Recent Heavy Flavor Results in CMS

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  - Observation of triple J/ψ production

HF studies in CMS China institutions

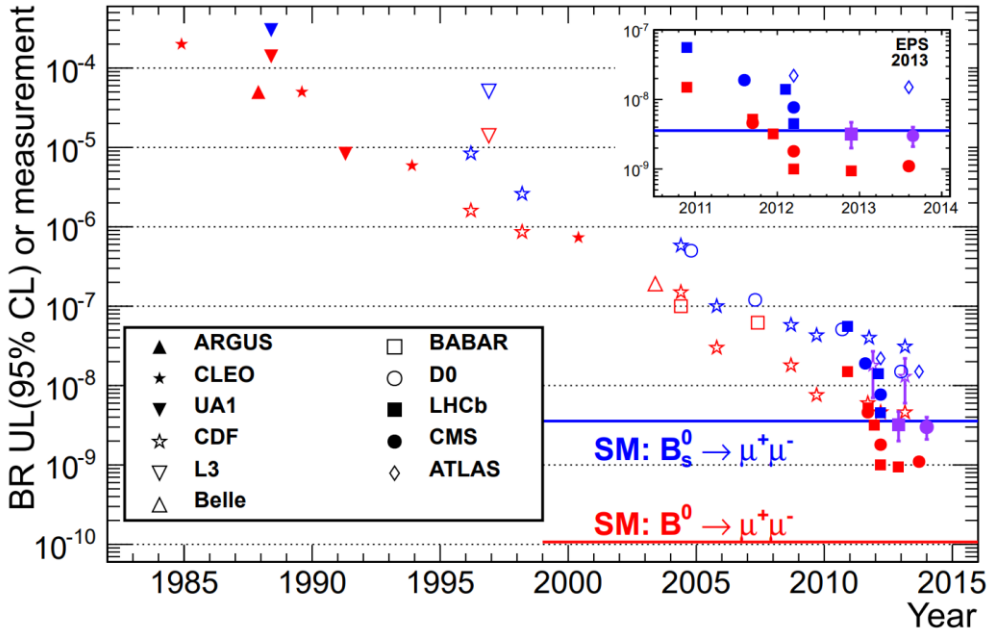
- Several topics on going in CMS China institutions

- PKU:
  - Study of $B^+ \to K^+\mu^+\mu^-, B^0 \to K^{*0}\mu^+\mu^-$

- NNU, THU and Fudan
  - Threshold structures in $J/\psi J/\psi$, $J/\psi\psi(2S)$, $J/\psi\Upsilon, \Upsilon\Upsilon\cdots$
  - Search for $\eta_b \to J/\psi J/\psi$ (Gao Xuyang, Nov. 25)
  - Study of $B^+ \to J/\psi\phi K^+$

Combination of the ATLAS, CMS and LHCb results on $B^0_{(s)} \to \mu^+\mu^-$

- $B^0_{(s)} \to \mu^+\mu^-$: Sensitive to new physics
- SM predication: $B(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.14) \times 10^{-9}$



ATLAS-CONF-2020-049, CMS PAS BPH-20-003, LHCb-CONF-2020-002

Combination of the ATLAS, CMS and LHCb results on $B^0_{(s)} \to \mu^+\mu^-$

- ATLAS:
  - $B(B^0_s \to \mu^+\mu^-) = \left(2.8^{+0.8}_{-0.7}\right) \times 10^{-9}$
  - $B(B^0 \to \mu^+\mu^-) = (-1.9 \pm 1.6) \times 10^{-10}$

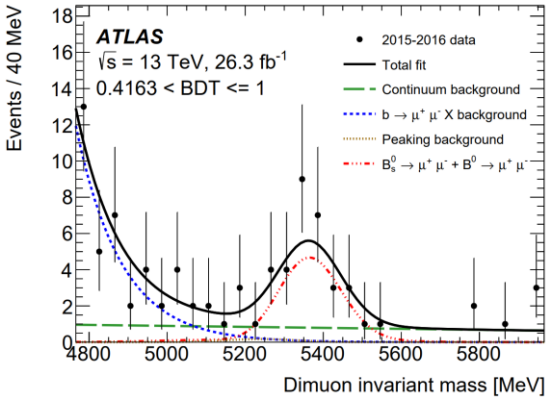
  JHEP04(2019)098

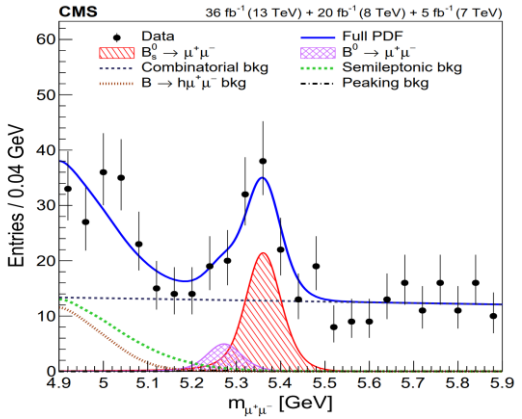
- CMS:
  - $B(B^0_s \to \mu^+\mu^-) = \left(2.9^{+0.7}_{-0.6}(\text{exp}) \pm 0.2(\text{frag})\right) \times 10^{-9}$
  - $B(B^0 \to \mu^+\mu^-) = \left(0.8^{+1.4}_{-1.3}\right) \times 10^{-10}$

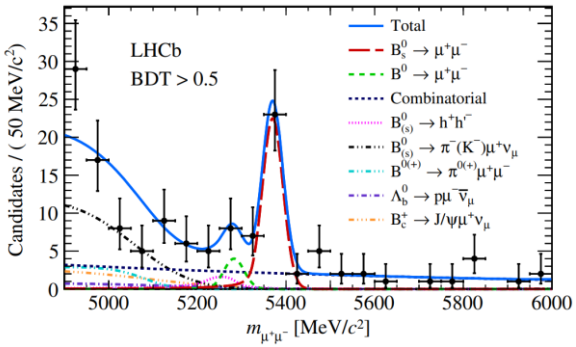
  JHEP04(2020)188

- LHCb:
  - $B(B^0_s \to \mu^+\mu^-) = \left(3.0 \pm 0.6^{+0.3}_{-0.2}\right) \times 10^{-9}$
  - $B(B^0 \to \mu^+\mu^-) = \left(1.5^{+1.2+0.2}_{-1.0-0.1}\right) \times 10^{-10}$

  PRL188(2017)191801







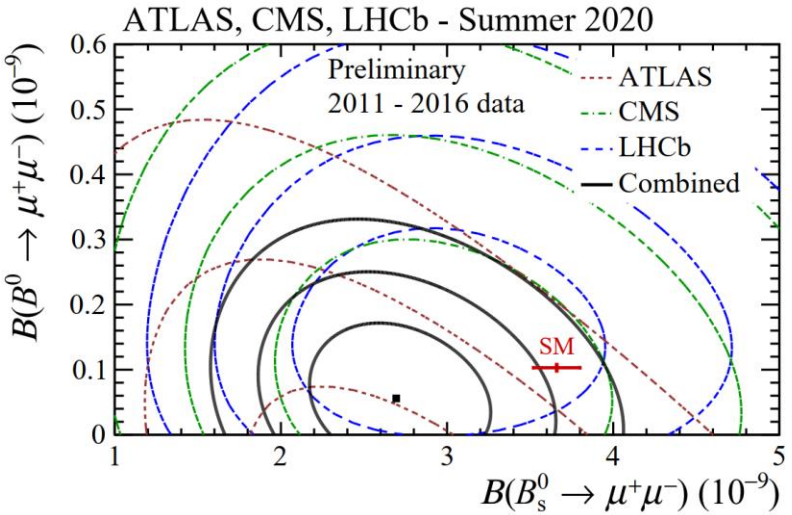
Combined BF of $B^0_{(s)} \to \mu^+\mu^-$

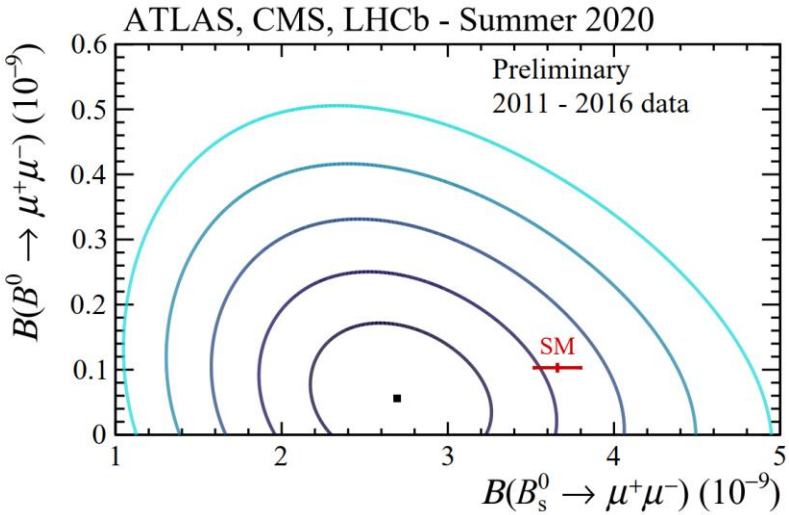
- Combined BF:

$$B\left(B_s^0 \to \mu^+\mu^-\right) = \left(2.69^{+0.37}_{-0.35}\right) \times 10^{-9}$$
$$B\left(B^0 \to \mu^+\mu^-\right) = (0.6 \pm 0.7) \times 10^{-10}$$

- Ratio of $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$:

$R = 0.021^{+0.030}_{-0.025}$, $R < 0.052\ (0.060)$ at 90% (95%) CL.

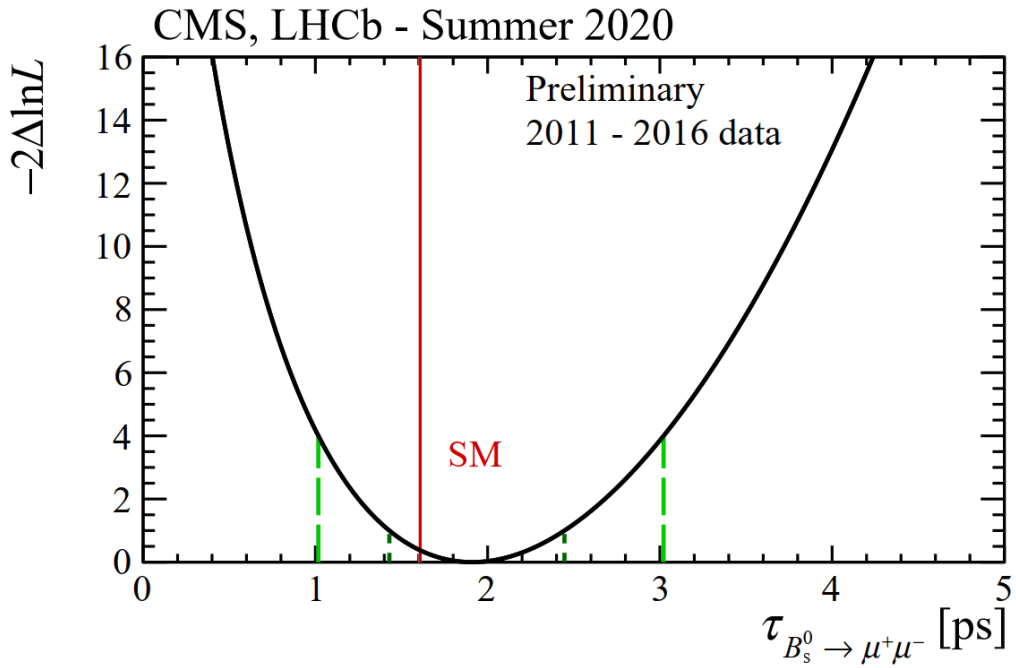




ATLAS-CONF-2020-049, CMS PAS BPH-20-003, LHCb-CONF-2020-002

Combined lifetime of $B_s^0 \to \mu^+\mu^-$

- Combined effective lifetime: $\tau_{B_s^0 \to \mu^+\mu^-} = 1.91^{+0.37}_{-0.35}$ ps.

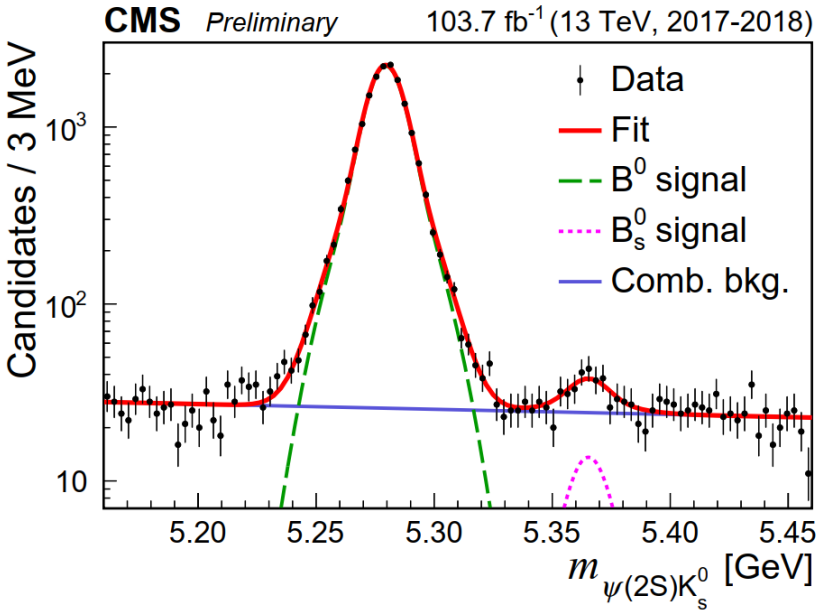


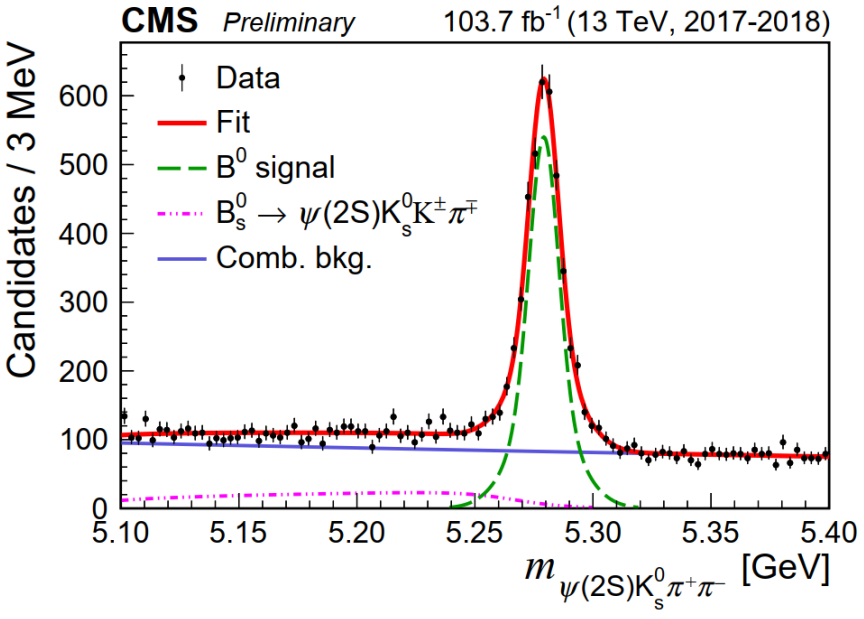
ATLAS-CONF-2020-049, CMS PAS BPH-20-003, LHCb-CONF-2020-002

HF results from CMS

Observation of $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ & $B_S^0 \to \psi(2S)K_S^0$

- Signal yields





- Relative branching fraction measurement

$$R_{\mathrm{s}} \cdot \frac{f_s}{f_d} = \frac{f_s}{f_d} \cdot \frac{\mathcal{B}(\mathrm{B_s^0} \to \psi(2\mathrm{S})\mathrm{K_S^0})}{\mathcal{B}(\mathrm{B^0} \to \psi(2\mathrm{S})\mathrm{K_S^0})} = (0.69 \pm 0.14\,(\mathrm{stat}) \pm 0.02\,(\mathrm{syst}))\%,$$

$$R_{\pi^+\pi^-} = \frac{\mathcal{B}(\mathrm{B^0} \to \psi(2\mathrm{S})\mathrm{K_S^0}\pi^+\pi^-)}{\mathcal{B}(\mathrm{B^0} \to \psi(2\mathrm{S})\mathrm{K_S^0})} = (48.0 \pm 1.3\,(\mathrm{stat}) \pm 3.2\,(\mathrm{syst}))\%.$$

Angular analysis of the decay $B^+ \to K^{*+}\mu^+\mu^-$

- $B^+ \to K^{(*)+}l^+l^-$: sensitive to new physics

- Angular analysis of $B \to K^*l^+l^-$: 3.1σ deviation from SM in some result PRL126.161802(2021)

- $R\left(K^{(*)}\right) = \frac{B\left(B^+ \to K^{(*)}\mu^+\mu^-\right)}{B\left(B^+ \to K^{(*)}e^+e^-\right)}$: $3.1(2.3)\sigma$ deviation from SM arxiv:2103.11769

Angular analysis of the decay $B^+ \to K^{*+}\mu^+\mu^-$

- A_{FB}: Forward-backward asymmetry of the muon
- F_L: Longitudinal polarization fraction of the K^{*+}
- Performed in q^2 regions: [1, 8.68], [10.09, 12.86], [14.18, 19] GeV^2

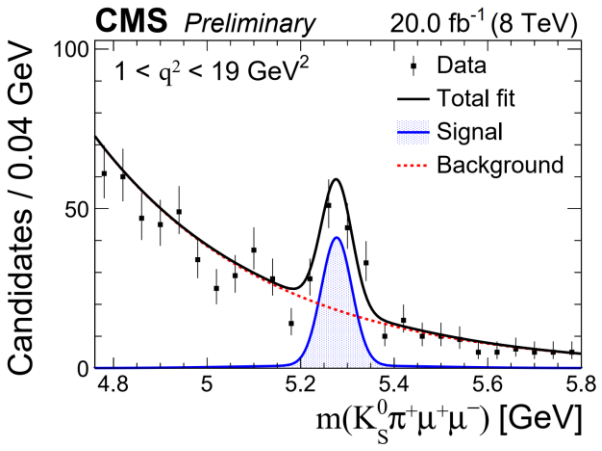
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\mathrm{K}\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}q^2} = \frac{9}{16}\left\{\frac{2}{3}\left[F_\mathrm{S} + 2A_\mathrm{S}\cos\theta_\mathrm{K}\right](1-\cos^2\theta_\ell)\right.$$
$$+ (1-F_\mathrm{S})\left[2F_\mathrm{L}\cos^2\theta_\mathrm{K}(1-\cos^2\theta_\ell)\right.$$
$$+ \frac{1}{2}(1-F_\mathrm{L})\left(1-\cos^2\theta_\mathrm{K}\right)(1+\cos^2\theta_\ell)$$
$$\left.\left. + \frac{4}{3}A_\mathrm{FB}\left(1-\cos^2\theta_\mathrm{K}\right)\cos\theta_\ell\right]\right\}.$$

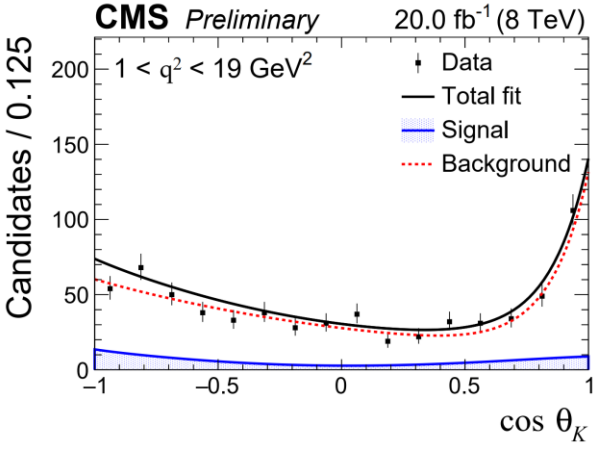
$$\mathrm{pdf}(m,\cos\theta_\mathrm{K},\cos\theta_\ell) = Y_S\,S^m(m)\,S^a(\cos\theta_\mathrm{K},\cos\theta_\ell)\,\epsilon(\cos\theta_\mathrm{K},\cos\theta_\ell)$$
$$+ Y_B\,B^m(m)\,B^{\theta_\mathrm{K}}(\cos\theta_\mathrm{K})\,B^{\theta_\ell}(\cos\theta_\ell).$$

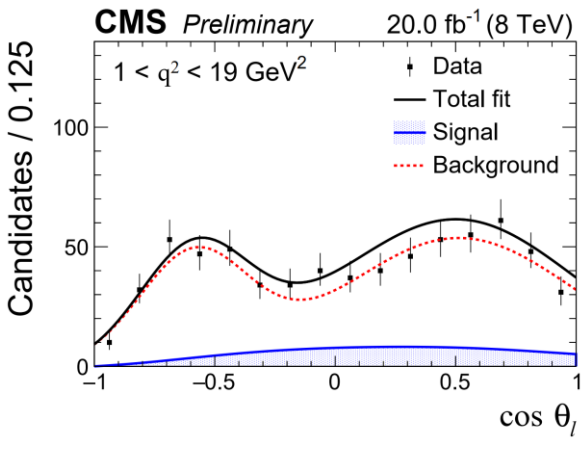
θ_K: angle between K_S^0 and direction opposite to B^+, in K^{*+} rest frame
θ_l: angle between μ^+ and direction opposite to B^+, in $\mu^+\mu^-$ rest frame

Angular analysis of the decay $B^+ \to K^{*+}\mu^+\mu^-$

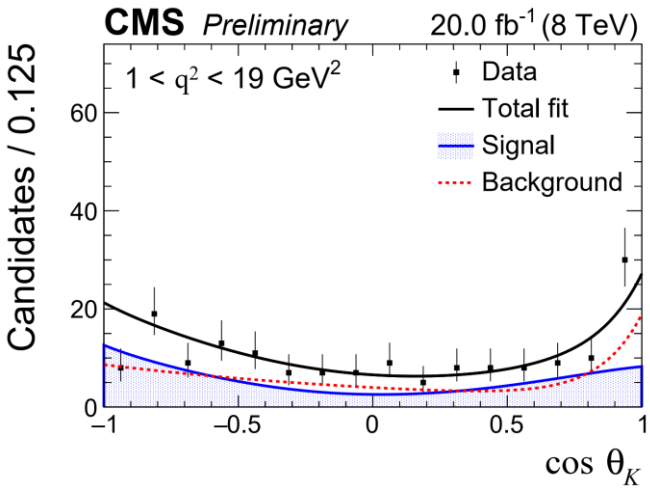
- 3D fit in [4.7, 5.8] GeV of all three q^2 regions

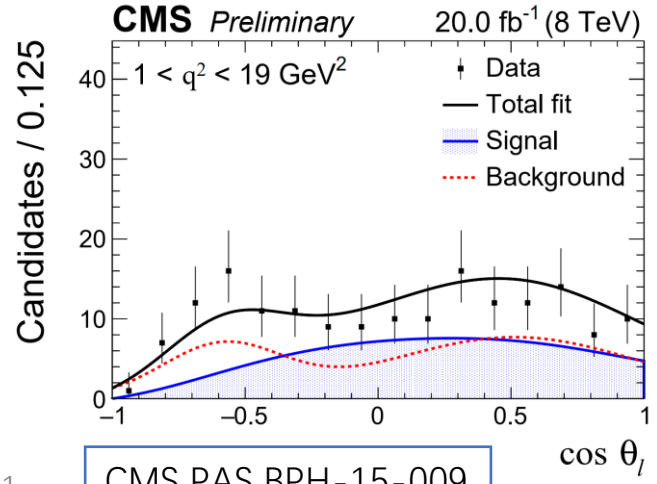






- Angular variables in B^+ signal region

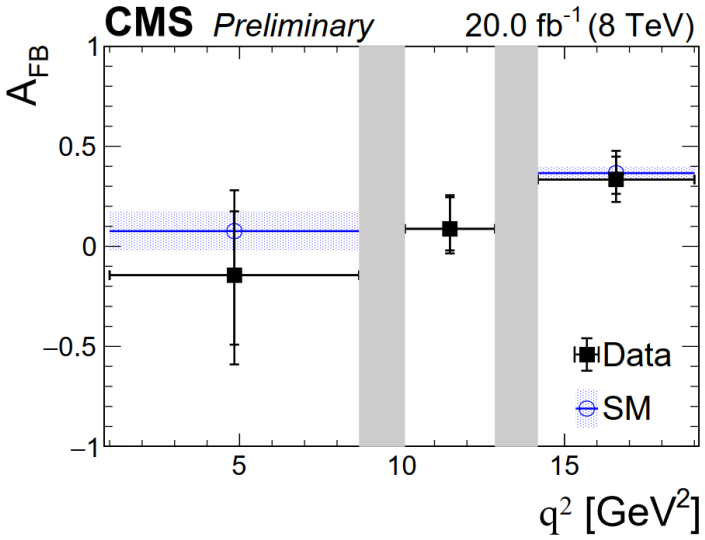


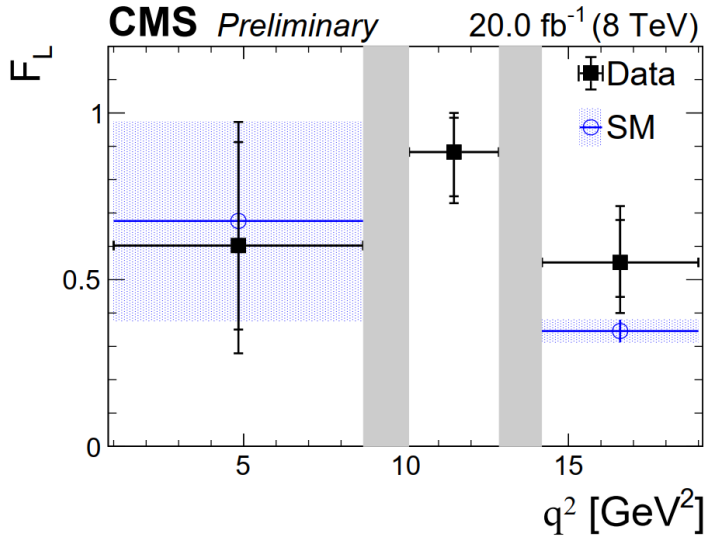


CMS PAS BPH-15-009

Angular analysis of the decay $B^+ \to K^{*+}\mu^+\mu^-$

- Measured A_{FB} and F_L
  - A_{FB}: Forward-backward asymmetry of the muon
  - F_L: Longitudinal polarization fraction of the K^{*+}





q^2 (GeV^2)	Signal yield	A_{FB}	F_{L}
$1.00 - 8.68$	22.1 ± 8.1	$-0.14^{+0.32}_{-0.35} \pm 0.17$	$0.60^{+0.31}_{-0.25} \pm 0.13$
$10.09 - 12.86$	25.9 ± 6.3	$0.09^{+0.16}_{-0.11} \pm 0.04$	$0.88^{+0.10}_{-0.13} \pm 0.05$
$14.18 - 19.00$	45.1 ± 8.0	$0.33^{+0.11}_{-0.07} \pm 0.05$	$0.55^{+0.13}_{-0.10} \pm 0.06$
$1.00 - 19.00$	90.0 ± 13.5	$0.17^{+0.10}_{-0.06} \pm 0.08$	$0.71^{+0.11}_{-0.09} \pm 0.06$

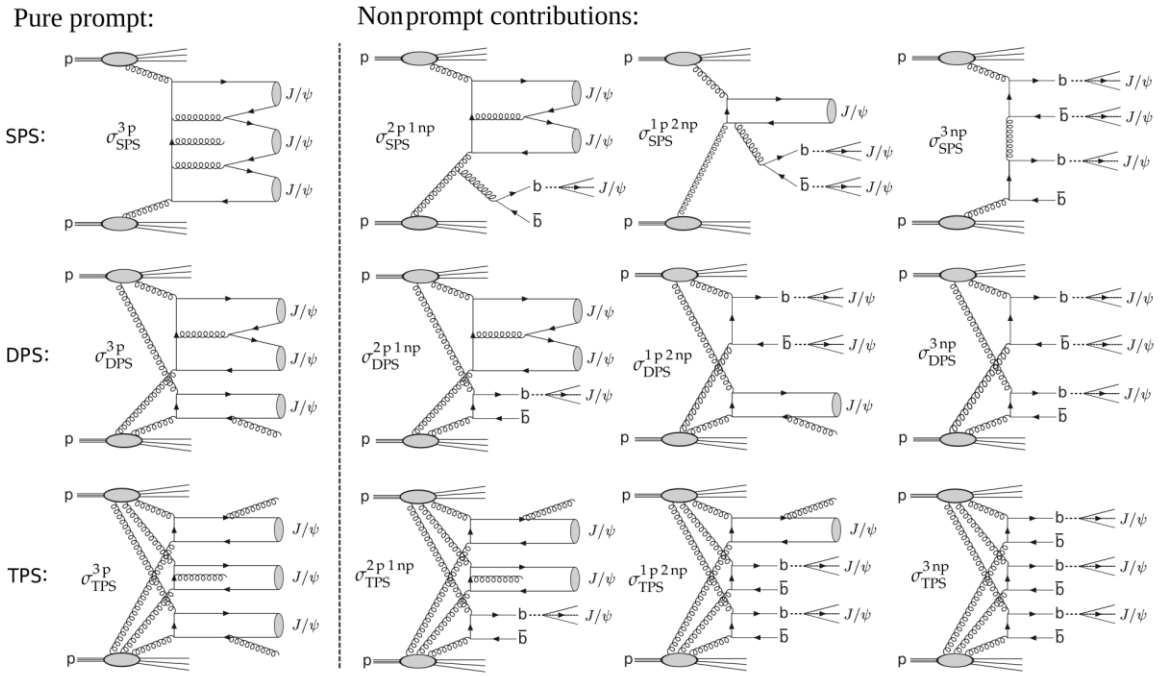
CMS PAS BPH-15-009

Observation of triple J/ψ production

- Multi-parton hard scattering at high p_T/M is useful to probe parton features/characteristics of the proton
- Single Parton Scattering, Double Parton Scattering
  - – Studied in experiments and theory
- Triple Parton Scattering – predicted in theoretical study

Phys. Rev. Lett. 122, 192002 (2019)
Huasheng Shao, Yujie Zhang

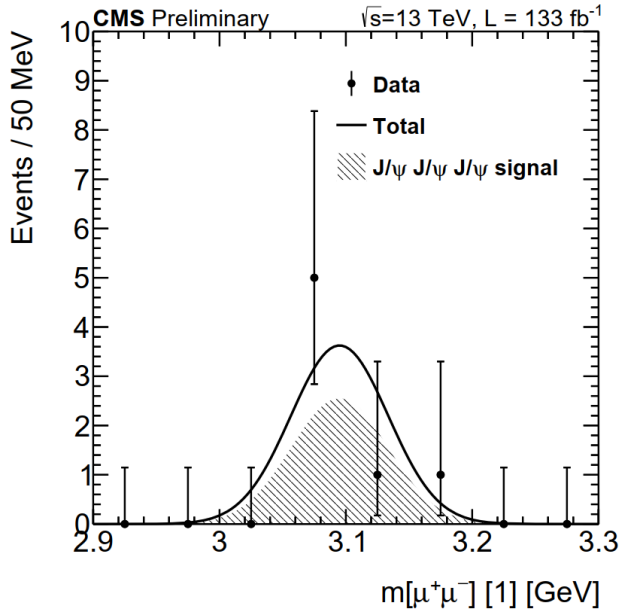
Feynman diagram of triple J/psi

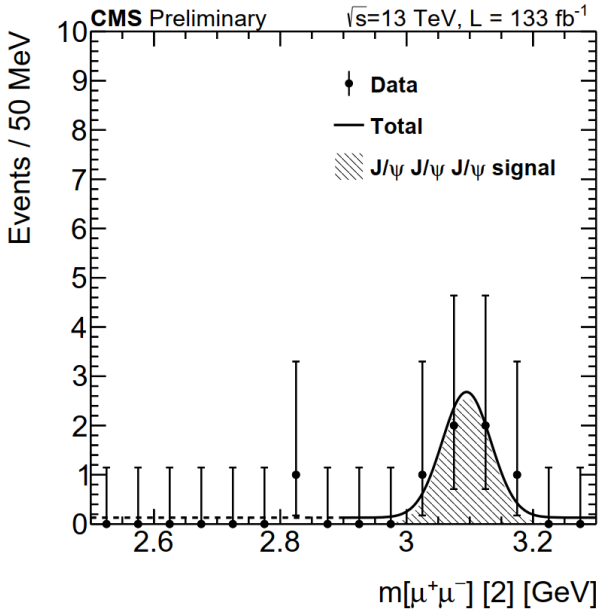


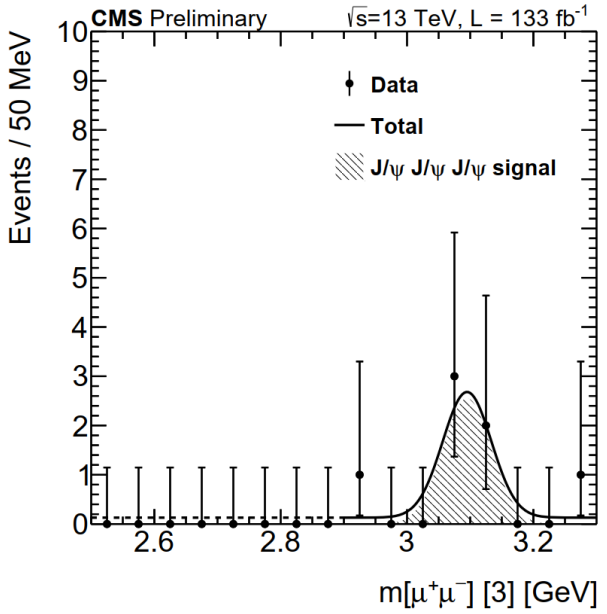
arXiv:2111.05370, submitted to Nature Physics

Observation of triple J/ψ production

- $N_{sig}^{3J/\psi} = 5^{+2.6}_{-1.9}$, Significance $>5\sigma$
- Production from: SPS (~6%), DPS (~74%),
  and TPS (~20%, first observation in experiment)
- $\sigma(pp \to J/\psi J/\psi J/\psi X) = 272^{+141}_{-104}(stat) \pm 17(syst)$fb







arXiv:2111.05370, submitted to Nature Physics

Observation of triple J/ψ production

✓Observation of $3J/\psi$ production (first time) at CMS

- New approach to study TPS/DPS

- Opportunity to explore possible structures in $2J/\psi, 3J/\psi$ final states in future
  - Study using $2J/\psi, J/\psi\psi(2S)$ ongoing at CMS
    - Gu Jinjing's talk on Nov. 25

Summary

- Several HF topics on going in different China institutions in CMS

- Recent HF results at CMS and a combined result are presented

Thanks