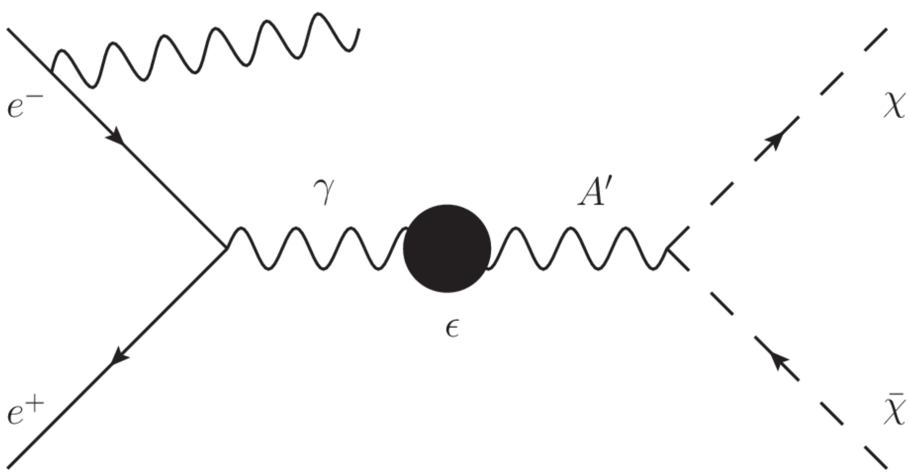
Dark photon → Invisibles
&
Low multiplicity @ Phase 2



Giacomo De Pietro

Università di Roma Tre *INFN Roma Tre*

8th Belle II Italian Meeting
20-21 November 2017 @ Pisa

Dark photon → Invisibles

Theory

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

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

Minimal model:

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

at low energies:

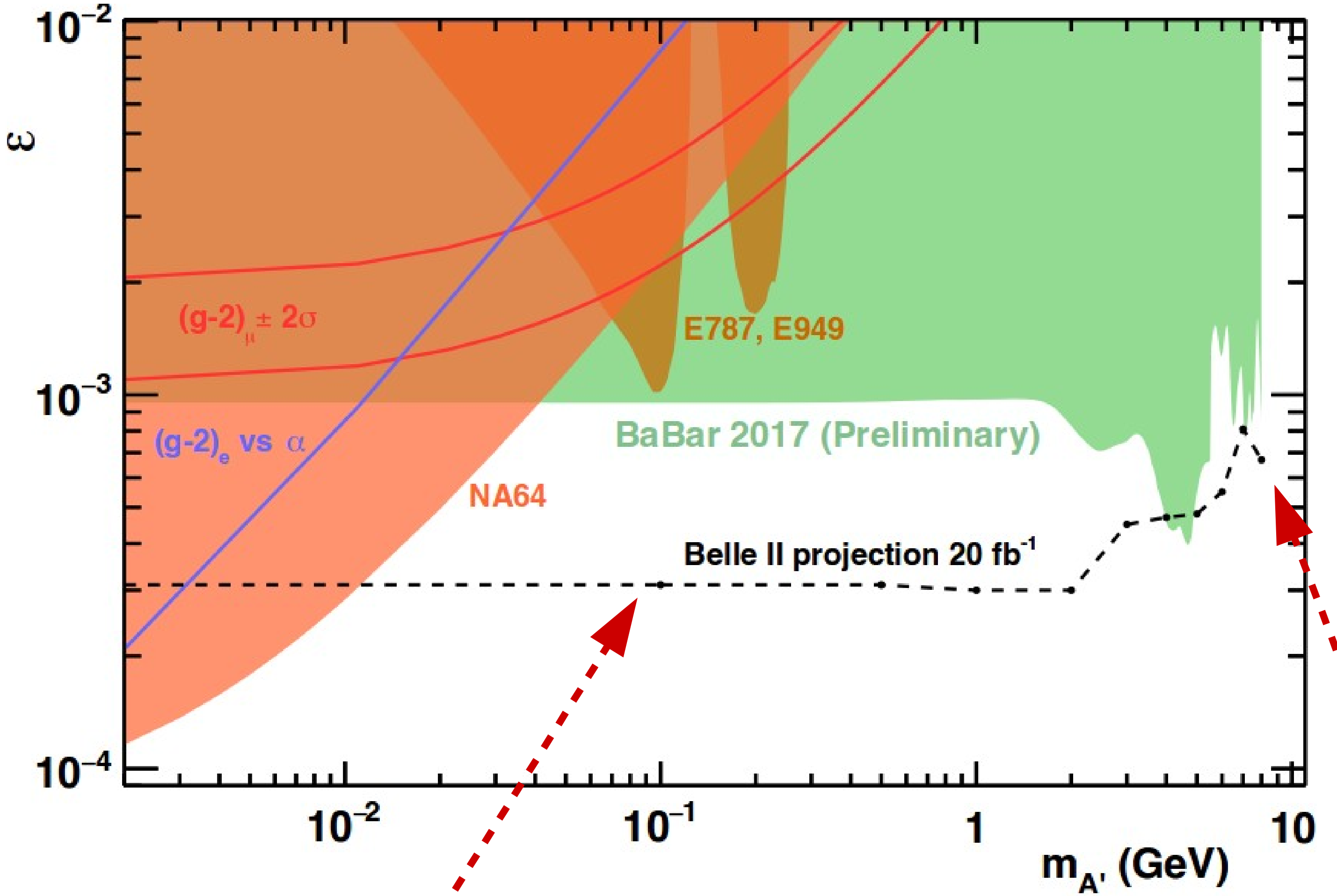
$$\boxed{\mathcal{L}_{\text{kin.mix.}} = \frac{1}{2}\epsilon F^{\mu\nu}F'_{\mu\nu}}$$

Free parameters *(to be measured)*:

ε (strength of the mixing)

m_A (mass of the dark photon)

Belle II perspective



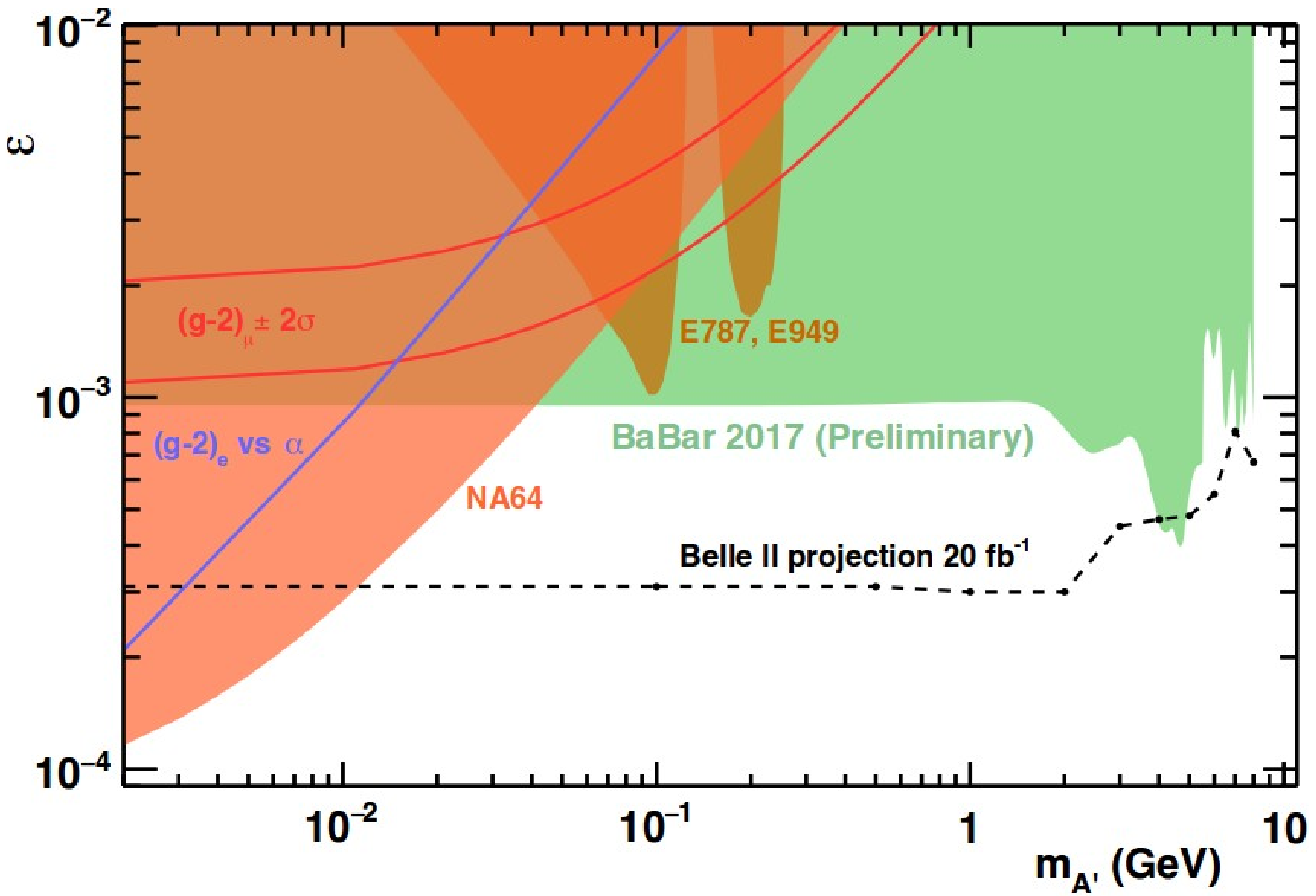
20 fb^{-1} @ Phase 2

- Barrel ECL without projective cracks in ?
- Better cover of ECL gaps with KLM

- Lower threshold of the trigger
- Higher CM energy

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

Belle II perspective



20 fb^{-1}

@ Phase 2

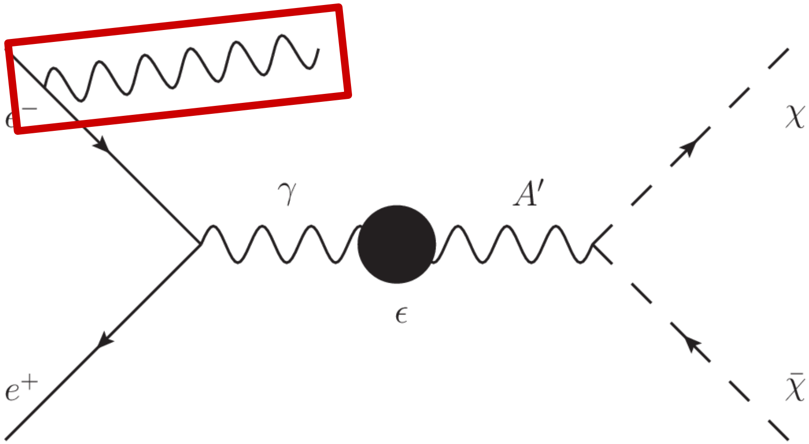
50 ab^{-1}

@ 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

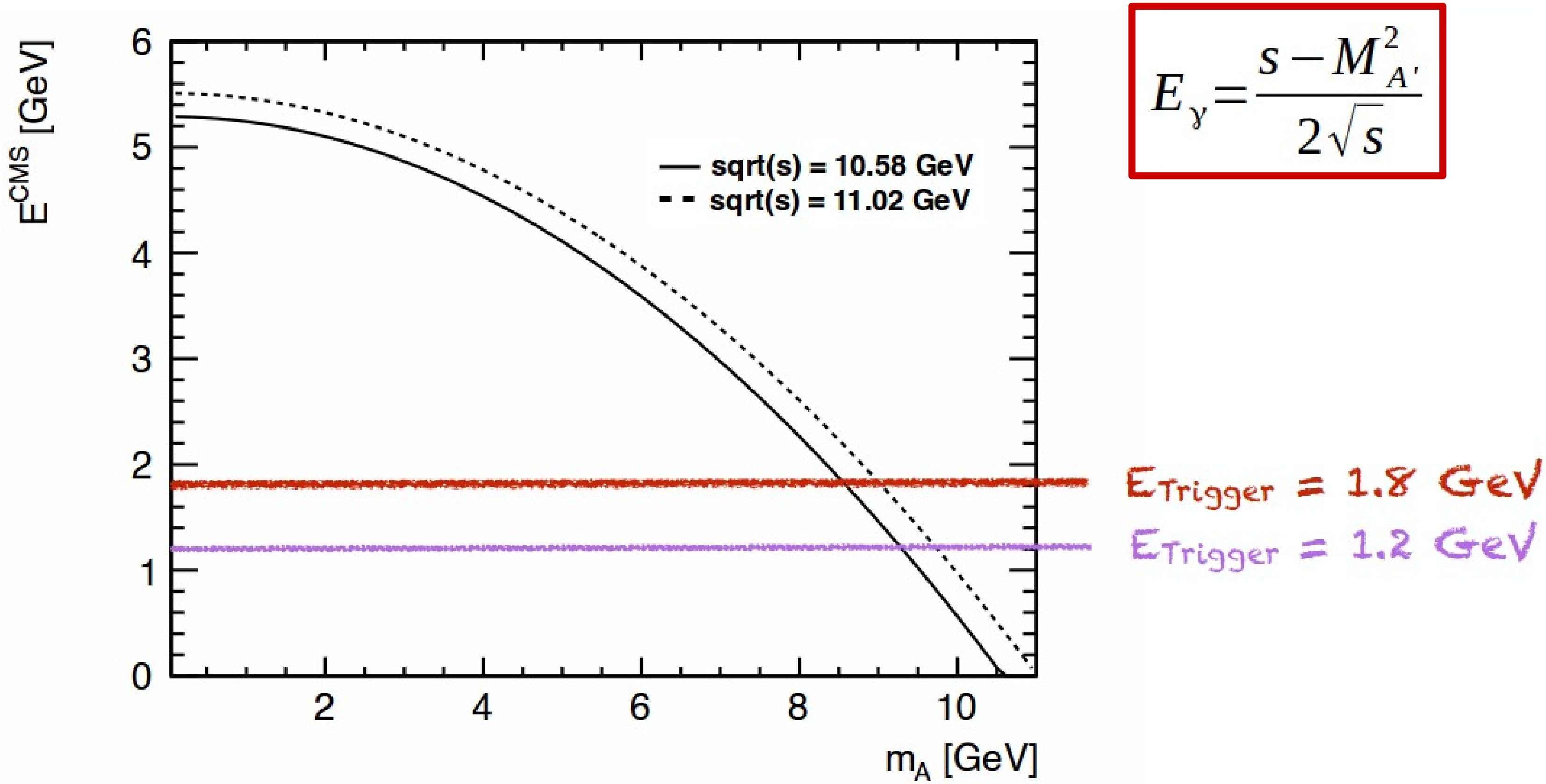


Only 1 photon in the detector

Needed a single photon trigger!

Signal: a "bump" at a

given energy of the detected photon



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

Trigger + Evt. selection

Two triggers for single photon:

1) **$E_{CM} > 2$ GeV**

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

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

Event selection requirements:

- cluster in barrel ECL and $E > E(\theta)$
- 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 or back-to-back

Backgrounds

Backgrounds

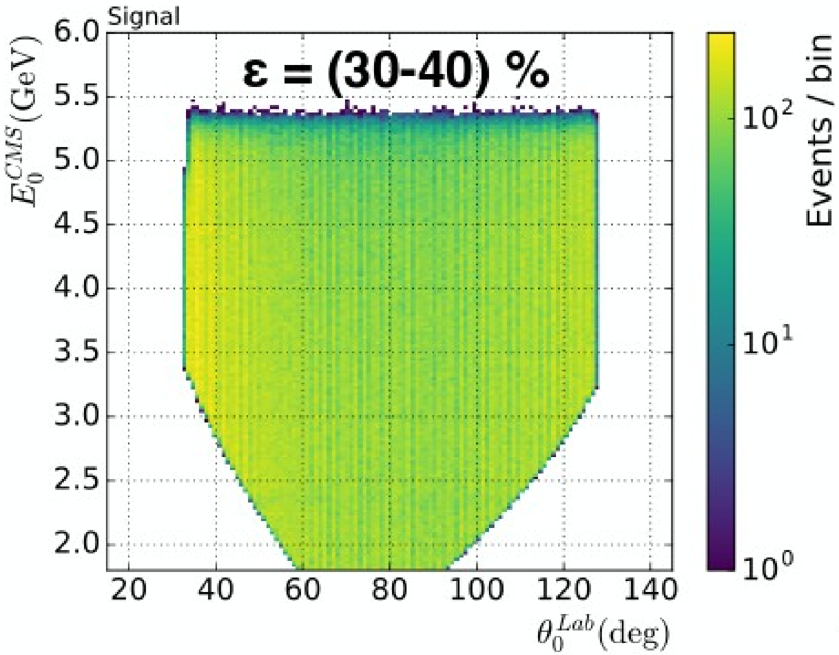
- $e^+e^- \to \gamma\gamma$, 1γ undetected: Peaking, identical to the signal for $m_{A'} < 1.6$ GeV/c^2. Photons can escape undetected through inefficient detector regions.
- $e^+e^- \to \gamma\gamma\gamma$, 1$\gamma$ undetected, 2nd out of the detector acceptance.
- $e^+e^- \to e^+e^-\gamma$, both electrons out of the detector acceptance (γ energy limited by kinematics).
- Beam background photons do not fake signal γ, but can be the 2nd γ in a signal event.
- Irreducible SM background $e^+e^- \to \nu\nu\gamma$ is negligible.

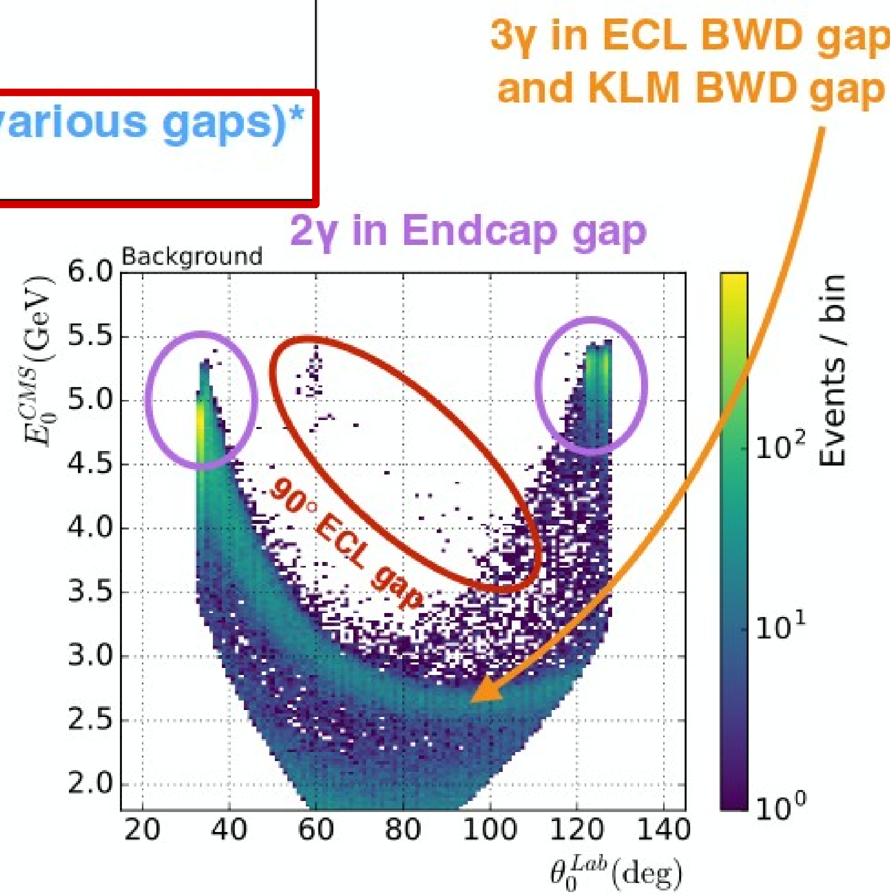
After selection

Signal and Background: After cuts.

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

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.





7

ECL ineffiecies

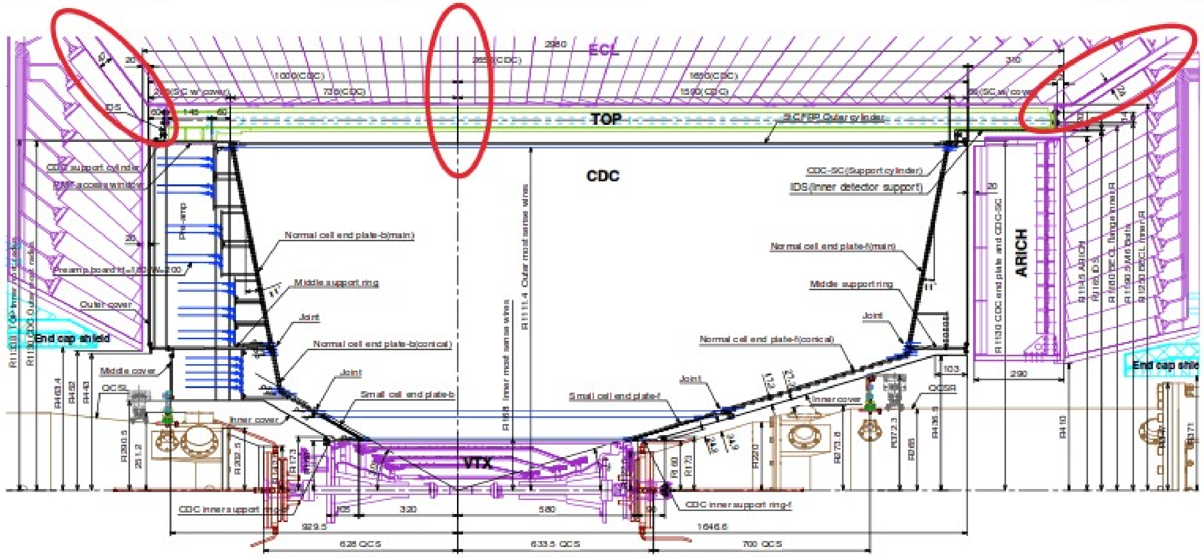
1) BWD gap

4) 1.5mm structure at 90°

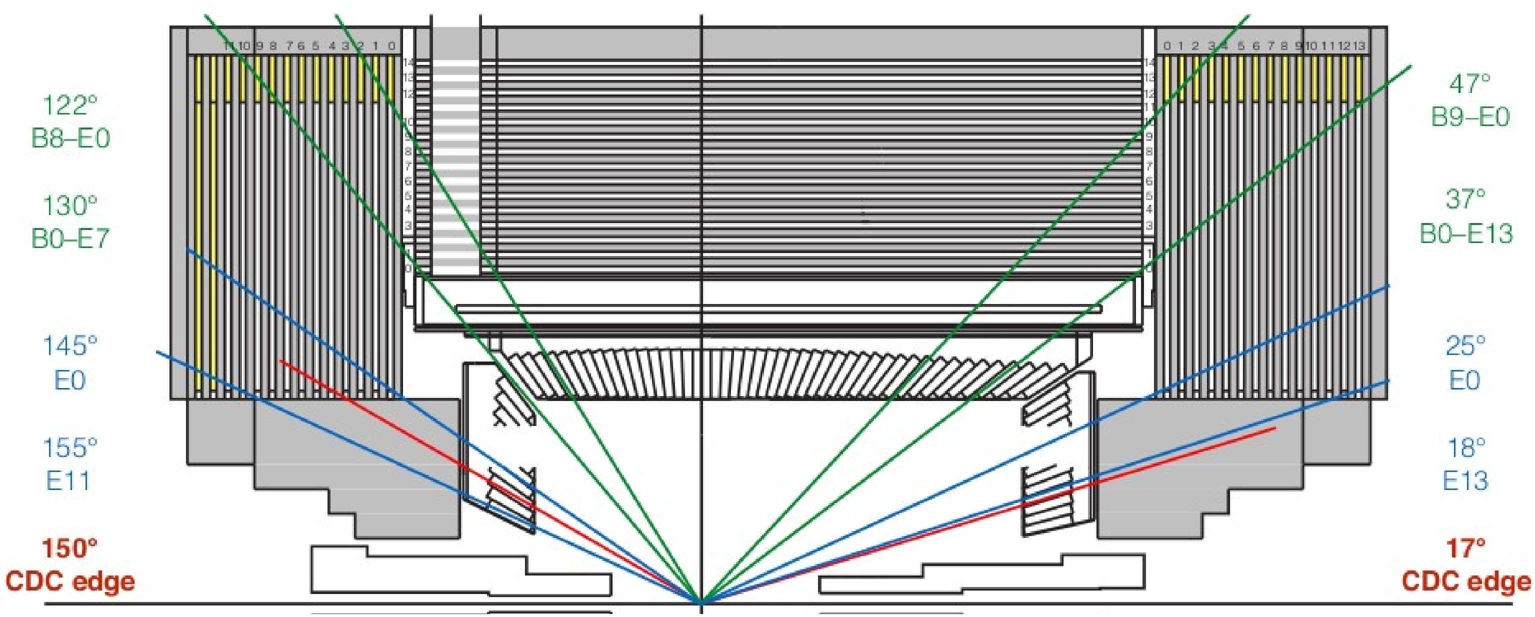
2) FWD gap

3) Projective cracks in endcaps

3) Projective cracks in endcaps



5) γ non-conversion probability ~3× 10^{-6}



KLM can cover the ECL inefficiencies!

KLM studies @ Roma Tre

Main goal(s):

- map of the KLM efficiency for the photon detection
- comparison data/MC: how much reliable are the geometry and simulation of the KLM?

Info contained in the KLMClusters data objects:

- time
- vector with cluster position
- momentum
- position and momentum errors
- # of layers with a cluster hit
- innermost layer with a cluster hit

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- time
- vector with cluster position
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- position and momentum errors
- # of layers with a cluster hit
- innermost layer with a cluster hit

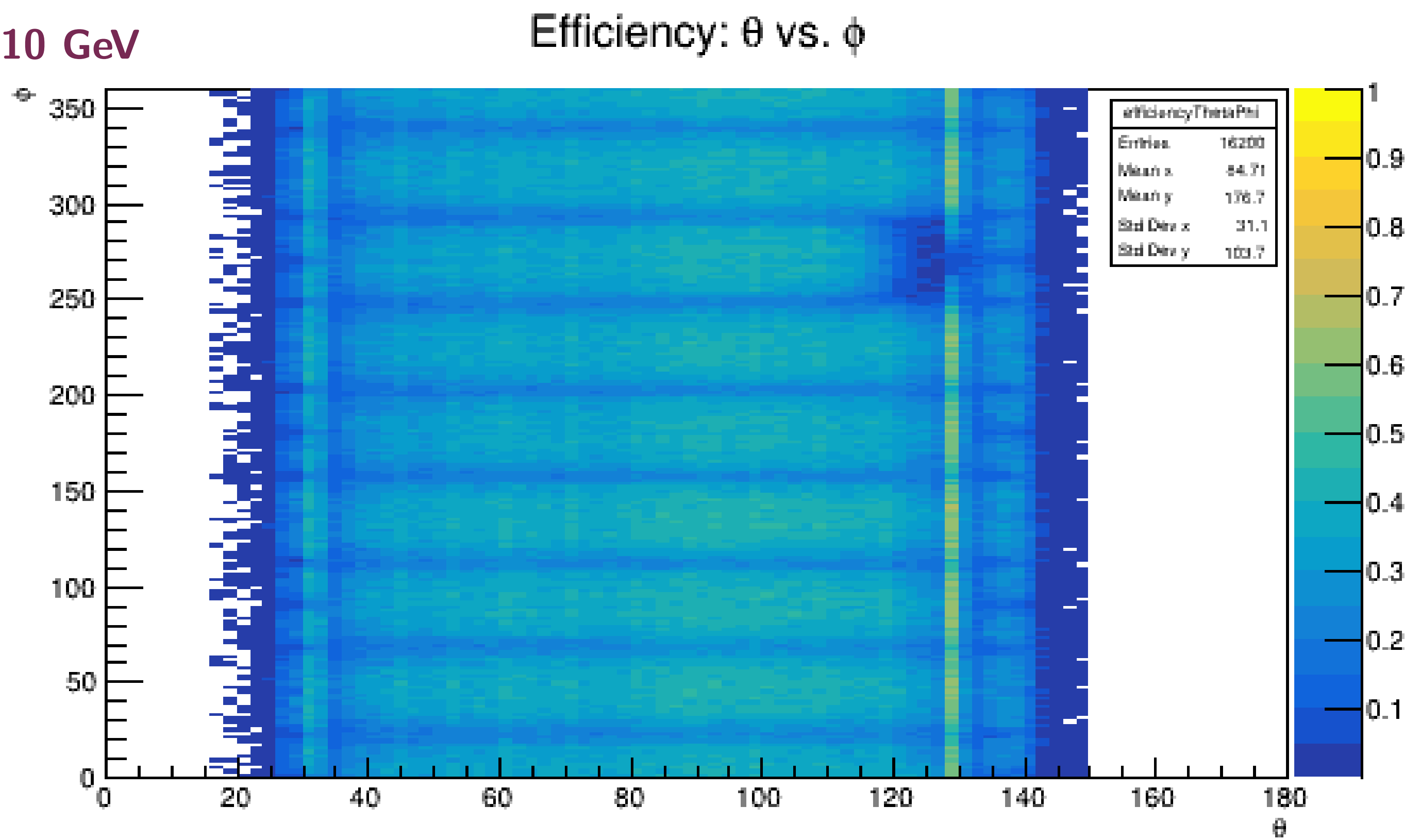
- requested this morning to Leo additional info about the shape of the cluster (number of 2D hits per layer)

KLM studies @ Roma Tre

Map of the KLM efficiency for the photon detection:

in principle, already available from MC photons generated with the ParticleGun

0 < E < 10 GeV



#MCPhotons with ? 1 KLMCluster / #MCPhotons generated

KLM studies @ Roma Tre

Map of the KLM efficiency for the photon detection:

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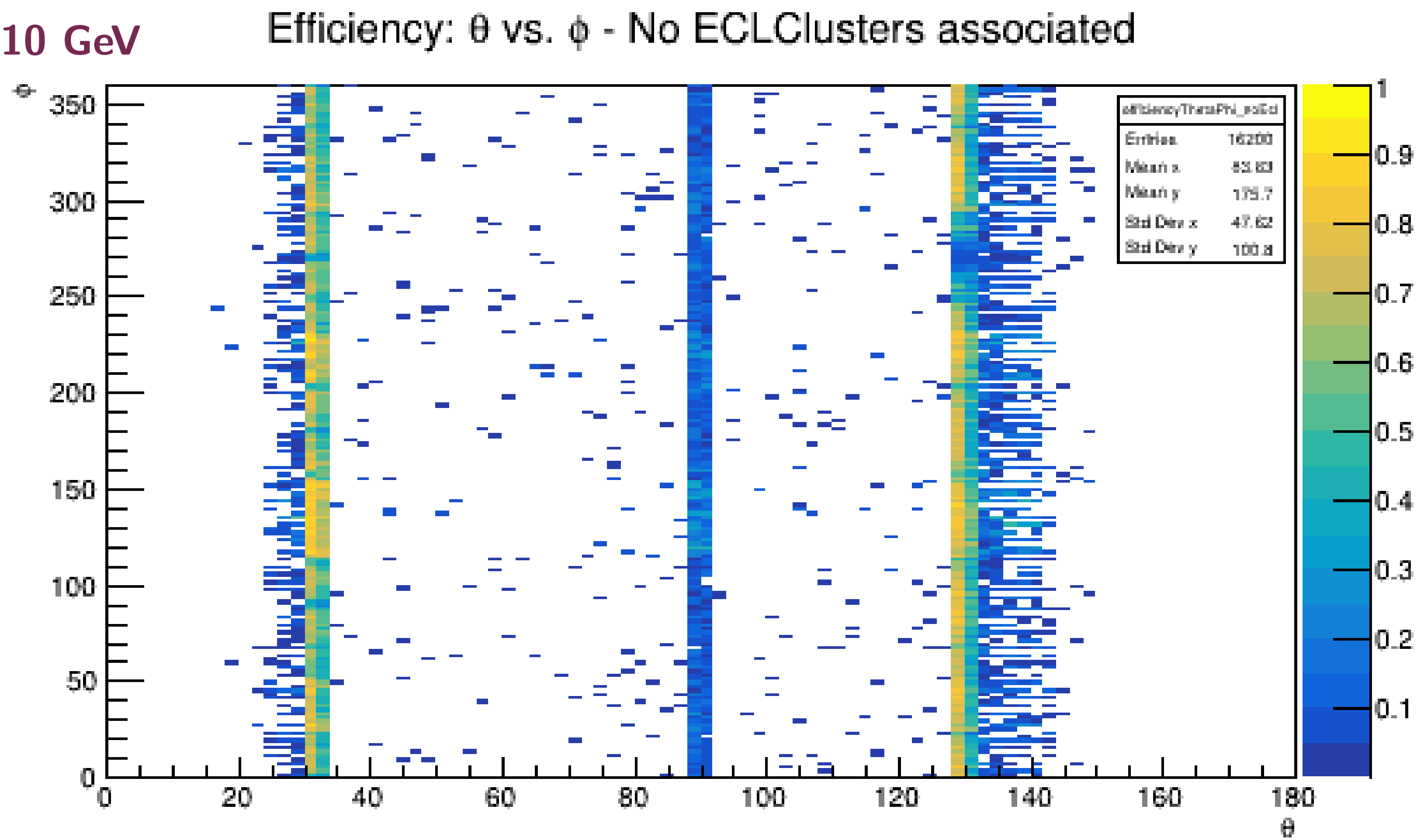

#MCPhotons with ? 1 KLMCluster && 0 ECLClusters /
#MCPhotons generated with 0 ECLClusters

KLM studies @ Roma Tre

But there is a "problem" with the simulation:
there are no informations at the mDST level
that tell us if a photon "reached" the KLM or not,
in order to apply the correct normalization.

NB: the function hasSeenInDetector(Const::KLM)
returns always 0 for photons,
even if they have a KLMCluster associated

KLM studies @ Roma Tre

But there is a “problem” with the simulation:

there are no informations at the mDST level

that tell us if a photon “reached” th… M or not,

in order to apply th… ion.

It's impossible to apply
the correct normalization
at the MC level :(

NB: th… sSeenInDetector(Const::KLM)

returns always 0 for photons,

even if they have a KLMCluster associated

KLM studies @ Roma Tre

Datasets available during Phase 2:

Sample	Note	Generated sigma nb	Percentage selected	Accepted sigma nb	Rate Hz 40 nb-1/sec	Fiducial efficiency %	Barrel efficiency %
Bhabha	0.5 & 5 deg	122760	0.150	184	7358	92.2	100
gamma gamma		25.2	12.4	3.1	125	96.9	100
e e e e		1693	0.28	4.7	188		
e e mu mu		67.8	3.1	2.1	84		
tau tau		0.919	91.9	0.8	34	94.6	97.6
mu mu		1.115	70.8	0.8	32	92.5	100
BB		1.05	100.0	1.1	42		
u u-bar		1.61	90.7	1.5	58		
d d-bar		0.4	90.4	0.4	14		
s s-bar		0.38	95.9	0.4	15		
c c-bar		1.3	100.0	1.3	52		
2gamma production of ALP	0.2 GeV					12.1	
	0.5 GeV					85.9	
	2 GeV					97.6	
	10 GeV					99.0	100
2gamma production of pi0	no tag					2.1	0.2
	1 tag						
ALP--> invisible	9.3 GeV					82.7	93.1
ALP --> gamma gamma	0.2 GeV					99.1	100
	0.5 GeV					99.3	
	3 GeV					99.6	
	9.3 GeV					99.7	
a' --> e e	0.5 GeV					97.8	100
a' --> invisible	0.5 GeV					83.6	100.0
	9.3 GeV					74.4	94.0
gamma pi+ pi-	0.5 GeV					96.3	99.9
tau --> e gamma						99.4	100.0
tau --> mu gamma						98.8	99.8
Y3S --> pi pi Y1S						44.0	49.8
TOTAL				200	8003		

KLM studies @ Roma Tre

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Y3S --> pi pi Y1S						44.0	49.8
TOTAL				200	8003		

For systematic studies:

?(mu mu) accepted: 0.8 nb
?(mu mu gamma) accepted: ~ 0.008 nb
mu mu gamma events: ~ 150000 (Phase 2)

e e gamma events are “less clean”, but more abundant!

KLM studies @ Roma Tre

I learned during the last days

how to use correctly gbasf2,

so I will start as soon as possible to look

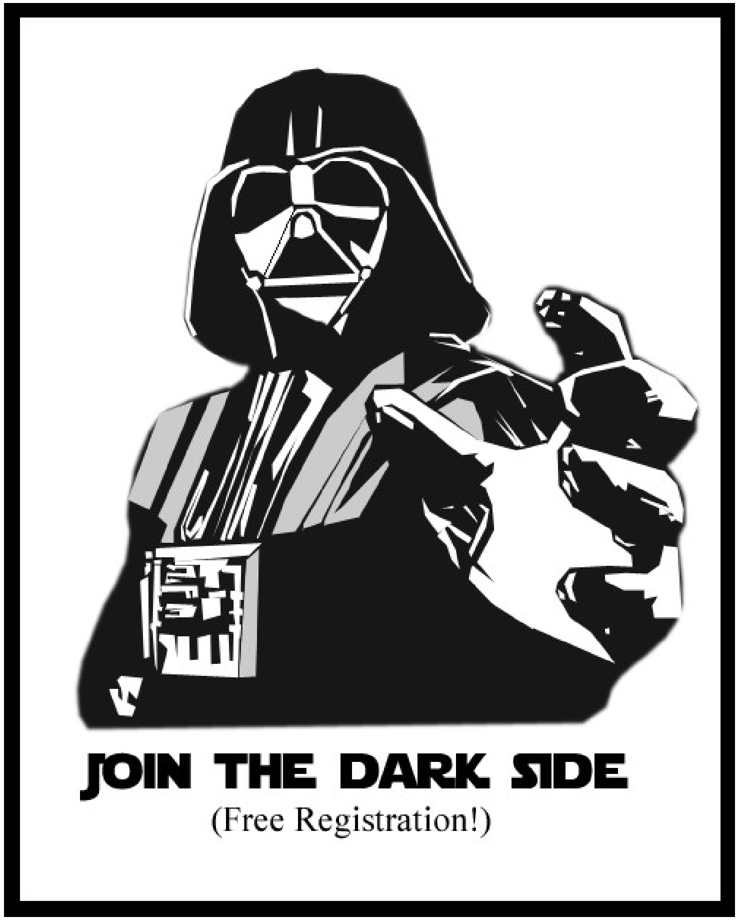
at the mu mu and mu mu gamma events

from the MC production, in order to measure the

KLM efficiency with the Phase 2 data.

KLM studies @ Italy

The Napoli group (with Francesco Di Capua) will join us for these analysis and studies (the activities need to be defined)



Brief overview of the other low multiplicity analyses during Phase 2

Overview

ee → γ + ALP, ALP→ γγ (single, di, and tri photons) and ee → ee+ALP (two photon production)	Searches	@Christopher Hearty @Torben Ferber	in progress, https://arxiv.org/abs/1409.4792 https://confluence.desy.de/download/attachments/53769418/20170526_ferber.pdf?version=1&modificationDate=1495742716842&api=v2 https://kds.kek.jp/indico/event/24563/session/21/contribution/120/material/slides/0.pdf	yes* (tri photon final state only)
$e^+ e^- \to \pi\pi \gamma_{ISR}$ (g-2)	Low Multiplicity	@Boris Shwartz @Torben Ferber @Yosuke Maeda @John Michael Roney	in progress, https://arxiv.org/pdf/1205.2228v1.pdf	no* (repeat BaBars QED study as a first step)
AFB $e^+ e^- \to l^+l^-$, $l = \mu,\tau$	Low Multiplicity	@Torben Ferber	in progress, help needed! http://www.actaphys.uj.edu.pl/fulltext?series=Reg&vol=46&page=2285	no* (repeat BaBars QED study as a first step)

Overview

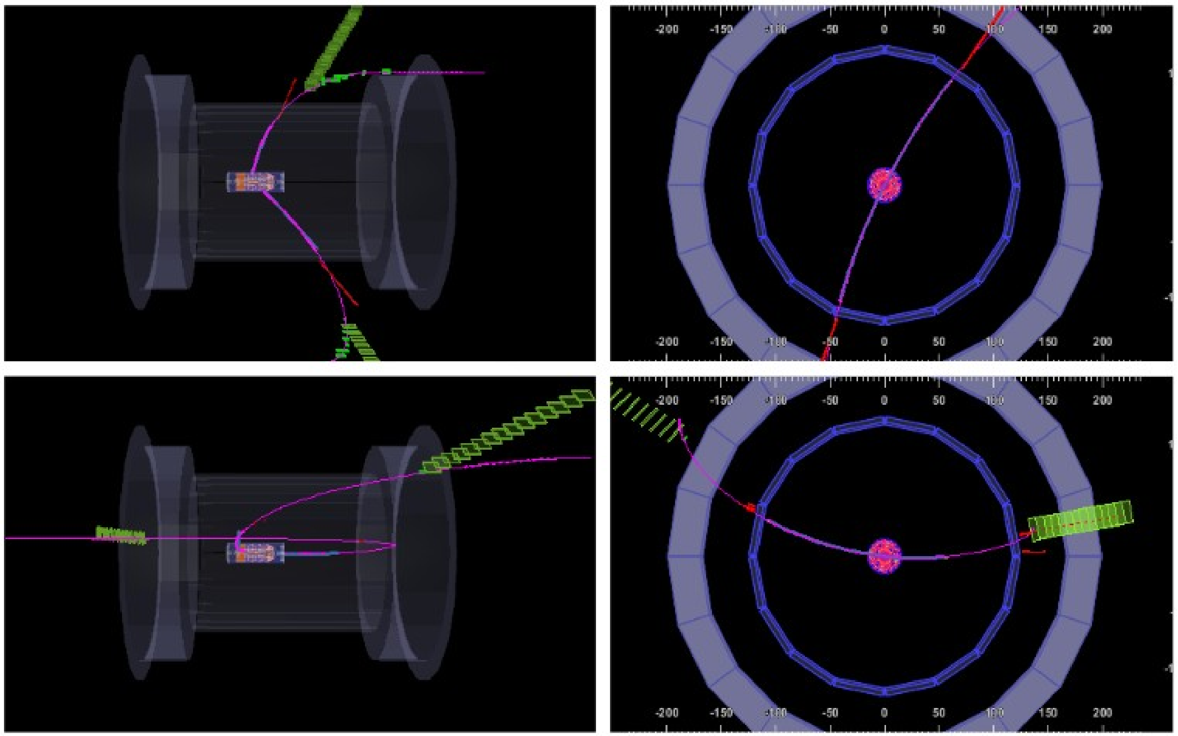
Luminosity Measurement	Low Multiplicity	@Robert Seddon	in progress, help needed!	yes
ee→ τ τ Φ, Φ→l^+l^-, l = e,μ,τ (dark skalar)	Searches	-	https://arxiv.org/abs/1606.04943	yes
$e^+ e^- \rightarrow \gamma_{ISR}$ + A', A'→W'W' (4l)	Searches	-	help needed!	?
$e^+ e^- \rightarrow \gamma_{ISR}$ + A', A'→A'H', H'→A'A' (6l)	Searches	-	help needed!	?
$e^+ e^- \rightarrow \gamma_{ISR}$ + A', A'→A'H', H'→invisible	Searches	-	help needed!	?
$e^+ e^- \rightarrow \gamma_{ISR}$ MM (magnetic monopoles)	Searches	@Dmitrii Neverov	http://pdg.lbl.gov/2010/reviews/rpp2010-rev-mag-monopole-searches.pdf https://arxiv.org/abs/1707.05295	yes

Overview

Luminosity Measurement	Low Multiplicity	@Robert Seddon	in progress, help needed!	yes
ee→ ττ Φ, Φ→l^+l^-, l = e,μ,τ (dark skalar)	Searches	-	https://arxiv.org/abs/1606.04943	yes
τ → e/μ invisible	Tau	-	Not published. *One can probably re-interpret a result from an existing Belle or BaBar 1 prong decay analysis but looking at the muon momentum spectrum and not detecting any peaks. http://pdglive.lbl.gov/BranchingRatio.action?parCode=S035&desig=102, http://pdglive.lbl.gov/BranchingRatio.action?parCode=S035&desig=103	yes*
$e^+ e^- \to \gamma_{ISR}$ + A', A'→hadrons	Searches	-	Best limits from KLOE2 up to ~1 GeV	
$e^+ e^- \to \gamma_{ISR}$ + A', A'→Pseudo Dirac DM with large mass splitting	Searches	-	Pseudo-Dirac DM with a large mass splitting. The higher mass DM particle will decay into the lower mass DM and an off-shell A', A' must decay to SM. Mass splitting <0.1 mass, final state will be missing energy and $e^+ e^- \gamma_{ISR}$.	yes, but very difficult final state

Search for monopoles

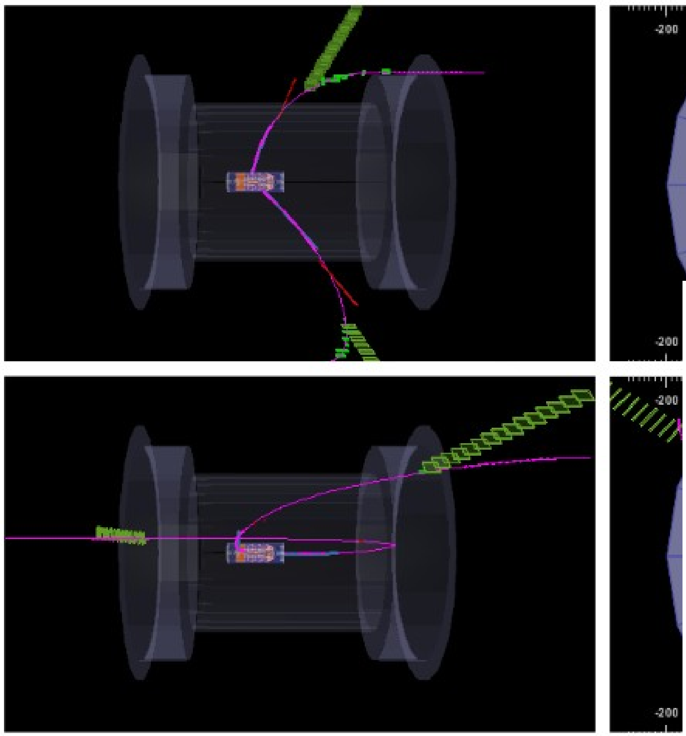
Example events, q=1, g=1e



11 Oct 2017 Monopole searches; Dmtirii Neverov; 28th B2GM 5

Search for monopoles

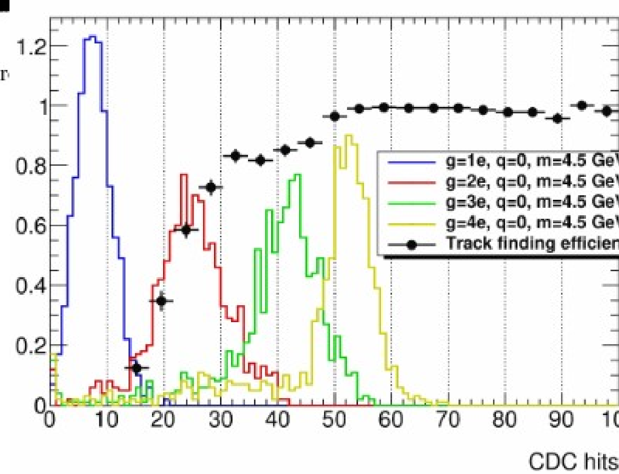
Example events, q=1, g=1e

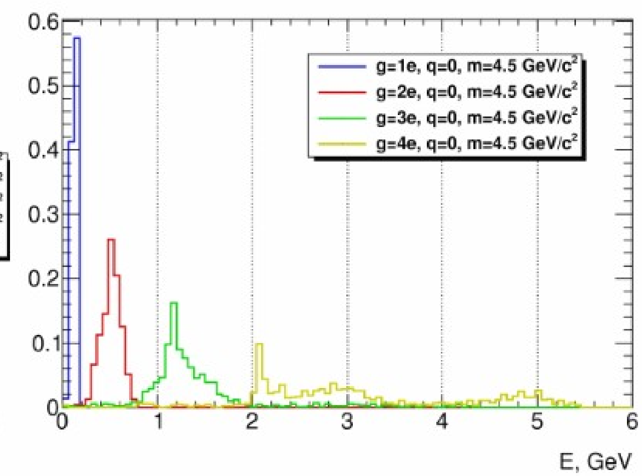


11 Oct 2017 Monopole searches; Dmtirii Never

Single monopole hits

- Leaves CDC, ECL, and KLM hits
- Because of extra β^2 factor in ionisation, heavy (4.5 GeV/c^2) monopoles of low charge give a faint signal
- Higher charge monopoles and dyons produce clear signal





11 Oct 2017 Monopole searches; Dmtirii Neverov; 28th B2GM 6

Search for monopoles

Example events, q=1, g=1e

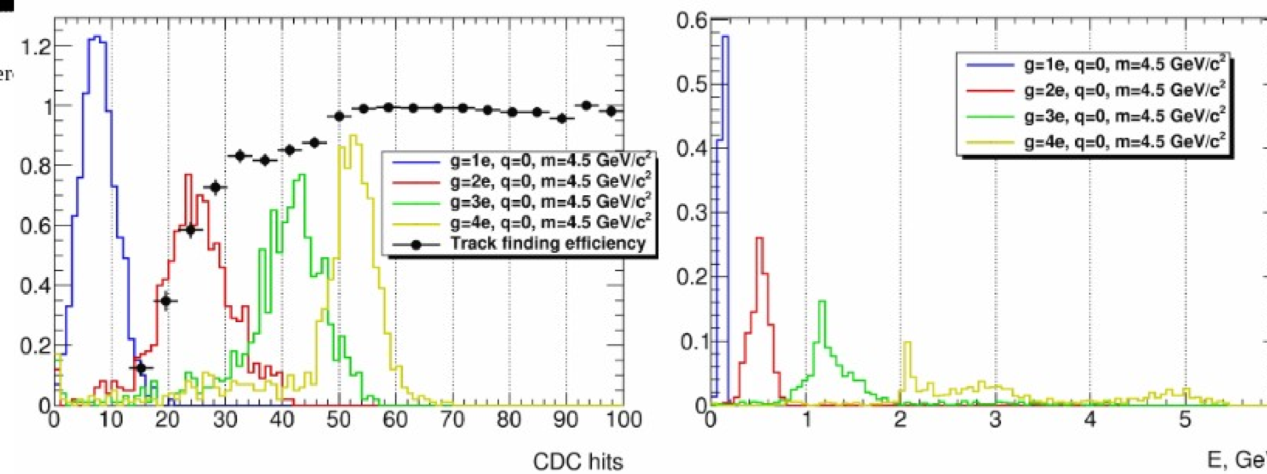
Few results for low-charge monopoles: during Phase 2 Belle II will be competitive with present results!

We have monopole simulation in basf2 from release-01-00-00 :)

e hits

opoles of

11 Oct 2017 Monopole searches; Dmtirii Never



11 Oct 2017 Monopole searches; Dmtirii Neverov; 28th B2GM 6

Backup slides

Dark photon

Search for dark photon

Dedicated experiments + Multipurpose experiments

Theory

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

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

Minimal model:

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

at low energies:

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

Free parameters *(to be measured)*:

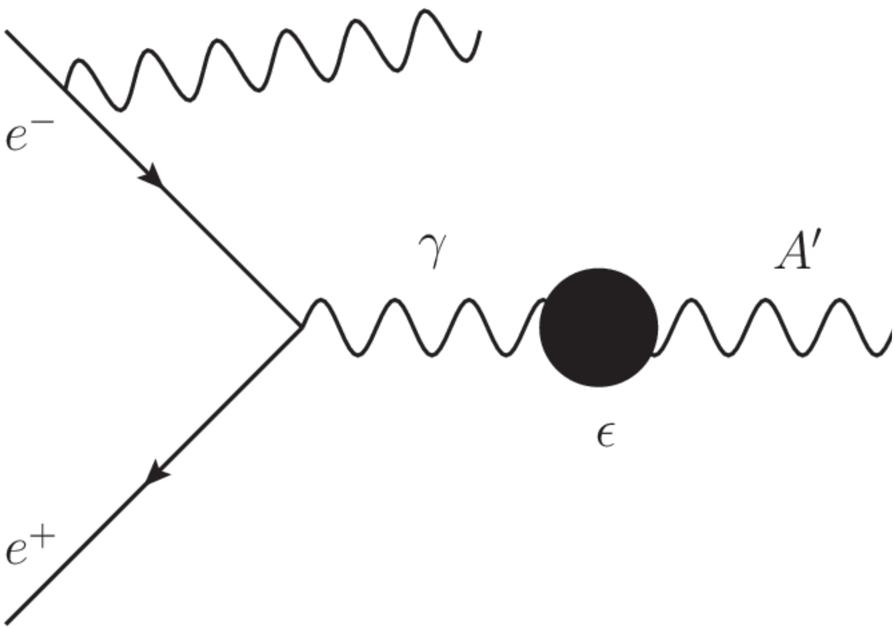
ε (strength of the mixing)

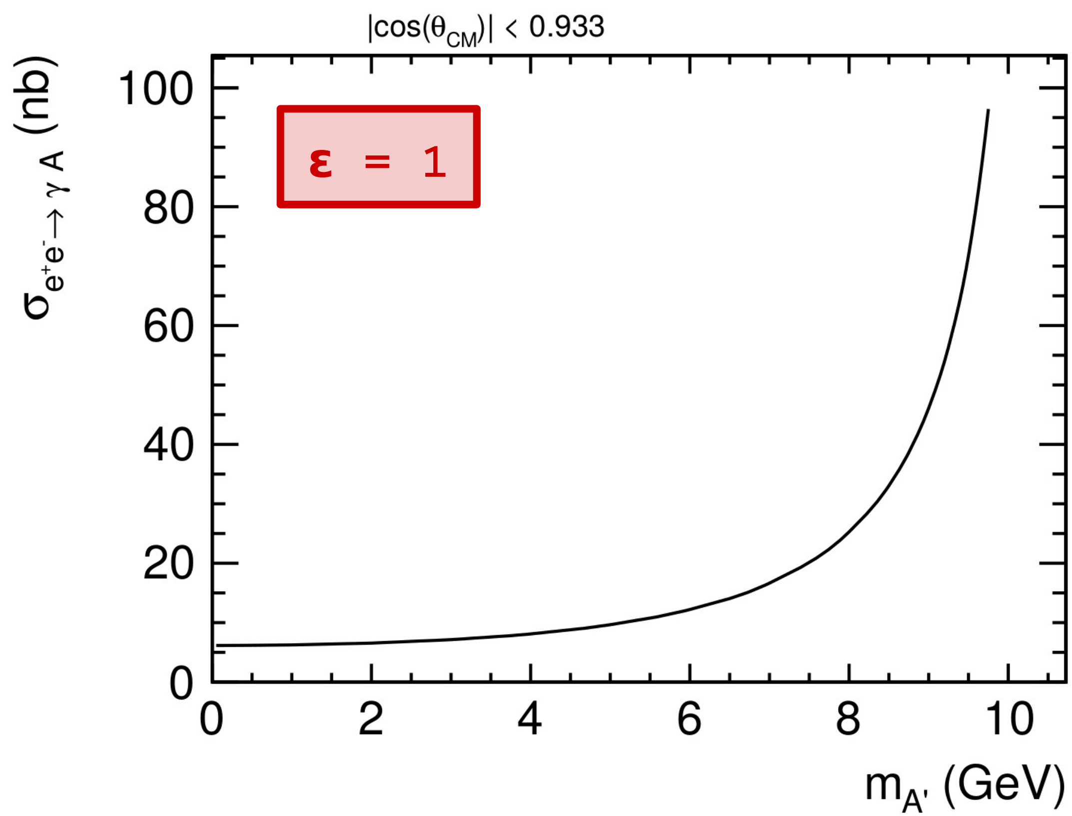
m_A (mass of the dark photon)

Production

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

I will focus on e^+e^- annihilation



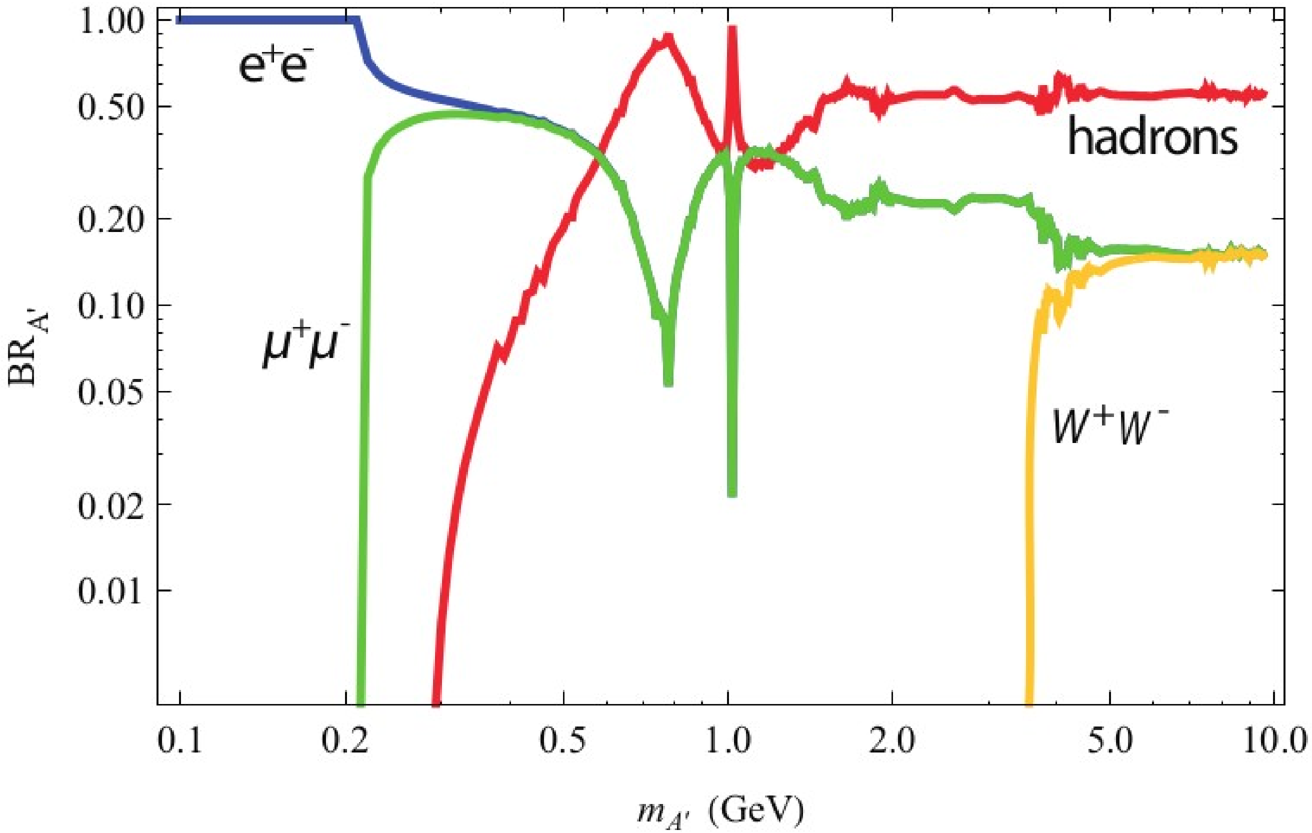


$$\frac{d\sigma(e^+e^- \to \gamma A')}{d\cos\theta} = \frac{\alpha\epsilon^2}{2s^2(s-m_{A'}^2)}\left(\frac{s^2+m_{A'}^4}{\sin\theta^2} - \frac{(s-m_{A'}^2)^2}{2}\right)$$

Visible decay

Two different scenarios: visible vs. invisible decay

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

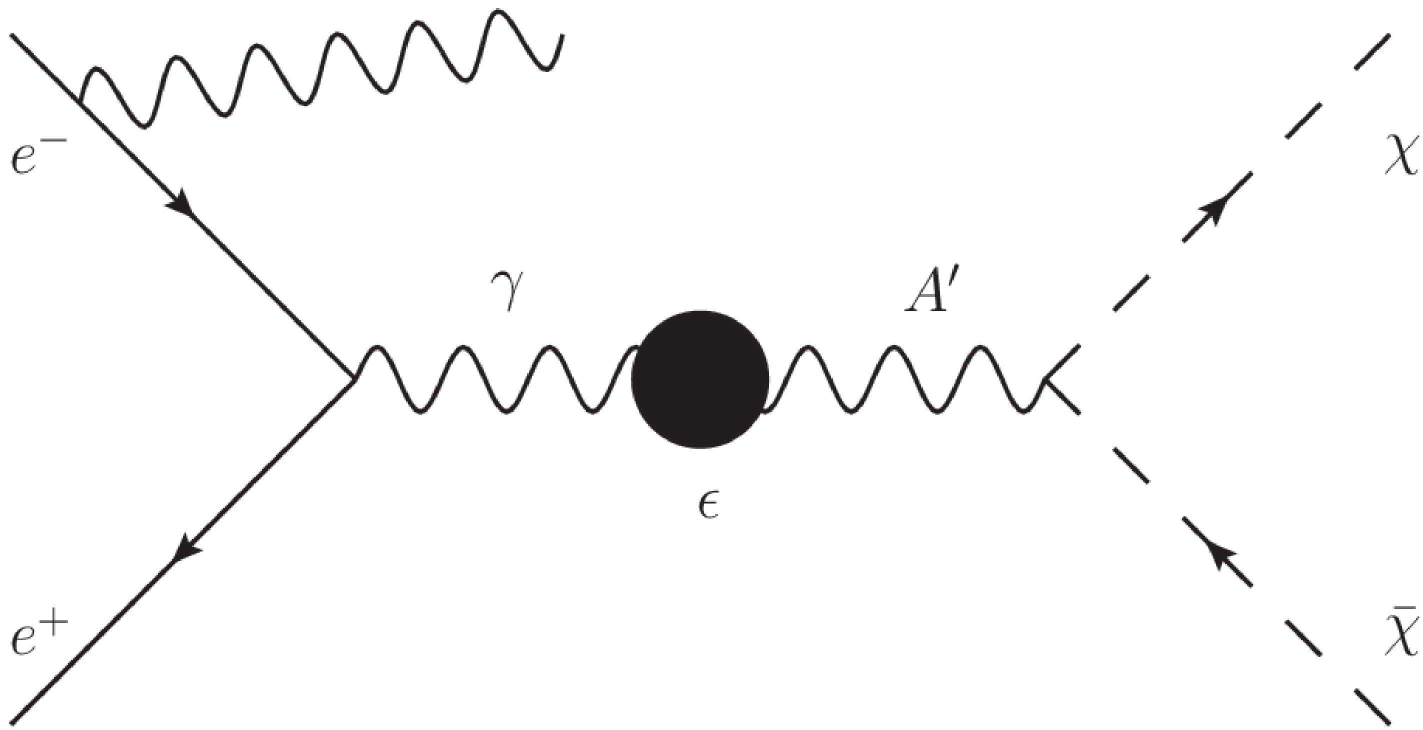


$$\Gamma_{A'\to \text{had}} = \frac{1}{3}\alpha\epsilon^2 M_{A'}\sqrt{1-\frac{4m_\mu^2}{M_{A'}^2}}\left(1+\frac{2m_\mu^2}{M_{A'}^2}\right)\times\frac{\Gamma(e^+e^-\to\text{hadrons})}{\Gamma(e^+e^-\to\mu^+\mu^-)}(E=M_{A'})$$

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



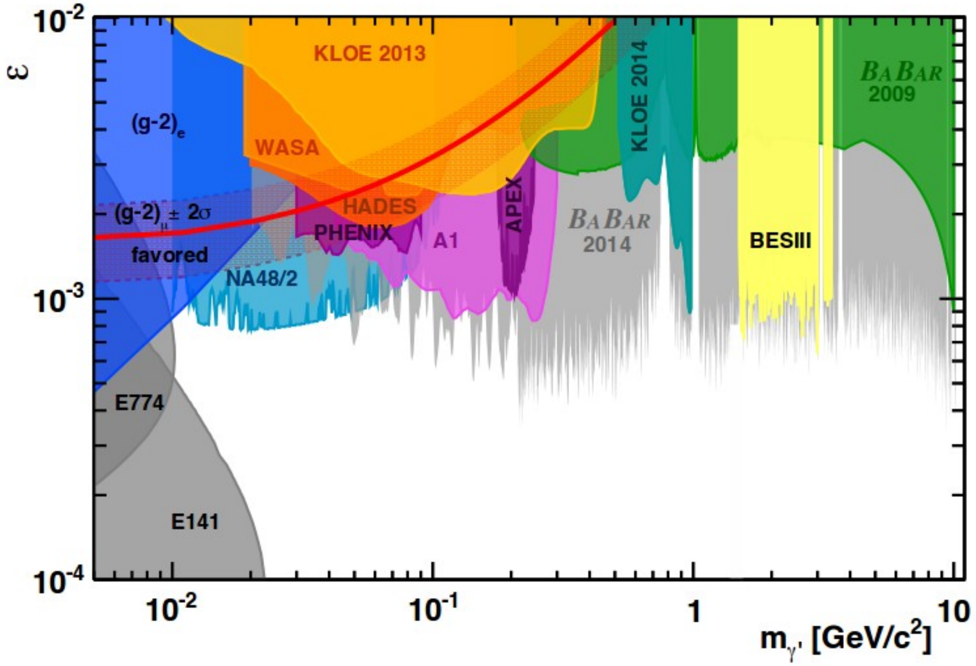
$$\Gamma_{A' \to \chi\chi} = \frac{1}{3}\alpha_D M_{A'} \sqrt{1 - \frac{4m_\chi^2}{M_{A'}^2}} \left(1 + \frac{2m_\chi^2}{M_{A'}^2}\right)$$

No suppression:

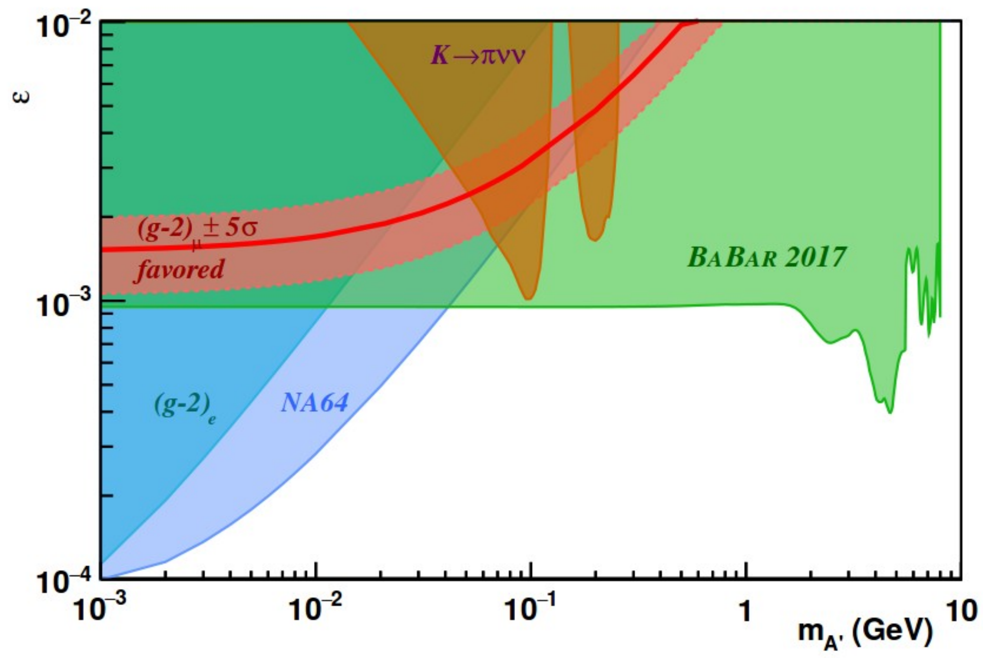
$\alpha_D >> \alpha\varepsilon^2$

Experimental status

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



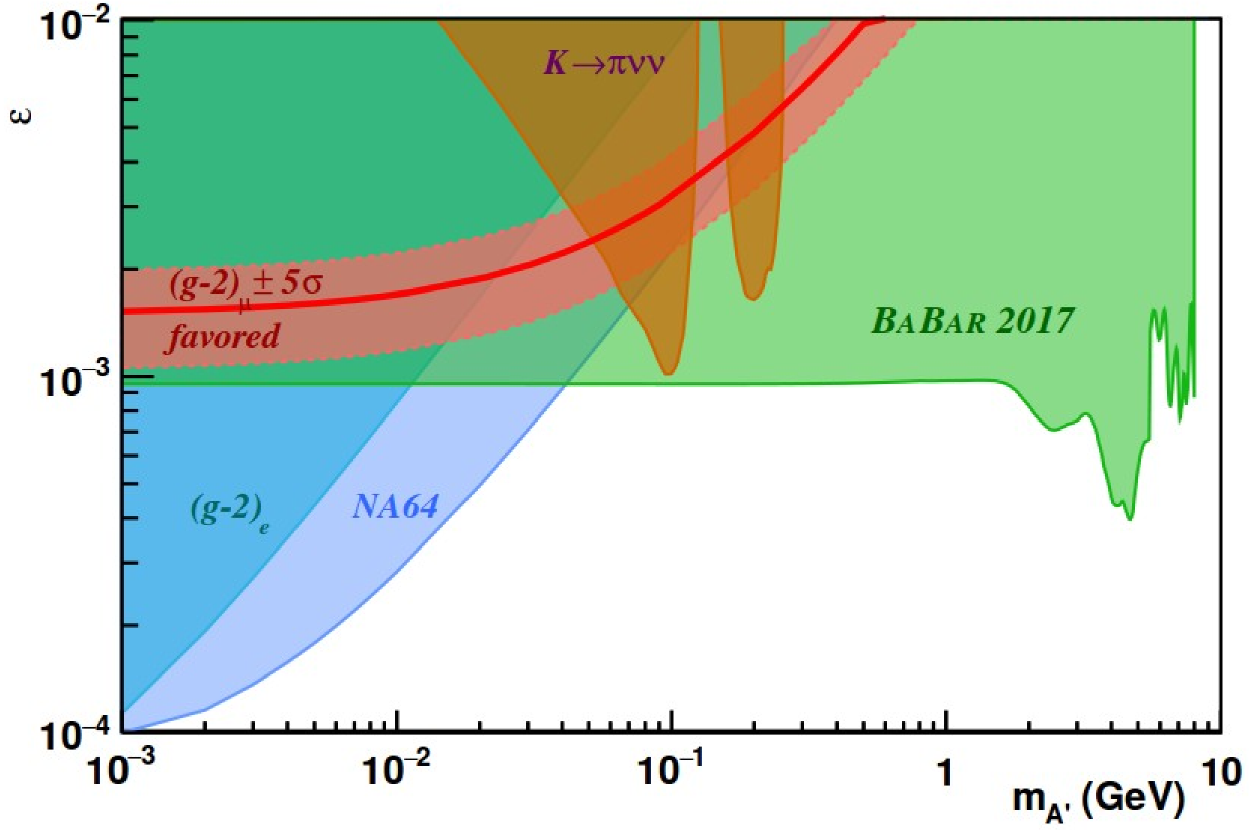
Invisible decay



No direct comparison between results reguarding visible and invisible decay

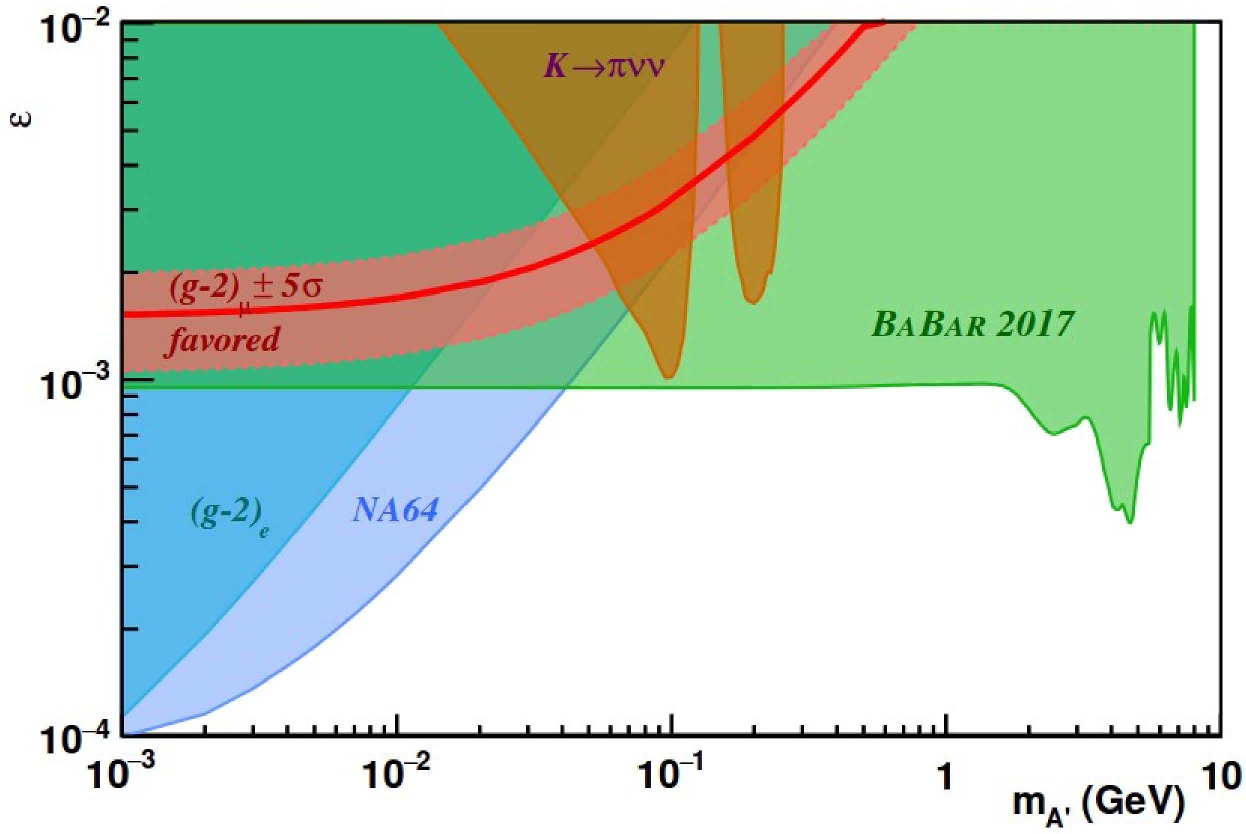
Many other results related to hadronic decays and different models/mechanisms

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**