European Strategy for Particle Physics

PARALLEL 1 / **ELECTROWEAK PHYSICS**

Electroweak inputs

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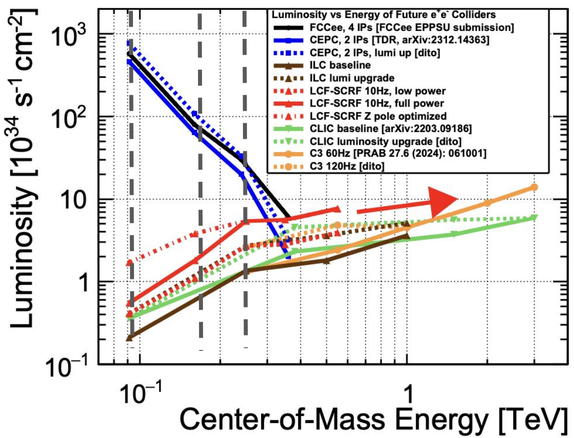
23-27 JUNE 2025 Lido di Venezia

[2503.19983]

Linear vs. Circular

- Z-pole (√s ~ 90 GeV)
- WW threshold (√s ~ 160 GeV)
- ZH threshold (√s ~ 250 GeV)



Circular

FCC-ee

- Huge luminosity
- 4IP
- absolute beam energy calibration up to 160 GeV

- 6×10^{12} Z (5 years)
- 2.4×10^{8} WW (2 years)

LEP3

- Luminosity = FCC-ee/3.5
- 2IP
- absolute beam energy calibration up to 90 GeV

- 2×10^{12} Z (6 years)
- 10^{8} WW (4 years)

Linear

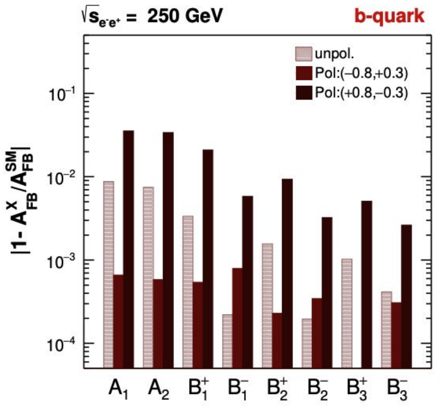
Linear Collider Facility (LCF)

- Luminosity / 1000
- 1,2 IP
- longitudinally polarised beams

- 5×10^{9} Z (2 years)
- 5×10^{7} WW (8 years)

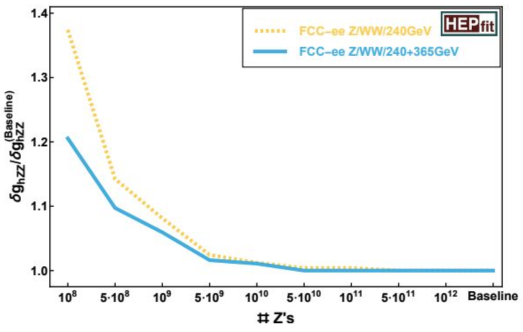
Why EWK precision at intensity frontier?

[2306.11413]



- Potential to test the consistency of the SM via loop corrections
  - $\sin^2\vartheta_W^{eff}$, m_W and other EWPOs parametrically depend on:
    - $\alpha_{QED}(m_Z)$, m_{top}, m_Z, $\alpha_S(m_Z)$, …
      - great precision is needed on these parameters to interpret potential deviations in terms of new physics
      - impacts Higgs precision physics
      - best to have many EWPOs to explore nature of BSM ‘signals’
- Programmes
  - Z lineshape:
    - m_Z, Γ_Z, $A_f(\sin\vartheta_W^{eff})$, $R_\ell = \Gamma_{had}/\Gamma_\ell$, $R_q = \Gamma_{qq}/\Gamma_{had}$, σ^0_{had}
    - $\alpha_{QED}(m_Z)$, $\alpha_S(m_Z)$
      - LCF: from lattice
      - FCC-ee, LEP3: direct measurement + Lattice
  - WW threshold (and above)
    - m_W, Γ_W, BR($W \to \ell\nu$), $\alpha_S(m_Z)$, triple/quartic gauge couplings

[2505.00272]



Caveats

- EWK factories will deliver 10^9 - 10^{12} Z
  - vs. LEP/SLD 10-100 reduction in statistical uncertainties
  - statistical accuracies on some of the measurements down to 10^{-6}
    - systematic projections should be intended as targets for detectors/th. calculations
      - improvement of 10-1000X vs LEP
      - some will be challenging to reach, HARD work is needed
    - several systematics are de-facto of statistical nature
    - some of the projections are contentious and being challenged

- Theory uncertainties and tools are NOT discussed here (see this afternoon for more in-depth discussion) lots of work to do!
  - missing higher orders, multi-photon emission
  - MC modelling
    - NP QCD (hadronization) / parton showers
      - will be determined + heavily constrained by data

Z lineshape

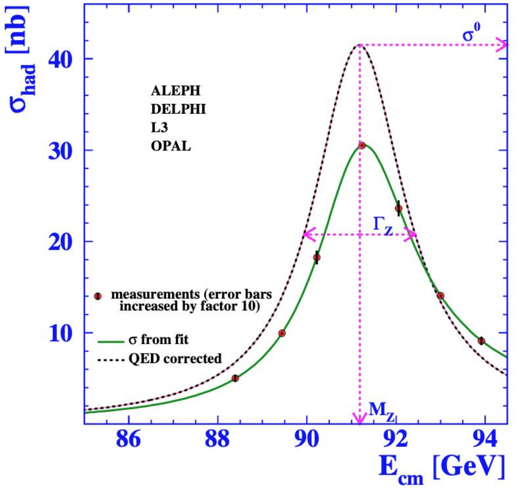
(the most challenging)

Z mass / Width

- **Z Mass** is a parametric input to xsec, width, BR, …
  - Current uncertainty **Δm_Z ~ 2 MeV (LEP)**
  - Statistical uncertainty scales as $\sim \Gamma_Z / 2\sqrt{N_Z^{\text{off-peak}}}$
    - 4 (7) keV at FCC-ee (LEP3)
    - 20 keV at LCF
  - Dominant systematic:
    - FCC-ee (LEP3): absolute beam energy calibration:
      - resonant depolarisation $\Delta\sqrt{s}$ ~ **Δm_Z ~ 100 keV**
        - achieved at LEP, ongoing effort to improve
    - LCF: absolute momentum scale
      - Δp ~ **Δm_Z ~ 200 keV** using J/ψ mass ($K_S \to \pi\pi$)
        - absolute limit 2 ppm (is 10 ppm more feasible?)

- **Z total width** is sensitive to fermion couplings and to BSM
  - Current **$\Delta\Gamma_Z$ ~ 2 MeV**
  - Dominant systematic:
    - relative absolute beam energy calibration
      - point-to-point $\Delta\sqrt{s}_{\text{p.t.p}}$ (uncorrelated component)
        - can be measured in-situ with μμ events
          - **$\Delta\Gamma_Z$ ~ 12 (25) (125) keV** at FCC-ee (LEP3) (LCF)

[0509008]



$$\Gamma_Z = \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau} + \Gamma_{had} + \Gamma_{inv}.$$

$$\sigma^0_{had} \equiv \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma_Z^2}$$

$$R^0_\ell \equiv \Gamma_{had}/\Gamma_{\ell\ell}$$

lepton universality:

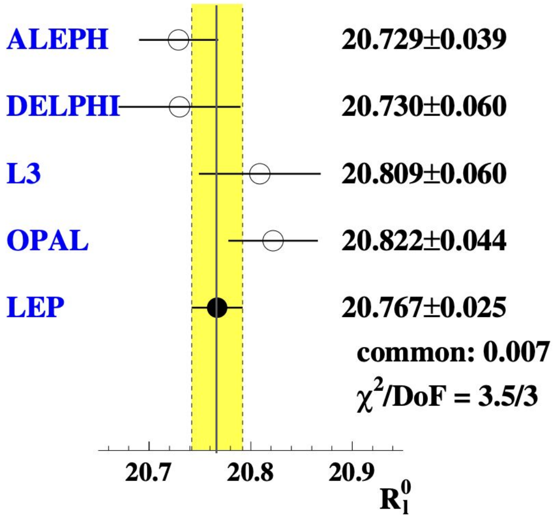
$$R^0_{inv} = \left(\frac{12\pi R^0_\ell}{\sigma^0_{had} m_Z^2}\right)^{\frac{1}{2}} - R^0_\ell - (3+\delta_\tau)$$

$$R^0_{inv} = N_\nu \left(\frac{\Gamma_{\nu\bar{\nu}}}{\Gamma_{\ell\ell}}\right)_{SM}$$

Leptonic Branching Ratios

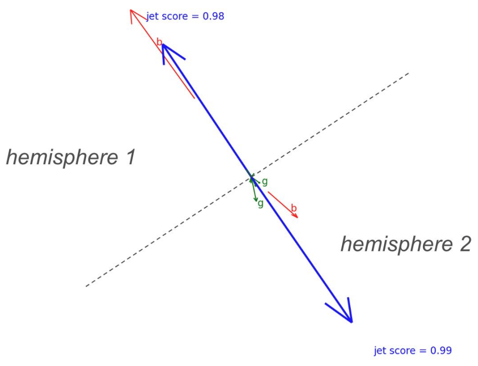
- Defined as $\mathbf{R_\ell = \Gamma_{had}/\Gamma_\ell}$ with $\ell = e, \mu, \tau$ measure individual axial-vector couplings to the Z
  - provides α_S measurement through radiation QCD corrections
- Current (relative) uncertainties ~ $\mathbf{10^{-3}}$
- Ratio, not affected to uncertainties luminosity, production cross-section etc ..
  - Dominant systematics:
    - acceptance determination at low angle for e, μ, (τ) (negligible for hadronic modes)
      - can be translated into detector requirement:
        - absolute polar angles (and radial, longitudinal)
          - 5-10 μm at 10°(20°) to match stat. accuracy at **FCC-ee (3×10^{-6})**
          - 10-20 μm at 10°(20°) to match stat. accuracy at LEP3 **(6×10^{-6})**
          - easily achievable at LCF (**10^{-4}**)
    - Low angle Bhabha subtraction increases uncertainty for e+e- channel

[0509008]



Hadronic Branching Ratios

- Defined as $\mathbf{R_q = \Gamma_q / \Gamma_{had}}$ with q = b, c, s measure individual chiral couplings to the Z → $(\sim g_L^{\ 2} + g_R^{\ 2})$
- Current (relative) uncertainties ~ $\mathbf{10^{-3}}$
- Dramatic improvements compared to LEP are expected, driven by:
  - Reduced beam-spot sizes, light beam-pipe
  - Light and precise vertex detectors (few μm single point resolution)
  - Particle ID allowing strange tagging (K+ identification up to 30-40 GeV)
    - and NEW measurement of R_s
  - Advanced AI flavor tagging algorithms
    - pure b, c and strange jets → background contamination negligible
- Dominant systematics:
  - Hemisphere correlations
    - mainly driven by QCD (gluon emissions, g→bb/cc, etc ..)
      - can be positive (negative) for hard (soft) emissions
    - can be reduced with (acoplanarity) cuts
    - measured directly in data
      - 10^9 (10^6) gluon splitting samples in FCC-ee (LCF)
- Projections:
  - **2(b) - 10(s) (4-10) x 10^{-6}** for **FCC-ee (LEP3)** and **50-200x 10^{-6}** for **LCF**



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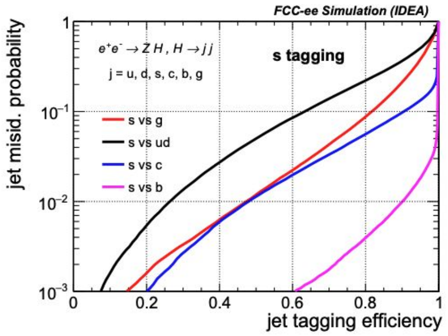


Asymmetries (LCF)

- $\mathbf{A_f}$ measures the asymmetry between Left (L) and Right (R) handed **Zff** couplings ($\sin^2\theta_W$):

$$\mathcal{A}_\mathrm{f} = \frac{g_\mathrm{Lf}^2 - g_\mathrm{Rf}^2}{g_\mathrm{Lf}^2 + g_\mathrm{Rf}^2}$$

- Linear colliders can measure $\mathbf{A_e}$ directly via LR asymmetry, using longitudinal beam polarisation combinations
  - very clean experimentally (measure total hadronic cross-section)
    - independent of Z decay mode
  - requires excellent control of initial state polarisation
    - determined by Blondel scheme
  - provided best measurement of $\mathbf{\sin^2\theta_W}$ at SLC

$$P_{e^-} \approx \pm 0.80,\ P_{e^+} \approx \pm 0.30$$

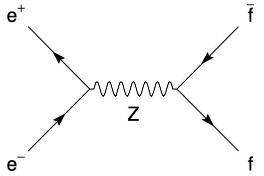
$$P_\mathrm{eff} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}} \approx 0.89$$

$$A_\mathrm{LR} = \frac{1}{P_\mathrm{eff}} \frac{N_L - N_R}{N_L + N_R} \approx A_e$$

  - provides a measurement of $\Delta A_e/A_e \sim 2 \times 10^{-4}$
    - $\Delta\sin^2\theta_W \sim 4 \times 10^{-6}$ (**100x** vs. today world average)

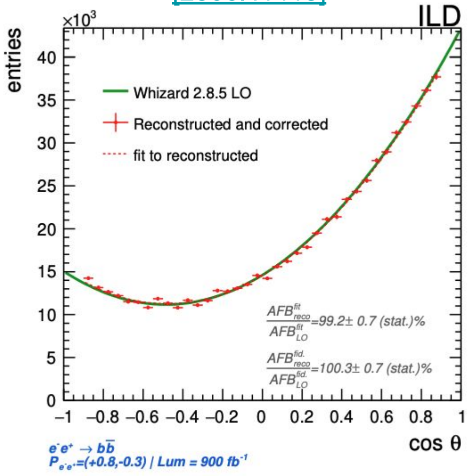
Other fermionic symmetries (LCF)

- A_f can then be measured as the Left Right - Forward Backward asymmetry:



$$A^f_{\mathrm{LR,FB}} = \frac{1}{P_{\mathrm{eff}}} \frac{(N^F - N^B)_L - (N^F - N^B)_R}{(N^F + N^B)_L + (N^F + N^B)_R} \propto A_f$$

[2306.11413]

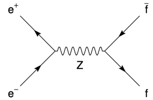


  - with a statistical uncertainty inflated by $1/\sqrt{B(Z\to f\bar{f})}$
  - systematics:
    - Modelling uncertainties (symmetric) cancel
    - initial state polarisation (from A_{LR})
    - Measured at few 10^{-4} (depending on the fermion species)
      - 20-100X better than LEP

Asymmetries (FCC-ee/LEP3)

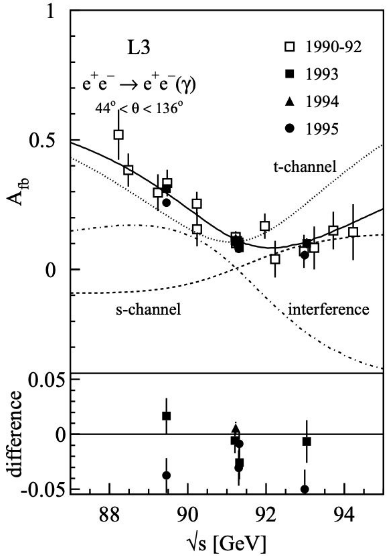
- At circular machines **A_f** can be measured through forward backward asymmetries in **ee → ff** :

$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}\sigma_{\text{tot}}\left[1+\cos^2\theta + \frac{8}{3}A_{\text{FB}}\cos\theta\right] \qquad A_{\text{FB}} = \frac{3}{4}A_e\,A_f$$



- To infer **A_f** , one has to measure **A_e** by other means:
  - In ee → ee, measure forward-backward asymmetry: $A^e_{\text{FB}} = \frac{3}{4}A^2_e$
    - Challenges:
      - Requires t-channel Bhabha + interference subtraction
        - can be controlled off-peak
      - Dominant systematics:
        - **A_{FB}** is measured off- and on-peak, and **$A_{FB}^{0,\ell}$** is extracted as the value at m_Z corrected of ISR, interference effects
        - $\Delta\sqrt{s}_{\text{p.t.p}}$ ~ 20 keV (uncorrelated component)
    - ΔA_e ~ 1.3 (2.6) x 10^{-5} at FCC-ee (LEP3)

[0509008]



Asymmetries: A_e from τ-polarisation

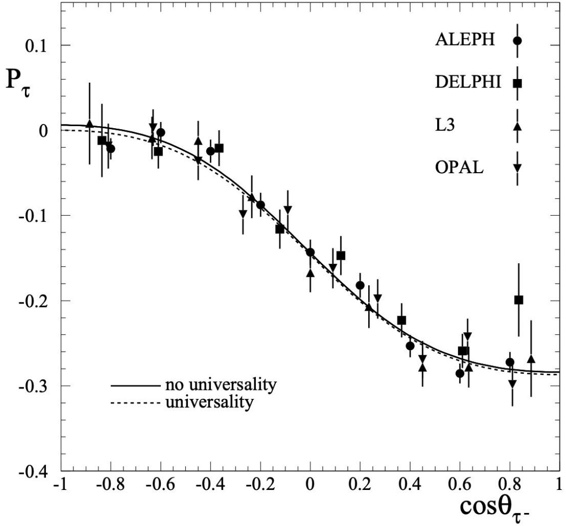
- Without longitudinally polarised beams, one can access final helicity in ee → ff using τ-leptons
  - exploit that ν_τ flies in the same (opposite) direction as τ for L(R) in the τ center-of-mass
- Can construct polarisation of final state as:

$A_{FB}^{pol(\tau)}$

$$\mathcal{P}_f = \frac{d(\sigma_r - \sigma_l)}{d\cos\theta} \bigg/ \frac{d(\sigma_r + \sigma_l)}{d\cos\theta} = -\frac{\mathcal{A}_f(1+\cos^2\theta) + 2\mathcal{A}_e\cos\theta}{(1+\cos^2\theta) + 2\mathcal{A}_f\mathcal{A}_e\cos\theta}$$

- A_e can then be accessed as the forward backward tau polarisation asymmetry:
  - Very clean measurement since minimally affected by potential data/MC mis-modelling, as long as they are FB symmetric
    - Example: hadronization tau decays
  - Non-tau backgrounds (bhabha, Z→$\mu\mu$), enough to assume 10x vs LEP
    - Big improvement to come with IP tau lifetime
    - $\Delta A_e/A_e \sim 2(4) \times 10^{-5}$ at FCC-ee (LEP3)

[0509008]



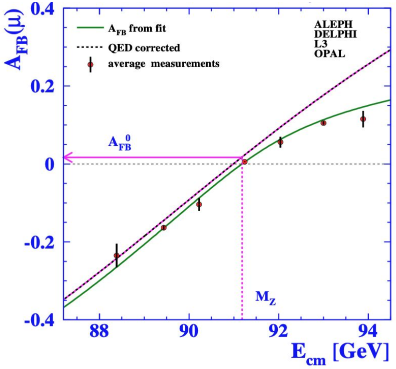
Other fermion asymmetries (FCC-ee/LEP3)

$$A_{FB}^{0,f} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

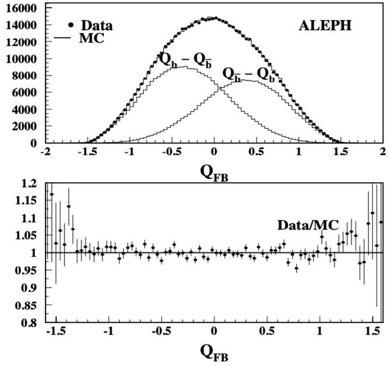
- Once $\mathbf{A_e}$ is known**,** $\mathbf{A_f}$ can then be measured from Forward-Backward asymmetries
  - dominant systematics:
    - $A_{FB}^{\mu,\tau}$: point-to-point energy calibration
      - $\Delta A_{FB}^{\mu} \approx 2.3$ [2.4] x 10^{-6} → $\Delta A_{\mu}/A_{\mu}$ ~ 3(6) x 10^{-5}
      - $\Delta A_{FB}^{\tau} \approx 2.7$ [2.4] x 10^{-6} → $\Delta A_{\tau}/A_{\tau}$ ~ 4(7) x 10^{-5}

- $\mathbf{A_q}$ for heavy flavors (q=b,c,s) requires the determination of the jet (hemisphere) charge
  - Measure simultaneously:
    - average FB hemisphere charge difference AND sum
    - Measure charge separation
    - → ΔA_{FB}^{q} ~ 5 x 10^{-6} → ΔA_q ~ 2 x 10^{-4}
  - dominant systematics:
    - Asymmetry in detector material (nuclear interactions produce excess of positive charge)
      - can be monitored with conversions
    - Background contamination
      - tagger purities much larger than LEP

[0509008]

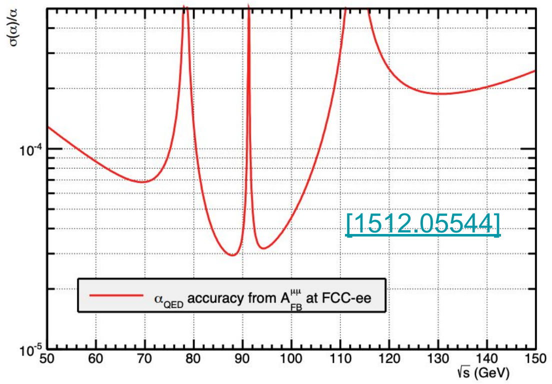


[0107033]



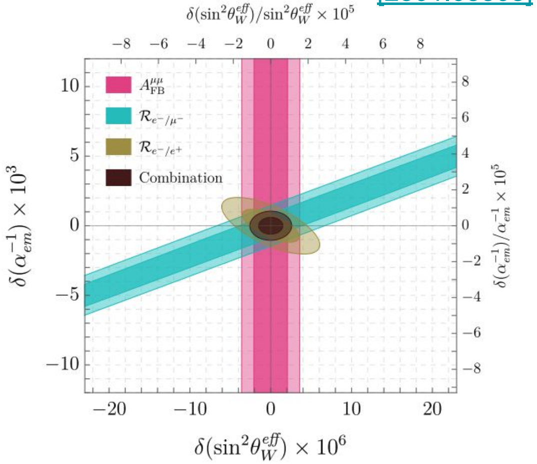
$\alpha_{QED}(m_Z)$, σ_{had}^{0}

$$\cos^2\theta_{\rm eff}^{\rm f}\sin^2\theta_{\rm eff}^{\rm f} = \frac{\pi\alpha(0)}{\sqrt{2}m_Z^2 G_F}\frac{1}{1-\Delta r^{\rm f}}$$



- Electro-magnetic constant
  - Dominant parametric uncertainty in EW precision ($\sin\vartheta_W^{eff}$ and m_W) fit:
    - Current uncertainty $\delta\alpha/\alpha$ = 1.4 x 10^{-4}
  - LCF has to assume required precision from Lattice
  - FCC-ee (LEP3) can directly measure it :
    - from off-peak FB asymmetry (interference with γ^*) in $\mu\mu$ events ($\delta\alpha/\alpha$ = 3x10^{-5})
      - small experimental uncertainty, stat dominated
      - Z-pole energy points chosen to optimize measurement !
    - from $R_{e+/e-}$, $R_{e-/\mu-}$ ($\delta\alpha/\alpha$ = 0.6x10^{-5})
      - e^+/e^- efficiency control (charge mis-id), material budget
      - e^-/μ^- acceptance difference (to be determined from 10^{11} lepton pairs)
    - Can then provide comparison with Lattice calculation
- Peak cross-section
  - Sensitive to Zee coupling and total width, provides N_ν
  - limited by luminosity determination , $\delta\mathscr{L}/\mathscr{L}$
    - Bhabha ~ 10^{-4} (FCC-ee, LEP3, LCF)
    - $e^+e^- \to \gamma\gamma$ ~ 2(4) 10^{-5} (FCC-ee, LEP3)

[2501.05508]



WW threshold and above

W mass / width (threshold scan) - Circular

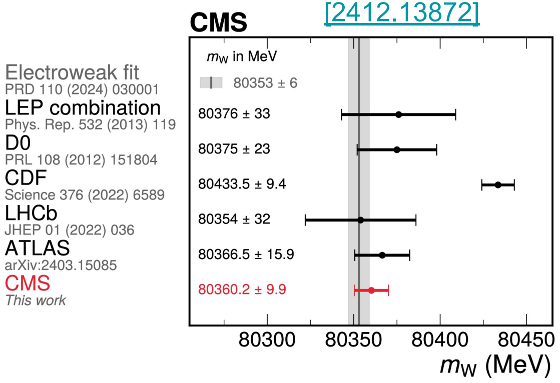
- **W mass** is a a crucial input to test SM consistency
  - Current uncertainty $\boldsymbol{\Delta m_W}$ **~ 10 MeV (LHC)**
- At lepton colliders, the simplest way is to measure it, is via a threshold scan, i.e cross-section vs. beam energy:
- With 2 or more energy points, m_W and Γ_W can be extracted simultaneously

$$\Delta m_{\mathrm{W}}(\mathrm{stat}) = \left(\frac{d\sigma_{\mathrm{WW}}}{dm_{\mathrm{W}}}\right)^{-1} \frac{\sqrt{\sigma_{\mathrm{WW}}}}{\sqrt{\mathcal{L}}}$$

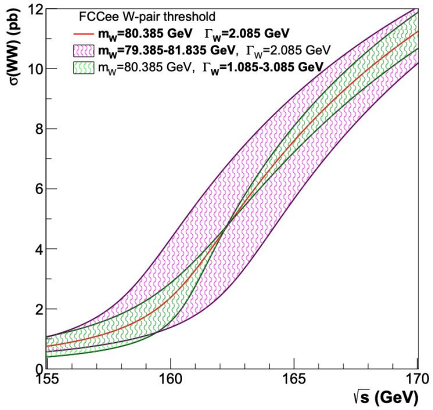
  - $\boldsymbol{\Delta m_W^{scan}}$(stat) **~ 400 keV** (FCC-ee)
  - $\boldsymbol{\Delta \Gamma_W^{scan}}$(stat) **~ 1MeV** (FCC-ee)

- Dominant systematics, beam energy calibration
  - Absolute energy calibration
    - Δm_W (syst) ~ 150 keV (FCC-ee) (300 keV on √s)
      - via resonant depolarisation (**only at FCC-ee**)
    - Δm_W (syst) ~ 700 keV (LEP3)
      - via radiative return Z **(at LEP3)**
- Through polarized scan, Δm_W (LCF) ~ 2 MeV (not in official run plan)

[2412.13872]



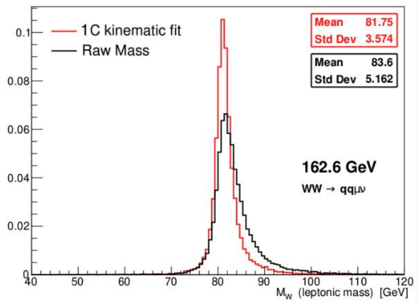
[2107.04444]



W mass, kinematic fit

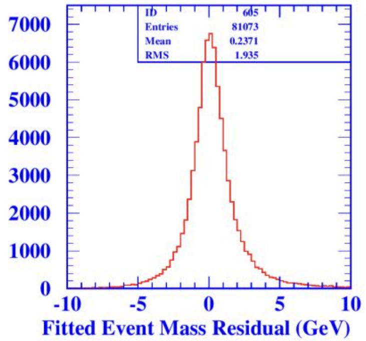
- **W mass** can also be accessed through direct reconstruction of decay products: a kinematic fit (done at LEP2)
  - can be performed at threshold (~ 160 GeV) → FCC-ee, LEP3
  - in the "boosted" regime (~ 240 GeV) → LCF, FCC-ee, LEP3
- Major sensitivity from the **qqℓν** channel (1C) (4 - 3)
  - Avoid issues with color reconnection
  - Use full 4-momentum constraints
    - Allows to fully resolve the neutrino kinematics → 4-3=1 constraint
  - Additional constraint that W masses are equal (2C)
  - Dominant systematics
    - absolute √s and BES calibration
      - FCC-ee : resonant depol. + di-muon
      - LEP3, ILC: radiative Z returns
    - hadronization
      - more important where WW system is boosted (since non isotropic)

M.Beguin



Δm_W^{kin}(stat) ~ **210** (400) **keV** - FCC-ee(LEP3)
Δm_W^{kin}(√s) ~ **160** (700) **keV** - FCC-ee (LEP3)

G. Wilson



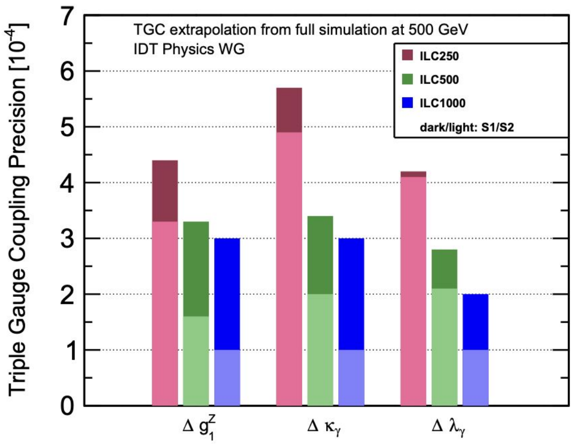
Δm_W^{kin}(stat) ~ **600 keV** (LCF)
Δm_W^{kin}(had.) ~ **1 MeV**

W properties

- Large **W** production rate can be exploited to constrain leptonic BRs
  - absolute measurement will be limited by luminosity determination
    - from $\gamma\gamma$ / BhaBha , $\delta\mathscr{L}/\mathscr{L} \sim 10^{-4}$
  - FCC-ee / LEP3 / LCF ~ 10^{-4} / 2 10^{-4} / 2 10^{-4}

$\mathcal{B}(W \to e\nu_e) \times 10^4$	1071	$\pm$	16	**0.13**	0.10	From WW and ZH threshold luminosity
$\mathcal{B}(W \to \mu\nu_\mu) \times 10^4$	1063	$\pm$	15	**0.13**	0.10	From WW and ZH threshold luminosity
$\mathcal{B}(W \to \tau\nu_\tau) \times 10^4$	1138	$\pm$	21	**0.13**	0.15	From WW scan ZH threshold luminosity

- Triple/Quartic Gauge couplings
  - through WW/VBS production
  - optimal observable analysis exploiting full 5D angular information of WW decays in semilep decay
  - LCF has powerful constraints thanks to:
    - Initial state polarisation
    - Higher energy
      - energy growth of relevant operators
      - higher luminosity
  - few 10^{-4} in reach at LCF



Conclusions

- For Z-pole precision measurements:
  - Linear Collider has the advantage of longitudinal polarisation
  - Circular colliders have the advantage of luminosity (300-1000)
- Per unit of luminosity, Chiral observables (asymmetries) are measured better at linear colliders ,
  - by ~ $1/A_e^2$ ~ 40
- However FCC-ee (LEP3) have 1000(300) more luminosity at the Z pole, so overall measurements are more precise by factors of:
  - $\sin^2\theta_W$ → **5** : **2** : **1** for FCC-ee : LEP3 : LCF
  - lepton universality/couplings → **30** : **15** : **1**
    - electromagnetic and strong coupling only at FCC-ee (LEP3)
  - m_Z → **2** : **2** : **1**
  - Γ_Z → **10** : **5** : **1**
- For the W mass, difference is milder, but resonant depol. makes a difference for FCC-ee vs LEP3/LCF
  - m_W → **4**: **1**: **1**
- Di-fermion production and multi-boson production can be uniquely probed by
  - linear colliders (ILC, CLIC, …) up to 500-3 TeV
  - muon collider up to 10 TeV
  - FCC-hh up to 40-50 TeV

Backup

Lepton universality tests and $\sin^2\theta_W$

Table 6: Projected ABSOLUTE uncertainties on value of $\sin^2\theta_W^{\text{eff}}$ obtained at the Z-pole from FCC-ee, LCvision, and LEP3. When two numbers are given, the first [second] corresponds to the projected statistical [systematic]; total uncertainty.

FCC

quantity	uncertainty	$\sin^2\theta_W^{\text{eff}}$
$A_{FB}^{0,\ell}$ (10^{-6})	1.4 [2.7]	0.75 [1.44] ; 1.6
$\mathcal{A}_e$ from $A_{FB}^{\text{pol}(\tau)}$	7 [20]	0.9 [2.5] ; 2.8
$A_{FB}^{0,b}$ (10^{-6})	4 [4]	0.74 [0.74] ; 1.03
$A_{FB}^{0,c}$ (10^{-6})	5 [5]	1.3 [1.3] ; 1.8
$A_{FB}^{0,c}$ (10^{-6})	7.4 [7.4]	1.4 [1.4] ; 1.9
FCC combination of $\sin^2\theta_W^{\text{eff}}$		0.4 [0.5] ; 0.7

LEP3

quantity	uncertainty	$\sin^2\theta_W^{\text{eff}}$
$A_{FB}^{0,\ell}$ (10^{-6})	2.6 [4.6]	1.4 [2.7] ; 3.0
$\mathcal{A}_e$ from $A_{FB}^{\text{pol}(\tau)}$	13 [39]	1.7 [4.7] ; 5.2
$A_{FB}^{0,b}$ (10^{-6})	7.8 [7.8]	1.4 [1.4] ; 2
$A_{FB}^{0,c}$ (10^{-6})	9.5 [9.5]	2.4 [2.4] ; 3.4
$A_{FB}^{0,c}$ (10^{-6})	14 [14]	2.6 [2.6] ; 3.6
LEP3 combination of $\sin^2\theta_W^{\text{eff}}$		0.75 [0.95] ; 1.35

LCvision

quantity	uncertainty	$\sin^2\theta_W^{\text{eff}}$
$\mathcal{A}_e$ from $A_{LR}(10^{-6})$	23 [19]	2.9 [2.4] ; 4
$\mathcal{A}_\mu$ from $A_{LRFB}^{(\mu)}$ (10^{-6})	100 [50]	12.6 [6.3] ; 14
$\mathcal{A}_\tau$ from $A_{LRFB}^{(\tau)}$ (10^{-6})	100 [50]	12.6 [6.3] ; 14
LCvision combination of $\sin^2\theta_W^{\text{eff}}$		2.75 [2.4] ; 3.7

Table 5: Projected RELATIVE uncertainties on partial-width ratios obtained on peak at the Z-pole from FCC-ee, LCvision, and LEP3. When two numbers are given, the first [second] corresponds to the projected statistical [systematic] uncertainty. .

Observable (value)	present uncertainty	FCC-ee **Stat.** [Syst.]	LCF **Stat.** [Syst.]	LEP3 **Stat.** [Syst.]	Comment and leading uncertainty
$R_\ell \equiv \frac{\Gamma_{\text{had}}}{\Gamma_\ell}$	20.767 ± 0.025				
relative uncertainty (10^{-6})	1200	1.5 [2.3]		2.8 [2.3]	Low angle acceptance
$R_e \equiv \frac{\Gamma_{\text{had}}}{\Gamma_e}$	20.804 ± 0.050				
relative uncertainty (10^{-6})	2400	3.4 [2.3]	200[500]	6.4 [2.3]	Low angle acceptance
$R_\mu \equiv \frac{\Gamma_{\text{had}}}{\Gamma_\mu}$	20.785 ± 0.033				
relative uncertainty (10^{-6})	1600	2.4 [2.3]	200 [200]	4.5 [2.3]	Low angle acceptance
$R_\tau \equiv \frac{\Gamma_{\text{had}}}{\Gamma_\tau}$	20.764 ± 0.045				
relative uncertainty (10^{-6})	2100	2.7 [2.3]	200 [200]	5.1 [2.3]	Low angle acceptance
LEPTON UNIVERSALITY Axial vector couplings					
R_e/R_ℓ	rel. (10^{-6})	3.1	600	5.8	
R_μ/R_ℓ	rel. (10^{-6})	2.8	300	5.3	
R_τ/R_ℓ	rel. (10^{-6})	3.6	300	6.8	
Vector couplings					
$A_{FB}^{0,e}$ / $A_{FB}^{0,\ell}$	rel. (10^{-6})	210	N.A.	390	
$A_{FB}^{0,\mu}$ / $A_{FB}^{0,\ell}$ or $\mathcal{A}_\mu/\mathcal{A}_e$	rel. (10^{-6})	157	700	295	
$A_{FB}^{0,\tau}$ / $A_{FB}^{0,\ell}$ or $\mathcal{A}_\tau/\mathcal{A}_e$	rel. (10^{-6})	183	700	345	
QUARK FLAVOURS					
$R_b \equiv \frac{\Gamma_b}{\Gamma_{\text{had}}}$	0.21629 ± 0.00066				
relative uncertainty (10^{-6})	3300	1.2 [1.6]	20 [60]	2.2 [3.0]	multiple flavour tags
$R_c \equiv \frac{\Gamma_c}{\Gamma_{\text{had}}}$ relative (10^{-6})	0.1721 ± 0.0030				
relative uncertainty (10^{-6})	17000	1.4 [2.2]	100[250]	2.6 [4.2]	multiple flavour tags
NEW! $R_s \equiv \frac{\Gamma_s}{\Gamma_{\text{had}}}$ relative (10^{-6})	**N.A.**				
relative uncertainty (10^{-6})	**N.A.**	2.5 [11]	–	4.7 [21]	multiple flavour tags