Search Prospect for Extremely Weakly-Interacting Particles in Gamma Factory

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Based on arXiv:2105.10289

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Features

Some obvious questions

- *How light are the particles ?* $\Longrightarrow \sim$ 1-100 MeV
- *How weak is the interaction strength ?* $\Longrightarrow \sim 10^{-9}$
- *Why probe at Gamma Factory ?* $\Longrightarrow$ coming later, stay tuned !

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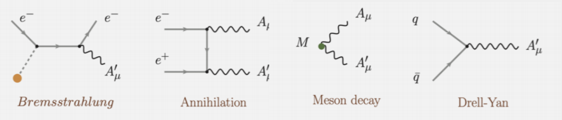
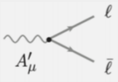
A possible candidate particle would be dark photons

Dark Photon

$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \varepsilon\, e \sum_f q_f \bar{f} \not{A}' f$$



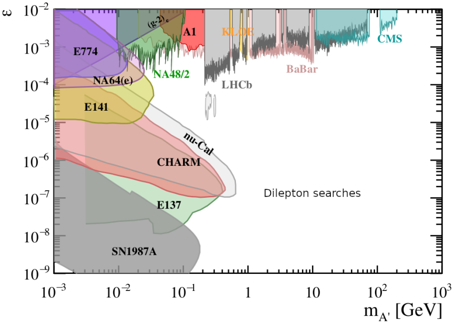


relevant production & decay channels

1) B. Holdom, Phys. Lett. B **166**, 196 (1986);

2) M. Fabbrichesi, E. Gabrielli and G. Lanfranchi, SpringerBriefs in Physics (2020), [arXiv:2005.01515].

Existing probes for light dark photon



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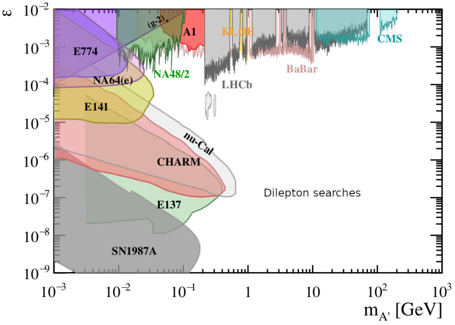

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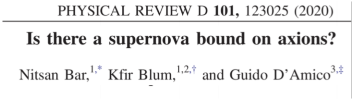
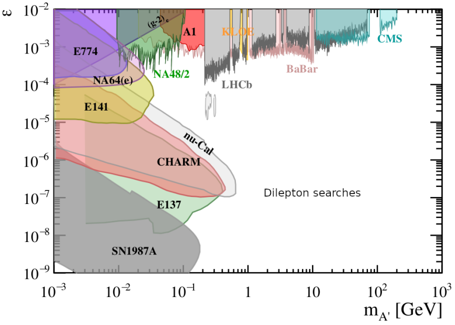
- Around low mass, only astrophysical probes from supernova cooling exists for $\varepsilon \lesssim 10^{-8}$.


PHYSICAL REVIEW D **101,** 123025 (2020)

Is there a supernova bound on axions?

Nitsan Bar,[1,*] Kfir Blum,[1,2,†] and Guido D'Amico[3,‡]



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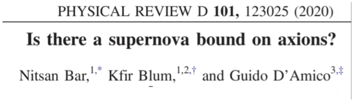
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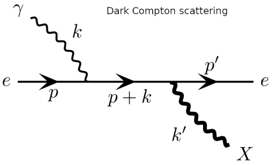
- Is a robust complementary probe possible ?

$\Downarrow$



How about photoproduction ?

Status of photoproduction

Difficulties

- *Dark photon production cross-section is proportional to* ε^4
- *Existing light sources cannot provide the required number of photons to probe such low coupling* ☹

M. W Krasy, Photon-2017
for intensity of GF vs. existing facilities

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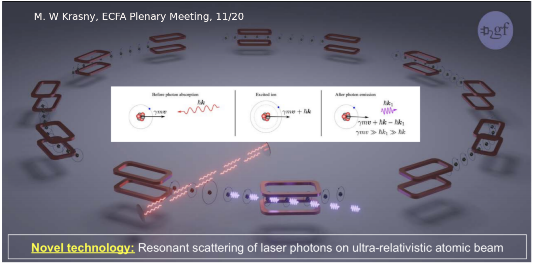


Gamma Factory at CERN - a New Intensity Frontier

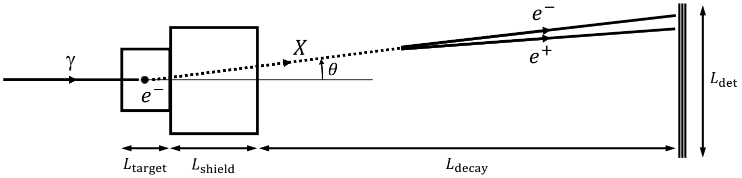
- $E_{\rm GF} = E_{\rm laser}\left(\sqrt{\frac{1+v/c}{1-v/c}}\right)^2 \approx 4\gamma^2 E_{\rm laser} \sim 10$ MeV-1 GeV
- Big jump in intensity (by 6 - 8 orders of magnitude) compared to existing photon sources

$$E_\gamma = 20\ \text{MeV},\quad \Phi_{\rm GF} = 10^{18}\ \text{s}^{-1},\quad N_{\rm GF} = 3\times10^{25}$$
$$E_\gamma = 200\ \text{MeV},\quad \Phi_{\rm GF} = 10^{17}\ \text{s}^{-1},\quad N_{\rm GF} = 3\times10^{24}$$
$$E_\gamma = 1.6\ \text{GeV},\quad \Phi_{\rm GF} = 10^{16}\ \text{s}^{-1},\quad N_{\rm GF} = 3\times10^{23}$$

D. Budker *et. al.*, Annalen Phys. **532**, no.8, 2000204 (2020)

- Huge potential for rare BSM searches

A minimal fixed-target setup



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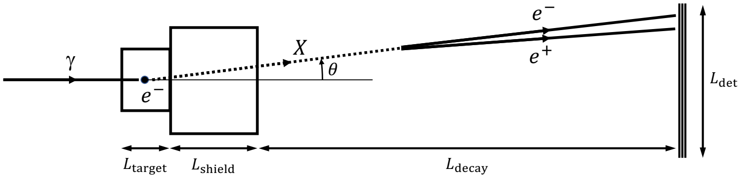
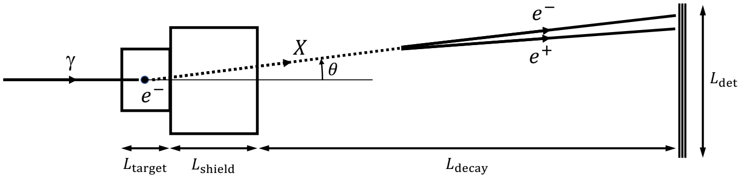


- Target is chosen to be a low-Z material to enhance new physics event rate



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A few feasible choices $\Longrightarrow$

$$\sigma_{\text{SM}}^{\text{H}}/Z = 36,\ 19,\ 20 \text{ mb for } E_\gamma = 20,\ 200,\ 1600 \text{ MeV}$$
$$\sigma_{\text{SM}}^{\text{Be}}/Z = 46,\ 38,\ 42 \text{ mb for } E_\gamma = 20,\ 200,\ 1600 \text{ MeV}$$
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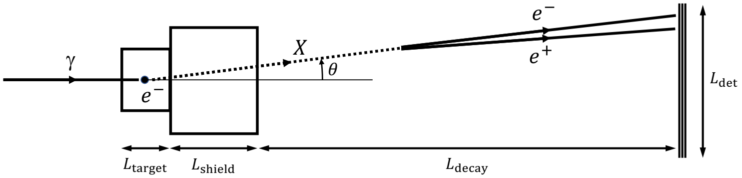

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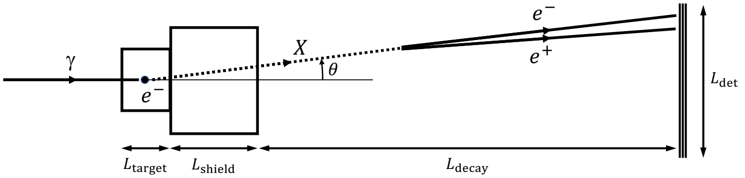

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A reasonable experimental setup : L_{target} (Graphite) $= 1$ m, L_{shield} (Pb) $= 2$ m

$L_{decay} = 12$ m, $L_{det} = 3$ m

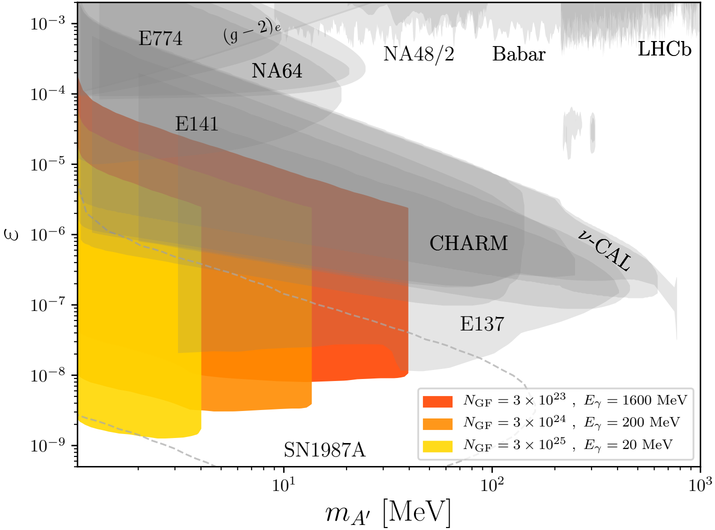
A rough estimate

$$
\begin{aligned}
N_S &= N_{\mathrm{GF}} P_{\mathrm{prod}} P_{\mathrm{decay}} P_{\mathrm{det}} \sim N_{\mathrm{GF}} \frac{Z\sigma_X}{\sigma_{\mathrm{SM}}} \frac{L_{\mathrm{decay}}}{d_{A'}} \\
&\sim N_{\mathrm{GF}} \frac{6\ \varepsilon^2\ 1\ \mathrm{mb}}{50\ \mathrm{mb}} \left[\frac{10\ \mathrm{MeV}}{m_{A'}}\right]^2 \frac{12\ \mathrm{m}}{6.5\times 10^5\ \mathrm{m}} \left[\frac{\varepsilon}{10^{-8}}\right]^2 \left[\frac{m_{A'}}{10\ \mathrm{MeV}}\right]^2 \\
&= 3\,\frac{N_{\mathrm{GF}}}{3\times 10^{24}} \left[\frac{\varepsilon}{2.6\times 10^{-9}}\right]^4
\end{aligned}
$$

Number of signal events are

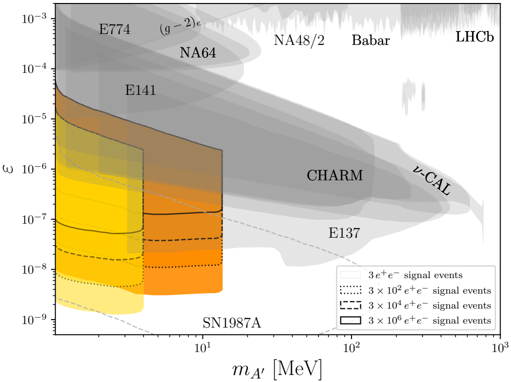
- Highly sensitive to ε
- Largely insensitive to dark photon mass
- Proportional to number of GF photons on target

Results

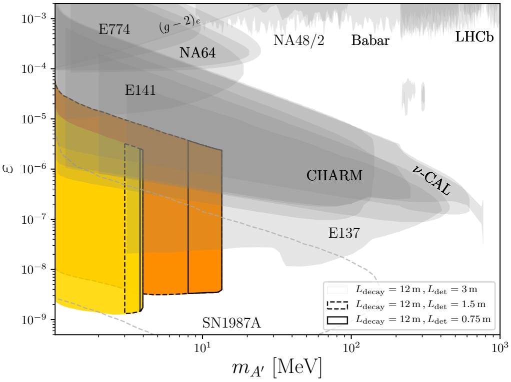


E774
$(g-2)_e$
NA64
NA48/2
Babar
LHCb
E141
CHARM
ν-CAL
E137
SN1987A
$N_{\rm GF} = 3 \times 10^{23}$, $E_\gamma = 1600$ MeV
$N_{\rm GF} = 3 \times 10^{24}$, $E_\gamma = 200$ MeV
$N_{\rm GF} = 3 \times 10^{25}$, $E_\gamma = 20$ MeV
ε
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^1
10^2
10^3
$m_{A'}$ [MeV]

Sensitivity vs. number of events



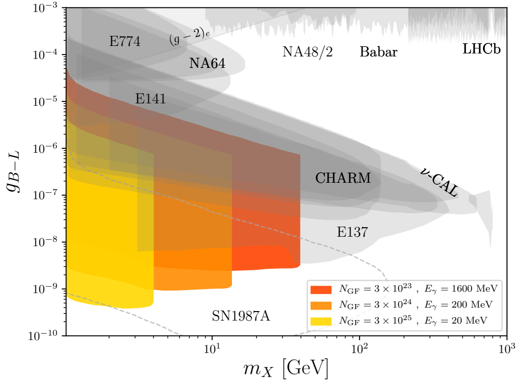
Sensitivity vs. length of detector



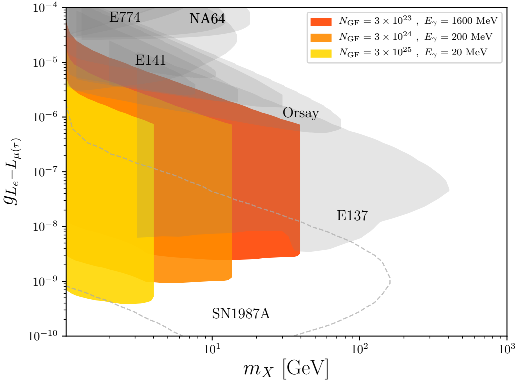
- Only a few hours of observation can probe new parameter space
- $L_{det}/L_{decay} \approx 1/3$, $L_{decay} \sim \mathcal{O}$ (10 m) for full sensitivity reach within a year

Anomaly free gauge bosons

$B - L$ gauge boson sensitivity

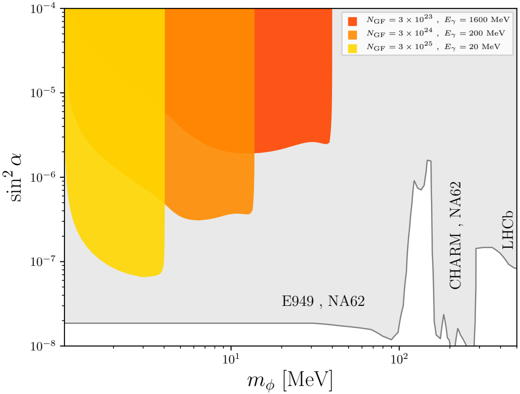


$L_e - L_{\mu(\tau)}$ gauge boson sensitivity

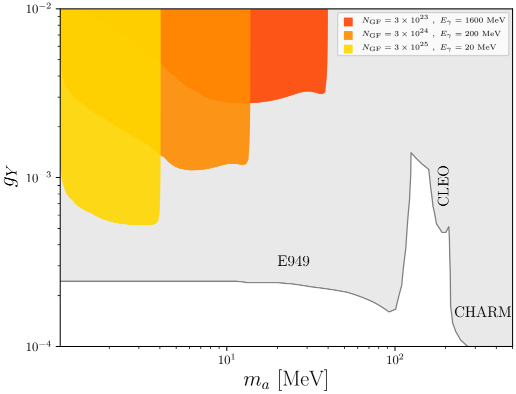


- Promising probe for anomaly free Gauge bosons
- $L_\mu - L_\tau$ gauge boson remains difficult to probe in this setup

Dark Higgs sensitivity



Dark pseudo scalar sensitivity



- Signal rate is compromised due to Yukawa suppressed dark mediator decay into electrons
- Even after one year of running, this setup does not probe new parameter region

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- We study the complementary sensitivity probe for light, weakly coupled dark photons in parameter region so far exclusive to only astrophysical probes
- We found promising reach also for the anomaly-free Gauge bosons
- The full potential of this facility for new physics still needs to be explored

see R. Balkin *et. al.*, arXiv:2105.15072 for ALP probe at GF

Thank you!