Summary of TLEP Workshop

Chris Tully
Princeton

Fermilab W&C
July 26, 2013

TLEP and VHE-LHC in 80-100km tunnel

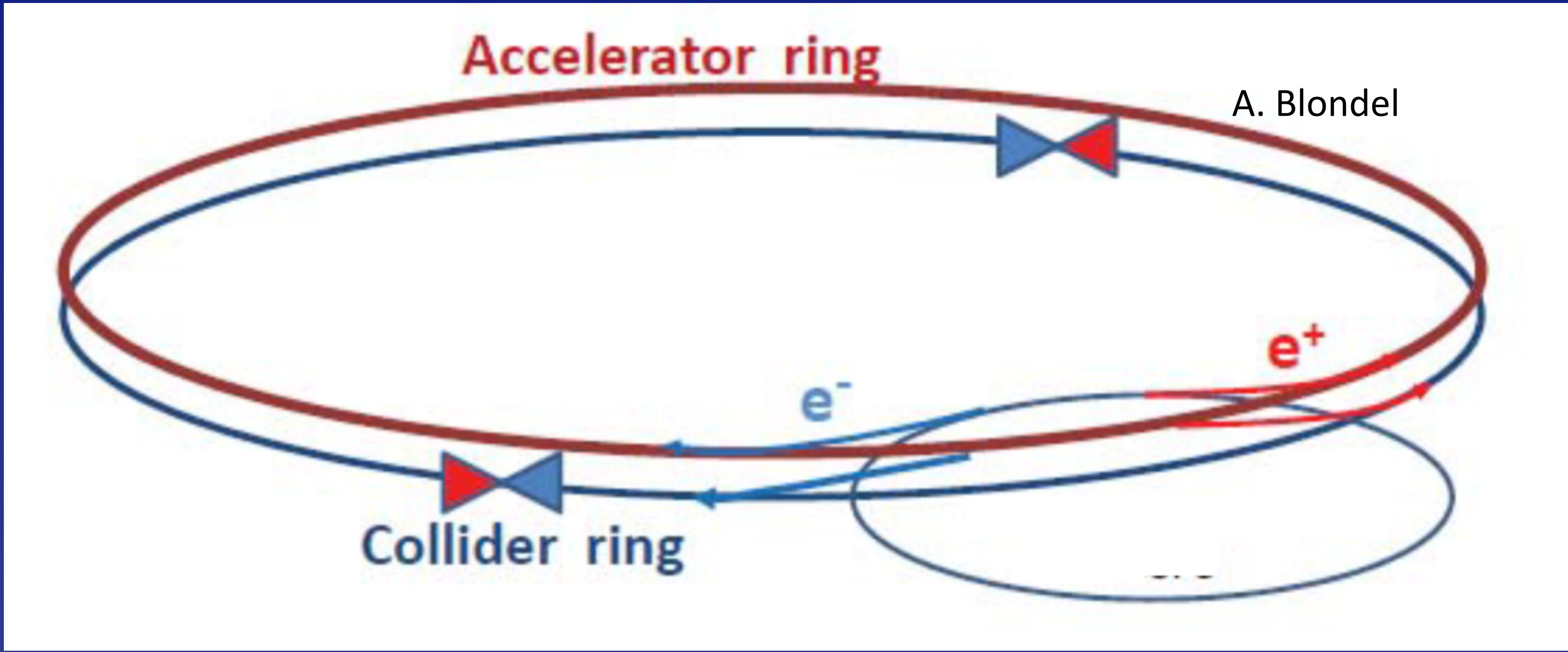
injection scheme: SPS+ →LHC → VHE-LHC too expensive (50 MW power for cryo)

L. Rossi

TLEP

double e^+e^- ring with top-up injection

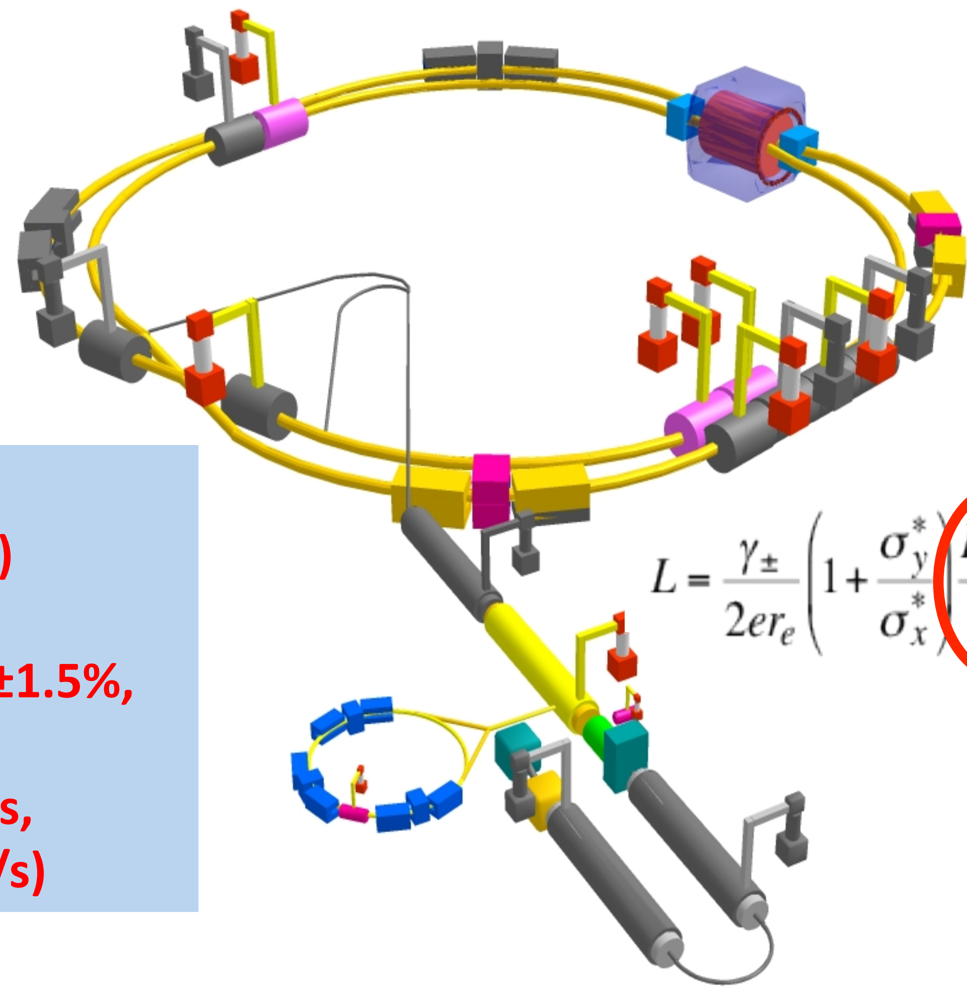
supports short lifetime & high luminosity



top-up experience: PEP-II, KEKB, light sources

SuperKEKB – a TLEP demonstrator

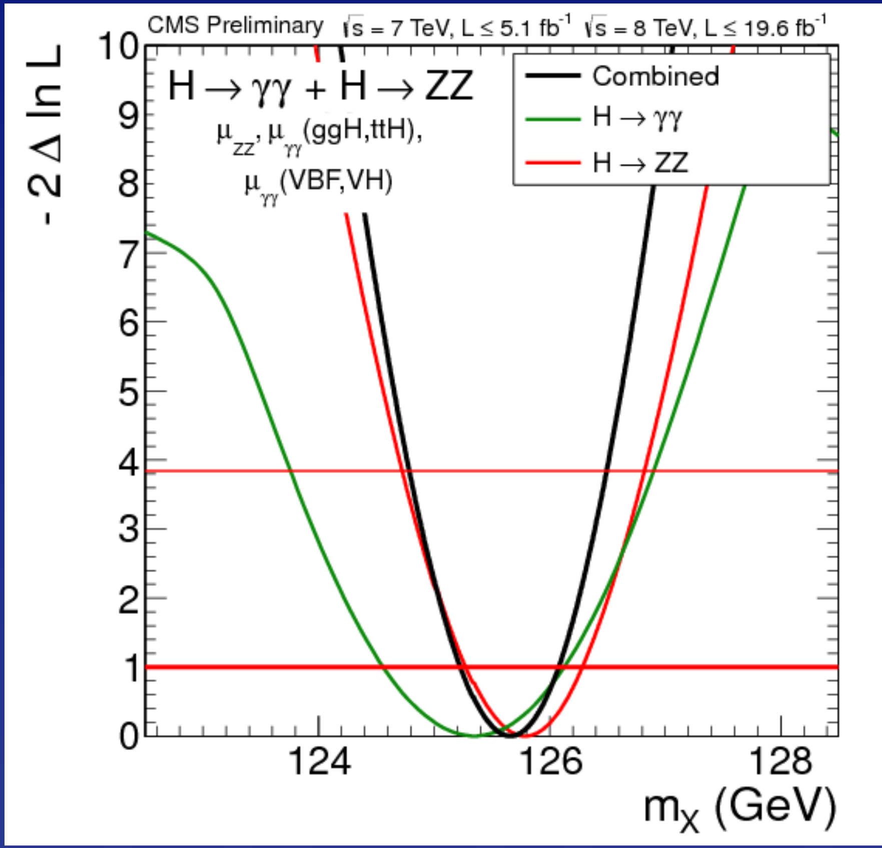
beam commissioning will start in early 2015 in Japan

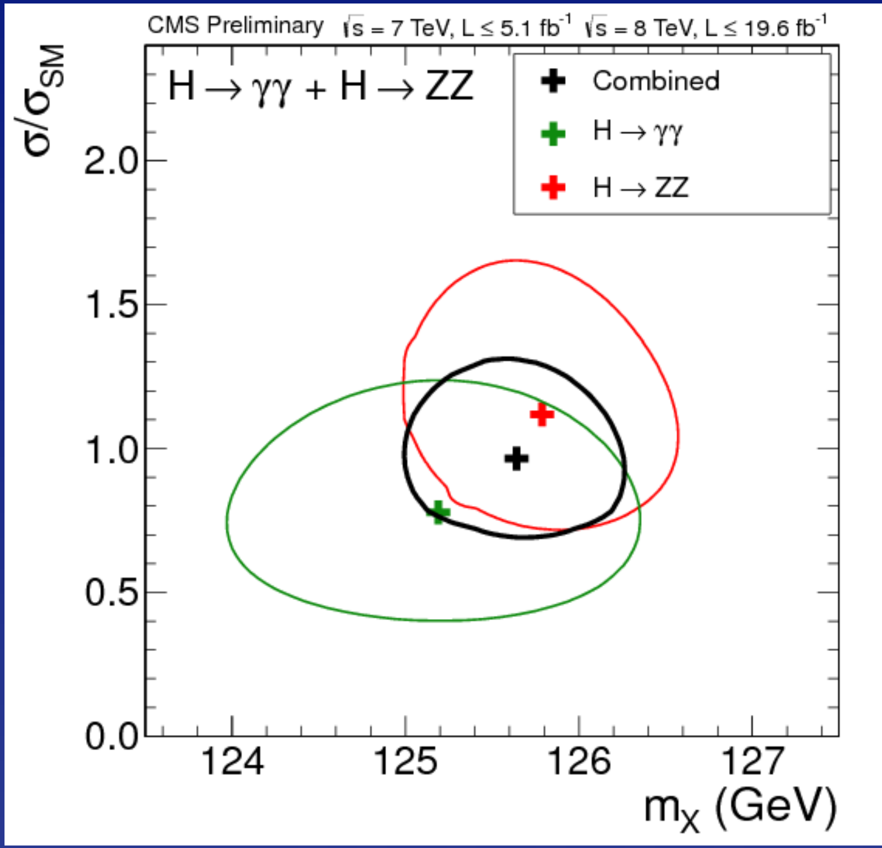


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

- b_y*=300 mm (TLEP: 1 mm)
- lifetime 5 min (TLEP: ~15min)
- e_y/e_x=0.25% ! (TLEP: 0.2%)
- off momentum acceptance (±1.5%, TLEP: ±2%)
- e^+ production rate ($2.5\text{x}10^{12}$/s, TLEP: <$1\text{x}10^{11}$/s)

Higgs Mass

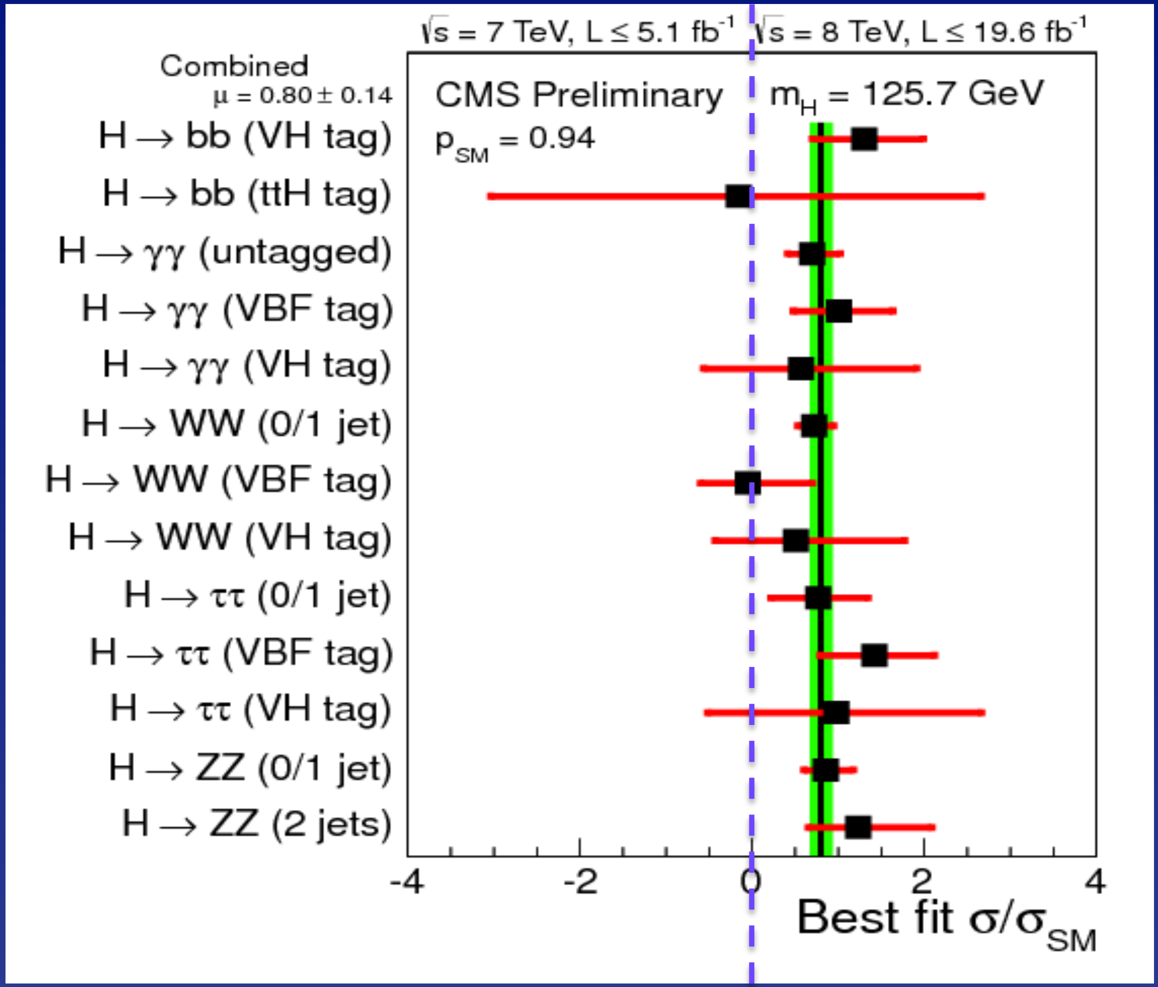




Higgs Mass = 125.7 +/- 0.3 +/- 0.3

Observed H→γγ Mass is affected by interference ~150 MeV

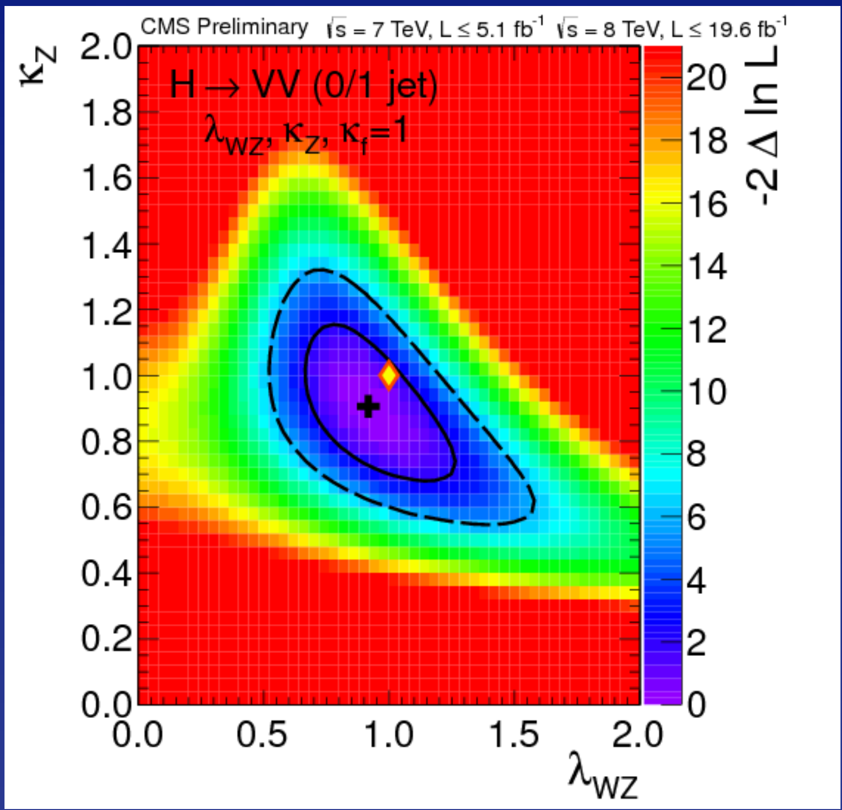
Dissecting the 126 GeV Resonance



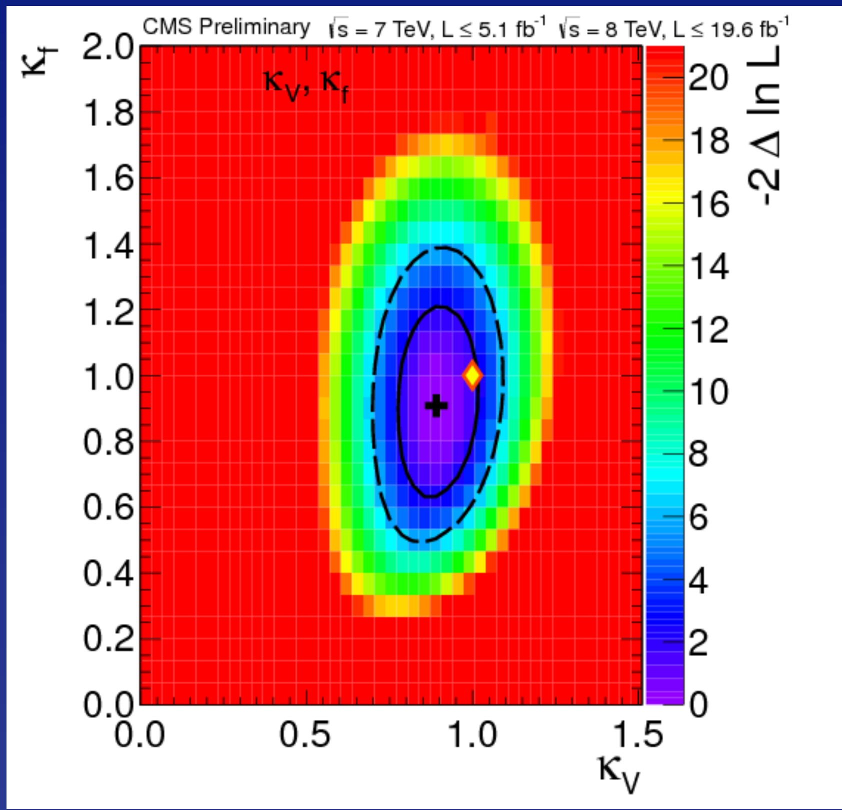
Limitation on prediction of H→bb (b mass, alphas, lattice QCD):
Width cannot be predicted to better than 4% - no discovery below 15-20% deviation unless it is in the ratio of branching ratios.

Test of Couplings

Custodial Symmetry



Fermions vs. Vector Bosons



IPAC’13 Shanghai

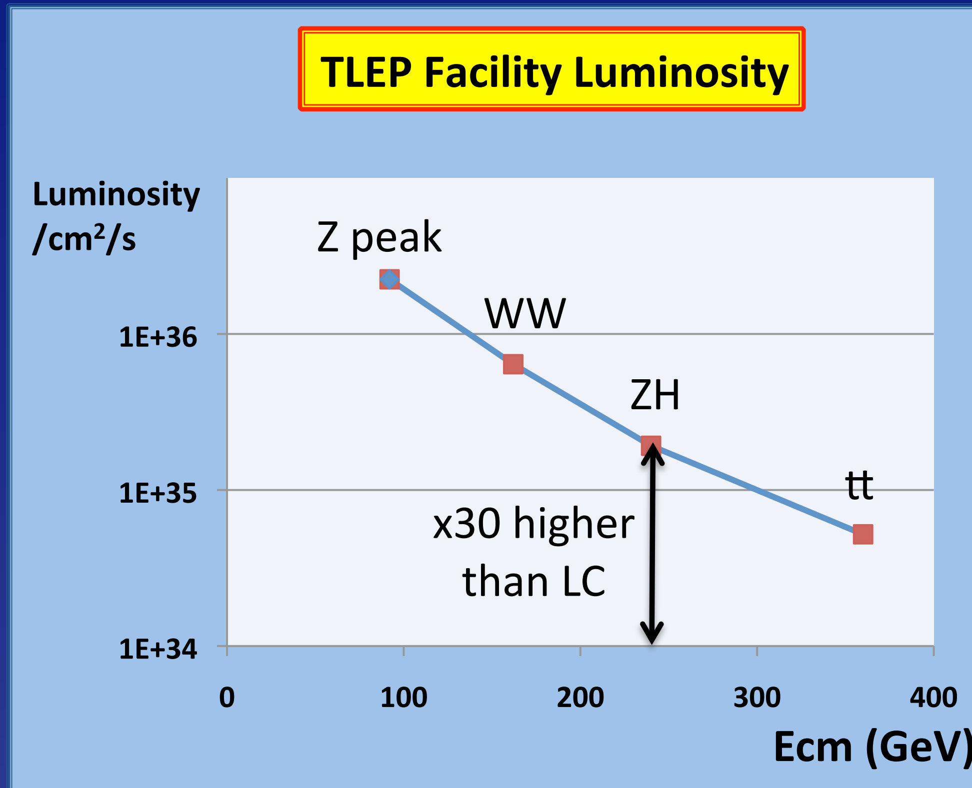
Table 1: TLEP parameters at different energies

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
circumf. [km]	80	80	80	80
beam current [mA]	1180	124	24.3	5.4
#bunches/beam	4400	600	80	12
#e−/beam [10^{12}]	1960	200	40.8	9.0
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
bending rad. [km]	9.0	9.0	9.0	9.0
κ_ε	440	470	470	1000
mom. c. α_c [10^{-5}]	9.0	2.0	1.0	1.0
$P_{loss,SR}$/beam [MW]	50	50	50	50
β^*_x [m]	0.5	0.5	0.5	1
β^*_y [cm]	0.1	0.1	0.1	0.1
σ^*_x [μm]	124	78	68	100
σ^*_y [μm]	0.27	0.14	0.14	0.10
hourglass F_{hg}	0.71	0.75	0.75	0.65
E^{SR}_{loss}/turn [GeV]	0.04	0.4	2.0	9.2
$V_{RF,tot}$ [GV]	2	2	6	12
$\delta_{max,RF}$ [%]	4.0	5.5	9.4	4.9
ξ_x/IP	0.07	0.10	0.10	0.10
ξ_y/IP	0.07	0.10	0.10	0.10
f_s [kHz]	1.29	0.45	0.44	0.43
E_{acc} [MV/m]	3	3	10	20
eff. RF length [m]	600	600	600	600
f_{RF} [MHz]	700	700	700	700
δ^{SR}_{rms} [%]	0.06	0.10	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	0.19	0.22	0.17	0.25
$\mathcal{L}$/IP[10^{32}cm^{-2}s^{-1}]	5600	1600	480	130
number of IPs	4	4	4	4
beam lifet. [min]	67	25	16	20

TLEP: A HIGH-PERFORMANCE CIRCULAR e^+e^- COLLIDER TO STUDY THE HIGGS BOSON

M. Koratzinos, A.P. Blondel, U. Geneva, Switzerland; R. Aleksan, CEA/Saclay, France; O. Brunner, A. Butterworth, P. Janot, E. Jensen, J. Osborne, F. Zimmermann, CERN, Geneva, Switzerland; J. R. Ellis, King’s College, London; M. Zanetti, MIT, Cambridge, USA.

http://arxiv.org/abs/1305.6498.



A possible TLEP running program

1. ZH threshold scan and 240 GeV running (200 GeV to 250 GeV)
   5+ years @$2x10^{35}$ /cm^2/s ➔ $2x10^6$ ZH events
   ++ returns at Z peak with TLEP-H configuration
   for detector and beam energy calibration

Higgs boson HZ studies
+ WW, ZZ etc..

2. Top threshold scan and (350) GeV running
   5+ years @$2x10^{35}$ /cm^2/s ➔ 10^6 ttbar pairs

Top quark mass
Hvv Higgs boson studies

3. Z peak scan and peak running , TLEP-Z configuration ➔ 10^{12} Z decays
   → transverse polarization of 'single' bunches for precise E_beam calibration
   2 years

Mz, Γ_Z R_b etc…
Precision tests and rare decays

4. WW threshold scan for W mass measurement and W pair studies
   1-2 years ➔ 10^8 W pairs

M_W, and W properties etc…

5. Polarized beams (spin rotators) at Z peak
   1 year at BBTS=0.01/IP ➔ 10^{11} Z decays

A_{LR}, A_{FB}^{pol} etc

6. Start of 100 TeV pp program

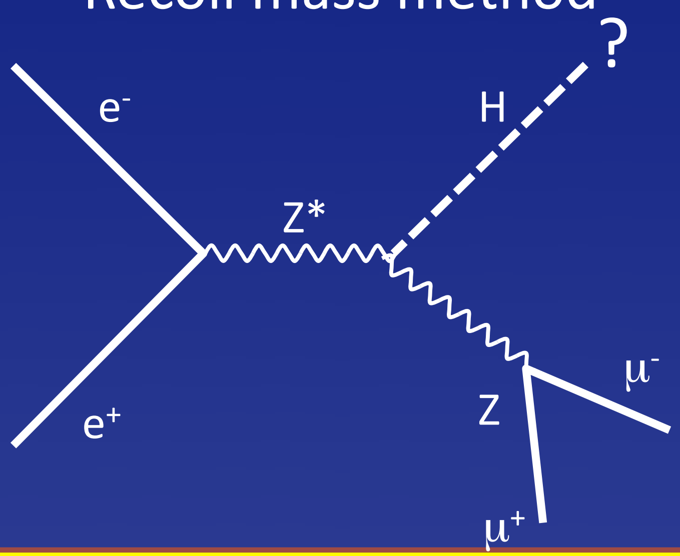
Higgs Boson Production Mechanism in e^+e^- collisions

Light Higgs is produced by "Higgsstrahlung" process close to threshold

Production cross-section has a maximum of ~200 fb

TLEP (4IP) 2. 10^{35}/cm^2/s ➔ 400'000 HZ events/year (2 million H(126) in 5 years)

"Recoil mass method"



Z – tagging by missing mass
➔a beam of Higgs bosons!

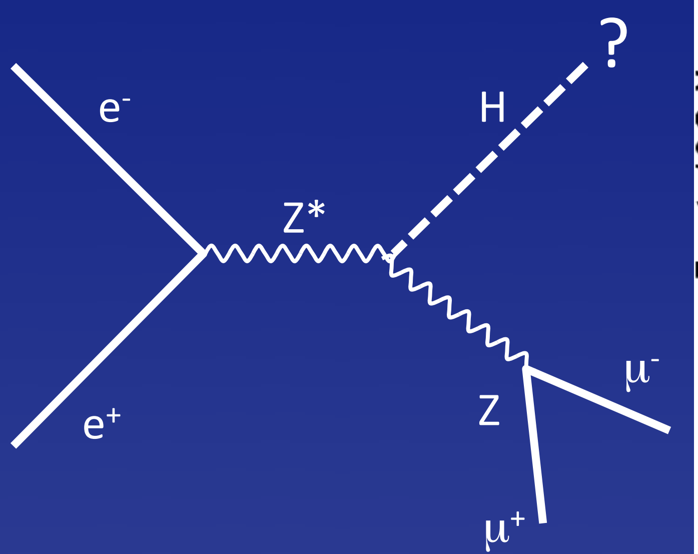
Need High Statistics for Z boson dilepton decay mode

For a Higgs of 125GeV, a centre of mass energy of 240GeV is optimal
➔ kinematical constraint near threshold for high precision in mass, width, selection purity

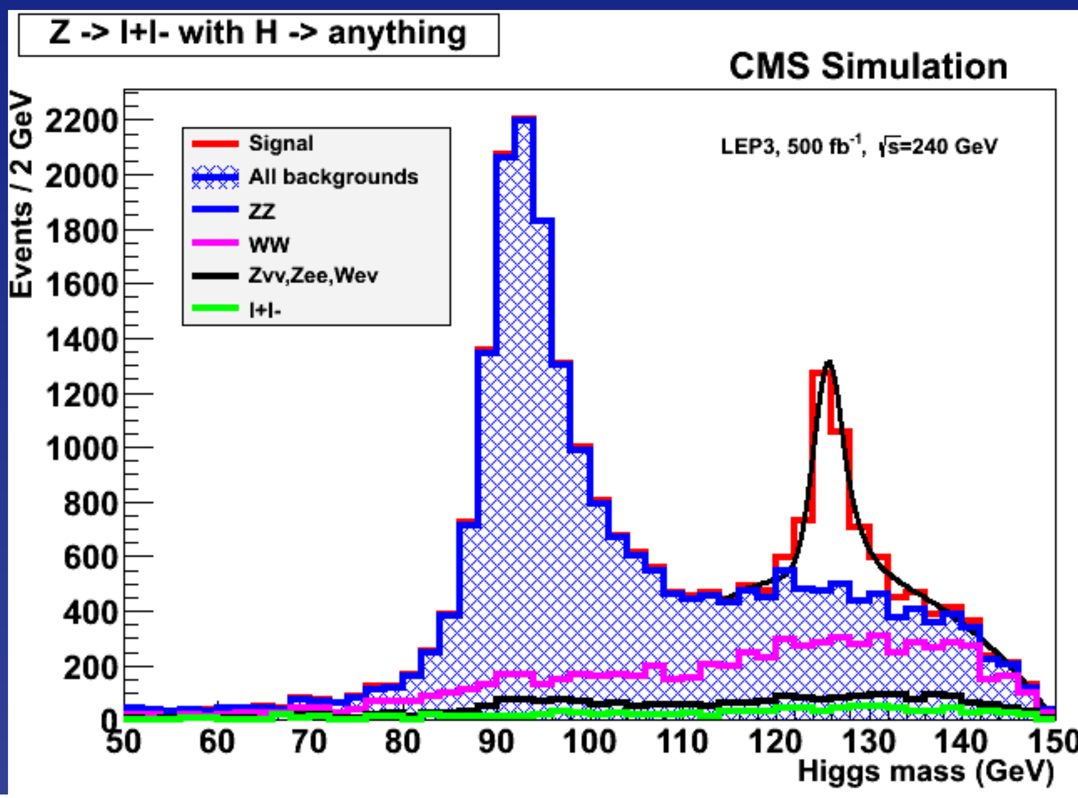
Z – tagging by missing mass

total rate $\propto g_{HZZ}^2$
ZZZ final state $\propto g_{HZZ}^4 / \Gamma_H$
➔ measure total width Γ_H

empty recoil = invisible width
'funny recoil' = exotic Higgs decay
easy control below threshold



Precision of 0.6%
on Higgs total width



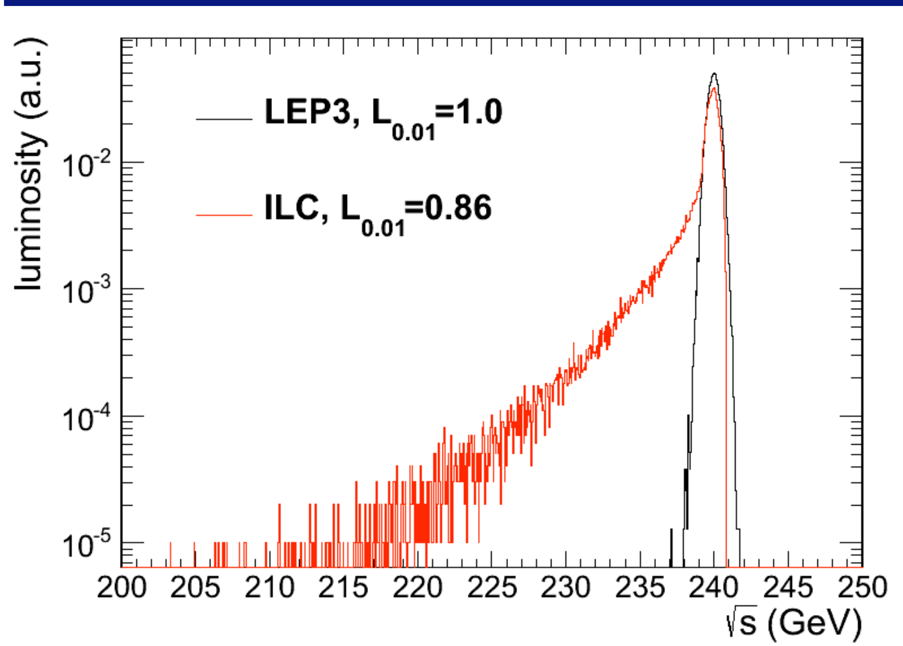
Higgs e^+e^- Factory Comparison
Nominal Linear (ILC 250-500 GeV) vs. Circular (TLEP 240-350 GeV)

Facility	ILC	TLEP (4 IP)	Improvement Factor (Circ/Lin)	Improvement Factor (Circ/Best HL-LHC)
Energy (GeV)	500	350		
$\int \mathcal{L}dt$ (fb^{-1})	+500	+1400		
$\Delta\Gamma_h/\Gamma_h$	6.0%	0.6%	x10	~x1000 or more
$\mathcal{B}_{\rm inv}$	$< 0.69\%$	$< 0.1\%$	x7	~x100 or more
$\Delta g_\gamma/g_\gamma$	8.4%	1.5%	x5	~Same
$\Delta g_{Z\gamma}/g_{Z\gamma}$	?	?		
$\Delta g_g/g_g$	2.5%	0.8%	x3	x3
$\Delta g_W/g_W$	1.4%	0.19%	x7	x10
$\Delta g_Z/g_Z$	1.3%	0.15%	x8	x13
$\Delta g_\mu/g_\mu$	–	6.2%	TLEP-only	~Same
$\Delta g_\tau/g_\tau$	2.5%	0.54%	x4	x3
$\Delta g_c/g_c$	3.0%	0.71%	x4	x100 or more
$\Delta g_b/g_b$	1.8%	0.42%	x4	x9
$\Delta g_t/g_t$	18%	13%	~Same	~Same or x2 Worse

http://www.snowmass2013.org/tiki-index.php?page=The+Higgs+Boson

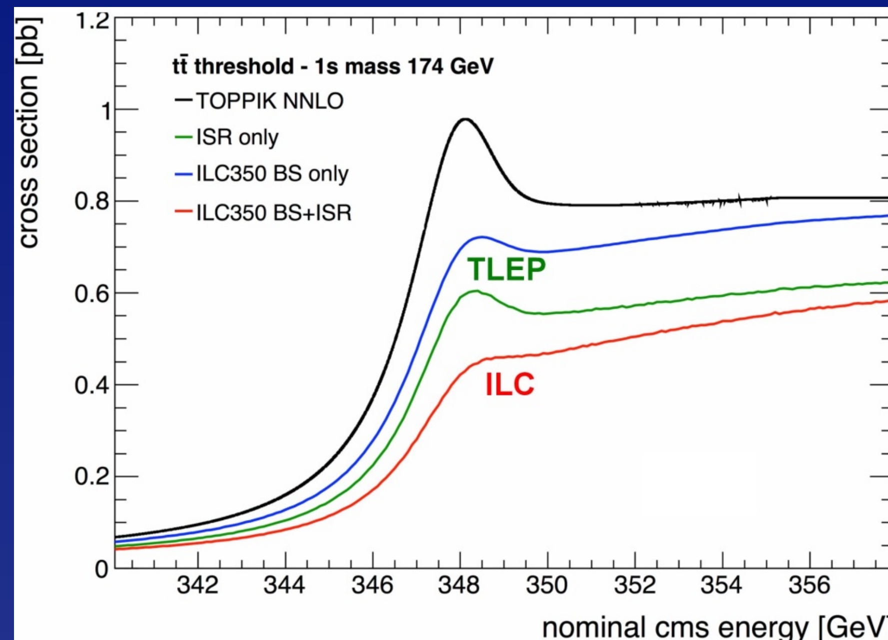
BEAMSTRAHLUNG and energy definition

Luminosity *E* spectrum



➔

Effect on top threshold



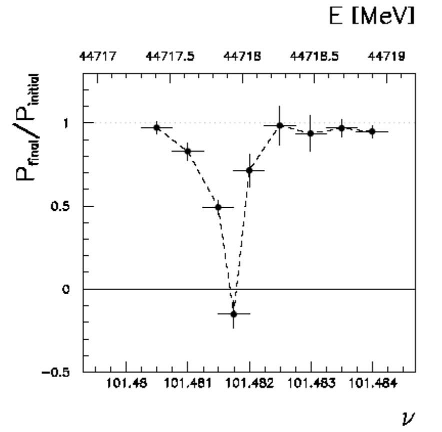
Beamstrahlung @TLEP is important for machine design but benign for physics:
particles are either lost or recycled on a synchrotron oscillation.
➔ some increase of 1-2 10^{-3} energy spread but no change of average energy
Little resulting systematic error – cross-check wrt orbit of 'single' bunches

Little EM background in the experiment, no issue for luminosity measurement, but shielding against synchrotron radiation has to be designed.

Beam polarization and E-calibration @ TLEP

Precise measurement of E_{beam} by resonant depolarization

~100 keV each time the measurement is made *LEP→*



At LEP transverse polarization was achieved routinely at Z peak.

instrumental in 10^{-3} measurement of the Z width in 1993

led to prediction of top quark mass (179+- 20 GeV) in Mar'94

Polarization in collisions was observed *(40% at BBTS = 0.04)*

At LEP, beam energy spread destroyed polarization above 61 GeV

$\sigma_E \propto E^2/\sqrt{\rho}$ → *At TLEP transverse polarization for calibration up to at least 81 GeV (WW)*

TLEP: use 'single' bunches to measure the beam energy continuously

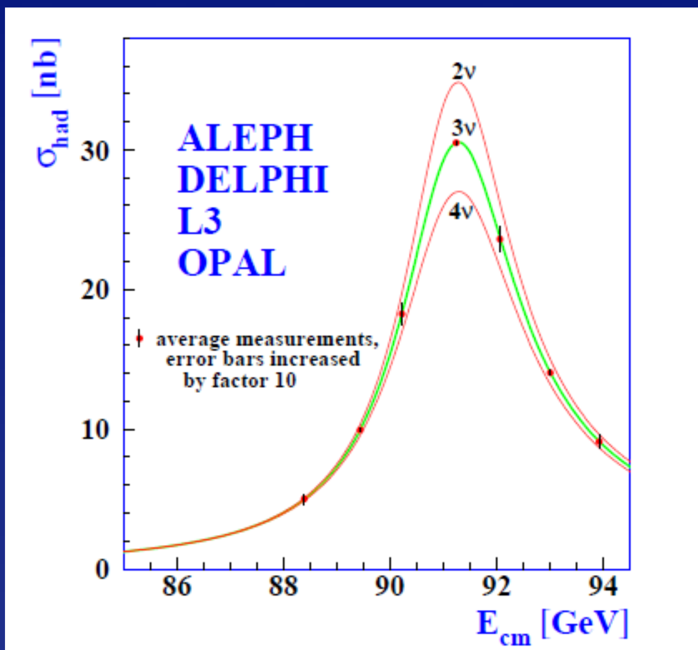
→*no interpolation errors due to tides, ground motion or trains etc…*

<< 100 keV beam energy calibration around Z peak and W pair threshold.

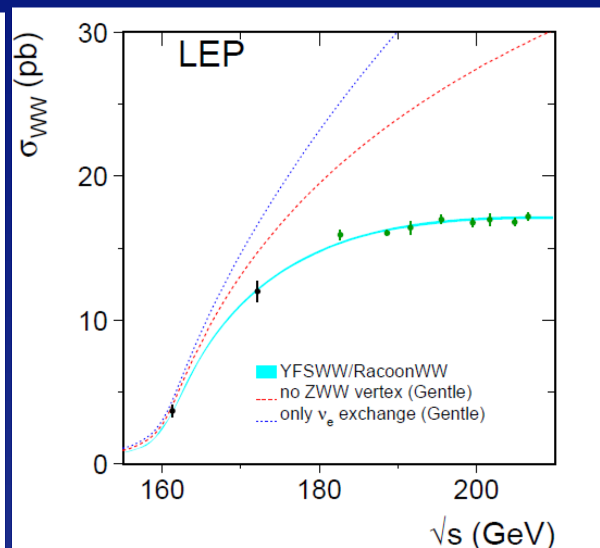
Δm_Z <0.1 MeV, $\Delta\Gamma_Z$ <0.1 MeV, Δm_W < 0.5 MeV

Precision tests of EWSB

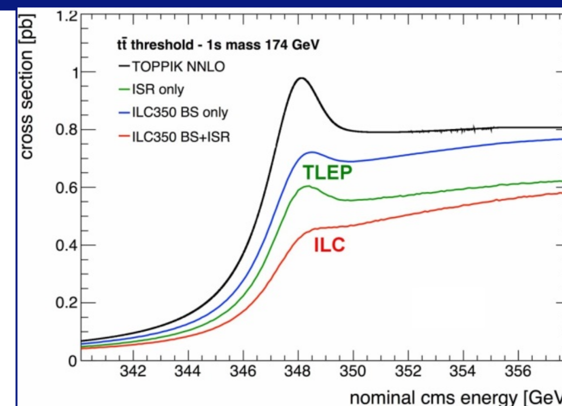
Z pole asymmetries, lineshape

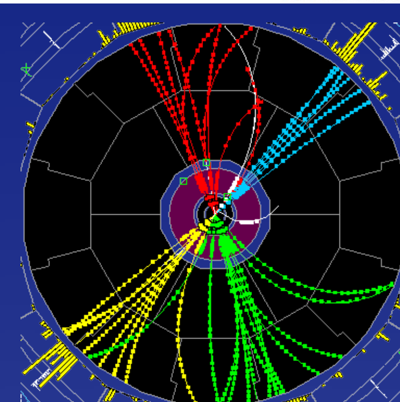


WW threshold scan



tt threshold scan





TLEP : Repeat the LEP1 physics program every 15 mn

Transverse polarization up to the WW threshold

- Exquisite beam energy determination (10 keV)

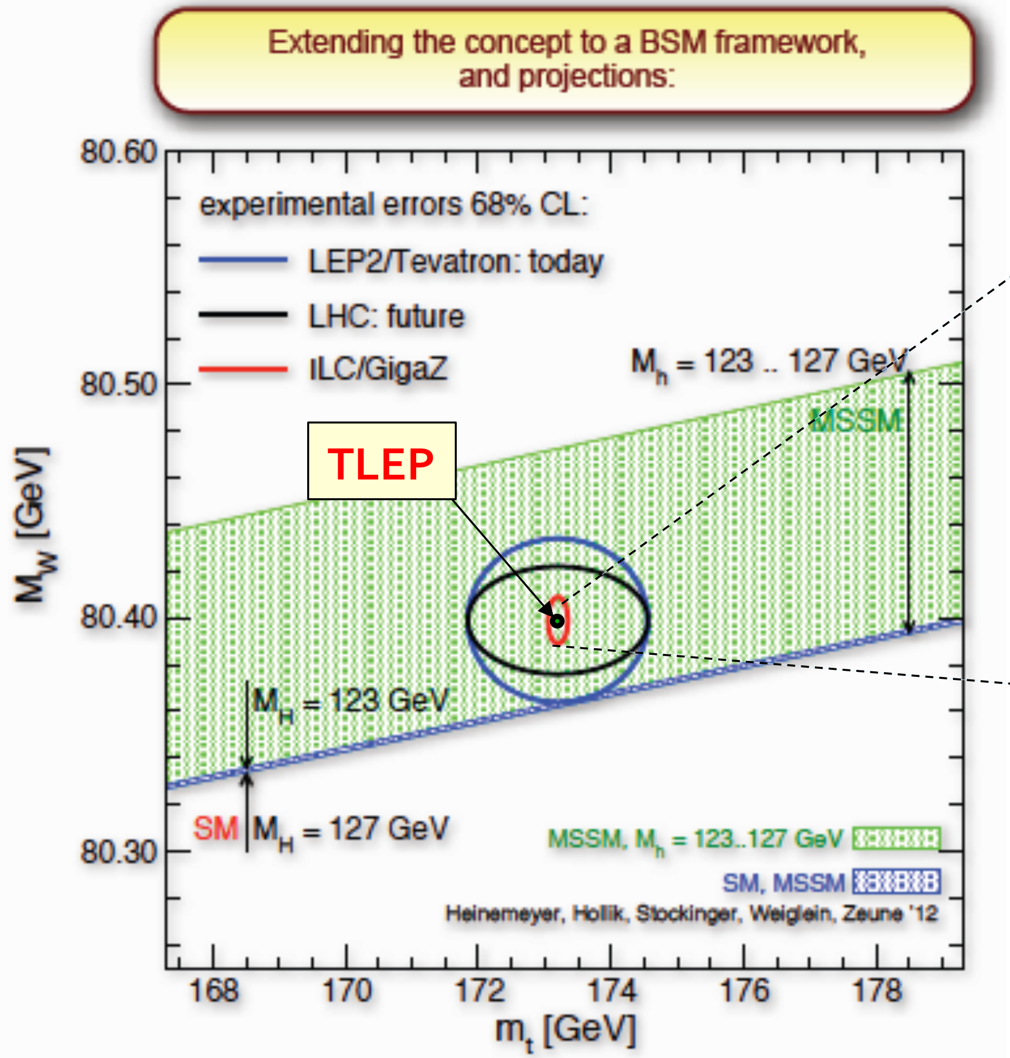
Longitudinal polarization at the Z pole

- Measure $\sin^2\theta_W$ to 2.10^{-6} from A_{LR}
- Statistics, statistics: 10^{10} tau pairs, 10^{11} bb pairs, QCD and QED studies etc…

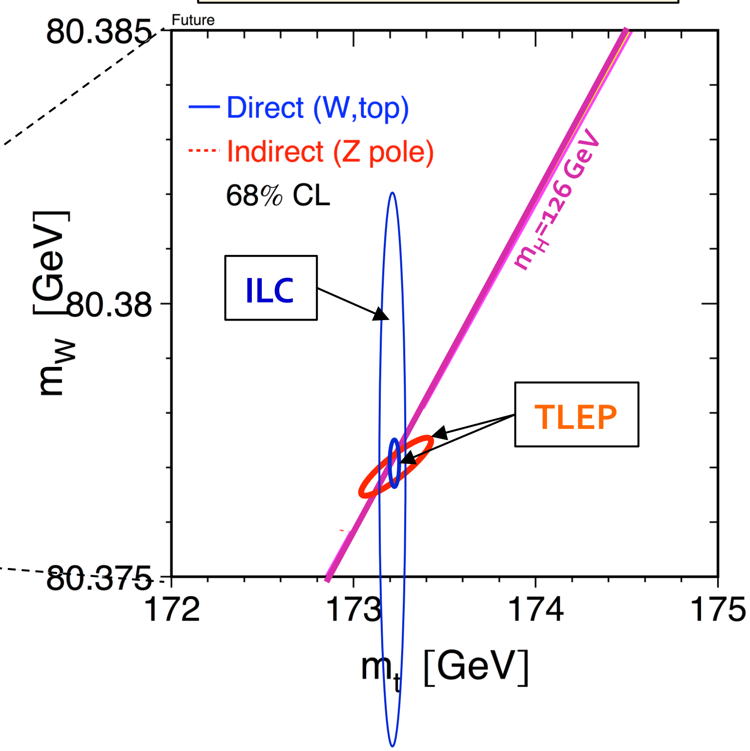
High Precision Program (Some Examples)

X	Physics	Present precision		TLEP target Precision –TBS	TLEP key	Challenge
M_Z MeV/c2	**Input**	91187.5 ±2.1	Z Line shape scan	**<±0.1** MeV/c^2	E_cal	QED corrections
Γ_Z MeV/c2	**$\Delta\rho$ (T) (no $\Delta\alpha$!)**	2495.2 ±2.3	Z Line shape scan	**<±0.1** MeV/c^2	E_cal	QED corrections
R	α_s, δ_b	20.767 ± 0.025	Z Peak	**± 0.002 - 0.0002**	Statistics	QED corrections
N_ν	**Unitarity of PMNS, sterile ν's**	2.984 ±0.008	Z Peak	**±0.001 (?)**	environment ->lumi meast	**QED corrections to Bhabha scat.**
R_b	δ_b	0.21629 ±0.00066	Z Peak	**±0.00002 - 5**	Statistics, small IP	Hemisphere correlations
A_{LR}	**$\Delta\rho$, ε_3, $\Delta\alpha$ (T, S)**	0.1514 ±0.0022	Z peak, polarized	**±0.000015**	4 bunch scheme	Design experiment
M_W MeV/c2	**$\Delta\rho$, ε_3, ε_2, $\Delta\alpha$ (T, S, U)**	80385 ± 15	Threshold scan	**0.5** MeV/c^2	E_cal & Statistics	
m_{top} MeV/c2	**Input**	173200 ± 900	Threshold scan	**10** MeV/c^2	E_cal & Statistics	Theory limit at 100 MeV?

Precision on W, t, H Masses

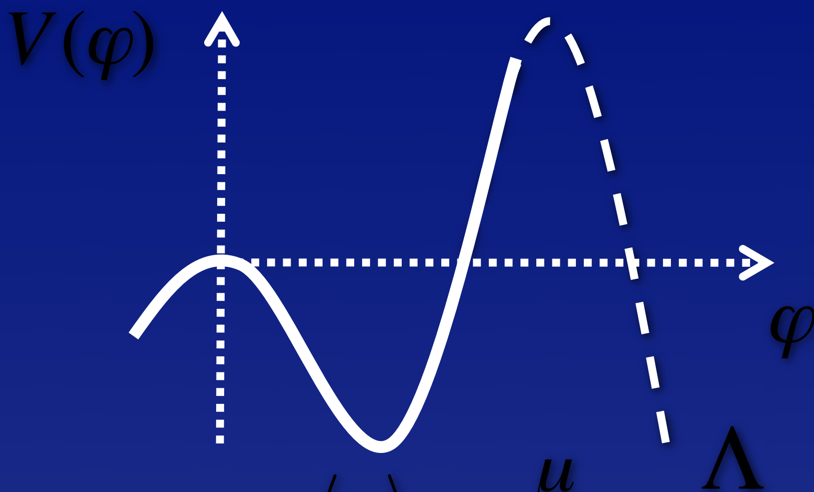


Warning : indicative only.
Complete study being done

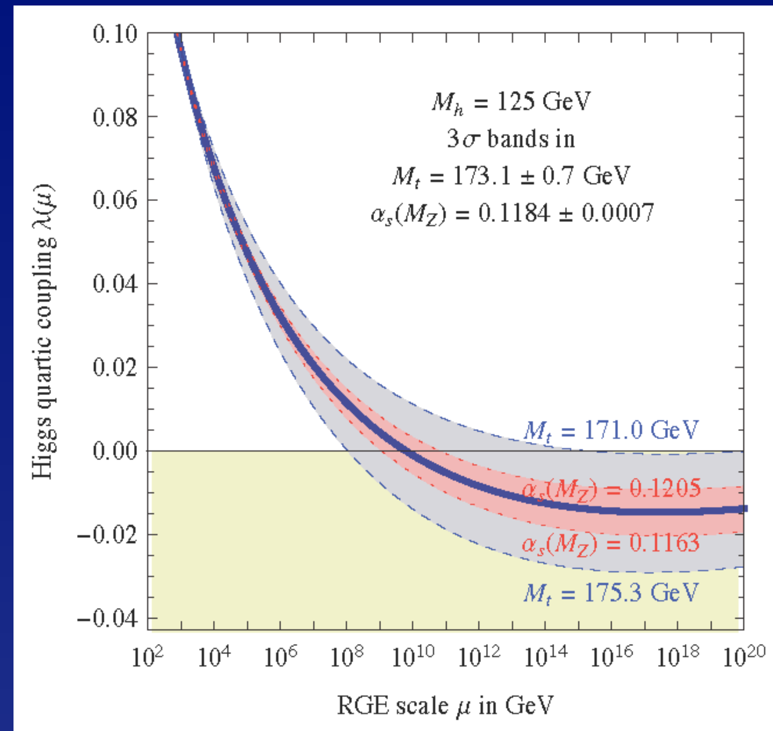


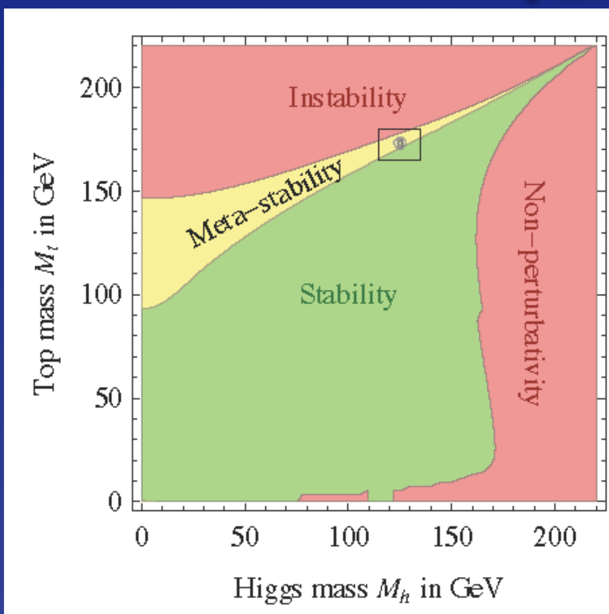
Very stringent SM closure test.
Sensitivity to weakly-interacting multi-TeV BSM Physics.

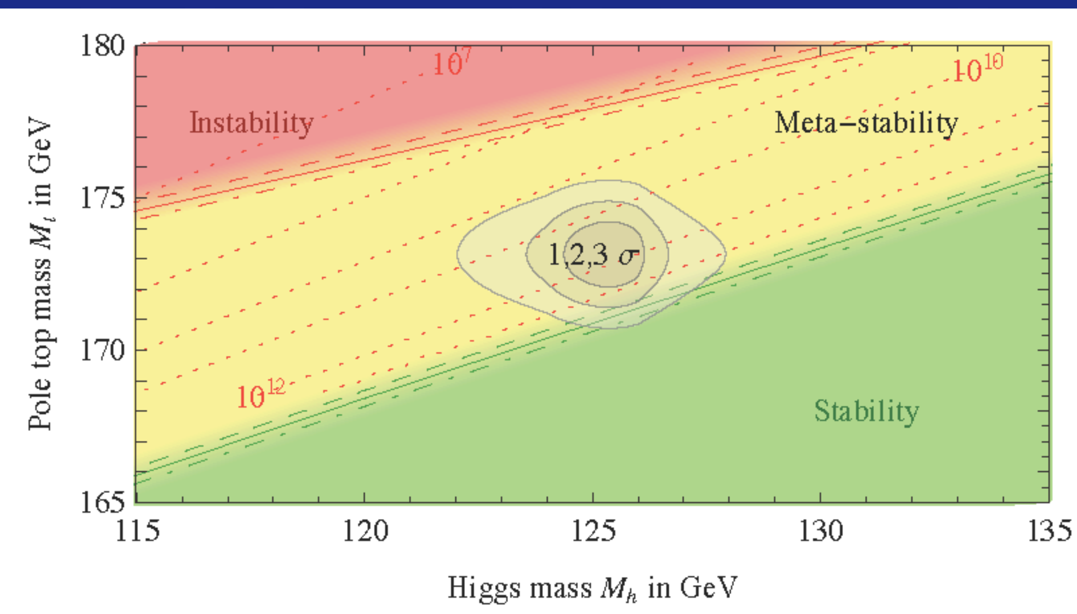
EW Vacuum



$$\langle \varphi \rangle = \frac{\mu}{\sqrt{2\lambda}}$$



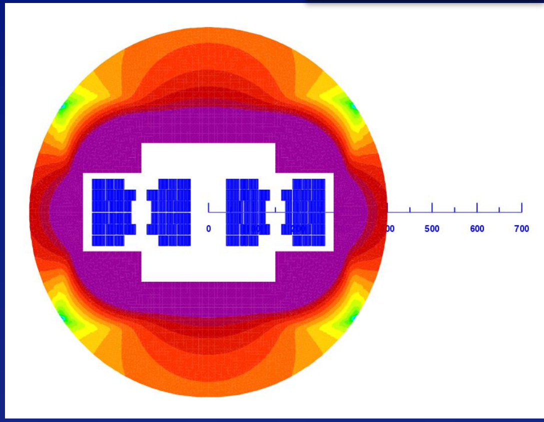




Development of the 100 TeV pp Collider

L. Rossi

- TLEP step towards **VHE-LHC**
  - 80-100 TeV pp collisions
  - Need to develop **15⁺ T** SC magnets
    - Needs R&D and time (TLEP won't delay VHE-LHC)

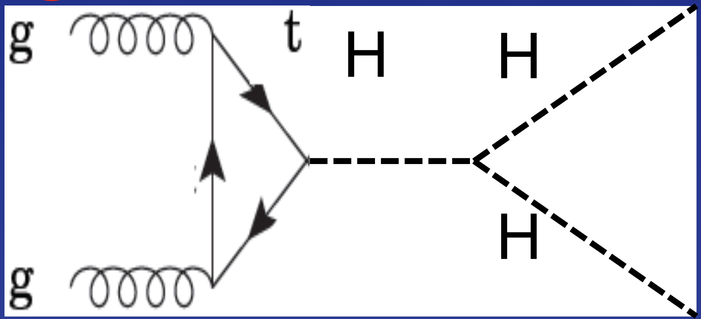


M. Mangano HE-LHC VHE-LHC

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42

Improvement of ~x50 in production cross-section

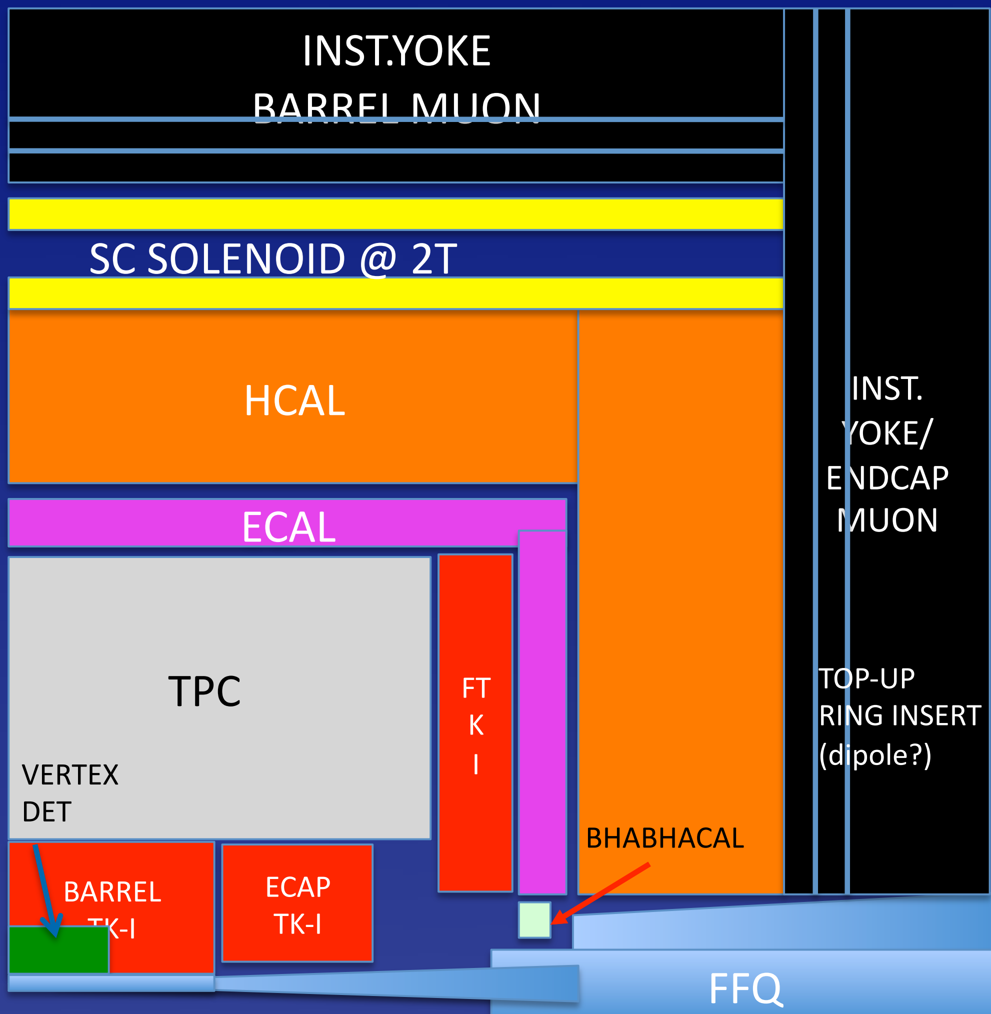
➔High statistics studies of ttH and HHH couplings
Highest mass reach for an extended Higgs sector



Push ttH precision to sub-percent – most important Yukawa coupling in the SM
Highest potential for precision self-coupling measurement (limited to 16-30% at ILC/LHC)

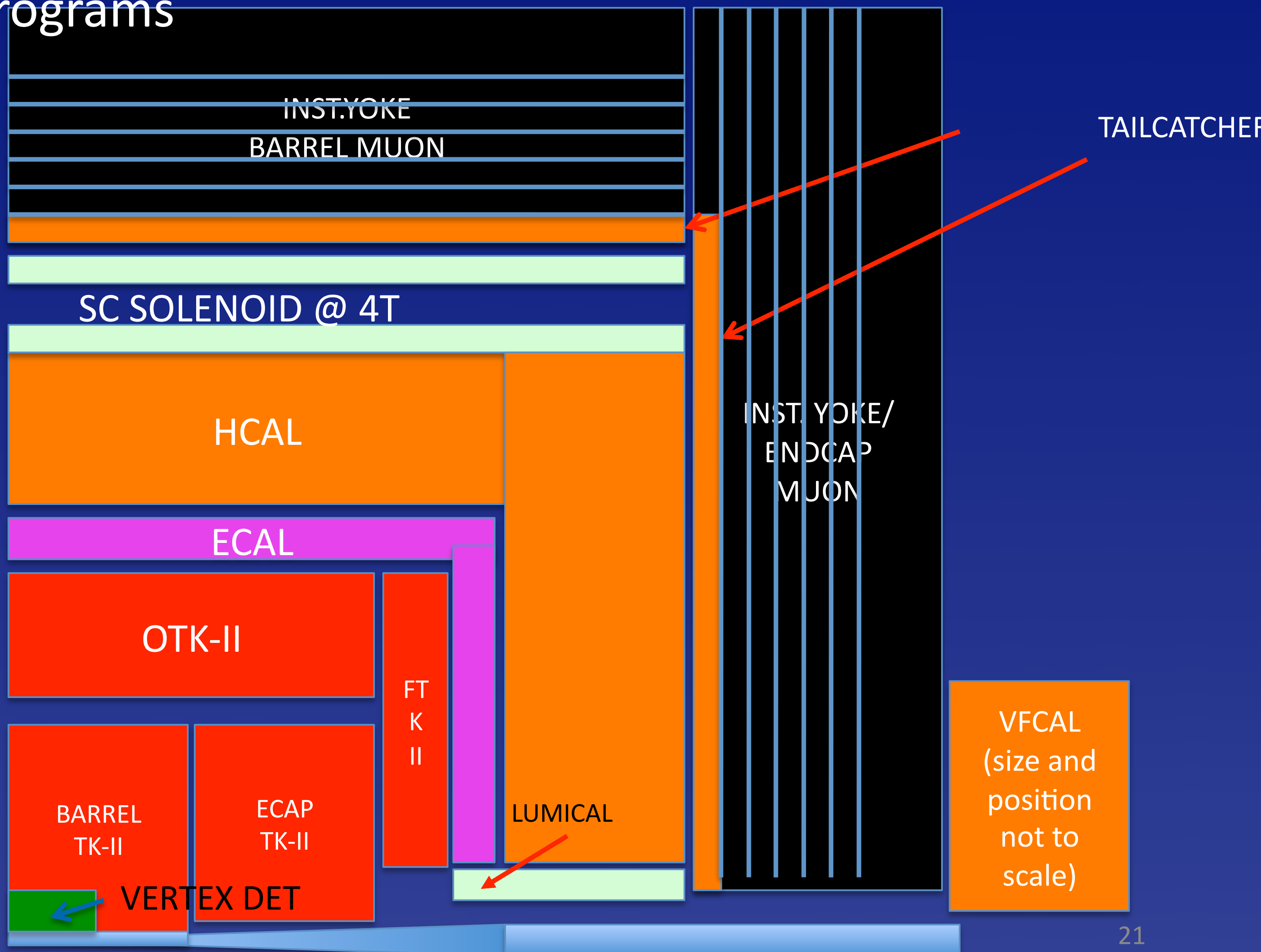
4π Detectors (e^+e^- Program)

- Exciting path to create infrastructure where the experimental halls are designed for planned intervention and transitions to different physics programs



4π Detectors (pp Program)

- Exciting path to create infrastructure where the experimental halls are designed for planned intervention and transitions to different physics programs



Design Study : http://tlep.web.cern.ch

Welcome new people interested in contributing:

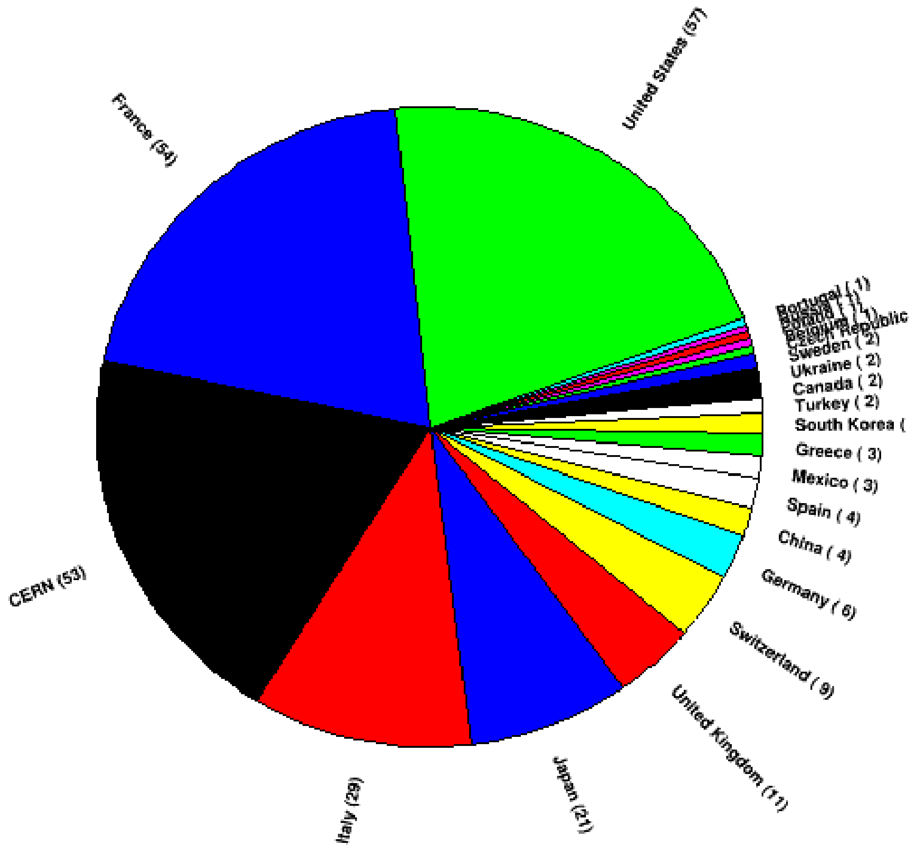
collaborators from all over the world

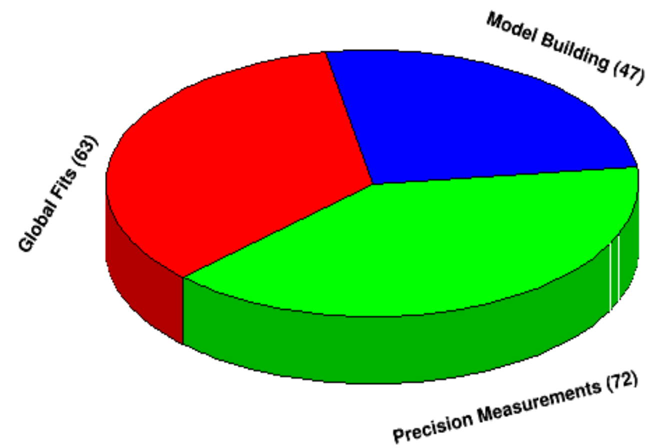
Next events: TLEP workshops 25-26 July 2013, Fermilab

16-18 October 2013, CERN

\+ Joint VHE-LHC+ TLEP kick-off meeting in February 2014

The first 270 subscribers (full nominative list can be found from TLEP web site)





The distribution of the country of origin reflects the youth of the TLEP project and the very different levels of awareness in the different countries.

The audience is remarkably well balanced between Accelerator, Experiment, and Phenomenology

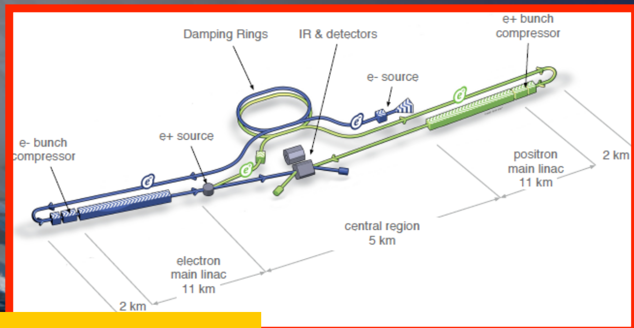
Major Challenges for Higgs Physics

- The LHC at 14 TeV will probe new physics at and above the TeV scale in a broad sweep
  - Beyond the LHC, the most promising avenue for future exploration is via the Higgs boson properties through high precision measurement.
    - What precision needs to be achieved to challenge our understanding of the universe and the laws of physics?
- The Higgs boson and the top quark were guaranteed discoveries based on exactly this strategy
  - The basis for the high precision measurements came from the Z factories (over 10^6 Z bosons produced on resonance and studied with polarized beams).

Roy Aleksan

From Higgs studies and electroweak high precision tests…

Linear Colliders
(ILC, CLIC)



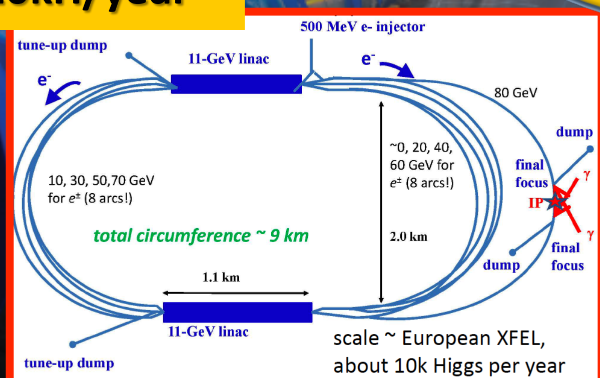
~14kH/year

Circular e^+e^- Colliders
(TLEP, super TRISTAN, IHEP…)

~400kH/year (4 det.)

Higgs Factories

~10kH/year



γγ Colliders
(SAPPHIRE, SILC, CLICHE, HFiTT)

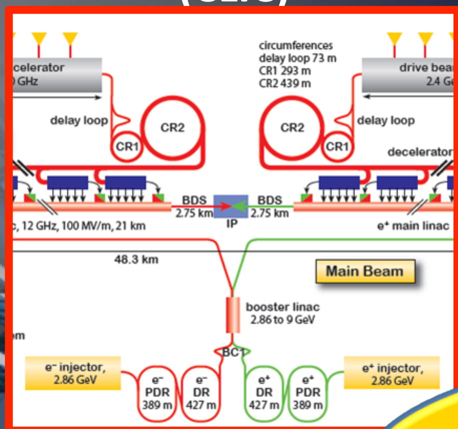
~10kH/year (2det.)

Muon Colliders
(ν-Fact. as possible 1st step)

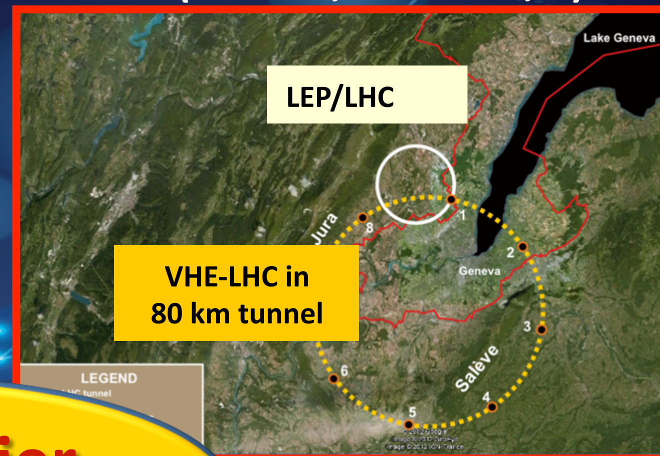
Roy Aleksan

…to HE-physics and -Frontier exploration

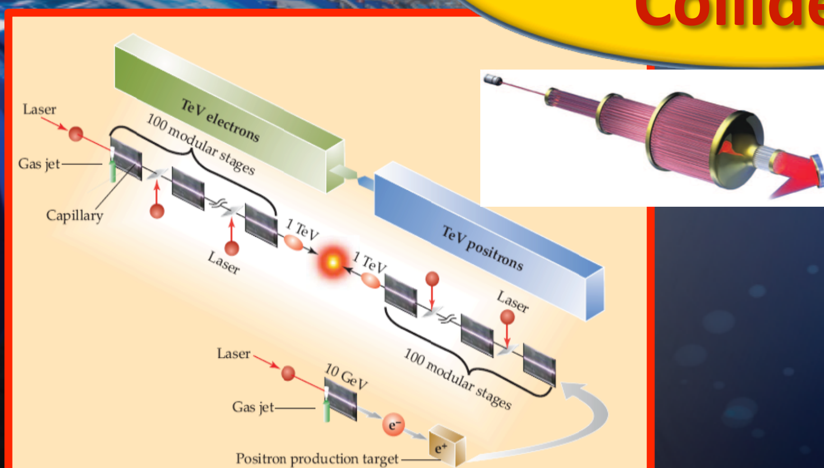
Linear Colliders
(CLIC)



pp Colliders
(HE-LHC, VHE-LHC,…)



HE-Frontier Colliders



Plasma Colliders

Muon Colliders
3-10 TeV

A Future with TLEP

- A precision Higgs physics program is compelling because the Standard Model precisely predicts all Higgs boson couplings and properties with no free parameters, now that the Higgs mass is known.
  - There is a vision for a precision Higgs program:
    - An order of magnitude increase in precision on fundamental parameters at the EW scale – and corresponding improvements in theory predictions
    - High statistics Higgs production in the ZH process to achieve push make a model sub-percent precision on the total width
  - 100 TeV pp collider is central to the long-term vision for the field:
    - The potential to go after high-p_T physics by embracing the largest technology challenges and energizing the next generation to move orders of magnitude beyond what we can do today