High Precision Timing: Detector Simulation Challenges - an ATLAS HGTD perspective

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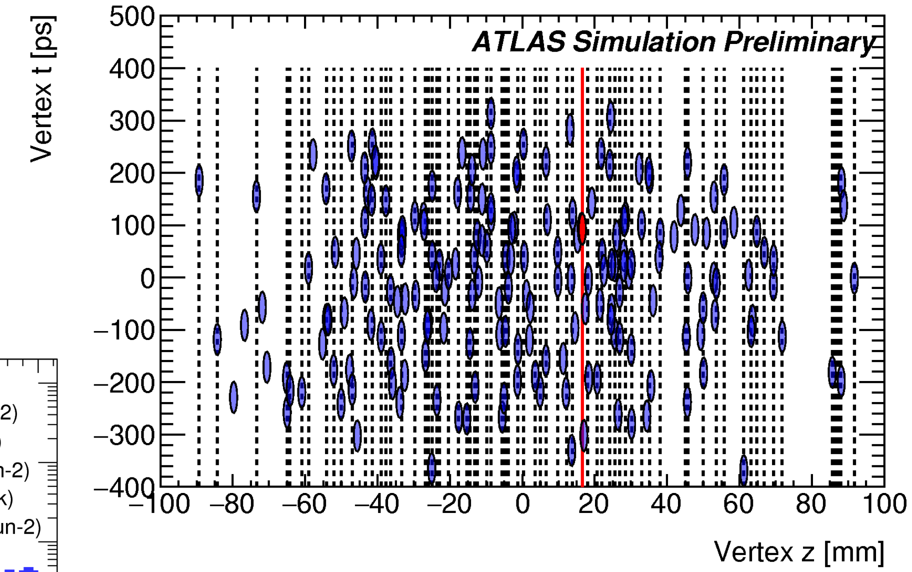
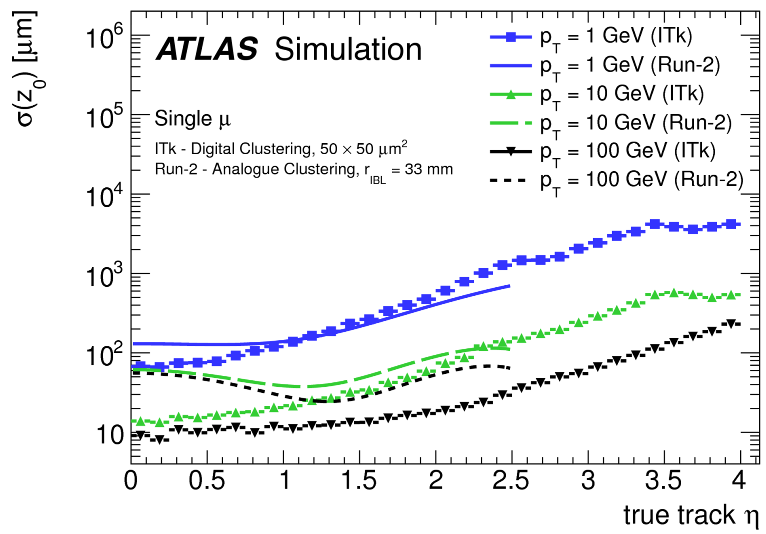
ECFA DRD7 - 14/03/2023

Introduction - HGTD in a nutshell

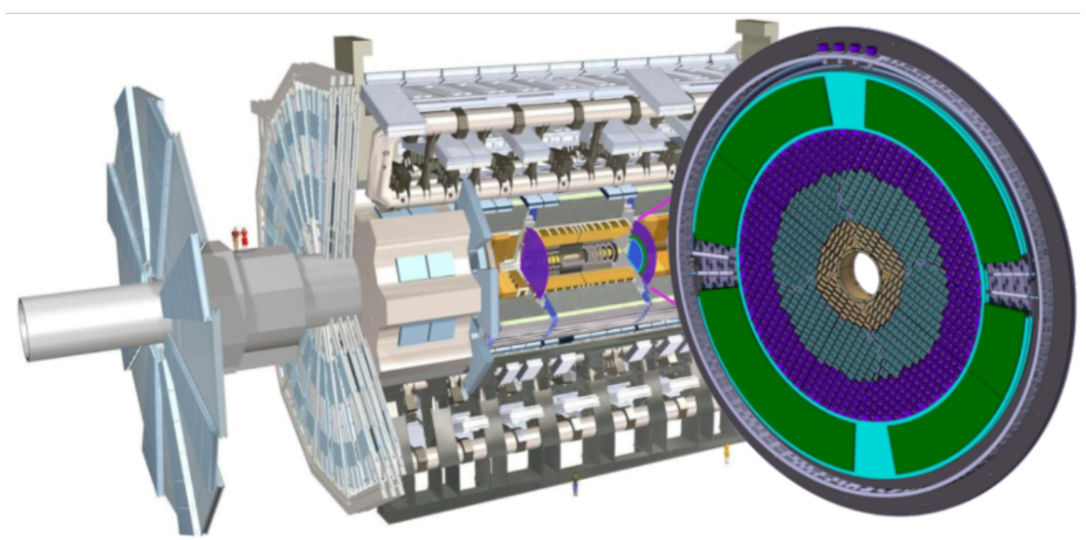
The High Luminosity phase of the LHC represents great challenges and opportunities to test new technologies for future detectors.



In the forward regions, the pile-up density will be comparable to the longitudinal (z_0) track resolution.



- Object performance reduced;
- Track-to-vertex ambiguity;
- Solution: add timing information with a small enough resolution, especially at high η.

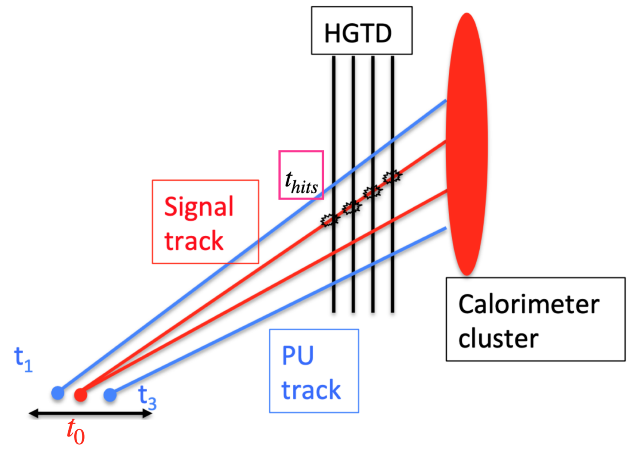


Coverage on **both endcap regions** outside of upgraded Inner Tracker: $2.4 < |\eta| < 4.0$

Per track (2/3 hits per track) timing resolution of $30 - 50\ ps$ up to a fluence of $2.5e15\ n_{eq}/cm^2$ (replacement foreseen) :

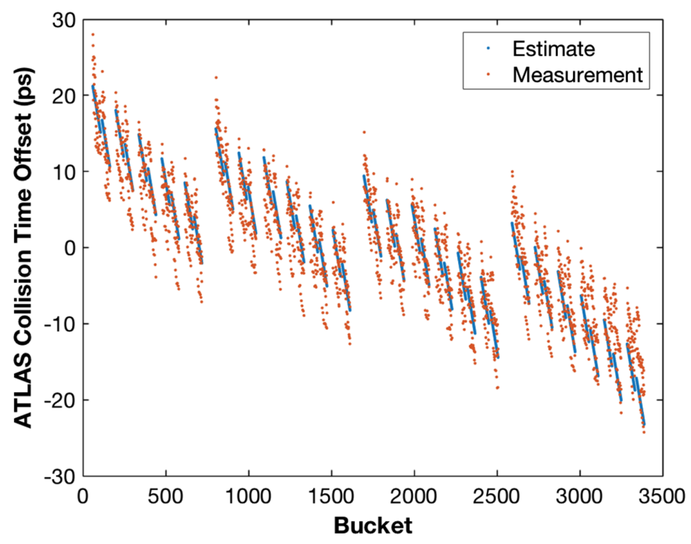
- **LGAD** (Low Gain Avalanche Detectors) of $50\ \mu m$ thickness;
- < 50 ps resolution per hit.

How time is distributed in HGTD



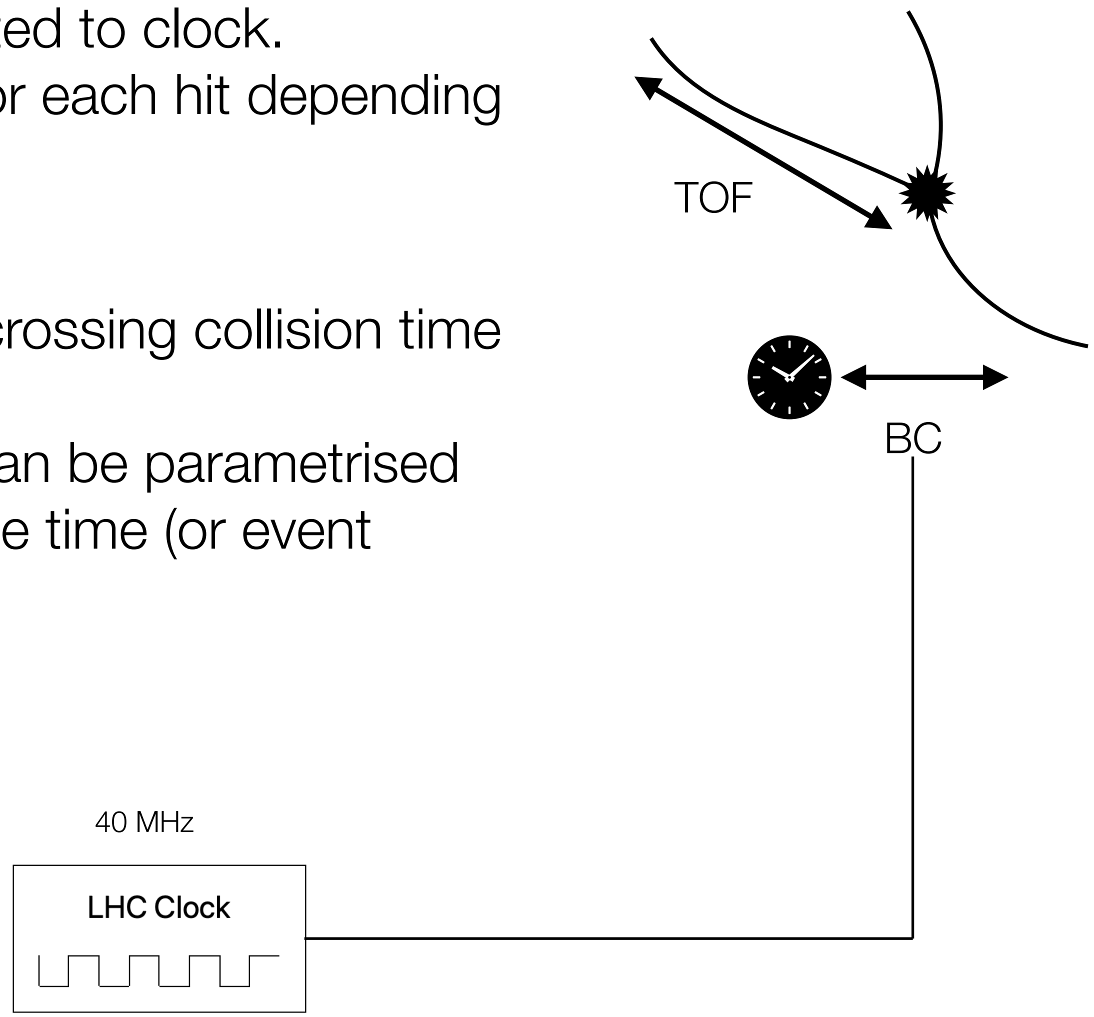
TOF: The first effect wee need to account is the time for the particule to reach the detector. For a same z-position, the time will differ depending on the hit R and the layer.

- One of the biggest effect we have to account for ~11 ns, but not related to clock.
- This is parameterised for each hit depending on its coordinates.



BC: with time the bunch crossing collision time changes slightly.

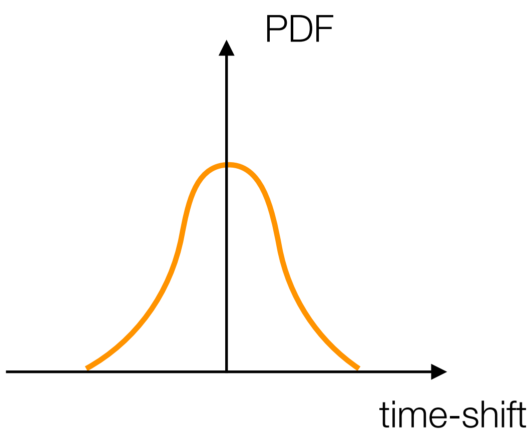
- This is measured and can be parametrised easily with respect to the time (or event number for simulation).

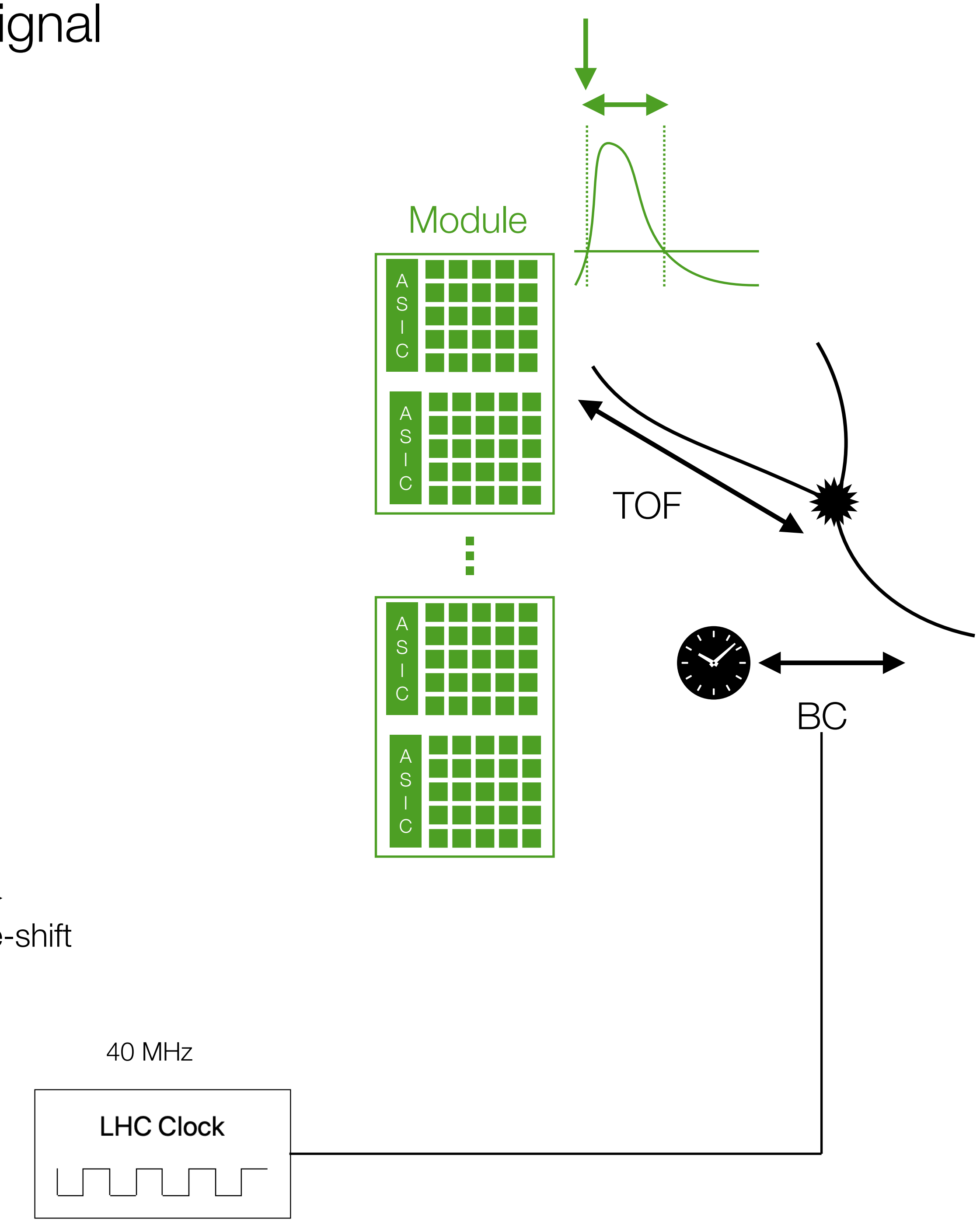


How time is distributed in HGTD

The first effects concerning the electronics and signal propagation are accounted as **jitters**:

➤ For the **ASIC** a conservative 35 ps jitter: path-length differences and internal jitter.

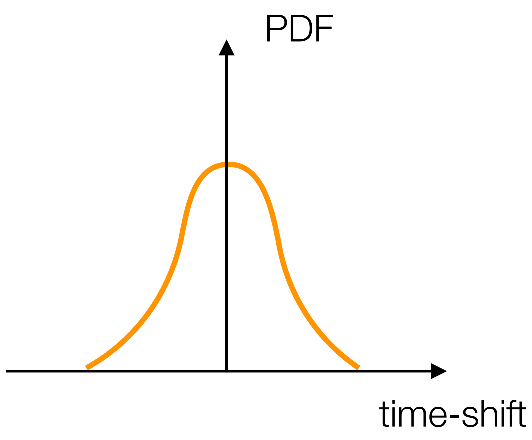


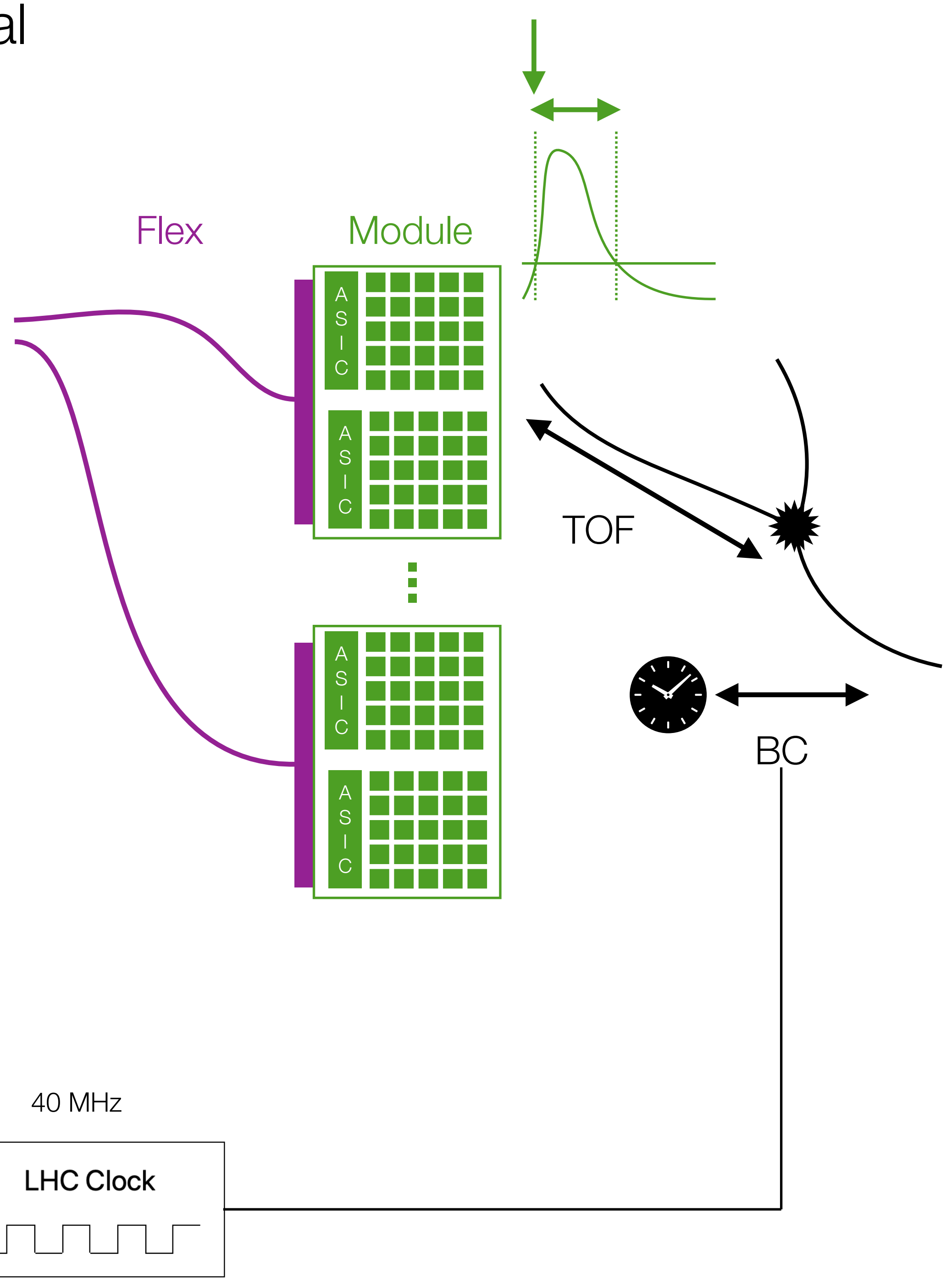


How time is distributed in HGTD

The first effects concerning the electronics and signal propagation are accounted as **jitters**:

- For the **ASIC** a conservative 35 ps jitter: path-length differences and internal jitter.
- The **Flex** effects include environment noise, inherent time jitters performance: measured by the HPTD group: 5 ps.





How time is distributed in HGTD

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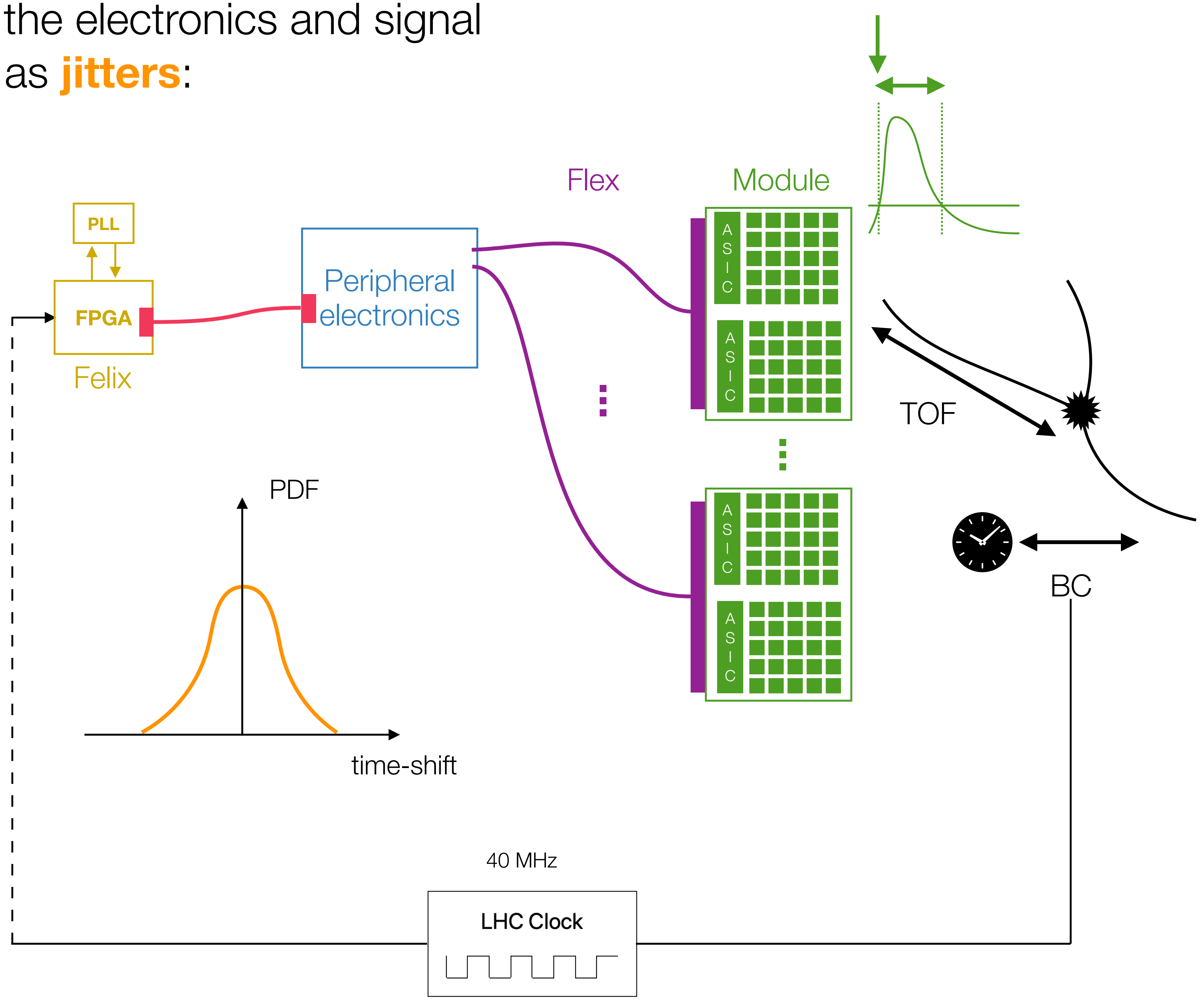
- For **Felix** the internal clock jitter has been estimated to be 5.2 ps.

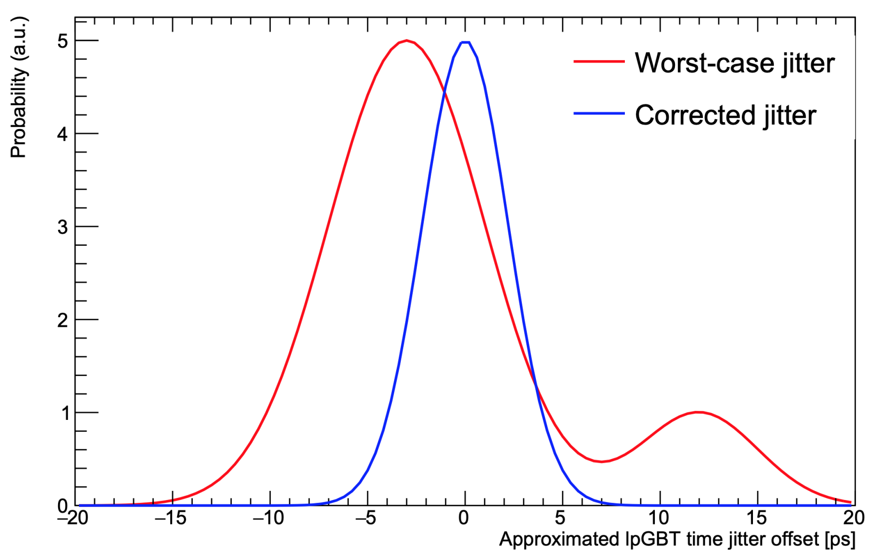


All this effects are **additive** in this simple analysis!

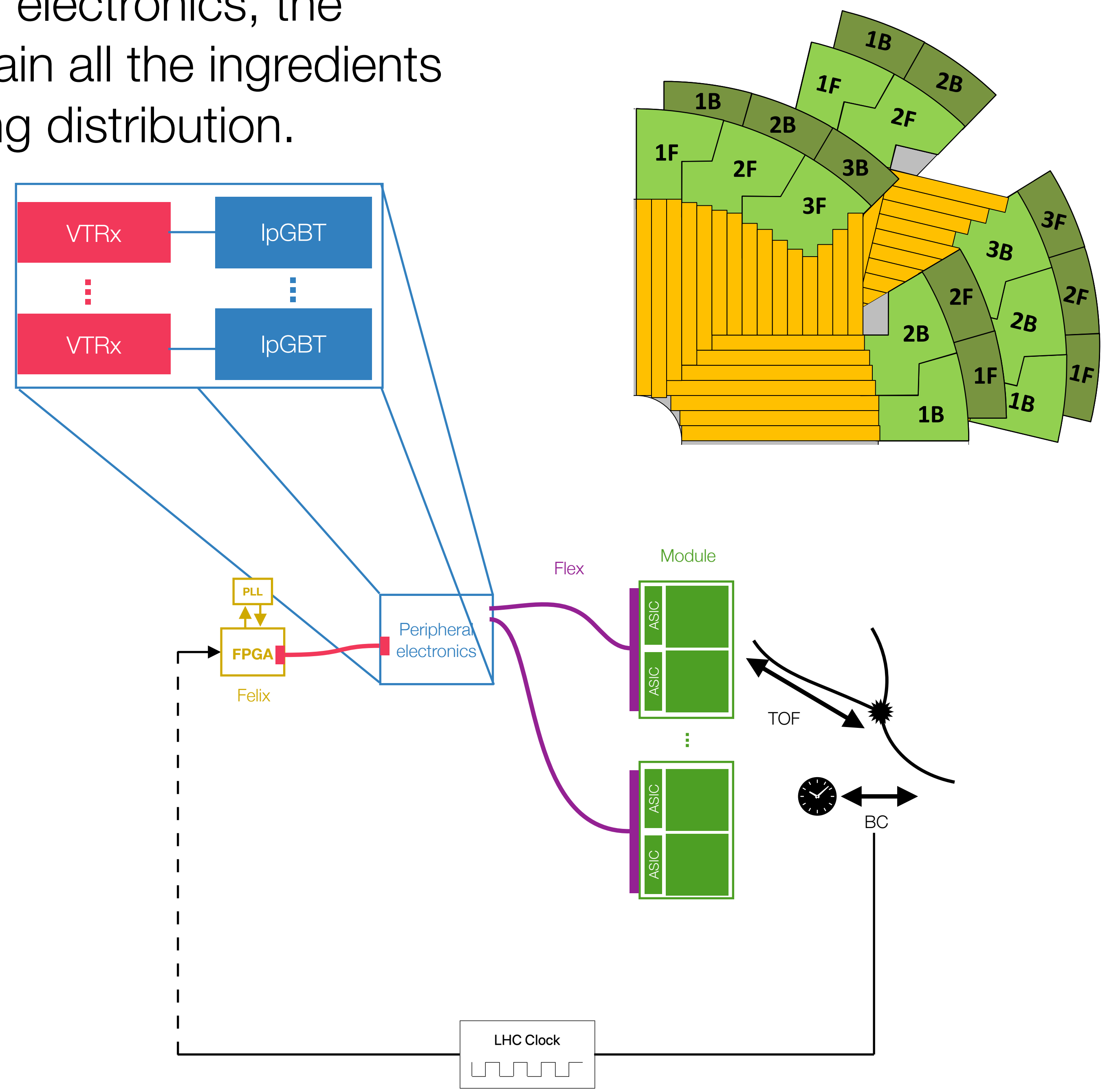
How time is distributed in HGTD

In between the ASIC and the off-detector electronics, the Peripheral Electronic Boards (PEBs) contain all the ingredients to deal with: Trigger, Data, DCS and timing distribution.

It also contains a specific tool to help us clean part of the jitters: the **Low Power Giga Bit Transceiver** (lpGBT) chip:

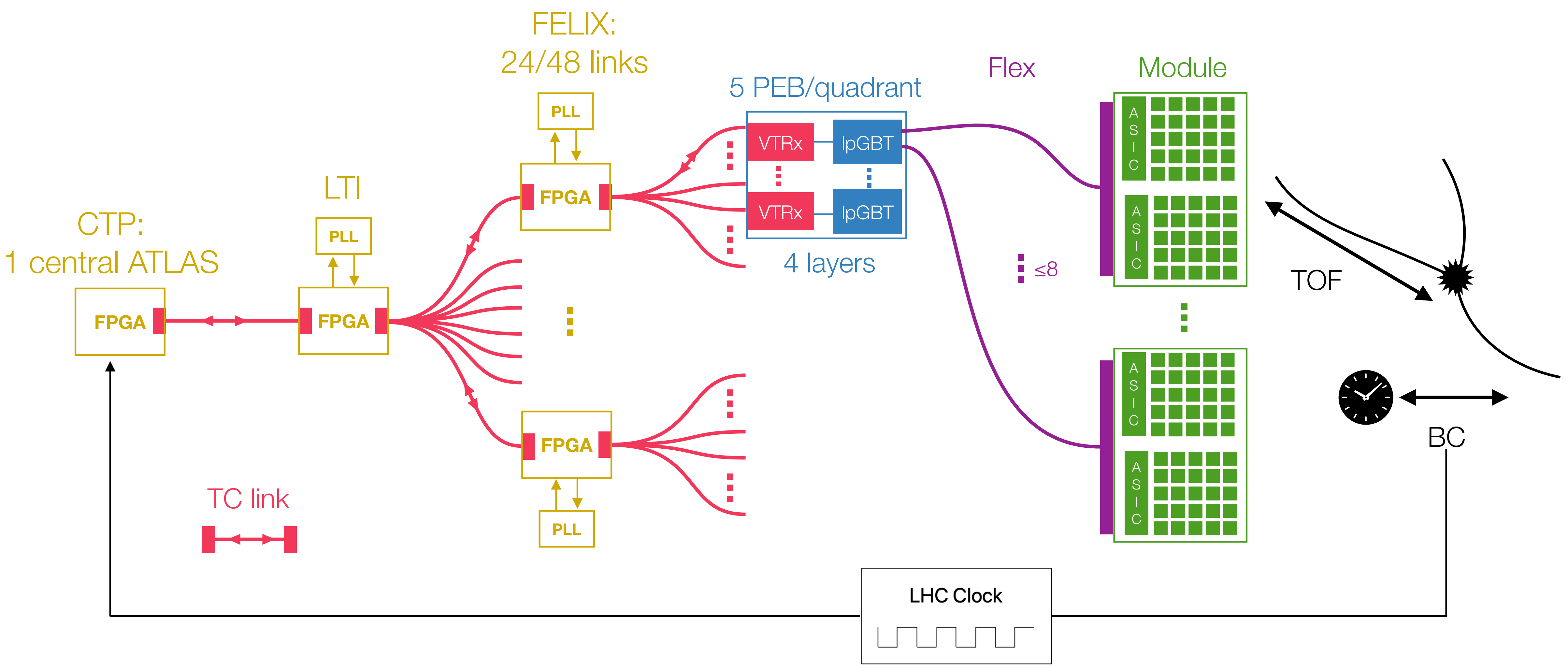


Recent results are showing that we could *remove the FELIX jitter* and only consider a **global 2.2 ps effect**.



How time is distributed in HGTD

The global sketch of the time distribution should more look like this:

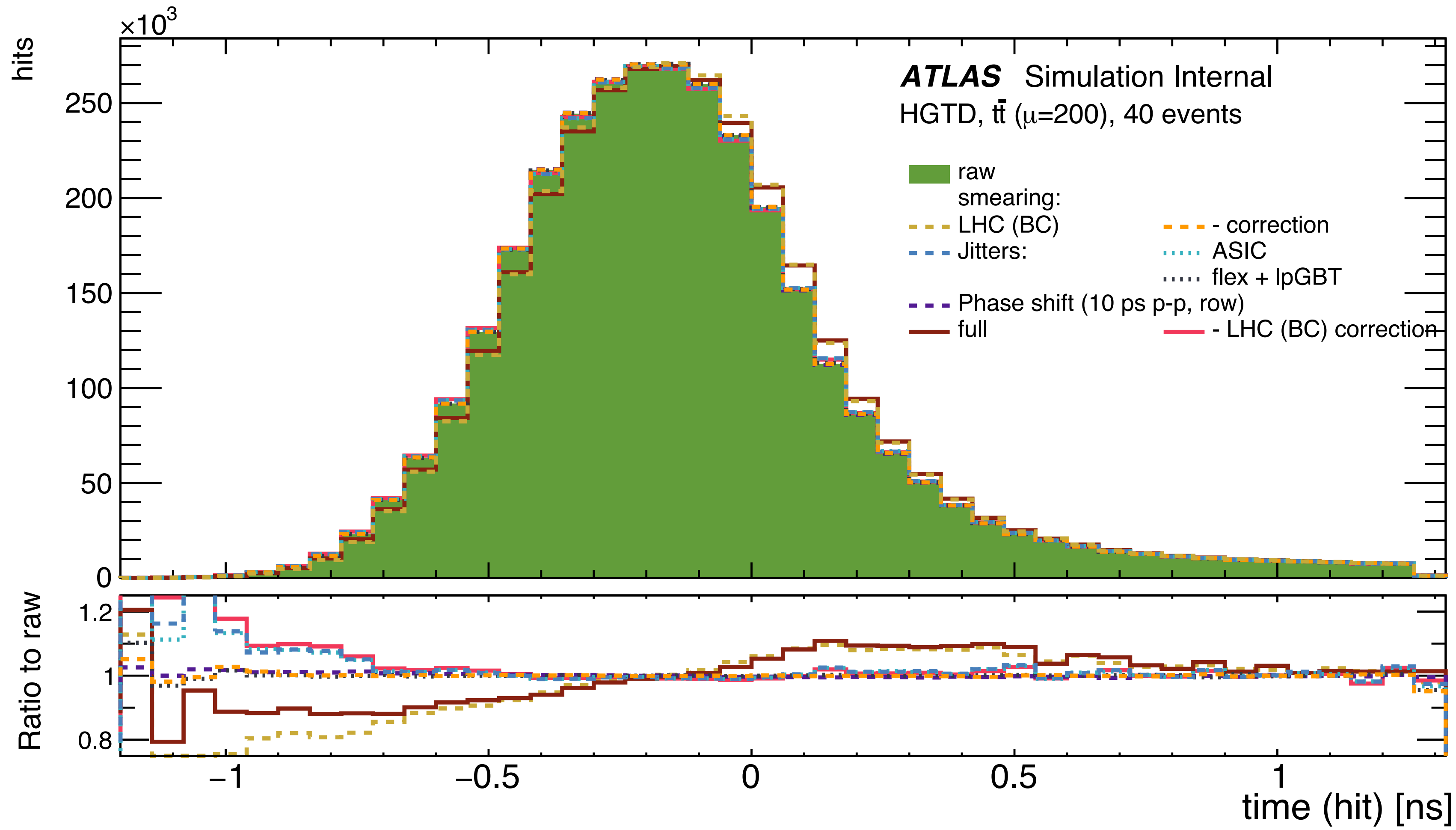


One aspect that hasn't been mentioned here is the **phase determinism** and its potential impact: we have many links that can reset at some point.
It may be **rare (TBD)**, but will desynchronise some **part of the detector** (which fraction ?) and by a **"big" amount** (O(10 ps)).

How to look at these effects

The first type of plots one can show is the effect of the various effect on a simulated **Time of Arrival (ToA)** inside the ASIC time window selected:

- A 2.5 ns window with a 100 ps step is selected by a "Phase Shifter";
- This selection is made once per ASIC and correct for most of Time of Flight effects;
- The other effects are shown as deviation from this "raw time".



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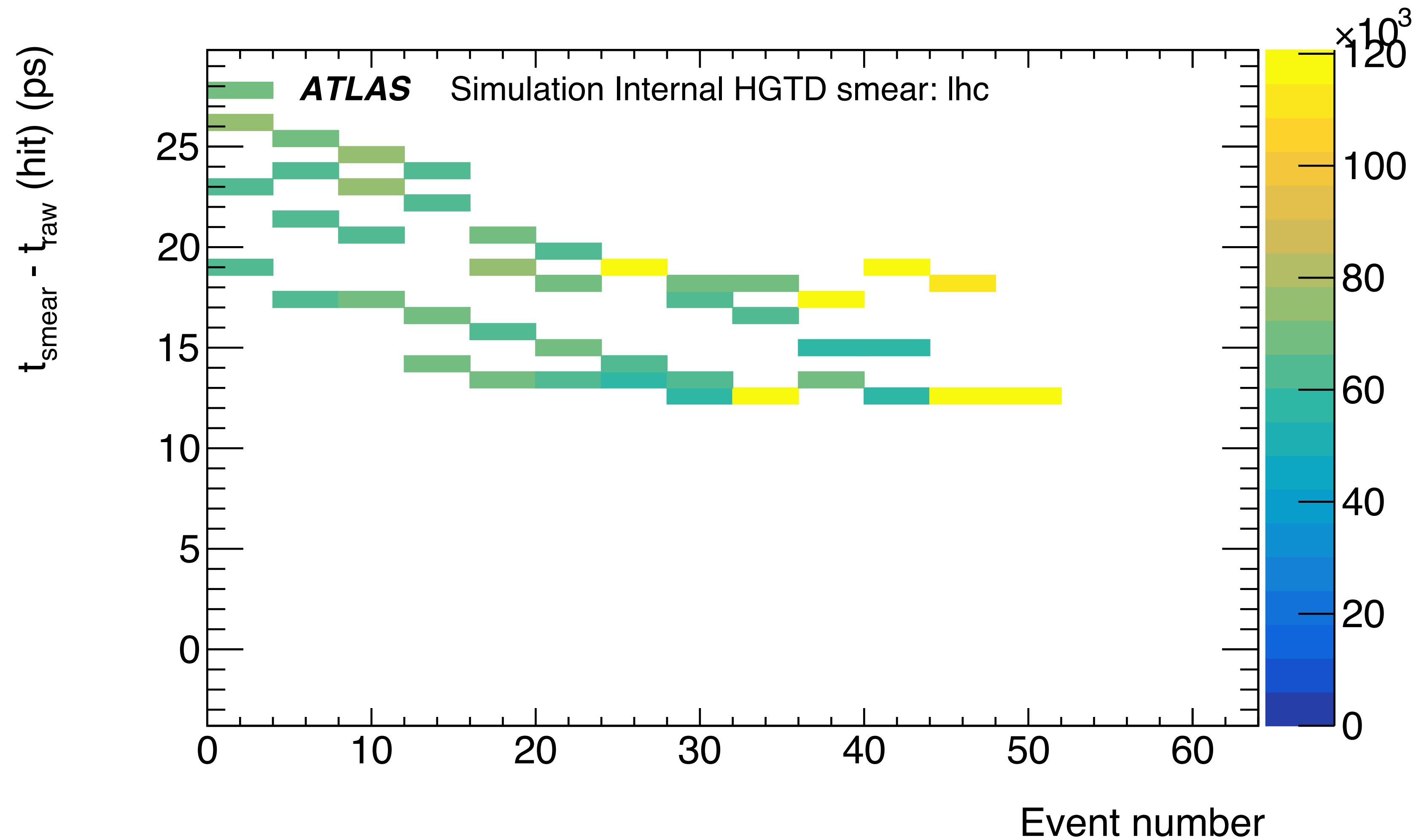
- A 2.5 ns window with a 100 ps step is selected by a "Phase Shifter";
- This selection is made once per ASIC and correct for most of Time of Flight effects;
- The other effects are shown as deviation from this "raw time".
- These effects can be also change over time.
- The remaining question is whether we can try to correct them ?



Residual time calibration

$$t[\text{calib, channel i}] = t[\text{raw, channel i}] - \langle t_{hits} \rangle$$

$$C_N = < t_{hits} >$$

Average of the hits on some time period

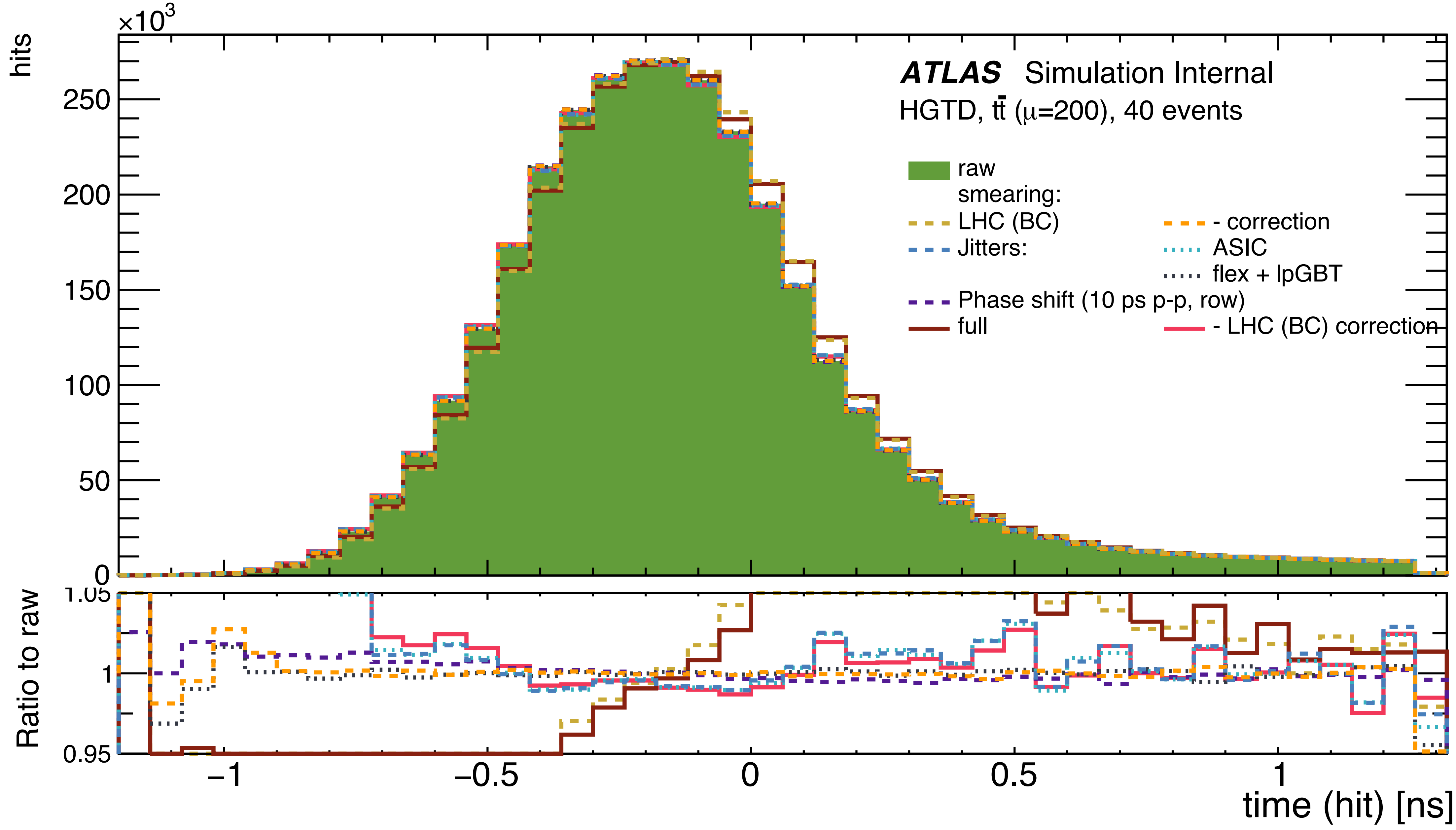
Opening discussion

In the studies conducted we have opened maybe **more questions** than solved issues, allowing to connect detector level and global LHC requirements:

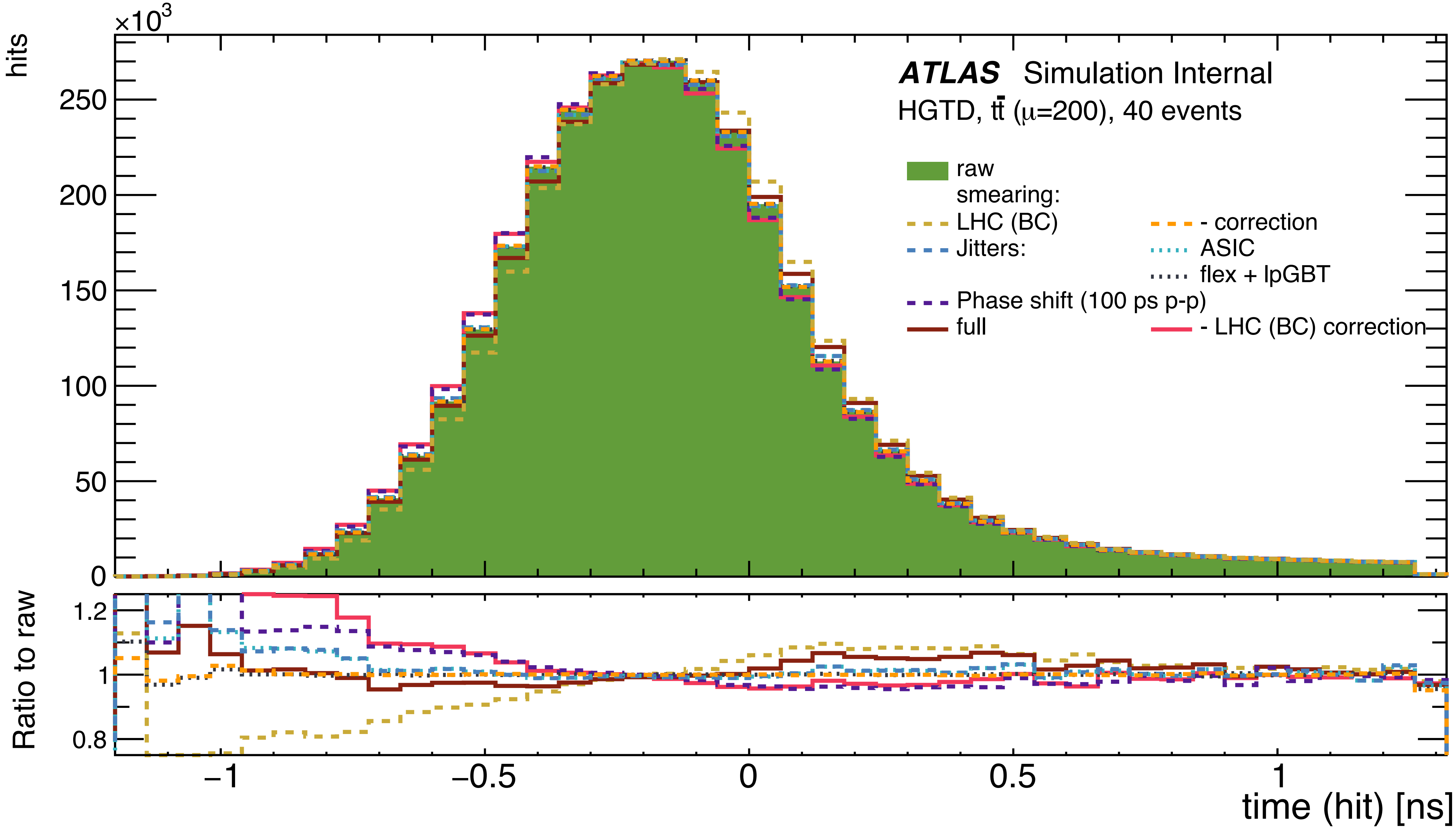
- One of the key question is the **mapping** of the effects:
  - it's not easy to get it clear when the project is still in the R&D phase.
- The **frequency** is also challenging:
  - Maybe we can rely on current detector experience ? But will LHC behave the same in High-lumi ?
- Is the **correlation** between the effects something we are sensitive to ?
- Which **figure of merit** to use:
  - The hit level is easy to extract but is it the most meaningful one ?
  - What about per track effects ?
- The **calibration** procedure also triggers a lot of decisions:
  - Offline vs Online ?
  - How often and what granularity ?
  - How well this mitigates the effects described earlier ?

BACK-UP

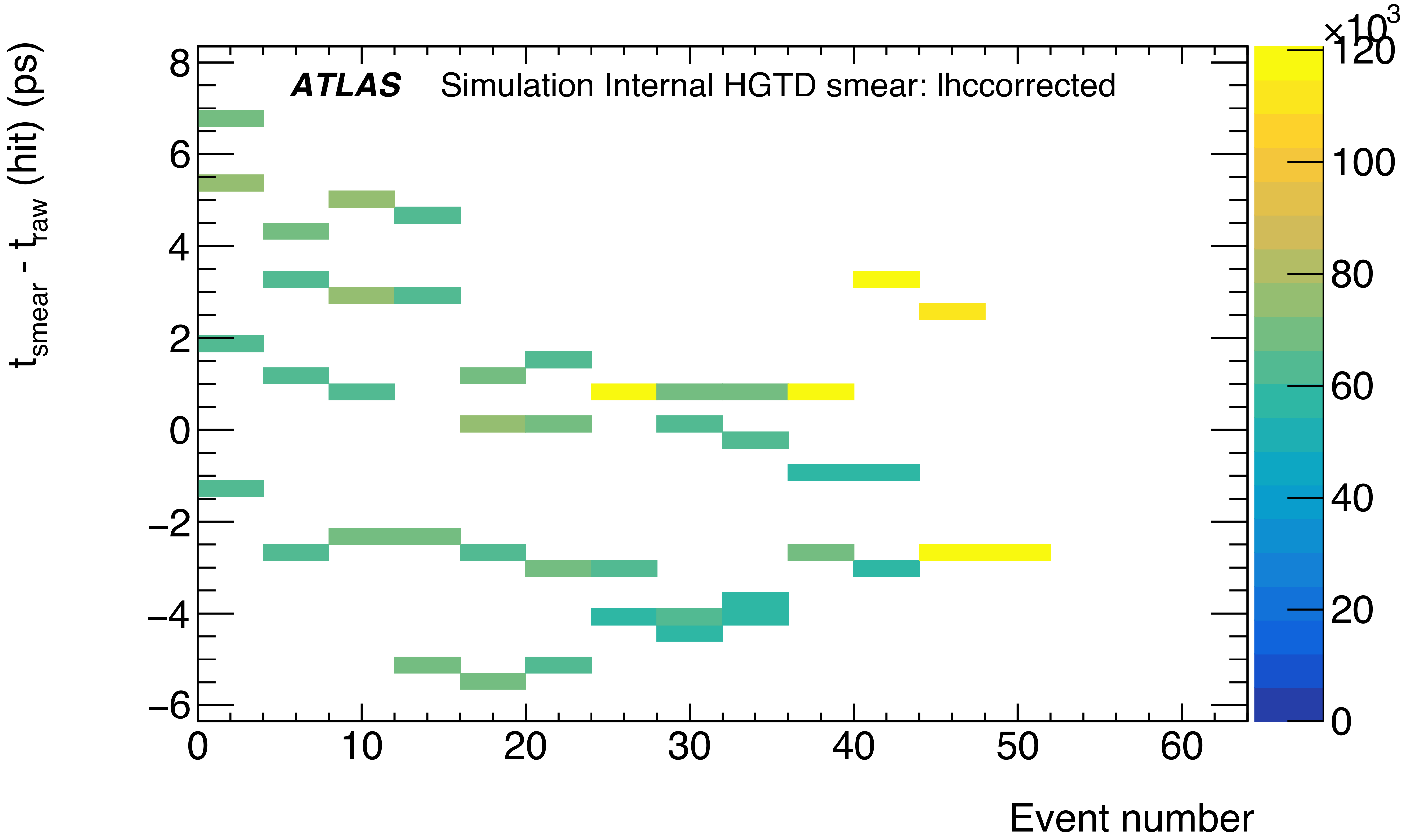
Zoomed effects



100ps Phase Shift

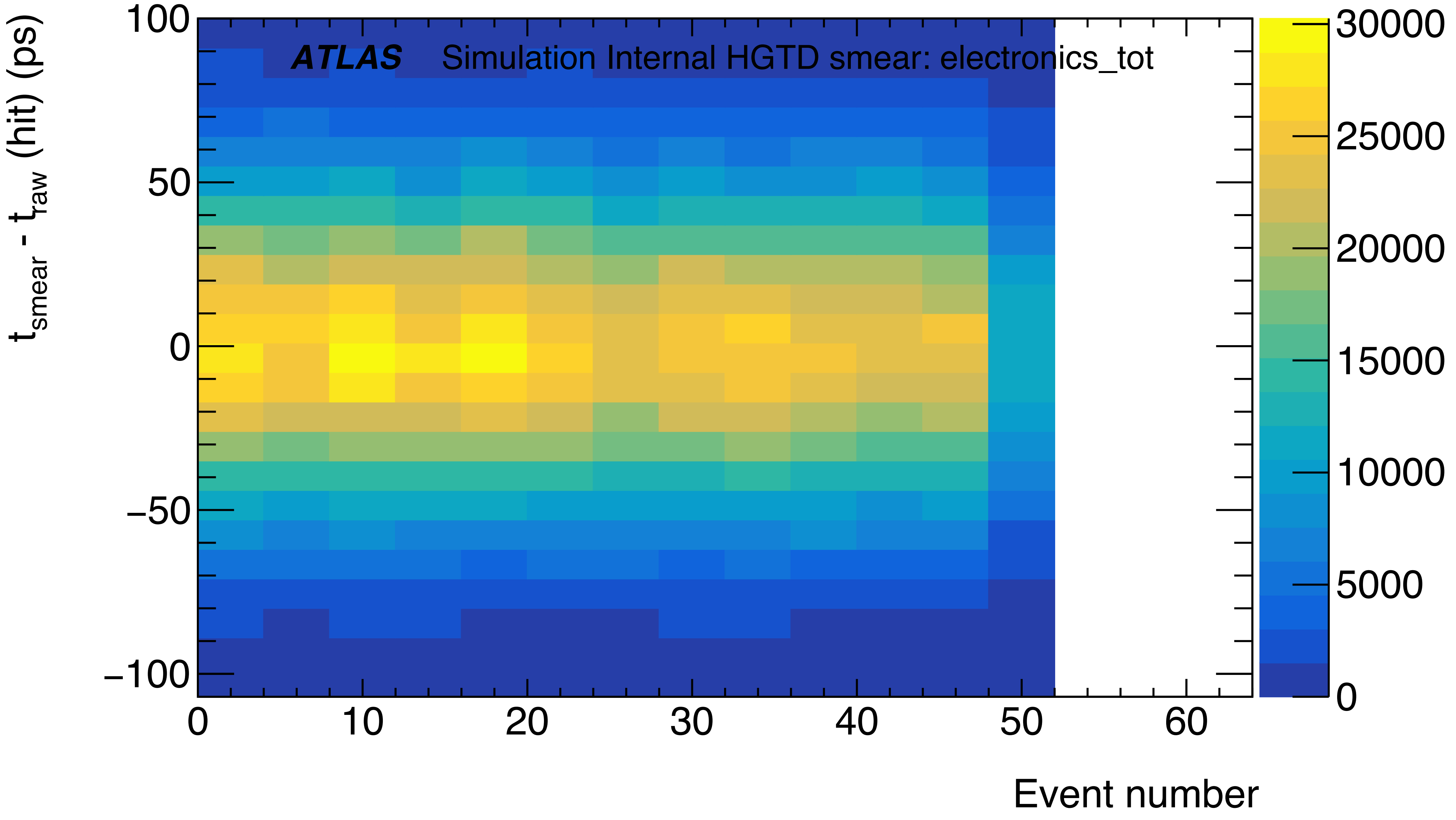


Other plots



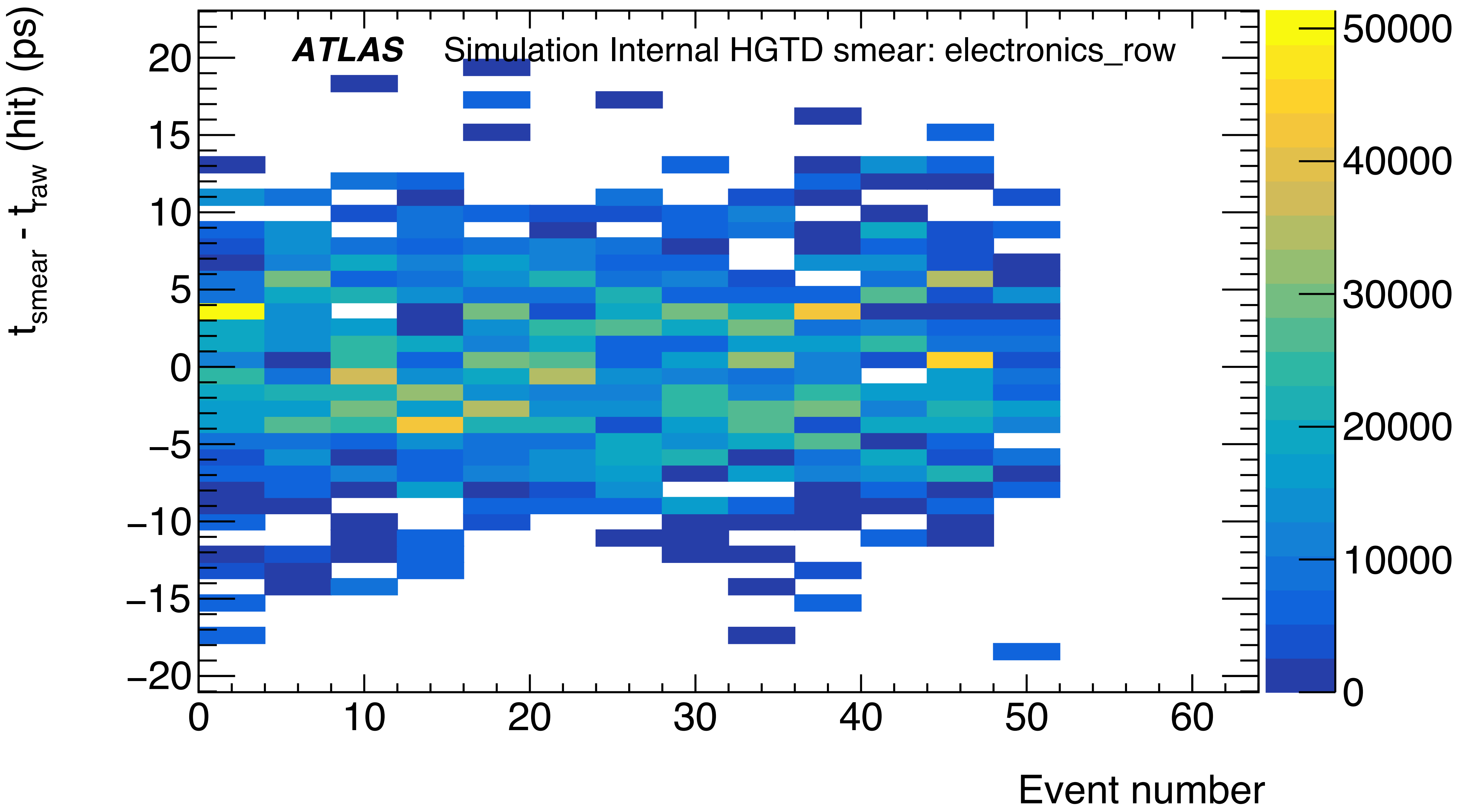
ATLAS Simulation Internal HGTD smear: lhccorrected
t_{smear} - t_{raw} (hit) (ps)
Event number
×10^3
120
100
80
60
40
20
0
8
6
4
2
0
−2
−4
−6
0
10
20
30
40
50
60

Other plots

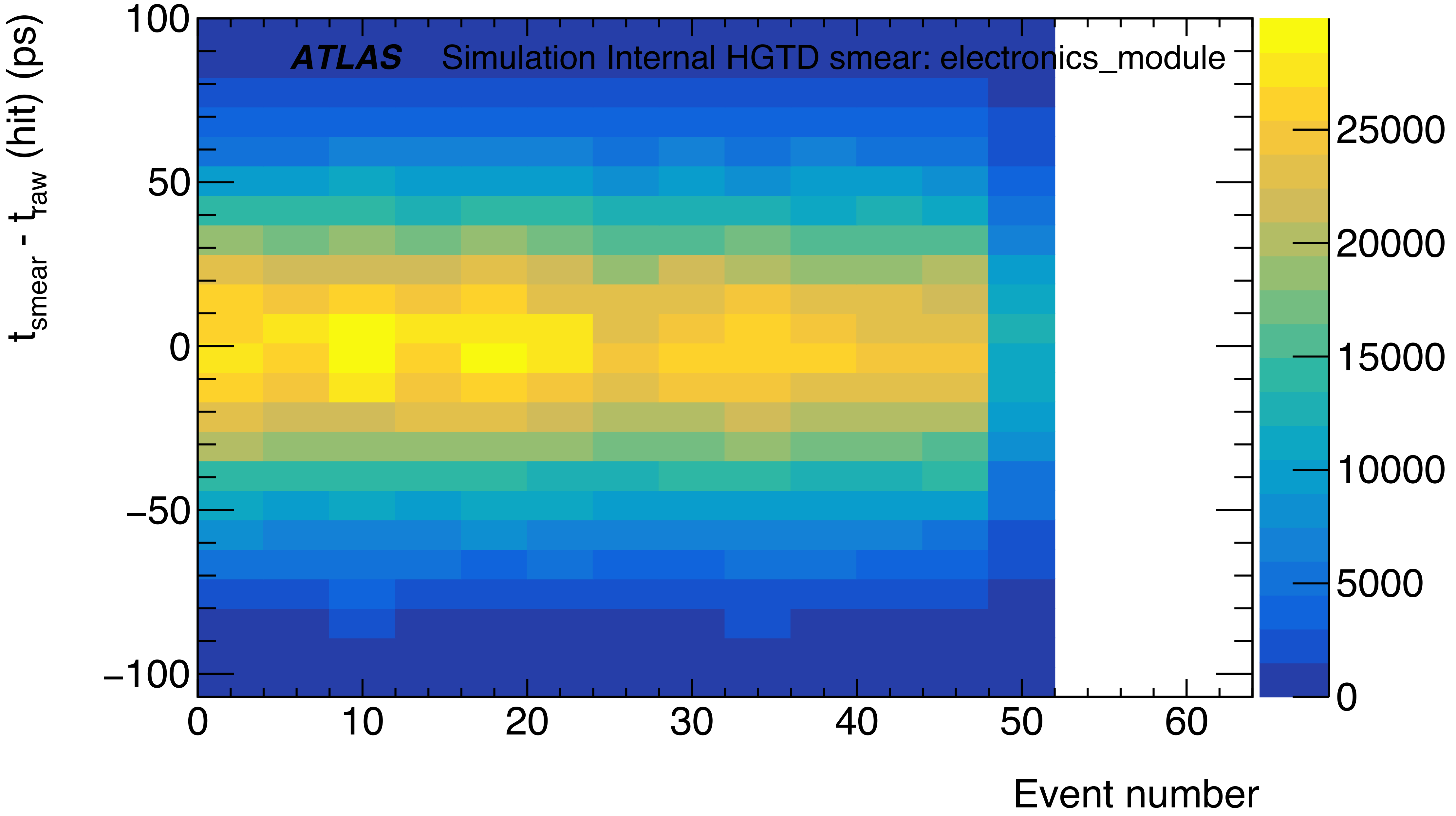


ATLAS Simulation Internal HGTD smear: electronics_tot
$t_{smear} - t_{raw}$ (hit) (ps)
Event number
100
50
0
−50
−100
0
10
20
30
40
50
60
30000
25000
20000
15000
10000
5000
0

Other plots

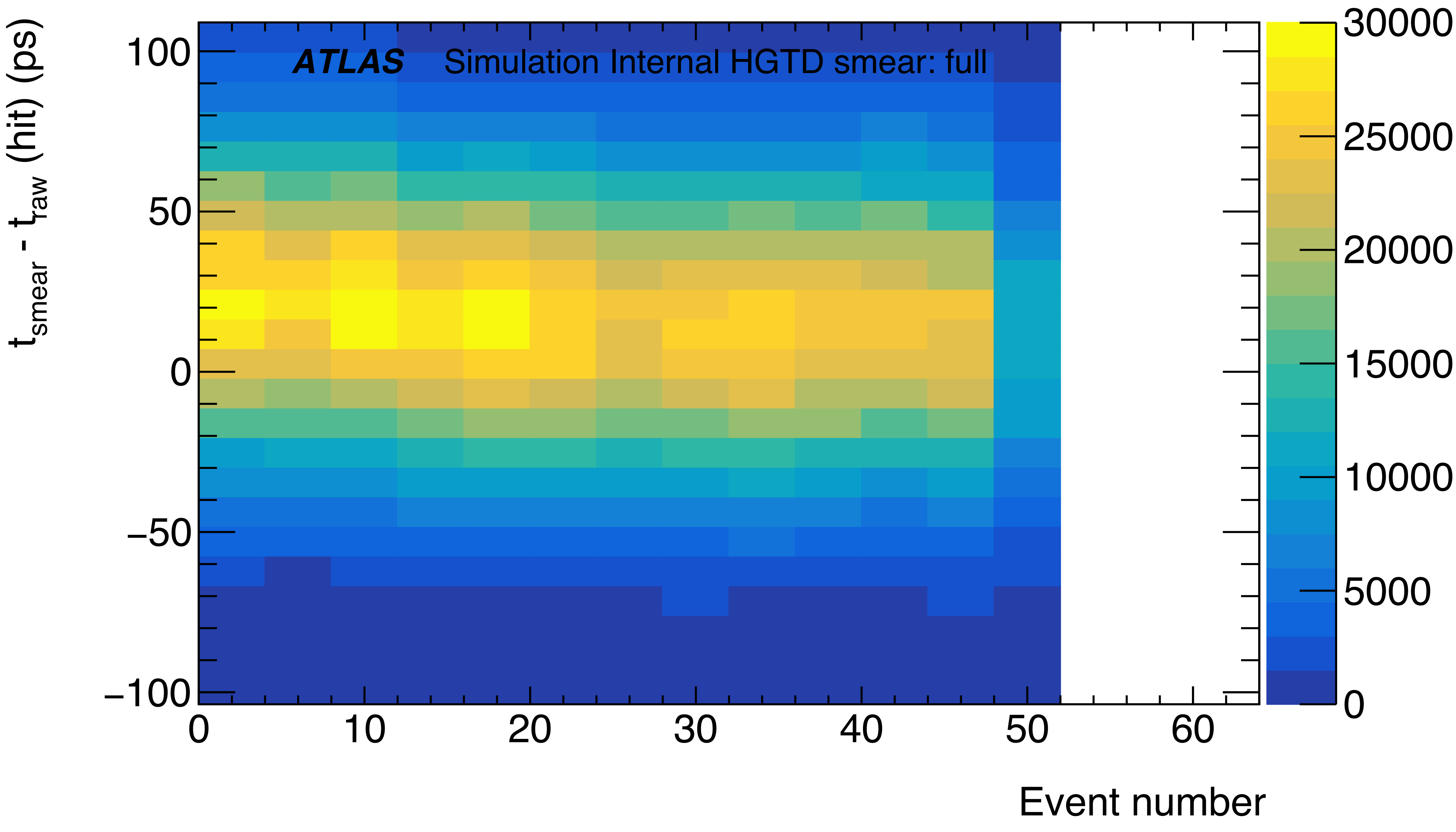

ATLAS Simulation Internal HGTD smear: electronics_row
t_{smear} - t_{raw} (hit) (ps)
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60
Event number
50000
40000
30000
20000
10000
0

Other plots



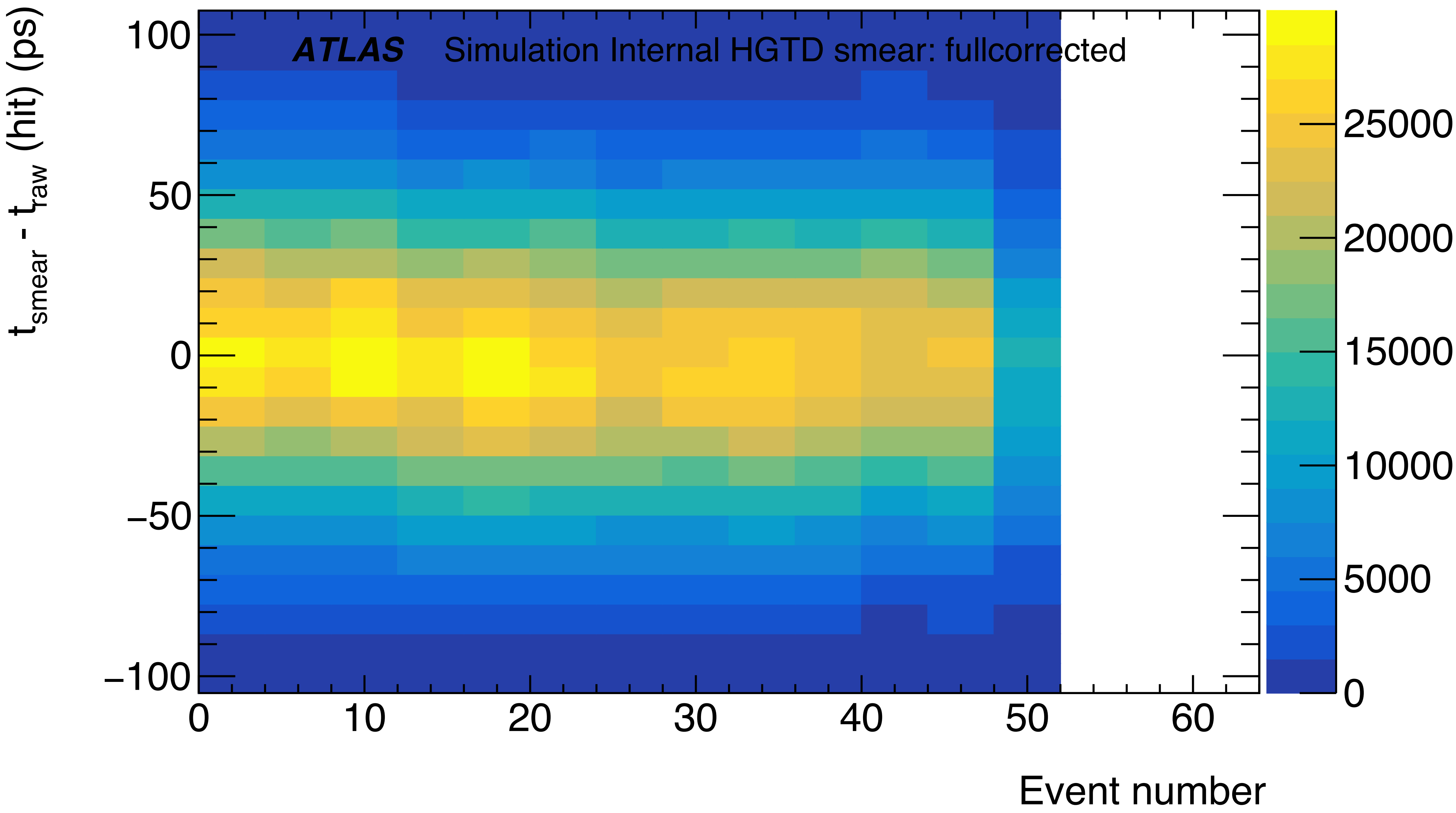
ATLAS Simulation Internal HGTD smear: electronics_module
$t_{smear} - t_{raw}$ (hit) (ps)
100
50
0
−50
−100
0
10
20
30
40
50
60
Event number
25000
20000
15000
10000
5000
0

Other plots



ATLAS Simulation Internal HGTD smear: full
$t_{smear} - t_{raw}$ (hit) (ps)
100
50
0
−50
−100
0
10
20
30
40
50
60
Event number
30000
25000
20000
15000
10000
5000
0

Other plots



ATLAS Simulation Internal HGTD smear: fullcorrected
t_{smear} - t_{raw} (hit) (ps)
100
50
0
−50
−100
0
10
20
30
40
50
60
Event number
25000
20000
15000
10000
5000
0