Physics Summary

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IJCLab and DMLab
May 19, 2023
LCWS

• Preparations
• Top
• Higgs
• Beyond
ECFA Study: KEY4HEP

- Physics, Physics Analysis Tools, Detectors
- Meetings:
  - https://indico.cern.ch/category/14055/
  - October 11-13, 2023 Paestum (south of Naples)
  - https://agenda.infn.it/event/34841/

Happy to work with C^3

Muon Collider

Started studies with ilcsoft will move to KEY4HEP

\[ E_{\text{JET}} = E_{\text{TRACK}} + E_{\gamma} + E_{n} \]

Many areas for fruitful collaboration:
- High granular calorimetry
- ParticleFlow reconstruction
- ...

Beam induced Background of course different
Different effects:
- Beamstrahlung
- Pair production of electrons/muons/hadrons
- Overlay due to bunch spacing

Expect and “observed” ILC/10
Whizard

“Workhorse” of the electron-positron studies

- NLO Automation (EW and QCD for ee)
- NLO differential fixed order
- Generic NLO-QCD Powheg like matching
- Top threshold: NLO-NLL QCD matched

- Improvements user interface.…
- Whizard on GPUs

Sherpa

One of the main generators used at LHC

- Now working on lepton version
- YFS resummation compared to KKMC

- NLO and NNLO with GRIFFIN (muon pairs)

<table>
<thead>
<tr>
<th></th>
<th>Born</th>
<th>YFS</th>
<th>YFS+Recola</th>
<th>YFS+GRIFFIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>2114.5 pb</td>
<td>1463.09 pb</td>
<td>1494.7(8) pb</td>
<td>1497.5(7) pb</td>
</tr>
</tbody>
</table>

- Validated against MADGRAPH
- To be released soon
- Includes Polarization
Tuning Pythia8

Goal: Move from Whizard1.95+Pythia6 to Whizard3+Pythia8

- Tune to Z data: Pythia8 standard best
- Test NLO Powheg of Whizard:

Modeling Center-of-Mass Energy Precision using Dimuons and Bhabhas at ILC

- Combine GuineaPig with Generator
- Final state: Muon pairs, electron pairs

Evaluating Detector and Physics Limitations on Center-of-Mass Energy Determination in e+e- Colliders Using Dileptons

\[ \sigma / \sqrt{s} = 0.1216 \pm 0.0004\% \text{ (cf 0.1217\% in TDR (0.190\% \oplus 0.152\%))/2} \]

Tracking detectors designed for ILC have the potential to measure beam energy related quantities with precision similar to the intrinsic energy spread using dimuon events (and also especially wide-angle Bhabha events).
Top Quark ATLAS

Differential and total cross sections

\[
\sigma_{t\bar{t}} = 859 \pm 4 \text{ (stat)} \pm 22 \text{ (syst)} \pm 19 \text{ (lumi)} \text{ pb}
\]

\[
\sigma_{tt\bar{t}\bar{t}} = 22.5^{+6.6}_{-5.5} \text{ fb}
\]

\[
\sigma_{t\gamma} \times B (t \rightarrow \ell v b) + \sigma_{t\rightarrow\ell v b q} = 303 \pm 9 \text{ (stat)}^{+33}_{-32} \text{ (syst)} \text{ fb}
\]

Mass measurement

\[
m_{t\bar{t}} = 172.21 \pm 0.20 \text{ (stat)} \pm 0.67 \text{ (syst)} \pm 0.39 \text{ (recoil)} \text{ GeV}
\]

Charge Asymmetry (prediction 1%)

\[
A^t_C = \frac{N(\Delta |y_{t\bar{t}}| > 0) - N(\Delta |y_{t\bar{t}}| < 0)}{N(\Delta |y_{t\bar{t}}| > 0) + N(\Delta |y_{t\bar{t}}| < 0)}
\]

\[
A^t_C = 0.0068 \pm 0.0015 \text{ (stat + syst)}
\]
Higgs Boson with CMS

$mh = 125.38 \pm 0.14$ GeV
Spin 0, Spin1 excluded 99.999% CL
Couplings: standard

Width via off-shell method:

$$\Gamma_H = 3.2^{+2.4}_{-1.7} \text{ MeV},$$

Projection HL-LHC

Probing EWSB with ATLAS

Sophisticated analyses with BDTs
Combined for three channels: 2.4

Combine with single Higgs

Definitely standard

HL-LHC:
Expected significance 3.4$\sigma$

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HL-LHC:
Expected significance 3.4$\sigma$
Revisit analysis:
- Improved b tagging
- Kinematic fitting with better error parametrization

Clear case for high energy

ILC CP Higgs in Fusion

- $\mathbf{ZZ}$ fusion (2 electrons)
- Background eliminated
- 68% efficiency
Motivation: N2HDM Model = THDM+real singlet
CMS 95GeV di-photon and di-tau

\[
\begin{align*}
&\text{BR}_{h_1}^{bb} & \text{BR}_{h_1}^{qq} & \text{BR}_{h_1}^{\ell\ell} & \text{BR}_{h_1}^{\tau\tau} \\
&0.005 & 0.348 & 0.198 & 0.412
\end{align*}
\]

Search for tau decays collinear approximation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Events expected</th>
<th>Events expected after</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presel.</td>
<td>Z mass</td>
<td>$h_1$ + rec</td>
</tr>
<tr>
<td>Signal</td>
<td>1738.75</td>
<td>1168.28</td>
<td>702.356</td>
</tr>
<tr>
<td>$q\bar{q}q$</td>
<td>150.922</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$q\bar{q}l\nu$</td>
<td>491142</td>
<td>2917.88</td>
<td>208.42</td>
</tr>
<tr>
<td>$q\ell\nu$</td>
<td>70134.4</td>
<td>444.201</td>
<td>0</td>
</tr>
<tr>
<td>$q\bar{q}ll$</td>
<td>17053.6</td>
<td>678.604</td>
<td>44.256</td>
</tr>
<tr>
<td>$q\bar{q}\tau\tau$</td>
<td>13011.5</td>
<td>7503.45</td>
<td>3219.26</td>
</tr>
<tr>
<td>$q\ell\nu\nu$</td>
<td>34.3705</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$h_2$</td>
<td>2552.55</td>
<td>895.052</td>
<td>22.1</td>
</tr>
<tr>
<td>Total</td>
<td>594079</td>
<td>12439.2</td>
<td>3494.39</td>
</tr>
</tbody>
</table>

With improved tau algorithm:

- many new physics models predict one/ several scalars below 125 GeV
- typical decays into $b\bar{b}$, $\tau^+\tau^-$
- cross sections could reach up to 50 fb from $Zh$ production
- decays of $h_{125} \rightarrow ss$ also within reach
- important connection to EWSB/ EW phase transitions

What if???
P-even, CP-violating Signals in Scalar-Mediated Processes

- Are new sources of CP violation present in the Higgs sector?
- P-even CP violation can arise in extended Higgs sectors
- Need to measure simultaneously:

1. $h_2 H^+ H^-$, $h_3 H^+ H^-$, $Zh_2 h_3$, (for $k = 2$ or 3),
2. $h_2 h_k h_k$, $h_3 H^+ H^-$, $Zh_2 h_3$, (for $k = 2$ or 3),
3. $h_2 h_k h_f$, $h_3 h_f h_f$, $Zh_2 h_3$, (for $k, f = 2$ or 3).

- Calls for high energy

Multi-photon signatures
THDM to determine CP

- A2HDM
- Interesting signature

Howard Haber

Kento Katayama

 Calls for high energy

ILC ($\sqrt{s} = 500$ GeV)

Excluded by the eEDM

$|\lambda_7|$
Electroweak Baryogenesis in aligned THDM

\[ \lambda_6 = 0 \]

A2HDM

\[
\begin{align*}
\lambda_1 & = \frac{M_2^2}{v^2} + \frac{\lambda_3 + \lambda_4 + \text{Re} \lambda_5}{2} \text{Re} \lambda_6 - \frac{1}{2} \text{Im} \lambda_5 \\
\lambda_2 & = \frac{M_2^2}{v^2} + \frac{\lambda_3 + \lambda_4 - \text{Re} \lambda_5}{2} \\
\lambda_5 & = \text{Re} \lambda_6
\end{align*}
\]

Test also CP in
- Gravitational Waves
- EDM
- Flavour

Calls for high energy

Radiative corrections impact on extended Higgs sectors

<table>
<thead>
<tr>
<th>125GeV Higgs</th>
<th>CP-even</th>
<th>CP-odd</th>
<th>Charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h \to ff )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( h \to VV )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( h \to Zh )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( A \to VV )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( H^\pm \to W^\pm 2\ell )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( h \to AA/H^+H^- )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>( H \to ZZ/WW )</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

Calculations made available in H-COUP v3
Jan Klamka  Long lived Particles with ILD

Z decay to muons

<table>
<thead>
<tr>
<th>$\Delta m$</th>
<th>1 GeV</th>
<th>2 GeV</th>
<th>3 GeV</th>
<th>5 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tot. eff. (correct / decays within TPC acceptance)</td>
<td>3.9%</td>
<td>37%</td>
<td>52.2%</td>
<td>60.4%</td>
</tr>
<tr>
<td>Correctness (correct / all found)</td>
<td>96.4%</td>
<td>97.4%</td>
<td>98.8%</td>
<td>98.6%</td>
</tr>
</tbody>
</table>

Long-lived, with $c\tau = 1$ m

Axion-like-particle and a photon

High efficiency

Search for hidden sectors

$C_2(\Delta y, \Delta \phi) = \frac{S(\Delta y, \Delta \phi)}{B(\Delta y, \Delta \phi)}$

Thrust axis used
Teresa Nunez

ILC Search for Staus

Supersymmetric partner of tau as NLSP

Keita Yumino

Tau Polarisation

Measurement of tau polarization measures asymmetry

Promising new method of reconstruction
Extensive searches in a multitude of signatures

**ATLAS BSM**

- Higgsino pairs
- top-philic resonances
- ALP
- Clockwork

**Presented here:**

- Large radius jets
- No Ambulance in sight

---

**CMS BSM**

Extensive searches in a multitude of signatures

**LFV: X → eμ**

**We shall see**
Heavy Neutrinos at ILC

Production and Decay:

BDT analysis:

ILC can probe the nature of the heavy neutrino

RH neutrino pair-production at ILC

Majorana with additional Z’

Lepton # violation is possible!

Same sign leptons possible

Very small SM BG!

Exclusion guaranteed 😊

Needs high energy
BSM physics at ILC250/500 with ILD

- Hadronic fraction
- Forward-backward asymmetry

- Improved TPC $dE/dx$

H2O, both pol., $b$ & $c$ quarks, $\sqrt{s}$=250&500 GeV

Good separation power against models

Isosinglet vectorlike leptons

$e^+e^- \rightarrow \tau^+\tau^-$, $ZZ\tau^+\tau^-$, $h\tau^+\tau^-$, $Z\tau^+\tau^+ + E'$, $hW^\pm\tau^\mp + E'$, $W^\pm W^\mp + E'$ (largest!)

Nice illustration of the use of in-person conference: better understanding of detector simulation!

Includes Beamstrahlung and ISR
XCC: XFEL Compton $\gamma\gamma$ Collider Higgs Factory

• 30-350TW optical laser
• 16.5GeV XFEL electron beam
• Effective Field $10^{14}$V/m

Revisiting the photon collider:
• XFELs+electron beams
• Lower CME
• Resonant production of Higgs
• One particle less to reconstruct
• Threshold for HH lower

Deviation from pert.QED (passing Schwinger limit)

Optical Beam Dump experiment: new physics search
• Good for ILC
• Uses ILC technology
• Uses ILC detector developments