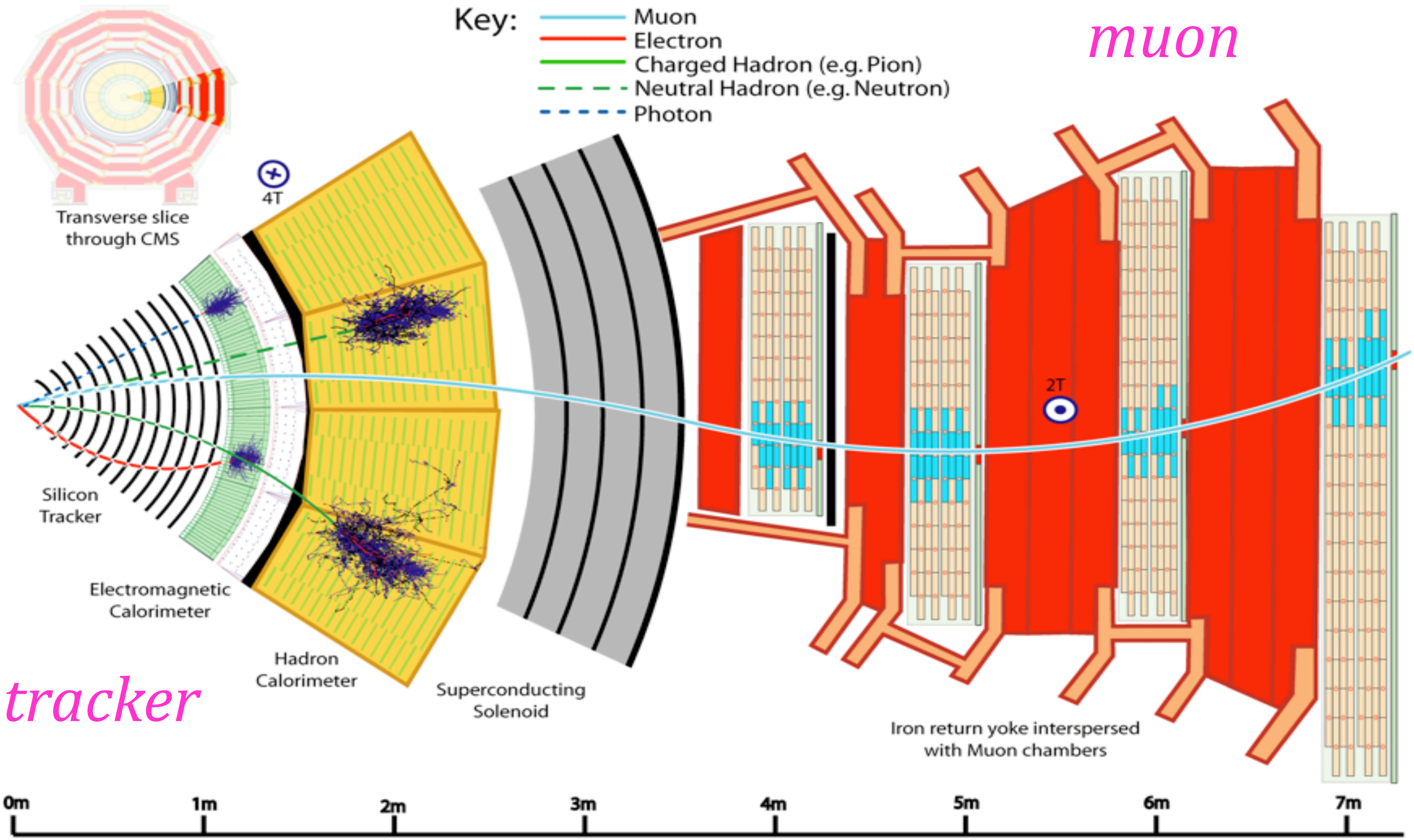
Observation of double upsilon at CMS

Kai Yi (University of Iowa) for the CMS Collaboration

Outline

- CMS detectors & triggers
- Motivation
- Observation of double upsilon
  - Double J/ψ differential cross section
  - Double Upsilon observation
- Summary

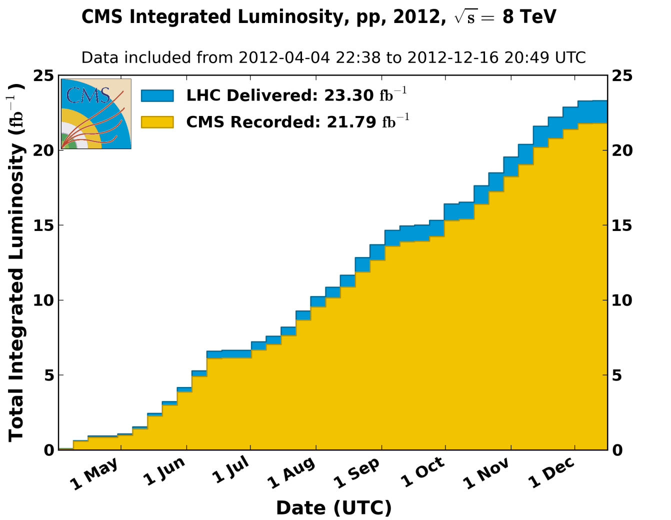
CMS Detector



CMS Detector Performance

Excellent muon/silicon detectors for quarkonium:

- Muon system
  - High-purity muon identification
  - Good dimu mass resolution ($\Delta m/m \sim 0.6\%$ for J/ψ)
- Silicon Tracking detector, B=3.8T
  - excellent track momentum resolution ($\Delta p_T/p_T \sim 1\%$
  - excellent vertex reconstruction and impact parameter resolution



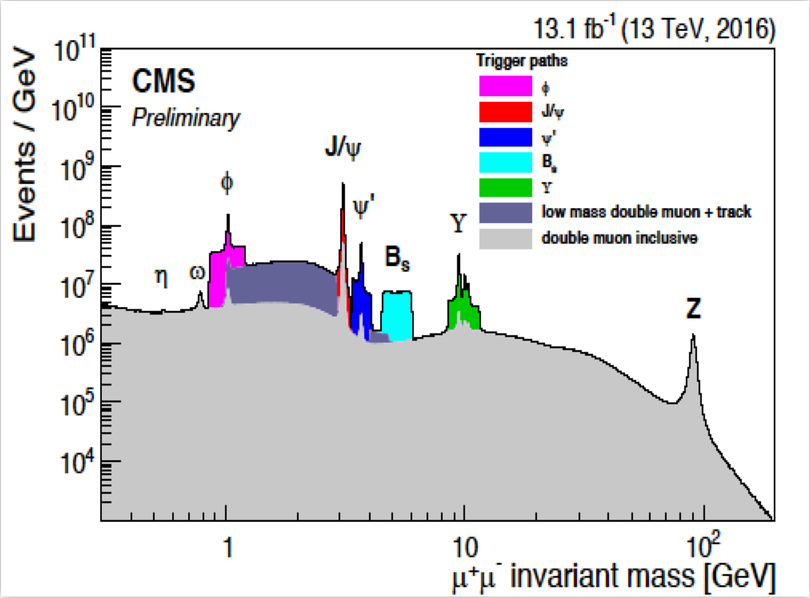
LHC luminosity and CMS trigger:

- *collect data at increasing instantaneous luminosity*
- *Triggers are essential ingredients*
  - *Special trigger for different analyses*

    combination of muon p_T, dimu p_T, dimu mass

    displaced dimuon vertex, and

    dimu+additional muon



Motivation

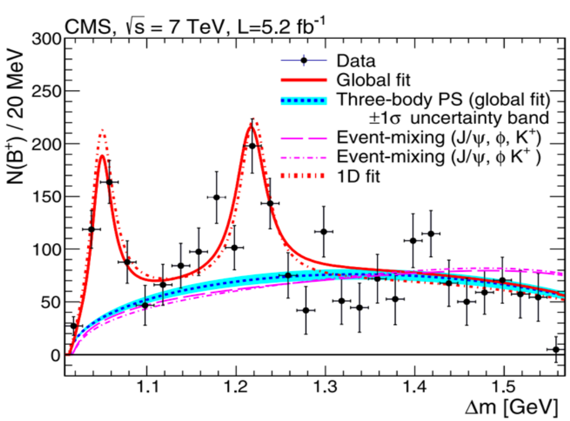
- Discovery of X(3872) in 2003 revitalized the interest in exotic meson searches (PRL 91, 262001)

- More than 20 new candidates have been observed since then, including penta-quark candidates.

- CMS is a good place for this topic, and has made contributions to this topic, such as X(3872) production cross section measurement, confirmation of X(4140)

- There are predications of possible exotic meson candidates composed of all heavy quarks

Phys.Lett. B734 (2014) 261



Phys.Rev. D19 (1979) 764-778

Table I(a). The quantum numbers and masses for the $(cc)_{\bar{3}}{}^* - (\bar{c}\bar{c})_3$ states (without spin-dependent forces between two clusters)

L	S	J^{PC}	Mass (GeV)
1	0	1^{--}	6.55
	1	$0^{-+}, 1^{-+}, 2^{-+}$	
	2	$1^{--}, 2^{--}, 3^{--}$	
2	0	2^{++}	6.78
	1	$1^{+-}, 2^{+-}, 3^{+-}$	
	2	$0^{++}, 1^{++}, 2^{++}, 3^{++}, 4^{++}$	
3	0	3^{--}	6.98
	1	$2^{-+}, 3^{-+}, 4^{-+}$	
	2	$1^{--}, 2^{--}, 3^{--}, 4^{--}, 5^{--}$	

Heavy tetra-quark bound states

- ***Heavy-quark tetra-quark states*** *Phys. Rev. D 86, 034004 (2012)*

---No solid prediction for heavy quarks, but a few simple models, i.e.

$c\bar{c}c\bar{c}$

$0^{++\prime}$: $M = 5.966\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -228.\,\mathrm{MeV}$,

$1^{+-\prime}$: $M = 6.051\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -142.\,\mathrm{MeV}$,

Above double η_c threshold
Below double J/ψ threshold
Search via ($\eta_c\eta_c$?), $J/\psi\mu^+\mu^-$, J/ψ^*

2^{++} : $M = 6.223\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = 29.5\,\mathrm{MeV}$.

Above double J/ψ threshold
Search via $J/\psi J/\psi$

$bc\bar{b}\bar{c}$

$0^{++}a$: $M = 12.359\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -191.\,\mathrm{MeV}$

$0^{++}b$: $M = 12.471\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -78.7\,\mathrm{MeV}$,

$1^{+-}a$: $M = 12.424\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -126.\,\mathrm{MeV}$

$1^{+-}b$: $M = 12.488\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -62.5\,\mathrm{MeV}$,

1^{++} : $M = 12.485\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -64.9\,\mathrm{MeV}$,

Below double B_c threshold
$J/\psi\Upsilon(1S)$ threshold
? ...

2^{++} : $M = 12.566\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = 16.1\,\mathrm{MeV}$.

Above double B_c threshold
$J/\psi\Upsilon(1S)$ threshold
Search via the above two channels

$b\bar{b}b\bar{b}$

$0^{++\prime}$: $M = 18.754\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -544.\,\mathrm{MeV}$,

$1^{+-\prime}$: $M = 18.808\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -490.\,\mathrm{MeV}$,

2^{++} : $M = 18.916\,\mathrm{GeV}$, $M - M_{\mathrm{th}} = -382.\,\mathrm{MeV}$.

Below double $\Upsilon(1S)$ threshold
Search via $\Upsilon(1S)\mu^+\mu^-$

Will be a breakthrough for exotic meson if established

Arguable to call below J/ψ mass events as J/ψ^* since J/ψ is very narrow, same for Υ^*

Motivation

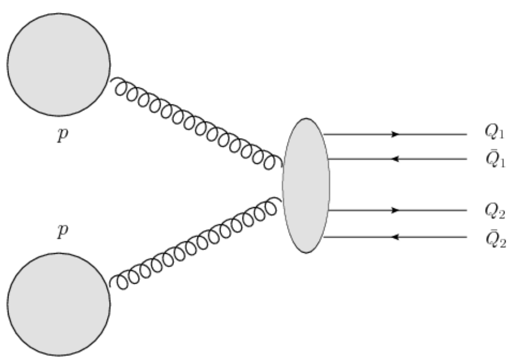
- The production of J/ψJ/ψ, ΥJ/ψ, ΥΥ are the benchmark measurements to evaluate the sensitivity of possible tetra-quark states composed of all heavy quarks at LHC

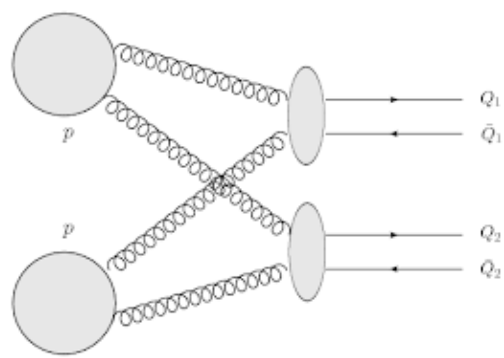
- On the other hand, the measurement of quarkonium and double quarkonium provide insight to the production mechanism.
  - Single Parton Scattering (SPS)
  - Double Parton Scattering (DPS)

- DPS production is expected to be significant at LHC

- Only SPS is relevant to the production of exotic mesons, DPS contributes as background events

SPS

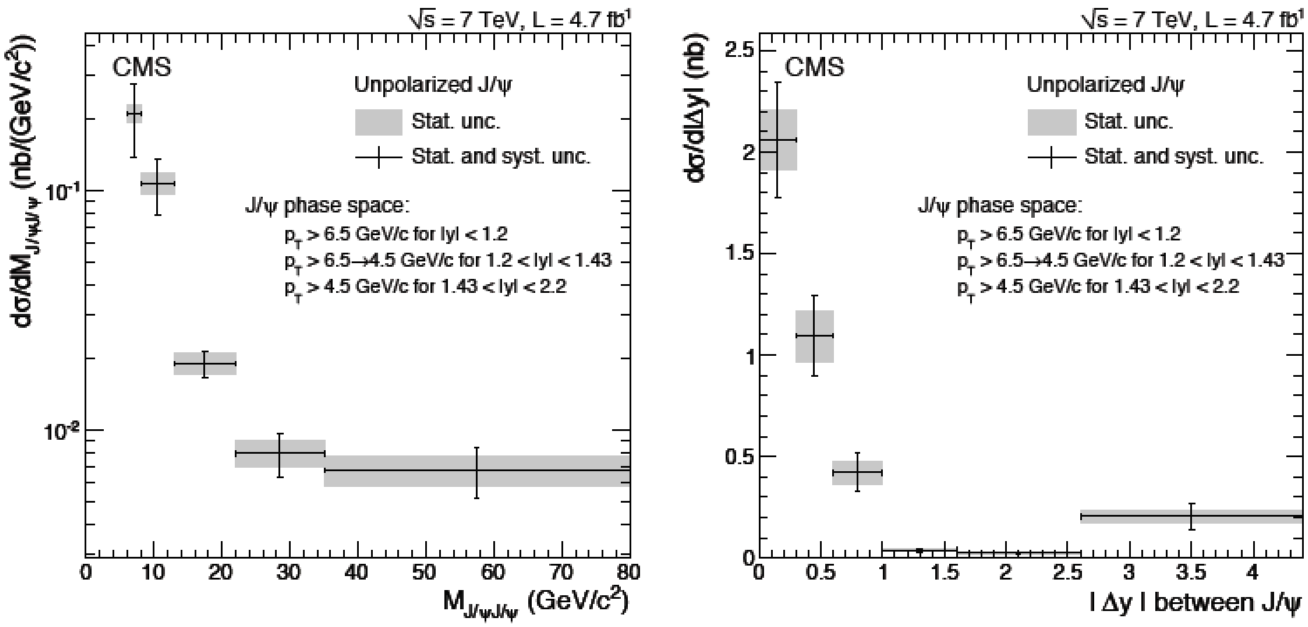




DPS

Double J/ψ cross section

JHEP 1409 (2014) 094



σ_{tot} = 1.49 ± 0.07(stat) ± 0.13(syst) nb, prompt component

We have observed double J/ψ events and measured its production cross section
Dominated by SPS, hint of DPS.

How about an upsilon pair?

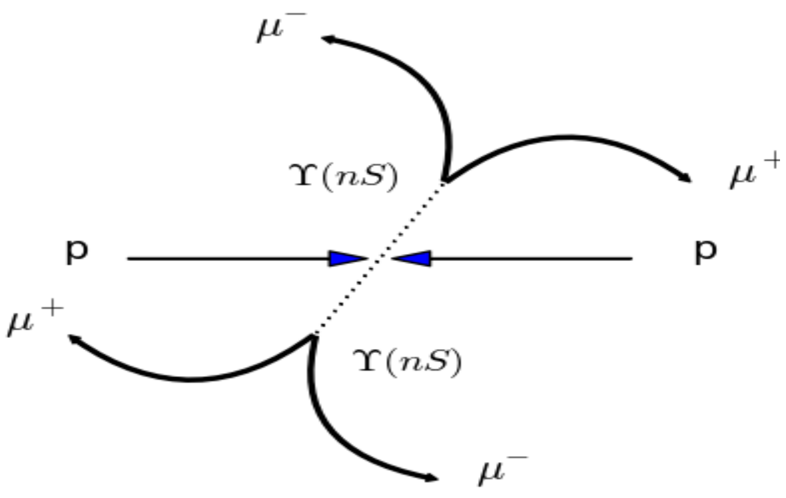
Observation of Y(1S)Y(1S)

JHEP 1705 (2017) 013

Motivation:

--Investigate the production mechanism: SPS vs DPS

--Benchmark measurement for 4b bound state searches



$$pp \rightarrow \Upsilon\Upsilon$$
$$\Upsilon \rightarrow \mu^+ \mu^-$$

Main selections:

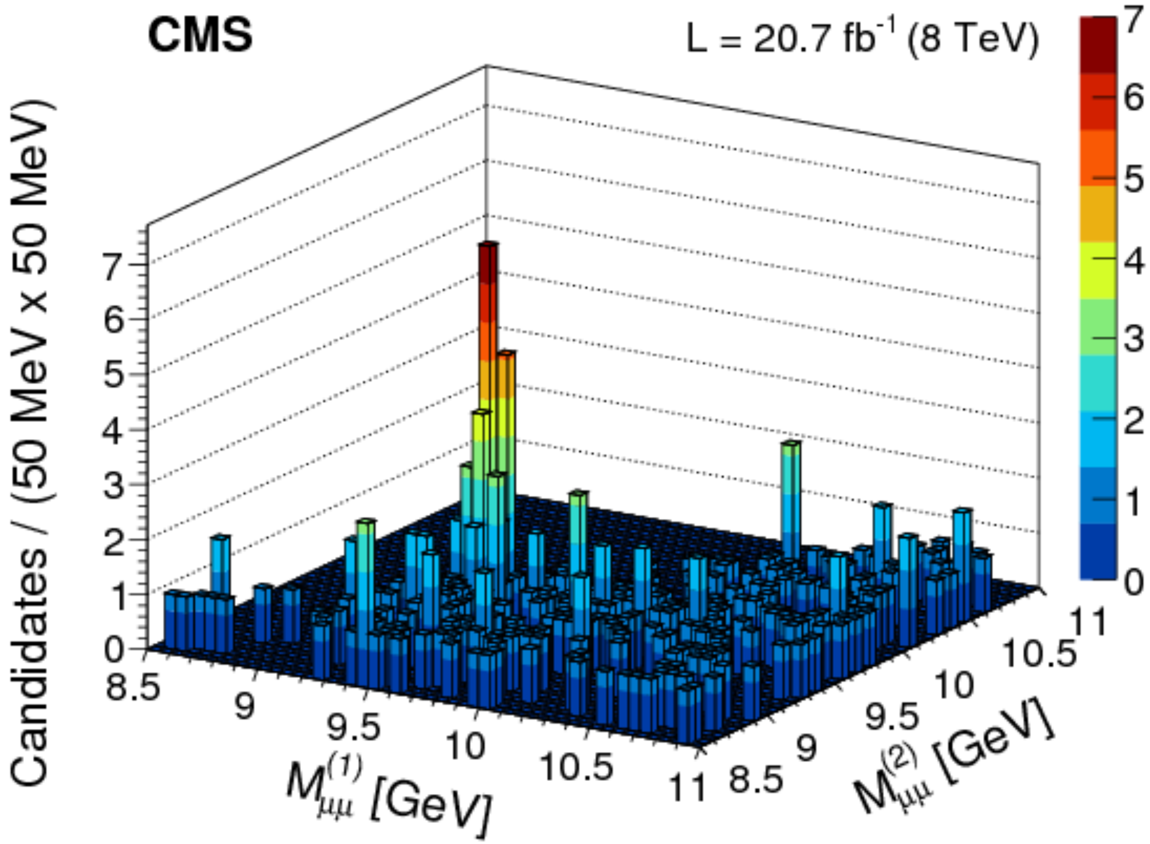
--muon p_T >3.5 GeV, pseudorapidity within 2.4

--Upsilon pseudorapidity within 2.0

--four-muons come from the same vertex: vertex-probability>5%

Two-dimensional scatter plot

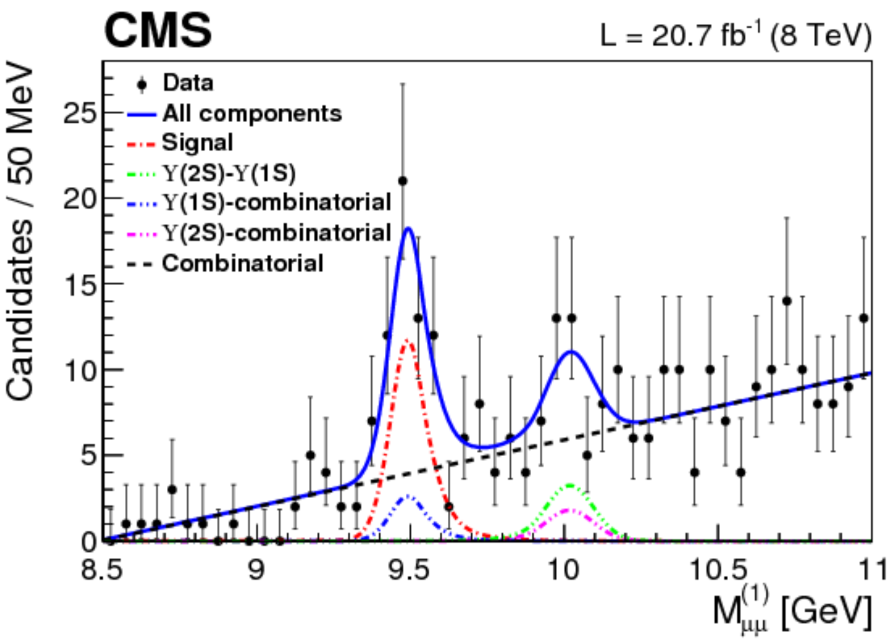
JHEP 1705 (2017) 013

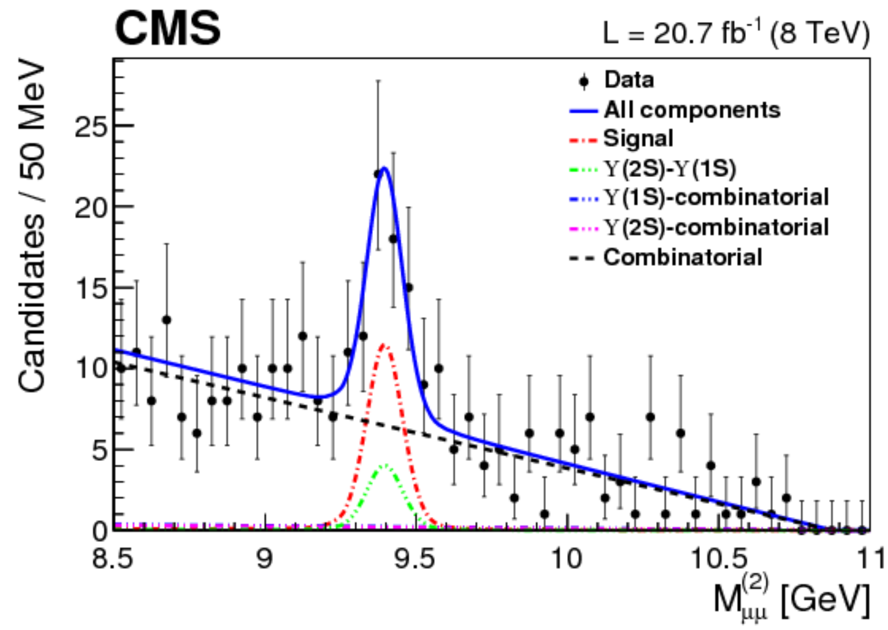


Two dimensional scatter plot of selected events,
Striking peaks at 9.5 GeV from both dimensions.

Scatter plot projection

JHEP 1705 (2017) 013





Main selections: Yield extraction from maximizing 2D likelihood PDF

--signal is modeled by two Crystal-ball functions

--background is modeled as 1st order polynomial

Number of Y(1S)Y(1S): 38±7

Significance: >>5sigma

Also see a hint of (Y(1S)Y(2S)

First time observation in the world

Y(1S)Y(1S) Cross section @ 8 TeV

Assuming unpolarized production of Y(1S) meson, the cross section of Y(1S)Y(1S) with pseudorapidity within 2.0 for each Y(1S), and p_T less than 50 GeV at 8 TeV is measured as:

$$\sigma(pp \rightarrow YY) = 68.8 \pm 12.7(stat) \pm 7.4(syst) \pm 2.8(BR)pb$$

Different assumptions of Y(1S) polarization gives the total cross section uncertainty between -38% and 36%

No enough statistics to separate SPS and DPS fractions.

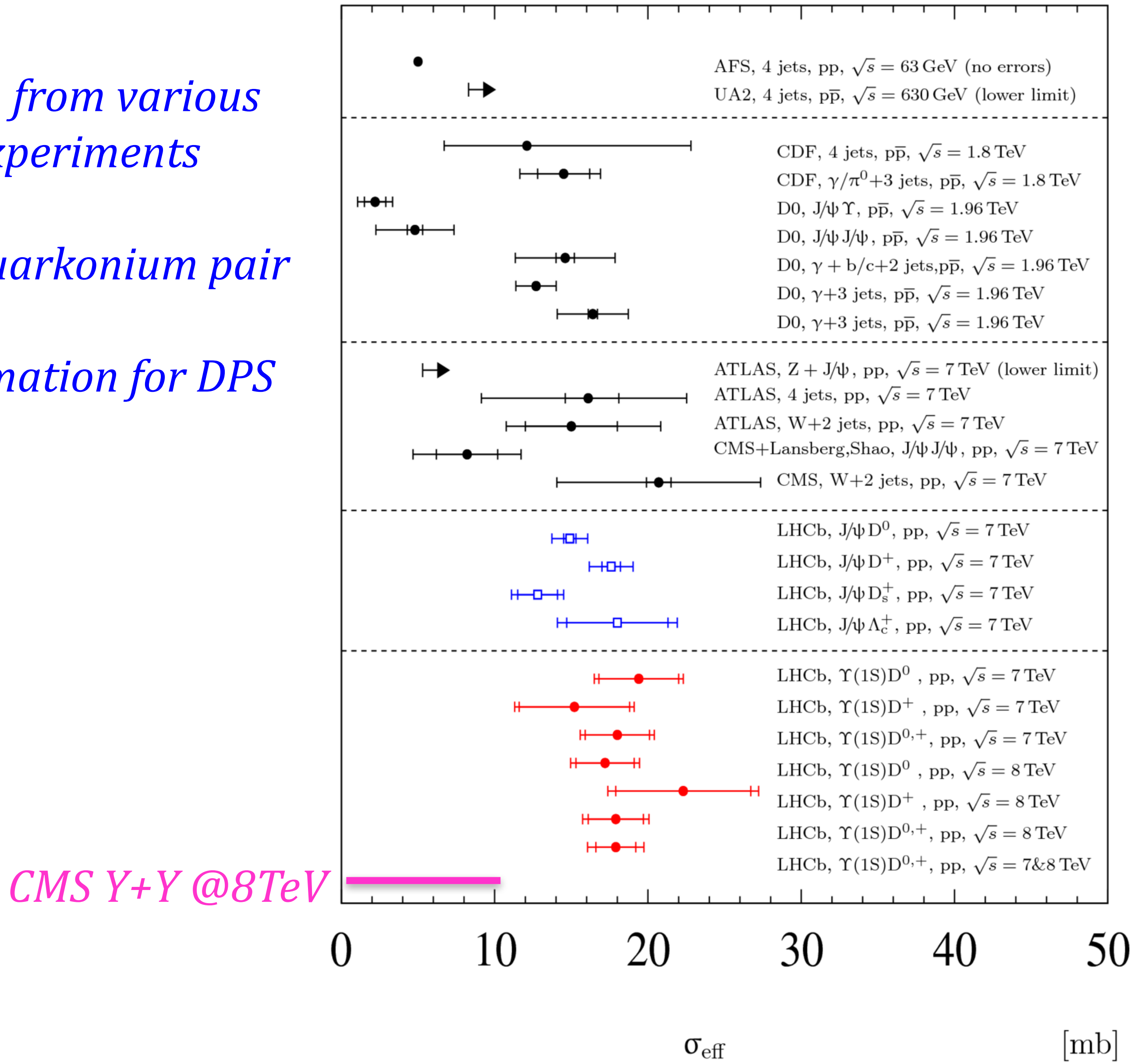
The effective cross section can be calculated by:

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

The effective cross section is between 6.6 and 1.32 mb assuming 10%-50% f_{DPS}

Comparison with other channels

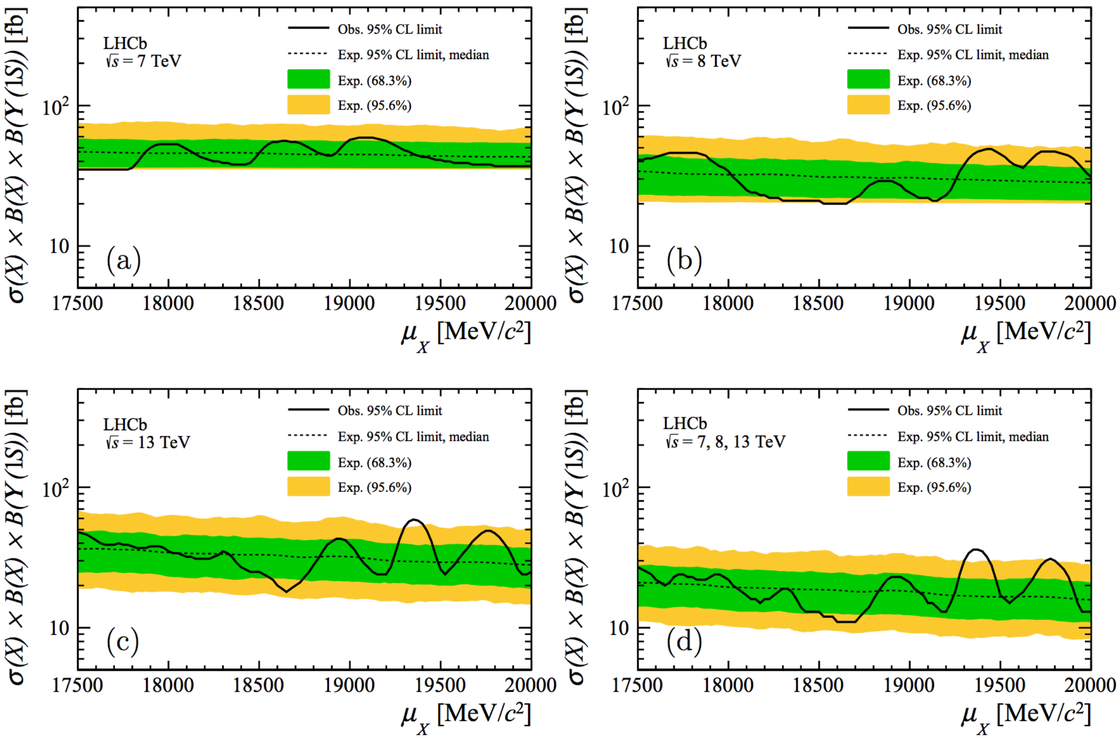
- *effective cross section from various channels at different experiments*
- *relatively small for quarkonium pair*
- *provide insight information for DPS*



Y(1S)Y(1S) SPS Cross section @ 8 TeV

Assuming f_{DPS} to be 10%-50%, the SPS cross section @8 TeV in CMS can be as large as [34,62] pb

CMS will be sensitive if tetra-quark state cross section is close to pb level @CMS.



LHCb limit

arXiv:1806.09707 [hep-ex]

No upsilon pair cross section reported from LHCb yet

Summary

- *CMS observed the upsilon pair production for the first time*

- *The fiducial cross section is measured as:*

$$\sigma(pp \rightarrow YY) = 68.8 \pm 12.7(stat) \pm 7.4(syst) \pm 2.8(BR)pb$$

- *provide insight to upsilon pair production mechanism*

- *The SPS cross section can be as large as 34-62 pb*

Stay tuned!