Hidden sector particle production at the ILC

based on arXiv: hep-ex/0802.3943
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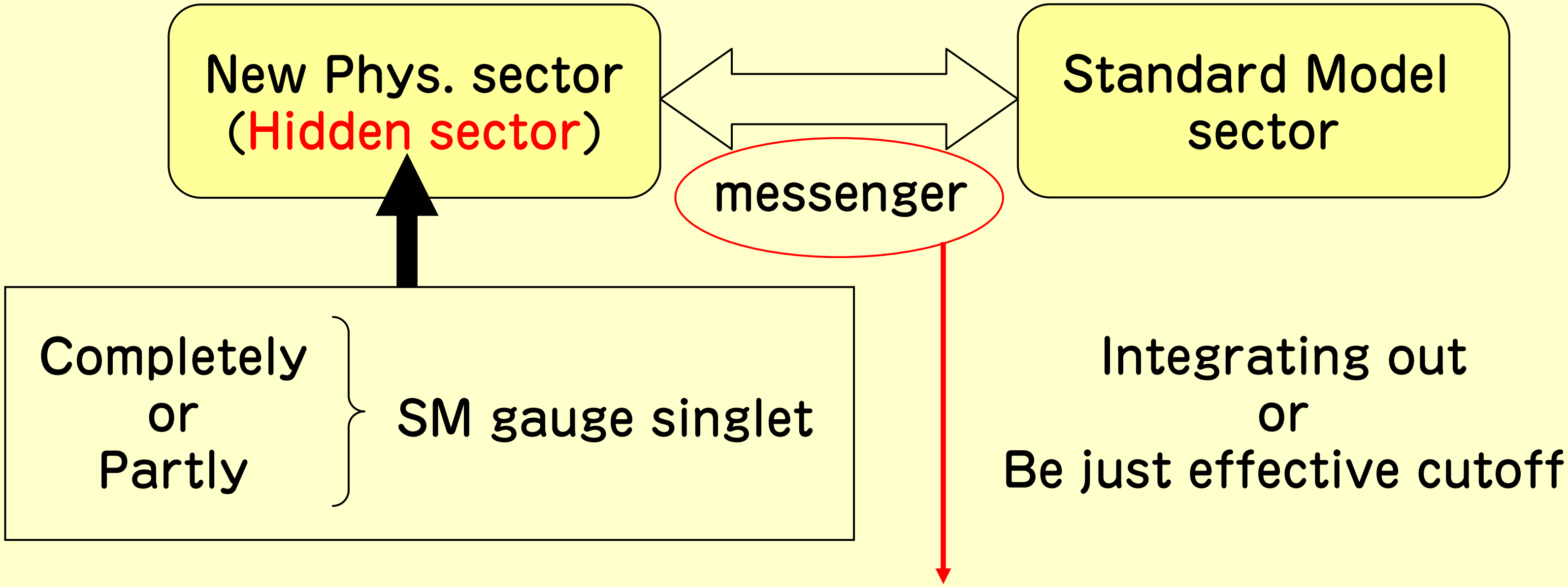
1.Introduction

New Physics (NP) models



Effective Lagrangian: $\mathcal{L} = \frac{c_n}{\Lambda^n} \mathcal{O}_{\rm NP} \mathcal{O}_{\rm SM}$

Candidate of New Particles: scalar, fermion, vector and tensor

We consider → scalar

$$\mathcal{L} \sim \frac{c}{\Lambda^{d_{SM}-3}} X \mathcal{O}_{\rm SM}$$

X: SM singlet scalar

$\Lambda \sim$ 1TeV

Above higher dim. couplings become strong!
→ It is Possible to product the hidden scalar at the ILC

But How we can get $\Lambda \sim$ 1TeV ?

Ex.) Can be realized by brane world scenario

Analysis of the X → Can apply to many models

Ex.) Singlet in NMSSM, Radion, Polonyi,…

These NP models have some impact on Higgs pheno. by the X.

2.Possible operators and our studies

With gauge boson:

Derivative couplings

$\frac{X}{\Lambda} G^a_{\mu\nu} G^{a\mu\nu}$ $\quad \mathcal{L}_{\rm SM} \sim \frac{\alpha_s}{4\pi v} h G^a_{\mu\nu} G^{a\mu\nu}$

Like Higgs →

$\frac{X}{\Lambda} F_{\mu\nu} F^{\mu\nu}$ $\quad \mathcal{L}_{\rm SM} \sim \frac{\alpha}{4\pi v} h F_{\mu\nu} F^{\mu\nu}$

$\frac{X}{\Lambda} Z_{\mu\nu} F^{\mu\nu}$ $\quad \mathcal{L}_{\rm SM} \sim \frac{eg}{16\pi^2 v} h Z_{\mu\nu} F^{\mu\nu}$

Not like Higgs →

Derivative

$\frac{X}{\Lambda} W^+_{\mu\nu} W^{-\mu\nu}$

$\frac{X}{\Lambda} Z_{\mu\nu} Z^{\mu\nu}$

Non derivative

$\mathcal{L}_{\rm SM} \sim 2\frac{m_W^2}{v} h W^+_\mu W^{-\mu}$

$\mathcal{L}_{\rm SM} \sim \frac{m_Z^2}{v} h Z_\mu Z^\mu$

With Higgs boson: $mXH^\dagger H$ $\quad \frac{X}{\Lambda}(H^\dagger H)^2$: Mixing with Higgs boson

With SM fermion: $\frac{X}{\Lambda}\overline{\Psi}\gamma^\mu\partial_\mu\Psi \to \frac{X}{\Lambda} m_f \overline{\Psi}\Psi$

→ Not important for light fermions

Our studies

Concentrate the X-gauge-gauge couplings

1) X-glue-glue, X-gamma-gamma, X-gamma-Z
2) X-W-W, X-Z-Z

Important point on this study

The X behaves like Higgs in its production process

⇓ Interesting issue

How to distinguish X from Higgs at ILC ?

with same masses

⇑

We have two methods to distinguish them

1) Big enhancement of the branching ratios

In the SM:

$$\mathcal{L}_{\mathsf{SM}} \sim \frac{\alpha_s}{4\pi v} h G^a_{\mu\nu} G^{a\mu\nu}$$

$$\mathcal{L}_{\mathsf{SM}} \sim \frac{\alpha}{4\pi v} h F_{\mu\nu} F^{\mu\nu}$$

No tree level couplings
Loop suppressed

For X case

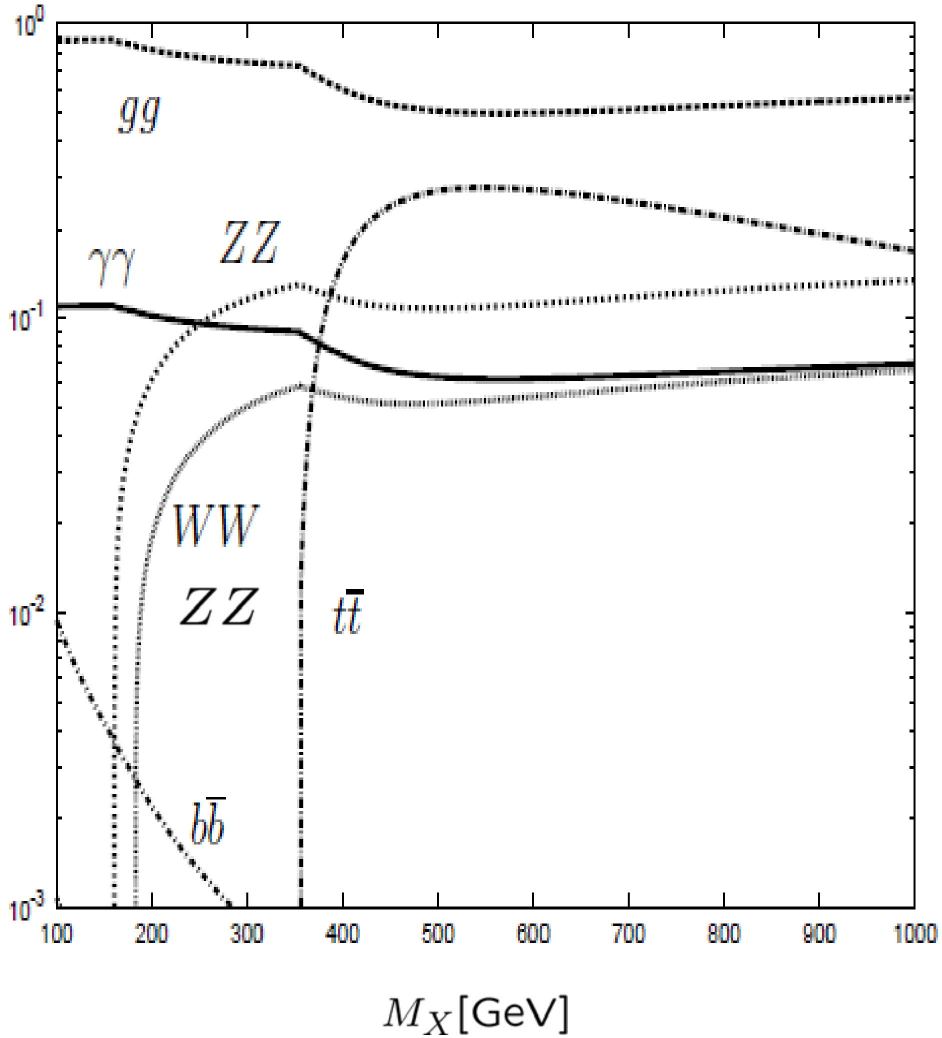
$$\frac{X}{\Lambda} G^a_{\mu\nu} G^{a\mu\nu}$$

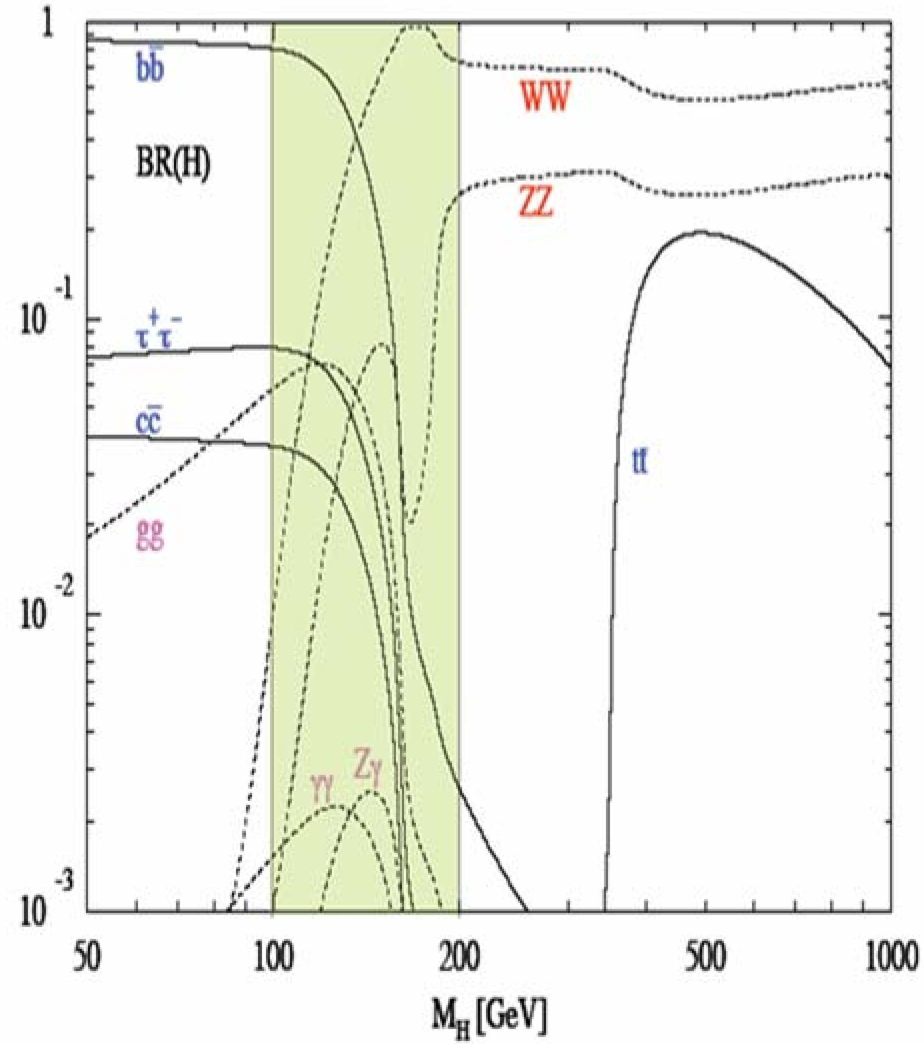
$$\frac{X}{\Lambda} F_{\mu\nu} F^{\mu\nu}$$

Higher dimensional OPs., but tree level

$$\frac{\alpha_s}{4\pi v} \sim \frac{1}{10\ \mathrm{TeV}}$$ If $\Lambda \sim 10\mathrm{TeV}$

Branching ratio is very much different





Result for universal order one couplings of higher dim. ops.

(In this situation, Zγ mode disappear)

2) Difference of coupling manner

In the SM

Higgs mechanism

$$\mathcal{L}_{\rm SM} \sim 2\frac{m_W^2}{v} h W_\mu^+ W^{-\mu}$$

$$\mathcal{L}_{\rm SM} \sim \frac{m_Z^2}{v} h Z_\mu Z^\mu$$

Mostly couples with longitudinal mode

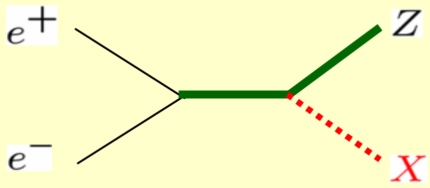
For X case

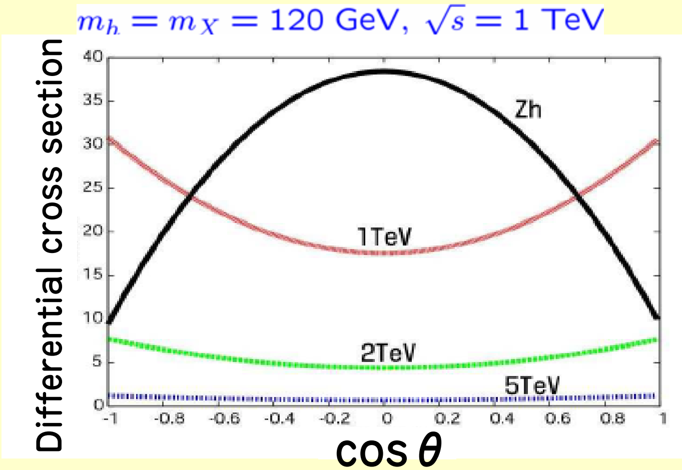
$$\frac{X}{\Lambda} W_{\mu\nu}^+ W^{-\mu\nu}$$

$$\frac{X}{\Lambda} Z_{\mu\nu} Z^{\mu\nu}$$

Mostly couples to transverse mode

X or Higgs production at ILC





$\Lambda \sim$ 1TeV → X strongly couples to gluons and photons

→ Tevatron bound is severe

Higgs search through two photon decay mode

Merrana & Wells, PRD 63 015006 (2000)

$$Rgg = \frac{\sigma_X \times Br(X \to \gamma\gamma)}{\sigma_{\mathrm{H}} \times Br(H \to \gamma\gamma)}$$

Tevatron Run Ⅱ

$\mathcal{L} \sim 1\ \mathrm{fb}^{-1}$ $R_{gg} < 50$

Small couplings with gauge bosons

→ <u>Become consistent with Tevatron bound</u>

However

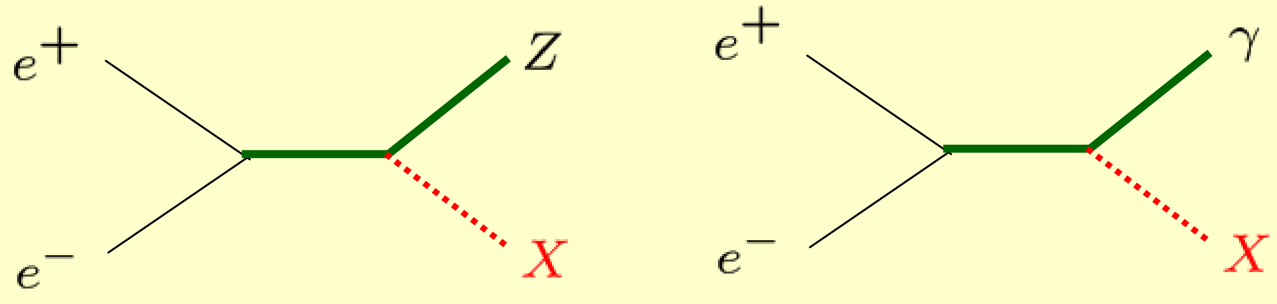
Small X-Z-Z coupling → The X cannot be detected at ILC

In this time, we concentrate a gluophobic scenario

(Can be realized brane world scenario)

3.Monte-Carlo Simulations

We study Associate X production @ ILC $\sqrt{s} = 500$ GeV



$X \to \gamma\gamma$

We used fast Monte-Carlo(QuickSim)

Interesting things to see and to compare to Higgs boson

Angular distribution of Z, photon

Polarization of Z,

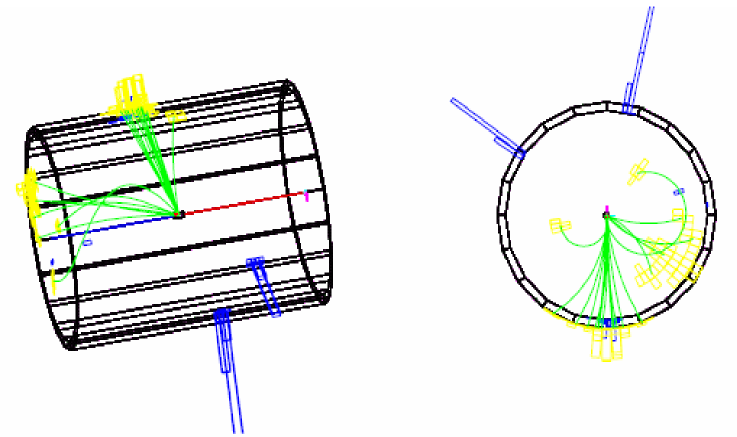
Two photons in the final state,

Less bb in the final state, etc

Our analysis is applicable to

anomalous Higgs Branching Ratio etc.

$e^+e^- \to ZX;\ X \to \gamma\gamma$



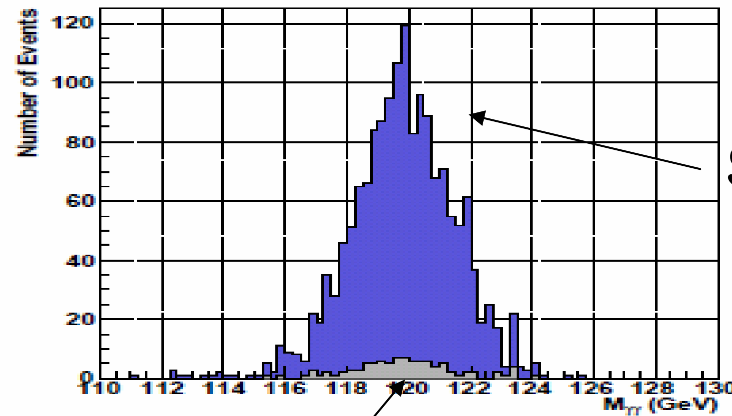
$\sigma_h \sim 57$ fb $\quad \sigma_X \sim 21$ fb

$m_X = m_h = 120$ GeV

$Br(X \to \gamma\gamma) = 1$

$Br(h \to \gamma\gamma) = 0.002$

Invariant mass dist. from 2γ



Signal

Background from SM Higgs

This mode shows a clear peak at m_X

Can we distinguish the X or Higgs?

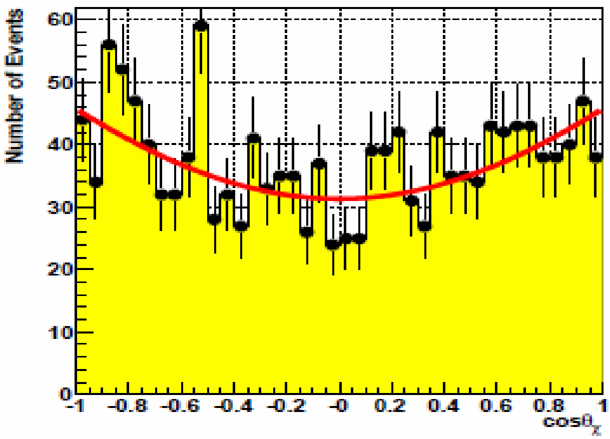
But...there is different model which give a similar result

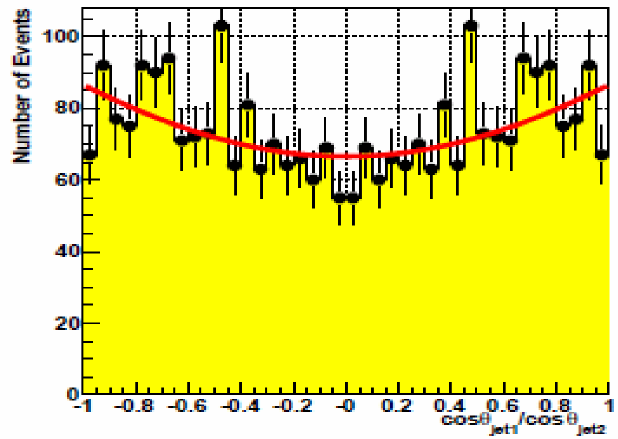
In NMSSM, if pseudo-scalar A is almost massless,

A decays to two photons: $e^+e^- \to ZH\ ;\ H \to AA \to \gamma\gamma\gamma\gamma$

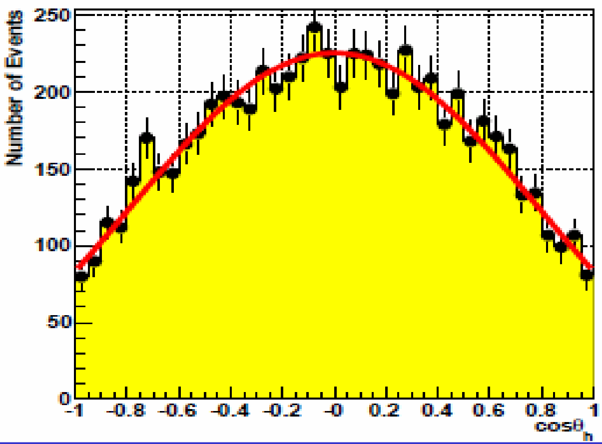
Since the pseudo-scalar is very light, two photons produced in its decay are almost collinear and will be detected as a single photon.

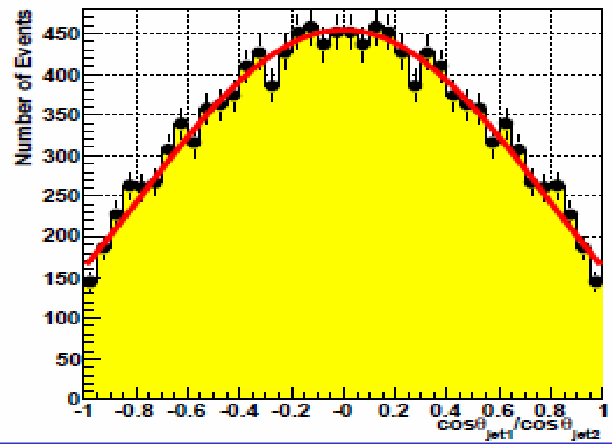
However angular distributions are quite different!





X production





Higgs production

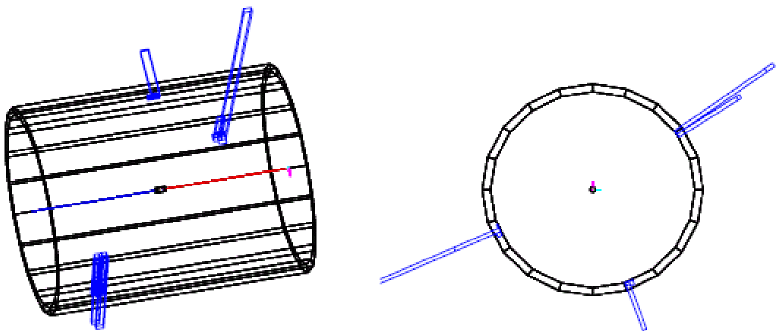
production angle of scalar

Reconstructed jets from Z

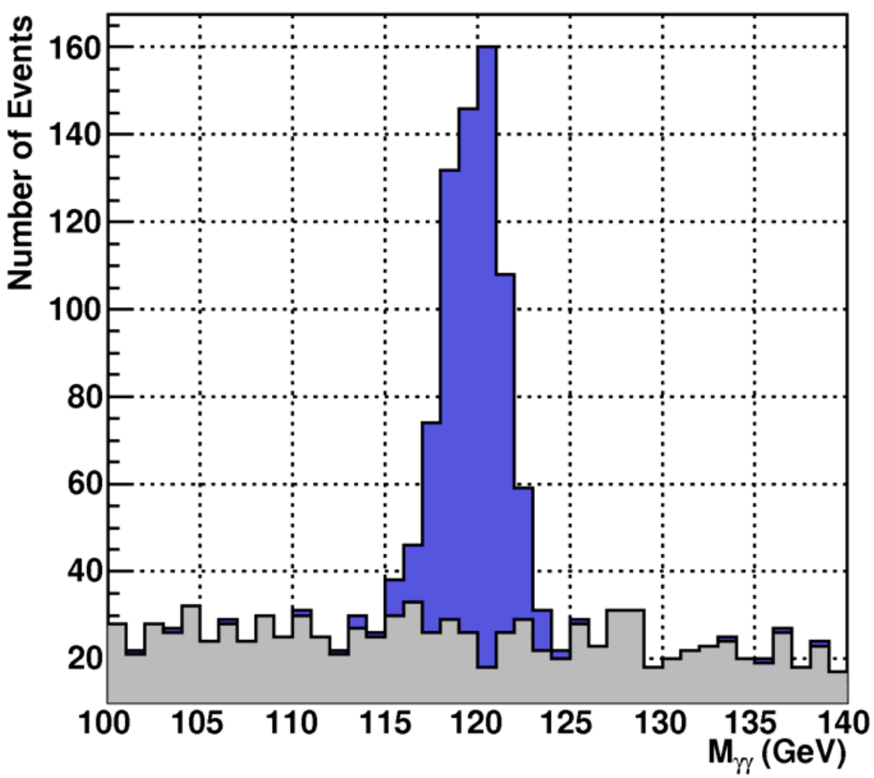
Cut	$Z\chi; \chi \to \gamma\gamma$	$Zh; h \to \gamma\gamma$	$Zh; h \to A^0 A^0$
No Cut	2187 (1.0000)	142 (1.000)	7087 (1.0000)
$N_{particles} \geq 4$	1738 (0.7947)	106 (0.747)	5692 (0.8032)
$N_{gammas} \geq 2$	1521 (0.8751)	96 (0.906)	4865 (0.8547)
Cut on $M_{\gamma\gamma}$	1499 (0.9855)	95 (0.990)	4828 (0.9924)
$N_{jets} = 2$ for Ycut $= 0.004$	1498 (0.9993)	95 (1.000)	4825 (0.9994)
Total Efficiency	0.6850 ± 0.0099	0.669 ± 0.040	0.6808 ± 0.0055

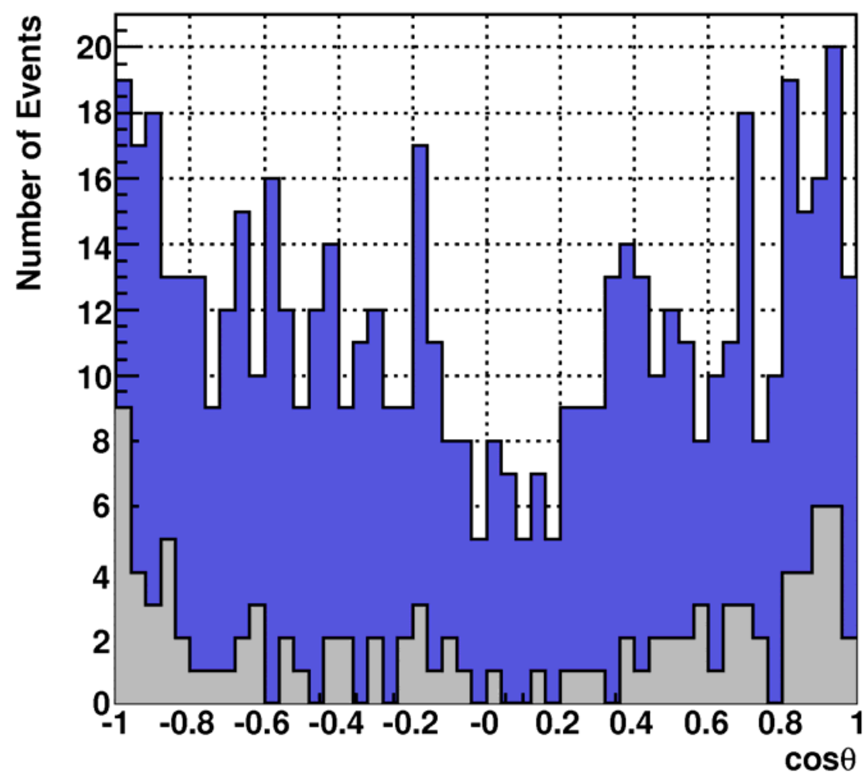
We can distinguish
the X from Higgs!

$e^+e^- \to \gamma X;\ X \to \gamma\gamma$ $\sigma_X \sim 52.5$ fb



Cut	Signal	Background
No Cut	600 (1.0000)	100000 (1.0000)
$N_{gammas} = 3$	575 (0.9583)	3746 (0.0375)
$E_{gamma} > 1$ GeV	575 (1.0000)	3730 (0.9959)
$\lvert\cos(\theta_j)\rvert \leq 0.999$	575 (1.0000)	3728 (0.9992)
$\lvert M_{\gamma\gamma} - m_\chi\rvert \leq 25$ GeV	573 (0.9965)	1332 (0.3573)
$\lvert\cos(\theta_\chi)\rvert$ and $\lvert\cos(\theta_a)\rvert \leq 0.99$	572 (0.9983)	1269 (0.9529)
Total Efficiency	0.9533 ± 0.0086	0.0127 ± 0.0001





4.Summary

We have investigated hidden sector particle production.

- Low cutoff scale → Can product the particle at the ILC
- Gluophobic scenario → Consistent with Tevatron bound
- Monte-Carlo sim. → Can distinguish the X from Higgs

Future work

We will investigate in a non gluophobic scenario

↓

- $X \to gg$ mode
- $X \to Z\gamma$ mode

These modes are interesting and important

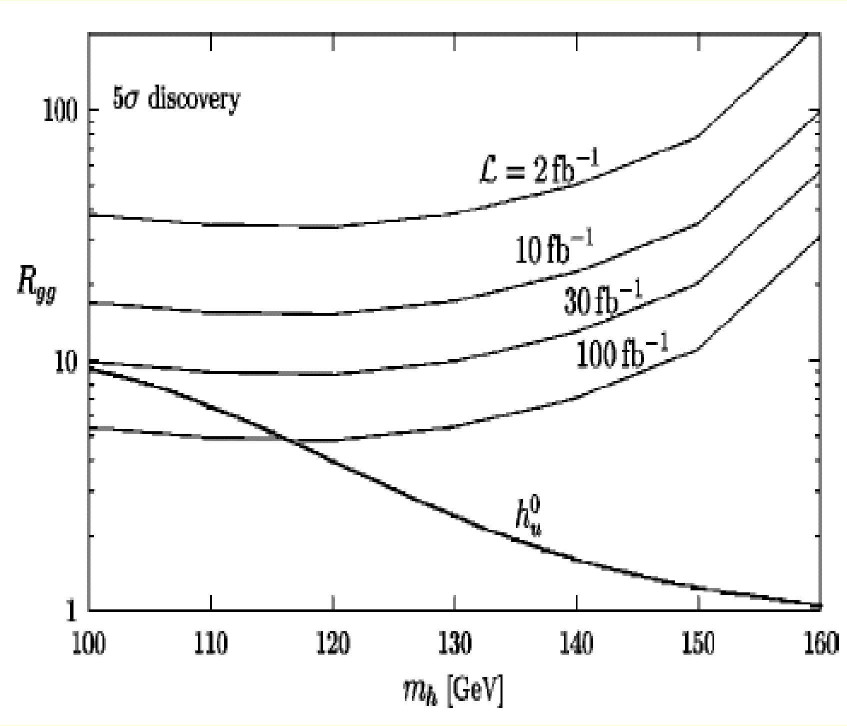
Buckup

Λ～1TeV → X strongly couples to gluons and photons

Strong constraint from Tevatron

Higgs search through two photon decay mode

Merrana & Wells, PRD 63 015006 (2000)



$$Rgg = \frac{\sigma_X \times Br(X \to \gamma\gamma)}{\sigma_{\mathrm{H}} \times Br(H \to \gamma\gamma)}$$

Tevatron Run Ⅱ

$\mathcal{L} \sim 1\ \mathrm{fb}^{-1}$ $R_{gg} < 50$

For SM Higgs:

$m_h = 120$ GeV

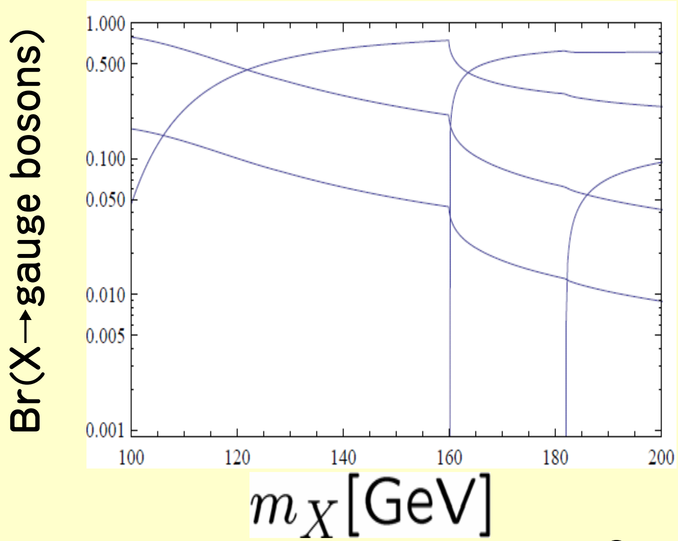
$\sigma_{\mathrm{H}} \sim 1$ pb

$Br(h \to \gamma\gamma) \sim 2 \times 10^{-3}$

Example of parameter set consistent with Tevatron bound

$$c_{gg} = 0.1,\ c_{\gamma\gamma} = 0.13,\ c_{ZZ} = 1,\ c_{Z\gamma} = 0.68$$

$$\Lambda = 1.56 \text{ TeV} \quad \sigma(e^+e^- \to ZX) = 21 \text{ fb}$$



For $m_X = 120$ GeV

gg	48%
$Z\gamma$	42%
$\gamma\gamma$	10%

→ Be small !

Br(X→Zγ) is very large

- Our guess → ~~Large SM BG → Can't detect~~
- Rough study → Not enough SM BG

If $C_{\gamma\gamma}$,C_{ZZ}∼0.1 → Disappear Zγ mode
But small X-Z-Z coupling
} Incompatible !

We concentrate a gluophobic scenario on this time
(Ex. Realized on brane world scenario)