First look at the TLEP Physics Case

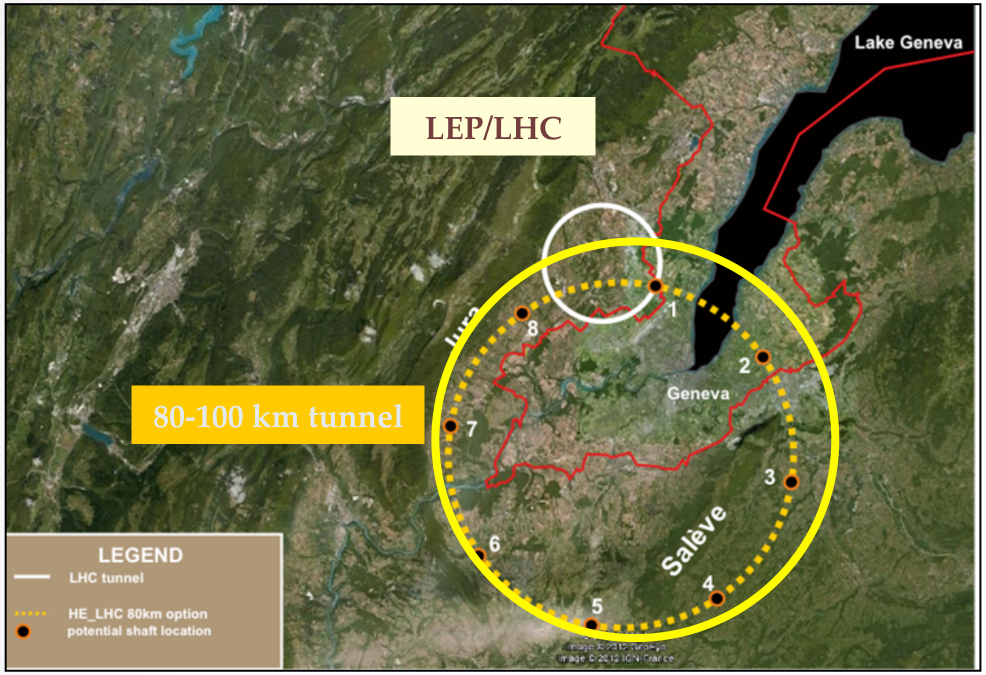
http://arxiv.org/abs/1308.6176

Patrizia Azzi – INFN Padova
For the TLEP Design Study Group
tlep.web.cern.ch

"The Higgs must be studied with the best precision we can muster"
Nigel Lockyer, Fermilab Director, Seattle, 01-July-2013

TLEP: A long-term strategy for HEP

- In a new 80-100 km circular tunnel :



First step

TLEP : e^+e^-, $\sqrt{s}$ up to 350 GeV+

- **Tera-Z : $\sqrt{s}\sim m_Z$**
- **Oku-W : $\sqrt{s}\sim 2m_W$**
- **Mega-Higgs : $\sqrt{s}\sim$240 GeV**
- **Mega-top : $\sqrt{s}\sim 2m_{top}$**

Followed by

VHE-LHC : pp collisions, $\sqrt{s}$ ~ 100 TeV with 15T magnets

> 50 years of ee, pp, ep physics

- Follow the successful historical path for high-energy physics
  - TLEP Physics case: Precision measurements sensitive to multi-TeV New Physics
    - With luminosity 10-1000 × larger than projects of similar timescale and cost
  - VHE-LHC Physics case: Direct search for New Physics in the 10-100 TeV range
    - Also allows the HHH coupling to be measured to a few %

The TLEP Design Study

- Excerpt from the CERN Medium Term Plan (2014-2018):

CERN/SPC/1012
CERN/FC/5747
CERN/3069

> - studies for high-energy proton-proton and electron-positron colliders in a new 80-100 km circular tunnel have already started. The aim is to have available Conceptual Design Reports by the time of the next update of the European Strategy for Particle Physics.

  - … and another 14 mentions of the TLEP and VHE-LHC
    - Approved by the CERN Council few months ago.

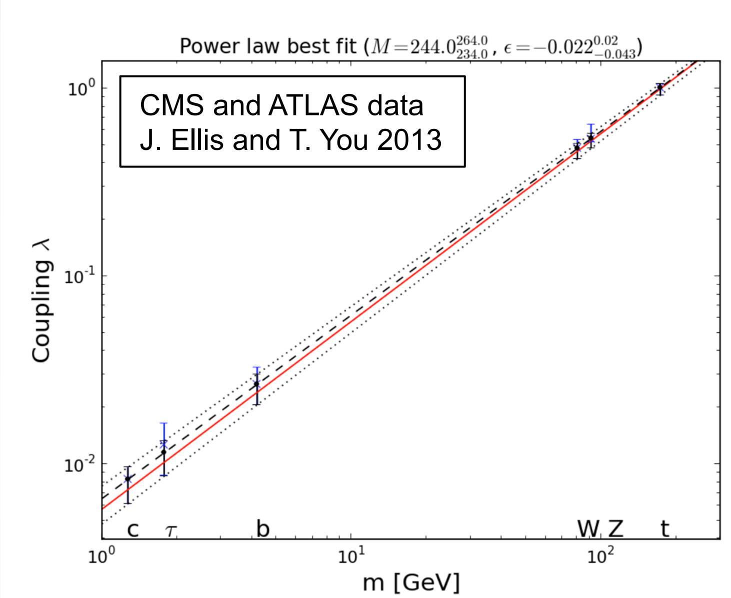
- Regular meetings:
  - The 5th TLEP Workshop at Fermilab, 25-26 July 2013 https://indico.fnal.gov/internalPage.py?pageId=2&confId=6983
  - Next workshops at CERN, 16-18 October 2013, http://indico.cern.ch/conferenceDisplay.py?confId=257713
  - …and in February 2014

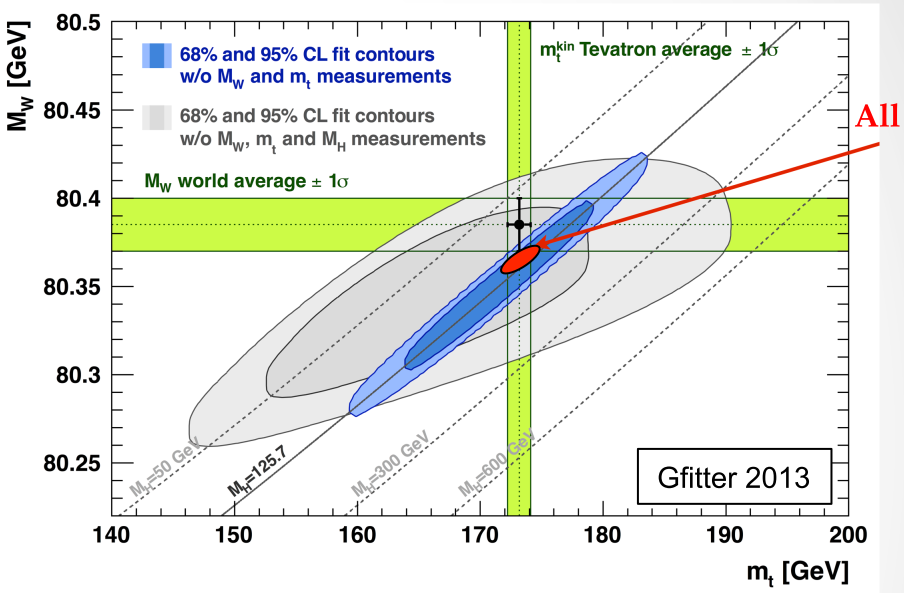
- Publications: "First Look at the Physics Case of TLEP":
  - http://arxiv.org/abs/1308.6176 and Authorea: https://www.authorea.com/users/1331/articles/2469

- You can contribute to the design study in the next 4-5 years
  - Join the study at http://tlep.web.cern.ch : Already ~322 collaborators (of which 33 from Italian Institues)

TLEP + VHE-LHC : Scientific Motivation

- A (very) Standard Higgs boson and a (very) Standard Model

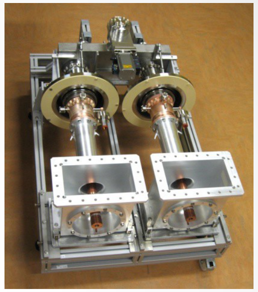




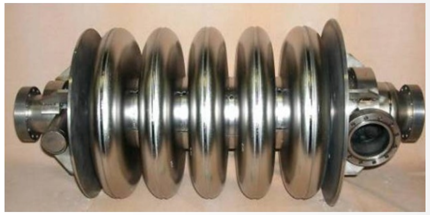
  - Need to measure Higgs properties and EWSB parameters with high(er) precision
    - "With the best precision we can muster"
      - Linear colliders are limited in luminosity in the Higgs Factory mode
- No new physics up to several 100's GeV (SUSY) or several TeV (Resonances)
  - Next run at 14 TeV will extend the coverage to ~500 GeV (SUSY) or more
    - Very strong incentive to look for and study heavier New Physics
      - Linear Colliders with √s = o(TeV) do not cover this Physics case

Energy and Luminosity at TLEP (1)

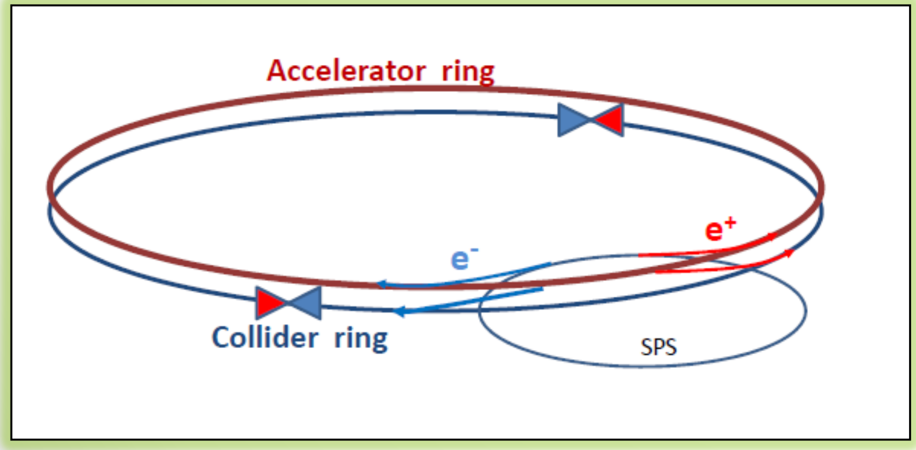
- At 350 GeV, beams lose 9 GeV / turn by synchrotron radiation
  - Need 600 5-cell SC cavities @ 20 MV/m in CW mode
    - Much less than ILC (8000 9-cell cavities@ 31 MV/m)
    - Length ~900 m, similar to LEP (7 MV/m)
  - 200 kW/ cavity in CW : RF couplers are challenging
    - Heat extraction, shielding against radiation, …
- Achieve luminosity with small vertical beam size : σ_y ~ 100 nm
  - A factor 30 smaller than at LEP2, but much more relaxed than ILC (6-8 nm)
    - TLEP can deliver 1.3 × 10^{34} $cm^{-2}s^{-1}$ per collision point at $\sqrt{s}$ = 350 GeV
- Small beam lifetime due to Bhabha scattering ~ 15 minutes
  - Need efficient top-off injection



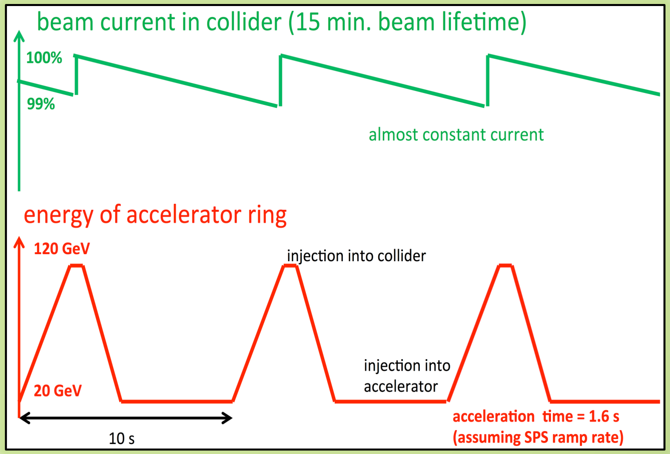
RF Coupler (ESS/SPL)



BNL 5-cell 700 MHz cavity



A. Blondel



F. Zimmermann

Energy and Luminosity at TLEP (2)

TLEP $HZ^0W^-W^+t\bar{t}$

INFN Istituto Nazionale di Fisica Nucleare Sezione di Padova

- At smaller √s, increase the number of bunches to saturate the RF power
  - Synchrotron radiation decreases like 1 / E^4
    - Give much less energy to many more bunches

$$L \propto P_{tot} \times \frac{\rho}{E_{beam}^3}$$

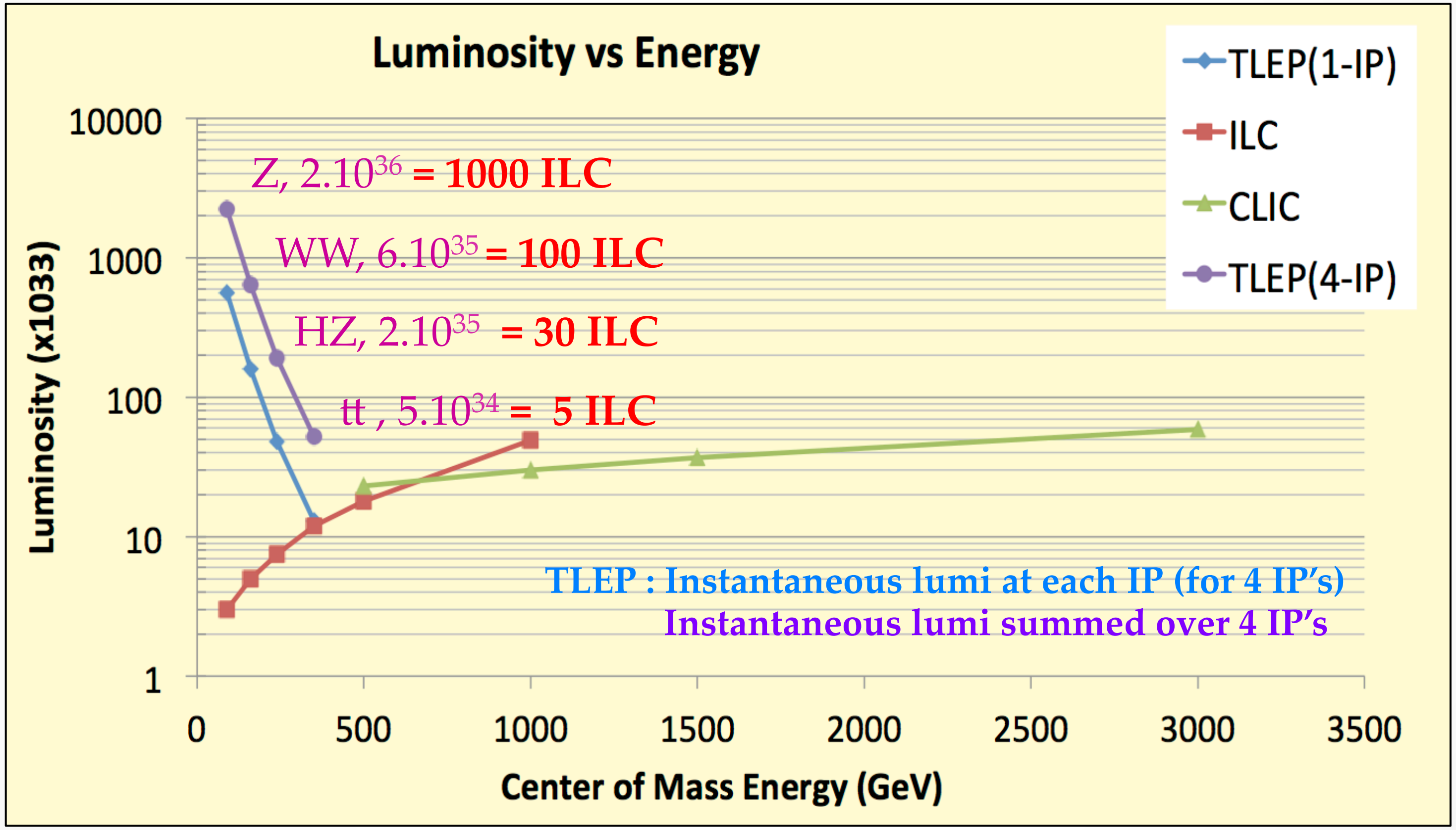
√s (GeV)	90	160	240	350
Luminosity ($\times 10^{34} cm^{-2}s^{-1}$)/IP	56	16	5	1.3
Vertical Beam Size (nm)	270	140	140	100
RF Cavity Gradient (MV/m)	3	3	10	20
Number of bunches	4400	600	80	12
Beam lifetime (mn)	67	25	16	27
Total AC power (MW)	250	250	260	284

M. Koratzinos et al.
arXiV:1305.6498

- (Parameters just published – but already obsolete…)

Energy and Luminosity at TLEP (3)

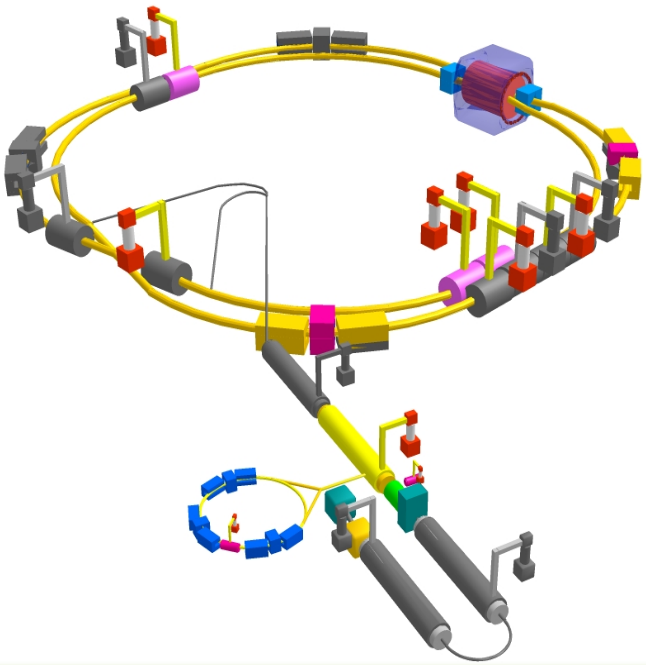
- Comparison with linear colliders
  - Bonus : circular colliders can have several IP's

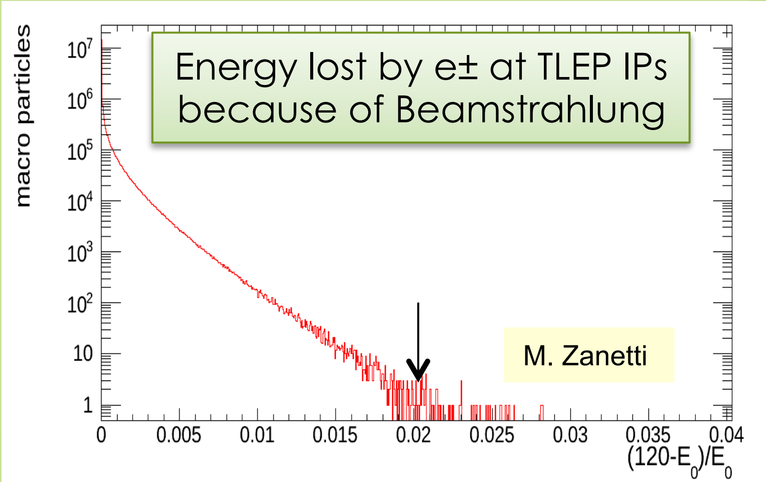


- Ultimate precision measurements possible only at circular colliders

Energy and Luminosity at TLEP (4)

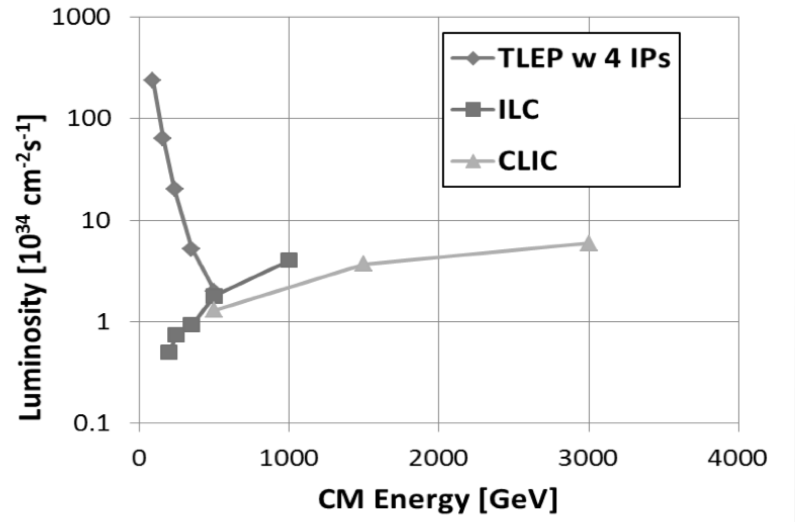
- Find the extrapolations optimistic ?
  - SuperKEKB will be a TLEP demonstrator
    - Beam commissioning starts early 2015
- Some SuperKEKB parameters :
  - Lifetime : 5 minutes
    - TLEP : 15 minutes
  - β^*_y : 300 μm
    - TLEP : 1 mm
  - σ_y : 50 nm
    - TLEP : 100 nm
  - $\varepsilon_y/\varepsilon_x$: 0.25%
    - TLEP : 0.20%
  - Positron production rate : 2.5×10^{12} / s
    - TLEP : $< 1 \times 10^{11}$ / s
  - Off-momentum acceptance at IP : ±1.5%
    - TLEP : ±2.0 to ±2.5%
      - (because of Beamstrahlung at IP's)





Energy and Luminosity at TLEP (5)

- TLEP Upgrades : Energy and luminosity can be further increased
  - Not in the baseline proposal
    - The design study will concentrate on a solid baseline
- Possible TLEP energy upgrade
  - Can reach $\sqrt{s}$ = 500 GeV, if justified by scientific arguments
    - By tripling the RF system (12 → 35 GV): 1.7 km instead of 600 m of cavities
    - With a luminosity of 0.5×10^{34} $cm^{-2}s^{-1}$ per interaction point
      - Hence similar to the ILC at $\sqrt{s}$ = 500 GeV



TLEP : Precision Needed

H. Baer et al., ILC TDR

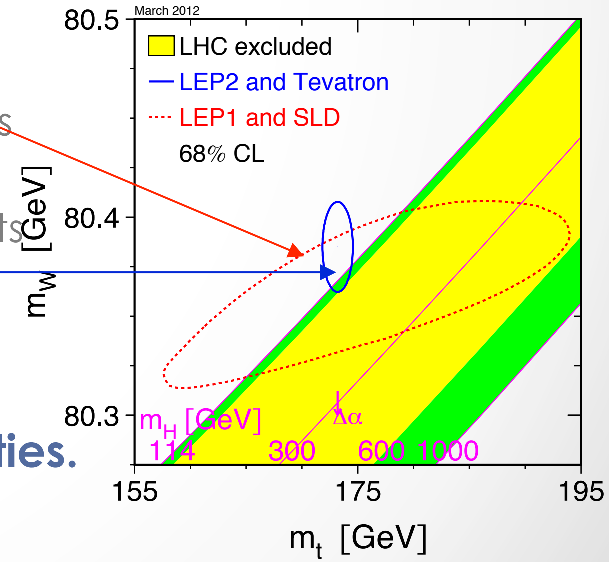
- Precision = sensitivity to New Physics
  - Typical deviations of SM Higgs couplings: with $|\delta| < 5\%$

$$\frac{g_{HXX}}{g_{HXX}^{SM}} \approx 1 + \delta \times \left(\frac{1\ \text{TeV}}{\Lambda_{\text{NP}}}\right)^2$$

(Exact value of δ depend on model & coupling)

  - Need at least a per-cent accuracy for a 5σ observation if Λ_{NP} = 1 TeV
  - Need sub-per-cent accuracy for multi-TeV New Physics scale
  - Need **millions** of Higgs bosons

  - Z pole measurements
    - LEP1 was sensitive to Λ_{NP}~ 1 TeV with 10^7 Z
      - Sensitivity to 10 TeV w/ 100 times smaller errors
    - Need at least **10^{11} Z decays**
  - Match precision with direct m_W and m_{top} measurements
    - Improve by at least one order of magnitude
      - **δm_W< 1 MeV and δm_{top}< 50 MeV**

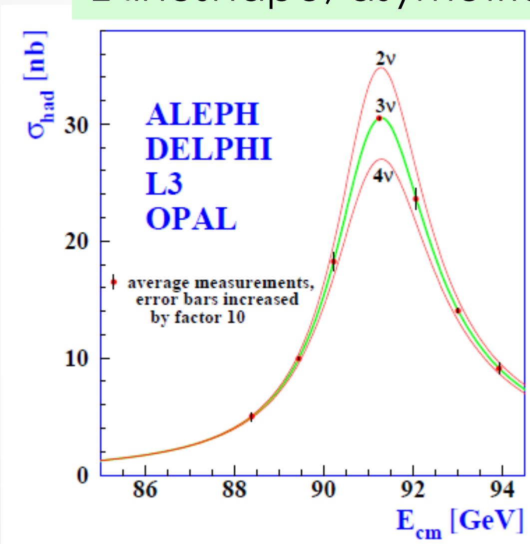


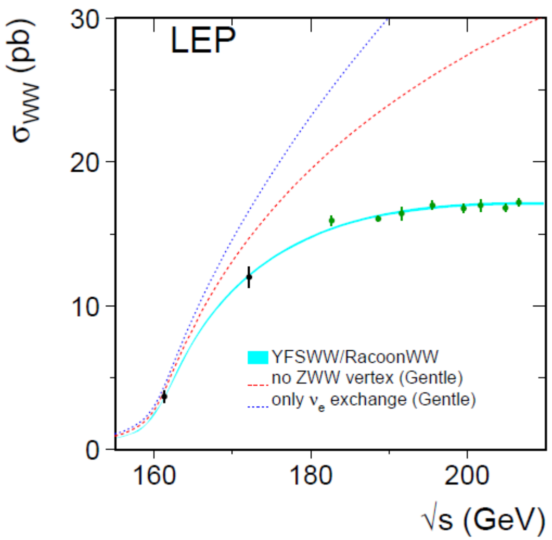
- **Need to reduce all systematic and theory uncertainties.**

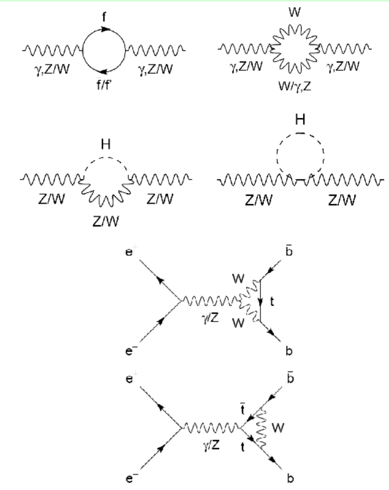
TLEP as a Tera-Z & Oku-W Factories (1)

- TLEP repeats the LEP1 physics program every 15 minutes
  - Transverse polarization up to the WW threshold
    - Exquisite beam energy determination with resonant depolarization
      - Up to 50 keV precision – unique at circular e^+e^- colliders
  - Measure m_Z, m_W, Γ_Z, … with unequalled accuracy

Z lineshape, asymetries | WW threshold scan | New Physics in loops ?



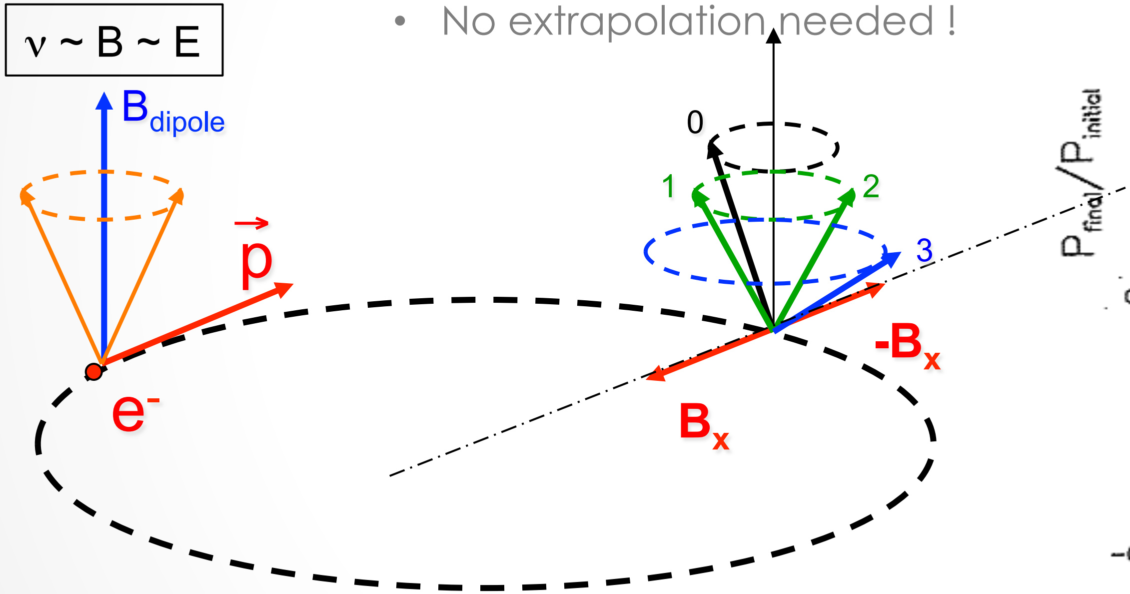


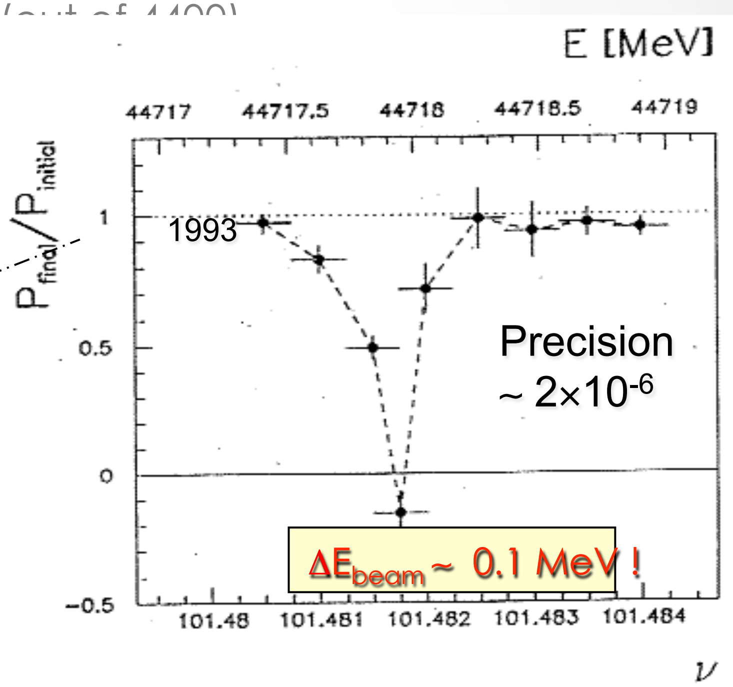


- EW loops sensitive to the existence of weakly-coupled heavy particles
  - For example, LEP predicted m_{top} = 172 ± 20 GeV in 1994 and the top was discovered at FNAL; then EW meas. now predict m_H = 100 ± 25 GeV

TLEP as a Tera-Z and Oku-W Factory (2)

- Beam energy measurement at TLEP
  - Ultra-precise resonant depolarization method, unique to a ring
    - Precision limited to 2 MeV at LEP1 by the extrapolation to collision conditions
  - At TLEP, can use few single bunches (out of 4400)
    - No extrapolation needed !





- Ultimate precision better than 0.1 MeV
  - (limited to 2 MeV @ LEP1: tides; TGV, rain; + extrapolation)
- Aim at performing one measurement every 20 minutes

TLEP as a Tera-Z & Oku-W Factory (3)

- Measurements with Tera-Z
  - Caution : TLEP will have 5×10^4 more Z than LEP
  - Predicting achievable accuracies with 250 times smaller statistical precision is difficult

Observable	Measurement	Current precision	TLEP stat.	Possible syst.	Challenge
m_Z (MeV)	Lineshape	91187.5 ± 2.1	0.005	< 0.1	QED corrections
Γ_Z (MeV)	Lineshape	2495.2 ± 2.3	0.008	< 0.1	QED corrections
R_l	Peak	20.767 ± 0.025	0.0001	< 0.001	Statistics
R_b	Peak	0.21629 ± 0.00066	0.000003	< 0.00006	$g \to bb$
N_ν	Peak	2.984 ± 0.008	0.00004	< 0.004	Lumi meas.
$\alpha_s(m_Z)$	R_l	0.1190 ± 0.0025	0.00001	0.0001	New Physics

NB: ILC limited to a factor > 30 larger errors

- The study is just beginning : errors might get better with increasing understanding
  - Used LEP knowledge so far. Will be revisited with the design study.
  - Much more to do at the Z peak: e.g., asymmetries, flavour physics (> 10^{11} b, > 10^{11} c, > 10^{10} t), rare Z decays, …

TLEP as a Tera-Z & Oku-W Factory (4)

- Measurements with Oku-W
  - Caution : TLEP will have 5×10^6 more W than LEP at the WW threshold
    - Predicting achievable accuracies with 1000 times smaller statistical precision is difficult

Observable	Measurement	Current precision	TLEP stat.	Possible syst.	ILC precision
m_W (MeV)	Threshold scan	80385 ± 15	0.3	< 0.5	7
N_ν	Radiative returns $e^+e^-\rightarrow\gamma Z, Z\rightarrow\nu\nu, ll$	2.92 ± 0.05	0.001	< 0.001	?
$\alpha_s(m_W)$	$B_{had} = (\Gamma_{had}/\Gamma_{tot})_W$	B_{had} = 67.41 ± 0.27	0.00018	< 0.0001	0.002

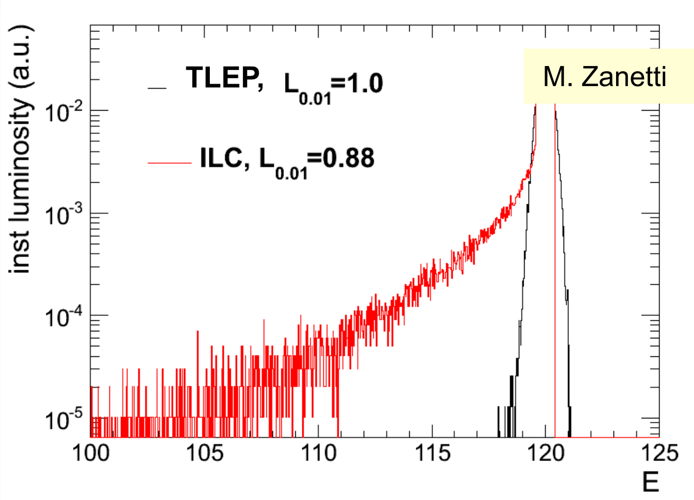
- Much more W physics to do at the WW threshold and above
  - e.g., Γ_W, λ_W, rare W decays, diboson couplings, …
- Measurement with longitudinal polarization
  - One year data taking with luminosity reduced to 20% of nominal (requires spin rotators)
    - 40% beam longitudinal polarization assumed – NB: kept polarization in collisions at LEP

Observable	Measurement	Current precision	TLEP stat.	Possible syst.	Challenge
A_{LR}	Z peak, polarized	0.1514 ± 0.0022	0.000015	< 0.000015	Design Experiment

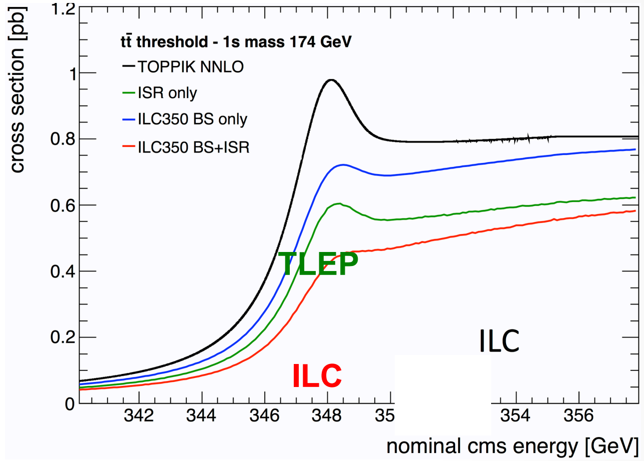
NB: ILC limited to a factor 10 larger errors

TLEP as a Mega-Top Factory

- Scanning the $t\bar{t}$ threshold at $\sqrt{s}$ ~ 350 GeV
  - Much smaller beamstrahlung at TLEP than at Linear Colliders (relaxed beam size)



Luminosity E Spectrum

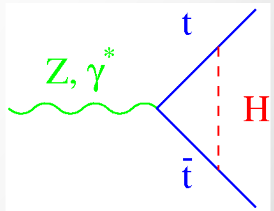


Luminosity E Spectrum

- No need to measure the luminosity spectrum @ TLEP : much reduced m_{top} uncertainty
- Slightly larger cross section @ TLEP : reduced statistical uncertainty
- Beam energy calibration from $e^+e^- \to WW$ and m_W ; α_s from Z and W leptonic decays.
- Still need to work on theoretical predictions (40 MeV uncertainty on m_{top})

	Lumi / 5 years	# top pairs	Δm_{top}	$\Delta\Gamma_{top}$	$\Delta\lambda_{top}/\lambda_{top}$
TLEP	4 × 650 fb^{-1}	1,000,000	10 MeV	12 MeV	13%
ILC	350 fb^{-1}	100,000	30 MeV	35 MeV	40%

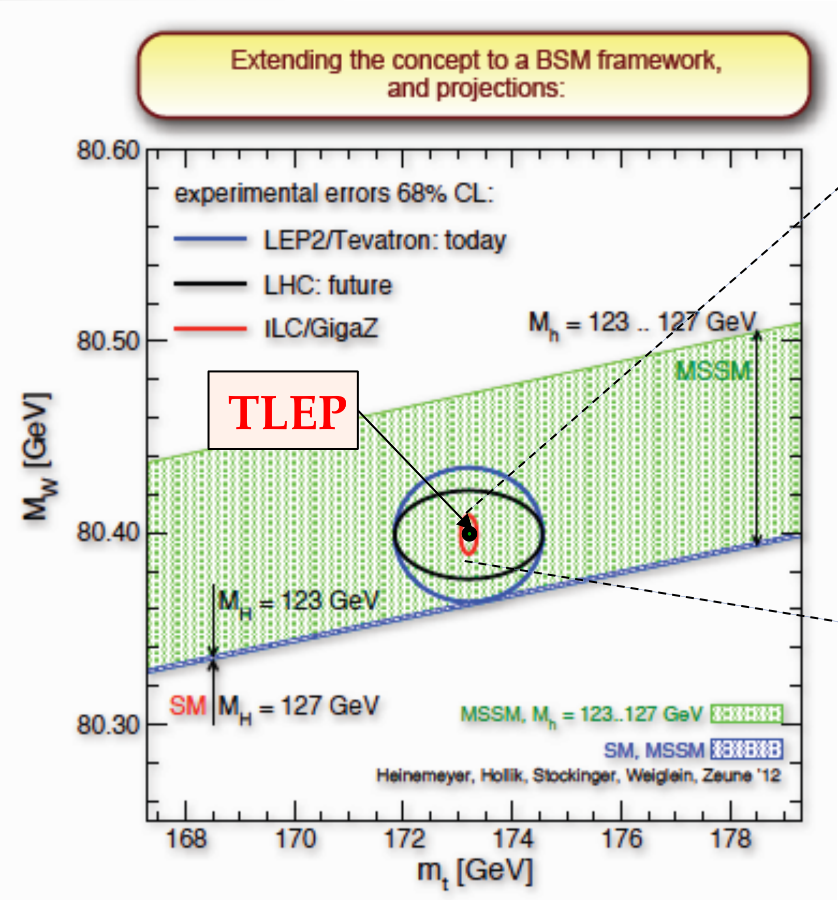
Stat. only



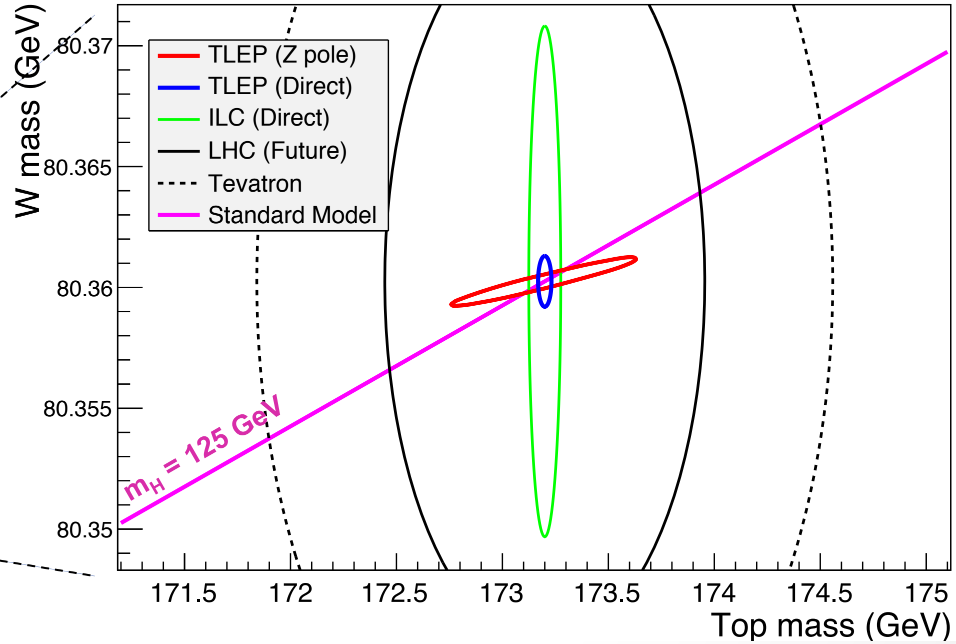
Rare top decays !

EWSB Precision test at TLEP: Summary(1)

- When m_W, m_{top} and m_H are known with precision …
  - … The standard model has nowhere to go !



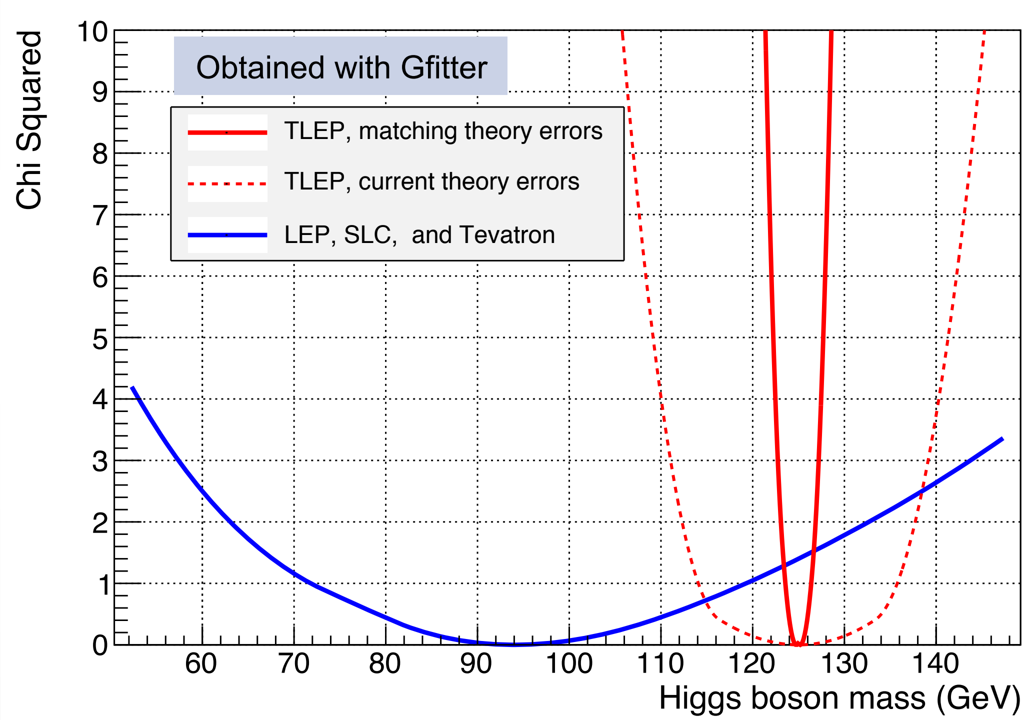
Obtained with Gfitter
(matching theory uncertainties)



Very stringent SM closure test.
Sensitivity to weakly-interacting BSM Physics at a scale > 10 TeV

EWSB Precision test at TLEP: Summary (2)

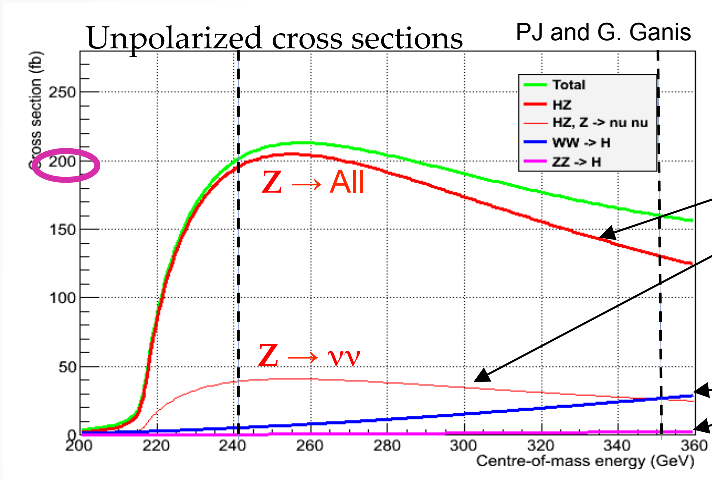
- Another viewpoint : m_H prediction from all EW measurements in the SM
  - $\sigma(m_H)$ would decrease from ±25 GeV (today) to ±1.4 GeV (with TLEP)

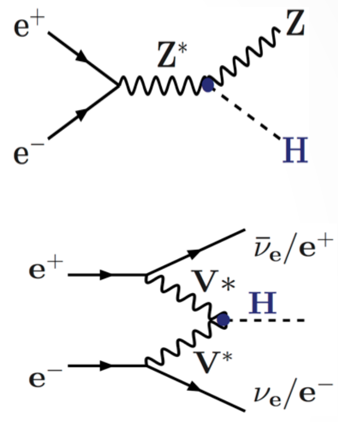


  - Need order of magnitude reduction of EW calculations uncertainties
    - And factor 5 improvement of the $alpha_{QED}(m_Z)$ precision
      - Within reach at the timescale of TLEP (see later)

TLEP as a Mega-Higgs Factory (1)

- Number of Higgs bosons produced at √s = 240-250 & 350 GeV

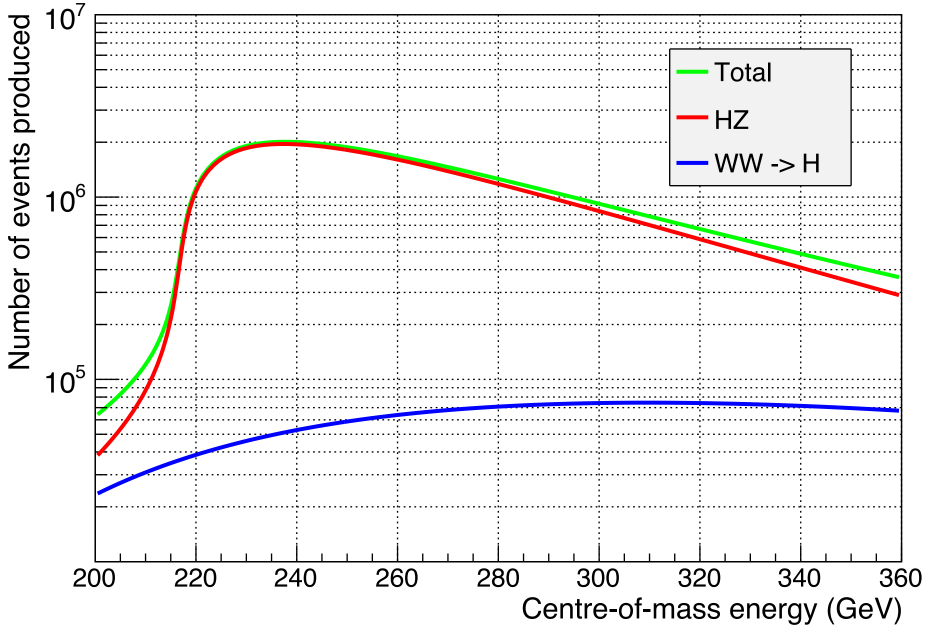




	ILC-250	TLEP-240	ILC-350	TLEP-350	
Lumi / 5 yrs	250 fb^{-1}	10 ab^{-1}	350 fb^{-1}	2.6 ab^{-1}	
Beam Polarization	80%, 30%	–	80%,30%	–	
# of HZ events	70,000	2,000,000	65,000	325,000	× 1.4
# of WW→H events	3,000	50,000	20,000	65,000	× 2.4

TLEP as a Mega-Higgs Factory (2)

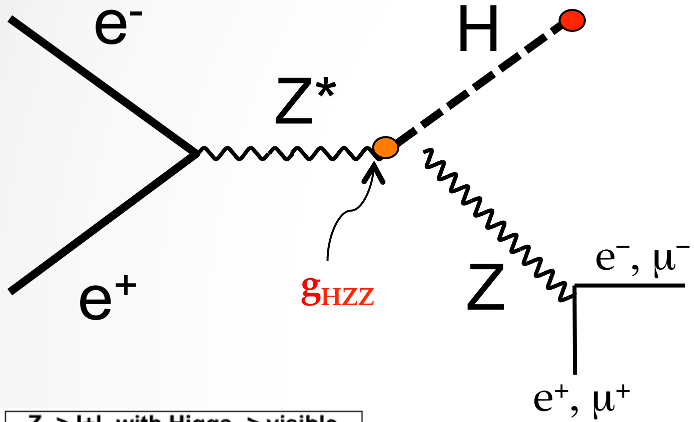
- Choice of the centre-of-mass energy
  - Maximize the number of Higgs events expected for 5 years at 4 IP's
    - With the very specific luminosity profile of TLEP (in $1/E^3$)

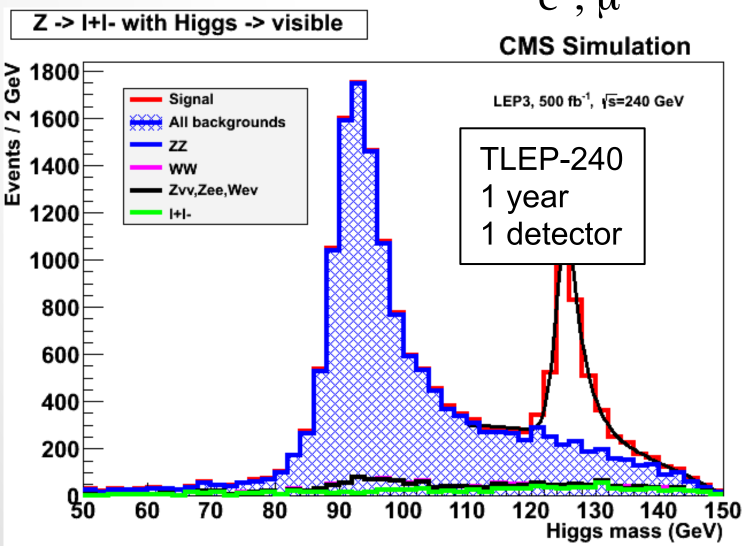


  - $\sqrt{s}$ = 240 GeV for HZ, $\sqrt{s}$ = 340-350 GeV for WW → H and the $t\bar{t}$ threshold scan

TLEP as a Mega-Higgs Factory (3)

- Example : $e^+e^- \rightarrow ZH \rightarrow l^+l^-$ + anything
  - Measure σ_{HZ}





Summary of the possible measurements:

(TLEP : CMS Full Simulation + some extrapolations for cc, gg)

ILC TDR

From P. Azzi et al. arXiV:1208.1662

	ILC-250	TLEP-240
σ_{HZ}	2.5%	0.4%
$\sigma_{HZ} \times BR(H\rightarrow bb)$	1.1%	0.2%
$\sigma_{HZ} \times BR(H\rightarrow cc)$	7.4%	1.2%
$\sigma_{HZ} \times BR(H\rightarrow gg)$	9.1%	1.4%
$\sigma_{HZ} \times BR(H\rightarrow WW)$	6.4%	0.9%
$\sigma_{HZ} \times BR(H\rightarrow \tau\tau)$	4.2%	0.8%
$\sigma_{HZ} \times BR(H\rightarrow ZZ)$	19%	3.1%
$\sigma_{HZ} \times BR(H\rightarrow \gamma\gamma)$	35%	3.0%
$\sigma_{HZ} \times BR(H\rightarrow \mu\mu)$	100%	13%
Γ_{INV} / Γ_H	< 1%	< 0.2%
m_H	40 MeV	8 MeV

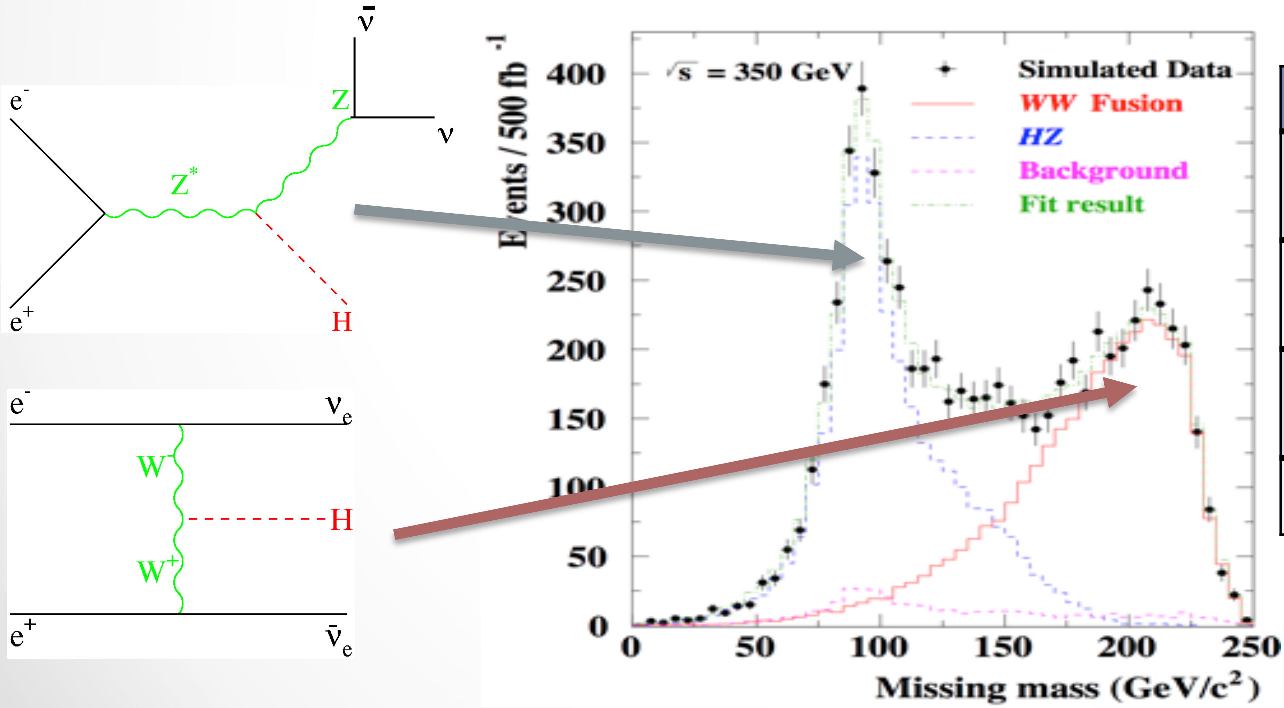
TLEP as a Mega-Higgs Factory (4)

- Determination of the total width
  - From the number of HZ events and of ZZZ events at √s = 240 GeV

$$\Gamma_H = \Gamma(H \to ZZ) \ / \, \mathrm{BR}(H \to ZZ) \ \propto \ \sigma_{HZ} \, / \, \mathrm{BR}(H \to ZZ)$$

  - From the bbνν final state at √s = 350 GeV (and 240 GeV)

$$\Gamma_H \propto \Gamma(H \to WW) \, / \, \mathrm{BR}(H \to WW) \ \propto \sigma_{WW \to H \to bb} \, / \, \mathrm{BR}(H \to WW) \ \times \ \mathrm{BR}(H \to bb)$$



Γ_H from:	ILC	TLEP
HZ→ZZZ @ 240	20%	3.2%
WW→H @240	12%	2.4%
WW→H @350	7%	1.2%
Combined	5.8%	1.0%

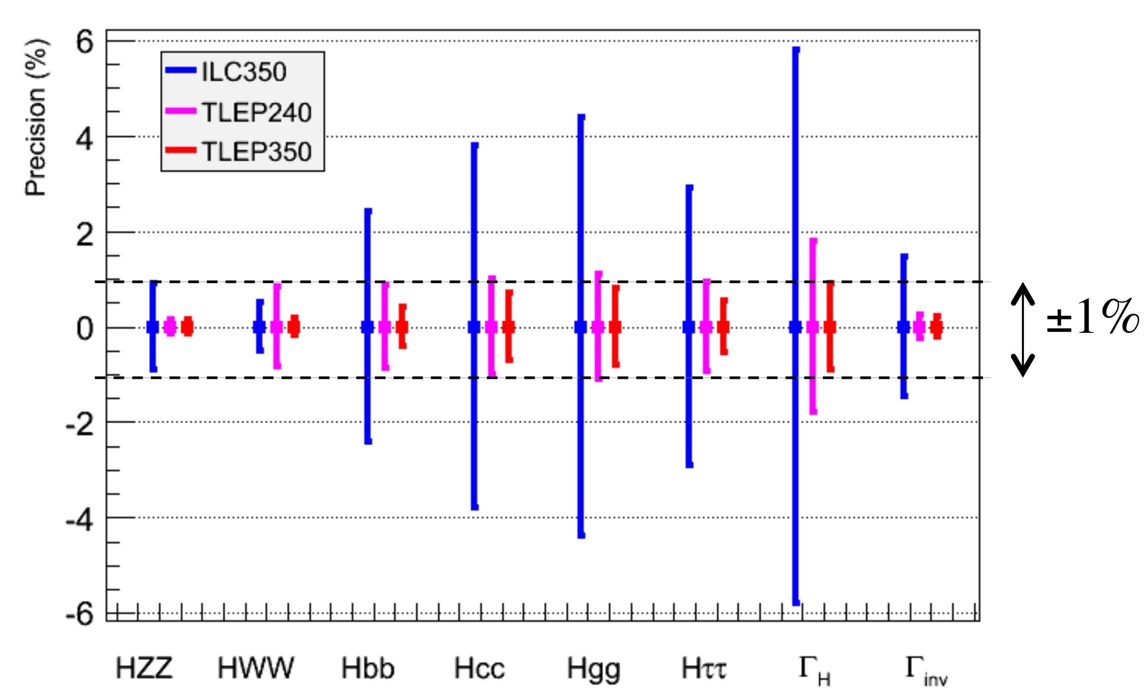
Note : μμ collider
$\Delta\Gamma_H/\Gamma_H \sim 5\%$

Global fit of the Higgs couplings (1)

- Model-independent fit

M. Bachtis

Coupling	g_Z	g_W	g_b	g_c	g_g	g_τ	g_μ	g_γ	BR_{exo}
LEP-240	**0.16%**	**0.85%**	**0.88%**	**1.0%**	**1.1%**	**0.94%**	**6.4%**	**1.7%**	**0.48%**
LEP-350	**0.15%**	**0.19%**	**0.42%**	**0.71%**	**0.80%**	**0.54%**	**6.2%**	**1.5%**	**0.45%**
ILC-350	**0.9%**	**0.5%**	**2.4%**	**3.8%**	**4.4%**	**2.9%**	**45%**	**14.5%**	**2.9%**



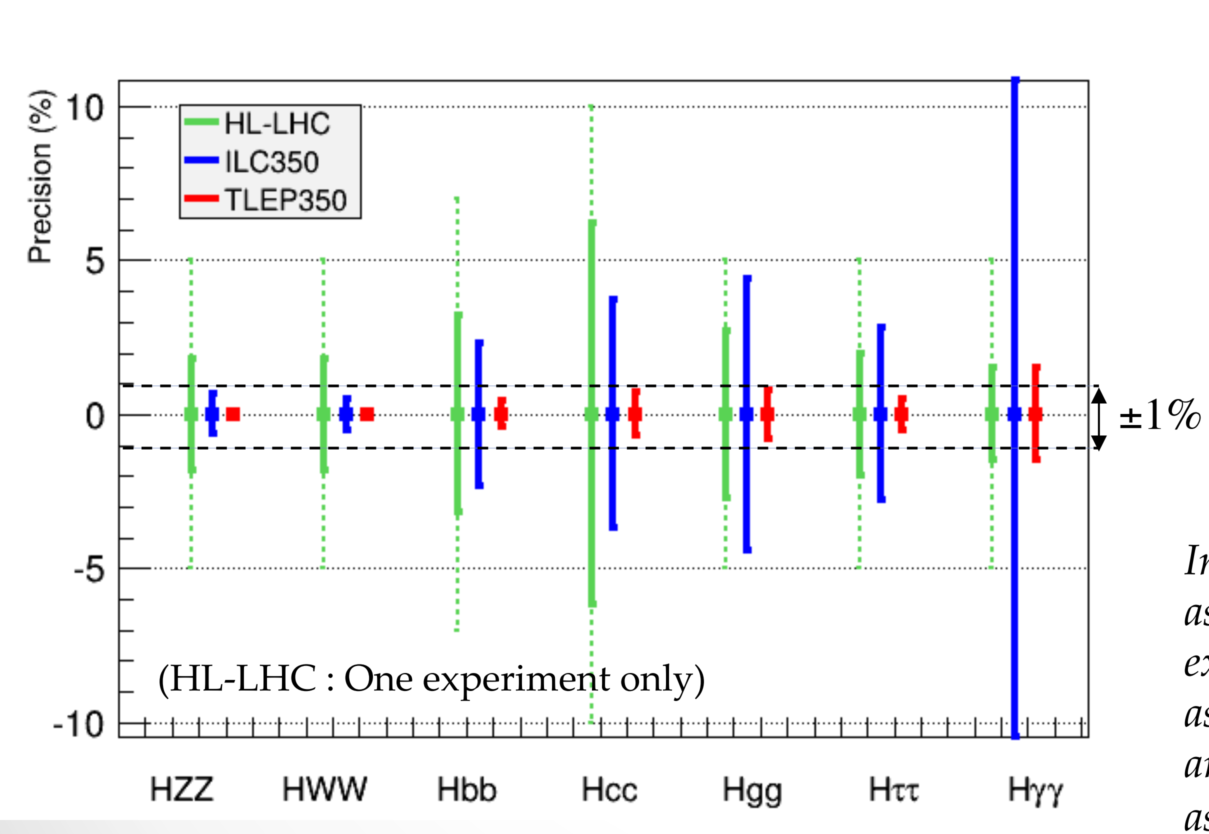
Facility	ILC	TLEP (4 IP)
Energy (GeV)	500	350
$\int \mathcal{L}dt$ (fb^{-1})	+500	+1400
$\Delta\Gamma_h/\Gamma_h$	6.0%	1.0%
$\mathcal{B}_{inv}$	< 0.69%	< 0.1%
$\Delta g_\gamma/g_\gamma$	8.4%	1.5%
$\Delta g_{Z\gamma}/g_{Z\gamma}$	?	?
$\Delta g_g/g_g$	2.5%	0.8%
$\Delta g_W/g_W$	1.4%	0.19%
$\Delta g_Z/g_Z$	1.3%	0.15%
$\Delta g_\mu/g_\mu$	–	6.2%
$\Delta g_\tau/g_\tau$	2.5%	0.54%
$\Delta g_c/g_c$	3.0%	0.71%
$\Delta g_b/g_b$	1.8%	0.42%
$\Delta g_t/g_t$	18%	13%

Snowmass 2013

- NB : Theory uncertainties must be worked out.

Global fit of the Higgs couplings (2)

- Model-dependent (seven-parameter) fit a-la-LHC
    - Assume no exotic Higgs decays, and $\kappa_c = \kappa_t$

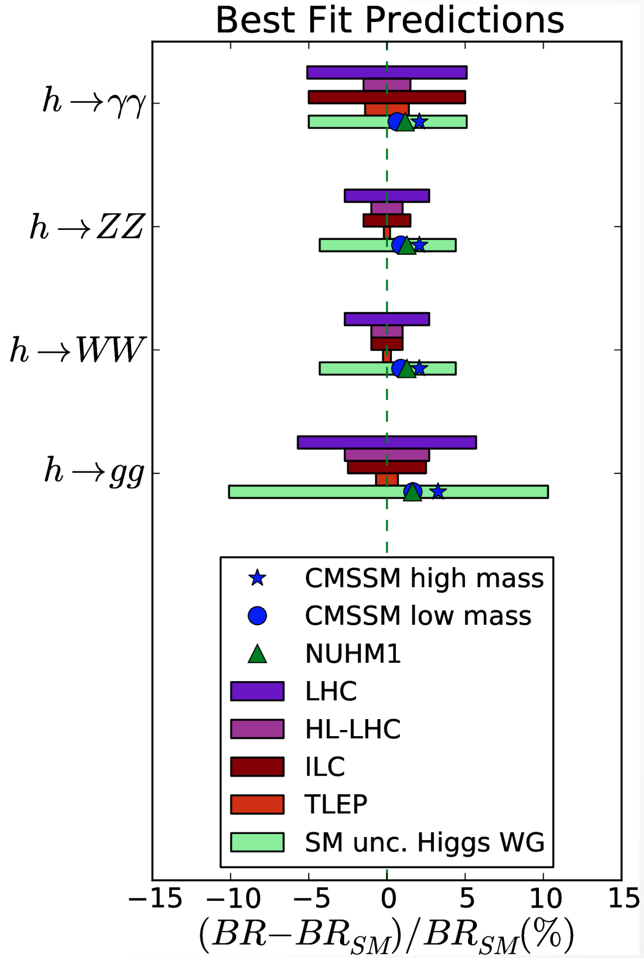


HL-LHC : One experiment only
… CMS Scenario 1
— CMS Scenario 2

In bold, theory uncertainty are assumed to be divided by a factor 2, experimental uncertainties are assumed to scale with 1/√L, and analysis performance are assumed to be identical as today

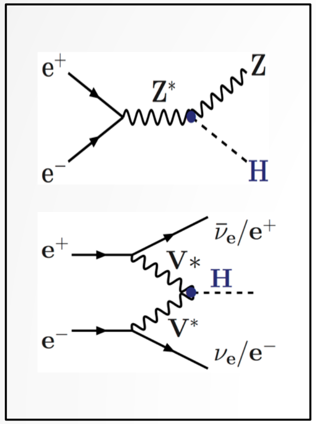
Global fit of the Higgs couplings (3)

- Quantitative added value from ILC – wrt HL-LHC – does not stick out clearly.
  - In contrast, sub-per-cent TLEP potential is striking for all couplings
- Only TLEP is sensitive to (multi-)TeV new physics with Higgs measurements
  - Much theoretical progress is needed to reduce accordingly theory uncertainties

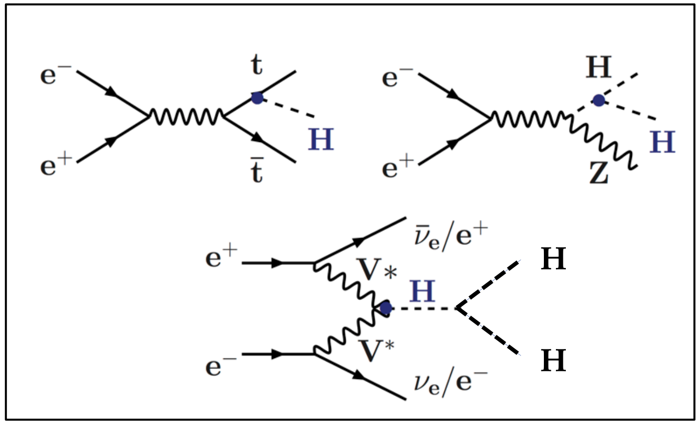


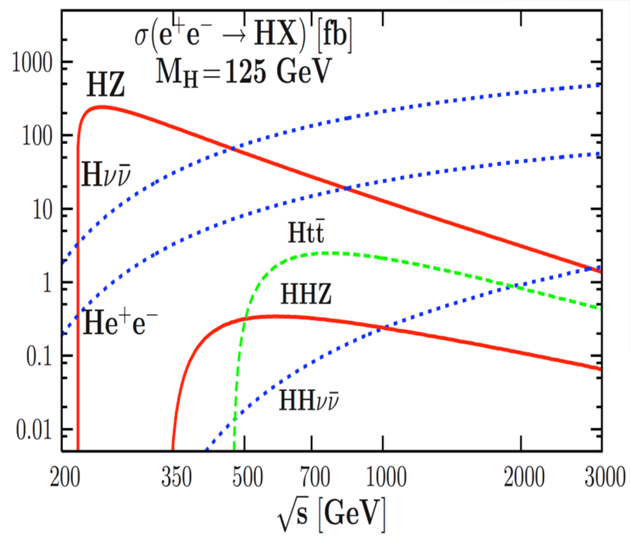
Higgs Physics with √s > 350 GeV ? (1)

- Signal cross sections in e^+e^- collisions



+

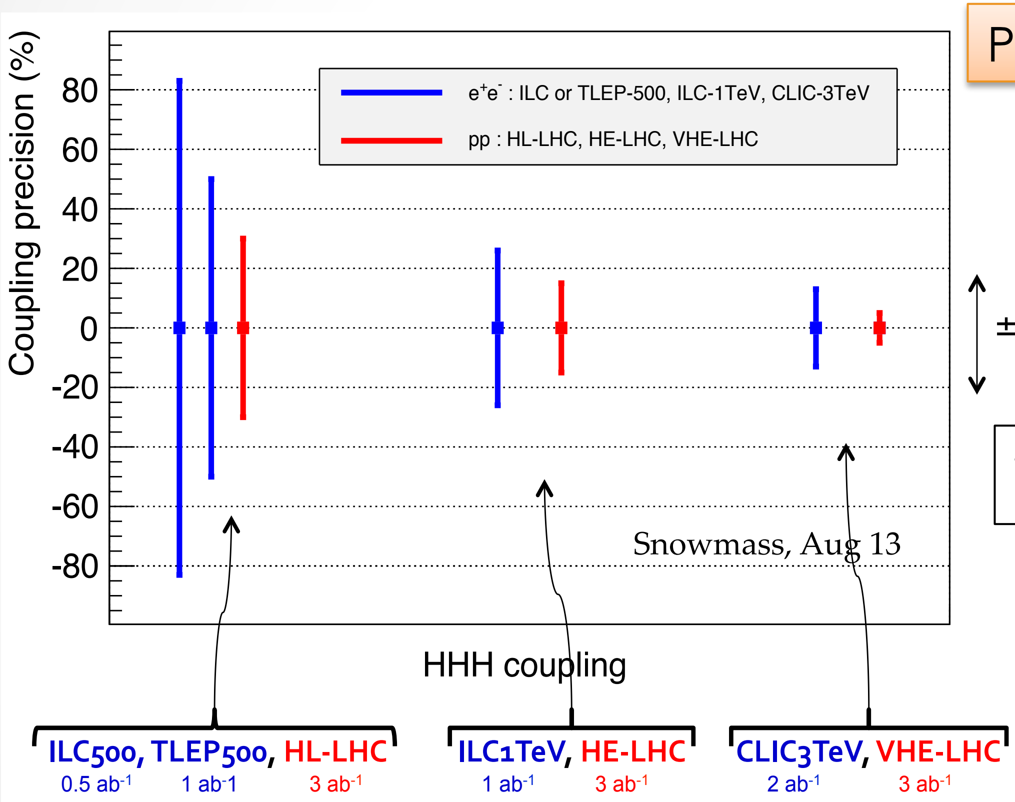




- Measurements at higher energy
  - √s > 350 GeV does not do much for couplings to c, b, g, Z, W, γ, μ and Γ_{tot}. (slide 15)
    - Invisible width best done at √s = 240 GeV
  - The ttH coupling benefits from higher energy
    - TLEP 350 : 13%
    - ILC 500 : 14% ; ILC 1 TeV : ~4% ; CLIC : ~4%
  - The HL-LHC will already do the measurement with 5% precision (and improving)
    - Sub-per-cent precision will need the ultimate pp machine at 100 TeV : VHE-LHC

Higgs Physics with √s > 350 GeV ? (2)

- Measurements at higher energy (cont'd)
  - Higgs tri-linear self coupling λ very difficult for all machines



Particularly difficult for √s=2-3 TeV

Few percent precision will need VHE-LHC

- Summary
  - For the study of H(126), the case for e^+e^- collisions above 350 GeV is not compelling.
    - A stronger motivation will exist if a new particle found (or inferred) at LHC
      - *IF e^+e^- collisions can bring substantial new information about it*

TLEP Cost (Very Preliminary) Estimate

- Cost in billion CHF

Cost for the 80 km version : the 100 km version might be cheaper.)

Bare tunnel	3.1 [1]
Services & Additional infrastructure (electricity, cooling, service cavern, RP, ventilation, access roads …)	1.0[2]
RF system	0.9 [3]
Cryo system	0.2 [4]
Vacuum system & RP	0.5[5]
Magnet system for collider & injector ring	0.8[6]
Pre-injector complex SPS reinforcements	0.5
Total	**7.0**

(1): J. Osborne, Amrup study, June 2012

(2): Extrapolation from LEP

(3): O. Brunner, detailed estimate, 7 May 2013

(4): F. Haug, 4th TLEP Days, 5 April 2013

(5): K. Oide : factor 2.5 higher than KEK, estimated for 80 km ring

(6): 24,000 magnets for collider & injector; cost per magnet 30 kCHF (LHeC);

As a self-standing project :

Same order of magnitude as LHC

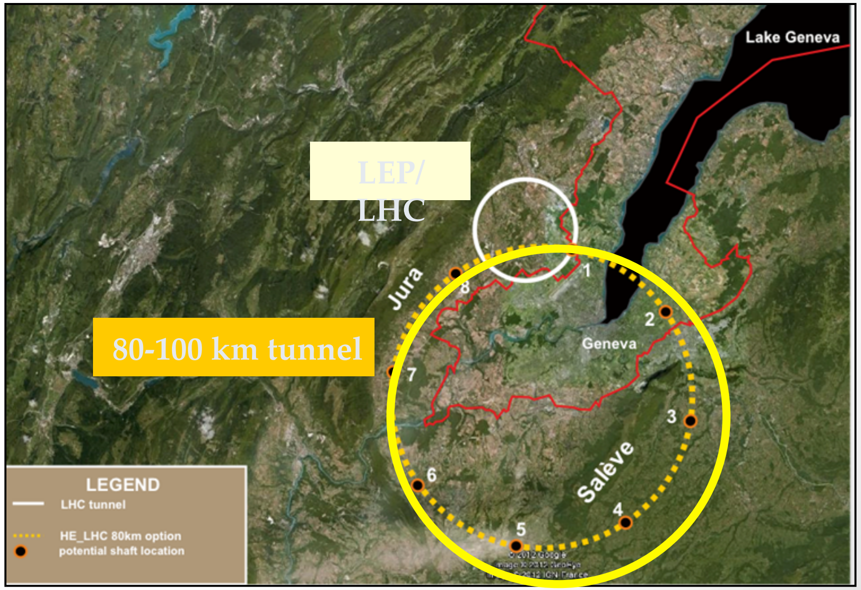
As an add-on to the VHE-LHC project :

Very cost-effective : about 2-3 billion CHF

Note: detector costs not included – count 0.5 per detector (LHC)

Cost per Higgs boson : 1 - 3 kCHF / Higgs

(ILC cost : 150 k$ / Higgs) [NB : 1CHF ~ 1$]



TLEP Cost (Very Preliminary) Estimate

- Cost in billion CHF

Cost for the 80 km version : the 100 km version might be cheaper.)

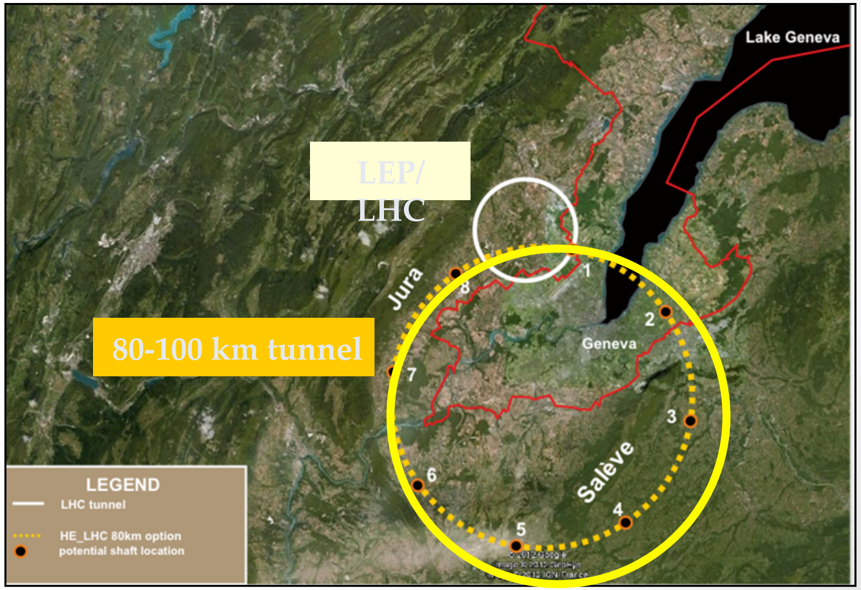
Bare tunnel	**3.1** [1]
Services & Additional infrastructure (electricity, cooling, service cavern, RP, ventilation, access roads …)	**1.0** [2]
RF system	**0.9** [3]
Cryo system	**0.2** [4]
Vacuum system & RP	**0.5**[5]
Magnet system for collider & injector ring	**0.8**[6]
Pre-injector complex SPS reinforcements	**0.5**
Total	**7.0**

Absolutely Preliminary
Not endorsed by anybody

As a self-standing project :
Same order of magnitude as LHC
As an add-on to the VHE-LHC project :
Very cost effective : about 2-3 billion CHF

Note: detector costs not included – count 0.5 per detector (LHC)

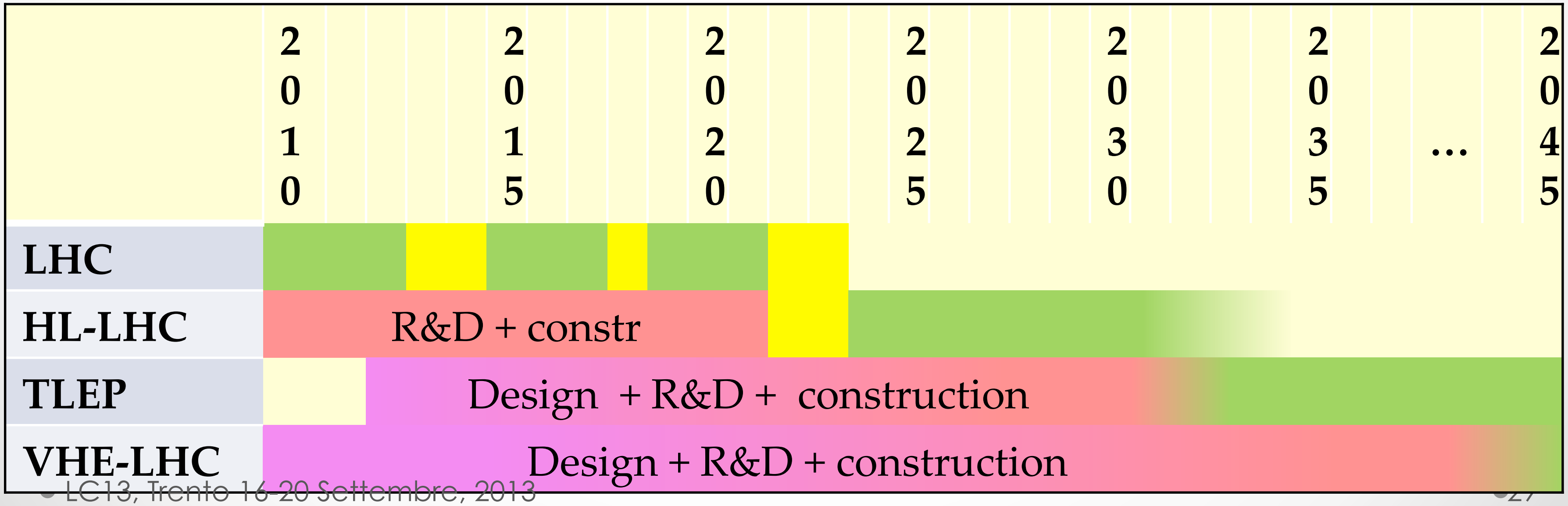
Cost per Higgs boson : 1 - 3 kCHF / Higgs
(ILC cost : 150 k$ / Higgs)   [NB : 1CHF ~ 1$]



(1): J. Osborne, Amrup study, June 2012
(2): Extrapolation from LEP
(3): O. Brunner, detailed estimate, 7 May 2013
(4): F. Haug, 4th TLEP Days, 5 April 2013
(5): K. Oide : factor 2.5 higher than KEK, estimated for 80 km ring
(6): 24,000 magnets for collider & injector; cost per magnet 30 kCHF (LHeC);

TLEP Possible Timescale

- Similar timescales for TLEP and ILC
  - ILC aims for Physics in 2027-2028
- TLEP
  - Design study : 2013-2017 ← **Now !**
  - Next European Strategy Workshop : 2017-2018
  - Decision to go and start digging : 2018-2019
  - Start installation in parallel with HL-LHC running : 2023 - …
  - Start running at the end of HL-LHC running : 2030 - …, for 12-15 years.

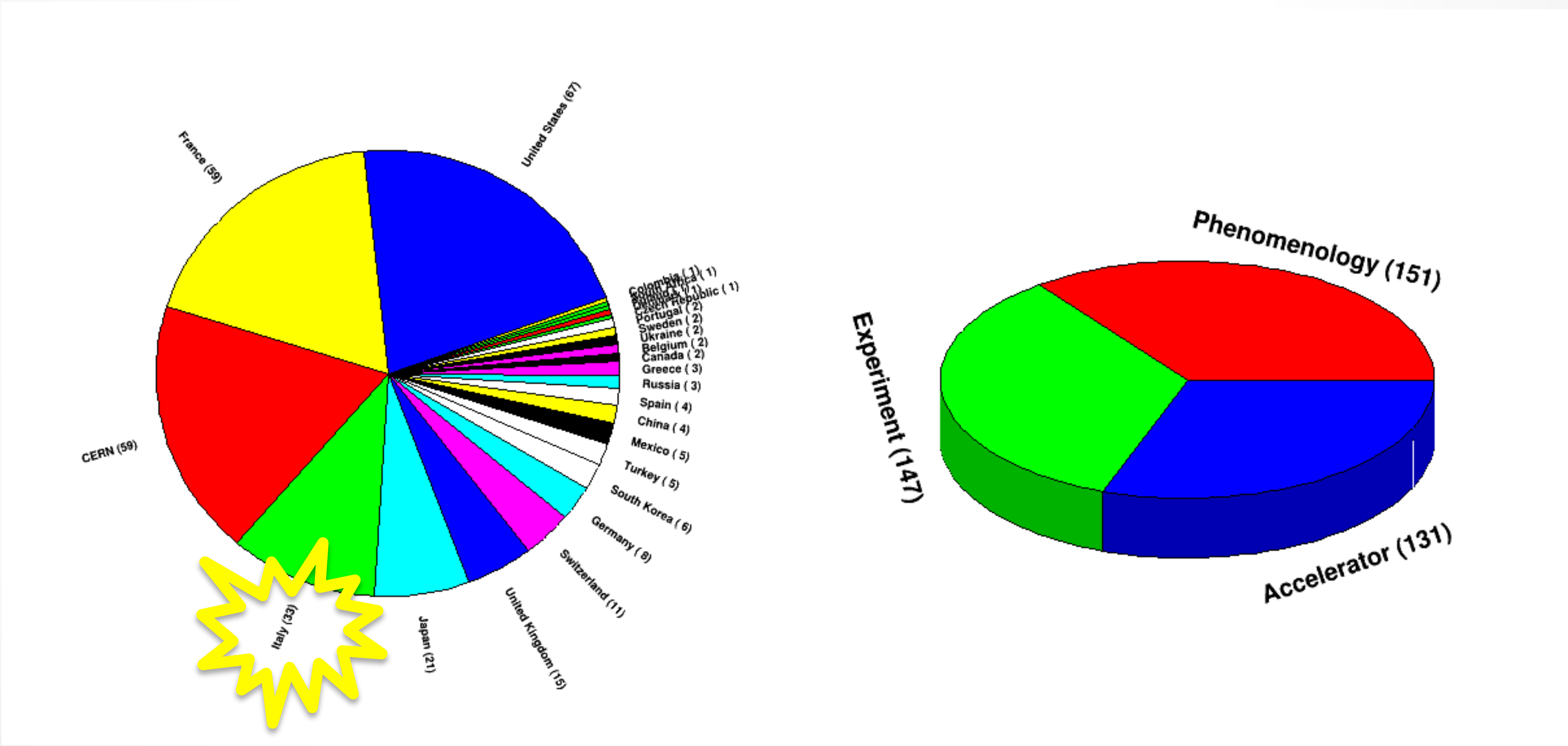


TLEP : Possible Physics Program

- Higgs Factory mode at $\sqrt{s}$ = 240 GeV: 5+ years
  - Higgs boson properties, WW and ZZ production.
    - Periodic returns at the Z peak for detector and beam energy calibration
- Top Threshold scan at $\sqrt{s}$ ~ 350 GeV: 5+ years
  - Top quark mass, width, Yukawa coupling; top quark physics; more Higgs boson studies.
    - Periodic returns at the Z peak for detector and beam energy calibration
- Z resonance scan at $\sqrt{s}$ ~ 91 GeV: 1-2 years
  - Get 10^{12} Z decays @ 15 kHz/IP. Repeat the LEP1 Physics Programme every 15 minutes.
    - Transverse polarization of "single" bunches for precise E_{beam} calibration
- WW threshold scan at $\sqrt{s}$ ~ 161 GeV: 1-2 years
  - Get 10^8 W decays; Measure the W mass; Precise W studies.
    - Transverse polarization of single bunches and returns to the Z peak.
- Longitudinally polarized beams at $\sqrt{s} = m_Z$: 1 year
  - Get 10^{11} Z decays, and measure A_{LR}, A_{FB}^{pol}, etc.
    - Polarization wigglers, spin rotators
- Luminosity, Energy, Polarization upgrades
  - If justified by scientific arguments (with respect to the upgrade to VHE-LHC)

Design Study (2013 – 2018) : People

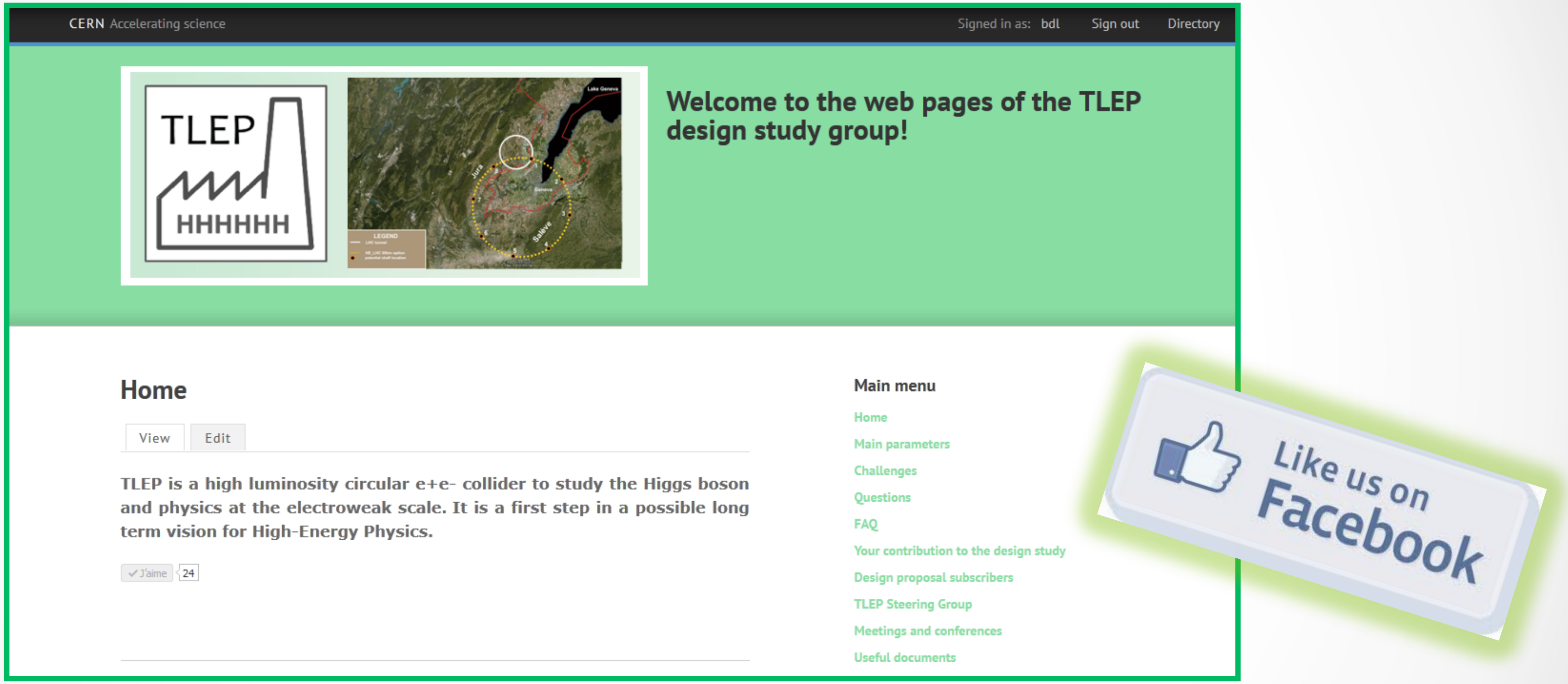
- 318 subscribers from 24 countries (+CERN)
  - Distribution reflects the level of awareness in the different countries
    - Subscribe at http://tlep.web.cern.ch !



  - Remarkable balance between accelerator, experiment and phenomenolgy

Design Study (2013 – 2018) : Events

- Web Site: http://tlep.web.cern.ch



- Next event : Sixth TLEP workshop 16-18 October 2013 @CERN http://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=257713
- Joint VHE-LHC + TLEP kick-off meeting in February 2014

Concluding Remarks (1)

- The discovery of H(126) brought new light on the next large machine
  - Prospects for the future now look very promising
    - The HL-LHC is already an impressive Higgs factory, with great potential
    - The run at 13-14 TeV may discover something else, likely beyond ILC reach
- It is important to choose the right machine for the future
  - We should not mortgage the future of HEP before knowing the results at 13TeV
    - The right machine must bring order(s) of magnitude improvement wrt LHC
      - Both in precision measurements and in discovery potential
      - The ILC project might not fulfill these needs
- A large e^+e^- circular collider could be the best complement to LHC
  - Per-mil precision on Higgs couplings; Unbeatable precision on EWSB parameters
    - Rare W,Z,t,H decays; N_ν measurement to < 10^{-3}; Direct α_s measurement; …
  - Most mature technology : supported by progress of e^+e^- factories for 20 years
    - SuperKEKB will be a precious demonstrator
    - Based on this experience, cost, power, and luminosity predictions will be reliable
  - It is a first step towards a 100 TeV pp collider and a long-term vision for HEP
    - Together with VHE-LHC it offers the most appealing "precision and discovery" package on the market

Concluding Remarks (2)

- The design study of TLEP has started
  - In close collaboration with the VHE-LHC design study
  - With worldwide collaboration (subscribers from Asia, Europe and USA)
  - With full support from the CERN Council
    - The study is now acted in the approved CERN MTP (2014-2018)

- The first proposed step is a design study report in 2015 …
  - … towards a CDR + cost estimate in 2018
    - For an informed decision to be taken in full knowledge of the LHC results
    - And with operational experience of SuperKEKB

- A solid backbone exists for both the Design and the Physics case of TLEP
  - The physics case is very rich, but demanding
    - We need you for the many challenges, and their solutions

- TLEP could be ready for physics in 2030
  - It is time to join now and enjoy the work together

Someone said it well…

- From 5th TLEP workshop (FNAL, 25-26 July 2013)
  - "Perspectives at a 100 TeV pp collider" by Nima Arkani-Hamed

(Slide 22)

This alone fully justifies the march to 100 TeV, in my view

[Tera-Z @ TLEP plays very important complementary role]

(Slide 41)

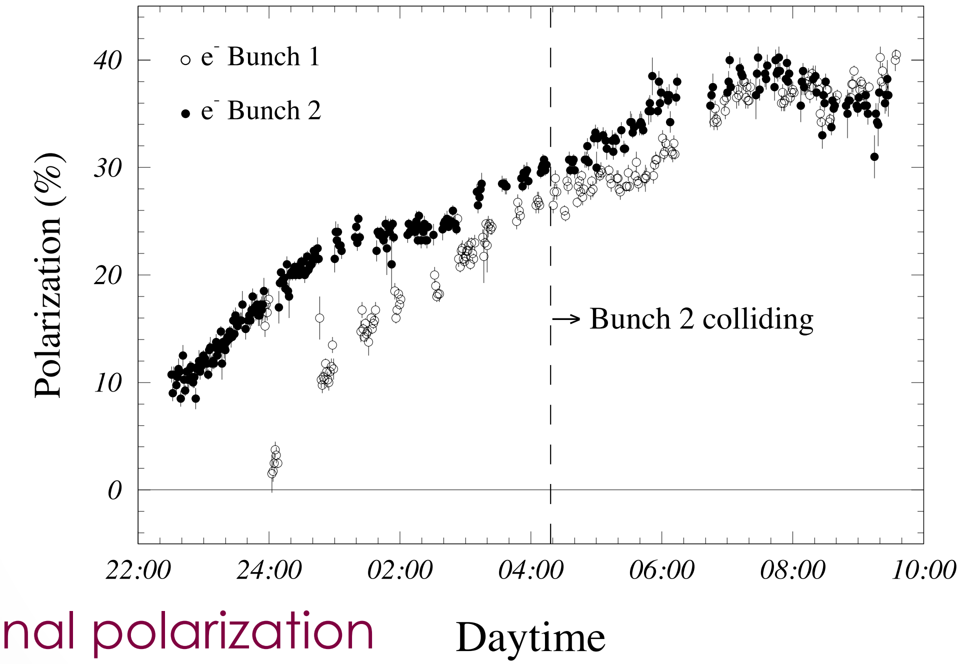
*EVERY student/post-doc/person with a pulse (esp. under 35) I know is ridiculously excited by even a glimmer of hope for a 100 TeV pp collider

These people don't suffer from SSC PTSD

BACKUP

TLEP as a Tera-Z and Oku-W Factory (5)

- Polarization in collisions
  - Often claimed to be impossible in e^+e^- rings because of depolarizing effects
    - It was actually achieved at LEP, and kept for several hours



- Longitudinal polarization
  - Was achieved at HERA with dedicated spin rotators
    - The feasibility at TLEP needs to be studied
      - Challenges : continuous top-up injection, large natural polarization time

Design Study (2013 – 2018) : Structure

26 Working Groups: Accelerator / Experiment / Phenomenology