SDA_02:
Electroweak Radiative Corrections for Higgs Studies at LHC and ILC(e^-e^- option)

Y. Kurihara
(KEK)

TYL/FKPPL Joint Workshop
04/June/2013 @ Seoul

Introduction

- Member List

FJPPL (TYL) application 2013-2014

Fiscal year april 1st 2013 – March 31st 2014

ID[1]:	Title:Electroweak Radiative Corrections for Higgs studies in LHC and future $e^- e^-$ collider					
	French Group			Japanese Group		
	Name	Title	Lab./Organis.[2]	Name	Title	Lab/Organis.[3]
Leader	Denis Perret-Gallix	Dr.	LAPP/IN2P3	Yoshimasa Kurihara	Dr.	KEK
				Junpei Fujimoto	Dr.	KEK
Members				P. H. Khiem	Mr.	KEK/Sokendai
				Kiyoshi Kato	Prof.	Kogakuin Univ.

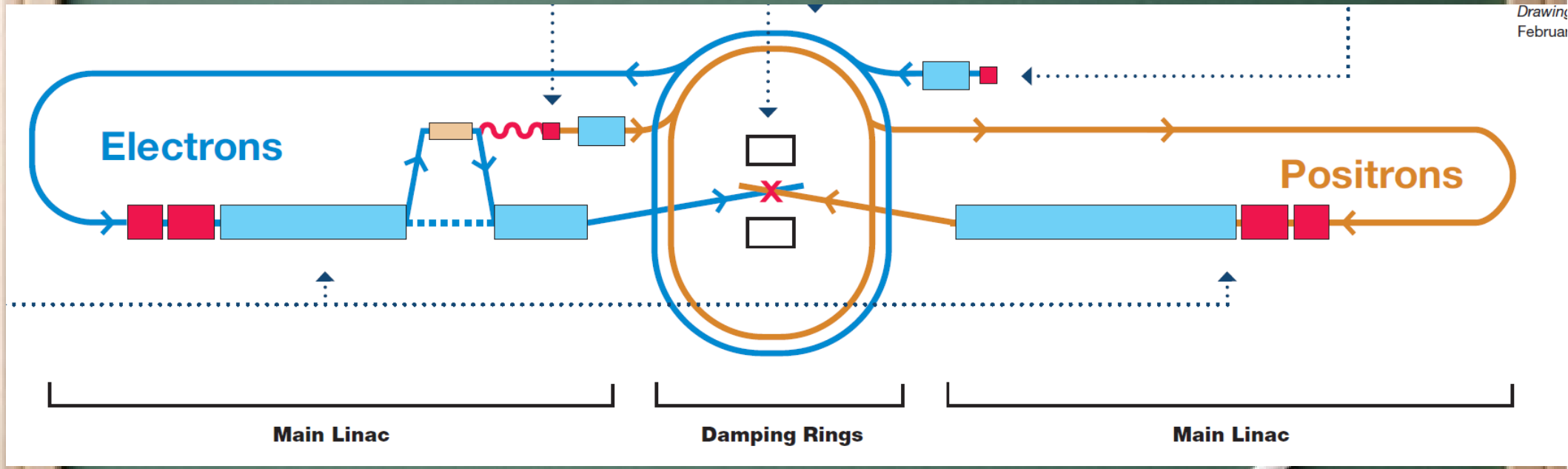
Introduction Electron-electron Collision in ILC

Introduction

- An e^-e^- option in ILC?
  - Higgs Studies are possible by the e^-e^- ILC.
  - Positron source is more difficult and more expensive than the electron source.
  - At a commissioning period of ILC, do we have to wait a e^+ beam??
  - An e^-e^- option must be considered seriously.

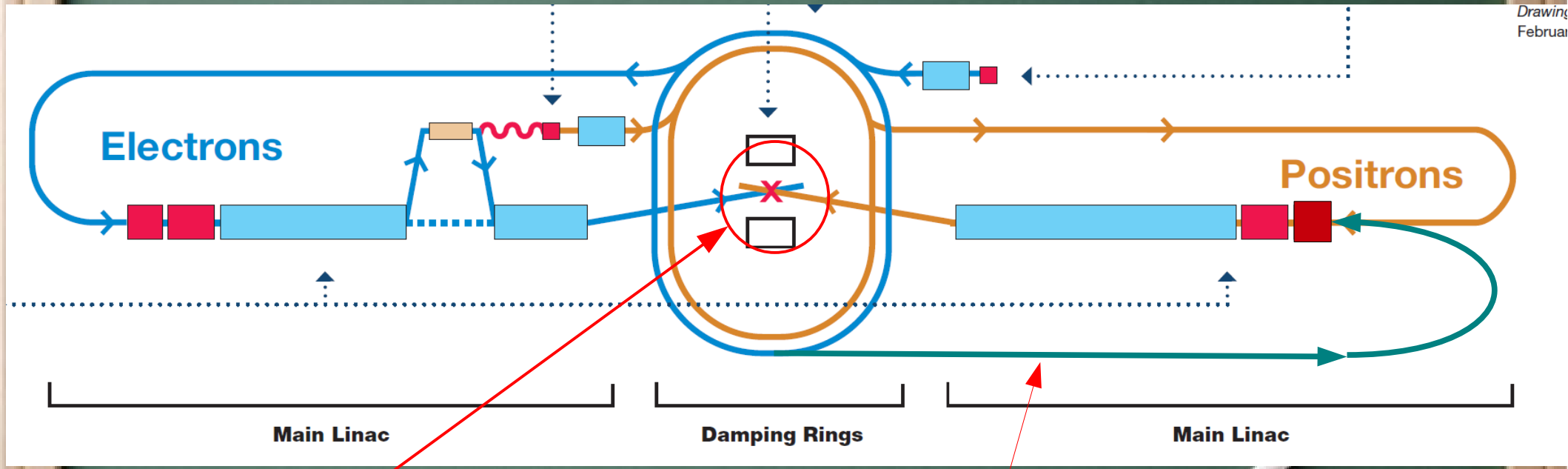
Introduction

- An e^-e^- option in ILC



Introduction

- An e^-e^- option in ILC

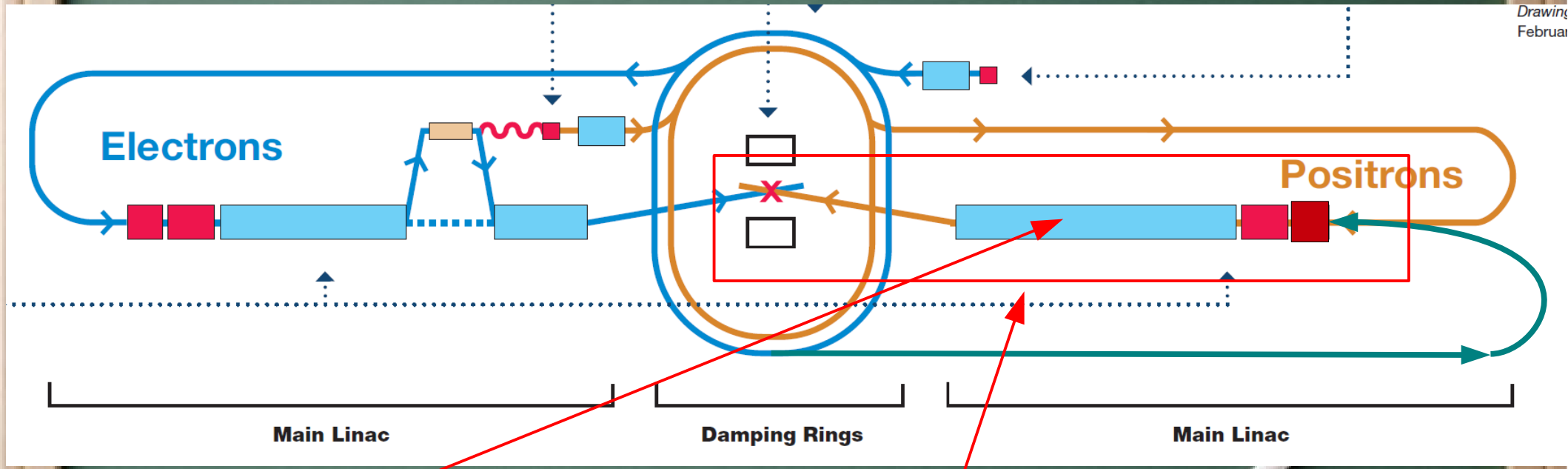


Special Extraction Line

Final focus system (crossing angle) is the same as the e^+e^- collider
Detector can be common to the e^+e^- collider

Introduction

- An e^-e^- option in ILC

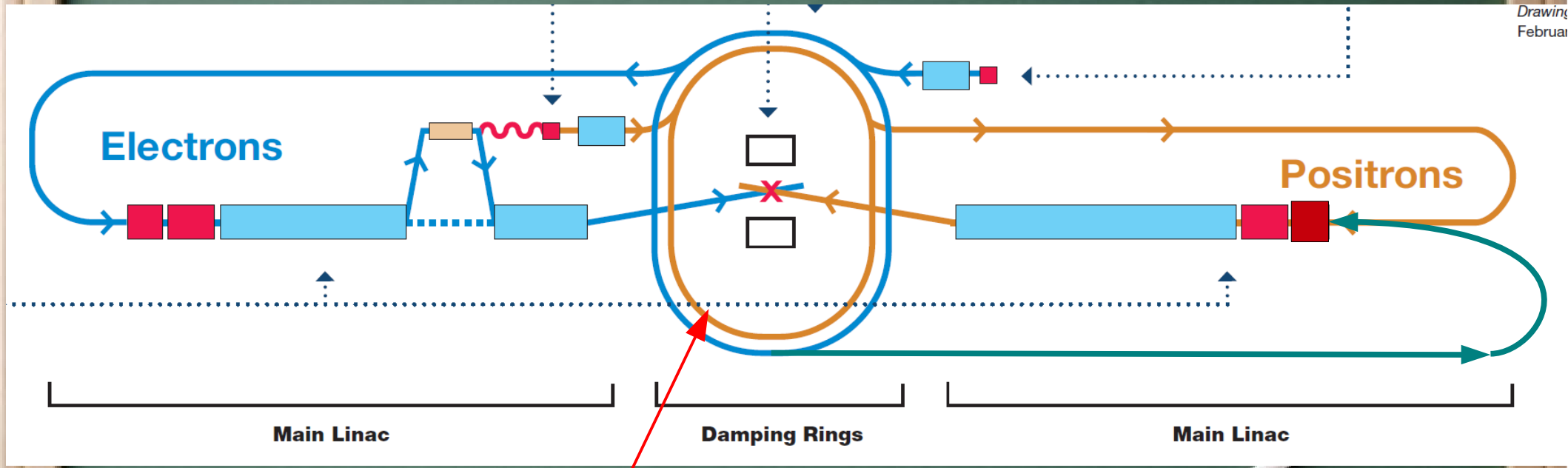


Acceleration Phase Change

Magnet Polarity Change

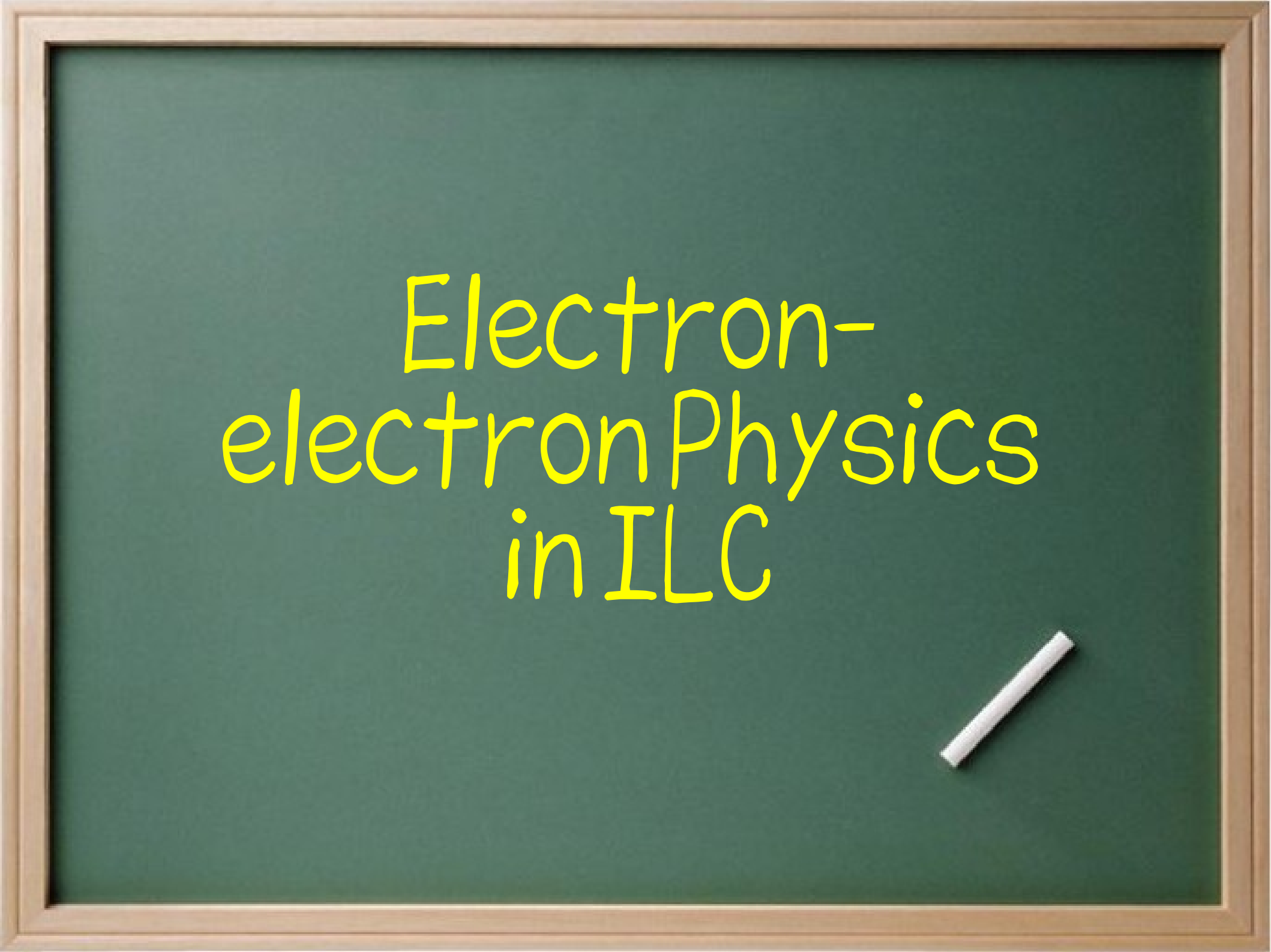
Introduction

- An e^-e^- option in ILC



Expensive positron dumping ring is not necessary

Earlier start of experiment may be possible!


Electron-
electron Physics
in ILC

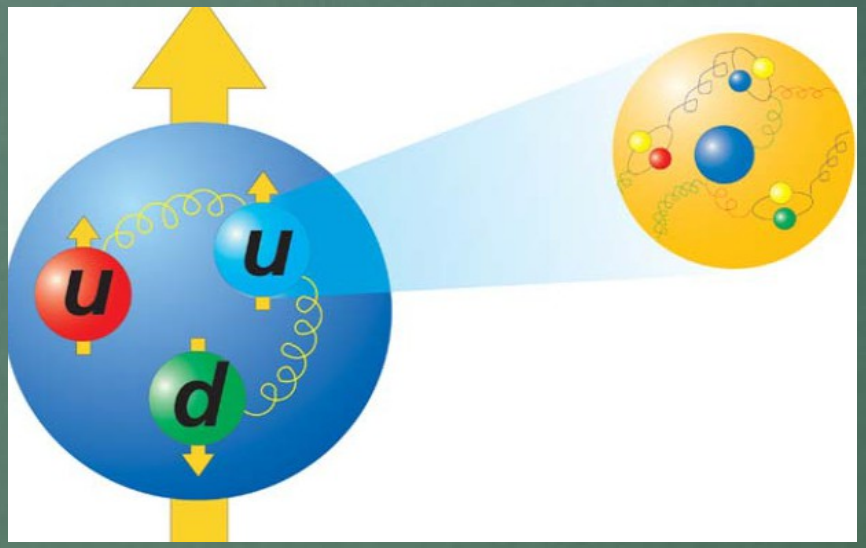
e^-e^- Physics

- What kinds of physics can be performed?
  - No e^-e^- annihilation of course.

e^-e^- Physics

- What kinds of physics can be performed?
  - No e^-e^- annihilation of course.

LHC: Proton-Proton Collider
Proton beam = {quark, anti-quark, gluon}-beams



http://www.interactions.org

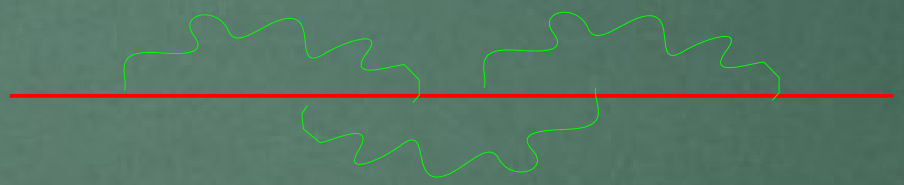
e^-e^- Physics

- What kinds of physics can be performed?
  - No e^-e^- annihilation of course.

ILC: e^-e^- collider option

Electron beam = {electron, photon, Z-boson}-beams

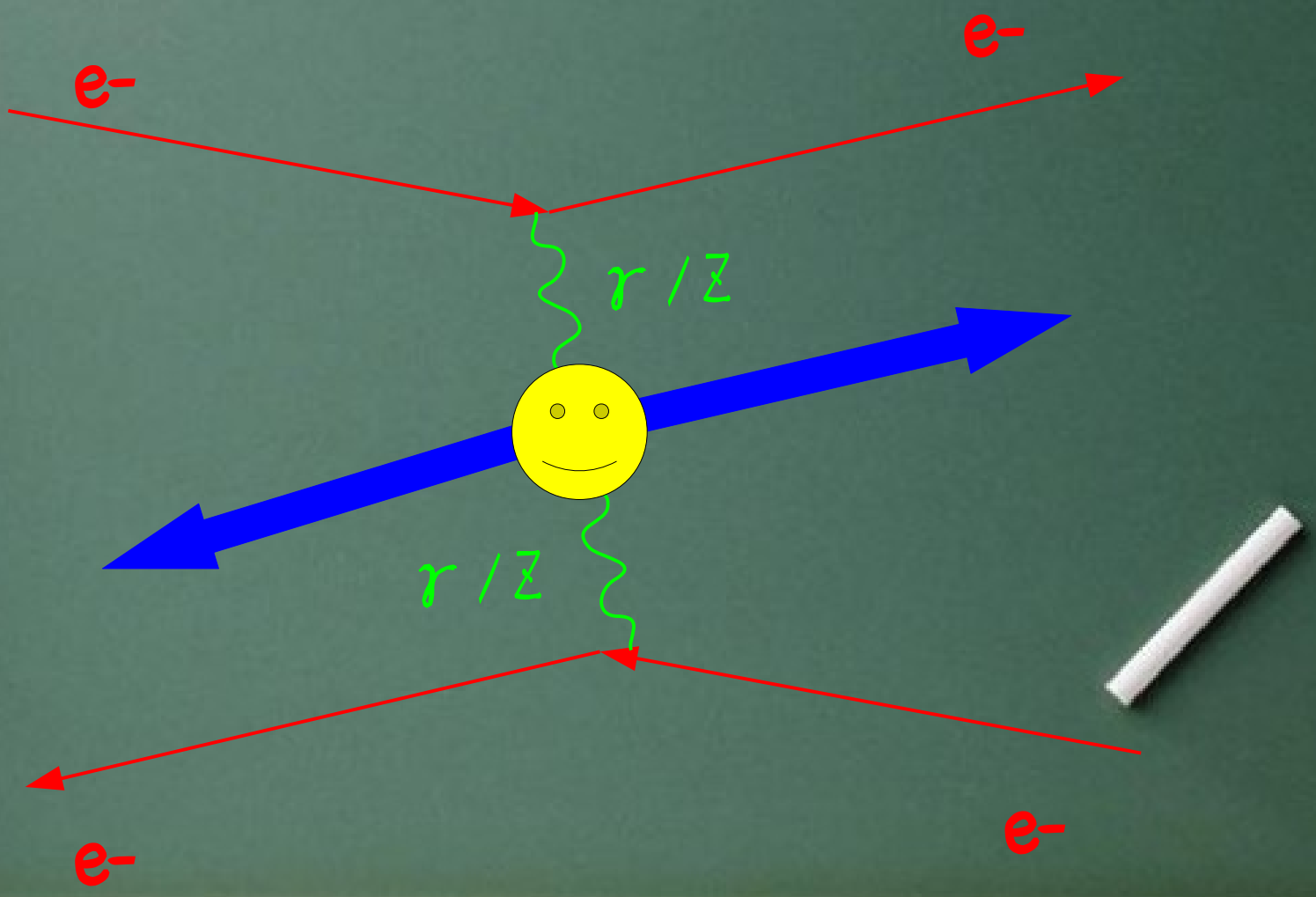
e^-e^- Collider → e^--photon, e^--Z, photon-photon
Z-Z, ⋯, colliders



Photons/Zs

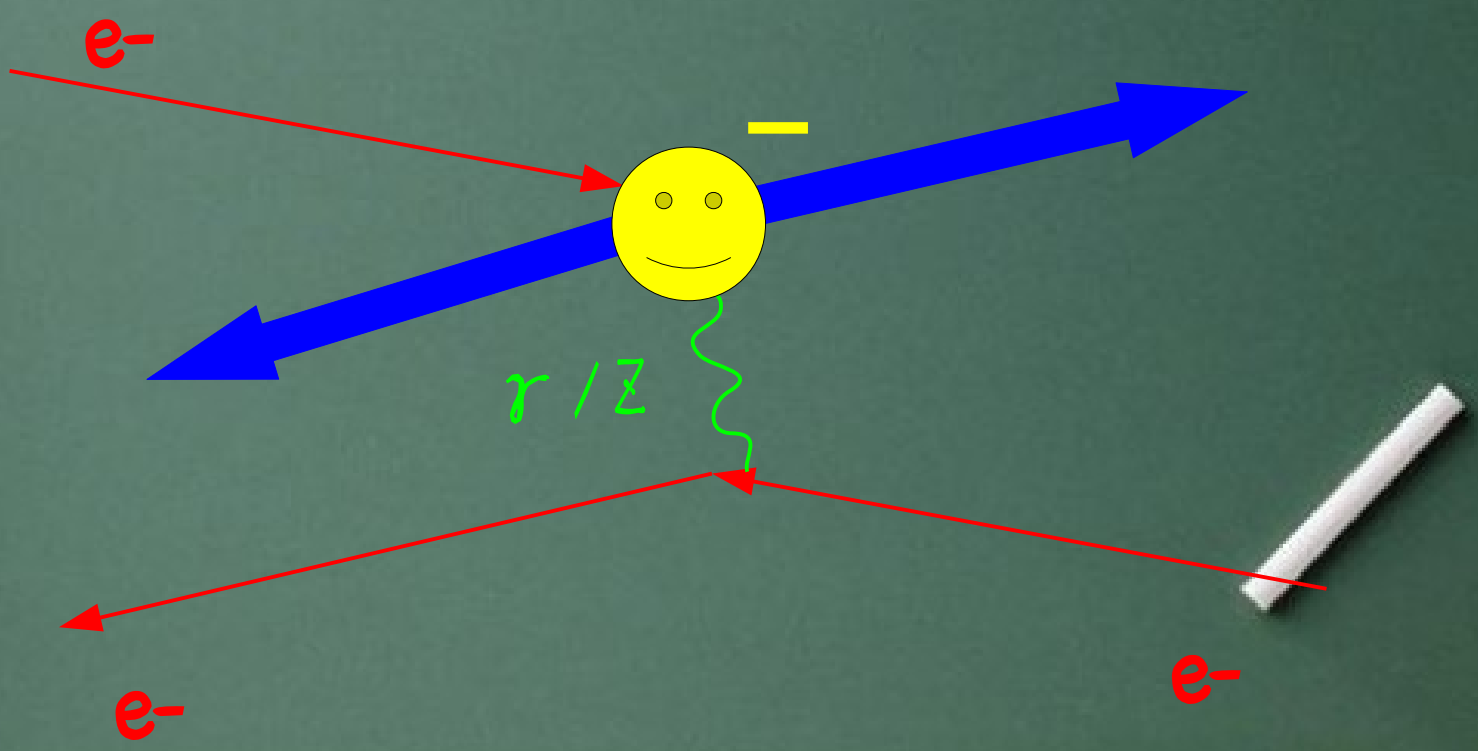
e^-e^- Physics

- What kinds of physics can be performed?



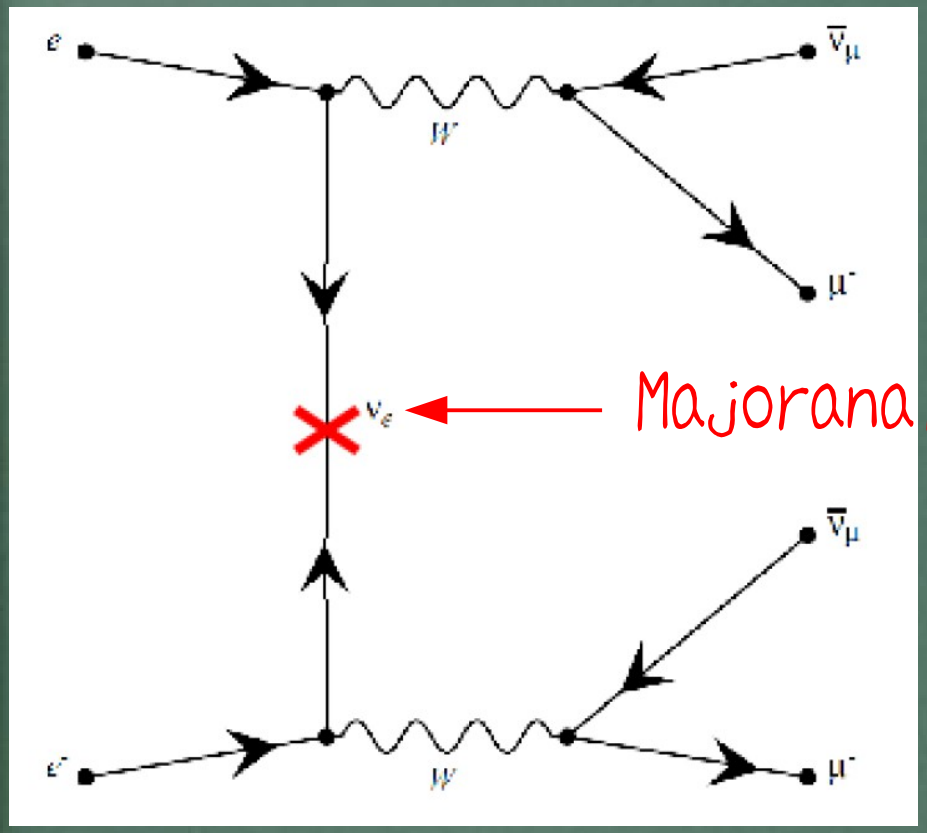
Introduction

- What kinds of physics can be performed?

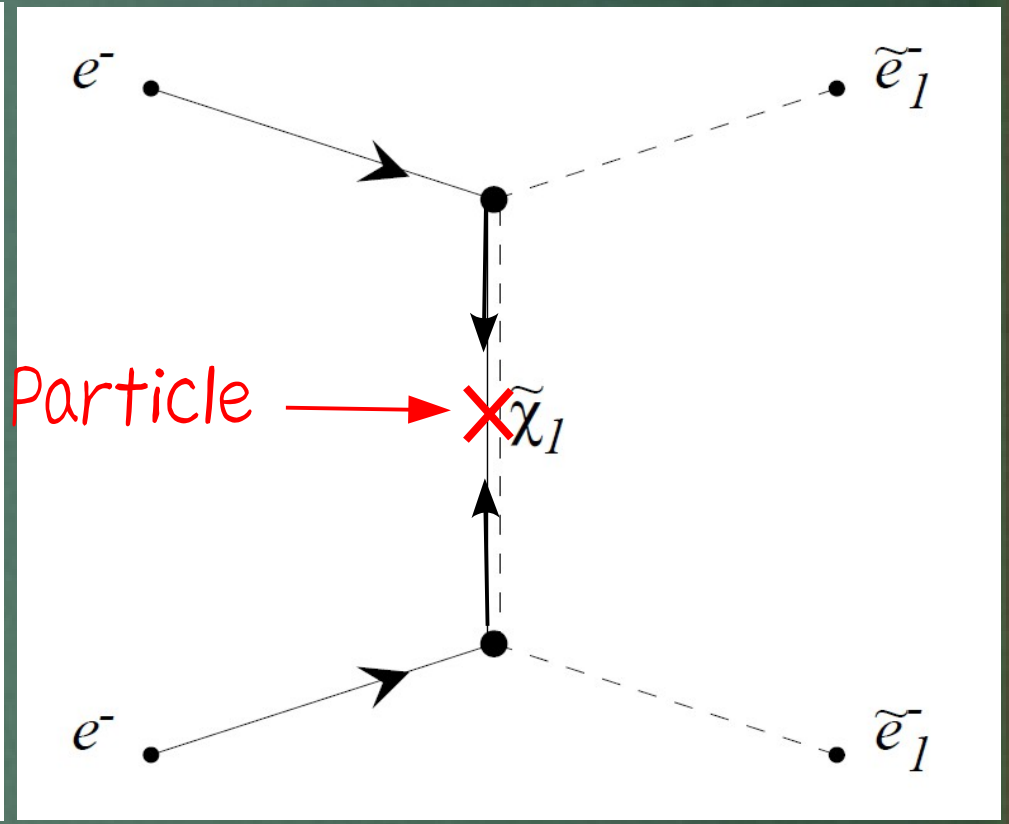


e^-e^- Physics

- What kinds of physics can be performed?



Majorana Particle



Majorana Neutrino Search

s-electon Search


Higgs Physics:
New Window to BSM

BSM Signal Search in Higgs couplings

Higgs boson signal in the effective model with the full set of dim-6 operators

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[2] *High Energy Accelerators Research Organization (KEK), Tsukuba, Ibaraki-ken, Japan*

BSM Signal Search in Higgs couplings

- *scalar-gauge boson sector*

$$O_{\Phi G} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})G^a_{\mu\nu}G^{a\mu\nu} \qquad O_{\Phi G} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$
$$O_{\Phi B} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})B_{\mu\nu}B^{\mu\nu} \qquad O_{\Phi B} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})B_{\mu\nu}\tilde{B}^{\mu\nu}$$
$$O_{\Phi W} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})W^i_{\mu\nu}W^{i\mu\nu} \qquad O_{\Phi W} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})W^i_{\mu\nu}\tilde{W}^{i\mu\nu}$$
$$O^{(1)}_{\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})D_\mu\Phi^\dagger D^\mu\Phi$$

- *scalar-fermion sector*

$$O_{t\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(\bar{Q}_L\Phi^c t_R)$$
$$O_{b\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(\bar{Q}_L\Phi b_R)$$
$$O_{\tau\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(\bar{L}_L\Phi\tau_R)$$

BSM Signal Search in Higgs couplings

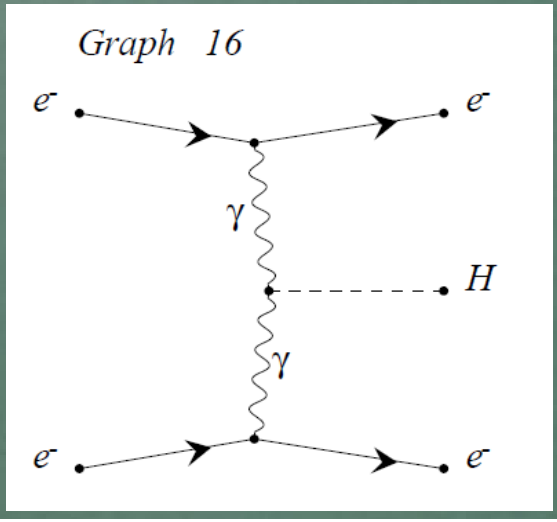
Effective operators	Triple vertices	Feynman rules
$O_{t\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_t)(\bar{Q}_L\Phi^c t_R)$	$\bar{t}\quad t\quad H$	$-M_t \cdot \frac{v}{\Lambda^2} \cdot C_{t\Phi}$
$O_{b\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_b)(\bar{Q}_L\Phi b_R)$	$\bar{b}\quad b\quad H$	$-M_b \cdot \frac{v}{\Lambda^2} \cdot C_{b\Phi}$
$O_{\tau\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_\tau)(\bar{L}_L\Phi\tau_R)$	$\bar{\tau}\quad \tau\quad H$	$-M_\tau \cdot \frac{v}{\Lambda^2} \cdot C_{\tau\Phi}$
$O_{\Phi G} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})G^a_{\mu\nu}G^{a\mu\nu}$	$G_\mu\quad G_\nu\quad H$	$-2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi G} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
$O_{\Phi B} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})B_{\mu\nu}B^{\mu\nu}$	$A_\mu\quad A_\nu\quad H$	$-2 \cdot c_W^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
	$A_\mu\quad Z_\nu\quad H$	$+2 \cdot c_W \cdot s_W \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
	$Z_\mu\quad Z_\nu\quad H$	$-2 \cdot s_W^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
$O_{\Phi W} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})W^i_{\mu\nu}W^{i\mu\nu}$	$A_\mu\quad A_\nu\quad H$	$-2 \cdot s_W^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
	$A_\mu\quad Z_\nu\quad H$	$-2 \cdot c_W \cdot s_W \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
	$Z_\mu\quad Z_\nu\quad H$	$-2 \cdot c_W^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
	$W_\mu^+\ W_\nu^-\ H$	$-2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu}p_1p_2 - p_1^\nu p_2^\mu)$
$O_\Phi^{(1)} = (\Phi^\dagger\Phi - \frac{v^2}{2})D_\mu\Phi^\dagger D^\mu\Phi$	$W_\mu^+\ W_\nu^-\ H$	$M_W^2 \cdot \frac{v}{\Lambda^2} \cdot C_\Phi^{(1)} \cdot g^{\mu\nu}$
	$Z_\mu\quad Z_\nu\quad H$	$M_Z^2 \cdot \frac{v}{\Lambda^2} \cdot C_\Phi^{(1)} \cdot g^{\mu\nu}$

BSM Signal Search in Higgs couplings

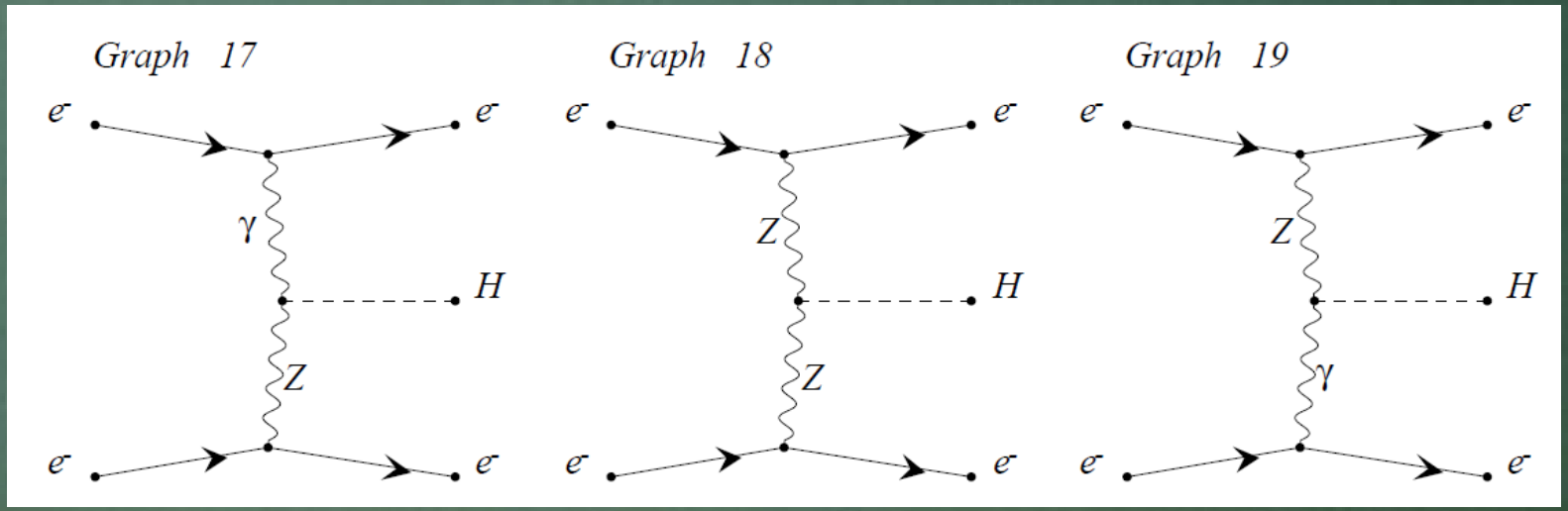
Triple vertices	Feynman rules
$\bar{t}\quad t\quad H$	$-\frac{M_t}{v}\cdot c$
$\bar{b}\quad b\quad H$	$-\frac{M_b}{v}\cdot c$
$\bar{\tau}\quad \tau\quad H$	$-\frac{M_\tau}{v}\cdot c$
$G_\mu\quad G_\nu\quad H$	$-\frac{2}{v}\cdot\frac{\alpha_s}{6\pi}\cdot c_G\cdot(g^{\mu\nu}p_1p_2-p_1^\nu p_2^\mu)$
$A_\mu\quad A_\nu\quad H$	$-\frac{2}{v}\cdot\frac{4\alpha}{9\pi}\cdot c_\gamma\cdot(g^{\mu\nu}p_1p_2-p_1^\nu p_2^\mu)$
$A_\mu\quad Z_\nu\quad H$	$+2\cdot c_W\cdot s_W\cdot(C_{\Phi B}-C_{\Phi W})\cdot\frac{v}{\Lambda^2}(g^{\mu\nu}p_1p_2-p_1^\nu p_2^\mu)$
$Z_\mu\quad Z_\nu\quad H$	$+\frac{2}{v}\cdot[M_Z^2\cdot a\cdot g^{\mu\nu}-a_Z\cdot(g^{\mu\nu}p_1p_2-p_1^\nu p_2^\mu)]$
$W_\mu^+\quad W_\nu^-\quad H$	$+\frac{2}{v}\cdot[M_W^2\cdot a\cdot g^{\mu\nu}-a_W\cdot(g^{\mu\nu}p_1p_2-p_1^\nu p_2^\mu)]$

Above couplings are implemented in GRACE

BSM Signal Search in Higgs couplings



Generated by GRACE



BSM Signal Search in Higgs couplings

LHC Experiment analysis

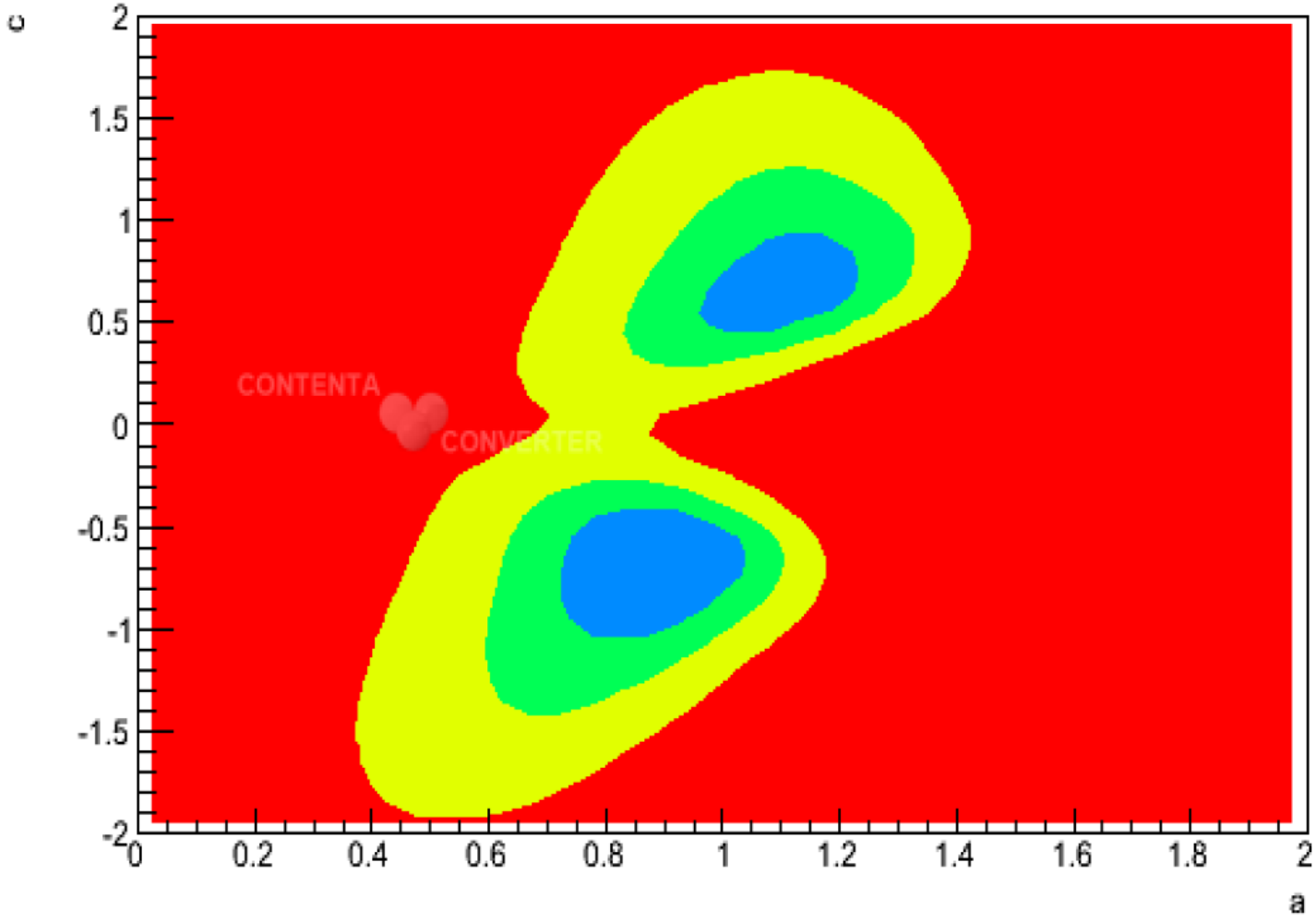
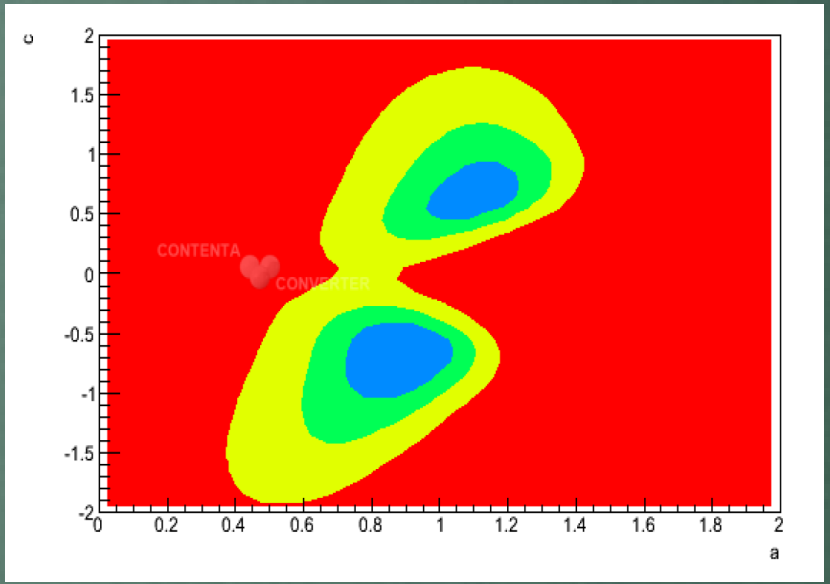


Figure 3: *(a) - global χ^2 fit in the (a, c) plane calculated with Higgs boson width for all two-particle, WW^* and ZZ^* decay channels within the production$\times$decay approximation, (b) - global χ^2 fit in the (a, c) plane from [9]*

BSM Signal Search in Higgs couplings

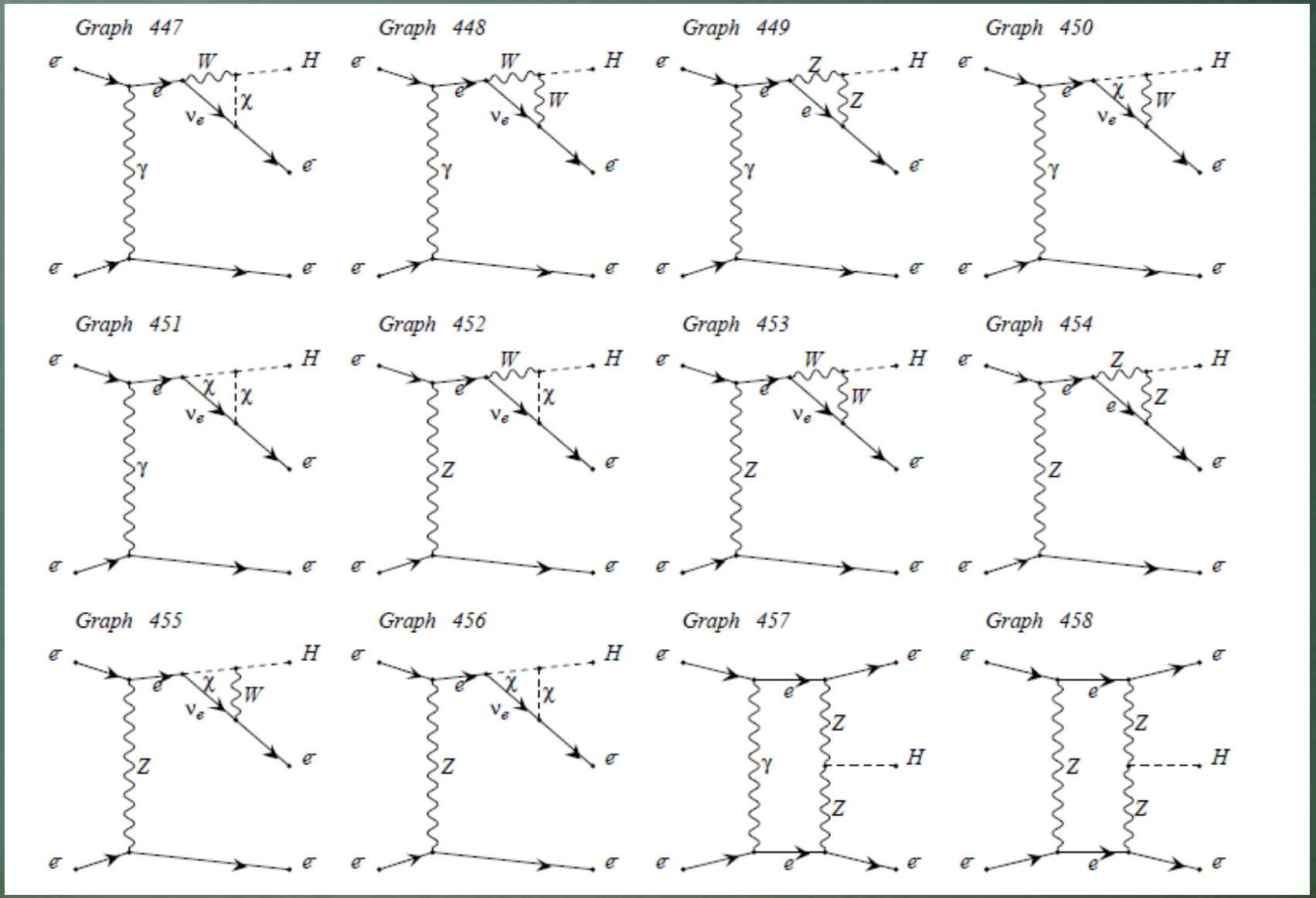
LHC Experiment analysis



???

in ILC(e+e-e-e-)

SM Higher Corrections



SM Higher Corrections

GRACE-Loop system

GRACE-Loop is a generic automated program for calculating High Energy Physics process [3].

- *All Feynman diagrams for a given process at fixing order of perturbation theory.*
- *A FORM or REDUCE code.*
- *A Fortran code generated for amplitude calculations.*
- *Kinematic library.*
- *The multi-dimensional integration by BASES.*
- *Event generation by SPRING.*

P.H. Khiem

SOKENDAI Univ. and KEK.

JPS meeting Mar. 2013 @Hirosima

[3] **Phys. Rept. 430 (2006) 117**

SM Higher Corrections

- Internal Consistency Check

	2Re(T*L)
Cuv=NLG=0,M_{photon}=10^(-19)	-8.480015062454 97E-003
Cuv=1000	-8.480015065339 81E-003
NLG=(10,2030,40,50)	-8.480015044158 96E-003
IR=10^(-17)	-8.480015063785 60E-003

SM Higher Corrections

- Result of full $O(\alpha)$ Correction

	Cross Section (pb)
Tree	7.659E-4
Soft	4.823E-3
Loop	-6.353E-3
Tree+Loop+soft	-7.639E-4
Hard	1.680E-3
Total	9.158E-4
1-Tree/Total	16 %

Photon mass $= 10^{-19}$ GeV

$\sqrt{s} = 250$ GeV, $M_H = 126$ GeV, No Cut.

Summary

Summary

- Higgs Physics @ LHC and e^-e^- ILC
  - General dim-6 operators in Higgs sector.
  - Effective vertices in GRACE System.
  - What can be achieved in LHC and ILC??
- Precise prediction with full electroweak $O(\alpha)$ correction
  - New Physics = |Measurements-SM predictions|
  - GRACE/Loop system
  - Precise study is necessary!
- An e^-e^- option of ILC is interesting!!