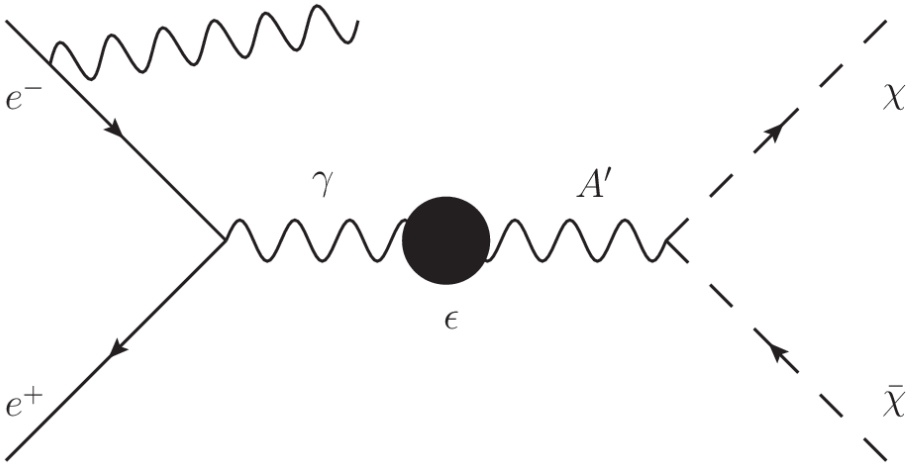
Dark photon → Invisibles during the Phase 2



Giacomo De Pietro

Università di Roma Tre *INFN Roma Tre*

7th Belle II Italian Meeting
4-5 May 2017 @ Trieste

Theory

Dark photon = boson mediator of a "dark interaction" between dark matter (and SM) particles

A dark photon could explain the muonic g-2 anomaly!

Minimal model:

$$\mathcal{L}_{\mathrm{A}'} = -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta_W}B^{\mu\nu}F'_{\mu\nu} - \frac{1}{2}m^2_{A'}A'^{\mu}A'_{\mu}$$

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at low energies:

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at low energies:

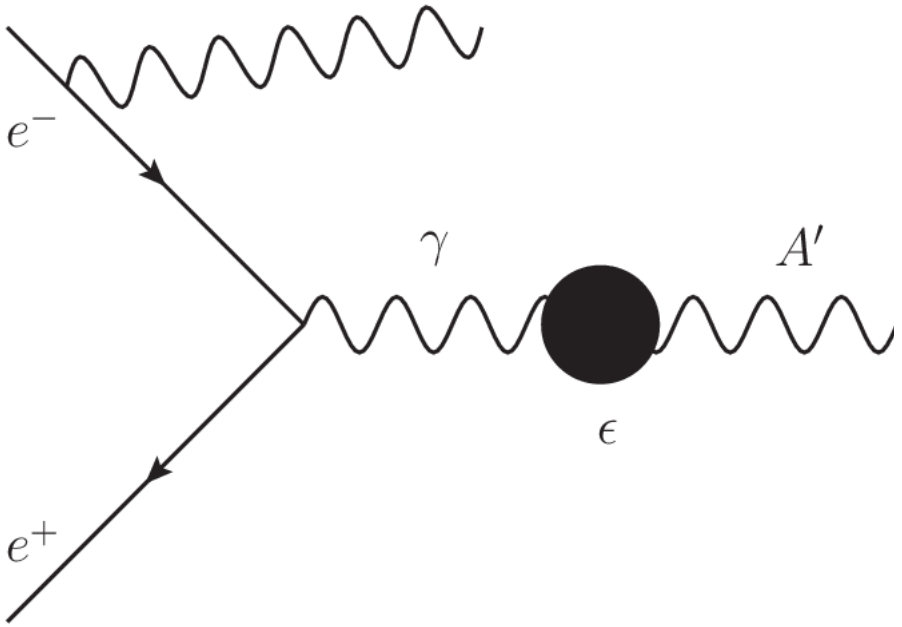
$$\boxed{\mathcal{L}_{\text{kin.mix.}} = \frac{1}{2}\epsilon F^{\mu\nu}F'_{\mu\nu}}$$

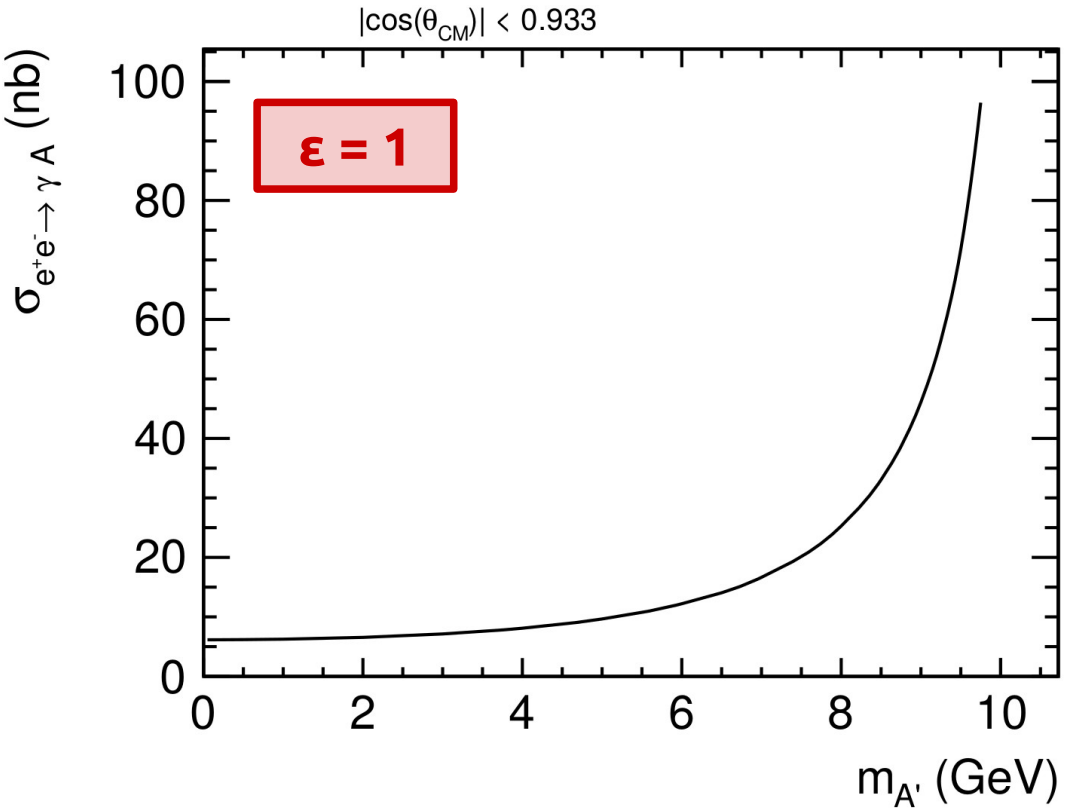
Free parameters (*to be measured*):
ε (strength of the mixing)
m_A (mass of the dark photon)

Production

Several production mechanisms at $e^+ e^-$ colliders:

I will focus on $e^+ e^-$ annihilation



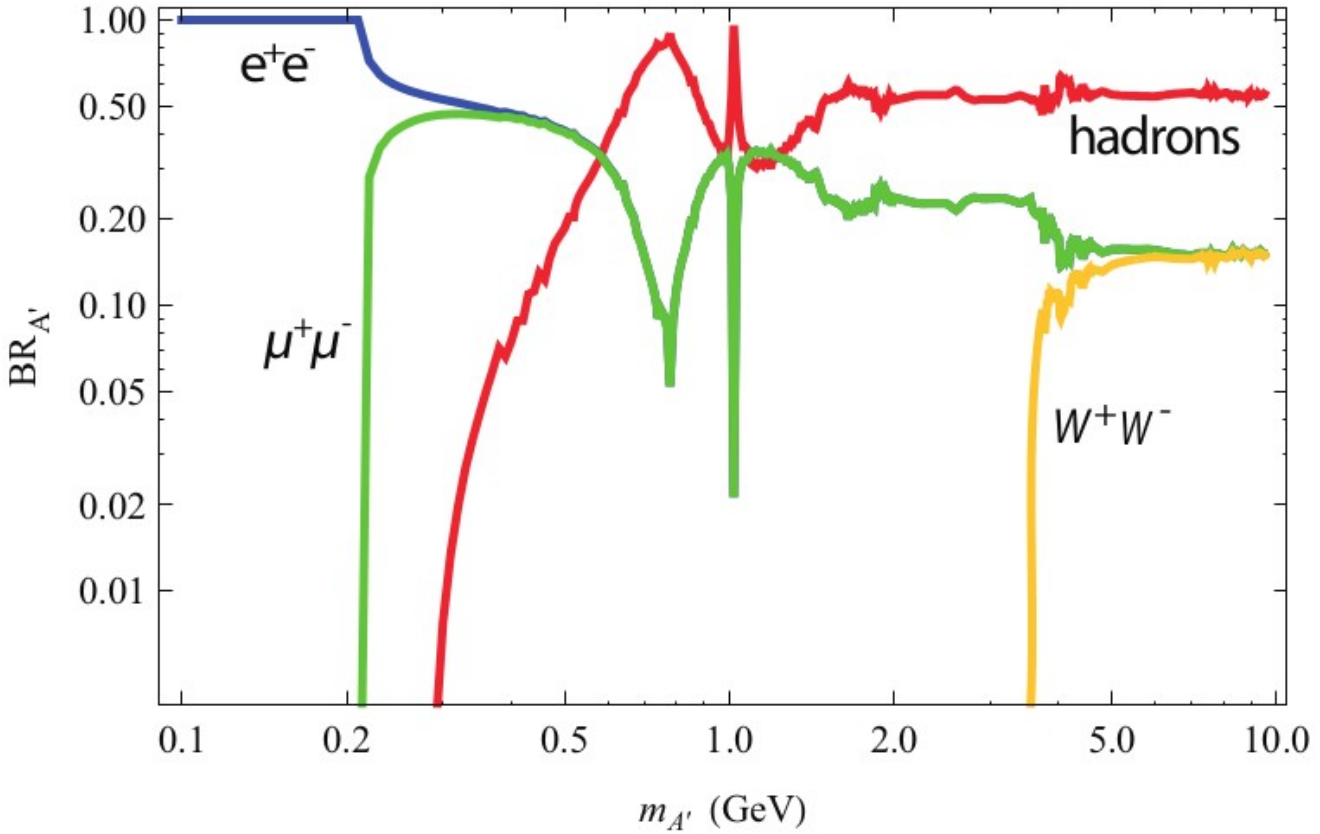


$$\frac{\mathrm{d}\sigma(e^+e^- \to \gamma A')}{\mathrm{d}\cos\theta} = \frac{\alpha\epsilon^2}{2s^2(s - m_{A'}^2)} \left(\frac{s^2 + m_{A'}^4}{\sin\theta^2} - \frac{(s - m_{A'}^2)^2}{2} \right)$$

Visible decay

Two different scenarios: visible vs. invisible decay

If $m_\chi > \frac{1}{2} m_A$: dark photon decays into SM particles

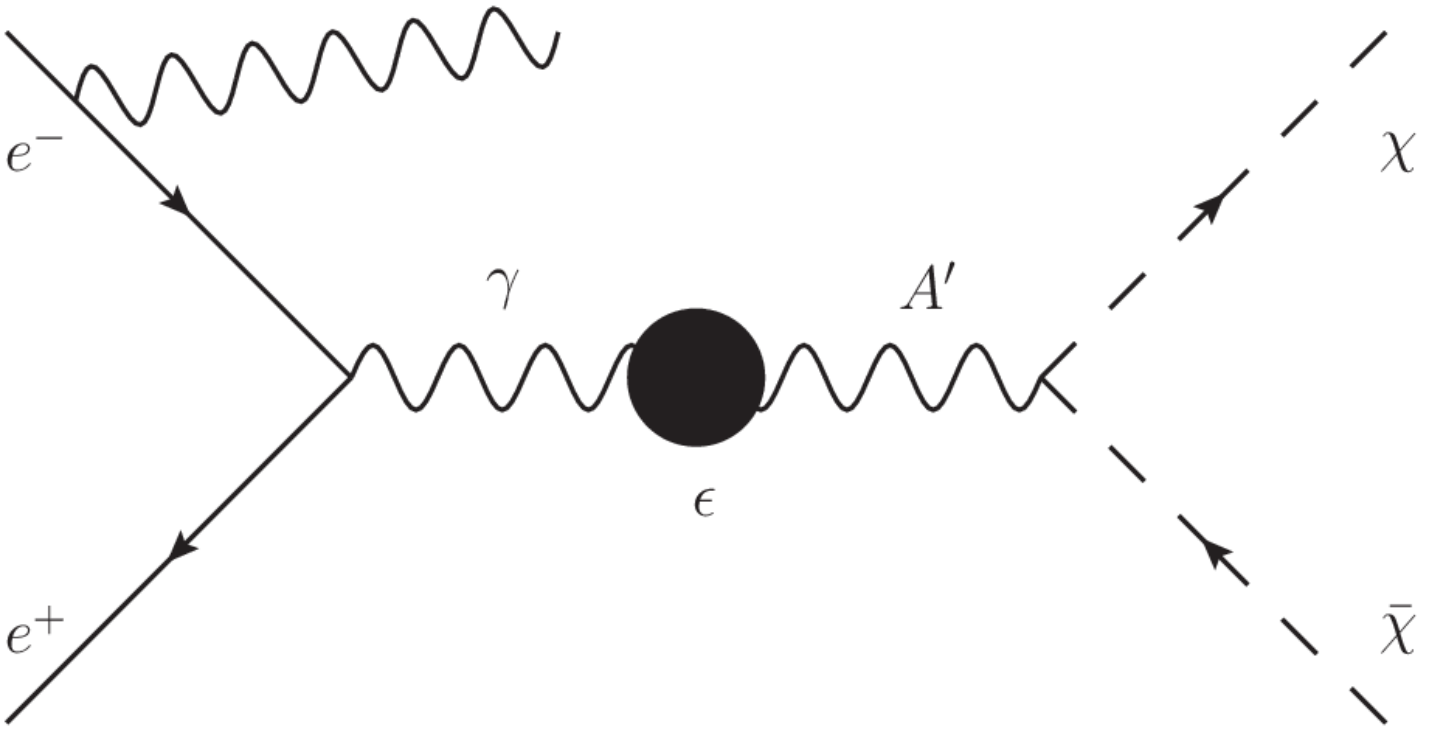


$$\Gamma_{A'\to \mathrm{had}} = \frac{1}{3}\alpha\epsilon^2 M_{A'}\sqrt{1-\frac{4m_\mu^2}{M_{A'}^2}}\left(1+\frac{2m_\mu^2}{M_{A'}^2}\right)\times\frac{\Gamma(e^+e^-\to \mathrm{hadrons})}{\Gamma(e^+e^-\to\mu^+\mu^-)}(E=M_{A'})$$

Invisible decay

If $m_\chi < \frac{1}{2}\, m_{A'}$: dark photon can decay into DM particles

Main decay if the coupling with DM isn't suppressed

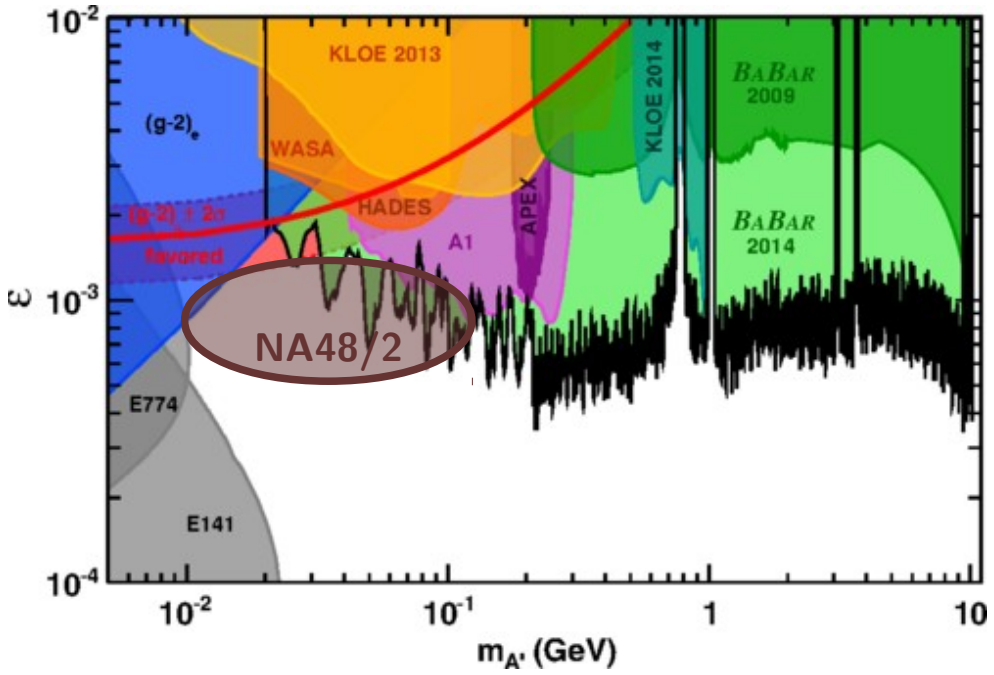


$$\Gamma_{A'\to\chi\chi} = \frac{1}{3}\alpha_D M_{A'} \sqrt{1-\frac{4m_\chi^2}{M_{A'}^2}}\left(1+\frac{2m_\chi^2}{M_{A'}^2}\right)$$

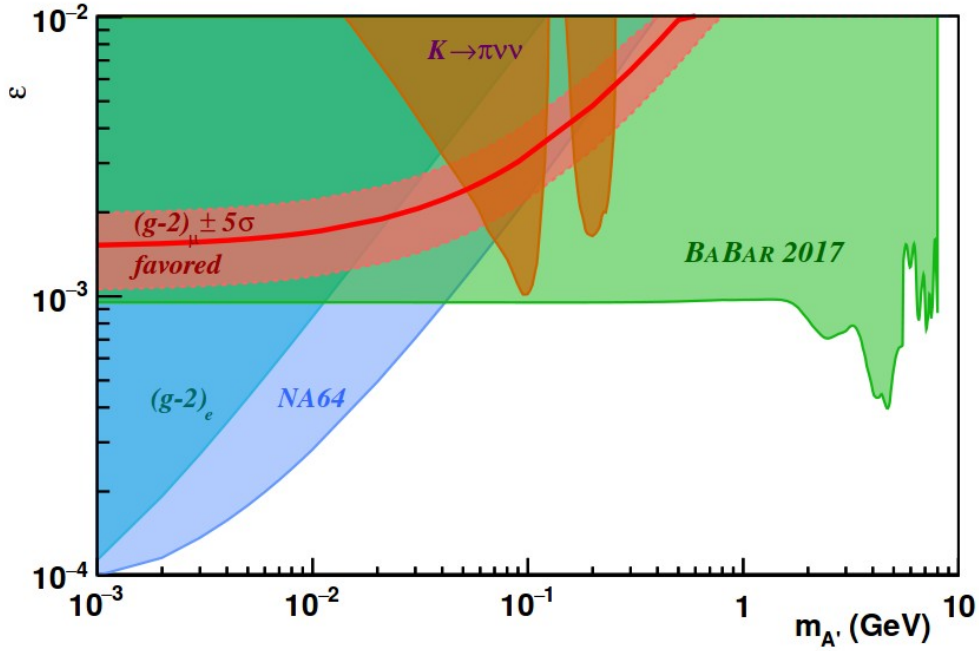
No suppression = $\alpha_D >> \alpha\varepsilon^2$

Experimental status

Visible decay ($\to l^+ l^-$)



Invisible decay

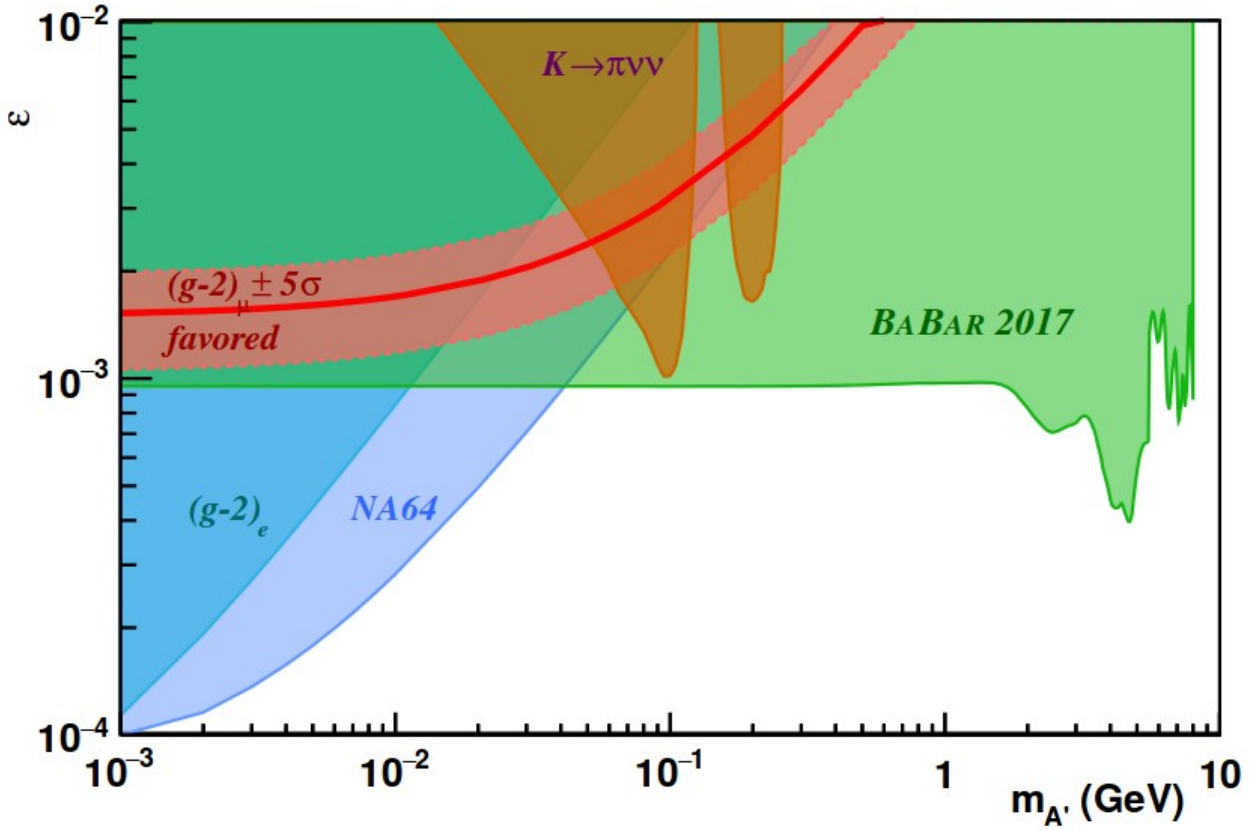


No direct comparison between results reguarding visible and invisible decay

Many other results related to hadronic decays and different models/mechanisms

Focus of this talk:
Dark photon → Invisibles

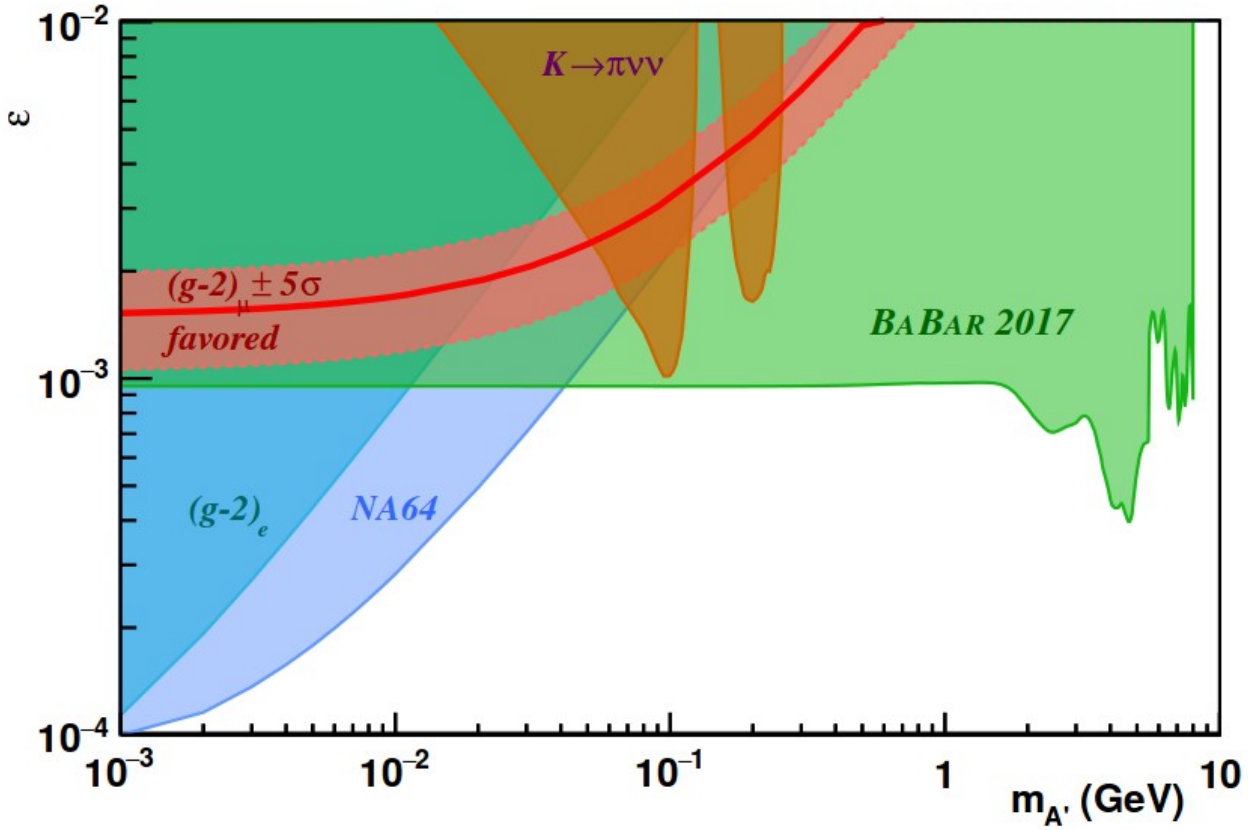
Dark photon → Invisibles



BaBar and NA64 **ruled out** the possibility to explain completely the g-2 anomaly introducing a dark photon

(**assuming light DM: $m_\chi < \frac{1}{2} m_A$**)

Dark photon → Invisibles

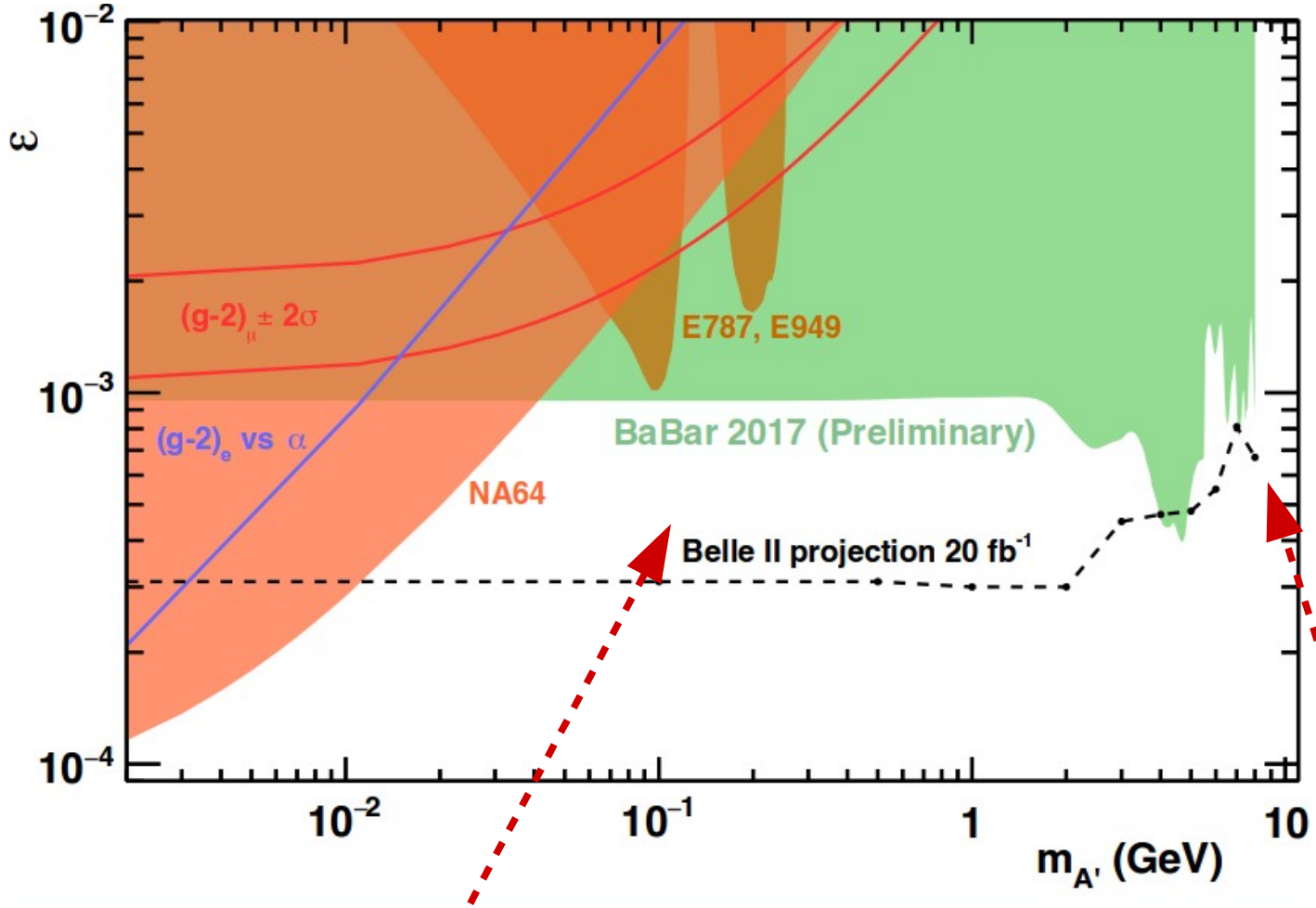


But:

- it can still ***partially*** **explain** the g-2 anomaly (+ other NP)

- it's still an important **portal to light DM**

Belle II perspective



20 fb^{-1} with Phase 2

Barrel ECL without projective cracks in Φ

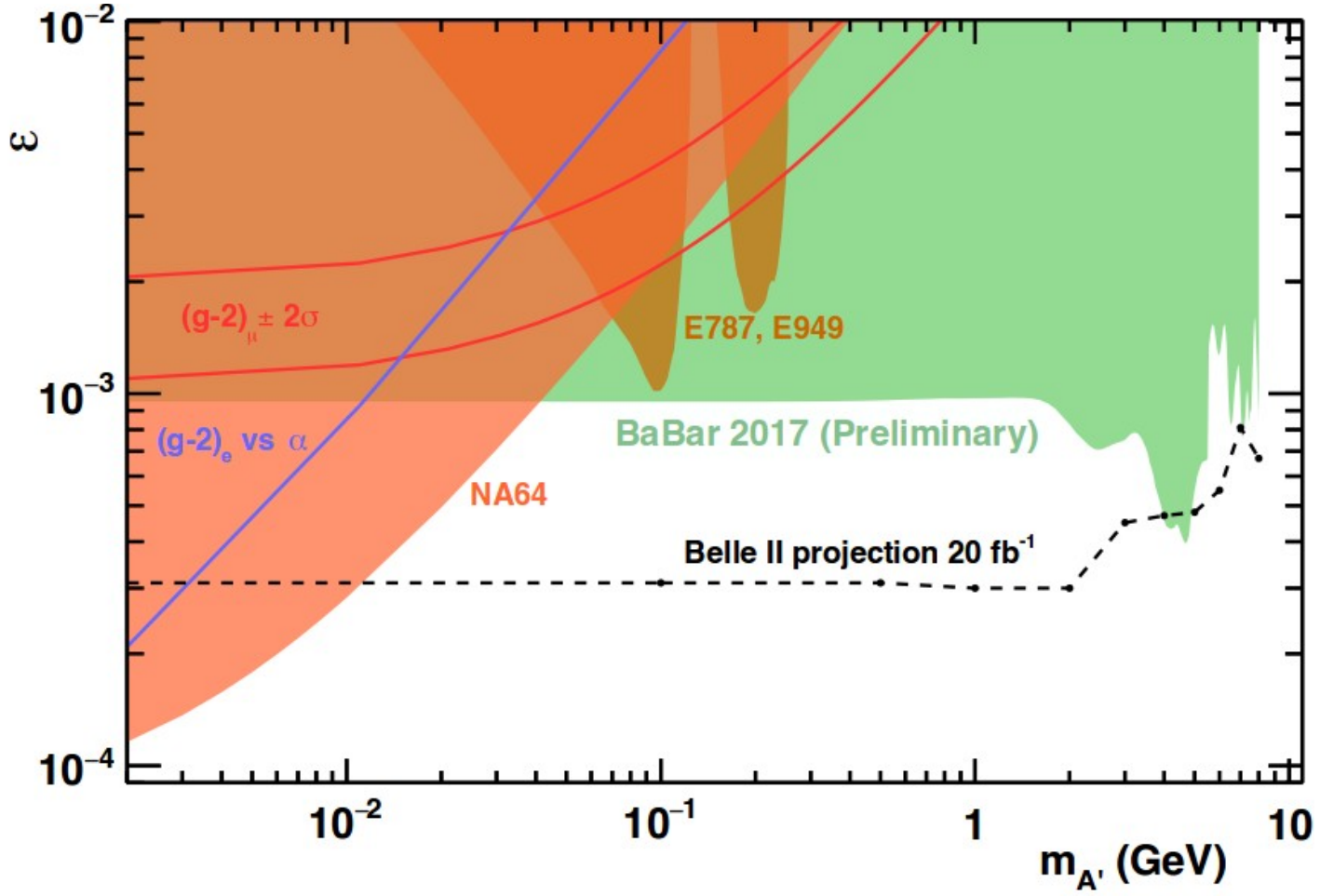
Better cover of ECL gaps from KLM

Lower threshold of the trigger

Higher CM energy

(@BaBar, lower trigger only with 2S and 3S)

Belle II perspective



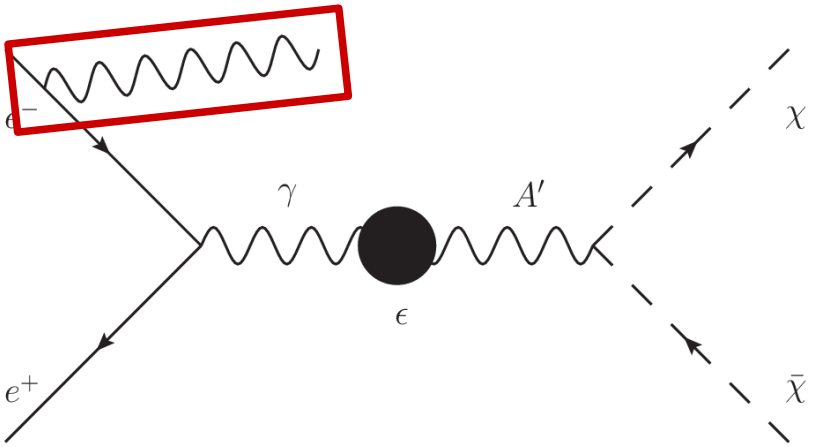
20 fb^{-1} with Phase 2

50 ab^{-1} with Phase 3 ?

Will it be possible to use the single photon trigger during the Phase 3 with the final luminosity?

This could be the only chance for us to do this measurement...

Exp. signature

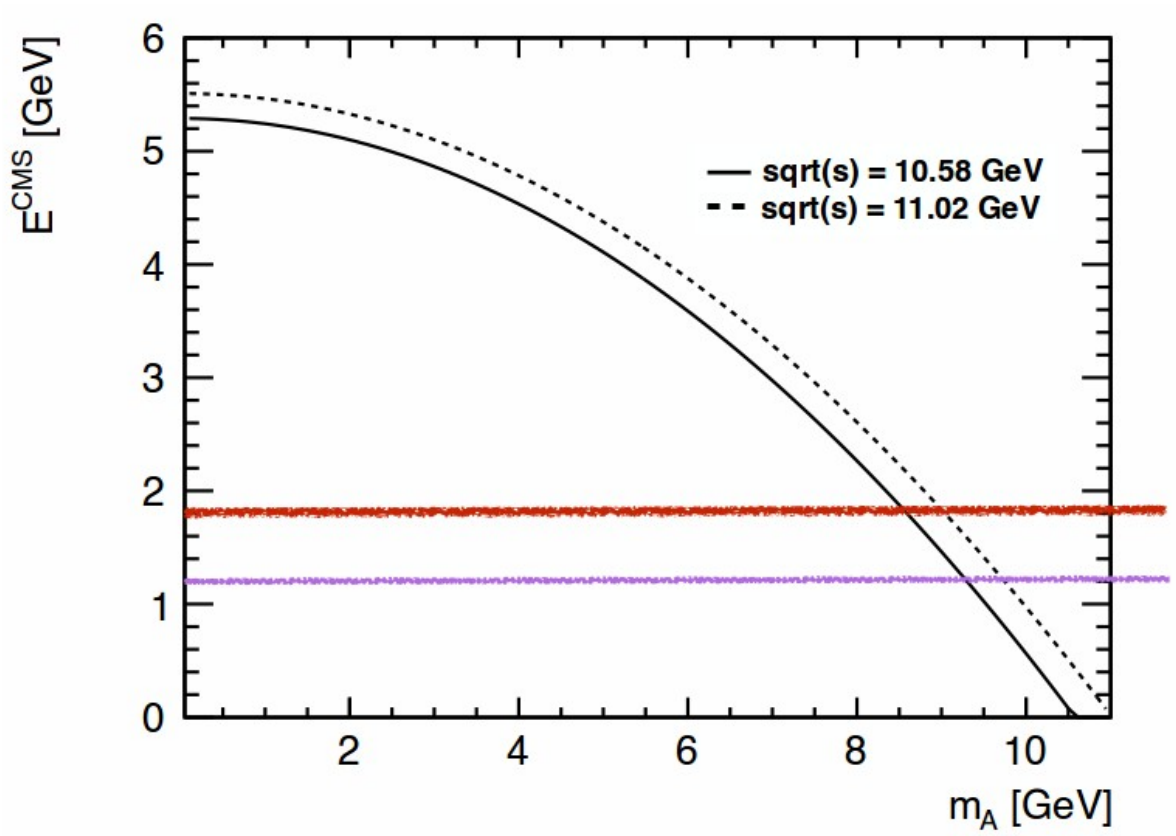


Only 1 photon in the detector

Needed a single photon trigger!

Signal: a "bump" at a

given energy of the detected photon



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

$E_{Trigger}$ = 1.8 GeV

$E_{Trigger}$ = 1.2 GeV

Trigger + Evt. selection

Two triggers for single photon:

1) $\mathbf{E_{CM} > 2\ GeV}$

2) $\mathbf{E_{CM} > 1\ GeV}$, $\mathbf{E_{CM}}$ **(2nd cluster)** $\mathbf{< 0.2\ GeV}$

Common features: $18.5° < \theta < 139.2°$, no Bhabba, no $\gamma\gamma$

Event selection requirements (for B2TiP study):

- $E_{CM} > 1.8$ GeV
- no clusters with $E_{CM} > 0.1$ GeV
- no tracks with pT > 0.2 GeV in CM
- no KLM clusters outside a 25° cone around the photon

Backgrounds

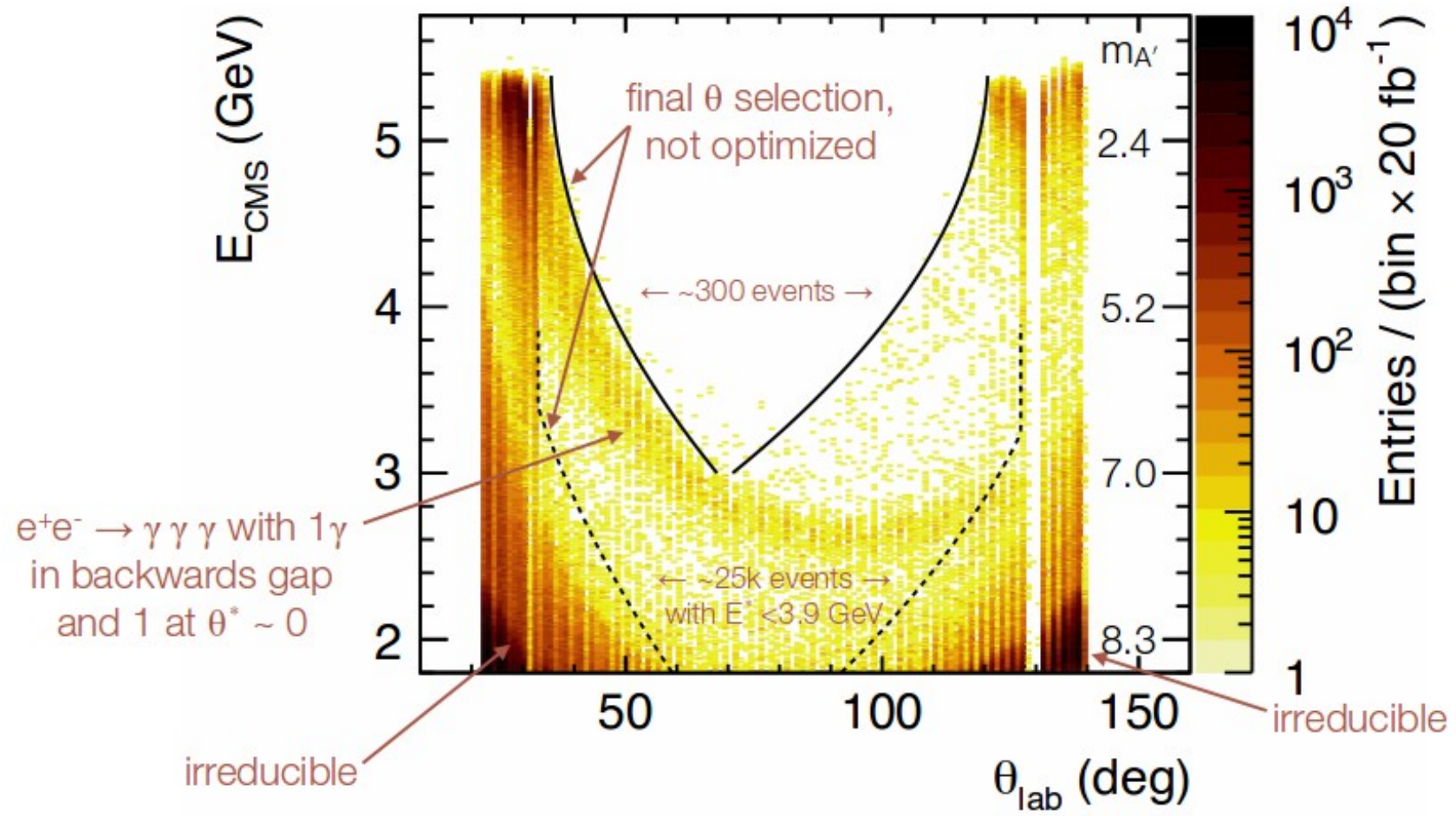
Backgrounds

- Irreducible: final state has only one photon in [12°,157°]
  - 2M events with $E^{*}>1.8$ GeV and $22° < \theta < 139°$ in 20 fb^{-1} (0.1 nb); E and θ are strongly correlated.
  - 85% due to radiative Bhabhas
  - 15% due to $e^{+}e^{-} \rightarrow \gamma\,\gamma\,(\gamma)$ (minimum 3 photons in final state)

- Reducible: two photons in detector, one of which is missed in both ECL and KLM

Backgrounds after cuts

Background in 20 fb^{-1}:



From B2TiP: release-00-07-02, Phase 2 Geometry, Scaled beam BKG

From rel-07 to rel-08

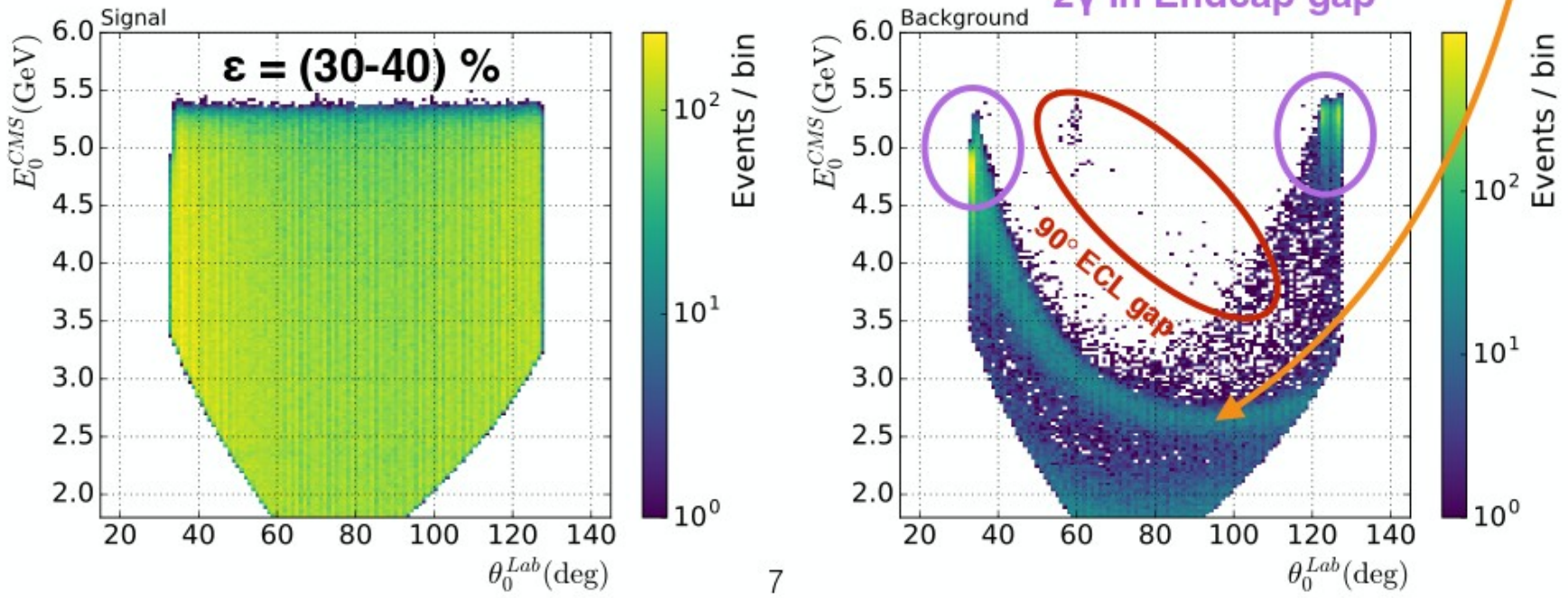
Release-00-08-00
Phase2 geometry
Phase 2 beam backgrounds

Signal and Background: After cuts.

Preselection (reconstructed):
ECL-N1 (gamma) clusters CMS energy sorted: G0, G1
33° < Theta0Lab < 127°
E0CMS dependent cut on Theta0Lab for low E0CMS
E1CMS < 0.1 GeV*
All Tracks p_t < 0.2 GeV
No KLM cluster back to back to G0
No KLM clusters in KLM veto regions (various gaps)*
*Needed after using new MC14 Phase2 background.

3γ in ECL BWD gap and KLM BWD gap

2γ in Endcap gap

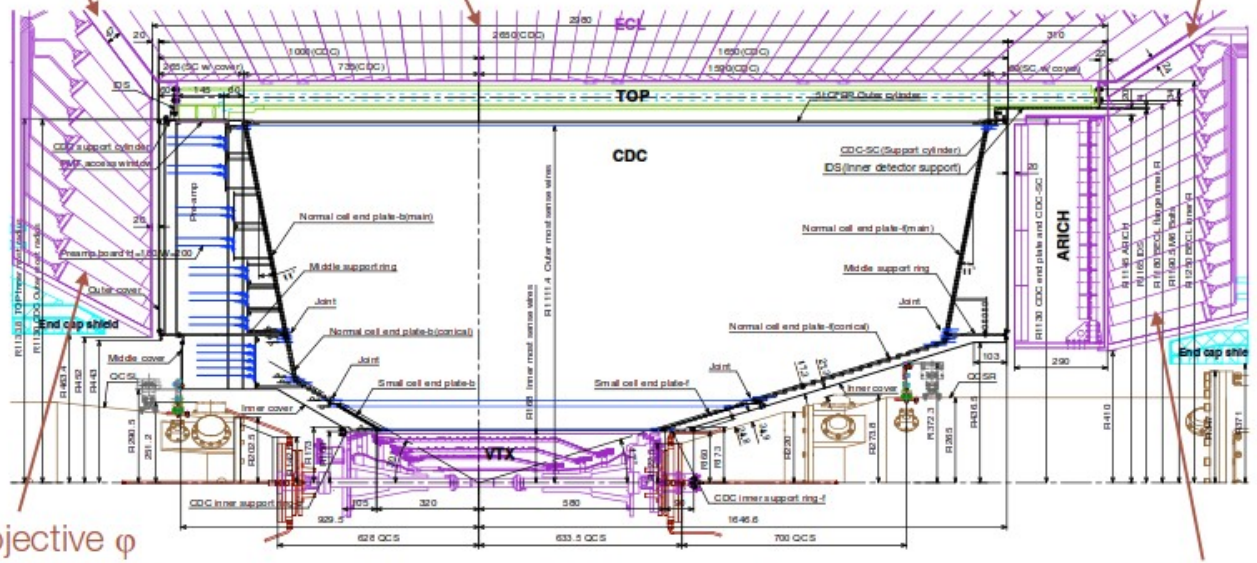


ECL ineffiecies

1. barrel/endcap gap

4. 1.5mm structure at 90°

2. barrel/endcap gap



3. projective φ cracks in endcaps

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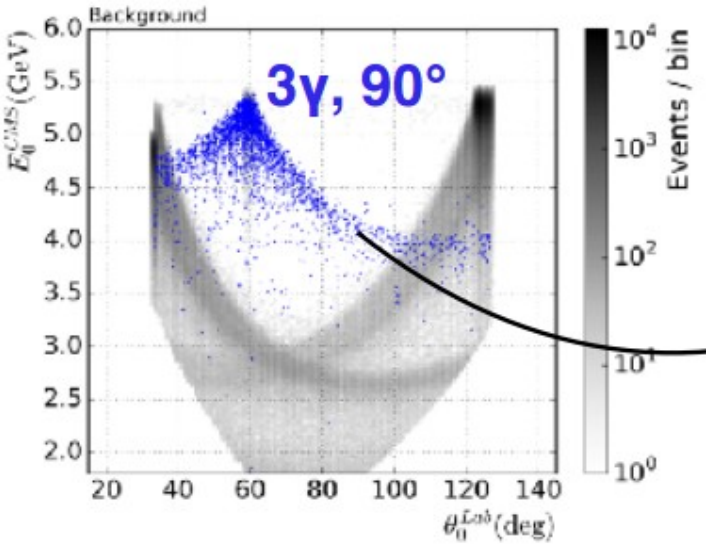
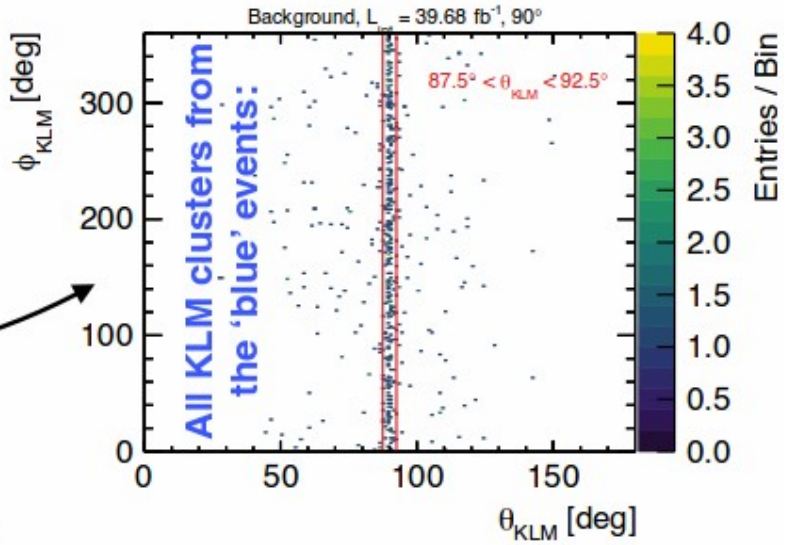
5. γ non-conversion 3 × 10^{-6}





The Roma Tre involvment

The studies presented so far have been done

by C. Hearty, T. Ferber and their group

During the last B2GM has been agreed that

we (me and the Roma Tre group) will collaborate with them

for this analysis, in particular reguarding

the detection of photons with the KLM

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At Roma Tre we will be involved
with the KLM commissioning

KLM studies @ Roma Tre

A sample of photons has been generated with the ParticleGun:

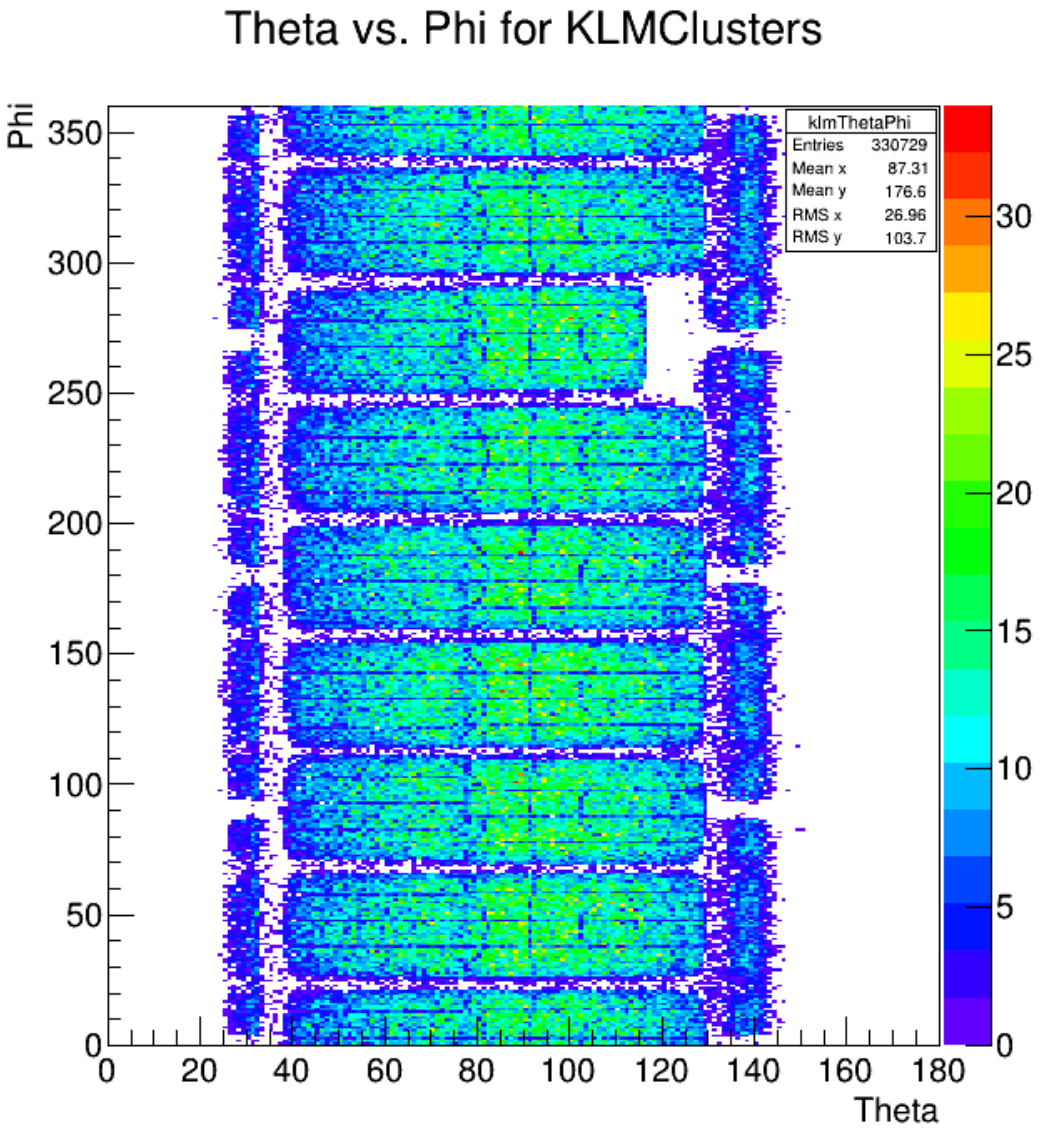
- release-00-08-00
- Phase 2 geometry
- Phase 2 beam background

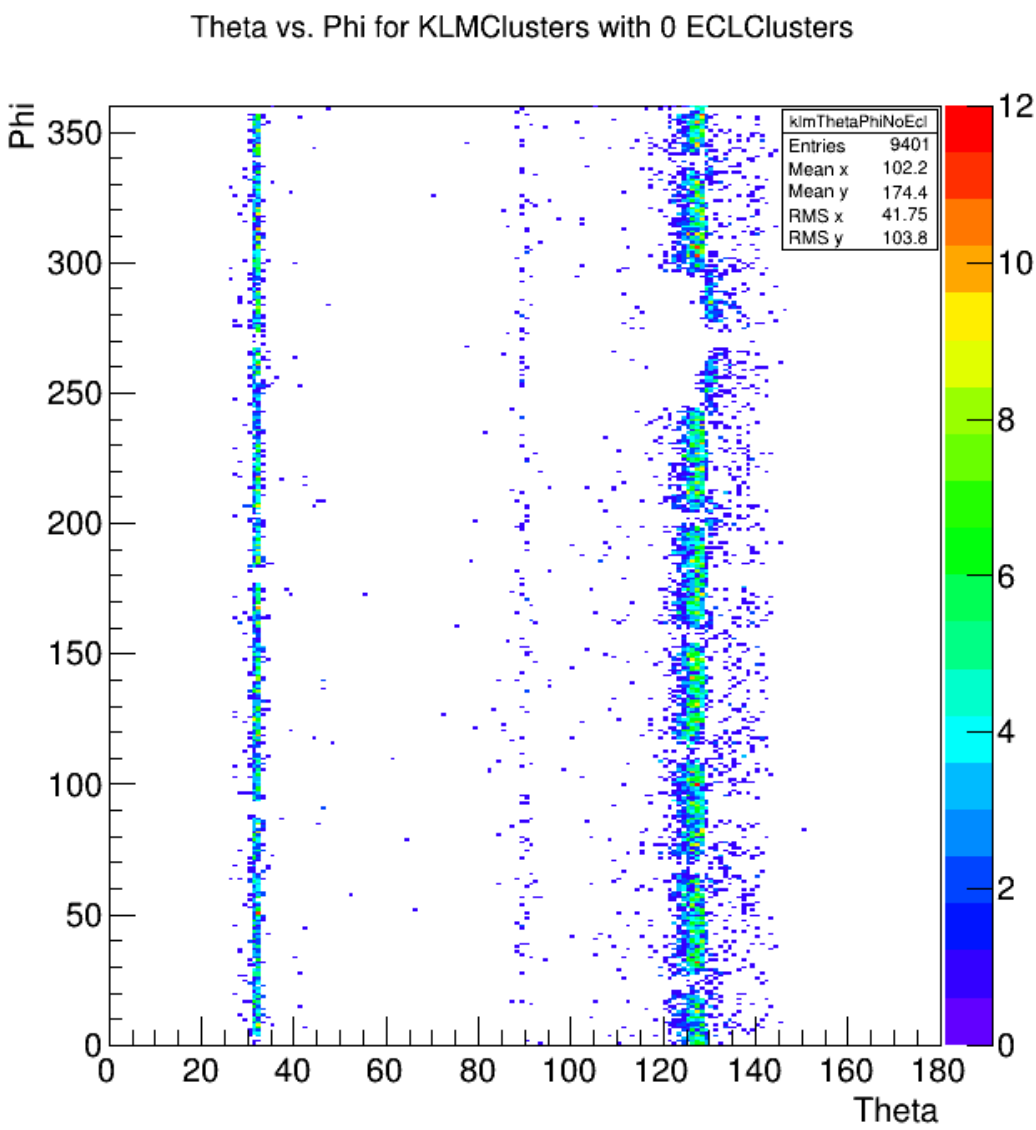
Info contained in KLMClusters data objects (available in the mDST):

- time
- vector with cluster position
- Lorentz vector with cluster momentum
- # of layers with a cluster hit
- innermost layer with a cluster hit
- momentum and position error matrices
- magnitude of the momentum
- magnitude of the energy
- a vector with (0,0,0) (K_L origin...)

KLM studies @ Roma Tre

KLM needed as veto for ECL gaps/inefficiencies





KLM studies @ Roma Tre

A list of problems to be studied/analyzed:

- map of KLM efficiency for photons (*ongoing*)

- more variables needed in the mDST for KLMClusters?

- how to handle with "double clusters" between barrel and endcap?

- etc.

An other fundamental study: plan the **analysis of μμγ events**

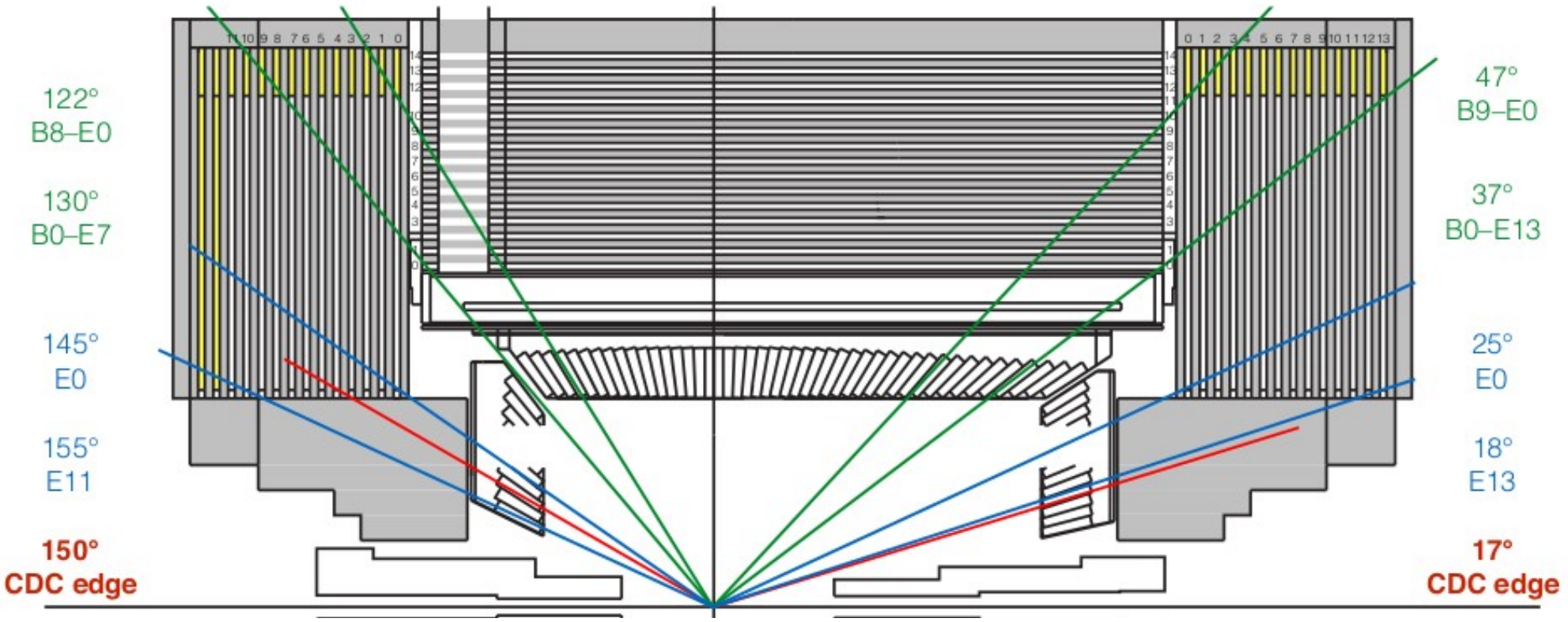
in order to map the ECL and KLM efficiencies

Backup slides

Search for dark photon

Dedicated experiments + Multipurpose experiments

KLM geometry



Ranges of θ	Sector definition
$47^\circ < \theta < 122^\circ$	*only barrel*
$37^\circ < \theta < 47^\circ + 122^\circ < \theta < 130^\circ$	*superposition between barrel and endcap*
$25^\circ < \theta < 37^\circ + 130^\circ < \theta < 145^\circ$	*only endcap*
$18^\circ < \theta < 25^\circ + 145^\circ < \theta < 155^\circ$	*part of the endcap*

Table 1: KLM sectors in ranges of θ.