Jet energy calibration and study of Left-Right Asymmetry using e⁺e⁻ → γZ process at the ILC

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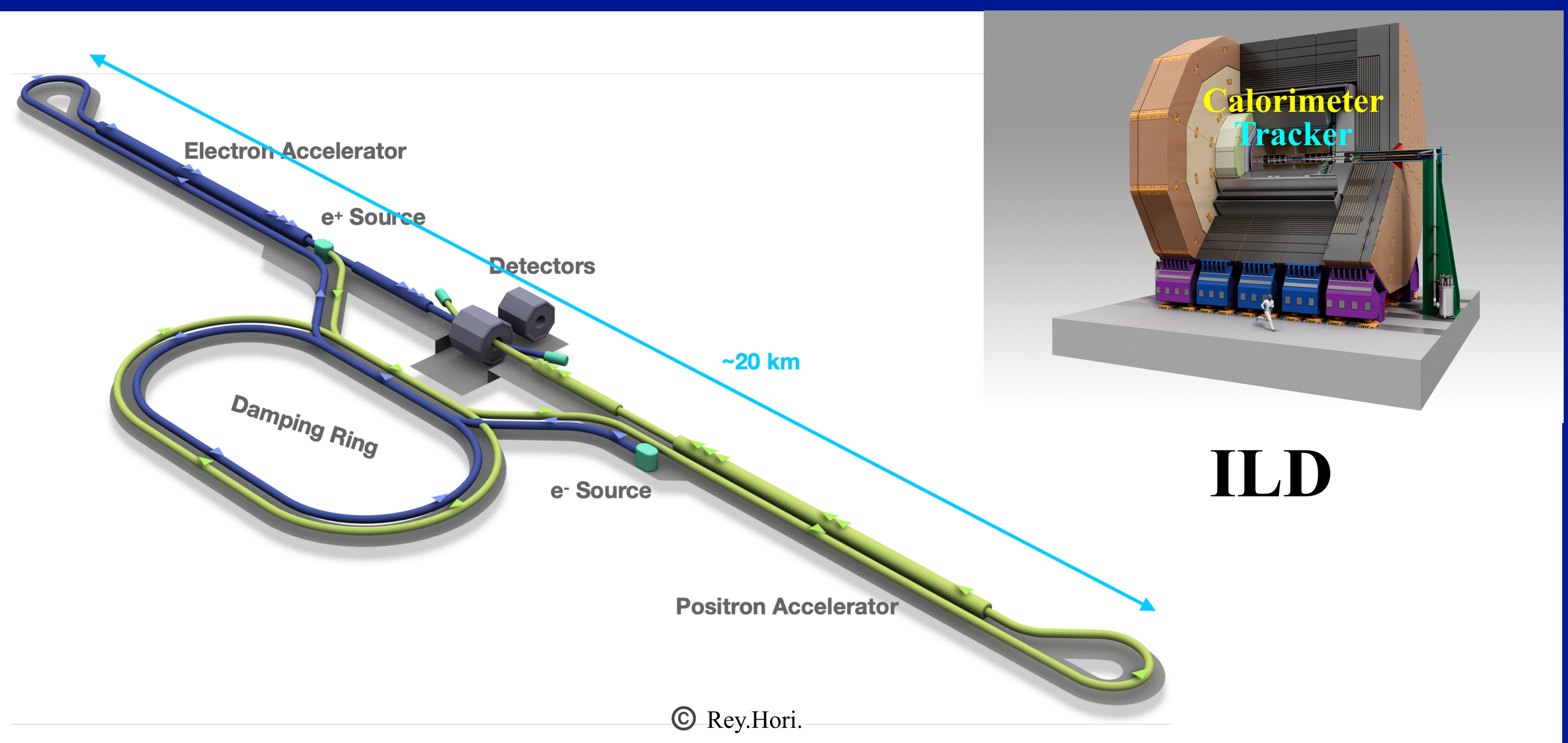
Abstract

We can calibrate the jet energy scale using $e^+e^- \to \gamma Z$ process with the uncertainty 5 to 20 MeV at the ILC.
If we can suppress the relative error on polarization to 0.1% and uncorrelated part of product of efficiency and luminosity to 0.016%, A_{LR} = 0.22810 ± 0.000178 (stat) ± 0.000174 (syst), 8.8 times better precision than that measured at the SLC.

1. International Linear Collider (ILC)



- Proposed high energy linear e^+e^- collider
- E_{CM} = 250 GeV, extendable to 1 TeV or higher
- Polarization: e^-: ±80% e^+: ±30%
- Well-defined initial state and small QCD background

→ perform various precision measurements including those regarding the Higgs boson properties

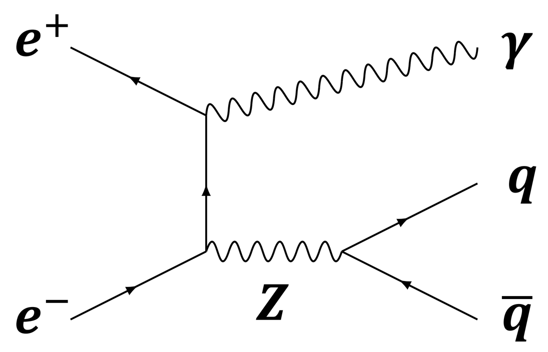
★ International Large Detector (ILD)

A detector concept for the ILC designed for Particle Flow Analysis (PFA)
: Reconstructing every individual particle created in an event by taking the best available measurement
i.e. tracker for charged particles, calorimeter for neutral particles

3. Motivation for the Jet Energy Calibration

ILD needs to precisely calibrate energy scales for various particles.

★ Purpose: To perform the jet energy calibration using the $e^+e^- \to \gamma Z$, $Z \to q\bar{q}$ process



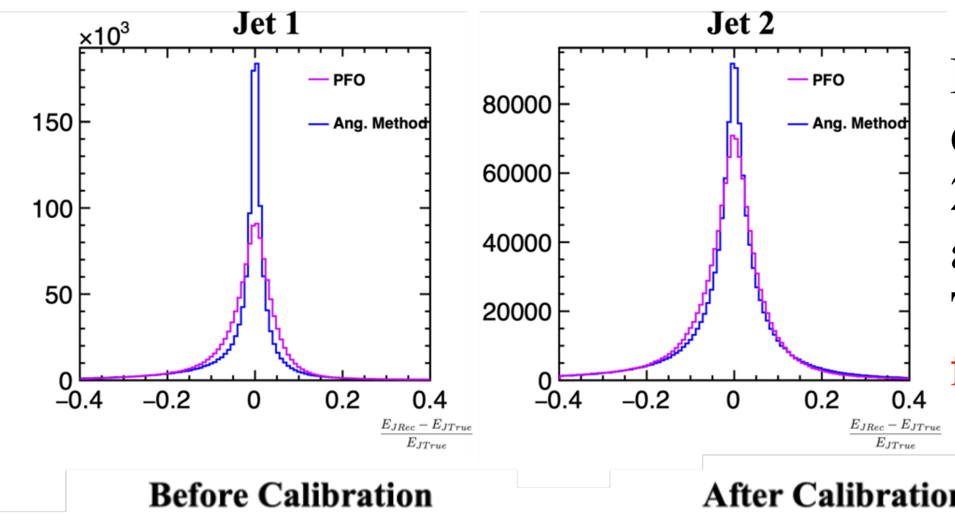
Jet energy can be reconstructed using measured γ and jet angles and jet masses.

4. Jet Energy Calibration

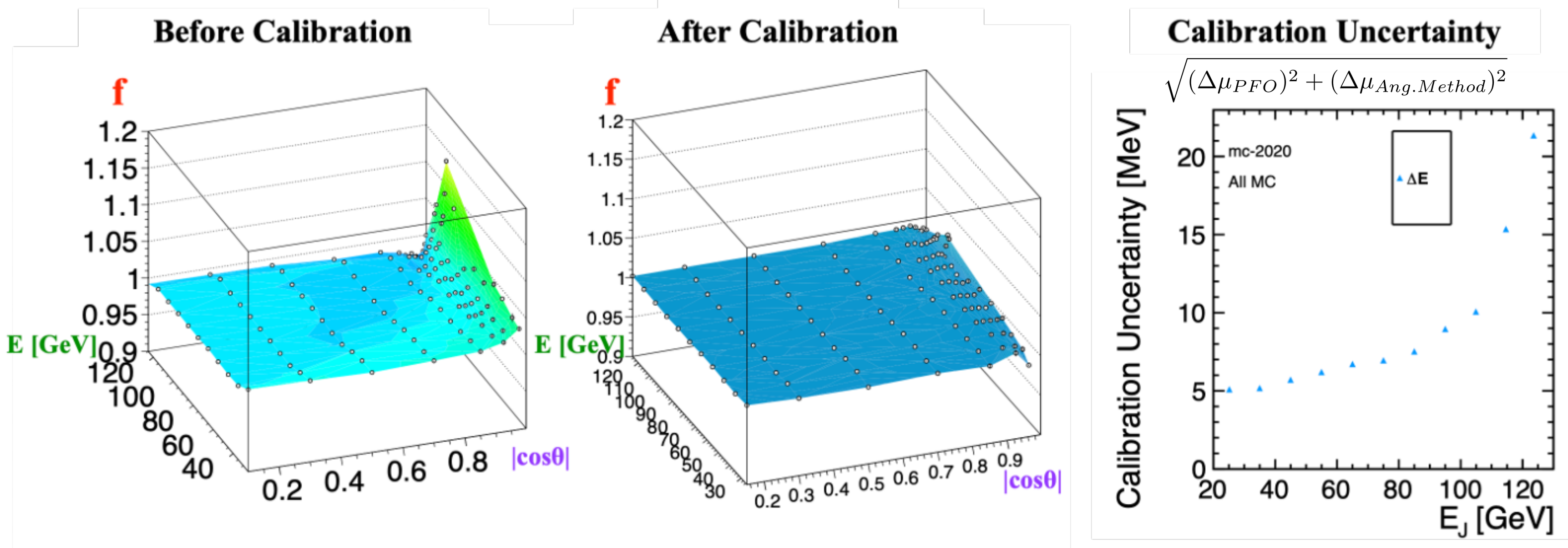
Angular Method: kinematically reconstruct the jet and photon energies
Inputs ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2}$) → Outputs ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

$$\begin{cases} \sqrt{|P_{J1}|^2+m_{J1}^2}+\sqrt{|P_{J2}|^2+m_{J2}^2}+|P_\gamma|+|P_{ISR}|=E_{CM} \\ \begin{pmatrix} \sin\theta_{J1}\cos\phi_{J1} & \sin\theta_{J2}\cos\phi_{J2} & \sin\theta_\gamma\cos\phi_\gamma \\ \sin\theta_{J1}\sin\phi_{J1} & \sin\theta_{J2}\sin\phi_{J2} & \sin\theta_\gamma\sin\phi_\gamma \\ \cos\theta_{J1} & \cos\theta_{J2} & \cos\theta_\gamma \end{pmatrix}\begin{pmatrix}|P_{J1}|\\|P_{J2}|\\|P_\gamma|\end{pmatrix}=\begin{pmatrix}(E_{CM}-|P_{ISR}|)\sin\alpha\\0\\\pm|P_{ISR}|\cos\alpha\end{pmatrix}\end{cases}$$

Beam Crossing Angle ≡ 2α = 14.0 mrad
ISR photon = additional unseen photon



Fit the $(E_{PFO}-E_{Ang.M})/E_{Ang.M}$ distribution for the uds jets with 2-Gaussian + 1-Exponential as a function of E and |cosθ|
Then derive the Calibration Factor
$f := E_{Ang.M}/E_{PFO}$



We can calibrate the jet energy scale with 5 to 20 MeV for 20 to 130 GeV jet.

2. Analysis Setup

Full Simulation: Geant4 based realistic detector simulation
- Realistic event reconstruction from detector signals
- With beamstrahlung and additional ISR photon effects

E_{CM}= 250 GeV with ∫Ldt=900 fb⁻¹ for each of the 2 polarization combinations
$\sin\theta_W$ = 0.22225

Signal signatures: 1 isolated energetic photon + 2 jets

Signal Photon Selection
1. choose neutral PFOs (PFA Objects) identified as photons by PFA
2. Eγ > 50 GeV
3. choose the photon candidate with energy closest to 108.4 GeV

Jet Clustering
All PFOs other than the selected photon are clustered into 2 jets

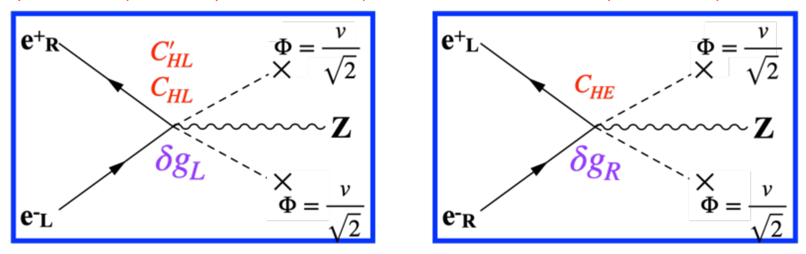
5. Motivation for the A_{LR} Measurement

★ SM effective field theory (SMEFT):

Express the deviation from the SM using dim-6 operators

$$\Delta\mathcal{L}=i\frac{c_{HL}}{v^2}\boxed{(\Phi^\dagger\overleftrightarrow{D^\mu}\Phi)}(\bar{L}\gamma_\mu L)+4i\frac{c'_{HL}}{v^2}\boxed{(\Phi^\dagger t^a\overleftrightarrow{D^\mu}\Phi)}(\bar{L}\gamma_\mu t^a L)+i\frac{\bar{c}_{HE}}{v^2}\boxed{(\Phi^\dagger\overleftrightarrow{D^\mu}\Phi)}(\bar{e}\gamma_\mu e)$$

$(vZ^\mu v)$ $(vt^aZ^\mu v)$ $(vZ^\mu v)$



Electroweak Precision Observables for Z boson are important.

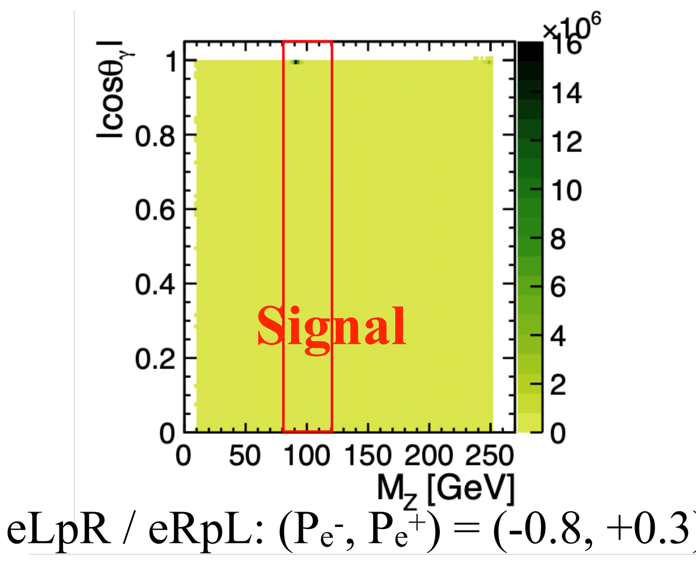
$$A_{LR}=A_e=\frac{g_{Le}^2-g_{Re}^2}{g_{Le}^2+g_{Re}^2}$$

Current best measurement (SLC)[A]
A_{LR} = 0.1514 ± 0.0019 (stat) ± 0.0011(syst)
→ Improve the precision ~10 times ??

[A] The ALEPH Collaboration, the DELPHI Collaboration, the L3 Collaboration, the OPAL Collaboration, the SLD Collaboration, the LEP Electroweak Working Group, the SLD electroweak and heavy flavour groups. Precision Electroweak Measurements on the Z Resonance, 2005, Phys.Rept.427:257-454,2006; arXiv:hep-ex/0509008. DOI: 10.1016/j.physrep.2005.12.006.

6. A_{LR} Measurement

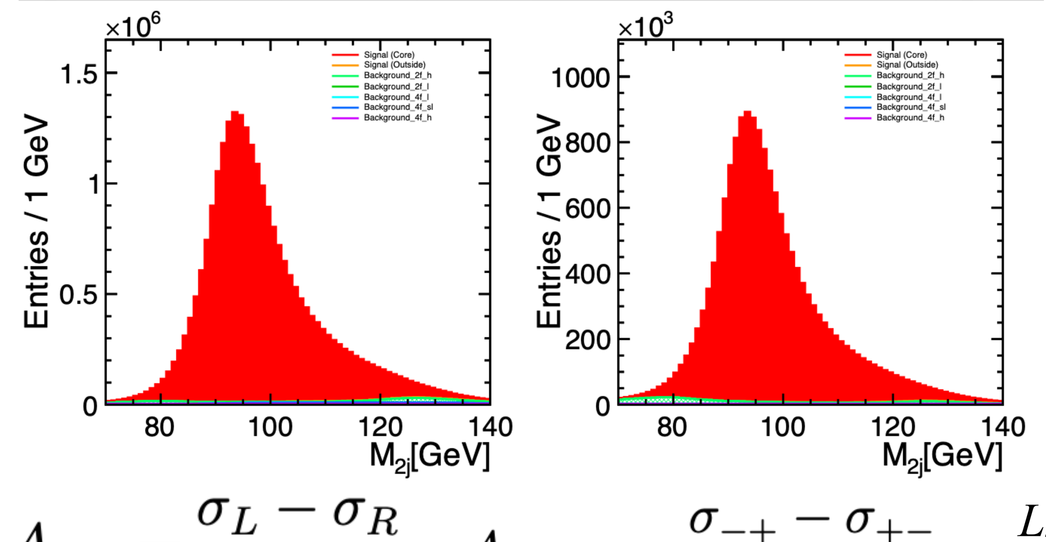
$e^+e^- \to \gamma Z$, $Z \to q\bar{q}$ process



eLpR / eRpL: (P_{e^-}, P_{e^+}) = (-0.8, +0.3) / (+0.8, -0.3) polarization

Background: All the events only with 2 jets in the final state
→ Following cuts were applied

Cut 1 $N_{\gamma(E>50\,\mathrm{GeV})}=0$
Cut 2 $120\,\mathrm{GeV}<E_{vis}<160\,\mathrm{GeV}$
Cut 3 $|\cos\theta_{2j}|>0.95$
Cut 4 $N_{J1}^{charged}+N_{J2}^{charged}>4$
Cut 5 $N_{J1}^{total}+N_{J2}^{total}>6$
Cut 6 $50\,\mathrm{GeV}<M_{2j}<160\,\mathrm{GeV}$
Cut 7 $\cos\theta_{12}>-0.99$ or $\frac{E_{J1}-E_{J2}}{E_{J1}+E_{J2}}>0.5$



Selection efficiency η:
0.74166 ± 0.00015 (eLpR)
0.74235±0.00014 (eRpL)

Background/Signal:
0.0500 (eLpR)
0.0462 (eRpL)

$$A_{LR}\equiv\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R},\quad A_{LRobs}\equiv\frac{\sigma_{-+}-\sigma_{+-}}{\sigma_{-+}+\sigma_{+-}}$$

L/R : 100% polarization
-/+ : Polarization at ILC

$$A_{LR}=A_{LRobs}\frac{1+|P_-||P_+|}{|P_-|+|P_+|}=A_{LRobs}\times f\qquad\left(\frac{\Delta A_{LR}}{A_{LR}}\right)^2=\left(\frac{\Delta A_{LRobs}}{A_{LRobs}}\right)^2+\left(\frac{\Delta f}{f}\right)^2$$

$$\left(\frac{\Delta f}{f}\right)^2=\left(\frac{|P_-|(1+|P_+|)(1-|P_+|)}{(|P_-|+|P_+|)(1+|P_-||P_+|)}\right)^2\left(\frac{\Delta|P_-|}{|P_-|}\right)^2+\left(\frac{|P_+|(1+|P_-|)(1-|P_-|)}{(|P_-|+|P_+|)(1+|P_-||P_+|)}\right)^2\left(\frac{\Delta|P_+|}{|P_+|}\right)^2$$

$$\left(\frac{\Delta A_{LRobs}}{A_{LRobs}}\right)^2=\left(\frac{2\left(\frac{N_{-+}}{\alpha}\right)\left(\frac{N_{+-}}{\beta}\right)}{\left(\frac{N_{-+}}{\alpha}-\frac{N_{+-}}{\beta}\right)\left(\frac{N_{-+}}{\alpha}+\frac{N_{+-}}{\beta}\right)}\right)^2\left(\left(\frac{\Delta\alpha}{\alpha}\right)^2+\left(\frac{\Delta\beta}{\beta}\right)^2+\left(\frac{\Delta N_{-+}}{N_{-+}}\right)^2+\left(\frac{\Delta N_{+-}}{N_{+-}}\right)^2\right)$$

$\alpha\equiv L_{-+}\eta_{-+}$
$\beta\equiv L_{+-}\eta_{+-}$,

If we can suppress the error Δf/f = 0.001 (0.1%)
Δα/α = Δβ/β (uncorrelated) = 0.00016 (0.016%)
A_{LR} = 0.22810 ± 0.000178 (stat) ± 0.000174 (syst)

8.8 times better than the error at the SLC