## **59. International Winter Meeting on Nuclear Physics** Jan 23<sup>rd</sup> – 27<sup>th</sup>, 2023

# Prospects for searches for a stable double strange hexaquark at Belle II

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### udsuds (H), long-standing saga (R. L. Jaffe, 1977\*)

- > Double strange six-quark state, same quark content as two  $\Lambda$  hyperons
- Privileged 6-quark combination, the spatial wave function can be totally symmetric >

### **Extremely fascinating object**

- > H would improve our understanding of the strength of  $\Lambda$ - $\Lambda$  interactions
- > Hyperon interactions are of fundamental interest in nuclear physics and nuclear astrophysics
- > A direct hyperon-hyperon scattering experiment is not feasible in a laboratory

#### Many theoretical calculations and experimental searches over the years



> At present no conclusion about its existence

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(\*) PRL 38 (1977) 195-198



#### H received revived interest in the last years

- Recent LQCD results
- Renewed theoretical effort >

#### G. R. Farrar, 2017<sup>\*</sup>: stable *H* is potentially an excellent dark matter (DM) candidate

- DM candidate within QCD
- Could have eluded all searches to date

 $\rightarrow$  Deep binding is facilitated by the unique symmetry structure of the H

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Whether the H is stable enough to be a DM candidate depends on its mass/binding energy

(\*) arXiv:1708.08951 [hep-ph]



### Deeply bound udsuds hexaquark







### Deeply bound udsuds hexaquark

Y(1,2,3) ideal to look for states w/ nonzero strangeness

- > Decay primarily in three gluons
- > ss quark pairs produced with ~ same probability as uu and dd











### Deeply bound udsuds hexaquark

### **Possible discovery strategy for stable** *H*

Searches @ BFactories:  $e^+e^- \rightarrow Y(1, 2, 3S) \rightarrow H \land \Lambda n\pi$ 



binding energy (B<sub>H</sub>)

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#### **BFactories**

e+e- colliders with  $E_{cm} \sim 10 \text{ GeV}$ 

Requirements

- > High luminosity
- **>** Good charged track

reconstruction capabilities

In the near future **Belle II@SuperKEKB** can play a major role!







### SuperKEKB





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#### Spectrum of bottomonium (bb)





## SuperKEKB





**Belle II dataset** 







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### Tracking detectors

- VerteX Detector (VXD)
  - > PiXel Detector (PXD, 2 layers)



- Silicon Vertex Detector (SVD, 4 layers)
- Central Drift Chamber (CDC)
- Particle identification subsystems
  - > Time Of Propagation (TOP) counter (central region)
  - Aerogel Ring-Imaging CHerenkov (ARICH, forward region)
- Outermost structures
  - Electromagnetic CaLorimeter (ECL)
  - Superconductive solenoid (1.5 T)
  - > K<sub>L</sub> and Muon detector (KLM)



# Tracking detectors > VXD: PXD (2 layers) + SVD (4 layers) > CDC CDC VXD

6 layers  $r_{in}$  (L1) = 1.4 cm r<sub>out</sub> (L6) = 13.5 cm

56 layers over 14K sense wires r<sub>out</sub> = 113 cm





 $Y(3S) \rightarrow H \land \land (+2n \pi)$ : analysis procedure

> Signal / background MC generation

> Signal events selection

> Particle-related optimization

> Best candidate selection

> Rest of event

> Upper limit (UL) sensitivity estimation w/ MC

Signal observation / UL derivation in data

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$$UL(M_S) = \frac{S_{up}(F(M_S), CI)}{N_{\Upsilon(3S)} \epsilon_S(M_S)}$$

#### Inputs from analysis

- > Signal efficiency  $\varepsilon_{\rm S}$
- > Number of background events F
- **>** CI = 90%
- > N<sub>Y(3S)</sub> depends on the luminosity

#### > Assumptions

- > Poisson counting experiment,  $\lambda = F$
- > H0: no signal, all observed events (n) are background (n = F)





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#### No existing limits from BaBar

#### **Novel measurement!**



### Outlook

### Double strange hexaquark @ B Factories: why/how

- Similarities between hadronic collisions and narrow bottomonia annihilations
- Good place to look for strange (exotic) baryons

Double strange hexaquark @ B Factories: where are we

- **>** Belle: PRL 110, 222002 (2013)
- **BaBar: PRL 122 (2019) 7, 072002**

Double strange hexaquark @ B Factories: future plans @ Belle II

- Cover whole H mass range (both stable and not-stable regime)
- > Study more possible decay channels (additional  $\pi$ s,  $\gamma$ , ...)
- Improve UL estimation (more data)





> Exciting years ahead with the Belle II experiment

- > Many intriguing physics perspectives (see also G. Casarosa and A. Boschetti talks)
- > Among others, the search for a stable H @ Belle II in the decay of Y(3S) is part of the program
- > With a relatively modest amount of data Belle II will make a **world-leading** measurement









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## Thank you for your attention!



# Additional material



## Belle II, luminosity projection





## SuperKEKB



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$$\mathcal{L} = \frac{\gamma_{\pm}}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{I_{\pm}\xi_{y\pm}}{\beta_y^*} \right) \left( \frac{R_{\mathcal{L}}}{R_{\xi_y}} \right)$$

Nucl. Instrum. Meth. A, vol 499, pp. 1-7, 2018

	KEKB	SuperKEKB
	LER ( $e^+$ ) / HER ( $e^-$ )	LER $(e^+)$ / HER
E [GeV]	3.5 / 8.0	4.0 / 7.0
$2\phi$ [mrad]	22	83
$\xi_x$	$0.127 \ / \ 0.102$	0.0028 / 0.0012
$\xi_y$	$0.129 \ / \ 0.090$	0.088 / 0.081
$eta_y^*$	5.9 / 5.9	0.27 / 0.30
I [A]	1.64 / 1.19	3.60 / 2.60
$\sigma^*_x \; [\mu { m m}]$	147 / 170	10.1 / 10.7
$\sigma_y^* \; [\mathrm{nm}]$	940 / 940	48 / 62
$\mathcal{L} \ [10^{35} \ {\rm cm}^{-2} \ {\rm s}^{-1}]$	0.211	8
$\int \mathcal{L} dt [ab^{-1}]$	1	50

