

Observation of $\Upsilon(1S) + Z$ Associated Production and Measurement of the Effective Double-Parton Scattering Cross Section in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

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The observation of the associated production of an $\Upsilon(1S)$ meson with a Z boson and a measurement of the ratio of its fiducial cross section to the fiducial cross section of the Z boson are presented. Both the $\Upsilon(1S)$ meson and the Z boson are identified via decays into a pair of opposite-sign muons. The analysis is based on proton-proton (pp) collision data at $\sqrt{s} = 13$ TeV collected with the CMS detector in 2016–2018 and corresponding to an integrated luminosity of 138 fb^{-1} . Using the production of the Z boson decaying into four muons as a normalization channel, the ratio of the fiducial cross sections $\sigma[pp \rightarrow Z + \Upsilon(1S)]\mathcal{B}(Z \rightarrow \mu^+\mu^-)\mathcal{B}[\Upsilon(1S) \rightarrow \mu^+\mu^-]$ to $\sigma(pp \rightarrow Z)\mathcal{B}(Z \rightarrow 4\mu)$ is measured to be $\mathcal{R}_{Z+\Upsilon(1S)} = [21.1 \pm 5.5(\text{stat}) \pm 0.6(\text{syst})] \times 10^{-3}$, where stat and syst denote the statistical and systematic uncertainties, respectively. The result is used to extract the effective double-parton scattering cross section $\sigma_{\text{eff}} = 13.0^{+7.7}_{-3.4} \text{ mb}$. In addition, for the first time, σ_{eff} is measured in bins of the transverse momentum of the $\Upsilon(1S)$ meson or of the Z boson.

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Despite extensive studies, the exact production mechanism of heavy quarkonia in hadron collisions has yet to be fully understood [1,2]. From a theoretical standpoint, quarkonium production is a two-step process. The first step involves the creation of a heavy quark-antiquark pair, while the second step involves its hadronization into a physical quarkonium state [3]. One can describe the first step using the methods of perturbative quantum chromodynamics, while the second step is inherently nonperturbative, and therefore, presents a much greater theoretical challenge. This is mainly because of difficulties in the calculation of long-distance matrix elements that express the hadronization probability of a heavy quark-antiquark pair into a quarkonium state [4].

The picture becomes even more complex for a quarkonium state produced in association with an electroweak boson, where none of the theoretical models can capture all aspects of the experimental results [5–11]. A major complication in the description of these processes stems from the interplay of two different production mechanisms. A quarkonium state in association with an electroweak boson can be produced either through the interaction of a single pair of partons, in a process known as single-parton scattering (SPS), or through the interactions of two pairs of

partons, known as double-parton scattering (DPS) [9,12–15]. The contribution of the DPS process can be quantified via a parameter known as the effective DPS cross section, σ_{eff} , which is closely related to the distribution of the partons within the nucleon in the plane transverse to the proton momentum [16].

So far, experimental measurements [6,17–28] and recent phenomenological studies [3,29–31] have provided only an integrated measurement of σ_{eff} over either a fiducial or the full phase space. The difference between the measurements of σ_{eff} for various processes is likely the result of the purely geometrical definition of σ_{eff} , which neglects parton correlations [32].

In this Letter, the associated production of an $\Upsilon(nS)$ meson ($n = 1, 2, 3$) with a Z boson is studied with a focus on the dominant $Z + \Upsilon(1S)$ production. By measuring the overall fiducial cross section for the $Z + \Upsilon(1S)$ process, as well as by splitting it into the SPS and DPS components, we obtain σ_{eff} both integrated over the analyzed phase space and in bins of $\Upsilon(1S)$ meson and Z boson transverse momenta (p_T). The measurement is based on proton-proton (pp) collision data at a center-of-mass energy of 13 TeV collected by the CMS experiment at the CERN LHC in 2016–2018 and corresponding to an integrated luminosity of 138 fb^{-1} [33–35]. Both the Z boson and the $\Upsilon(nS)$ meson are reconstructed using dimuon ($\mu^+\mu^-$) decays. In order to reduce the systematic uncertainties of the measurement, we normalize the signal cross section to that of Z boson production with a subsequent decay into a pair of dimuons (in what follows, denoted as 4μ) [36], which yields an identical final state with similar kinematical

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properties. The details of the CMS detector, the simulated signal and background samples, and the triggers used to collect the data are given in End Matter. Tabulated results are provided in the HEPData record for this analysis [37].

In the $Z + \Upsilon(nS)$ channel, the opposite-sign (OS) muon pairs forming the $\Upsilon(nS)$ meson and Z boson candidates are each fitted [38] to a common vertex, with the vertex probability required to exceed 5%. Each muon forming the $\Upsilon(nS)$ candidate must pass the *soft* identification requirement [39] (optimized for low- p_T muons typical of quarkonium decays) and have $p_T > 3$ GeV and pseudorapidity $|\eta| < 2.4$. The invariant mass of the $\Upsilon(nS)$ candidate is restricted to be within $8.5 < m_{\mu^+\mu^-} < 11$ GeV, and its rapidity is required to fall within $|y| < 2.4$. The two OS muons that form the Z candidate are required to pass the *tight* identification [39] (optimized for high- p_T muons), be within $|\eta| < 2.4$, and have $p_T > 30$ and > 15 GeV for the leading and subleading muon, respectively. To ensure that all muons originate from the same pp collision, the three-dimensional distance between the primary vertex and the muon track at its point of closest approach divided by its uncertainty, S_{IP} , is required to be less than 4 for each muon. The primary vertex corresponds to the hardest scattering in the event, evaluated using tracking information alone, as described in Section 9.4.1 of Ref. [40]. The invariant mass of the Z candidate must lie within 66–116 GeV, where a relatively wide window was used to better constrain the background. In case both possible OS muon pairings satisfy the above requirements, which happens in less than 1% of the events, we choose the pairing with the invariant mass of the Z candidate closest to the nominal Z boson mass [41].

All muons are required to be isolated from hadronic activity in the event. To satisfy this requirement, the scalar sum of transverse energy deposits in the calorimeters and the p_T of tracks is computed in a cone of radius $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ centered on the muon candidate, where $\Delta\phi$ is the difference in azimuthal angle. The p_T values of other muons from the Z or $\Upsilon(nS)$ candidates that fall within the isolation cone are subtracted from the isolation sum. The average hadronic activity in the event, which includes the effect of multiple interactions within the same or adjacent bunch crossings (pileup), is also subtracted from this sum [39]. The ratio of the corrected sum to the muon p_T , a quantity hereafter referred to as $\mathcal{I}$, is required to be smaller than 0.7 or 0.35 for muons forming the $\Upsilon(nS)$ or Z candidate, respectively. In addition, all four muons are required to originate from a common vertex with vertex fit probability $> 1\%$. This final requirement plays a crucial role in the signal channel, as it effectively suppresses events where the $\Upsilon(nS)$ meson and the Z boson originate from two independent pp interactions, which can occur in high-pileup conditions. Due to the relatively large $\Upsilon(nS)$ production cross section, the probability of such events is non-negligible; imposing a common vertex requirement reduces this background to a negligible level.

In the $Z \rightarrow 4\mu$ normalization channel, the selection is similar to that of Ref. [36]. We require events with at least four muons and examine all the electrically neutral combinations of 4μ that can be formed. The invariant mass of the 4μ , $m_{4\mu}$, must lie between 80 and 100 GeV. The leading (subleading) muon must have $p_T > 20$ (10) GeV, and the two trailing muons are required to have $p_T > 5$ GeV. All four muons must be within $|\eta| < 2.4$, pass the tight identification [39], and be separated from each other by $\Delta R > 0.02$. All four muons must have $\mathcal{I}$ less than 0.35 and $S_{IP} < 4$. All possible OS muon pairs in this channel must have an invariant mass $m_{\mu^+\mu^-} > 1$ GeV. The four muons are combined into two pairs of OS muons that maximize the mass difference between the pairs, with each pair required to have a vertex fit probability $> 5\%$. Unlike in the signal channel, we do not perform a common vertex fit for the four muons, as here the contribution from events with two muons stemming from one vertex and two muons stemming from another that has $m_{4\mu}$ in the 80–100 GeV window is negligible. While multiple four-muon candidates per event are allowed, all the selected events have only a single four-muon combination that satisfies the requirements.

In the signal channel, we implement an extended unbinned maximum likelihood fit in two dimensions to the Z and the $\Upsilon(nS)$ candidate invariant masses. We model the Z resonance mass shape with a Voigtian function, a convolution of Gaussian and Breit-Wigner distributions, assuming no Z/γ^* interference. The width of the Breit-Wigner function is fixed to the world-average value for the Z boson, 2.50 GeV [41], while that of the Gaussian function is fixed to a value determined from simulation because of the limited event count in the data. The mean of the Gaussian is also fixed to the world-average value of $m_Z = 91.188$ GeV [41]. As the natural widths of the $\Upsilon(nS)$ states are very small, we parametrize their mass shapes with Gaussian distributions with widths fixed to values determined from simulation studies. The combinatorial backgrounds for each mass combination are described by exponential functions with the parameters free in the fit. We create a two-dimensional (2D) template from these one-dimensional functions as a direct product of the functions that describe the mass spectra of the $\Upsilon(nS)$ and Z candidates. This fit includes eight yields: three $\Upsilon(nS)$ signal plus Z signal, three $\Upsilon(nS)$ signal plus Z background, one $\Upsilon(nS)$ background plus Z signal, and one $\Upsilon(nS)$ background plus Z background.

The projections of the 2D model onto the two variables of interest are shown in Fig. 1. The signal yields returned from the fit are 34.6 ± 9.0 for $Z + \Upsilon(1S)$, 2.9 ± 6.7 for $Z + \Upsilon(2S)$, and 13.9 ± 7.2 for $Z + \Upsilon(3S)$. These yields include both direct production and feed-down from heavier bottomonium states. The statistical significance of the $Z + \Upsilon(1S)$ signal is 5.3 standard deviations, as evaluated using Wilks's theorem [42] from the likelihood ratio of the

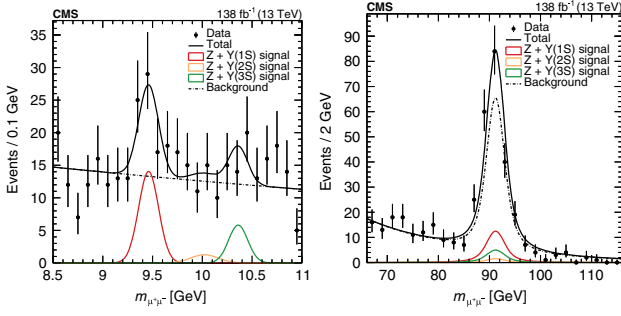


FIG. 1. Dimuon invariant mass distributions for the $\Upsilon(nS)$ (left) and Z (right) candidates. In each panel, the data are represented by points, with vertical bars indicating the statistical uncertainties. The solid black curve is the overall fit to the data. The red, yellow, and green curves correspond to the signal yields for the three $\Upsilon(nS)$ states, while the dash-dotted curve represents the background. The peaking background in the right plot originates from events in which the Z boson candidate is genuine, while the $\Upsilon(nS)$ meson candidate originates from the significant combinatorial background seen in the left plot.

default signal-plus-background fit and the background-only fit, by imposing $N[Z + \Upsilon(1S)] = 0$ while treating possible contributions from $Z + \Upsilon(2S)$ and $Z + \Upsilon(3S)$ as part of the background. To validate the fit, we performed 500 pseudoexperiments and checked that the distribution of the pulls is well described by a Gaussian function with a zero mean and a variance of unity. The significances of the $\Upsilon(2S)$ and $\Upsilon(3S)$ resonances are below 3 standard deviations. Consequently, in what follows, we focus on the $Z + \Upsilon(1S)$ case.

Using the results of this fit, the *sPlot* technique [43] is employed to assign weights to each event for each of the eight signal and background categories. Only the $Z + \Upsilon(1S)$ weights are considered signal and are used to obtain the background-subtracted $Z + \Upsilon(1S)$ signal distributions of the separations in rapidity (Δy) and azimuth between the Z and $\Upsilon(1S)$ candidates. It is confirmed that the variables used to extract the weights, namely, the dimuon masses associated with the Z boson and $\Upsilon(nS)$ candidates, and the Δy and $\Delta\phi$ variables to which the weights are applied, are independent. The SPS and DPS contributions are determined from an unbinned maximum likelihood fit to the 2D ($\Delta y, \Delta\phi$) distribution using 2D SPS and DPS templates obtained from simulation studies based on the kernel density estimation method [44]. The DPS template was additionally verified in the data using the event-mixing method. The result of the fit is the DPS fraction, which is found to be $f_{\text{DPS}} = 0.95 \pm 0.25$, where the uncertainty on the fraction is determined through a bootstrapping procedure. Applying the result for the DPS fraction f_{DPS} to the total yield $N_{Z+\Upsilon(1S)}^{\text{total}} = 34.6 \pm 9.0$, we find SPS and DPS yields of $N_{Z+\Upsilon(1S)}^{\text{SPS}} = 1.7 \pm 8.7$ and $N_{Z+\Upsilon(1S)}^{\text{DPS}} = 32.9 \pm 8.7$, respectively. The Δy and $\Delta\phi$ signal distributions and the fit projections are shown in Fig. 2.

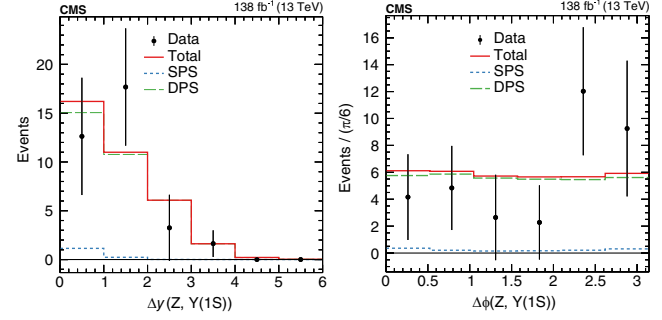


FIG. 2. Distributions of the Δy (left) and $\Delta\phi$ (right) separations between the $\Upsilon(1S)$ meson and the Z boson in data (black points with vertical bars indicating the statistical uncertainties) and the extracted DPS (green histogram), SPS (blue histogram), and SPS + DPS (red histogram) contributions from the template fit to the data. The distributions and corresponding uncertainties are obtained after the application of *sPlot* weights from an unbinned template fit to the Δy and $\Delta\phi$ variables.

In the normalization channel, we perform an extended unbinned maximum likelihood fit to the $m_{4\mu}$ distribution. The Z boson signal is modeled with a Voigtian function, with the width of the Breit-Wigner distribution fixed to the world-average value of the Z boson width and the Gaussian function parameters, including the mean, floating in the fit. The background is modeled via an exponential function with parameters floating in the fit. The resulting Z signal yield is 1860 ± 60 events. The $m_{4\mu}$ distribution and the fit projection are shown in Fig. 3.

We evaluate various systematic uncertainties that affect the results by changing the model and repeating the fits. The sources of systematic uncertainties considered include the signal and background shape parametrizations of the dimuon invariant mass spectra in the signal channel and the $m_{4\mu}$ spectrum in the normalization channel, limited event counts in simulated samples, uncertainties in world-average branching fractions, and uncertainty in the $\Upsilon(1S)$ production cross section calculation, which affects only the σ_{eff}

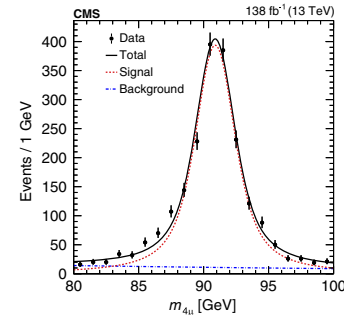


FIG. 3. The $m_{4\mu}$ distribution in the normalization channel with vertical bars on the data points indicating the statistical uncertainties. The result of the full fit is shown with the solid black line, while the signal and background components are shown with the dashed red and dash-dotted blue lines, respectively.

TABLE I. Summary of selection criteria applied to the signal $Z(\rightarrow \mu^+\mu^-) + \Upsilon(1S)(\rightarrow \mu^+\mu^-)$ and normalization $Z \rightarrow 4\mu$ channels. The “...” sign means that the selection is not applied.

Selection	$Z \rightarrow \mu^+\mu^- + \Upsilon(1S) \rightarrow \mu^+\mu^-$	$Z \rightarrow 4\mu$
All muons	$ \eta < 2.4, S_{\text{IP}} < 4$	$ \eta < 2.4, S_{\text{IP}} < 4$
Muon p_T [GeV]	$>30, 15, 3, 3$	$>20, 10, 5, 5$
Muon ID	Tight, tight, soft, soft	Tight for all muons
Isolation $\mathcal{I}$	$<0.35, 0.35, 0.7, 0.7$	<0.35 for all muons
Mass ranges [GeV]	$66 < m_{\mu^+\mu^-}^Z < 116, 8.5 < m_{\mu^+\mu^-}^{\Upsilon(1S)} < 11$	$80 < m_{4\mu} < 100$
Dimuon vertex fit probability	$>5\%$	$>5\%$
Four-muon vertex fit probability	$>1\%$	...

measurement. These uncertainties are detailed in End Matter. The results are dominated by the statistical uncertainty.

The ratio of fiducial cross sections $\mathcal{R}_{Z+\Upsilon(1S)} = \{\sigma[pp \rightarrow Z + \Upsilon(1S)]\mathcal{B}(Z \rightarrow \mu^+\mu^-)\mathcal{B}[\Upsilon(1S) \rightarrow \mu^+\mu^-] / \sigma(pp \rightarrow Z)\mathcal{B}(Z \rightarrow 4\mu)\}$, evaluated in the fiducial phase space defined by the p_T and η selections given in the first two rows of Table I, where $\sigma[pp \rightarrow Z + \Upsilon(1S)]$ is given by the sum of the two processes SPS and DPS and measured using the equation

$$\mathcal{R}_{Z+\Upsilon(1S)} = \left(\frac{N_{Z+\Upsilon(1S)}^{\text{SPS}}}{\epsilon_{Z+\Upsilon(1S)}^{\text{SPS}}} + \frac{N_{Z+\Upsilon(1S)}^{\text{DPS}}}{\epsilon_{Z+\Upsilon(1S)}^{\text{DPS}}} \right) \frac{\epsilon_Z}{N_Z}. \quad (1)$$

The efficiencies ϵ are calculated using simulated event samples as the ratio of the number of events passing all of the analysis requirements applied to the reconstructed quantities to the number of events passing the fiducial requirements applied to the generator-level quantities. They are $\epsilon_Z = 48.5\%$, $\epsilon_{Z+\Upsilon(1S)}^{\text{SPS}} = 50.1\%$, and $\epsilon_{Z+\Upsilon(1S)}^{\text{DPS}} = 42.4\%$. Theoretical uncertainties from the renormalization and factorization scales and from imprecise knowledge of the parton distribution functions largely cancel in the measured ratio. Using the results above, we get $\mathcal{R}_{Z+\Upsilon(1S)} = [21.1 \pm 5.5(\text{stat}) \pm 0.6(\text{syst})] \times 10^{-3}$. We further extract σ_{eff} using the equation

$$\sigma_{\text{eff}} = \frac{\sigma[\Upsilon(1S)] \mathcal{B}(Z \rightarrow \mu^+\mu^-) \mathcal{B}[\Upsilon(1S) \rightarrow \mu^+\mu^-]}{\mathcal{R}_{Z+\Upsilon(1S)}^{\text{DPS}} \mathcal{B}(Z \rightarrow 4\mu)} \times \frac{A_{Z+\Upsilon(1S)}}{A_Z}, \quad (2)$$

where $\mathcal{R}_{Z+\Upsilon(1S)}^{\text{DPS}} = [20.2 \pm 5.4(\text{stat}) \pm 0.6(\text{syst})] \times 10^{-3}$ is the DPS-only component of Eq. (1). The acceptances $A_{Z+\Upsilon(1S)}$ and A_Z are defined as the number of generated events passing the fiducial requirements applied to the generator-level quantities over the total number of generated events for each respective channel and are $(37.6 \pm 1.0)\%$ and $(26.3 \pm 0.8)\%$, respectively, where the uncertainties reflect the finite size of the simulated samples.

Details about the event generation are provided in End Matter. The $\Upsilon(1S)$ meson fiducial production cross section is calculated with HELAC-Onia to be 274 ± 5 nb [45–47]. The values of $\mathcal{B}(Z \rightarrow \mu^+\mu^-)$ and $\mathcal{B}[\Upsilon(1S) \rightarrow \mu^+\mu^-]$ are taken from Ref. [41], and $\mathcal{B}(Z \rightarrow 4\mu)$ is from Ref. [36]. The value of σ_{eff} is measured to be $13.0^{+7.7}_{-3.4}$ mb. The determination of the asymmetric uncertainties and comparison with several other σ_{eff} measurements are discussed in End Matter.

Extending the inclusive measurement, σ_{eff} is also measured in three bins each of the $\Upsilon(1S)$ meson and the Z boson p_T . Using the *sPlot* weights obtained from the fit, we extract the signal p_T distributions of the $\Upsilon(1S)$ meson and Z boson. The number of DPS events is obtained by subtracting the number of SPS events, which is estimated using the p_T distribution obtained from simulation scaled to match the total number of SPS events found in the data $N_{Z+\Upsilon(1S)}^{\text{SPS}} = 1.7 \pm 8.7$. Per-bin efficiencies are computed from simulation.

For the $\Upsilon(1S)$ p_T -binned measurement, the full $Z \rightarrow 4\mu$ sample is used for each bin, and the $\Upsilon(1S)$ meson production cross section in Eq. (2) is recalculated for each bin [45–47] (152 ± 4 , 77 ± 4 , and 45 ± 4 nb for the 0–5, 5–10, and 10–150 GeV bins, respectively). For the Z p_T -binned measurement, the $Z \rightarrow 4\mu$ sample is divided into the same p_T bins, with corresponding p_T -dependent efficiencies in Eq. (1), while the $\Upsilon(1S)$ meson production cross section in Eq. (2) is the same as for the inclusive measurement. The σ_{eff} measurements in bins of the $\Upsilon(1S)$ meson and Z boson p_T are shown in Fig. 4.

One might expect that, for the range of p_T probed, σ_{eff} would decrease as the $\Upsilon(1S)$ meson p_T increases and remain roughly independent of the Z boson p_T . The former is because the higher- p_T $\Upsilon(1S)$ mesons originate from gluons at higher Bjorken- x , which tend to be closer to the proton core, and, as a result, one observes a smaller σ_{eff} . In contrast, σ_{eff} as a function of the Z boson p_T could be expected to remain more or less constant, because in this case the scale is set by the mass of the Z boson, which is large in comparison to the changes in Bjorken- x of the quarks responsible for the Z boson production.

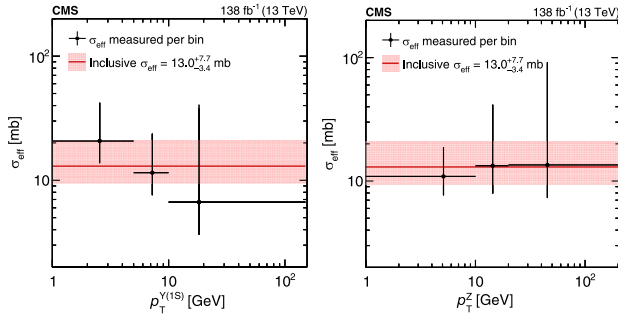


FIG. 4. Measurements of σ_{eff} in bins of the $\Upsilon(1S)$ meson (left) and Z boson (right) p_T . The data are represented by the points with the black vertical bars showing the total uncertainties, which are dominated by the statistical uncertainty. The horizontal bars represent the bin widths, and the x -axis position of each marker corresponds to the weighted average of the p_T distribution within the respective bin. The red line indicates the nominal value found for the inclusive σ_{eff} , and the pink shaded region shows its total uncertainties.

In summary, the first study of the associated production of an $\Upsilon(1S)$ meson and a Z boson in proton-proton collisions at $\sqrt{s} = 13$ TeV has been reported. Events with an Υ meson and a Z boson, each decaying into a pair of opposite-sign muons, have been reconstructed. After all selection requirements, 34.6 ± 9.0 events of $Z + \Upsilon(1S)$ production are observed. The statistical significance of the signal relative to the background-only expectation exceeds 5 standard deviations. The ratio of the fiducial cross section of $Z + \Upsilon(1S) \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ production to the fiducial cross section of $Z \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ production is measured to be $\mathcal{R}_{Z+\Upsilon(1S)} = [21.1 \pm 5.5(\text{stat}) \pm 0.6(\text{syst})] \times 10^{-3}$. The derived DPS cross section ratio, $\mathcal{R}_{Z+\Upsilon(1S)}^{\text{DPS}} = [20.2 \pm 5.4(\text{stat}) \pm 0.6(\text{syst})] \times 10^{-3}$, can be expressed in terms of the effective DPS cross section $\sigma_{\text{eff}} = 13.0^{+7.7}_{-3.4}$ mb, which is closely related to the transverse distribution of partons in the proton. Such a value is consistent with σ_{eff} values obtained from double-quarkonium measurements in pp and $p\bar{p}$ collisions [5–7,19,20,23,27]. For the first time, a binned measurement of the effective DPS cross section is performed in bins of $\Upsilon(1S)$ p_T or Z p_T . Such measurements provide extra information that can be used in studies of double-parton distribution functions [48].

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Data availability—Release and preservation of data used by the CMS Collaboration as the basis for publications is guided by the CMS data preservation, re-use, and open access policy [49].

- [1] A. Andronic *et al.*, Heavy-flavour and quarkonium production in the LHC era: From proton–proton to heavy-ion collisions, *Eur. Phys. J. C* **76**, 107 (2016).
- [2] N. Brambilla *et al.*, Heavy quarkonium: Progress, puzzles, and opportunities, *Eur. Phys. J. C* **71**, 1534 (2011).
- [3] J.-P. Lansberg, New observables in inclusive production of quarkonia, *Phys. Rep.* **889**, 1 (2020).
- [4] G. T. Bodwin, E. Braaten, and G. P. Lepage, Rigorous QCD analysis of inclusive annihilation and production of heavy quarkonium, *Phys. Rev. D* **51**, 1125 (1995); **55**, 5853(E) (1997).
- [5] ATLAS Collaboration, Measurement of J/ψ production in association with a $W^\pm$ boson with pp data at 8 TeV, *J. High Energy Phys.* **01** (2020) 095.
- [6] ATLAS Collaboration, Observation and measurements of the production of prompt and non-prompt J/ψ mesons in association with a Z boson in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, *Eur. Phys. J. C* **75**, 229 (2015).
- [7] ATLAS Collaboration, Measurement of the production cross section of prompt J/ψ mesons in association with a $W^\pm$ boson in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, *J. High Energy Phys.* **04** (2014) 172.
- [8] D. Acosta *et al.* (CDF Collaboration), Search for associated production of Υ and vector boson in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, *Phys. Rev. Lett.* **90**, 221803 (2003).
- [9] B. Gong, J.-P. Lansberg, C. Lorcé, and J. Wang, Next-to-leading-order QCD corrections to the yields and polar-

- isations of J/ψ and Υ directly produced in association with a Z boson at the LHC, *J. High Energy Phys.* **03** (2013) 115.
- [10] G. Li, M. Song, R.-Y. Zhang, and W.-G. Ma, QCD corrections to J/ψ production in association with a W-boson at the LHC, *Phys. Rev. D* **83**, 014001 (2011).
- [11] M. Song, W.-G. Ma, G. Li, R.-Y. Zhang, and L. Guo, QCD corrections to J/ψ plus Z^0 -boson production at the LHC, *J. High Energy Phys.* **02** (2011) 071; **12** (2012) 010(E).
- [12] M. Rinaldi and F. A. Ceccopieri, Double parton scattering and the proton transverse structure at the LHC, *J. High Energy Phys.* **09** (2019) 097.
- [13] M. Rinaldi and F. A. Ceccopieri, Hadronic structure from double parton scattering, *Phys. Rev. D* **97**, 071501 (2018).
- [14] J.-P. Lansberg and H.-S. Shao, Associated production of a quarkonium and a Z boson at one loop in a quark-hadron-duality approach, *J. High Energy Phys.* **10** (2016) 153.
- [15] M. Rinaldi, S. Scopetta, and V. Vento, Double parton correlations in constituent quark models, *Phys. Rev. D* **87**, 114021 (2013).
- [16] M. G. Ryskin and A. M. Snigirev, Fresh look at double parton scattering, *Phys. Rev. D* **83**, 114047 (2011).
- [17] CMS Collaboration, Observation of triple J/ψ meson production in proton-proton collisions, *Nat. Phys.* **19**, 338 (2023); **20**, 332(E) (2024).
- [18] CMS Collaboration, Observation of double J/ψ meson production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV, *Phys. Rev. D* **110**, 092002 (2024).
- [19] CMS Collaboration, Evidence for WW production from double-parton interactions in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **80**, 41 (2020).
- [20] LHCb Collaboration, Measurement of the J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **06** (2017) 047; **10** (2017) 068(E).
- [21] ATLAS Collaboration, Measurement of the prompt J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, *Eur. Phys. J. C* **77**, 76 (2017).
- [22] V. M. Abazov *et al.* (D0 Collaboration), Evidence for simultaneous production of J/ψ and Υ mesons, *Phys. Rev. Lett.* **116**, 082002 (2016).
- [23] V. M. Abazov *et al.* (D0 Collaboration), Observation and studies of double J/ψ production at the Tevatron, *Phys. Rev. D* **90**, 111101 (2014).
- [24] ATLAS Collaboration, Measurement of hard double-parton interactions in $W(\rightarrow l\nu) + 2$ jet events at $\sqrt{s} = 7$ TeV with the ATLAS detector, *New J. Phys.* **15**, 033038 (2013).
- [25] V. M. Abazov *et al.* (D0 Collaboration), Double parton interactions in $\gamma + 3$ jet events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, *Phys. Rev. D* **81**, 052012 (2010).
- [26] F. Abe *et al.* (CDF Collaboration), Double parton scattering in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, *Phys. Rev. D* **56**, 3811 (1997).
- [27] F. Abe *et al.* (CDF Collaboration), Study of four-jet events and evidence for double parton interactions in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, *Phys. Rev. D* **47**, 4857 (1993).
- [28] J. Alitti *et al.* (UA2 Collaboration), A study of multi-jet events at the CERN $p\bar{p}$ collider and a search for double parton scattering, *Phys. Lett. B* **268**, 145 (1991).
- [29] J.-P. Lansberg, H.-S. Shao, and N. Yamanaka, Indication for double parton scatterings in W^+ prompt J/ψ production at the LHC, *Phys. Lett. B* **781**, 485 (2018).
- [30] J.-P. Lansberg and H.-S. Shao, Phenomenological analysis of associated production of $Z^0 + b$ in the $b \rightarrow J/\psi X$ decay channel at the LHC, *Nucl. Phys. B* **916**, 132 (2017).
- [31] H.-S. Shao and Y.-J. Zhang, Complete study of hadroproduction of a Υ meson associated with a prompt J/ψ , *Phys. Rev. Lett.* **117**, 062001 (2016).
- [32] S. Bansal *et al.*, Progress in double parton scattering studies, in *Proceedings of 5th International Workshop on Multiple Partonic Interactions at the LHC* (2014).
- [33] CMS Collaboration, Precision luminosity measurement in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C* **81**, 800 (2021).
- [34] CMS Collaboration, CMS luminosity measurement for the 2017 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary, CERN CMS-PAS-LUM-17-004, 2018, <https://cds.cern.ch/record/2621960/>.
- [35] CMS Collaboration, CMS luminosity measurement for the 2018 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary, CERN CMS-PAS-LUM-18-002, 2019, <https://cds.cern.ch/record/2676164/>.
- [36] CMS Collaboration, Studies of $Z \rightarrow 4\ell$ decays in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV, [arXiv:2605.25158](https://arxiv.org/abs/2605.25158).
- [37] CMS Collaboration, Observation of $Y(1S) + Z$ associated production and measurement of the effective double-parton scattering cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV, HEPData record for this analysis (HEPData, Durham, UK, 2026), [10.17182/hepdata.159753](https://cds.cern.ch/record/2676164/).
- [38] K. Prokofiev and T. Speer, A kinematic and a decay chain reconstruction library, in *Proceedings of International Conference on Computing in High-Energy and Nuclear Physics (CHEP '04), Interlaken, Switzerland* (CERN, Geneva, Switzerland, 2004), [10.5170/CERN-2005-002.411](https://cds.cern.ch/record/2005-002.411).
- [39] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **13**, P06015 (2018).
- [40] CMS Collaboration, Technical proposal for the phase-II upgrade of the Compact Muon Solenoid, CMS, CERN Technical Proposals No. CERN-LHCC-2015-010, No. CMS-TDR-15-02, 2015, [10.17181/CERN.VU8I.D59J](https://cds.cern.ch/record/2015-010).
- [41] S. Navas *et al.* (Particle Data Group), Review of particle physics, *Phys. Rev. D* **110**, 030001 (2024).
- [42] S. S. Wilks, The large-sample distribution of the likelihood ratio for testing composite hypotheses, *Ann. Math. Stat.* **9**, 60 (1938).
- [43] M. Pivk and F. R. Le Diberder, sPlot: A statistical tool to unfold data distributions, *Nucl. Instrum. Methods Phys. Res., Sect. A* **555**, 356 (2005).
- [44] K. S. Cranmer, Kernel estimation in high-energy physics, *Comput. Phys. Commun.* **136**, 198 (2001).
- [45] J.-P. Lansberg and H.-S. Shao, Towards an automated tool to evaluate the impact of the nuclear modification of the gluon density on quarkonium, D and B meson production in proton-nucleus collisions, *Eur. Phys. J. C* **77**, 1 (2017).
- [46] H.-S. Shao, HELAC-Onia 2.0: An upgraded matrix-element and event generator for heavy quarkonium physics, *Comput. Phys. Commun.* **198**, 238 (2016).
- [47] H.-S. Shao, HELAC-Onia: An automatic matrix element generator for heavy quarkonium physics, *Comput. Phys. Commun.* **184**, 2562 (2013).

- [48] A. V. Manohar and W. J. Waalewijn, A QCD analysis of double parton scattering: Color correlations, interference effects and evolution, *Phys. Rev. D* **85**, 114009 (2012).
- [49] CMS Collaboration, 2020 CMS data preservation, re-use and open access policy, CERN Open Data Portal, CMS data availability statement, [10.7483/OPENDATA.CMS.1BNU.8V1W](https://opendata.cern.ch/record/10.7483/OPENDATA.CMS.1BNU.8V1W) (2020).
- [50] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [51] CMS Collaboration, Development of the CMS detector for the CERN LHC Run 3, *J. Instrum.* **19**, P05064 (2024).
- [52] CMS Collaboration, Performance of the CMS level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **15**, P10017 (2020).
- [53] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [54] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, *J. Instrum.* **16**, P05014 (2021).
- [55] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [56] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [57] CMS Collaboration, Performance of the CMS high-level trigger during LHC Run 2, *J. Instrum.* **19**, P11021 (2024).
- [58] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [59] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [60] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, *J. High Energy Phys.* **11** (2007) 070.
- [61] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, *J. High Energy Phys.* **06** (2010) 043.
- [62] T. Melia, P. Nason, R. Röntsch, and G. Zanderighi, W^+W^- , WZ and ZZ production in the POWHEG BOX, *J. High Energy Phys.* **11** (2011) 078.
- [63] P. Nason and G. Zanderighi, W^+W^- , WZ and ZZ production in the POWHEG-BOX-v2, *Eur. Phys. J. C* **74**, 2702 (2014).
- [64] CMS Collaboration, CMS PYTHIA 8 colour reconnection tunes based on underlying-event data, *Eur. Phys. J. C* **83**, 587 (2023).
- [65] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [66] S. Agostinelli *et al.* (GEANT4 Collaboration), Geant4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [67] CMS Collaboration, Measurement of the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ cross sections in pp collisions at $\sqrt{s} = 7$ TeV, *Phys. Lett. B* **727**, 101 (2013).
- [68] CMS Collaboration, Measurement of double-parton scattering in inclusive production of four jets with low transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **01** (2022) 177.

End Matter

Appendix—The CMS apparatus [50,51] is a multipurpose, nearly hermetic detector designed to trigger on [52,53] and identify electrons, muons, photons, and (charged and neutral) hadrons [39,54,55]. A global “particle-flow” algorithm [56] aims to reconstruct all the individual particles in an event by combining information provided by the all-silicon inner tracker and by the crystal electromagnetic and the brass and scintillator hadron calorimeters operating inside a 3.8 T superconducting solenoid with data from the gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. Muons are measured in a range $|\eta| < 2.4$, with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. The efficiency to reconstruct and identify muons is greater than 96%. Matching muons to tracks measured in the silicon tracker results in a relative p_T resolution, for muons with p_T up to 100 GeV, of 1% in the barrel and 3% in the endcaps.

Events of interest are selected using a two-tiered trigger system. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of 4 μ s [52]. The second level,

known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing and reduces the event rate to a few kHz before data storage [53,57]. The data were collected with a suite of double- and triple-muon triggers. Thresholds for the double-muon (triple-muon) triggers were 17 and 8 GeV (12, 10, and 5 GeV) for all three data-taking years. In 2017–2018, an additional triple-muon trigger with thresholds of 10, 5, and 5 GeV was also employed. The triggers are nearly 100% efficient for events passing the offline selection.

Simulated samples: For the signal process, two sets of Monte Carlo simulated event samples are produced: a DPS set, simulated at leading order (LO) using PYTHIA 8.240 [58], and an SPS set, created using the next-to-LO (NLO) HELAC-Onia 2.5.5 [46,47] parton-level event generator, interfaced with PYTHIA for the description of fragmentation and hadronization. Simulated DPS events contain $\Upsilon(1S)$ mesons produced promptly as well as events in which they come from “feed-down,” or the decays of more massive states, namely $\Upsilon(2S)$ and $\Upsilon(3S)$ mesons, as well as $\chi_{bJ}(1P)$ mesons, with total angular momenta $J = 0, 1$, and 2. The SPS event generation is made under the assumption that the $\Upsilon(1S)$ mesons produced in association

with a Z boson in the $pp \rightarrow \Upsilon(1S)Z$ process are dominantly produced from color singlet $b\bar{b}$ pairs, so that no color-octet terms are generated due to their expected smallness. Furthermore, only direct $\Upsilon(1S)$ meson production is considered, after having determined from simulation studies that accounting for feed-down decays of heavier bottomonium states leads to a negligible effect on the variables of interest, the rapidity difference Δy , and the azimuthal opening angle $\Delta\phi$ between the $\Upsilon(1S)$ meson's and the Z boson's momentum directions.

For the normalization channel, the matrix elements for the $Z \rightarrow 4\mu$ events are computed at NLO using POWHEG 2.0 [59–63], with the parton showering and hadronization described by PYTHIA.

For all samples, the CP5 underlying event tune [64] and the next-to-NLO NNPDF3.1 [65] parton distribution functions are used, while the detector response is simulated with the Geant4 [66] package. The effect of pileup is included by overlaying simulated minimum bias events on the hard-scattering process with the multiplicity profile matching that observed in the data.

Systematic uncertainties: The uncertainty from the limited number of data events is dominant for the measurements presented in this Letter. Nevertheless, we carefully evaluate various systematic uncertainties and summarize them in this section.

We examine the choice of the $\Upsilon(nS)$ signal model by changing the line shape description from a single Gaussian function for each of the three Υ states to a double Gaussian function. We observe a difference in the $Z + \Upsilon(1S)$ signal yield of 1.8%. We next explore the choice of the parametrization of the $\Upsilon(nS)$ background by replacing the default exponential function with a first-order polynomial function. The difference in the $Z + \Upsilon(1S)$ yield between the two methods is 0.3%.

We change the Z boson signal model from a Voigtian function to a sum of Voigtian and Gaussian functions, where the additional Gaussian function is meant to account for the fact that the detector resolution is not constant, but varies with the kinematics of the muons. In the signal channel, this results in a 1.1% change in the $Z + \Upsilon(1S)$ yield, while in the $Z \rightarrow 4\mu$ channel, the corresponding change in the event yield is 1.6%. Changing the Z candidate background model from an exponential function to a first-order polynomial function leads to a difference of 0.7% in the $Z + \Upsilon(1S)$ yield, while it results in a difference of 0.2% in the $Z \rightarrow 4\mu$ yield.

The overall effect of the limited event counts in simulated samples on the $\mathcal{R}_{Z+\Upsilon(1S)}$ calculation, where $\mathcal{R}_{Z+\Upsilon(1S)}$ is defined by Eq. (1), is 0.2%. The effect is also 0.2% on the inclusive σ_{eff} computation.

There are also uncertainties that arise from the limited knowledge of the various branching fractions used in the calculations. The uncertainties in the world-average $\Upsilon(1S) \rightarrow \mu^+\mu^-$ and $Z \rightarrow \mu^+\mu^-$ branching fractions are 1.6% and 0.2%, respectively [41]. The uncertainty in the $Z \rightarrow 4\mu$ branching fraction, per Ref. [36], which is a detailed CMS study of $Z \rightarrow 4\ell$ events, is 4.0%.

Uncertainties associated with the trigger, muon reconstruction and identification, and vertexing efficiency cancel in the ratio within the precision of the measurement.

The final source of systematic uncertainty relates to the $\Upsilon(1S)$ production cross section calculation. The $\Upsilon(1S)$ production cross section, 274 ± 5 nb [45–47], is taken from the HELAC-Onia event generator and is used in the inclusive σ_{eff} calculation. On top of this, we take the maximum difference between the theoretical fits to data at 7 TeV [45,46] and the CMS measurement of this cross section at the same energy [67] and assign this relative difference as an additional uncertainty in the $\Upsilon(1S)$ production cross section at 13 TeV. This uncertainty applies to both the inclusive and binned σ_{eff} results and is taken to be 1.9%.

The total systematic uncertainty for both the $\mathcal{R}_{Z+\Upsilon(1S)}$ and the σ_{eff} measurements is given by the sum in quadrature of the systematic uncertainties described in this section. The overall systematic uncertainty is 2.7% for the $\mathcal{R}_{Z+\Upsilon(1S)}$ result and 5.5% for the σ_{eff} result.

For the p_T -binned measurements, uncertainties pertaining to the line shapes chosen to describe the signal and background distributions are evaluated at the per-bin level; the alternative shapes chosen are the same as for the inclusive measurement. The uncertainties due to the finite sizes of the simulated samples are also calculated and applied bin by bin, while the uncertainties in the branching fractions used in the computations are common for all bins. Finally, in the case of the measurements binned in $\Upsilon(1S)$ p_T , uncertainties related to the use of the $\Upsilon(1S)$ cross sections are taken from HELAC-Onia at a per-bin level.

Summary of σ_{eff} measurements: The inclusive σ_{eff} result is compared with several previous σ_{eff} measurements in Fig. 5. We note that, while the ratios $\mathcal{R}$ have symmetric uncertainties because they depend linearly on the event yields in the signal channel, σ_{eff} values depend on the inverse of a typically small corresponding signal yield, leading to asymmetric uncertainties. To calculate the asymmetric uncertainties in the σ_{eff} measurements, we start from the values of the measurements' inverses, which have symmetric uncertainties. We next add or subtract each symmetric uncertainty from each central value, and then take the inverse of each of these results to get the lower and upper bounds, respectively, leading to asymmetric uncertainties.

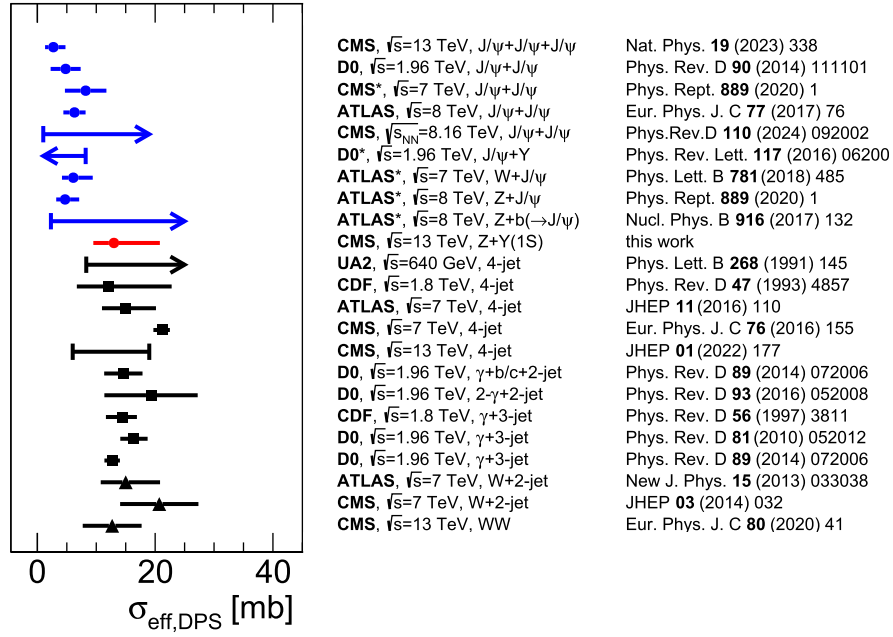


FIG. 5. A summary of σ_{eff} results measured using quarkonia (blue) and harder objects (black). The present result is shown in red. Arrows indicate that only the lower limits on σ_{eff} are available. The error bar without the central value corresponds to a range of σ_{eff} extractions using different MC models from a CMS 4-jet analysis [68]. For the results marked with an asterisk, more recent theoretical reinterpretations based on improved calculations of the corresponding SPS cross section are plotted.

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 N. De Filippis^{76a,76c} M. De Palma^{76a,76b} W. Elmetenawee^{76a,76b,tt} N. Ferrara^{76a,76c} L. Fiore^{76a} L. Longo^{76a}
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 D. Troiano^{76a,76b} R. Venditti^{76a,76b} P. Verwilligen^{76a} A. Zaza^{76a,76b} G. Abbiendi^{77a} C. Battilana^{77a,77b}
 D. Bonacorsi^{77a,77b} P. Capiluppi^{77a,77b} F. R. Cavallo^{77a} M. Cuffiani^{77a,77b} G. M. Dallavalle^{77a} T. Diotalevi^{77a,77b}
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 S. Costa^{78a,78b,vv} A. Di Mattia^{78a} A. Lapertosa^{78a} R. Potenza,^{78a,78b} A. Tricomi^{78a,78b,vv} J. Altork^{79a,79b}
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 E. Focardi^{79a,79b} T. Kello^{79a} G. Latino^{79a,79b} P. Lenzi^{79a,79b} M. Lizzo^{79a} M. Meschini^{79a} S. Paoletti^{79a}
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 M. Alves Gallo Pereira^{81a} F. Ferro^{81a} E. Robutti^{81a} S. Tosi^{81a,81b} A. Benaglia^{82a} F. Brivio^{82a}
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 S. Calzaferri^{85a} P. Montagna^{85a,85b} M. Pelliccioni^{85a} V. Re^{85a} C. Riccardi^{85a,85b} P. Salvini^{85a} I. Vai^{85a,85b}
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 L. Della Penna^{86a,86b} L. Fanò^{86a,86b} V. Mariani^{86a,86b} M. Menichelli^{86a} F. Moscatelli^{86a,aaa} A. Rossi^{86a,86b}
 A. Santocchia^{86a,86b} D. Spiga^{86a} T. Tedeschi^{86a,86b} C. Aimè^{87a,87b} C. A. Alexe^{87a,87c} P. Asenov^{87a,87b}
 P. Azzurri^{87a} G. Bagliesi^{87a} R. Bhattacharya^{87a} L. Bianchini^{87a,87b} T. Boccali^{87a} E. Bossini^{87a}
 D. Bruschini^{87a,87c} L. Calligaris^{87a,87b} R. Castaldi^{87a} F. Cattafesta^{87a,87c} M. A. Ciocci^{87a,87d} M. Cipriani^{87a,87b}
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 L. Martikainen^{88a,88b} J. Mijuskovic^{88a,88b} G. Organtini^{88a,88b} N. Palmeri^{88a,88b} R. Paramatti^{88a,88b}
 C. Quaranta^{88a,88b} S. Rahatlou^{88a,88b} C. Rovelli^{88a} F. Santanastasio^{88a,88b} L. Soffi^{88a} V. Vladimirov^{88a,88b}
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 L. Finco^{89a} M. Grippo^{89a,89b} B. Kiani^{89a,89b} L. Lanteri^{89a,89b} F. Legger^{89a} F. Luongo^{89a,89b} C. Mariotti^{89a}
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