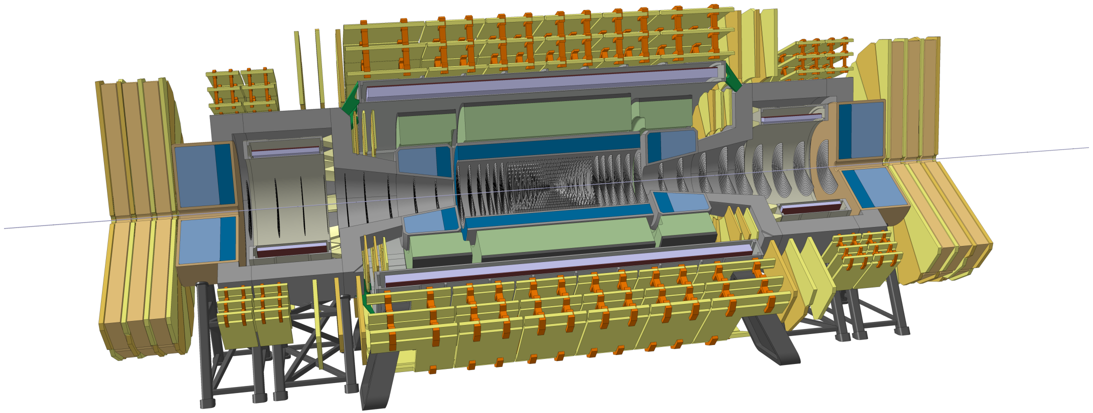
Introduction to FCC-hh physics studies

Heather Gray, Filip Moortgat



FCC Week in Amsterdam, April 2018

This session

Main goal of this afternoon's sessions: preview the material that will enter the "Physics Benchmarks" section of the FCC-hh CDR.

Introduction to FCC-hh physics analysis stud...	*Filip Moortgat*
Higgs and Electroweak symmetry breaking at the FCC-hh	*Michele Selvaggi*
Measurement of the Higgs Self-C...	*Dr Giacomo Ortona*
Rare top quark decays at a 100 TeV proton-proton collider	

Heavy resonance searches at the FCC-hh	*Clement Helsens*
Top squark searches at 100 TeV	*Loukas Gouskos*
Dark Matter: disappearing tracks	*Ryu Sawada*
Single Production of Charged Higgs Boso...	*Ilkay Turk Cakir*

+ two presentations of ongoing analyses at the end of each session

FCC-hh CDR 2018

1 – PHYSICS

Physics opportunities across all scenarios

2 Hadron Collider Summary

3 – Hadron Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment
- eh

4 Lepton Collider Summary

5 – Lepton Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment

6 High Energy LHC Summary

7 – High Energy LHC Comprehensive

- Accelerator
- Injectors
- Infrastructure

Refs to FCC-hh, HL-LHC, LHeC

You are here!
U bevindt zich hier!

- **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**

CDR outline: physics benchmarks

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
Reponsible: Michele Selvaggi

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

1.2.2 ttH Production
Reponsible: Michele Selvaggi, Valentin Volkl, Clement Helsens

1.2.2.1 $t\bar{t}H, H \to \gamma\gamma$
1.2.2.2 $t\bar{t}H, H \to$ *multileptons*
1.2.2.3 $t\bar{t}H, H \to bb$ *(boosted) ?*

1.2.3 Measurement of di-Higgs production
Reponsible: Michele Selvaggi, Sylvie Braibant, Giacomo Ortona, Biagio Di Micco, Nicola De Filippis, *et al.*

1.2.3.1 $HH \to bb\gamma\gamma$
1.2.3.2 $HH \to bbWW\ /\ bbZZ$
1.2.3.4 $HH \to bb\tau\tau$
1.2.3.5 $HH \to bbbb$ *(boosted)*

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

1.3 Searches for new physics

1.3.1 Resonances: ee, $\mu\mu$, jj
Reponsible: Clement Helsens, Michele Selvaggi

1.3.2 Resonances: WW, $t\bar{t}$
Reponsible: Clement Helsens, Michele Selvaggi

1.3.3 Supersymmetry: stop search
Reponsible: Loukas Gouskos

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

1.3.5 Dark Matter: disappearing tracks
Reponsible: 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 $\rightarrow$Zγ, 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)

Talk by Michele Selvaggi

Measurement of di-Higgs production

- HH $\rightarrow$bb$\gamma\gamma$, HH $\rightarrow$ bbWW / bbZZ, HH $\rightarrow$ bb$\tau\tau$, HH $\rightarrow$bbbb (boosted)

Talk by Giacomo Ortona

Measurement of Vector Boson Scattering $\longrightarrow$ Also covered in Michele's talk

Choice of benchmarks

Why all the Higgs channels?

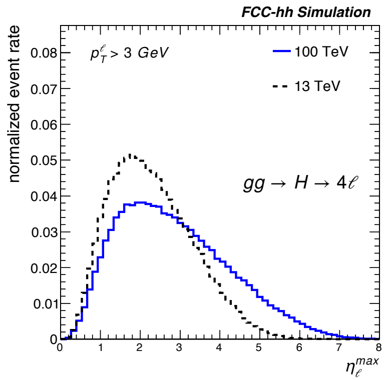
→ interesting to measure with high precision. Standalone + synergy with FCC-ee.

→ Higgs is “low mass” object at FCC-hh → benchmark for detector acceptance

Why all the di-Higgs channels?

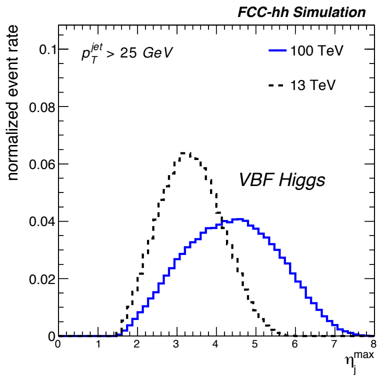
→ FCC-hh is only machine that can probe Higgs self-coupling to high precision (~4%)

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



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

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



Pseudorapidity of the most forward VBF jet in VBF Higgs production, at 13 TeV and 100 TeV

CDR

CDR benchmarks: BSM searches

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

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

Can we reach this?

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)

Can we reach this?

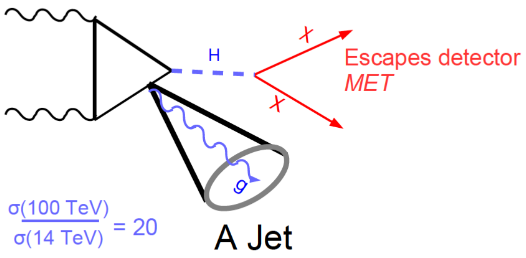
Why both monojet and disappearing track analysis?

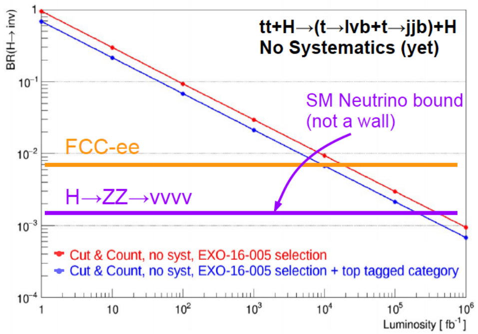
→ because disappearing track analysis is needed to reach the highest WIMP masses

→ monojet analysis also targets H→invisible decays

Monojet analysis

Short reminder of status of monojet analysis:





Targets DM and also invisible Higgs decays

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.

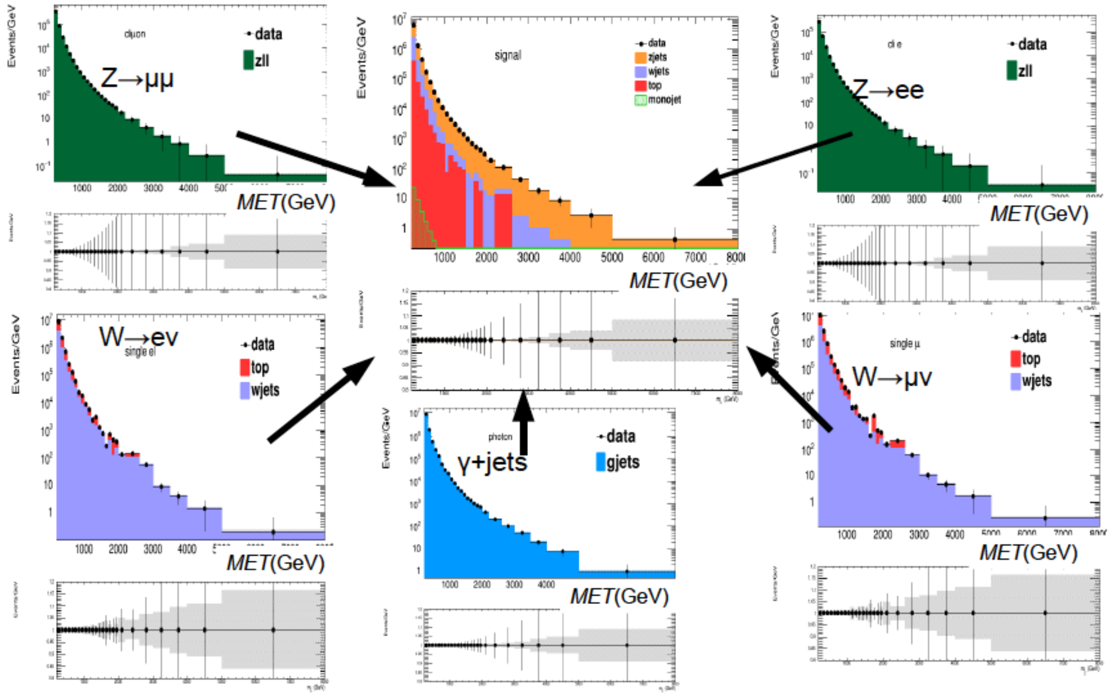
For more details: see presentations at the 2017 FCC week and at the FCC physics week last January

Phil Harris

Monojet: background prediction

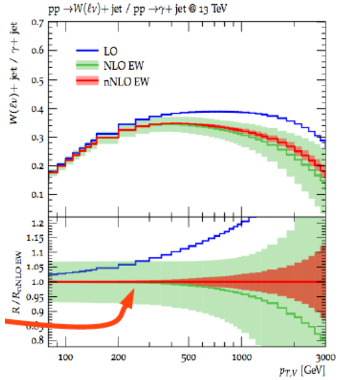
Key: simultaneous fit of Z→μμ, Z→ee, W→ eν, W→ μν and γ+jets

Phil Harris



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

1% precision reasonable assumption

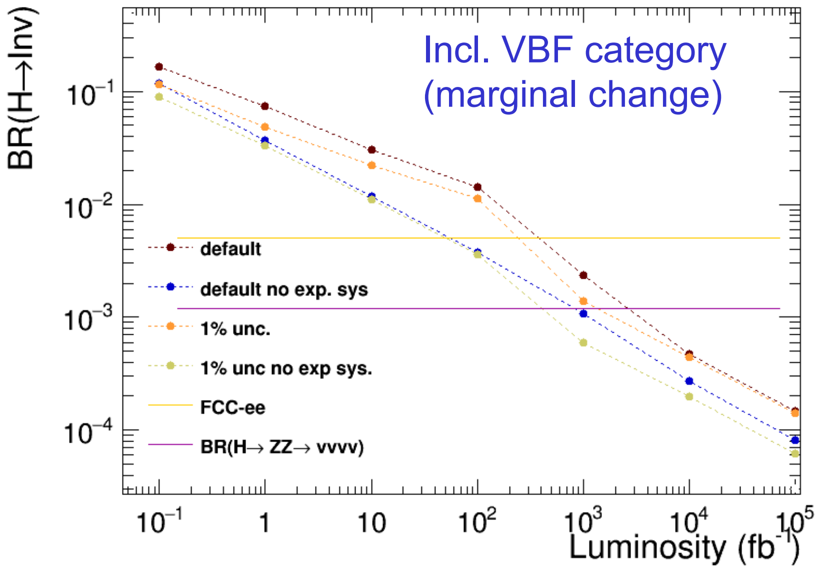


e.g.: **arxiv/1705.04664**

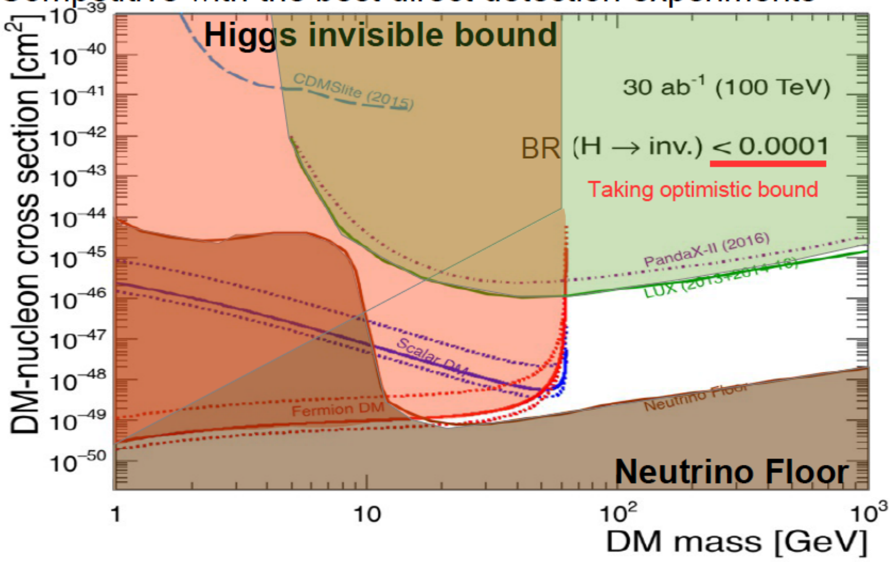
Monojet result

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

Phil Harris



Competitive with the best direct detection experiments



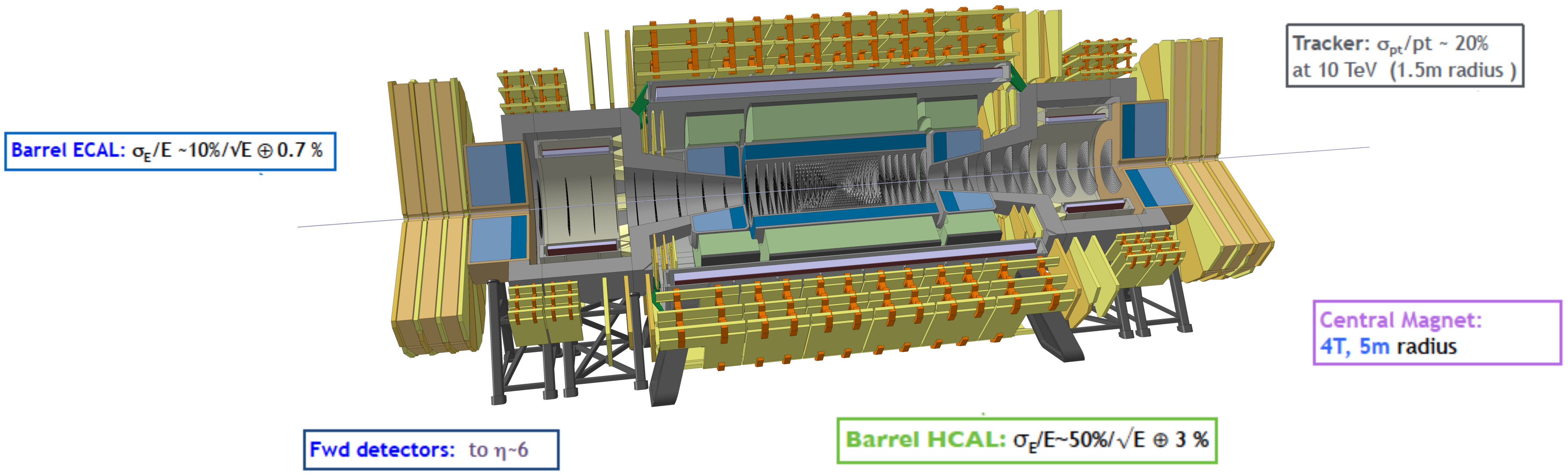
$H \rightarrow ZZ \rightarrow$ 4 neutrinos "wall" reached at ~ 1 ab^{-1}

Higgs invisible of 10^{-4} corresponds to g_{SM} from 10^{-3} to 10^{-2}

FCC-hh baseline detector

All physics studies in the CDR are based on a Delphes card that parametrizes the performance of a baseline FCC-hh detector

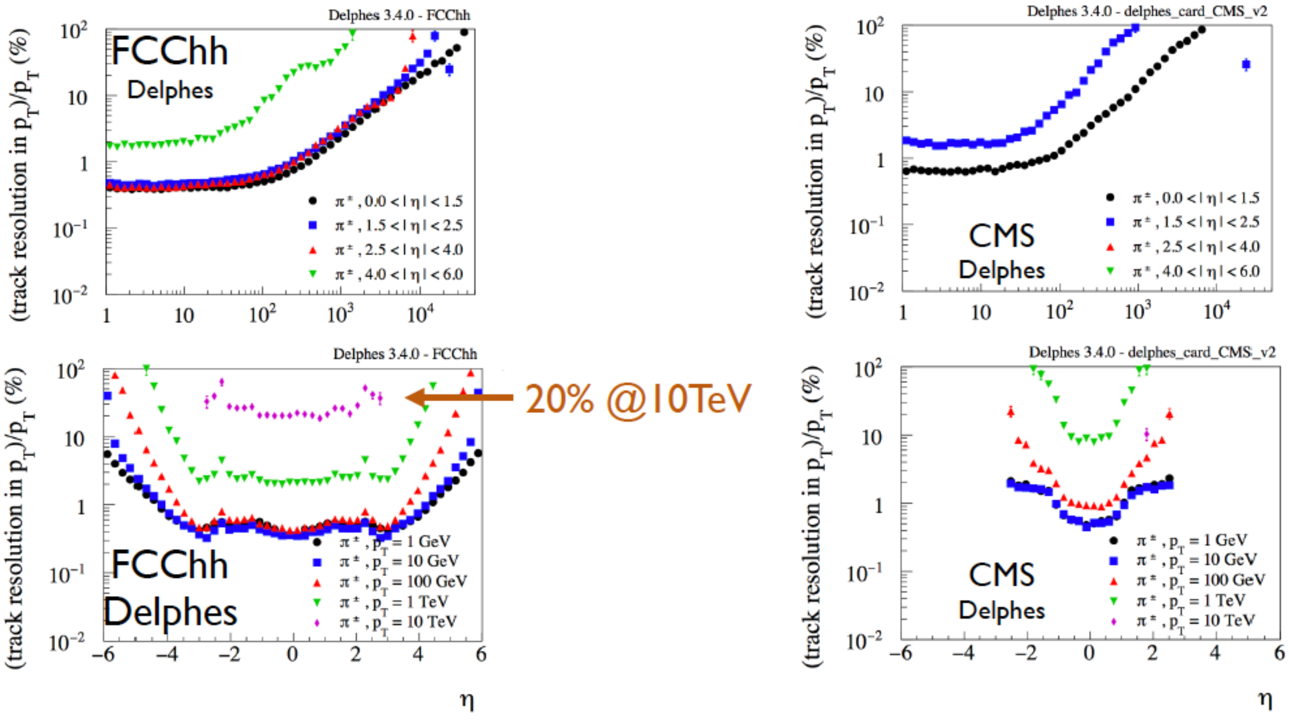
Note: FCC-hh Delphes card was frozen more than a year ago. Actual detector design may have evolved since then, but the performance should be roughly similar.



FCC-hh baseling tracking

Michele Selvaggi

Tracking performance



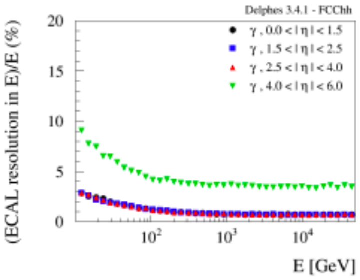
FCC-hh baseline ECAL

Michele Selvaggi

ECAL performance

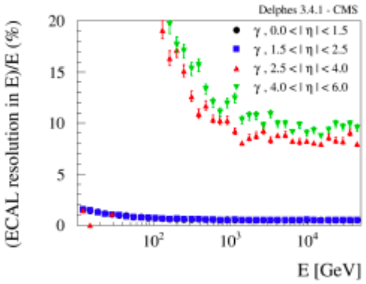
FCChh Delphes

	$\sigma(\eta,\varphi)$	$\sigma(E)/E$
$0 < \lvert\eta\rvert < 2.5$	0.0125	$10\% / \sqrt{E} \oplus 0.7\%$
$2.5 < \lvert\eta\rvert < 4.0$	0.025	$10\% / \sqrt{E} \oplus 0.7\%$
$4.0 < \lvert\eta\rvert < 6.0$	0.025	$30\% / \sqrt{E} \oplus 3.5\%$



CMS Delphes

	$\sigma(\eta,\varphi)$	$\sigma(E)/E$
$0 < \lvert\eta\rvert < 3.0$	0.02	$5\% / \sqrt{E} \oplus 0.5\%$
$3.0 < \lvert\eta\rvert < 5.0$	0.175 - 0.35	$200\% / \sqrt{E} \oplus 10\%$



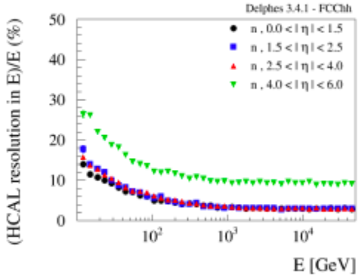
FCC-hh baseline HCAL

Michele Selvaggi

HCAL performance

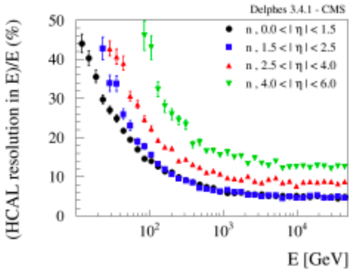
FCChh Delphes

	σ(η,φ)	σ(E)/E
0 < |η| < 2.5	0.025	50% / √E ⊕ 3%
2.5 < |η| < 4.0	0.05	50% / √E ⊕ 3%
4.0 < |η| < 6.0	0.05	100% / √E ⊕ 10%



CMS Delphes

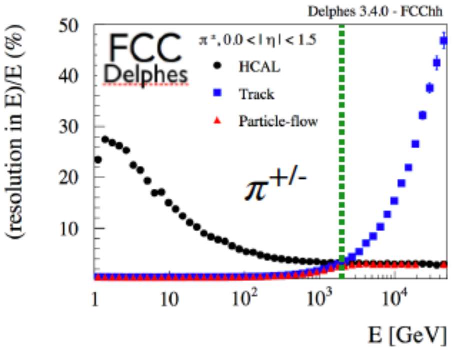
	σ(η,φ)	σ(E)/E
0 < |η| < 1.7	0.08	110 % / √E ⊕ 5%
1.7 < |η| < 3.0	0.175	110 % / √E ⊕ 5%
3.0 < |η| < 5.0	0.175 - 0.35	250% / √E ⊕ 13 %

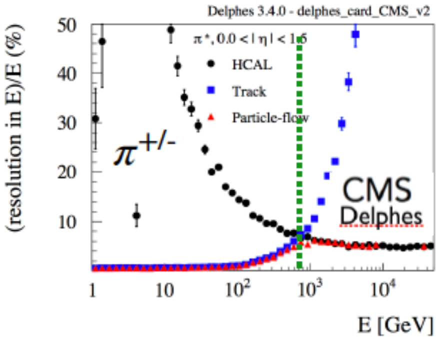


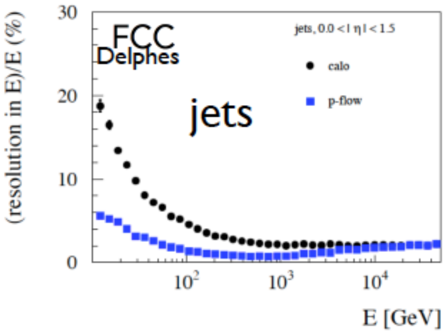
FCC-hh baseline Particle Flow

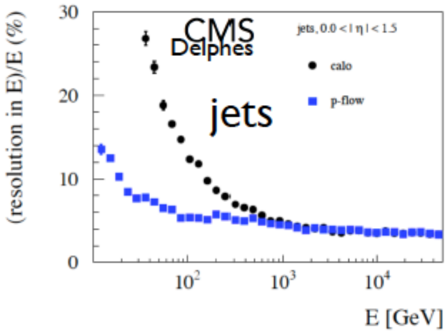
Michele Selvaggi

Particle Flow + Jet Performance



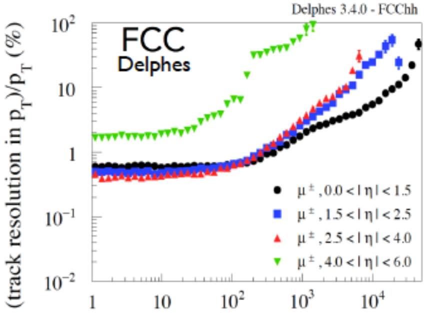


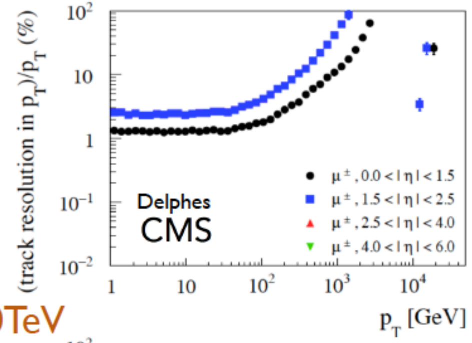




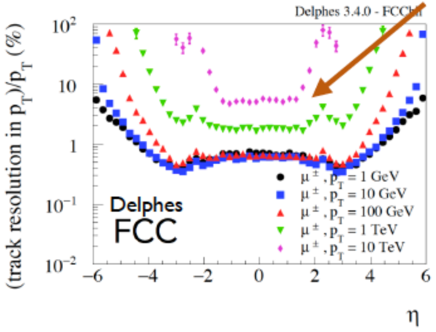
FCC-hh baseline muons

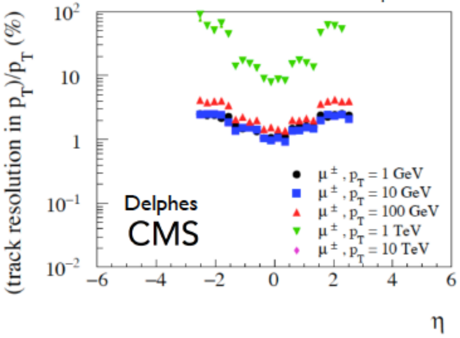
Muon performance



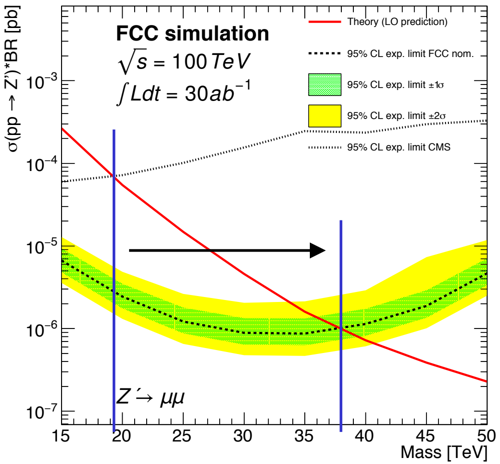


5% @10TeV





Does the detector really matter?
Could we just make a new CMS/ATLAS?



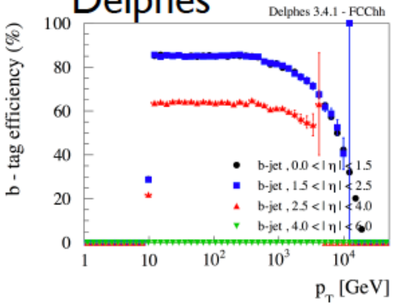
Z' → μμ limit assuming FCC-hh vs. CMS detector performance (both at 100 TeV)

Clement Helsens

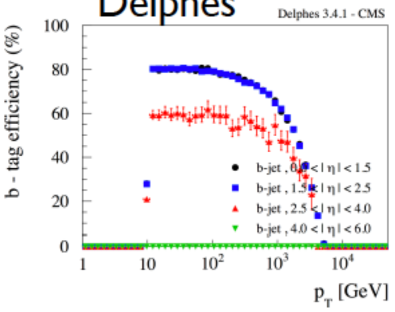
FCC-hh baseline b-tagging

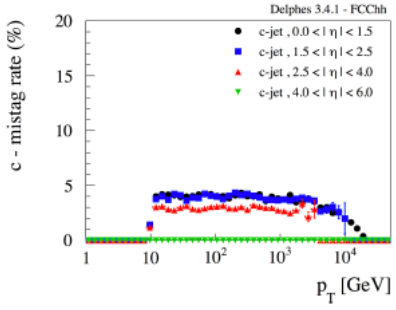
b-tagging performance

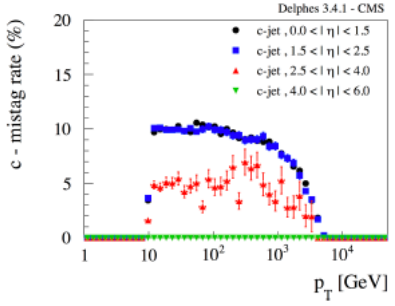
FCChh
Delphes



CMS
Delphes







Reminder

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/1l7SbsqIeXnuyPvhqMjPeiy8qsFdz8LoxQLEQYxbrNIU/edit

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

- Check the MC event database:
  http://fcc-physics-events.web.cern.ch/fcc-physics-events/index.php

Michele Selvaggi
Clement Helsens

Working group

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, Maksim Perfilov, Petr Mandrik, Ilkay Cakir, Orhan Cakir, …

Summary

- 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!