

Аномальные константы для 4-фотонной вершины в поляризованном фотон-фотонном рассеянии на коллайдере CLIC

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План доклада

- Коллайдер CLIC. Реальные фотоны, сгенерированные путем обратного комптоновского рассеяния лазерных фотонов на поляризованных пучках электронов.
- Эффективный Лагранжиан и аномальные калибровочные константы для вершины $\gamma\gamma\gamma\gamma$.
- Дифференциальные и полные сечения для процесса $\gamma\gamma \rightarrow \gamma\gamma$ с поляризованными начальными фотонами.
- Области значений аномальных констант, которые могут быть исключены на CLIC.
- Сравнение с аналогичными результатами, полученными для LHC и HL-LHC.

Light-by-Light (LBL) scattering at the CLIC

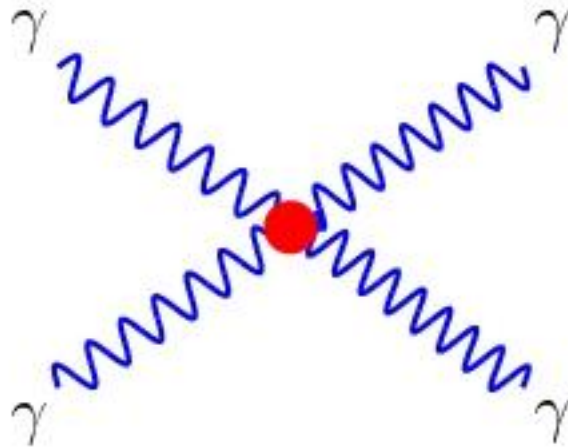


Diagram for process $\gamma\gamma \rightarrow \gamma\gamma$

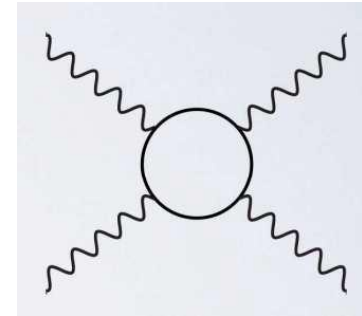
The goal is to examine anomalous quartic gauge couplings (QGCs) via reaction $\gamma\gamma \rightarrow \gamma\gamma$ at the CLIC

New physics contributions to 4γ couplings

New charged particles via loops

$$\zeta_i \sim Q^4 m^{-4}$$

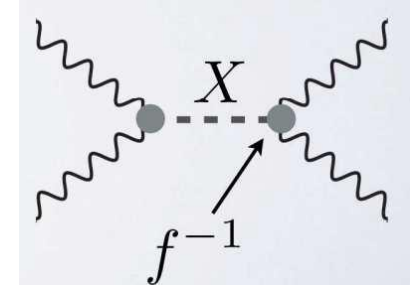
Example: top partner



New neutral particles at tree level

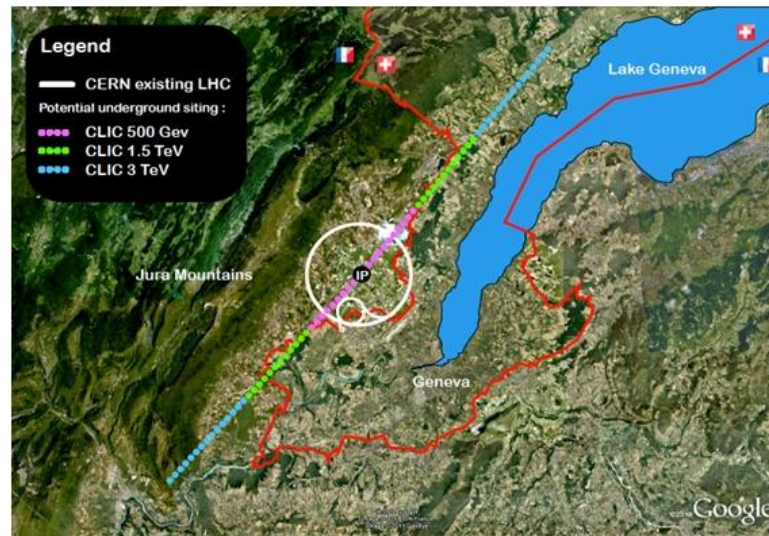
$$\zeta_i \sim f^{-2} m^{-2}$$

Example: KK gravitons, radion
(warped extra dimension)



If $f \sim \text{TeV}$ and $m_{\text{KK}} \sim \text{few TeV}$, then $\zeta_i \sim 10^{-14} - 10^{-13}$

Compact Linear Collider (CLIC)



	Beam energy	Integrated luminosity (unpolarized beams)
1st stage	190 GeV	1000 fb ⁻¹
2nd stage	750 GeV	2500 fb ⁻¹
3rd stage	1500 GeV	5000 fb ⁻¹

λ_0 is helicity of laser *photon beam*, and
 λ_e is helicity of *electron beam* before
 Compton backscattering (CB)

$$(\lambda_e^{(1)}, \lambda_0^{(1)}; \lambda_e^{(2)}, \lambda_0^{(2)}) = (0.8, 1; 0.8, 1) ,$$

$$(\lambda_e^{(1)}, \lambda_0^{(1)}; \lambda_e^{(2)}, \lambda_0^{(2)}) = (-0.8, 1; -0.8, 1)$$

**CLIC energy stages and integrated luminosities
 for unpolarized and polarized electron beams**

		L, fb^{-1}		
Stage	$\sqrt{s}, \text{GeV}$	$\lambda_e = 0$	$\lambda_e = -0.8$	$\lambda_e = 0.8$
2	1500	2500	2000	500
3	3000	5000	4000	1000

Differential cross section for LBL scattering

$$\begin{aligned} \frac{d\sigma}{d\cos\theta} = & \frac{1}{128\pi s} \int_{x_{1\min}}^{x_{1\max}} \frac{dx_1}{x_1} f_{\gamma/e}(x_1) \int_{x_{2\min}}^{x_{2\max}} \frac{dx_2}{x_2} f_{\gamma/e}(x_2) \\ & \times \left\{ \left[1 + \xi \left(E_\gamma^{(1)}, \lambda_0^{(1)} \right) \xi \left(E_\gamma^{(2)}, \lambda_0^{(2)} \right) \right] \right. \\ & \times (|M_{++++}|^2 + |M_{++--}|^2) \\ & + \left[1 - \xi \left(E_\gamma^{(1)}, \lambda_0^{(1)} \right) \xi \left(E_\gamma^{(2)}, \lambda_0^{(2)} \right) \right] \\ & \left. \times (|M_{+-+-}|^2 + |M_{+--+}|^2) \right\} \end{aligned}$$

$f_{\gamma/e}(x)$ = distribution of CB photon
in energy fraction $x = E_\gamma/E_e$

$\xi(E_\gamma, \lambda_0)$ = photon helicity

$$\xi(E_\gamma, \lambda_0) = \frac{\lambda_0(1-2r)[1-x+1/(1-x)] + \lambda_e r \zeta [1 + (1-x)(1-2r)^2]}{1-x+1/(1-x) - 4r(1-r) - \lambda_e \lambda_0 r \zeta (2r-1)(2-x)},$$

where $x = E_\gamma/E_e$, $r = x/\zeta(1-x)$, $\zeta = 4E_e E_0/m_e^2$, m_e being the electron mass.

$$f_{\gamma/e}(x) = \frac{1}{g(\zeta)} \left[1 - x + \frac{1}{1-x} - \frac{4x}{\zeta(1-x)} + \frac{4x^2}{\zeta^2(1-x)^2} + \lambda_0 \lambda_e r \zeta (1-2r)(2-x) \right],$$

where

$$\begin{aligned} g(\zeta) &= g_1(\zeta) + \lambda_0 \lambda_e g_2(\zeta), \\ g_1(\zeta) &= \left(1 - \frac{4}{\zeta} - \frac{8}{\zeta^2} \right) \ln(\zeta + 1) + \frac{1}{2} + \frac{8}{\zeta} - \frac{1}{2(\zeta + 1)^2}, \\ g_2(\zeta) &= \left(1 + \frac{2}{\zeta} \right) \ln(\zeta + 1) - \frac{5}{2} + \frac{1}{\zeta + 1} - \frac{1}{2(\zeta + 1)^2}. \end{aligned}$$

Effective Lagrangian

Effective Lagrangian of dimension-8 operators which contribute to anomalous quartic *neutral* gauge couplings

$$\begin{aligned}\mathcal{L}_{\text{QNGC}} = & \frac{c_8}{\Lambda^4} B_{\rho\sigma} B^{\rho\sigma} B_{\mu\nu} B^{\mu\nu} + \frac{c_9}{\Lambda^4} W_{\rho\sigma}^a W^{a\rho\sigma} W_{\mu\nu}^b W^{b\mu\nu} + \frac{c_{10}}{\Lambda^4} W_{\rho\sigma}^a W^{b\rho\sigma} W_{\mu\nu}^a W^{b\mu\nu} \\ & + \frac{c_{11}}{\Lambda^4} B_{\rho\sigma} B^{\rho\sigma} W_{\mu\nu}^a W^{a\mu\nu} + \frac{c_{13}}{\Lambda^4} B_{\rho\sigma} B^{\sigma\nu} B_{\nu\mu} B^{\mu\rho} + \frac{c_{14}}{\Lambda^4} W_{\rho\sigma}^a W^{a\sigma\nu} W_{\nu\mu}^b W^{b\mu\rho} \\ & + \frac{c_{15}}{\Lambda^4} W_{\rho\sigma}^a W^{b\sigma\nu} W_{\nu\mu}^a W^{b\mu\rho} + \frac{c_{16}}{\Lambda^4} B_{\rho\sigma} B^{\sigma\nu} W_{\nu\mu}^a W^{a\mu\rho}\end{aligned}$$

➡ Effective Lagrangian for anomalous $\gamma\gamma\gamma\gamma$ couplings

$$L_{\text{QNGC}}^{\gamma\gamma\gamma\gamma} = \varsigma_1 (F_{\mu\nu} F^{\mu\nu}) (F_{\rho\sigma} F^{\rho\sigma}) + \varsigma_2 (F_{\mu\nu} F^{\nu\rho} F_{\rho\sigma} F^{\sigma\mu})$$

Anomalous couplings ς_1, ς_2 have dimension -4

Differential and total cross sections

Electron beam helicities:

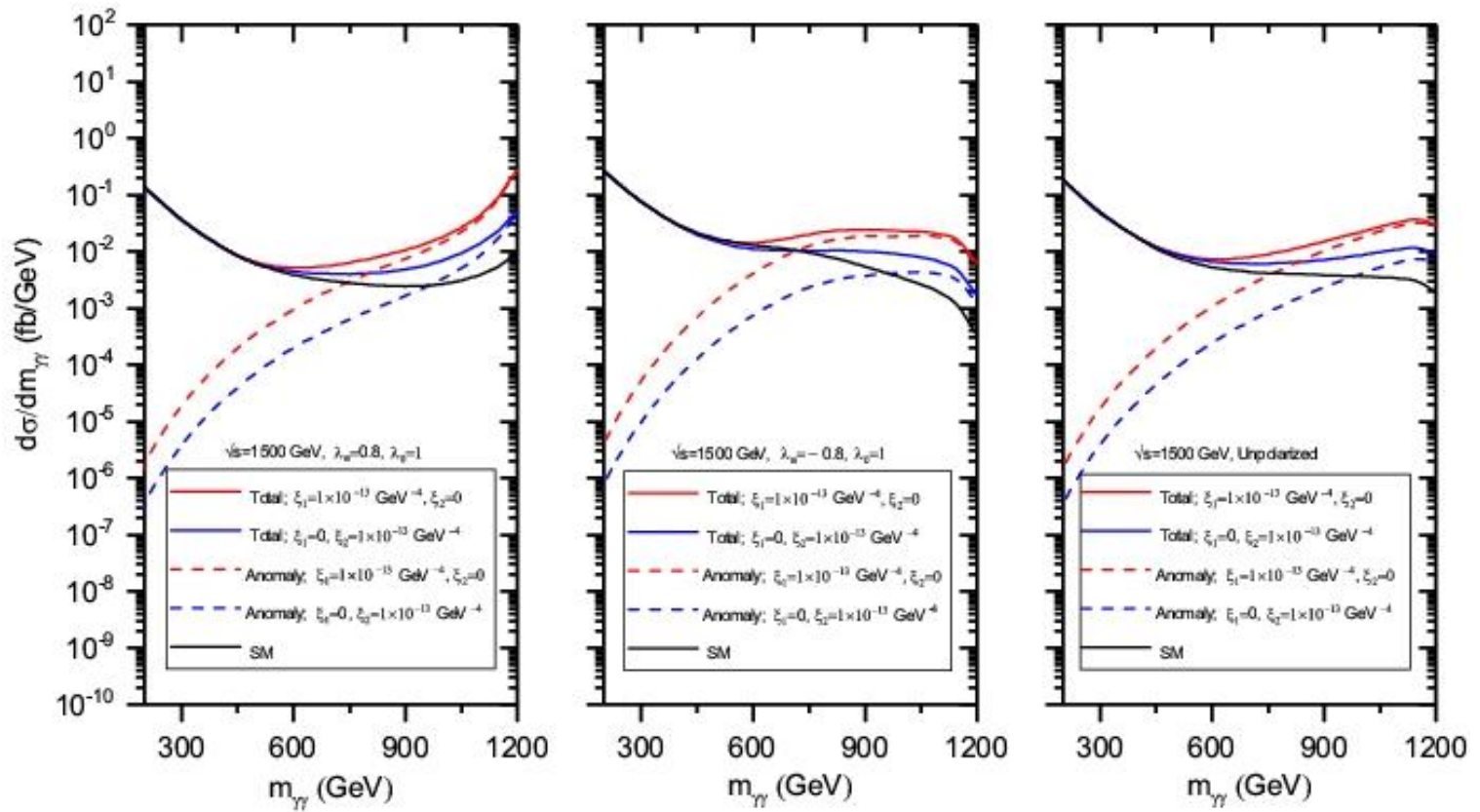
$$\lambda_e = 0.8, -0.8, \text{ and } 0 \text{ (unpolarized case)}$$

Cuts on the invariant mass and rapidities of final photons:

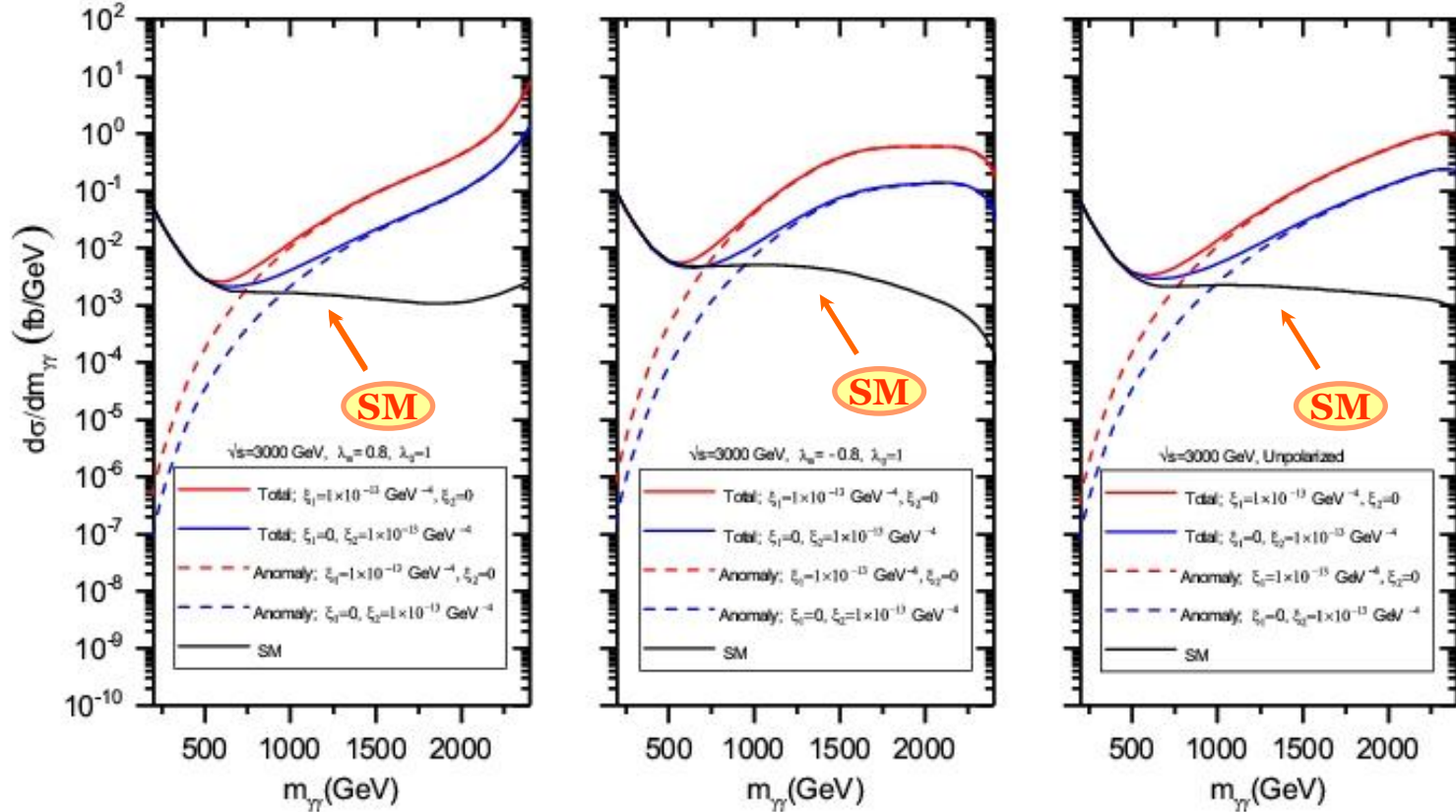
$$m_{\gamma\gamma} > 200 \text{ GeV}, \quad |\eta_{\gamma\gamma}| < 2.5$$

SM amplitude:

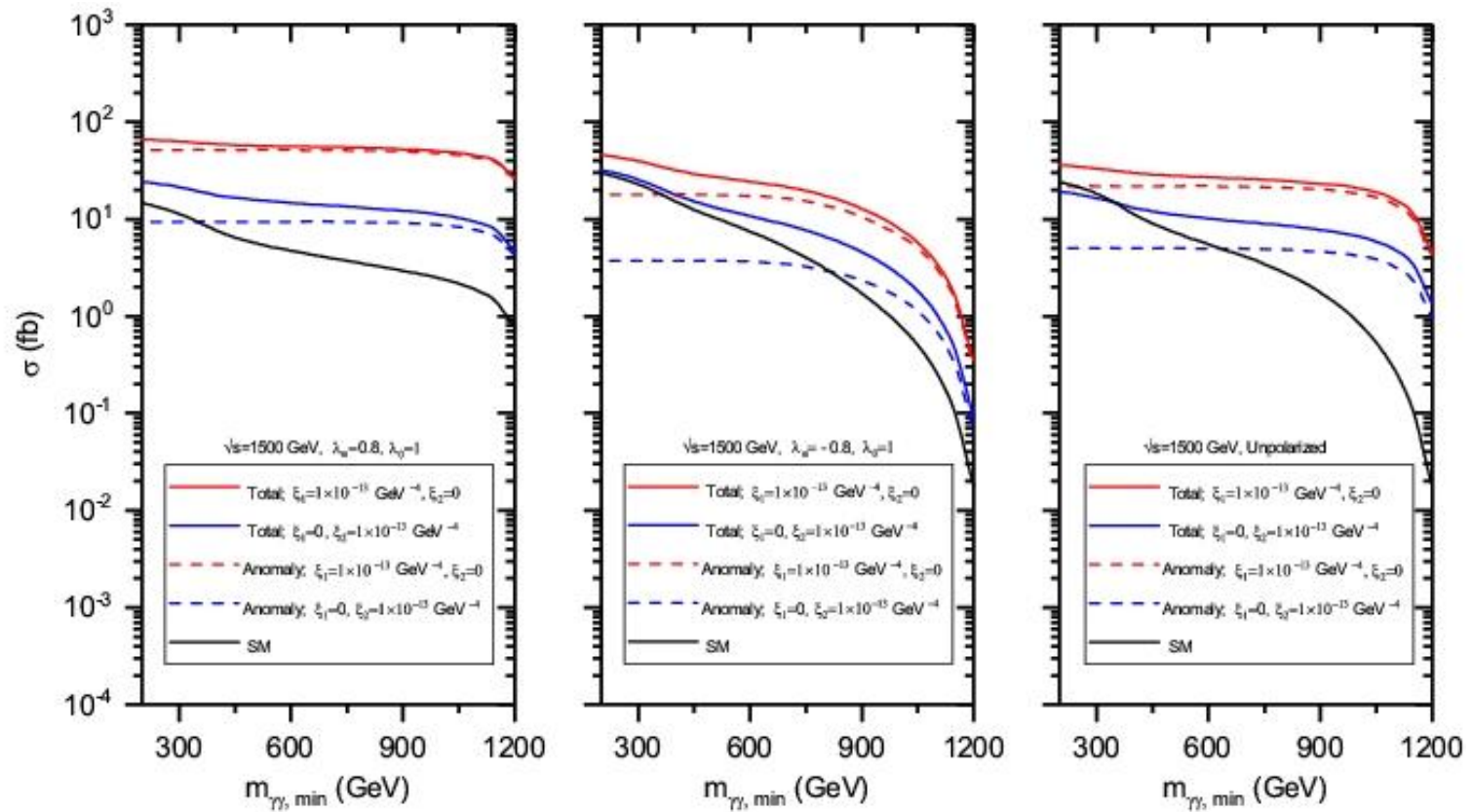
$$M_W \text{ (W-loop, dominates at } \sqrt{s} > 200 \text{ GeV)} \\ + M_f \text{ (fermion-loop) contributions}$$



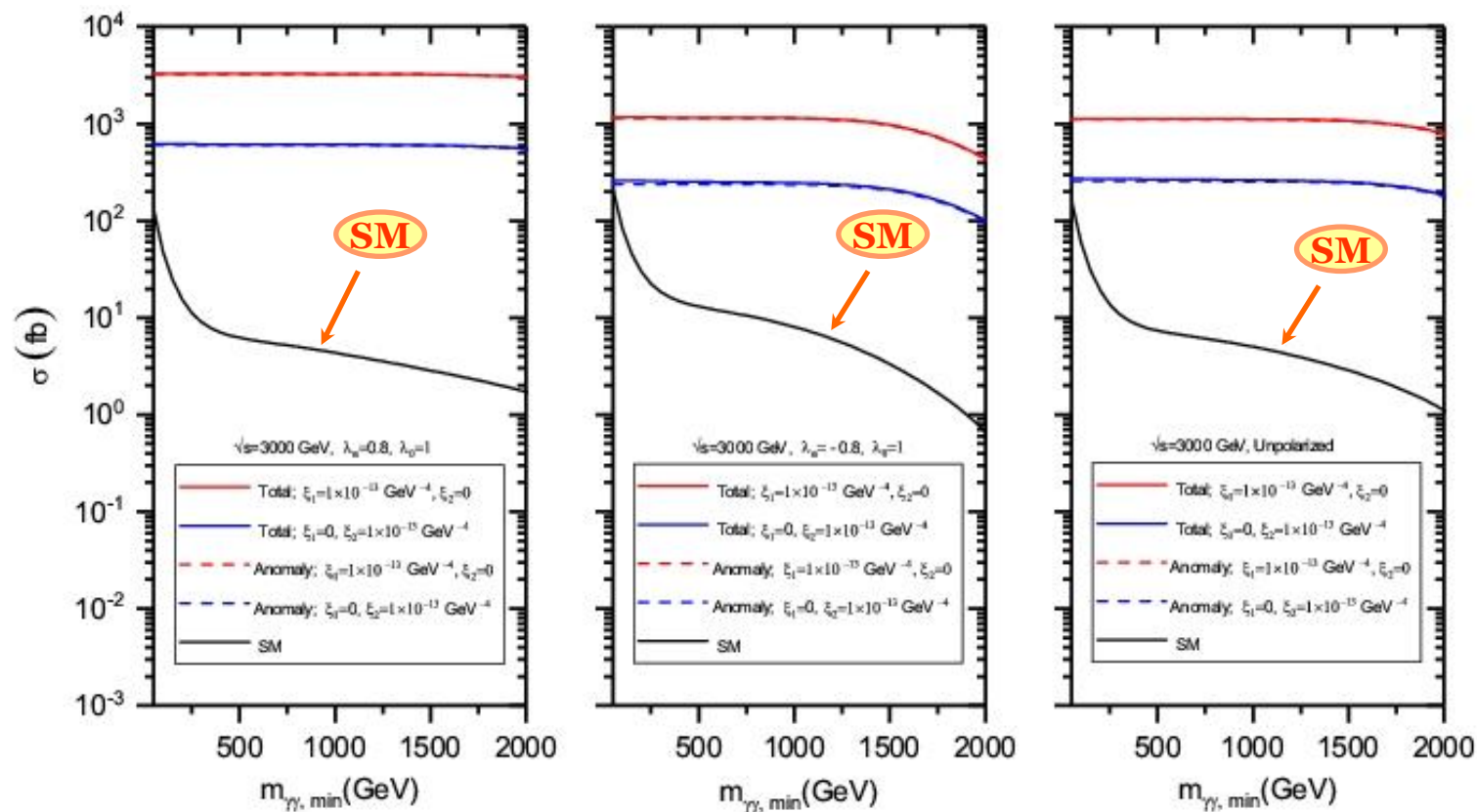
Differential cross sections for the process $\gamma\gamma \rightarrow \gamma\gamma$ as functions of invariant mass of outgoing photons at $\sqrt{s} = 1.5$ TeV. The left, middle and right panels correspond to $\lambda_e = 0.8, -0.8, 0$. The curves are (from top downwards): full, pure anomaly, SM cross sections.



The same as in the previous figure,
but for collision energy 3.0 TeV.



Total cross sections for the process $\gamma\gamma \rightarrow \gamma\gamma$ as functions of minimal invariant mass of outgoing photons at $\sqrt{s} = 1.5$ TeV. The left, middle and right panels correspond to $\lambda_e = 0.8, -0.8, 0$. The curves are (from top downwards): full, pure anomaly, SM cross sections.



The same as in the previous figure,
but for the collision energy 3.0 TeV.

Exclusion significance (δ = percentage systematic error)

$$S_{\text{excl}} = \sqrt{2} \left[s - b \ln \left(\frac{b+s+x}{2b} \right) - \frac{1}{\delta^2} \ln \left(\frac{b-s+x}{2b} \right) - (b+s-x) \left(1 + \frac{1}{\delta^2 b} \right) \right]^{1/2}$$

s (b) = number of signal (background) events

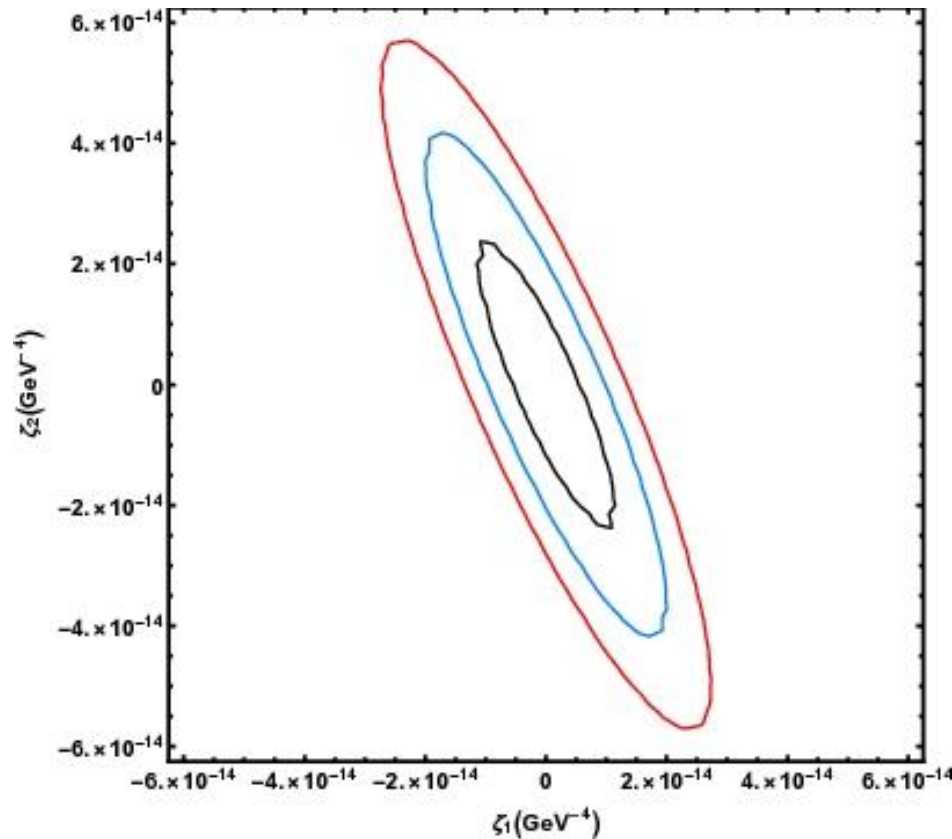
In the limit $\delta = 0$

$$S_{\text{excl}} = \sqrt{2 \left[s - b \ln \left(1 + \frac{s}{b} \right) \right]}$$

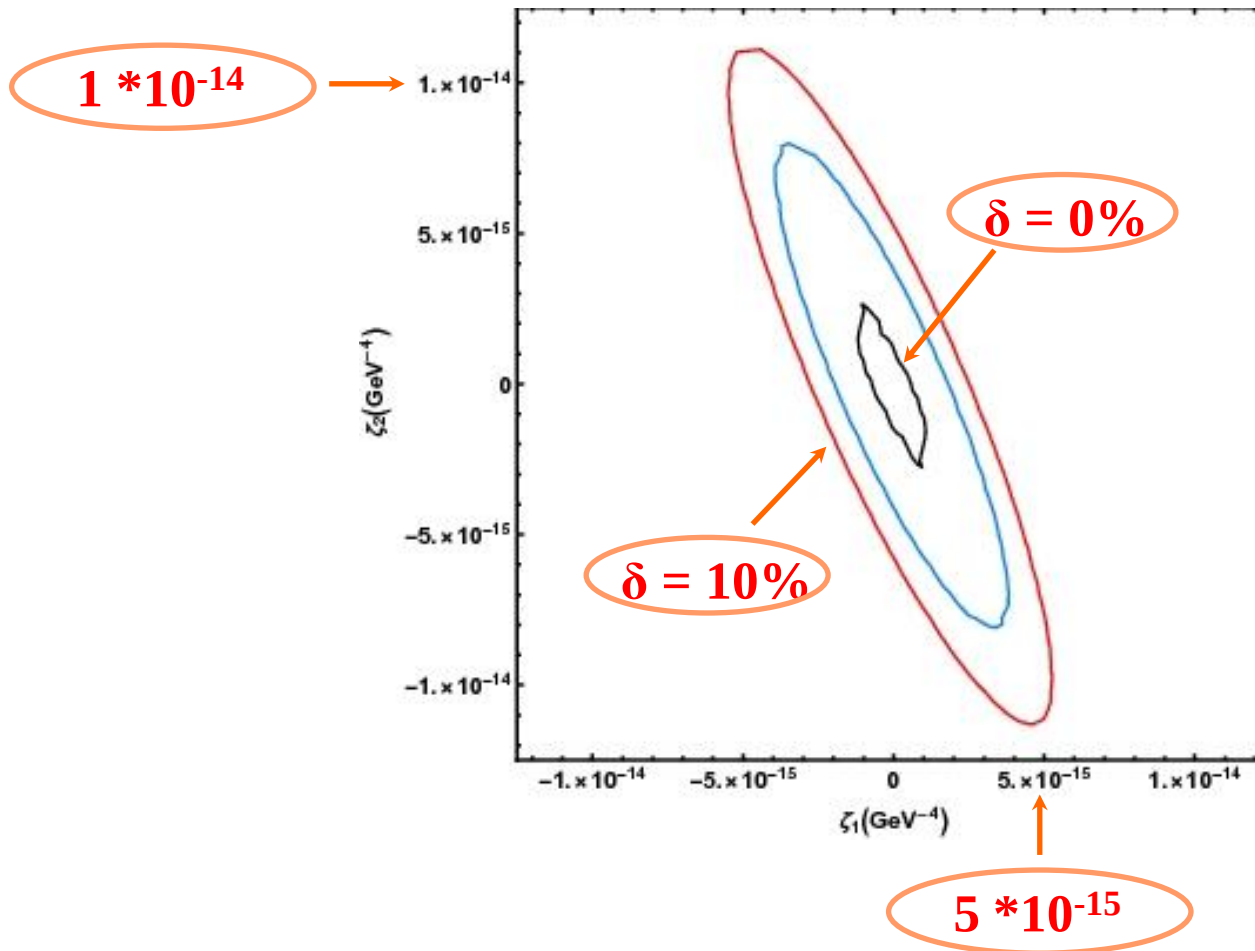
$s \ll b$


$$S_{\text{excl}} = \frac{s}{\sqrt{b}}$$

$S_{\text{excl}} \leq 1.645$ is the region that
can be excluded at 95% C.L.



95% C.L. exclusion region for anomalous couplings ζ_1 , ζ_2 for *unpolarized* LBL scattering at the CLIC. Systematic errors are 0%, 5%, and 10%. The collision energy is 1.5 TeV, the integrated luminosity is 2500 fb⁻¹.

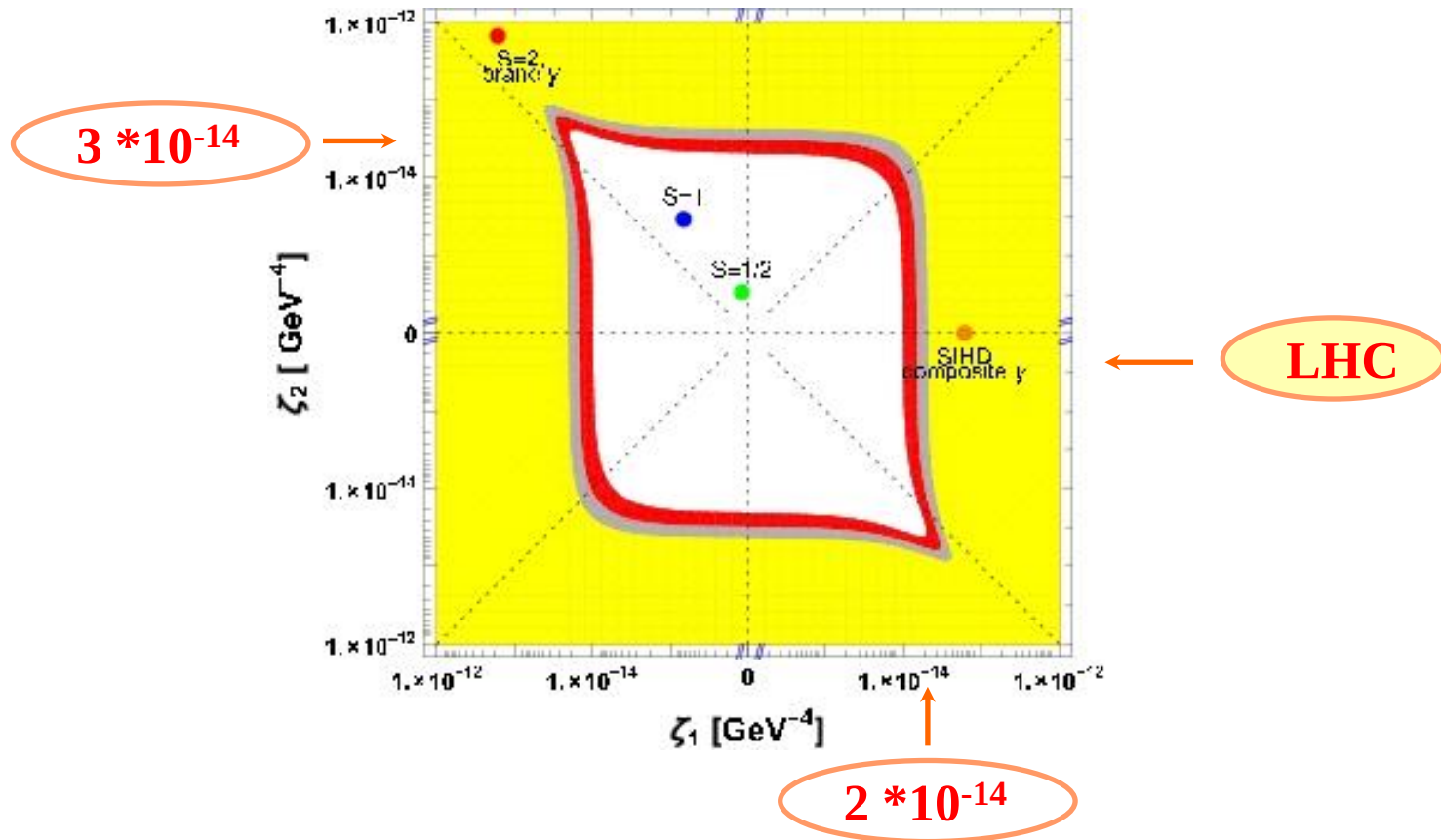


The same as in the previous figure, but for the collision energy 3.0 TeV and integrated luminosity 5000 fb⁻¹.

Exclusion limits on anomalous couplings for the LBL scattering at the CLIC for energy 3.0 TeV, and cut $m_{\gamma\gamma} > 1000$ GeV

Helicity		0	-0.8	0.8
Luminosity, fb ⁻¹		5000	4000	1000
$ \zeta_1 , \text{GeV}^{-4} (\zeta_2 = 0)$	$\delta = 0\%$	6.85×10^{-16}	8.82×10^{-16}	8.73×10^{-16}
	$\delta = 5\%$	1.90×10^{-15}	2.48×10^{-15}	1.56×10^{-15}
	$\delta = 10\%$	2.63×10^{-15}	3.37×10^{-15}	2.12×10^{-15}
$ \zeta_2 , \text{GeV}^{-4} (\zeta_1 = 0)$	$\delta = 0\%$	1.43×10^{-15}	1.85×10^{-15}	1.82×10^{-15}
	$\delta = 5\%$	3.99×10^{-15}	5.12×10^{-15}	3.28×10^{-15}
	$\delta = 10\%$	5.53×10^{-15}	7.10×10^{-15}	4.46×10^{-15}

Bounds on anomalous couplings for the LHC and HL-LHC



LHC, $L=300 \text{ fb}^{-1}$:

$$|\zeta_1| < 1.5 \cdot 10^{-14} \text{ GeV}^{-4}, |\zeta_2| < 3.0 \cdot 10^{-14} \text{ GeV}^{-4}$$

(Fichet et al., JHEP, 02, 165, 2015)

HL-LHC, $L=3000 \text{ fb}^{-1}$:

$$|\zeta_1| < 7.0 \cdot 10^{-15} \text{ GeV}^{-4}, |\zeta_2| < 1.5 \cdot 10^{-14} \text{ GeV}^{-4}$$

(Fichet et al., Phys. Rev. D 89, 114004, 2014)

Заключение

- Изучены аномальные константы для вершины $\gamma\gamma\gamma\gamma$ в рассеянии реальных фотонов, полученных в обратном комптоновском рассеянии лазерных фотонов на поляризованных электронных пучках на CLIC.
- Вычислены дифференциальные и полные сечения для процесса $\gamma\gamma \rightarrow \gamma\gamma$.
- Получены области значений аномальных констант, которые могут быть исключены в фотон-фотонном рассеянии на CLIC.
- Ограничения для энергии $\sqrt{s} = 3 \text{ TeV}$ - на порядок более жесткие, чем аналогичные ограничения, полученные для HL-LHC.

Спасибо за внимание!

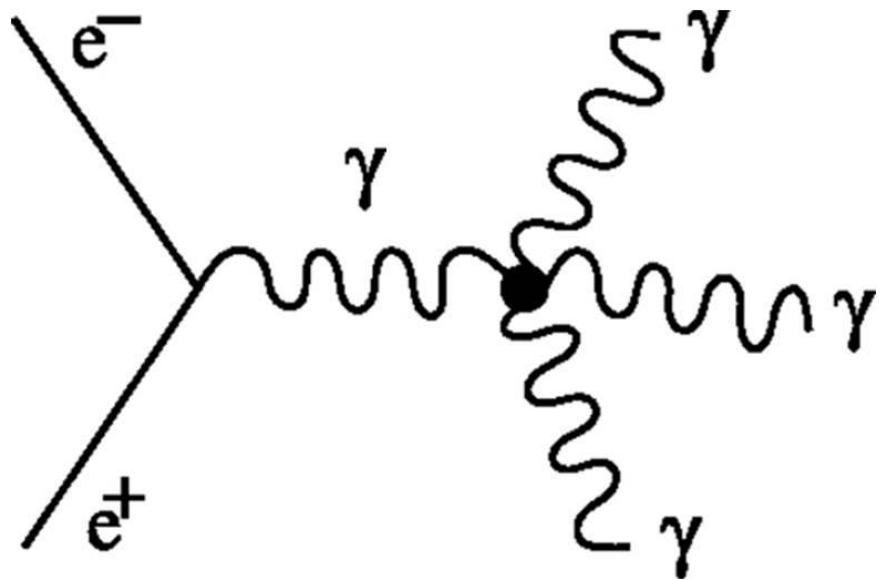
Вопросы есть?



Пора за работу!



Back-up slides



Discovery significance (δ = percentage systematic error)

$$S_{\text{dis}} = \sqrt{2} \left[(s+b) \ln \left(\frac{(s+b)(1+\delta^2 b)}{b + \delta^2 b(s+b)} \right) - \frac{1}{\delta^2} \ln \left(1 + \frac{\delta^2 s}{1 + \delta^2 b} \right) \right]^{1/2}$$

In the limit $\delta = 0$

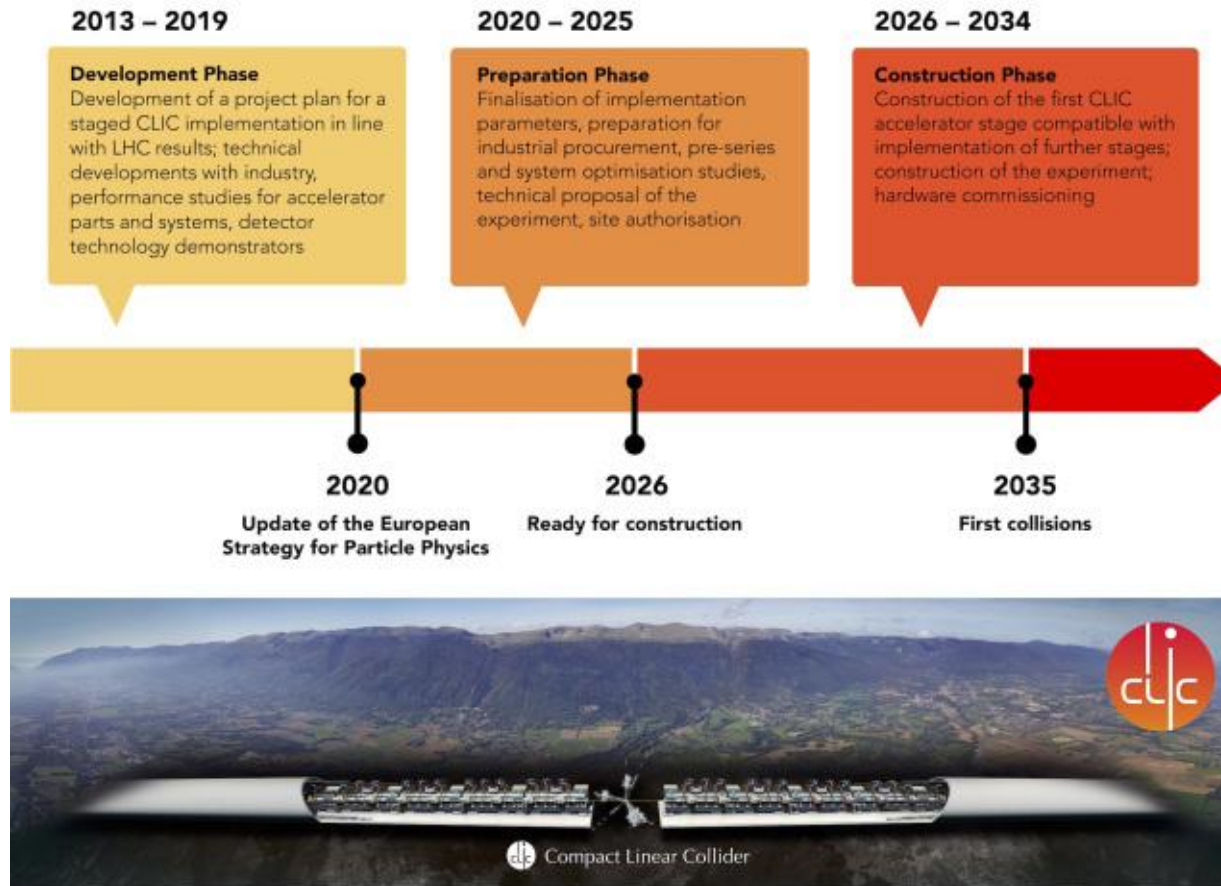
$$S_{\text{dis}} = \sqrt{2 \left[(s+b) \ln \left(1 + \frac{s}{b} \right) - s \right]}$$

$s \ll b$



$$S_{\text{dis}} = \frac{s}{\sqrt{b}}$$

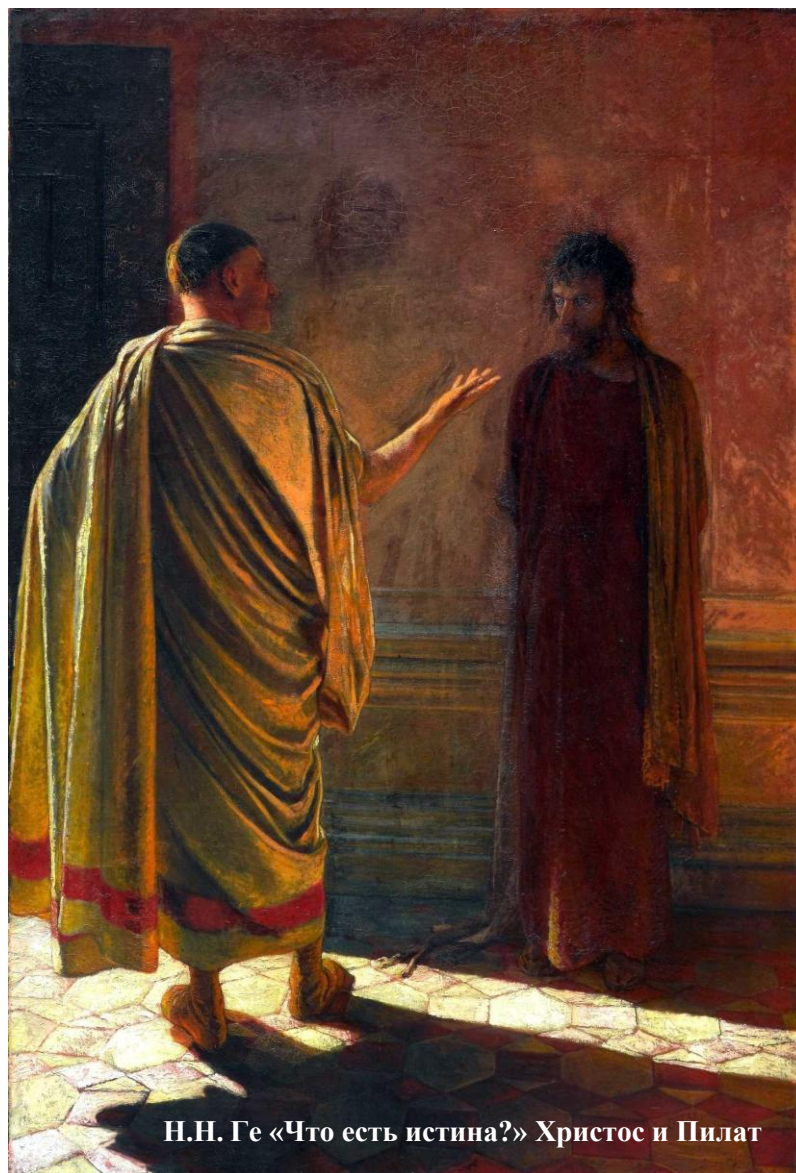
$S_{\text{dis}} \geq 5$ as discovery region



Я рад, товарищи, нарушить свои выступлением патриархальную летнюю тишину нашего Отдела.



Наука – это кладбище гипотез.
Анри Пуанкаре



Н.Н. Ге «Что есть истина?» Христос и Пилат

