CEPC Theory Discussion

Shufang Su • U. of Arizona

CEPC Workshop
April 9, IHEP
Outline

- Organization
- Physics
  - What has been done at preCDR?
  - What's next?
Organization
Theory Committee
Jianping Ma, Tao Han, Hongjian He, Xiaogang Wen, Shan Jin

2016 funded proposals

- Qinghong Cao: Near degenerate dark matter study @ CEPC, double parton scattering @ SPPC
- Jing Shu: Precision measurements and effective operators, TGC
- Qishu Yan: BSM phenomenology and Monte Carlo tools
- Pengfei Yin: Dark matter studies @ CEPC

Call for proposal (2016) in Sep
CDR Theory Effort

Liantao Wang

- working groups?
- timeline/plan?
- ...

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Physics opportunity at CEPC
Higgs/Z/W/t factory

90 - 350 GeV

- precision test (Z, W, H, t)
- exotic decay of H: dark matter, etc.
- rare decay
- direct new physics search: $E_{cm}/2$
Physics opportunity at CEPC
Higgs/Z/W/t factory

90 - 350 GeV

- precision test (Z, W, H, t)
- exotic decay of H: dark matter, etc.
- rare decay
- direct new physics search: $E_{cm}/2$
Summary of $e^+e^-$ colliders main parameters

- **CepC (2 IPs)**
  - $\sqrt{s}$: $54$ GeV
  - $\sigma$: $20$ km
  - $L$: $1.8 \times 10^8$ km
  - $\mathcal{L}$: $>99\%$

- **FCC-ee (4 IPs)**
  - $\sqrt{s}$: $100$ GeV
  - $\sigma$: $20$ km
  - $L$: $6 \times 10^7$ km
  - $\mathcal{L}$: $>99\%$

- **ILC**
  - $\sqrt{s}$: $31$ GeV
  - $\sigma$: $14.7$ km
  - $L$: $0.75$ km
  - $\mathcal{L}$: $58\%$
  - $\mathcal{L}$: $80%/30\%$

- **CLIC**
  - $\sqrt{s}$: $48$ GeV
  - $\sigma$: $100$ km
  - $L$: $6 \times 10^7$ km
  - $\mathcal{L}$: $33\%$
  - $\mathcal{L}$: $80%/\text{considered}$

Some typical energy points only

F. Gianotti, Higgs Hunting 2014
## e+e- Machine: Lum vs. \( E_{cm} \)

### Summary of e+e- Colliders Main Parameters

<table>
<thead>
<tr>
<th>( E_{cm} )</th>
<th>Running Time</th>
<th>Statistics (FCC-ee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b,c,\tau )</td>
<td></td>
<td>( 10^{11} ) b,c,\tau</td>
</tr>
<tr>
<td>90 GeV</td>
<td>1-2 yrs</td>
<td>( 10^{12} ) Z (Tera Z)</td>
</tr>
<tr>
<td>160 GeV</td>
<td>1-2 yrs</td>
<td>( 10^{8} ) - ( 10^{9} ) WW (Oku W)</td>
</tr>
<tr>
<td>240 GeV</td>
<td>4-5 yrs</td>
<td>( 2 \times 10^6 ) ZH (Mega H)</td>
</tr>
<tr>
<td>350 GeV</td>
<td>4-5 yrs</td>
<td>( 10^6 ) tt (Mega top)</td>
</tr>
</tbody>
</table>

---

### Details

- **Linear CepC (2 IPs)**
- **Circular**
- **Modified from original version:** [http://arxiv.org/pdf/1308.6176v3](http://arxiv.org/pdf/1308.6176v3)

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F. Gianotti, Higgs Hunting 2014

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Electroweak Precision Measurements
Tera Z, clean environment, $E_{cm}$ knows < 1 MeV, possible longitudinal polarization

- Z lineshape:
  - high precision $M_Z$ and $\Gamma_Z$
- Z partial width:
  - $N_\nu$ to 0.001 with $Z\gamma$, sterile neutrino, rare decay
- Long. polarized beam
  - $A_{LR}$ and $\sin^2\theta_W$

- $10^5$ more statistics than LEP
  - reduction of statistical uncertainty of a factor of 300
- exp systematic uncertainty
- Uncertainty in theoretical interpretation
EW Precision at Z pole

Baseline: 100 fb⁻¹ on Z-pole, 60 fb⁻¹ around Z-pole scan

Precision Electroweak Measurements at the CEPC

- Systematics dominate
- Potential improvements
  - energy calibration
  - more statistics

Zhijun Liang, xxx
### Electroweak Fit: \(S\) and \(T\) Oblique Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present data</th>
<th>CEPC fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_s(M_Z^2))</td>
<td>0.1185 ± 0.0006 ([23])</td>
<td>±1.0 \times 10^{-4} ([24])</td>
</tr>
<tr>
<td>(\Delta\alpha^{(5)}_{\text{had}}(M_Z^2))</td>
<td>(276.5 ± 0.8) \times 10^{-4} ([25])</td>
<td>±4.7 \times 10^{-5} ([26])</td>
</tr>
<tr>
<td>(m_Z) [GeV]</td>
<td>91.1875 ± 0.0021 ([27])</td>
<td>±0.0005</td>
</tr>
<tr>
<td>(m_t) [GeV] (pole)</td>
<td>173.34 ± 0.76_{\text{exp}} ([28]) ±0.5_{\text{th}} ([26])</td>
<td>±0.2_{\text{exp}}±0.5_{\text{th}} ([29, 30])</td>
</tr>
<tr>
<td>(m_h) [GeV]</td>
<td>125.14 ± 0.24 ([26])</td>
<td>&lt; ±0.1 ([26])</td>
</tr>
<tr>
<td>(m_W) [GeV]</td>
<td>80.385 ± 0.015_{\text{exp}} ([23])±0.004_{\text{th}} ([31])</td>
<td>(±3_{\text{exp}} ± 1_{\text{th}}) \times 10^{-3} ([31])</td>
</tr>
<tr>
<td>(\sin^2 \theta^\ell_{\text{eff}})</td>
<td>(23153 ± 16) \times 10^{-5} ([27])</td>
<td>(±2.3_{\text{exp}} ± 1.5_{\text{th}}) \times 10^{-5} ([32])</td>
</tr>
<tr>
<td>(\Gamma_Z) [GeV]</td>
<td>2.4952 ± 0.0023 ([27])</td>
<td>(±5_{\text{exp}} ± 0.8_{\text{th}}) \times 10^{-4} ([33])</td>
</tr>
<tr>
<td>(R_b \equiv \Gamma_b/\Gamma_{\text{had}})</td>
<td>0.21629 ± 0.00066 ([27])</td>
<td>±1.7 \times 10^{-4}</td>
</tr>
<tr>
<td>(R_{\ell} \equiv \Gamma_{\text{had}}/\Gamma_{\ell})</td>
<td>20.767 ± 0.025 ([27])</td>
<td>±0.007</td>
</tr>
</tbody>
</table>

Numbers in boldface: major CEPC inputs to the electroweak

---

In this section we will explain the details of a number of uncertainties that have gone into the fit in

Details of Electroweak Fit

C.L. contours of the improvements due to the other improved observables. For comparison, we also showed in each plot 68\%
m
Fig. improved (left), two improved (middle), and three of them improved (right) relative to the optimistic case of to the TLEP projection.

- Statistical uncertainty is reduced to be smaller than the systematic uncertainty, which is 0
- Precision could be improved slightly by a
- Precision could come from the ILC top threshold scan if it happened before or at the same time as CEPC;

Table 4 summarise the potential major improvements of sensitivities in the precision discussed above, always relative to the optimistic case from Table

If CEPC could perform energy calibration using the resonant spin depolarization method, which will

<table>
<thead>
<tr>
<th>CEPC</th>
<th>( m_t ) [GeV]</th>
<th>( m_W ) [GeV]</th>
<th>( \sin^2 \theta_{\text{eff}} )</th>
<th>( \Gamma_Z ) [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Error</td>
<td>±0.03_{\text{exp}} ± 0.1_{\text{th}}</td>
<td>(±2_{\text{exp}} ± 1_{\text{th}}) \times 10^{-3}</td>
<td>(±2.3_{\text{exp}} ± 1.5_{\text{th}}) \times 10^{-5}</td>
<td>(±1_{\text{exp}} ± 0.8_{\text{th}}) \times 10^{-4}</td>
</tr>
</tbody>
</table>

- \( S \) and \( T \) Oblique Parameters
- \( S \) and \( T \) plane in Fig.

**Challenge (opportunities)**
- 3 loop EW corrections
- one order of magnitude
- better than current

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If only improve one input at a time

Higgs Precision

- Deviation of SM Higgs couplings
- New coupling structures, beyond the SM
- Higgs couples to new particles
Infer Higgs total decay width
Determine all Higgs couplings (model-independent)

Y=b,c,g,W,Z,γ,τ,μ

- Determine all Higgs couplings (model-independent)
- Infer Higgs total decay width
- probe invisible Higgs decay
Higgs Precision

<table>
<thead>
<tr>
<th>$\Delta M_H$</th>
<th>$\Gamma_H$</th>
<th>$\sigma(ZH)$</th>
<th>$\sigma(\nu\nu H) \times \text{BR}(H \rightarrow bb)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.9 MeV</td>
<td>2.8%</td>
<td>0.51%</td>
<td>2.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$\sigma(ZH) \times \text{BR}$</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow bb$</td>
<td>0.28%</td>
<td>0.57%</td>
</tr>
<tr>
<td>$H \rightarrow cc$</td>
<td>2.2%</td>
<td>2.3%</td>
</tr>
<tr>
<td>$H \rightarrow gg$</td>
<td>1.6%</td>
<td>1.7%</td>
</tr>
<tr>
<td>$H \rightarrow \tau\tau$</td>
<td>1.2%</td>
<td>1.3%</td>
</tr>
<tr>
<td>$H \rightarrow WW$</td>
<td>1.5%</td>
<td>1.6%</td>
</tr>
<tr>
<td>$H \rightarrow ZZ$</td>
<td>4.3%</td>
<td>4.3%</td>
</tr>
<tr>
<td>$H \rightarrow \gamma\gamma$</td>
<td>9.0%</td>
<td>9.0%</td>
</tr>
<tr>
<td>$H \rightarrow \mu\mu$</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>$H \rightarrow \text{inv}$</td>
<td>–</td>
<td>0.28%</td>
</tr>
</tbody>
</table>
boson luminosities are comparable to that of the top quark. As expected, the luminosities of
at the 5 TeV partonic energy, the top quark luminosity is about 1. Incidentally, the electroweak gauge
in Fig. 1.2 (left) [12] and the electroweak gauge bosons in Fig. 1.2 (right) [12]. We see that the top quark,
the important theoretical implications Higgs couplings measurements at the CEPC.

Many theories for physics beyond the Standard Model (BSM) have been proposed over the past four
decades. A central theme motivating the construction of these models has been to address the question
of electroweak symmetry breaking. In most of these models, the Higgs couplings to the SM particles
are typically modified, either by new particles propagating in loops, or by mixture of the SM-like Higgs
of 300 fb LHC 300

precision of Higgs coupling measurement (Model-Independent Fit)
Implications of Higgs and EW Precision

- EW baryogenesis, Higgs potential
- Effective operators: wi/wo breaking of SM symmetry
- Naturalness, fine tuning
  - SUSY, fold SUSY, ...
  - Composite Higgs
- Higgs portal, UV completion
- ...

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Flavor Physics (from tera Z)

- CP violation in b, c, tau decay
- rare decay of b, c, tau
- tau EDM
- charged lepton flavor violation
To-do list
To-do list

Higgs precision

- more realistic simulations for various channels
- new channels, kinematic distributions
- Higgs “oblique” parameters
- SM loop corrections? sensitivity to top Yukawa?
- effective operator approach
- sensitivity to various BSM scenarios
- fully correlated analysis of Higgs precision (like EW precision fit of Z-pole)
- cosmo connection
- naturalness, fine tuning
- ...
To-do list

- EW precision measurements
  - more realistic simulations for $m_Z$, $\Gamma_Z$, $m_W$, $\sin^2\theta_W$ sensitivity
  - $m_W$, $\Gamma_W$ from WW threshold with high statistics but w/o polarization?
  - higher order corrections, reduce theory error.
  - 4-fermion contact interactions
  - sensitivity to various BSM scenarios
  - balancing between Higgs and Z factory running time
  - complementarity of Higgs and EW precision for BSM implication
  - do we need teraZ or more?
  - ...

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To-do list

- direct BSM searches, LHC blind spots
- potential of flavor physics
- QCD related issues: heavy quarkonia ...
- ttbar threshold?

Detector and accelerator requirements
- energy calibration, luminosity, polarization, ...
- precision of energy, momentum, angular measurements
- tau tag and polarization
- jet clustering/identification
- ...

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