Highlights from Tsinghua

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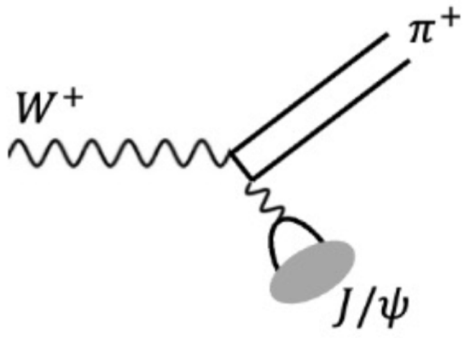
$W^{\pm}\to J/\psi\ \pi^{\pm}$ search

寻找W粒子衰变产生J/ψ+π粒子过程，试图完全重建末态粒子，发现W 粒子稀有衰变

对背景事例进行更加高效率的蒙特卡洛模拟，提高事例通过率

寻找信号与背景的差异，优化事例筛选条件

相互作用费曼图示意



基础事例筛选条件

Event Level Cut	leading $\mu\ p_T > 12GeV$
	sub-leading $\mu\ p_T > 6GeV$
	$p_T$cone20Z0/$\pi\ p_T < 1.0$
	$\pi\ p_T > 20GeV$
	$\lvert L_{xy}\rvert < 0.07$
	$\chi^2/ndf < 3$
Mass Window Cut	$2.6\ GeV < m_{J/\psi} < 3.5\ GeV$
	$65\ GeV < m_W < 95\ GeV$

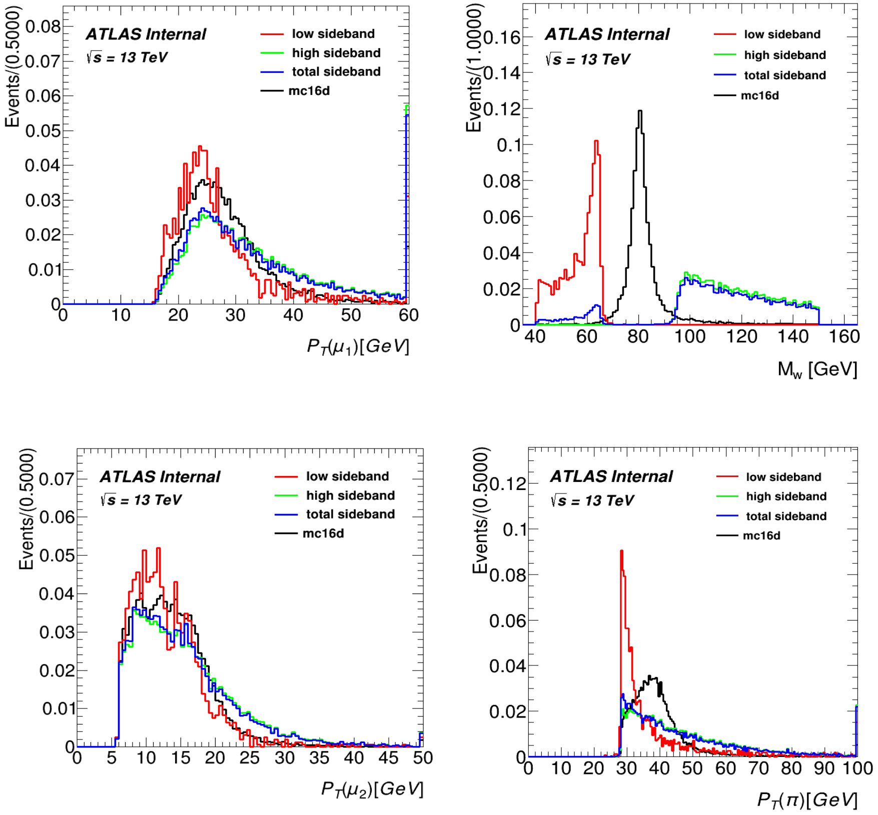
$W^{\pm} \to J/\psi\ \pi^{\pm}$ search

- 寻找W粒子衰变产生$J/\psi+\pi$粒子的过程，试图完全重建末态粒子对m_W进行精确测量
  - 事例触发器（trigger）的优化
    在不同的缪子相空间内利用不同的双缪子触发器，提升触发效率

事例筛选触发器选择

年份	触发器名称	触发器筛选效率
2015	HLT_mu6_mu4_bJpsimumu_noL2	72.1%
	HLT_mu18_mu8noL1	
2016	HLT_mu10_mu6_bJpsimumu	65.7%
	HLT_mu22_mu8noL1	
2017	HLT_mu11_mu6_bJpsimumu	67.0%
	HLT_mu22_mu8noL1	
2018	HLT_mu11_mu6_bJpsimumu	66.5%
	HLT_mu22_mu8noL1	

筛选后事例变量分布



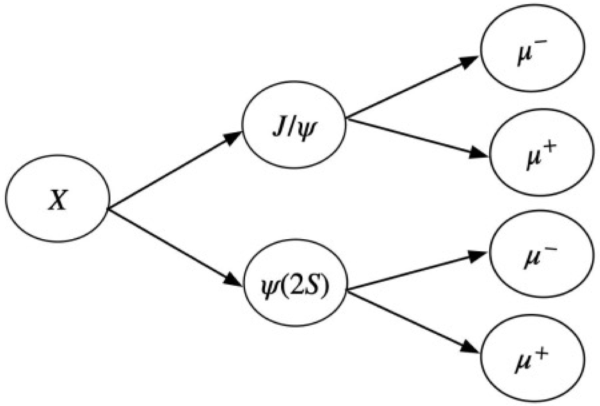
$W^{\pm} \longrightarrow J/\psi\ \pi^{\pm}$ search 进展

- 寻找W粒子衰变产生$J/\psi+\pi$粒子的过程，试图完全重建末态粒子对m_W进行精确测量
  - 事例触发器（trigger）的优化
    在不同的缪子相空间内利用不同的双缪子触发器，提升触发效率
  - 缪子孤立度的优化
    采用"临近纠正"算法，优化缪子局域度变量

- 完成了从release 21到release 25的迁移，已经申请了release 25的BPHY26 derivation格式数据，等待grid作业完成后进行分析。除了J/ψ信息外，新格式中加入了
  - 喷注即相应系统系统误差
  - 底夸克喷注标记及相应系统误差
  - MET即相应系统误差
  - Muon孤立度信息

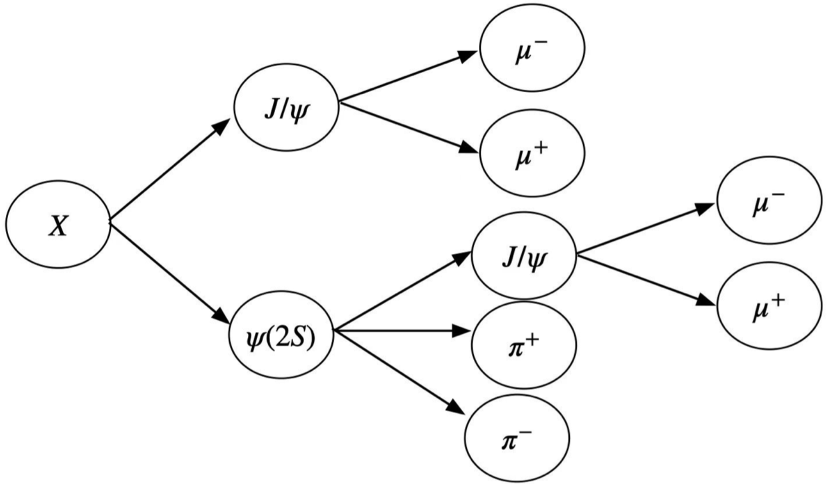
All-charm tetraquark search

[arXiv:2509.13101]



To better understand the all-charm tetraquark, the $J/\psi+\psi(2S)$ final state is investigated with two $\psi(2S)$ decay modes:

- $TQ \rightarrow J/\psi + \psi(2S) \rightarrow 4\mu$
- $TQ \rightarrow J/\psi + \psi(2S) \rightarrow 2J/\psi + 2\pi \rightarrow 4\mu + 2\pi$ (new)



Four muons (and two pions) are fitted to a common vertex by using the inner detector tracks, with J/ψ and ψ(2S) mass constraints

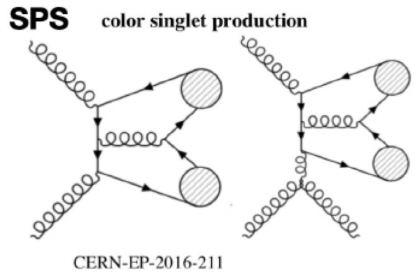
4μ channel		$4\mu + 2\pi$ channel	
SR	CR	SR	CR
Di-muon or tri-muon triggers, oppositely charged muons from each charmonium, *Loose* muons, $p_{T1,2,3,4} > 4, 4, 3, 3$ GeV and $\lvert\eta_{1,2,3,4}\rvert < 2.5$ for the four muons, $m_{J/\psi} \in [2.94, 3.25]$ GeV, $m_{\psi(2S)} \in [3.56, 3.80]$ GeV			
—		Two *loose* OS ID tracks with $p_T > 0.5$ GeV for pions, BDT requirement	
$\chi^2_{4\mu}/N < 3$, $\lvert L^{4\mu}_{xy}\rvert < 0.2$ mm, $\lvert L^{\text{charm}}_{xy}\rvert < 0.3$ mm, $m_{4\mu} < 11$ GeV		$\chi^2_{4\mu+2\pi}/N < 3$, $\lvert L^{4\mu+2\pi}_{xy}\rvert < 0.2$ mm, $\lvert L^{\text{charm}}_{xy}\rvert < 0.3$ mm, $m_{4\mu+2\pi} < 11$ GeV	
$\Delta R(J/\psi, \psi(2S)) < 0.25$	$\Delta R(J/\psi, \psi(2S)) \geq 0.25$	$\Delta R(J/\psi, \psi(2S)) < 0.25$	$\Delta R(J/\psi, \psi(2S)) \geq 0.25$

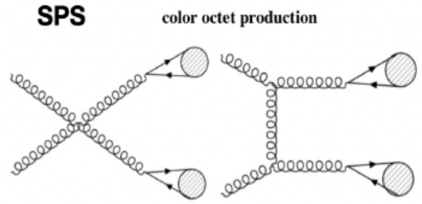
Background composition

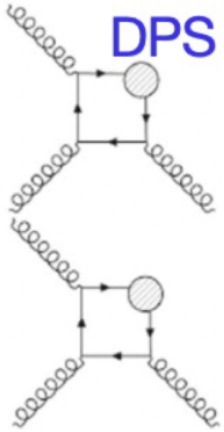
- The following backgrounds are estimated based on MC simulations, with kinematics corrections and normalizations obtained in dedicated CRs:
  - SPS (Single parton scattering) containing two prompt
  - DPS (Double parton scattering) containing two prompt ψ’ s
  - Non-prompt ψ’ s from $b\bar{b} \rightarrow J/\psi + \psi + X$
- The following can be estimated by data driven method (collectively called “others”)
  - Single ψ background containing only one real ψ candidate
  - Non-peaking background containing no real ψ candidate

The order of estimated backgrounds are “other”, non-prompt, DPS and SPS. Each background has a CR (same cuts as in slide 10 except for the ones listed below):

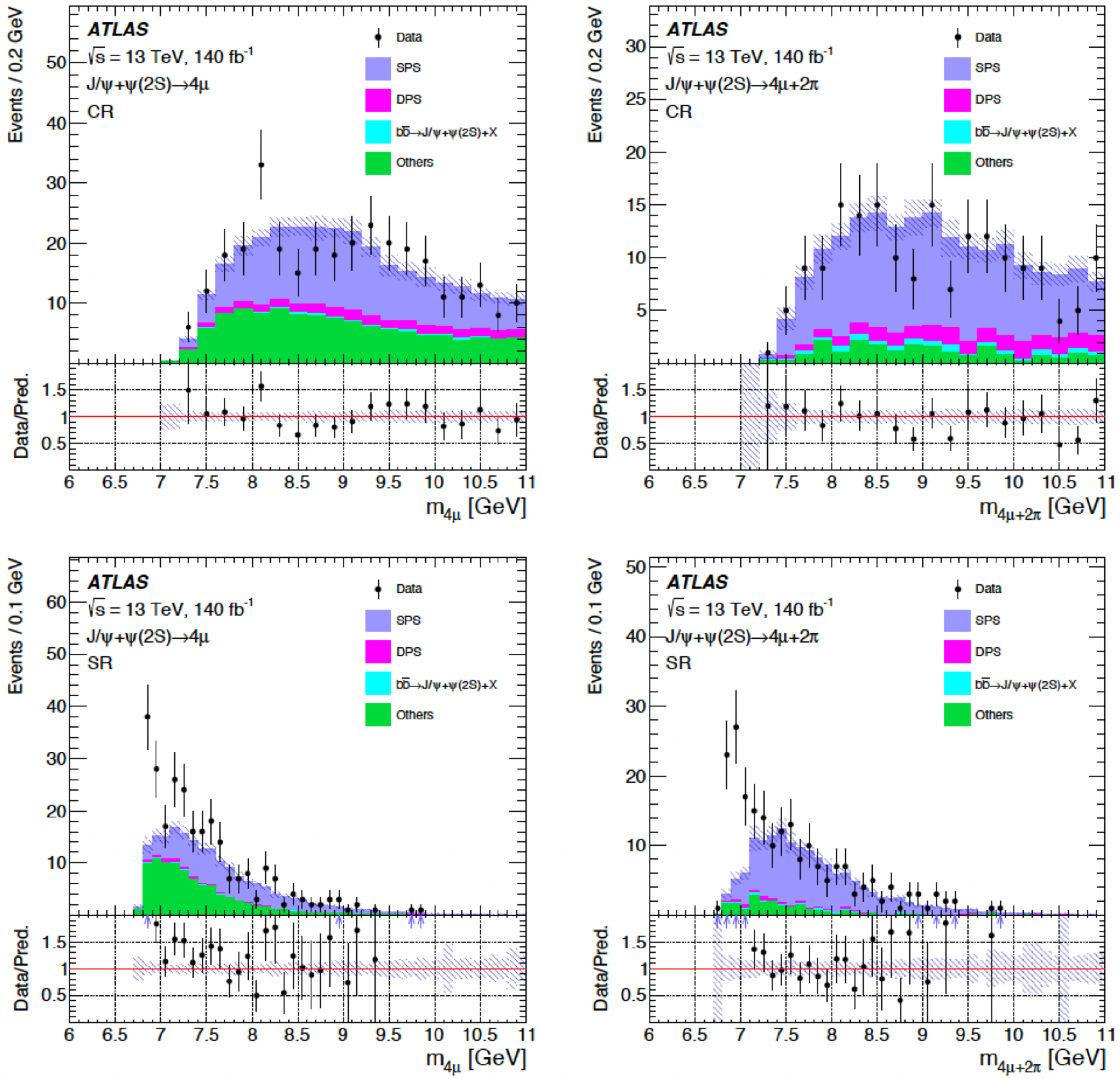
“others”	non-prompt	DPS	SPS
$m_{J/\psi} \in [2.60, 2.76]$ GeV or $m_{J/\psi} \in [3.34, 3.50]$ GeV for either J/ψ; $m_{\psi(2S)} \in [3.35, 3.48]$ GeV or $m_{\psi(2S)} \in [3.88, 4.10]$ GeV for $\psi(2S)$	$L_{xy}^{\text{charm}} > 0.3$ mm for either charmonium, $\chi^2_{4\mu(+2\pi)}/N < 15$, $m_{4\mu(+2\pi)} < 25$ GeV	No ΔR or BDT requirements, $m_{4\mu(+2\pi)} \in [14, 25]$ GeV	No ΔR or BDT requirements, $m_{4\mu(+2\pi)} \in [8, 12]$ GeV







Background estimation in analysis CRs and SRs



- The analysis CRs ($\Delta R \geqslant 0.25$) are SRs ($\Delta R < 0.25$) are defined with the same cuts (cf. slide 10) except the ΔR cut
- The analysis CRs are used to check the modelling of backgrounds and constrain the background normalization in SRs. For example, the Pythia8 model parameter "pT0timesMPI" can be checked below 8 GeV
- Fractions of different backgrounds in the SRs:

Channel	"others"	non-prompt	DPS	SPS
4μ	47%	0.8%	2.5%	49%
$4\mu + 2\pi$	14%	1.4%	3.6%	82%

The fit models

The signal resonances can be either standalone or interfering. They can interfere with each other or interfere with the SPS background. Three signal models are used.

Model A: two interfering BWs that decays to both di-J/ψ and J/ψ+ψ(2S)

$$f^A_{s,\text{di-}J/\psi}(x) = \left|\sum_{i=1}^{2} \frac{z_i}{m_i^2 - x^2 - i m_i \Gamma_i(x)}\right|^2 \sqrt{1 - \frac{4M^2_{J/\psi}}{x^2}} \otimes R(\boldsymbol{\theta}),$$

$$f^A_{s,J/\psi+\psi(2S)}(x) = \left|\sum_{i=1}^{2} \frac{z_i}{m_i^2 - x^2 - i m_i \Gamma_i(x)}\right|^2 \sqrt{1 - \left(\frac{M_{J/\psi} + M_{\psi(2S)}}{x}\right)^2} \otimes R(\boldsymbol{\theta}),$$

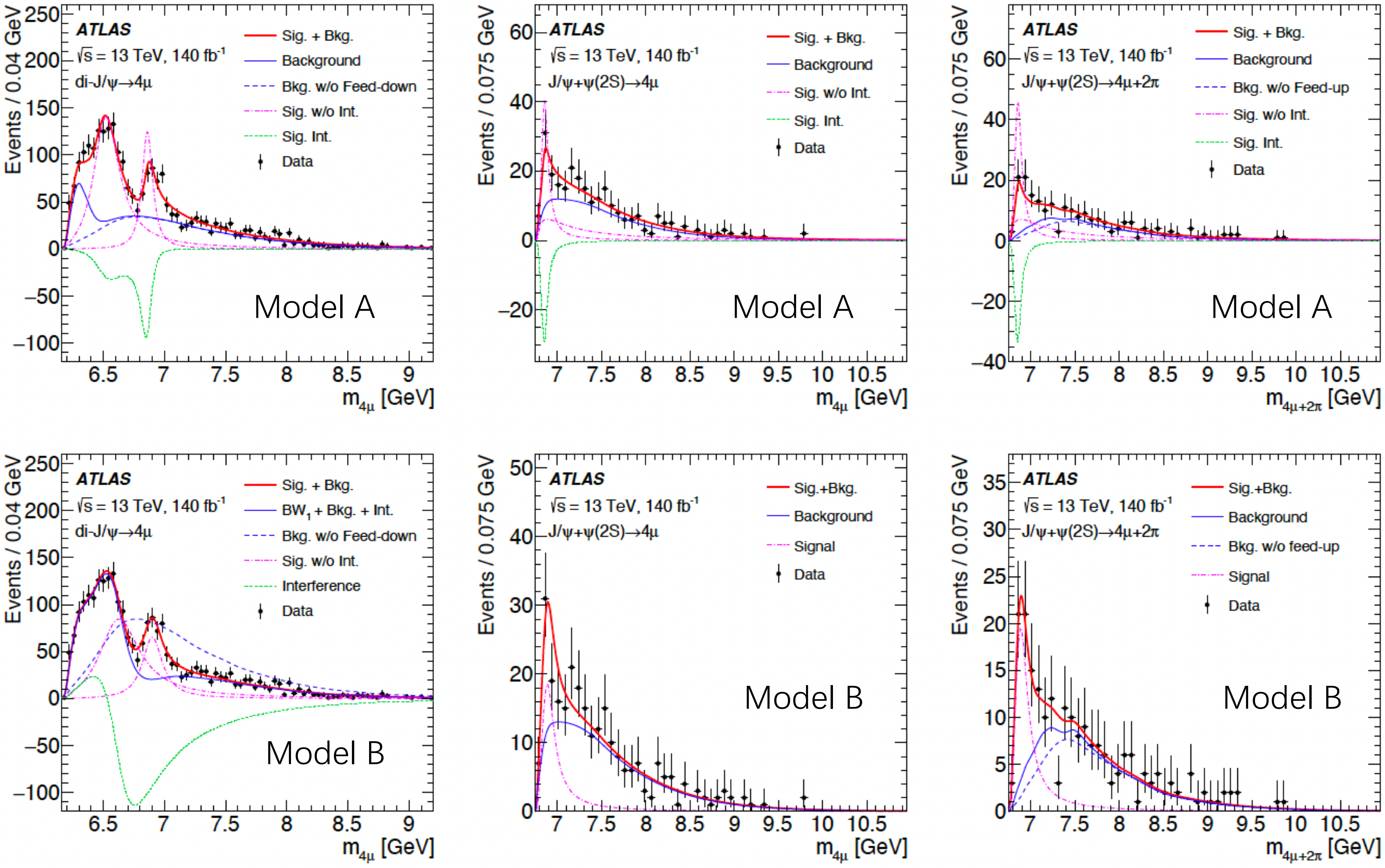
Model B: X(6900) is standalone and the other interferes with SPS. X(6900) decays to both di-J/ψ and J/ψ+ψ(2S)

$$f^B_{s+\text{SPS},\text{di-}J/\psi}(x) = \left(\left|\frac{z_1}{m_1^2 - x^2 - i m_1 \Gamma_1(x)} + A(x) e^{i\phi_{\text{SPS}}}\right|^2 + \left|\frac{1}{m_2^2 - x^2 - i m_2 \Gamma_2(x)}\right|^2\right) \sqrt{1 - \frac{4M^2_{J/\psi}}{x^2}} \otimes R(\boldsymbol{\theta}),$$

Model C: a single BW in the J/ψ+ψ(2S) channel

$$f^C_{s,J/\psi+\psi(2S)}(x) = \left|\frac{1}{m_2^2 - x^2 - i m_2 \Gamma_2(x)}\right|^2 \sqrt{1 - \left(\frac{m_{J/\psi} + m_{\psi(2S)}}{x}\right)^2} \otimes R(\boldsymbol{\theta}).$$

The fit results (1)



- The signal X(6900) yields in J/ψ+ψ(2S)→4μ and di-J/ψ→4μ are related by (R is ratio of its partial decay widths)

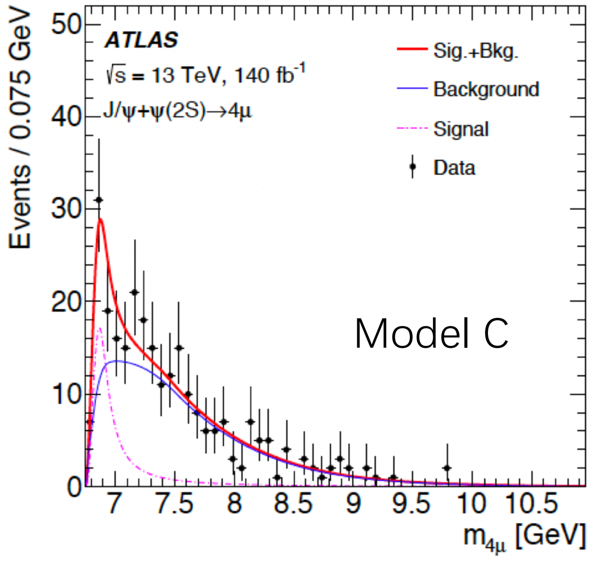
$$\frac{N_{4\mu}}{N_{\text{di-}J/\psi}} = R \cdot \frac{\mathcal{B}(\psi(2S) \to \mu\mu) \cdot \varepsilon_{4\mu}}{\mathcal{B}(J/\psi \to \mu\mu) \cdot \varepsilon_{\text{di-}J/\psi}},$$

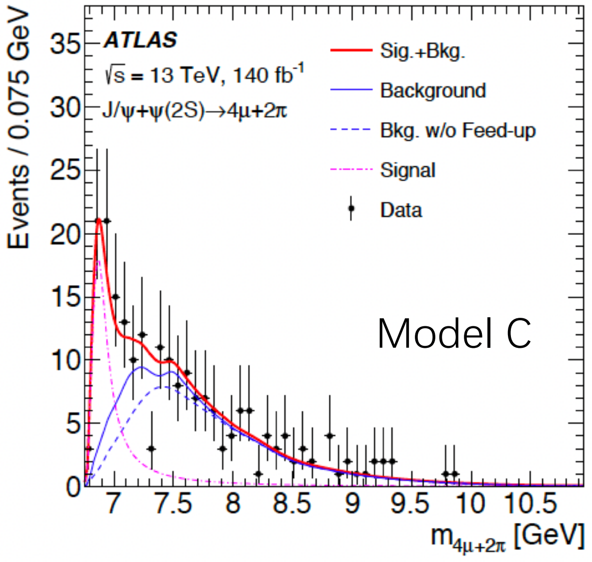
$N_{4\mu}/N_{\text{di-}J/\psi}(R=1) = 0.145\pm0.016$

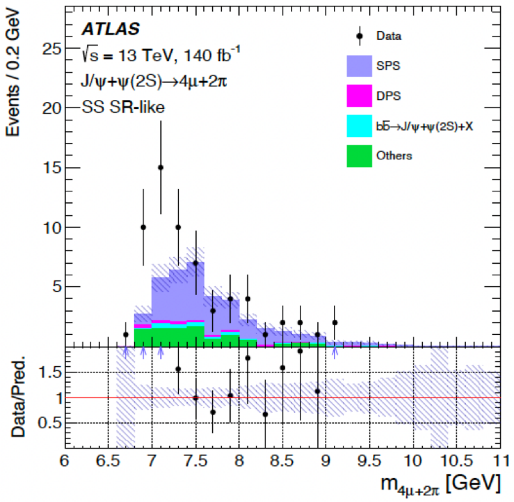
- Similarly, the X(6900) yields in J/ψ+ψ(2S)→4μ and J/ψ+ψ(2S)→4μ+2π are related by

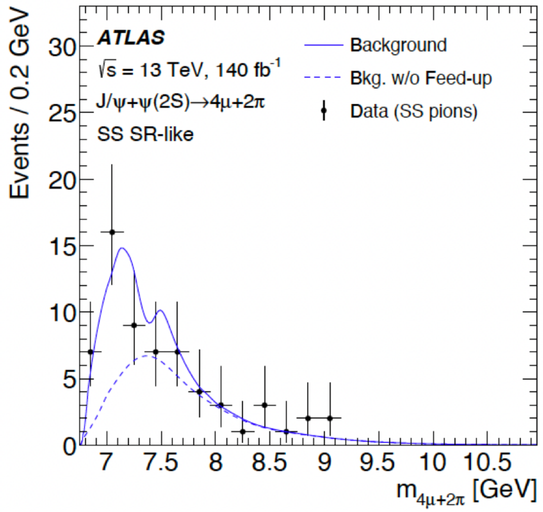
$N_{4\mu}/N_{4\mu+2\pi} = 0.880\pm0.072$

The fit results (2)









X(6900)

	model *A*	model *B*	model *C*
m / GeV	$6.860 \pm 0.023 \pm 0.010$	$6.902 \pm 0.008 \pm 0.010$	$6.884 \pm 0.017^{+0.058}_{-0.005}$
Γ / GeV	$0.082 \pm 0.032 \pm 0.015$	$0.183 \pm 0.025 \pm 0.007$	$0.178 \pm 0.054^{+0.176}_{-0.024}$
R	$1.08 \pm 0.20^{+0.40}_{-0.09}$	$0.93 \pm 0.17 \pm 0.11$	—

X(6600)

	model *A*	model *B*
m / GeV	$6.531 \pm 0.011 \pm 0.002$	$6.646 \pm 0.018 \pm 0.021$
Γ / GeV	$0.244 \pm 0.021 \pm 0.021$	$0.390 \pm 0.045 \pm 0.037$

- SS SR-like (two SS pions) events are used to constrain the feed-up in the OS regions
- A 8.9σ significance in the $J/\psi+\psi(2S)$ channel
- Ratio of partial decay widths is close to 1 – unexpected due to phase space consideration
- Fit favors a single resonance in $J/\psi+\psi(2S)$. An upper limit of 0.41 on the signal yield of X(7200) relative to X(6900) can be obtained

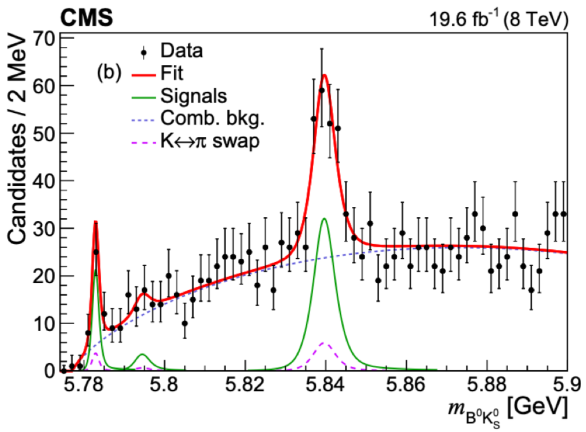
$\mathrm{B_s}$ Excited States in $B^0 + K_s$

- $B_s^*(b\bar{s})$ is an ideal laboratory for Heavy Quark Effective Theory (HQET). Measurment of mass and Br provides crucial constraints on the non-perturbative QCD potential models.
- The P-wave B_s^0 states are the bound states of b and s quarks with $L = 1$, We focus on the j_q=3/2 doublet:
  - $B_{s1}(j = \frac{3}{2}, J^P = 1^+) \rightarrow B_{s1}(5830)^0$
  - $B_{s2}^*(j = \frac{3}{2}, J^P = 2^+) \rightarrow B_{s2}^*(5840)^0$
- Try to observe new decay channels, and measure the branching fraction compared with known decay channels

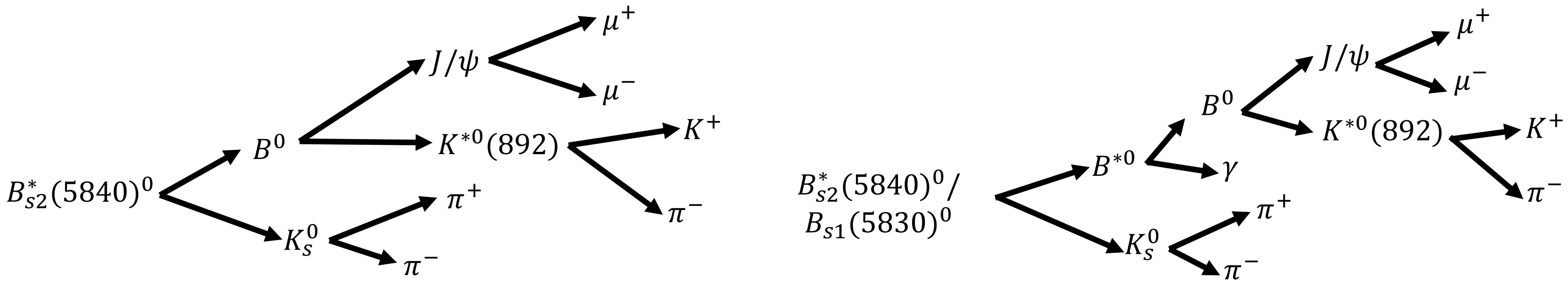
Decay channels	$B_{s1}(5830)$	$B_{s2}^*(5840)$
B^0K_s	forbidden	CMS(2018),6.3σ
$B^{*0}(1^-)K_s$	CMS(2018),3.9σ	Not observed

signal channel

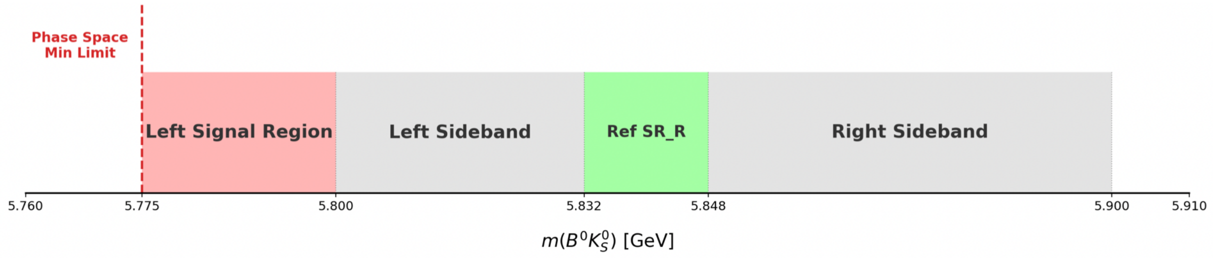
reference channel



B_s Excited States in $B^0 + K_s$



- No explicit reconstruction of the soft photon from the$B^{*0} \to B^0\gamma$ decay
- Dataset: Combined Run2 (139fb^{-1}) and partial Run3(data22-24,175fb^{-1}) pp collisions
- Cascade vertex fit for the full decay chain, LRT considered in Ks tracking
- Mass constraints on J/ψ, B^0 and K_S^0 to improve resolution.
- Mass windows for the Reference Channel, Signal Region of Interest, and Sidebands are shown

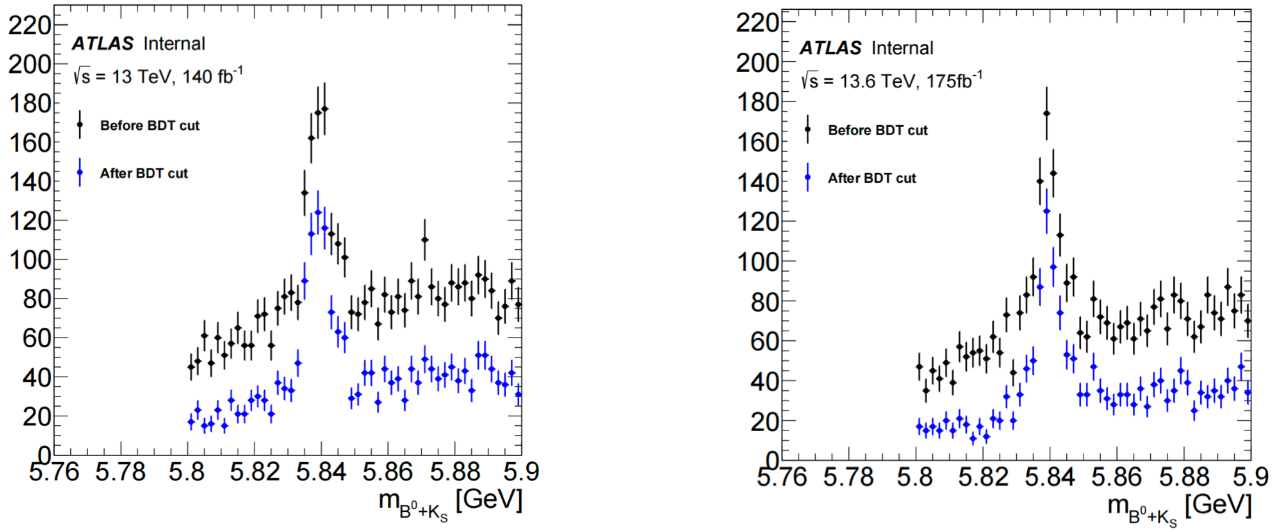


B_s Excited States in $B^0 + K_s$

- Gradient BDT is used to separate the signal and background after the pre-selection
  - The signal B_{s2}^* in SR_R and the SB data are used for training
  - A two-fold procedure is implemented to separate training and testing samples
- The BDT score cut is set at -0.38 according to the signal significance

BDT input variables

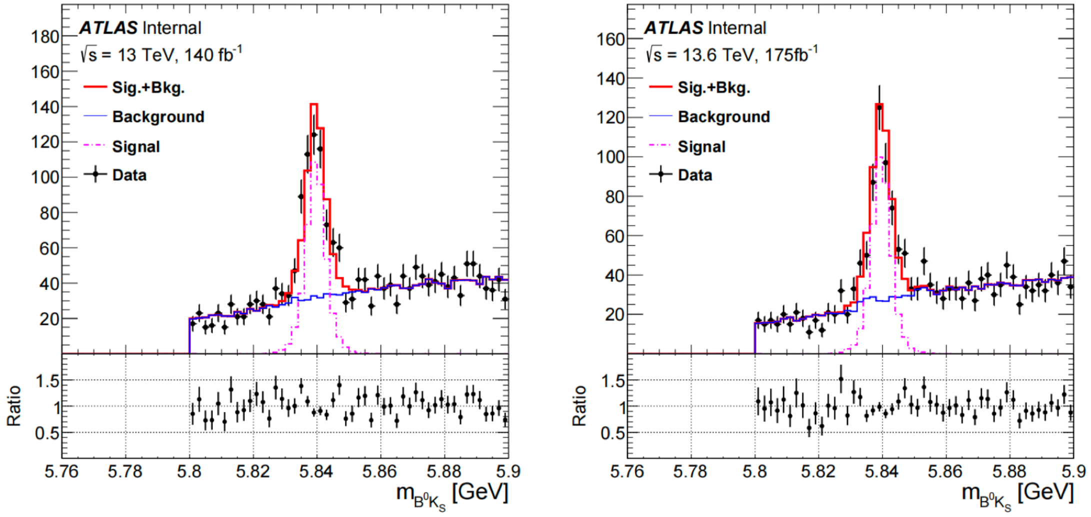
- $L_{xy}^{K_S}$.
- $L_{xy}^{B^0}$.
- $p_{\mathrm{T}}^{B^0 K_S} / \sum p_{\mathrm{T}}^{PV}$.
- $L_{xy}^{B^0 K_S}$.
- χ^2/N of $B^0 K_S$
- B^0 p_{T}.
- K_S p_{T}.
- $K^{\pm}$ p_{T}.



The $B^0 K_s$ mass distribution in $SR_R + S_B$ regions before and after BDT cut of run-2 (left) and run-3 (right)

$\mathrm{B_s}$ Excited States in $B^0 + K_s$

- Mixing a B^0 from one event with a K_s from a different event to simulate the non-resonant background shape
- The mixed-event sample is reweighted in $(\Delta R, p_T)$ to match the distribution of the data sidebands
- The reweighted mixed-event template is used as the primary background PDF in the final fit
- Dominant uncertainties arise from the reference channel normalization, including MC width modeling and the statistical precision of the fitted yield.



The $B^0 K_s$ mass distribution in $SR_R + S_B$ regions of run-2 (left) and run-3 (right)

Summary

- Three physics analyses ongoing

  - $W^{\pm} \rightarrow J/\psi\ \pi^{\pm}$ search: In progress, request EB this year (collaborating with Nanjing)

  - All-charm tetraquark in $J/\psi + \psi(2S)$: In journal review. Will publish soon

  - B_s Excited States in $B^{0} + K_{s}$: Initiated last year. Requesting EB now