Long-Lived Particles at Belle II and GAZELLE

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with

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First GAZELLE idea last year (draft never published)

Prospecting for long lived particles with GAZELLE

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We propose a new experiment GAZELLE (GAZELLE is the Approximately Zero-background Experiment for Long-Lived Exotics) at SuperKEKB, Tsukuba, Japan, to search for long lived particles

LOI for Snowmass21

RF6-2 Letter of Interest (LOI):
Long-lived particles at Belle II

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Meeting started two weeks ago

Where are food and wine?

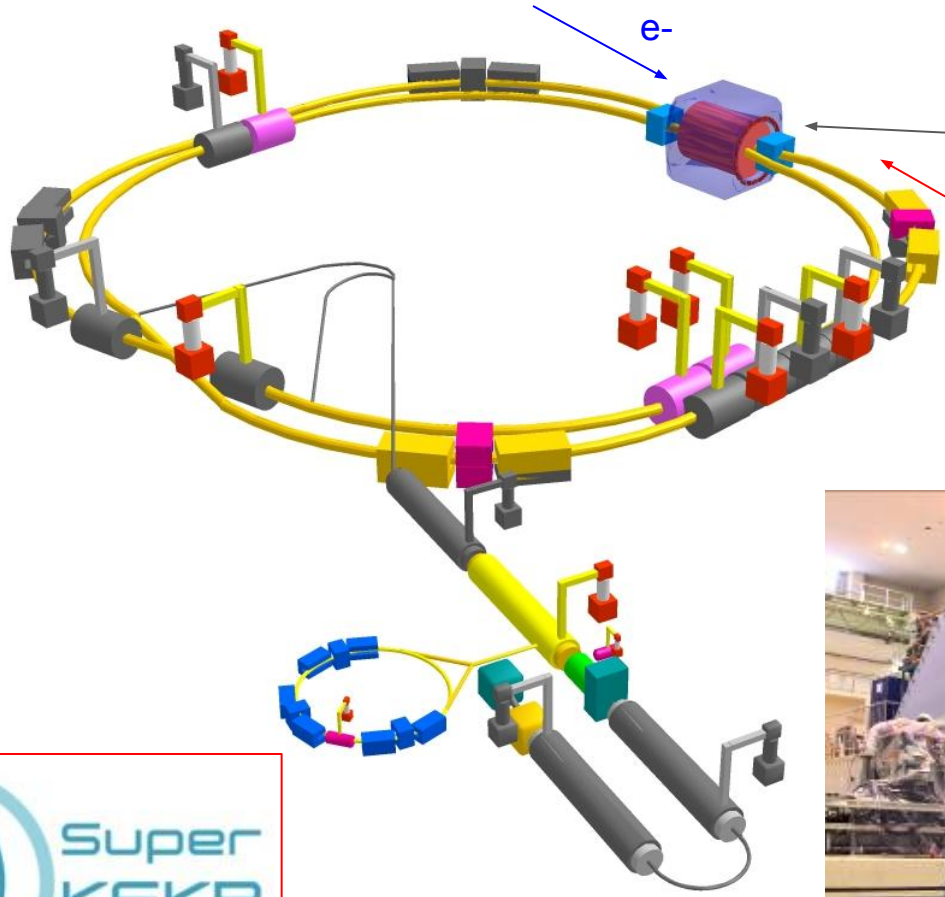
Due to Covid, meeting informally and ”shooting” ideas and questions is nearly impossible.

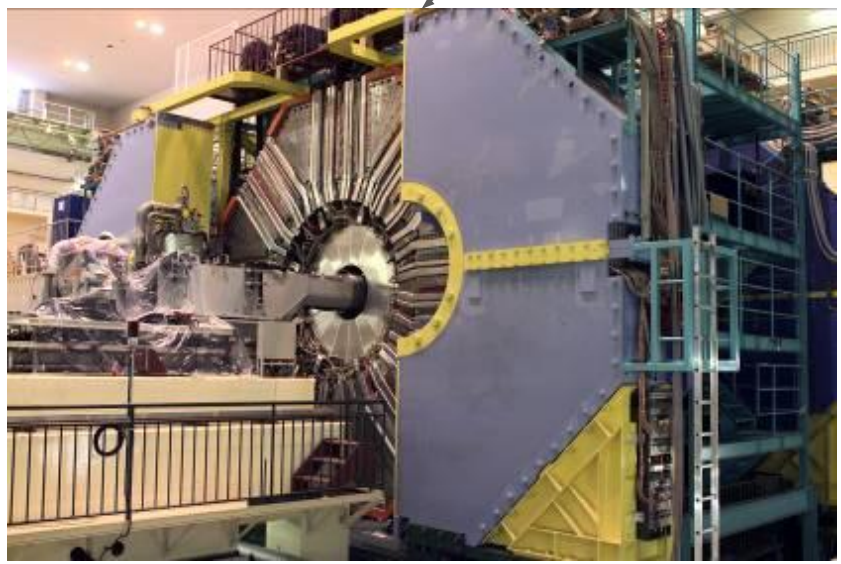
Sadly, instead of food and wine at Belica, I only have...

- Food for thoughts: Belle II potential for NP searches, interesting models for LLPs.
- Food for questions: work is at very initial stage, inputs and questions are welcome.
- Food for collaborations: short-term goal is to submit a ”white-paper(s)” for Snowmass21, if anyone wants to jump in.

Belle II at SuperKEKB

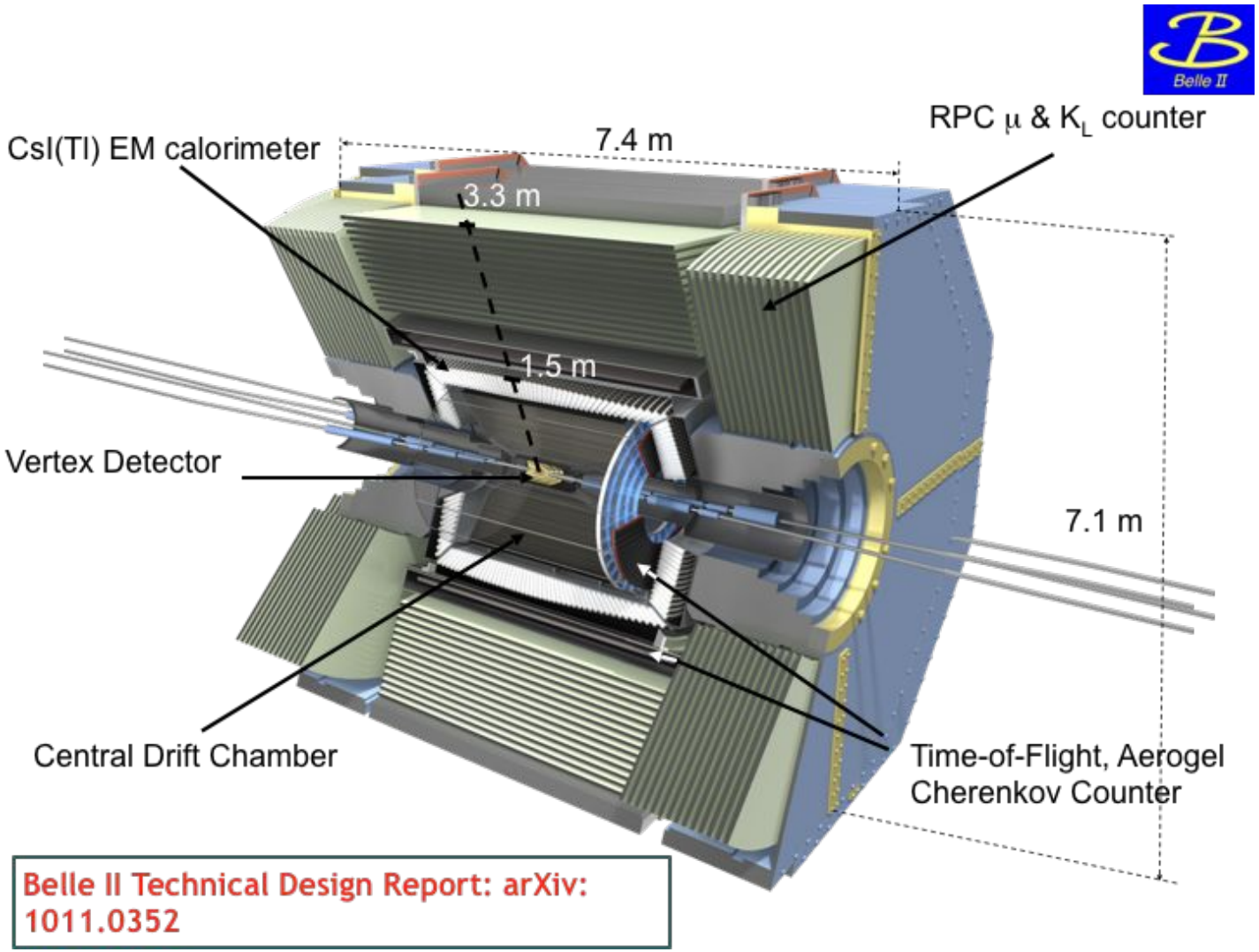
SuperKEKB: circular Electron - Positron collider in Tsukuba, Japan





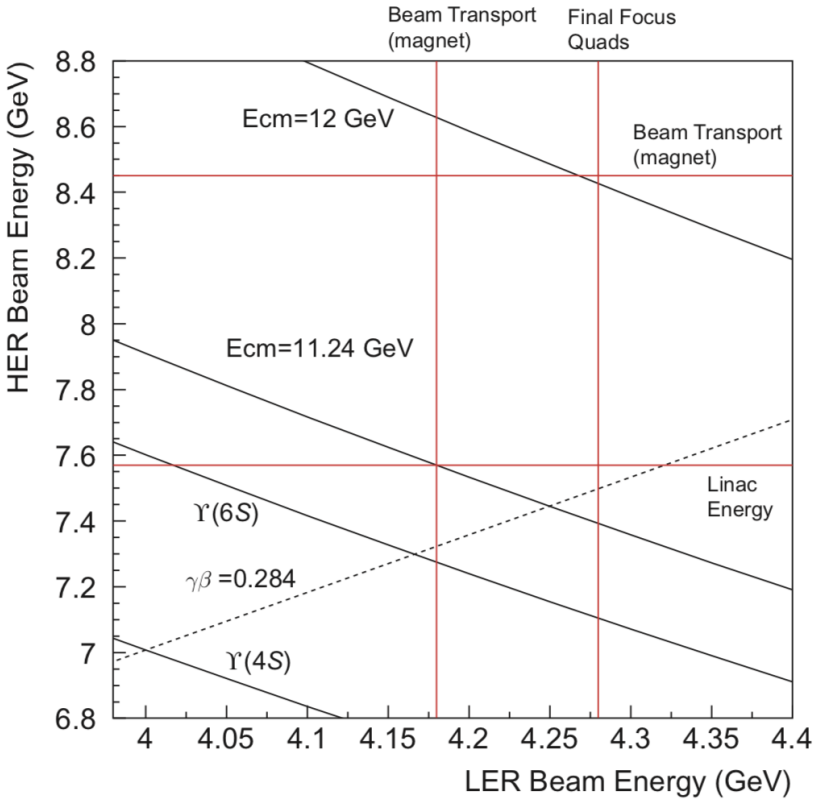
Belle II at SuperKEKB

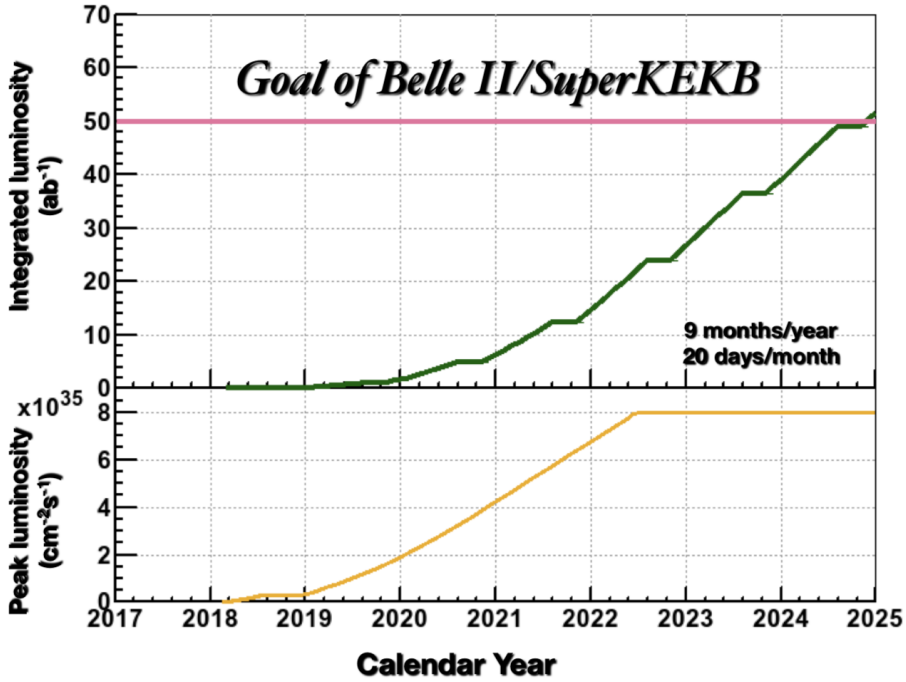
Wide angle coverage ($\sim 17^\circ - 150^\circ$) and low-background [Belle II Physics Book: 1808.10567].



Belle II at SuperKEKB

COM energy on the $\Upsilon(4S)(10.58\ \mathrm{GeV})$ resonance, produces $B^0\bar{B}^0$ pairs in 1^{--} state.





Luminosity goal is $50\ ab^{-1}$ $\rightarrow$ $\sim 10^{11}$ B, D and τ pairs produced

Long Lived Particles

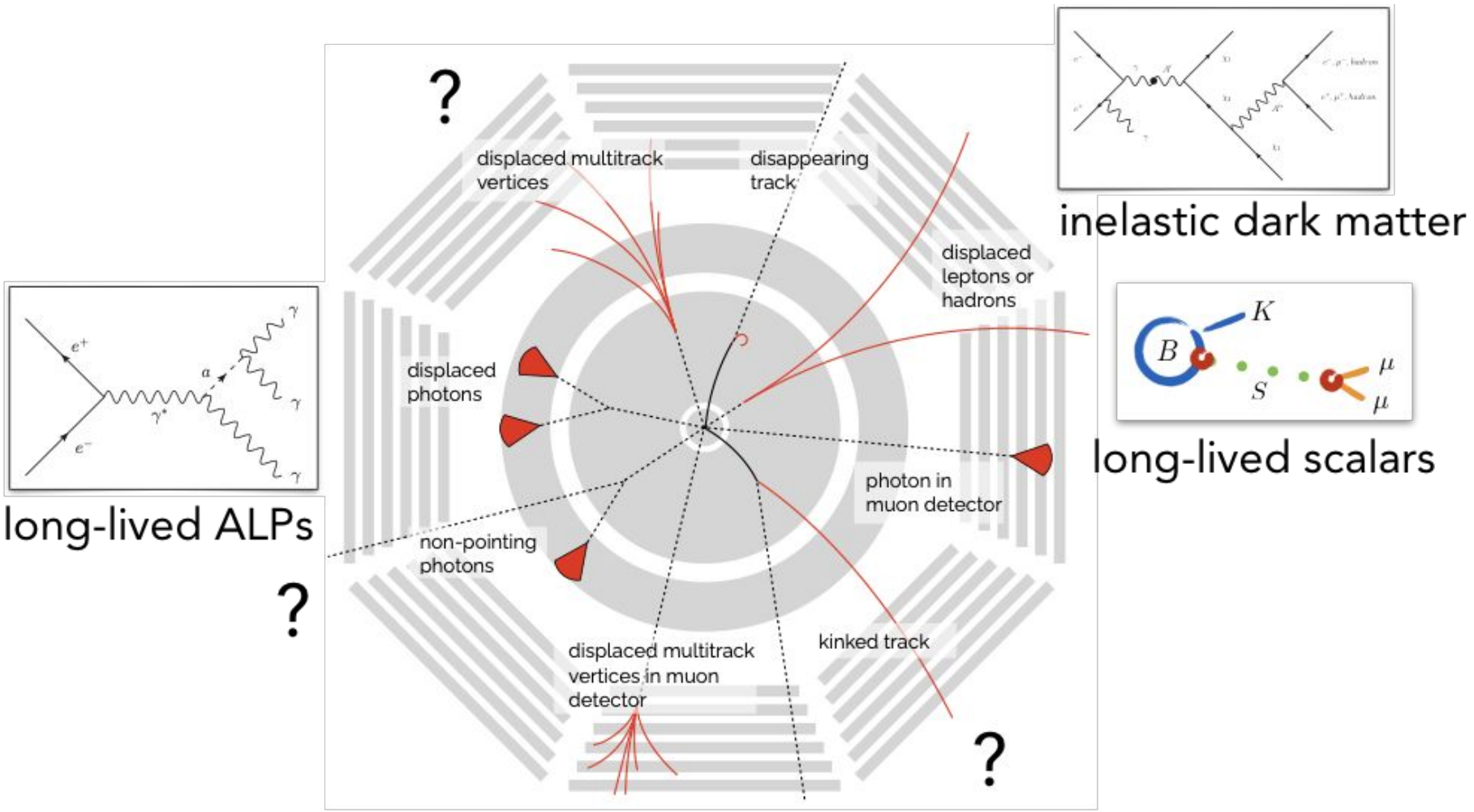
Long w.r.t. detector scales: displaced vertices or invisible decays.

Wide variety of physical motivations:

- Mediators to a Dark Sector (ex: dark photons)
- New $\sim$GeV scalar and pseudoscalars (ex: ALPs)
- Flavor specific models (ex: Heavy Neutral Leptons)

Other ideas?

Belle II gains in LLPs searches thanks to geometry (longer lifetimes) and luminosity (higher statistics)



Thanks Susanne Westhoff for the picture

What can we do?

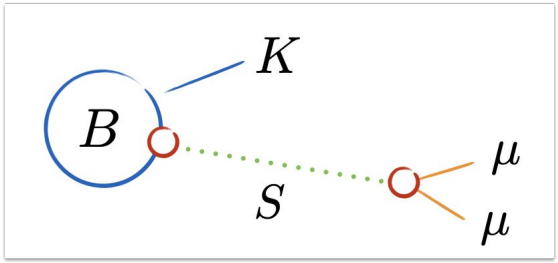
1. Provide interesting benchmarks (pheno people job)
2. Explore the reach of Belle II for these (experimentalists job)
3. New ideas to exploit Belle II potenital (joint effort)

Scalar portal

Light scalar mediator to DM mixing with the Higgs after EWSB [Filimonova, Schäfer, Westhoff: 1911.03490]

$$\mathcal{L}_{int} \supset -\lambda\phi|H|^2 - y_\chi \phi\bar{\chi}\chi \quad \Rightarrow \quad \mathcal{L}_{int} \supset y_\chi(s_\theta h\bar{\chi}\chi + c_\theta S\bar{\chi}\chi) + \sum_f \frac{m_f}{v}(c_\theta h\bar{f}f + s_\theta S\bar{f}f)$$

The scalar inherits Higgs-like hierarchical couplings to fermions.
Top loop-induced FCNC

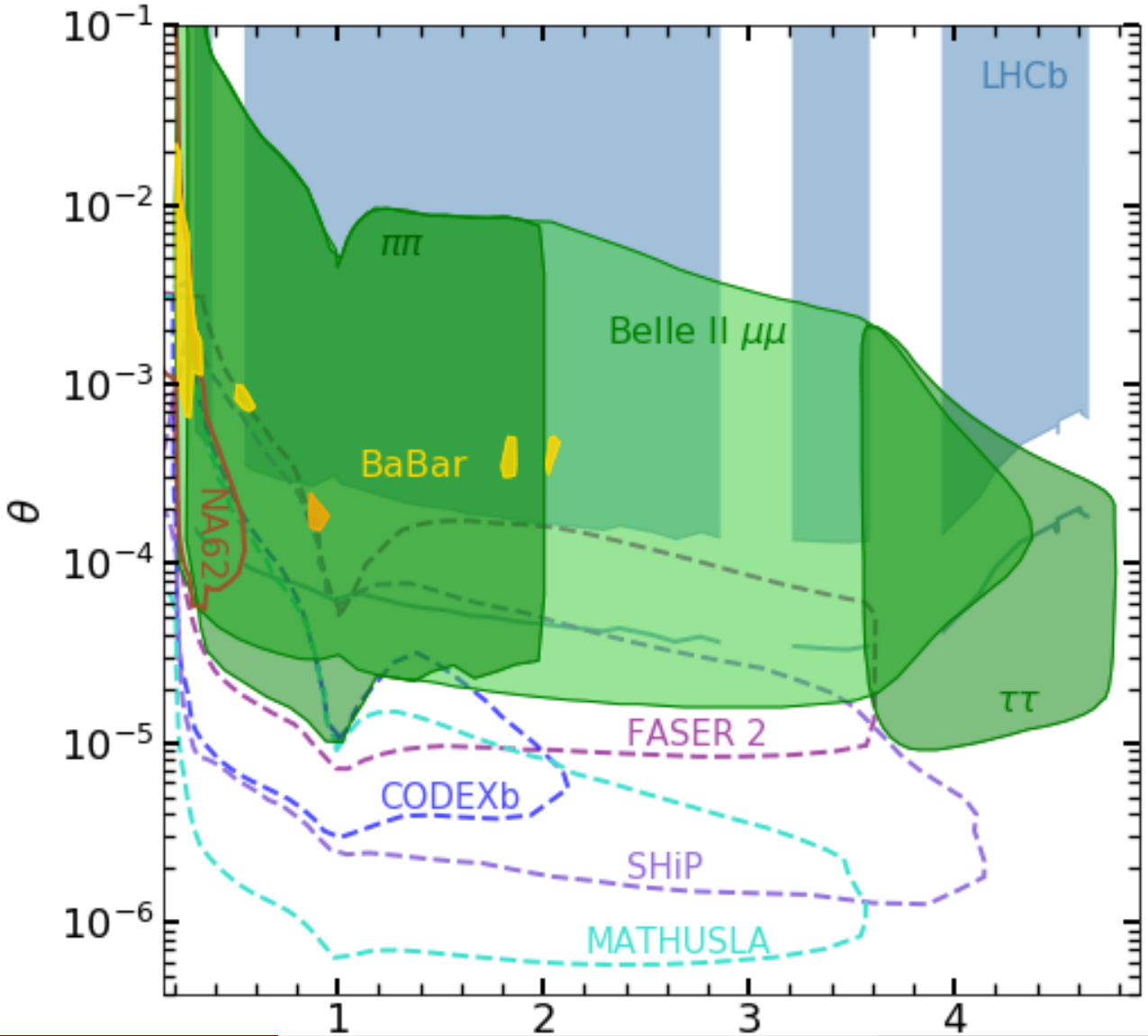


Visible decay:

$$\mathcal{B}(B \to KS)\mathcal{B}(S \to F) \propto s_\theta^2 \Gamma_F / \Gamma_{SM} \qquad F = 2\mu, 2\pi, 2\tau, 2D...$$

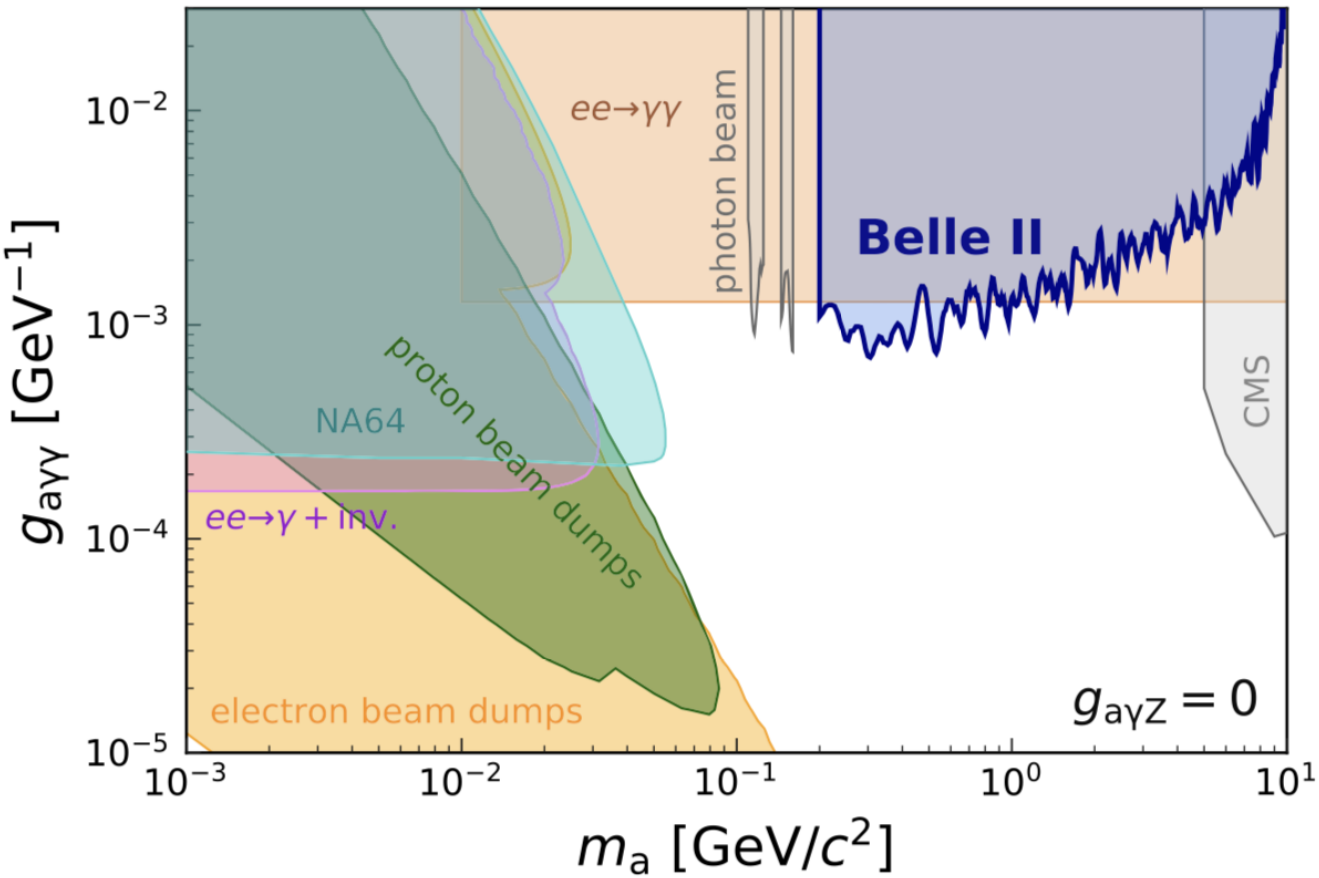
Visible decay

Assume S decays in the CDC with fully reconstructed final states (zero background)



ALPs

Search for $e^+e^- \to a\gamma, a \to \gamma\gamma$ using $445\ \mathrm{pb}^{-1}$ luminosity [PhysRevLett.125.161806]



Assumed $\mathcal{B}(a \to \gamma\gamma) = 100\%$. ALP models can include also $a\bar{f}f$ couplings.

Tau specific models

Heavy Neutral Lepton:

$$\mathcal{L}_{int} = \sum_{\alpha,I} c_{\alpha,I}(\bar{L}_\alpha H) N_I$$

After EWSB the HNL mixes with ν_α with mixing angle U_α.

Production:

Flavor universal: produced by $B^\pm \to N_\ell \ell^\pm$ and $B \to N_\ell D \ell$

Tau flavored: production dominated by τ decays, e.g. $\tau \to N\pi^-$

Decay:

Goes through off-sell W and Z into 2 or more leptons + neutrinos

Belle II reach study needs to be done, I expect similar - smaller than scalar due to multiparticle final state (if decays into CDC and fully reconstructed)

Tau specific models

Light scalar coupling with charged leptons (no mixing with the Higgs):

$$\mathcal{L}_{int} = \sum_{\alpha,\beta} \frac{y_{\alpha\beta}}{\Lambda} (\bar{L}_\alpha \tilde{H}) \ell_{R,\beta} S$$

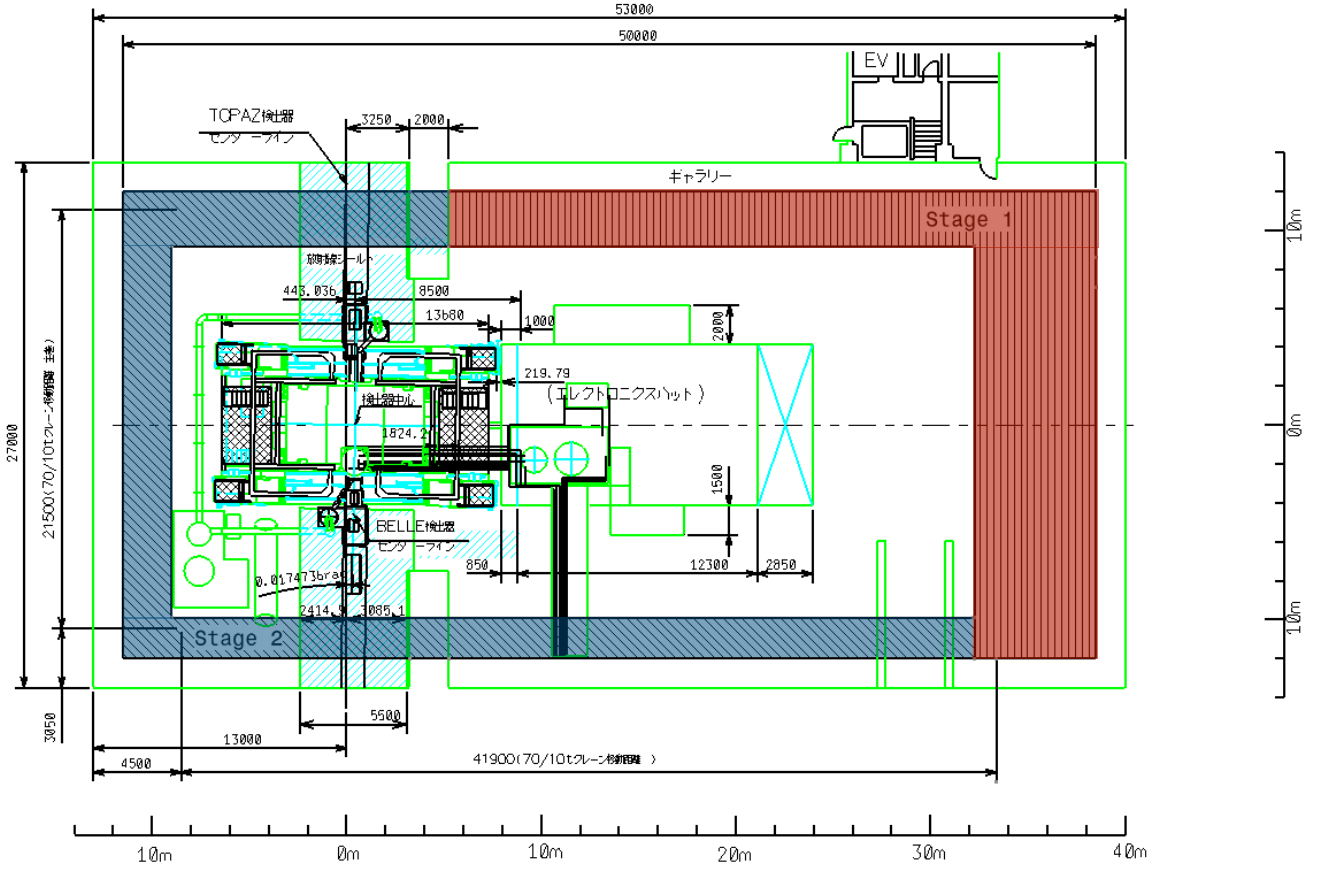
If $y_{23}, y_{32} \neq 0$ and other $y_{\alpha\beta}$ small, could explain $(g-2)_\mu$

- $m_S < m_\tau - m_\mu$ excluded by τ lifetime
- $m_S > m_\tau + m_\mu$ prompt decay through $S \to \tau\mu$
- $m_S \in [m_\tau - m_\mu, m_\tau + m_\mu]$ is long-lived, decays through $S \to \mu\tau^* \to \mu\nu X$ where $X = \mu\nu, e\nu, \pi, \rho...$

Prompt decay could be searched at Belle II, long-lived case could be searched at GAZELLE (next slides).

GAZELLE

GAZELLE is the Approximately Zero-background Experiment for Long- Lived Exotics[1]



Different locations are now being considered by Belle II people in the collab.

[1] It is a recursive acronym: https://en.wikipedia.org/wiki/Recursive_acronym.

Advantages

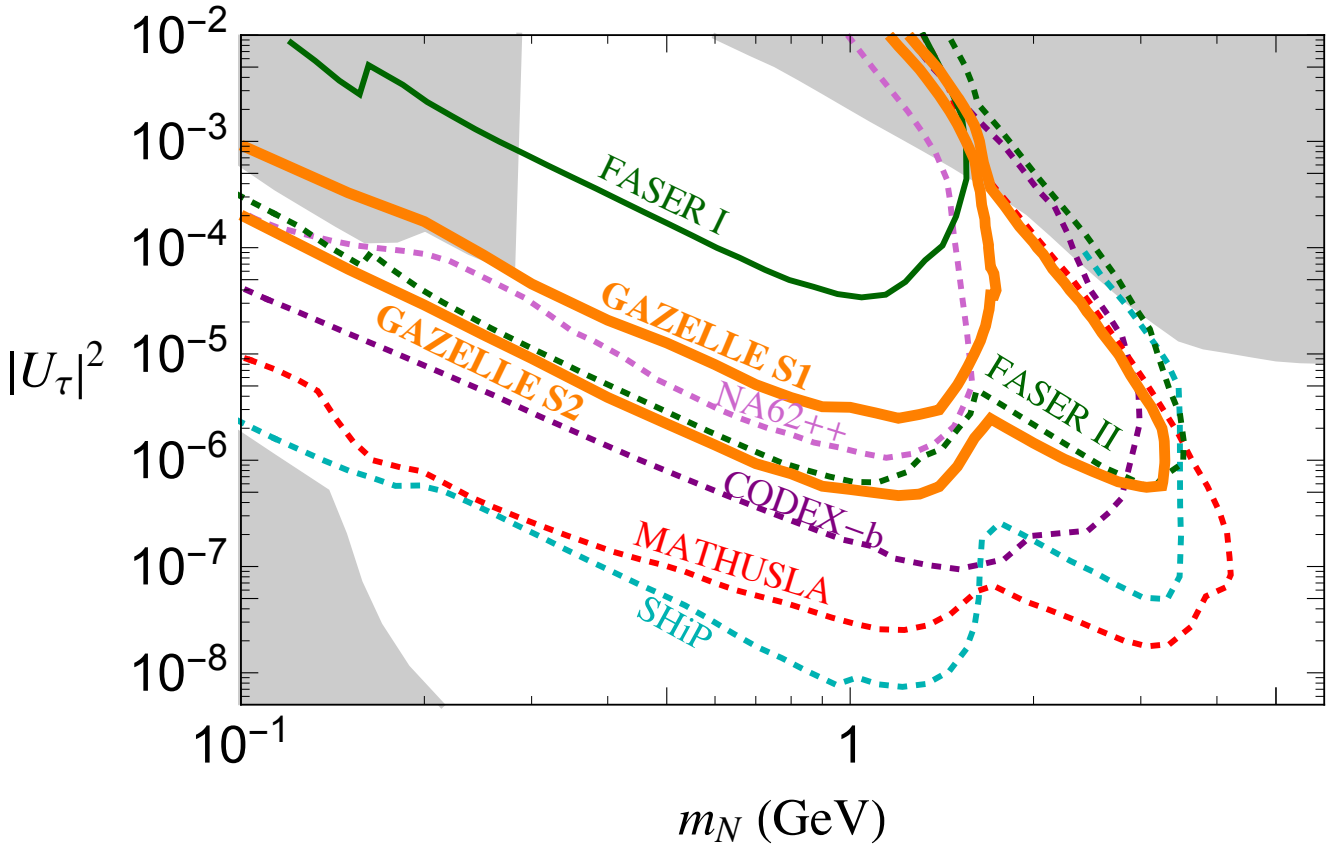
- Wide angular coverage, also means better mass reconstruction
- Most of the CR background can be rejected by requiring two (even #) charged tracks originating from inside Belle II concrete shielding (also kinematic constraints for 2-body decay)
- Correlating GAZELLE with Belle II would improve BG rejection and mass reconstruction

Open questions:

- What is the reach of GAZELLE compared to Belle II for different models (ALPs, Scalars, iDM...)?
- Muon can produce K_L in the concrete and these decay outside, what is the punch through rate of K_L?
- Flux of neutrons close to the shielding walls can become an issue at designed luminosity

Projections (Take them very carefully)

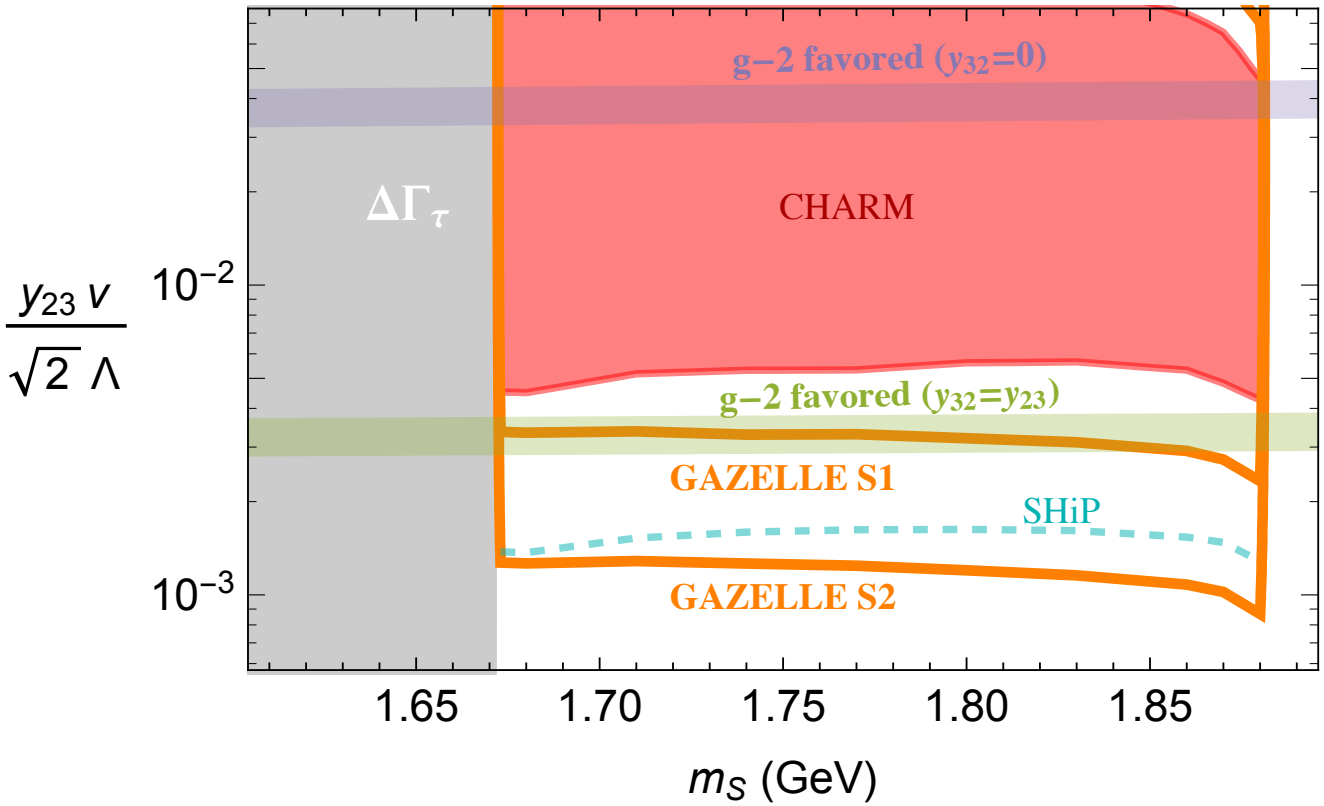
Reach for τ flavored Heavy Neutral Leptons



Stage 1: $50\ ab^{-1}$
Stage 2: $250\ ab^{-1}$

Projections (Take them very carefully)

Reach for τ flavored Light Scalar



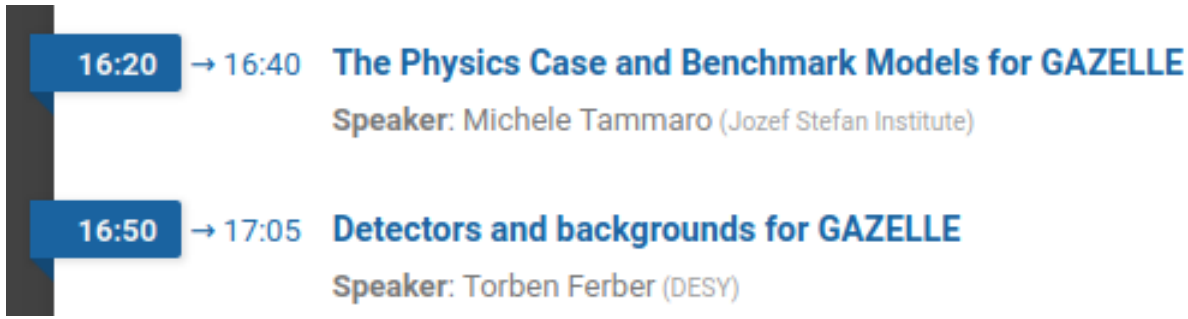
Stage 1: $50\ ab^{-1}$
Stage 2: $250\ ab^{-1}$

Conclusions and remarks

- Belle II is delivering data and will do more
- Lot of potential for LLP searches, pheno work and new ideas are welcome

If interested:

- Let's discuss
- Open workshop 10-11 Dec. at (virtually) DESY: "Long-lived particles at Belle II". On Friday 11th



Link Workshop: https://indico.belle2.org/event/2920/