Linear Collider Projects: Status and Prospects

FACULTY OF PHYSICS
WARSAW UNIVERSITY

A.F.Żarnecki

High Energy Physics Seminar

December 15th, 2017

Linear Collider Workshops (LCWS)

- LCWS 2016: Morioka, Japan
- LCWS 2015: Whistler, Canada
- LCWS 2014: Belgrade, Serbia
- LCWS 2013: Tokyo, Japan
- LCWS 2012: Arlington, USA
- LCWS 2011: Granada, Spain
- LCWS 2010: IHEP, China
- LCWS 2008: UIC, Chicago, USA
- LCWS 2007: DESY, Hamburg, Germany
- LCWS 2006: Bangalore, India
- LCWS 2005: Stanford, USA
- LCWS 2004: Paris, France
- LCWS 2002: Jeju Island, Korea
- LCWS 2000: Fermilab, USA
- LCWS99: Sitges, Spain
- 1995: Morioka, Japan
- 1993: Hawaii, USA
- 1991: Saariselka, Finland

INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

LCWS STRASBOURG 2017

CENTRE EUROPÉEN D'ÉTUDES JAPONAISES D'ALSACE
CEEJA

23-27 October
Convention Center (Palais des Congrès) **Strasbourg**, France

workshop will be devoted to the study of the
case for a high energy linear electron-positron
taking into account the recent results from
review the progress in the detector and
signs for both ILC and CLIC projects.

International Advisory Committee

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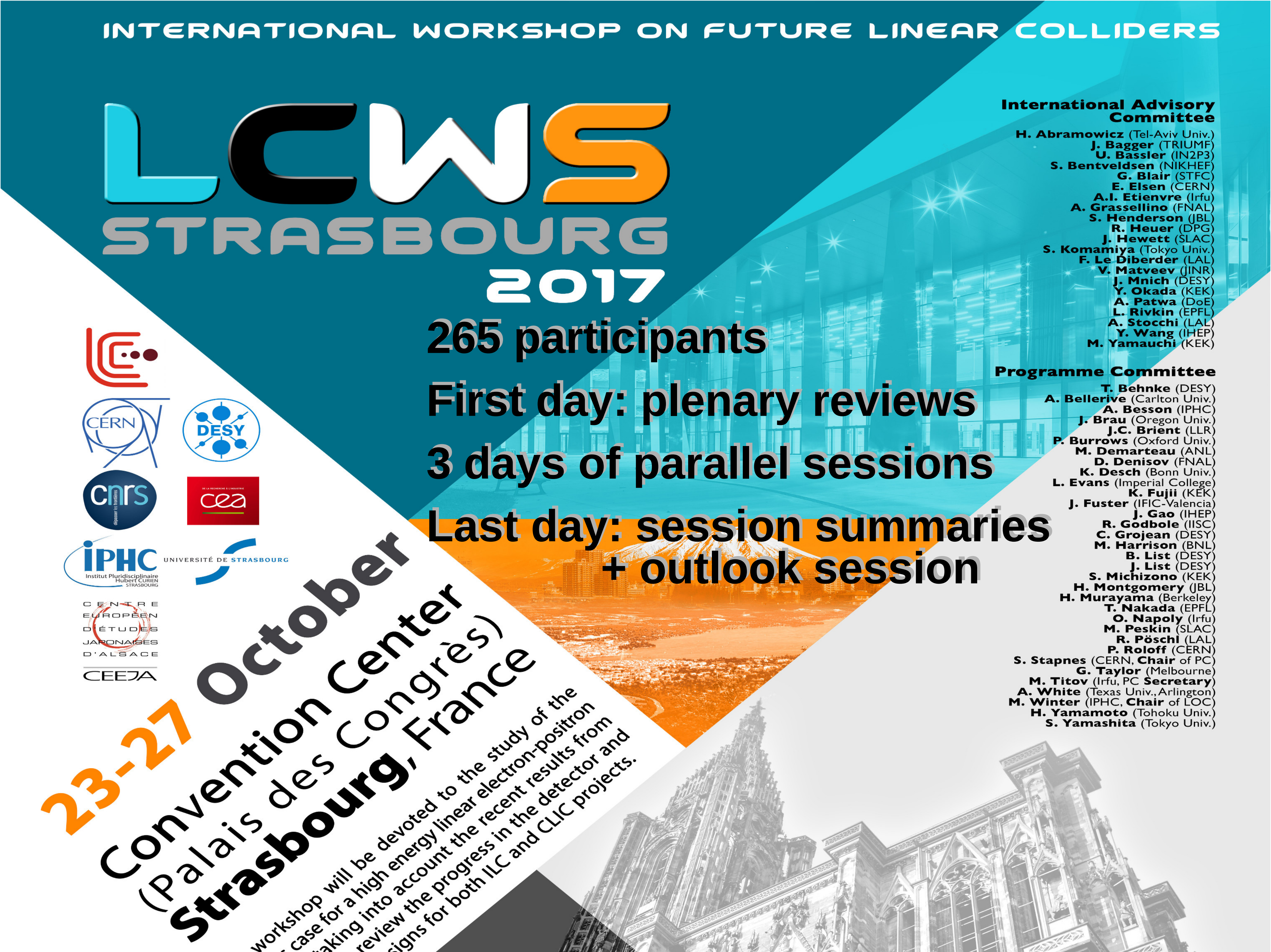


265 participants

First day: plenary reviews

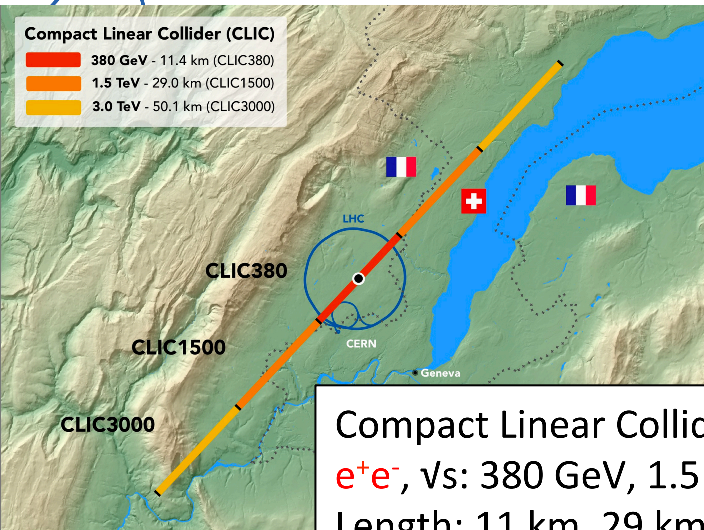
3 days of parallel sessions

Last day: session summaries
+ outlook session

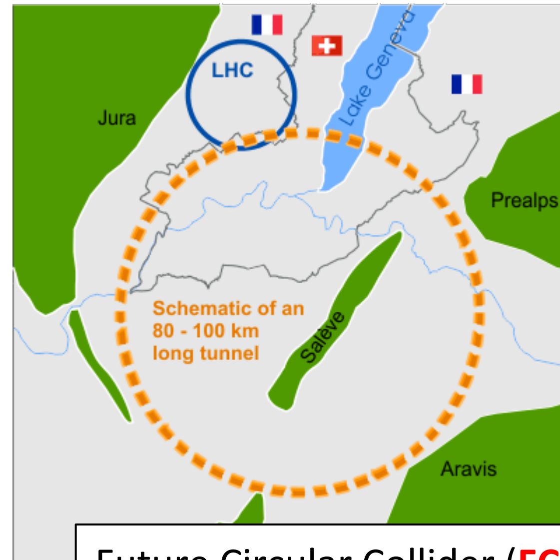
Status


INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS
LCWS
STRASBOURG
23-27 October 2017
Bruno Mazoyer LAL Orsay 2017

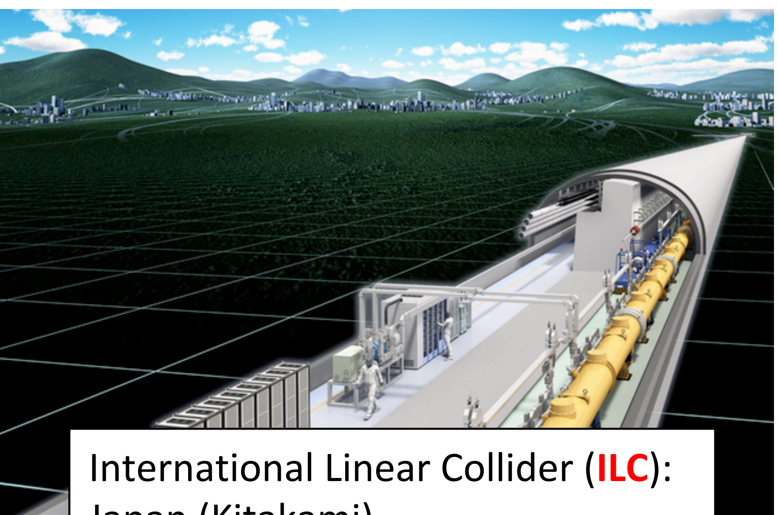
studies of high-energy e$^+$e$^-$ colliders



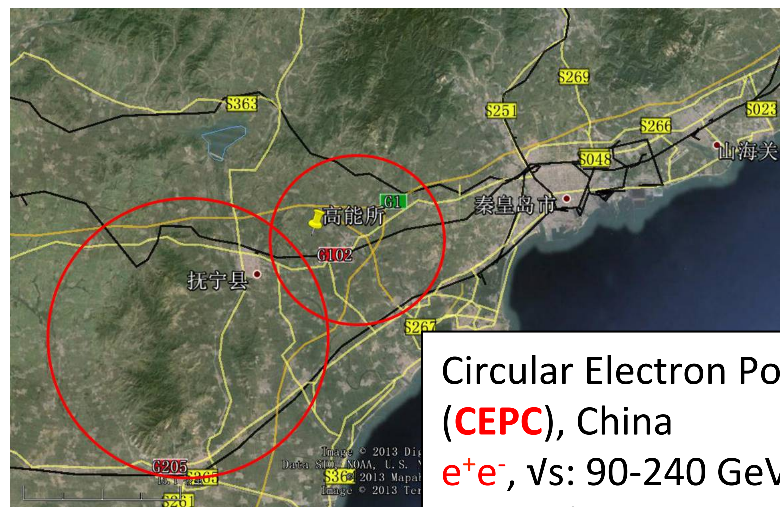
Compact Linear Collider (**CLIC**): CERN
e$^+$e$^-$, √s: 380 GeV, 1.5 TeV, 3 TeV
Length: 11 km, 29 km , 50 km



Future Circular Collider (**FCC-ee**): CERN
e$^+$e$^-$, √s: 90 - 350 GeV; FCC-hh pp
Circumference: 97.75 km



International Linear Collider (**ILC**): Japan (Kitakami)
e$^+$e$^-$, √s: 250 – 500 GeV (1 TeV)
Length: 17 km, 31 km (50 km)

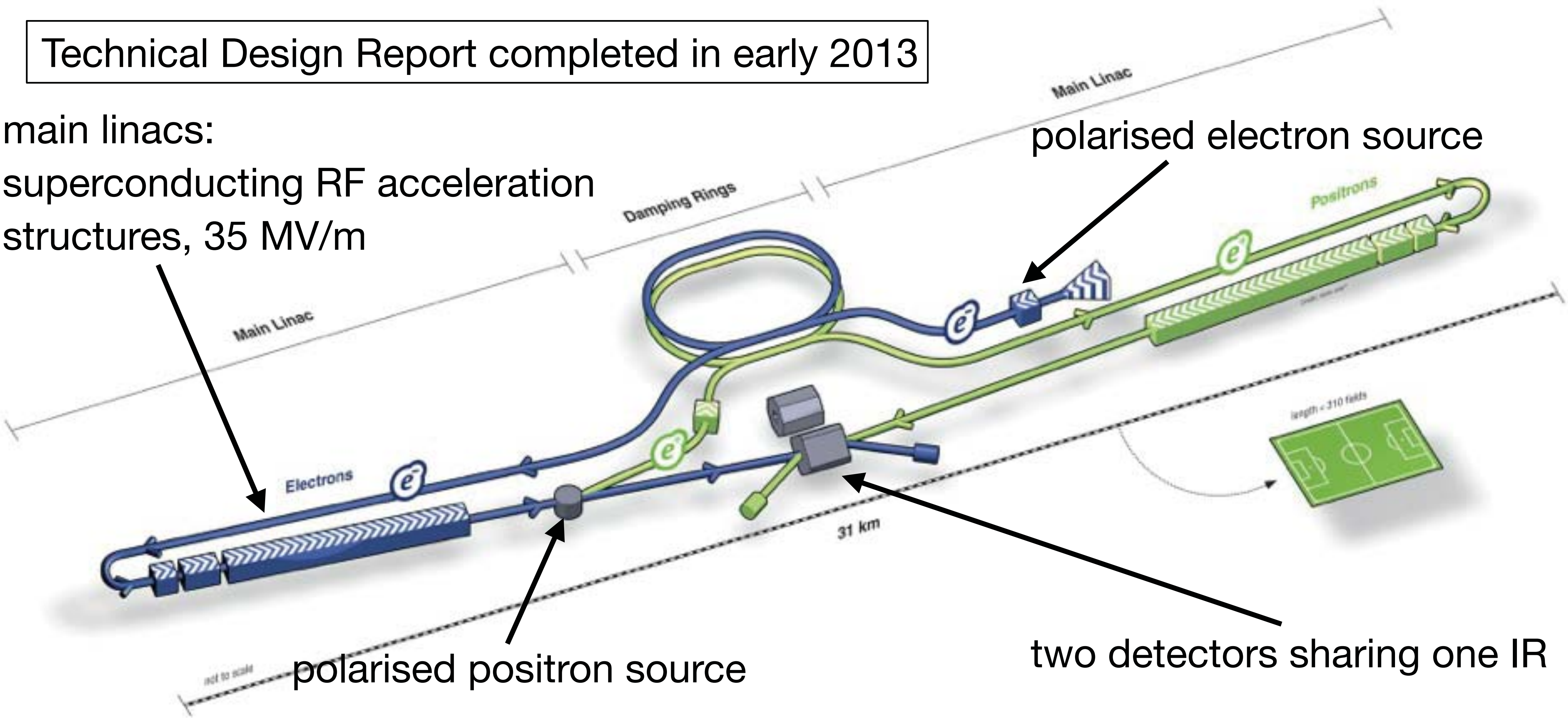


Circular Electron Positron Collider (**CEPC**), China
e$^+$e$^-$, √s: 90-240 GeV; SPPC pp,
Circumference: 100 km

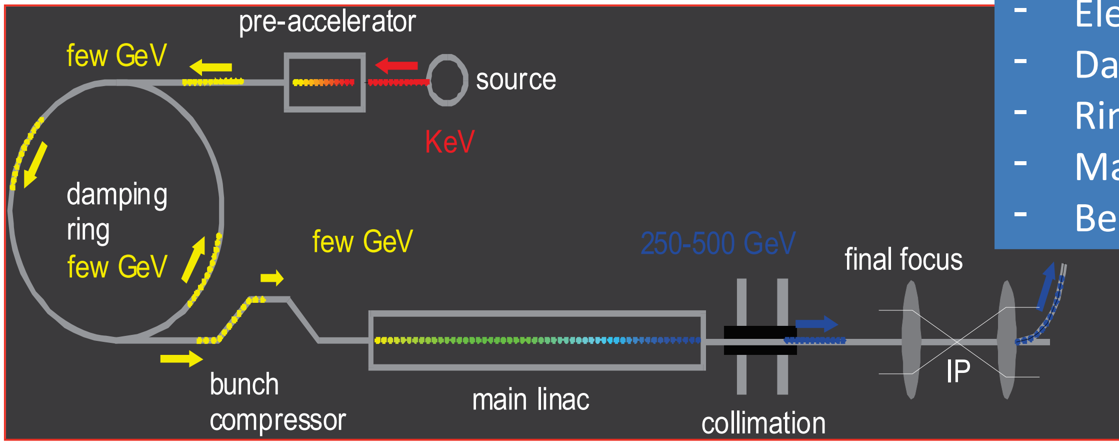
ILC - The International Linear Collider

- Currently the most advanced concept for a future energy frontier collider
  - e^+e^- collider, baseline energy 500 GeV, high luminosity: 2 x 10^{34} $cm^{-2}s^{-1}$
    - staged construction, starting from 250 GeV / 350 GeV
    - upgrade to 1 TeV possible (extension of linacs), luminosity upgrade by rate increase

Technical Design Report completed in early 2013



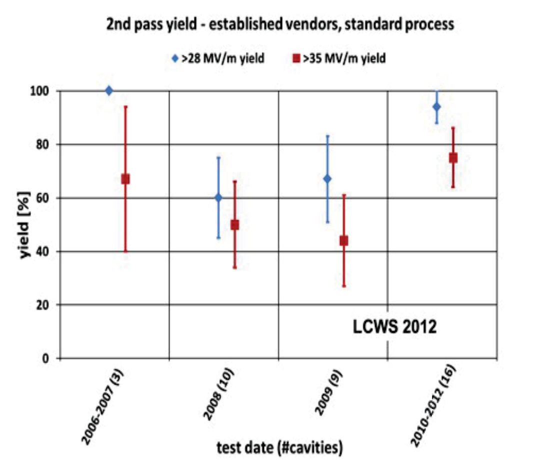
The ILC Accelerator Concept



- Electron and Positron Sources (e-, e+)
- Damping Ring (DR)
- Ring to ML beam transport (RTML)
- Main Linac (ML) : SCRF Technology
- Beam Delivery System (BDS)

1.3 GHz Nb 9-cellCavities	16,024
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436

Production yield: 94 % at > 35+/-20%
Average gradient: 37.1 MV/m
> R&D goal of 35 MV/m reached (2012)



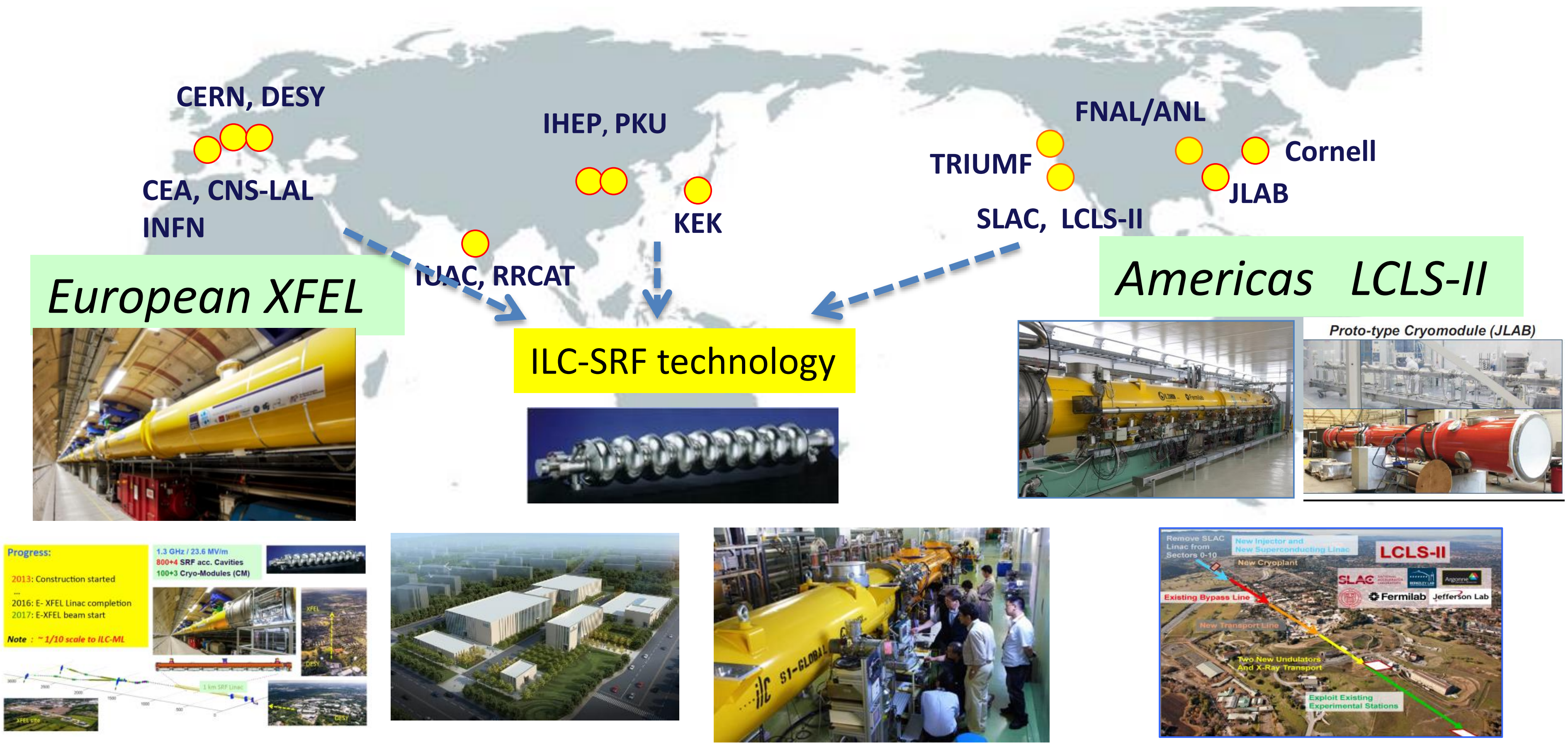
Cavity Production (EZ, RI)

Entirely produced by industry and delivered "ready to go"

Lesson learned #1: Yes you can do this and it worked really well

Lesson learned #2: Be prepared to invest a lot of effort into making it work

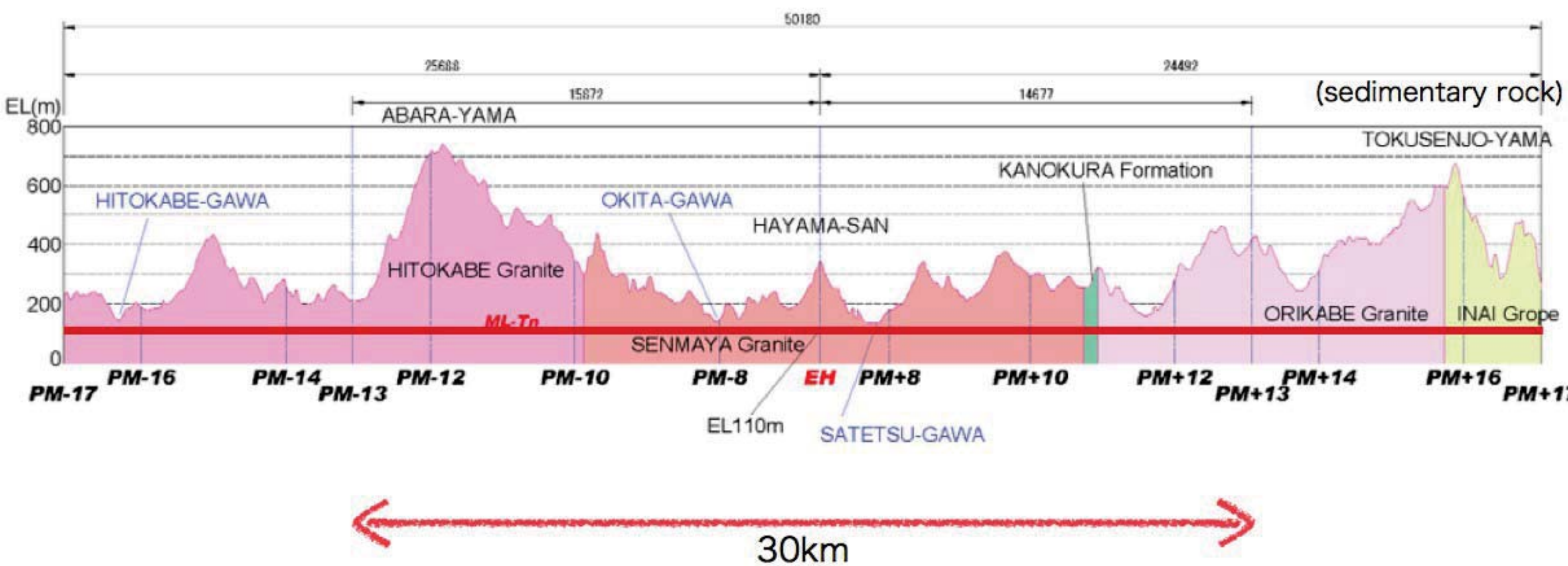
World wide Labs for SRF system



PAPS@IHEP *CFF/STF@KEK*

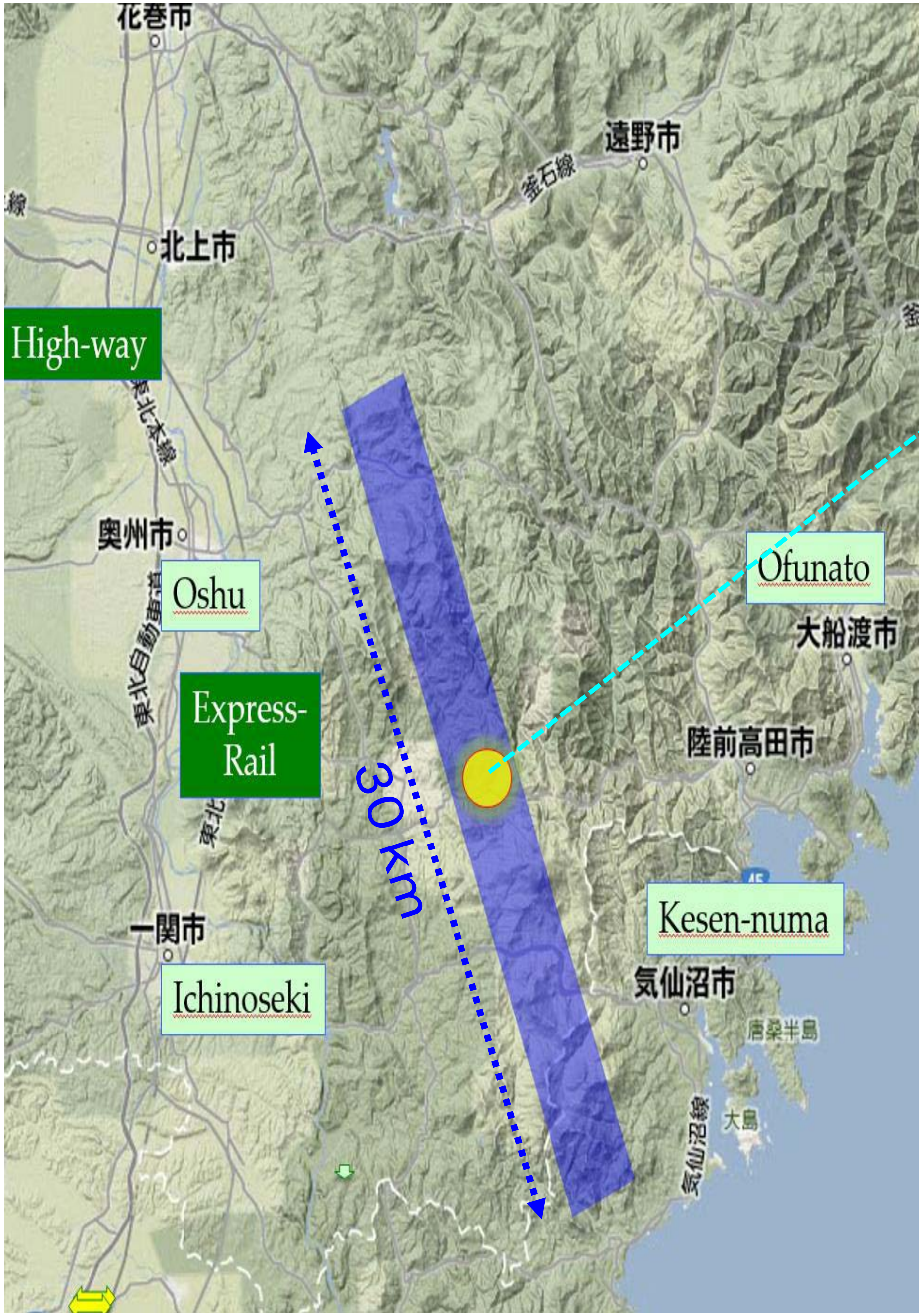
Asia

ILC preferred site - Kitakami



al

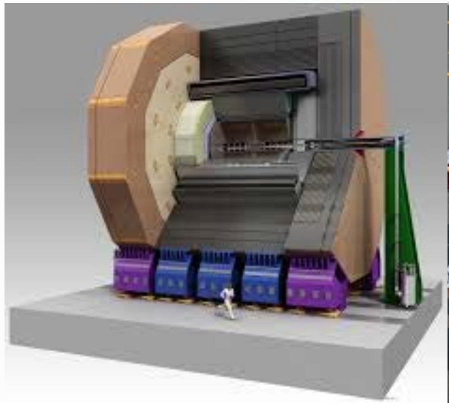

Tokyo
青森県
秋田県
岩手県
山形県
宮城県
新潟県
福島県


花巻市
遠野市
釜石線
北上市
High-way
東北本線
奥州市
Oshu
東北自動車道
Express-Rail
30 km
Ofunato
大船渡市
陸前高田市
Kesen-numa
気仙沼市
一関市
Ichinoseki
唐桑半島
大島


Phase 2
Phase 1 (30,549 m)
Phase 2
PM-13
PM-12
PM-10
PM-8
IR
PM+8
PM+10
PM+12
PM+13
800 m
600 m
400 m
200 m
0
Kitakami-site cross section
(a)
Granite
Sedimentary Rock

The ILD Experiment group

T. Behnke (LCWS-2017)



http://www.ilcild.org
http://confluence.desy.de/ILD

71 groups have signed up,
1 group pending approval
Currently around 420 members
on the central mailing list.

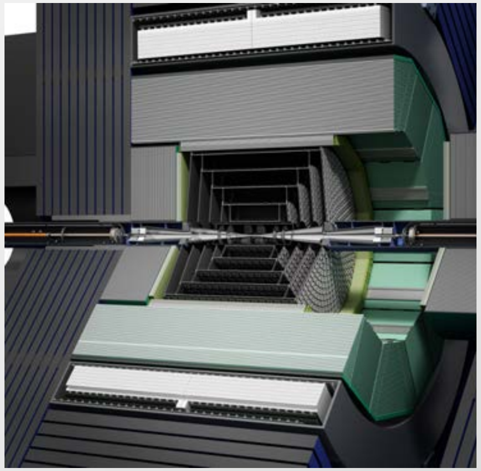
Organisation of the group in place and working.

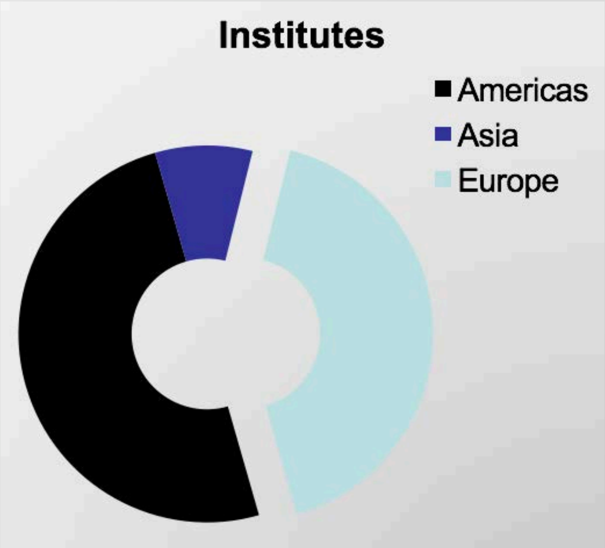
New: established central publication and speakers bureau, to organise talks and papers within ILD
(Chair K. Kawagoe)

Since 4-2017: 14 ILD talks at intl. conferences, 3 posters

Status of the consortium

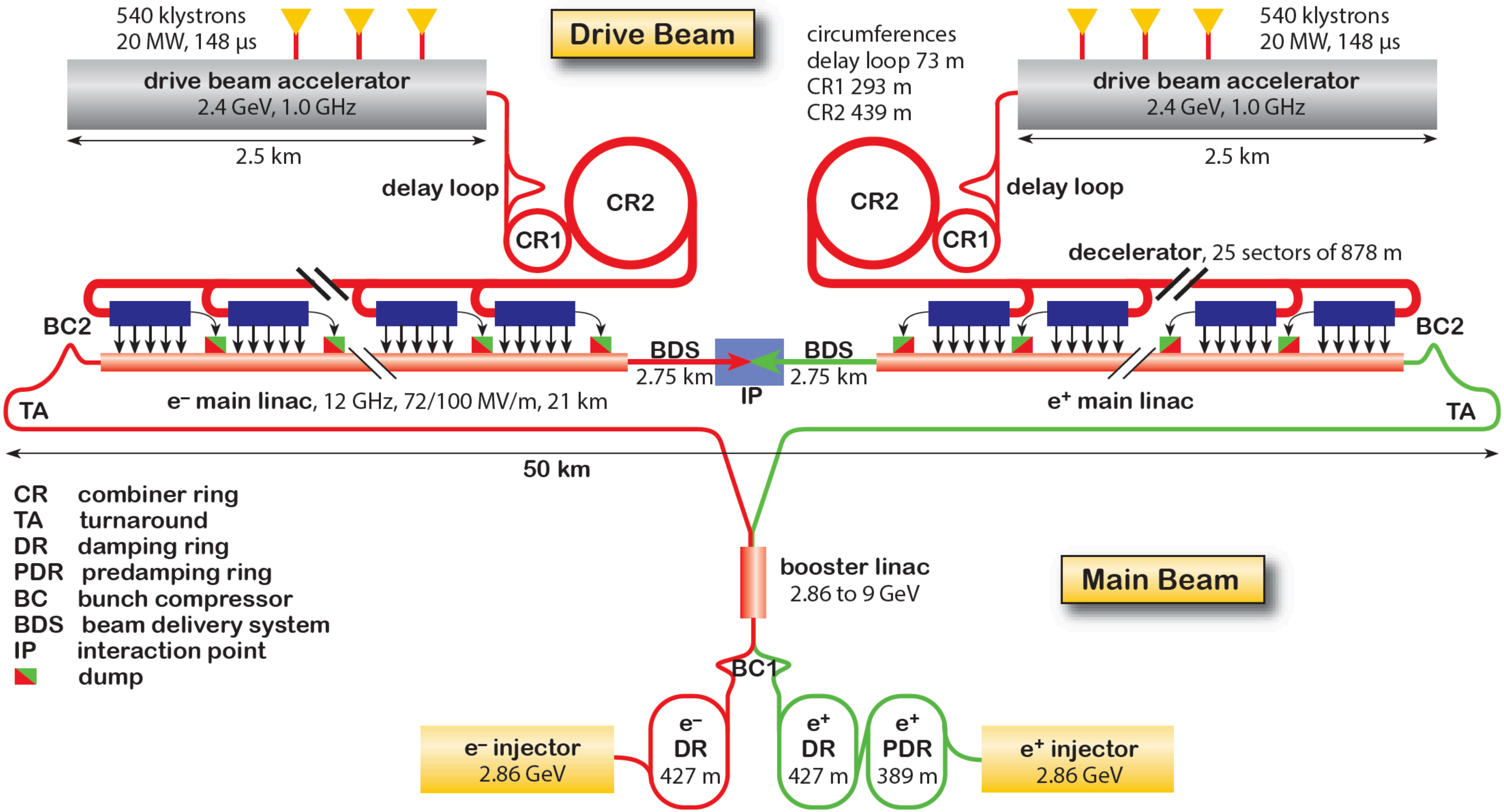
- Letter of Intent (2009) had ~ 275 Signatories from 72 institutions
- Consortium currently has 22 member institutions
  - 50 % from the US
  - 42 % from Europe
  - 8% from Asia
- SiD is committed to grow globally, especially in Asia
- Structures are in place to realize SiD once there is a green light from Japan





M. Stanitzki & A. White (LCWS-2017)

CLIC layout at 3 TeV

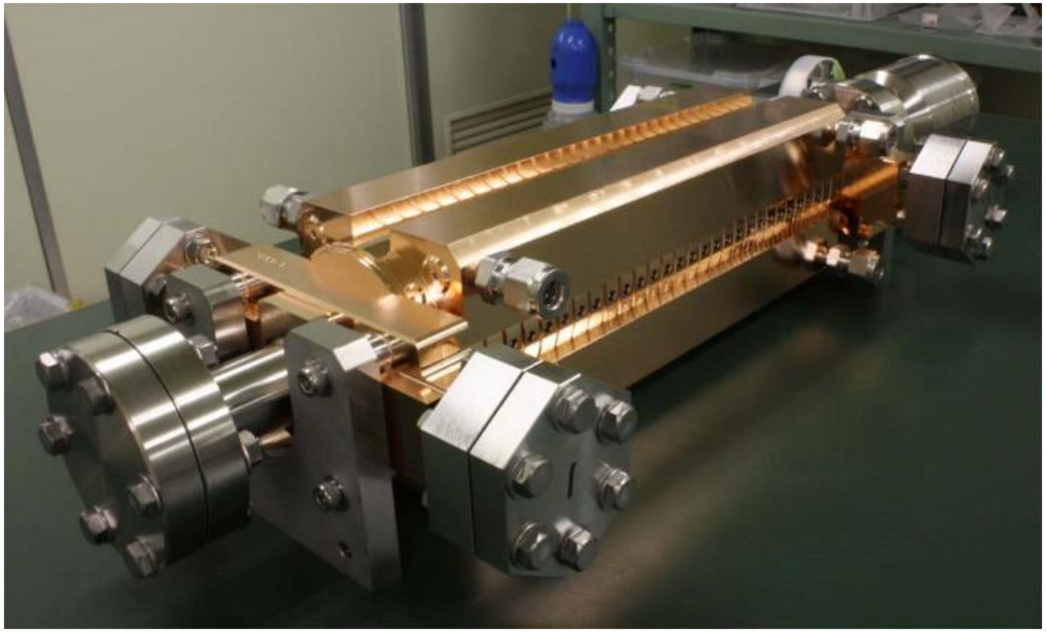


CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

CLIC accelerating structure

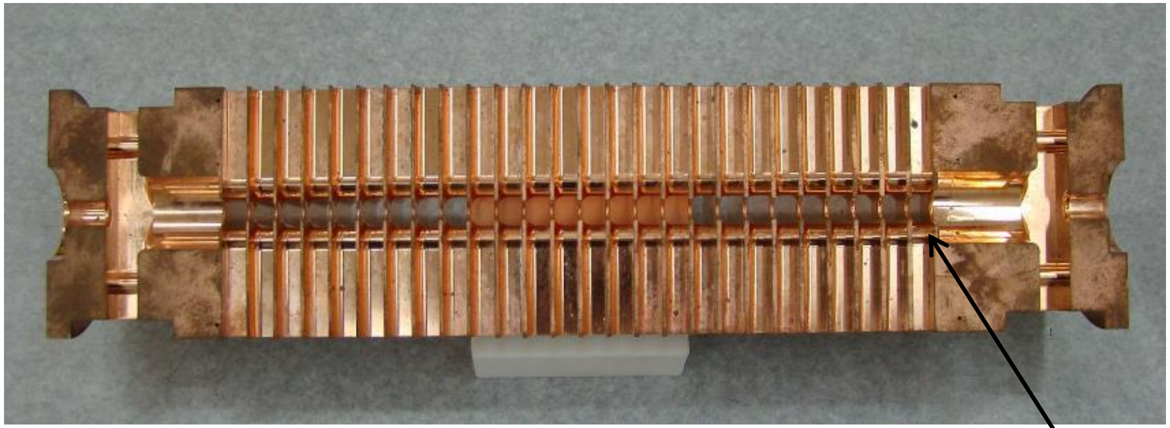
Outside

11.994 GHz X-band
100 MV/m
Input power ≈50 MW
Pulse length ≈200 ns
Repetition rate 50 Hz



HOM damping waveguide

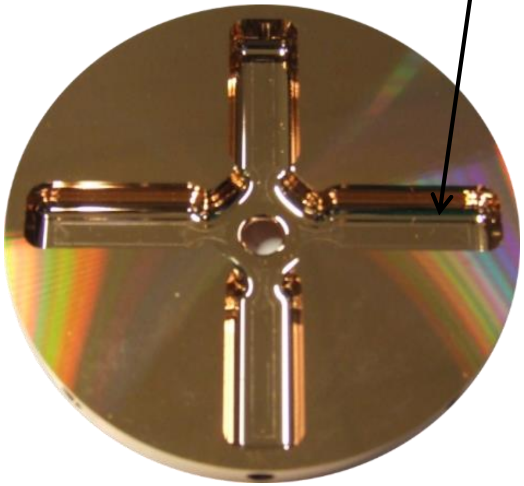
Inside



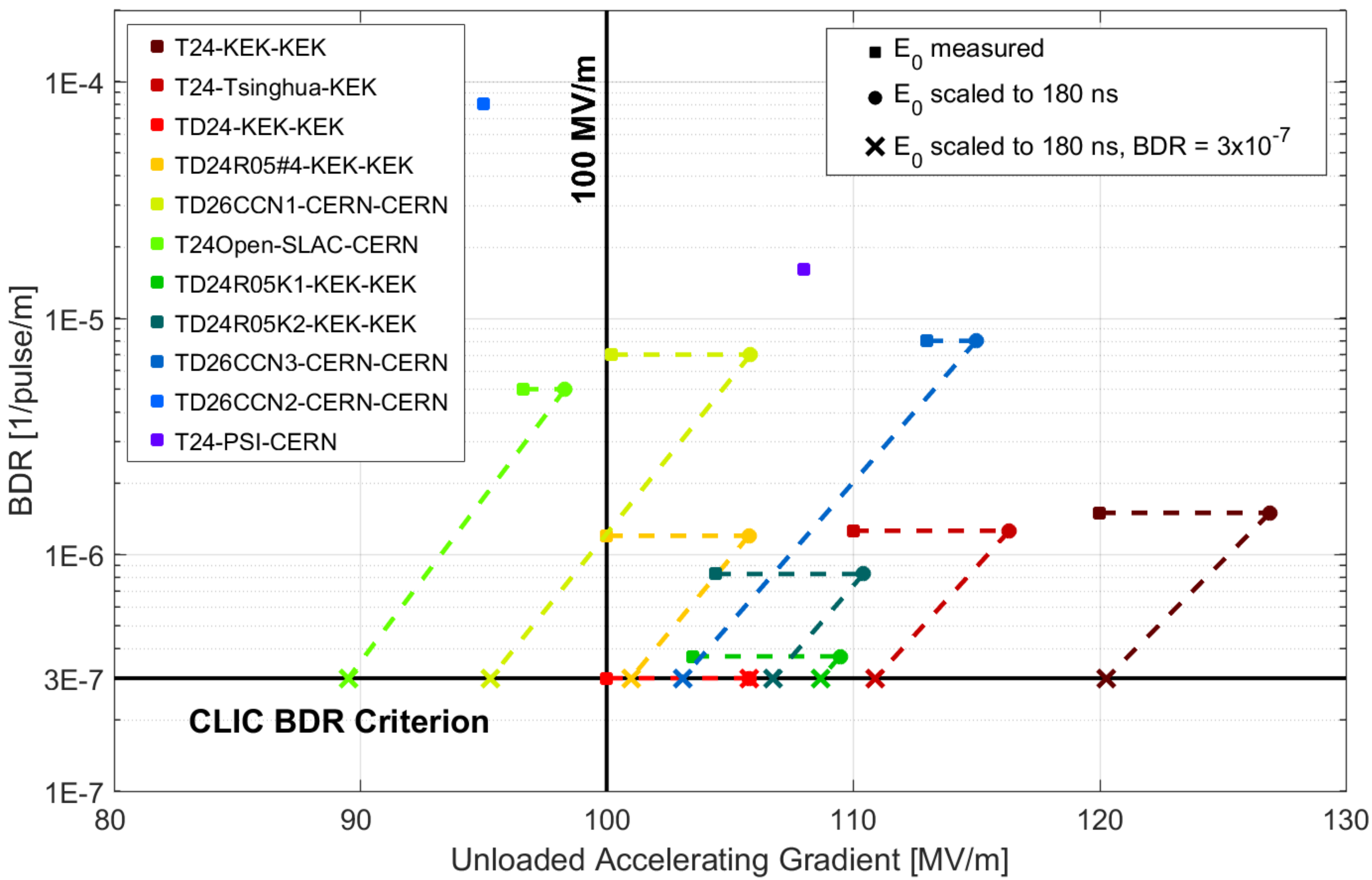
25 cm

6 mm diameter beam aperture

Micron–precision disk



Accelerating gradient summary: latest structure series



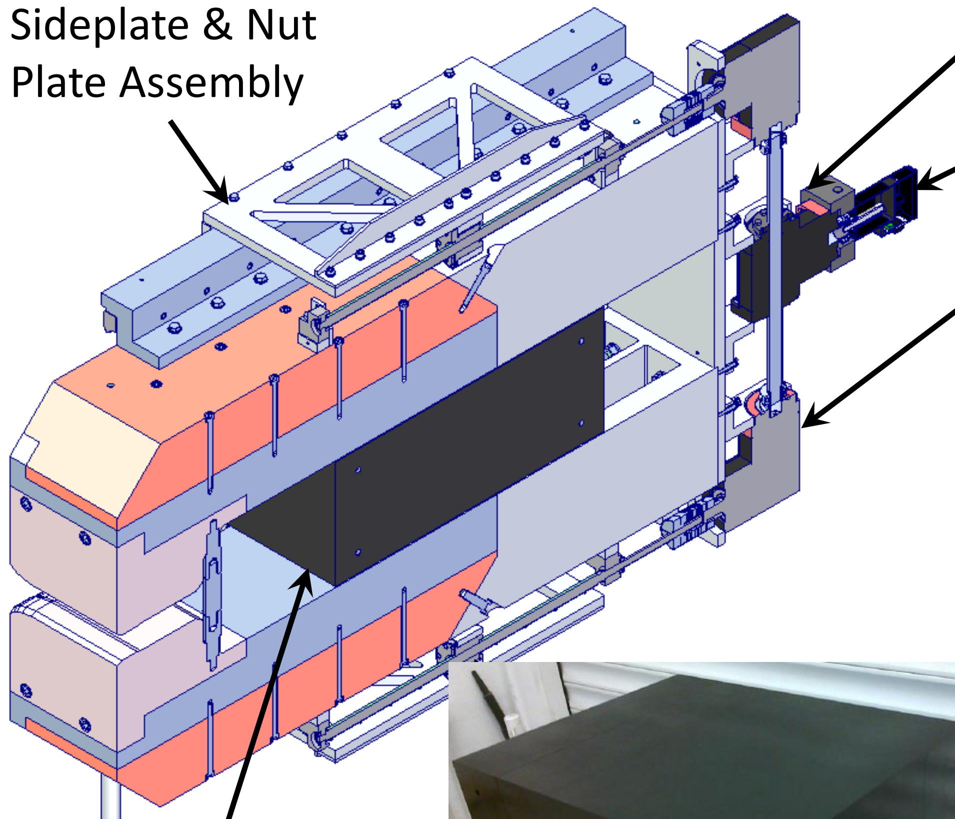
Jan Paszkiewicz, Walter Wuensch

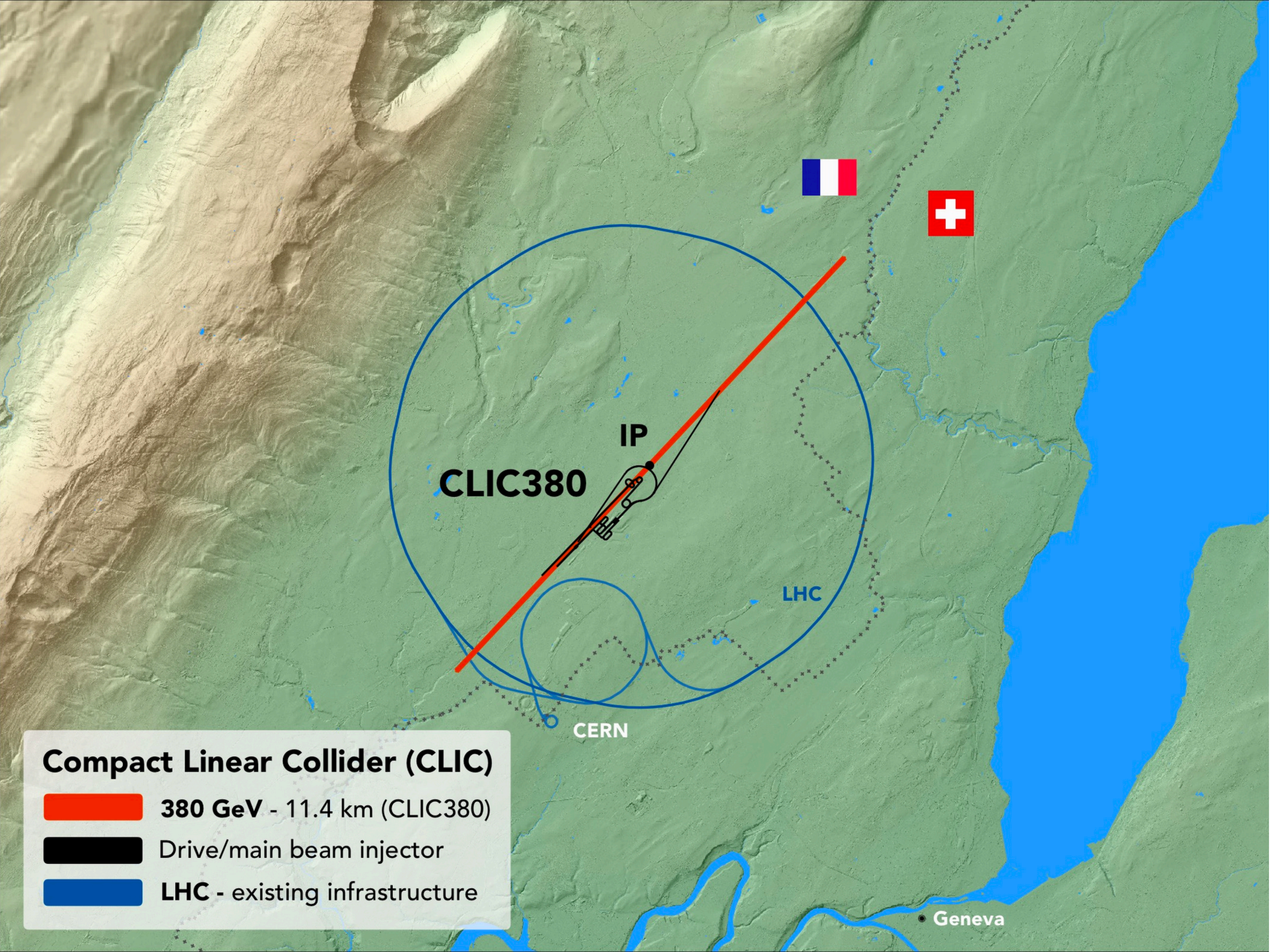
Adjustable-field PM prototypes

High Energy Quad

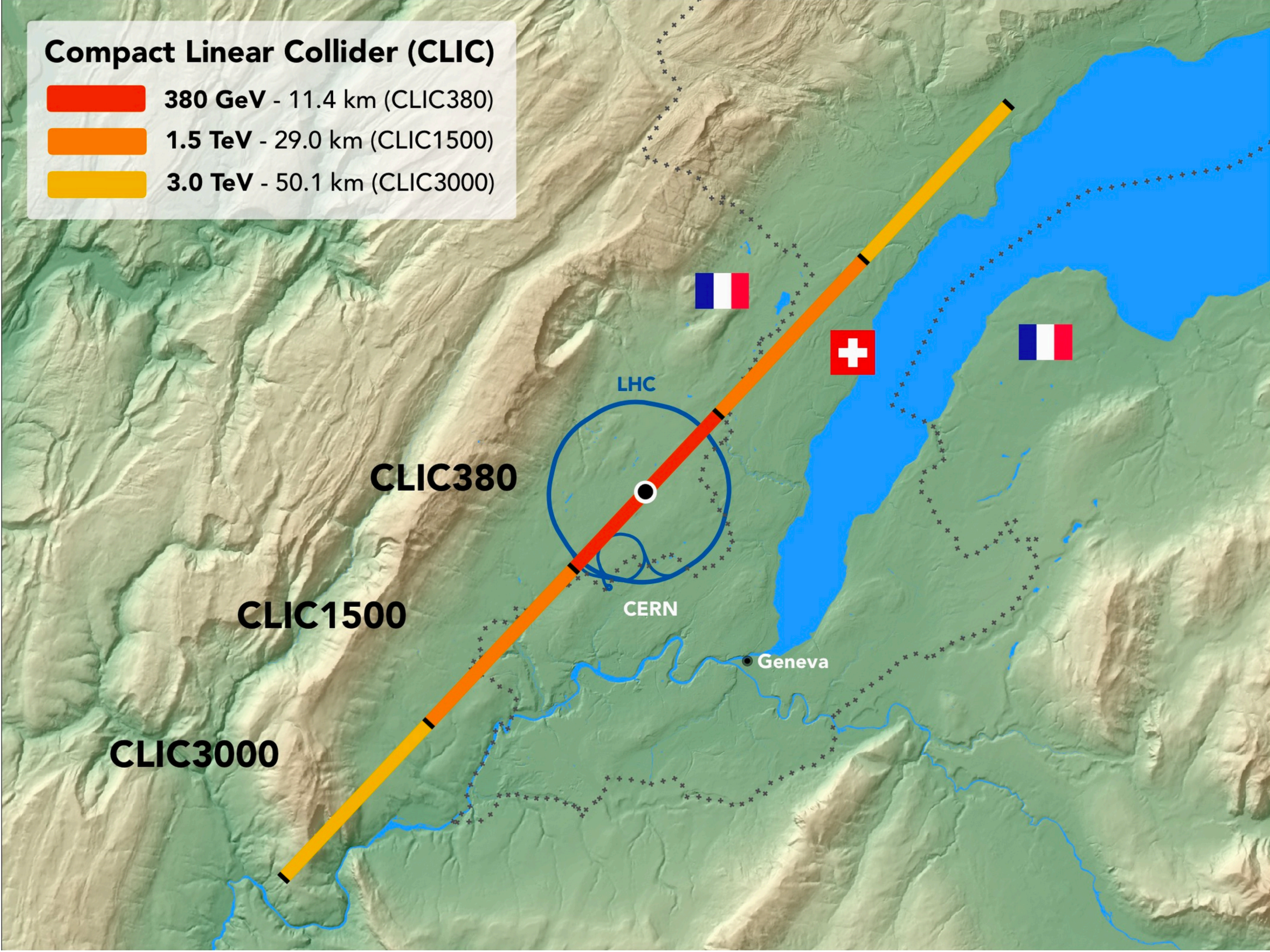
Low Energy Quad

Dipole design





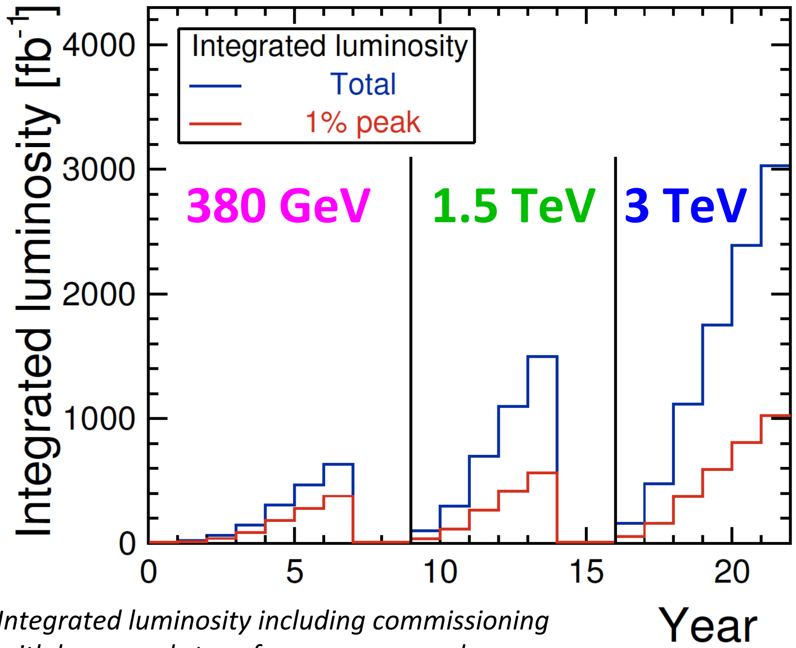
IP
CLIC380
LHC
CERN
Geneva
Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
Drive/main beam injector
LHC - existing infrastructure


Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva

CLIC staging scenario

The CLIC program builds on energy stages:

Maximizes* physics output, enables *realistic* funding profiles, delivers key physics *early



Integrated luminosity including commissioning with beam and stops for energy upgrades

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

Dedicated to top mass threshold scan

CERN-2016-004

- **380 GeV (350 GeV)**, 600 fb^{-1} : precision Higgs and top physics
- **1.5 TeV**, 1.5 ab^{-1} : BSM searches, precision Higgs, ttH, HH, top physics
- **3 TeV**, 3 ab^{-1} : BSM searches, precision Higgs, HH, top physics

CLIC is extendable! May profit from even more advanced technologies for high-E stages

CLIC collaborations

CLIC/CTF3 accelerator collaboration
~60 institutes from **28 countries**

http://clic-study.web.cern.ch/

CLIC detector and physics (CLICdp)
29 institutes from **18 countries**

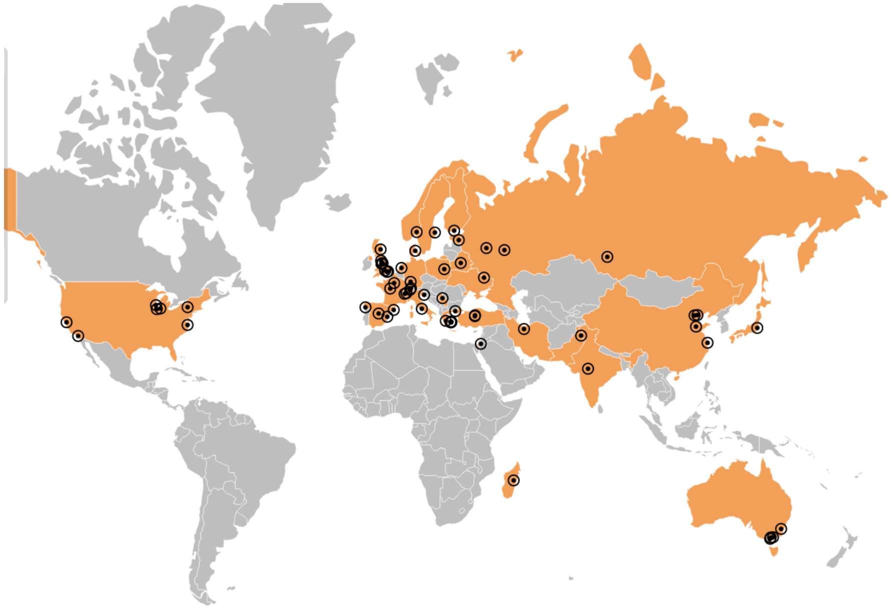
http://clicdp.web.cern.ch/

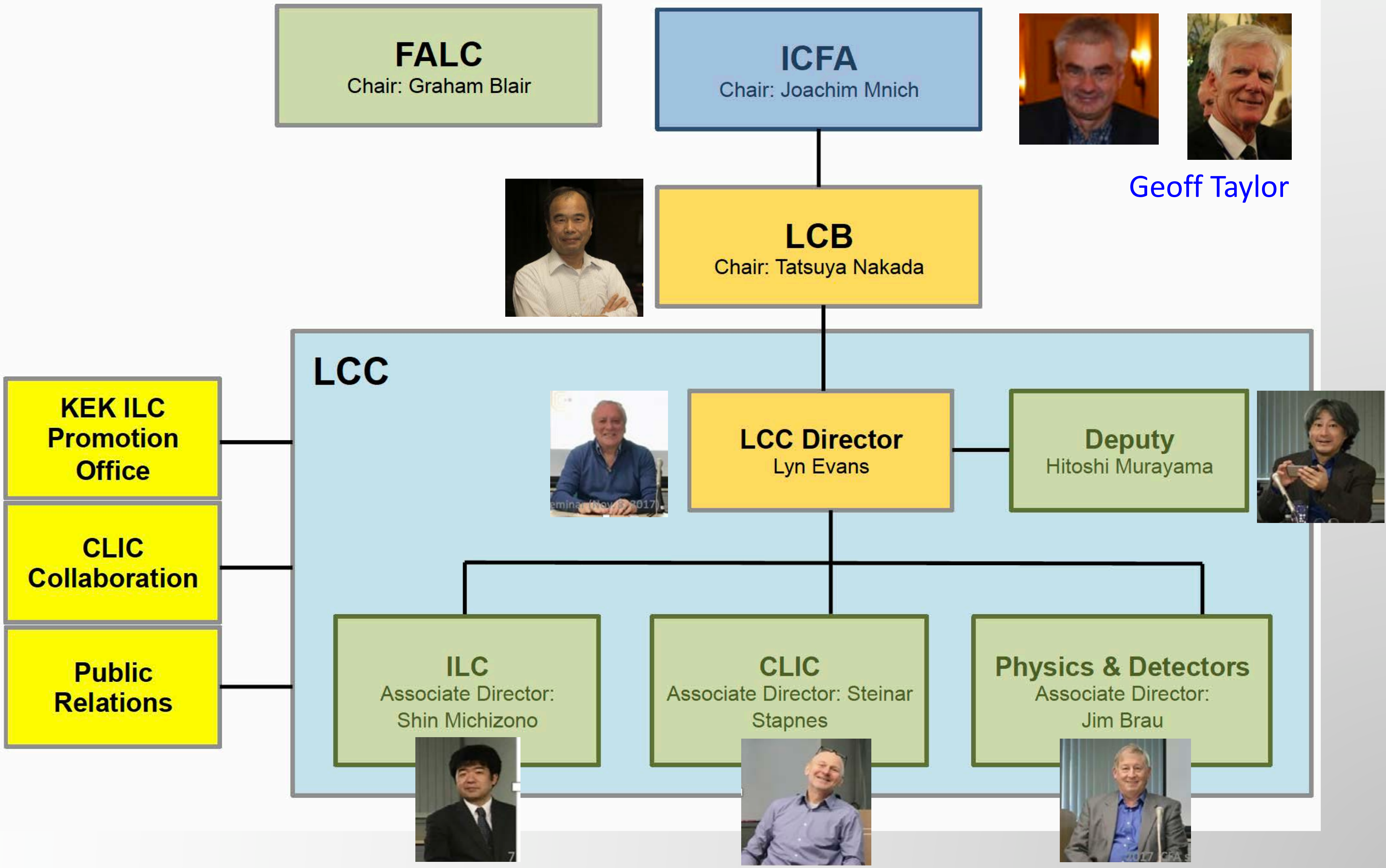
CLIC accelerator studies:

- CLIC accelerator design and development
- (Construction and operation of CTF3)

Focus of CLIC-specific studies on:

- Physics prospects and simulation studies
- Detector optimisation + R&D for CLIC




FALC
Chair: Graham Blair
ICFA
Chair: Joachim Mnich
Geoff Taylor
LCB
Chair: Tatsuya Nakada
LCC
KEK ILC Promotion Office
CLIC Collaboration
Public Relations
LCC Director
Lyn Evans
Deputy
Hitoshi Murayama
ILC
Associate Director:
Shin Michizono
CLIC
Associate Director: Steinar Stapnes
Physics & Detectors
Associate Director:
Jim Brau

In February 2012

- One of the Japanese HEP community statements: "**Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time."

In 2013

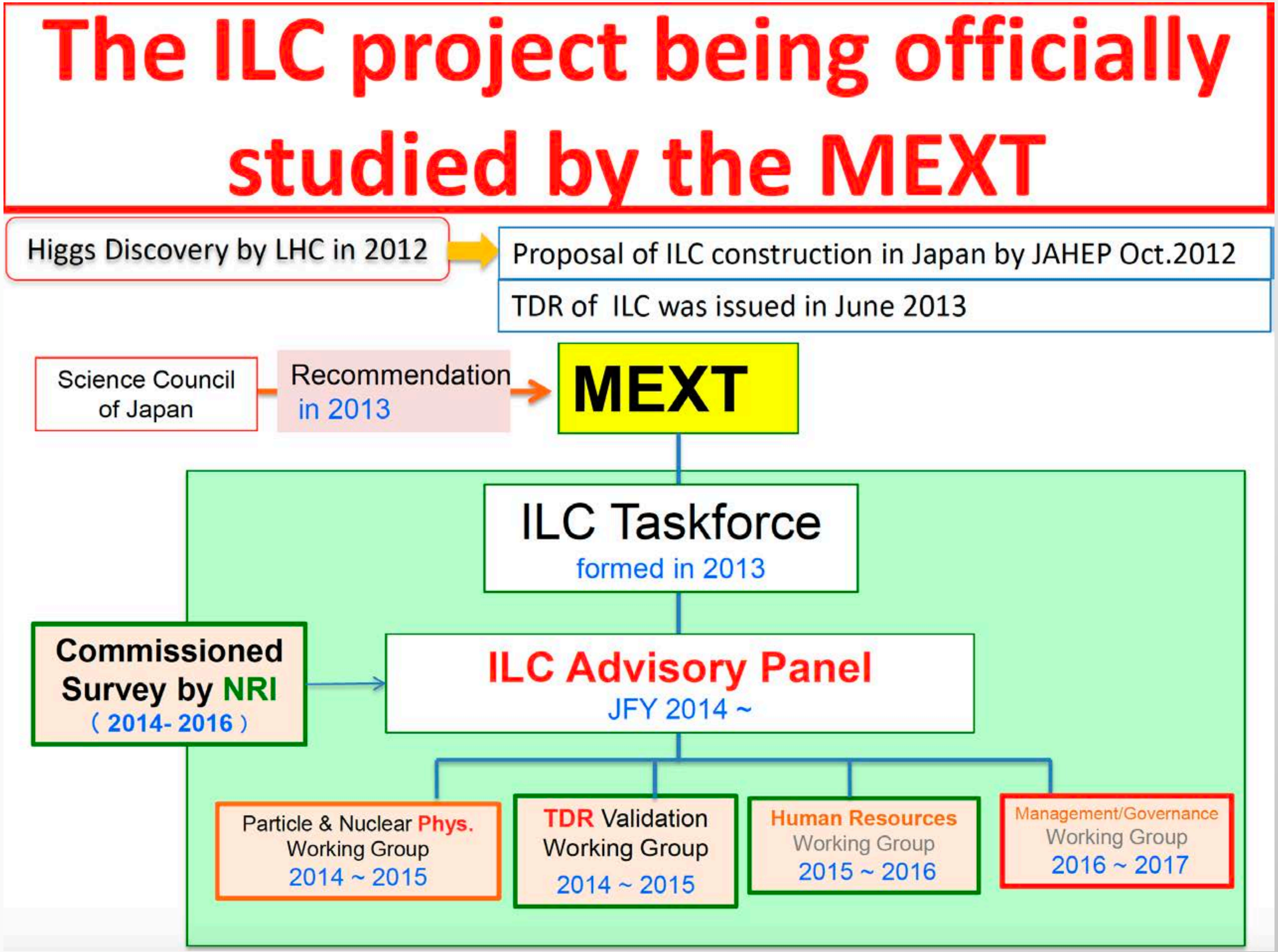
- January 2013 ICFA subpanel was created with a mandate:
  "The Linear Collider Board (LCB), as a sub-panel of ICFA, will promote the construction of an electron-positron linear collider and its detectors as a world-wide collaborative project."
  as well as the Linear Collider Collaboration (ILC, CLIC and Physics&Detector).
- ILC TDR submitted in June 2013

The European Strategy May 2013

- “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.”*

Japan: MEXT and Japanese Government towards ILC

S. Komamiya (ICFA-Seminar 2017)



By the end of 2016…

- Three of four high priority items of European Strategy realised
  - HL-LHC approved by the Council.
  - CERN neutrino platform for ν detector R&D being constructed.
  - R&D for the future high energy machine: high field magnet, high gradient acceleration and design studies for CLIC and FCC.
- Many technical works are being carried out for the ILC, but no visible progress in the political front.

Recent development in 2017

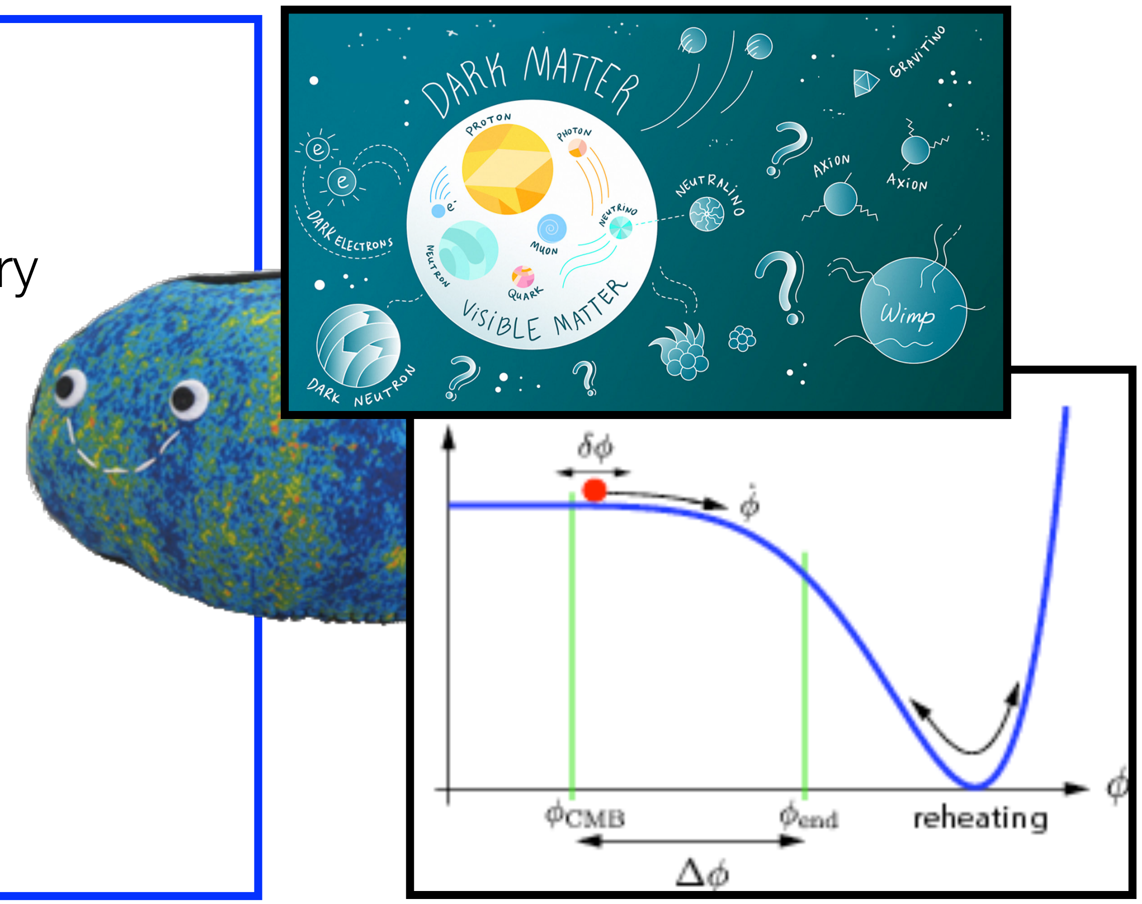
- A new statement from the Japanese Association for High Energy Physicists:
  "To conclude, in light of the recent outcomes of LHC Run 2, JAHEP proposes to promptly construct ILC as a Higgs factory with the center-of-mass energy of 250 GeV in Japan."
- Cost evaluation of a 250 GeV machine by the Linear Collider Collaboration gives a reduction of up to ~40% compared to the TDR cost for the 500 GeV machine.

Physics

The big questions for future colliders….

What we'd really like to know

- How can the Higgs boson be so light?
- What is the mechanism behind electroweak symmetry breaking?
- What is Dark Matter made out of?
- What drives inflation?
- Why is the universe made out of matter?
- What generates Neutrino masses?
- …



What we know:

- all hints for BSM come out of the electroweak sector, incl. Higgs

=> some new particles must be charged under electroweak interactions

What we don't know:

- participation in strong interaction?
- energy scale of new particles

=> no guarantee for direct production of new particles

=> need to explore different, complementary experimental approaches

… and how to tackle them at colliders

Our tools:

The Top and Bottom Quark

Z & W Bosons

The Higgs Boson

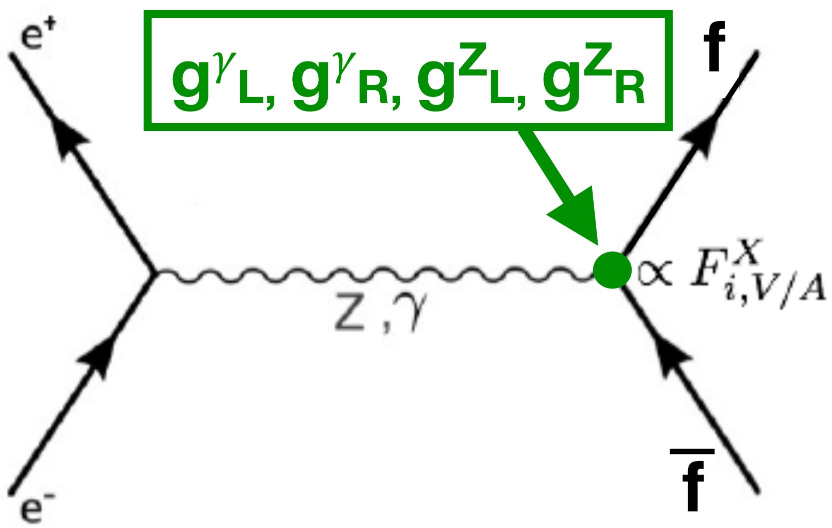
Discoveries of new particles ?

Choosing the next collider

- technical readiness, cost etc.
- **added physics value w.r.t.**
    - **HL-LHC**
    - and all kinds of other experiments

What is the added value of a 250 GeV e+e- Linear Collider ?

Electroweak precision in 2-fermion processes



Pure γ or pure Z^0 : $\sigma \backsim (F_i)^2 \Rightarrow$ No sensitivity to sign of Form Factors

Z^0/γ interference : $\sigma \backsim (F_i) \Rightarrow$ Sensitivity to sign of Form Factors

ILC 'provides' two beam polarisations

$P(e^-) = \pm 80\%$ → ← $P(e^+) = \mp 30\%$

3rd generation of quarks

- is heaviest
- closest connection to electroweak symmetry breaking
- could they be (partially) composite?

Polarised beams

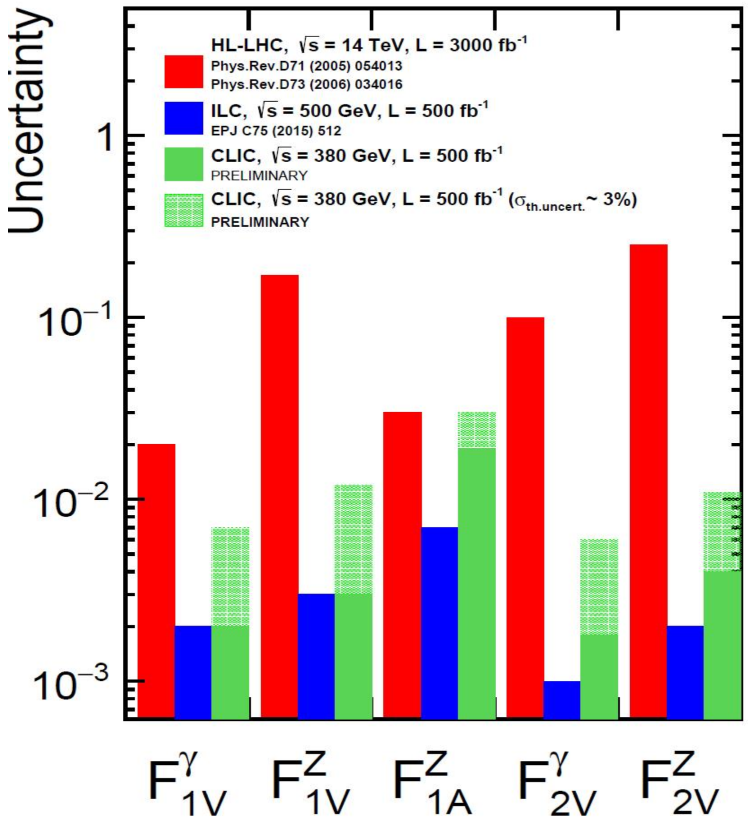
- allow to disentangle g^{γ} vs g^Z
- provide robustness against systematic uncertainties
- minimise higher-order corrections

The Top and Bottom Quark

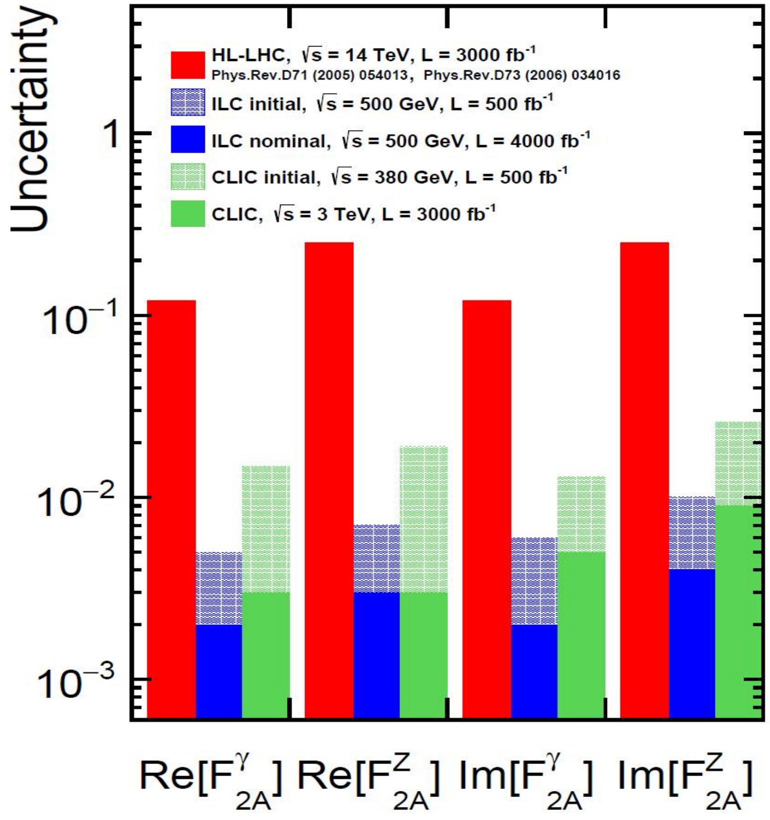
Top coupling sensitivity

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

vector axial tensor CPV



arXiv:1608.07537



arXiv:1710.06737

Measurements in the top sector can not constrain all EFT operators.

Compementary information need to be obtained from *b* sector !

Top at LHC and Tevatron

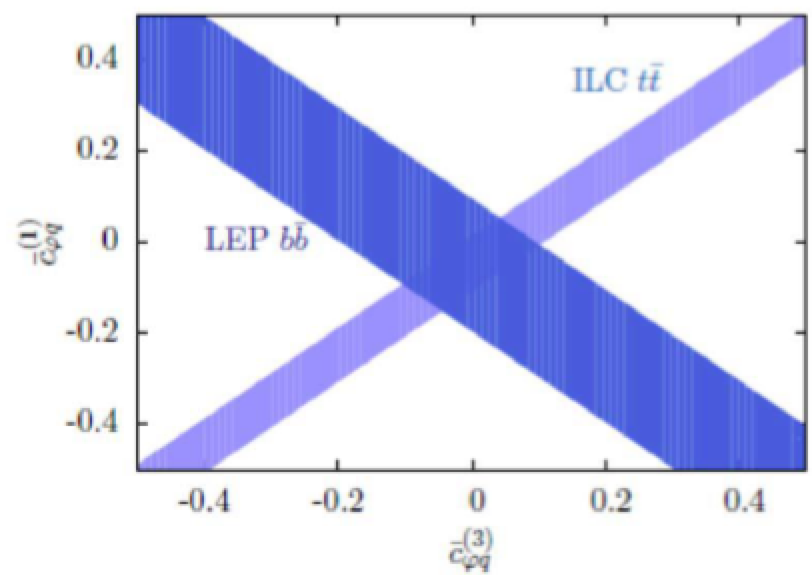
- As illustrated by the **EFT analysis**, the top and b sectors are fully complementary
- EW top interactions can be measured in various ways
- AFBt at **Tevatron** and charge asymmetry ACt at **LHC**
- **ttZ**, (ttW), ttH
- Top decay distribution (not discussed)
- Single top production (not discussed)

$$C_{1V} = \frac{v^2}{\Lambda^2}\Re\left[c^{(3)}_{\varphi q} - c^{(1)}_{\varphi q} - c_{\varphi u}\right]^{33}$$

$$C_{1A} = \frac{v^2}{\Lambda^2}\Re\left[c^{(3)}_{\varphi q} - c^{(1)}_{\varphi q} + c_{\varphi u}\right]^{33}$$

$$C_{2V} = \sqrt{2}\frac{v^2}{\Lambda^2}\Re\left[\cos\theta_W c_{uW} - \sin\theta_W c_{uB}\right]^{33}$$

$$C_{2A} = \sqrt{2}\frac{v^2}{\Lambda^2}\Im\left[\cos\theta_W c_{uW} + \sin\theta_W c_{uB}\right]^{33}$$

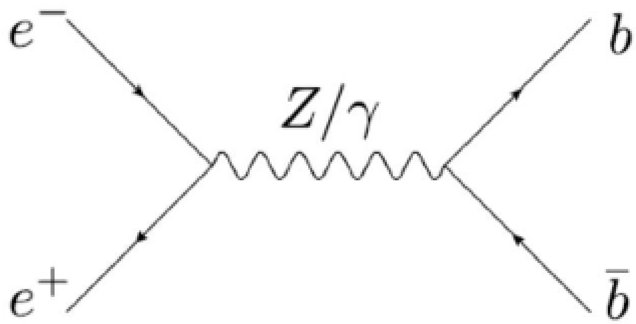


1505.06020

ILC250 can significantly improve *b measurements* from LEP

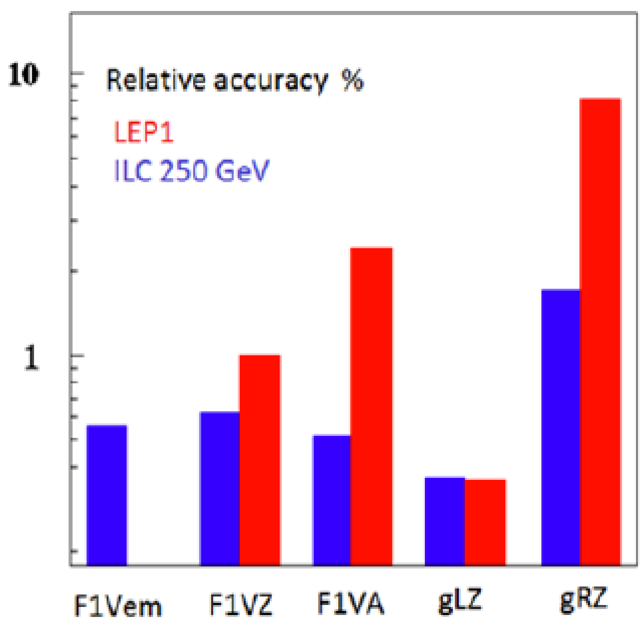
- **10^3** times higher luminosity
- beam **polarisation**
- better detector and reconstruction tools

What can be expect at ILC250 on ee->bb



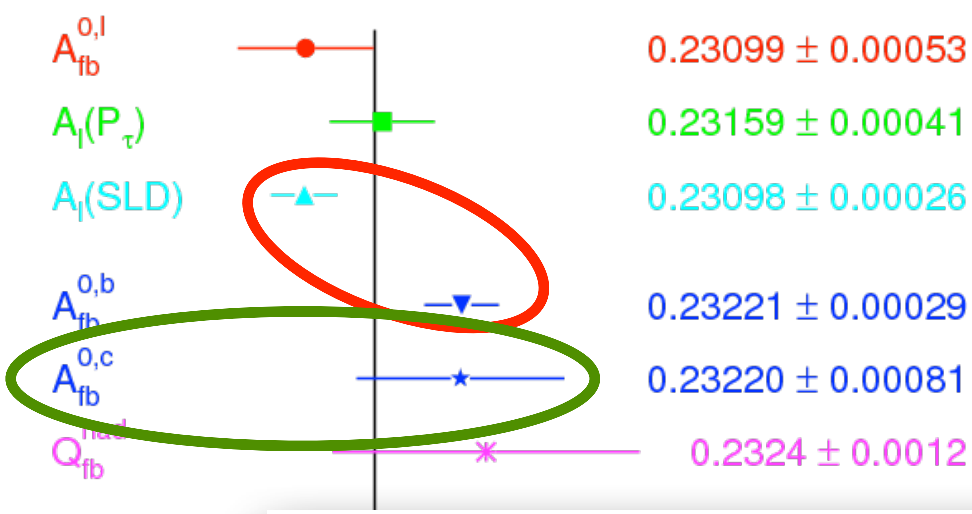
1709.04289

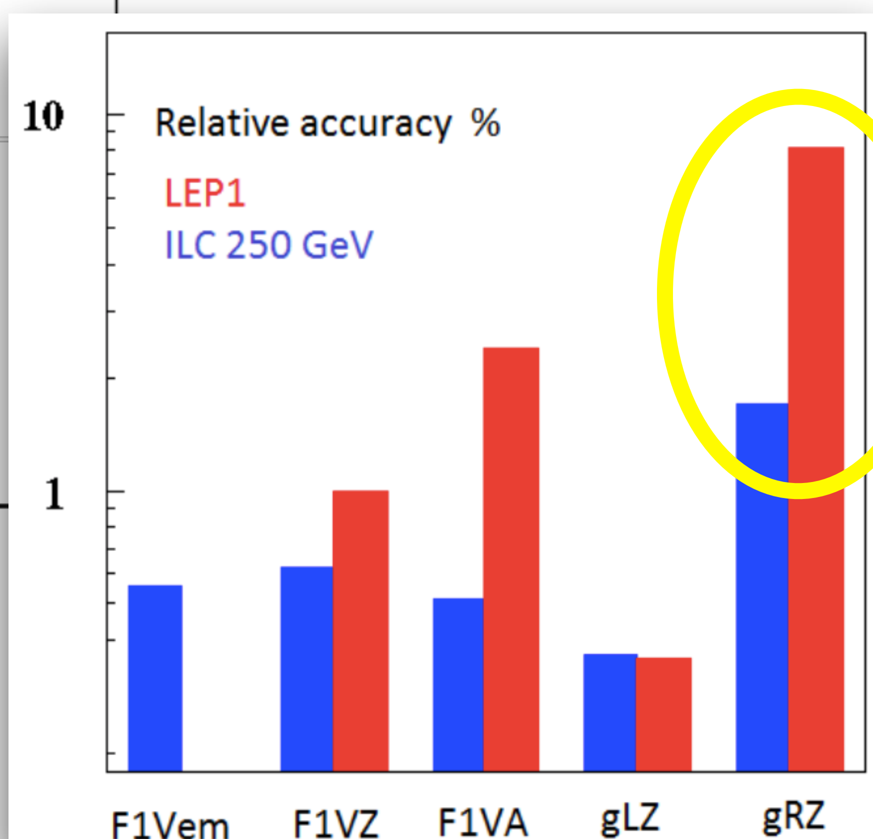
- $\delta g_{RZ}/g_{RZ}$ **~2%** sufficient to **confirm at >5σ** or to **discard** the LEP1 effect which is at the **25%** level
- Recall the sign uncertainty on LEP1 solutions **dg_{RZ}/g_{RZ}=25%** or **dg_{RZ}/g_{RZ}=-225%**
- Not a problem at 250 GeV to make the right choice for the sign
- ILC measurements with **beam polarisation** provide model independent access to **vector** and **tensor** couplings



ILC 250 GeV: The Bottom Quark

The Bottom Quark





arXiv:1709.04289

- **b_R compositeness** could explain e.g. long-standing tension between two most precise determinations of $\mathbf{sin^2\vartheta_{eff}}$- one of them from $A_{FB}{}^b(M_Z)$
- can we remeasure couplings of b_R and $A_{FB}{}^b$(250GeV) and improve on LEP1?

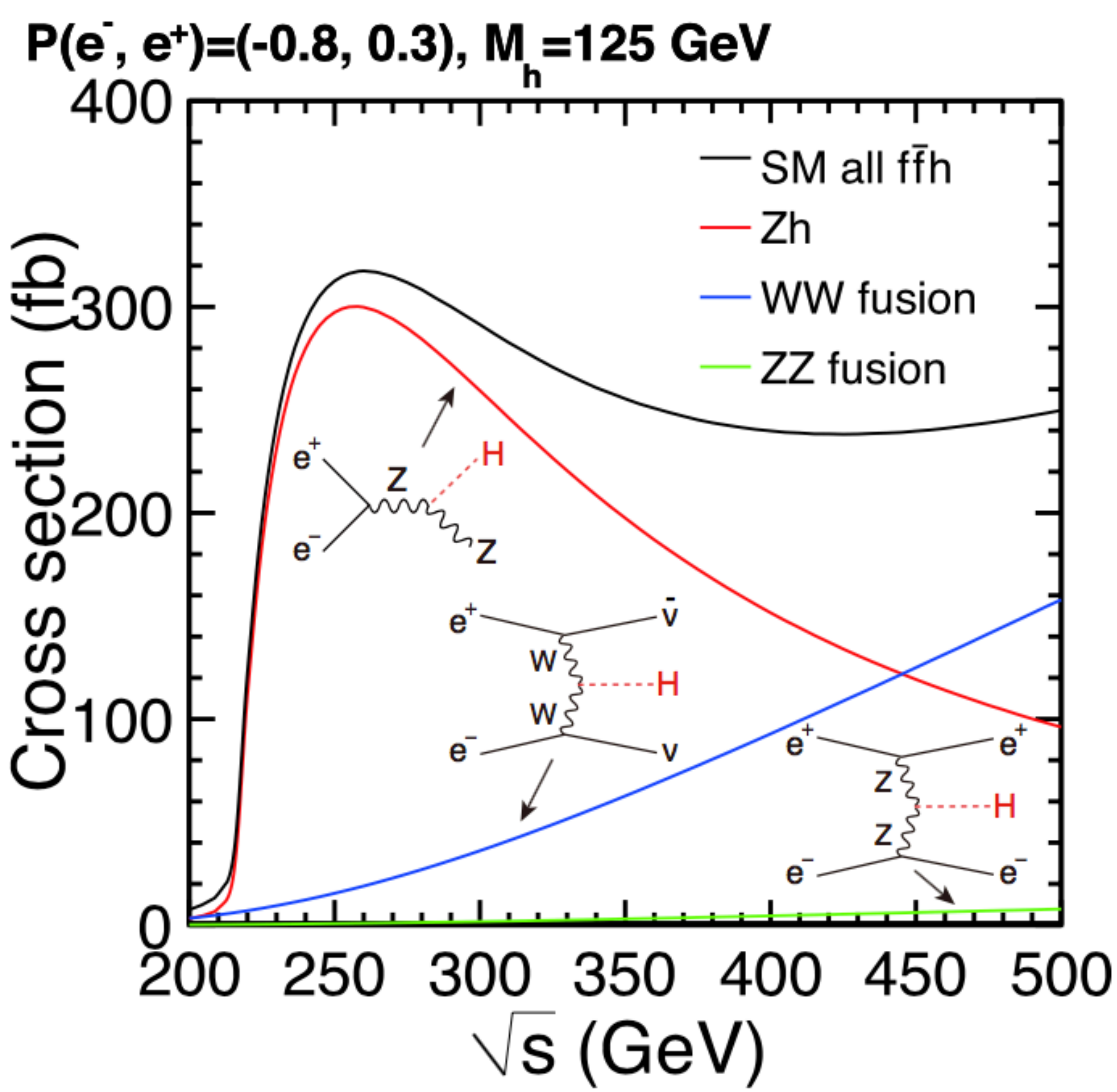
Yes, we can!

allows to probe NP scales up to ~60 TeV

expect at least similar improvement also for
charm quarks
=> profit from > 30 years of advances in detector technology!

Precision Higgs Physics @ 250 GeV

The Higgs Boson



- production dominated by Zh
- **2 ab^{-1} => ~600 000 Zh events**
- fantastic sample for measuring:
  - (recoil) mass
  - total Zh cross section: ***the*** key to model-independent determination of absolute couplings!
  - **h-> invisible (Dark Matter!): expected limited < 0.3% @ 95%**
  - all kinds of branching ratios
  - CP properties of h-fermion coupling
  - CP properties of Zh coupling
  - ….

Image courtesy of Stuart Miles at FreeDigitalPhotos.net

for up-to-date listings of individual precisions c.f. arXiv:1708.08912

Precision Measurement of M_h

The Higgs Boson

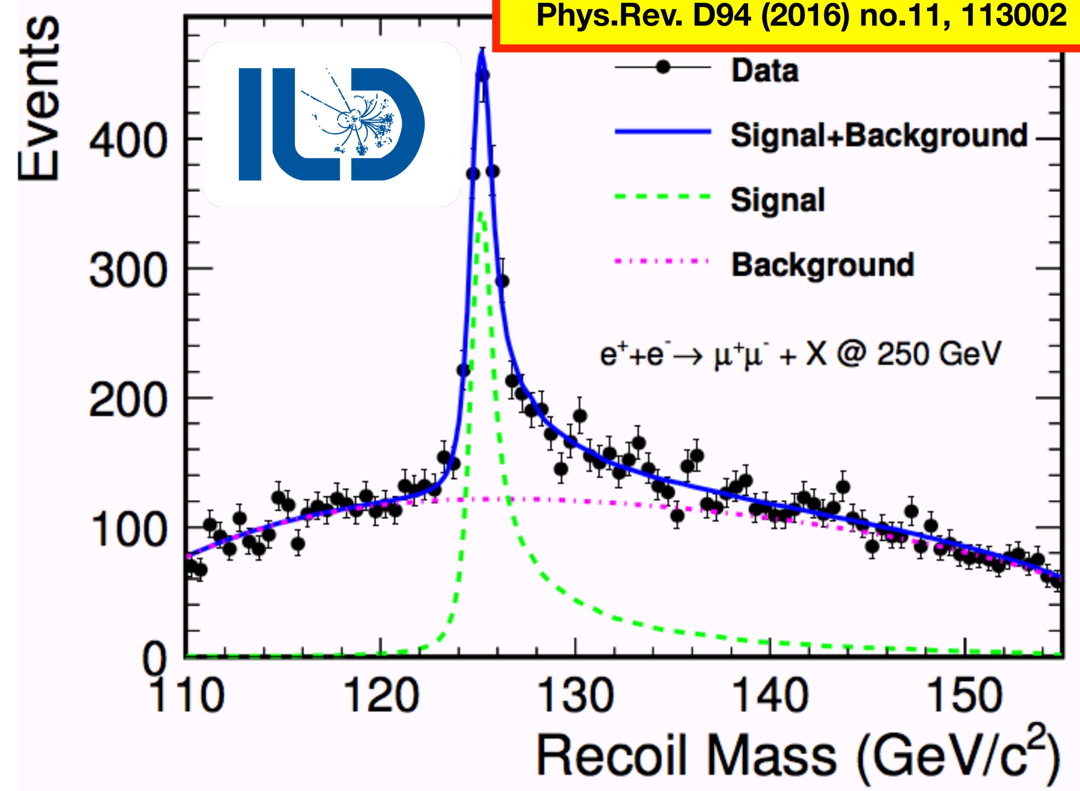
How well do we need to know the Higgs mass?

- for many applications, $\delta m_h \simeq 0.25$ GeV (or 0.2%) is ok
- notable exception: h->V V* partial widths very sensitive to m_h due to phase space!
  => relative errors for *effective couplings* $\sim\sqrt{\Gamma_V}$ and mass, assuming NWA for Higgs, relate as:

$$\delta_W = 6.9 \cdot \delta m_h, \qquad \delta_Z = 7.7 \cdot \delta m_h$$

for in depth discussion of parametric uncertainties c.f. Phys. Rev. D 89, 033006 (2014)

Phys.Rev. D94 (2016) no.11, 113002

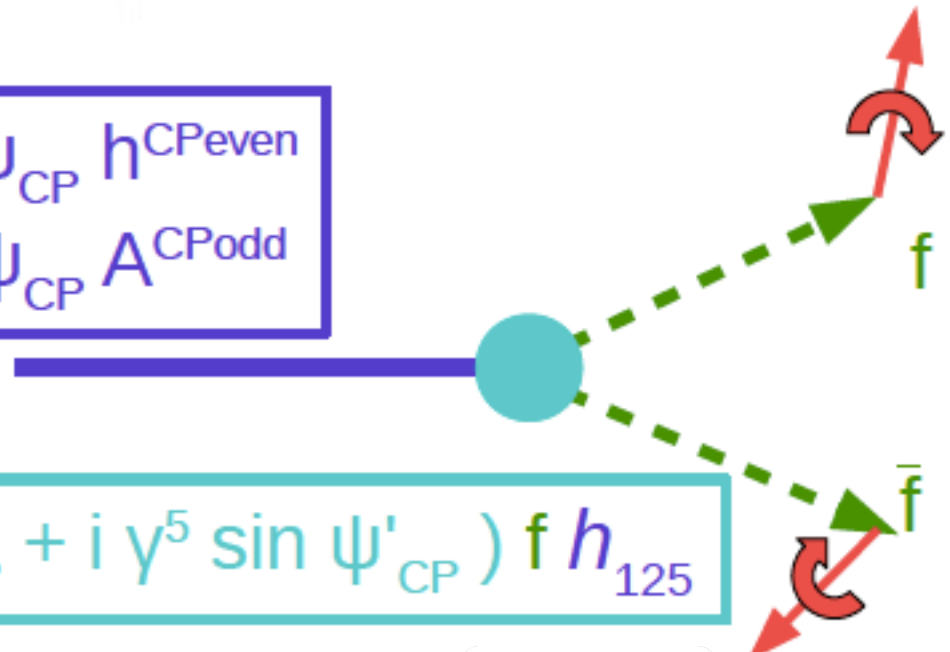


- **$\delta m_h = 0.2\%$ => $\delta_W = 1.4\%$ - not adequate for precision goal!**
- **leptonic recoil mass at ILC 250 GeV: $\delta m_h \simeq 14$ MeV => $\delta_W = 0.1\%$**
- watch impact of new beam parameters: => preliminary estimate: 20 MeV - still ok

The Higgs Boson

CP properties in h->$\tau\tau$

$h_{125} = \cos\psi_{CP}\, h^{CPeven} + \sin\psi_{CP}\, A^{CPodd}$

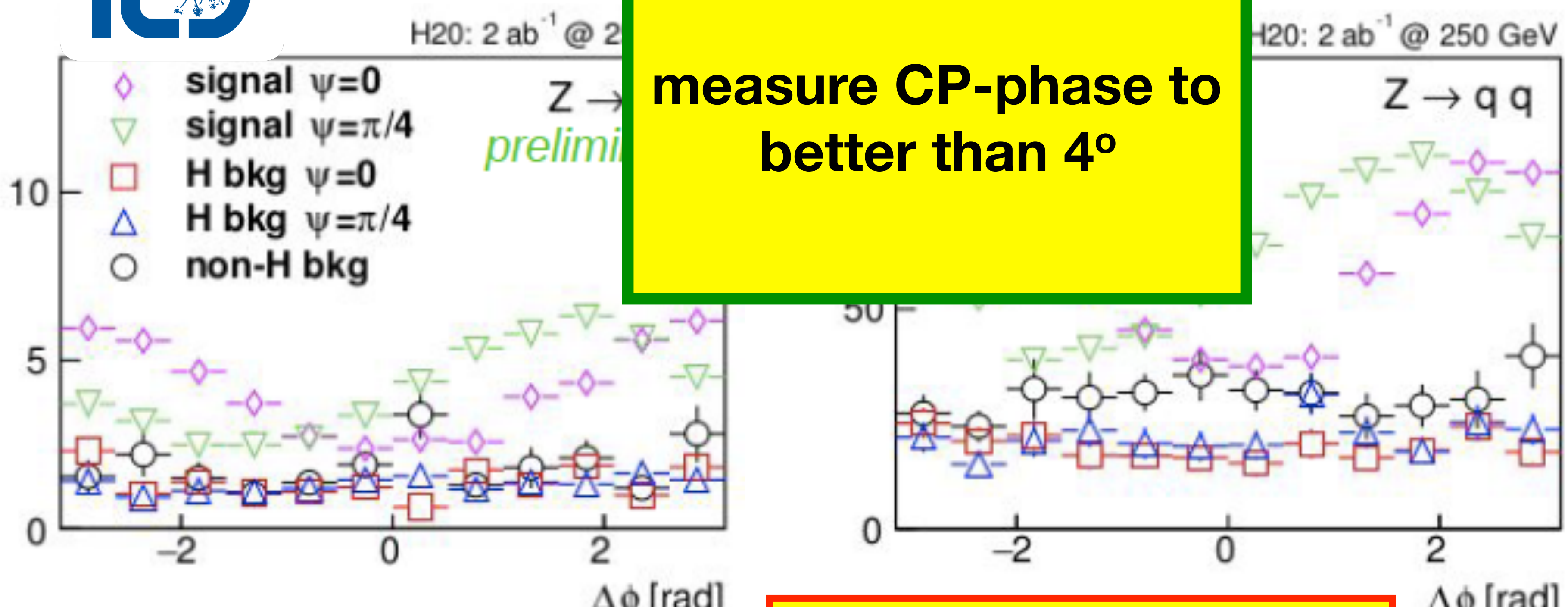


$g\, \bar{f}\, (\cos\psi'_{CP} + i\, \gamma^5 \sin\psi'_{CP})\, f\, h_{125}$

***h* is a spin 0 state:**

$| f\ \bar{f} > = | \uparrow\downarrow > + e^{2i\psi} | \downarrow\uparrow >$

[ψ = 0 CP even,
$\pi/2$ CP odd]



measure CP-phase to better than 4°

..and CPV in Zh coupling:

$$\Delta\mathcal{L}_{hZZ} = \frac{1}{2}\frac{\tilde{b}}{v} h Z_{\mu\nu} \tilde{Z}^{\mu\nu}$$

=> $\tilde{b}$ **to ±0.005**

based on NIM A810 (2016) 51-58

Higgs coupling precisions (in %)

	ILC250		+ILC500	
	κ fit	EFT fit	κ fit	EFT fit
$g(hbb)$	1.8	1.1	0.60	0.58
$g(hcc)$	2.4	1.9	1.2	1.2
$g(hgg)$	2.2	1.7	0.97	0.95
$g(hWW)$	1.8	0.67	0.40	0.34
$g(h\tau\tau)$	1.9	1.2	0.80	0.74
$g(hZZ)$	0.38	0.68	0.30	0.35
$g(h\gamma\gamma)$	1.1	1.2	1.0	1.0
$g(h\mu\mu)$	5.6	5.6	5.1	5.1
$g(h\gamma Z)$	16	6.6	16	2.6
$g(hbb)/g(hWW)$	0.88	0.86	0.47	0.46
$g(h\tau\tau)/g(hWW)$	1.0	1.0	0.65	0.65
$g(hWW)/g(hZZ)$	1.7	0.07	0.26	0.05
Γ_h	3.9	2.5	1.7	1.6
$BR h \to inv$	0.32	0.32	0.29	0.29
$BR h \to other$	1.6	1.6	1.3	1.2

A new way to determine the Higgs couplings

- **until recently: so-called κ-framework**
  - simple scaling of couplings which exist in the SM, e.g. $\frac{\Gamma(h \to ZZ^*)}{SM} = \kappa_Z^2 \; , \qquad \frac{\sigma(e^+e^- \to Zh)}{SM} = \kappa_Z^2$
  - no new operators considered
  - called “model-independent” because no assumptions on any size of coupling or total width
- **NEW: EFT-based framework**
  - consistent set of SU(2)xU(1) allowed dim-6 operators
  - even more “model-independent” since new momentum-dependent operators included, e.g.:

$$\delta\mathcal{L} = \frac{m_Z^2}{v}(1+\eta_Z)hZ_\mu Z^\mu + \zeta_Z \frac{1}{v} h Z_{\mu\nu} Z^{\mu\nu}$$

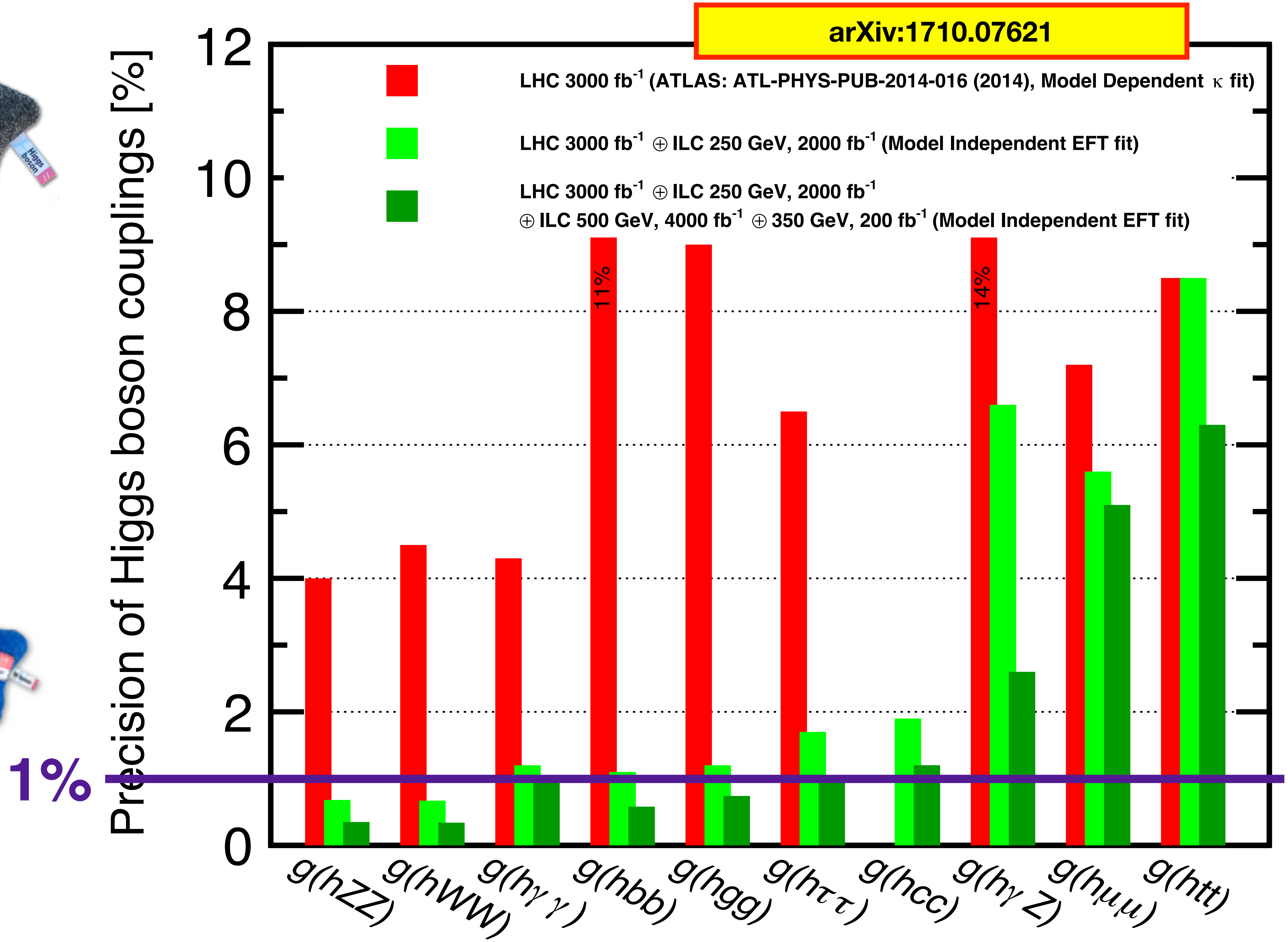
$$\Gamma(h \to ZZ^*)/SM = (1 + 2\eta_Z - 0.50\zeta_Z)$$
$$\sigma(e^+e^- \to Zh)/SM = (1 + 2\eta_Z + 5.7\zeta_Z)$$

  - general EFT fineprint: no light new particles…
    => treat H->invisible as additional degree of freedom
  - allows to include:
    - EWPO: current state assumed apart from Γ_W
    - **triple gauge couplings**

the following based on 10-parameter fit in arXiv:1708.08912

other approaches use up to 17 parameters

Higgs coupling precisions from full EFT fit



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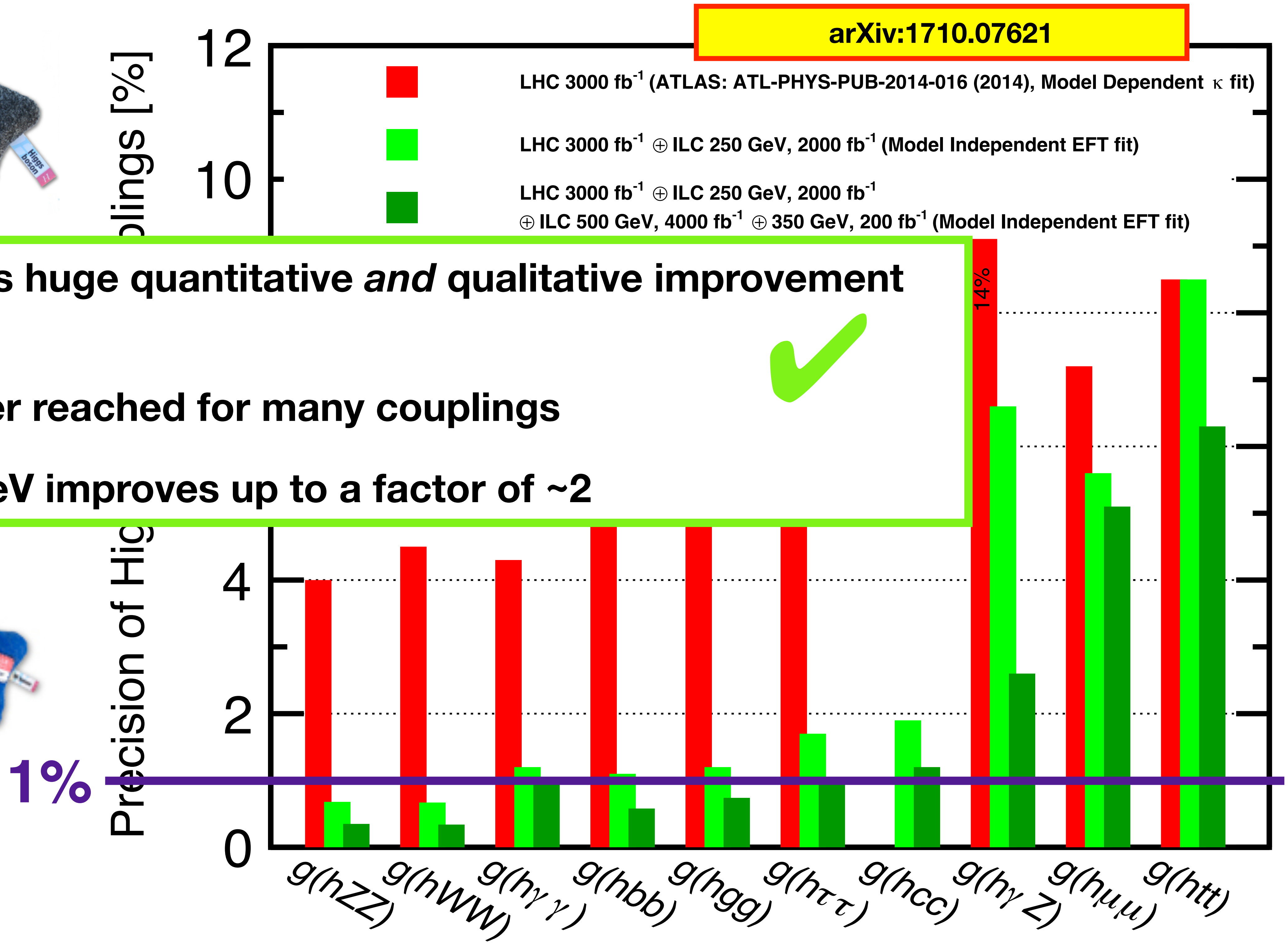
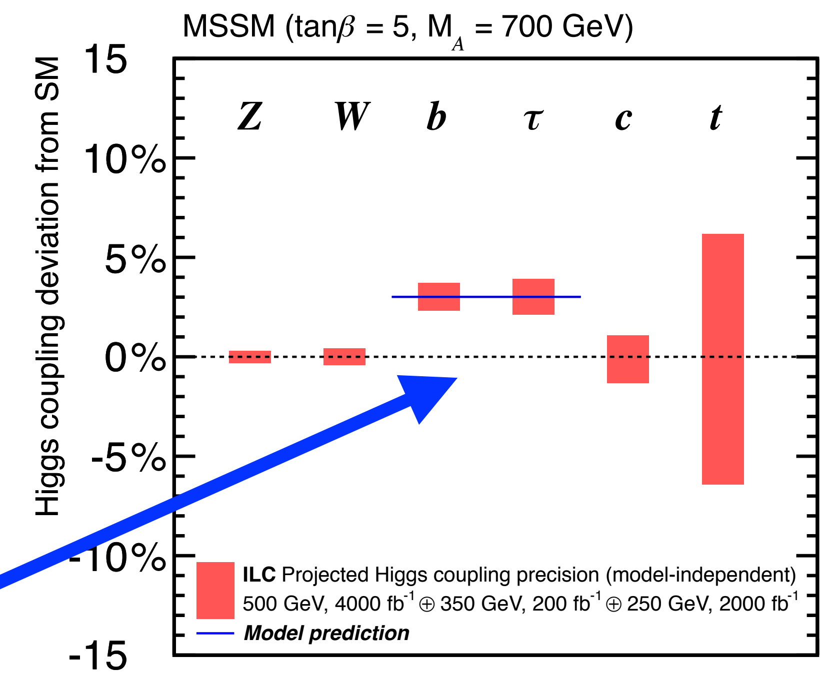


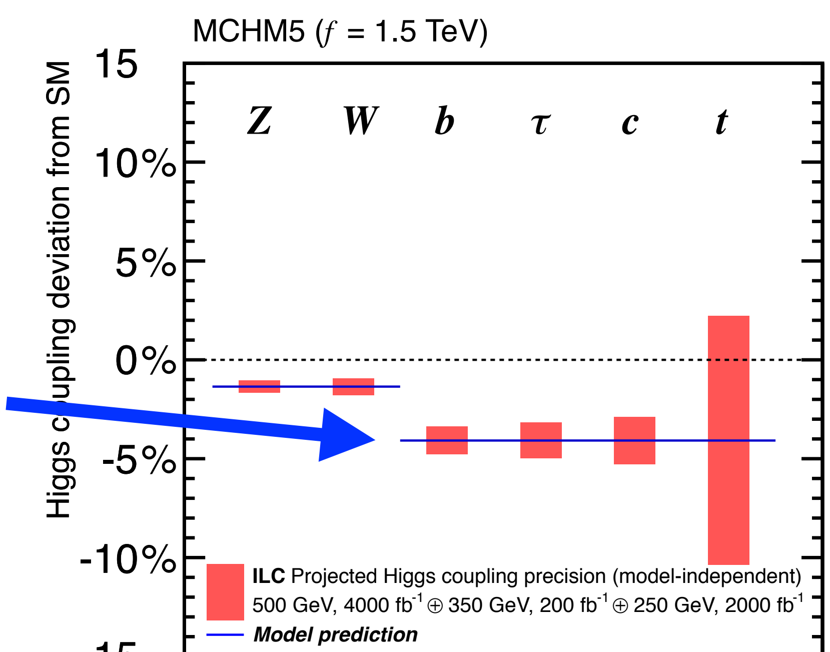
- ★ **250 GeV offers huge quantitative *and* qualitative improvement over HL-LHC** ✔
- ★ **~ 1 % or better reached for many couplings**
- ★ **adding 500 GeV improves up to a factor of ~2**

The Higgs Boson couplings

How big can BSM effects be?

- low scale new physics
  => modification of Higgs properties!
- different *patterns* of deviations from SM prediction for different NP models
- *size* of deviations depends on NP scale
  typically few percent on tree-level:
  - MSSM, eg: $$\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \text{TeV}}{m_A}\right)^2$$
  - Littlest Higgs, eg m_T=1TeV: $$\frac{g_{hgg}}{g_{h_{SM}gg}} = 1 - (5\% \sim 9\%)$$ $$\frac{g_{h\gamma\gamma}}{g_{h_{SM}\gamma\gamma}} = 1 - (5\% \sim 6\%),$$
  - Composite Higgs, eg: $$\frac{g_{hff}}{g_{h_{SM}ff}} \simeq \begin{cases} 1 - 3\%(1\ \text{TeV}/f)^2 & \text{(MCHM4)} \\ 1 - 9\%(1\ \text{TeV}/f)^2 & \text{(MCHM5)} \end{cases}$$



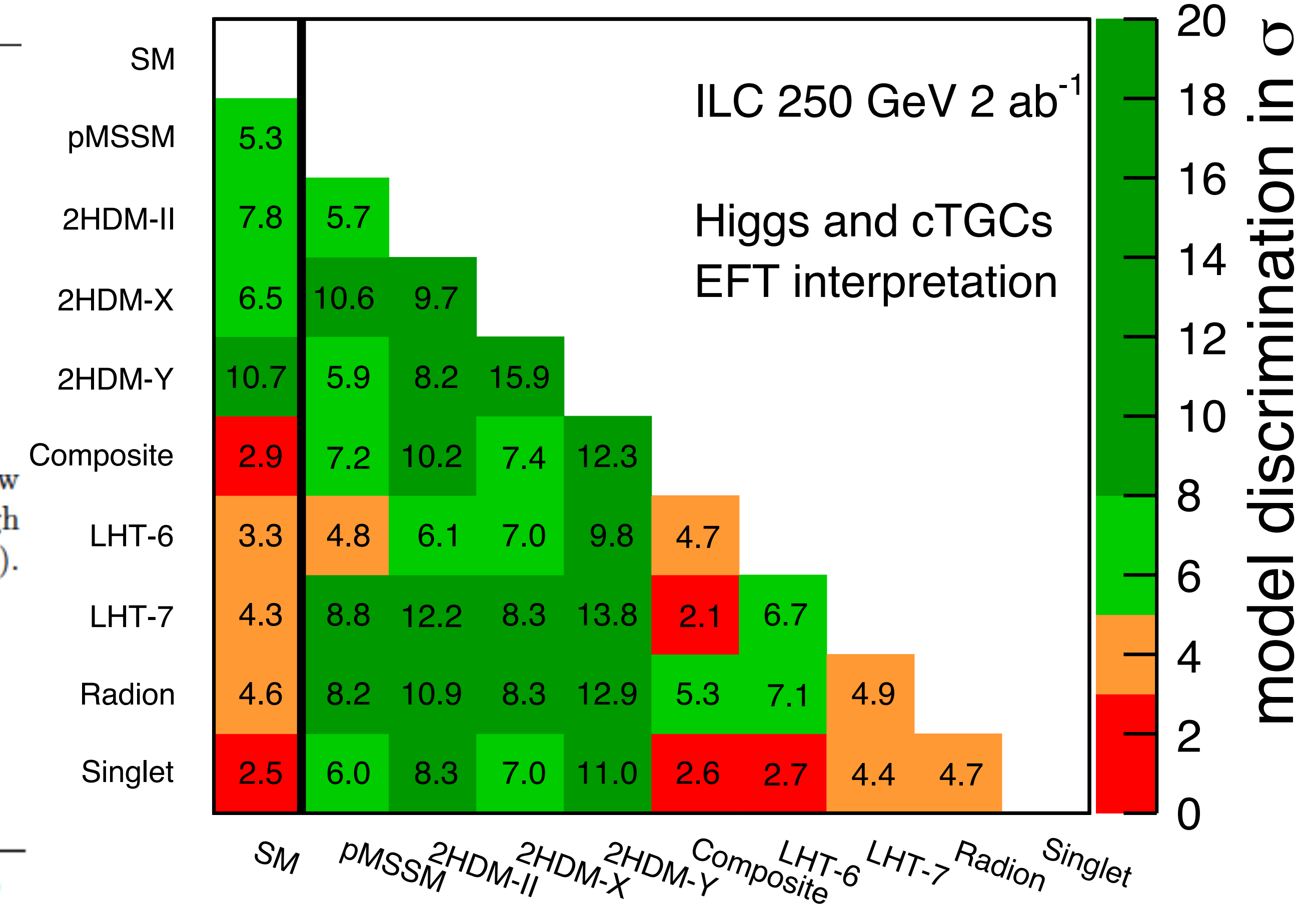


At least percent-level precision required!

New Physics Interpretation of Higgs & EW

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$
1	MSSM [36]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1
2	Type II 2HD [35]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1
3	Type X 2HD [35]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0
4	Type Y 2HD [35]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1
5	Composite Higgs [37]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1
6	Little Higgs w. T-parity [38]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5
7	Little Higgs w. T-parity [39]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0
8	Higgs-Radion [40]	-1.5	- 1.5	+10.	-1.5	-1.5	-1.5	-1.0
9	Higgs Singlet [41]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

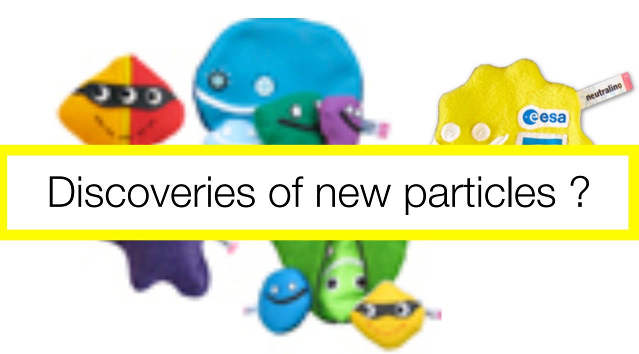
Table 3: Percent deviations from SM for Higgs boson couplings to SM states in various new physics models. These model points are unlikely to be discoverable at 14 TeV LHC through new particle searches even after the high luminosity era (3 ab^{-1} of integrated luminosity). From [15].



…or more generally speaking:

	$\Delta g(hVV)$	$\Delta g(ht\bar{t})$	$\Delta g(hb\bar{b})$
Composite Higgs	10%	tens of %	tens of %
Minimal Supersymmetry	$< 1\%$	3%	tens of %
Mixed-in Singlet	6%	6%	6%

arXiv:1708.08912



illustrates discovery and identification potential with examples of various BSM model points, all chosen to be unobservable at HL-LHC

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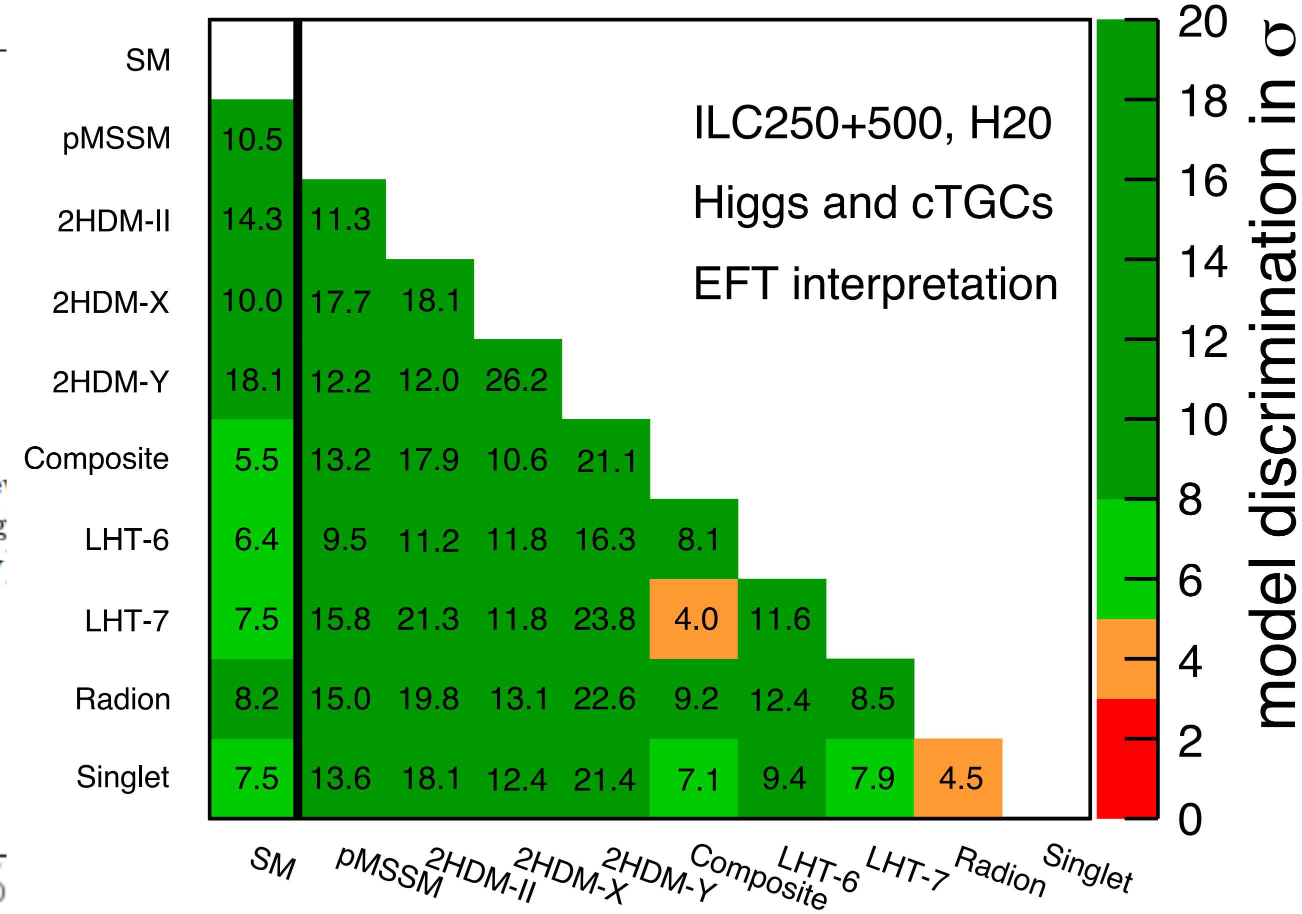

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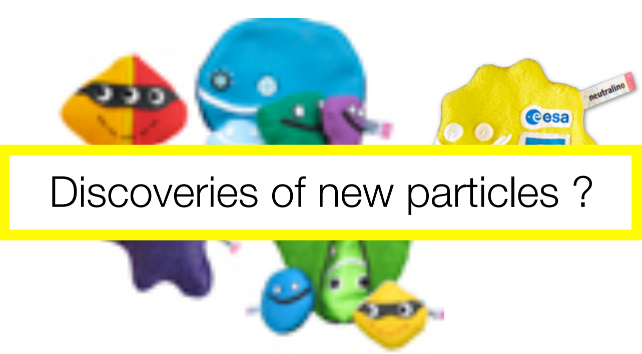

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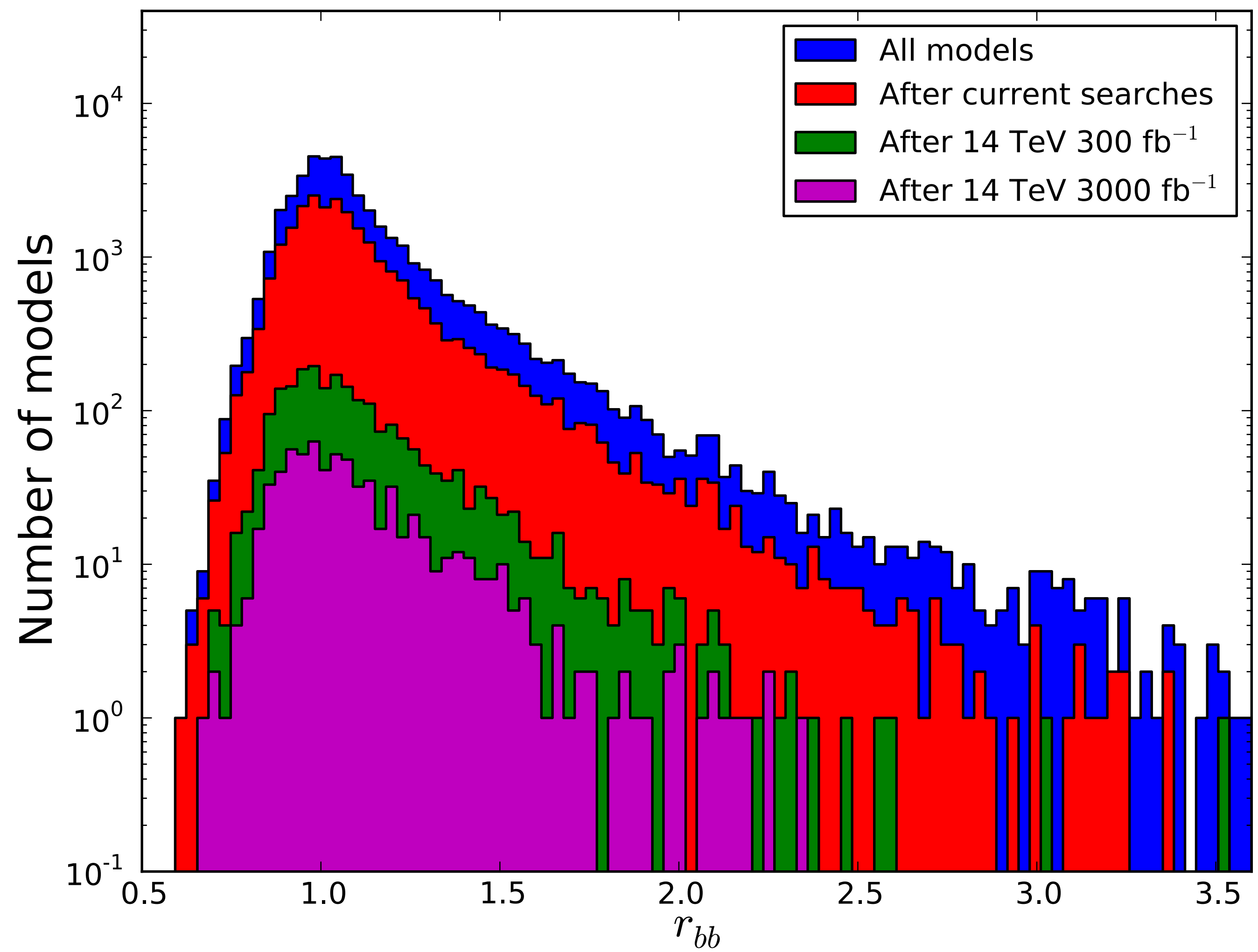
A closer look at SUSY: pMSSM scan

- scan over 250 000 pMSSM points

Phys. Rev. D 90, 095017 (2014)

- check against direct searches
- even after HL-LHC projections for direct searches, many models with sizeable coupling deviations remain!
- **EFT fit ILC 250 GeV: δg(hbb) = 1.7%**
- EFT fit ILC H20: δg(hbb) = 0.95%



$$r_X = \frac{\Gamma(h \to X)}{SM}$$

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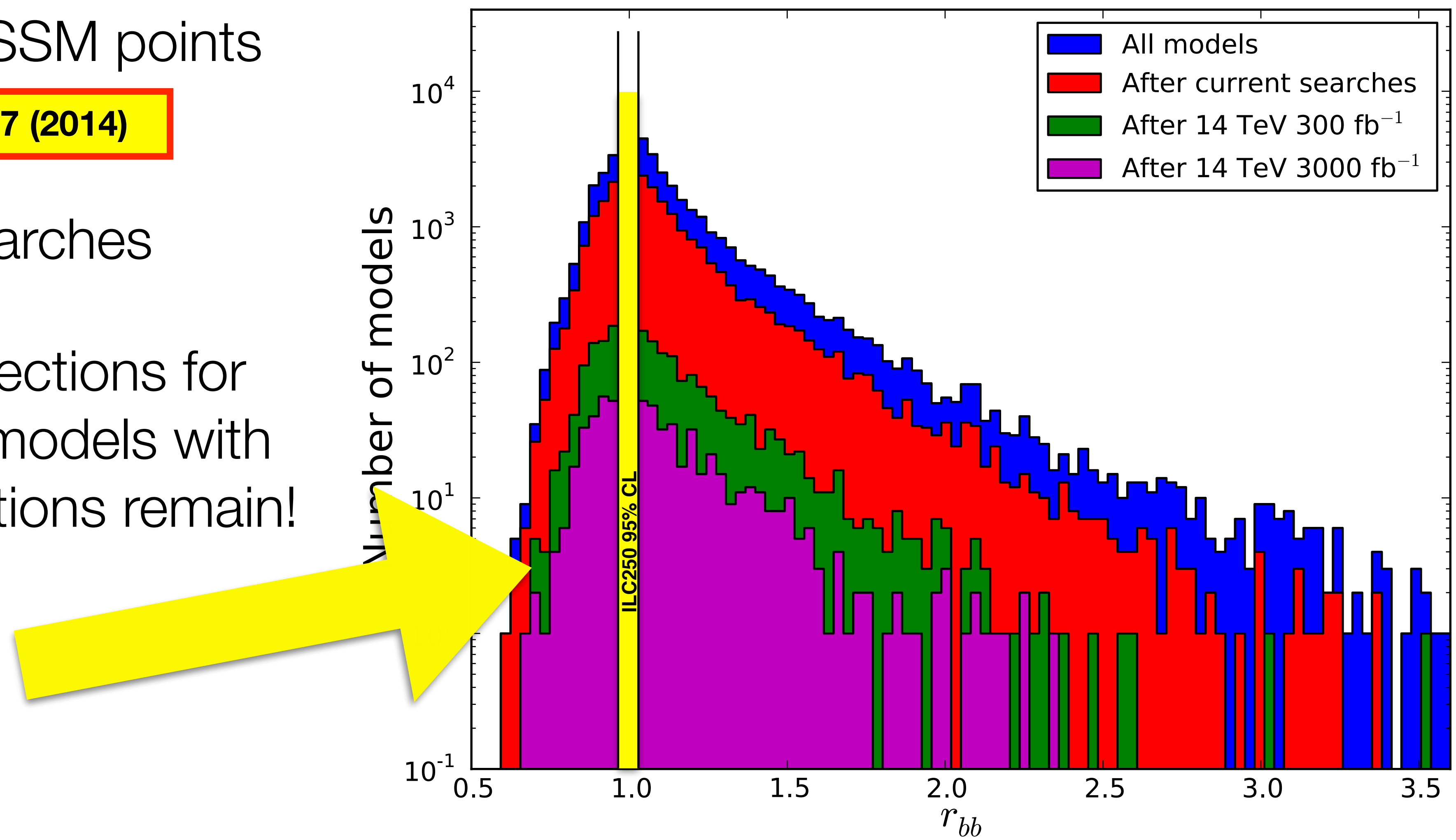

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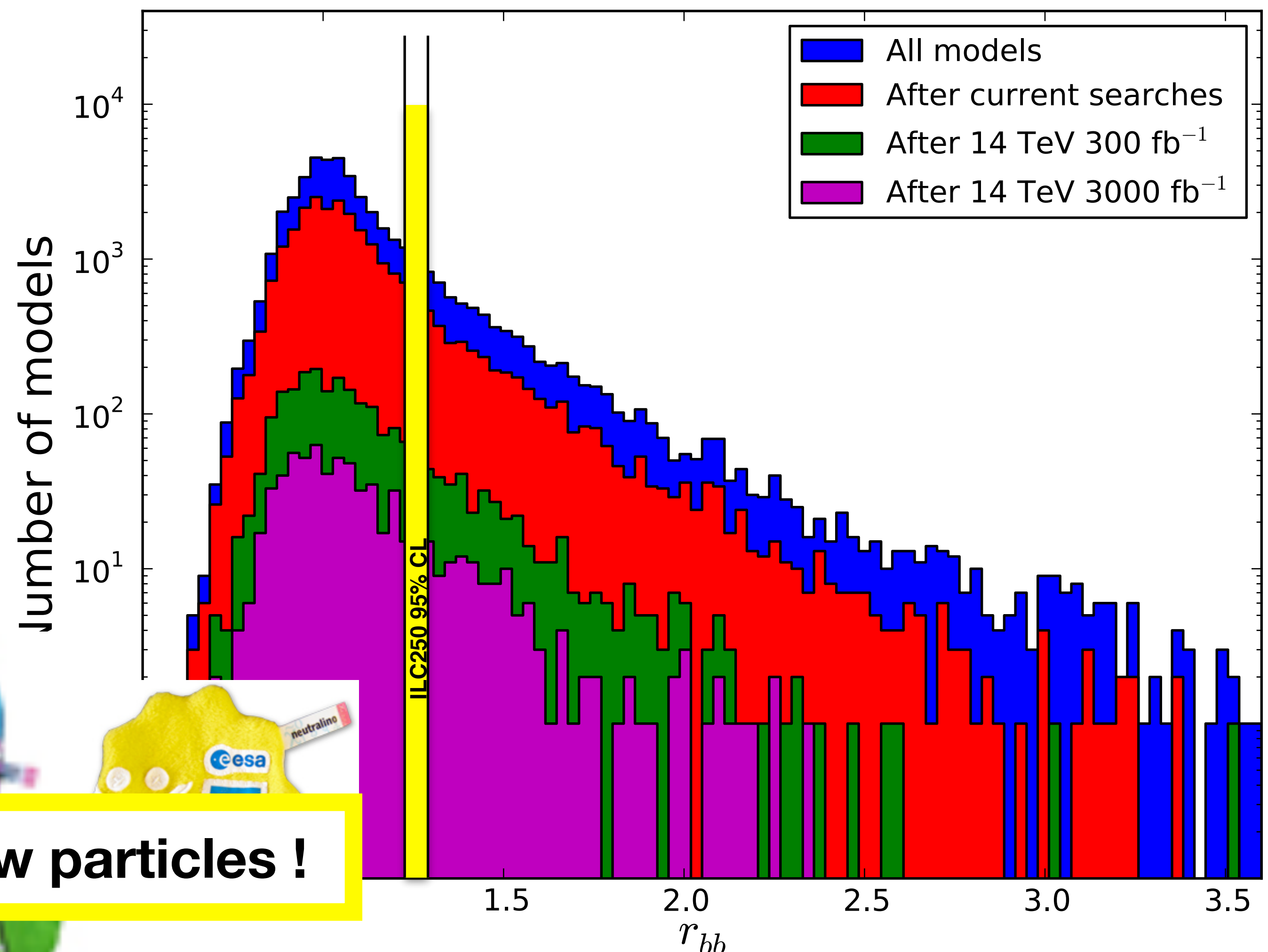


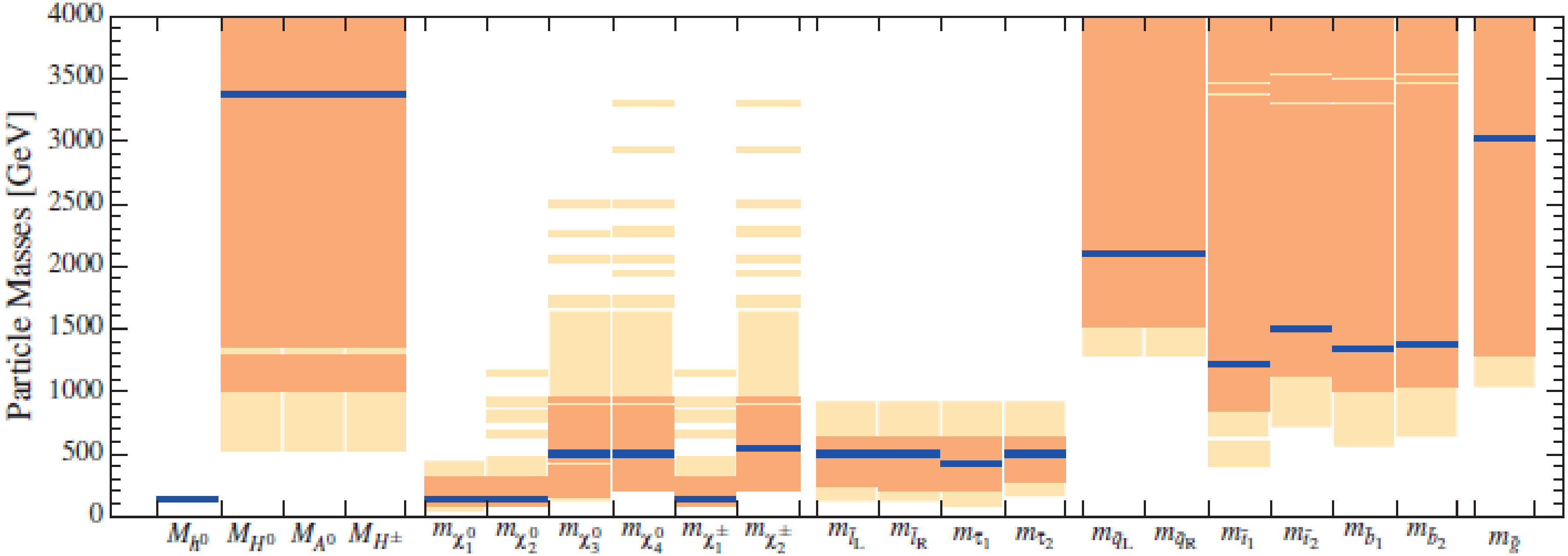
Discovery of new particles !

$$r_X = \frac{\Gamma(h \to X)}{SM}$$

BSM: prospects for direct searches at ILC250

[2015]

e^+e^- prospects for pMSSM10:



⇒ high colored masses

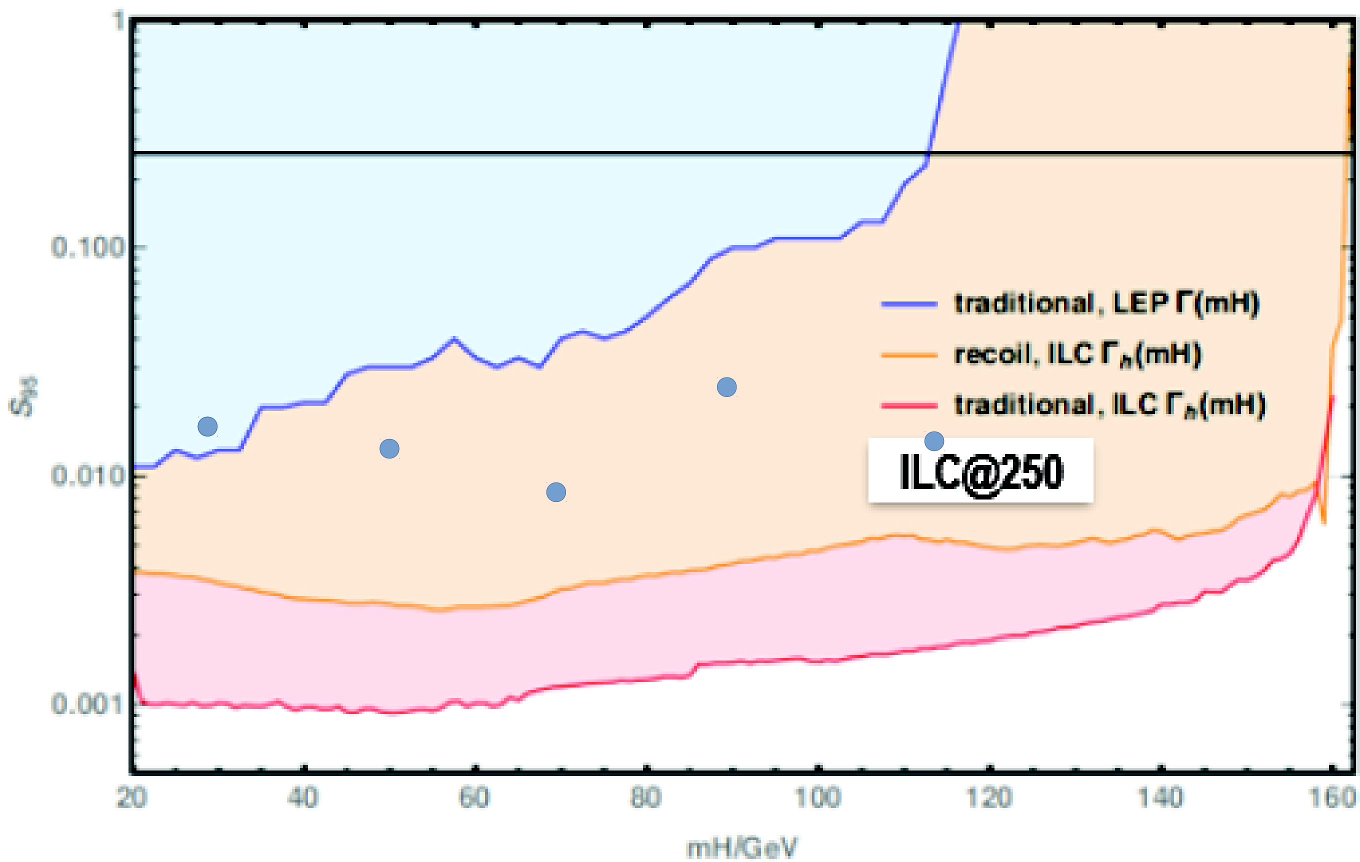
⇒ relatively low electroweak masses

partially with not too large ranges

⇒ clear prediction for ILC and CLIC

Application to ILC

- Combined limits for ILC at $\sqrt{s}$=250 GeV, (-80%,+30%), $\mathscr{L}$=2000fb^{-1}



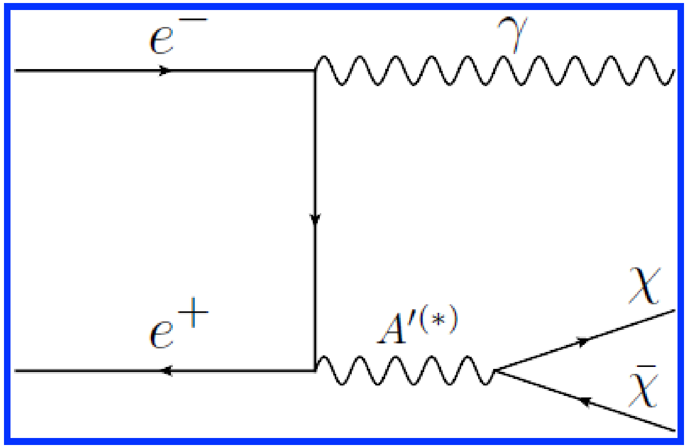
Projection from future LHC accuracy on couplings of state at 125 GeV

Klute ea '13,Lopez-Val ea '13

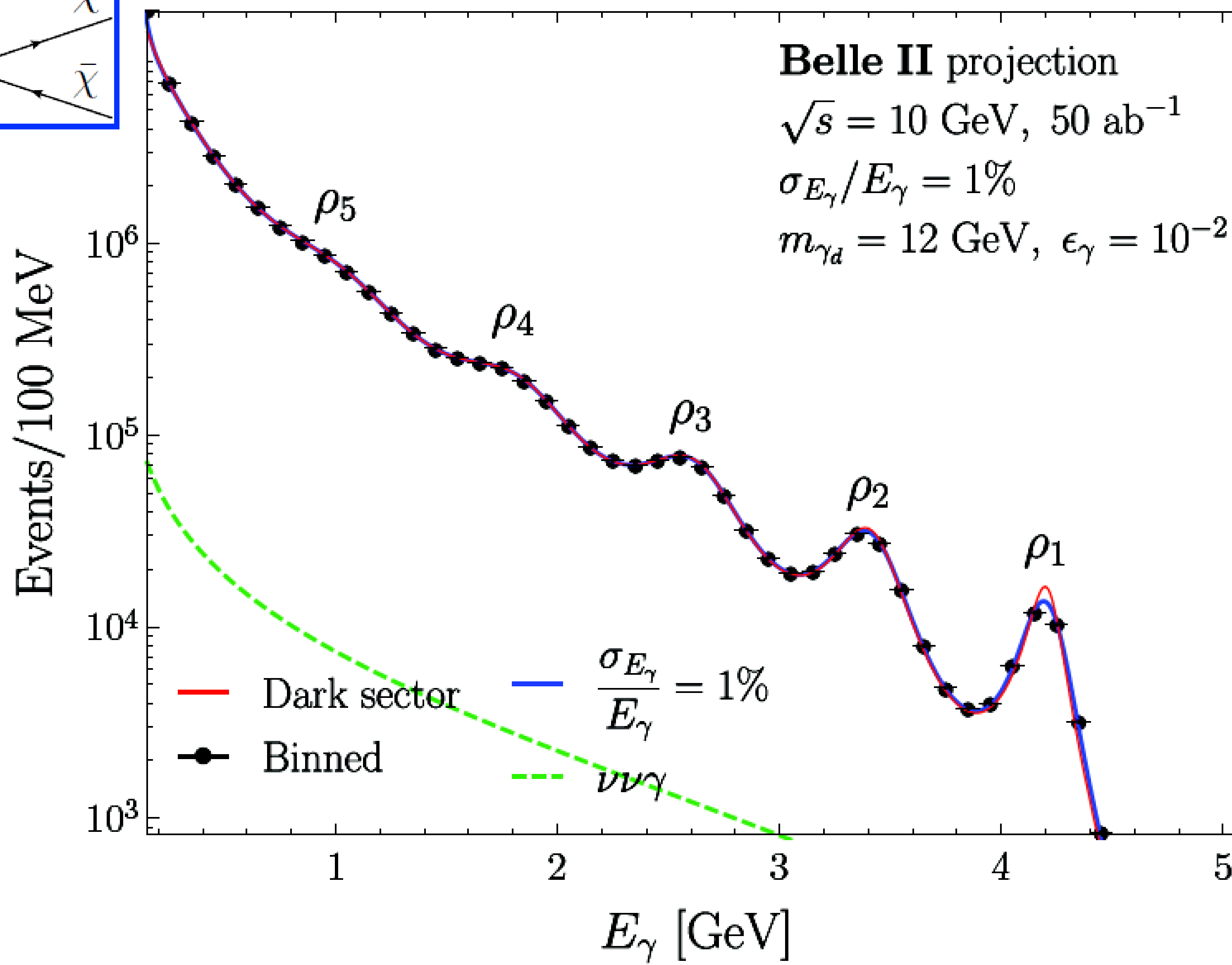
- Yan Wang *Searching for new light scalars at the ILC*

- *S95 ∈ [0.001-0.002] ('traditional' ILC) and [0.003-0.005] ('recoil',ILC)*

→ $g_{h1Z}/g^{SM}_{HZ} \in$ *[0.032-0.045]* *and [0.055- 0.071]*



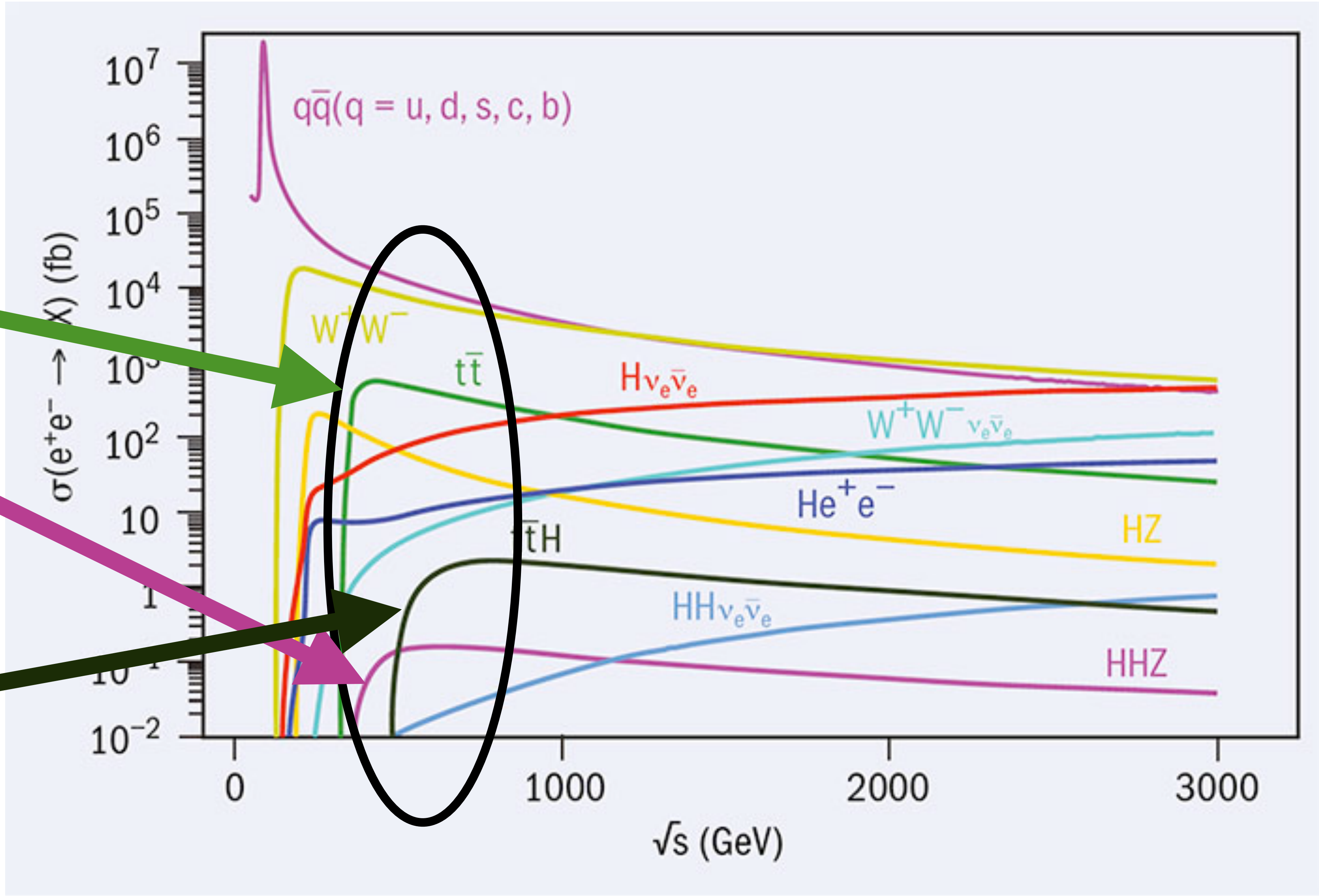
DM searches with $e^+e^- \to \gamma$ events



Hitoshi Murayama, *Dark Spectroscopy – a proposal for an ILC study*

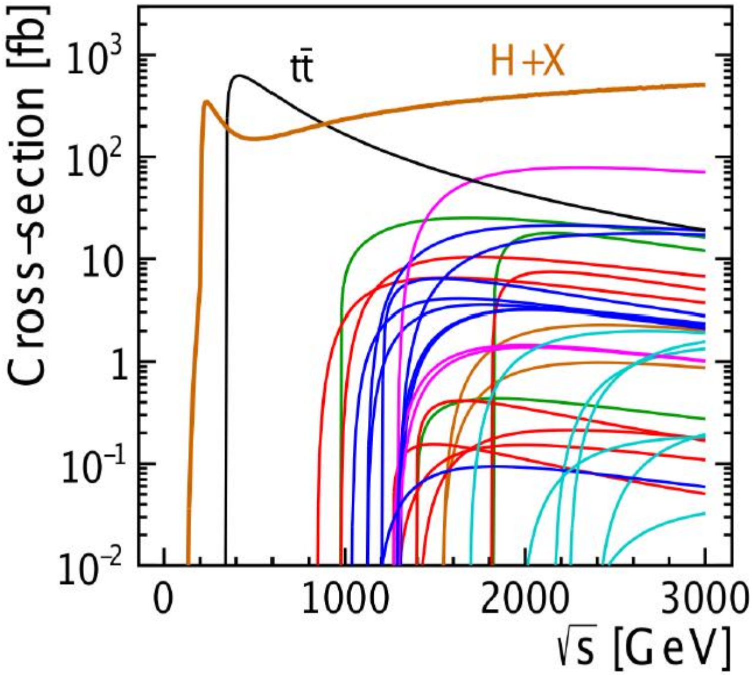
Why 250 GeV cannot be the end…

- **tt : ≳ 350 GeV**
- **ZHH : ≳ 450 GeV**
- **ttH : ≳ 500 GeV**

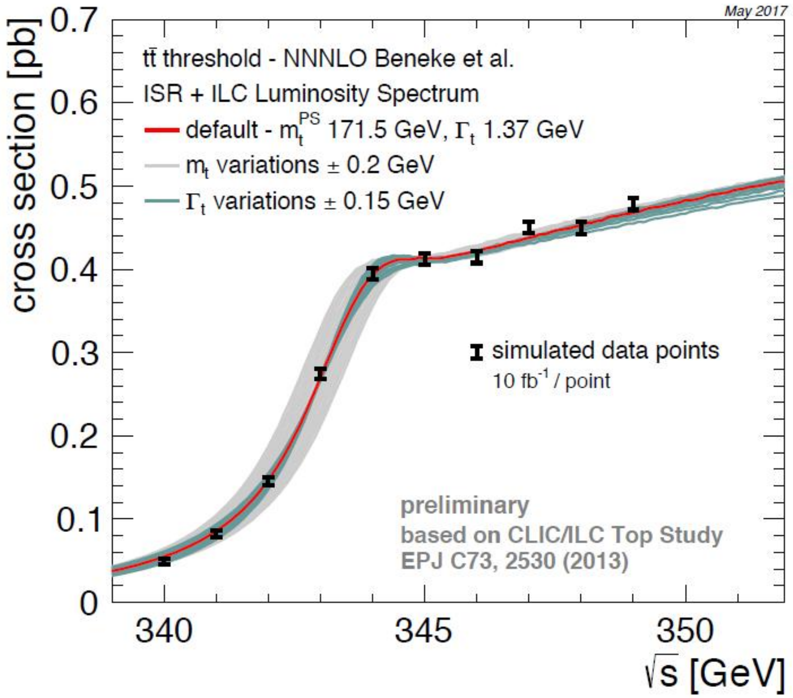


Top physics at 350-380 GeV

- Top mass (and width)
  - from threshold scan
  - from jet reconstruction
- Rare Top decays
- Precision electroweak couplings
- BSM physics in Top sector



Top threshold scan

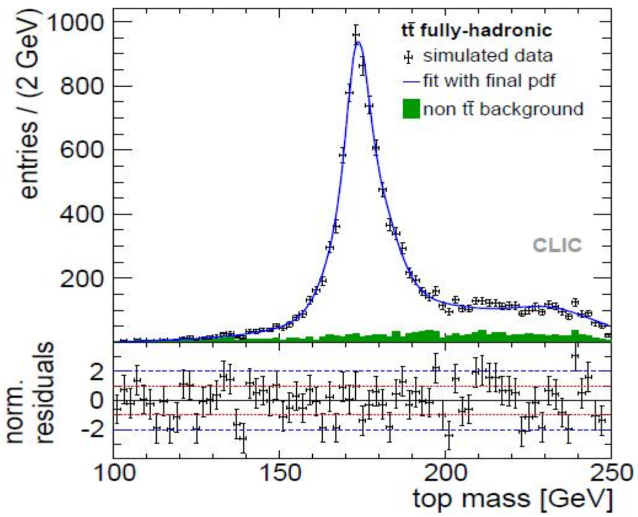


- 10 points, 10fb^{-1} each (1 year running at 350 GeV)
- Cross-section curve directly sensitive to the top mass, width, Yukawa coupling, strong coupling constant
- $\delta(m_t)$=±20MeV(stat) ±40MeV(syst) ±40 MeV(scale)
- $\delta(\Gamma_t)$=±45MeV(stat) ±60MeV(scale)

Frank Simon
Top@LC 2017

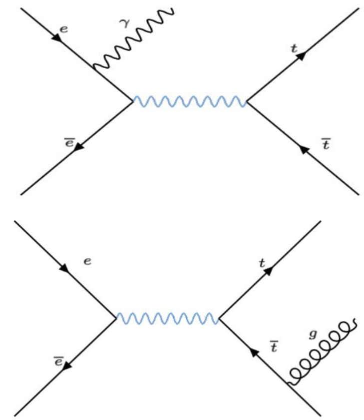
Top mass above threshold

Invariant mass reconstruction



- Experimental systematic error on m_t expected within ±100 MeV
- Significant theoretical errors from scale and colour reconnection uncertainties

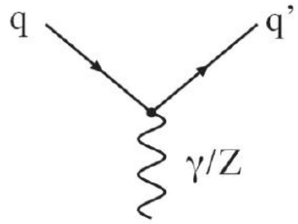
Radiative events

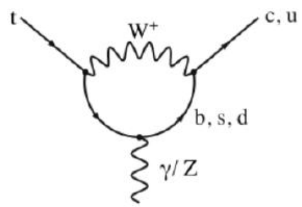


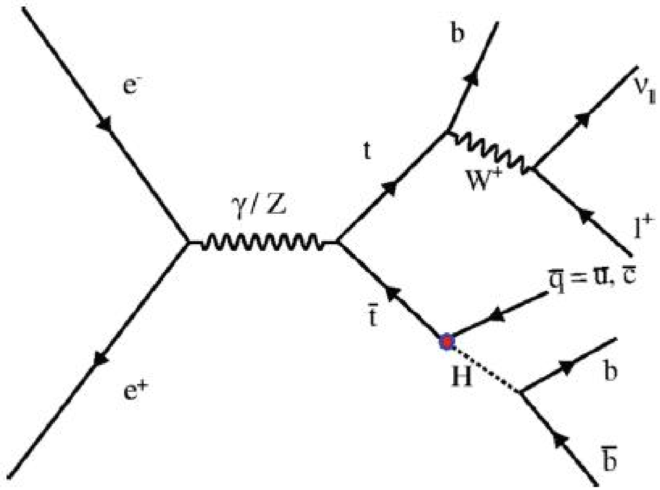
- Idea: measure differential cross-section of ISR (extra photon) or FSR (extra jet)
- Work in progress
- Very preliminary estimate: expect m_t precision of the order of ±100 MeV
- ➢ See the talk by Pablo at the Top session

Rare top decays

- The FCNC decays $t\to c\gamma/cZ/cg/cH$ have negligible branchings in the Standard Model (10^{-12}-10^{-14})
- Currently 2 channels are under study: $t\to c\gamma$ and $t\to cH$
- Signal: for $ee\to tt$ one top decays anomalously, another decay is standard, $t\to Wb$

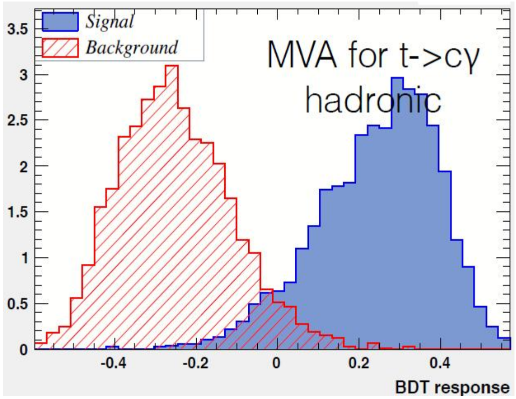


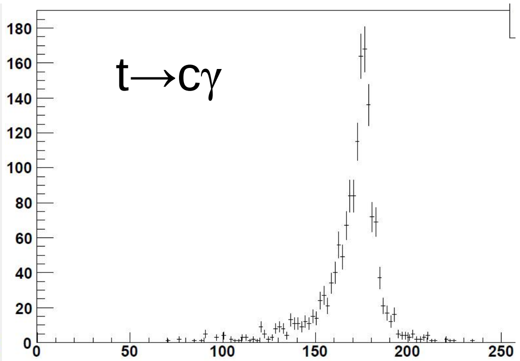




Rare top decays (work in progress!)

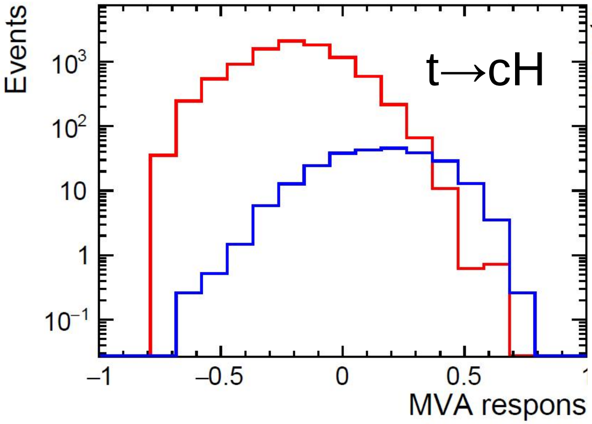
- $t \to c\gamma$
  - CLIC sensitivity: BR($t \to c\gamma$)<$0.3 \cdot 10^{-4}$ (95%CL)
  - Expected HL-LHC: $2 \cdot 10^{-4}$

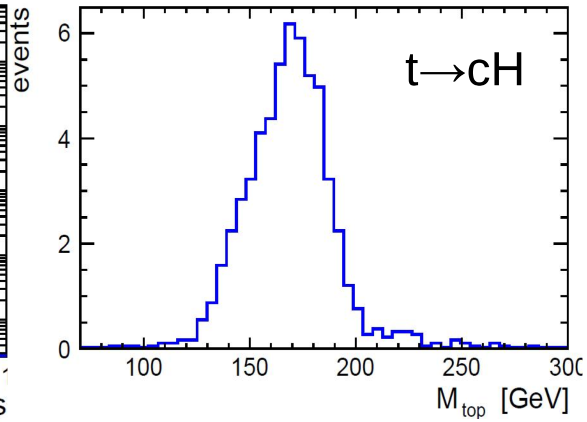




- $t \to cH$
  - CLIC sensitivity: BR($t \to cH$)<$1.6 \cdot 10^{-4}$ (95%CL)
  - Expected HL-LHC: $2 \cdot 10^{-4}$

➢ See talk by Filip at the Top session

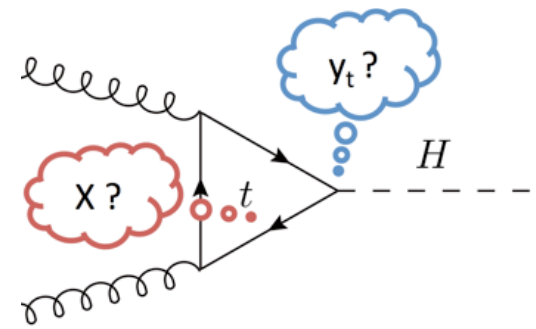


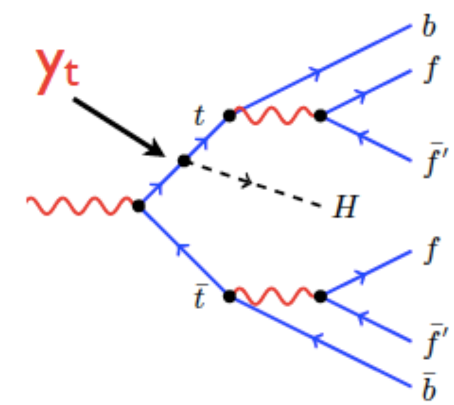


The Higgs and the Top

Direct Determination of the Top Yukawa Coupling

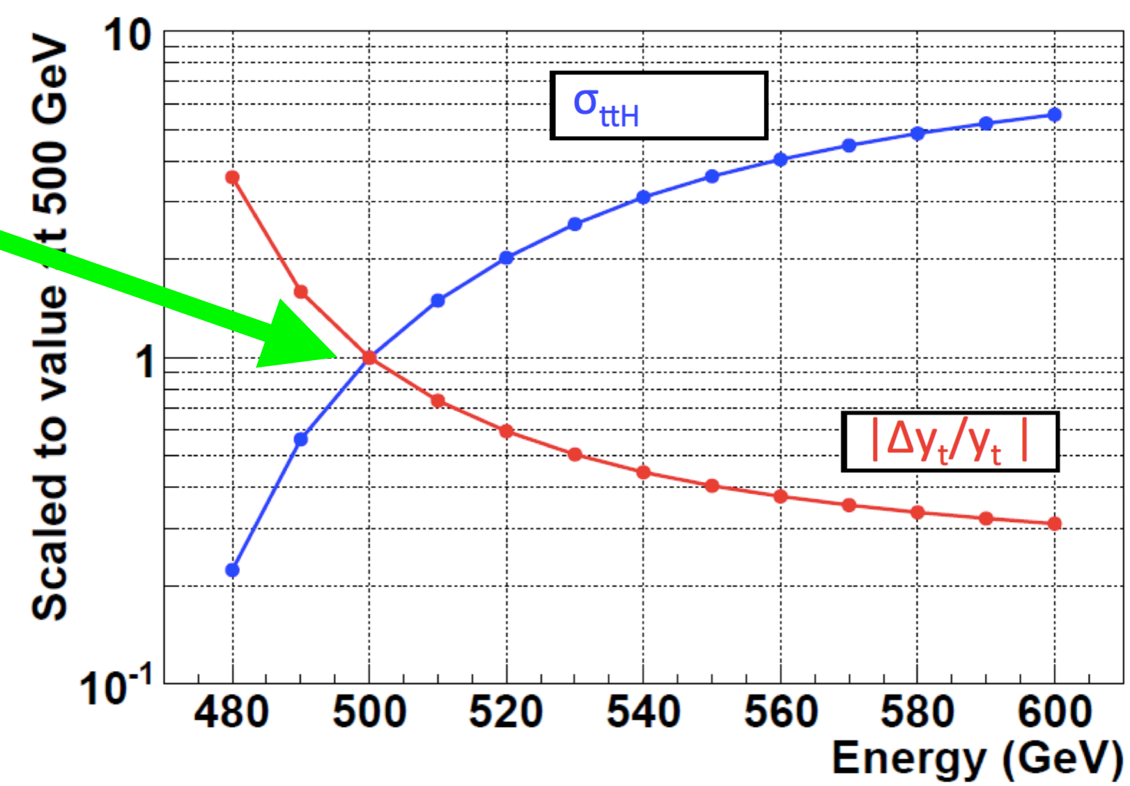
- **(HL-)LHC 14 TeV:**
  - SM σ(ttH) = 0.6 pb
  - "theory" studies indicate **δy_t ~15% (~10%)** with 300fb^{-1} (3ab^{-1}) might be possible **arXiv:1310.8361**



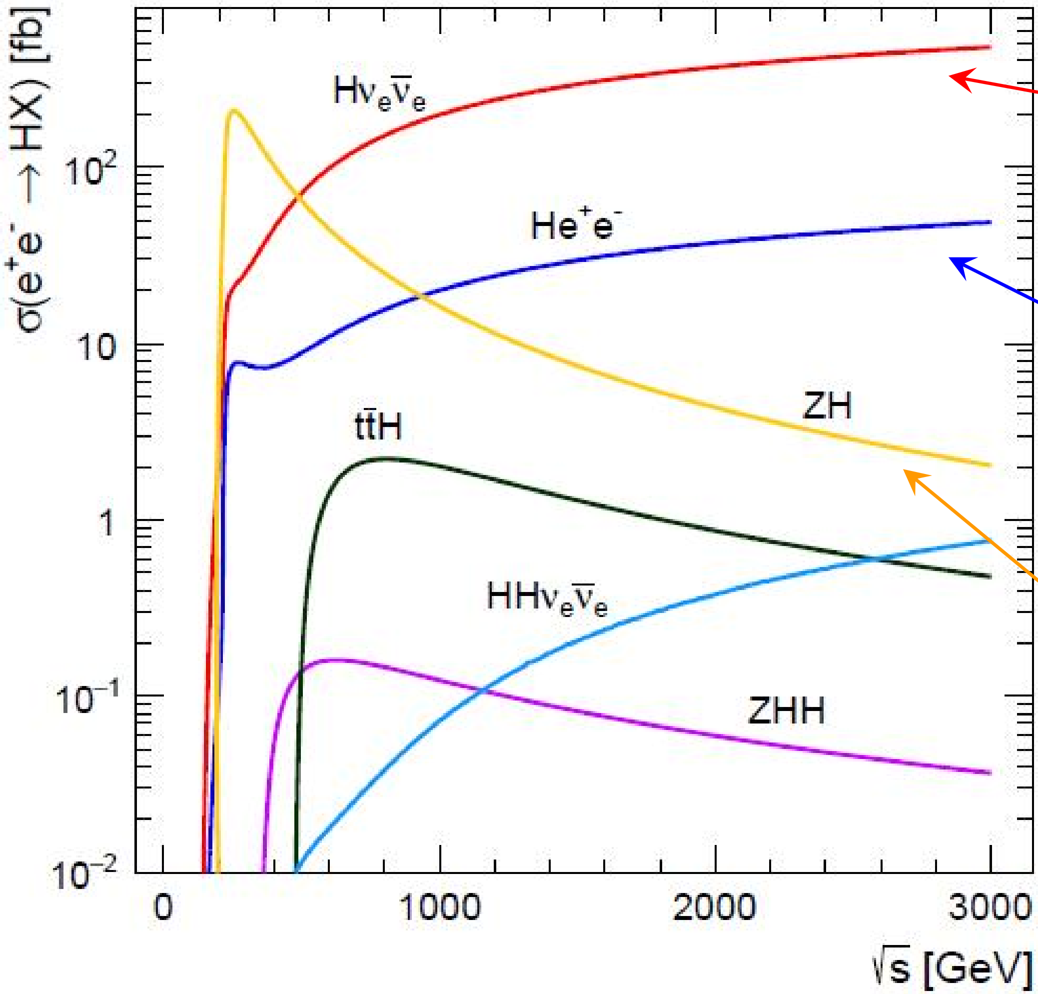


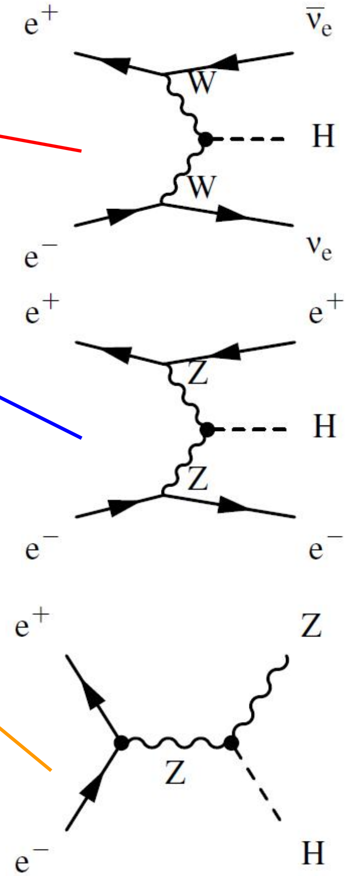
- **e^+e^-:**
  - **threshold at √s = 475 GeV**
  - SM σ(ttH) = 0.45fb @ 500 GeV => ILC full running scenario: **δy_t = 6.3%**
  - could be **2.5% if √s = 550 GeV**
  - **1 TeV, 4ab^{-1}: δy_t = 2%**
  - **CLIC 1.4 TeV, 1.5 ab^{-1}: δy_t = 4.2%**
    - no improvement at 3 TeV (σ drops)

Eur.Phys.J. C77 (2017) no.7, 475



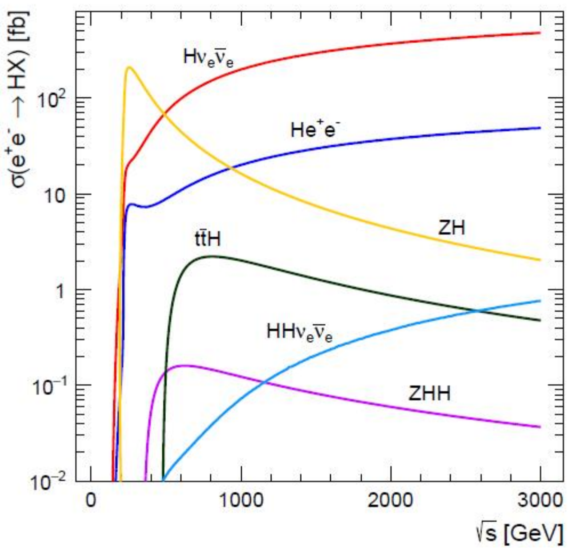
Higgs production at CLIC energies





Higgsstrahlung!

Expected Higgs statistics

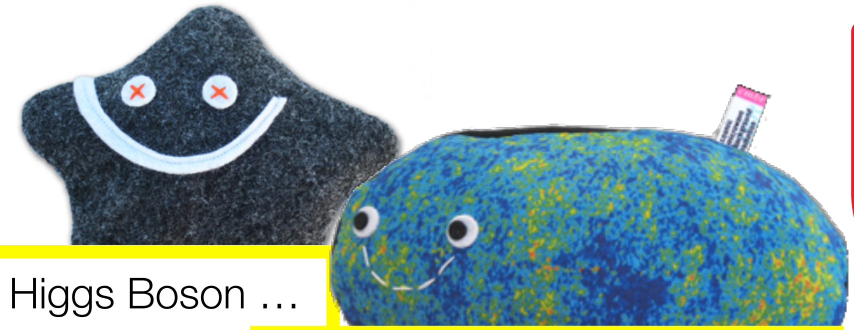


$\sqrt{s}$	350 GeV	1.4 TeV	3 TeV
$\mathscr{L}_{int}$	500 fb^{-1}	1.5 ab^{-1}	2 ab^{-1}
$\sigma(e^+e^- \to ZH)$	133 fb	8 fb	2 fb
$\sigma(e^+e^- \to H\nu_e\bar{\nu}_e)$	34 fb	276 fb	477 fb
$\sigma(e^+e^- \to He^+e^-)$	7 fb	28 fb	48 fb
# HZ events	68,000	20,000	11,000
# $H\nu_e\bar{\nu}_e$ events	17,000	370,000	830,000
# He^+e^- events	3,700	37,000	84,000

$P(e^-)=-80\%$: (HZ)x1.12, (H$\nu\nu$)x1.80

- The really big statistics will be provided by ee → H$\nu\nu$ at high energy running
- However, the ZH events at 350/380 GeV will provide a unique sample of “tagged” Higgses
  - Possibility of model-independent measurements

The Higgs self-coupling
Measurement Prospects

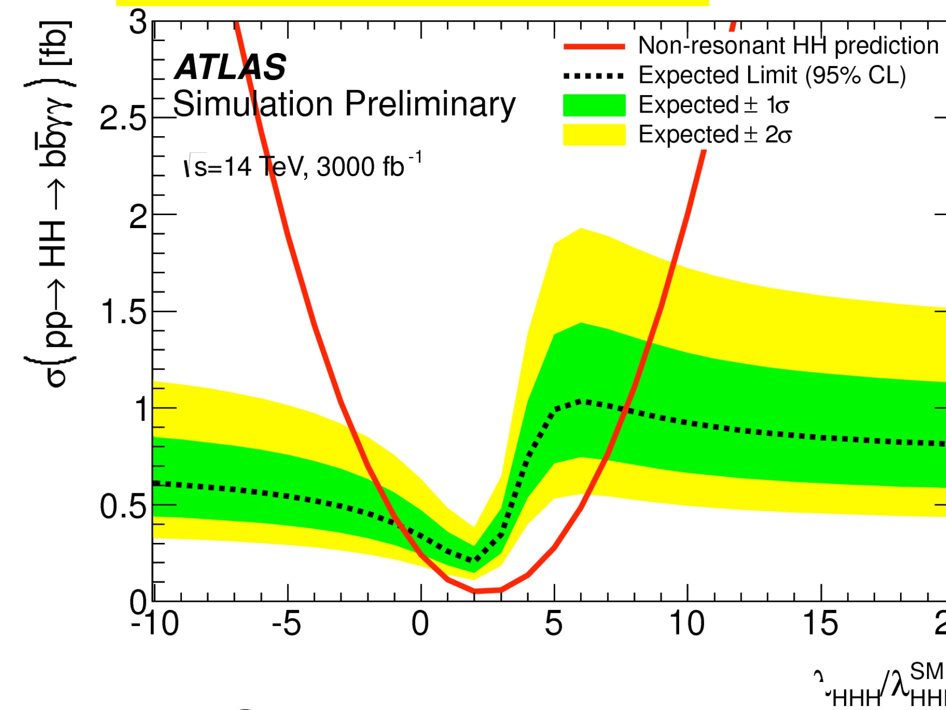


The Higgs Boson …

…and the universe

recent update: ATL-PHYS-PUB-2017-001

- **HL-LHC, generator-level + smearing:**
  1. Observation of HH < 3σ :(
  2. exclude extreme values of λ/λ_{SM} ≲0 and ≳ 8 assuming that all other couplings = SM



Dissertation C.Dürig, Uni Hamburg, 2016

- **e^+e^- at 500 GeV, ZHH, full simulation:**
  1. Observation of HH with ~8σ ✔
  2. extract $\lambda|_{SM}$ with 27% uncertainty
  3. recent demonstration that parametric uncertainties from other couplings well under control with full ILC Higgs program

arXiv:1708.09079

- **e^+e^- at > 500 GeV, vvHH, full simulation:**
  - 1 TeV, 4ab^{-1}: $\delta\lambda/\lambda\,|_{SM}$ = 10%
  - 1.4 TeV, 1.5ab^{-1}: $\delta\lambda/\lambda\,|_{SM}$ = 40%
  - + 3 TeV, 3ab^{-1}: $\delta\lambda/\lambda\,|_{SM}$ = 16%
  - upcoming improvement: exploit differential distributions at 3 TeV: expect ~ 10%

Eur.Phys.J. C77 (2017) no.7, 475

The Higgs self-coupling

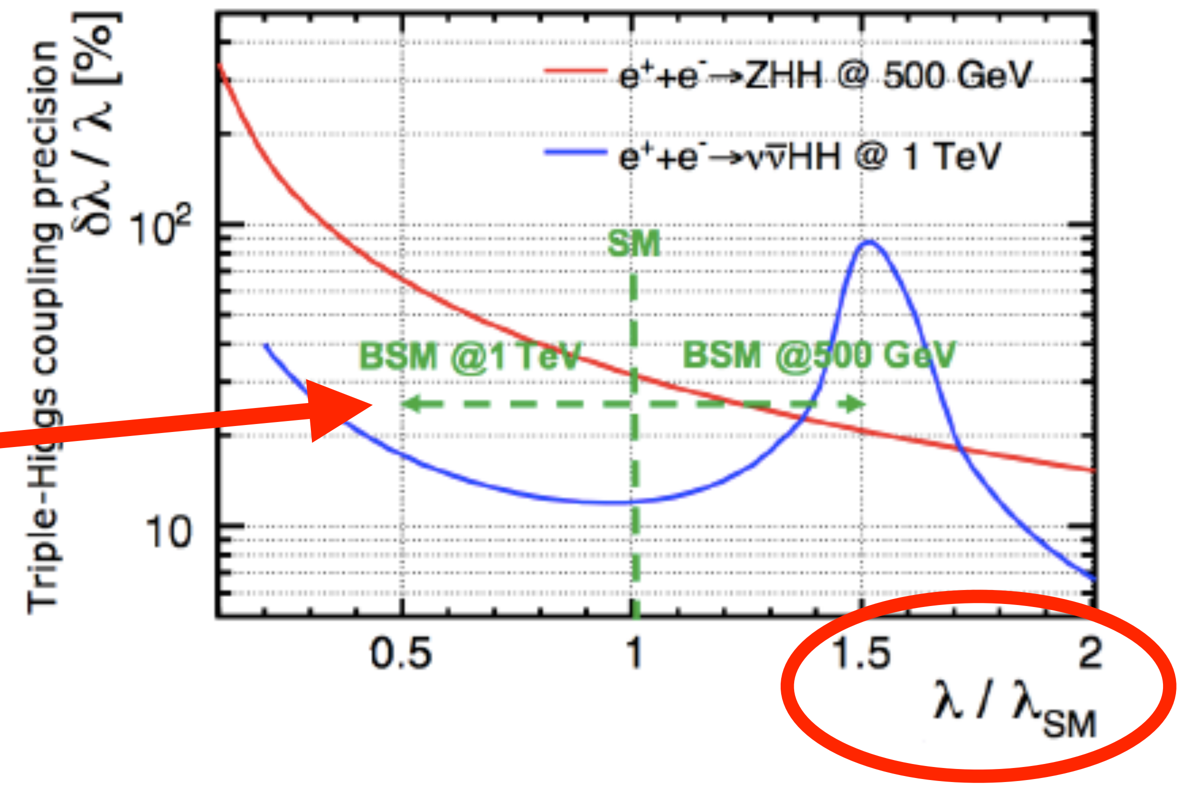
Measurement Prospects

In any case: e^+e^- offers significant added value w.r.t. HL-LHC

Important: achievable precision depends strongly on actual value of λ!

=> BSM can change the picture

=> with combination of ZHH and vvHH we're always on the safe side!



Dissertation C.Dürig, Uni

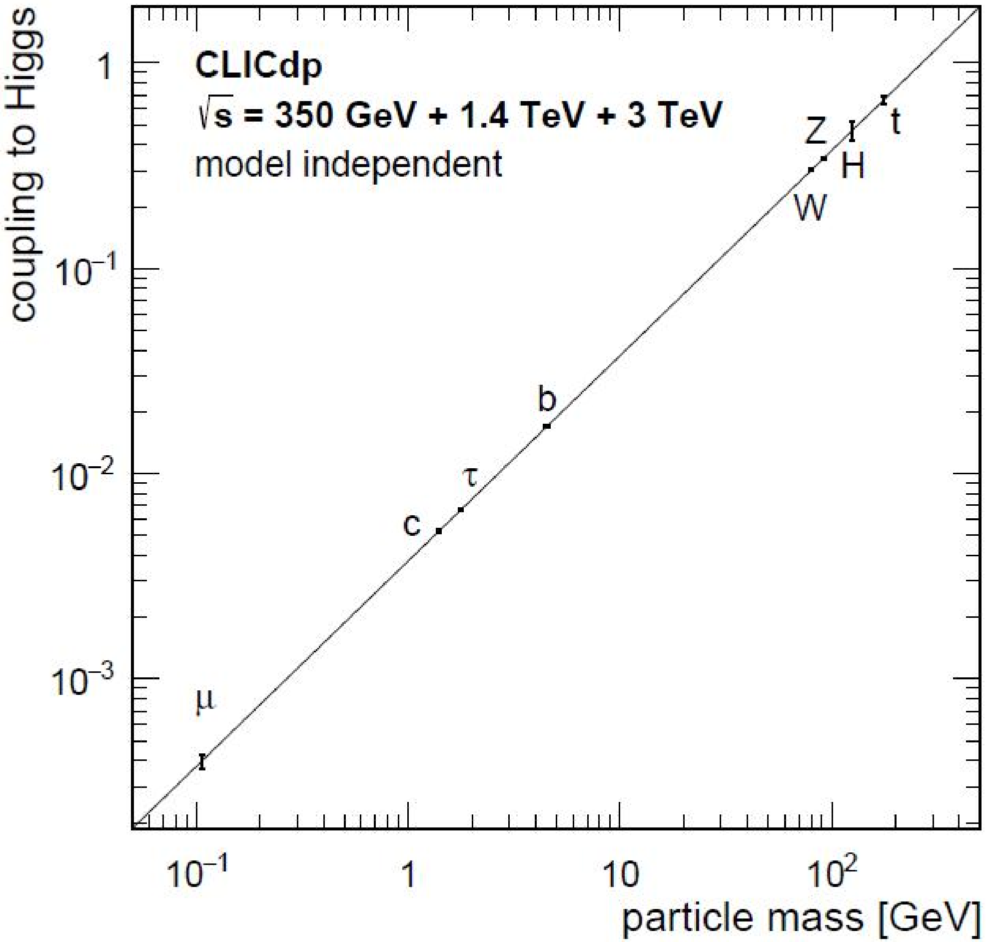
3. recent demonstration that parametric uncertainties from other couplings well under control with full ILC Higgs program

arXiv:1708.09079

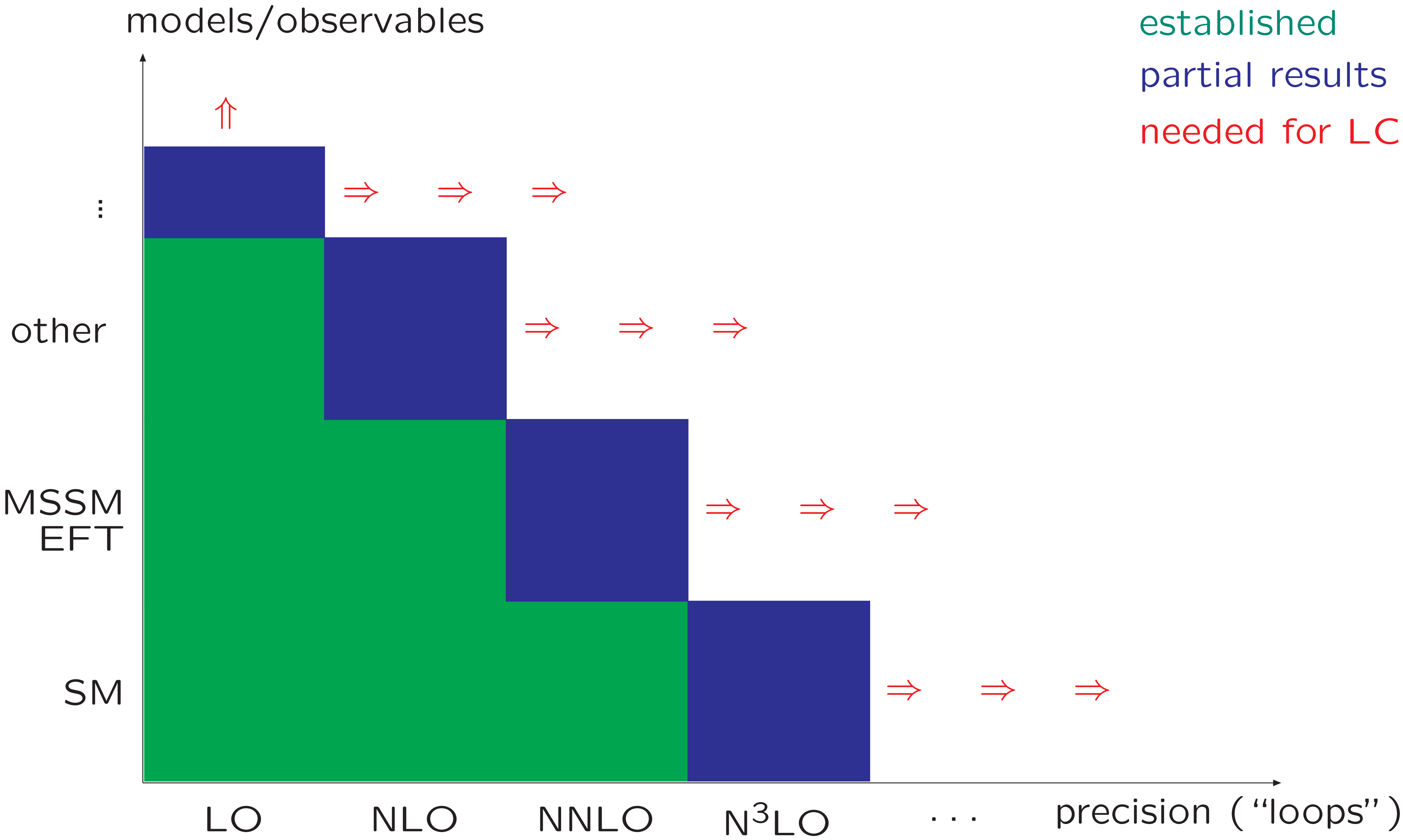
- 1.4 TeV, 1.5ab^{-1}: $\delta\lambda/\lambda\,|_{SM}$ = 40%
- + 3 TeV, 3ab^{-1}: $\delta\lambda/\lambda\,|_{SM}$ = 16%
- upcoming improvement: exploit differential distributions at 3 TeV: expect ~ 10%

Eur.Phys.J. C77 (2017)

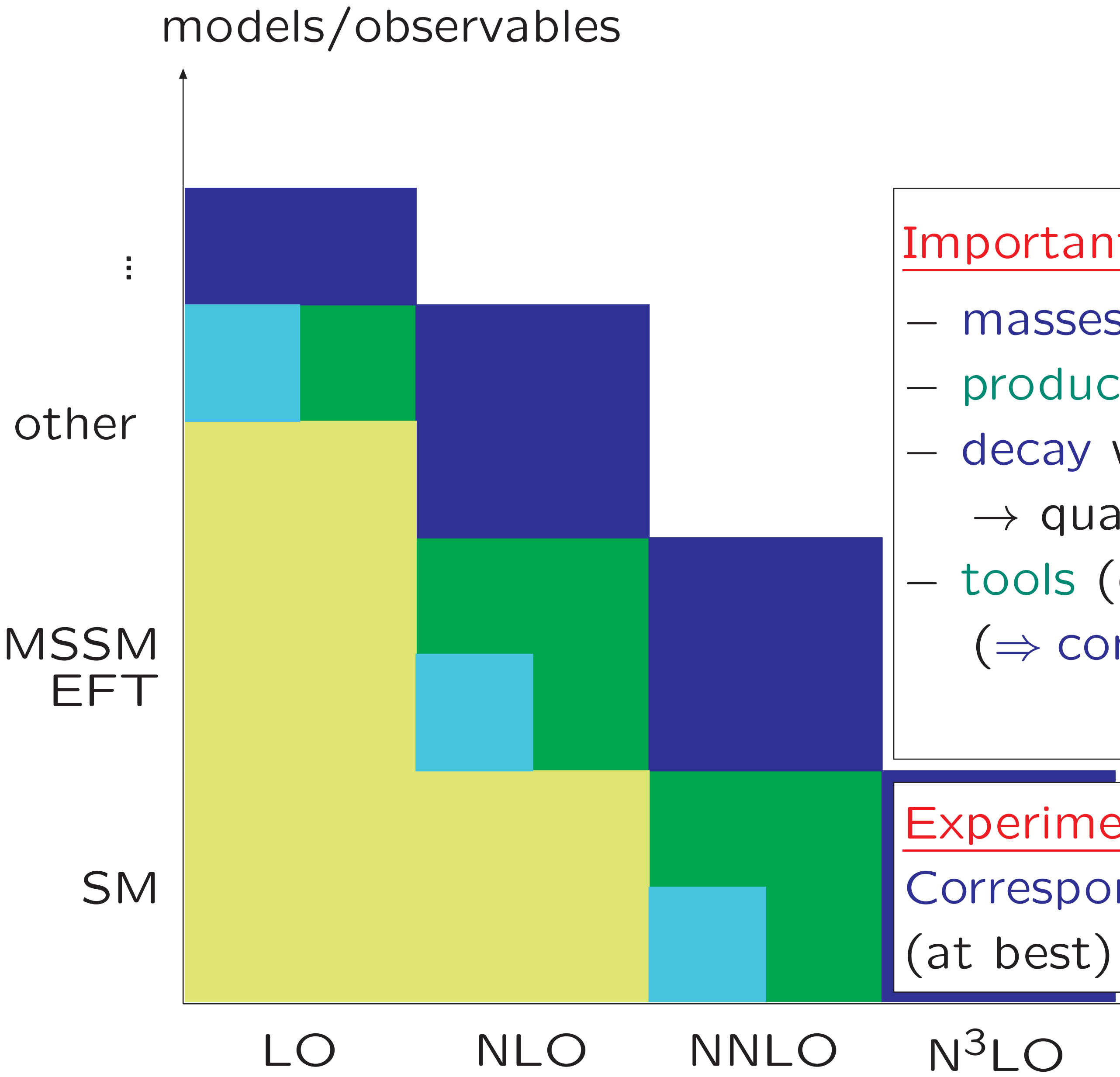
Higgs coupling precision



Higgs: theory situation



Higgs: experimental situation



Important observables:

– masses (parameter relations)
– production cross sections
– decay widths + distributions
  → quantum numbers
– tools (computer codes)
  (⇒ connection to experiment)

Experimental situation:

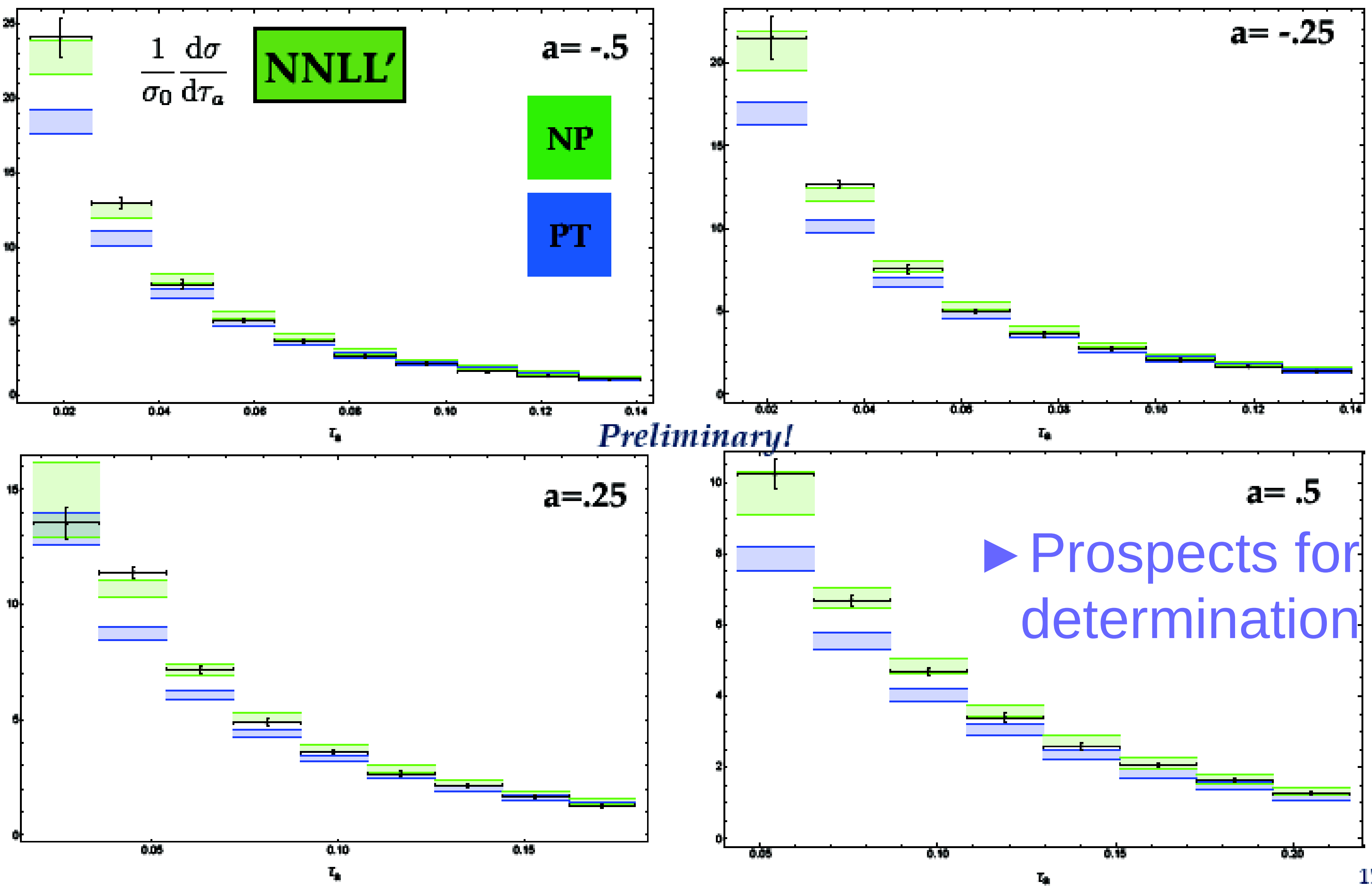
Corresponding analyses
(at best) full simulations

QCD: progress in event shape variable description in e^+e^-

Comparison with LEP data (L3)

NNLL' + $\mathcal{O}(\alpha_s^2)$ results $[Q = m_Z]$

$A = .283 \quad \alpha_s(m_Z) = .1161$

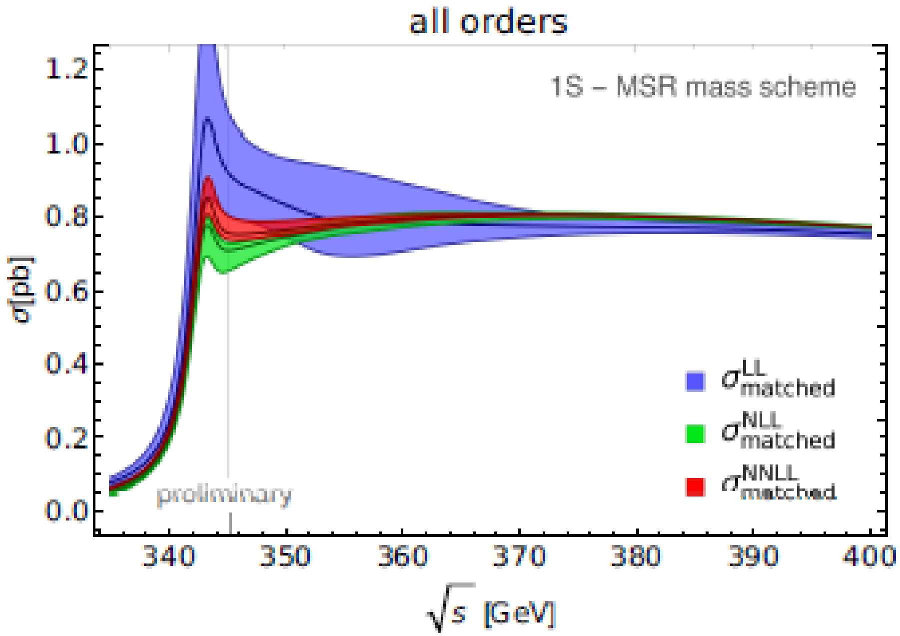


▶ Prospects for α_s determination

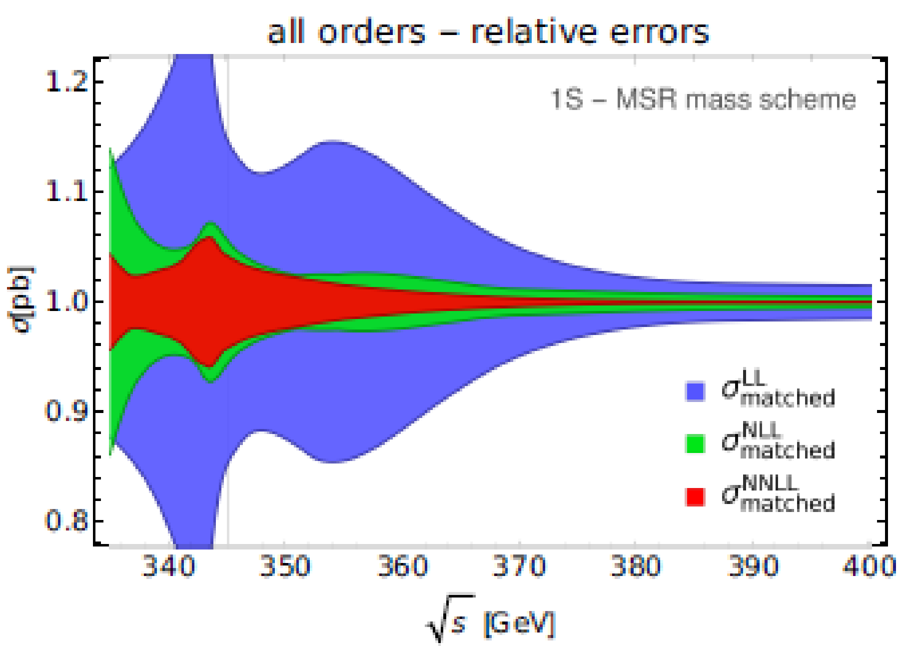
James Talbert et al. *Event shapes for precision QCD studies at lepton colliders*

QCD: progress in top threshold modeling

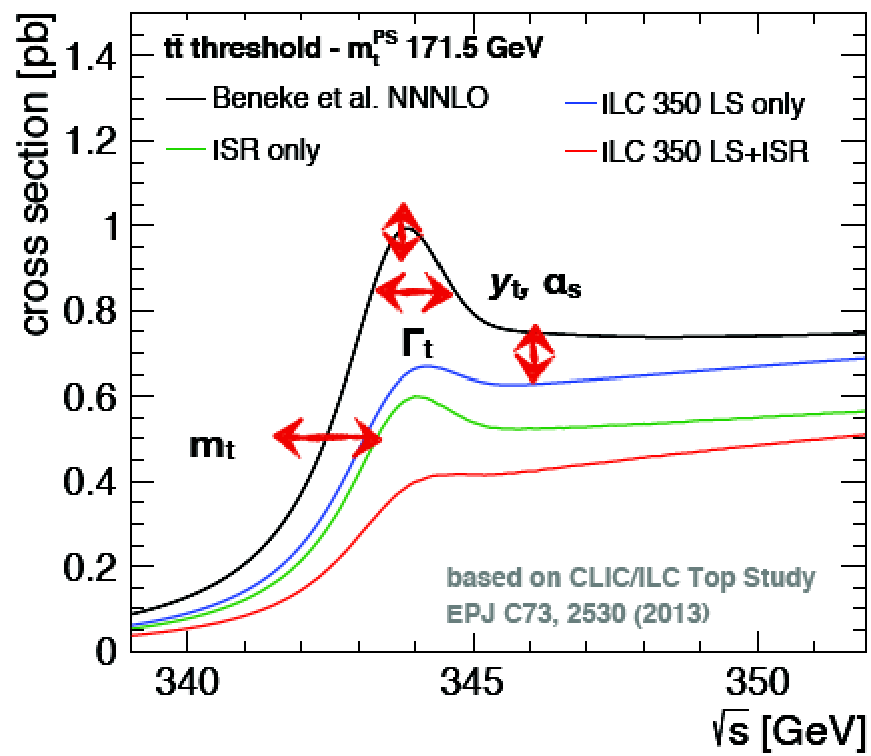
▶ reduced systematic uncertainties



$\sigma_{matched}$	σ_{NRQCD}		σ_{QCD}
LL	LL	$\longleftrightarrow$	NLO
NLL	NLL	$\longleftrightarrow$	NNLO
NNLL	NNLL	$\longleftrightarrow$	NN^3LO



Frank Simon, *Top threshold scan*



Angelika Widl *Threshold - Continuum Matching at NNLL*

Prospects

Bruno Mazoyer LAL Orsay 2017

Tatsuya Nakada (LCWS17- 2017)

- The Japanese Association for High Energy Physicists produced a new statement by July 2017:

  "To conclude, in light of the recent outcomes of LHC Run 2, **JAHEP proposes to promptly construct ILC as a Higgs factory with the center-of-mass energy of 250 GeV in Japan."**

  Documents are publically available at :

  - Japanese community statement http://www.jahep.org/files/JAHEP-ILCstatement-170816-EN.pdf
  - Japanese community study on physics of 250 GeV machine http://www.jahep.org/files/ILC250GeVReport-EN-FINAL.pdf

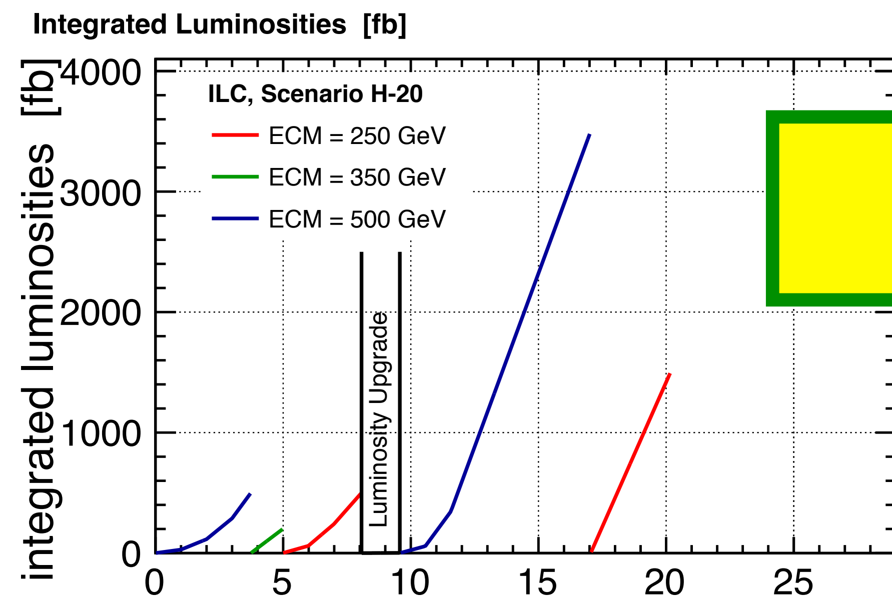
  (Full text included at the end of this presentation in backup slides)

- **This statement also implies a cost reduction of up to 40% as compared to the 500 GeV machine in the TDR.**

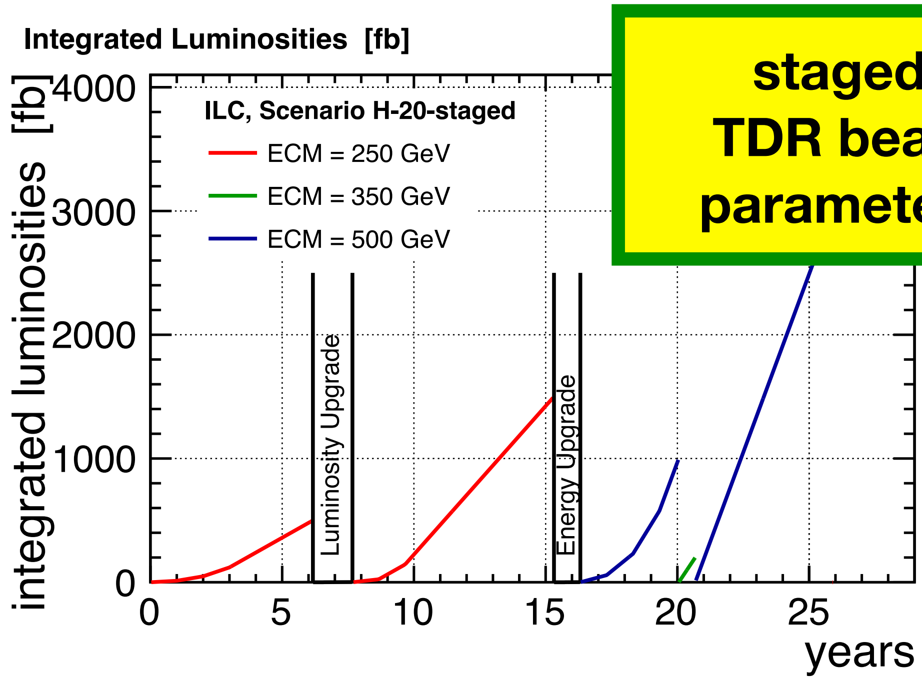
Looking beyond 250 GeV

A Linear Collider is *extendable* in length = energy !

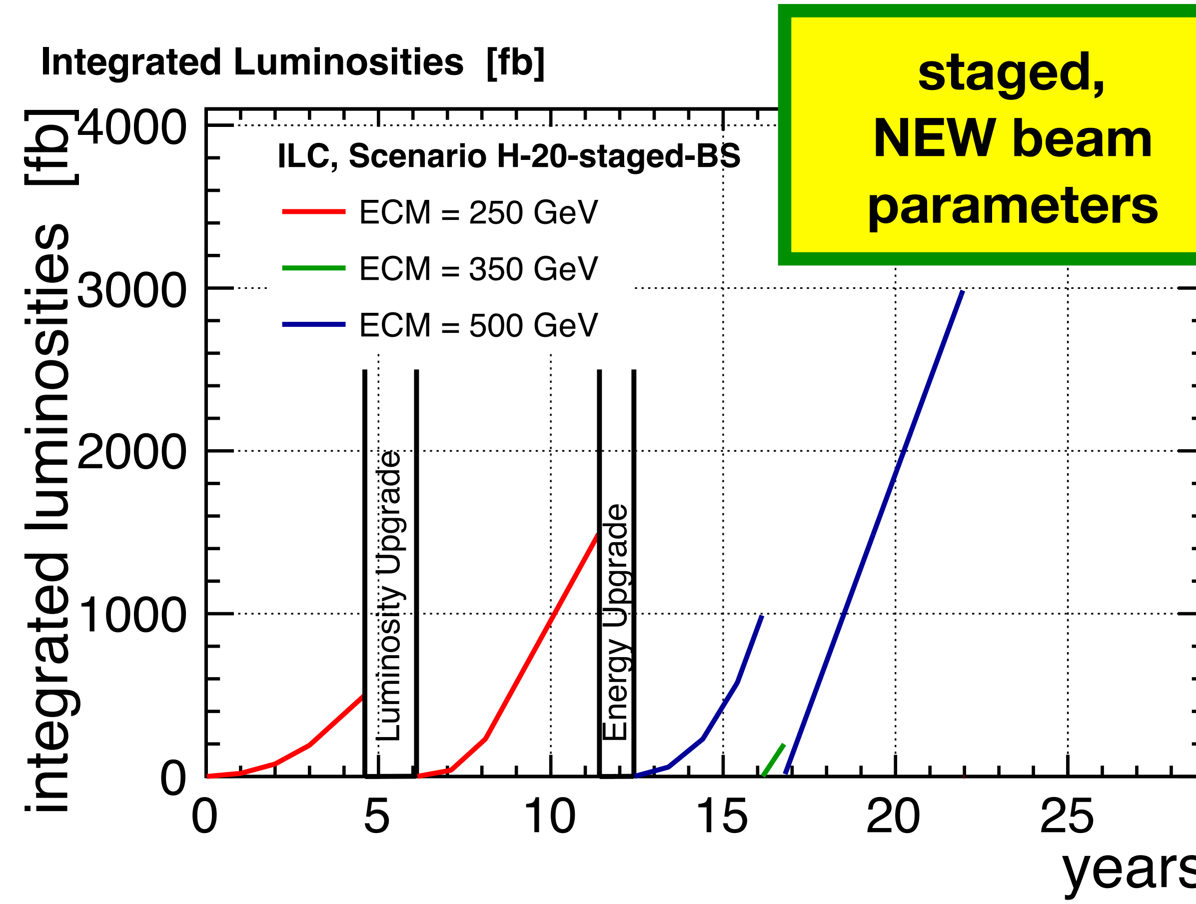
The *total* ILC run plan is still the full H-20 scenario



H-20

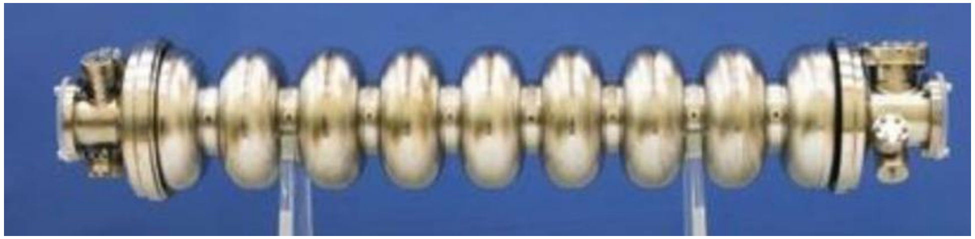


staged, TDR beam parameters



staged, NEW beam parameters

US-Japan cost reduction



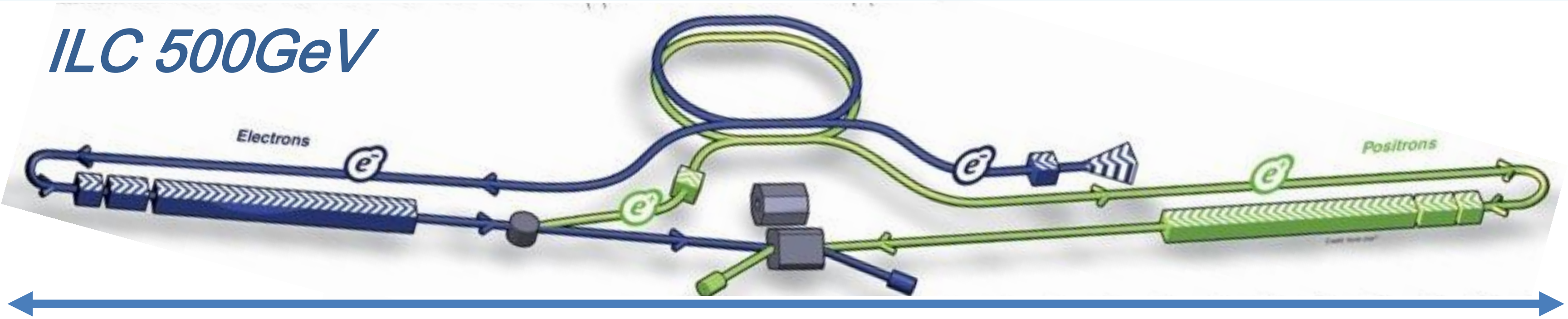
Cost reduction by technological innovation

Innovation of Nb (superconducting) material process: decrease in material cost

Innovative surface processing for high efficiency cavity by FNAL: decrease in number of cavities

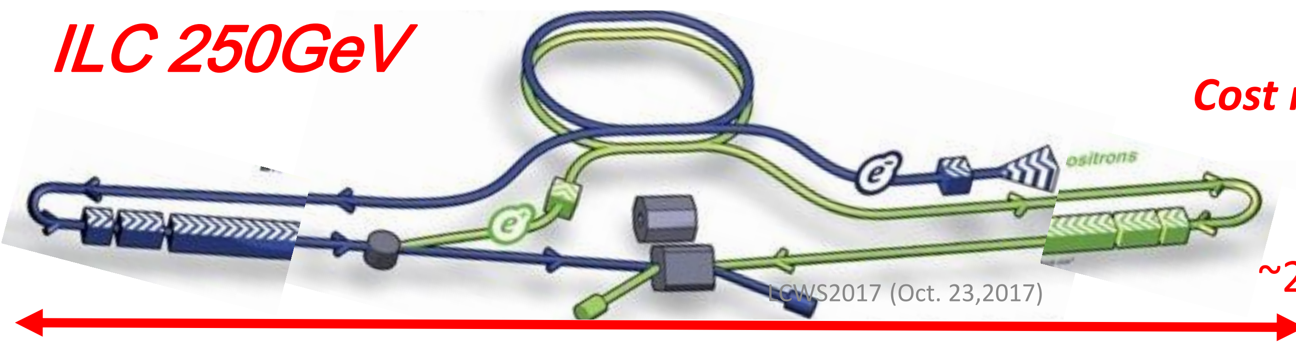
Staging

ILC 500GeV



~31km

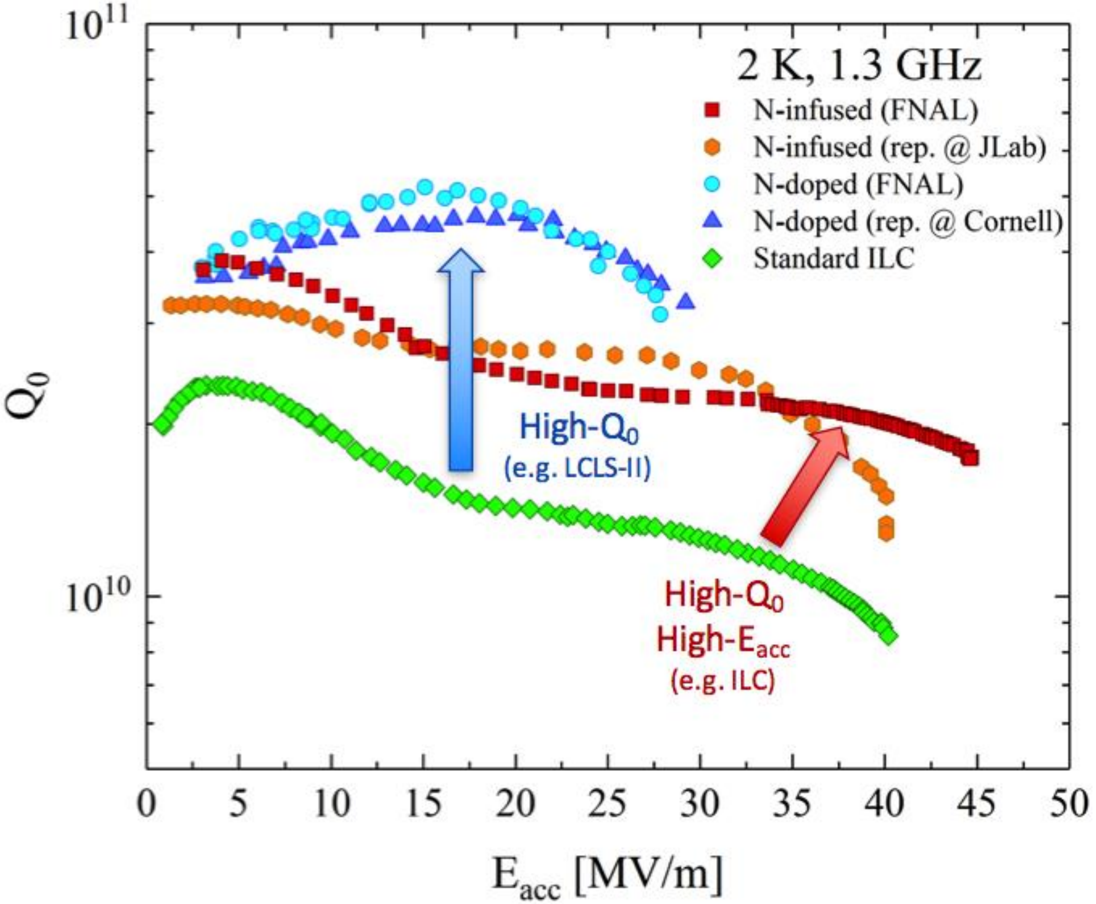
ILC 250GeV



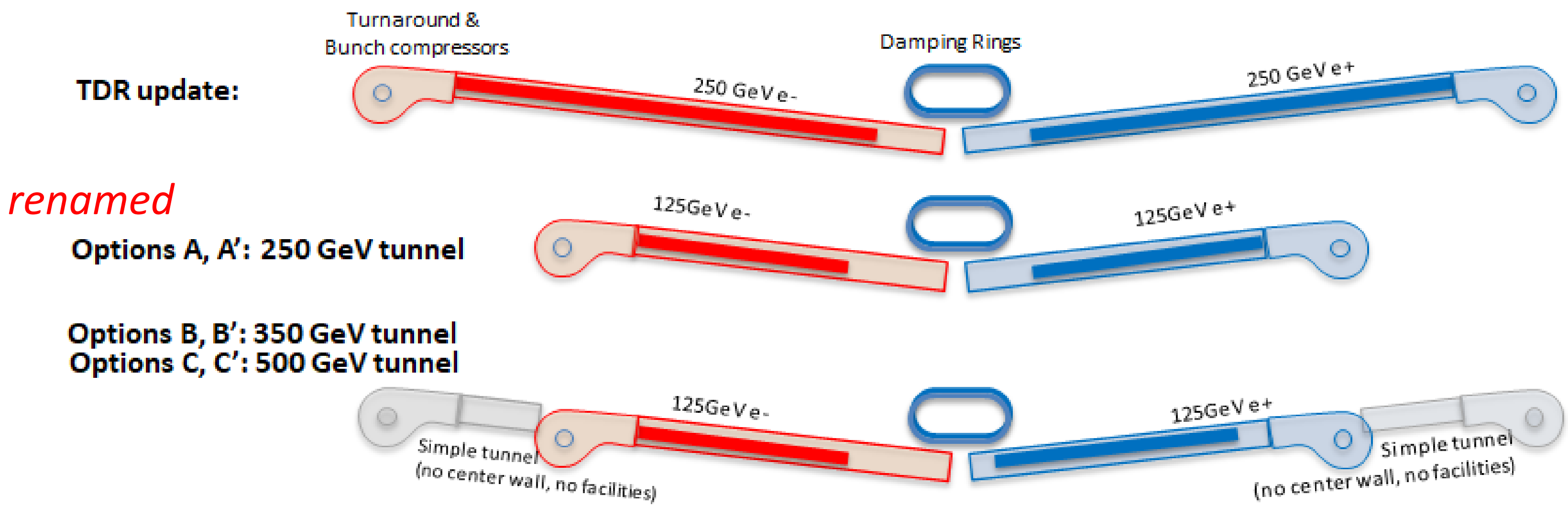
Cost reduction by compact ILC

~20km

R & D for *ILC – SRF* Cost Reduction



Options for ILC250GeV



Options	Gradient [MV/m]	E_{CM} [GeV]	Total E_{CM} Margin	n	Space margin	Reserved tunnel	Total tunnel
TDR update	31.5	500	2%	10	1,473 m	0 m	33.5 km
Option A		250	6%	6	583 m	0 m	20.5 km
Option B				6&8		3,238 m	27 km
Option C				6&10		6,477 m	33.5 km
Option A'	35			6	1,049 m	0 m	20.5 km
Option B'				6&8		3,238 m	27 km
Option C'				6&10		6,477 m	33.5 km

Results of cost estimate

The cost estimate is carried out with the ILCU (USD as of January, 2012).
RF unit cost and other unit cost is calculated from TDR.
The staging cost is obtained by subtracting the decreased number of units.
Reduced volume production effect and price fluctuation from 2012 are ignored because these depend on the different components.
Options A'/B'/C' include the effect the cost reduction R&D.

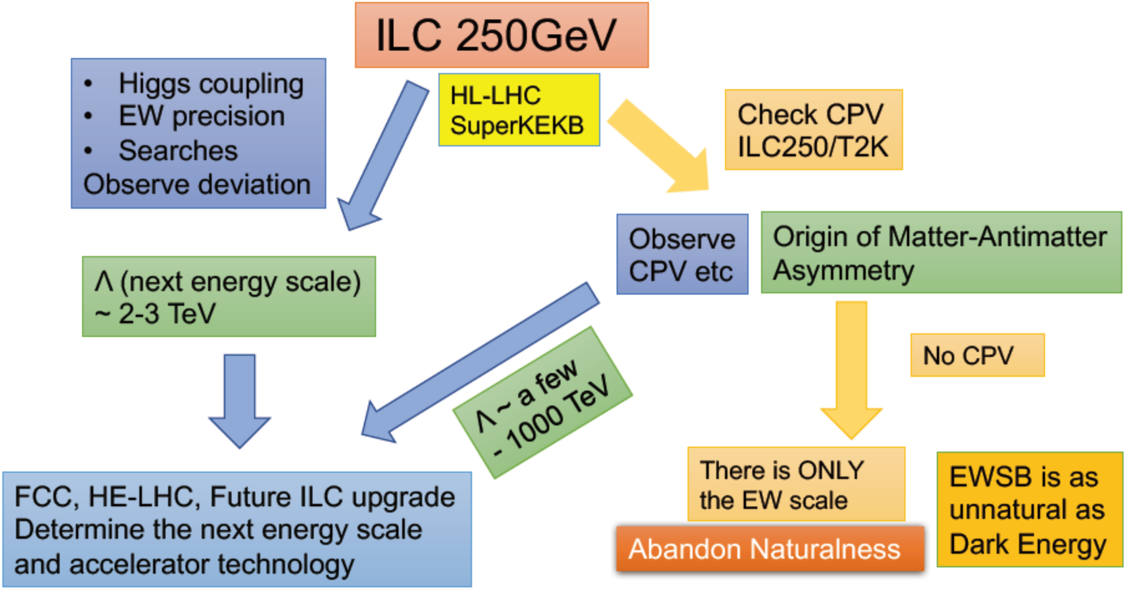
	e+/e- collision [GeV]	Tunnel Space for [GeV]	Value Total (MILCU)	Reduction [%]
TDR	250/250	500	7,980	0
TDR update	250/250	500	7,950	-0.4
Option A	125/125	250	5,260	-34
Option B	125/125	350	5,350	-33
Option C	125/125	500	5,470	-31.5
Option A'	125/125	250	4,780	-40
Option B'	125/125	350	4,870	-39
Option C'	125/125	500	4,990	-37.5

Y. Okada (LCWS-2017)

Conclusion of JAHEP statement July 2017:

- **ILC250 should run concurrently with HL-LHC** to enhance physics outcomes from LHC.
- Given that a new physics scale is yet to be found, ILC250 is expected to deliver physics outcomes that are nearly comparable to those previously estimated for ILC500 in **precise examinations of the Higgs boson** and the Standard Model.
- **The ILC250 Higgs factory, together with HL-LHC and SuperKEKB**, will play an indispensable role in the discovery of new phenomena originating from new physics with the **energy scale up to 2–3 TeV** and the elucidation of the origin of matter-antimatter asymmetry.
- A linear collider has a definite advantage for **energy-upgrade capability**. ILC250 possesses a good potential for its upgrades to reach the higher energy of new physics that the findings of ILC250 might indicate.

Determination of new physics energy scale



Physics of vacuum: change from Bottom-up approaches to Top-down approaches ($10^{11,16,19}$ GeV)

ICFA Statement

ICFA Statement on the ILC Operating at 250 GeV as a Higgs Boson Factory

The discovery of a Higgs boson in 2012 at the Large Hadron Collider (LHC) at CERN is one of the most significant recent breakthroughs in science and marks a major step forward in fundamental physics. Precision studies of the Higgs boson will further deepen our understanding of the most fundamental laws of matter and its interactions.

The International Linear Collider (ILC) operating at 250 GeV center-of-mass energy will **provide excellent science from precision studies of the Higgs boson**. Therefore, ICFA considers the ILC a key science project complementary to the LHC and its upgrade.

ICFA **welcomes the efforts** by the Linear Collider Collaboration on cost reductions for the ILC, which indicate that up to **40% cost reduction** relative to the 2013 Technical Design Report (500 GeV ILC) is possible for a 250 GeV collider.

ICFA emphasizes the **extendibility of the ILC to higher energies** and notes that there is large discovery potential with important additional measurements accessible at energies beyond 250 GeV.

ICFA thus supports the conclusions of the Linear Collider Board (LCB) in their report presented at this meeting and very strongly **encourages Japan to realize the ILC in a timely fashion** as a Higgs boson factory with a center-of-mass energy of 250 GeV **as an international project[1], led by Japanese initiative**.

[1]In the LCB report the European XFEL and FAIR are mentioned as recent examples for international projects.

Ottawa, November 2018

Diet members speeches at LCWS2017 in Strasbourg

Hon. Takeo KAWAMURA

Member, House of Representatives
Liberal Democratic Party

Constituency: Yamaguchi 3
Number of times elected: 10

Born: November 10, 1942
Education: Keio University

Current Position:
Director, Province Creation Headquarters of Liberal Democratic Party
Chair, Special Committee on Space and Marine Development of Liberal Democratic Party

Career:

2001–2004	Vice Minister of Education, Culture, Sports, Science and Technology
2003–2004	Minister of Education, Culture, Sports, Science and Technology
2008–2009	Chief Cabinet Secretary
2010–2014	Director, Election Headquarters of Liberal Democratic Party
2016	Chair, Committee on National Budget of House of Representatives

Hon. Ryu SHIONOYA

Member, House of Representatives
Liberal Democratic Party

Constituency: Shizuoka 8
Number of times elected: 9

Born: February 18, 1950
Education: Keio University

Current Position:
Chairman, Election Strategy Committee, Liberal Democratic Party

Career:

2008–2009	Minister of Education, Culture, Sports, Science and Technology
2011–2012	Chairman, Executive Council, Liberal Democratic Party
2012–2014	Chairman, Committee on Science-Technology-Innovation Strategy, Liberal Democratic Party

Hon. Tatsuo HIRANO

Member, House of Councilors
Liberal Democratic Party

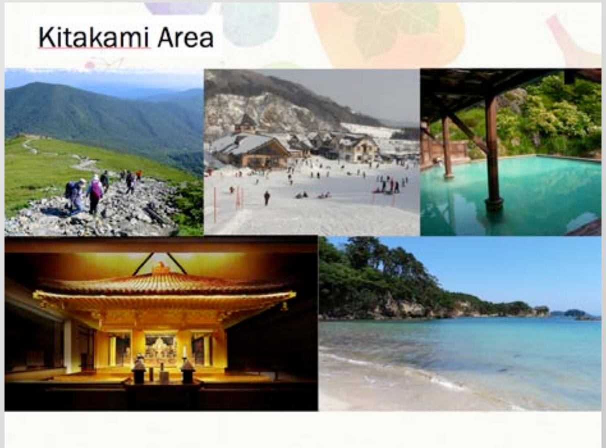
Constituency: Iwate
Number of times elected: 3

Born: May 2, 1954
Education: Tokyo University, Iowa State University
Ministry of Agriculture, Forestry and Fisheries (1977-2001)

Current Position:
Member, Agriculture, Forestry and Fisheries Committee
Member, Budget Committee
Executive Member, Special Committee on Reconstruction After Great East Japan Earthquake

Career:

2010	Chairman, Committee on Budget, House of Councilors
2010-2011	Senior Vice Minister of Cabinet Office for National Policy
2011-2012	Minister of Reconstruction Minister of State for Disaster Management
2012	Minister for Comprehensive Review of Measures in Response to the Great East Japan Earthquake



Highlights (personal) from Diet members speeches

- Cost reduction has had a very positive impact in Japanese politicians.
- The project is being discussed at very high political level in Japan.
- Japan understands the ILC as an International Research Infrastructure which needs the cooperation of countries outside Japan as ITER, International Space Station, CERN, etc...
- ILC is seen as "investing in future" and "regional revitalization" for internal Japanese politics.
- It is well understood by Japanese politicians that next year is crucial to the project and in particular to provide an input to the European Strategy update process.
- Visits and discussions with European politicians and governments are planed by next year seeking for future cooperation. Already happening in January 2018.
- The regional government in Kitakami is highly engaged and supportive to the project.

**** Full text of their speeches can be found in the backup slides of this talk.**

Translation of the Message from the ILC Federation of Diet members

The ILC project has been discussed in the Diet sessions many times. This took place not only in the Committees for Education, Science and Technology, and Innovation, but also in the Committee for Economy and Industry. Within the government, the discussion process is taking place in MEXT and the ILC Advisory Panel is scheduled to conclude at the end of this fiscal year.

The five-year strategy planning for particle physics in Europe will soon begin. We are very much aware that Japan should take a big step before the European discussions begin.

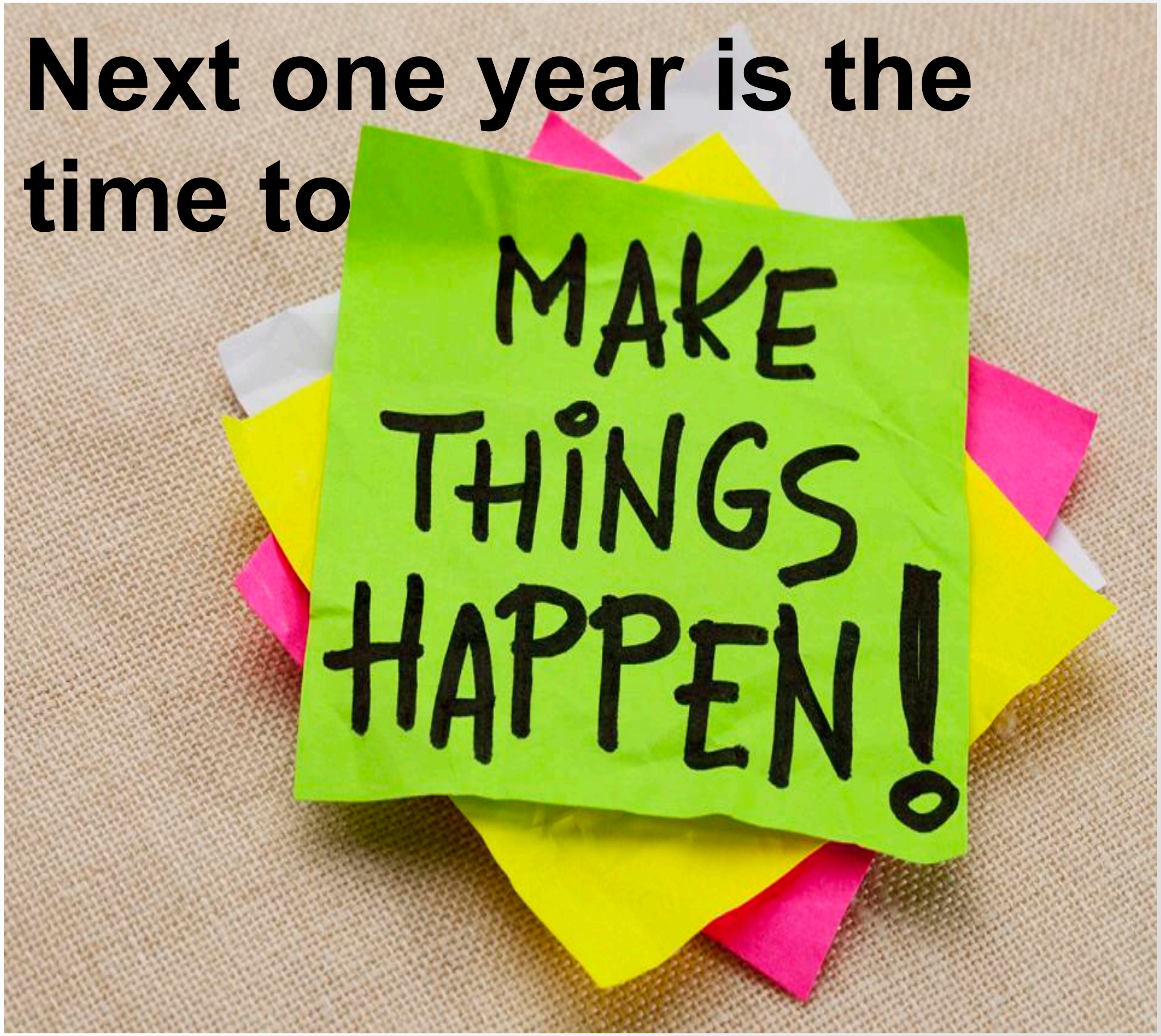
The most important agenda has always been the cost, both for Japan and for the world. I hear that progress has been made in the past six months to start the ILC with 20 km in length, with an upgrade path in stages. The international committee which will meet in Canada in about 10 days will officially announce this plan.

With this proposal from the committee in November, I believe the discussions about the International Linear Collider within our government will move to the new phase of working out concrete policy towards its realization. In addition, the budget request from MEXT is already being discussed for an increase, and we will advance the proposal to increase the R&D budget for the superconducting accelerating technology within the coalition of ruling parties.

The large cost reduction of the ILC has been communicated to various circles in politics, economic federations, and local areas here in Japan. I believe that they have been received very well. Together with Chairman Kawamura, I have met with Prime Minister Abe and briefed him of this plan. The MEXT Minister is also informed well.

It is very important to start negotiations with other countries concerning the ILC. I have been boosting international activities the last three years with Federation of Diet members led by the Honorable Kawamura. In February last year, we visited the US together with the Deputy Director-General from MEXT, and we had fruitful discussions with the Director of the Office of Science, Department of Energy. As a result of this discussion, we reached an agreement to open discussions on the ILC between Japanese and American governments in May the last year. The joint work is being performed to reduce the cost of the project, which is the prime challenge towards the realization of the ILC.

Next one year is the time to



Hon. Takeo Kawamura
LCWS2017-Strasbourg

The original article was published in the Iwate Nippo (November 30th edition).

岩手県 Iwate Prefecture The Golden Land, IWATE

On November 29th, the Federation of Diet Members for the ILC (FDMILC, Chair: Hon. Takeo Kawamura (House of Representatives, Yamaguchi 3rd District) met with Hon. Olivier Becht, a member of French Parliament (National Assembly), at the Diet building. The FDMILC, in order to create an international structure of coordination needed to realize the ILC, plans to visit Europe in the beginning of January 2018. At this meeting, they asked Hon. Becht to coordinate meetings between the FDMILC and French Parliament, to which Hon. Becht responded with positive support.

The FDMILC met with Hon. Becht in both the morning and afternoon, who came to Japan to discuss economic cooperation. Chair Kawamura, Secretary-General Ryu Shionoya (House of Representatives, Shizuoka 8th District), Hon. Tatsuo Hirano (House of Councilors, Iwate district), Hon. Takashi Fujiwara (House of Representatives, Tohoku proportional district), and others attended the meetings along with Mr. Hiroaki Takahashi, honorary chairman of the Tohoku Economic Federation.

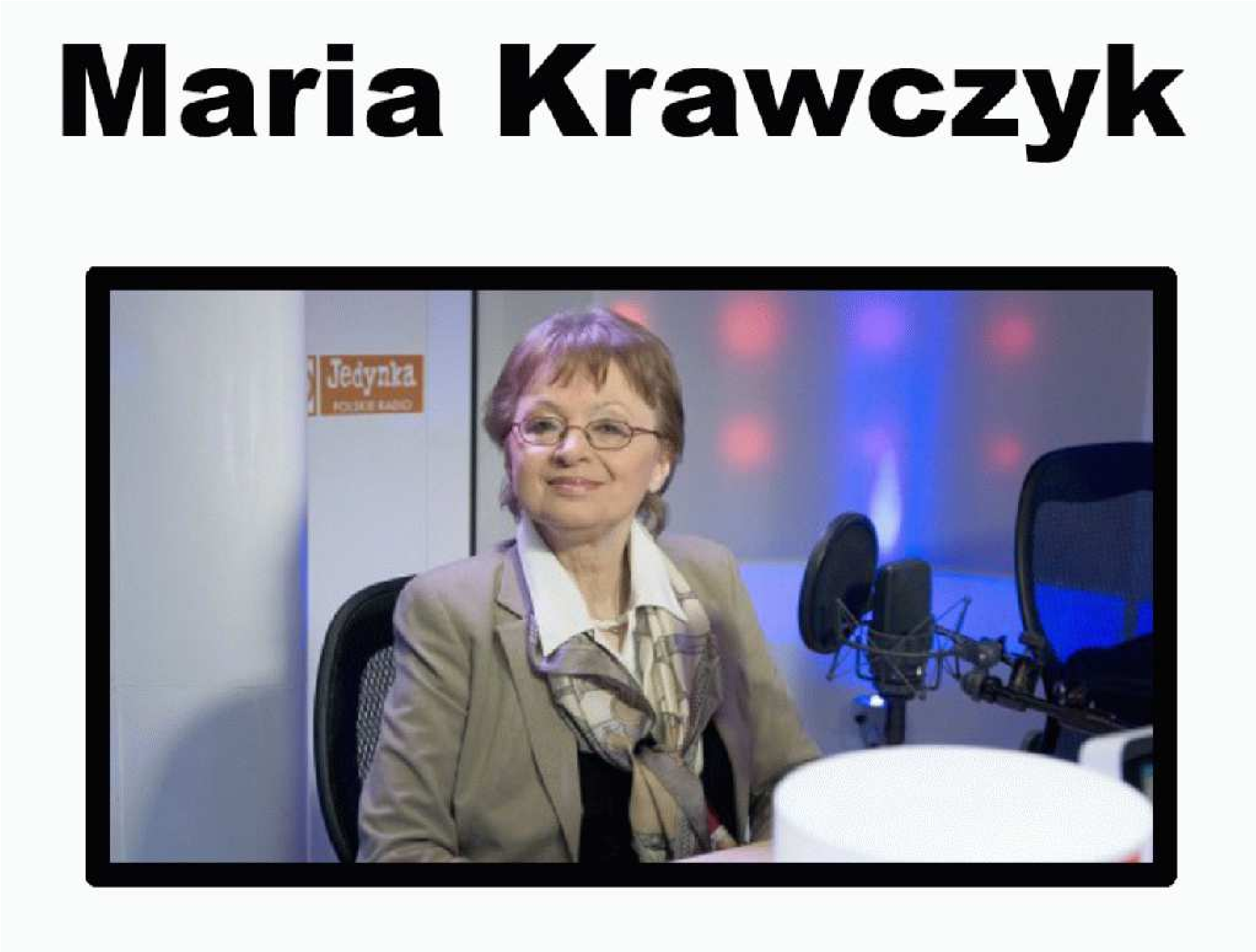
The FDMILC talked about the significance of the ILC, and how the costs are now greatly reduced in the new plan for the ILC which reduces the length of its initial stage. Along with its efforts to coordinate politically with the USA, the FDMILC will be visiting France and Germany on January 8-12, 2018. They told Hon. Becht of their plans, and asked for his help.

Hon. Becht has previously served as a mayor and assembly member in the Alsace region of France, which has ties with Iwate Prefecture. He also took part in the recent LCWS 2017 about the ILC. He responded, "The ILC is a necessary project, and will be good for the candidate site, Iwate. I will work to connect you with colleagues in Parliament."

After the meeting, Hon. Kawamura talked to Iwate Nippo and other news organizations. "It was so good to see how much he understands the ILC project. With our visit to Europe, we will further develop our relationship with the main players in the ILC project, so that the Japanese national government can give an indication within the 2017 fiscal year on whether or not it will host the ILC."

The ILC will be a large-scale linear collider that will uncover the secrets of the mysteries of the universe. Its candidate site is in the Kitakami mountains of Iwate Prefecture. Taking into account the opinions of the Panel of Experts installed at the Ministry of Education, Culture, Sports, Science, and Technology, the Japanese national government will make a decision on hosting the projects within 2018.

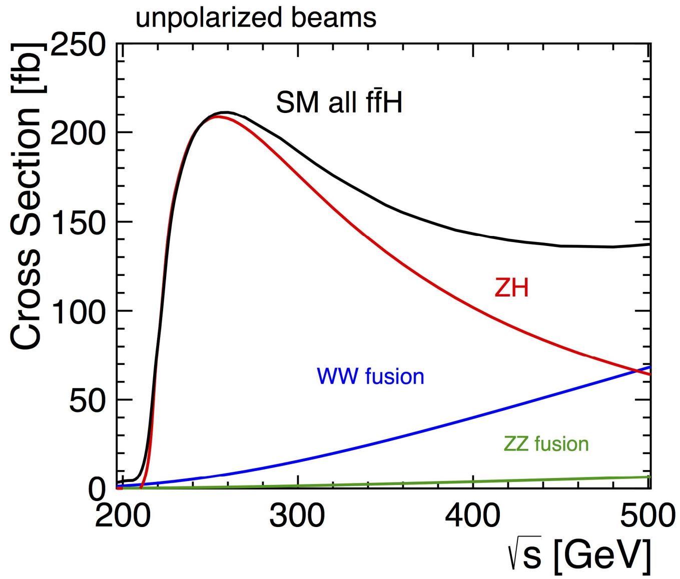
Maria was always there, always optimistic . . .

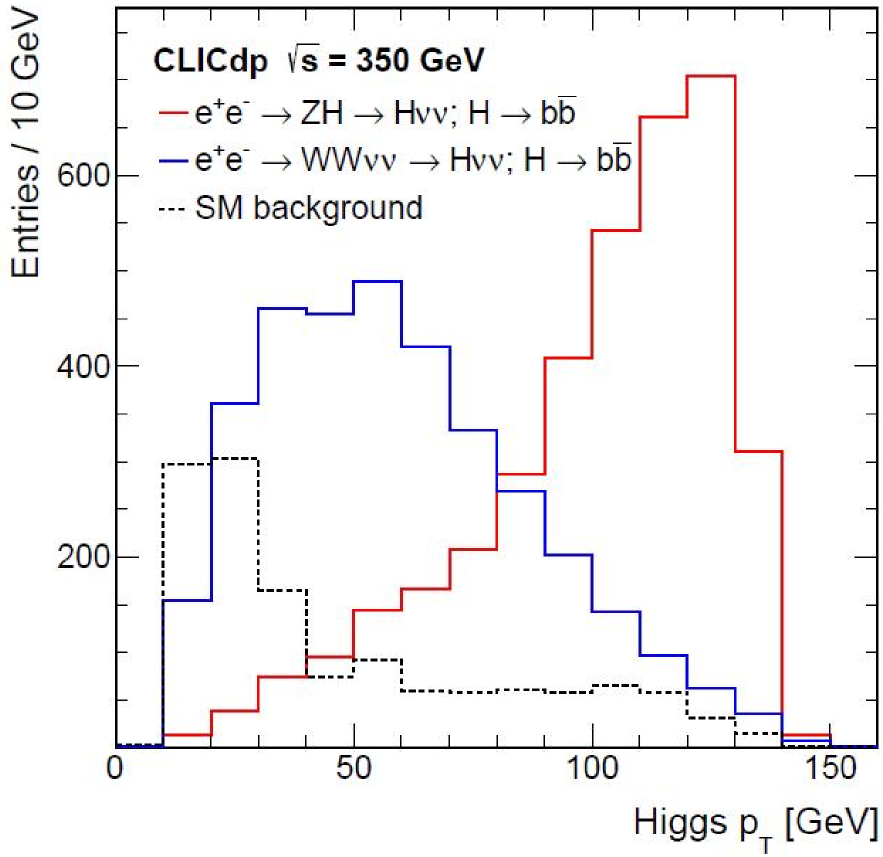



Entrée
eitzer
Thank you !

Separation of Higgsstrahlung and WW fusion

- At 380 GeV, WW fusion ee → Hνν is already a sizeable contribution
- It can be easily separated from ZH based on P_T of Higgs
- Helps to measure HZZ and HWW vertices





European Particle Physics Strategy Update

- Secretariat of the EPPSU is in place

Halina Abramowicz (chair), Keith Ellis (chair of the SPC), Jorgen d'Hondt (ECFA chair), Lenny Rivkin (Directors Group)

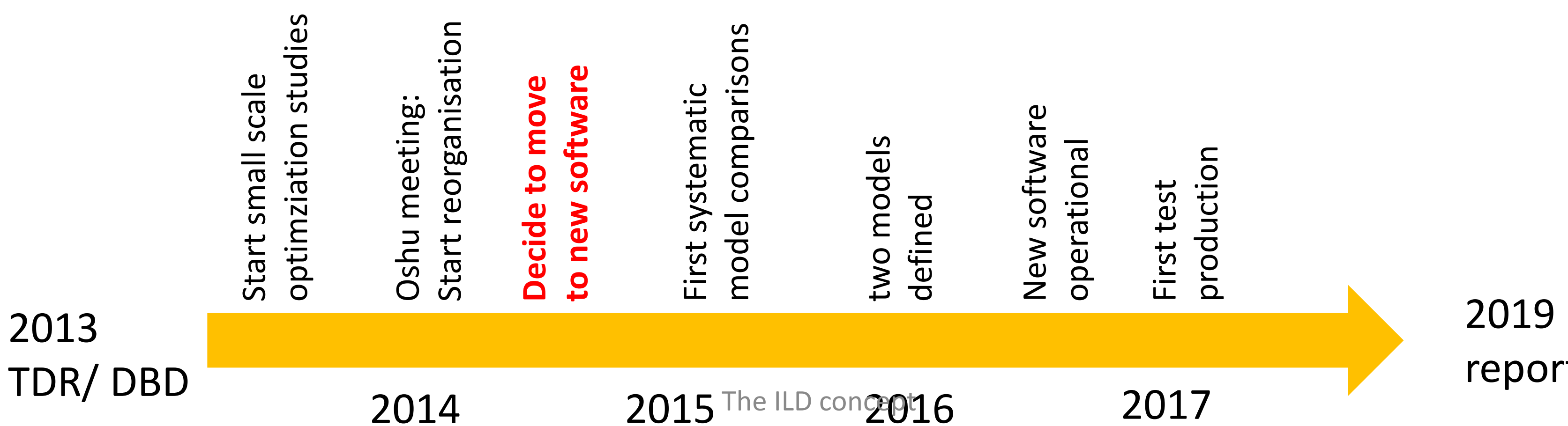
- Preliminary timeline
  - Official launching of the process – September 2018;
  - Collect inputs – end of 2018;
  - Open meeting – mid May 2019;
  - Drafting strategy update document – mid January 2020;
  - Conclusion of the process – May 2020.

ILD since 2013

Re-optimize ILD for optimal performance and cost/ performance ratio

Prepare the group to quickly move to a real collaboration once the start is given.

Provide a basis for realistic physics studies to make and improve the science case for the ILC. Most recently, strong push to make 250 GeV case



The Deliverable

Document the work in a comprehensive ILD document

- ILD philosophy and thinking
- ILD overall design
- ILD subdetector choices and options
- ILD engineering design
- ILD integration with ILC and into the Kitakami site

- ILD performance

- ILD physics performance

ILD
Report
(tbd)

Anticipated early 2019

CLIC roadmap

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

Documents for next European Strategy

Ingredients for a CLIC summary report

- ✓ Updated baseline for a staged Compact Linear Collider
  CERN yellow report CERN-2016-004
- ✓ Higgs Physics at the CLIC Electron-Positron Linear Collider
  Eur. Phys. J. C 77, 475 (2017)
- ✓ The New Optimised CLIC detector model CLICdet
  CLICdp-Note-2017-001
- Performance of CLICdet Detector Model
  CLICdp-Note early 2018
- An overview of CLIC Top Physics
  Complete draft before the end of 2017
- Extended BSM studies
  Publication planned 2018
- CLIC R&D report (main CLIC technology demonstrators)
  Summary publications 2018
- Plan for period 2019-2025 if CLIC supported by next strategy