Future Colliders: physics case and status of the Linear Collider

Juan A. Fuster Verdú, IFIC-València

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Thanks: P. Burrows,T. Behnke, K. Fujii, C. García, J. List, D. Melini, M. Stanitzki,H. Yamamoto…

Thanks to the organizers for the invitation to give this talk at the CTEQ-Mcnet School

(Sorry to not have shared more time with you)

Outline

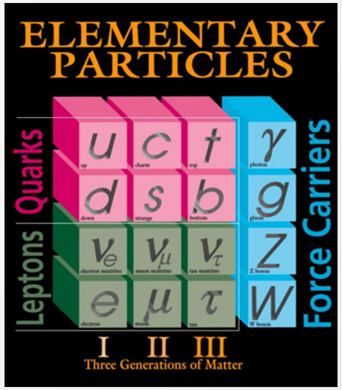
- Introduction
- Brief overview of future circular colliders; CepC/SppC & FCC-ee/hh
- The Linear Collider: ILC & CLIC
  - Accelerator
  - Physics case
  - Detectors
  - Situation in Japan
- Summary & conclusion

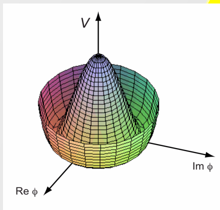
Standard Model

$$\mathcal{L}_{SM} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \mathcal{L}_{Yukawa}$$

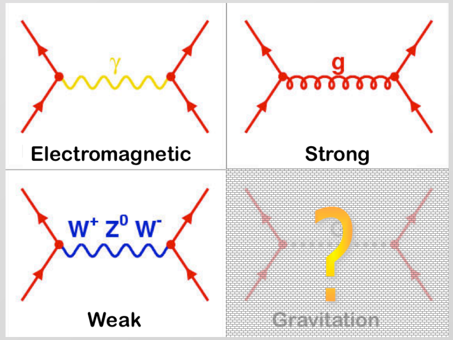
Symmetry

(~1980)





Higgs: EWSB



Particles

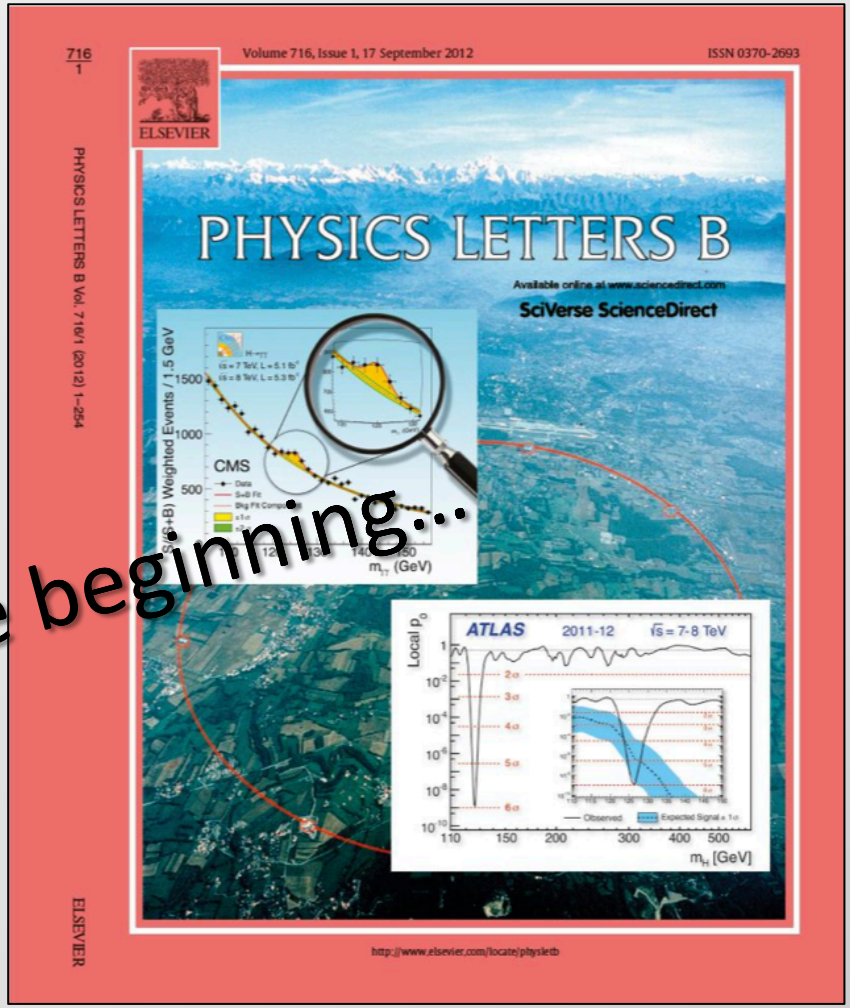
Interactions/Forces

Standard Model: Higgs-H(125) discovery

ATLAS y CMS
"Higgs-H(125) discovery"
Phys. Lett. B716 (2012)
4 Julio 2012

Physics Letters B cover

…this the beginning…



G-fitter experimental inputs

Fit is overconstrained

- all free parameters measured
  - most input from e^+e^- colliders
    - M_Z : $2 \cdot 10^{-5}$
  - but crucial input from hadron colliders:
    - m_t : $4 \cdot 10^{-3}$
    - M_H : $2 \cdot 10$…
    - M_W…
  - re… …al
    pre…
- require… …on calculations!

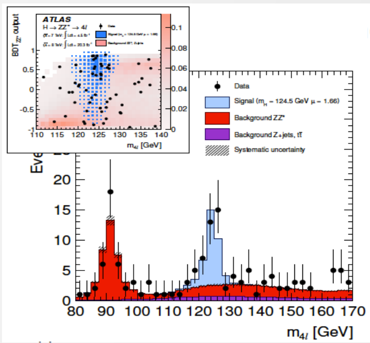
M_H [GeV]$^{(\circ)}$	125.14 ± 0.24	LHC
M_W [GeV]	80.385 ± 0.015	Tev.
Γ_W [GeV]	2.085 ± 0.042	
M…	…1.1875 ± 0.0021	LEP
[illegible]	…4952 ± 0.0023	
[illegible]	…40 ± 0.037	
[illegible]	…767 ± 0.025	
[illegible]	0.0171 ± 0.0010	
[illegible]	0.1499 ± 0.0018	SLD
…$_{\text{eff}}(Q_{\text{FB}})$	0.2324 ± 0.0012	
A_c	0.670 ± 0.027	SLD
A_b	0.923 ± 0.020	
$A_{\text{FB}}^{0,c}$	0.0707 ± 0.0035	LEP
$A_{\text{FB}}^{0,b}$	0.0992 ± 0.0016	
R_c^0	0.1721 ± 0.0030	
R_b^0	0.21629 ± 0.00066	
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]	173.34 ± 0.76	Tev.+LHC
$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$	2757 ± 10	

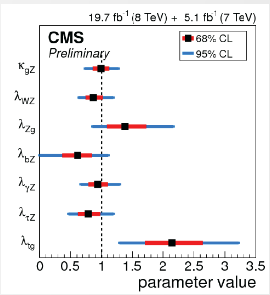
e+e- and polarization, many years later, still fundamental to constraint the Standard Model

R. Kogler G fitter 2016, FCC-Rome

The open questions about the “H(125)” :

1. is it the boson of the (minimal) Standard Model ?
2. is it an elementary or composite particle ?
3. is it unique/solitary ?
4. is it natural ?
5. is it the first supersymmetric particle ever observed ?
6. is it really “responsible” for the masses of all elementary particles ?
7. is it mainly produced by top quarks or by new heavy vector-like particles ?
8. is it at the origin of the matter-antimatter asymmetry ?
9. has it driven the inflationary expansion of the Universe ?





Ch. Grojean (ICHEP 2014) - S. Heinemeyer (KET 2016)

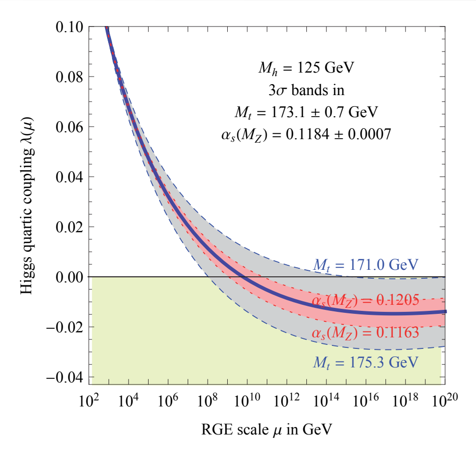
Need for precision and model independent tests

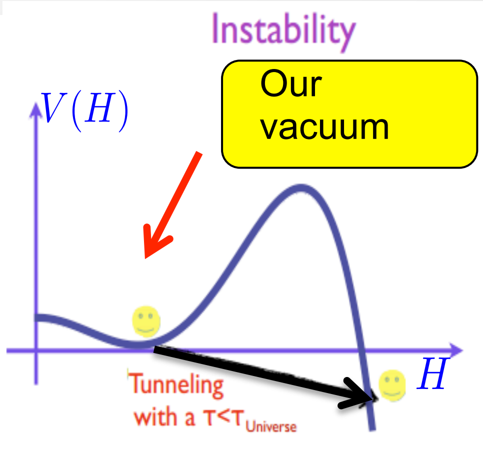
Stability of the Higgs potential

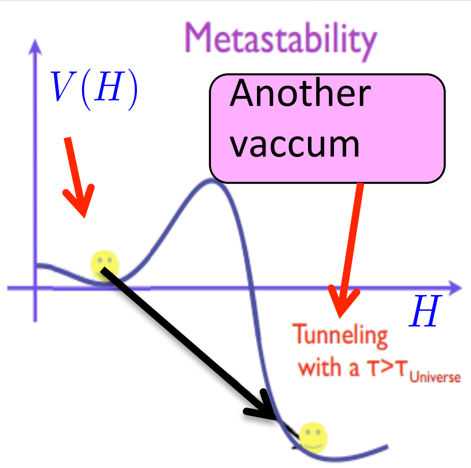
Vacuum Stability ($\lambda(\Lambda) \geq 0$)

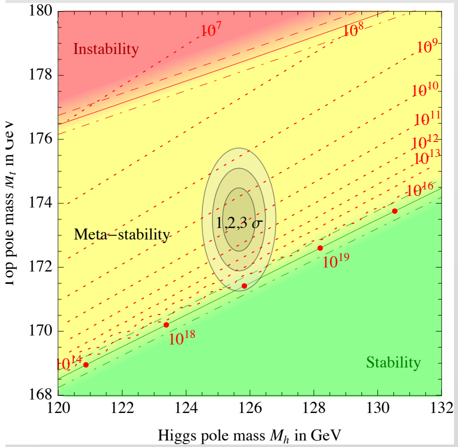
$\lambda(\Lambda)$ the $\overline{\text{MS}}$ quartic Higgs Coupling

Degrassi et al, **JHEP 1208 (2012) 098**
Butazzo et al, **1307.3536 (2013)**









Assume SM valid up to $\Lambda \leq M_{\text{planck}}$

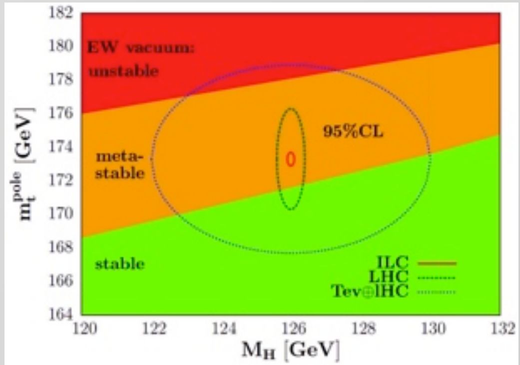
Alekhin et al, **Phys.Lett. B716 (2012) 214**

M_t = (173.35 ± 0.72) GeV $\longrightarrow$ M_h > (129.6 ± 1.5) GeV

M_h = (125.66 ± 0.34) GeV $\longrightarrow$ M_t < (171.36 ± 0.46) GeV

Take M_t from ttbar+1jet (pole mass)

M_t = (173.3 ± 2.1) GeV $\longrightarrow$ M_h > (129.4 ± 4.2) GeV



Need to measure M_t (in a well defined mass scheme) with high accuracy

ΔM_t < 150 MeV

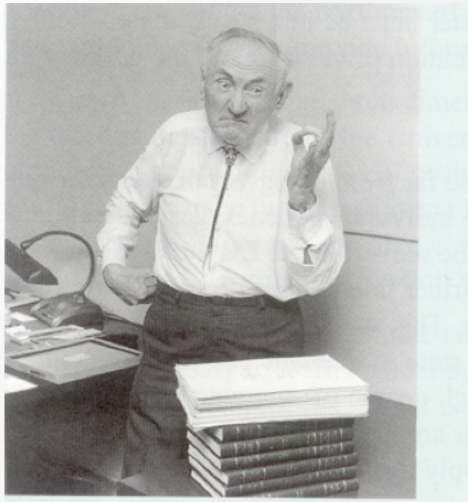
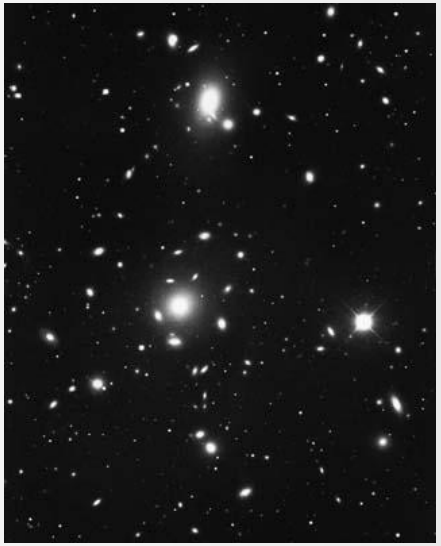


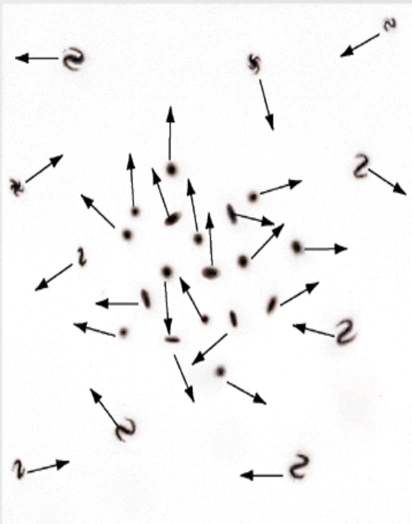
Figure 4.6 Fritz Zwicky (1898 – 1974). (California Institute of Technology)

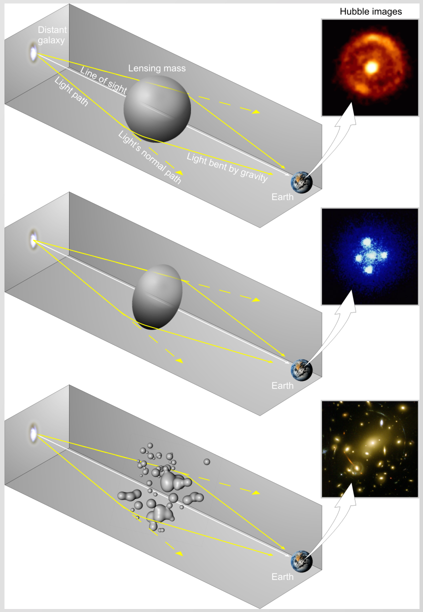
1930s: Fritz Zwicky, studied the Coma galaxy cluster infering the existence of unseen matter, which he referred to as *dunkle Materie* “Dark Matter”.

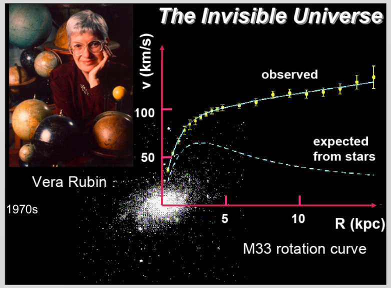
Since then many other observations confirm the existence of “Dark Matter” (gravitational lenses).

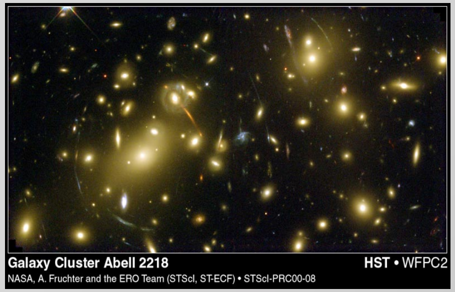
No candidate for “Dark Matter” in the SM



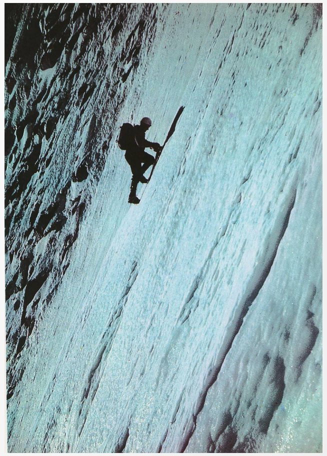




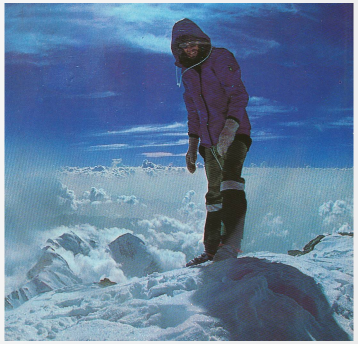




H(125) discovered and new challenges appear



Long and successful scientific programme, many studies, resources, and investigations during years of research in theory and experiment (PETRA, PEP, Babar, Belle, HERA, LEP, Tevatron, LHC, etc..) have led to build up the Standard Model



Reinhold Messner

Culminated with the discovery of H(125)

But.. this is just one more “step” which allows us to have a “better view” of what is next.

- One question answered, H(125)
- Many old questions remain (DM, etc..)
- New questions open

H(125) discovered and new challenges appear

Fundamental questions to answer:

- What establishes the Higgs mass ?, is it elementary/composite ?
- Which is the mechanism behind electroweak symmetry breaking ? (one or more Higgs)
- What is the nature of Dark Matter ?
- What drives inflation ?
- Why the Universe is made out of matter ?

Our (main) tools in High Energy Physics:

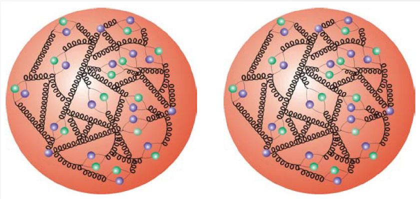
- H(125)

- Top quark
- W/Z bosons

- Searches for new physics – new particles

Our instruments: present/future colliders + detectors

Proton proton collisions

p  p

LHC

ATLAS EXPERIMENT

CMS

Running!

Today: ~30 fb^{-1} @ 7/8 TeV

~2021 300 fb^{-1} @ 13/14 TeV

~2035 3000 fb^{-1} @ 14 TeV HL-LHC

Proposal: FCC-hh @100 TeV

HE-LHC

Electron positron collisions

e^+ • • e^-

Linear colliders:

TDR ilc 250...500...1000 GeV

CDR clic 250...1500...3000 GeV

Circular colliders:

Proposal
CepC 90..250 GeV (50 km)
FCC-ee 240..350 GeV (80 km)

(other: γγ→H, ep→H+X, μμ→H)

Roman soldiers were making fun of an espartan as

he was a lame person and was going to a battle

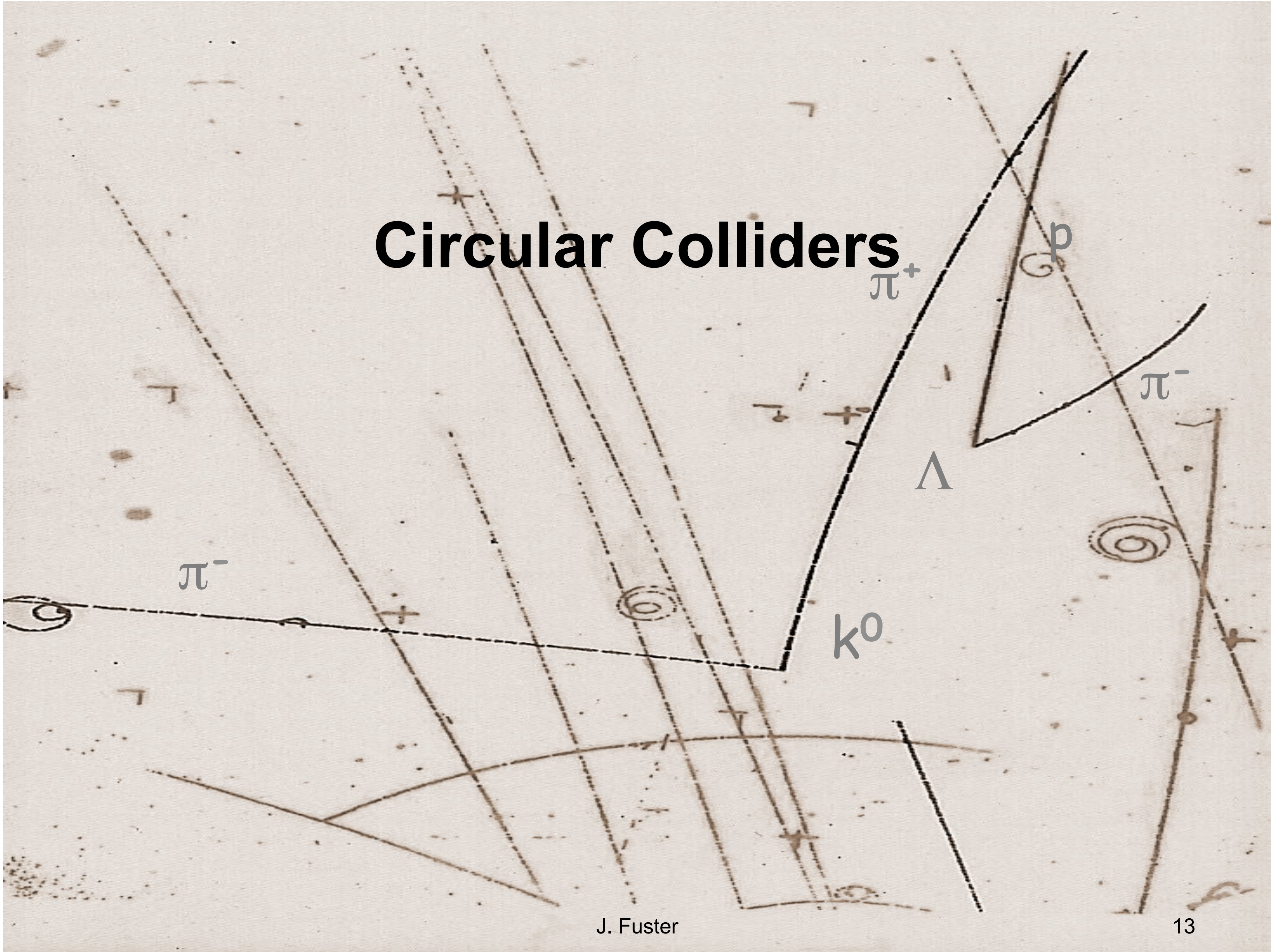
His answer was:

"my mission is to fight not to run, not to get away"

Valerio Máximo, year 31

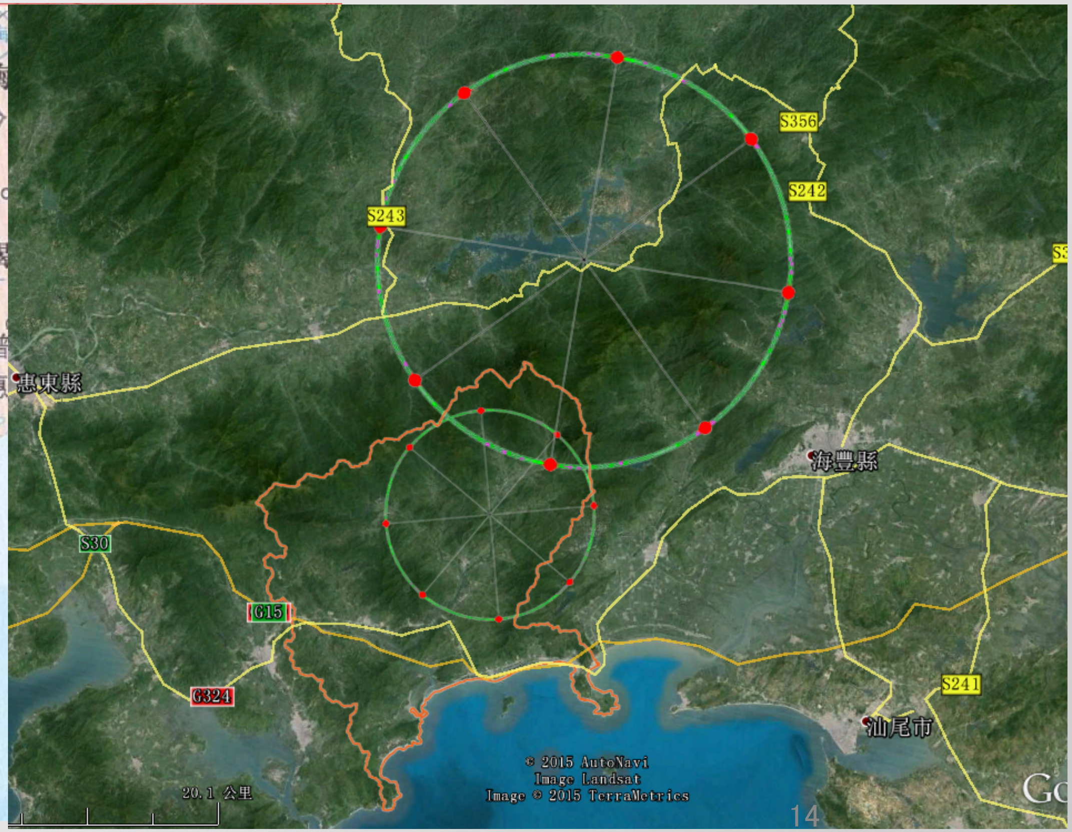
Factorum et dictorum memorabilium

Circular Colliders



CepC: Site selection

- Continue to work on site selection
- Previously investigated: 300 km north-east of Beijing
- A new possibility close to Hong Kong, invited by the local government



CepC: Accelerator parameters

	Pre-CDR	**H-high lumi.**		**H-low power**		**Z**
Number of IPs	2	2		2		2
Energy (GeV)	120	120		120		45.5
Circumference (km)	54	54		54		54
SR loss/turn (GeV)	3.1	2.96		2.96		0.062
Half crossing angle (mrad)	0	14.5	15	11.5	15	15
Bunch number	50	50	67	40	44	1100
Beam current (mA)	16.6	16.9	16.9	10.1	10.5	45.4
SR power /beam (MW)	51.7	50	50	30	31.2	2.8
Energy spread (%)	0.13	0.13	0.13	0.13	0.13	0.05
Energy acceptance (%)	2	2	2	2	2	
Life time due to beamstrahlung (minute)	47	53	36	41	32	
F (hour glass)	0.68	0.73	0.82	0.69	0.81	0.95
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	2.97	2.96	2.03	2.01	3.61

Y. Wang 2016, KET Munich

- **CEPC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
      - **Pre-CDR for R&D funding request**
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2028-2035
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2035-2042
  - Data taking: 2042 -

Y. Wang 2016, KET Munich

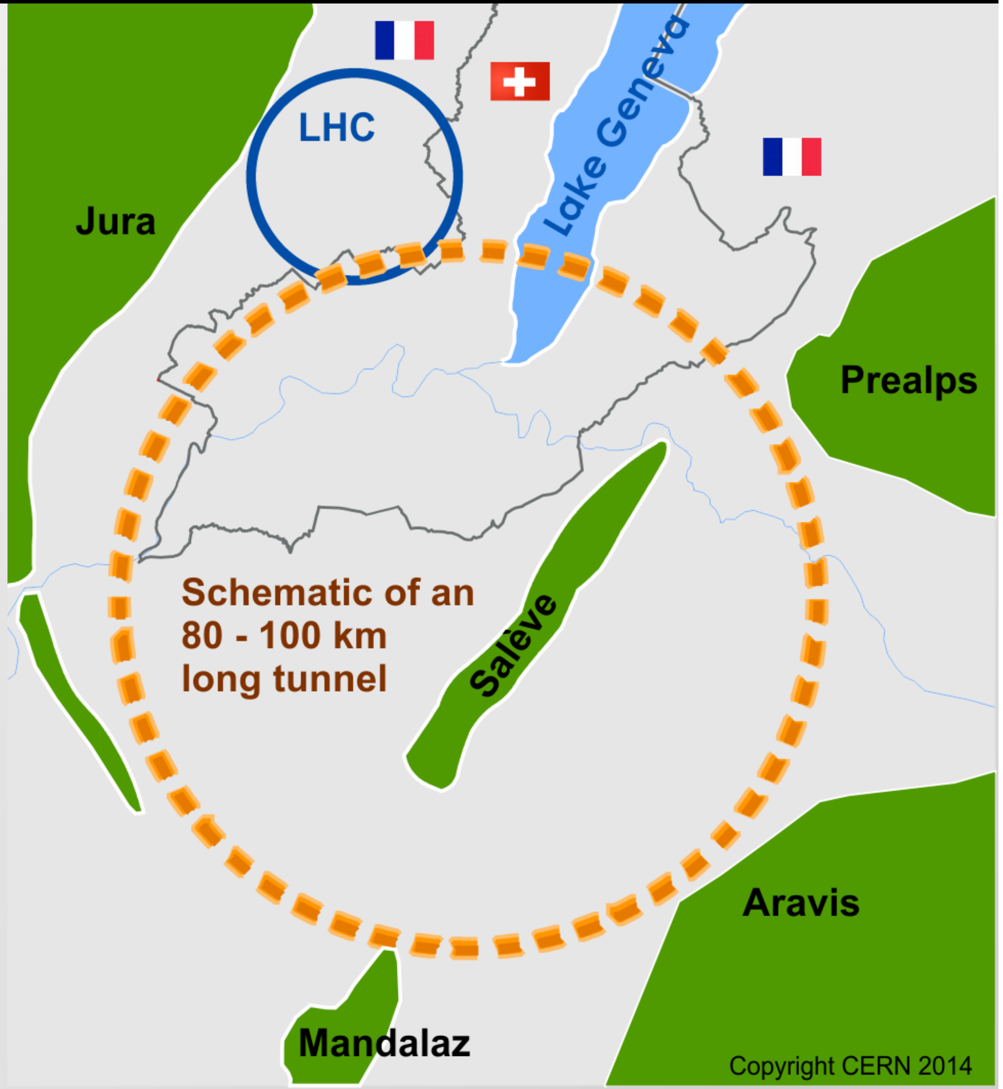
Future Circular Collider Study
GOAL: CDR and cost review for the next ESU (2019)

International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

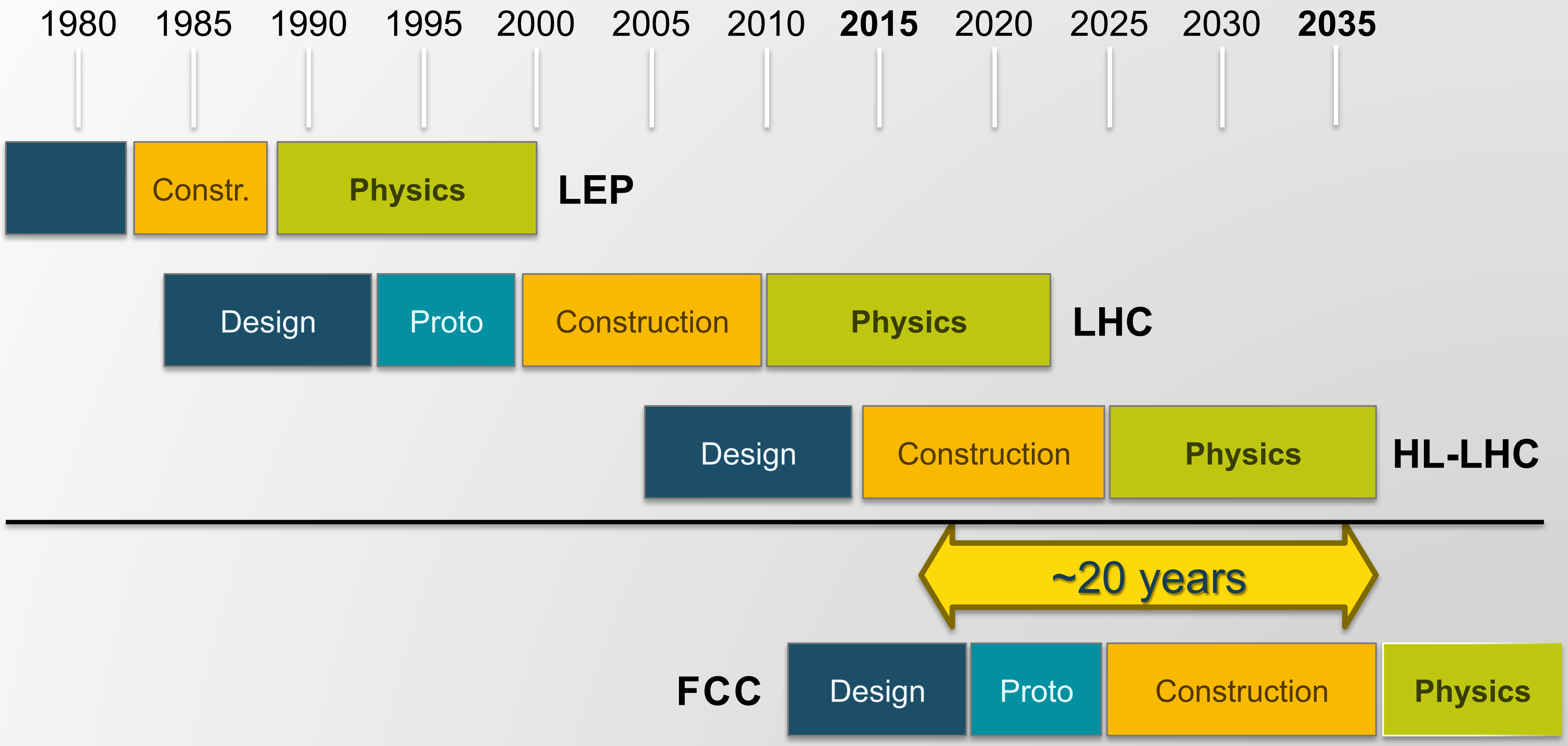
  ~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km tunnel infrastructure** in Geneva area, site specific
- ***e⁺e⁻* collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, FCC-hh & ERL
- **HE-LHC** with *FCC-hh* technology



M. Benedikt 2016, PECFA Gran Sasso

CERN Circular Colliders & FCC



Must advance fast now to be ready for the period 2035 – 2040
Goal of phase 1: CDR by end 2018 for next update of European Strategy

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Hadron collider parameters

parameter	FCC-hh		SPPC	HE-LHC* *tentative	(HL) LHC
collision energy cms [TeV]	100		71.2	>25	14
dipole field [T]	16		20	16	8.3
circumference [km]	100		54	27	27
# IP	2 main & 2		2	2 & 2	2 & 2
beam current [A]	0.5		1.0	1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25	25
beta* [m]	1.1	0.3	0.75	0.25	(0.15) 0.55
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	12	>25	(5) 1
events/bunch crossing	170	<1020 (204)	400	850	(135) 27
stored energy/beam [GJ]	8.4		6.6	1.2	(0.7) 0.36
synchrotr. rad. [W/m/beam]	30		58	3.6	(0.35) 0.18

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FCC-ee: accelerator parameters

parameter	FCC-ee					LEP2
physics working point	**Z**		**WW**	**ZH**	**tt_{bar}**	
energy/beam [GeV]	**45.6**		**80**	**120**	**175**	105
bunches/beam	30180	**91500**	**5260**	**780**	**81**	4
bunch spacing [ns]	7.5	**2.5**	**50**	**400**	**4000**	22000
bunch population [10^{11}]	1.0	**0.33**	**0.6**	**0.8**	**1.7**	4.2
beam current [mA]	1450	**1450**	**152**	**30**	**6.6**	3
luminosity/IP x $10^{34}cm^{-2}s^{-1}$	210	**90**	**19**	**5.1**	**1.3**	0.0012
energy loss/turn [GeV]	0.03	**0.03**	**0.33**	**1.67**	**7.55**	3.34
synchrotron power [MW]	**100**					22
RF voltage [GV]	0.4	**0.2**	**0.8**	**3.0**	**10**	3.5
rms cm *E* spread SR [%]	0.03	**0.03**	**0.05**	**0.07**	**0.10**	0.11
rms cm *E* spread SR+BS [%]	0.15	**0.06**	**0.07**	**0.08**	**0.12**	0.11

F. Zimmermann 2016, KET Munich

- **physics programs / energies:**
  - ***Z (45.5 GeV) Z pole,*** *'TeraZ' and high precision M_Z & Γ_Z*
  - ***W (80 GeV) W pair production*** *threshold, high precision M_W*
  - ***H (120 GeV) ZH production*** *(maximum rate of H's)*
  - ***t (175 GeV): $t\bar{t}$ threshold***, *H studies*
- **beam energy range from 35 GeV to ≈200 GeV**
- **highest possible luminosities** *at all working points*
- possibly ***H* (63 GeV) direct *s*-channel** production with **monochromatization** (**c.m. energy spread <6 MeV**, presentation at IPAC'16)
- **beam polarization up to ≥80 GeV** for beam energy calibration

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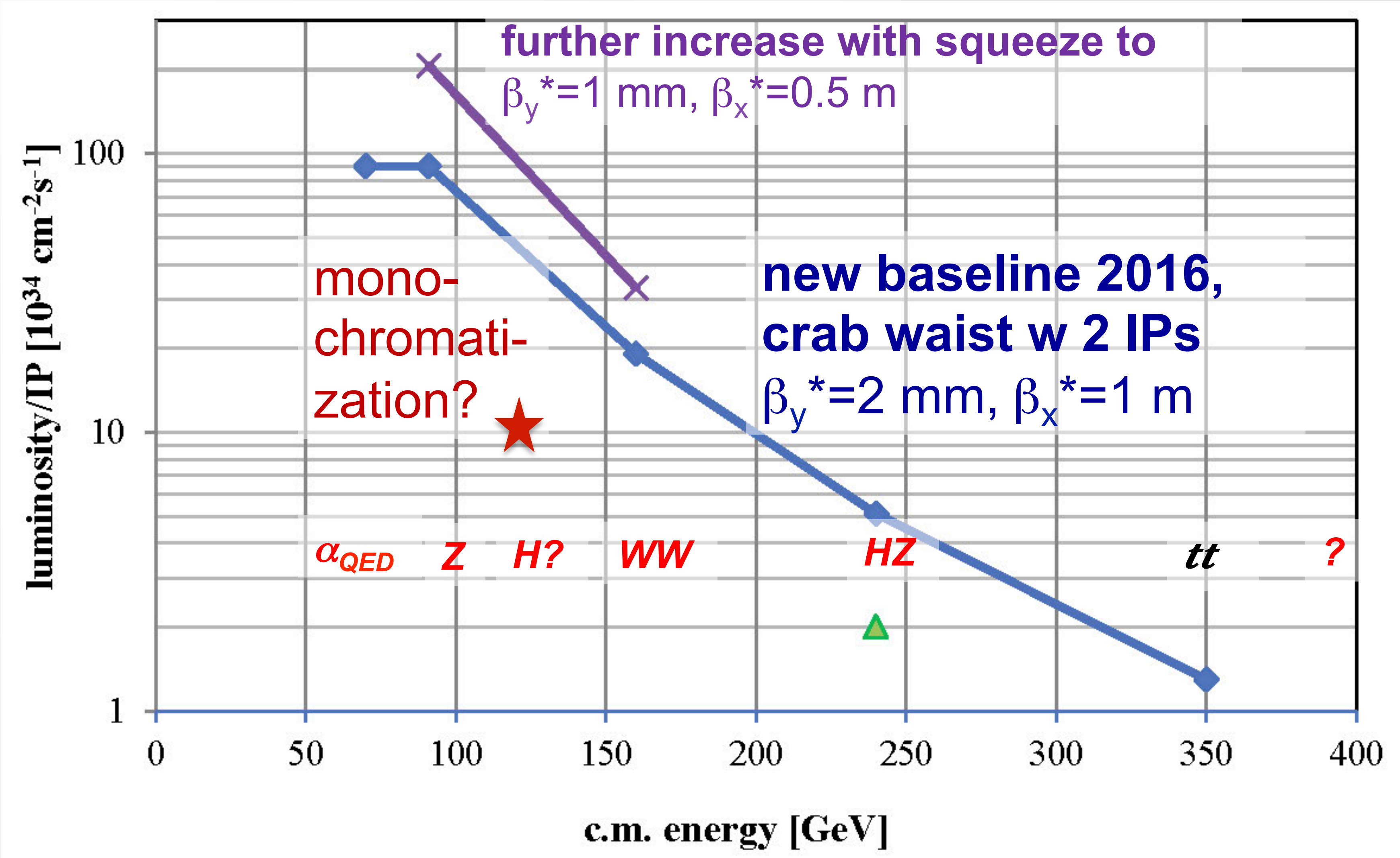
FCC-ee: physics requirements



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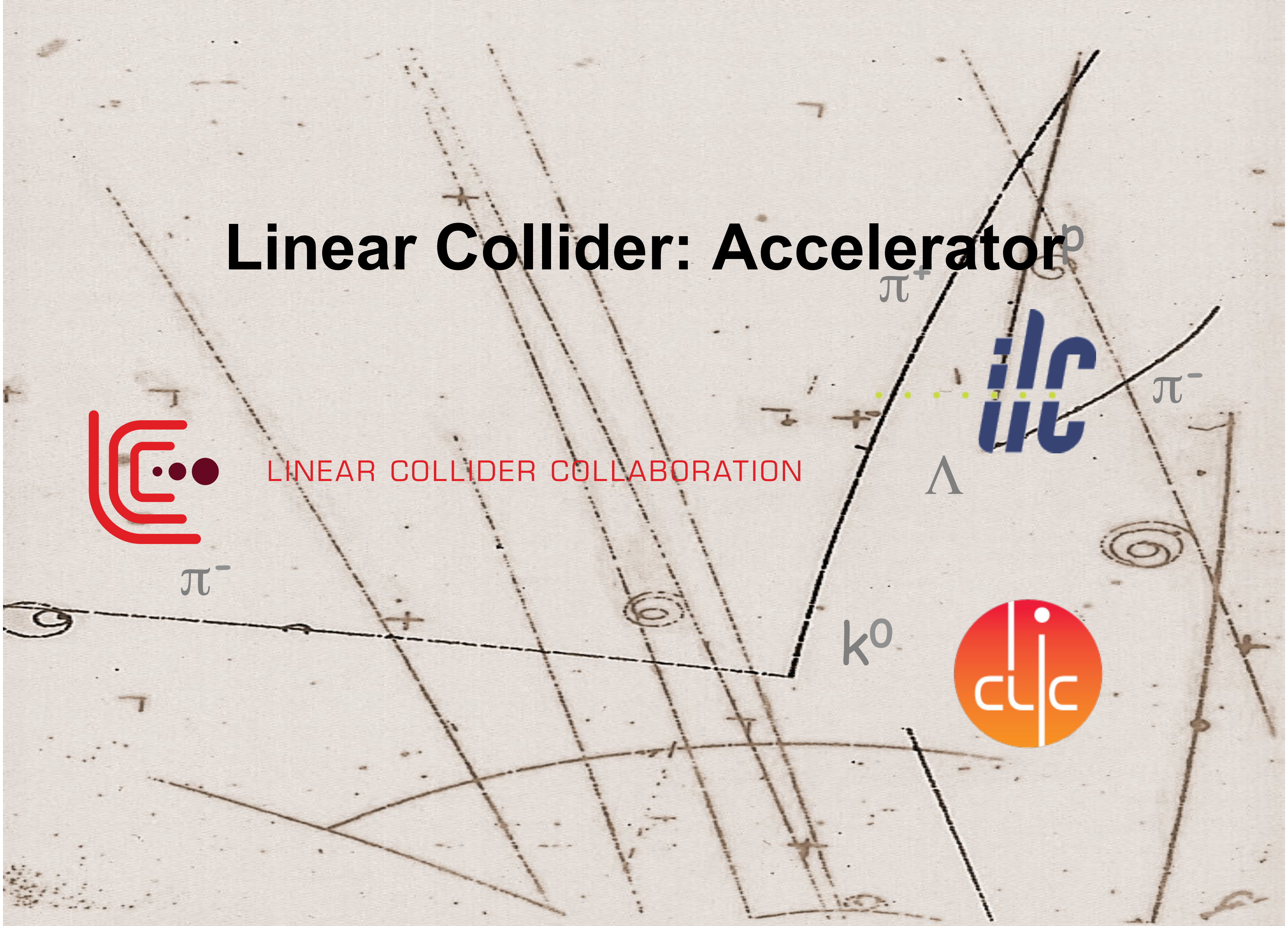
Linear Collider: Accelerator



ICFA
Chair: J. Mnich

FALC
Chair: J. Womersley

Program Adv. Committee
PAC – Chair: N. Holtkamp

Linear Collider Board
LCB – Chair: S. Komamiya

KEK

KEK LC Project Office

Regional Directors
B. Foster (EU)
H. Weerts (AMs)
A. Yamamoto (AS)

Linear Collider Collab.
LCC Directorate
Director: L. Evans

Deputy (Physics)
H. Murayama

ILC
M. Harrison
(Deputy) H. Hayano, N. Walker

CLIC
S. Stapnes

Physics & Detectors
H. Yamamoto

The Linear Collider Collaboration: LCB members

5 members x 3 regions + chair = 16 members + secretary

Chair Sachio Komamiya (The University of Tokyo)

Americas Jonathan Bagger (TRIUMF)
Nigel Lockyer (Fermilab Director)
David MacFarlane (SLAC)
Lia Merminga (TRIUMF)
Hugh Montgomery (Jefferson Lab)

Asia Jie Gao (IHEP, Beijing)
Rohini Godbole (Indian Institute of Science)
Sunkee Kim (RISP)
Atsuto Suzuki (KEK Director)
Yifang Wang (IHEP Director)

Europe Fabiola Gianotti (CERN Director-General)
Joachim Mnich (DESY Director of Particle Physics)
Victor Mateev (JINR Director)
Francois Le Diberder (IN2P3)
Lenny Rivkin (PSI)

Nominated by ECFA

Secretary Roy Rubinstein / Pushpa Bhat

Present LCC/LCB mandate and structure has been extended by ICFA to end of 2016.
Common fund was also approved by FALC till 2016.

February 25-26, 2016, KEK Tokai Campus

- At the recent 76th ICFA meeting, the committee discussed how to keep the ILC effort beyond the current mandate of LCB which was extended to the end of 2016.
- The committee decided that the international effort, led by ICFA, for an ILC in Japan should continue and set up a subgroup that will work on a new mandate and structure, to be proposed at the next ICFA meeting in August 2016.
- **Subgroup composition:** J. Mnich (DESY-ICFA), F. Gianotti (CERN), N. Lockyer (Fermilab), M. Yamauchi (KEK)

Press conference in Tokyo after the ICFA meeting

The Linear Collider Collaboration: European LC Forum

ECFA European Committee for Future Accelerators

European LC Forum

Purpose

Act as a bidirectional information channel from the European members of the LCB to the Linear Collider community in Europe.

Membership

- Senior members of the European Linear Collider community will be invited to join and participate in the forum. *(i.e. start with the list of colleagues nominated through RECFA)*
- The forum is open to all members of the European Linear Collider community. A web based application procedure will be implemented. *(e.g. a moderator/secretary decides to accept or reject an application, to prevent abuses)*

Activities

- Create a web space to share relevant documents from the LCB
- Organise regular video meetings before/after LCB meetings

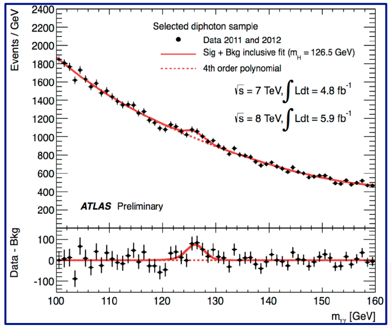
November 21/22 2013 94nd Plenary ECFA CERN 17

M. Krammer – PECFA, Nov 2013 (ECFA chair at this time)

ILC accelerator: roadmap

1980 ~
- Basic Study started

2004
- SCRF Technology selected



Higgs discovered

LHC

2005 2006 2007 2008 2009 2010 2011 2012 2013

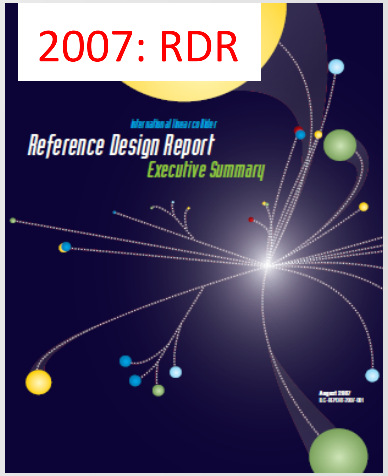
ILC - GLOBAL DESIGN EFFORT (GDE)

LCC

Linear Collider Collaboration

Ref. Design Report (RDR)

2007: RDR



2013: TDR

COMPLETED

A. Yamamoto - ICHEP 2014

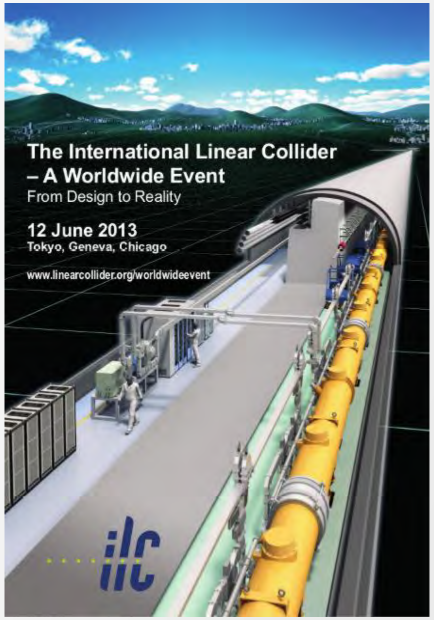
J. Fuster

ILC: From Design to reality

Official Completion of ILC TDR

"From Design to Reality"

June 12, 2013:



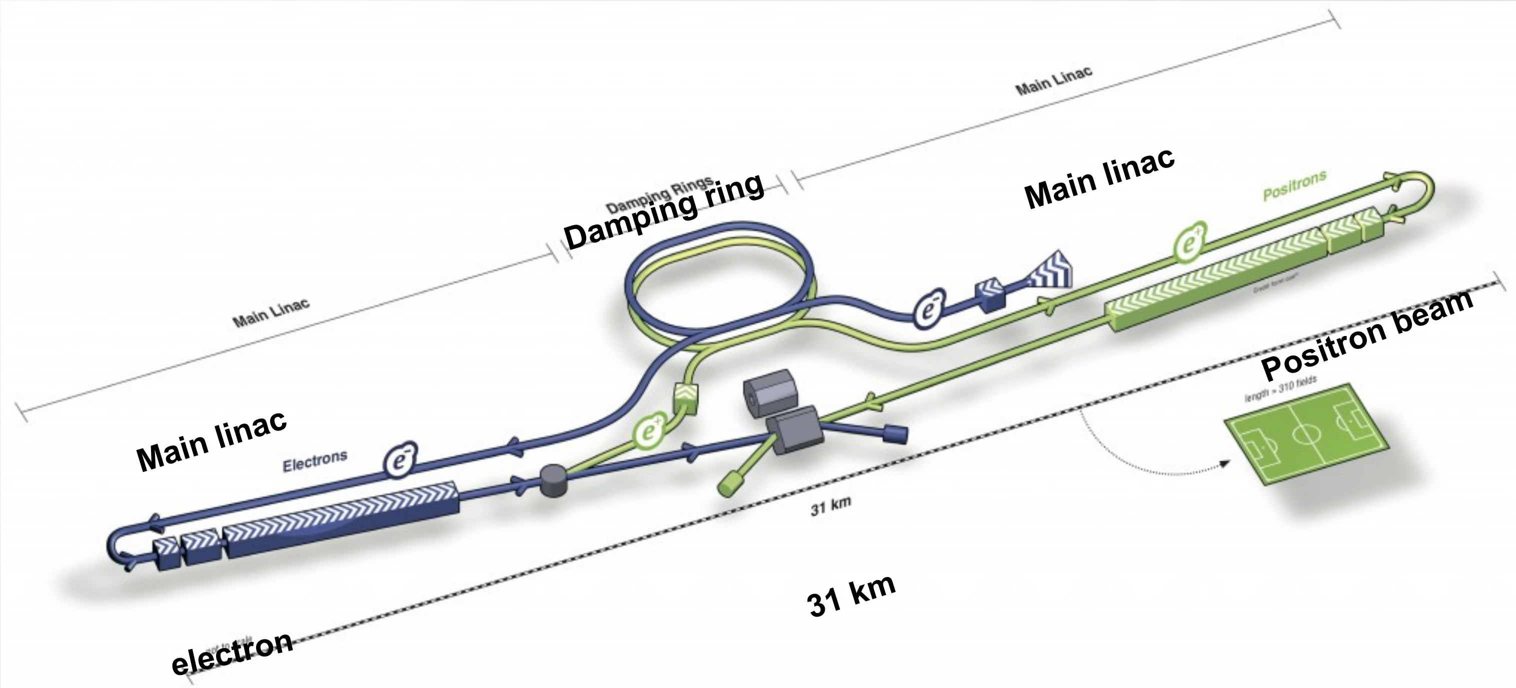
TDR handed to LCC Director Lyn Evans

ILC TDR published in a Worldwide Event:

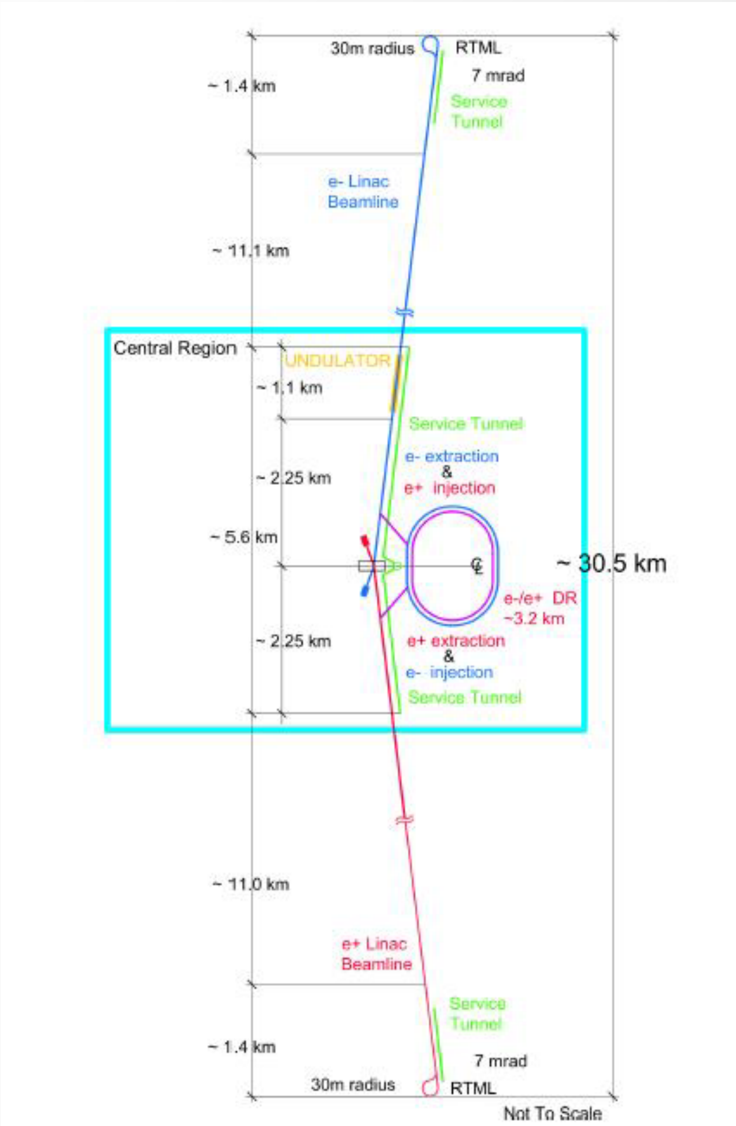
Tokyo → Geneva → Chicago

A. Yamamoto - ICHEP 2014

ILC (International Linear Collider)



- 500 GeV CM with 31 km → upgrade later to ~ 1TeV CM with 50 km
- Beam size at IP : 6 nm x 500 nm x 300 mm
- Luminosity ~ 2 x 10^{34} /cm^2s with the possibility to increase (x2)
- Polarization >80% e^-; 30-40% e^+



S. Komamiya - LP 2015

- Main advantages (linear colliders):
  - No energy loss due to synchrotron radiation ($\Delta E \sim (E/m)^4 R^{-1}$)
  - Extendibility (Length ~ Energy)
  - Polarization
  - Energy scanning

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8×10^{34} cm^{-2}s^{-1}
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
FF beam size (y)	**5.9** nm
E gradient in SCRF acc. cavity	**31.5** MV/m +/-20% Q_0 = 1E10

Demonstrated in TDR

Progress in 2014-2015

The ILC accelerator: SRF facilities worldwide

AMTF @DESY/E-XFEL, CM *STF-CFF @ KEK* *ASTA @ FNAL, TEDF @ JLab*

The ILC accelerator: SRF facilities worldwide

AMTF @DESY/E-XFEL, CM

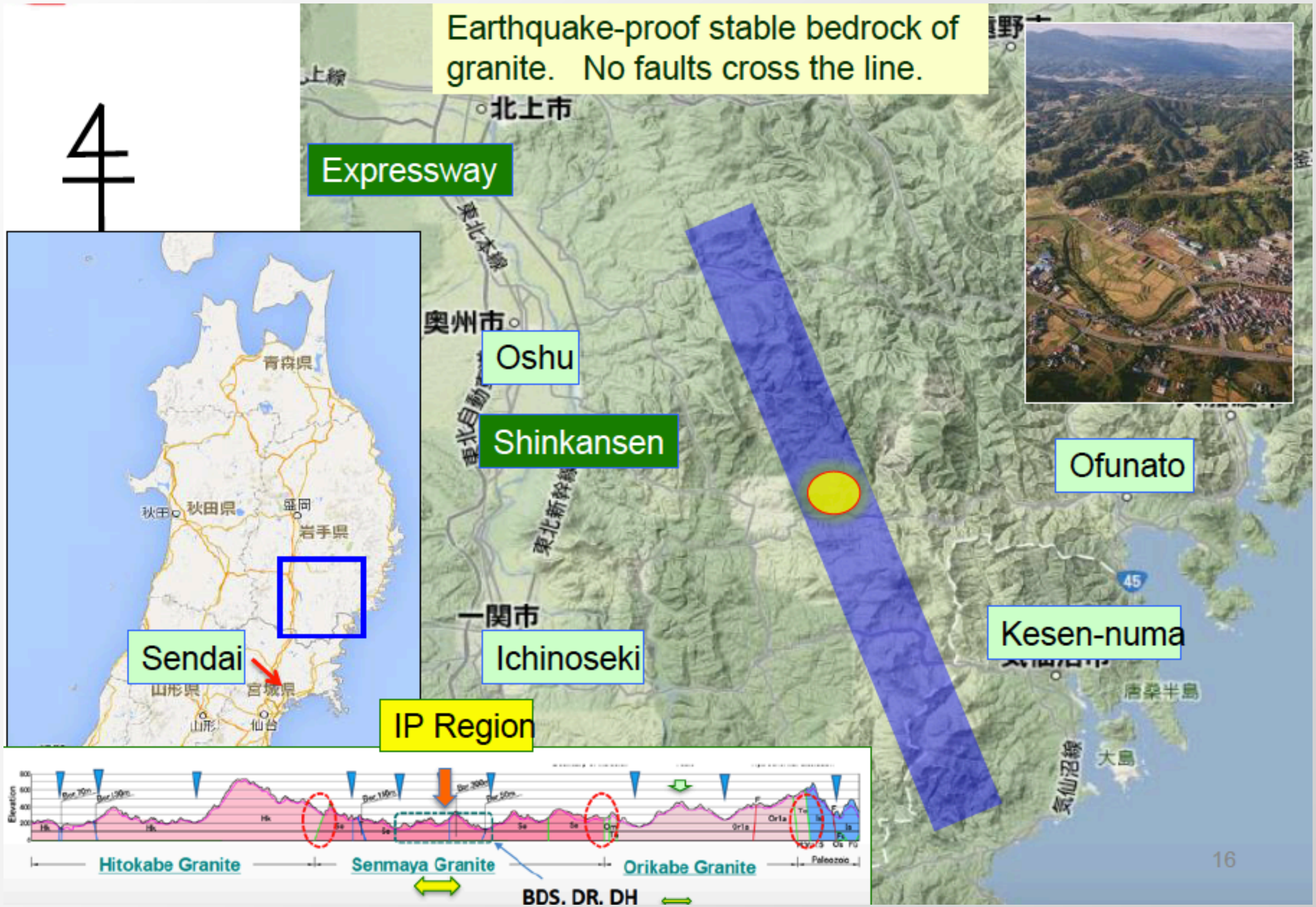
700 out of 800 cavities completed <30 MV/m>

STF-CFF @ KEK

Individual cavity gradient of 35 MV/m

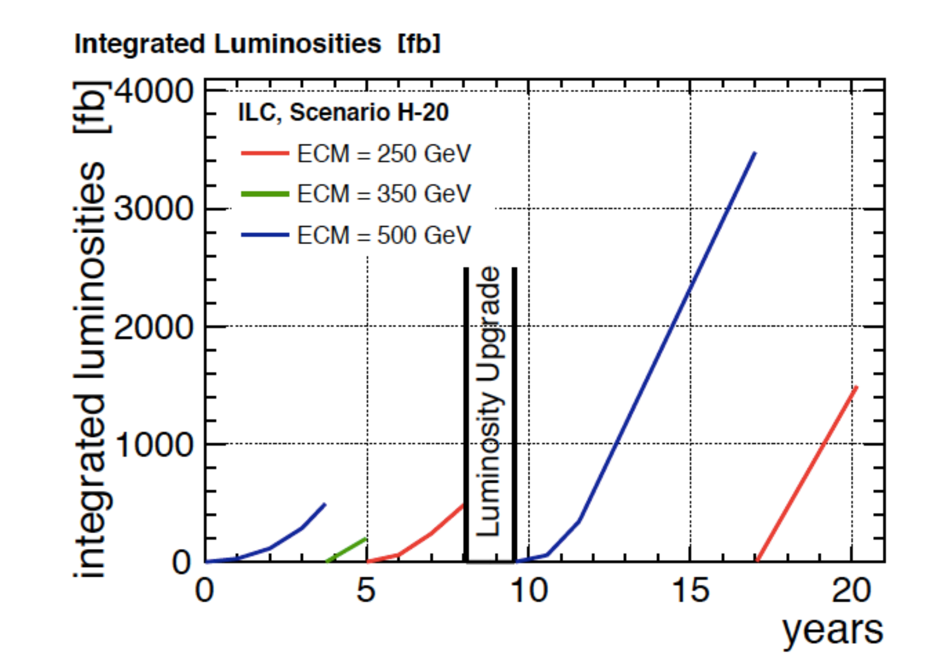
ASTA @ FNAL, TEDF @ JLab

Crymodule test facility at Fermilab reached <31.5 MV/m> exceeding ILC expects



Earthquake-proof stable bedrock of granite. No faults cross the line.
北上市
Expressway
奥州市
Oshu
Shinkansen
東北新幹線
Ofunato
一関市
Ichinoseki
Kesen-numa
唐桑半島
大島
青森県
秋田県
岩手県
Sendai
宮城県
仙台
IP Region
Hitokabe Granite
Senmaya Granite
Orikabe Granite
BDS. DR. DH
16

	Stage	500			500 LumiUP		
Scenario	$\sqrt{s}$ [GeV]	500	350	250	500	350	250
G-20	$\int \mathscr{L} dt$ [fb^{-1}]	1000	200	500	4000	-	-
	time [years]	5.5	1.3	3.1	8.3	-	-
H-20	$\int \mathscr{L} dt$ [fb^{-1}]	500	200	500	3500	-	1500
	time [years]	3.7	1.3	3.1	7.5	-	3.1



T. Barklow et al., arXiv:1506.07830

Recommended scenario (~20 years program):

- Starting at 500 GeV (500 fb^{-1}), then 350 (200 fb-1) and 250 GeV (500 fb^{-1}).
- Luminosity upgrade (1312 → 2625 bunches per pulse) then 3500 fb^{-1} at 500 GeV and 1500 fb^{-1} at 250 GeV.

Obviously, actual running scenario will depend on physics outcomes from LHC and ILC, and other factors

Phil Burrows (LCWS 2015)

Lucie Linssen (LHCP 2015)

- e^+e^- collisions $\sqrt{s}$ up to 3 TeV
- Luminosity: a few 10^{34} $cm^{-2}s^{-1}$
- Physics operation 350 GeV - 3 TeV
- 2-beam acceleration scheme
- At room temperature
- Gradient 100 MV/m
- Conceptual Design Report published in 2012

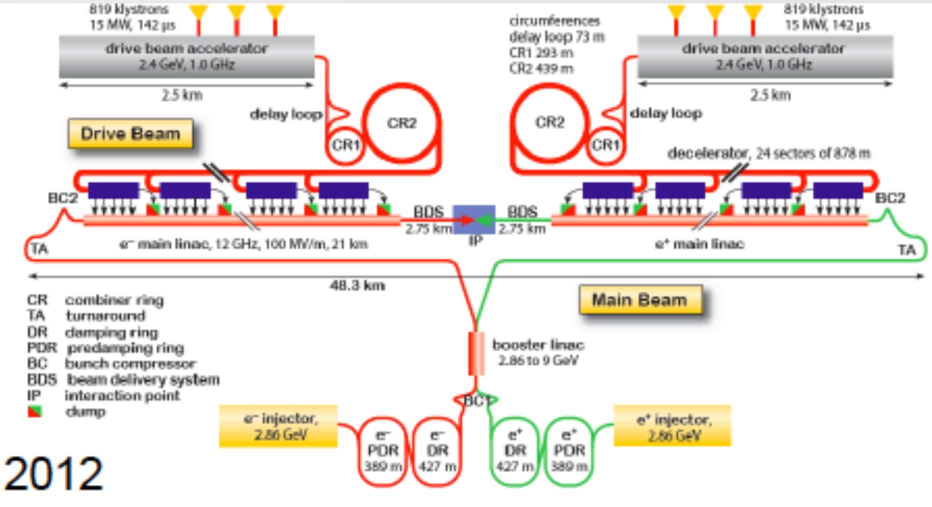
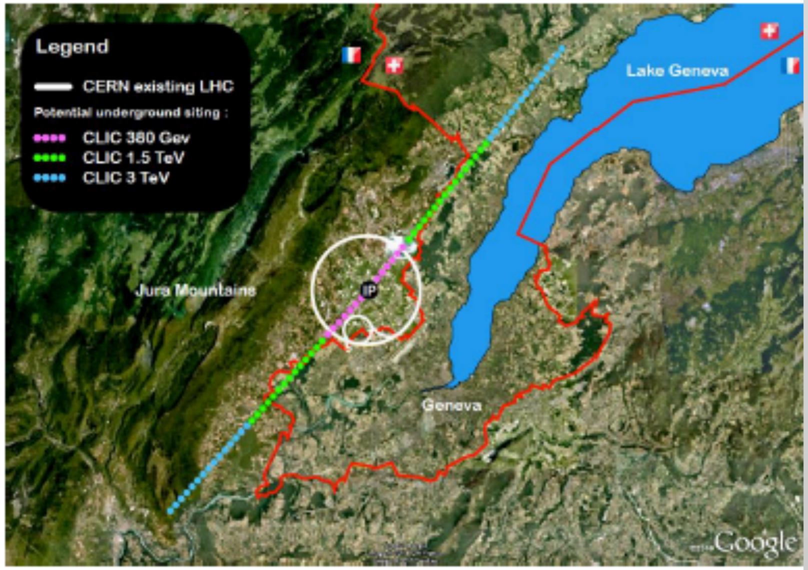
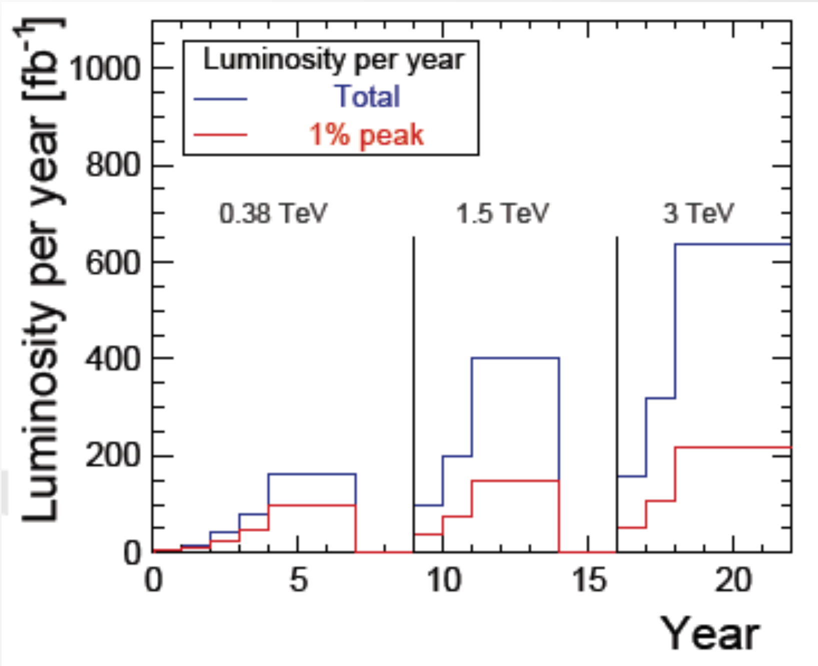


Fig. 3.1: Overview of the CLIC layout at $\sqrt{s} = 3$ TeV.

Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of $\sqrt{s}$	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	48



Current CLIC run model



Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{\text{int}}$ (fb^{-1})
1	380	500
	350	100
2	1500	1500
3	3000	3000

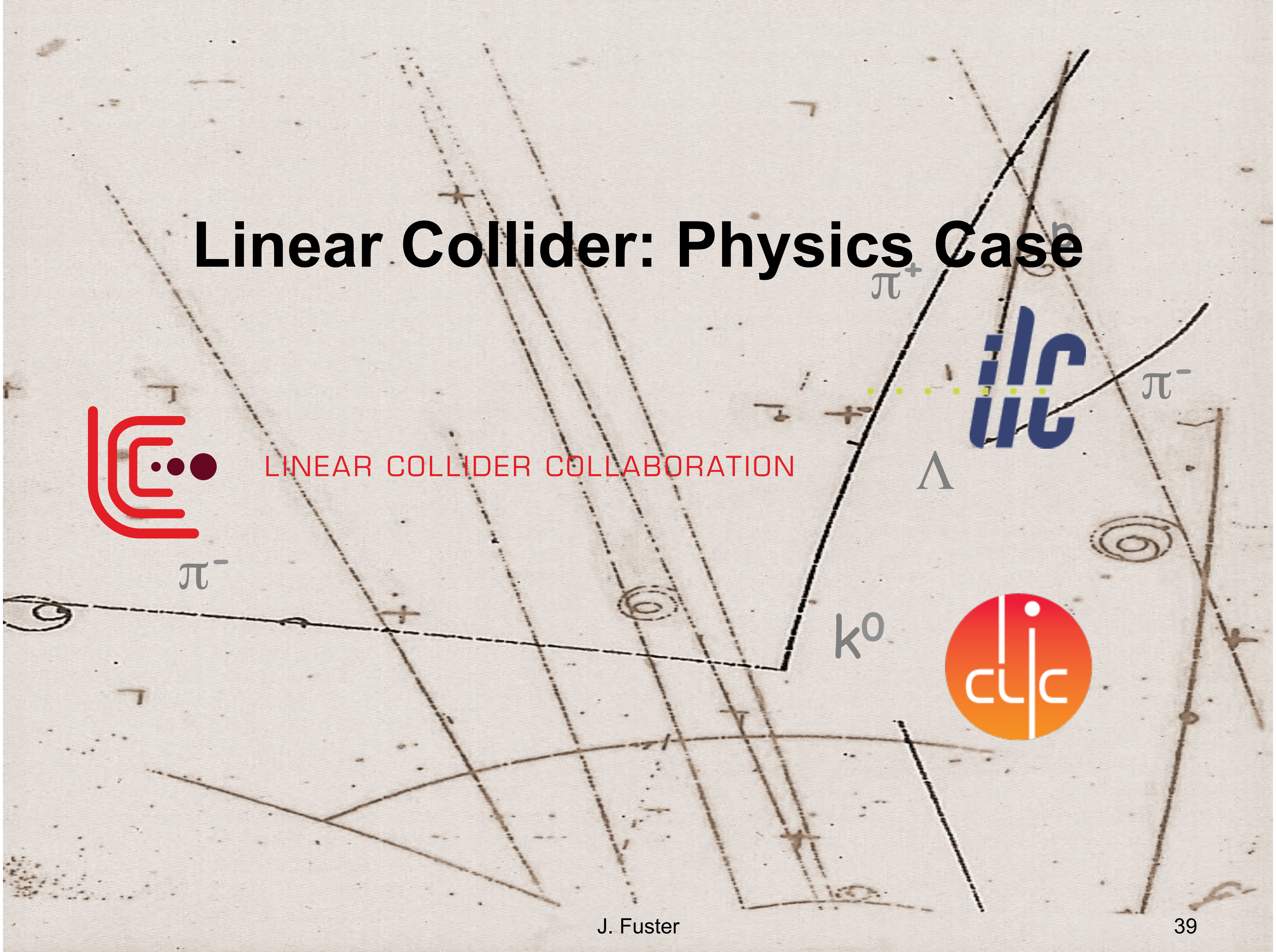
Phil Burrows (KET 2016)

HZ production
⇨ $\sqrt{s} \sim$ 250–450 GeV
Top at threshold
⇨ $\sqrt{s} >$ 350 GeV
Top pair production
⇨ $\sqrt{s} >$ 360 GeV
Recoil mass (HZ, Z->qq)
⇨ $\sqrt{s} <$ 400 GeV

- $\sqrt{s} \sim$ 380 GeV

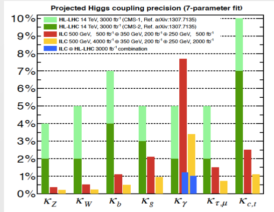
for first stage is good for both HZ and top physics programme – chosen as new baseline

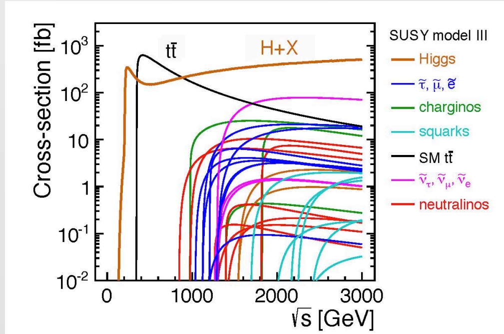
Linear Collider: Physics Case

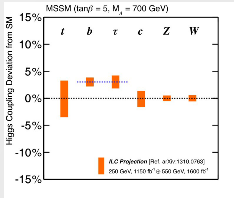


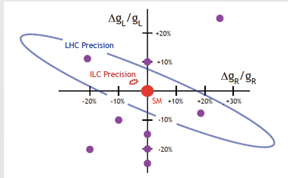
LINEAR COLLIDER COLLABORATION

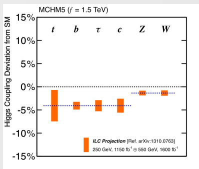
- **Physics case for the Linear Collider:**
  - Higgs physics (SM and non-SM)
  - Top
  - SUSY
  - Dark matter
  - New Z’ sector
  - Contact interactions
  - Extra dimensions
  - ….
- **ILC and CLIC physics case is very similar,** (energy range, technical readiness, backgrounds are the issue)

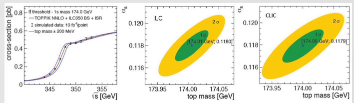


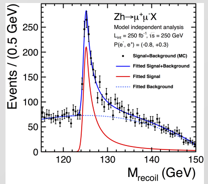


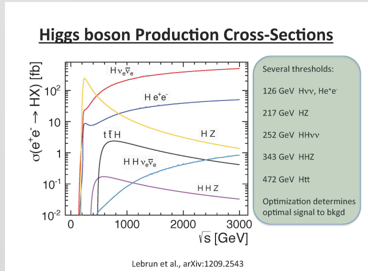


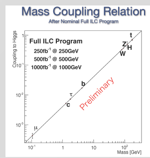


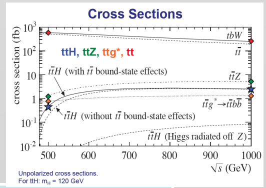






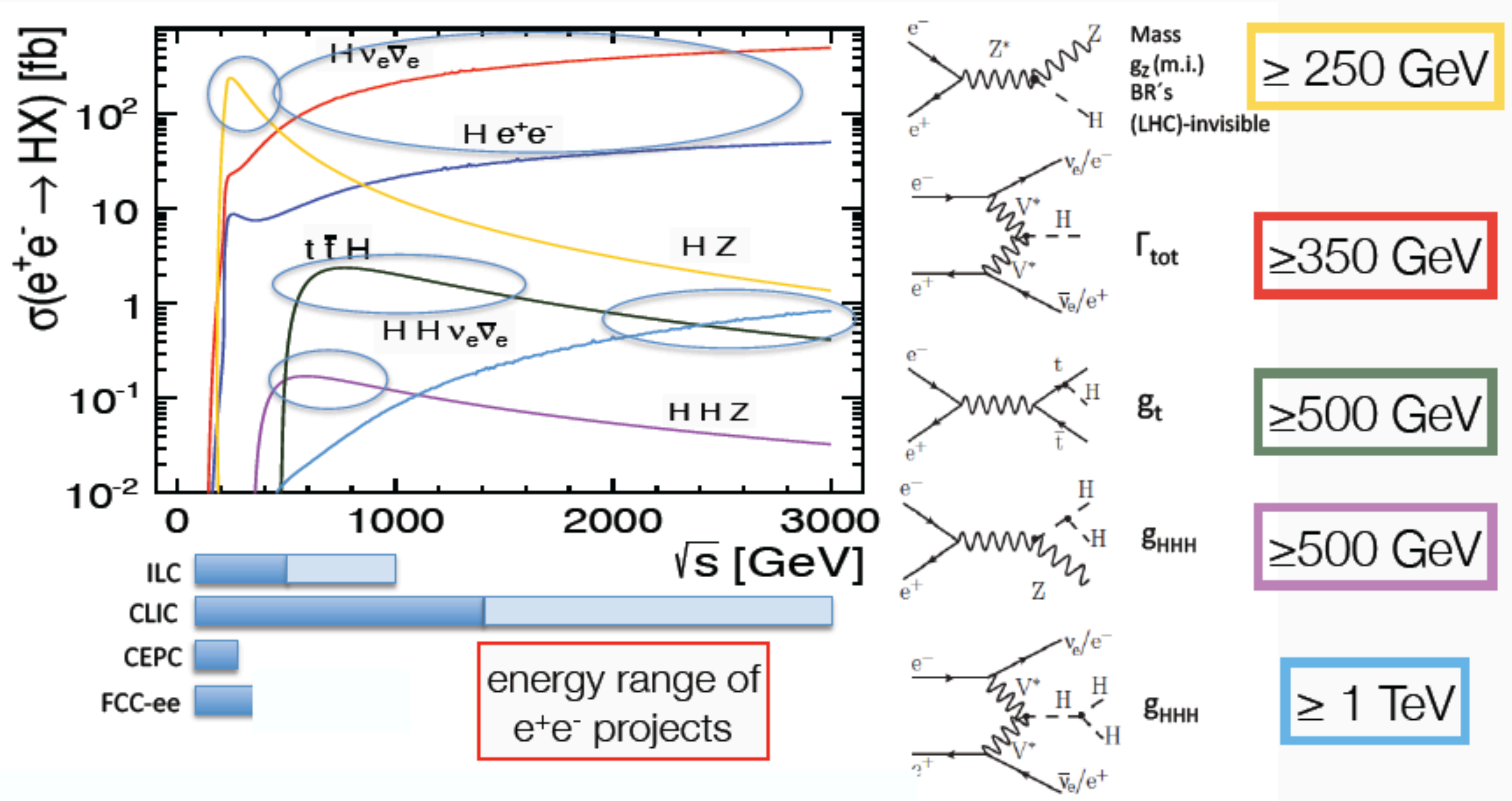






J. Brau et al.	The Physics Case for an e+e- Linear Collider, arXiv:1210.0202
K. Fujii et al.	Physics Case for the International Linear Collider, arXiv:1506.05992
L. Linssen et al **P. Lebrun et al**	CLIC CDR, arXiv:1202.5940,1209.2543
H. Baer et al.	ILC Technical Design Report, Volume 2, Physics at the International Linear Collider, , arXiv:1306.6352

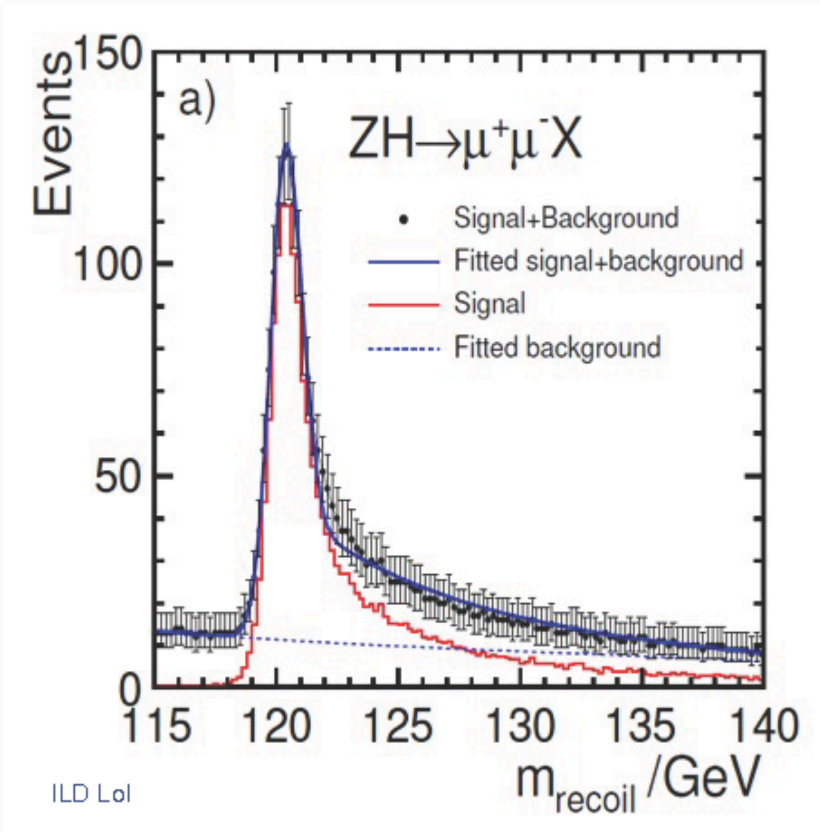

HIGGS
BOSON
TOP
QUARK

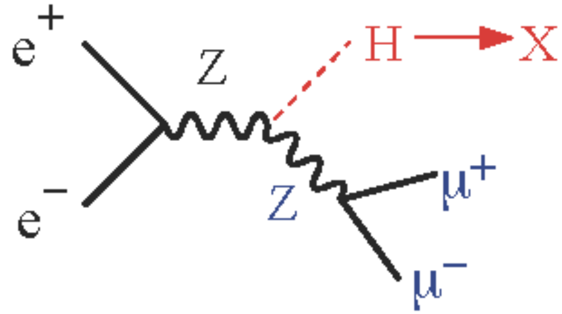


Many processes at different √s needed & accessible

J. List, KET2016

Recoil Mass





$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

Invisible decay detectable!

250 fb^{-1} @250 GeV
$\Delta\sigma_H/\sigma_H$ = 2.5%
Δm_H = 30 MeV
5ab^{-1} Δm_H = 6.7 MeV

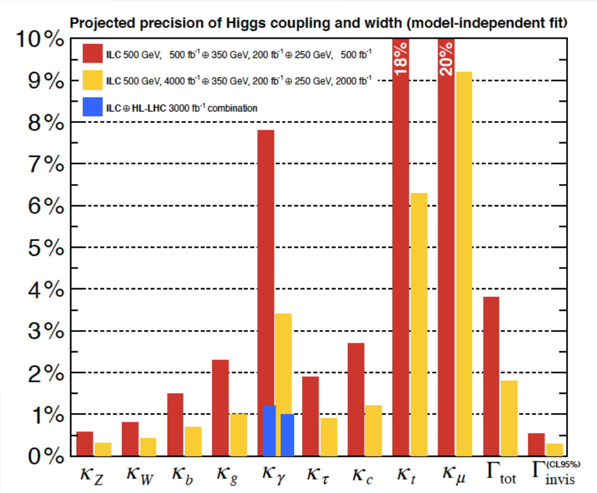
Model-independent absolute measurement of the HZZ coupling

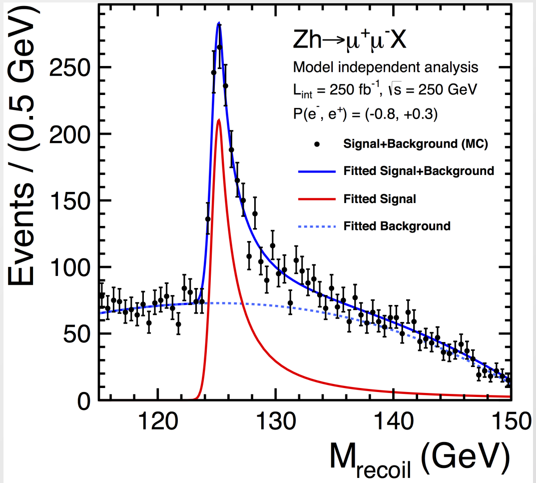
K.Fujii @ LCWS12, Oct.24, 2012

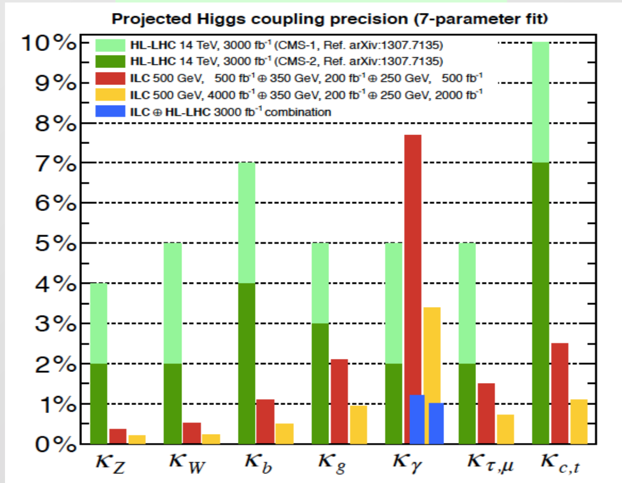
Linear Collider physics potential: Higgs couplings

ILC Model independent tests

Model dependent: LHC comparison



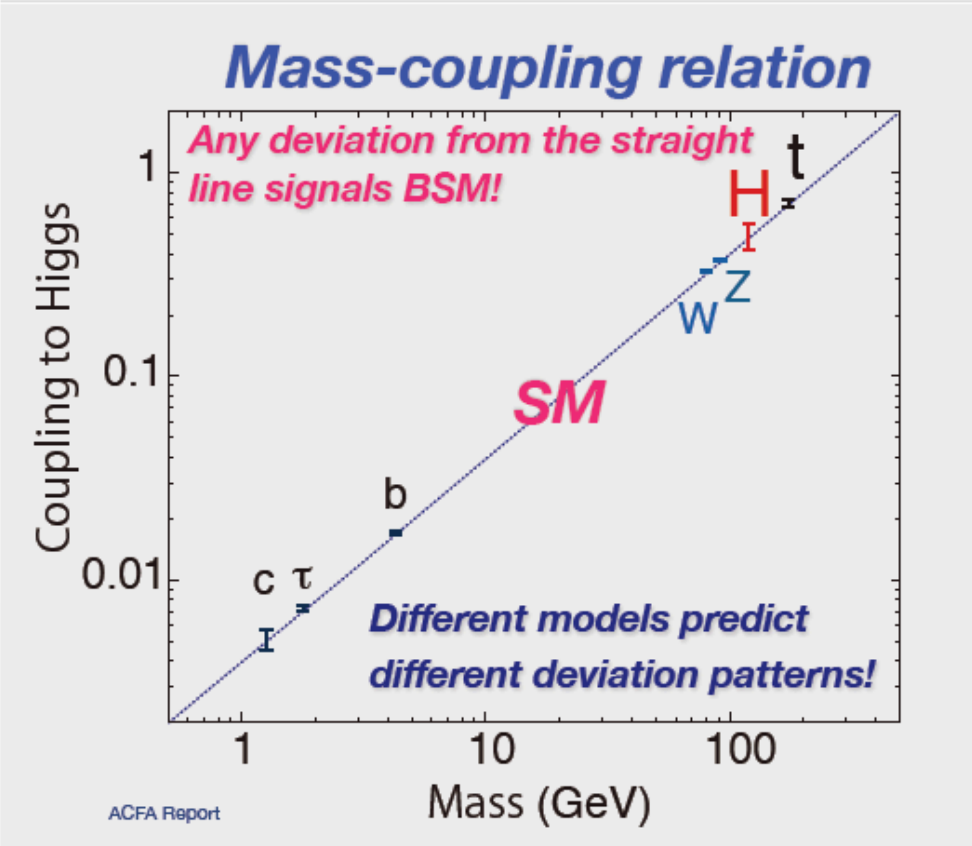




Model Independent tests allow for:

- No assumption for generation universality, unitarity, nor on BSM
- Apart from g, t, μ, accuracy is ~1 % or less (level that is meaningful in distinguishing models)
- The total Higgs width is extracted with a few percent uncertainty
- H->invisible with high accuracy
- Several channels (e.g.: H→cc, gg) very difficult in hadron collisions
- Coupling to the photon benefits from combination with HL-LHC which would provide Γ(H→γγ)/Γ(H→ZZ*)

Linear Collider physics potential: Deviations in Higgs couplings



New Physics at 1 TeV imply Δ~10%

%-level precision needed and HL-LHC not enough. Only ILC/CLIC can do it.

K. Fujii 2016, Paris

Decoupling Theorem

When new physics at scale *M* are large, low energy theory is the SM

Up to m^2/M^2 [O(1-10)% for M=TeV]

i.e., 1% precision will mean M=3 TeV for ILC reach (M. Peskin)

example 1: **Minimal SUSY**

(MSSM : tanβ=5, radiative correction factor ≈ 1)

$$\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$$

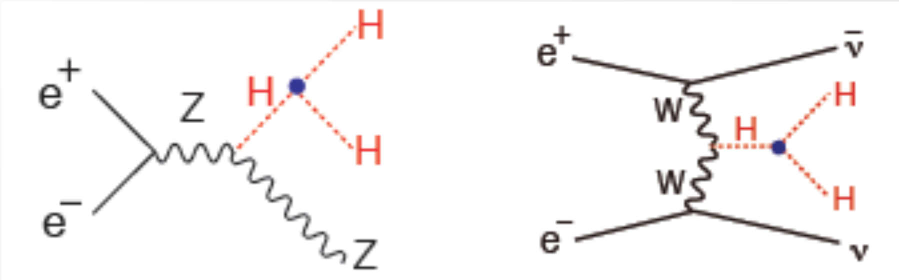
heavy Higgs mass

example 2: **Minimal Composite Higgs Model**

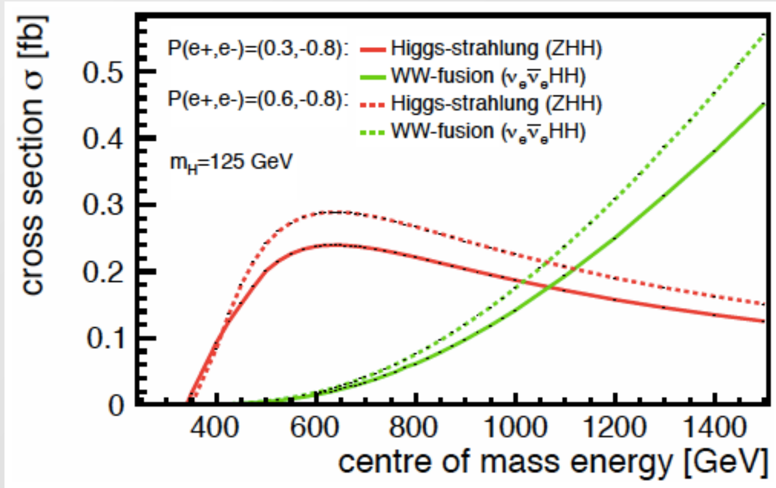
$$\frac{g_{hVV}}{g_{h_{SM}VV}} \simeq 1 - 8.3\% \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$$

composite scale

The Higgs self-coupling is at the heart of EWSB



Challenging channel (low cross-section and presence of irreducible backgrounds)



arXiv:1310.0763	ILC500	ILC500-up	ILC1000	ILC1000-up
$\sqrt{s}$ (GeV)	500	500	500/1000	500/1000
$\int \mathcal{L}dt$ (fb^{-1})	500	1600‡	500+1000	1600+2500‡
$P(e^-, e^+)$	$(-0.8, 0.3)$	$(-0.8, 0.3)$	$(-0.8, 0.3/0.2)$	$(-0.8, 0.3/0.2)$
$\sigma(ZHH)$	42.7%		42.7%	23.7%
$\sigma(\nu\bar{\nu}HH)$	–	–	26.3%	16.7%
λ	83%	46%	21%	13%

27% (H20)

CLIC (arXiv: 1307.5288)

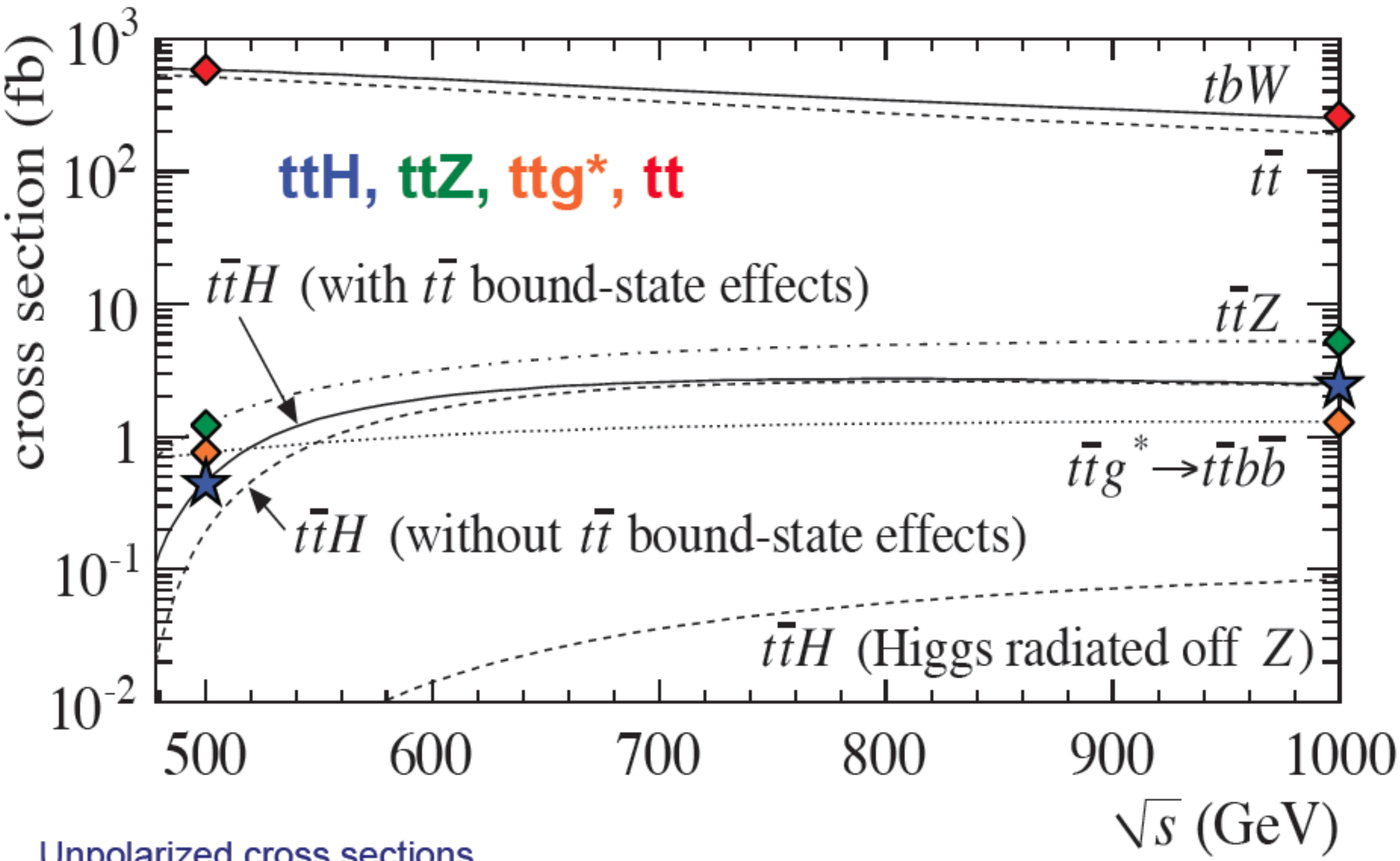
1.4 TeV (1.5 ab^{-1})	+3 TeV (2 ab^{-1})
21%	10%

On-going studies (full detector simulation) show the possibility to have Δ ~ O(10%)

K. Fujii, JCL 2016


Top quark
Sword
Higgs Boson
Higgs Boson

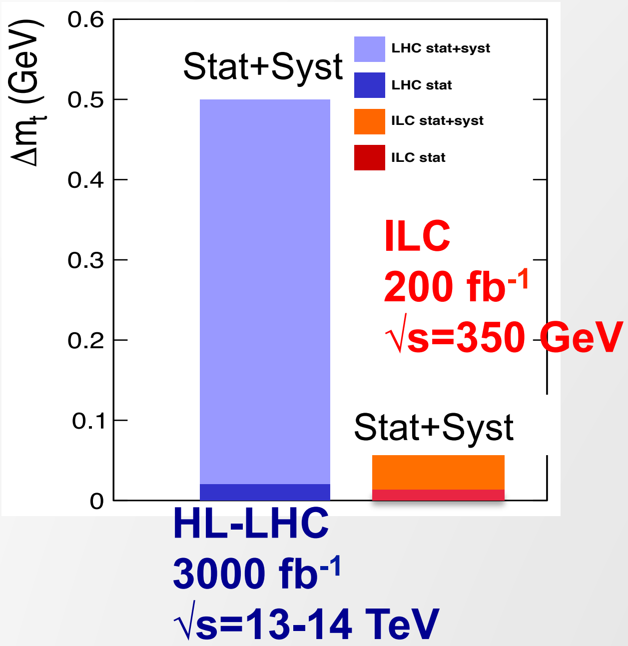
Cross Sections



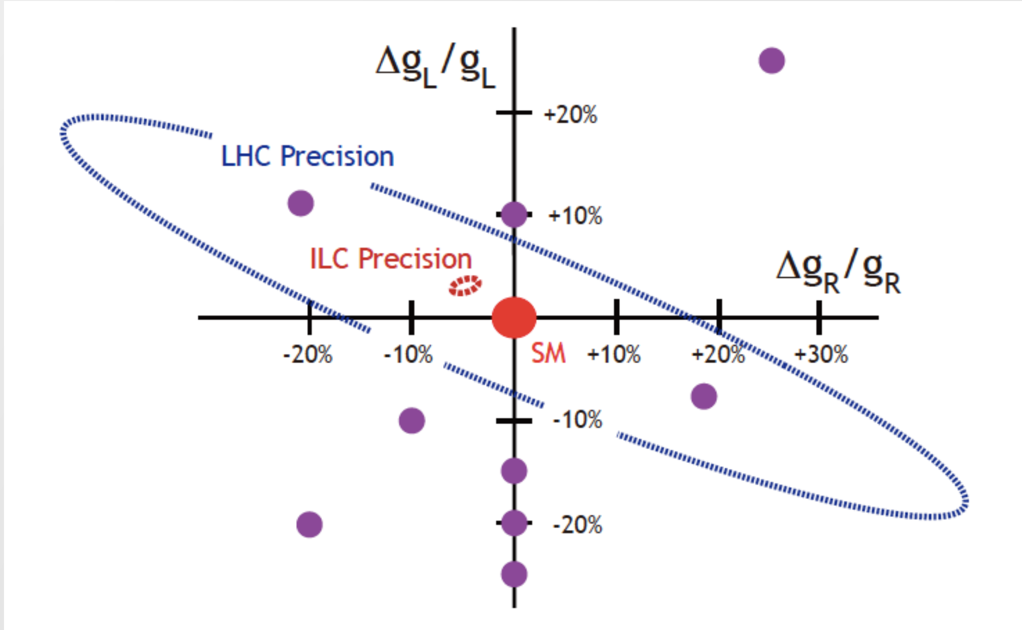
Unpolarized cross sections.
For ttH: m_H = 120 GeV

Linear Collider physics potential: top physics

Top mass @ 350 GeV (MS-bar)



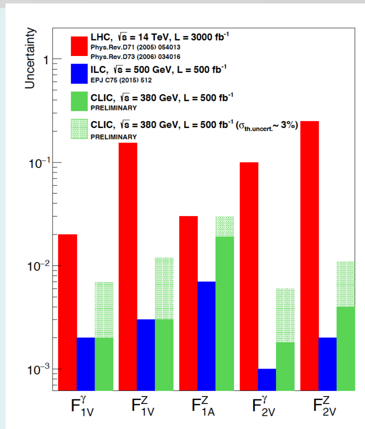
BSM: Anomalous top couplings @ >500 GeV

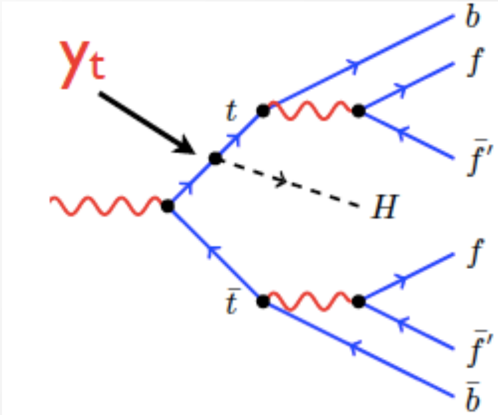


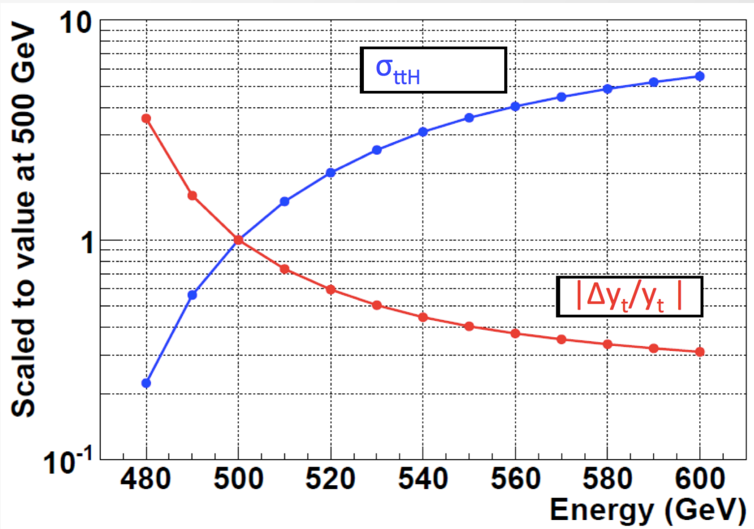
Top mass: Well defined mass scheme

Top anomalous couplings:

- Distinguish variety of BSM models.
- Use beam polarization (separates γ and Z, R and L)
- Sensitivity up to 20 TeV







Production threshold at 475 GeV

SM s(ttH) = 0.45fb @ 500 GeV

ILC running scenario Δy_t = 6.3%
(@550 GeV Δy_t = 2.5%)

@ 1 TeV and 4ab^{-1}; Δy_t = 2%

CLIC: @ 1.4 TeV and 1.5ab^{-1}; Δy_t = 4.4%

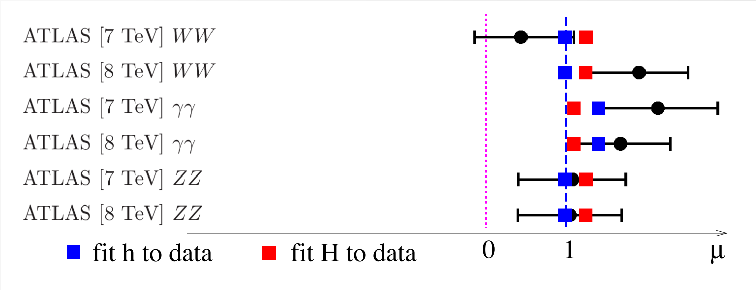
J. List, LHCSki2016


Brace yourself!
New physics is coming
(maybe)

One example:

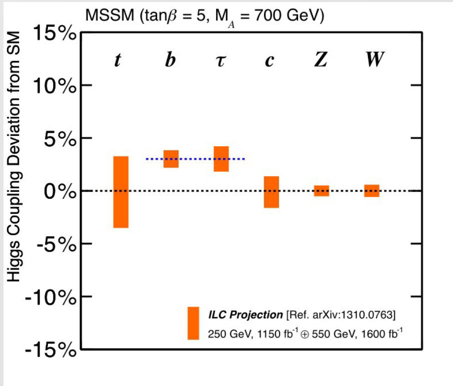
Fit LHC and Tevatron „signal strength“ parameters to the MSSM taking into account limits, B-physics constraints etc.

→ both h and H provide a reasonable fit

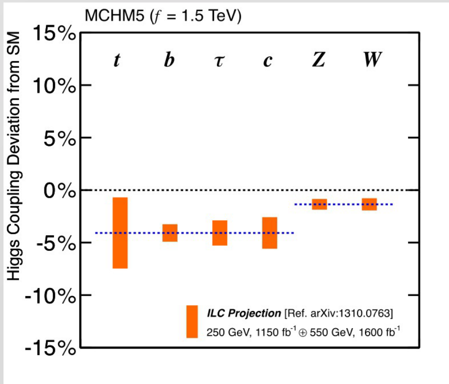


[Bechtle, Heinemeyer, Stal, Stefaniak, Weiglein, Zeune arXiv:1211.1955]

Supersymmetry



Composite Higgs



ILC 250+550 LumiUP

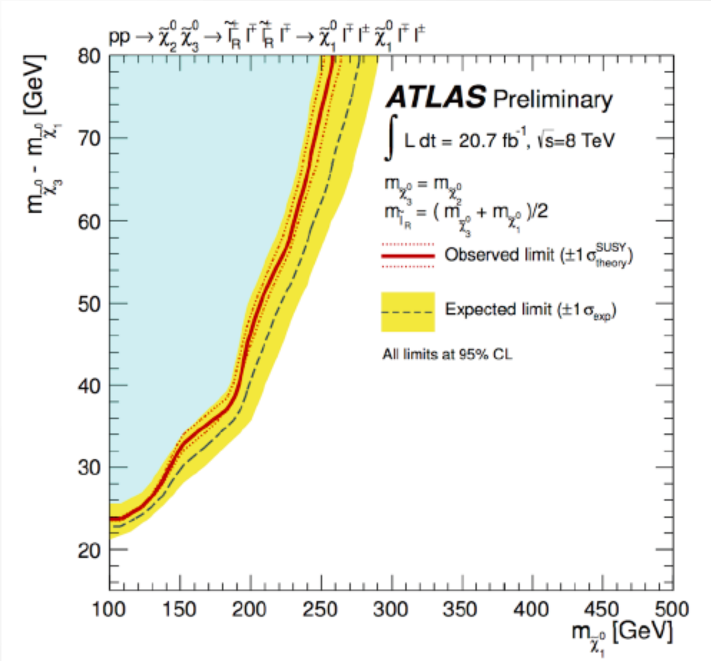
Supersymmetry:
$$g(\tau)/SM = 1 + 10\% \left(\frac{400\ \mathrm{GeV}}{m_A}\right)^2$$
$$g(b)/SM = g(\tau)/SM + (1-3)\%$$

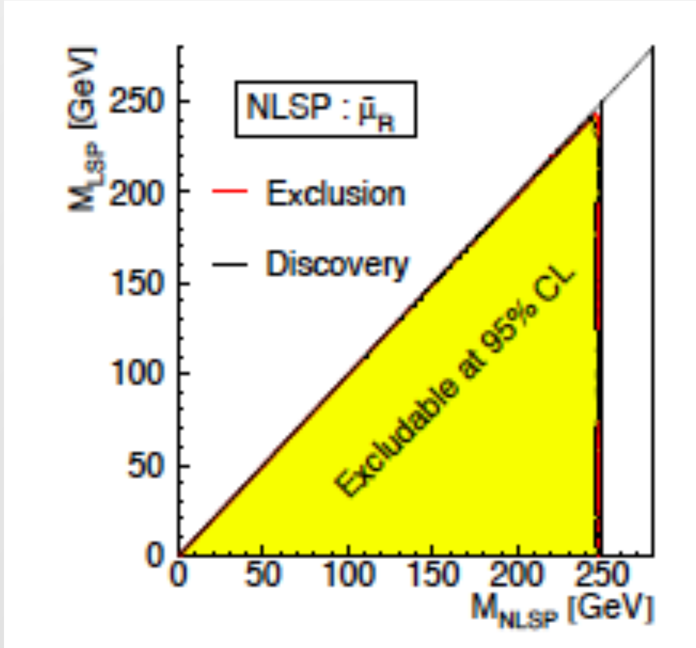
Little Higgs:
$$g(g)/SM = 1 + (5-9)\%$$
$$g(\gamma)/SM = 1 + (5-6)\%$$

Composite Higgs:
$$g(f)/SM = 1 + (3-9)\% \cdot \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$$

- tiny differences between best fit and SM
- tiny differences between h and H hypotheses
- Δμ/μ ≲ 5%-20%
- In general precision at ~% or better is requiried

New Physics: direct searches complementarity with LHC





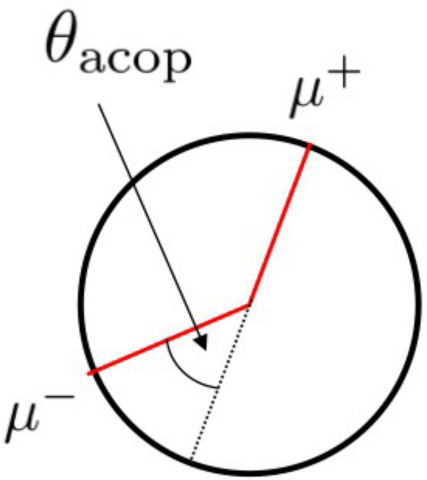
LHC:
Difficulty when mass difference is small

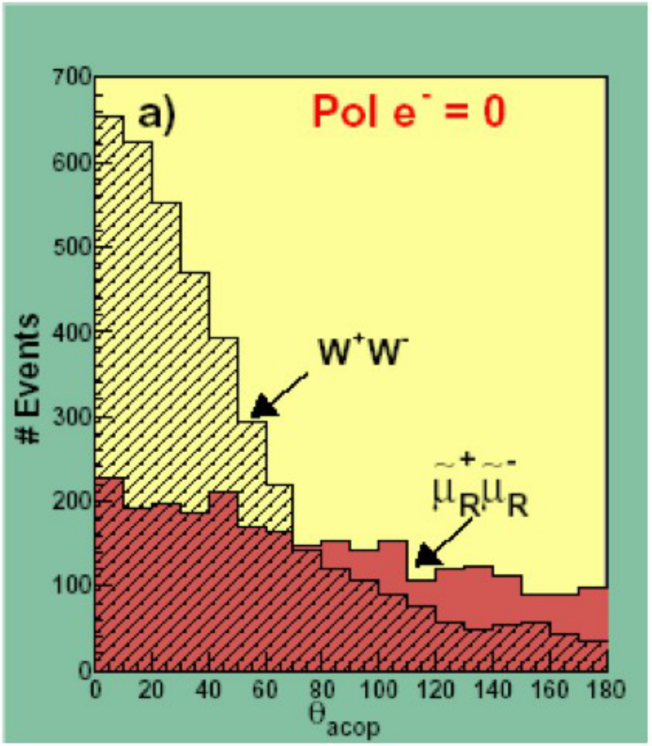
ILC/CLIC:
Good sensitivity up to kinematic limit for (essentially) any mass difference

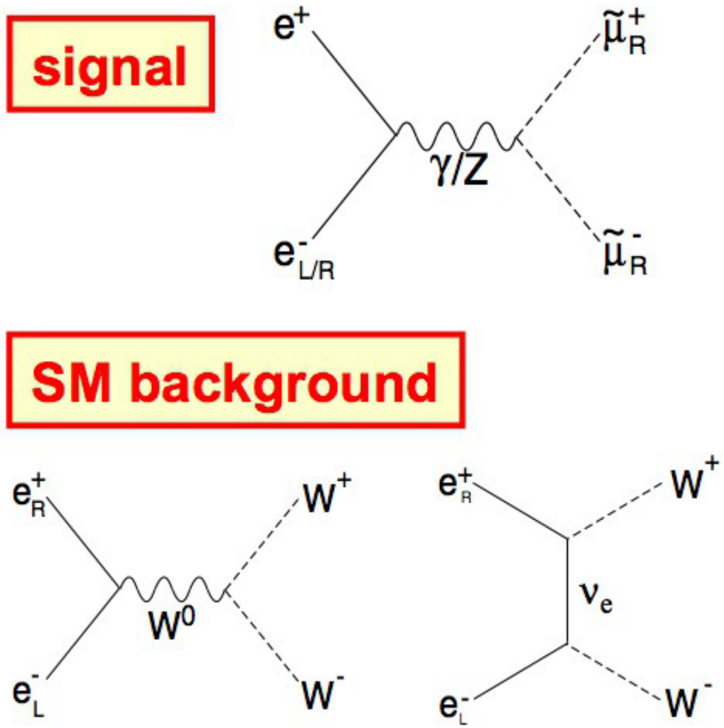
In general (even when no near degeneracy):

LHC can reach higher energy but could miss important phenomena. Tevatron could not have a clear signal of the Higgs though 20000 Higgs events were produced.

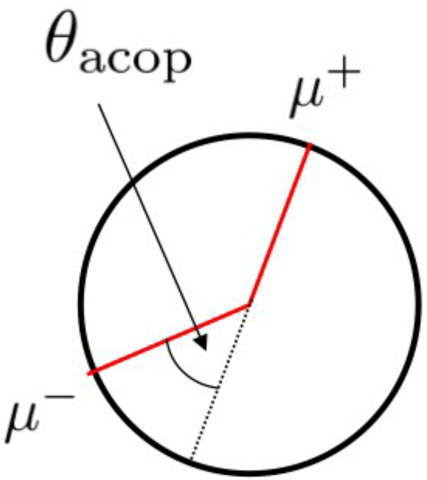
New Physics: direct searches (power of beam polarization)

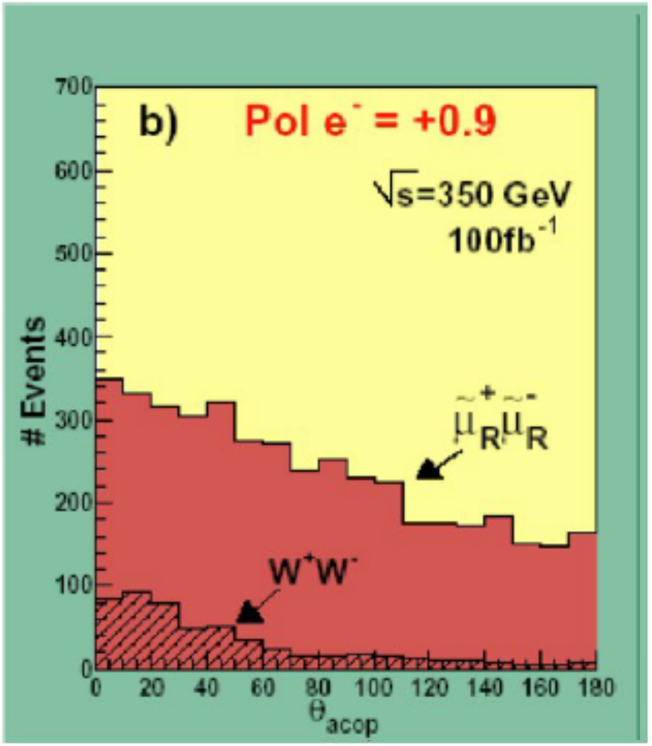


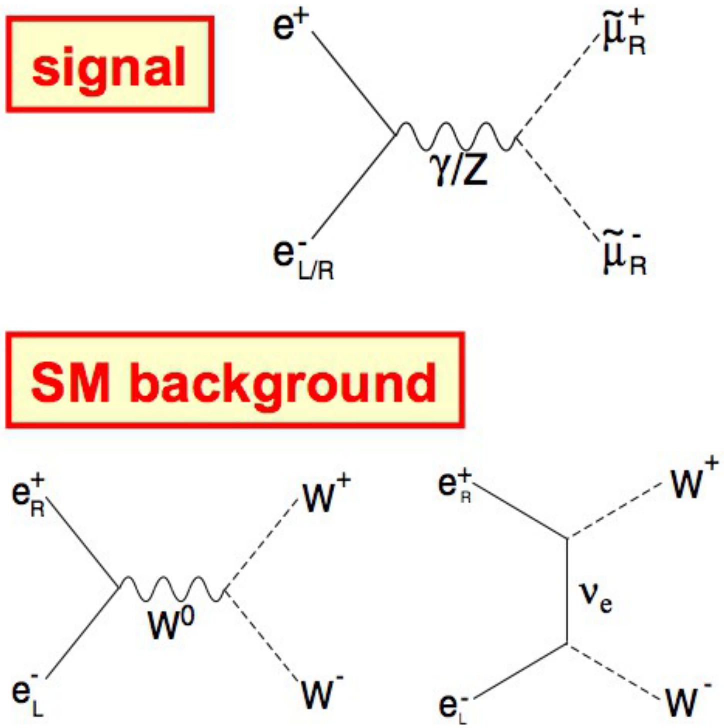




New Physics: direct searches (power of beam polarization)

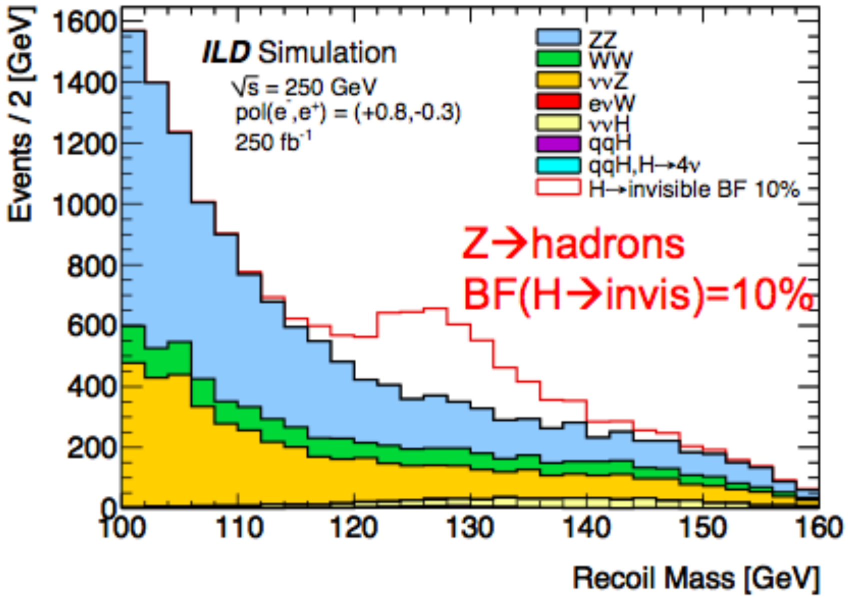






WIMP searches at colliders are complementary to direct/indirect searches.
Examples at the ILC:

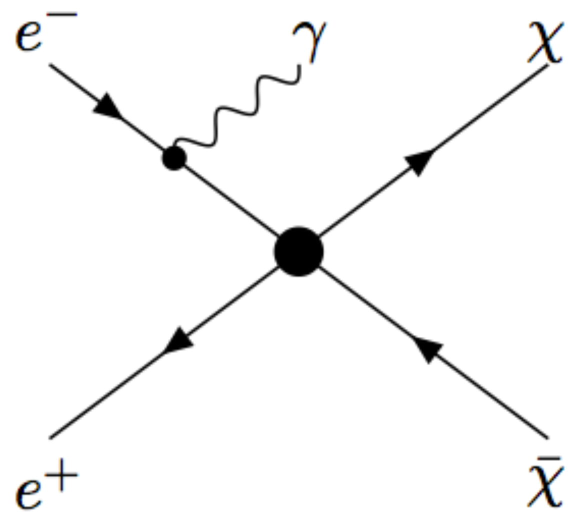
Higgs Invisible Decays



BR(H→invis.) < 0.4% at 250 GeV, 1150 fb^{-1}

Impact of jet energy resolution

Monophoton Searches

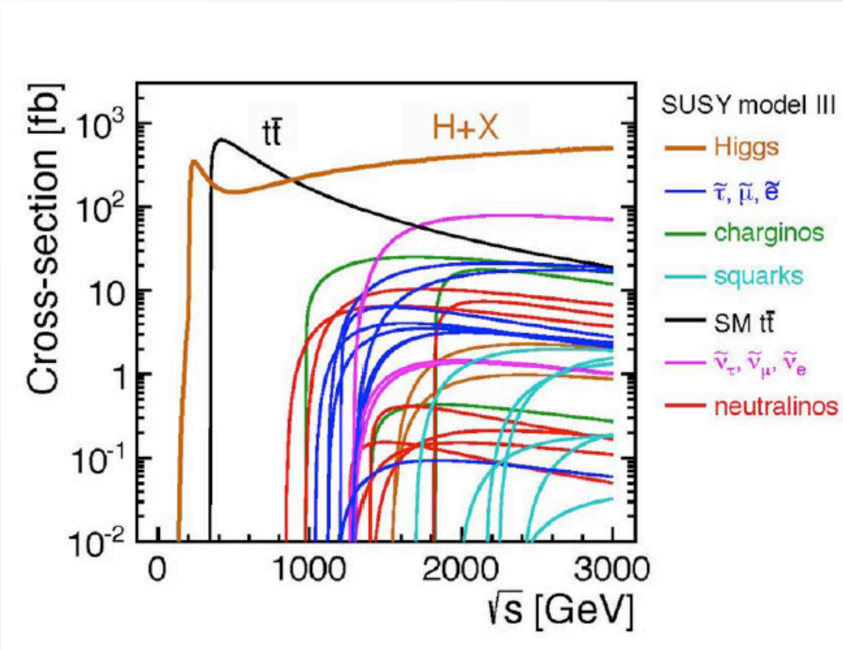


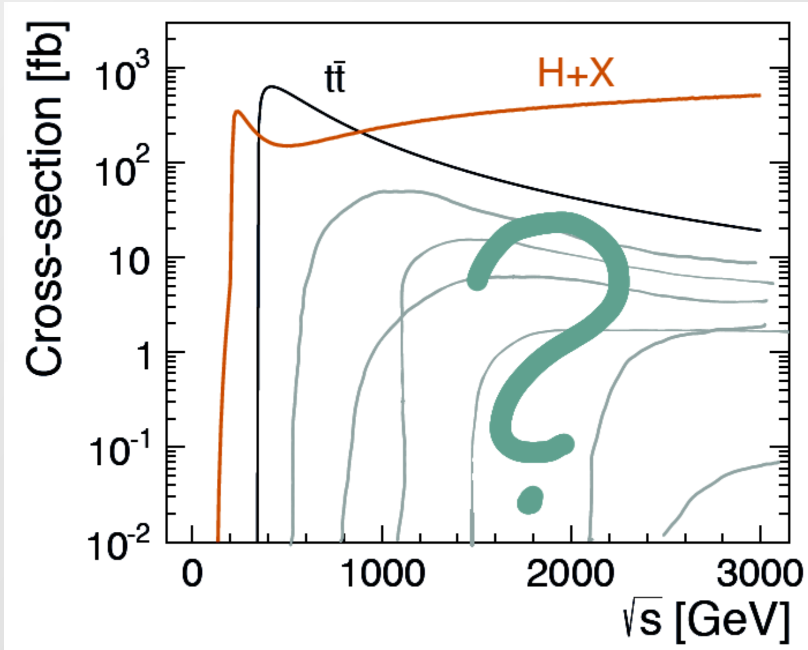
→ DM mass sensitivity nearly half √s

Soft photons, forward detectors

T. Tanabe - ILD 2014

New Physics: new particles





Search and precision exploration of potential new physics that may emerge from LHC

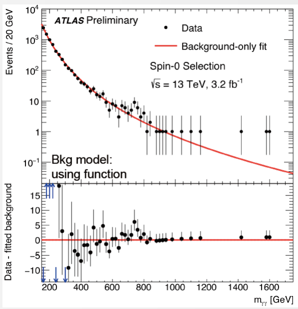
(ILC up to 1 TeV; CLIC up to 3 TeV)

Ph. Burrows – ICFA/LCB 2016, J-PARC

One session at ECFA-LC 2016 discussed X750 if confirmed:

- LC can elucidate the physics behind X750 by precision measurements on Higgs, top etc.
- 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 e+e- at high energy or future $\gamma\gamma$ option

- LC provides excellent complementary to LHC (as has been advocated in general for most potential new findings at LHC)
- K. Fuji et al., Implications of the 750 GeV gamma-gamma Resonance as a Case Study for the International Linear Collider, arXiv:1607.03829

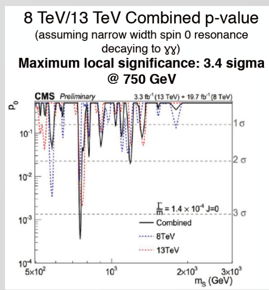


ATLAS:

13 TeV data, spin-0

2.0σ (global) 3.9σ (local)

Consistent with 8 TeV at 1.2σ

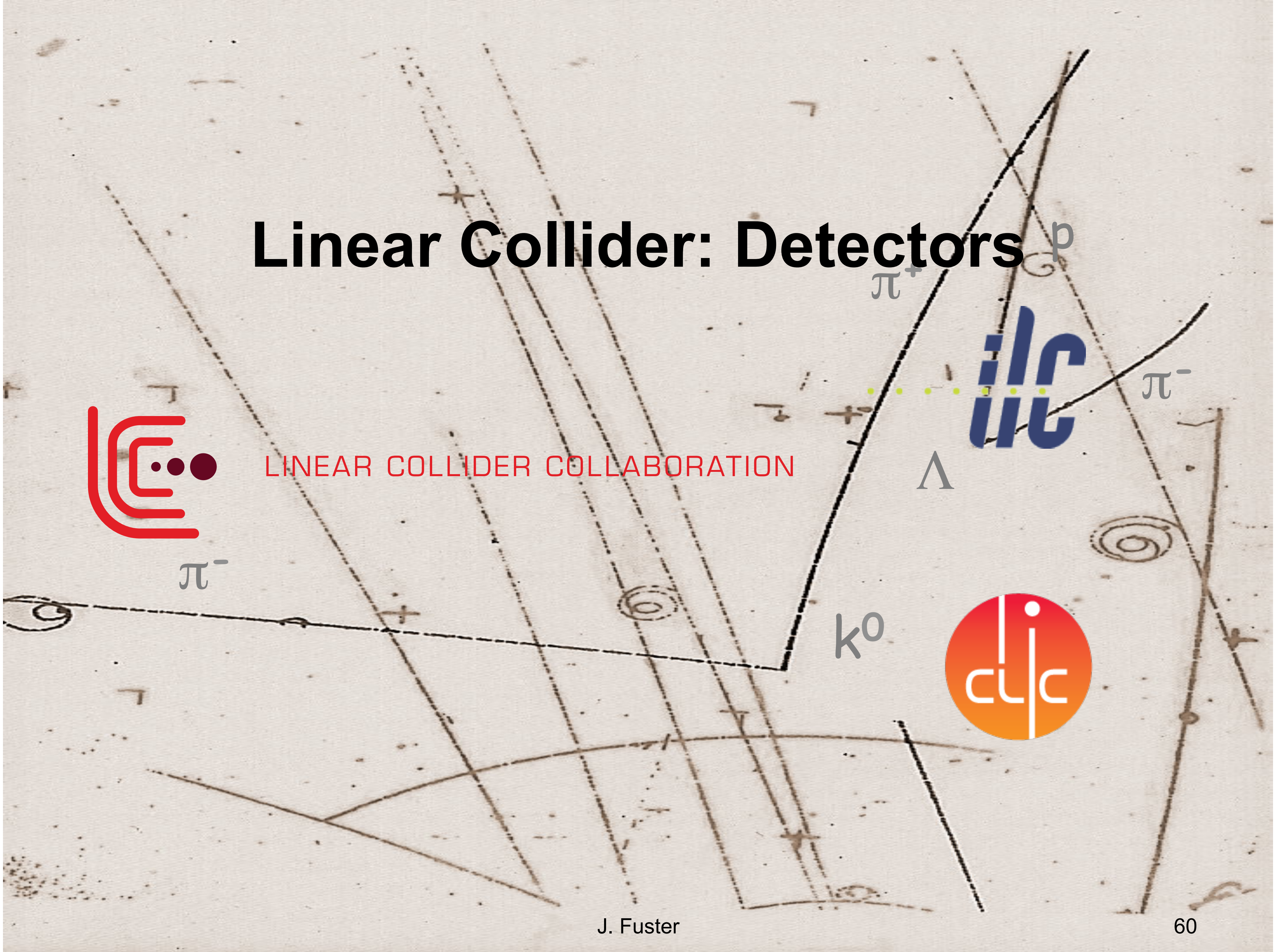


CMS:

13/8 TeV data, spin-0

3.4σ (local at 750 GeV)

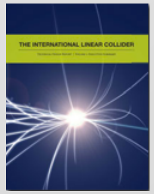
Linear Collider: Detectors

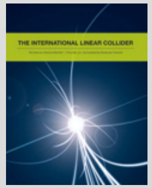


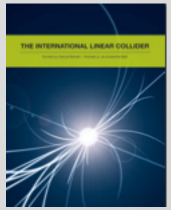
LINEAR COLLIDER COLLABORATION

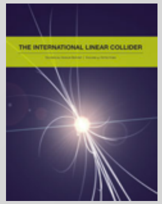
ILC Physics and Detector Roadmap

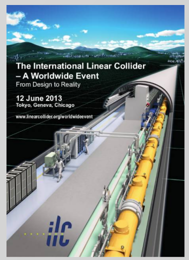
Aug. 2007	Detector Concept Report, Four detector concepts: LDC, GLD, SiD, 4th
Oct. 2007	ILCSC calls for LOIs and appoints Research Director (RD)
Jan. 2008	RD forms detector management
Mar. 2008	IDAG formed, Three LOIs grous identified
Mar. 2009	Three LOIs submitted (detector description, status of R&D, GEANT4 simulation, benchmark process, costs..)
Mar. 2009	IDAG began monitoring the progress
Aug. 2009	IDAG recommends validation of two (2) and ILCSC approves
Oct. 2009	Work plan of the validated groups
End 2011	Interim Report being produced http://www.linearcollider.org/about/Publications/interim-report
End 2012	Physics at the International Linear Collider (ILC TDR Vol. 2) Detailed Baseline Design Report (ILC TDR Vol. 4) http://www.linearcollider.org/ILC/Publications/Technical-Design-Report
June 12th 2013	Public TDR Launch event worldwide http://www.linearcollider.org/events/2013/ilc-tdr-world-wide-event







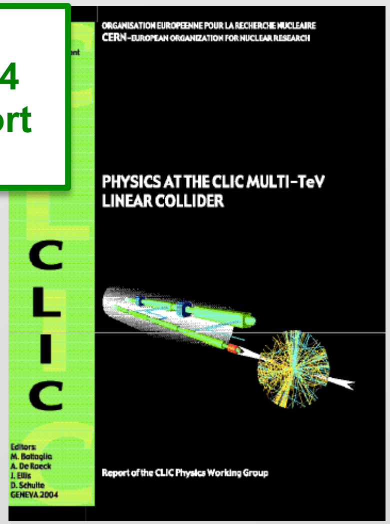


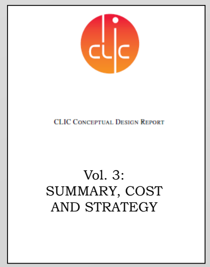


CLIC Physics and Detector Roadmap

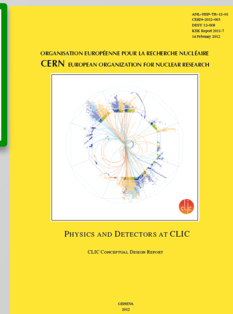
2001	"Physics motivations for future CERN accelerators" *http://arxiv.org/pdf/hep-ex/0112004v1*
2004	"Physics at the CLIC multi-TeV linear collider" Report on physics potential *http://inspirehep.net/record/667395?ln=en*
2008	New start of CLIC physics and detector studies First meetings between ILC and CLIC physics efforts Start Linear Collider Detector (LCD) effort @ CERN
2009	IDAG meeting: Plan ILC-CLIC cooperation Pursue ILD & SID concepts for CLIC CDR
2012	Publication of "Physics and Detectors at CLIC", CDR, *http://arxiv.org/abs/1202.5940* with >1300 signatories Publication of "The CLIC Programme: Towards a Staged e+e- Linear Collider exploring the Terascale", CDR, and *input to European Strategy process* *http://arxiv.org/abs/arXiv:1209.2543* Establishing a *"memorandum on Cooperation"* (MoC) for CLIC detector and Physics study, with CERN as the host laboratory
2013	*CLIC input to the Snowmass process* (with many new Higgs physics studies), *http://arxiv.org/abs/1307.5288* 20 institutes have signed the MoC

2004 report

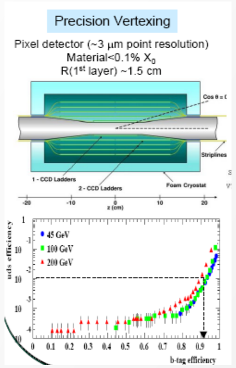


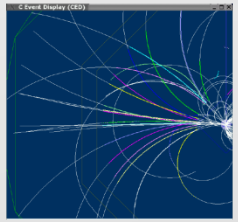


CDR 2012



Challenges for ILC (0.25-1.0 TeV)/CLIC (0.38-3.0 TeV) detectors





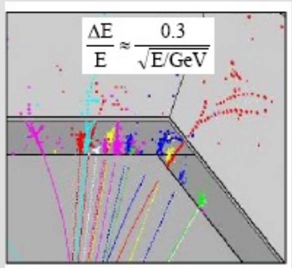
- Vertex, "flavour tag" (heavy quark and lepton identification)

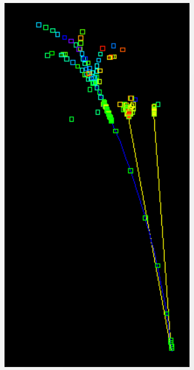
  ~1/5 $r_{beampipe}$, ~1/30 pixel size (ILC vs LHC),

  vtx 1-2 cm (ILC), vtx 2-3 cm (CLIC)

  $$(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$$

  $$\boxed{\sigma_{ip} = 5\mu m \oplus 10-15\mu m / p\sin^{3/2}\theta}$$



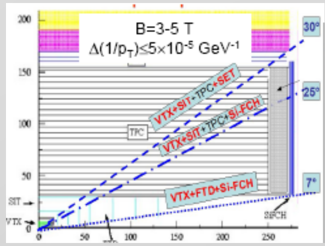


- Tracking, "recoil mass" $(e^+e^- \to Zh \to \ell^+\ell^- X)$

  ~1/6 material, ~1/7 resolution (ILC wrt LHC),

  B=4-5 T (CLIC and ILC)

  $$\boxed{\sigma(1/p) \leq 2\times 10^{-5}\,\mathrm{GeV}^{-1}}$$



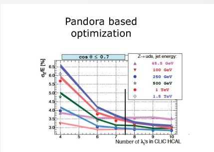
- Particle Flow, Jet Energy Rec. → Tracker+Calo.

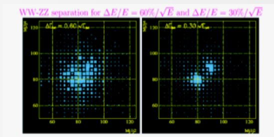
  Di-jet mass Resolution, Event Reconstruction, Hermitcity,

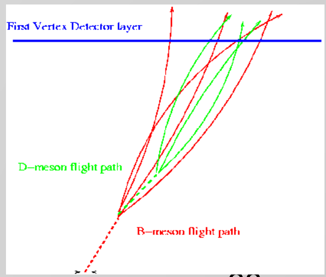
  Detector coverage down to very low angle

  CLIC vs ILC: Redesign Forward Region, HCAL 7,5 λ

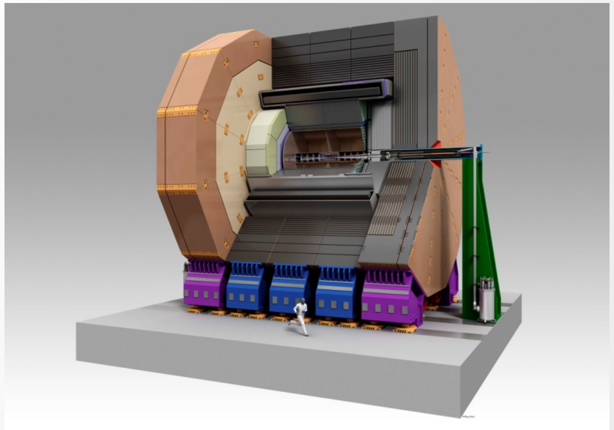
  $$\boxed{\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}}$$

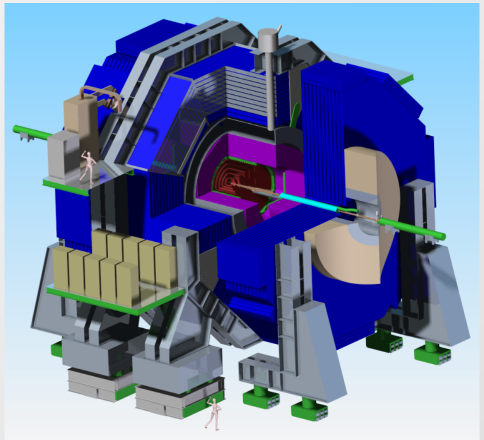


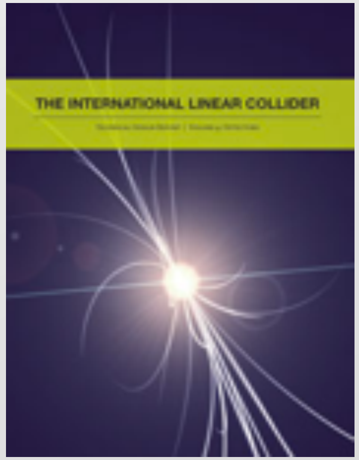




ILC Detectors: SiD & ILD







Major accomplishment was achieved to produce the Detailed Baseline Design report of the detectors for the ILC-TDR

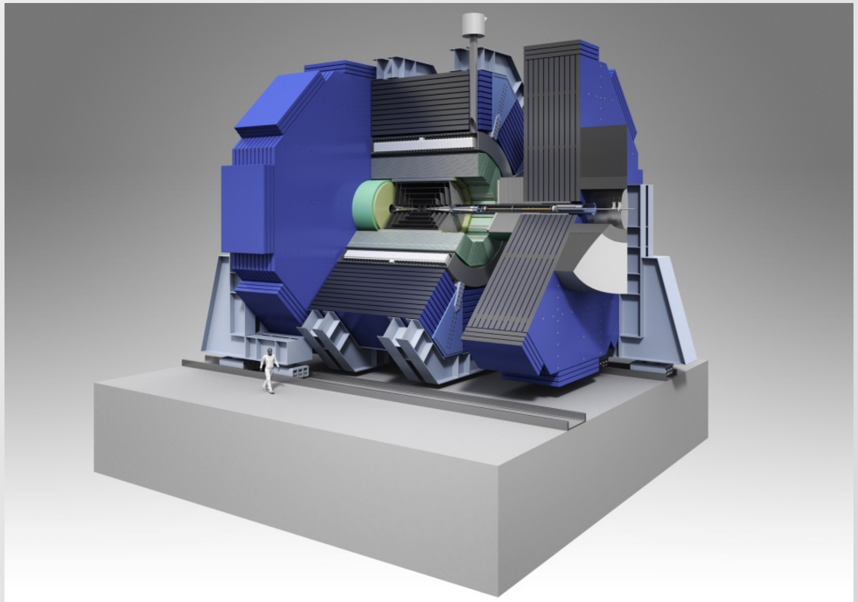
Successful cooperation between ILC and CLIC

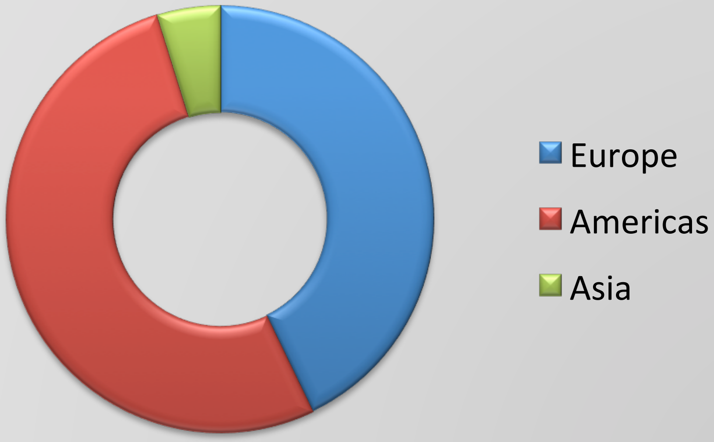
http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

SiD detector concept

SiD Consortium

- Has been established, byelaws in place
- Spokespersons:
  Marcel Stanitzki
  Andy White
- Institute Board chair:
  Philip Burrows
- 22 Groups have signed on
- www.silicondetector.org





ILD detector concept

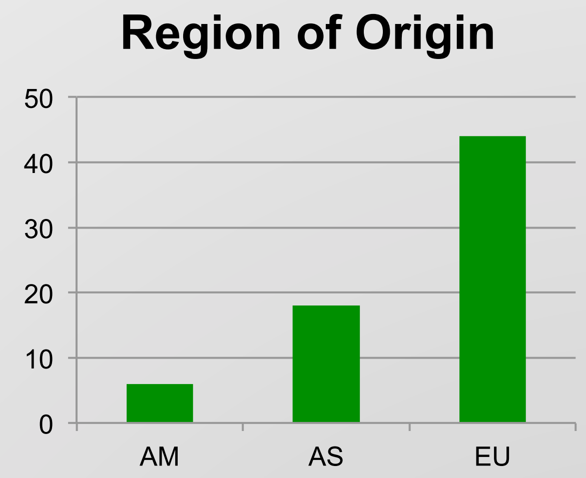
ILD Detector

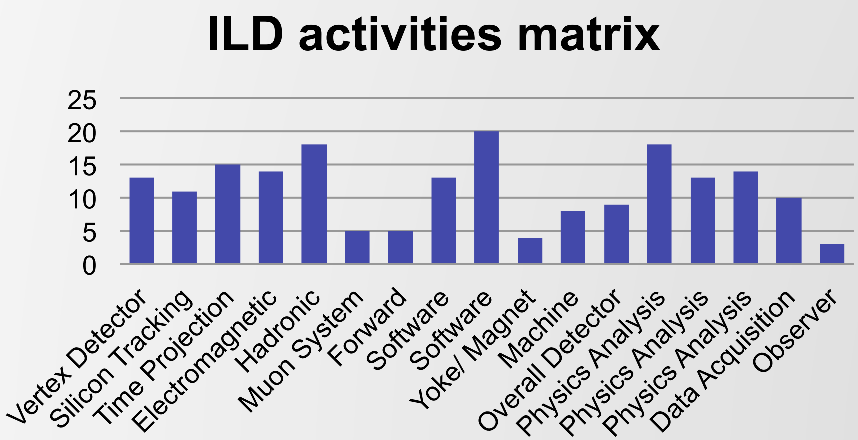
- Spokesperson: Ties Behnke
- Deputy spokesperson: Kiyotomo Kawagoe

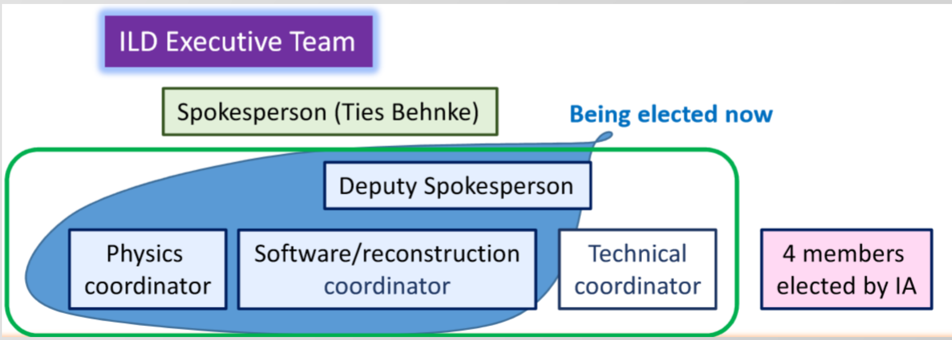
- Institute Assembly chair: Jan Timmermans
- Deputy chair: Tohru Takeshita

- 68 Groups have signed on

- http://www.ilcild.org/

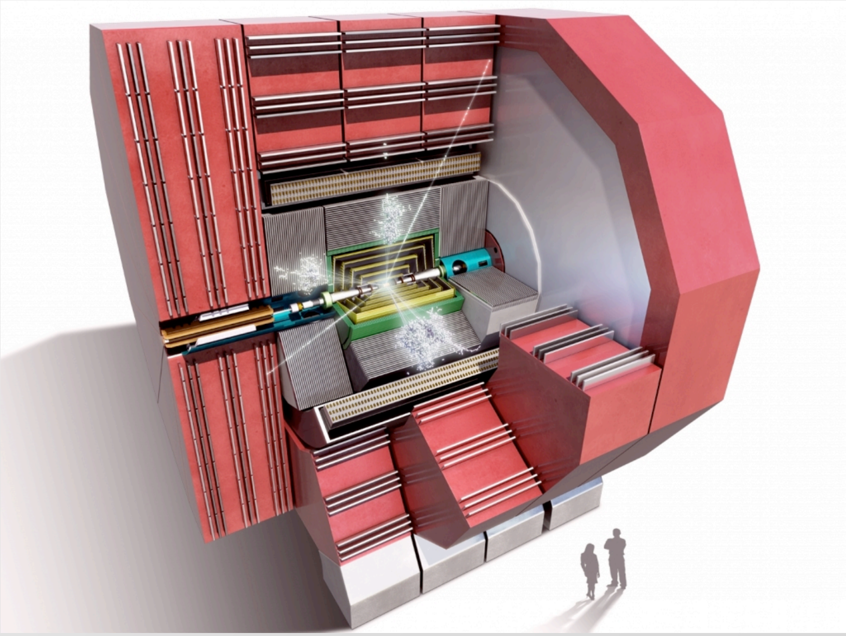






CLIC detector and physics (CLICdp)
Light-weight collaborative structure
based on "best effort", with CERN as host lab
~130 members from 23 institutions

http://clicdp.web.cern.ch/



Many activities in common with ILC
(in particular hardware R&D, software developments, physics studies)

CLIC-specific activities:
- Detector optimisation for CLIC
- Detector R&D where CLIC sets special requirements
- CLIC physics studies, staged approach

Linear Collider:
ILC situation and activities in Japan

LINEAR COLLIDER COLLABORATION

The ILC project: update of European strategy 2013

Proposed Update of the European Strategy for Particle Physics concerning ILC and CLIC activities:

- To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide

- There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation

The LC projects are well supported into the recognized priorities by the update of the European Strategy for particle physics

ICFA Statement on its Support of the ILC, its Endorsement of the Strategic Plans of Europe, Asia and the United States, and its Encouragement of International Studies of Future Circular Colliders

ICFA endorses the particle physics strategic plans produced in Europe, Asia and the United States and the globally aligned priorities contained therein. Here, ICFA reaffirms its support of the ILC, which is in a mature state of technical development and offers unprecedented opportunities for precision studies of the newly discovered Higgs boson. In addition, ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

J. Mnich (ICFA chair) – ICHEP 2014

AsiaHEP/ACFA Statement on ILC + CEPC/SPPC

AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development. The aim of ILC is to explore physics beyond the Standard Model by unprecedented precision measurements of the Higgs boson and top quark, as well as searching for new particles which are difficult to discover at LHC. The Higgs studies at higher energies are especially important for measurement of WW fusion process, to fix the full Higgs decay width, and to measure the Higgs self-coupling. In continuation of decades of world-wide coordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan. The past few years have seen growing interest in a large radius circular collider, first focused as a “Higgs factory", and ultimately for proton-proton collisions at the high energy frontier. We encourage the effort lead by China in this direction, and look forward to the completion of the technical design in a timely manner.

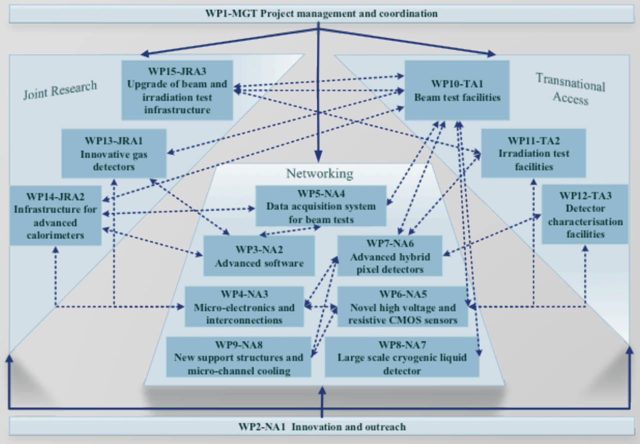
Y. Wang, FCC-Rome 2016, KET future e+e- colliders

European participation in LC R&D

Outlook (non-homogenous) to LC landscape by countries/labs:

- Czech Republic
- CERN
- France (IN2P3/CNRS and IRFU/CEA)
- Germany
- Holland
- Israel
- Norway
- Poland
- Serbia
- Spain
- United Kingdom

Key R&D issues	WPs related to activity
HL-LHC	
Radiation hard detectors : - New pixel and tracker detector - Forward Calorimeter - Micro-Electronics Beam and irradiation prototypes testing, Industrialisation process, Software simulation and reconstruction	WP 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 15
ILC	
Low mass pixel and track detectors, High granularity calorimeters, Low power electronics, Industrialisation, Combined system performance, Software simulation and reconstruction	WP 2, 3, 4, 5, 6, 7, 9, 10, 12, 13, 14, 15
CLIC (Compact Linear Collider)	
As for ILC, plus the need for nano-second time stamping in all systems	WP 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 15
Long-baseline neutrinos	
Large-scale cryogenic detectors, electronics Beam test	WP 2, 3, 8, 10
FCC (Future Circular Collider)	
See HL-LHC	WP 2, 3



AIDA-2020: about 25% include Linear Collider R&D related activities.

Extremely helpful to the LC European community

The ILC project: Support from ECFA

ECFA/16/453/Draft
Draft approved by RECFA, to be endorsed by PECFA
3 April 2016

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

ECFA STATEMENT ON THE DETECTOR R&D ACTIVITIES AND PHYSICS STUDIES FOR A FUTURE LINEAR COLLIDER IN THE CONTEXT OF THE EUROPEAN STRATEGY

After the discovery of the Higgs Boson in 2012 at CERN, Europe, the United States and countries represented in the Asian Committee for Future Accelerators (ACFA) have produced strategies for the future of accelerator-based particle physics. Altogether a coherent vision emerges of a roadmap for the next 20 years, endorsed by the International Committee for Future Accelerators.

The European Strategy ranks the full exploitation of the physics opportunities at the LHC and its future upgrades as Europe's top priority. It recommends a vigorous accelerator R&D programme to develop an ambitious post-LHC project at CERN at the high-energy frontier. These studies comprise proton-proton and electron-positron high-energy machines. The impressive scientific case for a lepton collider is recognised and both the International Linear Collider (ILC) and R&D towards the Compact Linear Collider (CLIC) are strongly supported. The strategy also recognises the importance of global cooperation on neutrino physics.

The implementation of these recommendations has led to the establishment of the Future Circular Collider (FCC) project, the CERN-KEK offices and the CERN Neutrino Platform. The role of the CERN-KEK offices is to increase the collaborative effort between CERN and KEK on accelerator R&D and construction projects of mutual interest. The goal of the CERN Neutrino Platform is to facilitate the contribution of the European neutrino community to the planned US and Japan projects, in particular through a significant R&D effort.

The conceptual design report for CLIC was produced in 2013. A Project Implementation Plan is scheduled in time for the next update of the European Strategy, around 2019. For the Future Circular Collider a conceptual design report is expected by the same time, describing both e^+e^- and pp collider options. The Technical Design Report for the ILC was published in 2012 and the Japan Association of High Energy Physicists proposed that the ILC be hosted in Japan as a global project. The Japanese Government is currently considering the proposal and has started informal talks with the USA and European countries. A decision by Japan to host the ILC is expected within the next few years. The Asia-Pacific High Energy Physics Panel and ACFA have recently issued a statement urging redoubled international efforts to realize the ILC.

As a component of the global strategy, a strong effort to develop detector technologies for experiments at future collider facilities is needed. This should be complemented by comprehensive studies of the science reach of these facilities.

ECFA acknowledges the role of the ILC- and CLIC-directed research in this area and the significant technological contributions this effort has already produced. ECFA strongly supports the continuation of this work with an adequate level of funding until a decision on the future direction of the field is taken. In this context collaborative efforts between Europe, USA and Asian countries, especially with Japan, are encouraged.

ECFA encourages the establishment of close links between the linear collider and circular collider communities, to maximise synergies and the use of resources in preparation for the challenges of the future. ECFA recognises that the well-developed linear collider structures and community are assets to the field and should be maintained until a decision on the future direction of the field is taken.

ECFA, Gran Sasso 2016

KET
Komitee für Elementarteilchenphysik

Conclusions of the

KET Workshop on Future e^+e^- Colliders[a]

Max-Planck-Institut für Physik Munich, May 2-3, 2016

1. The physics case for a future e^+e^- collider, covering energies from M_Z up to the TeV regime, is regarded to be very strong, justifying (and in fact requiring) the timely construction and operation of such a machine.[i]

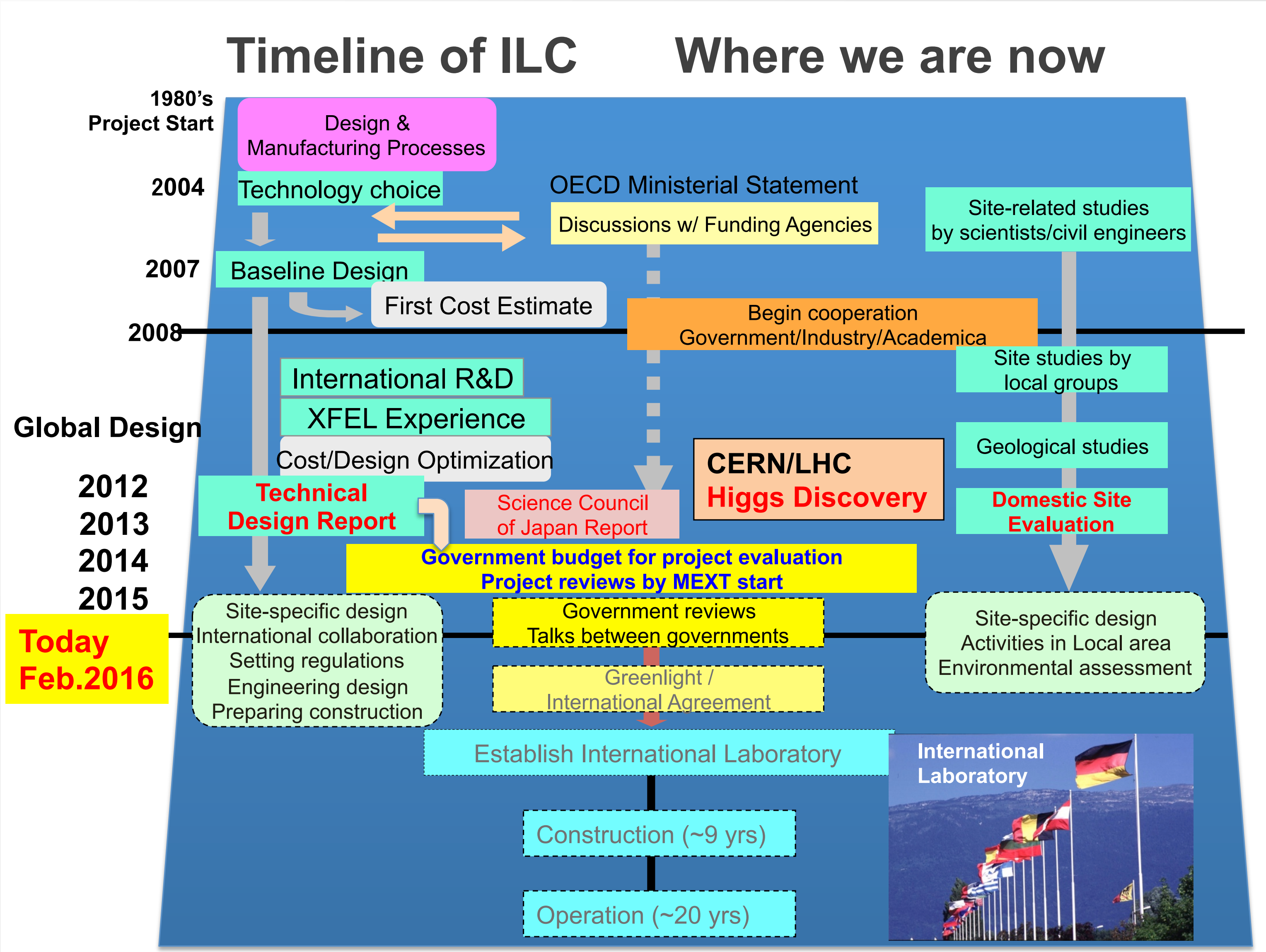
2. The ILC meets all the requirements discussed at this workshop.[ii] It is currently the only project in a mature technical state. Therefore this project, as proposed by the international community and discussed to be hosted in Japan, should be realised with urgency. As the result of this workshop, this project receives our strongest support.[iii]

3. FCC-ee, as a possible first stage of FCC-hh, and CEPC could well cover the low-energy part of the e^+e^- physics case, and would thus be complementary to the ILC.[iv]

4. CLIC has the potential to reach significantly higher energies than the ILC. CLIC R&D should be continued until a decision on future CERN projects, based on further LHC results and in the context of the 2019/2020 European Strategy, will be made.

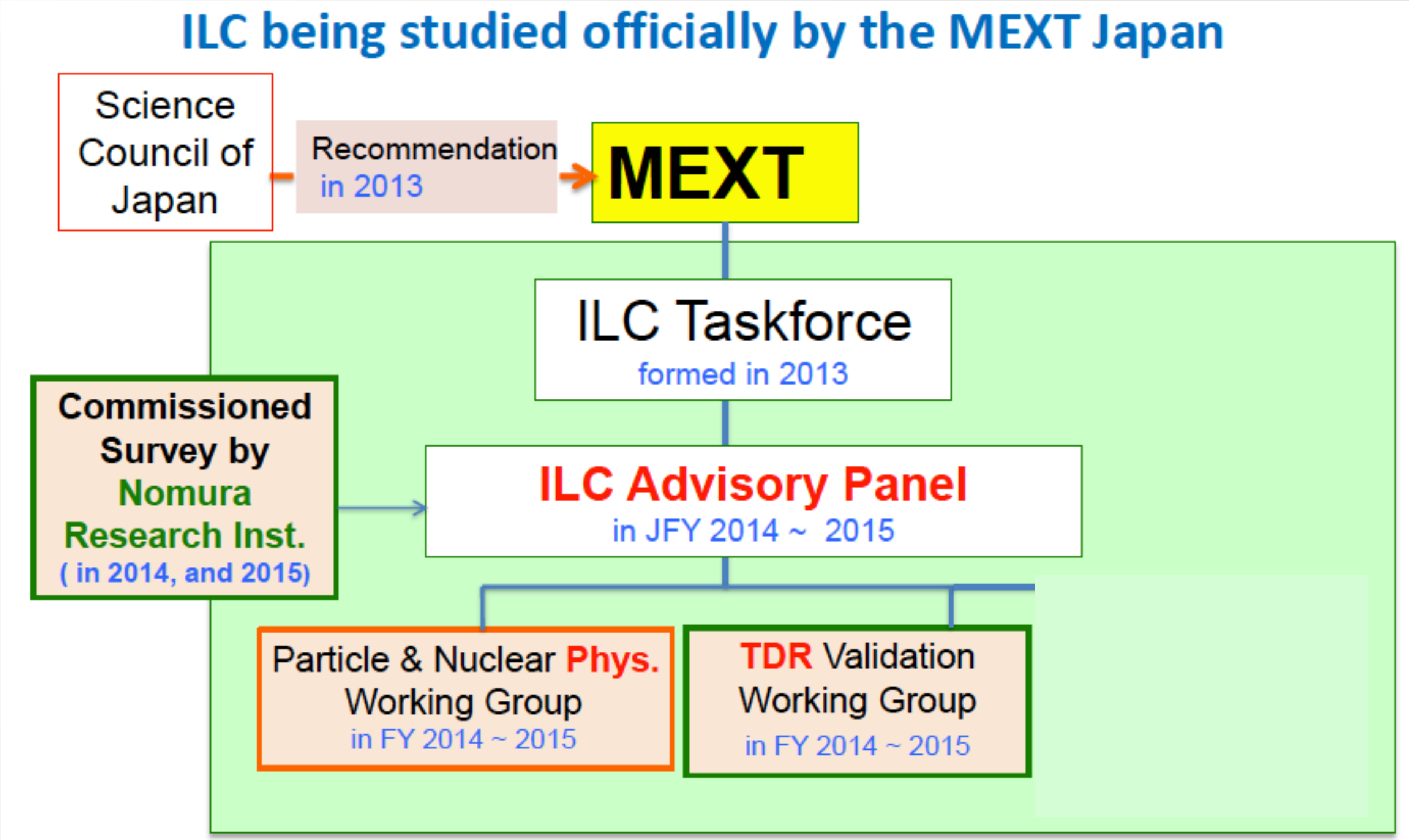
Topic	CEPC	FCC-ee	ILC	CLIC
Higgs Mass, couplings	+	+	+	+
Higgs self-coupling	-	-	+	+
Top physics	-	+	+	+
ew- precision parameters	+	+	+	-
BSM (direct searches)	-	-	+	+
Flexibility to new high mass signal	-	-	-	+
Maturity of project	-	-	+	-
Start by/before 2035	+	-	+	-

The ILC in Japan: political situation (S. Yamashita)

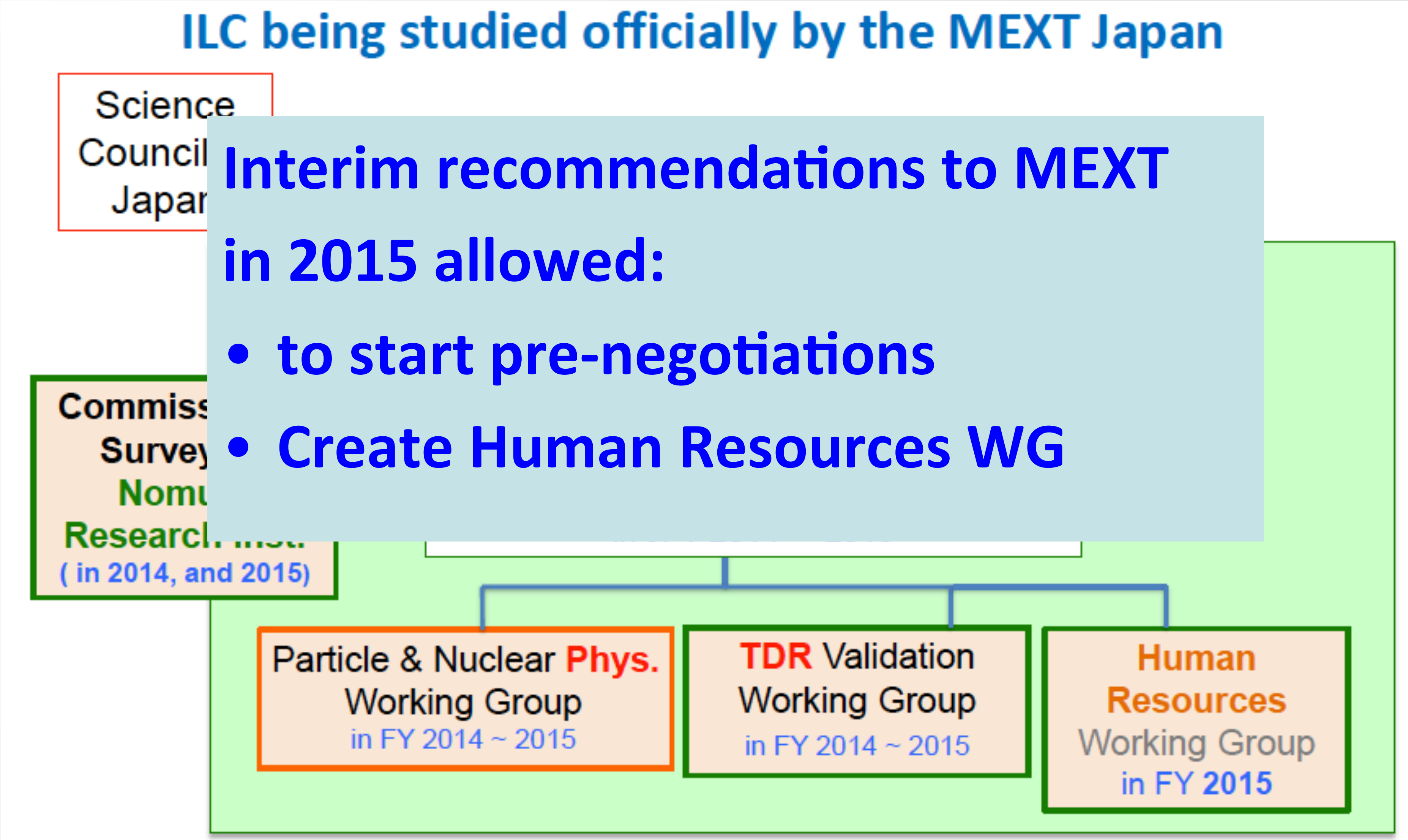


Japan: MEXT and Japanese Government towards ILC

Sachio Komamiya (LCWS 2015)



Sachio Komamiya (LCWS 2015)



Interim recommendations to MEXT in 2015 allowed:

- **to start pre-negotiations**
- **Create Human Resources WG**

Activity bodies in Japan for ILC

- 6 bodies

1. Federation of Diet members supporting ILC
2. MEXT: Ministry of Education, Sports, Culture, Science and Technology
3. Advanced Accelerator Association promoting Science and Technology (AAA) Industry-Academia
4. Local Bodies in Tohoku (bureau of Economy, business association, prefecture/city local governments, Universities).
5. Japanese Researchers HEP society and KEK
6. Japanese Embassy in US and Ministry of Foreign Affairs

Multilateral vs Bilateral

First try through multilateral discussion in 2013, but not successful.

- Multilateral is ideal but needs coherent moves and ground-work preparation in all countries at once.
- US likes bi-lateral rather than multilateral.
- EC (European Commission) and CERN would be the ideal coordination body for Europe. But EU Countries need individual (bi-lateral) discussion at the initial phase.

→ Switch from Multilateral to Bilateral since 2014:

- **US-Japan first, then expand to European countries, Russia, Asian countries and other nations / regions**

Growing Support and ongoing studies in local regions

- Very active efforts by local government, Universities, business groups, companies for preparation of ILC
- Progress in mapping (potentially) accelerator-related companies
- Wide-area regional/urban development: specific proposals (Multiple blueprints→synergy with ILC project)
- Regional economic effects (Estimates by university and private sector)

The ILC in Japan: media and social impact

Oshu City

Ichinoseki Station

Morioka

Tohoku tourism ad seen on Tokyo Metro

Posters and “Toy ILC” by school children of Oshu City welcoming international workshop on ILC

TIMING of the CONSTRUCTION PEAK

Construction period should care:

- the Olympic game 2020 in Tokyo (for Japan)
- Careful adjustment of the international budget profile not to overlap with cost peak of High Luminosity upgrades of LHC (especially for EU), and Neutrino program(s) (especially for US) (also human resources)
- Also with S&T big project in other area,

  notable example) ISS international Space station, ITER

The ILC in Japan: political situation summary

Strong support from the scientific community (new structure at KEK to promote ILC)

Support from industry (private sector responsible for 80% R&D funding in Japan)**:**

- >100 Companies, 40 Universities and Institutes, etc..

Support from government:

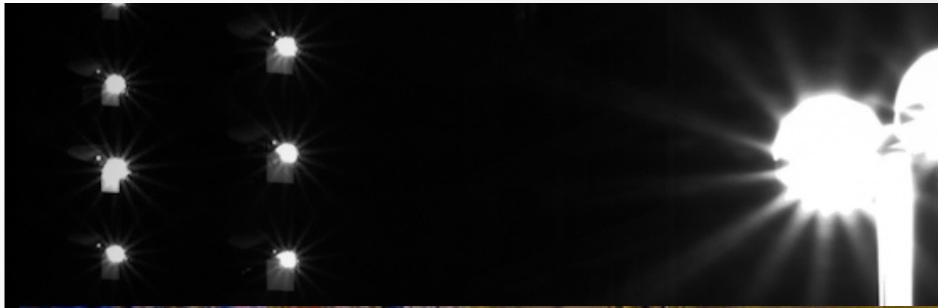
- Association of Diet Members to support the ILC (~150 Diet Members across all parties)
- ILC explicitly appears in the programme of LDP party
- Prime Minister Abe and several Ministers have publicly expressed their support

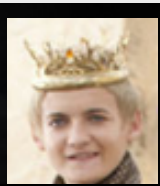
Enthusiastic local support in the region site (Tohoku, Kitakami)

Japanese government is very serious about ILC though decision is complicated and needs international reassurance before Japan can officially bid to host the ILC

A lot of activity “behind-the-scenes”. S. Yamashita (ECFA-LC 2016) about Japanese cultural aspects:

- Silence is a virtue
- Decisions are normally taken unanimously which implies a huge effort and tremendous ground-work before the discussion



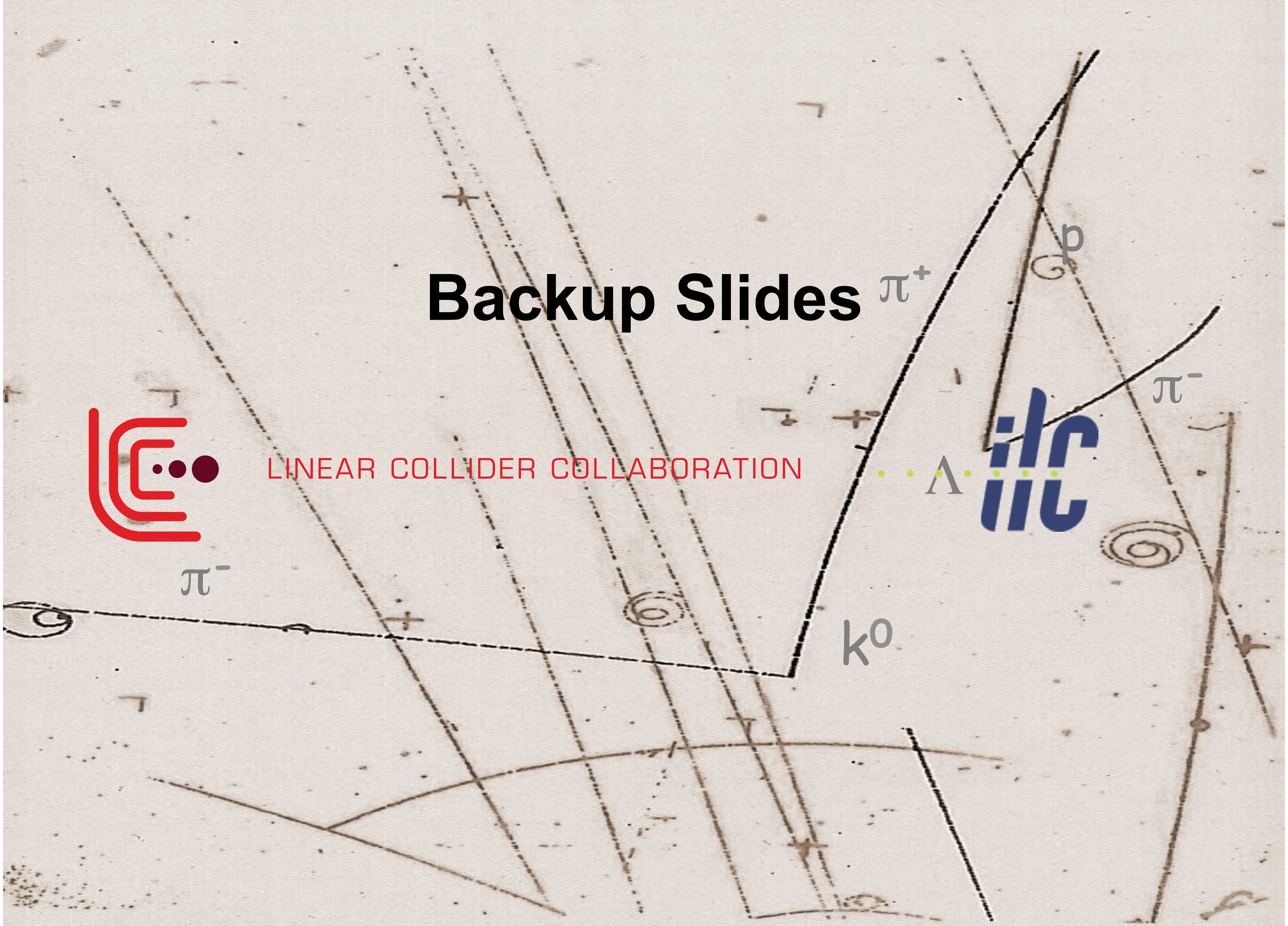


H(125) and top quark

Acknowledgements

- J. List
- D. Melini
- Ph. Burrows
- K. Fujii
- T. Behnke
- M. Stanitzki
- C. García
- H. Yamamoto
- …..

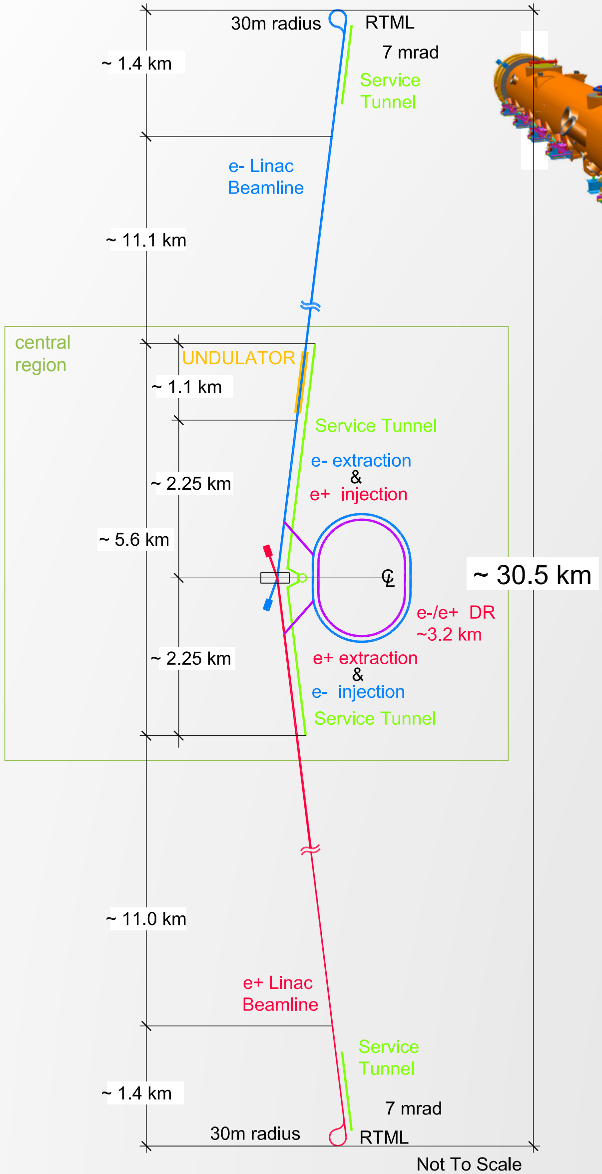
Backup Slides

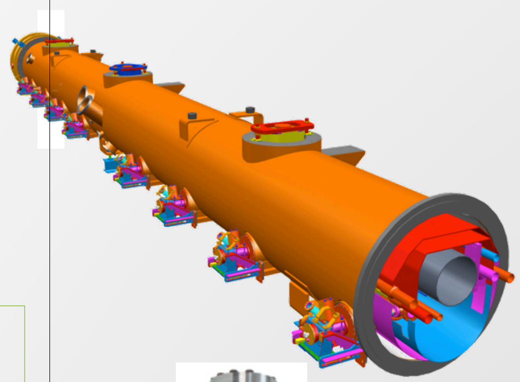


LINEAR COLLIDER COLLABORATION

ilc

ILC in a Nutshell





N. Walker – ILC Launch Event 2013

- 200-500 GeV E_{cm} e^+e^- collider
  $L \sim 2\times10^{34}\ cm^{-2}s^{-1}$
  - upgrade: ~1 TeV
- SCRF Technology
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs
- Developed as a truly global collaboration
  - **G**lobal **D**esign **E**ffort – **GDE**
  - ~130 institutes
  - http://www.linearcollider.org/ILC

ILC 500 GeV parameters

Physics	Max. E_{cm}	500 GeV
	Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
	Polarisation (e-/e+)	80% / 30%
	δ_{BS}	4.5%
Beam (interaction point)	σ_x / σ_y	574 nm / 6 nm
	σ_z	300 μm
	$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
	β_x / β_y	11 mm / 0.48 mm
	bunch charge	2×10^{10}
Beam (time structure)	Number of bunches / pulse	1312
	Bunch spacing	554 ns
	Pulse current	5.8 mA
	Beam pulse length	727 μs
	Pulse repetition rate	5 Hz
Accelerator (general)	Average beam power	10.5 MW (total)
	Total AC power	163 MW
	(linacs AC power	107 MW)

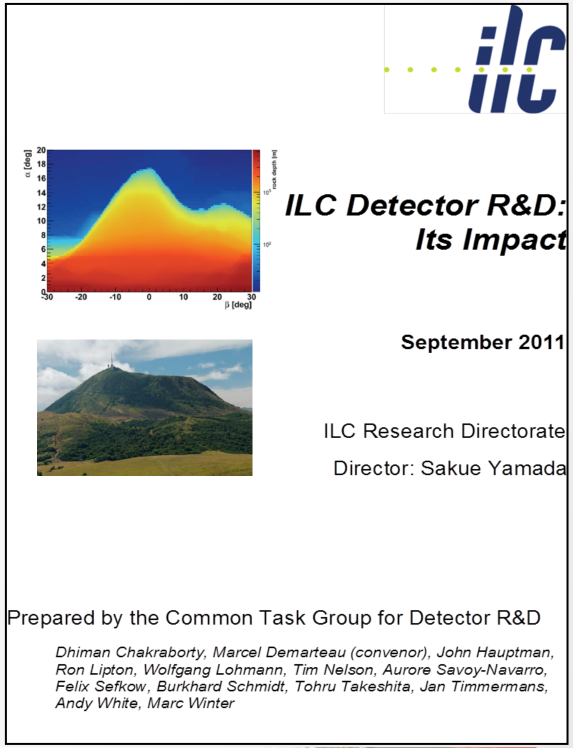
N. Walker – ILC Launch Event 2013

- Concept: increase n_b from 1312 → 2625
  - Reduce linac bunch spacing 554 ns → 336 ns

- Doubles beam power → ×2 $L = 3.6\times10^{34}\ cm^{-2}s^{-1}$

- AC power: 161 MW → 204 MW (est.)
  - shorter fill time and longer beam pulse results in higher RF-beam efficiency (44% → 61%)

Spinoffs derived from LC detector R&D


ILC Detector R&D:
Its Impact

September 2011

ILC Research Directorate

Director: Sakue Yamada

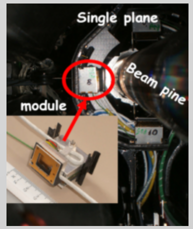
Prepared by the Common Task Group for Detector R&D

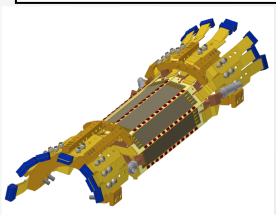
Dhiman Chakraborty, Marcel Demarteau (convenor), John Hauptman, Ron Lipton, Wolfgang Lohmann, Tim Nelson, Aurore Savoy-Navarro, Felix Sefkow, Burkhard Schmidt, Tohru Takeshita, Jan Timmermans, Andy White, Marc Winter

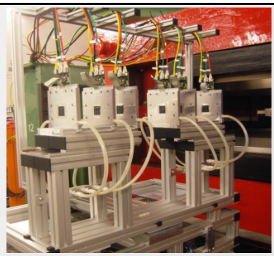
An study of the spinoffs derived by the LC detector R&D has been performed (worth reading!)

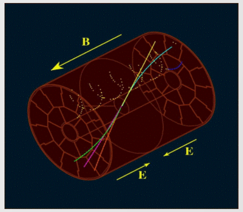
It includes:

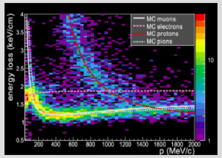
- HEP applications:
  - ✓ vertex developments (ALICE-ITS, CBM-FAIR,Star, BelleII)
  - ✓ TPC Micromegas (T2K)
  - ✓ Calorimeters (CMS)
  - ✓ Luminomiter and beam instrumentation (LHC, CMS)
  - ✓ trigger development (LHC, CAST)
  - ✓ software (Belle II, NOVA, AIDA, CLIC, μ-collider)
- None HEP applications:
  - ✓ X-ray imaging (astronomy, medicine, proton tomography, volcano tomography)
  - ✓ ASICs for Balloon experiments

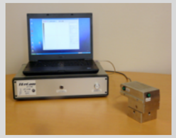


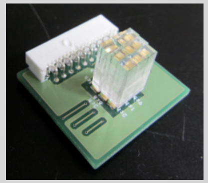


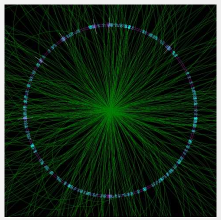


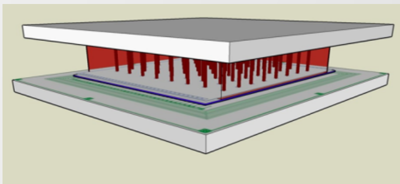












Sachio Komamiya (LCWS 2015)

“Summary of the ILC Advisory Panel’s Discussions to Date”

with English translation August 2015

As an official process of the Japanese Government towards the approval

⇒ **ICFA will respond to this report**

1. Discussion background …
2. Overview of discussions

(1) Science Merit of the ILC Project

The ILC is considered to be important because of its capability to investigate new physics beyond the Standard Model by exploring new particles and precisely measuring the Higgs boson and top quark. It should be also noted that the ILC might be able to discover a new particles which are difficult to be detected in LHC experiments…….

ILC experiments are able to search for new particles, different from the ones that LHC experiments have been searching for. In case these new particles are supersymmetric particles, ILC and LHC experiments can study them complementally. On the other hand ILC experiments can carry out more precise measurement of the Higgs boson and the top quark, which are beyond the reach of LHC experiments………

…

(2) Validation of TDR

(3) International Collaboration

(4) Social effect of the ILC Project **Economic effects, Industrial Spin-off**

Japan: MEXT and Japanese Government towards ILC

Sachio Komamiya (LCWS 2015)

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.

⇒ Discovery is not guaranteed at any frontier machines , but clear vision of discovery potential have been already demonstrated for ILC.

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.

⇒ Surely we will monitor LHC physics.

MEXT is contacting governments during the LHC 13 TeV Run.

Recent "ILC Progress Report" by LCC answers most of the technical items.

Recommendation 3: While presenting the total project plan, including not only the plan for the accelerator and related facilities but also the plan for other infrastructure as well as efforts pointed out in Recommendations 1 & 2, it is important to have general understanding on the project by the public and science communities.

⇒ Public relation will be reinforced by international team and by KEK and the Industry Supporters (AAA).

Discussions with scientists of the other fields have been undertaken by KEK DG.

ICFA/LCB are preparing a document to clarify the issues in the report of the ILC Advisory Panel by the end of this year.

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⇒ Discovery i

potential h

Recommenda

achievements

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This recommendations have enabled MEXT to start negotiations with other countries

So far, SM-like but we need more precision to understand its true nature..

The main questions:

- What are the couplings of this particle to other known elementary particles? Is its coupling to each particle proportional to that particles mass, as required by the BEH mechanism?

- What are the mass, total width, spin and $\mathcal{CP}$ properties of this particle? Are there additional sources of $\mathcal{CP}$ violation in the Higgs sector?

- What is the value of the particles self-coupling? Is this consistent with the expectation from the symmetry-breaking potential?

- Is this particle a single, fundamental scalar as in the SM, or is it part of a larger structure? Is it part of a model with additional scalar singlets/doublets/ldots? Or, could it be a composite state, bound by new interactions?

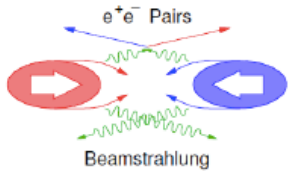
- Does this particle couple to new particles with no other couplings to the SM ("Higgs portal")? Is the particle mixed with new scalars of exotic origin, for example, the radion of extra-dimensional models?

Operating the ILC

- pulsed operation:
  - trains of N_{bunch} = 1315 / 2625 bunches, **530 / 270 ns bunch spacing**
  - train repetition rate: 5 – 10 Hz => 199 – 99 ms break

enables
- **triggerless readout of detectors => sensitivity to "subtle" signatures**
- **power pulsing => low mass tracker, dense calorimeter**

- collisions:
  - luminosity grows with energy
  - minimize beamstrahlung => flat beams 500x5 nm^2



ECM [GeV]	**250**	**250**	**500**	**250**	**500**	**1000**
rep. rate [Hz]	5	10	**5**	10	5	**5**
N_{bunch}	1315	1315	**1315**	2625	2625	**2625**
inst. lumi [10^{34} / cm^2 / s]	0.75	1.5	**1.8**	3	3.6	**3.6-4.9**
total power [MW]	**100**	**160**	**160**	**190**	**200**	**300**

	CEPC	**5 Hz, 1315 bunches**	**10 Hz, 1315 bunches**	**10 Hz, 2625 bunches**
inst. lumi [10^{34} / cm^2 / s]	**3.6 - 4**	0.75	1.5	**3**
total power [MW]	**498**	100	160 ?	**190**

ILC 75% of CepC luminosity with 40% of CepC wall-plug power.

Not a bad deal !!
(J. List, LHCSki2016)

Green-ILC WG
(Denis Perret-Gallix et al. http://green-ilc.in2p3.fr/)

SiD detector concept

SiD is moving ahead towards TDR

- Organization is in place
- Clear plan what "needs to be done" for a TDR

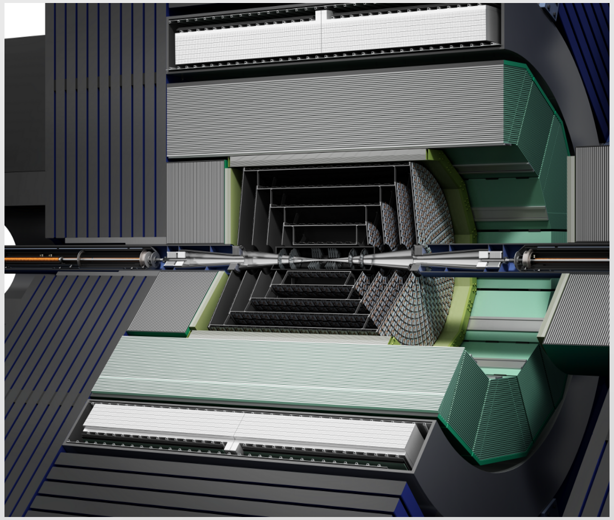
Severe lack of funding is slowing down progress

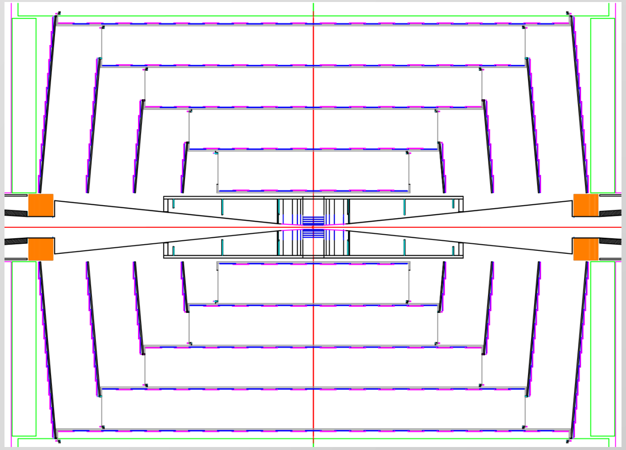
Consortium is growing

SiD remains committed to deliver a detector for the ILC

Latest Developments

- HCAL Task Force
  - ➢ Clear recommendation for changing the HCAL technology baseline
  - ➢ Currently under Consortium review
- SiD Software
  - ➢ SiD has decided to adopt the DD4HEP suite developed by CERN
- Optimizing SiD
  - ➢ Actively reviewing all sub-detector choices



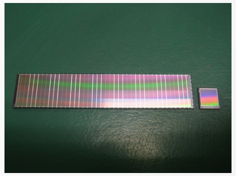


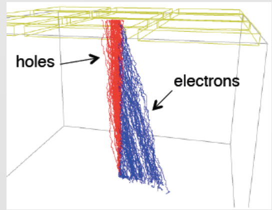
ILD detector concept

Goals and Strategies:

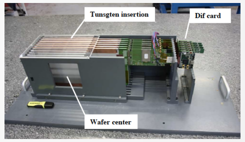
- Make the scientific case for the ILC
  - Move forward as one community
  - Join forces with SiD
  - Integrate theory and experiment
- Adapt the ILD design for the Japanese site
- Re-optimize the detector (cost – performance optimization)
  - ➢ Careful study needed of cost vs. performance
  - ➢ Strong focus on making the connection between the detector design and the physics performance explicit.
- ILD continues to be carried by a strong community
- To make real progress significantly larger resources are needed

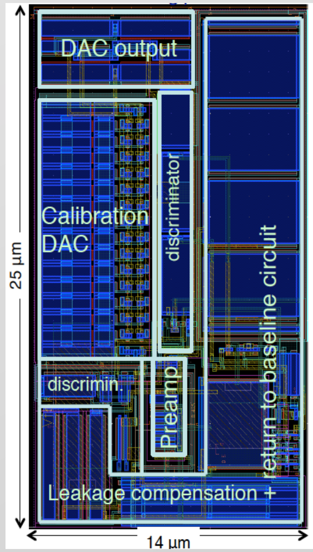
Challenges for ILC (0.25-1.0 TeV)/CLIC (0.38-3.0 TeV) detectors



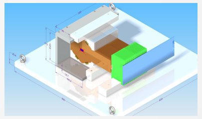


- Due to experimental conditions
  - Manageable occupancies in the presence of beam-induced background

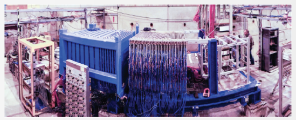




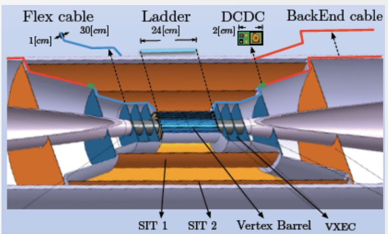
  - Radiation hardness for forward calorimetry

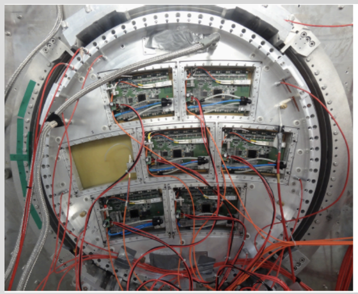


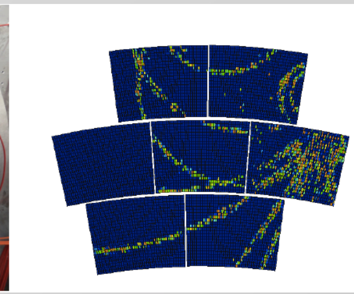
- Timing capabilities required for CLIC
  - All tracking detectors with ~10ns time-stamping capability



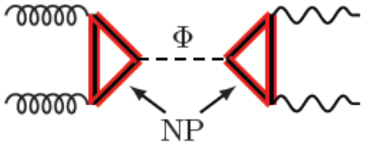
  - Time precision on calorimeter hits of ~1ns





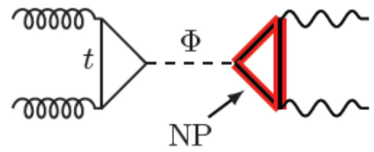


New LHC data, the unexpected X(750) ?



$$R_{\gamma\gamma} \sim \frac{\Gamma_{\gamma\gamma}}{m_\Phi}\mathcal{L}_{gg} \sim \frac{\Gamma_{\gamma\gamma}}{\text{MeV}}\,\text{fb}$$

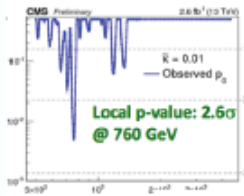
What ATLAS and CMS say



$$R_{\gamma\gamma} \sim \frac{\Gamma_{gg}}{\Gamma_{tt}}\frac{\Gamma_{\gamma\gamma}}{m_\Phi}\mathcal{L}_{gg} \sim \frac{\Gamma_{\gamma\gamma}}{\text{GeV}}\,\text{fb}$$

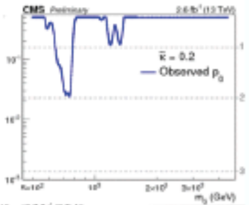
CMS Significance

Narrow

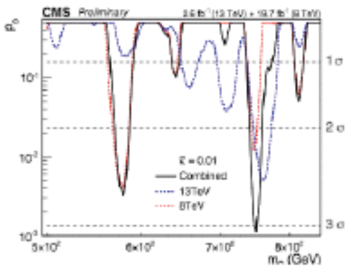


Equally plausible

Wide

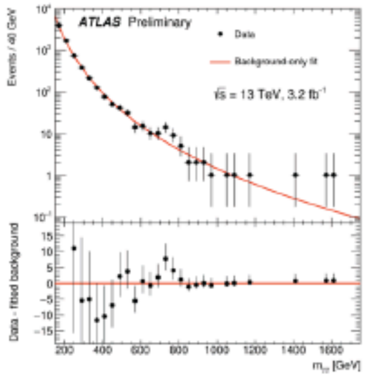


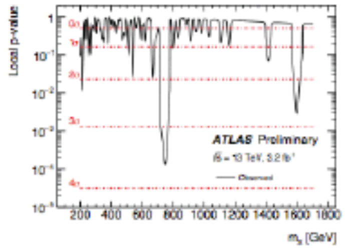
Combined with 8 TeV



3σ local

ATLAS data





narrow: 3.6 σ local
wide: 3.9 σ local
(equally plausible)

total signal rate: 5 - 10 fb

2.6 σ local excess at 760 GeV
1.2 σ with LEE (500 GeV - 4.5 TeV)

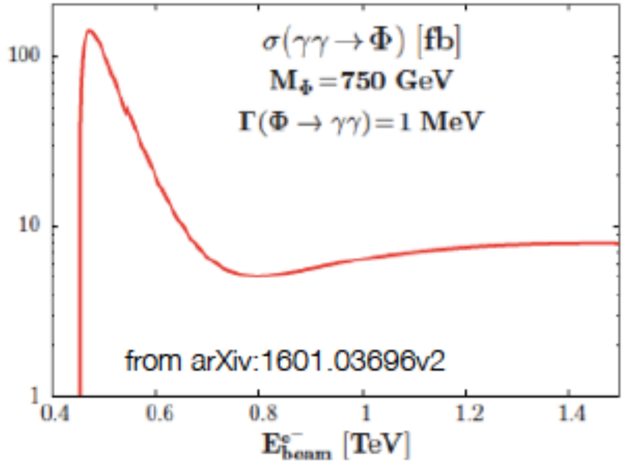
3.6 σ local excess at 750 GeV
2.0 σ with LEE (200 GeV - 2 TeV)

$\sigma(pp \to \gamma\gamma)$	8 TeV	13 TeV
CMS	(0.5 ± 0.6) fb	(6 ± 3) fb
ATLAS	(0.4 ± 0.8) fb	(10 ± 3) fb

Ch. Grojean

New LHC data, the unexpected X(750) ?

1. study the properties of the 750-GeV particle itself:
   - **LHC, HL-LHC will still provide a lot of information!**
   - FCC 100 TeV: increase cross section by factor 100
     => even more statistics, but still the same production mechanism (gluon-gluon fusion?)
   - the (only?) promising *alternative* way:
     $\gamma\gamma$ option of 1TeV e+e- Linear Collider !
     - ideal for *independent* precision determination of $\Gamma_{\gamma\gamma}$
     - and its CP properties



2. **study its effects on other known particles, in particular Higgs, top, EWPO**
   - in many possible models, deviations from SM well motivated
     - "tree-level": e.g. in 2HDM
     - through loops involving the 750 GeV particle
   - even null result (i.e. agreement with SM) provides important constraints on interpretation

   => bread & butter programme of future e+e- colliders is as crucial as ever !

J. List KET2016

DOE Goals for ILC Work

- Japan has expressed interest in hosting the International Linear Collider (ILC) and is actively working through a decision making process
- As recommended in the P5 strategic plan, DOE plans to provide modest and appropriate support through the period of Japanese decision making
  - U.S. has played key roles in the design of the ILC accelerator, including leadership in the Global Design Effort
  - Continued intellectual contributions to the accelerator and detector design are still necessary to enable a site-specific bid proposal
  - P5 recommended ILC support at some level in all budget Scenarios through a decision point within the next 5 years
- DOE is making an effort to maintain ILC accelerator activities in balance with other programmatic priorities

U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. Research Activities Related to Future Colliders - 3/23/2015 11

Andrew J. Lankford, FCC-Rome 2016

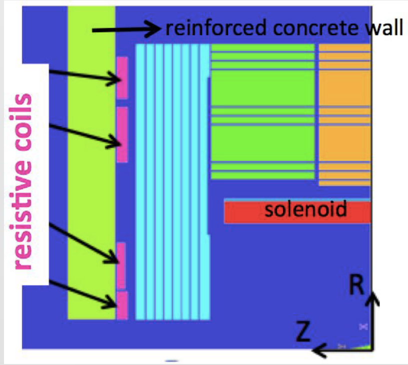
CLIC new detector concept

Re-optimising the detector concept for CLIC (from studies of CLIC_ILD & CLIC_SiD performance and optimization):

- Reducing occupancies
- Extending coverage in forward region

Main actions:

- Move QD0 to L*=6m outside detector yoke
- Number of muon layers reduced from 9 to 6
- Extend HCAL closer to beampipe



W ⇔ Z separation for different HCAL absorbers

New detector model to be used in future studies