FCC-ee vs 750GeV

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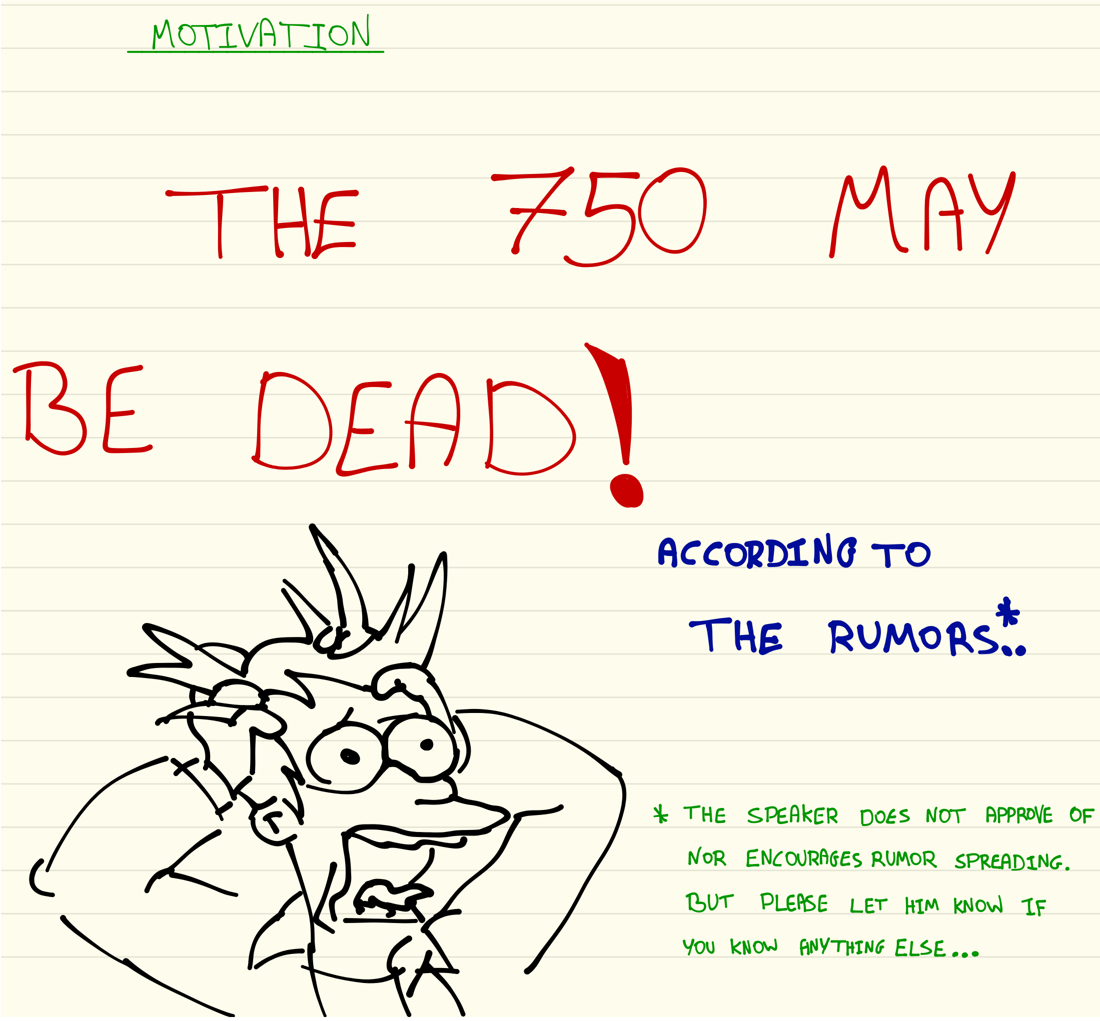
FCC-ee Physics VIDYO meeting
June 27, 2015

disclaimer:
most of the slides stolen
from K. Fujii @ Santander '16

“wait and see”?

T. Volansky @ NPKI’16, Seoul



“Mais je crois qu'il faut resister à la tentation. On ne va pas stopper la physique des particules chaque année pour un 3 sigma annuel qui va poser son ombre mystérieuse d'un endroit à l'autre. D'ailleurs en 2019 il faudra avoir décidé de la prochaine machine, et après il faudra s'y tenir, quelque soient les 3 sigmas qui ne manqueront pas de se présenter ici ou là -- et même s'ils s'avèrent être de réelles découvertes. Si le signal est réel tout comme s'il ne l'est pas, il faut envisager une recherche très large -- et je pense donc que le futur ne sera sans doute pas si dépendant que ça du résultat.” A. Blondel, private communication

750 GeV > E(FCC-ee reach)

If the 750GeV excess were real,
would the next obvious step be to construct a higher energy machine?

Indeed FCC-ee won't directly produce di-gamma on shell
(if there is anything to be produced... wait for 2016 results!)
but the di-gamma "particle" talks to SM
(at least to gamma's and hence to Z and/or W by U(1)xSU(2) invariance)
so we can see some of its imprints via precision measurements

LCC exercise:

Implications of the 750 GeV Resonance for the International Linear Collider

LCC Physics Working Group

Main and legitimate question:
what would be the added value of a low energy machine to LHC?

Our Attitudes towards X750

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.*** → this talk
   2. ***Possible energy upgrade with PLC option will open up even greater opportunities to uncover the new physics operating behind X750 together with LHC.*** → *next talk by Francois Richard*

K. Fujii @ Santader'16

Questions addressed in the note

1. If Φ (=X750) is real, what would the implications be for the program of the ILC?
2. Will the ILC be able to shed light on this resonance or on accompanying new physics?

K. Fujii @ Santader'16

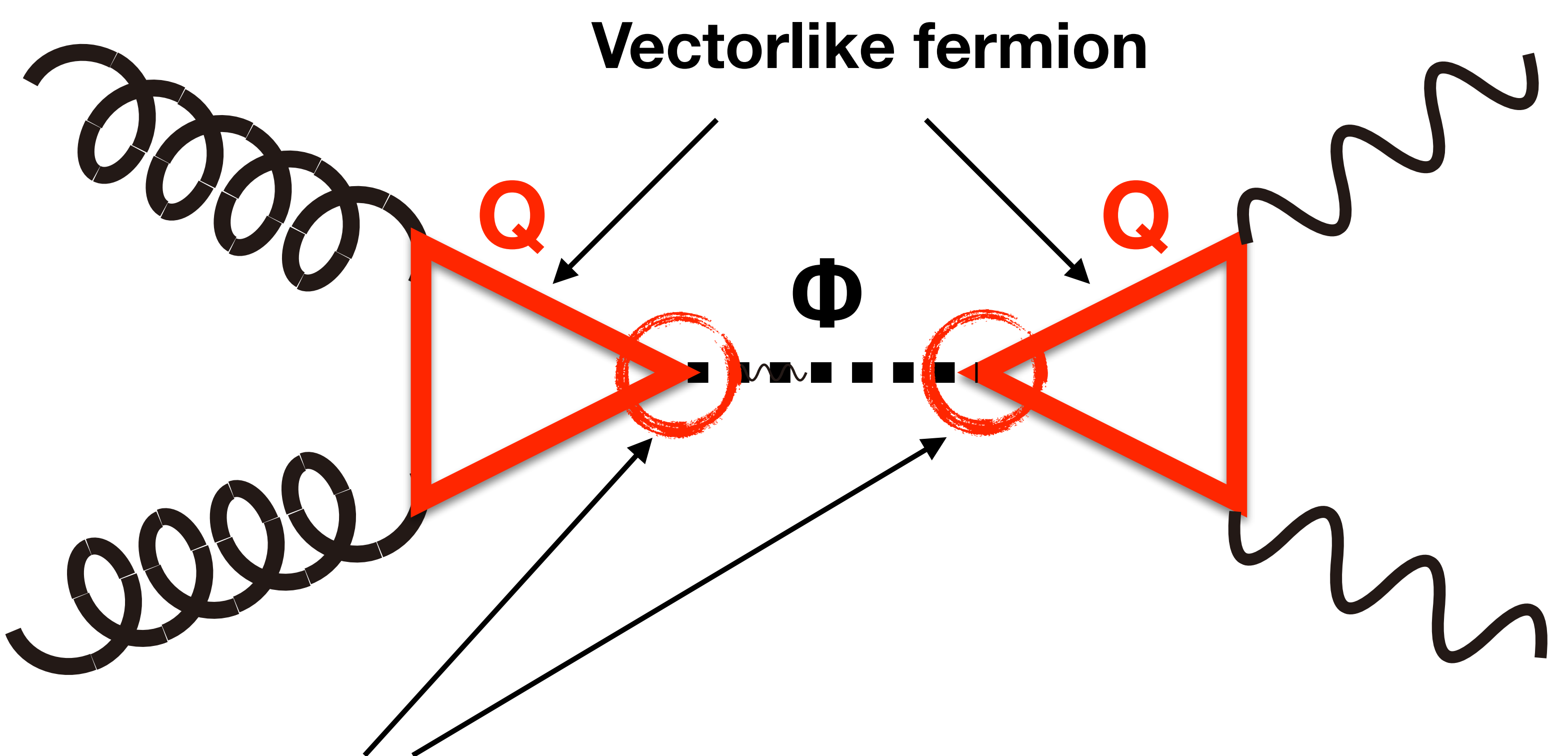
Caution

It might turn out that ***the Φ is a relatively minor player*** *in a new sector of physics that the LHC will begin to uncover in the next few years*.

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.

Φ = ***SM singlet*** coupling to ***vectorlike quarks and leptons***

Vectorlike quarks for both production and decay



$$\mathcal{L} \subset (m_\Psi + y\Phi)\overline{Q}Q$$

vector-like color-triplet quark: (I,Y)=(0,2/3)

$$A_1 = \frac{8}{9}\frac{y}{\pi m_Q}\ , \quad A_2 = 0\ , \quad A_3 = \frac{1}{3}\frac{y}{\pi m_Q}$$

$m_Q/y \sim 700$GeV y~1 → Q should have been discovered.

$1 < y < 3$ y~3 → non-perturbative

Except at y~3, Q will be discovered soon at LHC.

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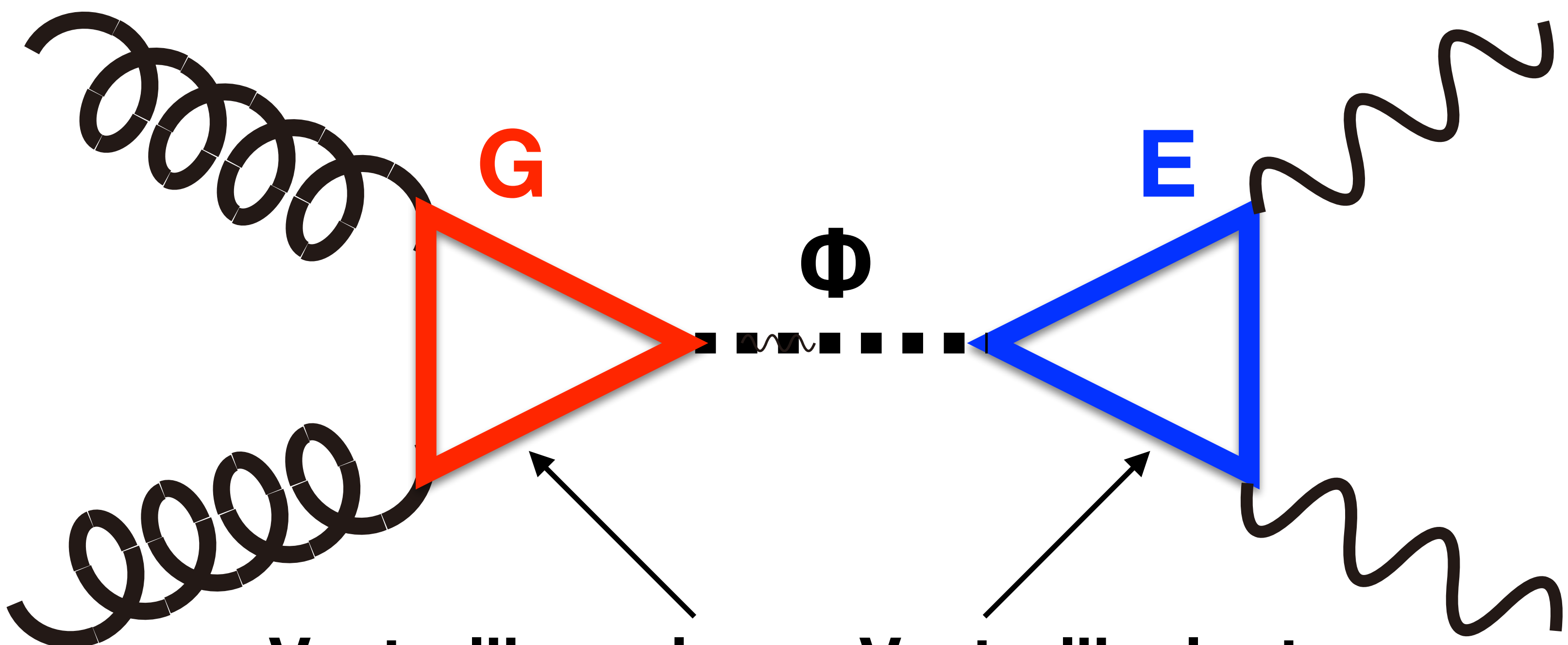
Vectorlike quarks ***for production and*** *vectorlike leptons* ***for decay***



Vectorlike color-octet quark

(I,Y)=(0,0)

Vectorlike lepton

(I,Y)=(0,1)

$$A_1 = \frac{2}{3}\frac{y}{\pi m_E}\,, \quad A_2 = 0\,, \quad A_3 = 2\frac{y}{\pi m_G}$$

m_E < 500 GeV

Easy to have m_G > 3TeV

G and E are probably beyond the reach of LHC.

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Φ mixing with H125 (=h)

To avoid large mixing with H125, we need Z_2 under which Φ is odd and H is even. But the Yukawa coupling:

$$\mathcal{L} \subset \ (m_\Psi + y\Phi)\overline{Q}Q$$

breaks Z_2. → ***shifts in H→γγ/gg couplings by 1 - 10%***

The extra scalar boson may induce a strongly 1st-order electroweak phase transition, opening the possibility of ***electroweak baryogenesis***.

→ ***shifts in h→γγ/gg couplings by 5 - 10%***

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Vectorlike quark mixing with top

In ***Little Higgs theories*** and *certain versions of the* ***Randall-Sundrum model***, *vectorlike quarks with charge 2/3*—***top quark partners***—cancel the divergence in the Higgs boson mass coming from top quark loops and thus *are a crucial ingredient in* ***solving the hierarchy problem***.

→ ***Top partners mix with the top***

→ ***deviation in the ttZ couplings.***

Models with Extended Higgs Sector

SM + a Singlet Higgs Boson (Φ) + Vector-like fermions

An SU(2) singlet scalar boson has the same quantum numbers, after symmetry breaking, as the Higgs boson and, in general, cannot avoid mixing with the Higgs boson. For a 750 GeV singlet, PEW measurements require

$$sin^2\theta_m < 0.12$$

→ The ***6% decrease in the hWW and hZZ couplings at maximum***.

Neutral heavy vectorlike fermion = DM: 300 GeV < m_ψ < 450 GeV
→ ***Mono-photon search at 1TeV ILC***

SM + a Doublet Higgs Boson (2HDM) + Vector-like fermions (Φ=H or A)

Non-observation of Φ→ττ, tt at LHC → ***tanβ~7***

→ ***LHC "wedge" region where bb→H/A→ττ for $M_{H/A}$>500GeV is difficult to observe. gg→H/A→ττ might also be difficult.***

→ ***shifts in H125 to ττ and bb couplings.***

→ ***750GeV H/A well within 5σ reach of ILC (H20)***.

Φ = H+A (double resonances sitting close together)

→ ***PLC option with transverse photon polarizations to separate H/A***.

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Bound State of New Constituents

Φ = a bound state of heavy colored fermions

→ ***continuum production of the constituents should be discovered at the LHC.***
→ radiative corrections produce ***O(5%) shift in the hbb coupling***.
→ ***precision H125 measurement at ILC.***
→ oblique correction of ***O(1%)***.
→ ***deviations in 2-fermion scattering ($e^+e^- \to \mu^+\mu^-/e^+e^-$) at ILC.***

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Pion of a New Strong Interaction Sector

Φ = pNGB of *new strong interactions* at multi-TeV

→ ***Additional pNGBs are expected in the LHC range.***

Composite Higgs models, models of ***partial compositeness***, ***Little Higgs*** models or even ***Twin Higgs*** models, are all having ***particular patterns of deviations in the Higgs (and also top) couplings***.

DM = the lightest pNGB → might be enhancing the Φ width (Φ→***DM DM)***
→ $m_{DM} < m_\Phi/2$

Thermal relic abundance of dark matter is correct for m_{DM} **~300 GeV**. If there are two pNGBs close in mass, so that the relic abundance is set by coannihilation, ***m_{DM} <100 GeV is favored*** (arXiv:1602.07297) → ***within the reach of 500 GeV ILC.***

(750 GeV) effects @ FCC-ee reach

	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.

LCC physics WG, to appear

(750 GeV) effects @ FCC-ee reach

LINEAR COLLIDER COLLABORATION

LC and X750: summary

- LC can elucidate the physics behind X750 by precision measurement on Higgs, top etc.

FCC-ee + EW precision measurements (test of SM structure)

- LC may be able to discover new particles related to X750 within its energy reach

- With energies ~1 TeV and above, LC could produce X750 directly through $\gamma\gamma$ option or e+e- at high energy

Provides excellent complementarity to LHC

H. Yamamoto @ Santader'16

(750 GeV) effects @ FCC-ee reach

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Provides excellent complementarity to LHC

many arguments apply to FCC-ee

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