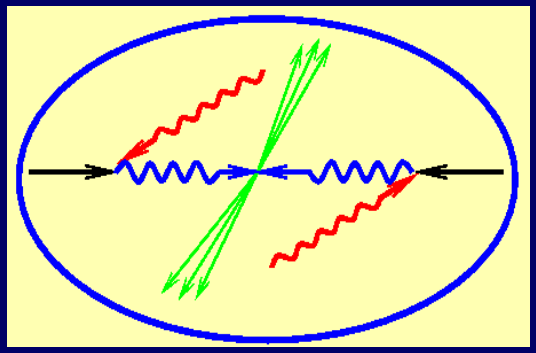
LC10 Frascati 3.12.2010



Gamma-gamma session at the International Workshop on Linear Colliders

Maria Krawczyk
Faculty of Physics
University of Warsaw

International Workshop on Linear Colliders
Geneva, October 18-22, 2010

(ECFA-CLIC-ILC Joint Meeting)

https://espace.cern.ch/LC2010/default.aspx

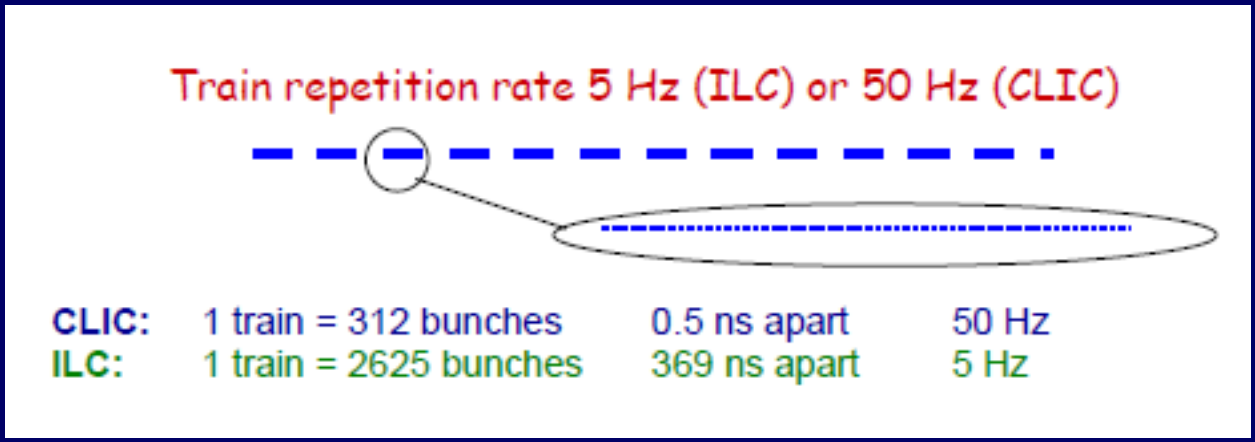
479 participants

Energy&Lumi

Towards a future Linear Collider and The Linear Collider studies at CERN

Steinar Stapnes (CERN)

		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
f_{RF}	[GHz]	12	12	1.3
G_{RF}	[MV/m]	80	100	31.5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	$[10^9]$	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	$[\mu m]$	2.4	0.66	10
ϵ_y	[nm]	25	20	40
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45



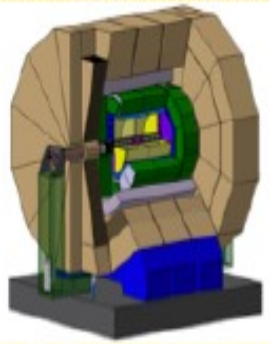
Combined ILC/CLIC working groups

	CLIC	ILC
Physics & Detectors	L. Linssen	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)		
Civil Engineering & Conventional Facilities		
Positron Generation		
Damping Rings		
Beam Dynamics		
Cost & Schedule		

Validated ILC concepts

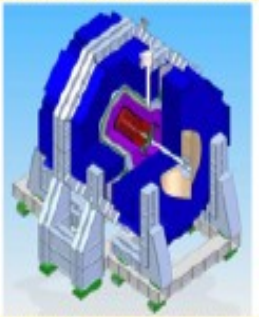
ILD: International Large Detector

"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC + Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



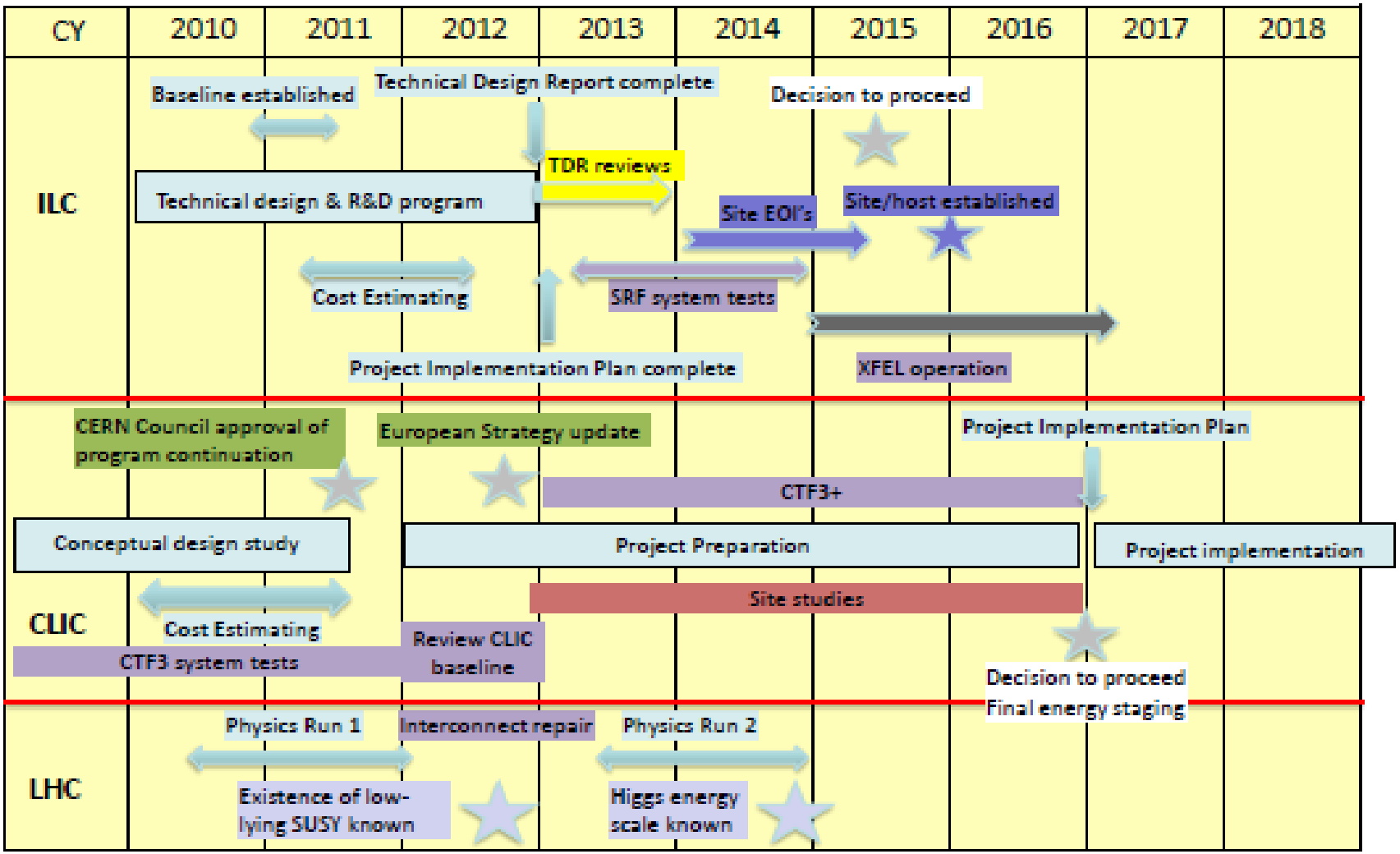
SiD: Silicon Detector

"Small" : tracker radius 1.2m
B-field : 5 T
Tracker : Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



CLIC detector concepts will be based on SiD and ILD.
Modified to meet CLIC requirements

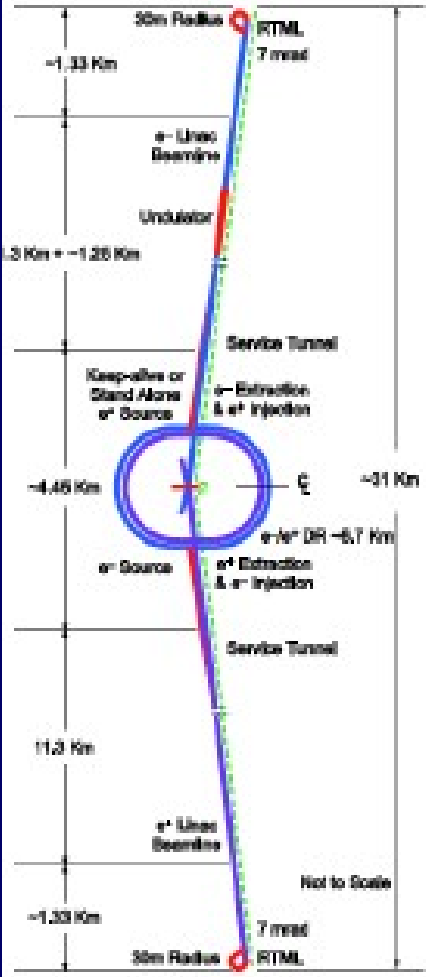
CLIC & ILC roadmaps



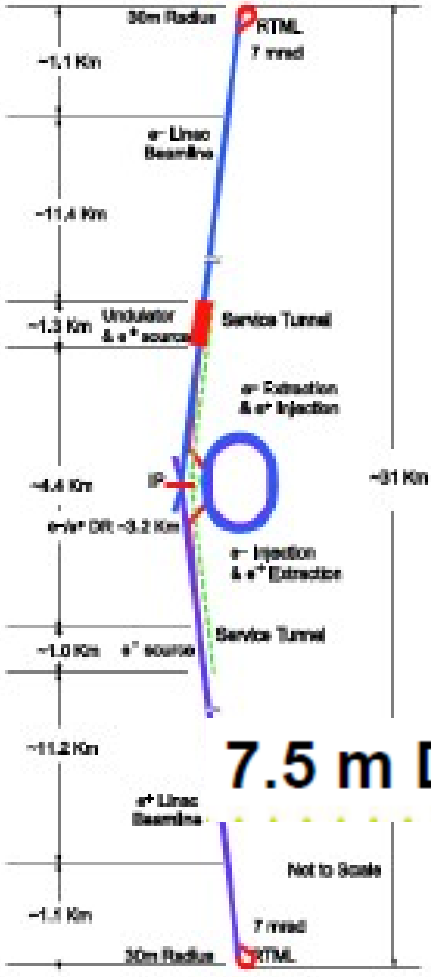
Ph.Lebrun

Proposed Design changes for TDR

RDR



SB2009



- Single Tunnel for main linac
- Move positron source to end of linac ***
- Reduce number of bunches factor of two (lower power) **
- Reduce size of damping rings (3.2km)
- Integrate central region
- Single stage bunch compressor

7.5 m Diameter Single Tunnel

ILC (250 GeV)-

From the LOIs to the DBDs- Coverage of Higgs Studies -

Roman Pöschl

Benchmarks for the LOIs 2009

$e^+e^- \rightarrow h^0Z^0$: 120 GeV Higgs @ 250 GeV

- Based on compelling arguments for a light Higgs

- Production at threshold

- Precision measurements to pin down nature of Higgs boson

- Higgs-strahlung cross section and recoil mass
  => Coupling Modifications wrt. SM?
  Precision in Higgs Mass (????),
  Currently no direct "application" for σ_{Mh} ~ 30 MeV

- Branching ratios into heavy quarks (and gluons)
  Scaling with quark mass, crucial test of nature of Higgs boson

Precision in ILD and SiD LOI
h → bb: 1-3%
h → cc: 10% (SID), 12% (ILD, shown at LCWS10)

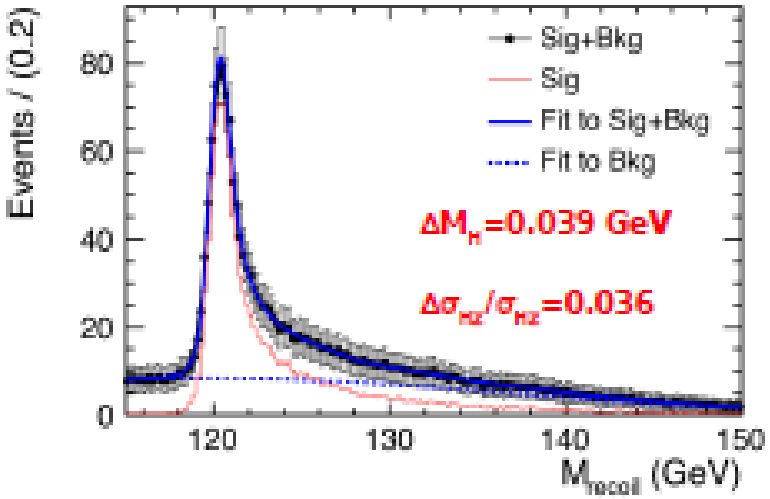
detailed baseline design (DBD)

Letters of Intents (LOIs)

Reminder - Results LOI 2009

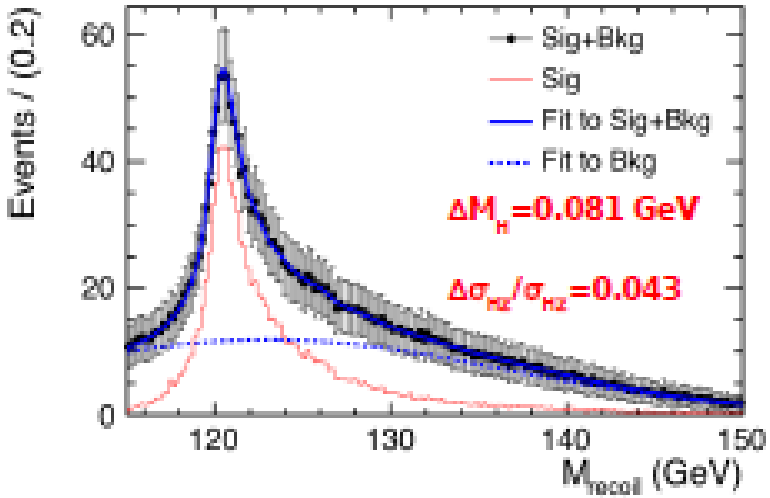
Total energy 250 GeV

Muon Channel



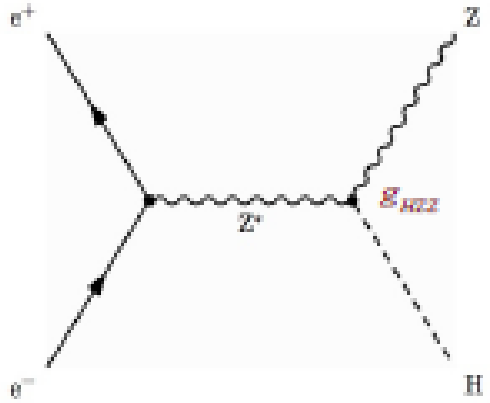
Very Precise Measurement
S/B = 8 in Peak Region

Electron Channel



Less Precise
Bremsstrahlung in detector material

Combined: ΔM_H=0.035 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.027



$$\sigma_{HZ} \sim g^2_{HZZ}$$

⇒ Precision in g_{HZZ} coupling 1-2%

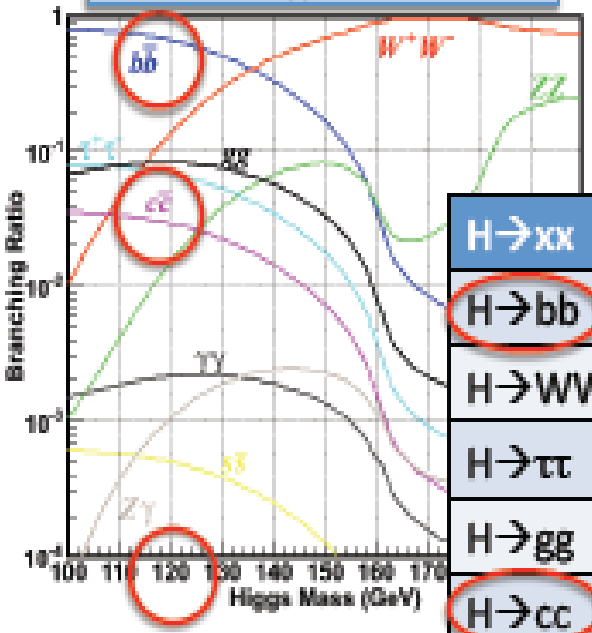
Sensitivity to 15% deviations
SM prediction of cross section

ZH Branching Ratio measurement

Higgs BR study at Ecm=250 GeV is one of the benchmark process in LOI

Higgs BR at Ecm=350 GeV is also the new benchmark process for DBD

BR at M_H=120 GeV

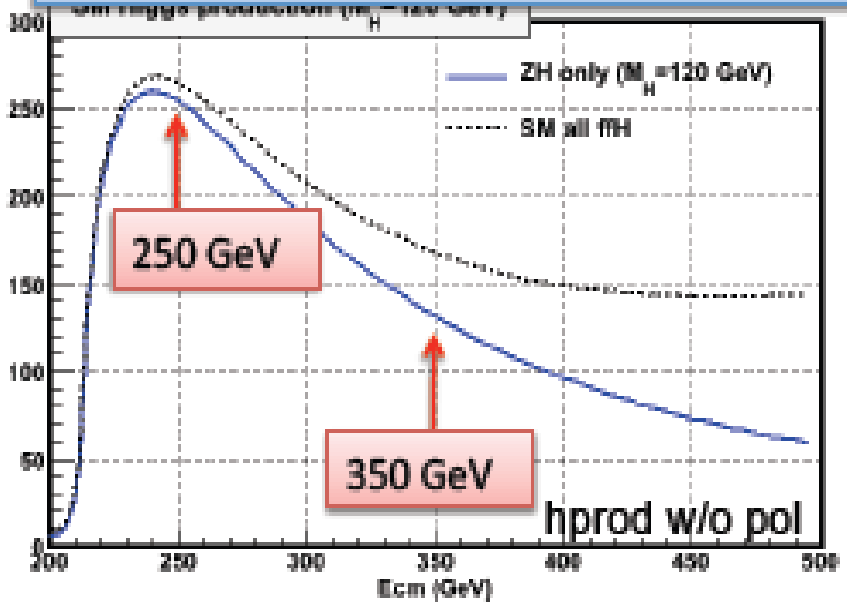


H→xx	BR
H→bb	66.7%
H→WW	14.0%
H→ττ	6.8%
H→gg	5.5%
H→cc	3.6%

(in pythia)

ZH (hprod)	254 fb^{-1}	131 fb^{-1}

SM Higgs production cross section



Cross section	Ecm=250GeV	Ecm=350GeV
ffH (w/ beam pol)	319.4 fb^{-1}	274.9 fb^{-1}

Summary of the $\gamma\gamma$ ECFA parallel session

Christophe Royon
IRFU-SPP, CEA Saclay

Linear Collider Workshop, Geneva, October 18-22 2010

On behalf of the $\gamma\gamma$ session conveners, Maria Krawczyk, Stephen Maxfield, Margarete Mühlleitner, Christophe Royon

$\gamma\gamma$ physics

Contents:

- Triple gauge and quartic anomalous coupling studies - Oldrich Kepka
- $\gamma\gamma \to$ hadrons for CLIC - Rohini M. Godbole
- Resonance-continuum interference effects for light Higgs Boson production at a photon collider, ie in $\gamma\gamma \to H \to b\bar{b}$ - Lance Dixon
- Feasibility study of Higgs pair production in a photon collider - Tohru Takahashi
- A sneak preview of the CLIC/PLC string hunter's companion - Tomasz Taylor
- Stop mass determination at ILC - Anna Skachkova (in Higgs/SUSY session)
- DIRAC gauginos and their scalar partners - Jan Kalinowski (in Higgs/SUSY session)

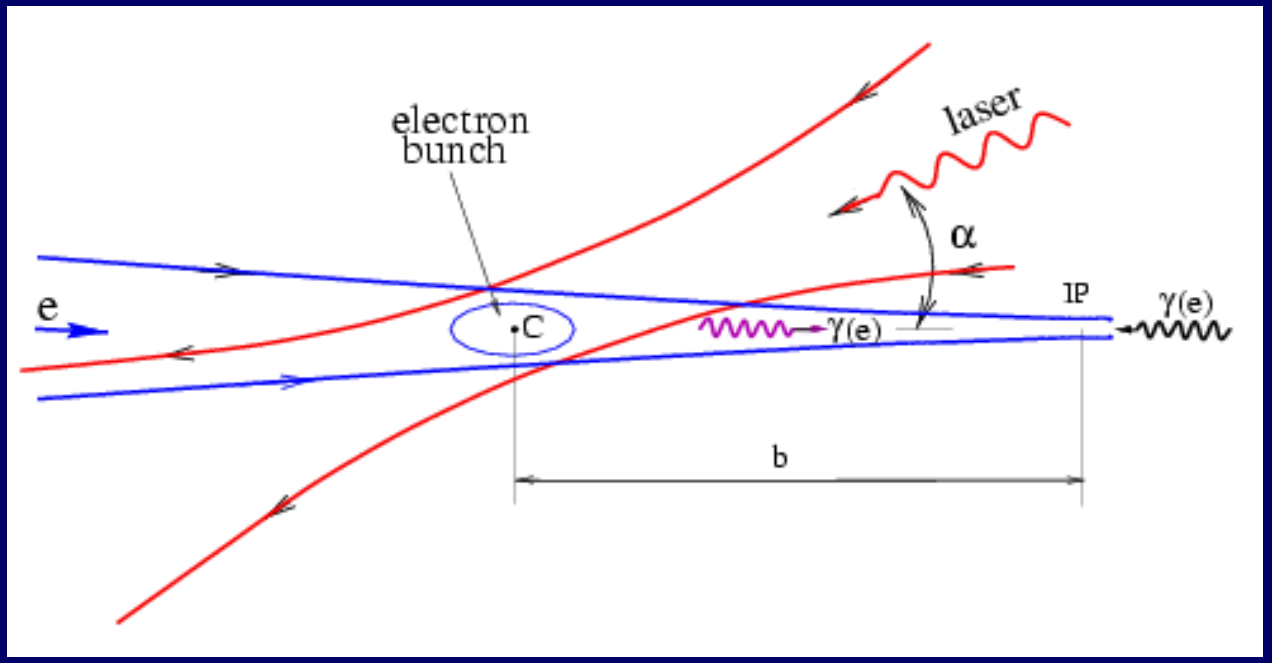
9 good reasons to build PLC

Introduction to Photon2007

1. Precision measurements of the light Higgs boson production (->bb) and distinguishing SM-like scenarios
1. Testing Higgs selfinteraction
2. Higher mass reach and covering LHC wedge
3. Establishing CP property of Higgs bosons
5. Search for SUSY particles
6. Complementarity to ILC and LHC
7. Photon structure and QCD tests
8. Anomalous W and t couplings
9. New physics in $\gamma\gamma \rightarrow \gamma\gamma$

Backward Compton Scattering- basic idea of the photon collider

Ginzburg, Telnov, Serbo, Kotkin ’81



- PLC = $\gamma\gamma$ and e γ options

PLC - main characteristics

- Variable energy and degree of polarization of the photon beams – both circular and linear
- (Almost) monochromatic spectrum possible (a high energy peak)
- Clean or dirty collider? Hadronic interaction of photon ……

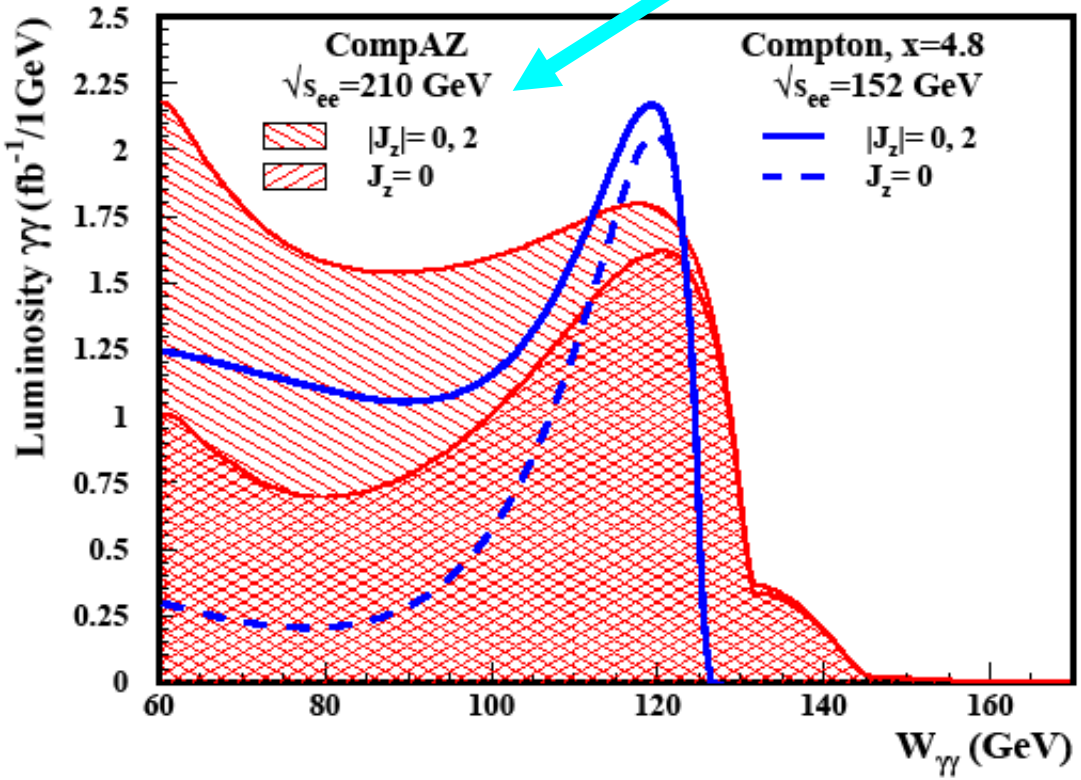
PLC at ILC

- For ILC with energy 500-1000 GeV:
- Energy $E_{\gamma\gamma}$ up to 0.8 E_{ee} (0.9 for $e\gamma$ option)
- Luminosity ~ 0.2 L_{ee}

  Annual luminosity 100 fb-1 (30 fb-1 in the peak)
- Mean energy spread in a peak: ~0.05-0.07
- Mean helicity at the peak: 0.9-0.95
- Important parameter x: $\omega_{max} = \frac{x}{x+1} E_0$ E_0 energy of e

x=4.5 to avoid e+e- pair production

Realistic $\gamma\gamma$ spectra (Telnov)



For J_z = 0, 2

Here J_z=0 peak for M=120 GeV

CompAZ parametrizaton (A.F.Żarnecki)

SM Higgs-resonance decaying in bb $\rightarrow \Gamma_{\gamma\gamma}$

Studies (symulations) by:

- Ohgaki, Takahashi, Watanabe 1997
- Jikia, Soldner-Rembold 1999
- Asner, Gronberg, Gunion 2001
- Niezurawski, Zarnecki, MK 2002
- Moenig, Rosca 2003

$\sim 2\ \% \rightarrow$

(+Br to bb from e+e-) 3 % accuracy for $\Gamma_{\gamma\gamma}$

In BSM $\Gamma_{\gamma\gamma}$ sensitive to SUSY particles, charged Higgs bosons, charged new particles (new generations..). Large deviation from the SM arises for strongly interacting models

Distinguishing SM-like scenarios possible

Note that h gamma gamma vertex has a phase !!

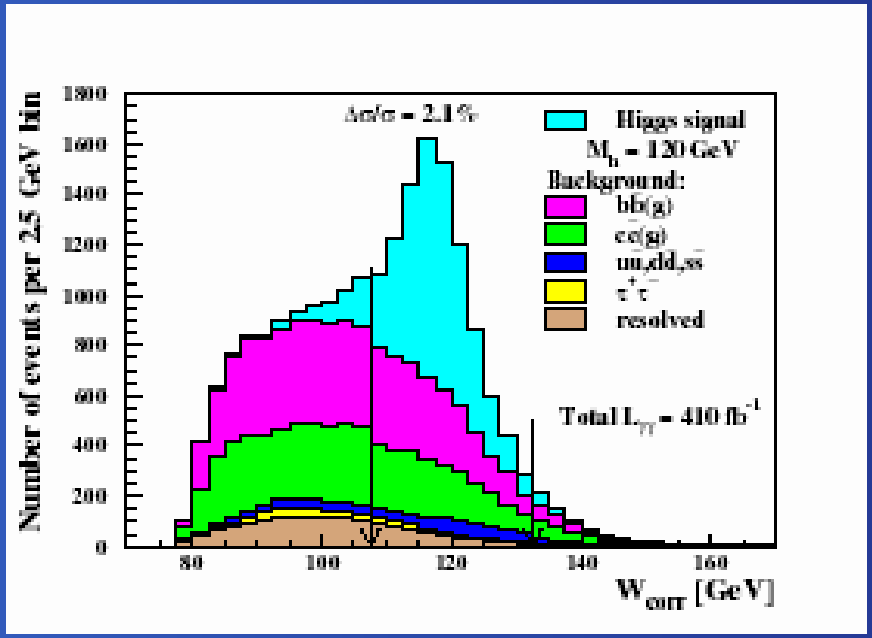
Higgs coupling to $\gamma\gamma$

$$\gamma\gamma \to h \to b\bar{b}$$

Niezurawski et al., NZK

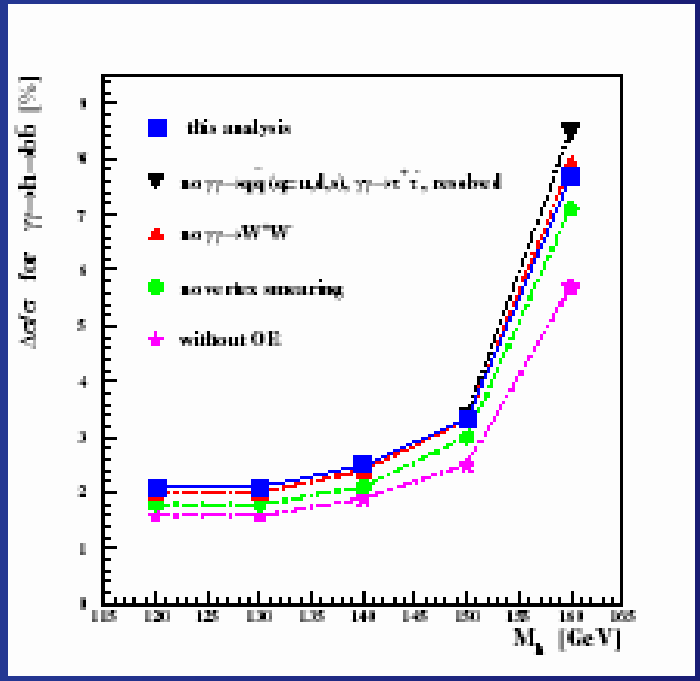
SM summary

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 $\gamma\gamma \to W^+W^-$

Resonance-Continuum Interference in $\gamma\gamma \to H \to b\bar{b}$

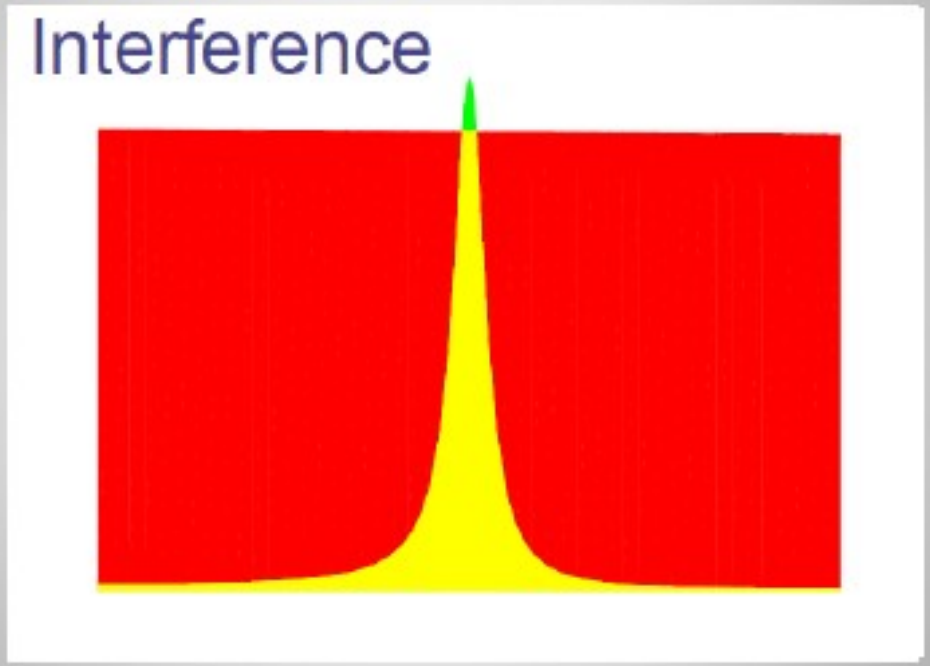
M_H<160 GeV

Lance Dixon (CERN & SLAC)
and Yorgos Sofianatos (SLAC)

0812.3712

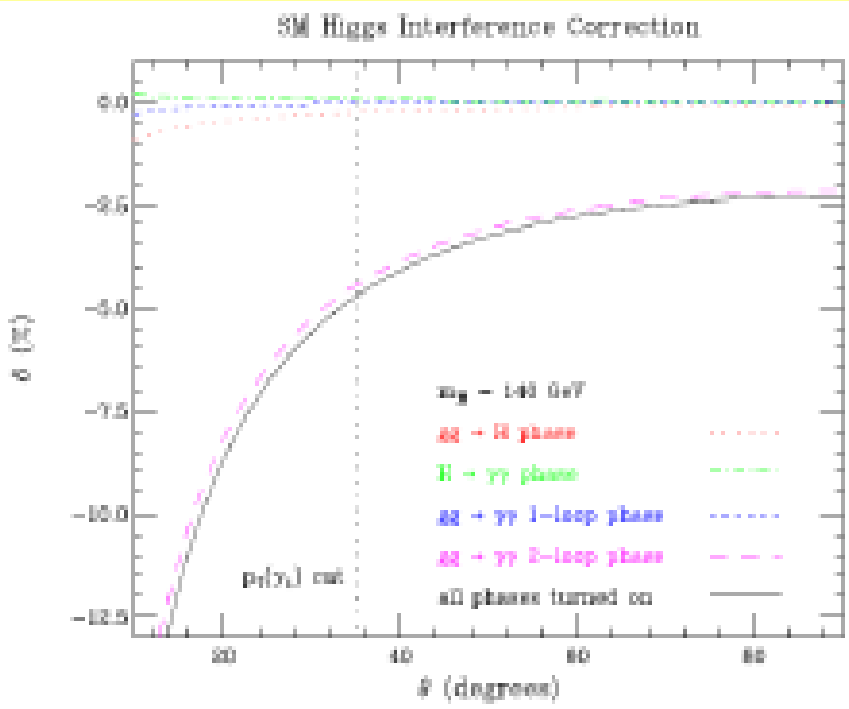
LCWS2010, CERN/Geneva, 19 October

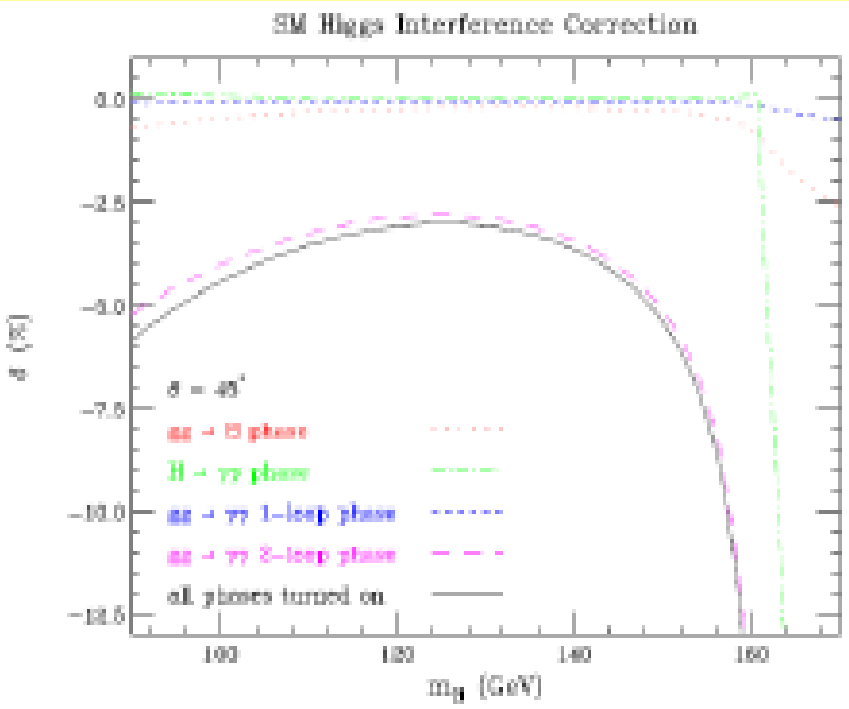
Motivation in pictures



So we should check whether the peak height is equal to this quantity to better than 2%.

- Another place resonance-continuum interference could be significant is in the SM Higgs $\gamma\gamma$ decay mode at the LHC (gluon fusion production). LD, Siu, hep-ph/0302233
- Here effect is 3-5%, smaller than currently envisaged experimental uncertainties, and smaller than some of the estimated theoretical uncertainties (but not all).
- But not a lot smaller.





Amplitude interference

- Total $\gamma\gamma \to b\bar{b}$ amplitude:

$$\mathcal{A}_{\gamma\gamma\to b\bar{b}} = -\frac{\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}}{\hat{s} - m_H^2 + i m_H \Gamma_H} + \mathcal{A}_{\text{cont}}$$

- Interference term has 2 pieces:

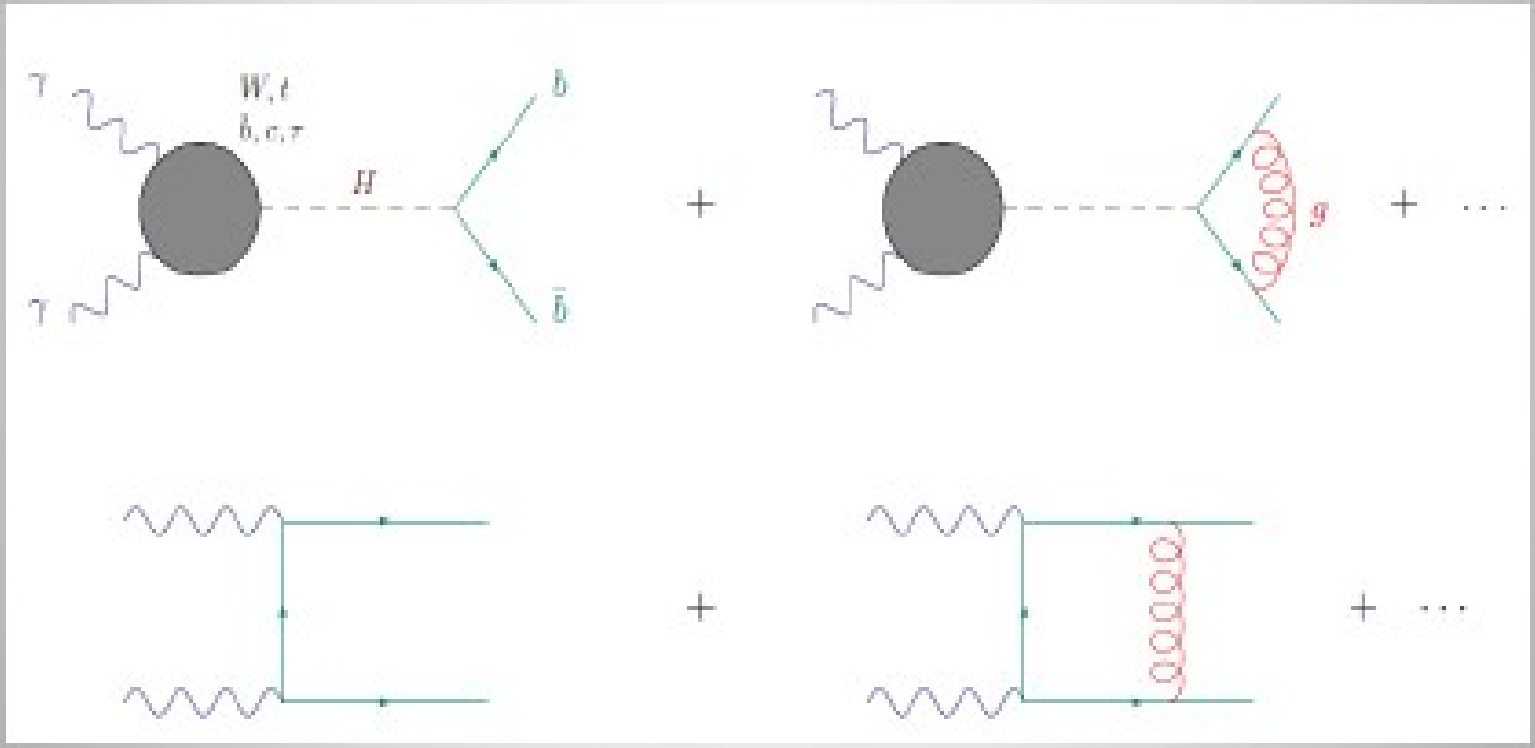
$$\delta\hat{\sigma}_{\gamma\gamma\to H\to b\bar{b}} = -2(\hat{s} - m_H^2)\frac{\text{Re}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}\mathcal{A}^*_{\text{cont}})}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2} - 2m_H\Gamma_H\frac{\text{Im}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}\mathcal{A}^*_{\text{cont}})}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2}$$

- First term vanishes upon integration over $\hat{s}$ as long as $\mathcal{A}_{\gamma\gamma\to H}$, $\mathcal{A}_{H\to b\bar{b}}$, $\mathcal{A}_{\text{cont}}$ don't vary too quickly

Dicus, Stange, Willenbrock, hep-ph/9404359

In search of a phase

- Need $\mathrm{Im}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}\mathcal{A}^{*}_{\mathrm{cont}}) \neq 0$
- All mostly real in SM.



Computing the phase

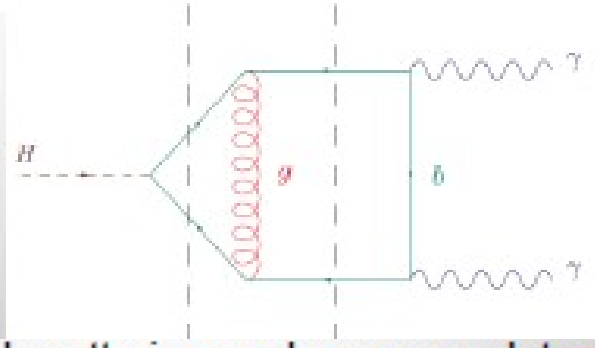
- A little algebra →

$$\delta \equiv \frac{\delta\sigma_{\gamma\gamma\to H\to b\bar{b}}}{\sigma_{\gamma\gamma\to H\to b\bar{b}}} = 2m_H\Gamma_H \,\mathrm{Im}\left\{\frac{\mathcal{A}^{\mathrm{tree}}_{\gamma\gamma\to b\bar{b}}}{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\mathcal{A}^{\mathrm{tree}}_{H\to b\bar{b}}}\left[1+\frac{\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar{b}}}{\mathcal{A}^{\mathrm{tree}}_{\gamma\gamma\to b\bar{b}}}-\frac{\mathcal{A}^{(2)}_{\gamma\gamma\to H}}{\mathcal{A}^{(1)}_{\gamma\gamma\to H}}-\frac{\mathcal{A}^{(1)}_{H\to b\bar{b}}}{\mathcal{A}^{\mathrm{tree}}_{H\to b\bar{b}}}\right]\right\}$$

$$= \frac{2m_H\Gamma_H}{\left|\mathcal{A}^{\mathrm{tree}}_{H\to b\bar{b}}\right|^2}\left[-\frac{\mathcal{A}^{\mathrm{tree}}_{\gamma\gamma\to b\bar{b}}\mathcal{A}^{*\mathrm{tree}}_{H\to b\bar{b}}}{\left|\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right|^2}\,\mathrm{Im}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\}\right.$$

$$\left.+\frac{1}{\mathrm{Re}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\}}\,\mathrm{Im}\left\{\mathcal{A}^{*\mathrm{tree}}_{H\to b\bar{b}}\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar{b}}-\mathcal{A}^{\mathrm{tree}}_{\gamma\gamma\to b\bar{b}}\mathcal{A}^{*(1)}_{H\to b\bar{b}}\right\}\right]$$

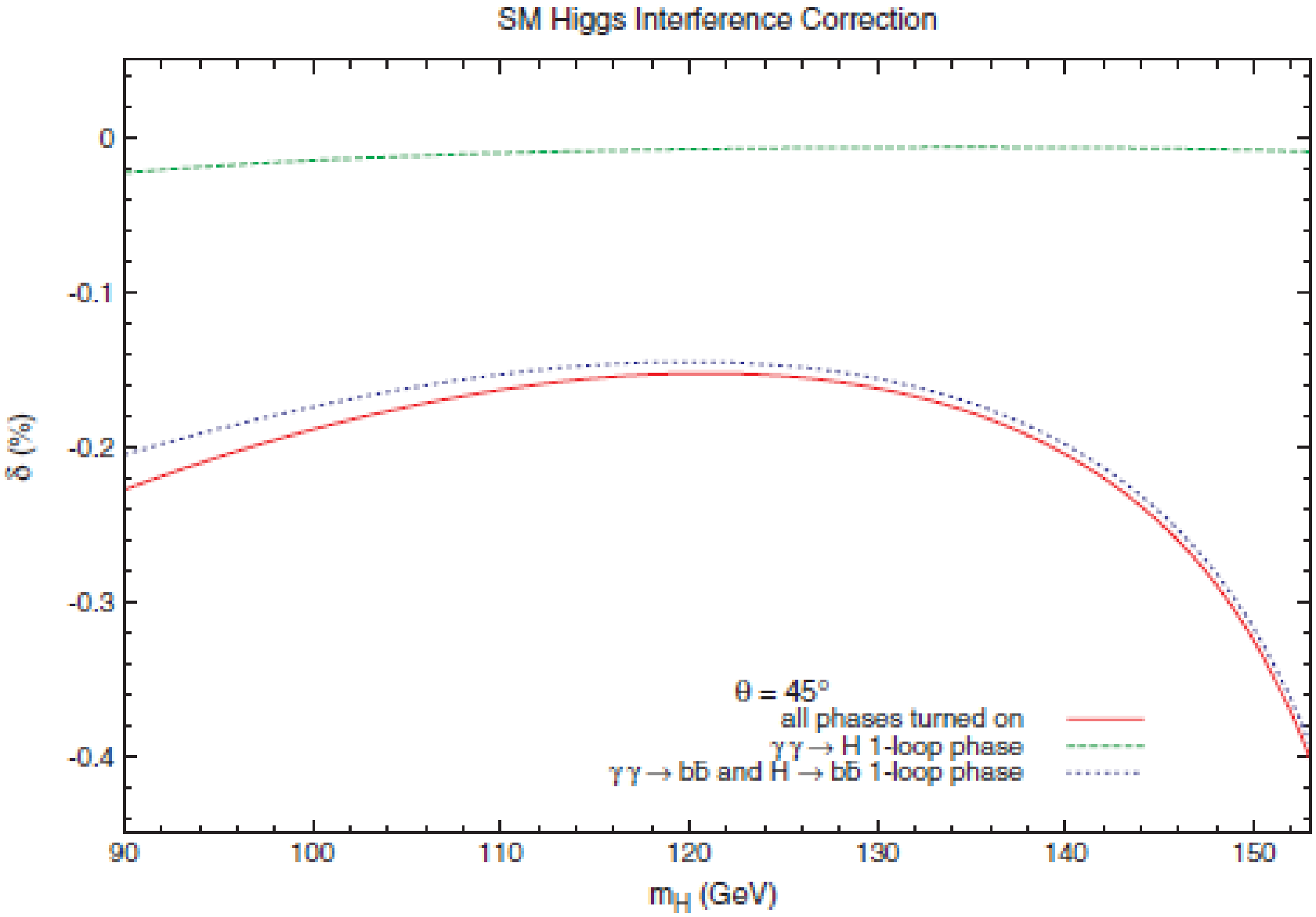
- 2nd term dominates
- Comes just from this cut graph



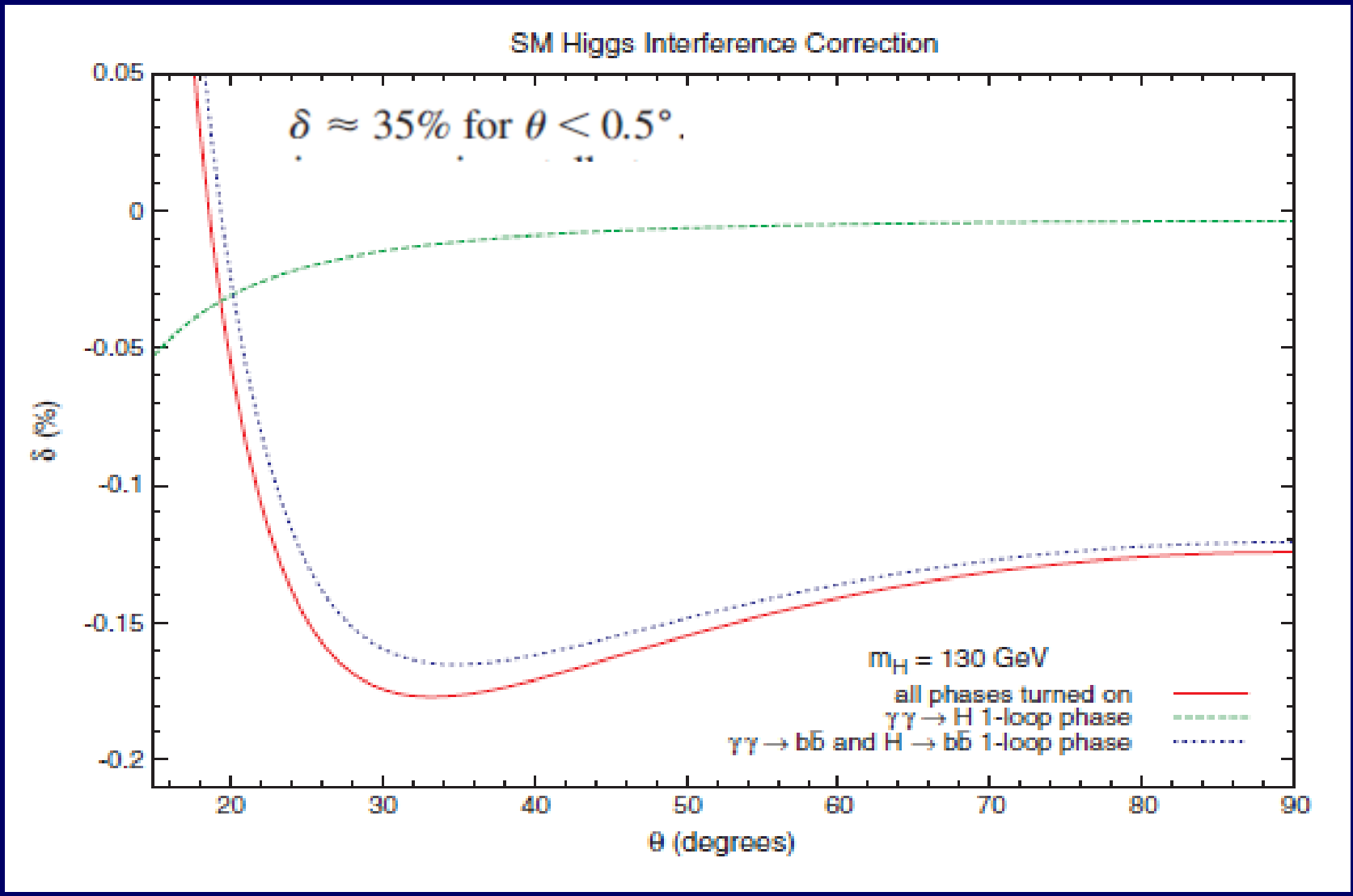
For all but very forward scattering angles, we can let $m_b \to 0$ in the brackets, obtaining:

$$\delta \approx \frac{128\pi Q_b^2\alpha\alpha_s m_H\Gamma_H}{v}\, m_b^2\, \frac{2\ln\left(\frac{m_H}{2m_b}\right)+2\ln\left(\sin\theta\right)+\ln\left(\frac{1-\cos\theta}{1+\cos\theta}\right)\cos\theta}{\sin^2\theta\,\left|\mathcal{A}^{\mathrm{tree}}_{H\to b\bar{b}}\right|^2\mathrm{Re}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\}} + \mathcal{O}\left(m_b^4\right)$$

Numerical result at 45°



Dependence on scattering angle



Conclusions

- In the SM, resonance-continuum interference in the process

$$\gamma\gamma \to H \to b\bar{b}$$

  is safely below the anticipated experimental uncertainties for

$$\Gamma(H \to \gamma\gamma) \times \mathrm{Br}(H \to b\bar{b})$$

- However, if there is evidence that the b quark Yukawa coupling is greatly enhanced over that in the SM, then the interference effect could be significant and should be investigated further, as a function of model parameters.

Feasibility study of Higgs pair production in a Photon Collider

Tohru Takahashi
Hiroshima University
for S.Kawada, N.Maeda, K.Ikematsu,
K.Fujii,Y.Kurihara ,,,

IWLC2010 CERN

Purpose of this study

Final goal: Study of Higgs self-coupling

$$\lambda = \lambda^{SM}(1 + \delta\kappa)$$

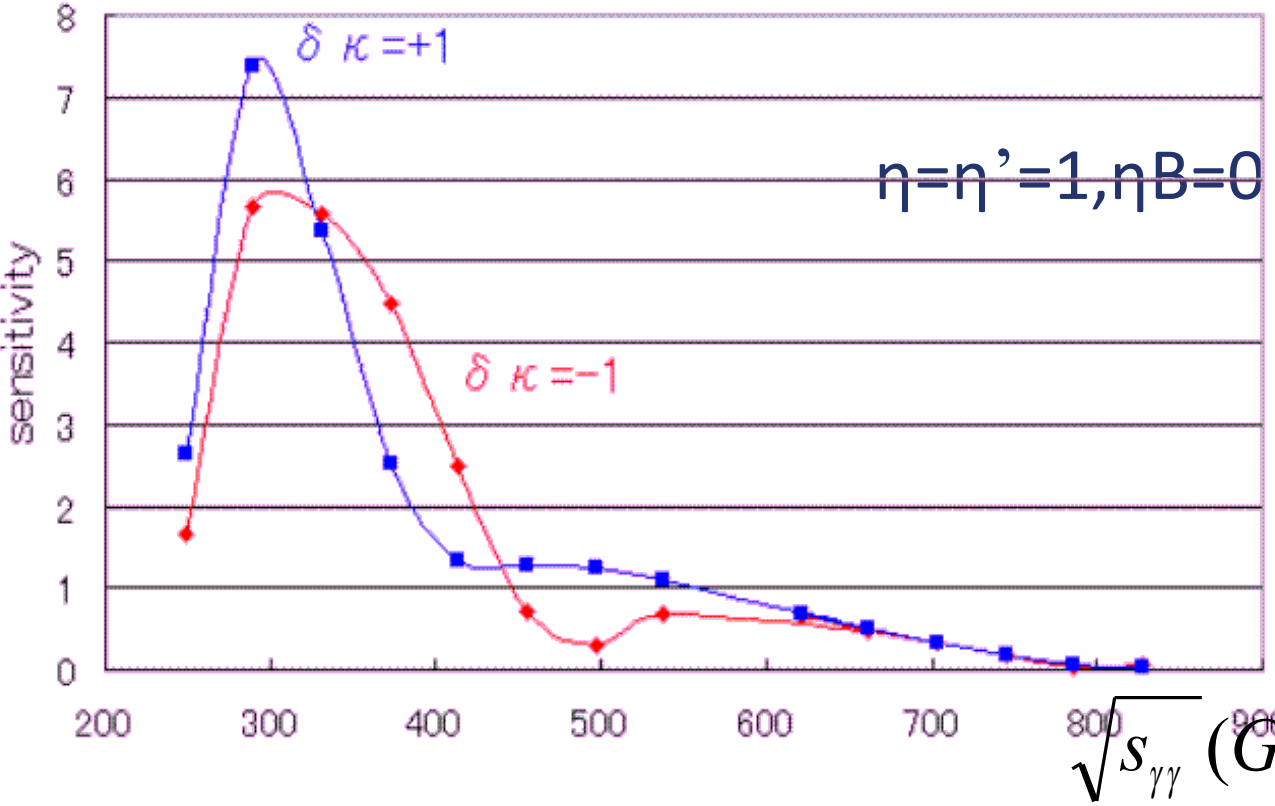
See feasibility of the measurement of Higgs pair creation in PLC.

how may events expected?

possible to suppress background?

Sensitivity vs energy

$$sensitivity \equiv \frac{N(\delta\kappa) - N_{SM}}{\sqrt{N_{obs}}} = \frac{L|\eta\sigma(\delta\kappa) - \eta'\sigma_{SM}|}{\sqrt{L(\eta\sigma + \eta_B\sigma_B)}}$$



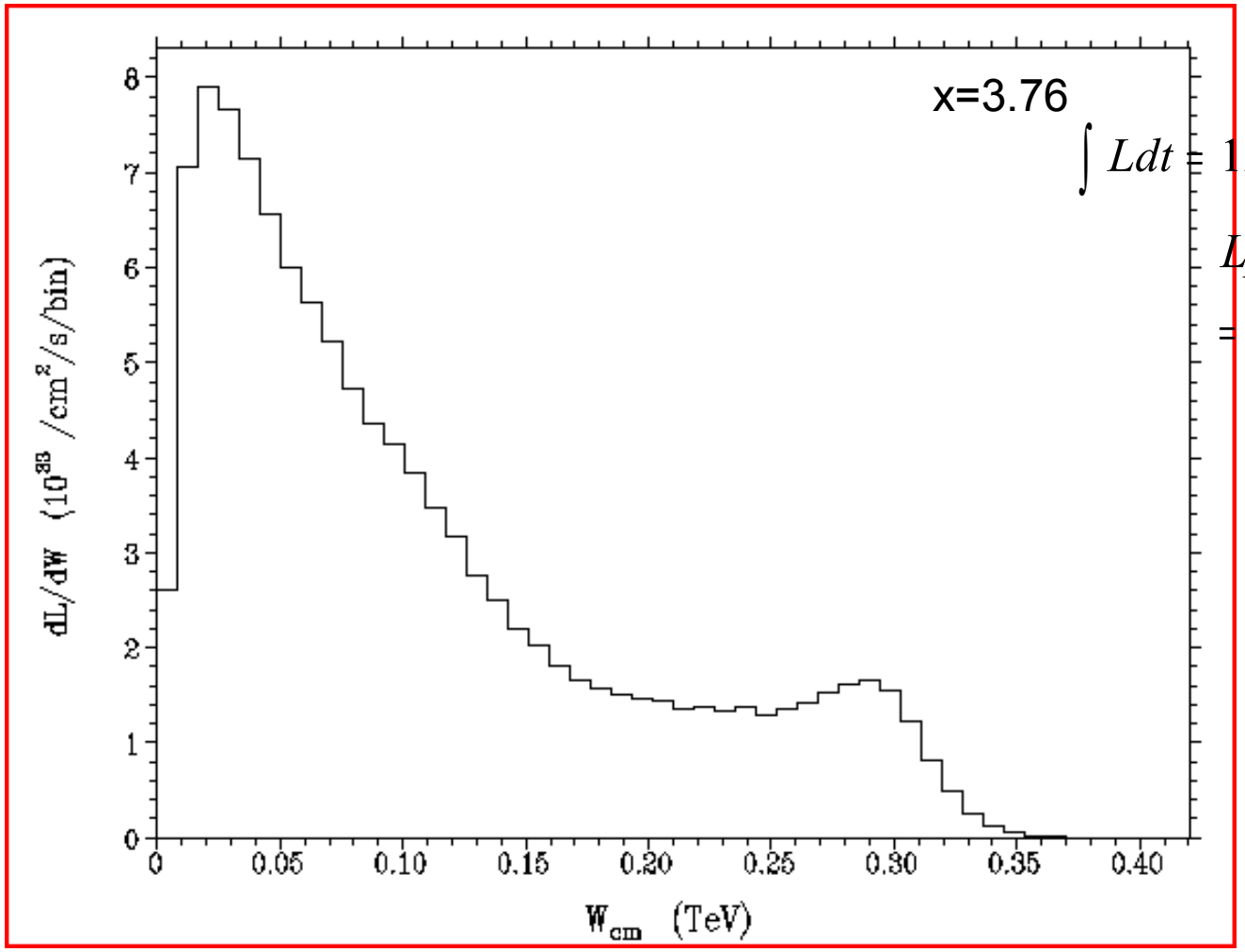
$$m_h = 120 GeV$$

$$\int Ldt = 1000\, fb^{-1}$$

Beam parameters $\sqrt{s_{\gamma\gamma}(peak)} \sim 300GeV$ (based on TESLA optimistic)

	x3.7	x4.8
Ee[GeV]	210	195
n(1010)	2	2
σz(mm)	0.35	0.35
γεx/y[m rad]	2.5/0.03	2.5/0.03
βx/y[mm]@IP	1.5/0.3	1.5/0.3
σx/y[nm]	96/4.7	99/5.5
λL[nm]	1054	770
x	3.76	4.8
Pulse Energy[J]	10	10
Lgeo(e-e-) [1034cm-2s-1]	8.7	8.1
Lpeak(γγ) [1034cm-2s-1]	1.2	0.7
Ltot(γγ)[1034cm-2s-1]	12.6	5.88

Luminosity Distribution



$\int Ldt = 12.6 \times 10^{34} [cm^{-2} s^{-1}]$

$Lpeak(> 260GeV)$

$= 1.2 \times 10^{34} [cm^{-2} s^{-1}]$

13events@Ltot=1000fb-1

~16events/year

$$\frac{1}{Ltot} \int \sigma\left(w_{\gamma\gamma}\right) \frac{dL}{dw_{\gamma\gamma}} dw_{\gamma\gamma} = 0.0131 fb$$

Signal & Main backgrounds

Signal : γγ->HH->4b

(16.4events/year)

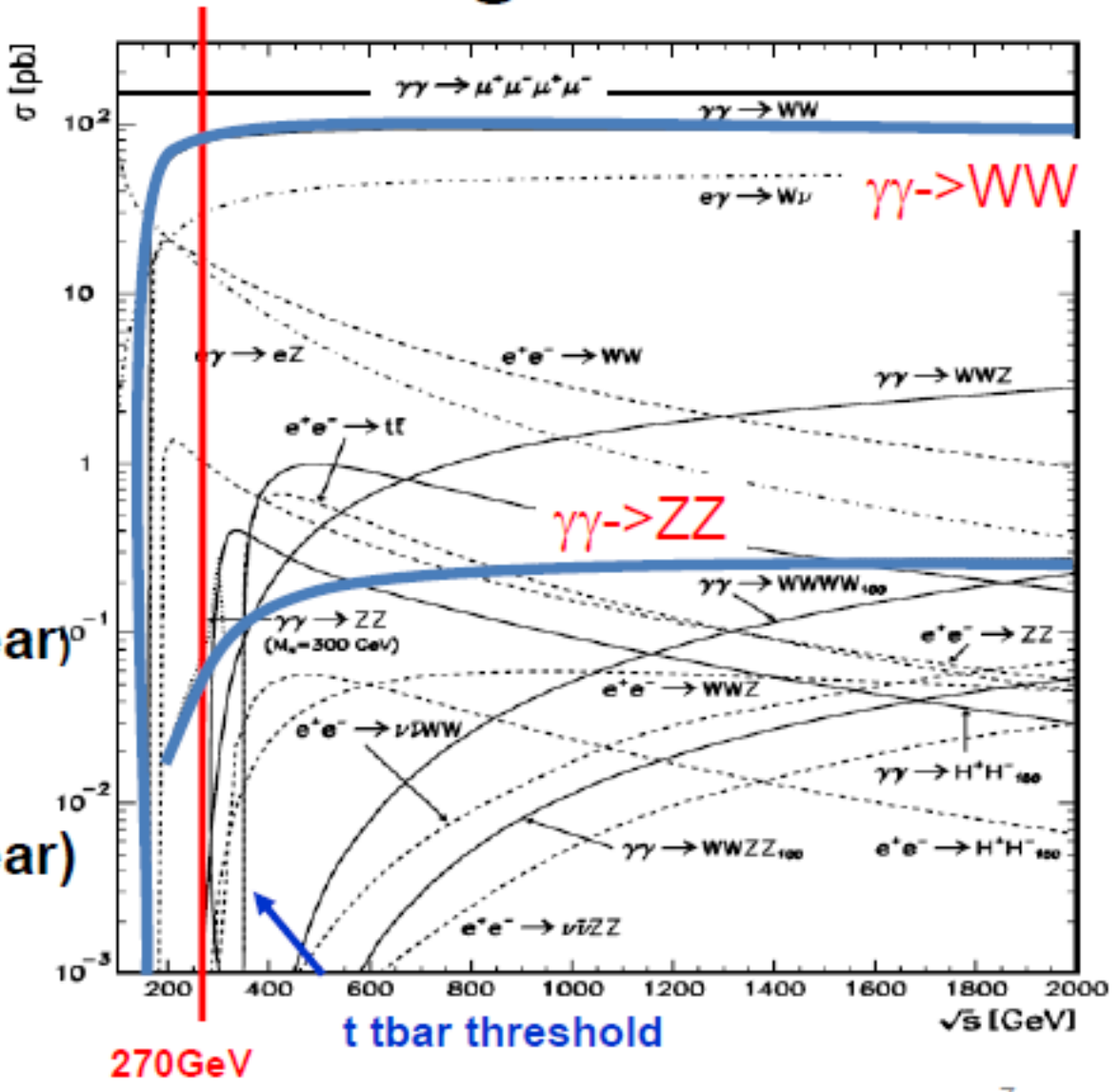
Main backgrounds

- γγ->WW->4q

(1.462*10^{7}events/year)

- γγ->ZZ->4b

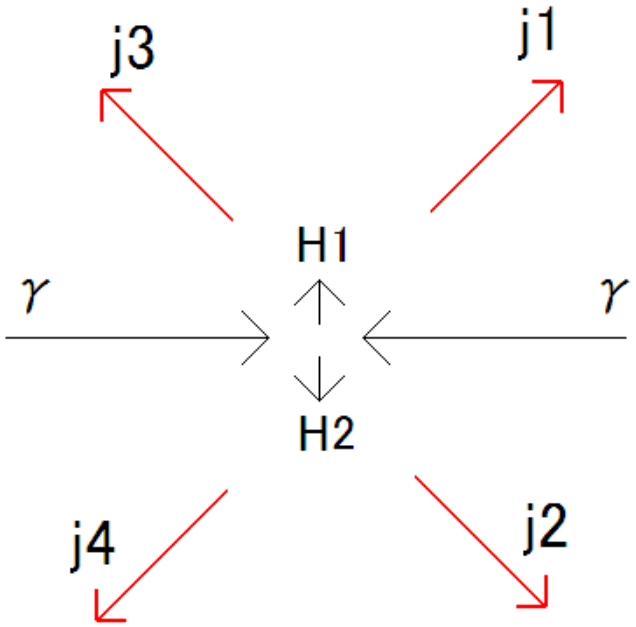
(1.187*10^{4}events/year)



Simulation & Analysis

- Event generation and detector simulation
- Reconstruct events
  - Jet clustering (reconstruct jets)
  - b-tagging (identification of b-quark)
    - nsig method was used in this study.
  - Reconstruct particles (determination of jet combination)
- Selection
  - Selection with Neural Network (NN)

Reconstruct particles



We have to choose two jets from 4 jets (j1-j4) in order to reconstruct original particle.

->There are 3 patterns of combination in a event.

->The jet of the least χ2 was chosen to be the most probable combination.

$$\chi_H^2 = \frac{(M_1 - M_H)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_H)^2}{\sigma_{2j}^2}$$

M1, M2 : reconstructed particle mass

MH : Higgs mass

σ2j : mass resolution

Selection (1)

β : Lorentz factor of reconstructed particle

θ : Angle between reconstructed particle and initial photon beam

$$\beta \geq 0.05, |\cos\theta| \leq 0.99$$

b-tagging

More than 3 b-flavor jets with (nsig=3.0, noffv=1) analysis

More than 2 b-flavor jets with (nsig=3.0, noffv=2) analysis

	generate	pre-selection
HH	5.0*10^4	29958
WW	7.5*10^7	83777
ZZ	1.0*10^6	87057

Selection (2) --- Neural Network (NN)

- 9 input parameters：
  - χ_H^2, χ_Z^2,
  - transverse (longitudinal) momentum,
  - # of b-flavor jets (2 patterns),
  - visible energy,
  - Y_{cut} value of jet clustering,
  - # of tracks
- Maximize statistical significance

$$S_{stat} \equiv \frac{N_{Sig} * \eta_{Sig}}{\sqrt{N_{Sig} * \eta_{Sig} + N_{BG} * \eta_{BG}}}$$

N: # of events occurring in 5 years

η: selection efficiency

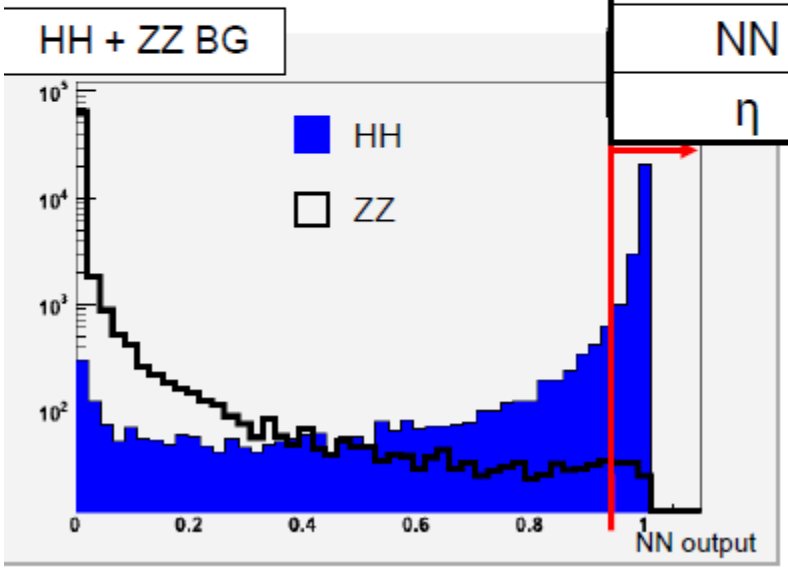
Sig: signal

BG: background

Analysis with CheatJetFinder --- ZZ BG

Cheated JetFinder:
100% correct parton assignment using generator information

	HH	ZZ
generate	$5.0*10^4$	$1.0*10^6$
NN	24191	85
η	0.484	**$8.5*10^{-5}$**

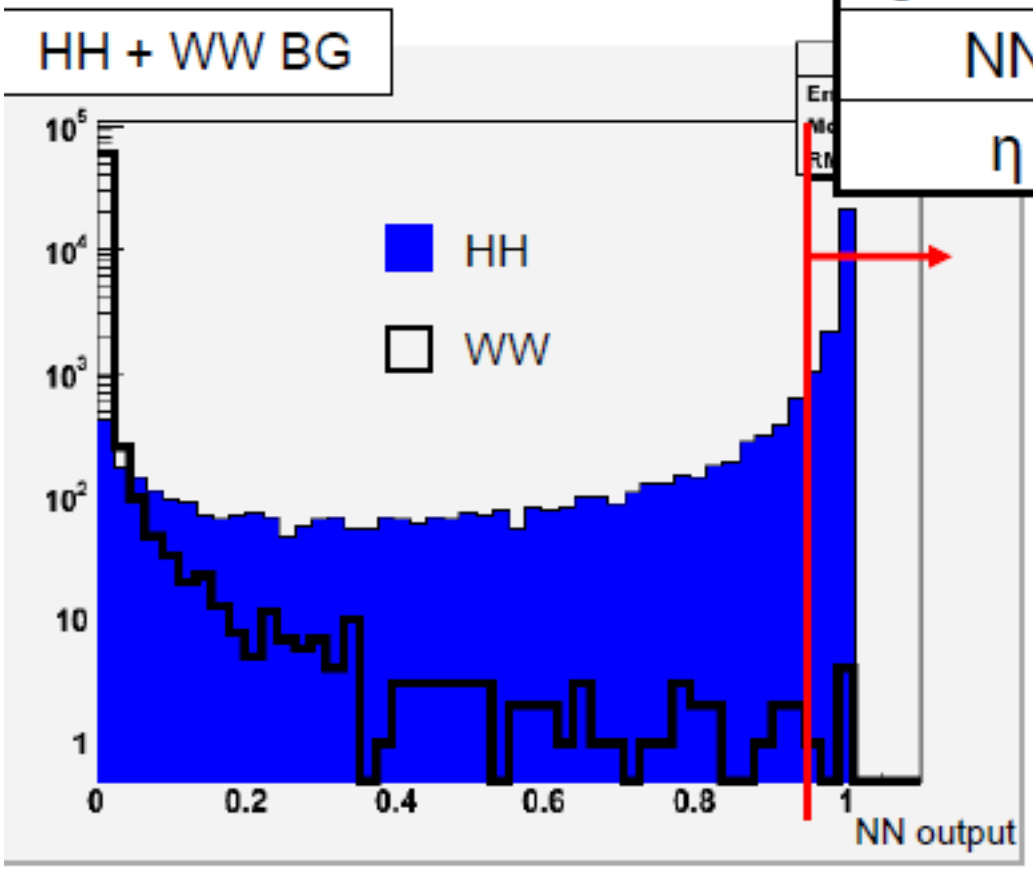


$S_{stat} = 5.9$

suppress ZZ background w/ improved cluctering

Analysis with CheatJetFinder --- WW BG

	HH	WW
generate	$5.0*10^4$	$7.5*10^7$
NN	24115	5
η	0.482	**$6.67*10^{-8}$**



$$S_{stat} = 5.9$$

good background suppresion for WW too

Summary

- We tried to see $\gamma\gamma$ -> HH in a photon collider based on TESLA optimistic parameters.
- gg CM energy of 270GeV is optimum for mh =120GeV
- backdournds
  - $\gamma\gamma$->WW has 10^6 times lager cross section
  - $\gamma\gamma$->ZZ has 10^3 times lager cross section
- It seems possible to suppress backgrounds with improved jet clustering technique.
  - statistical significance of 4.6 expected for WW and ZZ cut with perfect jet clustering
- more to do
  - optimize NN training
  - study jet clustering improvement (it is not just for HH analysis
  - $\gamma\gamma$->bbbb backgroud
    - we believe it is small for dangerous kinematical region
  - higher Higgs mass

A SNEAK PREVIEW OF "THE ILC/CLIC STRING HUNTER'S COMPANION"

Tomasz Taylor, Northeastern University, Boston

Based on work in progress with

Luis Anchordoqui, Wan-Zhe Feng, Haim Goldberg and Xing Huang

IWLC2010
Gamma-gamma session
19.X.2010

In string theory, elementary particles are quantized vibrations of fundamental strings. The zero modes are massless, the first harmonic have masses equal to the fundamental mass M, the second $\sqrt{2}\ M$, and in general:

$$M_N = \sqrt{N}M$$

These massive *REGGE* particles have higher spins, ranging from 0 to $N+1$ and come in SU(3)xSU(2)xU(1) representations copied from gauge bosons, quarks and leptons. For example, gluon's first Regge excitations are massive spin 0, 1 and 2 color octets. It is very unusual to have the standard model spectrum replicated, at approximately (up to loop corrections) the same mass level M, with higher spins, and then at each

$$\sqrt{N}M$$

If, as commonly believed, M is in the Planckian regime, we have nothing to say and this text is completely irrelevant.

However theoretically, M can be as low as we wish, of order of few TeVs, provided that Nature endowed us with large extra dimensions (say 1 mm). I wish that M were even lower, but Tevatron has already ruled out (not surprisingly) $M < 1\ TeV\ (now\ even\ 2.5\ TeV)$.

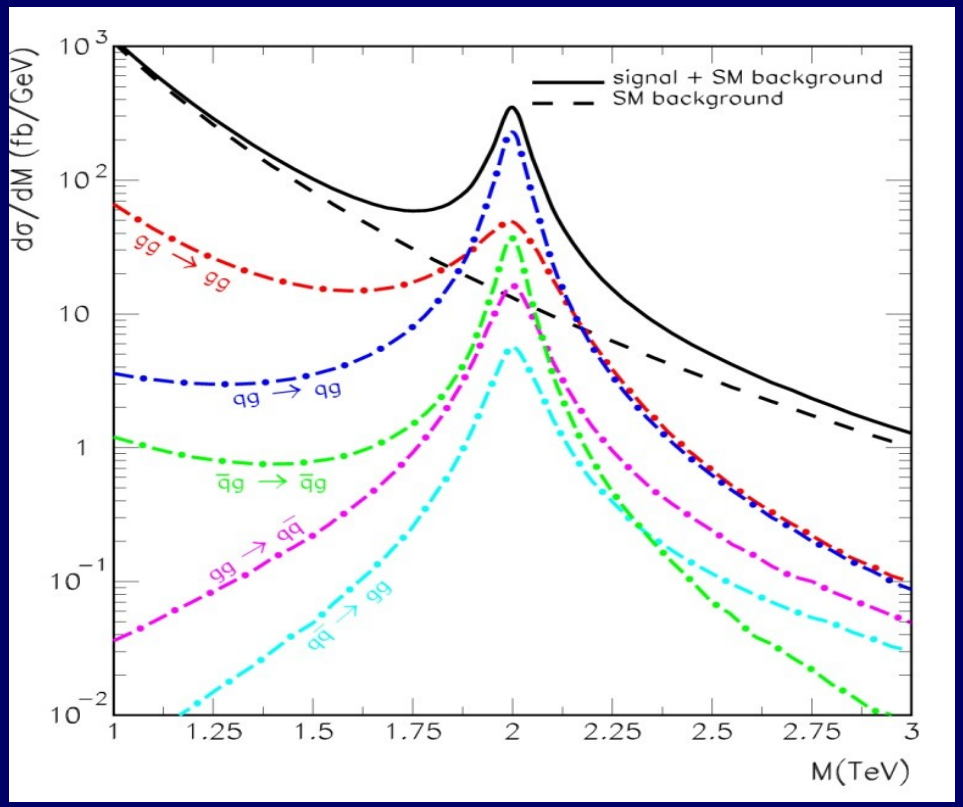
Such "low string mass" scenario seems far-fetched but it leads to some spectacular experimental consequences.

At this point, it is as plausible as supersymmetry, technicolor or your favorite beyond the standard model scenario.

LHC has the capacity of discovering strongly-interacting resonances with masses in practically all range up to $\left(\frac{\sqrt{s}}{2}\right)_{LHC}$,

in most obvious channels like

gluon+gluon → Regge resonance → 2 (or more) jets



The predicted widths $\Gamma \approx \alpha_s M$ are typical for "heavy gluons", even with higher spin.

Nevertheless, since it is unlikely the LHC will reach beyond the first string harmonics, people will ask us:
"how do you prove that it is a string Regge resonance and not the gluebot (??) predicted by Dr. X thirty years ago?"

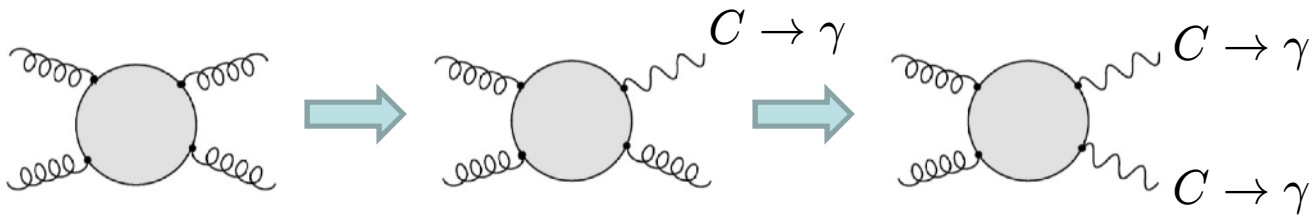
We will say:
"Wait till ILC/CLIC…"

Dijet mass distribution (assumed *M=2 TeV*) from L. Anchordoqui, H. Goldberg, D. Lust, S. Nawata, St. Stieberger, T.T., arXiv:0808.0497; The effects of $\sqrt{2M}$ resonances are not shown.

Additional Evidence: Photons as String Probes

$gg \to g\gamma \ , \ gg \to \gamma\gamma$

- Do not exist at tree level in the standard model
- But do exist at tree (i.e. disk) level in string theory and are enhanced by resonance contributions



Photons as String Probes
Phenomenology

- At collider, resonance formation and decay will populate the high $k_\perp$ region
- SM processes for $pp \to \gamma + jet$

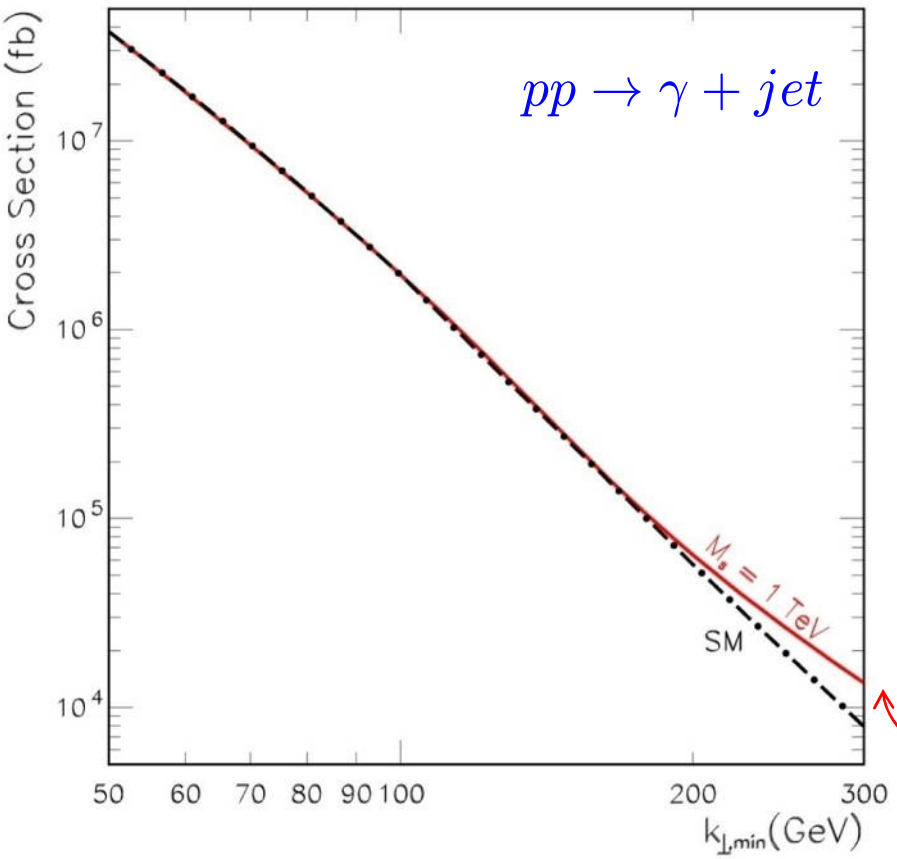
$$gq \to \gamma q, \quad g\bar{q} \to \gamma \bar{q}, \quad q\bar{q} \to \gamma g$$

lead to rapid $\sim k_\perp^{-5}$ falloff

- For a start, take as our signal the number N_{ev} of events above SM background for integrated cross section: (bump search later)

$$\sigma(pp \to \gamma + jet)|_{k_\perp(\gamma) > k_{\perp,\min}}$$

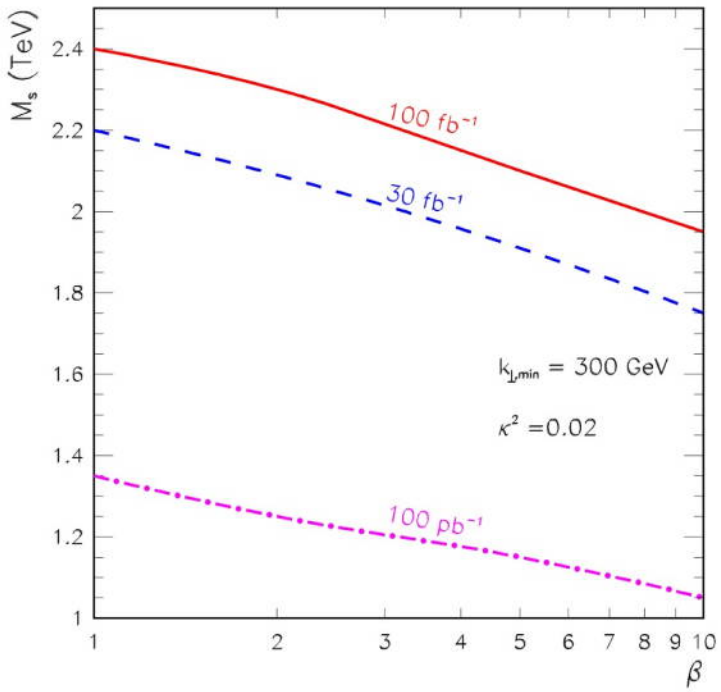
σ vs. $k_{\perp,\mathrm{min}}$



Nice signal but how many events?

$\sqrt{\text{SM background}} \approx 900$ for 100 fb^{-1} of data

Discovery reach at 5σ…



up to M ≈ 2.3 TeV

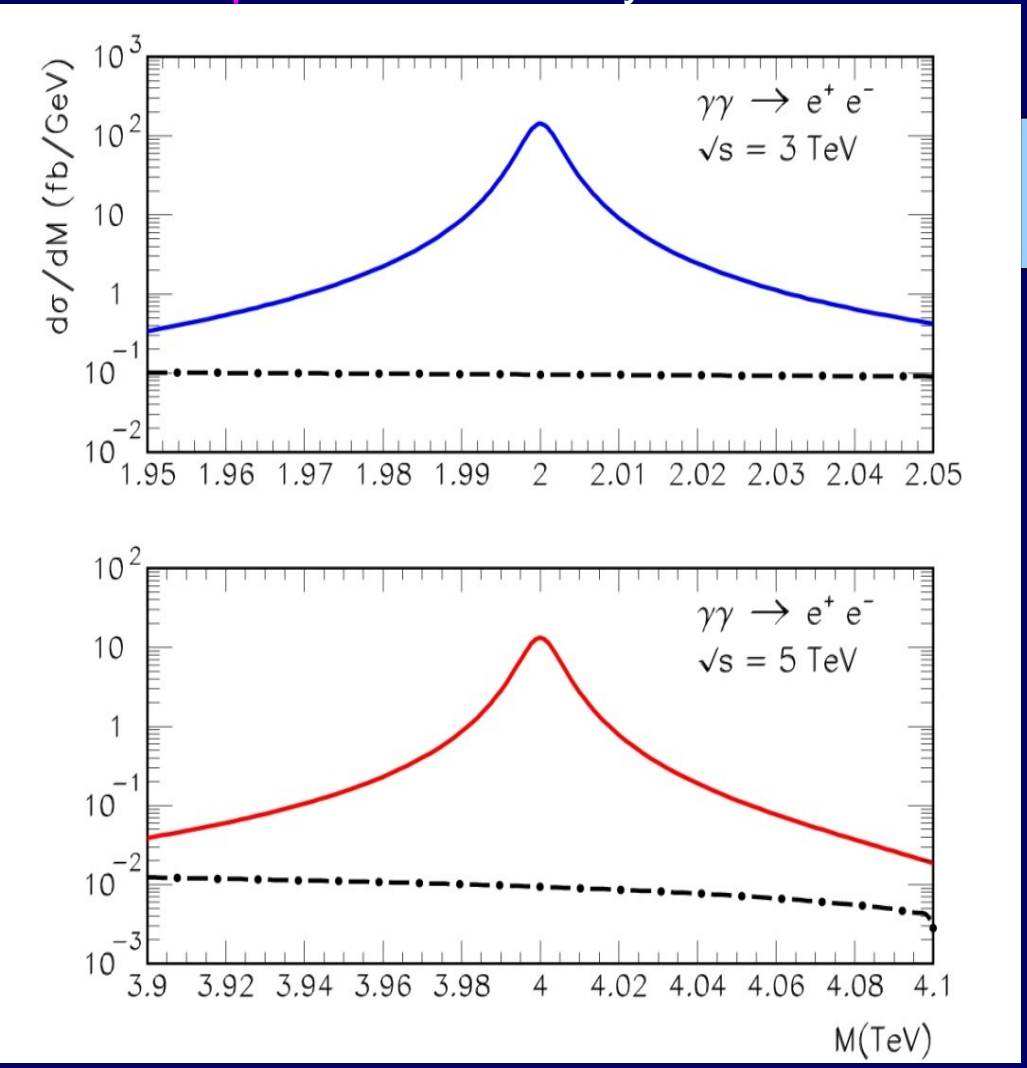
Major experimental background: misidentification with high $k_\perp$ π^0

[Gupta et al (CMS), 0705.2740]

$$\beta = \frac{\text{background due to misidentified } \pi^0 \text{ after isolation cuts}}{\text{QCD background from direct photon production}} + 1 \approx 2$$

e+e- collider sitting on a resonance would allow precise determination of the spin content of the first excited photon and Z (spin 0,1 and 2 with weights predicted by theory).

Photon-photon collider may be even more useful. For example: PLC



$\frac{d\sigma}{dM}$ (units of fb/GeV) vs. M (TeV)

plotted for the case of SM background (dashed line) and the (first resonance) string signal + background for e+e-

energy = 3 TeV (assume $M=2$ TeV)

= 5 TeV (assume $M=4$ TeV).

The next resonance would appear at $\sqrt{3}M$ because photons do not couple to $\sqrt{2}M$ resonances

(γ DFs from Jikia, Eboli et al [arXiv:hep-ph/9210277], Cheung [arXiv:hep-ph/9211262])

In addition, massive photons and Zs will be visible in $\gamma\gamma \rightarrow$ dijets and three jets.

Conclusion: Photons are excellent string probes.

Details to appear in “The ILC/CLIC String Hunter’s Companion”

Many thanks to Maria Krawczyk for introducing us to the ILC/CLIC project

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Opinions expressed are those of the authors and do not necessarily reflect the views of NSF.

Anomalous triple and quartic gauge couplings involving photons at the LHC

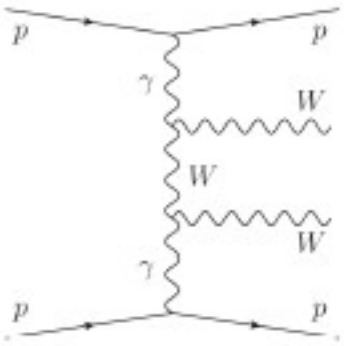
Oldřich Kepka

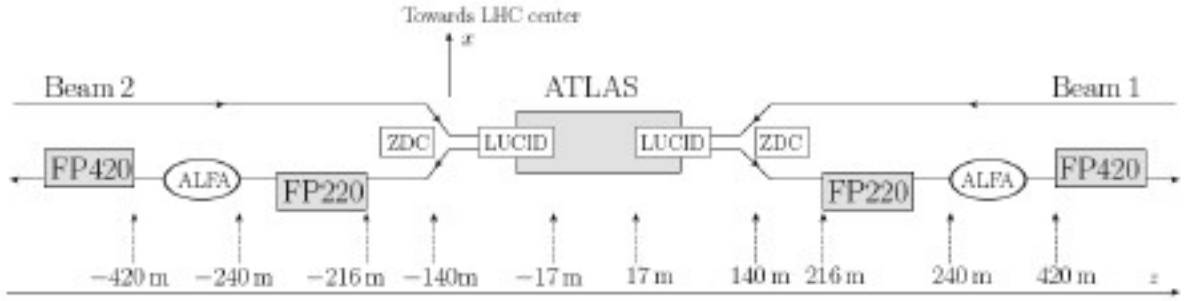
October 19, 2010, IWLC, Geneva

Institute of Physics, Academy of Sciences, Prague

E. Chapon, O. Kepka and C. Royon, Phys.Rev.D81:074003, 2010

W/Z pair production at the LHC and at ILC/CLIC - Oldřich Kepka

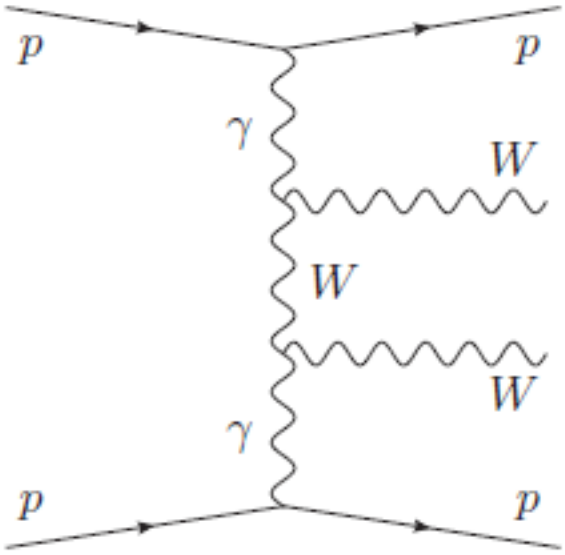




- Rich $\gamma\gamma$ physics at LHC
- Need to install forward proton detectors to tag final state intact protons (ATLAS Forward Physics project, same in CMS)

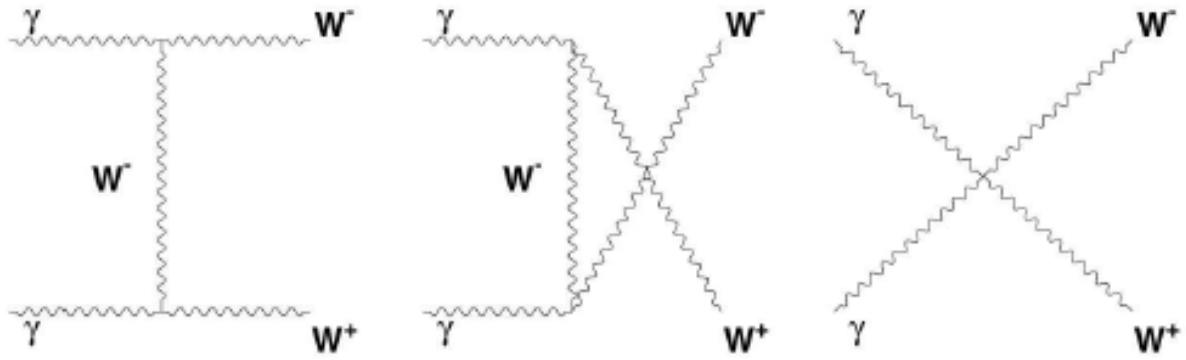
New physics at the LHC

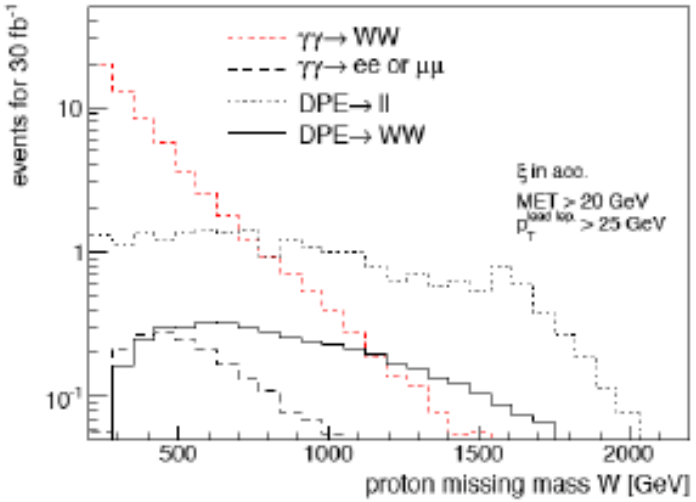
- using hadron accelerator as a photon collider
- exclusive QED process - induced by two photon
- same process possible at e^+e^- at the ILC, electron point like, photon beams intensive
- can study anomalous coupling of γ to W



- gaps in rapidity - regions devoid of particles, exchange of a photon
- only WW system produced and nothing else
- fractional momentum loss of the proton $\xi_i = (|\mathbf{p}_{bi}| - |\mathbf{p}_i|)/|\mathbf{p}_{bi}|$
- ξ measured with forward detectors installed far away from IP
- mass measured with excellent resolution ($\sim$ GeV)
- $M^2 \sim s\xi_1\xi_2$

SM Observation of W γ-induced production at the LHC

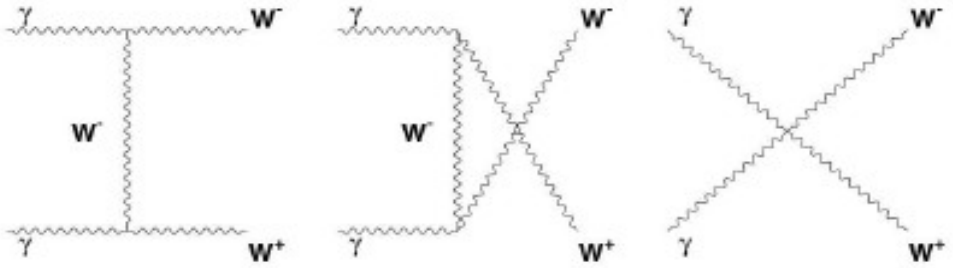




- discovery with $\mathcal{L}$=5 fb^{-1} (8 events, 1 background)
- big advantage, missing mass reconstructed with AFP: $W = \sqrt{s\xi_1\xi_2}$

cut / process $30\,\text{fb}^{-1}$	$\gamma\gamma \to ee$ $(\mu\mu)$	$\gamma\gamma \to \tau\tau$	DPE$\to ll$	DPE$\to WW$	$\gamma\gamma \to WW$
$p_T > 10$ GeV	24896	177	17931	8.8	95
after cuts	0	0	1.0	0.67	51

Quartic anomalous couplings



$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

Anomalous couplings a_0^W, a_C^W, a_0^Z, a_C^Z equal to zero in SM

Sensitivities at high luminosity

Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 95% CL
a_0^W/Λ^2	[-0.020, 0.020]	2.6×10^{-6} (1.4×10^{-6})
a_C^W/Λ^2	[-0.052, 0.037]	9.4×10^{-6} (5.2×10^{-6})
a_0^Z/Λ^2	[-0.007, 0.023]	6.4×10^{-6} (2.5×10^{-6})
a_C^Z/Λ^2	[-0.029, 0.029]	24×10^{-6} (9.2×10^{-6})

- improvement of sensitivities up to 4 orders of magnitude with 30 fb^{-1}

Study in progress for CLIC/ILC as a $\gamma\gamma$ collider

A need of PLC?