Physics Analysis at ILD

Report from Physics ILD WG

Priority No.1 = to realize ILC

What we need =

- **clear physics case**

Priority No. 2 = to realize ILD

What we need =

- **detector design, which is cost effective and technically feasible, to realize the physics**

The Goals of Physics Coordination

1) to make compelling physics case for ILC that can convince decision makers that ILC is worth the investment,
2) and to optimize ILD so as to realize the physics.

The Roles of the Physics Coordination

a) make a task list and set mile stones and timeline

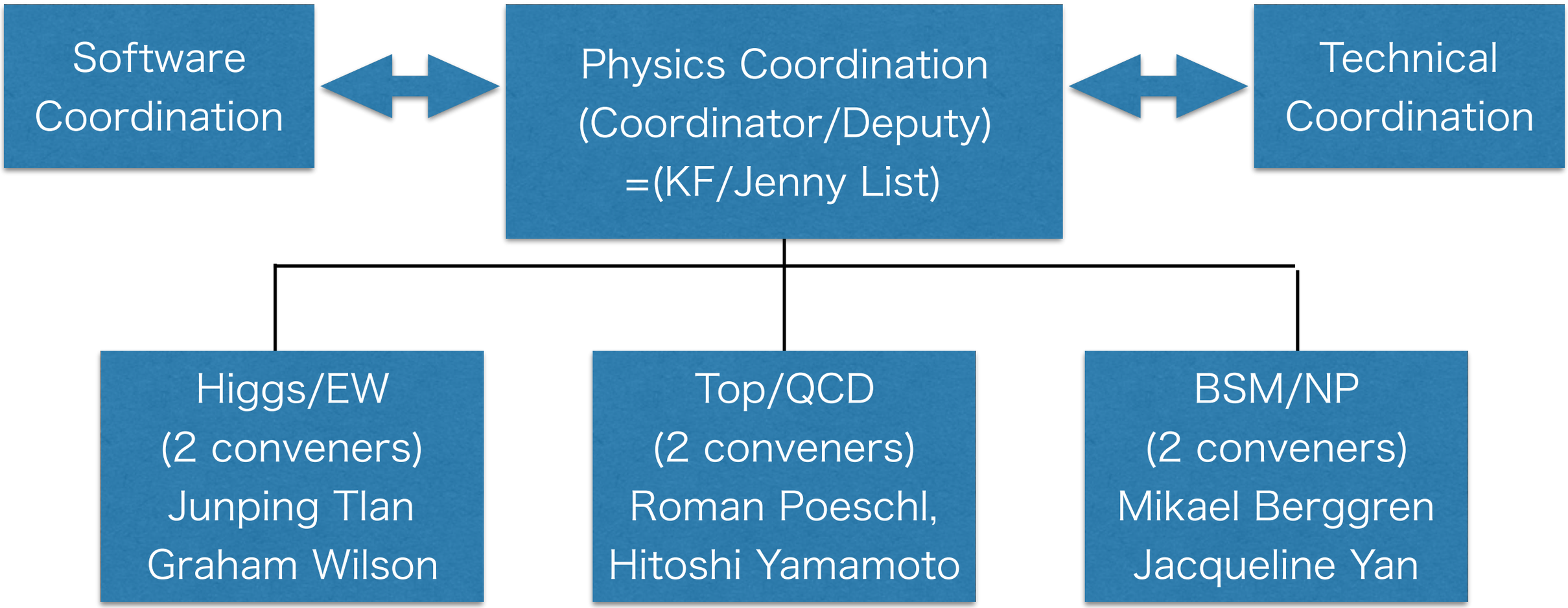
b) organize working groups / collaborate with other parts of ILD (in particular for detector optimization) as well as with the LCC physics WG.

c) monitor and, if needed, guide/help their progress

d) communicate the achievements to appropriate targets as needed,

e) thereby positively influencing decision makers, while contributing to international and regional strategy discussions.

Organigram



We may add more subgroups or task forces as needed.

Mailing List

Conveners' ML:

primarily for WG conveners, coordinator, and deputy:

ild-physics-conveners@desy.de created by Jenny

Use this mailing list also to send talk request.

Subgroup mailing lists:

ild-physics-bsm@desy.de	created by Mikael
ild-physics-top@desy.de	created by Roman
ild-physics-higgs@desy.de	created by Graham

mainly for communication among **active** people, not so much for every interested ILD member to stay informed.

Hurdles to clear

MEXT's Interim Summary (Excerpts)

Recommendation 1: The ILC project requires huge investment that is so huge that a single country cannot cover, thus it is indispensable to share the cost internationally. From the viewpoint that the huge investments in new science projects must be weighed based upon the scientific merit of the project, a clear vision on the discovery potential of new particles as well as that of precision measurements of the Higgs boson and the top quark has to be shown so as to bring about novel development that goes beyond the Standard Model of the particle physics. → ***ICFA support document***

Recommendation 2: Since the specifications of the performance and the scientific achievements of the ILC are considered to be designed based on the results of LHC experiments, which are planned to be executed through the end of 2017, it is necessary to closely monitor, analyze and examine the development of LHC experiments . Furthermore, it is necessary to clarify how to solve technical issues and how to mitigate cost risk associated with the project. → ***X750 report (arXiv:1607.03829)***

We need to demonstrate that ILC will advance our understanding of particle physics **qualitatively** beyond the information that will be available from the results expected from the future stages of the LHC.

Given that LHC Run2 found no new particles so far, we should probably readjust the weights of the three discovery scenarios in the ICFA letter. (→later)

Proposed Actions (shown at Santander)

1. Monitor the current activities and ***update the activity list (later)***
   1.1. Benchmark analyses (check manpower situation)
   1.2. Other more physics driven analyses
2. Plan for ***the followup of the ICFA letter (later)***
   2.1. Decide analyses to include (figures and tables?)
   2.2. Set up analysis teams (who does what?)
   2.3. Write the backup documents (svn/regular meetings)
   2.4. Work with LCC physics WG, but ILD will be the engine for this task.
3. Plan for ***the benchmark studies (next page)***
   3.1. Check if each benchmark process is properly worked on (who does what?).
   3.2. Enforce the analysis teams as needed.
4. Cultivate/involve new/young people for ***new analyses***
   4.1. Web page as an entry point
   Prepare a list of on-going/possible future studies / manuals / contact info.
   4.2. Communicate with students' supervisors.
   4.3. Software access/download
   4.4. Analysis tutorials (with soft. WG) (attached to WSs?)
   4.5. Involve theorists as needed (happening in all areas).

Benchmark Studies

benchmark processes for detector optimisation

process	physics	detector	Ecm	
H—>cc	BR	c-tag JER	any	H.Ono
H—>μμ	BR	high P tracking	500 GeV	S.Kawada
H—>ττ	BR, CP	τ reconstruction, PID track separation	250 GeV	D.Jeans
H—>bb	M_H, BR	JES, JER b-tag	500 GeV	A.Ebrahimi J.Tian
H—>invisible Z—>qq	Higgs Portal	JER	250 GeV	Y.Kato
eνW—>eνqq	M_W, TGC	JES, JER	500 GeV	K.Cotera G.Willson
tt-bar—>6-jet	top coupling A_{FB}	b-tag, JER jet charge	500 GeV	S.Bilokin Y.Sato
$\chi_1^+\chi_1^-, \chi_2^0\chi_1^0$ near degenerated	natural SUSY	low P tracking PID	500 GeV	J.Yan
γXX	WIMPs	Photon ER & ES Hermiticity	500 GeV	M. Habermehl

in total 9 = 5 (Higgs) + 2 (EW) + 2 (BSM) ***fully covered!***

Subgroup Activities

1. Higgs/EW WG (Junping Tian, Graham Wilson)

1. Higgs CP: H→τ+τ- in ννH (Vladimir Bocharnikov: ITEP) ***New***
2. **Higgs CP: H→τ+τ- in ZH (Daniel Jeans)** → Dec.8
3. **Anomalous HVV couplings (Tomohisa Ogawa)** → Dec.8
4. Higgs CP: ttH (Tomohisa Ogawa)
5. mH reconstruction using H→bb (Ali Ebrahimi)
6. **mH reconstruction using H→bb (Junping Tian)** → Dec.8
7. H→bb/cc/gg (Hiroaki Ono)
8. **H→WW in ZH (Mila Pandurovic)** → Dec.7
9. H→μ+μ- (Shin-ichi Kawada)
10. **H→invisible (Yu Kato)** → Dec.8
11. **HHH using HH→bbbb (Claude Duerig)** → Dec.6
12. HHH using HH→bbWW* (Masakazu Kurata)
13. **HHH : model indep. analysis with EFT (Junping TIan)** → Dec.6 (Tim B.)
14. mW with single W production (Katsu Kotera)
15. **Precision EW studies incl. mW, Z-pole (Graham Wilson)** → Dec.6

Beam energy/luminosity spectrum calibration: a common issue for precision mass measurements (mW, mH, mt)

News about documentation

- ννH, H→bb/cc/gg (separating ZH and WW-fusion) @ 350 GeV: PhD thesis by F. Mueller (DOI: 10.3204/PUBDB-2016-02659) (DESY-THESIS-2016-018).
- Higgs self-coupling, state-of-the-art ZHH analysis @ 500 GeV: PhD thesis by C. Duerig (DESY-THESIS-2016-027)
- Leptonic recoil analysis @ 250, 350, 500 GeV: **published yesterday in Phys. Rev. D94 (2016) 113002**, by J.Yan, et al.
- Higgs CP measurement using H→ττ @ 250 GeV: *draft being reviewed in ILD*, by D.Jeans

Prospects for the Full ILC Running Scenario

$\sqrt{s} = 500$ GeV, $\mathcal{L} = 4$ ab^{-1}, $P(e^+e^-) = (\pm 0.3, \mp 0.8)$

Measurement prospects for λ_{SM}

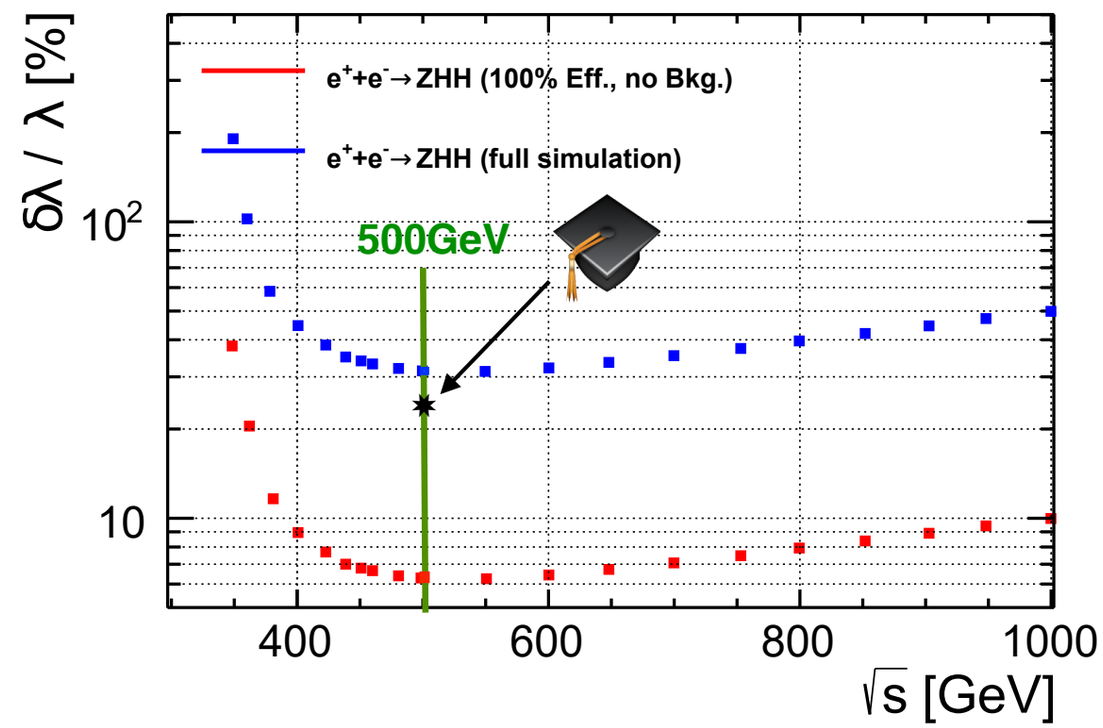
- for HH $\rightarrow$ bbbb

$$\frac{\Delta\sigma(ZHH)}{\sigma(ZHH)} = 21.1\% \rightarrow 5.9\sigma \text{ discovery}$$

- combined with HH $\rightarrow$ bbWW*

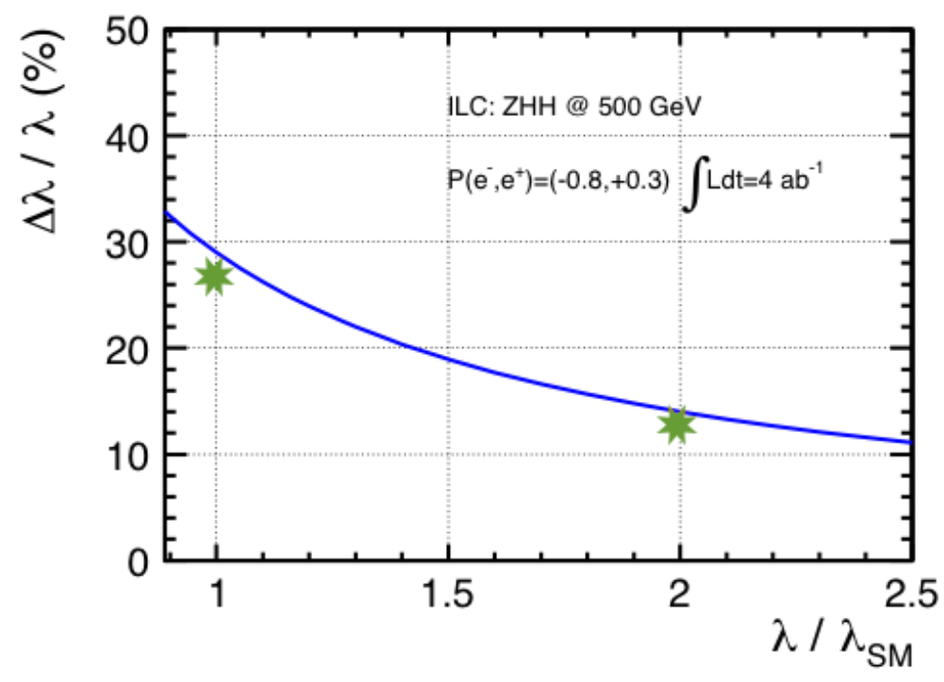
$$\frac{\Delta\sigma(ZHH)}{\sigma(ZHH)} = 16.8\% \rightarrow 8.0\sigma \text{ discovery}$$

- results in 26.6% precision on λ_{SM}
- advanced reconstruction gives 10% improvement
- combined with WW fusion @ 1TeV
  $\rightarrow$ 10% precision on λ_{SM}



Measurement prospects for $\lambda \neq \lambda_{SM}$

- σ_{ZHH} enhanced compared to SM
- less affected by additional diagrams
- e. g. $\lambda = 2\lambda_{SM}$ results in 13% precision on λ

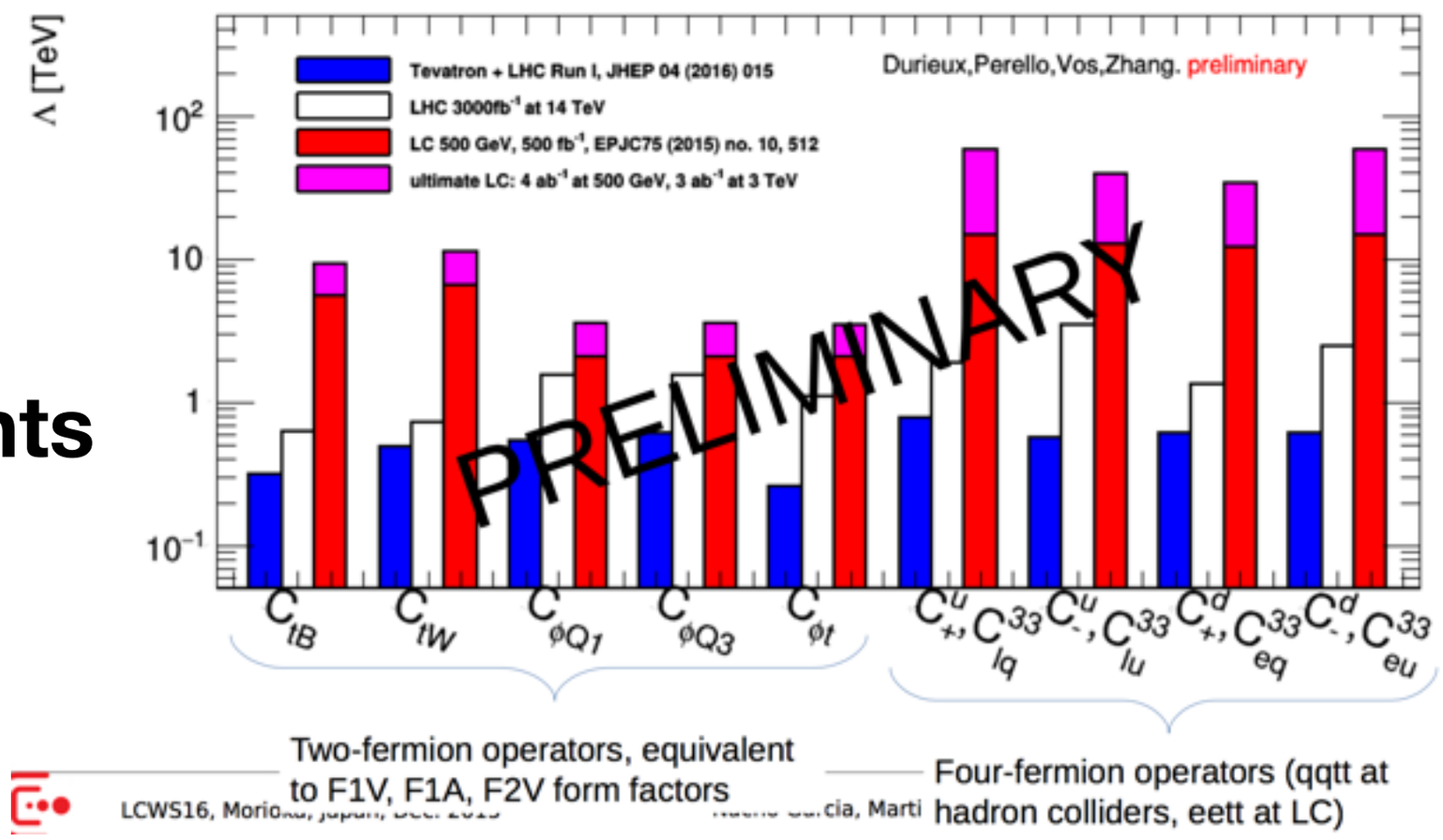


Subgroup Activities (continued)

2. Top/QCD WG (Roman Peoschl, Hitoshi Yamamoto)

1. e+e- → tt : semi-leptonic (Sviatslav Bilokin)
2. **e+e- → bb (Sviatslav Bilokin)** →Dec.6 (R.Poeschl)
3. **e+e- → tt : bbμ+μ-νν: MEM (Yo Sato)** →Dec.7
4. mt reconstruction at 1TeV or higher (Nacho Garcia, Martin Perello, Philipp Roloff, Rickard Strom) with CLICdp →Dec.8 (R.Strom)
5. **mt using radiative return to threshold (Março Boronat and Pablo Gomis)** →Dec.8 (M.Vos)
6. **Global fit with D6 EFT (Martin Perello, et al.)** →Dec.6 (M.Vos)

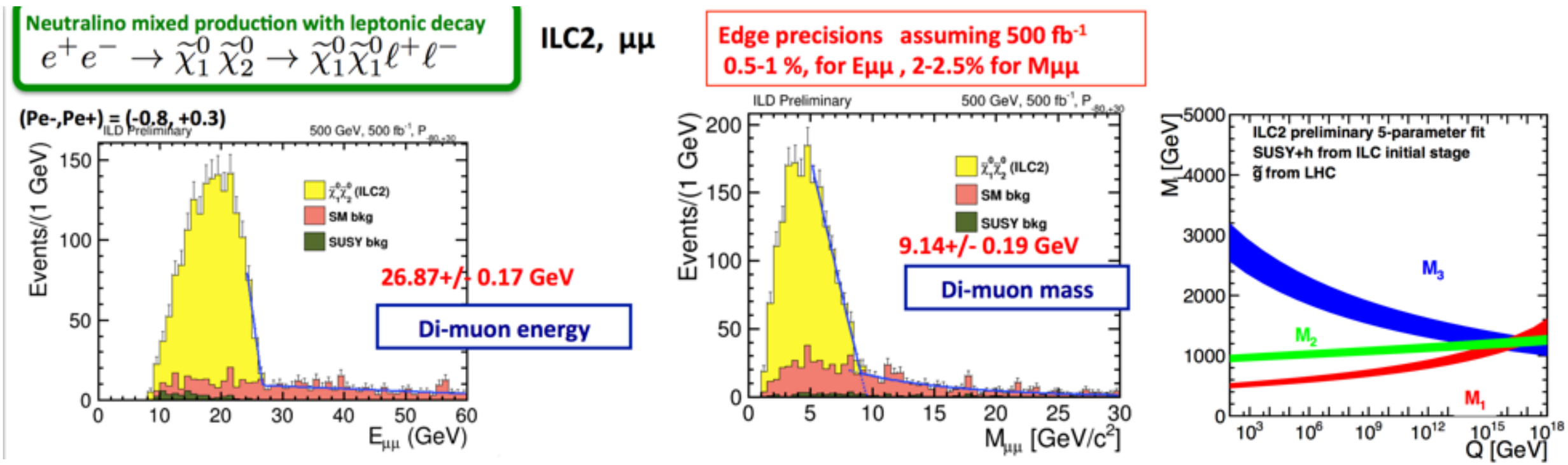
Form factors
→ EFT coefficients



Subgroup Activities (continued)

3. BSM WG (Mikael Berggren, Jacqueline Yan)

1. **Generic WIMP searches (Moritz Habermehl)** → Dec.8 (T. Tanabe)
2. **SUSY co-annihilation (Mikael Berggren)** → Dec.8
3. **Higgsinos (Jacqueline Yan)** → Dec.8
4. **SUSY parameters from Higgsinos (Suvi-Leena Lehtinen)** → Dec.8



News about documentation

- "Di-photon resonances at the ILC" (Junping Tian, KF, Hiroshi Yokoya) : Phys. Rev. D94 (2016) no.9 095015

More Publications

- ICHEP proceedings
  - "Top physics at CLIC and ILC"
    (circulated by Aleksander Zarnecki)
  - "Naturalness and light higgsinos:
    A powerful reason to build the ILC!"
    (circulated by Jenny)
  - "WIMP searches at the International Linear Collider"
    (circulated by Moritz)
  - "SUSY model and dark matter determination in the compressed spectrum region at the ILC"
    (circulated by Mikael)
  - "Precision Electroweak Measurements at a Future e+e- Collider"
    (circulated by Graham)
  - "500 GeV ILC Operating Scenarios" (submitted by Jim Brau)

Uncovered Topics

From κ_x to EFT

Precision H/t studies are moving to EFT for more model-independent analyses.
→ Need more precision measurements that constrain various EFT coefficients

- e+e- → H γ
- e+e- → WW, WWZ, … (TGC, QGC, etc.)
- 2-fermion processes :
  e+e- → e+e-, μ+μ-, τ+τ-, qq (light), cc)

ICFA Support Document

Support Document that follows up the ICFA letter

First authors' meeting held on Sep. 9

Discussed the structure and basic ideas about contents together with how to share the writing.

2nd authors' meeting held on Oct. 13

Reviewed the status of the draft and discussed the request from JHEPC and possible readjustment of the contents of the document.

3rd authors' meeting held on Nov. 1

Reviewed the status of the draft (significant progress, but there are still missing parts, expected to be filled in shortly) and discussed the timeline until LCWS 2016.

4th authors' meeting held on Nov. 16

Reviewed the status of the draft (significant progress, most part filled). All the part to be filled and frozen by next Monday for final editing by Jenny and KF until Nov. 28.

A draft sent to the plenary speakers at LCWS2016 on Nov. 29. We updated the draft further until Dec. 3 and sent it to LCC physics WG and Hitoshi Yamamoto on Dec. 4.

5th authors' meeting scheduled on Dec. 13

The ILC's Potential for Discovering New Particles

1. Introduction
2. Overview on BSM Scenarios
3. ILC Capabilities for Precision Measurement
4. Direct Production of New Particles at the ILC

   3, 4: Main body of the document

   There are different kinds of discoveries.
   Power of precision

   ILC is not a gleaner.
   Power of cleanliness

5. LHC Discovery Scenarios

   5-1) LHC Experiments do not discover new particles

   5-2) LHC experiments discover relatively light new particles

   5-3) LHC experiments discover heavy new particles

6. ILC and LHC, Complementarity and Synergy
7. Conclusions

New request from JHEP via Hitoshi Yamamoto

Yet Another Document Planned by JHEPC

To be completed in March 2017
Japanese HEP committee is planning to issue
a statement on the ILC physics case
based on the LHC Run2 results (so far).

Hitoshi hopes that the support document will be an input to this JHEPC statement

The recommendation by the MEXT panel said
Closely monitor, analyze, and examine the development of LHC experiments

The current LHC Run2 results indicate that there seem to be *no new particles easily discoverable at the LHC*, which leaves
case 3-1 (case 5-1 in the support document) :
No discoveries of new particles at LHC Experiments as the most likely scenario.

There were split opinions among the physics WG of the MEXT ILC Advisory panel for the case that LHC Run2 data suggest likely.

JHEPC wants to deliver a clear single voice message.

LCC physics WG's new particle discovery potential document will be inputs to this.

Proposed Actions

1. Monitor the current activities and ***update the activity list***
   1.1. Benchmark analyses (check manpower situation)
   1.2. Other more physics driven analyses

done!

2. Plan for ***the followup of the ICFA letter***
   2.1. Decide analyses to include (figures and tables?)
   2.2. Set up analysis teams (who does what?)
   2.3. Write the backup documents (svn/regular meetings)
   2.4. Work with LCC physics WG, but ILD will be the engine for this task.

basic materials installed, draft in editing process

3. Plan for ***the benchmark studies (next page)***
   3.1. Check if each benchmark process is properly worked on (who does what?).
   3.2. Enforce the analysis teams as needed.

fully covered

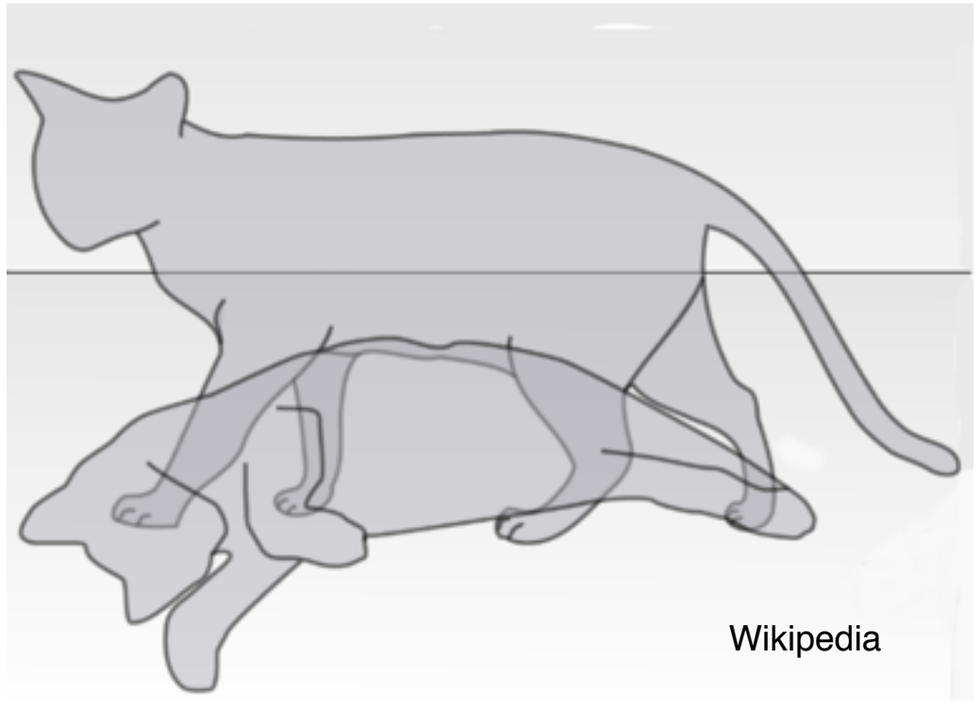
4. Cultivate/involve new/young people for ***new analyses***
   4.1. Web page as an entry point
   Prepare a list of on-going/possible future studies / manuals / contact info.
   4.2. Communicate with students' supervisors.
   4.3. Software access/download
   4.4. Analysis tutorials (with soft. WG) (attached to WSs?)
   4.5. Involve theorists as needed (happening in all areas).

Needs more effort

Backup

X750

had been Schrödinger's cat state



Now the box is open

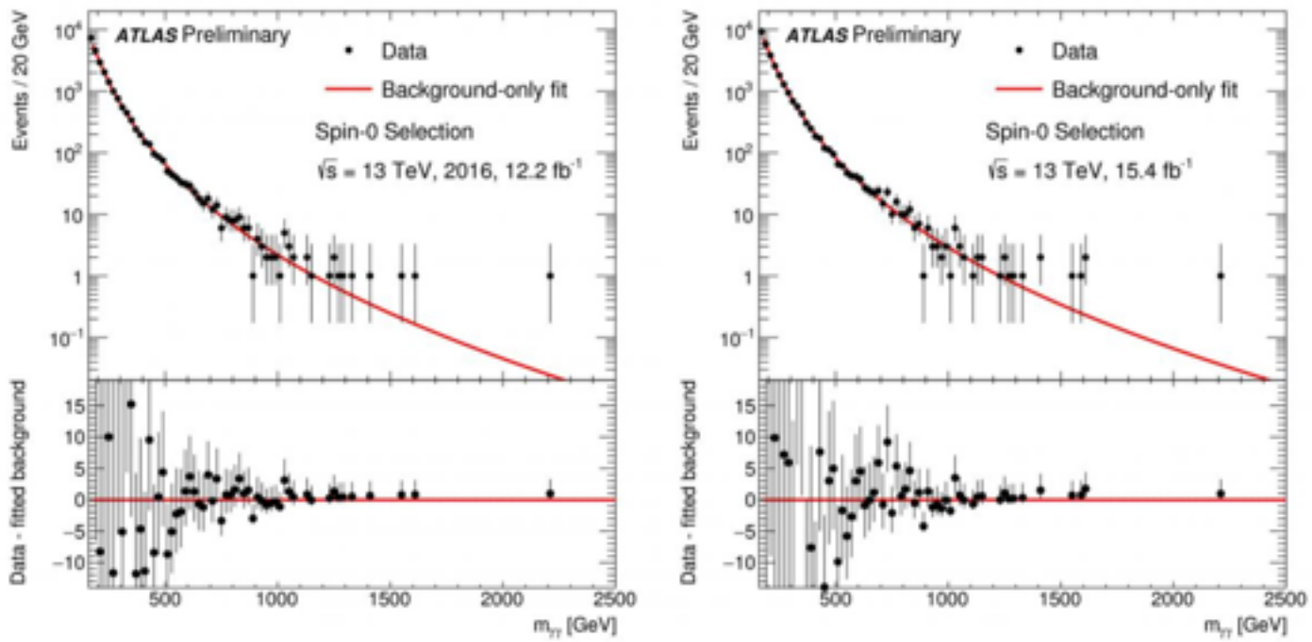


Figure 2: Invariant-mass distribution of the selected diphoton candidates, with the background-only fit overlaid, for 2016 data (left) and the combined 2015 and 2016 data (right). The difference between the data and this fit is shown in the bottom panel. (Image: ATLAS Experiment/CERN)

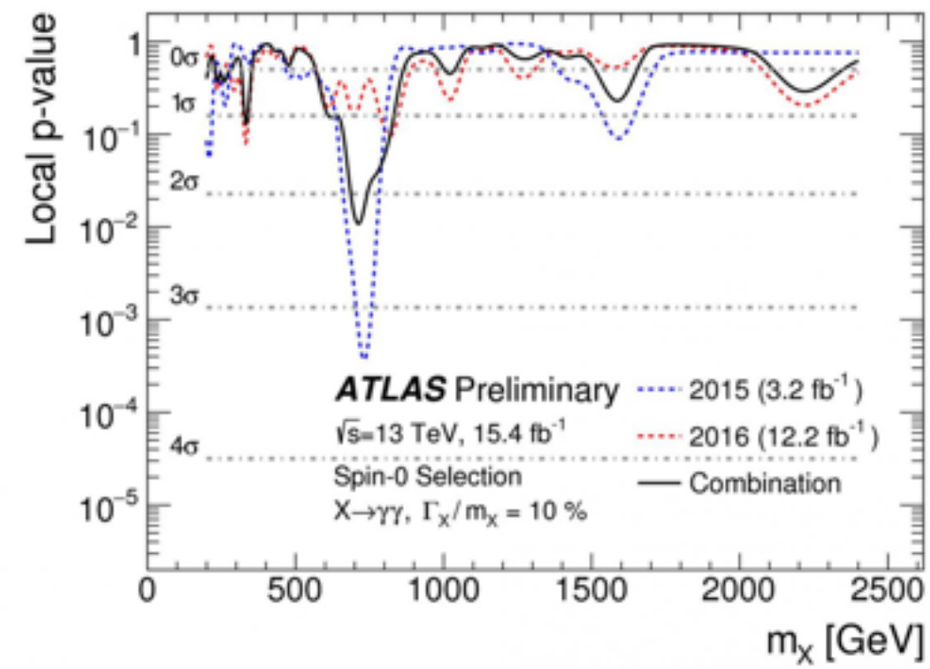
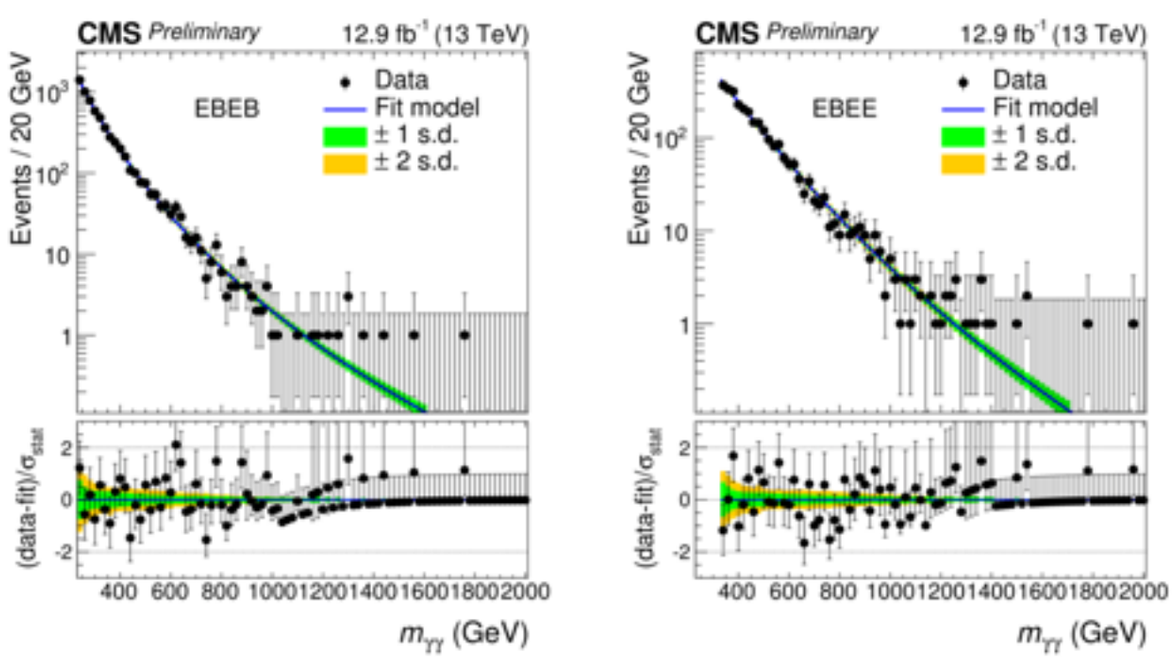


Figure 3: Probability that the background alone fluctuates up by the amount seen in data or more as a function of the mass for a certain width hypothesis of the new particle assumed in the search. (Image: ATLAS Experiment/CERN)



The CMS di-photon spectrum obtained with 12.9 fb^{-1} of 2016 data at 13 TeV (both photons in the ECAL barrel: left; at least one photon in the ECAL endcaps: right). No significant excess of events is observed over the background-only hypothesis. The mild excess near $m_{\gamma\gamma}$ ~750 GeV reported by CMS with 2012 and 2015 data is not confirmed with 2016 data.

and the cat is found dead.

Our (LCC Physics WG's) Stance has been

1. It's too early to get excited,
2. but if it is real, it is ***a good example of case 3*** in the ICFA letter to MEXT's ILC Advisory Panel:
   case 3: LHC discovers relatively heavy new particles *(which cannot be directly produced at the 500 GeV ILC)*
3. Since the MEXT Panel recommended to ***closely monitor, analyze, and examine the development of LHC experiments***, this is ***a good opportunity to do exercise for case 3***. → motivation for this note
4. In LCC's letter to the panel, it is stated that "***While performing precision studies of the Higgs boson and the top quark, we will prepare for the energy upgrade of the ILC*** *taking advantage of energy expandability enabled by its linear shape."*
5. *The note is intended to show*
   1. ***The 500 GeV ILC has a lot to say about X750*** ***through precision measurements*** *plus* ***possible discovery of NPs associated with X750****. → 1st part (section 3)*
   2. ***Possible energy upgrade with PLC option will open up even greater opportunities*** ***to uncover the new physics operating behind X750 together with LHC****. → 2nd part (section 4)*

And did the homework following MEXT's recommendation

ILC–NOTE–2016–067
DESY 16–145, IPMU16-0108
KEK Preprint 2016–9, LAL 16–185
MPP–2016–174, SLAC–PUB–16751

July, 2016

Implications of the 750 GeV $\gamma\gamma$ Resonance as a Case Study for the International Linear Collider

LCC Physics Working Group

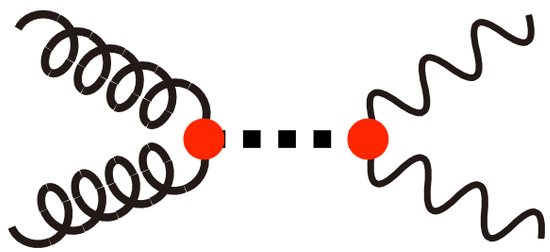
Keisuke Fujii[1], Christophe Grojean[2,3] Michael E. Peskin[4](conveners); Tim Barklow[4], Yuanning Gao[5], Shinya Kanemura[6], Hyungdo Kim[7], Jenny List[2], Mihoko Nojiri[1,8], Maxim Perelstein[9], Roman Pöschl[10], Jürgen Reuter[2], Frank Simon[11], Tomohiko Tanabe[12], Jaehoon Yu[13], James D. Wells[14]; Adam Falkowski[15], Shigeki Matsumoto[8], Takeo Moroi[16], Francois Richard[10], Junping Tian[12], Marcel Vos[17], Hiroshi Yokoya[18]; Hitoshi Murayama[8,19,20], Hitoshi Yamamoto[21]

ABSTRACT

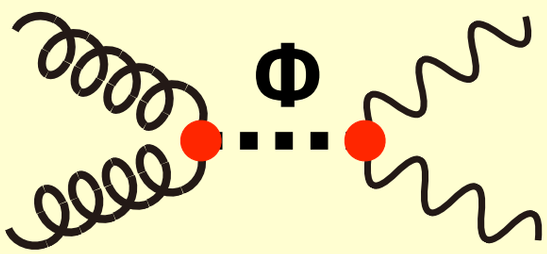
If the $\gamma\gamma$ resonance at 750 GeV suggested by 2015 LHC data turns out to be a real effect, what are the implications for the physics case and upgrade path of the International Linear Collider? Whether or not the resonance is confirmed, this question provides an interesting case study testing the robustness of the ILC physics case. In this note, we address this question with two points: (1) Almost all models proposed for the new 750 GeV particle require additional new particles with electroweak couplings. The key elements of the 500 GeV ILC physics program—precision measurements of the Higgs boson, the top quark, and 4-fermion interactions—will powerfully discriminate among these models. This information will be important in conjunction with new LHC data, or alone, if the new particles accompanying the 750 GeV resonance are beyond the mass reach of the LHC. (2) Over a longer term, the energy upgrade of the ILC to 1 TeV already discussed in the ILC TDR will enable experiments in $\gamma\gamma$ and e^+e^- collisions to directly produce and study the 750 GeV particle from these unique initial states.

Representative Models and Effects

Effective Couplings



Φ=RS radion

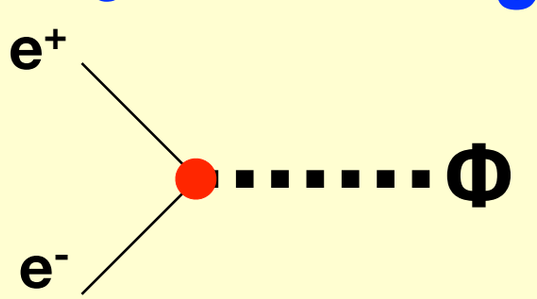


KK-loop correction
→ hWW, hZZ

~8% deviation expected for 5 TeV KK gluon.

Φ=RS gravition

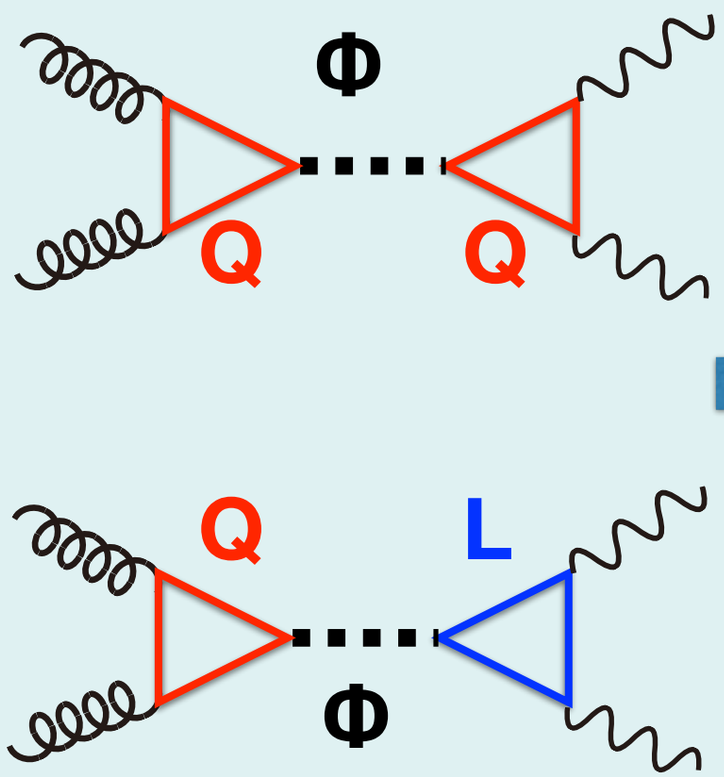
J=2

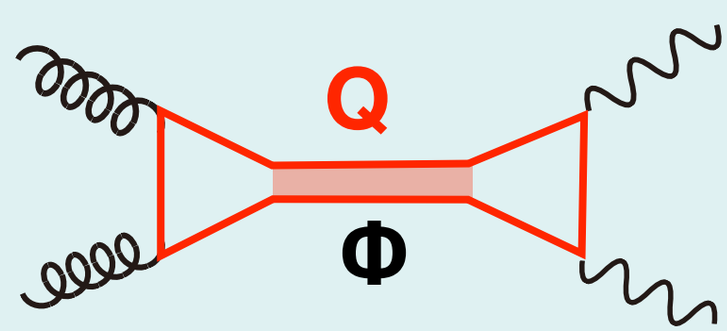


direct coupling to e^+e^-
→ s-channel Φ production

still not completely excluded.

Elementary Scalar

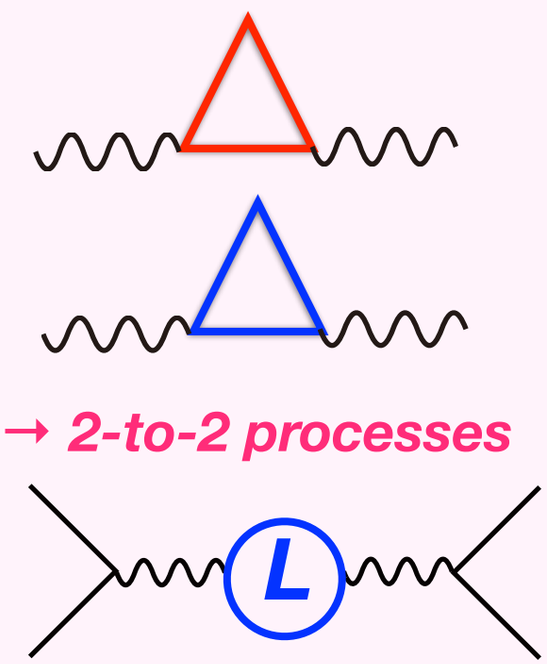




Resonance/pNGB

might be accompanied by DM within ILC's reach

Oblique Corrections



→ 2-to-2 processes

with δσ/σ=0.1%, ILC sensitivity exceeds LHC

Mixings

- Q-t mixing → ttZ
- L-τ mixing
- Φ-h mixing
  - → hγγ, hgg
  - → hWW, hZZ

a few % deviation expected → well within H20 target

	hWW hZZ	$hb\bar{b}$ $h\tau\tau$	$h\gamma\gamma$ hgg	$ht\bar{t}$	$h \to$ invis.	$h\tau\mu$	$t\bar{t}Z$	$ee \to$ $ee, \mu\mu$	$ee \to$ $\gamma+$ invis.
Vectorlike fermions		X	X	X			X	X	
2 Higgs doublet	X	X	X	X					
Higgs singlet	X	X		X			X		
NMSSM	X	X	X	X	X				X
Flavored Higgs	X	X	X			X			
NR bound state		X		X				X	
Pion of new forces		X	X	X	X		X	X	X
RS radion	X	X	X	X			X		
RS graviton	X	X		X			X		

Table 2: Anomalies in precision measurements expected to be visible at the ILC for the models of the Φ discussed in this section.

1. *The note is intended to show*

- ***The 500 GeV ILC has a lot to say about X750*** ***through precision measurements*** *plus* ***possible discovery of NPs associated with X750****.*

Section 3: This part is still relevant!

- ~~***Possible energy upgrade with PLC option will open up even greater opportunities to uncover the new physics operating behind X750 together with LHC.***~~

Section 4: now moot.

2. ***Our strategy stated in the ICFA letter to MEXT's ILC Advisory Panel is intact***: ***While performing precision studies of the Higgs boson and the top quark, we will prepare for the energy upgrade of the ILC*** *taking advantage of energy expandability enabled by its linear shape.*

This always applies!

Caution

For this reason, ***it is premature to discuss a new accelerator intended specifically to target the Φ*** or any other new particle that turns up in the early 13 TeV LHC data.

Indeed it is.