



Heavy Flavor Production and Rare Decays

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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 $\sim 0.6-1.5\%$ (depending on |y|).
 - Fake rate $\leq 0.1\%$ for pi,K; $\leq 0.05\%$ for proton.
 - MVA-based ID for $B \rightarrow \mu^+ \mu^-$ analysis.
- Complementary to LHCb



ATLAS/CMS: 13TeV HF performances





Recent results on selected topics

Production Measurements

- High precision tests of QCD; understand of evolution of heavy quarks to mesons; reference for Heavy Ion measurements
- Rare Decay Studies
 - Decay mechanism; High precision tests of SM; Probe new physics beyond SM
- Disclaims
 - Not exclusive, due to time limitation
 - Selections may have personal biases
 - More results from ATLAS, CMS and LHCb can be found at:
 - <u>https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults</u>
 - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH
 - <u>http://cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_all.html</u>
 - Contributions from Chinese colleagues are labeled as

CMS-IHEP CMS-PKU

LHCB-THU

Prompt ψ(nS) production cross section

- Measurements as a function of p_T in four bins of dimuon rapidity and integrated in rapidity (|y| < 1.2)</p>
- Prompt J/ψ and ψ(2S) cross sections up to p_T~100 GeV



Differential quarkonium cross section measurements at 13TeV



Y(nS) production ratios vs multiplicity





Prompt J/ψ pair production





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Y(1S) pair production@CMS



arXiv:1610.07095

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

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

The effective cross section:consistent with the range of values from the heavyquarkonium measurements





Quarkonium Polarization Measurement

CMS measurement of 7TeV data

- λ_θ, λ_φ, λ_{θφ} and λ in three different reference frames (HX, CS, PX) for the J/ψ, ψ(2S), Y(1S), Y(2S) and Y(3S) mesons
- As function of transverse momenta p_T, and dimuon rapidity |y|





CMS: Y(nS) polarization vs multiplicity

- The results do not show significant changes from low- to highmultiplicity pp collisions,
- large uncertainties preclude definite statements in the Y(2S) and Y(3S) cases.
- Analyses to be performed in pPb and PbPb, to understand quarkonium suppression patterns in nuclear collisions.





B+ production at 13 TeV



FCNC processes $b \rightarrow (X)\mu^+\mu^-$: golden indirect probes of NP

clean exp signature; robust theory calc; high sensitivity

Effective theory: model independent descriptions

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V_{\rm tq}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{i} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{i} + \sum \frac{c}{\Lambda_{\rm NP}^2} \underbrace{\mathcal{O}_{\rm NP}}_{i=3-6,8} \quad \begin{array}{ll} i=1,2 & \text{Tree} \\ i=3-6,8 & \text{Gluon penguin} \\ i=7 & \text{Photon penguin} \\ i=9,10 & \text{EW penguin} \\ i=S,P & (\text{Pseudo)scalar penguin} \end{array}$$

Differenct processes have sensitivities to different operators

 $\begin{array}{c|cccc} \hline & & B_{s,d} \rightarrow X_{s,d}\mu^+\mu^- & B_{s,d} \rightarrow \mu^+\mu^- & B_{s,d} \rightarrow X_{s,d}\gamma \\ \hline & \mathcal{O}_7 \sim m_b(\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu} & \checkmark & \checkmark \\ \hline & \mathcal{O}_9 \sim (\bar{s}_L \gamma^\mu b_L) (\bar{\ell} \gamma_\mu \ell) & \checkmark & \checkmark \\ \hline & \mathcal{O}_{10} \sim (\bar{s}_L \gamma^\mu b_L) (\bar{\ell} \gamma_5 \gamma_\mu \ell) & \checkmark & \checkmark \\ \hline & \mathcal{O}_{S,P} \sim (\bar{s}b)_{S,P} (\bar{\ell}\ell)_{S,P} & (\checkmark) & \checkmark \\ \hline & 2016/12/18 & \text{CLHCP2016} \end{array}$

Rare decay search: $B^0_{(s)} ightarrow \mu^+ \mu^-$

 $\mathcal{B}(B_s^0 \to \mu^+ \mu^-) = 3.0 + 1.0 \times 10^{-9}$

 $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = 3.5 + 2.1 \times 10^{-10}$

CMS: Phys. Rev. Lett. 111 (2013) 101804

$$\mathcal{B}(B_s^0 \to \mu^+ \mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+ \mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

Phys. Rev. Lett. 112 (2014) 101801

SM diagrams and prediction

CMS made it with full Run-I data

Simultaneous publication with LHCb
Each with >
$$4\sigma$$
 for $B_s \rightarrow \mu^+\mu^-$

 $\begin{aligned} \mathcal{B}(B^0_s \to \mu^+ \mu^-) &= 2.9 \, {}^{+1.1}_{-1.0} \, {}^{+0.3}_{-0.1} \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+ \mu^-) &= 3.7 \, {}^{+2.4}_{-2.1} \, {}^{+0.6}_{-0.4} \times 10^{-10} \\ \end{aligned}$ LHCb: Phys. Rev. Lett. 111 (2013) 101805

CMS&LHCb "deep" combination: First observation of $B_s \rightarrow \mu^+ \mu^-$

ATLAS new results

History: 30 years of search

2016/12/18 CLHCP2016

Complete description: 11 variables! Simplified description:

 F_L : Fraction of longitudinal polarization of the K* A_{FB} : Forward-backward asymmetry of the dilepton system

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

2016/12/18 CLHCP2016

+ CMS (7, 8 TeV)

LHCb

\star BaBar

+ Belle

CDF

12

14

16

CMS-PKU

18 q^2 (GeV²)

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

Summary

Many results on HF productions and rare decays from LHC experiments

- also see Jibo's talk
- Results of 13TeV are emerging
 - Excellent performance
 - More to come from
 - Run-II data
- Chinese groups are actively contributing will continue in future

谢谢! Thank you!

Extra meterials...

Recent results from ATLAS/CMS: a partial list

- Quarkonium xs@13 TeV(CMS) and non-prompt fraction (CMS & ATLAS)
- **b** quark fragmentation f_s/f_d(ATLAS)
- **Dependence of Y(nS) prod ratios on charged particle multiplicity@7 TeV(CMS)**
- B+ cross section and mass (CMS & ATLAS) 13TeV
- Y(nS) polarization vs particle multiplicity(CMS)
- Associated production of J/ψ and Z (ATLAS &CMS)
- Study of $B^+ \rightarrow J/\psi D_s^{*+}$ (ATLAS)
- Observation of $B^+ \rightarrow \psi(2S)\phi K^+$ (CMS)
- Observation and BF of $\Lambda_b \rightarrow \psi(2S) \Lambda$ (ATLAS)
- Observation of Y(1S) pair production (CMS)
- Helicity study of $\Lambda_b \rightarrow J/\psi \Lambda$ decays (ATLAS & CMS)
- Search for $X^+(5568) \rightarrow B_s \pi^+$ (CMS)
- **CP** violation phase in $B \rightarrow J/\psi \phi$ (ATLAS & CMS)
- **B**⁰_s ->J/ ψ f0(980) (CMS)
- $\Delta \Gamma_d / \Gamma_d$ of the *B*0 *B*0bar system (ATLAS)
- Search of $B_s \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$ (ATLAS & CMS)
- Angular analysis of $B \rightarrow K(^*)\mu^+ \mu^-$ (CMS)

Double Jpsi production@LHCb 13TeV

Using ~279 pb⁻¹ data at $\sqrt{s} = 13$ TeV

▶ Fiducial region: 2 < $y^{J/\psi}$ < 4.5, $p_{\rm T}^{J/\psi}$ < 10 GeV/c

➤Cut-based selection

➢Efficiency estimated using simulation & data

Signal yield obtained from simultaneous fit to the efficiency-corrected 2D $(M(\mu_1^+\mu_1^-), M(\mu_2^+\mu_2^-)))$ distribution

 $\succ \sigma(J/\psi J/\psi) = 13.5 \pm 0.9(\text{stat}) \pm 0.8(\text{syst}) \text{ nb}$