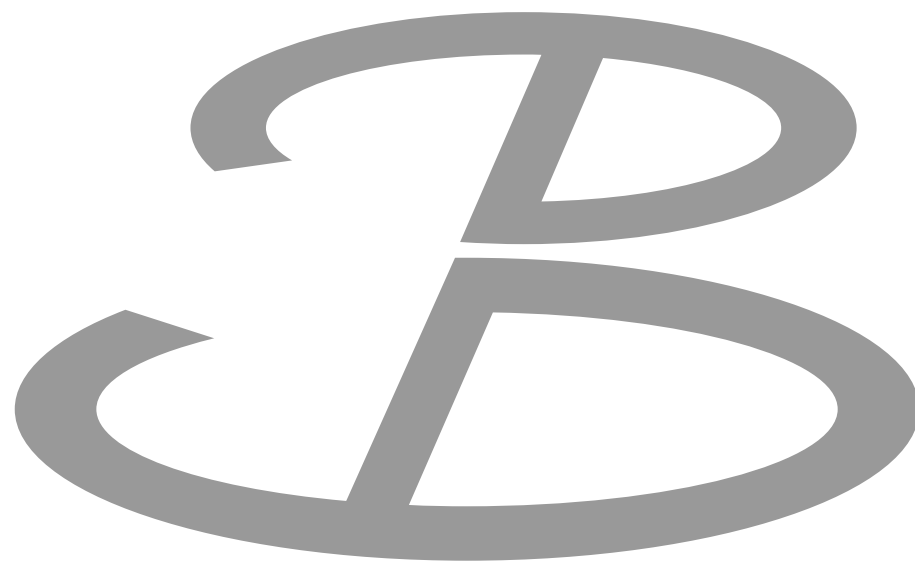


Dark sector physics with Belle II.

Sam Cunliffe

EPS HEP, Ghent, 11.07.2019

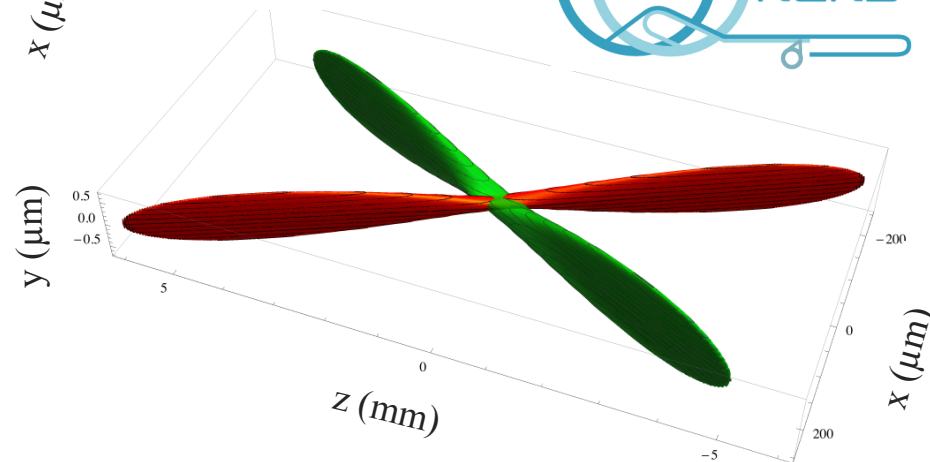
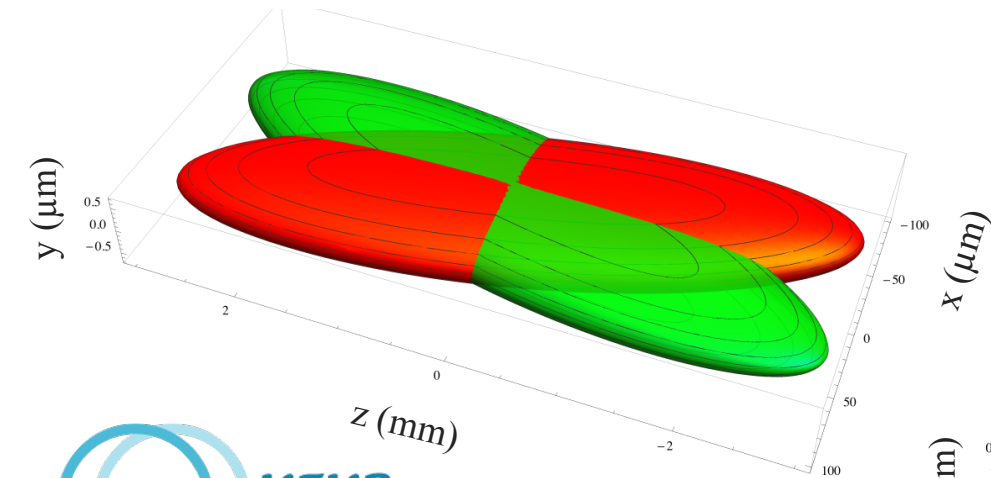
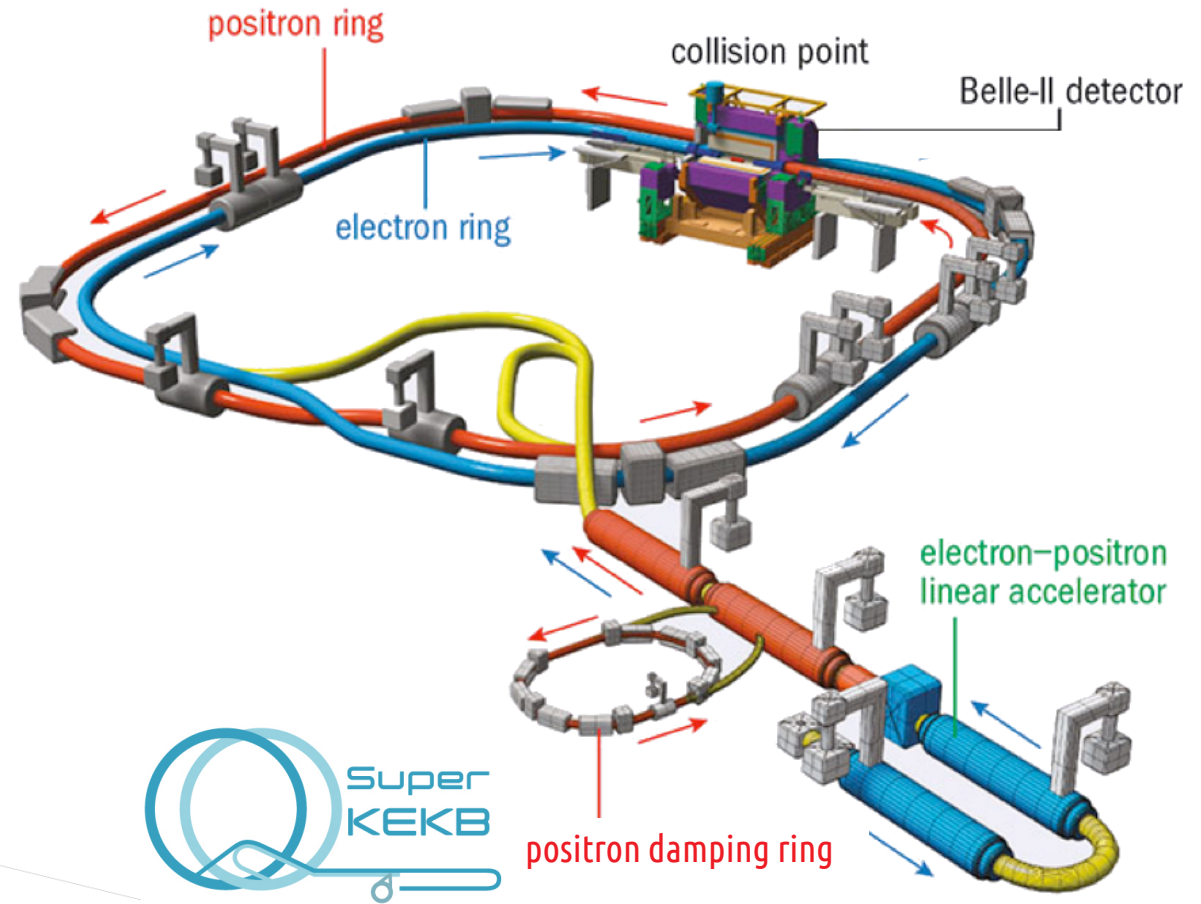


Belle II



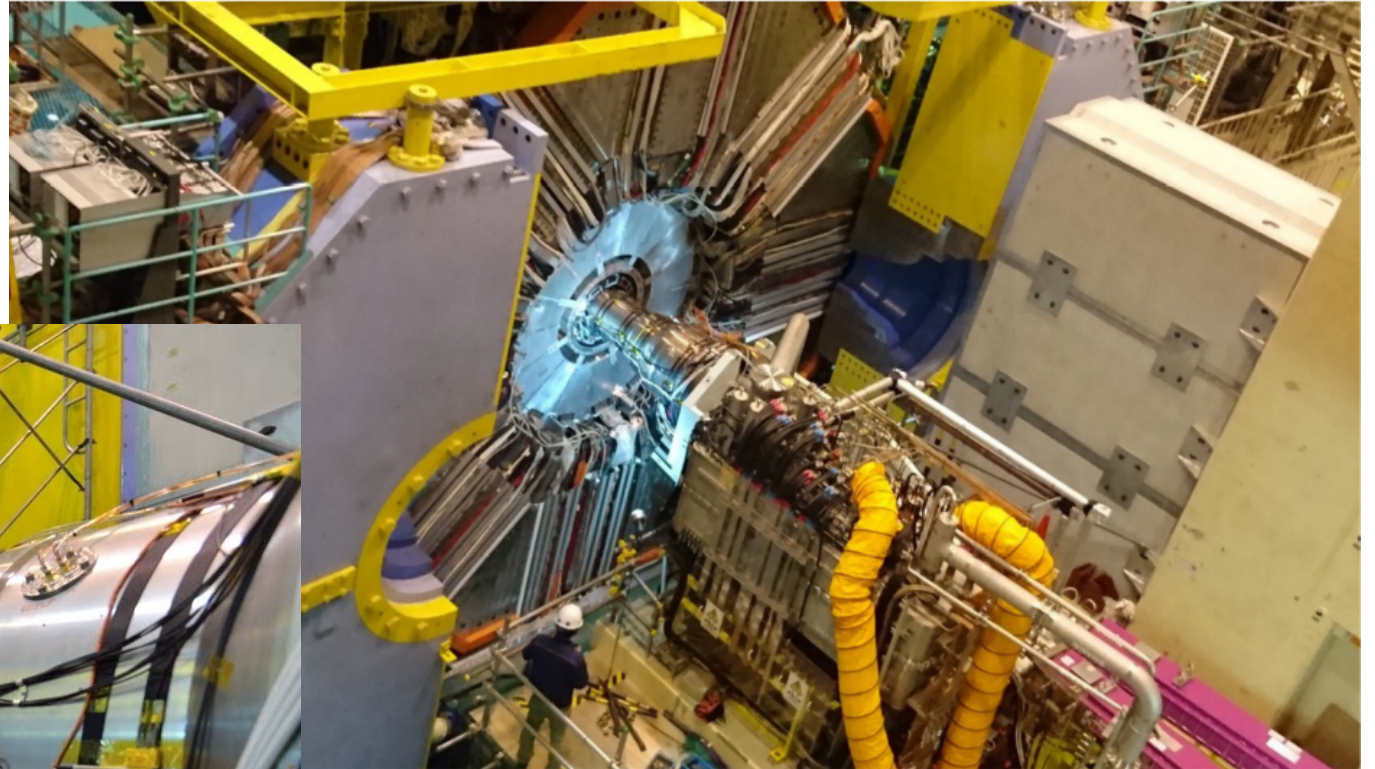
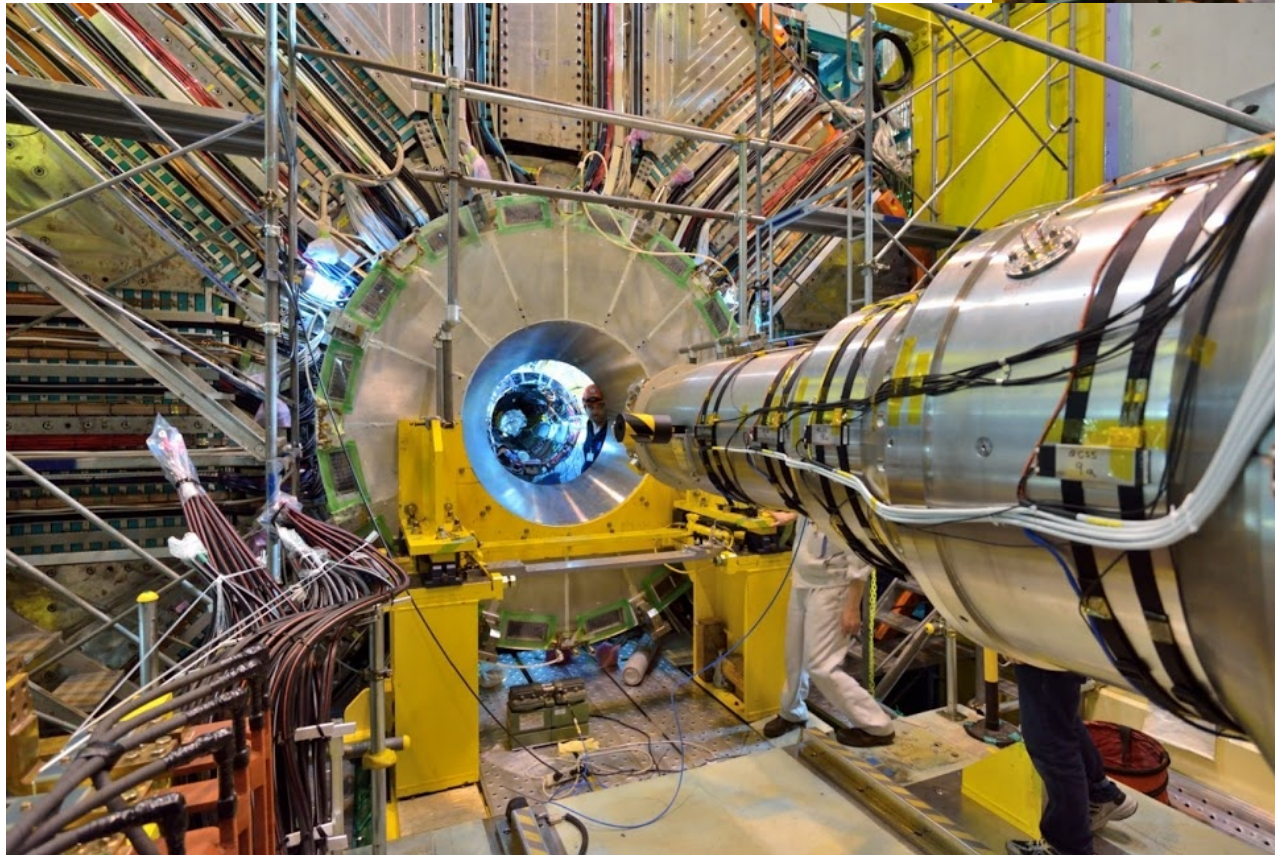
SuperKEKB

- Reason for the second iteration of the project: **upgraded accelerator**.
- A factor **40** increase in instantaneous luminosity
 - ▶ $\times 2$ from upgraded ring (higher beam current)
 - ▶ $\times 20$ β^* from final focus magnets.



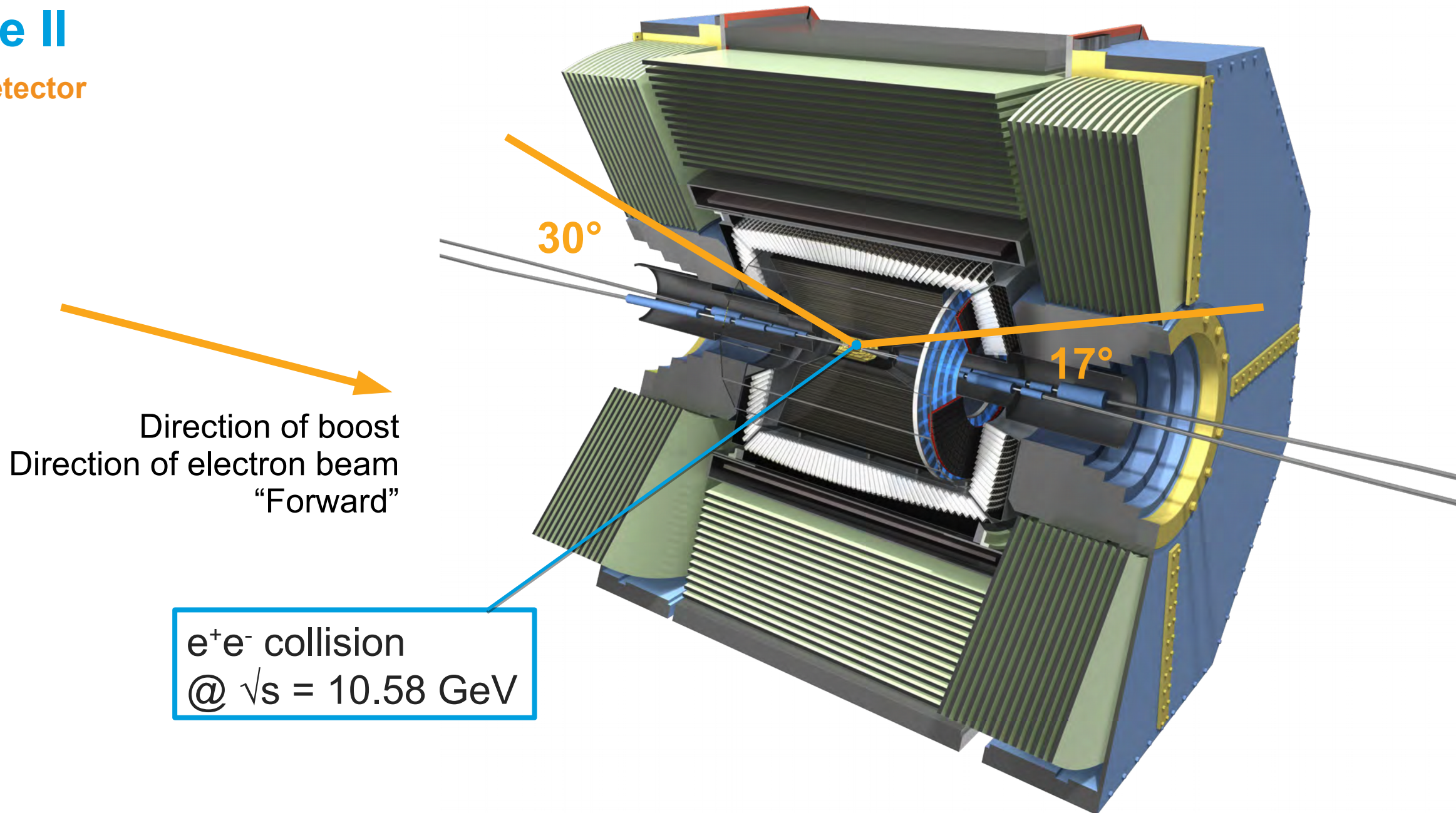
Final focus magnets

February 2018



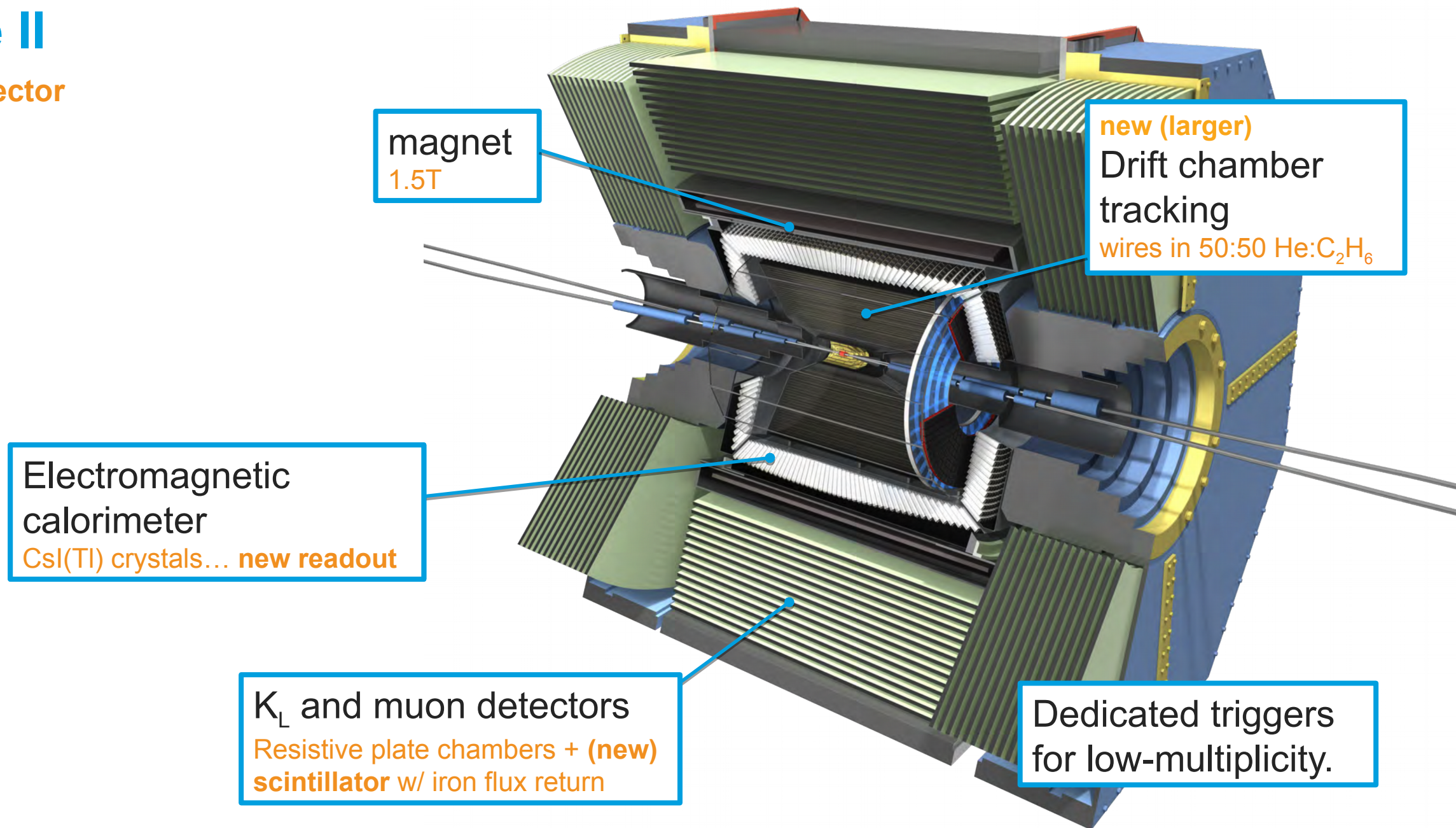
Belle II

The detector

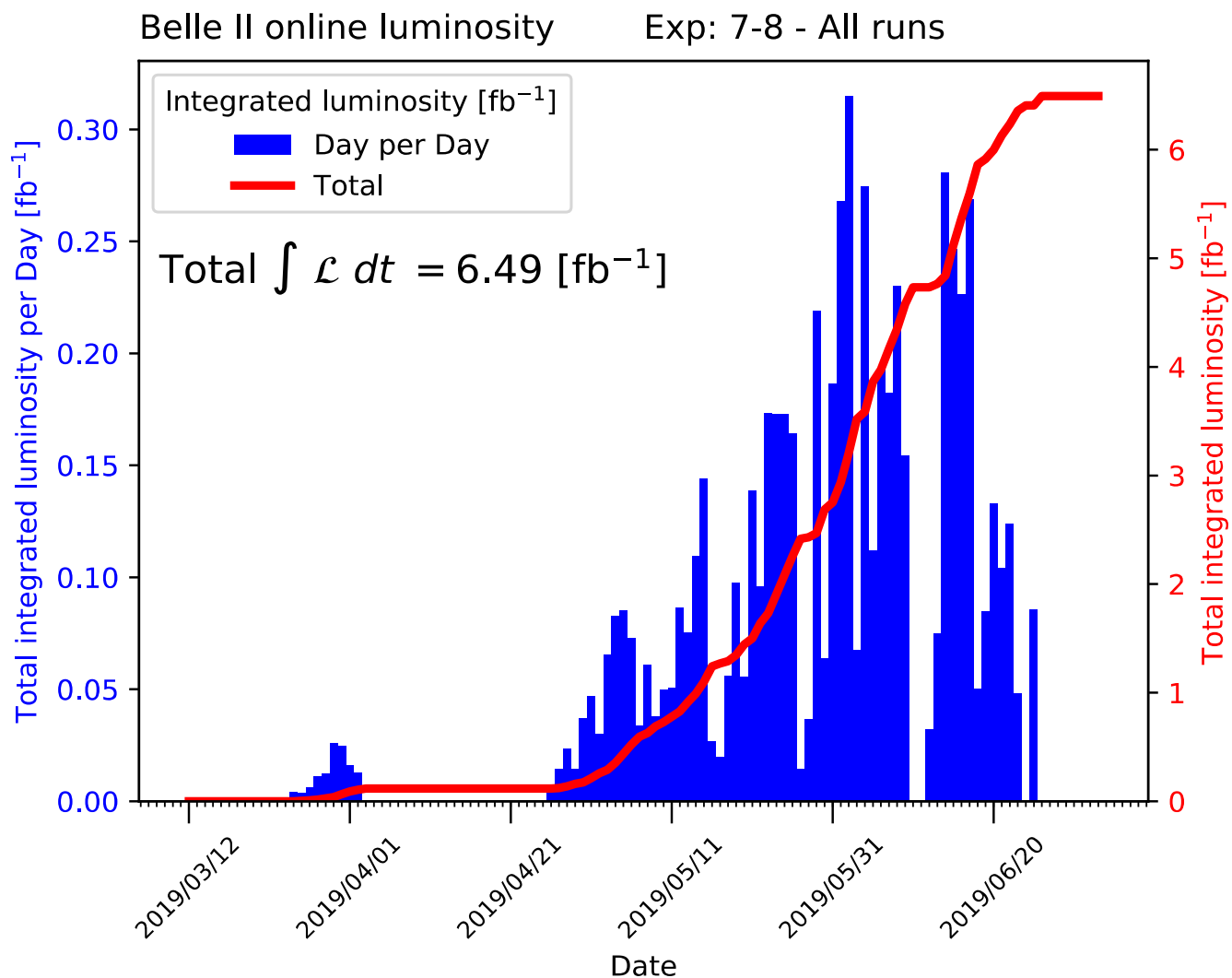


Belle II

The detector



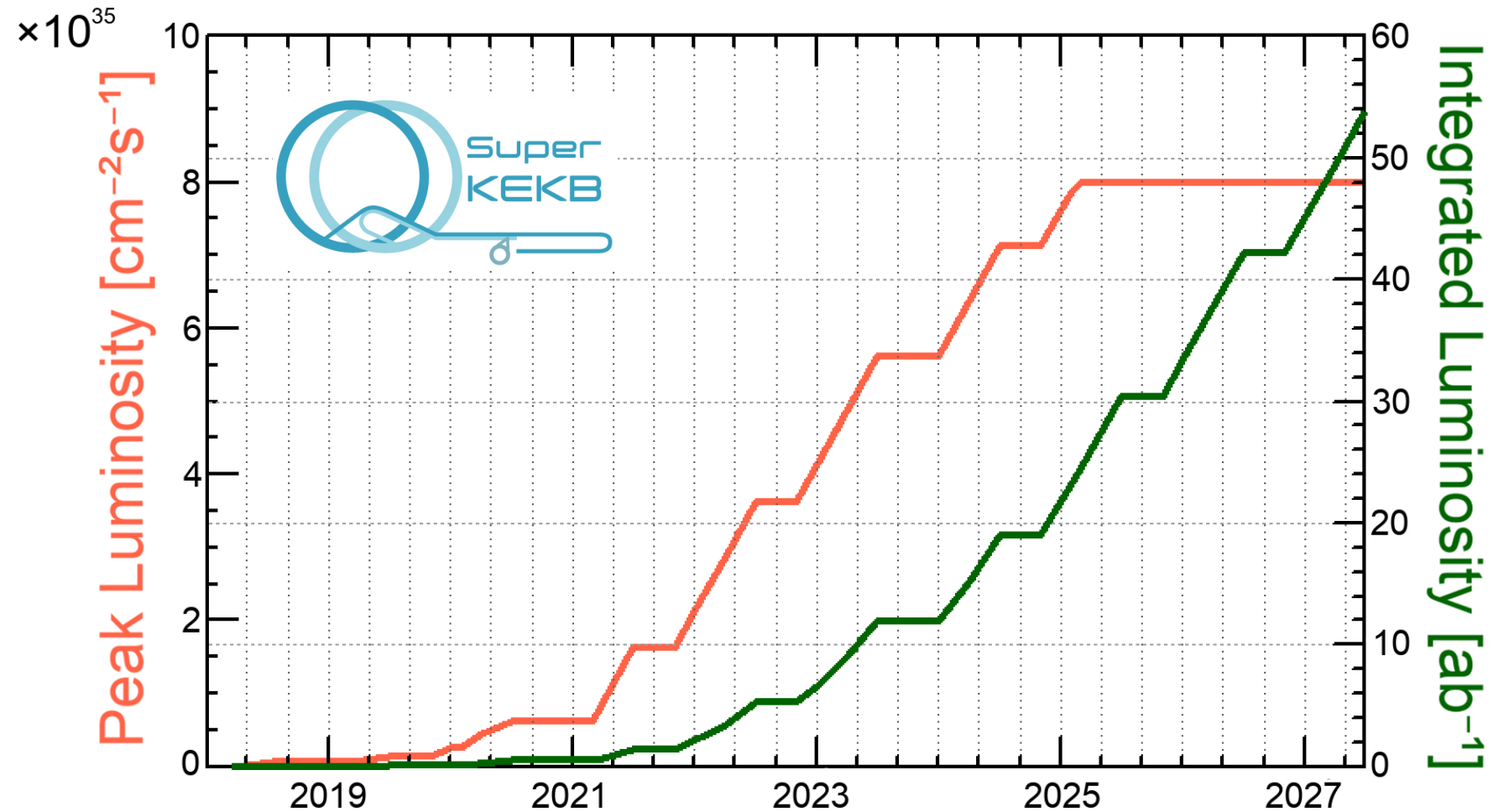
Data taking this year



Spokesperson, run coordinators
after the first fb^{-1}

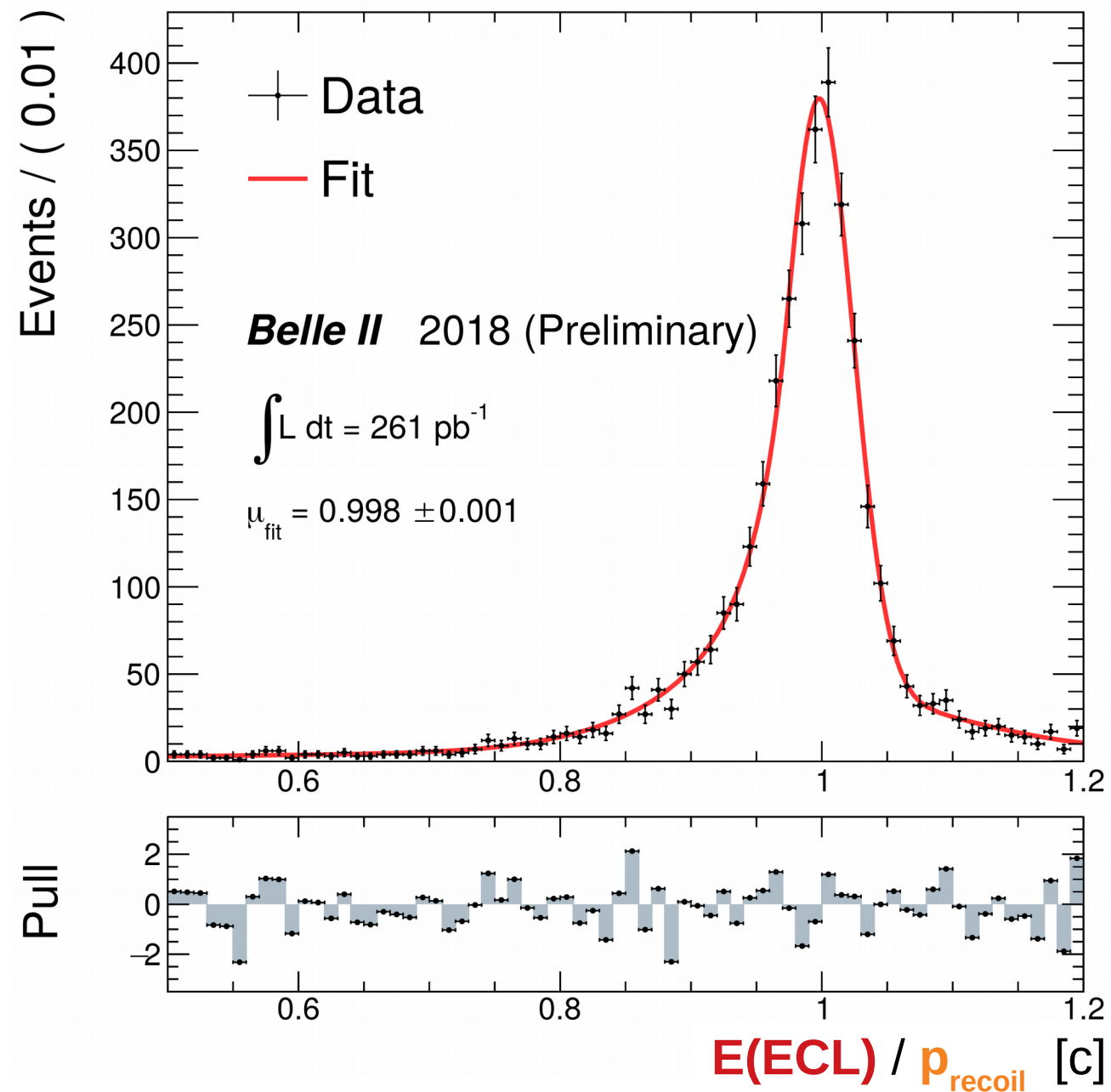
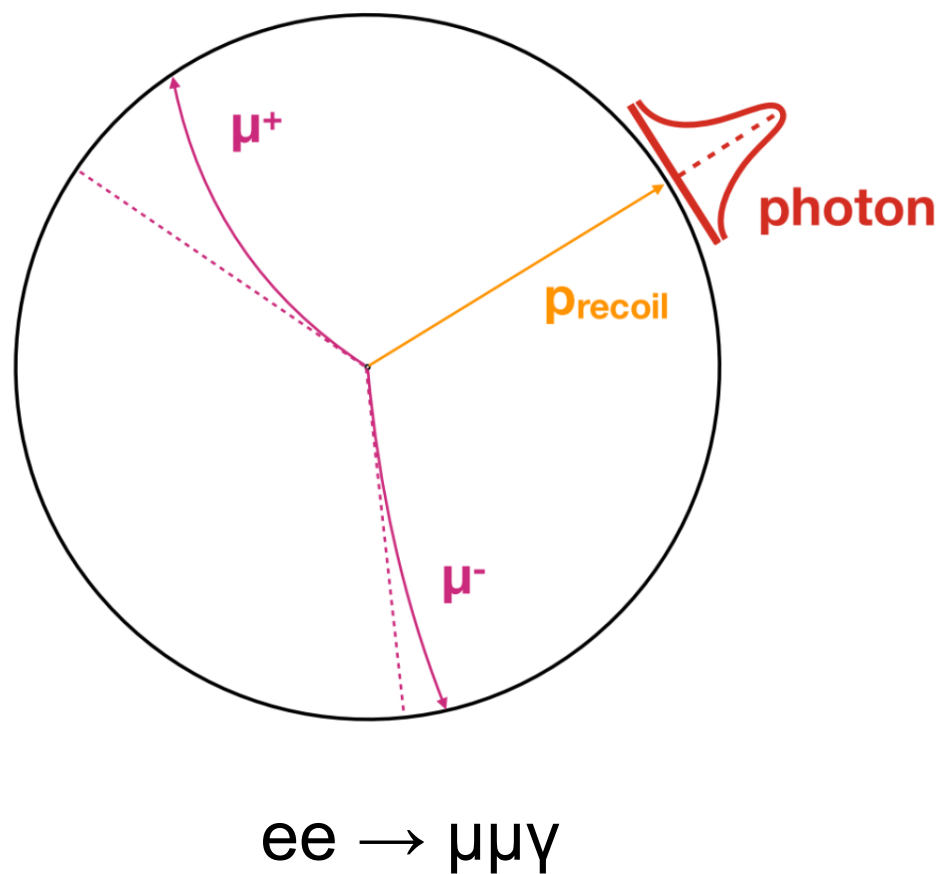
Data schedule

- Last year: 500 pb⁻¹.
 - ▶ *Commissioning* data.
- This year: ~6.5 fb⁻¹ **delivered**.
- Lifetime data set: 50 ab⁻¹.



Tracking and clustering

Radiative dimuon events in first data



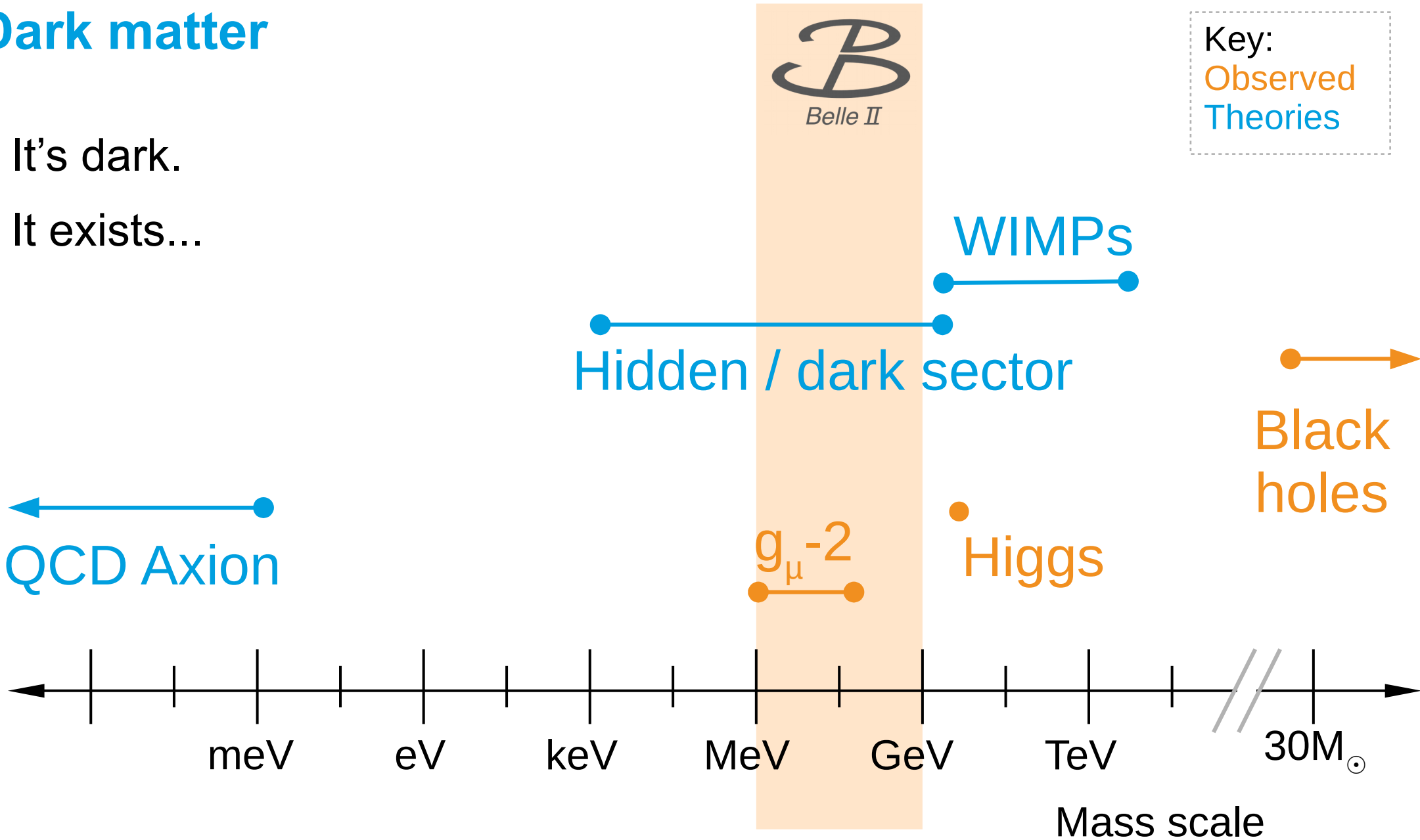
Dark matter

Dark matter

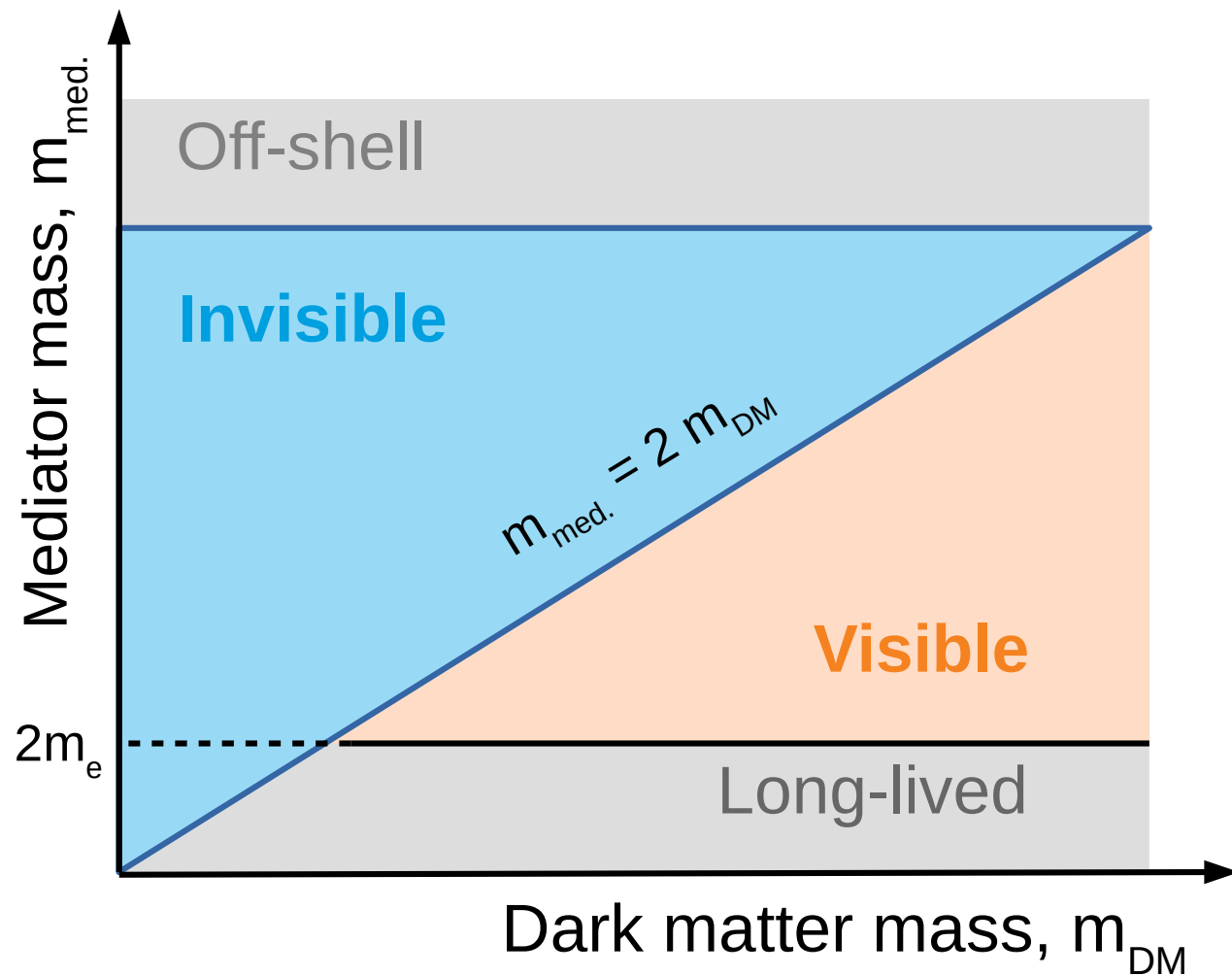
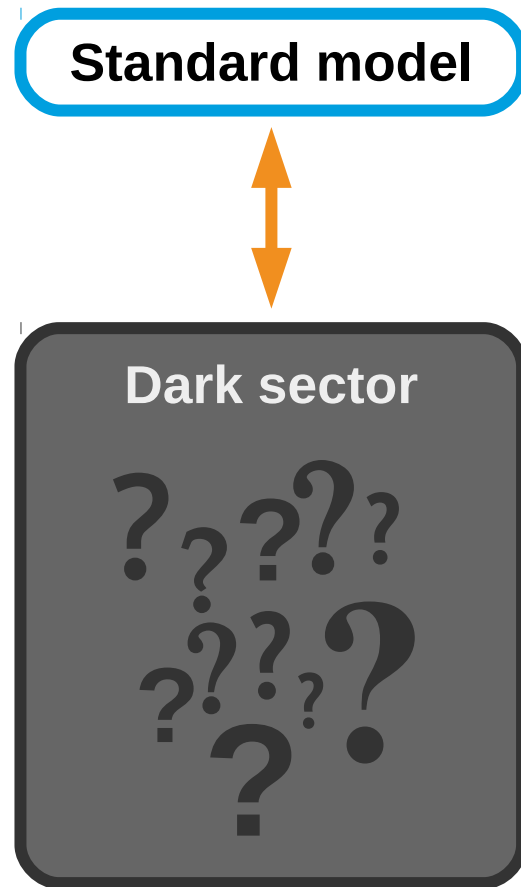
- It's dark.
- It exists...

Dark matter

- It's dark.
- It exists...



Dark sector



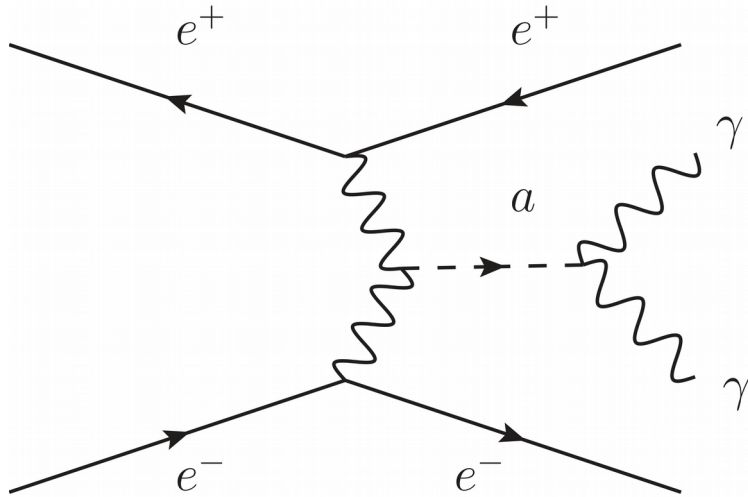
Axion-like particle

Theory

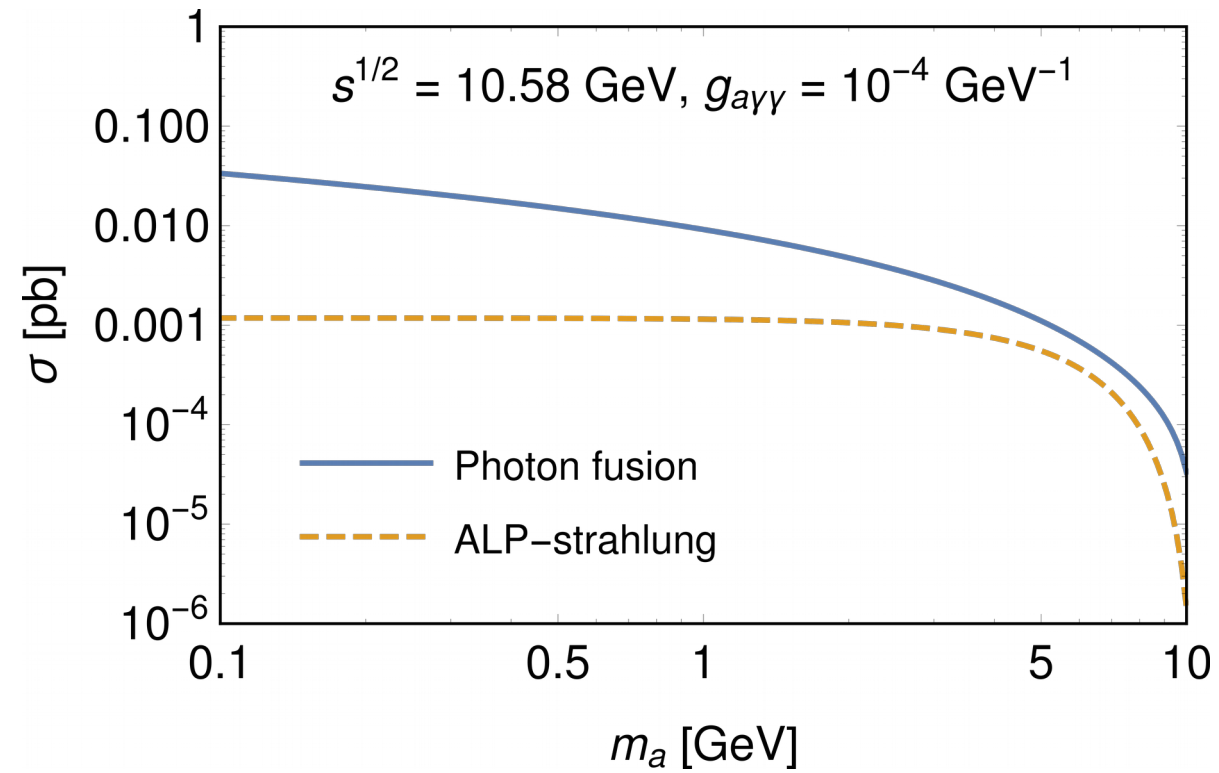
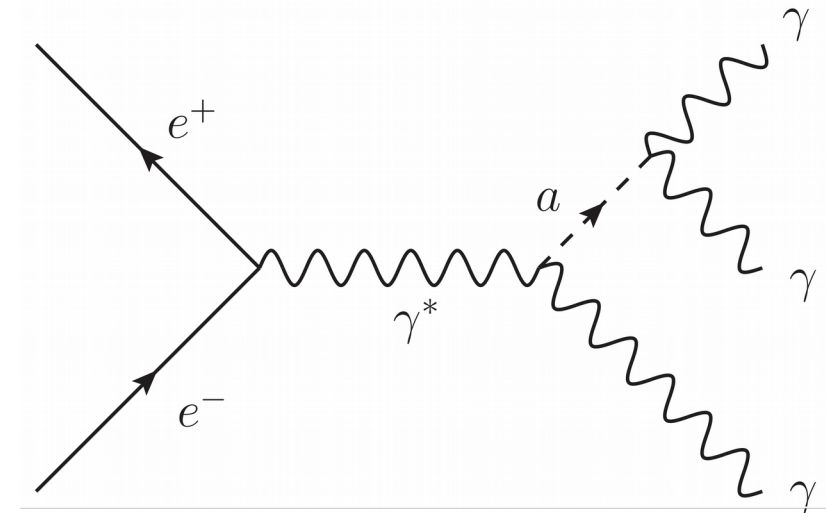
- After EWSB, four terms:

$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} a F_{\mu\nu} \tilde{Z}^{\mu\nu} - \frac{g_{aZZ}}{4} a Z_{\mu\nu} \tilde{Z}^{\mu\nu} - \frac{g_{aWW}}{4} a W_{\mu\nu} \tilde{W}^{\mu\nu}$$

Photon fusion



ALP-strahlung



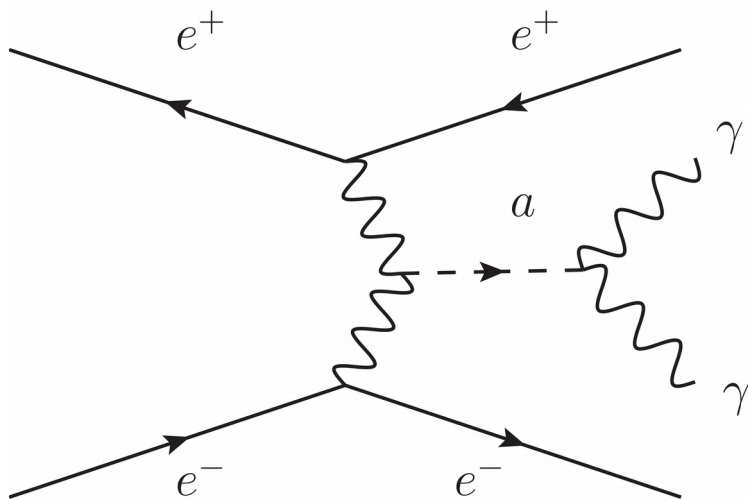
Axion-like particle

Theory

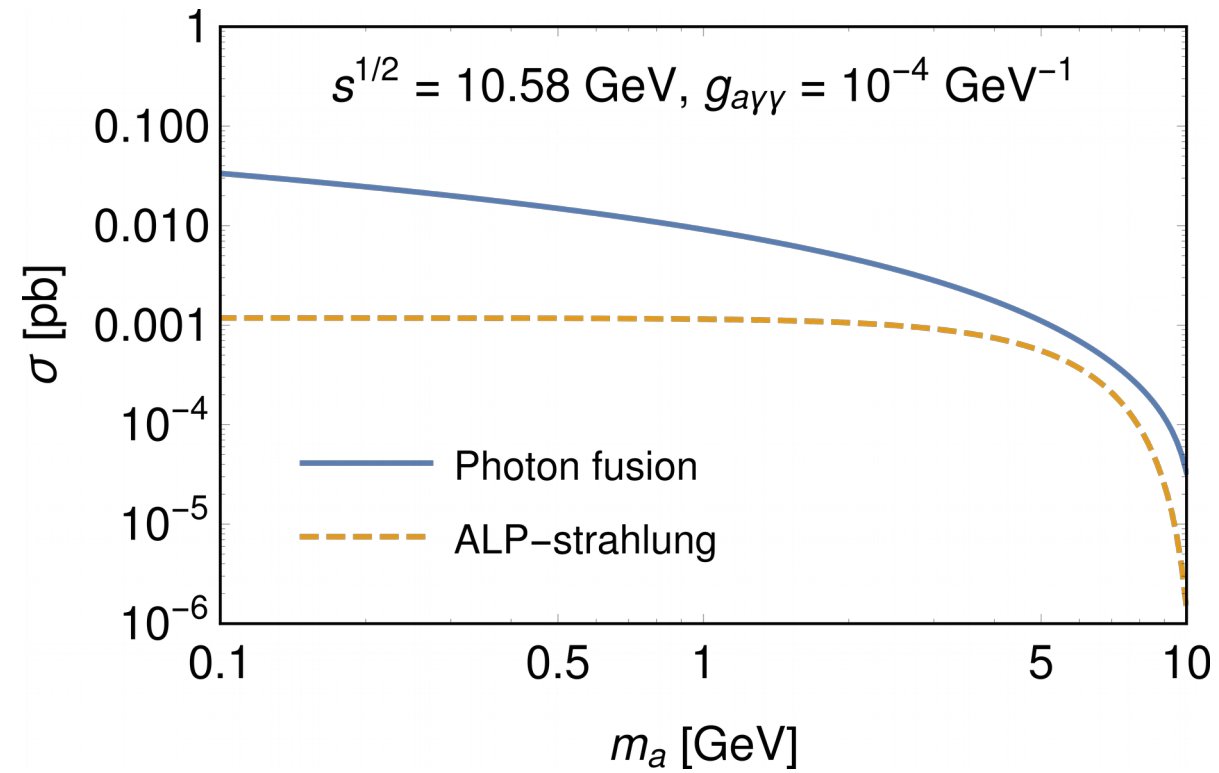
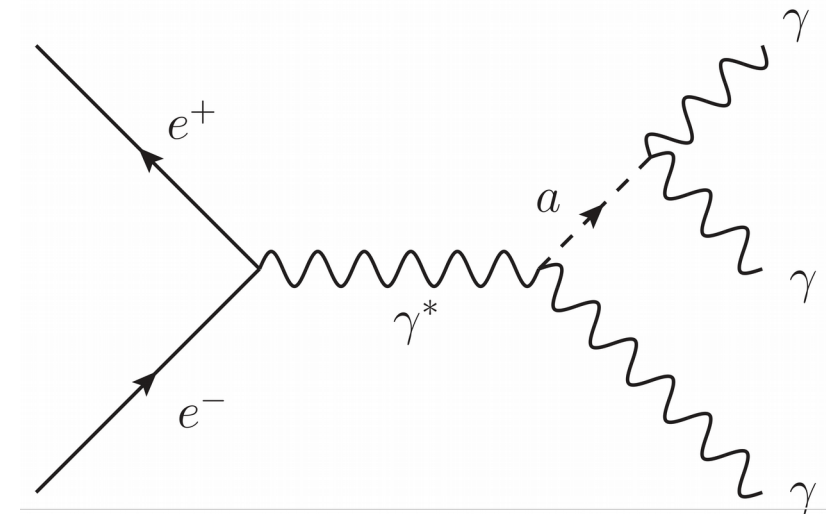
- After EWSB, four terms:

$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} a F_{\mu\nu} \tilde{Z}^{\mu\nu} - \frac{g_{aZZ}}{4} a Z_{\mu\nu} \tilde{Z}^{\mu\nu} - \frac{g_{aWW}}{4} a W_{\mu\nu} \tilde{W}^{\mu\nu}$$

Photon fusion



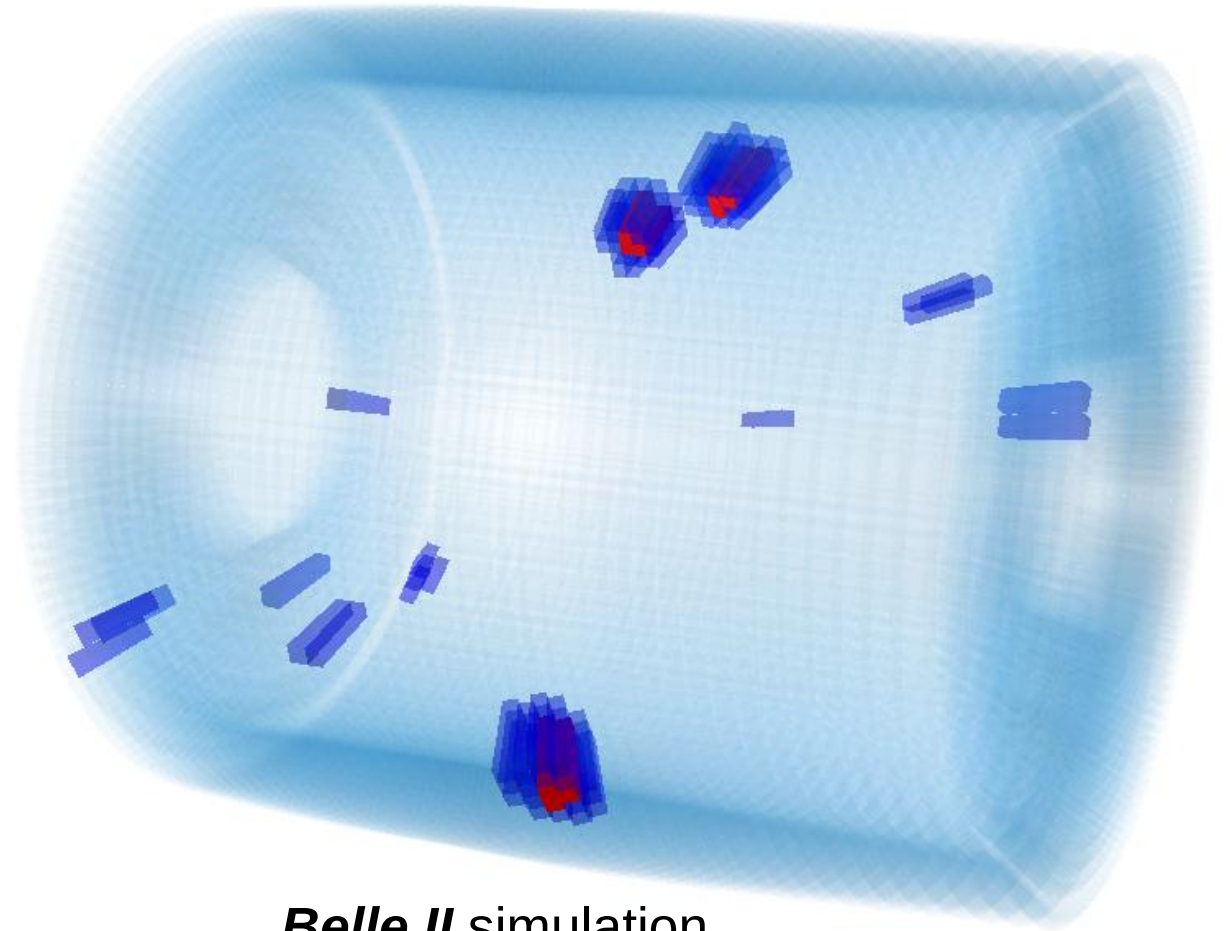
ALP-strahlung



ALPs @ Belle II

3 γ analysis

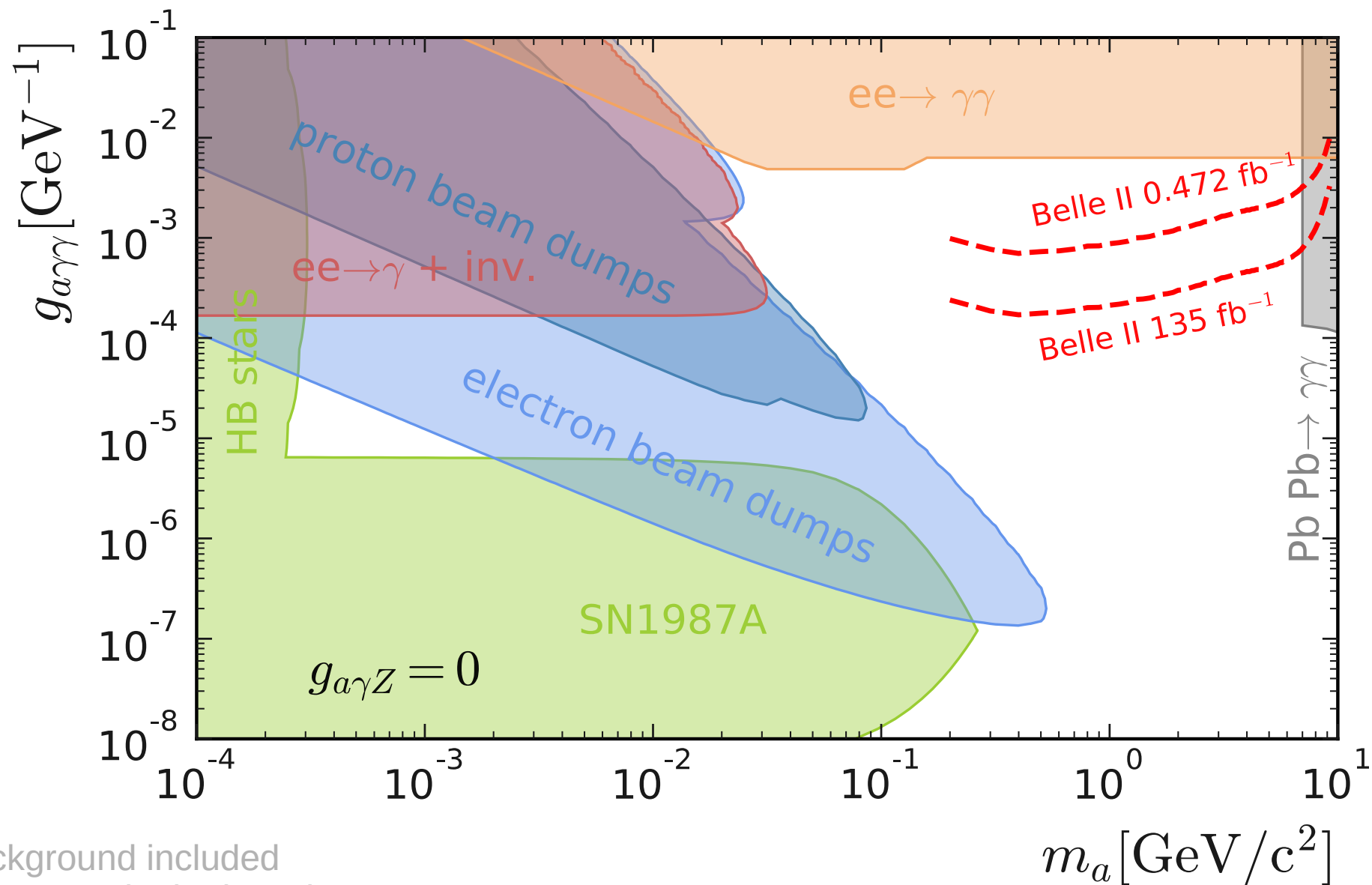
- ALP-strahlung is much easier experimentally.
 - ▶ Do this first.
- Three photons within tracking acceptance: add up to beam energy.
 - ▶ Zero tracks.
 - ▶ Bump on di-photon mass.
- The SM background: $ee \rightarrow \gamma\gamma(\gamma)$
 - ▶ Does not peak in $\gamma\gamma$.
 - ▶ Not a 2-body system: use angles & kinematics to suppress.



Belle II simulation
signal only

ALPs @ Belle II

Physics reach



No systematics.

Only (dominant) $ee \rightarrow \gamma\gamma\gamma$ background included

135fb⁻¹ assumes no $\gamma\gamma$ trigger veto in the barrel

Dark photon

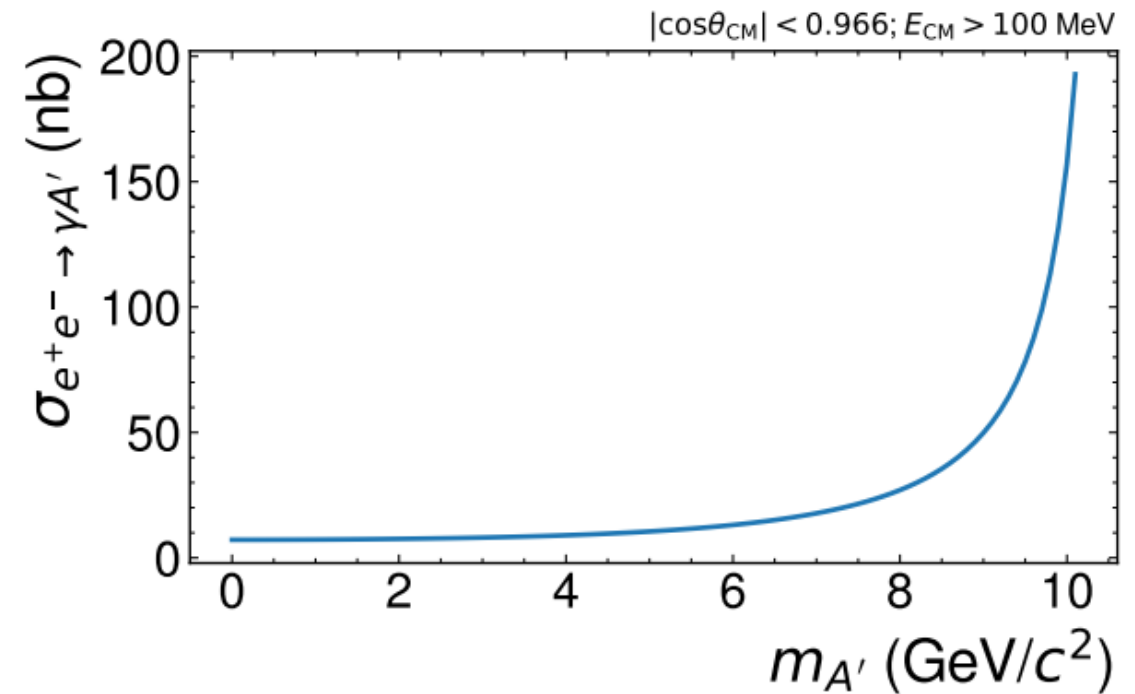
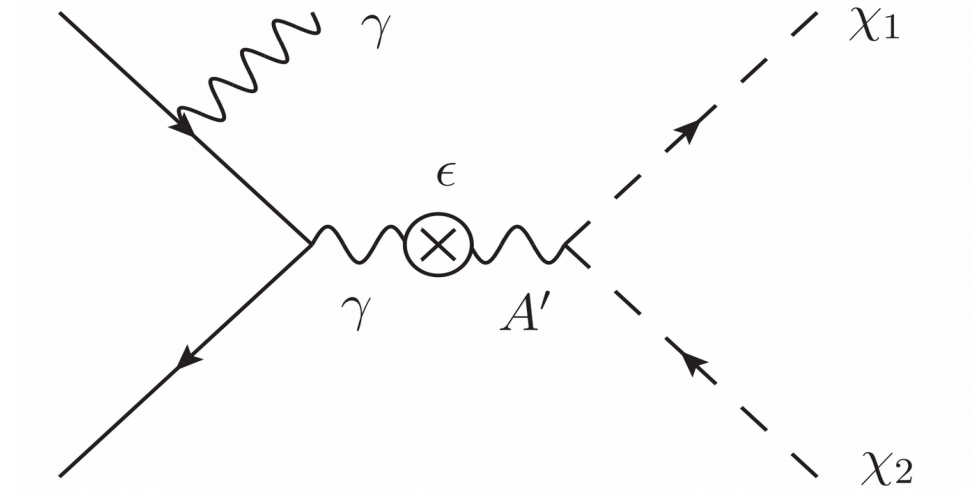
Theory

- Massive vector particle A' , mixes with the SM photon:

$$\mathcal{L} \supset \epsilon g_D A'_\mu J_{\text{EM}}^\mu$$

- Can decay directly to dark matter final state. Experimentally invisible $A' \rightarrow \chi_1 \chi_2$
- Can decay to two leptons $A' \rightarrow l^+ l^-$
- Experimentalist's trick: require ISR photon.

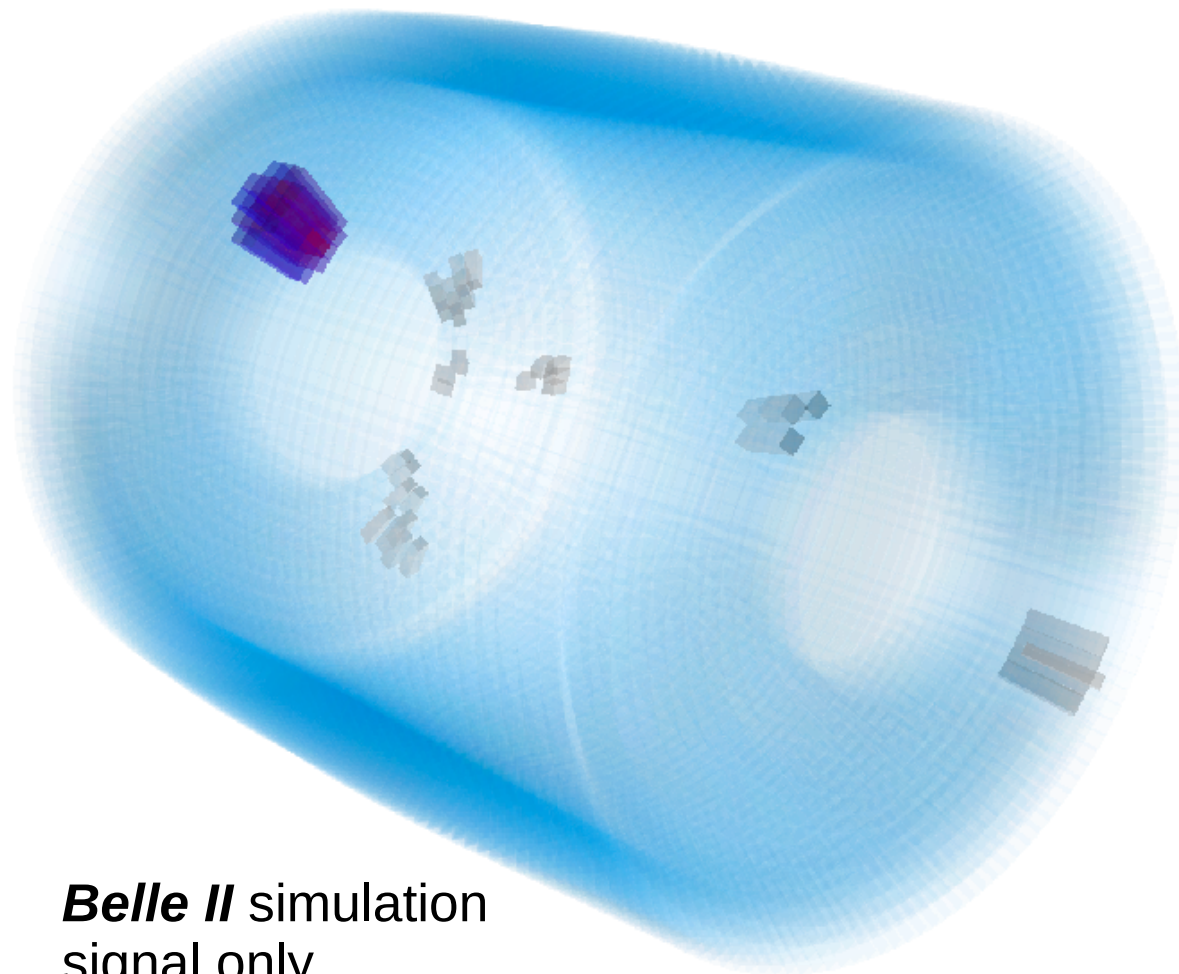
$$E_{\gamma_{\text{ISR}}} = \frac{s - m_{A'}^2}{2\sqrt{s}}$$



Dark photon

Analysis

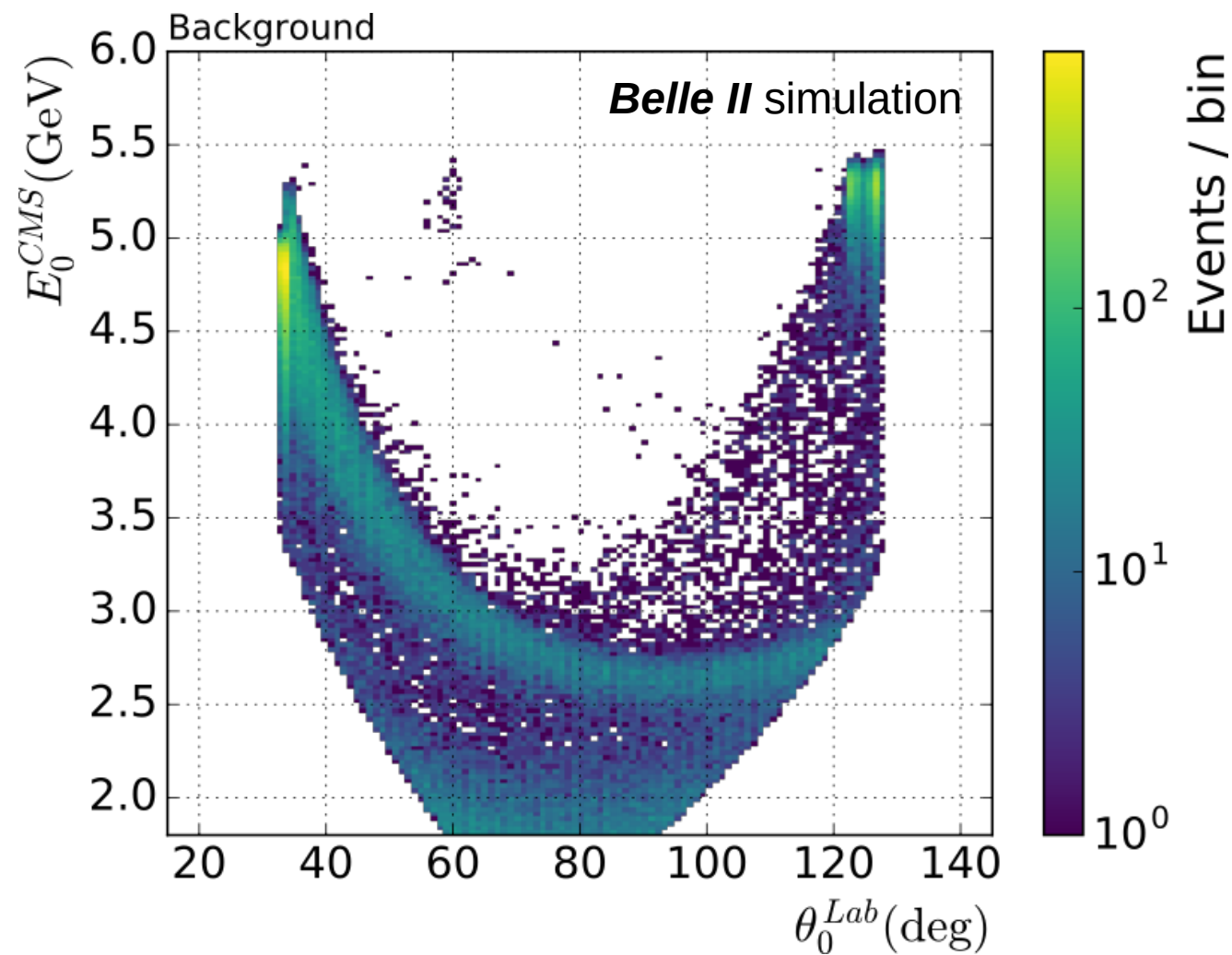
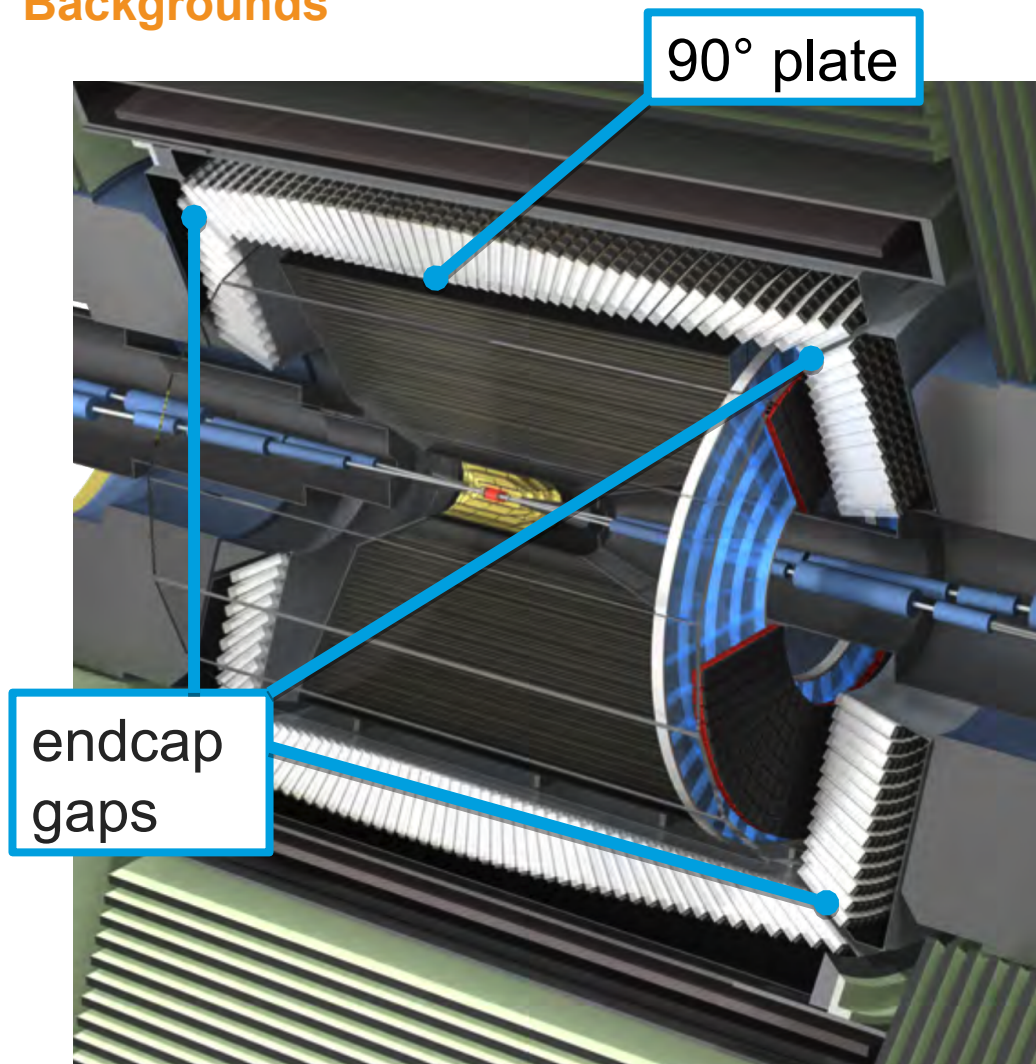
- First analysis: $ee \rightarrow \gamma A' \rightarrow \gamma (x_1 x_2)$
- One photon. (no tracks, other good photon clusters).
 - ▶ Bump search in recoil mass spectrum.
- **Backgrounds**
 - ▶ Cosmics
 - ▶ Beam interactions
 - ▶ $ee \rightarrow ee\gamma(\gamma)$
 - ▶ $ee \rightarrow \gamma\gamma(\gamma)$



Belle II simulation
signal only

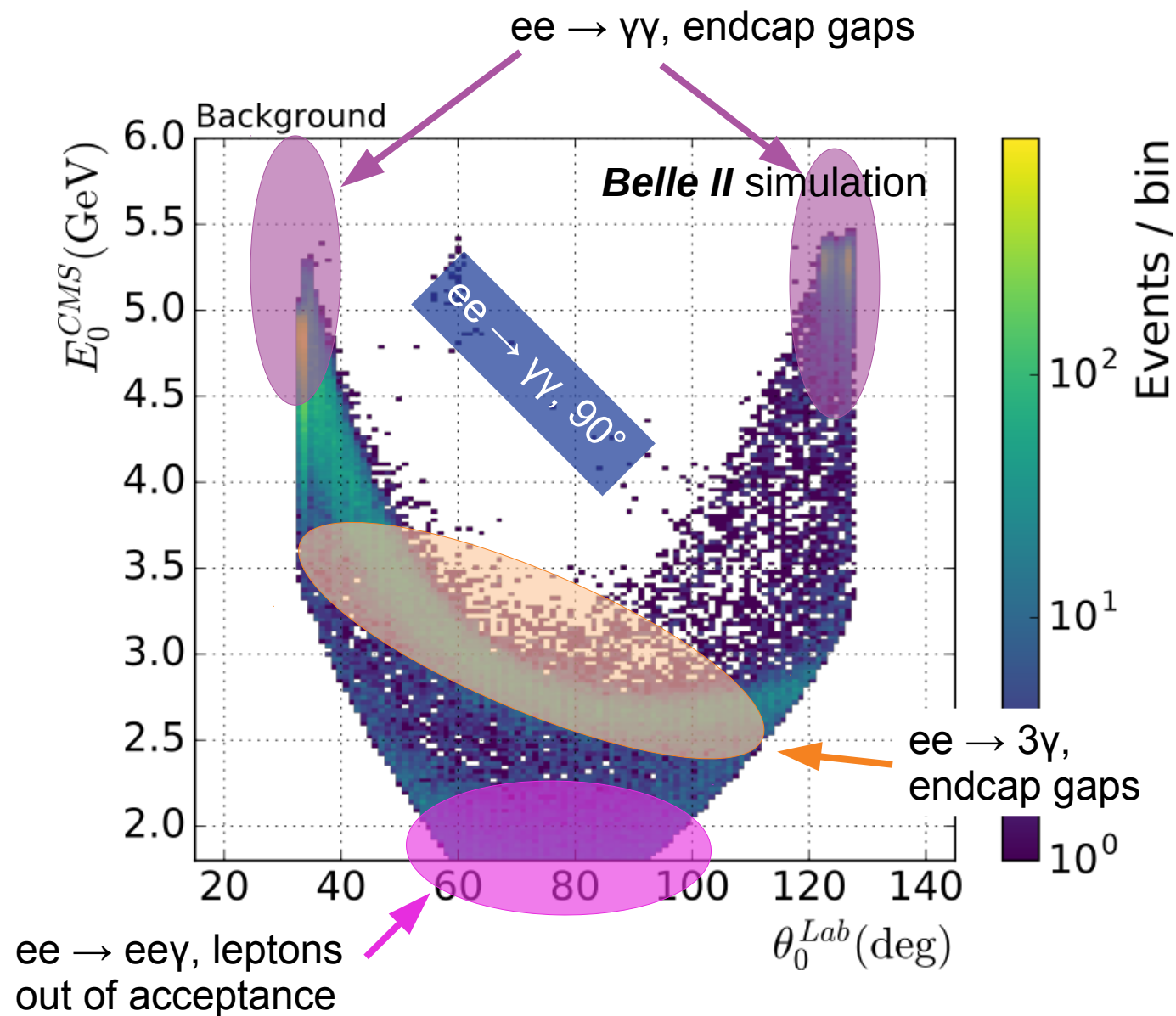
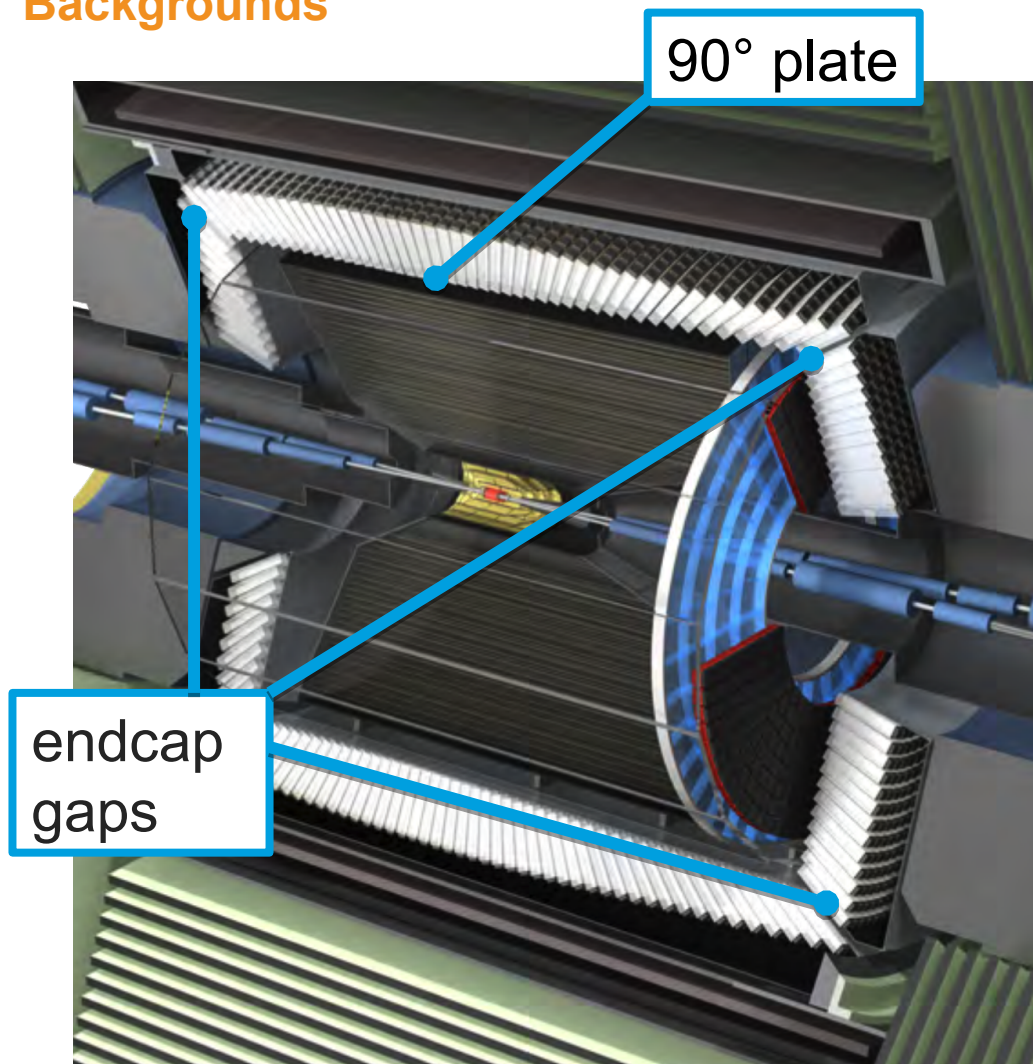
Dark photon

Backgrounds



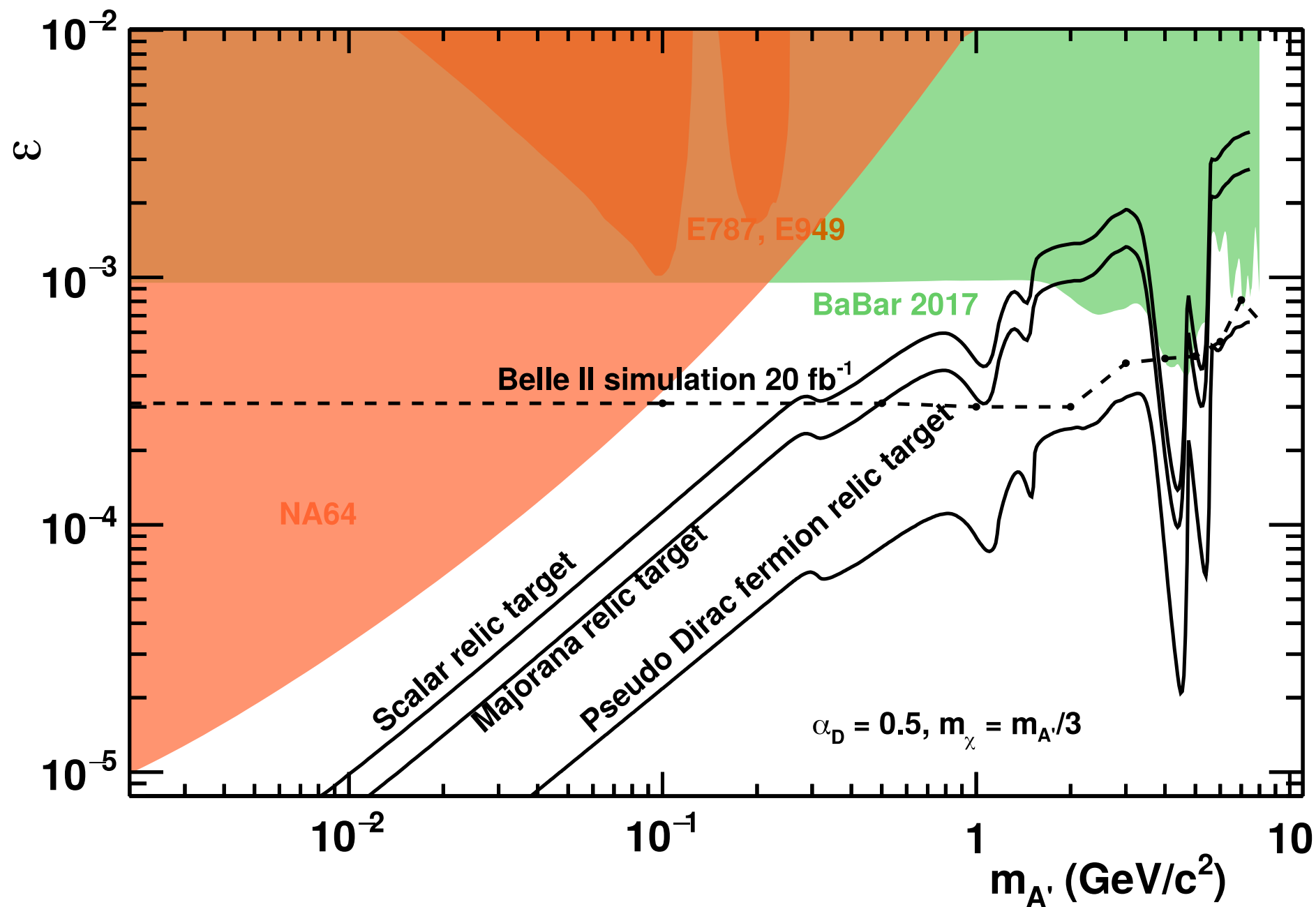
Dark photon

Backgrounds



Dark photon

Physics reach



The Belle II Physics book:

[arXiv:1808.10567](https://arxiv.org/abs/1808.10567)

BaBar 2017 analysis:

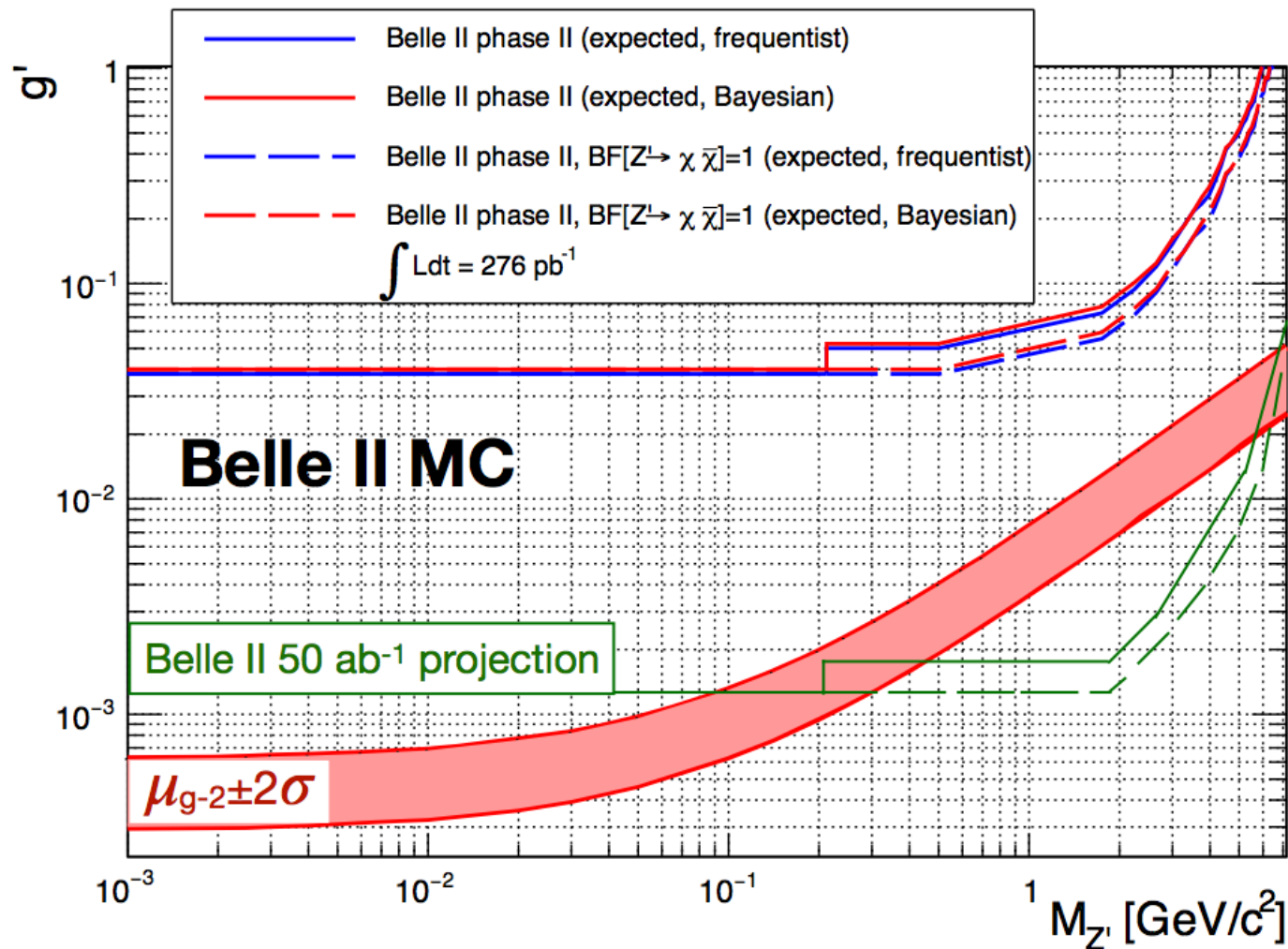
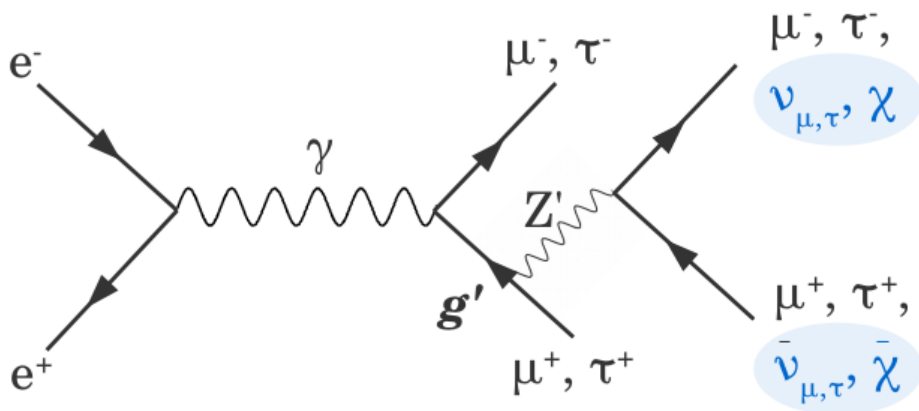
[PRL.119.131804](https://arxiv.org/abs/1710.03545)

NA64 2019 analysis:

[arXiv:1906.00176](https://arxiv.org/abs/1906.00176)

Z'

- “Dark photon” $\rightarrow$ Z' if non minimal.
- Mediator coupling to muons and taus, not electrons ($L_\mu - L_\tau$)
- $ee \rightarrow \mu\mu Z'$ ($Z' \rightarrow$ invisible)
- Bump hunt in recoil mass against $\mu\mu$. Nothing in the rest of the event.



Summary

- Next generation e^+e^- collider. Belle II taking data now.
- Dark sector physics $\rightarrow$ good prospects even with very early data.
- **3γ** : ALP-strahlung and decaying to two photons.
 - ▶ Experimentally clean.
 - ▶ Can perform analysis with *calibration* collisions data ($\sim 500 \text{ pb}^{-1}$ 2018).
- **Single γ** : dark photon decaying to stable dark matter.
 - ▶ Can improve limits from BaBar with 20 fb^{-1} .
- **$\mu\mu Z'$** : $L_\mu - L_\tau$ dark vector decaying to stable dark matter.
 - ▶ First analysis with early data.

Appendix

Contact

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