Anomalous quartic gauge boson couplings in photon-photon collision at the LHC

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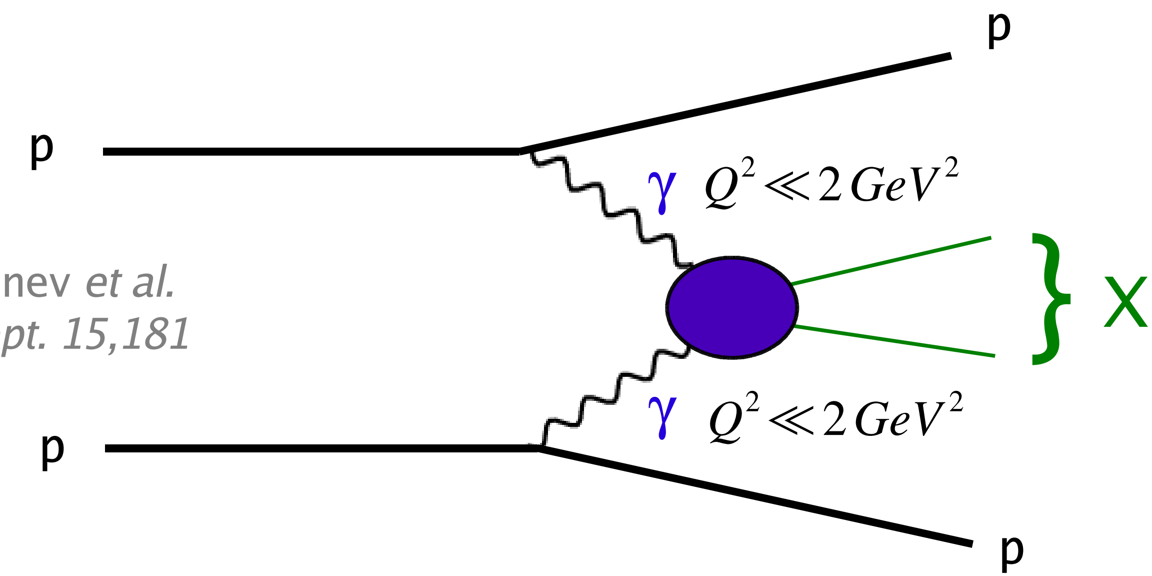
Outline :

- Equivalent photon approximation (EPA)
- $\gamma\gamma$ luminosities for the LHC
- Detection and tagging
- Limits estimation on genuine anomalous quartic gauge boson couplings
  - $\gamma\gamma \rightarrow WW$
  - $\gamma\gamma \rightarrow ZZ$
- Limits & unitary condition
- Prospects and Conclusions

LHC – also a photon-photon collider

V.M.Budnev *et al.*
Phys.Rept. 15,181



$$\sigma(\ pp \rightarrow (\gamma\gamma \rightarrow X)\ pp\ )$$

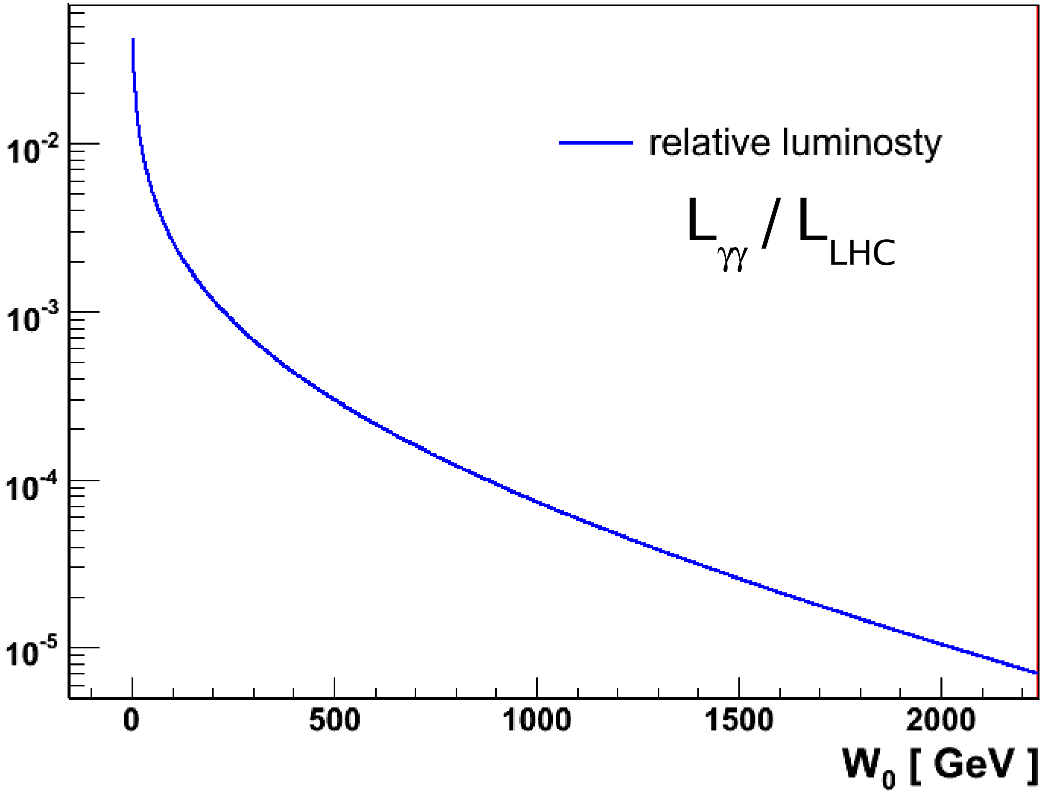
low γ virtuality (typical $Q^2 \sim 0.01\,GeV^2$) $\Rightarrow$

- factorization to
  - long distance photon exchange
  - short distance $\gamma\gamma \rightarrow$ X interaction
- zero degree scattered angels

$\gamma\gamma$ luminosities at the LHC

luminosity peaked at low $W_{\gamma\gamma}$

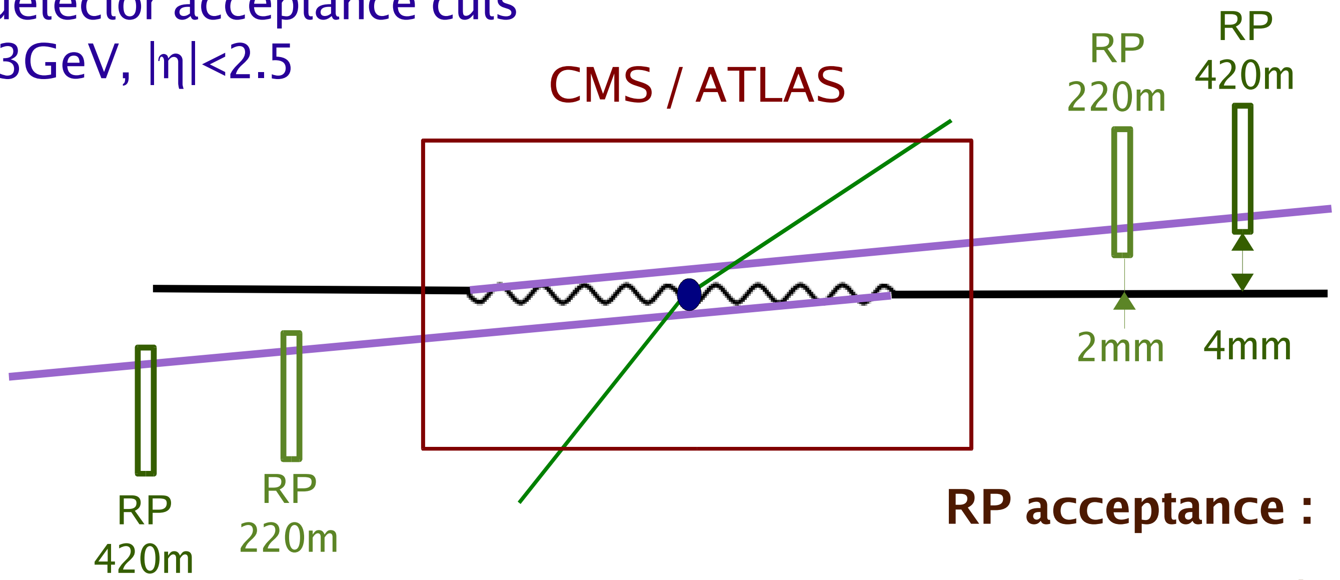
sizable charged pair production up to $W_{\gamma\gamma} \approx 500$GeV



relative photon-photon luminosity for $W_{\gamma\gamma} > W_0$ at LHC

Detection and tagging

main detector acceptance cuts
$p_t(\mu) > 3\,\mathrm{GeV}$, $|\eta| < 2.5$



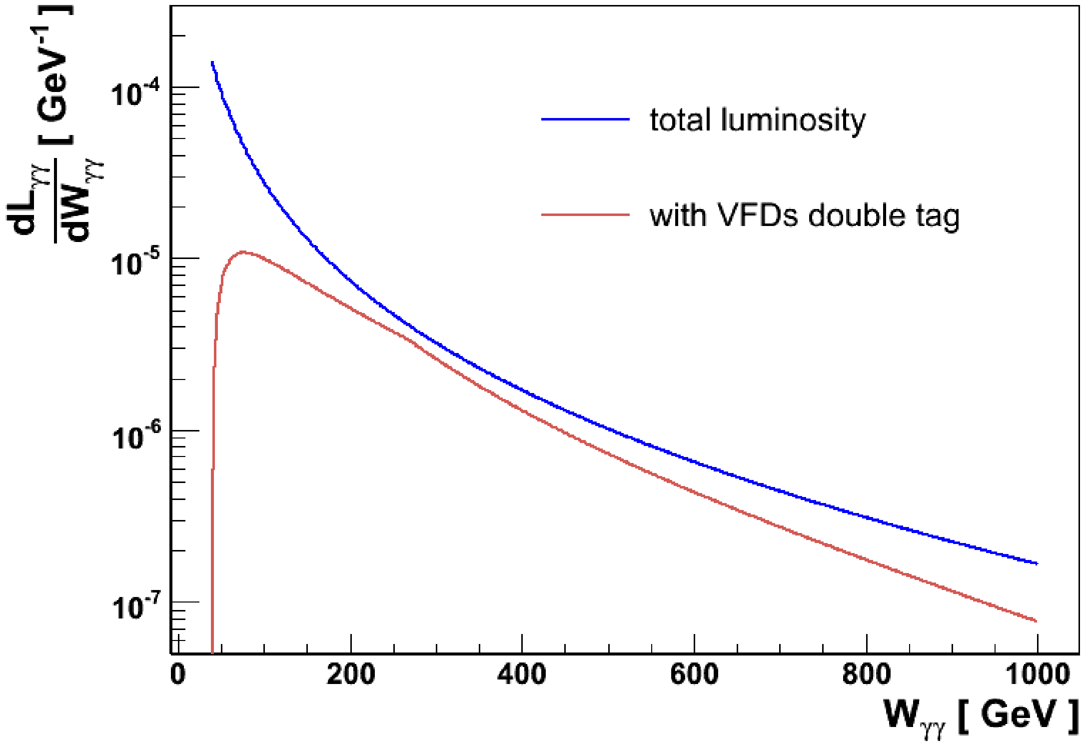
RP acceptance : by X.Rouby

$120\,\mathrm{GeV} <$ tagged $E_\gamma < 900\,\mathrm{GeV}$

RP 220m

$20\,\mathrm{GeV} <$ tagged $E_\gamma < 120\,\mathrm{GeV}$

RP 420m

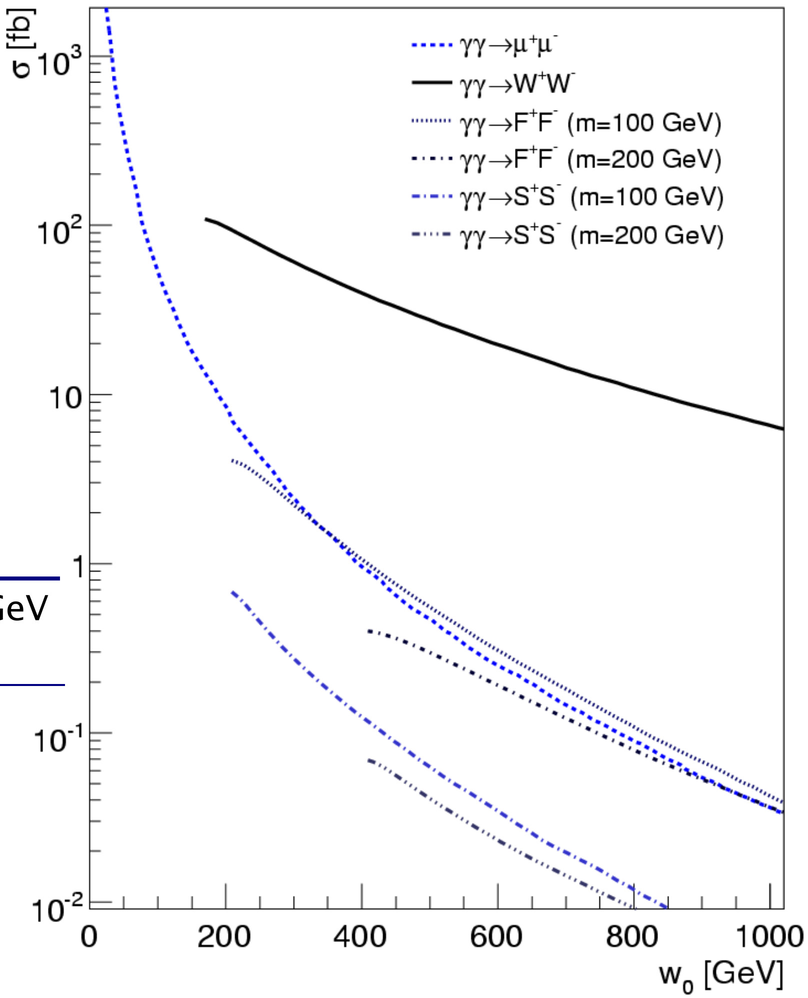


$$\sigma_{pp} = \int \sigma(W_{\gamma\gamma}) \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} dW_{\gamma\gamma}$$

γγ cross sections of main interest

- $\gamma\gamma \rightarrow \mu\mu$ first γγ process to be seen
- $\gamma\gamma \rightarrow W^+W^-$ very interesting SM process 108fb
- New physics !

Processes		[fb]	Generator
$\gamma\gamma \rightarrow \mu\mu$		72 500	LPAIR pt > 2 GeV $\lvert\eta\rvert < 3.1$
$\gamma\gamma \rightarrow$ WW		108	
→ FF	(m=100GeV)	4.06	MadGraph
→ FF	(m=200GeV)	0.40	/
→ SS	(m=100GeV)	0.68	MadEvent
→ SS	(m=200GeV)	0.07	



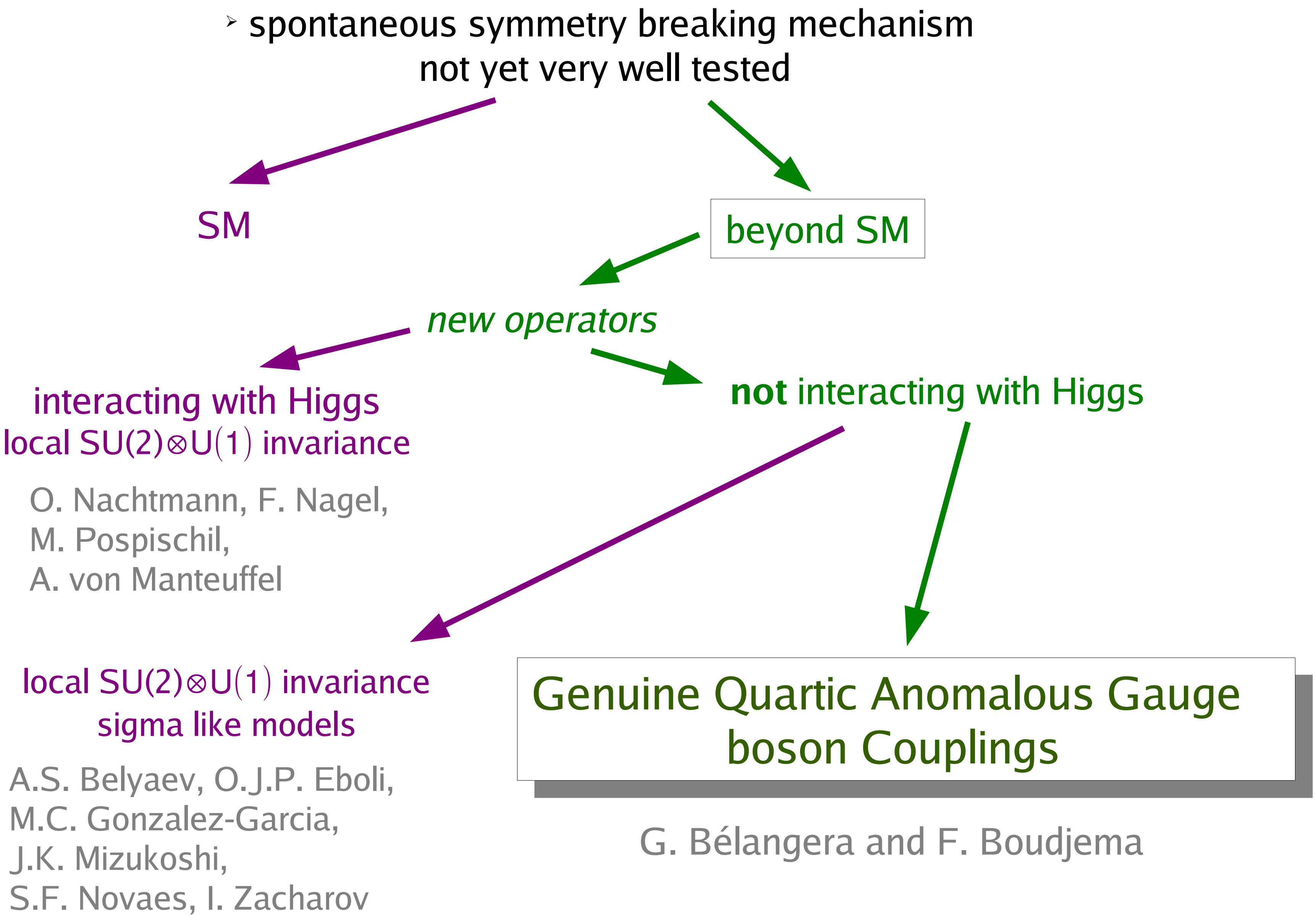
Cross sections for γγ processes as a function of the minimal γγ cms energy W_0

moreover :

lepton final states

clear signature – background suppression

Motivation of analysis of a weak boson sector



- spontaneous symmetry breaking mechanism not yet very well tested

SM

beyond SM

new operators

interacting with Higgs
local SU(2)⊗U(1) invariance

O. Nachtmann, F. Nagel,
M. Pospischil,
A. von Manteuffel

not interacting with Higgs

local SU(2)⊗U(1) invariance
sigma like models

A.S. Belyaev, O.J.P. Eboli,
M.C. Gonzalez-Garcia,
J.K. Mizukoshi,
S.F. Novaes, I. Zacharov

Genuine Quartic Anomalous Gauge boson Couplings

G. Bélangera and F. Boudjema

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EPA

γγ luminosity

γγ detection

cross sections

anomalous quartic gauge boson couplings

Lagrangian

Anomalous Lagrangian

we use Lagrangian for genuine anomalous quartic vector boson couplings which conserves C, P as well as local $U(1)_{em}$ and $SU(2)_C$

$$L_6^0 = \frac{-e^2}{8} \frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^-_\alpha - \frac{e^2}{16 \cos^2 \Theta_W} \frac{a_0^Z}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} Z^\alpha Z_\alpha$$

$$L_6^C = \frac{-e^2}{16} \frac{a_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W^-_\beta + W^{-\alpha} W^+_\beta) - \frac{e^2}{16 \cos^2 \Theta_W} \frac{a_C^Z}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} Z^\alpha Z_\beta$$

This gives a general auxiliary formula for a cross section (total or differential, with or without cuts) as a function of the anomalous parameters:

$$\sigma = \sigma_{SM} + \sigma_0 a_0 + \sigma_{00} a_0^2 + \sigma_C a_C + \sigma_{CC} a_C^2 + \sigma_{0C} a_0 a_C$$

Investigating sensitivity for anomalous quartic gauge couplings (AQGC)

Simple event counting in the main detector
with a two leptons (e or μ) signature within the acceptance cuts :

$$|\eta| < 2.5$$

$$p_T > 10\,GeV$$

- WW : $\gamma\gamma \to W^+W^- \to l^+l^-\nu_l\bar{\nu}_l$
- ZZ : $\gamma\gamma \to ZZ \to l^+l^- jj$ (no cuts on jets)

for a background we assume :

- WW : only SM γγ → WW
- ZZ : no background – as no tree level SM γγ → ZZ

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significance limits on the AQGC

if $N_{obs} = \sigma^{SM}_{cuts} \cdot L$, CL=95%

$$\sum_{k=0}^{N_{obs}} P_{Poisson}\left(\lambda^{up} = \sigma^{up} \cdot L;\ k\right) = 1 - CL$$

The calculated cross section CL=95% upper limits are :

σ^{up} [fb]	$\gamma\gamma \rightarrow W\,W$ $\sigma^{SM}_{cuts} = 4.081$ fb	$\gamma\gamma \rightarrow ZZ$ $N_{obs} = 0,\ \lambda^{up} = 2.996$
$L = 1\ fb^{-1}$	9.2	3.0
$L = 10\ fb^{-1}$	5.3	0.3

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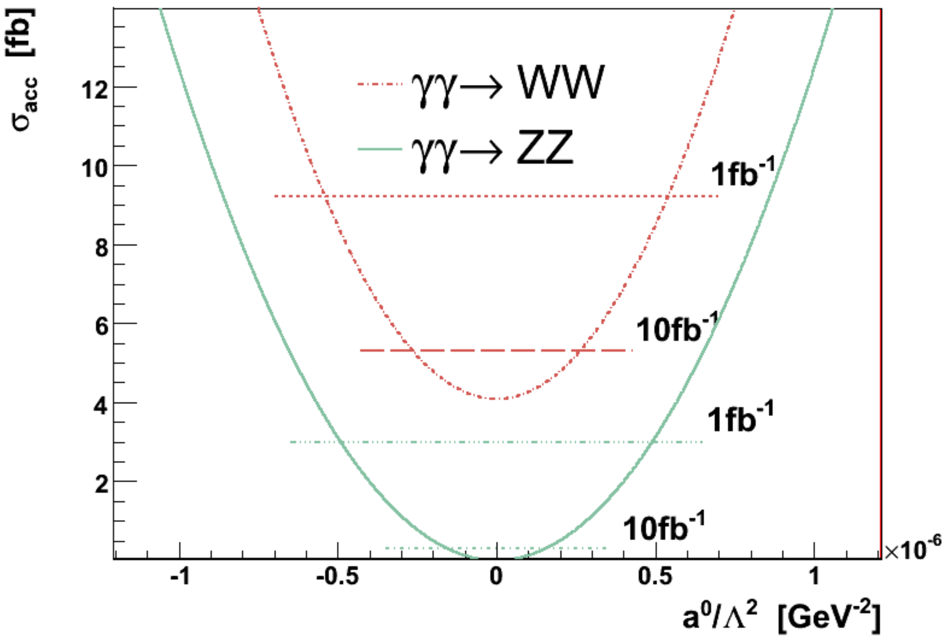
can be easily converted to the limit on the anomalous quartic couplings



Coupling	Limits $[GeV^{-2}]$ L=1fb^{-1}	 L=10fb^{-1}
$\lvert a_0^Z/\Lambda^2 \rvert$	$0.49 \cdot 10^{-6}$	$0.16 \cdot 10^{-6}$
$\lvert a_0^W/\Lambda^2 \rvert$	$0.54 \cdot 10^{-6}$	$0.27 \cdot 10^{-6}$

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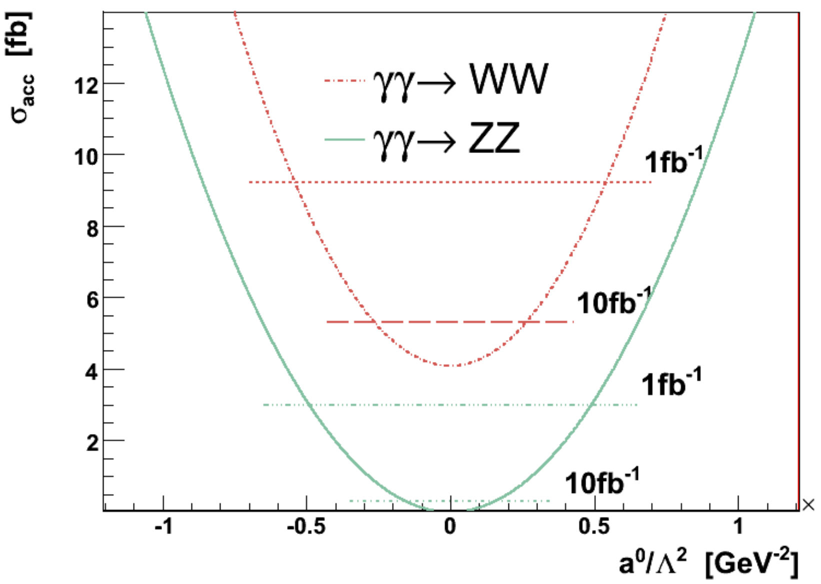

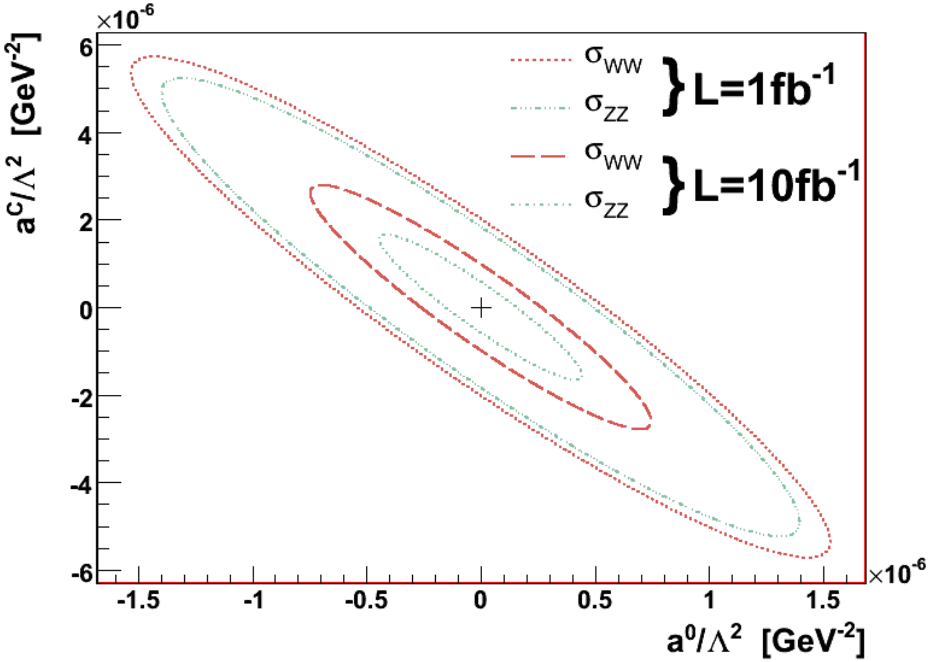

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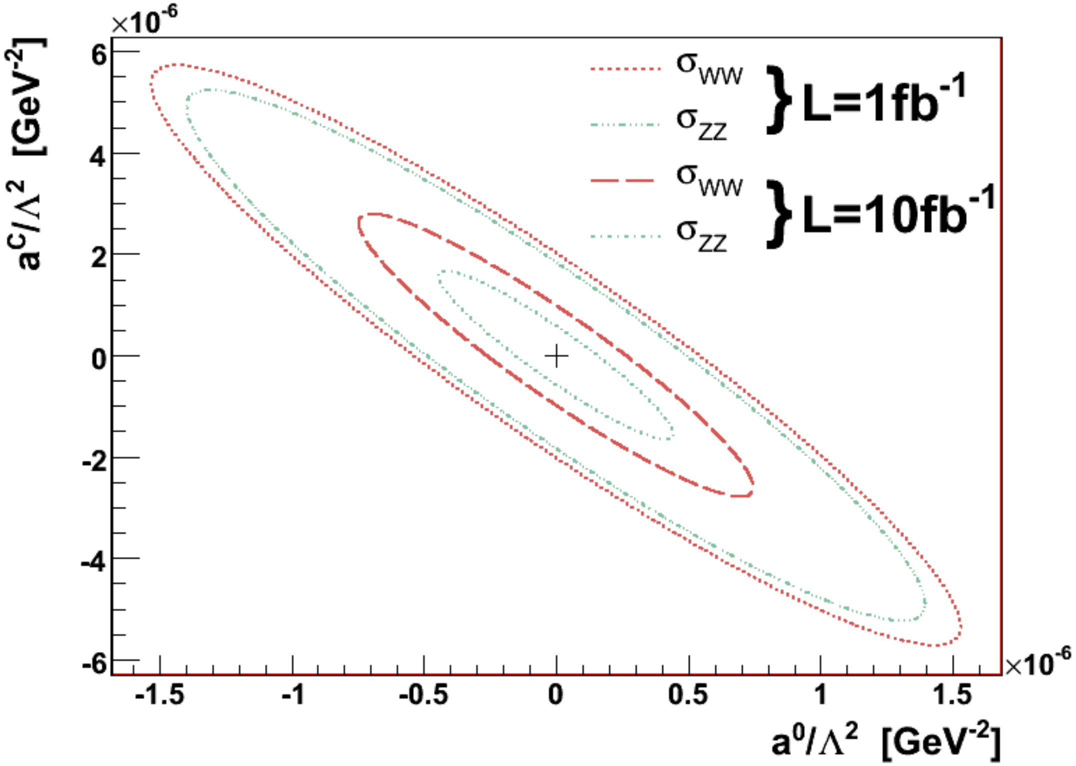

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$\lvert a_0^W/\Lambda^2\rvert$	$0.54\cdot10^{-6}$	$0.27\cdot10^{-6}$
$\lvert a_C^Z/\Lambda^2\rvert$	$1.84\cdot10^{-6}$	$0.58\cdot10^{-6}$
$\lvert a_C^W/\Lambda^2\rvert$	$2.02\cdot10^{-6}$	$0.99\cdot10^{-6}$

significance limits on the AQGC

Phys.Rev.D70:032005,2004

OPAL limits :

$$-0.007\ GeV^{-2} < a_0^Z/\Lambda^2 < 0.023\ GeV^{-2}$$

$$-0.020\ GeV^{-2} < a_0^W/\Lambda^2 < 0.020\ GeV^{-2}$$

$$-0.029\ GeV^{-2} < a_C^Z/\Lambda^2 < 0.029\ GeV^{-2}$$

$$-0.052\ GeV^{-2} < a_C^W/\Lambda^2 < 0.037\ GeV^{-2}$$

Coupling	Limits [GeV^{-2}] L=$1fb^{-1}$	L=$10fb^{-1}$
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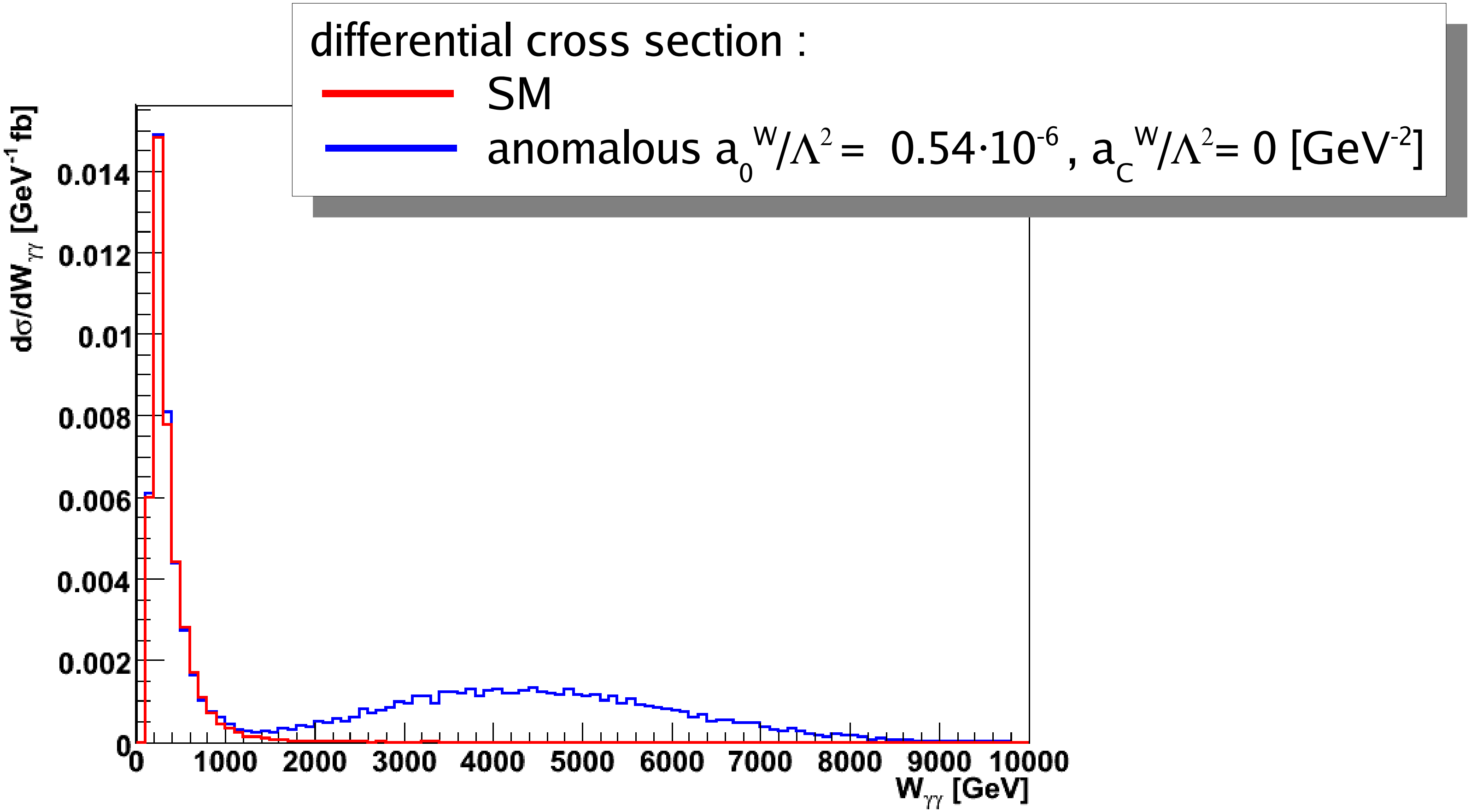
Unitary bound



Anomalous enhancement mostly at high $W_{\gamma\gamma}$ mass

Could couplings with value of these limits be realized in nature ?
How about unitary – is it not violated ?

Unitary bound

Could couplings with value of these limits be realized in nature ?

How about unitary – is it not violated ?

In non elastic scattering partial wave function a_L :

$$a_L = \frac{1}{32\pi} \int_{-1}^{1} M(\sqrt{s}, \cos\Theta) \cdot P_L(\cos\Theta)\, d\cos\Theta$$

Legendre Polynomial

must satisfy :

$$\beta \sum_{pol} |a_L|^2 < (1/2)^2$$

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Unitary bound

Could couplings within these limits be realized in nature ?

How about unitary – is it not violated ?

In non elastic scattering partial wave function a_L :

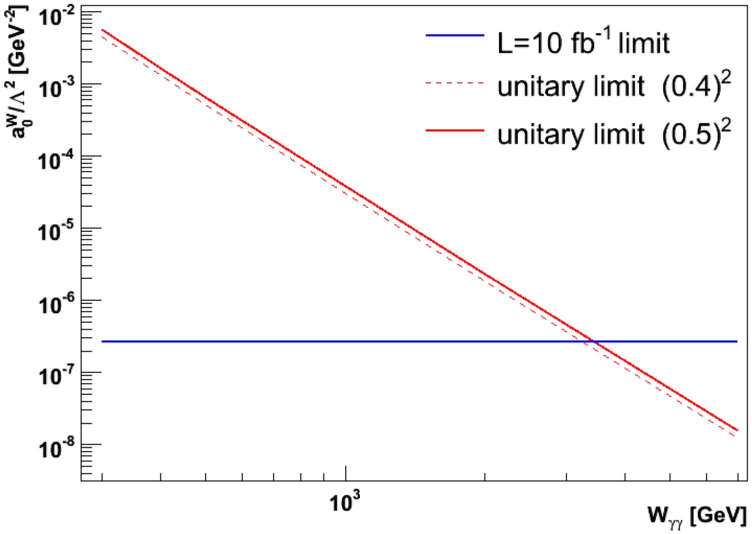
$$a_L = \frac{1}{32\pi}\int_{-1}^{1} M(\sqrt{s}, \cos\Theta, a_0, a_C)\cdot P_L(\cos\Theta)\, d\cos\Theta$$

must satisfy :

$$\beta \sum_{pol} |a_L(\sqrt{s}, a_0, a_C)|^2 < (1/2)^2$$

Unitary bound

$$\beta\sum_{pol}|a_L(\sqrt{s},a_0,a_C)|^2<(1/2)^2$$

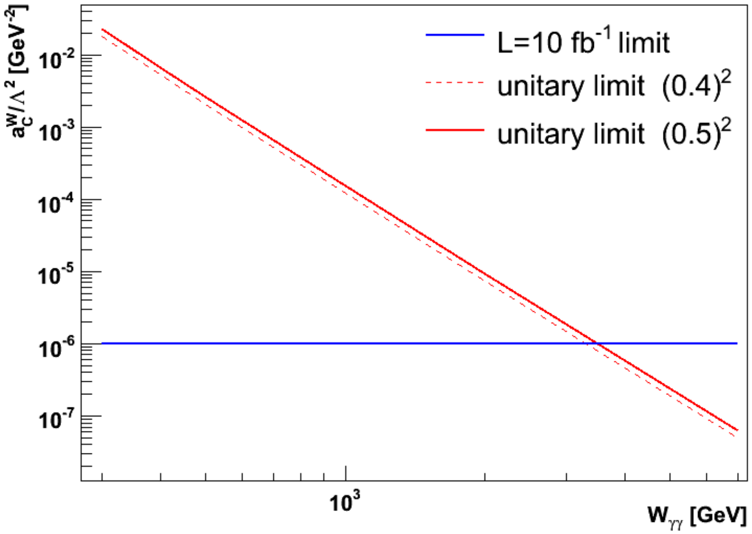


$a_{L=0}$ plotted (0.4 and ½)

$a_{L=1} = 0$

$a_{L=2}$ much smaller then ½ – can be neglected

- Unitary would be violated above 3TeV



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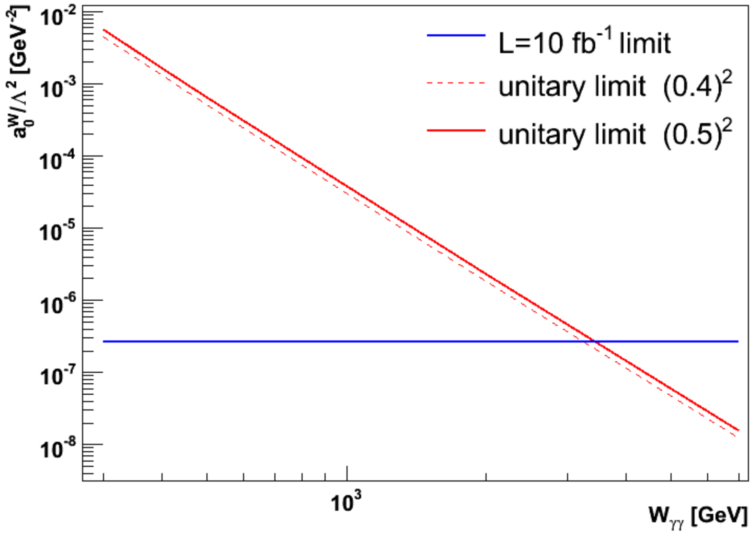

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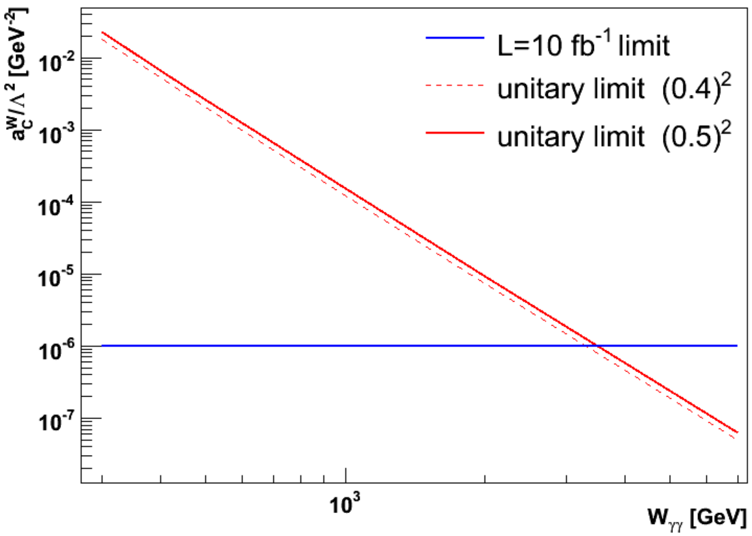

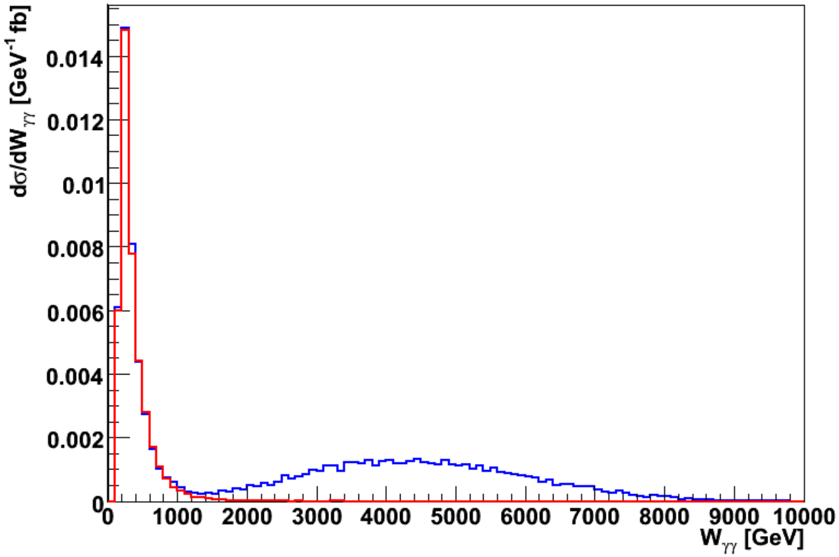

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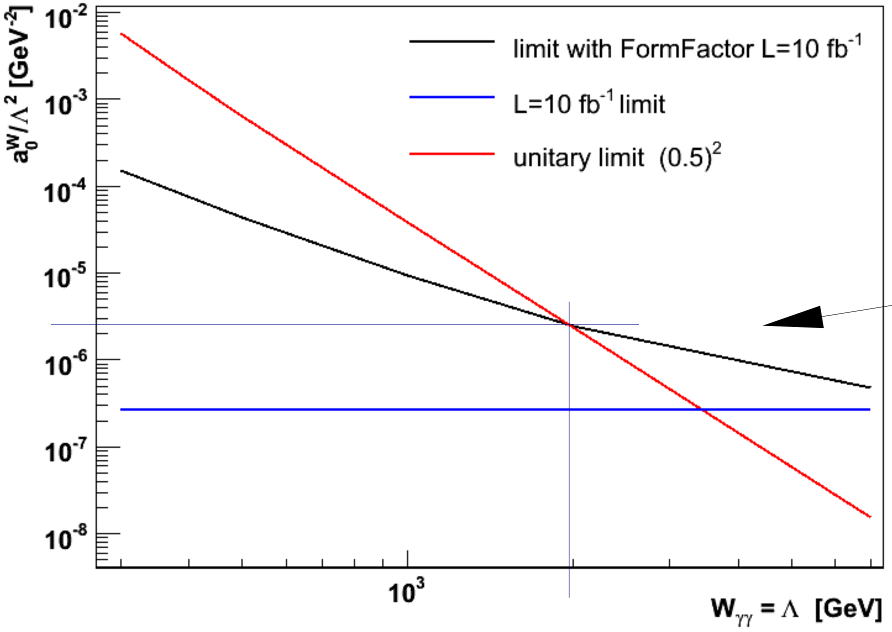
Unitary bound

one have to dump/remove unphysical too high $W_{\gamma\gamma}$ region

double tagging protons
⇒ $W_{\gamma\gamma}$ less then 1.8TeV

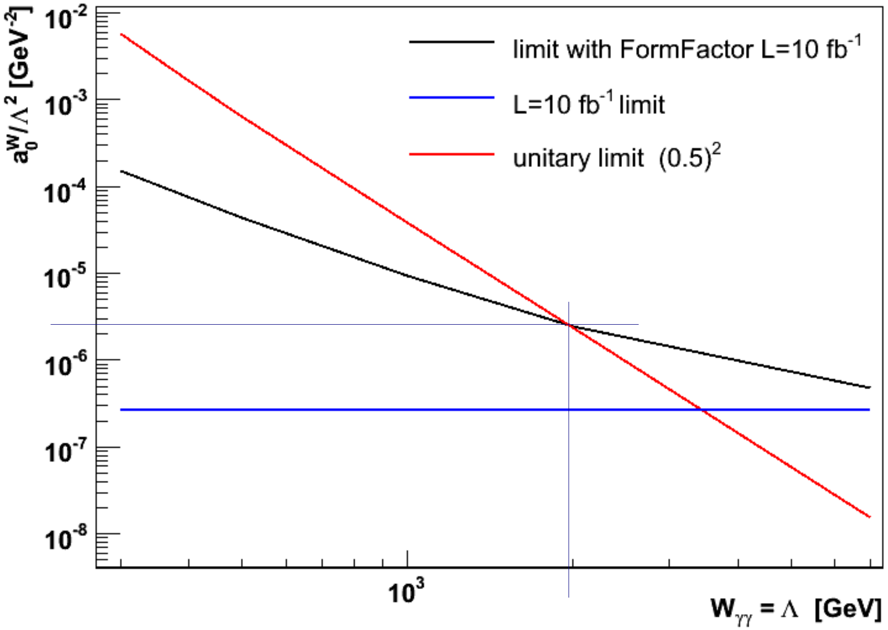
dipole form-factor

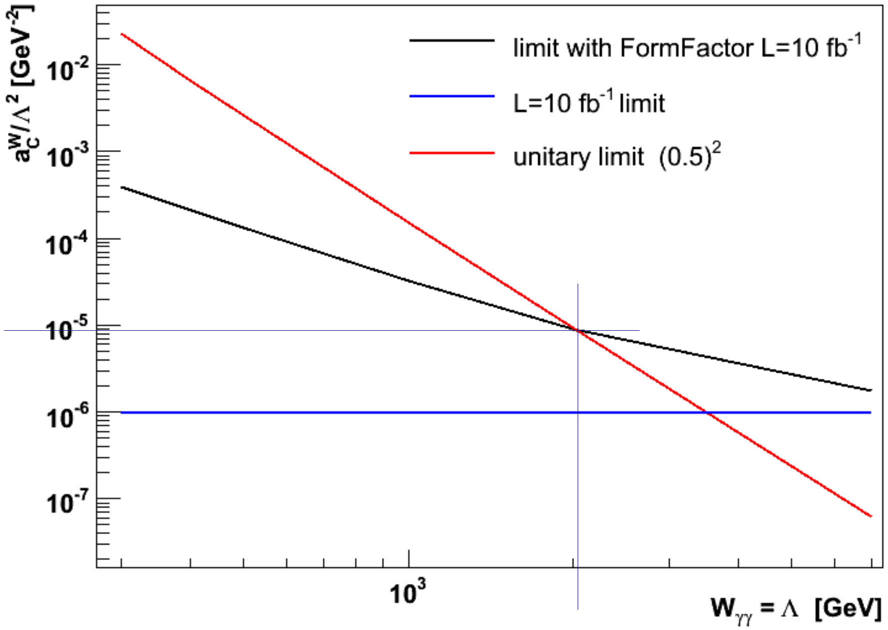
$$a \rightarrow \frac{a}{\left(1+\frac{W_{\gamma\gamma}^2}{\Lambda^2}\right)^X}$$



we used X=2

Unitary bound





dipole form-factor

$$a \rightarrow \frac{a}{\left(1+\frac{W_{\gamma\gamma}^{2}}{\Lambda^{2}}\right)^{2}}$$

Limits including form-factor :

$a_0^W/\Lambda^2 < 2.5 \cdot 10^{-6}\ \mathrm{GeV}^{-2}$

$a_Z^W/\Lambda^2 < 9 \cdot 10^{-6}\ \mathrm{GeV}^{-2}$

whilst LEP :

$a_0^W/\Lambda^2 < 2.0 \cdot 10^{-2}\ GeV^{-2}$

$a_Z^W/\Lambda^2 < 3.7 \cdot 10^{-2}\ GeV^{-2}$

for L = 10 fb^{-1}

about 10 000 times better !!!

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Perspective

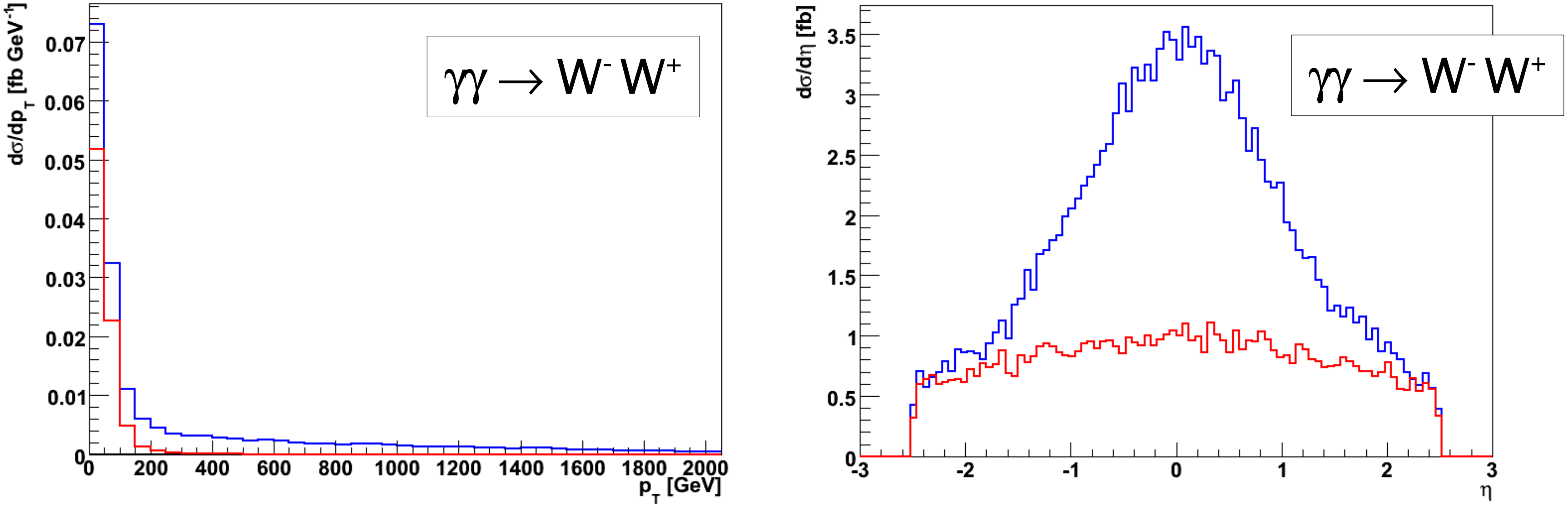
Perspective

- use semi leptons for WW → l ν j j enhancement ~ 6 times
- use of leptons p_T and/or η distributions – discriminating power

differential cross section :

🟥 SM

🟦 anomalous $a_0^W/\Lambda^2 = 0.54 \cdot 10^{-6}$, $a_C^W/\Lambda^2 = 0$ [GeV^{-2}]



Perspective

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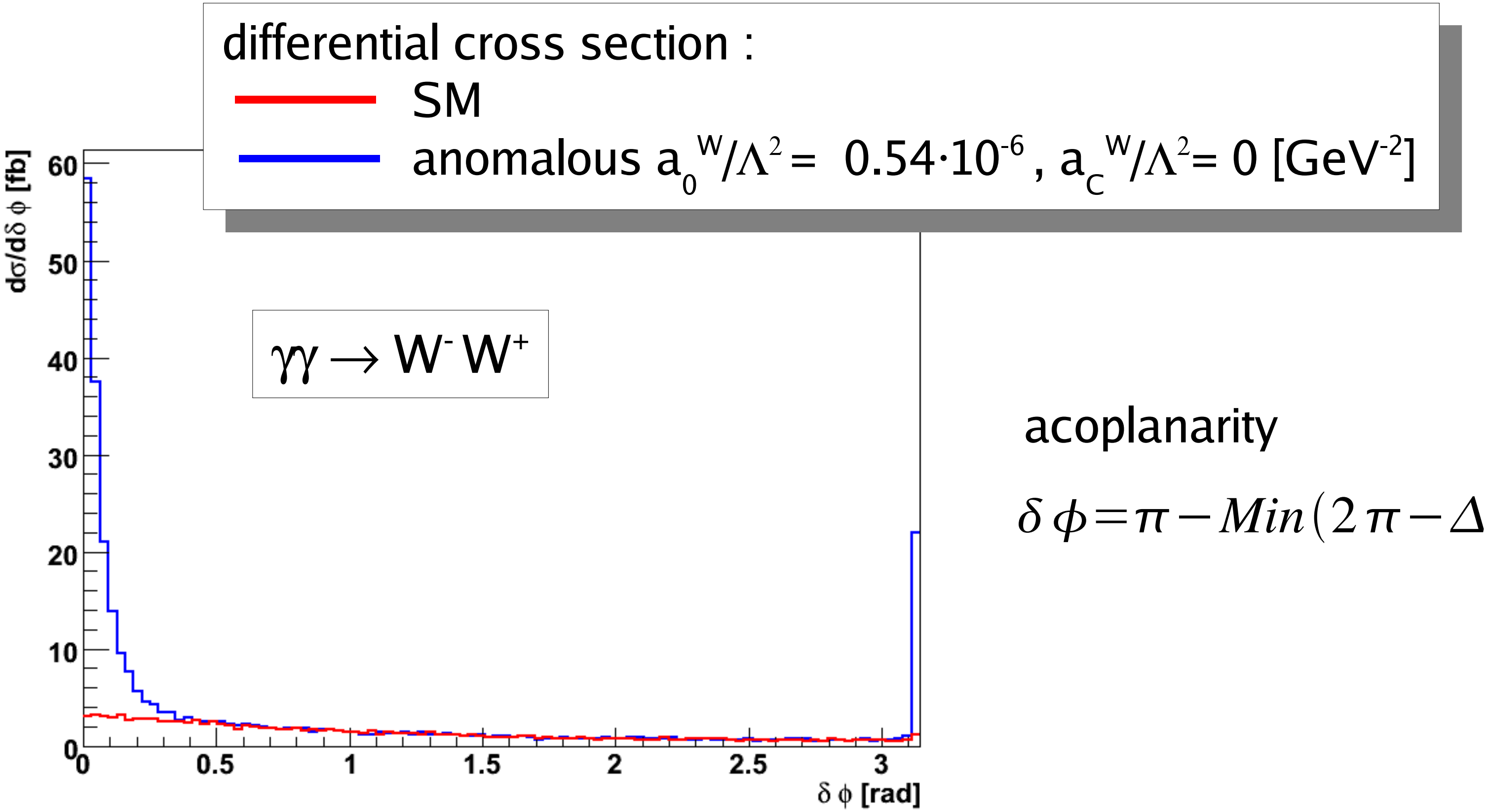
- use of leptons p_T and/or η distributions – discriminating power



acoplanarity

$$\delta\phi = \pi - Min(2\pi - \Delta\phi, \Delta\phi)$$

Conclusions

- LHC – a photon-photon collider
- limits for genuine anomalous γγWW, γγZZ could be 10 000 better than present limits

Louvain Photon group :

J.de Favereau, V. Lemaître, Y. Liu, S. Ovyn, T. Pierzchała,
K. Piotrzkowski, X. Rouby, N.Schul, M. Vander Donckt