XIth FCC-ee **Work**shop*):
THEORY AND EXPERIMENTS
Concluding remarks

*) **Work**: 118 (registered) participants for ~100 presentations

Organization: **congratulations and many thanks** to
-- J. Gluza, M. McCullough, C. Grojean + … (theory)
-- M. Dam, F. Bedeschi, W. Riegler and P. Azzi (experiments)
-- J. Hadre and N. Perrin

and all contributors

We have gone a long way!

2010-11-12 : ideas, wishes, basic concepts, (VHE-LHC, LEP3, TLEP), Higgs discovery

2013 ESPP2013 wants «ambitious post-LHC accelerator projet »

2014 FCC Kick-off meeting ('FCC=60 years of Physics')

2018 ESPP contributions and CDR submitted

➔ FCC can be done! Starting with the e+ e- collider.

2019➔ Start of a new time towards realization

2019 15 January CERN directorate New Year Presentation
https://indico.cern.ch/event/779524/
15 January Press release on FCC CDR release
FCC CDR (physics) presentation 4-5 March at CERN;
Plenary Meeting (ESPP) Granada 13-17 May (show up!)
FCC General meeting in 24-28 June in Brussels https://indico.cern.ch/event/727555

Thank you!

Yesterday's news

10.01.2019 | News | Press release | CHIPP

The FCC provides science for almost a century

Swiss particle physicists support the project to construct a 100 km circular accelerator infrastructure at CERN.

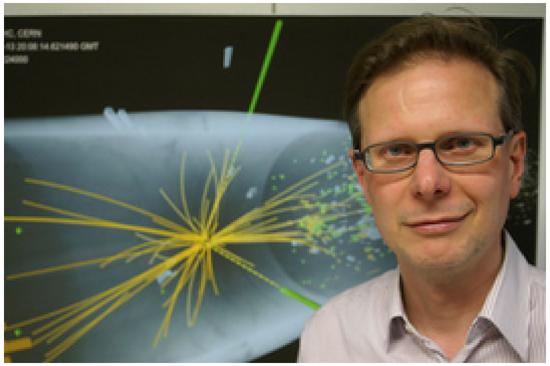


Image: B. Vogel, Switzerland

In spring 2020 the European particle physics community will decide on a new European Strategy highlighting the strategic long-term goals in this important field of fundamental research. In December 2018 Swiss scientists – organized by the Swiss Institute of Particle Physics / CHIPP – have formulated their input to the new European Strategy. Günther Dissertori – professor at ETH Zurich, member of the CHIPP Executive Board and incoming Scientific Delegate of Switzerland in the CERN Council – explains the main points of the Swiss strategic input.

Prof. Dissertori, Swiss particle physicists recently have established a new research roadmap. The new strategy will replace the roadmap of 2004 focussing on the CERN particle accelerator LHC which finally started operation in 2009...

Summary of workshop

Workshop was focused on

-- Precision calculations of theoretical predictions

-- Investigating detector technologies and designs

both: **to make the best of the data that FCC-ee can provide in particular w.r.t. 'uncertainties'**
both: important and critical items
both: VERY HIGH QUALITY and DEEP-DIGGING CONTRIBUTIONS

<u>As a consequence</u>

-- little discussion of grand scheme physics and BSM scenarios
-- little discussion of analysis techniques
-- little discussion on experimental systematic errors
-- limited discussion of how to design or optimize detectors
-- discussion on accelerator limited to MDI 'info' presentation, no EPOL.

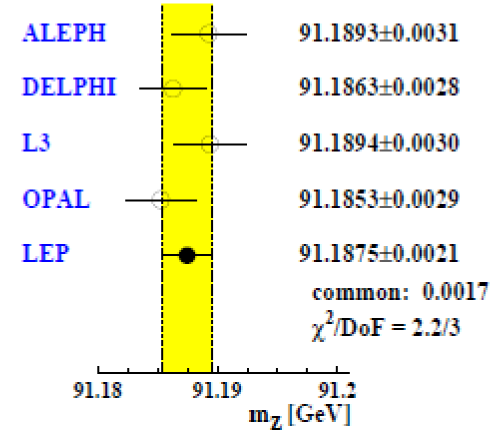
➔ Full Physics discussions will address these aspects in more detail.

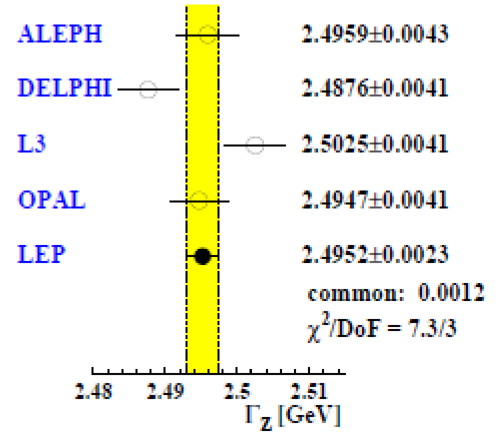
Target uncertainties(1)

1. The «floor» is statistics

e.g. LEP: m_Z = 91.1875 $\pm$ 0.0011(stat) $\pm$ 0.0017

Γ_Z = 2.4952 $\pm$ 0.0018(stat) $\pm$ 0.0012





$\pm$ 0.0017/12 (1.7/1.2 MeV) mostly from LEP energy scale worked until error smaller than **Z width** statistical error.
(original estimate in 1986 YR was 20 MeV)

NOBODY WANTS to be the DOMINANT SOURCE OF UNCERTAINTY
➔ for most problems, hard work will lead to uncertainty ~ O(statistical errors)
(not always… e.g. uncertainties due to hadronization and non pertubative QCD)

Target uncertainties(2a)

2. Information $\propto$ 1/(Uncertainty)^2

→ reduction of experimental errors goes through collecting ***independent information.***

Two examples:

a. **beam energy spread** affects the extraction of Γ_Z and m_W (effect on cross-sections)

→ in FCC-ee is is strongly affected by Beamstrahlung

-- it is very difficult to measure Beamstrahlung from the accelerator diagnostics

-- but information can be found in the acollinearity of muon pairs in e+e- → $\mu+\mu-$

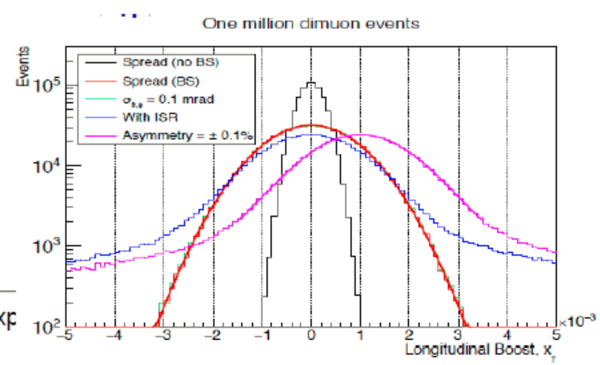
this quantity has *a priori* no useful physics information content

but is has precious information on beam energy shifts and energy spread.

➔ drastic reduction of error, becomes insignificant

- Energy spread (~100 MeV) will be measured
  - From $e^+e^- \to \mu^+\mu^-$ longitudinal boost
    - 10^6 events every 4 mins @ Z pole
      - Continuous 35 keV precision on $\delta\sqrt{s}$
    - Also measures $\Delta E = E^+ - E^-$ to at both IPs

Patrick Janot FCC-ee workshop: Theory and Exp CERN, 7-11 Jan 2019



Target uncertainties(2b)

b. point to point ECM errors in the Z line shape affect Γ_Z and $A_{FB}^{\mu\mu}$
Errors assumed in FCC-ee tables sor far are maximal.

Munchnoi proposes to use the electron recoil end point from the polarimeter
4 MeV precision every second… → short term monitoring of energy scale *->

We could also use the muon momentum in μ+μ- events (O(100-200MeV)per event)
Z peak **(-4)** point : 3 $10^{11(10)}$ muons → average measured to <O(1 **(3)**) keV <<100 keV

➔ careful (but probably inexpensive) organization of the data taking **and monitoring**

➔ **It is likely that the final systematics on Γ_Z and $A_{FB}^{\mu\mu}$ will be reduced by large factor**

c. similar comment applies to many of our experimental errors once one looks at them carefully (Rb, Rl etc…)

We cannot promise to match systematics with statistics, but this must be our target.

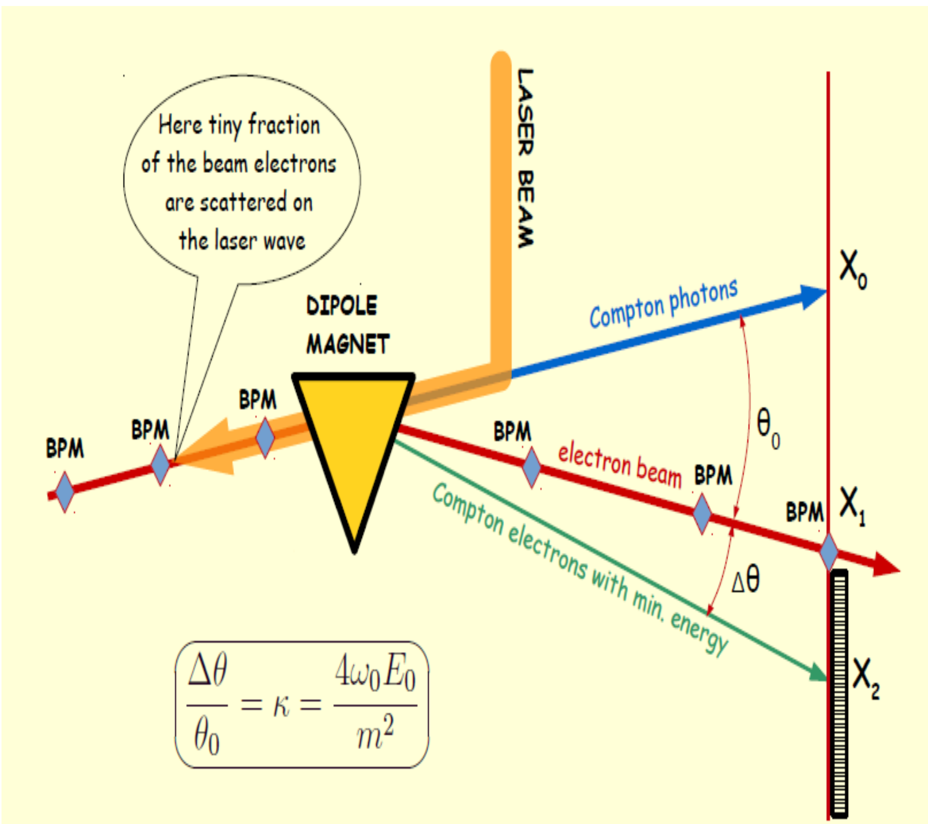
Hardware requirements: polarimeters

2 Polarimeters, one for each beam

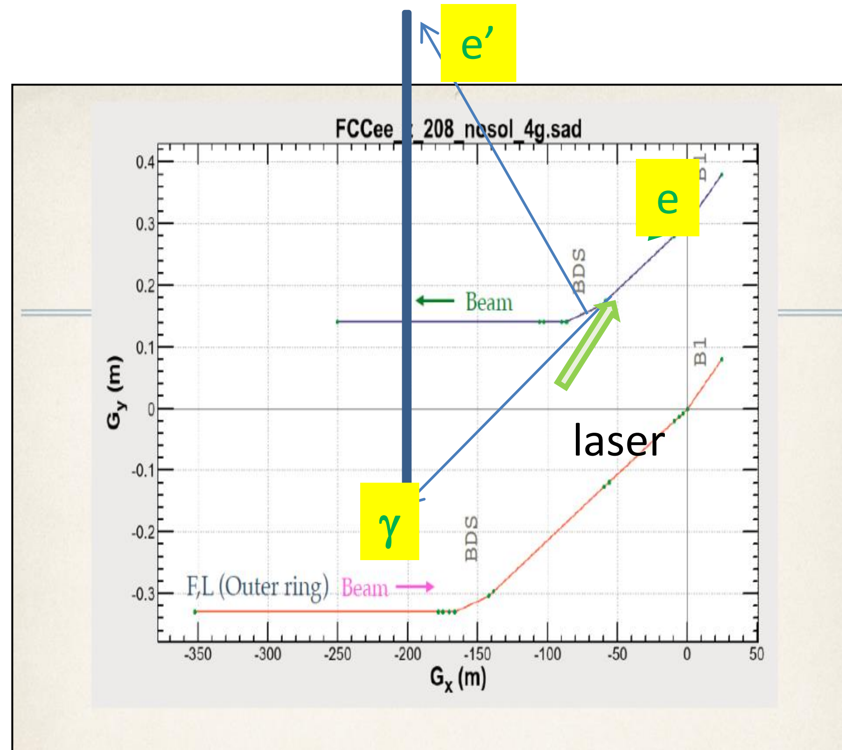
Backscattered Compton γ +e $\rightarrow$ γ + e **532 nm (2.33 eV) laser; detection of photon and electron.**

Change upon flip of laser circular polarization → beam Polarization ±0.01 per second

End point of recoil electron → beam energy monitoring ± 4 MeV per second



Munchnoy



install photon-electron IP on inner ring in points H and F *(Oide)*

Summary of Precisions & Lepton Universality

Mogens

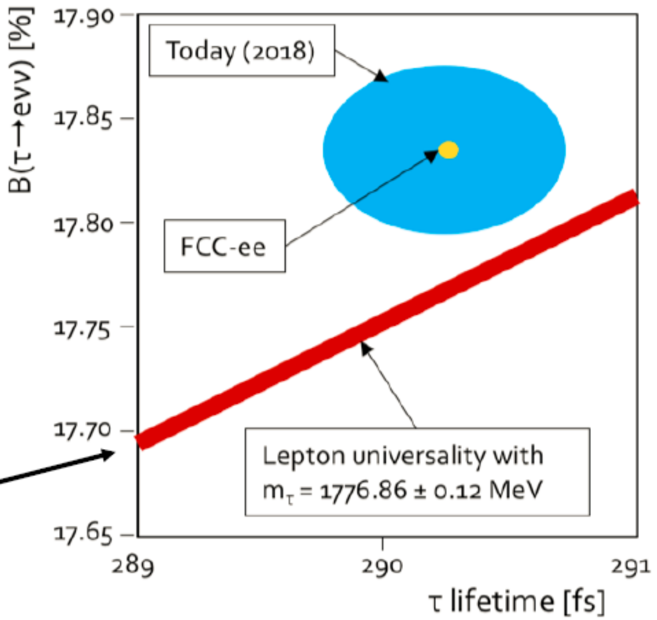
Observable	Measurement	Current precision	FCC-ee stat.	Possible syst.	Challenge
m_τ [MeV]	Threshold / inv. mass endpoint	1776.86 ± 0.12	0.004	0.1	Mass scale
τ_τ [fs]	Flight distance	290.3 ± 0.5 fs	0.001	0.04	Vertex detector alignment
$B(\tau\to e\nu\nu)$ [%]	Selection of $\tau^+\tau^-$, identification of final state	17.82 ± 0.05	0.0001	0.003	Efficiency, bkg, Particle ID
$B(\tau\to \mu\nu\nu)$ [%]		17.39 ± 0.05			

Lepton Universality Tests:

Quantity	Measurement	Current precision	FCC-ee precision
$\lvert g_\mu/g_e \rvert$	$\Gamma_{\tau\to\mu}/\Gamma_{\tau\to e}$	1.0018 ± 0.0014	Improvement by a factor 10 or more
$\lvert g_\tau/g_\mu \rvert$	$\Gamma_{\tau\to e}/\Gamma_{\mu\to e}$	1.0030 ± 0.0015	

With the precise FCC-ee measurements of lifetime and BRs, m_τ could become the limiting measurement in the universality test

$$\left(\frac{g_\tau}{g_\mu}\right)^2 \simeq \frac{\tau_\mu}{\tau_\tau} BF(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \left(\frac{m_\mu}{m_\tau}\right)^5$$



➔ same here: 'possible systematics' means: 'we are pretty sure we can achive this' but for our work we should focus on trying **to match the systematics with statistics**

<u>NB: these are very important, BSM sensitive measurements</u>

Target uncertainties(2c)

1. Analyse (independent) sources of errors and try to reduce them one by one

   for analysis : put all syst. errors to zero and analyse **one source at the time**
   final result is often very close to the quadratic sum of effect of individual sources

2. Take into account the fact that the same error sources affect different observables in a correlated way

ex: $\alpha_{QED}(m_Z)$ affects the prediction from m_z and G_F of both m_W and $\sin\theta_w^{eff}$

but cancels (at 1st order) in the relation between them.

➔ **not an excuse but extra motivation to measure these quantities as precisely as we can.**

$$\sin^2\theta_W^{eff}\cos^2\theta_W^{eff} = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\,G_F\,m_Z^2}\,\frac{1}{1+\Delta\rho}\,\frac{1}{1-\frac{\varepsilon_3}{\cos^2\theta_W}}$$

Uncertainties in m_{top}, $\Delta\alpha(m_z)$, m_H, etc….

$\Delta\sin^2\theta^{lept}_W$ ~ $\Delta\alpha(m_z)/3$ = 10^{-5} if we can reduce $\Delta\alpha(m_z)$ (see P. Janot)

2. Comparison with m_w/m_Z

Compare above formula with similar one:

$(1- m_W^2/m_Z^2)\,.\,m_W^2/m_Z^2 =$

$$\sin^2\theta_W\cos^2\theta_W = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\,G_F\,m_Z^2}\cdot\frac{1}{1-\left(-\frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho+2\frac{\cos^2\theta_W}{\sin^2\theta_W}\varepsilon_3+\frac{c^2-s^2}{s^2}\varepsilon_2\right)}$$

Where it can be seen that **$\alpha^2(m_z)$** cancels in the relation.

➔ $\sin\theta_w^{eff} = \kappa_{ew}\,(1- m_W^2/m_Z^2)$

➔ dont count it twice!

Detectors

I will not repeat the excellent summaries by Mogens, Werner, Franco and Patrizia
THANKS YOU!

Optimizing the detectors for FCC-ee requires leveraging
ideas, compentence and creativity of the whole experimental community
need tools and software support, → simulations (full, fast, clever)
→ start moving to the next step

it is clear that this is an effort the we need to amplify considerably in the next months

ESPP 2020

<------ LHC and HL-LHC operation -------->

FCC-ee accelerator R&D and technical design

FCC-ee accelerator construction, installation, commissioning

Set up of international experiment collaborations, detector R&D and concept development

FCC-ee detector technical design

FCC-ee detector construction, installation, commissioning

FCC-ee operation

Start exploring this step this week

Next steps:

0. please contibute to spread the word in resp. communities (countries, exp. collab)
1. please attend the Granada meeting ! (Fabiola dixit)
2. we will resume monthly physics VCs (feel free to volunteer)
   also may be able to intensify detector and simulation meetings

3. Target is high quality and richly attended Brussels meeting

4. Concerning detector discussions

0. much more detailed studies of detector requirements and R&D
   mapped on FCC-ee physics landscape is needed (Bedeschi)
1. need efficient software tools to ease start-up of newcomers (CERN support) (Patrizia)
2. funding schemes (beyond CERN) will be investigated for R&D and simulations
2. remain at the level of requirements and concept discussions + R&D
   for the next few years.
   Build up of experimental collaborations will follow with instructions from top level
   Should happen only when solid schedule is known.

IF YOU ARE NOT REGISTERED ON THE FCC-ee MAILING LIST PLEASE DO

http://cern.ch/fcc-ee → contact/join us → join us (fill form)

Thank you all for great contributions,

talk / see you/ soon,

… and lets continue to grow!