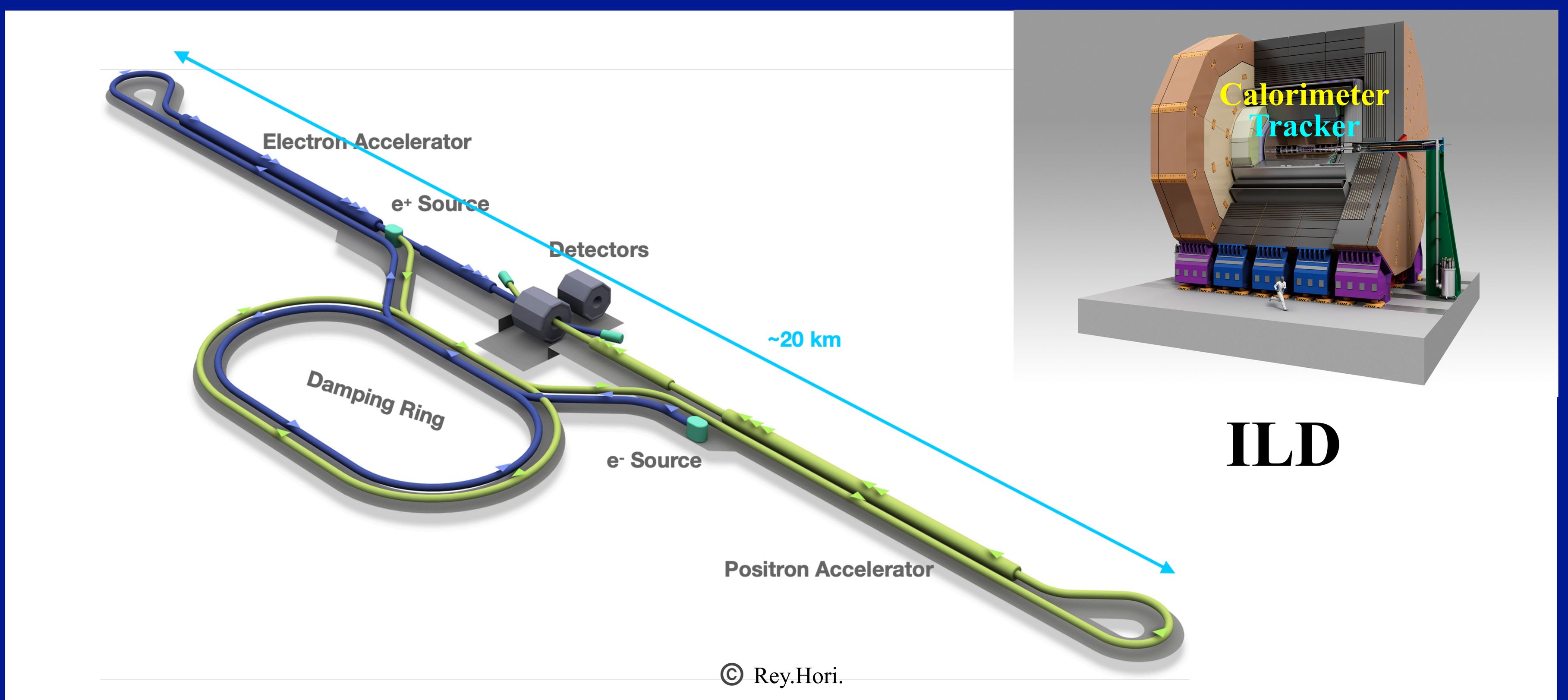
Jet energy calibration and study of Left-Right Asymmetry using e^+e^- -> γZ process at the ILC

Takahiro Mizuno, Keisuke Fujii, Junping Tian email: mizunot@post.kek.jp

Conclusion

We can calibrate the jet energy 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 from 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%
- The initial state is well defined 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 the event by taking the best available measurement
i.e. tracker for charged particles, calorimeter for neutral particles

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

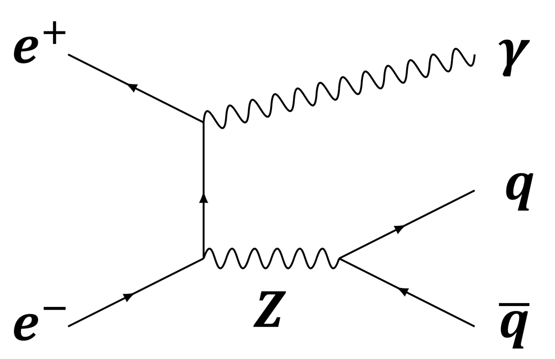
Signal Photon Selection
1. choose neutral PFOs (PFA Objects) identified as photons by PFA
2. $E\gamma$ > 50 GeV
3. choose the photon candidate with energy closest to 108.4 GeV

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

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 $e^+e^- \to \gamma Z$ process



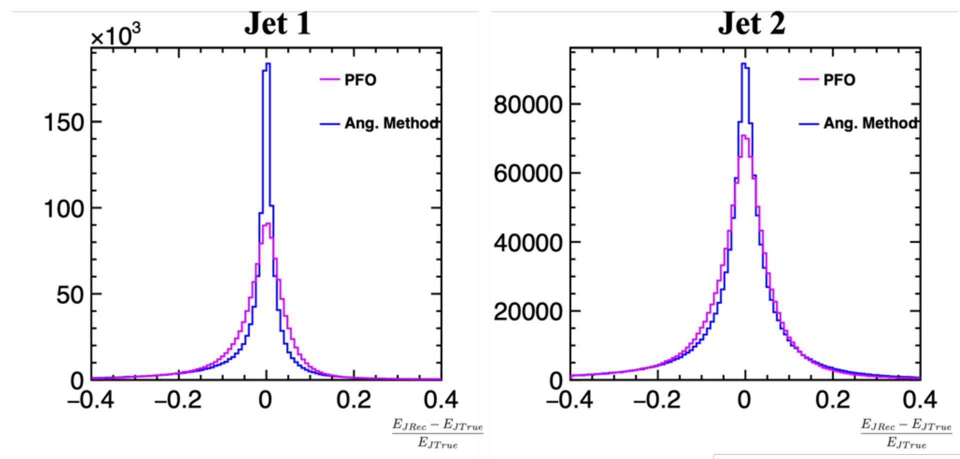
Jet energy can be reconstructed using measured γ and jet angles and jet masses.

4. Jet Energy Calibration

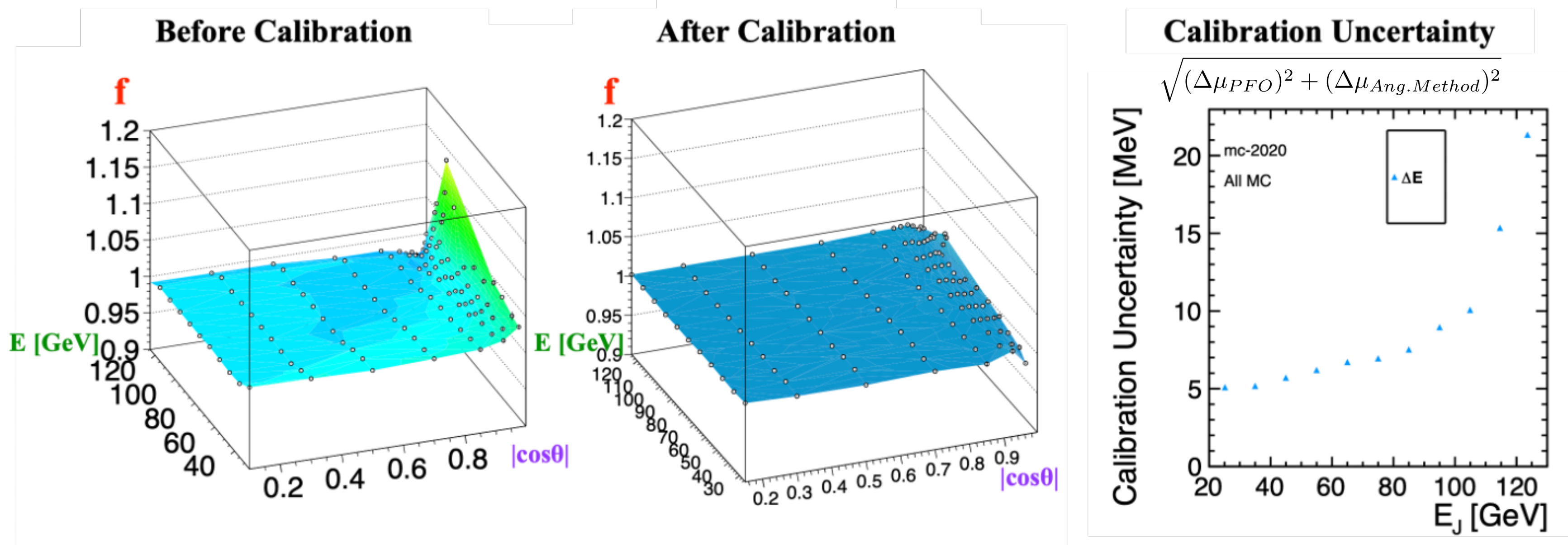
Angular Method: kinematically reconstruct the jet and photon energies
Inputs ($\theta_{J1},\theta_{J2},\theta_\gamma,\varphi_{J1},\varphi_{J2},\varphi_\gamma,m_{J1},m_{J2}$) → Outputs ($P_{J1},P_{J2},P_\gamma,P_{ISR}$)

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

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 about 5 to 20 MeV.

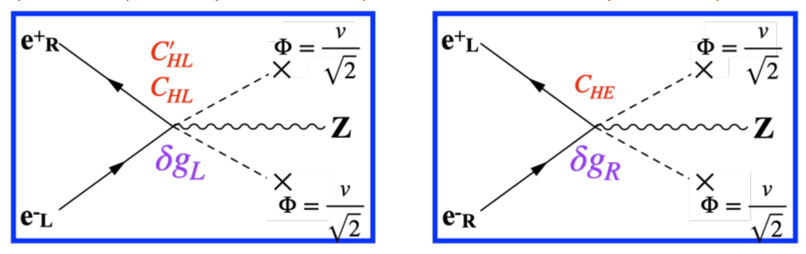
5. Motivation for the A_{LR} Measurement

★ SM effective field theory (SMEFT):

Express the deviation from the SM using dim-6 operators

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

$(\nu Z^\mu \nu)$ $(\nu t^a Z^\mu \nu)$ $(\nu Z^\mu \nu)$



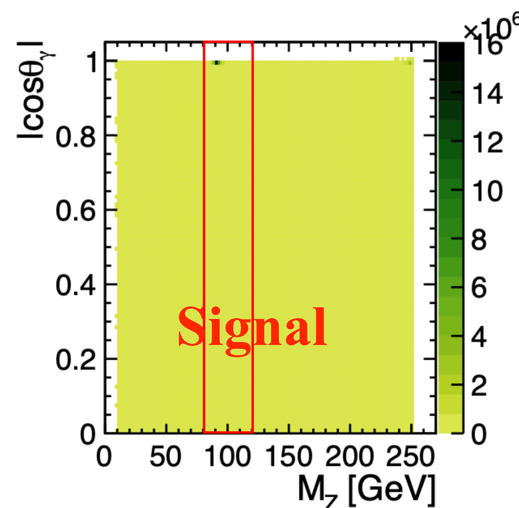
Electroweak Precision Observables for Z boson are important.

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

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

6. A_{LR} Measurement

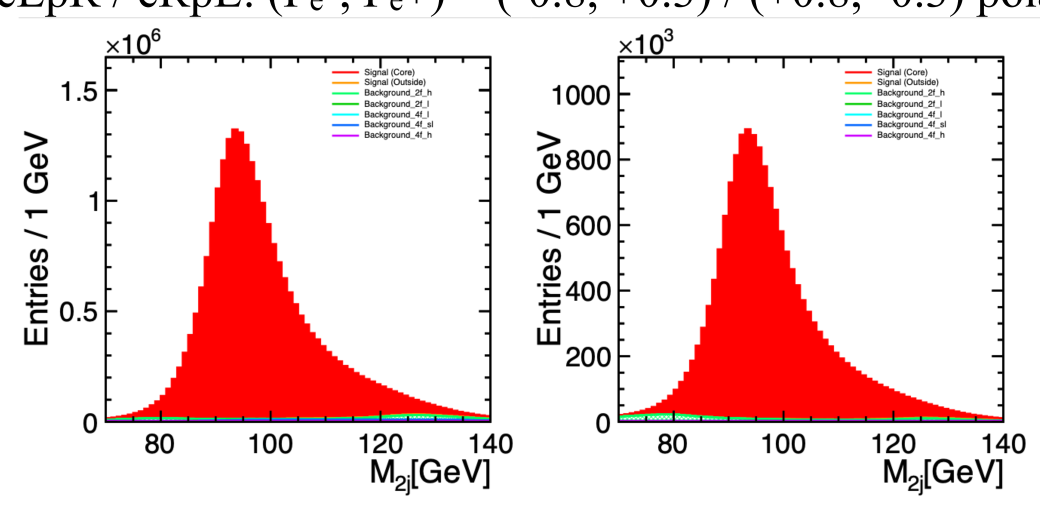
$e^+e^- \to \gamma Z$, $Z \to qq$ process



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

Cut 1 $N_{\gamma(E>50\,GeV)} = 0$
Cut 2 $120\,GeV < E_{vis} < 160\,GeV$
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 $50\,GeV < M_{2j} < 160\,GeV$
Cut 7 $\cos\theta_{12} > -0.99$ or $\frac{E_{J1}-E_{J2}}{E_{J1}+E_{J2}} > 0.5$

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



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

B/S:
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)