FCC-hh detector, physics benchmarks

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(on behalf of the FCChh group)

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Outline

- FCC-hh Detector
- Event generation
- Physics Benchmarks

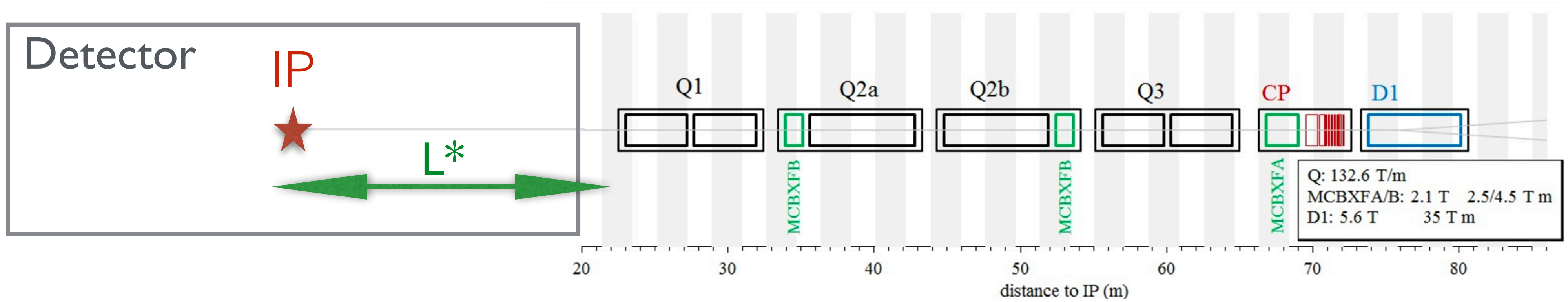
Motivations for FCC-hh

- ## Ultimate discovery machine
  - **directly** probe new physics up to **unprecendented** scale
  - discover/exclude:
    - heavy resonances "strong" m(q*) ≈ 50 TeV, [1606.00947]
      "weak" m(Z') ≈ 30TeV,
    - SUSY m(gluino) ≈ 10 TeV,
      m(stop). ≈ 5 TeV

- ## Precision machine
  - probe Higgs **self-coupling** to few % level, and %-level precision for top yukawa and rare decays
  - measure **SM parameters** with high precision
  - exploit **complementarity with e^+e^-** by probing **high dim.operators** in **extreme kinematic** regimes

[1606.09408]

Towards defining the FCChh detector
Machine constraints



- $L^* = 45$ m
  - Distance between **triplet and IP**
  - determines overall **longitudinal size** of detector

- Luminosity = [5×10^{34} - 30×10^{34}] cm^2s^{-1}
  - low lumi , N_{PU} = 170 (25ns)
  - high lumi , N_{PU} = **1020** (25ns) - 204 (5ns)

radiation

z_{vtx} resolution
CPU time
timing detector?

better for Tracking

Towards defining the FCChh detector

Physics constraints

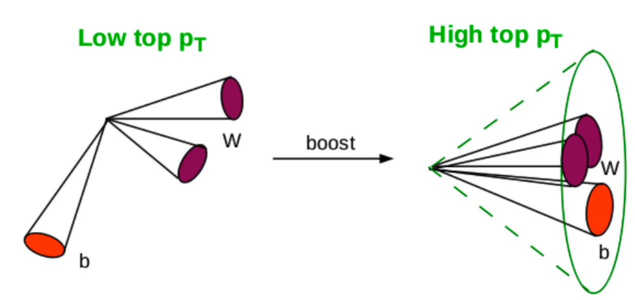
- **Physics objects will be more boosted**

Tracking: $\frac{\sigma(p)}{p} \approx \frac{p\sigma_x}{BL^2}$ calorimeters: $\frac{\sigma(E)}{E} \approx \frac{A}{\sqrt{E}} \bigoplus B$

- Tracking target : achieve **σ / p = 10-20% @10 TeV**
- Keep calorimeter **constant term** as small as possible.
- Long-lived particles live **longer**:

ex: 1 TeV **b-Hadron** travels **10 cm** before decaying
1 TeV **tau lepton** travels **2 cm** before decaying

→ re-think reconstruction, include **dE/dx ?**



Require **high granularity** (both in tracker and calos):

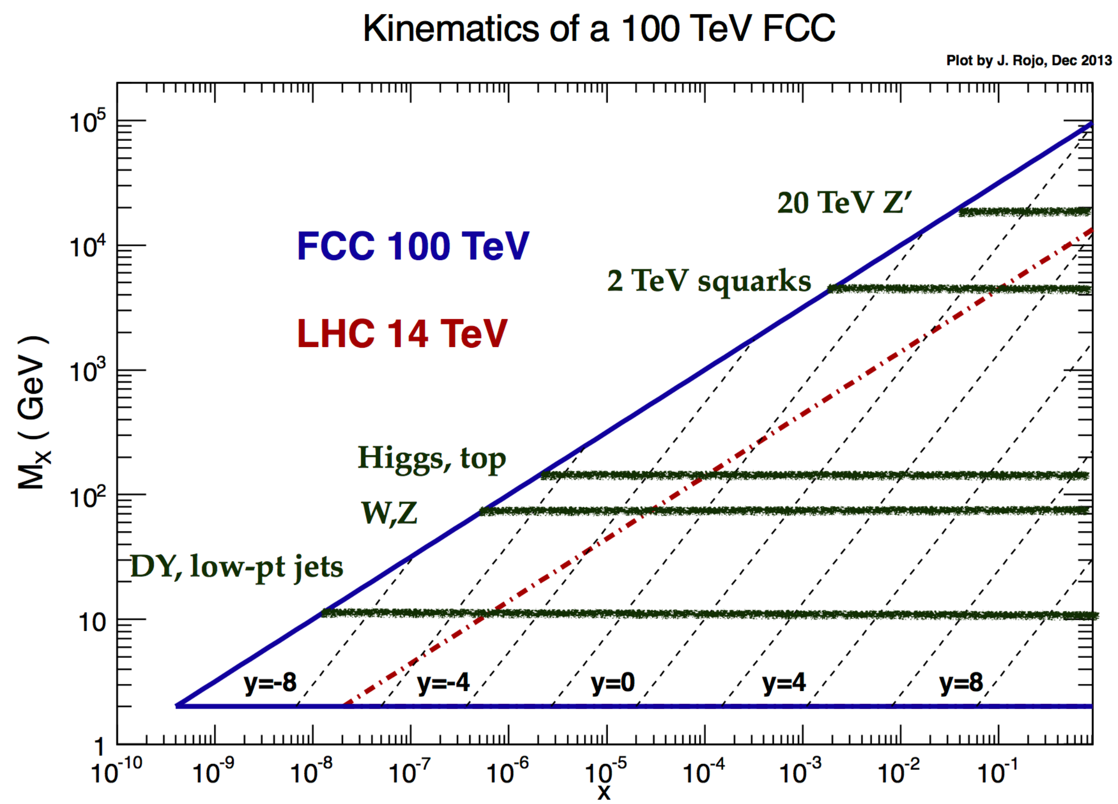
ex: W(10 TeV) will have decay products separated by DR = 0.01

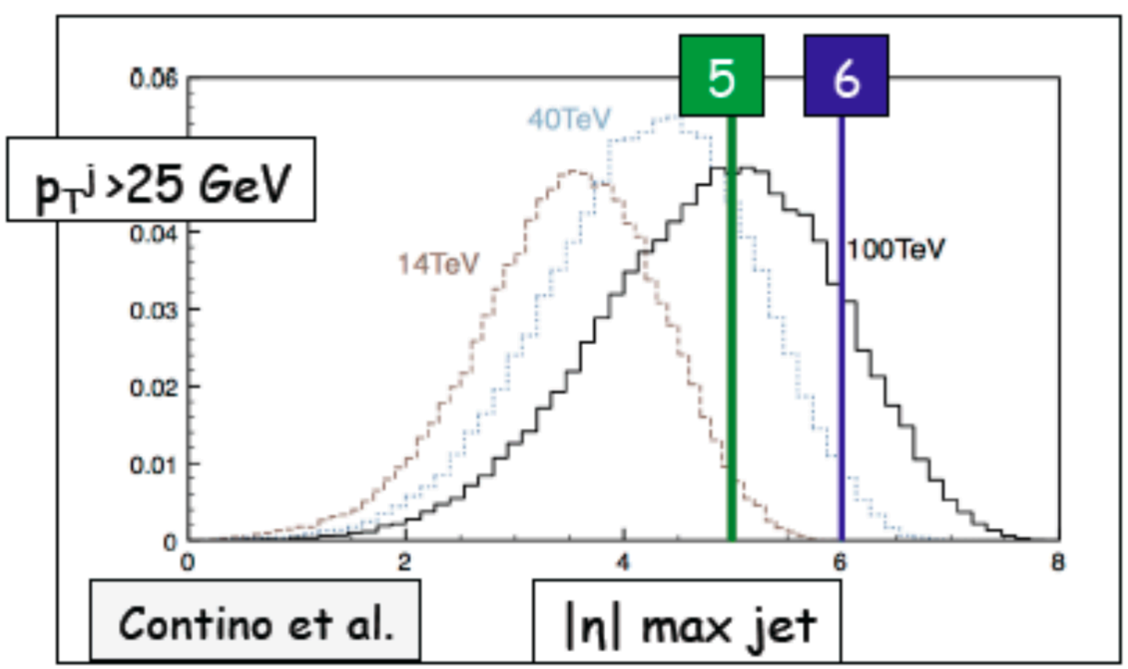
Towards defining the FCChh detector

Physics constraints

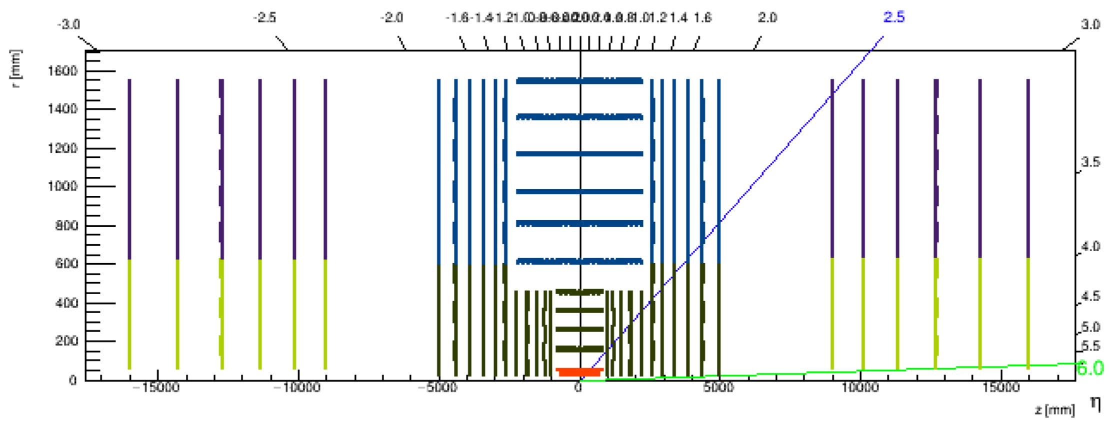
- **Physics will be more forward**
  - less for "high pT" physics
  - more for "low pT" physics (W/Z/Higgs, top)
  - in order to maintain sensitivity in need **large rapidity** (with tracking) and **low pT** coverage

→ 1k pile-up will certainly be an issue at large rapidities





General Features

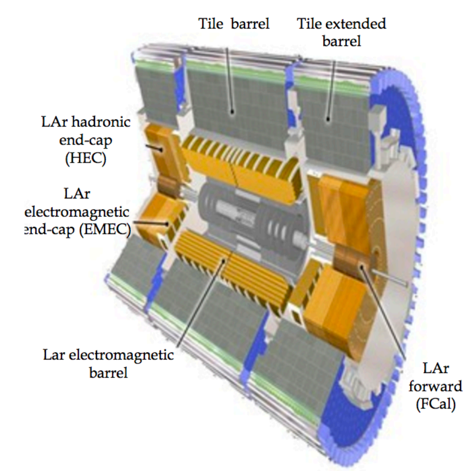


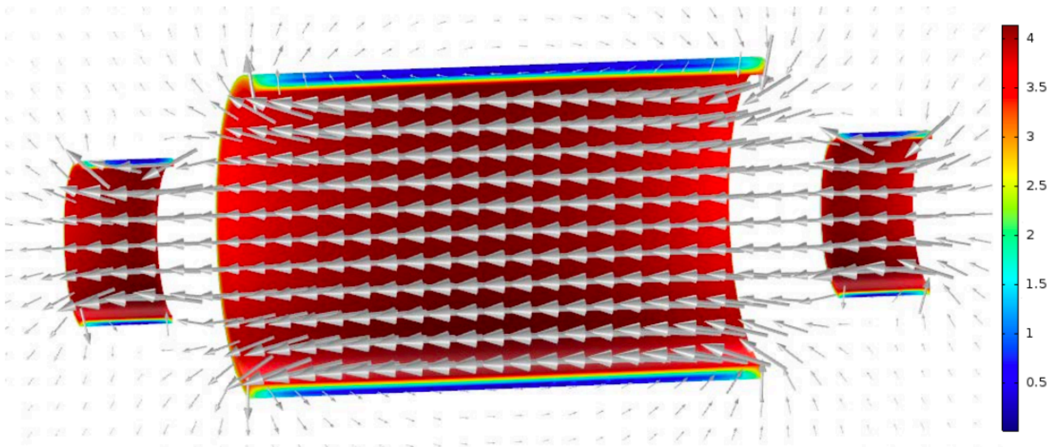
Tracker

- $-6 < \eta < 6$ coverage
- pixel : $\sigma_{r\phi}$ ~10µm, σ_Z ~15-30µm, X/X_0(layer) ~ 0.5-1.5%
- outer : $\sigma_{r\phi}$ ~10µm, σ_Z ~30-100µm, X/X_0(layer) ~ 1.5-3%

Calorimeters

- ECAL: LArg , $30X_0$, 1.6 λ, r = 1.7-2.7 m (barrel)
- HCAL: Fe/Sci , 9 λ, r = 2.8 - 4.8 m (barrel)
- endcaps and fwd to be defined (investigating HGCAL …)



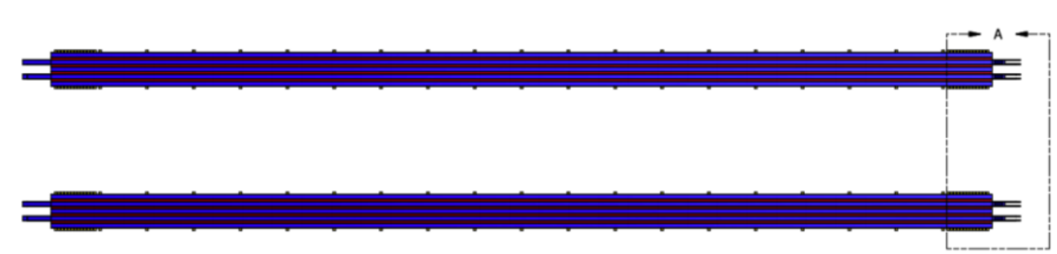


Magnet

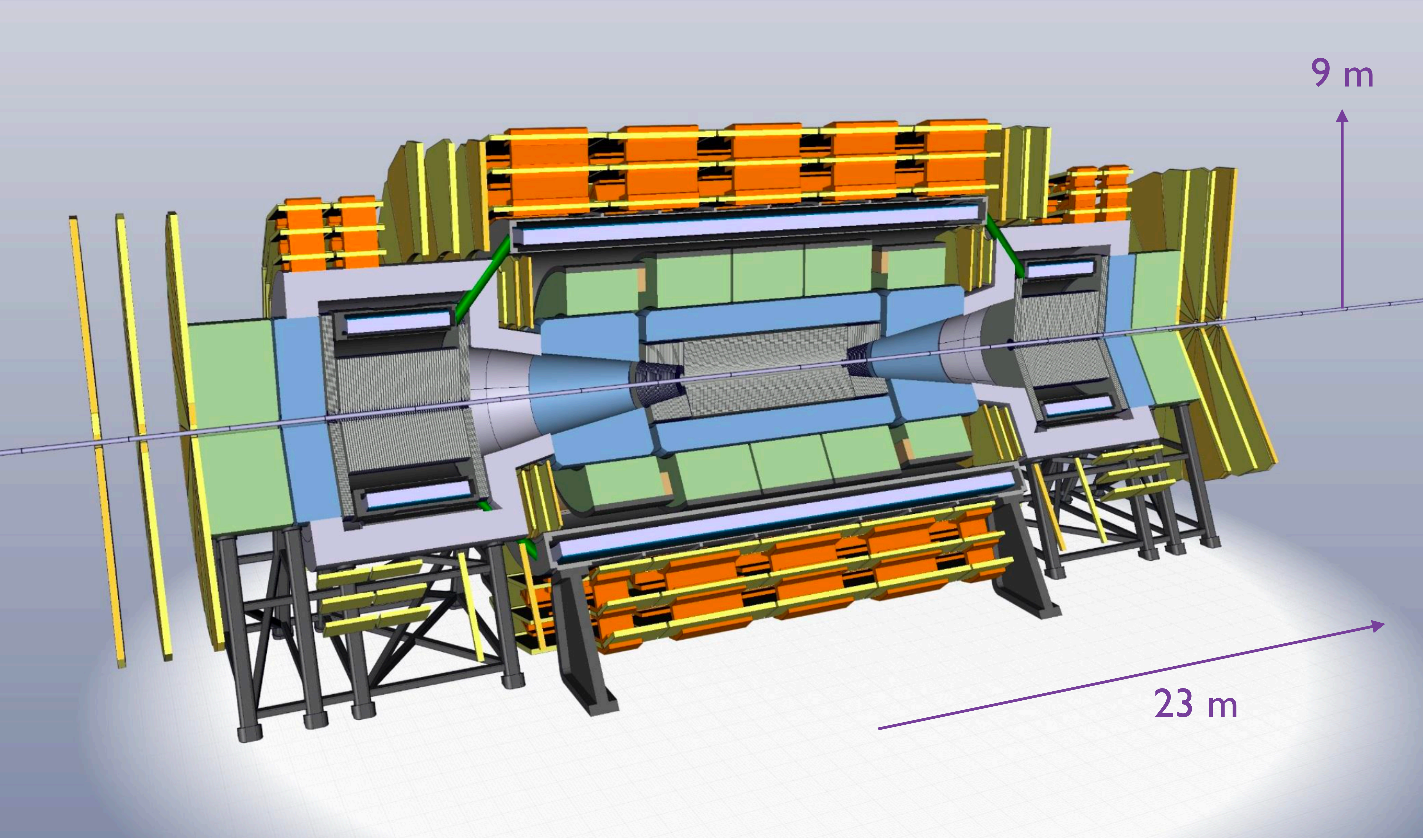
- central R = 5, L = 10 m, B = 4T
- forward R = 3m , L = 3m , B = 4T

Muon spectrometer

- Two stations separated by 1-2 m
- 50 µm pos., 70µrad angular

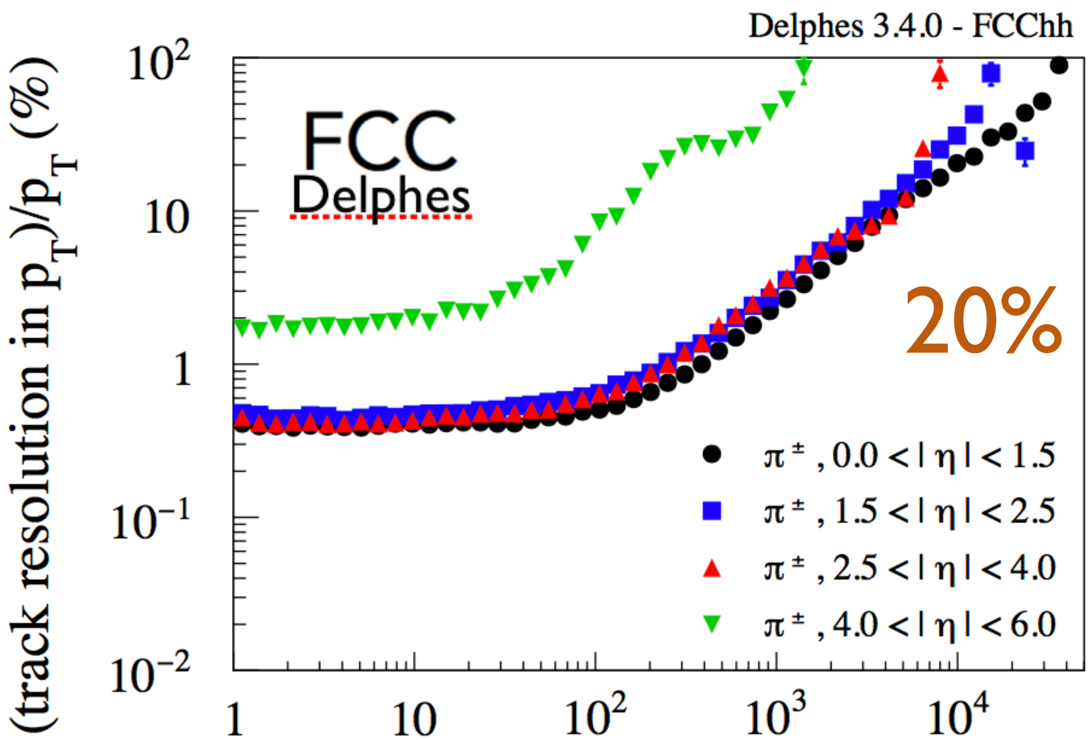


FCC-hh reference detector

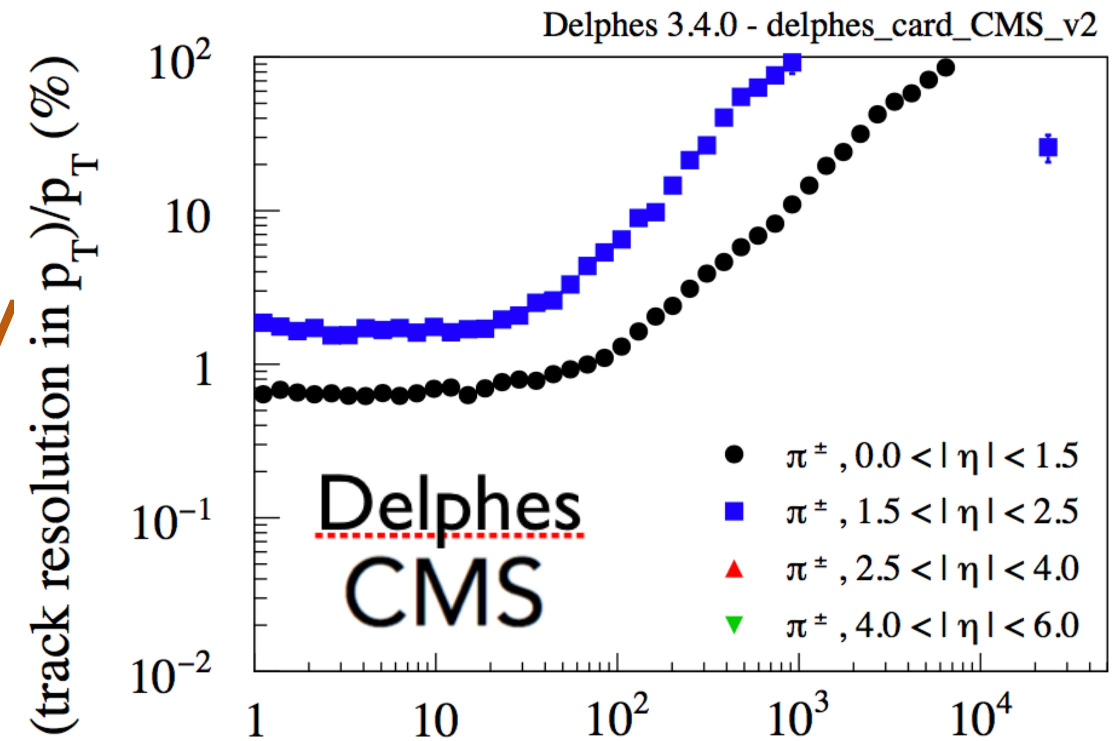


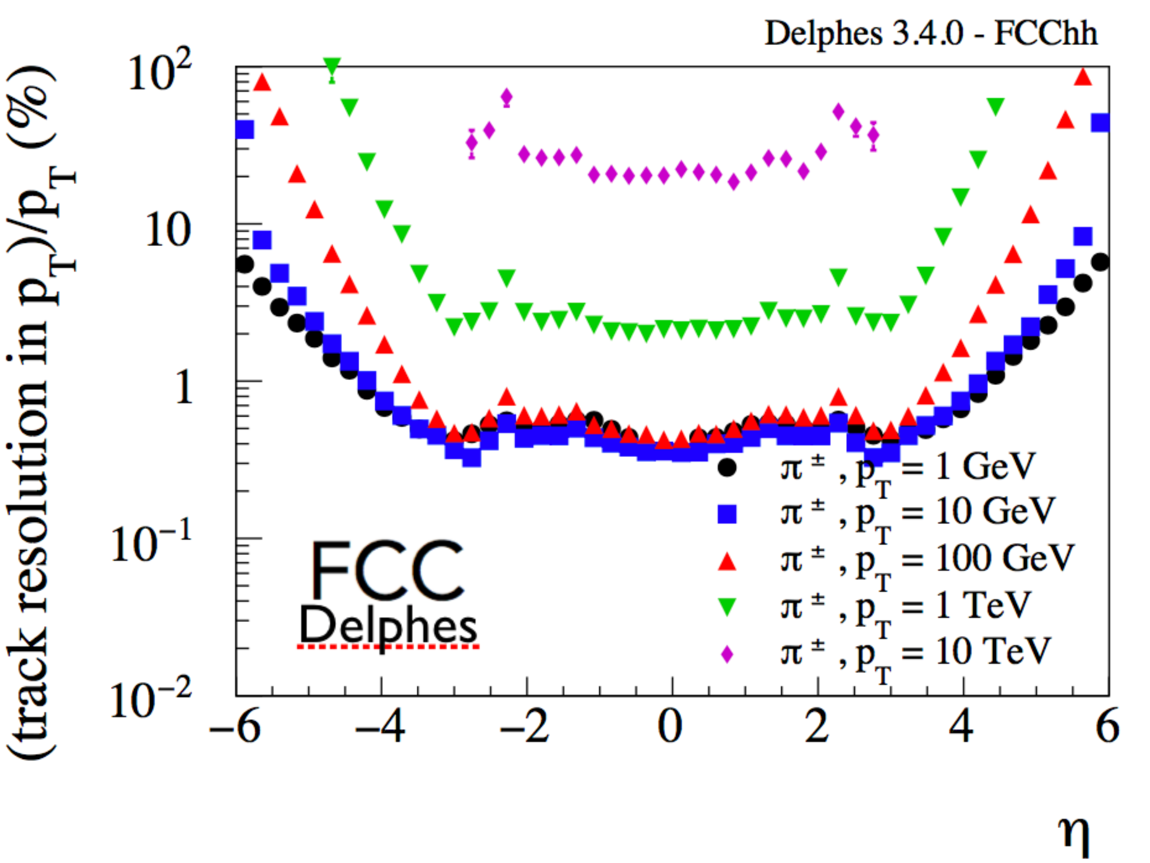
Performance

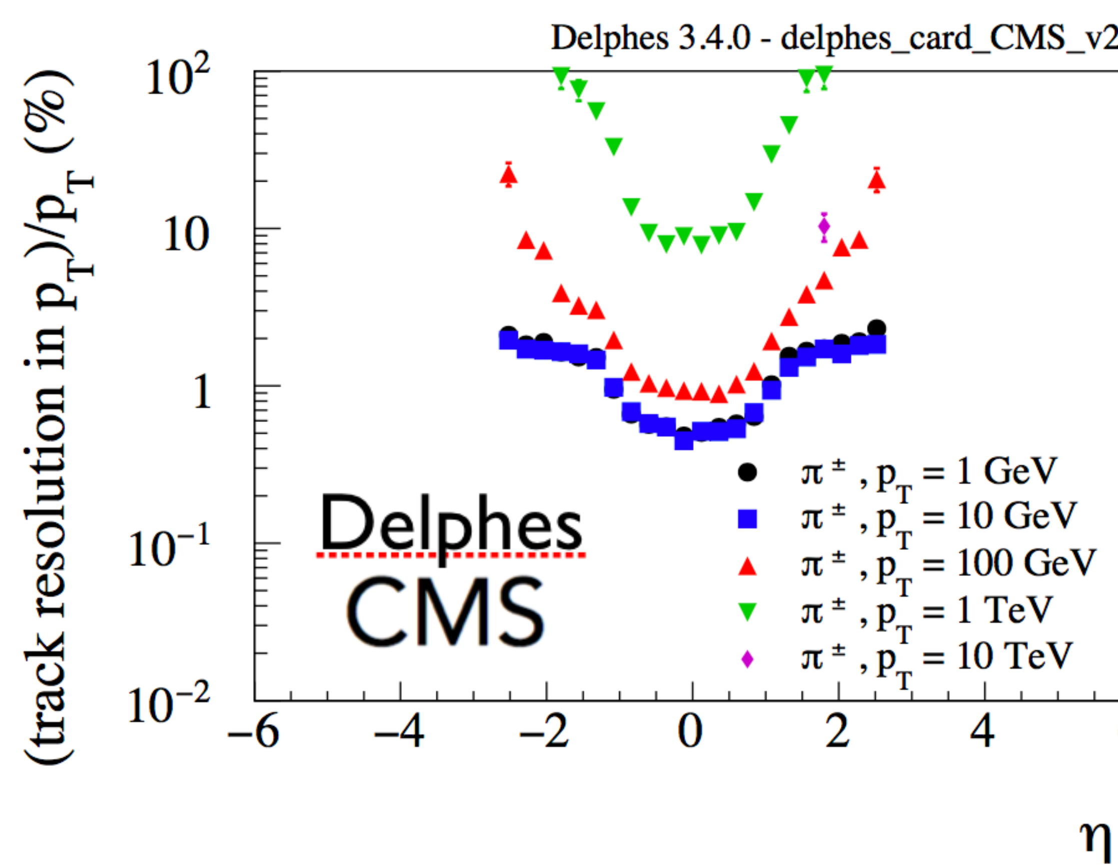
Tracking



20% @10TeV







Performance

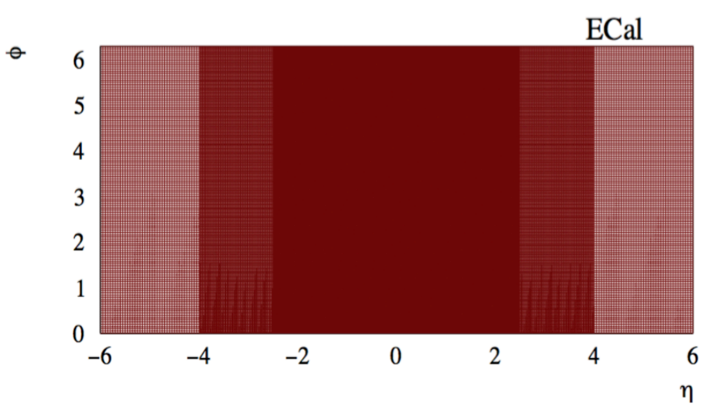
Calos

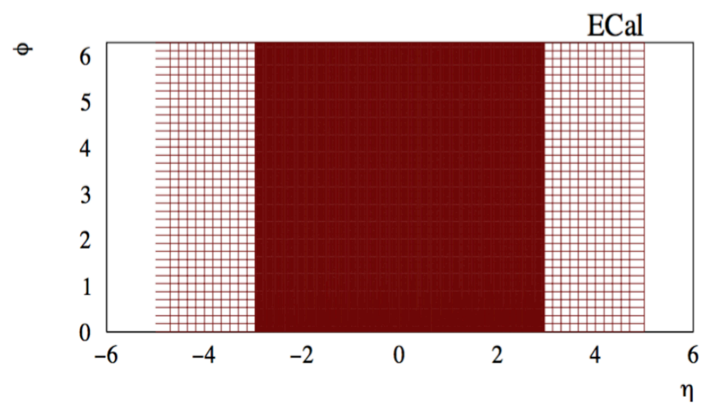
FCC

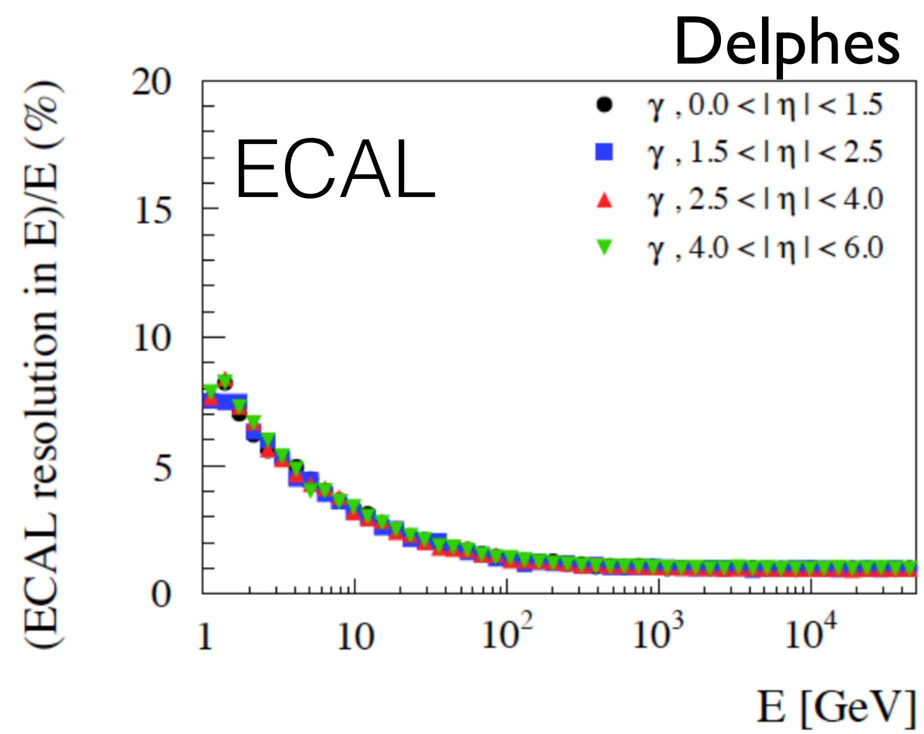
	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 2.5$	0.0125×0.0125	$\frac{10\%}{\sqrt{E}} + 1\%$
$2.5 < \lvert\eta\rvert < 4.0$	0.025×0.025	$\frac{10\%}{\sqrt{E}} + 1\%$
$4.0 < \lvert\eta\rvert < 6.0$	0.05×0.05	$\frac{10\%}{\sqrt{E}} + 1\%$

CMS

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 1.5$	0.02×0.02	$\frac{5\%}{\sqrt{E}} + 1\%$
$1.5 < \lvert\eta\rvert < 2.5$	0.02×0.02	$\frac{5\%}{\sqrt{E}} + 1\%$
$2.5 < \lvert\eta\rvert < 5.0$	$0.175 \times (0.175 - 0.35)$	$\frac{270\%}{\sqrt{E}} + 13\%$

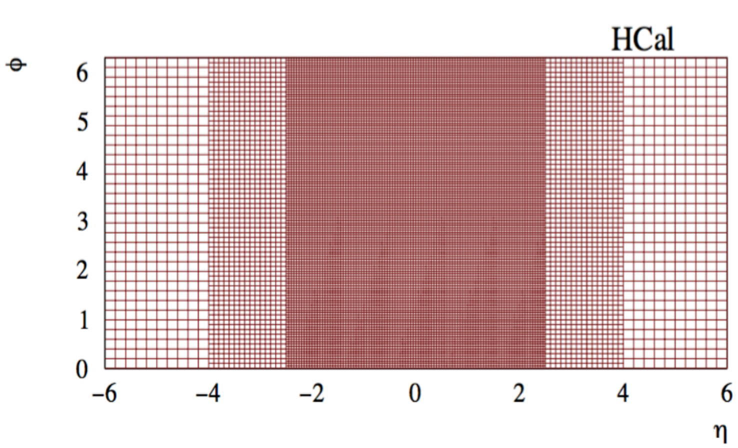


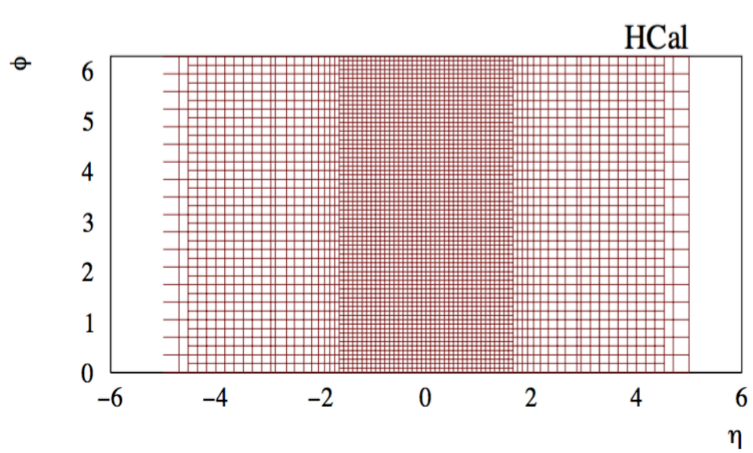


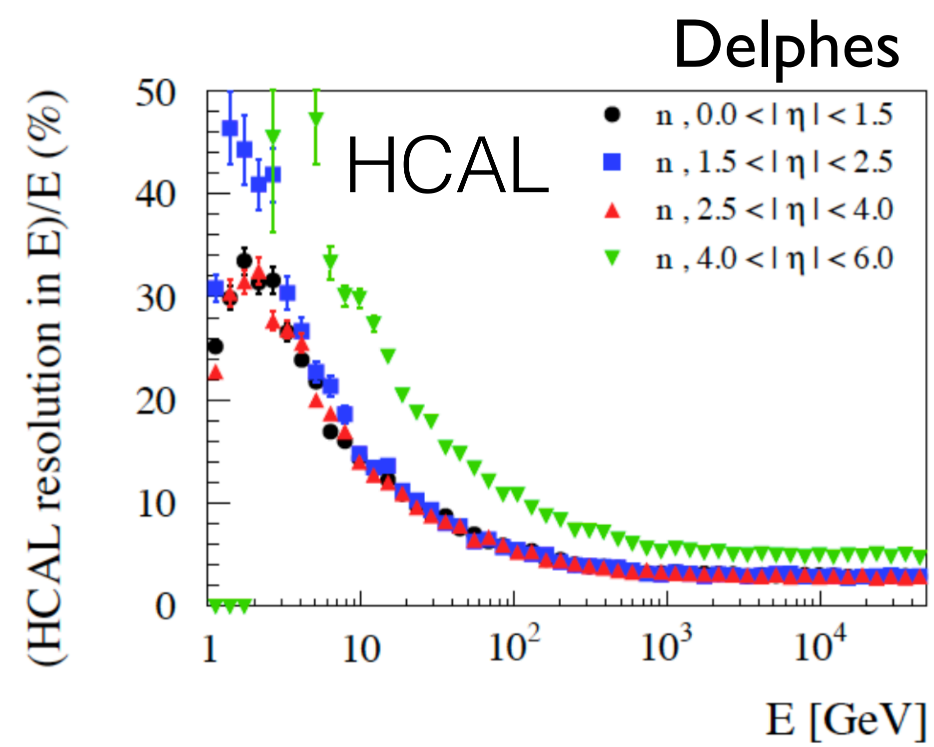


	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 2.5$	0.05×0.05	$\frac{50\%}{\sqrt{E}} + 3\%$
$2.5 < \lvert\eta\rvert < 4.0$	0.1×0.1	$\frac{50\%}{\sqrt{E}} + 3\%$
$4.0 < \lvert\eta\rvert < 6.0$	0.2×0.2	$\frac{100\%}{\sqrt{E}} + 5\%$

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 1.5$	0.1×0.1	$\frac{150\%}{\sqrt{E}} + 5\%$
$1.5 < \lvert\eta\rvert < 3.0$	0.2×0.2	$\frac{150\%}{\sqrt{E}} + 5\%$
$3.0 < \lvert\eta\rvert < 5.0$	$0.175 \times (0.175 - 0.35)$	$\frac{270\%}{\sqrt{E}} + 13\%$

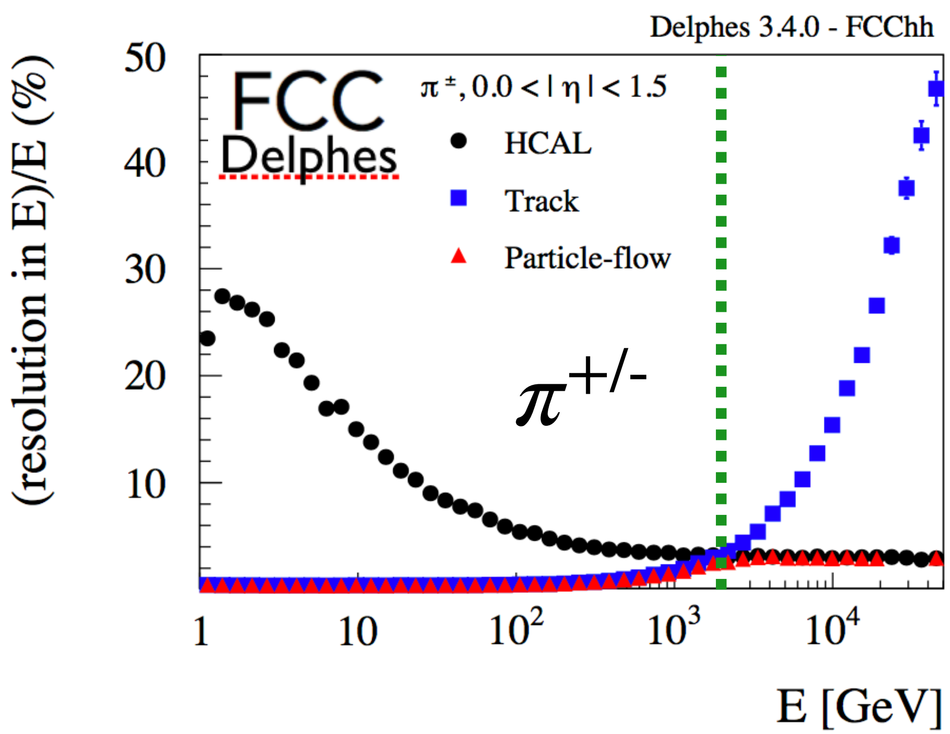


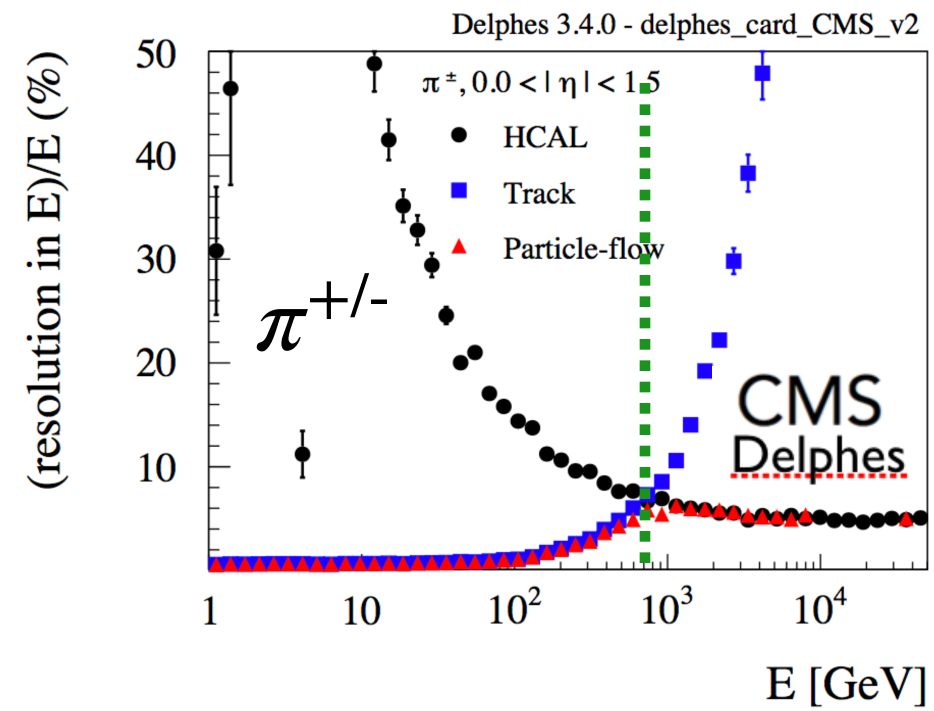


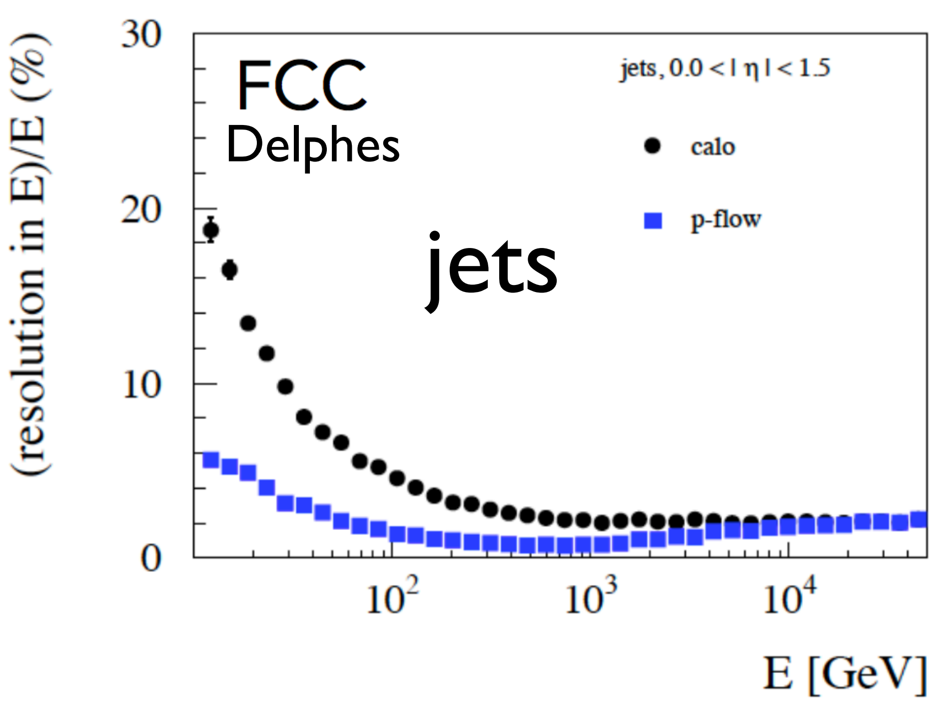


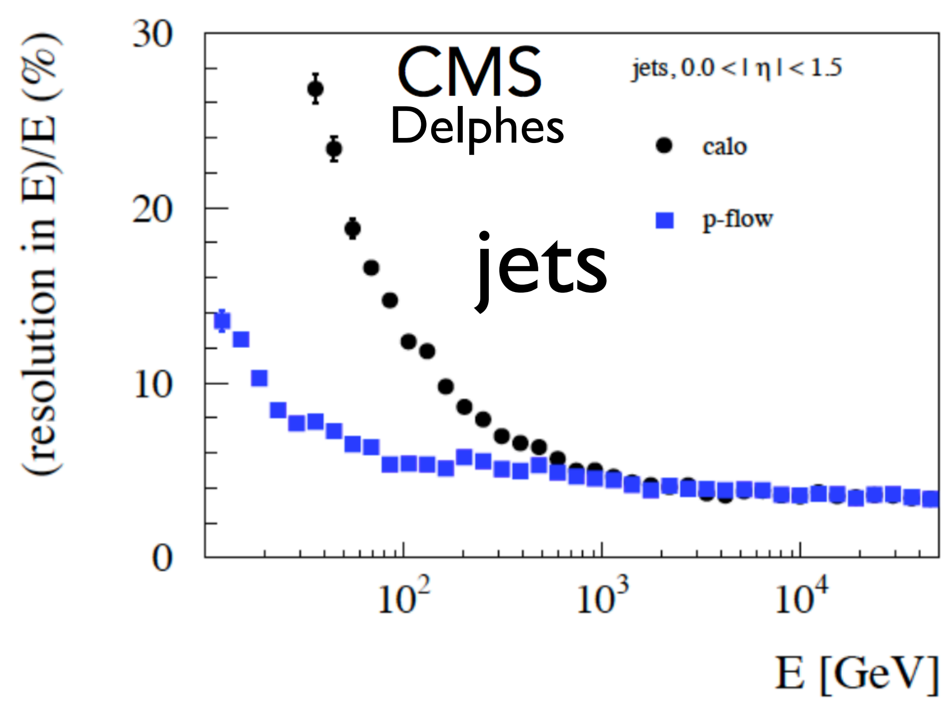
Performance

Particle-flow



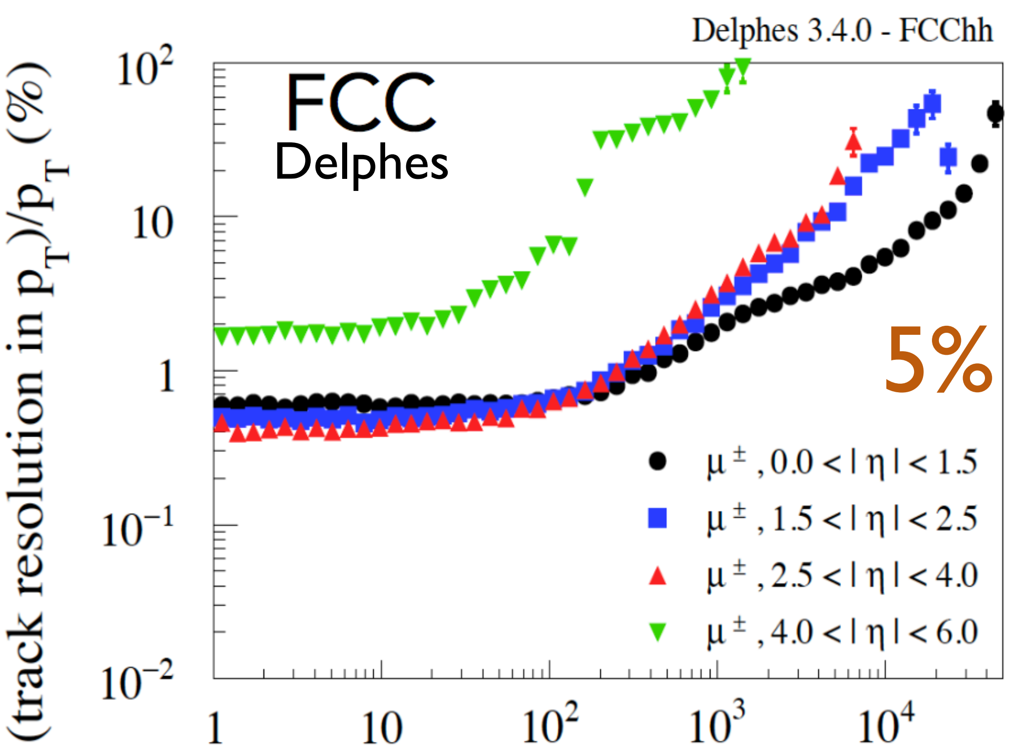




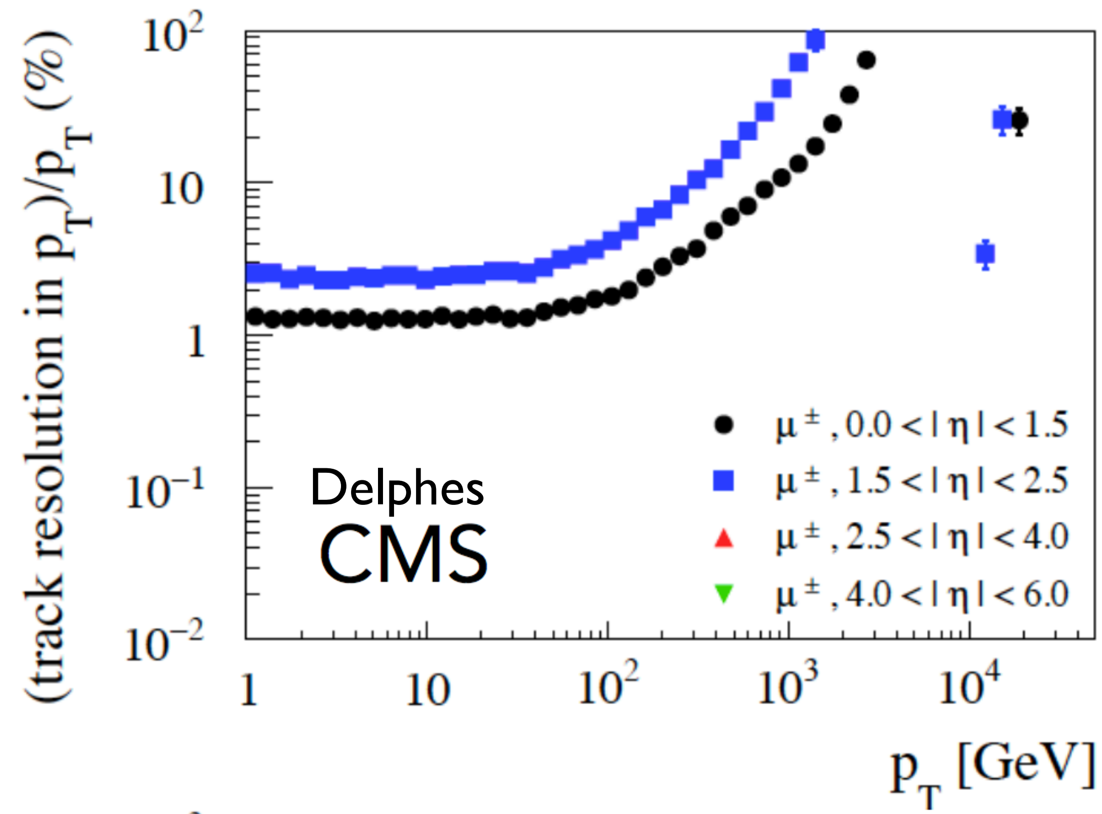


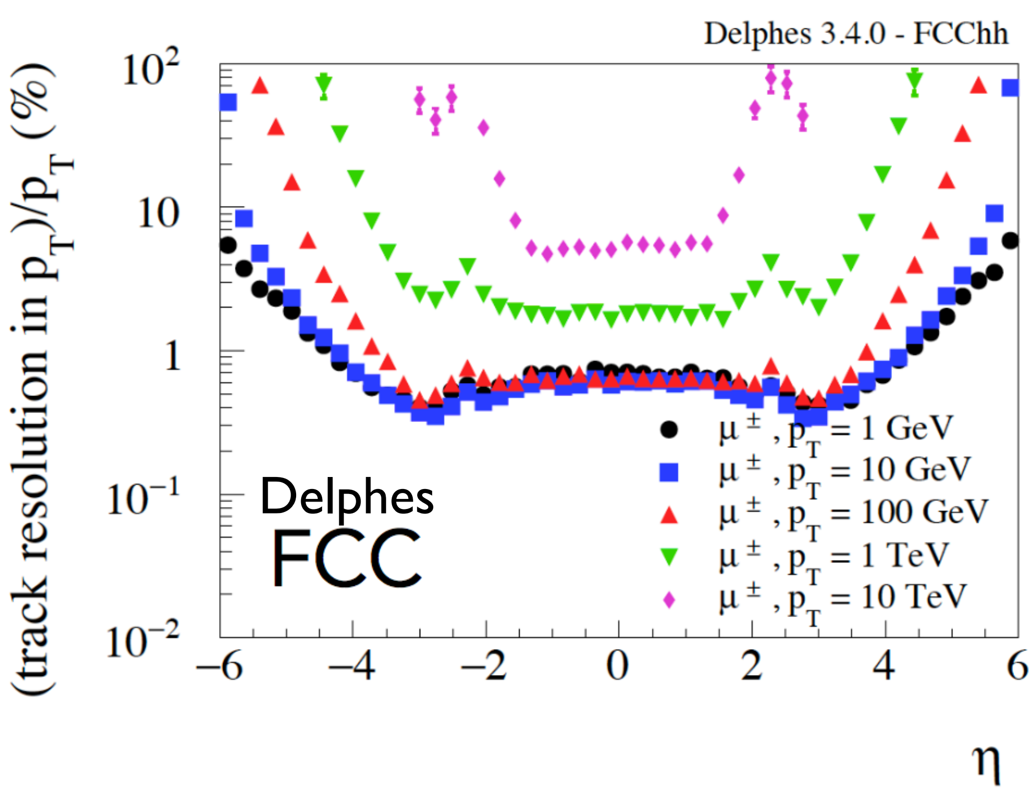
Performance

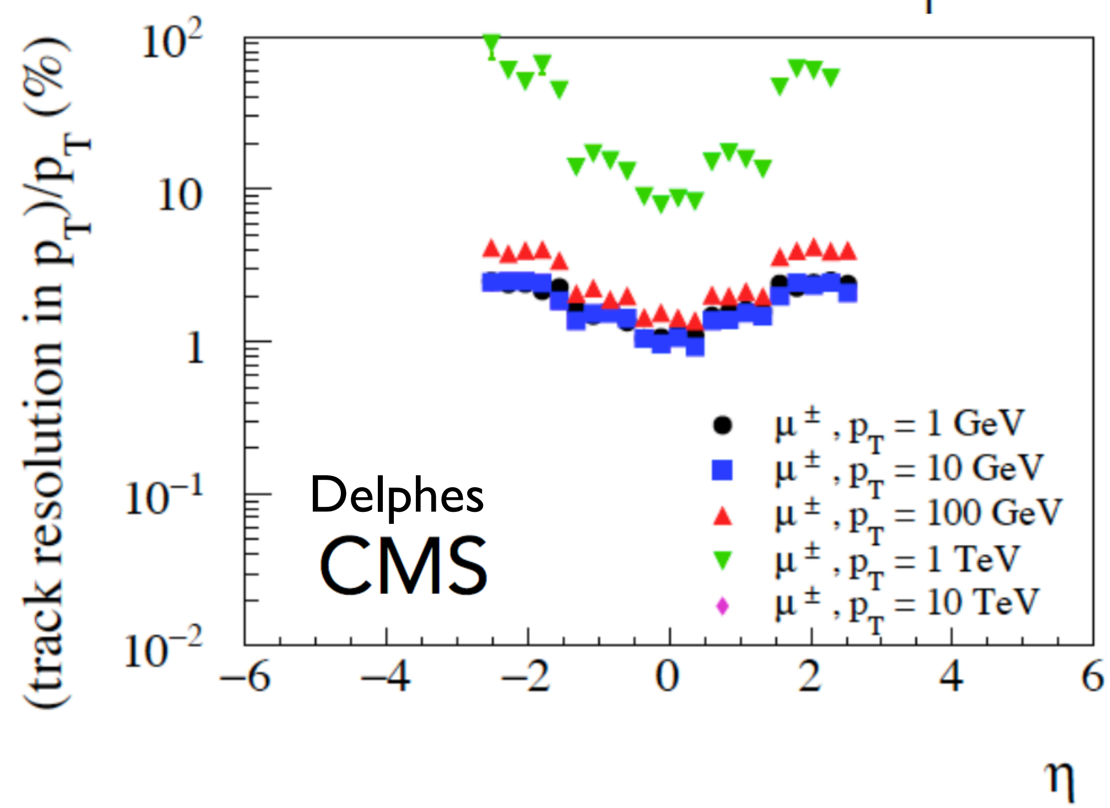
muons



5% @10TeV



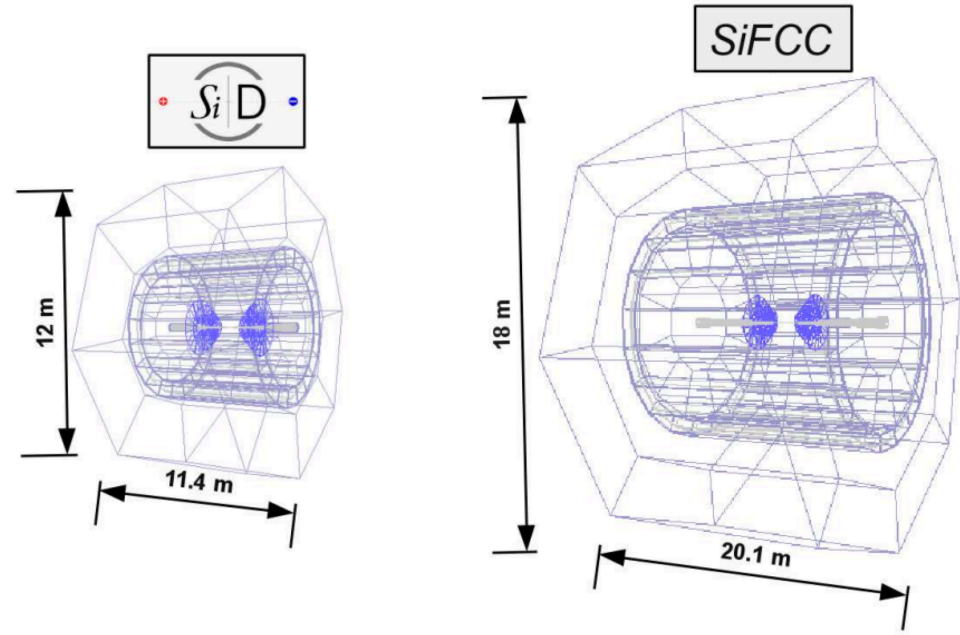




Other efforts

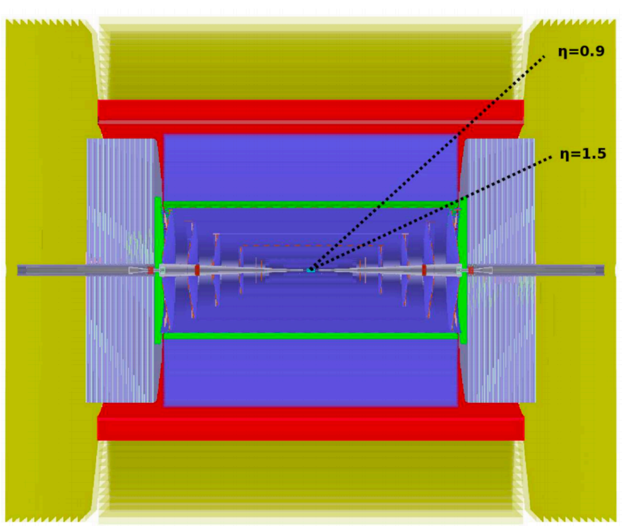
SiFCC (US)

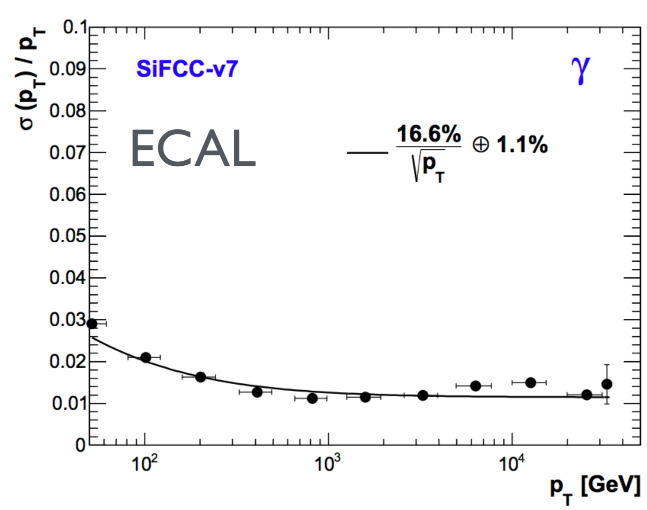
- scaled up SiD (ILD detector)
- B = 5T field,
- Tracker: $\sigma_{r\phi\ (inner)}$ ~7 µm, $\sigma_{r\phi\ (outer)}$ ~15 µm
- ECAL:
  - r = 2.1 - 2.3 m
  - 30 layers Si/W sampling, $35X_0$
- HCAL:
  - r = 2.3 - 4.7 m
  - 64 layers Steel Scintillator, 11.25 λ_I

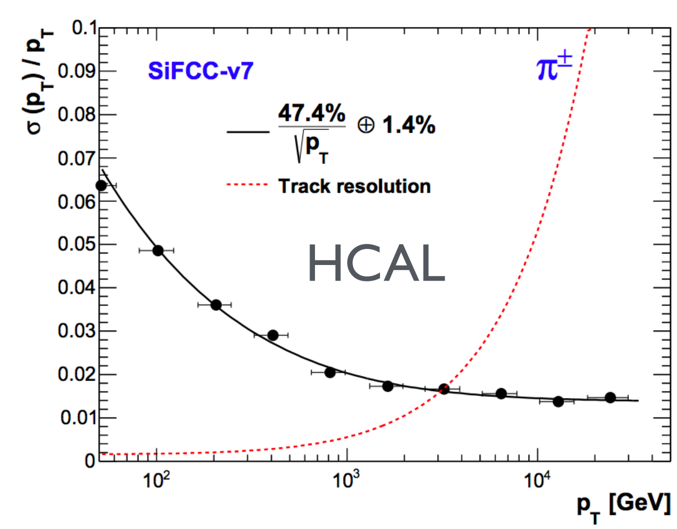


- larger tracker
- more compact calorimeter
- similar overall performance

[Chekanov et al. 1612.07291]







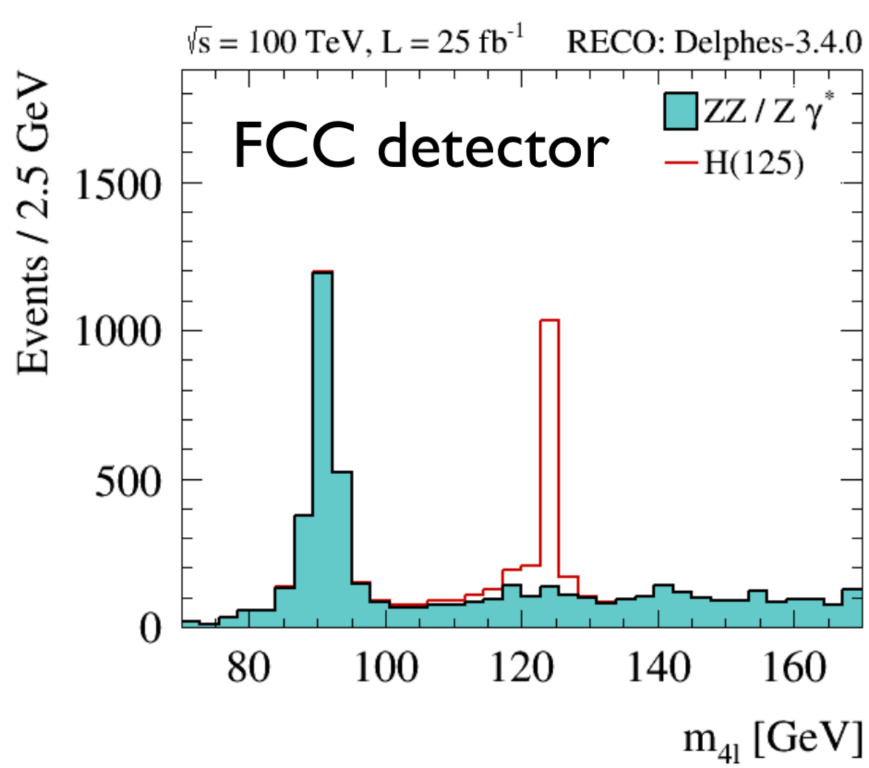
SppC (China)

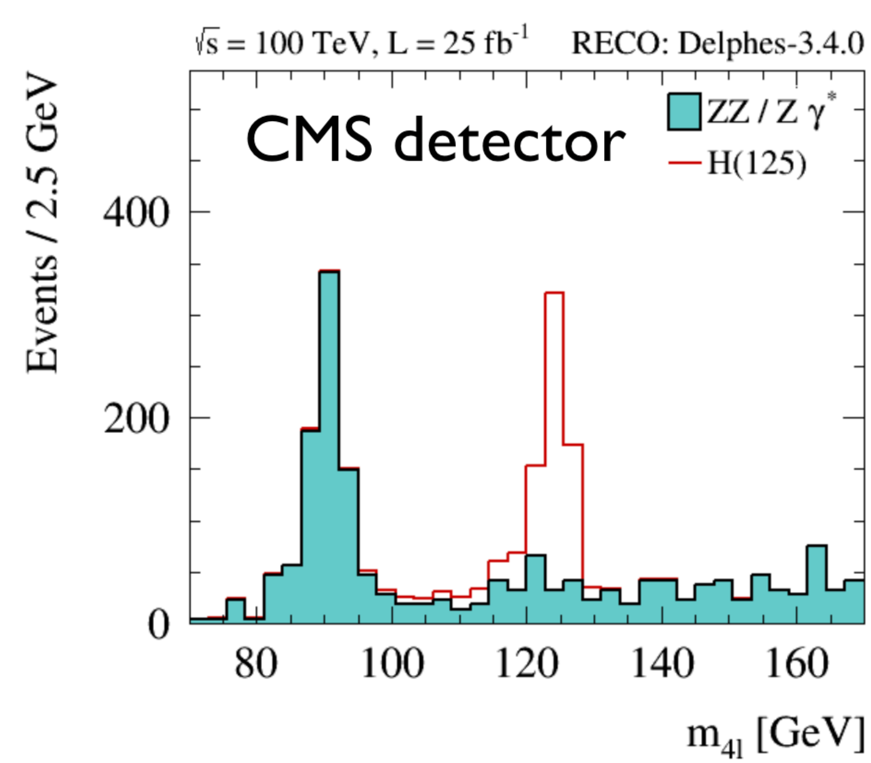
see Manqi Ruan's talk next …

Generate/simulate events in FCCSW

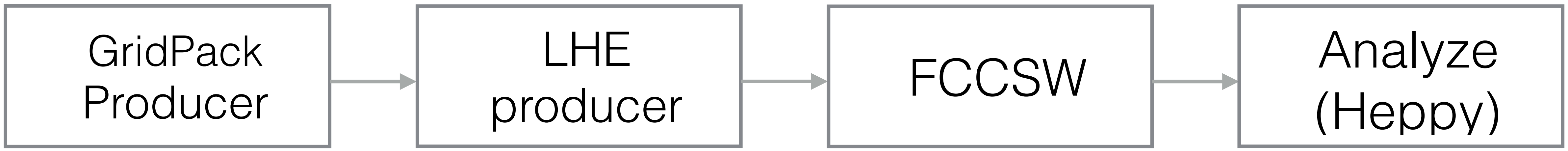
- **Performance** of baseline **FCC-hh detector** has been **parameterised** in a dedicated Delphes card
- Delphes itself has been fully integrated within the FCCSW framework (see Joschka's talk)
- **Full event generation** (Pythia + Delphes) + analysis (Heppy) sequence is available.
- Step-by-step **tutorial** is also available:

fccsw.web.cern.ch/fccsw/tutorials/fcc-tutorials/FccFullAnalysis.html





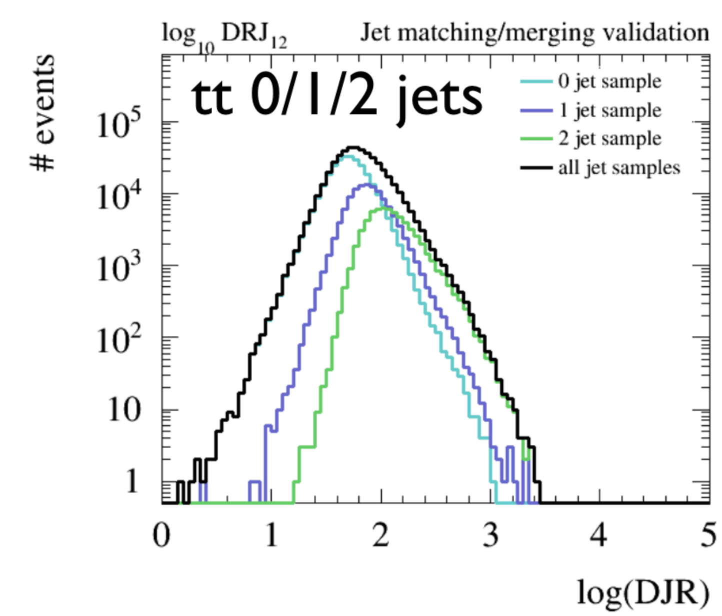
Event Generation



- Adapted a script[1] from CMS to produce **GridPacks** (now supports only MG5_aMC@NLO, soon others)
- Developed submission scripts[2] that allow to **generate large LHE samples** using lxBatch submission system
- We plan on **producing centrally** a set of samples of general interest:

  - W/Z/tt/H/QCD + N jets merged (n = 4/5?)
  - do we need slicing in HT bins?
  - what else? signals?

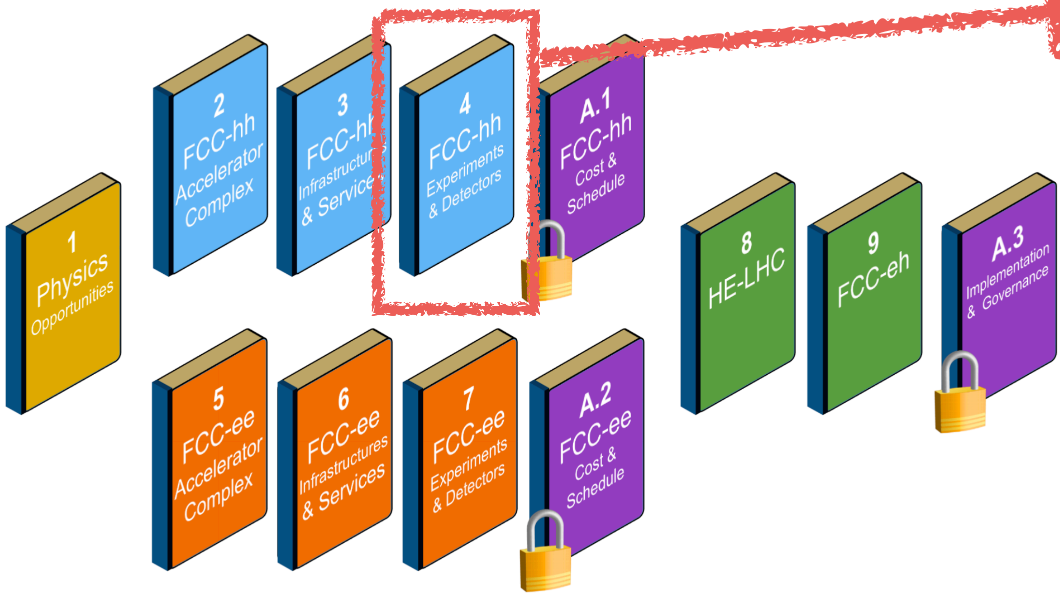
- **Matching/merging** validation[3] procedure is in place



[1] https://github.com/selvaggi/GridPackProducer
[2] https://github.com/clementhelsens/LHEventProducer
[3] https://github.com/HEP-FCC/fcc-physics/tree/master/pythia8/validation

Conceptual Design Report

Conceptual Design Report (CDR) for FCC has to be ready by end of 2018



Aim for a ≈ 200 page document, referring to support documents with more details.

Introduction, physics landscape: Benchmarks processes, overall detector requirements, parametrized performance

Physics performance: Performance for benchmark channels

Experiment environment, detector requirements: Luminosity, MDI, Radiation environment, pileup, tracker performance, tagging, ECAL, HCAL resolution and granularity, Muons, Reference design, DELPHES parametrization

Magnet systems: engineering of reference design and alternatives

Tracker: layout, performance, technology and data rate discussion

EMCAL: LAr, W/Si, performance and technology discussion, ideas on digital ECAL

HCAL: Fe/Scintillator (Tilecal type), W ?, SiPM technology, Forward, Timing

Muons: Principles of trigger versus identifier, performance, technologies

Trigger/DAQ: Principle concepts (full readout & HLT, hardware trigger)

Software: Simulation software for FCC detectors

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

Strategic R&D needs

Cost & schedule, relation to LHC detectors

Strategy:

- define benchmarks
- find volunteers (contact F. Moortgat, H. Gray)
- efforts should start very soon since 2018 is close …

Benchmarks analyses (SM)

Higgs physics:

- Higgs self-coupling (bbγγ, bbττ, bb+leptons)
- Top-Yukawa:
  - ttH, H → γ γ (threshold), H → b b (boosted)
- Rare Higgs decays (H → cc, H → μμ , H → Z γ)
- "Big Five": Higgs decays (H → 4l, WW ,γ γ, ττ, bb)
- VBF , VH

At **threshold** , **$20x10^9$** ggH events are produced at 30 ab^{-1}
With **pT(H) > 1 TeV** , **10^6 H events at disposal.**

With the exception of double Higgs production, some of these measurements can be performed in the **"boosted" regime**.

Extreme kinematics (large pT(H), m(VH)) enhance sensitivity to modifications of SM coupling through **anomalous couplings** / high dim. operators.

These can be nice **complementary precision** measurements to e^+e^-

Benchmarks analyses (SM)

Top physics couplings:

- tt ɣ /Z
- ttH/ttZ ratio? [1507.08169]
- tWb (single top s-channel)
- g t t

At **threshold** , 10^{12} top pairs events are produced at 30 ab^{-1}
With **pT(top) > 1 TeV** , **500 10^6 top pairs events at disposal.**

Same comments as for the Higgs apply here.

Key Experimental issues to be addressed in Higgs and Top studies are sensitivity to:

- final state pT, η acceptance (especially for VBF) and resolution
- tagging efficiencies and mistag rates (c, b , top , higgs)
- id efficiencies and fake rates

Benchmarks analyses (BSM)

"Strong" SUSY:

- gluinos, squarks: jets + MET, s.s dileptons + jets + MET:
  - M_g = 12 TeV, M_{LSP} = 100 GeV
  - M_g = 8 TeV, M_{LSP} = 7.8 TeV (compressed region)

- stops: 0/1 leptons + jets + MET:
  - Ms_{top} = 9 TeV, M_{LSP} = 100 GeV
  - Ms_{top} = 5 TeV, M_{LSP} = 4.8 TeV (compressed region)

Key aspects are:

- lepton pT thresholds in compressed scenarios
- MET resolution
- tracking/ calo granularity in boosted regions
- lepton id requirements in boosted leptonic top decays

Benchmarks analyses (BSM)

"Weak SUSY/ DM":

- EW-ino: - boosted/ compressed points?
- DM : SU(2) multiplets/ simplified models?

Key experimental challenges:
- lepton id, lepton threshold in compressed regions?
- MET tails

"Heavy Resonances":

- Z' → tt, jj, ee/μμ:

  $M_Z = 5, 30$ TeV

Key aspects are:
- boosted tops
- high pT electron/muon resolution

In order to make sure we have some solid studies for the 2018 CDR focus on a few key benchmark studies.

Conclusion

- A **reference detector** for preliminary studies at p p @ 100 TeV has been defined.
- The detector **performance** has been **parameterised** in Delphes.
- This does not mean the detector is frozen for ever.
- On the contrary, we will keep improving the design.
- Present benchmark should be used as a **reference point** from which one can **explore deviations** in performance (in better or worse).
- Event **generation** + parameterised **detector simulation** chain is available for anyone to use, within the FCCSW.
- Tools are in place to explore the potential of the FCC-hh detector
- Benchmarks physics studies are being defined.
- It is time to start doing some physics !

In order to follow the FCChh activities, subscribe to the e-group:

fcc-experiments-hadron