
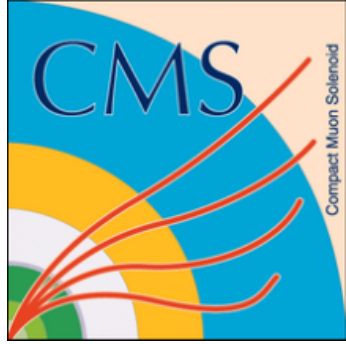


# CMS Results on Upsilon Pair Production

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On behalf of the CMS calibration

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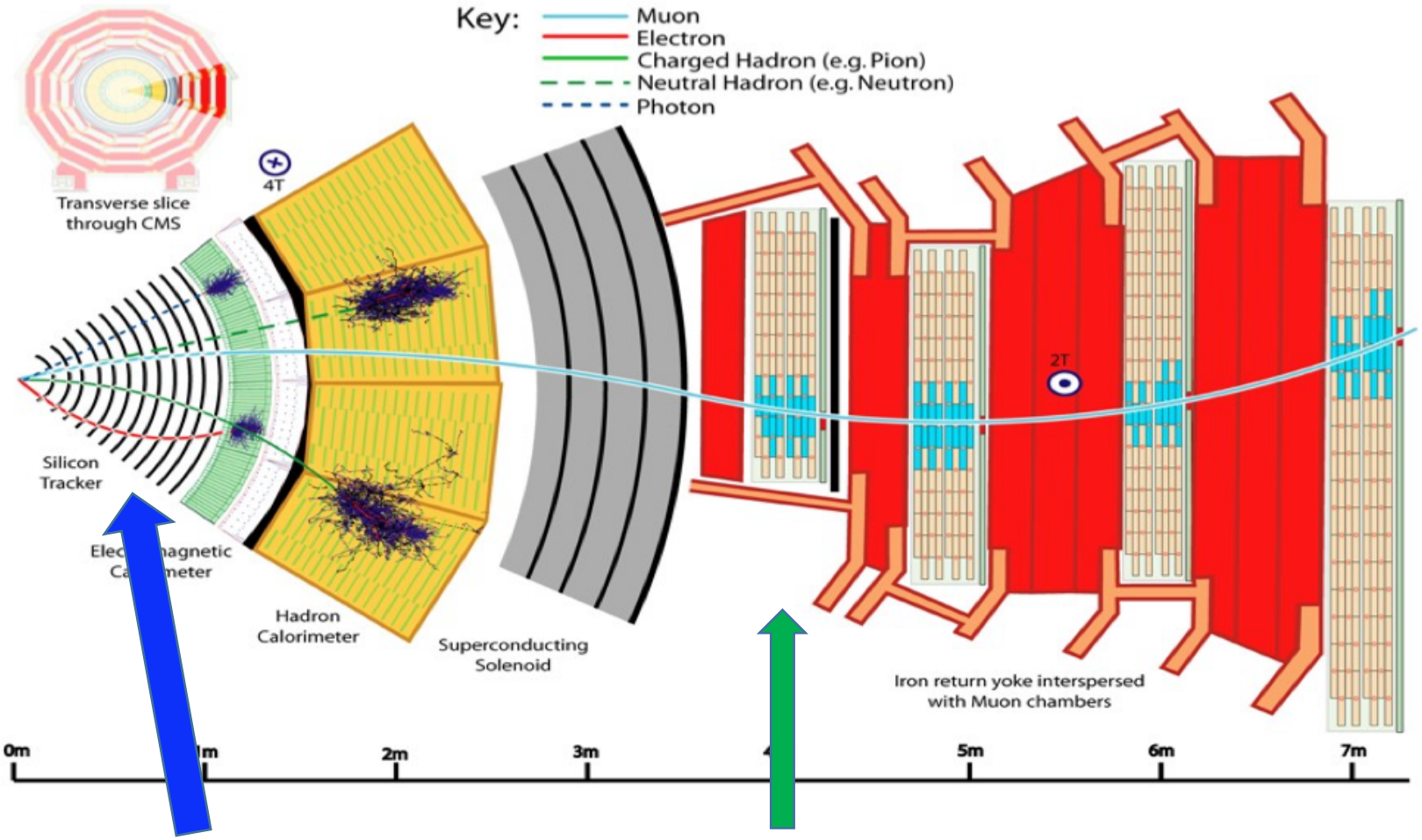
# Outline

- CMS @ LHC
- Motivation
- Analysis strategy
- Results
- Summary

**CMS PAS BPH-14-008**
**JHEP 05 (2017) 013**

Public page:
http://cms-results.web.cern.ch/cms-results/public-results/publications/BPH-14-008/index.html

# CMS Overview




- Relevant sub-detector elements for this analysis are inner tracking system and muon system.

# CMS Performance

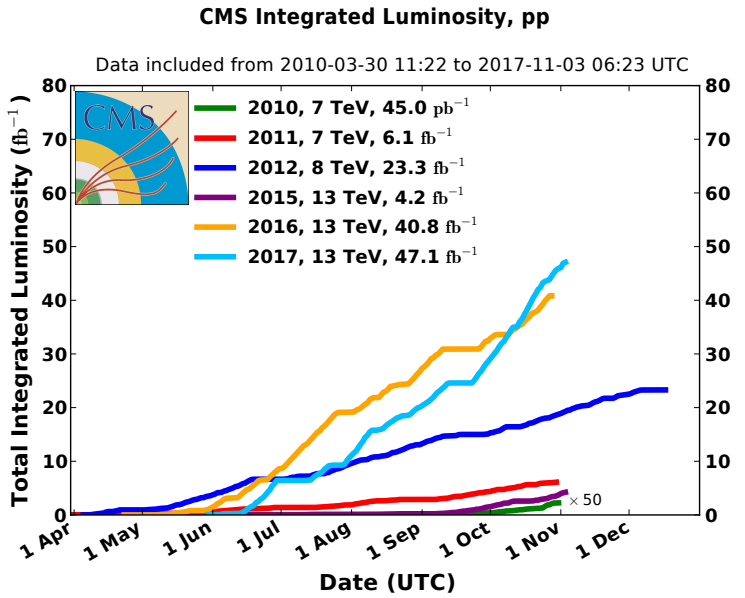
- Excellent muon/silicon detectors for quarkonium

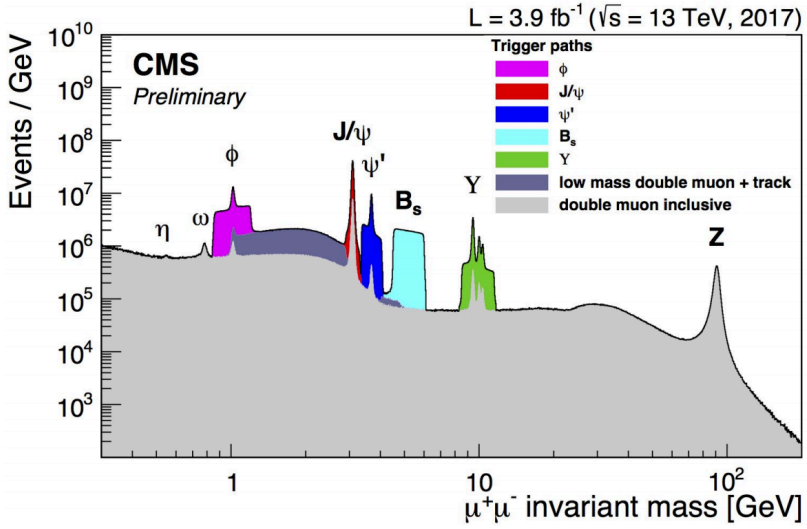
Muon system:

- ✓ High-purity muon identification.
- ✓ Good dimuon mass resolution $\frac{\sigma(m)}{m} \sim (0.6\%)$ for J/ψ.
- ✓ Strong background rejection capabilities.

Silicon tracking detector, B=3.8T

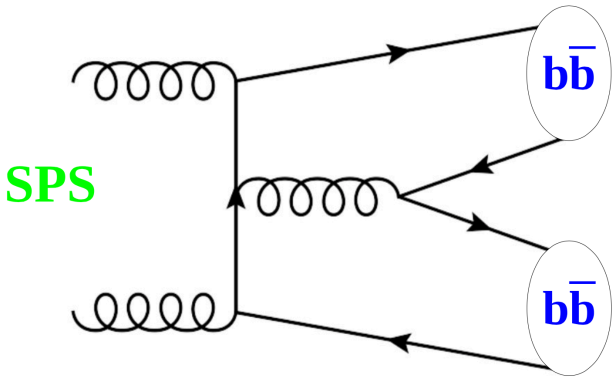
- ✓ Excellent track momentum resolution ($\frac{\Delta P_T}{P_T} \sim 1\%$)
- ✓ Excellent vertex reconstruction and impact parameter resolution

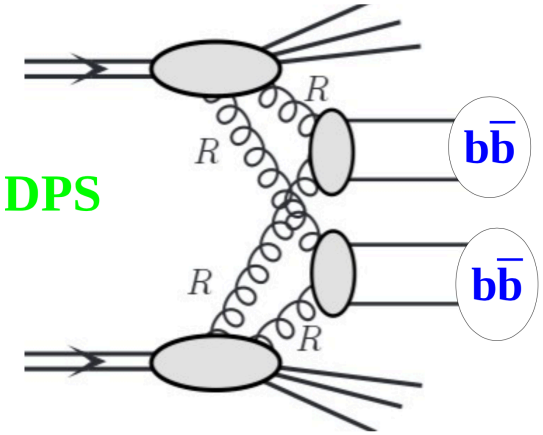


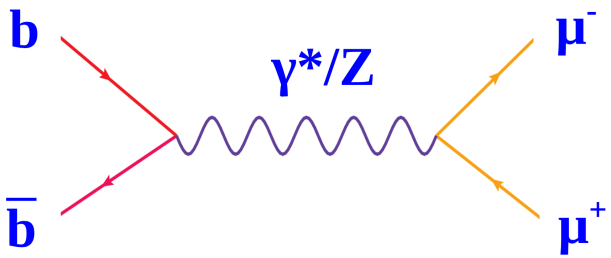



# Motivation for Double Quarkonium Production

- Production of double-quarkonium have been focus of interest since the observation of first $J/\psi$-pair production at NA3 in 1982. High luminosity and high center-of-mass energy at the LHC allows to probe production mechanism and test models.
- Pair production quarkonium can provide important information about the production mechanism (SPS or DPS).



# Motivation for Double Quarkonium Production

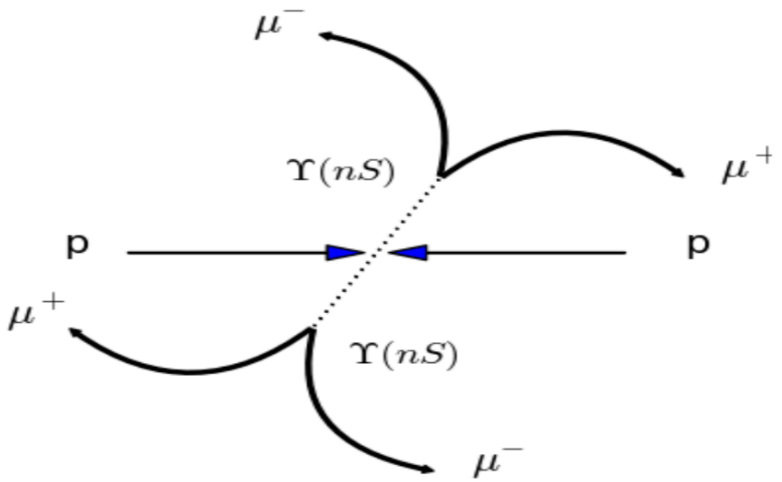
- LHCb, CMS and ATLAS has measured prompt $J/\psi$-pair production.

LHCb: Phys.Lett. B707 (2012) 52–59
ATLAS: Eur. Phys. J. C 77 (2017) 76
CMS: JHEP 09 (2014) 094

- The production of $\Upsilon$-pair has never been observed/searched in any experiment.

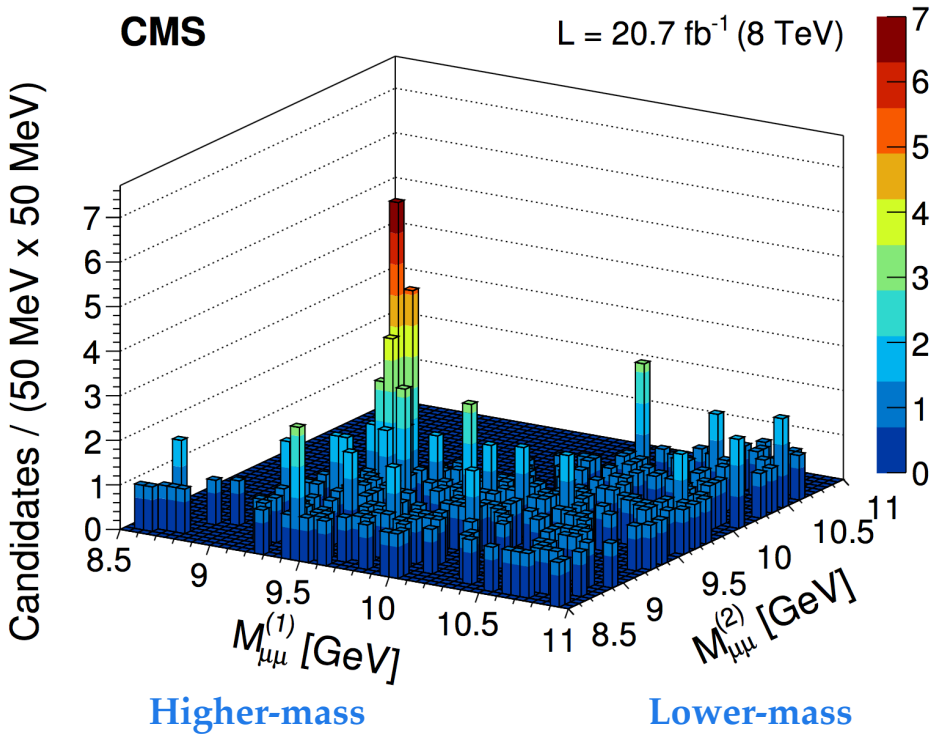
- New measurements in this frontier will potentially benefit other measurements:
  i. Rare Higgs decay to pair of quarkonium
  ii. Enhance sensitivity of matrix elements for SPS production
  iii. Test factorization hypothesis for DPS production ($\sigma_{\mathrm{eff}}$)
  iv. Resonance searches (four B bound states)

# ϒϒ Selection




- The data we are using is collected by CMS detector in 2012 with an integrated luminosity of $20.07 fb^{-1}$ at 8TeV.
- Require events contains four muons with zero total charge.
- Require muons are in detector coverage; $P_T^{\mu} > 3.5\text{GeV}$, $|\eta^{\mu}| < 2.4$.
- Muons required to satisfy CMS soft muon identification criteria.
- Require four muons system and dimuon system point to the same vertex.

# Selected ϒϒ Candidates




Five categories are considered:

- ϒ(1S)ϒ(1S) signal
- ϒ(2S)ϒ(1S) signal
- ϒ(1S)–combinatorial
- ϒ(2S)–combinatorial
- combinatorial–combinatorial

other contributions are negligible.

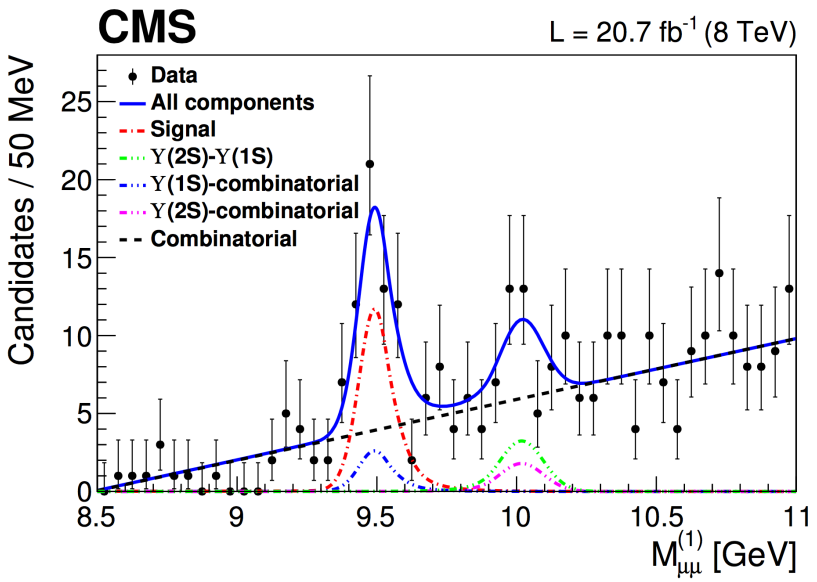
- Two-dimensional scatter plot of selected ϒϒ candidates.
- **Significant excess of events around 9.5GeV.**

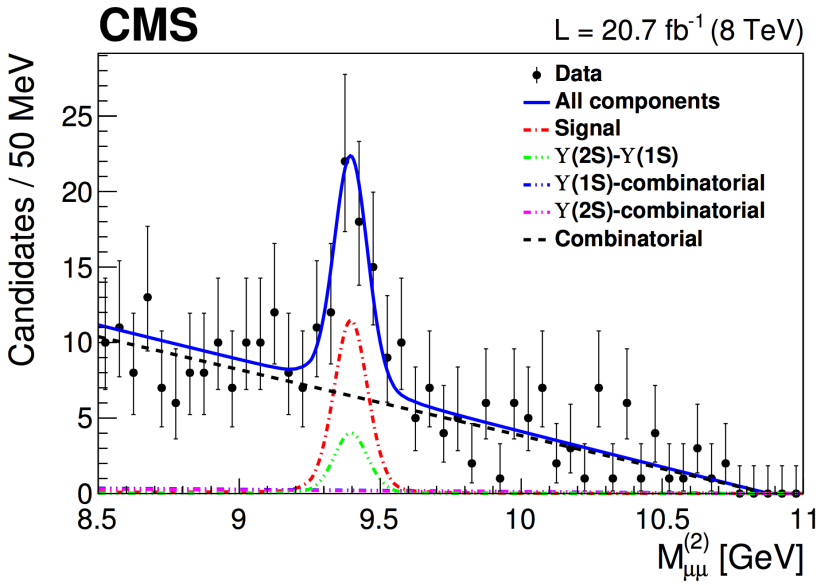
# Acceptance × Efficiency

- Acceptance and efficiency corrections are done on **event-bases using data-embedding method**.
- This method is expected to **minimize model dependence** of correction factors.
- Acceptance corrections are determined by **simulation isotropic decay of $\Upsilon$ mesons** into pair of muons. Acceptance for each event is the number of times $\Upsilon$ mesons are found in detector coverage divided by the total trials.
- Efficiency corrections are calculated by repeatedly substituting measured muon momenta into a CMS reconstruction chain.
- Acceptance and efficiency corrections have been validated using signal MC SPS and DPS models.

# Yield Extraction and Fitting Results

- Each muon pair is modeled as Signal Peak + Flat Background
  - ✓ Signal Model: **Double Crystal Ball function**. Parameters are extracted from signal MC samples and fixed.
  - ✓ **Background Model: 1st order Chebyshev Polynomial.**




$$N_{\Upsilon(1S)\Upsilon(1S)} = 38 \pm 7, \sim 9.6\sigma$$
$$N_{\Upsilon(2S)\Upsilon(1S)} = 13^{+6}_{-5}, \sim 2.6\sigma$$

# Systematic Uncertainties

- Several sources of systematic uncertainties have been considered.

| Component | Uncertainty (%) |
|---|---|
| Resonance shape | 7.9 |
| Simulation | 4.9 |
| Efficiency | 3.7 |
| Acceptance | 2.8 |
| Integrated luminosity | 2.6 |
| Total | 10.7 |

- Uncertainty due to polarization of $\Upsilon$ is studied separately for various extreme scenarios, highest variation is quoted.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\lambda_{\theta 1}$ | +1 | +1 | +0.5 | −0.5 | +0.5 | −1 | +1 | −0.5 | −0.5 | −1 |
| $\lambda_{\theta 2}$ | +1 | +0.5 | +0.5 | +0.5 | −0.5 | +1 | −1 | −0.5 | −1 | −1 |
| Change (%) | +36 | +26 | +18 | −2 | −3 | −9 | −9 | −19 | −29 | −38 |

**Table 2.** Relative change in percent of the acceptance-corrected $\Upsilon(1S)\Upsilon(1S)$ yield for different polarization assumptions with respect to that for $\lambda_{\theta 1} = \lambda_{\theta 2} = 0$.

- Uncertainty due to BR is quoted separately.

# Cross Section $\sigma_{fid}$

*Master formula for cross-section.*

*YY yield from 2D fit*

$$\sigma(pp \to YY) = \frac{N_{fit}^{YY}}{BR(Y \to \mu\mu)^2 \cdot L} \cdot \frac{\sum_{i=K} 1/(\varepsilon_i \cdot a_i)}{K}$$

*BR fraction and integrated luminosity from lookup table.*

*Average efficiency and acceptance, calculated on event-by-event bases for efficiency > 1% events*

❖ Assuming both $\Upsilon(1S)$ mesons decay isotropically, the total cross section of $\Upsilon(1S)$ pair production within $|y^{\Upsilon}| < 2.0$ and $P_T^{\Upsilon} < 50\text{GeV}$

$$\sigma_{fid}(pp \to \Upsilon(1S)\Upsilon(1S)) = 68.8 \pm 12.7(\text{stat.}) \pm 7.4(\text{syst.}) \pm 2.8(\mathcal{B})\text{pb}$$

- ✓ Different assumptions of $\Upsilon(1S)$ polarization imply modifications to the cross section ranging from -38% to 36%.
- ✓ Uncertainty of cross section is dominated by statistics (~20%). Both individual and total systematic uncertainty are below the statistical precision.

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# Cross Section $\sigma_{eff}$

$$\sigma_{\mathrm{eff}} = \frac{[\sigma(\Upsilon)]^2}{2\, f_{\mathrm{DPS}}\, \sigma_{\mathrm{fid}}\, [\mathcal{B}(\Upsilon(1\mathrm{S}) \to \mu^+\mu^-)]^2}$$

- An effective cross section is also estimated using our result:

$$f_{DPS} \approx 10\%, \qquad \sigma_{eff} \approx 6.6\mathrm{mb}$$

or

$$f_{DPS} \approx 30\%, \qquad \sigma_{eff} \approx 2.2\mathrm{mb}$$

Consistent with the range of values from heavy-quarkonium measurements (2-8mb), smaller than that from multi-jet studies (12-20mb).

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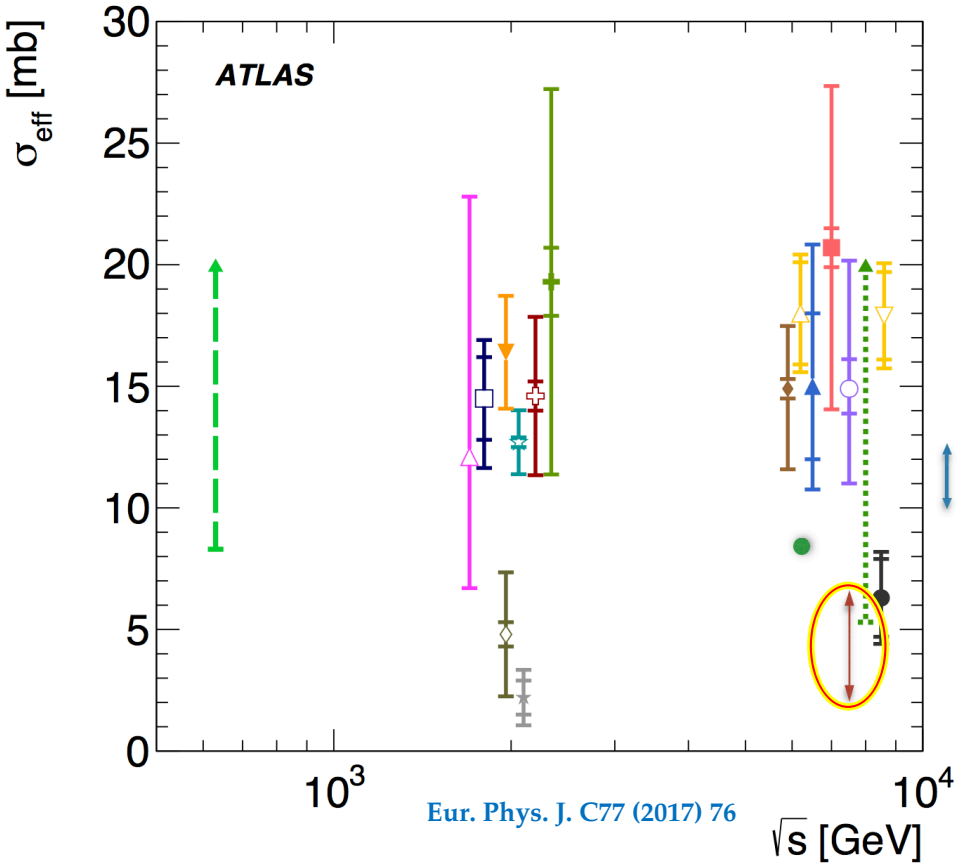
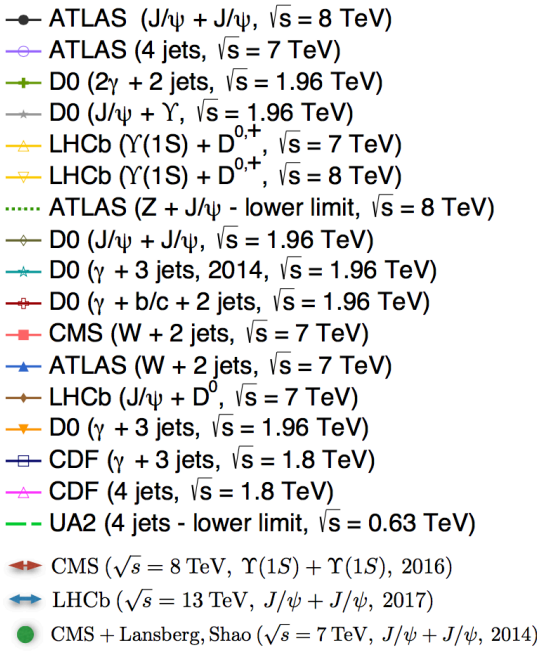
# $\sigma_{eff}$ for Double Parton Scattering




- ✓ Data largely in agreement with NLO* SPS + LO DPS, contributions from feed-down and/or intrinsic parton transverse momentum may be needed.
- ✓ $\sigma_{eff}$ measured from prompt di-J/ψ and di-Υ(1S) generally lower than from other final states.
- ✓ Theoretical predictions of the dependence of $\sigma_{eff}$ on the process and the centre-of-mass energy are needed.

Expect a lot more $\sqrt{s} = 13$ TeV results.

# Summary

- **Observed simultaneous $\Upsilon\Upsilon$ events** for the first time.
- Cross section of simultaneous production of two $\Upsilon(1S)$ mesons is measured for the first time. No enough statistics to separate SPS and DPS fractions.
- Provide a benchmark for terra-b quark state at LHC.
- Planning to extend study on differential cross section with the new data.


# Additional Materials

# References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