Physics benchmarks, FCC-hh detector specifications

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(on behalf of the FCChh group)

CERN
Outline

• Physics Benchmarks
• FCC-hh Detector baseline
• Physics Object performance
Motivations for FCC-hh

- **Ultimate discovery machine**
  - directly probe new physics up to unprecedented scale
  - discover/exclude:
    - heavy resonances  
      “strong” \( m(q^*) \approx 50 \text{ TeV} \),
    “weak” \( m(Z') \approx 30 \text{ TeV} \),
    - SUSY  
      \( m(\text{gluino}) \approx 10 \text{ TeV} \),
      \( m(\text{stop}) \approx 5 \text{ TeV} \)

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

**Goals for CDR:**
- Define a set of key physics benchmarks
- Evaluate — optimize detector performance by maximizing physics reach for such benchmarks
Physics Benchmarks
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 (VBS)
- BSM Higgs (H^+/− → tb)

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

Large statistics allow to these measurements to 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^-
Top physics

Top physics couplings:
- $t\bar{t}\gamma/Z$
- $t\bar{t}H/t\bar{t}Z$ ratio?
- $tWb$ (single top s-channel)
- $gtt$
- FCNCs, rare decays

At threshold, $10^{12}$ top pairs events are produced at 30 ab$^{-1}$
With $p_T(top) > 1$ TeV, $500 \times 10^6$ 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 $p_T, \eta$ 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:
  \[ M_g = 12 \text{ TeV}, M_{\text{LSP}} = 100 \text{ GeV} \]
  \[ M_g = 8 \text{ TeV}, M_{\text{LSP}} = 7.8 \text{ TeV} \text{ (compressed region)} \]

- stops: 0/1 leptons + jets + MET:
  \[ M_{\text{stop}} = 9 \text{ TeV}, M_{\text{LSP}} = 100 \text{ GeV} \]
  \[ M_{\text{stop}} = 5 \text{ TeV}, M_{\text{LSP}} = 4.8 \text{ TeV} \text{ (compressed region)} \]

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: 3/4 leptons + MET
- Higgsino (disappearing tracks)  
- Dark Matter

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

“Heavy Resonances”:

- $Z' \to tt, jj, ee/\mu\mu$:
  $M_{Z'} = 5, 30$ TeV

Key aspects are:
- boosted tops
- high pT electron/muon resolution
Detector design
Luminosity, Pile-Up scenari

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

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

L$^*$

Detection

$z_{VX}$ resolution

CPU time

timing detector

better for Tracking

Ilaria Besana

Zbynek Drasal
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

→ precision muon up to |η| < 4
→ calorimetry up to |η| < 6
→ Can we deal with 1k pile-up will at large rapidities?
Towards defining the FCChh detector

Physics constraints

- Physics objects will be more boosted

Tracking: \( \frac{\sigma(p)}{p} \approx \frac{p \sigma_x}{B L^2} \)

- Tracking target: achieve \( \sigma / p = 10-20\% \) at 10 TeV
- Muons target: \( \sigma / p = 5\% \) at 10 TeV
- Keep calorimeter constant term as small as possible.
- Long-lived particles live longer:
  - example: 5 TeV b-Hadron travels 50 cm before decaying
  - 5 TeV tau lepton travels 10 cm before decaying

\( \rightarrow \) re-think reconstruction, include \( dE/dx \)?

Require high granularity (both in tracker and calos):

- example: \( W(p_T = 10\text{ TeV}) \) will have decay products separated by \( \Delta R = 0.01 \)

30 ab\(^{-1}\) needed for 5\( \sigma \) 

\( Z' \) with \( \sigma(p)/p = 10\% \)
Detector Baseline
Detector Baseline

Tracker
- $-6 < \eta < 6$ coverage
- pixel: $\sigma_{\phi} \sim 10\mu m$, $\sigma_{Z} \sim 15-30\mu m$, $X/X_0$(layer) $\sim 0.5-1.5\%$
- outer: $\sigma_{\phi} \sim 10\mu m$, $\sigma_{Z} \sim 30-1000\mu m$, $X/X_0$(layer) $\sim 1.5-3\%$

Calorimeters
- ECAL: LArg, $30X_0$, 1.6 $\lambda$, $r = 1.7-2.7$ m (barrel)
- HCAL: Fe/Sci, 9.2 $\lambda$, $r = 2.8 - 4.8$ m (barrel)
- endcaps and fwd to be defined
- investigating Digital ECAL

Muon spectrometer
- Two stations separated by 1-2 m
- $50\mu m$ pos., $70\mu rad$ angular

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

see later for dedicated presentations on sub-detectors
FCC-hh reference detector

Tracker: $\sigma_{pt}/pt \sim 20\%$ at 10 TeV (1.5m radius)

Central Magnet:
$4T$, $5m$ radius

Barrel ECAL: $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

Barrel HCAL: $\sigma_E/E \sim 50\%/\sqrt{E} \oplus 3\%$

Fwd detectors: to $\eta \sim 6$

Barrel HCAL:
$9m$

23 m
Object parameterisation for Physics
Parameterised Performance

Tracking

20% @ 10 TeV
### Parameterised Performance

**ECAL**

<table>
<thead>
<tr>
<th>FCChh</th>
<th>Delphes</th>
<th>CMS</th>
<th>Delphes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma(\eta, \phi)$</td>
<td>$\sigma(\eta)/E$</td>
<td>$\sigma(\eta, \phi)$</td>
</tr>
<tr>
<td>$0 &lt;</td>
<td>\eta</td>
<td>&lt; 2.5$</td>
<td>0.0125</td>
</tr>
<tr>
<td>$2.5 &lt;</td>
<td>\eta</td>
<td>&lt; 4.0$</td>
<td>0.025</td>
</tr>
<tr>
<td>$4.0 &lt;</td>
<td>\eta</td>
<td>&lt; 6.0$</td>
<td>0.025</td>
</tr>
</tbody>
</table>

**Diagrams:**

- **Delphes 3.4.1 - FCChh**
- **Delphes 3.4.1 - CMS**
### Parameterised Performance

#### HCAL

| $0 < |\eta| < 2.5$ | $0.025$ | $50\% / \sqrt{E} \pm 3\%$ |
| $2.5 < |\eta| < 4.0$ | $0.05$ | $50\% / \sqrt{E} \pm 3\%$ |
| $4.0 < |\eta| < 6.0$ | $0.05$ | $100\% / \sqrt{E} \pm 10\%$ |

#### CMS Delphes

| $0 < |\eta| < 1.7$ | $0.08$ | $110\% / \sqrt{E} \pm 5\%$ |
| $1.7 < |\eta| < 3.0$ | $0.175$ | $110\% / \sqrt{E} \pm 5\%$ |
| $3.0 < |\eta| < 5.0$ | $0.175 - 0.35$ | $250\% / \sqrt{E} \pm 13\%$ |

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**FCChh Delphes**

![Graph 1](image1)

**CMS Delphes**

![Graph 2](image2)
Performance

Particle-flow

![Graph 1: FCC Delphes](image1)

- **π⁺, 0.0 < 1 |η| < 1.5**
- HCAL
- Track
- Particle-flow

![Graph 2: CMS Delphes](image2)

- **π⁺/⁻**
- HCAL
- Track
- Particle-flow

![Graph 3: FCC Delphes](image3)

- Jets
- Calo
- p-flow

![Graph 4: CMS Delphes](image4)

- Jets
- Calo
- p-flow
Parameterised Performance

muons

5% @10TeV
Parameterised Performance

b-tagging

FCChh Delphes

CMS Delphes
Conclusions

- **Benchmarks for physics** studies have been defined.
- A reference detector for preliminary studies at p p @ 100 TeV has been defined.
- The detector **performance** has been **parameterised** in Delphes.
- Detector baseline should be used as a reference point from which one can **explore deviations** in performance (in better or worse).
- Tools are in place to explore the potential of the FCC-hh detector in view of the CDR.

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

fcc-experiments-hadron
Thank you