

CMS heavy flavour production and decay properties

D. Strom

Vrije Universiteit Brussel

On behalf of the CMS Collaboration

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Outline

- **Introduction**
- **CMS heavy flavour production and decay properties**
 - Prompt $\psi(nS)$ production cross sections @ $\sqrt{s} = 7$ TeV
 - $\Upsilon(nS)$ production cross sections @ $\sqrt{s} = 7$ TeV
 - $\Upsilon(nS)$ polarizations @ $\sqrt{s} = 7$ TeV
 - B_c^+ ratio and production cross sections @ $\sqrt{s} = 7$ TeV
 - A sneak peek at @ $\sqrt{s} = 13$ TeV

Please see the following talks for more CMS heavy flavour results this week:

- **CP violation and rare B decays – J. Pazzini, Wednesday parallel session**
 - **HF spectroscopy and exotic states – L. Cristella, Friday parallel session**
 - **Angular analysis $B^0 \rightarrow K^* \mu^+ \mu^-$ – A. Boletti, Poster session**
 - **Friday HF plenary session**
- **Summary and outlook**

Introduction

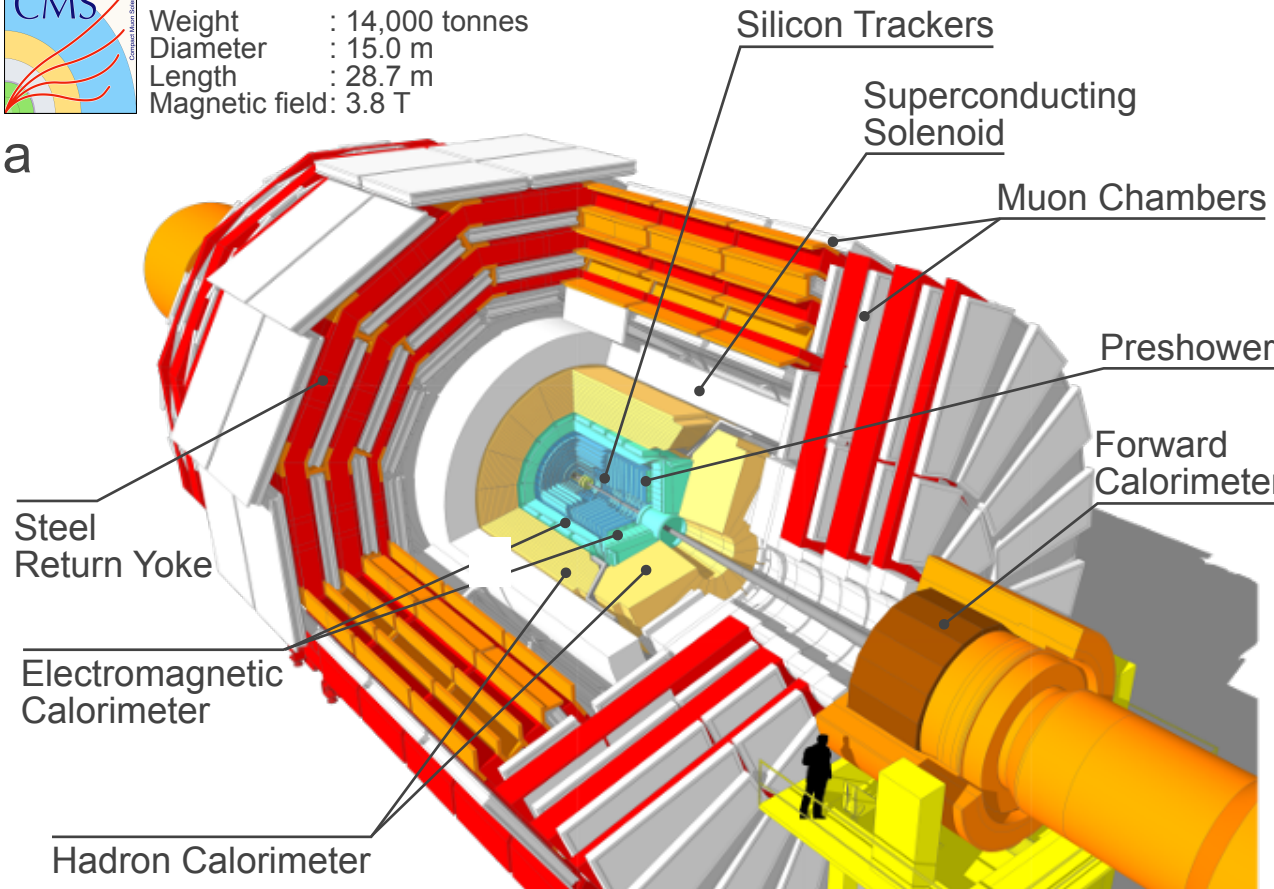
- The focus of this talk is on heavy flavour production and decay properties measured with the **CMS** detector at the **LHC**.
- There are several **key motivations** for measuring heavy flavour properties:
 - Physics beyond the SM (CP violation studies)
 - Advances in b and c hadron spectroscopy
 - Powerful test of pQCD and effective theory predictions
 - Probe and constrain a variety of new physics scenarios, including Supersymmetry
- The CMS detector is particularly well-suited to study the final states containing a $J/\psi(\rightarrow\mu^+\mu^-)$

- Most common heavy flavour physics signatures in CMS are based on **muons** in the final state.
- Heavy flavour program relies on **inner tracking** and **muon detectors** for trigger and reconstruction.
- Enable the measurement of muon momenta over the pseudorapidity range $|\eta| < 2.4$.
- **Data samples**
 - $\sqrt{s} = 7 \text{ TeV}$, $L \sim 5 \text{ fb}^{-1}$ (2011)
 - $\sqrt{s} = 8 \text{ TeV}$, $L \sim 20 \text{ fb}^{-1}$ (2012)
 - $\sqrt{s} = 13 \text{ TeV}$, $L \sim 20 \text{ pb}^{-1}$ (2015)



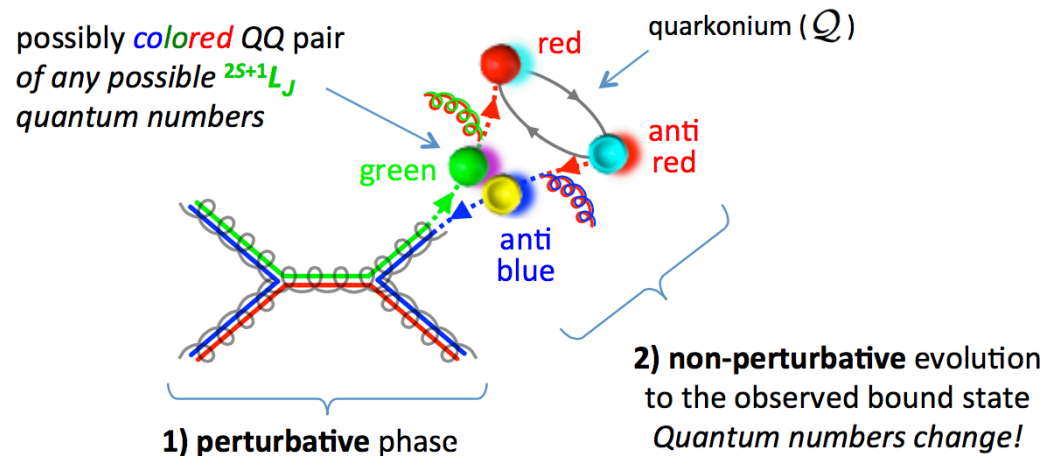
CMS Detector
Weight : 14,000 tonnes
Diameter : 15.0 m
Length : 28.7 m
Magnetic field: 3.8 T

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Quarkonium production

- Studies of heavy-quarkonium production are important to improve our understanding of non-perturbative QCD.
- The nonrelativistic QCD (NRQCD) approach factorizes high- p_T quarkonium production into (perturbative) short-distance and (non-perturbative) long-distance scales:
 - Production of the initial quark-antiquark pair
 - Hadronization of the initial pair into the observed bound state



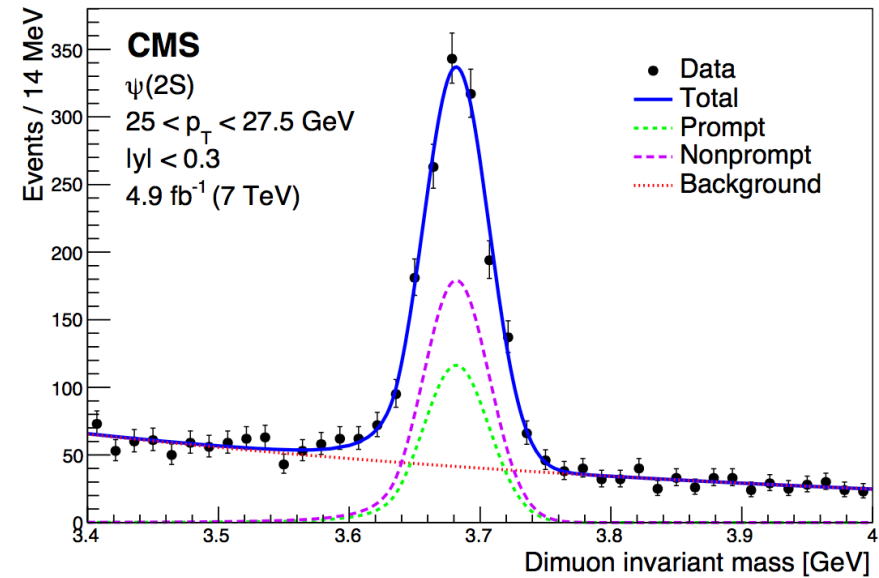
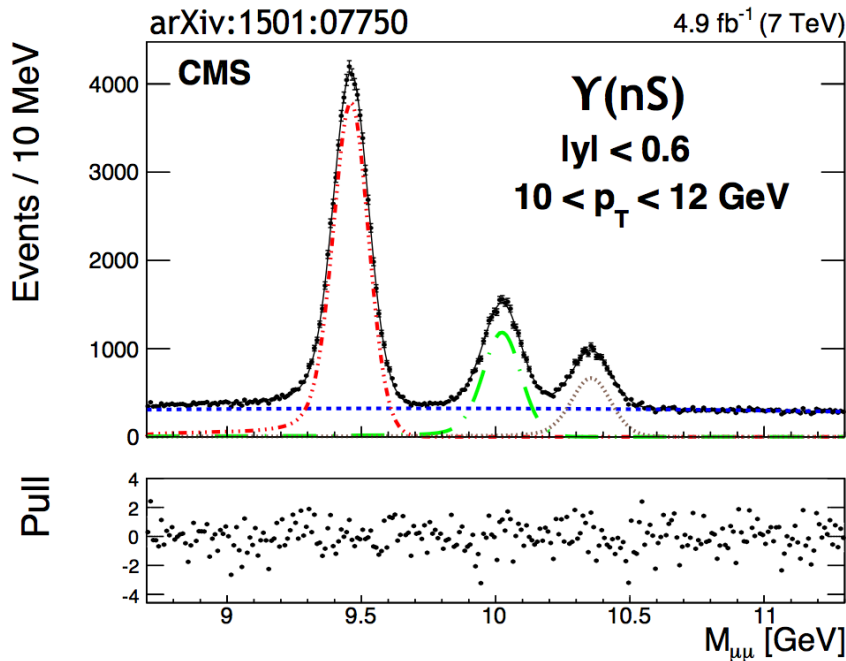
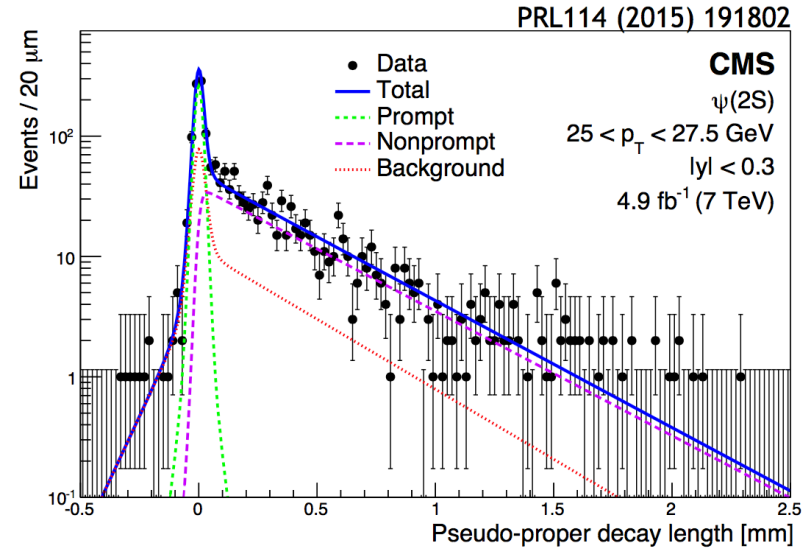
Production cross-section measurements

- Prompt $\psi(nS)$ **PRL 114 (2015) 191802**
- $\Upsilon(nS)$ **arXiv: 1501:07750, accepted by PLB**

- Data collected at LHC in 2011:
 - pp collisions at $\sqrt{s} = 7$ TeV
 - Dimuon trigger in the J/ψ , $\psi(2S)$, and $\Upsilon(nS)$ mass windows
 - Luminosity up to $L=4.9$ fb⁻¹
 - Measured rapidity range $|y| < 1.2$

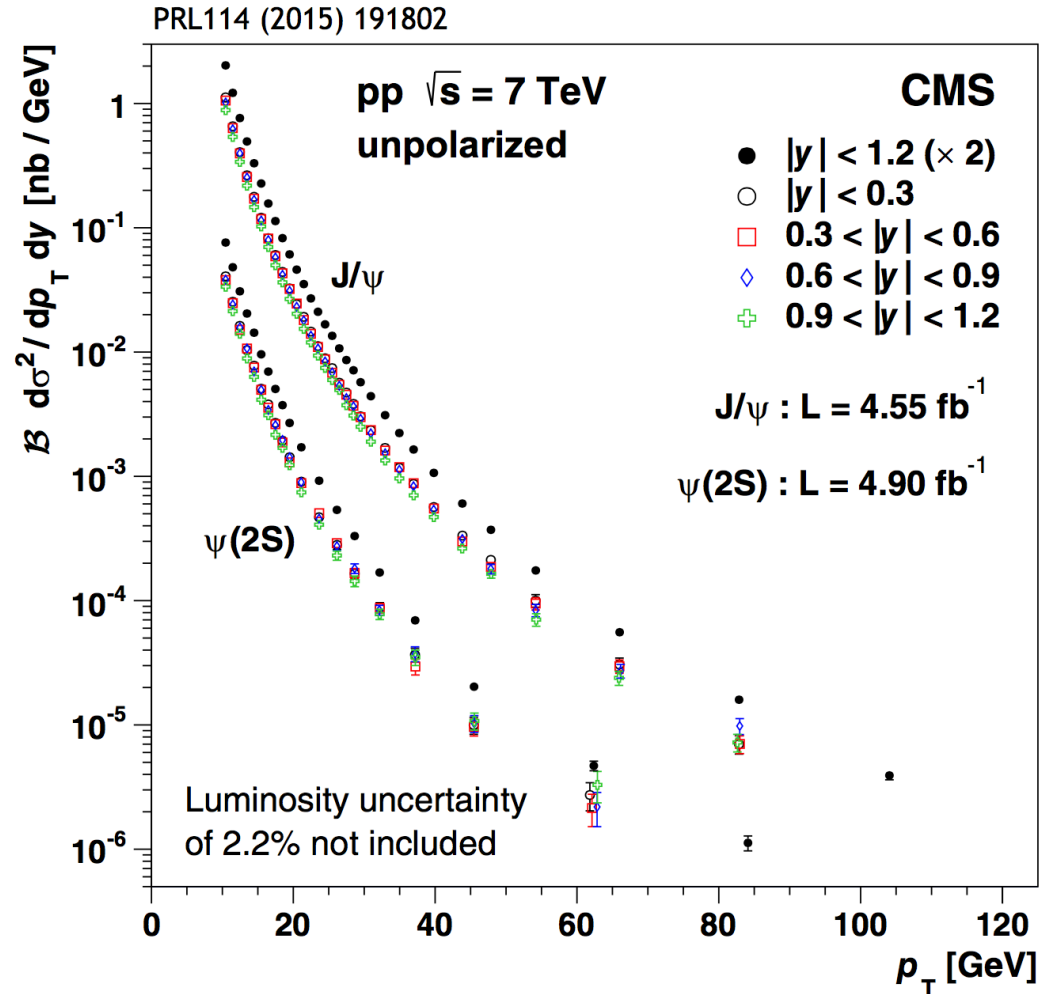
Yield determination

- Yields determined using an maximum likelihood fit to the dimuon mass and, for the $\psi(nS)$, the pseudo-proper decay length distributions
- Signal mass shape:
 - Crystal ball function for $\psi(nS)$
 - Determined using measured muon momenta and their uncertainties for $\Upsilon(nS)$



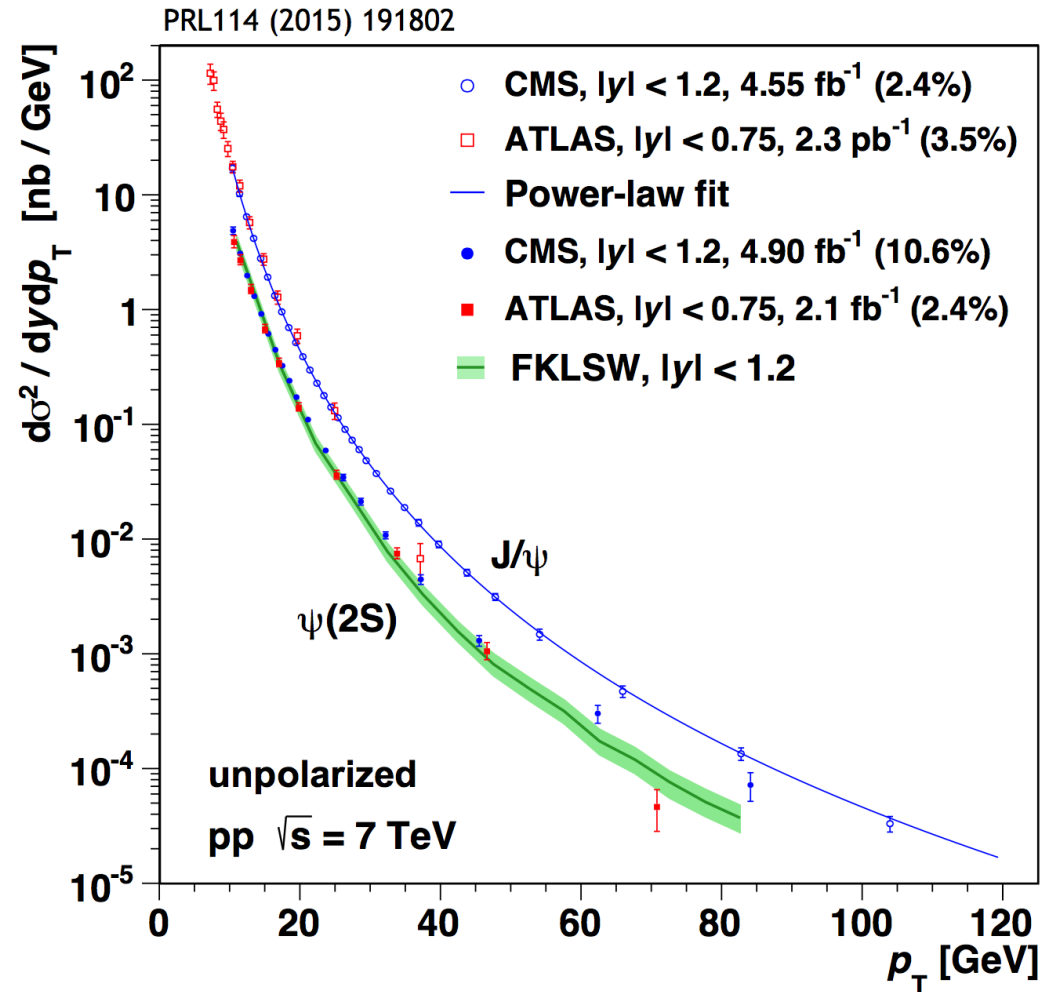
Prompt $\psi(nS)$ cross sections

- J/ψ and $\psi(2S)$ differential p_T cross sections times the branching fraction for 4 rapidity bins and integration up to 1.2
- Acceptance is calculated for four polarizations:
 $\lambda_\theta = 0, \pm 1, 0.1(J/\psi)/0.03(\psi(2S))$
 $\lambda_\phi = \lambda_{\theta\phi} = 0$
- Cross sections are almost independent of rapidity.



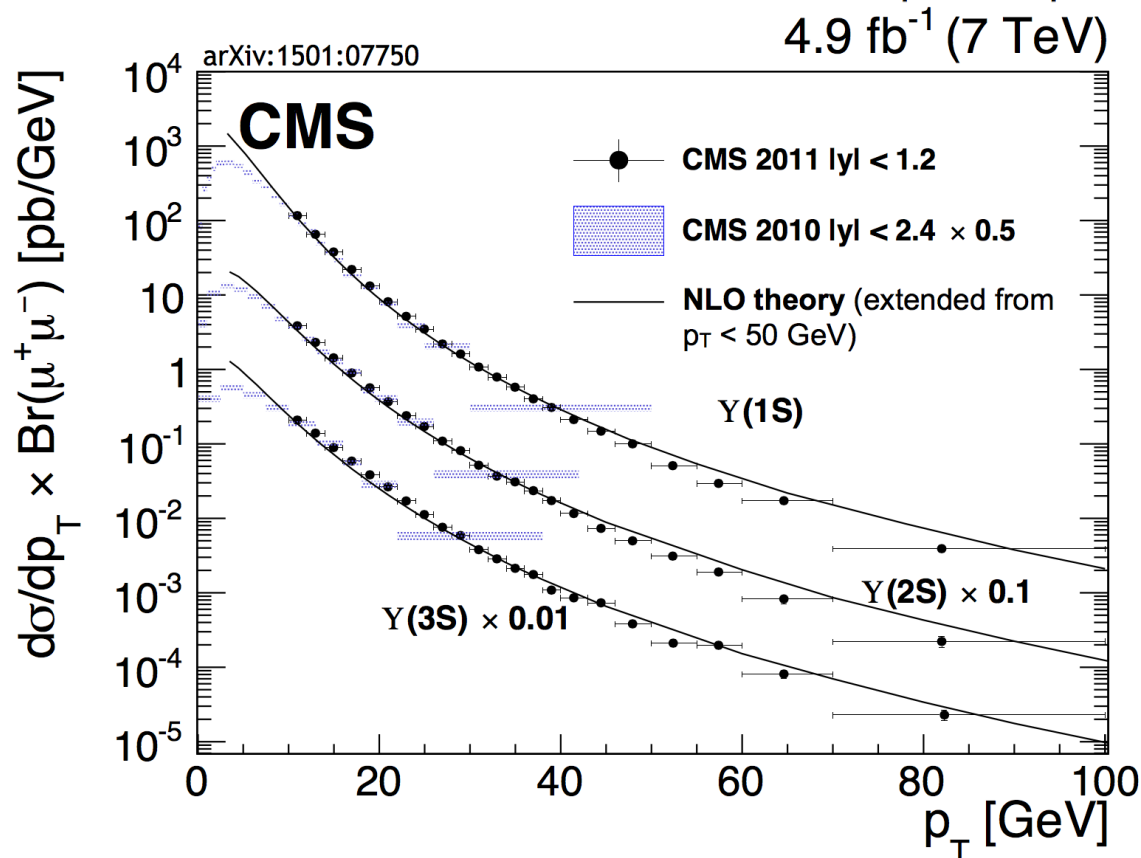
Prompt $\psi(nS)$ cross sections

- J/ψ and $\psi(2S)$ differential cross sections comparing CMS (circles) and ATLAS (squares).
- Cross sections are almost independent of rapidity.
- Cross sections integrated over rapidity $|y| < 1.2$ extend to $p_T = 120$ and 100 GeV.
- Curve shows a fit from a power-law function to the J/ψ cross section data.



$\Upsilon(nS)$ cross sections

- $\Upsilon(nS)$ differential p_T cross sections times branching fractions.
- Results shown use acceptance calculated with polarization measured with CMS data (PRL 110 (2013) 081802).
- Acceptances are also calculated for $\lambda_\theta = 0, \pm 1; \lambda_\phi = \lambda_{\theta\phi} = 0$



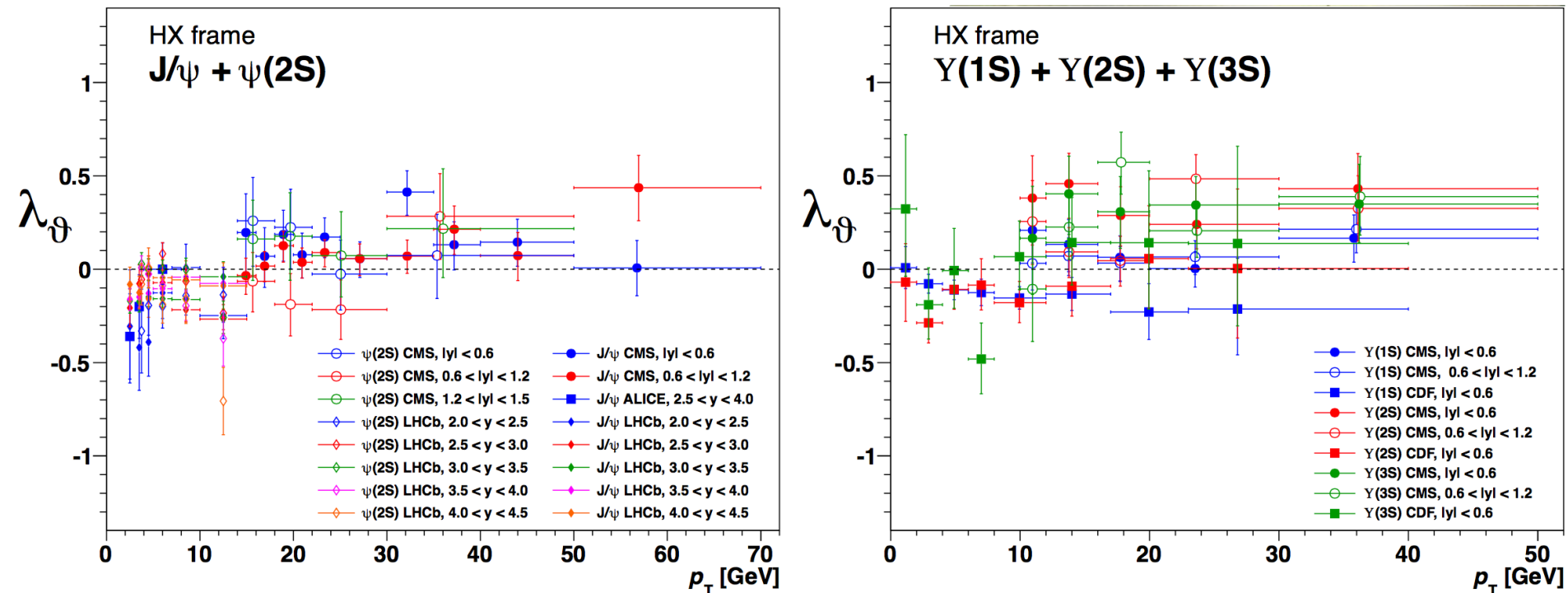
Polarization measurements

- Prompt $\psi(nS)$ **PLB 727 (2013) 381**
- $\Upsilon(nS)$ **PRL 110 (2013) 081802**

- Data collected at LHC in 2011:
 - pp collisions at $\sqrt{s} = 7$ TeV
 - Dimuon trigger in the J/ψ , $\psi(2S)$, and $\Upsilon(nS)$ mass windows
 - Luminosity corresponds to $L=4.9 \text{ fb}^{-1}$

Polarization measurements

- Experiments have only recently provided reliable polarization results.
- Polarization parameters measured from dimuon decay angular analysis.
- No evidence for large polarization values observed.
- No significant dependence on p_T , y , state (charmonia, bottomonia) or feed-down contribution from heavier states.

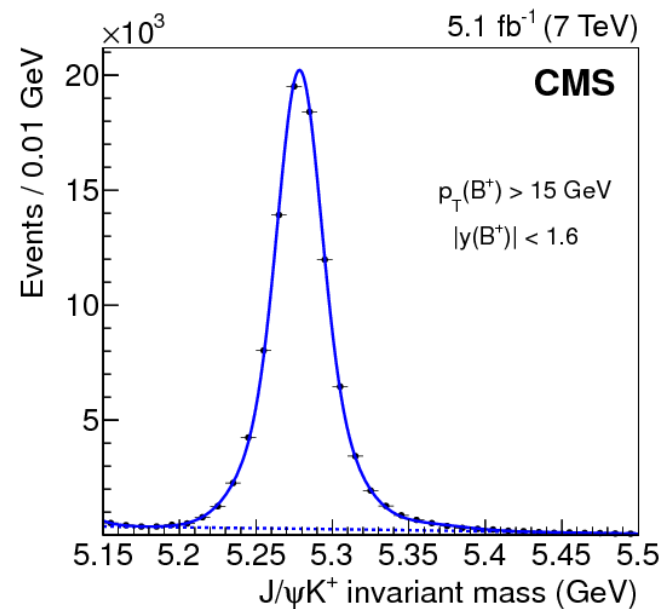
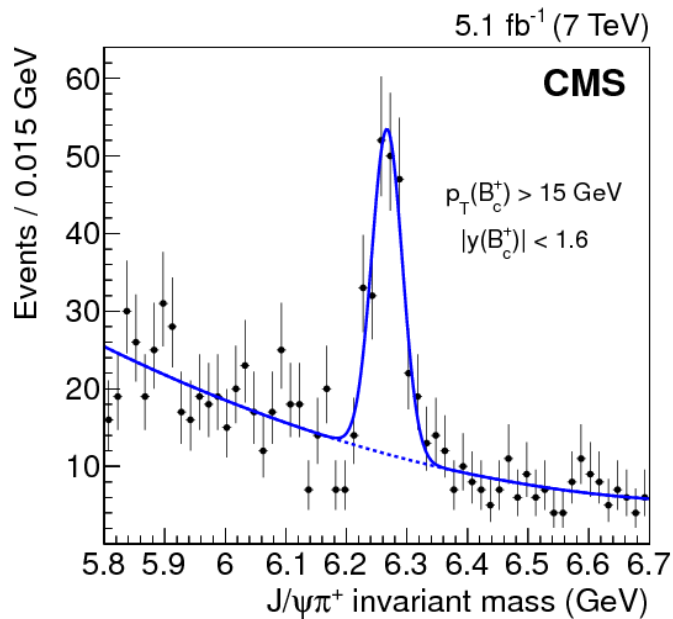


B_c Production

- $B_c \rightarrow J/\psi + \pi^+(\pi^+\pi^-)$ **JHEP 01 (2015) 063**
- Data collected at LHC in 2011:
 - pp collisions at $\sqrt{s} = 7$ TeV
 - Using a displaced-vertex dimuon trigger
 - Luminosity corresponds to $L=5.1 \text{ fb}^{-1}$
- Kinematic region of the measurement:
 $|y| < 1.6, p_T > 15 \text{ GeV}$

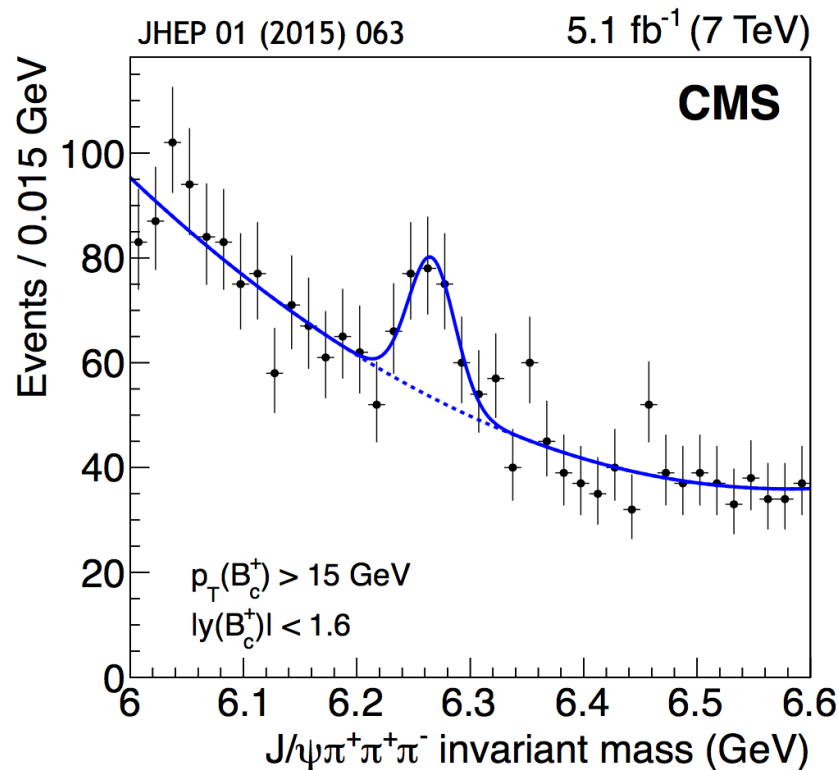
- Ratio of production cross section times branching fraction:

$$R_{c/u} = \frac{\sigma(B_c^\pm) \cdot BR(B_c^\pm \rightarrow J/\psi\pi^\pm)}{\sigma(B^\pm) \cdot BR(B^\pm \rightarrow J/\psi K^\pm)}$$
$$= (0.48 \pm 0.05(\text{stat.}) \pm 0.05(\text{syst.}) \pm 0.05(\tau_{B_c}))\%$$



- Relative branching fraction:

$$R_{B_c} = \frac{BR(B_c^\pm \rightarrow J/\psi \pi^\pm \pi^+ \pi^-)}{BR(B_c^\pm \rightarrow J/\psi \pi^\pm)}$$
$$= 2.55 \pm 0.80(\text{stat.}) \pm 0.33(\text{syst.})_{-0.01}^{+0.04}(\tau_{B_c})$$

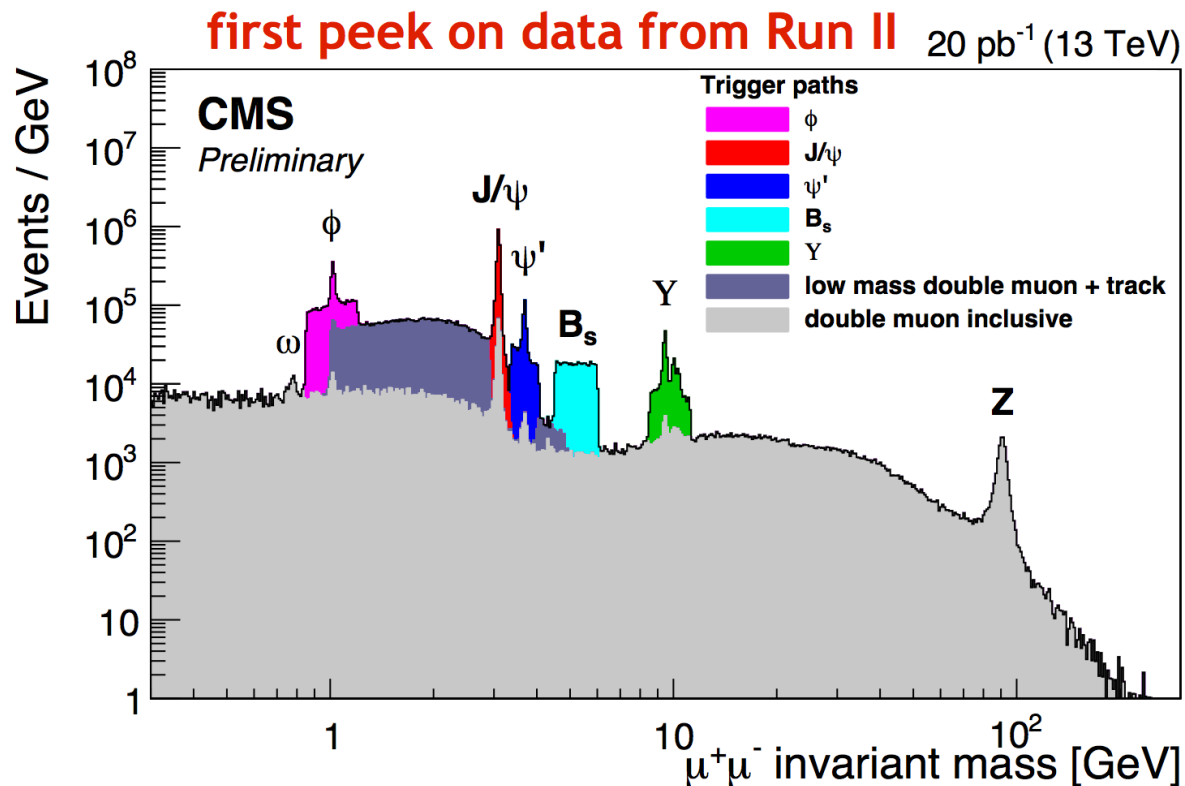


Quarkonium and HF production in Run II

- Run II data taking at $\sqrt{s} = 13$ TeV started this year.
- Almost double the cross sections.
- Expected luminosity delivered by the LHC in 2015: $\sim 9 \text{ fb}^{-1}$.
- Measurements expected at even higher p_T .

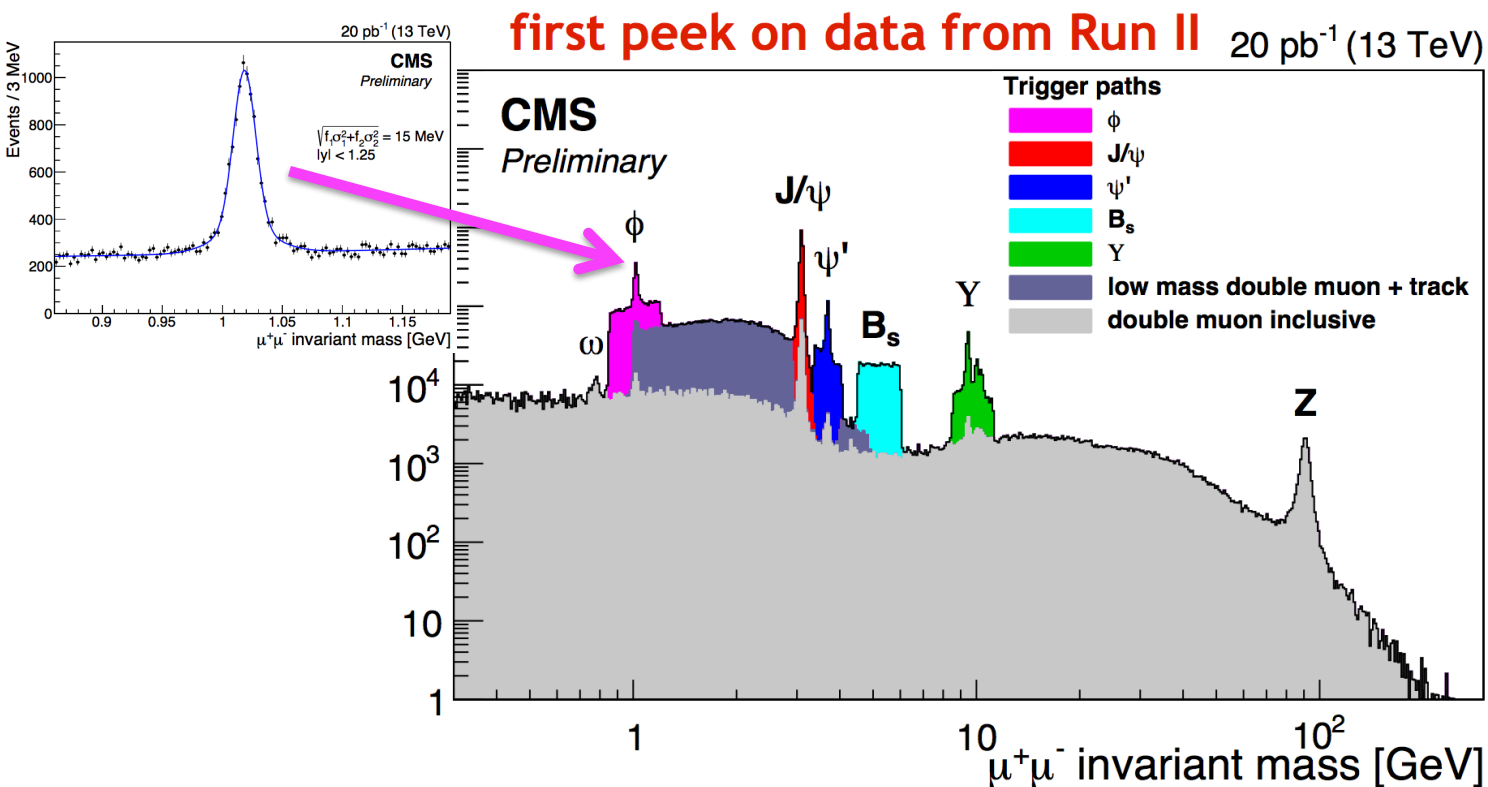
Quarkonium and HF production in Run II

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- Expected luminosity delivered by the LHC in 2015: ~ 9 fb $^{-1}$.
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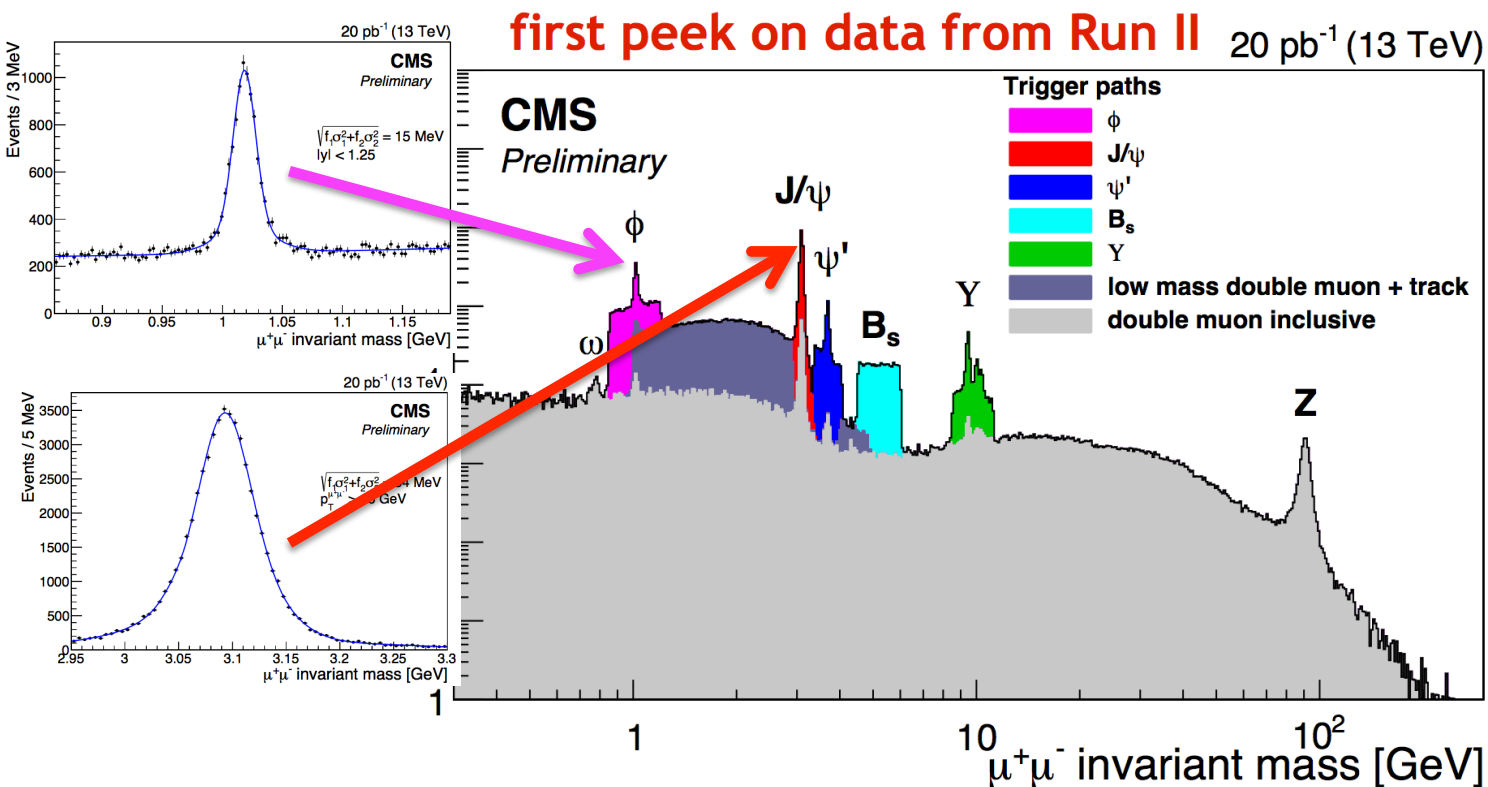
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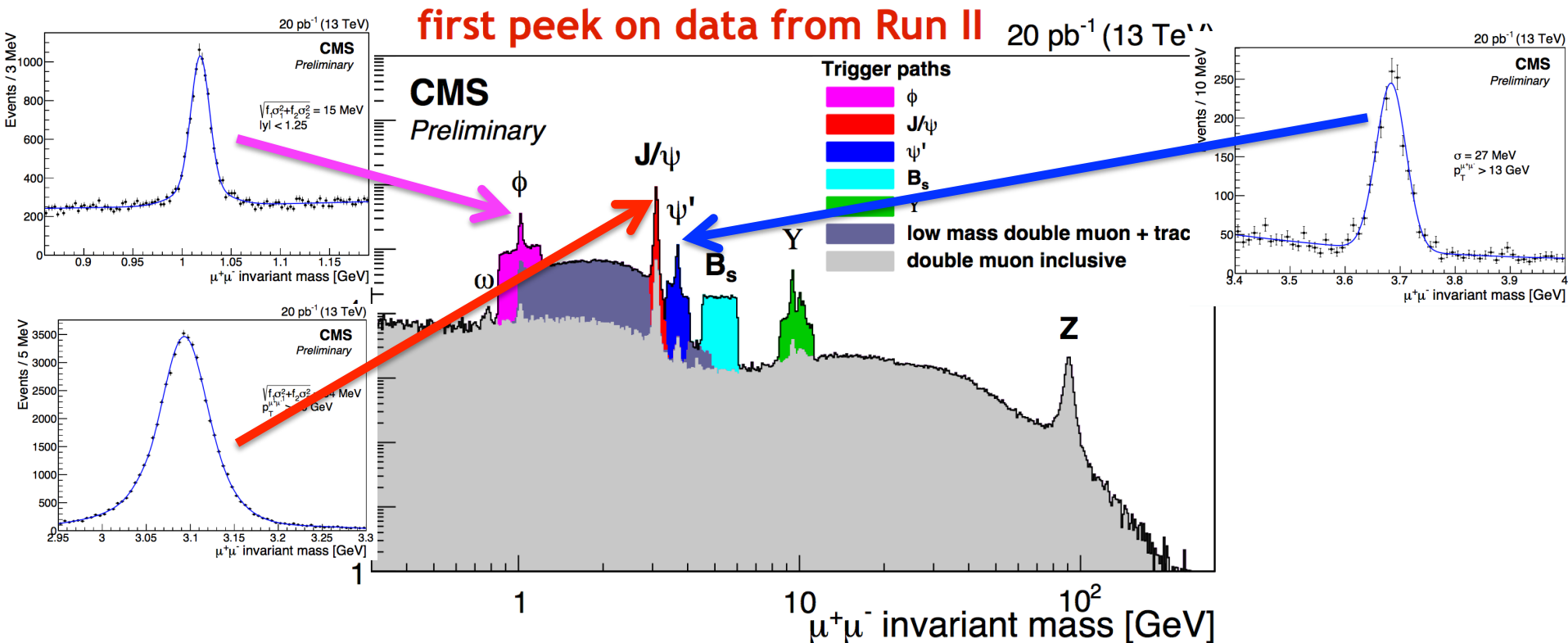
Quarkonium and HF production in Run II

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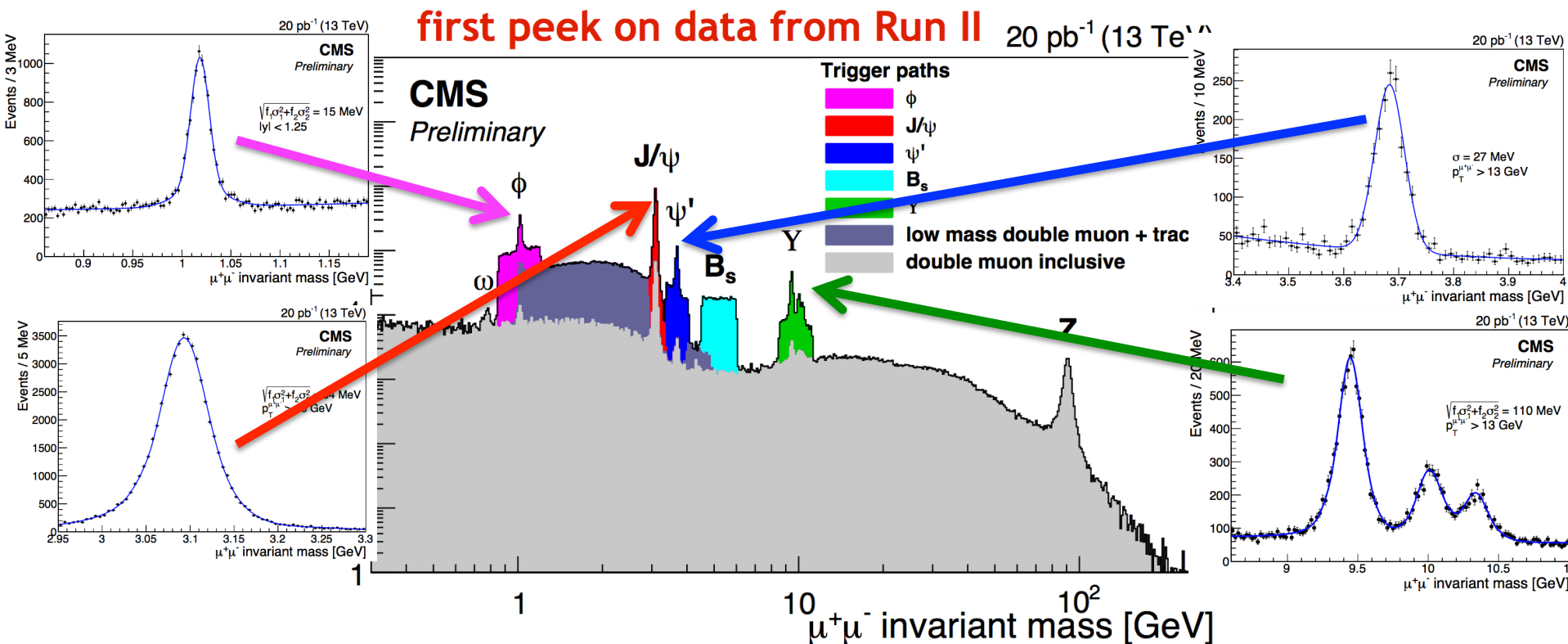
Quarkonium and HF production in Run II

- Run II data taking at $\sqrt{s} = 13$ TeV started this year.
- Almost double the cross sections.
- Expected luminosity delivered by the LHC in 2015: $\sim 9 \text{ fb}^{-1}$.
- Measurements expected at even higher p_T .



Quarkonium and HF production in Run II

- Run II data taking at $\sqrt{s} = 13$ TeV started this year.
- Almost double the cross sections.
- Expected luminosity delivered by the LHC in 2015: $\sim 4 \text{ fb}^{-1}$.
- Measurements expected at even higher p_T .



Summary and Outlook

- CMS continues to carry out a rich program of heavy-flavour production and decay measurements using LHC Run I data.
- Prompt $\psi(nS)$ production cross sections, $\Upsilon(nS)$ production cross sections, $\Upsilon(nS)$ polarizations, B_c^+ ratio and production cross sections at $\sqrt{s} = 7$ TeV were presented.
- CMS detector successfully started Run II operations at $\sqrt{s} = 13$ TeV.
Very exciting times ahead:
 - Almost double the cross sections,
 - Extend the high p_T reach of measurements,
 - Measure quarkonium cross sections and polarizations.
 - First peek at known peaks.
- Stay tuned for exciting new results from CMS!