Gamma-gamma collider with Energy < 12 GeV based on European XFEL

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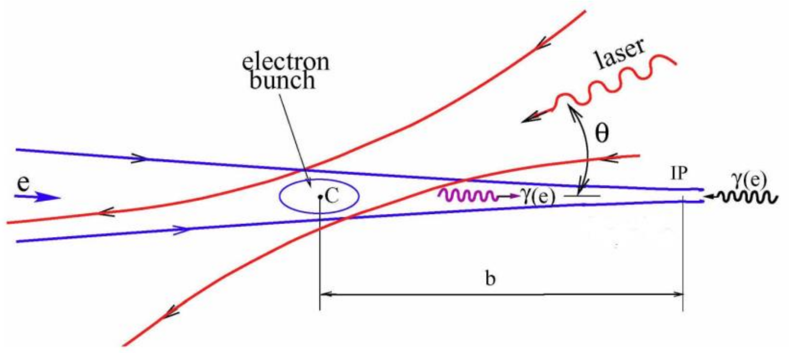
Gamma-gamma collider

- Addition to e^+e^- colliders
- Compton backscattering
- Getting access to $\gamma\gamma$ and γe processes



V. I. Telnov 2020

$$\omega_m \approx \frac{x}{x+1} E_0$$

$$x = \frac{4E_0\omega_0}{m^2c^4} \simeq 15.3 \left[\frac{E_0}{\text{TeV}}\right] \left[\frac{\omega_0}{\text{eV}}\right] = 19 \left[\frac{E_0}{\text{TeV}}\right] \left[\frac{\mu\text{m}}{\lambda}\right]$$

Gamma-gamma collider

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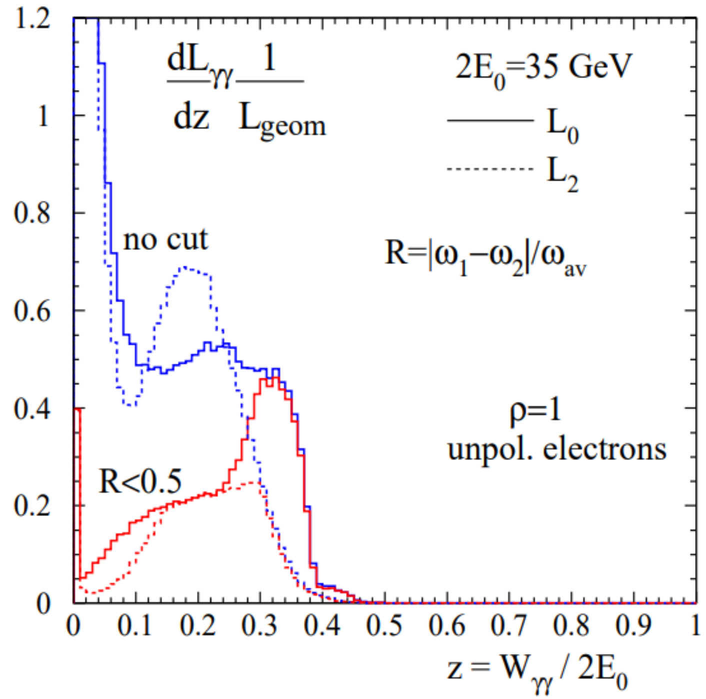
- Use European XFEL (E_0 = 17.5 GeV)
- At the beam dump

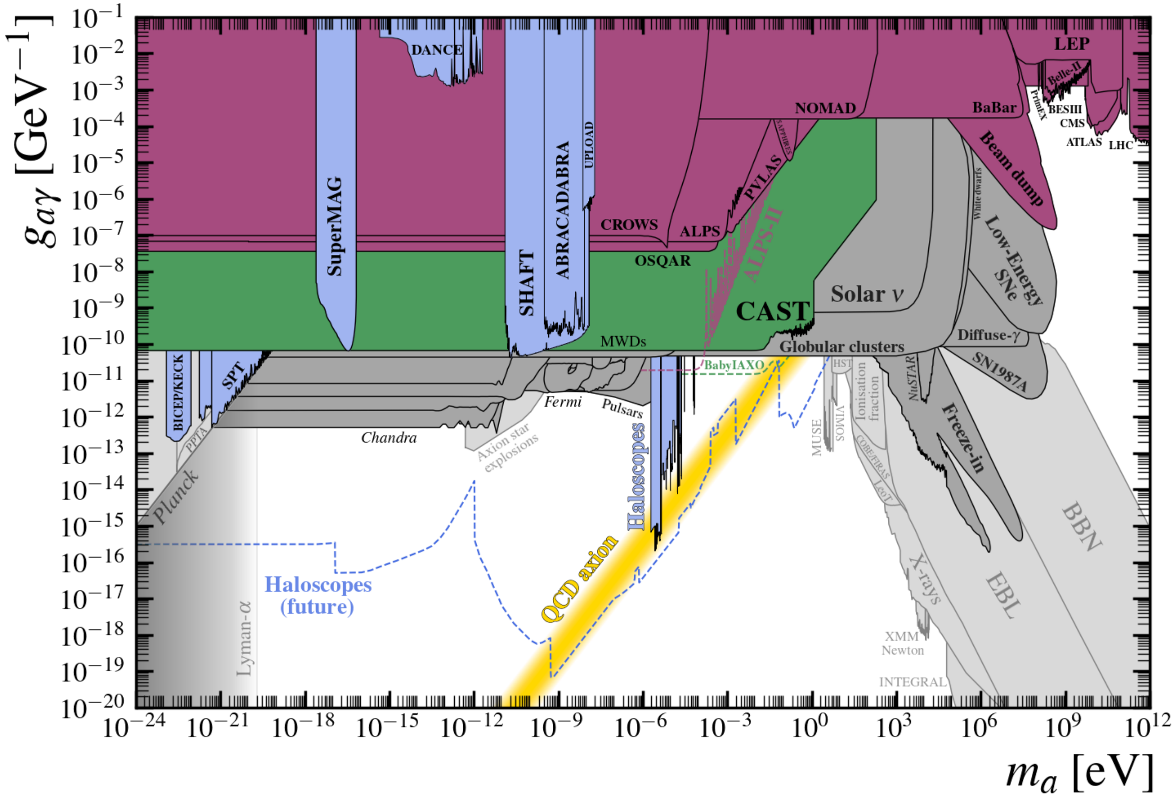
- 12 GeV peak
- Excellent for $b\bar{b}$ and $c\bar{c}$ range



[V. I. Telnov 2020]

Gamma-gamma collider

- Additional hadronic resonances [V. I. Telnov 2020:2007.14003v2]
- Possible four-quark states
- Looking for BSM particles
  - (Dark photon)
  - ALPs
- Indirect tests of SM physics
  - Precision observables



[FIPS Workshop 2022]

Dark photon

- Extra U(1): $SU(3)_C \otimes SU(2)_L \otimes U_1(1) \otimes U_2(1)$
- Mixing between the two U(1) groups

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}^2 V_\mu V^\mu$$

- Mixing between photon, Z-boson and dark photon

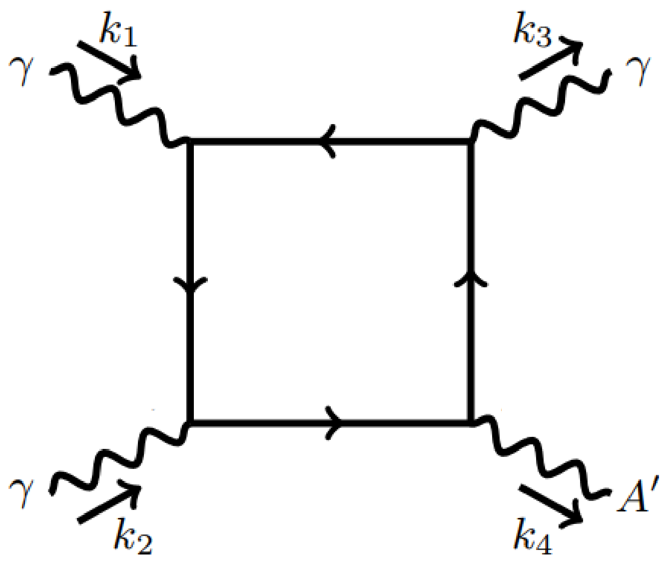
$$\begin{pmatrix} W_\mu^3 \\ B_\mu \\ \tilde{A}'_\mu \end{pmatrix} = \begin{pmatrix} c_W & s_W & -s_W\varepsilon \\ -s_W & c_W & -c_W\varepsilon \\ t_W\varepsilon & 0 & 1 \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \\ A'_\mu \end{pmatrix}$$

Dark photon

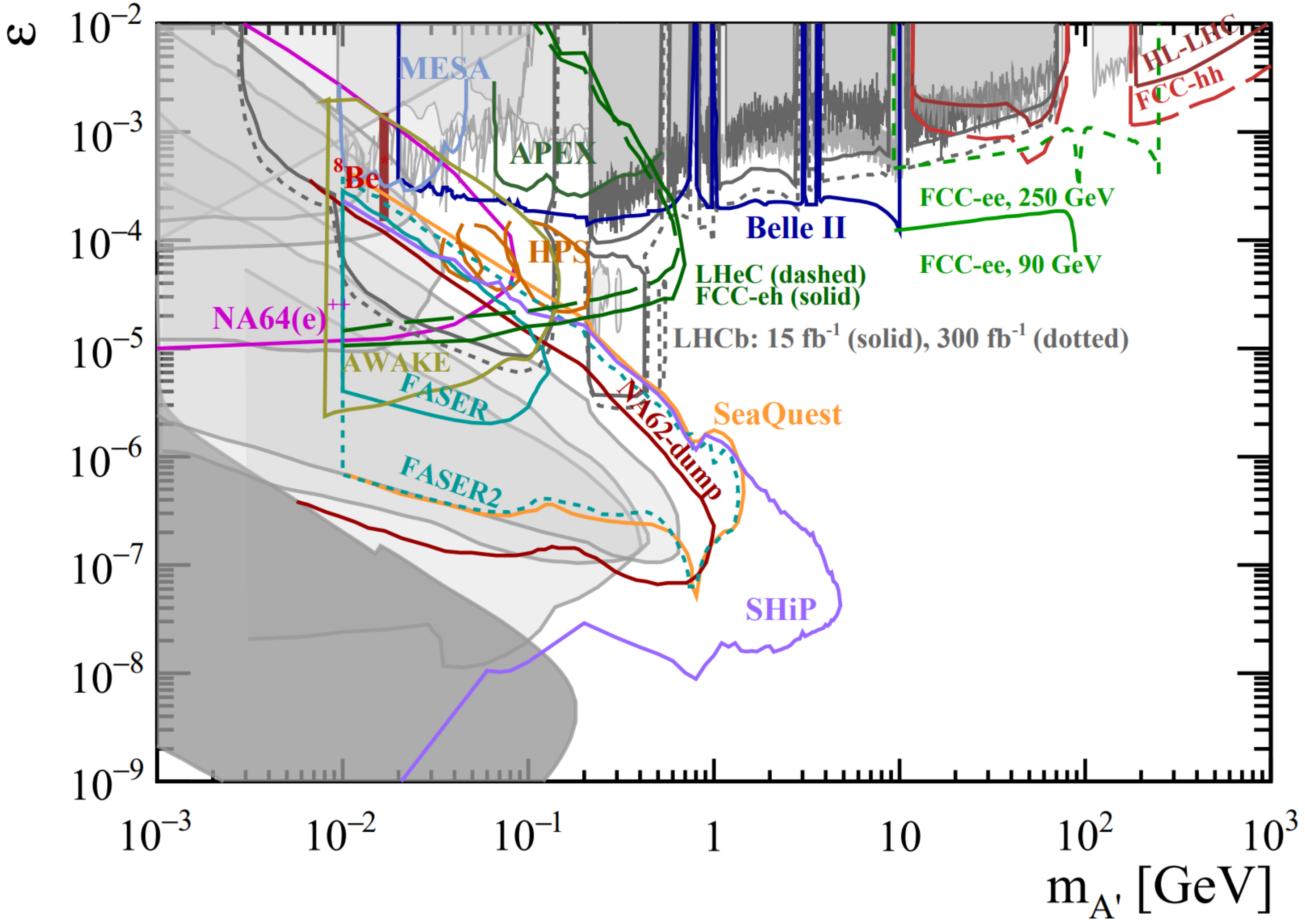
- Massless
  - Massless only interacts through operators of dimension higher than 4
- Massive
  - Mass through Stückelberg or dark Higgs mechanism
  - Possible dark matter candidate for $m_{A'} < 1$ MeV and $\varepsilon < 10^{-9}$

- Visible and invisible decays
  - Searches at colliders and beam dump experiments

Dark photon at a gamma-gamma collider

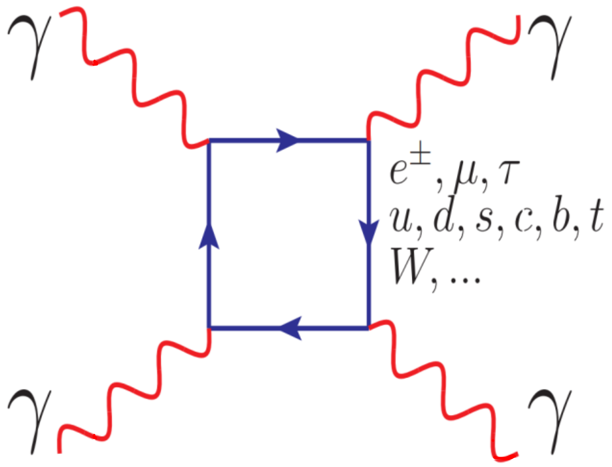


- Every fermion except for top
- So far only looked at low energy

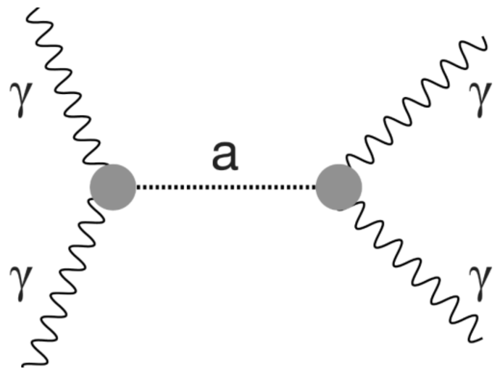


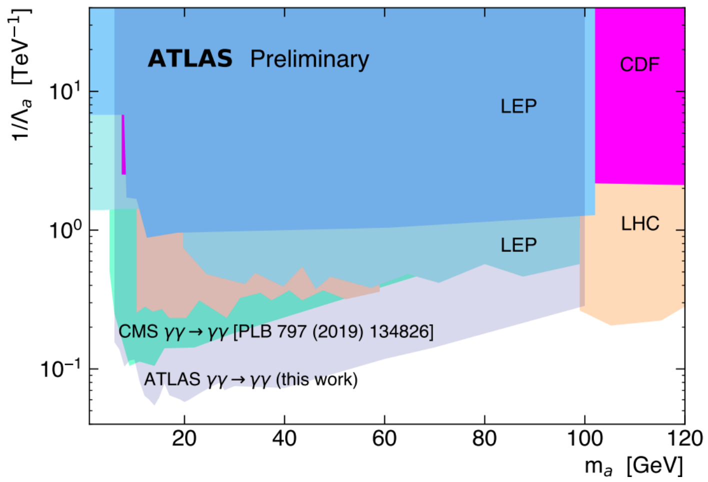
[M. Fabbrichesi 2020]

Light-by-light scattering

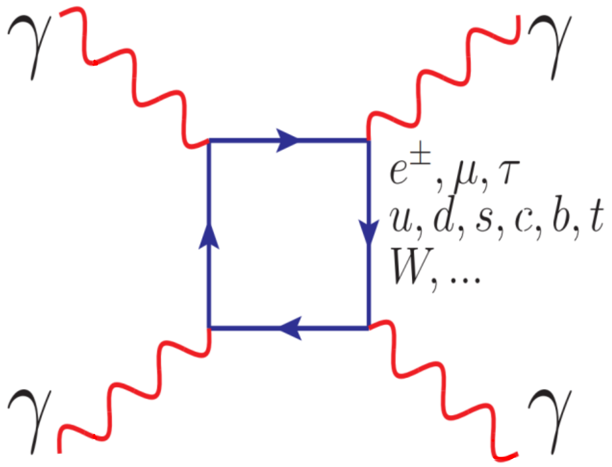


- Has been done for a long time [Lifshitz, De Tollis, Karplus, Neuman]
- So far observed by ATLAS
  - most recent results from 2020
- Possibility to observe BSM contributions





Light-by-light scattering



$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2}\frac{1}{4\omega^2}|M_{fi}|^2$$

$$|M_{fi}|^2 \to \frac{1}{2}\{2|M_{++++}|^2 + 2|M_{++--}|^2 + 2|M_{+-+-}|^2 + 2|M_{+--+}|^2 + 8|M_{+++-}|^2\}$$

M_{++++} , M_{++--} und M_{+++-}

Light-by-light scattering

$$\frac{1}{8\alpha^2} M_{++++} = -1 - \left(2 + \frac{4t}{s}\right) B(t) - \left(2 + \frac{4u}{s}\right) B(u)$$
$$- \frac{2(t^2+u^2)}{s^2} - \frac{8}{s}[T(t) + T(u)]$$
$$+ \frac{4}{t}\left(1 - \frac{2}{s}\right) I(s,t) + \frac{4}{u}\left(1 - \frac{2}{s}\right) I(s,u)$$
$$+ \left[\frac{2(t^2+u^2)}{s^2} - \frac{16}{s} - \frac{4}{t} - \frac{4}{u} - \frac{8}{tu}\right] I(t,u)\,,$$

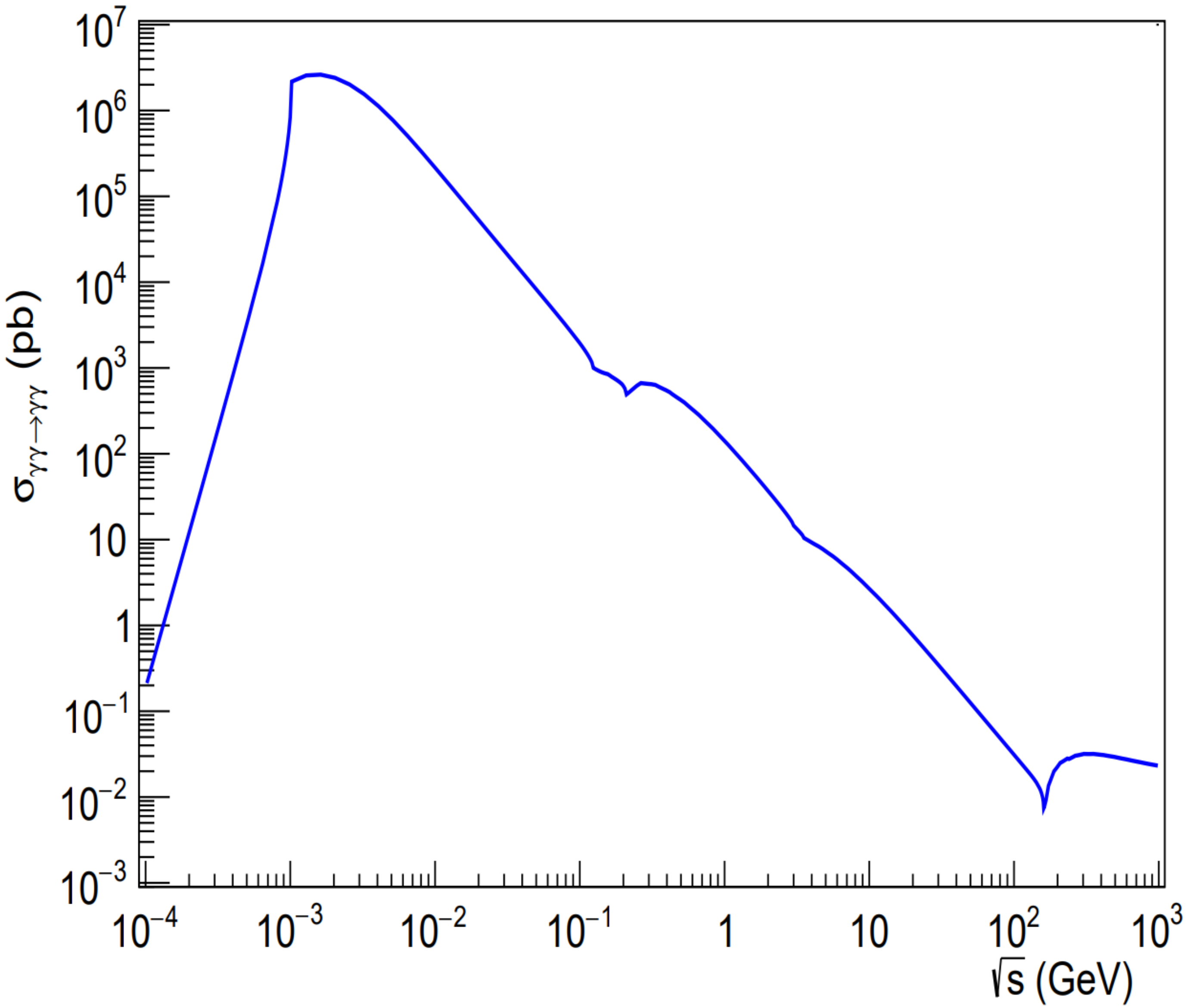
$$\frac{1}{8\alpha^2} M_{+++-} = 1 + 4\left(\frac{1}{s} + \frac{1}{t} + \frac{1}{u}\right)[T(s) + T(t) + T(u)]$$
$$- 4\left(\frac{1}{u} + \frac{2}{st}\right) I(s,t) - 4\left(\frac{1}{t} + \frac{2}{su}\right) I(s,u)$$
$$- 4\left(\frac{1}{s} + \frac{2}{tu}\right) I(t,u)\,,$$

$$\frac{1}{8\alpha^2} M_{++--} = 1 - \frac{8}{st} I(s,t) - \frac{8}{su} I(s,u) - \frac{8}{tu} I(t,u)\,.$$

$$B(r) = \frac{1}{2}\int_0^1 \mathrm{d}y \ln\{1 - i\varepsilon - 4ry(1-y)\} =$$
$$= \left(1 - \frac{1}{r}\right)^{\frac{1}{2}} \sinh^{-1}\sqrt{-r} - 1 \qquad (r < 0);$$
$$= \left(\frac{1}{r} - 1\right)^{\frac{1}{2}} \sin^{-1}\sqrt{r} - 1 \qquad (0 < r < 1);$$
$$= \left(1 - \frac{1}{r}\right)^{\frac{1}{2}} \cosh^{-1}\sqrt{r} - 1 - \frac{\pi i}{2}\left(1 - \frac{1}{r}\right)^{\frac{1}{2}} \qquad (1 < r).$$

$$T(r) = \int_0^1 \frac{\mathrm{d}y}{4y(1-y)} \ln\{1 - i\varepsilon - 4ry(1-y)\} =$$
$$= (\sinh^{-1}\sqrt{-r})^2 \qquad (r < 0);$$
$$= -(\sin^{-1}\sqrt{r})^2 \qquad (0 < r < 1);$$
$$= (\cosh^{-1}\sqrt{r})^2 - \tfrac{1}{4}\pi^2 - i\pi\cosh^{-1}\sqrt{r} \qquad (1 < r).$$

$$I(r,s) = I(s,r) = \int_0^1 \frac{\mathrm{d}y}{4y(1-y) - (r+s)/rs}\cdot$$
$$\cdot\{\ln[1 - i\varepsilon - 4ry(1-y)] + \ln[1 - i\varepsilon - 4sy(1-y)]\}\,,$$



$\sigma_{\gamma\gamma\to\gamma\gamma}$ (pb)
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
$\sqrt{s}$ (GeV)

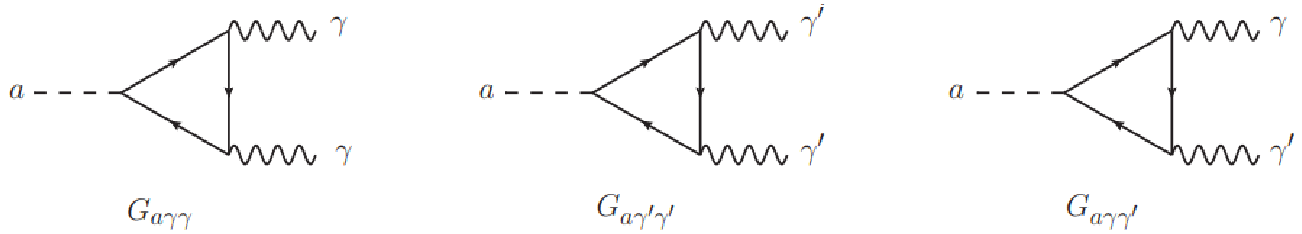
"KSVZ model"

- KSVZ-type axion [Kim, Shifman, Vainshtein, Zakharov]
  - (Very) heavy quark and (nearly) sterile axion
- With dark photon

$$\mathcal{L}_{\text{axion portal}} = \frac{G_{agg}}{4} a G_{\mu\nu}\tilde{G}^{\mu\nu} + \frac{G_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} + \cdots$$

$$\mathcal{L}_{\text{vector portal}} = \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$

$$\mathcal{L}_{\text{dark axion portal}} = \frac{G_{a\gamma'\gamma'}}{4} a F'_{\mu\nu}\tilde{F}'^{\mu\nu} + \frac{G_{a\gamma\gamma'}}{4} a F_{\mu\nu}\tilde{F}'^{\mu\nu}$$



Conclusion

- Gamma-gamma colliders are great additions to e^+e^- colliders
- At European XFEL first look at the technology for future colliders
- $b\bar{b}$ and $c\bar{c}$ production range is covered

Outlook

- SM LbyL vs different BSM contributions
- Automation of SM part
- SANC

Thank you for listening

Gamma-gamma collider

$2E_0$	GeV	35
N per bunch	10^{10}	0.62
Collision rate	kHz	13.5
σ_z	μm	70
$\varepsilon_{x,n}/\varepsilon_{y,n}$	mm · mrad	1.4/1.4
β_x/β_y at IP	μm	70/70
σ_x/σ_y at IP	nm	53/53
Laser wavelength λ	μm	0.5
Parameters x and ξ^2		0.65, 0.05
Laser flash energy	J	3
Laser pulse duration	ps	2
f# $\equiv F/D$ of laser system		27
Crossing angle	mrad	~ 30
b (CP–IP distance)	mm	1.8
$\mathcal{L}_{ee,\text{geom}}$	10^{33} cm^{-2}s^{-1}	1.45
$\mathcal{L}_{\gamma\gamma}$ $(z > 0.5z_m)$	10^{33} cm^{-2}s^{-1}	0.19
$W_{\gamma\gamma}$ (peak)	GeV	12

[V. I. Telnov 2020]