The case for QCD and γ-γ studies at TLEP

6th TLEP Workshop

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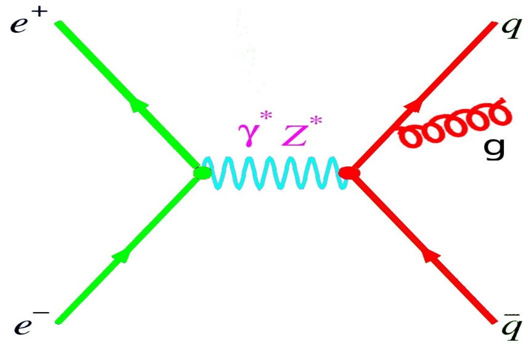
CERN

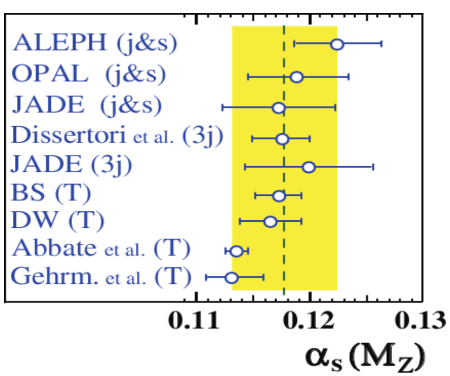
QCD in e^+e^- collisions at TLEP

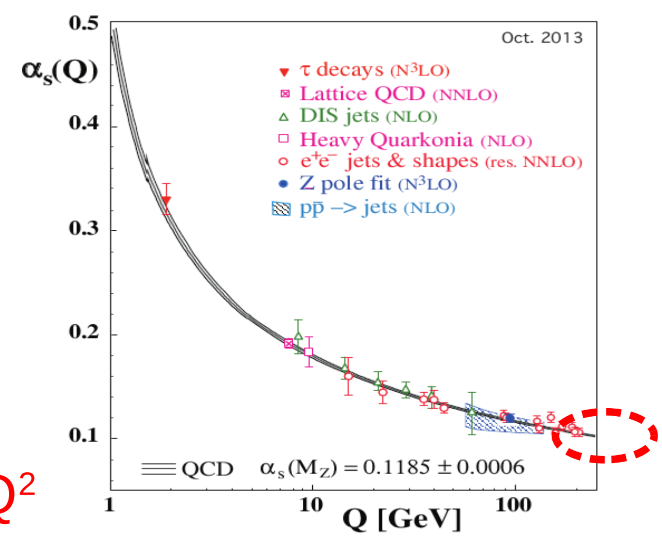
- e^+e^- collisions provide an extremely clean environment with fully-controlled initial-state to probe q,g dynamics:



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,$\tau\rightarrow$ hadrons (Dissertori,Pich's talks)
  - NNLO: 3-jets rates, event shapes (thrust)



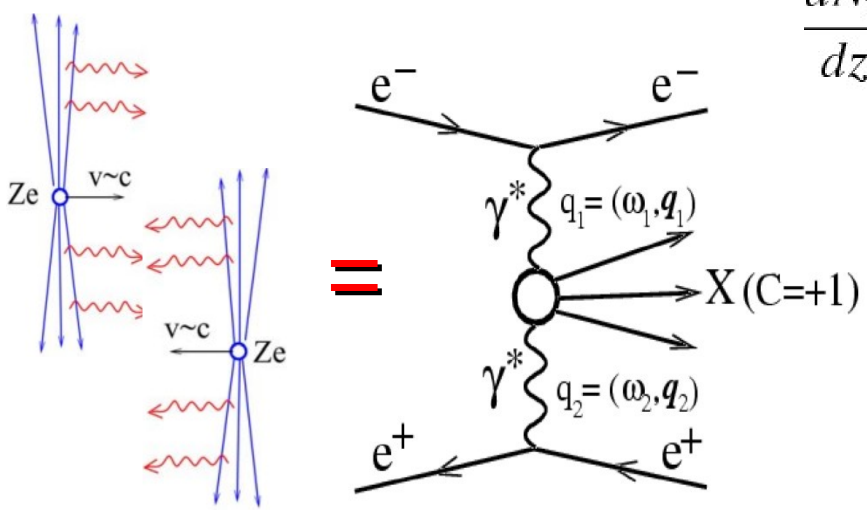


- TLEP vs. LEP: much higher stats & higher Q^2

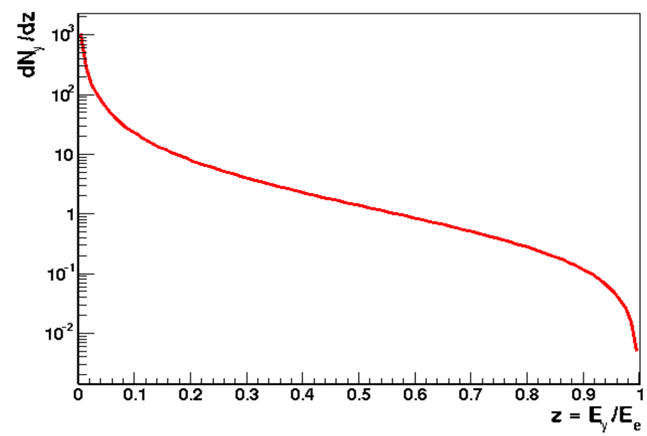
γ γ interactions in an e^+e^- collider

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

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



Soft bremsstrahlung γ spectrum

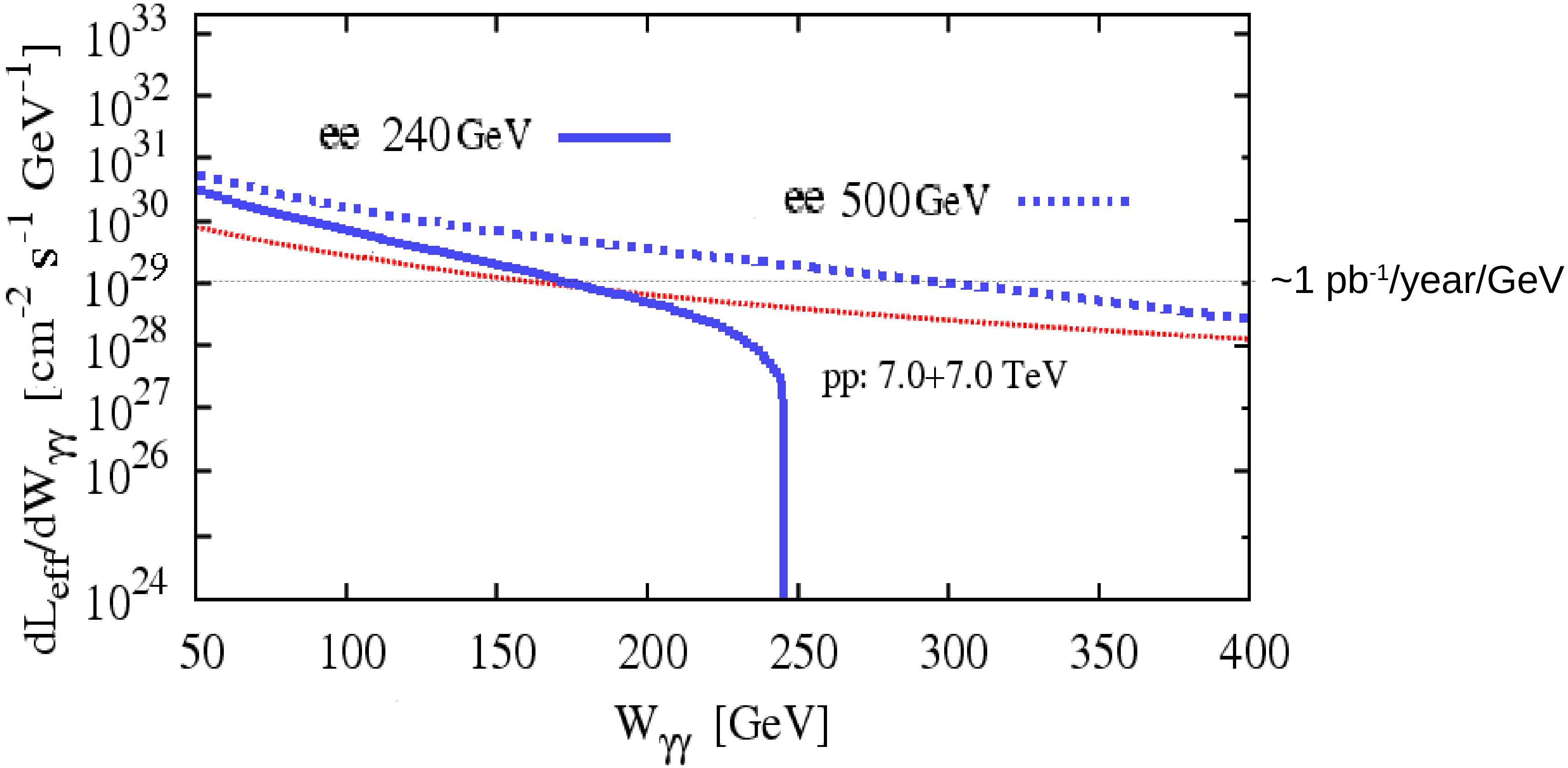


- Photon-photon collisions provide complementary physics capabilities to e+e- (e.g. for scalar C-even systems) but w/ reduced lumis & energies:
  - $\mathscr{L}_{\gamma\gamma}(W_{\gamma\gamma}>0.1\cdot E_e) \sim 10^{-2}\,\mathscr{L}_{e+e-}$
  - $\mathscr{L}_{\gamma\gamma}(W_{\gamma\gamma}>0.5\cdot E_e)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

(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: $\mathscr{L}_{eff}$(γγ)~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 $\gamma\gamma$ collider

Reaction	Remarks	
$\gamma\gamma \to H, h \to bb$	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	
$\gamma\gamma \to H, A \to bb$	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	
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\tilde{t}$ stoponium	
$e\gamma \to \tilde{e}^-\tilde{\chi}^0_1$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}^0_1}$	
$\gamma\gamma \to \gamma\gamma$	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]

"Golden" physics channels for TLEP($\gamma\gamma$)

Reaction	Remarks	
$\gamma\gamma \to H, h \to bb$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV	SM Higgs
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[A.deRoeck PLHC'08]

“Golden” physics channels for a γγ collider

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

SM Higgs

SUSY

BSM

Anomalous couplings

top

QCD

[A.deRoeck PLHC'08]

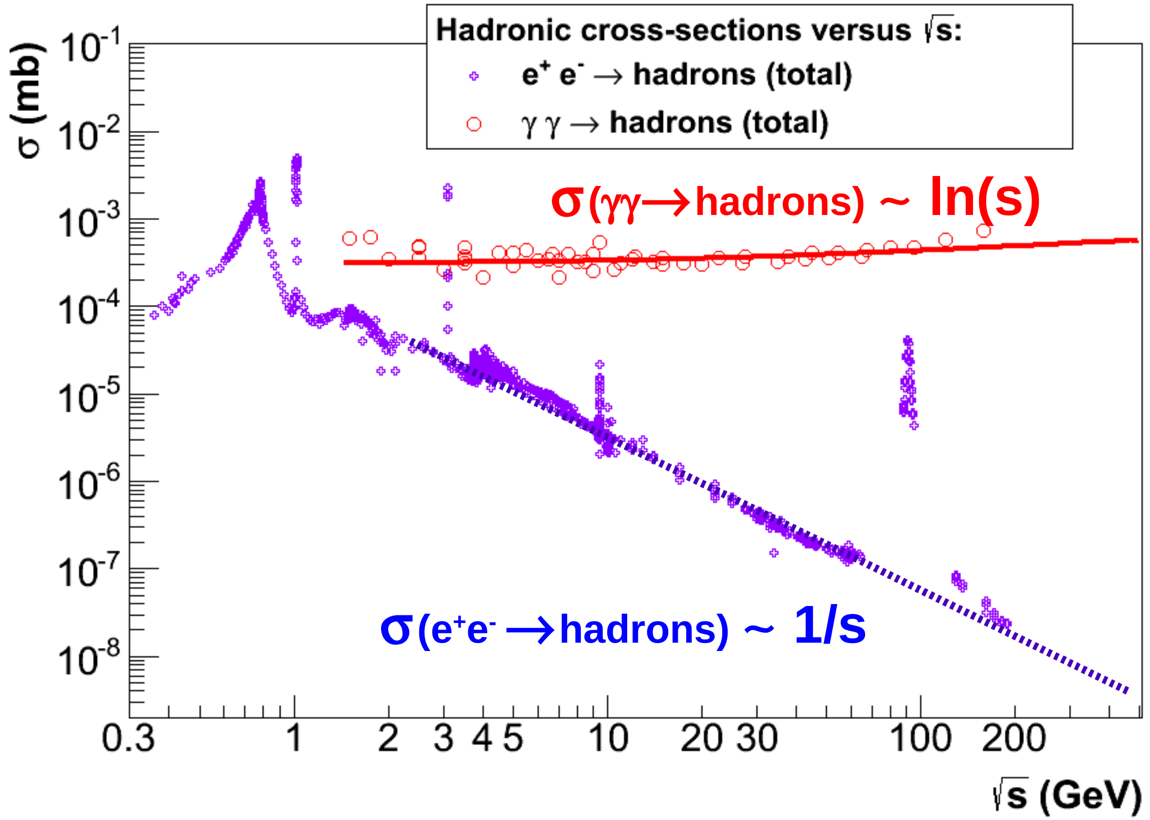
A fraction of them can be studied at TLEP(γγ)

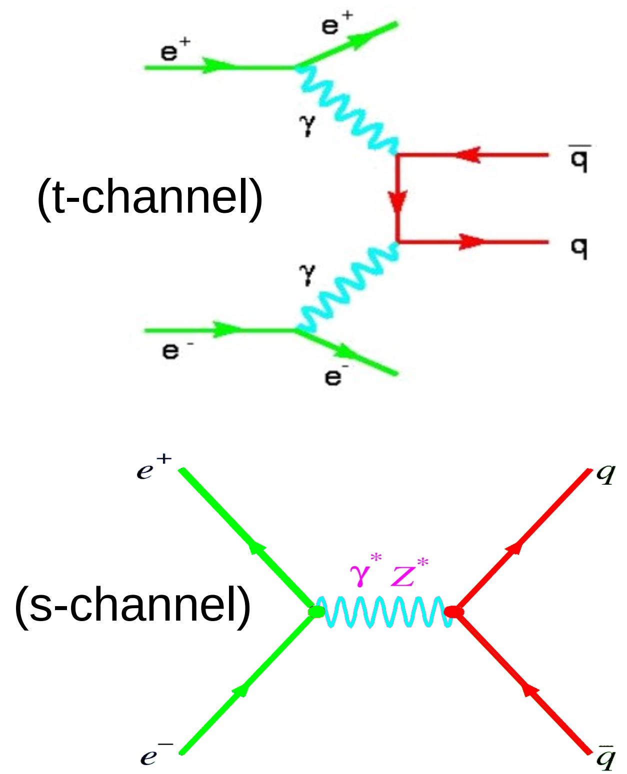
A few simple cases (QCD,anomal.couplings) follow ...

Real quantitative studies needed

QCD: γ γ vs. e^+e^- collisions

- Hadron production cross section versus sqrt(s):





- At √s~300 GeV, γγ x-secions are ~$5\cdot10^4$ times higher:

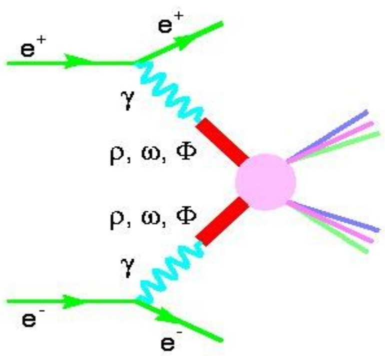
σ(γγ→hadrons)~ 5 μb

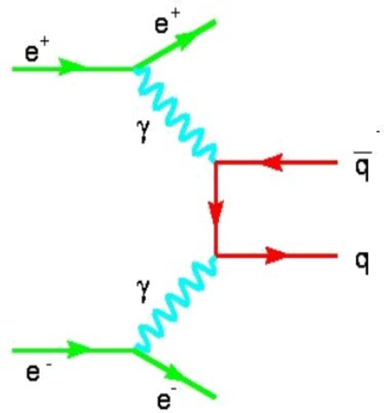
σ(ee→hadrons)~ 0.1 nb

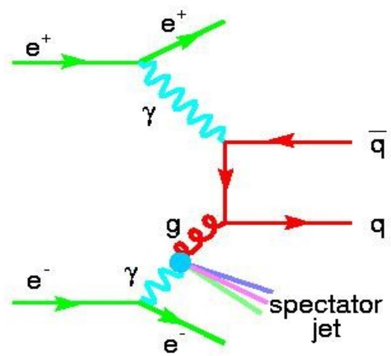
Hadron yields "just" ~2 orders of magnitude higher, taking into account $\mathscr{L}_{eff}$ ~ $10^{-(2\text{-}3)}$ reduction penalty

QCD at TLEP(γγ)

- Leading QCD contributions in γ γ collisions:







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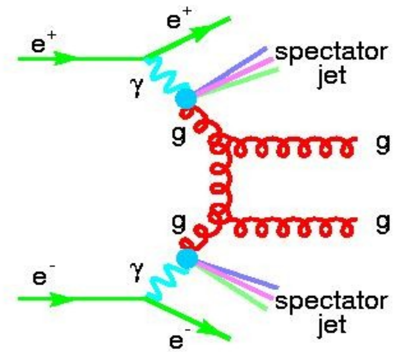
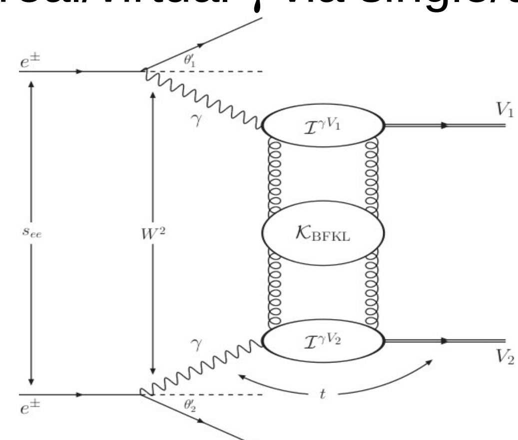


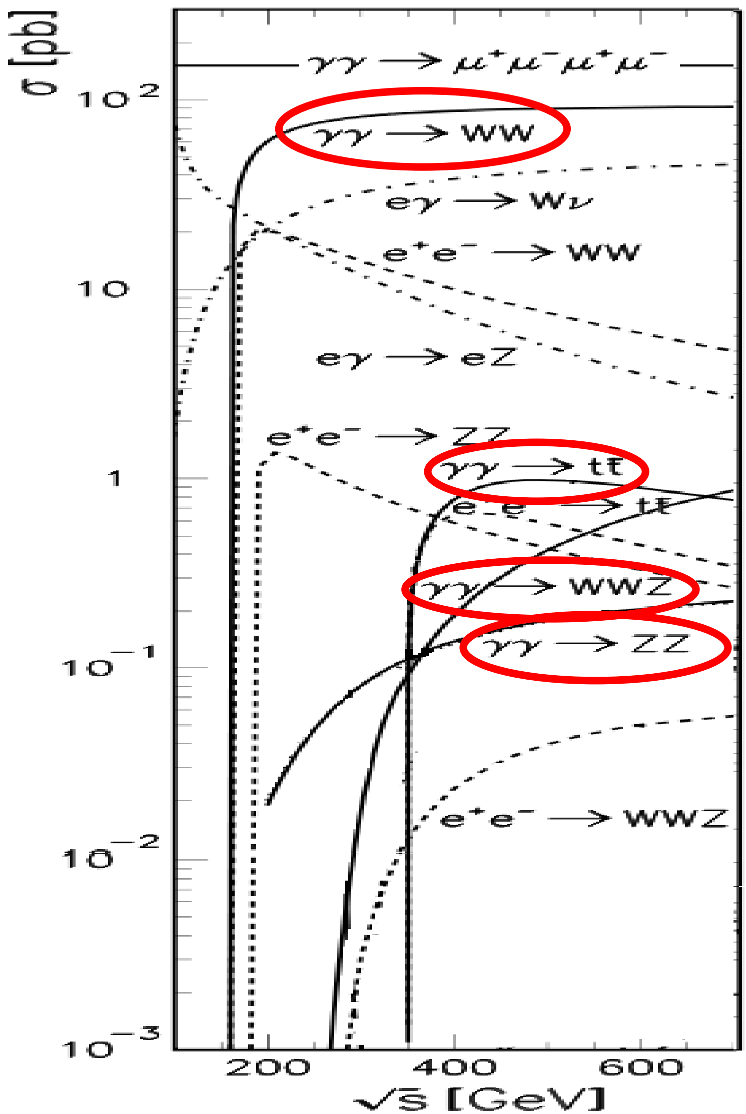
(double resolved)

Soft (VMD) | **Direct** | **γ-"hadron"** | **"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 $\gamma\gamma \to \rho\rho, J/\varphi, J/\varphi, YY$:

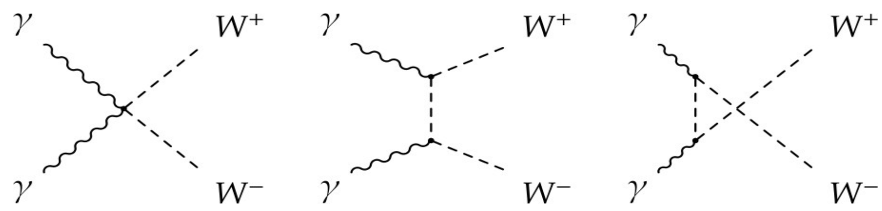


Anomalous couplings at TLEP(γγ)



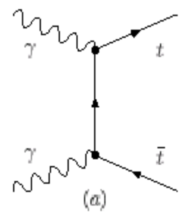
[PLC, TESLA hep-ex/0108012]

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



σ ~ 20–90 pb (160–500 GeV)

- $\gamma\gamma \rightarrow$ t-tbar :



σ ~ 1 pb (>340 GeV)

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

σ ~ 20–150 fb (280–500 GeV)

- Also nice opportunities in eγ mode:
e.g. $e\gamma \rightarrow W\nu$ (again for anomalous couplings)

Anomalous e.m. τ moments at TLEP(γγ)

- Magnetic moment of tau-lepton: a_τ = 1.17734(2)e-4 (QED)

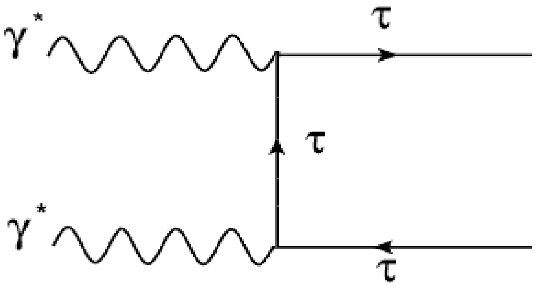
  Current LEP bounds: $-0.052 < a_\tau < 0.013$

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

  Current LEP (also BELLE) limit: $|d_\tau| < 3.1\cdot10^{-16}$ e cm

- Anomalous moments via $\gamma\gamma \to \tau\tau$:

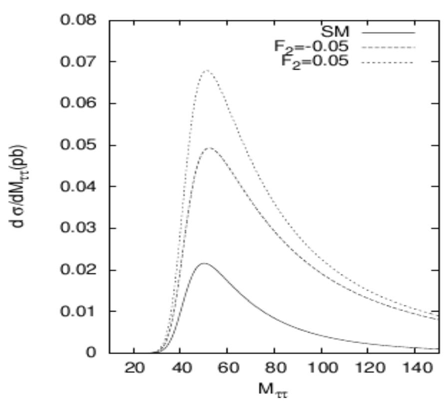
[Billur,Koksal, arXiv:1306.5620]

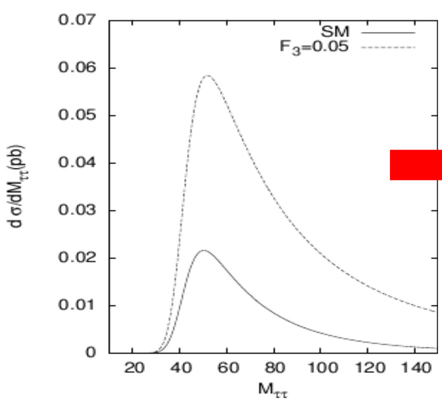


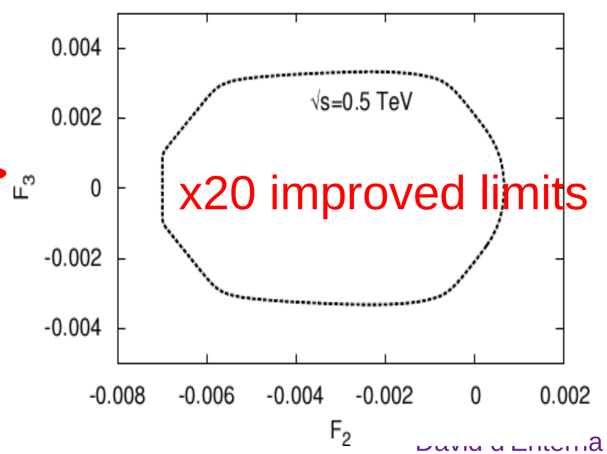
$$\Gamma^\nu = F_1(q^2)\gamma^\nu + \frac{i}{2m_\tau}F_2(q^2)\sigma^{\nu\mu}q_\mu + \frac{1}{2m_\tau}F_3(q^2)\sigma^{\nu\mu}q_\mu\gamma^5$$

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

- Two-photon di-tau at CLIC (or TLEP) at 0.5 TeV, $2\cdot10^{34}$ cm^{-2}s^{-1}:



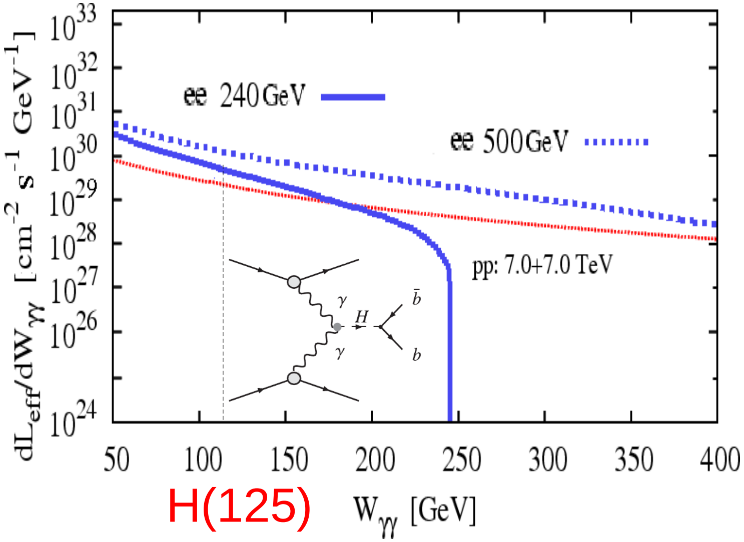




Other new processes for TLEP(γγ)

■ Observation of $\gamma\gamma \rightarrow H(bb)$?

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



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

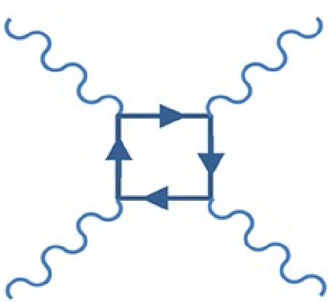
System	$\sqrt{s_{NN}}$ (TeV)	$\sigma(\gamma\gamma \rightarrow H)$ elastic (pb) [$m_H = 120$ GeV/c^2] H total	$H \rightarrow b\bar{b}$
pp	14	$0.18 \cdot 10^{-3}$	$0.13 \cdot 10^{-3}$

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

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

■ Observation of light-by-light scattering $\gamma\gamma \rightarrow \gamma\gamma$?

[DdE & Silveira PRL111 (2013) 080405]



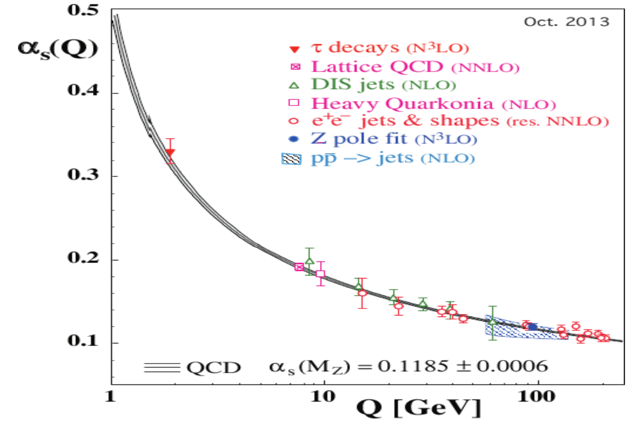
Observable at the LHC for $m_{\gamma\gamma}$>5 GeV in Pb-Pb mode (Z^4-enhanced photon fluxes).

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

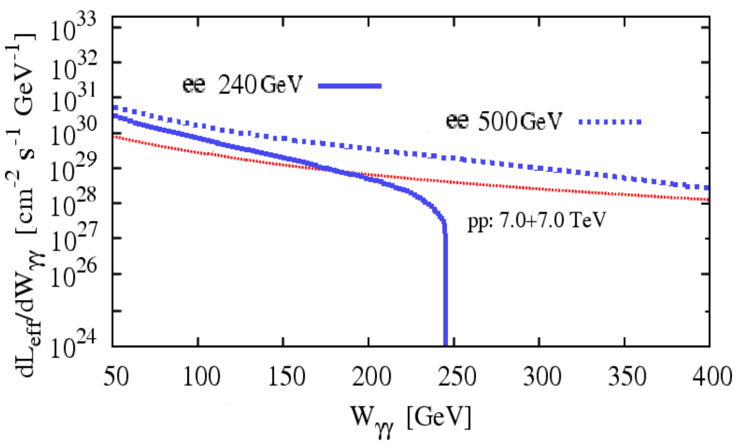
($e^+e^- \rightarrow \gamma\gamma$ background removed via double $e^\pm$-tag)

Summary: QCD & γγ physics at TLEP

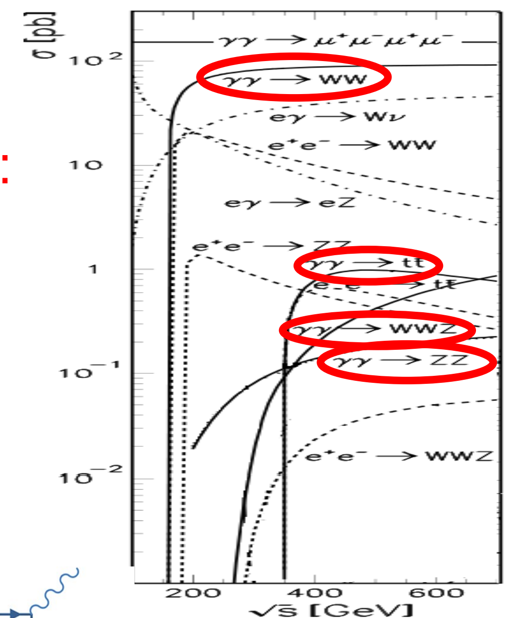
- Beyond-NNLO $\alpha_s(Q)$ w/ high stats/Q^2: (crucial for many precision SM fits)



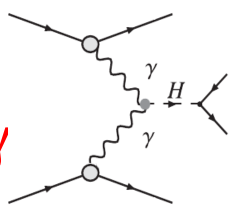
- Fraction of photon-collider physics accessible via EPA fluxes:
  $\mathscr{L}_{eff}$(TLEP,γγ)~5–10×$\mathscr{L}_{eff}$(pp,γγ)

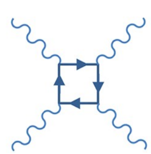


- Constraints on anomalous (top, gauge) couplings:
- Limits on anomalous τ e.m. moments



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

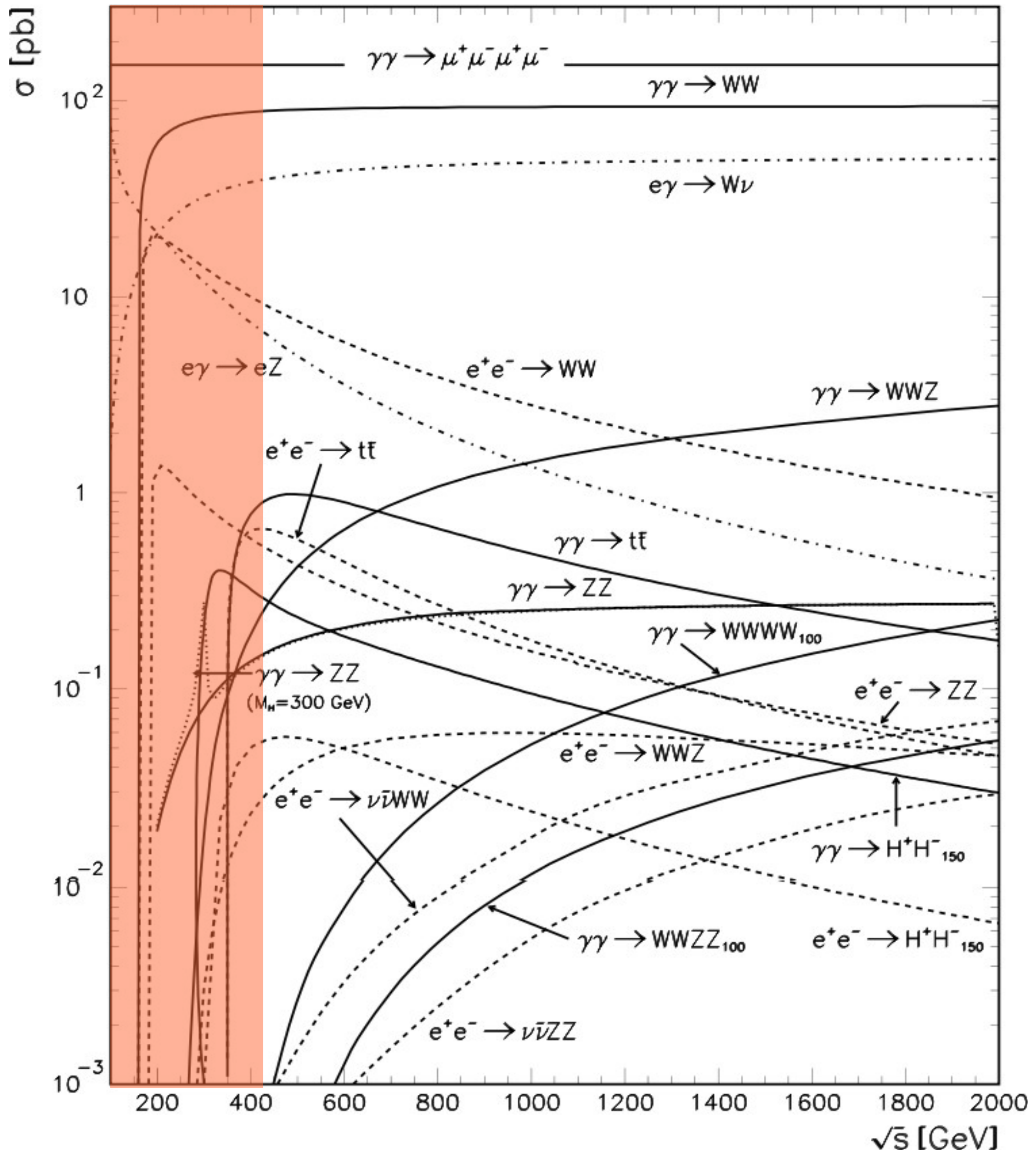




- Quantitative/realistic studies needed for all measurements

Backup slides

Anomalous gauge couplings at TLEP(γγ)



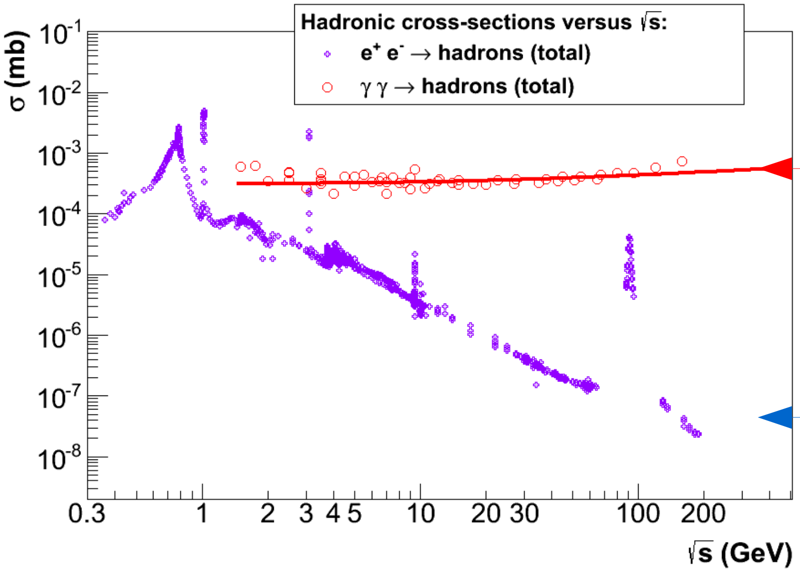
[PLC, TESLA
hep-ex/01/08012]

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 $\gamma \rightarrow V, q\bar{q}$ fluctuations interact strongly and give largest contribution to $\gamma\,\gamma$ cross sections:



$\sigma(\gamma\gamma \rightarrow$ hadrons) ~ ln(s)

Rise as pp,p$\bar{p}$ colls. consistent w/ Regge phenomenology

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

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