HEP Detectors: Requirements from Long-Lived Particle Searches

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Introduction

- New detector (and collider) designs need to explicitly take into account the many, varied LLP signatures from their inception
  - Ignoring LLPs at this stage can easily preclude future searches
- We’ve brainstormed a list of some key topics for discussion
- Goals:
  - Spark discussion (minimal discussion slide-by-slide, larger discussion at end)
  - Outline major detector topics relevant for LLP searches
  - Frame which studies should be prioritized by the community over the year

Please use the **Raise Hand** feature or chat (Zoom or #cpm_topic_131) to comment.
Aside: Collider Environments (ee, μμ, pp, AA, Ap, ep, ...)

- Properties of the collider itself can play a role in LLP sensitivity
  - Achievable integrated luminosity / Achievable hard scatter energy
  - Need to reduce detector occupancy / particle multiplicity
  - Levels of beam-induced backgrounds
  - Beam-spot size
  - Time between collisions (and status of detector readout)
  - Differences in radiation hardness requirements among colliders

- Many of the topics discussed today need to be studied explicitly considering the **collider environment** the detector sits in!
General Requirements

- **Hermiticity**
  - Different geometry choices that provide similar hermeticity for prompt particles can differ drastically in their coverage of particles not originating at the interaction point

- **Geometry**
  - Interplay of geometry choice with hermeticity, trigger-capabilities, and even data-rate reduction need to keep in mind LLP needs

- **High granularity at large radius**
  - Identifying decays of LLP in various sub-systems away from the interaction point and distinguish them from detector-specific backgrounds (including beam-induced backgrounds)

- **Particle ID**
  - Measurement of ionization energy loss and timing can boost particle ID capabilities and offer unique handles for LLP direct identification

- **Timing (more later)**

- **Dataflow/software must be defined to not prevent LLP searches**
  - Inclusive initial reconstruction and/or nimble re-reconstruction
Inner Tracker

- Particle ID (ToF, dE/dx, etc)
  - Need concrete statements on requirements for future detectors
- Large radius pixels
  - Or, more generally, ability for precision-tracking at outer radii
- Minimum radius of first layer(s)
  - “Short”-lived BSM particles, interplay with MET (and missing mass) analyses
- Depending on environment, one can also explore the advantages of TPCs or a mixed TPC+Si system to allow identification of LLP-specific signatures
  - E.g. kinked track, or good measurement of ionization energy loss
  - What are the trade-offs depending on the split in radius between Si and TPC?
Calorimeters

- Segmentation / Geometry
- Stopping power for stopped particle searches
- Sensitivity to delayed particles’ decay
  - e.g. readout and powering during non-colliding bunches)
- Ability to convert photons for sensitivity to displacement
- Pileup/BIB suppression

Muon Spectrometers

- Non-pointing reconstruction capabilities
- High granularity for vertexing
- Detector volume / extent
- Cosmic ray efficiency for vetoes
Timing information

- Sub-detector timing resolution
- Out-of-time acceptance
  - Extend readout window without accepting too much e.g. BIB
- Limitations from shaper response times
- Shower evolution and time-based pointing info
  - “Backwards-going” particle sensitivity
- Dedicated timing detectors
  - Pileup suppression, Slow ToF, 4D displaced vertexing
Trigger (when relevant)

- **Late triggers**
  - Slight delays, beta ~ O(0.1)
  - Very out of time, apparent beta << 0.1

- **Displaced object triggers**
  - Hardware tracking abilities
  - Trade-off between simplifications and loss of coverage for LLPs (e.g. Looser trigger roads)

- **Direct detection triggers**
  - SMP/HSCP/CLLP triggering, large ionization

- **Interplay between HW and SW triggering**

- **Latency for far detector triggering**

- **Detector geometry to enable smart triggering**
Far detectors

- Proposals for add-ons to existing detectors such as CODEX-b, MATHUSLA, ...
- Future colliders could have pre-excavated, shielded experimental halls
  - In forward and central regions
- Integration with trigger and DAQ system for combined analyses vs continuous data-taking for maximum acceptance
- Pointing capabilities towards the IP
- Particle ID?
- Quite a few slides/LoIs on this
Snowmass exercise wish-list

- How BRN Higgs requirements compared to LLP needs?
  - Most of what discussed above fits or extends these requirements
  - Any non-trivial conflict / compromise?

- Even few basic studies could help translate features discussed today into “proto”-requirements as done in the table here
List of (potentially) relevant Lols
[Very quick assessment by authors, apologies for omissions]

Including LLP in their scope:
- TRACK-BASED TRIGGERS FOR EXOTIC SIGNATURES
- Recent Progress and Next Steps for the MATHUSLA LLP Detector
- 4 Dimensional Trackers
- Triggering on charged particles using silicon pixel detectors
- The road ahead for CDFx
- FASE5v2: A Forward Neutrino Experiment at the HL-LHC
- Scintillator Extrusions for Mega-detectors: MATHUSLA Letter of interest for Snowmass 2021

General
- Muon Collider solidifying the physics case
- Muon Collider experiment: requirements for new detector R&D and reconstruction tools
- A selection of benchmark studies at FCC-ee
- From FCC Physics and Experiments Design Study
- CEPC Detectors
- Belle II Detector Upgrades
- Silicon Vertex Detector for circular electron-positron collider
- Time of Flight Detector for circular electron-positron collider
- Detector optimization and detector technology R&D for the GLC detector and for the GLO detector of FCC-ee
- PRECISION TIMING DETECTORS FOR FUTURE COLLIDERS
- Large area CMOS monolithic active pixel sensors for future colliders
- SIIUQ Snowmass 2021
- IDEA detector Letter of Intent

Could be relevant if extended to LLP (small effort req.)
- Identification of TeV hadrons, Transition Radiation Detectors
- Time Projection Chamber R&D Letter of Intent
- 28nm CMOS for 4D Tracker Readout Chips
- High Precision Timing and High Rate Detectors
- Self-driving data trigger, filtering, and acquisition systems for high-throughput physics facilities
- Physics potential of timing layers in future collider detectors
- Towards ultra high granularity calorimetry
- Particle Flow Calorimeters for the Circular Electron Positron Collider
- 1 reconstruction and identification using machine learning techniques with Dual-Readout Calorimeter at future e+e- colliders
BACKUP