Central exclusive production of J/ψ and $\psi(2S)$ mesons in pp collisions at $\sqrt{s} = 13$ TeV in LHCb

[JHEP 10 (2018) 167]

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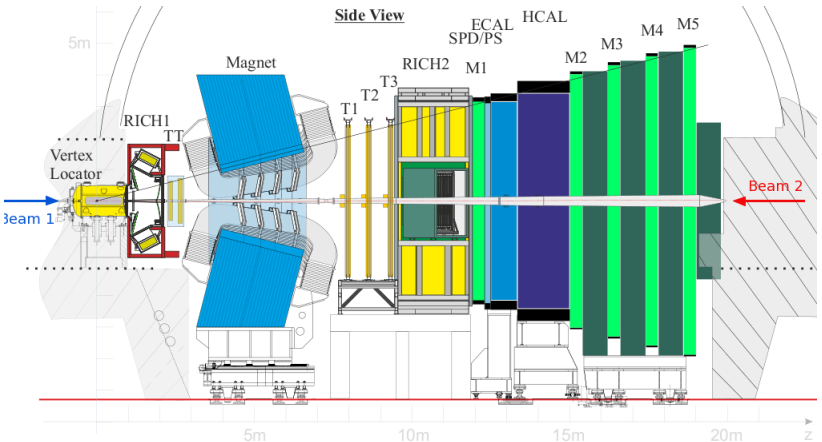
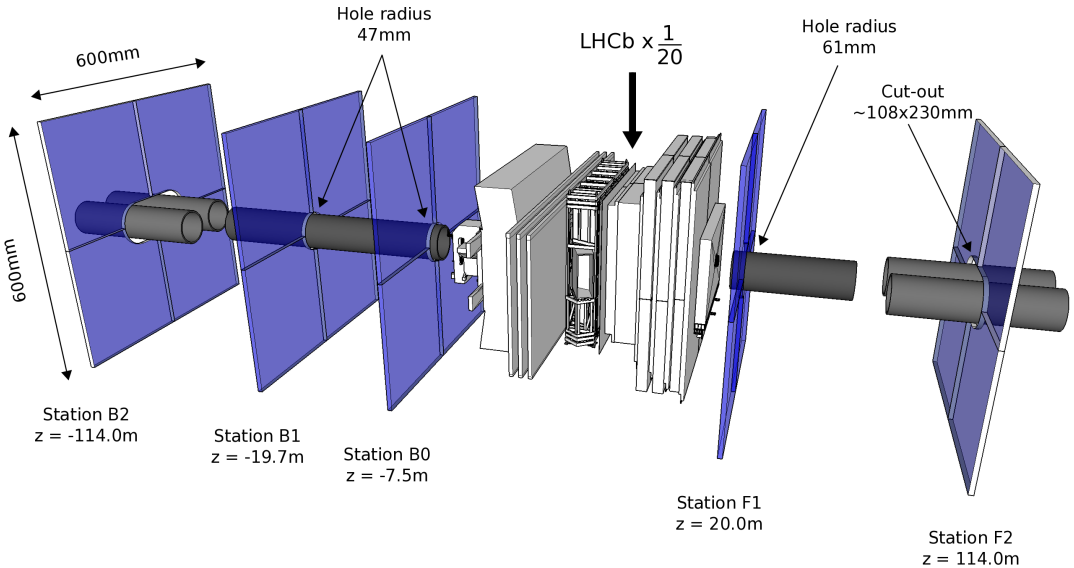
Outline

LHCb detector

1. Single arm spectrometer $\rightarrow$ In the forward region, $2 < \eta < 5$
2. Flexible trigger $\rightarrow$ able to trigger on low momentum objects.
3. Fixed target capability via gas injection (SMOG).
4. Run II: HeRSCheL



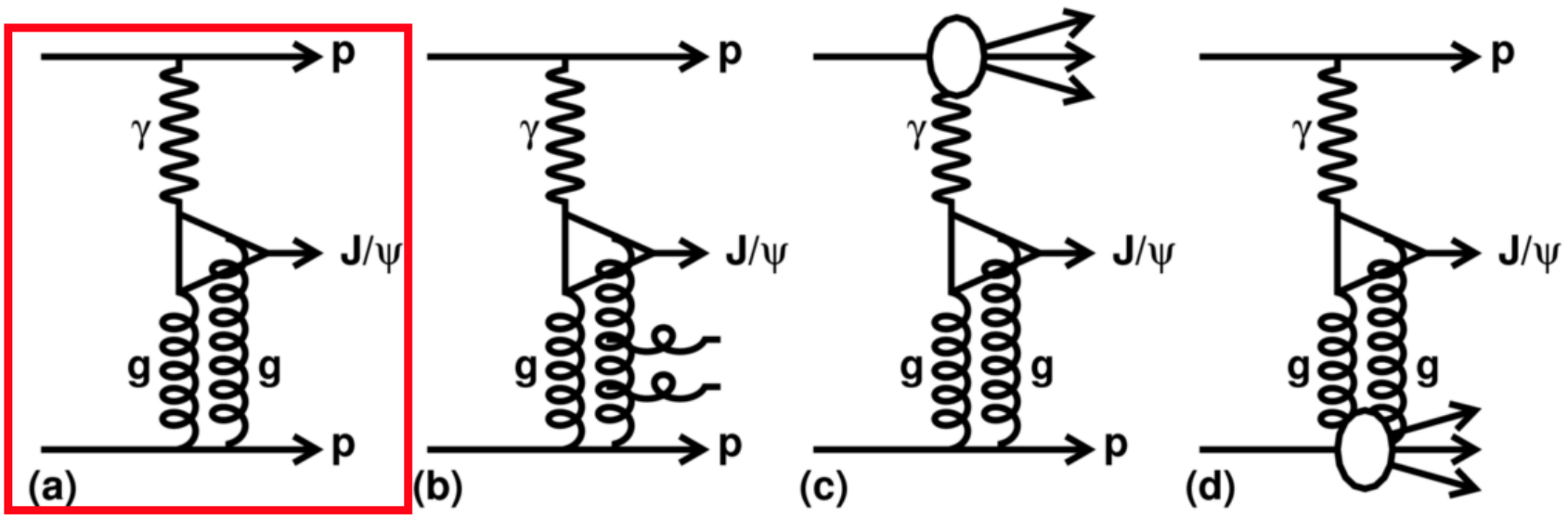
(a) Schematic view of the current LHCb detector [2014 JINST 9 P12005]
VELO $-3.5 < \eta < -1.5$ and $2 < \eta < 5$.



(b) HeRSCheL (High Rapidity Shower Counters for LHCb): new high rapidity shower counters in RunII
$-10 < \eta < -5$, and $5 < \eta < 10$
[JINST 13 (2018) P04017].

Central exclusive production (CEP)

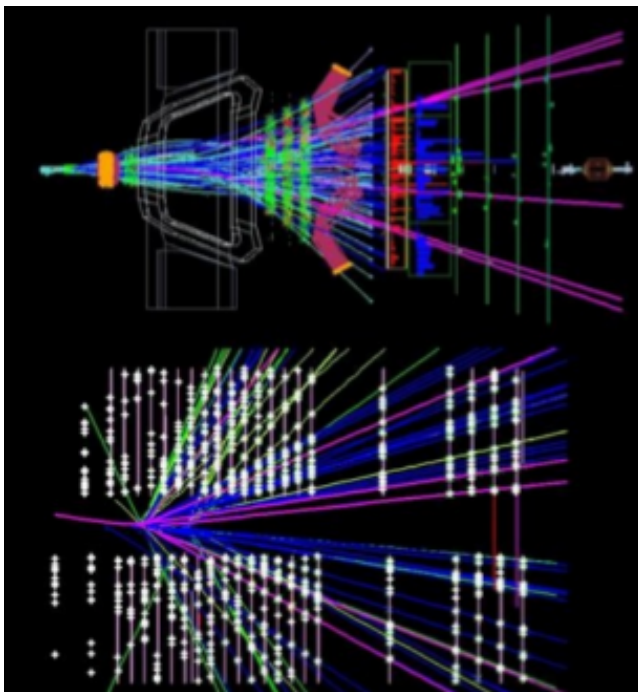
J/ψ and $\psi(2S)$ in CEP are produced through the fusion of a photon and a pomeron (a colorless strongly-coupled object).



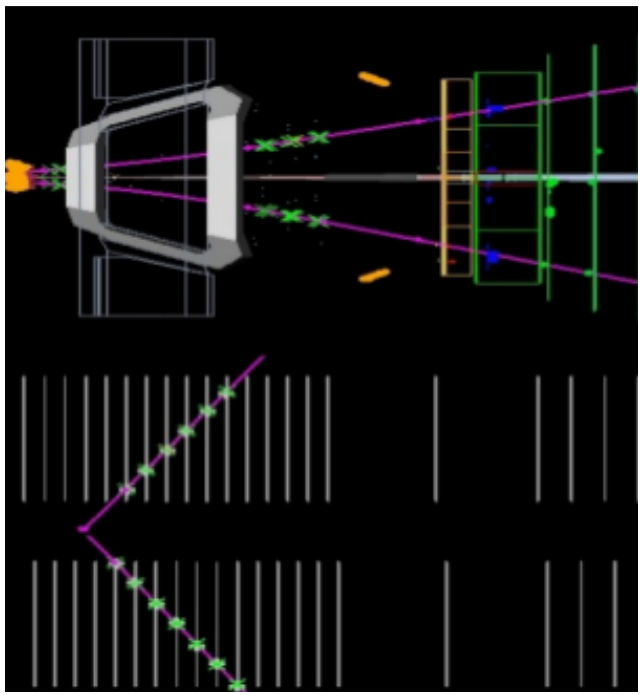
Feynman diagrams of diffractive-production mechanisms of J/ψ mesons at the LHC, where the double gluon system being emitted from the beam proton constitutes the pomeron.
(a) is the pure CEP process (signal),
(b) has additional gluon radiation, and
(c) and (d) involve proton dissociation.
[JINST 13 (2018) no.04, P04017].

Central exclusive production (CEP)

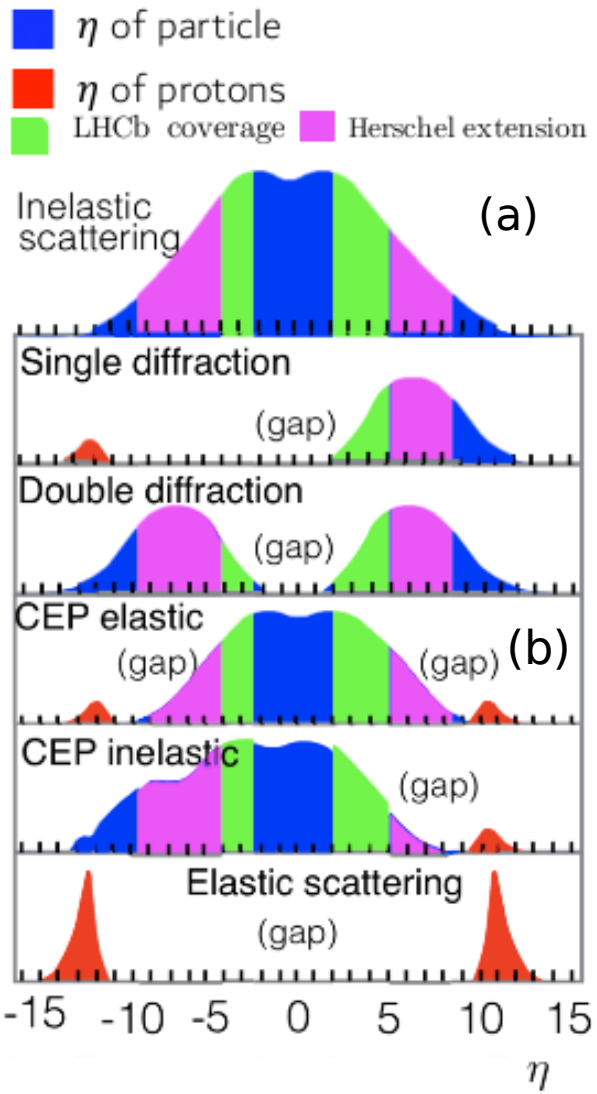
1. CEP event → diffractive process of pp→p+X+p
   - HeRSCheL → able to detect forward particle showers and veto events with these



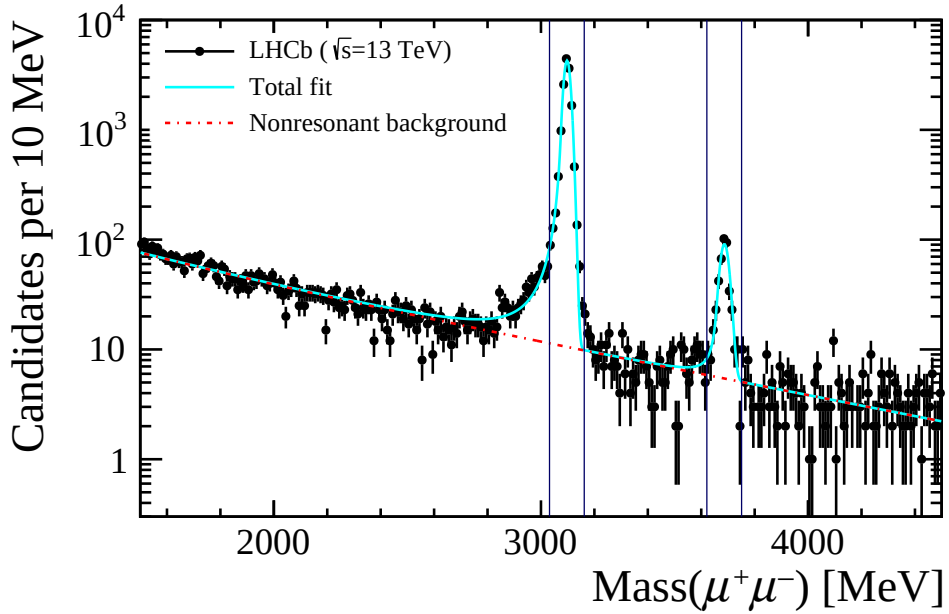
(a) Inelastic pp collision.



(b) CEP elastic pp collision.



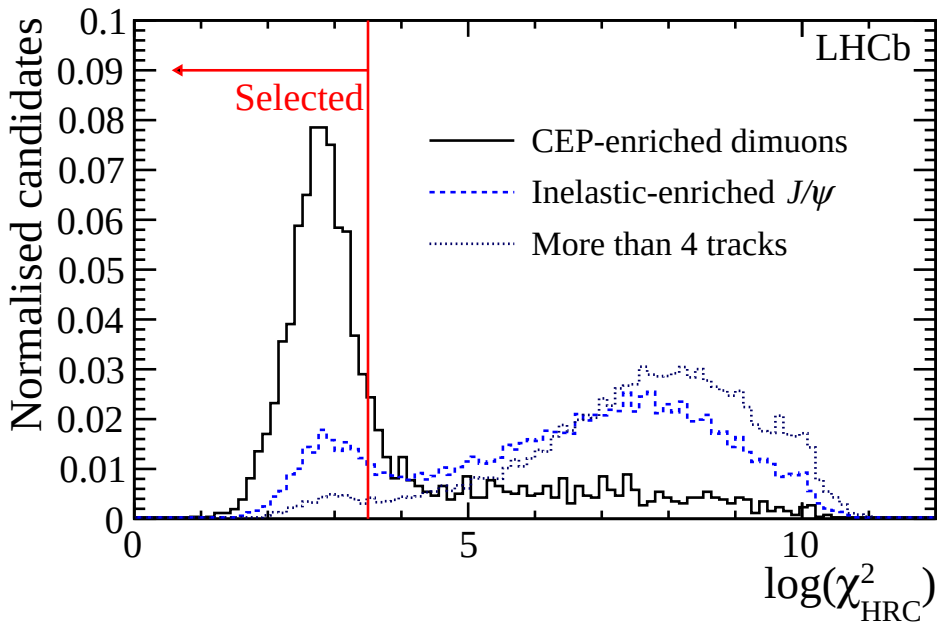
Selections



Invariant mass distribution of dimuon candidates
[JHEP 10 (2018) 167]

- $2 < \eta < 4.5$, $p_T^2 < 0.8(GeV/c)^2$
- Crystal Ball func. (signal) + exponential func. (background)
  - The J/ψ and $\psi(2S)$ mass windows of the signal
  - The nonresonance regions (background) $\rightarrow$ electromagnetic CEP dimuons events
- J/ψ background : a fraction of 0.009 ± 0.001
- $\psi(2S)$ background : a fraction of 0.161 ± 0.018

HeRSCheL to discriminate CEP events

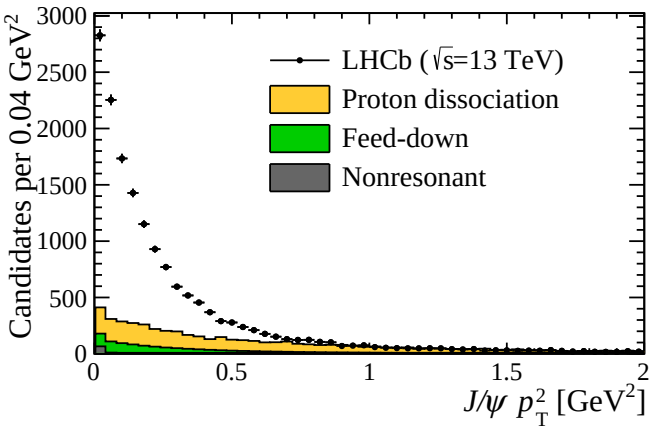


The distributions of χ^2_{HRC} (The digitised signals undergo a callibration procedure and the summed signal) for three classes of low-multiplicity-triggered events [JHEP 10 (2018) 167].

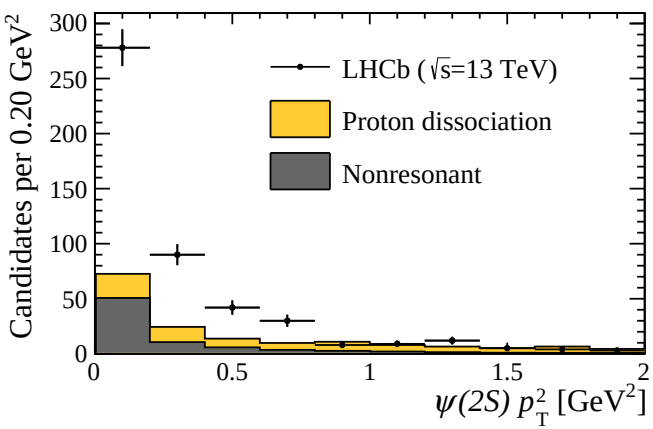
- CEP-enriched dimuons: events in the nonresonant dimuon sample ($p_T^2 < 0.01 GeV^2$, a purity of 97% for electromagnetic CEP events)
- Inelastic-enriched J/ψ: $p_T^2 > 1 GeV^2 \rightarrow$ selecting inelastic events with proton dissociation
- Good discrimination between CEP ($log(\chi^2_{HRC}) < 3.5$) and non-CEP candidates.
- $log(\chi^2_{HRC}) < 3.5$ Selection: J/ψ signal $\rightarrow$ 14753 candidates
  $\psi(2S)$ signal $\rightarrow$ 440 candidates

HeRSCheL to discriminate CEP events

[JHEP 10 (2018) 167]



(a) p_T^2 distribution of J/ψ candidates when data is below the HeRSCheL threshold.



(b) p_T^2 distribution of $\psi(2S)$ candidates when data is below the HeRSCheL threshold.

Background fractions for $J/\psi(\psi(2S))$

→Non-resonant estimated from DiMuon mass: 0.009±0.001

→Feed-down estimated using data: 0.060 ± 0.002

→Proton dissociation with a new technique (HeRSCheL): 0.175±0.015

Purity of signal sample

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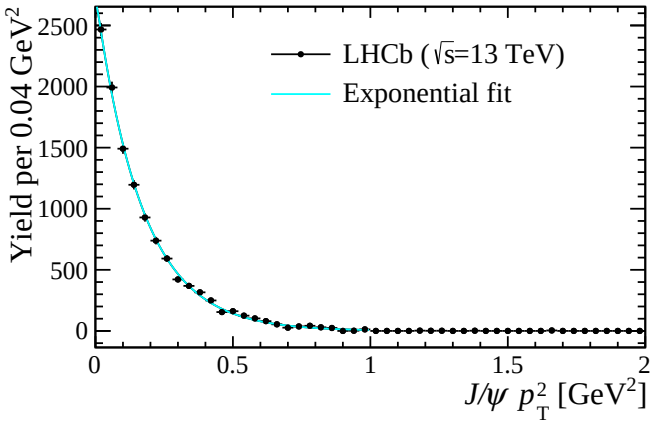
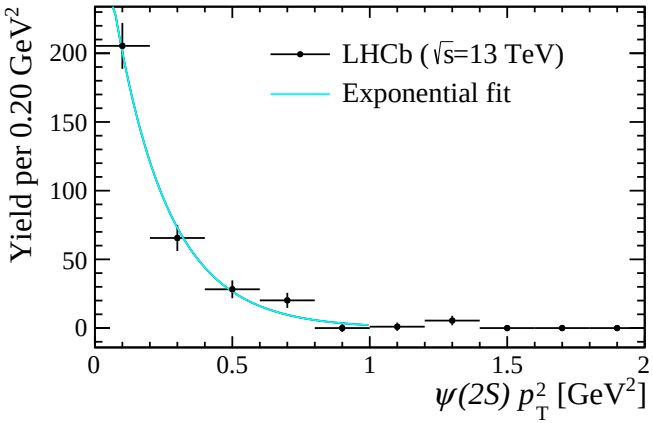


(a) CEP signal for the J/ψ selections.



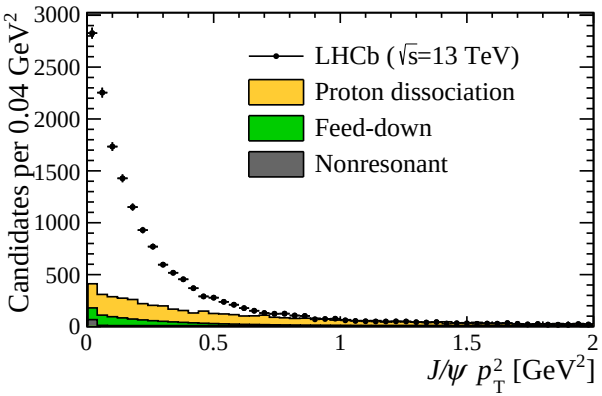
(b) CEP signal for the $\psi(2S)$ selections.

- Signal J/ψ and $\psi(2s)$ distributions as a function of p_T^2
  obtained by subtracting proton dissociation background.
- Fit is performed to single exponential ($\exp(-b_{sig}\, p_T^2)$)
  Well described by $b_{sig} = 5.93 \pm 0.08 GeV^{-2}$,
  consistent with extrapolations from previous pp at $\sqrt{s}$ =7 TeV and from H1 results.
- In $0 < p_T^2 < 0.8 GeV^2$;
  J/ψ: 0.175±0.015 candidate (due to proton-dissociation events)
  $\psi(2s)$: 0.11 ± 0.06 candidate

Purity of signal sample, Run I vs Run II

- Background level of Run II (with HeRSCheL) roughly halved compared to Run I (without HeRSCheL) analysis.

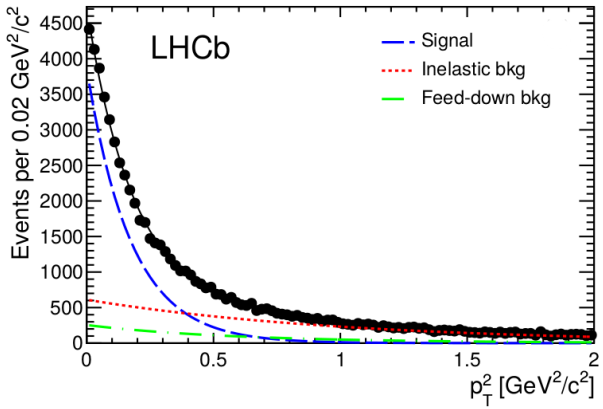
pp $\sqrt{s}$ = 13TeV [JHEP 10 (2018) 167]



(a)CEP signal for the J/ψ candidates

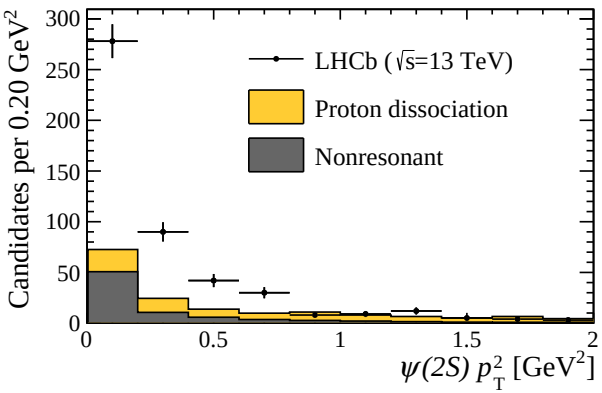
Signal purity 0.755 ± 0.015

pp $\sqrt{s}$ = 7TeV [J. PHYS. G41 (2014) 055002]



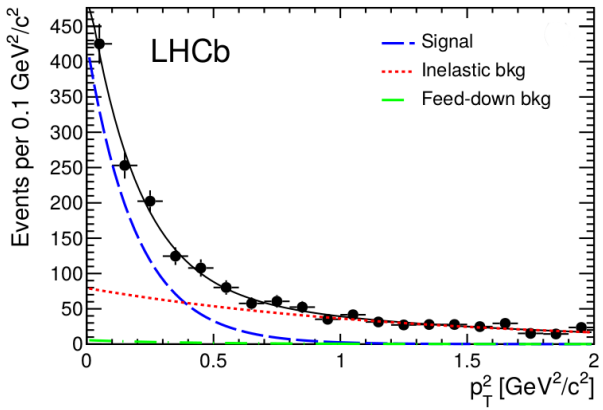
(b)CEP signal for the J/ψ candidates

Signal purity $0.592 \pm 0.012 \pm 0.030$



(c)CEP signal for the $\psi(2S)$ candidates

Signal purity 0.726 ± 0.061



(d)CEP signal for the $\psi(2S)$ candidates

Signal purity $0.52 \pm 0.07 \pm 0.03$

Differential Cross-section calculation

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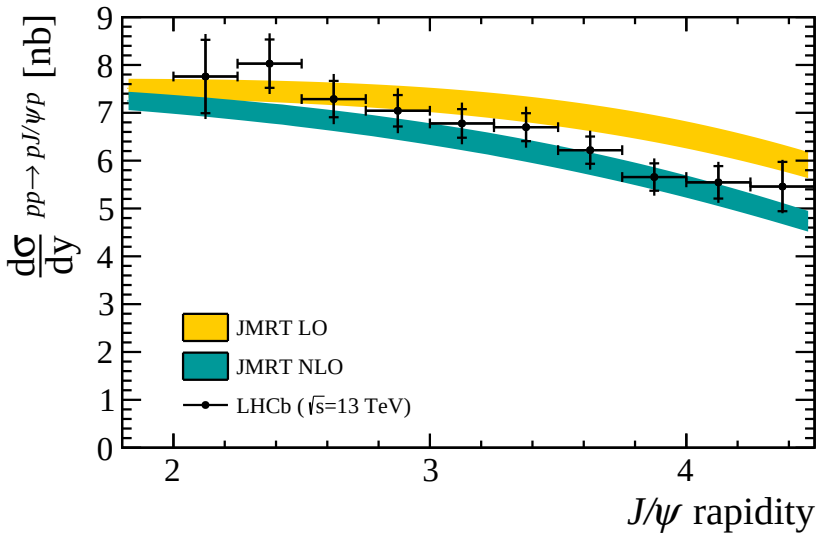
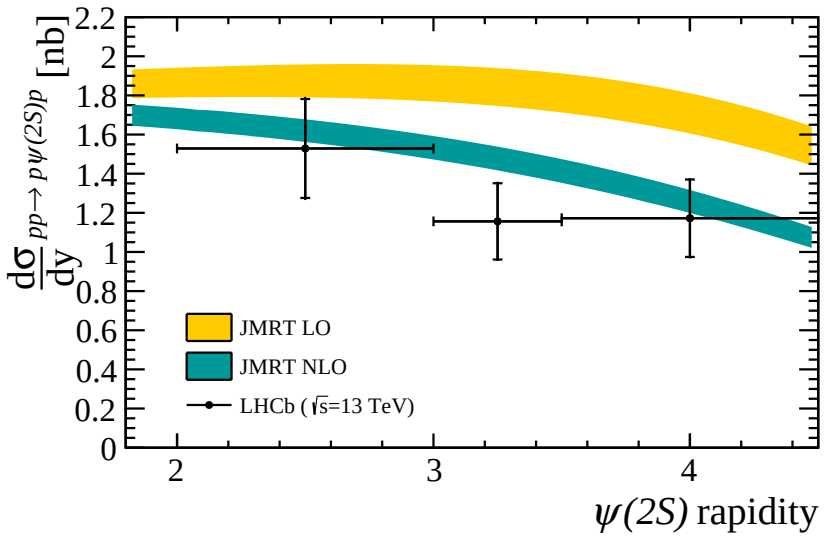


(a) Differential cross-sections compared to LO and NLO theory JMRT predictions for the J/ψ meson.



(b) Differential cross-sections compared to LO and NLO theory JMRT predictions for the $\psi(2S)$ meson.

1. The differential cross-section: $\frac{d\sigma_{\psi\to\mu^+\mu^-}}{dy}(2.0<\eta_\mu<4.5)=\frac{PN}{\epsilon_{rec}\epsilon_{sel}\Delta y\epsilon_{single}L_{tot}}$

   N : the number of selected events
   ϵ_{rec} and ϵ_{sel} : the efficiencies
   P : the purity
   Δy : the width of the rapidity bin
   L_{tot} : the integrated luminosity
   $\epsilon_{single}=e^{-\mu}=0.3329\pm0.0003$: the efficiency for selecting single interaction events.

2. Total cross-sections;

   $\sigma_{J/\psi\to\mu^+\mu^-}(2<\eta<4.5)=435\pm18(stat)\pm11(syst)\pm17(lumi)pb$
   $\sigma_{\psi(2S)\to\mu^+\mu^-}(2<\eta<4.5)=11.1\pm1.1(stat)\pm0.3(syst)\pm0.4(lumi)pb$

Systematic uncertainties

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Source	J/ψ analysis (%)	$\psi(2S)$ analysis (%)
HeRSCheL veto	1.7	1.7
2 VELO track	0.2	0.2
0 photon veto	0.2	0.2
Mass window	0.6	0.6
p_{T}^2 veto	0.3	0.3
Proton dissociation	0.7	0.7
Feed-down	0.7	-
Nonresonant	0.1	1.5
Tracking efficiency	0.7	0.7
Muon ID efficiency	0.4	0.4
Trigger efficiency	0.2	0.2
Total excluding luminosity	2.5	2.7
Luminosity	3.9	3.9

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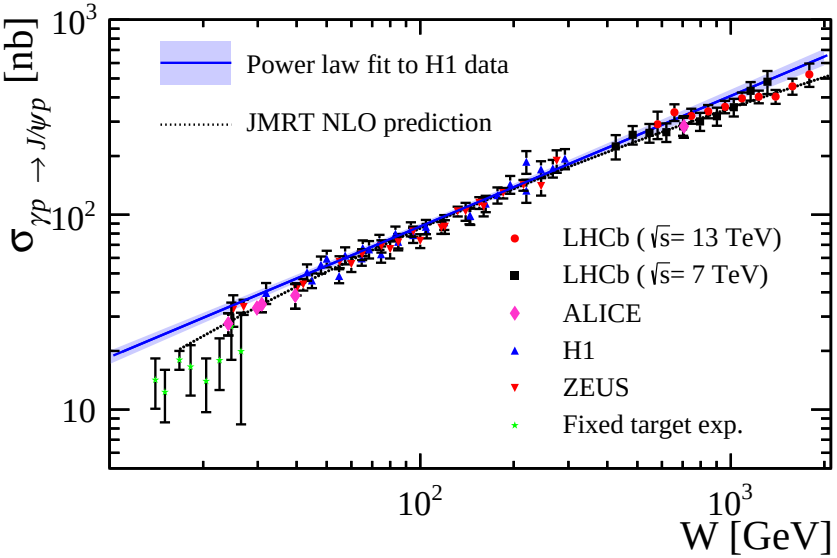
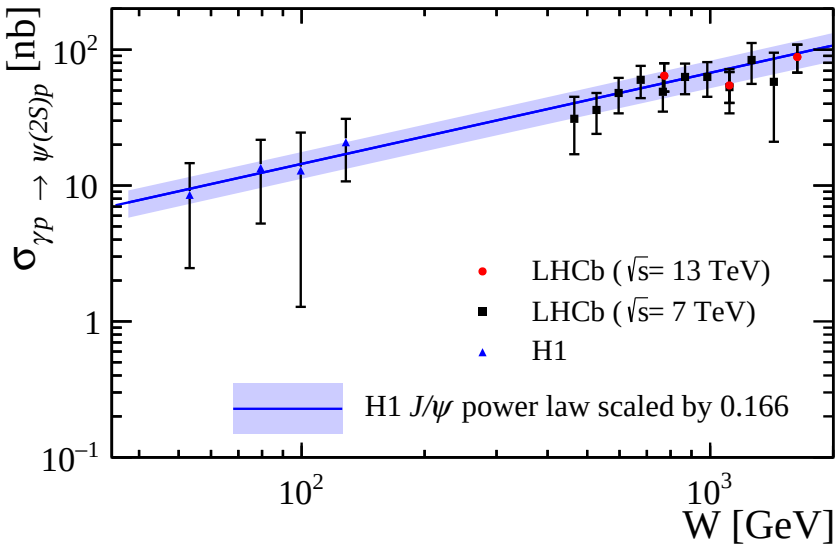
- Proton dissociation:
  Uncertainty due to imperfect modelling in the fit to $p_T^2(\mu^+\mu^-)$;
  determined using alternative models
- Tracking efficiency:
  Uncertainty due to variation of efficiencies determined from the calibration data sample

Differential cross-sections

[JHEP 10 (2018) 167]



(a) Compilation of photoproduction cross-sections for various experiments. The plot uses the J/ψ data.



(b) Compilation of photoproduction cross-sections for various experiments. The plot uses the $\psi(2S)$ data.

- The power-law fit to H1 data [Eur. Phys. J. C 73 (2013) 2466] and it can be seen that this is insufficient to describe the J/ψ data at the highest energies.
- The cross-section for the CEP of vector mesons in pp is related to the photoproduction cross-section, $\sigma_{\gamma p \to \psi p}$;

$$\sigma_{pp \to p\psi p} = r(W_+)k_+ \frac{dn}{dk_+}\sigma_{\gamma p \to \psi p}(W_+) + r(W_-)k_- \frac{dn}{dk_-}\sigma_{\gamma p \to \psi p}(W_-)$$

r : the gap survival factor
$k_\pm \equiv M_\psi / 2e^{\pm y}$: the photon energy
$dn/dk_\pm$: the photon flux
$W_\pm^2 = 2k_\pm\sqrt{s}$: the invariant mass of the photon-proton system

- Using the HERA and H1 parametrisation;

$$\sigma_{\gamma p \to J/\psi} = 81(W/90GeV)^{0.67}$$

Summary

- 1. Measurements of the central exclusive production of J/ψ and $\psi(2S)$ are presented.
  - Good performance of HeRSCheL $\rightarrow$ low background level
  - Important tests of QCD in the forward region.

- 2. Active program to study CEP in pp, pPb and PbPb

Backup

Differential cross-section calculation, Run I vs Run II

2. Total cross-sections;

Run II, pp $\sqrt{s} = 13$ TeV

$\sigma_{J/\psi \to \mu^+\mu^-}(2 < \eta < 4.5) = 435 \pm 18(stat) \pm 11(syst) \pm 17(lumi)pb$

$\sigma_{\psi(2S) \to \mu^+\mu^-}(2 < \eta < 4.5) = 11.1 \pm 1.1(stat) \pm 0.3(syst) \pm 0.4(lumi)pb$

Run I, pp $\sqrt{s} = 7$ TeV [J. PHYS. G41 (2014) 055002];

$\sigma_{J/\psi \to \mu^+\mu^-}(2 < \eta < 4.5) = 291 \pm 7(stat) \pm 19(syst)pb$

$\sigma_{\psi(2S) \to \mu^+\mu^-}(2 < \eta < 4.5) = 6.5 \pm 0.9(stat) \pm 0.4(syst)pb$