Lessons from LEP and final steps towards the Final Report of the Feasibility Study

FCC Week
13 June, 2024

Eric Torrence
Oregon

Outline

A talk in 2 parts…

- Lessons from LEP (and beyond)
  - This is entirely my opinion/fault
- Final steps towards the Final Report of the Feasibility Study
  - On behalf of Guy Wilkinson and Jacqueline Keintzel
  - They should correct me if I mis-represent anything

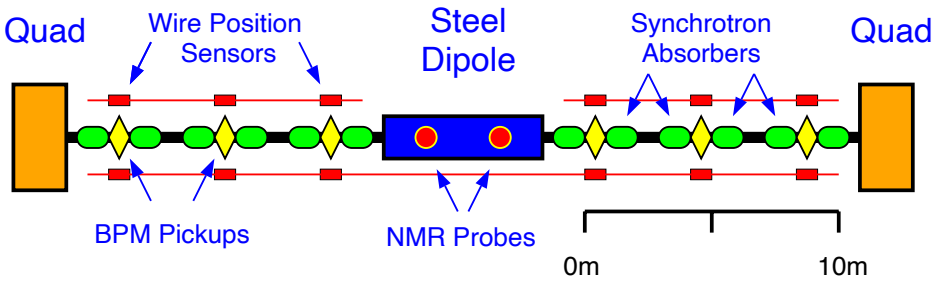
Who is this guy?

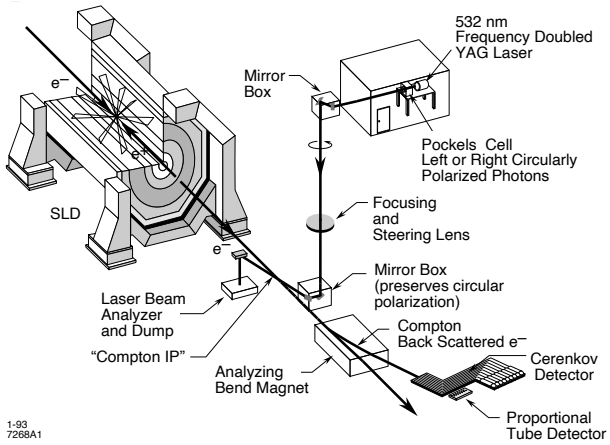
- Have done no work in the EPOL group
- First FCC meeting I have attended

Who is this guy?

- Have done no work in the EPOL group
- First FCC meeting I have attended

- 2008-now - ATLAS Luminosity
- 1997-2007ish - e^+e^- Beam Energy Calibration
  - Initially at LEP2, including LEP Spectrometer, W mass
  - Later LC (NLC/ILC) studies, along with other MDI issues
  - ILC extraction-line spectrometer design
- 1992-1997 - Beam Polarization
  - SLC/SLD Compton polarimeter, A_{LR}





Everything old is new again

Beam Parameter Measurements

2005 INTERNATIONAL LINEAR COLLIDER WORKSHOP

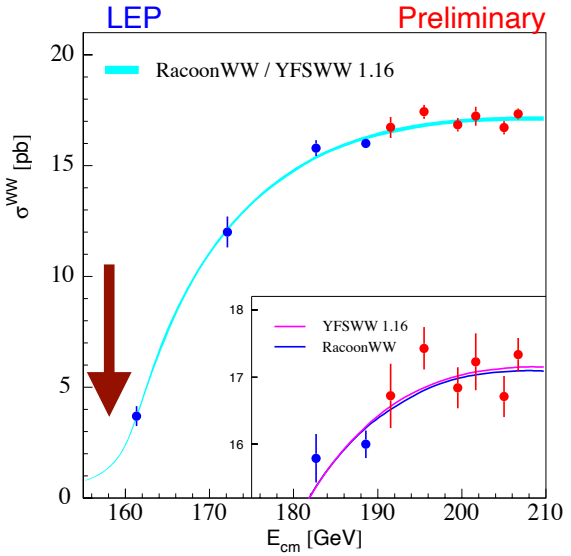
Stanford, California, USA 18-22 March, 2005

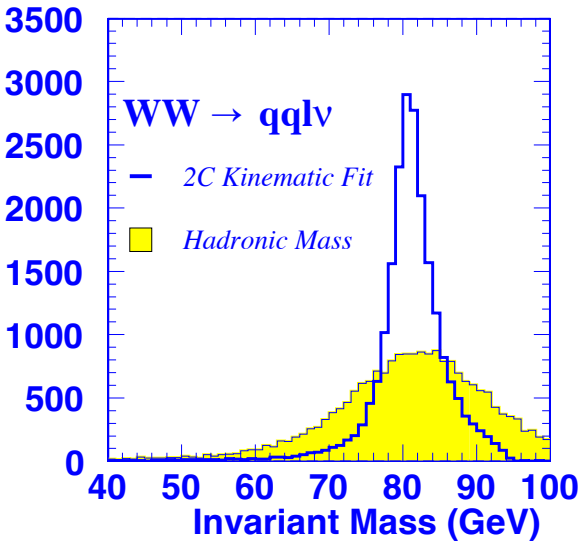
- The last time I really thought about these issues was in a linear-collider context, almost 20 years ago
- I am still getting up to speed on the FCC design and EPOL plans, but the work done is impressive
- There are still some common themes

Apologies if this talk is obvious to everyone…

Why Beam Energy?

- Cornerstone of precision EW measurements
  - Z, W, top, Higgs mass
  - Also necessary for Z-pole A_f extraction
- Lineshape/resonance scans
  - Z mass, WW threshold, tt threshold
  - Systematically very clean
  - Lots of pressure to move to more "interesting" energies (LEP2 never did a WW threshold scan)
- Direct reconstruction
  - Constrained kinematic fits
  - WW pairs at LEP2
  - ZH → llbb at FCC?





FCC Requirements/Goals

	√s (GeV)	Stat Error	Syst Error	d√s/√s Goal x10^{-6}
Z	91	4 keV	100 keV	1
W	160	500 keV	300 keV	2
top	350	17 MeV		100

From CDR EPOL note: https://arxiv.org/pdf/1909.12245

- Stunning precision targets
  - I was initially (circa 2012) very skeptical
  - 2019 CDR note convinced me this wasn't completely crazy (impressive piece of work)
- d√s / √s ~ 1 x 10^{-6} at Z pole (***or better***) absolute
  - x10 better needed (relative) point-to-point
- ~ 2 x 10^{-6} at WW threshold (RDP should be OK)
- ~ 1 x 10^{-4} at higher energies (no RDP) Higgs, top

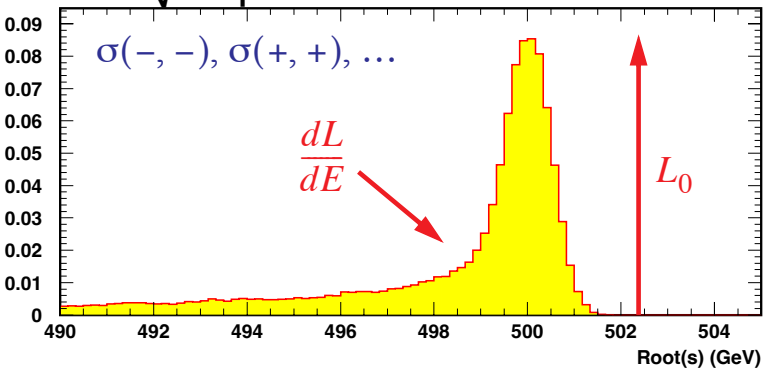
Critical Ingredients

- Absolute calibration with ultimate accuracy
  - Resonant depolarization provides this
  - Need to do this relatively frequently - systematics
  - RDP on pilot bunches is a great idea, but somewhat expensive in time (lumi)
    - Will always be under pressure to reduce time spent on this
    - Injecting polarized beams could be a big plus
  - Measures $\langle E_{beam} \rangle$ - must be transferred to $\sqrt{s}$ at each IP
- Fast relative measurements
  - Important for operational stability, tuning, monitoring
  - Key for finding/correcting systematic effects
- Offline, detector-based in-situ measurements and “cross-checks”
  - Ultimate test of IP corrections
  - Important to limit systematics
  - Required at high energy where RDP doesn’t work
  - Implies detector performance requirements

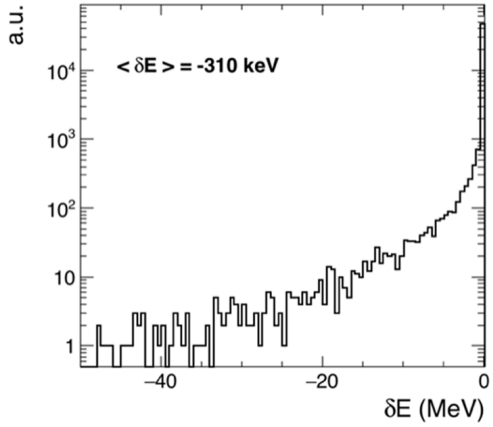
Big Caveat

- Discuss beam energy (RDP), really need dL / d √s
  - Mean <√s> and width (shape) including tails
  - Producing physics at each IP
  - Beware of unexpected correlations with luminosity!
- What happens at the IP is not the same as what you can measure with RDP (<E_{beam}>) - energy calibration transfer
  - Many sources understood, but can still be surprised
  - Generally must ***measure*** this difference, hard to model
  - Smaller effects at FCC than ILC, but 10^{-6} is also small…

ILC √s spectrum



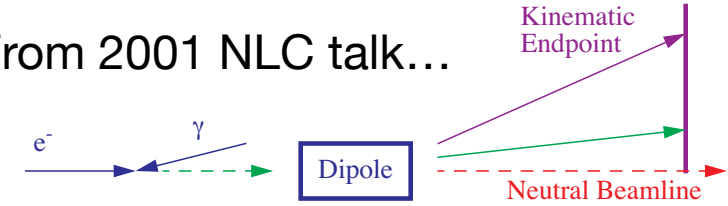
FCCee @ Z



Compton polarimeter/spectrometer

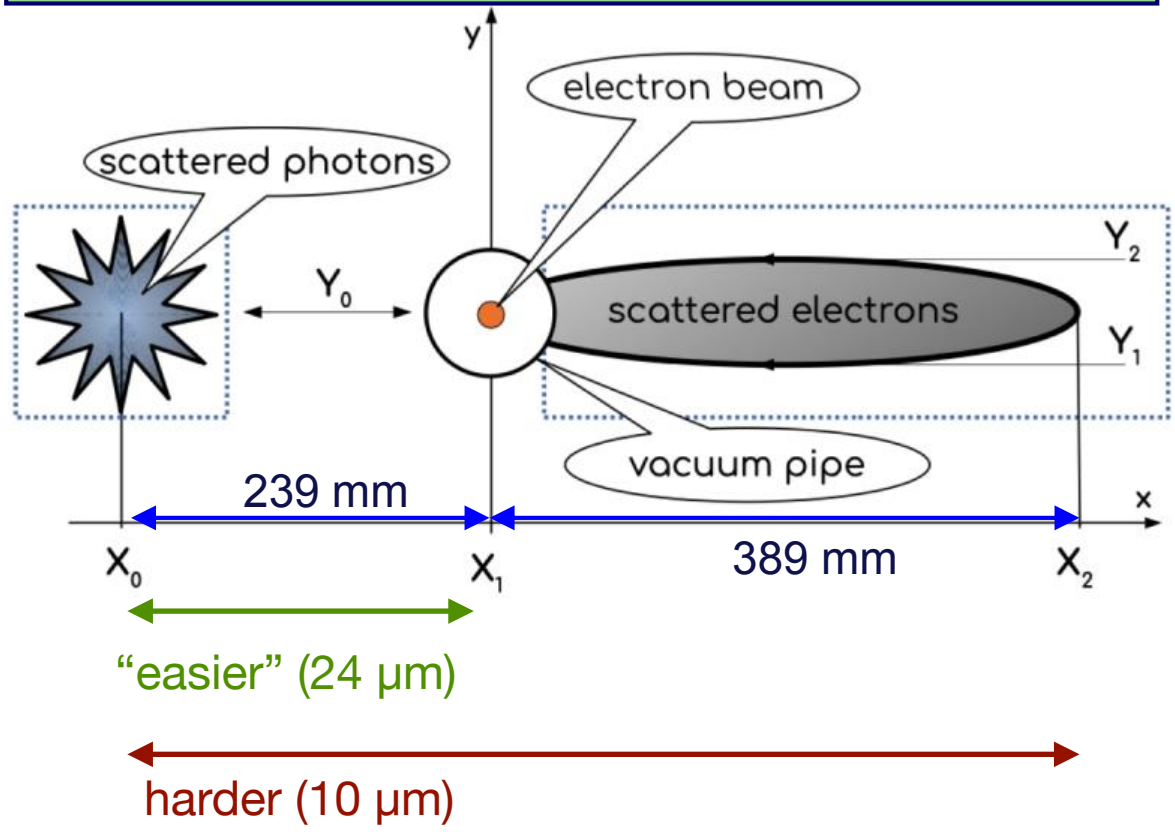
- Compton polarimeter can provide relative "spectrometer-style" E_{beam} measurement
  - Not as easy as you might think
  - Works much better at lower E_{beam}
- Max rate asymmetry at e kinematic endpoint
  - good for longitudinal polarimetry
- Energy of kinematic endpoint E' least sensitive to E_{beam}
  - Arguably works at 45 GeV (dE'/dE_{beam} ~ 13%)
  - Worse sensitivity at 80 GeV (~6%)
  - Endpoint energy E' invariant in large E_{beam} limit
- Better to measure angle from scattered photons to something closer to the outgoing electron beam
  - Fitting asymmetry spectrum may work - only longitudinal P
  - Planar detector geometry a plus for alignment/precision
- Measures E_{beam} at a fixed point in the ring!

From 2001 NLC talk…



Polarimeter layout

Profiles At 96 m from Laser IP



A 10 μm measurement of the endpoint gives a 5 MeV (10^{-4}) relative E_{beam} measurement at Z pole, worse at higher energies

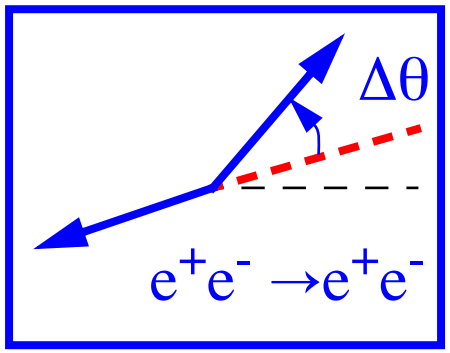
From RDP to IP

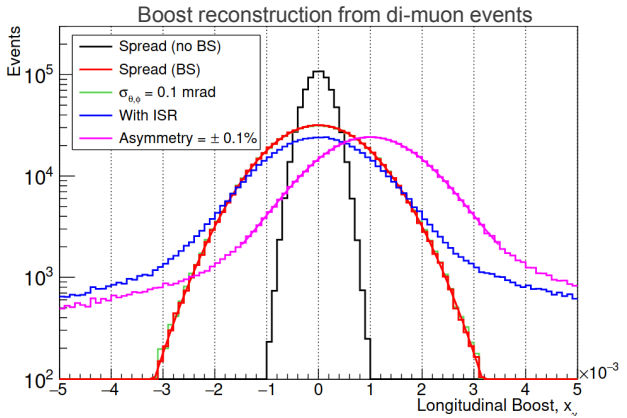
- Expect ~40 MeV energy loss per turn at Z pole
  - 370 MeV at WW, grows quickly from there, 10 GeV at ttbar
- Additionally may have evolution between RDP measurements
  - Try to minimize this as much as possible, continuous RDP
- Need to understand this 40 MeV to ~0.1% or better (not impossible, x10 harder at WW threshold?)
- Many known (and possibly unknown) effects
  - Synchrotron/impedance losses
  - Beam-beam effects
  - Dispersion at IP - collision alignment (100 keV/nm at D=1um)
  - What about continuous injection? - slightly different E_{beam}
  - Don’t forget LEP train saga - unknown unknowns!

I believe it is imperative to have an independent IP-based measurement!

Di-fermions

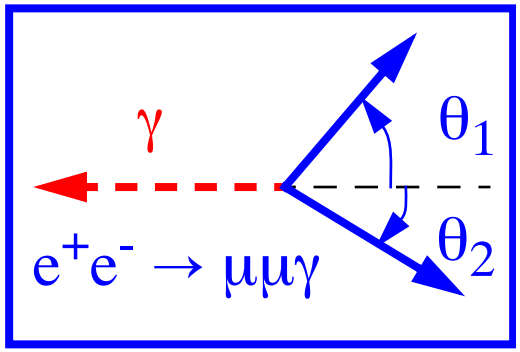
- Can use e^+e^- → ff acolinearity to measure ***boost*** at IP
  - High statistics at Z-pole
  - Useful to constrain $\Delta\sqrt{s}$ from RDP mean, validate E model
  - In particular sensitive to $\sqrt{s}$ ***width***
  - Primary tool for understanding beamstrahlung at ILC
- Requires good absolute angular difference measurements
  - Detector requirement
- Above Z-pole statistics drop
  - Can augment with Bhabha scattering, but not too-far forward
  - Silicon detector plane from 200-400 mRad ideal (~200 R)



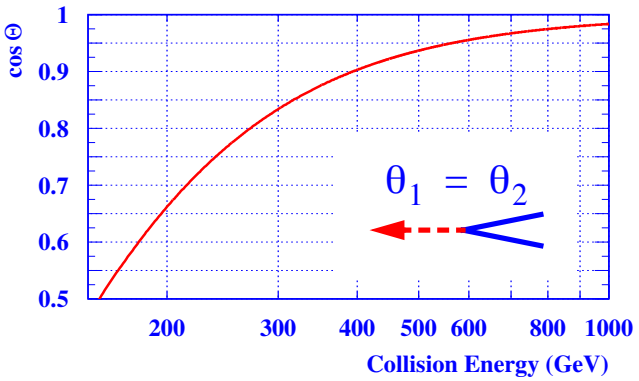


Radiative Returns

- Above Z-pole can transfer calibration from Z mass (s'/s)
  - Purely angular measurement
  - Demonstrated at LEP2 (stat limited)
  - I would ensure detector can make this measurement to 100 keV at WW threshold (cross-check of extrapolation)



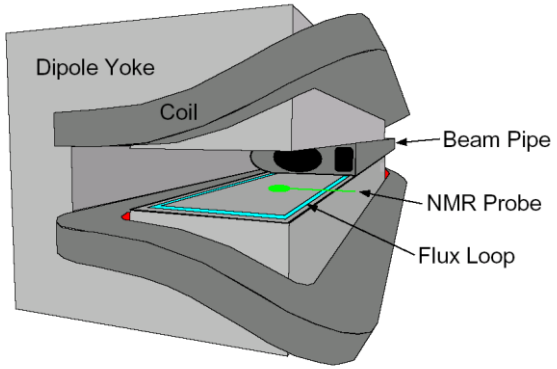
- May be best hope at higher energies (ttbar)
  - Opening angle becomes small
  - 500 mRad max at $\sqrt{s}$ = 350 GeV
  - Silicon detector from 200-400 mRad would maintain acceptance
  - Ideally measure $\delta\theta \sim 0.1$ degree (Γ_Z)
  - CDR discusses WW, ZZ, also useful, but in my opinion qqqq is a non-starter…



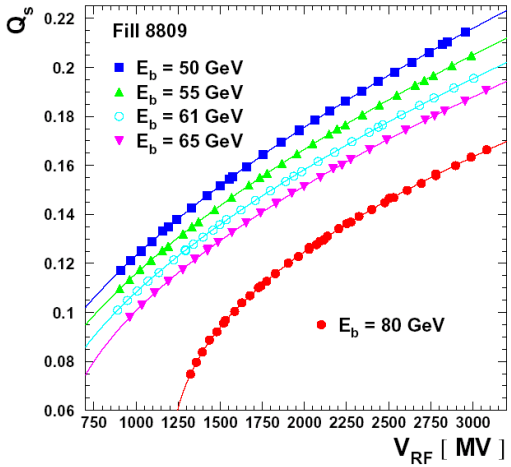
ttbar Threshold Extrapolation

- LEP2 used 3 separate methods to extrapolate RDP

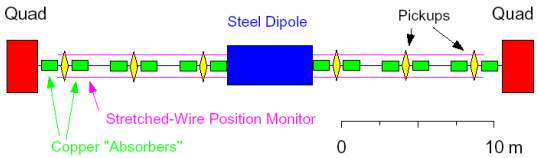
Flux loop



Synchrotron tune vs V_{RF}



In-line spectrometer

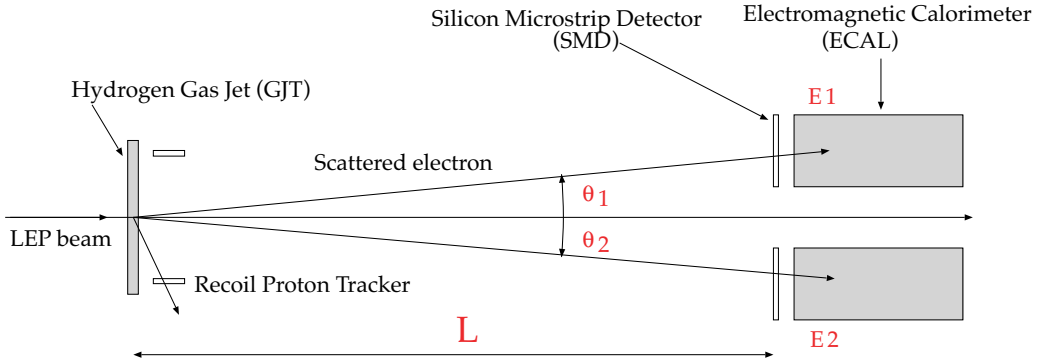


Agreement lead us to believe dE_b/E_b = 10 MeV uncertainty

- Keep thinking of ideas (here is one):

Møller scattering

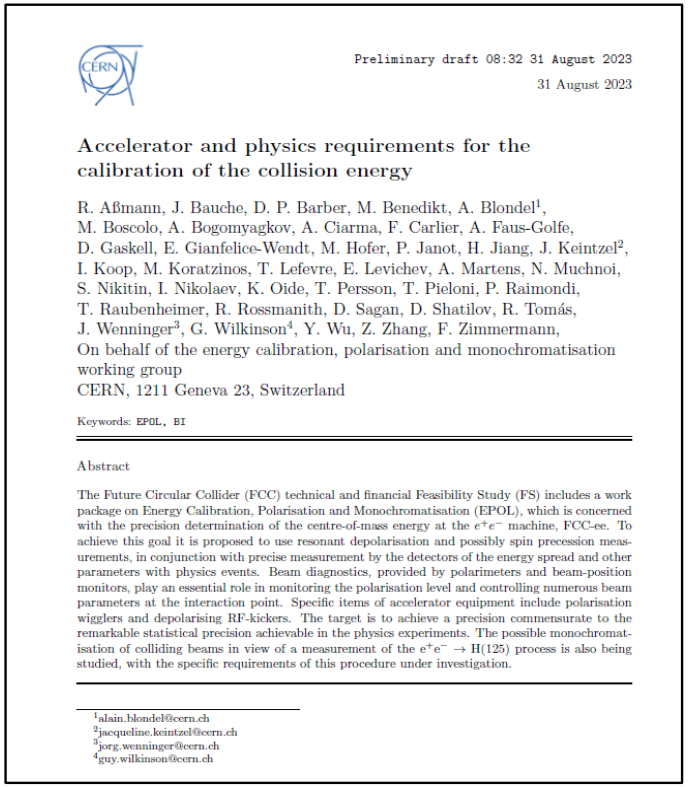
LEP2 yellow report
2 MeV (syst) in 30 minutes
Could this work?



Part 2: Final steps towards Final Report of Feasibility Study

Report Timeline

- Draft of final Feasibility Report ready by end of 2024 for review
  - 3 volumes, EPOL will enter in accelerator and detector/physics volumes
- EPOL requirements document needed on similar timescale (update of midterm review note)
- To be able to converge, can incorporate new work up until ~September 2024
  - Leaves time for small updates and clarifications to studies before end of year



Preliminary draft 08:32 31 August 2023
31 August 2023

Accelerator and physics requirements for the calibration of the collision energy

R. Aßmann, J. Bauche, D. P. Barber, M. Benedikt, A. Blondel[1], M. Boscolo, A. Bogomyagkov, A. Ciarma, F. Carlier, A. Faus-Golfe, D. Gaskell, E. Gianfelice-Wendt, M. Hofer, P. Janot, H. Jiang, J. Keintzel[2], I. Koop, M. Koratzinos, T. Lefevre, E. Levichev, A. Martens, N. Muchnoi, S. Nikitin, I. Nikolaev, K. Oide, T. Persson, T. Pieloni, P. Raimondi, T. Raubenheimer, R. Rossmanith, D. Sagan, D. Shatilov, R. Tomás, J. Wenninger[3], G. Wilkinson[4], Y. Wu, Z. Zhang, F. Zimmermann,
On behalf of the energy calibration, polarisation and monochromatisation working group
CERN, 1211 Geneva 23, Switzerland

Keywords: EPOL, BI

Abstract

The Future Circular Collider (FCC) technical and financial Feasibility Study (FS) includes a work package on Energy Calibration, Polarisation and Monochromatisation (EPOL), which is concerned with the precision determination of the centre-of-mass energy at the e^+e^- machine, FCC-ee. To achieve this goal it is proposed to use resonant depolarisation and possibly spin precession measurements, in conjunction with precise measurement by the detectors of the energy spread and other parameters with physics events. Beam diagnostics, provided by polarimeters and beam-position monitors, play an essential role in monitoring the polarisation level and controlling numerous beam parameters at the interaction point. Specific items of accelerator equipment include polarisation wigglers and depolarising RF-kickers. The target is to achieve a precision commensurate to the remarkable statistical precision achievable in the physics experiments. The possible monochromatisation of colliding beams in view of a measurement of the $e^+e^- \rightarrow H(125)$ process is also being studied, with the specific requirements of this procedure under investigation.

[1]alain.blondel@cern.ch
[2]jacqueline.keintzel@cern.ch
[3]jorg.wenninger@cern.ch
[4]guy.wilkinson@cern.ch

Midterm Review

Questions raised by the Scientific Advisory Committee:

- Provide more details about the polarimeter design and performance
  - This work is underway, effort growing, status shown today, appears to be in good shape - talk from R. Kieffer
  - Tunnel length to laser a bit of a civil engineering issue
- Establish feasibility and performance of monochromatization (for Higgs Yukawa measurement)
  - Studies have been done - talk from A. Faus-Golfe Tues.
  - Will be written up as a NIM article in early Summer
- Improve understanding of in-situ physics measurements in the detectors
  - Need to continue working on this

Final Thoughts from me

- Challenging precision targets on collision energy both at Z pole and above
  - Really the foundation of the FCCee physics program
- Impressive work done for CDR and Feasibility Study
  - I am much less skeptical than I was 10 years ago
- Need to continue to understand how in-situ measurements can help measure collision energy and constrain systematics, particularly above RDP energies
  - May include additional detector requirements, particularly forward tracking angular resolution
- Strongly believe ability to inject polarized beams should be studied as an option
  - Would provide more operational flexibility, potentially significant luminosity increase