Introduction to FCC-hh physics studies

Heather Gray, Filip Moortgat

FCC Week in Amsterdam, April 2018
Main goal of this afternoon’s sessions: preview the material that will enter the "Physics Benchmarks" section of the FCC-hh CDR.

+ two presentations of ongoing analyses at the end of each session
FCC-hh CDR 2018

- Required for end 2018, as input for European Strategy Update
- Common physics summary volume
- Three detailed volumes FCChh, FCCee, HE-LHC
- Three summary volumes FCChh, FCCee, HE-LHC

You are here! U bevindt zich hier!
FCC-hh Physics Benchmark Studies

1.1 Introduction
Heather Gray, Filip Moortgat

Discussion on physics motivation of the benchmark channels.

1.2 Higgs and Electroweak Symmetry Breaking

1.2.1 Higgs Properties
Responsible: Michele Selvaggi

1.2.1.1 $H \rightarrow ZZ$
1.2.1.2 $H \rightarrow \gamma \gamma$
1.2.1.3 $H \rightarrow Z \gamma$
1.2.1.4 $H \rightarrow \mu \mu$

1.2.2 tH Production
Responsible: Michele Selvaggi, Valentin Volli, Clement Helsens

1.2.2.1 $t\bar{t}H$, $H \rightarrow \gamma \gamma$
1.2.2.2 $t\bar{t}H$, $H \rightarrow multijets$
1.2.2.3 $t\bar{t}H$, $H \rightarrow hh$ (hoasted)?

1.2.3 Measurement of di-Higgs production
Responsible: Michele Selvaggi, Sylvie Brabant, Giacomo Orsina, Biagio Di Meco, Nicola De Filippis, et al.

1.2.3.1 $HH \rightarrow bb\gamma\gamma$
1.2.3.2 $HH \rightarrow bbWW / bbZZ$

1.2.3.4 $HH \rightarrow bb\nu\nu$
1.2.3.5 $HH \rightarrow bbbh$ (hoasted)

1.2.4 Measurement of Vector Boson Scattering
Responsible: Andre Szajder, et al.

1.3 Searches for new physics

1.3.1 Resonances: $ee, \mu\mu, jj$
Responsible: Clement Hebsens, Michele Selvaggi

1.3.2 Resonances: $WW, t\bar{t}$
Responsible: Clement Hebsens, Michele Selvaggi

1.3.3 Supersymmetry: stop search
Responsible: Lukas Goszczos

1.3.4 Dark Matter: monojet + DM, $t\bar{t}$ + DM, VBF + DM
Responsible: Phil Harris

1.3.5 Dark Matter: disappearing tracks
Responsible: Ryu Sawada, Koji Terashi, Masahiko Saito

Repository in Overleaf
~20 pages of material at this point, still a few sections missing
CDR physics benchmarks

CDR benchmarks: Higgs and EWSB

Measurement of Higgs properties
- $H \rightarrow ZZ$, $H \rightarrow \gamma\gamma$, $H \rightarrow Z\gamma$, $H \rightarrow \mu\mu$
- $t\bar{t}H, H \rightarrow \gamma\gamma$, $t\bar{t}H, H \rightarrow$ multileptons, $t\bar{t}H$, $H \rightarrow bb$ (boosted)

Measurement of di-Higgs production
- $HH \rightarrow bb\gamma\gamma$, $HH \rightarrow bbWW / bbZZ$, $HH \rightarrow bb\tau\tau$, $HH \rightarrow bbbb$ (boosted)

Measurement of Vector Boson Scattering

Talk by Michele Selvaggi

Talk by Giacomo Ortona

Also covered in Michele’s talk
Choice of benchmarks

Why all the Higgs channels?
→ interesting to measure with high precision. Standalone + synergy with FCC-ee.
→ Higgs is “low mass” object at FCC-hh → benchmark for detector acceptance

Why all the di-Higgs channels?
→ FCC-hh is only machine that can probe Higgs self-coupling to high precision (~4%)

E.g.: use H→ZZ to define muon acceptance

E.g.: use VBF Higgs to define calorimeter acceptance

Pseudorapidity of the most forward muon in H→ZZ*→4mu, at 13 TeV and 100 TeV

Pseudorapidity of the most forward VBF jet in VBF Higgs production, at 13 TeV and 100 TeV
Searches for new physics
- Resonances: $ee$, $\mu\mu$, $jj$
- Resonances: $WW$, $t\bar{t}$
- Supersymmetry: stop
- Dark Matter: monojet + DM, $t\bar{t}$ + DM
- Dark Matter: disappearing tracks

CDR benchmarks: BSM searches

Talk by Clement Hensens
Talk by Loukas Gouskos
Talk by Ryu Sawada
Choice of benchmarks

Why Z’ resonances?
→ occur in many models of new physics
→ drives high-p_T detector performance

Why supersymmetric top partner?
→ because it has to be below ~ 10 TeV, if tan β >~ 4
  (to keep m_h ~ 125 GeV)
→ great test bench for high-p_T top tagging

Why focus on Dark Matter?
→ thermal WIMP: wino up to ~3 TeV, Higgsino up to ~1.1 TeV
  (above that: too much DM in the Universe)

Why both monojet and disappearing track analysis?
→ because disappearing track analysis is needed to reach the highest
  WIMP masses
→ monojet analysis also targets H→invisible decays

Can we reach this?
Can we reach this?
Monojet analysis

Short reminder of status of monojet analysis:

Developments since FCC week 2017:
• now using the official FCC-hh Delphes card
• apart from monojet channel, also the ttH and VBF H channel were studied.

Targets DM and also invisible Higgs decays

For more details: see presentations at the 2017 FCC week and at the FCC physics week last January

Phil Harris
Monojet: background prediction

Key: simultaneous fit of $Z \rightarrow \mu\mu$, $Z \rightarrow ee$, $W \rightarrow ev$, $W \rightarrow \mu\nu$ and $\gamma+jets$

Needs precise calculation of differential $W/Z$ and gamma/Z ratios at 100 TeV

1% precision reasonable assumption

Phil Harris

e.g.: arxiv/1705.04664
Monojet result

Expt. sys.: 0.5%/0.25%/5% e/μ/τ efficiency & 1% lumi

H → ZZ → 4 neutrinos "wall" reached at ~ 1 ab⁻¹

Higgs invisible of 10⁻⁴ corresponds to g_{SM} from 10⁻³ to 10⁻²
All physics studies in the CDR are based on a Delphes card that parametrizes the performance of a baseline FCC-hh detector.

Note: FCC-hh Delphes card was frozen more than a year ago. Actual detector design may have evolved since then, but the performance should be roughly similar.
FCC-hh baseling tracking

Tracking performance

20% @10 TeV
FCC-hh baseline ECAL

ECAL performance

<table>
<thead>
<tr>
<th>FCCChh Delphes</th>
<th>CMS Delphes</th>
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<tbody>
<tr>
<td>$0 &lt; \eta &lt; 2.5$</td>
<td>$0 &lt; \eta &lt; 3.0$</td>
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<tr>
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<td>$3.0 &lt; \eta &lt; 5.0$</td>
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<tr>
<td>$4.0 &lt; \eta &lt; 6.0$</td>
<td>$0.0 &lt; \eta &lt; 1.5$</td>
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<table>
<thead>
<tr>
<th>$\sigma(\eta,\phi)$</th>
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<tr>
<td>$0.0125$</td>
<td>$0.02$</td>
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<td>$0.025$</td>
<td>$0.175 \pm 0.35$</td>
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<table>
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<tr>
<th>$\alpha(\text{E}/\text{E})$</th>
<th>$\alpha(\text{E}/\text{E})$</th>
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<tbody>
<tr>
<td>$10% / \sqrt{E} \oplus 0.7%$</td>
<td>$5% / \sqrt{E} \oplus 0.5%$</td>
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<tr>
<td>$30% / \sqrt{E} \oplus 3.5%$</td>
<td>$200% / \sqrt{E} \oplus 10%$</td>
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FCC-hh baseline HCAL

HCAL performance

<table>
<thead>
<tr>
<th>FCChh</th>
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<th>$\sigma(E)/E$</th>
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<td>$0 &lt;</td>
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![Graph showing HCAL resolution for FCChh and CMS](image1.png)

![Graph showing HCAL resolution for CMS](image2.png)
FCC-hh baseline Particle Flow

Particle Flow + Jet Performance

Michele Selvaggi
FCC-hh baseline muons

Muon performance

Does the detector really matter? Could we just make a new CMS/ATLAS?
FCC-hh baseline b-tagging

\(b\)-tagging performance

![FCChh Delphes](image1)

![CMS Delphes](image2)
FCC-hh physics analysis meeting:

There is a bi-weekly informal meeting to discuss FCC-hh physics analysis studies, with a focus on the CDR but also beyond. If you are interested in attending, please join the fcc-experiments-hadron@cern.ch email list to keep informed about the dates & topics that will be discussed.

How to get started on 100 TeV Physics studies?

• Pick a topic from the list of 100 TeV Physics Channels:
  https://docs.google.com/document/d/1I7SbsqleXnuyPvhqMjPeiy8qsFdz8LoxQLEQYxbrNIU/edit

• Follow the FCC Pythia + Delphes + Heppy tutorial:
  http://fccsw.web.cern.ch/fccsw/tutorials/fcc-tutorials/FccFullAnalysis.html

• Check the MC event database:
Many thanks to all the people who have been actively involved in the Physics analysis studies in the past year!

Michele Selvaggi, Clement Helsens, David Jamin, Valentin Volkl, Michelangelo Mangano, Andre Sznajder, Loukas Gouskos, Allan Sung, Joe Incandela, Sylvie Braibant, Biagio Di Micco, Giacomo Ortona, Nicola De Filippis, Phil Harris, Kristian Hahn, Ryu Sawada, Koji Terashi, Masahiko Saito, Lev Dudko, MaksimPerfilov, Petr Mandrik, Ilkay Cakir, Orhan Cakir, …
• FCC-hh physics analysis working group has been focusing on studying a number of physics benchmarks in the context of the FCC-hh CDR

• Preview of the results in the upcoming presentations

• Plan to have a first complete draft of the Physics Benchmark chapter in the coming weeks

• Plenty more analysis topics to study. Please get in touch if you’re interested!