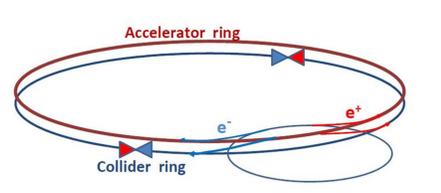




Physics at FCC-ee

The TLEP design study is now part and parcel of the FCC design study as FCC-ee

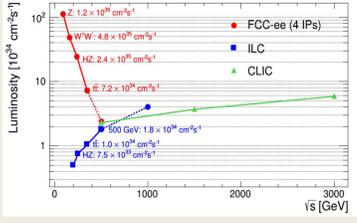


Design principle and event rates

When the Higgs boson mass became known at the end of 2011, the possibility of a **High Luminosity e+e- Higgs Factory** was born using a similar design than the b-factory: e+ and e- storage rings, low β_y^* (1mm), top-up injection. **This naturally welcomes several IPs and detectors.**

This could fit in the LEP/LHC tunnel (LEP3).... but consensus was to organize the study in a new 100km tunnel (FCC):

- no interference with LHC
- able to host a 100 TeV pp
- can reach above top threshold
- Luminosity grows with radius!



10¹² Z,
10⁹ WW,
2.10⁶ ZH
10⁶ tt

NB: ILC as of TDR. Luminosity upgrades for ILC and FCC-ee are being discussed -- and costed.

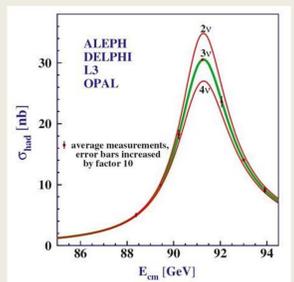
arXiv:1308.6176

First look was exciting!

Second look gets better and better

Z FACTORY a unique discovery potential

The measurement of the invisible width and the search for sterile neutrinos are only examples of the **huge discovery potential of the Z factory.**



At the end of LEP:
Phys.Rept.427:257-454,2006
 $N_\nu = 2.984 \pm 0.008$

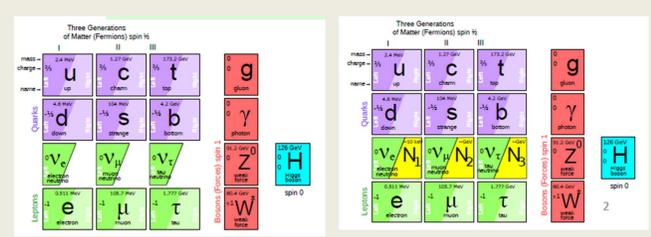
This 2σ deficit could potentially be explained by the presence of the right handed (aka sterile) partner of a known neutrino

This measurement comes essentially from the hadronic cross section at the peak of the resonance and is systematically dominated.

Thanks to the high luminosity it becomes possible to improve it using radiative decays:

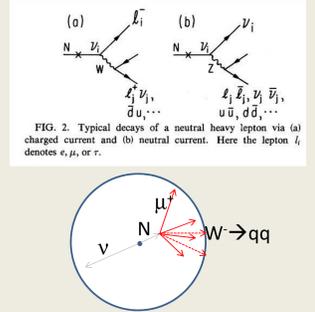
$$N_\nu = \frac{\gamma Z(\text{inv})}{\Gamma_\nu} \frac{\Gamma_{e,\mu}}{\Gamma_{e,\mu}(SM)}$$

Performing this measurement (Blondel, Ganjour) at the WW threshold (161 GeV) → $\Delta N_\nu = \pm 0.0010$
at 126 GeV (in search of $e+e- \rightarrow H(126)!$) → $\Delta N_\nu = \pm 0.0006$
a dedicated run at 105 GeV → $\Delta N_\nu = \pm 0.0004$
Thus providing extremely sensitive probes of Dark Matter (Giudice)



Since 1998 it is established that neutrinos have mass and this very probably implies new degrees of freedom → «sterile», very small coupling to known particles completely unknown masses (eV to ZeV), nearly impossible to find. but could perhaps explain all: DM, BAU, ν -masses → **THE SIMPLEST SCENARIO FOR NEW PHYSICS.** (Shaposhnikov)

The RH neutrinos are produced in Z decay by mixing with the active ones.: The mixing angle is equal to the ratio of masses and is very small!
→ long lifetimes displaced vertices, with very small backgrounds!
→ observation of RH neutrinos in the domain where they can generate the baryon asymmetry of the Universe becomes possible.!



Precision measurements

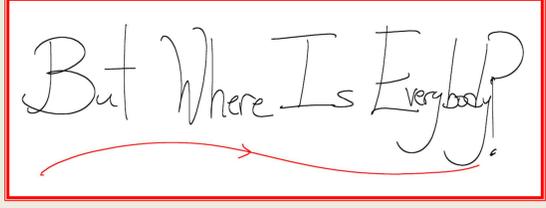
A tool for discovery
Now that the Higgs boson is found, the SM has nowhere to go!
→ Any deviation in precision measurements is sign of new physics with weak couplings (such as SUSY)

100keV energy calibration using resonant beam depolarization
Lessons from LEP → continuous measts on both beams using non-colliding bunches.
Energy spread scales as $1/\sqrt{R}$ → Polarization sufficient for energy calibration at the W threshold.

Goal precisions on m_Z, Γ_Z : 100 keV . On m_W : 500 KeV.

High statistics will also allow precise measurements of Z partial widths such as $Z \rightarrow b\bar{b}$ and $Z \rightarrow \nu\bar{\nu}$ and of Z pole asymmetries

BIG QUESTIONS



At higher masses -- or at smaller couplings?

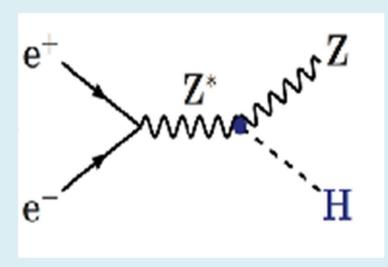
With the discovery of the Higgs Boson, the Standard Model seems to have been completed, and could be extrapolated up to the Planck scale... However we know that new physics is needed to account for the following experimental facts
-- the existence of **Dark matter**
-- the **Baryon asymmetry of the Universe**
-- the existence and smallness of **neutrino masses.**
A high precision e+e- collider as Z,W, H and top factory can give precious answers:
-- **high precision measurements** can reveal the existence of new physics with weak couplings,
-- **the measurements of invisible widths** of the Z and Higgs bosons can best probe WIMP dark matter
-- **Unique searches for rare phenomena** such as sterile neutrinos thanks to the availability of 10^{12} (or 10^{13} with crab waist) Z decays

Target precisions

Quantity	Present precision	Measured from	Statistical uncertainty	Systematic uncertainty
m_Z (keV)	91187500 ± 2100	Z Line shape scan	5 (6) keV	< 100 keV
Γ_Z (keV)	2495200 ± 2300	Z Line shape scan	8 (10) keV	< 100 keV
R_l	20.767 ± 0.025	Z Peak	0.00010 (12)	< 0.001
N_ν	2.984 ± 0.008	Z Peak	0.00008 (10)	< 0.004
N_ν	2.92 ± 0.05	$Z_\gamma, 161$ GeV	0.0010 (12)	< 0.001
R_b	0.21629 ± 0.00066	Z Peak	0.000003 (4)	< 0.000060
A_{LR}	0.1514 ± 0.0022	Z peak, polarized	0.000015 (18)	< 0.000015
m_W (MeV)	80385 ± 15	WW threshold scan	0.3 (0.4) MeV	< 0.5 MeV
m_{top} (MeV)	173200 ± 900	tt threshold scan	10 (12) MeV	< 10 MeV

HIGGS FACTORY

«A tagged Higgs beam»



2 10⁶ ZH events in 5 years

(constrained fit including 'exotic')

	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%
Htt 13%
also, but better done at the hadron colliders : HHH and Htt (HL-LHC, FCC-hh)
from effect on HZ threshold arXiv:1312.3322v1
from effect on tt threshold

Also search for new physics in rare H decays ($H \rightarrow N_i \nu_i$ etc.)

To know more:

The FCC-ee web page <http://cern.ch/FCC-ee> where you can find slides of workshops from the early LEP3 days to the recent FCC-ee workshop
You can also subscribe to the study (follow «join us») to contribute brains, ideas ,
or contact a working group convener:

- Experiments A. Blondel, P. Janot**
- WG1: Electroweak physics at the Z pole (R. Tenchini, E. Locci)
 - WG2: Di-boson production and W mass measurement (R. Tenchini, E. Locci)
 - WG3: H(126) properties (M. Klute, K. Peters)
 - WG4: Top quark physics (P. Azzi)
 - WG5: QCD and $\gamma\gamma$ physics (D. d'Enterria, P. Skands)
 - WG6: Flavour physics (S. Montell, J. Kamenik)
 - WG7: Experimental signatures of new physics (M. Pierini, C. Rogan)
 - WG8: Experimental environment , MDI (N. Bacchetta)
 - WG9: Offline software and computing (F. Gianotti, P. Janot)
 - WG10: Online software (C. Leonidopoulos)
 - WG11: Detector designs (A. Cattai, G. Rolandi)
- Phenomenology J. Ellis, C. Grojean**
- Model Building and New Physics (A. Weyler)
 - Precision EW calculations (S. Heinemeyer)
 - QCD and $\gamma\gamma$ Physics (see above)
 - Flavour Physics (see above)
 - Global Analysis, Combination, Complementarity (J. Ellis)

LONG TERM VISION

The combination of **FCC-ee** and the **FCC-hh** offers, for a great cost effectiveness, the best precision and the best search reach of all options presently on the market.