γγ and eγ physics
highlights

A.F.Żarnecki (Warsaw U.)

experimental group conveners:

- Piotr Niezurawski (Warsaw U),
- Steven Maxfield (U Liverpool)

theory conveners:

- Michael Krämer (Edinburgh U),
- Maria Krawczyk (Warsaw U)

Milestones

Photon Collider Workshops:

- LBL 1994
- DESY 2000
- FNAL 2001
- Kazimierz (Poland) 2005

Contributions to:

- Tesla TDR (Appendices, Chapter 1)
  Intern.Journ.of Mod.Phys.A 19(2004)5097
- First LHC / ILC Study Group Report,
  Phys. Rept. 426 (2006) 47
- CPNSH report, CERN-2006-009

Nearest future:

- contribution to the DCR Physics Chapter
- preparation of the PLC Physics review

$\gamma\gamma$ physics web page:

https://www.desy.de/~maxfield/ggcol/lcgg.html

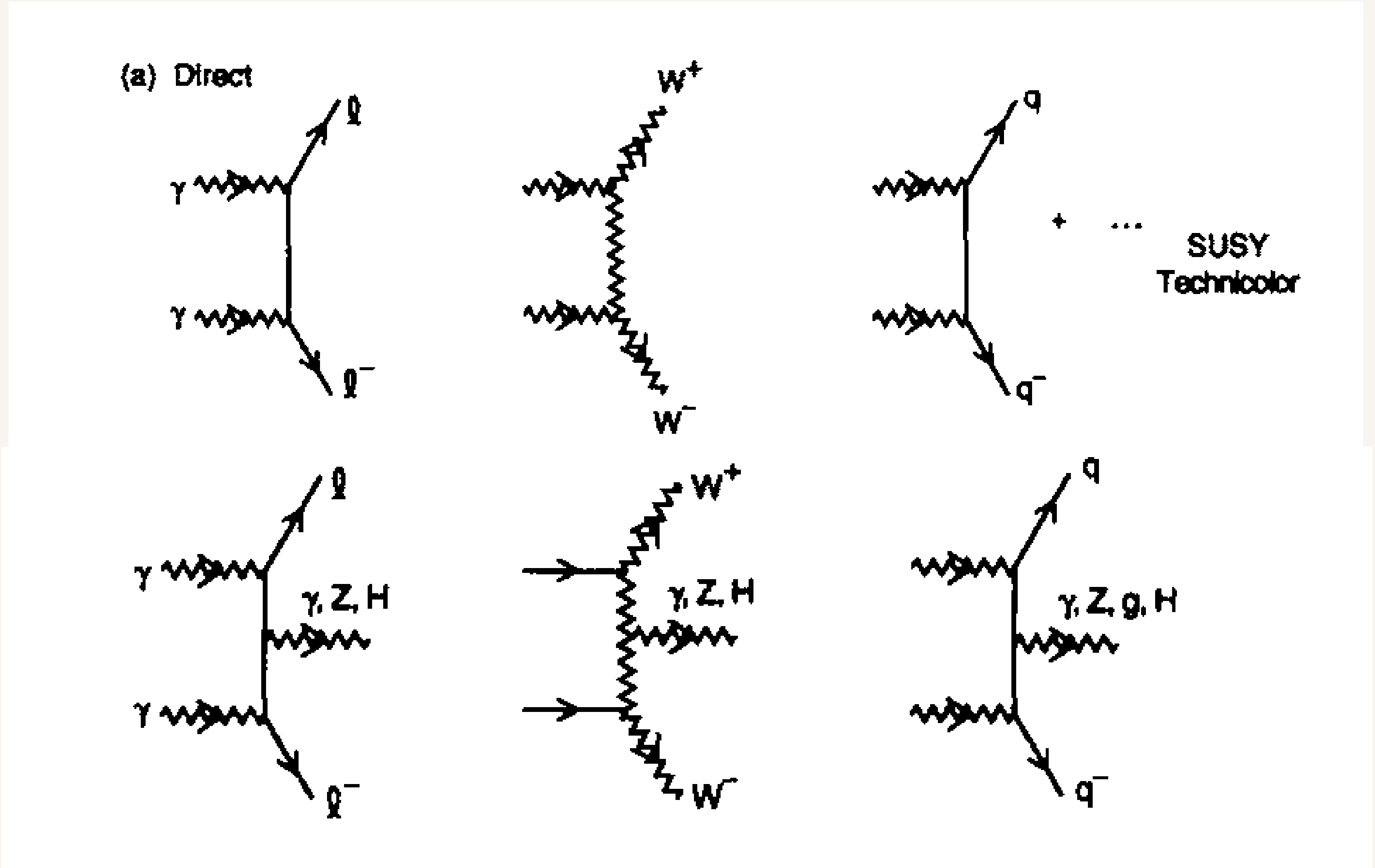
1. INTRODUCTION

THE PHYSICS CASE: EWSB/SUSY/QCD

- Higgs: $H\gamma\gamma$ coupling: qu-effect: window to high scales
  extended mass reach for heavy Higgs
  CP violation $\sim$ beam polarization
- Charged particles: $W^{\pm}$-boson, *top*-quark multi-pole moments
- SUSY: extd mass reach for selectrons $\tilde{e}$ in ass with light neutralino
  mass measurement of sneutrino $\tilde{\nu}_e$
- QCD: mechanism for total hadronic cross section
  γ quark/gluon : DIS $e\gamma$
  high p_T jets
- Varia: Majorana neutrinos, e^*, etc

P.M. Zerwas and SJB

Two-Photon Collisions in the Standard Model



$\gamma\gamma$ Cross sections

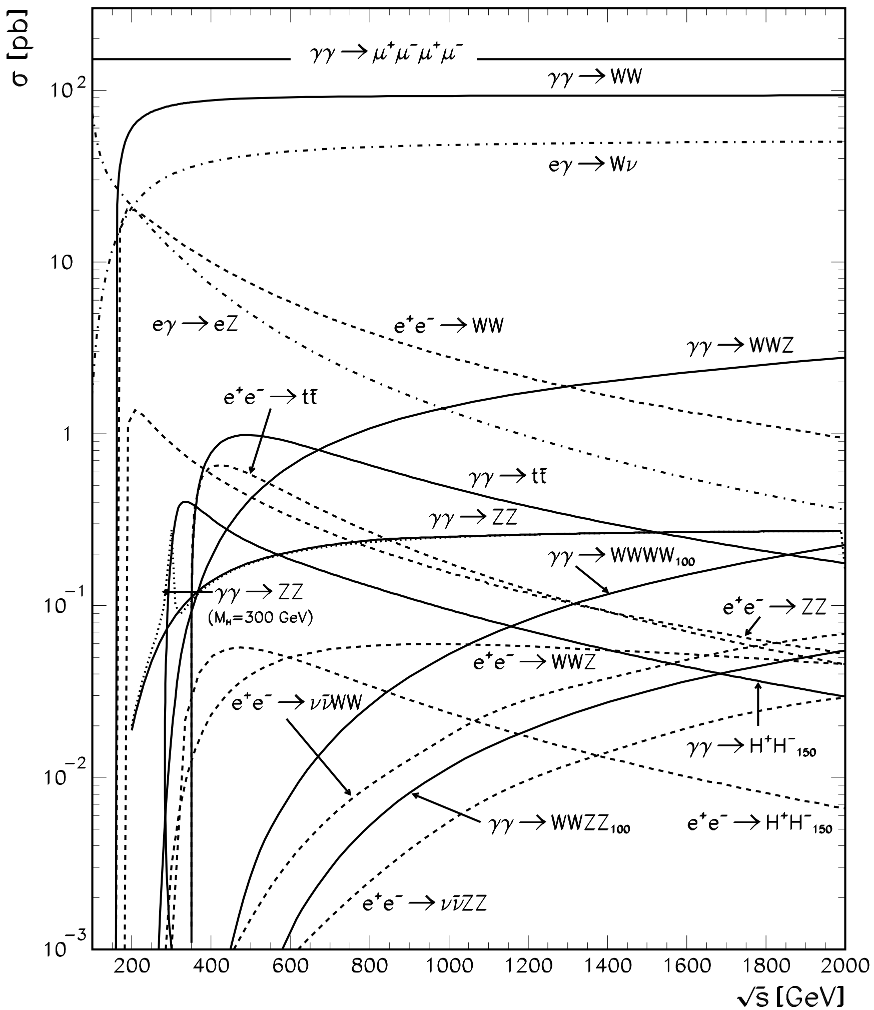
pointlike : $\gamma\gamma \sim 3$ to $10 \times e^+e^-$

examples : t, $W^\pm$, $H^\pm$, $\tilde{e}$, $\tilde{\chi}^\pm$, ...

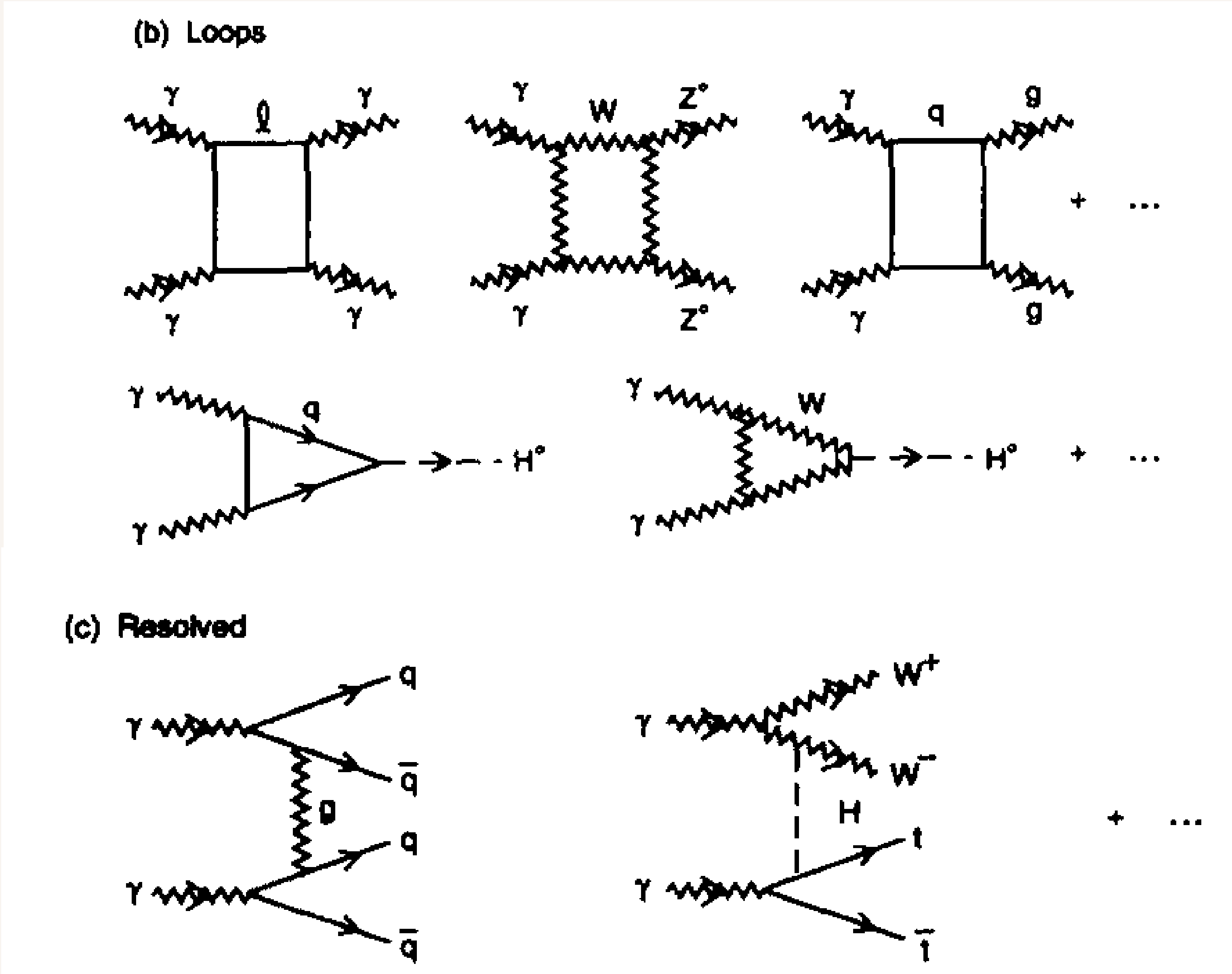
large size : 10 to 10^5 fb $\Rightarrow$

10^3 to 10^7 evts

for $\mathcal{L} = 100$ fb^{-1}

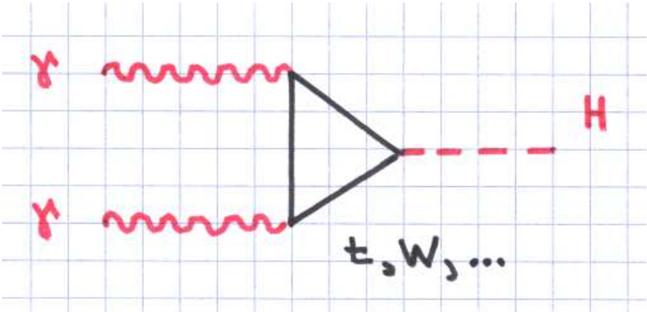


Illustrations of High-Energy Two-Photon Collisions in the Standard Model



2. ELECTROWEAK SYMMETRY BREAKING

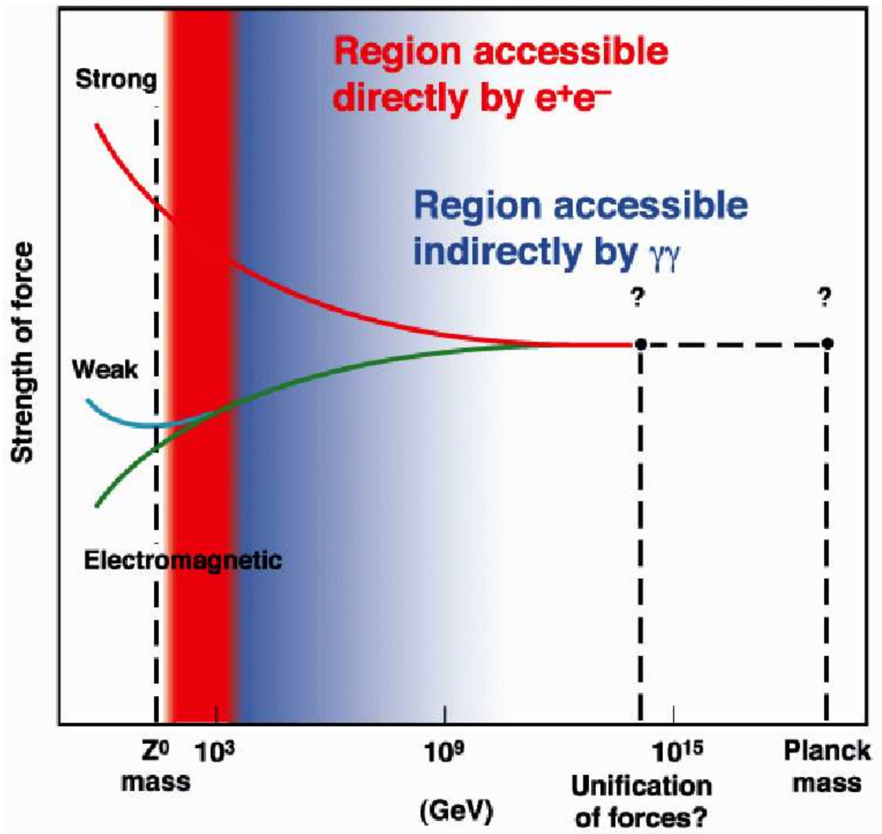
a) LIGHT HIGGS IN $\gamma\gamma$ COLLISIONS



$$\sigma_{\gamma\gamma} = \Gamma_{\gamma\gamma}\, \hat{\sigma}\, d\mathcal{L}/dm^2_{\gamma\gamma}(M^2_H)$$

– sharp onset for polarized beams

– helicities $\lambda_1 = \lambda_2$ enh. signal / sup. bkgd

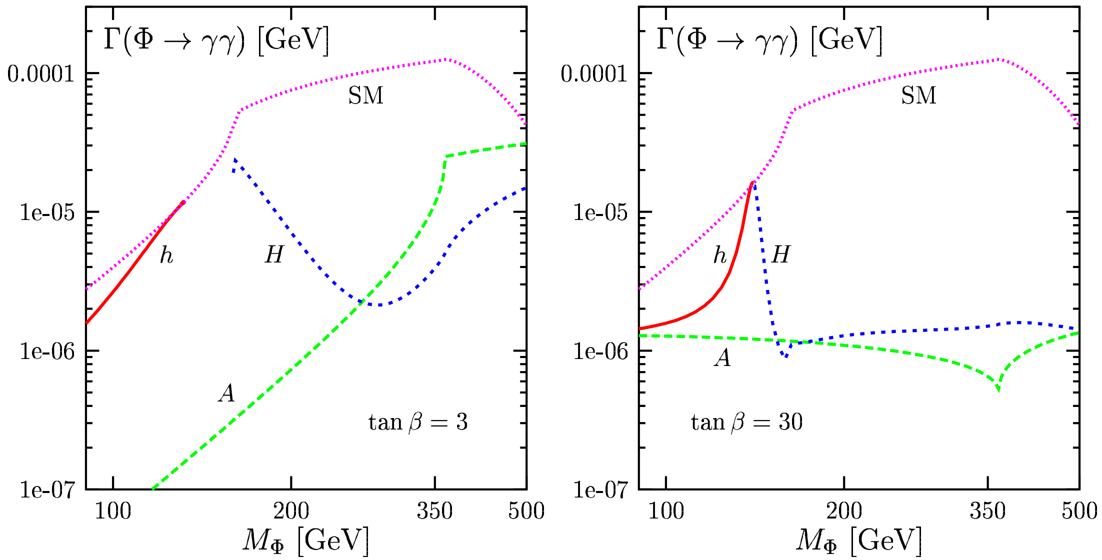


2. ELECTROWEAK SYMMETRY BREAKING

$\Gamma_{\gamma\gamma}$ sensitivity to:

a) SUSY loop contributions

F: Djouadi



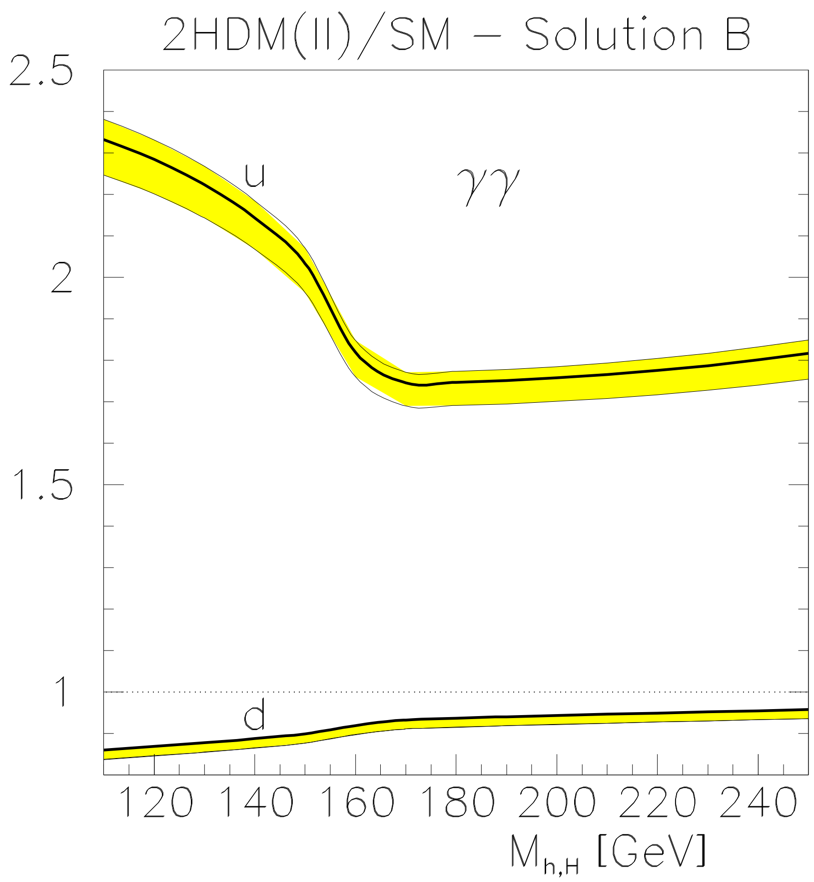
2. ELECTROWEAK SYMMETRY BREAKING

$\Gamma_{\gamma\gamma}$ sensitivity to:

a) SUSY loop contributions

b) $H^{\pm}$ loop in general 2HDM

F: Ginzburg, Krawczyk, Osland



2. ELECTROWEAK SYMMETRY BREAKING

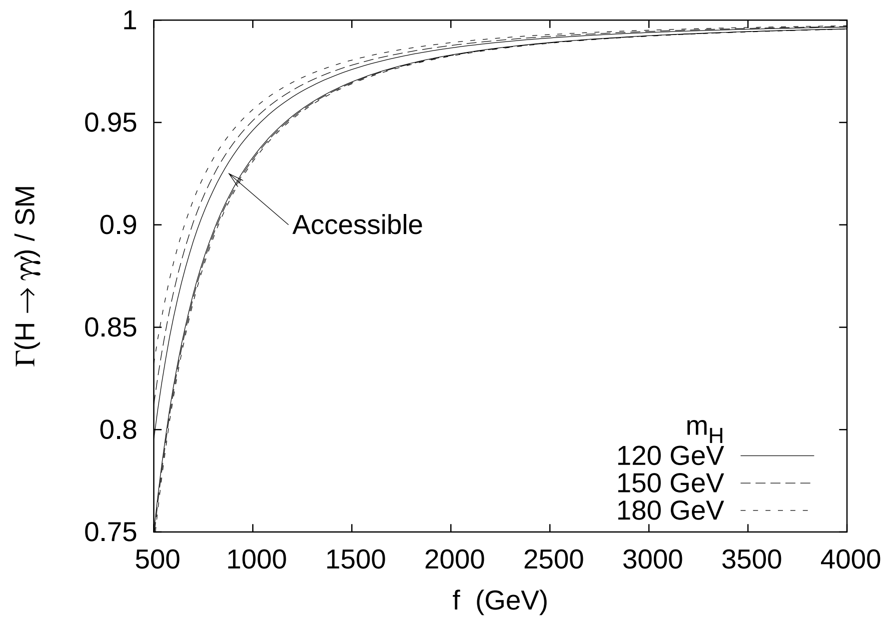
$\Gamma_{\gamma\gamma}$ sensitivity to:

a) SUSY loop contributions

b) $H^{\pm}$ loop in general 2HDM

c) Little Higgs dof's $\sim$ sev. TeV

F: Logan



2. ELECTROWEAK SYMMETRY BREAKING

$\Gamma_{\gamma\gamma}$ sensitivity to:

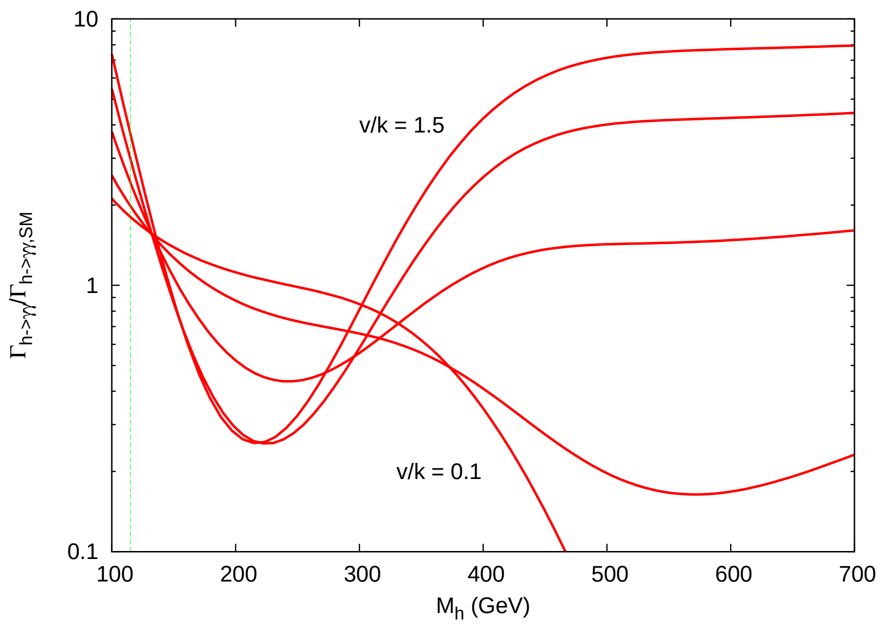
a) SUSY loop contributions

b) $H^{\pm}$ loop in general 2HDM

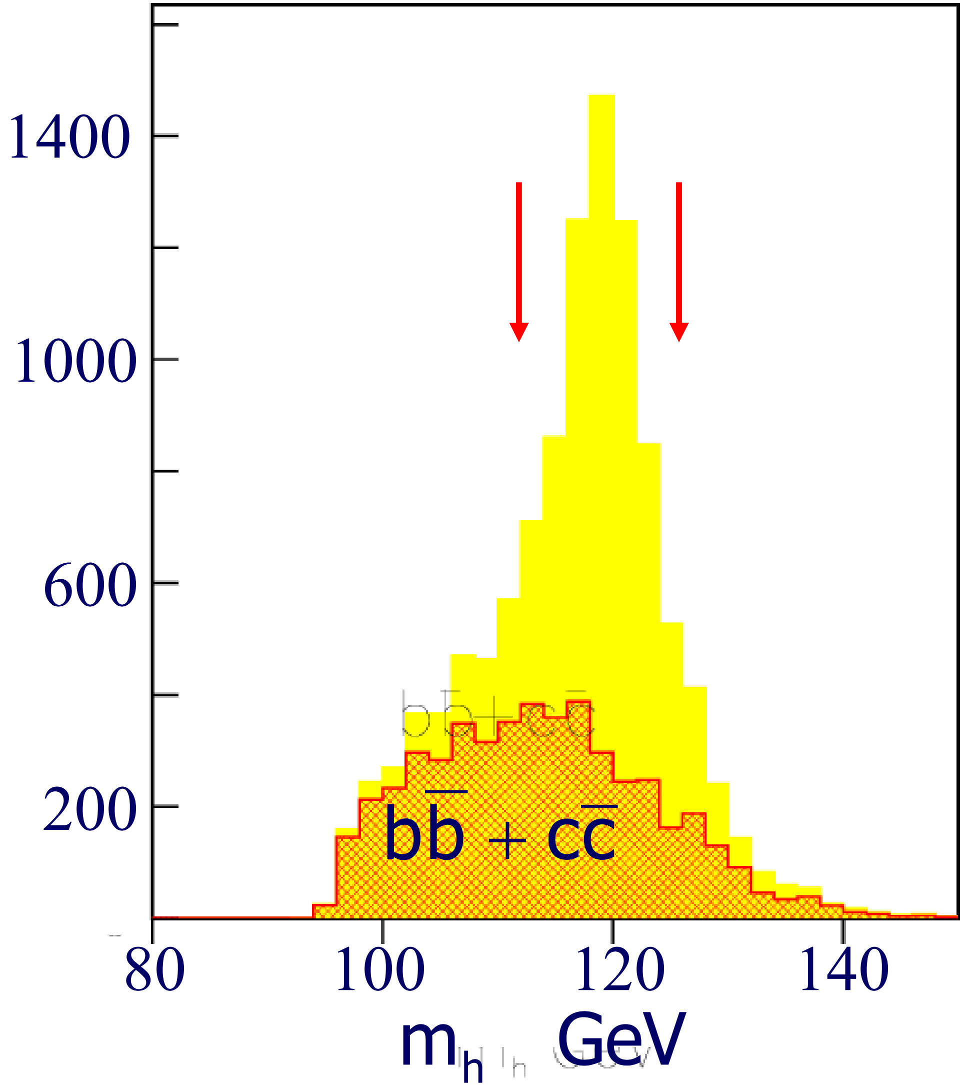
c) Little Higgs [width/pseudoscalar]

d) KK in extra-space dimensions

F: Lillie



Invariant Mass Spectrum



$$N_{sig} = 4505 \text{ events}$$

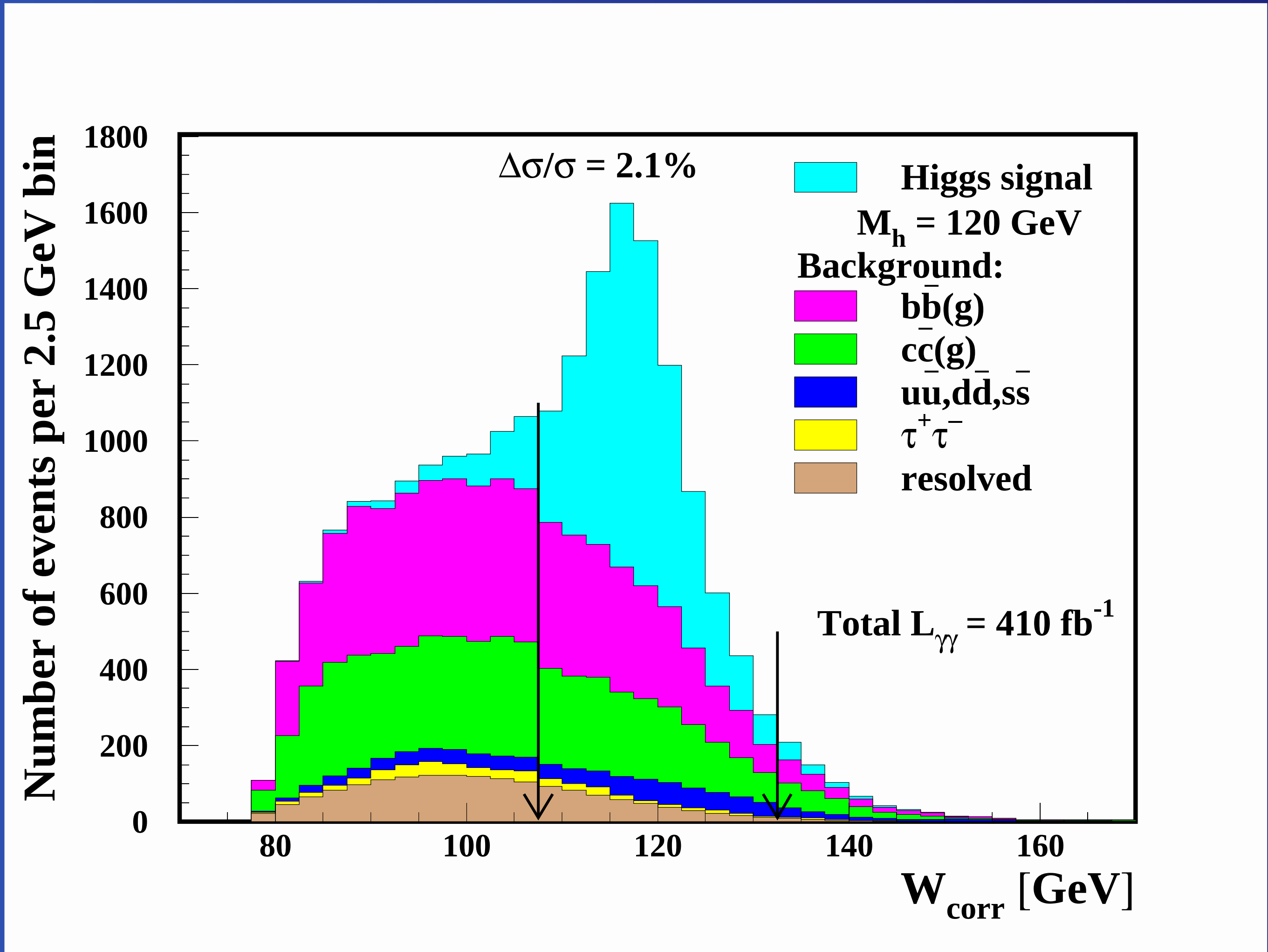
$$N_{bkg} = 1698 \text{ events}$$

$$\frac{\Delta\left[\Gamma(h \to \gamma\gamma) BR(h \to b\bar{b})\right]}{\left[\Gamma(h \to \gamma\gamma) BR(h \to b\bar{b})\right]} = \frac{\sqrt{N_{obs}}}{N_{obs} - \langle N_b \rangle} = 1.7\%$$

SM, $M_h = 120$ GeV

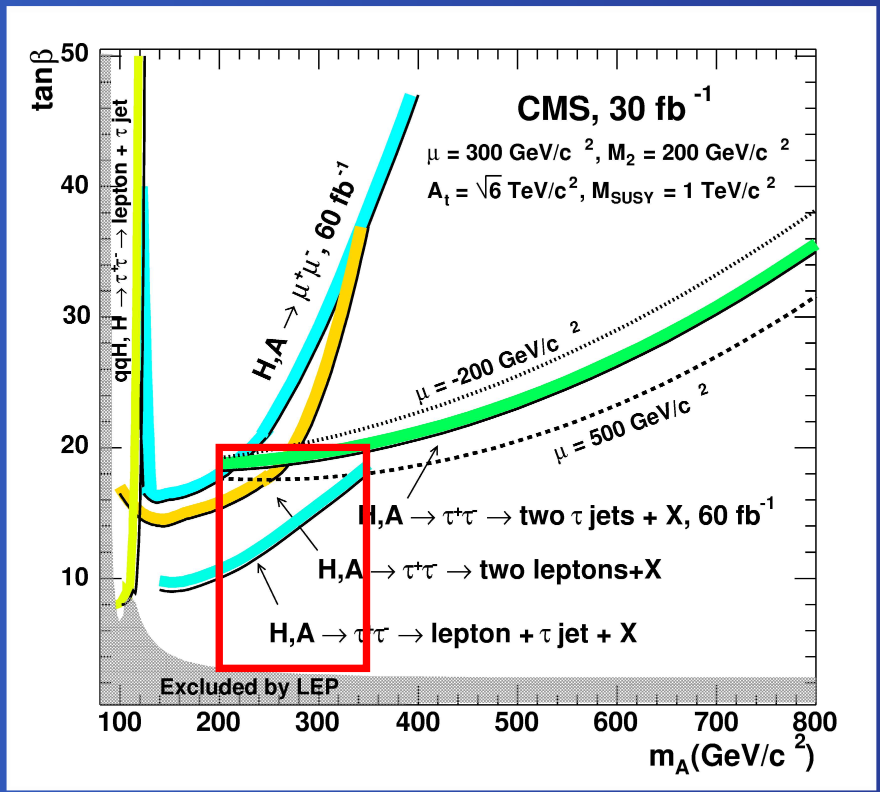
NŻK

Final results



Introduction

LHC wedge



From: CMS NOTE 2003/033
(the same results as in newer CMS CR 2004/058)

Two analyses
with MSSM parameter set:
$M_A =$ 300 GeV
$\tan\beta = 7,\ M_2 = \mu =$ 200 GeV

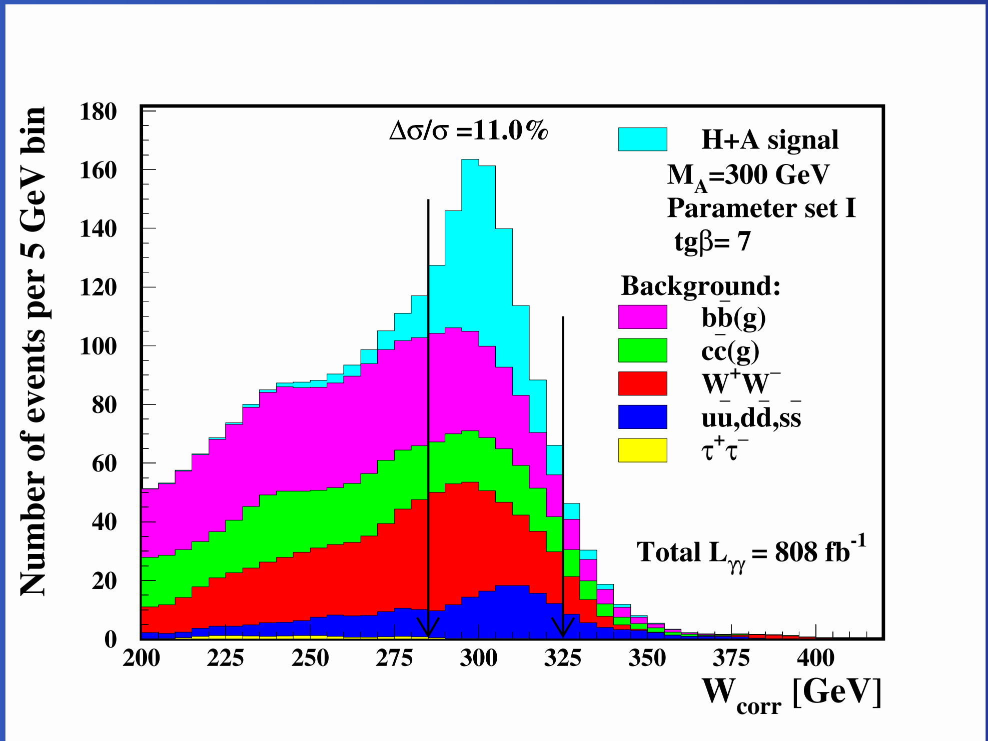
MKSZ
M. Mühlleitner, M. Krämer, M. Spira,
P. Zerwas, Phys. Lett. B 508 (2001) 311.
$S/B \approx 35$
$(300 \pm 3$ GeV)

NŻK
P. Nieżurawski, A.F. Żarnecki, M. Krawczyk,
Acta Phys. Pol. B 37 (2006) 1187.
$S/B \approx 2$
$(300 \pm 5$ GeV, only $\gamma\gamma \to b\bar{b}(g)$ background)

NŻK: Precision at PLC

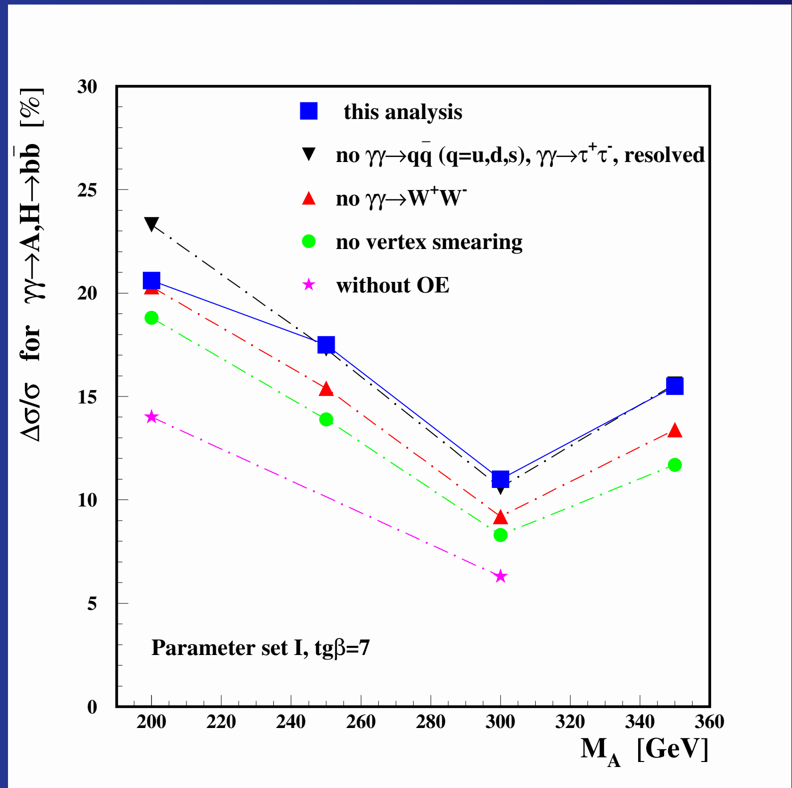
Precision of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement

Results for $M_A = 300$ GeV



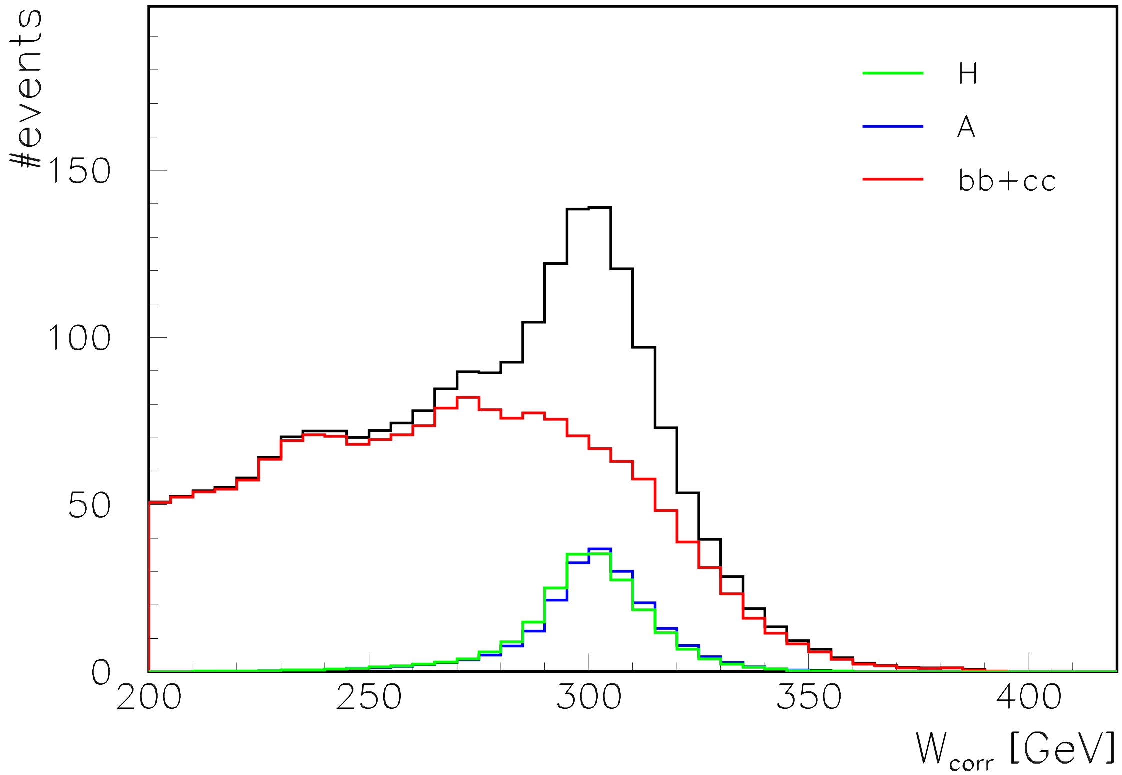
Corrected invariant mass distributions.
For 300 ± 5 GeV and with only $\gamma\gamma \to b\bar{b}(g)$ background: $S/B \approx 2$

Results for $M_A = 200$-350 GeV



our previous results compared

H and A contributions

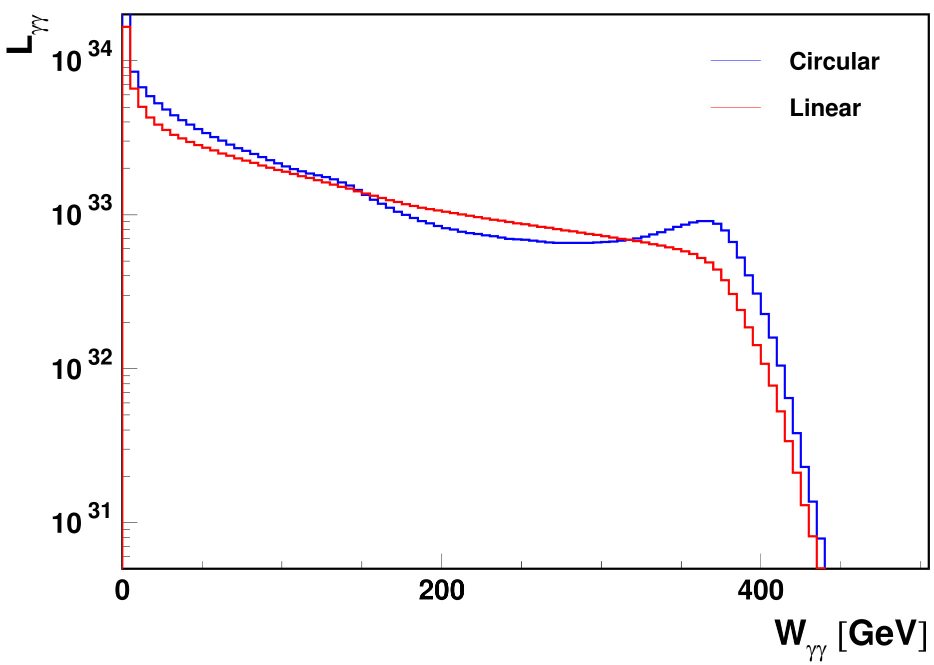


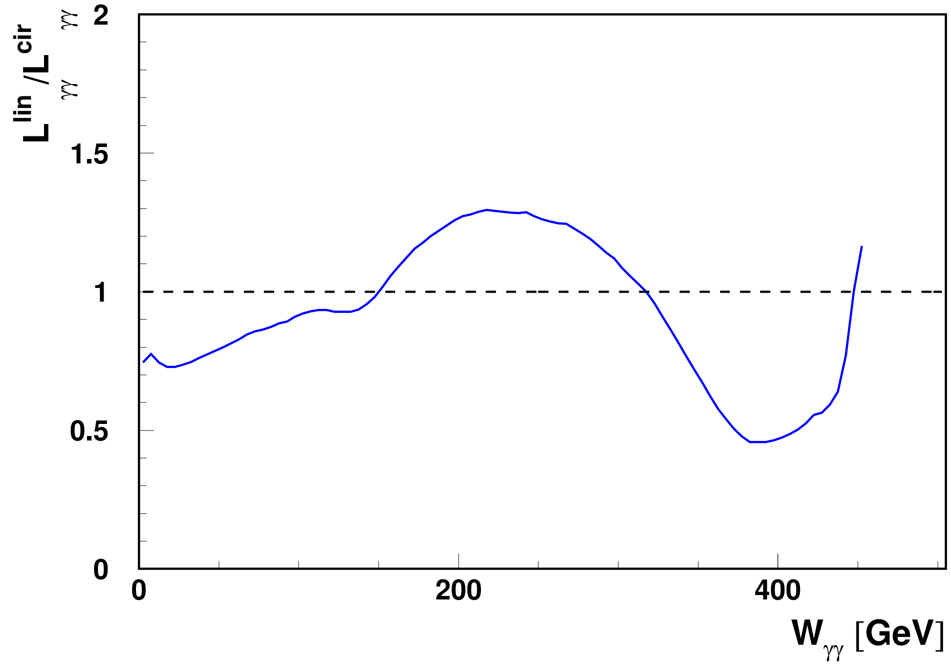
We can not distinquish H and A contributions

Luminosity

Luminosity spectra for linear laser polarization. E_e = 250 GeV

CAIN simulation results





100 % linear laser polarization, unpolarized electrons:

Background increases by factor ~ 2. Signal down by factor ~ 5 !

1 Introduction

Four-fermion production at a future $\gamma\gamma$ collider:

- large $\gamma\gamma \to \mathrm{WW} \to 4f$ cross section: $\sigma_{\mathrm{total}} \to 80\,\mathrm{pb}$ at high energies

  $\hookrightarrow$ precision signal / background to new physics
- test of $\gamma\mathrm{WW}$ and $\gamma\gamma\mathrm{WW}$ couplings
- s-channel Higgs production $\gamma\gamma \to \mathrm{H} \to \mathrm{WW}/\mathrm{ZZ} \to 4f$

Requirements from theory:

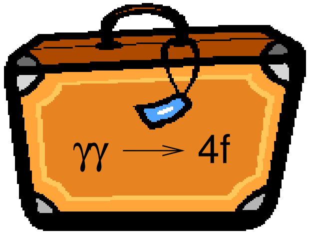
Predictions at %-level or better achieved by

- thorough description of decays of resonant gauge bosons
- inclusion of radiative corrections
- optional inclusion of non-standard gauge-boson couplings
- special improvements for Higgs production

Requirements neither fulfilled by multi-purpose Monte Carlo generators nor by previous dedicated analyses !

$\Rightarrow$ Motivation for constructing the dedicated event generator COFFER$\gamma\gamma$ to fill this gap

2 The Monte Carlo generator



Bredenstein, S.D., Roth '04–'05

Features of the generator COFFER$\gamma\gamma$

(COrrections to Four-FERmion production in $\gamma\gamma$ collisions)

- Complete lowest-order matrix elements
  - ◇ compact results in terms of Weyl–van-der-Waerden spinor products
  - ◇ massless fermions (mass effects restored in corrections)
  - ◇ loop-induced or effective $\gamma\gamma\mathrm{H}$ coupling
  - ◇ anomalous triple and quartic gauge-boson couplings
- Radiative corrections to $\gamma\gamma \to \mathrm{WW} \to 4f(+\gamma)$

  in "double-pole approximation" (DPA) similar to $\mathrm{e}^+\mathrm{e}^-$ case

  Aeppli, v.Oldenborgh, Wyler '93; Beenakker, Berends, Chapovsky '98
  Jadach et al. '99; Denner, S.D., Roth, Wackeroth '99
- Multi-channel Monte Carlo integration with adaptive weight optimization

  Berends, Kleiss, Pittau '94 Kleiss, Pittau '94
- Realistic γ beam spectrum, e.g., by COMPAZ Zarnecki '02

Note: all parts checked by a second independent Monte Carlo generator !

A FORTRAN code for $\gamma\gamma \to ZZ$ in SM and MSSM

G.J. Gounaris

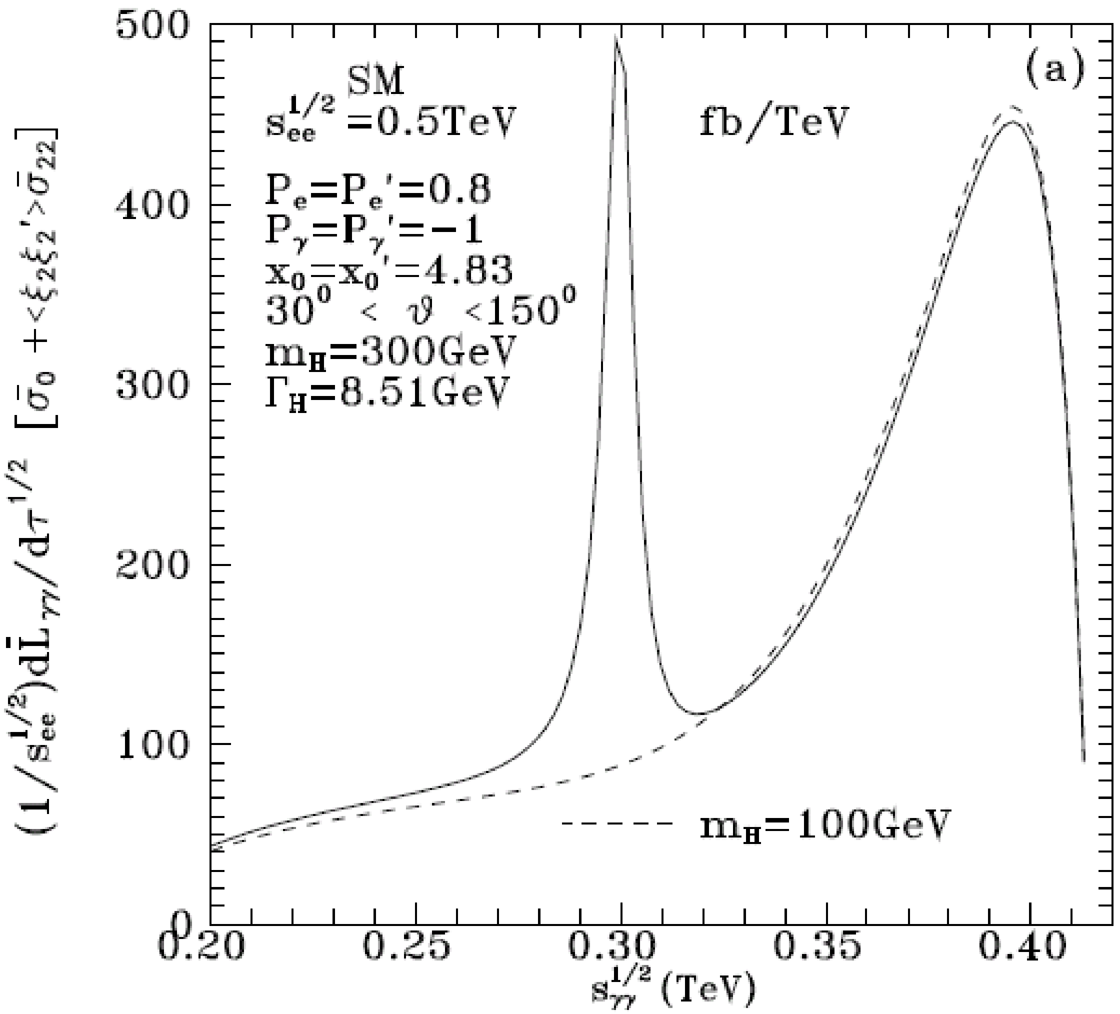
Based on the publications:

- **Th. Diakonidis , GJG, J. Layssac, hep-ph/0610085**
- **GJG, P. Porfyriadis, F.M. Renard, Eur. Phys. J. C19:57 (2001), hep-ph/0010006.**
- **GJG, P. Porfyriadis, J. Layssac, F.M. Renard, Eur. Phys. J. C13:79(2000), hep-ph/9909243.**
- **The whole code is contained in the file gamgamZZ.tar.gz downloaded from**

http://users.auth.gr/~gounaris/FORTRANcodes/

It contains 4 sub-codes called, sm1, mssm1, sm2 and mssm2.
A Readme.dat file explains everything.
Real SM and MSSM parameters are assumed.

Cross sections for polarized e$^{\pm}$ beams, integrated over the azimuthal angles in SM



$$\bar{\sigma}_j \equiv \sigma_j$$

$$\tau = \frac{s_{\gamma\gamma}}{4E_e^2}$$

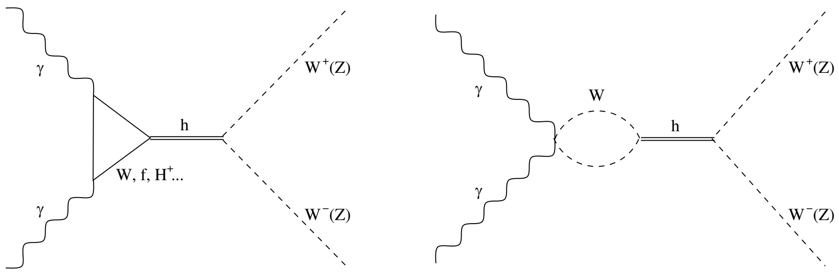
$$x_0 = \frac{4E_e\omega_{\text{lazer}}}{m_e^2}$$

E_e =energy of the e$^{\pm}$ beams.

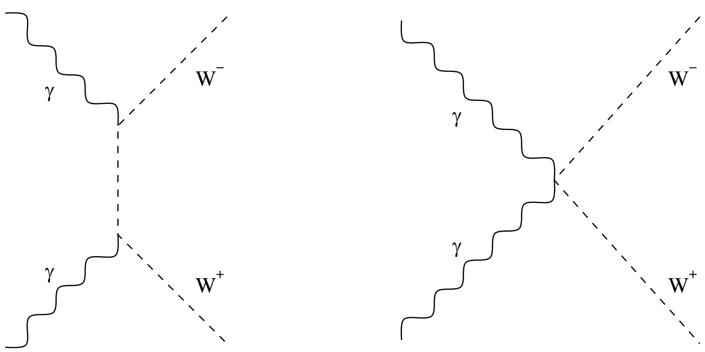
A Higgs peak may be visible in SM, if m_H large.

PLC

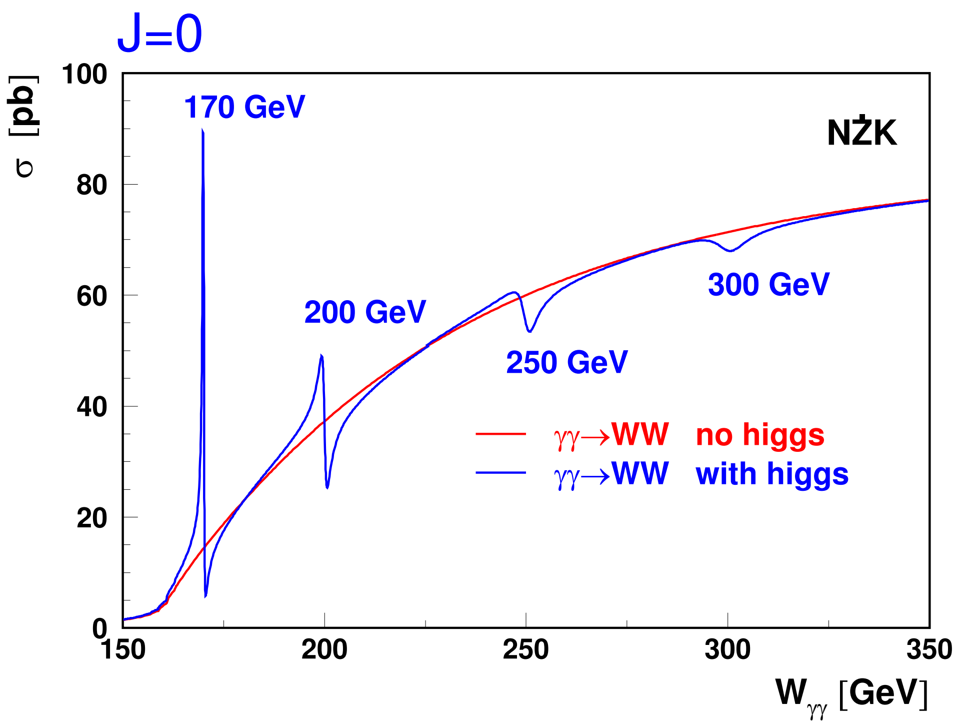
For resonant $\gamma\gamma \rightarrow h \rightarrow W^+W^-$ signal



there is a large non-resonant bg.



Large interference effects are expected in the considered mass range

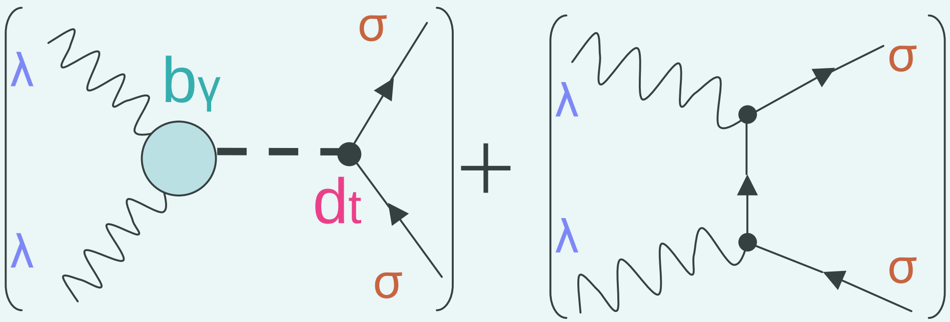


Interference is sensitive to the phase of the two-gamma amplitude

2. Observables in γγ→ $t\,\bar{t}$

- Helicity amplitudes

We consider the process $\gamma(\lambda)\,\gamma(\lambda) \to t(\sigma)\bar{t}(\sigma)$.

$M^{\sigma\sigma}_{\lambda\lambda} =$  $= [M_\phi]^{\sigma\sigma}_{\lambda\lambda} + [M_{cont}]^{\sigma\sigma}_{\lambda\lambda}$

bγ : γγϕ coupling
dt : t tϕ coupling

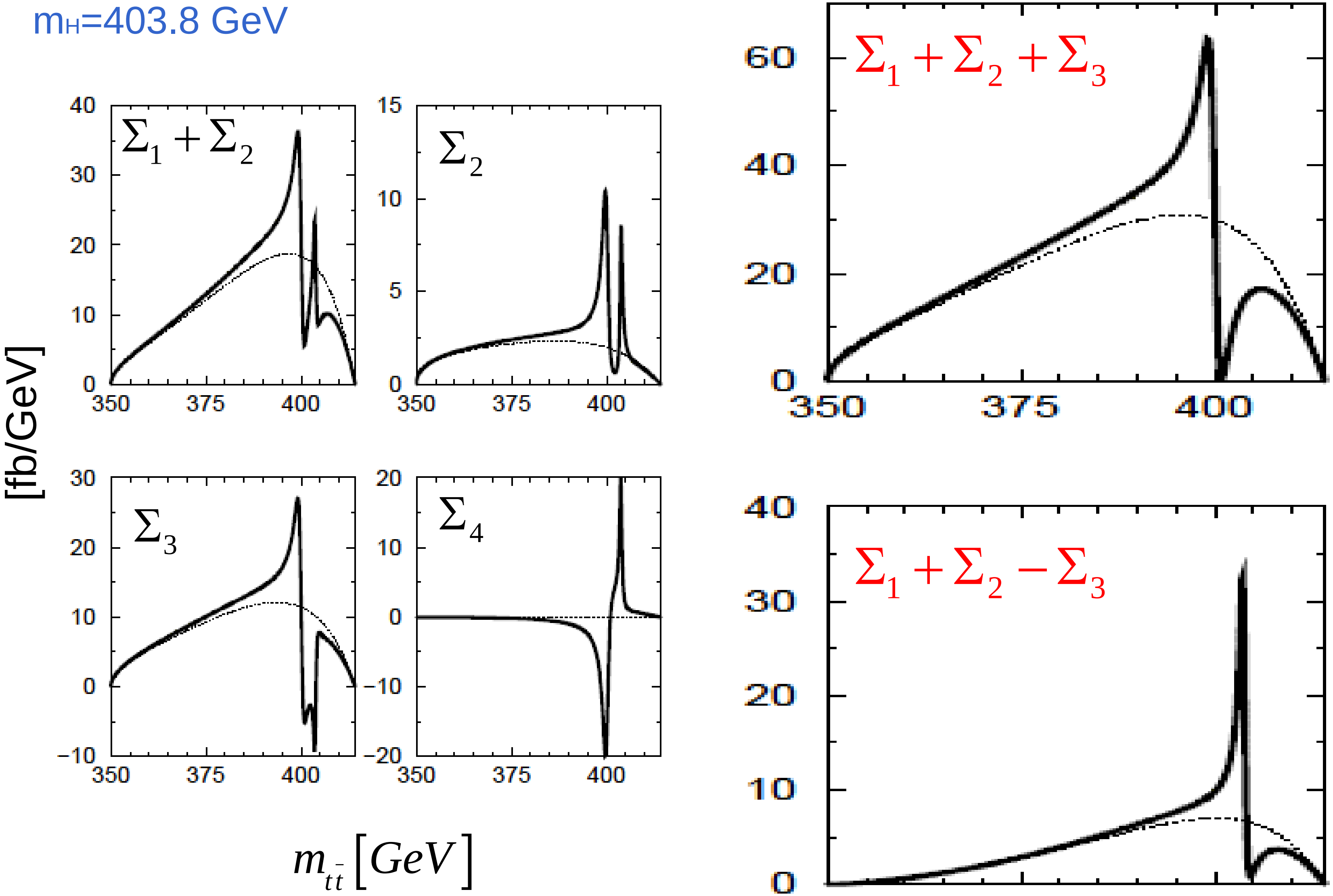
$$L_{\phi\gamma\gamma} = \frac{1}{m_\phi}\left(b_\gamma^H A_{\mu\nu}A^{\mu\nu} + b_\gamma^A \tilde{A}_{\mu\nu}A^{\mu\nu}\right)\phi$$

$$L_{\phi tt} = \bar{t}\left(d_t^H + i d_t^A \gamma_5\right)t\phi$$

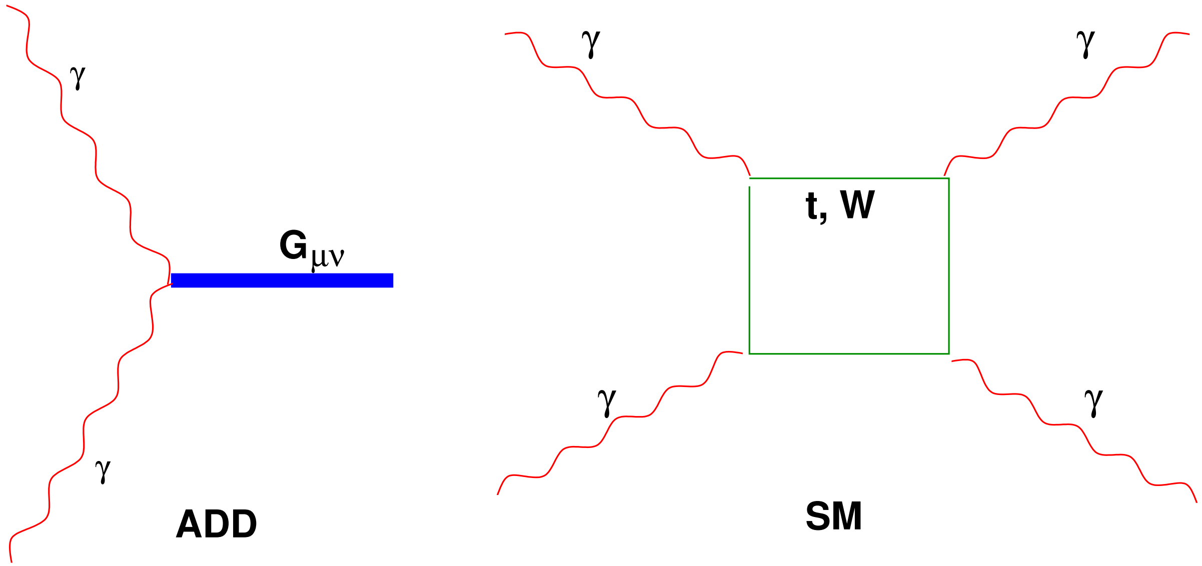
$$\left[M_\phi\right]^{\sigma\sigma}_{\lambda\lambda} = \left(b_\gamma^H + i\lambda b_\gamma^A\right)\left(\beta\sigma d_t^H - i d_t^A\right)\frac{\sqrt{s}}{m_\phi}\frac{s}{m_\phi^2 - s - i m_\phi \Gamma_\phi}$$

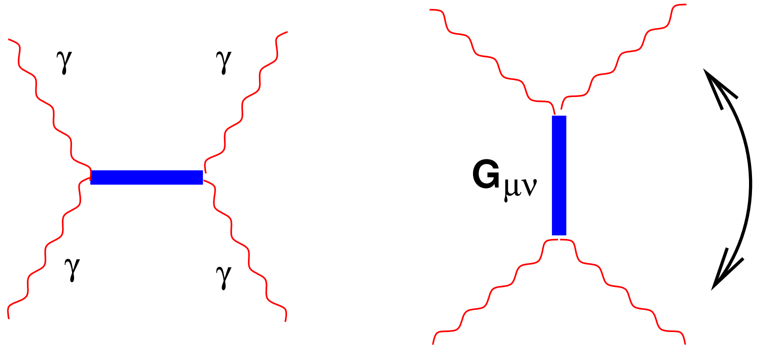
$$\left[M_{cont}\right]^{\sigma\sigma}_{\lambda\lambda} = \frac{8\pi\alpha Q_t^2}{1-\beta^2\cos^2\Theta}\frac{\beta\sigma + \lambda}{\gamma}$$

MSSM (tanβ=3)
m_A=400.0 GeV
m_H=403.8 GeV



Light-by-light Scattering

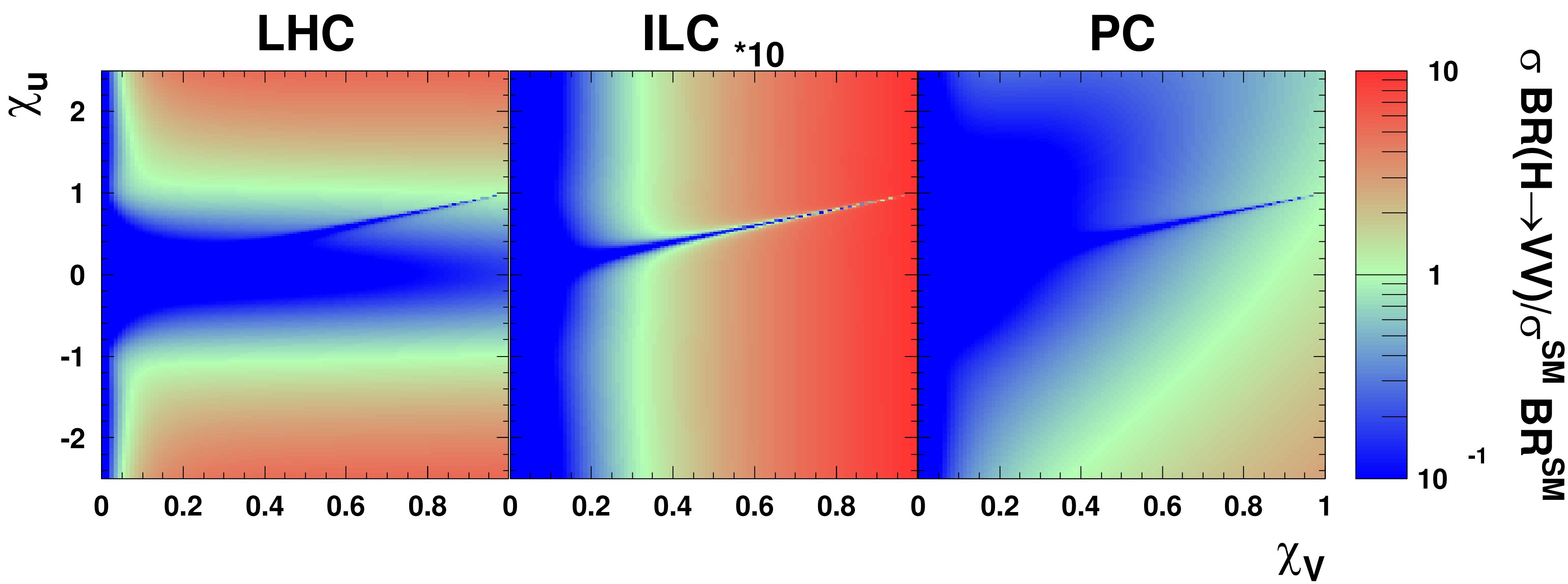




LHC $\oplus$ ILC $\oplus$ PC

Measurements at LHC, ILC and Photon Collider are complementary, being sensitive to different combinations of Higgs-boson couplings

Cross sections $\times$ BR relative to SM $\quad M_H = 250 GeV$



Charge asymmetry in $\gamma\gamma \to \mu^+\mu^- + \nu' s$, $\gamma\gamma \to W^\pm \mu^\mp + \nu' s$ with polarized photons. New results

I. F. Ginzburg, K.A. Kanishev,
Sobolev Inst. of Mathematics, SB RAS
and Novosibirsk State University
Novosibirsk

M. Cannoni, O. Panella
Istituto Nazionale di Fisica Nucleare,
Perugia, Italy

• Charge asymmetry in processes like

$$\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu, \quad \gamma\gamma \to W^\pm\mu^\mp\nu$$

appears due to P nonconservation in the SM.

• Processes like

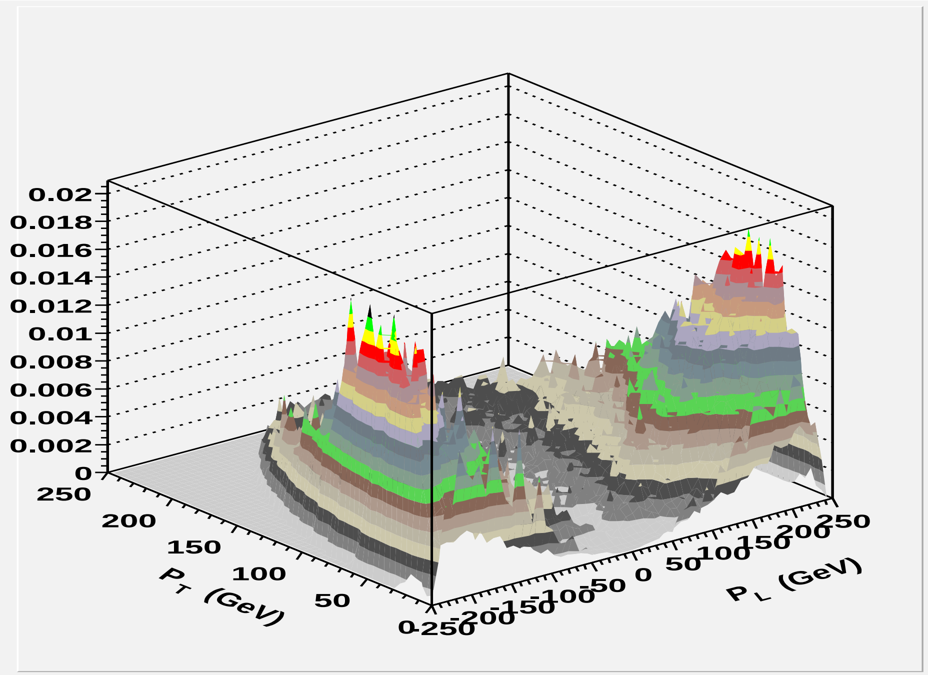
$$\gamma\gamma \to \tau\mu\nu\nu \ (\gamma\gamma \to W\tau\nu) \quad \to \quad \mu^+\mu^-\nu\nu\nu\nu \ (W\mu\nu\nu\nu)$$

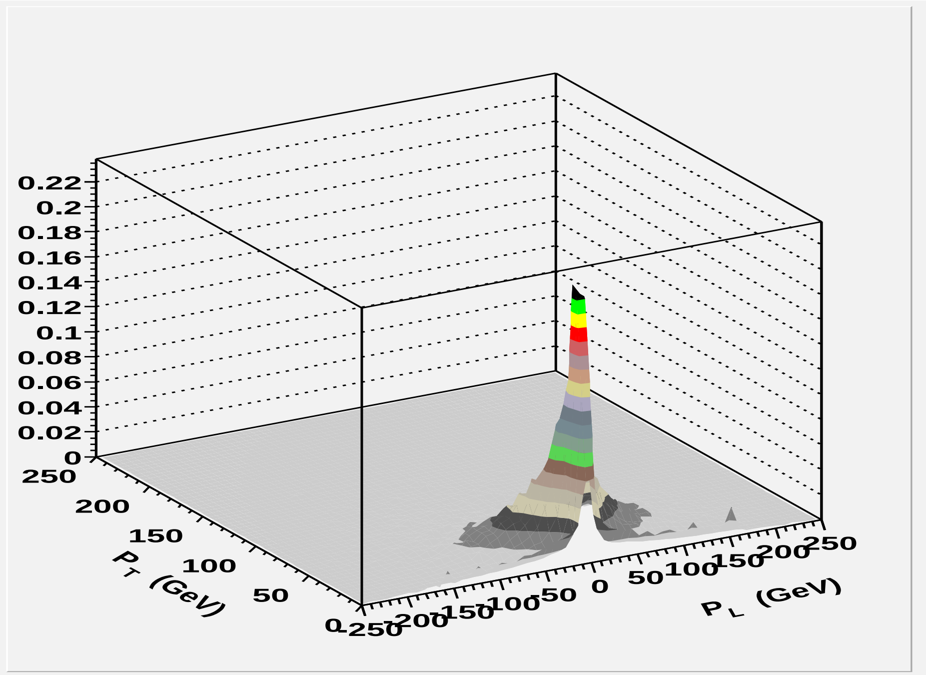
(with $\tau \to \mu\nu_\mu\nu_\tau$ decay) produce the same observable final state enhancing total event rate by 37% (17%). We consider such cascade processes.

• Taking into account same effects for e^+e^-, $e^+\mu^-$, μ^+e^- enhance statistics by 4 times.

Difference between distributions of positive and negative muons in $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$.

Both photons are left polarized: $\gamma_-\gamma_-$.





Negative μ distribution.

Positive μ distribution.

4. STRONG INTERACTIONS AND QCD

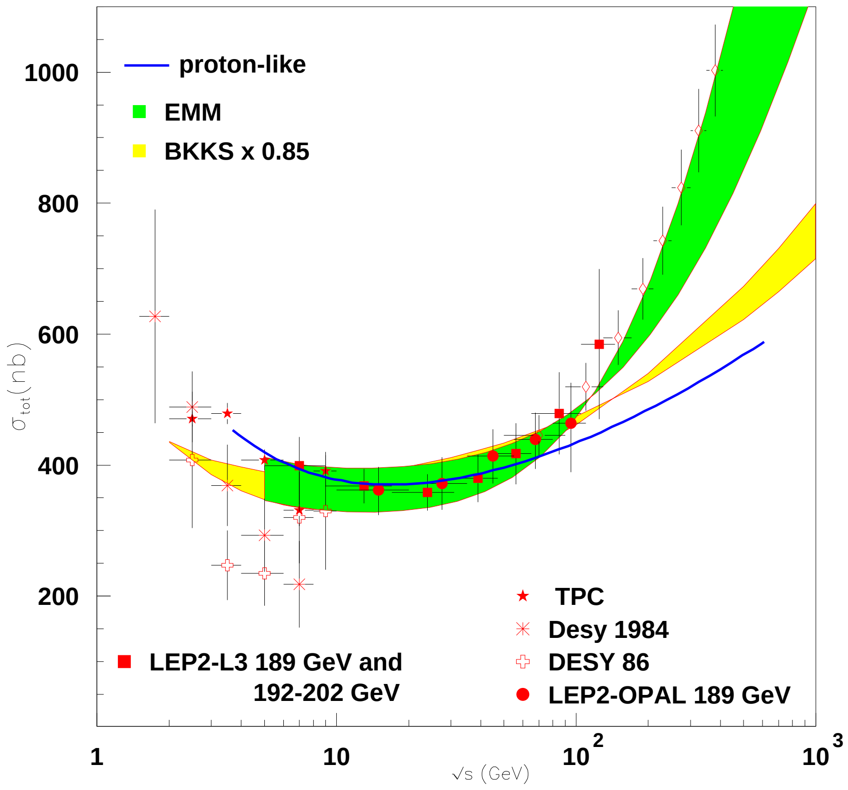
- $\gamma\gamma \to hadrons$: variety of models : standard SI $[\gamma \sim P]$ Donnachie, Landshoff

F: Block, Gregores, Halzen, Pancheri

pQCD / mini-jet models

Badelek, Krawczyk, Kwiecinski, Stasto

Godbole, Pancheri



$$\sigma = Bs^{-\eta} + As^{\varepsilon} + Cs^{\varepsilon_1}$$

- Fit3

C≠ 0 ε=0.093

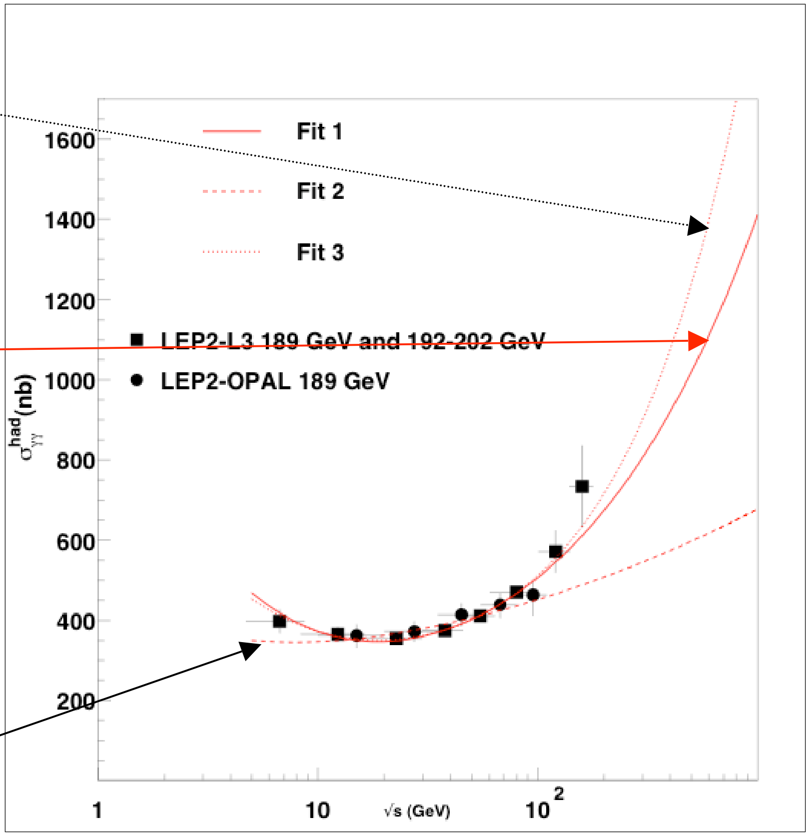
ε_1=0.418

- Fit 1

C=0 ε=0.250

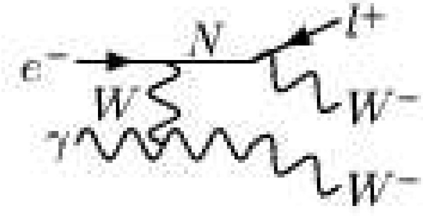
- Fit2

C=0 ε=0.093 as in pp



MAJORANA NEUTRINOS

PROCESS: $e^- \gamma \to e^+ W^- W^-$

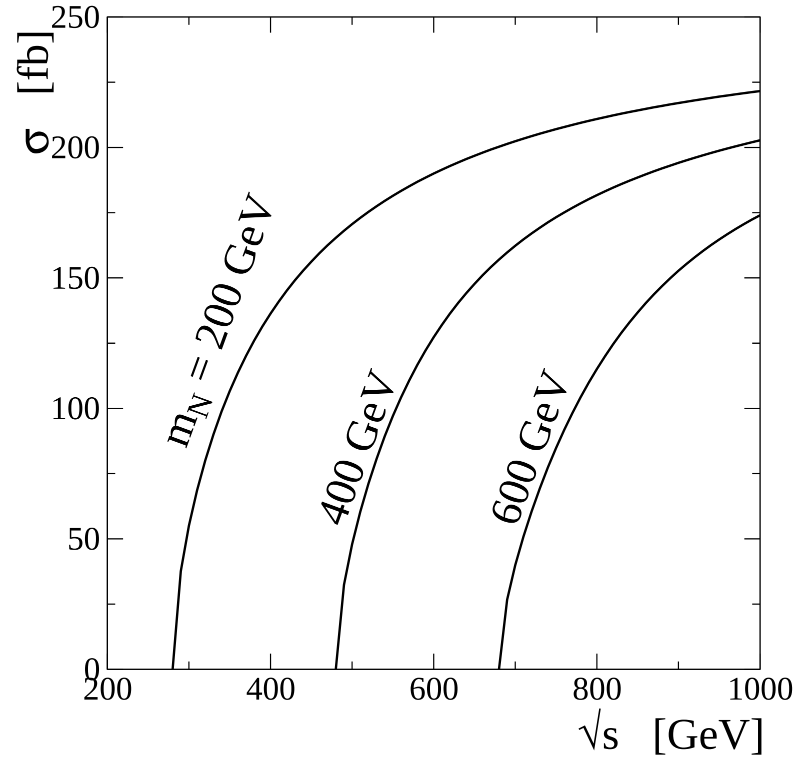


specific *Majorana N* signal /

sizable cross section for $X_{eN} = 0.07$ $\Rightarrow$

little SM bkgd: CC $e^- \gamma \to \nu_e W^- W^- W^+$

[Bray, Lee, Pilaftsis]



We need $\gamma\gamma$ because

if light h : $\Gamma(h \to \gamma\gamma)\, B(h \to b\bar{b}) \sim 2\%$

$\Rightarrow \Gamma(h \to \gamma\gamma) \sim 2\%$ sensitive to new particles

~~CP~~ by $\gamma\gamma$ polarization far more sensitive than $e^+e^- \to hZ$ because $h\gamma\gamma$ is a loop amp.

if $m_{H,A} < 0.8\sqrt{s_{e^+e^-}}$: Possible discovery

CP & ~~CP~~

↳ mixing (ϵ) and direct (ϵ')

$$\gamma\gamma \begin{array}{l} \nearrow H, A \searrow \\ \searrow \text{QED} \nearrow \end{array} t\bar{t},\ W^+W^-$$

interference allows us to measure the phase of $\phi\gamma\gamma$ vertex.

in addition : $\gamma\gamma \to W^+W^-, t\bar{t}$ ($J = 0, 2$) to supplement $e^+e^- \to W^+W^-, t\bar{t}$ ($J = 1$) precision phys.

Reaction	Remarks
$\rightarrow H, h \rightarrow b\bar{b}$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV
$\rightarrow H \rightarrow WW(^*)$	SM Higgs, 140$< M_H < 190$ GeV
$\rightarrow H \rightarrow ZZ(^*)$	SM Higgs, 180$< M_H < 350$ GeV
$\rightarrow H \rightarrow \gamma\gamma$	SM Higgs, 120$< M_H < 160$ GeV
$\rightarrow H \rightarrow t\bar{t}$	SM Higgs, $M_H > 350$ GeV
$\rightarrow H, A \rightarrow b\bar{b}$	MSSM heavy Higgs, interm. $\tan\beta$
$\rightarrow \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections
$\rightarrow \tilde{g}\tilde{g}$	measurable cross sections
$\rightarrow H^+H^-$	large cross sections
$\rightarrow S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium
$\rightarrow \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \rightarrow \gamma\gamma$	non-commutative theories
$e\gamma \rightarrow eG$	extra dimensions
$\gamma\gamma \rightarrow \phi$	Radions
$e\gamma \rightarrow \tilde{e}\tilde{G}$	superlight gravitions
$\rightarrow W^+W^-$	anom. W inter., extra dimensions
$\rightarrow W^-\nu_e$	anom.W couplings
$\rightarrow 4W/(Z)$	WW scatt., quartic anom. W,Z
$\rightarrow t\bar{t}$	anomalous top quark interactions
$\rightarrow \bar{t}b$	anomalous Wtb coupling