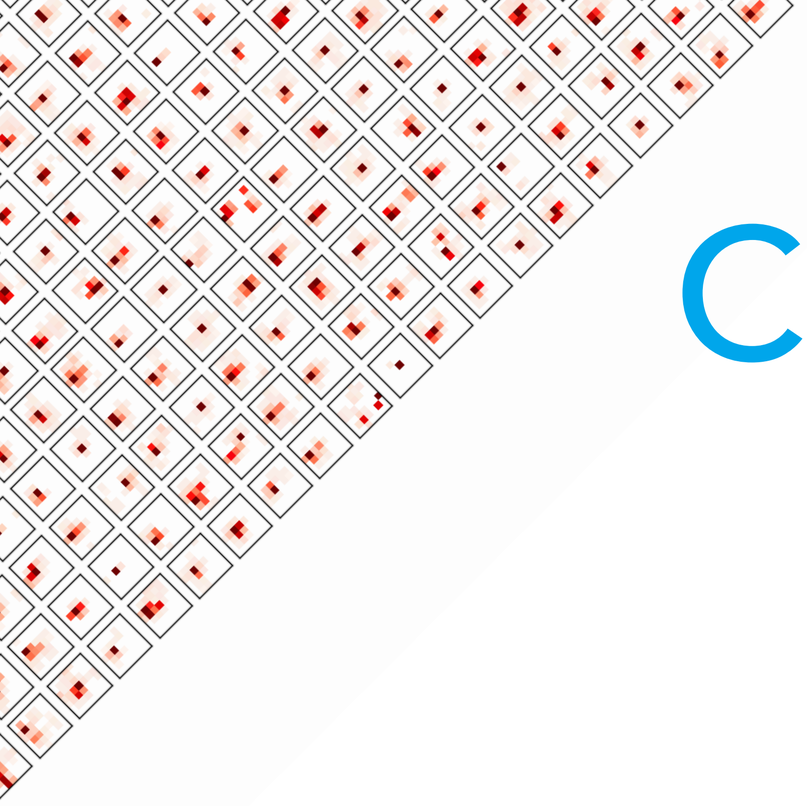


Collider Searches for Light Dark Sectors.

(Ferber, Hagner, Niebuhr, Schmidt-Hoberg)

2019-03-20, Quantum Universe Kickoff Meeting, Hamburg

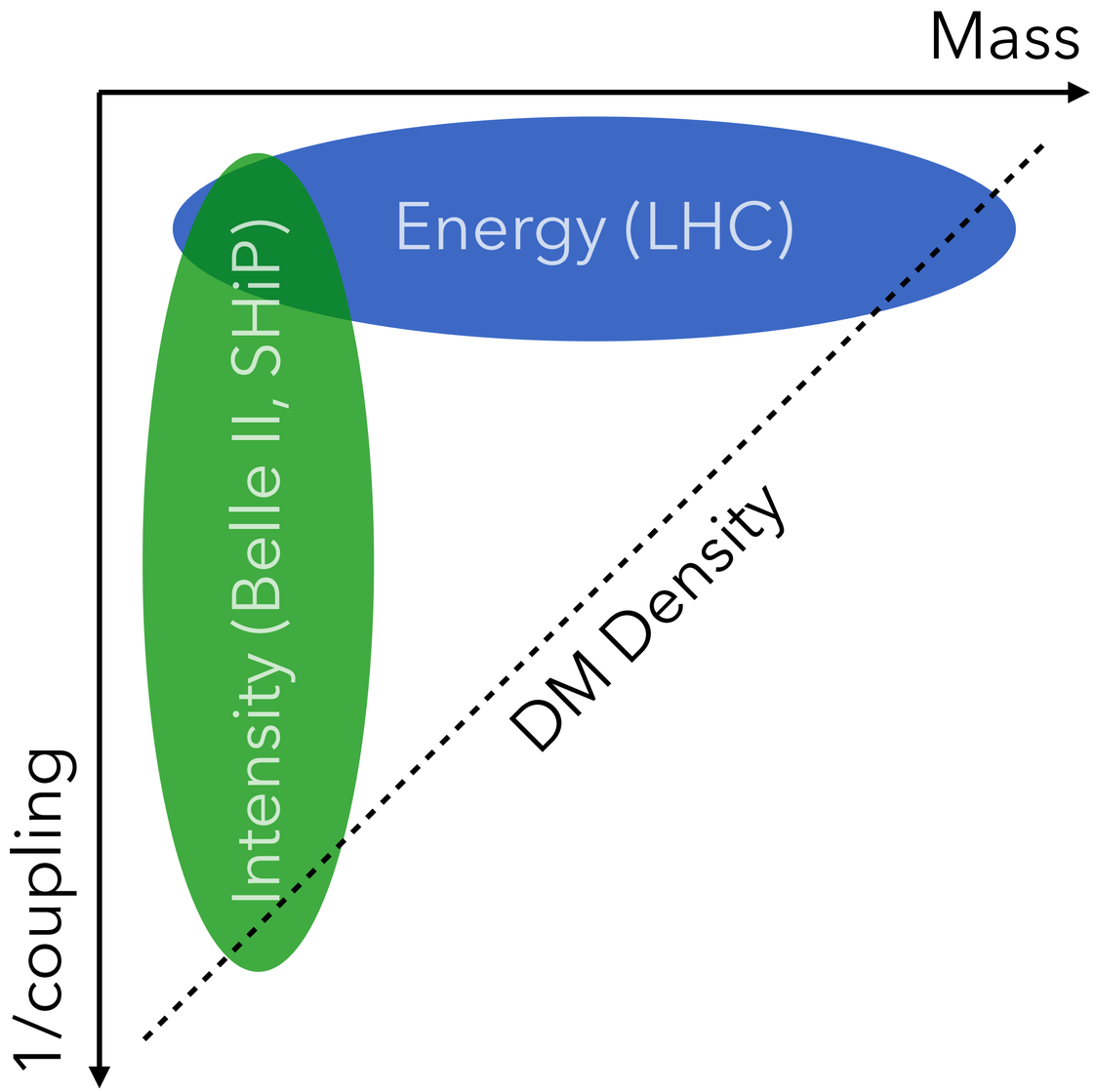
Torben Ferber (torben.ferber@desy.de)

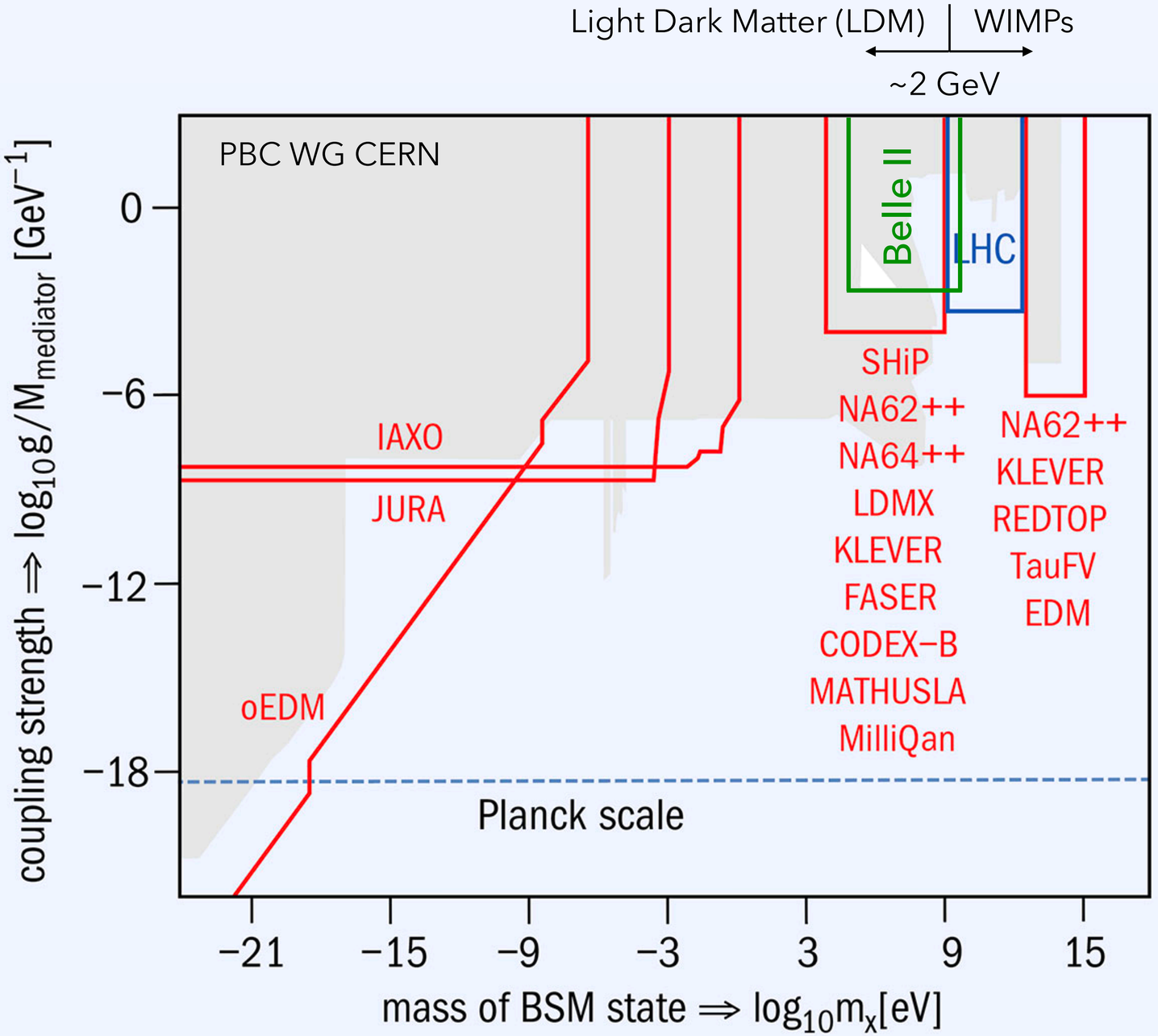
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

HELMHOLTZ Young Investigators

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

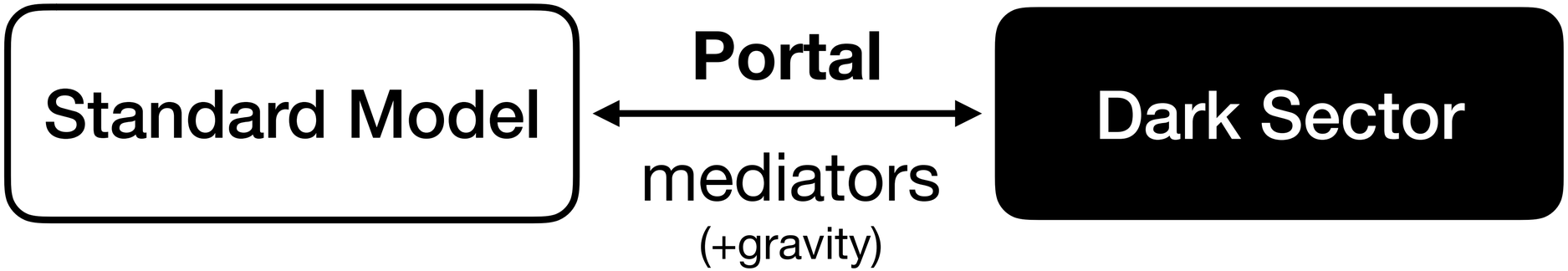
DESY.


Mass
Energy (LHC)
Intensity (Belle II, SHiP)
DM Density
1/coupling



Belle II: 2019-2027
SHiP: 2027+

Portal Models



Only **three sizeable interactions (or portals) to a Dark Sector**, unsuppressed by the (possibly large) NP scale Λ.

$$\mathcal{L} = \sum_{n=k+l-4} \frac{c_n}{\Lambda^n} \mathcal{O}_k^{(\mathrm{SM})} \mathcal{O}_l^{(\mathrm{med})} = \mathcal{L}_{\mathrm{portals}} + \mathcal{O}\left(\frac{1}{\Lambda}\right)$$

$$= \boxed{-\frac{\epsilon}{2} B^{\mu\nu} A'_{\mu\nu}} - H^\dagger H (AS + \lambda S^2) - Y_N^{ij} \bar{L}_i H N_j + \mathcal{O}\left(\frac{1}{\Lambda}\right)$$

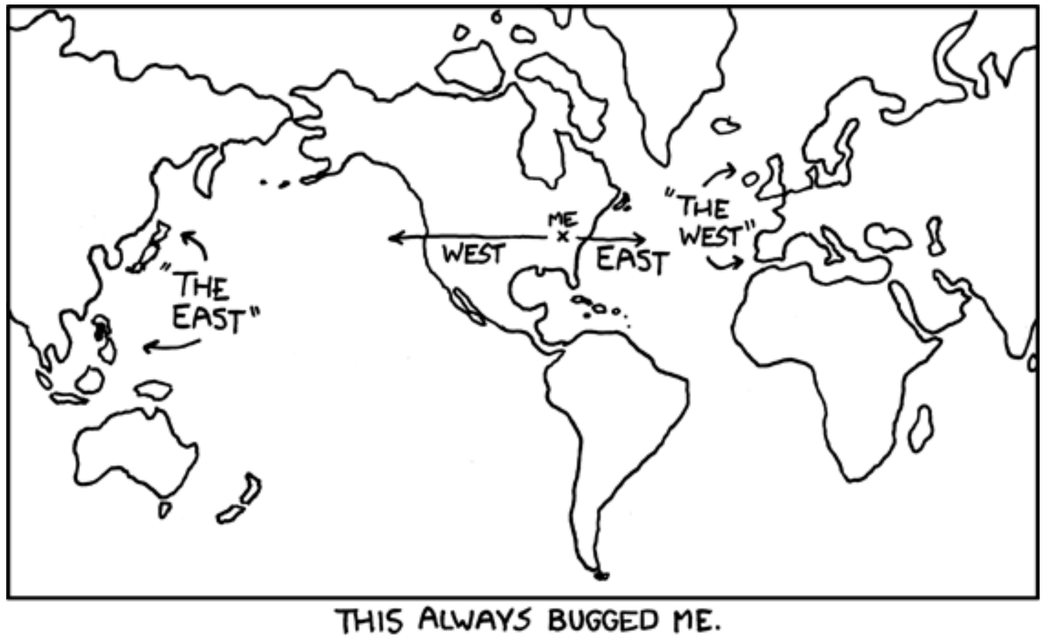
Higgs Neutrinos

Vector Portal: Massive A' mixes with SM γ via strength parameter ε

Dark Photons: Terminology

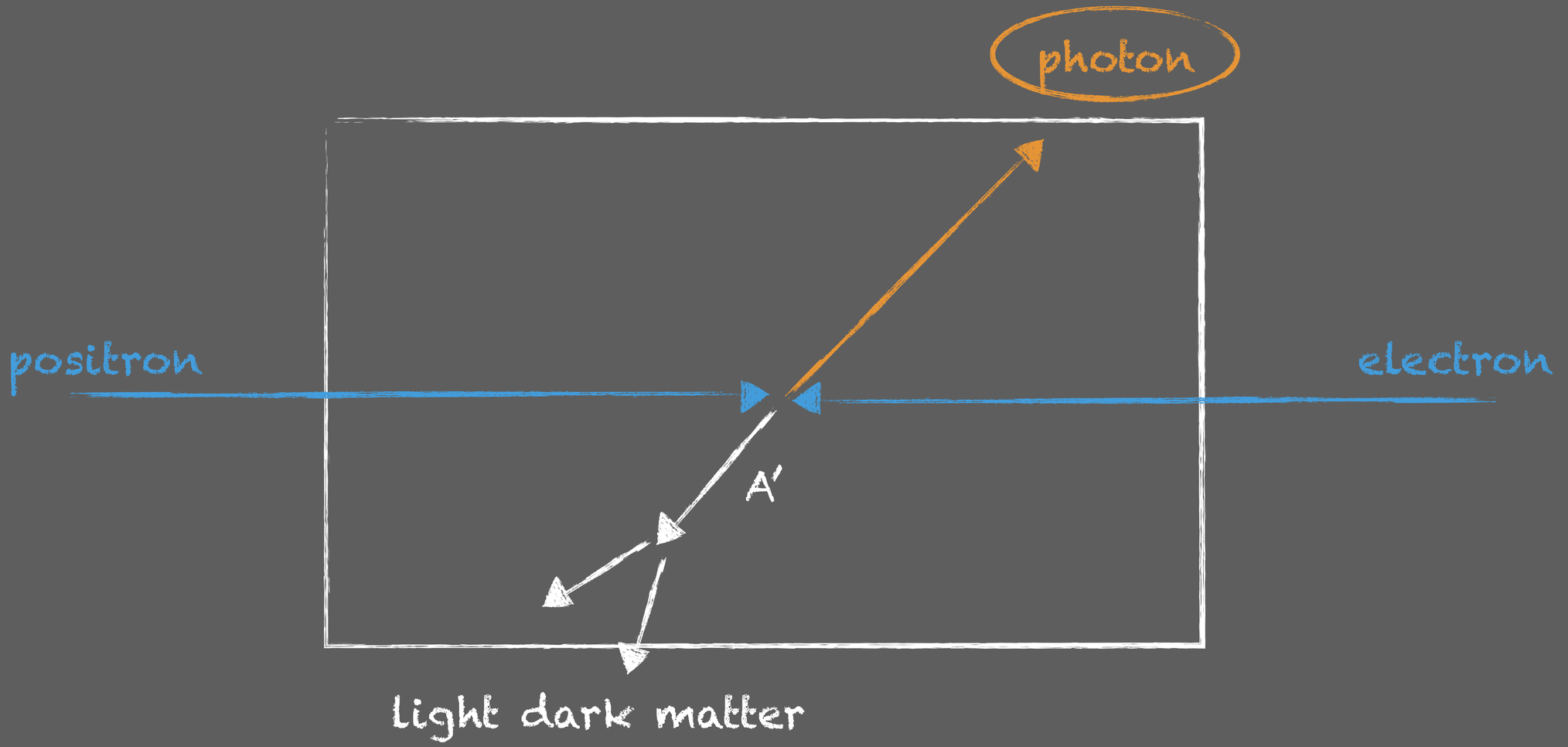
- Different terms for (basically) the same things in literature. I will **use**:
  - Hidden Sector =
    Secluded Sector = **Dark Sector**
  - **Dark Photon** = Hidden Photon
    = Heavy Photon = U-Boson = $\gamma_D = \gamma' =$ **A'**
  - $a'/a =$ **ε** via kinetic mixing
    (sometimes ε^2 or $y(\varepsilon)$ in plots)

https://xkcd.com/503/



- **Z' != A'**: A' via kinetic mixing, Z' via explicit couplings

Invisible Dark Photon decays at Belle II

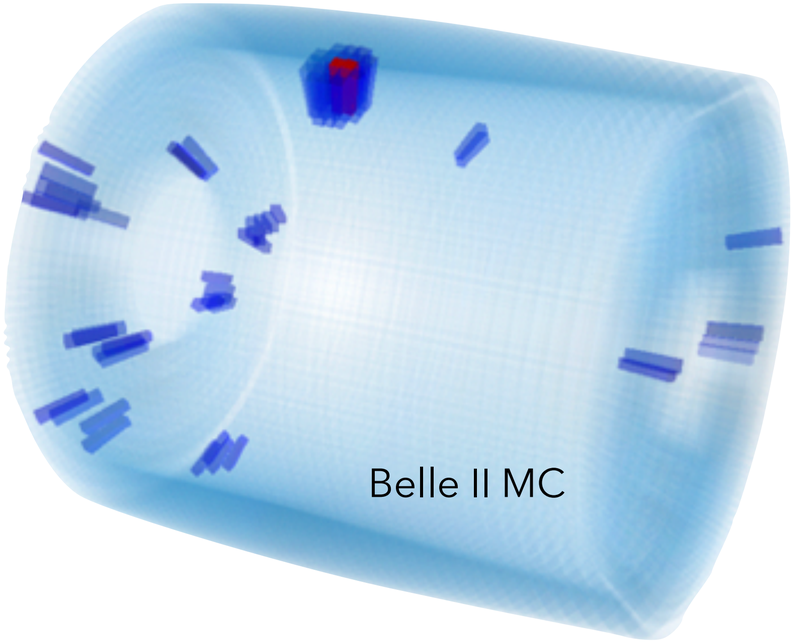


Invisible Dark Photon decays at Belle II

- Requirements:
  - Single photon trigger ($E_{th} \approx 1$GeV)
  - Efficient and calibrated calorimeter
    BaBar's problem:
    projective ECAL → large backgrounds
  - Efficient outer detector to veto
    calorimeter gaps and punch-throughs
- SM backgrounds are ee→γγ(γ) and
  ee→ ee(γ) where one misses all but one γ

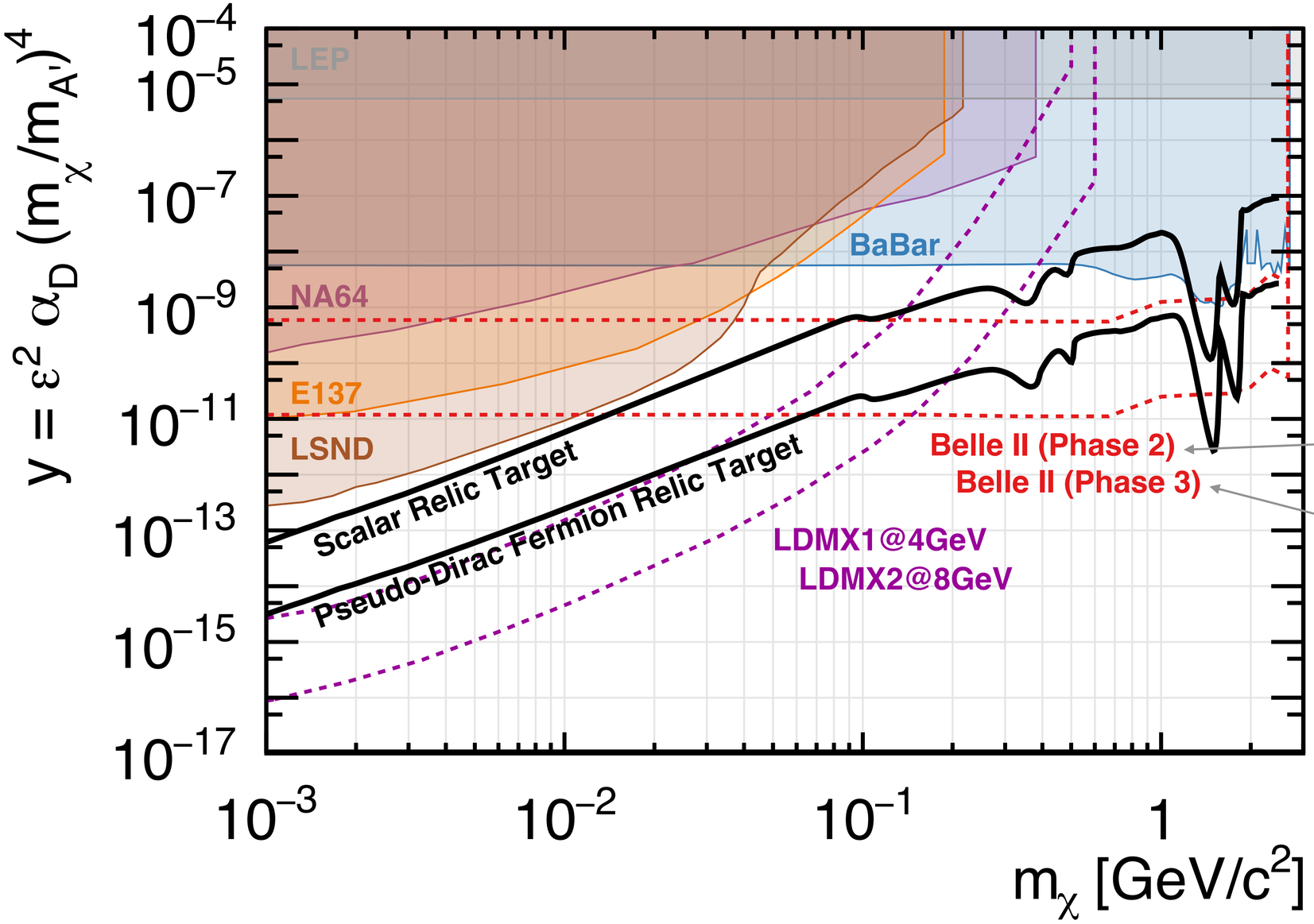
$$E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$$

Belle II Phase 3
need ~1 year data



Invisible Dark Photon decays at Belle II

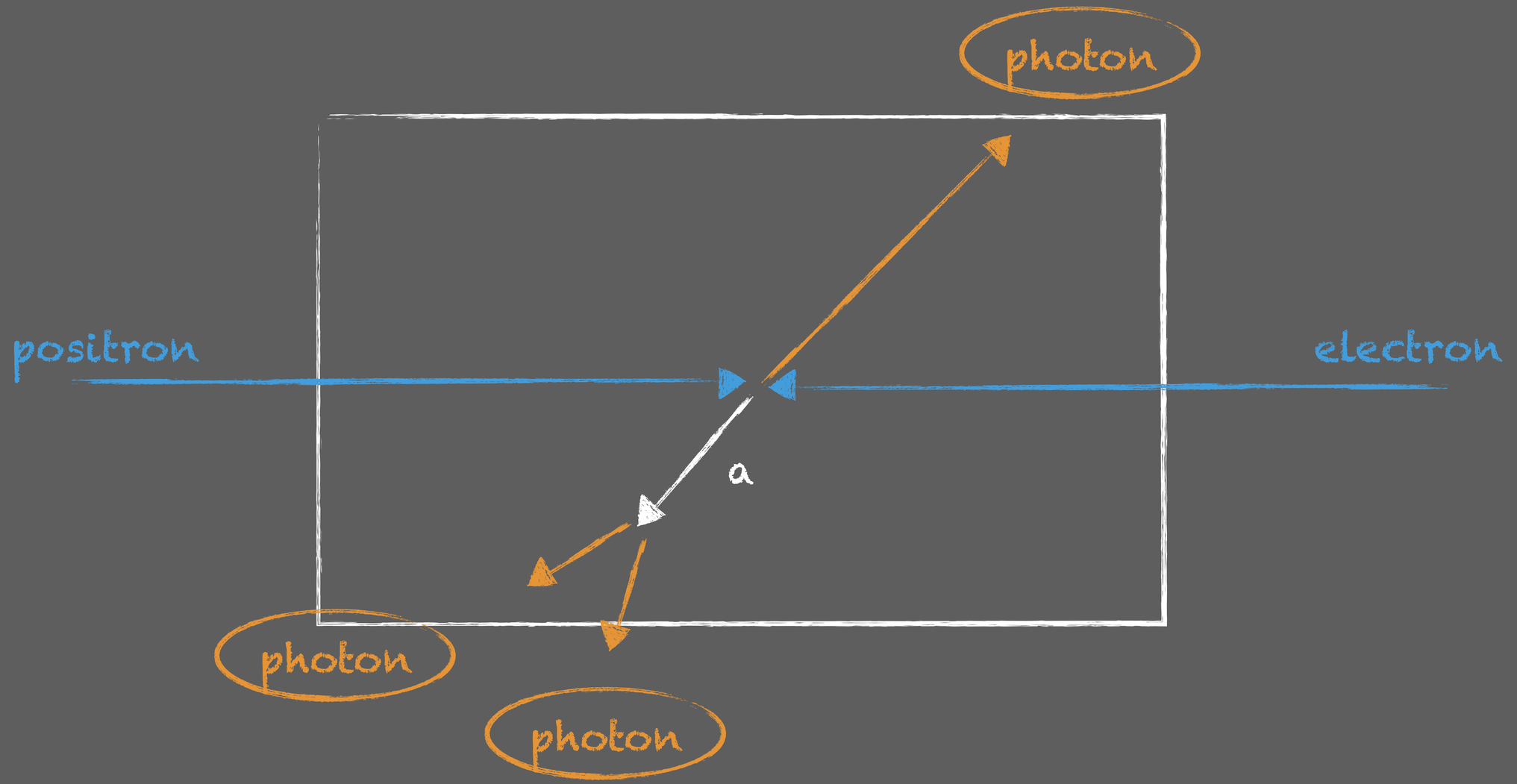
J. Alexander et al. (2016), arXiv:1608.08632
Natalia Toro, private communication (2017)
J. P. Lees et al., BaBar (2017), Phys. Rev. Lett. 119, 131804 (2017)
TF, **Schmidt-Hoberg et al.**, Belle II Physics book (2018),arxiv:1808.10567



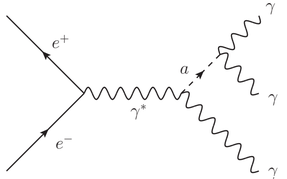
20 fb^{-1} (summer 2019)

50 ab^{-1} (2027)
Assuming no L1 prescale.

Axion-like particles at Belle II

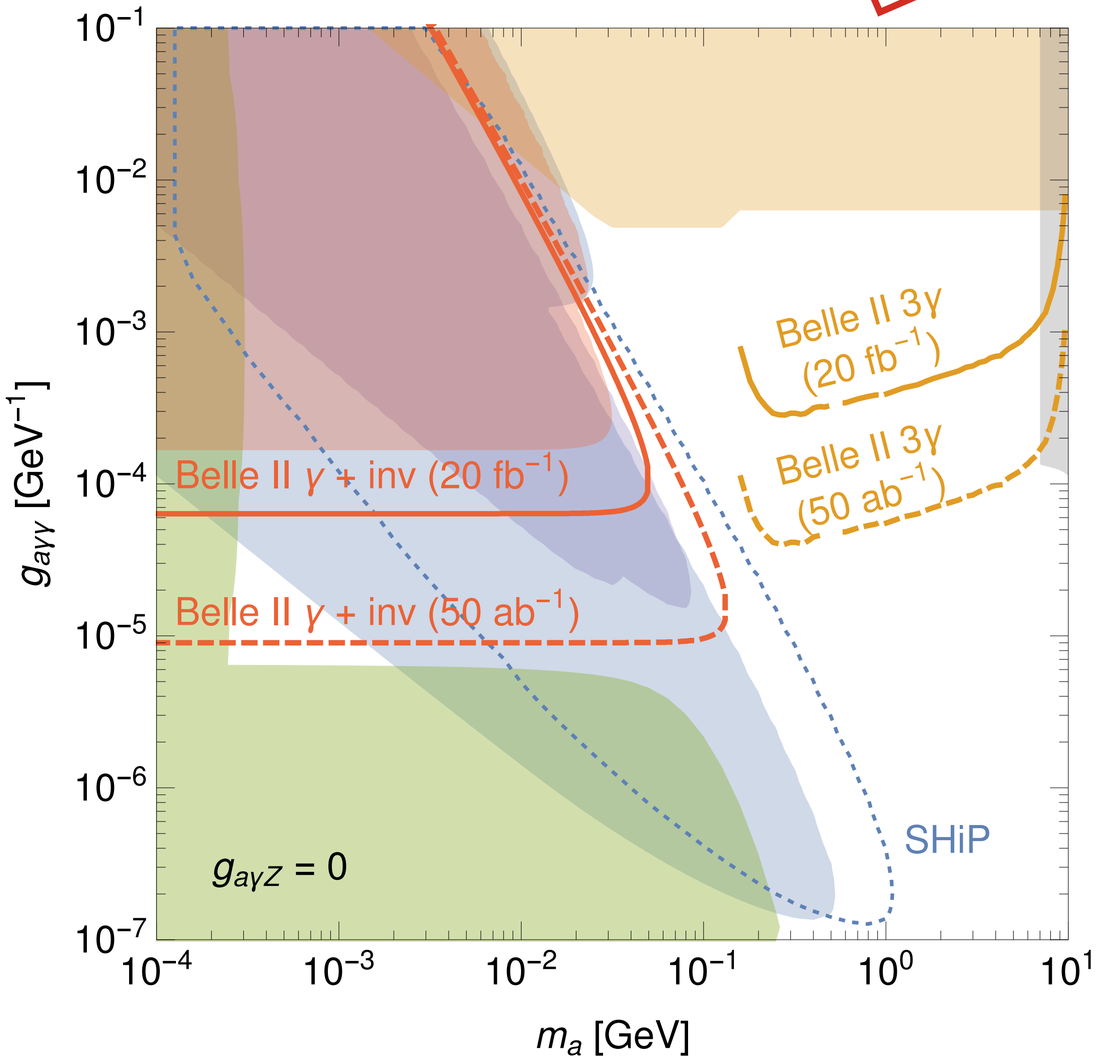


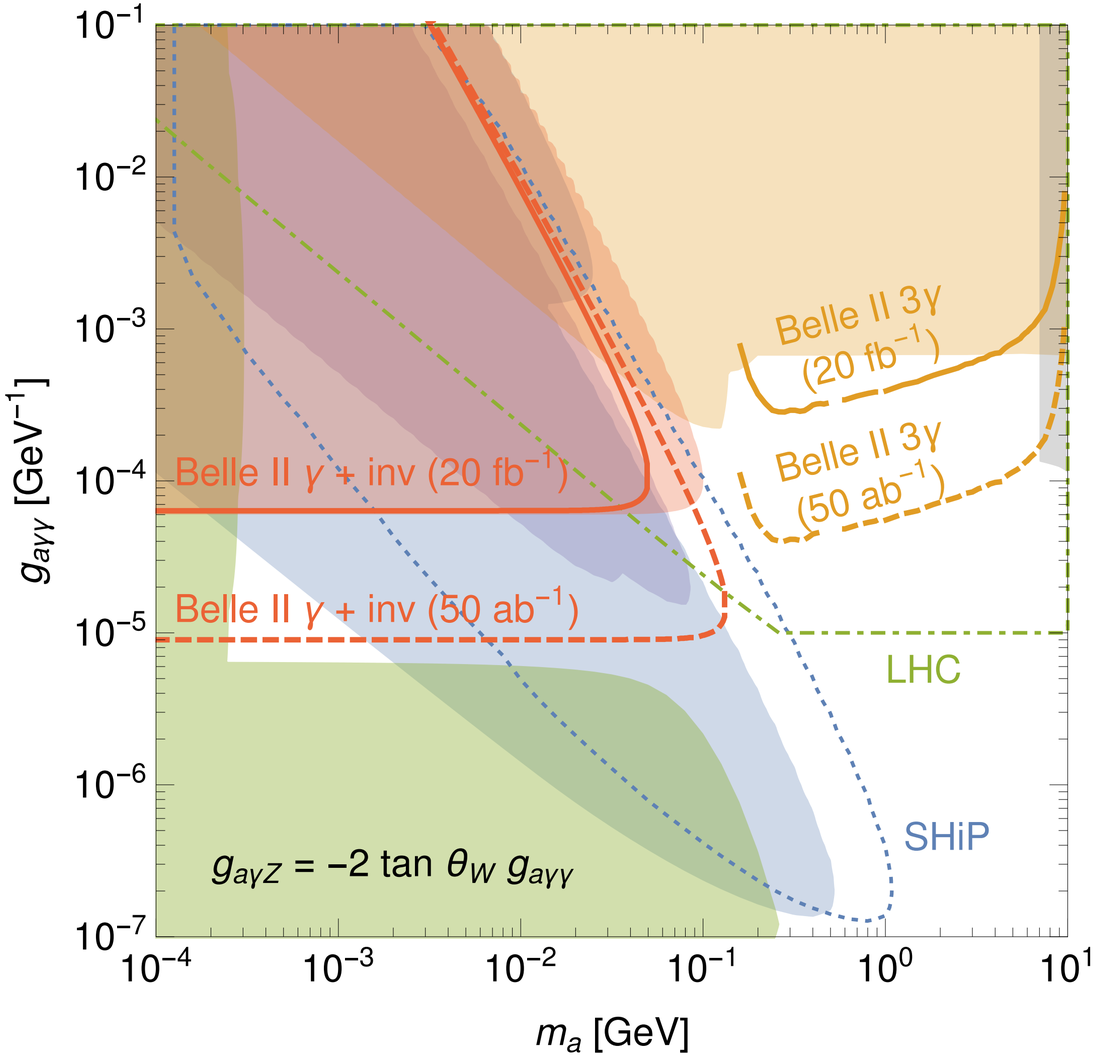
ALPs



Belle II Phase 2 analysis ongoing

TF, **Schmidt-Hoberg**, Kahlhöfer, Dolan, Hearty
JHEP 1712 (2017) 094

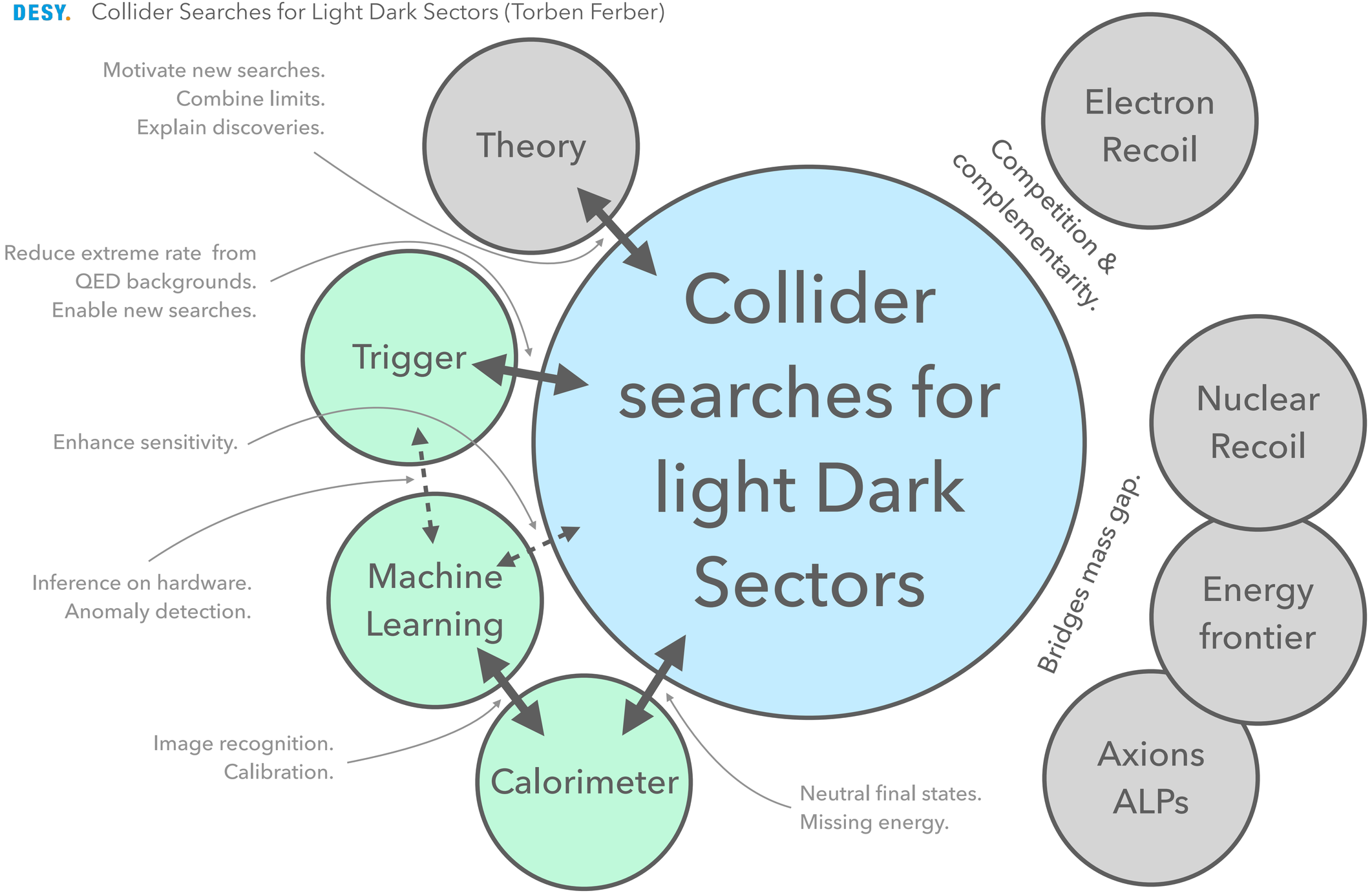




Other signatures at Belle II

- Avoid electron couplings: $Z' \rightarrow$ invisible, $Z' \rightarrow \mu\mu$, and LVF $Z' \rightarrow \mu e$
- Displaced vertices from long-lived mediators or DM decays
- Long-lived ALPs and boosted ALPs (merging photons)
- ALPs with gluon couplings via B decays or via decays into hadrons
- Complex missing energy cascades (e.g. inelastic DM)
- Upsilon decays
- …

Several new projects initiated


Motivate new searches.
Combine limits.
Explain discoveries.
Theory
Reduce extreme rate from
QED backgrounds.
Enable new searches.
Trigger
Enhance sensitivity.
Inference on hardware.
Anomaly detection.
Machine Learning
Image recognition.
Calibration.
Calorimeter
Neutral final states.
Missing energy.
Collider searches for light Dark Sectors
Competition & complementarity.
Electron Recoil
Bridges mass gap.
Nuclear Recoil
Energy frontier
Axions ALPs

Summary

- First two searches are ongoing with the 2018 Belle II dataset:
  ALP→γγ (lead by DESY), and Z'→invisible (DESY contribution).

- Belle II will start physics data taking this week.

- Established and ongoing cooperation between experiments and DESY theory (ALPs, Belle II physics book, SHiP physics book).

- Room for improvement within QU: Theory collaboration with UHH, experimental collaboration in analysis methods (including ML), calorimeter reconstruction, and trigger development.

Contact

DESY.

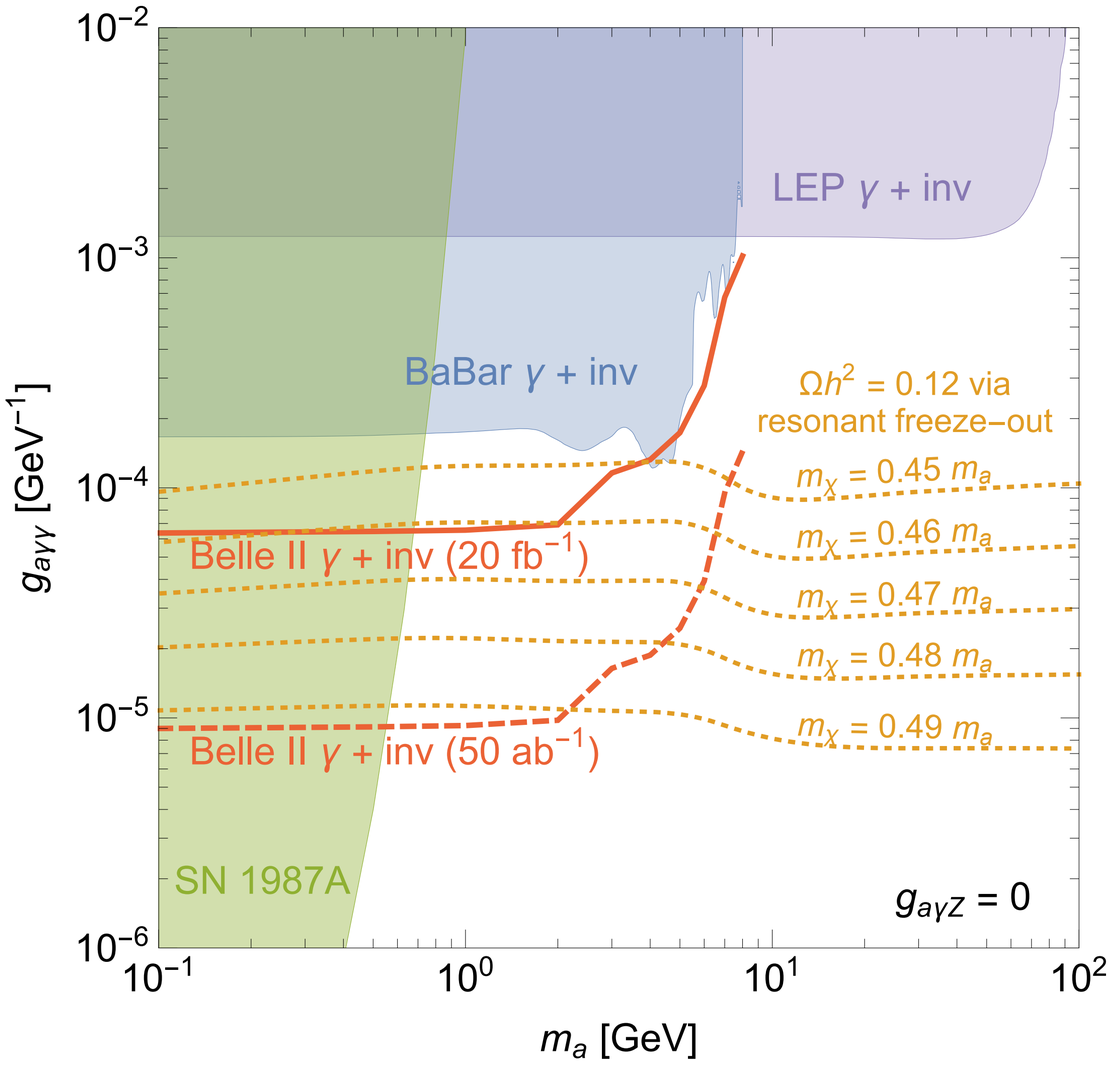
Deutsches Elektronen Synchrotron
www.desy.de

Torben Ferber
torben.ferber@desy.de
ORCID: 0000-0002-6849-0427

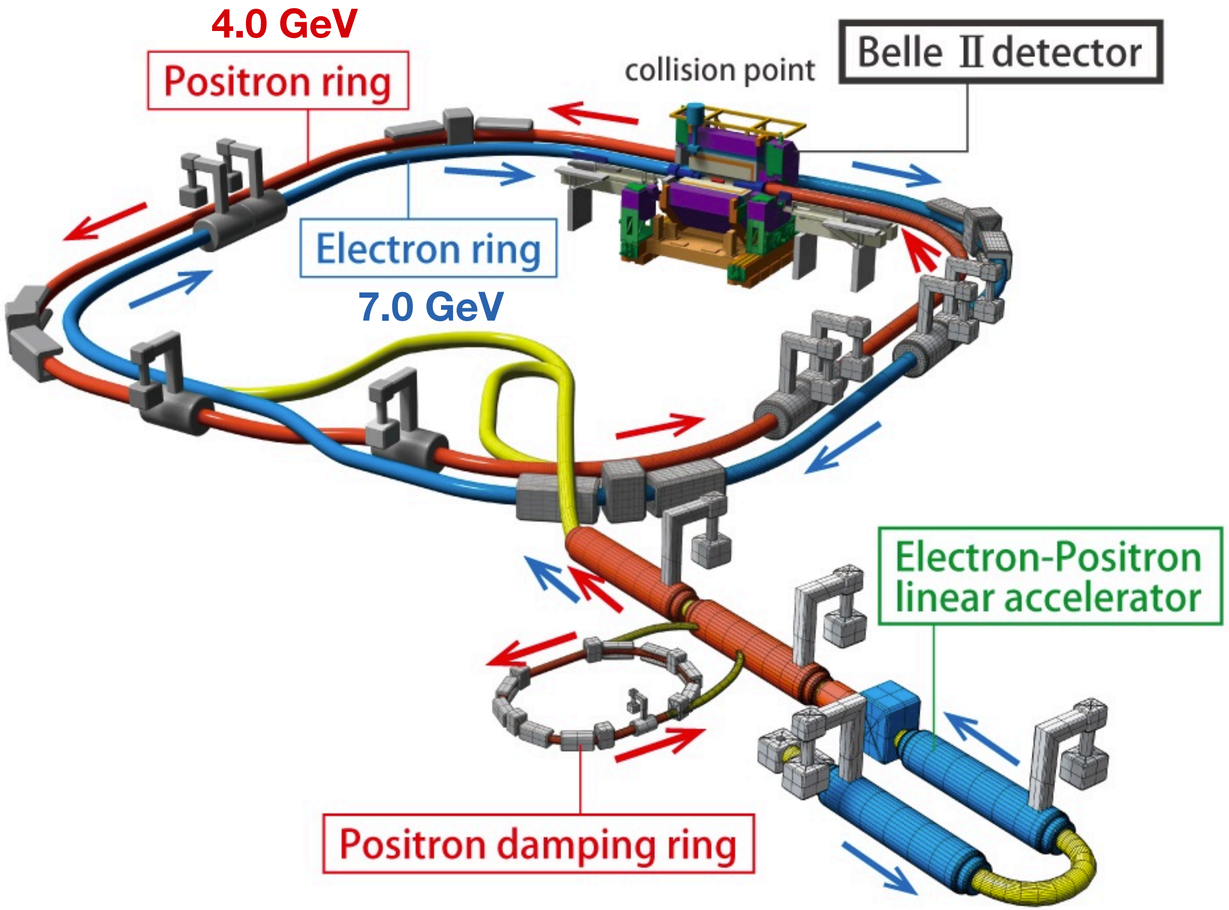
Backup

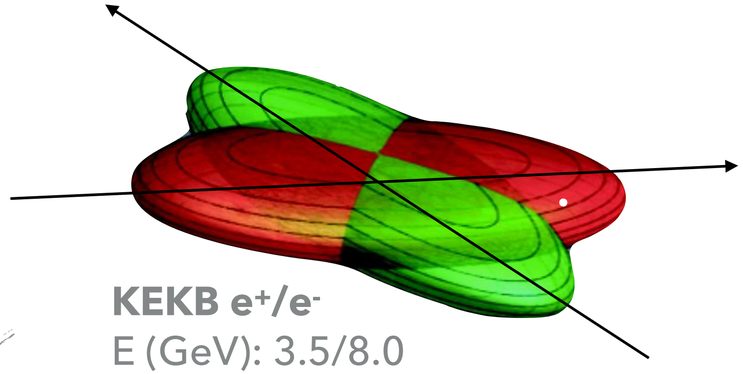
ALPs

TF, **Schmidt-Hoberg**, Kahlhöfer, Dolan, Hearty
JHEP 1712 (2017) 094

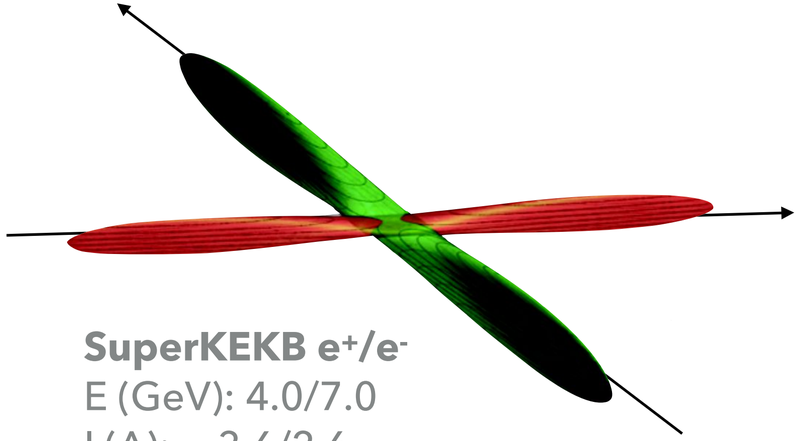


SuperKEKB



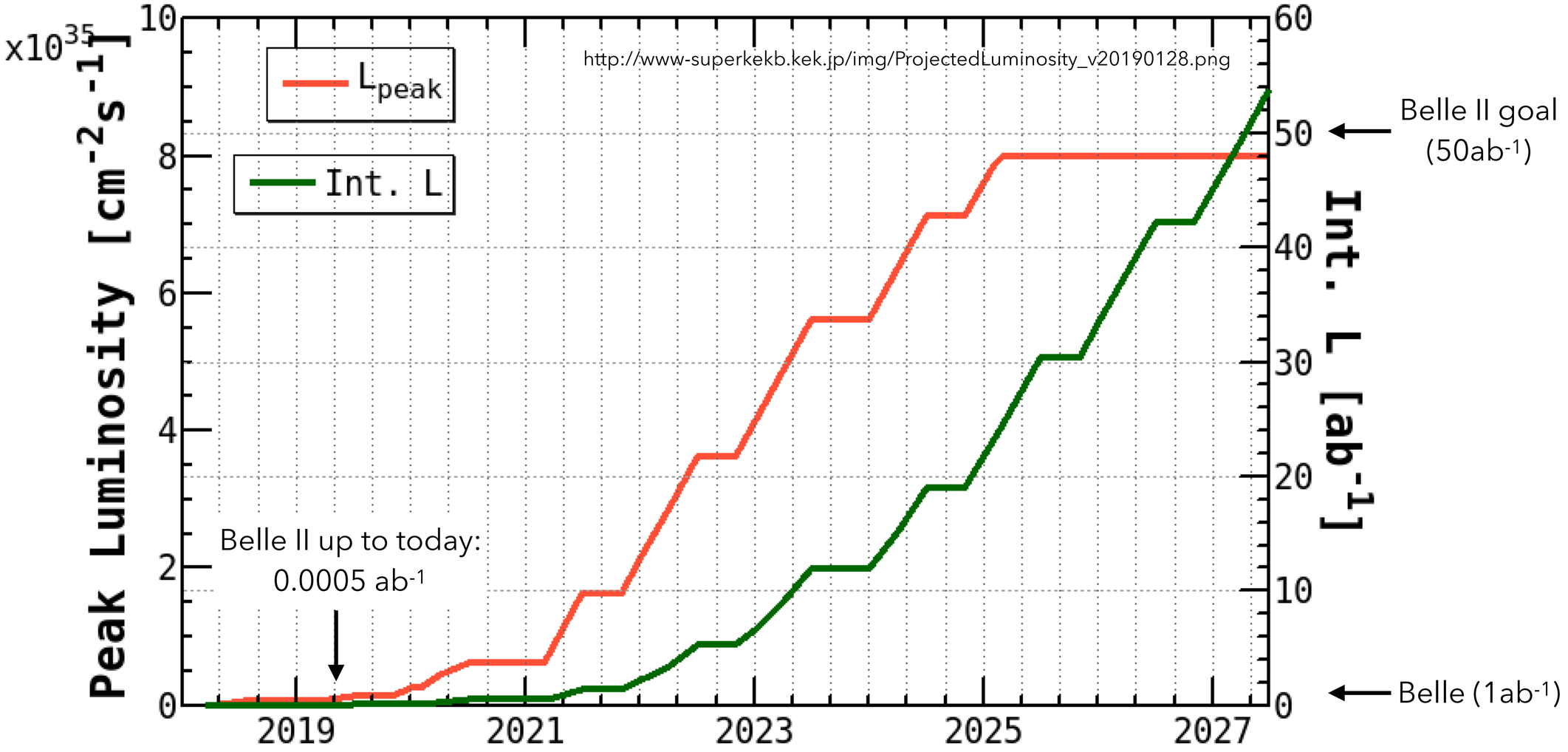


KEKB e^+/e^-
E (GeV): 3.5/8.0
I (A): ~ 1.6/1.2
β^*_y (mm): ~5.9/5.9
Crossing angle (mrad): 22

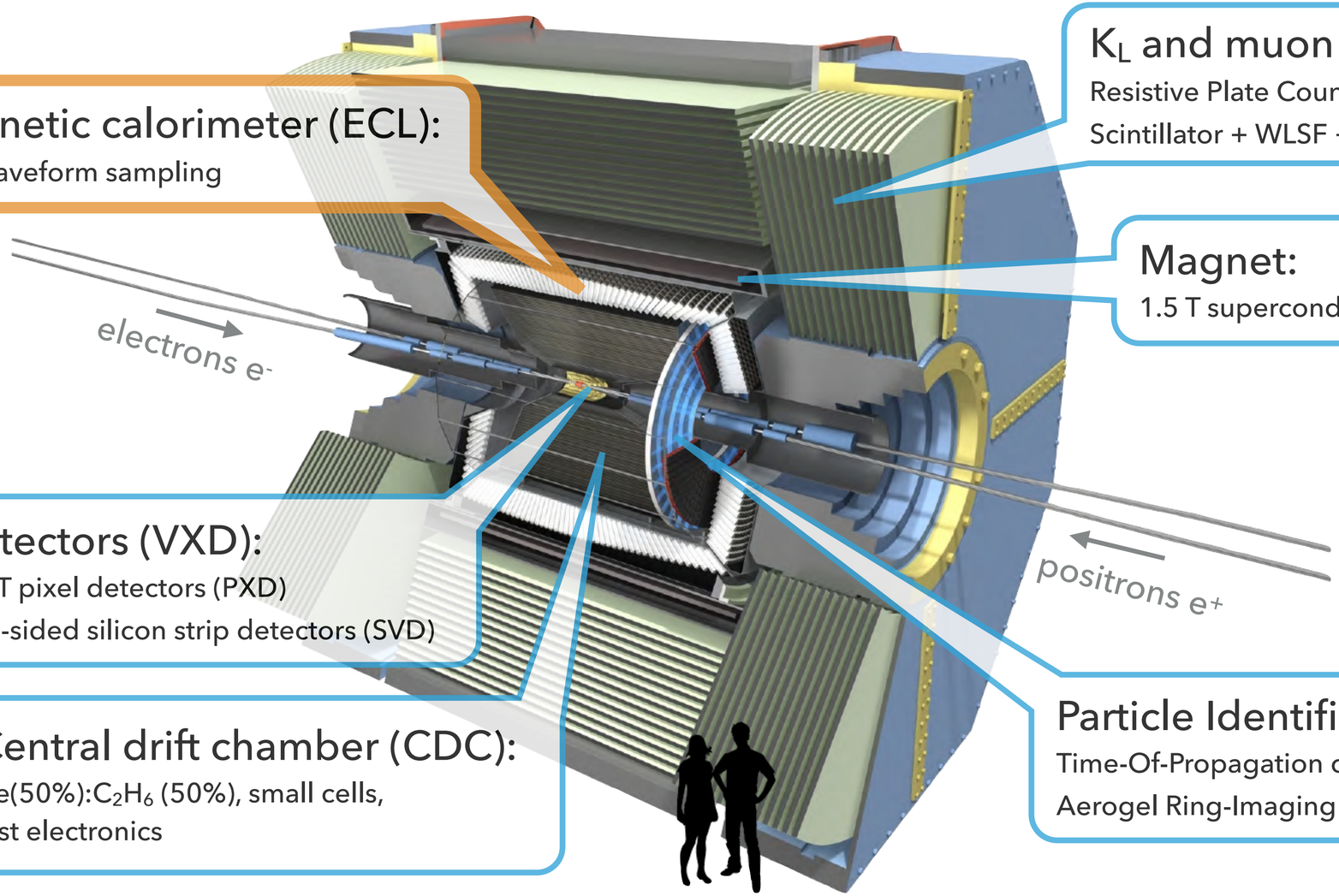


SuperKEKB e^+/e^-
E (GeV): 4.0/7.0
I (A): ~ 3.6/2.6
β^*_y (mm): ~0.27/0.3
Crossing angle (mrad): 83
→ **Luminosity increase x40**

Belle II at SuperKEKB



Belle II at SuperKEKB



Electromagnetic calorimeter (ECL):
CsI(Tl) crystals, waveform sampling

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

Trigger:
Hardware: < 30 kHz
Software: < 10 kHz

Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD)
4 layer double-sided silicon strip detectors (SVD)

Central drift chamber (CDC):
He(50%):C_2H_6 (50%), small cells,
fast electronics

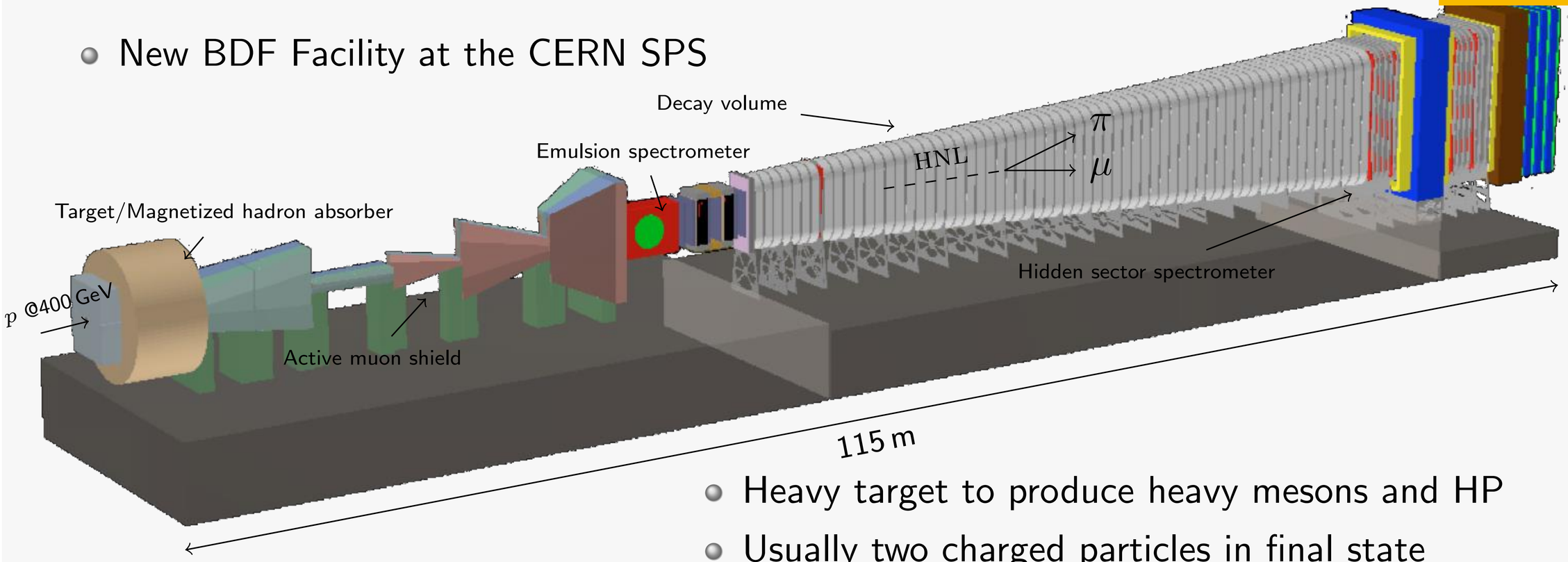
Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

SHiP

Daniel Bick

- New BDF Facility at the CERN SPS



- Heavy target to produce heavy mesons and HP
- Usually two charged particles in final state
  $\rightarrow$ far away from target
- Long evacuated decay vessel followed by detectors
- Can test a large variety of models predicting HP

SHiP

Daniel Bick

The SHiP Tracker:

- 5 m long straw tubes operated horizontally
- 10 m high detector
- Four stations, 18000 straw tubes
- Station design (frame)
- Development of the straw mechanics
  - Production of straw modules to be inserted into the frame