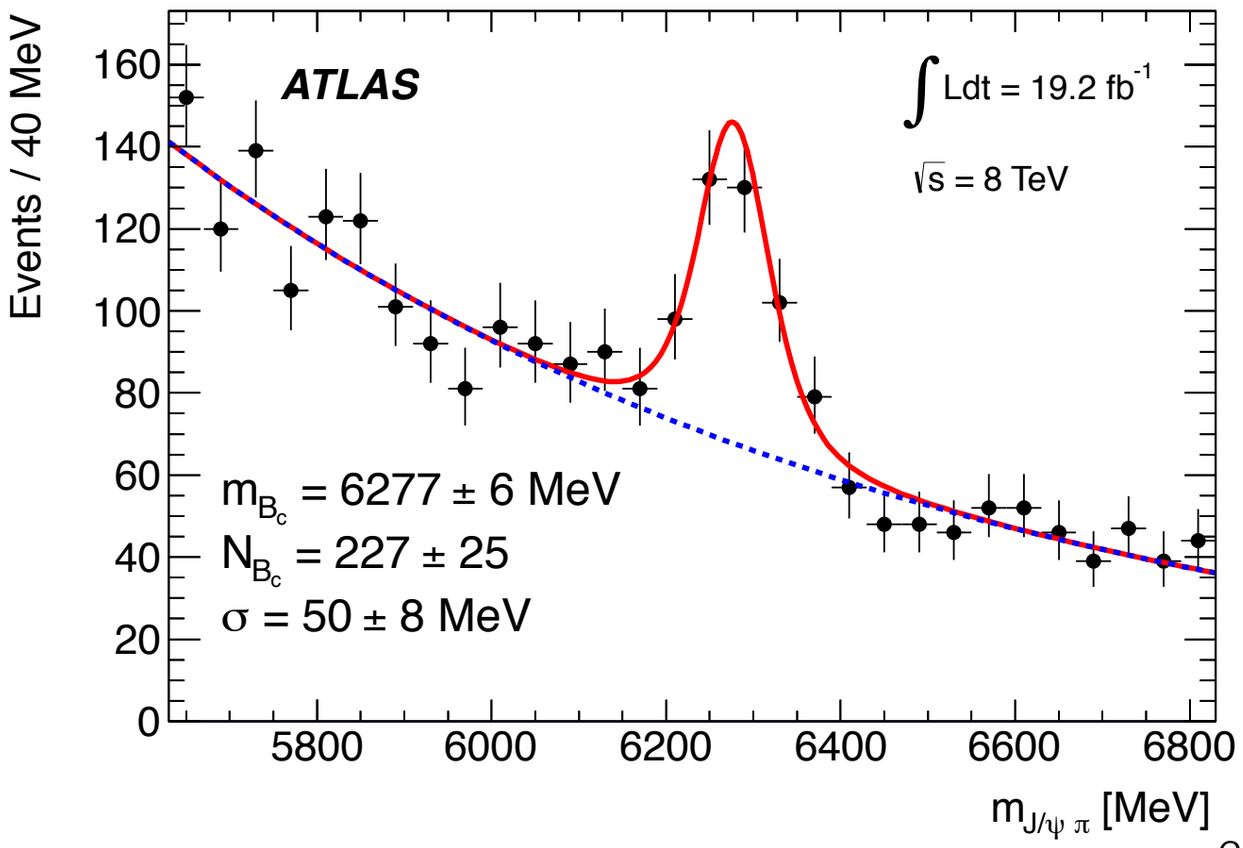
$B_c(2S)$ observation at ATLAS

- <u>Phys. Rev. Lett. 113, 212004 (2014)</u>
- ground state: B_C—>$J/\Psi(\mu\mu)\pi$

- peak searched in mass difference distribution

$$Q = m(B_C(2S)) - m(B_C) - 2m(\pi)$$





- selection optimised differently for 7 TeV and 8 TeV data

- extended unbinned maximum likelihood fit to get number of $B_C^{\pm}$

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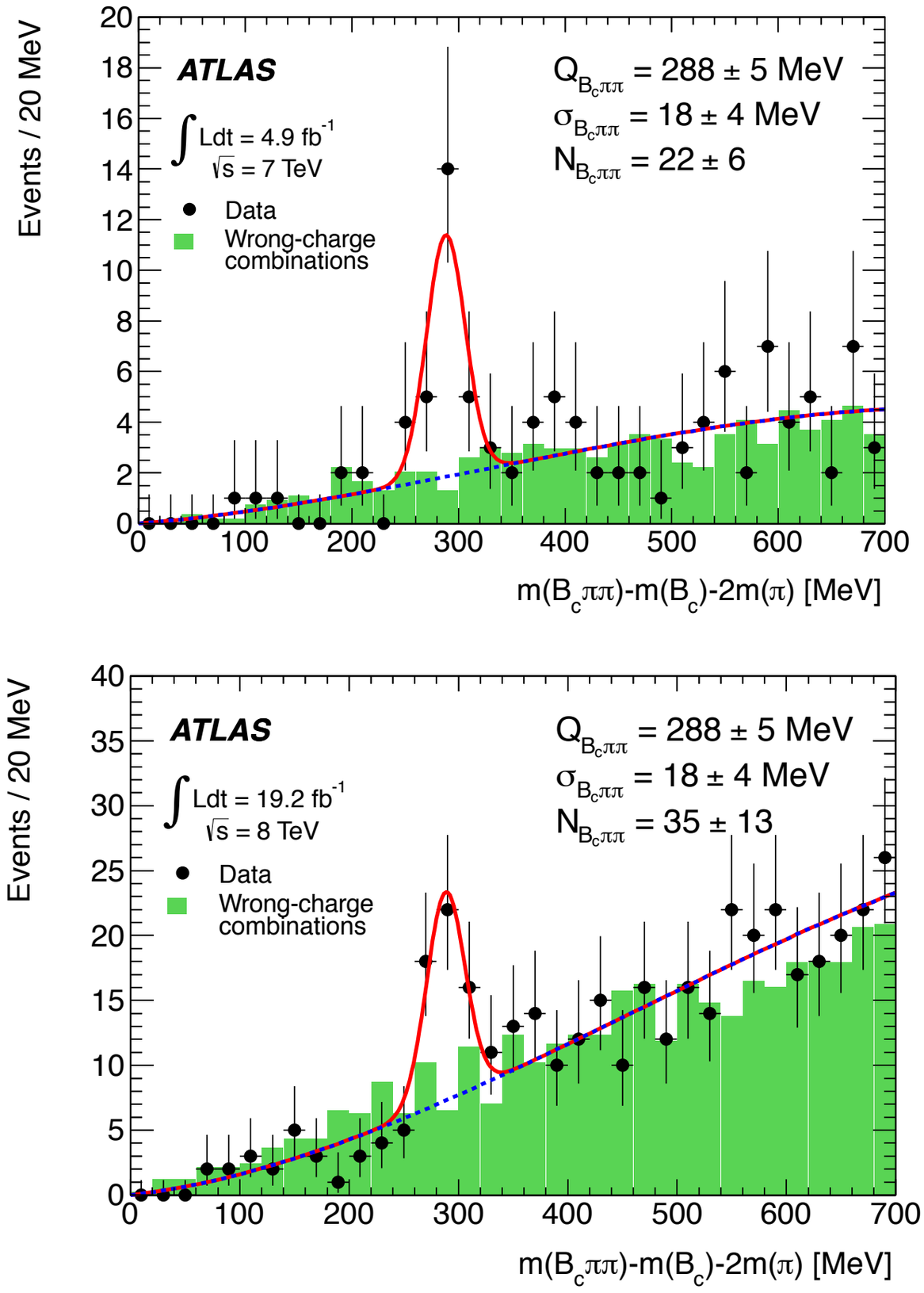
$B_c(2S)$ observation at ATLAS



- select B_C candidates ±3 sigma from centre of the Gaussian peak
- $B_C(2S)$ candidate:
  - 3 tracks from B_C and two tracks (2π) fitted simultaneously
    - must intersect in two different vertices
    - momentum of B_C candidate must point to the pions vertex
- extended unbinned maximum likelihood fit in mass difference spectrum to extract number of $B_C(2S)$

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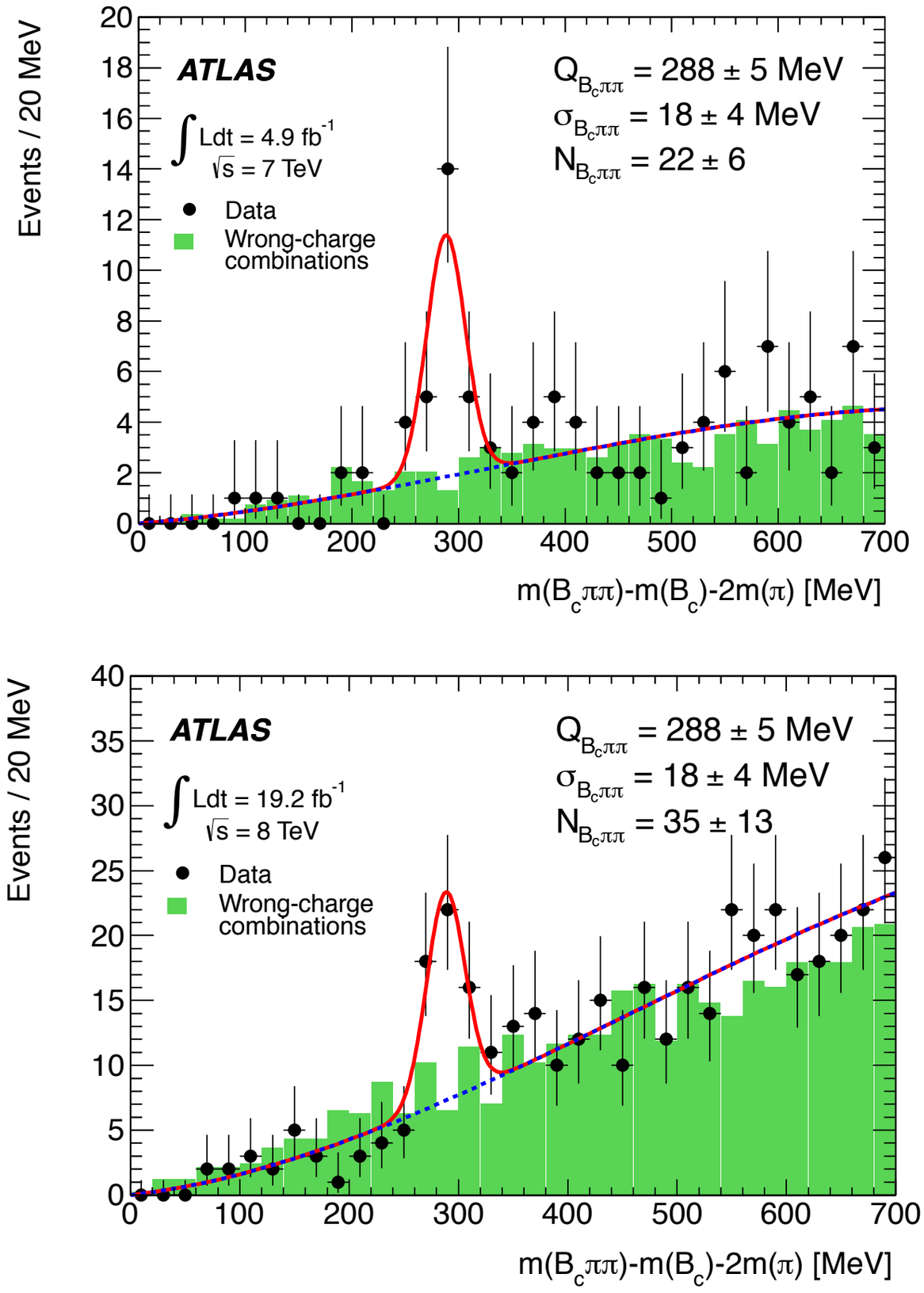
$B_c(2S)$ observation at ATLAS



- peak at Q = $288.3 \pm 3.5_{stat} \pm 4.1_{syst}$ MeV
- corresponds to mass $m(B_c(2S)) = 6842 \pm 4_{stat} \pm 5_{syst}$ MeV
  - no $B_c^*(2S)$ hypothesis
- consistent with theory [6835,6917] MeV
- significance:
  - 5.2 sigma combining 7 and 8 TeV
- first observation of B_c excited state
- similar analysis recently performed by LHCb (arXiv:1712.04094)
  - no evidence found
- further studies underway

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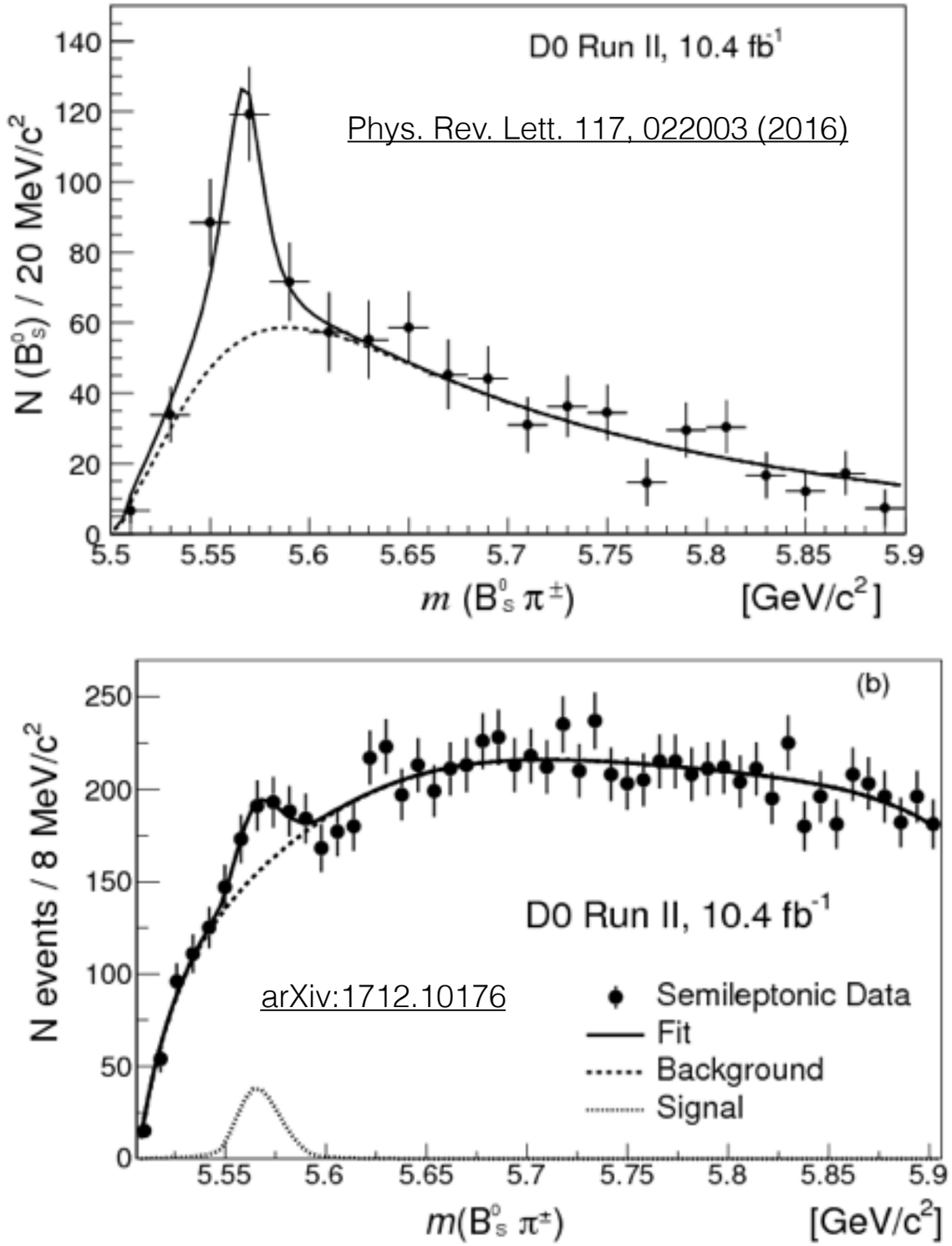
Search for a structure in B^0_s $\pi^{\pm}$ spectrum

- D0 published evidence of X(5568) state in the B^0_s $\pi^{\pm}$ spectrum via:
  - B^0_s to J/Ψ (μ μ) ϕ(K K)
  - B^0_s to $\mu^+ D_s^-$ (ϕ[KK]π^-) X
    - X = neutrino



- m = 5567.8±2.9$_{stat}$ $^{+0.9}_{-1.9}$ MeV
- Γ=21.9±6.4$_{stat}$ $^{+5.0}_{-2.5}$ MeV
- significance 5.1sigma

- interpreted as a tetraquark made of 4 different quarks (b, s, u, d)

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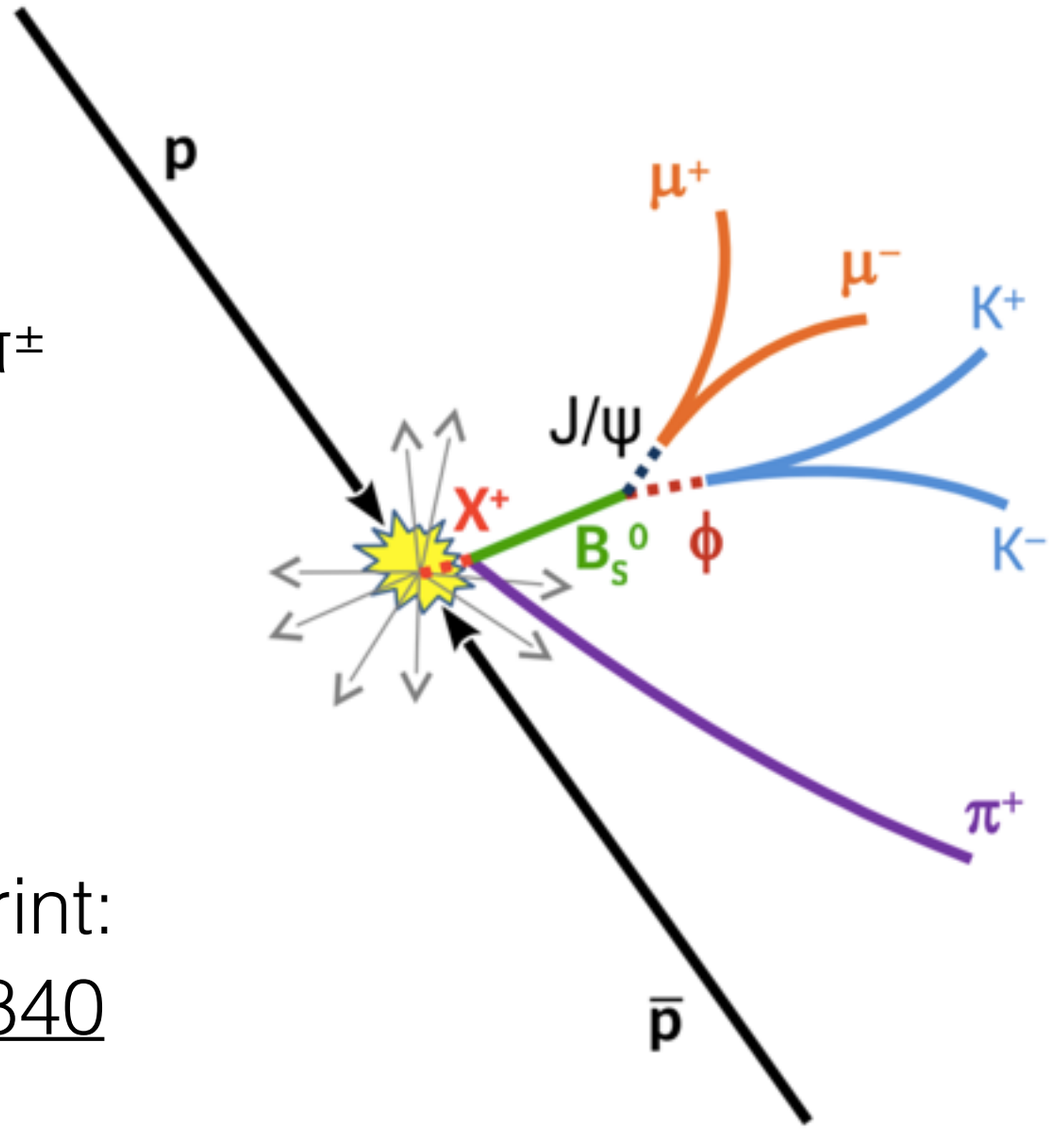
tetraquark search at ATLAS

- Search for tetraquarks in B^0_s $\pi^\pm$ decays in ATLAS

- exploit well know B^0_s decay
  - B^0_s —> J/Ψ(μμ) ϕ (KK)

- Paper accepted by PRL. E-print: https://arxiv.org/abs/1802.01840



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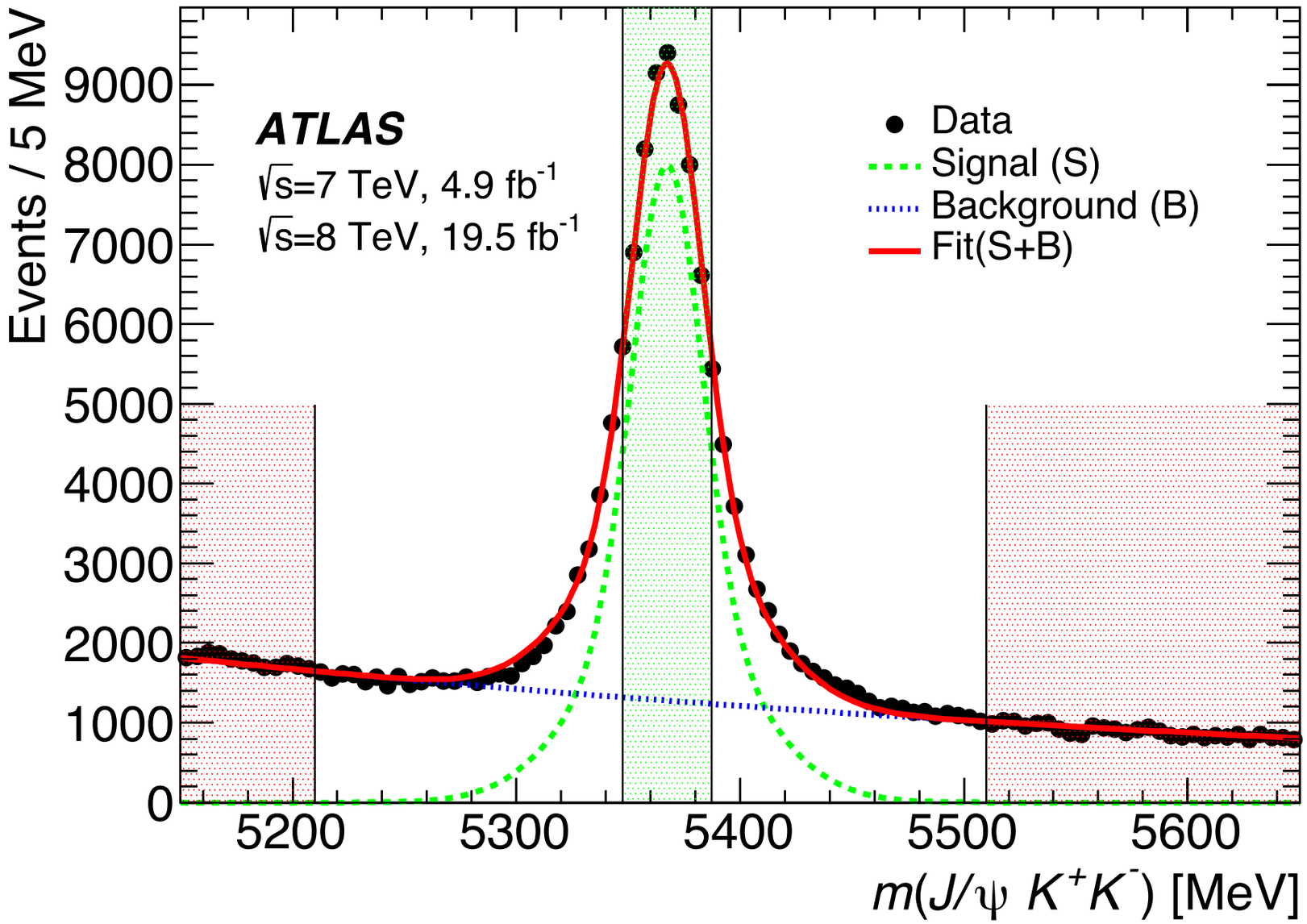
tetraquark search at ATLAS

- unbinned extended maximum likelihood fit on B^0_s —> J/Ψ ϕ candidates mass
  - $m_{fit}(B^0_s)$ = 5366.6±0.1$_{stat}$ MeV

- fit model
  - sig: double gaussian
  - bkg: exponential

- keep events in [5346.6,5386.6] MeV range for further investigation
  - fit: N(B^0_s) = 52750±280stat



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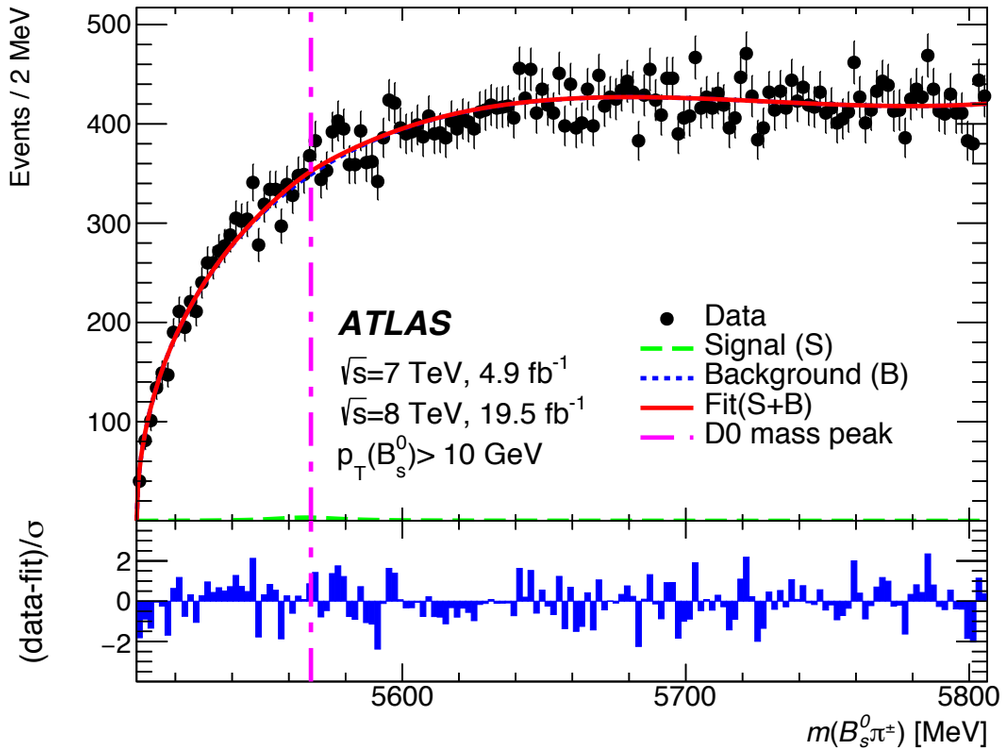
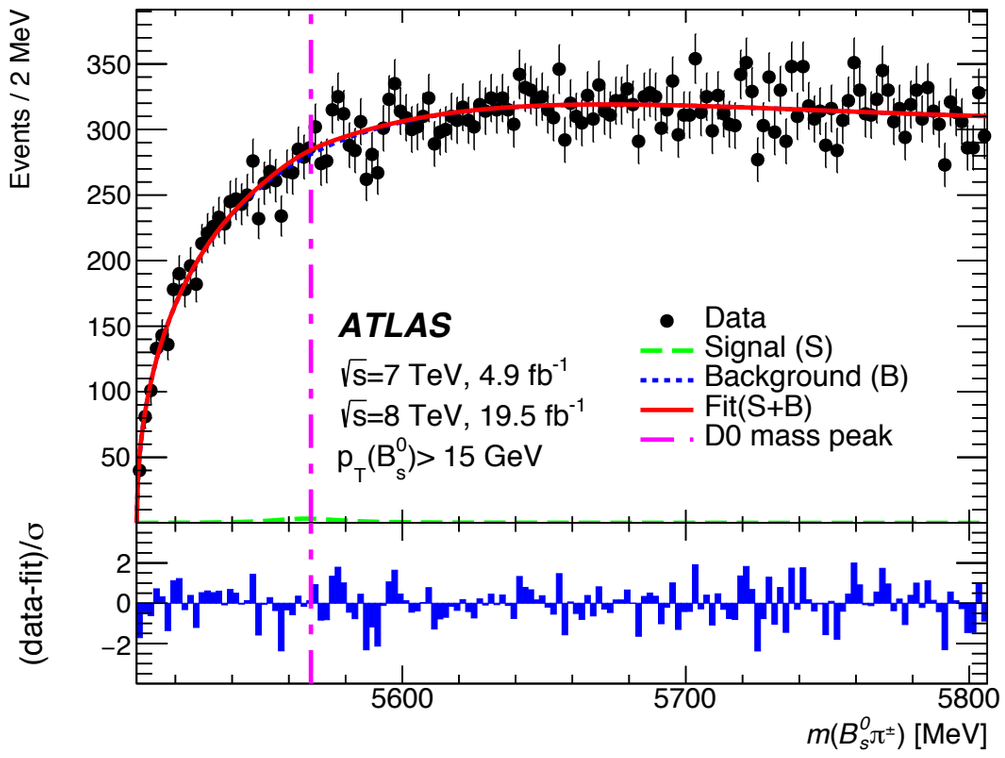
tetraquark search at ATLAS





- combine B^0_s with tracks from same PV
  - pion hypothesis
- mass variable
  $m(J/\Psi\ K\ K\ \pi) - m(J/\Psi KK) + m_{fit}(B^0_s)$
  - $m_{fit}(B^0_s) = 5366.6$ MeV
- extended unbinned maximum likelihood fit on mass difference distribution
  - two fits $p_T(B)>10$ GeV, $p_T(B) > 15$ GeV
    - as performed by other experiments

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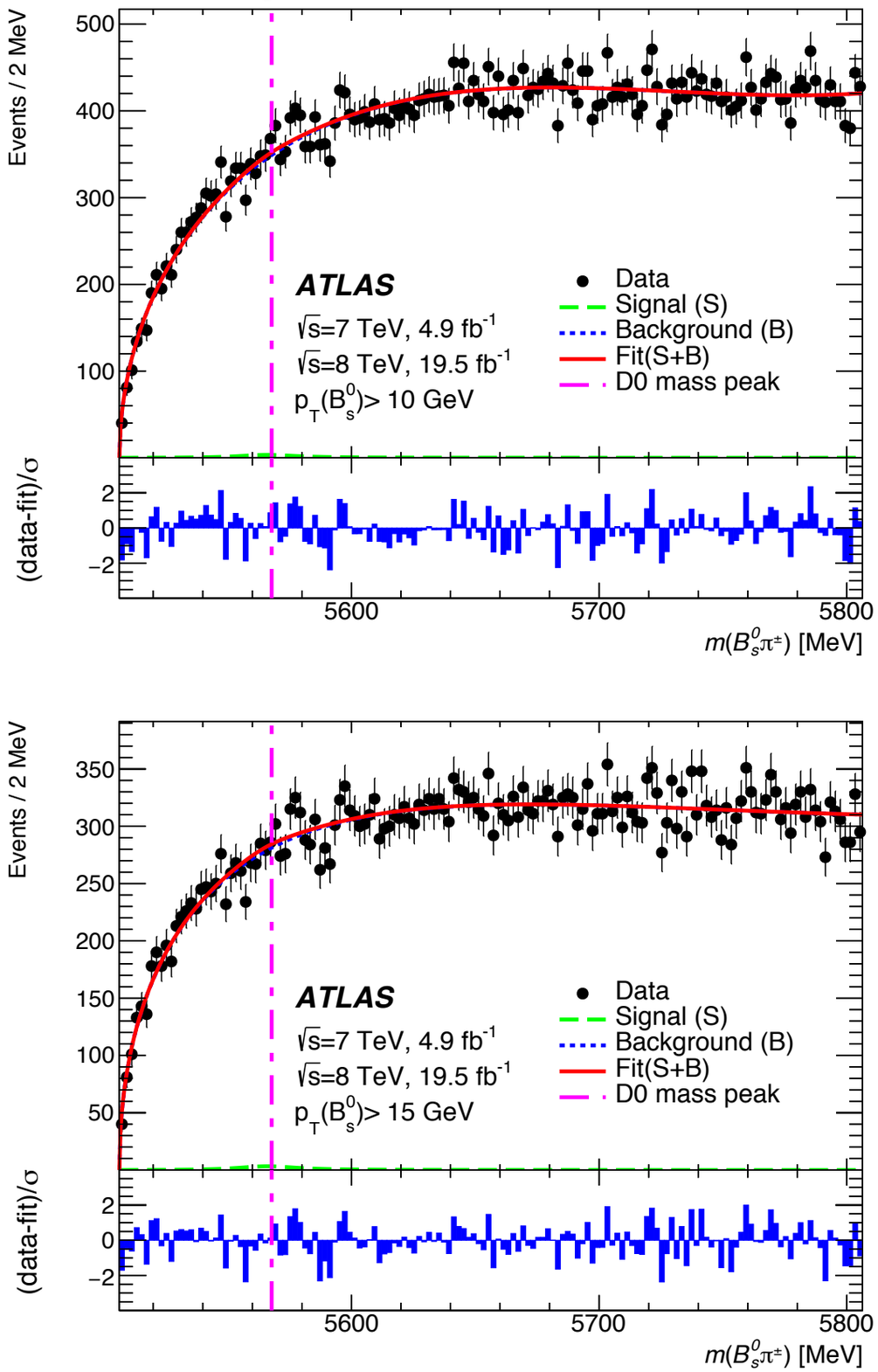
tetraquark search at ATLAS

D0 peak



- no significant X(5568) signal observed
- fitted X(5568) yield:
  - N(X) = 60 ±140 (p_T(B) > 10 GeV)
  - N(X) = -30 ±150 (p_T(B) > 15 GeV)
  - stat only

95%CL upper limits

- N(X) < 382 (p_T(B) > 10 GeV)
- N(X) < 356 (p_T(B) > 15 GeV)
- stat + syst

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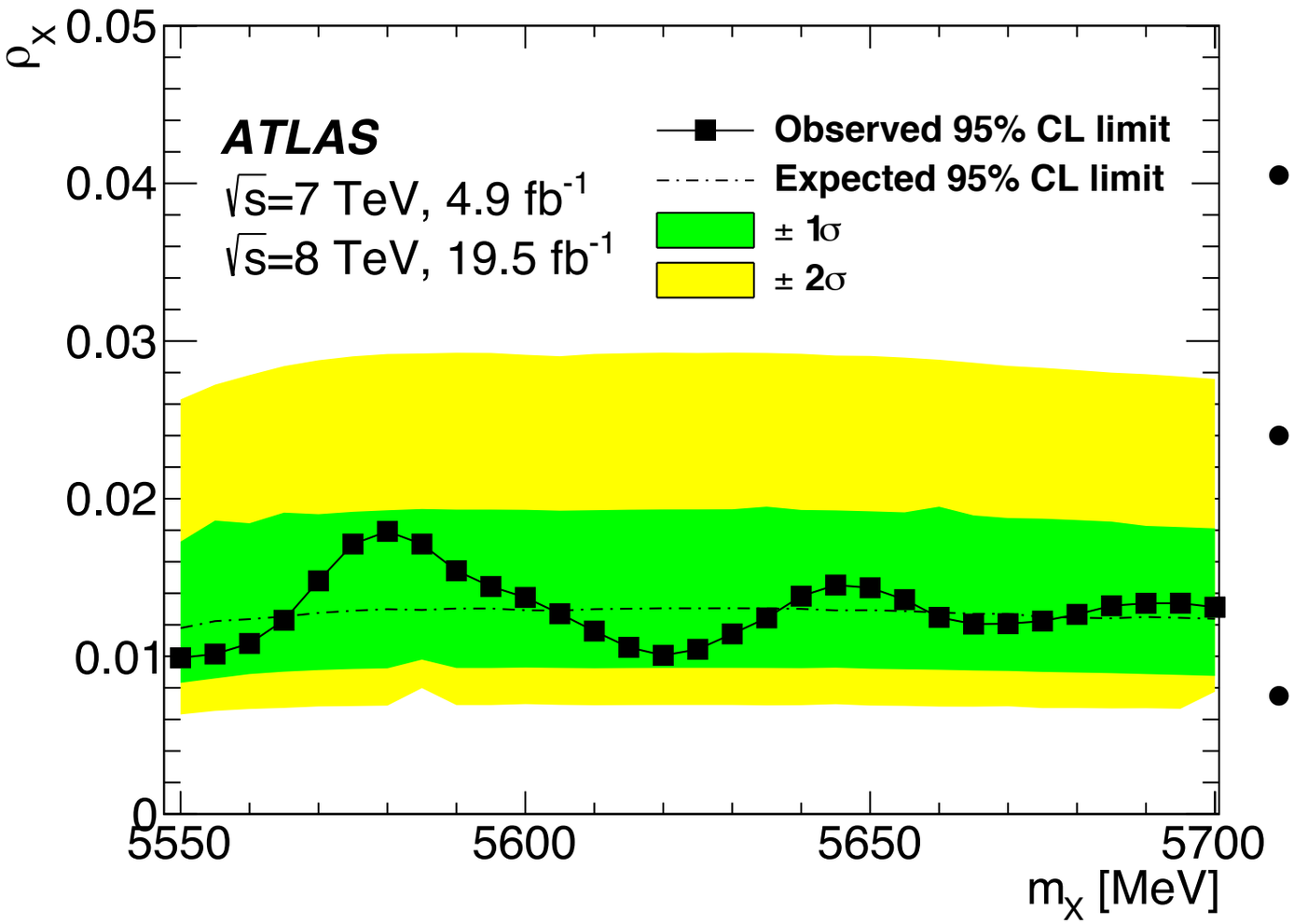
tetraquark search at ATLAS

- extract 95% CL upper limits on production rate
- Measure relative to B^0_s, for $p_T(B) > 10$ GeV:

$$\rho_X \equiv \frac{\sigma(pp \to X + \text{anything}) \times \mathcal{B}(X \to B_s^0 \pi^\pm)}{\sigma(pp \to B_s^0 + \text{anything})} = \frac{N(X)}{N(B_s^0)} \times \frac{1}{\epsilon^{\text{rel}}(X)}$$



- Signal: Breit-Wigner (D0 observation)
- scan range 5550 - 5700 MeV every 5 MeV
- systematic uncertainties included

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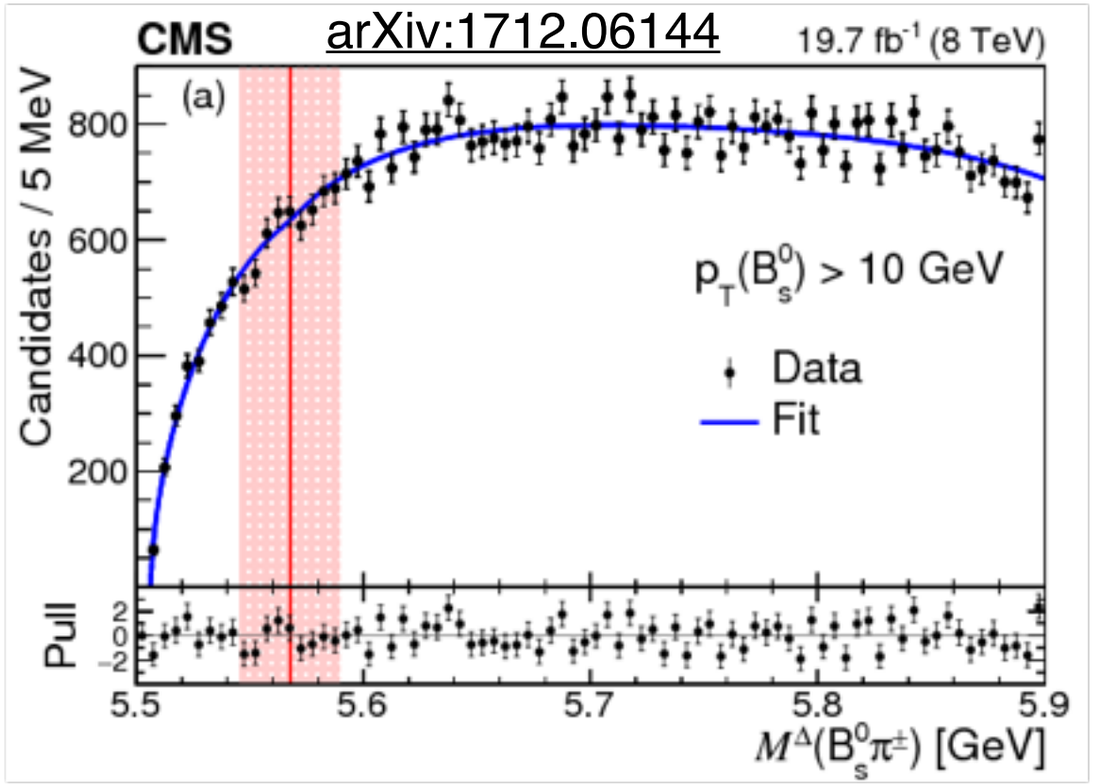
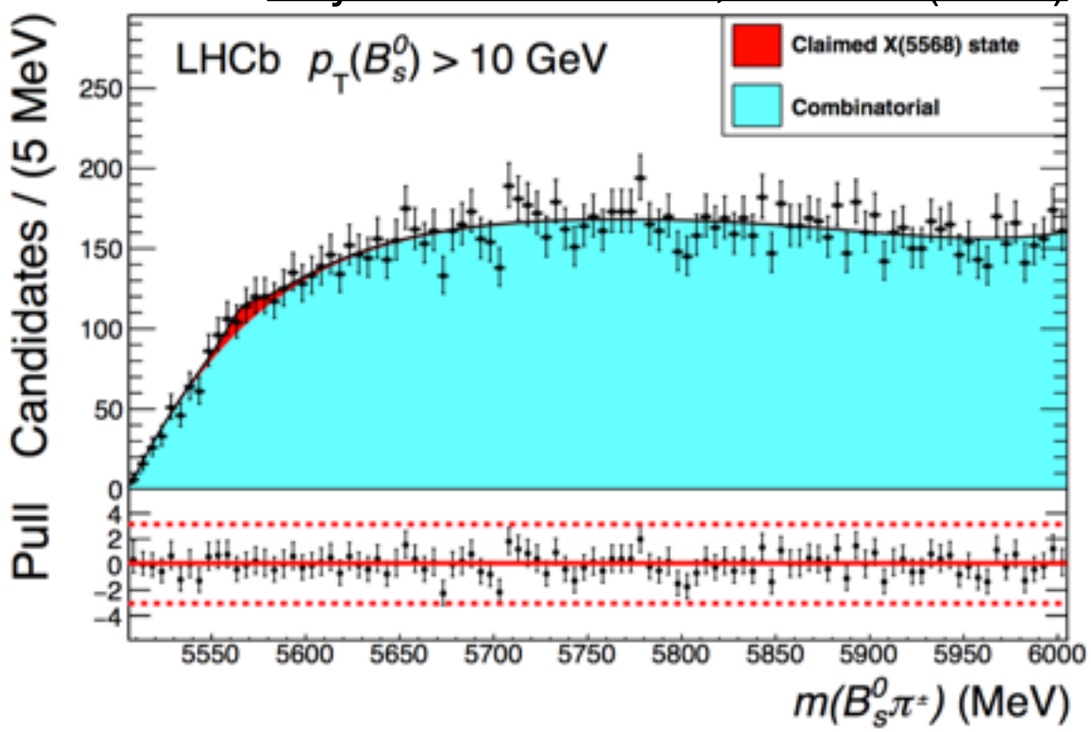
tetraquark search at other experiments

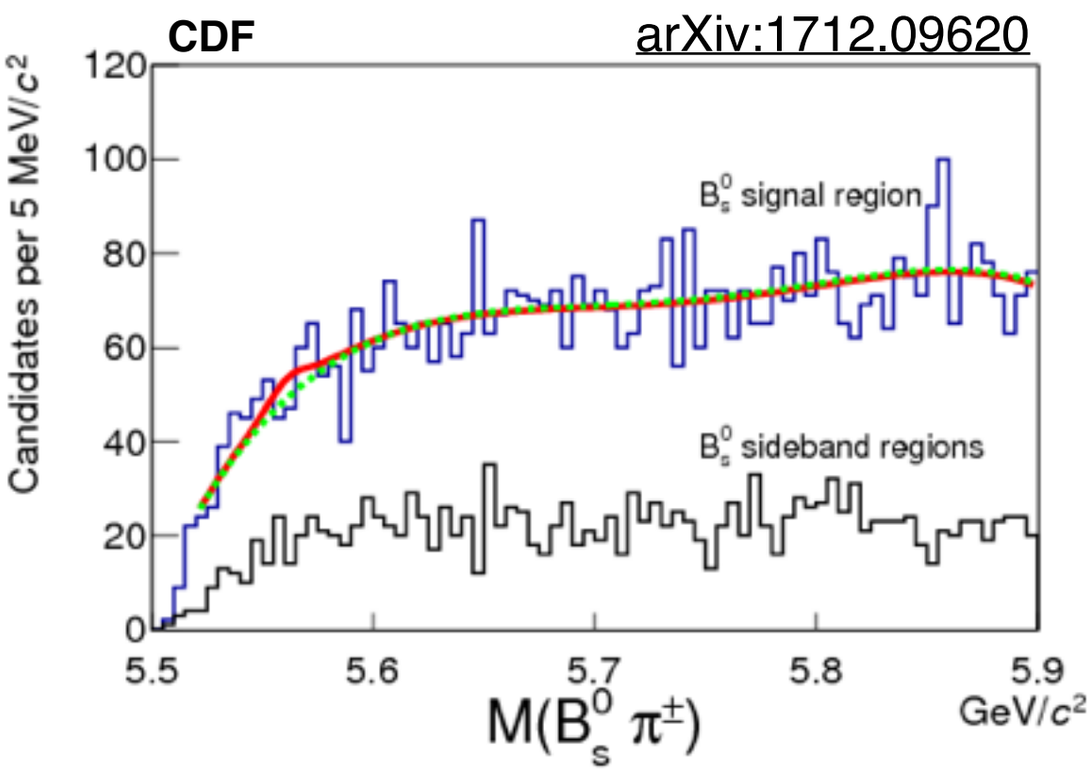
- X(5568) has been searched also by other collider experiments



arXiv:1712.06144



Phys. Rev. Lett. 117, 152003 (2016)



arXiv:1712.09620

no significant X(5568) signal observed

	ρ_X
D0	(8.6±1.9±1.4)%
ATLAS	< 0.015
CMS	< 0.011
LHCb	< 0.024
CDF	< 0.067

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conclusions

- B_c meson excited state $B_c(2S)$ observed at ATLAS
  - process: $B^{\pm}_c(2S)$ —> $B^{\pm}_c$ (J/Ψ[μμ] $\pi^{\pm}$) $\pi\pi$
  - more studies on this new state underway
- ATLAS has searched for the new structure reported by D0
  - called X(5568)
- exploit X(5568) —> B^0_s (J/Ψ [μ μ] ϕ[K K]) $\pi^{\pm}$ channel
- no significant signal observed
  - upper limits set

BACKUP

$B_c(2S)$ observation at ATLAS event selection

- selection optimised separately for the two datasets because of:
  - change in center of mass energy
  - change in pile-up conditions
- differences between the cuts applied on the datasets:

7 TeV dataset

- pion from Bc decay
  - $d_0/\sigma(d_0) > 5$
- PV identification:
  - PV with highest Σp_T^2
- J/Ψ vertex fit:
  - χ^2/NDOF < 2

8 TeV dataset

- pion from Bc decay
  - $d_0/\sigma(d_0) > 4.5$
- PV identification:
  - closest PV in 3D from reconstructed Bc decay vertex
- J/Ψ vertex fit:
  - χ^2/NDOF < 1.5