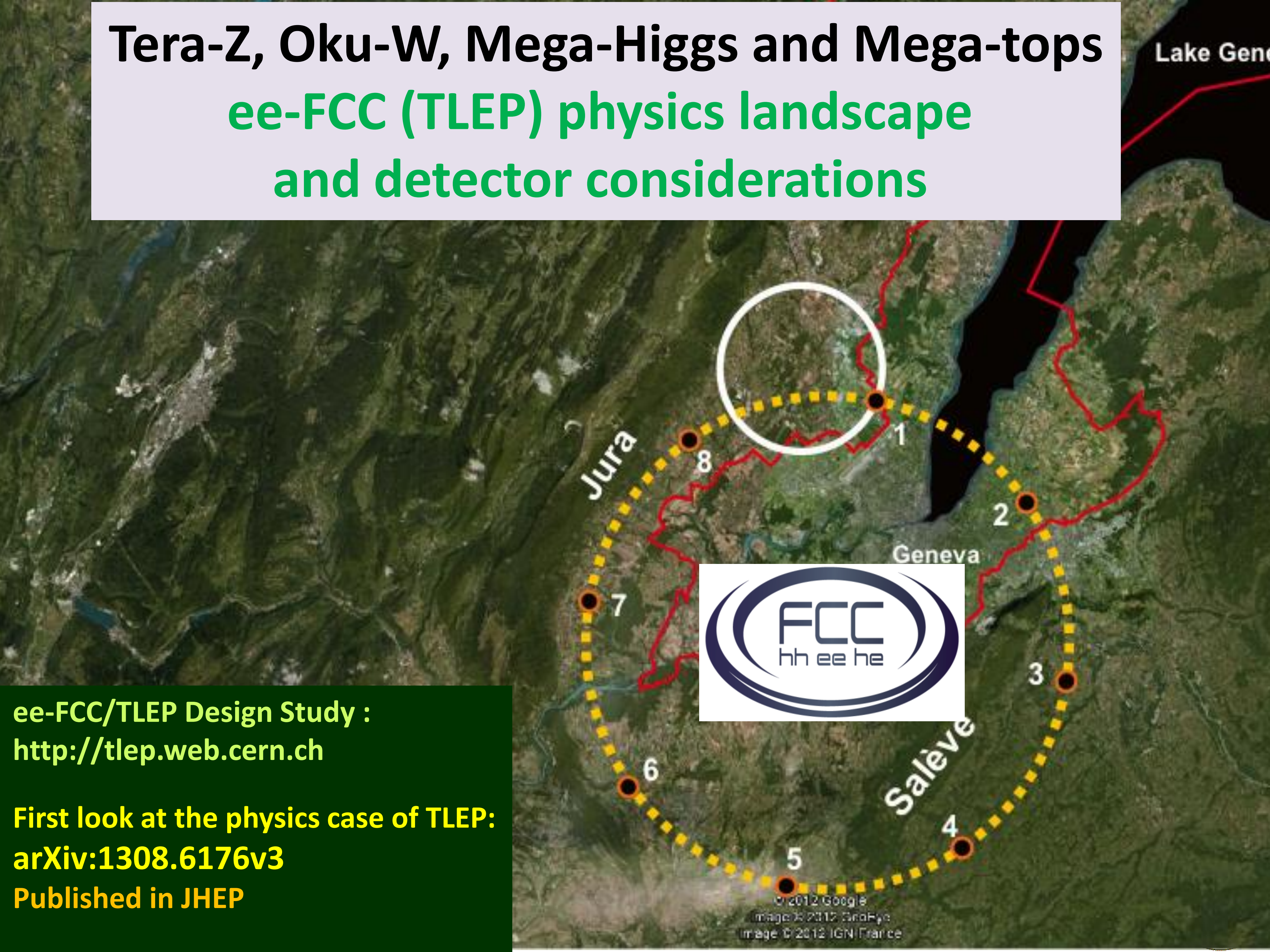
Tera-Z, Oku-W, Mega-Higgs and Mega-tops

ee-FCC (TLEP) physics landscape and detector considerations



ee-FCC/TLEP Design Study :
http://tlep.web.cern.ch

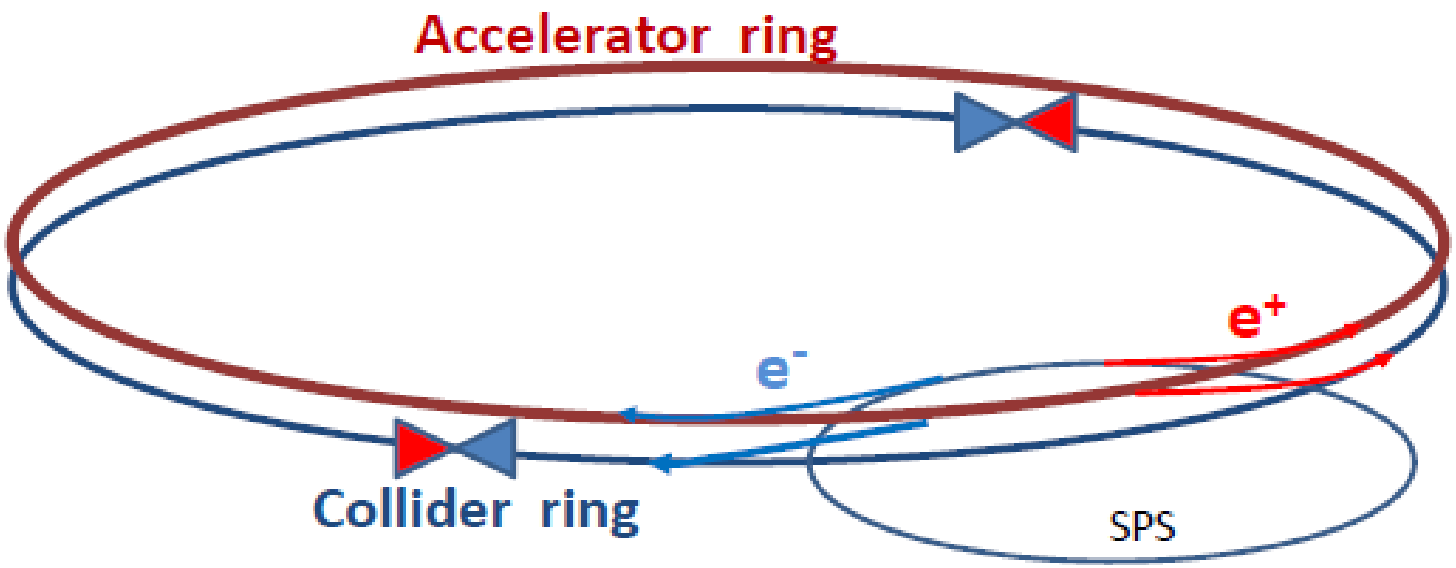
First look at the physics case of TLEP:
arXiv:1308.6176v3
Published in JHEP

Original motivation: now that m_H and m_top are known, explore EW region with high precision with High Luminosity machine

Discovery of New Physics in rare phenomena or precision measurements

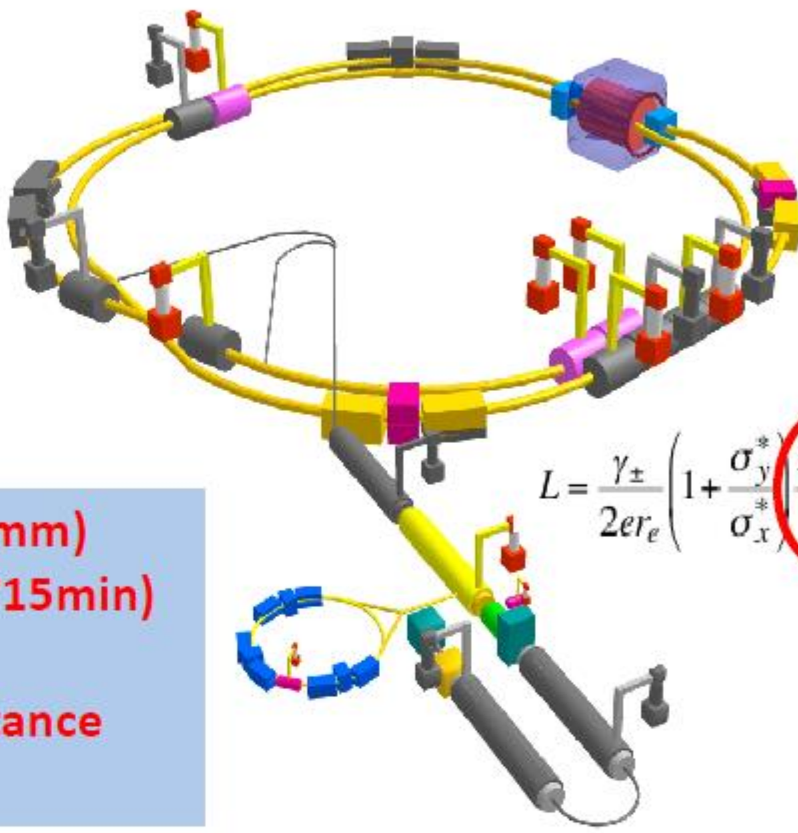
ILC studies → need increase over LEP 2 (average) luminosity by a factor 1000
How can one do that without exploding the power bill?

Answer is in the B-factory design: a very low vertical emittance ring with higher intrinsic luminosity . electrons and positrons have a much higher chance of interacting ➔ much shorter lifetime (few minutes)
➔ feed beam continuously with a ancillary accelerator



SuperKEKB – TLEP demonstrator!

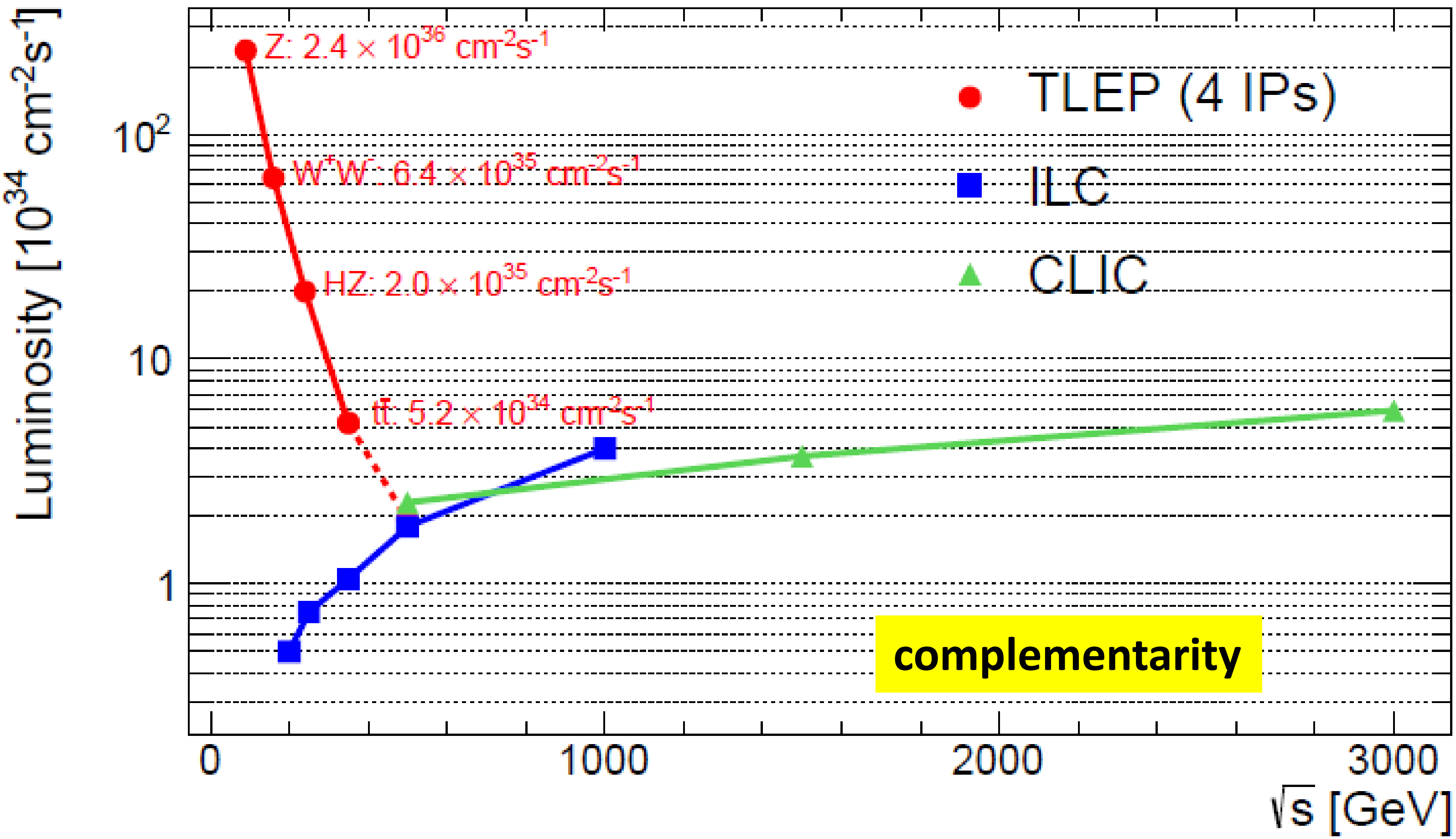
beam commissioning will start in early 2015



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

- β_y*=300 μm (TLEP: 1 mm)
- lifetime 5 min (TLEP: ~15min)
- $\varepsilon_y/\varepsilon_x$=0.25% (~TLEP)
- off momentum acceptance
- e^+ production rate

Goal performance of e+ e- colliders



Combined know-how {LEP, LEP2 and b-factories} applied for large e+e- ring collider
High Luminosity + Energy resolution and Calibration → precision on Z, W, H, t

Key parameter table

now with a real lattice

Parameter	Z	W	H	tt	LEP2
E (GeV)	45	80	120	175	104
I (mA)	1400	152	30	7	4
No. bunches	**16’700**	**4’490**	**1’330**	**98**	**4**
$\beta^*_{x/y}$ (mm)	500 / 1	500 / 1	500 / 1	1000 / 1	1500 / 50
ε_x (nm)	29	3.3	1	2	30-50
ε_y (pm)	60	7	2	2	~250
ξ_y	0.03	0.06	0.09	0.09	0.07
L (10^{34} $cm^{-2}s^{-1}$)	28	12	5.9	1.8	0.012

→ At the Z : 20 ns (or smaller) spacing

beam sizes significantly smaller than LEP

$N_b > Q_x$ → requires separate vac. chambers for e+ and e-

STATISTICS

($e^+e^- \rightarrow ZH$, $e^+e^- \rightarrow W^+W^-$, $e^+e^- \rightarrow ZH$,[$e^+e^- \rightarrow t\bar{t}$])

	TLEP-4 IP, per IP	statistics
circumference	100 km	
max beam energy	175 GeV	
no. of IPs	4	
Luminosity/IP at 350 GeV c.m.	$1.8\times10^{34}\ cm^{-2}s^{-1}$	10^6 $t\bar{t}$ pairs
Luminosity/IP at 240 GeV c.m.	$5.9\times10^{34}\ cm^{-2}s^{-1}$	2 10^6 ZH evts
Luminosity/IP at 160 GeV c.m.	$1.2\times10^{35}\ cm^{-2}s^{-1}$	10^8 WW pairs
Luminosity/IP at 90 GeV c.m.	2.8 $10^{35}\ cm^{-2}s^{-1}$	10^{12} Z decays

Z W H t factory. (see the old logo)

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First look at the physics case of TLEP

PUBLISHED

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JHEP01(2014)164

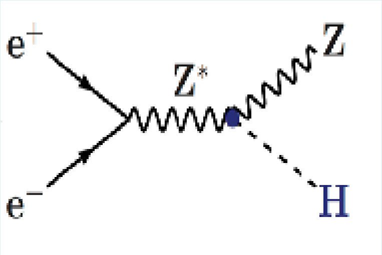
best-of ee-FCC/TLEP #1: Higgs factory

(constrained fit
including ‘exotic’)

Best across the board

	4 IPs TLEP	(2 IPs)
g_{HZZ}	0.05%	(0.06%)
g_{HWW}	0.09%	(0.11%)
g_{Hbb}	0.19%	(0.23%)
g_{Hcc}	0.68%	(0.84%)
g_{Hgg}	0.79%	(0.97%)
$g_{H\tau\tau}$	0.49%	(0.60%)
$g_{H\mu\mu}$	6.2%	(7.6%)
$g_{H\gamma\gamma}$	1.4%	(1.7%)
BR_{exo}	0.16%	(0.20%)

total width 0.6%
HHH 28%
H*tt* 13%



$2\ 10^6$ ZH events in 5 years

«A tagged Higgs beam».

sensitive to new physics in loops

invisible width = (dark matter?)

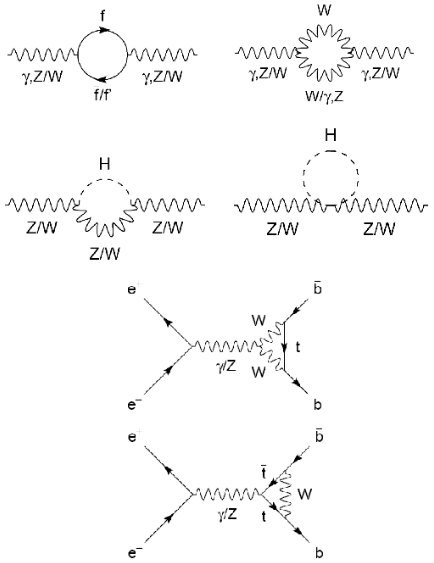
also (but better done at the
hadron colliders HL-LHC, VHE-LHC:

from effect on HZ threshold
arXiv:1312.3322v1
from effect on $\bar{t}t$ threshold

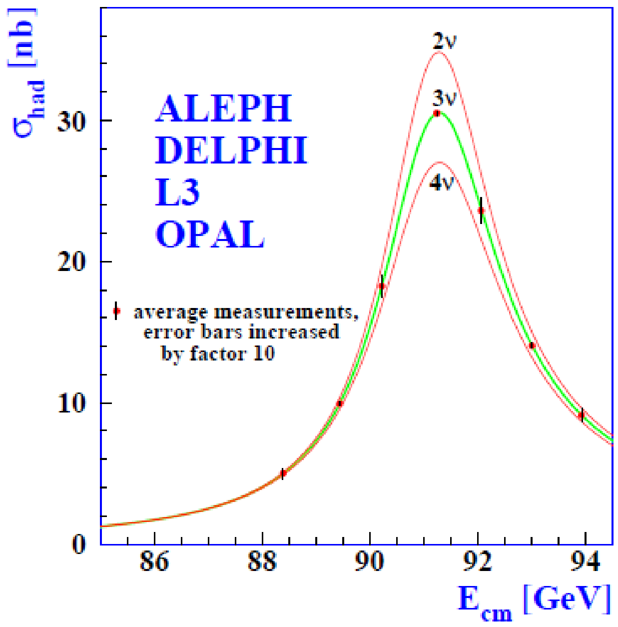
TERA-Z and Oku-W

Precision tests of the closure of the Standard Model

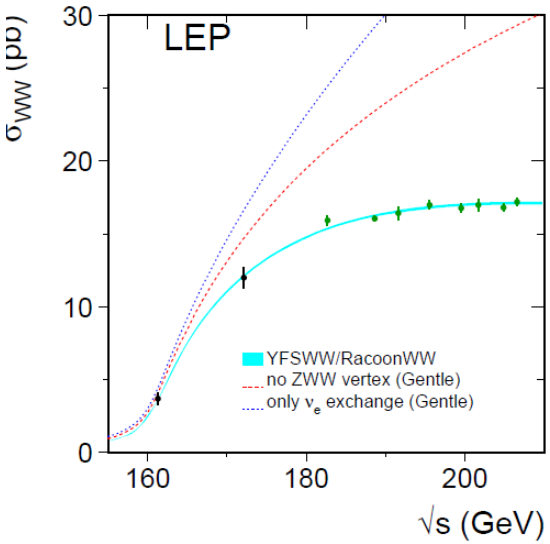
Precision tests of EWSB

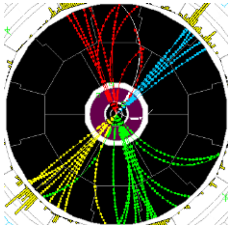


Z pole ssymmetries, lineshape

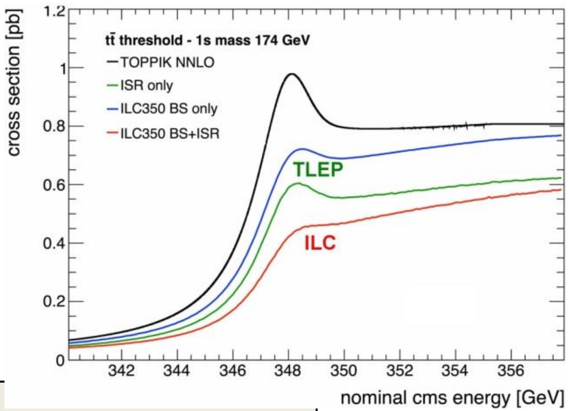


WW threshold scan





tt threshold scan



TLEP : Repeat the LEP1 physics programme 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…

Frank Simon

Example (from Langacker& Erler **PDG 2011**)

$\Delta\rho = \varepsilon_1 = \alpha(M_Z)\,.\,T$

$\varepsilon_3 = 4\sin^2\theta_W\ \alpha(M_Z)\,.\,S$

$\Delta\rho$ today = 0. 0004+0.0003−0.0004

-- is consistent with 0 at 1σ
-- is sensitive to non-conventional Higgs bosons (e.g. in SU(2) triplet with 'funny v.e.v.s)
-- is sensitive to Isospin violation such as $m_t \neq m_b$ or **ibid for stop-sbottom**

$$\rho_0 = 1 + \frac{3\,G_F}{8\sqrt{2}\pi^2}\sum_i \frac{C_i}{3}\,\Delta m_i^2\ , \qquad (10.63)$$

where the sum includes fourth-family quark or lepton doublets, $\binom{t'}{b'}$ or $\binom{E^0}{E^-}$, right-handed (mirror) doublets, non-degenerate vector-like fermion doublets (with an extra factor of 2), and scalar doublets such as $\binom{\tilde{t}}{\tilde{b}}$ in Supersymmetry (in the absence of L–R mixing).

Present measurement implies

$$\sum_i \frac{C_i}{3}\,\Delta m_i^2 \le (52\ \mathrm{GeV})^2.$$

Most e.g. SUSYmodels have these symmetries embedded from the start

Similarly:

$$S = \frac{C}{3\pi}\sum_i \Big(t_{3L}(i) - t_{3R}(i)\Big)^2,$$

best-of ee-FCC/TLEP #2: Precision EW measts

Asset: -- high luminosity (10^{12} Z decays + 10^8 Wpairs + [illegible] top pairs)
-- exquiste energy calibration up and above [illegible]hold

Quantity	Present precision	Measured from	[illegible]ity	Systematic uncertainty
m_Z (keV)	91187500 ± 2100	Z Li[illegible]	[illegible] (6) keV	< 100 keV
Γ_Z (keV)	2495200 ± 2300	[illegible]	8 (10) keV	< 100 keV
R_ℓ	20.767 ± 0.025	[illegible]	0.00010 (12)	< 0.001
N_ν	2.984 ± 0.0[illegible]	[illegible]	0.00008 (10)	< 0.004
N_ν	2.92 [illegible]	[illegible]61 GeV	0.0010 (12)	< 0.001
R_b	0.21[illegible]	Z Peak	0.000003 (4)	< 0.000060
A_{LR}	[illegible]	Z peak, polarized	0.000015 (18)	< 0.000015
m_W (MeV)	[illegible]	WW threshold scan	0.3 (0.4)MeV	< 0.5 MeV
m_{top} [illegible]	[illegible] 900	$t\bar{t}$ threshold scan	10 (12) MeV	< 10 MeV

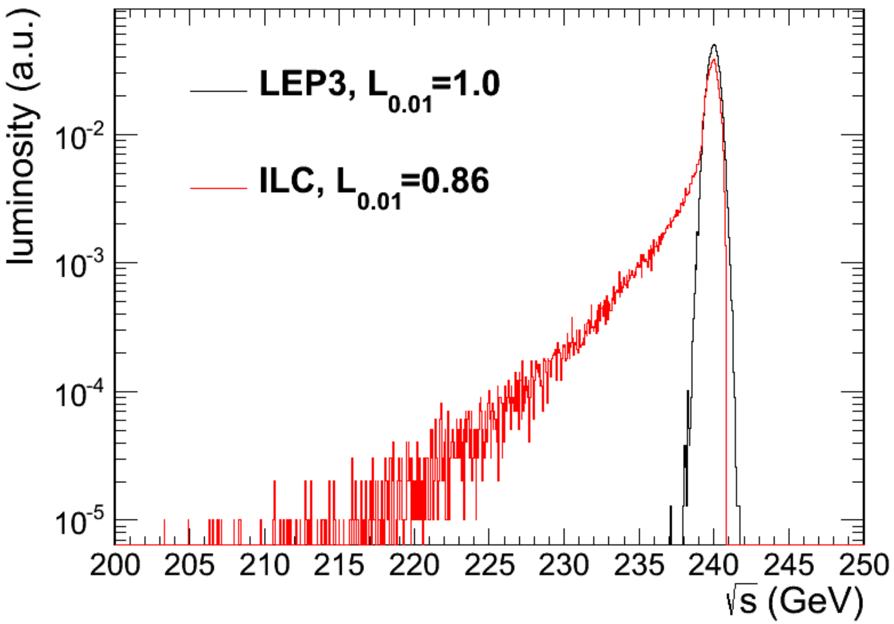
[illegible] from W and Z hadronic widths
[illegible] of magnitude on FCNCs and rare decays etc. etc.

[illegible] study to establish possibility of corresponding precision theoretical calculations.

As another example of the importance of precision measurements, the LEP determination of $\alpha_s(m_Z)$ was already able, in association with $\sin^2\theta^{\rm eff}_{\rm W}$, to distinguish between supersymmetric and non-supersymmetric models of grand unification [55–58]. The prospective TLEP accuracies on these quantities would take this confrontation between theory and experiments to a completely new level.

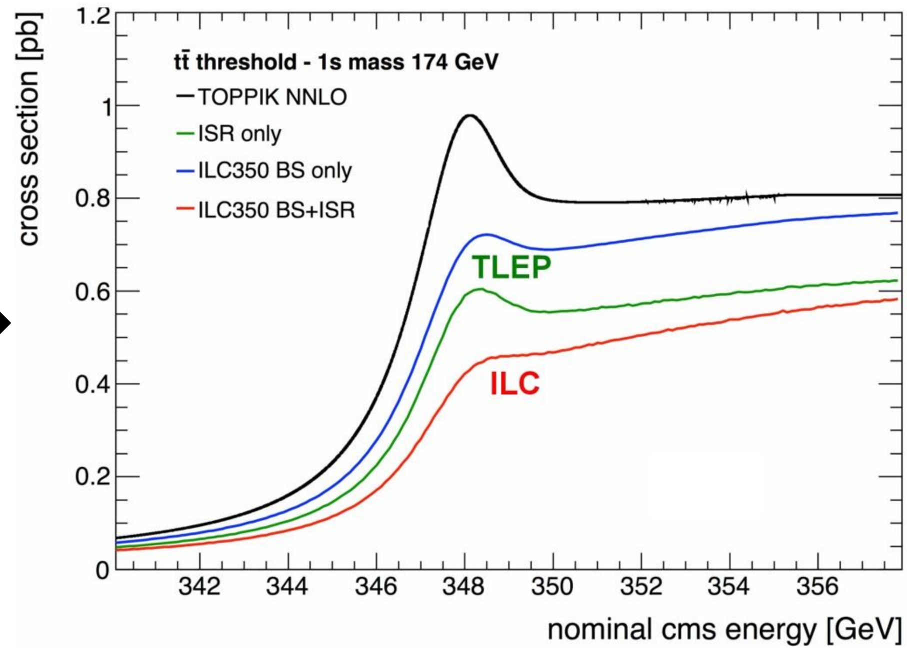
BEAMSTRAHLUNG

Luminosity *E* spectrum



➔

Effect on top threshold

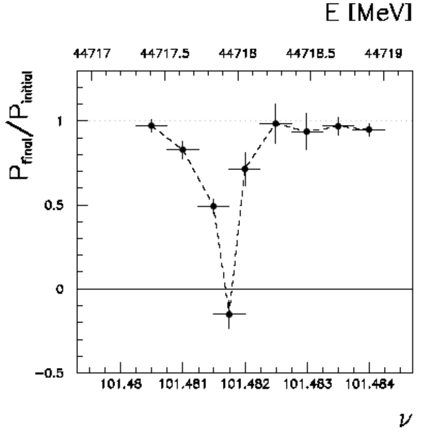


TLEP operates at Beamstrahlung limit, this is a dominant factor for accelerator design.

Beamstrahlung @TLEP is benign for physics: particles are either lost or recycled on a synchrotron oscillation

➔ some increase of energy spread
but no change of average energy
Little EM background in the experiment.

Beam polarization and E-calibration @ TLEP



Precise meast of E_{beam} by resonant depolarization
~100 keV each time the meast is made

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 March 1994

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

At LEP beam energy spread destroyed polarization above 60 GeV
$\sigma_E \propto E^2/\sqrt{\rho}$ ➔ *At TLEP transverse polarization up to at least 80 GeV*
to go to higher energies requires spin rotators and siberian snake

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

Rare decays

-- FCNC: $Z \rightarrow e + \tau$ $Z \rightarrow \mu + \tau$

-- Heavy neutrinos (they *must* be somewhere!)

neutrino counting and search for explicit $Z \rightarrow$ ν-N
(with N-> νX or eX' and possibly displayed vertices)

-- other final states with single or double photons and jets

-- flavour physics...

-- and many others ($Z \rightarrow \gamma\gamma\gamma$ etc)

-- How far can one go with 10^{12} Z decays?

Neutrino counting at TLEP

given the very high luminosity, the following measurement can be performed

$$N_\nu = \frac{\dfrac{\gamma Z(inv)}{\gamma Z \rightarrow ee,\mu\mu}}{\dfrac{\Gamma_\nu}{\Gamma e,\mu}\ (SM)}$$

The common γ tag allows cancellation of systematics due to photon selection, luminosity etc. The others are extremely well known due to the availability of O(10^{12}) Z decays.

The full sensitivity to the number of neutrinos is restored , and the theory uncertainty on $\frac{\Gamma_\nu}{\Gamma_e}\ (SM)$ is very very small.

A good measurement can be made from the data accumulated at the WW threshold where σ (γ Z(inv)) ~4 pb for $|\cos\theta_\gamma|$ <0.95

161 GeV (10^7 s) running at $1.6\times10^{35}/cm^2/s$ x 4 exp → 3×10^7 γ Z(inv) evts, ΔN_ν =0.0011
adding 5 yrs data at 240 and 350 GeV .... ΔN_ν =0.0008

A better point may be 105 GeV (20pb and higher luminosity) may allow ΔN_ν =0.0004?

FLAVOUR(267104)-ERC-23 TUM-HEP 850/12 SISSA 25/2012/EP CFTP/12-013

arxiv:1208.3654

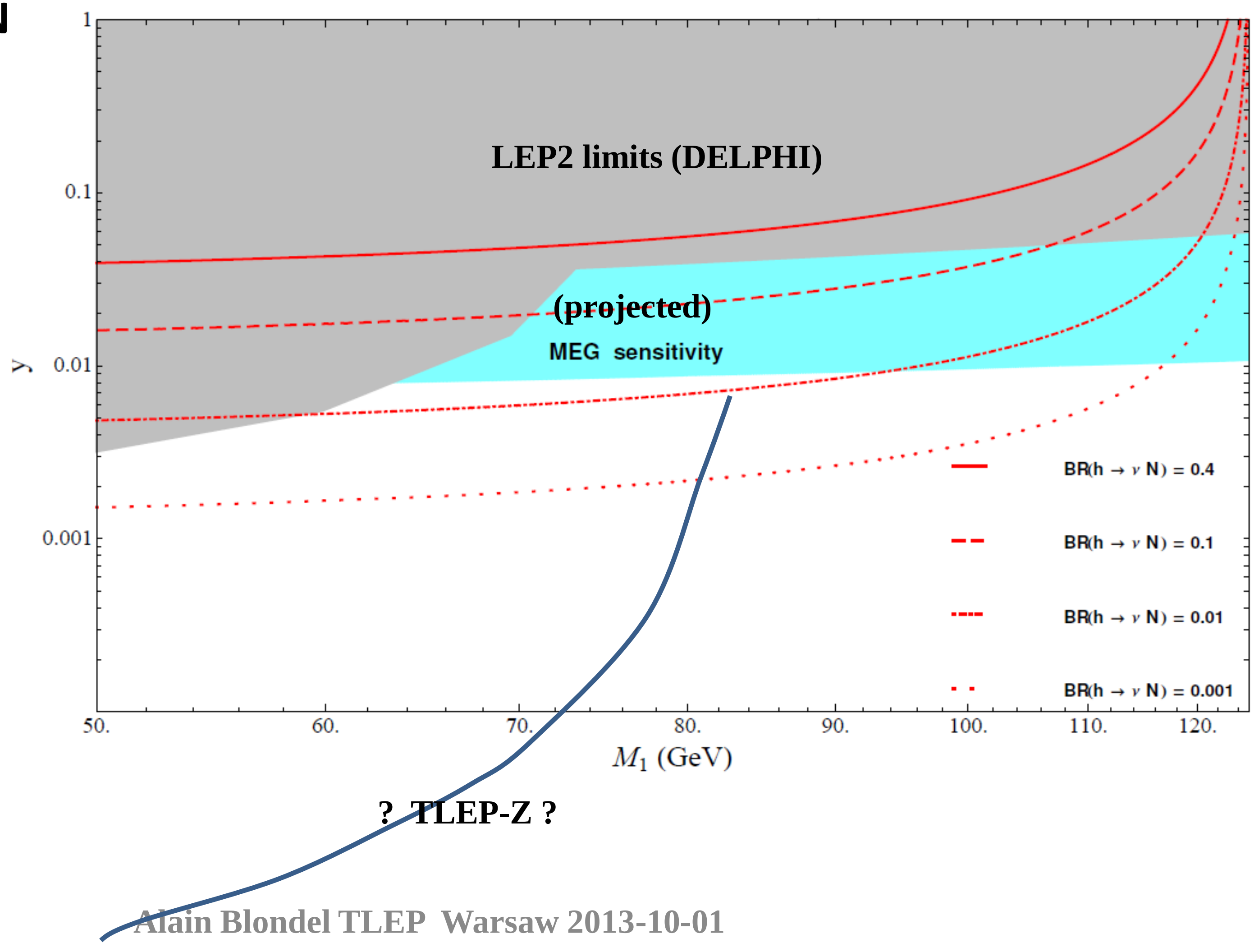
H-> νN

or

Z-> νN

Higgs Decays in the Low Scale Type I See-Saw Model

C. Garcia Cely[a], A. Ibarra[a], E. Molinaro[b] and S. T. Petcov[c,d] 1



Future Circular Collider Study - FCC

Mandate

Scope

The main emphasis of the conceptual design study shall be the long-term goal of a hadron collider with a centre-of-mass energy of the order of 100 TeV (currently referred to as VHE-LHC) in a new tunnel of 80-100 km circumference for the purposes of studying physics at the highest energies. The hadron collider and its detectors shall determine the basic requirements for the tunnel, surface and technical infrastructures. The corresponding hadron injector chain shall be included in the study, taking into account the existing CERN accelerator infrastructure and long-term accelerator operation plans. The performance and cost of the hadron collider shall be compared to a high-energy LHC based on the same high-field magnet technology and housed in the LHC tunnel.

The conceptual design study shall also include a lepton collider and its detectors (currently referred to as TLEP), as a potential intermediate step towards realization of the hadron facility. The design of the lepton collider complex shall be based on the hadron collider infrastructure and any substantial incompatibilities with respect to the hadron collider infrastructure requirements shall be analysed and quantified. Potential synergies with linear collider detector designs should be considered.

What detector for TLEP ? (1)

- First approach (ILC/CLIC)
  - Push detector design towards highest achievable performance

Mark Thomson
"A detector for TLEP
Synergies with ILC/CLIC"

- +++ Clearly suitable to cover the full TLEP physics programme
- – Might be over-designed ?
- – – Power pulsing is not a option at TLEP
  - Either more cooling (material) or less channels (granularity)
- – – – Cost !
  - 0.5 to 1 B$ each – and TLEP may want to have 4 of them

Second approach (LHC)

PJ et al. (arXiv.1208.1662, 1308.6176)
"First look at the physics case of TLEP"

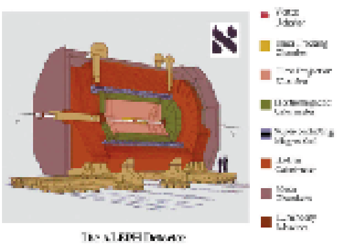
- Use existing LHC detectors

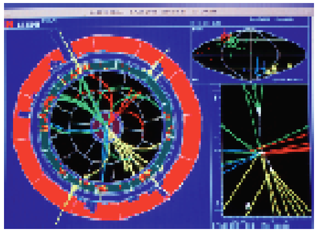
- +++ Realistic, most conservative
  - sub-optimal hadron calorimetry, lots of material, $\Delta p_T/p_T$
- ++ can cope with TLEP-Z event rate
- – not thought for e^+e^- collisions
- – – cost !
  - Almost 0.5 BCHF / detector

Third approach (LEP)

Tried back in the mid 1990's
For the studies of "NLC"

- Use LEP-like detectors



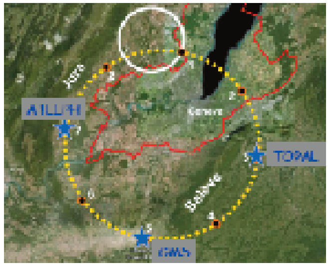


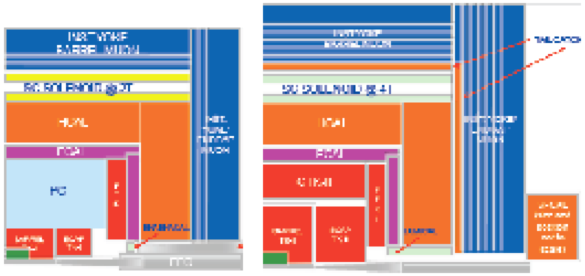
- +++ Cost !
  - 100 MCHF / detector – Could easily afford four of them.
- ++ Realistic, conservative enough, globally suitable
- – TLEP-Z event rate ?
- – – Outdated/not challenging technology ?

Fourth approach (FCC)

Emilio Meschi
talks at TLEP Workshops

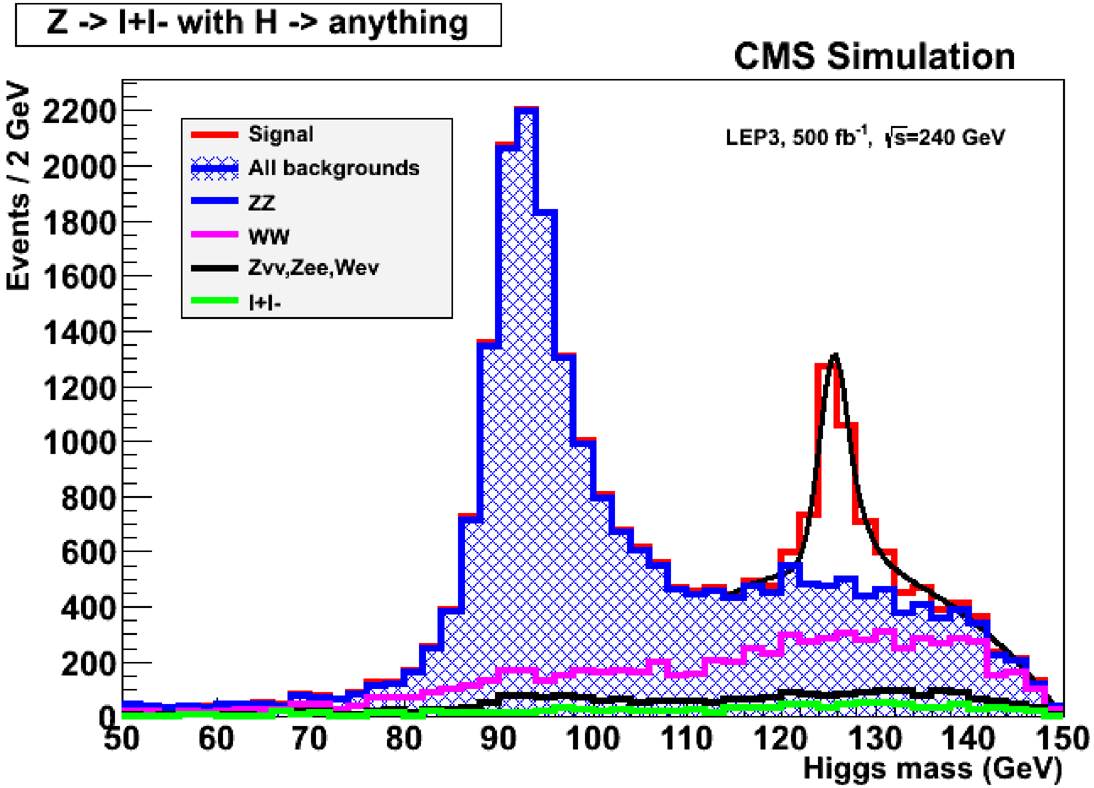
- A detector common to TLEP and VHE-LHC ?





- Pros and cons need to be worked out
  - Can a detector and its electronics survive half a century ?

Is it actually desirable ?



So far results use LEP event generators X CMS simulations
Already some interesting results (better for γγ, worse for $b\bar{b}$, wrt ILC TDR)

1. e+e- TLEP/CepC specifics

-- physics aims and requirements ➔

Z peak : many!!!

-- very small systematics on e.g. $R_l = \frac{\Gamma_l}{\Gamma_{had}}$, $R_{b,c} = \frac{\Gamma_{b,c}}{\Gamma_{had}}$,

-- luminosity measurement

-- search for rare decays like Z➔ $\mu\tau$

-- flavour physics

➔ emphasis on hermiticity, trigger redundancy, well defined fid region

➔ PID_0=e/mu/tau/hadron/b/c

WW (invariant masses using hadronic systems)

ZH all of the above!

ttbar all of the above!

rare events (single or multi photon states) EMCAL resoluton and hermiticity

do we need p/K/pi particle ID or is PID_0 enough?

is there more physics (two-photon)?

trade offs? (granularity vs resolution) etc...

Low angle region

--- need to understand Machine Detector Interface (MDI)

-- size and location of final focus elements, L* ~ 4m

-- synchrotron radiation masks, residual levels

-- EM radiation from Beamstrahlung

-- beam pipe size

-- physics need in hermiticity in detection, measurement or veto

➔ simulation ←→ design

TLEP/CepC Time structure and data rate

-- higher rate than LEP but events similar

-- (CW) time structure with varirable bunch spacing

-- varying from Z factory to top factory (~ 330 μs/16000 bunches = 20ns)

more like LHC!

-- radiation levels (small?)

-- essentially no pile-up

-- not a pulsed machine like ILC /CLIC

→ cannot use pulsed electronics but does not need to be hadron rad-hard as in LHC

→ data rate can go as high as 50kHz to write on tape

-- Several IPs desirable

-- how far beyond 350 is it useful to go (e.g. for top quark couplings) ?

-- probably magnetic field need not be as strong as LC. (1/2?)

Conclusions

ee-FCC (TLEP) is quite different from CLIC wrt physics aims

Mandate to ee-FCC design study to investigate synergy for detector designs

In comparison with CLIC or ILC

-- these are also e+e- detectors (largely similar)
-- energy is lower (?smaller detectors, less B-field?)
-- CW machine (bunch spacing from 20ns to 1μs)
  ➔ no pulsed electronics
  ➔ no pile-up
-- high statistics, especially for Tera-Z, search for rare phenomena
  ➔ systematics will often dominate
-- high precision in beam energy definition and calibration
-- several IPs, each detector can be more specialized