Dark Matter Search at Belle/Belle2

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INFN – Roma 3

on behalf of the Belle II Collaboration

OUTLINE OF THE TALK

- **Belle II and SuperKEKB**
- **Search of the dark photon invisible decay in Phase 2**
- **Alternative LDMA searches**
- **Search of ALP**
- **Summary**

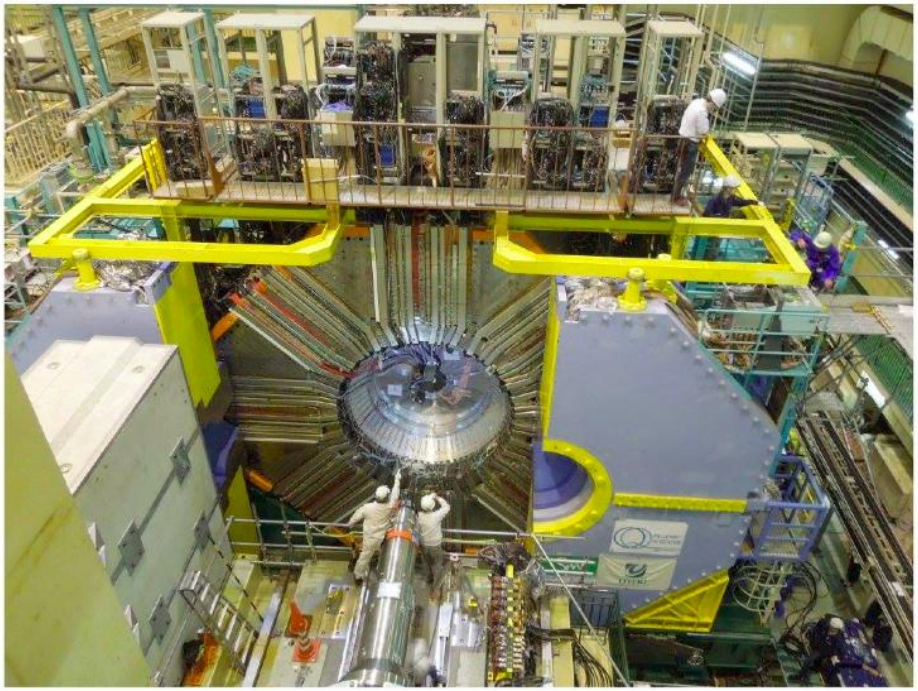
Light Dark Matter 2017

La Biodola – Isola d'Elba, 24-28 May 2017

Breaking news

Belle II succesfully rolled in on April 11th

perfectly in time with plans (and sakura)



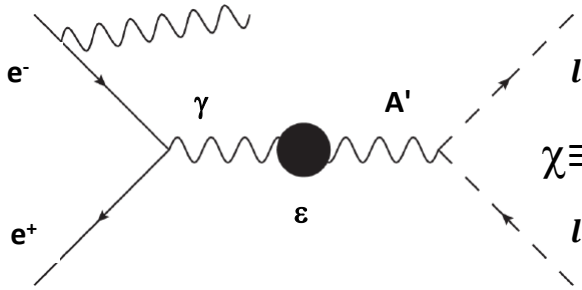
Introduction

See M.Pospelov's talk

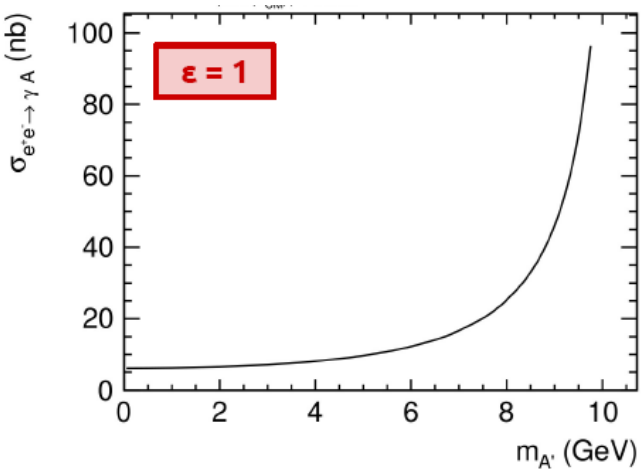
Some astrophysical observations suggest the possibility of the existence of a new light (GeV scale) hidden dark sector with a mediator A′ (dark photon), weakly coupled to the Standard Model via kinetic mixing, and light dark matter.

P. Fayet, Phys. Lett. B **95**, 285 (1980),
P.Fayet, Nucl. Phys. B **187**, 184 (1981)

At e^+e^- colliders



χ≡dark matter particle



two basic scenarios depending on **A′** vs matter mass relationship

$m_\chi > 1/2\ m_{A'} \Rightarrow$ A′ visible decays (SM particles) →

$A' \to l^+l^-$

$A' \to \pi^+\pi^-$

$h'\ A'$ dark higgstrahlung

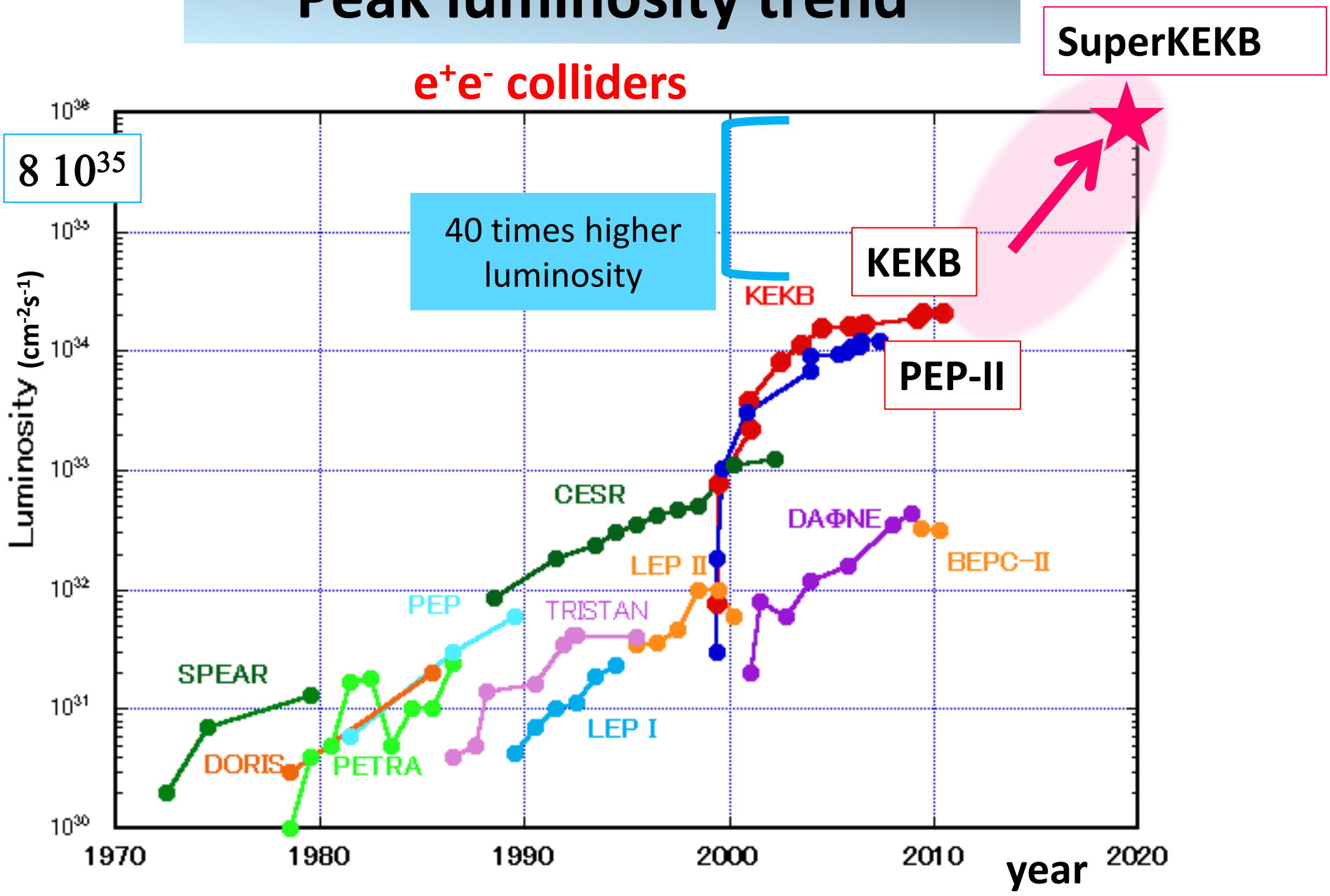
↳ $h' \to A'A'$, $A'A'A' \to 6\ l^\pm + \pi^\pm$

$m_\chi < 1/2\ m_{A'} \Rightarrow$ A′ invisible decays to LDMA →

$A' \to \chi\bar{\chi}$

access to light dark matter particles

Peak luminosity trend



From KEKB to SuperKEKB

Super KEKB uest for BSM

Beam-beam parameter

Lorentz factor

Beam current

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

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Classical electron radius

Beam size ratio@IP 1 ~ 2 % (flat beam)

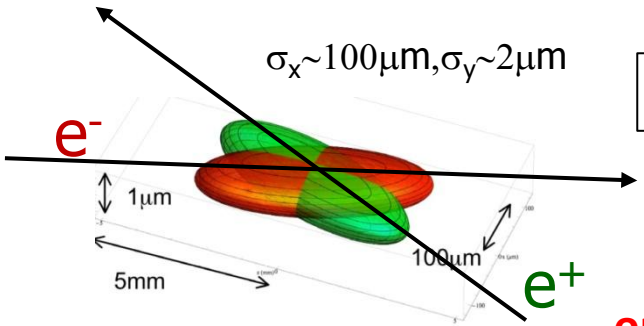
Vertical beta function@IP

x20 x2

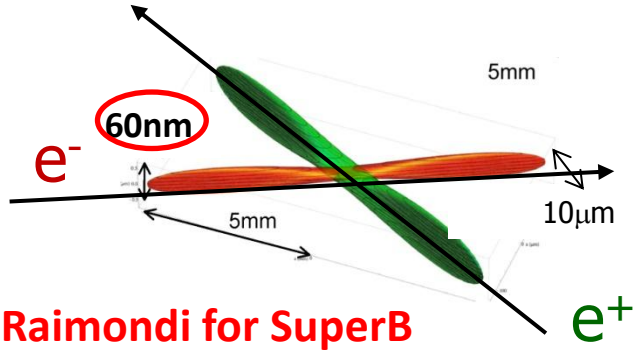
(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y



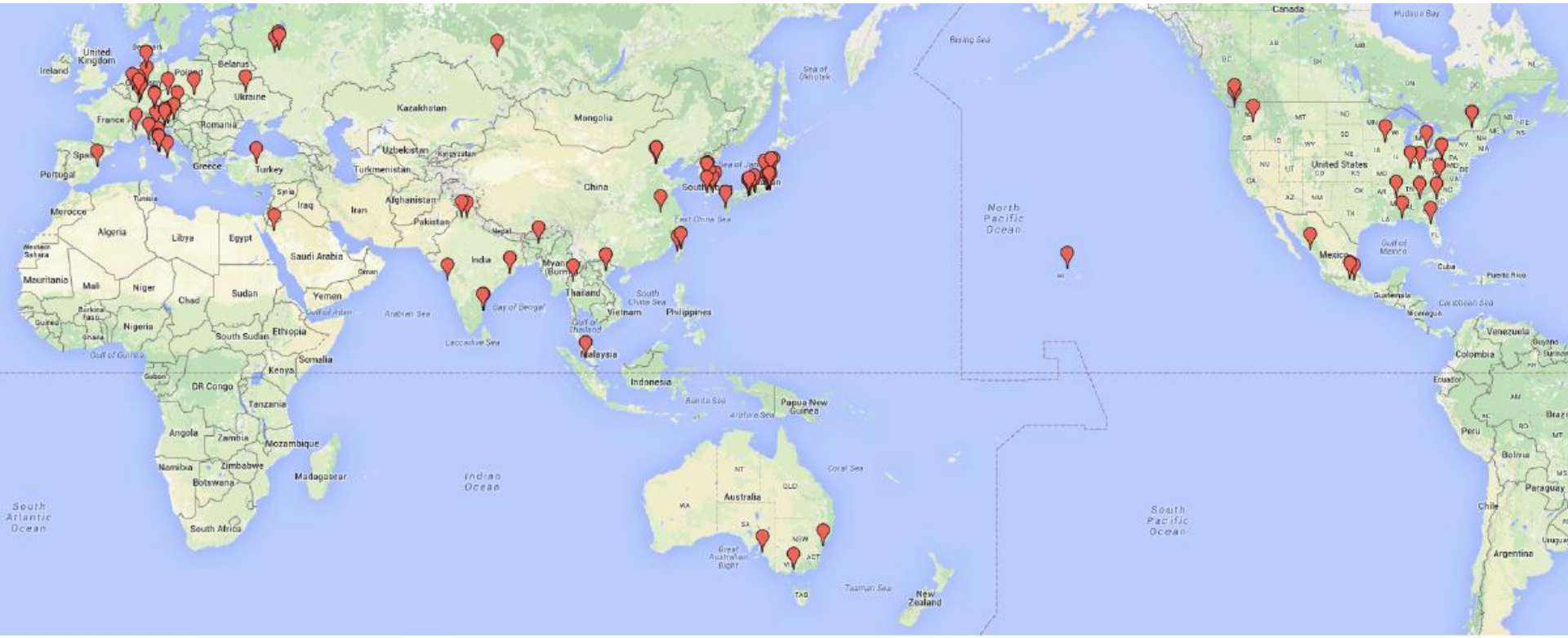
Nano-Beam scheme



originally proposed by P.Raimondi for SuperB

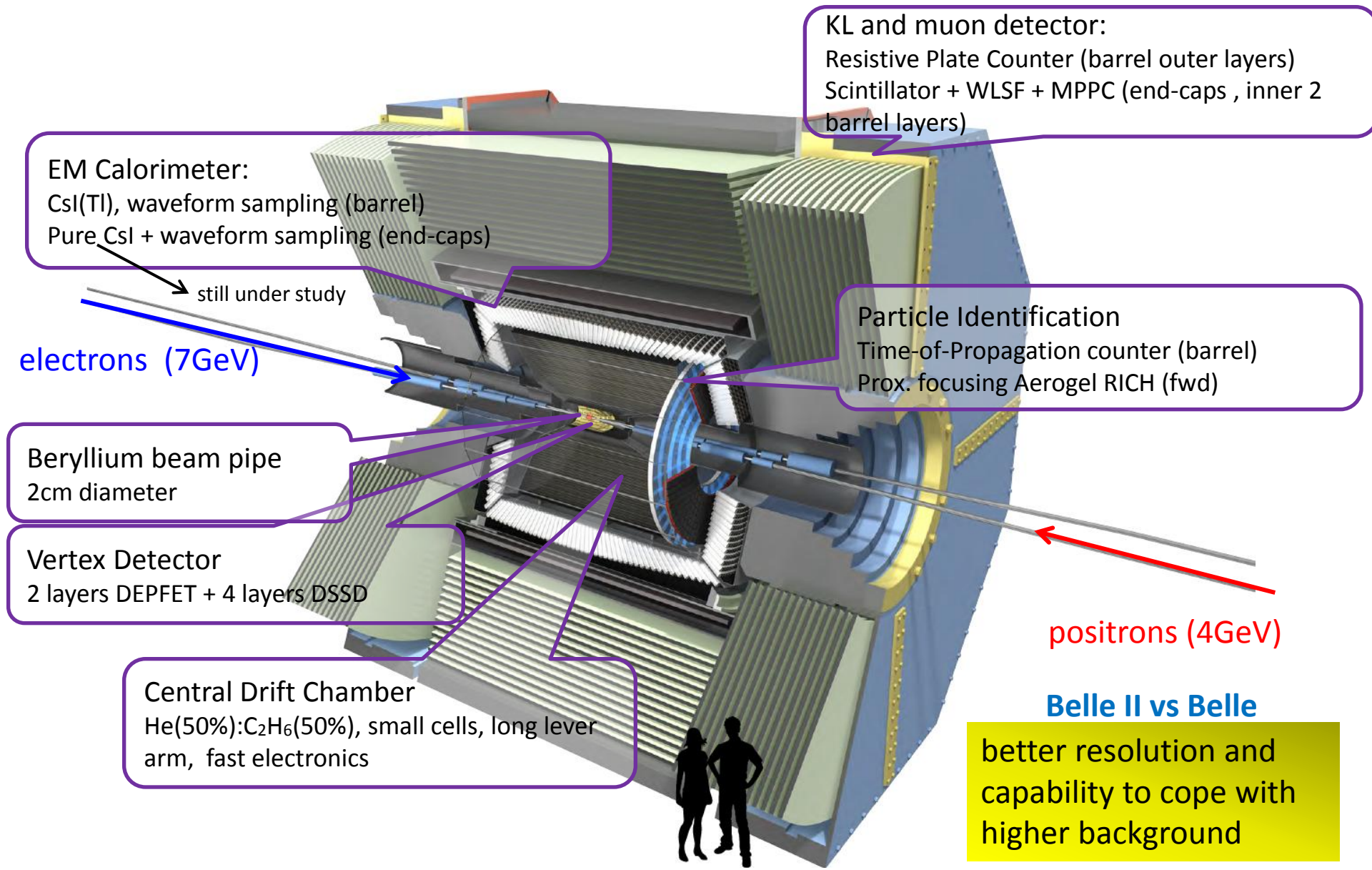
... For a 40x increase in intensity you have to make the beam as thin as a few x100 atomic layers!

Belle II Collaboration



- 23 countries
- ~ 100 institutions
- ~ 700 members (~ 250 graduate students)

Belle II detector



KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

still under study

electrons (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

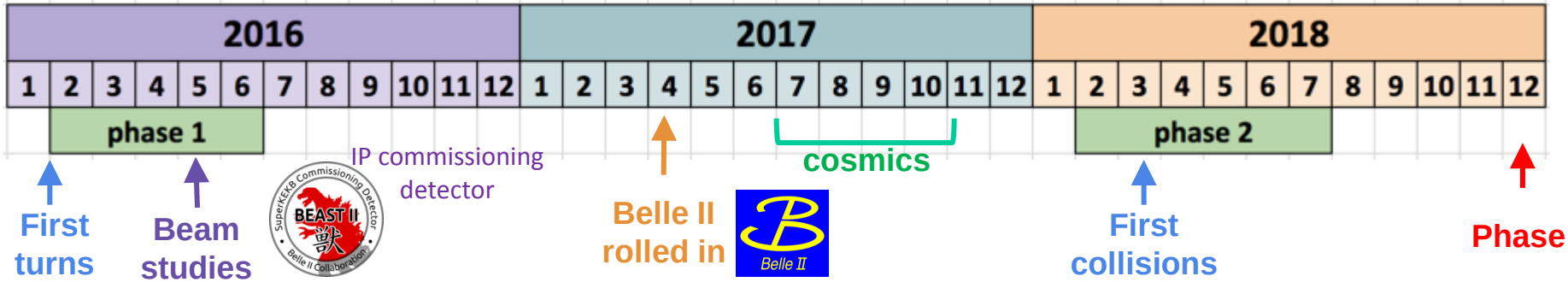
Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics

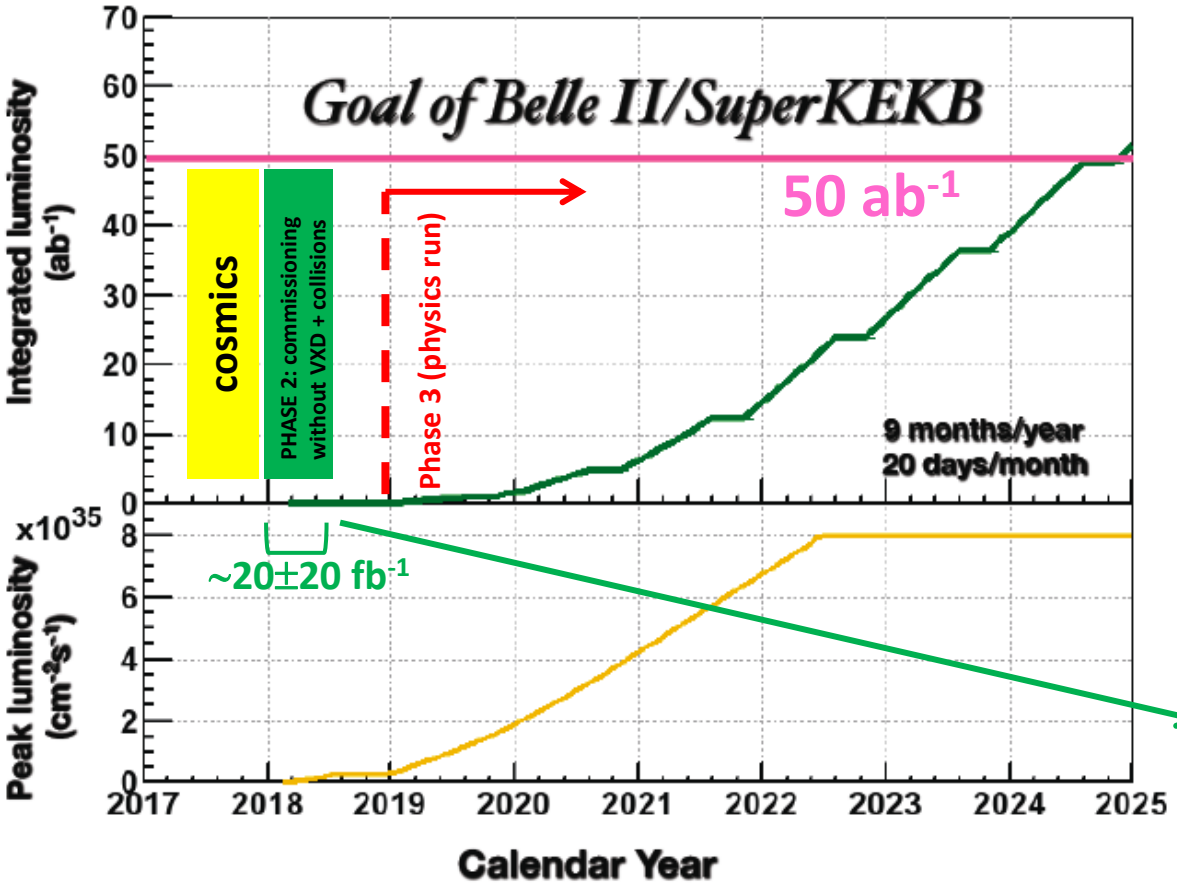
positrons (4GeV)

Belle II vs Belle

better resolution and capability to cope with higher background

Belle II + SuperKEKB schedule





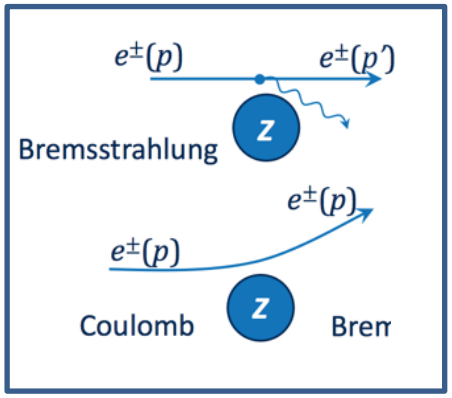
- **phase-1 (done)**
  - Beam commissioning
- **phase-2 (Jan. 2018)**
  - Beam BG measurement
  - Belle II detector with partial vertex sensors
- **phase-3 (Dec. 2018)**
  - Physics running
  - Full Belle II detector

20±20 fb^{-1} for physics analysis without VXD

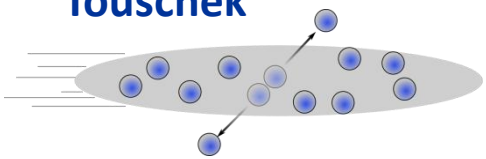
Beast 2 outcome

Paper in preparation: to be submitted to NIM A

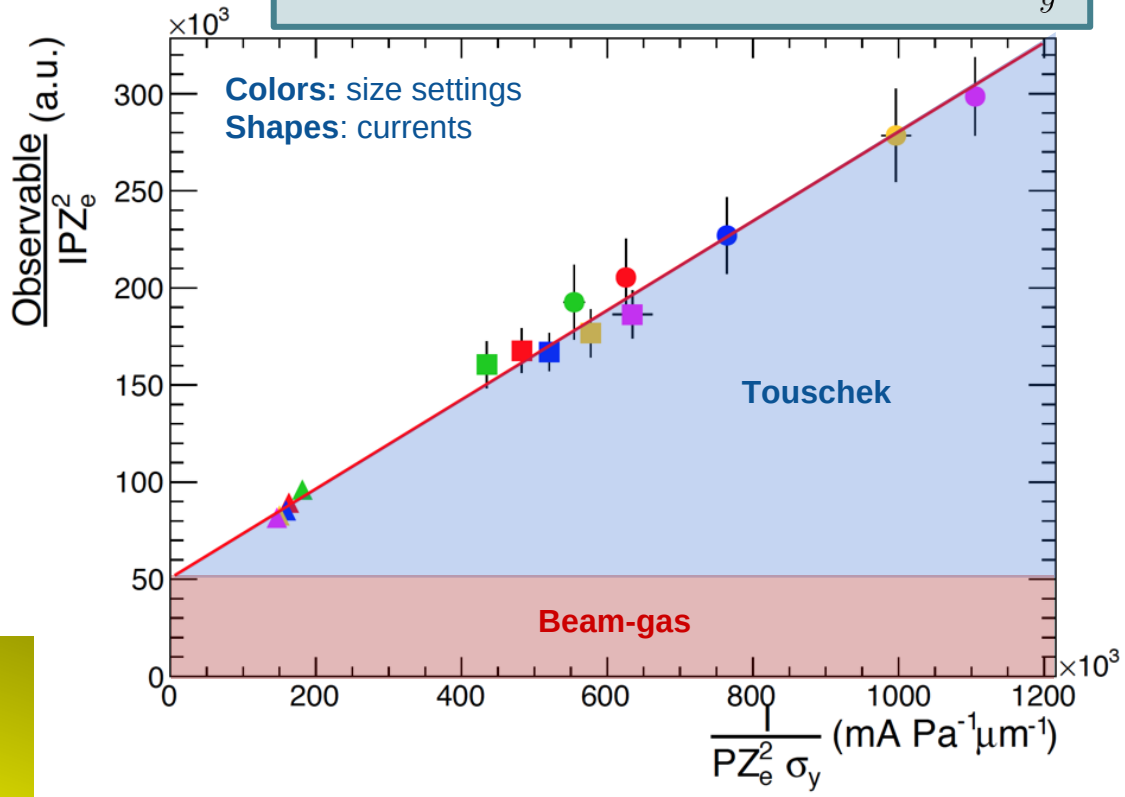
Beam-gas



Touschek



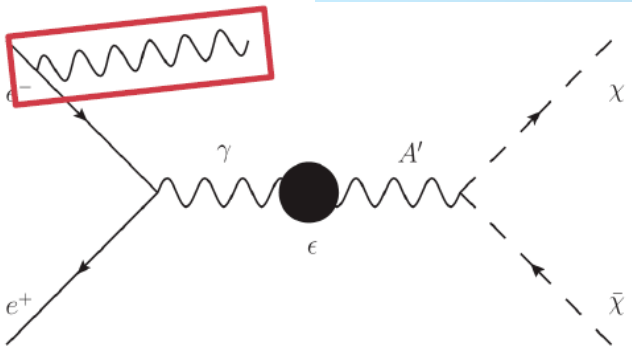
$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$



Good agreement with the model in terms of beam-gas and Touschek effect background description

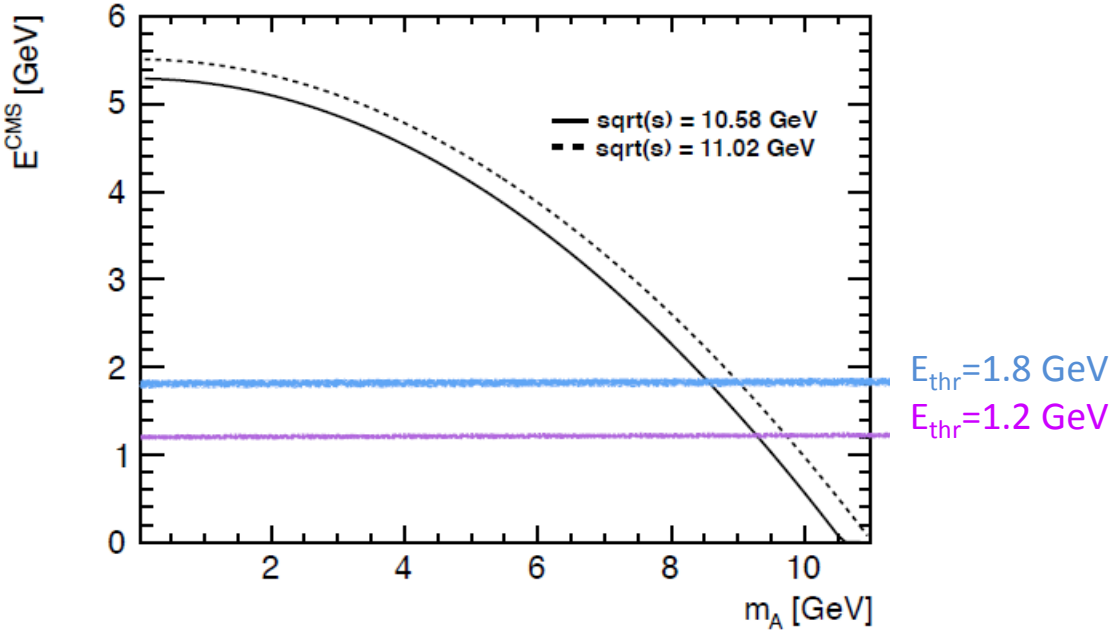
Beam background control is a key point in a missing energy search

Experimental signature

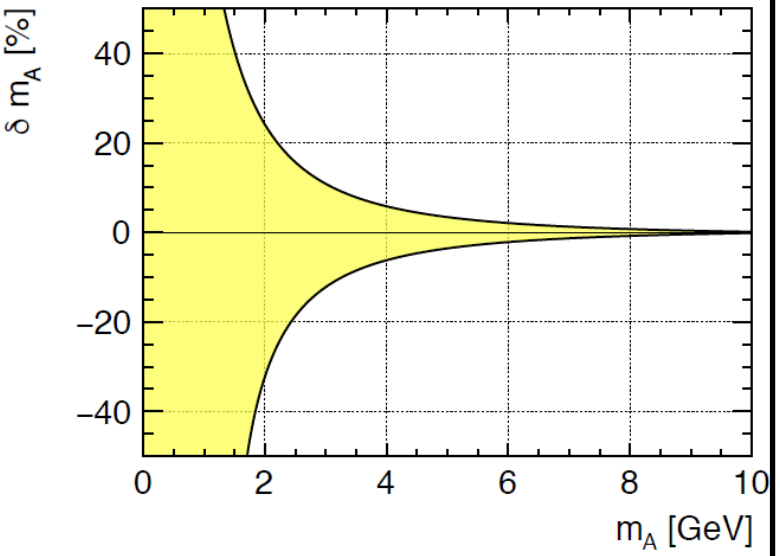


Only **one photon** in the detector.
Needs a **single photon trigger**

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



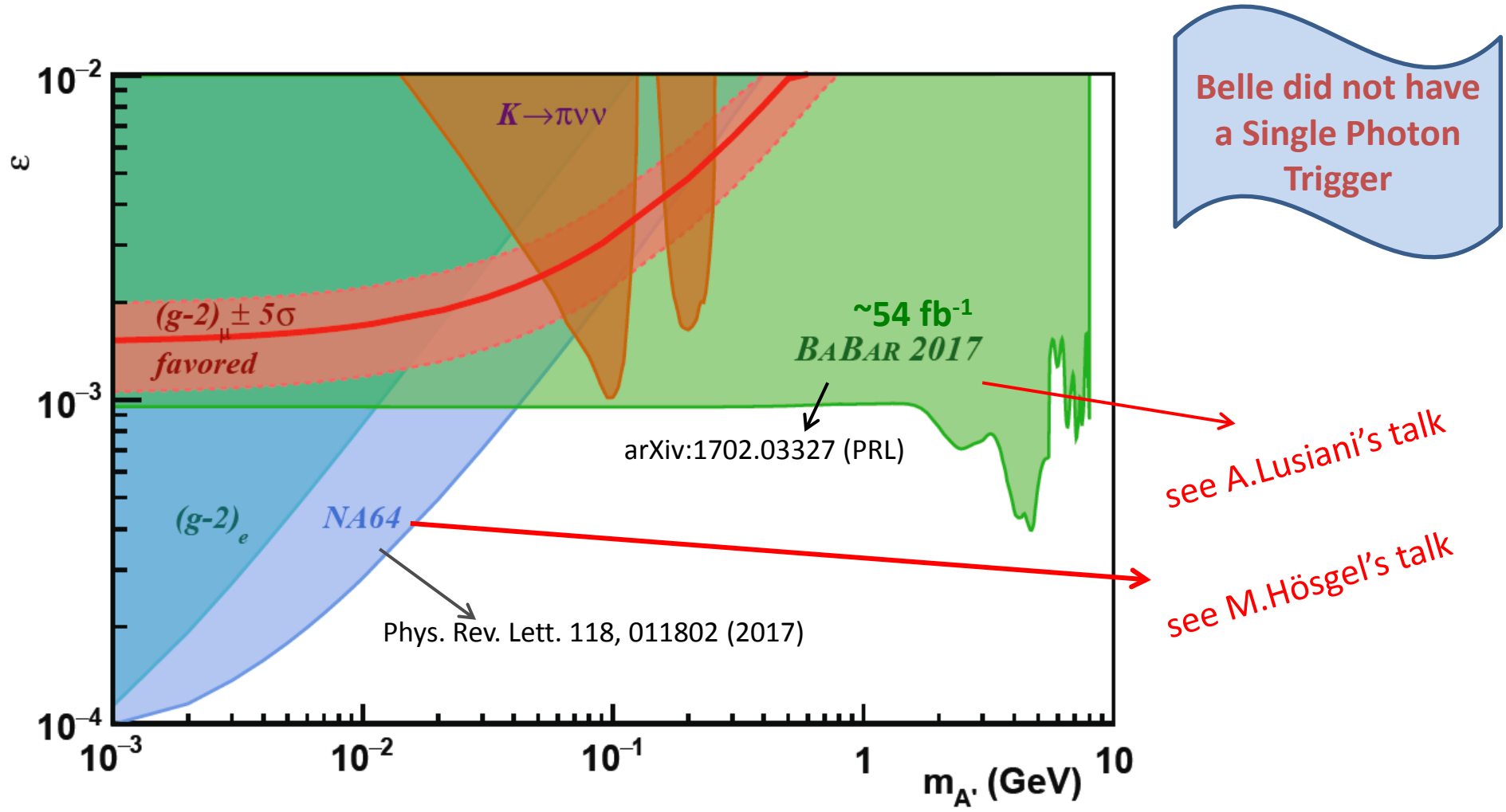
Dark photon mass resolution



Too poor to measure $m_{A'}$ below ~2.5 GeV, but still possible to make an observation

Running SuperKEKB at Y(6S) in Phase 2 would be an interesting option (provided beam conditions are clean enough)

Dark photon to invisible: existing limits



$(g\text{-}2)_\mu$ anomaly explanation ruled out by NA64 and BaBar

Single photon trigger(s)

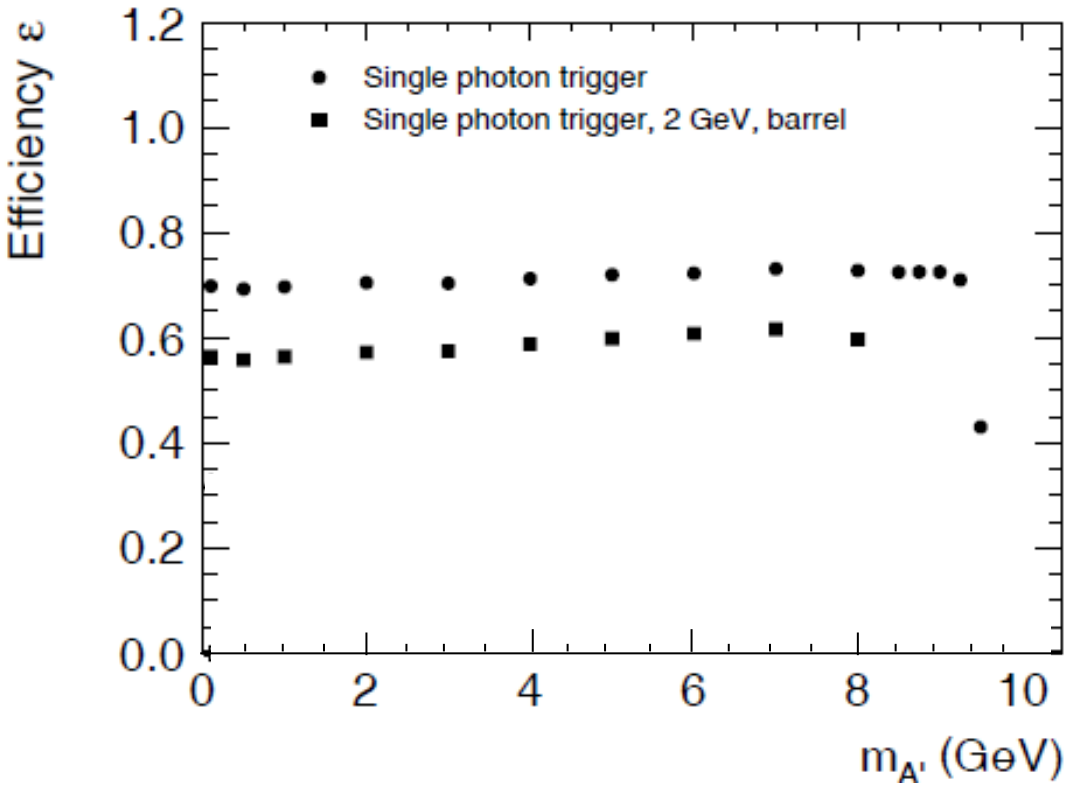
Two level 1 single photon triggers, both excluding the innermost ECL crystal towers

- $E_{\gamma 1}^{CMS} > 1$ GeV, with the second cluster energy $E_{\gamma 2}^{CMS} < 0.2$ GeV → ~4 nb
- $E_{\gamma 1}^{CMS} > 2$ GeV ∩ Bhabha veto ∩ $e^+e^- \to \gamma\gamma$ veto → ~2.5 nb

↓

mostly $e^+e^- \to e^+e^-\gamma$

to be compared with ~ 10 nb hadronic+leptonic cross section
⇒ ~10 kHz at 8×10^{35} $cm^{-2}s^{-1}$



Trigger efficiency is expected to be high and mostly limited by acceptance (up to 95% within angular acceptance)

Very preliminary simulation studies

Basic selections and backgrounds

Two main detectors involved:

- ECL for photon detection
- KLM to seal the apparatus (veto)

+ CDC to efficiently reject events with charged particles

Look for an isolated photon and then fight (strongly) against backgrounds

- $E_\gamma^{CMS} > 1.8$ GeV
- No KLM clusters back to back
- No KLM clusters in veto regions (various ECL gaps)
- Additional θ_{lab} dependent selection on E_γ^{CMS}

Backgrounds

Mostly from high cross section QED processes:

- $e^+e^- \rightarrow e^+e^-\gamma(\gamma)$
- $e^+e^- \rightarrow \gamma\gamma(\gamma)$

Events with only one photon within acceptance (irreducible) or more than one photon, the others being missed because of ECL and KLM inefficiencies (reducible)

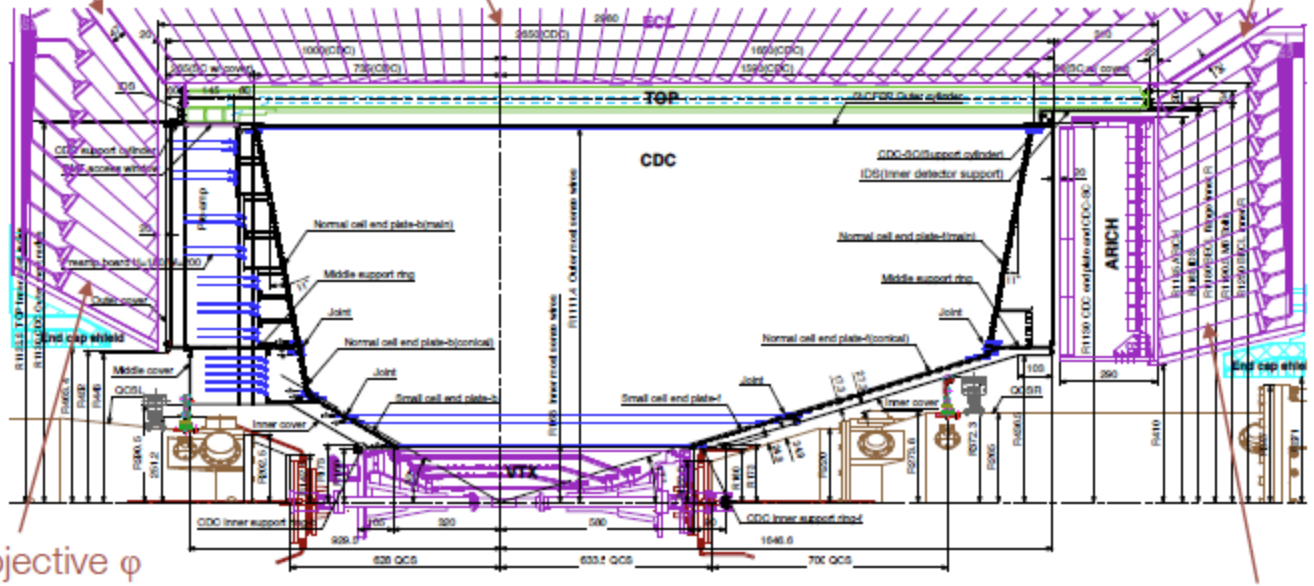
ECL inefficiency

Sources of ECL inefficiency (in order of importance)

1. barrel/endcap gap

4. 1.5mm structure at 90°

2. barrel/endcap gap



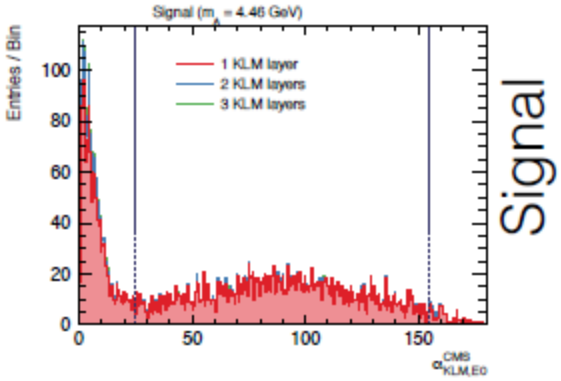
3. projective φ cracks in endcaps

3. projective φ cracks in endcaps

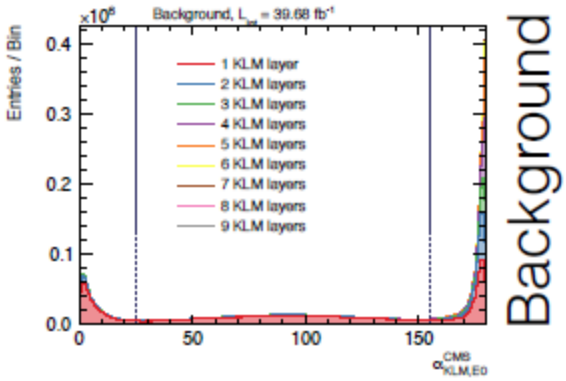
5. γ non-conversion 3×10^{-6}

KLM veto

Veto on KLM cluster back to back to the candidate singe photon

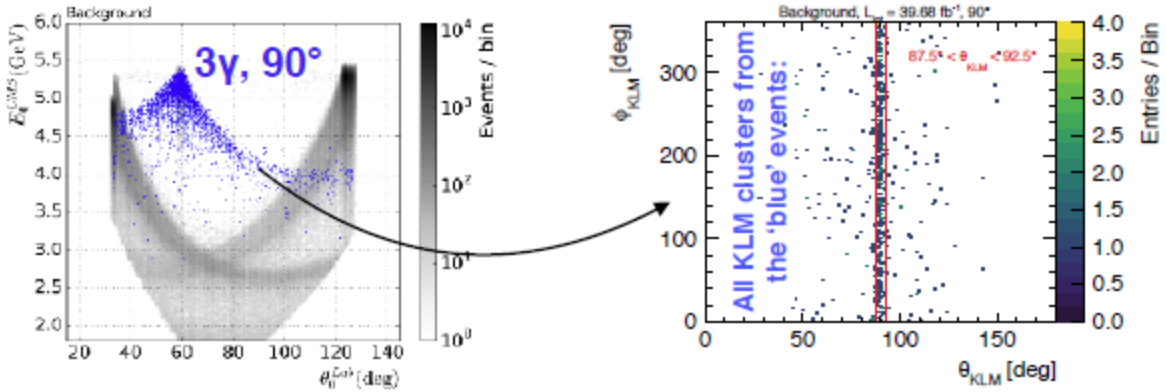


Signal



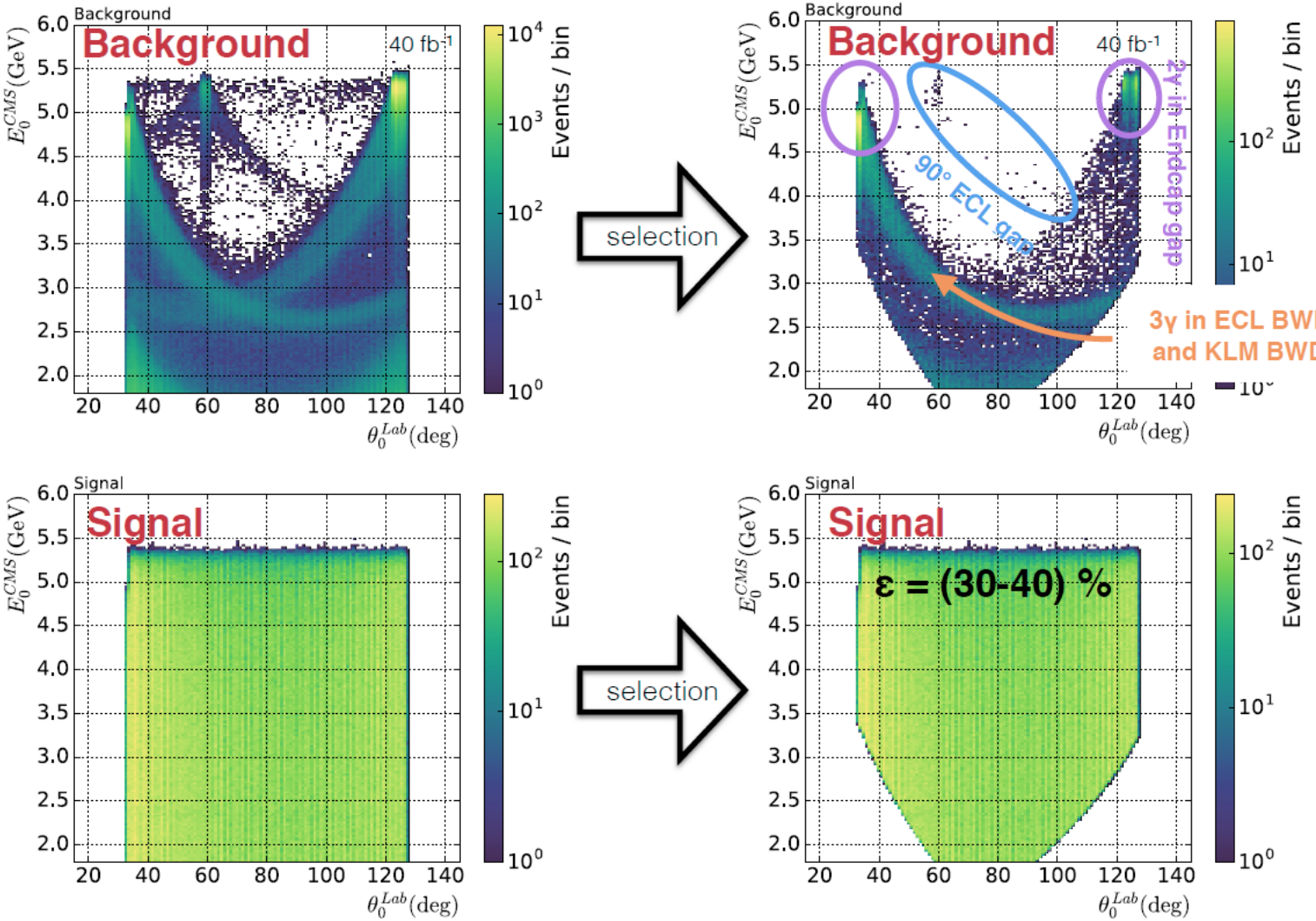
Background

Veto on KLM cluster for the 90^0 ECL gap



Cosmics + Phase 2 $e^+e^- \rightarrow \mu^+\mu^-\gamma$ will be used to get detailed maps of gaps and materials (cables, pipes, …) inside the gaps

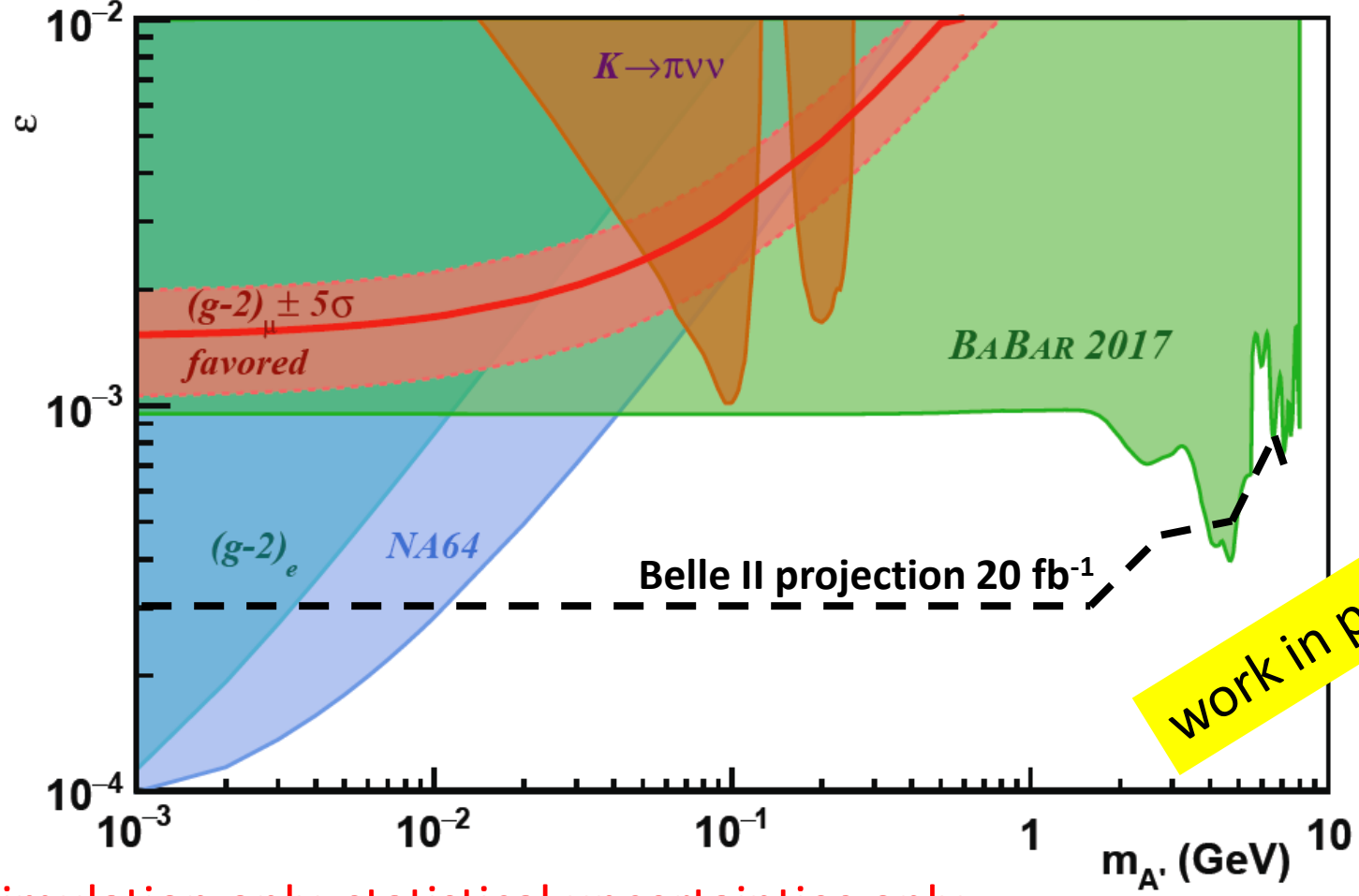
Effect of selections on signal and background



After selections most of the background is made of $e^+e^- \to \gamma\gamma(\gamma)$ with $\geq 3\gamma$

Belle II projection (simulation)

B2TiP: The Physics Prospects for Belle II (in preparation for submission to PTEP, 2017)



Simulation only, statistical uncertainties only

It would be tempting to extrapolate beyond Phase 2 (up to 50 ab^{-1}), but the sustainability of the single photon trigger rate at higher luminosities must be checked

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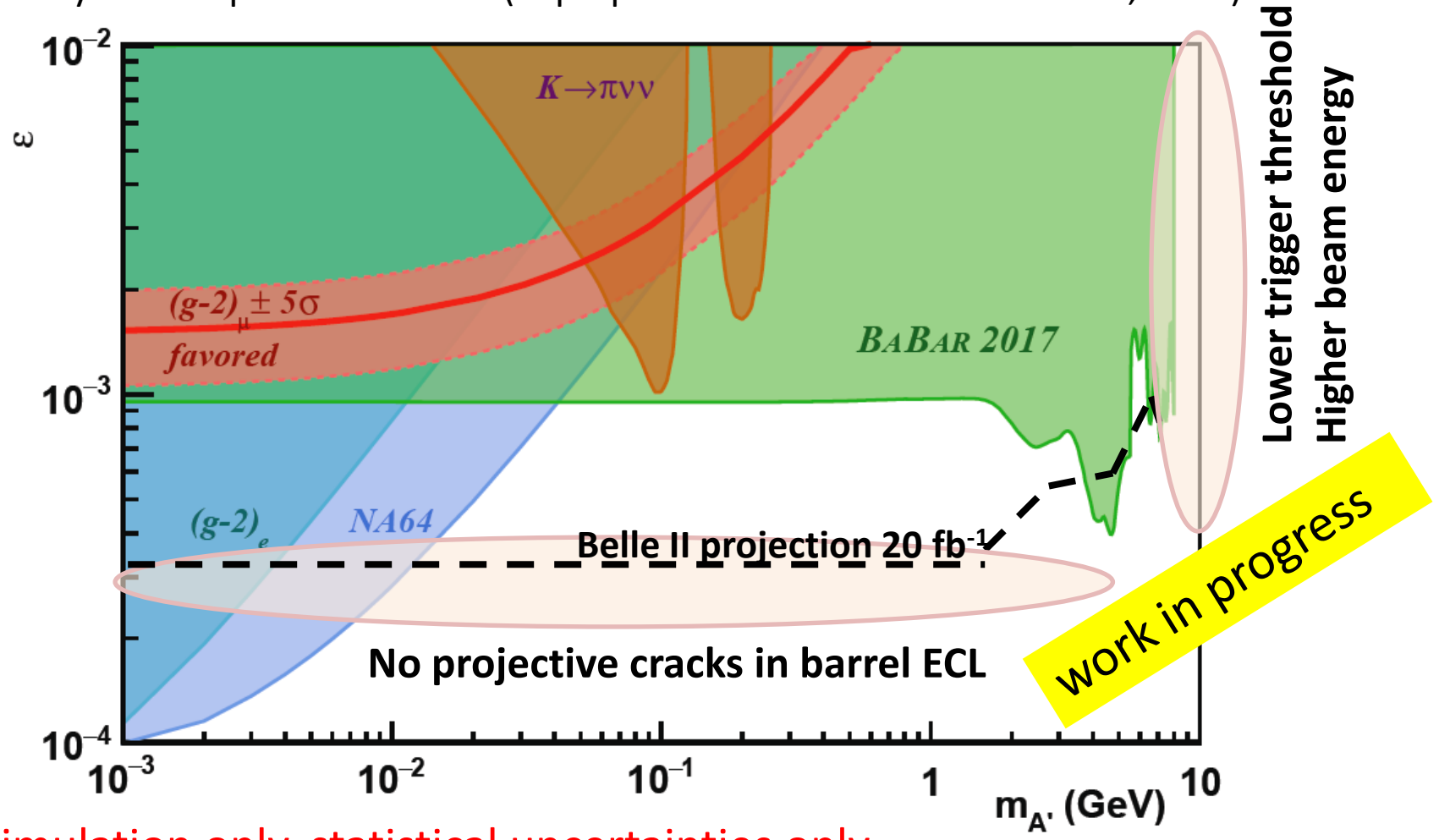
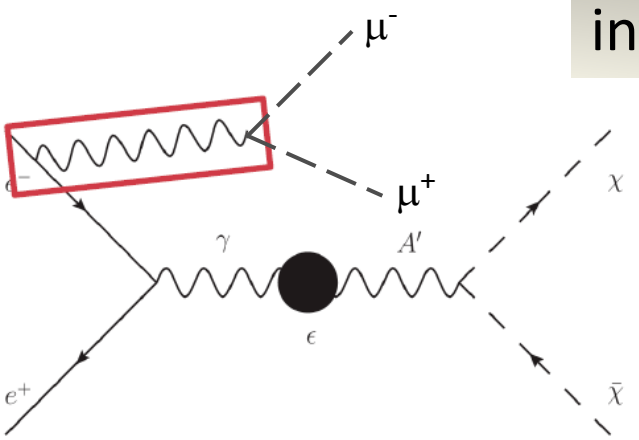


Simulation only, statistical uncertainties only

It would be tempting to extrapolate beyond Phase 2 (50 ab^{-1}), but the sustainability of the single photon trigger rate at higher luminosities must be checked

Alternative LDMA searches



invisible dark photons + muons

- no limits available
- no special trigger required
- under evaluation
- requires int. luminosities beyond Phase 2

Y(1S) → invisible

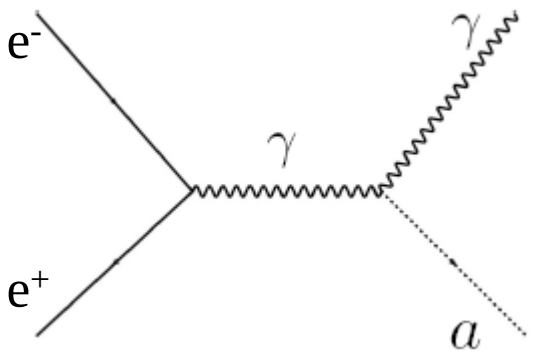
$e^+e^- \rightarrow Y(3S) \xrightarrow{4.4\%} \pi^+\pi^- Y(1S)$, $Y(1S) \rightarrow$ invisible

$e^+e^- \rightarrow Y(2S) \xrightarrow{18.1\%} \pi^+\pi^- Y(1S)$, $Y(1S) \rightarrow$ invisible

SM: BR $(Y(1S) \rightarrow \nu\bar{\nu}) \approx 9.9x10^{-6}$ { BaBar: $<3.3x10^{-4}$; Belle: $< 3x10^{-3}$

- $Y(1S) \rightarrow \chi\bar{\chi}$ if kinematically allowed [Phys. Rev. D **80,** 115019, 2009]
- new mediators (Z′, A^0, h^0) or SUSY particles might enhance $Y(1S) \rightarrow \nu\bar{\nu}$ [Phys. Rev. D **81**, 054025, 2010]
- In absence of new physics, Belle II should be able to measure $Y(1S) \rightarrow \nu\bar{\nu}$

Axion Like Particle search



theory papers	arXiv:1409.4792 arXiv:1611.09355 arXiv:1607.01022

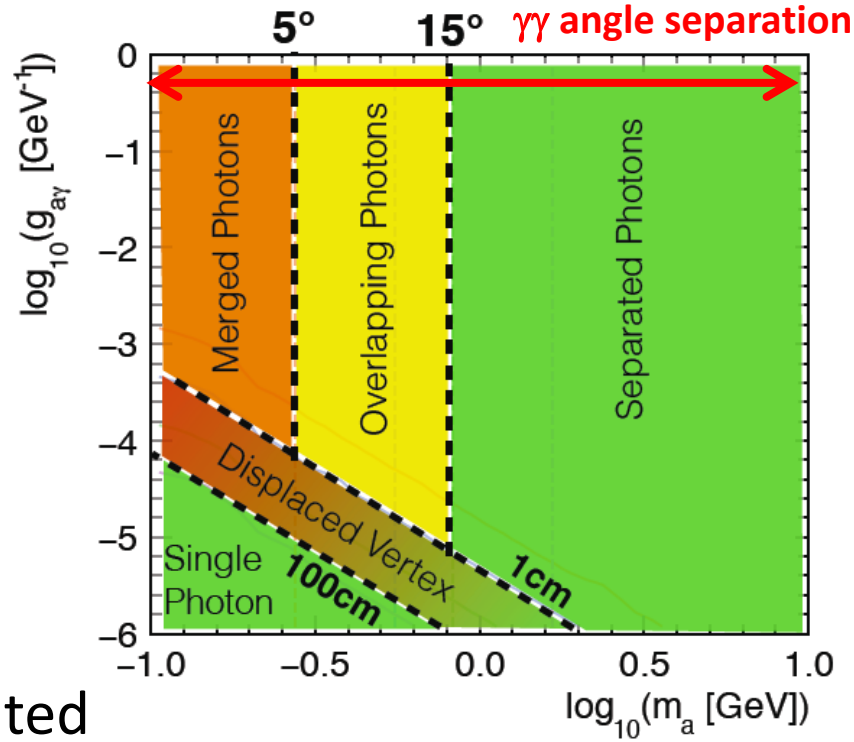
For Belle II the coupling $g_{a\gamma}$ has by far the largest cross section.

a→γγ assumed

three photon final state, but …

- γ's from axion decay can overlap or be merged for low *a* masses
- for very low couplings, *a* can fly away undected

Three, two and one photon final states



Sensitivities in Phase 2 being investigated

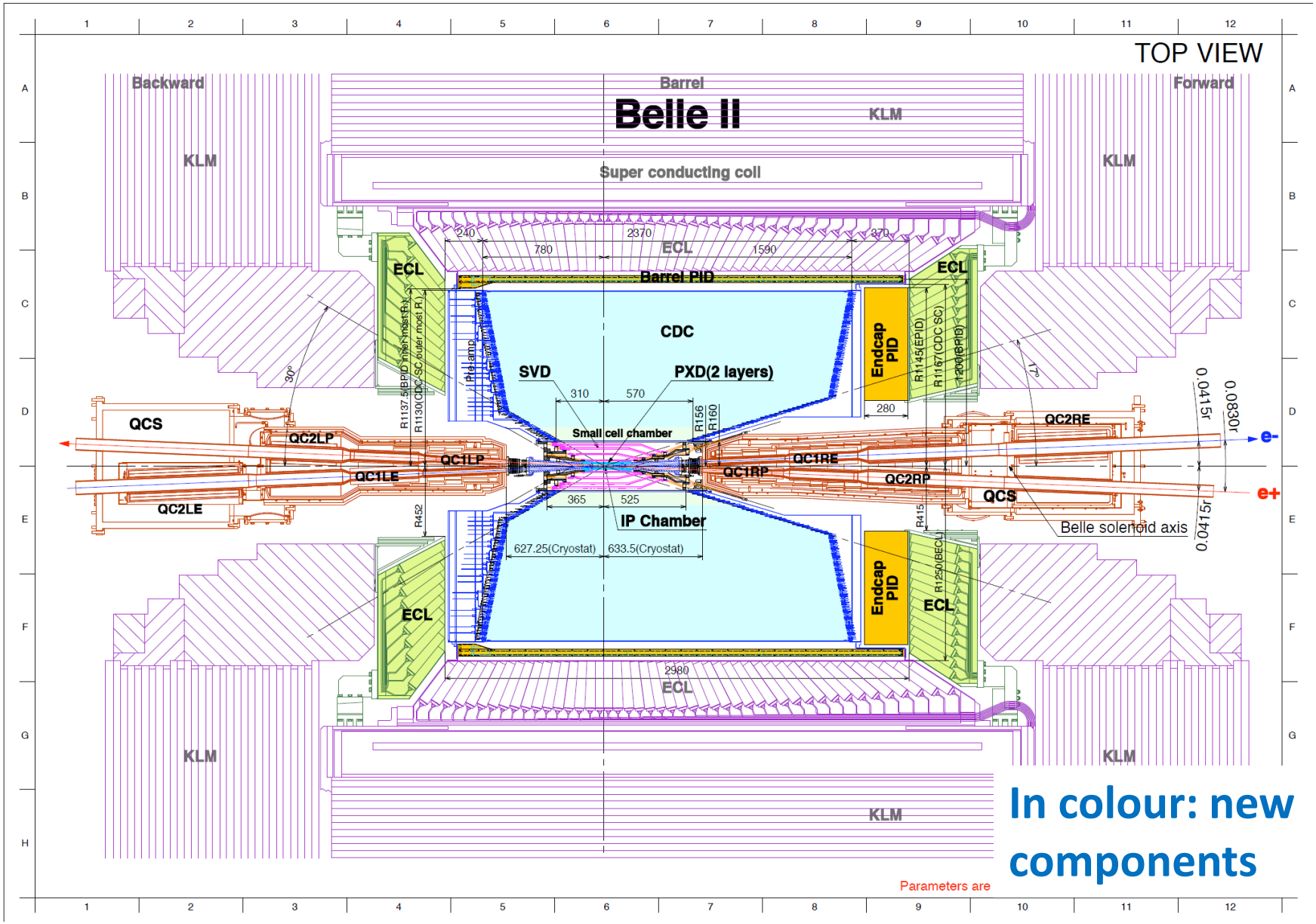
Summary

- Belle II succesfully rolled in to its final position in SuperKEKB;
- Detector (no VXD) commissioning by the end of 2017 until mid 2018 (Phase 2);
- 20 ± 20 fb^{-1} expected for physics in Phase 2;
- The search for the invisible decay of the dark photon to light dark matter looks very promising, even in Phase 2;
- Higher sensitivity than BaBar, mainly due to the non projective geometry of the calorimeter cracks;
- Alternative LDMA searches $e^+e^- \rightarrow \mu^+\mu^- A'$ ($A' \rightarrow$ invisible) and $\Upsilon(1S) \rightarrow$ invisible are under investigation and potentially interesting for Phase 3,
- The search for ALP in three, two and one photon final states is under study;
- Belle II physics run will start by the end of 2018, with the goal of collecting 50 ab^{-1} (50 x Belle) by 2025.

Thanks to T.Ferber, C.Hearty

SPARE SLIDES

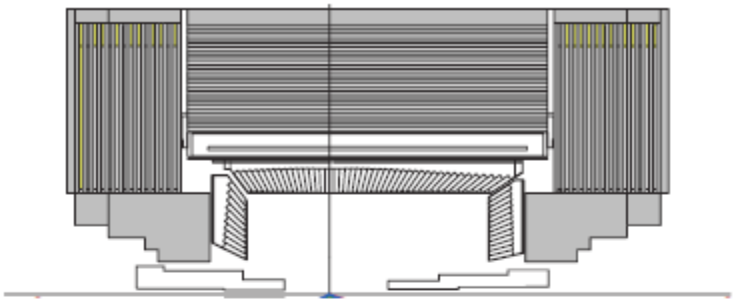
Belle II vs Belle detector



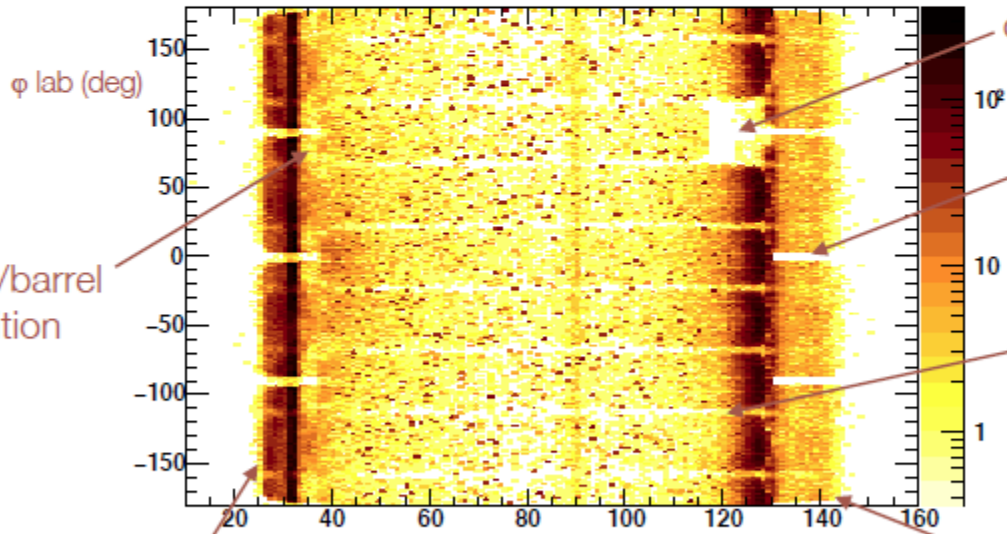
In colour: new components

KLM inefficiency

Sources of KLM inefficiency



φ_{lab} vs θ_{lab} of all KLM clusters in $e^+e^- \to \gamma\,\gamma\,(\gamma)$



chimney

endcap sector boundary

endcap/barrel transition

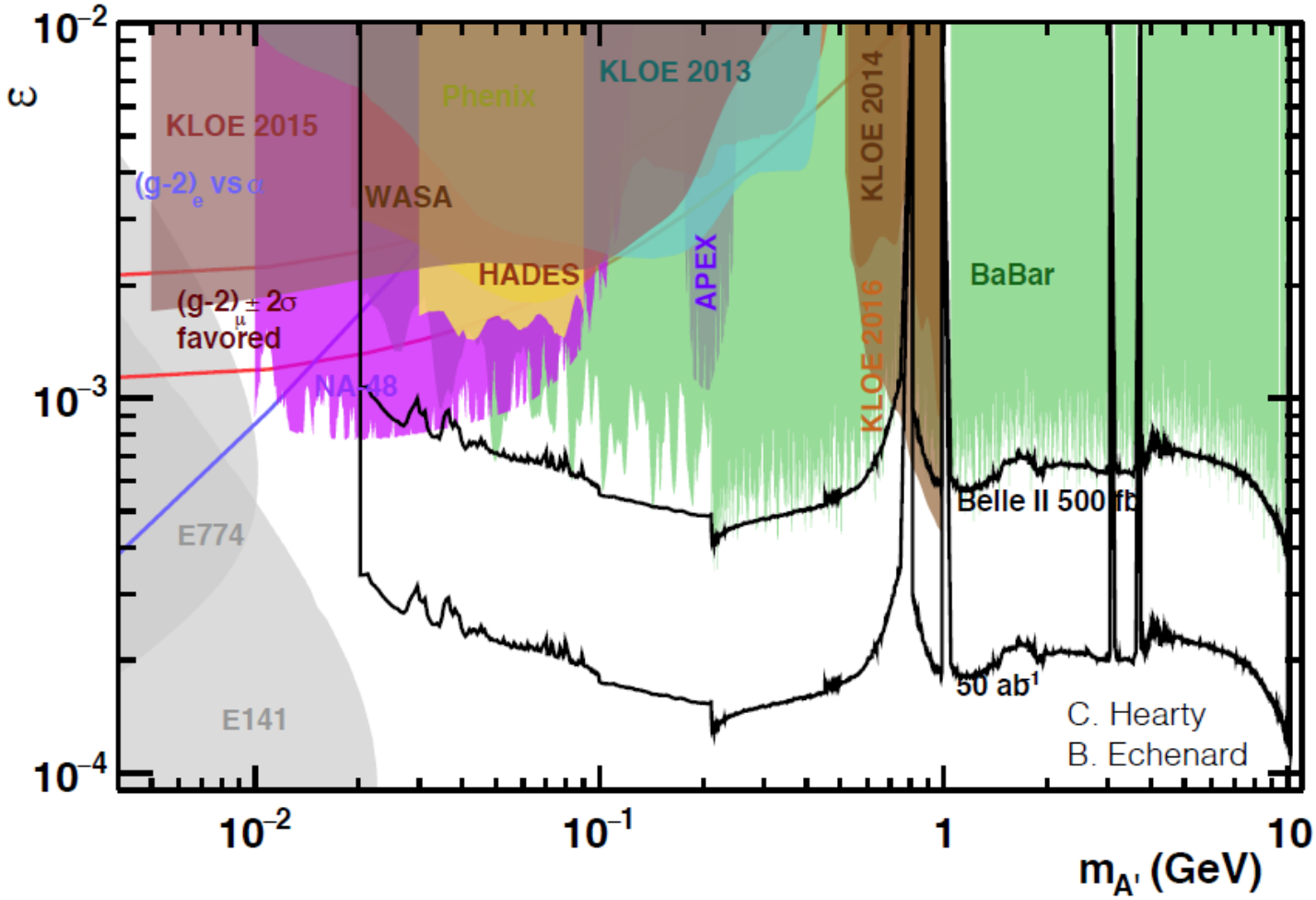
barrel sector boundary

no KLM behind innermost ECL endcaps

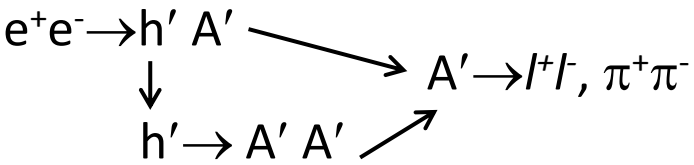
no KLM behind innermost ECL endcaps

Dark photon to visible (leptons)

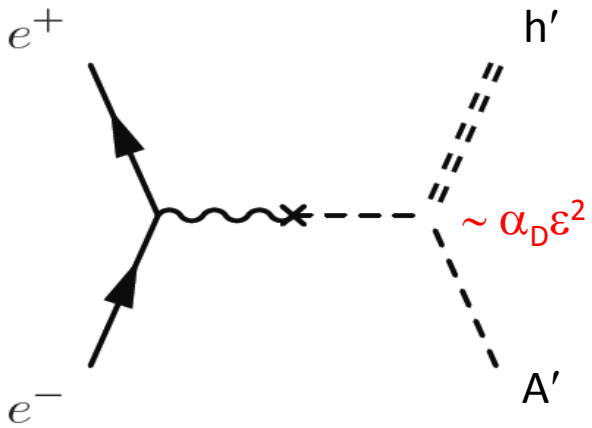
Belle II limits scaled from BaBar: PRL 113, 201801 (2014)

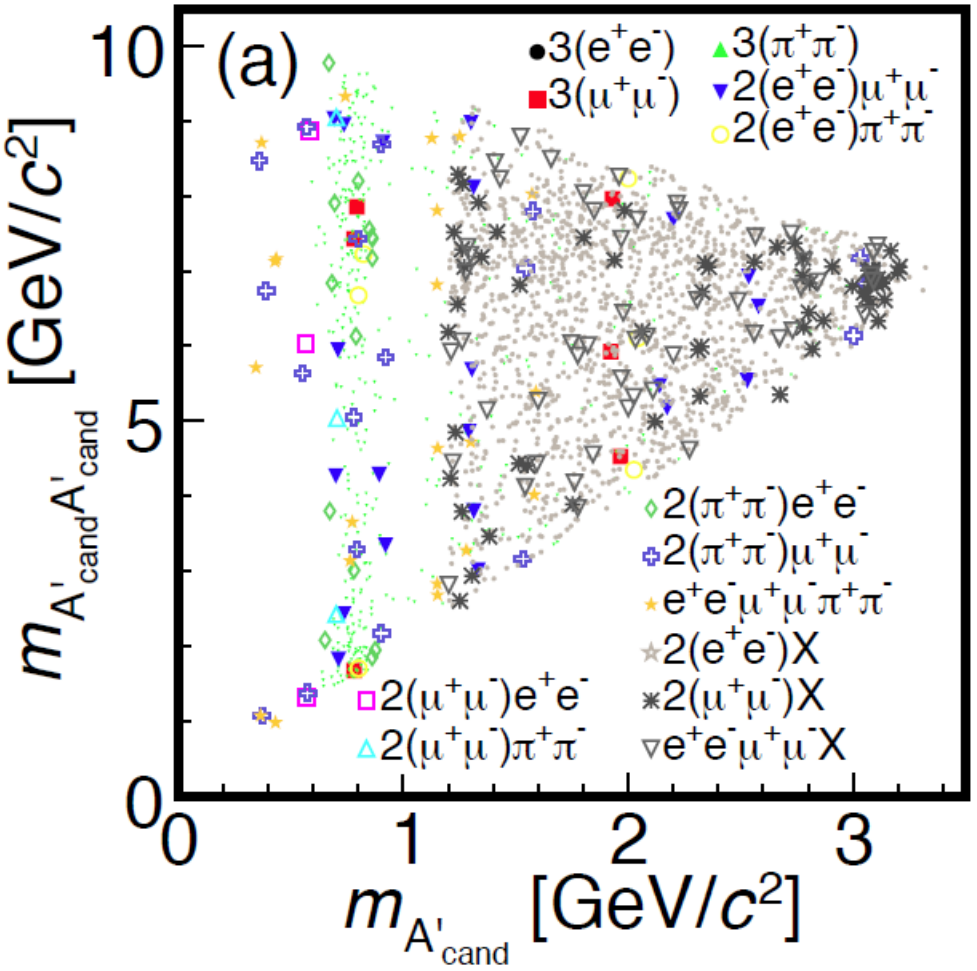


Dark Higgsstrahlung in Belle



⇒ Six particle ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$) final states





Dark Higgsstrahlung in Belle

90% CL limits in $\alpha_D \varepsilon^2$