FCC-ee: Experiments and Detectors Summary

For more info: FCC-ee session Tuesday 24 March

and http:cern.ch/fcc-ee

(FCC-ee initially known as TLEP)

Future Circular Collider Study - FCC

Mandate

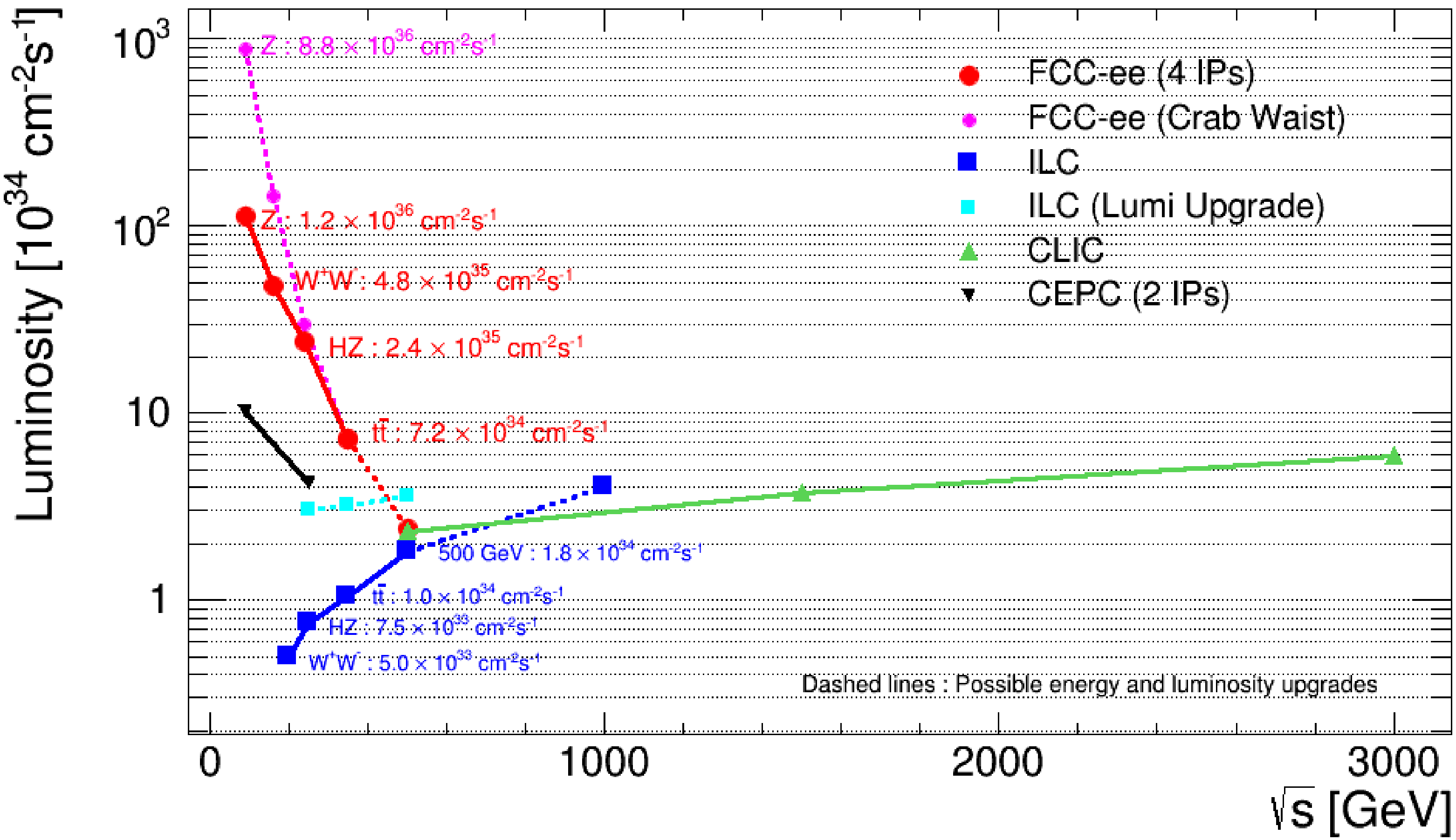
Scope

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.

Geneva, December 1st 2013

Rolf Heuer
Director General
CERN



Overlap in Higgs/top region, but differences and complementarities between linear and circular machines:
Circ: High luminosity, experimental environment (up to 4 IP), E_{CM} calibration
Linear: higher energy reach, longitudinal beam polarization

FCC-ee: PARAMETERS & STATISTICS

	TLEP-4 IP, per IP	statistics
circumference	80-100 km	
max beam energy	175 GeV	
no. of IPs	4	
Luminosity/IP at 350 GeV c.m.	1.3×10^{34} cm^{-2}s^{-1}	10^6 $t\bar{t}$ pairs (5y)
Luminosity/IP at 240 GeV c.m.	6.0×10^{34} cm^{-2}s^{-1}	2 10^6 ZH (5y)
Luminosity/IP at 160 GeV c.m.	1.6×10^{35} cm^{-2}s^{-1}	10^8 WW (1y)
Luminosity/IP at 90 GeV c.m.	2. $10^{35/36}$ cm^{-2}s^{-1}	$10^{12/13}$ Z (2y)

Detectors must do all this:

1. Higgs Physics (F. Yu, Klute)

Invisible and exotic widths, subpercent measurements of partial widths, ZH coupling, CPV

What is missed wrt LC are precisely the strong points of HL-LHC&FCC-hh: ttH, HHH couplings

2. Precision EW and QCD measts (Tenchini, Was, Gluza)

complete set of new precision tests using Z, W H top (SM has nowhere to go!)
one to two orders of magnitude improvements over present results
Sensitivity to new Weak physics scale raised by factor ~5-10 wrt HL-LHC,
well matched to FCC-hh.

yes, 'pursue the physics associated with neutrino masses'

3. Flavour and Rare phenomena

FCNC, LFV, RH neutrinos, single top, lepton and quark flavour physics (Z pole, top)

4. Complete searches in LHC 'holes'

Phyics case is very strong (as pointed out in ESPP and P5)
LEP & Linear collider studies designed suitable detectors for this energy

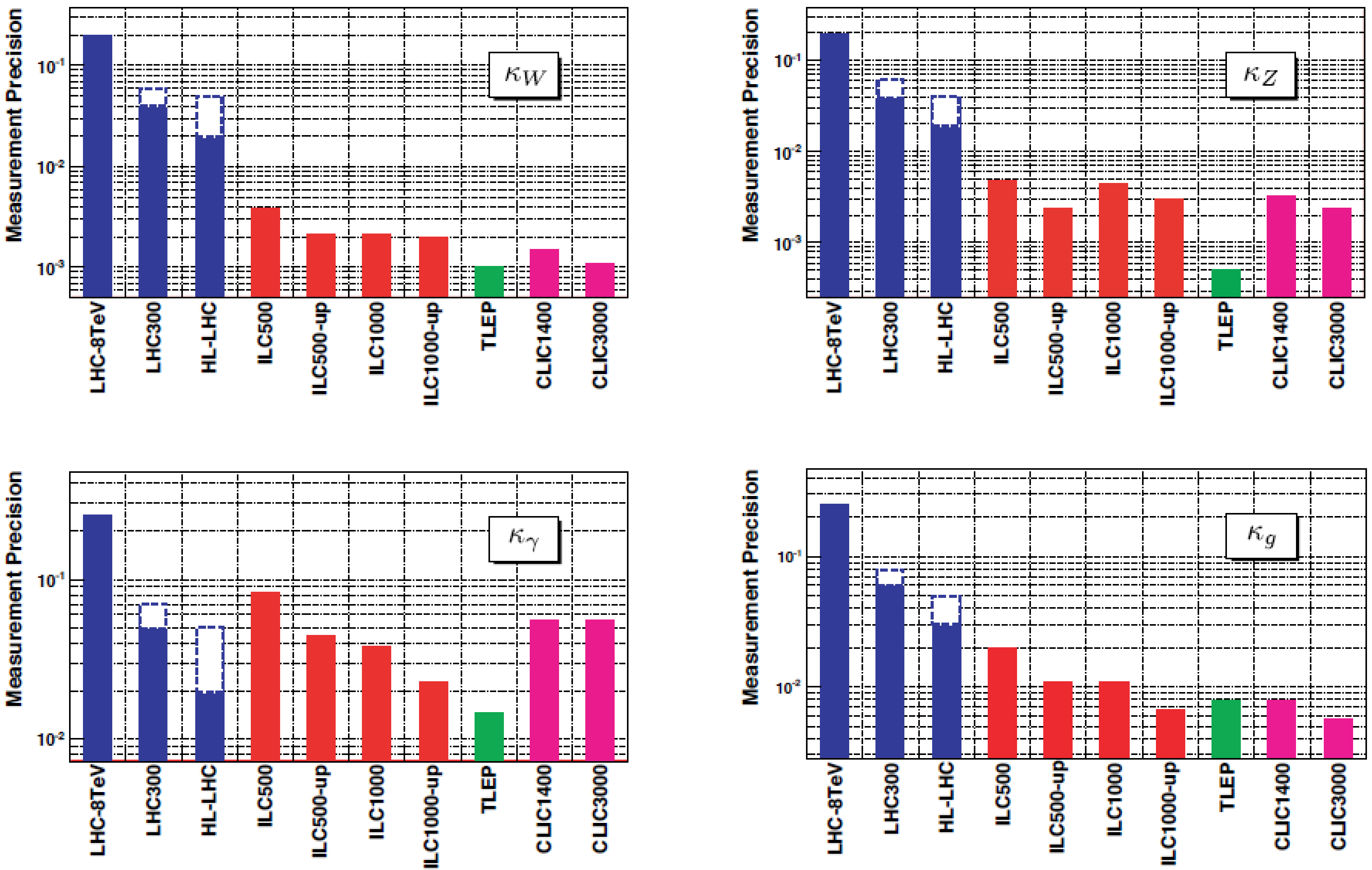
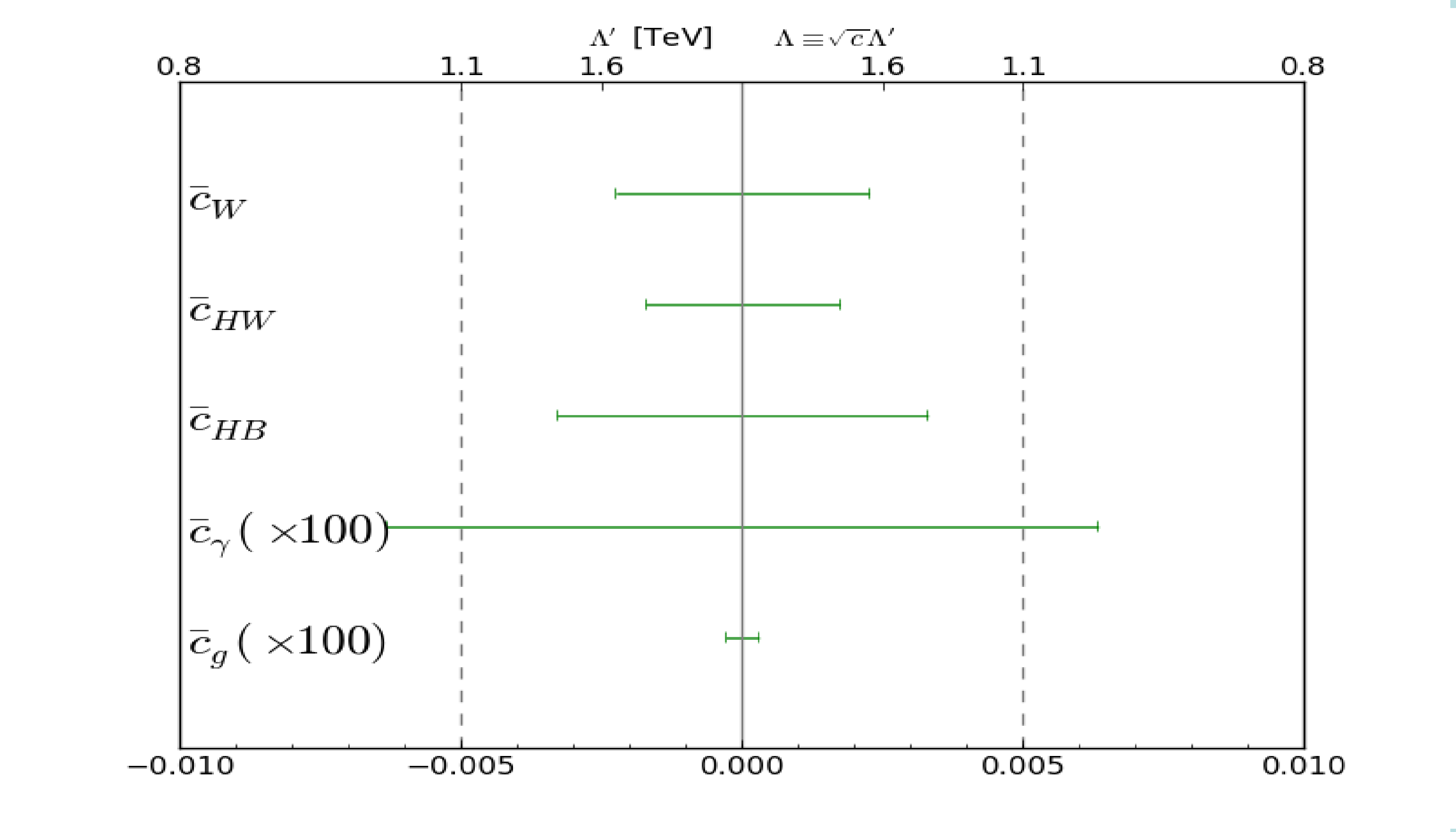


Figure 1-3. *Measurement precision on κ_W, κ_Z, κ_γ, and κ_g at different facilities.*

FCC-ee Higgs Measurements vs EFTs



- LHC constraints
- **FCC-ee** constraints

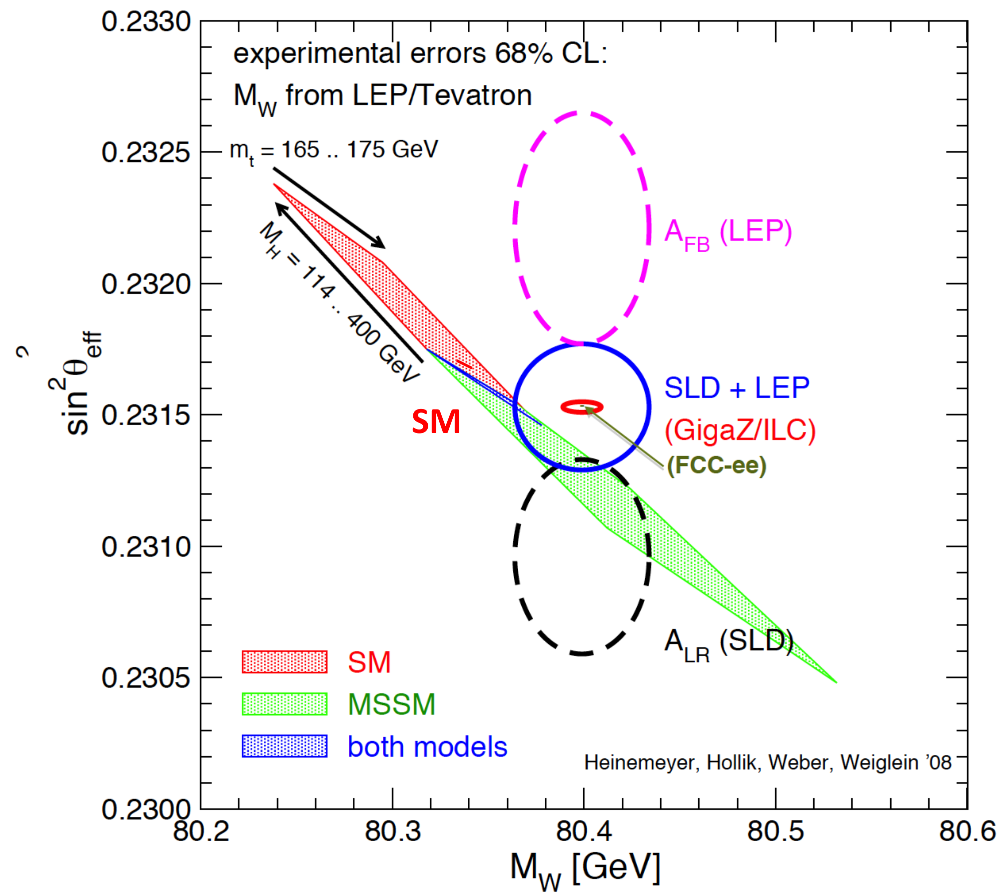
JE, Sanz & You

A Sample of Essential Quantities:

X	Physics	Present precision		TLEP stat Syst Precision	TLEP key	Challenge
M_Z MeV/c2	Input	91187.5 ±2.1	Z Line shape scan	0.005 MeV <±0.1 MeV	E_cal	QED corrections
Γ_Z MeV/c2	$\Delta\rho$ (T) (no $\Delta\alpha$!)	2495.2 ±2.3	Z Line shape scan	0.008 MeV <±0.1 MeV	E_cal	QED corrections
R_ℓ	α_s , δ_b	20.767 ± 0.025	Z Peak	0.0001 ± 0.002 - 0.0002	Statistics	QED corrections
N_ν	Unitarity of PMNS, sterile ν's	2.984 ±0.008	Z Peak Z+γ(105/161)	0.00008 ±0.004 0.0004-0.001	->lumi meast Statistics	**QED corrections to Bhabha scat.**
R_b	δ_b	0.21629 ±0.00066	Z Peak	0.000003 ±0.000020 - 60	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 (161 GeV)	0.3 MeV <1 MeV	E_cal & Statistics	QED corections
m_{top} MeV/c2	Input	173200 ± 900	Threshold scan	10 MeV	E_cal & Statistics	Theory limit at 100 MeV?

Precision Measurements and New Physics

- **With the Higgs discovery the SM has nowhere to go!**
- **Any deviation is now ‘new physics’ , 5σ is discovery.**
- **Indirect but inclusive information on new physics with ~weak couplings**
- **Precise knowledge of m_{top} is essential**
- **full analysis of discovery power including all observables is missing.**



Tenchini, Was, Gluza, Fan

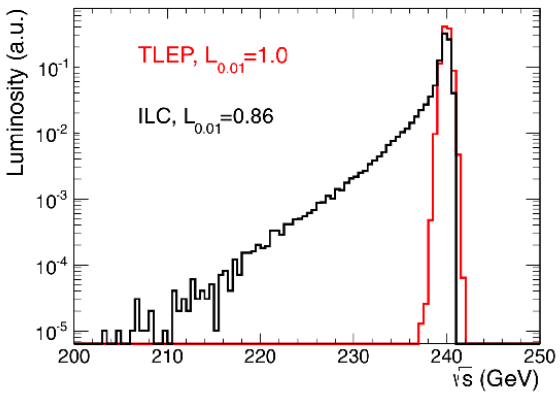
Experimental conditions

-- 2-4 IPs L^*~2m

-- bunch crossing spacing from 2-5 ns (Z) up to 3μs (top)

-- no pile-up (<0.001 at FCC-Z/CrabWaist)

-- beamstrahlung is mild for experiments



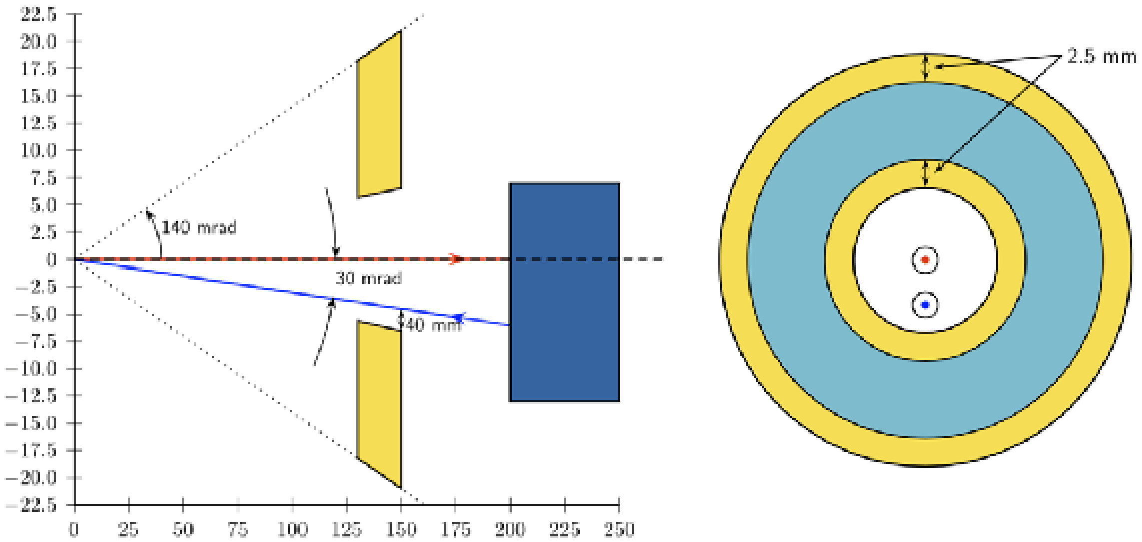
	FCCZ	FCCZ, c.w	CEPC	FCC ZH	ILC500
Npairs / BX	200	9900	3260	640	165000
Leading process	96% LL	65% LL	80% LL	90% LL	60% BH
Epairs / BX (GeV)	86	2940	2600	570	400000
Leading process	100% LL	100% LL	98% LL	96% LL	70% BH

-- Beam energy calibration for Z and W running

-- IR design with crossing angle is not trivial

➔ a challenging magnet design issue.

Of particular importance: luminosity monitors



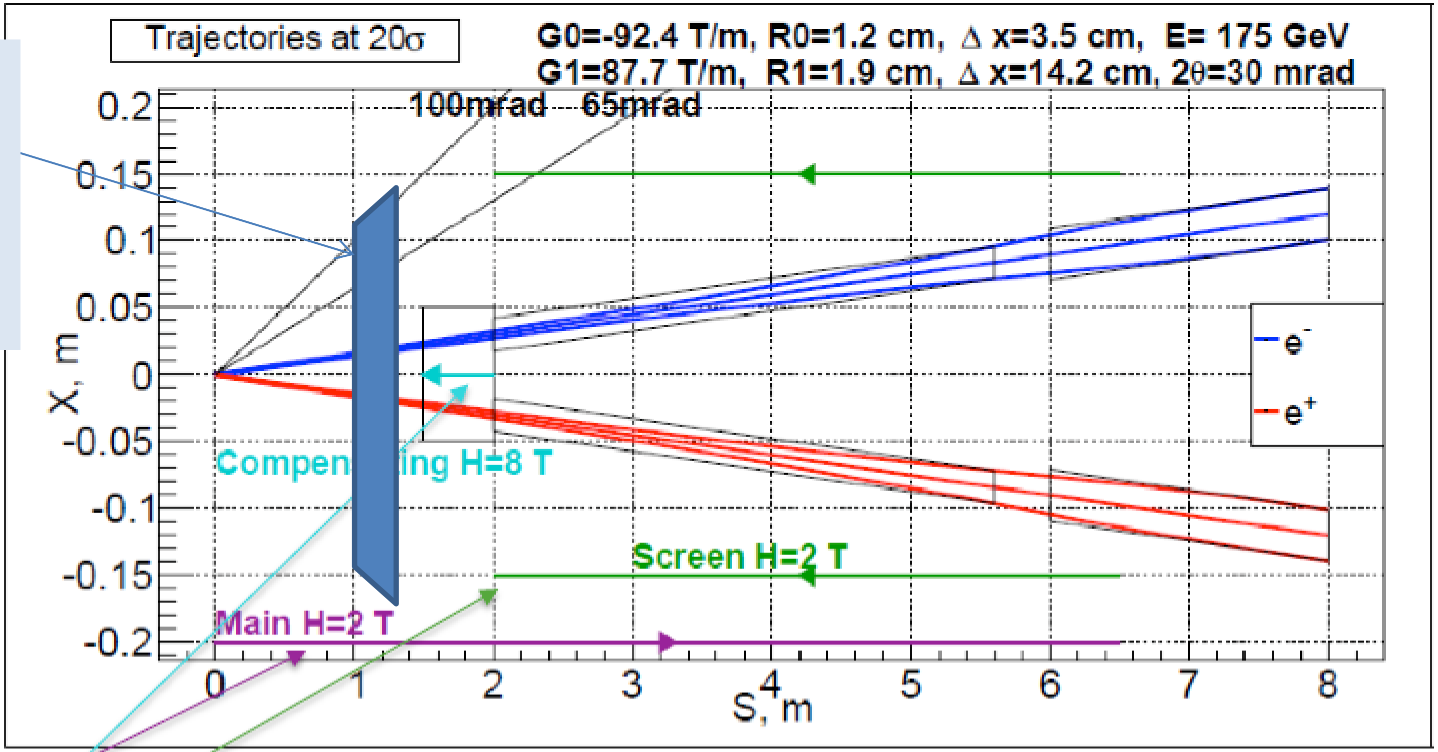
M. Dam

Requirements dominated by Z line shape and peak cross-section measurements

Shift in parameter for a shift of $+10^{-4}$ in acceptance

z_{front} [mm]	r_{min} [mm]	r_{max} [mm]	θ_{min} [mrad]	θ_{max} [mrad]	σ [nb]	δz_{front} [μm]	δr_{min} [μm]	δr_{max} [μm]
1000	80	115	80	115	10	50	−2.1	6.1
1300	89	157	68	121	18	65	−3.0	17
1500	95	185	63	123	23	75	−3.5	26

Luminosity monitor centered on outgoing beam



Beams are crossing detector B-field at an angle of 0.015 mrad. Need compensation.

- Here assumed +2 Tesla detector main field
- Screening of quadrupoles: - 2 Tesla
- Compensation for beam path through detector: - 8 Tesla over one quarter of path

Very strong influence of solenoid edges on vertical emittance especially at Z peak

- May in the end put an effective limit on the strength of the detector field

Bogomyagkov, Dam, Koratzinos

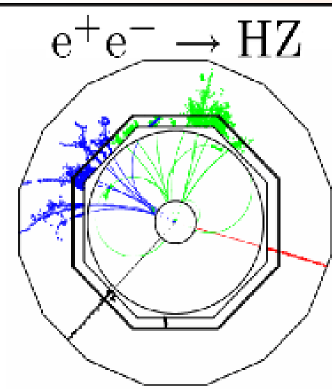
LC Detector Requirements

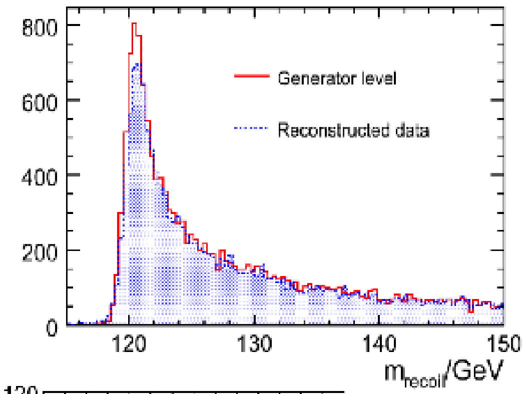
★ **momentum:** (1/10 x LEP)

e.g. Muon momentum

Higgs recoil mass

$$\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}$$



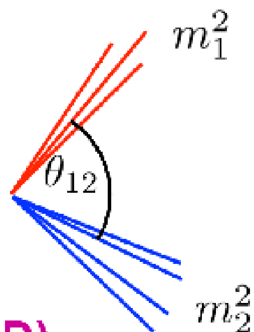


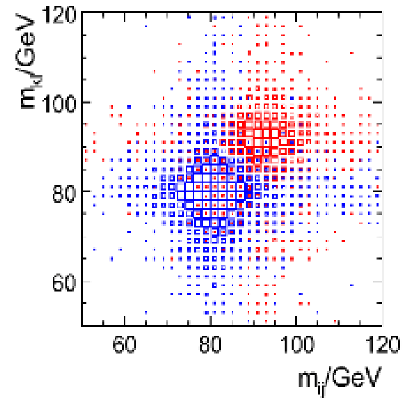
★ **jet energy:** (1/3 x LEP/ZEUS)

e.g. W/Z di-jet mass separation

EWSB signals

$$\frac{\sigma_E}{E} \approx 3-4\,\%$$



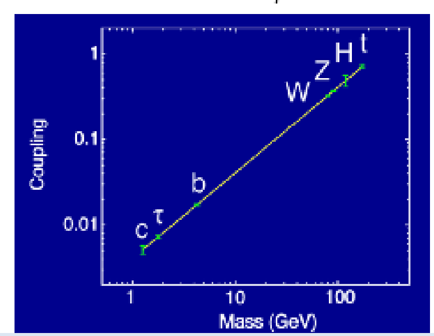


★ **impact parameter:** (1/3 x SLD)

e.g. c/b-tagging

Higgs BR

$$\sigma_{r\phi} = 5 \oplus 10/(p\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$



Also Linssen, Vos, Behnke, Wilson)

★ **hermetic:** down to θ = 5 mrad

e.g. missing energy signatures in SUSY

Need to be revisited for the specific requests of FCC-ee (this was shown for CEPC, M. Ruan, H. Zhu)

Input from Physics to the accelerator design

0. Nobody complains that the luminosity is too high (the more you get, the more you want)

1. Do we need polarized beams?

-1- transverse polarization:

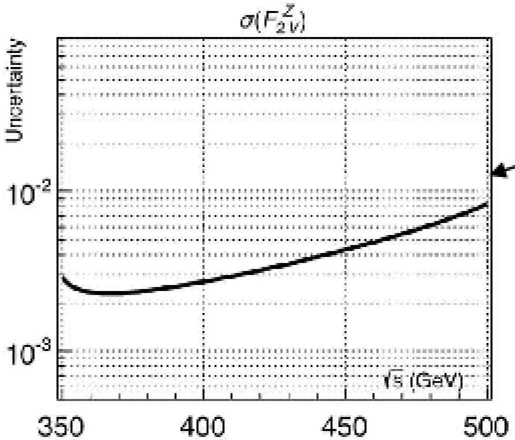
continuous beam Energy calibration with resonant depolarization
central to the precision measurements of m_Z , m_W , Γ_Z
requires 'single bunches'
a priori doable up to W energies -- workarounds exist above (e.g. γZ events)
large ring with small emittance offers *a priori* excellent prospects
need wigglers; simulations ongoing (E. Gianfelice, M. Koratzinos)

-2- longitudinal polarization requires spin rotators and is very difficult at high energies
-- We recently found that it is not necessary to extract top couplings (Janot, Azzi)
-- improves Z peak measurements *if loss in luminosity is not too strong*
but brings no information that is not otherwise accessible

2. What energies are necessary?

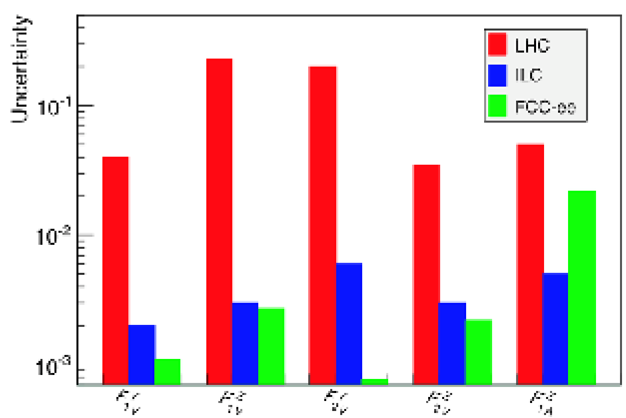
-- in addition to Z, W, H and top listed the following are being considered
-- e+e- → H(125.2) (requires monochromatization A. Faus) (under study)
-- e+e- at ~70 GeV (Z-γ interference)
-- e+e- at top threshold + <~20 GeV for top couplings (E_max up to 180 -185 GeV)
-- no obvious case for going to 500 GeV

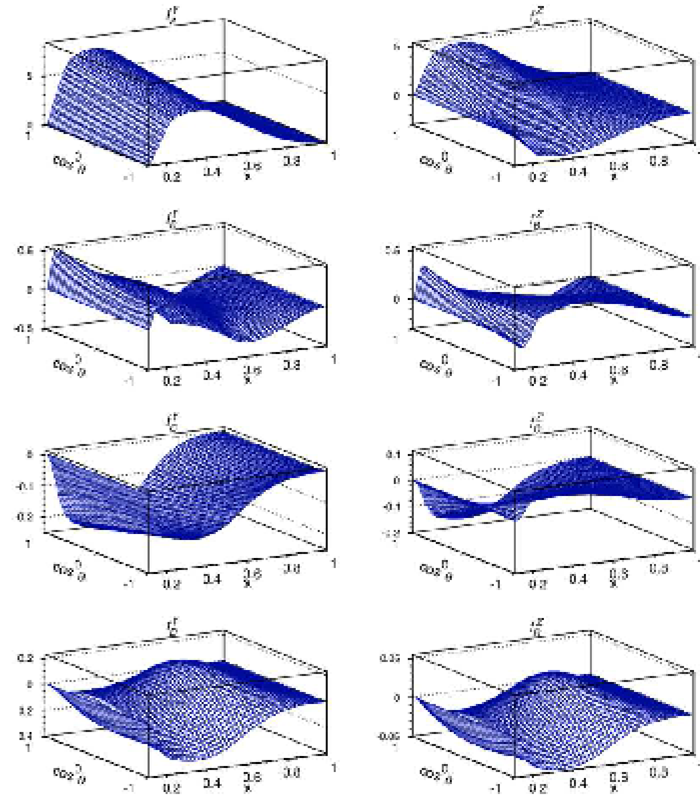
Determination of top-quark EW couplings via measurement of top-quark polarization.
In semileptonic decays, fit to lepton momentum vs scattering angle

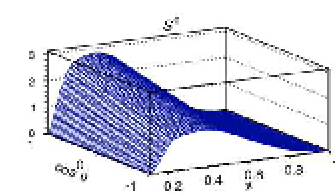


Typically best sensitivity just above production threshold

Momenta up to: 175 GeV







Patrick Janot
arXiv:1503.01325v2

Patrizia Azzi:
Top physics at FCC-ee

Next plans for FCC-ee

-- quality of FCC-ee experiments is intimately related to accelerator performance
  -- available energy points
  -- Luminosities
  -- beam polarization and energy calibration
  -- knowledge of other beam parameters (e.g. energy spread vs Z width)

reinforce work hand-in-hand

-- we can (mostly out of LEP experience) project fairly well the experimental precisions
  -- sometimes they are vertiginously small
  $\Delta \sin^2\theta_W^{eff} = 5\ 10^{-6}$, Δm_Z= 0.1 MeV $\Delta\Gamma_Z$= 0.1 MeV Δm_W = 0.5 MeV $\Delta\sigma_{ZH}/\sigma_{ZH} \sim 10^{-3}$ etc...
  careful revisiting will be necessary.

-- full use of precision measurements requires a considerable improvement
  in the theory calculations
  -- for the measurements themselves (e.g. Full two loops exponentiated for the QED ISR)
  -- for the interpretation; full three loop calculations for EWRCs
    and on inputs ($\Delta\alpha$_QED(m_Z)) *Was, Gluza, Heynemeyer, Kuhn, Frietas, Jadach, Ward..*

On our horizon:

-- we have regular VIDYO conferences on Monday 15:00 -- 17:00 (both acc. and phys.)

-- regular meetings of heavy flavour (leptons or quarks) and software group
-- more coming.

-- workshop on precision calculations for Future Colliders
13-14 July, CERN

-- workshop on interpretation of precision SM tests
in the fall : -- to what new physics are these sensitive
-- extracting info from a series of different measurements

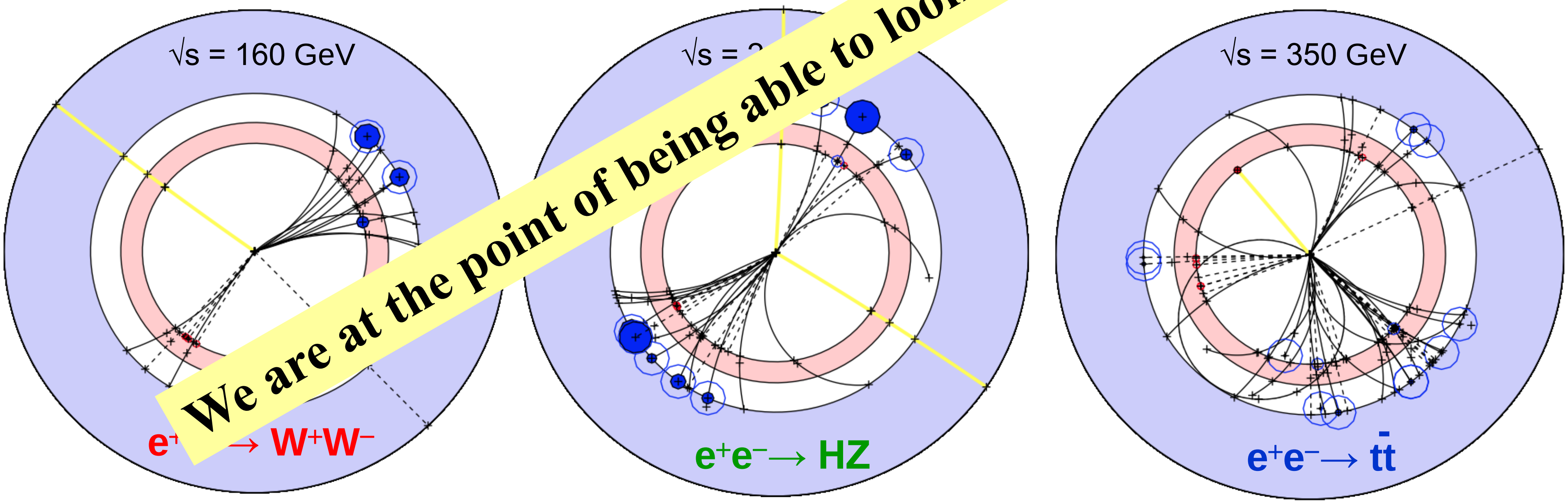
-- Workshop on detectors technologies for future e+e- colliders being set-up
(should get input from accelerator design and from phenomenological 'interest')
initiate magnet design issues
investigate requirement from precision flavour and searches
adapt LC detector designs to FCC-ee cxperimental conditions
create bridge towards e+e- communities working together

-- working on a 1st phase report on the scoping exercize, delineating phisics potential
and work needed to achieve it (first one was published in 2013

Activities common to FCC-ee, -hh, -eh (2)

- **Offline software developments** Subscribe to fcc-experiments-s… …@cern.ch
  - Conveners: Colin Bernet & Benedikt Hegner
  - Weekly meetings and monthly tutorials towards enabling ph… …lyses

We are at the point of being able to look at FCC-ee events!



Overall twiki page : https://twiki.cern.ch/twiki/bin/viewauth/FCC/FccSoftware

Fill the complemntarity matrix

- Physics coordination: FCC-ee, -hh, -eh coordinators + project m… …s
  - Ensure that all physics studies progress as one single endeavour
    - Propose physics topics to be used in the study of complem… …nd synergies

Subject		ee	hh	eh
Higgs Physics	Precision studies Higher dimension oper… Composite Higgs Rare and exo… Multiple …n Ext…			
Interface with Cosmology	…genesis …ght-handed/(almost) sterile neutrinos			
EW Symmetry Brea…	WW scattering Supersymmetry Extra dimensions Composite models			
Flavour C… …ng	Rare H,Z,W,top decays Lepton flavor violation			
E… …s of the SM	Extra vector-like fermions $SU(2)_R$ models Leptoquarks			
…CD	Perturbation theory, structure functions Modelling final states			
EW/SM precision issues	Precision measts (m_Z,m_W,m_t,α,$\alpha_s(m_Z)$,$\sin^2\theta_W$.R_b… Higher-order EW corrections W,Z triple and quadruple couplings Top (anomalous) couplings Charm/bottom flavor studies			

Suggest that we form (a) small working group(s) to establish the matrices

Conclusions:

FCC-ee is a very powerful Z,W,H, and top factory

-- beautiful «Higgs factory» ... and much more!
-- complete set of precision EW measurements including top quark
-- real potential for discovery in rare processes and precision measurements
    -- up to ~ FCC-hh energy scales for weakly coupled particles
    -- much more than an intermediate step!
-- new ideas keep coming up.

-- beautifully complementary to HL-LHC and FCC-hh
    -- the combination of FCC-ee and FCC-hh is ‘invincible’
        (quote from a referree to my funding proposal)

We have set up the structure for the study and scoped the critical questions to be resolved
    -- improving synergy with other e+e- projects to share detector experience, R&D
    -- emphasize on the need to work together with the accelerator group
        IR integration and backgrouds, beam energy calibration

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.

An e+e- collider can provide the next outstanding opportunity [after LHC/HL-LHC] to investigate the properties of the Higgs in detail. [...] the physics case is extremely strong.