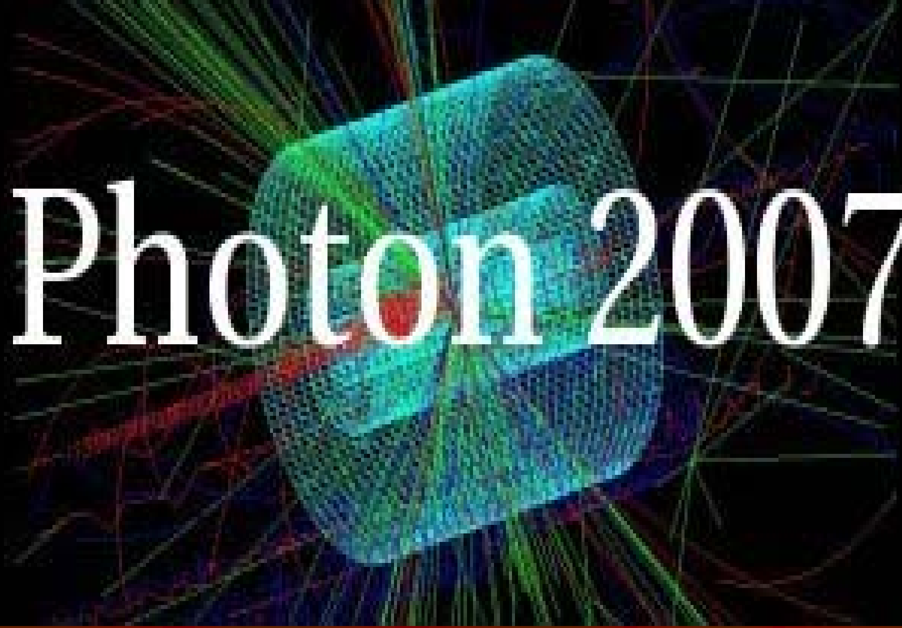


La Sorbonne

Paris 9-13 July 2007

Maria Krawczyk
University of Warsaw

Photon 2007

- Int. Conference on the Structure and Interactions of the Photon (since 1994; and Proton from 2003)
- 17 th Int. Workshop on Photon-Photon Collisions

  (Int. Coll on Photon-Photon Collisions in Electron-Positron Storage Rings, Paris 1973)
- Int. Workshop on High Energy Photon Linear Collider (included in 2005; first in LBL in 1994)

Photon 2009 ?

- Int. Conference on the Structure and Interactions of the Photon and Proton ?
  - HERA, Tevatron, LHC?
- 18 th Int. Workshop on Photon-Photon Collisions
  - LEP? LHC? Low energy precision data: g-2, B decays…
- Int. Workshop on High Energy Photon Linear Collider
  - ILC/LHC (plans for CLIC?)
- Astrophysics

The Past-Today-The Future

- Photon2005
- Open questions
- Linear Photon Collider

Photon 2005

- The Photon:its First Hundred Years and the Future:

  The Centenary (Warsaw)

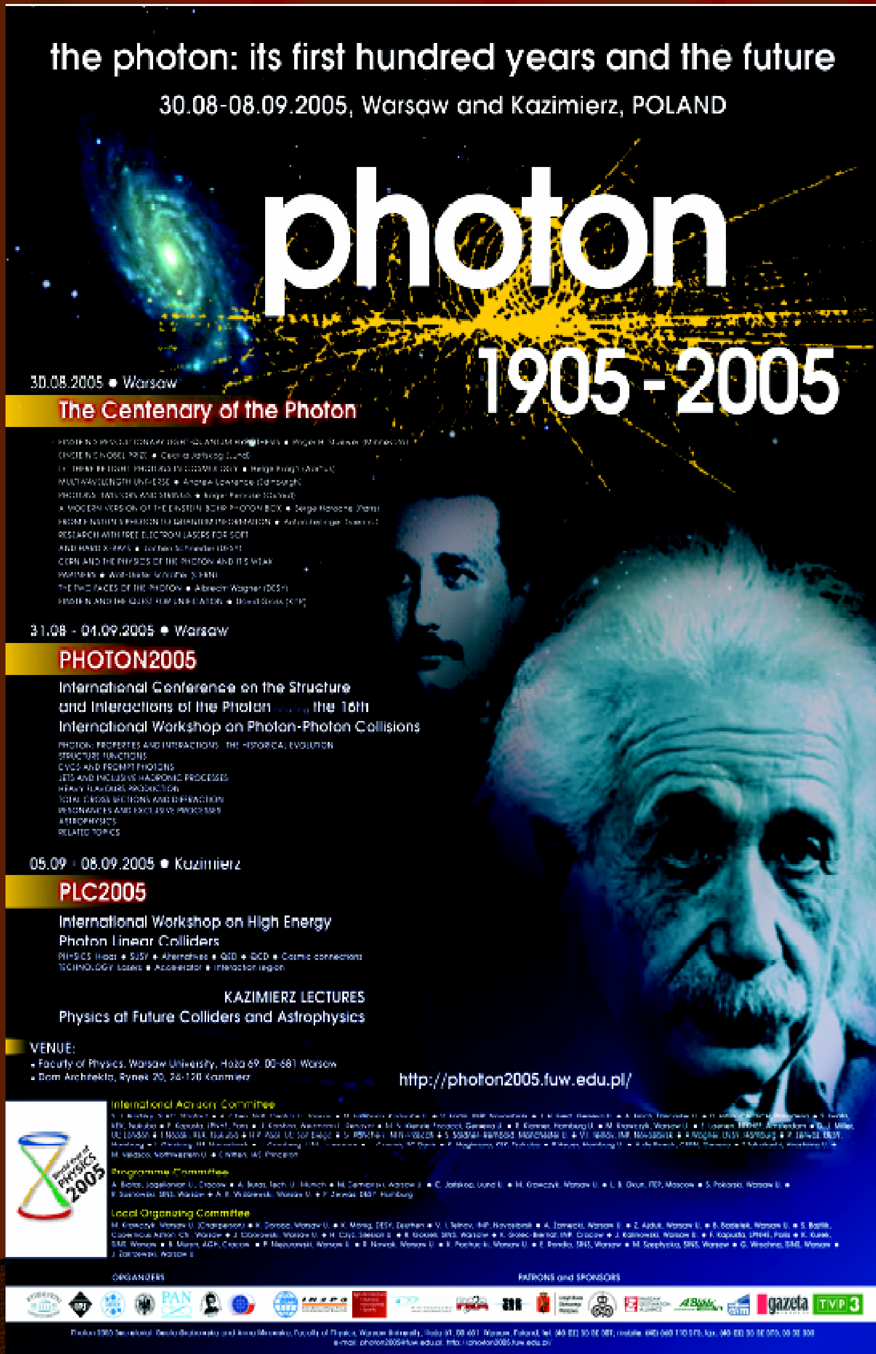
  PHOTON2005 (Warsaw)

  PLC2005 (Kazimierz)

- Proceedings

  Acta Physica Polonica 37 (2006) vol 3/4 - 800 pages

- e-Proceedings



The Centenary

- Struewer *Compton*
- Okun *Mass,charge*
- Kragh *Cosmology*
- Jarlskog *Nobel prize*
- Lawrence *Astrophysics*
- Penrose *Strings*
- Zeilinger *Quantum inform.*
- Haroche *Atoms*
- Schneider *Lasers*
- Schlatter *CERN*
- Wagner *DESY*
- Gross *Unification*

PHOTON 2005 (Royal Castle)

Resonances and total section

Strings and PLC technology

PLC2005 in Kazimierz

Rolf
David
John

David Miller Fest

Topics at PHOTON2005

- History of hadronic interaction of photons

  VMD, QCD …
- collisions γ^*- γ and γ^*- γ^*

  and structure functions of the photon
- F_2^γ

  QCD

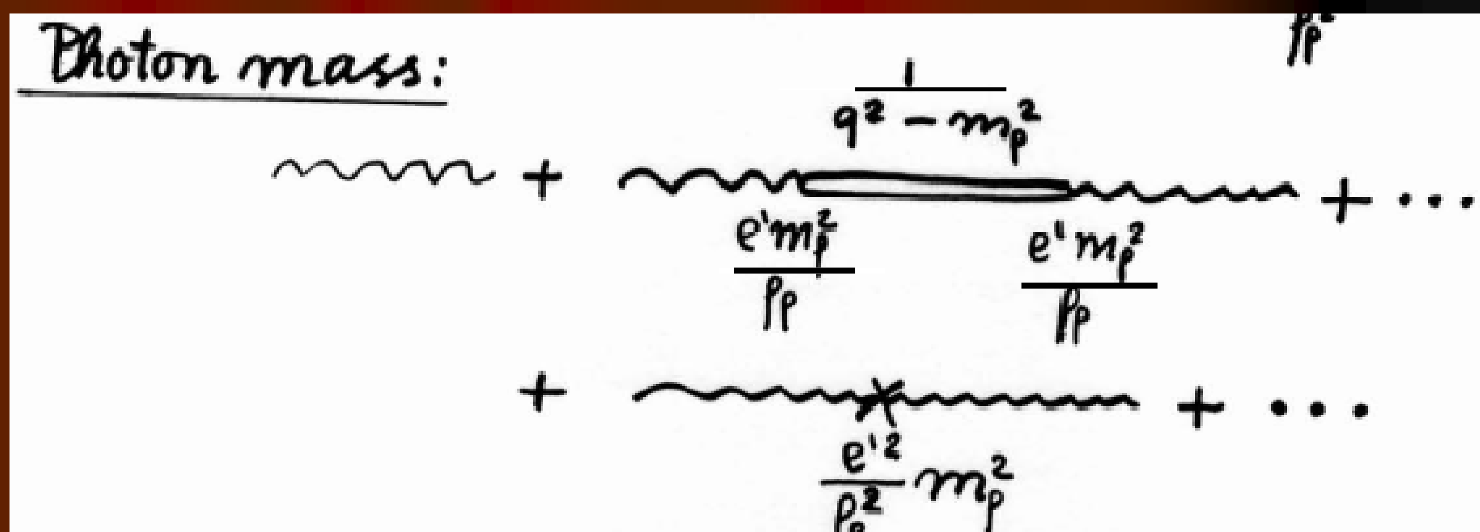
  Parton densities in the photon – new parametrizations, heavy quarks in γ
- Resolved photon processes

Lagrangian [e2=e’2/(1+e’2/fρ2)] Correct one by Kroll,Lee,Zumino’67

- Photon propagator?

For q2->0: 1/q2

$$\mathcal{L}'_{mix} = \frac{e' m_\rho^2}{f_\rho} \rho'_\mu A'^\mu - \frac{1}{2}\left(\frac{e'}{f_\rho}\right)^2 m_\rho^2 A'^2_\mu$$



Hadronic behaviour of the photon

- Measurement of the coupling constant

(Novosibirsk,Orsay' 66/7)

$$\frac{e^2}{4\gamma_\rho^2} = \frac{\alpha\pi}{\gamma_\rho^2} = \frac{1}{4\pi^2\alpha}\int_{4m_\pi^2} \sigma_{e^+e^-\to\rho^0\to 2\pi}(m^2)\,dm^2.$$

- Stodolski' 67 sum rule - 20 % missing

$$\sigma_{\gamma p}(W^2) = \sum_{\rho^0,\omega,\phi} \sqrt{16\pi}\sqrt{\frac{\alpha\pi}{\gamma_V^2}}\sqrt{\frac{d\sigma^0_{\gamma p\to Vp}}{dt}(W^2)}.$$

- -> Generalized Vector Dominance (GVD)

Schildknecht,Sakurai'72

More…

- **Direct photons and fragmentation**
- **Total cross sections and diffraction**
- **DVCS**
- **Exclusive processes i resonances**

- **Curves and finite number of photons –**

Stodolski: Lorentz transf. can not change number of photons, there is a class o situation without IR- catastrophe (if initial and final velocity are the same velocity)

example for n=38.8

Open questions in particle physics

- Photons and hadrons

  g-2 – vacuum polarisation, light-on-light (lbl)

  (new $e^+e^- \to \rho\ \rho$)

  $\gamma\ \gamma \to$ b b (new data, new analysis)

  direct photon (di-photon) production

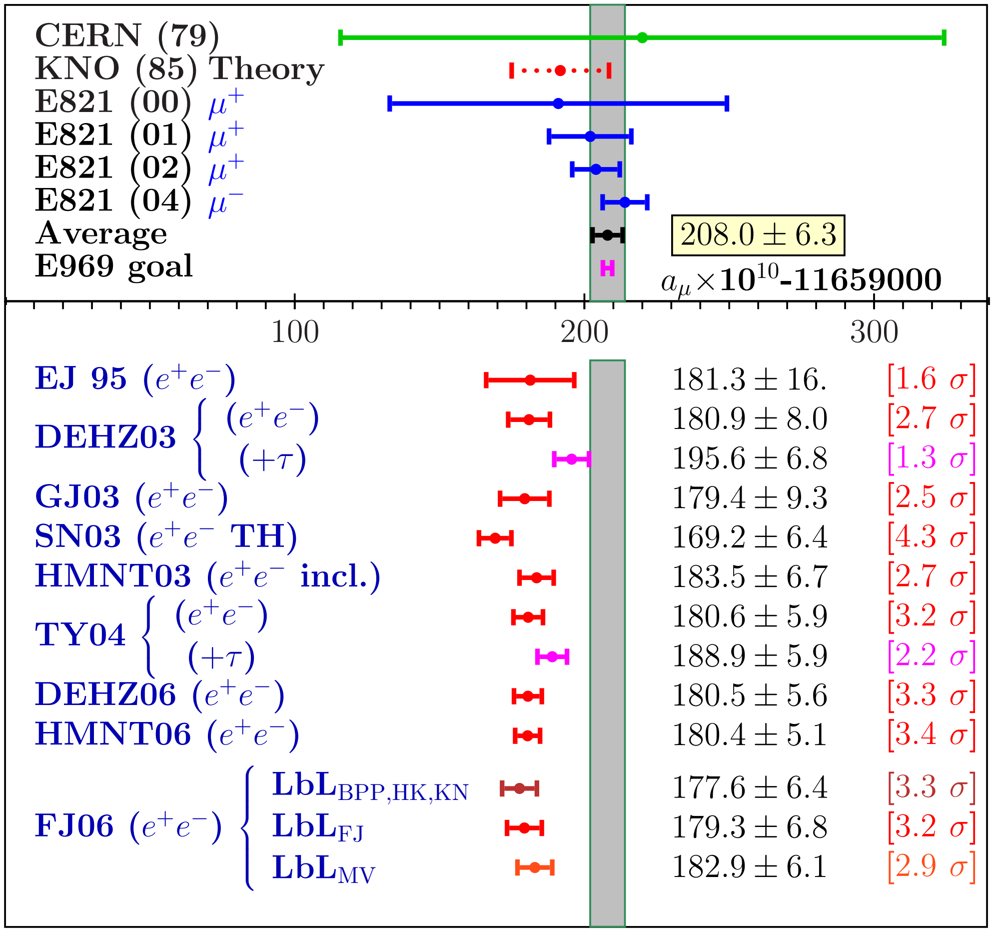
  (new data, new analysis)

- Photons and Higgs sector

- QED+U(1): photon and paraphoton, charge and paracharge, minicharged particles

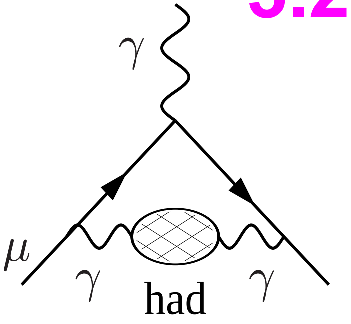
Light from the hidden sector: Ahlers et al. Hep ph/0706283

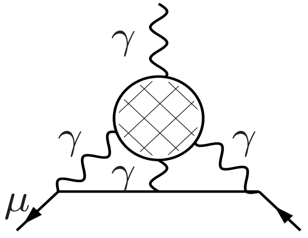
g-2 for muon (Jegerlehner'07)



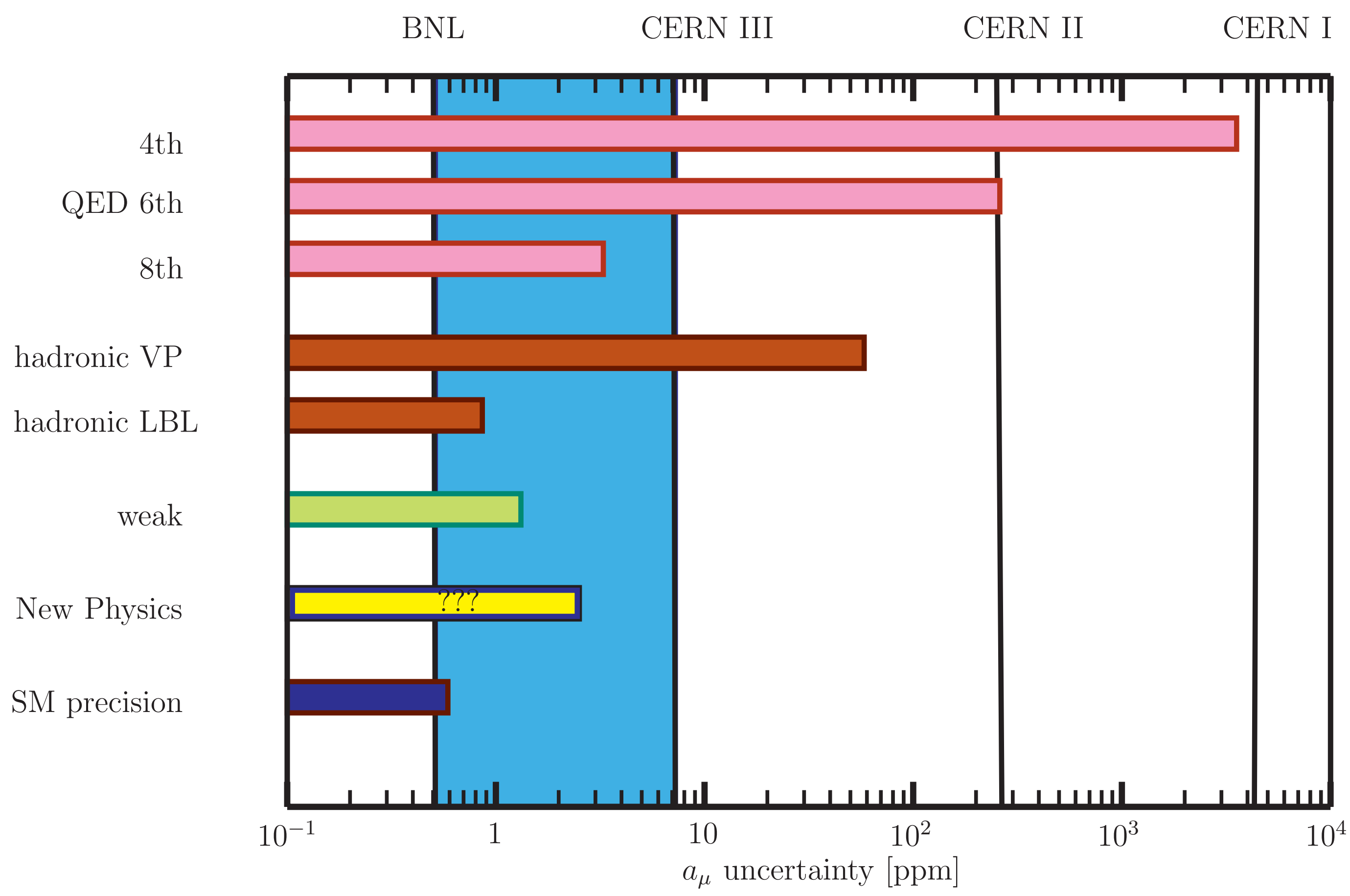
$\delta\, a_\mu = (287 \pm 91)\ 10^{-11}$

3.2 σ





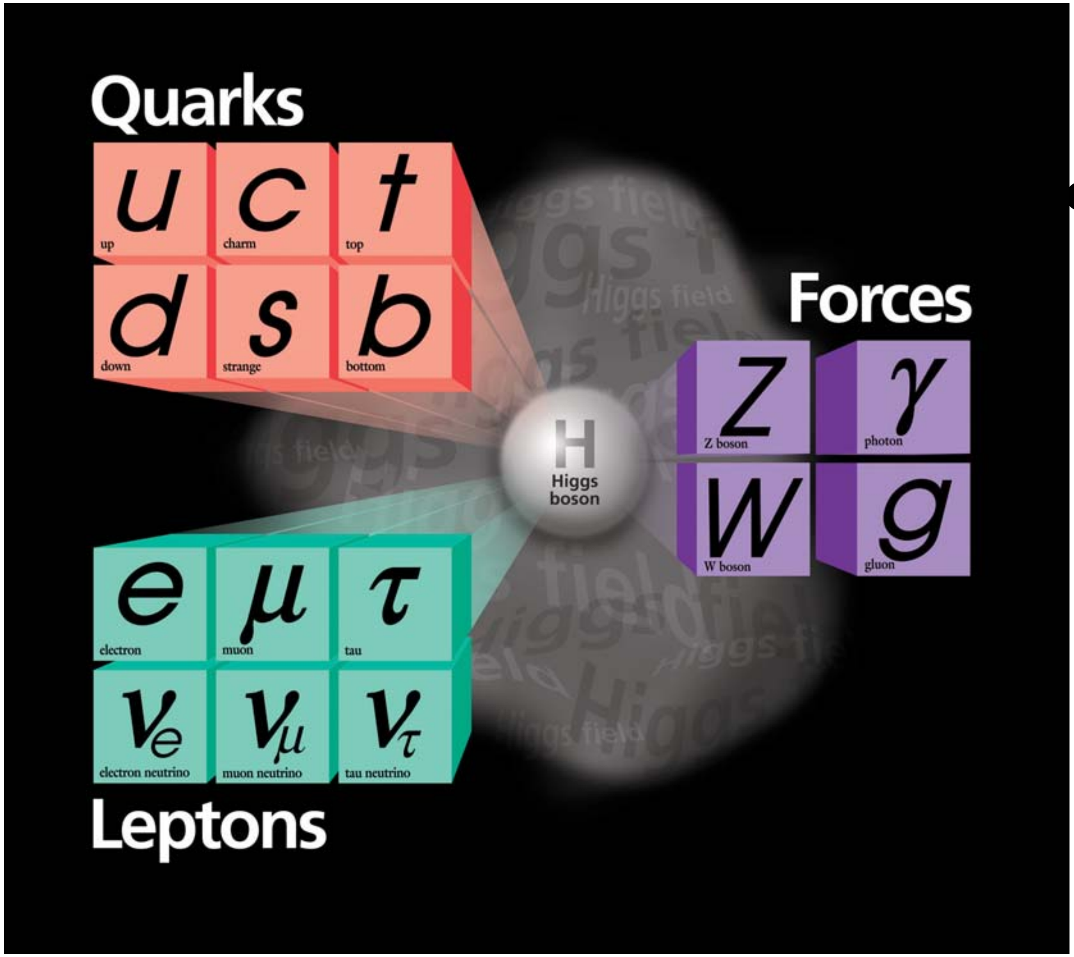
g-2 for muon – sensitivity



Photon and Higgs sector

- EWSB should leave photon massless
- Neutral Higgs boson can couple only via loop with photons – nondecoupling of heavy fermions
- CP property or possible mixing of the neutral Higgs bosons if more exist beyond the Standard Model can be determined in higgs-gamma-gamma
- Direct coupling possible with charged Higgs bosons

Standard Model



One doublet of scalar fields introduced

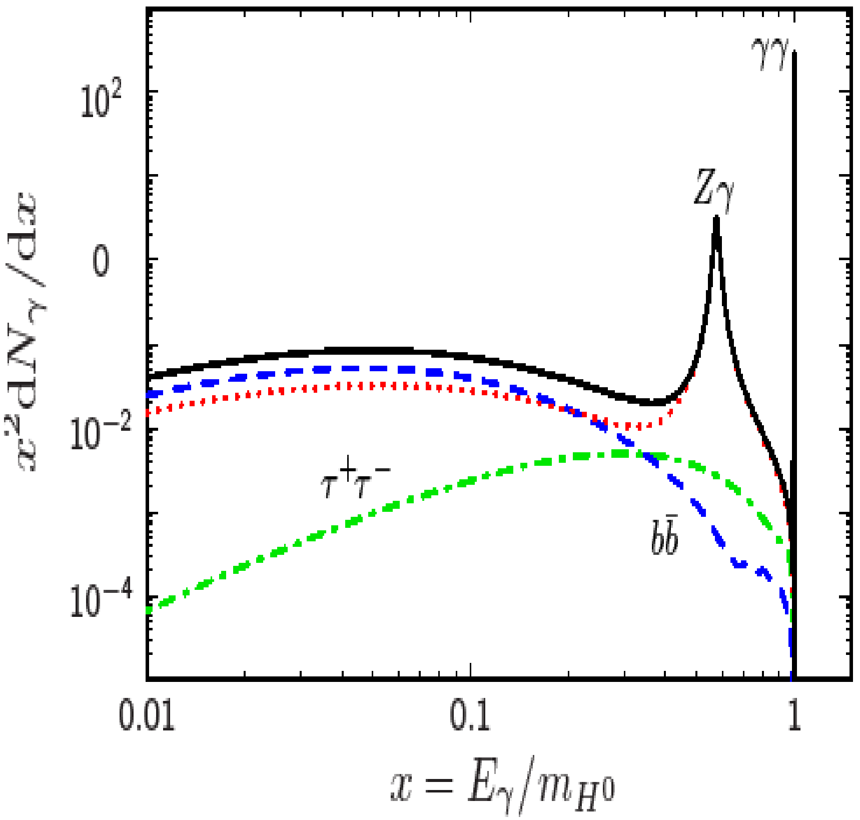
-> W and Z bosons massive;
one scalar neutral Higgs particle h

Inert Doublet Model

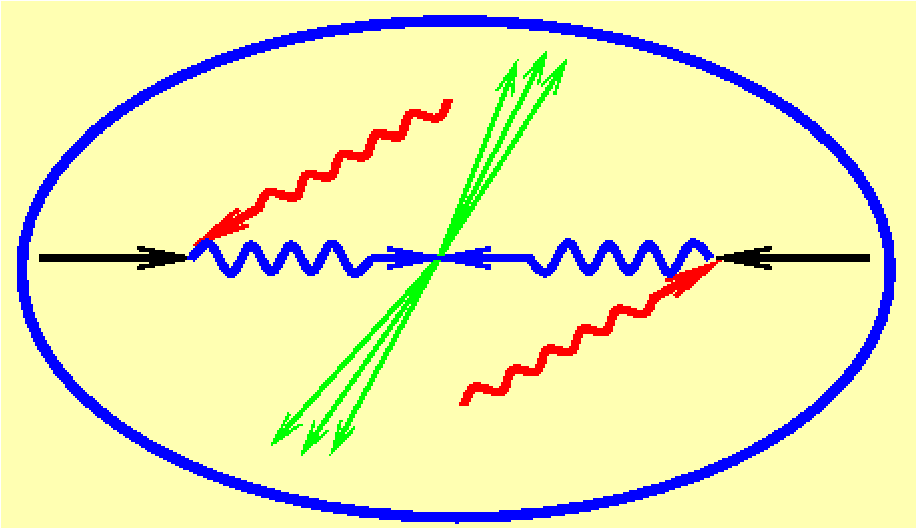
Ma'78, Barbieri..'05, Honorez..'07,..

Significant Gamma Lines from Inert Higgs Dark Matter - Gustafsson astro-ph/0703512

- Adding another scalar doublet with no direct coupling to fermions
- The unbroken discrete Z_2 symmetry makes the new scalars *inert* – the lightest one H is a candidate for Dark Matter. For a H mass between 40 and 80 GeV -> the correct cosmic abundance(WMAP).
- The loop-induced mono-chromatic $\gamma\gamma$ and the $Z\gamma$ final states (from HH -> $\gamma\gamma$ and the $Z\gamma$) would be exceptionally strong
- Ideal to search for in the upcoming GLAST exp.



PHOTON LINEAR COLLIDER



Parameters for the ILC

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

LCWS'07 DESY, Hamburg

International Linear Collider Workshops

Accelerator Physics

Year	Workshop	Location
1988	LC88	SLAC
1990	LC90	KEK
1991	LC91	Protvino
1992	LC92	Garmisch
1993	LC93	SLAC
1995	LC95	KEK
1997	LC97	BINP, Zvenigorod
1999	LC99	INFN, Frascati
2002	LC02	SLAC
2004	1st ILC Workshop	KEK
2005	2nd ILC Workshop	Snowmass

Particle Physics

Year	Workshop	Location
1991	LCWS91	Saariselkä, Finland
1993	LCWS93	Waikoloa, HI
1995	LCWS95	Morioka-Appi, Japan
1999	LCWS99	Sitges, Barcelona, Spain
2000	LCWS00	Fermilab Batavia, IL USA
2002	LCWS02	Jeju, Korea
2004	LCWS04	Paris, France
2005	LCWS05	Stanford, USA
2006	LCWS06	Bangalore, India

17 years ago ...

Bjorn Wiik's Final Words at LCWS 91 (Saariselkä)

- It is clear that a 500-GeV, high luminosity e^+e^- collider has a unique physics programme and can be justified even if it starts operation several years after the turn on of the large hadron colliders. This justification is based on present knowledge and does not need input from the hadron colliders.

Physics at PLC

- The PLC is an ideal observatory of the scalar sector of the SM and beyond, leading to important and in many cases complementary to the e^+e^- ILC case tests of the EW symmetry breaking mechanism.
- On the other hand PLC is also a natural place to study in detail hadronic interaction of photons.

PHOTON LINEAR COLLIDER - $\gamma\gamma$ and γe options

Photon Linear Collider (PLC) is considered to be an option of ILC.
It is based on laser beams back-scattered from high energy electrons
(Ginzburg et al.'1980)

- Conversion $e \to \gamma$ is very efficient: small angular spread, energy and luminosity of $\gamma\gamma$ collision comparable of the energy and luminosity of the ee option; high polarization..

- PLC offers a unique opportunity to study a resonant production of the neutral Higgs bosons

$$\gamma\gamma \to \mathrm{H}$$

via loop with all charged fundamental particles of the theory!

- Detailed studies of various high energy $\gamma\gamma$ and $e\gamma$ processes for definite polarizations possible

Photon-photon processes

- Formation of neutral resonance with other quantum numbers than in e^+e^- ($C = +$) among other neutral Higgs particles (scalars and pseudoscalars, or mixture)

- Higher mass reach since particles can be produced individually

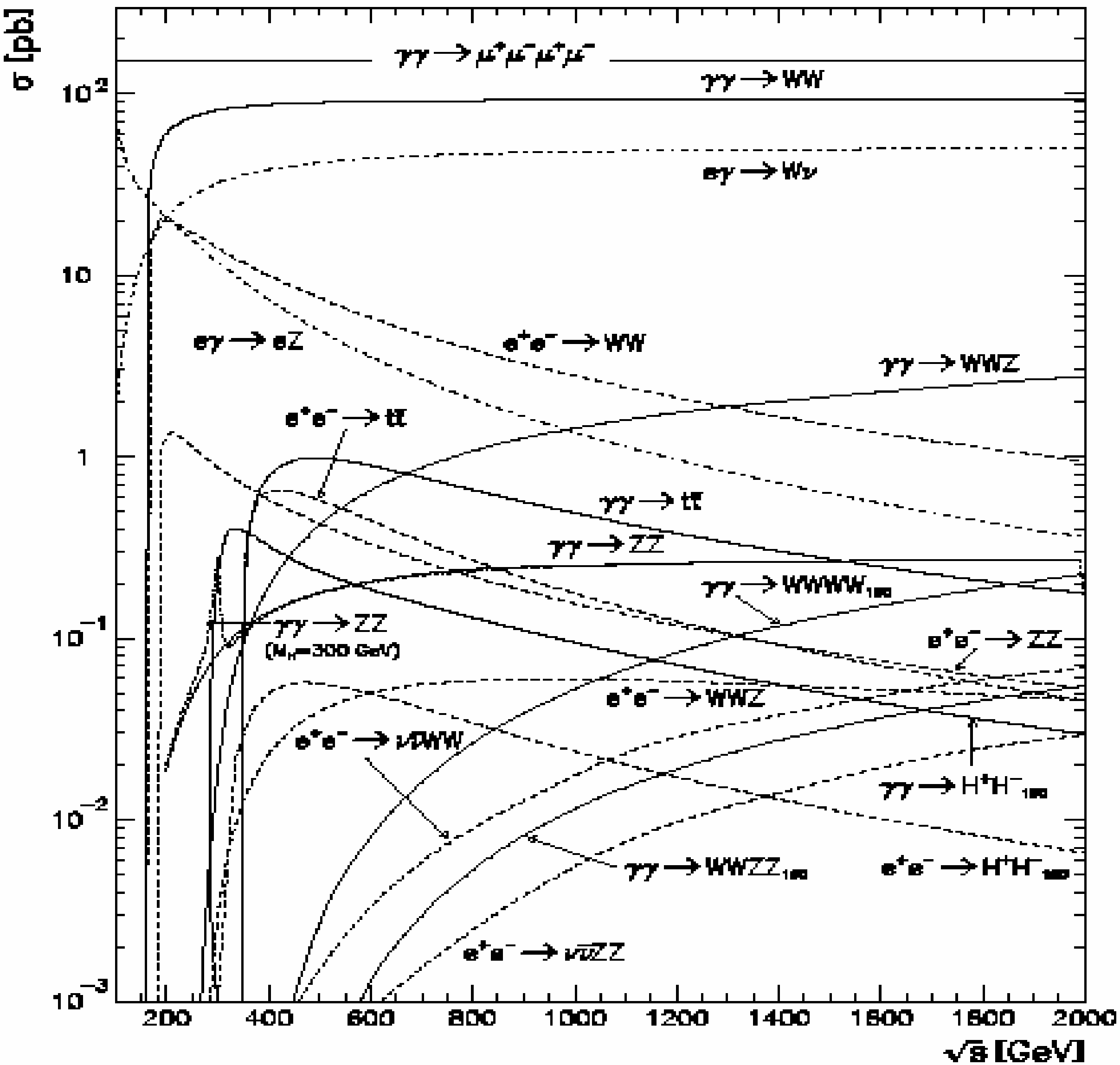
- Polarization, polarization ...

- The $\gamma\gamma H$ loop is sensitive to all charged fundamental particles of the theory - NON-DECOUPLING (in general)

- Direct pair production of charged scalars, fermions, vectors

- Pair production of neutral scalars, fermions, vectors via loops, among other $\gamma\gamma \rightarrow \gamma\gamma$

- Measurement of parton densities of really real photons (in $e\gamma$ measurements of F_2). Also for polarized photons...



σ [pb]
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
200
400
600
800
1000
1200
1400
1600
1800
2000
√s [GeV]
$\gamma\gamma \rightarrow \mu^+\mu^-\mu^+\mu^-$
$\gamma\gamma \rightarrow WW$
$e\gamma \rightarrow W\nu$
$e\gamma \rightarrow eZ$
$e^+e^- \rightarrow WW$
$\gamma\gamma \rightarrow WWZ$
$e^+e^- \rightarrow t\bar{t}$
$\gamma\gamma \rightarrow t\bar{t}$
$\gamma\gamma \rightarrow ZZ$
$\gamma\gamma \rightarrow WWWW$
$\gamma\gamma \rightarrow ZZ$
(M_H=300 GeV)
$e^+e^- \rightarrow ZZ$
$e^+e^- \rightarrow WWZ$
$e^+e^- \rightarrow \nu\bar{\nu}WW$
$\gamma\gamma \rightarrow H^+H^-$
$\gamma\gamma \rightarrow WWZZ$
$e^+e^- \rightarrow H^+H^-$
$e^+e^- \rightarrow \nu\bar{\nu}ZZ$

TESLA TDR

Golden processes	PLC2000 proc.
$\gamma\gamma \to H, h \to b\bar{b}$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV
$\gamma\gamma \to H \to WW(^*)$	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 β
$\gamma\gamma \to H^+H^-$	large cross sections
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections
$\gamma\gamma \to \tilde{g}\tilde{g}$	measurable cross sections
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium
$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \to \gamma\gamma$	non-commutative theories
$e\gamma \to eG$	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
$\gamma e \to W^-\nu_e$	anom.W couplings
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions
$\gamma e \to \bar{t}b\nu_e$	anomalous Wtb coupling
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section
$\gamma e \to e^-X,\ \nu_eX$	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

For Higgs sector

Photon Linear Collider offers

- Precise measurement of the light Higgs resonance (decay to bb)

- Distinquishing SM-like scenarios:

  $\gamma\gamma h(H)$ (possible non-decoupling of H^+)

- Establishing CP properties of Higgs bosons,

among other for "SM-like" h ($\sim h_1$) and HA mixing (h_2, h_3):
for $h_2 \to WW/ZZ$

  - full simulation for Photon Linear Collider (PLC)
  - synergy LHC-LC-PLC

- Heavy Higgs boson production and covering LHC wedge (Spira et al.)

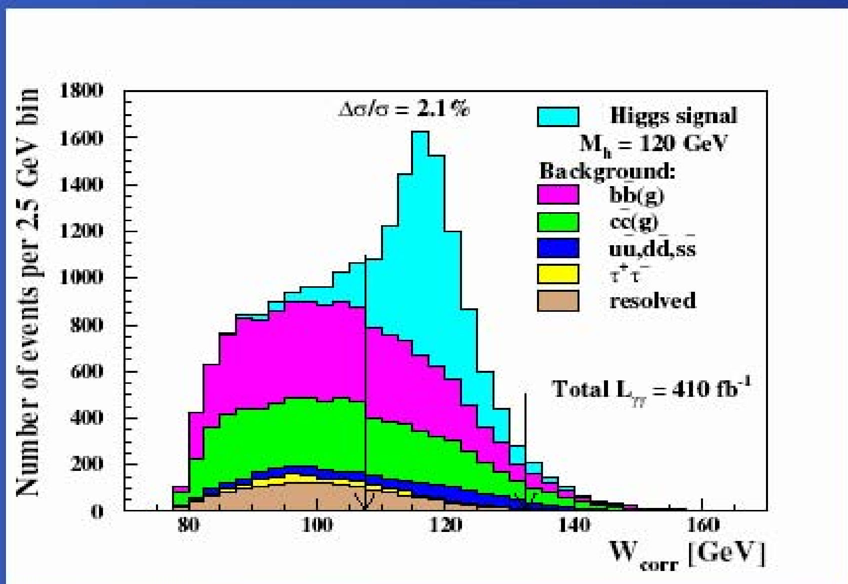
- Higgs self-coupling study in HH pair production (Belusevic and Jikia'04)

- Determination of $\tan\beta$ in $\tau^+\tau^-$ fusion (Muhlleitner et al)

Precision for mass 120 GeV: 2%

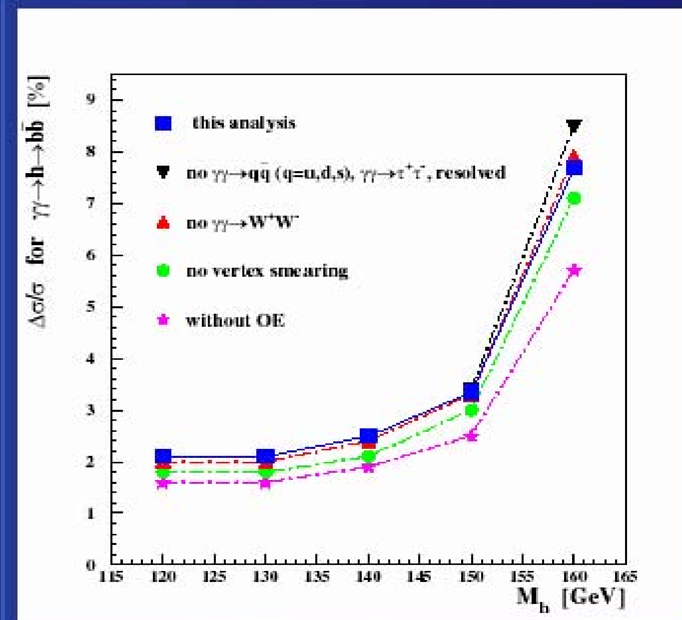
SM summary

Results for $M_h = 120$ GeV



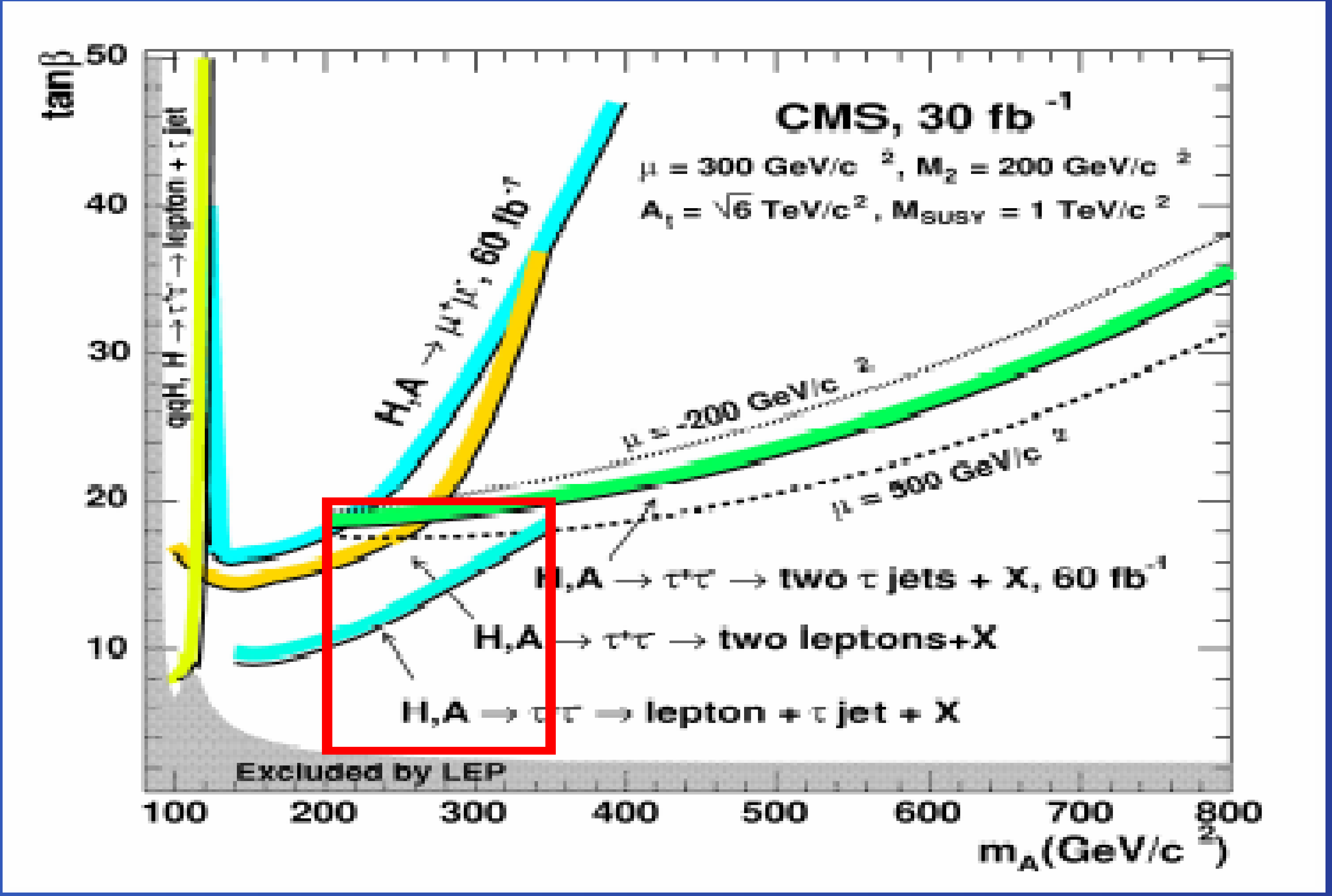
Corrected invariant mass distributions for signal and background events

Results for $M_h = 120$-160 GeV



For $M_h = 150$, 160 GeV additional cuts to reduce $\gamma\gamma \to W^+W^-$

LHC wedge

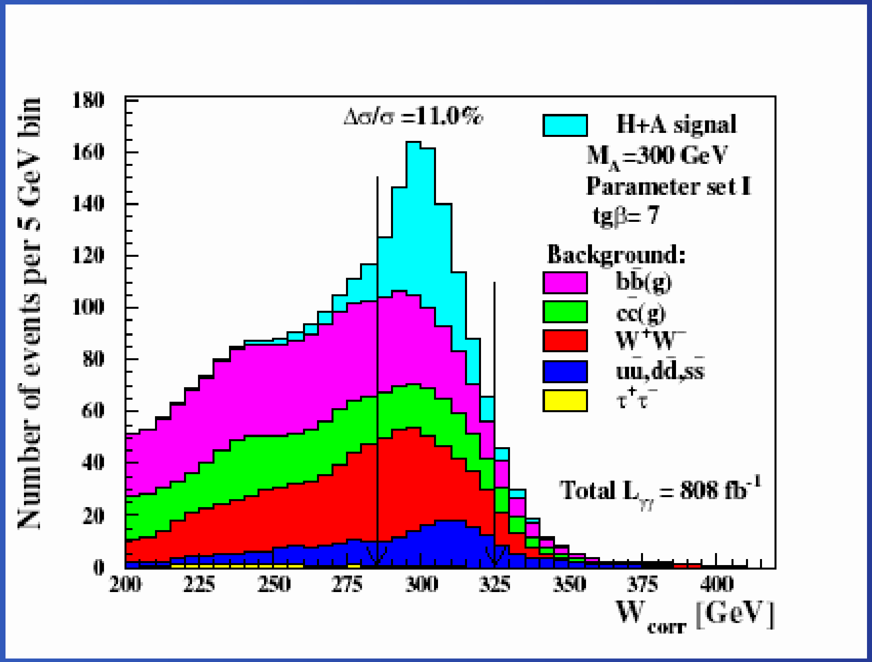


From: CMS NOTE 2003/033

(the same results as in newer CMS CR 2004/058)

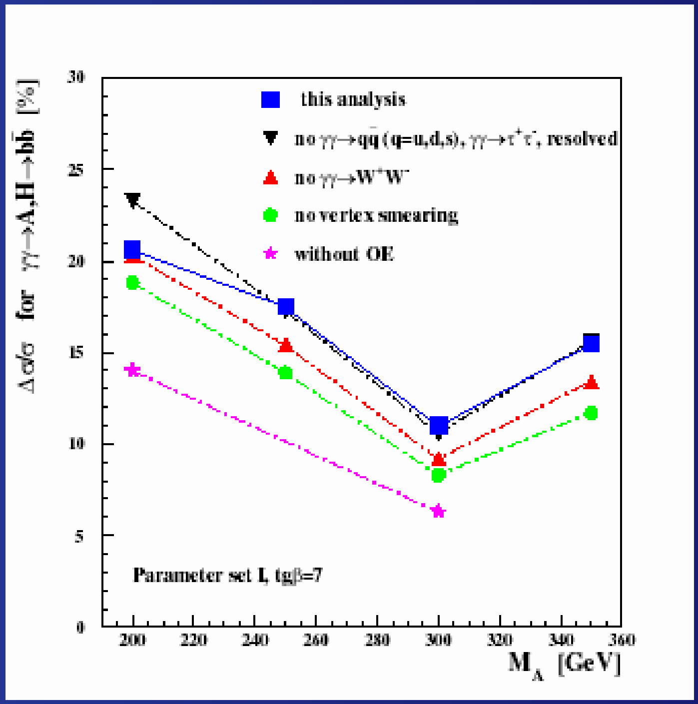
H/A MSSM Higgs – full simulation

Results for $M_A = 300$ GeV



Corrected invariant mass distributions

Results for $M_A = 200$-350 GeV



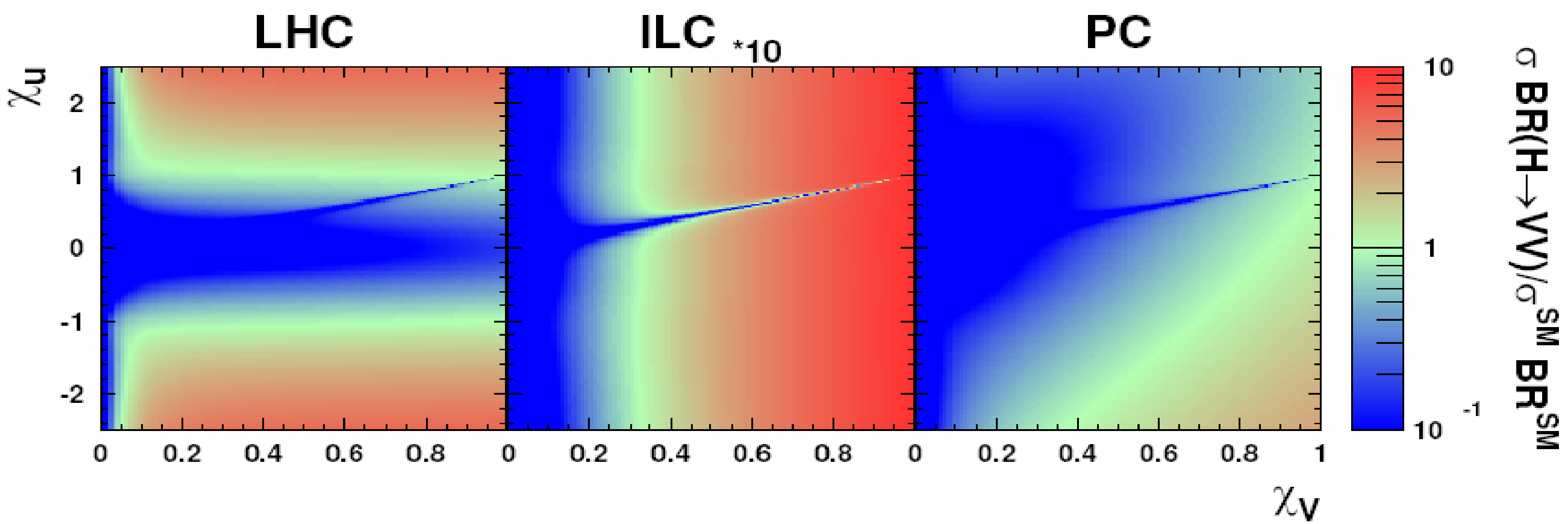
our previous results compared

Higgs decay to WW/ZZ in 2HDM

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 $\quad M_H = 250 GeV$



Conclusion

Important and unique features of PLC:

- Direct production of charged particles
- Higgs-boson factory (and CP laboratory)
- Large mass reach
- Covering LHC wedge of MSSM
- Precise measurement of fundamental $\Gamma_{\gamma\gamma}$

WHAT PLC CAN AND CANNOT DO (TESLA TDR'2001)

Gamma-Gamma Planners' (GGP) meeting in Kazimierz, Sept,7, 2005 (PLC2005), - based on the notes by David J. Miller

Present: V.Telnov, A.Finch, M.Krawczyk, J.Dainton, S. Maxfield, F.Kapusta, I. Ginzburg, P.M.Zerwas, F.Zarnecki, P.Pniez, K.Moenig, J.Gronberg, D.J.Miller

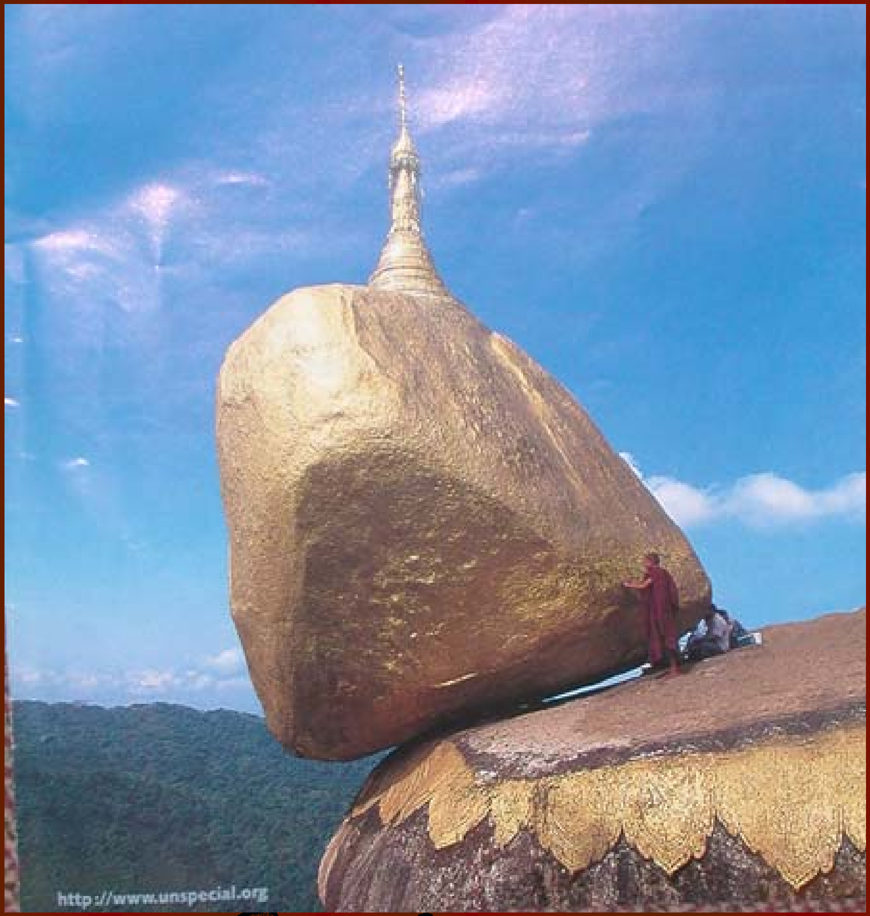
The $\gamma\,\gamma$ and eγ upgrade options are not part of the baseline ILC design.

If provision for the PLC option is to be included in the Reference Design Report at the end of 2006, the list of issues need to be tackled and convincing arguments given before the middle of 2006, on

- Optical Cavity
- Beam Dump
- Luminosity maintenance
- Crossing Angle
- Backgrounds
- Physics

The list of processes whose study will justify the PLC option needs to be reviewed. Some vital analyses are still missing (http://photon2005.fuw.edu.pl)

Photon Linear Collider



Fruitful meeting!

- **Photon 2007**