Исследование аномального четырёх-бозонного взаимодействия на коллайдере CLIC

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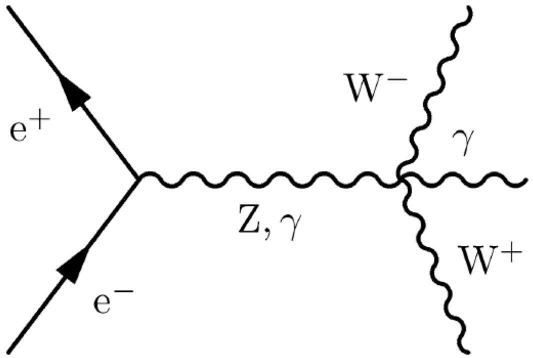
(совместно с В.Макаренко, Минск)

Мультибозонные вершины

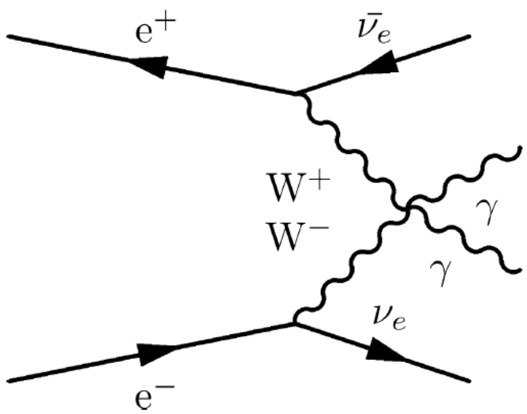
- Стандартная Модель – это неабелева теория, включающая самодействие промежуточных бозонов. Лагранжиан СМ включает вершины:
  - 3-бозонные вершины WWZ, WWγ
  - 4-бозонные WWWW, WWZZ, WWZγ, WWγγ
- Многие теории (напр. BESS) предсказывают новую физику в 4-бозонных вершинах, в то время как 3-бозонные совпадают со СМ

Вершина WW$\gamma\gamma$ на коллайдерах

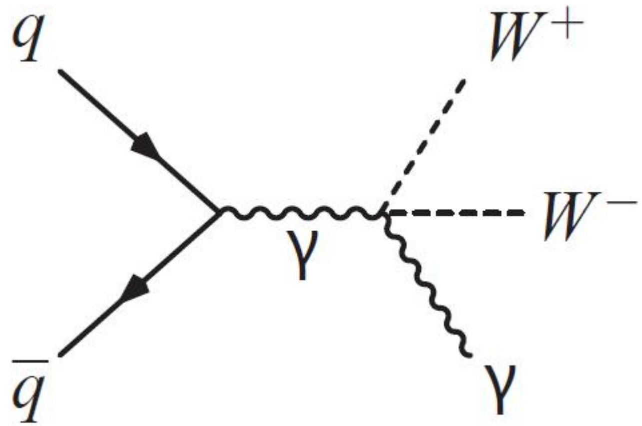
Электрон-позитронные



(a)

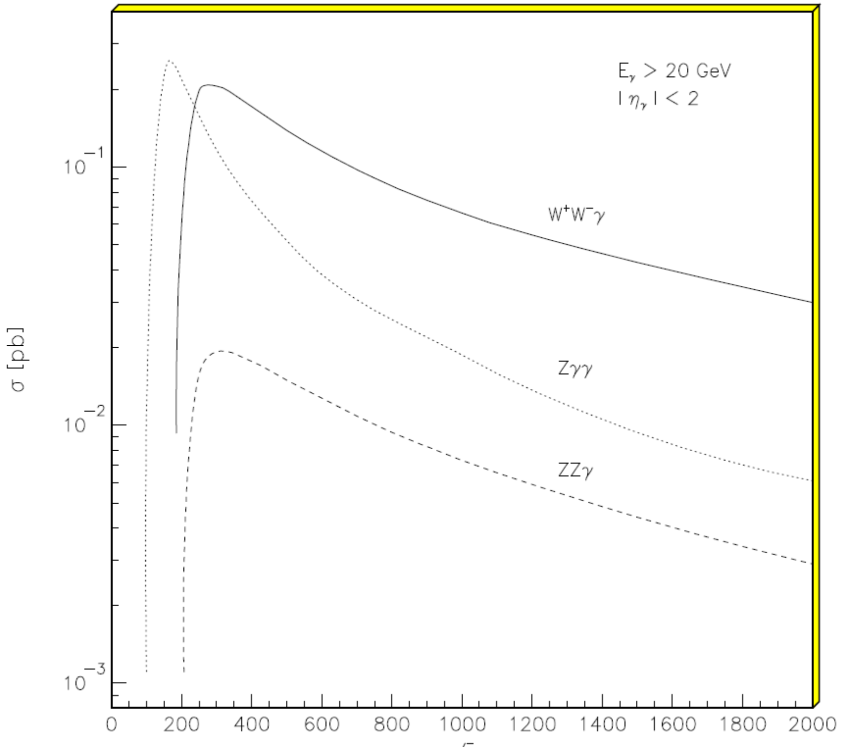


Адронные коллайдеры

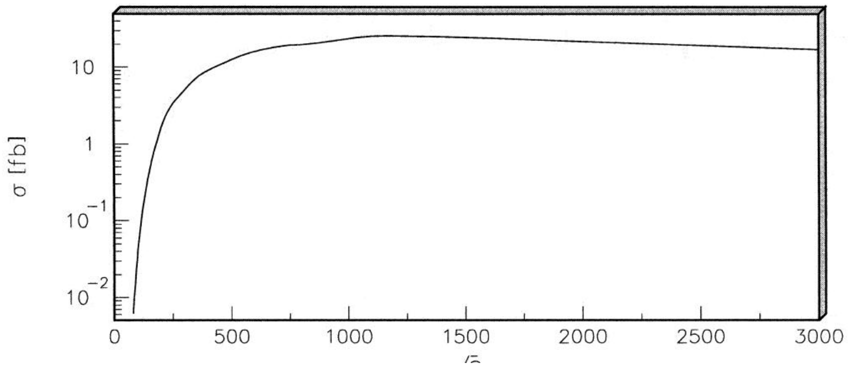


Сечения ее-коллайдеров для вершины WWγγ

γ→WWγ



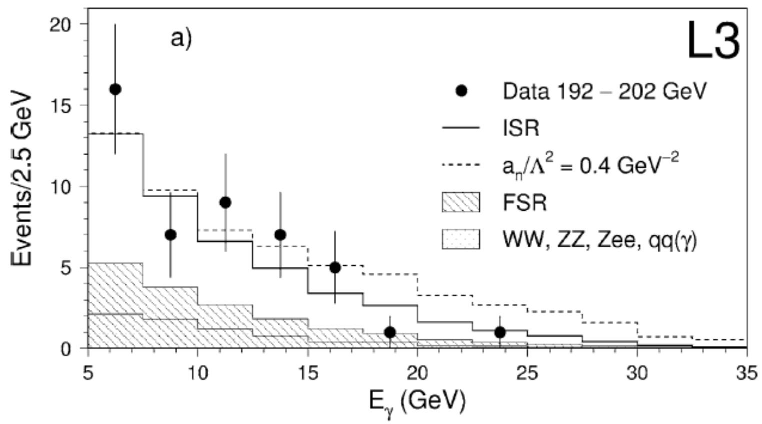
WW →γγ

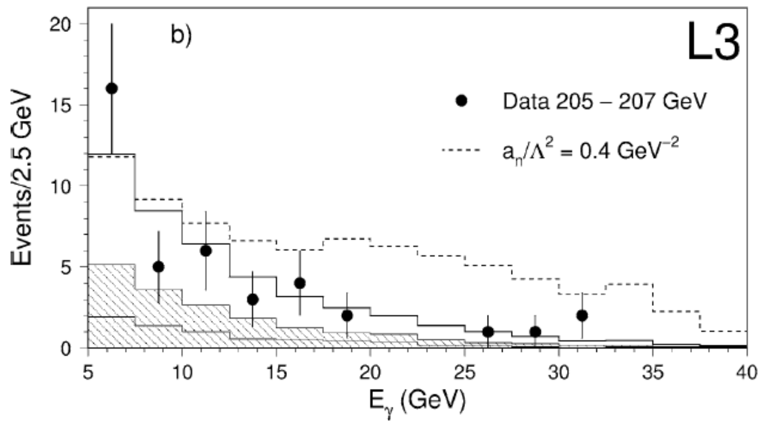


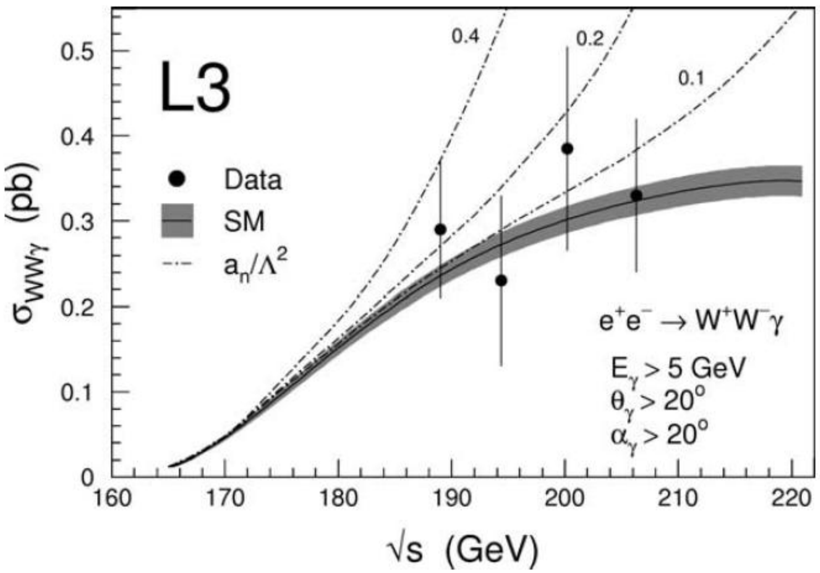
•Сечения WW →γγ невелики (мала WW-светимость)

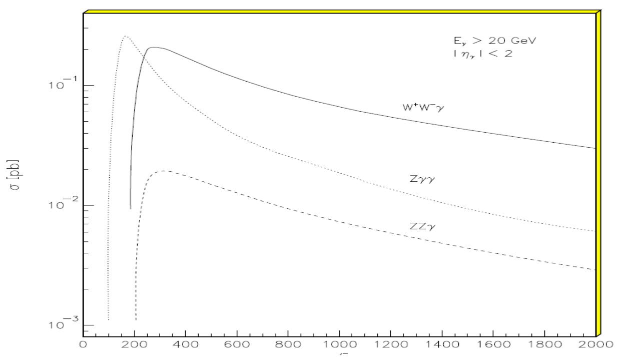
•Распад на WWγ подавлен по сравнению с 2-частичными

Экспериментальные результаты на LEP

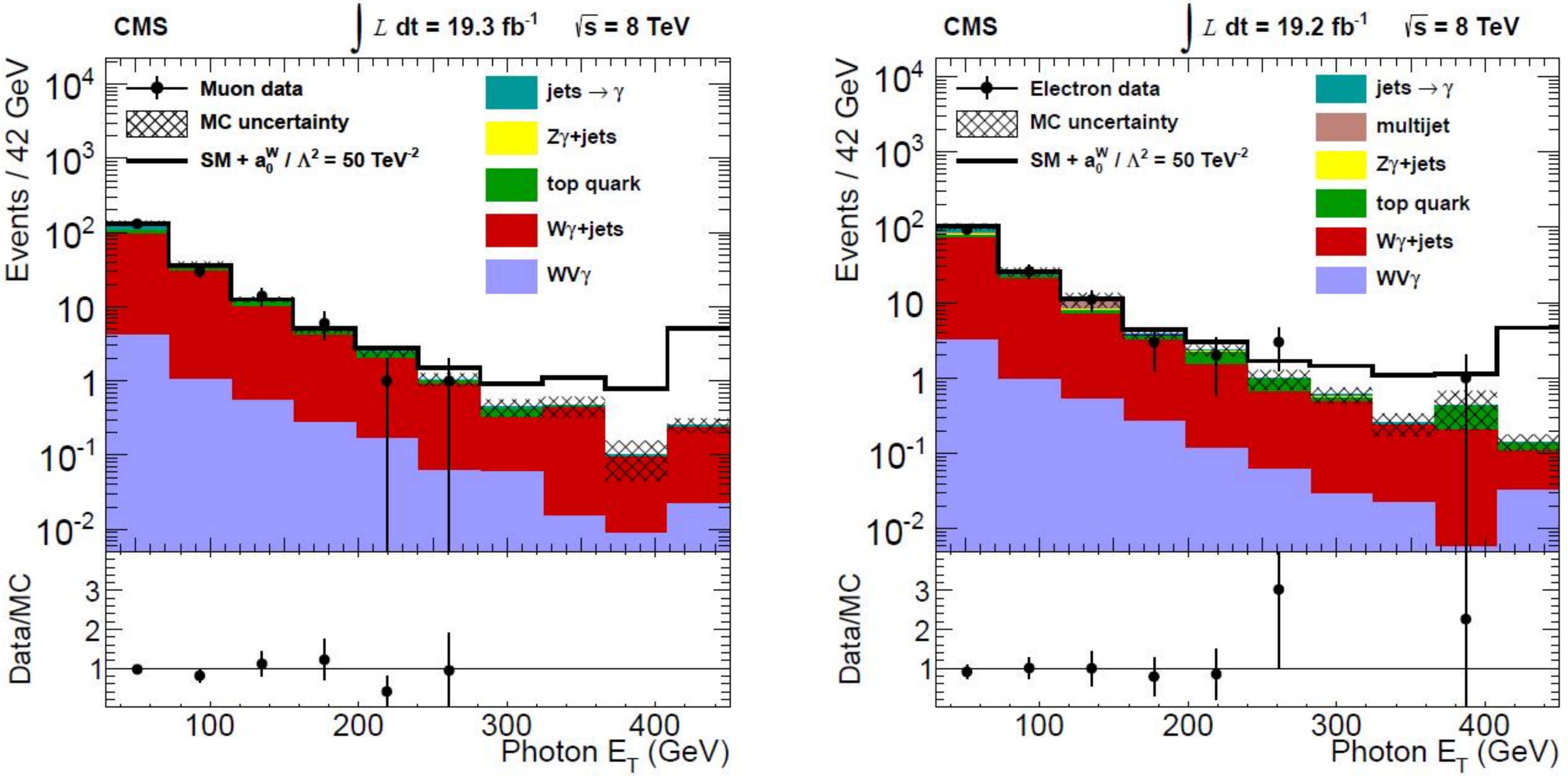






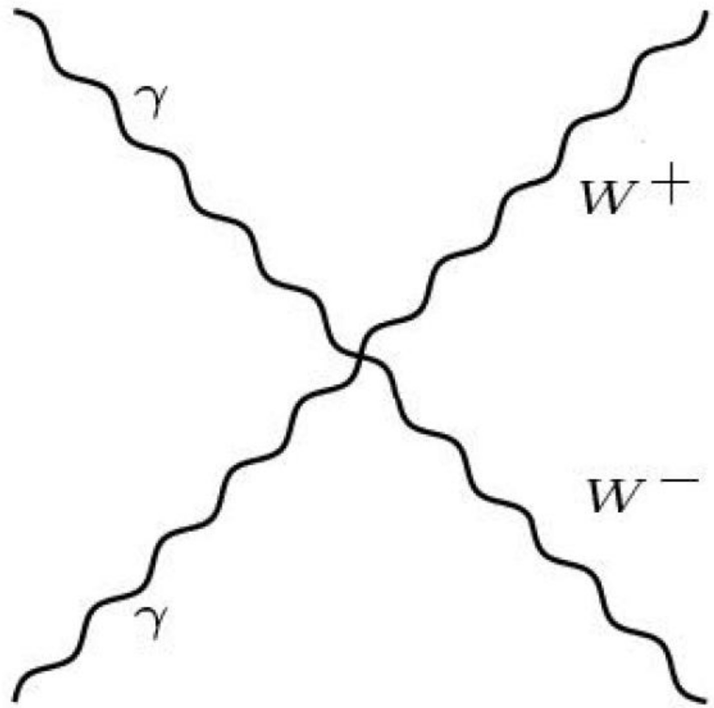


Экспериментальные результаты на LHC

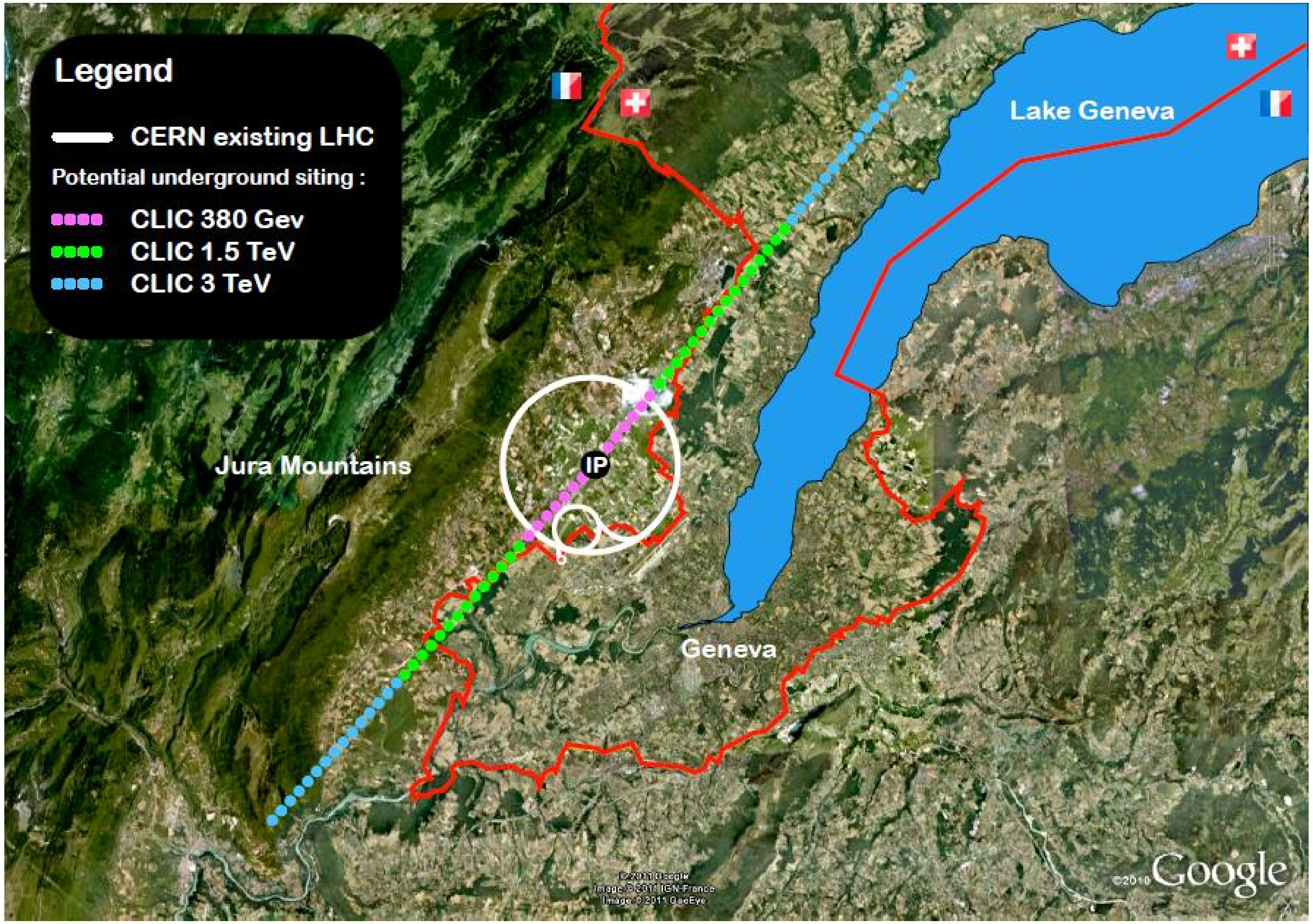


Предложение

- Предлагается изучать вершину WWγγ на коллайдере CLIC через ранее не исследовавшуюся диаграмму γγ → WW



Коллайдер CLIC



Параметры CLIC

- Энергия e^+e^- столкновений:
  380 – 1400 – 3000 ГэВ
- Интегральная светимость при этих энергиях:
  500 – 1500 – 3000 $фб^{-1}$
- Мгновенная светимость: $6x10^{34}$

Альтернативные проекты e^+e^- коллайдеров

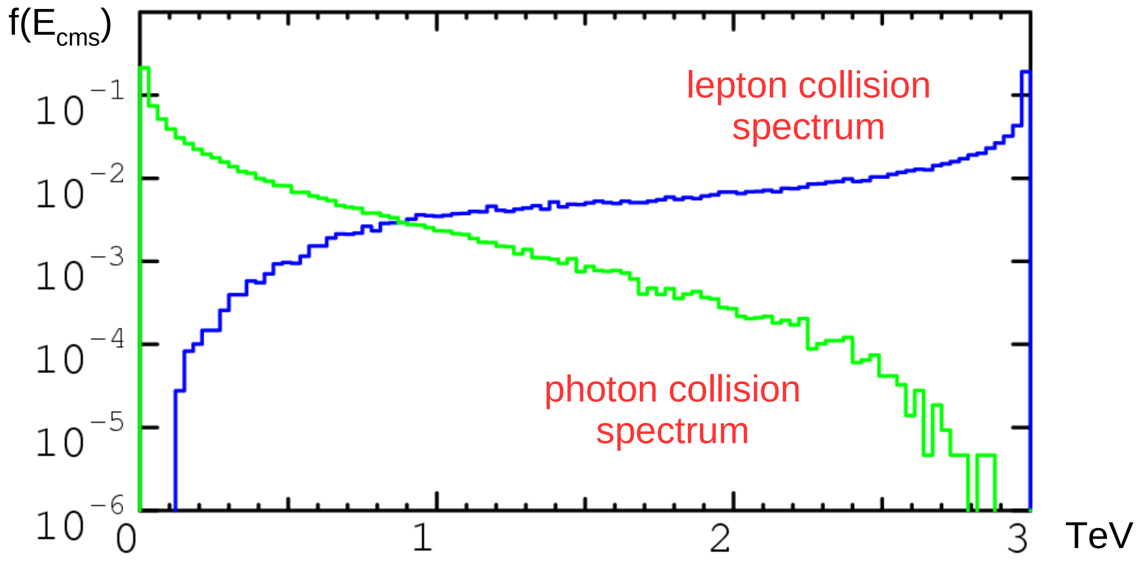
- CEPC: 70 km, 250 GeV, Higgs physics
- FCC: 100 km, 350 GeV, Higgs + Top
- ILC: 30 km, 500-1000 GeV, Higgs, Top, discoveries
- CLIC: 50 km, 3000 GeV, Higgs, Top, discoveries

Столкновения фотонов на CLIC

- При максимальных энергиях CLIC значительная (порядка половины) часть пучковых частиц излучает фотон перед точкой столкновения
- Эти фотоны сталкиваются, создавая значительный “pile-up” через реакцию $\gamma\gamma \rightarrow qq$
- Однако столкновения жёстких фотонов можно использовать для поиска новой физики

Energy spectrum of colliding photons

CLIC is not only a lepton collider ⇒



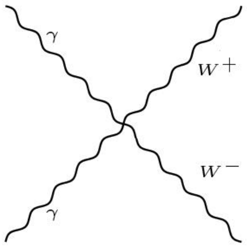
GUINEA-PIG simulation →

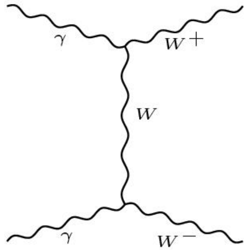
<u>For 3 TeV beams:</u>

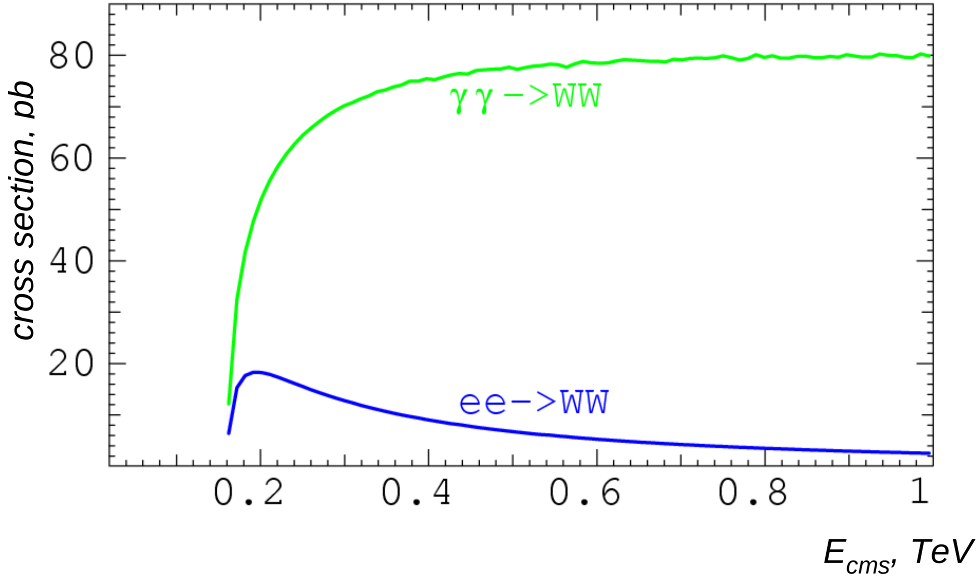
- $L_{e\gamma} / L_{ee} \sim 0.78$
- $L_{\gamma\gamma} / L_{ee} \sim 0.68$
- $L_{\gamma\gamma} / L_{ee} \sim 0.27$ for $E_{\gamma\gamma} > 2\ M_W$

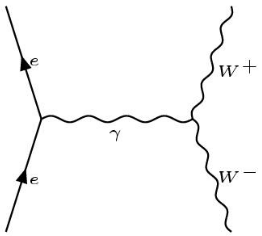
Process γγ → WW

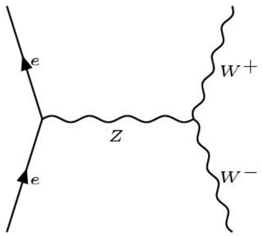
- Cross section in photonic collisions is much higher than in leptonic

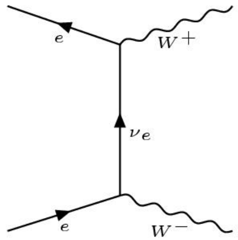


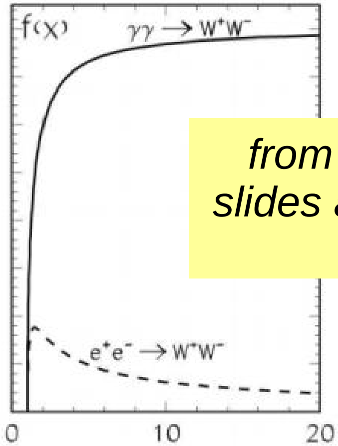












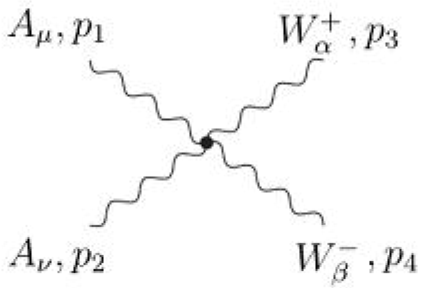
from V.Telnov slides at LCVS'11

Possible physics in γγ → WW

- Anomalous quartic gauge boson couplings (AQGC) in AAWW-vertex:

Effective field theories can be constructed to quantify potential deviations from the SM by introducing genuine AQGC

Standard model



$$\mathrm{i}e^2 C\left[2g_{\mu\nu}g_{\alpha\beta} - g_{\nu\alpha}g_{\mu\beta} - g_{\alpha\mu}g_{\nu\beta}\right] +$$

$$\begin{aligned}\mathrm{i}\frac{e^2}{8\Lambda^2}\times\{&4\,a_0\,g^{\alpha\beta}[(p_1p_2)g^{\mu\nu} - p_1^\nu p_2^\mu] \\ &+ a_c\,[(p_1^\alpha p_2^\beta + p_1^\beta p_2^\alpha)g^{\mu\nu} + (p_1p_2)(g^{\mu\alpha}g^{\nu\beta} + g^{\nu\alpha}g^{\mu\beta}) \\ &\quad - p_1^\nu(p_2^\beta g^{\mu\alpha} + p_2^\alpha g^{\mu\beta}) - p_2^\mu(p_1^\beta g^{\nu\alpha} + p_1^\alpha g^{\nu\beta})] \\ &+ 4\,\tilde{a}_0\,g^{\alpha\beta}p_{1\rho}p_{2\sigma}\varepsilon^{\mu\rho\nu\sigma}\}\end{aligned}$$

$$\mathcal{L}_0 = -\frac{e^2}{16\Lambda^2}a_0 F^{\mu\nu}F_{\mu\nu}\bar{W}^\alpha\bar{W}_\alpha,$$

$$\mathcal{L}_c = -\frac{e^2}{16\Lambda^2}a_c F^{\mu\alpha}F_{\mu\beta}\bar{W}^\beta\bar{W}^\alpha,$$

$$\tilde{\mathcal{L}}_0 = -\frac{e^2}{16\Lambda^2}\tilde{a}_0 F^{\mu\alpha}\tilde{F}_{\mu\beta}\bar{W}^\beta\bar{W}^\alpha,$$

AQGC: scale factor

- Standard AQGC notation leads to violation of unitarity

  - additional form-factor is introduced:

$$a_{0,C}^{W}(W_{\gamma\gamma}^{2}) = \frac{a_{0,C}^{W}}{\left(1 + \frac{W_{\gamma\gamma}^{2}}{\Lambda_{\text{cutoff}}^{2}}\right)^{2}}.$$

  - Λ_{cutoff} is traditionally set to 500GeV

Latest measurements:

CMS:
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ATLAS:
Phys.Rev.Lett. 115 (2015) no.3, 031802
CERN-EP-2016-167

LEP-2:
Eur.Phys.J. C20 (2001) 201-215
Phys.Rev. D70 (2004) 032005

PDG review:
pdg.lbl.gov/2016/reviews/rpp2016-rev-wz-quartic-couplings.pdf

How to select γγWW-vertex events

- WW hadronic decays

  rate: ~47%

  - included into γγ →hadrons study,
  - hard to separate γγWW vertex
  - huge background

- WW semileptonic decays

  rate: ~7% per mode $\{e^+ + jets\}$, $\{e^- + jets\}$, $\{\mu^+ + jets\}$, $\{\mu^- + jets\}$

  - two jets with $m_{inv} \sim M_W$
  - single lepton along opposite charged beam
  - E_{miss}
  - high background

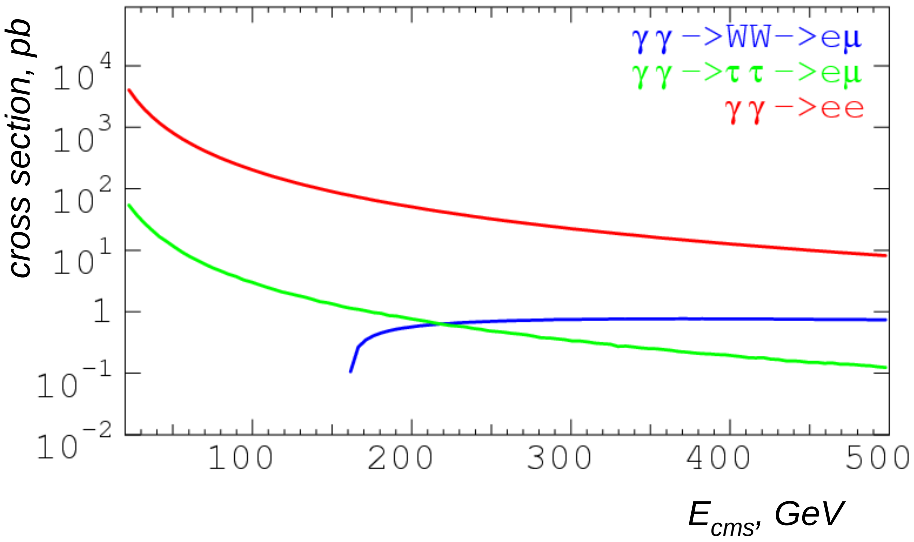
- WW leptonic decays

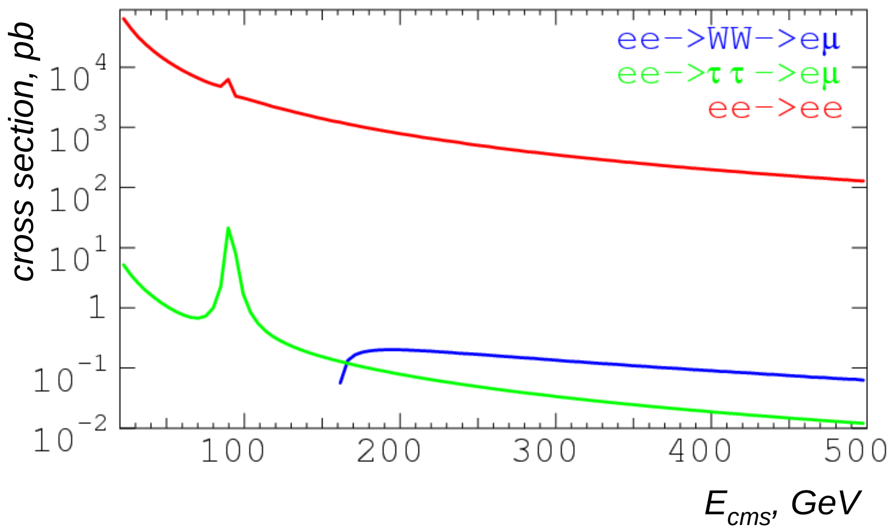
  rate: ~1% per pair of $\{e^+e^-\}$, $\{e^+\mu^-\}$, $\{\mu^+e^-\}$, $\{\mu^+\mu^-\}$

  - two non-collinear leptons (incl. different flavour case)
  - no other particles in final state
  - E_{miss}

No significant background in $e^-\mu^+$ and $e^+\mu^-$ channels!

WW-decay: WW→ee$\nu_e\nu_e$ vs. WW→eμ$\nu_e\nu_\mu$





Cross sections (pb) for

- γγ → WW →ee$\nu_e\nu_e$, eμ$\nu_e\nu_\mu$
- γγ →ττ → ee$\nu_e\nu_e$, eμ$\nu_e\nu_\mu$
- γγ → ee

Cuts:

- e,μ polar angle cut 10^o

Cross sections (pb) for

- ee → WW →ee$\nu_e\nu_e$, eμ$\nu_e\nu_\mu$
- ee → ττ→ ee$\nu_e\nu_e$, eμ$\nu_e\nu_\mu$
- ee → ee

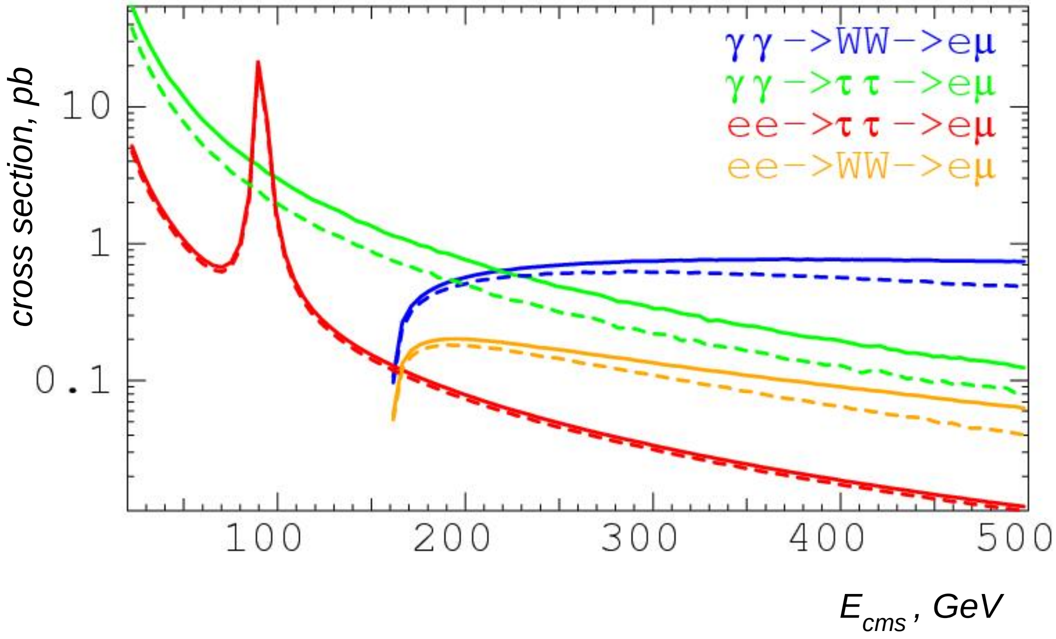
Cuts:

- e,μ polar angle cut 10^o

Conclusion:

due to huge background from {γγ,ee→ee} we'll use study eμ channel only

γγ → eμ and background processes



Cross sections (pb) * BR for

$\gamma\gamma$,ee → WW → $e\mu\nu_e\nu_\mu$

$\gamma\gamma$,ee → ττ → $e\mu\nu_e\nu_\mu$

solid lines:

e,μ polar angle cut *10^o*

dashed lines:

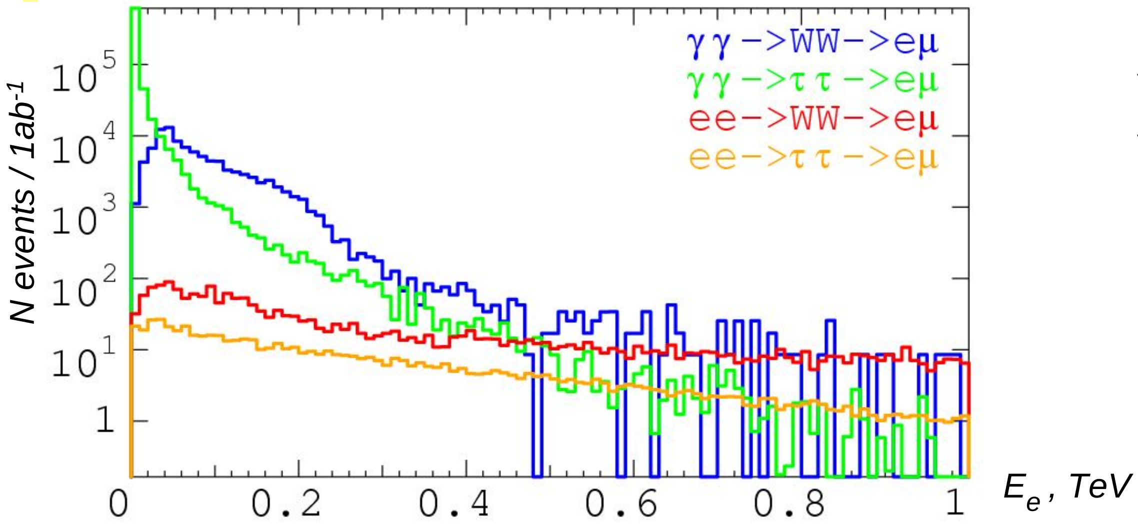
e,μ polar angle cut *20^o*

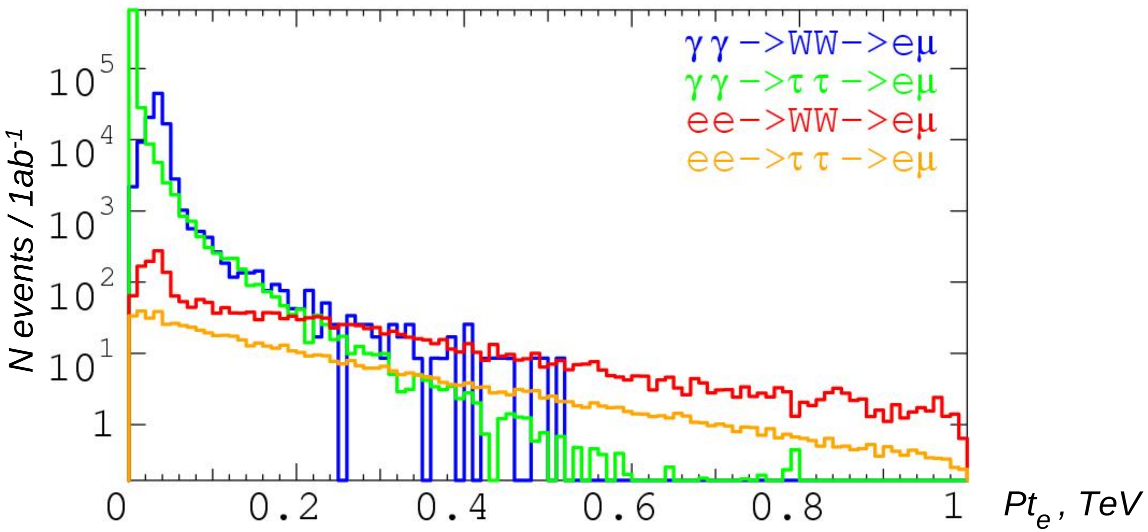
Signal process (SM): blue lines

We expect significant amount of signal events

$\gamma\gamma \to e\mu$ and background processes

Next we apply beam spectrum:

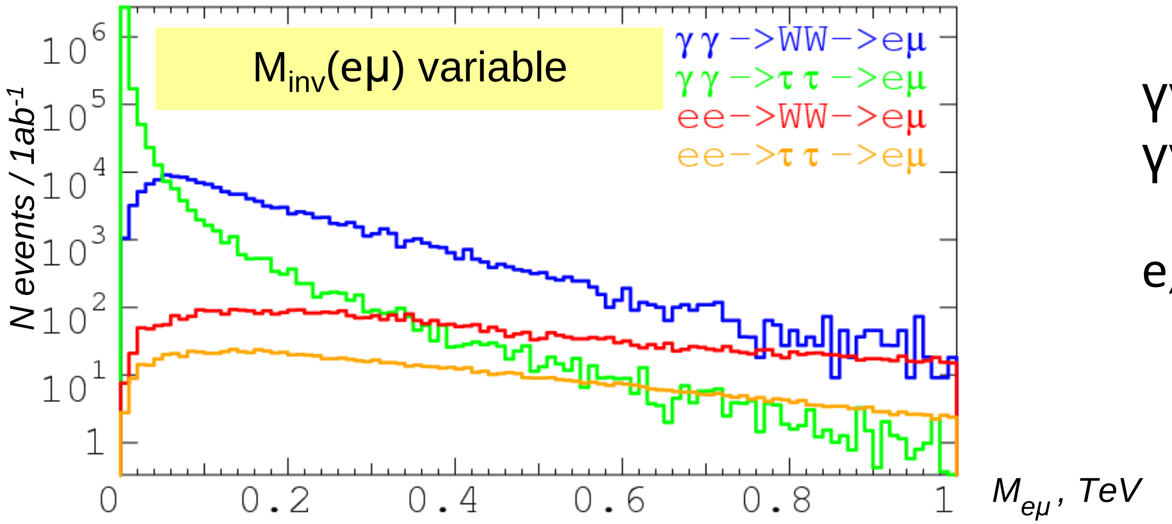




$\gamma\gamma$, ee $\to$ WW $\to e\mu\nu_e\nu_\mu$
$\gamma\gamma$, ee $\to \tau\tau \to e\mu\nu_e\nu_\mu$

e, μ polar angle cut: *10^o*

$\gamma\gamma \to e\mu$ and background processes



$\gamma\gamma$, ee $\to$ WW $\to e\mu\nu_e\nu_\mu$

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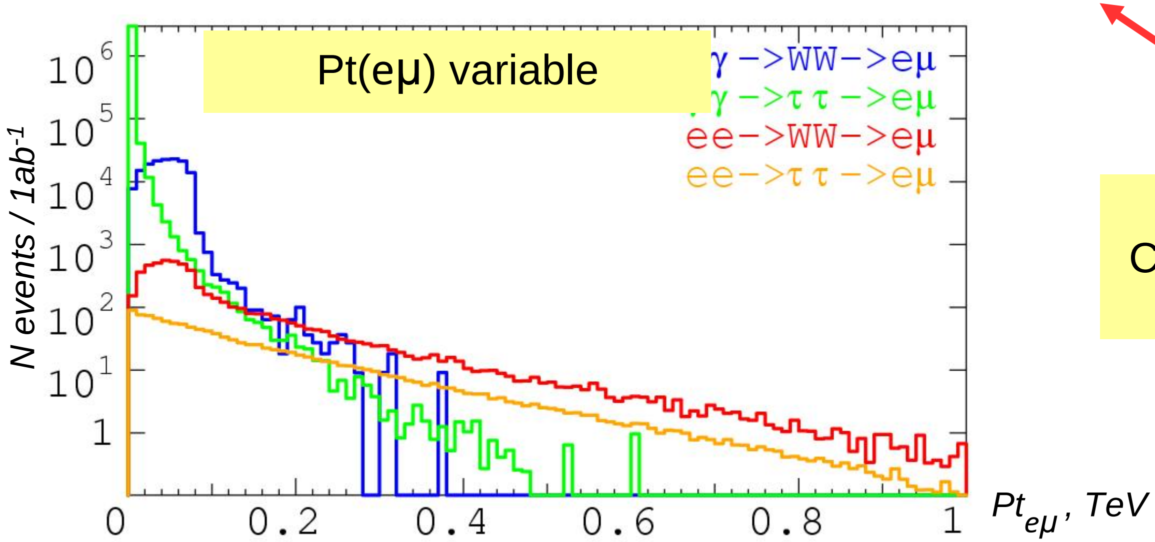
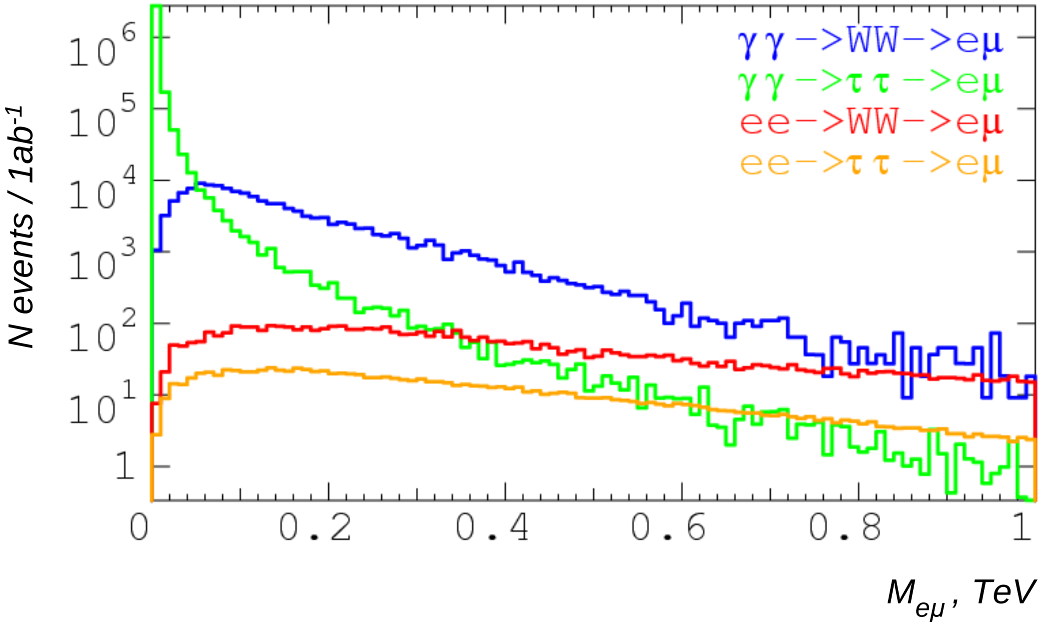


Clear signal events separation

CLIC vs. LHC

Compare events number to latest CMS results:



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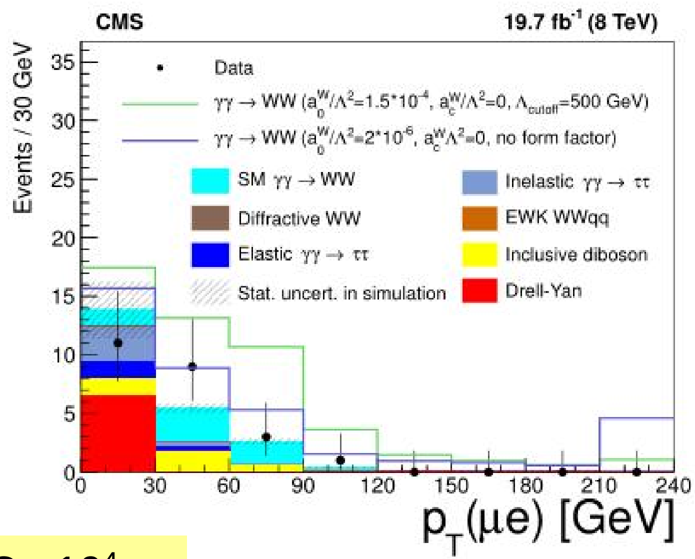
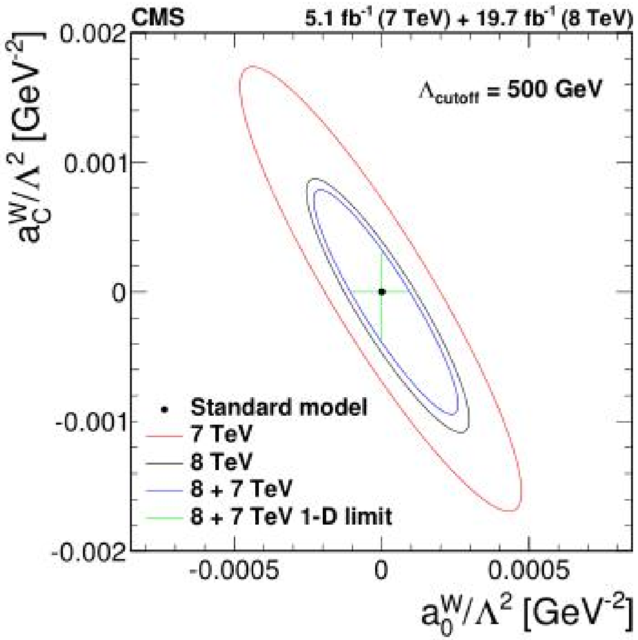


Signal events factor CLIC / LHC ~10^4

CLIC vs. LHC

- Energy scale similar to LHC study
- Signal events ~10^4 times more

Constant	a_0/Λ^2 , GeV^{-2}	a_c/Λ^2 , GeV^{-2}
Previous limit (95% CL)	$-1.5 \dots +1.5 \times 10^{-4}$	$-5 \dots +5 \times 10^{-4}$
Estimated CLIC limit (95% CL)	$\sim -1 \dots +1 \times 10^{-6}$	$\sim -4 \dots +4 \times 10^{-6}$



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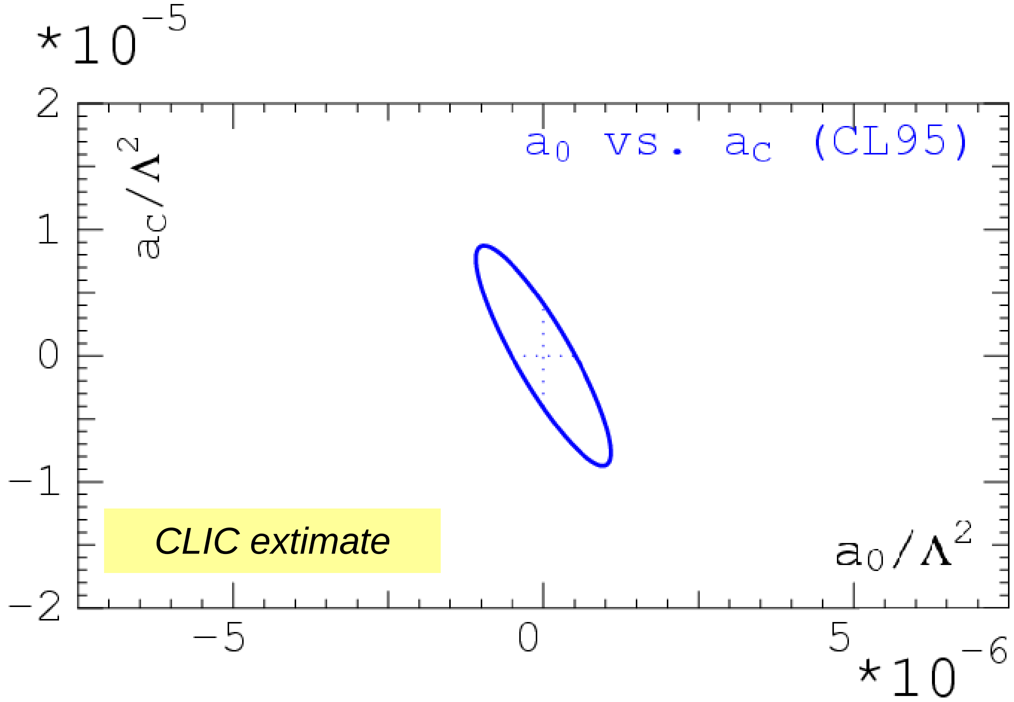
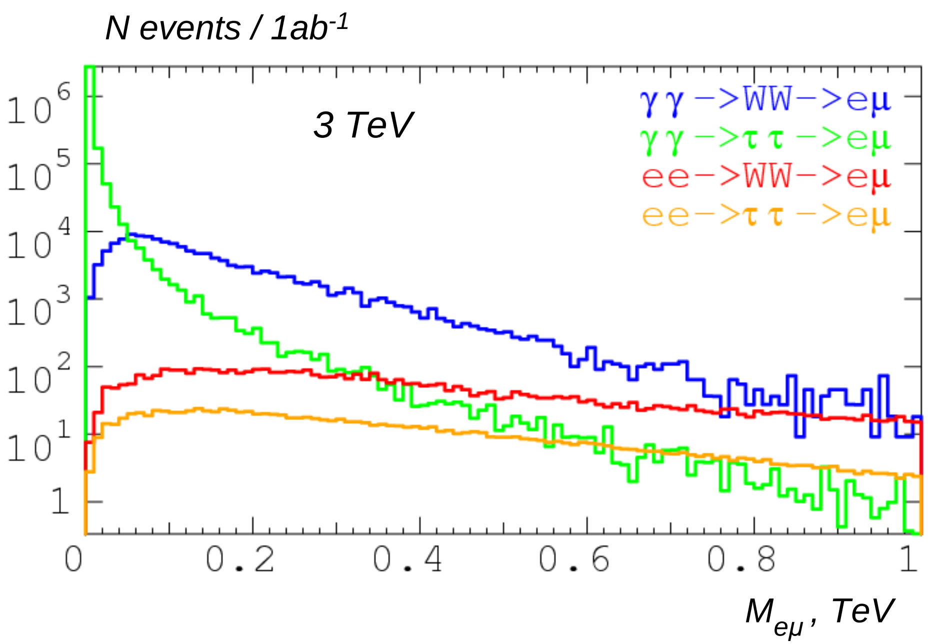
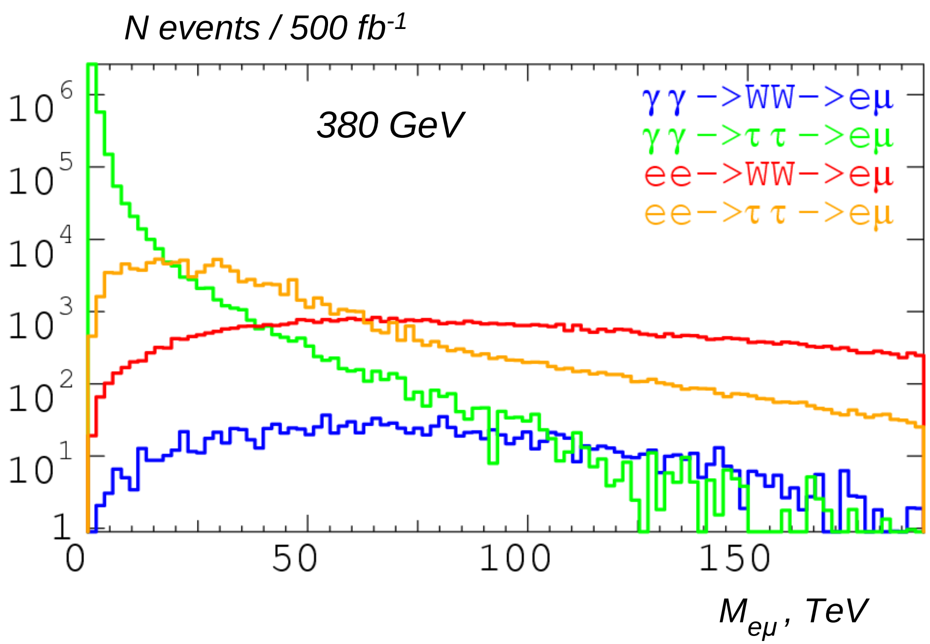


CLIC extimate

3 TeV vs. 380 GeV





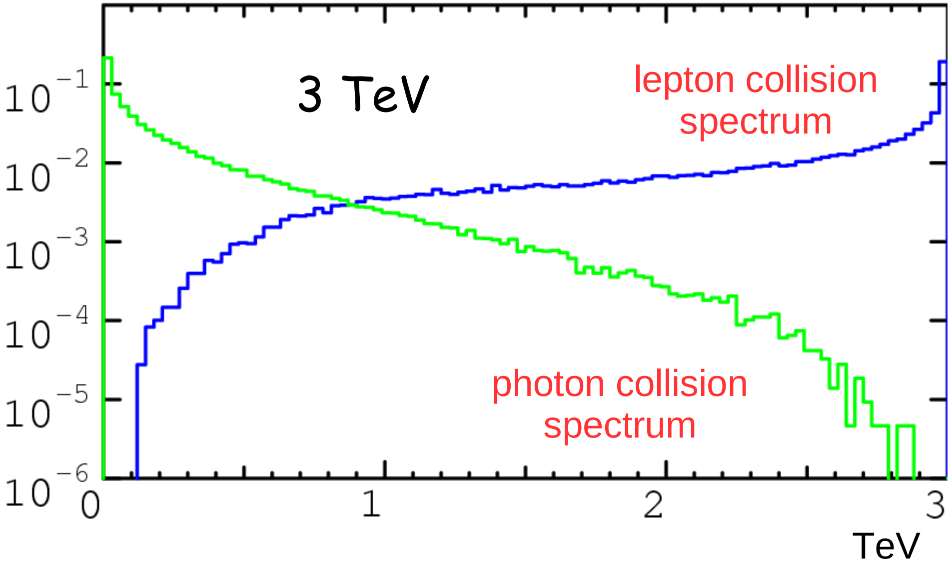
$\gamma\gamma$, ee $\longrightarrow$ WW $\longrightarrow e\mu\nu_e\nu_\mu$

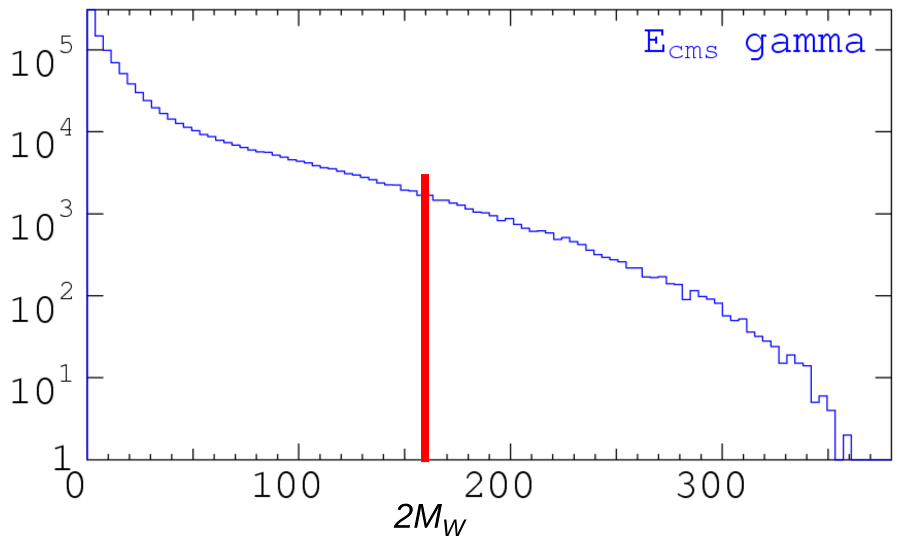
$\gamma\gamma$, ee $\longrightarrow \tau\tau \longrightarrow e\mu\nu_e\nu_\mu$

$M_{inv}(e\mu)$ variable

e, μ polar angle cut: *10^o*

3 TeV vs. 380 GeV





Collision		350 GeV	0.5 TeV	1.4 TeV	3 TeV
ee	L_{ee}/L_{ee}	1.0	1.0	1.0	1.0
eg	L_{eg}/L_{ee}	0.45	0.50	0.75	0.79
ge	L_{ge}/L_{ee}	0.45	0.50	0.75	0.79
gg	L_{gg}/L_{ee}	0.23	0.31	0.64	0.69

Conclusions

• The background photon collisions may be used for search of new physics $\gamma\gamma WW$ couplings.

• The WW decay into leptons with different flavour looks promising.

• The process $\gamma\gamma \to WW \to e\mu\nu_e\nu_\mu$ provides a clear test for anomalous quartic gauge boson couplings:

- low background
  - basic background from tau-lepton decays

- high event number (~10^4 factor to current to LHC data)
  ⇒ significant increase is expected for previous AQGC limits

•The super-high CLIC energy is required to study this process. Energy of CEPC (250 GeV), FCC (380 GeV) and ILC (500 GeV) are insufficient!