A New Track Trigger for the Proton-Radius Measurement at COMPASS++/Amber

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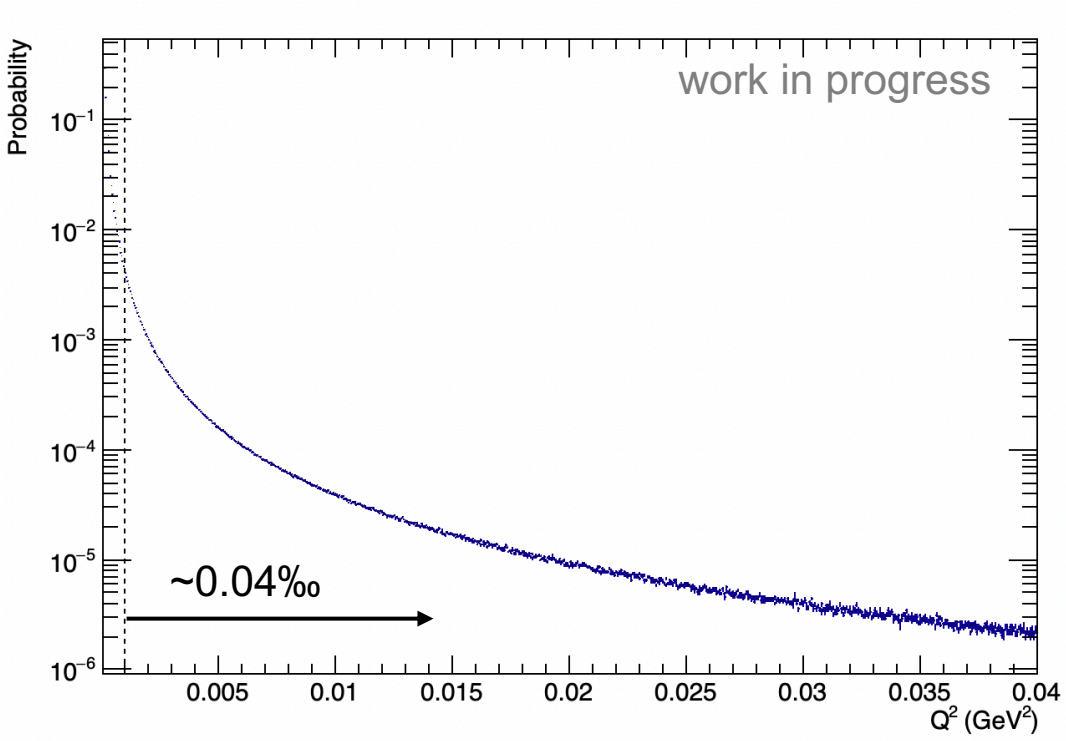
Measurement of the Q^2 Spectrum at COMPASS

- high-intensity muon beam
  $$\phi_\mu \sim 2 \cdot 10^6\ /s \text{ - } 2 \cdot 10^7\ /s$$
- would correspond to data rates of 3 GB/s – 30 GB/s (~7-70 PB per year)
- without trigger selection only ~0.04‰ interesting events (for $Q^2 \geq 10^{-3}\ \text{GeV}^2$)

→ remove the “unscattered” ($Q^2 < 10^{-3}\ \text{GeV}^2$) muons with a *kink trigger*



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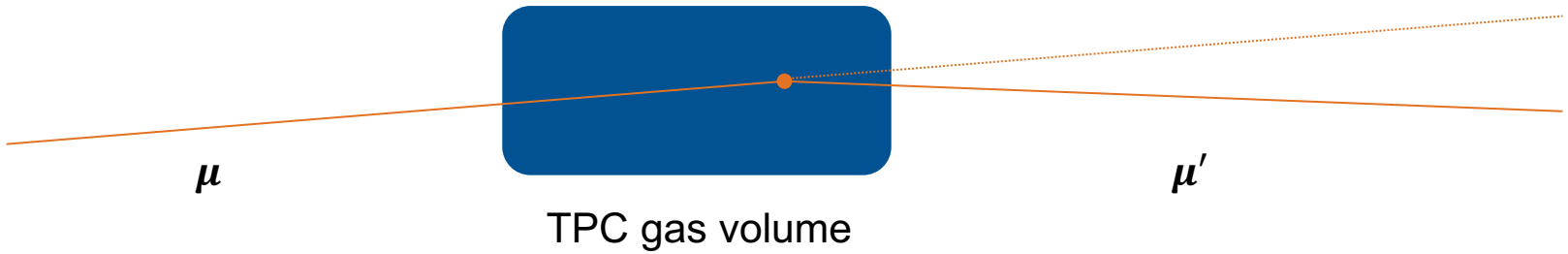
Triggering on Scattered Muons



Requirements

- reject unscattered muons below $Q^2 <$ *threshold* ($\leq 10^{-3}$ GeV ^{2})
- high trigger efficiency for scattered muons with $Q^2 > 10^{-3}$ GeV ^{2} ($\gtrsim$90%)
- low material budget (source of multiple scattering)
- large active area (large beam profile)
- withstand high beam rate without pile up

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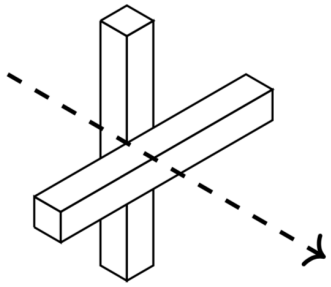
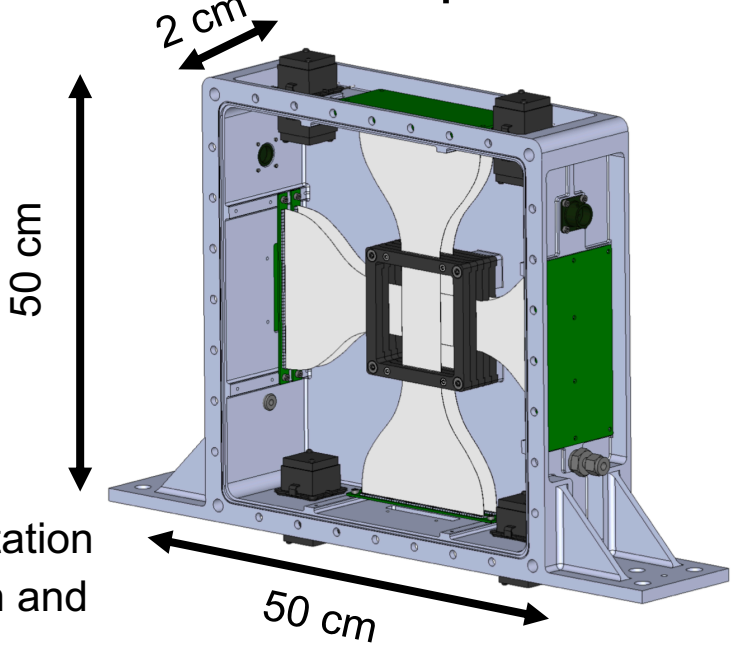
Fiber-Trigger Stations: Scintillating Plastic Fibers Coupled to Silicon Photomultipliers

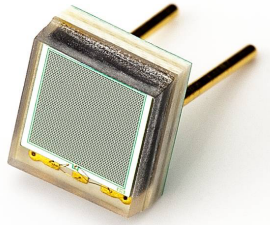




Tracking Station

- layers of scintillating plastic fibers with alternating orientation
- 400 fibers per layer with 200 μm x 200 μm cross section and ~400 mm length
- 4 layers (2 oriented horizontally, 2 oriented vertically)
- relative shift of layers by 100 μm → 100 μm x 100 μm effective "pixel" size *(would also satisfy scatter-angle reconstruction precision)*
- each fiber individually read out by two 1 mm x 1 mm silicon photomultipliers (one on each end)

✓ low material budget (~4% contribution)



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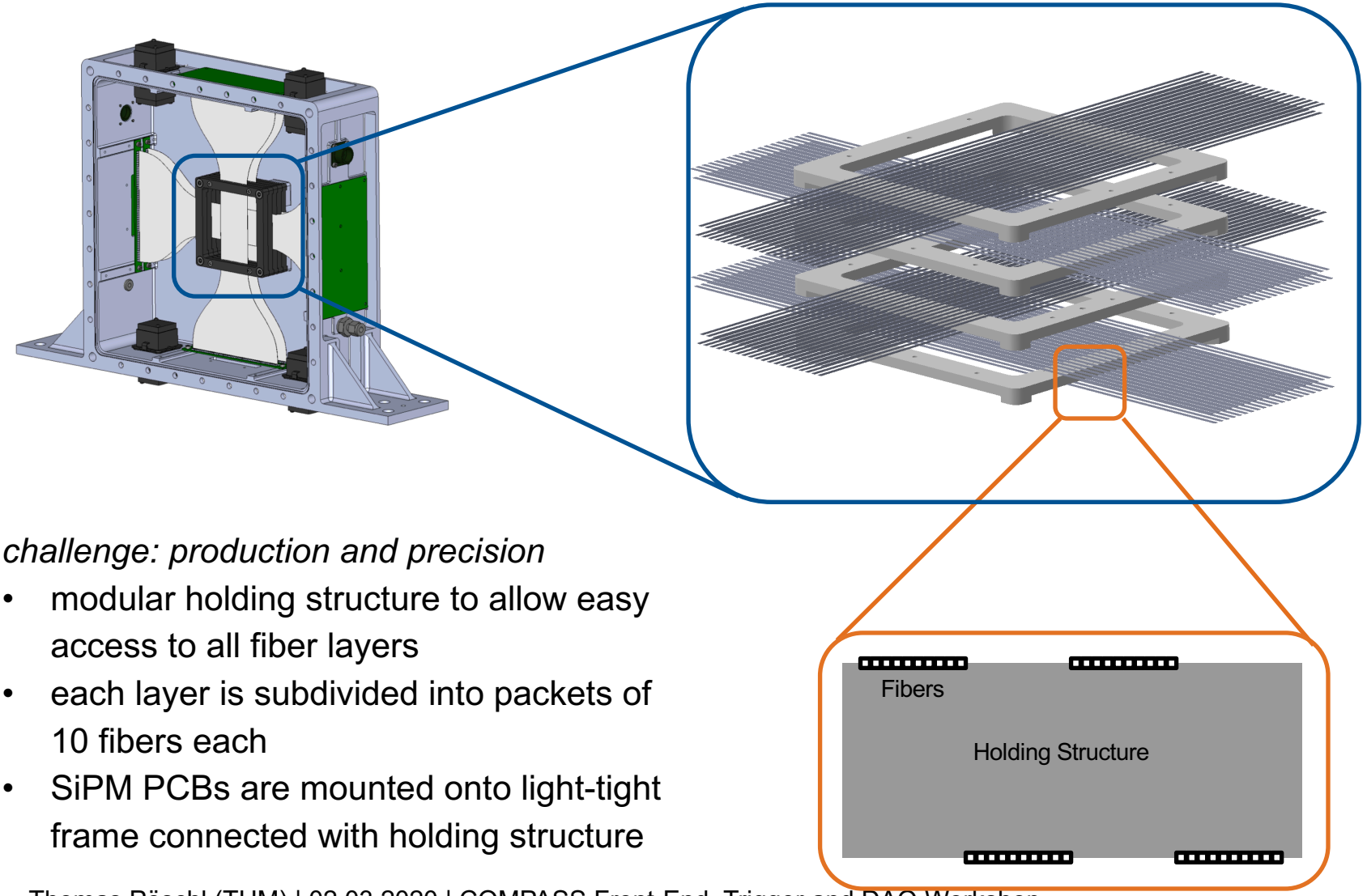
Mechanical Setup of the Tracking Station



challenge: production and precision

- modular holding structure to allow easy access to all fiber layers
- each layer is subdivided into packets of 10 fibers each
- SiPM PCBs are mounted onto light-tight frame connected with holding structure

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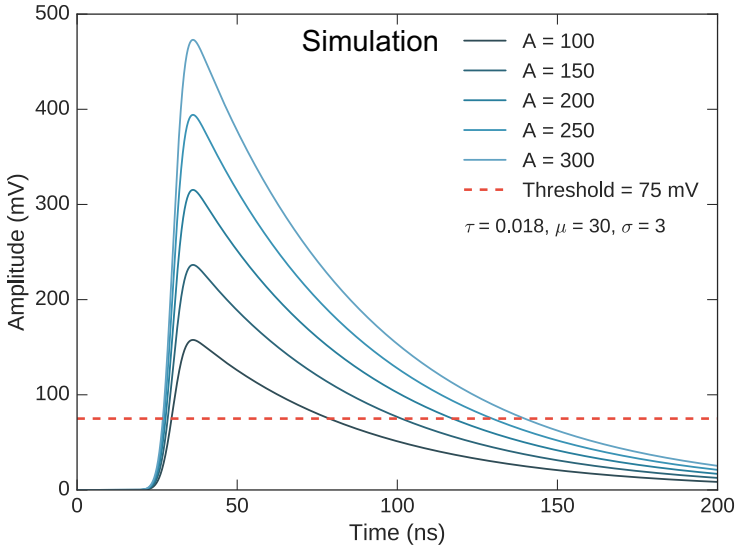
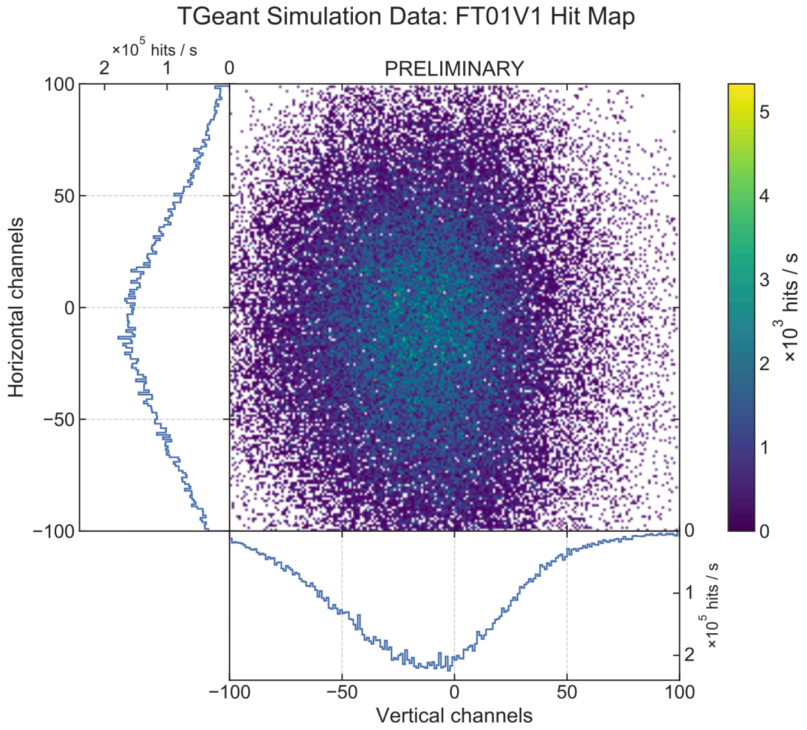
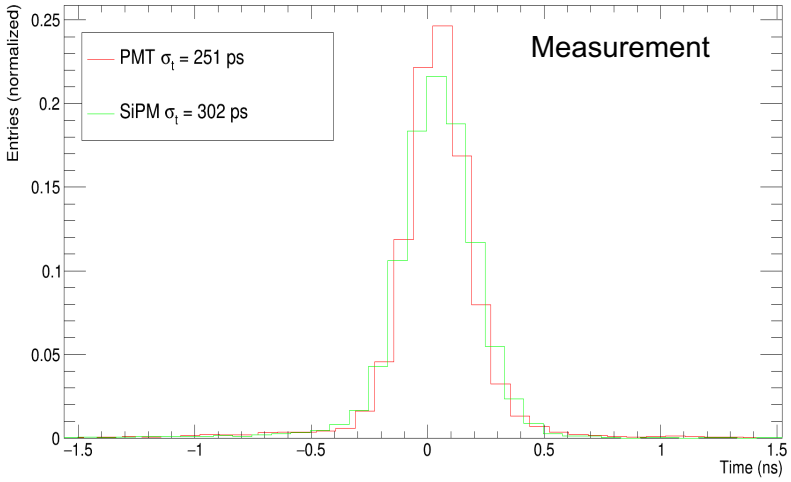
Signal Characteristics

- ✓ very fast: organic scintillator ~ 2 ns
  SiPMs ~ 10 – 100 ns
- ✓ good single-channel time resolution
- ✓ no pile-up for expected beam settings (up to $10^7\ /s$)







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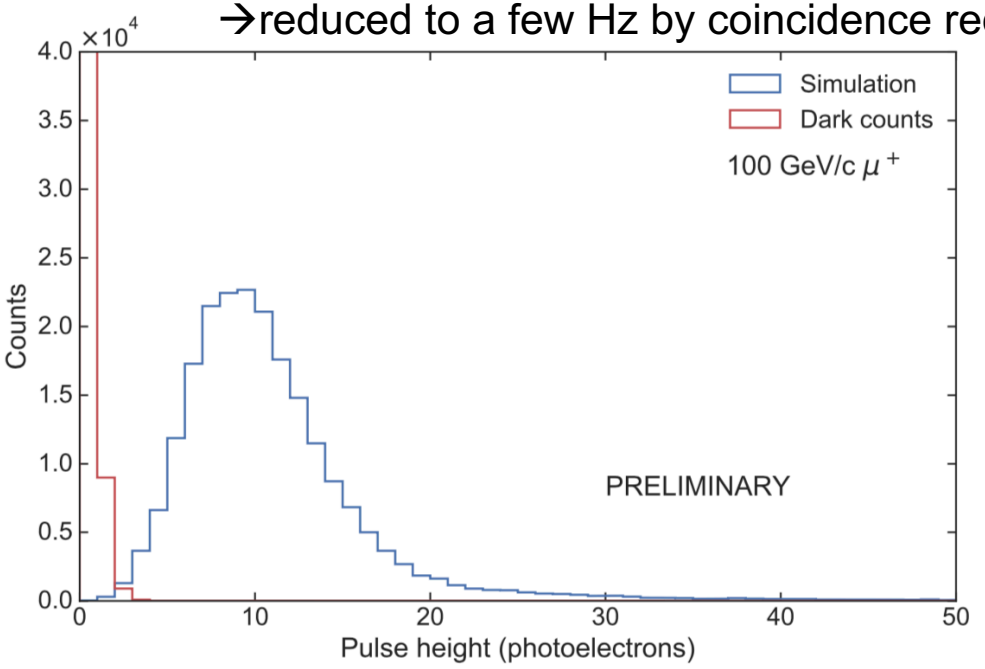
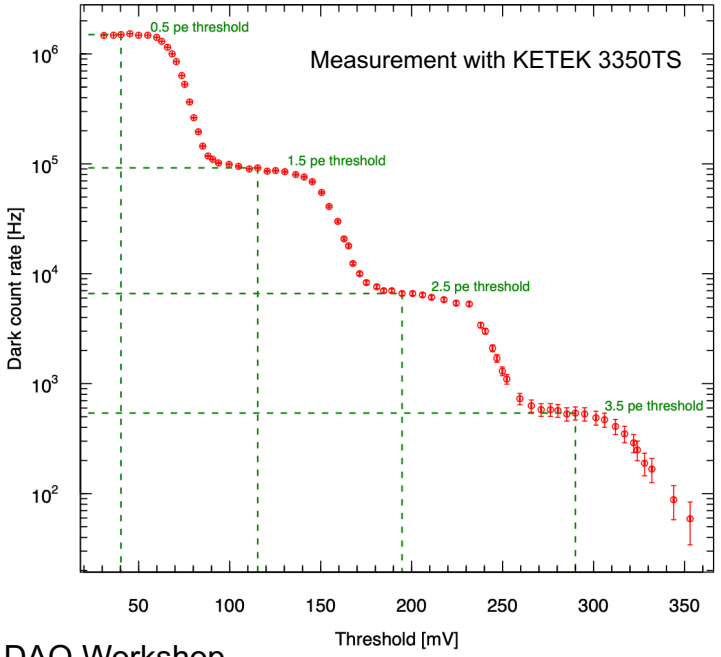
Challenge: Having a High Detection Efficiency for the Muon

- high-energy muons are nearly minimum-ionizing: ~40 keV energy deposition in 200 μm fiber
  (coupling of two successional fibers to one SiPM can be used to double the energy deposition; drawback: higher material budget)
- together with scintillation efficiency, photon transport, and detection efficiency of SiPMs we expect **only ~10 photoelectrons (p.e.) in average** (Poisson distributed)
- noise level of SiPMs ~10 kHz @ 2 p.e.
  →reduced to a few Hz by coincidence requirement of two SiPMs on one fiber





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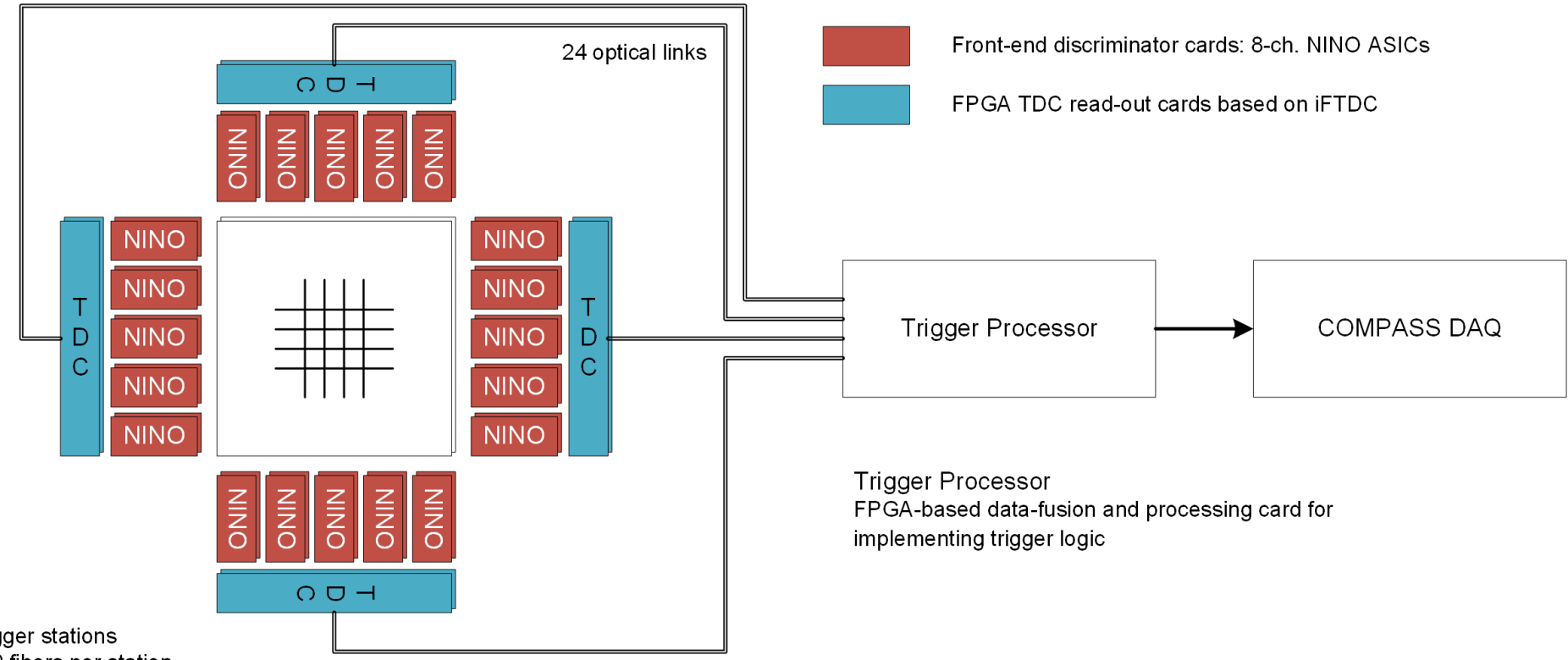
Electrical Setup of the Tracking Stations (work in progress)



3 trigger stations
1600 fibers per station
3200 SiPMs per station

challenge: allowed latency for trigger ~4μs (including digitalization and trigger distribution)

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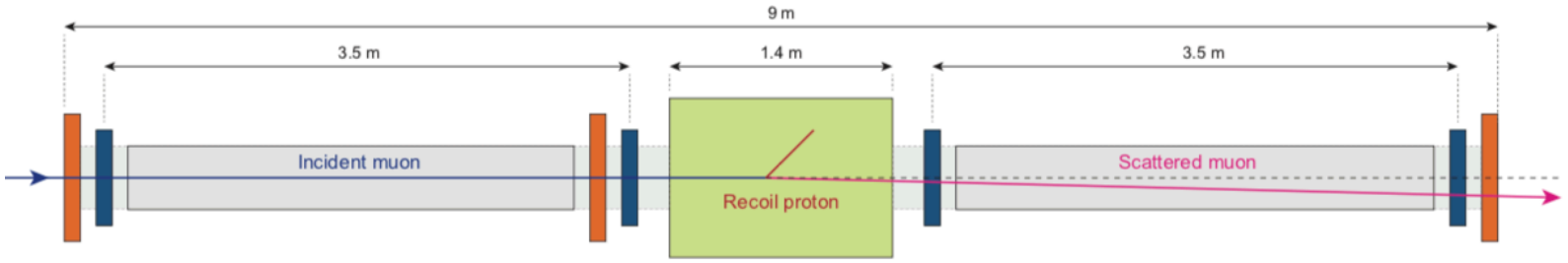
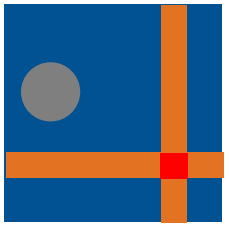
Identification of a Scattered Muon



Trigger Station 1 | Trigger Station 2 | Trigger Station 3

- determines track parameters of incoming muon ---- straight-line extrapolation ---->



✓ only one trigger station within the scattering-sensitive measurement regime (minimize multiple scattering) (1,2 ←→ 3 can be switched)
simple calculation for online triggering (FPGA based)

- **low-Q^2 resolution limited by fiber cross-section and lever arm**

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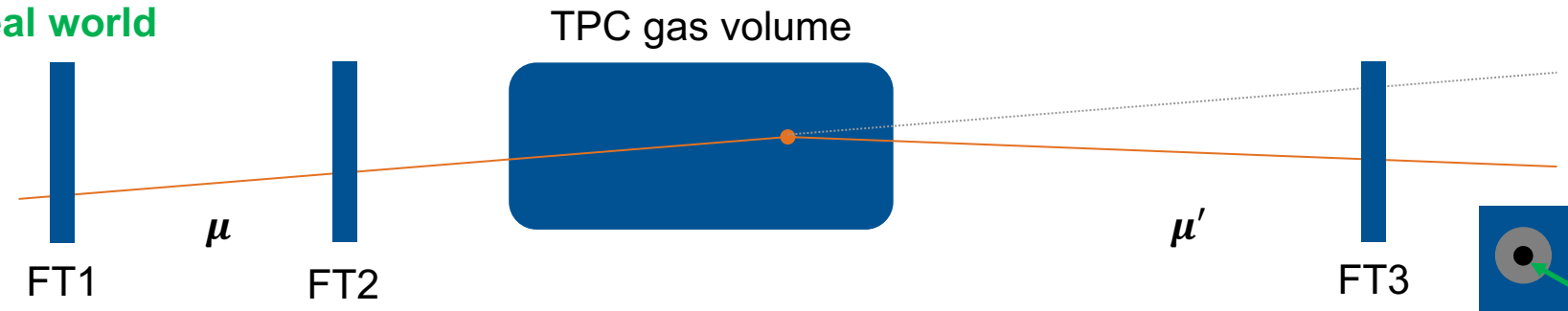
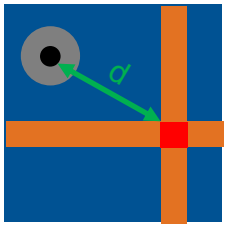
Trigger Logic: Straight-Line Extrapolation Algorithms

Ideal world





1. calculate track parameters and **hypothetical unscattered hit point on FT 3**

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{\substack{FT3 \\ no-scat}} = \begin{pmatrix} z_{FT3} m_x + x_{FT1} & -m_x z_{FT1} \\ z_{FT3} m_y + x_{FT1} & -m_y z_{FT1} \\ z_{FT3} & \end{pmatrix} \text{ with } m_x = {}^{\Delta x}/_{\Delta z},\ m_y = {}^{\Delta y}/_{\Delta z}$$

2. calculate minimum distance from hit-point to trigger
   has to be done only once (with approximations)
   $d_{min} = \tan\theta_{min}\,\Delta z$

3. check if distance between hit and hypothetical unscattered hit point (d) larger than d_{min} → trigger

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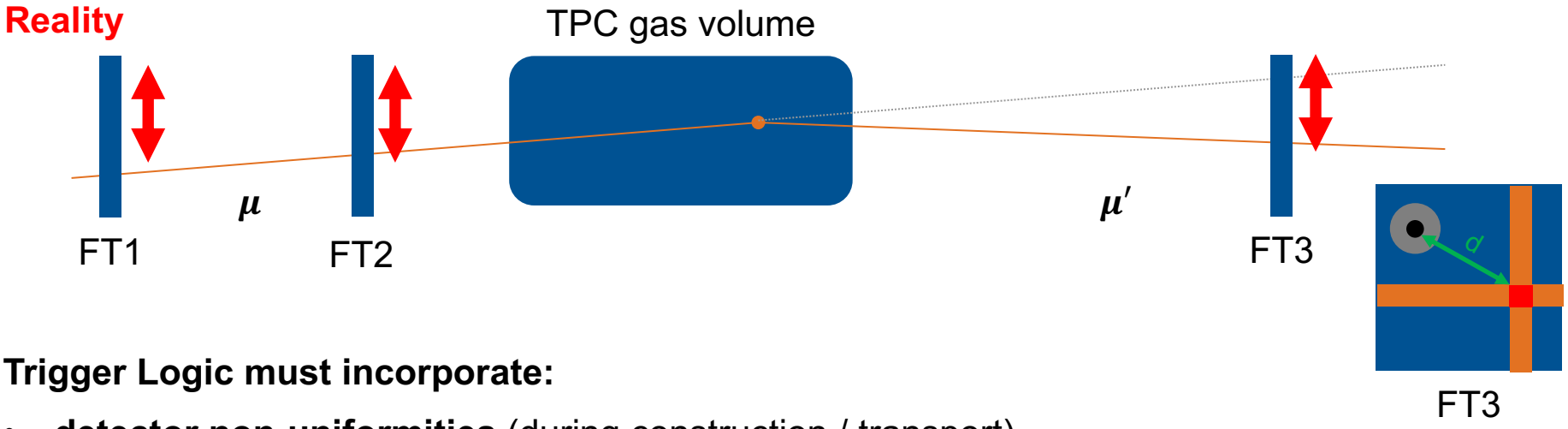

Trigger Logic must incorporate:

- **detector non-uniformities** (during construction / transport)
  - to be measured at least once, in the beginning of data taking period
- **run-by-run alignment** of the detectors during data taking

  up to 100 μm shift measured in 2018 test campaign for silicon stations

  → **online calibration tool required**

suitable algorithms and requirements are currently investigated

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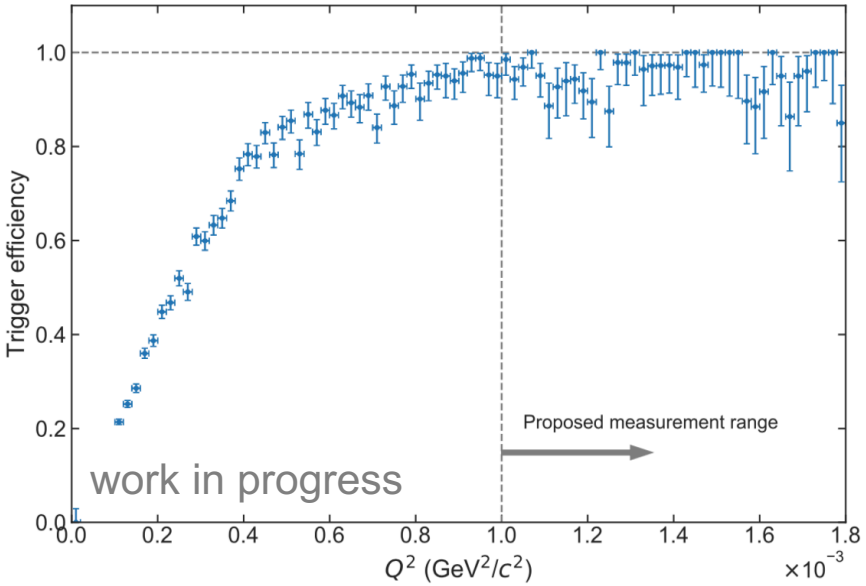
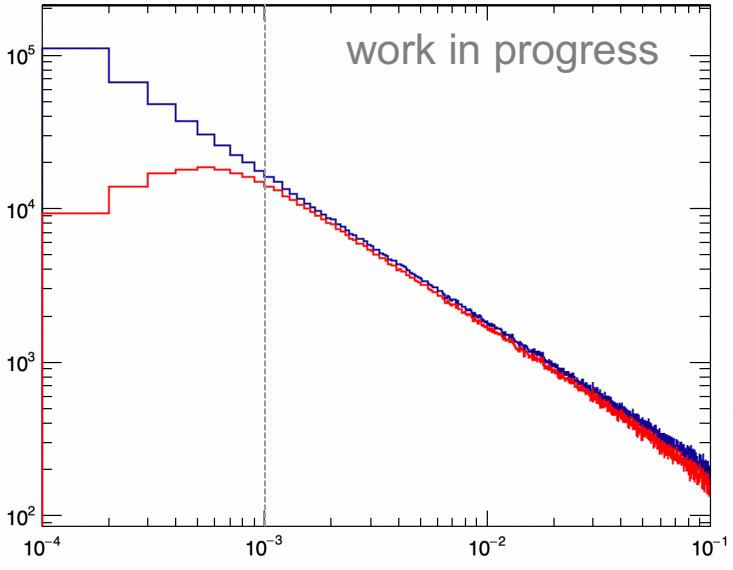
Simulation of Trigger Efficiency and Rejection Efficiency





- efficiency: 97% @ $Q^2 = 10^{-3}$ GeV^2
- rejection power: 96.5% @ $Q^2 < 10^{-3}$ GeV^2

note: for maximum beam intensity, this would still give trigger rates of 700 kHz

Systematic Studies to be done

- misalignment studies
- influence of mechanical tolerances (gaps between fibers, fiber-size variations, …)
- tune trigger threshold
- acceptance correction for measurement range
- investigate correlation between trigger efficiency and proton-radius parameters

Thank you for your attention!

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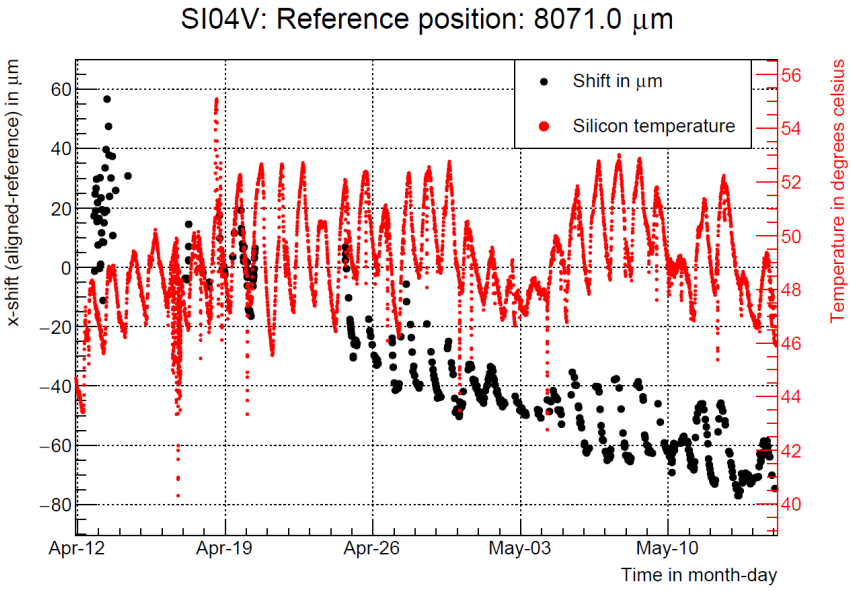

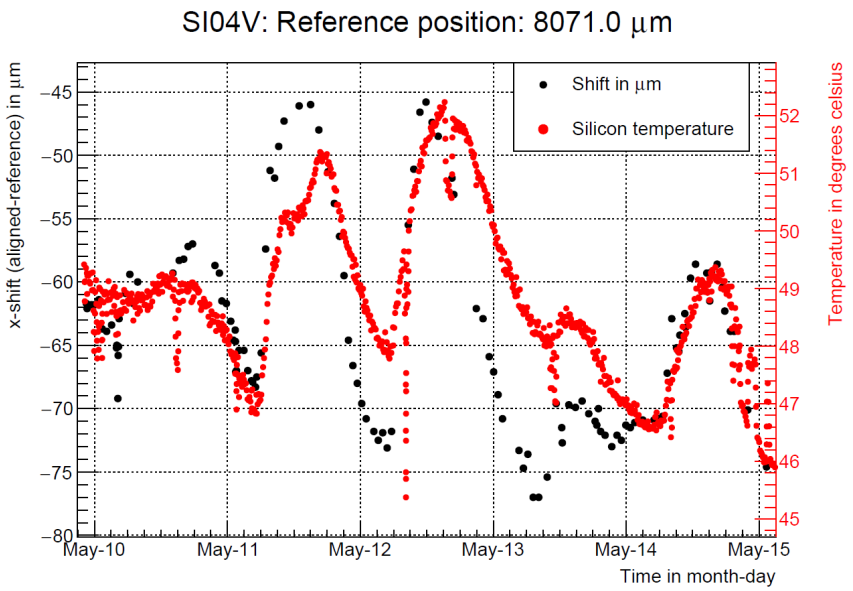

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Current workplan for the DAQ Workshop

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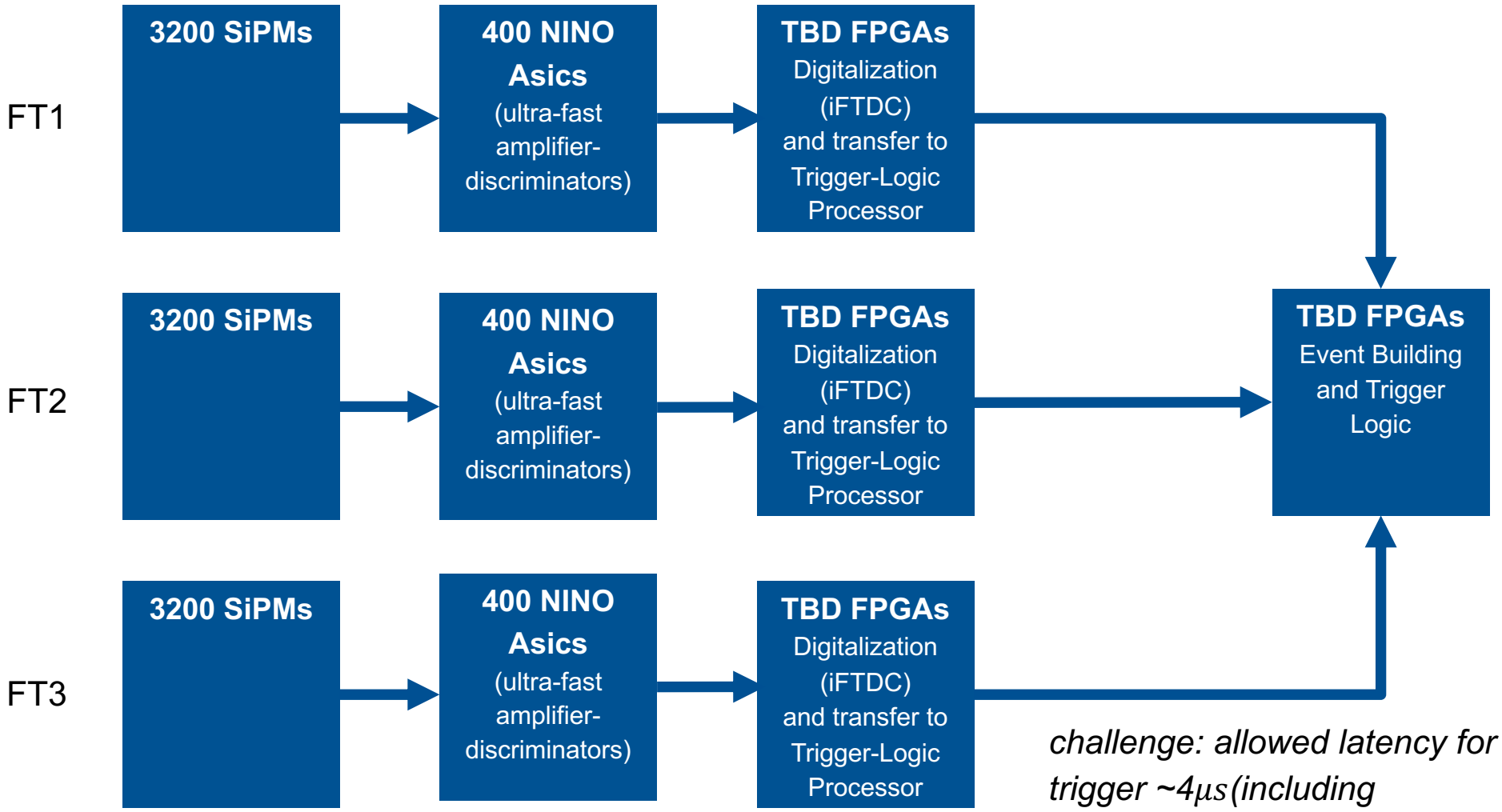

challenge: allowed latency for trigger ~4μs (including distribution)