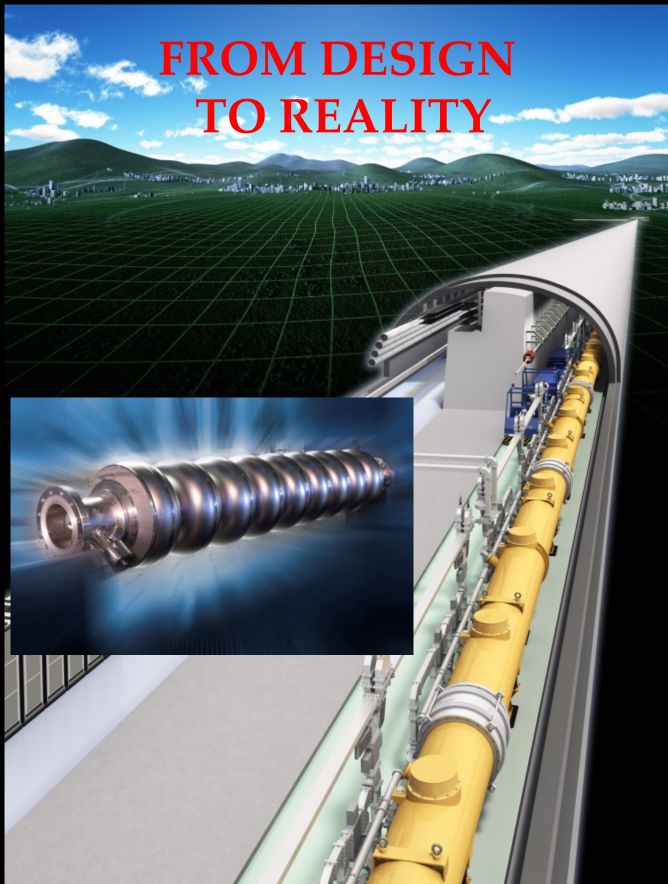
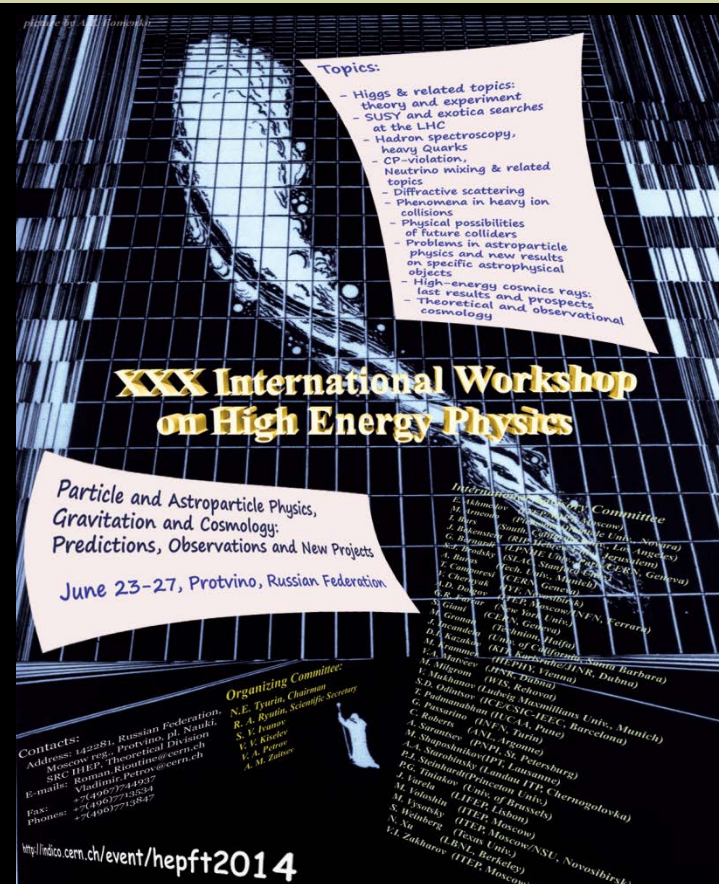
Global ILC Project in Japan: Accelerator / Physics / Detectors



Maxim Titov (CEA Saclay, France)

XXX International Workshop on High Energy Physics,
Protvino, Russia, June 23 - 27, 2014

Acknowledgments to 1000's people for their hard work who advanced the ILC project to the TDR stage

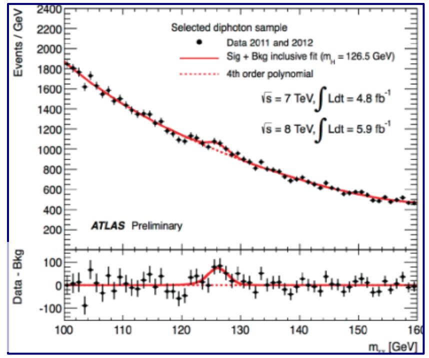


Outline the Talk:

- ❖ ILC Accelerator: SRF & Global Cooperation
- ❖ ILC Physics: Top, Higgs, SUSY/ BSM
- ❖ ILC Detector Technologies
- ❖ Global ILC Project: The Way Forward

The International Linear Collider (ILC) – From Design to Reality

2012 - Discovery of Higgs Boson:
"Revolution in Particle Physics"



Higgs discovered

LHC

2005 2006 2007 2008 2009 2010 2011 2012 2013

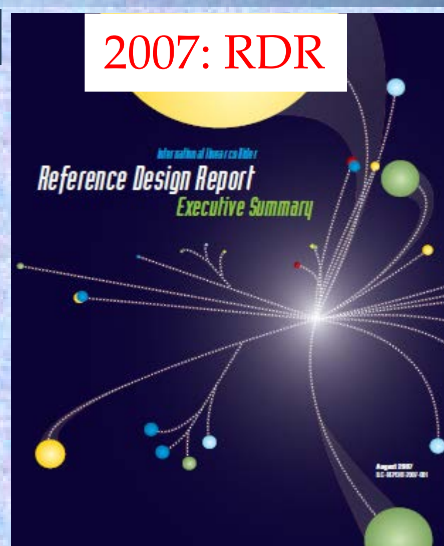
2004

ILC - GLOBAL DESIGN EFFORT (GDE)

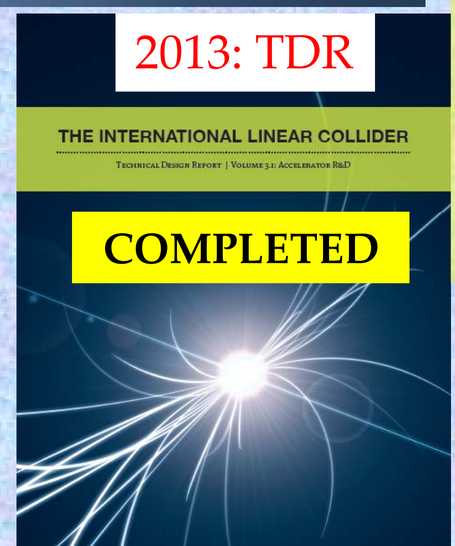
LCC

Ref. Design Report (RDR)

2007: RDR



2013: TDR

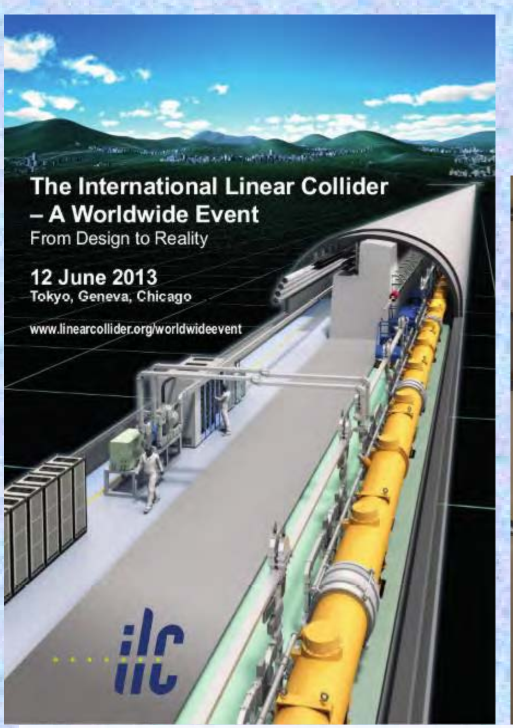


COMPLETED

Linear Collider Collaboration

June 12, 2013: Official Completion of ILC TDR
"A World-Wide Event – From Design to Reality"

https://agenda.linearcollider.org/conferenceOtherViews.py?view=standard&confId=6004



ILC TDR published in a Worldwide Event: Tokyo → Geneva → Chicago

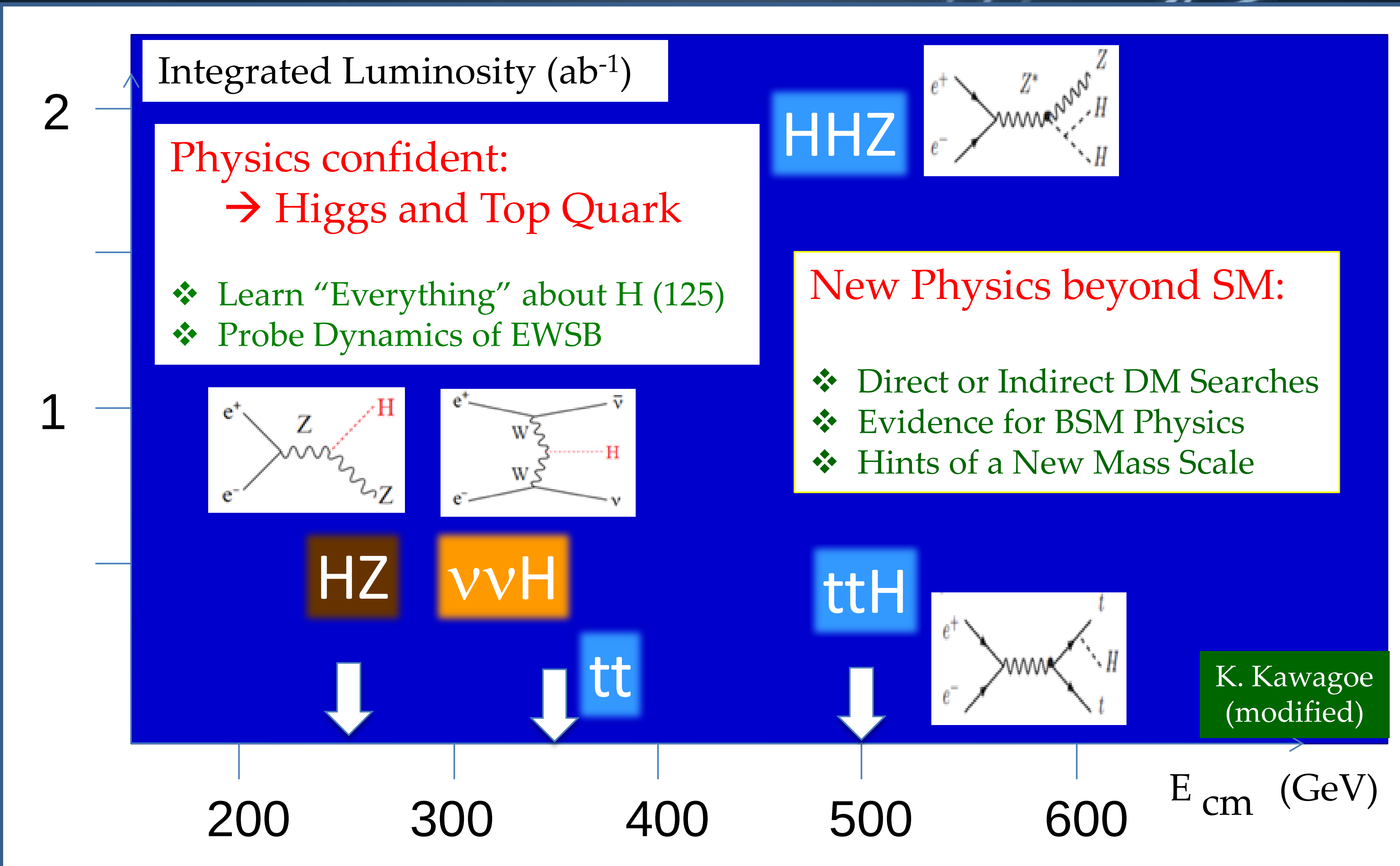
TDR handed to LCC Director Lyn Evans

As compared to other projects of a similar scale (ITER, LHC, ATLAS, CMS, ALMA, XFEL, FAIR, ESS, SSC), the quality of the TDR documentation presented by the GDE team is equal or superior to that utilized to launch into a similar process

→ THE ILC IS "READY TO GO AHEAD" !

The Rising Sun of the Linear Collider → ILC as the "Higgs Factory"

❖ Discovery of a 125 GeV Higgs has reinforced the importance of the ILC



HISTORY OF COLLIDERS (Thinking of the Future):

- Precision measurements of neutral current (*i.e.* polarized e+d) **predicted** m_W, m_Z
  → UA1/UA2 **discovered** *W/Z* particles
    → LEP **nailed** the gauge sector

- Precision measurements of *W,Z*(LEP+Tevatron) **predicted** m_H
  → LHC **discovered** *a Higgs particle*
    → LC **nails** the Higgs sector?

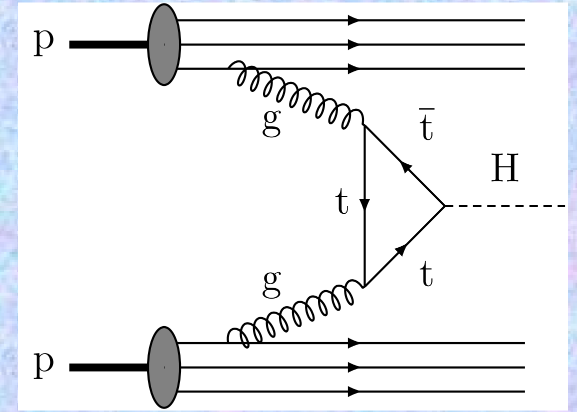
- Precision measurements of Higgs **(HL-LHC + LC) will nail the** "New Energy Scale" ?

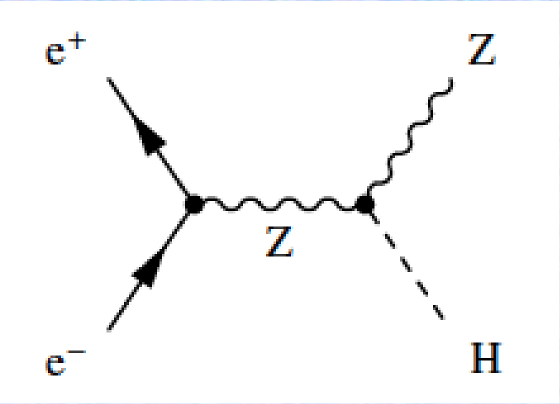
Why ILC Today ?

Problem: no argument for a particular energy scale yet ☹

Push Energy Frontier Beyond LHC (HE-LHC, CLIC, FCC-pp)☺

Hadron vs Lepton Colliders





p-p collisions	e^+e^- collisions
Proton is compound object → Initial state not known event-by-event → Limits achievable precision	e^+/e^- are point-like → Initial state well defined (√s / polarization) → High-precision measurements
Circular colliders feasible	Linear Colliders (avoid synchrotron rad.)
High rates of QCD backgrounds → Complex triggering schemes → High levels of radiation	Cleaner experimental environment → trigger-less readout → Low radiation levels
High cross-sections for colored-states	Superior sensitivity for electro-weak states

The ILC Accelerator Complex: How It Works ?

Ring to Main Linac
(including bunch compressors
→ reduce σz to eliminate
hourglass effect at IP)

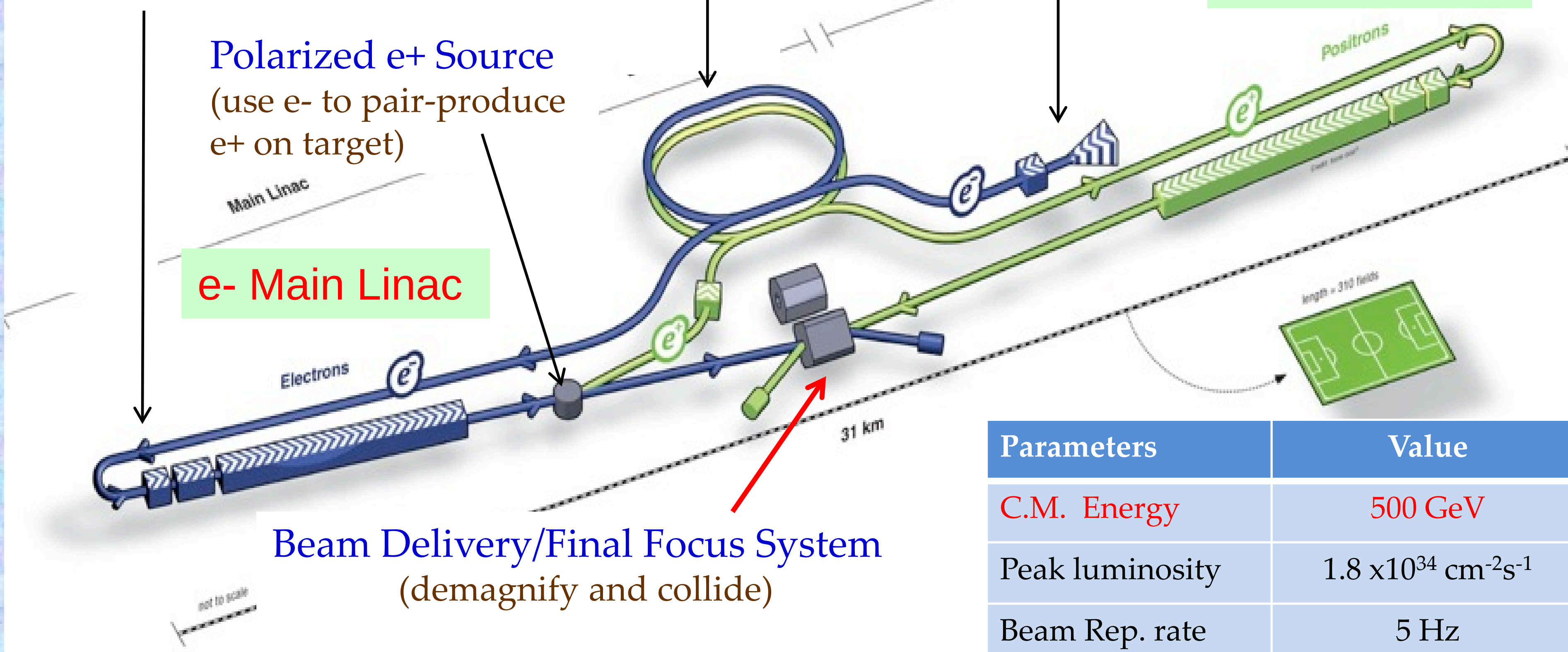
Damping Rings
(reduce emittance
→ smaller transverse
IP size achievable)

Polarised Electron Source
(deliver stable beam current)

Polarized e+ Source
(use e- to pair-produce
e+ on target)

e+ Main Linac

e- Main Linac



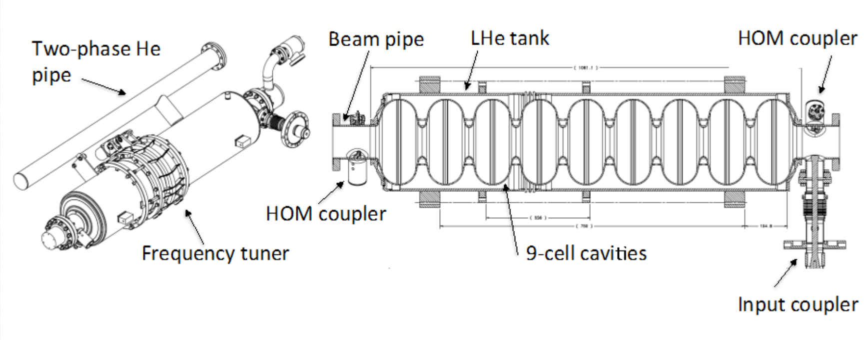
Beam Delivery/Final Focus System
(demagnify and collide)

Two detectors ("Push-Pull" option)

ILC TDR: key accelerator technologies in hand after extensive R&D

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

The ILC Superconducting RF Cavity



Parameter	Value
Fundamental	1.300 GHz
Average accelerating gradient	31.5 MV/m (±20%)
Quality factor	≥ 1 x 10 10
Active length	1.038 m
Total length	1.247 m
Numbers of cells	9
Cell construction	2.6 mm thick Niobium sheet metal
Niobium material	RRR > 300
Weight	35 kg

1.3 GHz (9-cell Nb) Cavities	16,024
Cryomodules	1,855
10 MW MB Klystrons & modulators	436

Approximately 20 years of R&D worldwide →
Mature technology, overall design & control of cost

Why is the Trend Towards Super-Conducting RF ?

There are a number of advantages from SRF technology:

- Ultra-high Q_0 (10^{10}):
  - small surface resistance → almost zero power (heat) in cavity walls
  - use relatively low-power microwave source to 'charge up' cavity
- Long beam pulses (~1 ms)
  → intra-pulse feedback
- Larger aperture / smaller beam loss
  → better beam quality with larger aperture - lower wakefields
- Future work will focus on engineering:
  - Cryomodule (thermal insultation)
  - Cryogenics
  - Gradient to be further improved

Luminosity:

RF efficiency

RF power / beam current

$$L \propto \frac{\eta P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

Vertical emittance (tiny beams)

- For given total power (electricity bill !), luminosity proportional to RF efficiency ILC: ~160MW @ 500GeV
- Capable of efficiently accelerating high beam currents
- Low impedance aids preservation of high beam quality (low emittance)

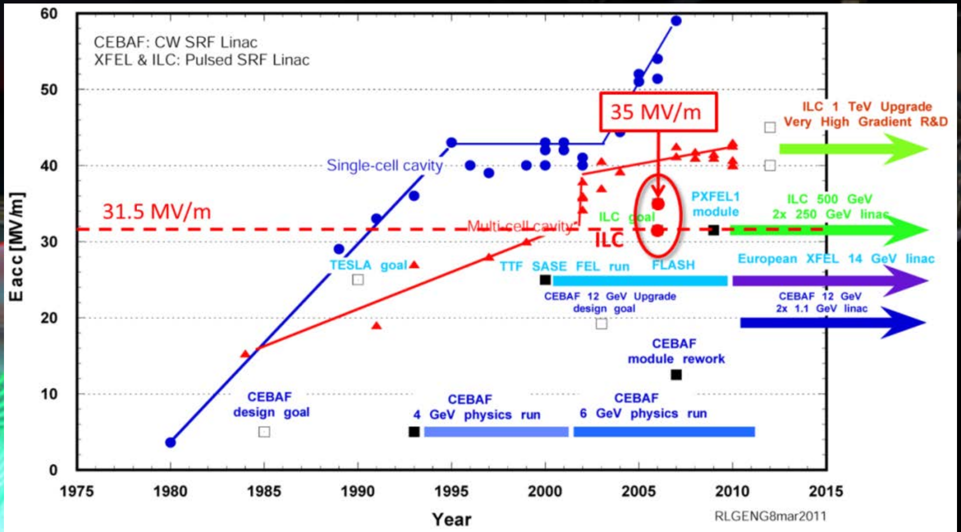
→ Ideal for Linear Collider

ILC will extend basic science reach through technology coupled with precision & control

SRF Cavity Gradients: Performance and Industrialization

Continued progress in SRF Gradients:

- ❖ Breakthrough of 45 MV/m gradient and a record of 60 MV/m achieved in 1-cell (1300 MHz) Nb cavity
- ❖ Gradient demonstration of 45-50 MV/m in 9-cell cavity is foreseen in next 5 years.



Goal is to increase the number of qualified vendors in the Americas and Asia regions

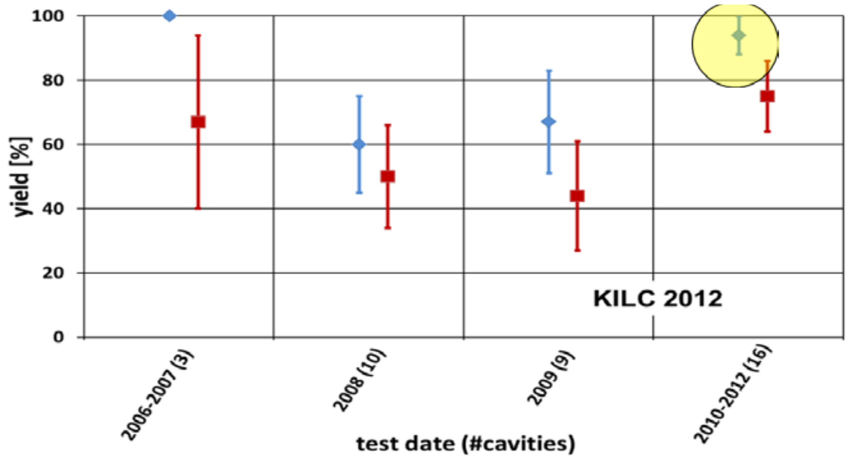
- ➢ Production yield: 94 % (±6%) at > 28 MV/m
  → acceptable for ILC mass production
- ➢ Average gradient (2nd pass): 37.1 MV/m
  → exceeds 2005 GDE R&D goal
- ➢ ILC (linac) gradient spec. : 31.5 MV/m ± 20%

- ❖ GDE global database: Asia – KEK; Europe – DESY; US – JLab, FNAL, Cornell
- ❖ Qualified cavity vendors: Asia – 2; Europe – 2; US – 1

Yearly Progress in Cavity Gradient Yield:

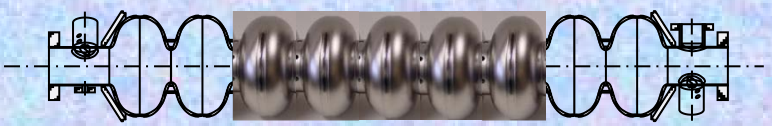
> 28 MV/m yield > 35 MV/m yield

2nd pass: if gradient < 35MV/m and $Q_0 < 8 \times 10^9$

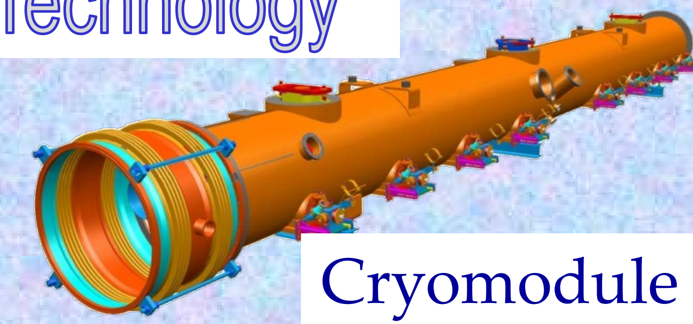


Global Superconducting RF Linac Technology

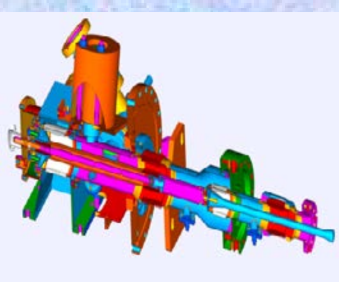
RF Cavity

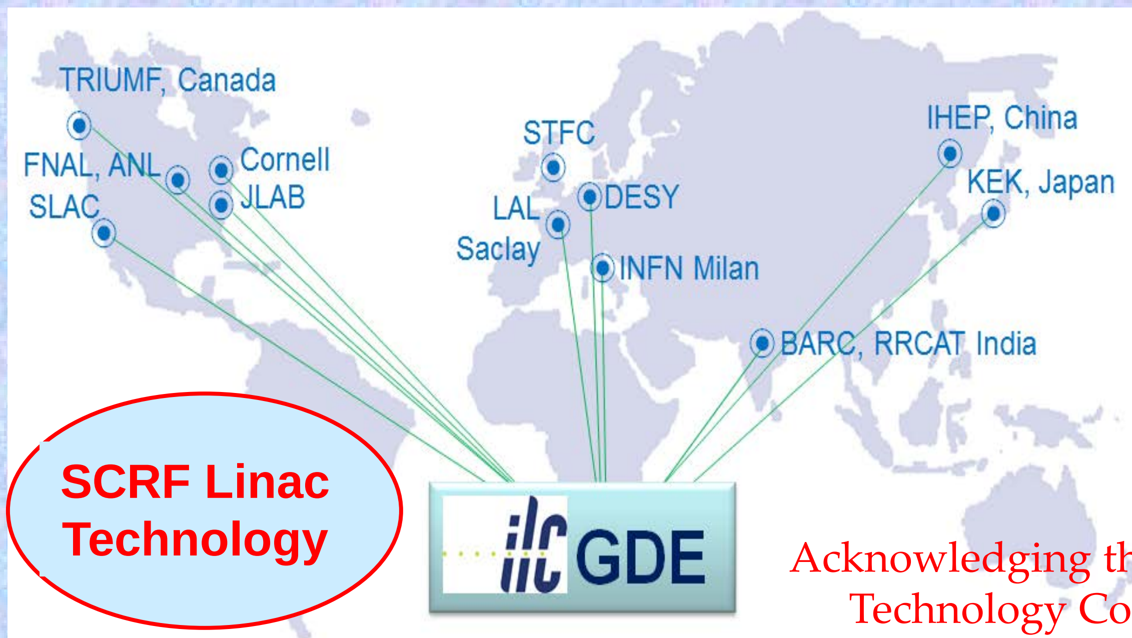


Cryomodule



Power Coupler

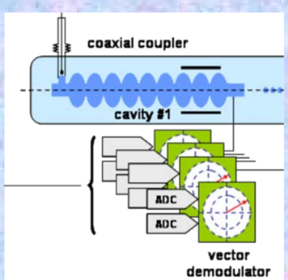




Frequency Tuner

Acknowledging the efforts of the Tesla Technology Collaboration (TTC)

LLRF

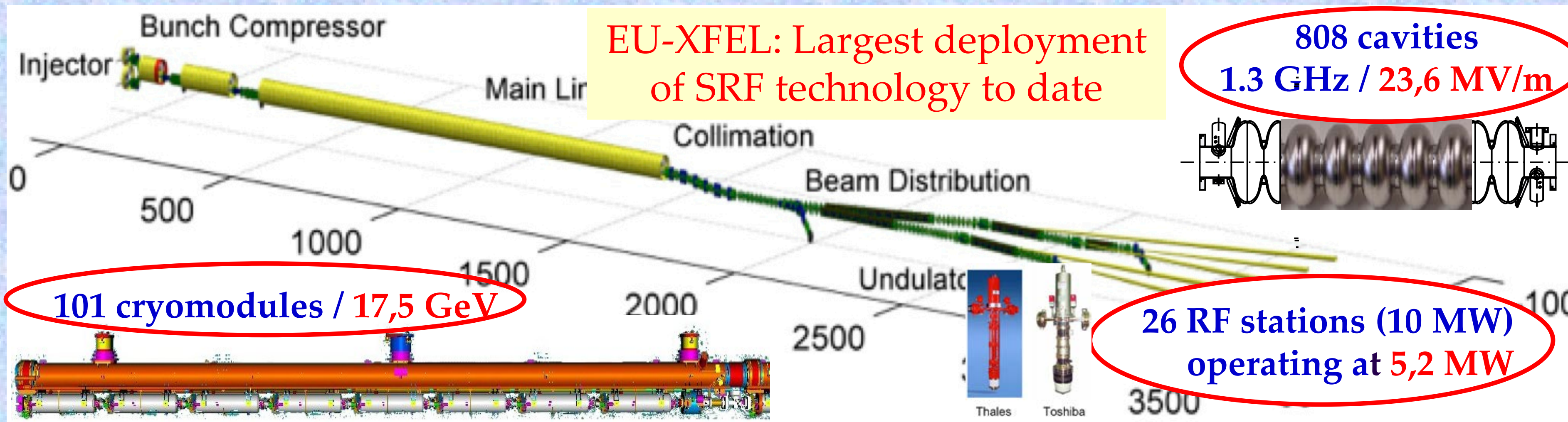


RF power

HOMs (higher order modes) coupler

Promote development of 1.3 GHz cavities, expertize and infrastructure in <u>all 3 regions</u>

European XFEL @ DESY



EU-XFEL: Largest deployment of SRF technology to date

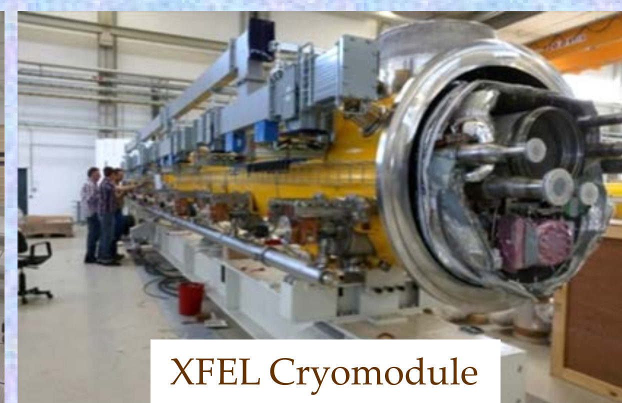
808 cavities
1.3 GHz / 23,6 MV/m

101 cryomodules / 17,5 GeV

26 RF stations (10 MW)
operating at 5,2 MW


Vertical Cavity RF Test @ DESY


Cavity String Assembly @ CEA


XFEL Cryomodule

Institute	Component 7 Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

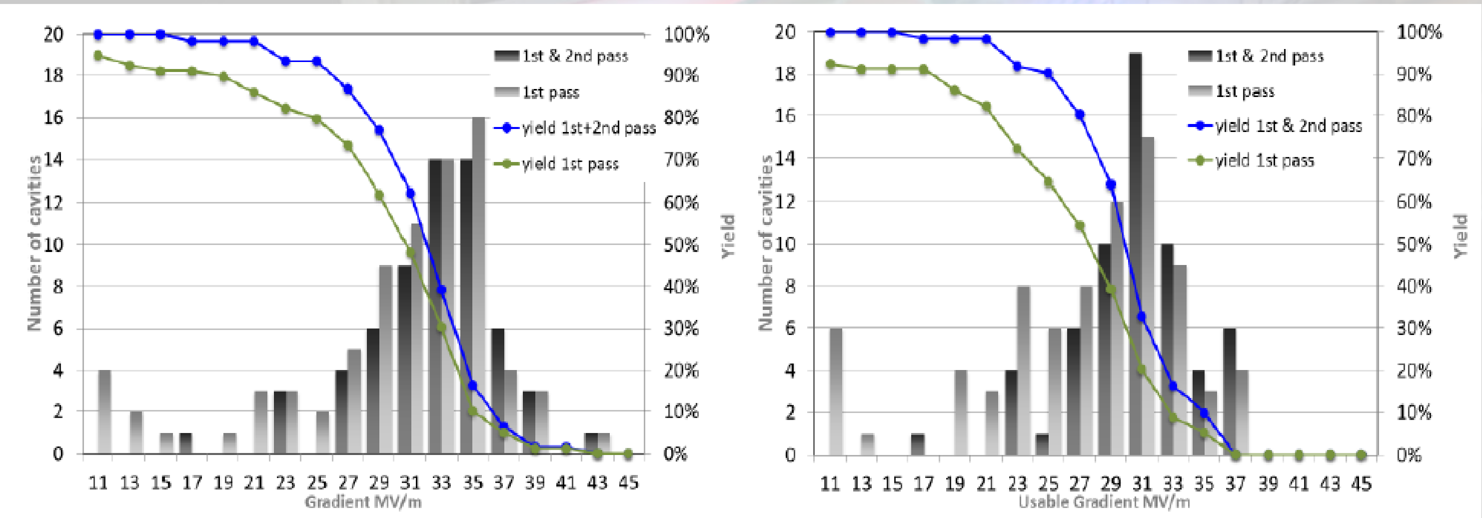
XFEL Linac: the ultimate 'integrated systems test' for ILC

→ Commissioning with beam: beginning of 2016

Industrial Mass Production of SRF Cavities for EU - XFEL

- 800 XFEL SRF cavities for XFEL at DESY (5% of ILC @500 GeV)
  → unique statistical sample to study properties of mass-produced cavities
- Industrial production (RI, ZANON) yields gradients > 23.5 MV/m (XFEL spec)

Yield of usable maximum gradient of 64 cavities (status as of Sep. 2013)
→ 50 cavities passed in 1st test + 14 cavities after re-treatment (2nd pass)



Status of May 2014:

~ 300 XFEL cavities were produced by EZ, RI → similar gradient performance

D. Reschke, SRF 2013 TTC 2014

Average maximum gradient: (30.9 ± 4.4) MV/m

Average usable gradient: (29.0 ± 3.9) MV/m

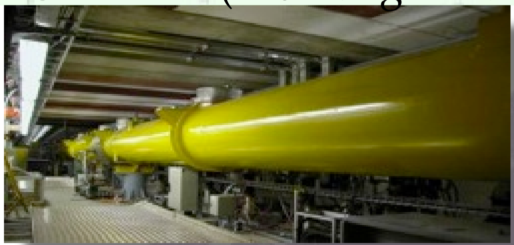
- Yield for high-gradient cavities is limited by local defects in individual cells:
  → quench of cavity or eventually field emission (excessive X-rays)

E.g.(recipes for post-treatment):

- Geometrical defects limit gradient < 20 MV/m → mechanical polishing
- ILC: < 20% cavities with < 35 MV/m on the first-pass test → 2nd pass includes HPR or light EP

Global Cooperation for ILC Accelerator

TTF/FLASH (DESY) ~1 GeV
ILC-like beam
ILC-RF unit (* lower gradient)



STF / STF2 (KEK)
Quantum Beam experiment
ILC Cryomodule Test : S1-Global

CesrTA (Cornell)
electron cloud
low emittance

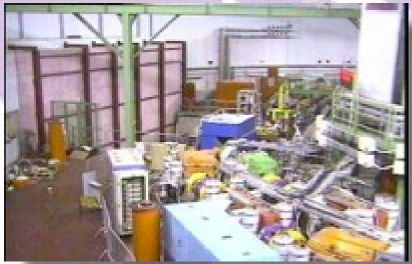
DESY

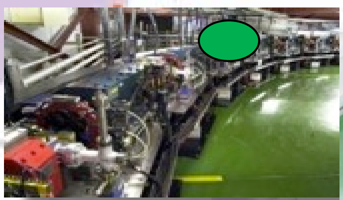
INFN Frascati

KEK, Japan

FNAL

Cornell





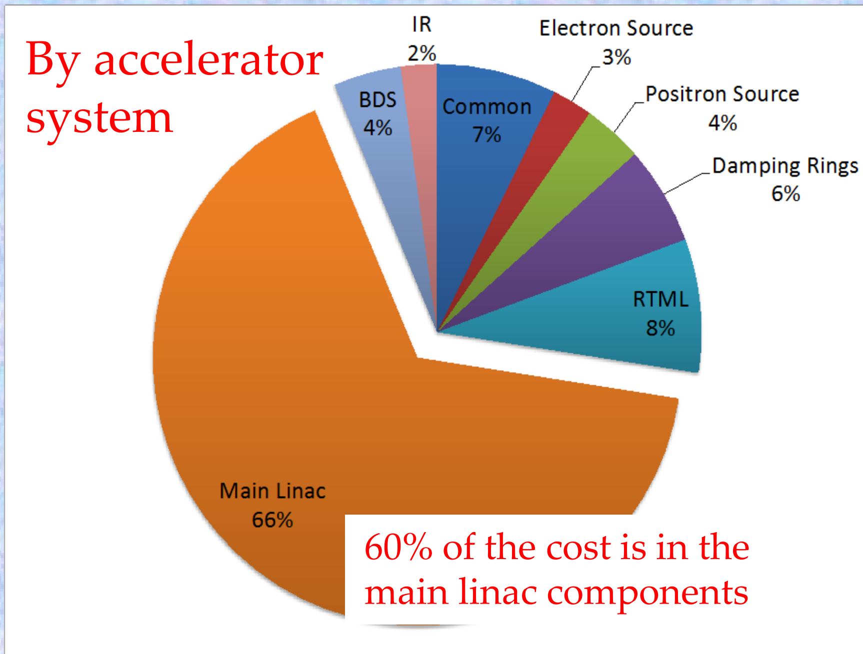
DAfNE (INFN Frascati)
kicker development
electron cloud

ATF & ATF2 (KEK)
Ultra-low beam emittance
Final focus optics
KEKB electron-cloud

NML /ASTA (FNAL)
ILC RF unit test

❖ Solid SRF technological base for the ILC on a global scale is now in place
(EU: XFEL@ DESY; US: Future LCLS-II@SLAC; Japan: Development of ILC-Hub-Lab@KEK)

ILC TDR Value Estimate and Timeline



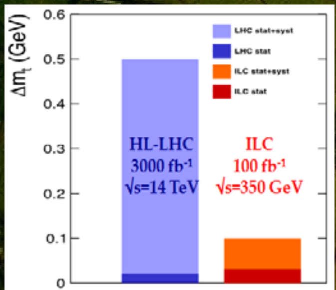
Average project cost (site-independent):

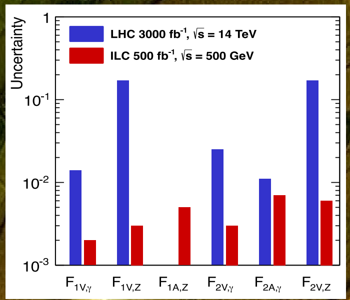
- 7.8 Billion ILCU
- 22.6 Million person-hours

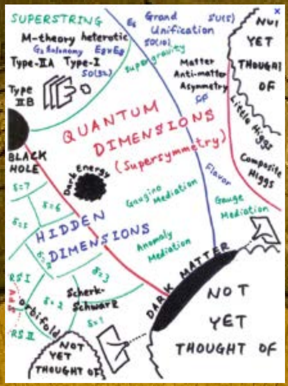
ILC Timeline:

Progress and Prospect

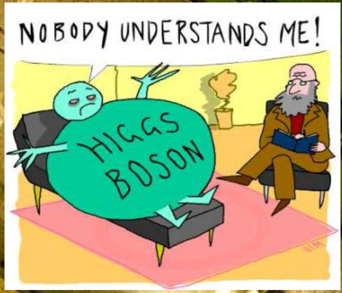
Top Quark Frontier:
(mass, EW couplings, FCNC, polarization, …)

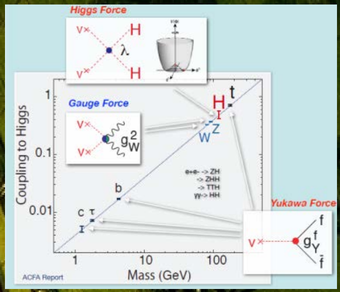






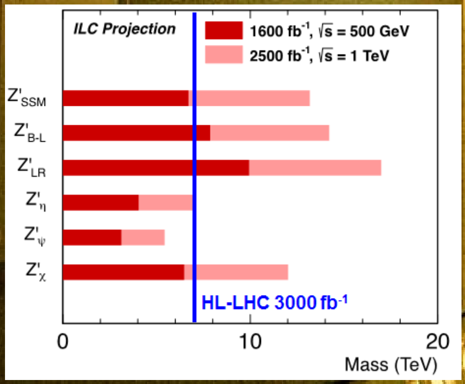
Higgs Frontier – "Next Energy Scale"
(couplings, invisible decays, self-coupling)



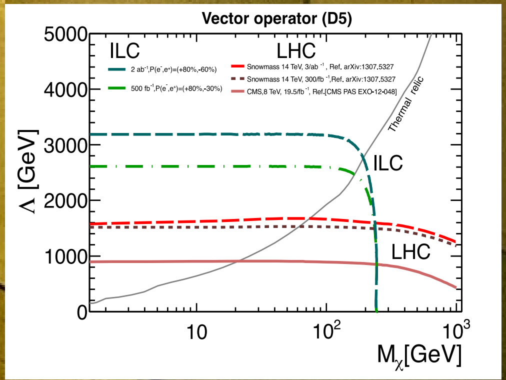


ILC PHYSICS: KEY PILLARS

SUSY / BSM Frontier:



Dark Matter Frontier:

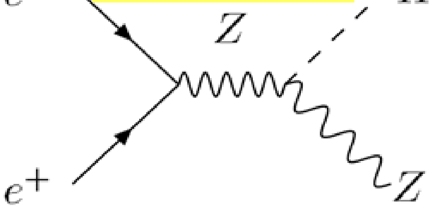


Physics Prospects with LC: Power of Beam Polarization

Polarized beam(s) provide great diagnostics : e_L and e_R - different particles in gauge interactions

❖ Enhance effective luminosity:

$L_{eff} = (1 - P_{e+}P_{e-})$



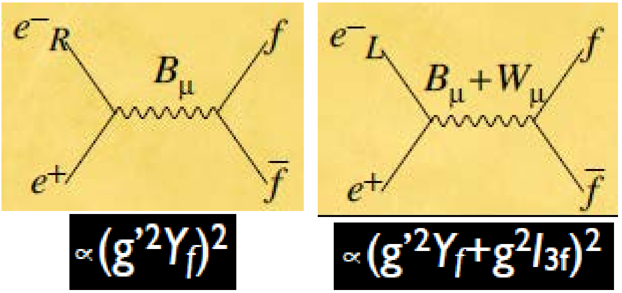
$e^+_R\, e^-_L \rightarrow ZH$
$e^+_L\, e^-_R \rightarrow ZH$

~~$e^+_L\, e^-_L \rightarrow ZH$~~
~~$e^+_R\, e^-_R \rightarrow ZH$~~

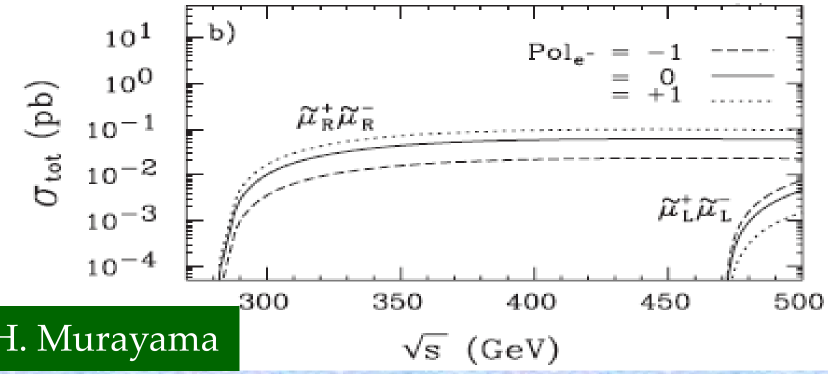
~ 30 % lumi gain for P(e-,e+) = (±80%; ∓30%)

Cross section (in fb) for m_H = 125 GeV							
		250	350	500	1000	1400	3000
ZH	unpolar.	211	134	64.5	16.1	8.5	2.0
	polar.	318	198	95.5	22.3	10.0	2.4
$\nu_e\nu_e$ H	unpolar.	20.8	34.1	71.5	195	278	448
	polar.	36.6	72.5	163	425	496	862
e+e-H	unpolar.	7.7	7.4	8.9	20.1	27.3	48.9
	polar.	11.2	10.4	11.7	24.7	32.9	56.5

❖ Determine quantum #s (if new particle found)



$U(1)_Y$ - gauge boson $B\mu$
$SU(2)_L$ – gauge boson $W^0\mu$
Yf -hypercharge of new particle



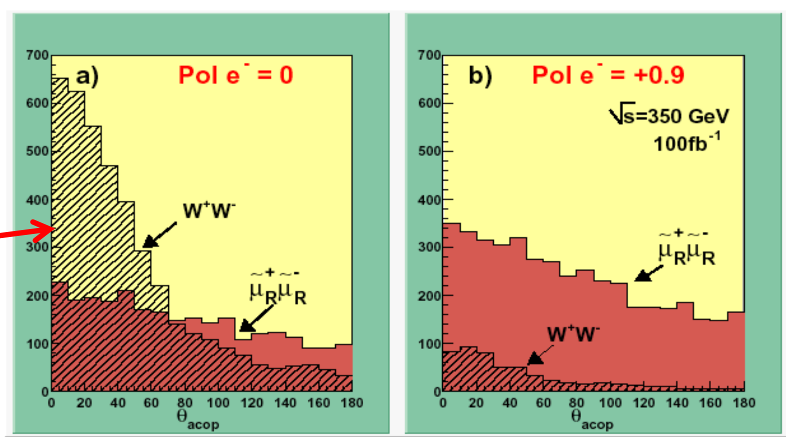
H. Murayama

❖ SM background suppression

Example: Muon spair production

Background rejection:

→ prominent example is the suppression of the WW SM production: with (Pe−,Pe+)=(+80%,0) polarization the W+W− cross section scales by a factor 0.2.



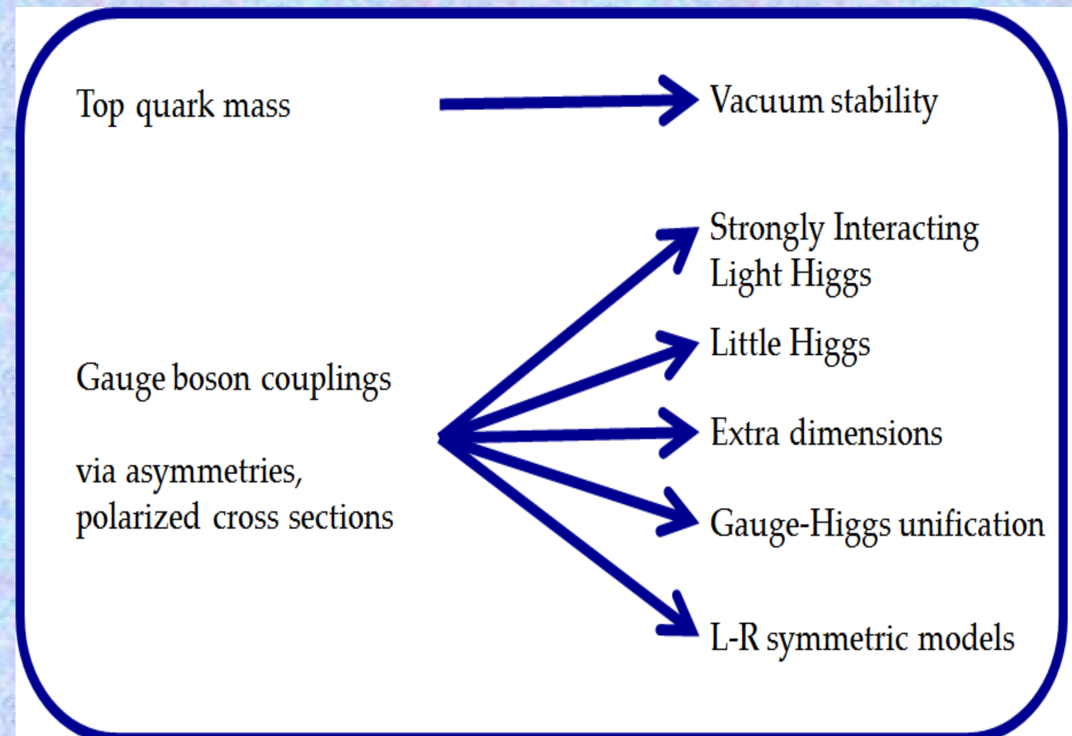
“Window to New Physics” via the Top Quark Sector

- Top quark has a very special role: heaviest fundamental fermion → most strongly coupled to EWSB sector (intimately related to the dynamics behind the SB mechanism)

- Top Mass at the ILC:

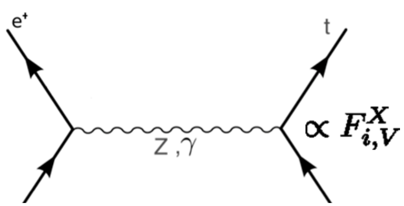
1) From reconstructed invariant mass
   (E > ttbar thr., L=100 fb^{-1})
   → relation between measured mass to a well--defined parameter that is a suitable theoretical input

2) Measure from ee → ttbar threshold scan
   (350 GeV, Lint = 10 x 10 fb^{-1})
   → Relation to well-defined mtop (calculated to higher orders –theoretically) well under control

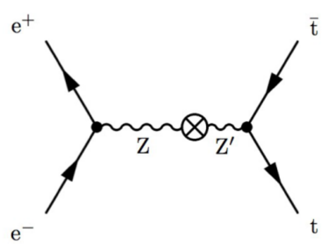


Electroweak production of ttbar:

SM:



BSM:



Testing the Chiral structure of the SM (ttZ coupling):

BSM physics modify the electro-weak ttX SM vertex
by Vector and Axial couplings to the X = γ ; Z^0

$$\Gamma_\mu^{ttX}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F_{1V}^X(k^2)+\gamma_5F_{1A}^X(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF_{2V}^X(k^2)+\gamma_5F_{2A}^X(k^2)\right)\right\}, \quad (2)$$

- LHC: top quark couples either to γ or Z^0

$$\sigma \backsim (F_i)^2 \Rightarrow \text{No sensitivity to sign of Form Factors}$$

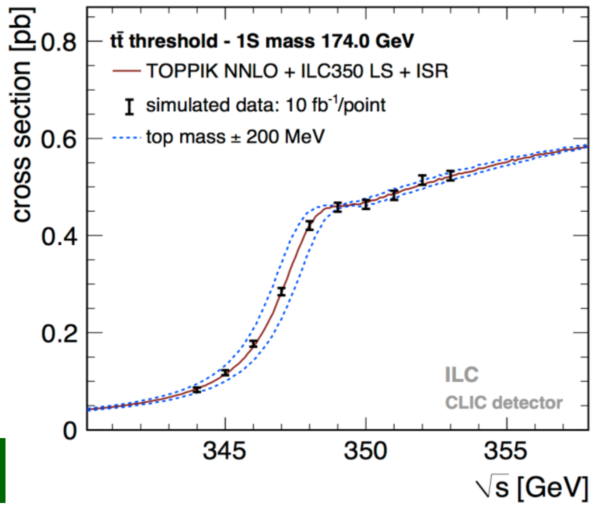
- ILC: γ / Z^0 interference

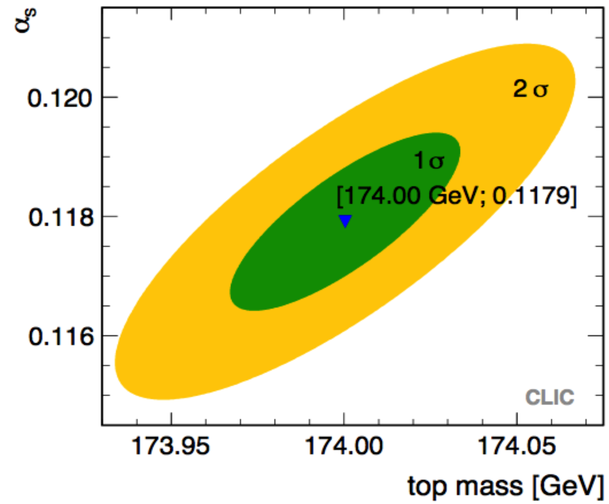
$$\sigma \backsim (F_i) \Rightarrow \text{Sensitivity to sign of Form Factors}$$

Precision Measurement of the Top Quark Mass

Top quark mass threshold measurement at the ILC:

Initial-state radiation (ISR) & luminosity spectrum (LS) affect the cross section as a function of the CM energy:





The cross section in the threshold region depends on the αs

→ The 1S top mass and αs are simultaneously extracted in a 2D fit

arXiv: 1303.3758

Stat. and syst. errors on m_{top} (ILC):

1S top mass and α_s combined 2D fit	
m_t stat. error	27 MeV
m_t theory syst. (1%/3%)	5 MeV / 9 MeV
α_s stat. error	0.0008
α_s theory syst. (1%/3%)	0.0007 / 0.0022

arXiv: 1311.2028

ILC:

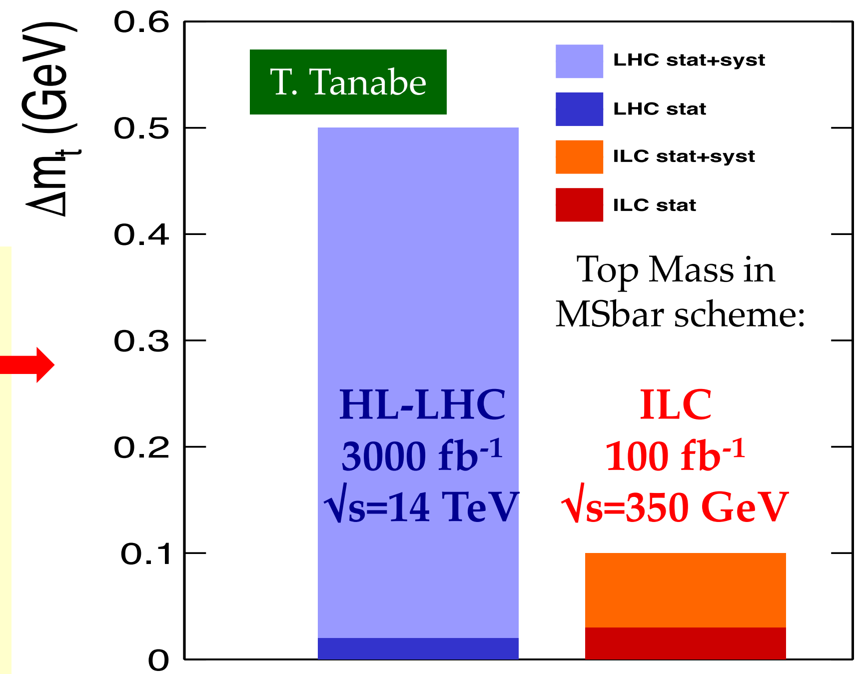
O(100MeV) conversion from 1S to MSbar mass

→ precision of O(120MeV) achievable

LHC / HL-LHC:

Dominated (already) by systematic error

→ hard to go below 0.5 GeV - what kind of mass (it is justified $m_{MC}=m_{POLE}$ to level of 200-500 MeV)?

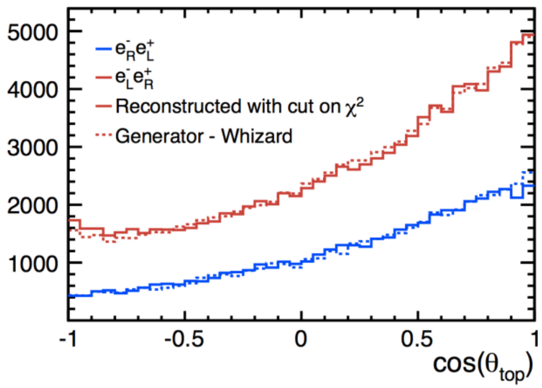


Top Quark Electroweak Couplings

With two beam polarizations → number of observables sensitive to chiral structure of ttX vertex:

Use Number of Observables:

Cross-section	Forward backward asymmetry	Fraction of right-handed top quarks
σ_I	$A^t_{FB,I} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$	$(F_R)_I = \frac{(\sigma_{t_R})_I}{\sigma_I}$



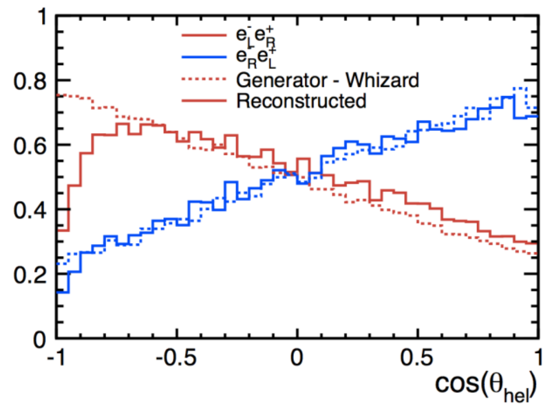
Polar angle of top quark (calculated from the decay products in the hadronic decay branch)

Precision on A_{FB} ~ 2%

Slope of distribution of helicity angle (angular distribution of the decay lepton in the rest frame of the t quark):

Precision on slope λ_t ~ 3%

arXiv: 1307.8102
arXiv: 1311.2028

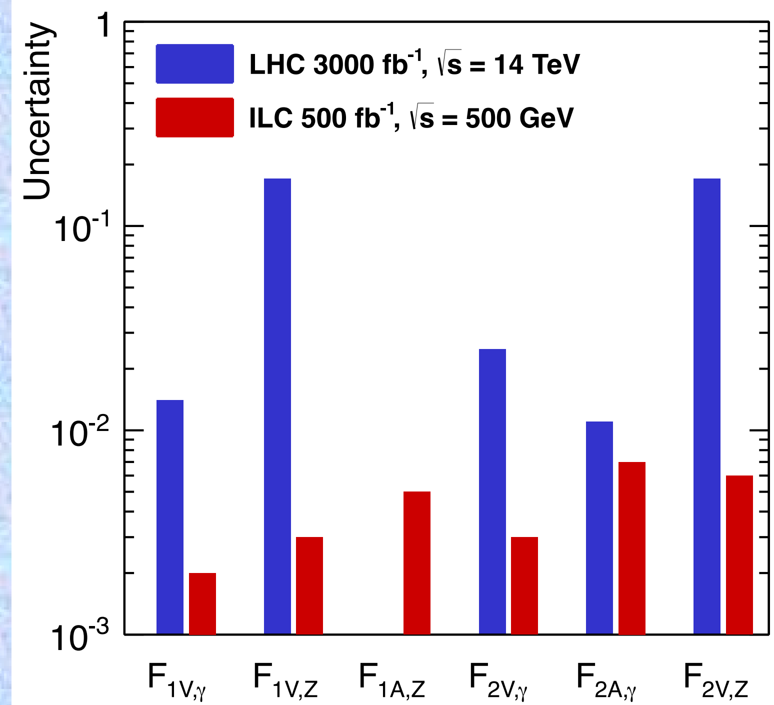


❖ Need to control experimental (e.g. top angle) and theoretical uncertainties (e.g. electroweak corrections)

❖ Precision determination of the form factors: F^γ_{2V}, F^Z_{2V}

$$F^\gamma_{1V}, F^Z_{1V}, F^\gamma_{1A} = 0, F^Z_{1A}$$

Accuracy on CP conserving couplings:



❖ Potential for measurement of CP violating couplings at ILC under study

Impact of BSM Physics on Top Sector

❖ Chiral structure of EW top couplings expected to be sensitive to the BSM sources
→ variety of models predict modifications to t_L and t_R due to couplings to new strong sector

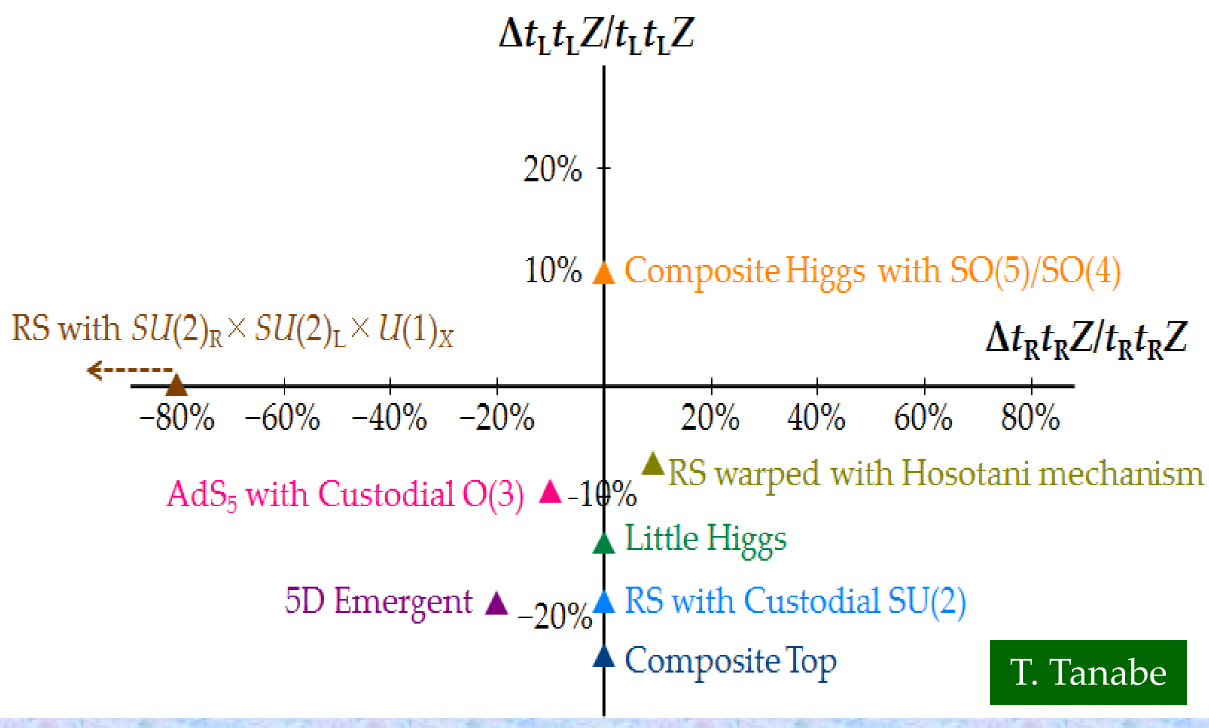
➢ Disentangling of t_L and t_R is essential to separate models (difficult at LHC)

➢ ILC: no assumption about the photon couplings → right and left-handed couplings are determined independently

➢ ILC: uncertainty goes from 0.6 % → 0.25%, if one assumes photon cannot acquire an axial component

arXiv: 1403.2893

Deviations for different models for new physics scale at ~1 TeV



T. Tanabe

	LHC	ILC
$t_L t_L Z$	±8%	±0.6%
$t_R t_R Z$	−240%, +40%	±1.4%
$t_L t_L \gamma$	−7%, +12%	±0.6%
$t_R t_R \gamma$	−7%, +12%	±0.6%

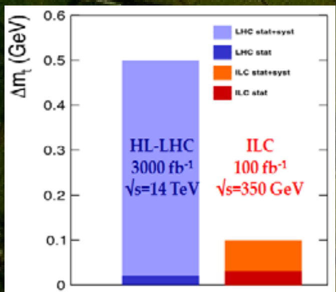
❖ Beam polarization (both e- and e+) is essential to distinguish the ttZ and ttγ couplings → rather unique for the ILC

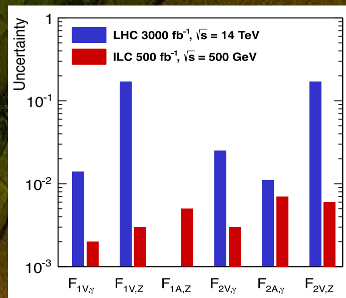
❖ ILC provides a unique opportunity to measure electroweak top couplings → powerful test of the chiral structure

❖ ILC sensitivity to FCNC couplings (up to 10^{-6})

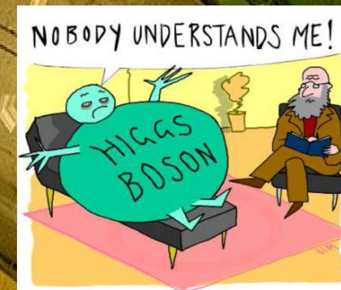
ILC PHYSICS: KEY PILLARS

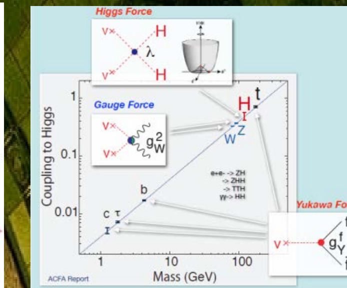
Top Quark Frontier:
(mass, EW couplings, FCNC, polarization, …)



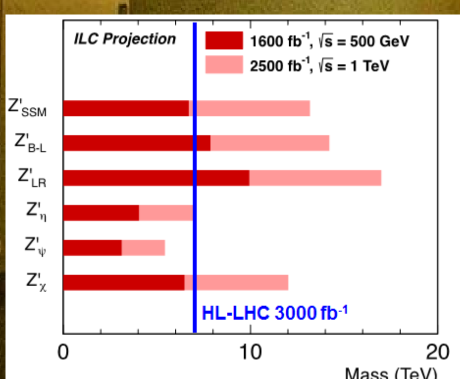


Higgs Frontier – “Next Energy Scale”
(couplings, invisible decays, self-coupling)

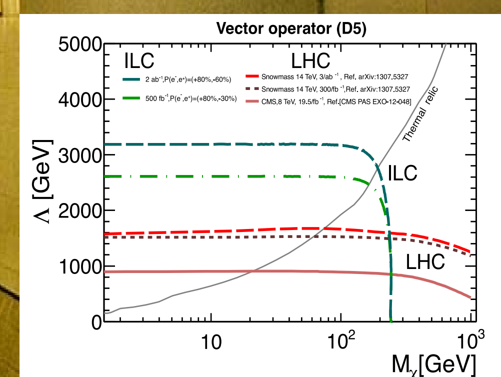




SUSY / BSM Frontier:

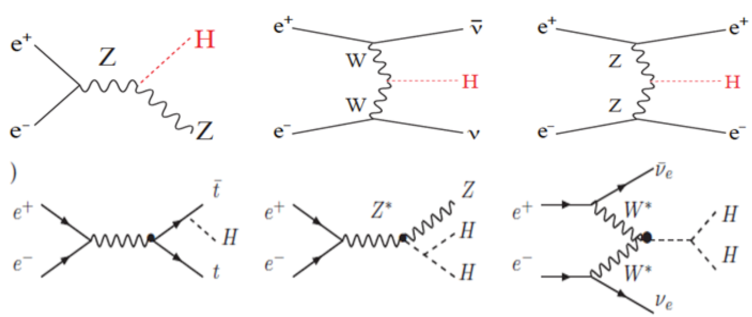


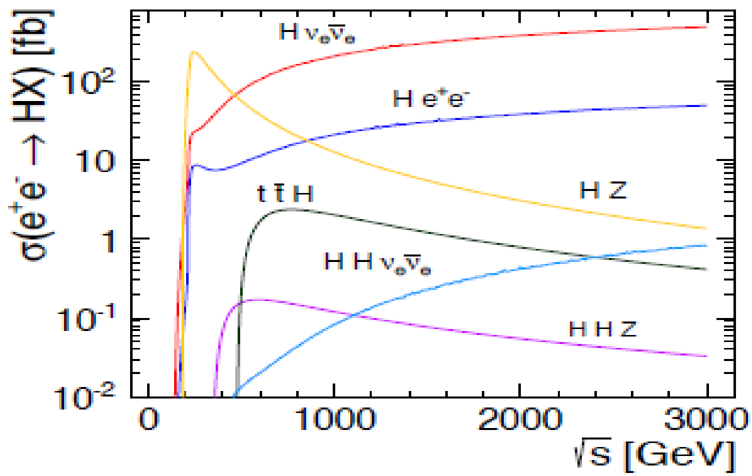
Dark Matter Frontier:



The LC is a "Higgs Factory" and the Energy Frontier Machine

Higgs Boson Production at LC:





- Higgs mass → Vacuum stability
- Higgs Couplings → Supersymmetry, Composite Higgs models, Two-Higgs Doublet Model
- Invisible decay → Dark Matter
- Self-coupling → Electroweak baryogenesis

Staged Running Program:

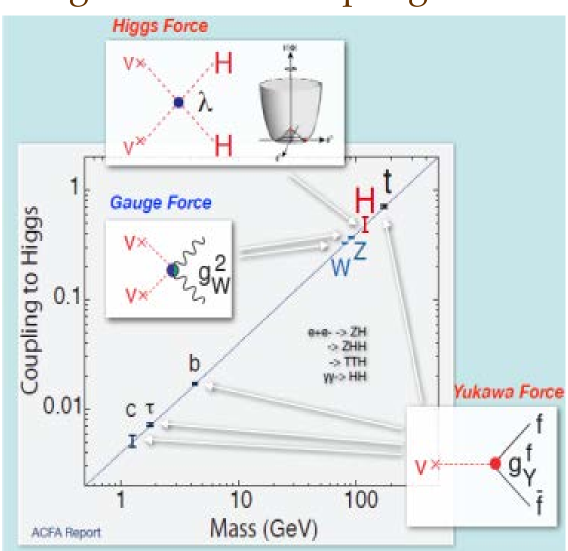
- ❖ Start with a Higgs Factory 250 GeV
- ❖ Upgrade to ~ 500 GeV (TDR baseline)

- ❖ Technical extendibility of energy staging to ~ 1 TeV has to be secured

Baseline ILC Program (250 + 500 + 1000 GeV):

Model-independent global fit for couplings:

ILC's precisions on will ultimately reach sub-% level (luminosity upgrade)!



Control of systematics:

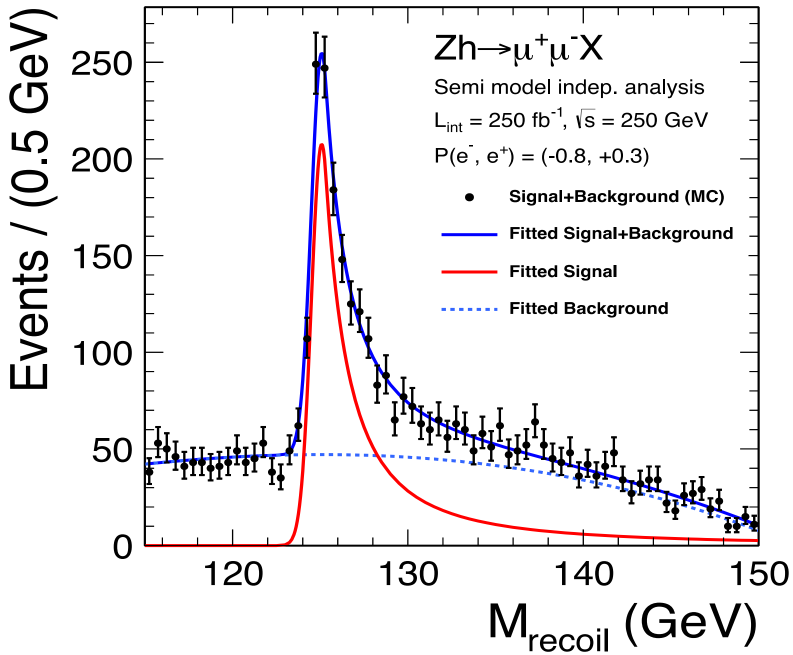
Systematic Errors

	Baseline	LumUp
luminosity	0.1%	0.05%
polarization	0.1%	0.05%
b-tag efficiency	0.3%	0.15%

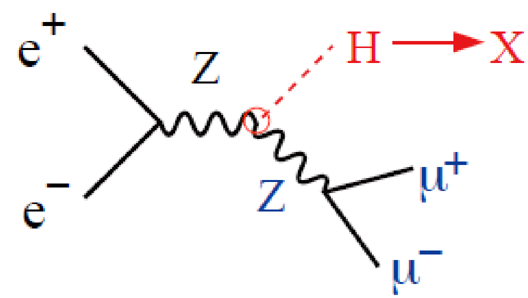
arXiv: 1310.0763

The Flagship of ILC @ 250 GeV: Recoil Mass Measurement

"Window" to absolute measurements of all σ(ZH) x BR and model-independent determination of Higgs boson couplings, total width (e.g. invisible Higgs, H → cc, modes undetectable at LHC)

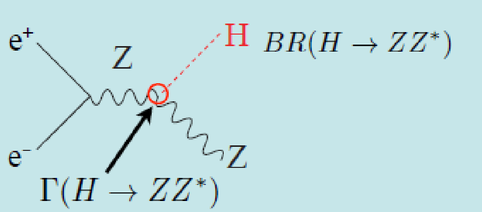


Higgs recoil analysis →
identify 2 opposite charged leptons with invariant mass consistent with M_Z



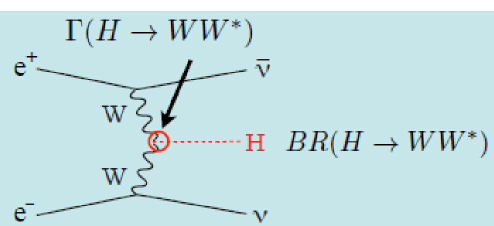
$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Statistical uncertainty on σ(ZH) at √s = 250 GeV eventually limits the precision on all BR measurements:



BR=O(1%): precision limited by low stat. for H->ZZ* events

$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$
$\Delta\Gamma_H/\Gamma_H \simeq 20\%$



More advantageous but not easy at low E

$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$
$\Delta\Gamma_H/\Gamma_H \simeq 11\%$

C.F.Durig, Helmholtz Alliance 6th WS, Dec. 2012

$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$ $m_H = 125\,\mathrm{GeV}$

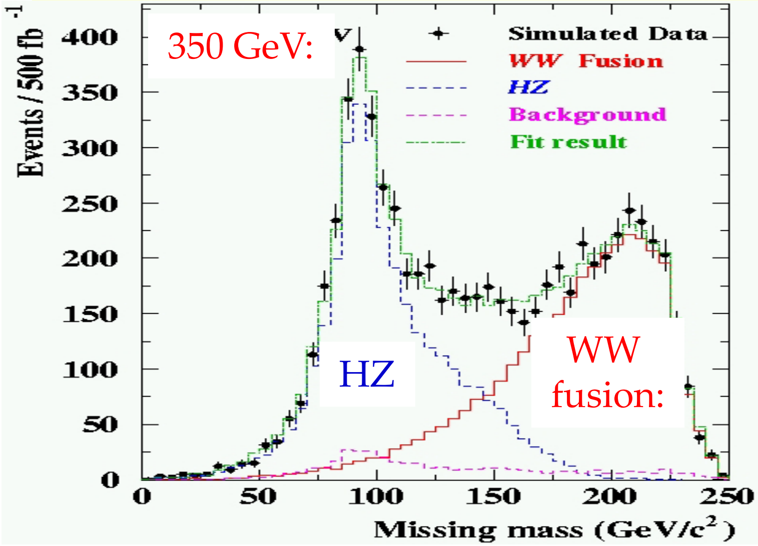
$$\Delta\sigma_H/\sigma_H = 2.6\%$$
$$\Delta m_H = 30\,\mathrm{MeV}$$
$$BR(\mathrm{invisible}) < 1\%\,@\,95\%\,\mathrm{C.L.}$$

scaled from mH=120 GeV

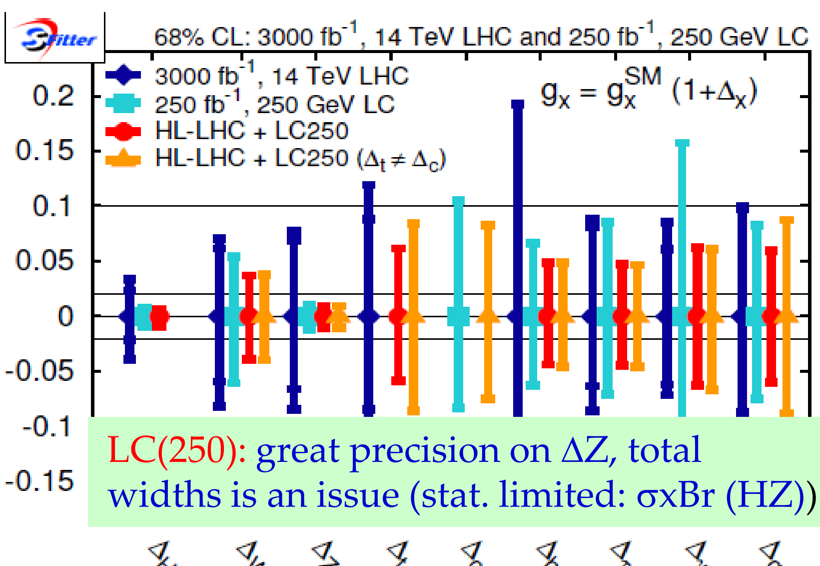
K. Fujii

ILC @ 500 GeV: Total Higgs Width / Coupling Measurements

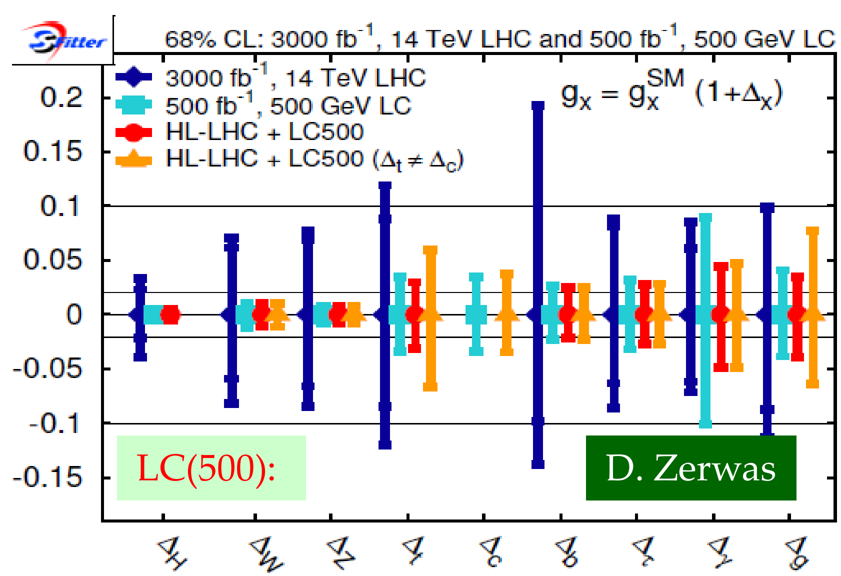
Hadron experiments cannot directly measure a narrow Higgs width (< 5 MeV) → cannot simultaneously constrain the couplings and new contributions to the total width



- ➢ Model-independent handle of total Higgs width:
- → Processes e+e- → ZH (Z → νν) and e+e- → Hνν are separated by a fit to the missing mass distribution
- → Use information on the HWW coupling from σ(e+e- → Hνν) to determine Γ(H→ WW)
- →Take Br(H → WW) and: $\Gamma_{tot} = \dfrac{\Gamma_{WW}}{BR(H \to WW)}$
- → A precision of 5% on Γ_{tot} at 500 GeV can be reached



LC(250): great precision on ΔZ, total widths is an issue (stat. limited: σxBr (HZ))



LC(500):

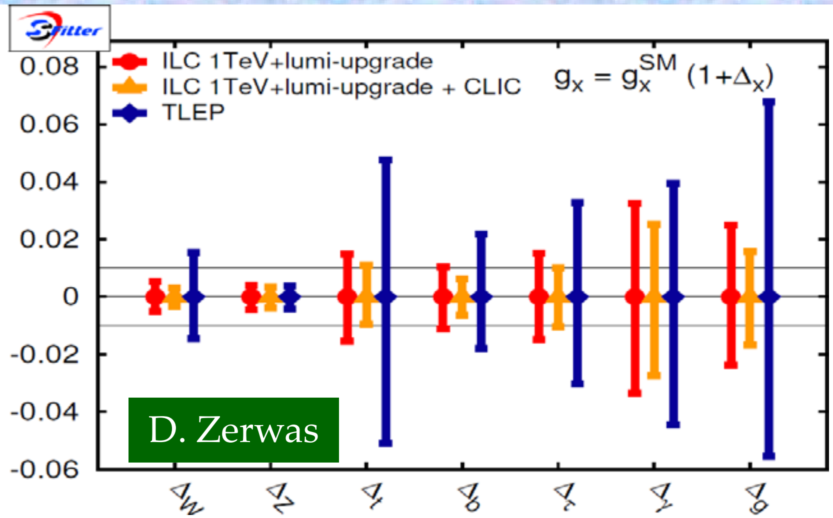
D. Zerwas

Higgs Couplings Measurements: Theory Errors and "Ultimate Precision"

- Theory uncertainties on BR are very important
  → Need to match superb experimental precision and sensitivity to new physics

- TLEP (350 GeV) - ttH is not measured directly:

→Non-measurement of Δt means determination via Δc; H→cc theory error leads to deterioration of precision
- cascades into Δg
- impacts the total width



ILC Model Independent Global Fit for Couplings:

250 GeV: 250 fb^{-1}
500 GeV: 500 fb^{-1}
1 TeV: 1000 fb^{-1}

Baseline ILC Program:

coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	1.3%	1%	1%
HWW	4.8%	1.1%	1.1%
Hbb	5.3%	1.6%	1.3%
Hcc	6.8%	2.8%	1.8%
Hgg	6.4%	2.3%	1.6%
Hττ	5.7%	2.3%	1.6%
Hγγ	18%	8.4%	4%
Hμμ	91%	91%	16%
Γ	12%	4.9%	4.5%
Htt	-	14%	3.1%
HHH	-	83%(*)	21%(*)

Luminosity Upgrade:

250 GeV: 250 fb^{-1} → 250 GeV: 1150 fb^{-1}
500 GeV: 500 fb^{-1} → 500 GeV: 1600 fb^{-1}
1 TeV: 1000 fb^{-1} → 1 TeV: 2500 fb^{-1}

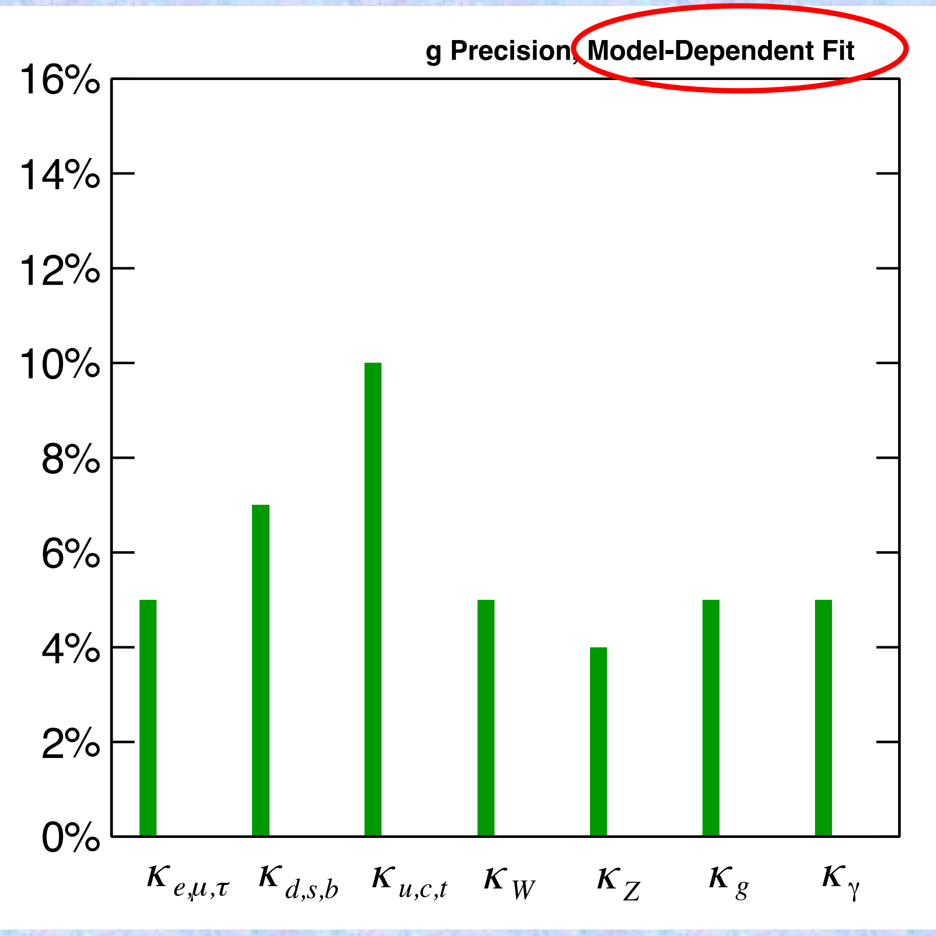
coupling	250 GeV	250 GeV + 500	250 GeV + 500 GeV + 1 TeV
HZZ	0.6%	0.5%	0.5%
HWW	2.3%	0.6%	0.6%
Hbb	2.5%	0.8%	0.7%
Hcc	3.2%	1.5%	1%
Hgg	3%	1.2%	0.93%
Hττ	2.7%	1.2%	0.9%
Hγγ	8.2%	4.5%	2.4%
Hμμ	42%	42%	10%
Γ	5.4%	2.5%	2.3%
Htt	-	7.8%	1.9%
HHH	-	46%(*)	13%(*)

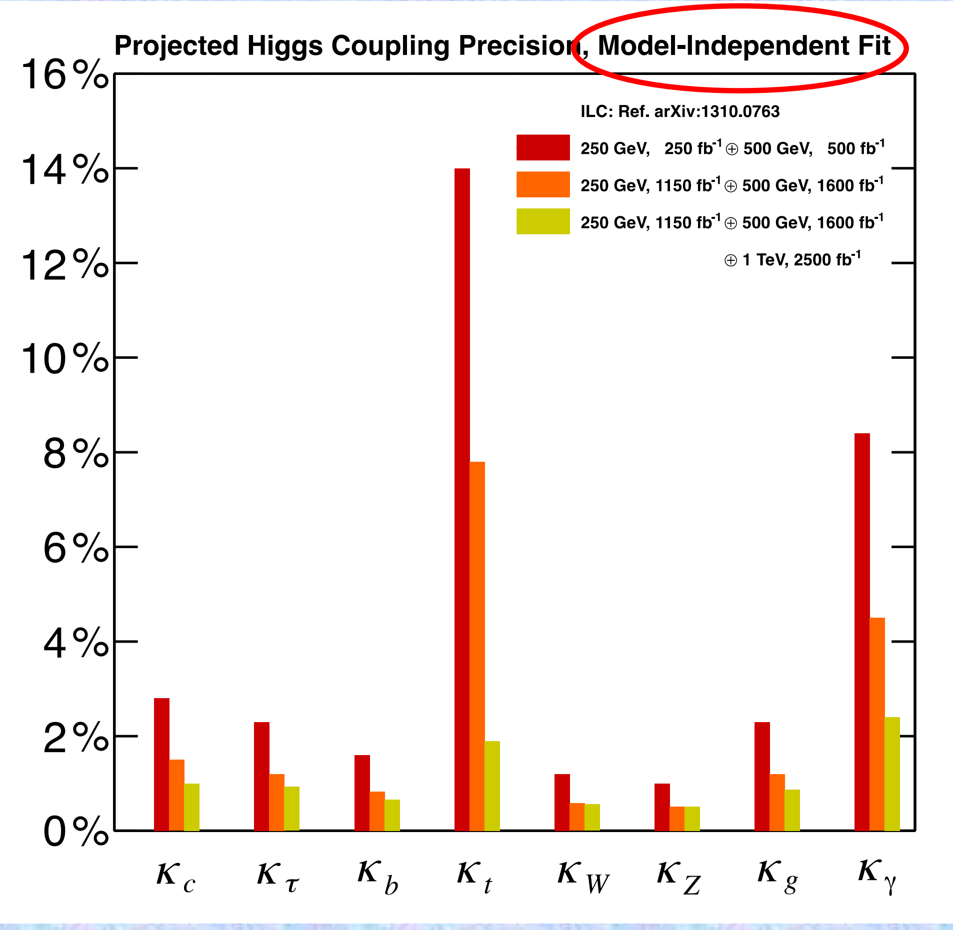
K. Fujii

Higgs Couplings: Physics Prospects with HL-LHC and ILC

arXiv: 1310.8361

T. Tanabe





Model-independent coupling determination is unique to the ILC

Effect of New Physics on Higgs Couplings

- ➢ Deviations in Higgs couplings is a signature of many BSM theories
  → The pattern of deviations can be specific for each model.

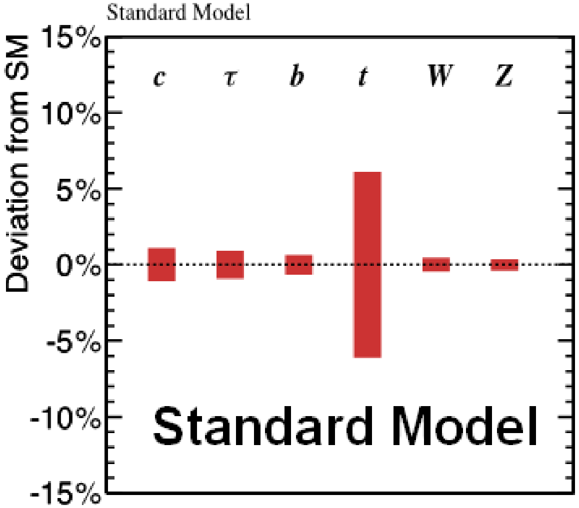
- ➢ Sensitivity to BSM physics manifesting itself only through deviations to Higgs couplings
  (no new particles observable at LHC):

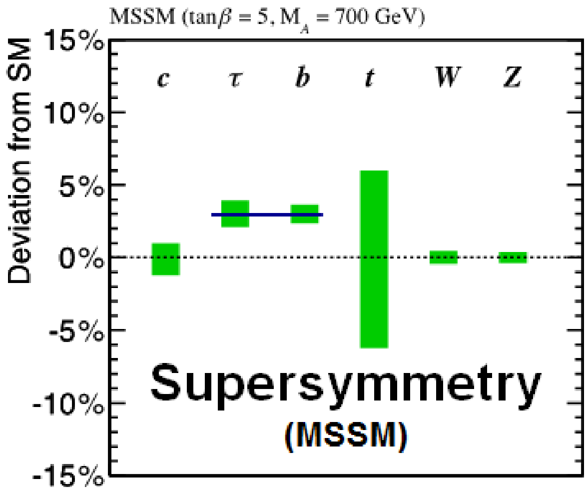
Model	k_V	k_b	k_γ
Singlet mixing	~ 6 %	~ 6 %	~ 6 %
2 HDM	~ 1 %	~ 10 %	~ 1 %
Decoupling MSSM	~ 0 %	~ 1.6 %	< 1.5 %
Composite	~ -3 %	~ -(3-9) %	~ - 9 %
Top Partner	~ -2 %	~ -2 %	~ + 1 %

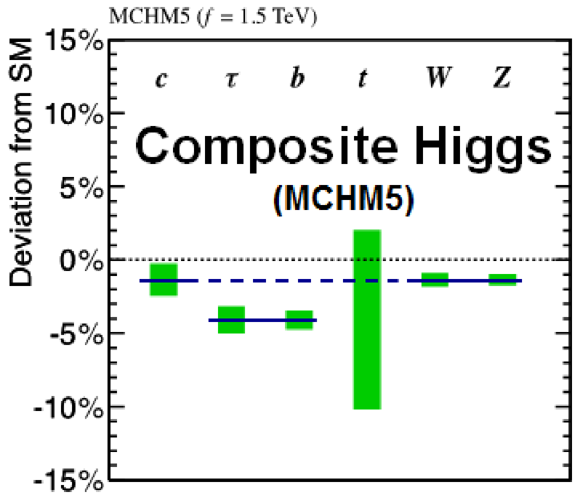
Precision Higgs coupling measurements at the ILC at the 1% level enable us to fingerprint the different models

ILC: Lumi 1920 fb^{-1}, sqrt(s) = 250 GeV, Lumi 2670 fb^{-1}, sqrt(s) = 500 GeV

T. Tanabe







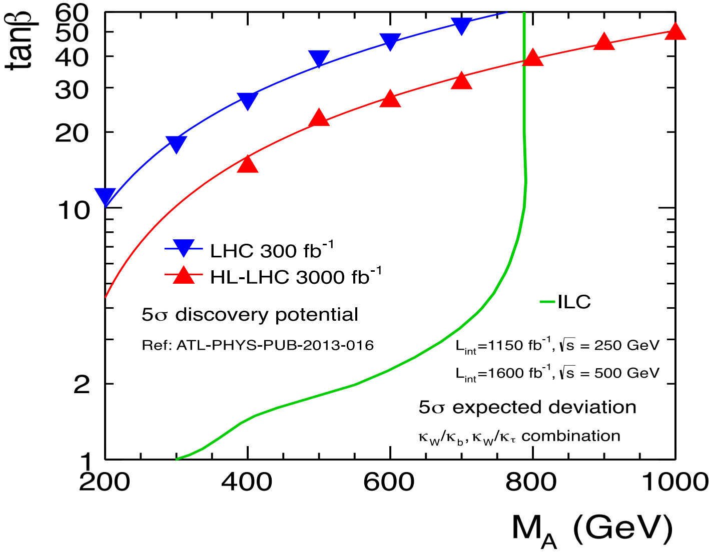
- ❖ We must examine this Higgs to the fullest extent !
  → It may be the only clue to leave the SM oasis and cross the desert !!!

BSM Higgs: Heavy Higgs Mass Reach

- **LHC:** Heavy Higgs direct search
- **ILC:** Indirect search via effect on Higgs couplings BR(h→WW)/BR(h→bb)

ILC:
Lumi 1920 fb^{-1}, sqrt(s) = 250 GeV
Lumi 2670 fb^{-1}, sqrt(s) = 500 GeV

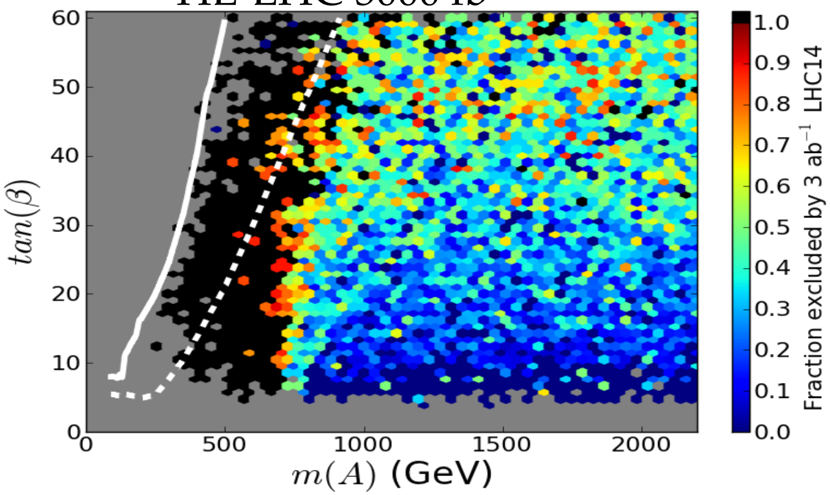
T. Tanabe



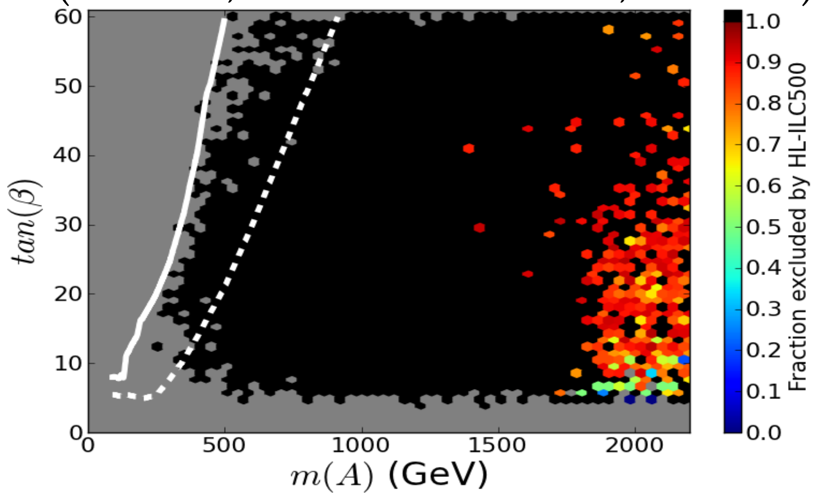
Combined effect of γγ, ττ, bb channels

Cahill-Rowley, Hewett, Rizzo

HL-LHC 3000 fb^{-1}

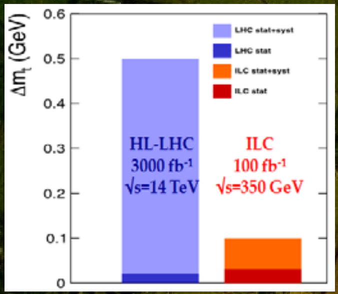


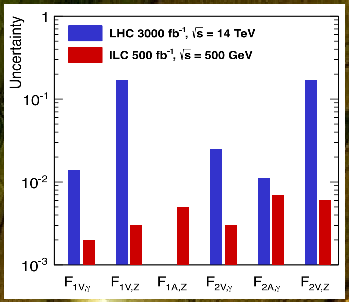
ILC (1150 fb^{-1}, 250 GeV & 1600 fb^{-1}, 500 GeV)

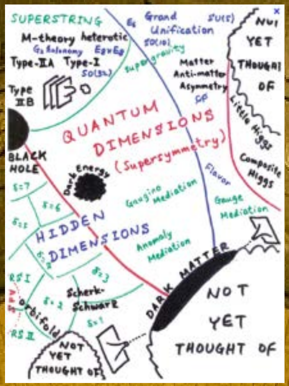


*the fraction of models having given parameters that are excluded by the combined HL-LHC or ILC searches

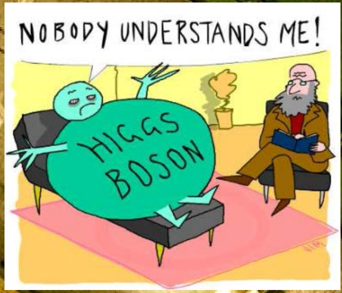
Top Quark Frontier:
(mass, EW couplings, FCNC, polarization, …)

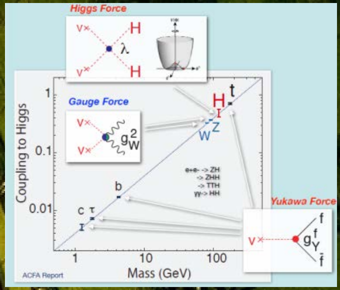






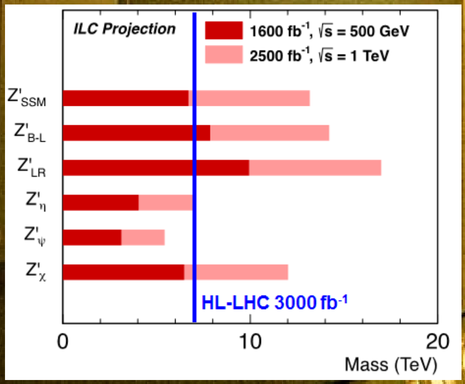
Higgs Frontier – "Next Energy Scale"
(couplings, invisible decays, self-coupling)



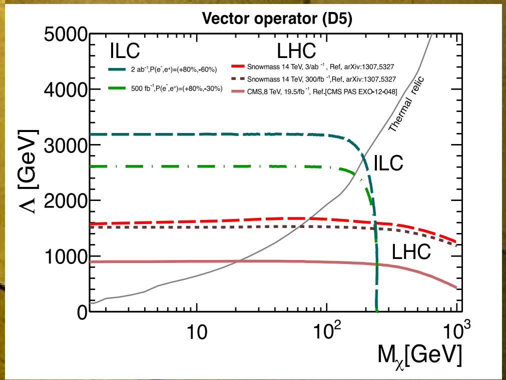


ILC PHYSICS: KEY PILLARS

SUSY / BSM Frontier:



Dark Matter Frontier:

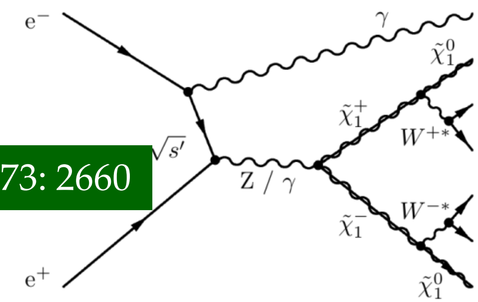


SUSY Precision Measurements: LC as a Higgsino Factory

Light Higgsino scenario:

$e^+e^- \rightarrow \chi_1^+ \chi_1^- \gamma(\mathrm{ISR})$

$e^+e^- \rightarrow \chi_1^0 \chi_2^0 \gamma(\mathrm{ISR})$



- Almost mass denerate light higgsinos: $\chi_1^\pm$; χ_1^0 ; χ_2^0
  $\rightarrow \Delta M(\chi_1^\pm, \chi_1^0)$ & $\Delta M(\chi_2^0, \chi_1^0)$ < a(sub) GeV

EPJ C(2013) 73: 2660

- Other supersymmetric particles are heavy a few TeV

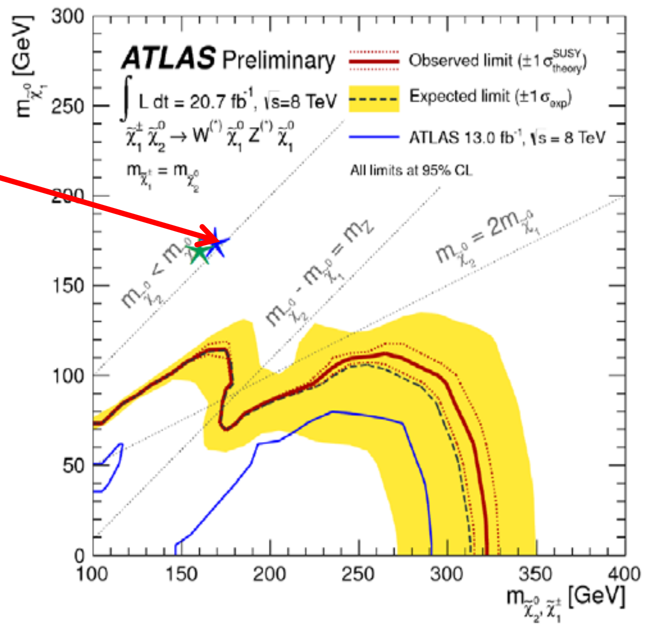
It is extremely challenging for LHC to observe or resolve such low energetic and "degenerate sparticles »

dm770

Particle	Mass (GeV)
h	127
$\tilde{\chi}_1^0$	166.59
$\tilde{\chi}_1^\pm$	167.36
$\tilde{\chi}_2^0$	167.63
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2-3 \times 10^3$

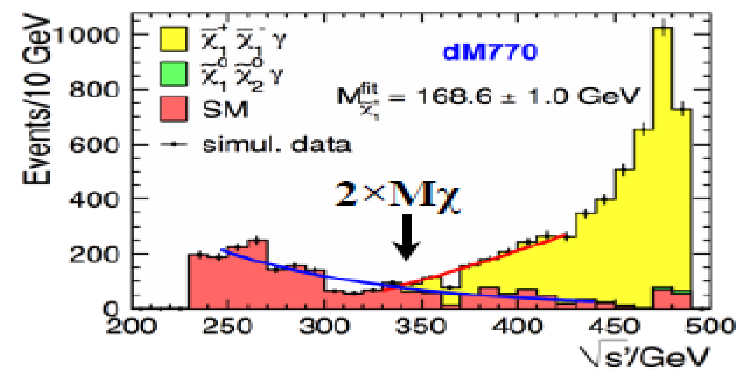
Mass Spectrum

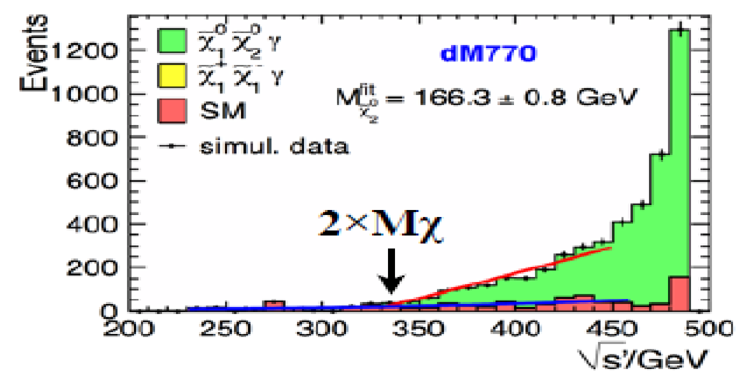
$\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 0.77$ GeV



Ref: ATLAS-CONF-2013-035

Recoil mass of hard ISR photon is used to measure mass of χ_1^+ , χ_2^0





Precision on mass and cross section determination (500 fb⁻¹ @ 500 GeV):

$$\delta(\sigma \times BR) \simeq 1.5\%$$

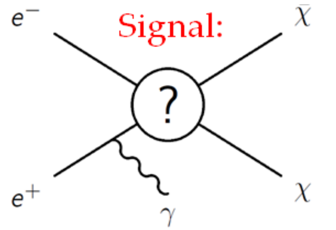
$$\delta M_{\tilde{\chi}_1^\pm}(M_{\tilde{\chi}_1^0}) \simeq 1.5(1.6)\ \mathrm{GeV}$$

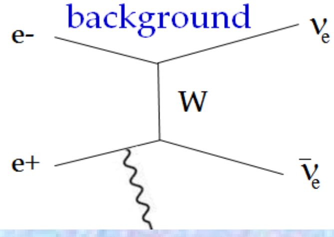
$$\delta \Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \simeq 20\ \mathrm{MeV}$$

Model – Independent (WIMP / Dark Matter) Searches

Signature: ISR photon + E_T^{miss}

$$\mathcal{L}_{\rm int} = \frac{1}{\Lambda^2}\mathcal{O}_i$$



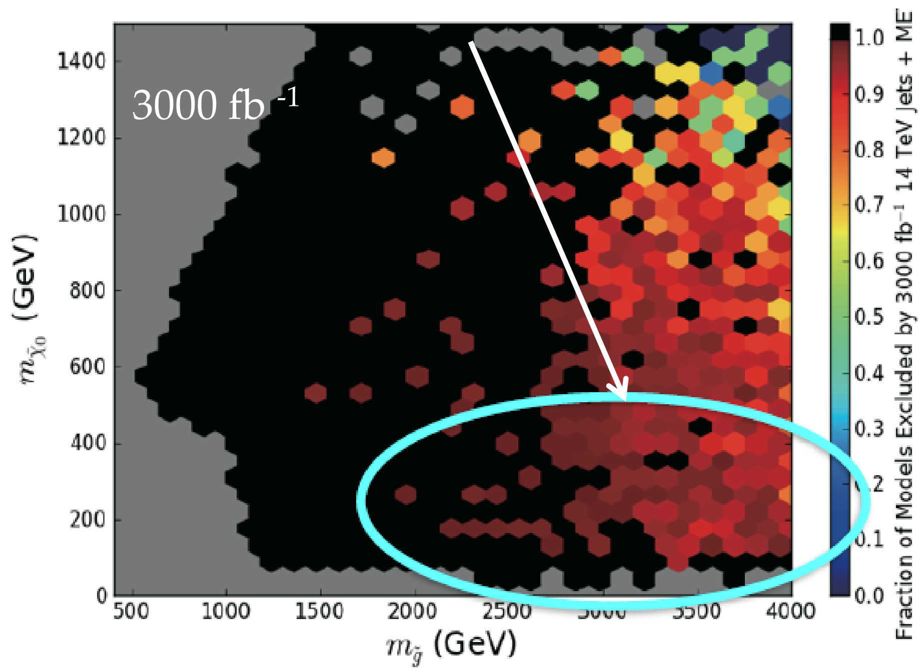


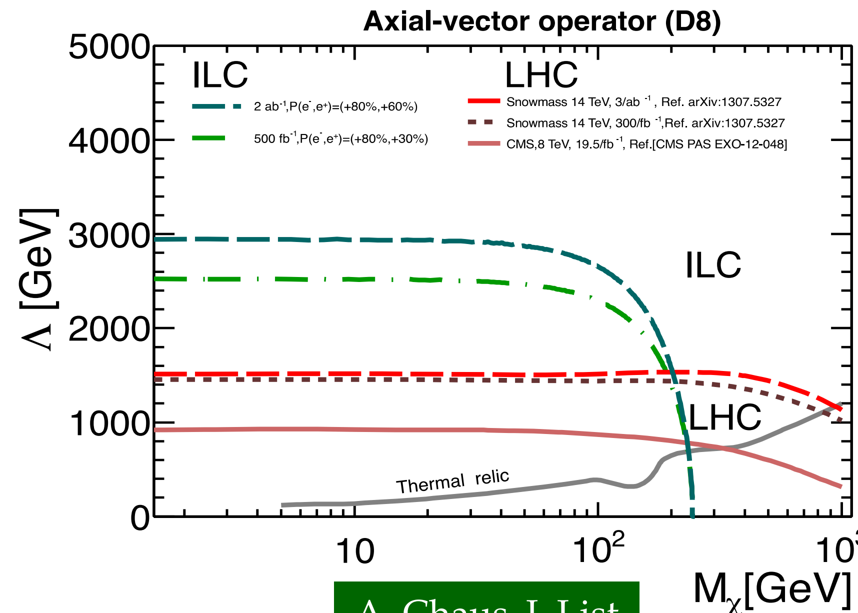
Polarization (e+,e-) is very important:

→ Suppress ee→νν(γ) bkg.
→ Distinguish models /operators (axial, vector, axial-vector)

$$\mathcal{O}_A = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\overline{\ell}\gamma^\mu\gamma^5\ell)$$

Loopholes of HL-LHC → Hunting Ground of ILC





A. Chaus, J. List

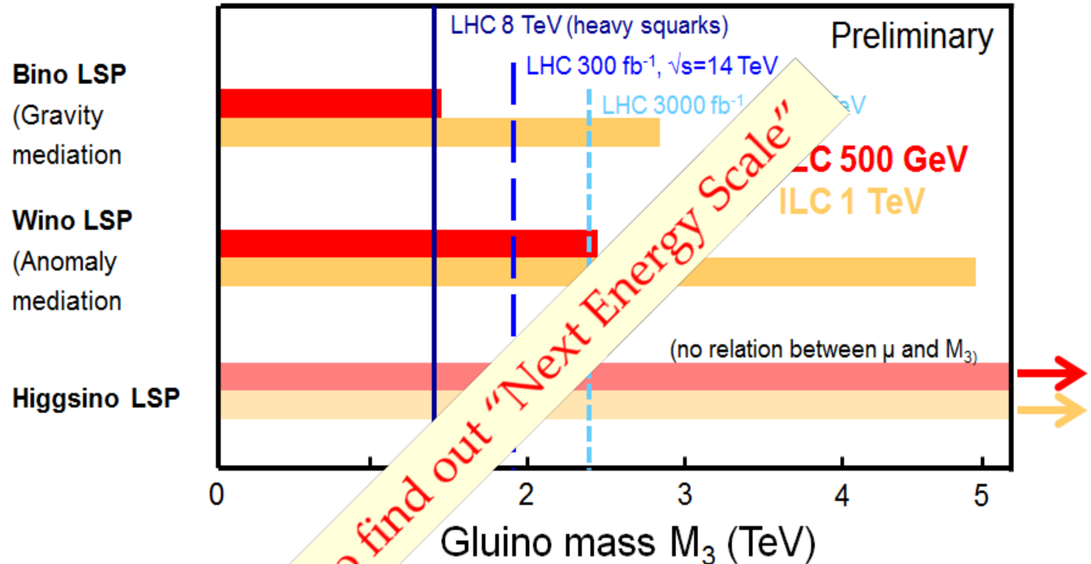
- **LHC sensitivity:** Mediator mass up to Λ~1.5 TeV
- **ILC sensitivity:** Mediator mass up to Λ~3 TeV for DM mass up to ~√s/2

Sensitivity to SUSY and BSM Effects

- Gluino search (LHC)
- Chargino/Neutralino search (ILC)
  → Comparison assuming gaugino mass relations

- No gluinos at the LHC
  → not the end of light SUSY

(Higgsino LSP: no mass relation connecting the Higgsino mass parameter (μ) with the gaugino masses (e.g. models - gluino mass is arbitrarily large, while Higgsino mass small))

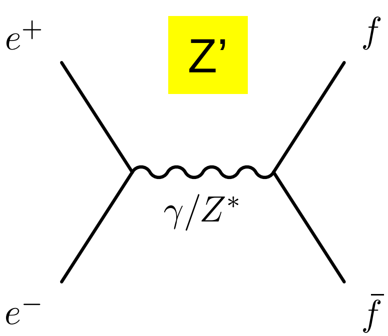


T. Tanabe

We have to exploit all opportunities to find out "Next Energy Scale"

Searches for Z′ : Heavy Neutral Gauge Bosons

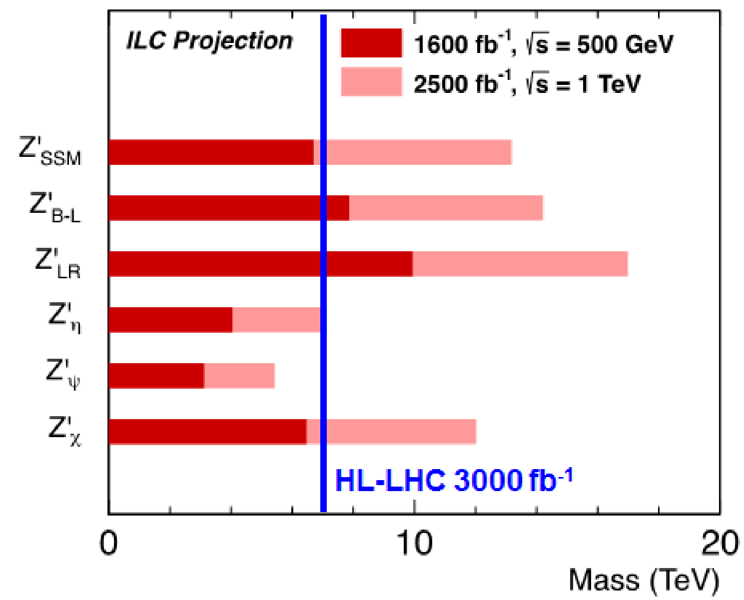
E.g.: L-R symmetric models, string-inspired model (E8) …



- Direct search for heavy resonances (Z′) at the LHC (mass determination)

- Indirect searches via interference effects at the ILC (coupling measurements and model discrimination)

beam polarizations improve reach and discrimination power



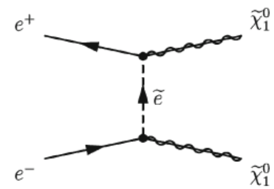
Neutrino Connection and Grand Unification

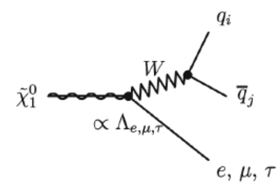
Origin of neutrino mass → Connects flavor-changing neutralino decays to neutrino mixing angles

If R-parity violation is the origin of the ν-mass → one predicts the value of the mixing angle Θ_{23}

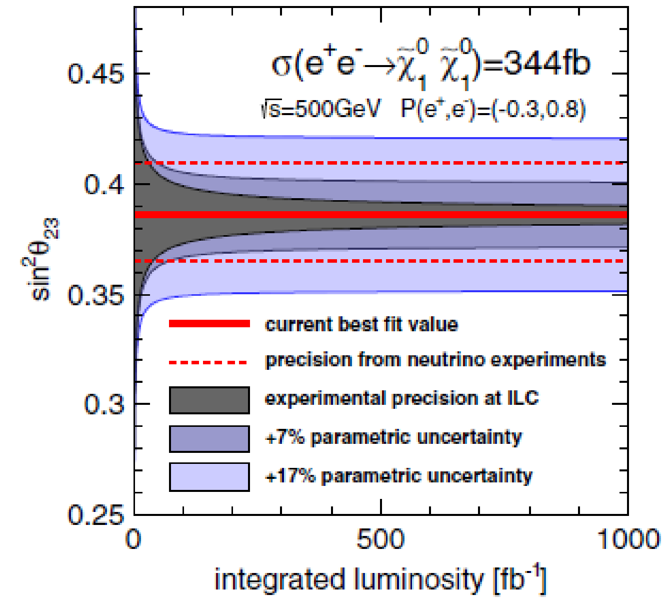
Study neutrino mixing angle by analyzing neutralino decays:

$$\tan^2(\theta_{23}) \simeq \frac{O^2_{\tilde{\chi}^0_1 W\mu}}{O^2_{\tilde{\chi}^0_1 W\tau}} = \frac{\mathrm{BR}(\tilde{\chi}^0_1 \to W\mu)}{\mathrm{BR}(\tilde{\chi}^0_1 \to W\tau)}$$





EPJ C74 (2014)2720



Gaugino mass relation:

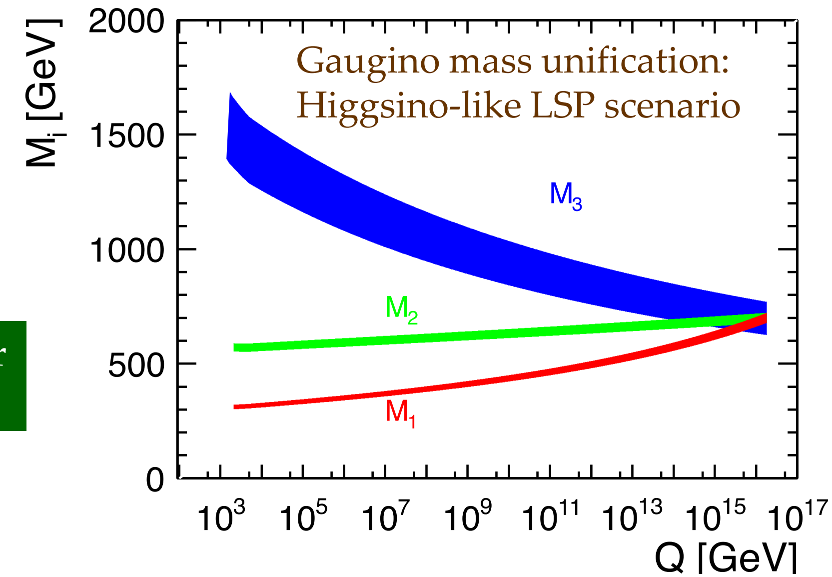
(if ILC see chargino the gluino mass can be predicted assuming the mass relation → scale of next pp collider) :

Check of M_1-M_2 relation → discrimination of SUSY spontaneous symmetry breaking scenario !

LHC: gluino discovery→ mass determination

H. Baer
J. List

ILC: Higgsino discovery → M1, M2 via mixing between Higgsino and Bino/Wino



ILC Detector Challenges: R&D Collaborations and Group Efforts

Individual R&D Efforts
(e.g. vertex detectors):

MAPS
CMOS

DEPFET

FPCCD

Chronopixel

R&D Collaborations:

Time Projection
Chamber
for Linear
Collider

Forward
calorimeters
for Linear
Collider

Highly granular
calorimeters
for Linear
Collider

LC Detector Challenges: The Higgs is an Important Driving Factor

❖ **VERTEX**: flavour tag, IP resolution ($H \rightarrow bb$, cc $\tau\tau$)
~1/5 $r_{beampipe}$,1/30 pixel size, ~1/10 resolution (ILC vs LHC)

$$\sigma_{IP} = 5 \oplus \frac{10}{p\sin^{3/2}\theta}(\mu m)$$

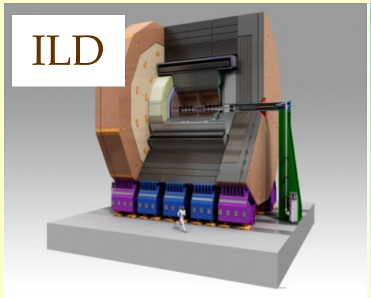
❖ **TRACKING**: recoil mass to Higgs ($e^+e^- \rightarrow ZH \rightarrow llX$)
~1/6 material, ~1/10 resolution (ILC vs LHC); B = 3.5 – 5T

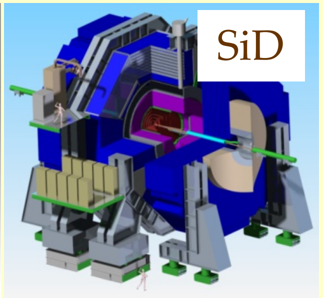
$$\sigma(1/p) = 2 \times 10^{-5}(\mathrm{GeV}^{-1})$$

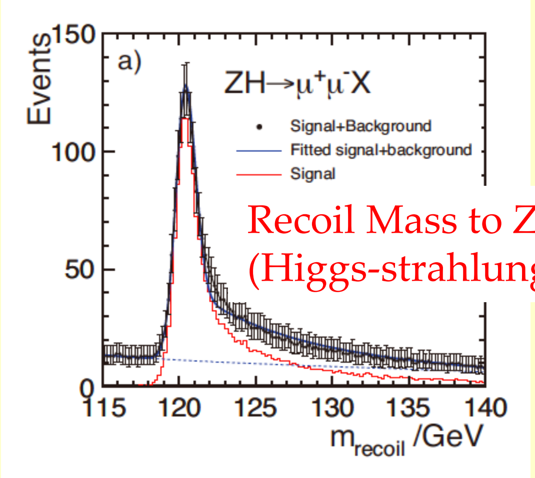
❖ **CALORIMETRY:** particle flow, di-jet mass resolution
1000x granularity, ~1/2 resolution (ILC vs LHC);
detector coverage down to very low angle

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

"Push-pull Option" – 2 detectors:
similar concepts/different realizations
(central tracking with Si or TPC)







Recoil Mass to Z
(Higgs-strahlung):

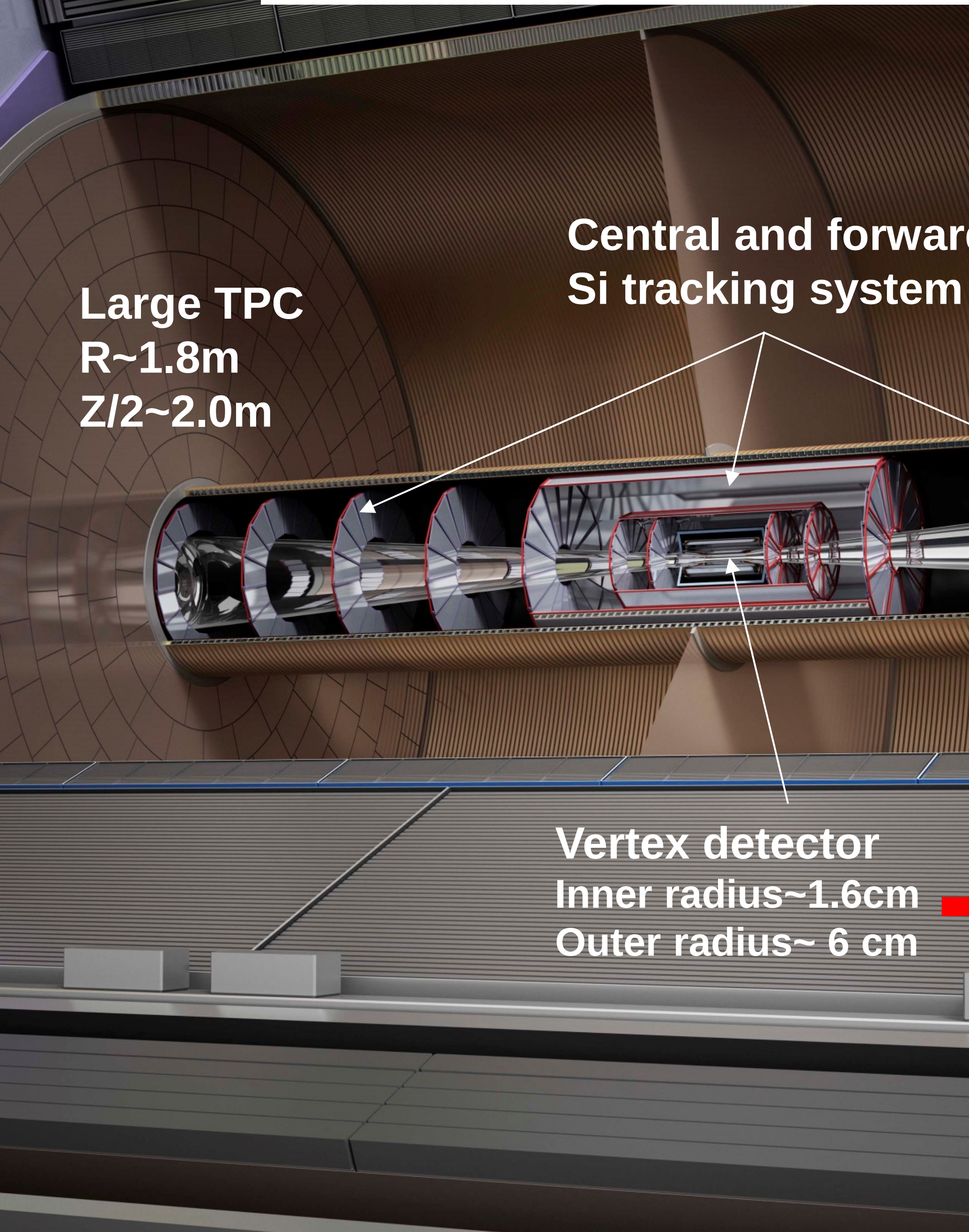
ILC TDR: June 2013 - Detailed Baseline Design (DBD) for Detectors
http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

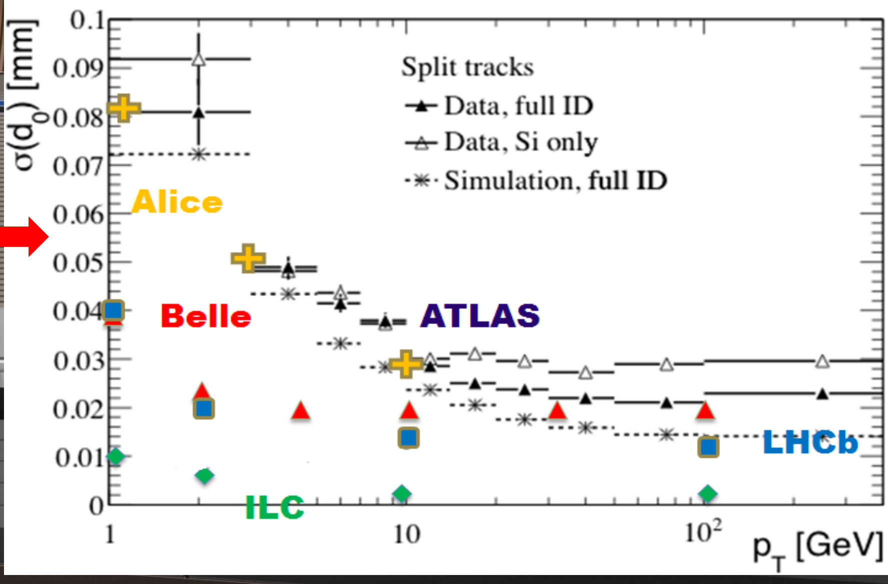
- ❖ Key detector R&D technologies have been demonstrated with prototypes in test beams
- ❖ Physics performance has been studies in full simulations
- ❖ Major engineering R&D efforts and optimization of detector concepts are still needed

Tracking Systems – ILC Example

Low mass for tracking & vertexing

- Thin silicon sensors
  - ~50 µm for pixel vertex detectors
- Light support structures
  - e.g. advanced endplate for TPC





Vertex Detector System

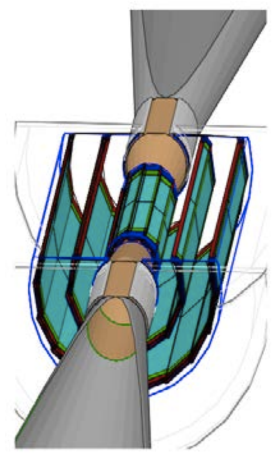
State-of-the-art pixel technologies: CMOS MAPS, DEPFET, FPCCD, 3D, Chronopixel, SOI

Motivation:

- high efficiency & purity flavor tagging (bottom, charm, tau, jet-flavor → e.g. b/c-quark separation for Higgs decays, b-quark charge measurement

Approach:

- 2-sided ladders concept, very low power
- unprecedented granularity & material budget (ultra-thin ~ 50µm sensors)

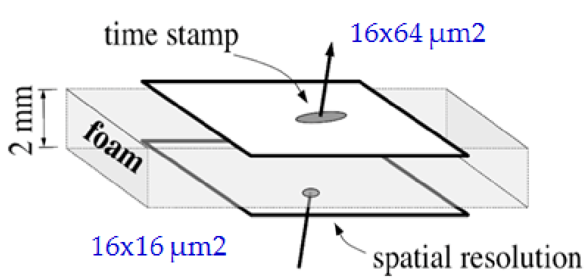


A complex set of highly correlated issues:

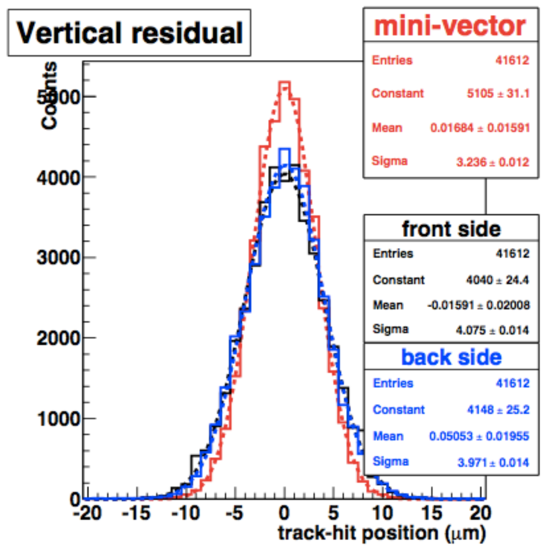
- pixel sensors
- staves/ladders: thermo-mechanical aspects and services

→ need careful thinking in terms of material budget and power cycling, besides the usual speed/resolution/ data flow requirement

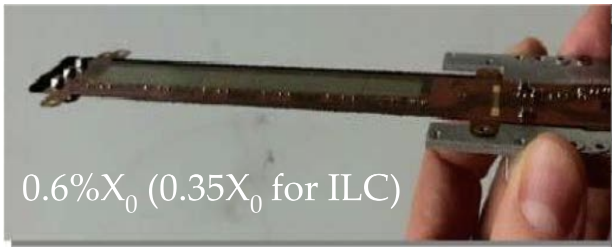
CMOS MAPS: Spatial Resolution and Time Stamping



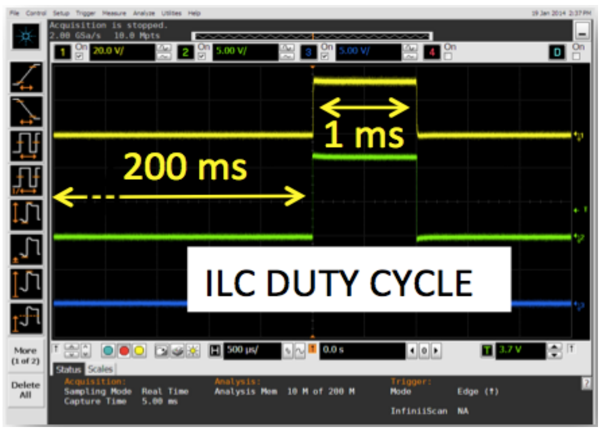
~ 3µm track resolution achieved:



Ultrathin ladder - PLUME



DEPFET: Mechanical ladder tested for power pulsing



Central Tracking – Time Projection Chamber

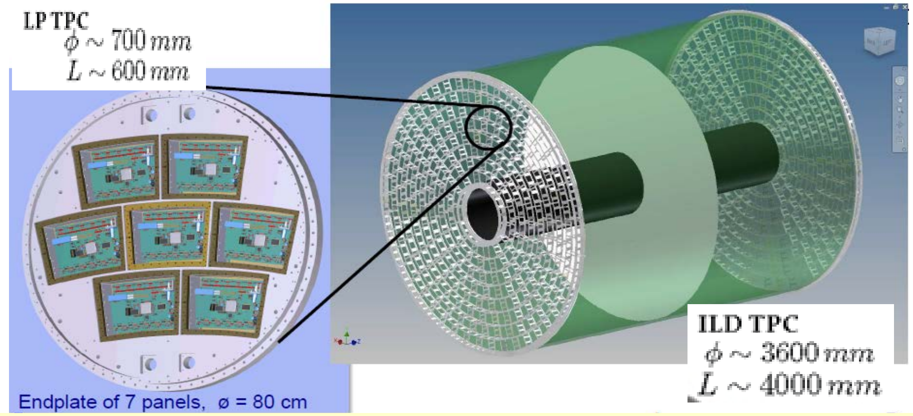
ILCTPC with MPGD-Readout

→ spatial resolution < 100 μm @ 4T

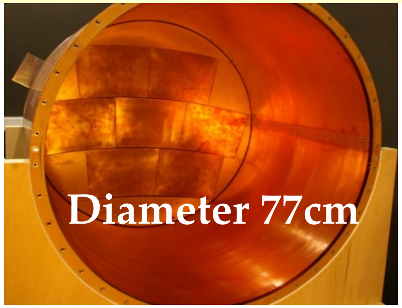
(precise momentum: e+e-→ZH→*ll*H)

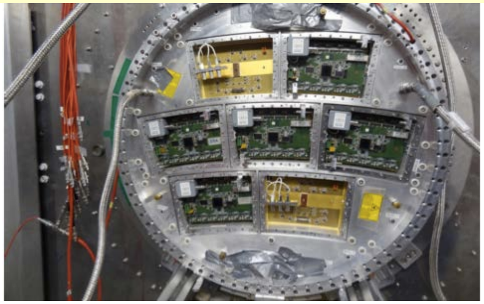
- Wet-etched triple GEMs
- Laser-etched GEMs 100μm thick ("Asian")
- GEM + pixel readout

- Resistive MM with dispersive anode
- InGrid (integrated Micromegas grid with pixel readout)

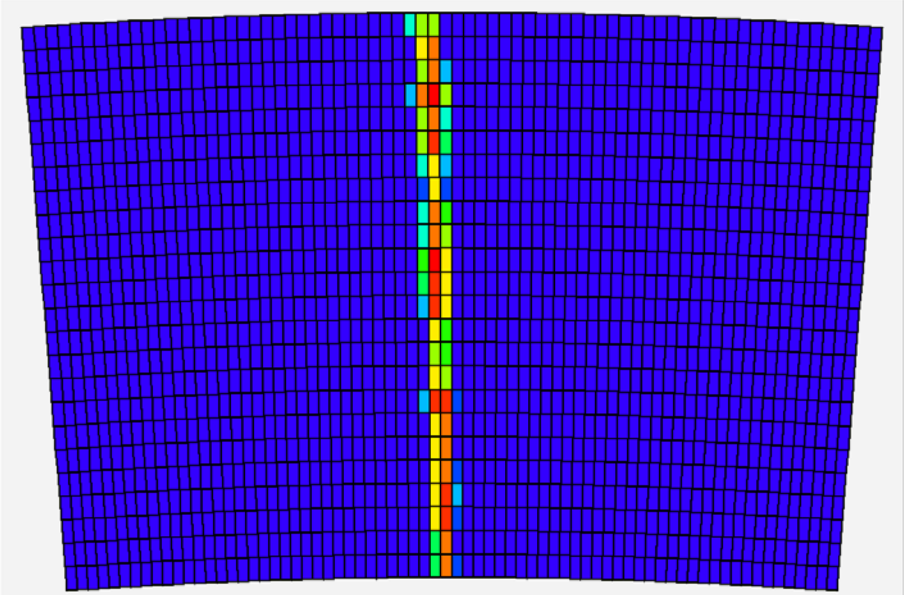


Large TPC Prototype with versatile endplate @ DESY

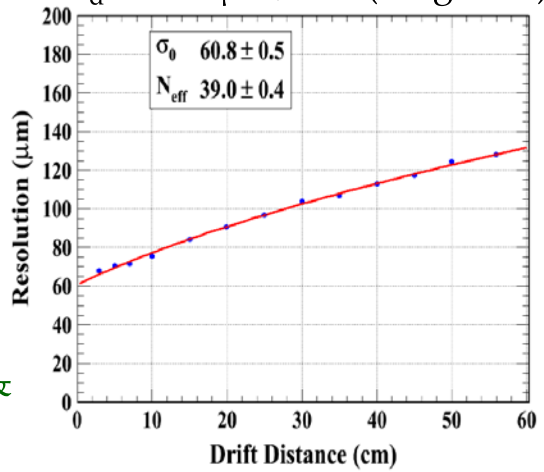




Resistive Micromegas @ DESY Test-Beam:



Resistive MM: B=1 T C_d = 94.2 μm/√cm (Magboltz)



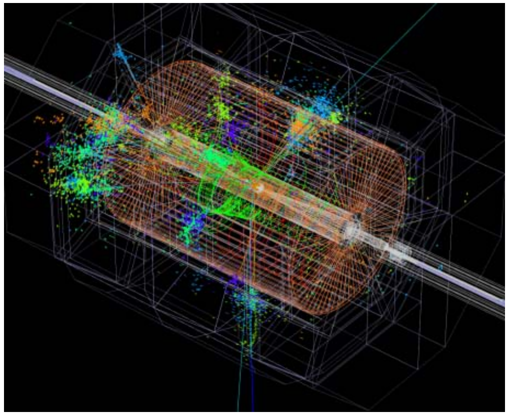
Goal for final TPC can be reached:

- GEM / MM performance similar
  → both extrapolate to better than 100 μm at B=3.5 T & drift length 2.25 m

State-of-the-Art in Calorimetry: Particle Flow

❖ R&D in Calorimetry is an LC driven effort → a marriage with "Particle Flow Algorithm" (pioneering work) has delivered a proof of principle and been established experimentally

Goal is $\Delta E_{jet}/E_{jet}$- 3-4% :
(separate hadronic W/Z decays)

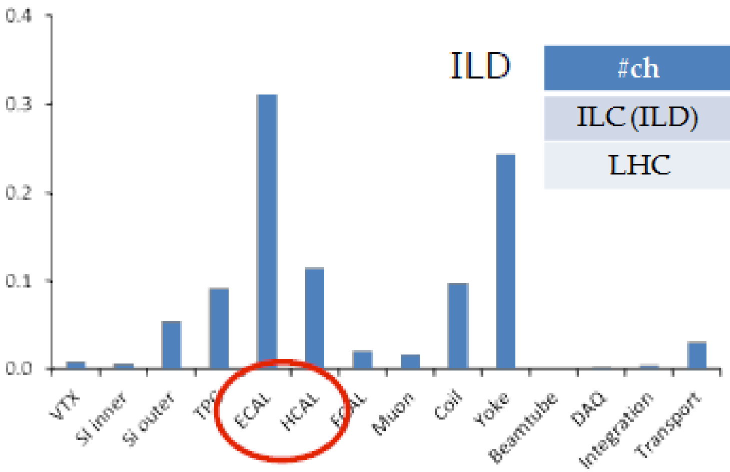


❖ PFA Algorithm (jet energy carried by …):

- Charged particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$)): 65 % - most precise measurement by tracker up to 100 GeV
- Photons: 25% - measurement by ECAL
- Neutral Hadrons: 10% - measurement by HCAL and ECAL

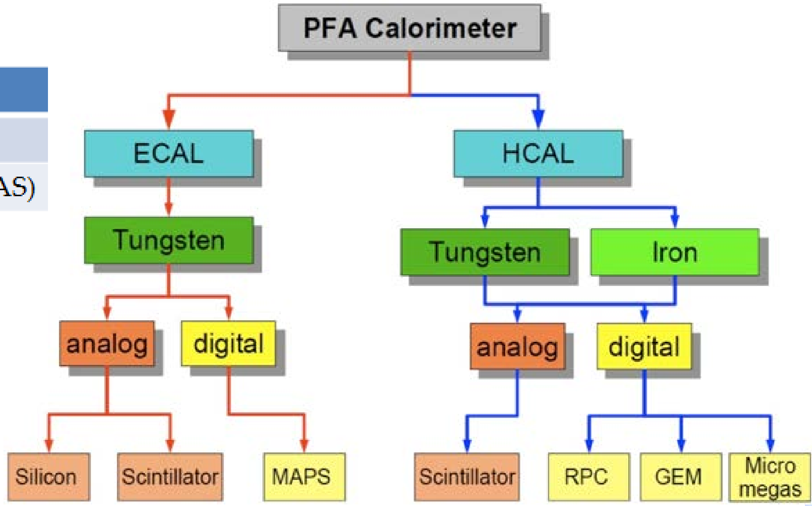
❖ Overlap between showers compromises correct assignment of calo hits ("Confusion Term"):
→ control by highly pixelised calorimeter readout
→ new technologies (Si, SiPM, MPGD,RPC, etc …)

Detector cost is driven by instrumented area rather than channel count

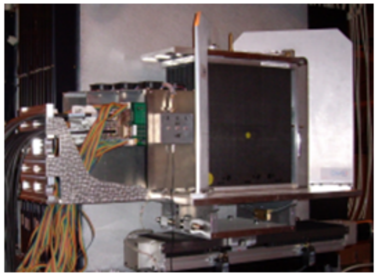
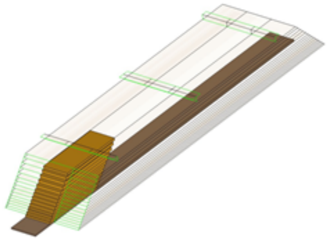
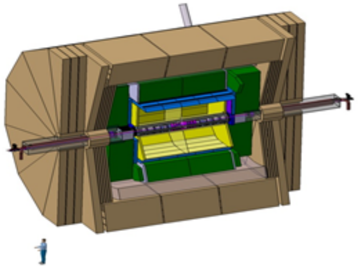


#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

ILD/SiD Calorimeter Concepts:



Calorimeter Technologies: Towards Final Systems

Physics Prototype	Technological Prototype	LC detector
Proof of principle 2003 - 2011	Engineering challenges 2010 - …	
		
Number of channels : 9720	Number of channels : 45360	ECAL : number of channels : ~100 10^6
Pixel size: 1x1 cm^2	Pixel size: 0.55x0.55 cm^2	
Weight : ~ 200 Kg	Weight : ~ 700 Kg	Total Weight : ~130 t

CALICE (SiW ECAL):

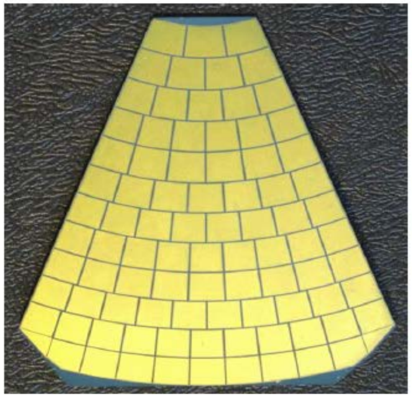
❖ From first prototypes to full calorimeter systems

→ technological integration (power pulsing, compact design, scalability)

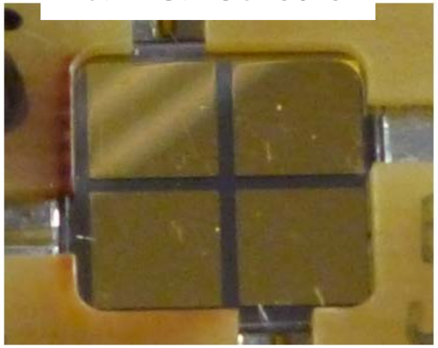
→ R&D oriented towards LC but synergies with other projects (e.g.CMS ECAL Endcap Upgrade)

Forward Calorimetry (FCAL):

❖ LumiCal provies integrated luminosity measurement
❖ BeamCal Provides instant luminosity measurement and assists beam tuning

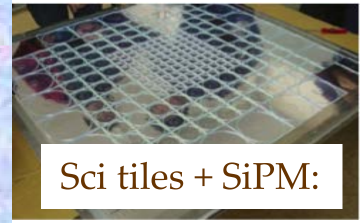


BeamCal Sensors:



Hadron Calorimetry (HCAL):

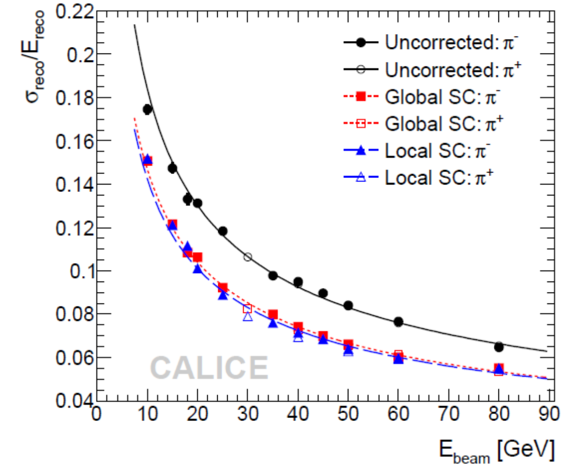
Large Scale Prototypes:



Sci tiles + SiPM:

$1m^3$ abs.: steel or W

Excellent hadronic energy resolution by software compensation



ILC Detector R&D: Spin-Offs is a Key Word to Survive

ILC Detector R&D:
Its Impact

September 2011

ILC Research Directorate

Director: Sakue Yamada

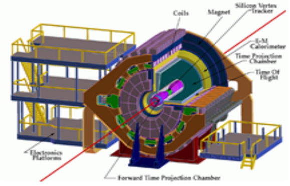
Prepared by the Common Task Group for Detector R&D

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

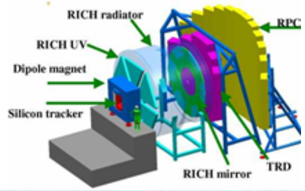
Major Impact in HEP Domain Beyond ILC:

CMOS-MAPS Initial Objective: ILC (with staged performance)
→ applied to hadron experiments with intermediate requirements (STAR, ALICE, CBM)

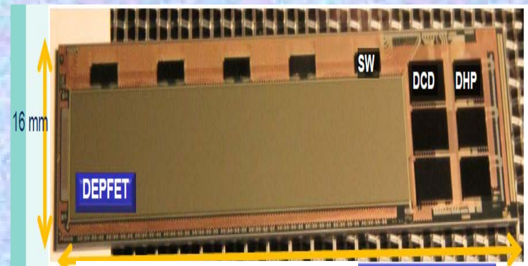
STAR 2012
Solenoidal Tracker @ RHIC (~ 1600 cm2)



CBM 2017
Compressed Baryonic Matter(~ 500 cm2)



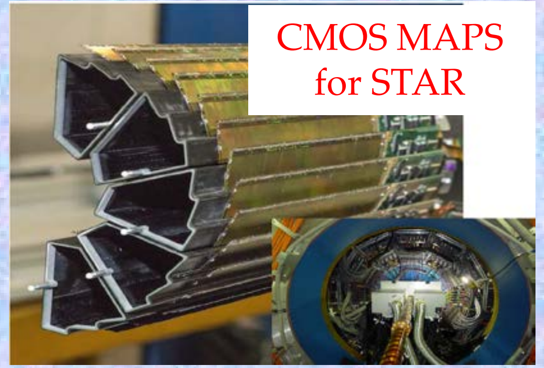
ALICE 2018
A Large Ion Colliderr (Inner Tracker System):



DEPFET for Belle II

Belle II pixel cell design
640x192 pixels matrix
50x75x50 µm³ pixel cells

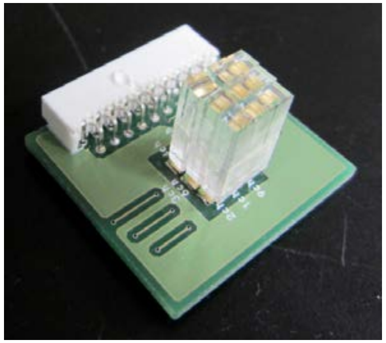
CMOS MAPS for STAR



… Outside High Energy Physics:

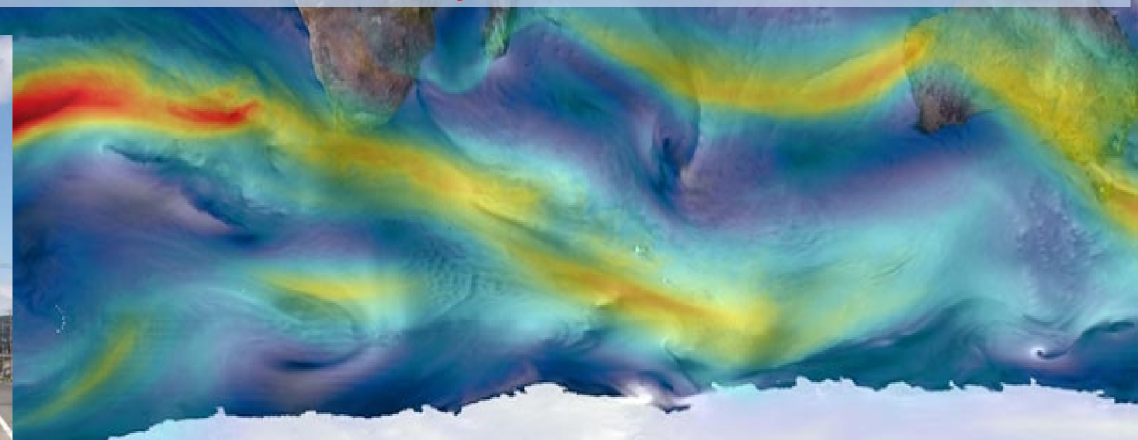
Prototype for PET Applications:

3x3 array of LYSO crystals with SiPMs (300 ps time resolution):



TRECAM (Tumor Resection CAMera): miniaturized gamma-camera for breast cancer surgery

49 x 49 mm² field of view
$LaBr_3$:Ce crystal optically coupled to a multi-anode photomultiplier tube



International Linear Collider in Japan,

The First Global HEP Project in Asia

Kitakami promotion videos:
http://www.pref.iwate.jp/seisaku/suishin/ilc/024538.html

The Way Forward

The <u>ILC is a Global Project</u>, to be designed and constructed by a worldwide cooperation of scientists and engineers

The TDR is the evidence that the ILC can be built now within "carefully estimated envelope" based on the real EU-XFEL@DESY project costs

Today, launching the project (= ILC approval by governments) has the highest priority

→ We need to make sure that we can launch the project <u>GLOBALLY</u>

→ We need a <u>VISION, STRATEGY and HARD WORK</u> to materialize our belief

The Way Forward: Recent ILC Progress in Japan

❖ The candidate site is unified by the Japanese HEP

August 2013:

In August 2013, the Japanese site evaluation committee by scientists and experts in Japan recommended the Kitakami-site as a candidate for ILC. Internal Review Committee concluded that the proposed site is in good geological conditions.

❖ Japanese government makes a move

Hitoshi Murayama | 23 January 2014

Japan's House of Representatives room.

December 24, 2013:

MEXT (not researchers) requested \$0.5M for ILC → approved in Dec. 2013

❖ Japanese government allocates "investigation budget" for the ILC as an official project (for the first time)

❖ KEK sets up Planning Office for the ILC

ILC Project Preparation Office
Director: KEK-DG

Deputy Director

ILC Project Unit
Advanced R&D and Engineering Design

Coordination Unit
Coordination and Integration of Internal / External Efforts

Development anticipated:

KEK Organiation (2014)
→ All-JP Organization
→ Global Org. (2015)

February 6, 2014:

❖ Oversight a broad range of activities required for ILC realization

❖ Expert committee has been setup under MEXT:

Kick-off Meeting:
May 8, 2014

Task Force

Academic Experts Committee

Particle・Nuclear Physics WG

TDR Validation WG

❖ Investigate the reliability on hosting the ILC in Japan (report to be completed in FY 2015)

The Way Forward: Japan Started High Level International Discussions

Positive Reference from Japan Prime Minister

October 2012

March 2013

April 30,2013: US-Japan Symposium in Washington D.C

100 invited participants from US-Japan (each ~50 persons) from HEP researchers, industry, political and government

US-Japan Advanced Science and Technology Symposium

This symposium gathers US and Japanese leaders from policy makers for the field of science and innovation, academia and industry. ... ussion will cover the US-Japan co-operati ... he realization of economic growth as well as methods and policies for the development of scientific and technical human resources.

With the ILC as an example, …

Next meeting – July 2014

MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Jan. 2014:
MEXT Minister, Japan to Secretary of Energy, USA:

Dr. Ernest Moniz
Secretary of Energy
Department of Energy
1000 Independence Ave. SW
Washington DC 20585
United States of America

February 7, 2014

Dear Secretary Moniz,

It was a great pleasure to talk with you when I visited the United States recently. In our conversation, I explained the current situation regarding the International Linear Collider (ILC) project in Japan, and I would like to reiterate what I said through this letter.

It was a great pleasure to talk with you when I visited the United States recently. In our conversation, I explained the current situation regarding the International Linear Collider (ILC) project in Japan, and I would like to reiterate what I said through this letter.

Researchers in the United States, Europe and Japan have been discussing and continuing their R&D with enthusiasm in the ILC project. Considering the significance and benefit of the ILC project, I believe that discussion from a wider perspective is essential. For this, I recognize that working-level informal exchanges of views among Japan, the United States and / or Europe should be started from the current stage.

However, the priorities for academic and scientific projects and the financial status vary between the countries. Therefore, for making a decision of whether or not to join the ILC project, discussion and sharing of the consensus about the scientific significance and challenges between government and scientists in each country that is interested in the ILC project is indispensable. I understand that the project prioritization process in the field of particle physics in the United States is ongoing. The United States is one of the leading countries in the field of particle physics research in the world, and I hope that substantial

→ Similar letters from MEXT were sent to: CERN DG and European Government

The Way Forward: ILC International Support

US P5 Report Released May 22, 2014:

Rec. #1 ("HEP Global Nature") →

"Pursue the most important opportunities wherever they are …"

Project/Activity	Scenario A	Scenario B	Senario C
Large Projects			
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y
HL-LHC	Y	Y	Y
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced
ILC	R&D only	R&D, possibly small hardware contri-butions. See text.	Y
NuSTORM	N	N	N
RADAR	N	N	N

- Japan is expressing growing interest in hosting the ILC (substantial resources could enter the project)
- European Strategy for Particle Physics (2013)

 - There is a strong scientific case for an electron-positron collider, complementary to the LHC … and whose energy can be upgraded … The European groups are eager to participate.

- US Particle Physics Prioritization Panel (P5 Report) (May 2014)

 - Motivated by the strong scientific importance of the ILC … … 'Play a world-leading role in the ILC experimental program and provide critical expertise and components to the accelerator, should this exciting scientific opportunity be realized in Japan.'

 - Participation by the U.S. in ILC project construction depends on a number of key factors, some of which are beyond the scope of P5 → This is a reminder that the financial scale of the ILC in Japan is such that high-level political agreements need to be established.

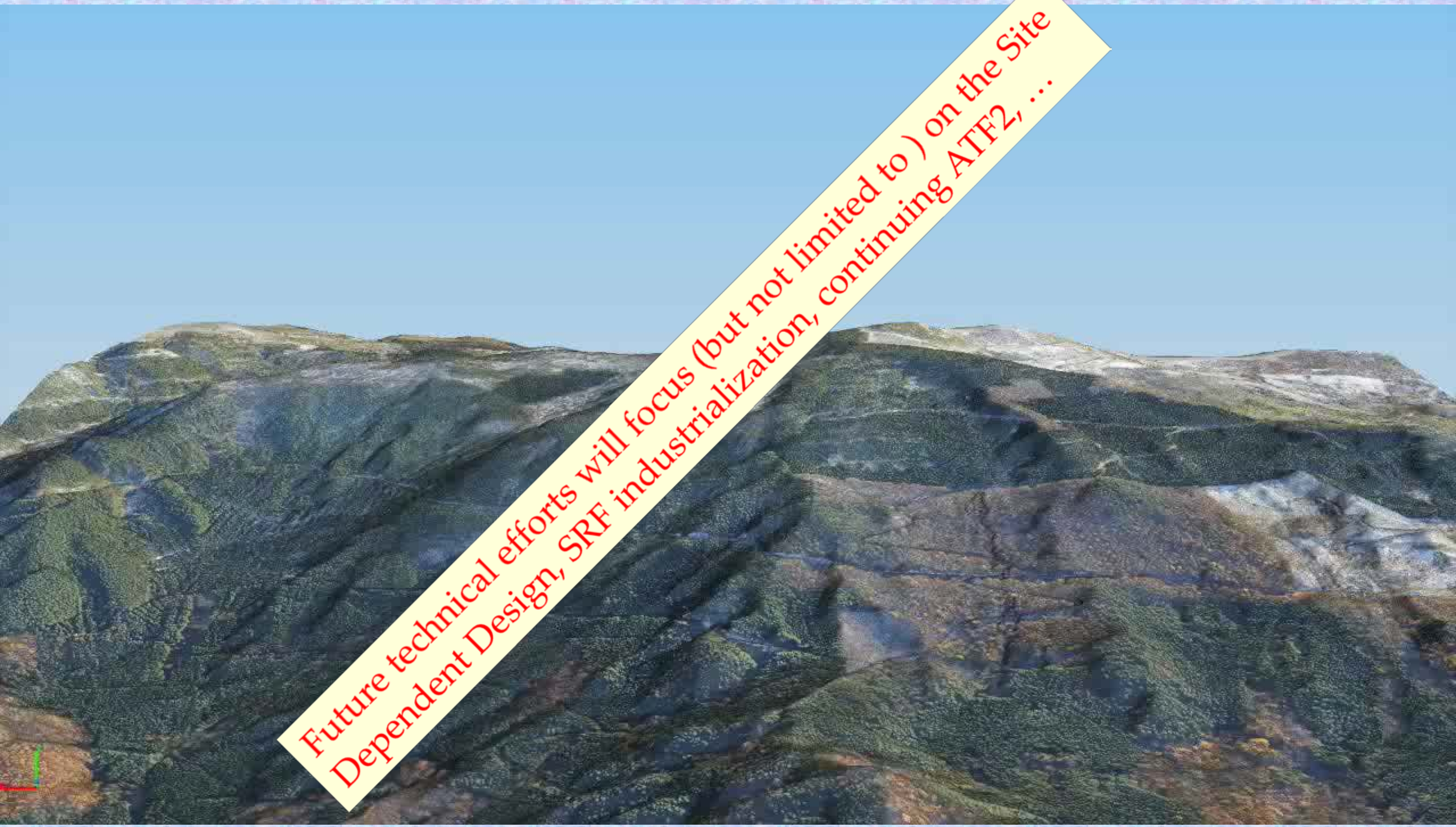
Executive Summary: as the physics case is extremely strong, all budget scenarios include ILC support at some level through a decision point within the next 5 years

ILC Site Candidate Location in Japan: Kitakami Area

ILC Accelerator Design Integration and 3D Modelling

B. List,
L. Hagge

EDMS (Engineering Data Management) will have a 3D system model of all ILC technical areas
(design integration, accelerator layout, Kitakami geology, tunnel/cavern requirements, civil engineering)



Future technical efforts will focus (but not limited to) on the Site Dependent Design, SRF industrialization, continuing ATF2, …

Summary and Outlook

Photo: Courtesy S. Ganjour (CEA Saclay)

HEP Community

Governments

Worldwide Cooperation

GLOBAL
ILC PROJECT
IN JAPAN:

❖ Very strong physics case
→ Model-Independent Top/Higgs Measurements
→ SUSY, BSM Physics, DM searches …

❖ Today, is the only mature technology for the future accelerator at the energy frontier

Concluding Wish:
May all "ILC coming challenges"
face ZERO RESISTANCE !!!
(ILC uses "Superconducting Technology")

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