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Supplemental material: “$\psi(2\mathrm{S})$ suppression in Pb–Pb collisions at the LHC”

ALICE Collaboration*

Abstract

The production of the $\psi(2S)$ charmonium state was measured with ALICE in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, in the dimuon decay channel. A significant signal was observed for the first time at LHC energies down to zero transverse momentum, at forward rapidity ($2.5 < y < 4$). The measurement of the ratio of the inclusive production cross sections of the $\psi(2S)$ and J/ψ resonances is reported as a function of the centrality of the collisions and of transverse momentum, in the region $p_{\mathrm{T}} < 12$ GeV/c. The results are compared with the corresponding measurements in pp collisions, by forming the double ratio $[\sigma^{\psi(2S)}/\sigma^{J/\psi}]_{\mathrm{Pb-Pb}}/[\sigma^{\psi(2S)}/\sigma^{J/\psi}]_{\mathrm{pp}}$. The $\psi(2S)$ nuclear modification factor R_{AA} was also obtained as a function of both centrality and p_{T}. The results show that the $\psi(2S)$ resonance yield is strongly suppressed in Pb–Pb collisions, by a factor up to ~ 3 with respect to pp. Furthermore, the $\psi(2S)$ suppression in Pb–Pb collisions is stronger than the one observed for the J/ψ by a factor ~ 2. Comparisons of cross section ratios with previous SPS findings by the NA50 experiment, and of R_{AA} with higher-p_{T} results at LHC energy are also reported. These results and the corresponding comparisons with calculations of transport and statistical models address questions on the presence and properties of charmonium states in the quark–gluon plasma formed in nuclear collisions at the LHC.

*See Appendix A for the list of collaboration members

1 Invariant-mass plots and fits

The dimuon invariant mass distributions, after mixed-event background subtraction, are reported in Fig. 1 and Fig. 2, together with the result of fits used to extract the number of J/ψ and $\psi(2S)$. Detailed information is hereafter given on the fit inputs, further details on the procedure are reported in the Letter.

For the fits as a function of centrality, 60 variations of the fit inputs were considered. They correspond to: (i) two different choices for the resonance shapes, either Crystal Ball (CB) function or a pseudo-Gaussian with a mass-dependent width [1]; (ii) five possible choices for the background shape, a variable-width Gaussian, an exponential or the sum of two exponential functions, a 1$^{\text{st}}$ or 2$^{\text{nd}}$ degree polynomial; (iii) two choices of the fitting range, either $2.2 < m_{\mu\mu} < 4.5$ GeV/c^2 or $2 < m_{\mu\mu} < 5$ GeV/c^2; (iv) two choices for the normalization range of the mixed-event background, either $2 < m_{\mu\mu} < 8$ GeV/c^2 or $2.5 < m_{\mu\mu} < 7$ GeV/c^2; (v) two choices for the tails of the CB function, either from Monte Carlo or from a high-statistics data sample collected in pp collisions at 13 TeV. The minimum significance of the ψ(2S) signal as a function of centrality is 7.6 (60–90%) and increases by a factor ~ 8 for central events. Numerical values on ψ(2S)-related quantities are given in Table 1.

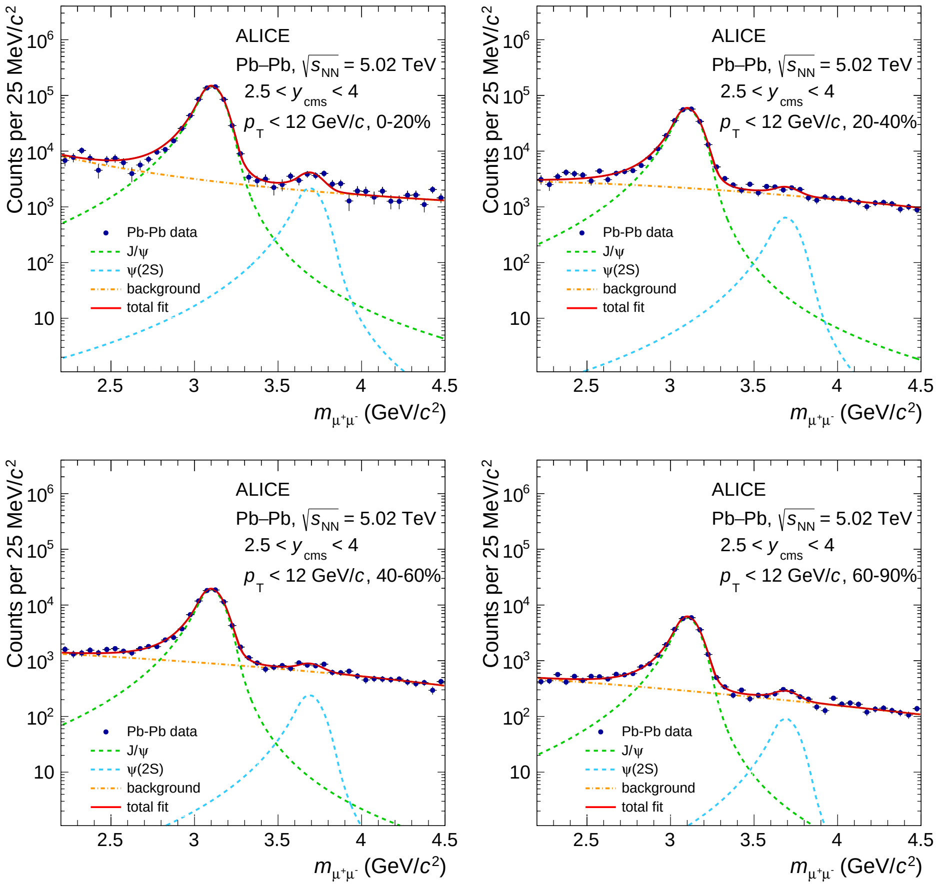

Figure 1: The opposite-sign invariant mass spectrum of mass pairs, for the four centrality intervals used in the data analysis, after mixed-event background subtraction. The kinematic domain is $2.5 < y < 4$, $p_{\rm T} < 12$ GeV/c ($0.3 < p_{\rm T} < 12$ GeV/c for the two most peripheral intervals). The result of one among the 60 χ^2 minimization fit is reported, corresponding to a CB function for the signal, a variable-width Gaussian for the background, $2 < m_{\mu\mu} < 5$ GeV/c^2 fitting range, a $2 < m_{\mu\mu} < 8$ GeV/c^2 normalization range of the mixed-event background, and CB tails obtained from Monte Carlo. The contribution of the J/ψ and $\psi(2S)$ resonances and of the background continuum as obtained from the fit are also reported.

For the fits as a function of transverse momentum, 36 variations of the fit inputs were considered, They correspond to: (i) two different choices for the resonance shapes, either Crystal Ball (CB) function or a pseudo-Gaussian with a mass-dependent width [1]; (ii) three possible choices for the background shape, a variable-width Gaussian, an exponential, a 2$^{\text{nd}}$ degree polynomial; (iii) two choices of the fitting range, either $2.2 < m_{\mu\mu} < 4.5$ GeV/c^2 or $2 < m_{\mu\mu} < 5$ GeV/c^2; (iv) two choices for the normalization range of the mixed-event background, either $2 < m_{\mu\mu} < 8$ GeV/c^2 or $2.5 < m_{\mu\mu} < 7$ GeV/c^2; (v) two choices for the tails of the CB function, either from Monte Carlo or from a high-statistics data sample collected in pp collisions at 13 TeV. The minimum significance of the $\psi(2\text{S})$ signal as a function of p_{T} is 11.3 at high p_{T}, with an increase of a factor ~ 3 at low p_{T}.

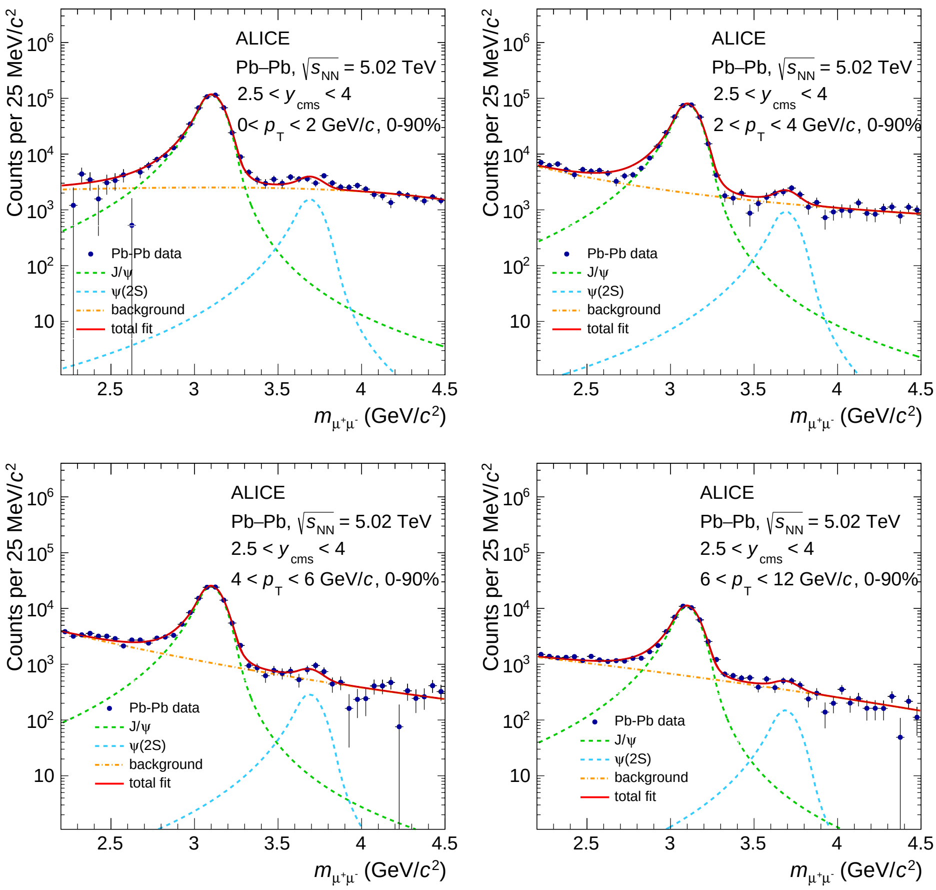

Figure 2: The opposite-sign invariant mass spectrum of mass pairs, for the four transverse momentum intervals used in the data analysis, after mixed-event background subtraction. The kinematic domain is $2.5 < y < 4$ and the centrality interval is 0–90%. The result of one among the 60 χ^2 minimization fit is reported, corresponding to a CB function for the signal, a variable-width Gaussian for the background, a $2 < m_{\mu\mu} < 5$ GeV/c^2 fitting range, $2 < m_{\mu\mu} < 8$ GeV/c^2 normalization range of the mixed-event background, and CB tails obtained from Monte Carlo. The contribution of the J/ψ and $\psi(2S)$ resonances and of the background continuum as obtained from the fit are also reported.

Table 1: With reference to Figs. 1 and 2, number of $\psi(2S)$ signal counts and background counts in a 3σ interval around the $\psi(2S)$ mass. The relative statistical uncertainty on the final number of $\psi(2S)$ is also listed.

Centrality	N_{sig}	N_{bck}	Stat. unc. (%)
0–20%	9675	14211	17.7
20–40%	2474	13917	22.9
40–60%	928	5530	23.2
60–90%	342	1645	21.6
p_T (GeV/c)			
0–2	4342	22223	22.4
2–4	3494	10791	17.9
4–6	1094	4541	30.4
6–12	567	2996	33.6

2 p_T dependence of the (double) ratios of the $\psi(2S)$ and J/ψ cross sections

In Fig. 3 the p_T-dependence of the ratio of the $\psi(2S)$ and J/ψ production cross sections for Pb–Pb collisions, in 0–90% centrality, is presented and compared to the corresponding pp results. The pp ratios increase as a function of p_T, while for Pb–Pb no significant rise is present. The double ratio values are also shown, indicating a significant relative suppression of the $\psi(2S)$, slightly increasing with p_T up to a value of ~ 0.5.

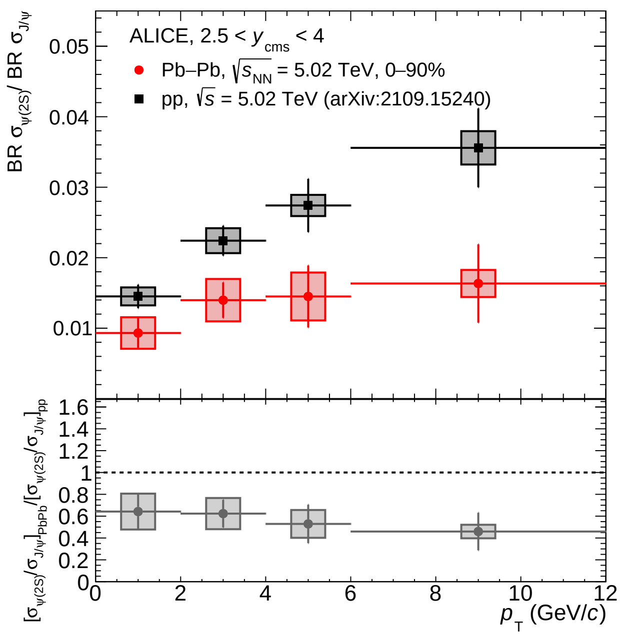

Figure 3: The ratio of the $\psi(2S)$ and J/ψ cross sections as a function of p_T, not corrected for the corresponding branching ratios BR of the dimuon decay, compared to measurements in pp collisions [2]. In the lower panel the double ratios of the Pb–Pb and pp values are shown.

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References

[1] **ALICE** Collaboration, J. Adam *et al.*, "Quarkonium signal extraction in ALICE", ALICE-PUBLIC-2015-006. `https://cds.cern.ch/record/2060096`.

[2] **ALICE** Collaboration, S. Acharya *et al.*, "Inclusive quarkonium production in pp collisions at $\sqrt{s} = 5.02$ TeV", `arXiv:2109.15240 [nucl-ex]`.

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S. Acharya [125], D. Adamová [86], A. Adler[69], G. Aglieri Rinella [32], M. Agnello [29], N. Agrawal [50], Z. Ahammed [132], S. Ahmad [15], S.U. Ahn [70], I. Ahuja [37], A. Akindinov [140], M. Al-Turany [97], D. Aleksandrov [140], B. Alessandro [55], H.M. Alfanda [6], R. Alfaro Molina [66], B. Ali [15], A. Alici [25], N. Alizadehvandchali [114], A. Alkin [32], J. Alme [20], G. Alocco [51], T. Alt [63], I. Altsybeev [140], M.N. Anaam [6], C. Andrei [45], A. Andronic [135], V. Anguelov [94], F. Antinori [53], P. Antonioli [50], N. Apadula [74], L. Aphecetche [103], H. Appelshäuser [63], C. Arata [73], S. Arcelli [25], M. Aresti [51], R. Arnaldi [55], I.C. Arsene [19], M. Arslandok [137], A. Augustinus [32], R. Averbeck [97], M.D. Azmi [15], A. Badalà [52], J. Bae [104], Y.W. Baek [40], X. Bai [118], R. Bailhache [63], Y. Bailung [47], A. Balbino [29], A. Baldisseri [128], B. Balis [2], D. Banerjee [4], Z. Banoo [91], R. Barbera [26], F. Barile [31], L. Barioglio [95], M. Barlou[78], G.G. Barnaföldi [136], L.S. Barnby [85], V. Barret [125], L. Barreto [110], C. Bartels [117], K. Barth [32], E. Bartsch [63], F. Baruffaldi [27], N. Bastid [125], S. Basu [75], G. Batigne [103], D. Battistini [95], B. Batyunya [141], D. Bauri[46], J.L. Bazo Alba [101], I.G. Bearden [83], C. Beattie [137], P. Becht [97], D. Behera [47], I. Belikov [127], A.D.C. Bell Hechavarria [135], F. Bellini [25], R. Bellwied [114], S. Belokurova [140], V. Belyaev [140], G. Bencedi [136], S. Beole [24], A. Bercuci [45], Y. Berdnikov [140], A. Berdnikova [94], L. Bergmann [94], M.G. Besoiu [62], L. Betev [32], P.P. Bhaduri [132], A. Bhasin [91], M.A. Bhat [4], B. Bhattacharjee [41], L. Bianchi [24], N. Bianchi [48], J. Bielčík [35], J. Bielčíková [86], J. Biernat [107], A.P. Bigot [127], A. Bilandzic [95], G. Biro [136], S. Biswas [4], N. Bize [103], J.T. Blair [108], D. Blau [140], M.B. Blidaru [97], N. Bluhme[38], C. Blume [63], G. Boca [21,54], F. Bock [87], T. Bodova [20], A. Bogdanov[140], S. Boi [22], J. Bok [57], L. Boldizsár [136], A. Bolozdynya [140], M. Bombara [37], P.M. Bond [32], G. Bonomi [131,54], H. Borel [128], A. Borissov [140], A.G. Borquez Carcamo [94], H. Bossi [137], E. Botta [24], Y.E.M. Bouziani [63], L. Bratrud [63], P. Braun-Munzinger [97], M. Bregant [110], M. Broz [35], G.E. Bruno [96,31], D. Budnikov [140], H. Buesching [63], S. Bufalino [29], O. Bugnon[103], P. Buhler [102], Z. Buthelezi [67,121], S.A. Bysiak[107], M. Cai [6], H. Caines [137], A. Caliva [97], E. Calvo Villar [101], J.M.M. Camacho [109], P. Camerini [23], F.D.M. Canedo [110], M. Carabas [124], A.A. Carballo [32], F. Carnesecchi [32], R. Caron [126], J. Castillo Castellanos [128], F. Catalano [24,29], C. Ceballos Sanchez [141], I. Chakaberia [74], P. Chakraborty [46], S. Chandra [132], S. Chapeland [32], M. Chartier [117], S. Chattopadhyay [132], S. Chattopadhyay [99], T.G. Chavez [44], T. Cheng [97,6], C. Cheshkov [126], B. Cheynis [126], V. Chibante Barroso [32], D.D. Chinellato [111], E.S. Chizzali [II,95], J. Cho [57], S. Cho [57], P. Chochula [32], P. Christakoglou [84], C.H. Christensen [83], P. Christiansen [75], T. Chujo [123], M. Ciacco [29], C. Cicalo [51], F. Cindolo [50], M.R. Ciupek[97], G. Clai[III,50], F. Colamaria [49], J.S. Colburn[100], D. Colella [96,31], M. Colocci [32], M. Concas [IV,55], G. Conesa Balbastre [73], Z. Conesa del Valle [72], G. Contin [23], J.G. Contreras [35], M.L. Coquet [128], T.M. Cormier[I,87], P. Cortese [130,55], M.R. Cosentino [112], F. Costa [32], S. Costanza [21,54], J. Crkovská [94], P. Crochet [125], R. Cruz-Torres [74], E. Cuautle[64], P. Cui [6], A. Dainese [53], M.C. Danisch [94], A. Danu [62], P. Das [80], P. Das [4], S. Das [4], A.R. Dash [135], S. Dash [46], A. De Caro [28], G. de Cataldo [49], J. de Cuveland[38], A. De Falco [22], D. De Gruttola [28], N. De Marco [55], C. De Martin [23], S. De Pasquale [28], S. Deb [47], R.J. Debski [2], K.R. Deja[133], R. Del Grande [95], L. Dello Stritto [28], W. Deng [6], P. Dhankher [18], D. Di Bari [31], A. Di Mauro [32], R.A. Diaz [141,7], T. Dietel [113], Y. Ding [126,6], R. Divià [32], D.U. Dixit [18], Ø. Djuvsland[20], U. Dmitrieva [140], A. Dobrin [62], B. Dönigus [63], J.M. Dubinski[133], A. Dubla [97], S. Dudi [90], P. Dupieux [125], M. Durkac[106], N. Dzalaiova[12], T.M. Eder [135], R.J. Ehlers [87], V.N. Eikeland[20], F. Eisenhut [63], D. Elia [49], B. Erazmus [103], F. Ercolessi [25], F. Erhardt [89], M.R. Ersdal[20], B. Espagnon [72], G. Eulisse [32], D. Evans [100], S. Evdokimov [140], L. Fabbietti [95], M. Faggin [27], J. Faivre [73], F. Fan [6], W. Fan [74], A. Fantoni [48], M. Fasel [87], P. Fecchio[29], A. Feliciello [55], G. Feofilov [140], A. Fernández Téllez [44], L. Ferrandi [110], M.B. Ferrer [32], A. Ferrero [128], C. Ferrero [55], A. Ferretti [24], V.J.G. Feuillard [94], V. Filova [35], D. Finogeev [140], F.M. Fionda [51], F. Flor [114], A.N. Flores [108], S. Foertsch [67], I. Fokin [94], S. Fokin [140], E. Fragiacomo [56], E. Frajna [136], U. Fuchs [32], N. Funicello [28], C. Furget [73], A. Furs [140], T. Fusayasu [98], J.J. Gaardhøje [83], M. Gagliardi [24], A.M. Gago [101], C.D. Galvan [109], D.R. Gangadharan [114], P. Ganoti [78], C. Garabatos [97], J.R.A. Garcia [44], E. Garcia-Solis [9], K. Garg [103], C. Gargiulo [32], A. Garibli[81], K. Garner[135], P. Gasik [97], A. Gautam [116], M.B. Gay Ducati [65], M. Germain [103], C. Ghosh[132], M. Giacalone [25], P. Giubellino [97,55], P. Giubilato [27], A.M.C. Glaenzer [128], P. Glässel [94], E. Glimos [120], D.J.Q. Goh[76], V. Gonzalez [134], L.H. González-Trueba [66], M. Gorgon [2], S. Gotovac[33], V. Grabski [66], L.K. Graczykowski [133], E. Grecka [86], A. Grelli [58], C. Grigoras [32], V. Grigoriev [140], S. Grigoryan [141,1], F. Grosa [32], J.F. Grosse-Oetringhaus [32], R. Grosso [97], D. Grund [35], G.G. Guardiano [111], R. Guernane [73], M. Guilbaud [103], K. Gulbrandsen [83], T. Gundem [63], T. Gunji [122], W. Guo [6], A. Gupta [91], R. Gupta [91], S.P. Guzman[44], L. Gyulai[136], M.K. Habib[97], C. Hadjidakis[72], F.U. Haider[91], H. Hamagaki[76], A. Hamdi[74], M. Hamid[6], Y. Han[138], R. Hannigan[108], M.R. Haque[133], J.W. Harris[137], A. Harton[9], H. Hassan[87], D. Hatzifotiadou[50], P. Hauer[42], L.B. Havener[137], S.T. Heckel[95], E. Hellbär[97], H. Helstrup[34], M. Hemmer[63], T. Herman[35], G. Herrera Corral[8], F. Herrmann[135], S. Herrmann[126], K.F. Hetland[34], B. Heybeck[63], H. Hillemanns[32], C. Hills[117], B. Hippolyte[127], B. Hofman[58], B. Hohlweger[84], G.H. Hong[138], M. Horst[95], A. Horzyk[2], R. Hosokawa[14], Y. Hou[6], P. Hristov[32], C. Hughes[120], P. Huhn[63], L.M. Huhta[115], C.V. Hulse[72], T.J. Humanic[88], A. Hutson[114], D. Hutter[38], J.P. Iddon[117], R. Ilkaev[140], H. Ilyas[13], M. Inaba[123], G.M. Innocenti[32], M. Ippolitov[140], A. Isakov[86], T. Isidori[116], M.S. Islam[99], M. Ivanov[12], M. Ivanov[97], V. Ivanov[140], M. Jablonski[2], B. Jacak[74], N. Jacazio[32], P.M. Jacobs[74], S. Jadlovska[106], J. Jadlovsky[106], S. Jaelani[82], L. Jaffe[38], C. Jahnke[111], M.J. Jakubowska[133], M.A. Janik[133], T. Janson[69], M. Jercic[89], S. Jia[10], A.A.P. Jimenez[64], F. Jonas[87], J.M. Jowett[32,97], J. Jung[63], M. Jung[63], A. Junique[32], A. Jusko[100], M.J. Kabus[32,133], J. Kaewjai[105], P. Kalinak[59], A.S. Kalteyer[97], A. Kalweit[32], V. Kaplin[140], A. Karasu Uysal[71], D. Karatovic[89], O. Karavichev[140], T. Karavicheva[140], P. Karczmarczyk[133], E. Karpechev[140], U. Kebschull[69], R. Keidel[139], D.L.D. Keijdener[58], M. Keil[32], B. Ketzer[42], A.M. Khan[6], S. Khan[15], A. Khanzadeev[140], Y. Kharlov[140], A. Khatun[116,15], A. Khuntia[107], M.B. Kidson[113], B. Kileng[34], B. Kim[16], C. Kim[16], D.J. Kim[115], E.J. Kim[68], J. Kim[138], J.S. Kim[40], J. Kim[94], J. Kim[68], M. Kim[18,94], S. Kim[17], T. Kim[138], K. Kimura[92], S. Kirsch[63], I. Kisel[38], S. 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