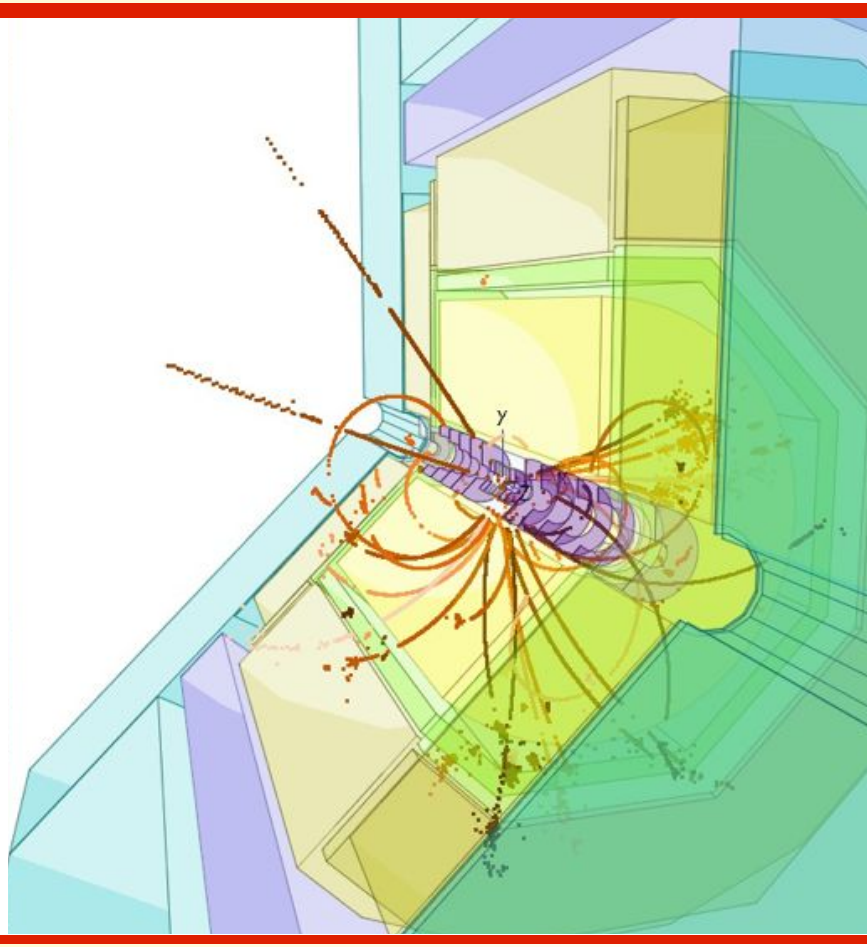
Future Linear Colliders

Higgs–Maxwell Meeting, 17 February 2016

- Machines context
- Physics motivations
- Accelerator developments
- Detector collaboration developments
- Timelines and outlook

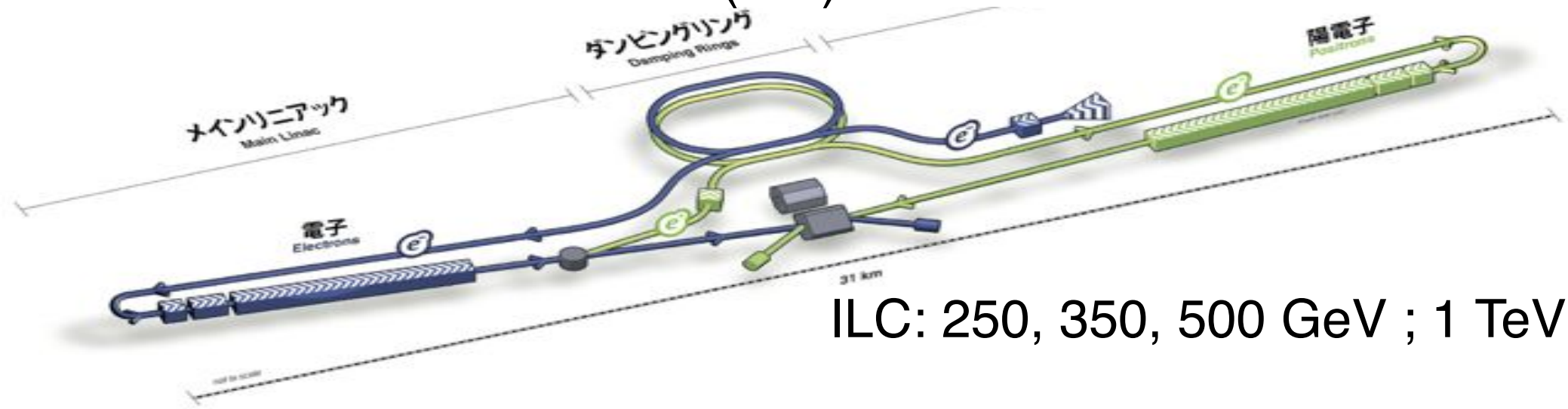


Aidan Robson

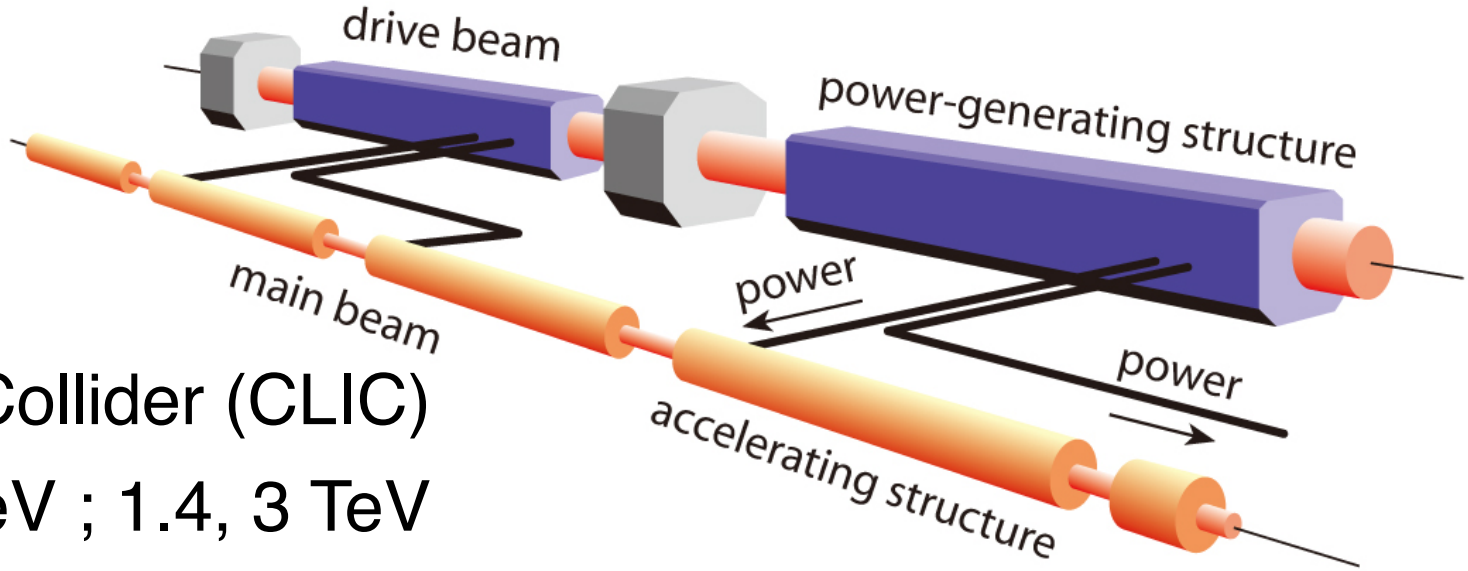
University of Glasgow | Experimental Particle Physics

Machines context

International Linear Collider (ILC)



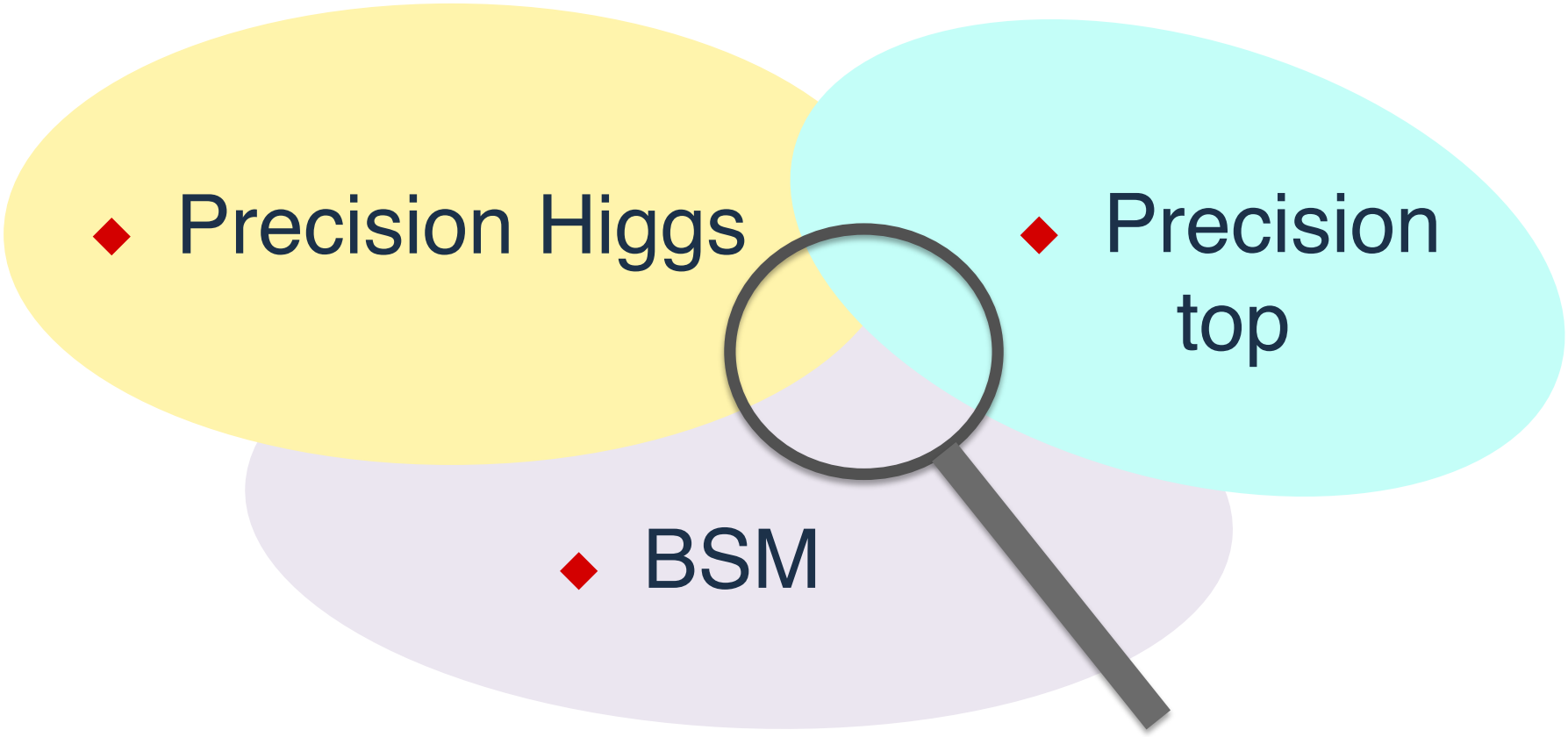
ILC: 250, 350, 500 GeV ; 1 TeV



Compact Linear Collider (CLIC)

CLIC: 380 GeV ; 1.4, 3 TeV

Physics motivations



Higgs overview

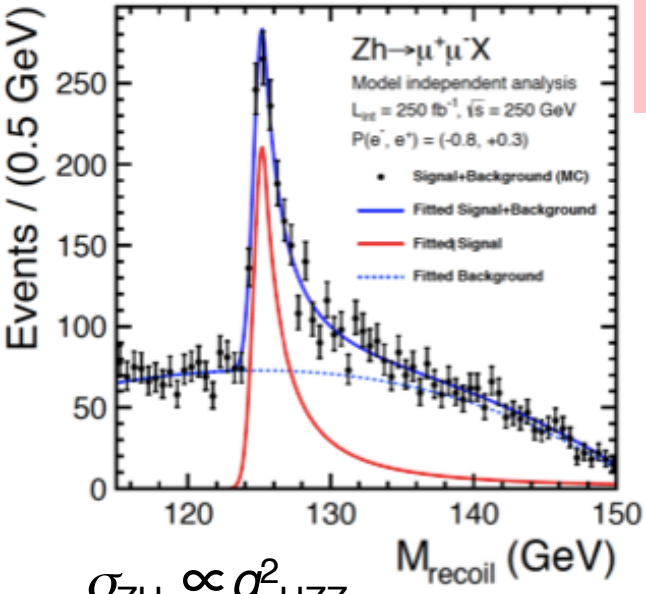
$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$

σ x Br → Br → g coupling

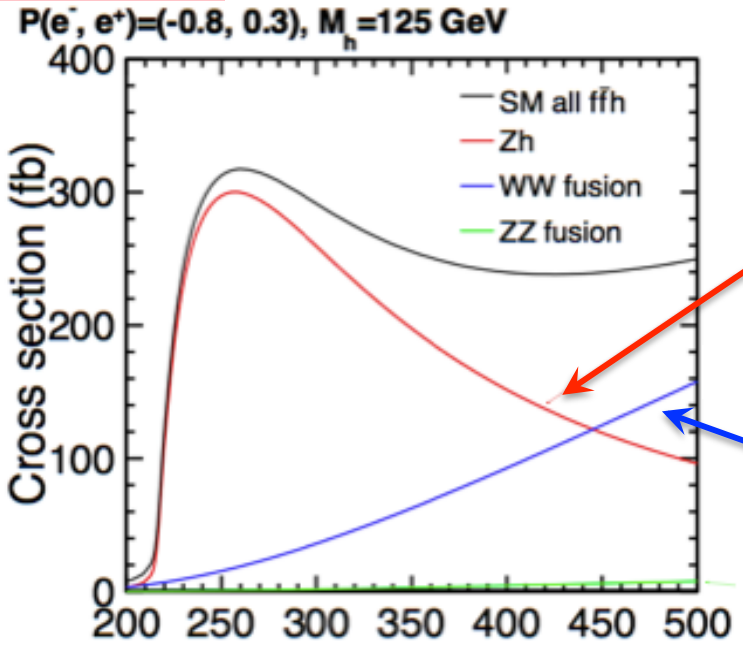
σ from recoil mass → the key → Γ_H total width

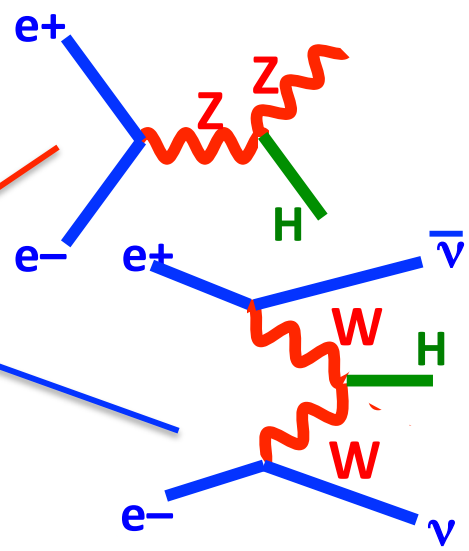
(need WW fusion for precision total width -> higher $\sqrt{s}$)

$$\frac{\sigma_{ZH}\ .Br(H->bb)}{\sigma_{\nu\nu H}\ .Br(H->bb)} \propto \frac{g^2_{HZZ}}{g^2_{HWW}}$$



$\sigma_{ZH} \propto g^2_{HZZ}$





after Fujii/Tanabe

$\sigma_{\nu\nu H}\ .Br(H->WW) \propto g^4_{HWW}/\Gamma_H$

Higgs overview

$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$

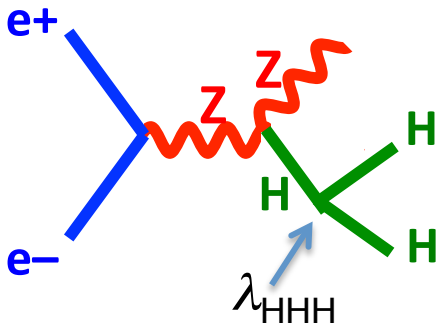
σ x Br → Br → g coupling

the key

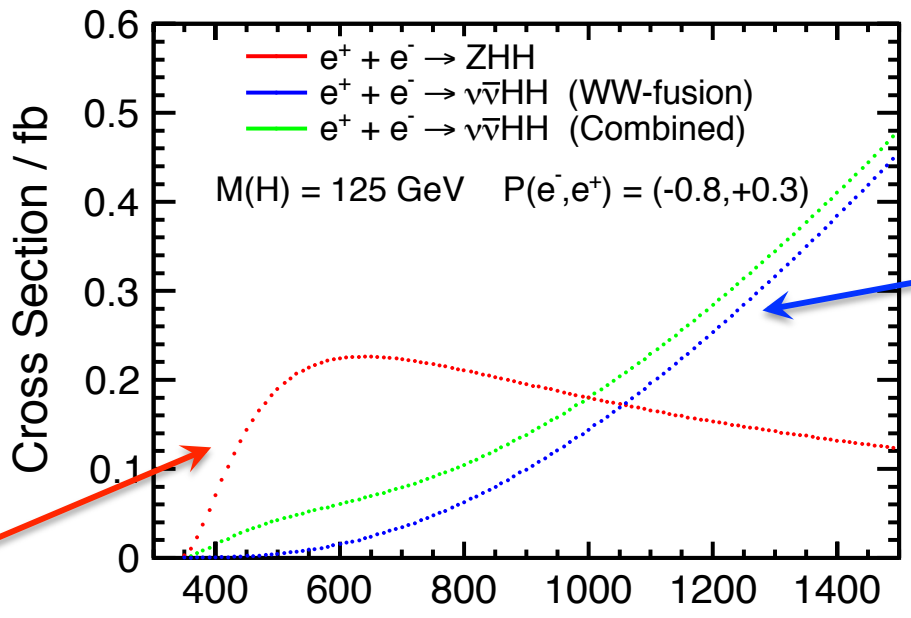
σ from recoil mass → Γ_H total width

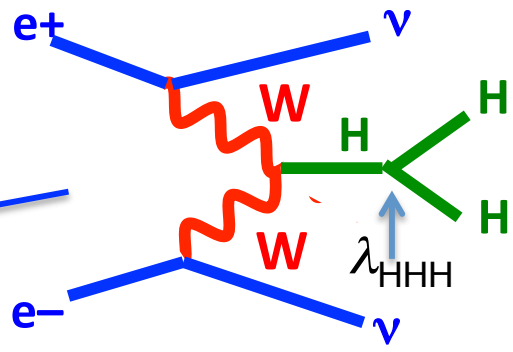
(need WW fusion for precision total width -> higher $\sqrt{s}$)

Higher energies: ttH, HH



dominates around $\sqrt{s}$=500GeV





dominates at higher $\sqrt{s}$

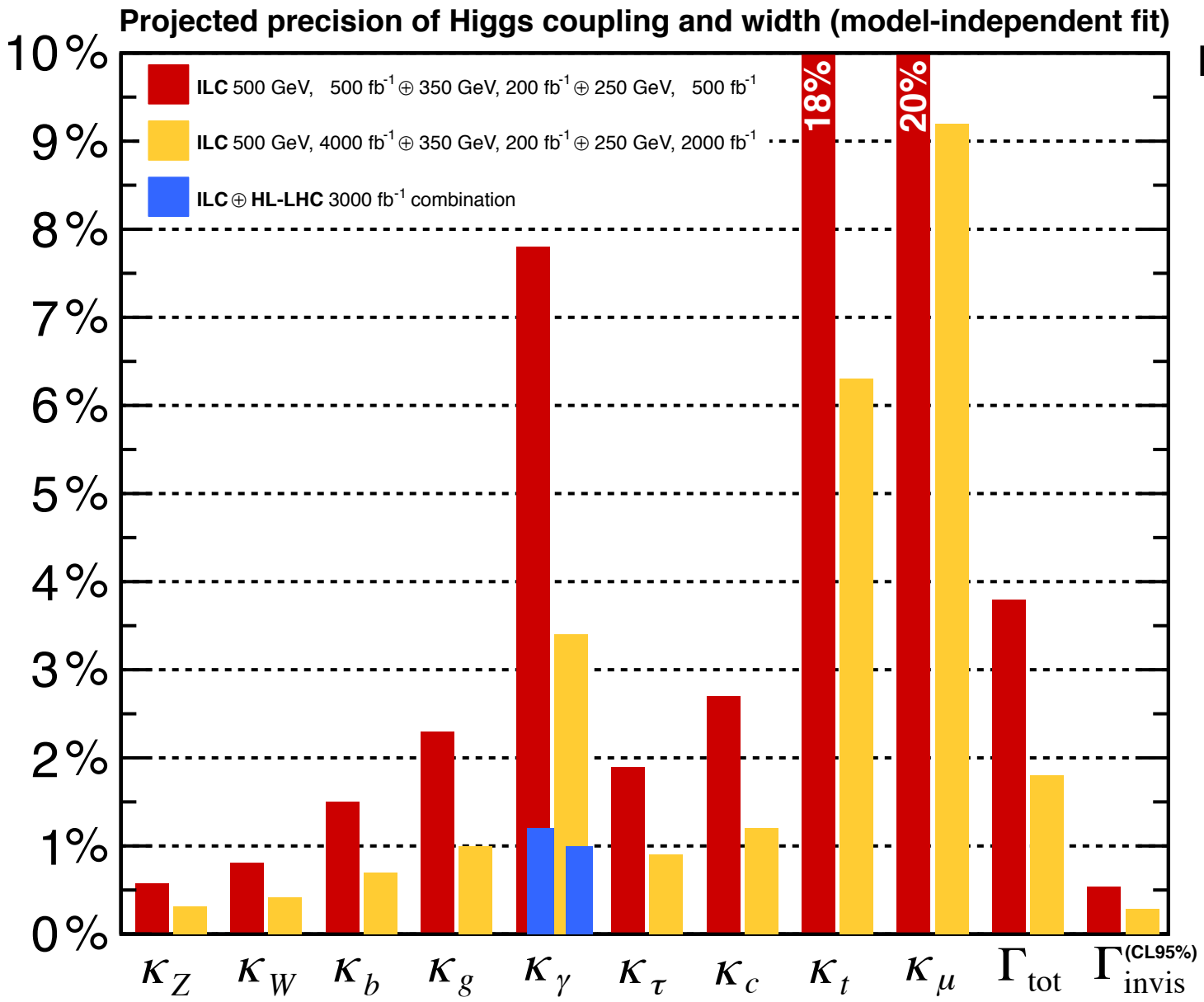
Higgs couplings – BSM sensitivity

example scenarios in which $M \sim 1$TeV for new particles

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

arXiv: 1310.8361

Higgs couplings



model-independent

ILC
500GeV, 500 fb^{-1}
350GeV, 200 fb^{-1}
250GeV, 500 fb^{-1}
(8 years)

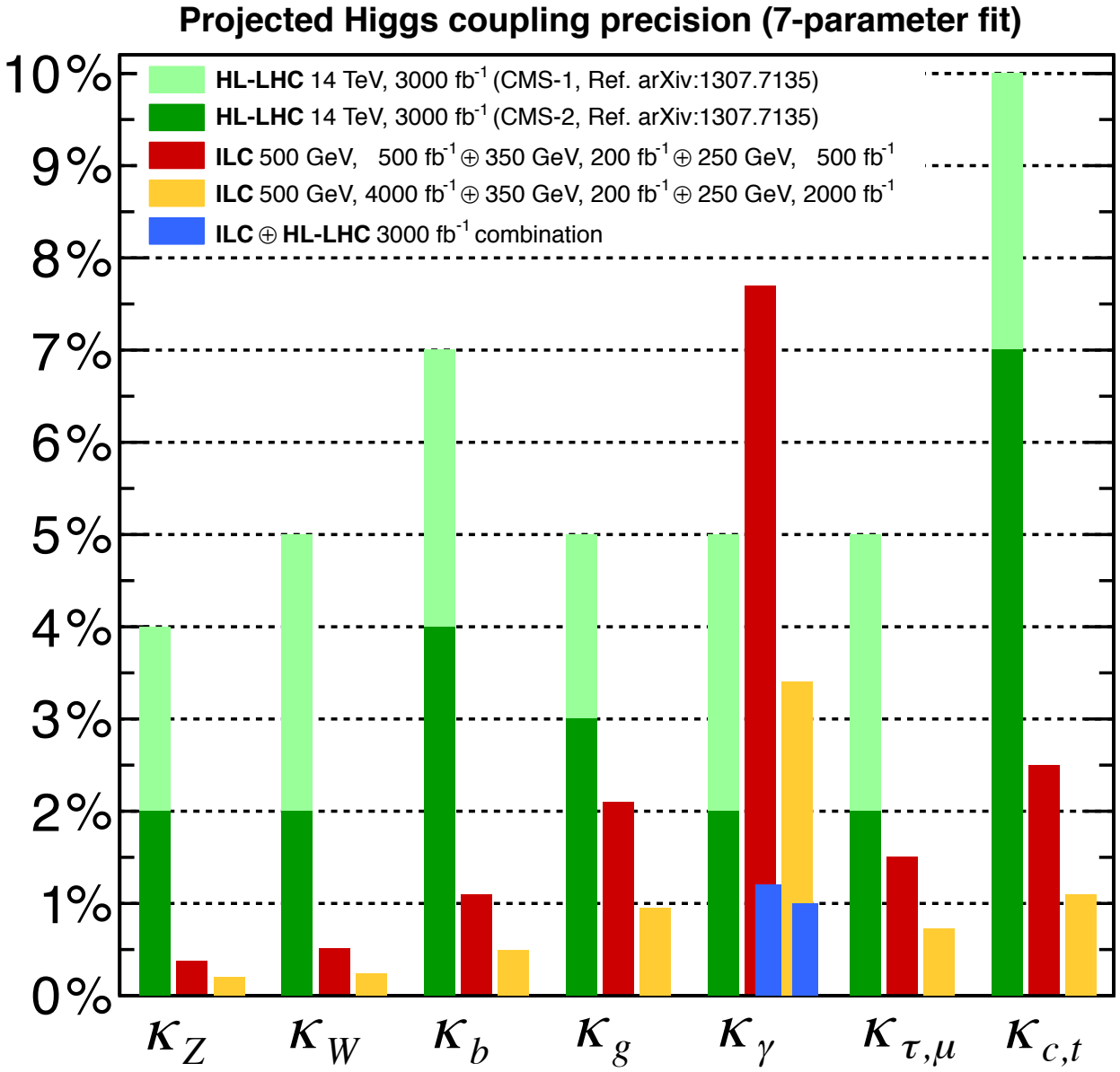
ILC
500GeV, 4000 fb^{-1}
350GeV, 200 fb^{-1}
250GeV, 2000 fb^{-1}
(+10 years)

ILC+HL-LHC 3000 fb^{-1}

TeV-scale NP gives O(1%) deviations on H couplings

...compare to HL-LHC

with LHC can only compare model-dependent fits:



assumes fractional shift in κ is equal for u,c,t ; for d,s,b ; and for e,μ,τ ; and no Higgs decay to invisible/exotic particles

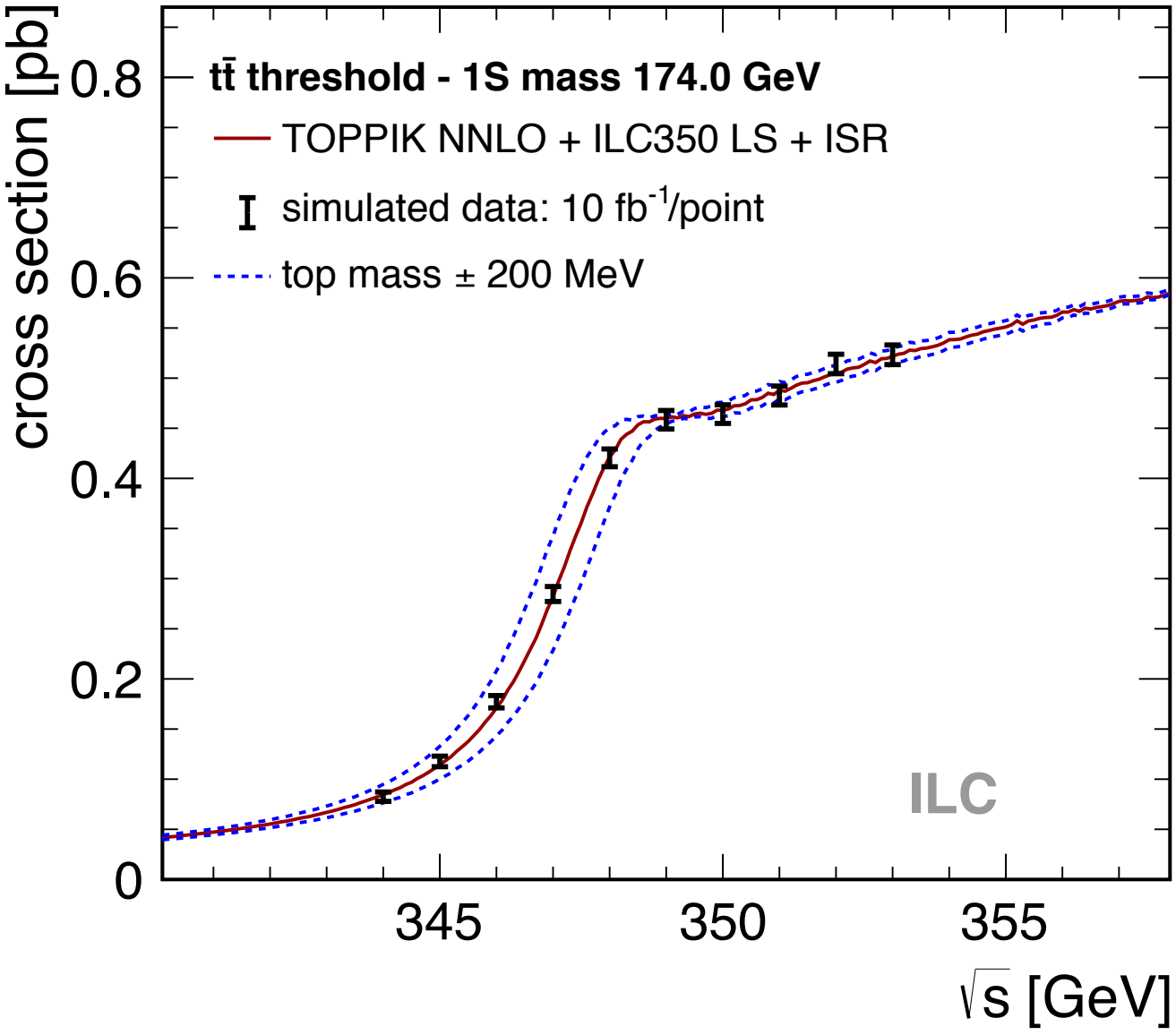
Higgs couplings

Coupling √s (TeV)→ L (fb^{-1}) →	LHC 14 3000(1 expt)	CepC 0.24 5000	FCC-ee 0.24 +0.35 13000	ILC 0.25+0.5 6000	CLIC 0.38+1.4+3 4000	FCC-hh 100 40000
K_W	2-5	1.2	0.19	0.4	0.9	
K_Z	2-4	0.26	0.15	0.3	0.8	
K_g	3-5	1.5	0.8	1.0	1.2	
K_γ	2-5	4.7	1.5	3.4	3.2	< 1
K_μ	~8	8.6	6.2	9.2	5.6	~ 2
K_c	--	1.7	0.7	1.2	1.1	
K_τ	2-5	1.4	0.5	0.9	1.5	
K_b	4-7	1.3	0.4	0.7	0.9	
$K_{Z\gamma}$	10-12	n.a.	n.a.	n.a.	n.a.	
Γ_h	n.a.	2.8	1.	1.8	3.4	
BR_{invis}	<10	<0.28	<0.19	<0.29	<1	
K_t	7-10	--	13% ind. tt scan	6.3	<4	~ 1 ?
K_{HH}	?	35% from K_Z model-dep	20% from K_Z model-dep	27	11	5-10

Units are %

summary table from Fabiola Gianotti LP15

Precision top physics



observe 1S 'bound state'
$\Delta m_t \sim 50$ MeV

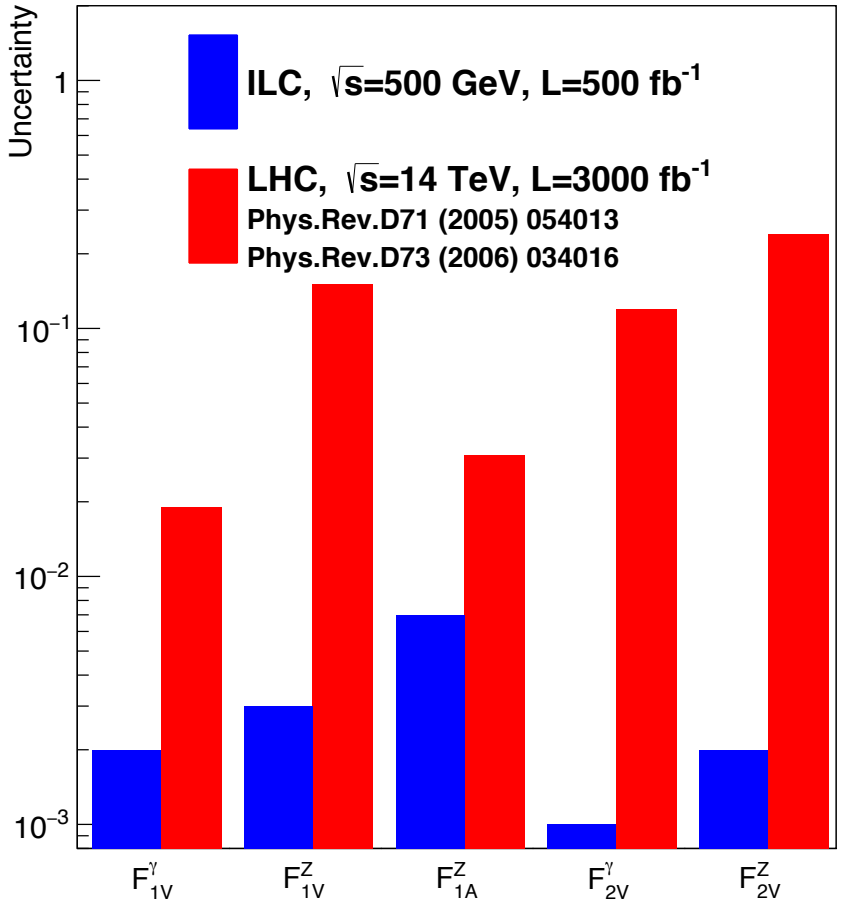
Precision top physics

parameterisation of ttX vertex

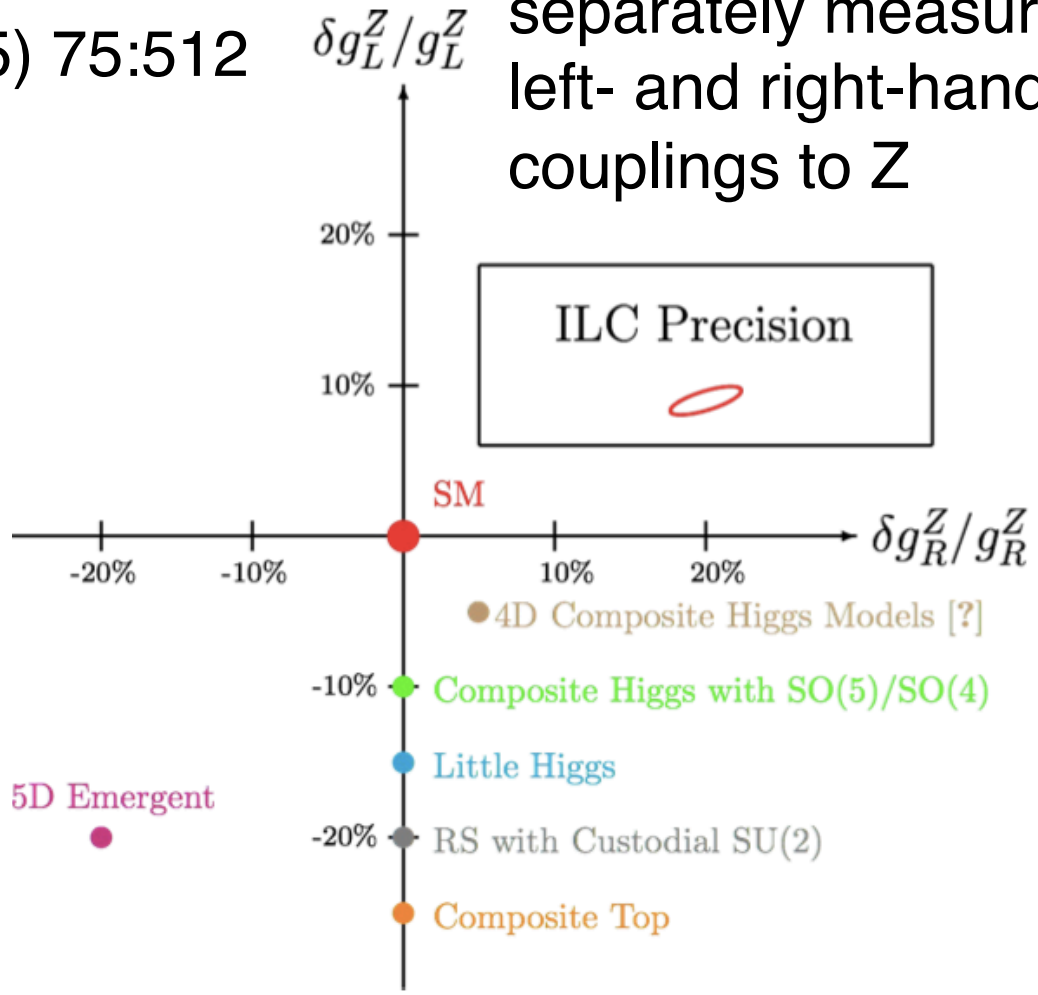
$$\Gamma_\mu^{ttX}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F_{1V}^X(k^2)+\gamma_5 F_{1A}^X(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF_{2V}^X(k^2)+\gamma_5 F_{2A}^X(k^2)\right)\right\}$$

Vector Axial Tensorial CPV

EPJ C (2015) 75:512



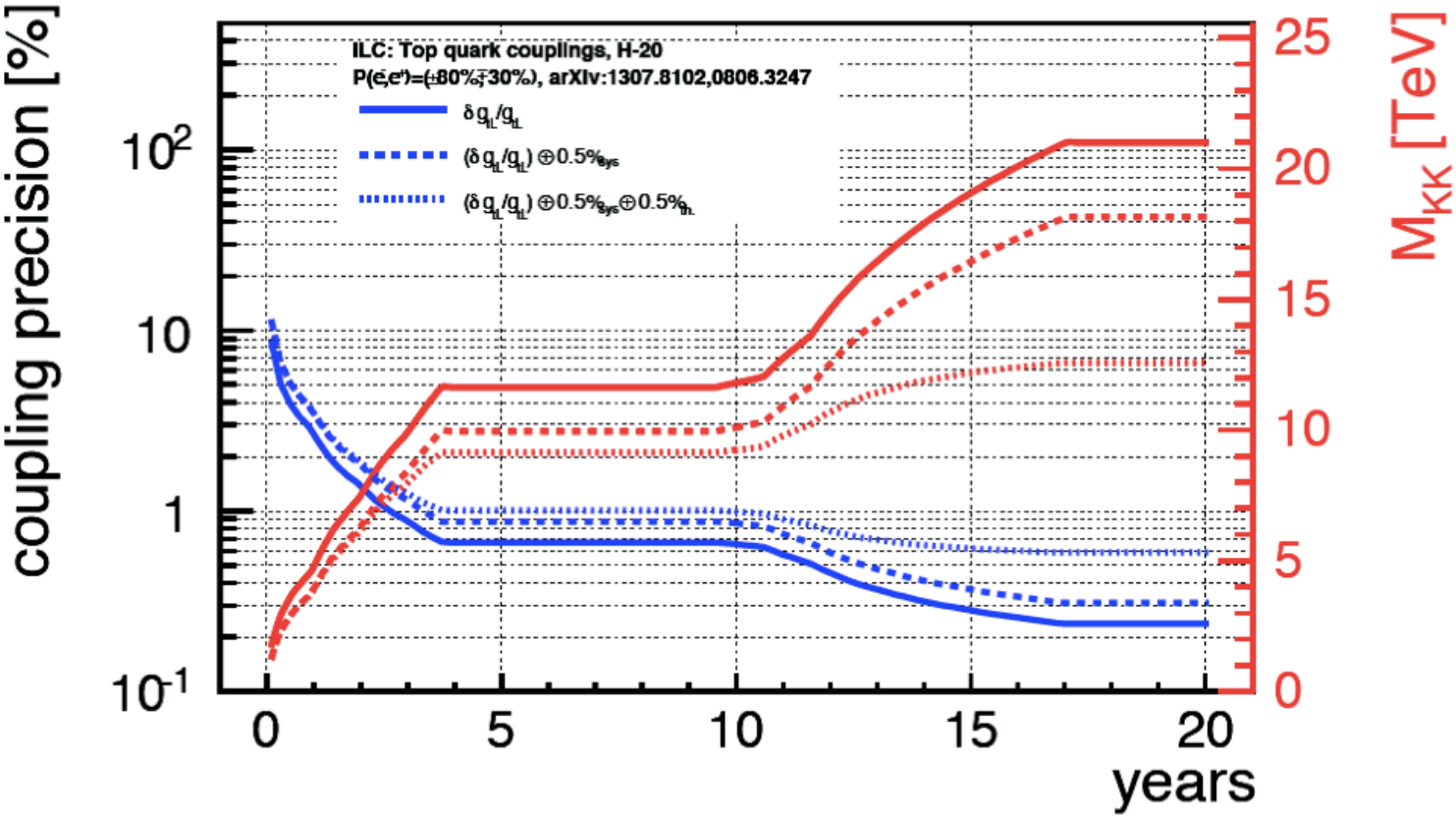
separately measure left- and right-handed couplings to Z



Precision top physics

H20: 500/fb @ 500 GeV, 200/fb @ 350 GeV, 500/fb @ 250 GeV, 3500/fb @ 500 GeV, 1500/fb @ 250 GeV

Based on phenomenology described in Pomerol et al. arXiv:0806.3247

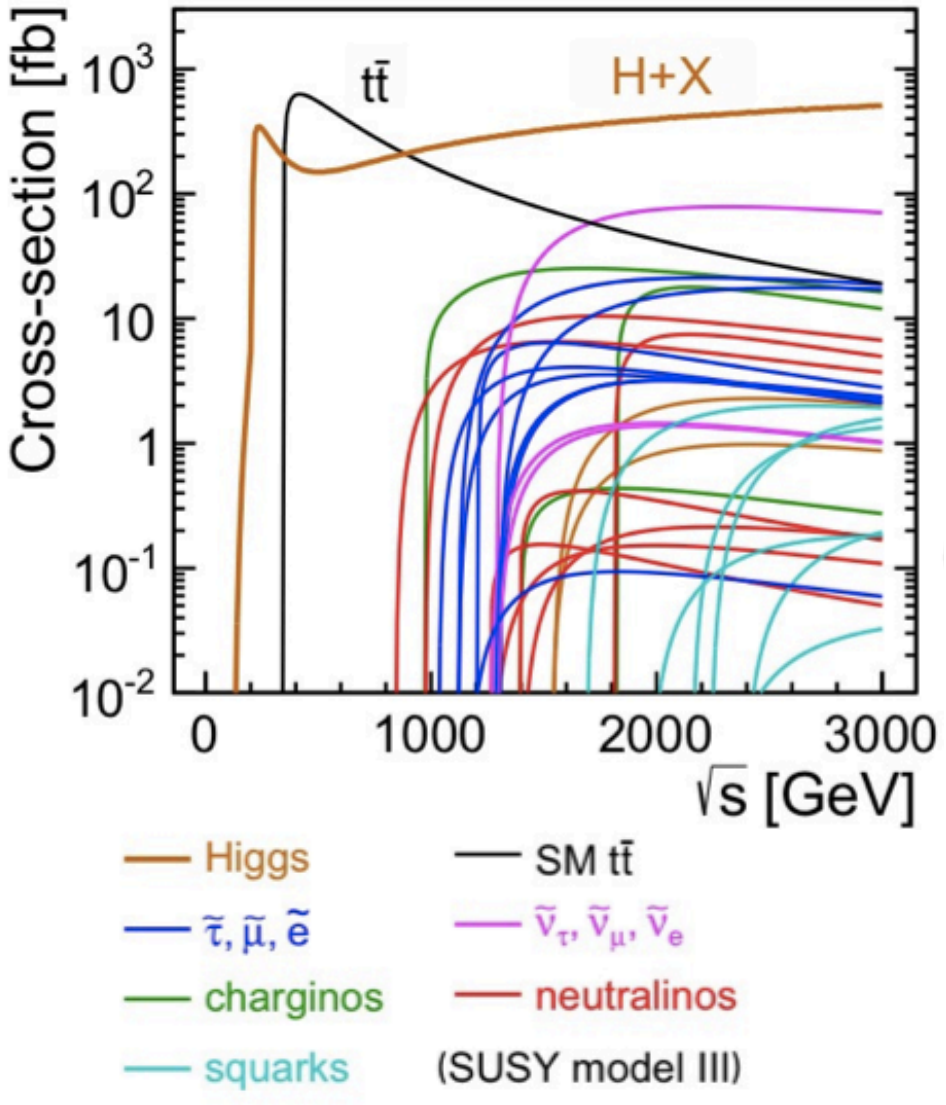


Sensitive to Higgs-sector resonance coupling to top; probes scales of ~25TeV in typical scenarios

From Ignatio Garcia / Marcel Vos

Direct BSM

1. example: 'SUSY model III'

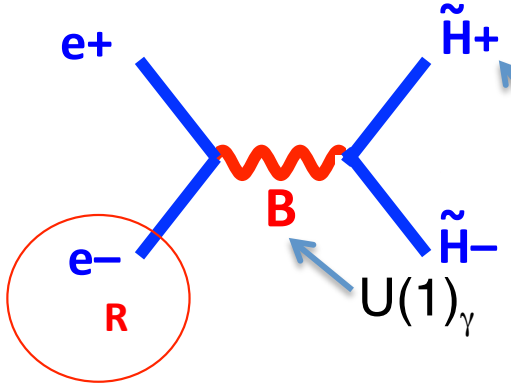


2. example: 'compressed' spectrum

$\tilde{W}$ and $\tilde{B}$ excluded by LHC where well-separated in mass from LSP. But if mass difference < 20GeV, visible decay products too soft to trigger.

3. example: disentangling couplings to new particle

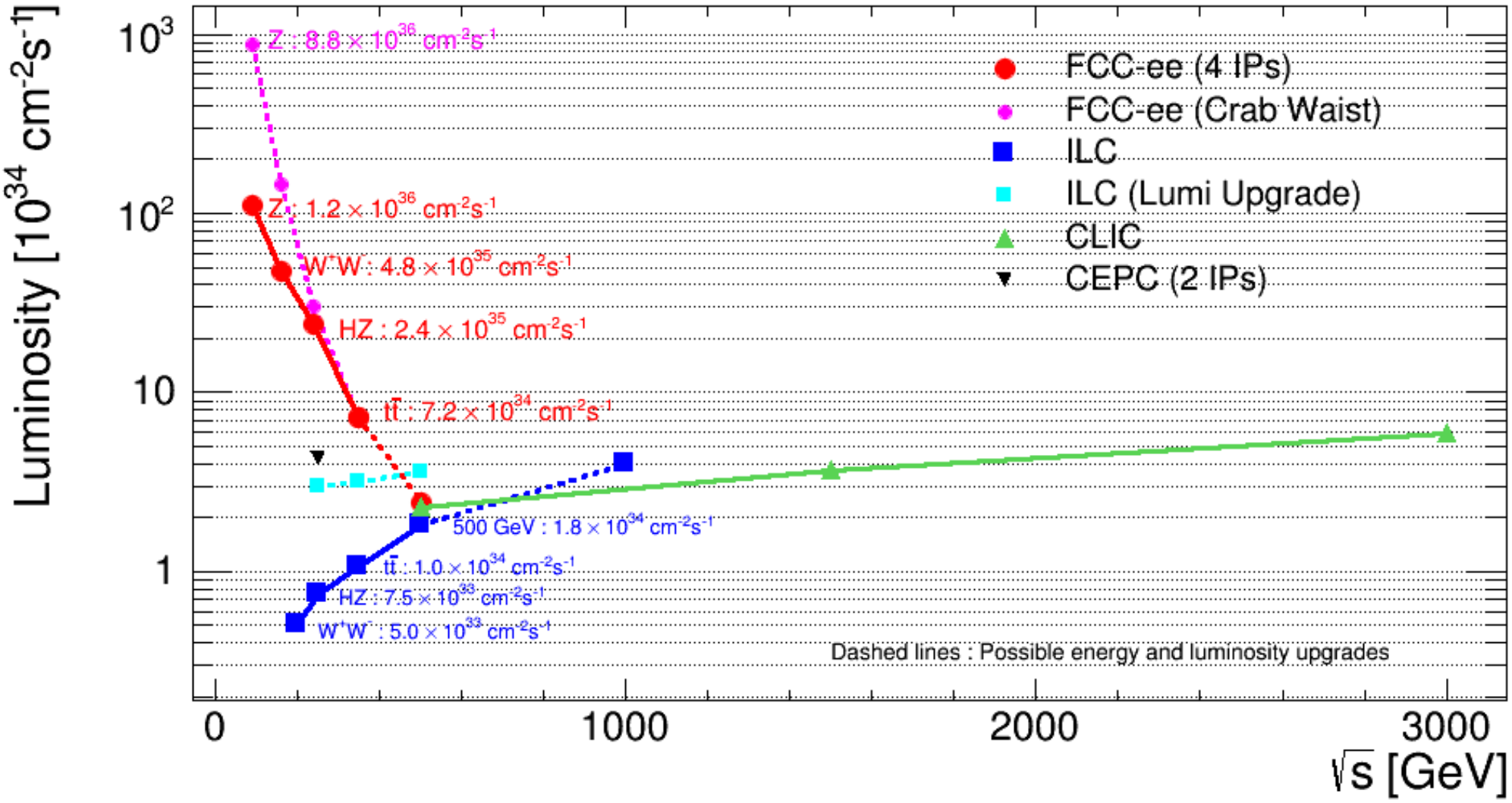
Polarized beams -> decomposition:



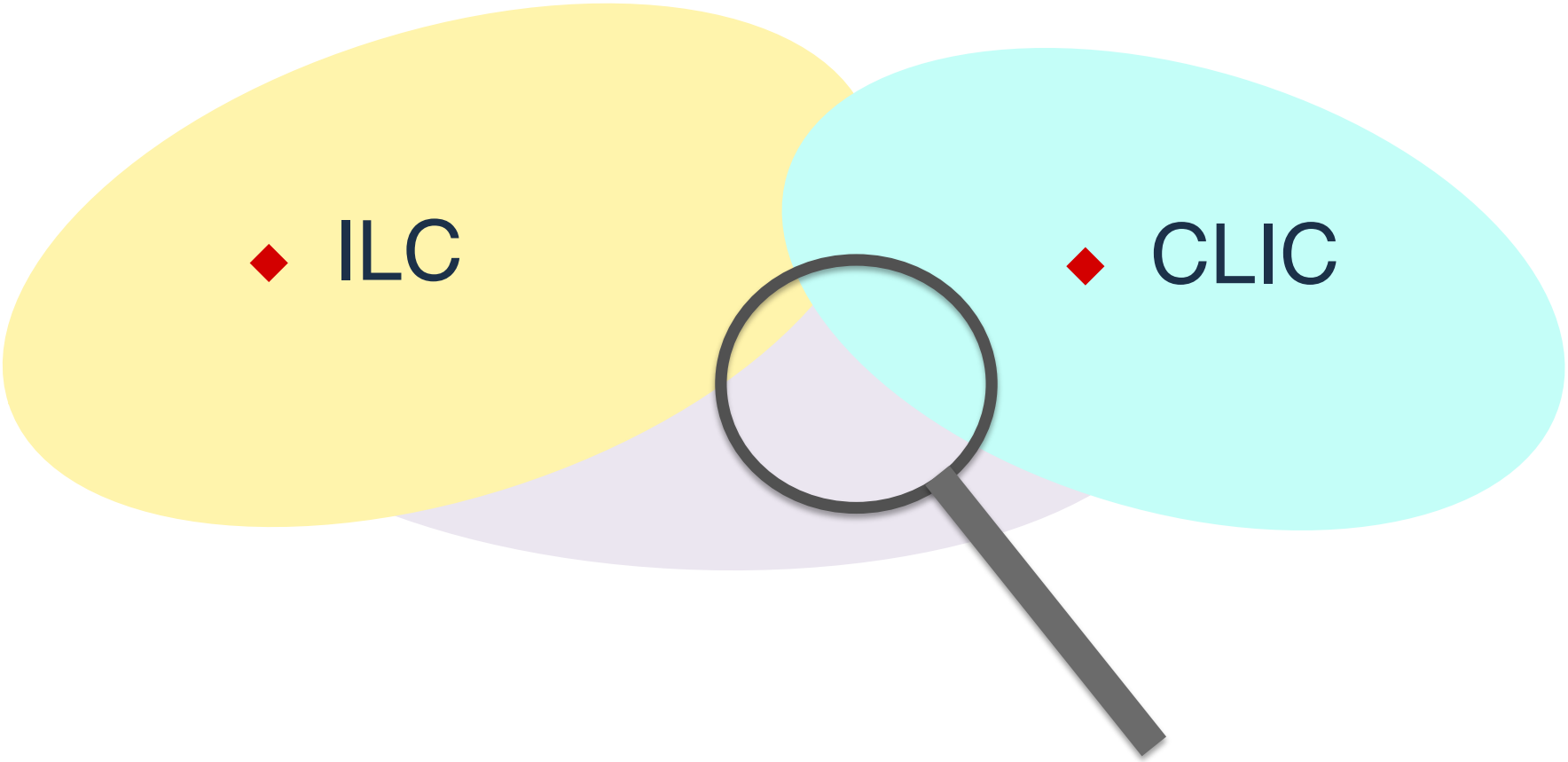
Only $\tilde{H}^\pm$ components of $\tilde{\chi}_1^\pm$ contribute

$\tilde{\chi}_1^\pm = \alpha\tilde{W}^\pm + \beta\tilde{H}^\pm$

Physics reach



Accelerator developments



NB, ‘LCC’ is Linear Collider Collaboration,
– umbrella group directed by Lyn Evans

ILC accelerator developments

Global Design Effort (GDE) 2005–12

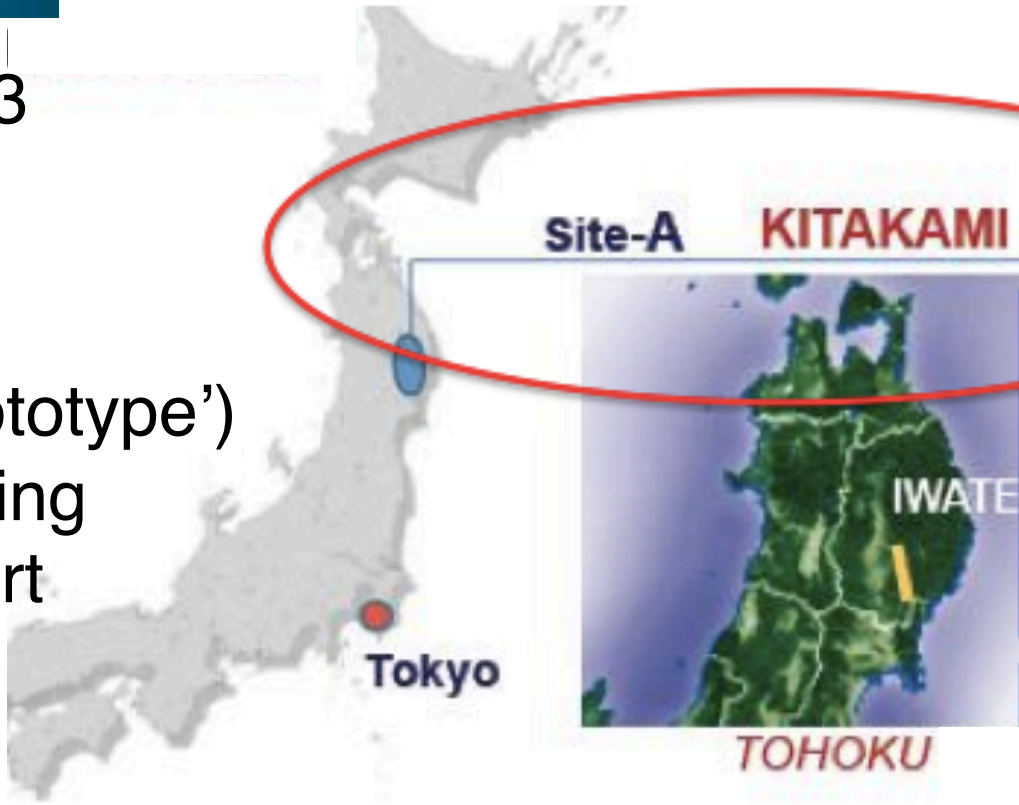
Reference Design Report 2007

engineering design phase

TDR 2013

site-specific design

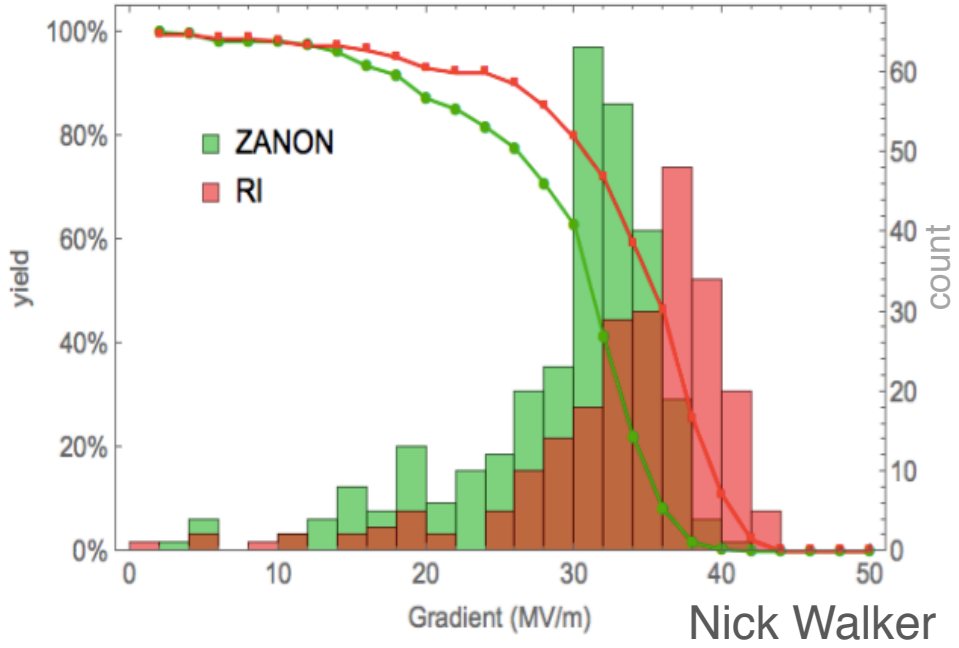
- Mature technology
- XFEL is being constructed (‘prototype’)
- Japan making decision on hosting
- 10-years construction could start
  ~now -> physics in 2028



ILC accelerator developments

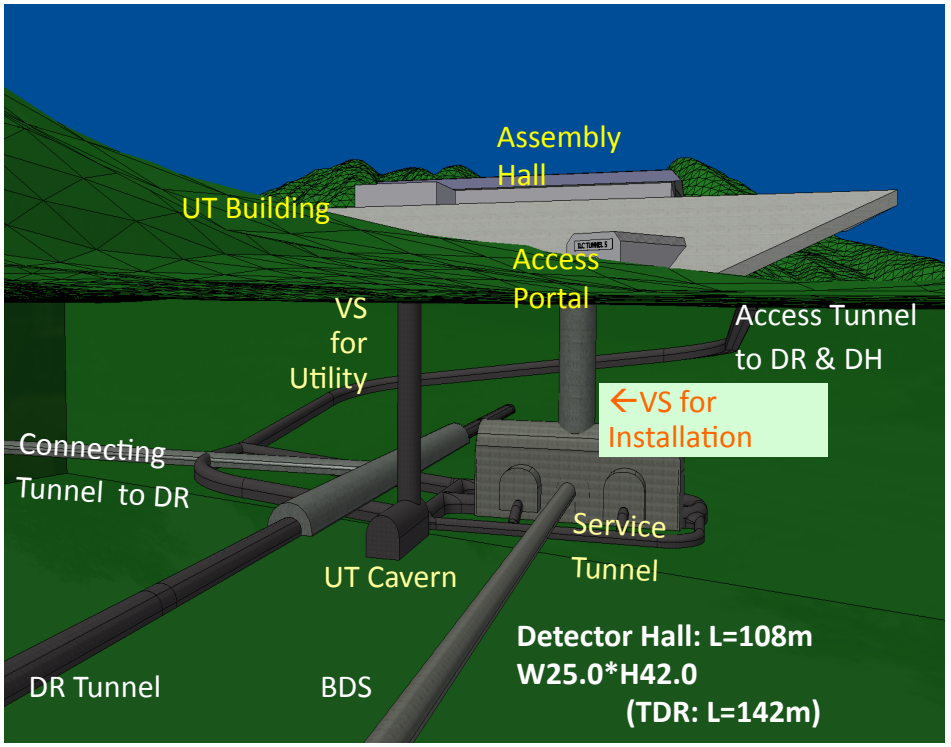
XFEL is 5%-scale ‘ILC prototype’, needs 24 MV/m ;
ILC needs 31.5 MV/m

European XFEL **Test results: MAX GRADIENT**



Nick Walker

Site-specific adaptations: vertical shaft



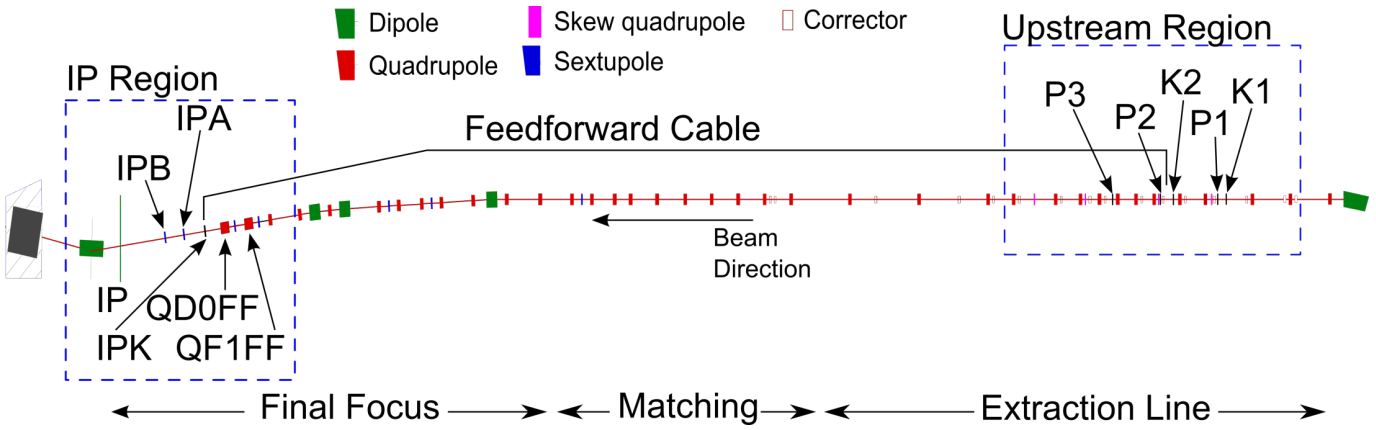
ILC current challenges:

- positron source
- final focus, nm-size beams

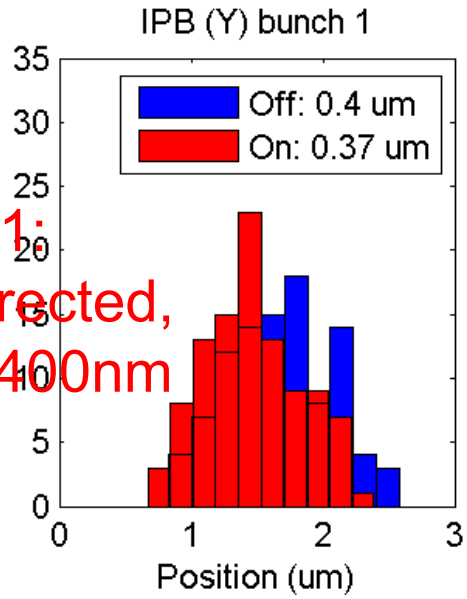
Accelerator developments

Example highlight:

FONT – Feedback on Nanosecond Timescale
– for both ILC and CLIC



Phil Burrows



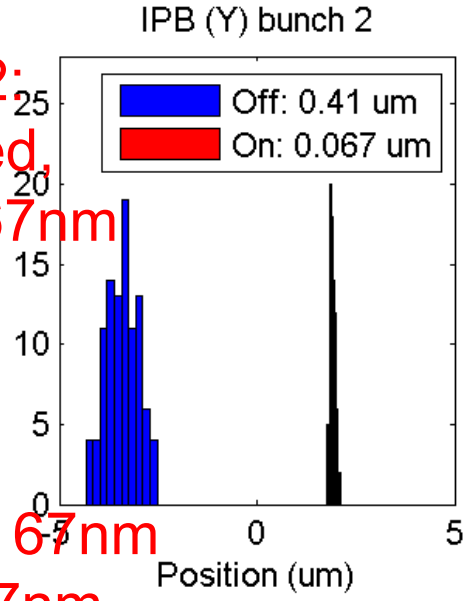
Bunch 1:
not corrected,
jitter ~ 400nm

At ATF2 (KEK)

Aim to stabilise beam in IP region using 2-bunch spill:

1. Upstream FB: monitor beam at IP
2. Feed-forward from upstream BPMs → IP kicker (IPK)
3. Local IP FB using IPBPM signal and IP kicker

Aim is 37nm beam



Bunch 2:
corrected,
jitter ~ 67nm

Corrected jitter 67nm
→ resolution 47nm

Accelerator developments

 developing:

- normal-conducting accelerating cavities (Cockcroft)
- cavity diagnostics (Manchester, Liverpool)
- crab cavities and klystrons (Lancaster)
- feed-forward systems and diagnostics (John Adams)
  – machine–detector interface and beam delivery system
- diagnostics, permanent magnets and RF (ASTeC)

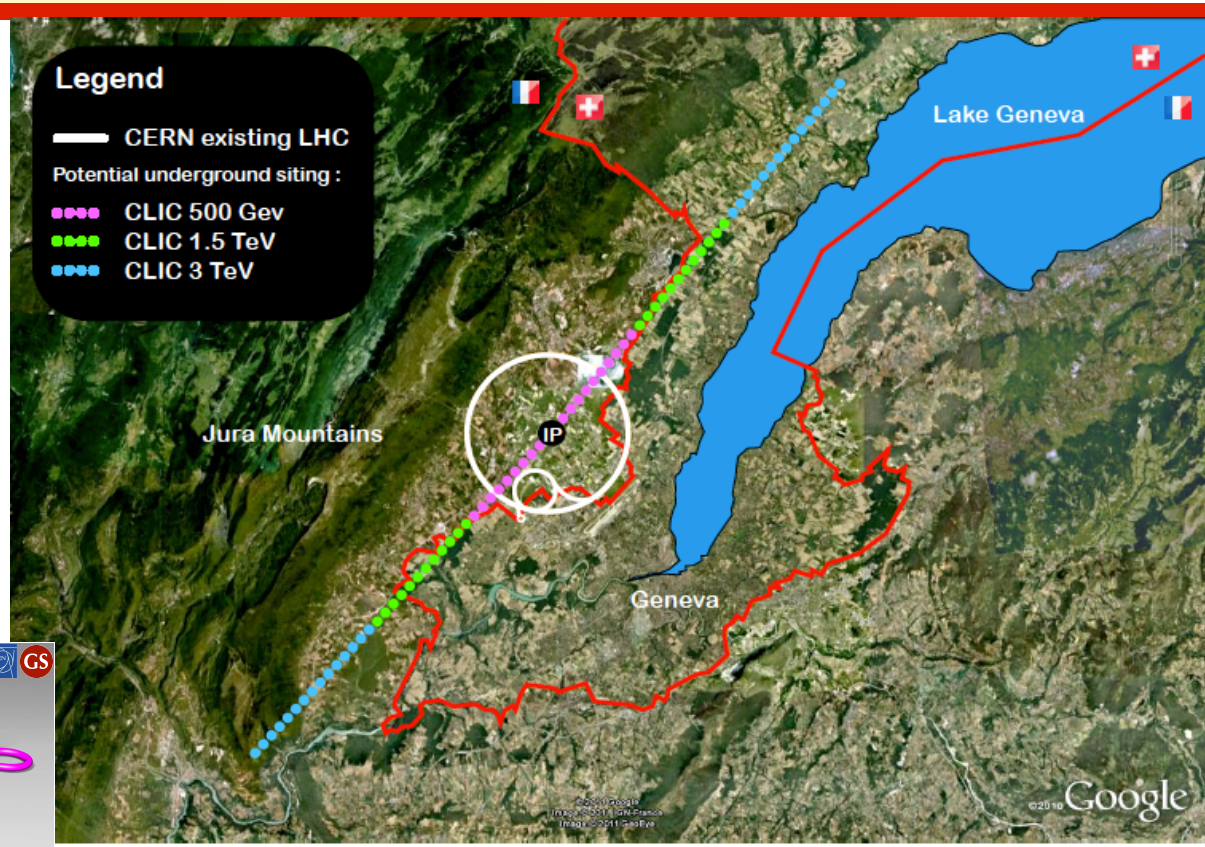
most work is generic, for both ILC and CLIC

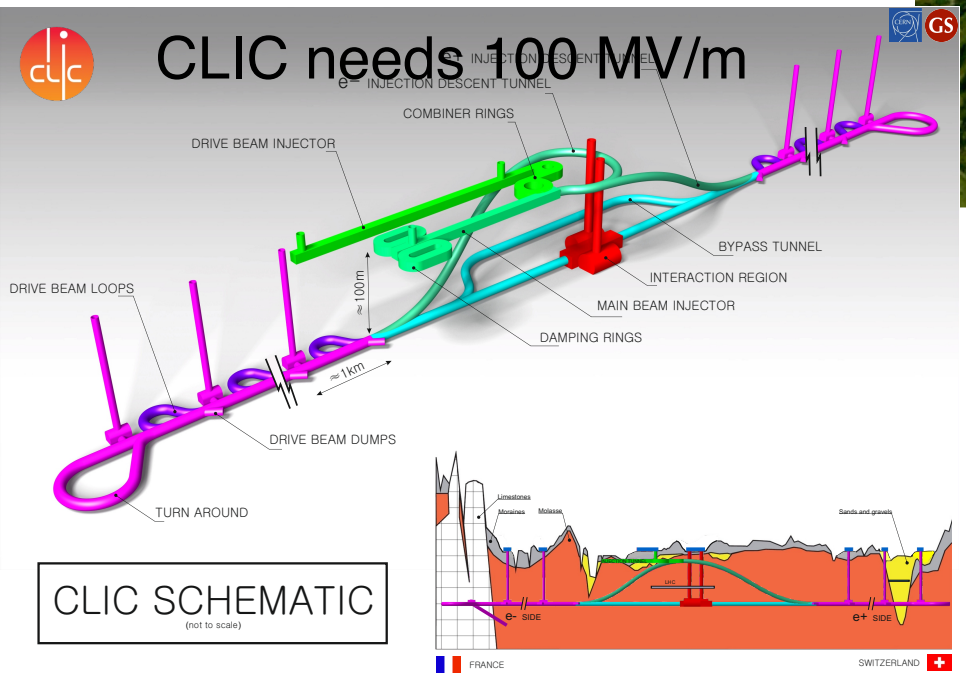
CLIC accelerator developments

Phil Burrows (Oxford) Spokesman

(~50 institutes, including ASTeC, Dundee, Lancaster, Manchester, Oxford, RHUL;
CLIC-UK supported by >£5M from CERN since 2011)

CDR 2012. TDR 2022?
Construction 2023–2030?

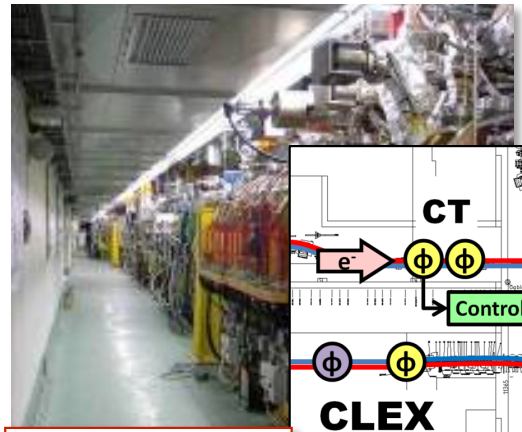




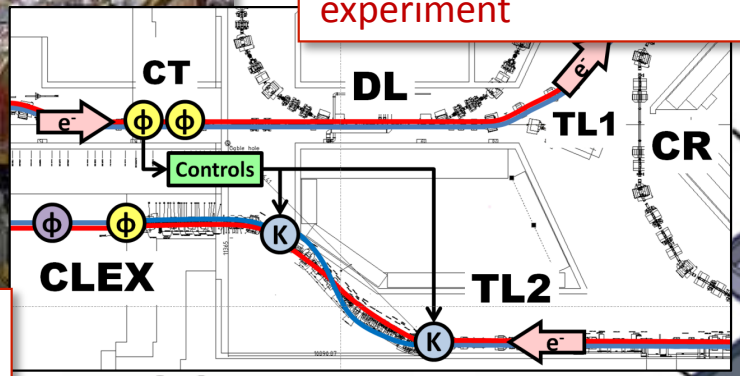
- developing project plan 2018 -> TDR 2022?
- high-gradient accelerating structure test results good
- experimental verification at CLIC Test Facility (CTF3) very successful
- looking at power reductions, optimizations

CLIC accelerator developments

CTF3 2015-16



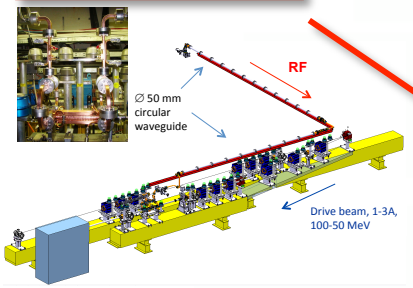
Dogleg Beam loading experiment



Phase feed-forward experiment

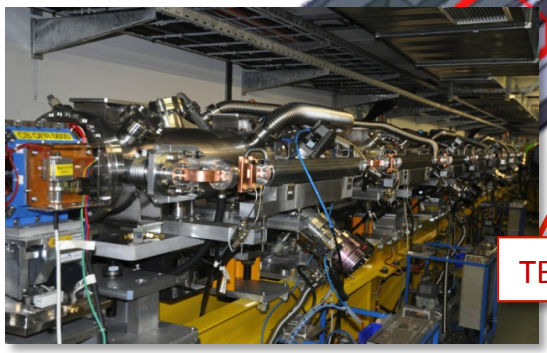
Diagnostics R&D using CALIFES

Linac

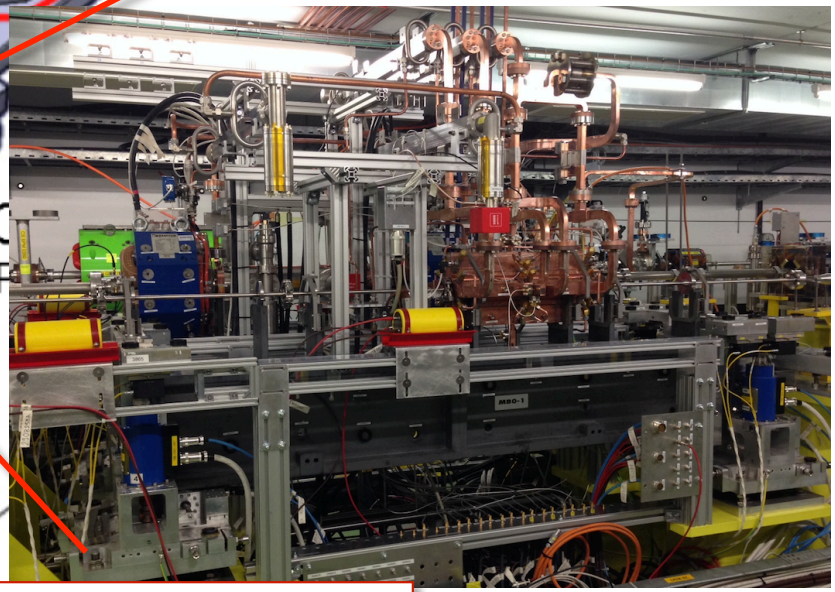


TBTS

TBL



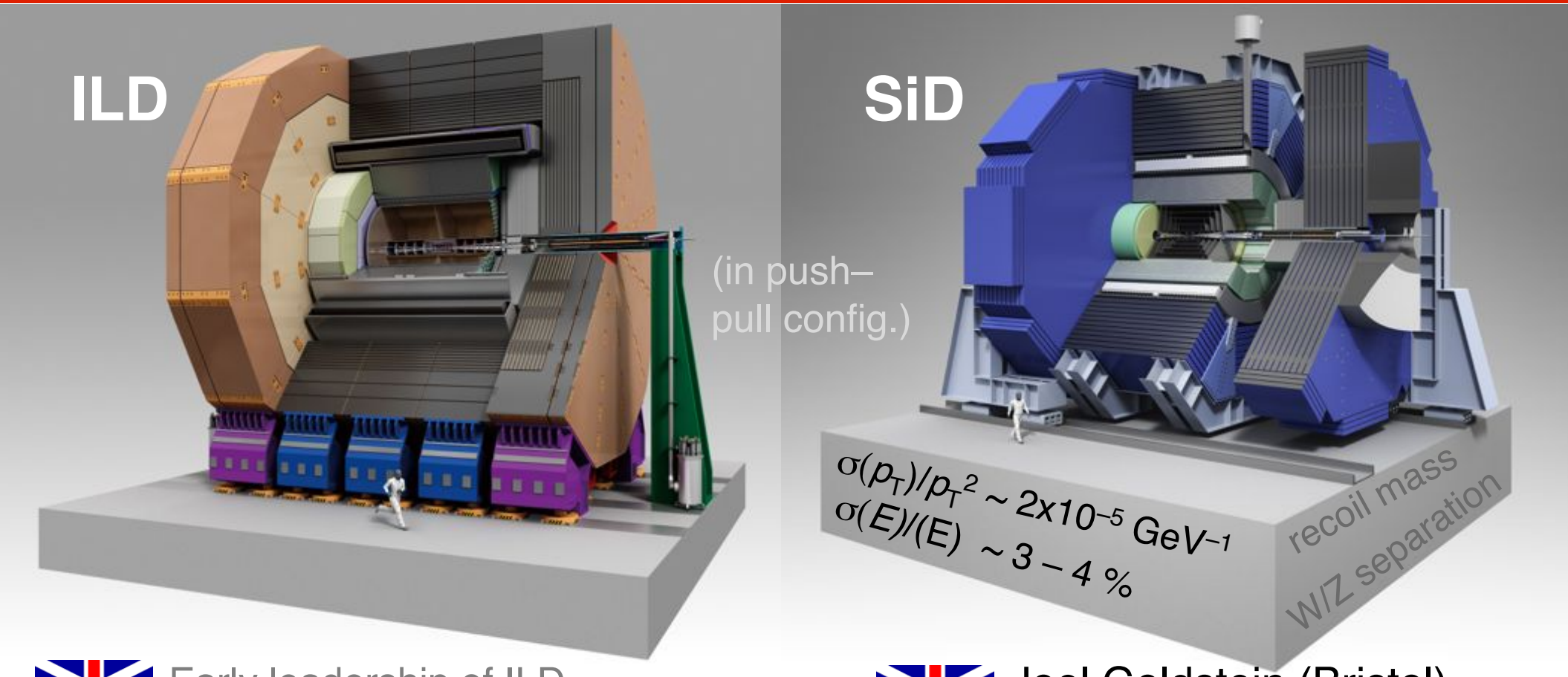
TBL deceleration



Two Beam Module, Wake-field monitors…

Steinar Stapnes

ILC detector collaborations



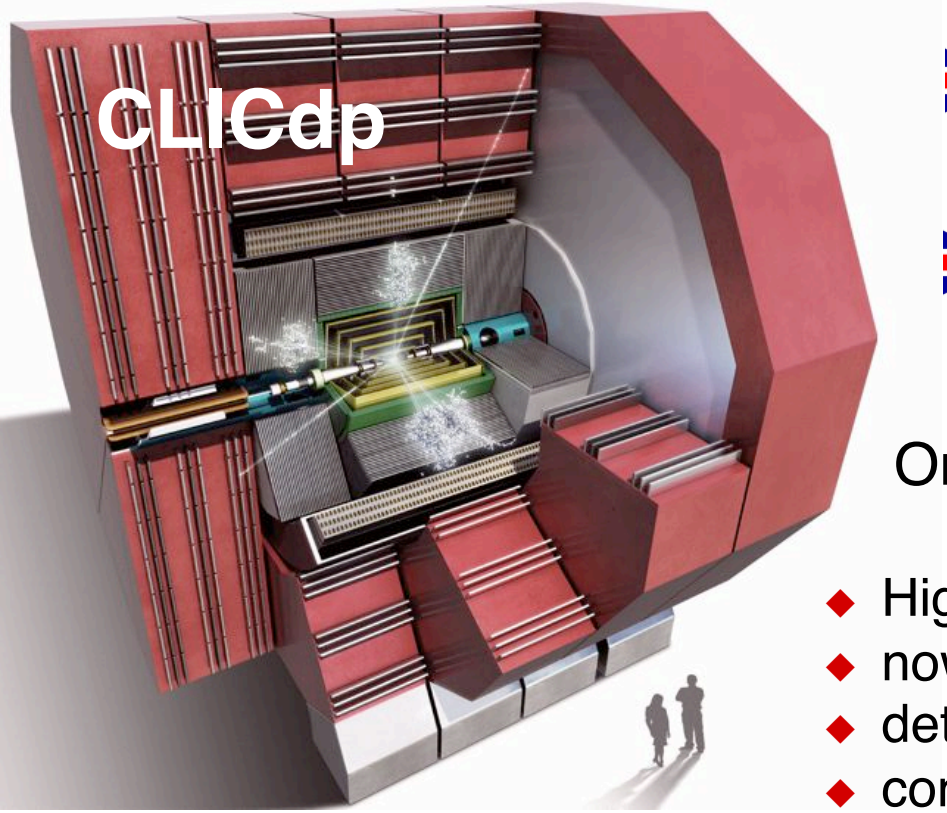
Early leadership of ILD physics/optimization

Joel Goldstein (Bristol)
Vertex group convenor

Phil Burrows (Oxford)
Collaboration Board chair

- Adopting more formal structures
- LoIs 2009/10; now moving towards TDRs
- Converging on common L*, working on fringe fields…

CLIC detector collaboration



26 institutes from
16 countries

John Marshall (Cambridge)
Physics group convenor

Aidan Robson (Glasgow)
Collaboration Board chair

Ongoing priorities:

- Higgs benchmarking studies (paper in progress)
- now focus on top and BSM capabilities
- detector optimisation -> new CLIC detector concept
- continuing vertex technology R&D
- continuation of fine-grained calorimeter R&D
- start of main silicon tracker R&D
- development of new software tools

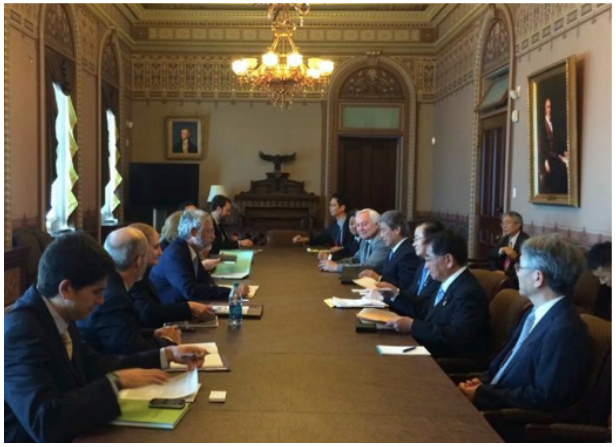
Cambridge, Glasgow, Liverpool, Bristol, Edinburgh active in physics studies, software and simulation development, and silicon hardware development – all overlapping with ILC

Global status 1: ILC

The ILC story so far…
Japanese HEP community proposed to host ILC
Kitakami site was chosen
Science Council of Japan (~Royal Society) made report with reservations
MEXT (Japanese ministry) set up committee to investigate:
– significance of physics, readiness of technology
– regional economic effects
– costs profile and international cost-sharing prospects

- Internal Japanese process ongoing. Interim MEXT report Aug 2015:
  asks for more clarity on BSM prospects
  includes statement allowing initiation of serious talks with other countries
  recommends more engagement by public & other science communities
- Final reports to MEXT in spring 2016
- Nomura commissioned to produce further reports
  visited UK in autumn 2015
- Expect decision some time in 2017?

There is high-level Japanese government support
e.g. Federation of Diet members for the ILC
and Prime Minister Abe

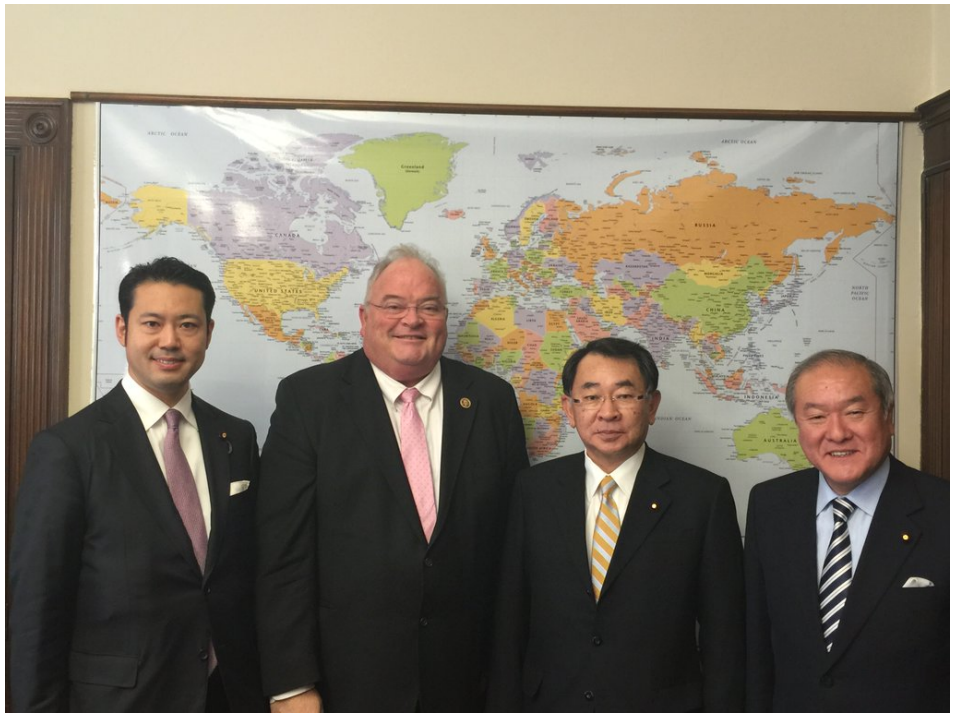


Lyn Evans & Japanese delegation at the White House

Global status 2: ILC

Thursday 11th February:

Highest-yet US–Japan political meetings
- MEXT Assistant Vice-Minister and secretariat, MEXT Director of HE&NP
- Diet Members, AAA Japan, Embassy
- DoE, Members of Congress, physicists…

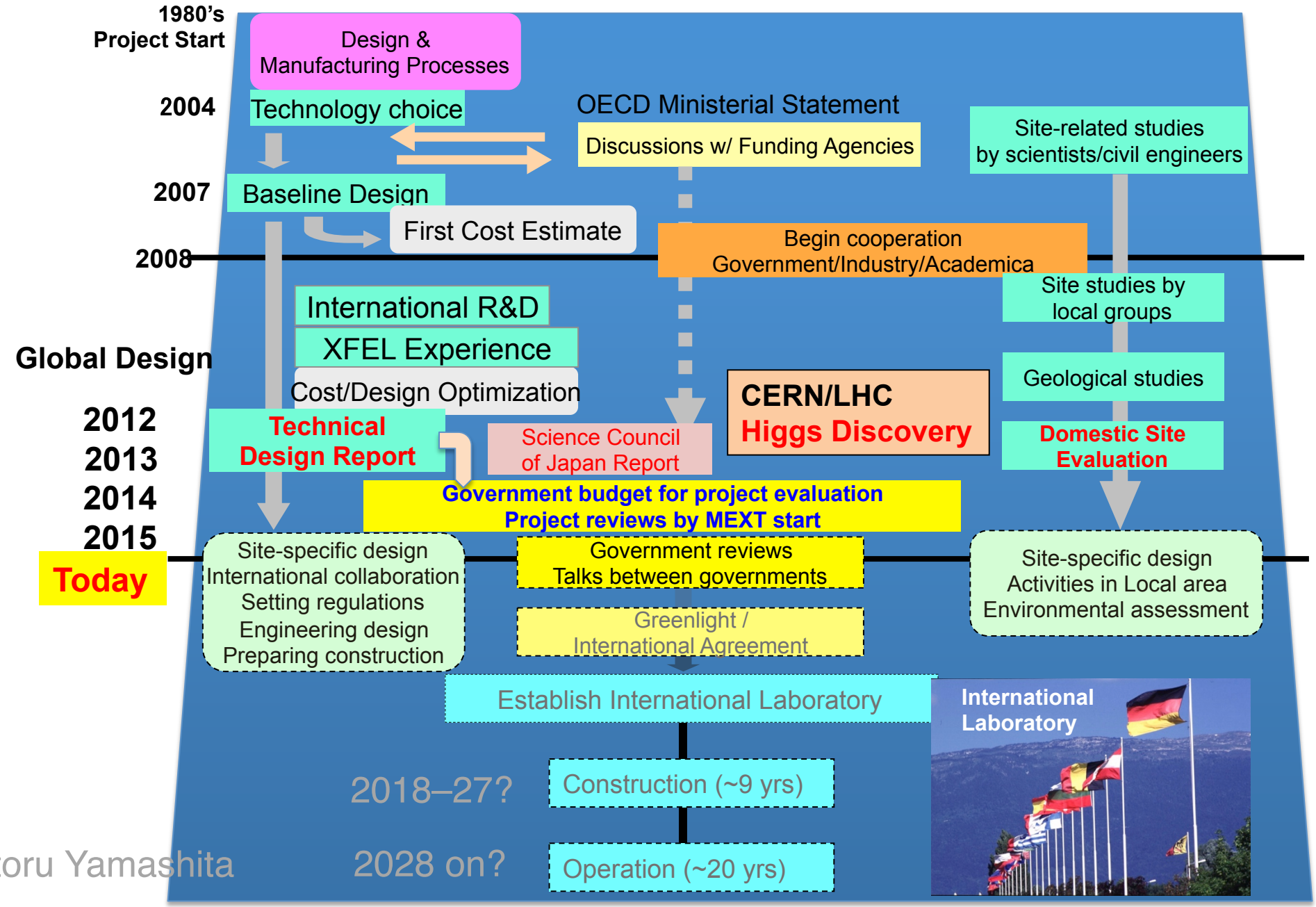


US representative and 3 Diet Members

Lyn Evans

'last time I was in this building I was persuading the US to join the LHC'

ILC Timelines



Satoru Yamashita

Global status 3: CLIC

- CLIC development continues, preparing Project Plan for 2018
  ready for next European Strategy update

  CLIC TDR 2022?
  Construction 2023–2030?

- CERN medium-term plan (5 years) foresees
  choice between FCC and CLIC at next European Strategy
  and FCC & CLIC fusing into common ‘energy frontier’ budget from 2020

Outlook

- Internationally, ILC, CLIC proceeding in parallel
- ILC is mature and ready for construction!
- UK working in range of linear collider areas:
  accelerators
  detectors
  software
  physics studies,
  – particularly where ILC and CLIC overlap – with good visibility

- Next few years critical for decision-making

Thanks to all who contributed: Phil Burrows, Mark Thomson, Joost Vossebeld, Veronique Boisvert, Matt Wing, Nigel Watson, Fergus Wilson