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

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DESY.

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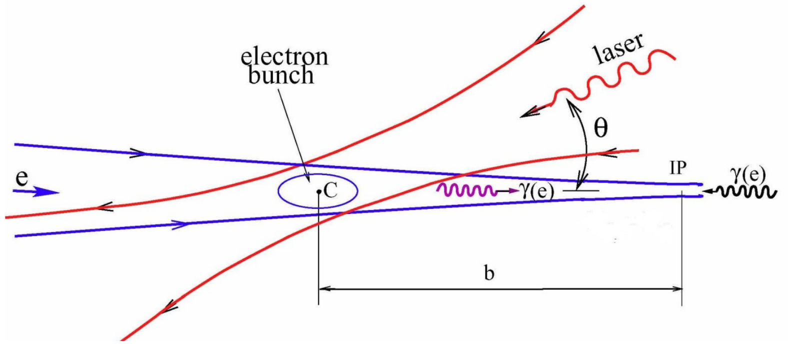
Gamma-gamma collider

- Addition to ee-colliders
- Compton backscattering
- Getting access to $\gamma\gamma$ and γe processes

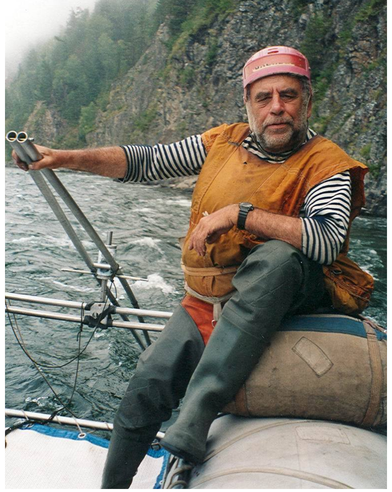


[V. Telnov `20]

$$\omega_{max} = \frac{x}{x+1+\xi^2} E_0$$

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

Gamma-gamma collider



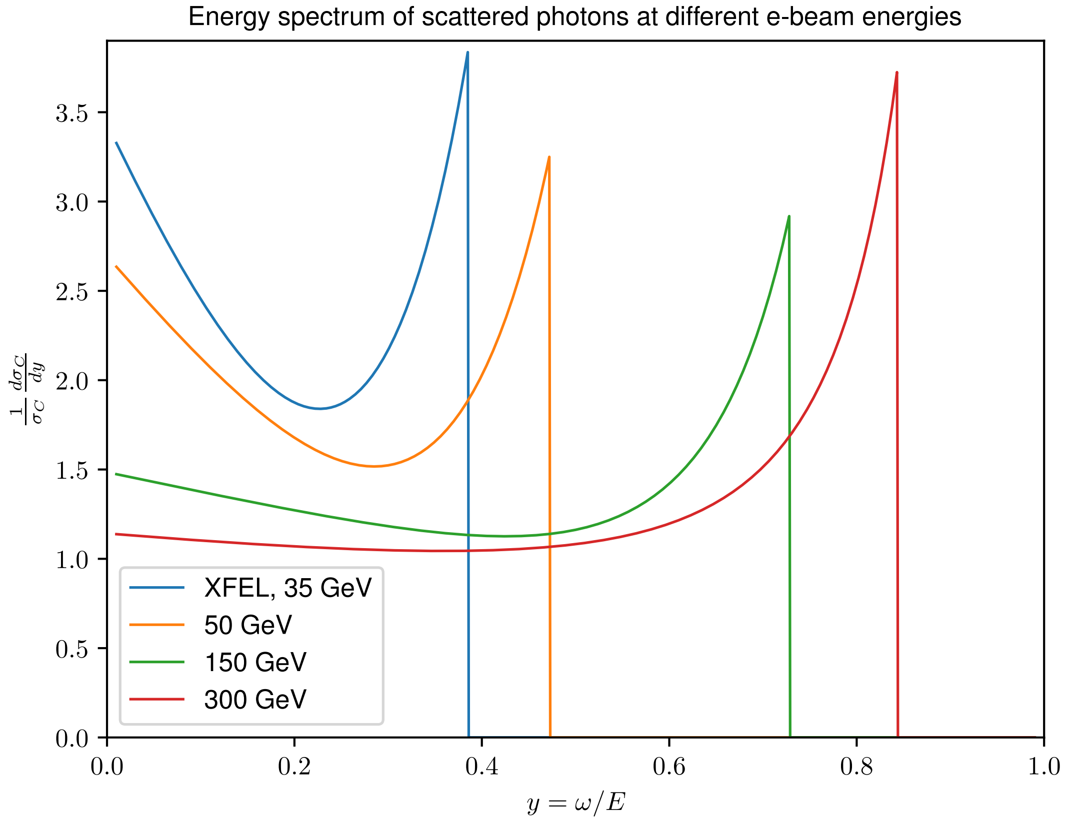
[I. Ginzburg `83]

- Compton backscattering

$$\sigma_c = \frac{2\sigma_0}{x}\left[\left(1-\frac{4}{x}-\frac{8}{x^2}\right)\ln(x+1)+\frac{1}{2}+\frac{8}{x}-\frac{1}{2(x+1)^2}\right]$$

- Energy spectrum

$$\frac{1}{\sigma_c}\frac{\mathrm{d}\sigma_c}{\mathrm{d}y} \equiv f(x,y)$$
$$= \frac{2\sigma_0}{x\sigma_c}\left[1-y+\frac{1}{1-y}-\frac{4y}{x(1-y)}+\frac{4y^2}{x^2(1-y)^2}\right]$$

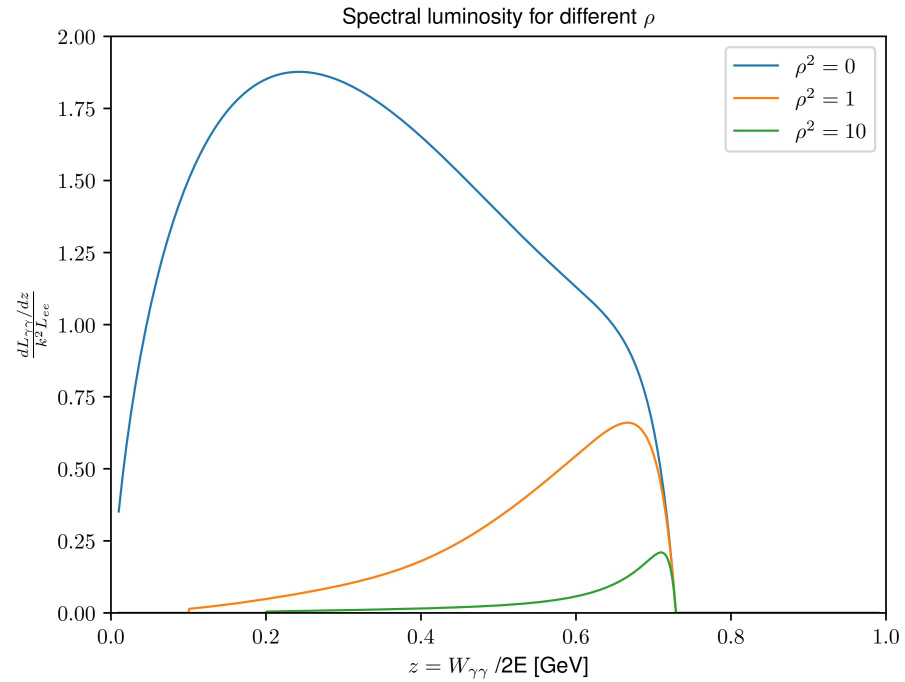


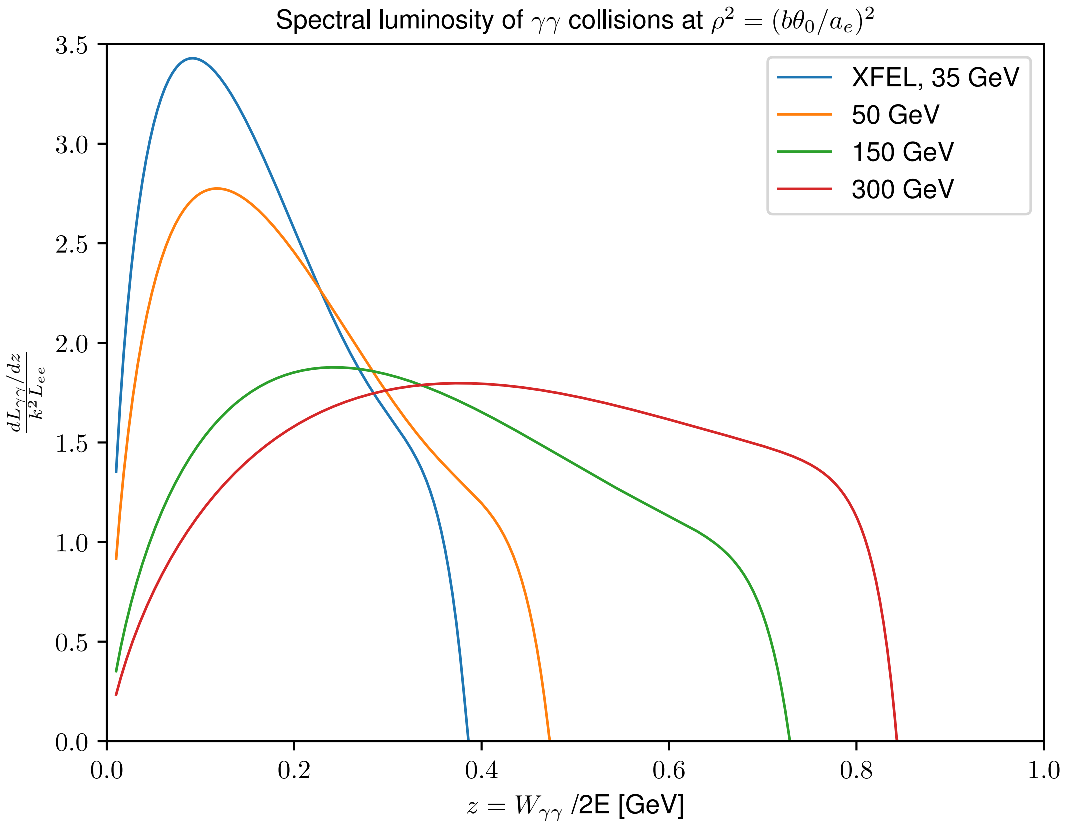
[I. Ginzburg `83]

Gamma-gamma collider

- Spectral luminosity

$$\frac{1}{k^2 L_{ee}} \frac{\mathrm{d}L_{\gamma\gamma}}{\mathrm{d}z} = 2z \int_{z^2/y_{max}}^{y_{max}} f(x,y) f\left(x, \frac{z^2}{y}\right) \frac{\mathrm{d}y}{y}$$





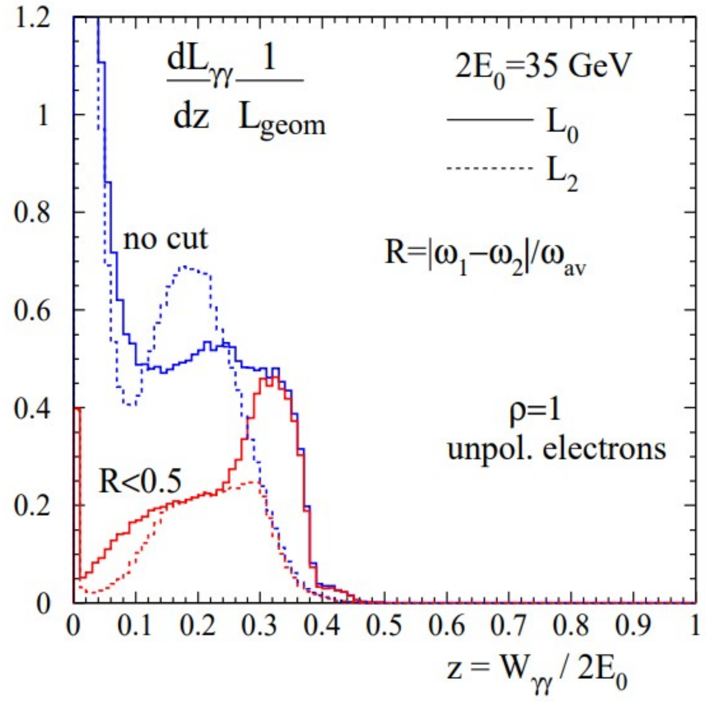
$$\rho = \frac{b\theta_0}{a_e}$$

Gamma-gamma collider

$$\omega_{max} = \frac{x}{x+1+\xi^2} E_0$$

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

- Use European XFEL (E_0 = 17.5 GeV)
  - Project idea for the beam dump [V. Telnov]

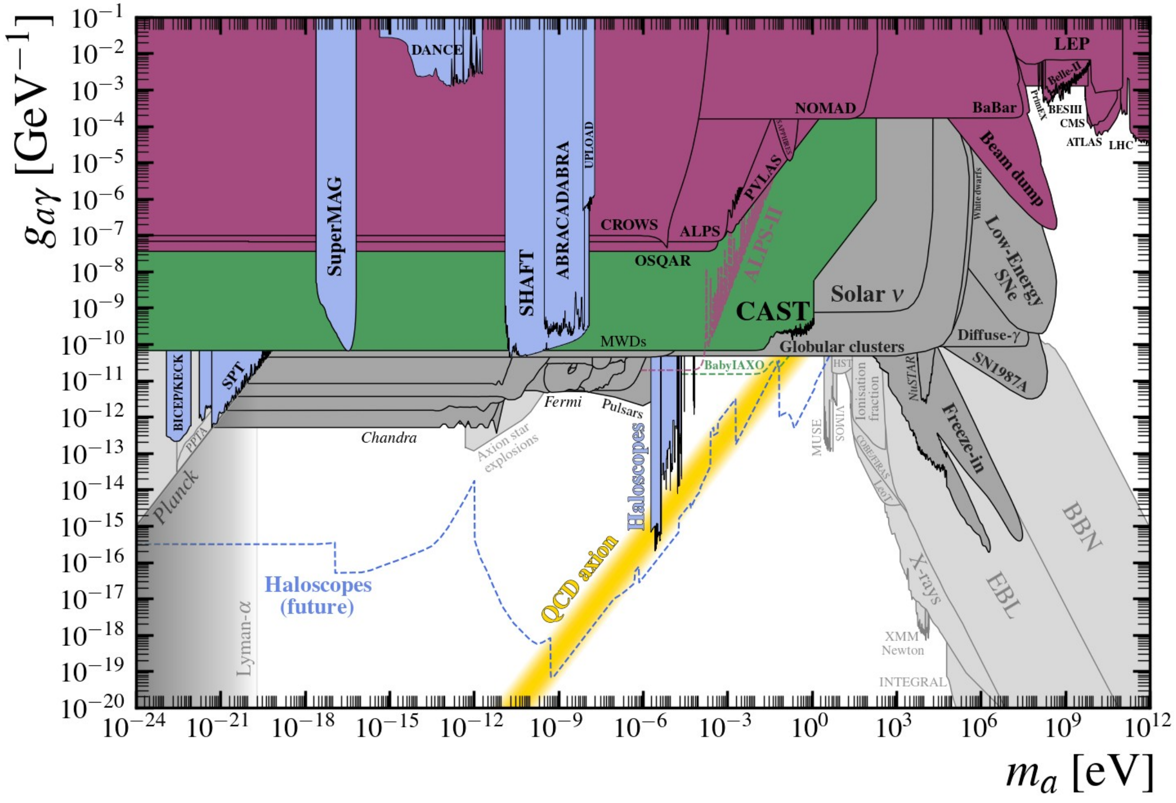


- 12 GeV peak
- Excellent for $b\bar{b}$ and $c\bar{c}$ range

Gamma-gamma collider

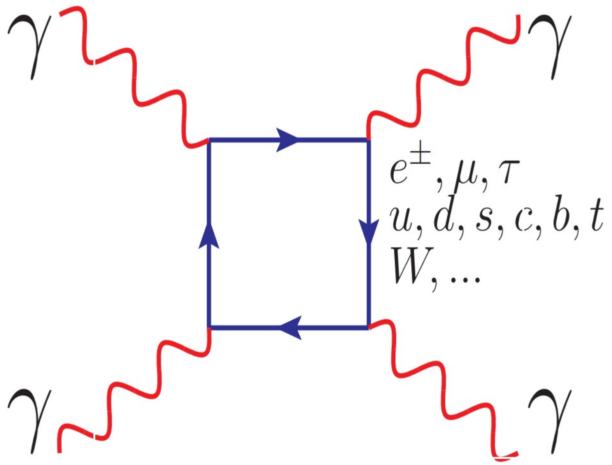
- Additional hadronic resonances [V. Telnov `20]
- Possible four-quark states

- Looking for BSM particles
  - ALPs
  - Mixed models
- Indirect tests of SM physics
  - Precision observables

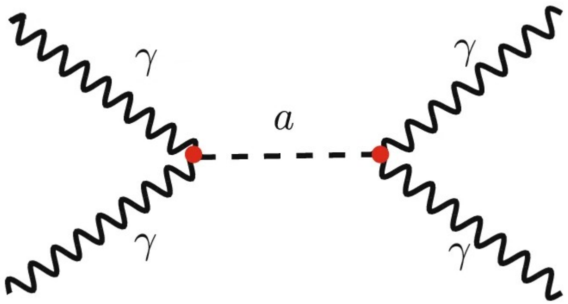


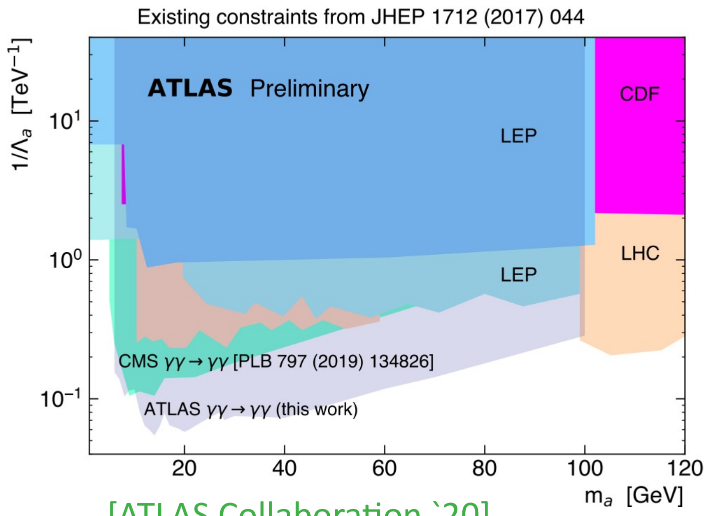
[FIPS Workshop `22]

Light-by-light scattering



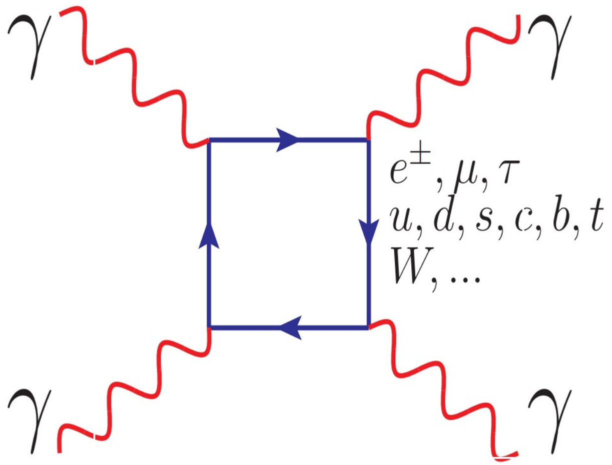
- Has been done for a long time [Lifshitz, De Tollis, Karplus, Neuman]
- So far observed by ATLAS
  - most recent results from 2020
- Possibility to observe BSM contributions





[ATLAS Collaboration `20]

Light-by-light scattering



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

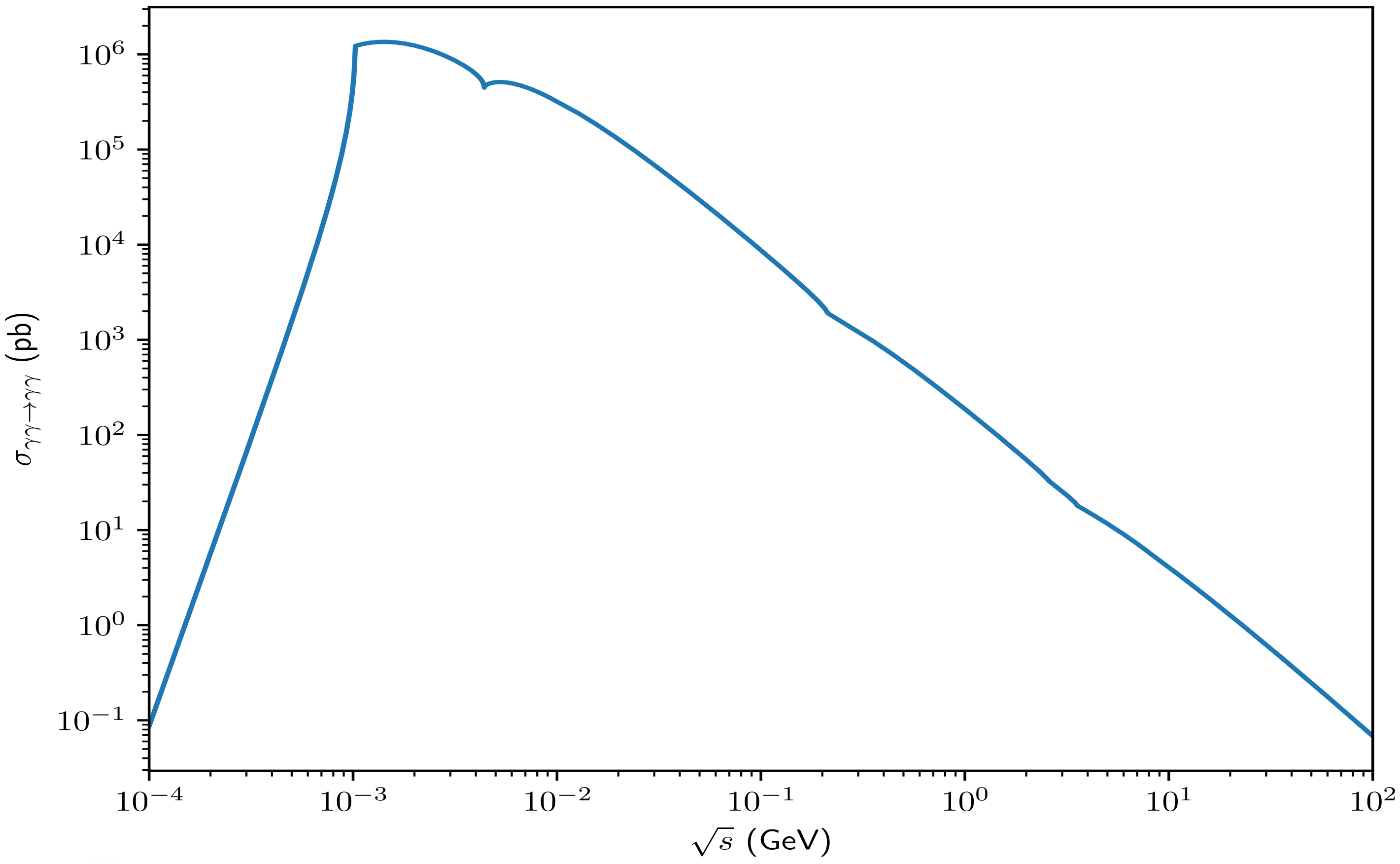
- Helicity amplitudes

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

$$M_{++++}\ ,\ M_{++--}\ \text{und}\ M_{+++-}$$

Light-by-light scattering

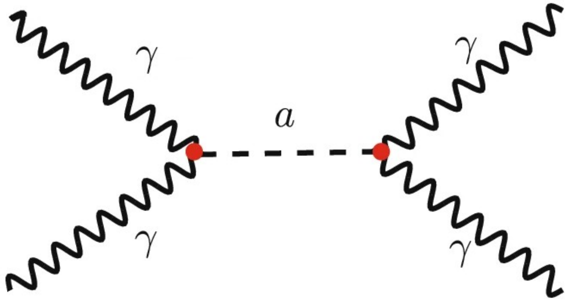
- Only fermionic contributions
- Electron contribution dominant



$$\mathrm{d}\sigma = 2\int_0^{z_{max}} \mathrm{d}z\ z \int_{z^2/y_{max}}^{y_{max}} \mathrm{d}y\ \frac{1}{y} f(x,y) f\left(x, \frac{z^2}{y}\right) \mathrm{d}\sigma^{\gamma\gamma\to\gamma\gamma}$$

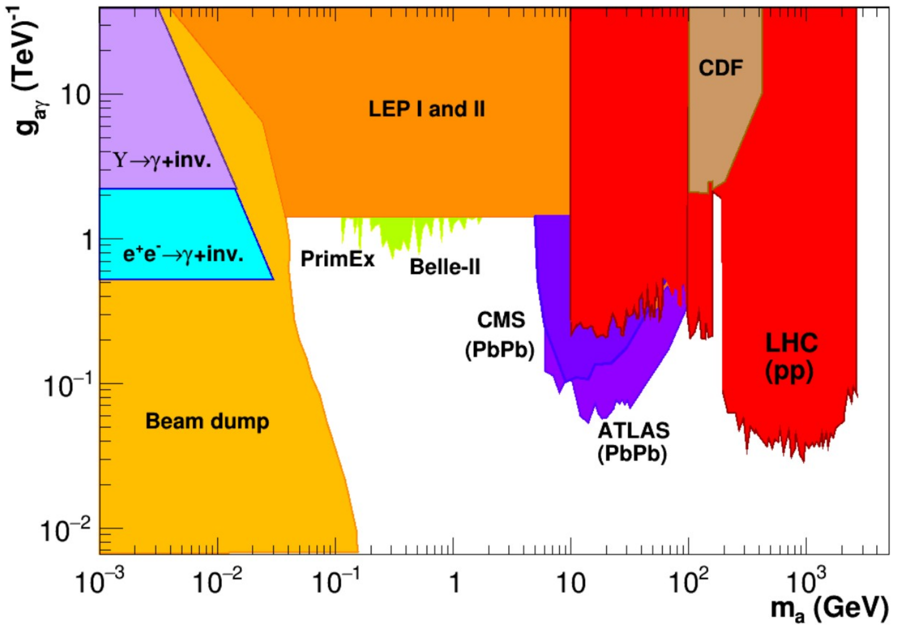
Axion-Like Particles

- $\mathcal{L}_{ALPs} = \frac{1}{2}\partial^\mu a \partial_\mu a - \frac{1}{2} m_a^2 a^2 - \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu}$



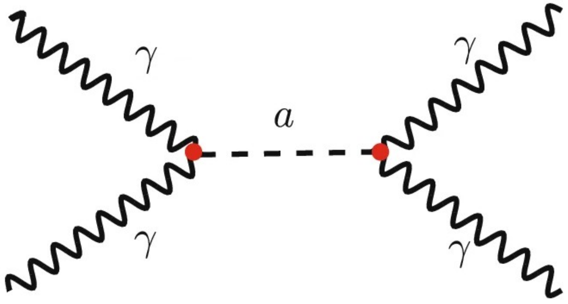
- Main contribution from s-channel

$$\mathcal{M}_{ALPs} = -\frac{1}{2}\frac{g_{a\gamma\gamma}^2 s^2}{s - m_a^2 + i m_a \Gamma}$$



[D. d'Enterria `21]

ALPs



- With helicity amplitudes [C. Baldenegro et al. `18]

$$\frac{d\sigma}{d\Omega}^{\gamma\gamma\to\gamma\gamma} = \frac{1}{128\pi^2 s}(|\mathcal{M}_{++++}|^2 + |\mathcal{M}_{+-+-}|^2 + |\mathcal{M}_{+--+}|^2 + |\mathcal{M}_{++--}|^2)$$

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

- Final cross-section dependent on photon luminosity

$$\frac{d\sigma}{d\Omega} = \int \frac{d\mathcal{L}}{d\hat{s}}^{\gamma\gamma} \frac{d\hat{\sigma}}{d\Omega}^{\gamma\gamma\to\gamma\gamma} d\hat{s}$$

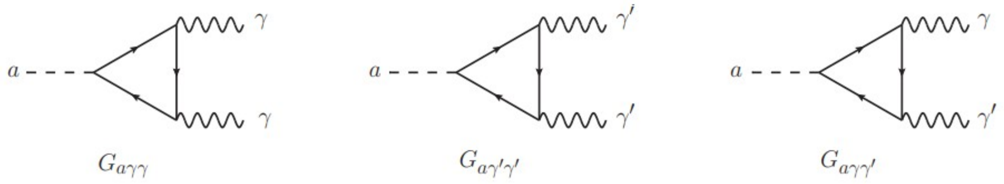
  - Using CAIN [Kaoru Yokoya]

Conclusion

- Gamma-gamma colliders are great additions to any ee-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
  - Full ALPs check with CAIN luminosity
  - Mixed model [K. Kaneta, H. Lee, S. Yun `17]



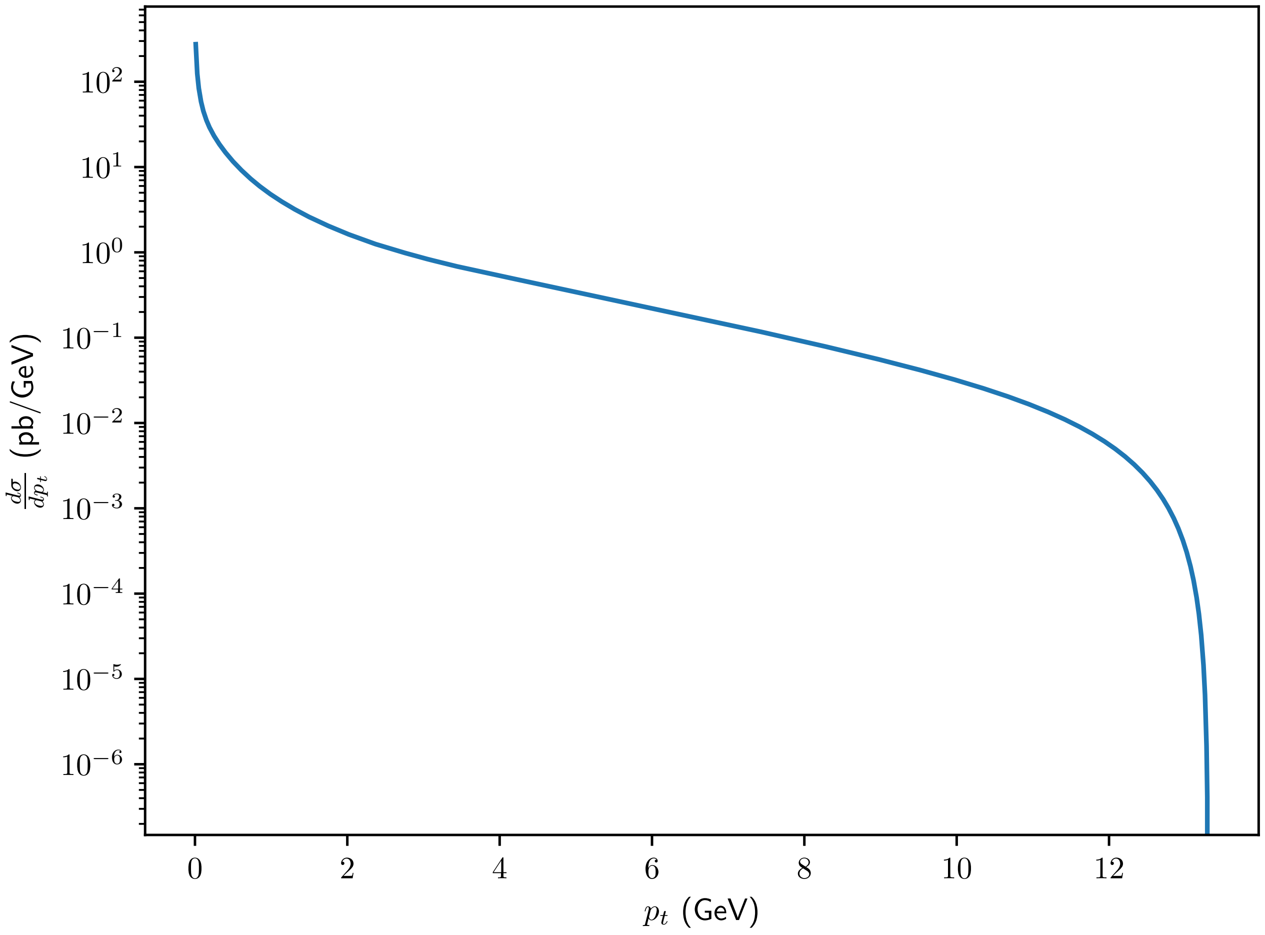
Thank you for listening

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
$\mathcal{L}_{ee,\mathrm{geom}}$	$10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.45
$\mathcal{L}_{\gamma\gamma}\ (z > 0.5z_m)$	$10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	0.19
$W_{\gamma\gamma}$ (peak)	GeV	12

[V. Telnov `20]

Light-by-Light scattering



“Dark Axion model”

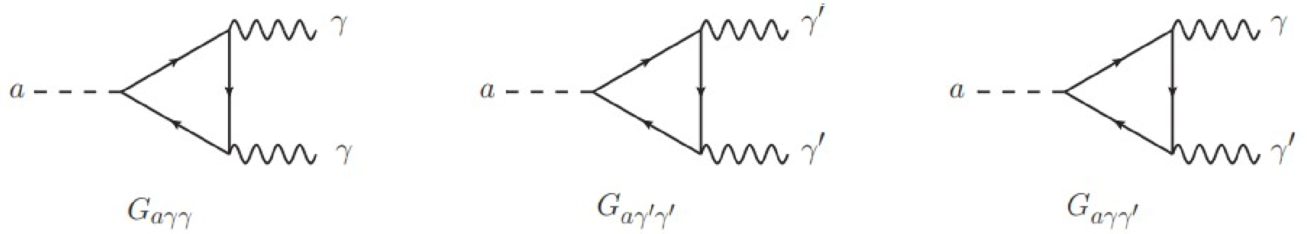
[K. Kaneta, H. Lee, S. Yun `17]

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

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

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

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



Light-by-light scattering

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

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

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

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

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

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

ALPs

$$\Gamma = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$