C3 - Muon collider detector common needs

Open discussion points

Goals of this discussion

As exemplified by Max's presentation, some common themes appear in both Muon Collier as well as C^3 detector requirements/wish-list

- however, environments differ very significantly;
- Identifying synergies for detector R&D between them allow to maximize usefulness of today's R&D for future colliders – different timescales

Goals for today:

Identify new common needs we haven't thought of yet

Identify possible technologies for R&D that could serve both machines in common

Figure out where we need further studies to pin down requirements precisely

Tracker

(Sample of) Motivation:

- Common: momentum & impact parameter resolution, efficiency

(Sample of) Requirements:

- High magnetic field: 3-5 T
- Low-radius innermost layer: 14/30mm
- Best-possible resolution 3-5μm
- μ-col specific: radiation hardness
- C3: lightweight (great for μ-col as well)

Technology and R&D directions

- Silicon tracking a prominent option for both
  - Gaseous detector possible certainly for C^3, not very explored for larger radii of μ-col
- Common items: Mechanics, Cooling*, thin Si sensors, FE readout / integrated, …
  - For C^3, options to push to limits likely not affordable for a μ-col, e.g. no active cooling, power pulsing? Note on bunch “trains” collision rate: ILC: 5Hz, C3: 120Hz, μ-col: 100kHz (1 bunch only)
- Max. affordable material budget and radiation hardness requirements might point in different directions for some of the technological choices

Timing (mostly tracker but also beyond)

Motivation:

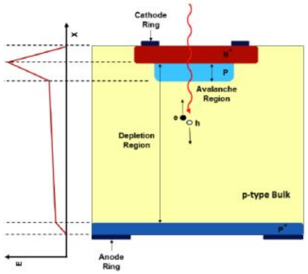
- C3: mostly particle ID (K/pi separation)
- μ-col: mostly BIB rejection

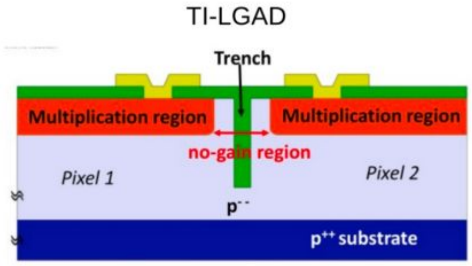
Requirements:

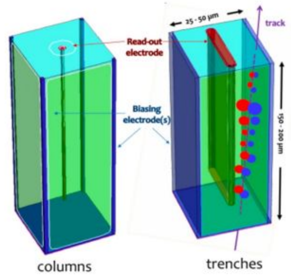
- C3: ~10ps timing layer
- μ-col: at least ~30ps timing in most layers

Technology and R&D directions for **sensors**

- LGADs sensors
  - Great timing demonstrated, many new ideas to push towards O(10um) resolution
- 3D silicon sensors
  - Great for rad. hardness, need development to push timing resolution
- LYSO crystals + SiPMs
  - Mostly for single-layer timing or embedded in a calorimeter?
- Explore new materials/composites







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Technology and R&D directions for **FE electronics**

- Minimize power consumption and channel size
  - Implications on cooling -> mass
- Reduce channel size to be compatible with position resolution req.
- Increase amount of on-detector "logic"
  - Real-time processing, more functionalities; push towards 28nm technology

ASIC	Technology	Pitch	Total size	Power consumption	TID tolerance
ALTIROC	130 nm	1.3 mm	$19.5 \times 19.5\ \text{mm}^2$	5 mW/chan	2 MGy
ETROC	65 nm	1.3 mm	$20.8 \times 20.8\ \text{mm}^2$	3 mW/chan	1 MGy
RD53A/HL-LHC pixels	65 nm	50 μm	$20 \times 11.6\ \text{mm}^2$	< 10 μW/chan	5–15 MGy

Calorimeters

Both need **high granularity** and **fast timing**, for different reasons:

CCC

- Good energy resolution, particle ID/flow requires high granularity
- 3-5 ns bunch spacing requires good timing resolution and readout

Muon collider

- High granularity, fast timing resolution are important for BiB suppression
- Need timing per-cell, not just timing layer
- Small Integration time reduces BIB impact

Both collaborations beginning from same CALICE-ish designs → **common ground**

- ECal: Silicon+Tungsten
- HCal: Scintillator+SiPM with lead/steel absorber

[Not studied yet at 10 TeV muon collider, only 3 TeV …. may have to change]

Dual readout is a compelling option also - but would need small cell size to be a good option at muon collider

Differences: radiation hardness (more stringent in MuCol, especially forward); potential need for hit selection at readout level, …

Muon detector

Gaseous chambers are the obvious options.

- for a μ-col, away enough from IP that BIB suppression does not play as dominant of a role

Many possible commonalities in both environments:

- Need for eco-friendly gas options
- Fast readout with good timing resolution

Dimensions will likely differ significantly (different momentum range), but might not impact as strongly the technological choices (?)

DAQ/Software

Quite large bandwidth requirements when taking into account the desire for minimal trigger-bias.

- Implication also on handling offline large data volumes
- Data transmission

Hardware accelerators and algorithms that take full advantage of them

Usage of modern heterogeneous resources

Auxiliary detectors and programs

Proposed for both current and future accelerators, external detectors (relatively far from the main detector) with more specific functionalities and physics goals

- Detection of long-lived particle decays (large volumes preferred, position depends on target mass as well)
- Beam-dump facilities and detectors
- Identification of very-forward leptons ???
    - e.g. in VBF-dominated production

Backup materials

Useful links

- Muon collider forum report: https://arxiv.org/pdf/2209.01318.pdf
- Muon detector needs talk (Tova Holmes): https://indico.fnal.gov/event/56615/contributions/253774/attachments/162471/214755/2022-12-16-DetectorNeeds.pdf
- SiD for CCC slides (Andy White): https://indico.slac.stanford.edu/event/7016/contributions/3246/attachments/1461/3869/SiD_for_CCC_2.pdf
- Fast timing requirements for a Muon Coillider (Larry Lee): https://indico.fnal.gov/event/22303/contributions/246181/attachments/157684/206422/072122_LLee_MuonColliderTiming_Snowmass.pdf
- …

Table A-2. *Computational resources expected at future Energy Frontier colliders.*

Collider Scenario	Event size	Event rate	Data/year
HL-LHC general purpose expt	4.4 MB	10 kHz	0.6 EB
FCC-ee Z-pole, one expt	1 MB	100 kHz	2 EB
CEPC 240 GeV, one expt	20 MB	2 Hz	260 PB
ILD 500 GeV	178 MB	5 Hz	14 PB
CLIC 3 TeV, 1 expt	88 MB	50 Hz	110 PB
Muon Collider, 1 expt	50 MB	2 kHz	2 EB
FCC-hh, 1 expt	50 MB	10 kHz	10 EB