Carleton UNIVERSITY
Canada's Capital University

ATLAS New Small Wheel (NSW) small-strip Thin Gap Chamber (sTGC) simulation in Athena

Alain Bellerive, **Stephen Weber**
Carleton University

ATLAS EXPERIMENT

Canadian Association of Physicists
Association canadienne des physiciens et physiciennes

CAP Congress
Congrès de l'ACP

uOttawa

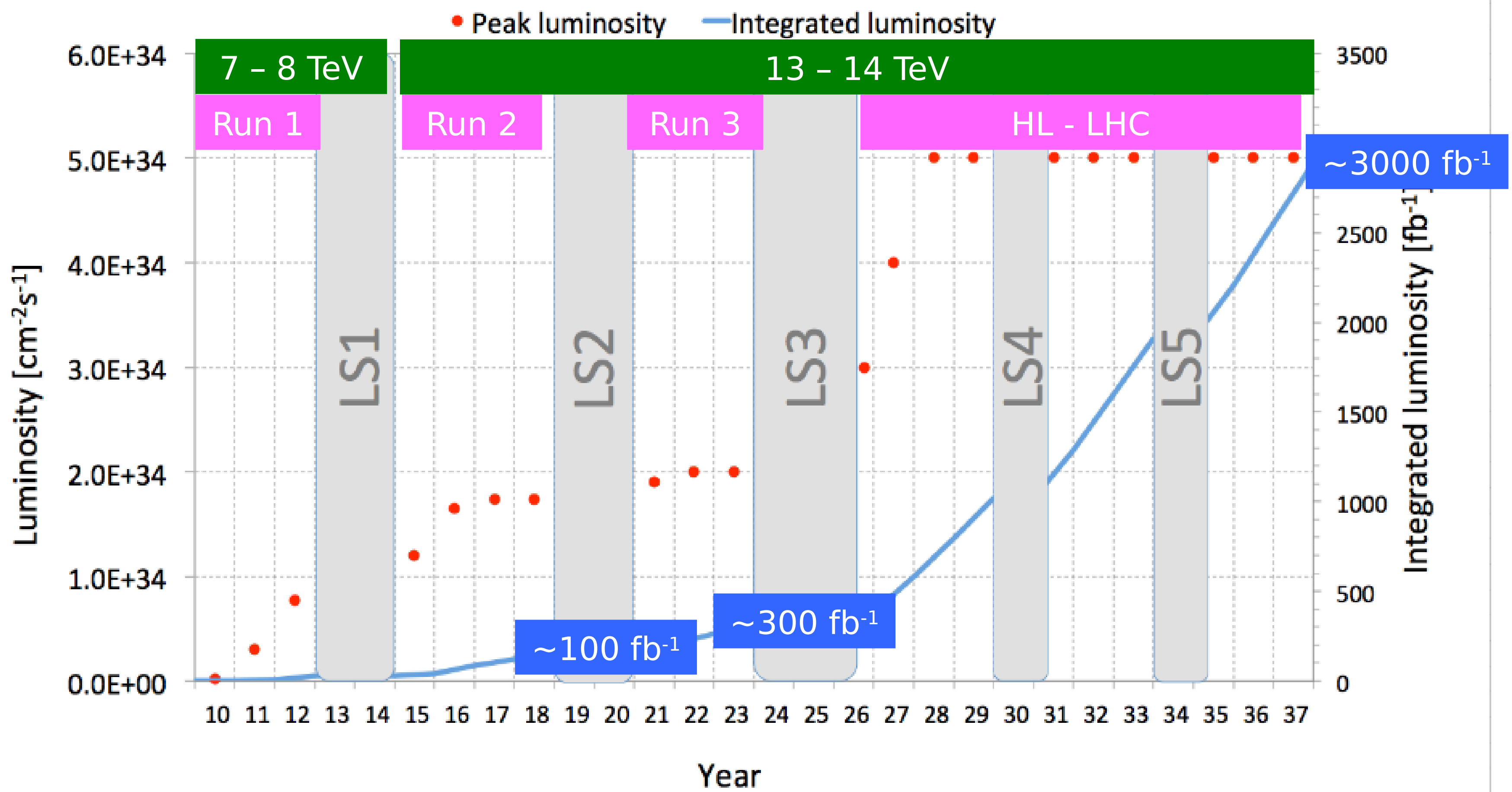
Outline

- Introduction
  - Motivation
- The New Small Wheel (NSW)
- The small-strip Thin Gap Chambers (sTGC)
  - Signal simulation (charge distribution)
  - Timing simulation
  - Deadtime (pile-up)
- Summary and Conclusion

Why Upgrade? Harsher Conditions at the LHC

Upgrade **ATLAS** to increase data aquisition **rate**

→ Accelerate the study of the Higgs, the standard model and new physics



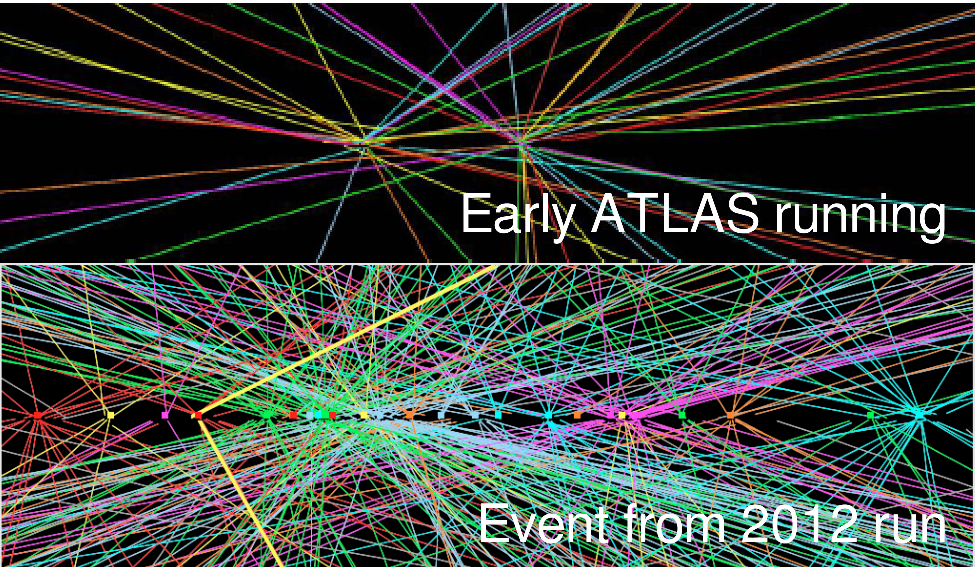
Increased Rate due to higher Luminosity, more Energy and smaller Bunch Spacing (25 ns)

Collecting the data

<u>ATLAS collision rate</u>:

- <u>Original</u>: 25 every **50 ns**
- <u>Future</u>: 50-100 every **25 ns**

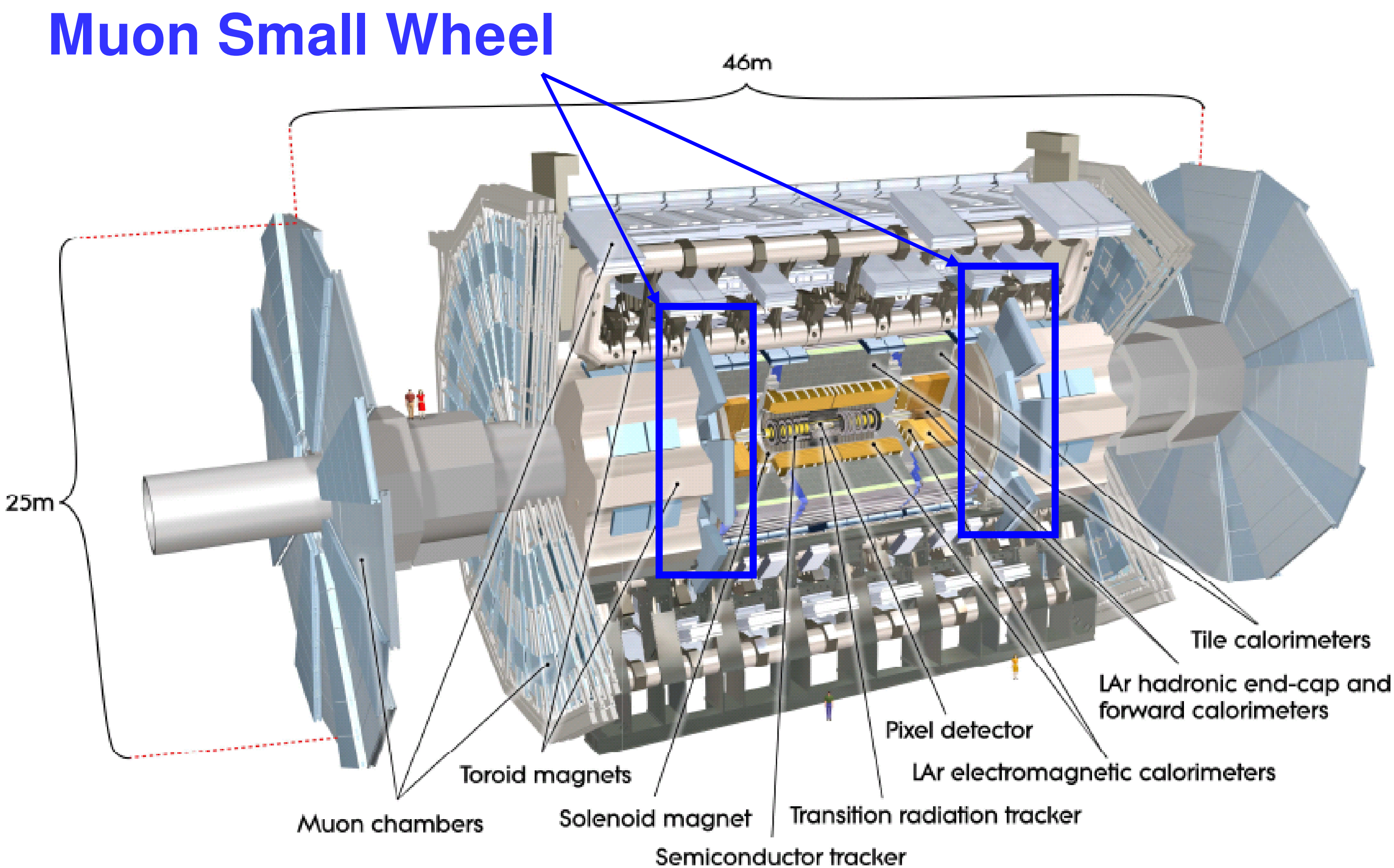
Collisions in one event in ATLAS



Run 3 will have even more collisions!

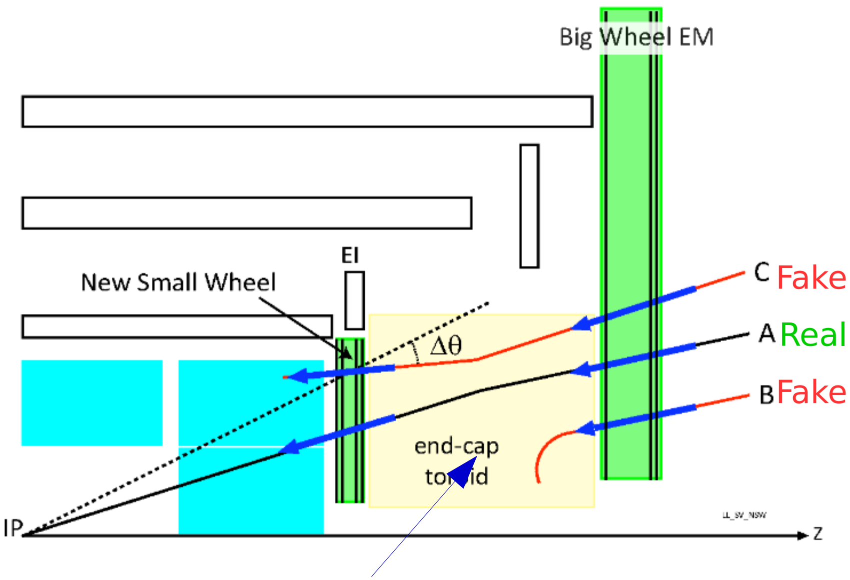
- With current **Muon Small Wheel** the trigger cannot handle Run 3 rate
- Key trigger selection looks for energetic muons
- Trigger designed for original luminosity of **1×10^{34} $cm^{-2}s^{-1}$**
- The **High Luminosity LHC** trigger will need to handle luminosity of **5×10^{34} $cm^{-2}s^{-1}$**
- To collect interesting events we need to **<u>enhance</u>** ATLAS trigger capability

Small Wheel in ATLAS



The Small Wheels are the most forward muon chambers → highest event rate

Why a New Small Wheel at ATLAS?

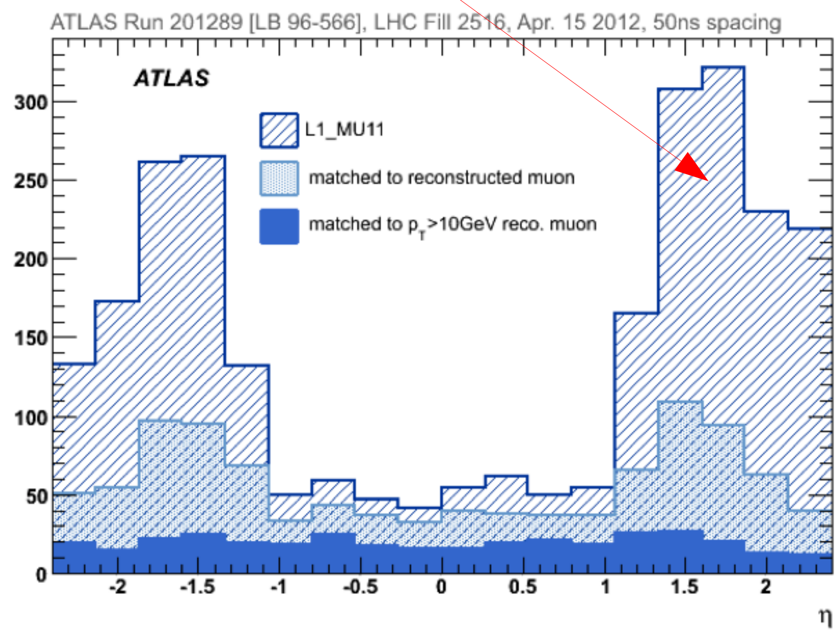


Magnetic Field

Current trigger relies mainly on the **Big Wheel**

Difficult to distinguish between **A**, **B** and **C** above

Fake muon triggers are overwhelming in the end cap regions



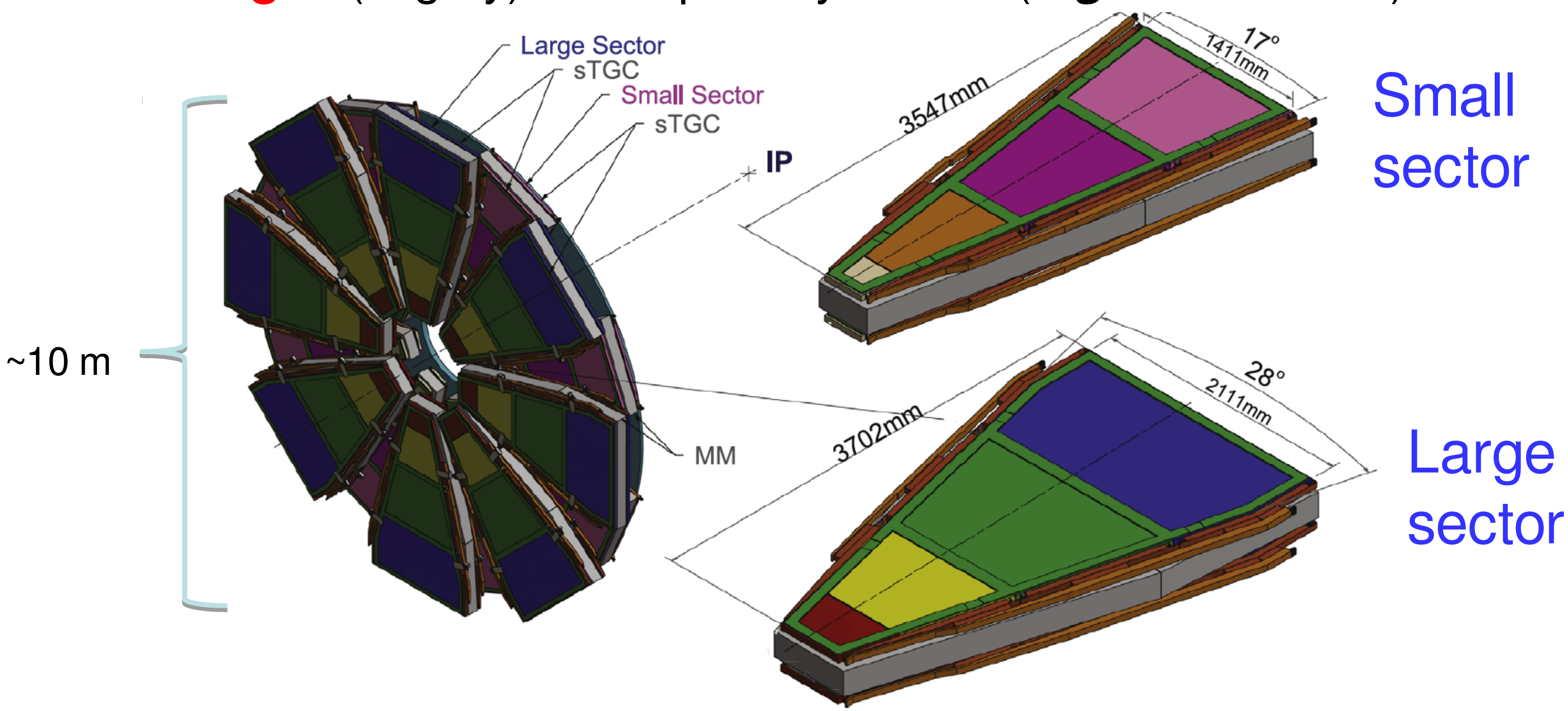
The **NSW** will simultaneously **improve tracking performance** and **reduce fake rate** by an order of magnitude

New Small Wheel Technologies

The **NSW** must provide angular resolution of <1 mrad or less to the IP, and so a spatial resolution of <100 um per layer, in <1 μs

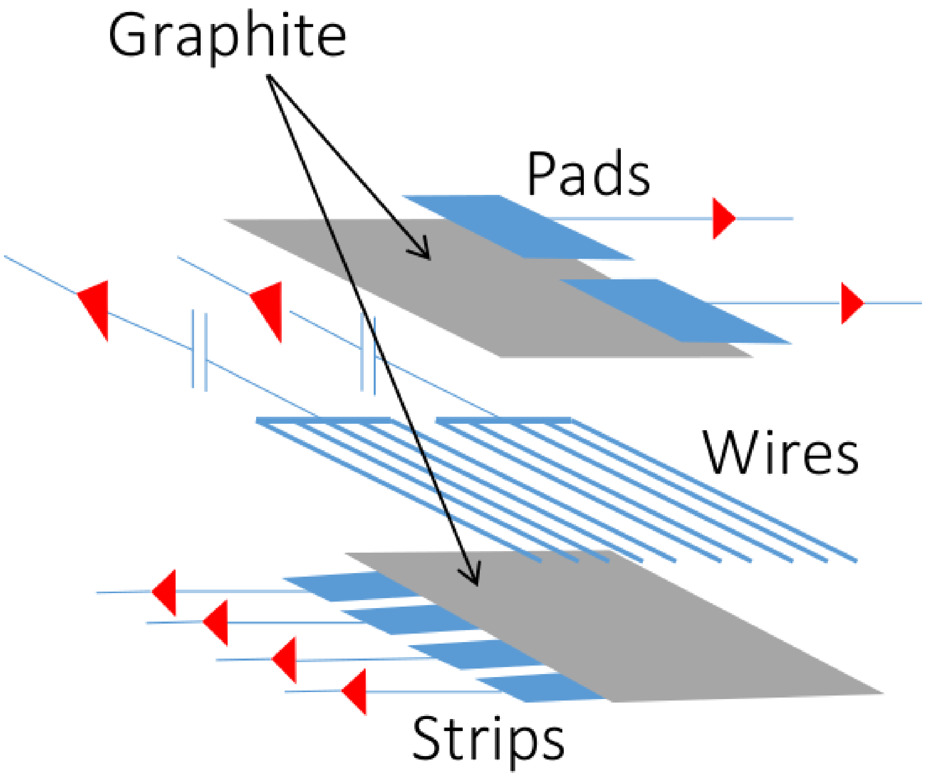
To satisfy the requirements, use two separate technologies:

1. **sTGC** (in color below) as the primary trigger (***very fast***)
2. **MicroMegas** (in grey) as the primary tracker (***high-resolution***)



sTGC's are the outer chambers → longer lever arm → **<u>better angular resolution</u>**

The small-strip Thin Gap Chamber (sTGC)



<u>Gas</u>: pentane / CO_2 (45% / 55% vol.)
2.8 mm gas gap

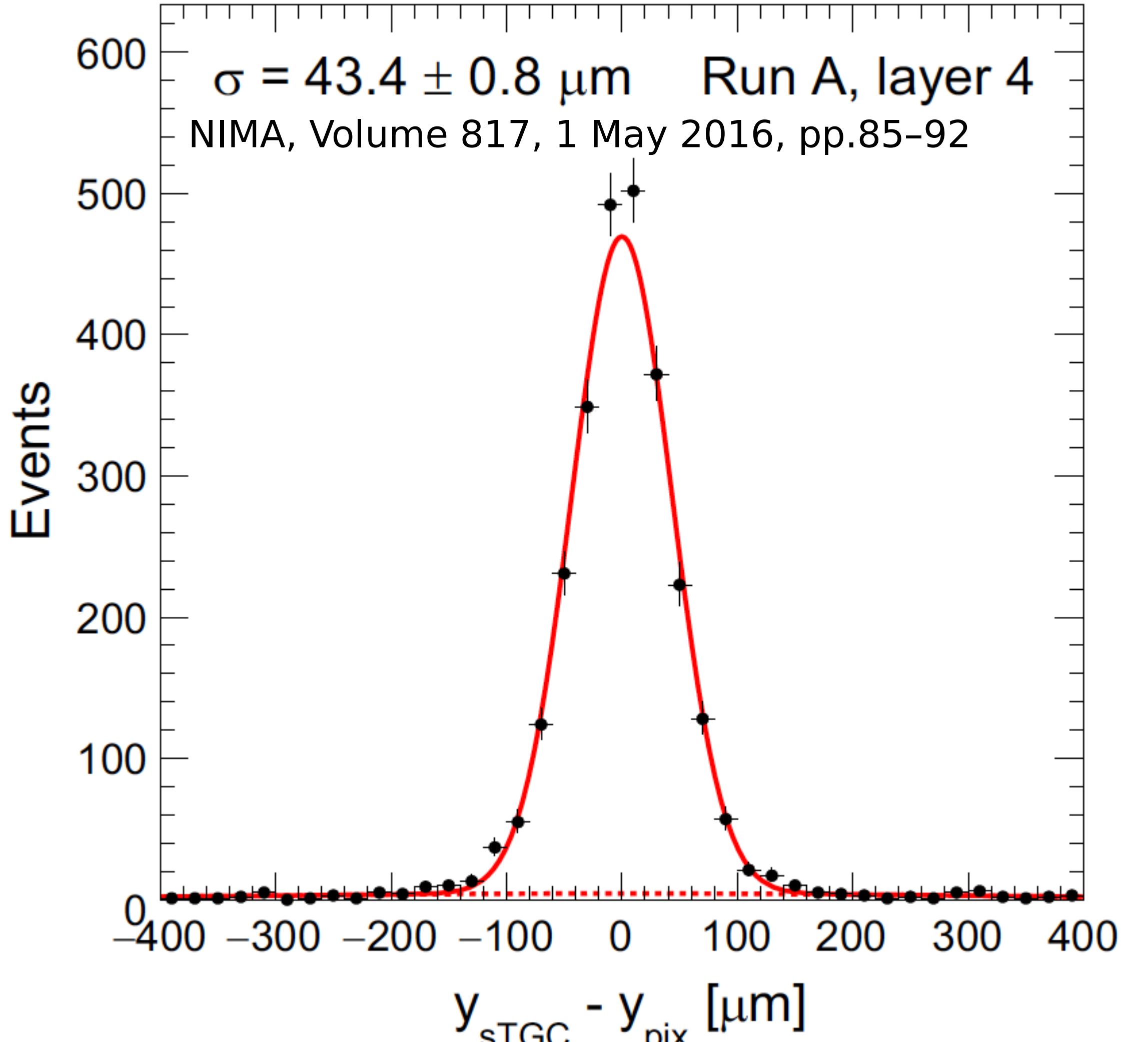
<u>Anode</u>: wires (at 2900 V) **1.8 mm** pitch
<u>Cathode</u>: pads and strips, **3.2 mm** pitch

<u>Resistive layer</u>: mitigates 10kHz/cm^2 rate protection against discharge

<u>Pads</u>: for **<u>triggering</u>** and to determine areas of interest for strip readout
<u>Strips</u>: for **<u>tracking</u>** in the precision coordinate (η)

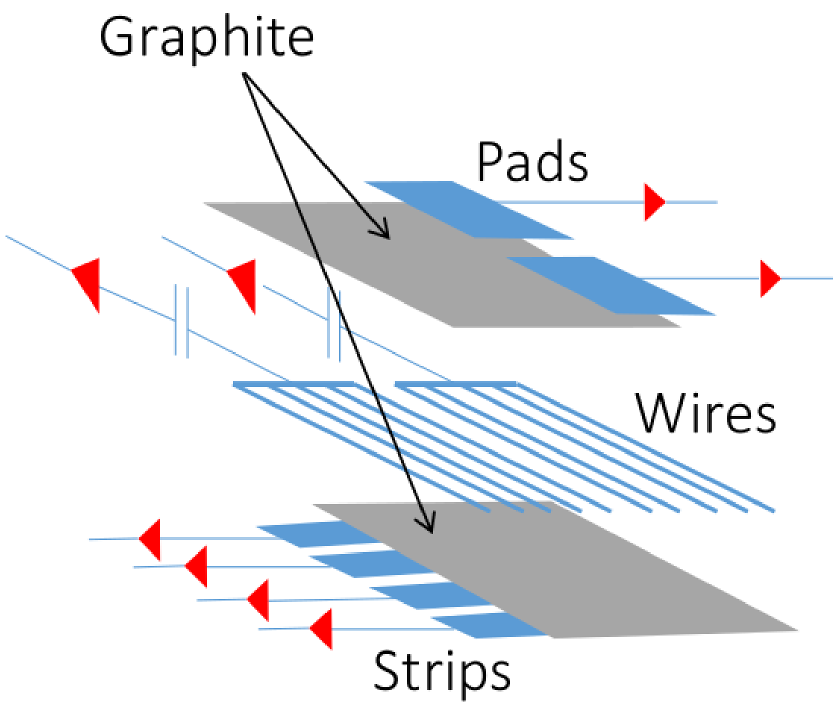
Single-hit strip spatial resolution

σ = 45 ± 8 μm All runs – All layers



Resolution determined with respect to precise pixel telescope measurements (y_{pix})

Simulation Geometry Validation



Important to have accurate geometry for digitization results to be correct

We took the approach of simulating a hit on every **pad** of every **layer**
→ Ensure that the simulation returns the correct **pad** every time

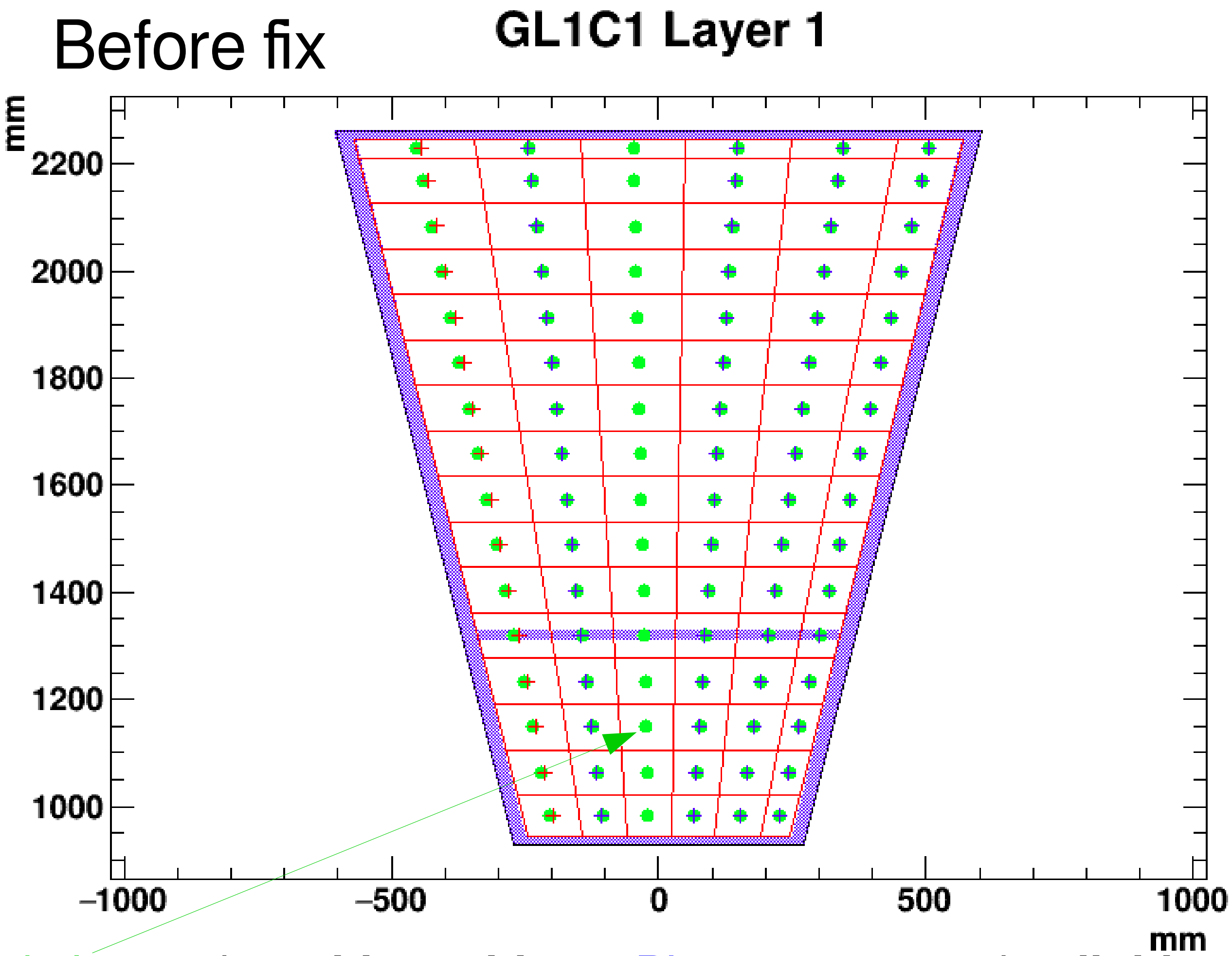
Geometry is defined by the **NSW xml**:
`MuonSpectrometer/MuonG4/NSW_Sim/trunk/data/stations.v1.73.xml`

And by the package:
`MuonReadoutGeometry-03-03-03`

Simulation Geometry Validation

Visualization of pad geometry was implemented to *understand*, *categorize* and **fix** geometry problems

Before fix

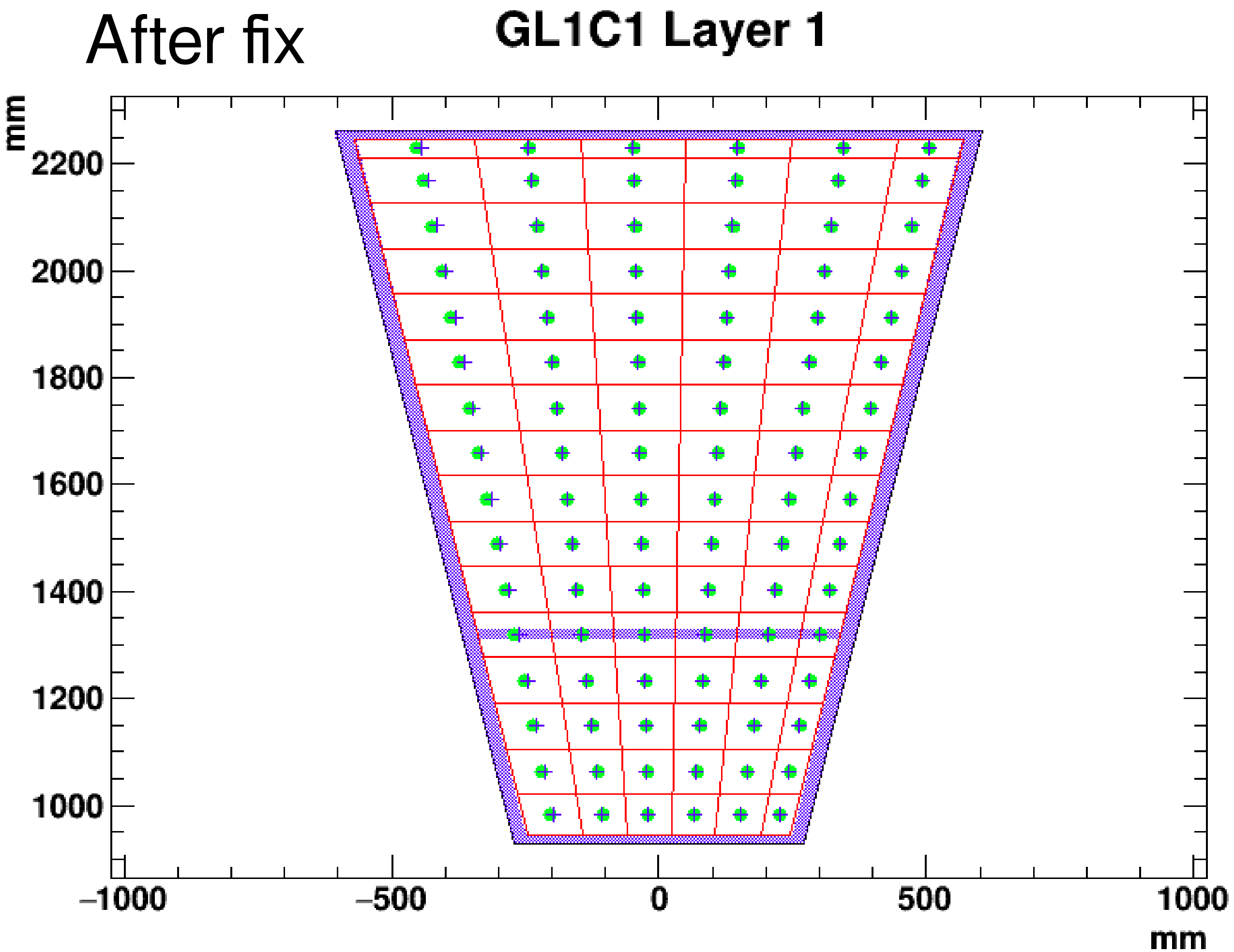


Green circles are input **hit positions**, Blue crosses are the **digitized position**, Red crosses are positions returned **more than once** (Wrong pad!)

Simulation Geometry Validation

Half of the layers were *inverted* in the geometry -> **hits created on the wrong pad**

After fix

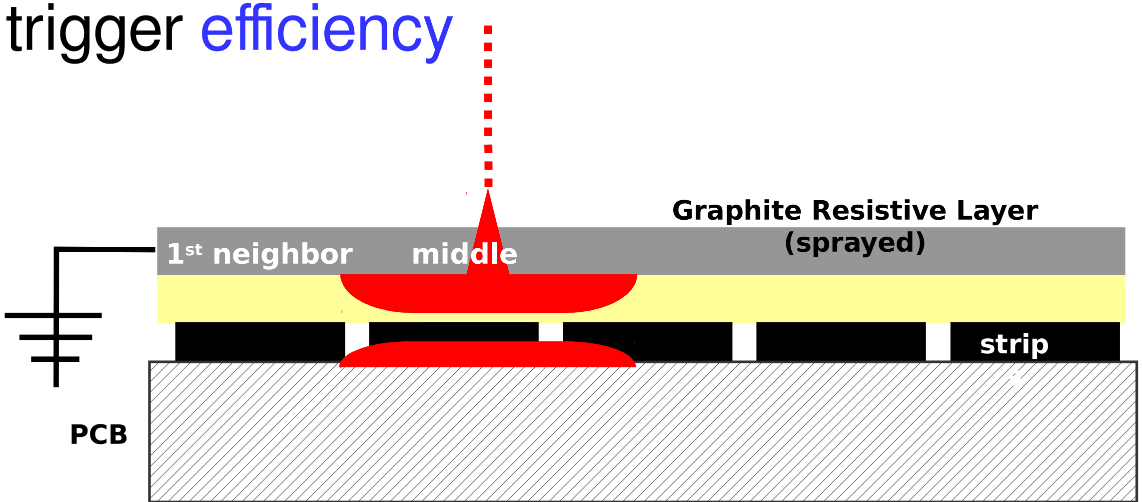


Green circles are input **hit positions**, Blue crosses are the **digitized position**

sTGC signal simulation

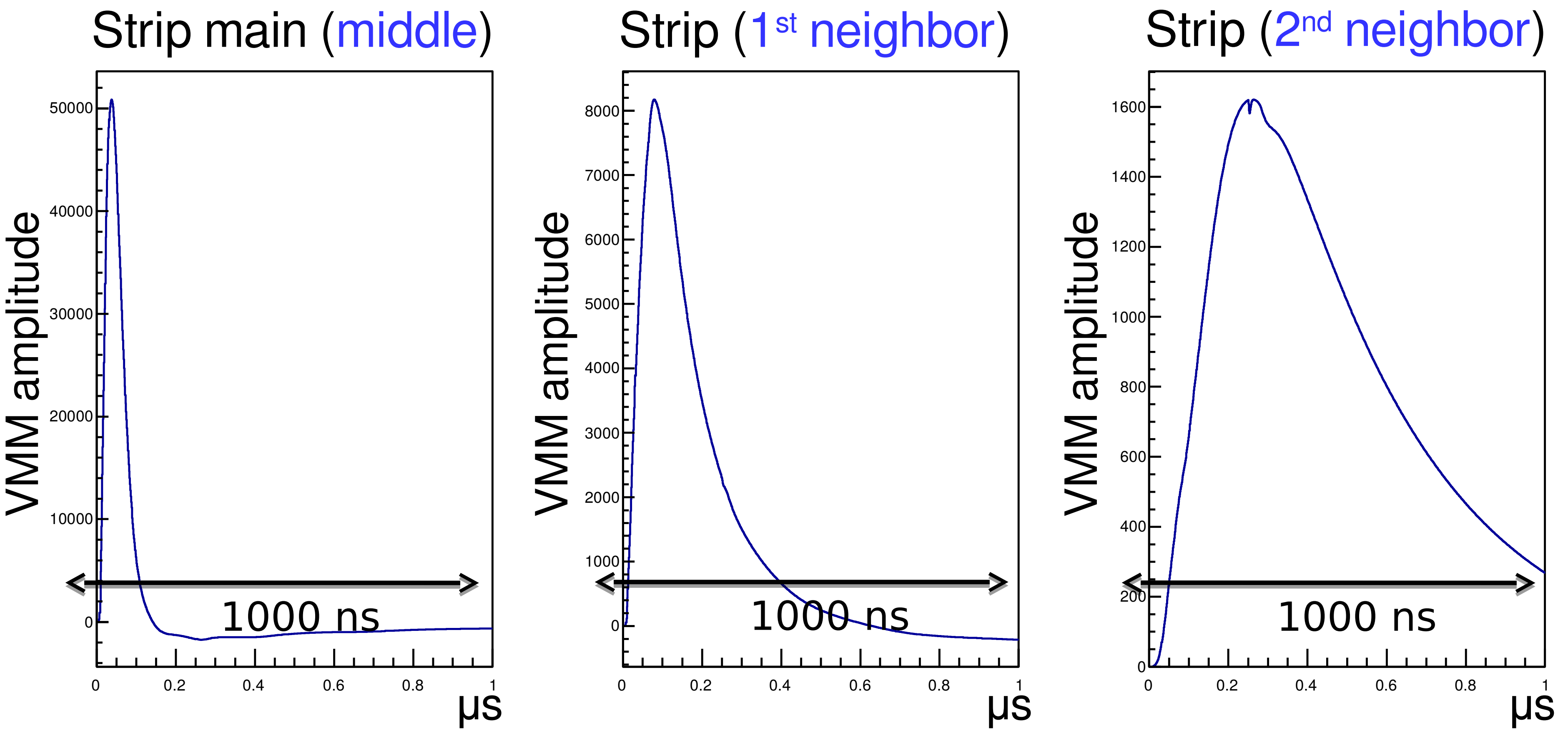
Raw induced signal $\otimes$ Resistive layer $\otimes$ Electronics response

- Simulate **full waveform** of signal on strips after the VMM readout chip
- Study of time delay associated with the **resistive layer** (carbon coating)
- Allows for **detailed** trigger simulation
- Investigate pad trigger efficiency



sTGC signal simulation

Shaped and amplified **sTGC** electronic signal versus time



The charge signal time profile is **different on each strip**

This will be reflected in the simulation

sTGC timing simulation

Need to assign BCID: detector electronics will determine which bunch crossing (BC) a digitized hit corresponds to

Start with a global hit time for Geant4 and account for several Physical timing effects:

- Time of flight (ToF) = (global hit position)/(speed of light)
- Detector Jitter (J_d): *statistical* fluctuation from **charge drift time**
- Electronic Jitter (J_e): *statistical* fluctuation of **readout electronics**
- Strip propagation time (SPT): time for signal to **propagate to the readout** down a strip

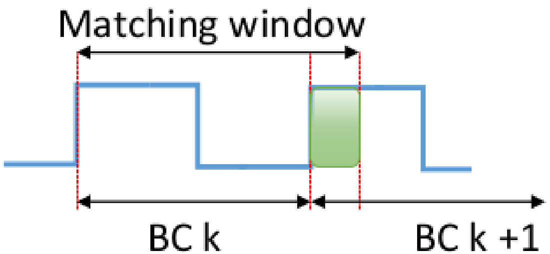
$$\text{Digit time} = \text{global hit time} - \text{ToF} + J_d + J_e + \text{SPT}$$

Then BCID is determined:

-25 ns < (Digit time) < **5** ns → **Previous BC**

0 ns < (Digit time) < **30** ns → **Current BC**

25 ns < (Digit time) < **55** ns → **Next BC**



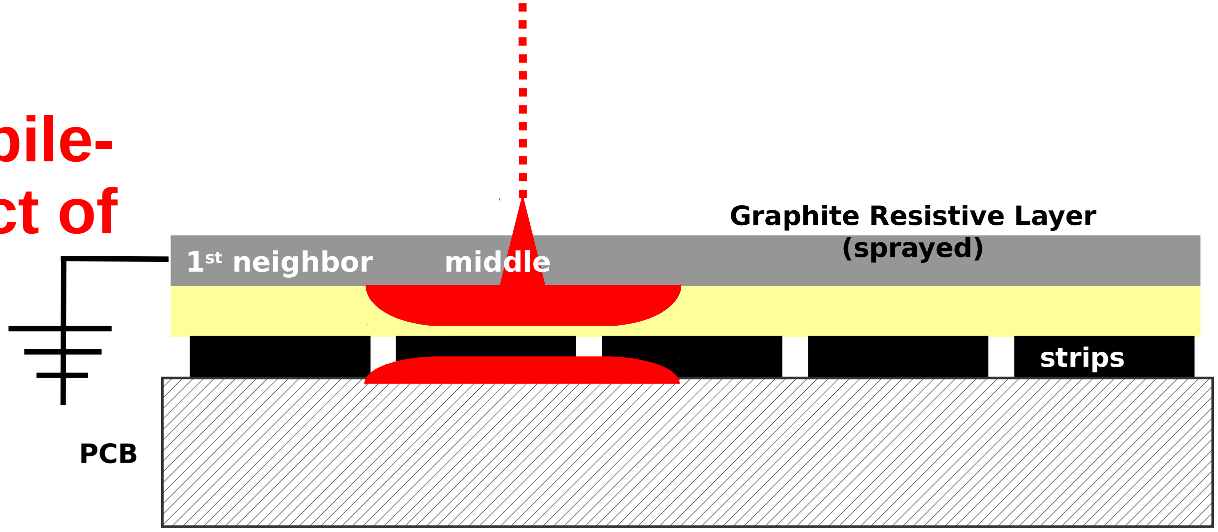
sTGC Deadtime Simulation

Hit deposited on sTGC channel

Charge is converted by ADC in VMM readout chip
Takes **~250 ns** for strip channel (precise 10 bit ADC)
~140 ns for pad channel (6 bit ADC)

2nd hit arrives within *digitization time window* -> channel is dead

Must simulate with pile-up to study the effect of this deadtime!



Pile-up Digitization

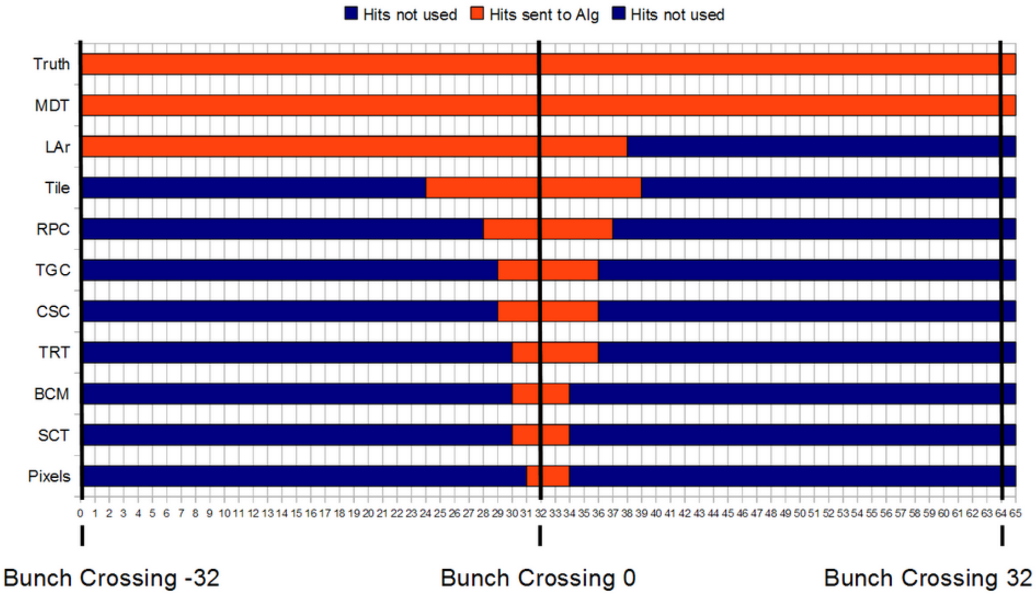
Pile-up events are sourced from separate input samples
2 types of pile-up events: **low pT** (abundant) and **high pT** (rare)

Pile-up events are included from a set number of **BC** before and after the **current BC**

For sTGC the electronics deadtime of the **strip** digitization is **~250 ns**
-> Need to consider pile-up from at least 10 BC (225 ns)

Bunch structure will affect deadtime

More time between filled bunches
-> less deadtime due to pile-up



Code for pile-up deadtime is *in place and functional*; need to determine parameters and validate

Summary and Conclusion

- LHC upgrades provide the opportunity to **really improve** our knowledge of the Higgs boson, the Standard Model and the search for new physics
- However, in its current state **ATLAS** would be unable to take **full advantage** of these opportunities
- The first full scale **sTGC** module meets the specification with single-hit spatial resolution ($\sigma = 45 \pm 8\ \mu m$)
- **sTGC** digitization simulation is underway to test whether pile-up induced electronics deadtime will be acceptable

Backup

sTGC deadtime simulation

Pad deadtime structure

80 ns | **60 ns** → **140 ns** deadtime

Time over threshold
Allows strips to be read out

Digitize pad charge
via **6 bit ADC**

Strip deadtime structure

30 ns | **220 ns** → **250 ns** deadtime

Strip signal peaking time

Digitize strip charge
via **10 bit ADC**

Neighbor on mode will add another strip on each end of the cluster
Strips activated by **neighbor on mode** will be dead for ~250 ns as well

Neighboring strip channels will be delayed, time for the charge to diffuse in the resistive layer → **longer deadtime**

Pile-up event rate in HL-LHC

Rough estimation:

Inelastic cross section assumed: 70 mb

HL-LHC luminosity assumed: 7.0×10^{34} Hz/cm^2

Event rate = Luminosity * Cross section.

→ $(70\times10^{-27}\,\text{cm}^2) \times (7.0\times10^{34}\,\text{Hz/cm}^2) = 4900$ MHz

Head-on meetings between bunches at every collision point occur every 25 ns → 40 MHz

But, the entire ring is not filled with bunches

<crossing rate> = number of bunches × revolution frequency =

$2808 \times (3\times10^{8}\,\text{m/s}) / (26.73\times10^{3}\,\text{m}) = 31.5\,\text{MHz} = 1/(31.7\,\text{ns})$

Thus, the average bunch spacing in the LHC in real life is ~32 ns

(4900 MHz/31.5 MHz) ≈ **160 events per bunch crossing**