Silicon Sensor Simulation in the LHCb Monte Carlo Framework

Tomasz Szumlak on **behalf of the LHCb Collaboration**

Radiation effects at the LHC experiments and impact on operation and performance
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Outline

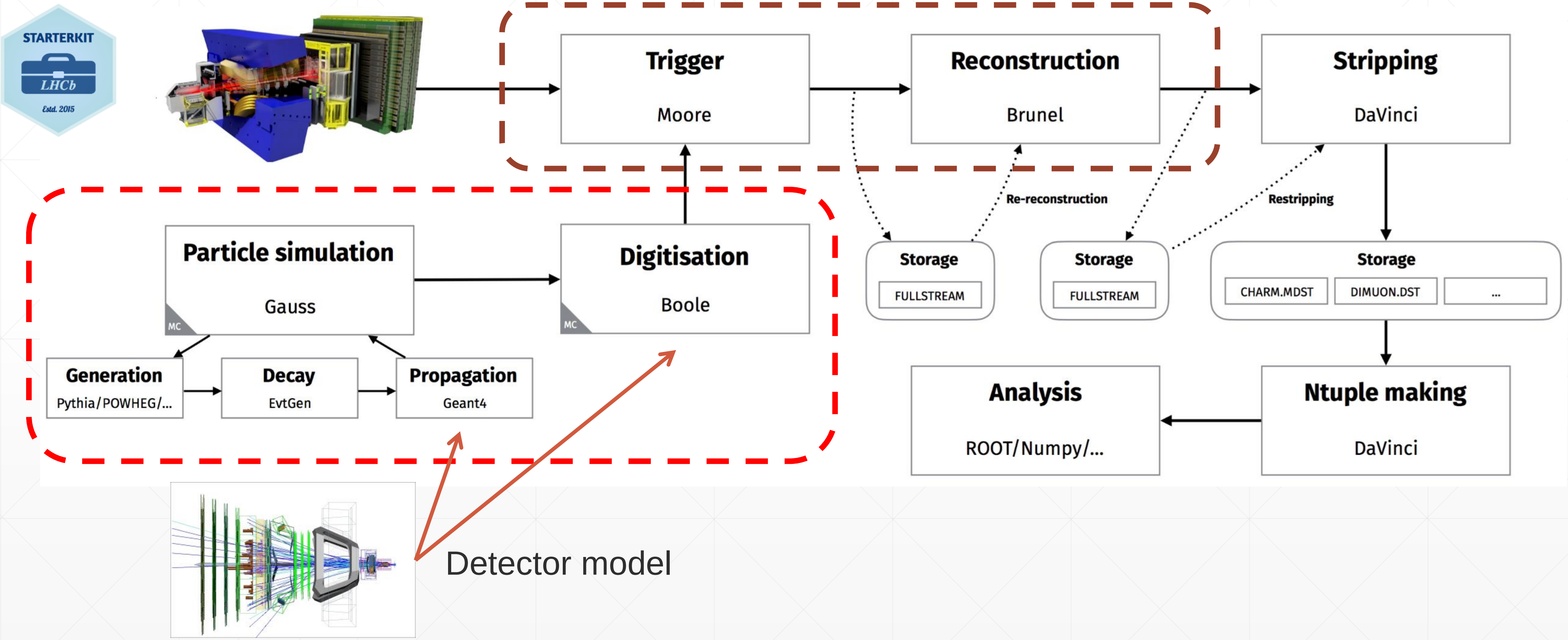
- Current silicon response simulation framework
- Tell1 (Trigger Electronics Level 1) electronics readout board emulation
- Silicon simulation for the upgraded detectors

A general overview

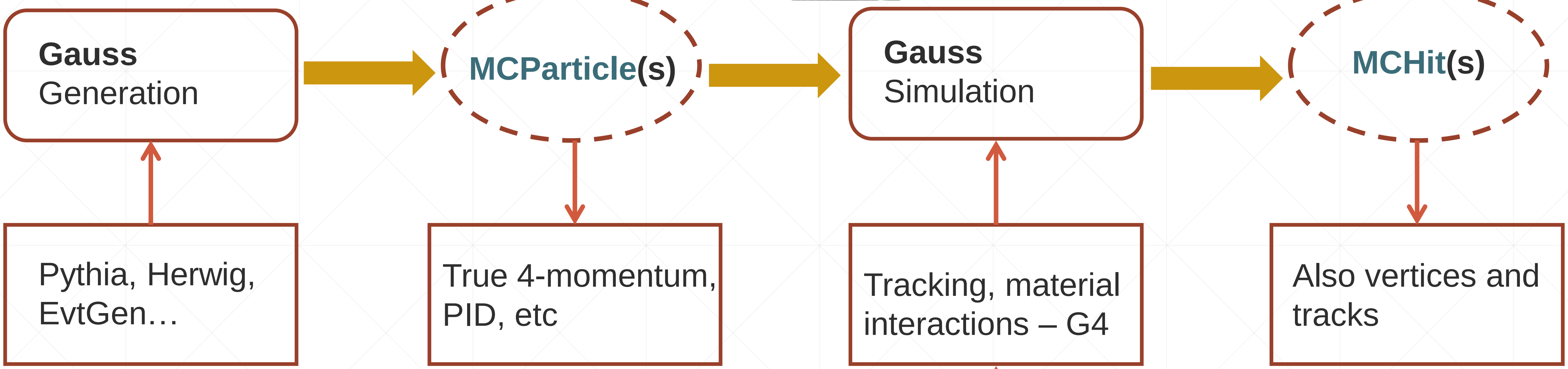
- Profiting from the fact that all of the tracking detectors are micro-strip ones and readout by the same ASIC we provided a common framework for silicon simulation within LHCb
- The overall idea of the deposited charge (Geant4) distribution within the silicon bulk is the same
- Common code to model the Beetle readout chip response using dedicated configurations to evaluate detector specific front-end response pulse shapes
- Very similar digitisation code (analogue to digital)
- Due to different granularity and geometry the clusterisation is the most distinct part of the whole procedure
- Packing the clusters into RawBank follows again the same pattern

LHCb Software Suite

Real detector



Simulation Software Suite



Gauss
Generation

MCParticle(s)

Gauss
Simulation

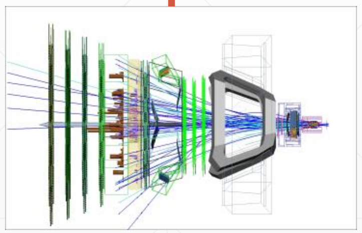
MCHit(s)

Pythia, Herwig, EvtGen…

True 4-momentum, PID, etc

Tracking, material interactions – G4

Also vertices and tracks



- **First part of the simulation**
  - „Generate” physics (**MCParticles**)
  - Use detailed detector description (geometry and materials) to trace generated particles
  - At the end we obtain **MCHits**, **MCVertices** etc. These are used to emulate detector response

Simulation Software Suite

MCHit(s)

Boole
Det Response

VELO – distribute G4 charge within sensors

Full DAQ board emulation

Process MC data the same way the real are processed

RawBuffer

„Reconstructed" clusters

Moore/Brunel
Trigger/Tracking

- ☐ **Second part of the simulation**
  - Use „true" hits to simulate detector response
  - Read-out electronics (**Beetle**)
  - DAQ board (**Tell1**)
  - RawBuffer with structure identical to the real detector output

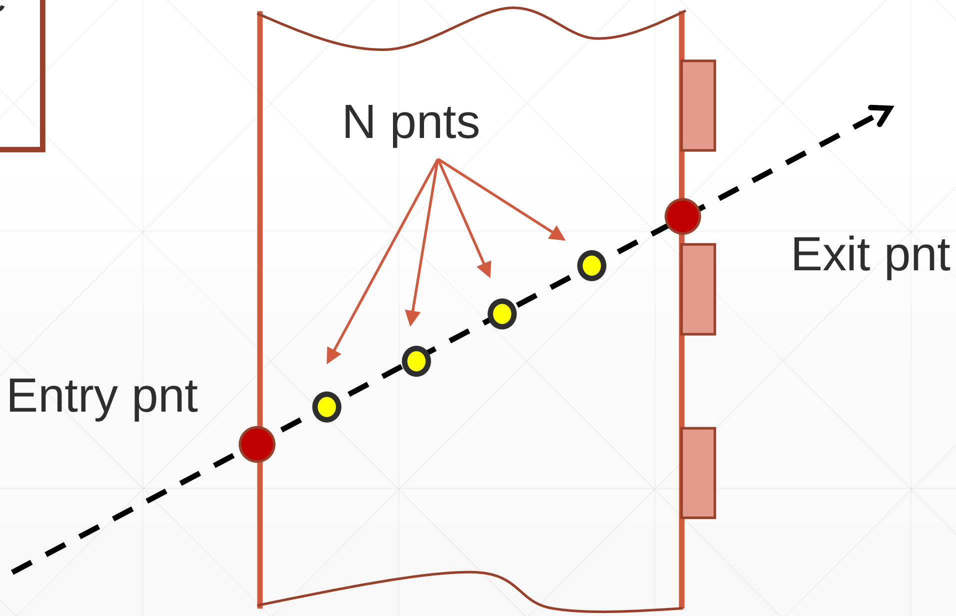
Front end response (analogue signal)

Boole
Det Response

VELO – distribute G4 charge within sensors

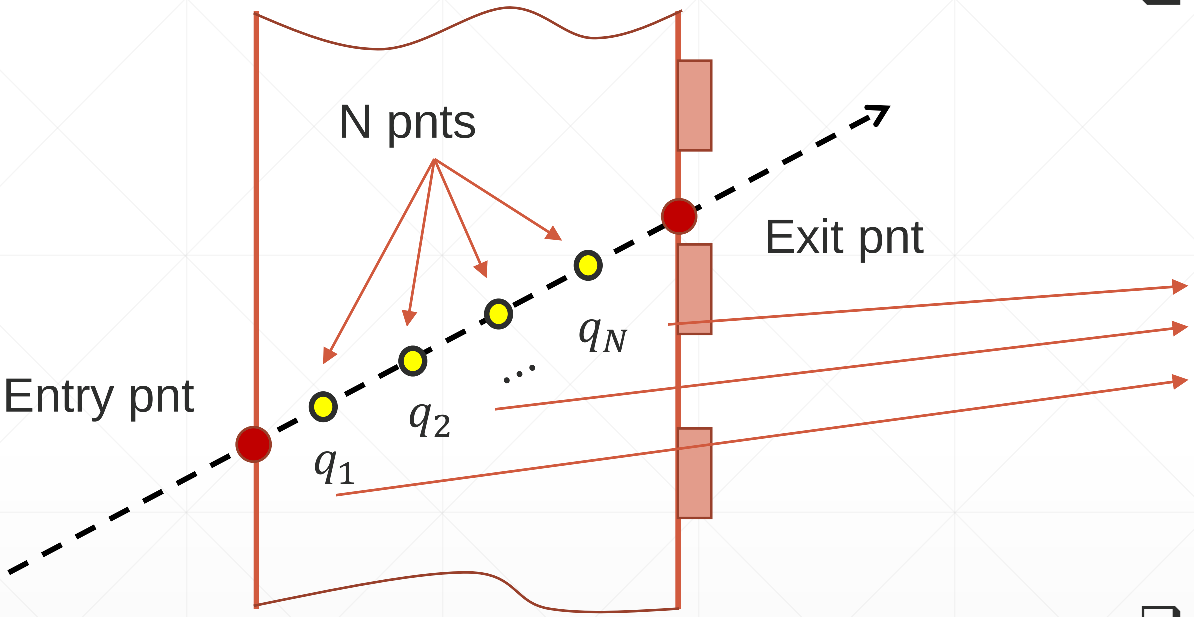
MCHits for each studied BX (SO)

Distribute the charge in silicon bulk using MCHit



- First step is to distribute the deposited charge given by the MCHit objects
- Calculate the distance (in strip pitch) between entry and exit points
- Calculate the number of points where the charge will be distributed (there is a max number of steps per strip)

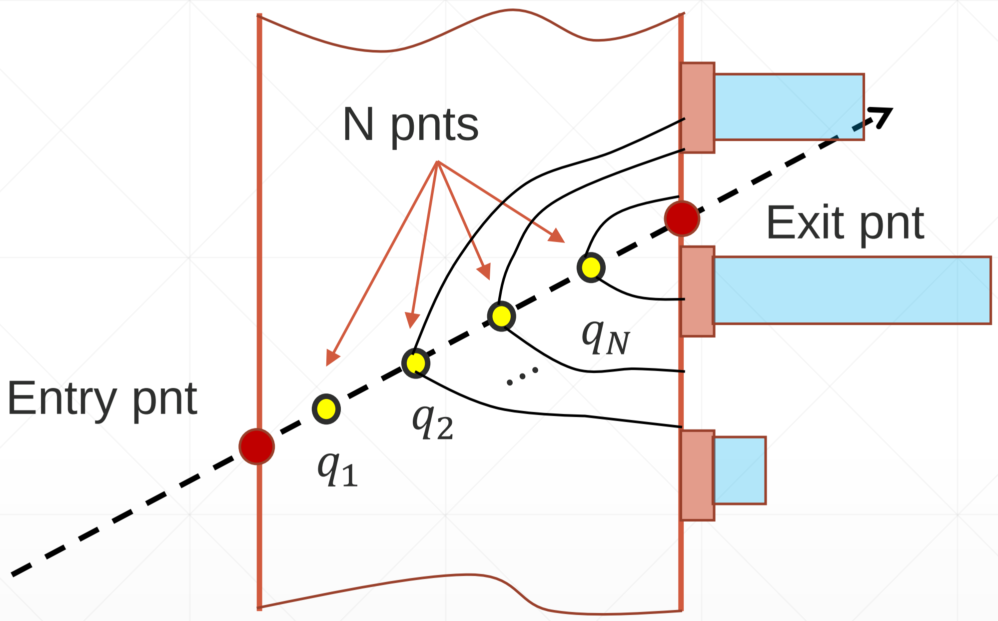
Front end response (analogue signal)



- Starting with generated total charge taken from G4 generated deposit, at each point we allocate partial charge that has three components:
  - Uniform component (the same value for each point)
  - Random component drawn from a normal distribution
  - δ ray generation
- Generated charge normalisation to the total deposited energy at the end to avoid anomalus events

- **At this level, if requested we can use the radiation damage tool to simulate CCE loss and DML charge leakage**

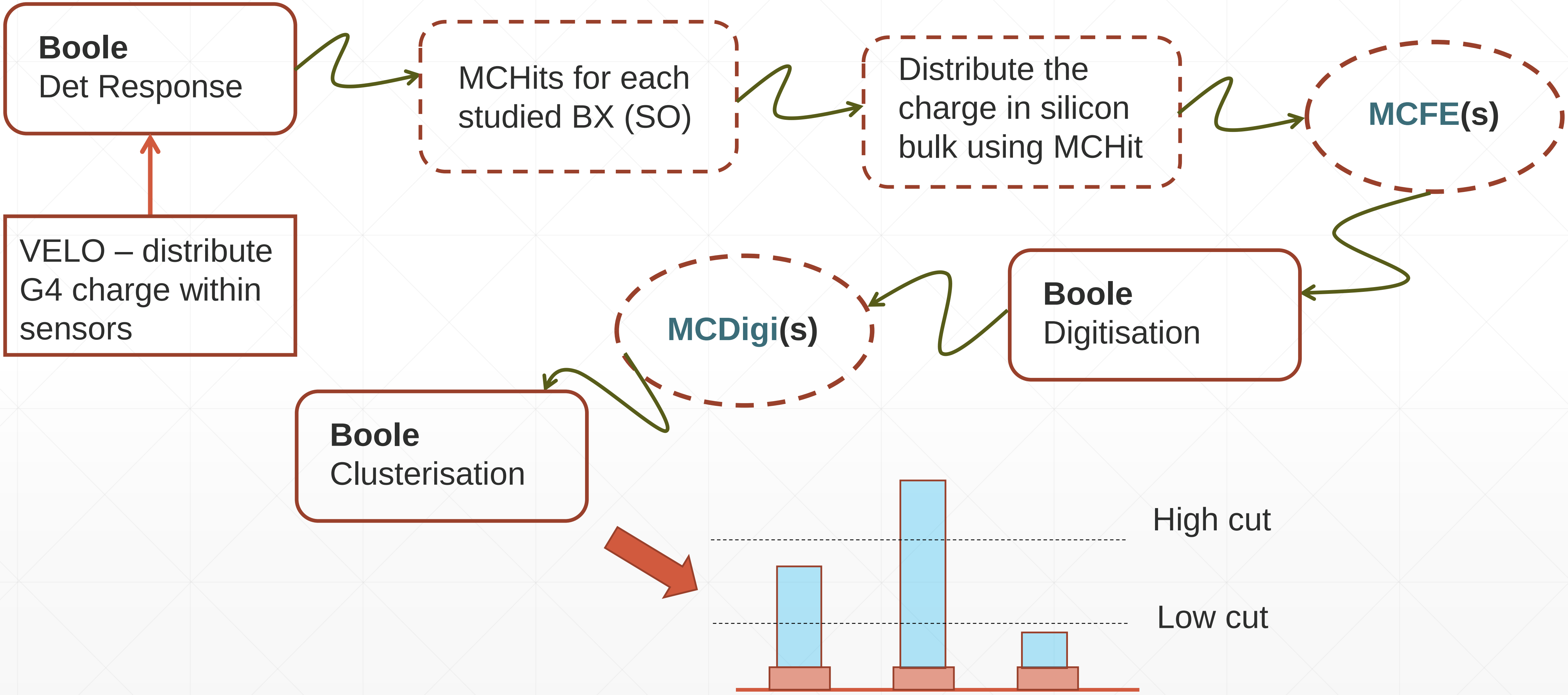
Front end response (analogue signal)



- ☐ Diffusion simulation
- ☐ Use **gaussian smearing** to calculate collected charge on strips
- ☐ If simulating radiation damage the „normal" diffusion can be scaled
- ☐ Introduce **capacitive coupling** (strip x-talk)
- ☐ Add **noise** taken from data
- ☐ If the **spill-over** is simulated repeat that whole procedure and use Beetle response tool to figure out the charge reminder

- ☐ Now we have front-end analogue signals (MCFE) that can be digitised

Detector Model



Boole
Det Response

VELO – distribute G4 charge within sensors

MCHits for each studied BX (SO)

Distribute the charge in silicon bulk using MCHit

MCFE(s)

Boole
Digitisation

MCDigi(s)

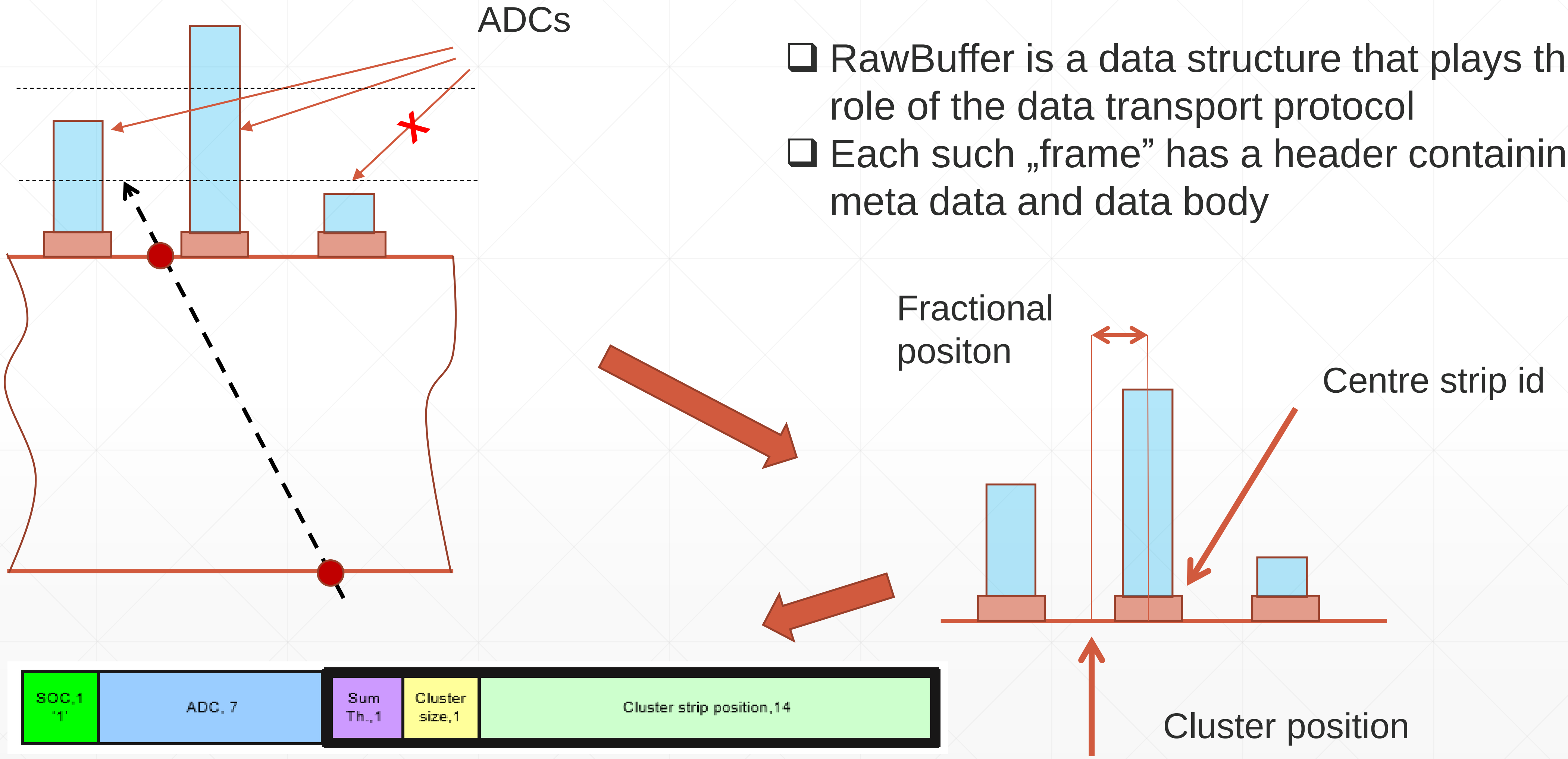
Boole
Clusterisation

Clusterisation

- Complicated geometry and relatively high granularity make this process quite complicated for the Velo
- For these reasons the emulation code was partially ported to simulation s/w
- We use bit-perfect high level code that corresponds to the VDL machine code: reordering, zero-suppression and clusterisation
- Configuration is also taken from the calibration data stream: noise, threshold level, problematic channels

Raw buffer – beyond is only trigger…

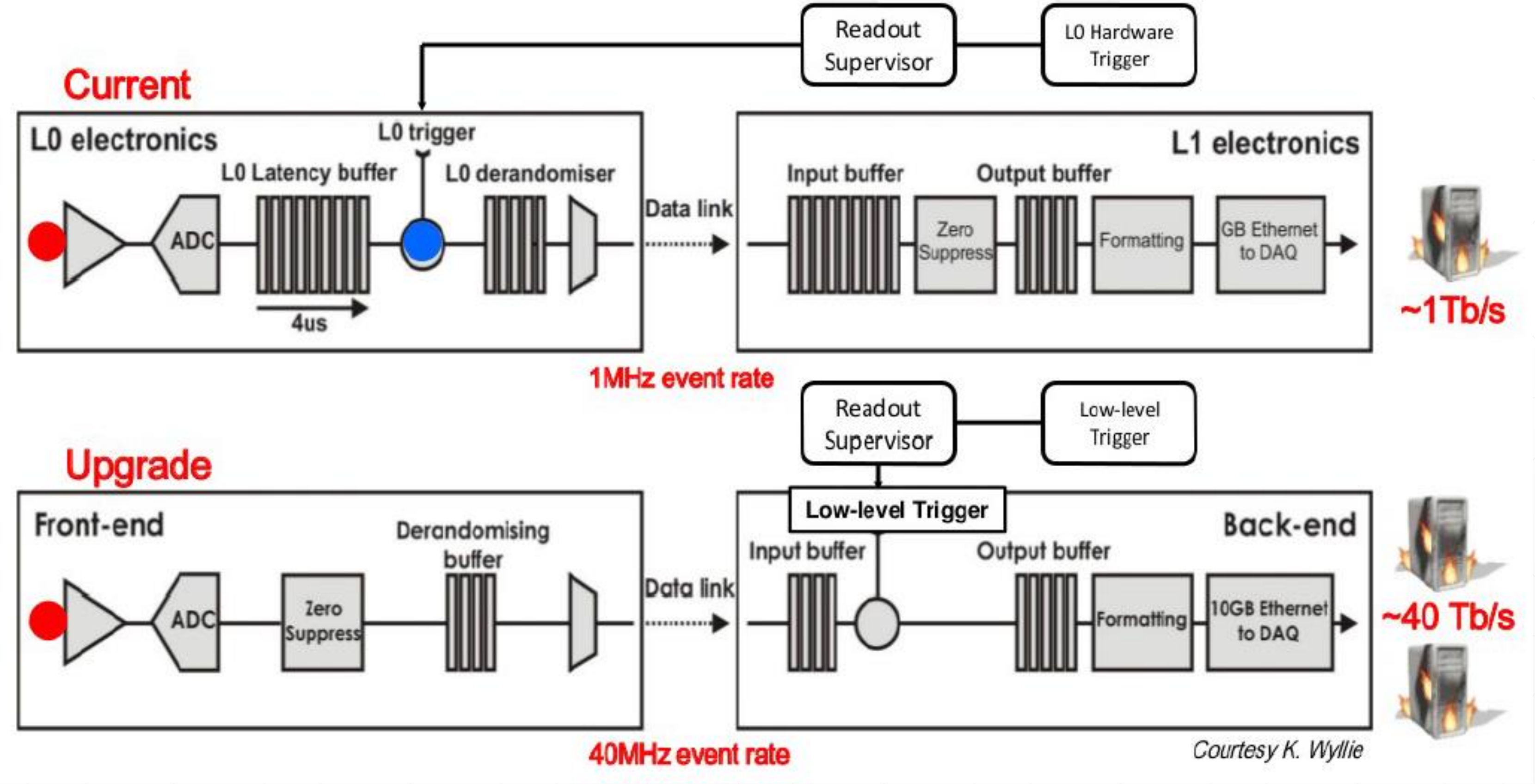
- ❑ RawBuffer is a data structure that plays the role of the data transport protocol
- ❑ Each such „frame” has a header containing meta data and data body



SOC,1 '1'	ADC, 7	Sum Th.,1	Cluster size,1	Cluster strip position,14

Upgrade

- ❑Trigger-less
- ❑ Sends out data with the machine frequency
- ❑ On chip zero-suppression (SoC)



Courtesy K. Wyllie

Silicon simulation and digitisation

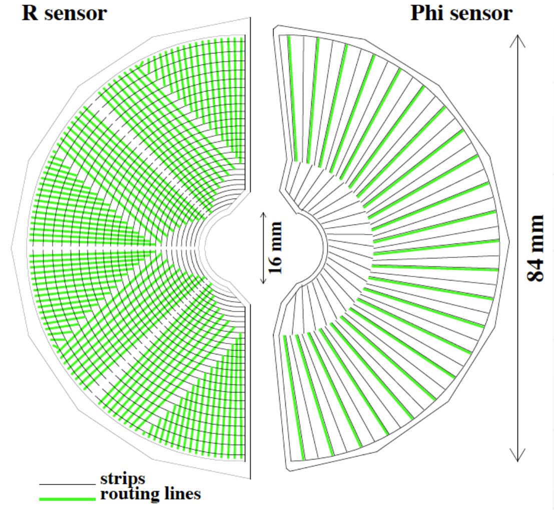
- The overall idea very similar to the current s/w – use MCHits to distribute charge, include noise, couplings, radiation damage
- Analogue to digital conversion using test beam results
- VELO pixel – the output RawBuffer contains time ordered super-pixels that are going to be further processed by HLT (High Level Trigge)
- Upstream Tracker – the output RawBuffer contains zero-suppressed data that going to be spill-over corrected and clustered in HLT

Conclusions

- ❑ We use Pythia8/Geant4 to get hits and deposited energy (need also detector model)
- ❑ Simplified energy deposition in bulk and detailed information regarding total noise, readout electronics response, sensor x-talk, etc.
- ❑ Introduce radiation damage induced effects at this level (CCE, double metal layer, resolution)
- ❑ Similar approach for the upgrade (different detectors, different output format and further processing)

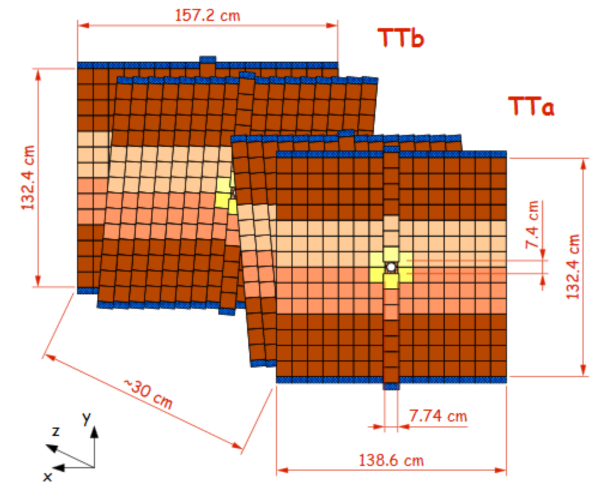
Current VELO

- Silicon (n^+-on-n) micro-strip detectors
- 2x21 planes (R and ϕ)
- Floating pitch: $\sim 40 - 100\ \mu m$, thickness: $300\ \mu m$
- ~180 000 readout channels
- Total silicon area $\sim 0.32\ m^2$
- Detectors operate at $-8^o\ C$



Current TT

- Silicon (p-on-n) micro-strip detectors
- Four planes $(0^o, +5^o, -5^o, 0^o)$
- Pitch: $183\ \mu m$, thickness: $500\ \mu m$
- Long readout strips (up to $37\ cm$)
- ~143 000 readout channels
- Total silicon area $\sim 8\ m^2$
- Detectors operate at $5^o\ C$



Current IT

- Silicon (p-on-n) micro-strip detectors
- Four boxes and four planes $(0^o, +5^o, -5^o, 0^o)$
- Pitch: $198\ \mu m$, thickness: $320\ \mu m$ and $410\ \mu m$
- ~130 000 readout channels
- Total silicon area $\sim 4.2\ m^2$
- Detectors operate at $5^o\ C$