Electroweak physics at CEPC

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Institute of High Energy Physics, Chinese Academy of Sciences
• Electron-positron circular collider
  • Higgs Factory \( (E_{\text{cms}}=250\text{GeV}, \ 10^6 \text{Higgs}) \)
    • Precision study of Higgs coupling in ZH runs
    • complementary to ILC
    • See Manqi and Gang’s talk this morning in Higgs section for more details
  • Z factory \( (E_{\text{cms}}=91 \text{GeV}, \ 10^{10} \text{Z Boson}) \) :
    • Precision Electroweak measurement in Z pole running
    • Major focus of this talk

• Preliminary Conceptual Design Report( Pre-CDR) available :
  • [http://cepc.ihep.ac.cn/preCDR/volume.html](http://cepc.ihep.ac.cn/preCDR/volume.html)
• Aiming to finalize Conceptual Design Report (CDR) next year
CEPC detector (1)

- ILD-like design with some modification for circular collider
  - No Power-pulsing
- Tracking system (Vertex detector, TPC detector, 3.5T magnet)
  - Expected Impact parameter resolution: less than 5μm
  - Expected Tracking resolution: $\delta(1/P_t) \sim 2 \times 10^{-5} \text{(GeV}^{-1})$
- Calorimeters: Concept of Particle Flow Algorithm (PFA) based
  - Expected jet energy resolution: $\sigma_{E/E} \sim 0.3/\sqrt{E}$
Motivation

- CEPC have very good potential in electroweak physics.
- Precision measurement is important
  - It constrain new physics beyond the standard model.
  - Eg: Radiative corrections of the W or Z boson is sensitive to new physics.
The prospect of CEPC electroweak physics in pre-CDR study

- Expected precision on some key measurements in CEPC Pre-CDR study based on projections from LEP and ILC.
  - [http://cepc.ihep.ac.cn/preCDR/volume.html](http://cepc.ihep.ac.cn/preCDR/volume.html)
- From now to next year, plan to update the study for Conceptual Design Report (CDR) with full detector simulation

<table>
<thead>
<tr>
<th>Observable</th>
<th>LEP precision</th>
<th>CEPC precision</th>
<th>CEPC runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_Z$</td>
<td>2 MeV</td>
<td>0.5 MeV</td>
<td>$Z$ lineshape</td>
</tr>
<tr>
<td>$m_W$</td>
<td>33 MeV</td>
<td>3 MeV</td>
<td>$ZH$ ($WW$) thresholds</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>1.7%</td>
<td>0.15%</td>
<td>$Z$ pole</td>
</tr>
<tr>
<td>$\sin^2 \theta_{WW}^\text{eff}$</td>
<td>0.07%</td>
<td>0.01%</td>
<td>$Z$ pole</td>
</tr>
<tr>
<td>$R_b$</td>
<td>0.3%</td>
<td>0.08%</td>
<td>$Z$ pole</td>
</tr>
<tr>
<td>$N_\nu$ (direct)</td>
<td>1.7%</td>
<td>0.2%</td>
<td>$ZH$ threshold</td>
</tr>
<tr>
<td>$N_\nu$ (indirect)</td>
<td>0.27%</td>
<td>0.1%</td>
<td>$Z$ lineshape</td>
</tr>
<tr>
<td>$R_\mu$</td>
<td>0.2%</td>
<td>0.05%</td>
<td>$Z$ pole</td>
</tr>
<tr>
<td>$R_\tau$</td>
<td>0.2%</td>
<td>0.05%</td>
<td>$Z$ pole</td>
</tr>
</tbody>
</table>
Z mass measurement

- LEP measurement: $91.1876 \pm 0.0021$ GeV
- CEPC possible goal: 0.5 MeV
  - Z threshold scan runs is needed to achieve high precision.
  - Stat uncertainty: 0.2 MeV
  - Better to have more than 10 fb$^{-1}$ for off-peak runs (6 off-peaks runs)
- Syst uncertainty: $\sim 0.5$ MeV
  - Beam energy uncertainty need to be better than 5 ppm
  - start to Establishing a accelerator model relating the measured beam energy
  - Study of the resonant depolarization technique to measure beam energy (LEP approach)
Physics Requirement for accelerator

- Expected Beam momentum scale uncertainty
  - CEPC pre-CDR: 500keV precision \((10^{10} - 10^{11} Z)\)
  - FCC-ee: 100keV precision \((10^{13} Z)\)
- Precision of beam energy measurement may have a big impact to Z pole running program.
  - Pre-CDR requirement: 5-10 ppm level uncertainty on \(P_{\text{beam}}\)
  - preliminary study with compton scattering (BEPC-II approach)
  - may be able to reach 1MeV precision from
    - preliminary study in G-Y. Tang’s talk
      [http://indico.ihep.ac.cn/event/6495/session/4/contribution/29/material/slides/0.pdf](http://indico.ihep.ac.cn/event/6495/session/4/contribution/29/material/slides/0.pdf)

- Toward CDR: check scenario of 1ppm uncertainty on \(P_{\text{beam}}\)
  - Requested by FCC-ee experts to do more study
  - beam polarization issue and resonant depolarization method (LEP approach)
Branching ratio ($R^b$)

- LEP measurement: $0.21594 \pm 0.00066$
  - Stat error: 0.44%
  - Syst error: 0.35%
  - Typically using 65% working points

- CEPC pre-CDR
  - Expected Stat error: 0.04%
  - Expected Syst error: 0.07%
  - Expect to use 80% working points
    - 15% higher efficiency than SLD
    - 20-30% higher in purity than SLD

### Uncertainty

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>LEP</th>
<th>CEPC</th>
<th>CEPC improvement</th>
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<tbody>
<tr>
<td>charm physics modeling</td>
<td>0.2%</td>
<td>0.05%</td>
<td>tighter b tagging working point</td>
</tr>
<tr>
<td>hemisphere tag correlations for b events</td>
<td>0.2%</td>
<td>0.1%</td>
<td>Higher b tagging efficiency</td>
</tr>
<tr>
<td>gluon splitting</td>
<td>0.15%</td>
<td>0.08%</td>
<td>Better granularity in Calo</td>
</tr>
</tbody>
</table>
Branching ratio ($R^b$): uncertainty in gluon splitting

- Discrepancy of parton shower (PS) and matrix element calculation.
- Data/MC discrepancy in high jet multiplicity

Backward-forward asymmetry measured from b jet

- LEP measurement: $0.1000^{+0.0017}_{-0.0017}$ (Z peak)
  - Method 1: Soft lepton from b/c decay ($\sim$2%)
    - Select one lepton from b/c decay, and one b jets
    - Select lepton charge ($Q_{\text{lepton}}$) and jet charge ($Q_{\text{jet}}$)
  - Method 2: jet charge method using Inclusive b jet ($\sim$1.2%)
    - Select two b jets
    - Use event Thrust to define the forward and background
    - Use jet charge difference ($Q_F - Q_B$)

$Q_{\text{lepton}} - Q_{\text{jet}}$ in method 1

$Q_F - Q_B$ in method 2
Backward-forward asymmetry measured from b jet

* LEP measurement: $0.1000^{+0.0017}_{-0.0017}$ (Z peak)
  * Method 1: Soft lepton from b/c decay (~2%)
  * Method 2: Jet charge method using Inclusive b jet (~1.2%)
  * Method 3: D meson method (>8%, less important method)

* CEPC pre-CDR
  * Focus more on method 2 (inclusive b jet measurement)
  * For CDR study, will try to find
  * Expected Systematics (0.15%):

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<td>0.05%</td>
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</tr>
<tr>
<td>tracking resolution</td>
<td>0.8%</td>
<td>0.05%</td>
<td>better tracking resolution</td>
</tr>
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<td>hemisphere tag correlations for b events</td>
<td>1.2%</td>
<td>0.1%</td>
<td>Higher b tagging efficiency</td>
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<tr>
<td>QCD and thrust axis correction</td>
<td>0.7%</td>
<td>0.1%</td>
<td>Better granularity in Calo</td>
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</tbody>
</table>
QCD correction to Thrust

- Uncertainty $A_{fb\_b}$ due to QCD correction to Thrust
  - Higher order QCD effect is major systematics

CERN-EP/98-23

<table>
<thead>
<tr>
<th>Error source</th>
<th>$C_{QCD}^{\text{quark}}$ (%)</th>
<th>$C_{QCD}^{\text{part}, T}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b\bar{b}$ or $c\bar{c}$</td>
<td>0.23</td>
<td>0.15</td>
</tr>
<tr>
<td>$\alpha_s(m_Z^2)$ ($0.119 \pm 0.004$)</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Higher order corrections</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Total error</td>
<td>0.37</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Weak mixing angle $\sin^2 \theta_{\text{lept}}^{\text{eff}}$

- **LEP/SLD**: $0.23153 \pm 0.00016$
  - 0.1% precision.
  - Stat error is one of limiting factor.

- **CEPC**
  - Systematics error: 0.01%
    - Input From Backward-forward asymmetry measurement
    - The precision $mZ$ is another limiting factor (uncertainty on $P_{\text{beam}}$)

### Correlations

<table>
<thead>
<tr>
<th></th>
<th>$m_Z$</th>
<th>$\Gamma_Z$</th>
<th>$\sigma_{\text{had}}^0$</th>
<th>$R^0_\ell$</th>
<th>$A_{\text{FB}}^{0,\ell}$</th>
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<tbody>
<tr>
<td>$\chi^2/\text{dof} = 172/180$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ALEPH</td>
</tr>
<tr>
<td>$m_Z , [\text{GeV}]$</td>
<td>91.1893 ± 0.0031</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Gamma_Z , [\text{GeV}]$</td>
<td>2.4959 ± 0.0043</td>
<td>0.038</td>
<td>0.033</td>
<td>0.011</td>
<td>0.246</td>
</tr>
<tr>
<td>$\sigma_{\text{had}}^0 , [\text{nb}]$</td>
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<td>-0.092</td>
<td>-0.383</td>
<td>1.000</td>
<td></td>
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<td>$R_\ell^0$</td>
<td>20.729 ± 0.039</td>
<td>0.033</td>
<td>0.011</td>
<td>0.246</td>
<td>1.000</td>
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<tr>
<td>$A_{\text{FB}}^{0,\ell}$</td>
<td>0.0173 ± 0.0016</td>
<td>0.071</td>
<td>0.002</td>
<td>0.001</td>
<td>0.076</td>
</tr>
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</table>


W mass measurement (1)

- PDG precision: $80.385 \pm 0.015 \text{ GeV}$
  - Possible goal for CEPC pre-CDR: 3 MeV
- Three methods for W mass measurements:
  - 1. WW Threshold scan ($\sqrt{s}=160\text{GeV}$):
    - Advantage: Very robust method, can achieve high precision.
    - Disadvantage
      - Higher cost, Require dedicated runs $>1000\text{fb}^{-1}$ on WW threshold ($\sim 160\text{GeV}$)
W mass measurement (2)

- Direct measurement of the hadronic mass (method for pre-CDR)
  - Based on $10^{10}$ $Z\rightarrow$ hadrons sample to calibrate jet energy scale ($<3$ MeV)
  - Advantage:
    - No additional cost: measured in ZH runs ($\sqrt{s}=250$ GeV)
    - Higher statistics: 10 times larger than WW threshold region
    - Lower requirement on beam energy uncertainty.
  - Disadvantage:
    - Can not get better precision than 3 MeV
    - Require Beam momentum measurement: 10 ppm level on $P_{beam}$

By Manqi

CERN-PH-EP/2006-004
Summary

• CEPC electroweak physics in Preliminary Conceptual Design Report.
  • Expected precision based on projections from LEP and ILC.
• Aim for more realistic study with full simulation for CDR next year.
  • Mainly focus on fullsim study on key measurements.
  • Understand Detector requirements and accelerator requirements
    • $m_W$
    • Weak mixing angle
    • $m_Z$
    • $A_{fb\_B}$
    • $R_B$
• Short of manpower in Z/W physics
• Need help from international collaborations
• Need input from theorists to improve the measurements!
  • Interpretations
  • Higher order calculations
  • New ideas
  • ......

• Welcome to join this effort
From Pre-CDR to CDR

- Propagate beam momentum scale uncertainty to all EW measurement.
- Give a clear physics requirement to accelerator

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Correlations

- $m_Z$ | $\Gamma_Z$ | $\sigma^0_{\text{had}}$ | $R^0_\ell$ | $A^{0,\ell}_{\text{FB}}$
- 1.000 | 0.038 | 0.092 | 0.033 | 0.071 | 0.001 | -0.076 | 1.000

ALEPH
Branching ratio ($R^{\mu\mu}$)

- LEP result: 0.2% total error (Stat: 0.15%, Syst: 0.1%)
- CEPC: 0.05% total error expected
  - Better EM calorimeter is the key

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<th>CEPC</th>
</tr>
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<tr>
<td>Radiative events ($Z\rightarrow\mu\mu\gamma$)</td>
<td>0.05%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Photon energy scale</td>
<td>0.05%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Muon Momentum scale</td>
<td>0.009%</td>
<td>&lt;0.003%</td>
</tr>
<tr>
<td>Muon Momentum resolution</td>
<td>0.005%</td>
<td>&lt;0.003%</td>
</tr>
</tbody>
</table>
CEPC detector (2)

- Calorimeters:
  - Concept of Particle Flow Algorithm (PFA) based
  - EM calorimeter energy resolution: $\sigma_{E/E} \sim 0.16/\sqrt{E}$
  - Had calorimeter energy resolution: $\sigma_{E/E} \sim 0.5/\sqrt{E}$
  - Expected jet energy resolution: $\sigma_{E/E} \sim 0.3/\sqrt{E}$

Jet energy (Higgs self-coupling, W/Z separation)
- $\sim 1/2$ resolution (wrt LHC)

Jet energy resolution at CEPC:

$\sigma_{E/E} = 0.3/\sqrt{E\text{(GeV)}}$
Plan for Weak mixing angle

- More details in Mengran’s talk

Truth distribution
From Z fitter

unFolding matrix

Reco level distribution