Istituto Nazionale
di Fisica Nucleare
SEZIONE DI PISA

FCC Week 2018
9-13 April 2018
Beurs van Berlage

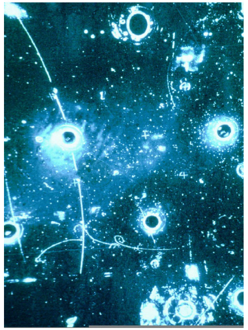
EW measurements at FCC

Roberto Tenchini
INFN Pisa

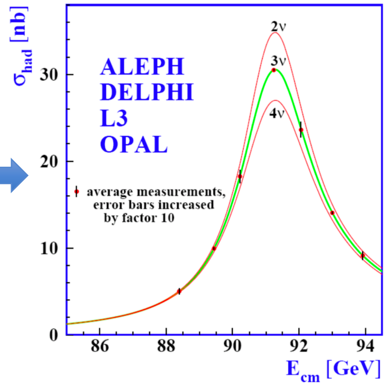
Acknowledgements: P. Azzurri, A. Blondel, M. Boscolo, D. Britzger, M. Dam, J. Gu, P. Janot, M. Klein, F. Piccinini

ee, ℓp, pp collisions and electroweak physics

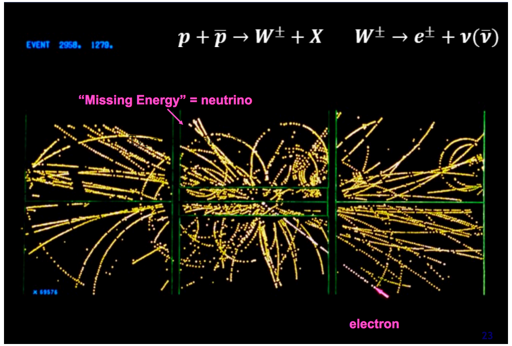
Deep Inelastic scattering and discovery of neutral currents (1973)



LEP and high precision EW physics (1989-2000)



proton antiproton collisions and discovery of Z, W bosons(1983)



In this talk I will mostly discuss FCC-ee, with some perspectives for FCC-eh.
FCC-hh → talk of Andrea Wulzer

FCC-ee operation model assumed for the CDR

- Integrated luminosity goals for Z and W physics
  - 150 ab^{-1} around the Z pole (~ 25 ab^{-1} at 88 and 94 GeV, 100 ab^{-1} at 91 GeV)
  - 10 ab^{-1} around the WW threshold (161 GeV with ±few GeV scan)

LEP (4 IPs)
0.6 fb^{-1}
2.4 fb^{-1}

working point	luminosity/IP $[10^{34}\ cm^{-2}s^{-1}]$	total luminosity (2 IPs)/ yr	physics goal	run time [years]
Z first 2 years	100	26 ab^{-1}/year	**150 ab^{-1}**	**4**
Z later	200	52 ab^{-1}/year		
W	32	8.3 ab^{-1}/year	**10 ab^{-1}**	**1**
H	7.0	1.8 ab^{-1}/year	**5 ab^{-1}**	**3**
top (350 GeV)	0.8	0.2 ab^{-1}/year	**0.2 ab^{-1}**	**1**
top later (365 GeV)	1.5	0.38 ab^{-1}/year	**1.5 ab^{-1}**	**4**

These are important, too, for WW physics !

EW Physics observables at FCC-ee

TeraZ (5×10^{12} Z)

From data collected in a lineshape energy scan:

- Z mass (key for jump in precision for ewk fits)
- Z width (jump in sensitivity to ewk rad corr)
- R_l = hadronic/leptonic width ($\alpha_s(m^2_Z)$, lepton couplings)
- peak cross section (invisible width, N_ν)
- $A_{FB}(\mu\mu)$ ($\sin^2\theta_{eff}$, $\alpha_{QED}(m_Z^2)$, lepton couplings)
- Tau polarization ($\sin^2\theta_{eff}$, lepton couplings, $\alpha_{QED}(m_Z^2)$)
- R_b, R_c, $A_{FB}(bb)$, $A_{FB}(cc)$ (quark couplings)

OkuWW (10^8 WW)

From data collected around and above the WW threshold:

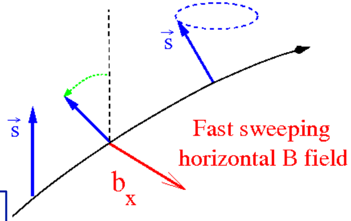
- W mass (key for jump in precision for ewk fits)
- W width (first precise direct meas)
- $R^W = \Gamma_{had}/\Gamma_{lept}$ ($\alpha_s(m^2_Z)$)
- Γ_e , Γ_μ , Γ_τ (precise universality test)
- Triple and Quartic Gauge couplings (jump in precision, especially for charged couplings)

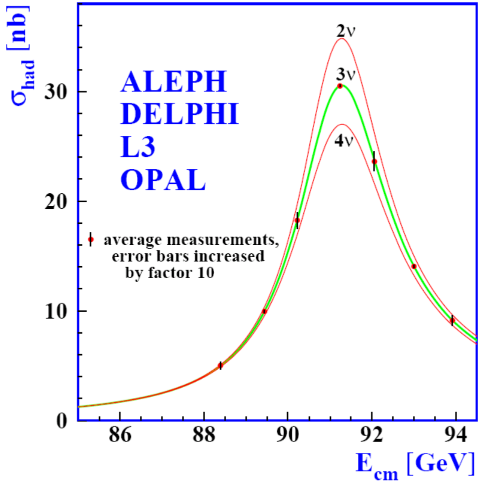
Determination of Z mass and width

- uncertainty on m_Z (≈ 100 KeV) is dominated by the correlated uncertainty on the centre-of-mass energy at the two off peak points

at FCC-ee continuous E_{CM} calibration (resonant depolarization) gives Δ E_{CM} ≈ 10 KeV (stat) + 100 KeV (syst)

A. Blondel, talk on Tuesday and poster session





- the off peak point-to-point anti-correlated uncertainty has a similar impact (≈ 100 KeV) on Γ_Z

The exact choice of the off peak energies for m_Z , Γ_Z is not very crucial at FCC-ee (differently from LEP) because of the high statistics. Instead the exact choice is crucial for $\alpha_{QED}(m_Z^2)$ which is driving the choice of $\sqrt{s_-}$ ≈ **88 GeV** and $\sqrt{s_+}$ ≈ **94 GeV** (slide 10).

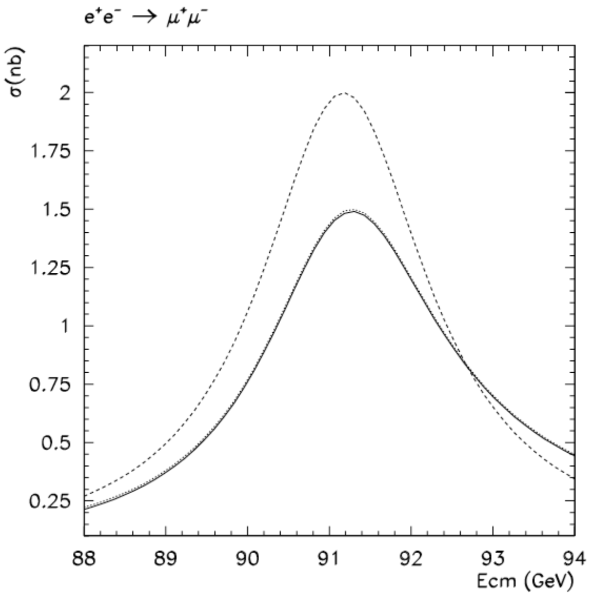
See table in P. Janot talk on Tuesday

Lineshape: radiator, γ-Z interference

- The lineshape is highly asymmetric (ISR), radiator function $H(s',s)$ used for de-convolution known at leading $O(\alpha^3)$ equivalent to ≈ 100 KeV on mass and width (**need higher orders for FCC-ee**).

$$\boxed{\sigma_{f\bar{f}}(s) = \int_{4m_f^2}^{s} ds' H(s,s')\hat{\sigma}_{f\bar{f}}(s')}$$

- FCC-ee **precision calls for a model independent fit of the lineshape (S-matrix) where γ-Z interference is measured independently**

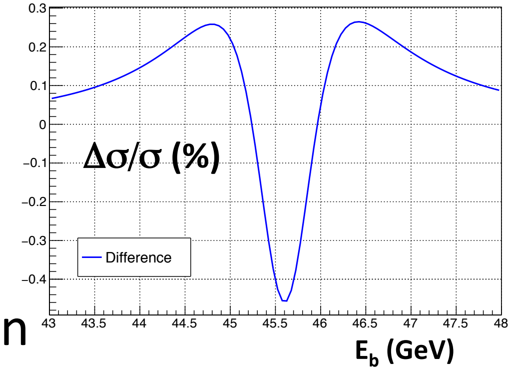


→ A measurement of the γ-Z interference term for 100 keV precision for m_Z, Γ_Z requires 100 fb^{-1} collected at CM energy of ≈ 60-70 GeV ... or use the 160 GeV run !

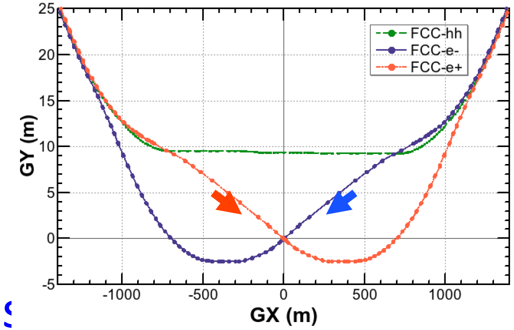
Γ_Z and beam energy spread

- The beam energy spread affects the lineshape changing the cross section by

$$\delta\sigma \simeq 0.5\frac{d^2\sigma}{dE^2}\epsilon^2_{CMS}$$



- The size of the energy spread (≈ 60 MeV) and its impact on Γ_Z (≈4 MeV) is similar to LEP, but the approach to tackle the corresponding systematic uncertainty different because of FCC-ee beam crossing angle
- At LEP it was controlled at 1% level by measuring the longitudinal size of the beam spot, at FCC-ee can be measured with similar precision from the scattering angles of $\mu^+\mu^-$ events



Control of energy spread with $\mu^+\mu^-$

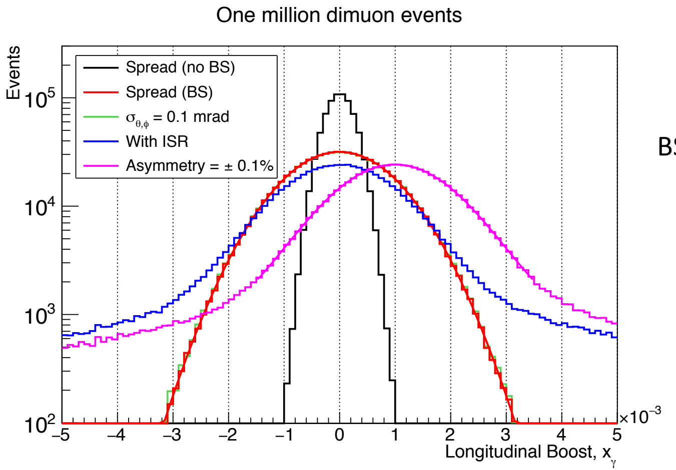
- FCC-ee: Asymmetric optics with beam crossing angle α of 30 mrad
- α is measured in e+e-→$\mu^+\mu^-(\gamma)$

$$\alpha = 2\arcsin\left[\frac{\sin(\varphi^- - \varphi^+)\sin\theta^+\sin\theta^-}{\sin\varphi^-\sin\theta^- - \sin\varphi^+\sin\theta^+}\right]$$

together with γ (ISR) energy, both distributions sensitive to energy spread.

- Energy spread measured at 0.1% with 10^6 muons (4 min at FCC-ee)
- Current calculations of ISR emission spectrum sufficient
- Detector requirement on muon angular resolution 0.1 mrad

Patrick Janot, talk at Tuesday session and poster



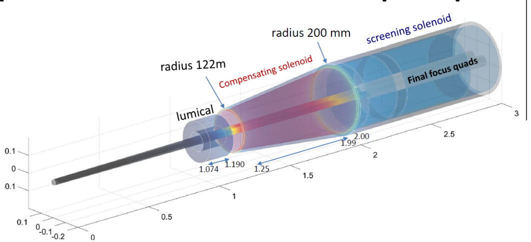
BS=beamstrahlung

$$x_\gamma = -\frac{x_+\cos\theta^+ + x_-\cos\theta^-}{\cos(\alpha/2) + |x_+\cos\theta^+ + x_-\cos\theta^-|}$$

Can keep related systematic uncertainty on Γ_Z at less than 30 keV

Measurement of luminosity, σ_{had} and neutrino families

- Goal on theoretical uncertainty from higher order for low angle Bhabha is 0.01%, corresponding to a **reduction of a factor 8 in uncertainty on number of light neutrino families** (we are already not far ≈ 0.02%)
  - Another goal is a point to point relative normalization of 5 10^{-5} for Γ_Z
- To match this goal an accuracy on detector construction and boundaries of ≈ 2 μm is required
  - clever acceptance algorithms, a la LEP, with independence on beam spot position should be extended to beam with crossing angle
  - luminometer fixed to central beam pipe



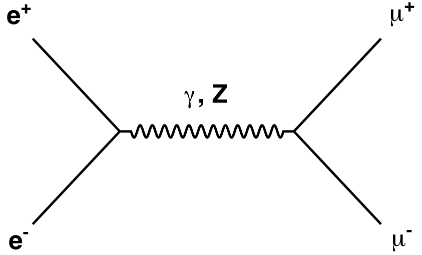
- Can potentially reach an uncertainty of 0.01% also with e+e-→$\gamma\gamma$, statistically 1.4 ab^{-1} are required (theory uncertainty already at this level, requires control of large angle Bhabha)

Mogens Dam, talk at Tuesday session

e.m. coupling: direct measurement of $\alpha_{QED}(m_Z^2)$

At LEP hadronic contributions to the vacuum polarization as external input (dispersion relations+ lower energy experiments) $\Delta_{rel} \approx 10^{-4}$

FCC-ee: direct measurement with better precision



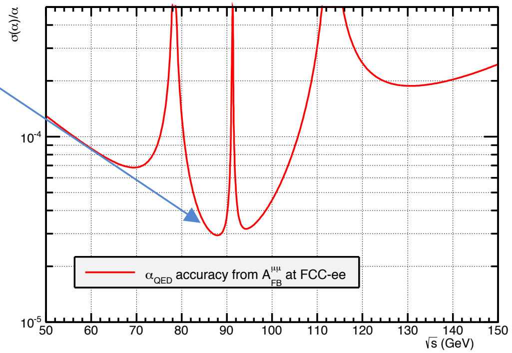
Patrick Janot: JHEP 02 (2016) 53

$$A_{FB}^{\mu\mu} = \frac{N_F^{\mu+} - N_B^{\mu+}}{N_F^{\mu+} + N_B^{\mu+}} \approx f(\sin^2 \vartheta_W^{eff}) + \alpha_{QED}(s) \frac{s - m_Z^2}{2s} g(\sin^2 \vartheta_W^{eff})$$

Type	Source	Uncertainty
Experimental	$E_{\rm beam}$ calibration	1×10^{-5}
	$E_{\rm beam}$ spread	$< 10^{-7}$
	Acceptance and efficiency	negl.
	Charge inversion	negl.
	Backgrounds	negl.
Parametric	m_Z and Γ_Z	1×10^{-6}
	$\sin^2\theta_W$	5×10^{-6}
	G_F	5×10^{-7}
Theoretical	QED (ISR, FSR)	$< 10^{-6}$
	Missing EW higher orders, QED(IFI)	few 10^{-4}
	New physics in the running	0.0
Total (except missing EW higher orders)	Systematics	1.2×10^{-5}
	Statistics	3×10^{-5}

Optimal centre-of-mass energies for a 3×10^{-5} uncertainty on α_{QED} : $\sqrt{s}_-$ = **87.9 GeV** and $\sqrt{s}_+$ = **94.3 GeV**

Work on EWK theoretical corrections required to reach $\approx 3\ 10^{-5}$



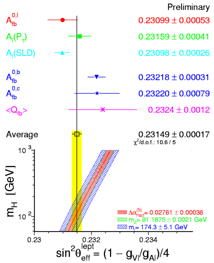
$\sigma(\alpha)/\alpha$ plot, for a year of running at any $\sqrt{s}$

FCC-ee strategy for neutral couplings and $\sin^2\theta_{eff}$

$$\boxed{\mathcal{A}_e = \frac{2 g_{Ve} g_{Ae}}{(g_{Ve})^2 + (g_{Ae})^2} = \frac{2 g_{Ve}/g_{Ae}}{1 + (g_{Ve}/g_{Ae})^2}}$$

- Muon forward backward asymmetry at pole, $A_{FB}^{\mu\mu}$ (m_Z) gives $\sin^2\theta_{eff}$ with 5 10^{-6} precision
  - **uncertainty driven by knowledge on CM energy**
  - **assumes muon-electron universality**
- **Tau polarization can reach similar precision without universality assumption**
  - tau pol measures A_e and A_τ, can input to $\mathbf{A_{FB}^{\mu\mu} = 3/4\ A_e\ A_\mu}$ to measure separately electron, muon and tau couplings, (together with Γ_e , Γ_μ , Γ_τ)
- Asymmetries A_{FB}^{bb}, A_{FB}^{cc} provide input to quark couplings together with Γ_b, Γ_c

NOTE that LEP approach was different: all asymmetries were limited by statistics and primarily used to measure $\sin^2\theta_{eff}$



tau polarization plays a central role at FCC-ee

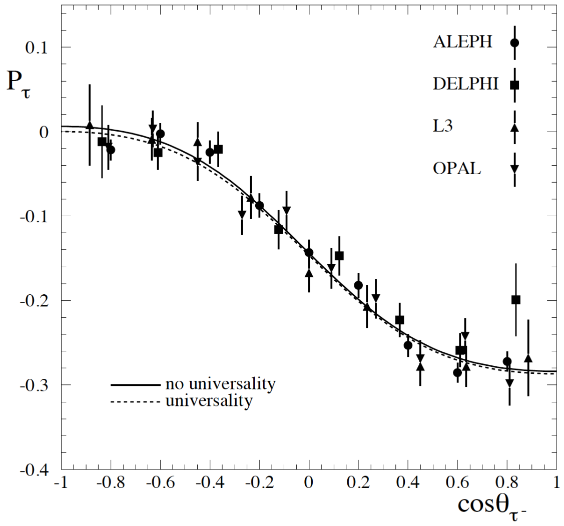
- Separate measurements of A_e and A_τ from

$$P_\tau(\cos\theta) = \frac{A_{pol}(1+\cos^2\theta) + \frac{8}{3}A^{FB}_{pol}\cos\theta}{(1+\cos^2\theta) + \frac{8}{3}A_{FB}\cos\theta}$$

$$A_{pol} = \frac{\sigma_{F,R} + \sigma_{B,R} - \sigma_{F,L} - \sigma_{B,L}}{\sigma_{tot}} = -A_f$$

$$A_{pol}^{FB} = \frac{\sigma_{F,R} - \sigma_{B,R} - \sigma_{F,L} + \sigma_{B,L}}{\sigma_{tot}} = -\frac{3}{4}A_e$$

Measured P_τ vs $\cos\theta_{\tau^-}$



At FCC-ee

- very high statistics: improved knowledge of tau parameters (e.g. branching fraction, tau decay modeling) with FCC-ee data
- use best decay channels (e.g. $\tau \rightarrow \rho\nu_\tau$ decay very clean), note that detector performance for photons / π^0 very relevant

→ **measure $\sin^2\theta_{eff}$ with 6.6 10^{-6} precision**

A_{FB}^{bb} : from LEP to FCC-ee

LEP combination dominated by statistics, projection for FCC-ee considers conservative reduction of various uncertainty components

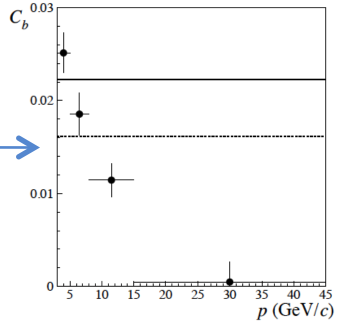
	ΔAFB(b)
STATISTICS	0.00156
UNCORRELATED SYSTEMATIC	0.00061
QCD CORRECTION	0.00030
LIGHT QUARK FRAGMENTATION	0.00013
SEMILEPTONIC DECAYS MODELLING	0.00013
CHARM FRAGMENTATION	0.00006
BOTTOM FRAGMENTATION	0.00003
TOTAL SYSTEMATIC ERROR	0.00073

→ 0.00002

→ Most of this depends on stat.

→ Can be reduced with improved calculations and proper choices of analysis methods (e.g. measure the asymmetry as a function of jet parameters, etc.)

Simple method to reduce QCD corrections for lepton analysis: raise cut un lepton momentum, as statistics is no longer dominant



Improved measurements also for the charm sector: A_{FB}^{cc}

Precisions on coupling ratio factors, A_f

$$\boxed{\mathcal{A}_e = \frac{2 g_{Ve} g_{Ae}}{(g_{Ve})^2 + (g_{Ae})^2} = \frac{2 g_{Ve}/g_{Ae}}{1 + (g_{Ve}/g_{Ae})^2}}$$

	Statistical uncertainty	Systematic uncertainty	improvement w.r.t. LEP
$\mathcal{A}_e$	$5. \times 10^{-5}$	$1. \times 10^{-4}$	50
$\mathcal{A}_\mu$	2.5×10^{-5}	1.5×10^{-4}	30
$\mathcal{A}_\tau$	$4. \times 10^{-5}$	$3. \times 10^{-4}$	15
$\mathcal{A}_b$	2×10^{-4}	30×10^{-4}	5
$\mathcal{A}_c$	3×10^{-4}	80×10^{-4}	4
$\sin^2\theta_{W,eff}$ (from muon FB)	10^{-7}	$5. \times 10^{-6}$	100
$\sin^2\theta_{W,eff}$ (from tau pol)	10^{-7}	6.6×10^{-6}	75

Relative precisions, but for $\sin^2\theta_{eff}$

Partial widths ratio (R_l)

- $R_l = \Gamma_l/\Gamma_{had}=\sigma_l/\sigma_{had}$ is a robust measurement, necessary input for a precise measurement of lepton couplings (and $\alpha_s(m^2_Z)$)
- Exploiting FCC-ee potential requires an accurate control of acceptance, particularly for the leptons
  - acceptance uncertainties were sub-dominant at LEP, but need to be reduced by a factor ≈ 5 to match precision goal on R_l of 5 10^{-5}
  - knowledge of boundaries, mechanical precisions: need to exploit 40 years of improvements in technology, need to use clever selections (at LEP was necessary only for luminosity)
  - fiducial acceptance is asymmetric in azimuth at FCC-ee because of 30 mrad cross angle→ boost in trasverse direction β_x = tg(α/2) ≈ 0.015, however can measure ϕ^* and cos(θ^*) event by event for dileptons !

Measurement of R_b : double tagging

Divide event in two hemispheres according to thrust direction

- F_1 fraction of single tag
- F_2 fraction of double tag

$$F_1 = R_b(\varepsilon_b - \varepsilon_{uds}) + R_c(\varepsilon_c - \varepsilon_{uds}) + \varepsilon_{uds}$$

$$F_2 = R_b(C_b\varepsilon_b^2 - \varepsilon_{uds}^2) + R_c(\varepsilon_c^{\ 2} - \varepsilon_{uds}^{\ 2}) + \varepsilon_{uds}^{\ 2}$$

$$R_b \approx \frac{C_b F_1^{\ 2}}{F_2}$$

$$\varepsilon_b \approx \frac{F_2}{C_b F_1}$$

LHC detectors and current taggers can reach three times b tagging efficiency at same suppression of charm and uds, in a more harsh environment → sizeable improvement possible at FCC-ee

- statistical uncertainty coming from double tag sample
- **systematic uncertainty from hemisphere correlations becomes dominating**

Efficient and pure secondary vertex finding will be important to study gluon splitting and nasty sources of correlations (e.g. momentum correlations) → **keep b-tag efficiency flat in momentum**

FCC-ee projections conservatively consider reduction of uncertainty on hemisphere correlations from ≈0.1% (LEP) to ≈0.03%

Improved measurements also for the charm sector: R_c

Precisions on normalized partial widths $R_f = \sigma_f/\sigma_{had}$

	Statistical uncertainty	Systematic uncertainty	improvement w.r.t. LEP
R_μ (R_ℓ)	10^{-6}	5×10^{-5}	20
R_τ	1.5×10^{-6}	10^{-4}	20
R_e	1.5×10^{-6}	3×10^{-4}	20
R_b	5×10^{-5}	3×10^{-4}	10
R_c	1.5×10^{-4}	15×10^{-4}	10

Relative precisions

Precisions on vector and axial neutral couplings

fermion type	g_a	g_v
e	1.5×10^{-4}	2.5×10^{-4}
μ	2.5×10^{-5}	$2. \times 10^{-4}$
τ	0.5×10^{-4}	3.5×10^{-4}
b	1.5×10^{-3}	1×10^{-2}
c	2×10^{-3}	1×10^{-2}

Relative precisions

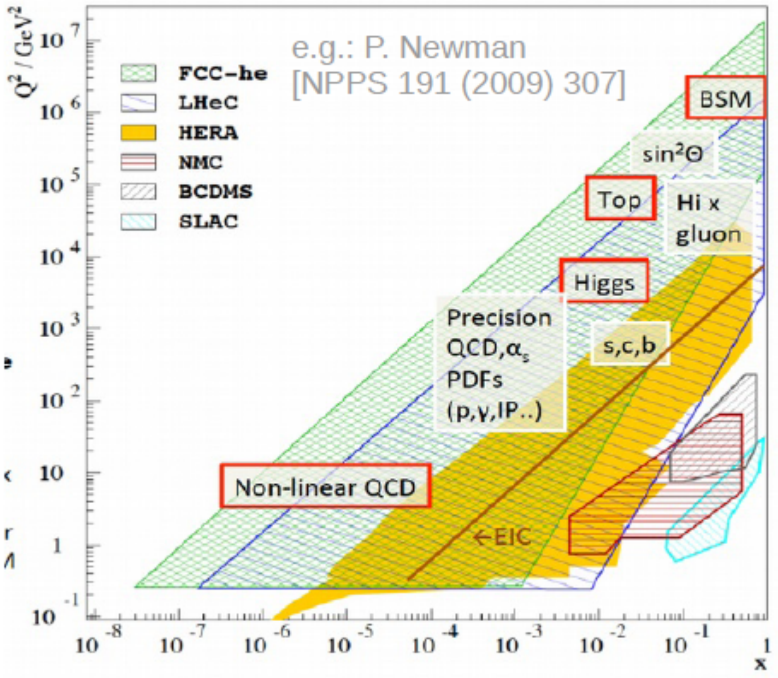
Improvements 1 – 2 orders of magnitudes with respect to LEP, depending on the fermion
(Still need to explore the potential for a measurement of the s quark coupling)

See talk of Jorge De Blas for impact on EFT operators

Electroweak physics at FCC-eh

Electron ring
- Energy recovery linac: E_e = 60 GeV
- Polarisation up to P_e ~ 80%
- Similar concept for LHeC & FCC-eh

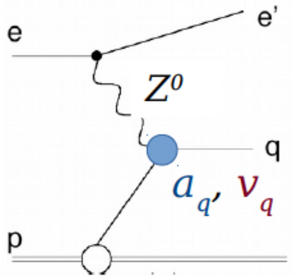
Center-of-mass energies
- LHeC: √s ~ 1.3 TeV
- FCC-eh: √s ~ 3.5 TeV
- Up to 1 ab^{-1} integrated luminosity



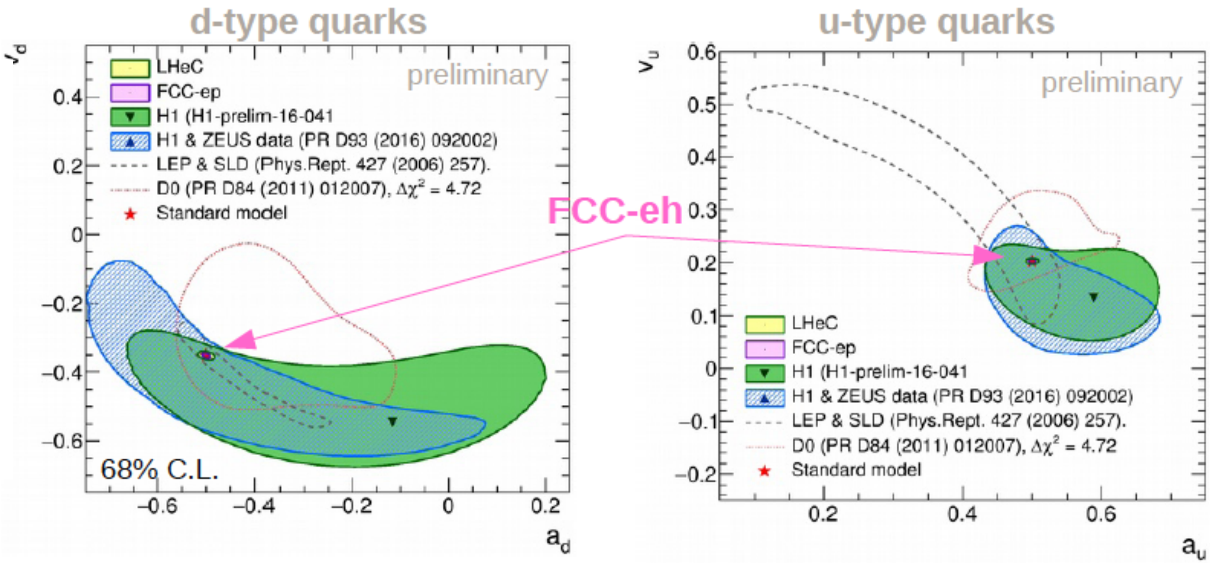
EW at FCC-eh in comparison to HERA
- CC Large increase of kinematic range
- CC Largely improved experimental precision
- NC γ/Z-interference and ZZ effects will become important (higher Q^2)

Precise measurements of u, d couplings at FCC-eh

Daniel Britzger at 2nd FCC physics workshop



$$a_q = I^{(3)}_{q,L} \qquad v_q = I^{(3)}_{q,L} - 2\,Q_q \sin^2\theta_W$$



Polarization of the electron beam, up to 80%, improves precision

Weak neutral quark couplings

- u- and d-quark couplings determined simultaneously
- Very precise measurements feasible

a_u = 0.5 +/- 0.003
a_d = -0.5 +/- 0.005
v_u = 0.20 +/- 0.002
v_d = -0.35 +/- 0.005

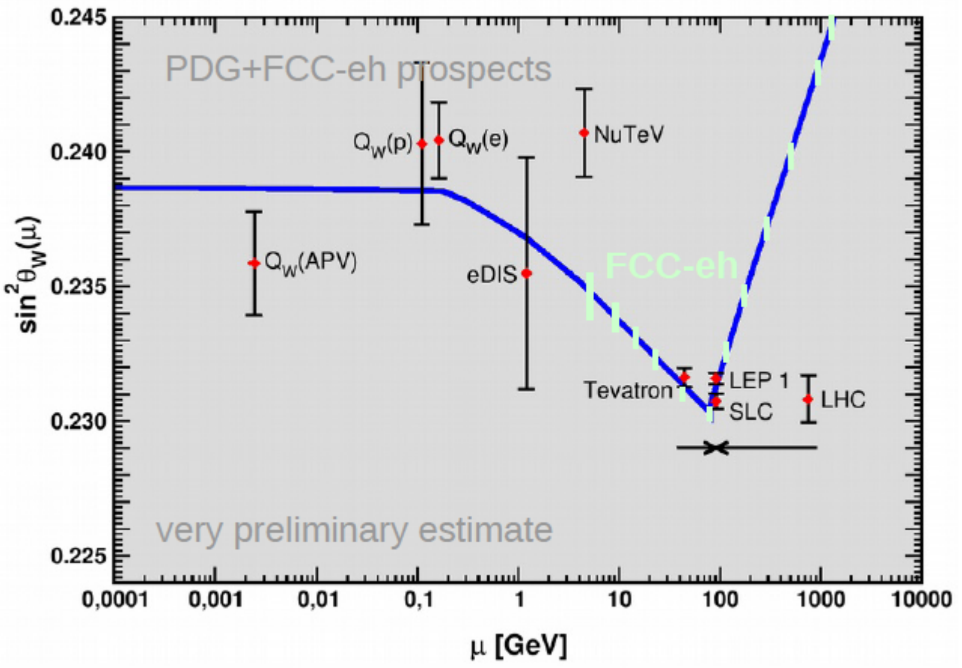
FCC-eh: measurement of the weak scale dependence

Can measure the scale dependence of the neutral coupling up to ≈ 1 TeV

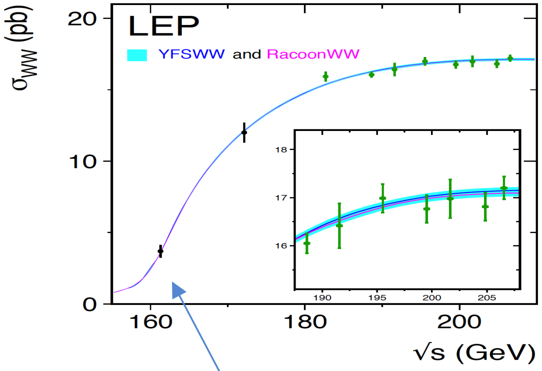
Note that the definition of $\sin^2\theta_W$ here is

$$\sin^2 2\theta_W(m_Z)_{\overline{MS}} = \frac{4\pi\alpha}{\sqrt{2}G_\mu m_Z^2\,[1-\Delta\hat{r}(m_t,m_h)]}$$

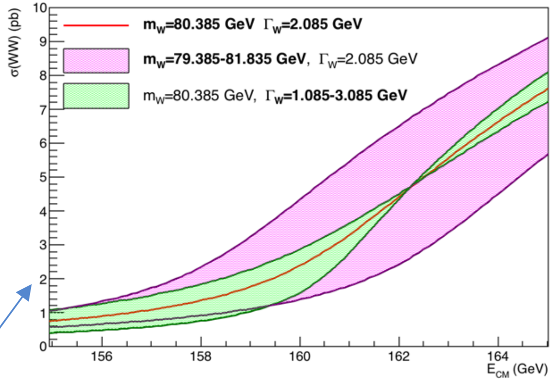
which is $\sin^2\theta_W = e/g$ where g is the SU(2) weak coupling



W mass and width from WW cross section

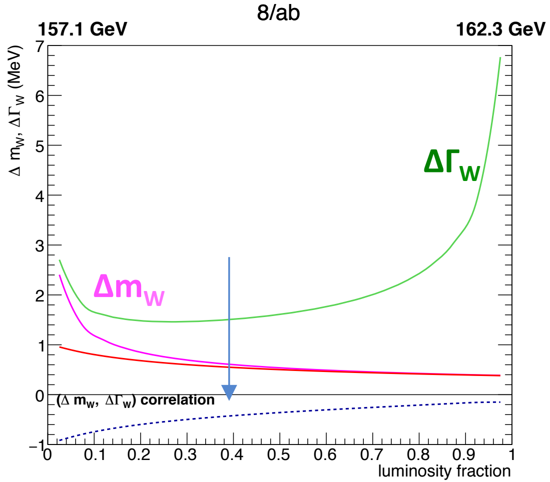


At LEP2 √s=161 GeV with 11/pb
➔ m_W=80.40±0.21 GeV



Sensitivity to mass and width is different at different E_{CM}: can optimize mass AND width by choosing carefully two energy points.

- Same concept can be used to minimize systematics (e.g. due to backgrounds)
- Centre-of-mass known by resonant depolarization (available at ≈ 160 GeV)
- Luminosity from Bhabha, requirements similar to Z pole case



with E_1=**157.1** GeV E_2=**162.3** GeV f=**0.4**
Δm_W=0.62 $\Delta\Gamma_W$=1.5 (MeV)

need syst control on :

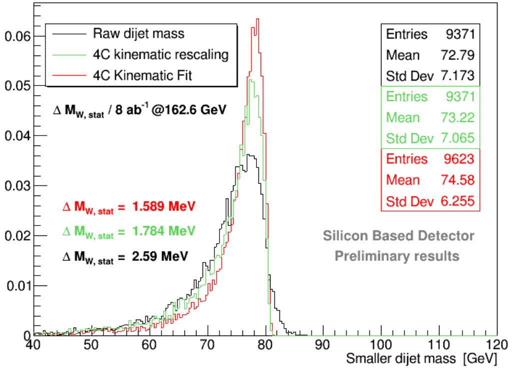
- **ΔE(beam)<0.35 MeV ($4x10^{-6}$)**
- **Δε/ε, ΔL/L < 2 10^{-4}**
- **$\Delta\sigma_B$<0.7 fb (2 10^{-3})**

W mass from di-jet invariant mass (standard at LEP)

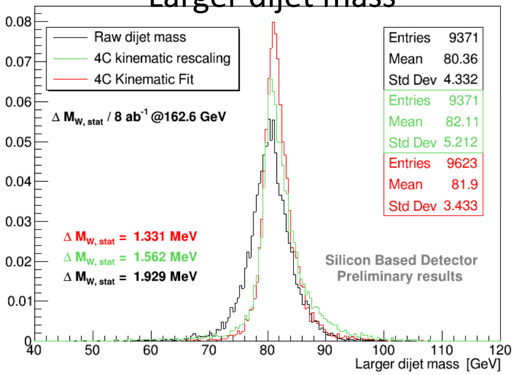
Marina Béguin, poster session

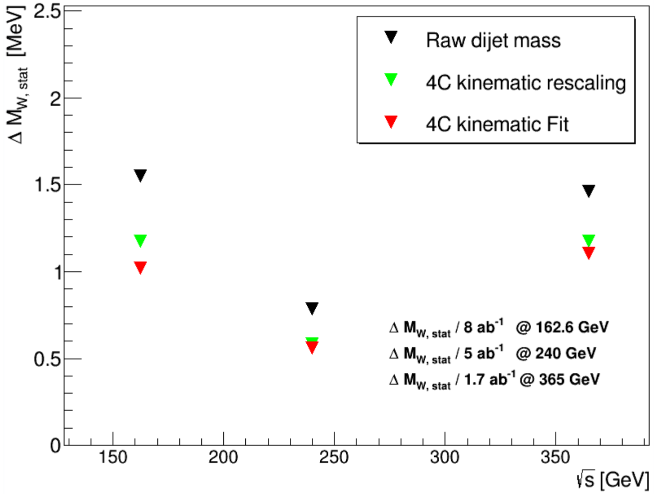
- Work in progress, started with the 4-quark channel, exploring resolution and kinematic fits (knowledge of beam energy crucial here, too !)
- Statistical uncertainty at the ≈ 1 MeV level
- Need to investigate how statistics can help in reducing LEP systematics (e.g. fragmentation, jet mass)
- Best result will be provided by the lvqq channel (no color reconnection)

Smaller dijet mass



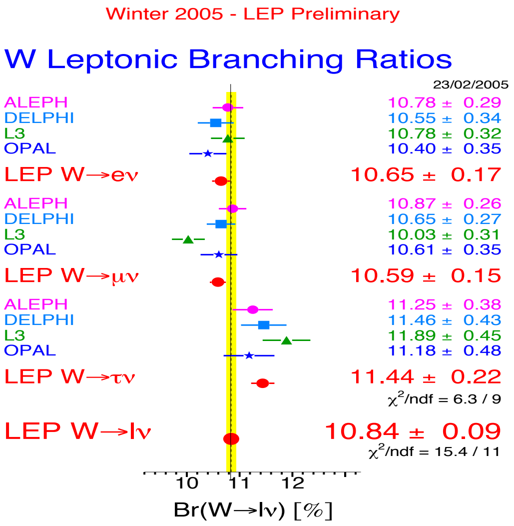
Larger dijet mass

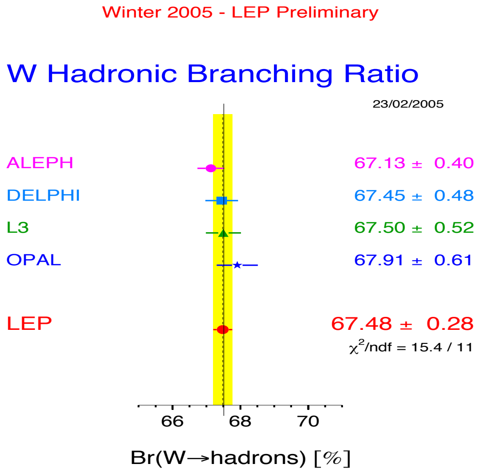




Statistical uncertainties with various kinematic fit option, as a function of the centre-of-mass

W decay Branching Fractions





8/ab@160GeV + 5/ab@240GeV

➔ 30M+ 80M W-pairs

➔ ΔBR(qq) (stat) =[1] 10^{-4} (rel)

➔ $\Delta\alpha_S \approx (9\ \pi/2)\Delta BR \approx 2\ 10^{-4}$

➔ ΔBR(e/μ/τν)(stat)=[4]10^{-4} (rel)

requires excellent control of lepton id
i.e. cross contaminations in signal channels
(e.g., τ➔e,μ versus e,μ channels)

lepton universality test at 2% level

tau BR 2.8 σ larger than e/μ

➔ **FCCee @ 4 10^{-4} level**

quark/lepton universality at 0.6%

➔ **FCCee @ 10^{-4} level**

Flavor tagging ➔W coupling to c & b-quarks (V_{cs}, V_{cb} CKM elements)

FCC-eh : measurement of W mass from NC/CC ratio

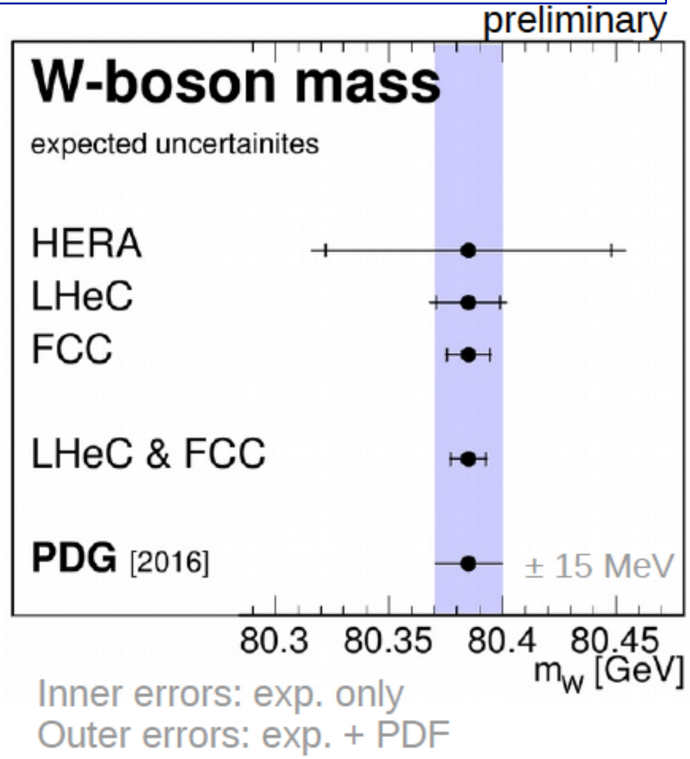
Daniel Britzger at 2nd FCC physics workshop

W-boson mass from NC&CC DIS data

- All other masses expected to be known
- HERA $\pm\, 63_{(exp)} 29_{(PDF)}$ MeV
- LHeC $\pm\, 14_{(exp)} 10_{(PDF)}$ MeV
- FCC $\pm\, 9_{(exp)} 4_{(PDF)}$ MeV

High precision for W-boson mass

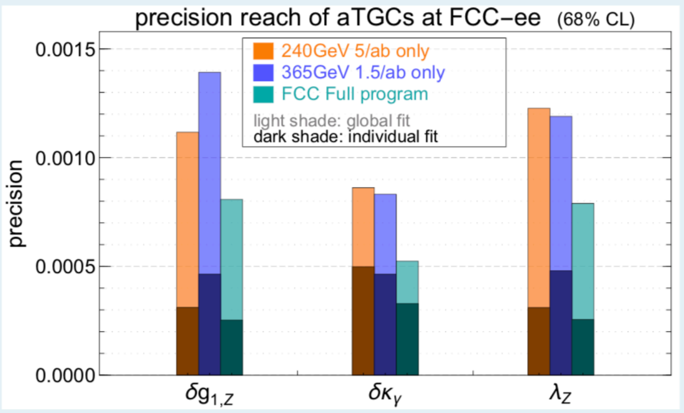
- CC kinematics constraint by IS + FS measurements
  -> no missing E_T needed
  -> IS photon tagging would be crucial
- PDF (QCD) uncertainties are small

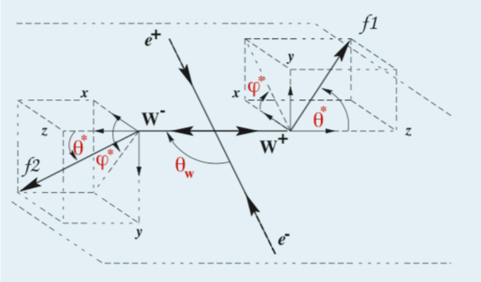


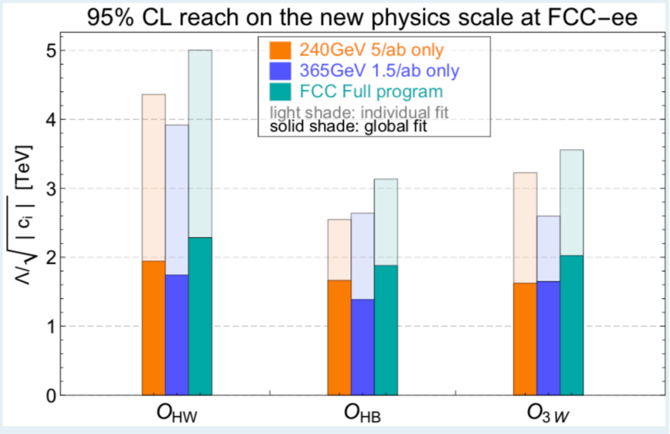
poster by Jiayin Gu

FCC-ee : probing the TGCs at high precision

- Based on expected luminosity at 161, 240, 350 and 365 GeV
- Consider CP-even dimension 6 operators, SU(2)XU(1) symmetry leaves three independent anomalous couplings
- Include both total cross section and angles
- For the moment only statistical uncertainties
- **One order of magnitude improvement with respect to LEP**







poster by Dubovyk, Freitas, Gluza, Grzanka, Jadach, Riemann, Usovitsch

Precision calculations for the FCC-ee

- From Workshop on EW precision calculations held in January.
- Next decade: complete 3 loop calculation, will provide the needed precision
- Need to invest adequate resources

Matches the demand in precision by the experiment !

Bottom line: YES we will be able to use EWPO with the precision provided by the experiments !

Three-loop corrections needed: theory estimations [3]

	δ_1 :	δ_2 :	δ_3 :	δ_4 :	δ_5 :	$\delta\Gamma_Z$ [MeV]
	$\mathcal{O}(\alpha^3)$	$\mathcal{O}(\alpha^2\alpha_s)$	$\mathcal{O}(\alpha\alpha_s^2)$	$\mathcal{O}(\alpha\alpha_s^3)$	$\mathcal{O}(\alpha_{bos}^2)$	$\sqrt{\sum_{i=1}^{5}\delta_i^2}$
TH1	0.26	0.3	0.23	0.035	0.1	0.5
TH2	0.13	0.15	0.11	0.017	$\mathbf{10^{-4}}$	$\sqrt{\sum_{i=1}^{5}(\delta_i/2)^2} \sim \mathbf{0.2}$
TH3	0.026	0.03	0.023	0.0035	$\mathbf{10^{-4}}$	$\sqrt{\sum_{i=1}^{5}(\delta_i/10)^2} \sim \mathbf{0.05}$

Table 2: At FCC-ee: $\mathbf{\Delta\Gamma_Z \sim 0.1}$ **MeV**.

TH1 = 0.5 MeV (2016): Estimate of residual uncertainty of theoretical errors for Γ_Z [4]. Does not match the FCC-ee demand.

TH2 = 0.2 MeV: Value derives from TH1 by assuming the uncertainty ("no-go") to be solved ("how-to") by calculating the unknowns at an accuracy of 50% (1 digit). Would be not sufficent.

TH3 = 0.05 MeV: Like TH2, but assuming an accuracy of 10% (corresponding to a knowledge of 2 relevant digits) for the so far unknown weak 3-loops and QCD 4-loops. Matches the demand.

Term δ_5 was unknown in TH1 and was determined in [3] with 4 relevant digits. The δ_5 is 5 times bigger than its assumed uncertainty in TH1!

Conclusions

- The efforts of the past 2-3 years have shown that FCC for EW is not just a repetition of LEP with huge statistics: **the considerable physics potential** has required, and will **require new strategies, new solutions and a lot of interesting work for experiment and theory**.
- The prize is a **gain of 1 – 2 orders of magnitude in precision for EWPO**
- Writing of the CDR, describing what has been understood todate, is in progress