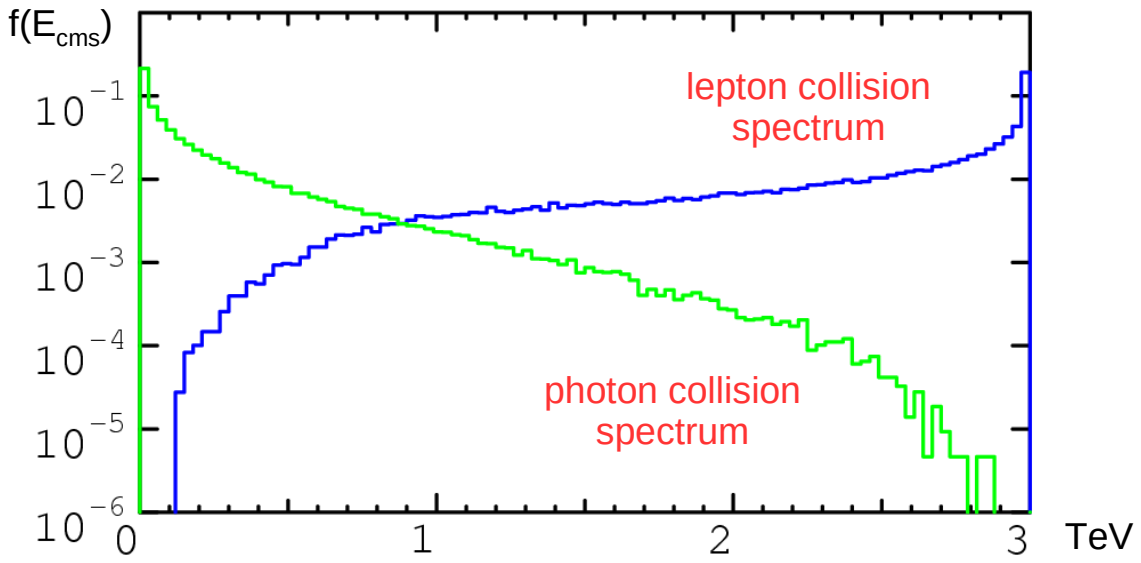
Anomalous gauge boson couplings measurement in photon-photon collisions

V. Makarenko (INP BSU, Minsk)

I. Boyko (JINR, Dubna),

Energy spectrum of colliding photons

CLIC is not only a lepton collider ⇒



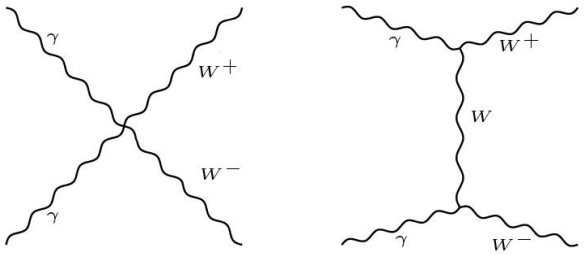
GUINEA-PIG simulation →

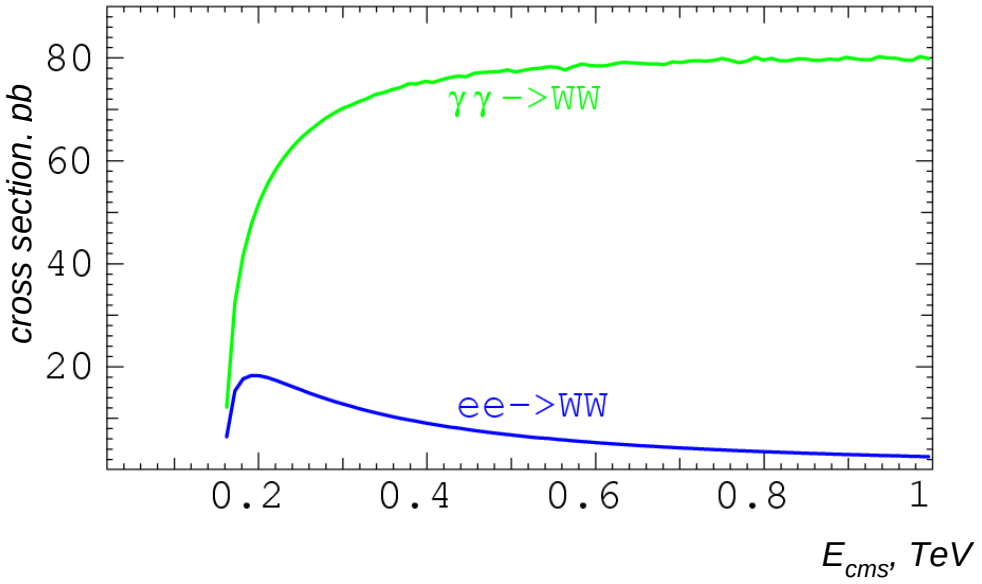
For 3 TeV beams:

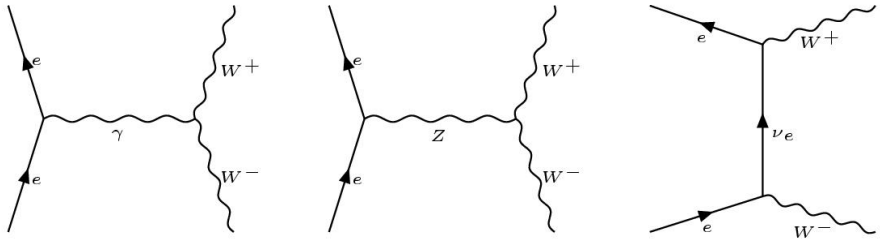
- $L_{e\gamma} / L_{ee} \sim 0.78$
- $L_{\gamma\gamma} / L_{ee} \sim 0.68$
- $L_{\gamma\gamma} / L_{ee} \sim 0.27$ for $E_{\gamma\gamma} > 2 M_W$

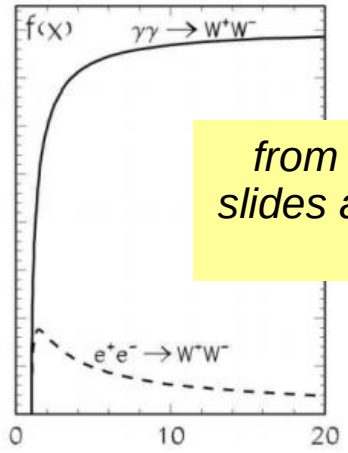
Process γγ → WW

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







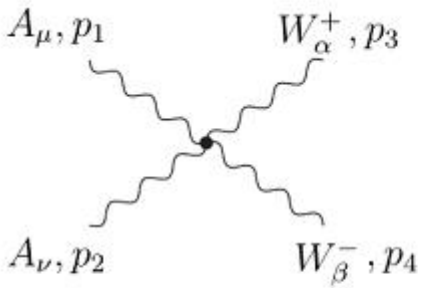


from V.Telnov slides at LCVS'11

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

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

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

$$\mathcal{L}_0 = -\frac{e^2}{16\Lambda^2}a_0F^{\mu\nu}F_{\mu\nu}\bar{W}^\alpha\bar{W}_\alpha,$$

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

$$\tilde{\mathcal{L}}_0 = -\frac{e^2}{16\Lambda^2}\tilde{a}_0F^{\mu\alpha}\tilde{F}_{\mu\beta}\bar{W}^\beta\bar{W}^\alpha,$$

AQGC: scale factor

- Standard AQGC notation leads to violation of unitarity

  - additional form-factor is introduced:

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

  - Λ_{cutoff} is traditionally set to 500GeV

Latest measurements:

CMS:
JHEP 1608 (2016) 119

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

Codes used

Beam spectrum:

- GUINEA-PIG,
- event files from
  http://clic-beam-beam.web.cern.ch/clic-beam-beam/

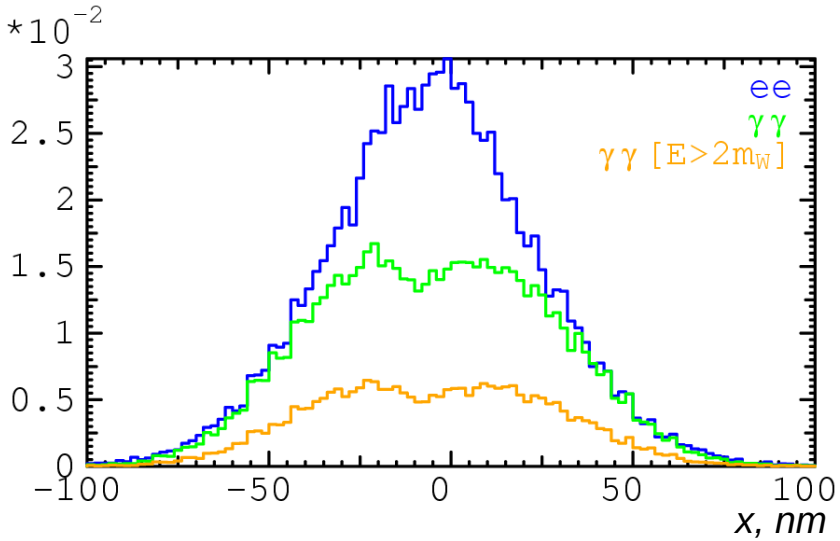
Monte-Carlo, cross sections:

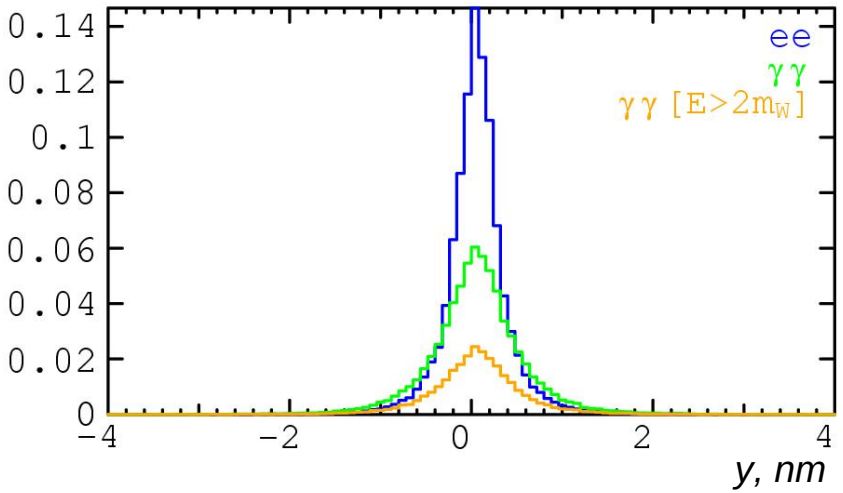
- own codes

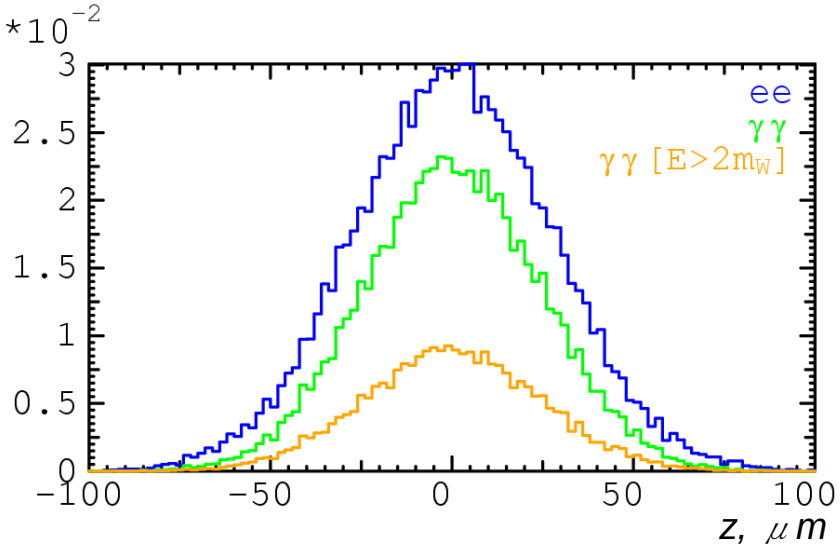
Can we separate $\gamma\gamma$ events by IP ?

IP distribution in gamma-gamma collisions

GUINEA-PIG simulation







Photonic processes can't be separated by IP

How to select γγWW-vertex events

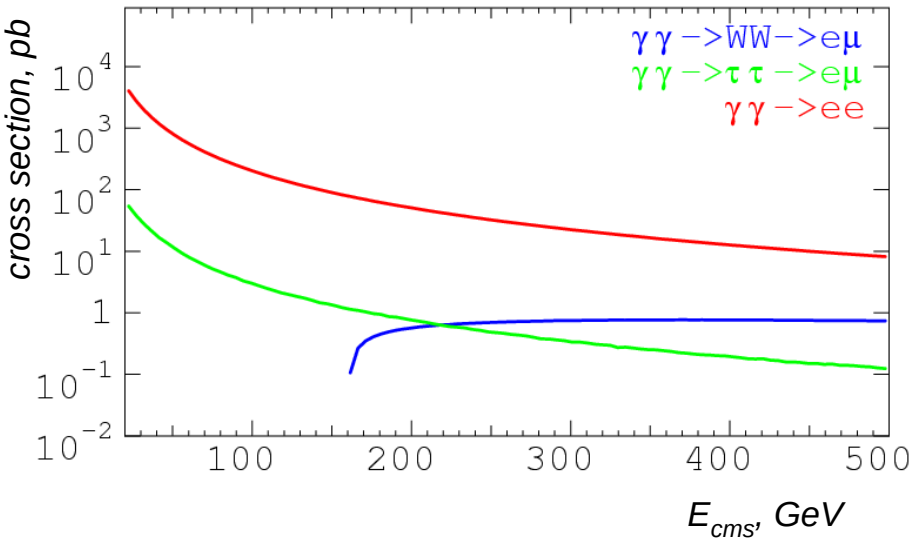
- WW hadronic decays
  rate: ~47%
  - included into γγ →hadrons study,
  - hard to separate γγWW vertex
  - huge background

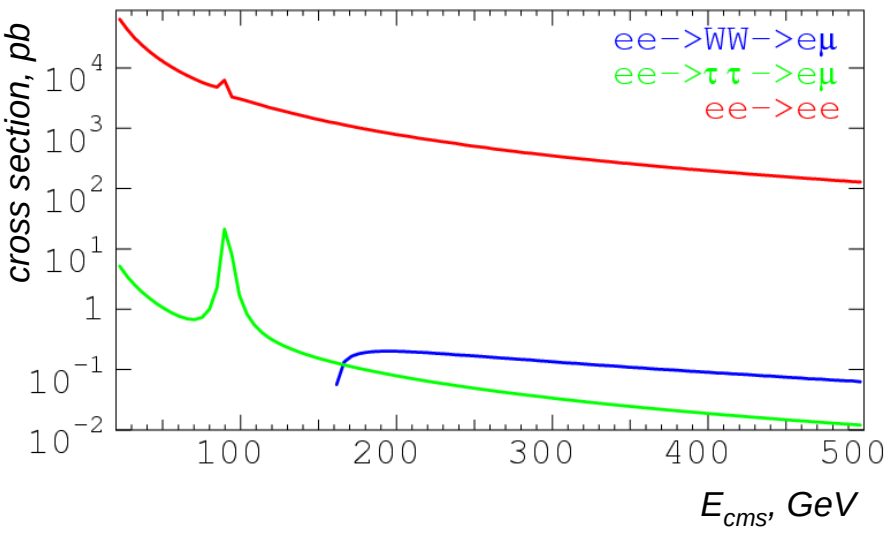
- WW semileptonic decays
  rate: ~7% per mode {e^++*jets*}, {e^-+*jets*}, {μ^++*jets*}, {μ^-+*jets*}
  - two jets with $m_{inv} \sim M_W$
  - single lepton along opposite charged beam
  - E_{miss}
  - high background

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

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

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

$\gamma\gamma \to ee$

Cuts:

e,μ polar angle cut 10°

Cross sections (pb) for

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

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

$ee \to ee$

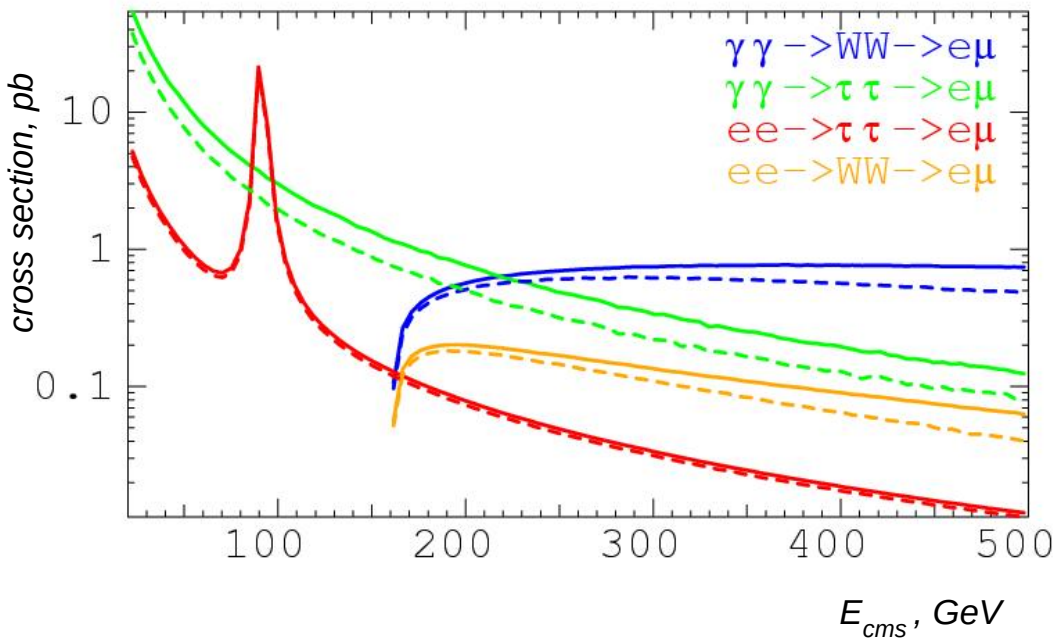
Cuts:

e,μ polar angle cut 10°

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

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

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

solid lines:

e,μ polar angle cut 10^o

dashed lines:

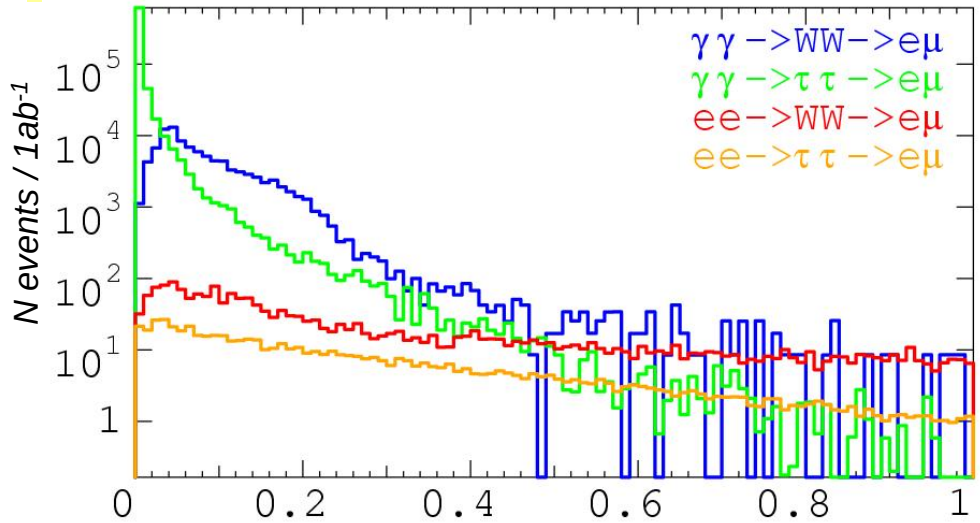
e,μ polar angle cut 20^o

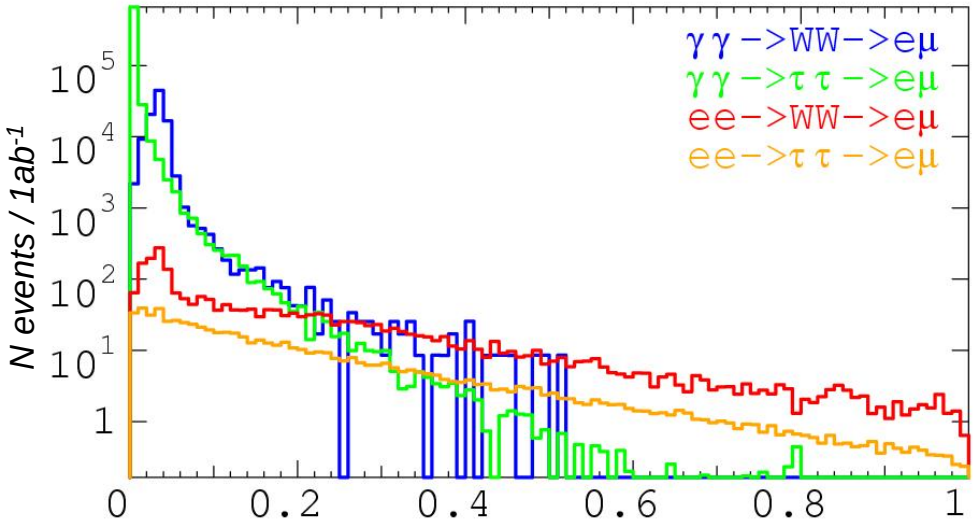
Signal process (SM): blue lines

We expect significant amount of signal events

γγ → eμ and background processes

Next we apply beam spectrum:



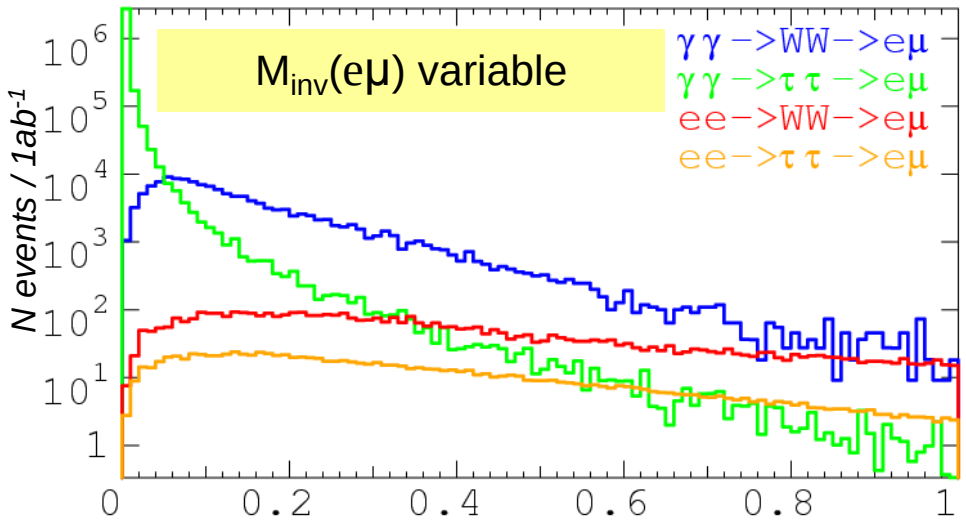


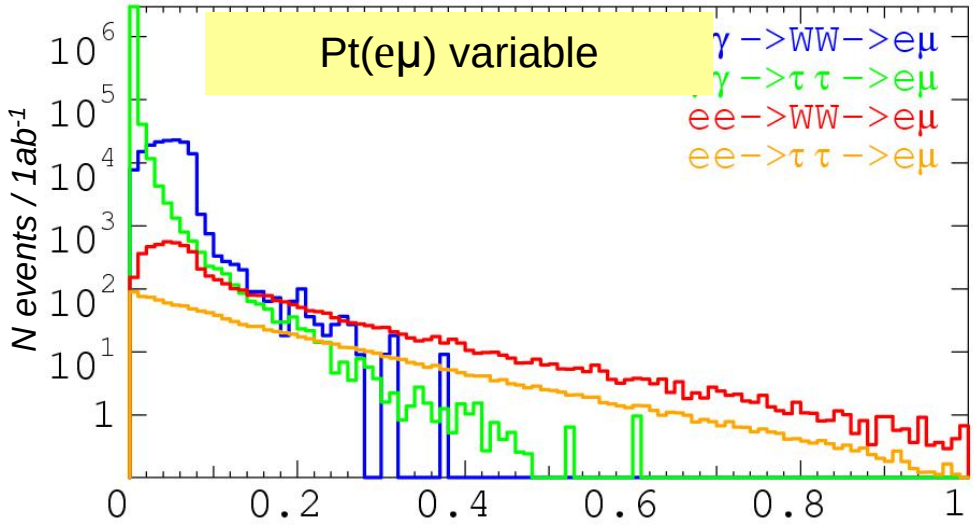
$\gamma\gamma$, ee $\rightarrow$ WW $\rightarrow e\mu\nu_e\nu_\mu$

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

e, μ polar angle cut: 10^o

γγ → eμ and background processes





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

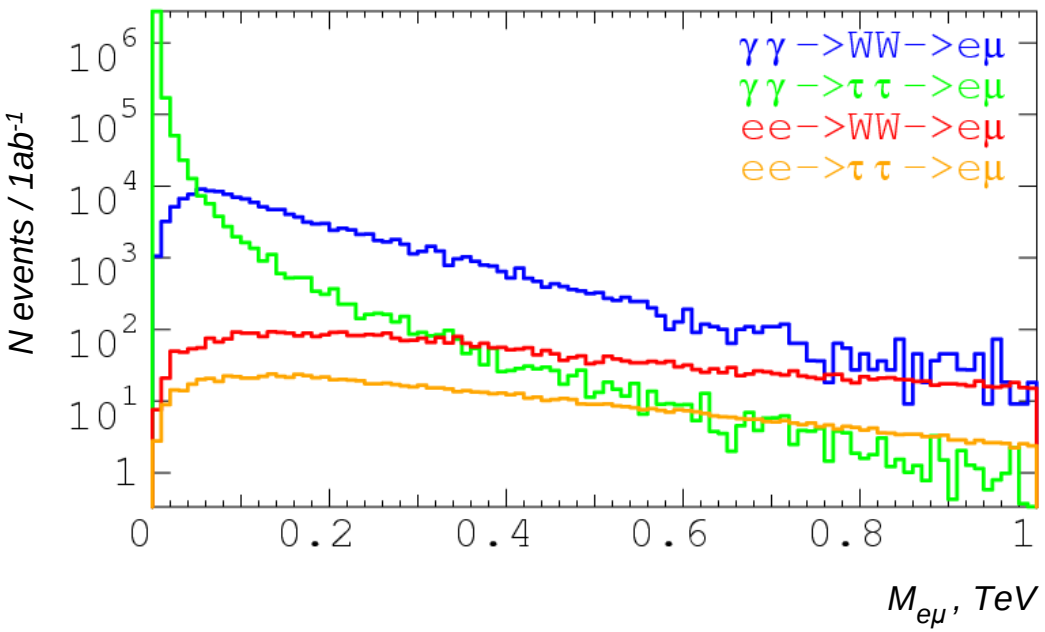
$\gamma\gamma, ee \rightarrow \tau\tau \rightarrow e\mu\nu_e\nu_\mu$

e, μ polar angle cut: 10^o

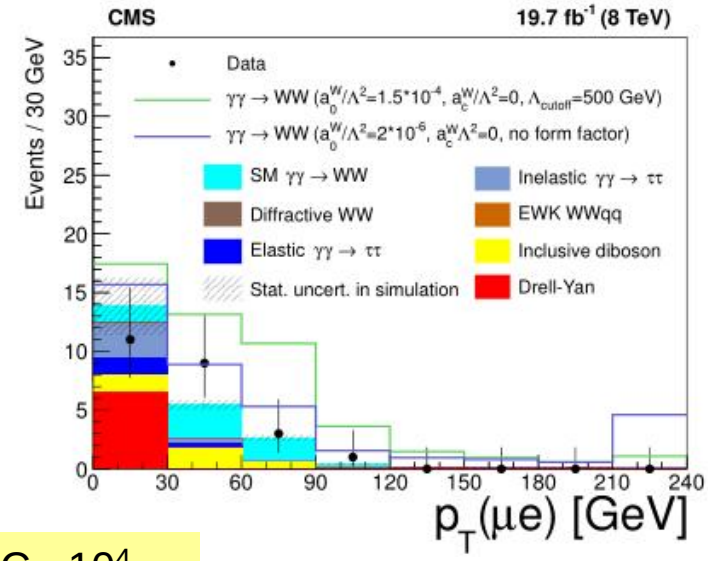
Clear signal events separation

CLIC vs. LHC

Compare events number to latest CMS results:



JHEP 1608 (2016) 119

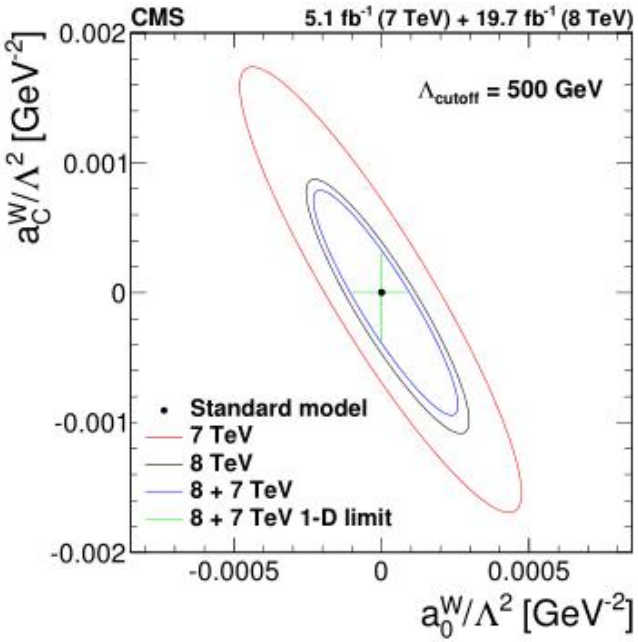


Signal events factor CLIC / LHC ~10^4

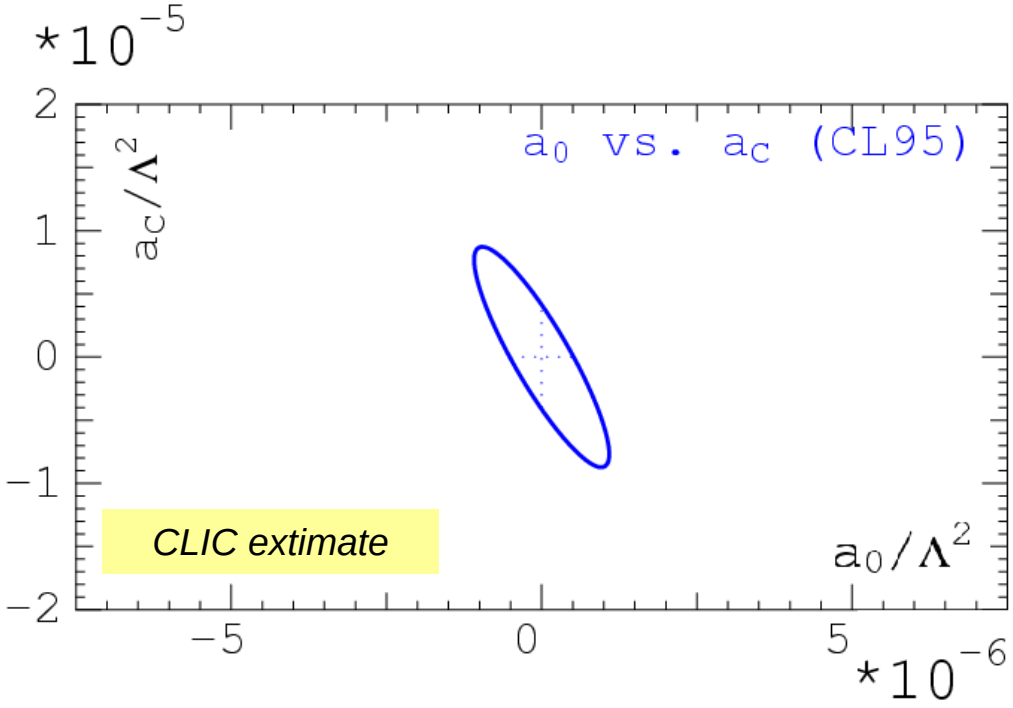
CLIC vs. LHC

- 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 … + 1.5 *x10^{-4}*	−5 … +5 *x10^{-4}*
Estimated CLIC limit (95% CL)	*~ −1 … +1 x10^{-6}*	*~ −4 … +4 x10^{-6}*



JHEP 1608 (2016) 119



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.

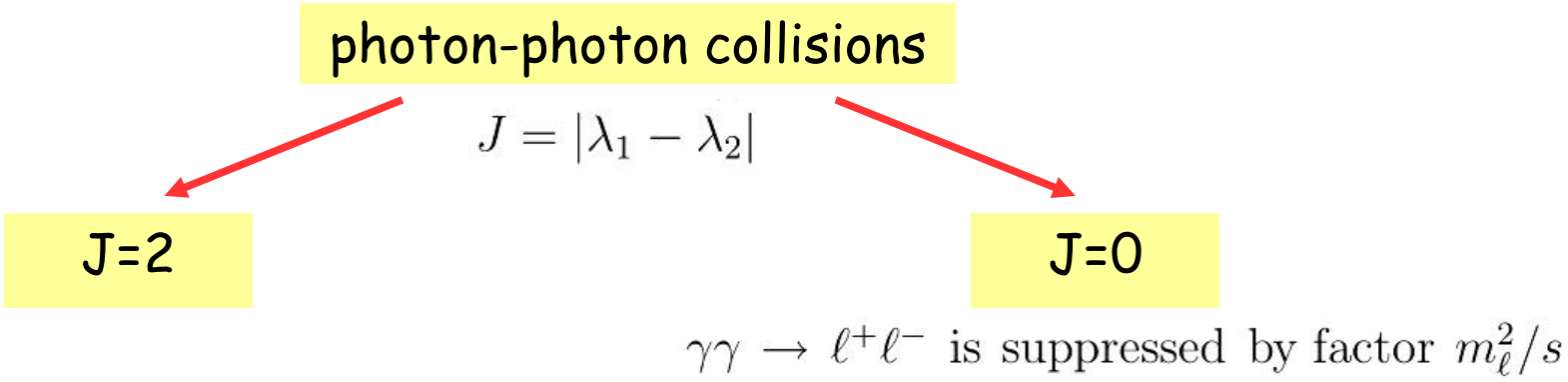
• The process $\gamma\gamma \rightarrow WW \rightarrow e\mu\nu_e\nu_\mu$ provides a clear test for anomalous quartic gauge boson couplings:

- low background
  - basic background from tau-lepton decays
- high event number (~10^4 factor to current to LHC data)
  $\Rightarrow$ significant increase is expected for previous AQGC limits

Backup slides

Luminosity measurement in photon-photon collisions

Different measurement schemes are required for two helicity modes:



Luminosity can be measured using:

- $\gamma\gamma \to e^+e^-$ process
  - huge cross section
  - huge background from $e^+e^- \to e^+e$
    - can be suppressed by applying cut on M(ee): $M(ee) << E_{nominal}$

Luminosity can be measured using:

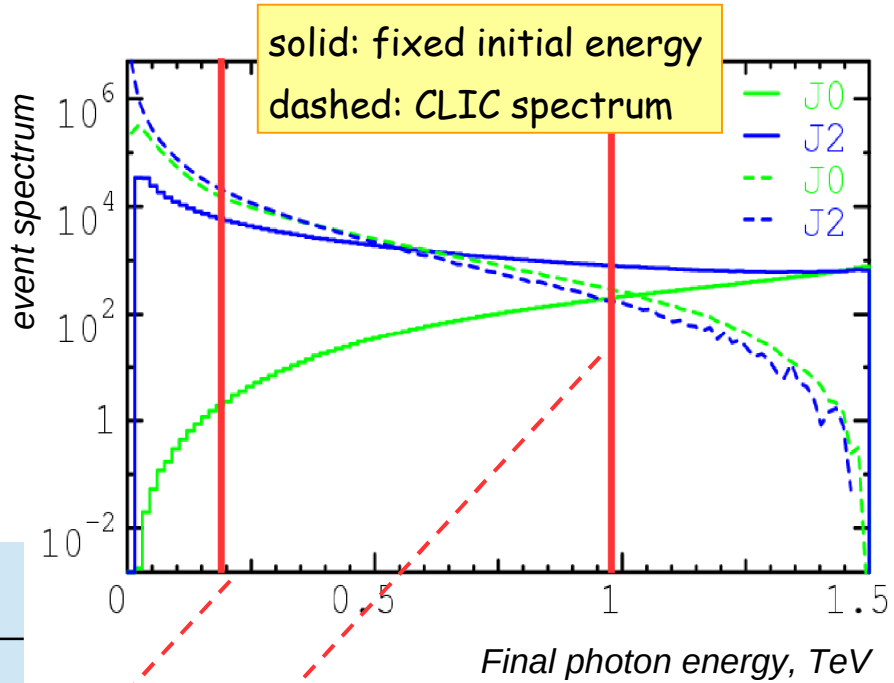
- exclusive $\gamma\gamma \to e^+e^-\gamma$ process
  - small cross section
  - huge background from $\gamma\gamma \to ee\gamma$ scattering in J=2 events

Luminosity measurement in J=0 mode

exclusive $\gamma\gamma \to e^+e^-\gamma$ process

- Cross section in J=2 mode is much higher (solid lines on plot)
- In experiment J=2 and J=0 events are mixed ⇒

we need to suppress J=2 events!



Possible selection scheme

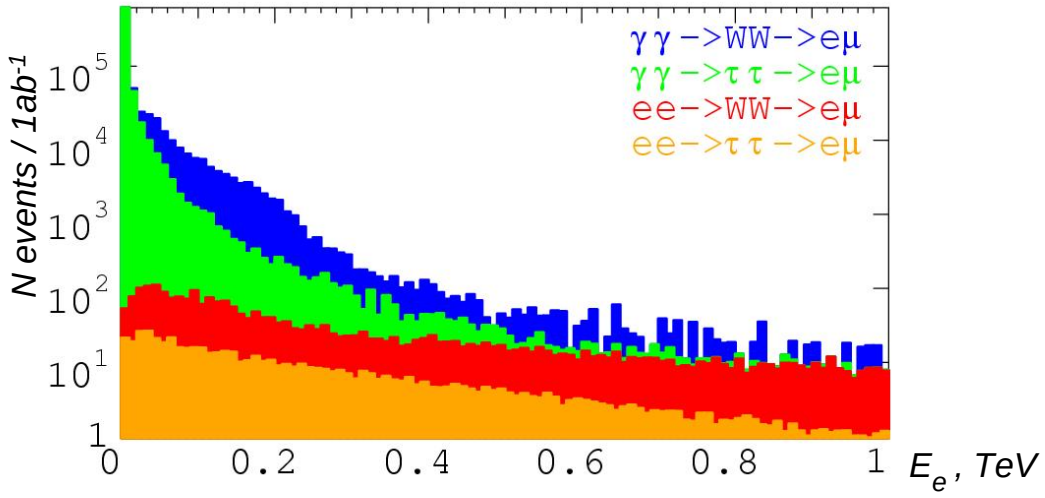
Cross section, pb	J2	J0
3 TeV fixed energy	0.0312	0.0018
3 TeV spectrum	1.476	0.300
2W production region	0.448	0.059
Photon selection E>200 GeV	**0.0165**	**0.0158**
Photon selection E>1000 GeV	0.00013	0.00024

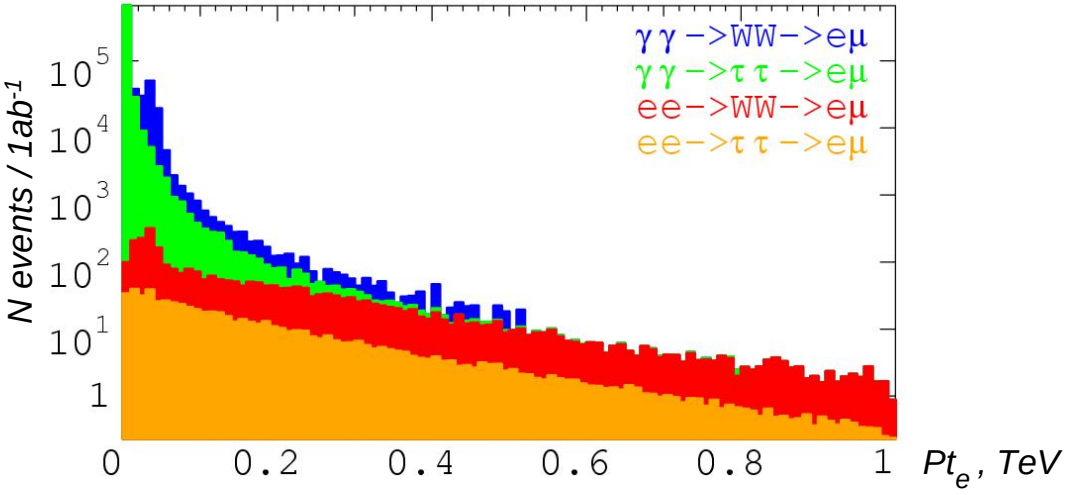
Conclusion:

- Approx. 10^4 signal events / 1 ab^{-1}
- Probably enough to measure luminosity with reasonable precision

γγ → eμ and background processes

Next we apply beam spectrum:





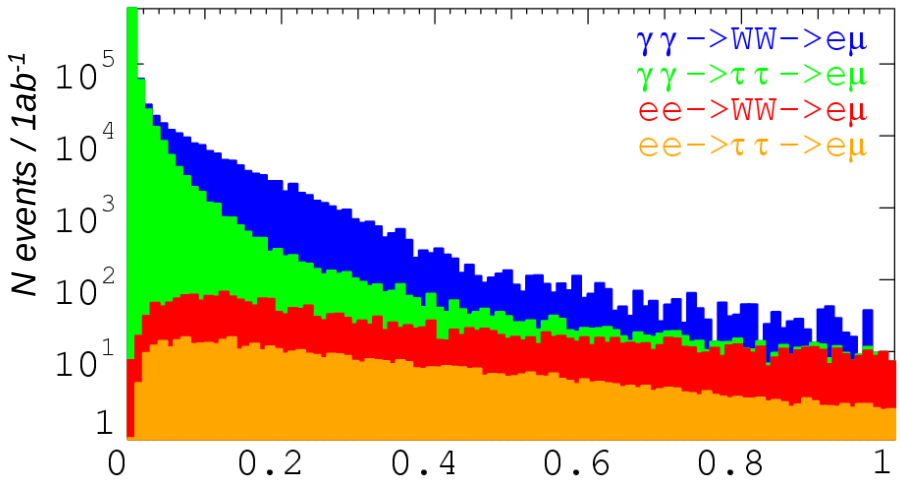
$\gamma\gamma, ee \rightarrow WW \rightarrow e\mu\nu_e\nu_\mu$

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

e, μ polar angle cut: 10^o

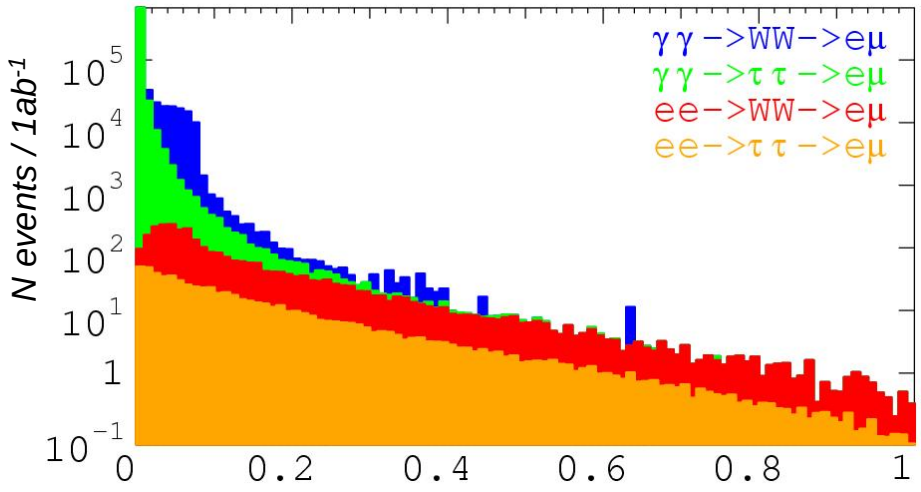
γγ → eμ and background processes

M_{inv}(eμ) variable



$M_{e\mu}$, TeV

Pt(eμ) variable



$Pt_{e\mu}$, TeV

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

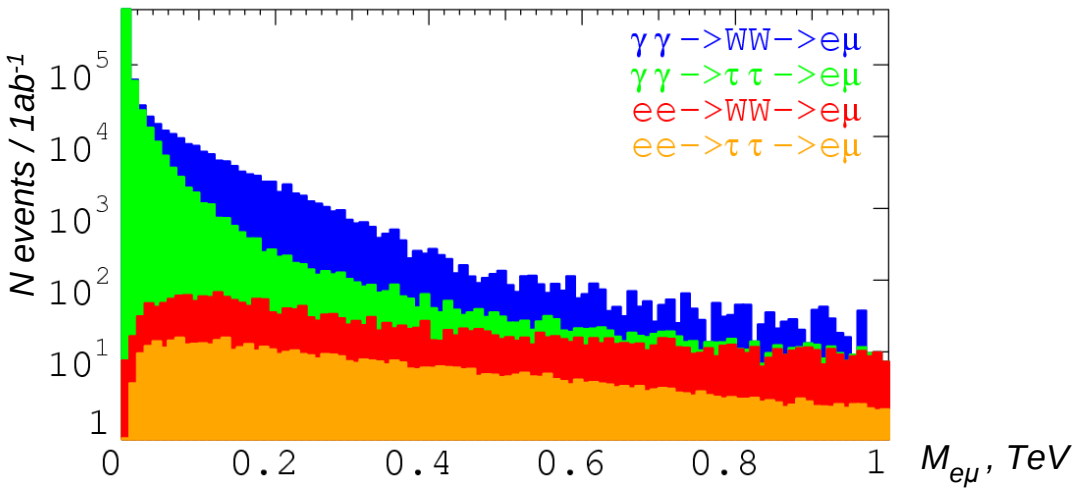
$\gamma\gamma, ee \rightarrow \tau\tau \rightarrow e\mu\nu_e\nu_\mu$

e, μ polar angle cut: 10^o

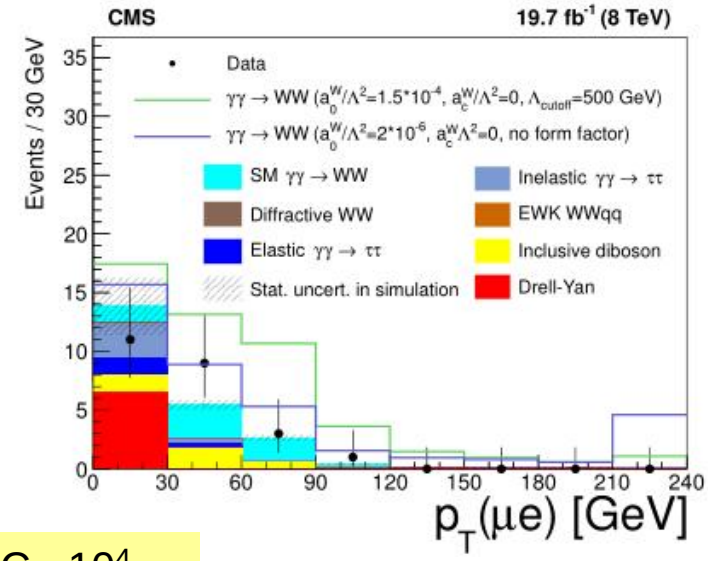
Clear signal events separation

CLIC vs. LHC

Compare events number to latest CMS results:



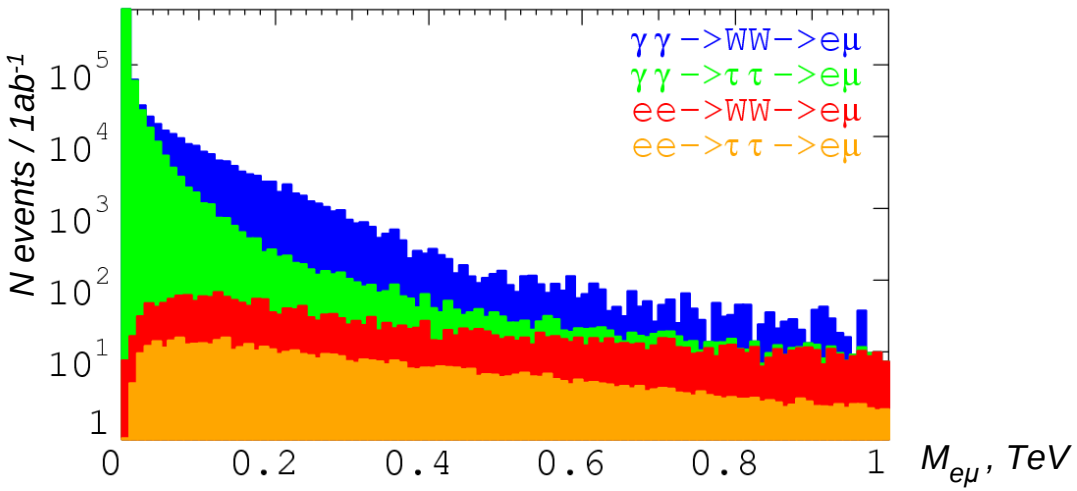
JHEP 1608 (2016) 119



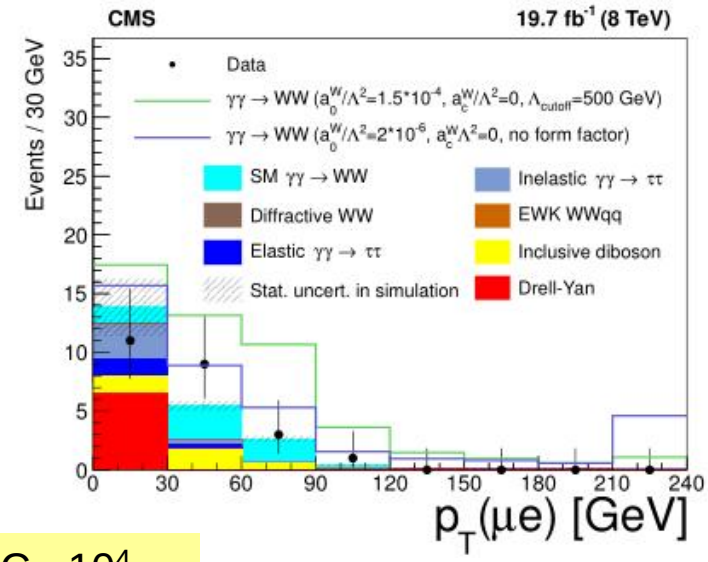
Signal events factor CLIC / LHC ~10^4

CLIC vs. LHC

Compare events number to latest CMS results:



JHEP 1608 (2016) 119



Signal events factor CLIC / LHC ~10^4