The Performance and the software of the CEPC detector

Manqi Ruan
Performance

- Determined by
  - Detector design
  - Reconstruction algorithm

- Characterized at
  - Physics Objects
  - Higgs Signal
  - Benchmark Physics Analyses
Two classes of Concepts

- PFA Oriented concept using High Granularity Calorimeter
  - + TPC (ILD-like, Baseline)
  - + Silicon tracking (SiD-like)

- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter

https://indico.ihep.ac.cn/event/6618/
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816
CEPC Baseline Software

Generators (Whizard & Pythia)
Data format & management (LCIO & Marlin)
Simulation (MokkaC)
Digitizations
Tracking
PFA (Arbor)
Single Particle Physics Objects Finder (LICH)
Composed object finder (Coral)
Tau finder
Jet Clustering (FastJet)
Jet Flavor Tagging (LCFIPLus)
Event Display (Druid)
General Analysis Framework (FSClasser)
Fast Simulation (Delphes + FSClasser)

CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)
Status of simulation-performance study

<table>
<thead>
<tr>
<th></th>
<th>Geant4-Simulation</th>
<th>Digitization</th>
<th>Reconstruction</th>
<th>Performance-Object</th>
<th>Performance-Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-Silicon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APODIS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

See Chengdong Fu's talk
Performance at
Lepton
Kaon
Photon
Tau
JET

Arbor & Objects

Physics Objects

---


---

Applied on Higgs physics, et.al

Precision Higgs Physics at CEPC

Initial assessments of Higgs physics potential at the CEPC based on the white paper (to be submitted)

Tracking

- Per mille level momentum resolution -> per mille level mass resolution for H->mumu

See Mingrui Zhao's talk

CEPC-RECO-2018-003
Critical energy to separate an evenly decay $\pi_0$: 30 GeV

*See Hang Zhao's talk*
Photon: resolution

- A Higgs mass resolution of 1.7/2.5\% is achieved in the Higgs to di-photon final states with simplified/baseline geometry

- The geometry defects correction could be efficiently corrected (Preliminary)

See Yuqiao Shen’s talk
Tau finding at hadronic events

TAURUS (Tau ReconstrUction toolS): an overall efficiency*purity higher than 70% is achieved for $qq\tau\tau$, and $qq\tau\nu$ events

See Zhigang Wu's talk
Jets

• Boson Mass Resolution: Total reconstructed mass of hadronic events
  - 3.8% at baseline (benchmarked with vvH, H→gluons process)
  - Be applied directly to event with one color singlet
    • W, Z, H signal separation at lvqq, ll(vv)+qq events (Appreciated in Triplet Gauge Boson Coupling measurements)
    • Analysis of qqH, Higgs decays into non-jet final states, for example, qqH, H→taus, inv, photons, muons...
    • ...
  • Jet Clustering: Single jet response (Jet energy scale/resolution)
    - Differential measurements with jet directions
    - Events with more than one color singlet:
      • WW/ZZ/ZH event separation in 4-jet final state
      • ...
Massive Boson Separation

WW sample: using $\mu\nu q\bar{q}$ sample, Plot: the visible mass without the muon

See Peizhu Lai’s talk

CEPC Preliminary

CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),

An Analysis Example: $g(H\tau\tau)$ at qqH

- TAURUS: di-tau system
- The rest particles are identified as the di-jet: to distinguish the ZZ/ZH background & **improves the accuracy by more than a factor of 2**
- Isolated tracks are intentionally defined as tau candidate: be distinguished by the VTX

![Graphs showing analysis results]

**Table 6** Cut Flow of MC sample for qqH → $\tau\tau$ selection on signal and inclusive SM backgrounds, $E_{Le}/E_{Lm}$ represents the energy of the leading electron or muon, $M_{\tau\tau}^{col}$ is the $\tau\tau$ mass calculated with collinear approximation, Pull1 and Pull2 are the pulls of the leading $\tau$ pairs.

<table>
<thead>
<tr>
<th></th>
<th>2f</th>
<th>sw</th>
<th>sz</th>
<th>WW</th>
<th>ZZ</th>
<th>$qH\tau\tau$</th>
<th>total Bkg</th>
<th>$\sqrt{S+B}/S$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Statistic</td>
<td>722467499</td>
<td>17600512</td>
<td>8181853</td>
<td>45834351</td>
<td>5552013</td>
<td>43526</td>
<td>799636228</td>
<td>64.96</td>
</tr>
<tr>
<td>NCh&lt;10</td>
<td>246181175</td>
<td>12413358</td>
<td>1776493</td>
<td>42431059</td>
<td>4996124</td>
<td>42697</td>
<td>307798209</td>
<td>41.09</td>
</tr>
<tr>
<td>110GeV &lt; $E_{\text{Re}} &lt; 235GeV$</td>
<td>156540856</td>
<td>11866685</td>
<td>850064</td>
<td>28223344</td>
<td>2736725</td>
<td>41647</td>
<td>200217674</td>
<td>33.97</td>
</tr>
<tr>
<td>65GeV &lt; $E_{Le} &lt; 45GeV$, $E_{Lm} &lt; 65GeV$</td>
<td>152933720</td>
<td>3078507</td>
<td>637385</td>
<td>20225454</td>
<td>2464417</td>
<td>39762</td>
<td>179339683</td>
<td>33.68</td>
</tr>
<tr>
<td>$N_{+} &gt; 0$, $N_{-} &gt; 0$</td>
<td>361749</td>
<td>191343</td>
<td>12624</td>
<td>1018569</td>
<td>105854</td>
<td>20212</td>
<td>1690139</td>
<td>6.47</td>
</tr>
<tr>
<td>90GeV &lt; $M_{\tau\tau}^{col}$ &lt; 160GeV</td>
<td>8762</td>
<td>19373</td>
<td>1521</td>
<td>122226</td>
<td>36453</td>
<td>15489</td>
<td>188335</td>
<td>2.91</td>
</tr>
<tr>
<td>70GeV &lt; $M_{\tau\tau}^{col}$ &lt; 90GeV</td>
<td>1439</td>
<td>3715</td>
<td>912</td>
<td>24188</td>
<td>31244</td>
<td>14660</td>
<td>61498</td>
<td>1.88</td>
</tr>
<tr>
<td>$M_{\text{rec}} (GeV) &gt; 100GeV$</td>
<td>0</td>
<td>1319</td>
<td>573</td>
<td>9853</td>
<td>8424</td>
<td>14619</td>
<td>20299</td>
<td>1.27</td>
</tr>
<tr>
<td>Pull1 &gt; 0, Pull2 &gt; 0</td>
<td>0</td>
<td>590</td>
<td>238</td>
<td>3426</td>
<td>6266</td>
<td>12402</td>
<td>10520</td>
<td>1.22</td>
</tr>
</tbody>
</table>

See Dan Yu's Poster

BMR < 4% (baseline of 3.8%) is crucial
Jet Energy Scale & Resolution

- JES ~ with 1% of the unity (without correction)
- JER ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
- Both Superior to LHC experiments by 3-4 times

See Peizhu Lai’s talk
Can we separate the full hadronic WW/ZZ events: Yes!...

- Force all reconstructed particles into 4 jets, identify the event with minimal chi-2. Preliminary Jet clustering optimization is performed to minimize Overlap Area

- Separation power is mainly limited by the Jet-Clustering

See YongFeng Zhu's talk
Summary

• CEPC, a super Higgs/W/Z factory, requests high **efficiency, purity, and precision** reconstruction of all key physics objects
  - Tracker & Calorimeter intrinsic resolution: better is better!
  - BMR < 4% is crucial

• Performance at the baseline (APODIS + Arbor) fulfills the physics requirements
  - All key physics objects tamed
  - Clear Higgs signature in all SM Higgs decay modes
  - Clear distinguish between the Signal and SM backgrounds → 0.1% – 1% relative error in Higgs coupling measurements

• To do
  - Reconstruction - Optimization, iterate with detector design: to address the challenges at TDR
  - Identification of jet, jet flavor, gluon jet, and **color singlet**
  - Data preservation, deep learning, parallel computing
  - Lots of challenges & excitements
Many Thanks to

C. Fu, Geant 4 & Tracking
X. Zhao, Software & production
Dan, Lepton ID, Tau, PFA
P. Lai, Jet Calibration
F. An, Pid & Flavor
Z. Wu, VTX Optimization
H. Liang, Generator
Y. Wang, Calo optimization

Y. Shen, Photon
M. Zhao, Tracking, TPC,
G. Li, Generator & Flavor tagging
H. Zhao, Calo Optimization & PFA Clustering
Y. Zhu, Jet
T. Zhen, K_short & Lambda
M. Ruan, PFA, Object,

See also:

Xianghu Zhao & Mingrui Zhao's talks on Software/production
Taifan Zhen's talk on Ks & Λ reconstruction
Hao Liang & Fenfen An's talks on Higgs/Flavor benchmark analysis
YueXin Wang's Poster on Alternative Calorimeter study
backup
**Leptons**

**BDT method using 4 classes of 24 input discrimination variables.**

Test performance at: Electron = E\_likeness > 0.5 ; Muon = Mu\_likeness > 0.5

Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

Kaon

Highly appreciated in flavor physics @ CEPC Z pole
TPC dEdx + ToF of 50 ps

At inclusive Z pole sample:
Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

Photons - conversion

In the barrel region: Roughly 6-10% of the photons converts before reaching the Calorimeter.
Jet Energy Resolution

Amplitude ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
Depends on the Flavor, direction and jet energy
Superior to LHC experiments by 3-4 times

11/11/18

2018 International CEPC Workshop
Flavor Tagging

- Using LCFIPlus Package from ilcsoft
- At Higgs->2 jet samples:
  - Clear separation between different decay modes
- Typical Performance at Z pole sample:
  - B-tagging: eff/purity = 80%/90%
  - C-tagging: eff/purity = 60%/60%
Two catalogues:
- Leptonic environments: i.e, $ll\tau\tau(ZZ/ZH), \nu\nu\tau\tau(ZZ/ZH/WW), Z\rightarrow\tau\tau$;
- Jet environments: i.e, $ZZ/ZH\rightarrow qq\tau\tau, WW\rightarrow qq\nu\tau$;

Ph.D thesis: D. Yu, reconstruction of leptonic objects at $e^+e^-$ Higgs factory
An ILD-like detector at the CEPC

- Different collision environments/rates:
  - MDI design & Implementation: CEPC-SIMU-2017-001

- The CEPC Event rate is significantly higher than linear colliders, charged kaon id can strongly enhance the CEPC flavor physics program
  - TPC Feasibility: JINST-12-P07005 (2017)

- No power pulsing at CEPC detector
  - A significant reduction of the readout channel, especially the Calorimeter Granularity: JINST-13-P03010 (2018)
  - HCAL Optimization

- 3 Tesla Solenoid: requested by the Accelerator/MDI
APODIS Geometry
Width of the Light jets: 6GeV/8GeV (Left/Right Plots)
Physics Objects: Tamed

Higgs mass/GeV

PHOTON

LEPTON

KAON

TAU

BMR

JER

JET FLAVOR
Higgs Signal at APODIS

240GeV
ννHiggs, Higgs→μμ
Mean 125
Sigma 0.240

CEPC-RECO-2018-002
CEPC-Doc id 174, 175

Lepton tracks & Photon Clusters

CEPC CDR
ννH, H→γγ

Baseline
Intrinsic
Higgs to bb, cc, gg (Jets)

- $\nu\nu$Higgs, $\nu\nu\rightarrow bb$
  - Mean: 125 ± 0.042
  - Sigma: 4.508 ± 0.037
  - 3.6%

- $\nu\nu$Higgs, $\nu\nu\rightarrow cc$
  - Mean: 125 ± 0.034
  - Sigma: 4.796 ± 0.032
  - 3.8%

- $\nu\nu$Higgs, $\nu\nu\rightarrow di-gluon$
  - Mean: 125 ± 0.029
  - Sigma: 4.696 ± 0.025
  - 3.8%
Higgs to WW, ZZ (Jets + leptons + neutrinos)

Table 2. Benchmark resolutions ($\sigma$/Mean) of reconstructed Higgs boson mass, comparing to LHC results.

<table>
<thead>
<tr>
<th></th>
<th>Higgs $\rightarrow \mu\mu$</th>
<th>Higgs $\rightarrow \gamma\gamma$</th>
<th>Higgs $\rightarrow bb$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEPC (APODIS)</td>
<td>0.20%</td>
<td>2.59%(^1)</td>
<td>3.63%</td>
</tr>
<tr>
<td>LHC (CMS, ATLAS)</td>
<td>~2% [19, 20]</td>
<td>~1.5% [21, 22]</td>
<td>~10% [23, 24]</td>
</tr>
</tbody>
</table>

\(^1\) primary result without geometry based correction and fine-tuned calibration. [https://arxiv.org/abs/1806.04992](https://arxiv.org/abs/1806.04992)
Higgs benchmark analyses

\[ \sigma(\ell^+\ell^-) \text{ measurements} \]

\[ \text{Br}(H \to \mu\mu) \]

\[ \text{Br}(H \to WW) \]

\[ \sigma(vvH) \times \text{Br}(H \to bb) \]

\[ \text{Br}(H \to \tau\tau) \text{ (Asimov)} \]