Studies of Tracker Timing and Granularity for the Muon Collider Environment

Hannsjörg Weber (Fermilab / Humboldt-Universität zu Berlin)

On behalf of Sergo Jindariani (Fermilab) , Ron Lipton (Fermilab),
Simone Pagan Griso (LBNL), Nazar Bartosik (INFN Torino),
Massimo Casarsa (INFN Trieste), Lawrence Lee (Harvard U)

Fermilab

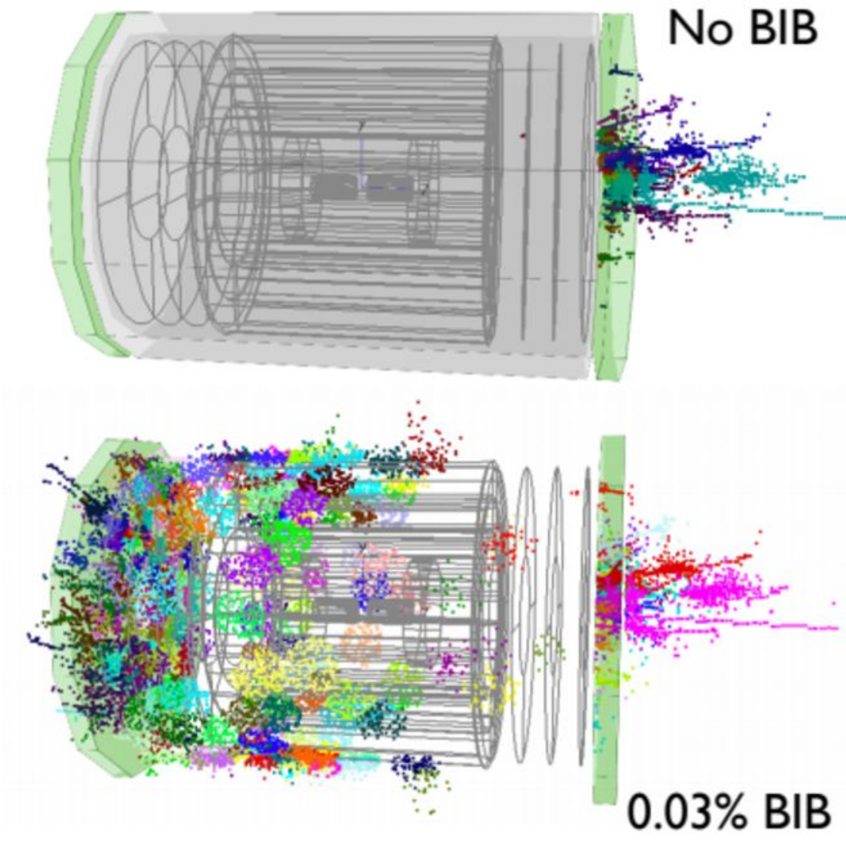
HUMBOLDT-UNIVERSITÄT ZU BERLIN

A challenging environment at muon collider

- As discussed on Saturday in the Muon Collider Symposium I (B08.00002), the **beam induced background (BIB)** creates a huge challenge for the detectors.
  - The detector is bombarded by O(100) million (mostly soft) particles per beam crossing out of which O(1) million are charged.

- The challenge for the tracker is to be able to reconstruct particle trajectories in that environment.
  - To be able to do efficient tracking, we need a low tracker occupancy.

By M. Swiatlowski



How do we study the tracker occupancy?

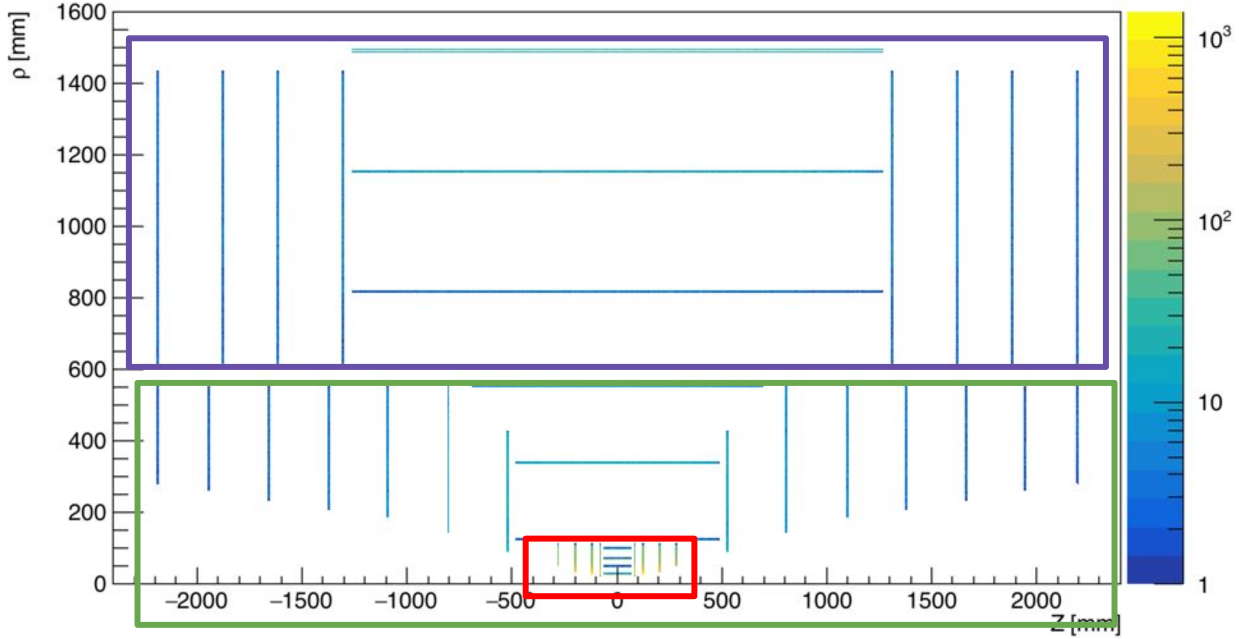
- In order to be able to perform tracking at a muon collider experiment at high efficiency and precision (similar to e^+e^- machine), we need to require a decently low tracker occupancy.
  - Our goal is to achieve an occupancy of 1%.
  - What granularity and special resolution can give us that goal.

- Luckily we can study this using only BIB events.
  - Significantly more hits from BIB than from hard scatter event - by orders of magnitudes.

- What we study here, is using BIB hits generated using the MARS code. The muon beam energy is 750 GeV (i.e. $\sqrt{s}$ = 1.5 TeV).

The muon collider tracker layout

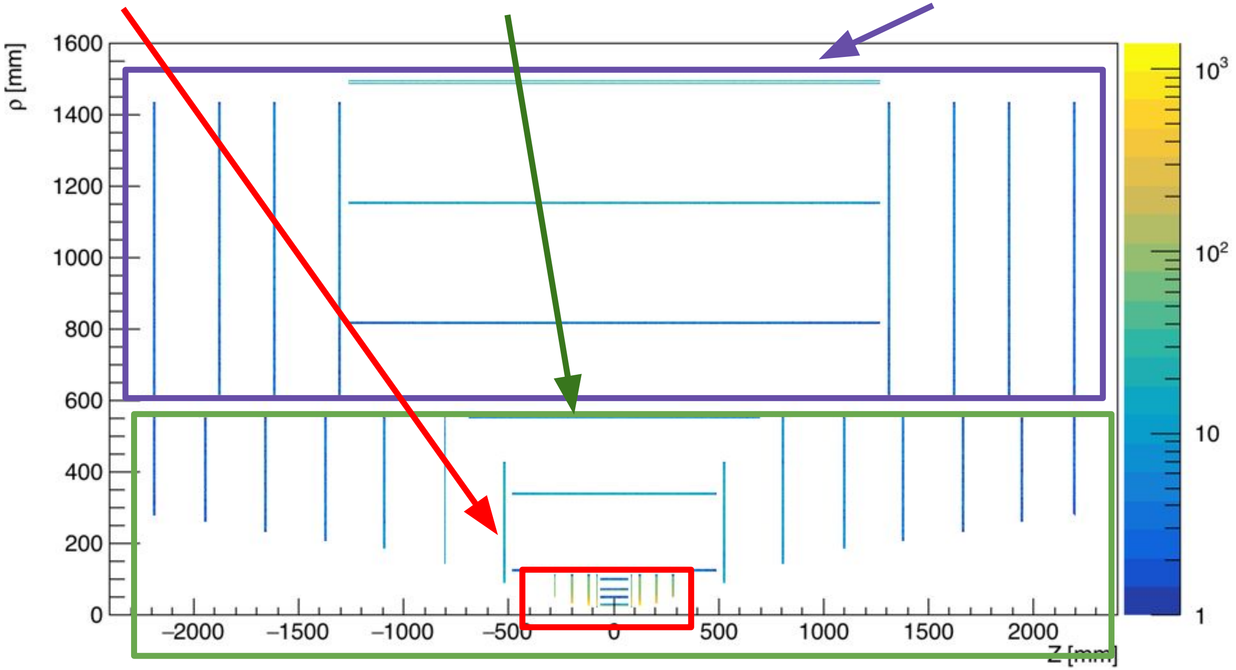
- The tracker has a **vertex** tracker with 4 double layers in the center and 4 layers on each endcap, 3 (3) central layers and 8 (4) layers for each **inner** (**outer**) tracker endcaps.



The muon collider tracker layout

- For the purpose of these slides, I label all layers:

Vertex Barrel: 0-7 | Inner Barrel: 24-26 | Outer Barrel: 41-43
Vertex Endcap: 8-23 | Inner Endcap: 27-40 | Outer Endcap: 44-51



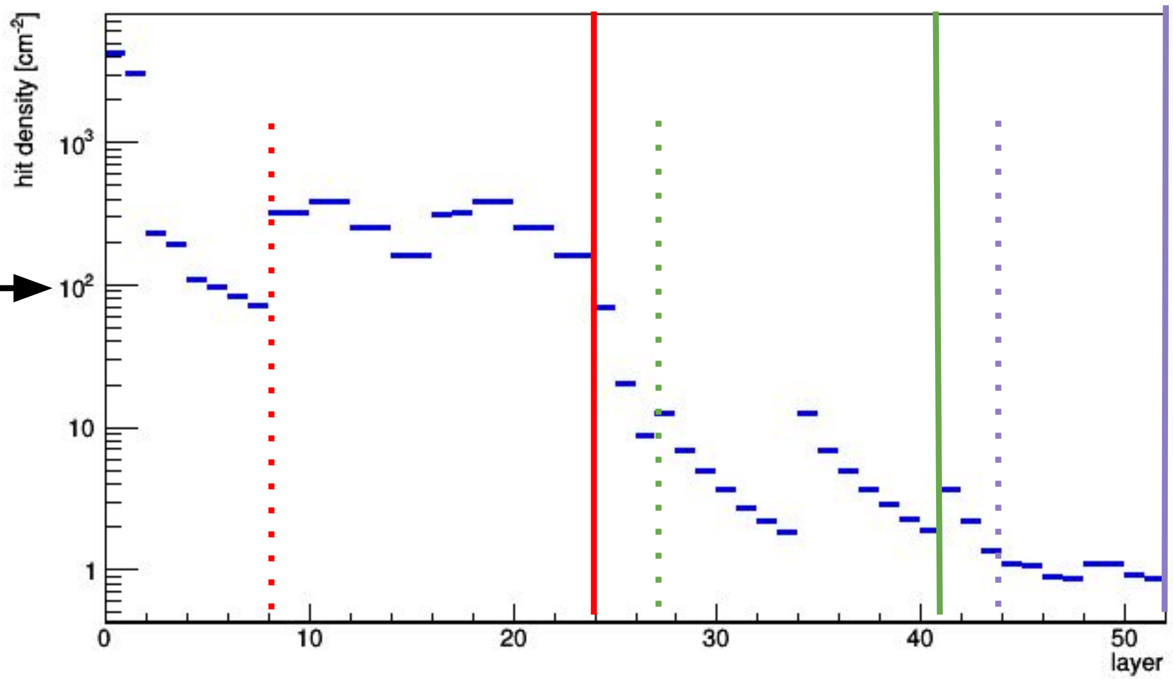
The muon collider tracker layout

- For the purpose of these slides, I label all layers:

Vertex Barrel: 0-7 | Inner Barrel: 24-26 | Outer Barrel: 41-43

Vertex Endcap: 8-23 | Inner Endcap: 27-40 | Outer Endcap: 44-51

100 hits / cm^2 →



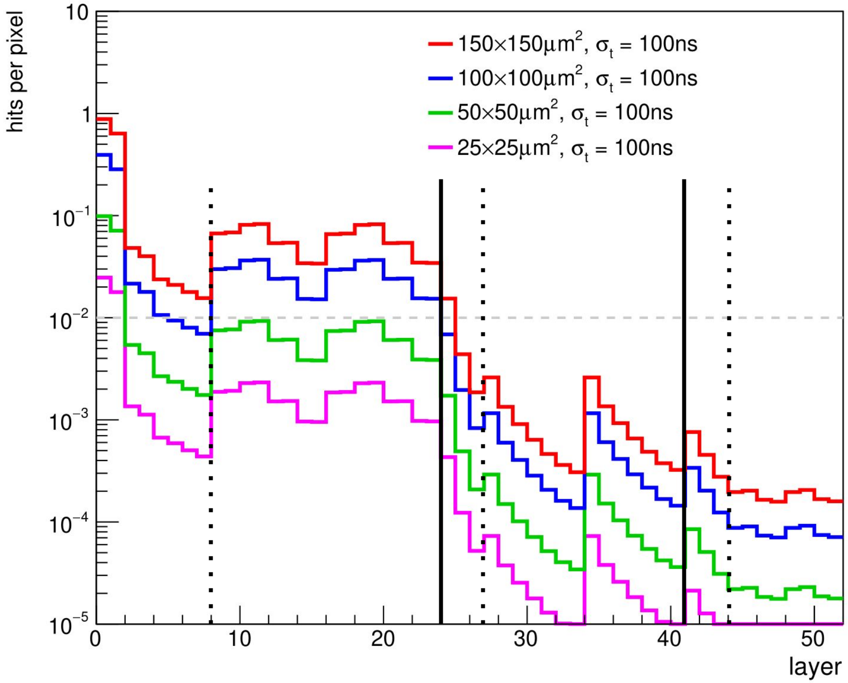
The hit energy threshold is 1.8 keV.

What do we study?

- We look at the per-readout channel (pixel) occupancy. We want this number $\leq 1\%$.
- We have two parameters:
  - **Pixel size**: This defines our position resolution. We test how many pixels light up (are hit by at least one BIB hit).
  - **Pixel timing**: This defines our timing resolution: We assume a resolution σ_t. We smear the hit's time by that resolution. We require the hit to be within $< 3\,\sigma$, $\sigma = \sqrt{\sigma_t^2 + \sigma_b^2}$, with $\sigma_b = 25$ ps being the time spread of the collision area.
- We adjust these two parameters to see if we can achieve a low occupancy.

How occupancy looks "without" timing

- First, we look at pixels without *significant* timing requirements.

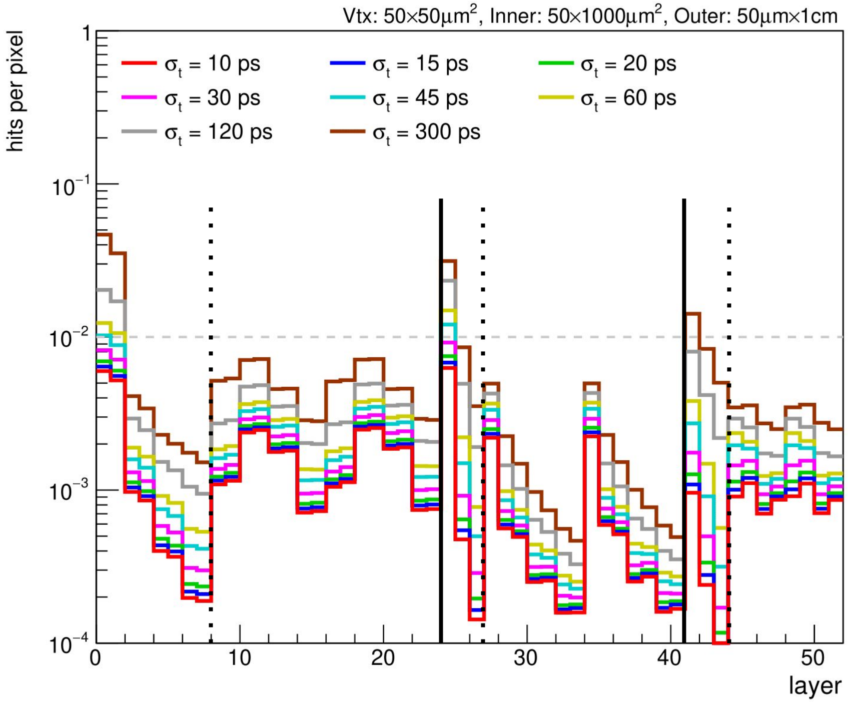


- Timing is essential for the vertex detector.
- Also inner/outer tracker benefits, as we don't want to finely pixelate these detectors.

- Note: no digitization was applied. The $25\times25\mu m^2$ number is very optimistic.

Look at timing impact on the detector

- First, we choose a reasonable readout unit size (like short strips for the outer tracker). Then, play with assumption on timing capability of the detector.

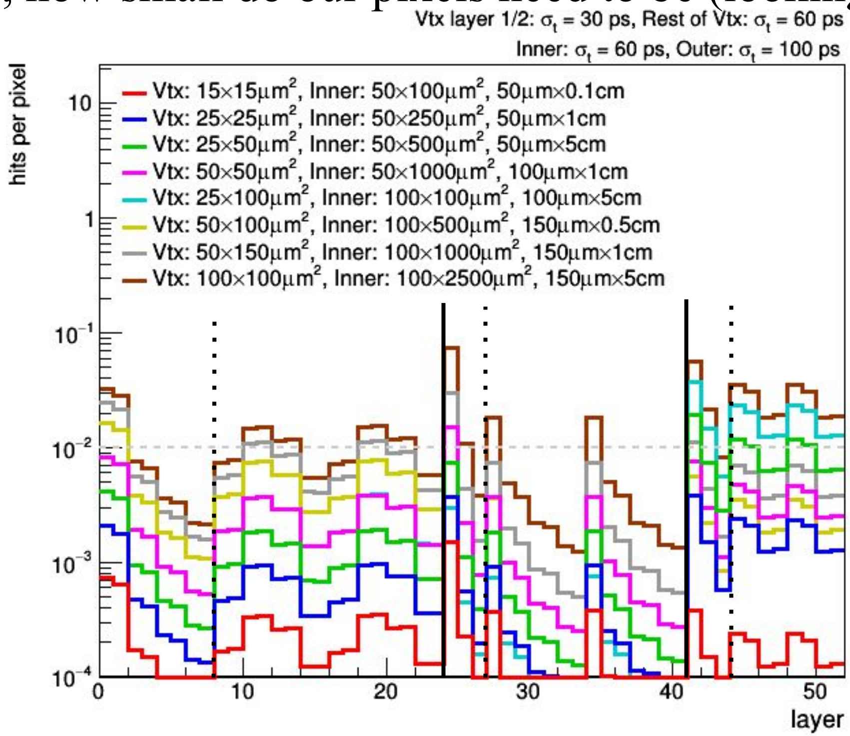


- Setting a tight timing can immensely reduce occupancy.
- Especially important in the barrel, but also very helpful in endcaps.

- For barrel, very good timing necessary (30-60 ps). Equally good timing useful for the endcaps.

Given that timing, how small do pixels need to be?

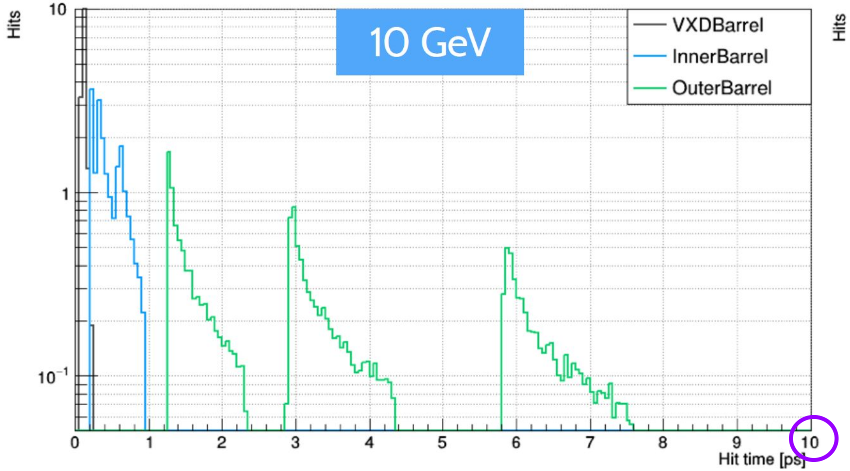
- Assuming a tight, but not extreme timing capabilities of the tracker,
- , how small do our pixels need to be (looking just at the occupancy)?

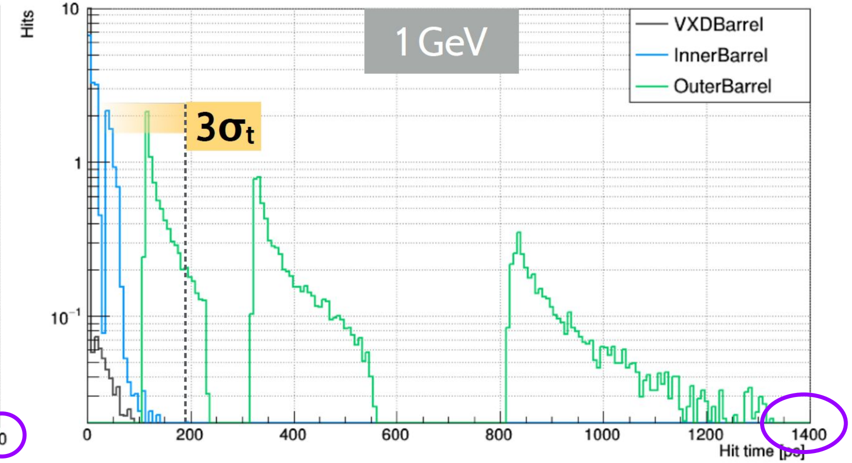


- Small pixels for the vertex is necessary.
- The inner tracker (especially barrel part) needs macropixels (long side ≲1mm)
- The outer tracker needs short strips (long side ≲1cm).

However, there is one more thing

- When we want to do tracking, we want to reconstruct as many collision particles as possible, especially slow particles (such as 1 GeV muons or pions).

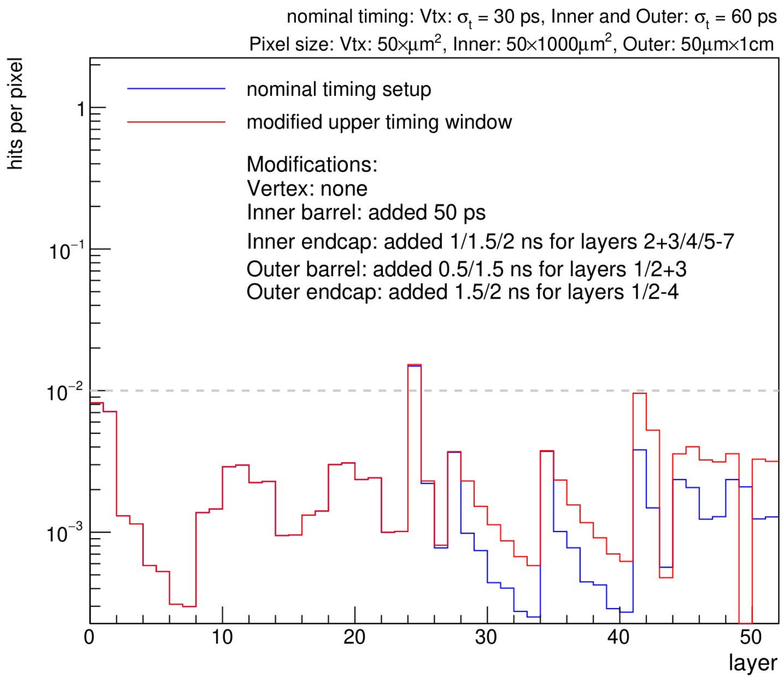




- Shown are hit times simulated (unsmeared) hits for 10 GeV (left) and 1 GeV (right) muons.
- A tight timing requirement removes all hits from low momentum particles from outermost layers!
  - We need to adjust our timing window!

Opening up timing window

- We need to open up the timing window on the upper side (i.e. for times after the collision).



- This should depend on β of the slow moving particle. Here, a proof-of-concept shown with staggered opening of the timing window: from no opened window for the vertex, to allowing delayed times of up to 2 ns for outermost layers.

- As only outer layers (that had low occupancy) are affected, we can handle this change!

Summary

- Studies related to the tracker timing and granularity for the environment at the muon collider have been shown.
- In order to achieve low tracker occupancy, we need good timing and small pixels in the innermost region.
- For outer regions, we need to relax timing requirements (to allow for slowly moving particles from the collision).
  - But with our configuration of macropixels and short strips (long sides at the order of 1mm and 1cm, respectively), we can allow for this relaxation.

- The technical requirements for a tracking detector as thought out by most collider experiments (either ee, pp, or μμ) will suffice for the environment at a muon collider.
  - Pixel size similar to those of HL-LHC innermost tracker.
  - Timing resolution similar to HL-LHC timing layers.
  - Number of readout channels similar to that of HL-LHC trackers.