Dark matter searches at Belle II.

Sam Cunliffe

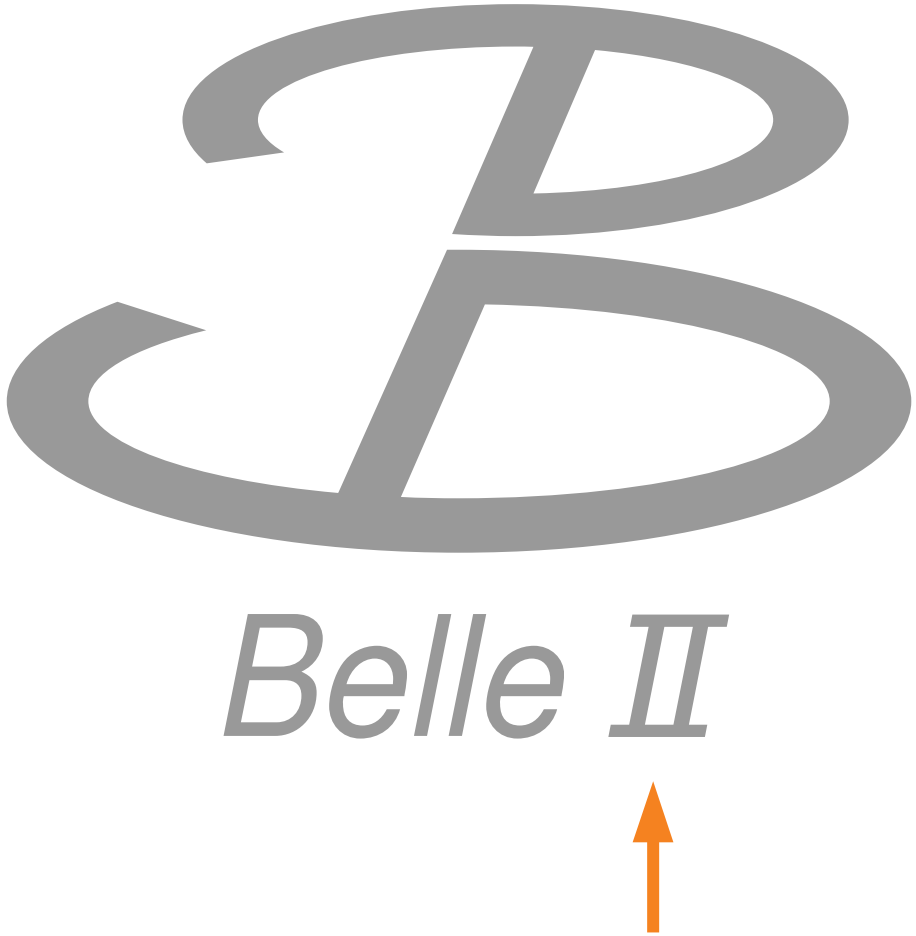
Rencontres de Blois, 05.06.2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

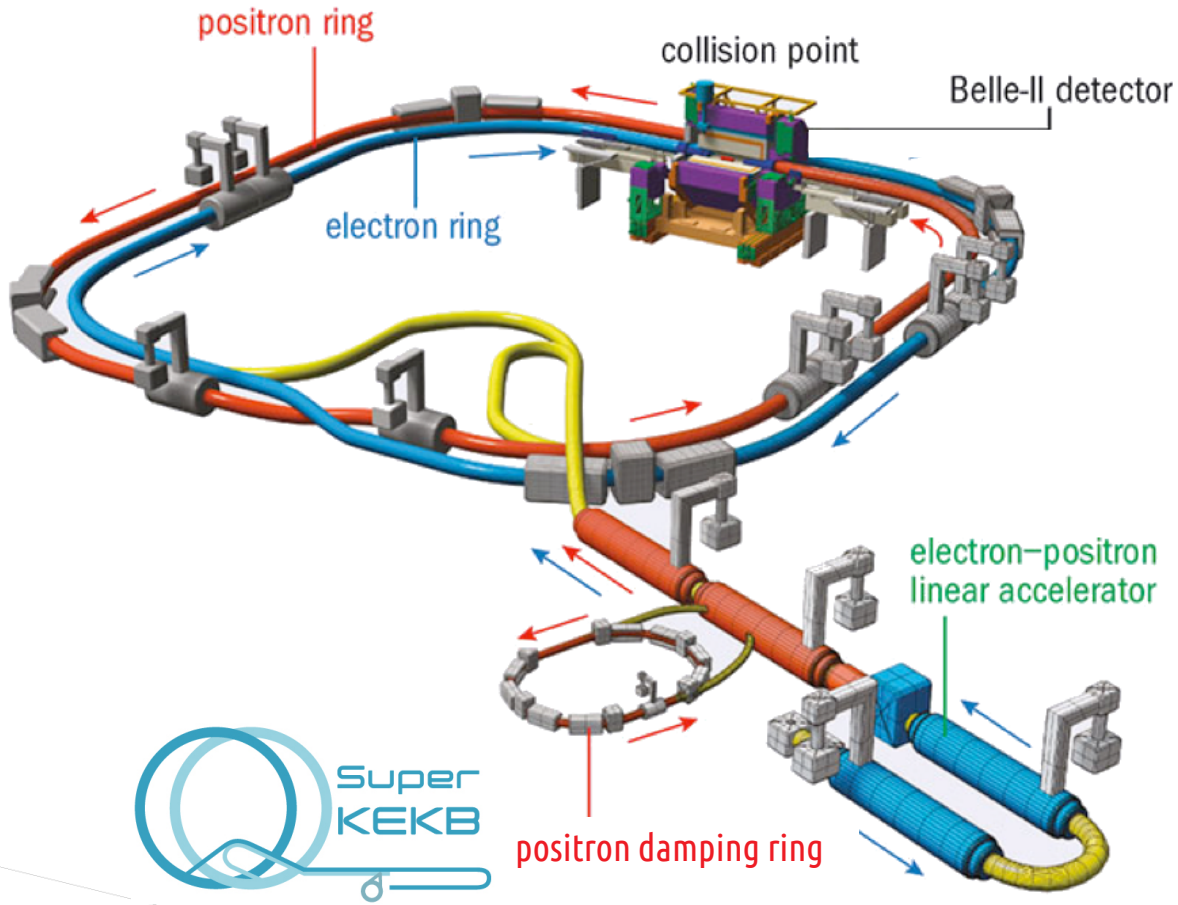
Belle II

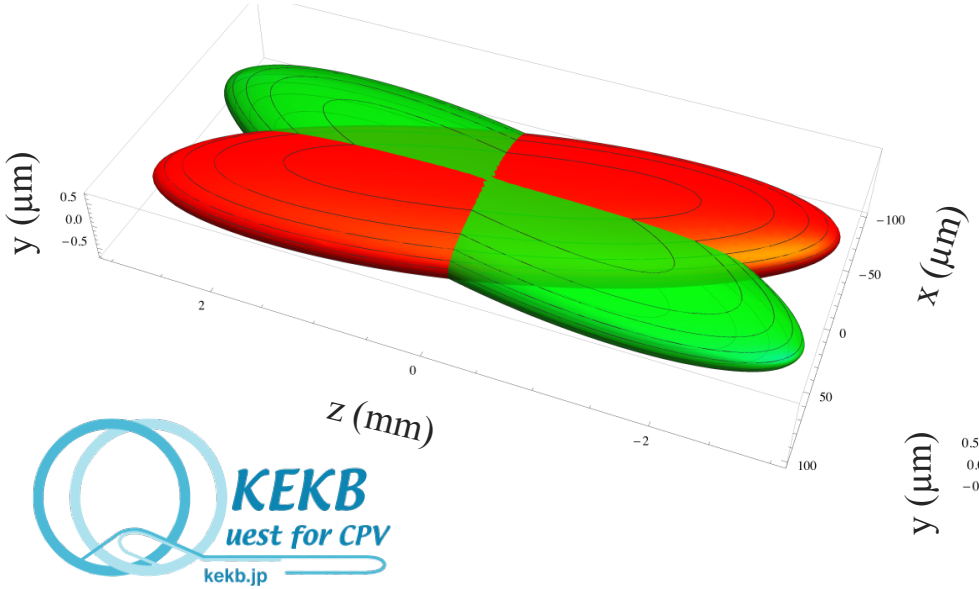
DESY.

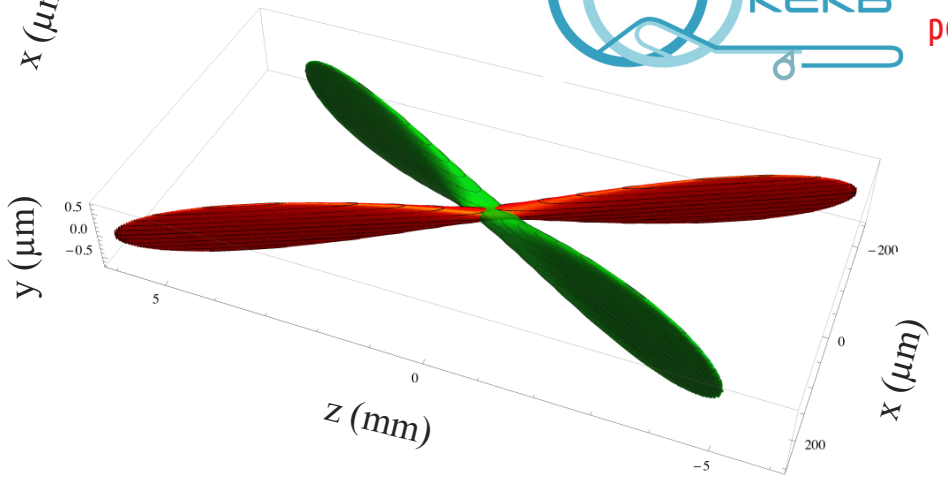

Belle II

SuperKEKB

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

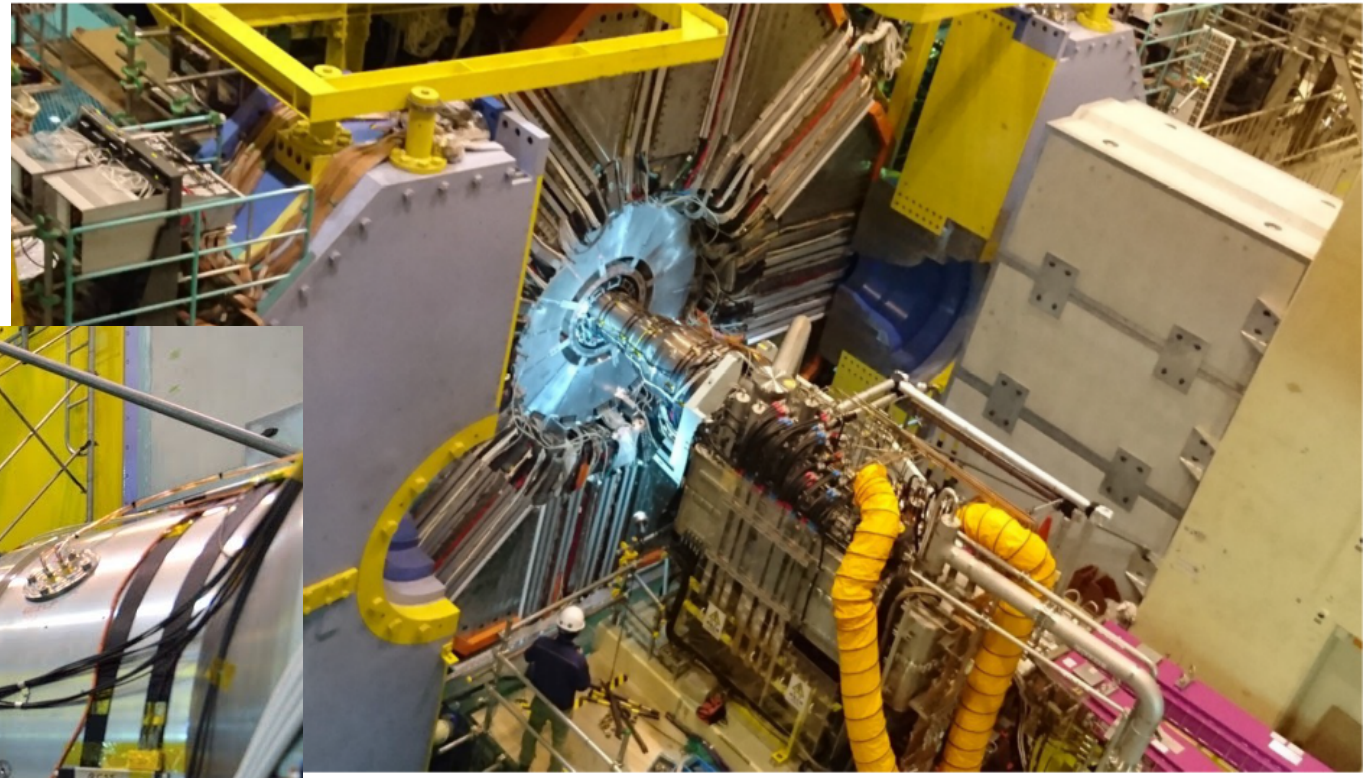


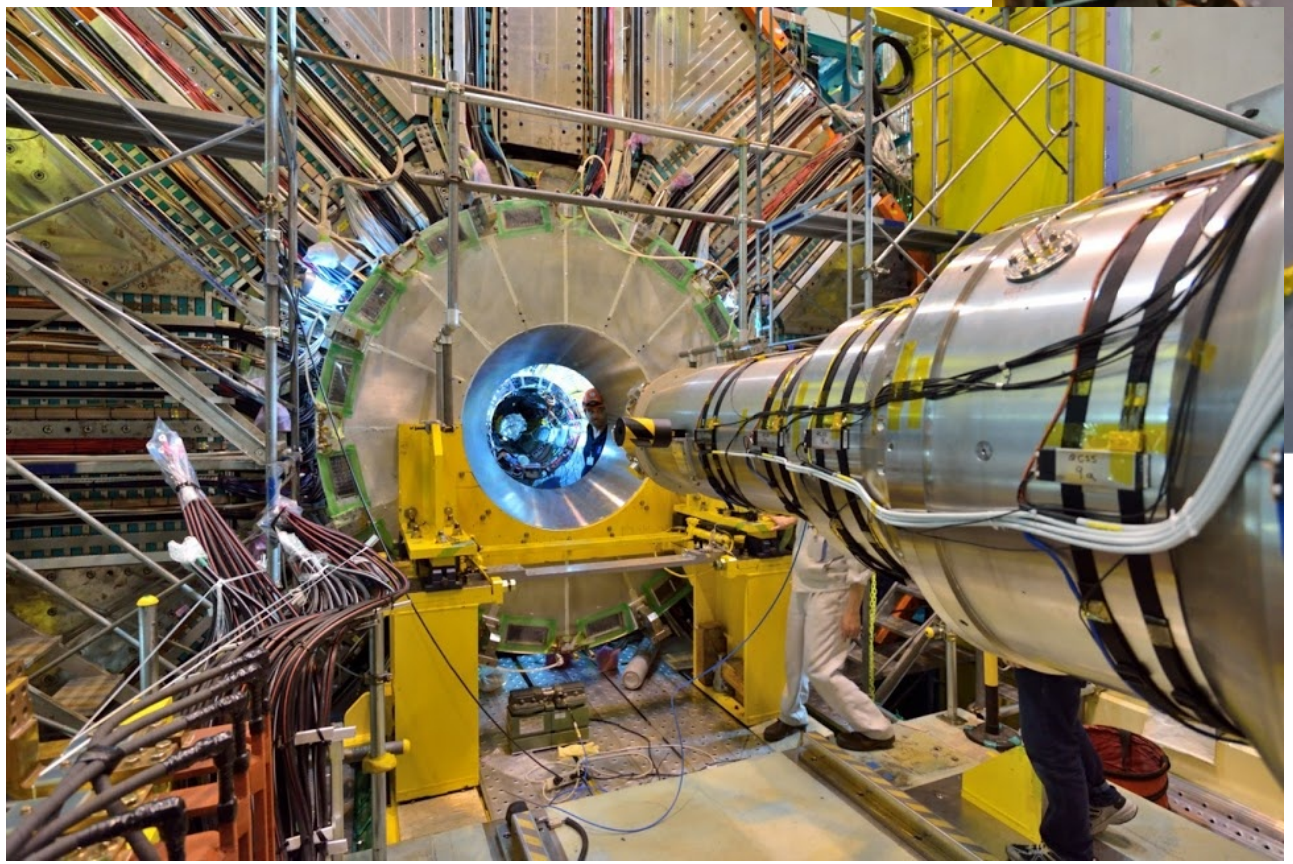




Final focus magnets

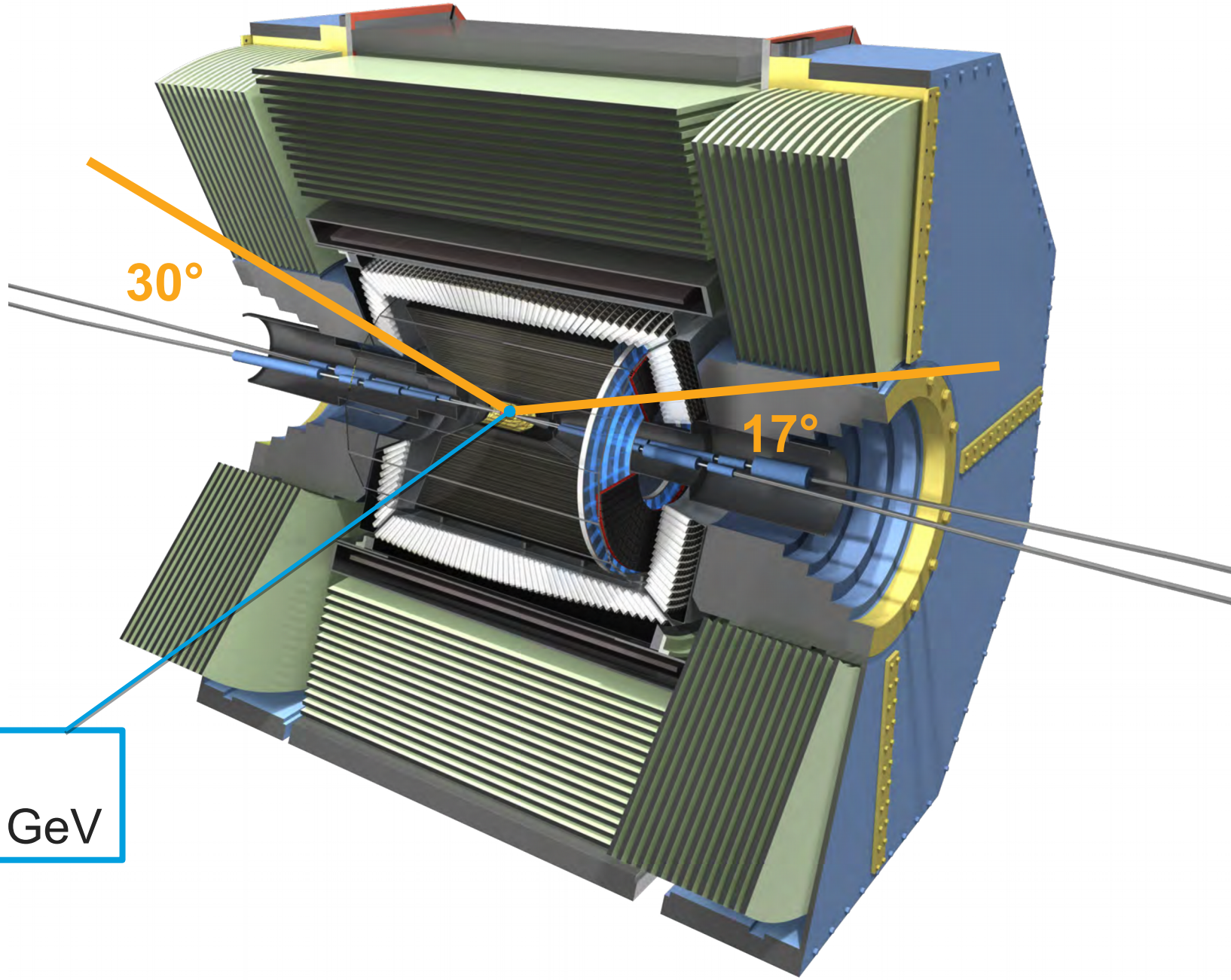
February 2018





Belle II

The detector

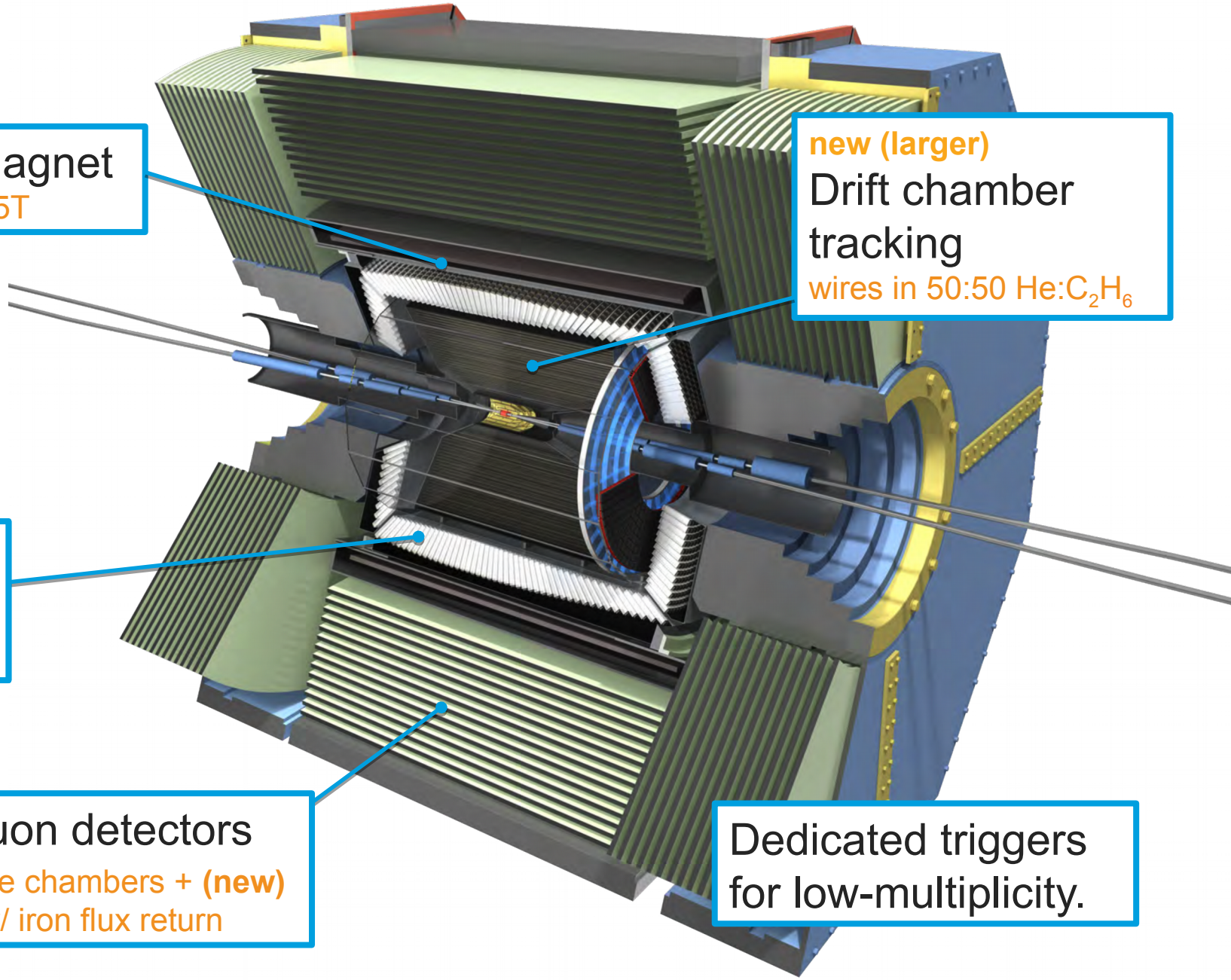


Direction of boost
Direction of electron beam
“Forward”

e^+e^- collision
@ $\sqrt{s}$ = 10.58 GeV

Belle II

The detector



magnet
1.5T

new (larger)
Drift chamber tracking
wires in 50:50 $He:C_2H_6$

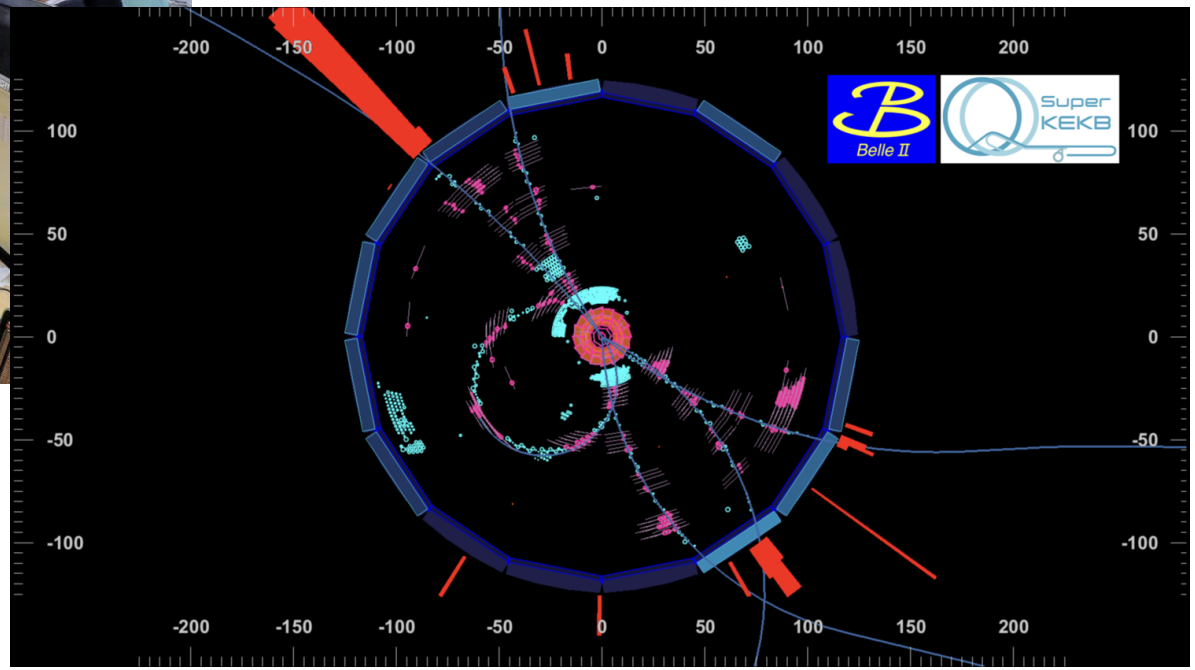
Electromagnetic calorimeter
CsI(Tl) crystals… **new readout**

K_L and muon detectors
Resistive plate chambers + **(new) scintillator** w/ iron flux return

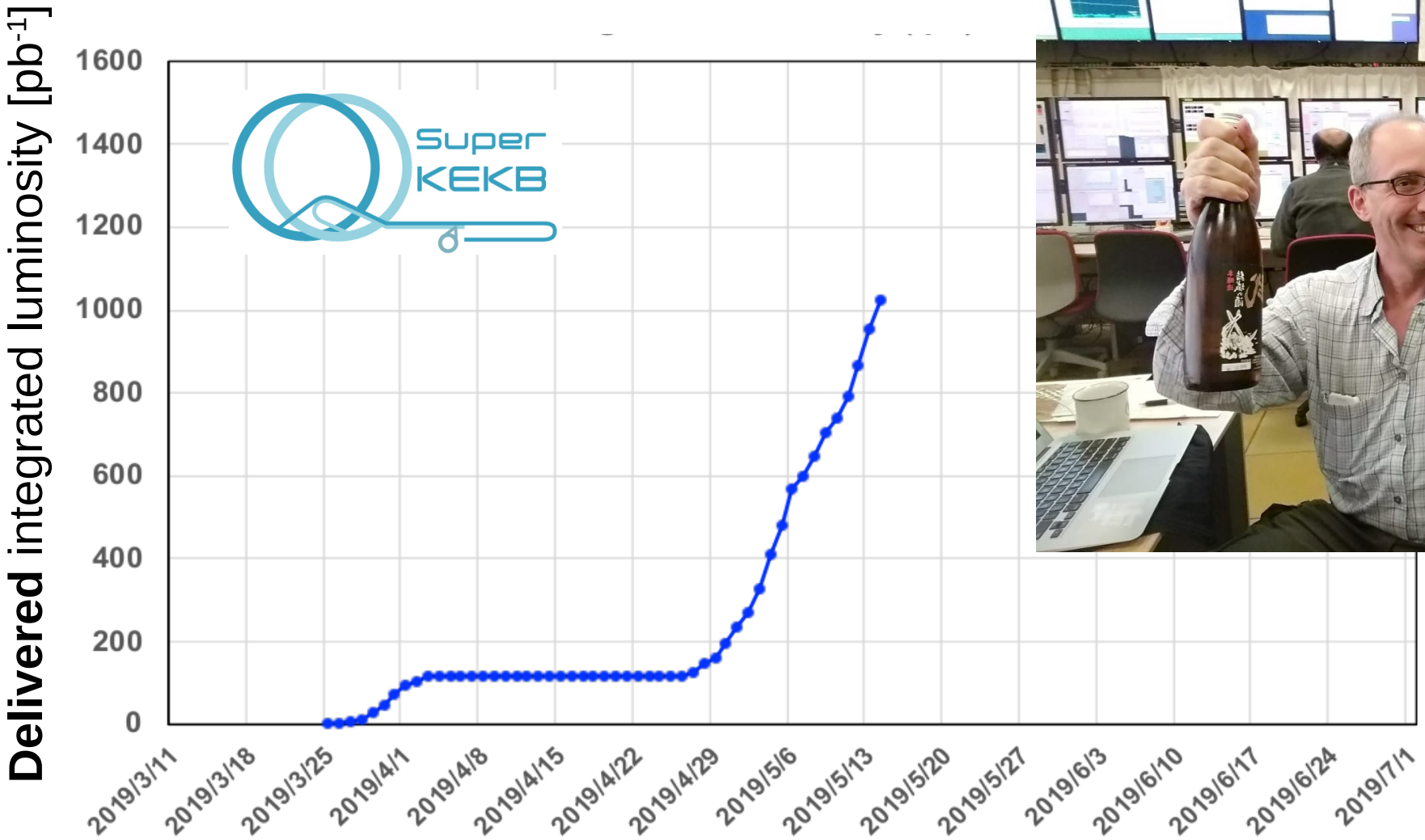
Dedicated triggers for low-multiplicity.

First collisions of 2019

25 March

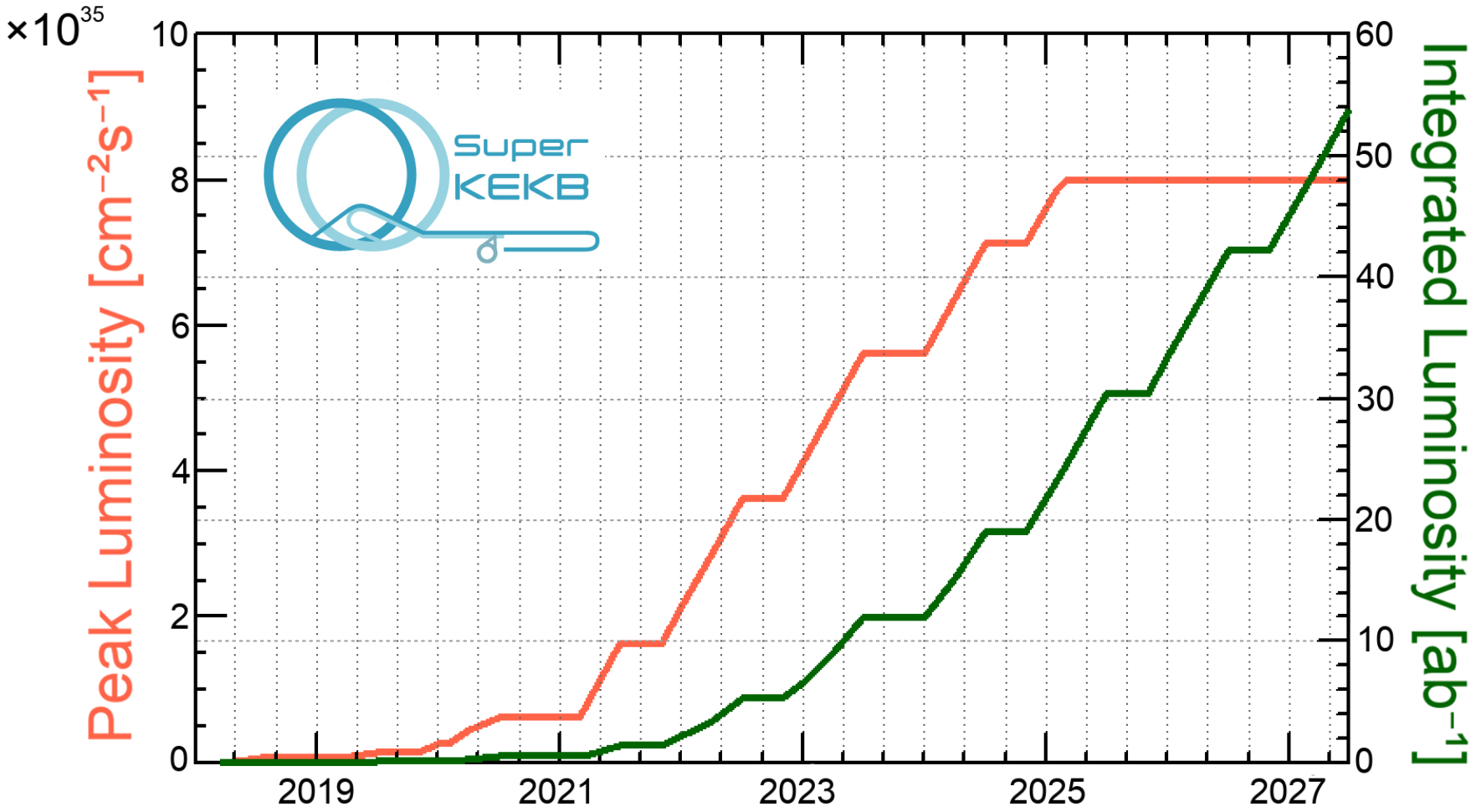


Recent milestone



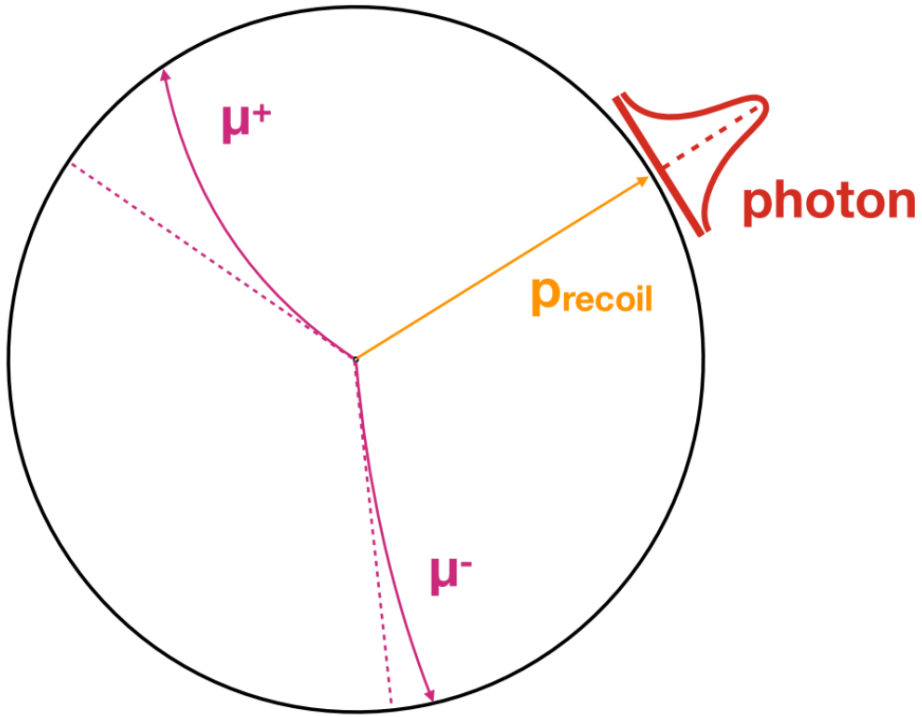
Data schedule

- Last year: 500 pb^{-1}.
  - *Commissioning* data.
- Up to now this year: ~2.5 fb^{-1} ***delivered***.
- Lifetime data set: 50 ab^{-1}.

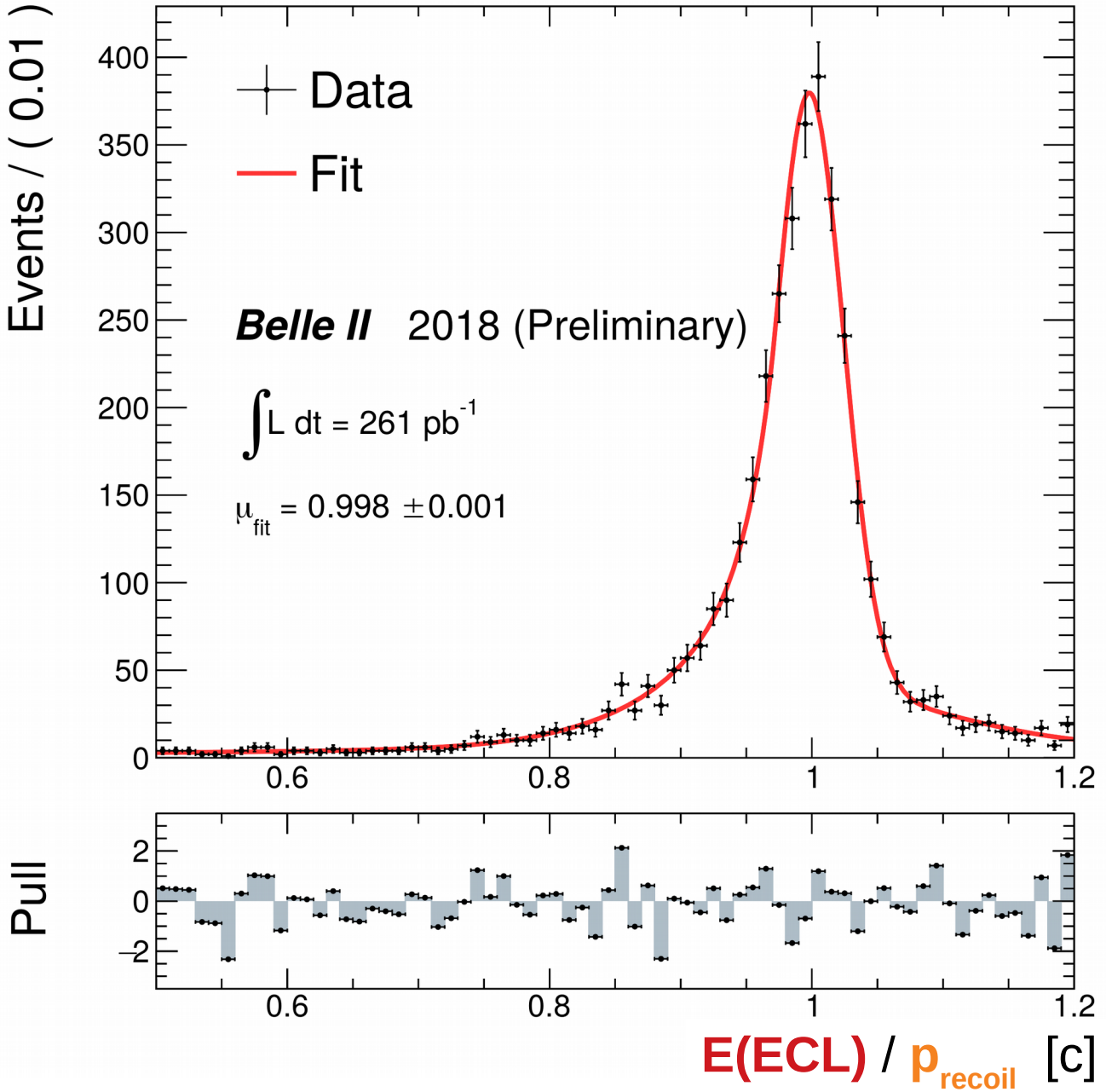


Tracking and clustering

Radiative dimuon events in first data



ee → μμγ



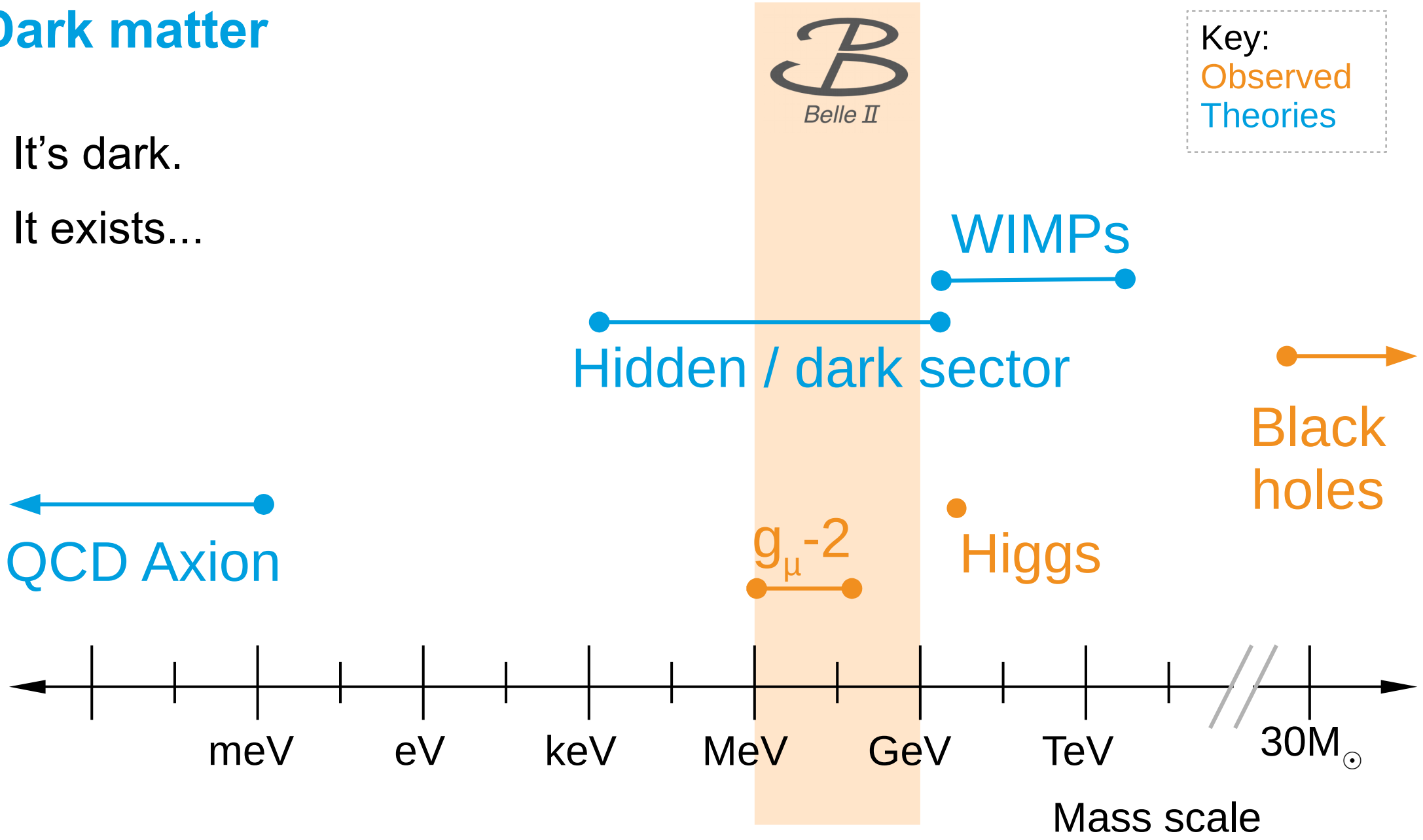
Dark matter

Dark matter

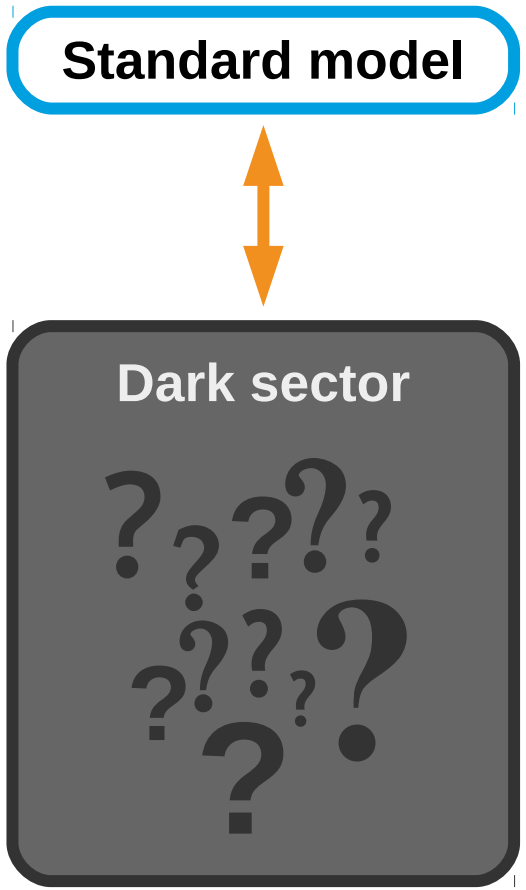
- It’s dark.
- It exists...

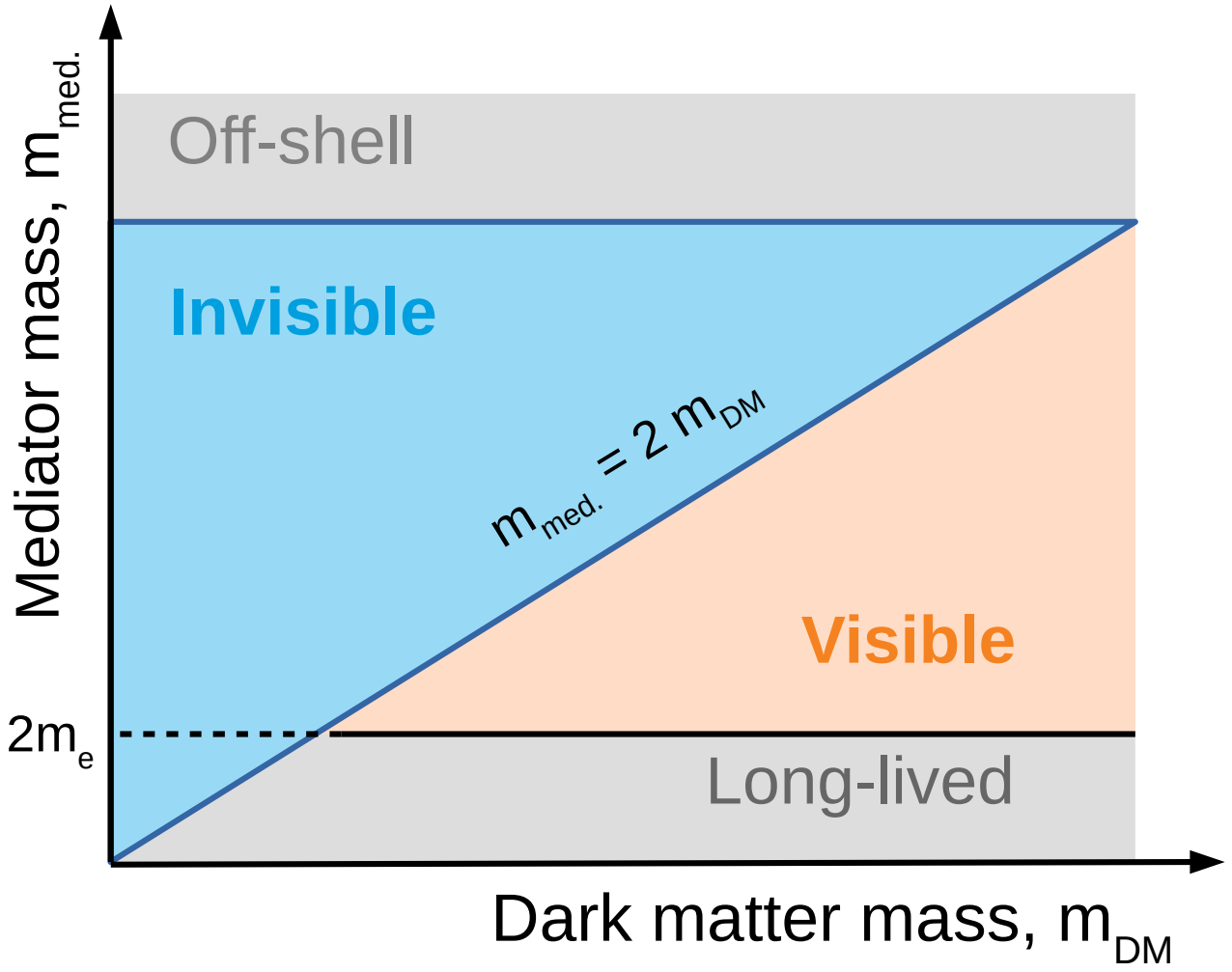
Dark matter

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



Dark sector


Standard model
Dark sector

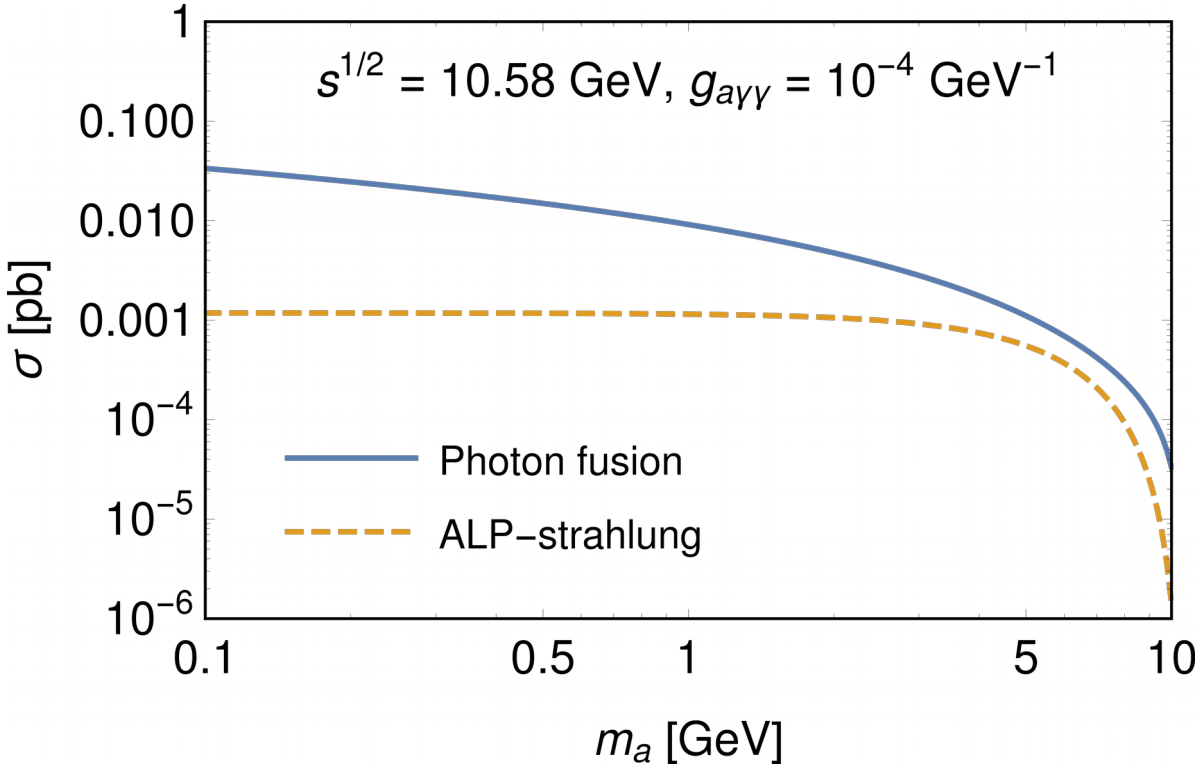

Mediator mass, $m_{med.}$
Off-shell
Invisible
$m_{med.} = 2\, m_{DM}$
Visible
$2m_e$
Long-lived
Dark matter mass, m_{DM}

Axion-like particle

Theory

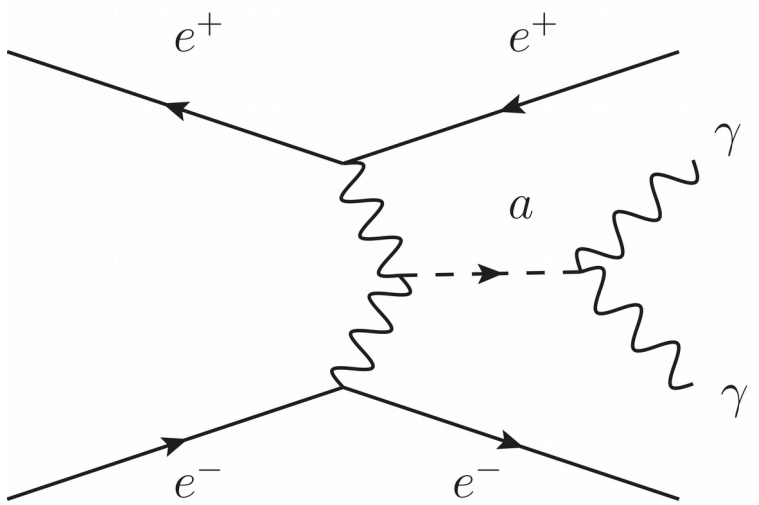
- After EWSB, four terms:

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

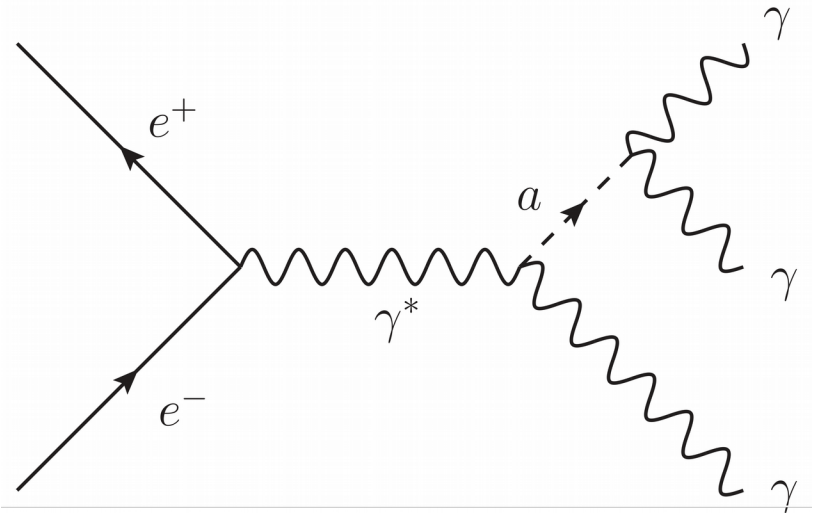


JHEP 1712 (2017) 094

Photon fusion



ALP-strahlung



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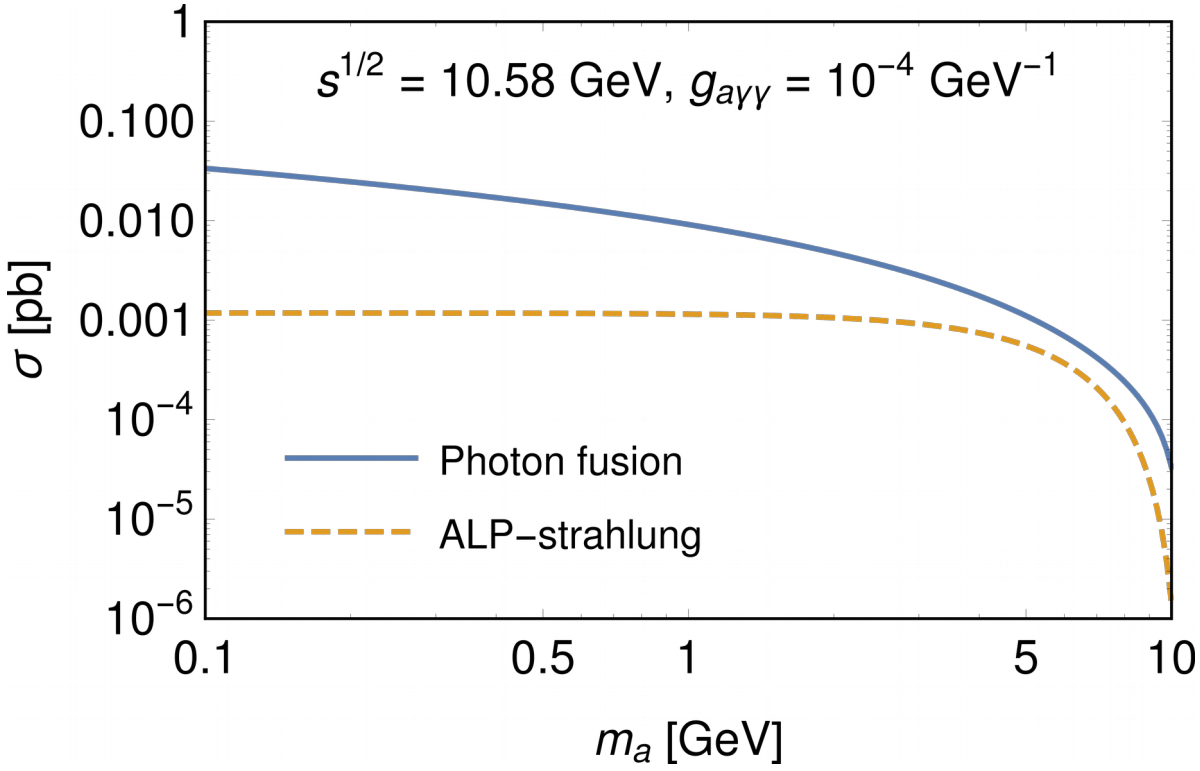

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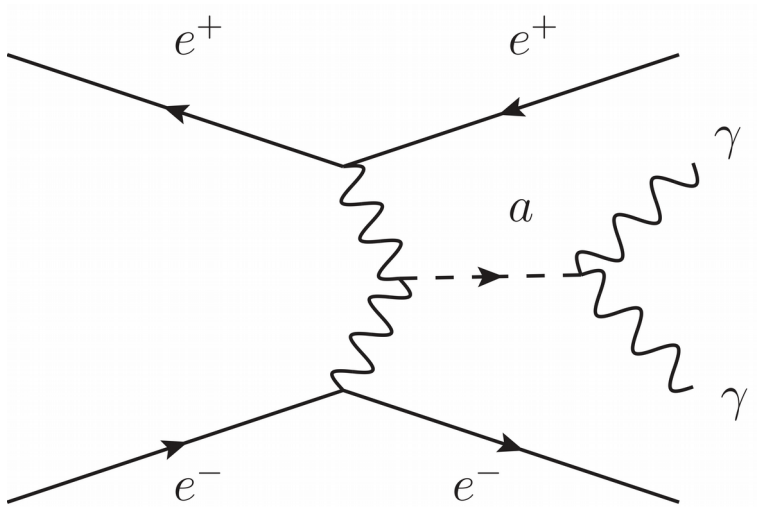
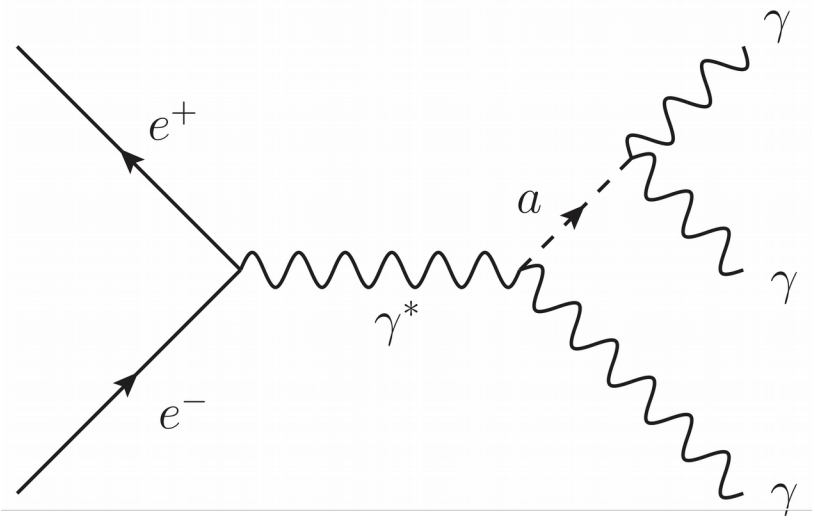


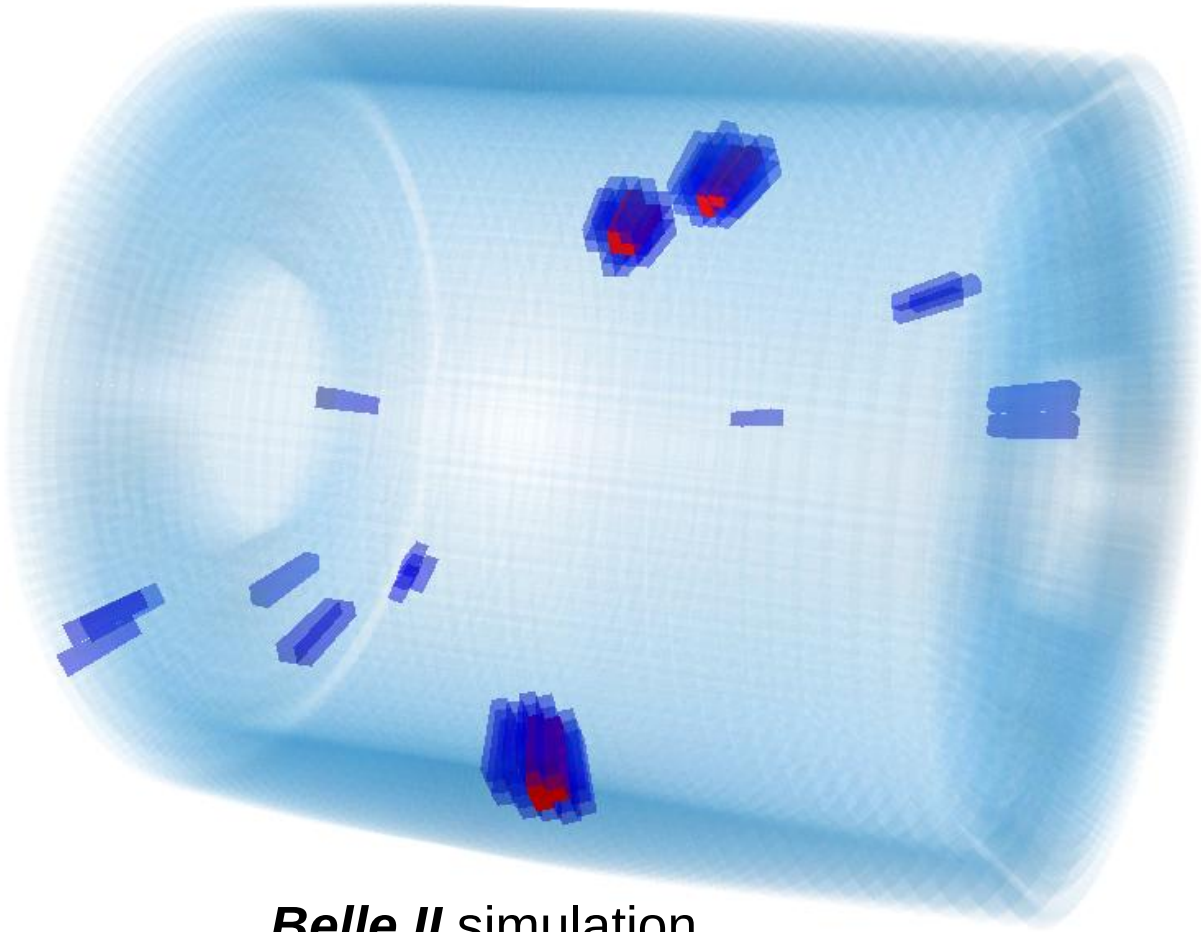
ALP-strahlung



ALPs @ Belle II

3γ analysis

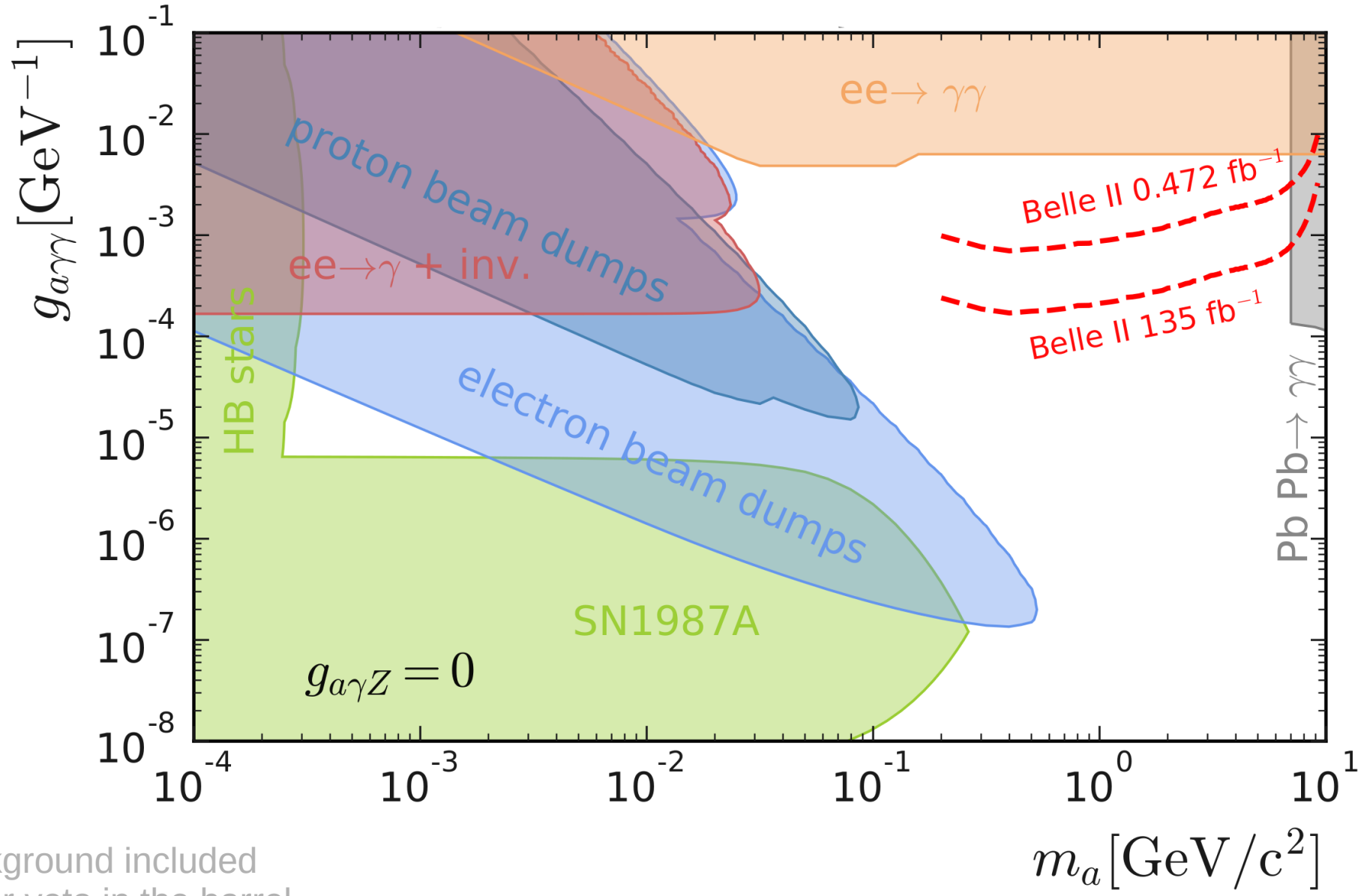
- ALP-strahlung is much easier experimentally.
  - Do this first.
- Three photons within tracking acceptance: add up to beam energy.
  - Zero tracks.
  - Bump on di-photon mass.
- The SM background: **ee → γγ(γ)**
  - Does not peak in γγ.
  - Not a 2-body system: use angles & kinematics to suppress.



Belle II simulation
signal only

ALPs @ Belle II

Physics reach



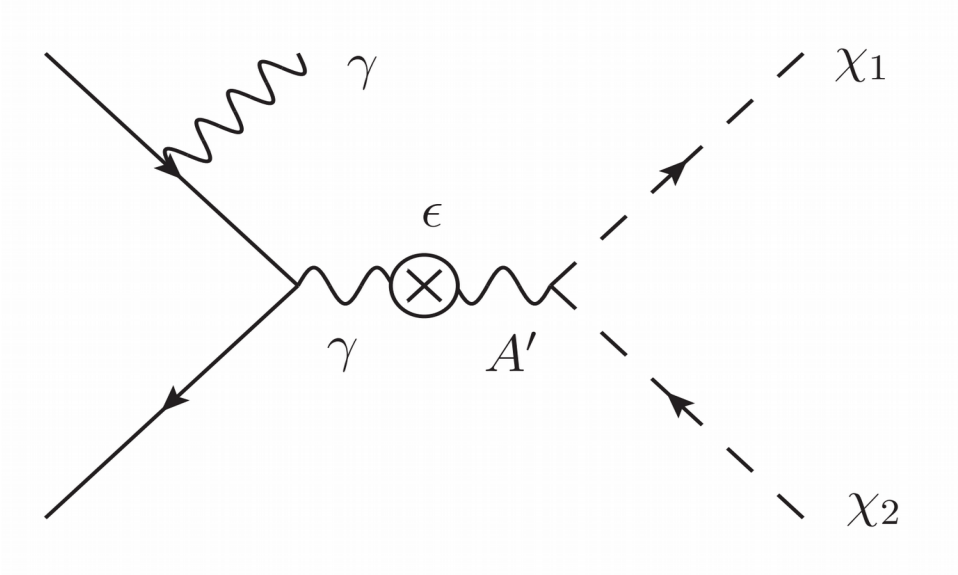
No systematics.
Only (dominant) ee→yyy background included
135fb -1 assumes no yy trigger veto in the barrel

Dark photon

Theory

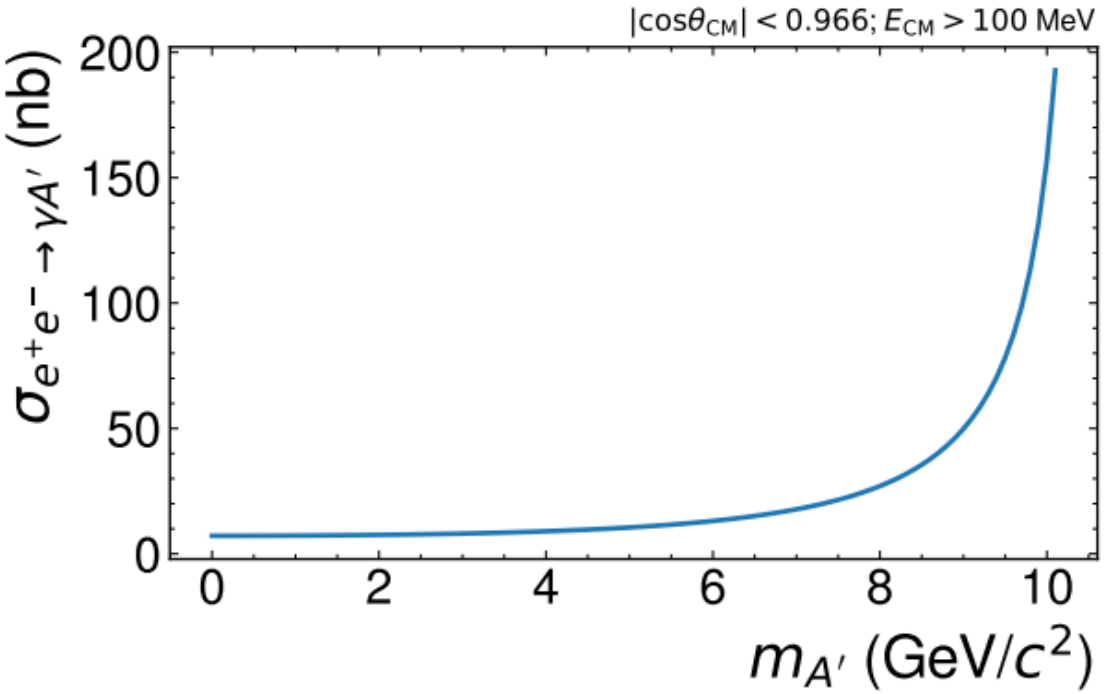
- Massive vector particle A', mixes with the SM photon:

$$\mathcal{L} \supset \epsilon g_D A'_\mu J^\mu_{\mathrm{EM}}$$



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

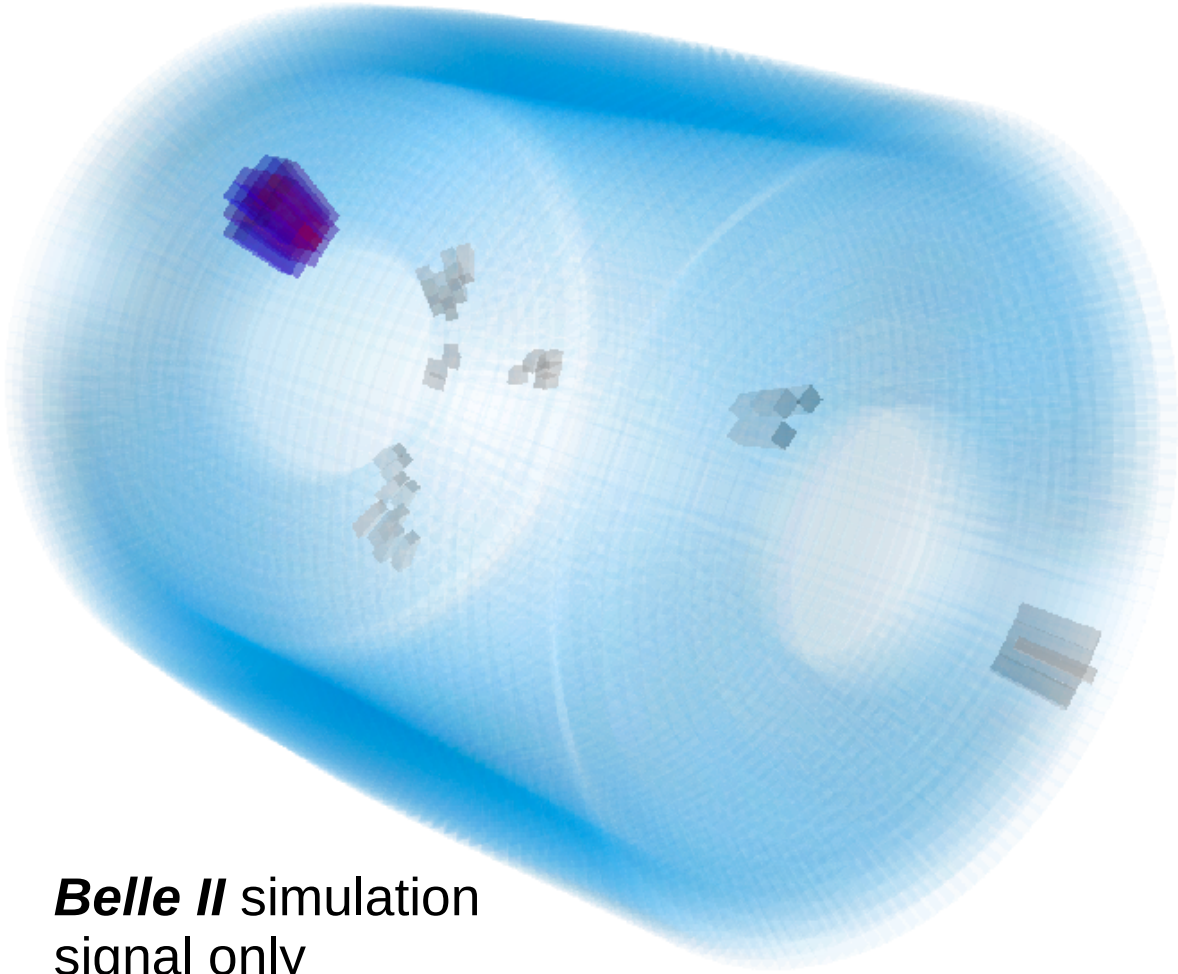
$$E_{\gamma_{\mathrm{ISR}}} = \frac{s - m^2_{A'}}{2\sqrt{s}}$$



Dark photon

Analysis

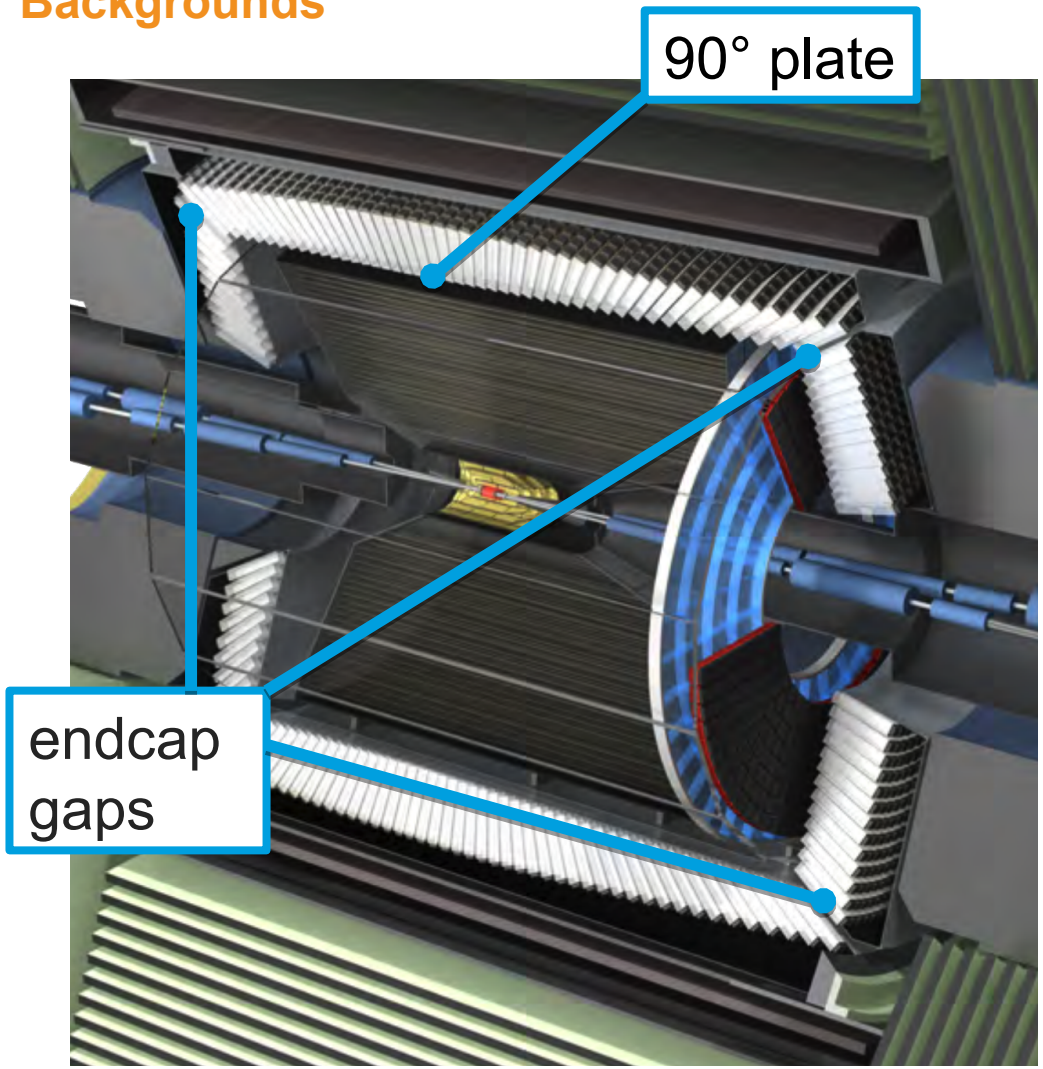
- First analysis: **ee → γA' → γ($\chi_1\chi_2$)**
- One photon. (no tracks, other good photon clusters).
  - Bump search in recoil mass spectrum.
- **Backgrounds**
  - Cosmics
  - Beam interactions
  - ee → eeγ(γ)
  - ee → γγ(γ)

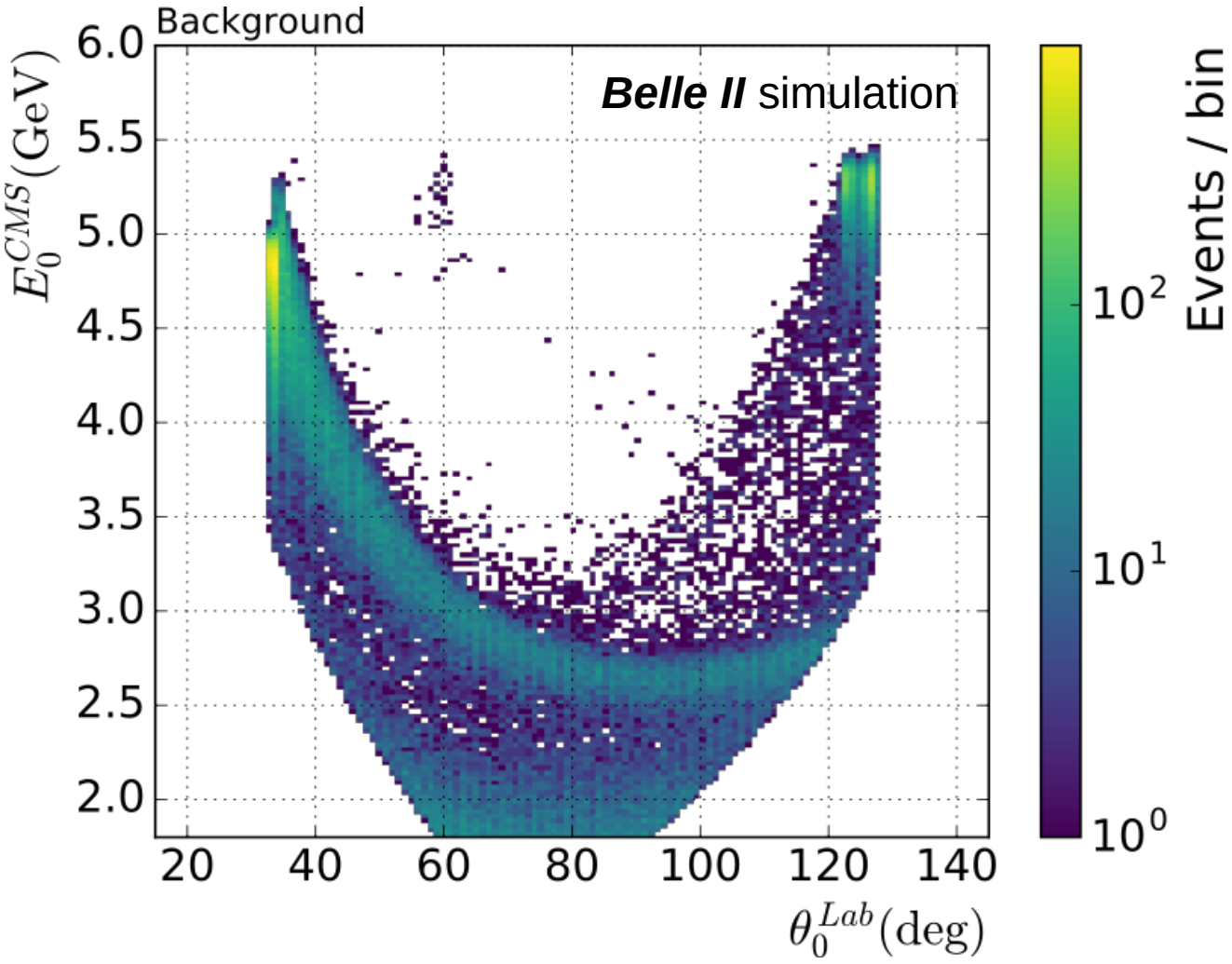


Belle II simulation
signal only

Dark photon

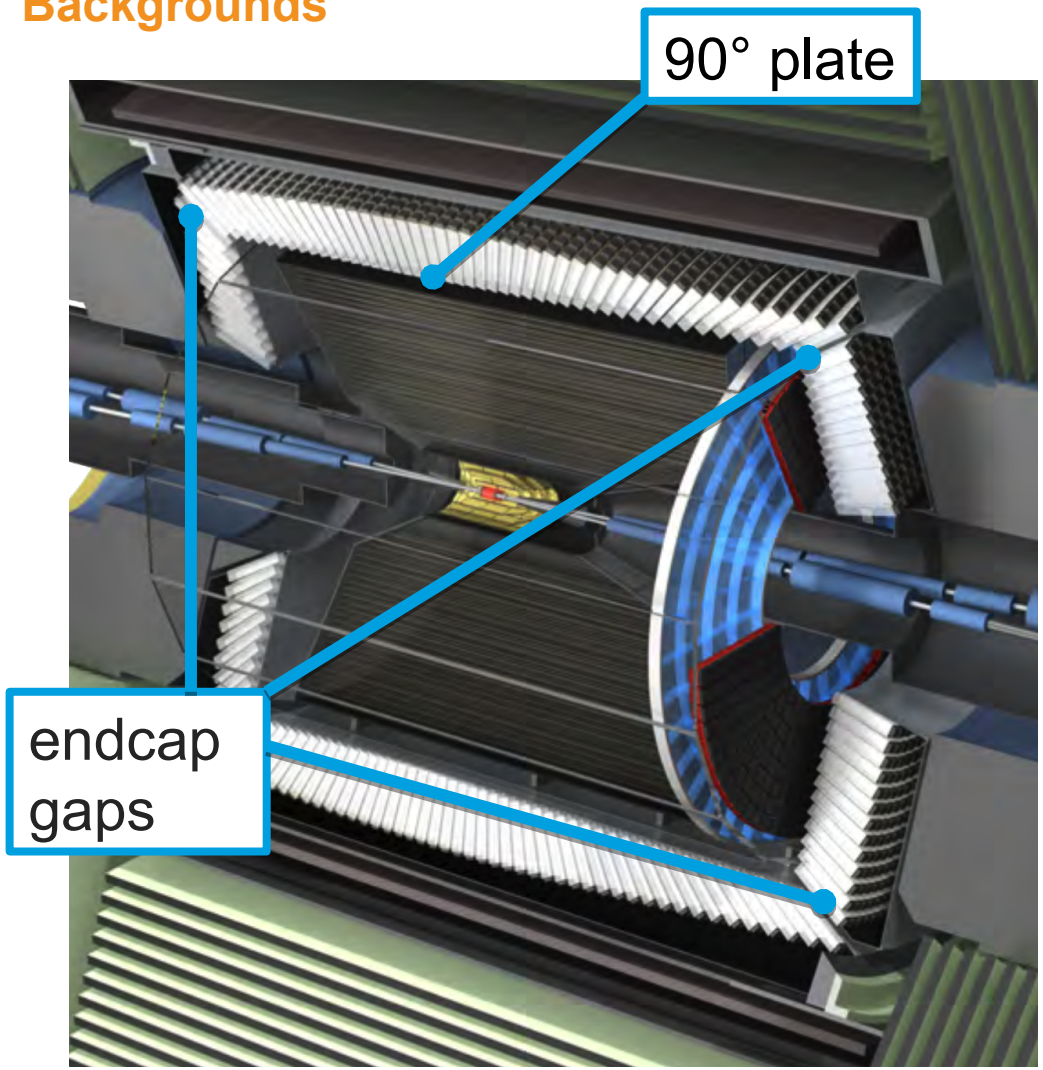
Backgrounds

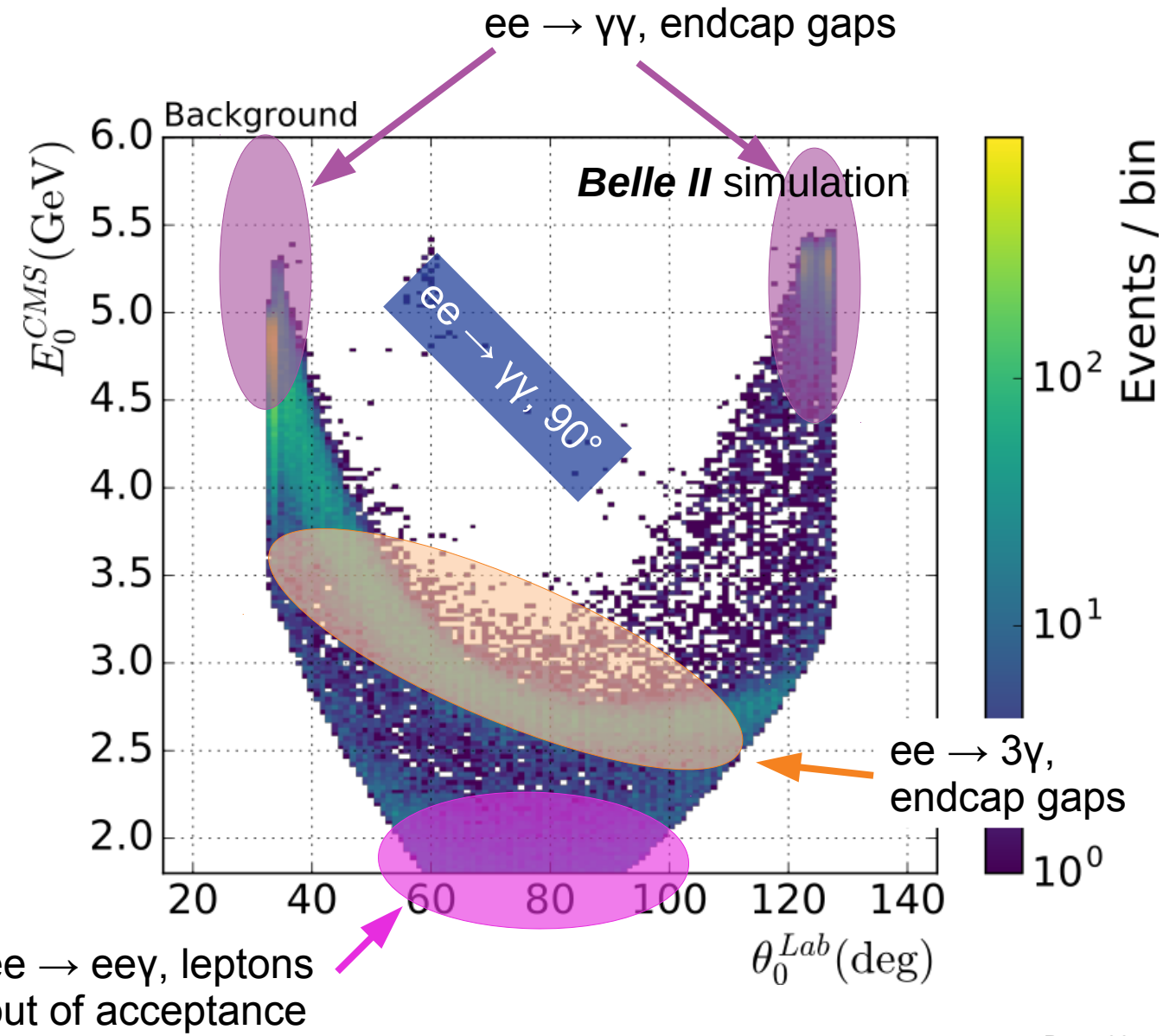




Dark photon

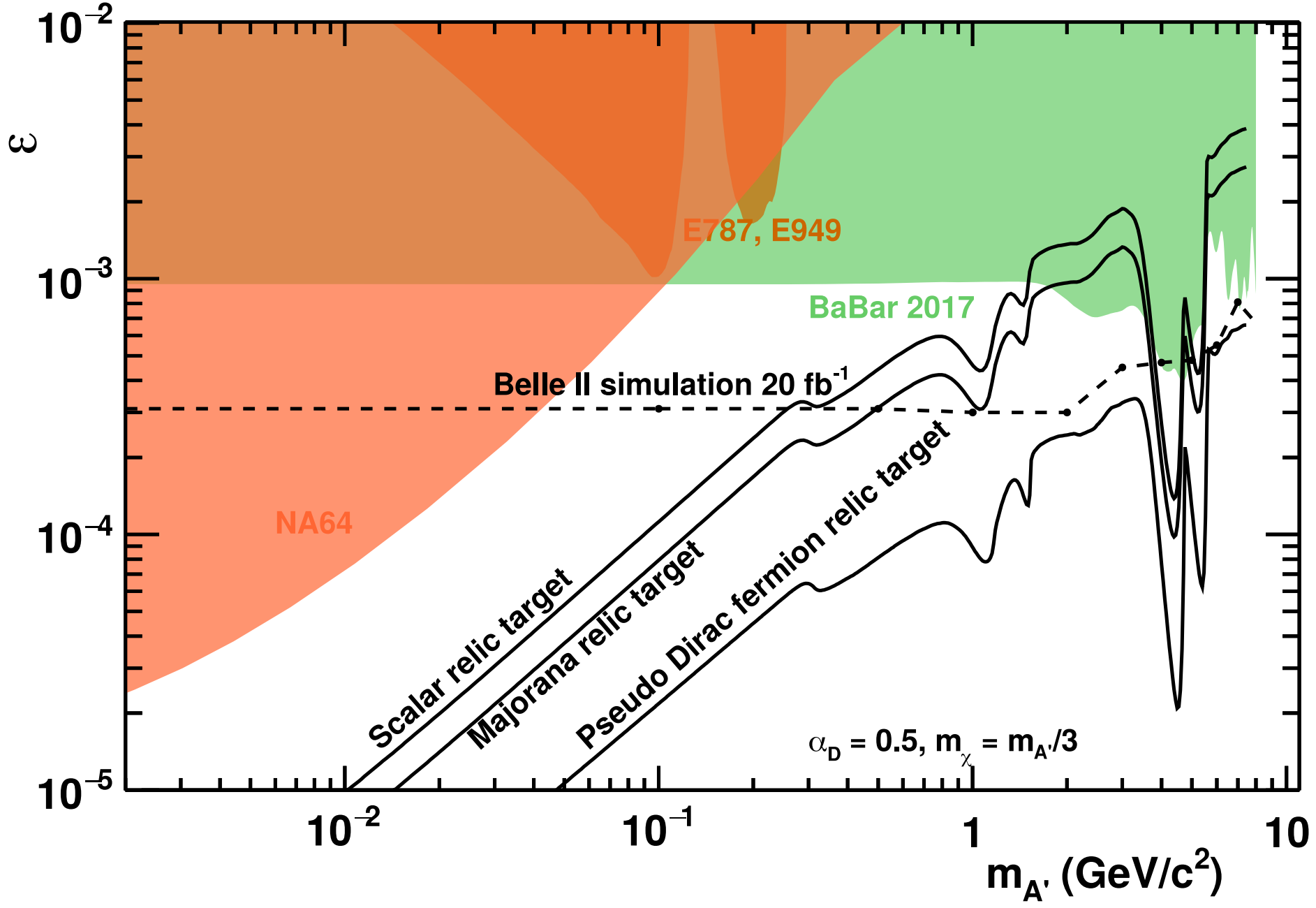
Backgrounds





Dark photon

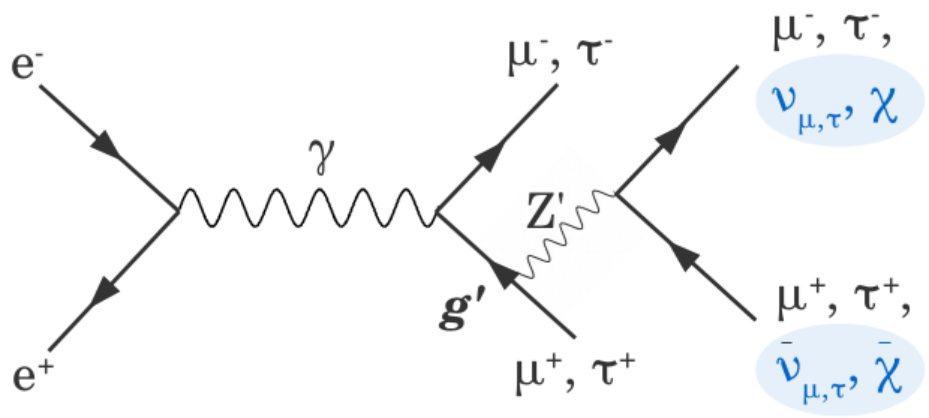
Physics reach

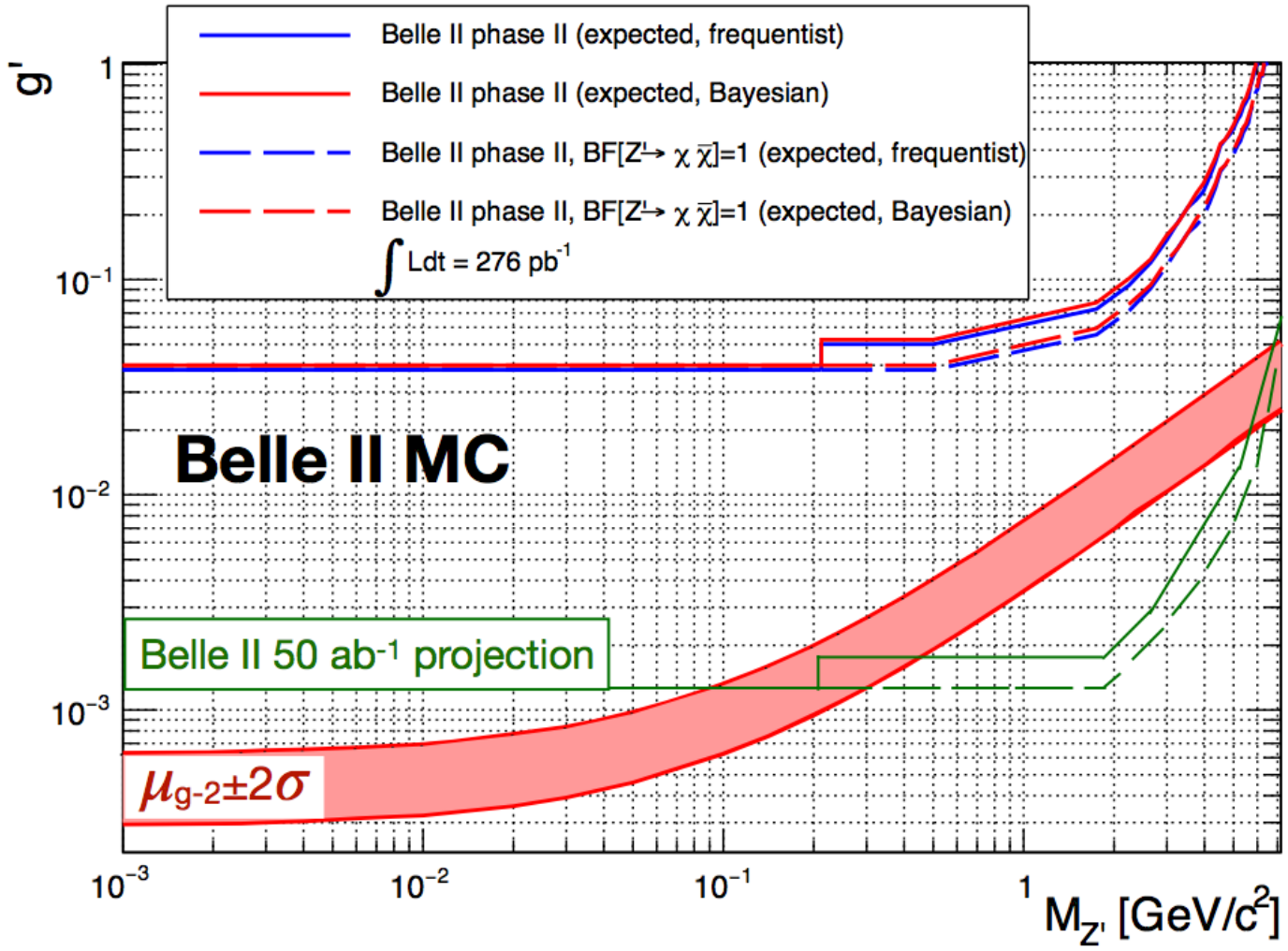


The Belle II Phyiscs book
arXiv:1808.10567
BaBar's analysis
PRL.119.131804

Z’

- “Dark photon” → Z’ if non minimal.
- Mediator coupling to muons and taus, not electrons (L_μ - L_τ)
- ee → μμZ’ (Z’ → invisible)
- Bump hunt in recoil mass against μμ. Nothing in the rest of the event.

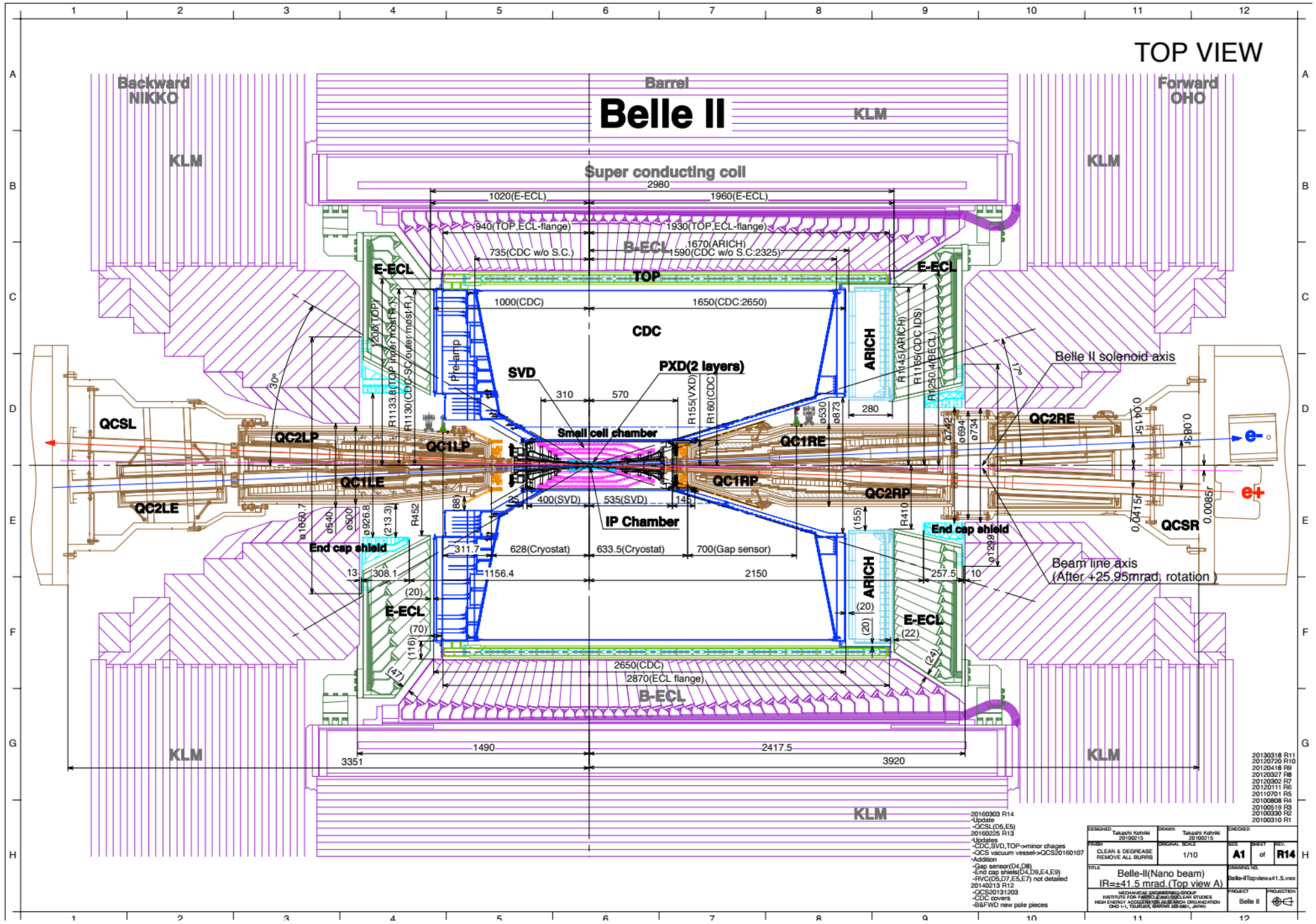




Summary

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

Appendix


TOP VIEW
Backward
NIKKO
Barrel
Belle II
KLM
Forward
OHO
Super conducting coil
2980
1020(E-ECL)
1960(E-ECL)
940(TOP,ECL-flange)
1930(TOP,ECL-flange)
735(CDC w/o S.C.)
B-ECL
1670(ARICH)
1590(CDC w/o S.C:2325)
E-ECL
TOP
1000(CDC)
1650(CDC:2650)
CDC
ARICH
SVD
PXD(2 layers)
310
570
Small cell chamber
IP Chamber
400(SVD)
535(SVD)
145
280
Belle II solenoid axis
QCSL
QC2LP
QC1LP
QC1LE
QC2LE
QC1RE
QC1RP
QC2RP
QC2RE
QCSR
e-
e+
End cap shield
311.7
628(Cryostat)
633.5(Cryostat)
700(Gap sensor)
1156.4
2150
257.5
Beam line axis
(After +25.95mrad. rotation)
2650(CDC)
2870(ECL flange)
1490
2417.5
3351
3920
20160303 R14
-Update
-QCSL(D5,E5)
20160225 R13
-Updates
-CDC,SVD,TOP->minor chages
-QCS vacuum vessel->QCS20160107
-Addition
-Gap sensor(D4,D8)
-End cap shields(D4,D9,E4,E9)
-RVC(D5,D7,E5,E7) not detailed
20140213 R12
-QCS20131203
-CDC covers
-B&FWD new pole pieces
20130318 R11
20120720 R10
20120418 R9
20120327 R8
20120302 R7
20120111 R6
20110701 R5
20100808 R4
20100519 R3
20100330 R2
20100310 R1
DESIGNED Takashi Kohriki 20100215
DRAWN Takashi Kohriki 20100215
CHECKED
FINISH CLEAN & DEGREASE REMOVE ALL BURRS
ORIGINAL SCALE 1/10
SIZE A1
SHEET of
REV. R14
TITLE Belle-II(Nano beam) IR=±41.5 mrad.(Top view A)
DRAWING NO. Belle-IITopview±41.5.vwx
MECHANICAL ENGINEERING GROUP INSTITUTE FOR PARTICLE AND NUCLEAR STUDIES HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION OHO 1-1, TSUKUBA, IBARAKI 305-0801, JAPAN
PROJECT Belle II
PROJECTION

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