Physics Studies for FCC-hh
Introduction

Filip Moortgat (CERN) and Heather Gray (LBNL)

Physics at the FCC-hh

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider

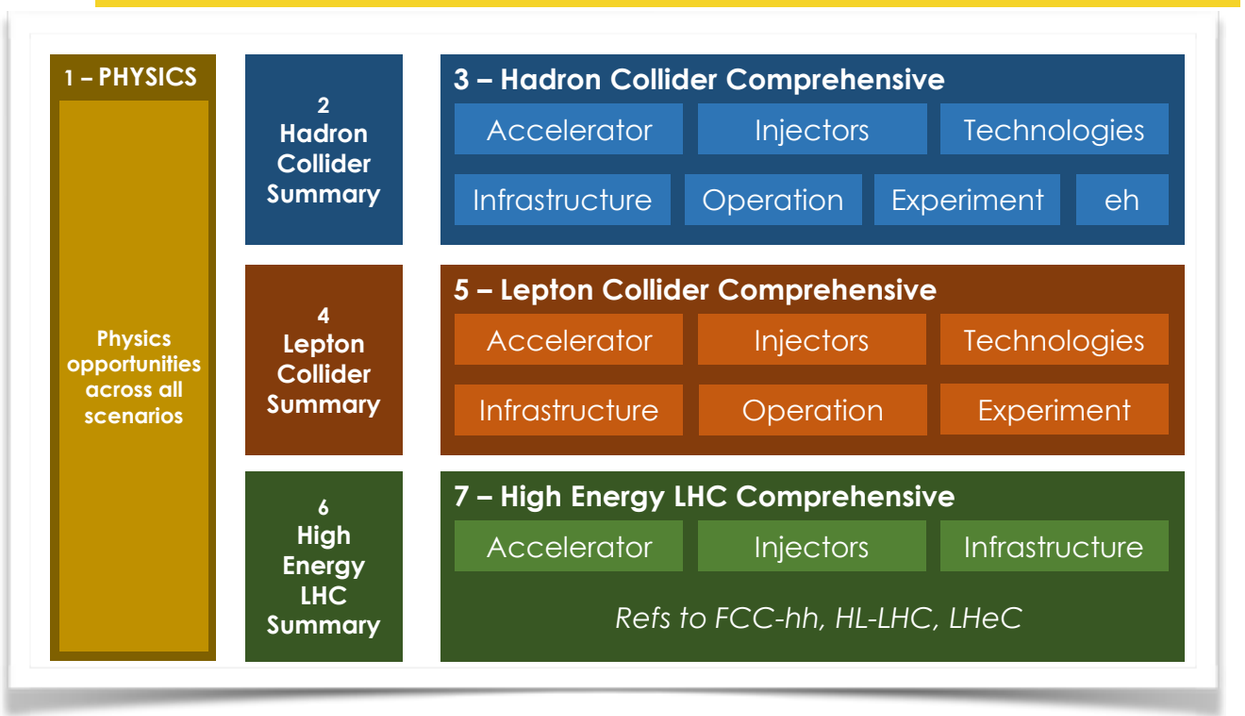
- **Volume 1: SM processes** (238 pages) arXiv:1607.01831
- **Volume 2: Higgs and EW symmetry breaking studies** (175 pages) arXiv:1606.09408
- **Volume 3: beyond the Standard Model phenomena** (189 pages) arXiv:1606.00947
- **Volume 4: physics with heavy ions** (56 pages) arXiv:1605.01389
- **Volume 5: physics opportunities with the FCC-hh injectors** (14 pages)

Physics case of the FCC-hh
see M. Mangano, Wed morning

- Study of Higgs and top quark properties and exploration of **EWSB phenomena**
- **Mass reach** enhanced by factor ~ E / 14 TeV
- Can we answer **Yes/No** questions like this?
  - Is DM a thermal WIMP?
  - Did baryogenesis take place during the EW phase transition?
  - Is the SM dynamics all there is at the TeV scale?
  - Is there a TeV-scale solution to the hierarchy problem?

?

CDR, 2018



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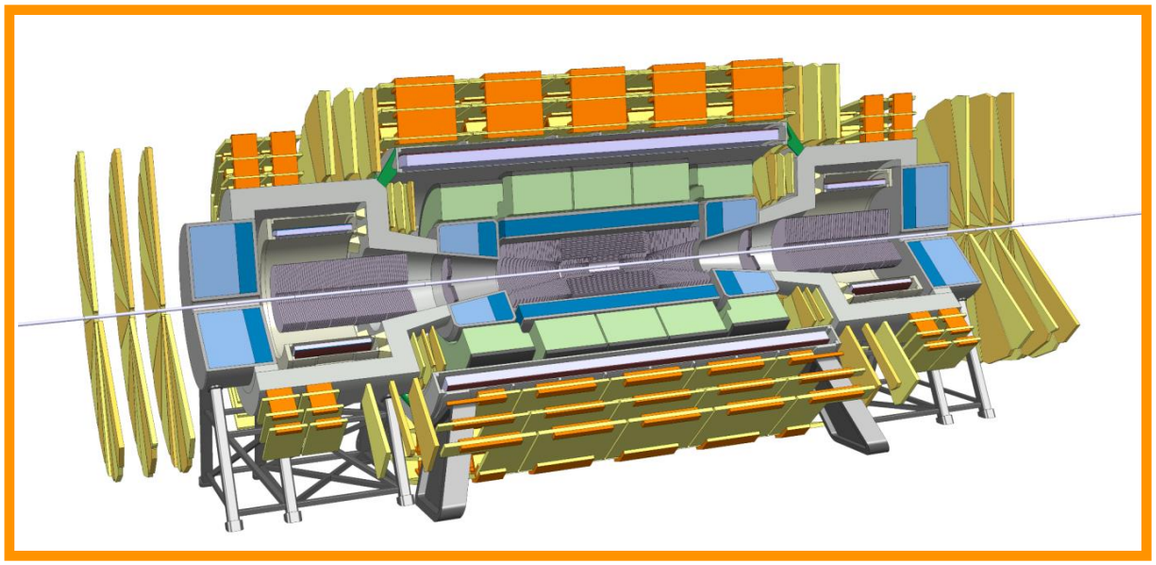
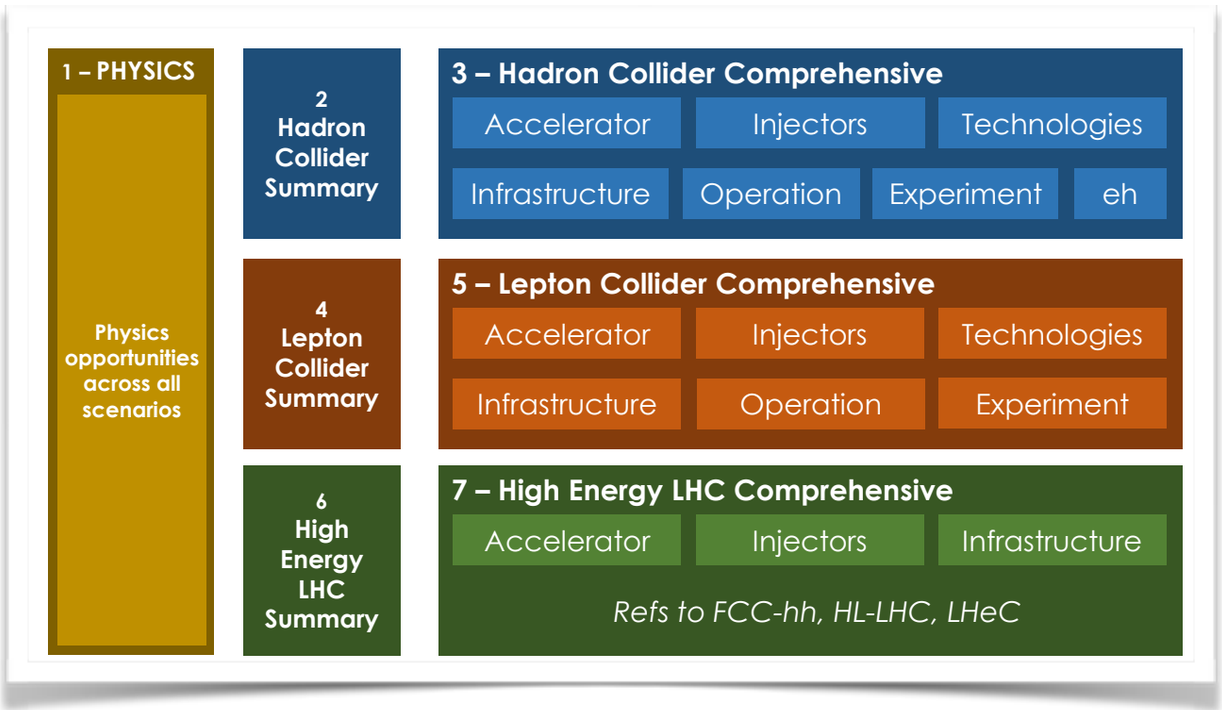
Experimental analysis effort began in mid-2014

Physics analysis studies coordinated by F. Moortgat and H. Gray together with software, detector (W. Riegler) and phenomenology (M. Mangano)

Monthly meetings (since February) announced on fcc-experiments-hadron e-group

Performance assumptions discussed in M. Selvaggi's talk on Wed





FCC-hh TDR Outline

FCC Detector and Experiments CDR Outline

Benchmarks processes, detector requirements from physics
Definition of the benchmark processes with main backgrounds
Detector requirements 'from physics' in terms of
momentum resolution, energy resolutions, acceptance and
objects like e/gamma performance, jet performance, tau, b, Etmiss, Muons, Trigger

Experiment, detector requirements from environment:
Luminosity, radiation environment, luminous region, pileup
Discussion of the reference detector and alternative ideas

Software:
Simulation software for FCC detectors

Magnet systems:
Engineering of reference design and discussion of alternatives

Tracker:
Layout, performance, technology and data rate discussion

EMCAL:
Liquid Argon and Silicon, performance and technology discussion, ideas on digital ECAL

HCAL:
Organic Scintillators, Liquid Argon, SiPM technology, Silicon

Muons:
Principles of trigger versus identifier, standalone and combined performance, technologies

Trigger/DAQ:
Principle concepts in relation to HL-LHC

Physics performance:
DELPHES formulation in relation to ATLAS/CMS Performance for benchmark channels

Cavern and infrastructure:
Cavern and shaft dimensions, installation scenarios, sidecavern, access, safety, shielding, activation, maintenance scenarios

Cost Goals, Strategic R&D:
Extreme radiation environment, large area silicon sensors, high speed links, microelectronics, radiation hard scintillators, Liquid Argon Technology, High precision timing detectors …

Studies from this group will contribute to two sections

Benchmarks

Superset of benchmarks established for the CDR, more details in M. Selvaggi's talk on Wed

Higgs physics & Electroweak Symmetry Breaking
Higgs self-coupling (*bb*ɣɣ, bbττ, *bb+leptons*)
Top-Yukawa: - ttH, H → ɣ ɣ, H → bb
Rare Higgs decays (H → cc, *H → μμ* , *H → Z* ɣ)
"Big Five": Higgs decays (H → *4l, WW ,*ɣ ɣ, ττ, bb)
WW scattering
Other Higgs (*H+/-* → *tb*), A →tt

Strong SUSY
gluinos, squarks: jets + MET, s.s dileptons + jets + MET
stops: 0/1 leptons + jets + MET

Weak SUSY
EW-ino: 3/4 leptons + MET
Higgsino (disappearing tracks)
Dark Matter

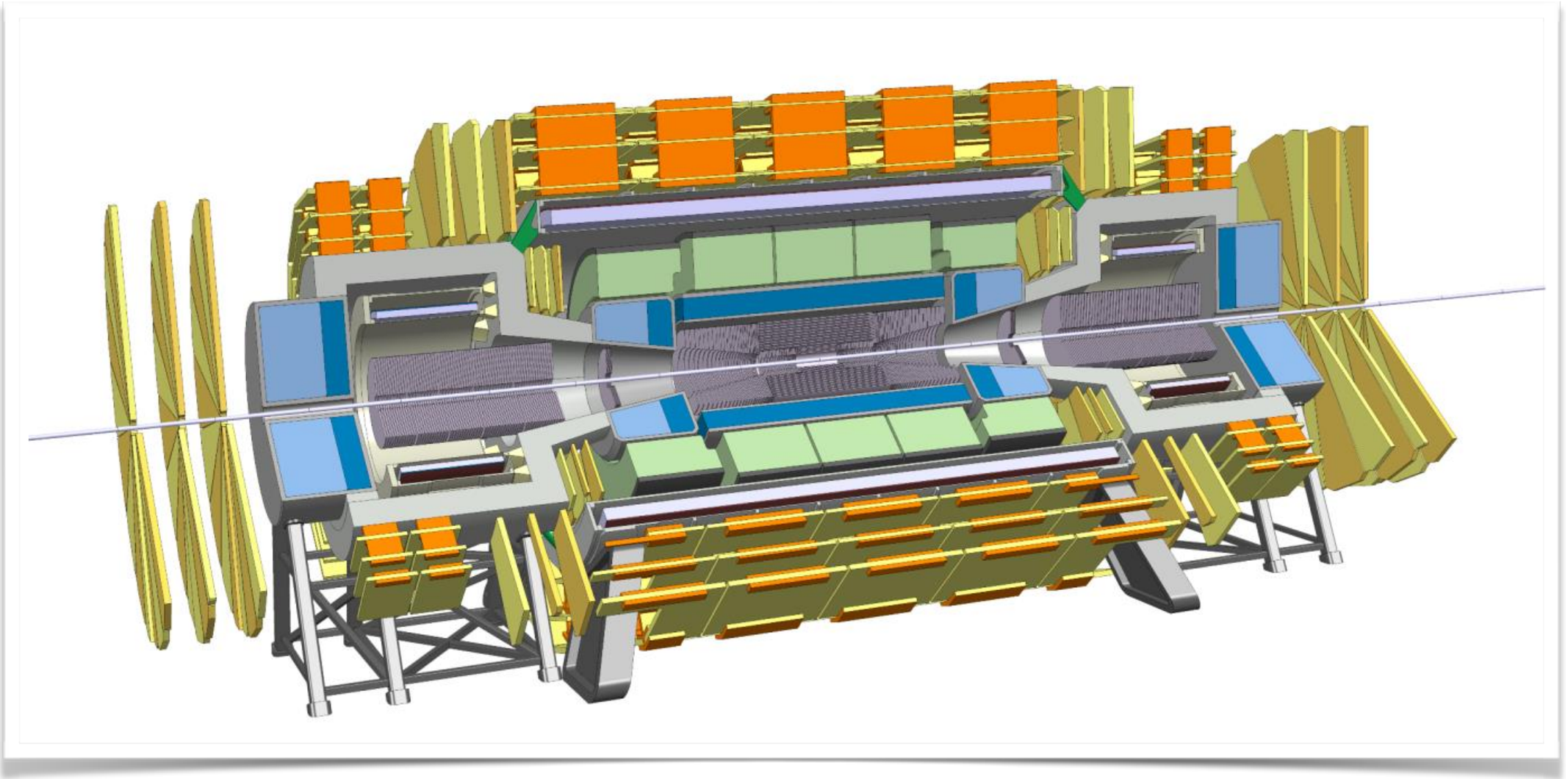
Top physics
tt ɣ /Z
tWb (single top s-channel)
FCNCs
rare decays

Heavy Resonances
Z' → tt, *jj, ee/μμ*:
M_Z = 5, 30 TeV
Diboson
m(q*) = 50TeV

Benchmarks serve one (or both) of these goals:
1) illustrate sensitivity/reach for key physics channels
2) act as a benchmark for detector performance
(calorimeter granularity, momentum resolution, …)

See **talks** in this session by P. Harris, B. di Micco, M. Selvaggi, O. Cakir, R. Sawada
Italics: studies currently ongoing (at least at a minimal level).
There are many opportunities for volunteers to join!

Reference Detector for the CDR



4T, 10m bore solenoid, 4T forward solenoids , no shielding coil

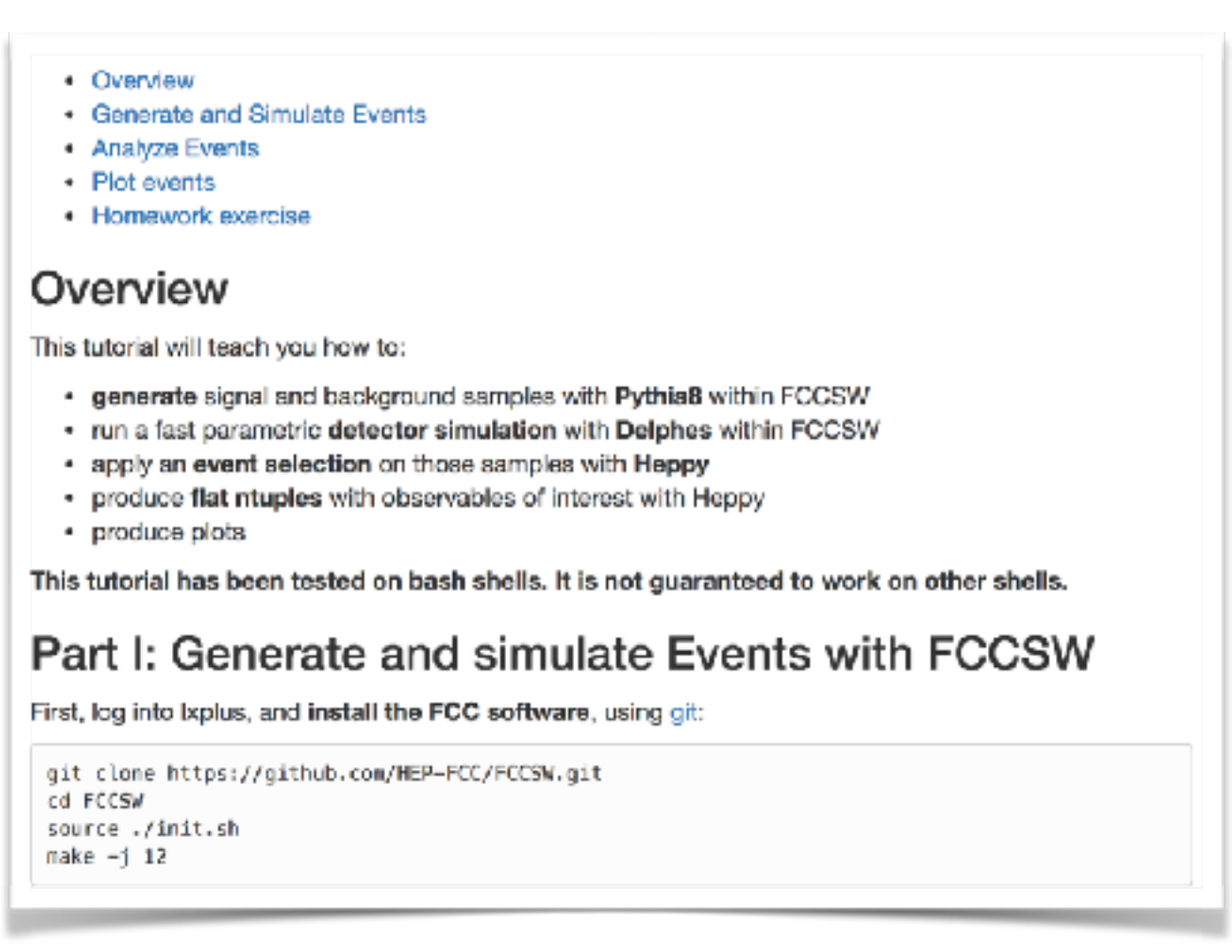
→ 14 GJ Stored Energy
→ Rotational symmetry for tracking and trigger !
→ 20m Diameter (≈ ATLAS)
→ 15m shaft

The performance of this reference detector has been implemented in DELPHES and will be used for the CDR studies

W. Riegler, Mon afternoon

Reminder: Getting started

- Pick a topic from the benchmarks or propose your favourite topic
- Follow the FCC Pythia + Delphes + Heppy tutorial (M. Selvaggi)
  - Note that v0.8.1 of the FCC software was just released
- Check the MC event database (C. Helsens, M. Selvaggi)
  - Les Houches events (many sample available)
  - FCC events (via Delphes) (in progress)



- Overview
- Generate and Simulate Events
- Analyze Events
- Plot events
- Homework exercise

Overview

This tutorial will teach you how to:

- **generate** signal and background samples with **Pythia8** within FCCSW
- run a fast parametric **detector simulation** with **Delphes** within FCCSW
- apply an **event selection** on those samples with **Heppy**
- produce **flat ntuples** with observables of interest with Heppy
- produce plots

This tutorial has been tested on bash shells. It is not guaranteed to work on other shells.

Part I: Generate and simulate Events with FCCSW

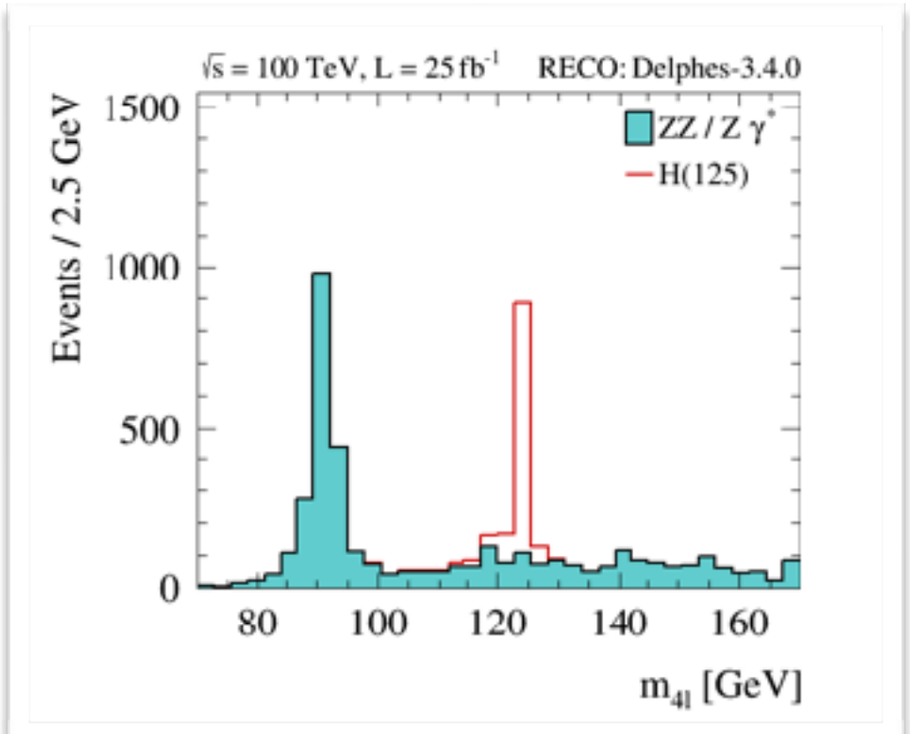
First, log into lxplus, and **install the FCC software**, using git:

```
git clone https://github.com/HEP-FCC/FCCSW.git
cd FCCSW
source ./init.sh
make -j 12
```

Produce H→ZZ plots from scratch within ~20 mins

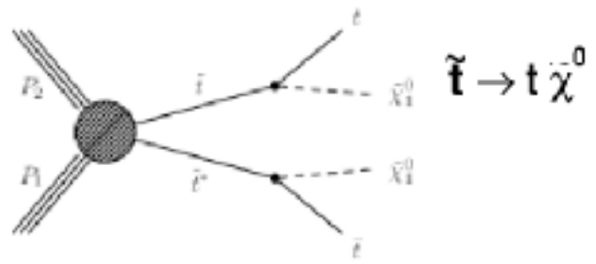
Little software expertise needed

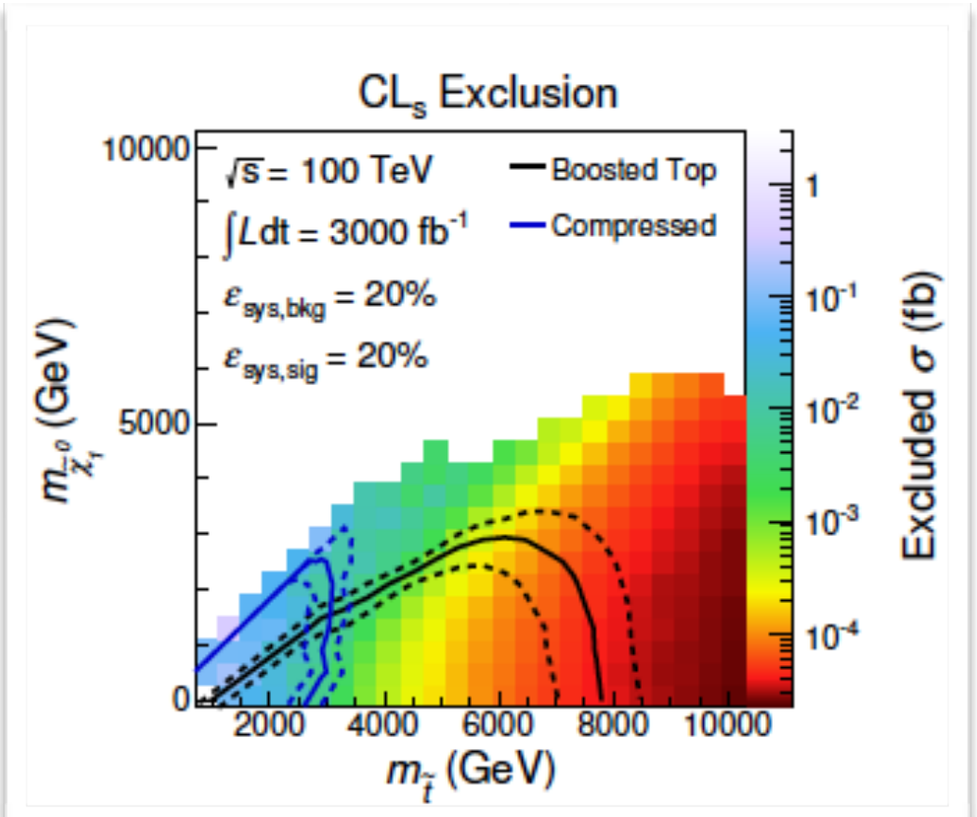
Very low threshold to contribute

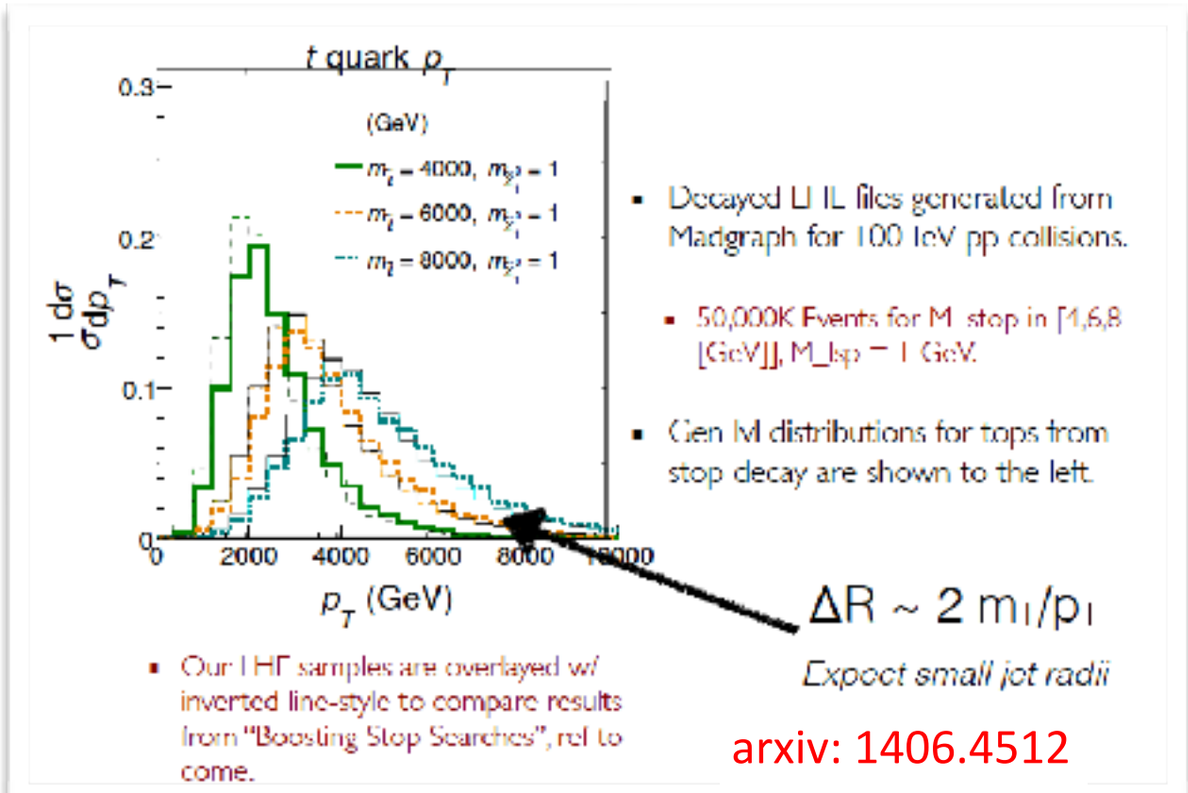


Searches for Supersymmetry: Stop searches

Colegrove/Incandela (UCSB)







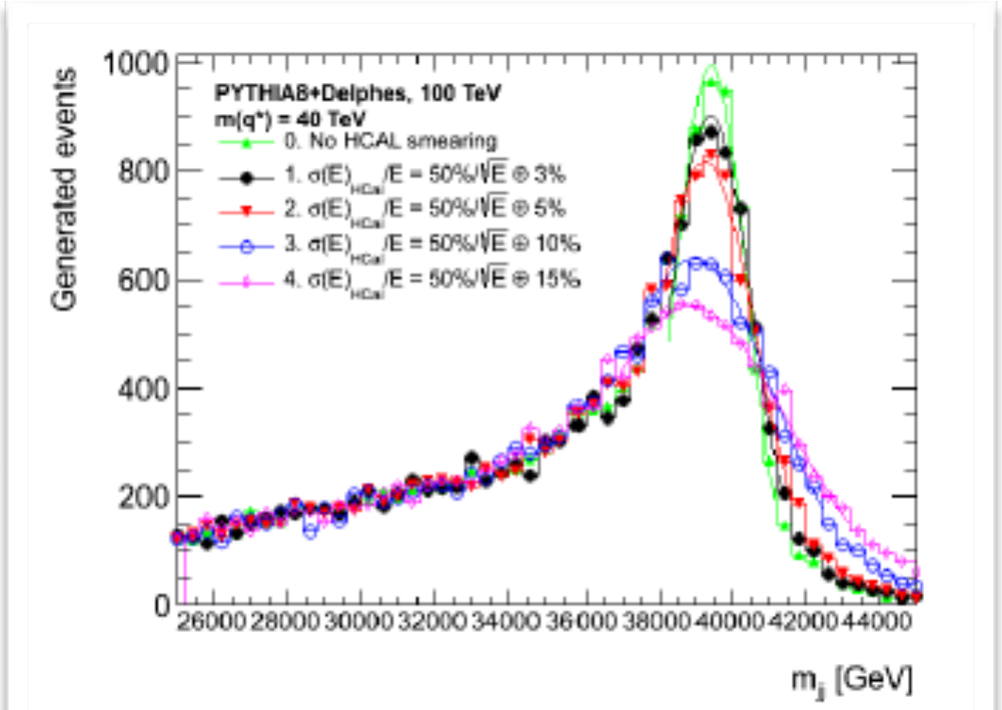
Stop discovery up to ~8 TeV for 30 ab^{-1}
(exclusion ~ 9-10 TeV)

Plan: study boosted top reconstruction (calorimeter granularity dependence?) and consider also a muonic top tagger

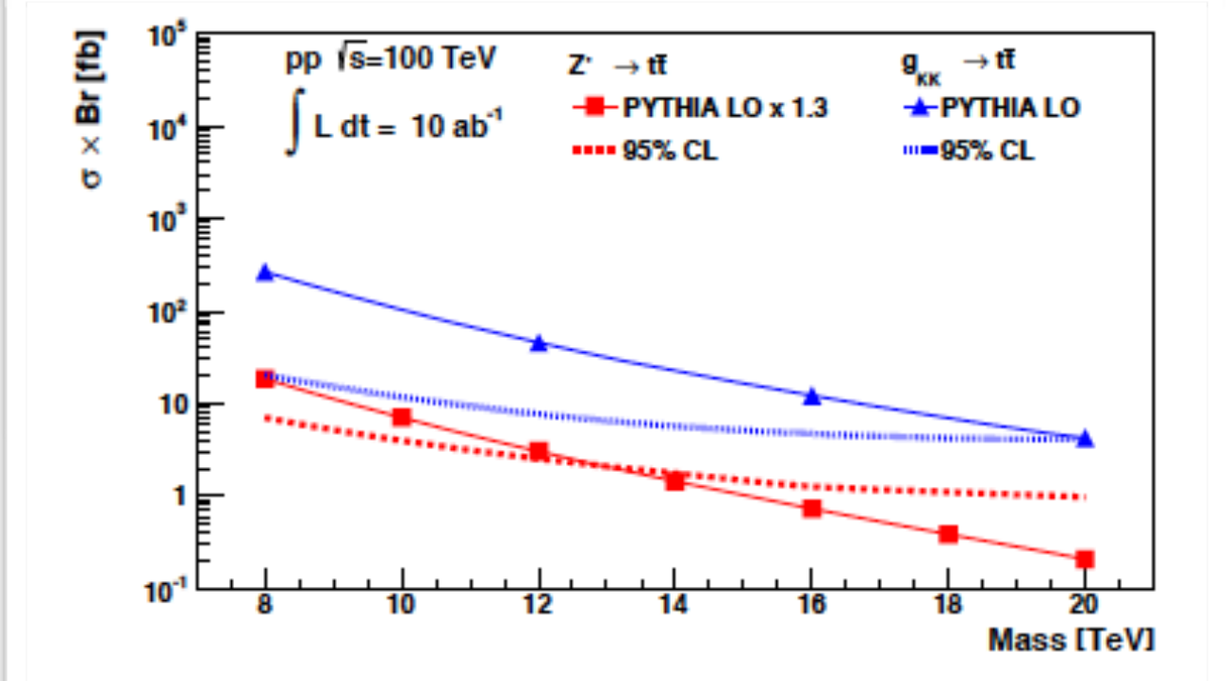
BSM Resonances

- High mass resonances are excellent benchmarks for physics object performance (muons, electrons, jets). Studies may include variations on the reference detector layout
- (e.g. increase/decrease granularity) to understand potential gains/losses.

jj-resonance



tt-resonance



- 2 bachelor students currently working on Z' to ee and mumu
- 4 CERN summer students will work on FCC-hh physics studies

Today's agenda

Introduction	*Filip Moortgat et al.*
"Pavillon"	10:30 - 10:40
Dark Matter searches	*Philip Coleman Harris*
"Pavillon"	10:40 - 11:00
DI-Higgs studies	*Biagio Di Micco*
"Pavillon"	11:00 - 11:15
Higgs properties	*Michele Selvaggi*
"Pavillon"	11:15 - 11:35
Top FCNC	*Orhan Cakir*
"Pavillon"	11:35 - 11:45
Disappearing Track	*Ryu Sawada*
"Pavillon"	11:45 - 11:55