

# Measurement of the $e^+e^- \rightarrow K^+K^-\psi(2S)$ Cross Section at Center-of-Mass Energies from 4.699 to 4.951 GeV and Search for $Z_{cs}^\pm$ in the $Z_{cs}^\pm \rightarrow K^\pm\psi(2S)$ Decay

M. Ablikim<sup>1</sup>, M. N. Achasov<sup>4,c</sup>, P. Adlarson<sup>76</sup>, O. Afedulidis<sup>3</sup>, X. C. Ai<sup>81</sup>, R. Aliberti<sup>35</sup>, A. Amoroso<sup>75A,75C</sup>, Q. An<sup>72,58,a</sup>, Y. Bai<sup>57</sup>, O. Bakina<sup>36</sup>, I. Balossino<sup>29A</sup>, Y. Ban<sup>46,h</sup>, H.-R. Bao<sup>64</sup>, V. Batozskaya<sup>1,44</sup>, K. Begzsuren<sup>32</sup>, N. Berger<sup>35</sup>, M. Berlowski<sup>44</sup>, M. Bertani<sup>28A</sup>, D. Bettoni<sup>29A</sup>, F. Bianchi<sup>75A,75C</sup>, E. Bianco<sup>75A,75C</sup>, A. Bortone<sup>75A,75C</sup>, I. Boyko<sup>36</sup>, R. A. Briere<sup>5</sup>, A. Brueggemann<sup>69</sup>, H. Cai<sup>77</sup>, X. Cai<sup>1,58</sup>, A. Calcaterra<sup>28A</sup>, G. F. Cao<sup>1,64</sup>, N. Cao<sup>1,64</sup>, S. A. Cetin<sup>62A</sup>, X. Y. Chai<sup>46,h</sup>, J. F. Chang<sup>1,58</sup>, G. R. Che<sup>43</sup>, Y. Z. Che<sup>1,58,64</sup>, G. Chelkov<sup>36,b</sup>, C. Chen<sup>43</sup>, C. H. Chen<sup>9</sup>, Chao Chen<sup>55</sup>, G. Chen<sup>1</sup>, H. S. Chen<sup>1,64</sup>, H. Y. Chen<sup>20</sup>, M. L. Chen<sup>1,58,64</sup>, S. J. Chen<sup>42</sup>, S. L. Chen<sup>45</sup>, S. M. Chen<sup>61</sup>, T. Chen<sup>1,64</sup>, X. R. Chen<sup>31,64</sup>, X. T. Chen<sup>1,64</sup>, Y. B. Chen<sup>1,58</sup>, Y. Q. Chen<sup>34</sup>, Z. J. Chen<sup>25,i</sup>, Z. Y. Chen<sup>1,64</sup>, S. K. Choi<sup>10</sup>, G. Cibinetto<sup>29A</sup>, F. Cossio<sup>75C</sup>, J. J. Cui<sup>50</sup>, H. L. Dai<sup>1,58</sup>, J. P. Dai<sup>79</sup>, A. Dbeyssi<sup>18</sup>, R. E. de Boer<sup>3</sup>, D. Dedovich<sup>36</sup>, C. Q. Deng<sup>73</sup>, Z. Y. Deng<sup>1</sup>, A. Denig<sup>35</sup>, I. Denysenko<sup>36</sup>, M. Destefanis<sup>75A,75C</sup>, F. De Mori<sup>75A,75C</sup>, B. Ding<sup>67,1</sup>, X. X. Ding<sup>46,h</sup>, Y. Ding<sup>40</sup>, Y. Ding<sup>34</sup>, J. Dong<sup>1,58</sup>, L. Y. Dong<sup>1,64</sup>, M. Y. Dong<sup>1,58,64</sup>, X. Dong<sup>77</sup>, M. C. Du<sup>1</sup>, S. X. Du<sup>81</sup>, Y. Y. Duan<sup>55</sup>, Z. H. Duan<sup>42</sup>, P. Egorov<sup>36,b</sup>, Y. H. Fan<sup>45</sup>, J. Fang<sup>1,58</sup>, J. Fang<sup>59</sup>, S. S. Fang<sup>1,64</sup>, W. X. Fang<sup>1</sup>, Y. Fang<sup>1</sup>, Y. Q. Fang<sup>1,58</sup>, R. Farinelli<sup>29A</sup>, L. Fava<sup>75B,75C</sup>, F. Feldbauer<sup>3</sup>, G. Felici<sup>28A</sup>, C. Q. Feng<sup>72,58</sup>, J. H. Feng<sup>59</sup>, Y. T. Feng<sup>72,58</sup>, M. Fritsch<sup>3</sup>, C. D. Fu<sup>1</sup>, J. L. Fu<sup>64</sup>, Y. W. Fu<sup>1,64</sup>, H. Gao<sup>64</sup>, X. B. Gao<sup>41</sup>, Y. N. Gao<sup>46,h</sup>, Yang Gao<sup>72,58</sup>, S. Garbolino<sup>75C</sup>, I. Garzia<sup>29A,29B</sup>, L. Ge<sup>81</sup>, P. T. Ge<sup>19</sup>, Z. W. Ge<sup>42</sup>, C. Geng<sup>59</sup>, E. M. Gersabeck<sup>68</sup>, A. Gilman<sup>70</sup>, K. Goetzen<sup>13</sup>, L. Gong<sup>40</sup>, W. X. Gong<sup>1,58</sup>, W. Gradl<sup>35</sup>, S. Gramigna<sup>29A,29B</sup>, M. Greco<sup>75A,75C</sup>, M. H. Gu<sup>1,58</sup>, Y. T. Gu<sup>15</sup>, C. Y. Guan<sup>1,64</sup>, A. Q. Guo<sup>31,64</sup>, L. B. Guo<sup>41</sup>, M. J. Guo<sup>50</sup>, R. P. Guo<sup>49</sup>, Y. P. Guo<sup>12,g</sup>, A. Guskov<sup>36,b</sup>, J. Gutierrez<sup>27</sup>, K. L. Han<sup>64</sup>, T. T. Han<sup>1</sup>, F. Hanisch<sup>3</sup>, X. Q. Hao<sup>19</sup>, F. A. Harris<sup>66</sup>, K. K. He<sup>55</sup>, K. L. He<sup>1,64</sup>, F. H. Heinsius<sup>3</sup>, C. H. Heinz<sup>35</sup>, Y. K. Heng<sup>1,58,64</sup>, C. Herold<sup>60</sup>, T. Holtmann<sup>3</sup>, P. C. Hong<sup>34</sup>, G. Y. Hou<sup>1,64</sup>, X. T. Hou<sup>1,64</sup>, Y. R. Hou<sup>64</sup>, Z. L. Hou<sup>1</sup>, B. Y. Hu<sup>59</sup>, H. M. Hu<sup>1,64</sup>, J. F. Hu<sup>56,j</sup>, S. L. Hu<sup>12,g</sup>, T. Hu<sup>1,58,64</sup>, Y. Hu<sup>1</sup>, G. S. Huang<sup>72,58</sup>, K. X. Huang<sup>59</sup>, L. Q. Huang<sup>31,64</sup>, X. T. Huang<sup>50</sup>, Y. P. Huang<sup>1</sup>, Y. S. Huang<sup>59</sup>, T. Hussain<sup>74</sup>, F. Hölzken<sup>3</sup>, N. Hüskens<sup>35</sup>, N. in der Wiesche<sup>69</sup>, J. Jackson<sup>27</sup>, S. Janchiv<sup>32</sup>, J. H. Jeong<sup>10</sup>, Q. Ji<sup>1</sup>, Q. P. Ji<sup>19</sup>, W. Ji<sup>1,64</sup>, X. B. Ji<sup>1,64</sup>, X. L. Ji<sup>1,58</sup>, Y. Y. Ji<sup>50</sup>, X. Q. Jia<sup>50</sup>, Z. K. Jia<sup>72,58</sup>, D. Jiang<sup>1,64</sup>, H. B. Jiang<sup>77</sup>, P. C. Jiang<sup>46,h</sup>, S. S. Jiang<sup>39</sup>, T. J. Jiang<sup>16</sup>, X. S. Jiang<sup>1,58,64</sup>, Y. Jiang<sup>64</sup>, J. B. Jiao<sup>50</sup>, J. K. Jiao<sup>34</sup>, Z. Jiao<sup>23</sup>, S. Jin<sup>42</sup>, Y. Jin<sup>67</sup>, M. Q. Jing<sup>1,64</sup>, X. M. Jing<sup>64</sup>, T. Johansson<sup>76</sup>, S. Kabana<sup>33</sup>, N. Kalantar-Nayestanaki<sup>65</sup>, X. L. Kang<sup>9</sup>, X. S. Kang<sup>40</sup>, M. Kavatsyuk<sup>65</sup>, B. C. Ke<sup>81</sup>, V. Khachatryan<sup>27</sup>, A. Khoukaz<sup>69</sup>, R. Kiuchi<sup>1</sup>, O. B. Kolcu<sup>62A</sup>, B. Kopf<sup>3</sup>, M. Kuessner<sup>3</sup>, X. Kui<sup>1,64</sup>, N. Kumar<sup>26</sup>, A. Kupsc<sup>44,76</sup>, W. Kühn<sup>37</sup>, J. J. Lane<sup>68</sup>, L. Lavezzi<sup>75A,75C</sup>, T. T. Lei<sup>72,58</sup>, Z. H. Lei<sup>72,58</sup>, M. Lellmann<sup>35</sup>, T. Lenz<sup>35</sup>, C. Li<sup>43</sup>, C. Li<sup>47</sup>, C. H. Li<sup>39</sup>, Cheng Li<sup>72,58</sup>, D. M. Li<sup>81</sup>, F. Li<sup>1,58</sup>, G. Li<sup>1</sup>, H. B. Li<sup>1,64</sup>, H. J. Li<sup>19</sup>, H. N. Li<sup>56,j</sup>, Hui Li<sup>43</sup>, J. R. Li<sup>61</sup>, J. S. Li<sup>59</sup>, K. Li<sup>1</sup>, K. L. Li<sup>19</sup>, L. J. Li<sup>1,64</sup>, L. K. Li<sup>1</sup>, Lei Li<sup>48</sup>, M. H. Li<sup>43</sup>, P. R. Li<sup>38,k,l</sup>, Q. M. Li<sup>1,64</sup>, Q. X. Li<sup>50</sup>, R. Li<sup>17,31</sup>, S. X. Li<sup>12</sup>, T. Li<sup>50</sup>, W. D. Li<sup>1,64</sup>, W. G. Li<sup>1,a</sup>, X. Li<sup>1,64</sup>, X. H. Li<sup>72,58</sup>, X. L. Li<sup>50</sup>, X. Y. Li<sup>1,64</sup>, X. Z. Li<sup>59</sup>, Y. G. Li<sup>46,h</sup>, Z. J. Li<sup>59</sup>, Z. Y. Li<sup>79</sup>, C. Liang<sup>42</sup>, H. Liang<sup>1,64</sup>, H. Liang<sup>72,58</sup>, Y. F. Liang<sup>54</sup>, Y. T. Liang<sup>31,64</sup>, G. R. Liao<sup>14</sup>, Y. P. Liao<sup>1,64</sup>, J. Libby<sup>26</sup>, A. Limphirat<sup>60</sup>, C. C. Lin<sup>55</sup>, D. X. Lin<sup>31,64</sup>, T. Lin<sup>1</sup>, B. J. Liu<sup>1</sup>, B. X. Liu<sup>77</sup>, C. Liu<sup>34</sup>, C. X. Liu<sup>1</sup>, F. Liu<sup>1</sup>, F. H. Liu<sup>53</sup>, Feng Liu<sup>6</sup>, G. M. Liu<sup>56,j</sup>, H. Liu<sup>38,k,l</sup>, H. B. Liu<sup>15</sup>, H. H. Liu<sup>1</sup>, H. M. Liu<sup>1,64</sup>, Huihui Liu<sup>21</sup>, J. B. Liu<sup>72,58</sup>, J. Y. Liu<sup>1,64</sup>, K. Liu<sup>38,k,l</sup>, K. Y. Liu<sup>40</sup>, Ke Liu<sup>22</sup>, L. Liu<sup>72,58</sup>, L. C. Liu<sup>43</sup>, Lu Liu<sup>43</sup>, M. H. Liu<sup>12,g</sup>, P. L. Liu<sup>1</sup>, Q. Liu<sup>64</sup>, S. B. Liu<sup>72,58</sup>, T. Liu<sup>12,g</sup>, W. K. Liu<sup>43</sup>, W. M. Liu<sup>72,58</sup>, X. Liu<sup>38,k,l</sup>, X. Liu<sup>39</sup>, Y. Liu<sup>81</sup>, Y. Liu<sup>38,k,l</sup>, Y. B. Liu<sup>43</sup>, Z. A. Liu<sup>1,58,64</sup>, Z. D. Liu<sup>9</sup>, Z. Q. Liu<sup>50</sup>, X. C. Lou<sup>1,58,64</sup>, F. X. Lu<sup>59</sup>, H. J. Lu<sup>23</sup>, J. G. Lu<sup>1,58</sup>, X. L. Lu<sup>1</sup>, Y. Lu<sup>7</sup>, Y. P. Lu<sup>1,58</sup>, Z. H. Lu<sup>1,64</sup>, C. L. Luo<sup>41</sup>, J. R. Luo<sup>59</sup>, M. X. Luo<sup>80</sup>, T. Luo<sup>12,g</sup>, X. L. Luo<sup>1,58</sup>, X. R. Luo<sup>64</sup>, Y. F. Lyu<sup>43</sup>, F. C. Ma<sup>40</sup>, H. Ma<sup>79</sup>, H. L. Ma<sup>1</sup>, J. L. Ma<sup>1,64</sup>, L. L. Ma<sup>50</sup>, L. R. Ma<sup>67</sup>, M. M. Ma<sup>1,64</sup>, Q. M. Ma<sup>1</sup>, R. Q. Ma<sup>1,64</sup>, T. Ma<sup>72,58</sup>, X. T. Ma<sup>1,64</sup>, X. Y. Ma<sup>1,58</sup>, Y. M. Ma<sup>31</sup>, F. E. Maas<sup>18</sup>, I. MacKay<sup>70</sup>, M. Maggiora<sup>75A,75C</sup>, S. Malde<sup>70</sup>, Y. J. Mao<sup>46,h</sup>, Z. P. Mao<sup>1</sup>, S. Marcello<sup>75A,75C</sup>, Z. X. Meng<sup>67</sup>, J. G. Messchendorp<sup>13,65</sup>, G. Mezzadri<sup>29A</sup>, H. Miao<sup>1,64</sup>, T. J. Min<sup>42</sup>, R. E. Mitchell<sup>27</sup>, X. H. Mo<sup>1,58,64</sup>, B. Moses<sup>27</sup>, N. Yu. Muchnoi<sup>4,c</sup>, J. Muskalla<sup>35</sup>, Y. Nefedov<sup>36</sup>, F. Nerling<sup>18,e</sup>, L. S. Nie<sup>20</sup>, I. B. Nikolaev<sup>4,c</sup>, Z. Ning<sup>1,58</sup>, S. Nisar<sup>11,m</sup>, Q. L. Niu<sup>38,k,l</sup>, W. D. Niu<sup>55</sup>, Y. Niu<sup>50</sup>, S. L. Olsen<sup>64</sup>, S. L. Olsen<sup>10,64</sup>, Q. Ouyang<sup>1,58,64</sup>, S. Pacetti<sup>28B,28C</sup>, X. Pan<sup>55</sup>, Y. Pan<sup>57</sup>, A. Pathak<sup>34</sup>, Y. P. Pei<sup>72,58</sup>, M. Pelizaeus<sup>3</sup>, H. P. Peng<sup>72,58</sup>, Y. Y. Peng<sup>38,k,l</sup>, K. Peters<sup>13,e</sup>, J. L. Ping<sup>41</sup>, R. G. Ping<sup>1,64</sup>, S. Plura<sup>35</sup>, V. Prasad<sup>33</sup>, F. Z. Qi<sup>1</sup>, H. Qi<sup>72,58</sup>, H. R. Qi<sup>61</sup>, M. Qi<sup>42</sup>, T. Y. Qi<sup>12,g</sup>, S. Qian<sup>1,58</sup>, W. B. Qian<sup>64</sup>, C. F. Qiao<sup>64</sup>, X. K. Qiao<sup>81</sup>, J. J. Qin<sup>73</sup>, L. Q. Qin<sup>14</sup>, L. Y. Qin<sup>72,58</sup>, X. P. Qin<sup>12,g</sup>, X. S. Qin<sup>50</sup>, Z. H. Qin<sup>1,58</sup>, J. F. Qiu<sup>1</sup>, Z. H. Qu<sup>73</sup>, C. F. Redmer<sup>35</sup>, K. J. Ren<sup>39</sup>, A. Rivetti<sup>75C</sup>, M. Rolo<sup>75C</sup>, G. Rong<sup>1,64</sup>, Ch. Rosner<sup>18</sup>, M. Q. Ruan<sup>1,58</sup>, S. N. Ruan<sup>43</sup>, N. Salone<sup>44</sup>, A. Sarantsev<sup>36,d</sup>, Y. Schelhaas<sup>35</sup>, K. Schoenning<sup>76</sup>, M. Scodeggio<sup>29A</sup>, K. Y. Shan<sup>12,g</sup>, W. Shan<sup>24</sup>, X. Y. Shan<sup>72,58</sup>, Z. J. Shang<sup>38,k,l</sup>, J. F. Shangguan<sup>16</sup>, L. G. Shao<sup>1,64</sup>, M. Shao<sup>72,58</sup>, C. P. Shen<sup>12,g</sup>, H. F. Shen<sup>1,8</sup>, W. H. Shen<sup>64</sup>, X. Y. Shen<sup>1,64</sup>, B. A. Shi<sup>64</sup>, H. Shi<sup>72,58</sup>, H. C. Shi<sup>72,58</sup>, J. L. Shi<sup>12,g</sup>, J. Y. Shi<sup>1</sup>, Q. Q. Shi<sup>55</sup>, S. Y. Shi<sup>73</sup>, X. Shi<sup>1,58</sup>, J. J. Song<sup>19</sup>, T. Z. Song<sup>59</sup>, W. M. Song<sup>34,1</sup>, Y. J. Song<sup>12,g</sup>, Y. X. Song<sup>46,h,n</sup>, S. Sosio<sup>75A,75C</sup>, S. Spataro<sup>75A,75C</sup>, F. Stieler<sup>35</sup>, S. S. Su<sup>40</sup>, Y. J. Su<sup>64</sup>, G. B. Sun<sup>77</sup>, G. X. Sun<sup>1</sup>, H. Sun<sup>64</sup>, H. K. Sun<sup>1</sup>, J. F. Sun<sup>19</sup>, K. Sun<sup>61</sup>, L. Sun<sup>77</sup>, S. S. Sun<sup>1,64</sup>, T. Sun<sup>51,f</sup>, W. Y. Sun<sup>34</sup>, Y. Sun<sup>9</sup>, Y. J. Sun<sup>72,58</sup>, Y. Z. Sun<sup>1</sup>, Z. Q. Sun<sup>1,64</sup>, Z. T. Sun<sup>50</sup>, C. J. Tang<sup>54</sup>, G. Y. Tang<sup>1</sup>, J. Tang<sup>59</sup>, M. Tang<sup>72,58</sup>, Y. A. Tang<sup>77</sup>, L. Y. Tao<sup>73</sup>, Q. T. Tao<sup>25,i</sup>, M. Tat<sup>70</sup>, J. X. Teng<sup>72,58</sup>, V. Thoren<sup>76</sup>, W. H. Tian<sup>59</sup>, Y. Tian<sup>31,64</sup>, Z. F. Tian<sup>77</sup>, I. Uman<sup>62B</sup>, Y. Wan<sup>55</sup>, S. J. Wang<sup>50</sup>, B. Wang<sup>1</sup>, B. L. Wang<sup>64</sup>, Bo Wang<sup>72,58</sup>, D. Y. Wang<sup>46,h</sup>, F. Wang<sup>73</sup>, H. J. Wang<sup>38,k,l</sup>, J. J. Wang<sup>77</sup>, J. P. Wang<sup>50</sup>, K. Wang<sup>1,58</sup>, L. L. Wang<sup>1</sup>, M. Wang<sup>50</sup>, N. Y. Wang<sup>64</sup>, S. Wang<sup>38,k,l</sup>, S. Wang<sup>12,g</sup>, T. Wang<sup>12,g</sup>, T. J. Wang<sup>43</sup>, W. Wang<sup>73</sup>, W. Wang<sup>59</sup>, W. P. Wang<sup>35,58,72,o</sup>, X. Wang<sup>46,h</sup>, X. F. Wang<sup>38,k,l</sup>, X. J. Wang<sup>39</sup>, X. L. Wang<sup>12,g</sup>, X. N. Wang<sup>1</sup>, Y. Wang<sup>61</sup>, Y. D. Wang<sup>45</sup>, Y. F. Wang<sup>1,58,64</sup>, Y. L. Wang<sup>19</sup>, Y. N. Wang<sup>45</sup>, Y. Q. Wang<sup>1</sup>, Yaqian Wang<sup>17</sup>, Yi Wang<sup>61</sup>, Z. Wang<sup>1,58</sup>, Z. L. Wang<sup>73</sup>, Z. Y. Wang<sup>1,64</sup>, Ziyi Wang<sup>64</sup>, D. H. Wei<sup>14</sup>, F. Weidner<sup>69</sup>, S. P. Wen<sup>1</sup>, Y. R. Wen<sup>39</sup>, U. Wiedner<sup>3</sup>, G. Wilkinson<sup>70</sup>, M. Wolke<sup>76</sup>, L. Wollenberg<sup>3</sup>, C. Wu<sup>39</sup>, J. F. Wu<sup>1,8</sup>, L. H. Wu<sup>1</sup>, L. J. Wu<sup>1,64</sup>, X. Wu<sup>12,g</sup>, X. H. Wu<sup>34</sup>, Y. Wu<sup>72,58</sup>, Y. H. Wu<sup>55</sup>,

Y. J. Wu<sup>31</sup>, Z. Wu<sup>1,58</sup>, L. Xia<sup>72,58</sup>, X. M. Xian<sup>39</sup>, B. H. Xiang<sup>1,64</sup>, T. Xiang<sup>46,h</sup>, D. Xiao<sup>38,k,l</sup>, G. Y. Xiao<sup>42</sup>, S. Y. Xiao<sup>1</sup>, Y. L. Xiao<sup>12,g</sup>, Z. J. Xiao<sup>41</sup>, C. Xie<sup>42</sup>, X. H. Xie<sup>46,h</sup>, Y. Xie<sup>50</sup>, Y. G. Xie<sup>1,58</sup>, Y. H. Xie<sup>6</sup>, Z. P. Xie<sup>72,58</sup>, T. Y. Xing<sup>1,64</sup>, C. F. Xu<sup>1,64</sup>, C. J. Xu<sup>59</sup>, G. F. Xu<sup>1</sup>, H. Y. Xu<sup>67,2,p</sup>, M. Xu<sup>72,58</sup>, Q. J. Xu<sup>16</sup>, Q. N. Xu<sup>30</sup>, W. Xu<sup>1</sup>, W. L. Xu<sup>67</sup>, X. P. Xu<sup>55</sup>, Y. Xu<sup>40</sup>, Y. C. Xu<sup>78</sup>, Z. S. Xu<sup>64</sup>, F. Yan<sup>12,g</sup>, L. Yan<sup>12,g</sup>, W. B. Yan<sup>72,58</sup>, W. C. Yan<sup>81</sup>, X. Q. Yan<sup>1,64</sup>, H. J. Yang<sup>51,f</sup>, H. L. Yang<sup>34</sup>, H. X. Yang<sup>1</sup>, T. Yang<sup>1</sup>, Y. Yang<sup>12,g</sup>, Y. F. Yang<sup>1,64</sup>, Y. F. Yang<sup>43</sup>, Y. X. Yang<sup>1,64</sup>, Z. W. Yang<sup>38,k,l</sup>, Z. P. Yao<sup>50</sup>, M. Ye<sup>1,58</sup>, M. H. Ye<sup>8</sup>, J. H. Yin<sup>1</sup>, Junhao Yin<sup>43</sup>, Z. Y. You<sup>59</sup>, B. X. Yu<sup>1,58,64</sup>, C. X. Yu<sup>43</sup>, G. Yu<sup>1,64</sup>, J. S. Yu<sup>25,i</sup>, M. C. Yu<sup>40</sup>, T. Yu<sup>73</sup>, X. D. Yu<sup>46,h</sup>, Y. C. Yu<sup>81</sup>, C. Z. Yuan<sup>1,64</sup>, J. Yuan<sup>34</sup>, J. Yuan<sup>45</sup>, L. Yuan<sup>2</sup>, S. C. Yuan<sup>1,64</sup>, Y. Yuan<sup>1,64</sup>, Z. Y. Yuan<sup>59</sup>, C. X. Yue<sup>39</sup>, A. A. Zafar<sup>74</sup>, F. R. Zeng<sup>50</sup>, S. H. Zeng<sup>63A,63B,63C,63D</sup>, X. Zeng<sup>12,g</sup>, Y. Zeng<sup>25,i</sup>, Y. J. Zeng<sup>59</sup>, Y. J. Zeng<sup>1,64</sup>, X. Y. Zhai<sup>34</sup>, Y. C. Zhai<sup>50</sup>, Y. H. Zhan<sup>59</sup>, A. Q. Zhang<sup>1,64</sup>, B. L. Zhang<sup>1,64</sup>, B. X. Zhang<sup>1</sup>, D. H. Zhang<sup>43</sup>, G. Y. Zhang<sup>19</sup>, H. Zhang<sup>81</sup>, H. Zhang<sup>72,58</sup>, H. C. Zhang<sup>1,58,64</sup>, H. H. Zhang<sup>34</sup>, H. H. Zhang<sup>59</sup>, H. Q. Zhang<sup>1,58,64</sup>, H. R. Zhang<sup>72,58</sup>, H. Y. Zhang<sup>1,58</sup>, J. Zhang<sup>59</sup>, J. Zhang<sup>81</sup>, J. J. Zhang<sup>52</sup>, J. L. Zhang<sup>20</sup>, J. Q. Zhang<sup>41</sup>, J. S. Zhang<sup>12,g</sup>, J. W. Zhang<sup>1,58,64</sup>, J. X. Zhang<sup>38,k,l</sup>, J. Y. Zhang<sup>1</sup>, J. Z. Zhang<sup>1,64</sup>, Jianyu Zhang<sup>64</sup>, L. M. Zhang<sup>61</sup>, Lei Zhang<sup>42</sup>, P. Zhang<sup>1,64</sup>, Q. Y. Zhang<sup>34</sup>, R. Y. Zhang<sup>38,k,l</sup>, S. H. Zhang<sup>1,64</sup>, Shulei Zhang<sup>25,i</sup>, X. M. Zhang<sup>1</sup>, X. Y. Zhang<sup>40</sup>, X. Y. Zhang<sup>50</sup>, Y. Zhang<sup>1</sup>, Y. Zhang<sup>73</sup>, Y. T. Zhang<sup>81</sup>, Y. H. Zhang<sup>1,58</sup>, Y. M. Zhang<sup>39</sup>, Yan Zhang<sup>72,58</sup>, Z. D. Zhang<sup>1</sup>, Z. H. Zhang<sup>1</sup>, Z. L. Zhang<sup>34</sup>, Z. Y. Zhang<sup>77</sup>, Z. Y. Zhang<sup>43</sup>, Z. Z. Zhang<sup>45</sup>, G. Zhao<sup>1</sup>, J. Y. Zhao<sup>1,64</sup>, J. Z. Zhao<sup>1,58</sup>, L. Zhao<sup>1</sup>, Lei Zhao<sup>72,58</sup>, M. G. Zhao<sup>43</sup>, N. Zhao<sup>79</sup>, R. P. Zhao<sup>64</sup>, S. J. Zhao<sup>81</sup>, Y. B. Zhao<sup>1,58</sup>, Y. X. Zhao<sup>31,64</sup>, Z. G. Zhao<sup>72,58</sup>, A. Zhemchugov<sup>36,b</sup>, B. Zheng<sup>73</sup>, B. M. Zheng<sup>34</sup>, J. P. Zheng<sup>1,58</sup>, W. J. Zheng<sup>1,64</sup>, Y. H. Zheng<sup>64</sup>, B. Zhong<sup>41</sup>, X. Zhong<sup>59</sup>, H. Zhou<sup>50</sup>, J. Y. Zhou<sup>34</sup>, L. P. Zhou<sup>1,64</sup>, S. Zhou<sup>6</sup>, X. Zhou<sup>77</sup>, X. K. Zhou<sup>6</sup>, X. R. Zhou<sup>72,58</sup>, X. Y. Zhou<sup>39</sup>, Y. Z. Zhou<sup>12,g</sup>, Z. C. Zhou<sup>20</sup>, A. N. Zhu<sup>64</sup>, J. Zhu<sup>43</sup>, K. Zhu<sup>1</sup>, K. J. Zhu<sup>1,58,64</sup>, K. S. Zhu<sup>12,g</sup>, L. Zhu<sup>34</sup>, L. X. Zhu<sup>64</sup>, S. H. Zhu<sup>71</sup>, T. J. Zhu<sup>12,g</sup>, W. D. Zhu<sup>41</sup>, Y. C. Zhu<sup>72,58</sup>, Z. A. Zhu<sup>1,64</sup>, J. H. Zou<sup>1</sup>, J. Zu<sup>72,58</sup>

(BESIII Collaboration)

<sup>1</sup> *Institute of High Energy Physics, Beijing 100049, People's Republic of China*

<sup>2</sup> *Beihang University, Beijing 100191, People's Republic of China*

<sup>3</sup> *Bochum Ruhr-University, D-44780 Bochum, Germany*

<sup>4</sup> *Budker Institute of Nuclear Physics SB RAS (BINP), Novosibirsk 630090, Russia*

<sup>5</sup> *Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*

<sup>6</sup> *Central China Normal University, Wuhan 430079, People's Republic of China*

<sup>7</sup> *Central South University, Changsha 410083, People's Republic of China*

<sup>8</sup> *China Center of Advanced Science and Technology, Beijing 100190, People's Republic of China*

<sup>9</sup> *China University of Geosciences, Wuhan 430074, People's Republic of China*

<sup>10</sup> *Chung-Ang University, Seoul, 06974, Republic of Korea*

<sup>11</sup> *COMSATS University Islamabad, Lahore Campus, Defence Road, Off Raiwind Road, 54000 Lahore, Pakistan*

<sup>12</sup> *Fudan University, Shanghai 200433, People's Republic of China*

<sup>13</sup> *GSI Helmholtzcentre for Heavy Ion Research GmbH, D-64291 Darmstadt, Germany*

<sup>14</sup> *Guangxi Normal University, Guilin 541004, People's Republic of China*

<sup>15</sup> *Guangxi University, Nanning 530004, People's Republic of China*

<sup>16</sup> *Hangzhou Normal University, Hangzhou 310036, People's Republic of China*

<sup>17</sup> *Hebei University, Baoding 071002, People's Republic of China*

<sup>18</sup> *Helmholtz Institute Mainz, Staudinger Weg 18, D-55099 Mainz, Germany*

<sup>19</sup> *Henan Normal University, Xinxiang 453007, People's Republic of China*

<sup>20</sup> *Henan University, Kaifeng 475004, People's Republic of China*

<sup>21</sup> *Henan University of Science and Technology, Luoyang 471003, People's Republic of China*

<sup>22</sup> *Henan University of Technology, Zhengzhou 450001, People's Republic of China*

<sup>23</sup> *Huangshan College, Huangshan 245000, People's Republic of China*

<sup>24</sup> *Hunan Normal University, Changsha 410081, People's Republic of China*

<sup>25</sup> *Hunan University, Changsha 410082, People's Republic of China*

<sup>26</sup> *Indian Institute of Technology Madras, Chennai 600036, India*

<sup>27</sup> *Indiana University, Bloomington, Indiana 47405, USA*

<sup>28</sup> *INFN Laboratori Nazionali di Frascati, (A)INFN Laboratori Nazionali di Frascati, I-00044, Frascati, Italy; (B)INFN Sezione di Perugia, I-06100, Perugia, Italy; (C)University of Perugia, I-06100, Perugia, Italy*

<sup>29</sup> *INFN Sezione di Ferrara, (A)INFN Sezione di Ferrara, I-44122, Ferrara, Italy; (B)University of Ferrara, I-44122, Ferrara, Italy*

<sup>30</sup> *Inner Mongolia University, Hohhot 010021, People's Republic of China*

<sup>31</sup> *Institute of Modern Physics, Lanzhou 730000, People's Republic of China*

<sup>32</sup> *Institute of Physics and Technology, Peace Avenue 54B, Ulaanbaatar 13330, Mongolia*

<sup>33</sup> *Instituto de Alta Investigación, Universidad de Tarapacá, Casilla 7D, Arica 1000000, Chile*

<sup>34</sup> *Jilin University, Changchun 130012, People's Republic of China*

<sup>35</sup> *Johannes Gutenberg University of Mainz, Johann-Joachim-Becher-Weg 45, D-55099 Mainz, Germany*

<sup>36</sup> *Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia*

<sup>37</sup> *Justus-Liebig-Universität Giessen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany*

<sup>38</sup> *Lanzhou University, Lanzhou 730000, People's Republic of China*

<sup>39</sup> *Liaoning Normal University, Dalian 116029, People's Republic of China*

- <sup>40</sup> Liaoning University, Shenyang 110036, People's Republic of China
- <sup>41</sup> Nanjing Normal University, Nanjing 210023, People's Republic of China
- <sup>42</sup> Nanjing University, Nanjing 210093, People's Republic of China
- <sup>43</sup> Nankai University, Tianjin 300071, People's Republic of China
- <sup>44</sup> National Centre for Nuclear Research, Warsaw 02-093, Poland
- <sup>45</sup> North China Electric Power University, Beijing 102206, People's Republic of China
- <sup>46</sup> Peking University, Beijing 100871, People's Republic of China
- <sup>47</sup> Qufu Normal University, Qufu 273165, People's Republic of China
- <sup>48</sup> Renmin University of China, Beijing 100872, People's Republic of China
- <sup>49</sup> Shandong Normal University, Jinan 250014, People's Republic of China
- <sup>50</sup> Shandong University, Jinan 250100, People's Republic of China
- <sup>51</sup> Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China
- <sup>52</sup> Shanxi Normal University, Linfen 041004, People's Republic of China
- <sup>53</sup> Shanxi University, Taiyuan 030006, People's Republic of China
- <sup>54</sup> Sichuan University, Chengdu 610064, People's Republic of China
- <sup>55</sup> Soochow University, Suzhou 215006, People's Republic of China
- <sup>56</sup> South China Normal University, Guangzhou 510006, People's Republic of China
- <sup>57</sup> Southeast University, Nanjing 211100, People's Republic of China
- <sup>58</sup> State Key Laboratory of Particle Detection and Electronics, Beijing 100049, Hefei 230026, People's Republic of China
- <sup>59</sup> Sun Yat-Sen University, Guangzhou 510275, People's Republic of China
- <sup>60</sup> Suranaree University of Technology, University Avenue 111, Nakhon Ratchasima 30000, Thailand
- <sup>61</sup> Tsinghua University, Beijing 100084, People's Republic of China
- <sup>62</sup> Turkish Accelerator Center Particle Factory Group, (A)Istinye University, 34010, Istanbul, Turkey; (B)Near East University, Nicosia, North Cyprus, 99138, Mersin 10, Turkey
- <sup>63</sup> University of Bristol, (A)H H Wills Physics Laboratory; (B)Tyndall Avenue; (C)Bristol; (D)BS8 1TL
- <sup>64</sup> University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
- <sup>65</sup> University of Groningen, NL-9747 AA Groningen, The Netherlands
- <sup>66</sup> University of Hawaii, Honolulu, Hawaii 96822, USA
- <sup>67</sup> University of Jinan, Jinan 250022, People's Republic of China
- <sup>68</sup> University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom
- <sup>69</sup> University of Muenster, Wilhelm-Klemm-Strasse 9, 48149 Muenster, Germany
- <sup>70</sup> University of Oxford, Keble Road, Oxford OX13RH, United Kingdom
- <sup>71</sup> University of Science and Technology Liaoning, Anshan 114051, People's Republic of China
- <sup>72</sup> University of Science and Technology of China, Hefei 230026, People's Republic of China
- <sup>73</sup> University of South China, Hengyang 421001, People's Republic of China
- <sup>74</sup> University of the Punjab, Lahore-54590, Pakistan
- <sup>75</sup> University of Turin and INFN, (A)University of Turin, I-10125, Turin, Italy; (B)University of Eastern Piedmont, I-15121, Alessandria, Italy; (C)INFN, I-10125, Turin, Italy
- <sup>76</sup> Uppsala University, Box 516, SE-75120 Uppsala, Sweden
- <sup>77</sup> Wuhan University, Wuhan 430072, People's Republic of China
- <sup>78</sup> Yantai University, Yantai 264005, People's Republic of China
- <sup>79</sup> Yunnan University, Kunming 650500, People's Republic of China
- <sup>80</sup> Zhejiang University, Hangzhou 310027, People's Republic of China
- <sup>81</sup> Zhengzhou University, Zhengzhou 450001, People's Republic of China
- <sup>a</sup> Deceased
- <sup>b</sup> Also at the Moscow Institute of Physics and Technology, Moscow 141700, Russia
- <sup>c</sup> Also at the Novosibirsk State University, Novosibirsk, 630090, Russia
- <sup>d</sup> Also at the NRC "Kurchatov Institute", PNPI, 188300, Gatchina, Russia
- <sup>e</sup> Also at Goethe University Frankfurt, 60323 Frankfurt am Main, Germany
- <sup>f</sup> Also at Key Laboratory for Particle Physics, Astrophysics and Cosmology, Ministry of Education; Shanghai Key Laboratory for Particle Physics and Cosmology; Institute of Nuclear and Particle Physics, Shanghai 200240, People's Republic of China
- <sup>g</sup> Also at Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and Institute of Modern Physics, Fudan University, Shanghai 200443, People's Republic of China
- <sup>h</sup> Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People's Republic of China
- <sup>i</sup> Also at School of Physics and Electronics, Hunan University, Changsha 410082, China
- <sup>j</sup> Also at Guangdong Provincial Key Laboratory of Nuclear Science, Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China
- <sup>k</sup> Also at MOE Frontiers Science Center for Rare Isotopes, Lanzhou University, Lanzhou 730000, People's Republic of China
- <sup>l</sup> Also at Lanzhou Center for Theoretical Physics, Lanzhou University, Lanzhou 730000, People's Republic of China
- <sup>m</sup> Also at the Department of Mathematical Sciences, IBA, Karachi 75270, Pakistan
- <sup>n</sup> Also at Ecole Polytechnique Federale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
- <sup>o</sup> Also at Helmholtz Institute Mainz, Staudinger Weg 18, D-55099 Mainz, Germany

<sup>p</sup> Also at School of Physics, Beihang University, Beijing 100191, China

We perform the first investigation of the process  $e^+e^- \rightarrow K^+K^-\psi(2S)$  and report its Born cross sections over a range of center-of-mass energies from 4.699 to 4.951 GeV. The measurements are carried out using several partial reconstruction techniques using data samples collected by the BESIII detector with a total integrated luminosity of  $2.5 \text{ fb}^{-1}$ . We search for new tetraquark candidates  $Z_{cs}^\pm$  in the decays  $Z_{cs}^\pm \rightarrow K^\pm\psi(2S)$ . No significant  $Z_{cs}^\pm$  signals are observed.

At the frontier of Quantum Chromodynamics (QCD), exotic hadrons containing heavy quarks have been the subject of much experimental and theoretical effort. Interest was originally stimulated two decades ago with the discovery of the first exotic (non- $q\bar{q}$ ) candidate, the  $X(3872)$ , by Belle in 2003 [1]. Subsequently, additional exotic candidates involving a charm-anticharm pair, *e.g.*, the  $Y(4260)$  [2] and  $Z_c(3900)$  [3, 4], were also experimentally established. Interpreting their nature is a high priority for both experiment and theory.

Various experiments have measured a series of  $e^+e^-$  cross sections to both hidden-charm and open-charm final states, *e.g.*,  $e^+e^- \rightarrow \pi^+\pi^-J/\psi$  [5],  $\pi^+\pi^-h_c$  [6],  $\pi^+\pi^-\psi(2S)$  [7], and  $D^{(*)}D^{(*)}(\pi)$  [8–10], and have observed candidate vector states in the center-of-mass energy ( $\sqrt{s}$ ) dependence of those cross sections that do not fit within the conventional charmonium spectrum. Moreover, processes with strange mesons in the final state, such as  $e^+e^- \rightarrow K\bar{K}J/\psi$  [11–14], have also been studied. BESIII observed a new structure in the  $\sqrt{s}$ -dependence of the  $e^+e^- \rightarrow K^+K^-J/\psi$  cross section [14] at a mass of 4.710 GeV, called the  $Y(4710)$ . This structure is one of the heaviest vector charmonium-like states observed to date. BESIII also measured the  $\sqrt{s}$ -dependence of the cross section for the process  $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$  [15], and found a structure around 4.79 GeV, with a mass that is distinct from the  $Y(4710)$ . Further studies are needed to clarify the nature of these two structures in processes containing strange mesons. A study of the process  $e^+e^- \rightarrow K^+K^-\psi(2S)$  is an important extension of previous efforts, and the  $e^+e^-$  annihilation datasets collected above the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  threshold at BESIII make this possible.

Unlike the  $X$  and  $Y$  states, the isovector  $Z$  states must be exotic since they contain at least a light quark and antiquark in addition to an isosinglet heavy quark–antiquark pair. In 2013, the tetraquark candidate  $Z_c(3900)^\pm$  was observed decaying to  $\pi^\pm J/\psi$  in the  $\pi^+\pi^-J/\psi$  system by the BESIII and Belle experiments [3, 4]. Charged structures have also been observed in the  $\pi^\pm\psi(2S)$  invariant mass spectrum in both the  $B \rightarrow K\pi^\pm\psi(2S)$  [16] and  $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$  [17] reaction channels. Several tetraquark candidates have been observed in both hidden- and open-charm processes. BESIII reported the observation of a charged open-strange hidden-charm structure  $Z_{cs}(3985)$  in the  $K^+$  recoil-mass

spectra in the  $e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$  process [18] with a mass and width of  $M = 3992.2 \pm 1.7 \pm 1.6 \text{ MeV}/c^2$  and  $\Gamma = 7.7_{-3.8}^{+4.1} \pm 4.3 \text{ MeV}$ . This was the first observation of a tetraquark candidate involving both strange and charm quarks. Soon after, LHCb reported observations of the  $Z_{cs}(4000)$  and  $Z_{cs}(4220)$  decaying to  $J/\psi K^+$  via the reaction  $B^+ \rightarrow J/\psi\phi K^+$  [19]. The mass and width of the  $Z_{cs}(4000)$  were found to be  $M = 4003 \pm 6_{-14}^{+4} \text{ MeV}/c^2$  and  $\Gamma = 131 \pm 15 \pm 26 \text{ MeV}$ , and for the  $Z_{cs}(4220)$ ,  $M = 4216 \pm 24_{-30}^{+43} \text{ MeV}/c^2$  and  $\Gamma = 233 \pm 52_{-73}^{+97} \text{ MeV}$ . The  $Z_{cs}(3985)$  from BESIII and the  $Z_{cs}(4000)$  from LHCb have similar masses but quite different widths. According to calculations in the hadro-charmonium picture [20, 21], the  $Z_{cs}(3985)$  and  $Z_{cs}(4000)$  can be assigned to  $\psi(2S) \otimes K$  hadro-charmonia, while the  $Z_{cs}(4220)$  could be assigned to a  $\psi(2S) \otimes K^*$  or  $\chi_{c1}(2P) \otimes K^*$  state. In addition, BESIII searched for  $Z_{cs} \rightarrow KJ/\psi$  in the process  $e^+e^- \rightarrow K^+K^-J/\psi$ , but no significant signals were observed [14]. As a natural extension, a search for the  $Z_{cs}$  in the decay  $Z_{cs} \rightarrow K^\pm\psi(2S)$  is very interesting.

In this Letter, we report the first measurement of the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  Born cross sections ( $\sigma$ ) at  $\sqrt{s}$  from 4.669 to 4.951 GeV using  $2.5 \text{ fb}^{-1}$  of  $e^+e^-$  annihilation data collected by the BESIII detector. To investigate intermediate  $Y$  states that could be produced through the reaction  $e^+e^- \rightarrow Y \rightarrow K^+K^-\psi(2S)$ , the  $\sqrt{s}$ -dependent ratio between  $\sigma(e^+e^- \rightarrow K^+K^-\psi(2S))$  and  $\sigma(e^+e^- \rightarrow K^+K^-J/\psi)$  is also provided. Taking advantage of the largest signal yield at 4.843 GeV, we search for new tetraquark candidates  $Z_{cs}^\pm$  in the  $Z_{cs}^\pm \rightarrow K^\pm\psi(2S)$  decay channels.

The BESIII detector is described in Ref. [22]. The Monte Carlo (MC) samples are generated with KKMC [23] in conjunction with EVTGEN [24]. The detector simulation is based on GEANT4 [25]. The inclusive MC samples, which include open-charm hadronic processes, continuum processes, and the effects due to initial-state-radiation (ISR), are produced with ten times the data luminosity to study the backgrounds. The signal MC samples,  $e^+e^- \rightarrow K^+K^-\psi(2S)$ ,  $\psi(2S) \rightarrow J/\psi + (\pi^+\pi^-, \pi^0\pi^0, \eta, \pi^0, \gamma\gamma)$  or  $\ell^+\ell^-$ ,  $J/\psi \rightarrow \ell^+\ell^-$  ( $\ell = e, \mu$ ), are generated to determine the detection efficiencies. The criteria of charged track selection and kaon identification are the same as those in Ref. [14]. To reconstruct the  $J/\psi$  or  $\psi(2S)$  in their leptonic decays, two charged particles with momenta greater

than 1.0 GeV/c and opposite charges are identified as the lepton pair from the  $J/\psi$  or  $\psi(2S)$  decay. Electrons and muons are discriminated by requiring their deposited energies in the electromagnetic calorimeter (EMC) to be greater than 0.8 GeV and less than 0.4 GeV, respectively.

A partial reconstruction technique is used to improve the reconstruction efficiency in the measurement. We take advantage of two aspects of the signal signature. First, the  $\psi(2S)$  decays dominantly through channels with a  $J/\psi$  in the final state, including  $\psi(2S) \rightarrow J/\psi + (\pi^+\pi^-, \pi^0\pi^0, \eta, \pi^0, \gamma\gamma)$  [26]. Furthermore, since the  $\sqrt{s}$  range is close to the threshold for  $e^+e^- \rightarrow K^+K^-\psi(2S)$  production, the primary kaons have low momentum and low detection efficiency. Based on these features, four approaches are developed to reconstruct the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  signals. The selection criteria of the four approaches are orthogonal and do not contain events in common.

In the first approach (i), we tag the  $K^+$ , the  $K^-$ , and the  $J/\psi$  from the  $\psi(2S)$  decay, and then identify the signal  $\psi(2S)$  using the mass recoiling against the  $K^+K^-$  system ( $RM(K^+K^-)$ ). This approach aims to reconstruct signals using all  $\psi(2S)$  decay channels that contain a  $J/\psi$  in the final state. The  $J/\psi$  mass window is set to be  $3.05 < M(\ell^+\ell^-) < 3.15$  GeV/c<sup>2</sup>, where  $M(\ell^+\ell^-)$  is the lepton pair invariant mass. The selection criteria are optimized by maximizing  $S/\sqrt{S+B}$ , where  $S$  is the number of signal events and  $B$  is the number of background events, estimated according to the inclusive MC samples. To suppress backgrounds caused by  $\mu/\pi$  misidentification, at least one muon from  $J/\psi \rightarrow \mu^+\mu^-$  needs to penetrate more than three layers of the muon chamber (MUC).

In the second approach (ii), we only tag one kaon (the  $K^+$  or  $K^-$ ) by requiring there be exactly one charged kaon detected and then reconstruct the  $\psi(2S)$  through the  $\psi(2S) \rightarrow \pi^+\pi^-J/\psi$  decay. A one-constraint kinematic fit constraining the mass of the missing kaon is further applied and is used to extract its four-momentum. The resulting  $\chi_{1C}^2$  is required to be less than 50. The requirement on the  $J/\psi$  mass window is the same as that in (i). This method is designed to recover those signal candidates with only one reconstructed kaon.

In the third approach (iii), we tag the  $K^+$ , the  $K^-$ , and the  $\psi(2S)$  in the decay  $\psi(2S) \rightarrow \ell^+\ell^-$  ( $\ell = e, \mu$ ). The  $\psi(2S)$  mass window is required to be  $3.631 < M(\ell^+\ell^-) < 3.726$  GeV/c<sup>2</sup>.

In the fourth approach (iv), we tag only one kaon (the  $K^+$  or  $K^-$ ), analogous to (ii), but the  $\psi(2S)$  is reconstructed through  $\psi(2S) \rightarrow \ell^+\ell^-$ . The  $\chi_{1C}^2$  of the kinematic fit to the missing kaon mass is required to be less than 15. To suppress Bhabha background in the  $\psi(2S) \rightarrow e^+e^-$  channel, events with  $e^+$  and  $e^-$  polar angles in the region  $\cos(\theta_{e^+}) > 0.85$  and  $\cos(\theta_{e^-}) < -0.85$  are vetoed.

Figure 1 shows the total  $RM(K^+K^-)$  distribution us-

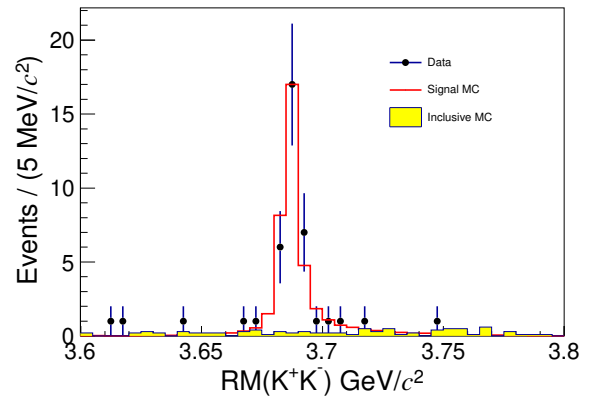


FIG. 1. Distribution of  $RM(K^+K^-)$  at  $\sqrt{s} = 4.843$  GeV. The points with error bars are data, the red histogram is for the signal MC events, and the yellow filled histogram is for the inclusive MC events.

ing selected events from all four approaches at  $\sqrt{s} = 4.843$  GeV. A distinct  $\psi(2S)$  signal peak is evident. According to a study of the inclusive MC samples, there are no peaking backgrounds. The signal yield at each energy point is obtained by counting events in the  $\psi(2S)$  signal region [3.67, 3.71] GeV/c<sup>2</sup>, which covers around  $\pm 3\sigma$  of the signal shape according to the signal MC distribution. The background in the signal region is estimated using sidebands that are two times wider than the signal region. For  $\sqrt{s} > 4.8$  GeV, the sidebands are [3.61, 3.65] and [3.73, 3.77] GeV/c<sup>2</sup>, while for  $\sqrt{s} < 4.8$  GeV, due to the limited available phase space, only the lower energy sideband is used. Assuming the observed events in the signal and sideband regions follow Poisson distributions, a likelihood defined as  $\mathcal{L}(x, y|s, b, \tau) = Pois(x|s + \tau b)Pois(y|b)$  is used to extract the signal yield, the statistical uncertainties, and the signal significance. Here,  $x(s)$  and  $y(b)$  correspond to the observed (expected) yields in the signal and sideband regions, respectively, and  $\tau$  is the ratio of the width of the signal region to that of the sideband. The maximum likelihood (ML)  $\mathcal{L}_{\max}$  is obtained by scanning  $s$  and  $b$ , where the corresponding  $s$  value is taken as the signal yield. The errors are the difference between the  $s$  with a likelihood of  $e^{-0.5}\mathcal{L}_{\max}$  and  $\mathcal{L}_{\max}$ , respectively. The significance is estimated by comparing the difference of log ML values  $\Delta(-2\ln\mathcal{L}_{\max})$  by setting  $s$  to be zero and nonzero. All results are listed in the Supplemental Material [27].

The Born cross section of  $e^+e^- \rightarrow K^+K^-\psi(2S)$  is calculated as

$$\sigma^B = \frac{N_s}{\mathcal{L}_{\text{int}}\epsilon_r(1+\delta)\frac{1}{|1-\Pi|^2}}, \quad (1)$$

where  $N_s$  is the number of signal events and  $\mathcal{L}_{\text{int}}$  is the integrated luminosity. The efficiency  $\epsilon_r$  is  $\mathcal{B}(\ell\ell)(\epsilon_{\text{iv}} + \epsilon_{\text{iii}}) + [\mathcal{B}(\pi^+\pi^-J/\psi)\epsilon_{\text{ii}} + \mathcal{B}(XJ/\psi)\epsilon_{\text{i}}]\mathcal{B}(J/\psi \rightarrow \ell\ell)$ , where  $\mathcal{B}(\ell\ell)$  is the sum of the branching fractions for  $\mathcal{B}(\psi(2S) \rightarrow ee)$

and  $\mathcal{B}(\psi(2S) \rightarrow \mu\mu)$ ,  $\mathcal{B}(J/\psi \rightarrow \ell\ell)$  is the combined branching fraction for  $\mathcal{B}(J/\psi \rightarrow ee)$  and  $\mathcal{B}(J/\psi \rightarrow \mu\mu)$ ,  $\mathcal{B}(XJ/\psi)$  is the total branching fraction of all  $\psi(2S)$  decays that contain a  $J/\psi$ , and  $\mathcal{B}(\pi^+\pi^-J/\psi)$  is the branching fraction of  $J/\psi \rightarrow \pi^+\pi^-J/\psi$ . All of these branching fractions are taken from the Particle Data Group [26]. In addition,  $\epsilon_i$ ,  $\epsilon_{ii}$ ,  $\epsilon_{iii}$ , and  $\epsilon_{iv}$  are the average efficiencies of the electron and muon channels for the four reconstruction approaches, respectively, and  $(1 + \delta)$  is the radiative correction factor obtained by a QED calculation [28]. A Breit-Wigner (BW) function is used to describe the lineshape of the observed cross section and extract the ISR corrected efficiencies and  $(1 + \delta)$  by iterating the input lineshape until convergence according to the method in Ref. [29]. The  $\frac{1}{1 - \Pi^2} = 1.055$  is the vacuum polarization factor taken from QED with an accuracy of 0.05% [30]. The measured Born cross sections are listed in the Supplemental Material [27].

The dressed cross section ( $\sigma^B/|1 - \Pi|^2$ ) is shown in Fig. 2 (a) as a function of  $\sqrt{s}$ . By assuming the observed  $e^+e^- \rightarrow K^+K^-\psi(2S)$  signals are from a vector resonance  $Y$  decay, a phase space modified BW function is fit to the energy-dependent dressed cross section using  $\sigma^{\text{dressed}} = |BW(\sqrt{s})|^2$ , with  $BW(\sqrt{s})$  defined as

$$BW(s) = \frac{M}{\sqrt{s}} \cdot \frac{\sqrt{12\pi\Gamma_{\text{tot}}\Gamma_{ee}\mathcal{B}_{Y \rightarrow K^+K^-\psi(2S)}}}{s - M^2 + iM\Gamma_{\text{tot}}} \cdot \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M)}}, \quad (2)$$

where  $M$ ,  $\Gamma_{\text{tot}}$ , and  $\Gamma_{ee}$  are the mass, total width, and di-electron partial width of the resonance  $Y$ , respectively;  $\mathcal{B}_{Y \rightarrow K^+K^-\psi(2S)}$  is the branching fraction of  $Y \rightarrow K^+K^-\psi(2S)$ ; and the phase space of the three-body decay is  $\Phi(\sqrt{s}) = \iint \frac{1}{(2\pi)^3 32(\sqrt{s})^3} dm_{23}^2 dm_{12}^2$ .

A ML fit is performed to extract the resonance parameters. The fit results are  $M = 4787.7 \pm 17.7$  MeV/ $c^2$ ,  $\Gamma = 110.3 \pm 33.9$  MeV, and  $\Gamma_{ee}\mathcal{B}_{Y \rightarrow K^+K^-\psi(2S)} = 0.13 \pm 0.02$  eV. The ML value is  $-\ln\mathcal{L} = -30.9$ . Alternatively, the signals could be produced from the decay of an established resonance, e.g.  $Y(4710)$  [14], and the continuum process. To examine this, we use an exponential function as used in Refs. [31, 32],  $\sigma(\sqrt{s}) = p_1 \cdot \Phi(\sqrt{s})e^{p_0(\sqrt{s} - M_{\text{th}})}$ , to describe the line shape, where  $p_0$  and  $p_1$  are the free parameters, and  $M_{\text{th}} = 2m_{K^\pm} + m_{\psi(2S)}$ . The ML of the fit is  $-\ln\mathcal{L} = -29.5$ , similar to the previous approach.

In addition, we provide the  $\sqrt{s}$ -dependent ratio of  $\sigma(e^+e^- \rightarrow K^+K^-\psi(2S))$  to  $\sigma(e^+e^- \rightarrow K^+K^-J/\psi)$  as shown in Fig. 2(b), where the  $\sqrt{s}$ -dependent Born cross sections  $\sigma(e^+e^- \rightarrow K^+K^-J/\psi)$  are taken from the BESIII measurement in Ref. [14]. If the reactions  $e^+e^- \rightarrow K^+K^-\psi(2S)$  and  $e^+e^- \rightarrow K^+K^-J/\psi$  proceed through the same mechanisms, the  $\sqrt{s}$ -dependent ratio is likely to indicate a similar trend to that of phase space, shown as the solid curve in Fig. 2(b). The measured ratio at  $\sqrt{s} = 4.843$  GeV has about a  $2\sigma$  statistical deviation from that of phase space, which could indicate that a distinct production mechanism for  $e^+e^- \rightarrow K^+K^-\psi(2S)$

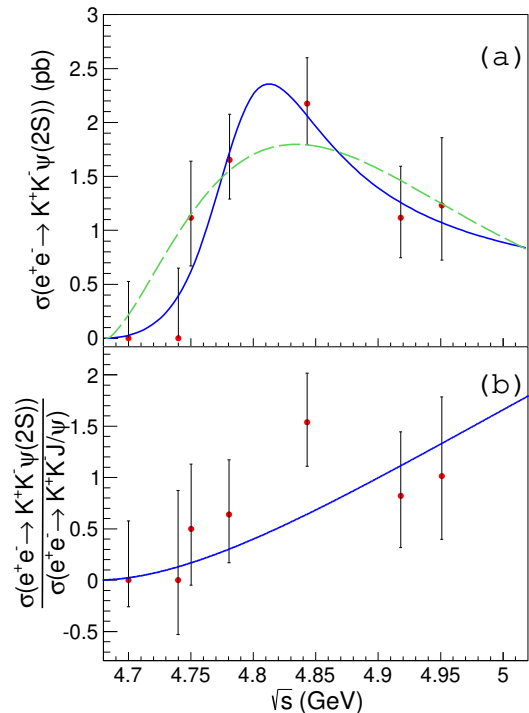


FIG. 2. The  $\sqrt{s}$ -dependent cross section of  $e^+e^- \rightarrow K^+K^-\psi(2S)$  is shown in (a), while the ratio  $\sigma(K^+K^-\psi(2S))/\sigma(K^+K^-J/\psi)$  in (b). The error bars are statistical only. In (a), the solid curve is the fit using a single BW function, and the dashed curve denotes the exponential function. In (b), the solid curve is the ratio of the phase space of the three-body  $K^+K^-\psi(2S)$  to  $K^+K^-J/\psi$  reactions.

may exist.

The systematic uncertainties for the Born cross section measurement mainly originate from the detection efficiency, the ISR correction factor, the integrated luminosity, and the input branching fractions. The sources of the uncertainty from the detection efficiencies include the tracking, particle identification, the kinematic fit, the  $J/\psi/\psi(2S)$  mass window, the muon identification with MUC, and the signal generation model. The systematic uncertainty due to tracking and particle identification is 1.0% for each track according to studies of the control samples  $e^+e^- \rightarrow \pi^+\pi^-J/\psi$  [33] and  $J/\psi \rightarrow K_S^0 K^\pm \pi^\mp$  [34]. The uncertainties caused by the kinematic fit, the  $J/\psi$  mass selection, and the muon selection with the MUC are studied with a control sample of  $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$ . To estimate the systematic uncertainty caused by the generator model, we produce the MC samples of the processes  $e^+e^- \rightarrow f\psi(2S) \rightarrow K^+K^-\psi(2S)$  ( $f = f_2(1270)$ ,  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_2'(1525)$ ) or  $e^+e^- \rightarrow K^\pm Z_{cs}^\pm \rightarrow K^+K^-\psi(2S)$ . The efficiency difference compared to the nominal value is 4.3% and is taken as the systematic uncertainty. The uncertainty due to the ISR correction factor is estimated by replacing the BW function in the MC generation with



the exponential function applied in the fit scheme. The integrated luminosity is measured with the Bhabha scattering process with an uncertainty of 1.0% [35]. The total systematic uncertainty at each energy point is obtained by adding all these systematic uncertainties in quadrature. The systematic uncertainties discussed above are summarized in the Supplemental Material [27].

Since the data sample at  $\sqrt{s} = 4.843$  GeV gives the largest  $e^+e^- \rightarrow K^+K^-\psi(2S)$  signal yield, we use it to search for intermediate states in the  $K^+K^-\psi(2S)$  system. Figure 3 shows the invariant mass squared distribution of the system recoiling against the  $K^\pm$ ,  $RM^2(K^\pm)$ .

We perform a simultaneous fit to the  $RM^2(K^+)$  and  $RM^2(K^-)$  spectra to extract the  $Z_{cs}^\pm$  signal yield. The fit function consists of three components: the  $Z_{cs}^\pm$  signal, contributions from the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  non-resonance process, and non- $(K^+K^-\psi(2S))$  backgrounds. The  $Z_{cs}^\pm$  signal shape is described with  $f(X) = \sigma(X) \otimes \int PHSP \cdot (|\frac{1}{X-M^2-iM\Gamma}|^2 + |\frac{1}{Y-M^2-iM\Gamma}|^2) dY$ , where  $X$ ,  $Y$  are  $RM^2(K^+)$  and  $RM^2(K^-)$ , respectively, and  $M$  and  $\Gamma$  are the  $Z_{cs}$  mass and width.  $PHSP$  denotes the two-dimensional distribution of  $RM^2(K^+)$  versus  $RM^2(K^-)$  obtained with the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  phase space MC sample, and  $\sigma(X)$  is the resolution of  $RM^2(K^\pm)$ . The shape of the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  non-resonance process is obtained from the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  phase space MC sample. The contribution of the non- $K^+K^-\psi(2S)$  background is estimated by the  $\psi(2S)$  sidebands in data. In the fit, the mass and width of the resonance, the magnitudes of the  $Z_{cs}$  signal and the non-resonance  $e^+e^- \rightarrow K^+K^-\psi(2S)$  process are free parameters. The interference between different processes are ignored due to the limited statistics. To localize the position of the  $Z_{cs}$  signal, a series of fits are implemented by scanning the  $Z_{cs}$  mass in the physical mass region. The local p-value is obtained by comparing the likelihood to that of the background-only null hypothesis. Figure 4 shows the local p-values as a function of the  $Z_{cs}$  mass. The masses around 4.205 GeV and 4.315 GeV give the minimum local p-values.

We perform two fits to the  $RM^2(K^\pm)$  distribution. In Fit I, the mass of the  $Z_{cs}$  is assumed to be around 4.205 GeV with a reflection at higher mass. In Fit II, the mass of the  $Z_{cs}$  is around 4.315 GeV with a reflection at lower mass. Figure 3 shows the fit results. Fit I gives a mass and width for the  $Z_{cs}^\pm$  of  $M = 4208.4 \pm 3.1$  MeV/ $c^2$  and  $\Gamma = 6.1 \pm 5.7$  MeV, with a global significance including the look-elsewhere effect of  $1.2\sigma$ . For Fit II,  $M = 4316.0 \pm 2.7$  MeV/ $c^2$  and  $\Gamma = 9.0 \pm 8.6$  MeV, with a global significance of  $1.1\sigma$ . The uncertainties here are statistical only.

In summary, we investigate the process  $e^+e^- \rightarrow K^+K^-\psi(2S)$  using data samples at  $\sqrt{s}$  from 4.699 to 4.951 GeV collected by the BESIII detector at the BEPCII collider. We report the first measurement of the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  Born cross sections. The

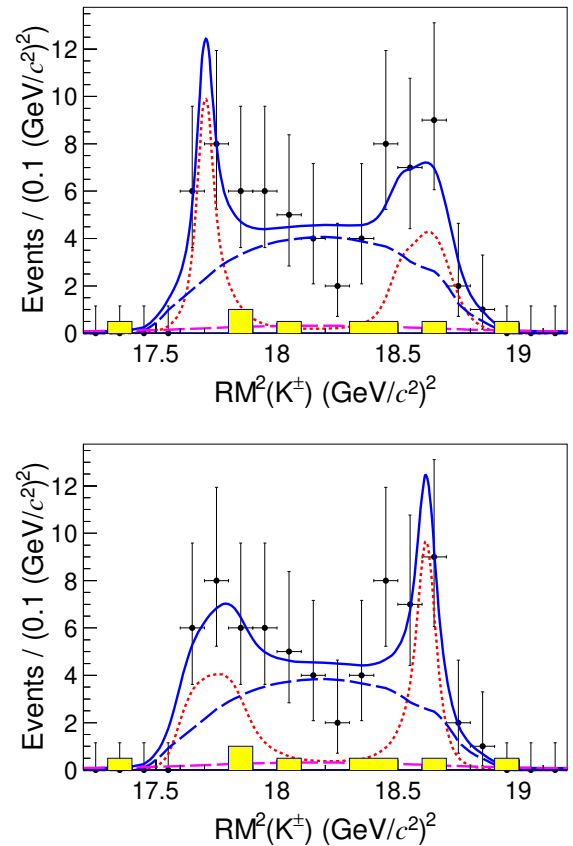


FIG. 3. Distribution of  $RM^2(K^\pm)$ . The top plot shows the results from Fit I, and the lower one shows the Fit II results. The dots with error bars are data, the solid blue lines are the total fit results, the red dotted lines represent the signal, the blue dashed line indicate the  $e^+e^- \rightarrow K^+K^-\psi(2S)$  non-resonant contributions, and the pink dashed lines show the non- $K^+K^-\psi(2S)$  background. The sideband distributions are shown by the yellow filled histograms.

$\sqrt{s}$ -dependence can be well-described as the decay of a single vector resonance with or without a superimposed continuum process. However, an empirical non-resonant function produces similar fit quality. Furthermore, the  $\sqrt{s}$ -dependent ratio of  $\sigma(e^+e^- \rightarrow K^+K^-\psi(2S))$  to  $\sigma(e^+e^- \rightarrow K^+K^-J/\psi)$  is provided using values taken from our measurement in Ref. [14]. At  $\sqrt{s} = 4.843$  GeV, a deviation of about  $2\sigma$  with respect to the ratio of their phase spaces is found, which may imply a new resonance with hidden strangeness to produce the  $K^+K^-\psi(2S)$  signals. We search for new tetraquark candidates  $Z_{cs}^\pm$  in the  $Z_{cs}^\pm \rightarrow K^\pm\psi(2S)$  decay through the study of the observed  $e^+e^- \rightarrow K^+K^-\psi(2S)$  signals. The simultaneous fit to the  $RM^2(K^+)$  and  $RM^2(K^-)$  spectra gives two best fit results with the  $Z_{cs}^\pm$  masses around 4.208 GeV/ $c^2$  and 4.315 GeV/ $c^2$ , respectively. A mass of 4.208 GeV/ $c^2$  is in the vicinity of the  $Z_{cs}(4220)$  reported by LHCb [19]. These measurements add to our

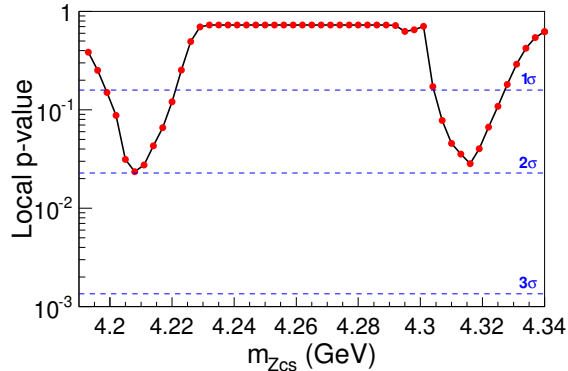


FIG. 4. The local p-values as a function of the  $Z_{cs}$  mass.

knowledge of exotic hadrons with strangeness, and provide inspiration for new research directions in both the theoretical and experimental sectors.

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