

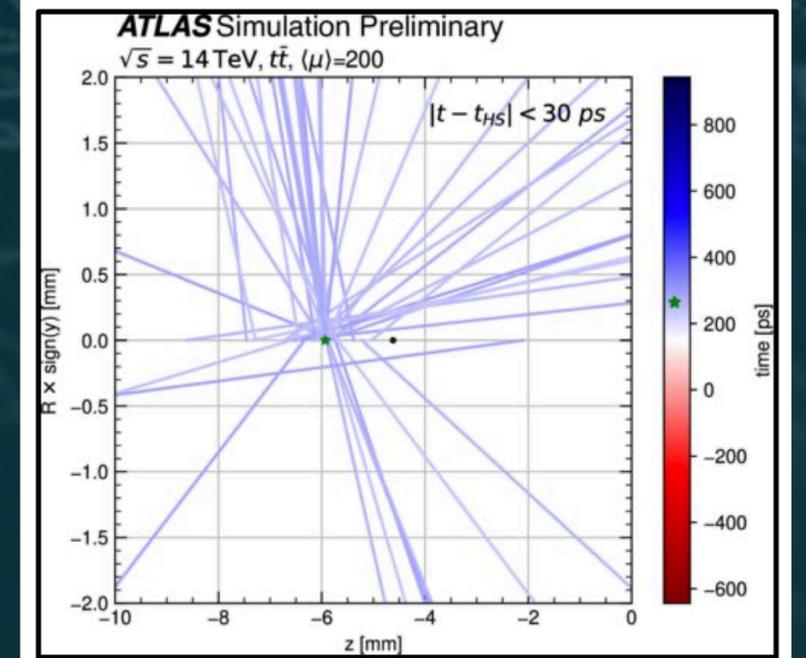
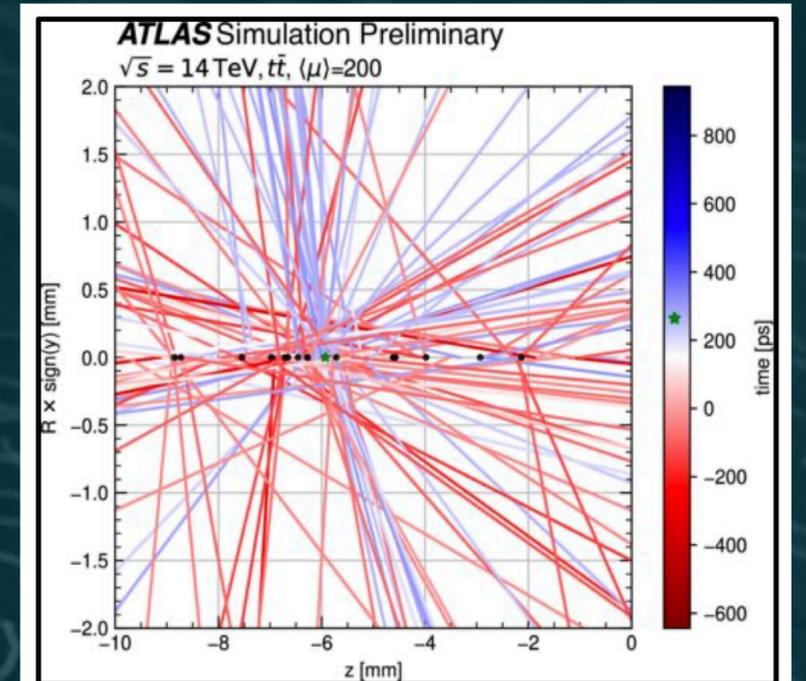
4D Tracker Testbed

LESA Workshop, SLAC - 04.09.25

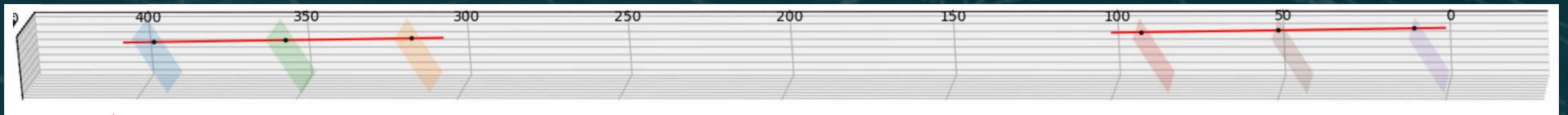
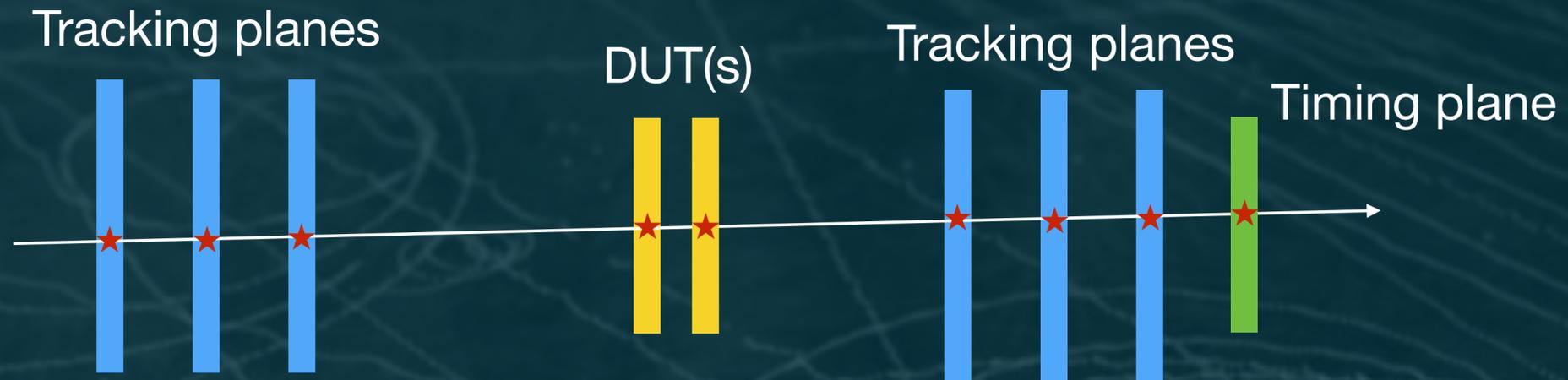
M. Garcia-Sciveres, T. Heim, S. Pagan-Griso,
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Tracking and Timing

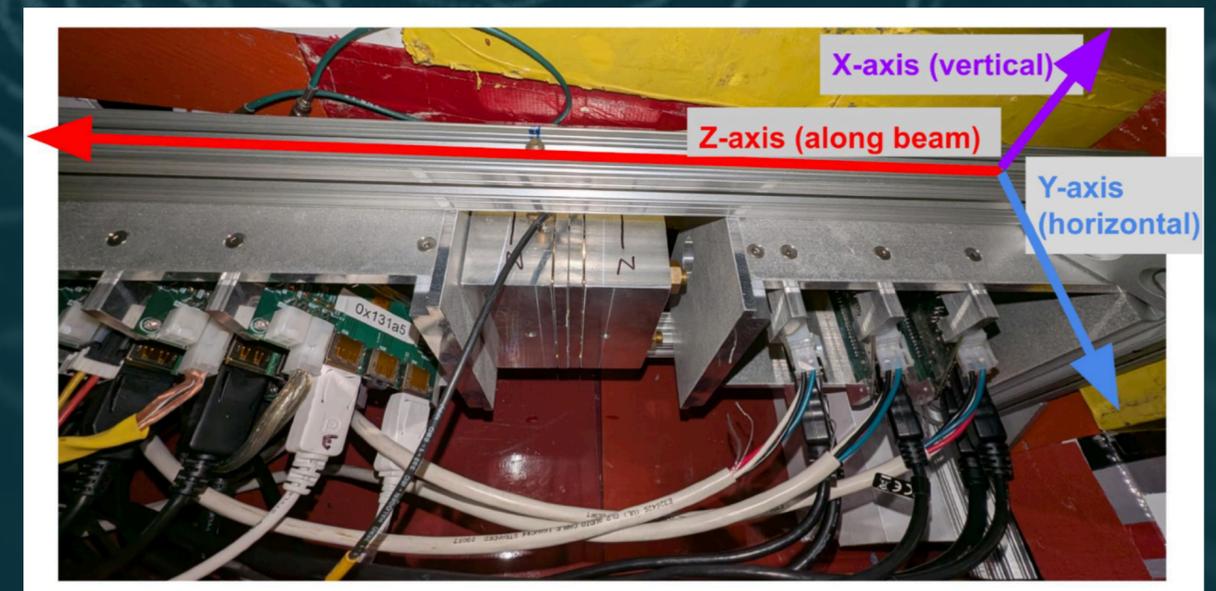
- 4D Tracking = 3D spatial $O(50\mu\text{m})$ + $O(30\text{ps})$ temporal resolution
- Current ATLAS/CMS tracker upgrades already have 50 μm spatial resolution, but only 25ns time resolution (bunch to bunch)
- Addition of timing precision helps to resolve multiple concurrent collisions (~ 200 for HL-LHC $\rightarrow \sim 2000$ for FCC-hh) or beam induced background rejection (Muon Collider)
- 4D tracking technology deemed necessity for future colliders \rightarrow Lots of R&D work already going on (LGADs, ASIC development, system design)



Typical Testbeam Telescope



- Typical use case for a beam telescope is to reconstruct particle tracks (spatially) to compare against a device under test (telescope technology usually based on existing detector technology)
- Currently timing typically inferred either by double-stacking DUTs (which have precision timing) or using a timing reference plane
- Purpose is aid DUT (typically sensors) development



Telescopes as a Testbed

- Detector R&D faces an increasing gap in testing between in-house bench testing and detector operation
- Operation in a testbeam environment can fill some of that gap, but requirements are different from typical sensor DUTs
- Even better: a multi-plane setup made from detectors under development force the R&D to critically look at system aspects
- Bonus: telescope can be used simultaneously to test DUTs with potential new features (depending on beam conditions)
- At least for ATLAS tracker upgrade testbeams have been heavily underutilized during R&D period, which either delayed detection of bugs or could delay detection to starting operation



Testbeam at ESA back in ~2018

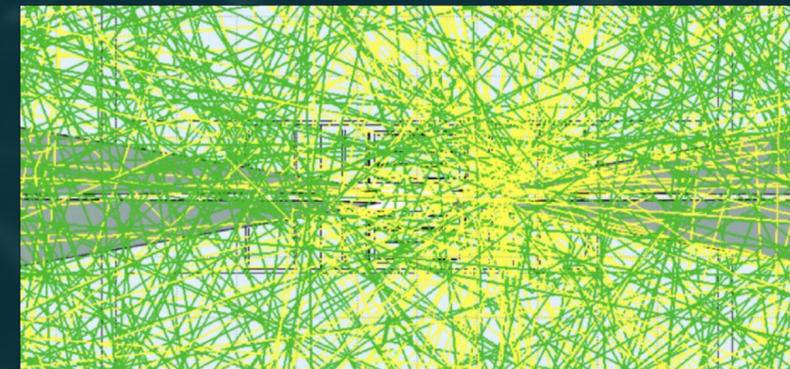
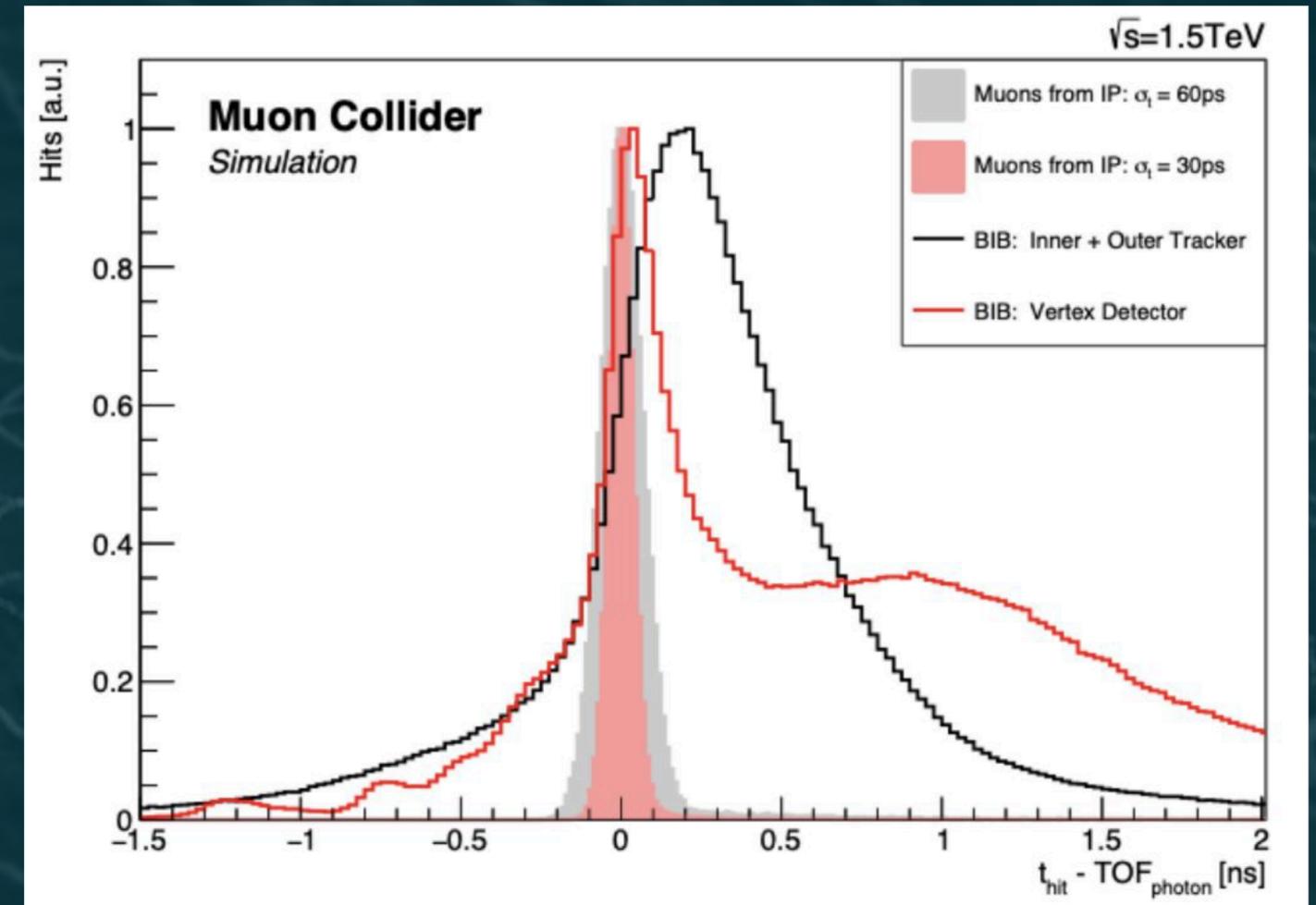
Desired Beam Conditions



- **Bunched beam** highly preferred over continuous beam
- Would like to **synchronize detector** to beam to mimic detector operation
- Small number of concurrent particles
 - Due to all particles being basically parallel, creates a lot of ambiguity during track reconstruction, typically wisdom says **~3-5 particles per detector timing window** -> Can potentially be improved with tracking software?
 - But large number of particles in tight bunch can be used to test timing dispersion over large area or other high hit rate features of novel detectors
- **High repetition rate** (>1MHz)
 - Detectors often designed for **O(40MHz)** bunch crossing, might not read everything out but allows to push system to the edge
 - Additionally helps for any measurement that requires statistics (1M tracks per measurement typical)

Muon Collider Environment

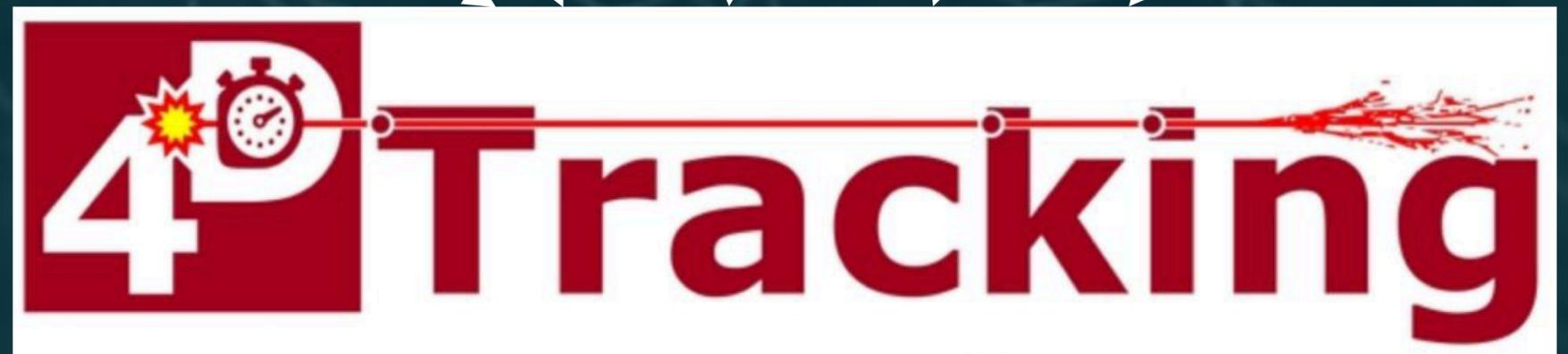
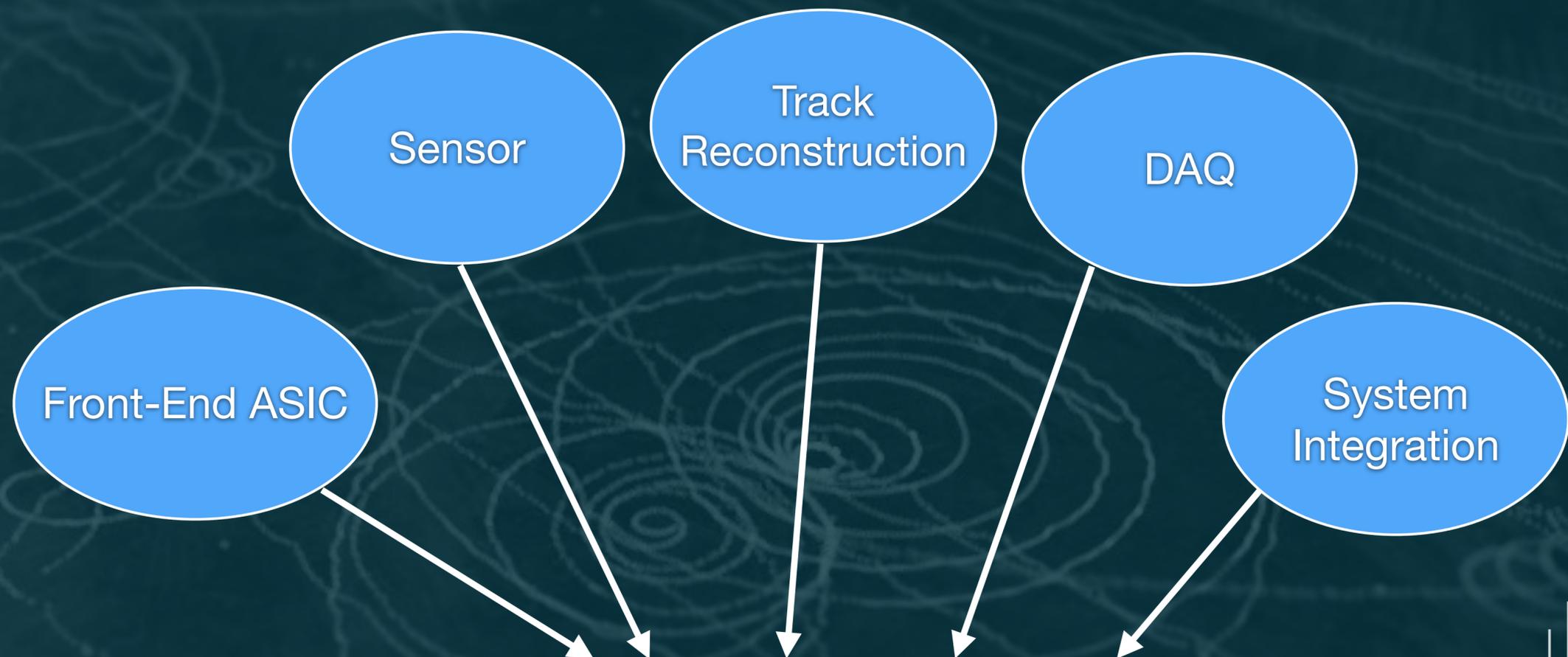
- Muon decay creates enormous and unique background in Muon Collider environment
- Would be interesting to have the possibility to mimic this in a testbeam environment
- Combating this background will be a major R&D thrust and testing it will be rather complicated
- Emulation on the bench close to impossible
- Would require bunch to spread over $O(1\text{ns})$
- Additional up-shot: with a $O(30\text{ps})$ 4D tracker can load bunch up with many more particles (more than 5~) and still do tracking as they can be distinguished in the temporal plane
- This would allow for even faster data collection



4D Tracker Demonstrator Proposal



- Goals:
 - **Coalesce** on-going detector R&D into a demonstrator milestone
 - **Demonstrate** the full process chain from particles to 4D tracks on disk
 - **Understand** system aspects that affect precision timing or how to synchronize a large detector system
 - **Provide** a telescope for future detector development



Tentative Plan for LESA

- Have existing development in collaboration with KEK for large area (16cm²) high rate (1MHz) telescope based on ITkPix modules (1ns timing at best)
- KEK beam line also “low” energy electrons, will require some additional work to reduce mass (cooling)
- Have also deployed an ITkPix telescope at Bella (LBL) for Muons for Safety&Science project
- Special feature: addition of magnet allows momentum measurement of incoming particle
- Besides better system integration these are ready to go and would enable full usage of increased rep rate @ LESA
- Testing could still be beneficial for ATLAS Upgrade to better understand operation, learned a lot in operating the above two telescopes
- 4D Tracking demonstrator would be much smaller scale (~16mm²) and initially added DUT-like to ITkPix telescope
- R&D accelerating now and prototypes should be available in ~2 years
- As R&D progress expand to multi-plane 4D detector and depending on available funding and community interest could expand to larger area detectors

