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

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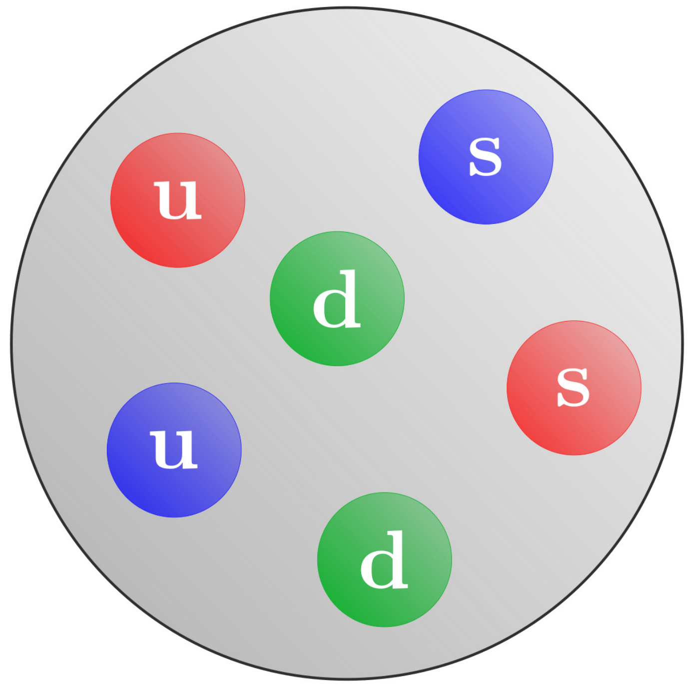
Belle II

Double strange hexaquark



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

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

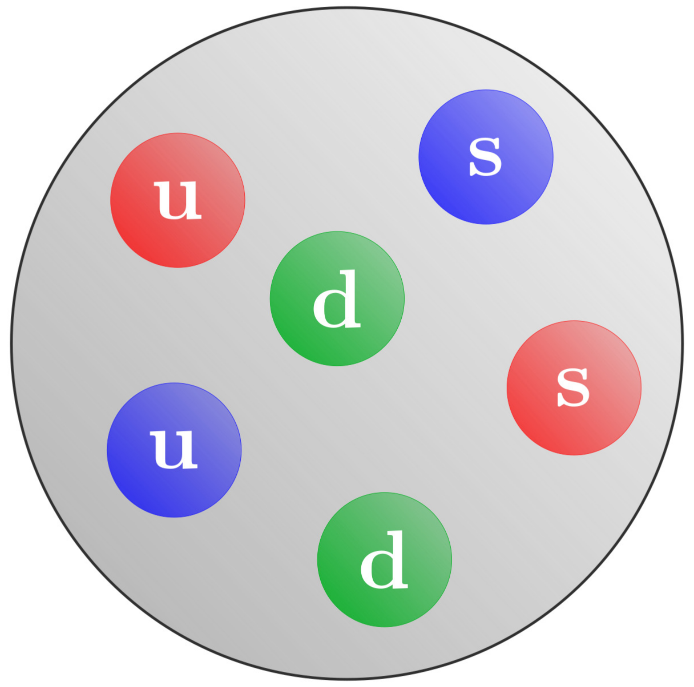
Extremely fascinating object

- *H* would improve our understanding of the strength of Λ-Λ 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 in the years

- At present no conclusion about its existence

Double strange hexaquark



H received revived interest in the last years

- Recent LQCD results
- Renewed theoretical effort

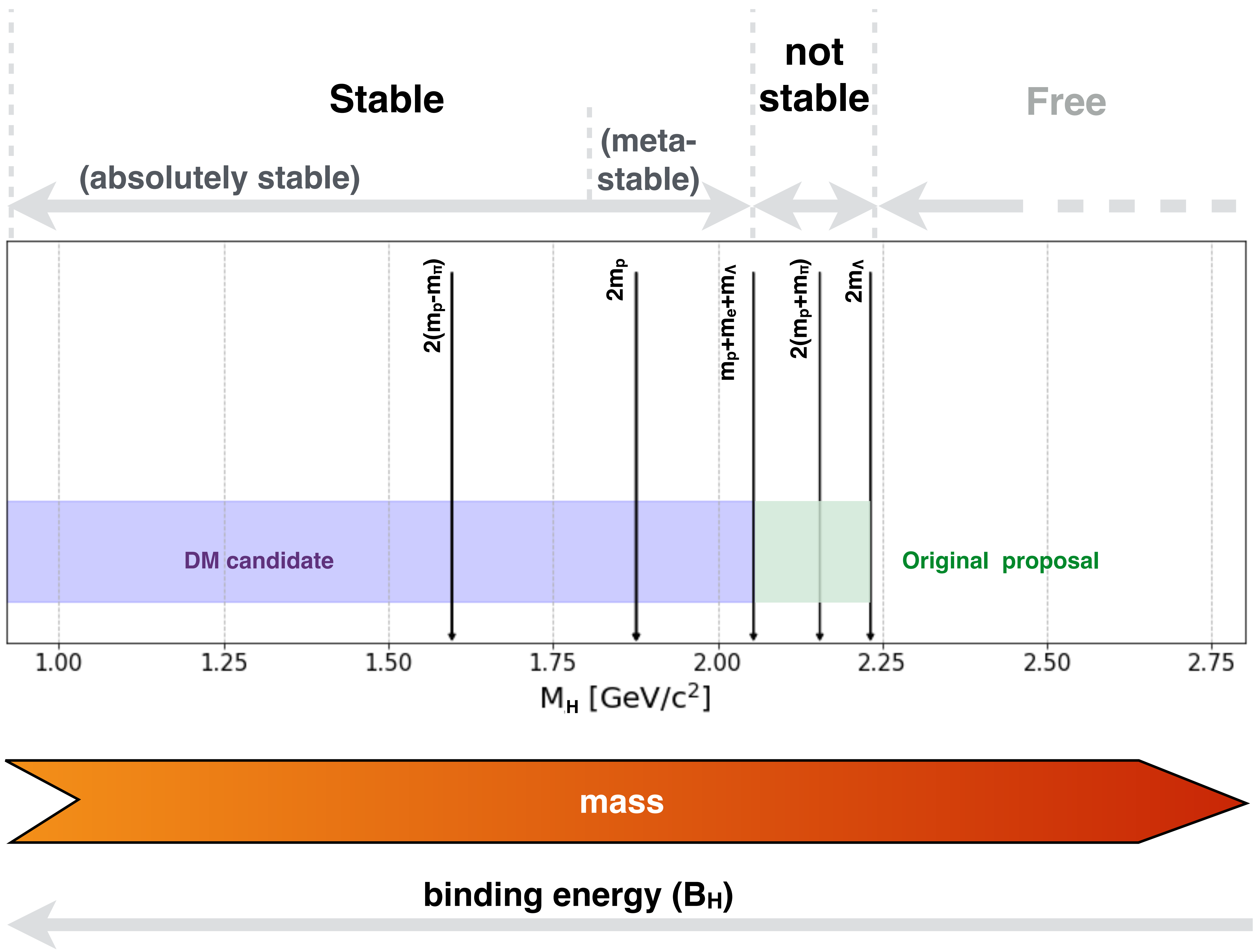
G. R. Farrar, 2017: **stable *H*** is potentially an excellent dark matter (DM) candidate

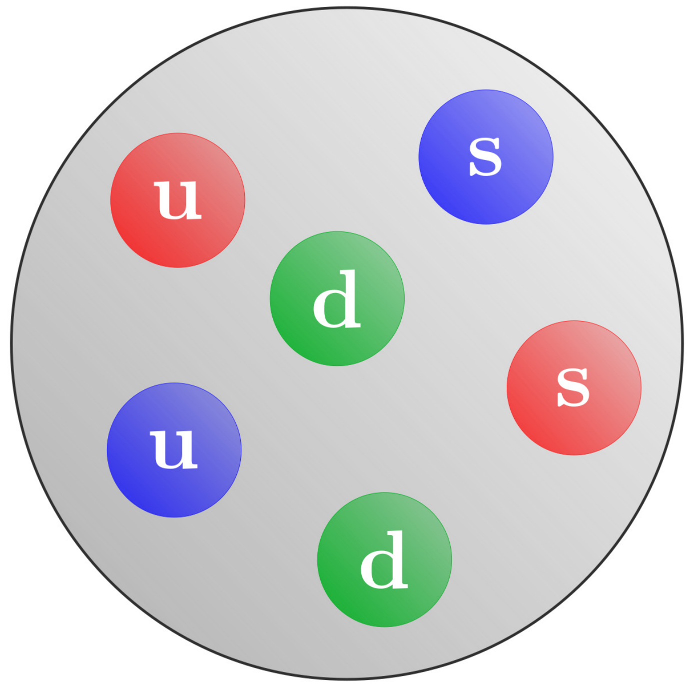
- DM candidate within QCD
- Could have eluded all searches to date

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

- Deep binding is facilitated by the unique symmetry structure of the *H*

Deeply bound udsuds hexaquark

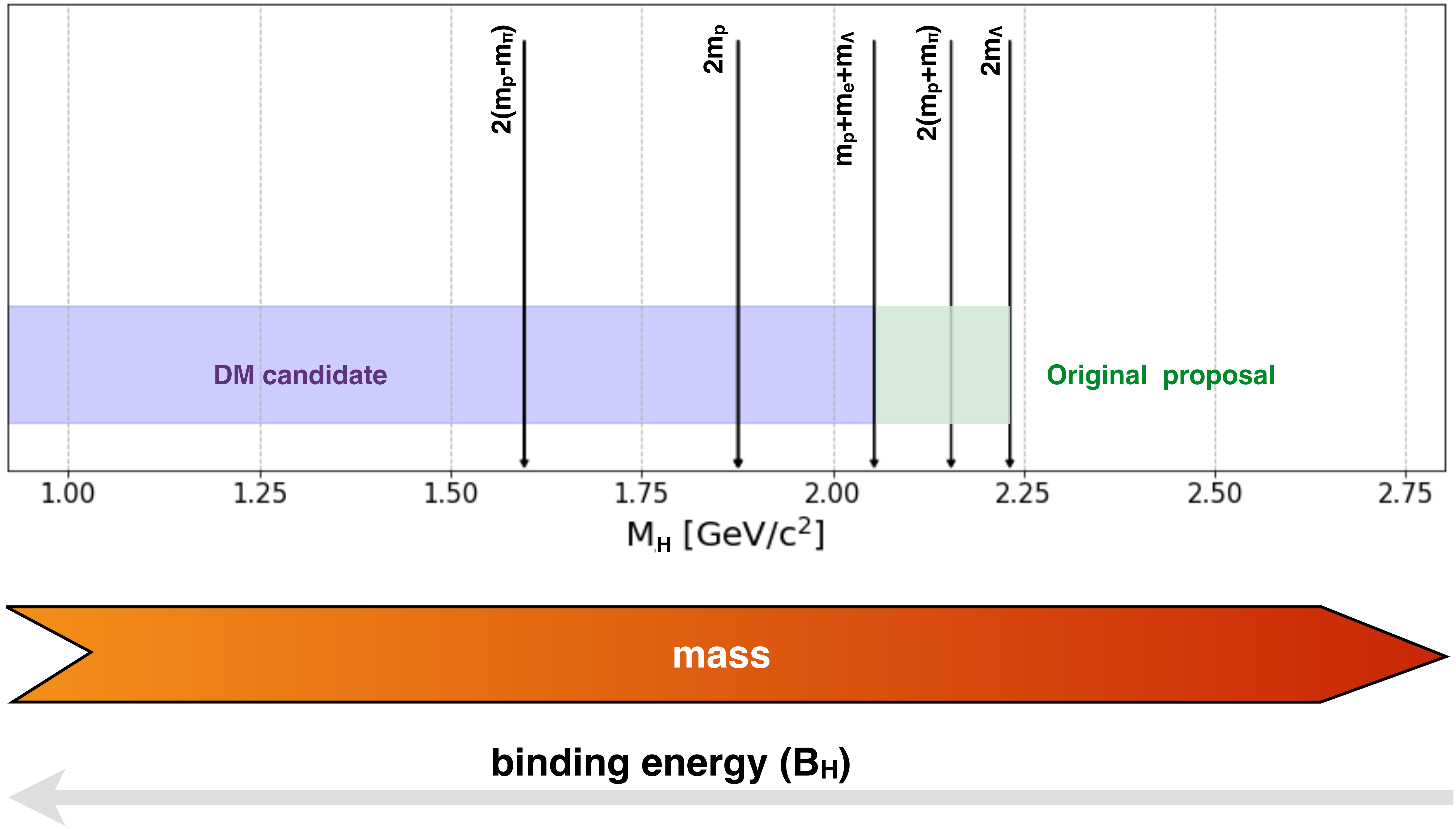




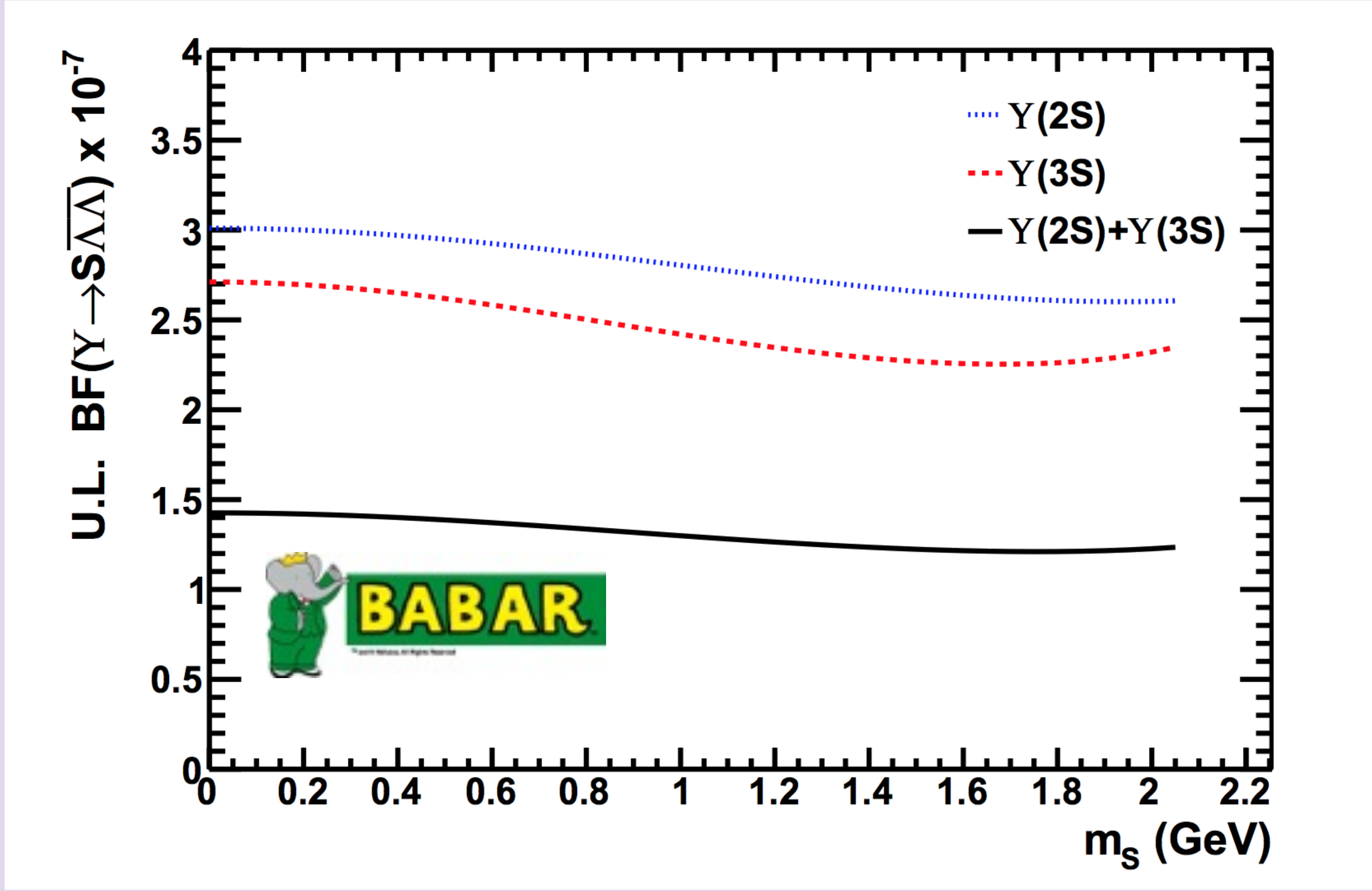
Deeply bound udsuds hexaquark

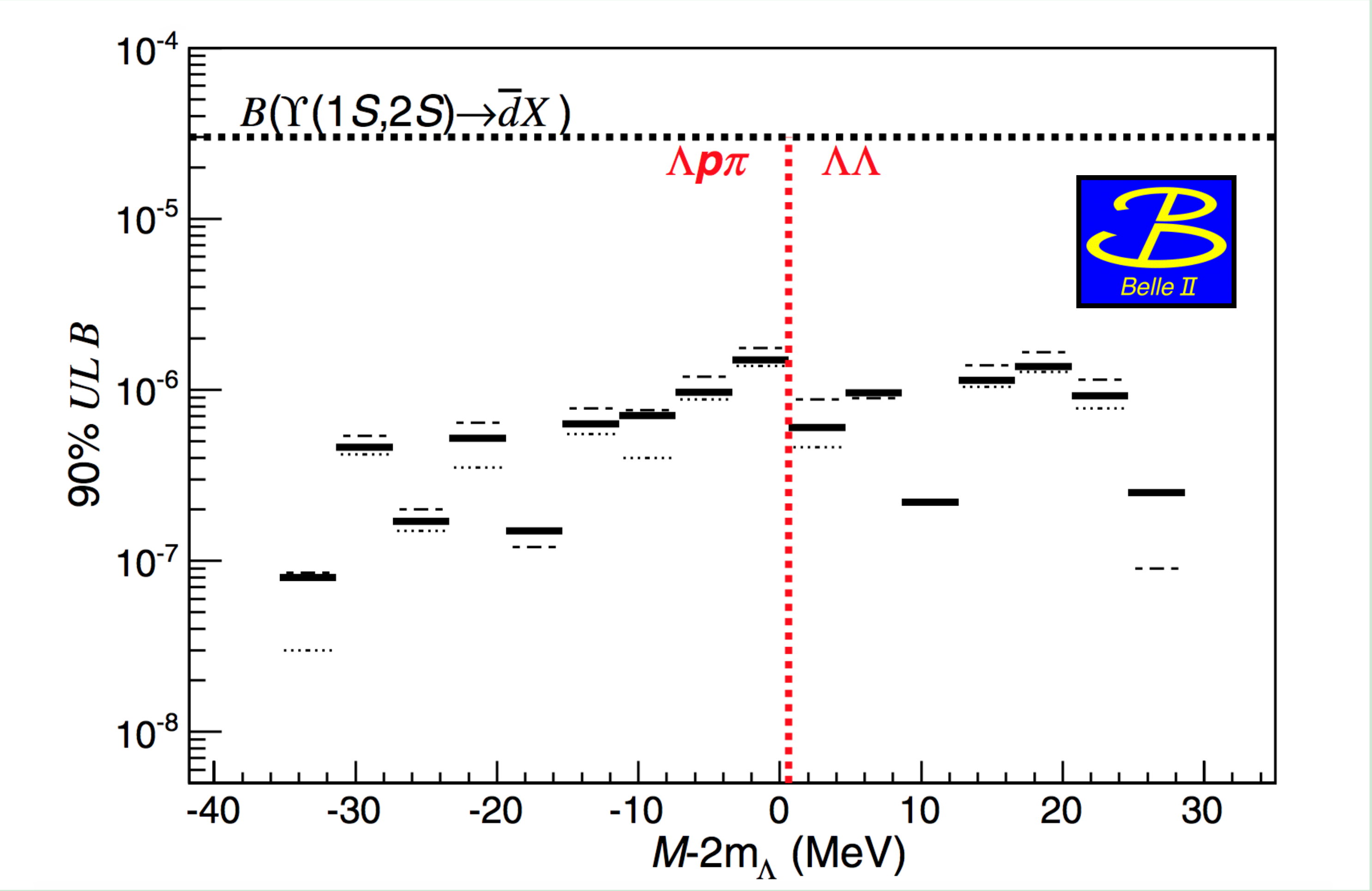
Υ(1,2,3) ideal to look for states w/ nonzero strangeness

- Decay primarily in three gluons
- $s\bar{s}$ quark pairs produced with ~ same probability as $u\bar{u}$ and $d\bar{d}$



PRL 122 (2019) 7, 072002





PRL 110, 222002 (2013)

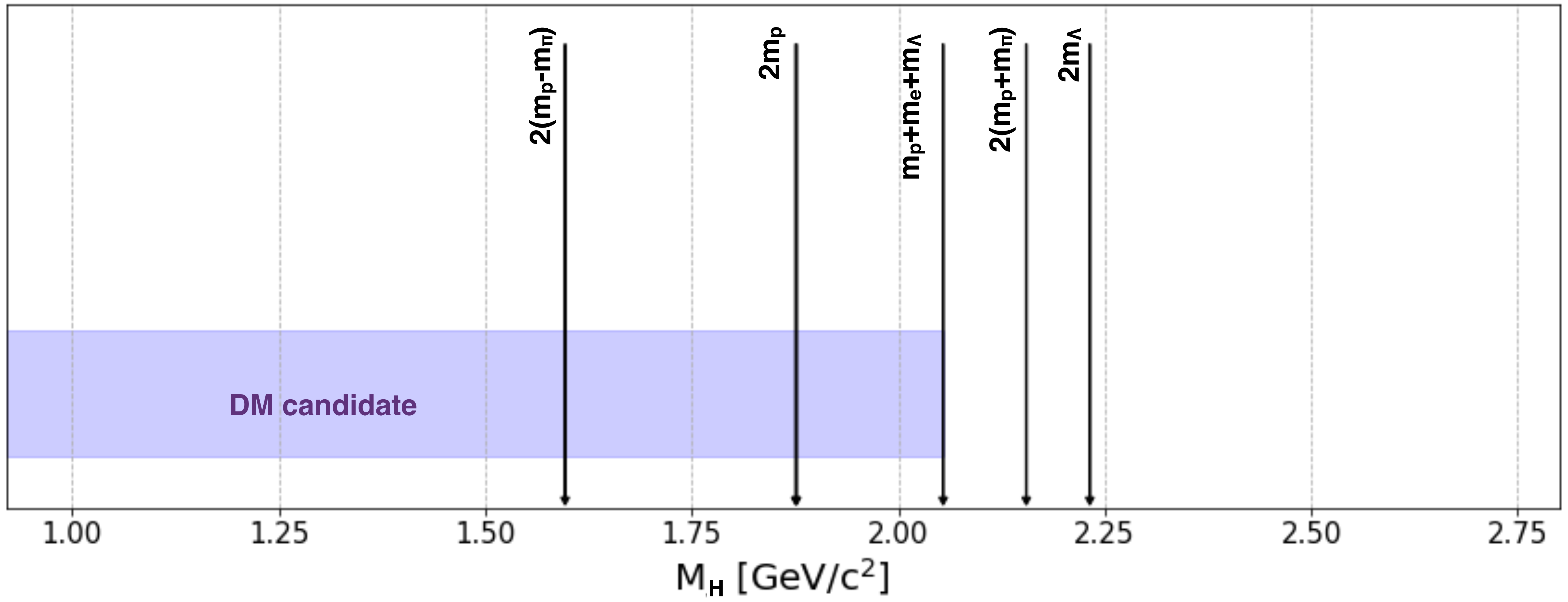
BFactories

e^+e^- colliders with

E_{cm} ~ 10 GeV

Possible discovery strategy for stable *H*

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



mass

binding energy (B_H)

Requirements

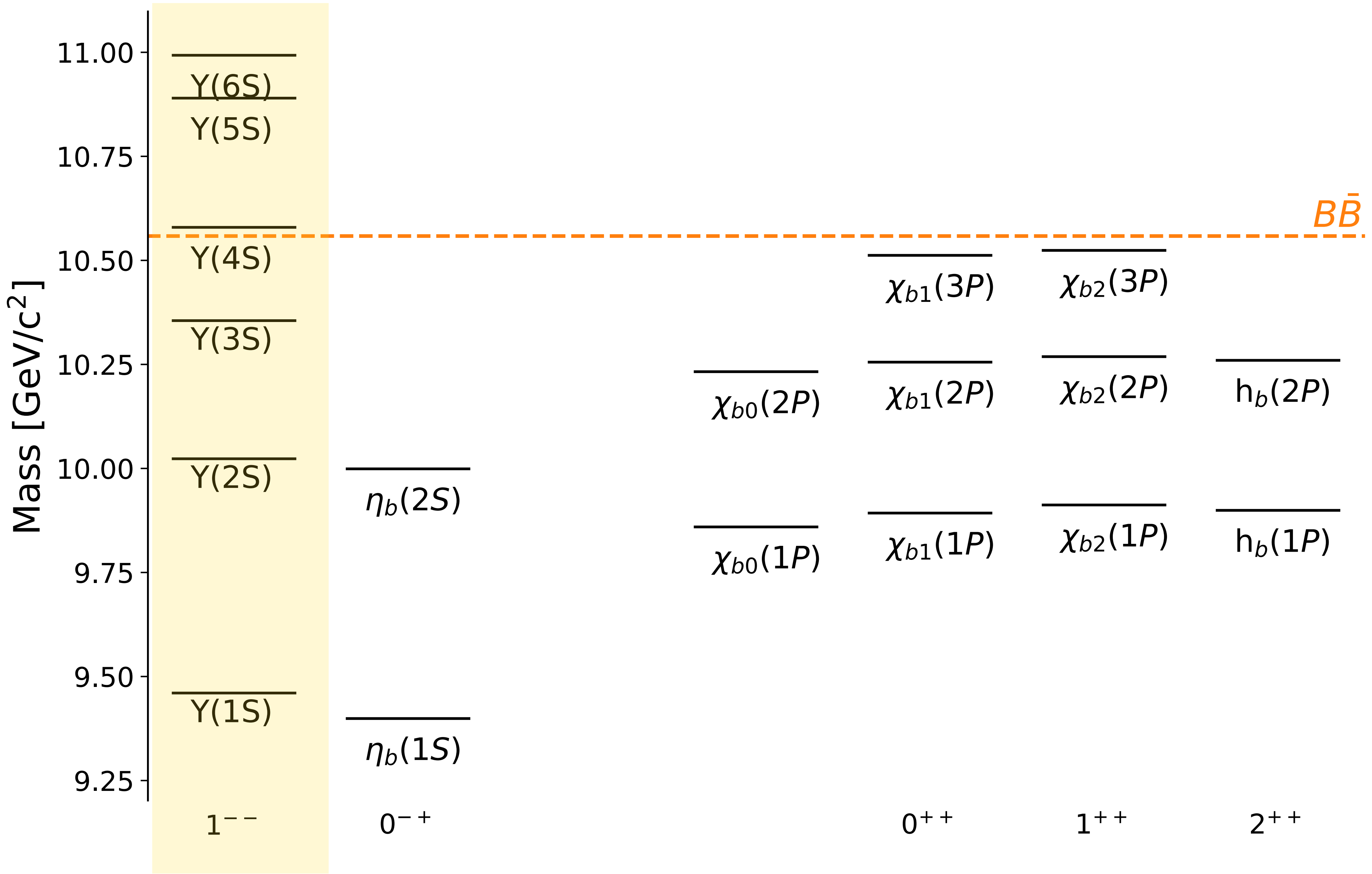
- **High luminosity**
- **Good reconstruction capabilities of charged tracks**

In the near future

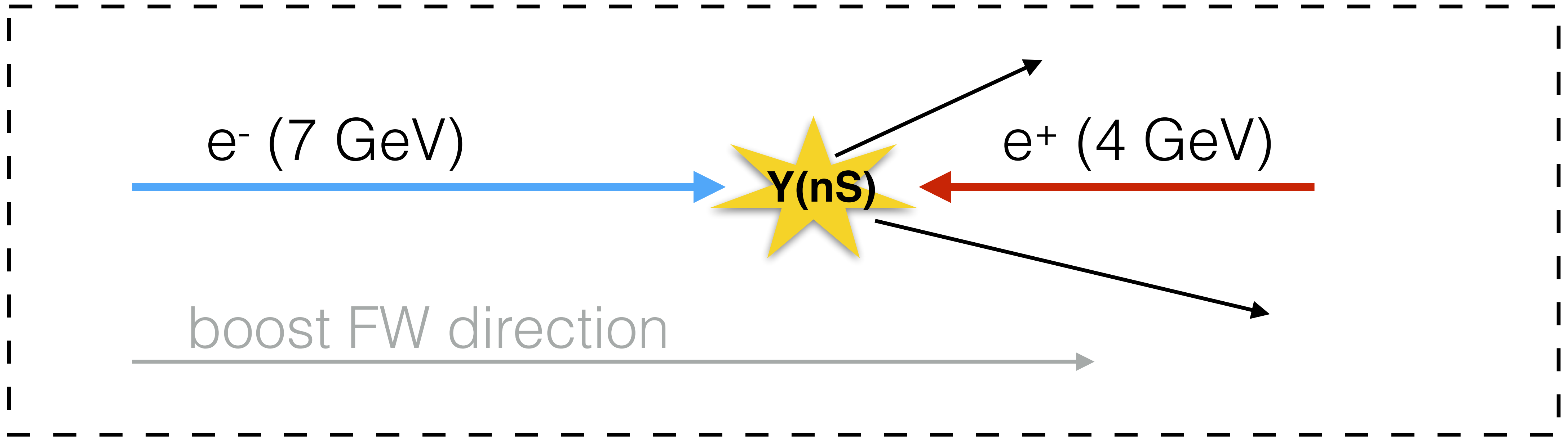
Belle II@SuperKEKB can play a major role!

SuperKEKB

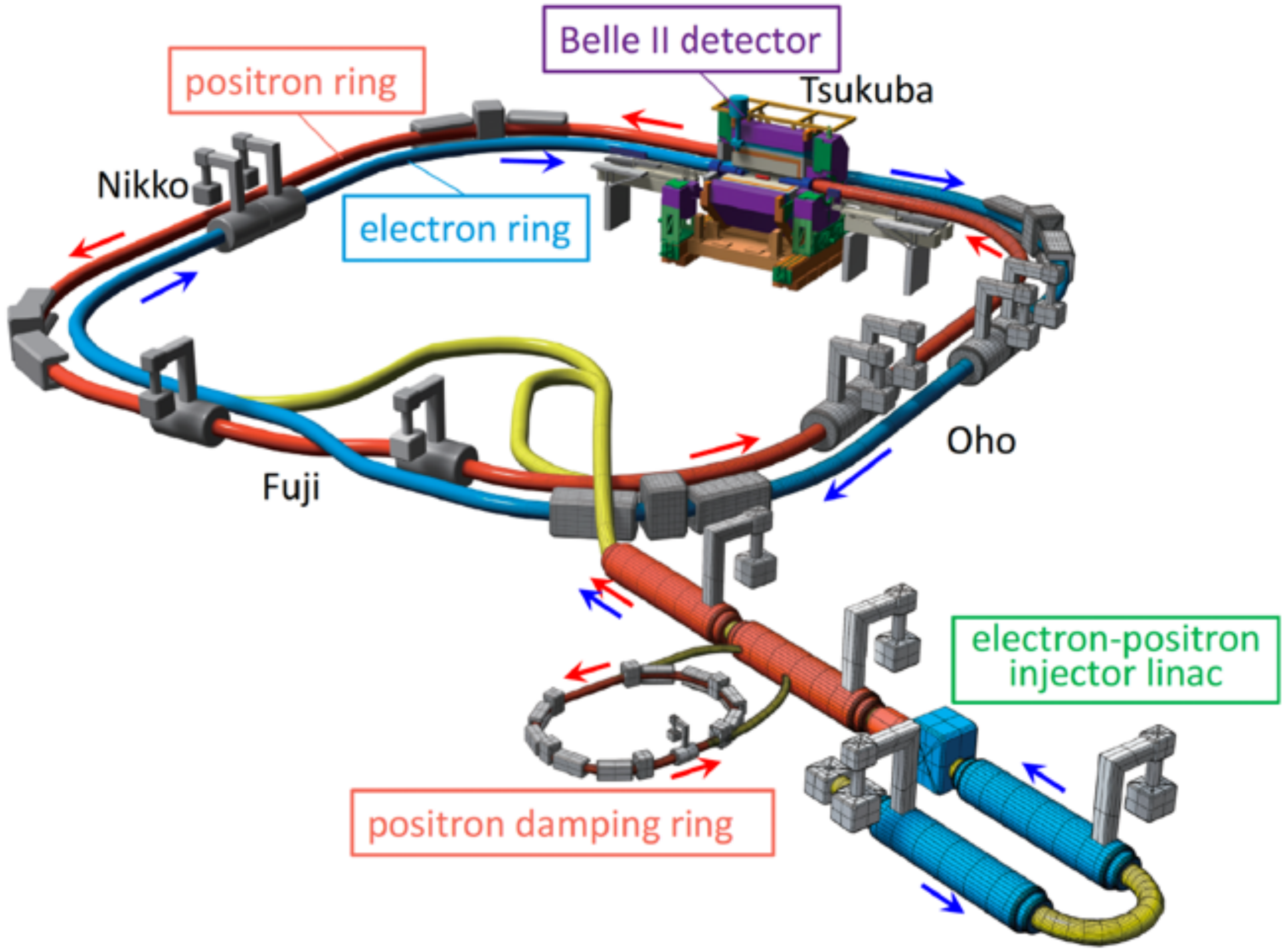
Spectrum of bottomonium ($b\bar{b}$)



E_{cm} ~ 10 GeV



SuperKEKB



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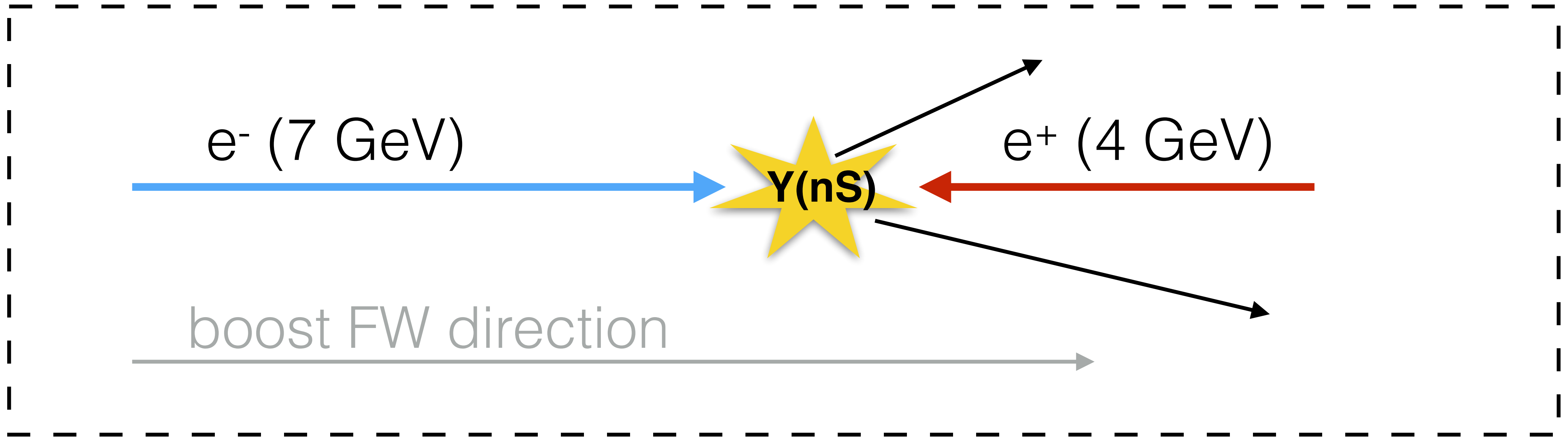
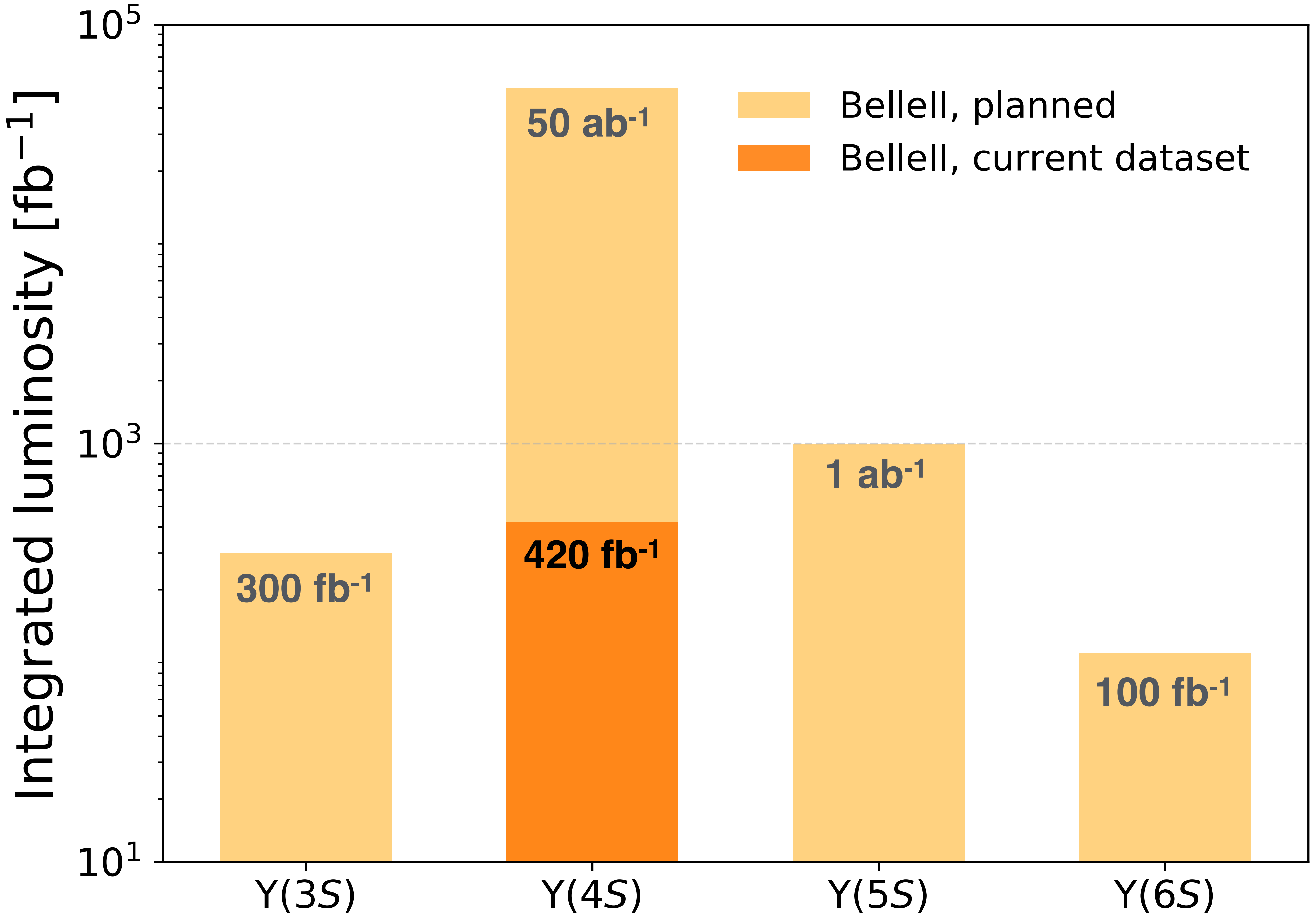
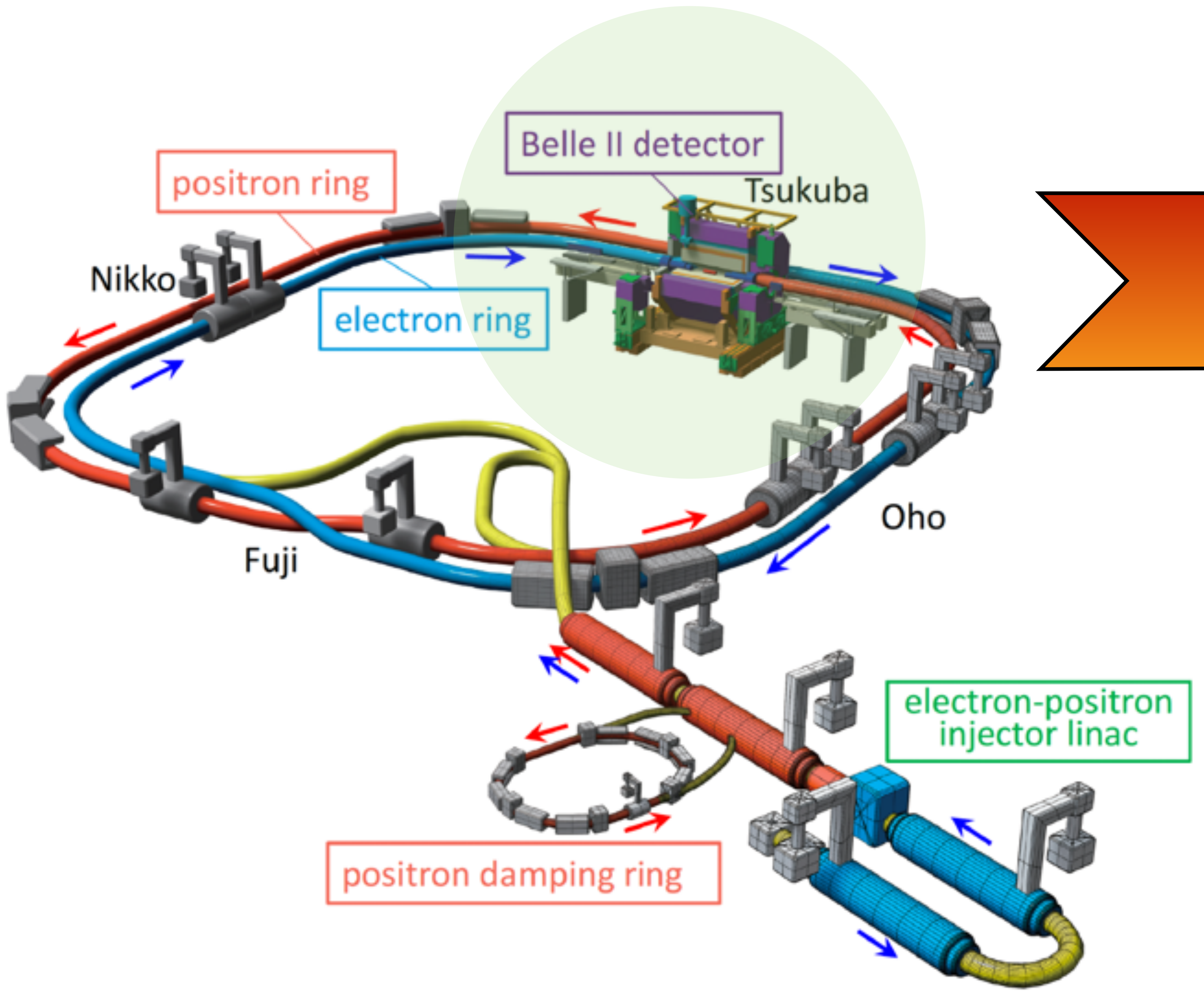
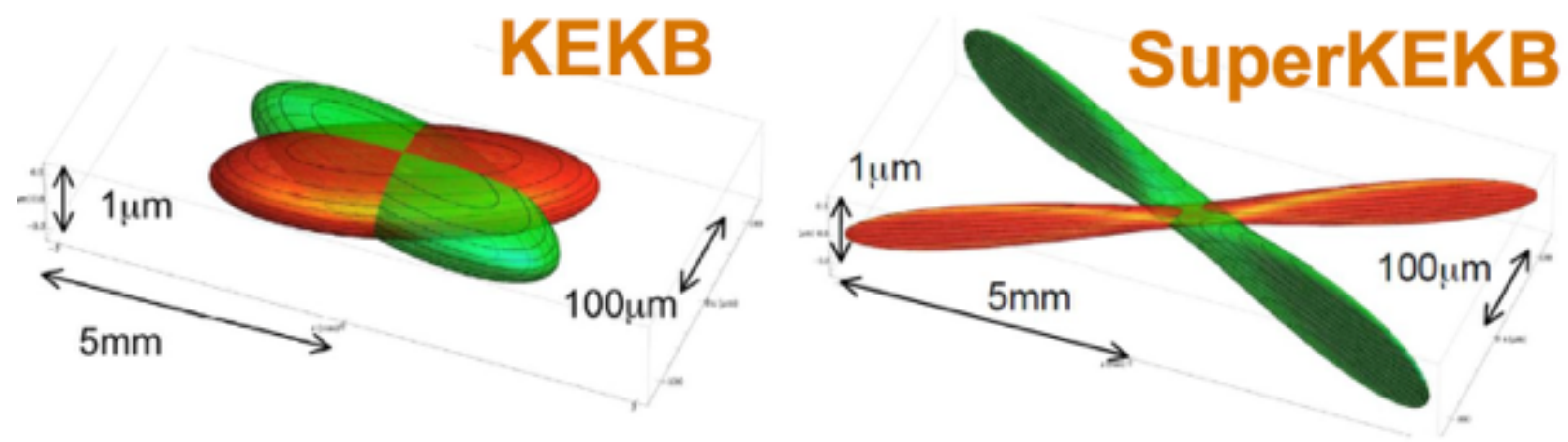


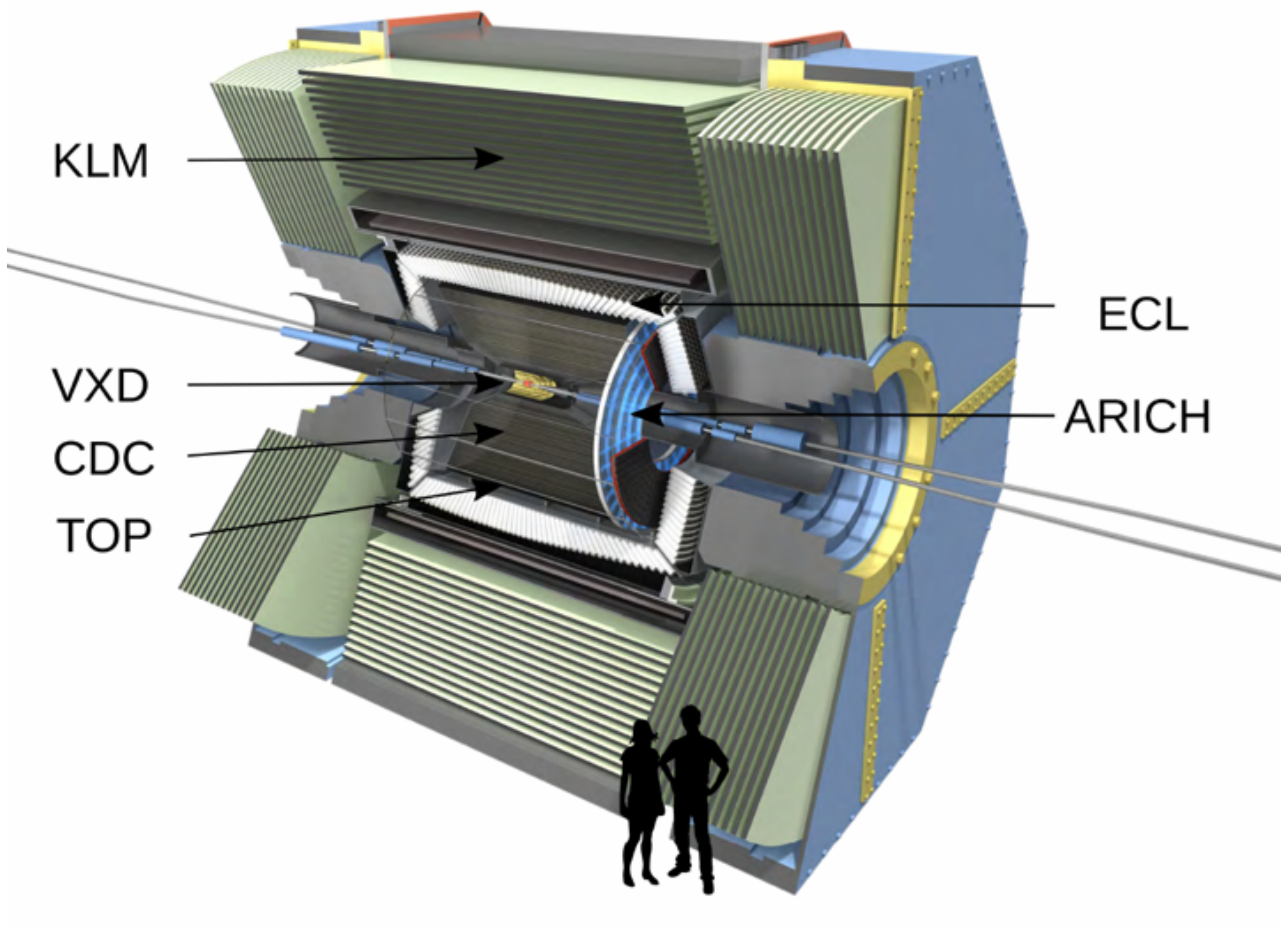
Belle II dataset



Belle II







arXiv:1011.0352, 2010

Tracking detectors

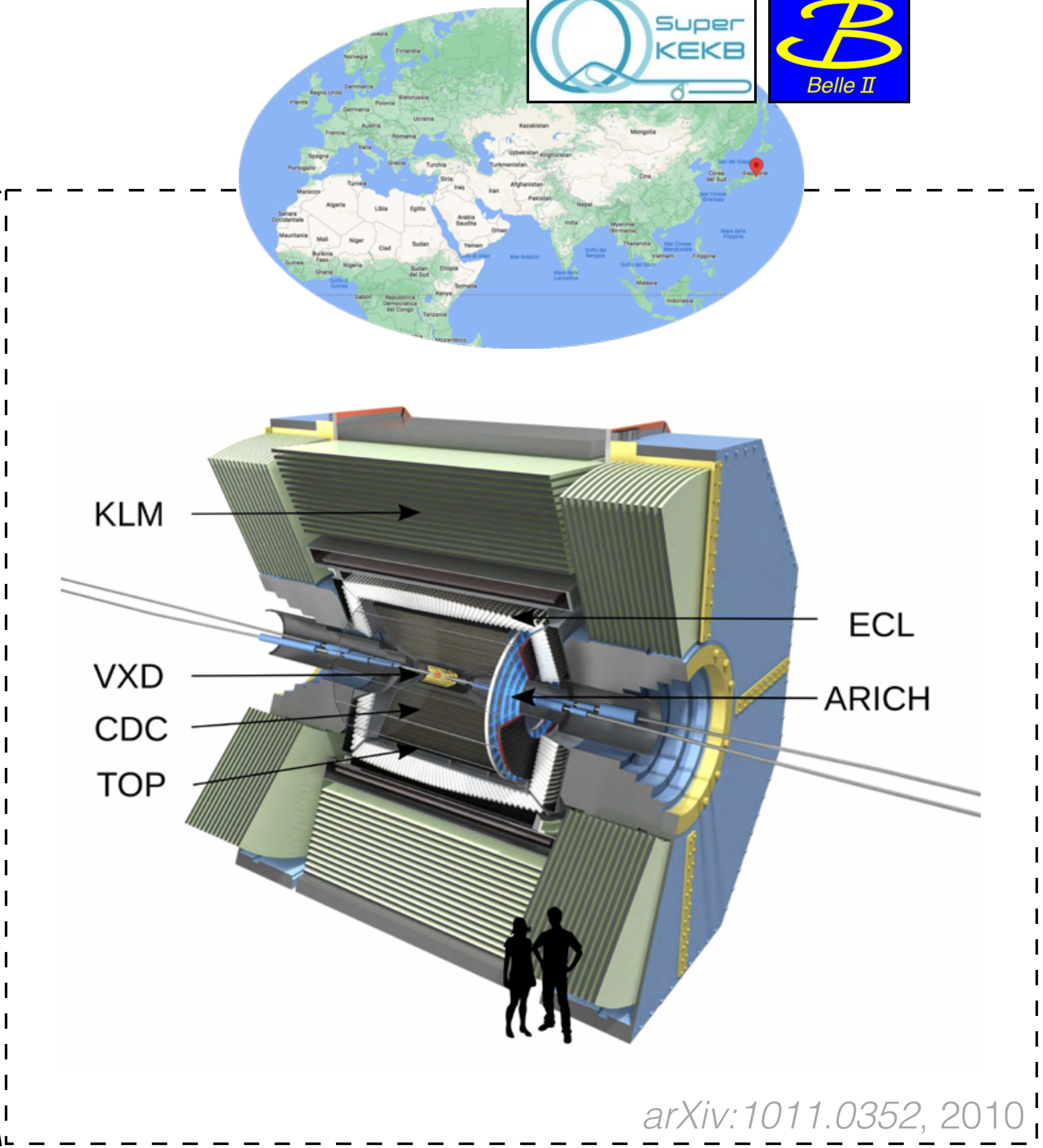
- VerteX Detector (VXD)
  - PiXel Detector (PXD, 2 layers)
  - Silicon Vertex Detector (SVD, 4 layers)
- Central Drift Chamber (CDC)

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_L and Muon detector (KLM)



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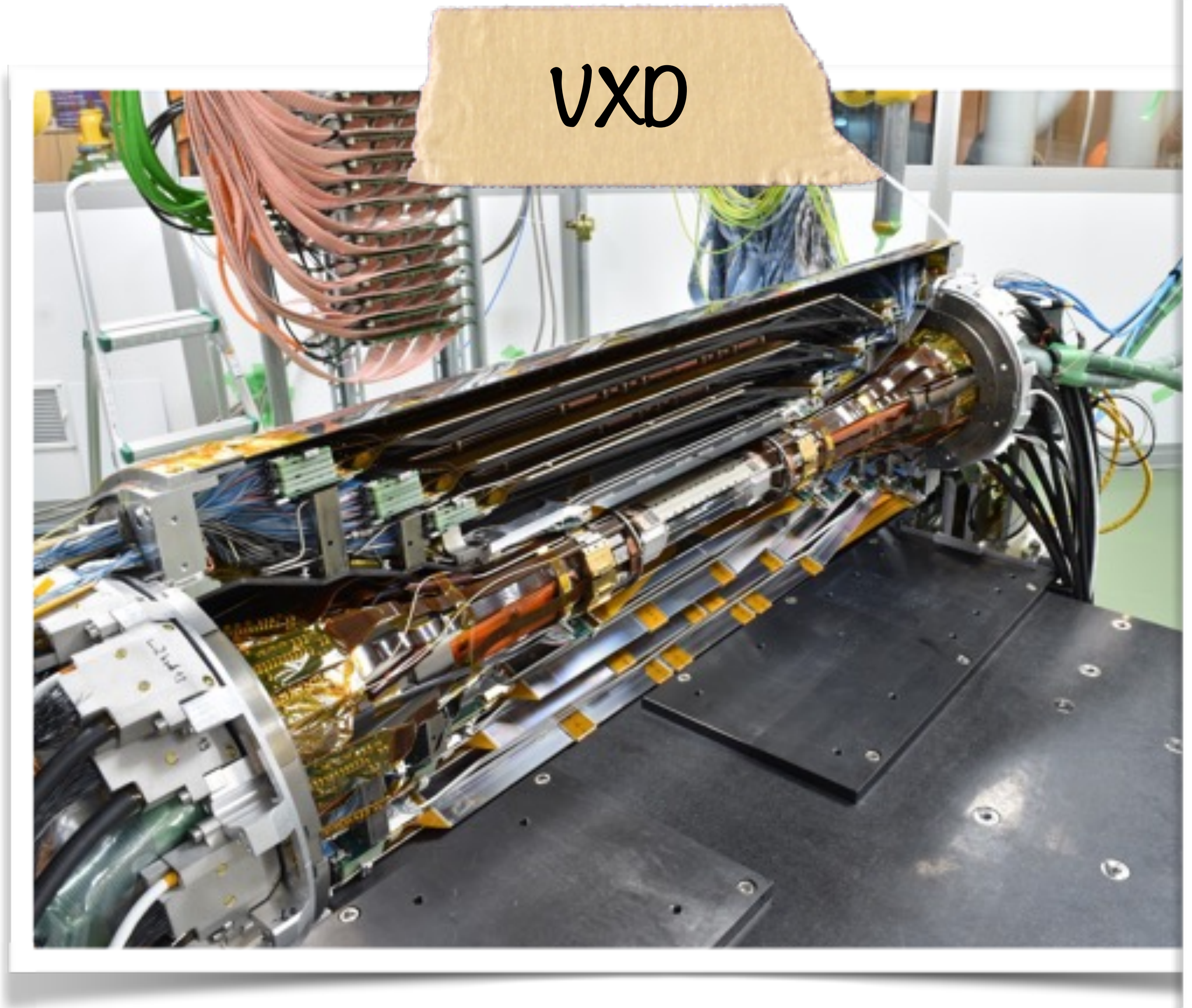
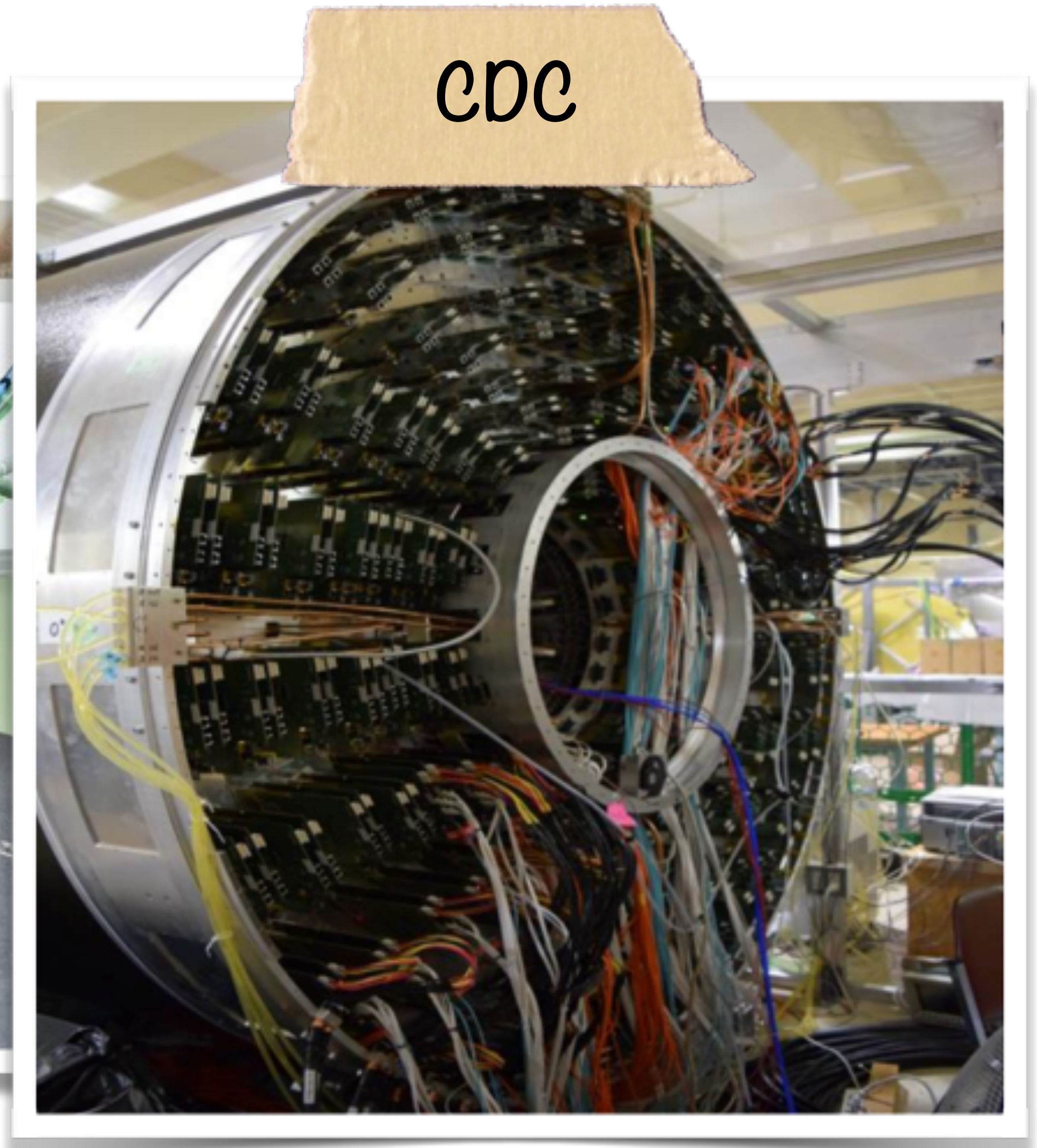
Tracking detectors

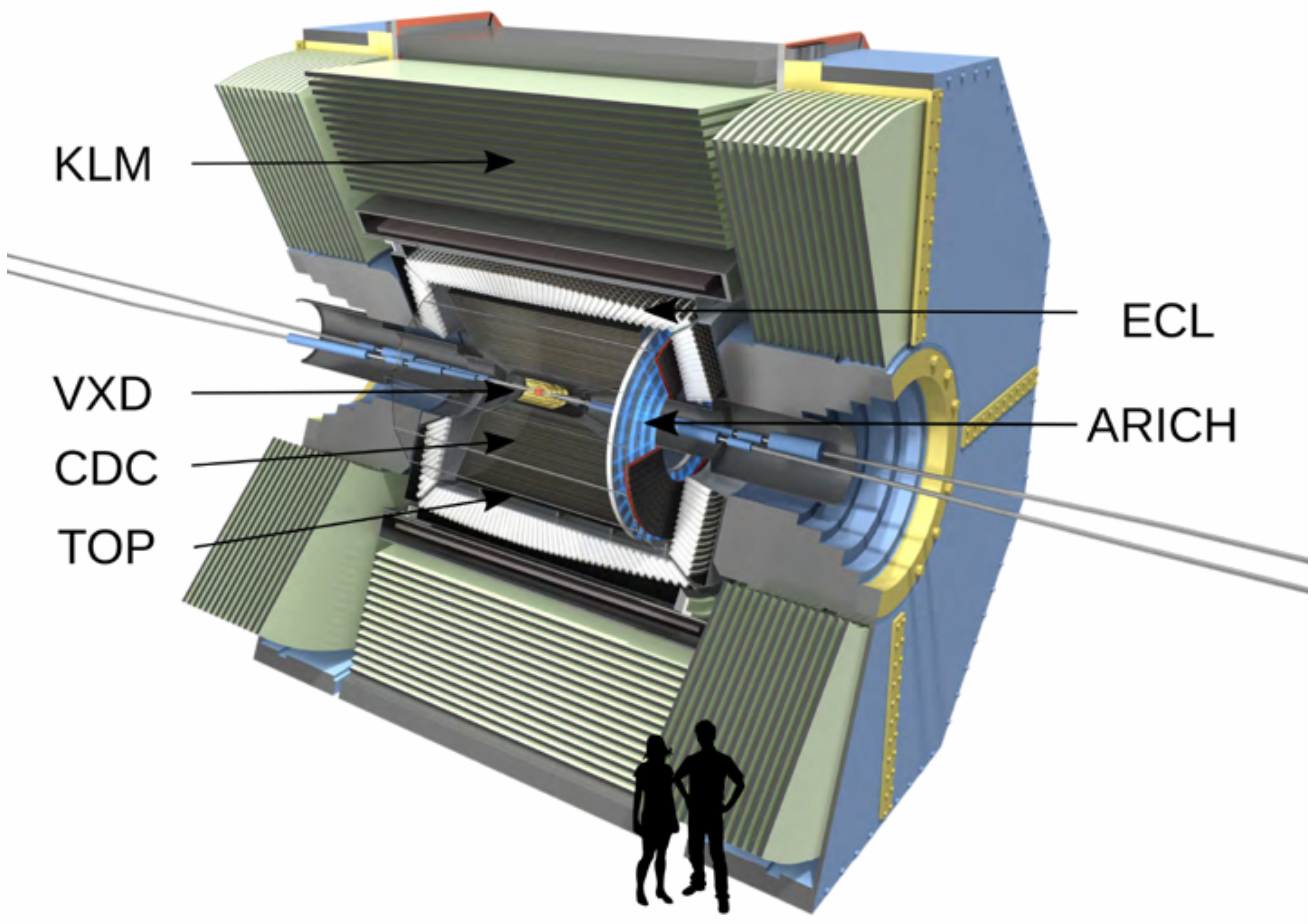
- VXD: PXD (2 layers) + SVD (4 layers)
- CDC



6 layers
r_{in} (L1) = 1.4 cm
r_{out} (L6) = 13.5 cm



56 layers
over 14K sense wires
r_{out} = 113 cm



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$\Upsilon(3S) \rightarrow H\,\Lambda\,\Lambda\,(+\,2n\,\pi)$: 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

Deeply bound uuddss hexaquark @ Belle II

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

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- Inputs from analysis
  - Signal efficiency ε_S
  - Number of background events F
  - CI = 90%
  - $N_{\Upsilon(3S)}$ depends on the luminosity
- Assumptions:
  - Poisson counting experiment, λ = F
  - H0: no signal, all observed events (n) are background (n = F)

Deeply bound uuddss hexaquark @ Belle II

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Υ(3S) → H Λ Λ (+ 2n π): analysis procedure

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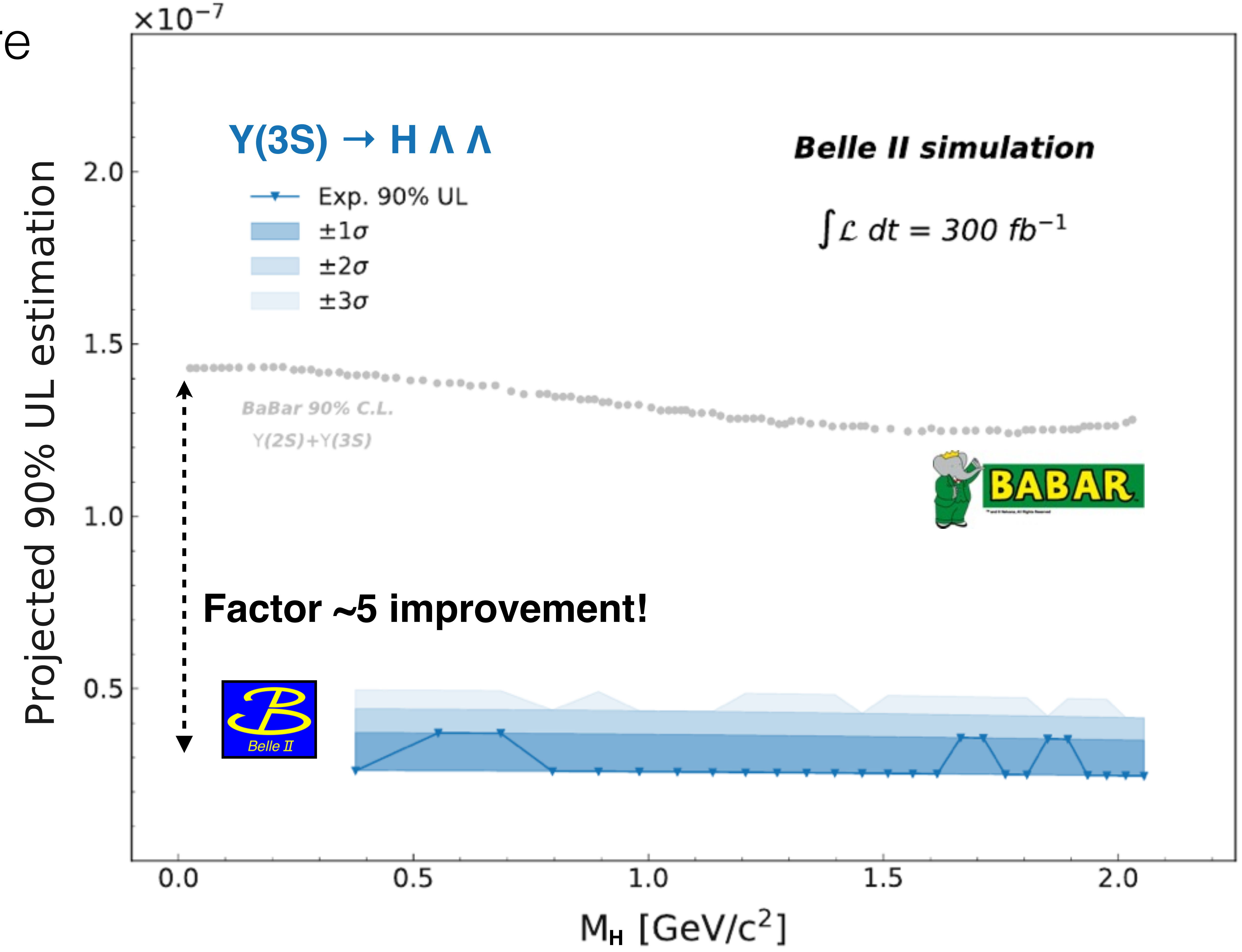

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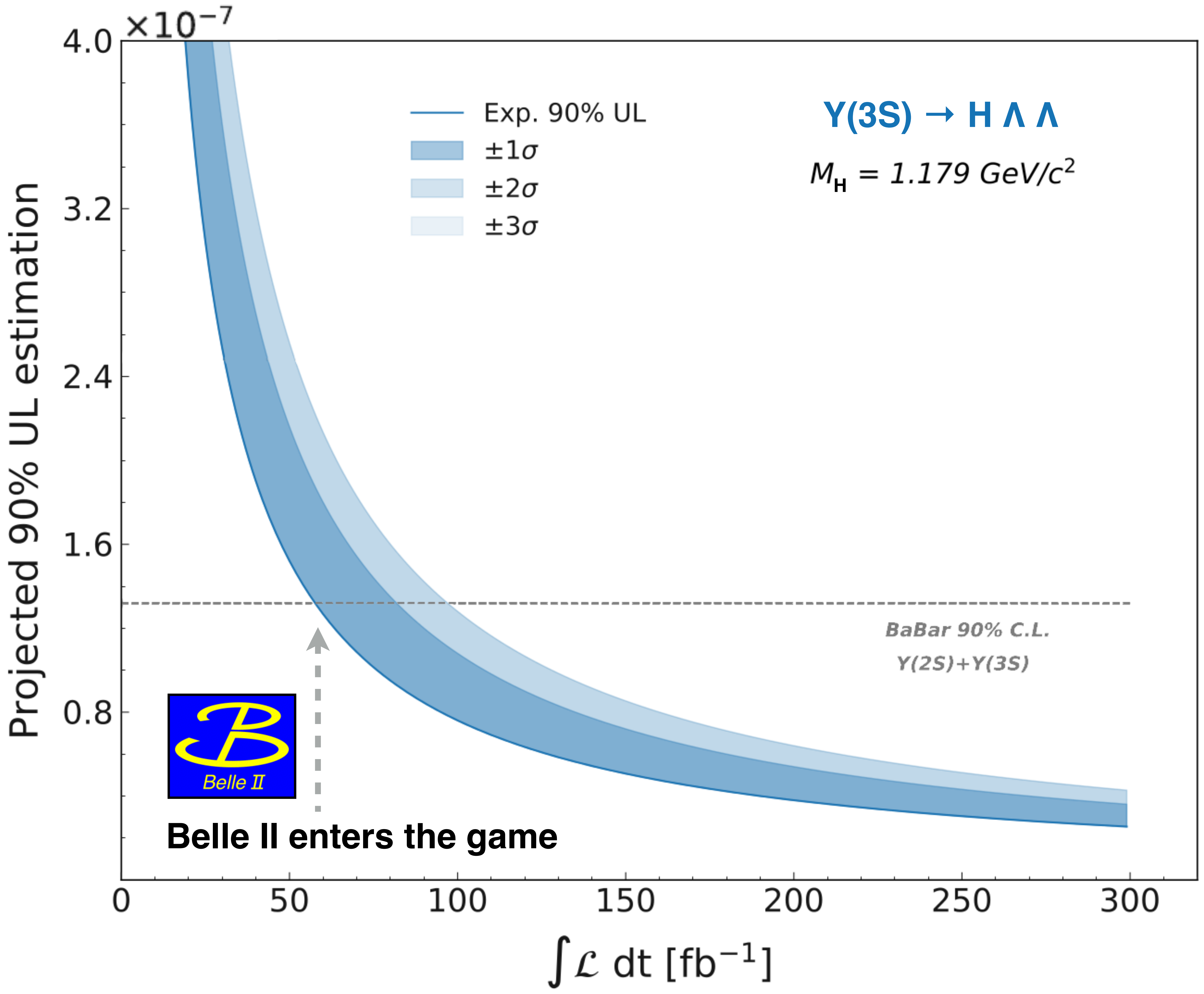
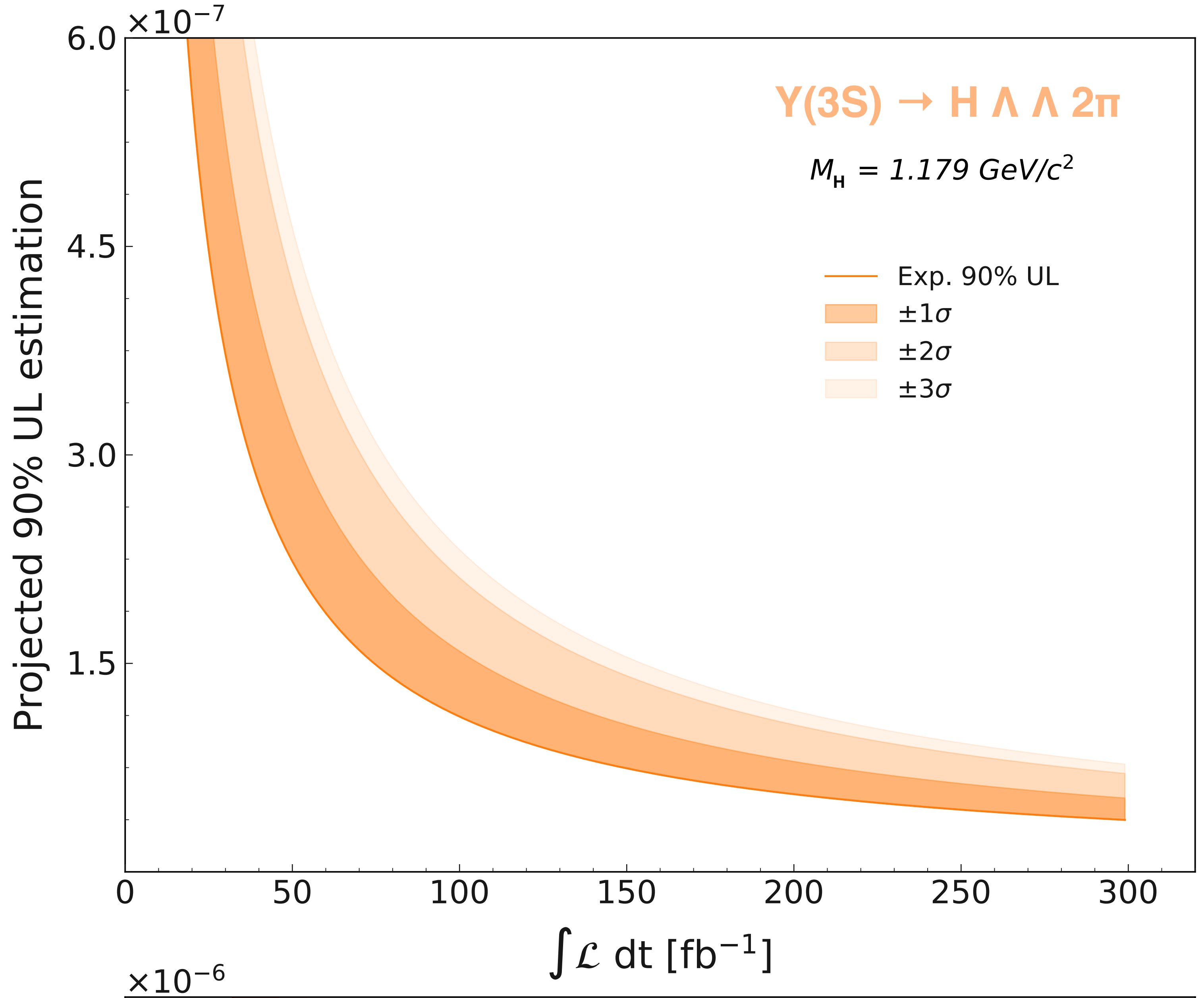
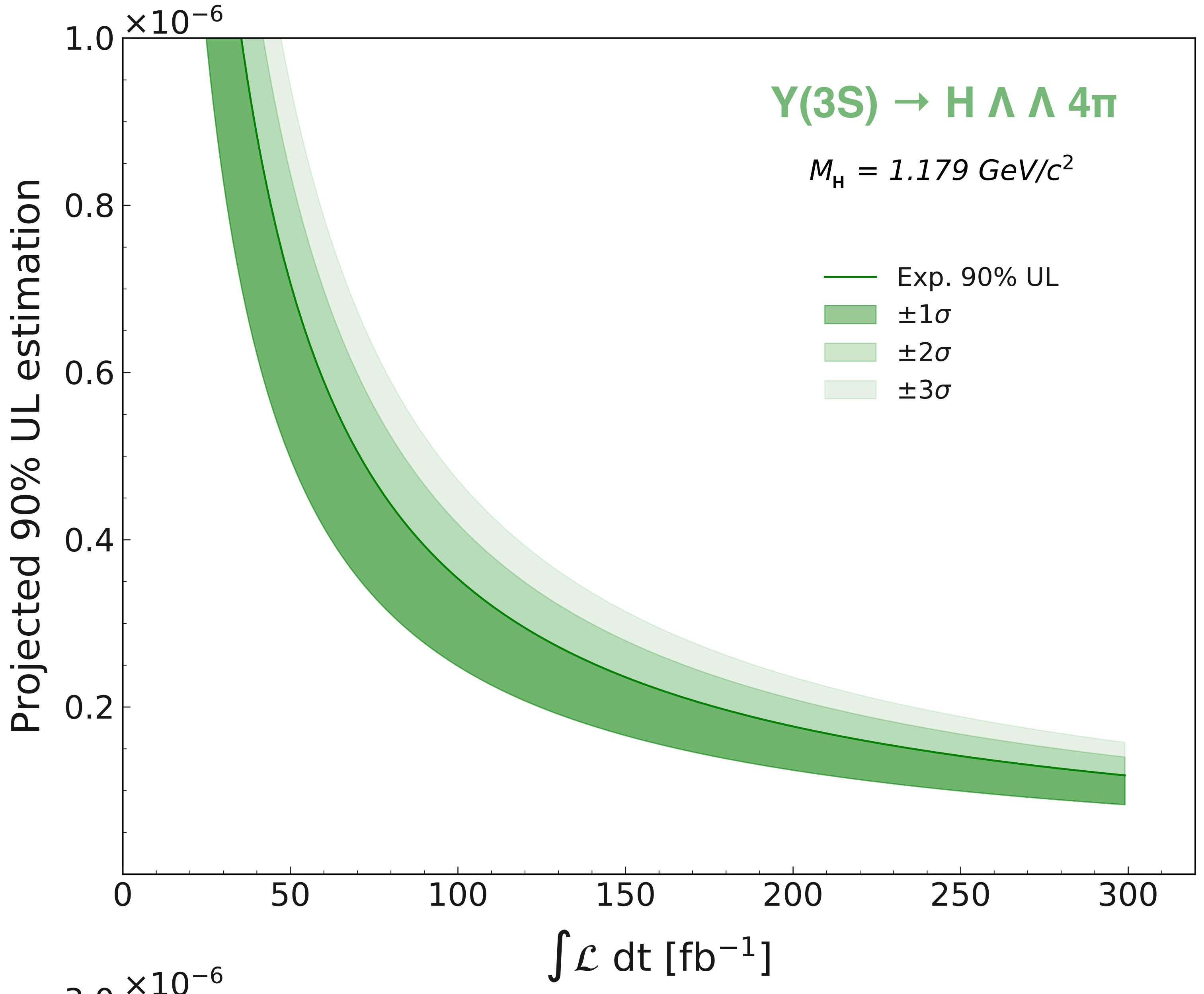
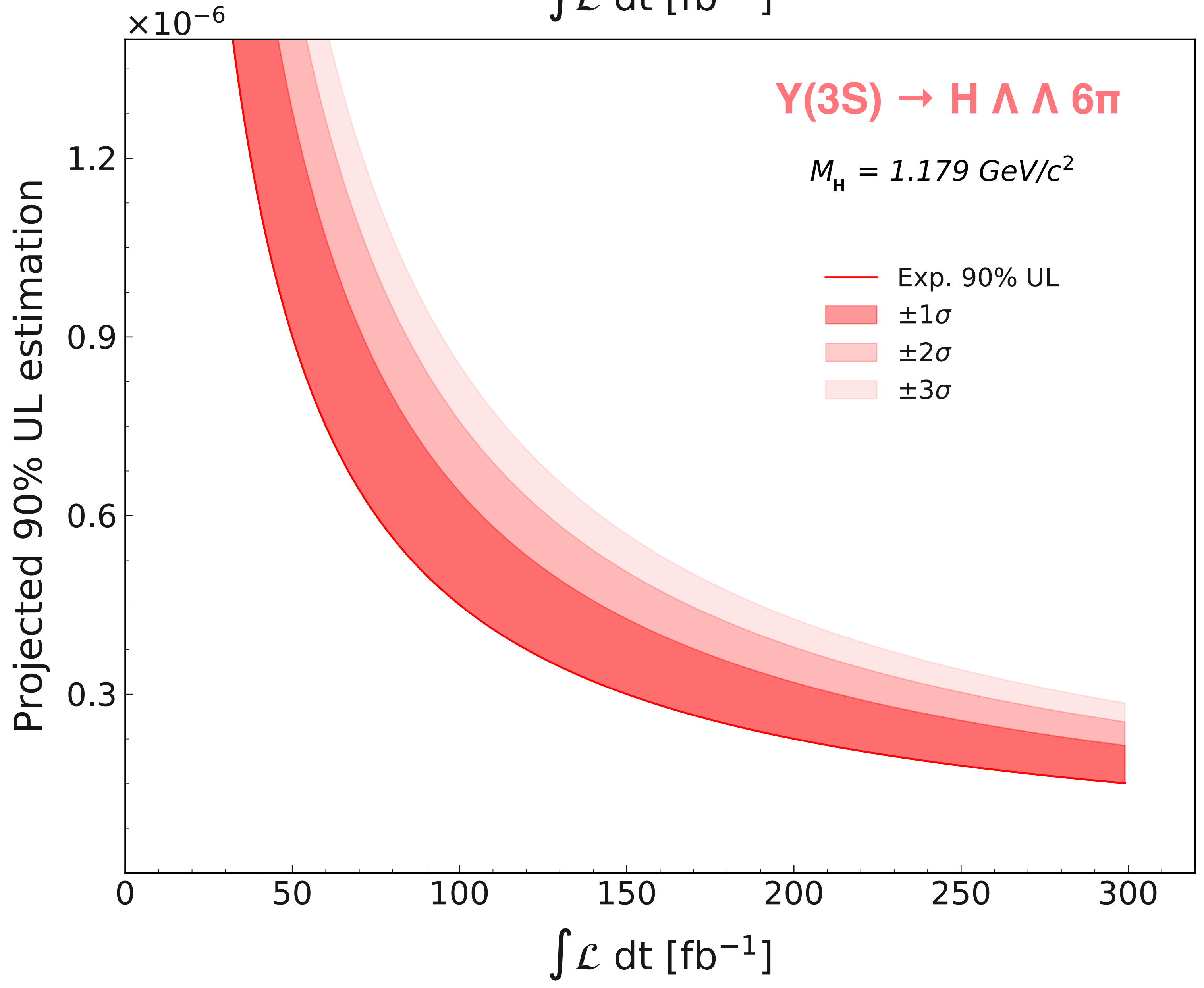


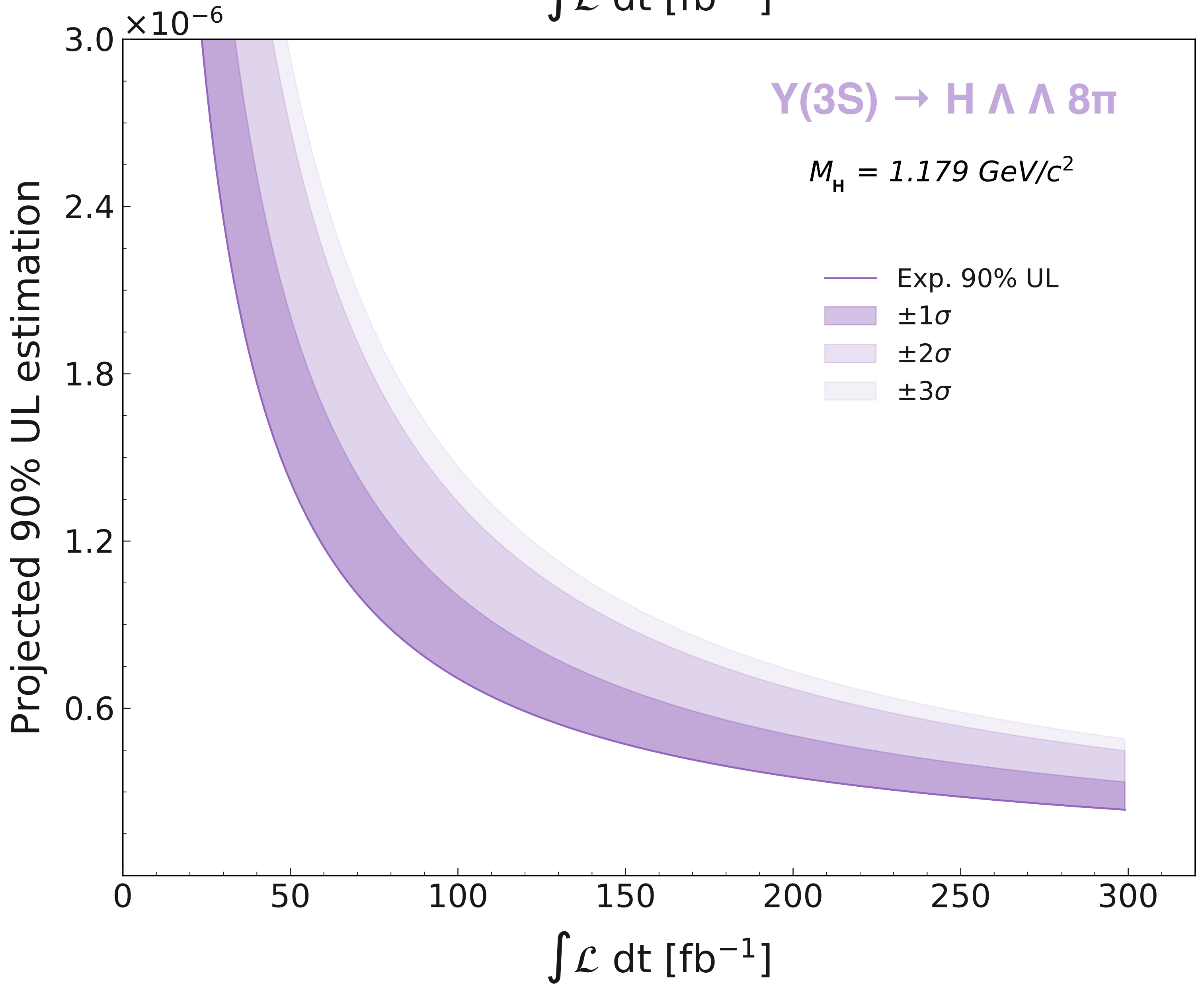
BABAR

Deeply bound uuddss hexaquark @ Belle II





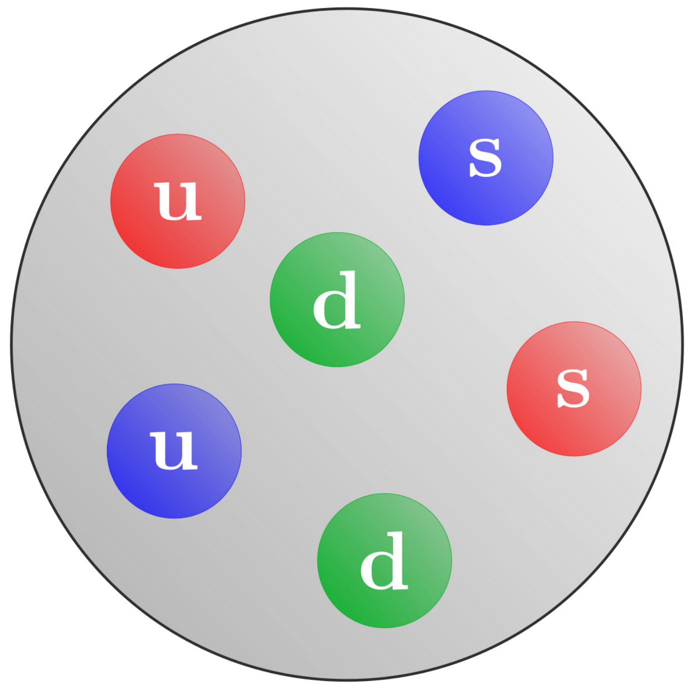




No existing limits from BaBar

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**

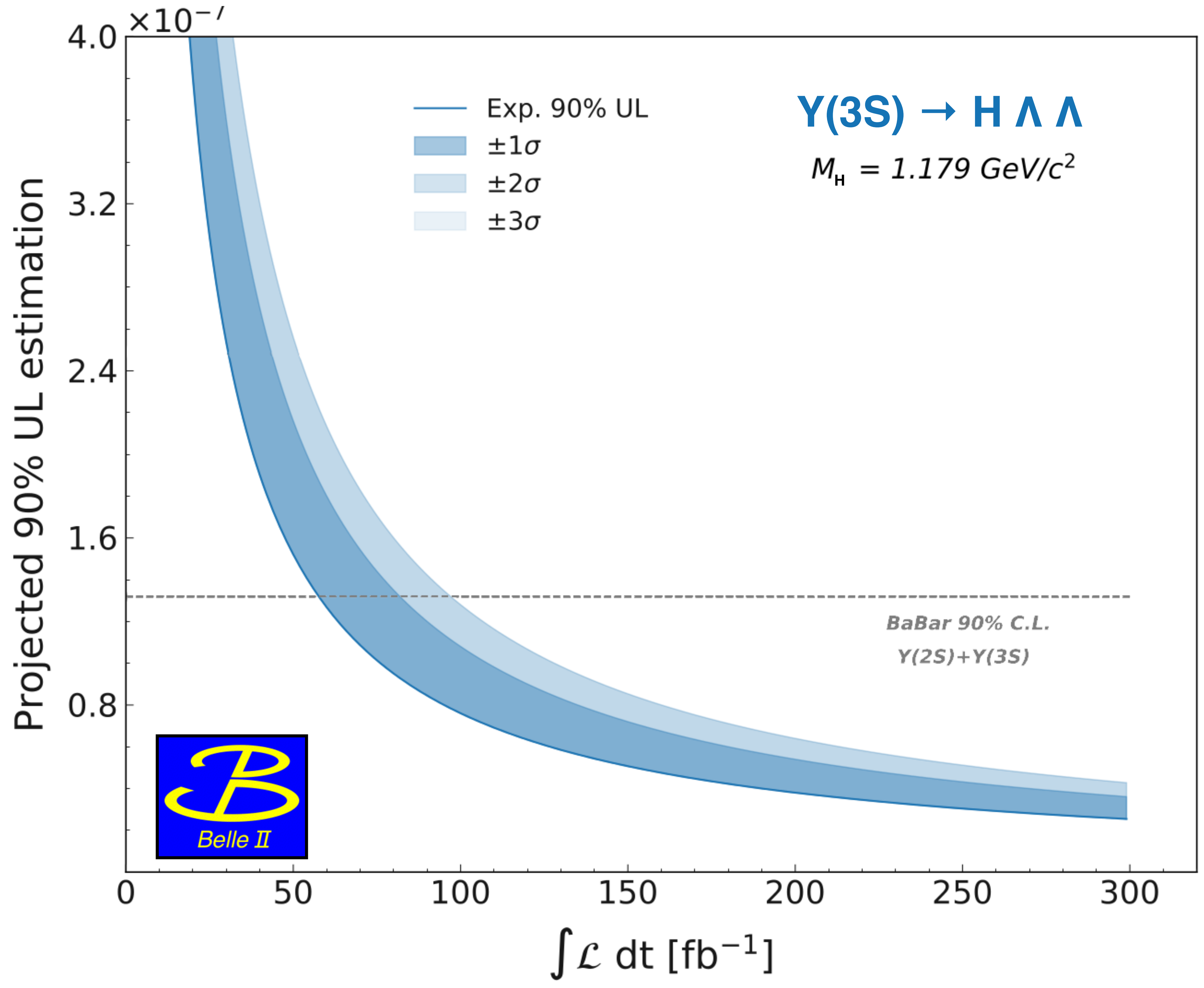
- *Belle: PRL 110, 222002 (2013)*
- *BaBar: PRL 122 (2019) 7, 072002*

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 πs, γ, ..)
- Improve UL estimation (more data)

Conclusions

- Exciting years ahead with the Belle II experiment
- Many intriguing perspectives for baryon and exotics physics (see also John Yelton's talk on Wednesday)
- Among others, **the search for a stable *H* @ Belle II in the decay of Υ(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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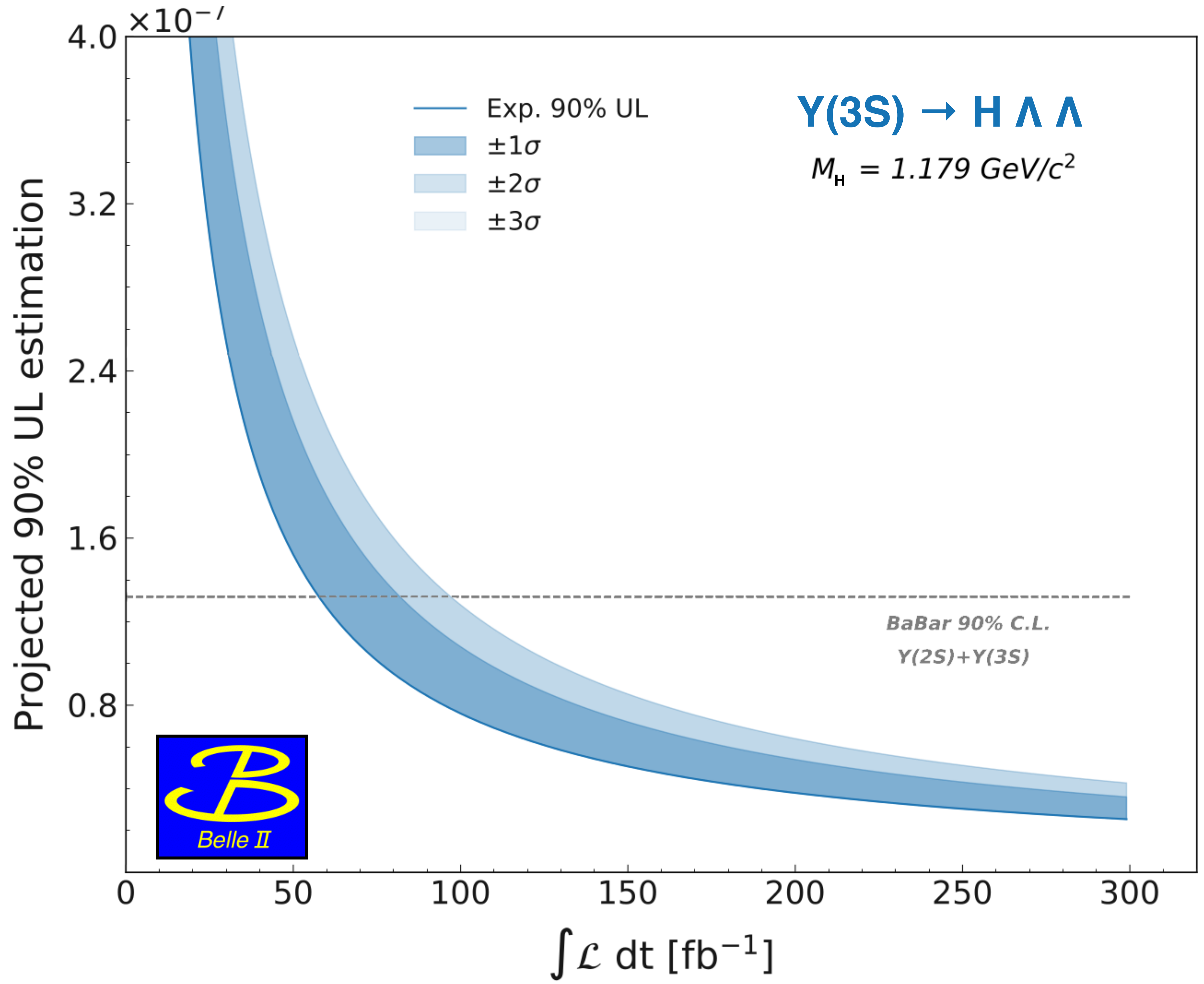
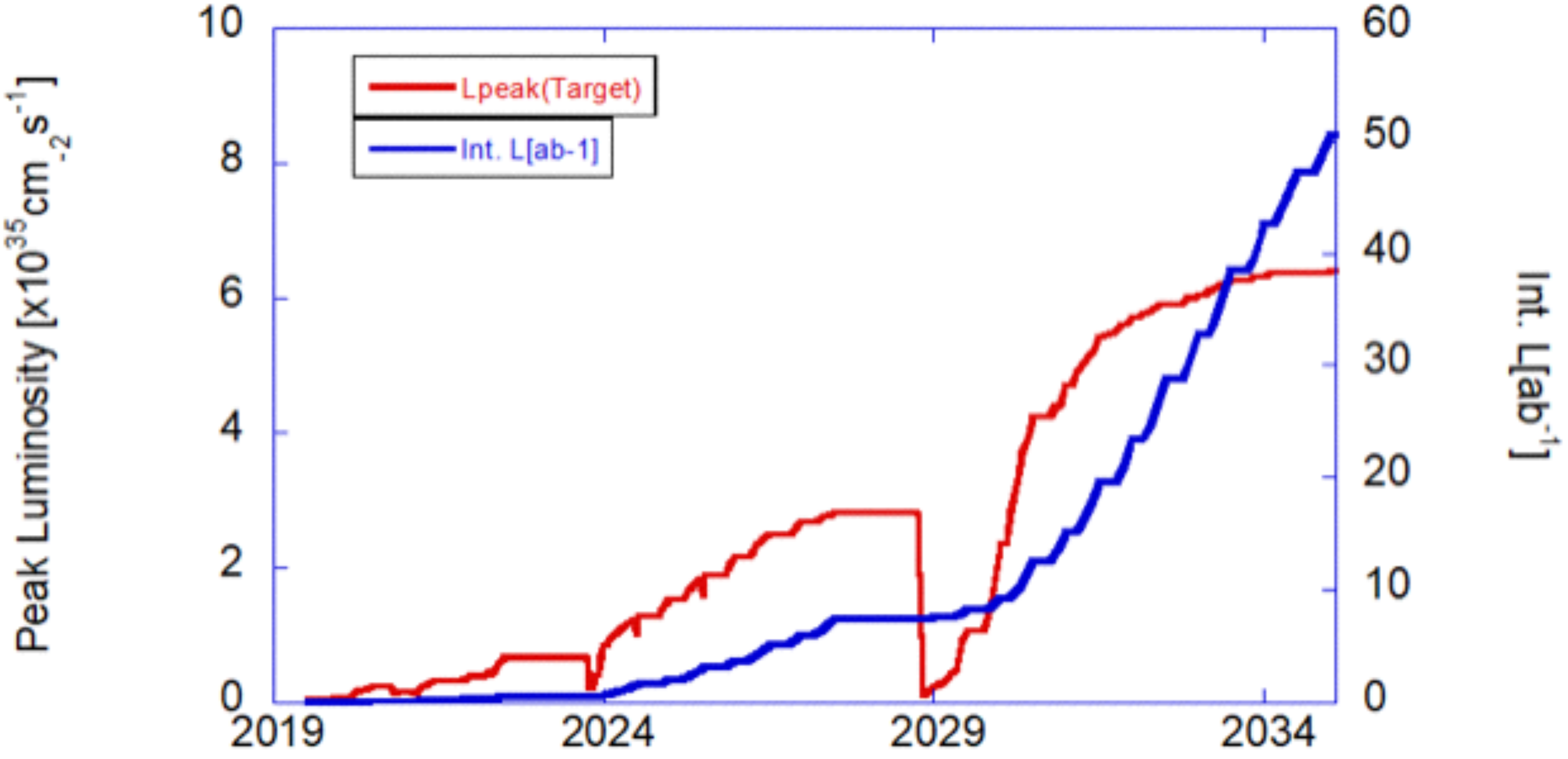


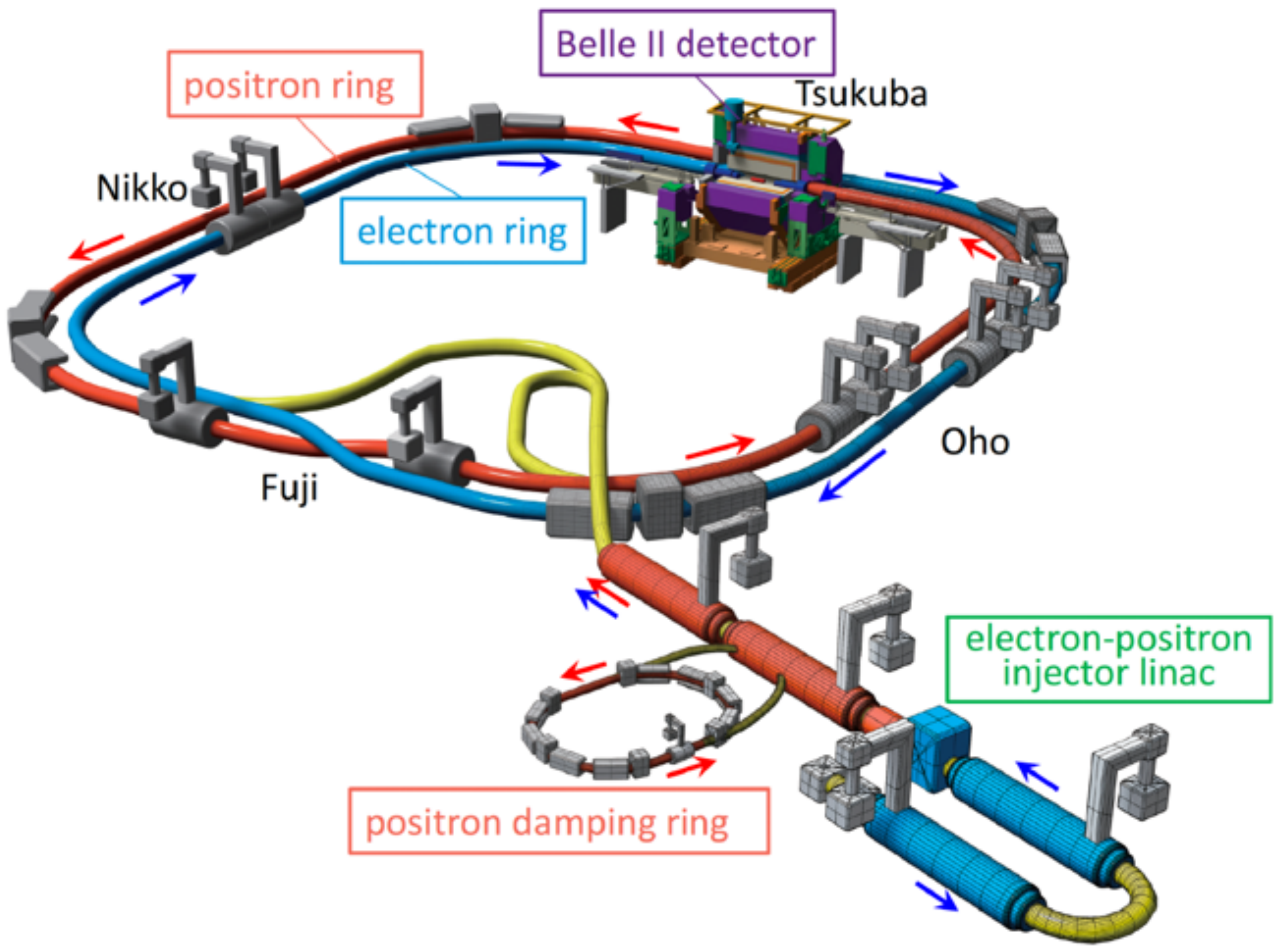
Thank you for your attention!

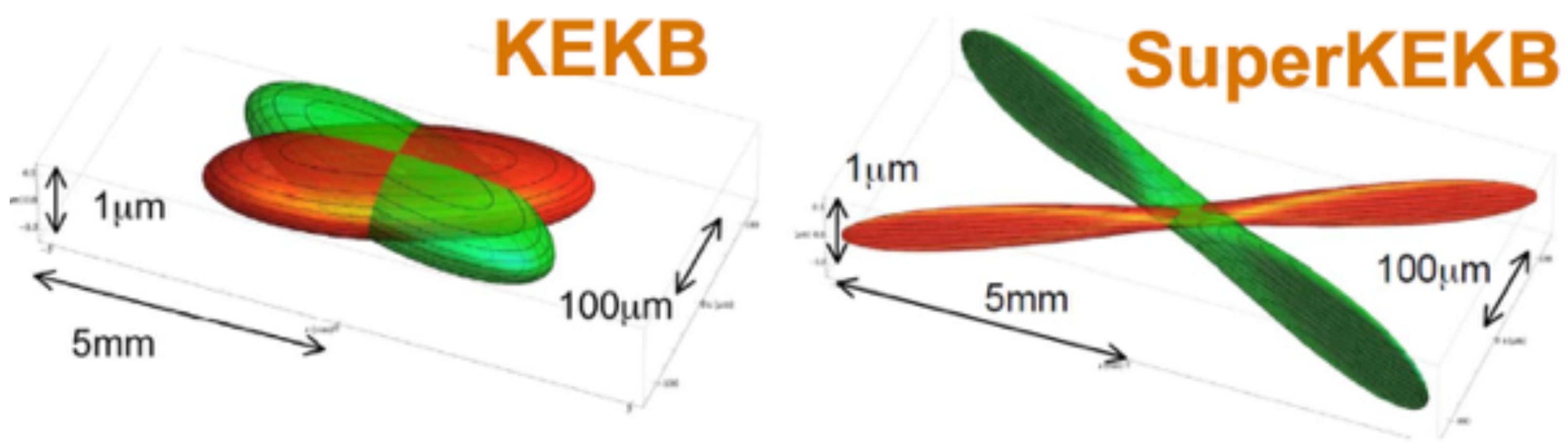
Additional material

Belle II, luminosity projection



SuperKEKB





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

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

	KEKB LER (e^+) / HER (e^-)	SuperKEKB LER (e^+) / HER (e^-)
E [GeV]	3.5 / 8.0	4.0 / 7.0
2ϕ [mrad]	22	83
ξ_x	0.127 / 0.102	0.0028 / 0.0012
ξ_y	0.129 / 0.090	0.088 / 0.081
β_y^*	5.9 / 5.9	0.27 / 0.30
I [A]	1.64 / 1.19	3.60 / 2.60
σ_x^* [μm]	147 / 170	10.1 / 10.7
σ_y^* [nm]	940 / 940	48 / 62
$\mathcal{L}$ [10^{35} cm^{-2} s^{-1}]	0.211	8
$\int \mathcal{L}$ dt[ab$^-$1]	1	50