HGTD t0 calibration

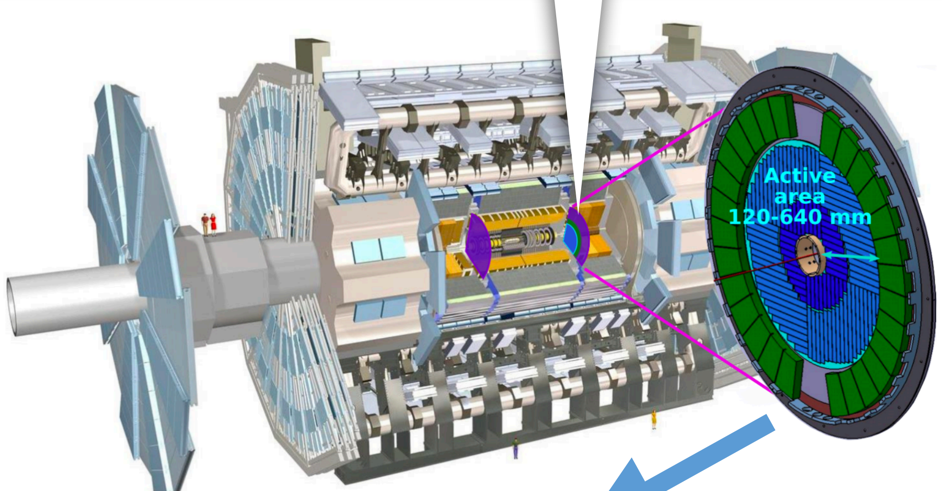
Ludovica Aperio Bella

most of the material from here : TDR and Emma's talk

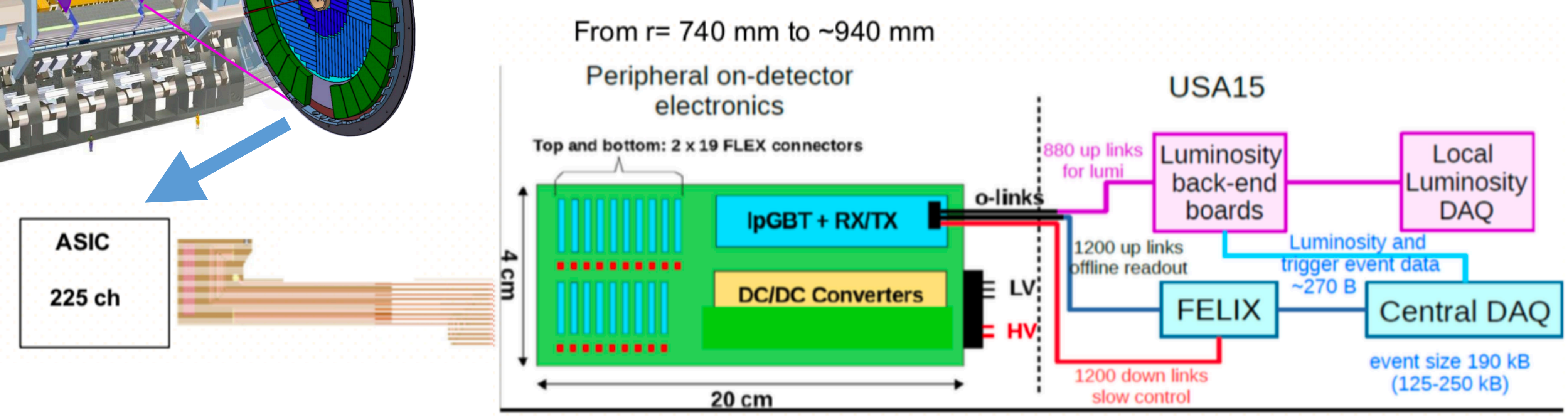
10.06.19

HGTD overview

Pseudorapidity coverage: 2.4<|η<4.0
Radial extension: 12 cm < R < 64 cm

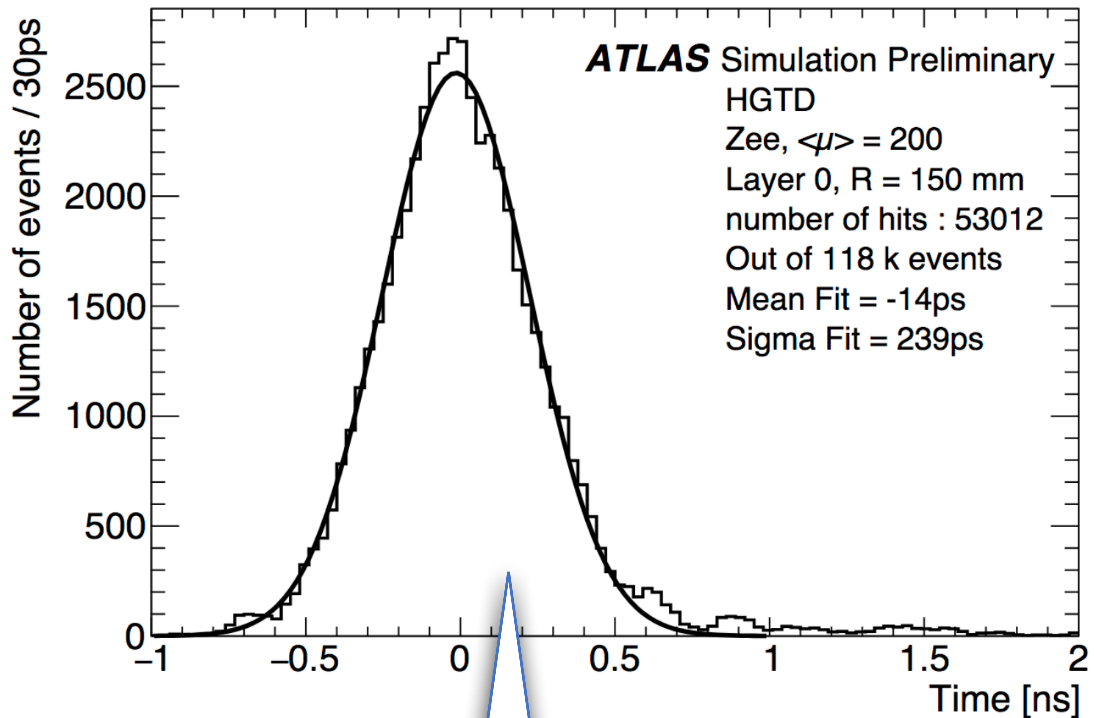


- Thin Low Gain Avalanche Detectors (LGADs): pixel detector with coarse spatial resolution but precision timing (30 ps per track)
  - 2 double planar layers in each endcap
  - overlapping sensors for each layer (larger overlap at inner radii)
- Specially-designed ASIC ALTIROC front-end



Why t0 calibration?

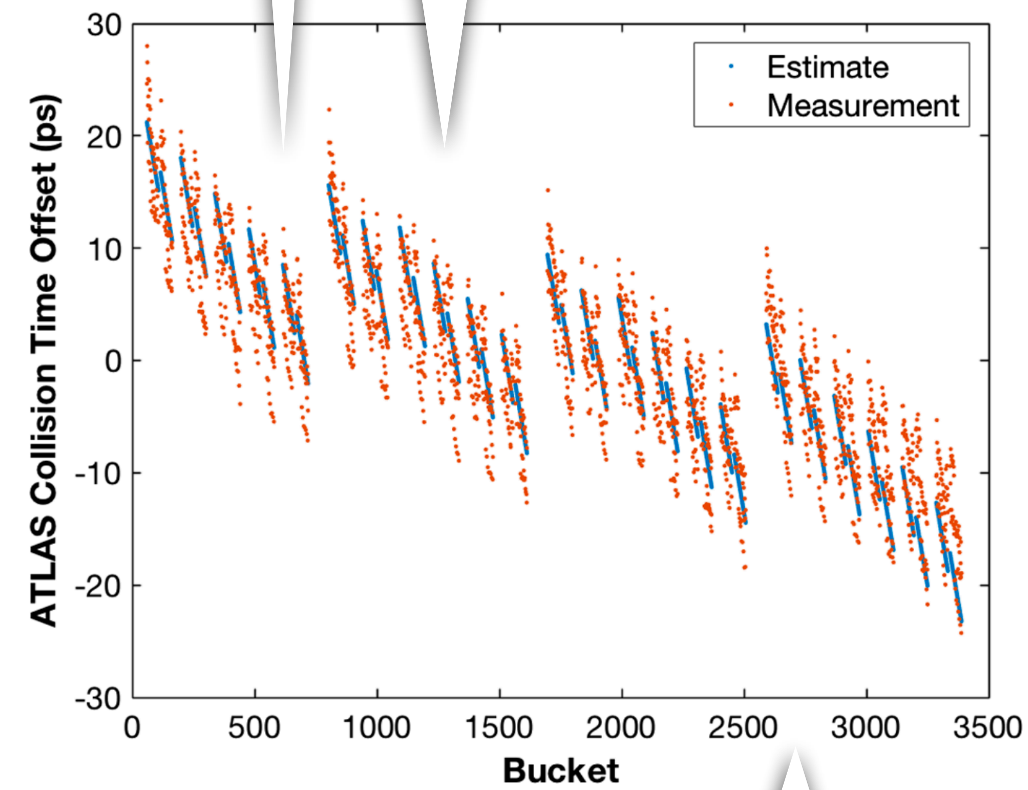
- The time of arrival of a hit measured in the HGTD will be different between pixels
  - Need calibration to keep expected time resolution of 30–50 ps
- **Static variations** — ie ToF, flex cable length, etc
- **Dynamic variations** — ie day/night variation of the LHC clock
- Corentin's study: plot timing distribution of simulated hits in Zee sample
- Can calibrate pixel t_{hit} using mean of distribution

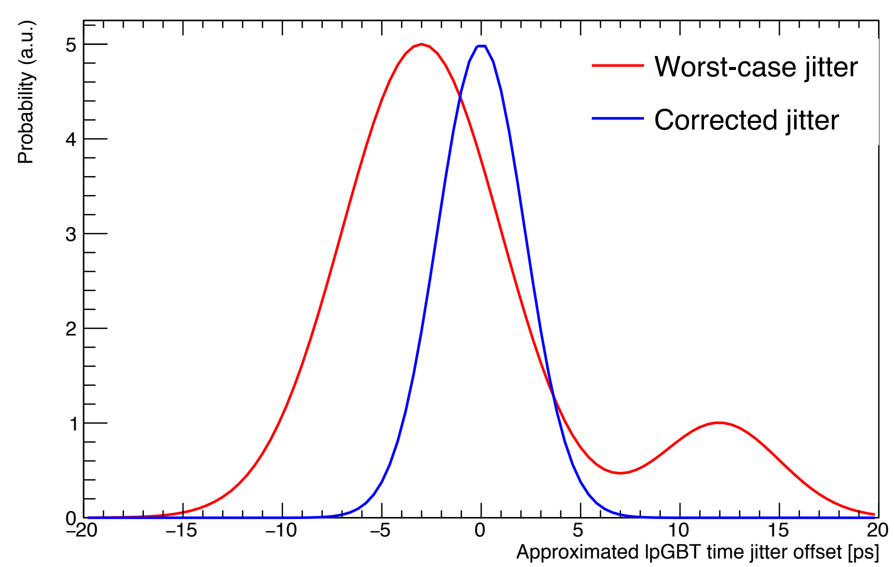


Gaussian core derived from the time dispersion of the LHC collision => Precision of a few ps can be reached with 10000 hits per pixel

Timing Variation

- **LHC per-bunch variation**: using ATLAS collision time offset from paper
- **Felix jitter**: taking 5.19ps jitter from timing performance study
- Three separate random Gaussian 5ps jitter to model **lpGBT, FLEX,** and **ASIC**
    - Temporary numbers to be updated when timing performance studies are available
- Static radially-dependent ToF variation of 0-70 ps
    - No significant impact on these per-sensor hit distributions





Timing variation

- **Can't calibrate away event-by event random fluctuations**
    - (But are included in study anyway)
- Performance of calibration procedure will depend on how many longer-term variations (heat cycles or other effects) affect the time measurement , but these are largely unknown…
    - Instead parameterize these long-term variations and study how large / fast they could be and still meet our targets
    - Sinusoidally varying 100ps time offset with period of 100µs - 1day

Details

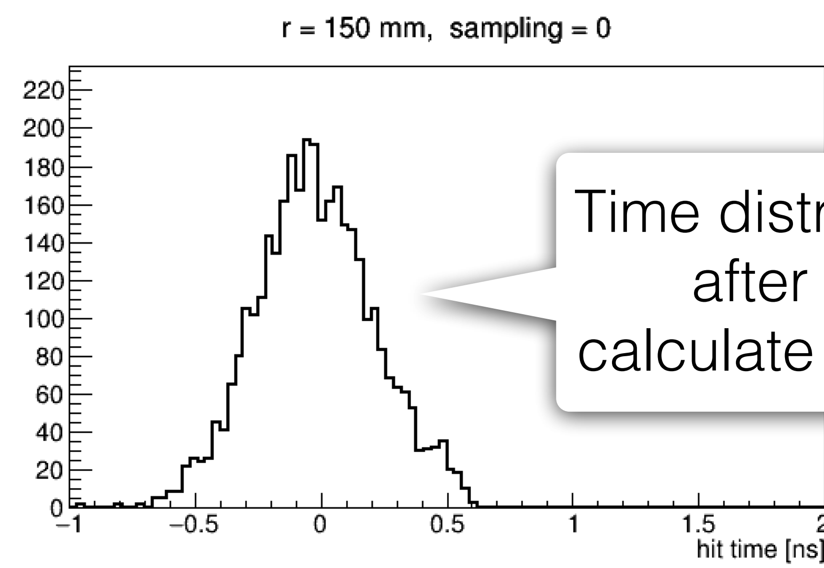
- Code forked from hgtd-simulation gitlab
  - https://gitlab.cern.ch/etolley/hgtd-simulation/tree/master
- Samples: /eos/atlas/atlascerngroupdisk/det-hgtd/samples/aod/20.20.10.7/Zee/MU200/
- Assuming event readout rate of 1MHz

actual calibration works with inputs: time and positions of hits
all the jitter component are emulated with smearing
radius and pad size define by hands
no additional information about the events structure (eg Bunch-crossing)

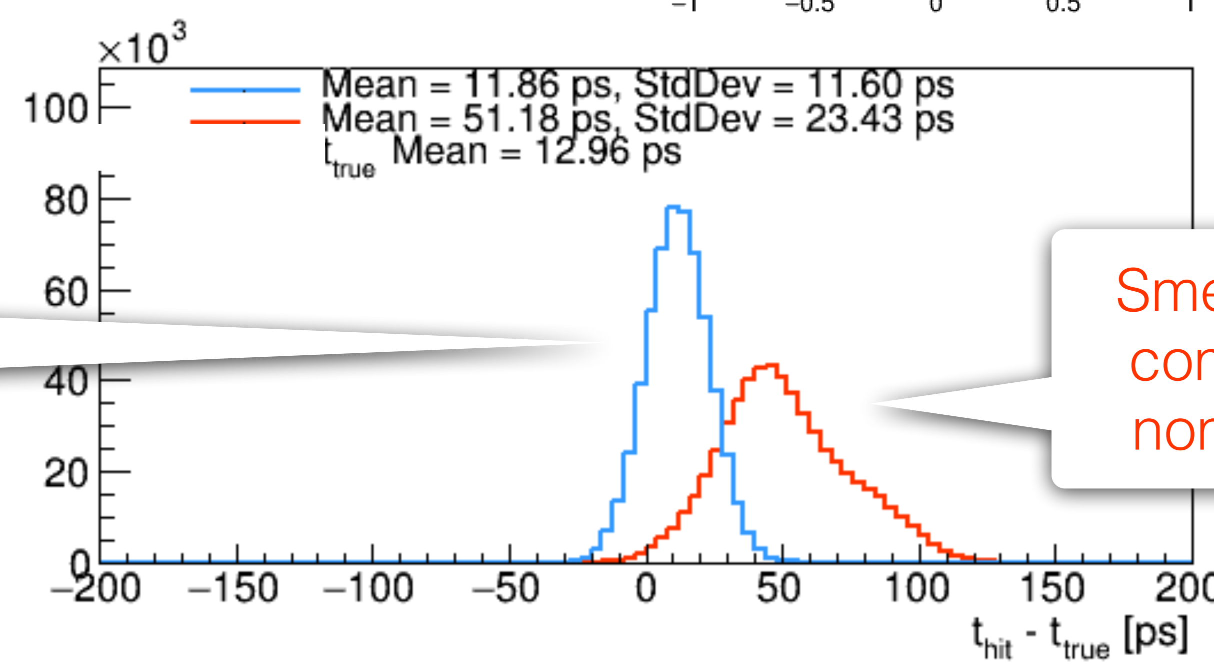
Calibration procedure

t0 from a 15x15 grid of channels —> corresponding to 1 ASIC

- Derive t0 correction on a subset of MC events
- Apply to independent dataset and evaluate performance
- Measure the resolution



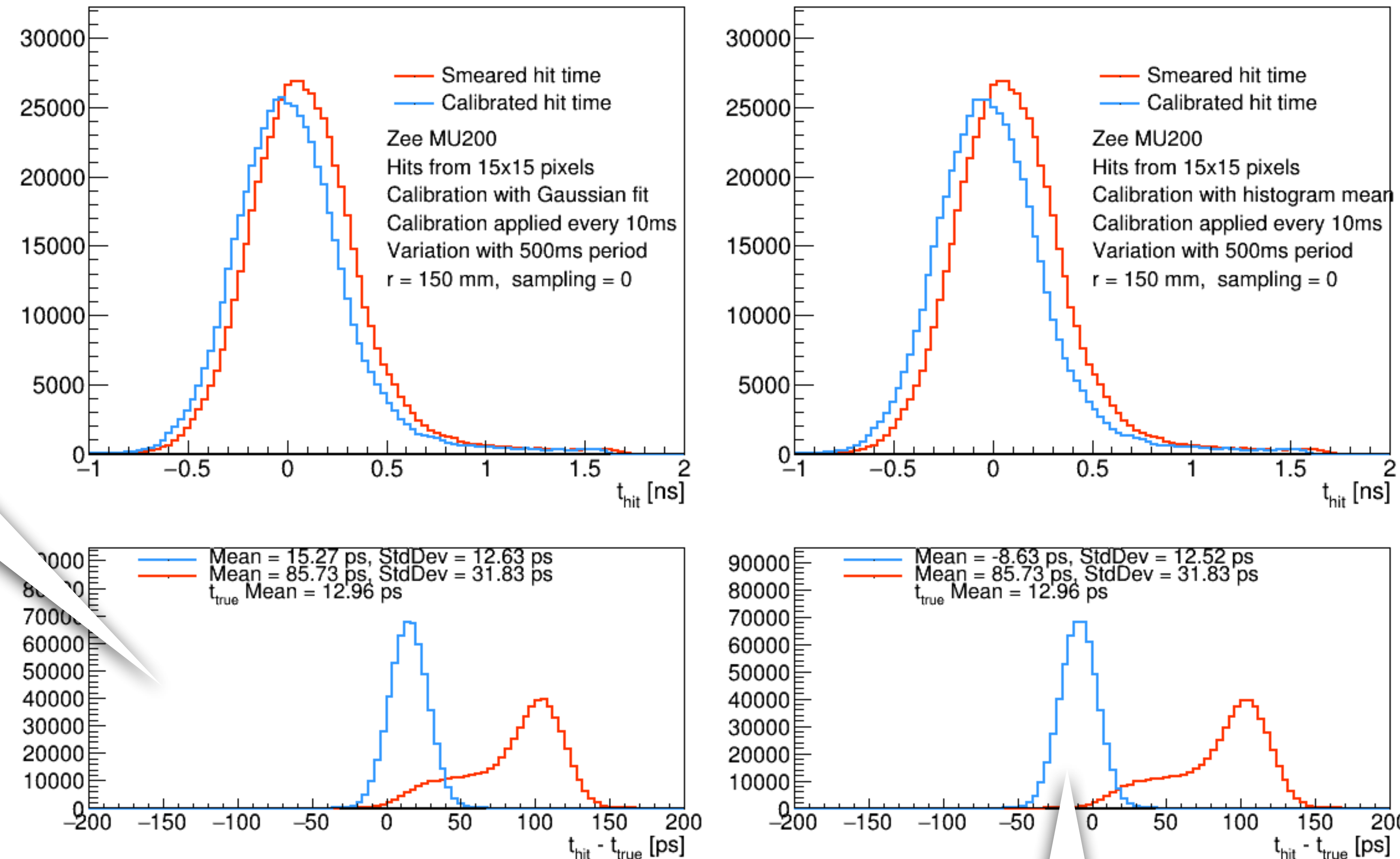
Time distribution of hits after 10ms => calculate t0 from mean



Calibrated time: apply LHC drift correction and t0 calibration

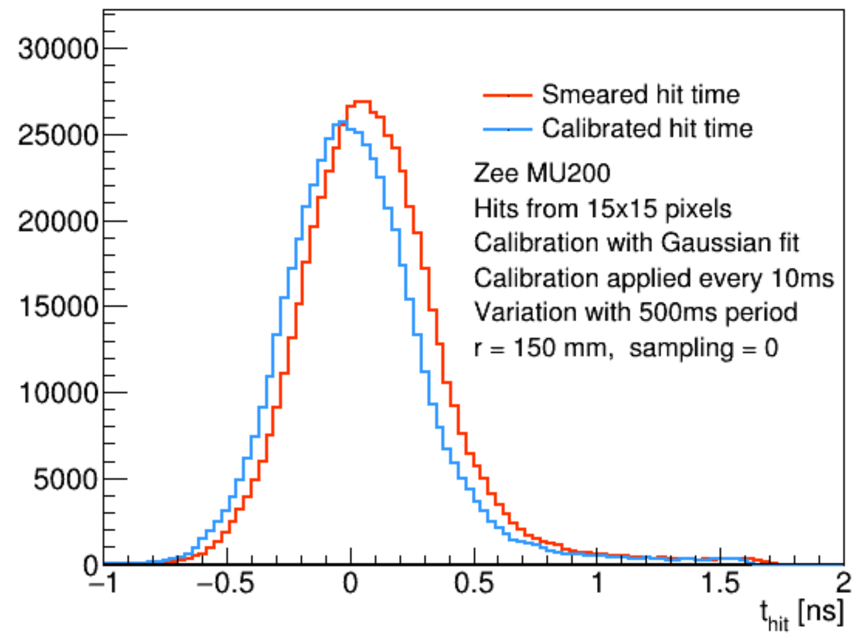
Smeared time compared to nominal time

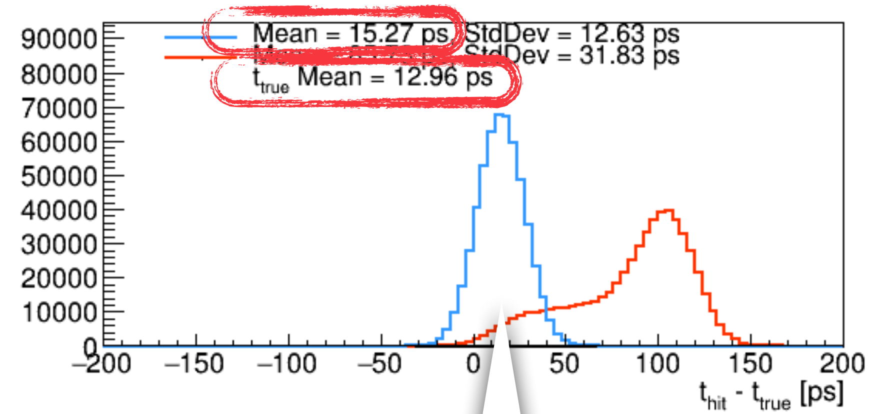
Nice improvement:
32ps -> 13 ps
resolution



Very similar performance with Gaussian fit vs arithmetic mean to derive t0 correction

Detailed procedure I



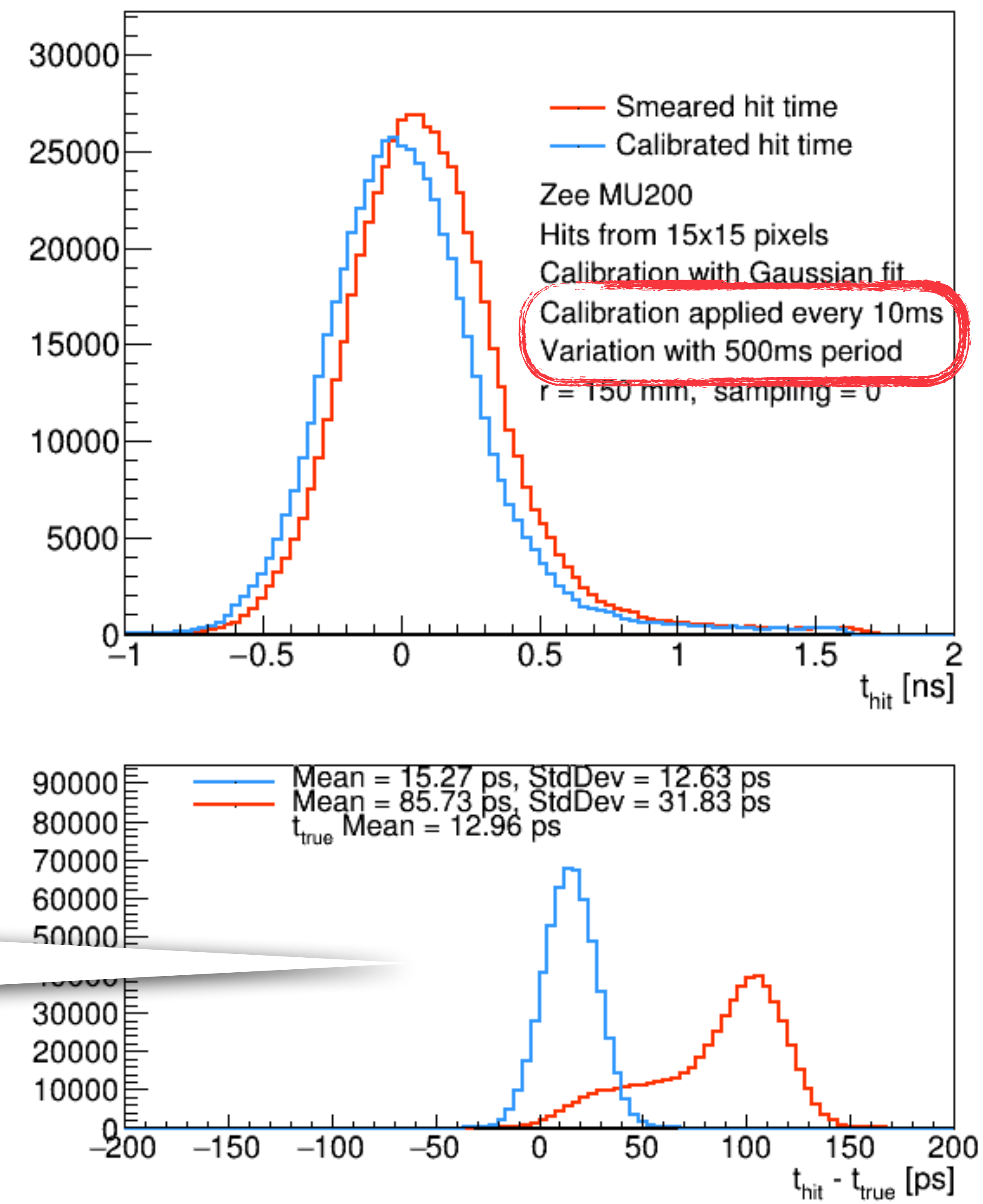


Resolution is not centered at zero

- Calibration procedure tries to set mean of timing distribution to zero
- However, true timing distribution does not necessarily have zero mean
  - Distribution has long tail on LHS
  - Spikes/structures from low min bias stats (should be fixed in new samples)
- Average offset & therefore mean of histogram will be correlated with t_true

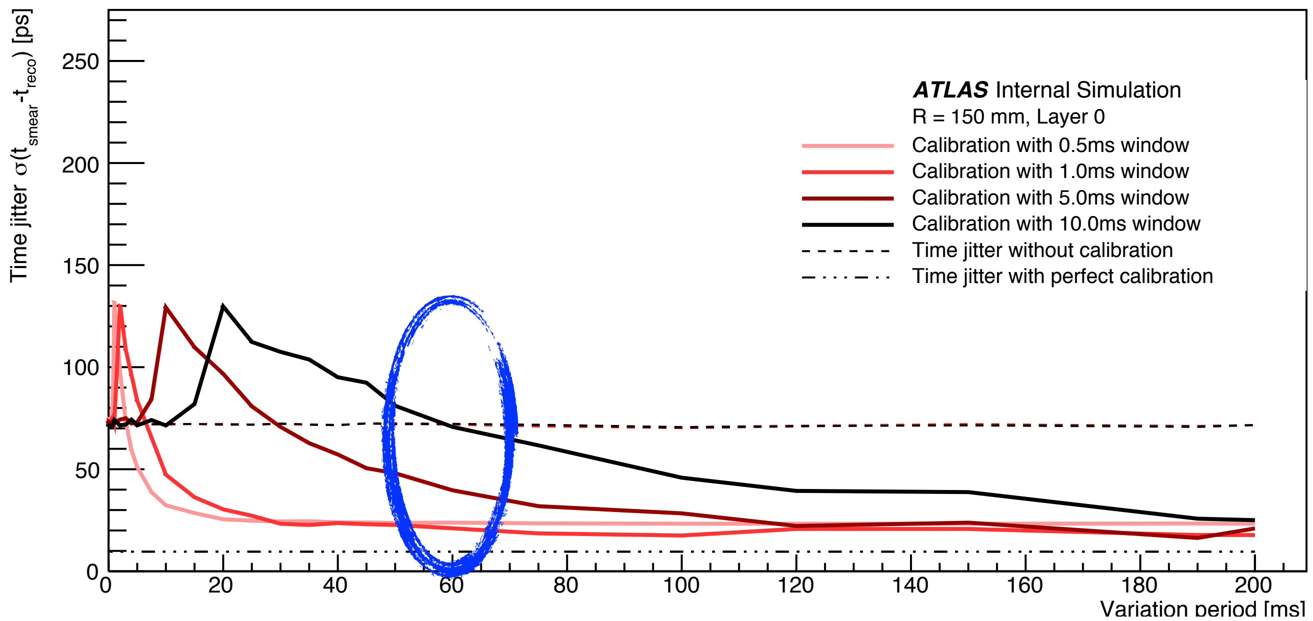
Detailed procedure II

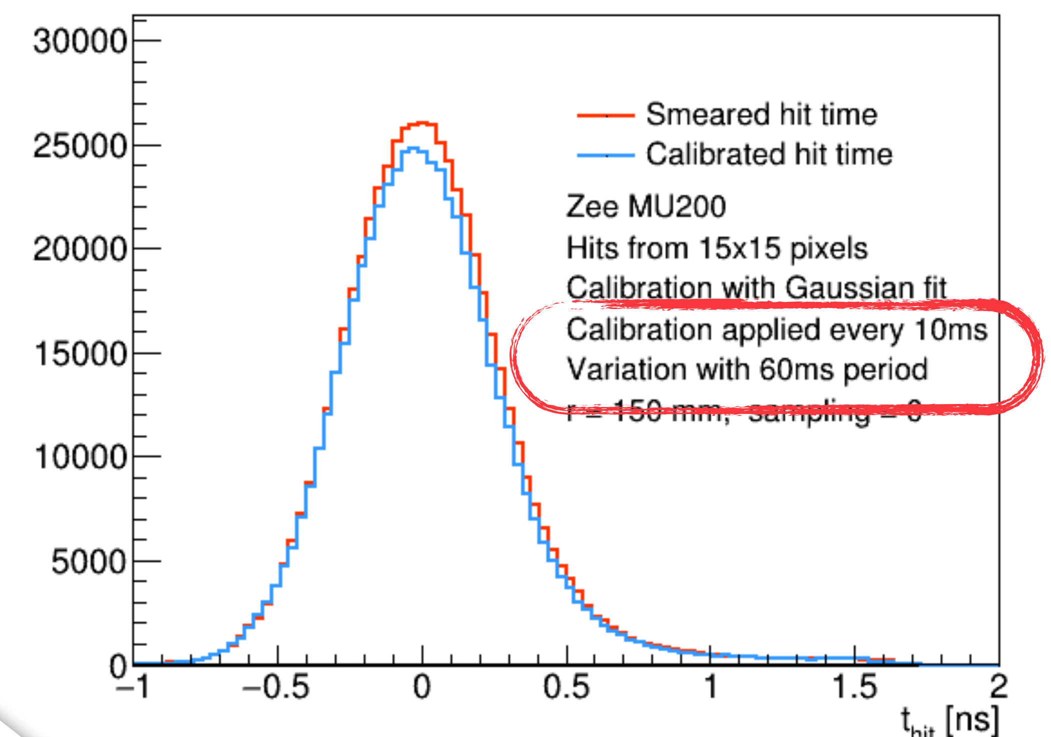
Calibration performance depends on timescale of effects being calibrated away….



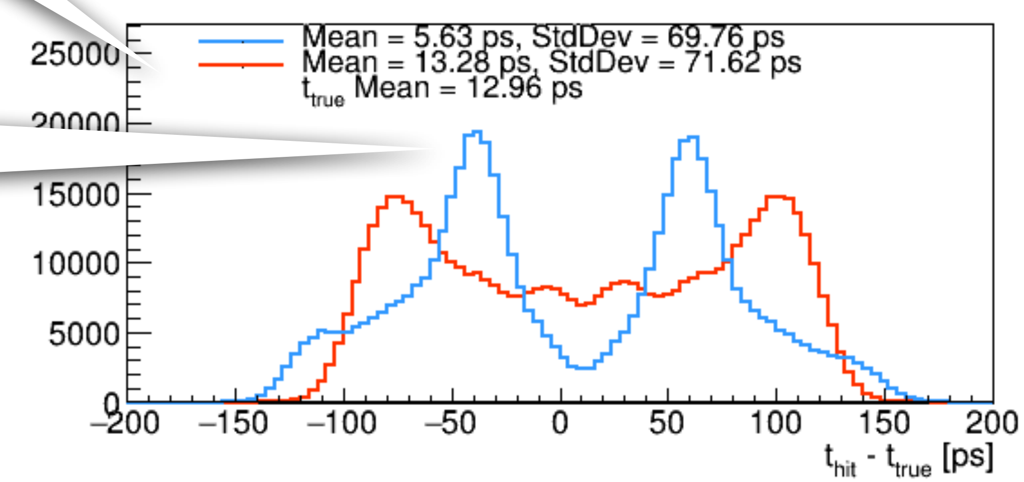
calibration timescale << variation timescale
calibration works 👍

Detailed procedure III



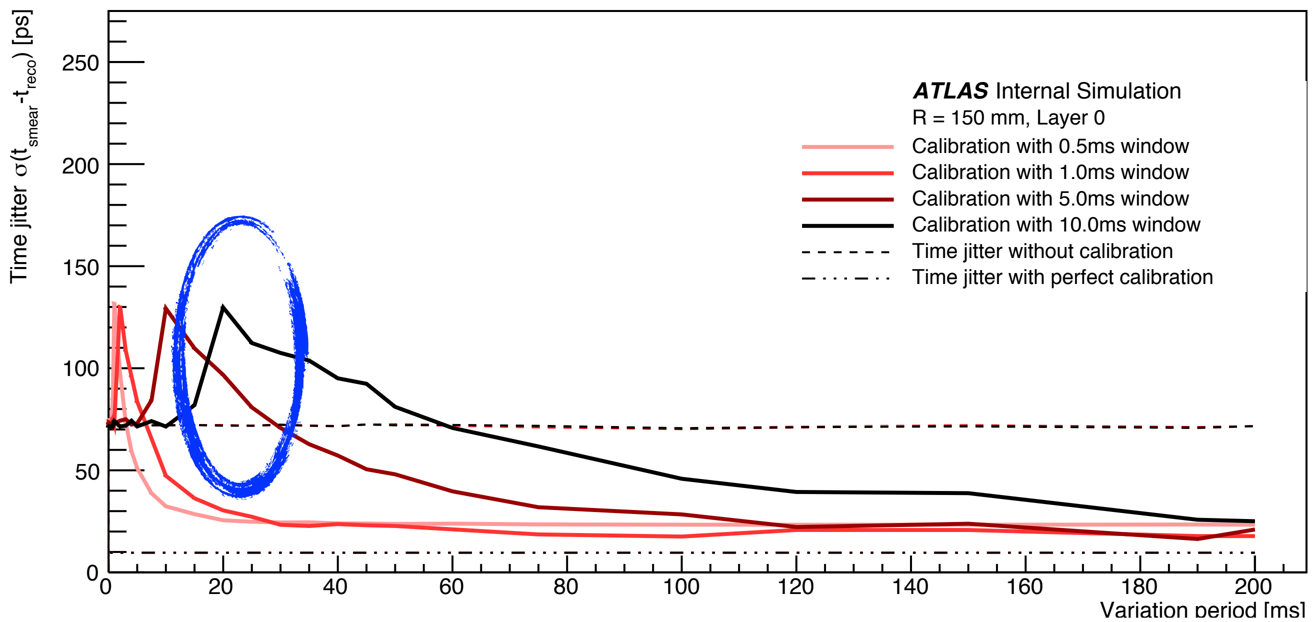


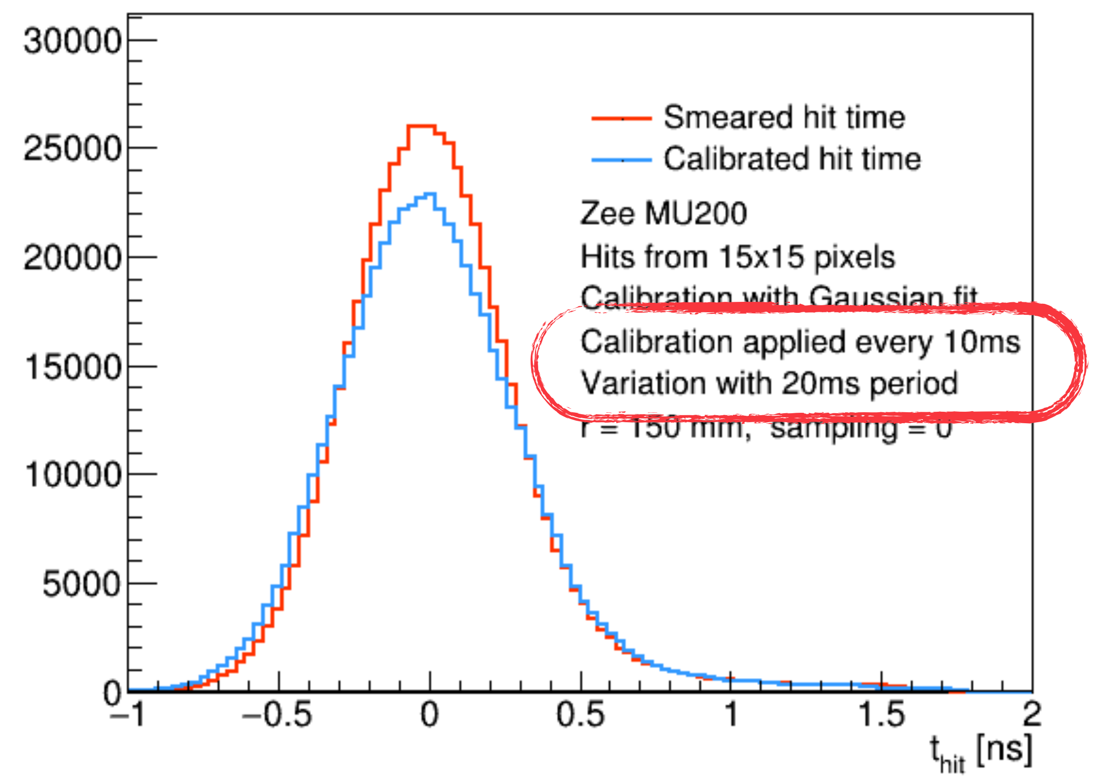
as variation timescale gets smaller, calibration provides worse resolution

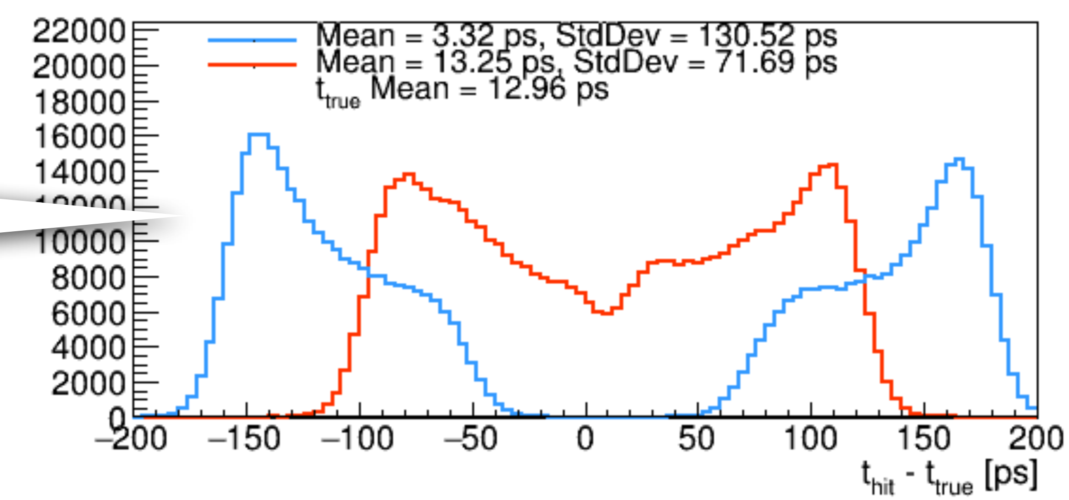


peaks for calibration resolution at **time difference** between hit **data collected for calibration** and **data to which calibration is applied**
Median difference of ~ 35ps

Detailed procedure IV

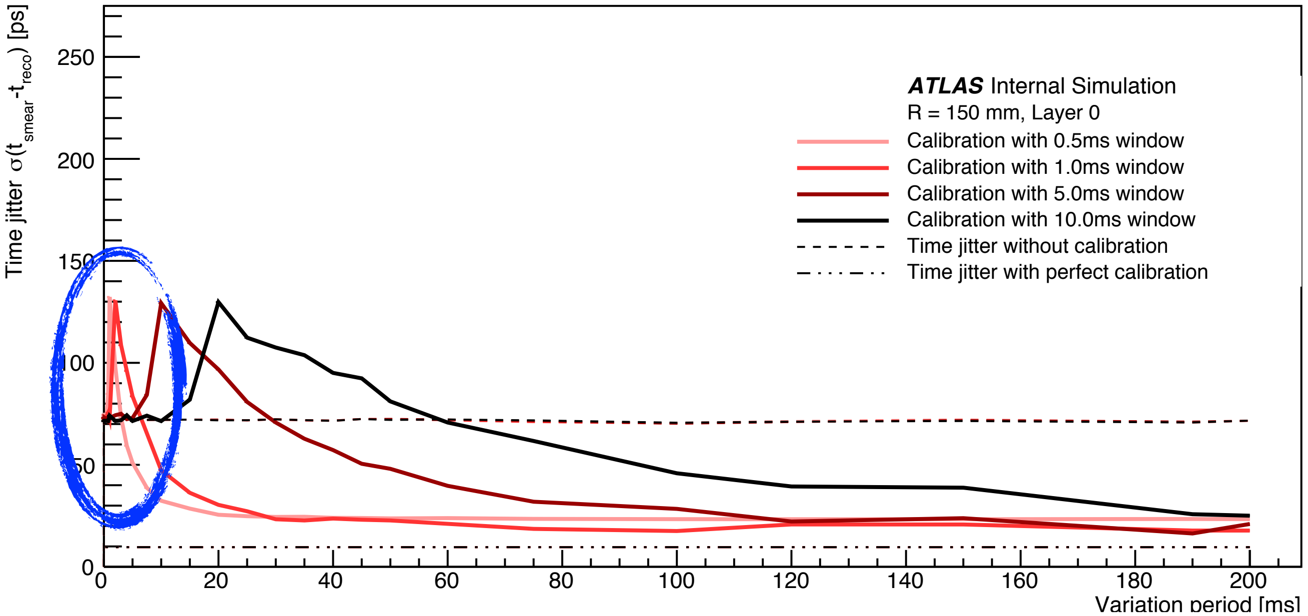


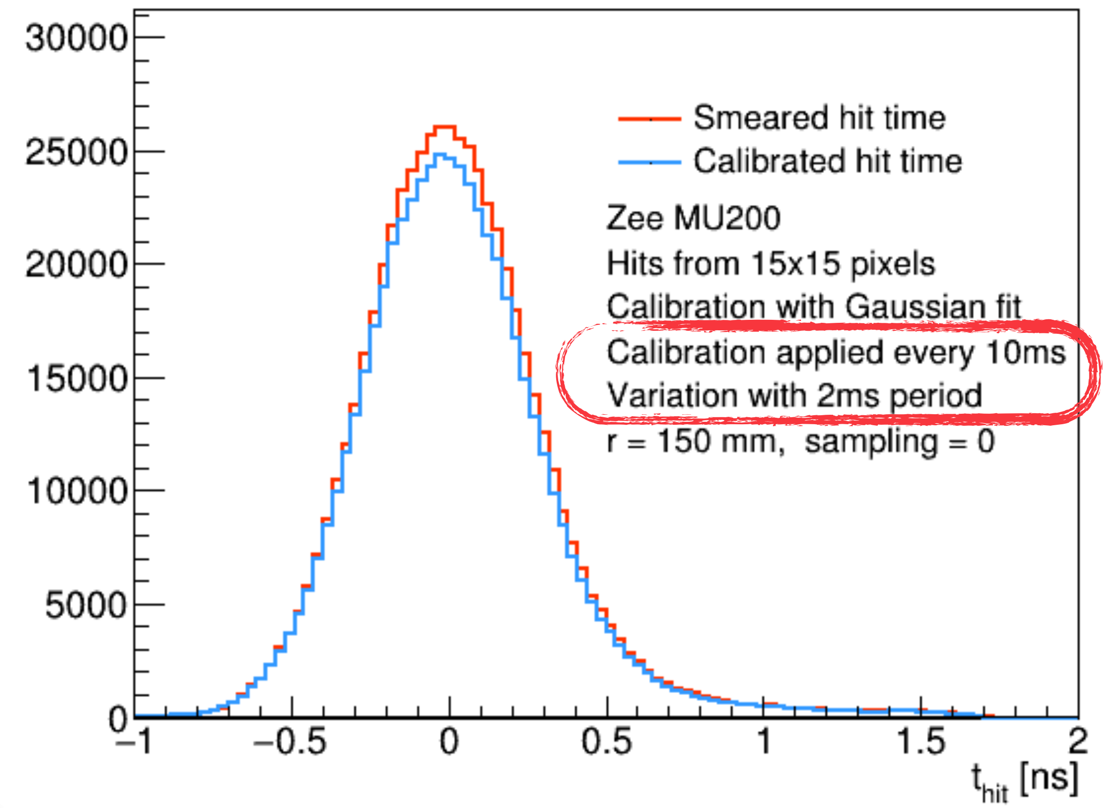




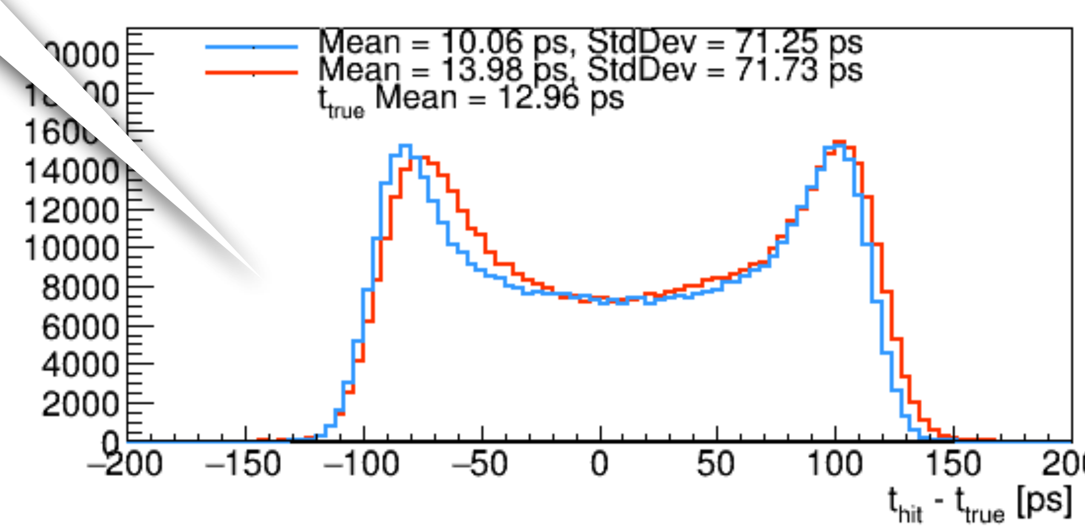
calibration timescale = 2*variation timescale
maximally incorrect

Detailed procedure V



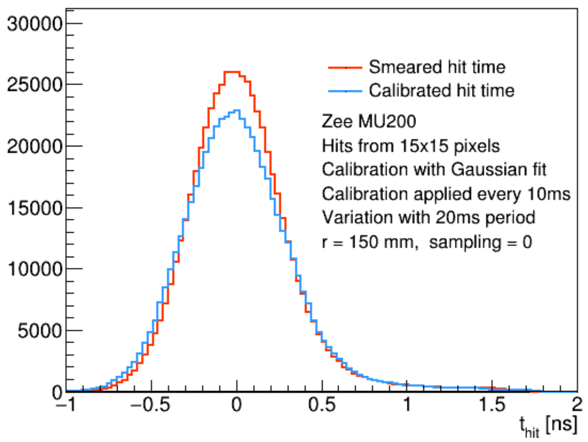


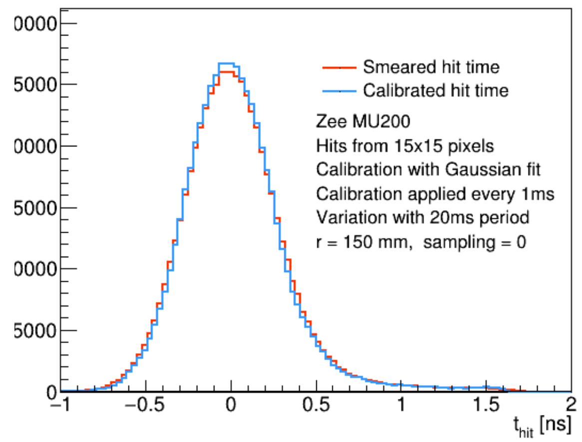
calibration timescale > variation timescale
No significant improvement

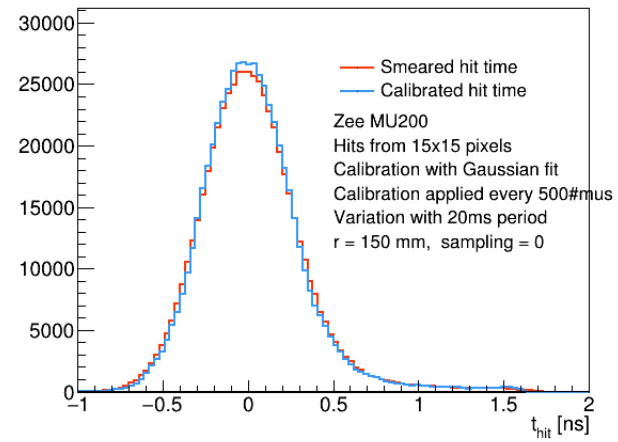


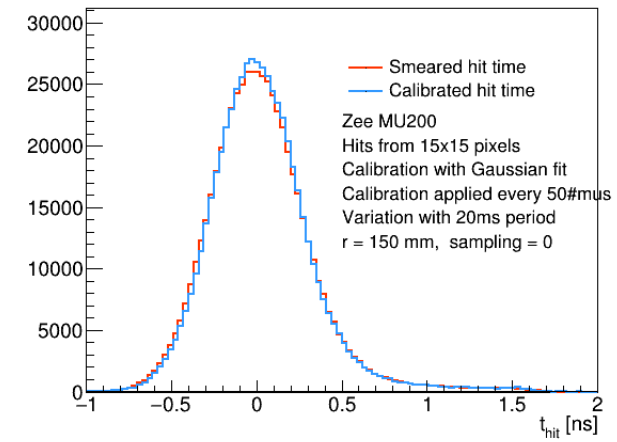
Calibration timescale needs to be much shorter than variation => lower limit on timescale of variations that can be calibrated away

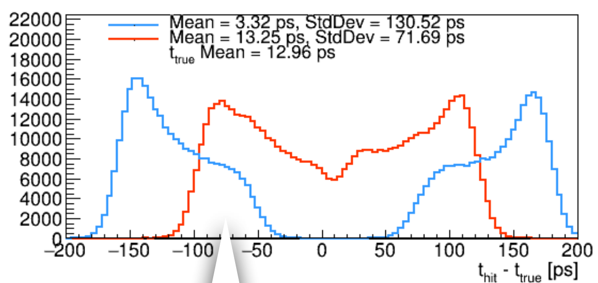
Summary

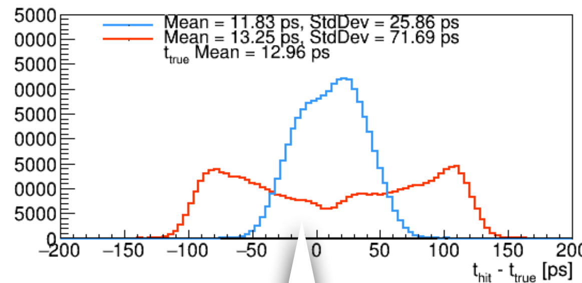


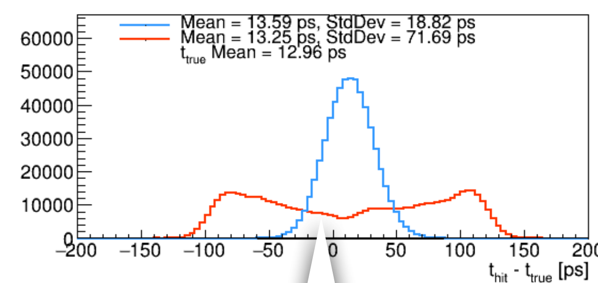


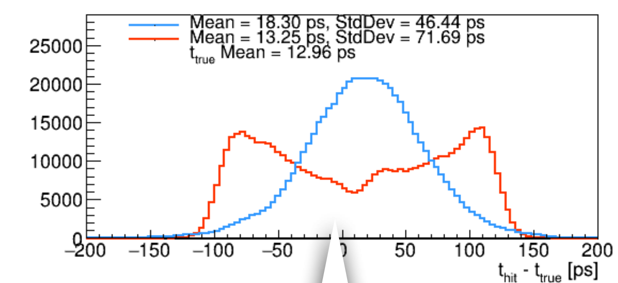












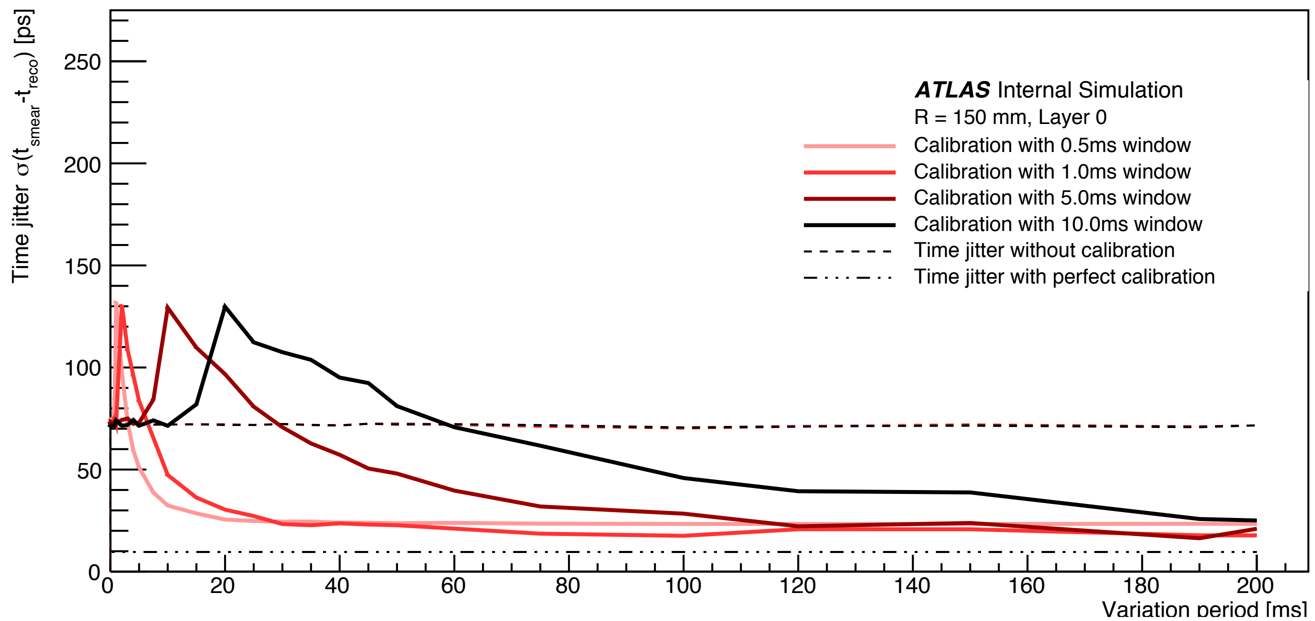
Calibration timescale too long!

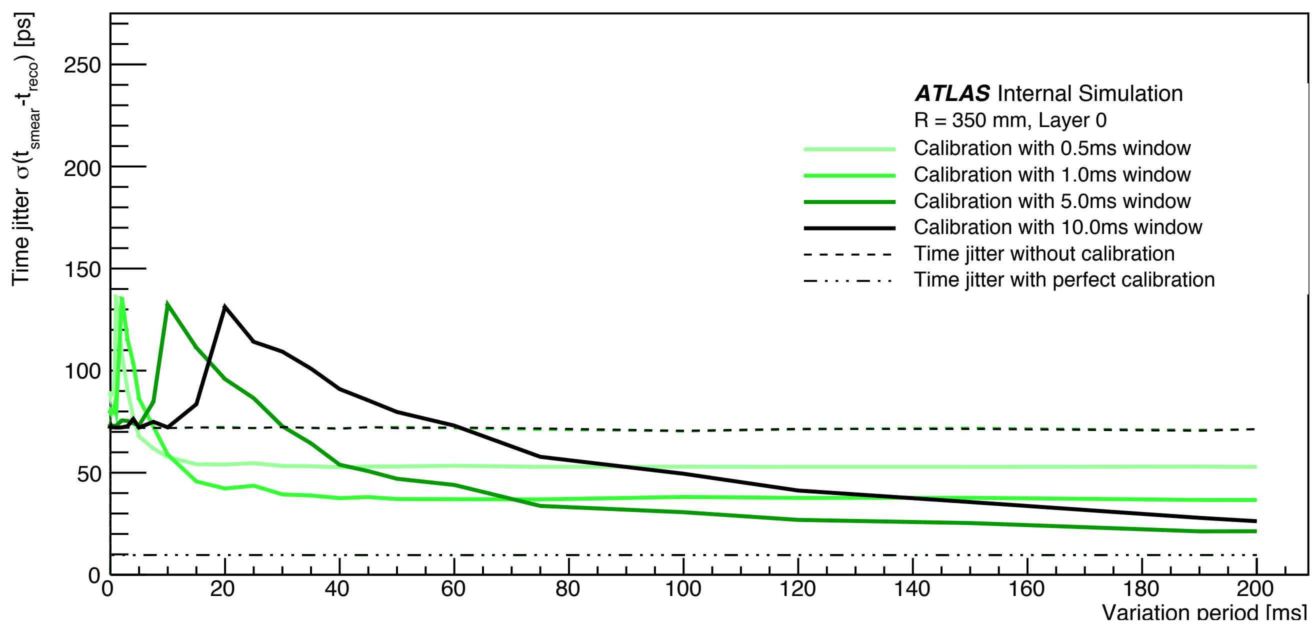
Getting better

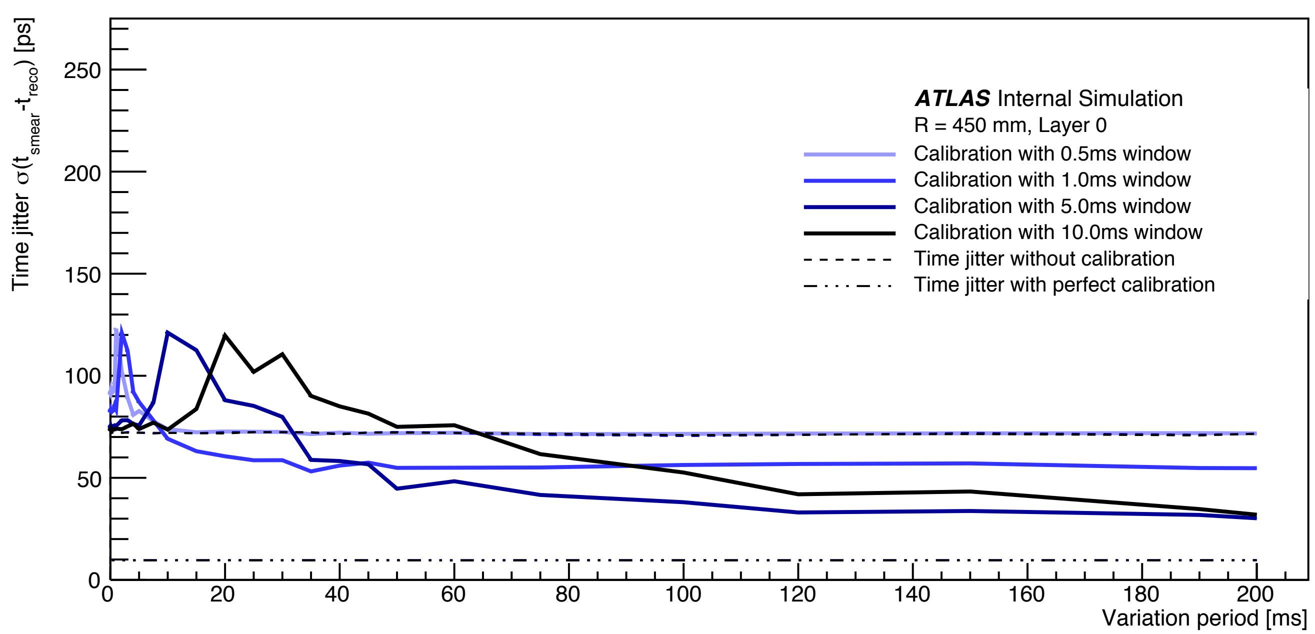
Just right

Limited stats in calibration histogram affects precision => **poor performance below 100µs**

ASIC t_0 precision for different clock variations







Hit time resolution $t_{smear} - t_{reco}$ after the calibration procedure as a function of the variation period, and for several different choices of calibration window time, shown for r = 150 mm, R = 350 mm, and r = 450 mm.

NB. difference between the 3 plots the statistic collected in the pad considered

Smaller calibration window sizes can reduce t_0 jitter when shorter-term variations affect the hit time. However, longer calibration windows, which can collect more statistics and therefore more precisely determine t_0, result in a better hit time calibration.

In general, more accurate calibrations can be calculated to correct for longer-term variations, and should result in smaller total clock jitter.

How to improve ?

The optimal calibration window size is a function of both the period of the variation to be corrected and the hit rate of the channel. More hits collected in a longer time period result in a better calibration, but the calibration window size needs to be small compared to the scale of the variation.

- When accounting for the expected jitter from components of the readout system and LHC bunch crossing time drift, the clock jitter of approximately 10 ps can be reached. If add unknown sources of jitter the calibration procedure can reduce the total jitter to 20 ps for the time variations studied.

- This calibration procedure uses **conservative** values of clock jitter contributions. **Conservative** estimates for the expected ALTIROC and FLEX timing jitter were used
  - improving input clock variation smearing
  - improving simulation and get more information
    - rate/hits relation, bunch-crossing, pileup

```
Online/Offline Calibration:
The practical constraints of this plan (ie computational cost and data size of calibration, compression scheme)
how much data would this generate (numbers * bytes per number *frequency)
- then we compress the data because it will be too much to write out completely. one possible compression scheme: only write out the
constant for an ASIC when it changes
- then we apply the calibration at the Tier0 during the usual calibration loop, NN hours after data-taking (edited)
The $t_0$ correction may be calculated online in the FELIX, or offline. The calibration will be applied offline.
```

backup

Time resolution

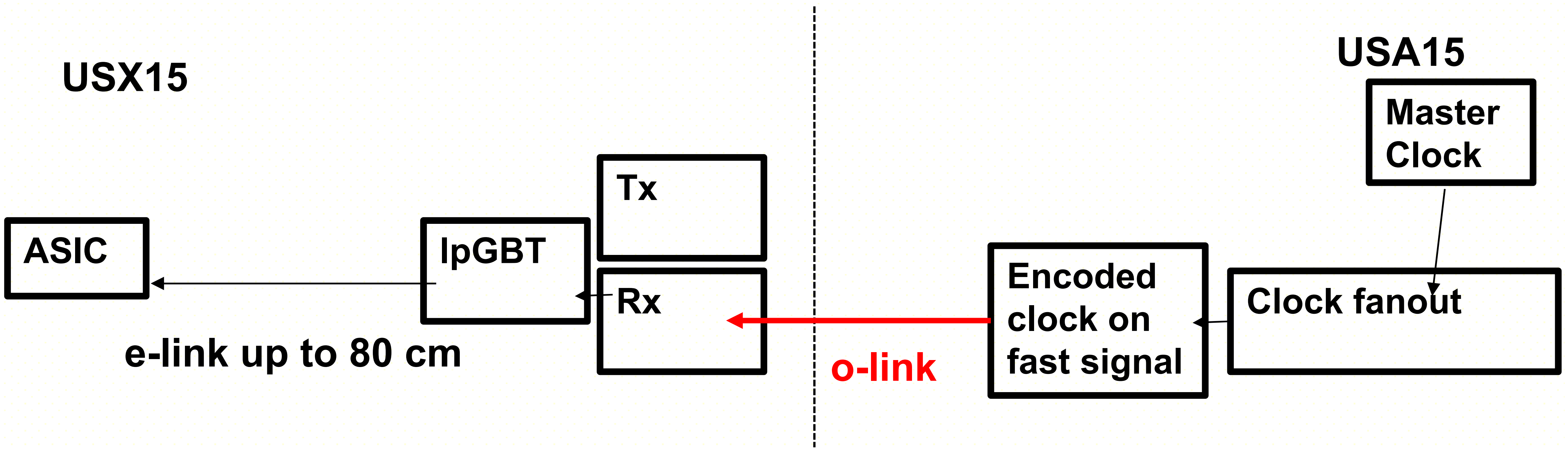
$$\sigma^2_{\mathrm{total}} = \sigma^2_{\mathrm{L}} + \sigma^2_{\mathrm{elec}} + \sigma^2_{\mathrm{clock}}$$

1) Sensor : 20-25 ps non irradiated, 40-50 ps after irradiation

2) Electronics jitter : < 25 ps
   TDC 20 ps lsb → < 5 ps
   Time walk after TOT correction < 10 ps

3) Clock and calibration :
   - local jitter < 10 ps
   - channel to channel intercalibration < 10 ps

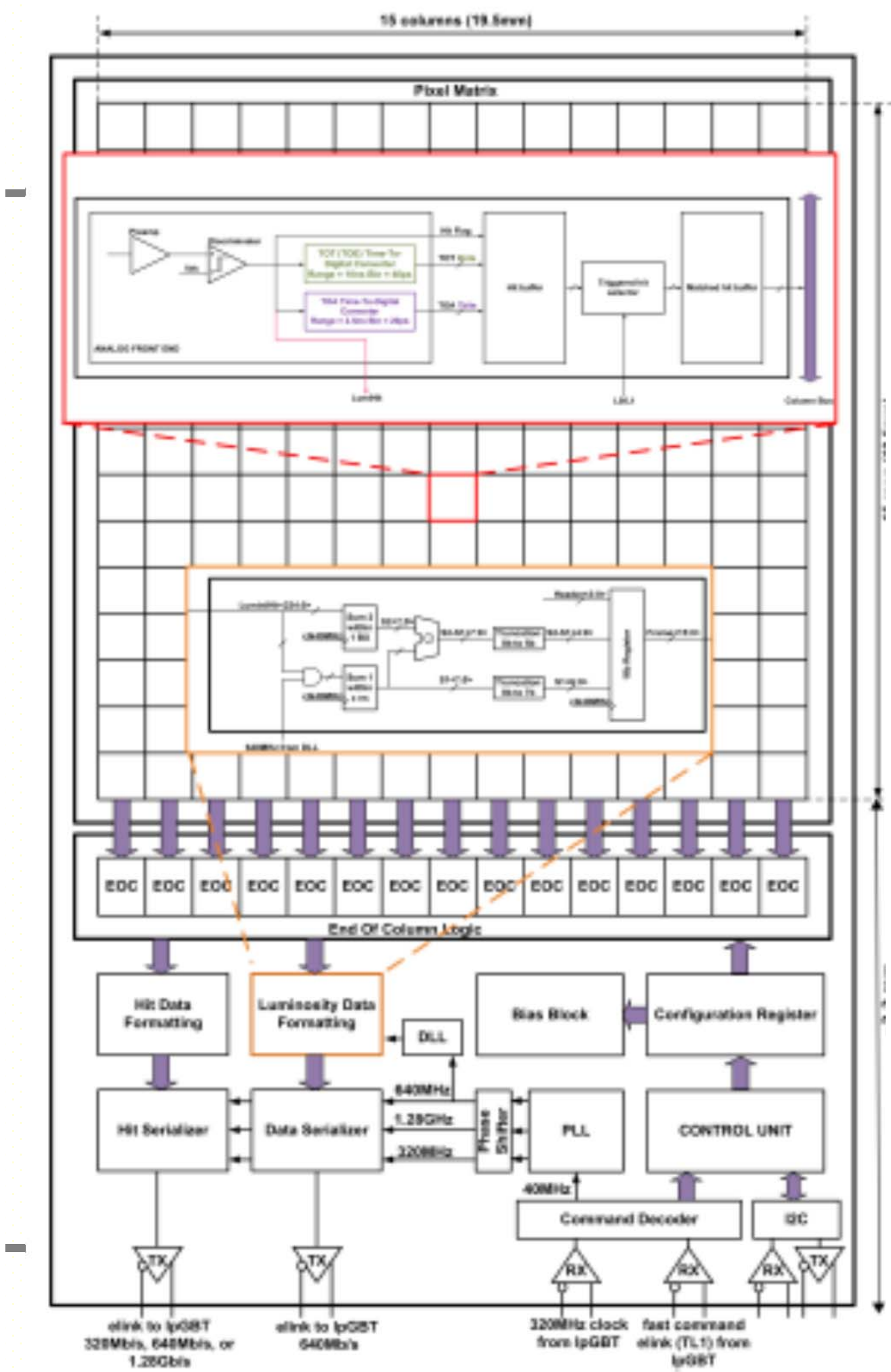
Clock distribution to ASIC



Any jitter or long term stability on the 40 MHz clock will induce a time resolution degradation

All clocks inside ASIC ALTIROC built from the 40 MHz encoded in the fast command of the lpGBT

lpGBT clock jitter : < 5 ps ?



ALTIROC and CLOCK

Input 40 MHz decoded from lpGBT

PLL to build 320 and 640 MHz clocks

Phase shifter common to 40/320/640 MHz (similar to phase shifter in 65 nm for lpGBT), accuracy ~100 ps
40 MHz phase adjusted as TDC active only over +1.25 ns around BC
Luminosity window (3.125 ns) centered on BC
Another PLL after phase shifter is jitter too large

Clock distribution to each channel as synchronous as possible

Internal pulser

T0 calibration

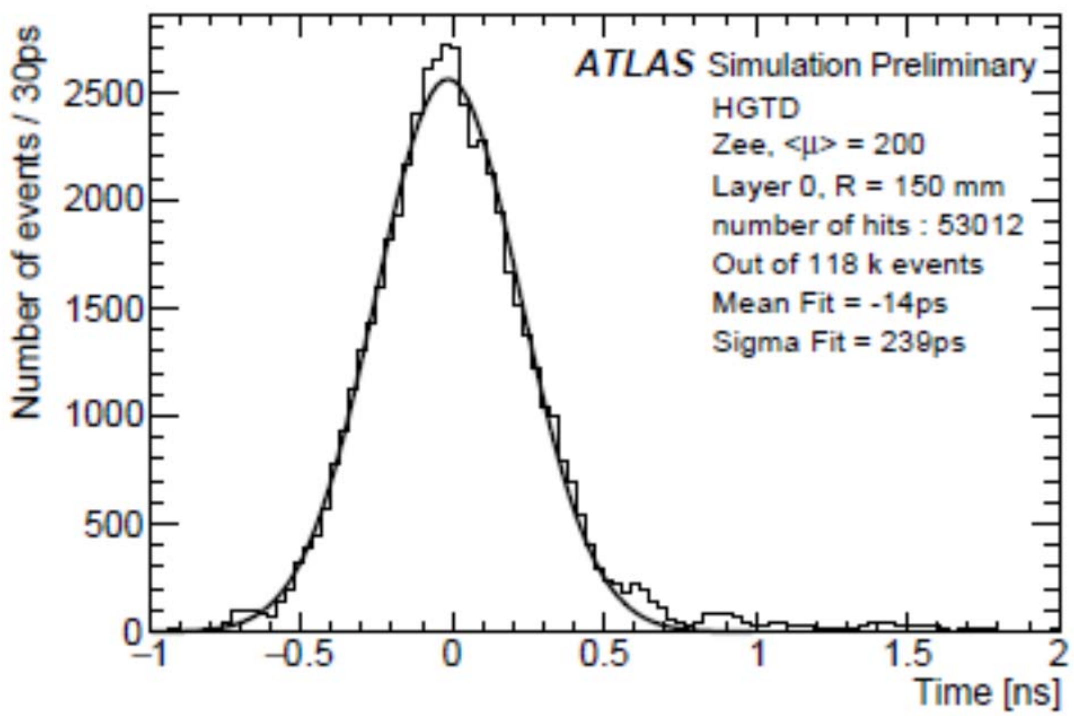
Static contribution :

- Clock distribution in ASIC (similar in each ASIC)
- Different path length of the flex (e-link) as a function of ASIC position
  → can be measured with internal pulser, should stable with time
- Average Time of Flight of particles as a function of radius
  → can be computed, and measured with data.
  (partially compensated by flex length)

Dynamic contribution :

- Any dependence of the clock from USA15 to peripheral electronics (@-30 °c)
  - Very fast variation, seen as jitter on individual channel : cleaner ?
  - Phase variation (→T0) :
    Long/medium term (as day/night variation of 200 ps in ATLAS.)
    → use data to correct/monitor
  - Send back to USA15 the 40 MHz to compare with master clock ?

T0 calibration with data



Inclusive hit time distribution in a pixel : rms 240 ps

→ Can measured T0 of pixel to better than 5 ps with 10000 hits

Taken into account occupancy, it corresponds to 10^5 events at inner radius and 10^6 events at higher radius

Assuming trigger rate of 10 kHz

→ Will take 10s at inner and 100 s at higher radius

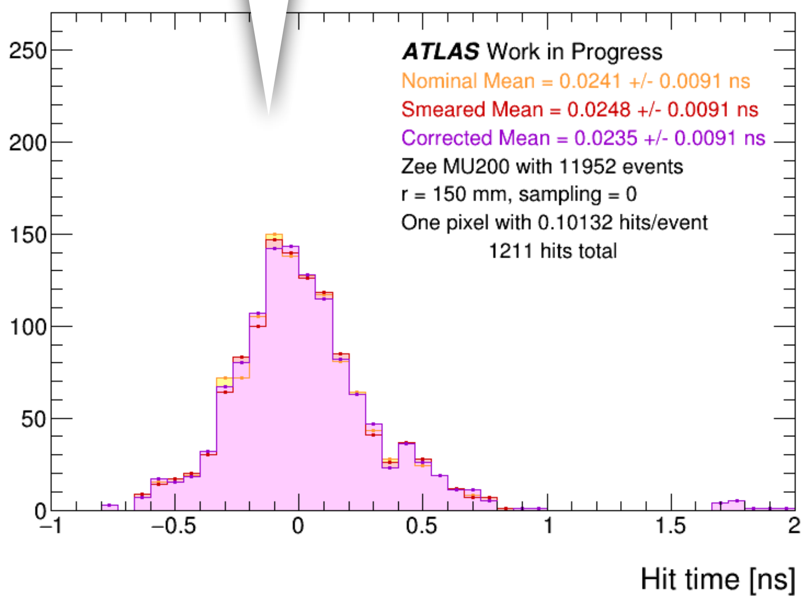
→ As static contribution in ASIC can average t0 over ASIC (225 channels) → every 50 ms if needed

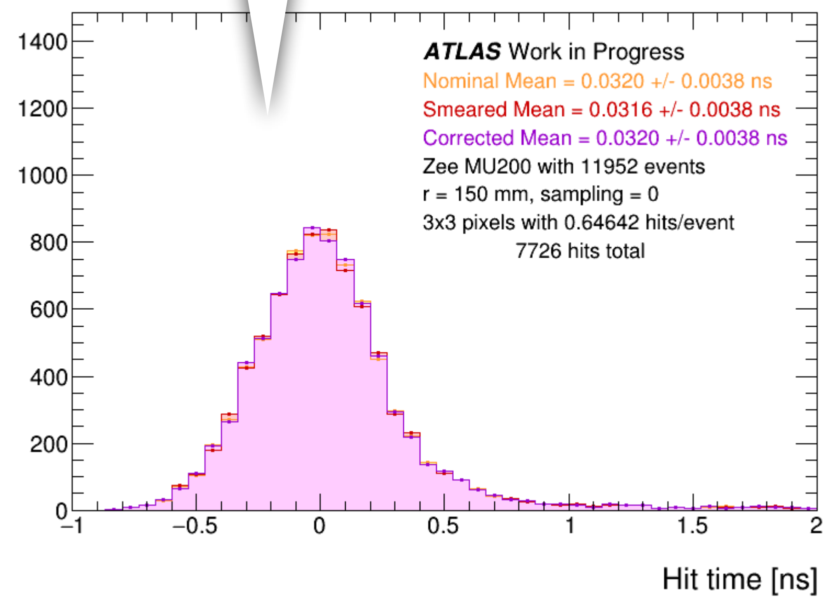
Any variation larger than 20 kHz not corrected with data calibration

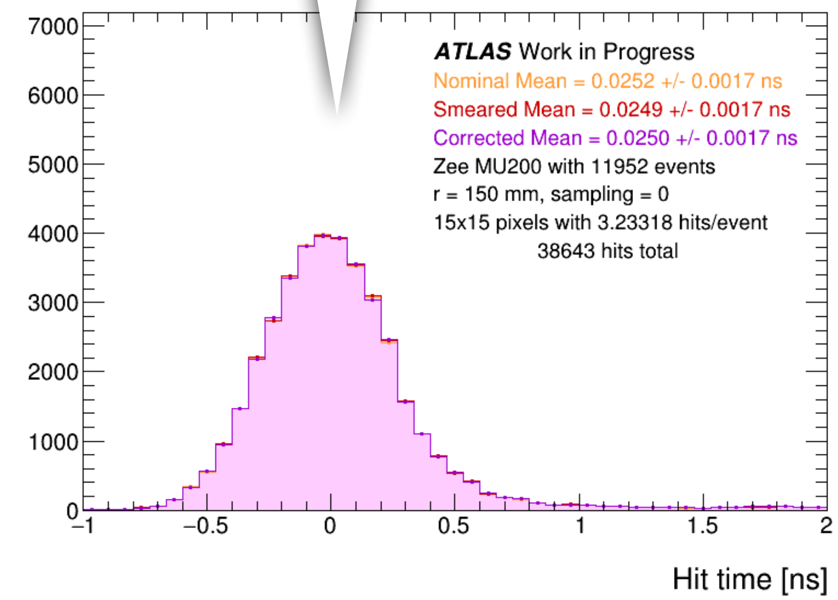
1 pixel with ~1200 hits and ~10ps precision

3x3 grid of pixels with ~8000 hits and ~3ps precision

15x15 grid of pixels with ~40k hits and ~1ps precision

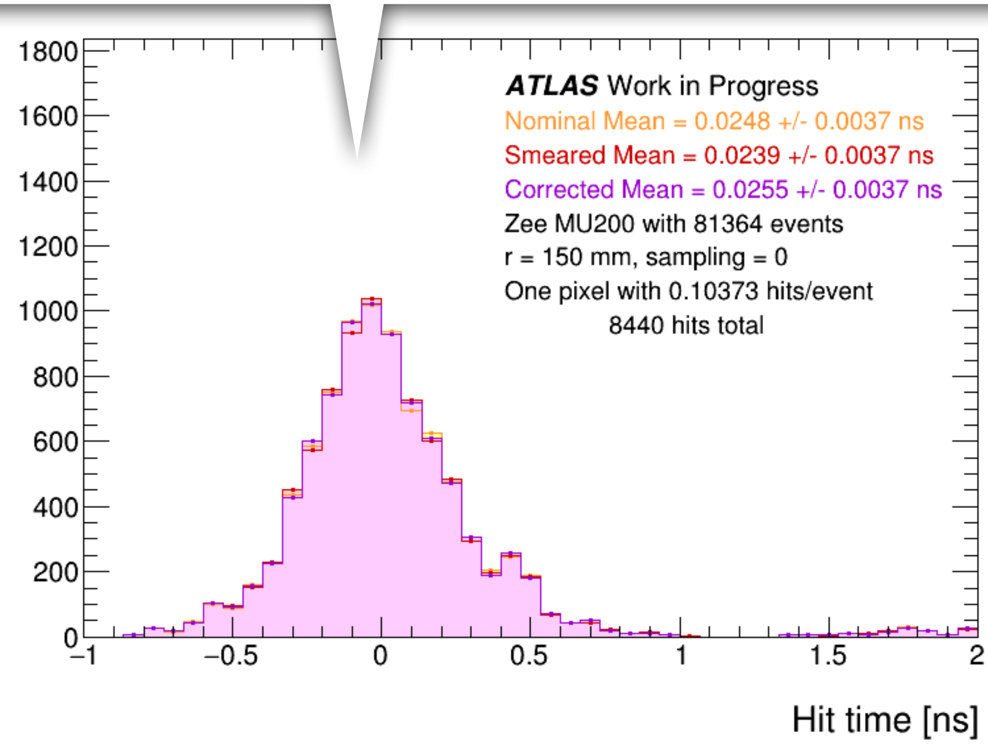






- Can also count hits from neighboring sensors
- Read by same ASIC => subject to the same time jitter and offsets

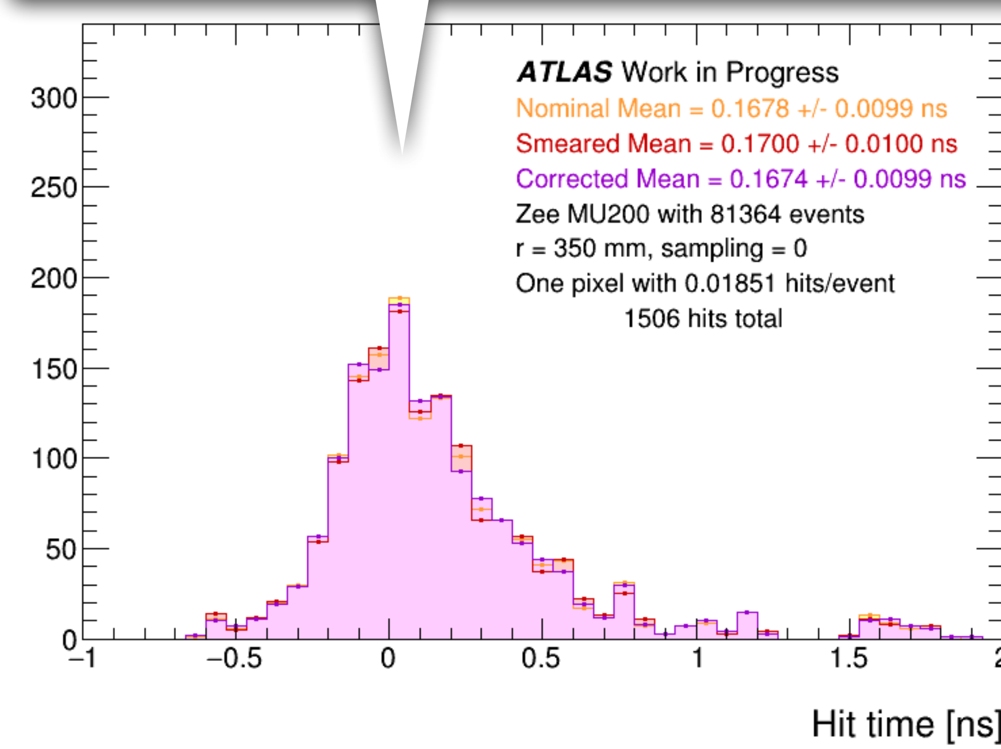
~3ps precision with ~8000 hits at r=150mm



w

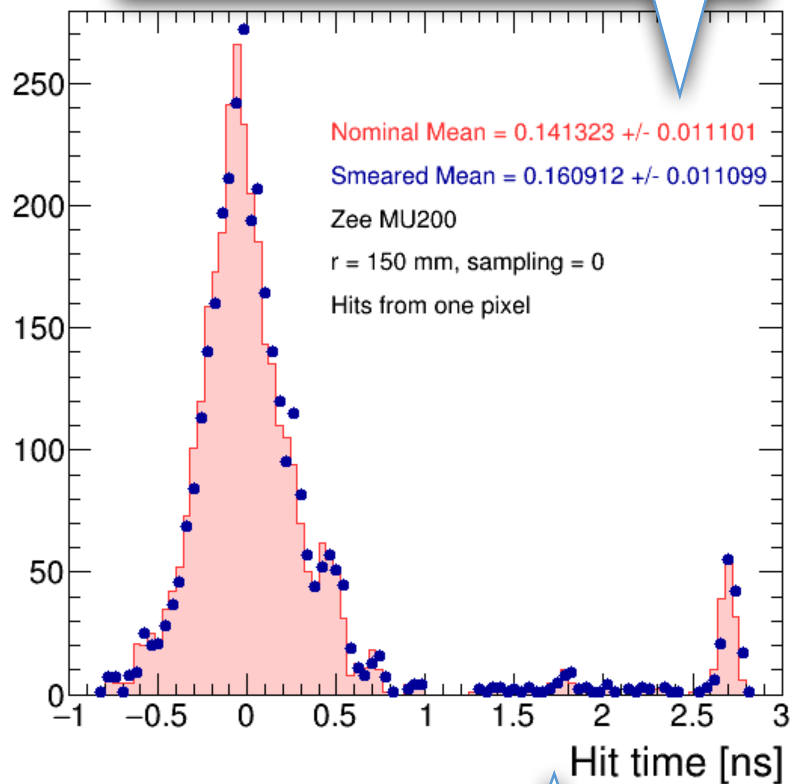
p

~10ps precision with ~1500 hits at r=350mm

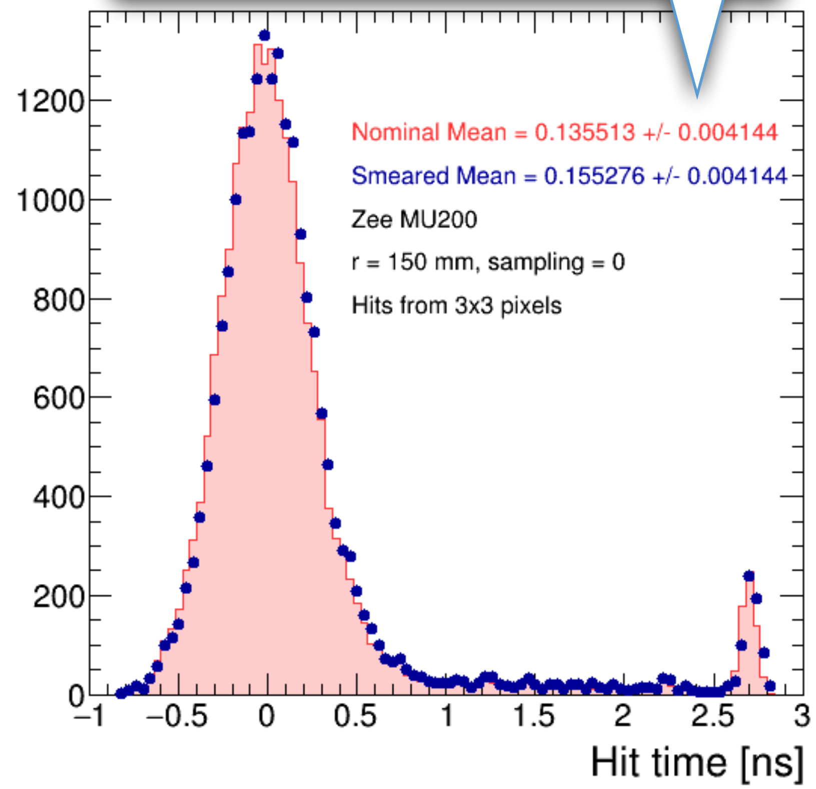


- Can get a precision of ~10ps with ~1500 hits, ~3ps with 10k hits
- However, hit rate is geometry dependent => **need over 500k events to get ps level precision at higher radii**

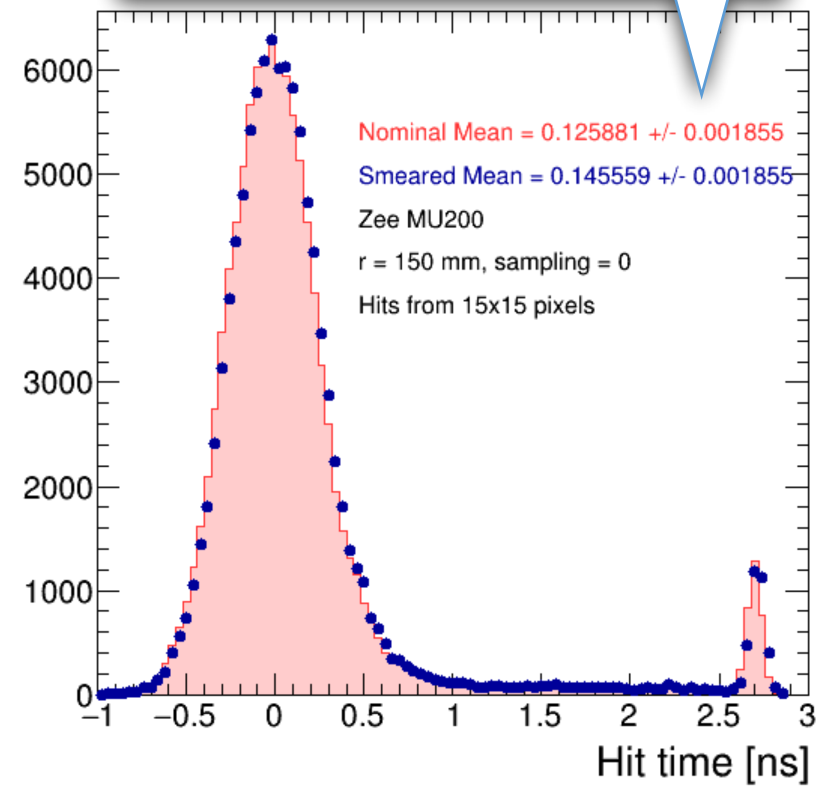
Single hit: 11 ps precision



3x3: 4 ps precision



15x15: 1 ps precision



Structures get smeared out as more pixels sampled