Detectors for the Energy Frontier

Petra Merkel, Dmitri Denisov

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Near-term future

- HL-LHC, well defined
- Challenges: high PU, high radiation environment, large data throughput and strong data reduction needs
- At Fermilab:
  - Outer Tracker upgrade: module assembly (complex double layer, pixels & strips, input to track trigger), radhard optical links
  - Tracker Trigger: R&D, AM-based, one of three options in CMS
  - Pixels: sensor (small pixels, edgeless) and ASIC R&D (in RD53 with ATLAS)
  - HGCal: silicon-based high granularity forward calorimeter (sensor design, FE electronics, cooling, cassette assembly)
  - Had calo: radhard scintillatorand photodetection R&D
  - Fast Timing layer: LGAD Si sensors, ps-timing electronics, R&D and construction

Longer-term Future

- Today there are three areas for future energy frontier colliders
  - High luminosity LHC – many challenging and important detector developments are actively progressing
    - The HL-LHC accelerator and detector upgrades is the main CERN priority and highest US priority according to P5
  - "Higgs factory" – a collider (most probably e^+e^-) with a center of mass energy 250 GeV and above and high luminosity to study the Higgs boson properties
  - "~100 TeV" pp collider to get to the "next energy frontier" an order of magnitude above LHC
    - High energy LHC (~25 TeV) is among options
- Detectors to be used at future colliders are defined by the physics to be studied and accelerator parameters
  - e^+e^- - luminosity ~10^{34} and above and energy 250-500 GeV
  - pp – luminosity ~10^{35} and energy 14-100 TeV

Detectors for ~100 TeV pp Collider

- We would like to detect all “well know” stable particles including products of short lived objects decays: pions, kaons, muons, etc.
  - Need 4π detector with layers of tracking, calorimetry and muon system
- Central tracker
  - Most challenging is to preserve momentum resolution for ~10 times higher momentum tracks vs LHC
- Calorimetry
  - Getting better with energy: hadronic energy resolution ~50%/$\sqrt{E}$, 2% at 1TeV
  - Length of shower increase has log(E) dependence – not a major issue
- Muon system
  - Main challenge is momentum resolution and showering of muons as they are becoming “electron-like” due to large γ factor
- Occupancies and radiation doses
  - Up to luminosity 10^{35} cm^{-2} sec^{-1} looks reasonable, challenging for above both due to pileup and radiation ageing (especially in the forward region)

Detectors for 250-500 GeV e^+e^- Collider

- Similar to hadron colliders we need 4π detector with layers of tracking, calorimetry and muon system
- Currently main goal of such colliders is high precision physics
  - Z, Higgs and top factory
  - Interaction rate is relatively low - no issues with triggering or radiation dose in the central region
- Central tracker
  - High momentum resolution, excellent secondary vertex reconstruction
- Calorimeter
  - Very high energy resolution to separate W and Z hadronic decays
- Muon system
  - Hermetic muon system with small punch through and high momentum resolution
- Forward region of these detectors will be challenging due to radiation of electrons when bunches are crossing each other

Some ideas for long-range detector R&D needs

- ASICs & sensors: few-nm architecture, 3D-silicon, CMOS technology, monolithic sensors, 8” wafers, in-house bump bonding
- Other semiconductor materials (diamonds, Ga, ?)
- New materials: carbon nano tubes (e.g. for cables), graphene
- New scintillators, fiber materials
- New (to FNAL) technologies: e.g. Micro Pattern Gas Detectors
- On-site Testbeam facility crucial; on-site irradiation facility would be fantastic
- Also see CPAD and previous Snowmass recommendations: https://www.anl.gov/hep/initiatives/coordinating-panel-advanced-detectors/reports