# The case for QCD and γ-γ studies at TLEP

## 6th TLEP Workshop

## CERN, Geneva – 17th Oct 2013

David d'Enterria

CERN

# Some thoughts for QCD and γ-γ studies at TLEP

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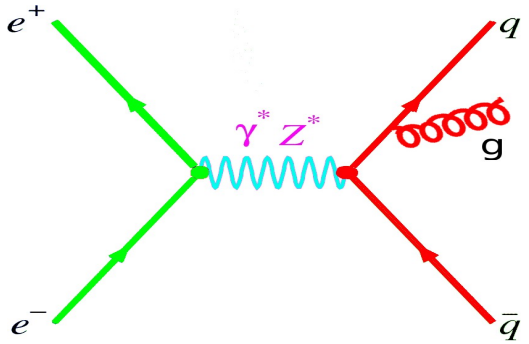
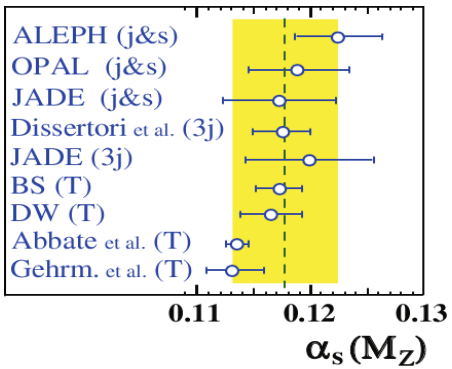
# QCD in $e^+e^-$ collisions at TLEP

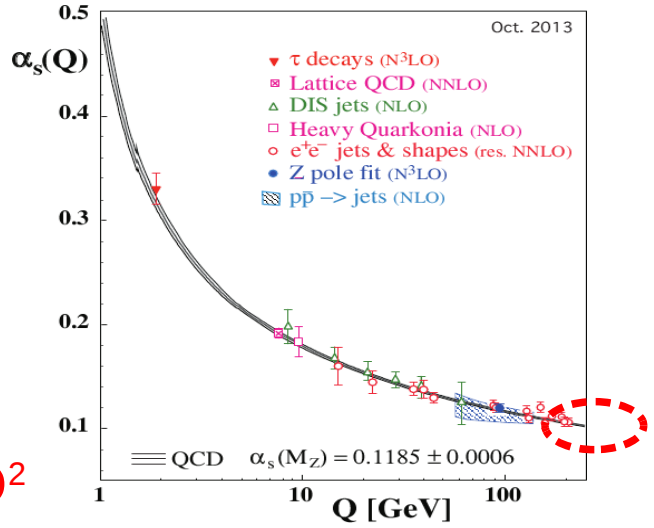
- $e^+e^-$ collisions provide an extremely clean environment with fully-controlled initial-state to probe q,g dynamics:




Advantages compared to p-p at the LHC:
- Electroweak initial-state with known kinematics
- No QCD "underlying event"
- Smaller QCD radiation (only in final-state) & smaller non-perturbative effects (no PDFs)

- $\alpha_s(Q_0)$,crucial for many SM precision fits, accessible w/ high accuracy:
  - $N^3LO$: hadronic cross sections, also W,τ→ hadrons (Dissertori,Pich's talks)
  - NNLO: 3-jets rates, event shapes (thrust)

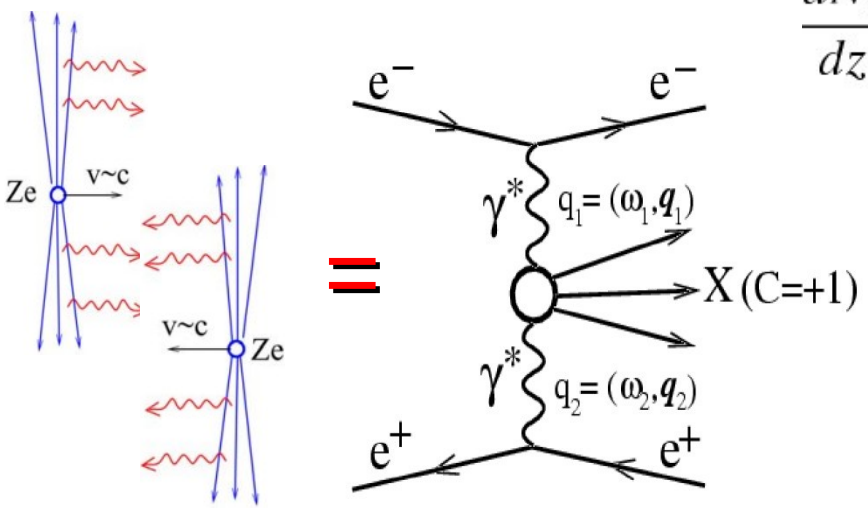



- TLEP vs. LEP: much higher stats & higher $Q^2$

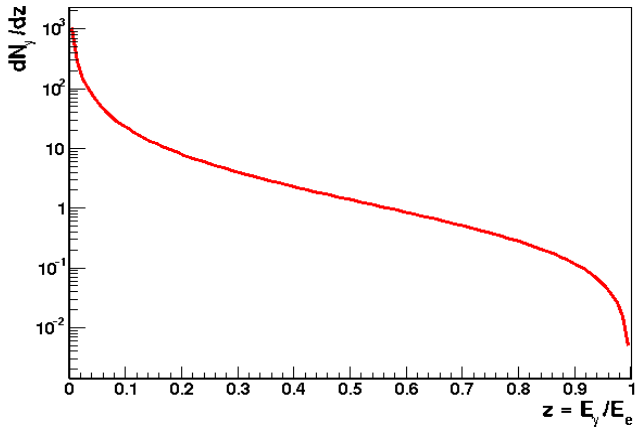
# $\gamma\,\gamma$ interactions in an $e^+e^-$ collider

- Electromagnetic field of high-energy charge = equivalent photon flux. Weizsäcker-Williams (EPA) spectrum for $e^\pm$ beam:




$$\frac{dN_\gamma}{dz} \approx \frac{\alpha_{em}}{2\pi}\frac{1}{z}\left[1+(1-z)^2\right]\ln\frac{Q^2_{max}}{Q^2_{min}}\,, \quad z=\omega/E_e$$

Soft bremsstrahlung $\gamma$ spectrum

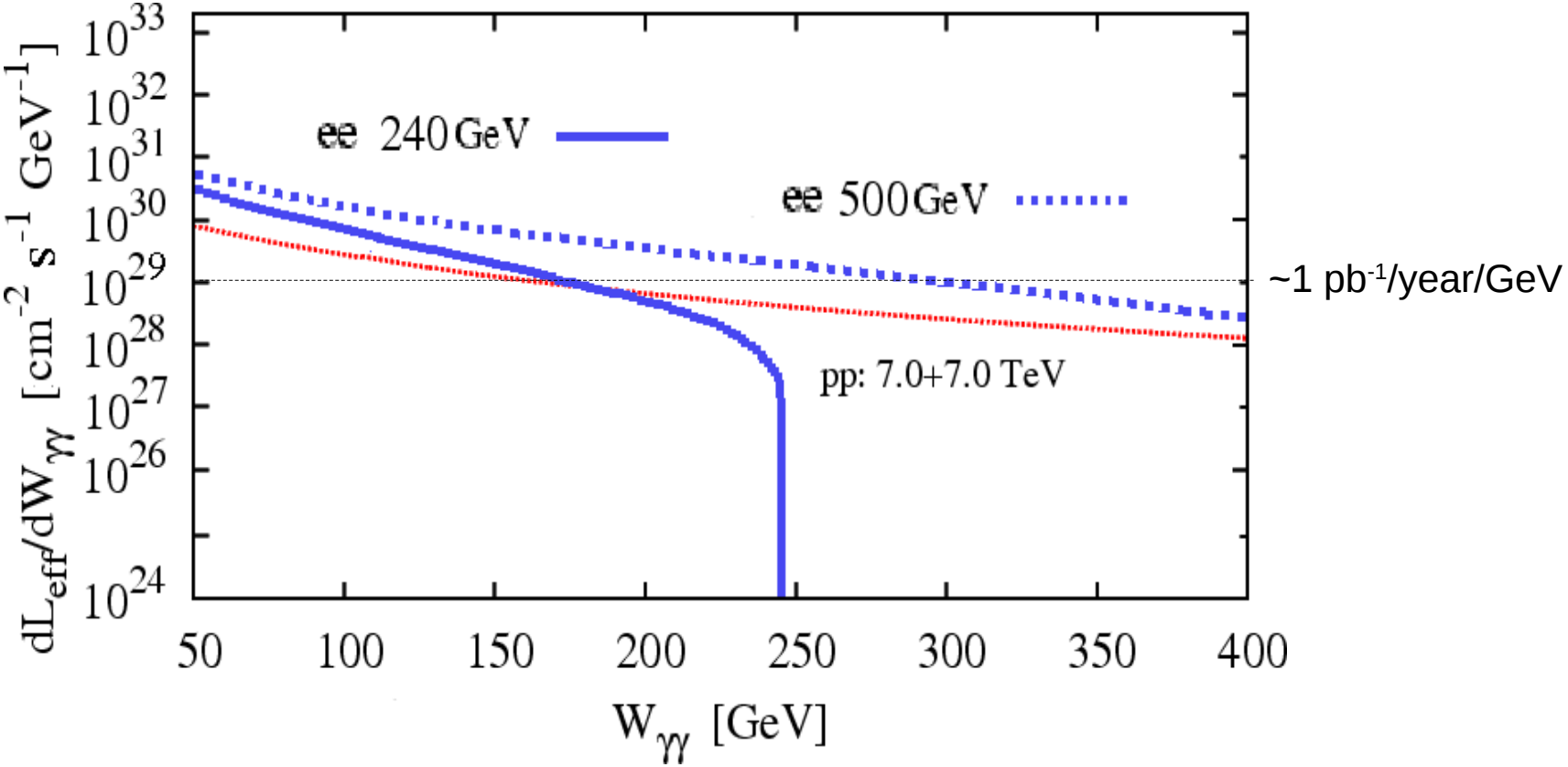



- Photon-photon collisions provide complementary physics capabilities to e+e- (e.g. for scalar C-even systems) but w/ reduced lumis & energies:
  - $\mathscr{L}_{\gamma\gamma}(W_{\gamma\gamma}>0.1\cdot E_e) \sim 10^{-2}\,\mathscr{L}_{e+e-}$
  - $\mathscr{L}_{\gamma\gamma}(W_{\gamma\gamma}>0.5\cdot E_e) \sim 0.4\cdot 10^{-3}\,\mathscr{L}_{e+e-}$

(Main reason for Compton-backscattered laser-photons at PLC: $E_\gamma \sim E_e$, $\mathscr{L}_{\gamma\gamma} \sim 0.8\cdot\mathscr{L}_{e+e-}$)

# Effective γ γ luminosities at TLEP

- Fig. of merit: Convolve $e^+e^-$ EPA spectra, scale by $\mathscr{L}_{ee}$~$10^{34}$ $cm^{-2}s^{-1}$




- Thanks to large TLEP lumi: $\mathscr{L}_{eff}(\gamma\gamma)$~5–10 times higher than p-p(γγ) at LHC over large $W_{\gamma\gamma}$ range (and without huge LHC p-p pileup).
- Forward detectors (~mrad) needed to double tag outgoing e+e-

# "Golden" physics channels for a γγ collider

| Reaction | Remarks | |
|---|---|---|
| $\gamma\gamma \to H, h \to b\bar{b}$ | SM/MSSM Higgs, $M_{H,h} < 160$ GeV | SM Higgs |
| $\gamma\gamma \to H \to WW(^*)$ | SM Higgs, $140 < M_H < 190$ GeV | |
| $\gamma\gamma \to H \to ZZ(^*)$ | SM Higgs, $180 < M_H < 350$ GeV | |
| $\gamma\gamma \to H \to \gamma\gamma$ | SM Higgs, $120 < M_H < 160$ GeV | |
| $\gamma\gamma \to H \to t\bar{t}$ | SM Higgs, $M_H > 350$ GeV | |
| $\gamma\gamma \to H, A \to b\bar{b}$ | MSSM heavy Higgs, interm. $\tan\beta$ | SUSY |
| $\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$ | large cross sections | |
| $\gamma\gamma \to \tilde{g}\tilde{g}$ | measurable cross sections | |
| $\gamma\gamma \to H^+H^-$ | large cross sections | |
| $\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$ | $\tilde{t}\bar{\tilde{t}}$ stoponium | |
| $e\gamma \to \tilde{e}^-\tilde{\chi}_1^0$ | $M_{\tilde{e}\ldots} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$ | |
| $\gamma\gamma \to \gamma\gamma$ | non-commutative theories | BSM |
| $e\gamma \to eG$ | extra dimensions | |
| $\gamma\gamma \to \phi$ | Radions | |
| $e\gamma \to \tilde{e}\tilde{G}$ | superlight gravitions | |
| $\gamma\gamma \to W^+W^-$ | anom. $W$ inter., extra dimensions | Anomalous couplings |
| $e\gamma \to W^-\nu_e$ | anom.$W$ couplings | |
| $\gamma\gamma \to 4W/(Z)$ | $WW$ scatt., quartic anom. $W$,$Z$ | |
| $\gamma\gamma \to t\bar{t}$ | anomalous top quark interactions | top |
| $e\gamma \to \bar{t}b\nu_e$ | anomalous $Wtb$ coupling | |
| $\gamma\gamma \to$ hadrons | total $\gamma\gamma$ cross section | QCD |
| $e\gamma \to e^-X, \nu_e X$ | NC and CC structure functions | |
| $\gamma g \to q\bar{q},\ c\bar{c}$ | gluon in the photon | |
| $\gamma\gamma \to J/\psi\, J/\psi$ | QCD Pomeron | |

[A.deRoeck PLHC'08]

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[A.deRoeck PLHC'08]

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| $\gamma\gamma \to J/\psi\, J/\psi$ | QCD Pomeron | QCD |

A few simple cases (QCD,anomal.couplings) follow …

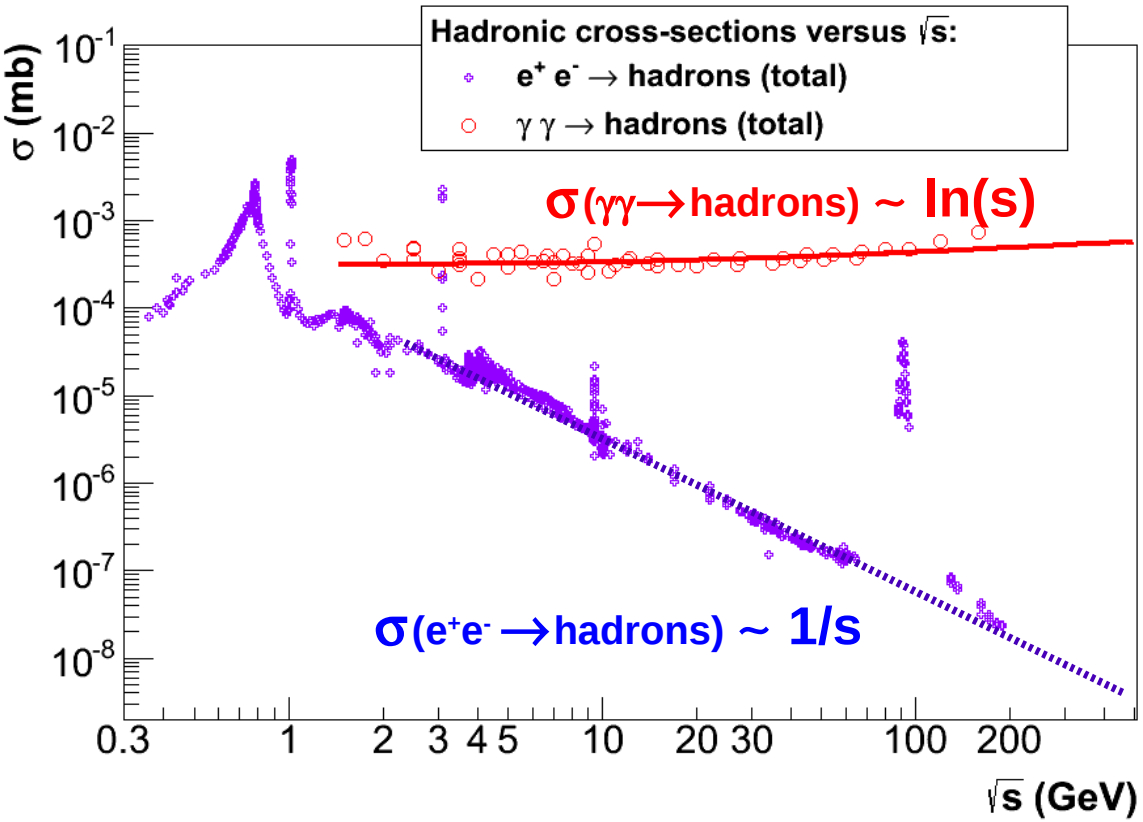
A fraction of them can be studied at TLEP(γγ)

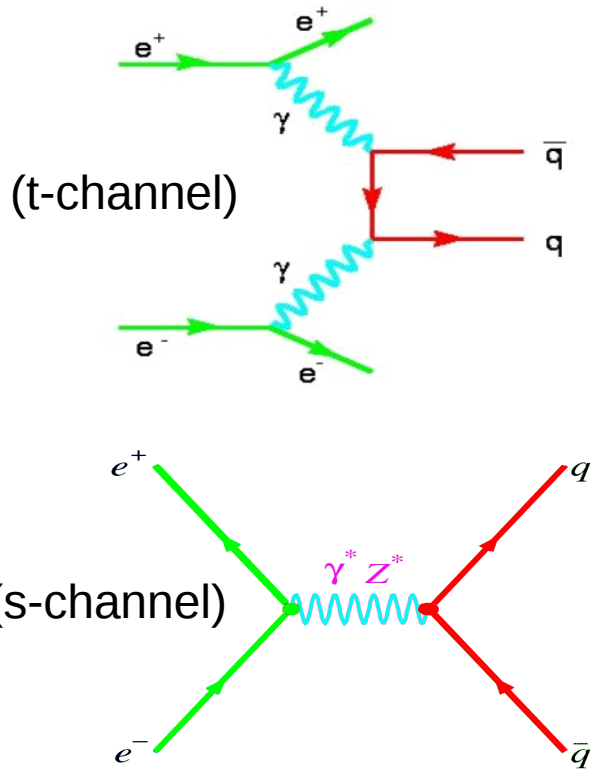
Real quantitative studies needed

[A.deRoeck PLHC'08]

# QCD: $\gamma\gamma$ vs. $e^+e^-$ collisions

- Hadron production cross section versus sqrt(s):




- At $\sqrt{s}$~300 GeV, $\gamma\gamma$ x-secions are ~$5 \cdot 10^4$ times higher:

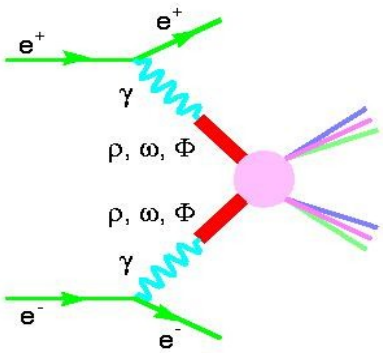
$\sigma(\gamma\gamma \rightarrow \text{hadrons}) \sim 5\ \mu b$

$\sigma(ee \rightarrow \text{hadrons}) \sim 0.1\ nb$

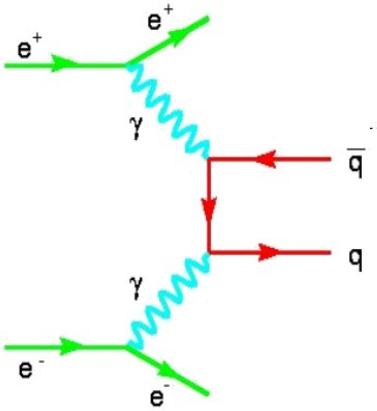
Hadron yields "just" ~2 orders of magnitude higher, taking into account $\mathscr{L}_{eff} \sim 10^{-(2\text{-}3)}$ reduction penalty

# QCD at TLEP(γγ)

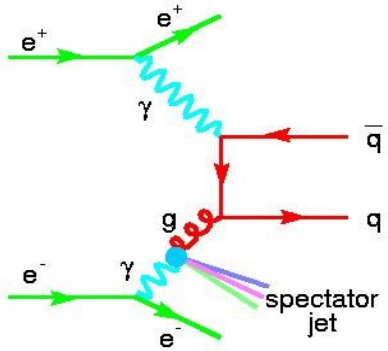
- Leading QCD contributions in γ γ collisions:




**Soft (VMD)**

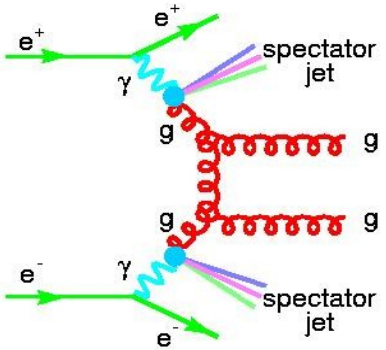



**Direct**




(single resolved)

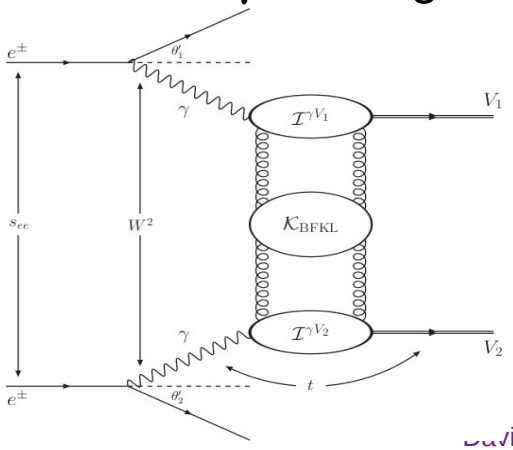
**γ-"hadron"**



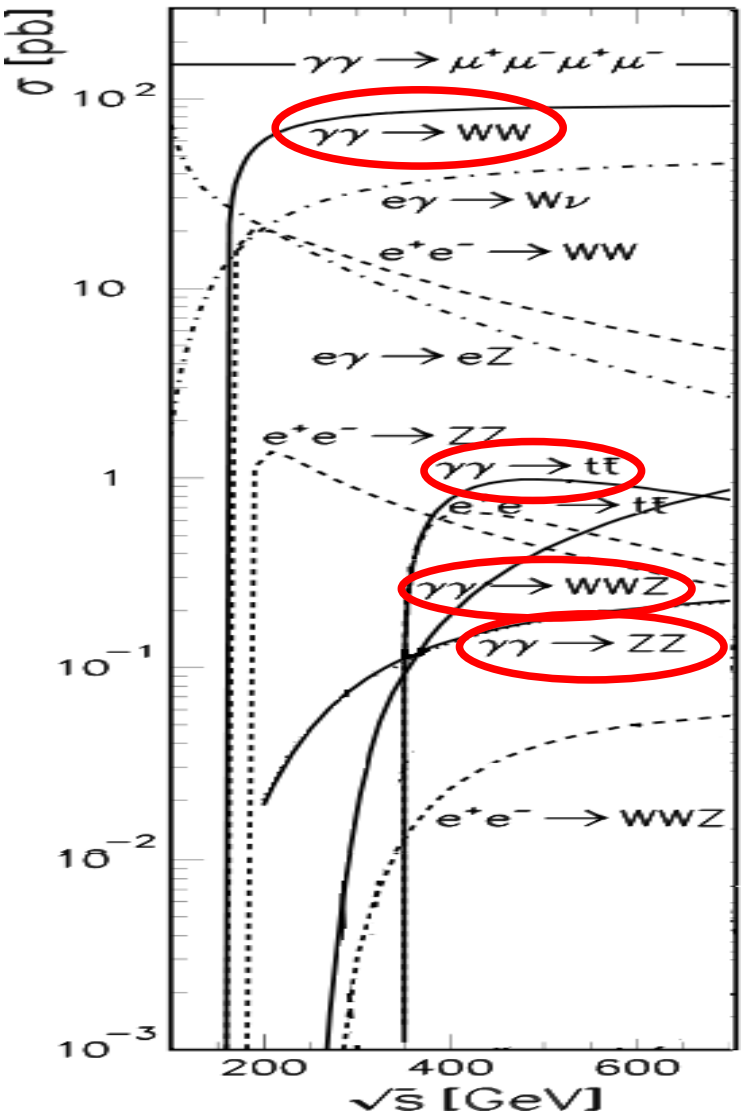

(double resolved)

**"hadron"-"hadron"**

- $\sigma_{tot}(\gamma\gamma)$, (di)jets, resonances, ch.hadrons, heavy-Q,... via $e^{\pm}$ untagged
- Photon QED&QCD struct.functions: quasireal/virtual γ via single/double tags
- BFKL dynamics via $\gamma\gamma \to \rho\rho, J/\varphi, J/\varphi, \Upsilon\Upsilon$:

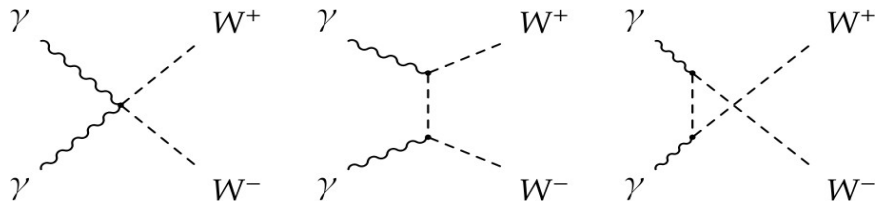


# Anomalous couplings at TLEP(γγ)



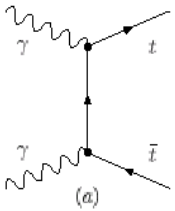

[PLC, TESLA hep-ex/0108012]

- $\gamma\gamma \to WW$ quartic/trilinear couplings:




$\sigma$ ~ 20–90 pb (160–500 GeV)

- $\gamma\gamma \to$ t-tbar :




$\sigma$ ~ 1 pb (>340 GeV)

- $\gamma\gamma \to ZZ$, $\gamma\gamma \to WWZ$ quartic couplings:

$\sigma$ ~ 20–150 fb (280–500 GeV)

- Also nice opportunities in $e\gamma$ mode:

e.g. $e\gamma \to W\nu$ (again for anomalous couplings)

# Anomalous e.m. τ moments at TLEP(γγ)

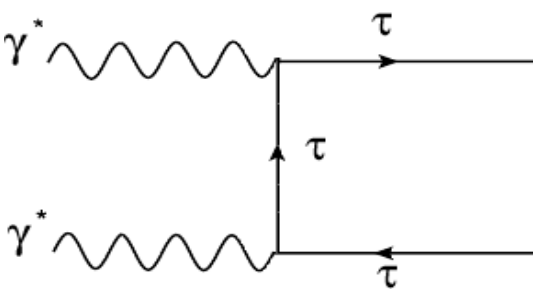
- Magnetic moment of tau-lepton: $a_\tau$ = 1.17734(2)e-4 (QED)

  Current LEP bounds: $-0.052 < a_\tau < 0.013$

- Electric dipole-moment of tau-lepton: $|d_\tau| < 10^{-34}$ e cm

  Current LEP (also BELLE) limit: $|d_\tau| < 3.1 \cdot 10^{-16}$ e cm

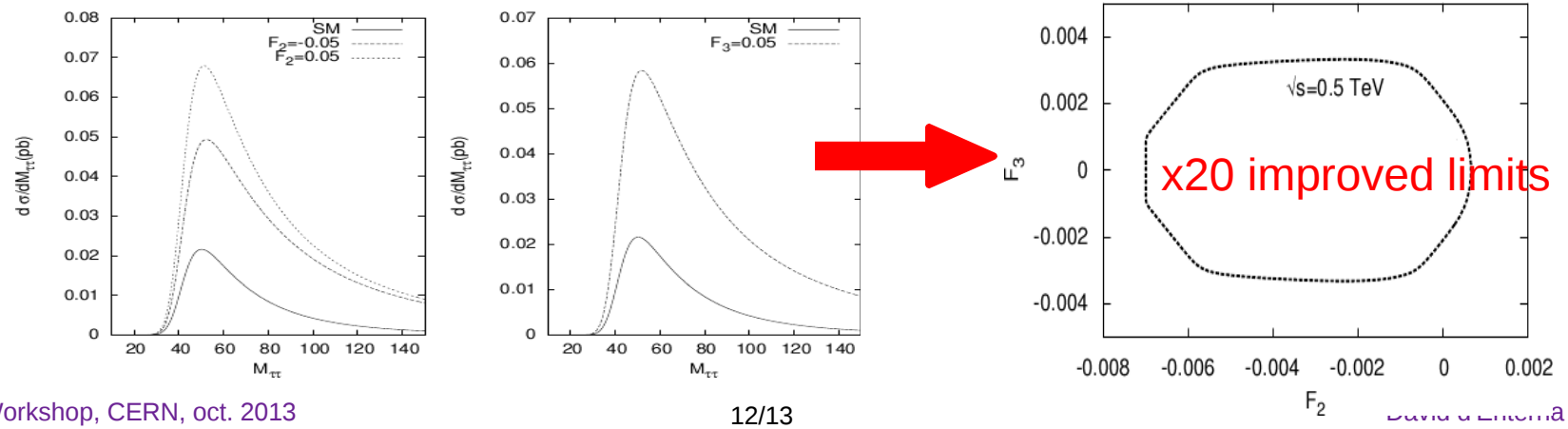
- Anomalous moments via $\gamma\gamma \to \tau\tau$ : [Billur,Koksal, arXiv:1306.5620]




$$\Gamma^\nu = F_1(q^2)\gamma^\nu + \frac{i}{2m_\tau}F_2(q^2)\sigma^{\nu\mu}q_\mu + \frac{1}{2m_\tau}F_3(q^2)\sigma^{\nu\mu}q_\mu\gamma^5$$

$$F_1(0) = 1,\ F_2(0) = a_\tau,\ F_3(0) = \frac{2m_\tau d_\tau}{e}.$$

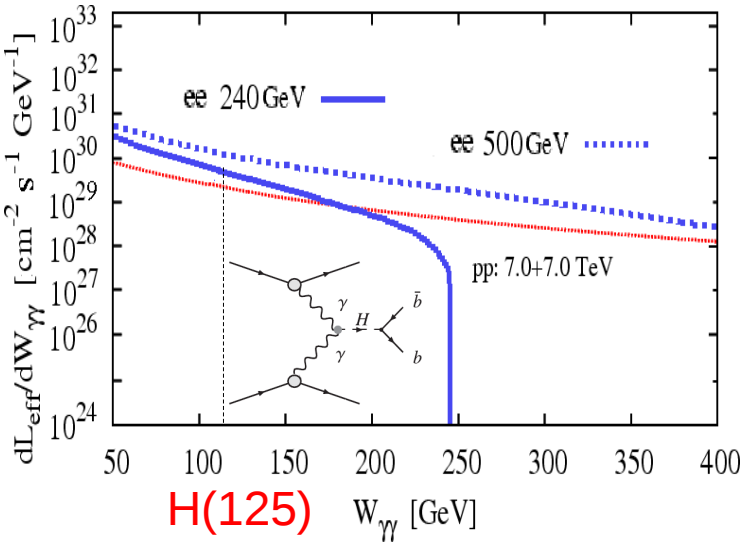
- Two-photon di-tau at CLIC (or TLEP) at 0.5 TeV, $2 \cdot 10^{34}$ cm$^{-2}$s$^{-1}$:



# Other new processes for TLEP(γγ)

- Observation of γγ→H(bb) ?

[DdE & Lansberg, PRD 81 (2010) 014004]




Produced in pp(γγ) at LHC (not visible due to PU):

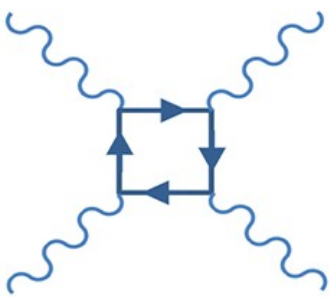
| System | $\sqrt{s_{NN}}$ (TeV) | $\sigma(\gamma\gamma \to H)$ elastic (pb) [$m_H = 120$ GeV/$c^2$] $H$ total | $H \to b\bar{b}$ |
|---|---|---|---|
| $pp$ | 14 | $0.18 \cdot 10^{-3}$ | $0.13 \cdot 10^{-3}$ |

| System | $\mathcal{L}_{AB}$ (cm$^{-2}$ s$^{-1}$) | $\Delta t$ (s) | $\langle N_{pileup} \rangle$ | $N_{Higgs}$ total ($H \to b\bar{b}$) |
|---|---|---|---|---|
| $pp$ (14 TeV) | $10^{34}$ | $10^7$ | 25 | 77 (55) |

TLEP: $\mathcal{L}_{eff}$(γγ)+no-PU could allow for observation

- Observation of light-by-light scattering γγ→γγ ?

[DdE & Silveira PRL111 (2013) 080405]



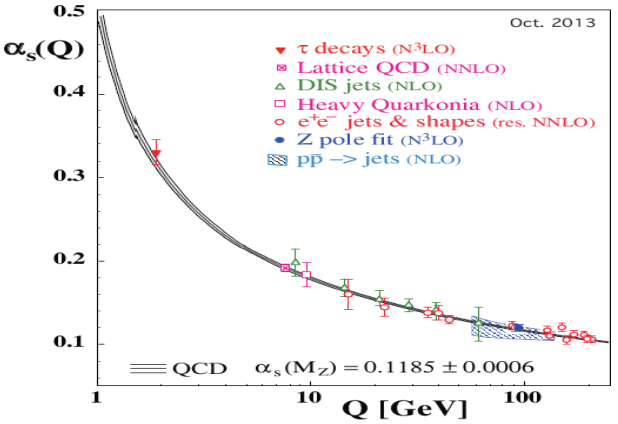
Observable at the LHC for $m_{\gamma\gamma}$>5 GeV in Pb-Pb mode ($Z^4$-enhanced photon fluxes).

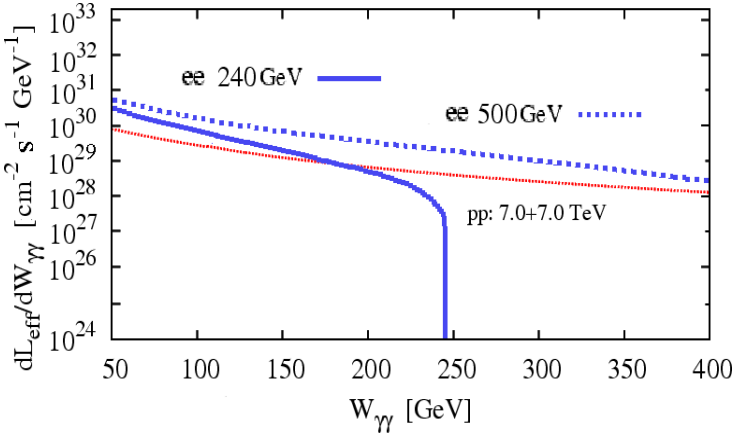
Could be visible (at lower $m_{\gamma\gamma}$) at TLEP too

($e^+e^- \to \gamma\gamma$ background removed via double $e^{\pm}$-tag)

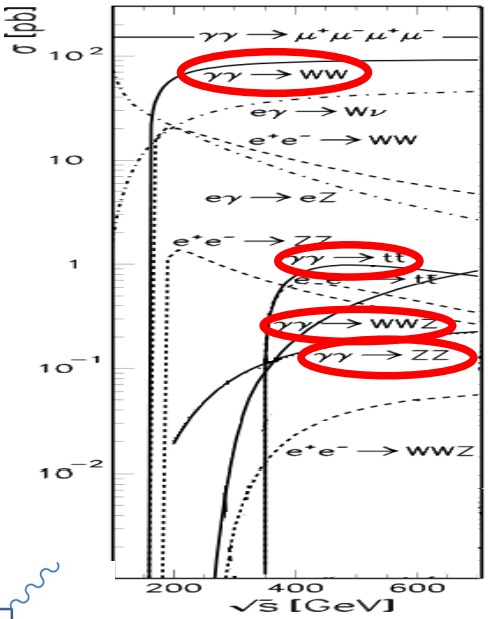
# Summary: QCD & γγ physics at TLEP

- Beyond-NNLO $\alpha_s(Q)$ w/ high stats/$Q^2$: (crucial for many precision SM fits)
- Fraction of photon-collider physics accessible via EPA fluxes: $\mathscr{L}_{eff}(TLEP,\gamma\gamma) \sim 5\text{–}10 \times \mathscr{L}_{eff}(pp,\gamma\gamma)$

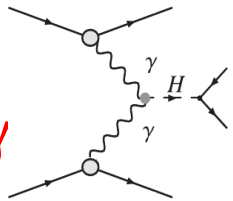


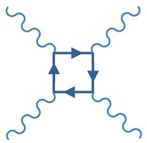




- Constraints on anomalous (top, gauge) couplings:
- Limits on anomalous τ e.m. moments




- QCD via photon-photon: $\sigma_{tot}(\gamma\gamma)$, γ struct. function, BFKL,...
- Other processes: γγ→H(bb), γγ→γγ

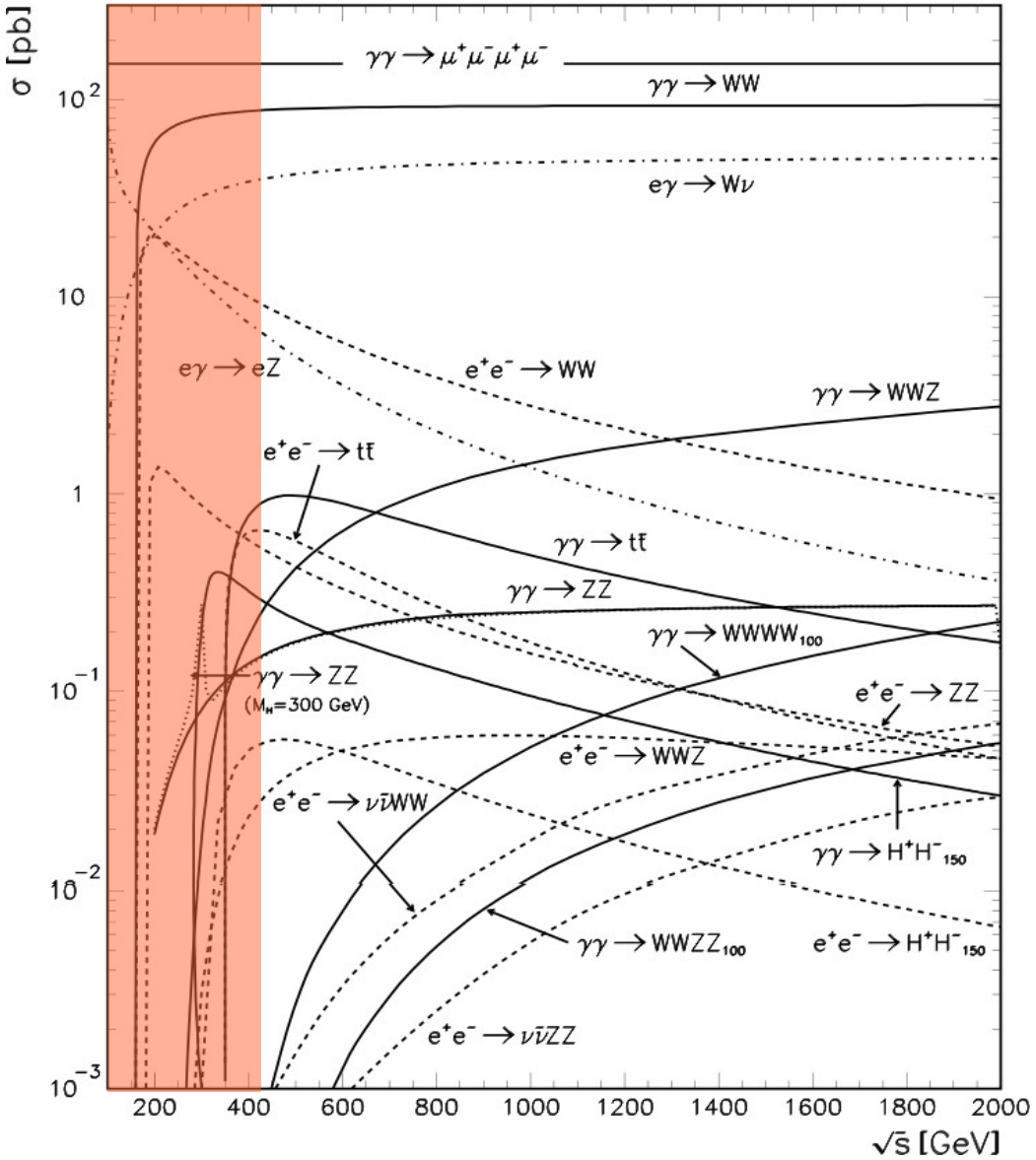


- Quantitative/realistic studies needed for all measurements

# Backup slides

# Anomalous gauge couplings at TLEP(γγ)



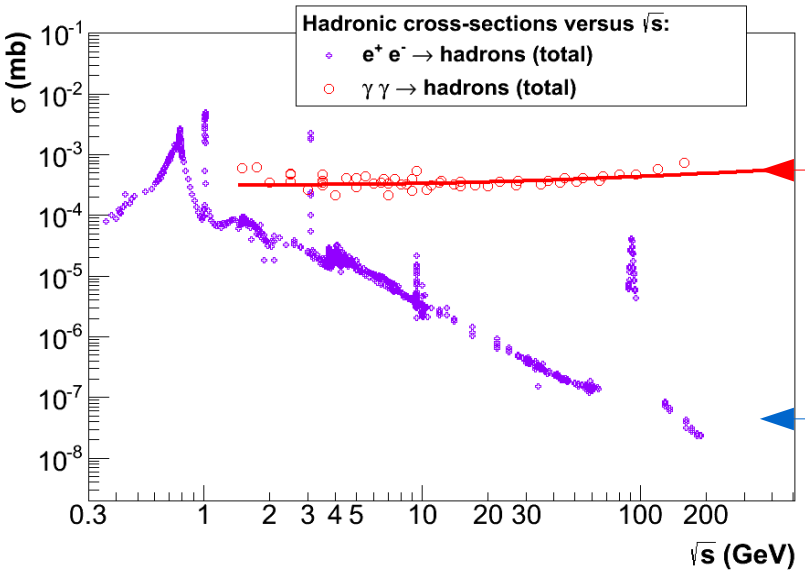

[PLC, TESLA hep-ex/01/08012]

# QCD: $\gamma\gamma \rightarrow$ hadrons

High-energy photon can interact point-like (e.g. Compton scatt.) or quantum fluctuating into fermion-antifermion or vector-meson ($J=1^{--}$):

$$|\gamma\rangle = c_0\,|\gamma_0\rangle + \sum_{V=\rho^0,\omega,\phi,J/\psi,\Upsilon} c_V|V\rangle + \sum_{q=u,d,s,c,b} c_q|q\bar{q}\rangle + \sum_{l=e,\mu,\tau} c_l|l^+l^-\rangle$$

In practice: $\gamma \approx \gamma_0$ , but $\gamma$ V,qq̄ fluctuations interact strongly and give largest contribution to $\gamma\gamma$ cross sections:




$\sigma(\gamma\gamma \rightarrow \text{hadrons}) \sim \ln(s)$

Rise as pp,pp̄ colls. consistent w/ Regge phenomenology

$\sigma(e^+e^- \rightarrow \text{hadrons}) \propto 1/s$

High-energy $\gamma\gamma$ collisions complementary to more "conventional" $e^+e^-$,