# Update on CLICpix planar-sensor assembly simulations

# - Simulation of the readout -

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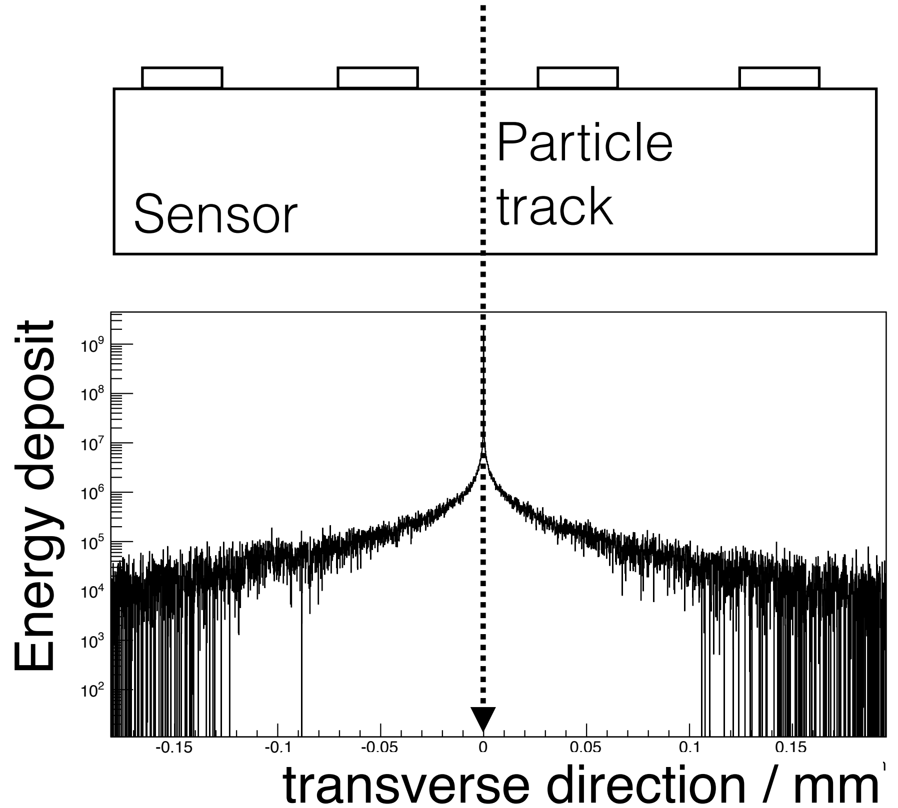
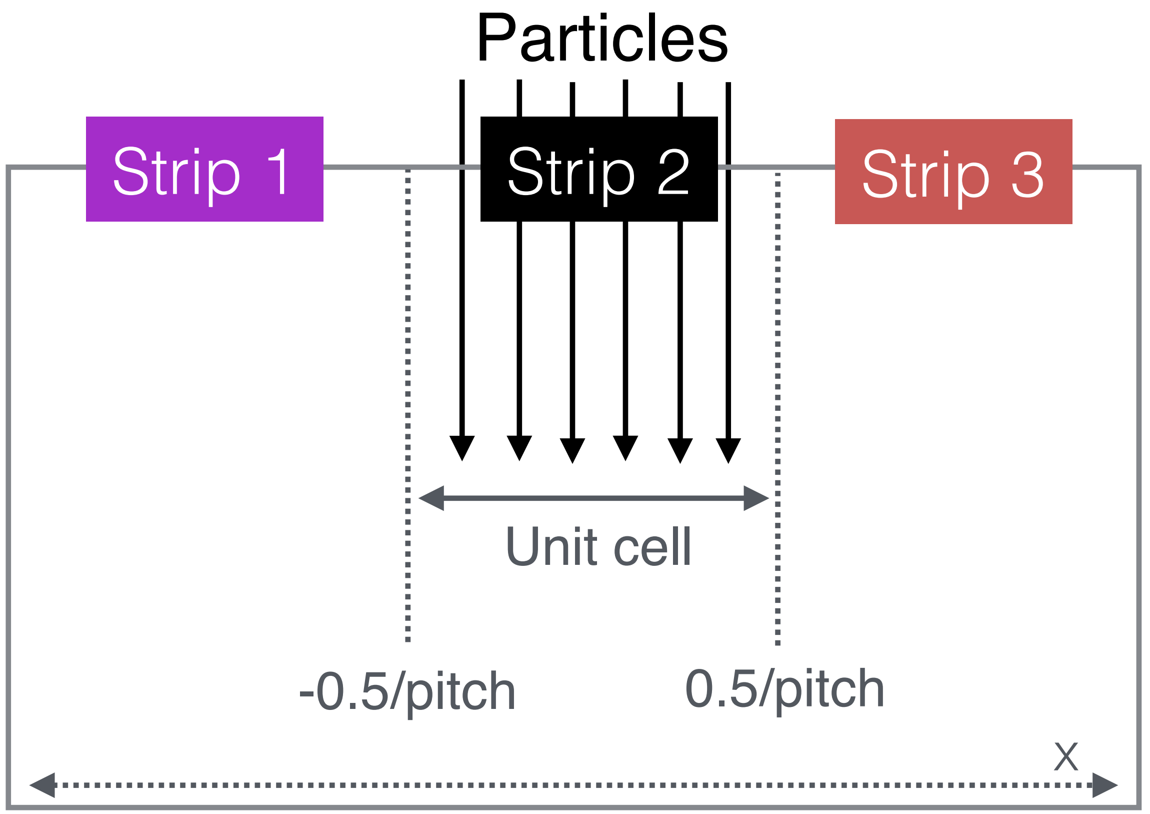
# The simulation in a nutshell

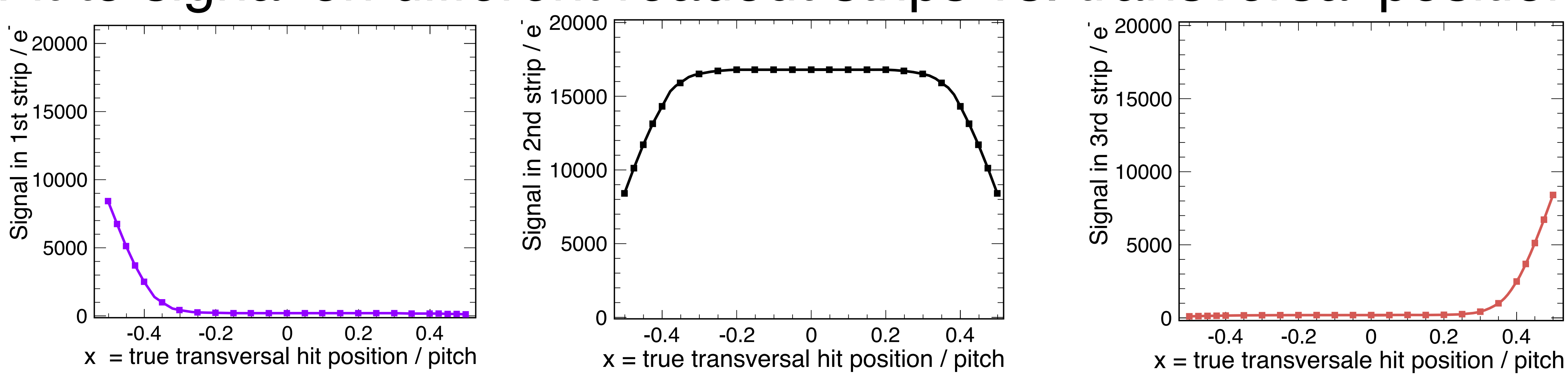
GEANT4 simulation of energy deposit in silicon sensor:




Finite element simulation of sensor with T-CAD:

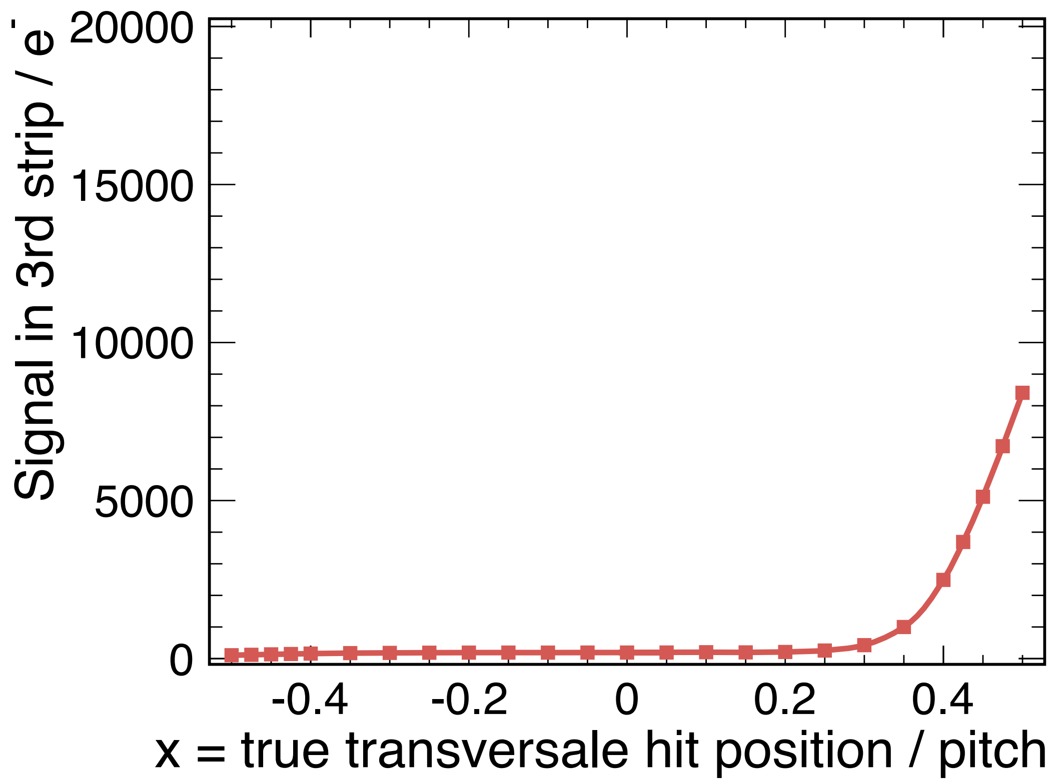



Fit to signal on different readout strips vs. transversal position x:



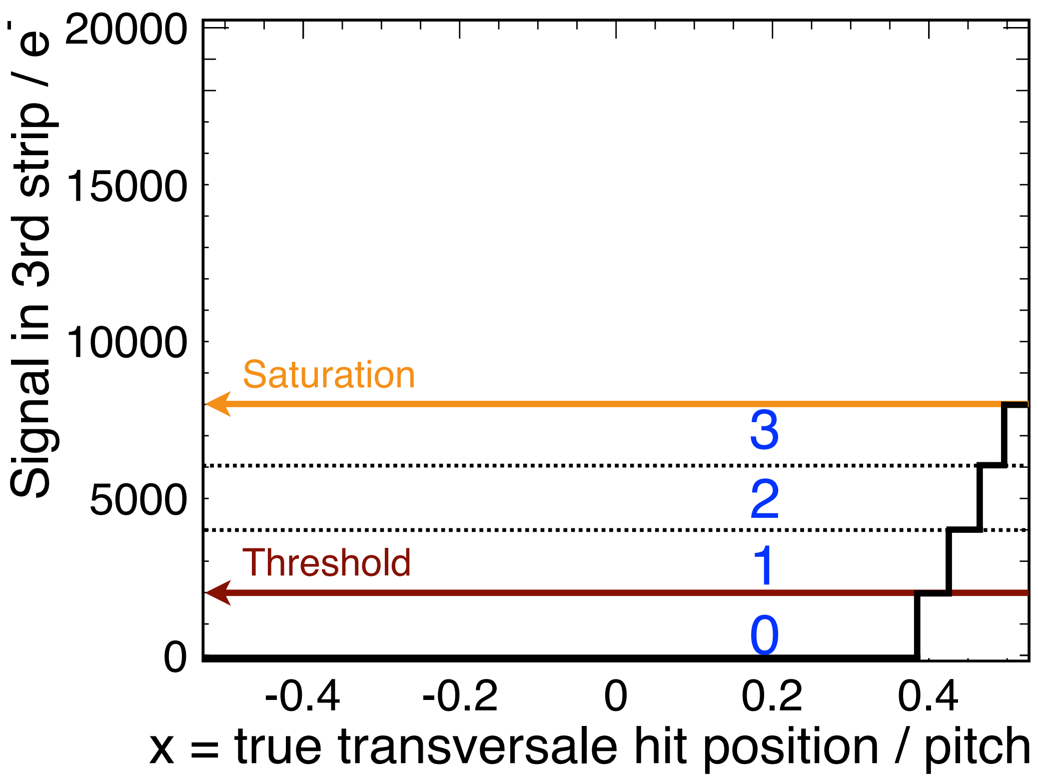
# Digitalisation / implementation in the simulation

Analog information, interpolation of signal:




Digitali- sation

Example of digitalisation with 2 bits (4 bit states):




- Apply threshold
- Define saturation
- Define number of bits
- Equally spacing of bit states between threshold and saturation

3 parameters:

- Threshold
- Saturation
- Number of bits

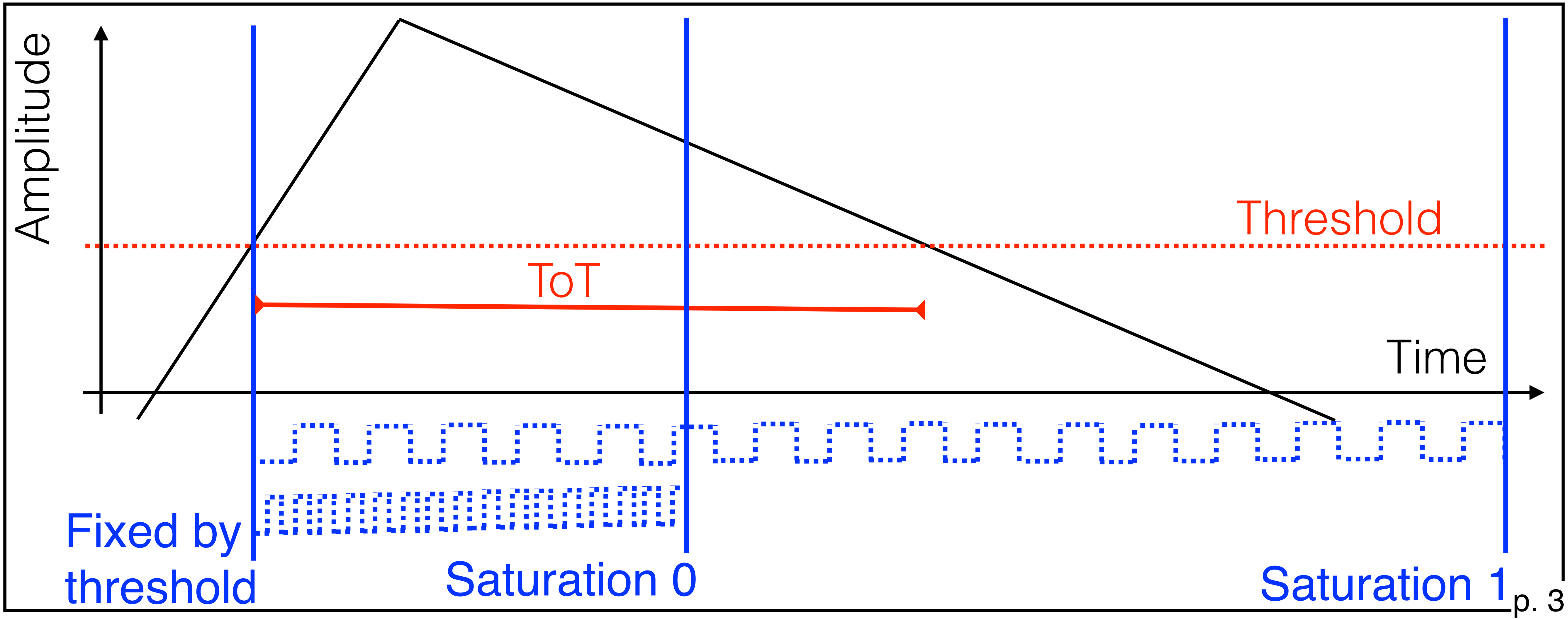
# Digitalisation / CLICpix test-beam data

- Data recorded during test-beam period in August 2015 at SPS with CLICpix planar-sensors of 200 μm thickness

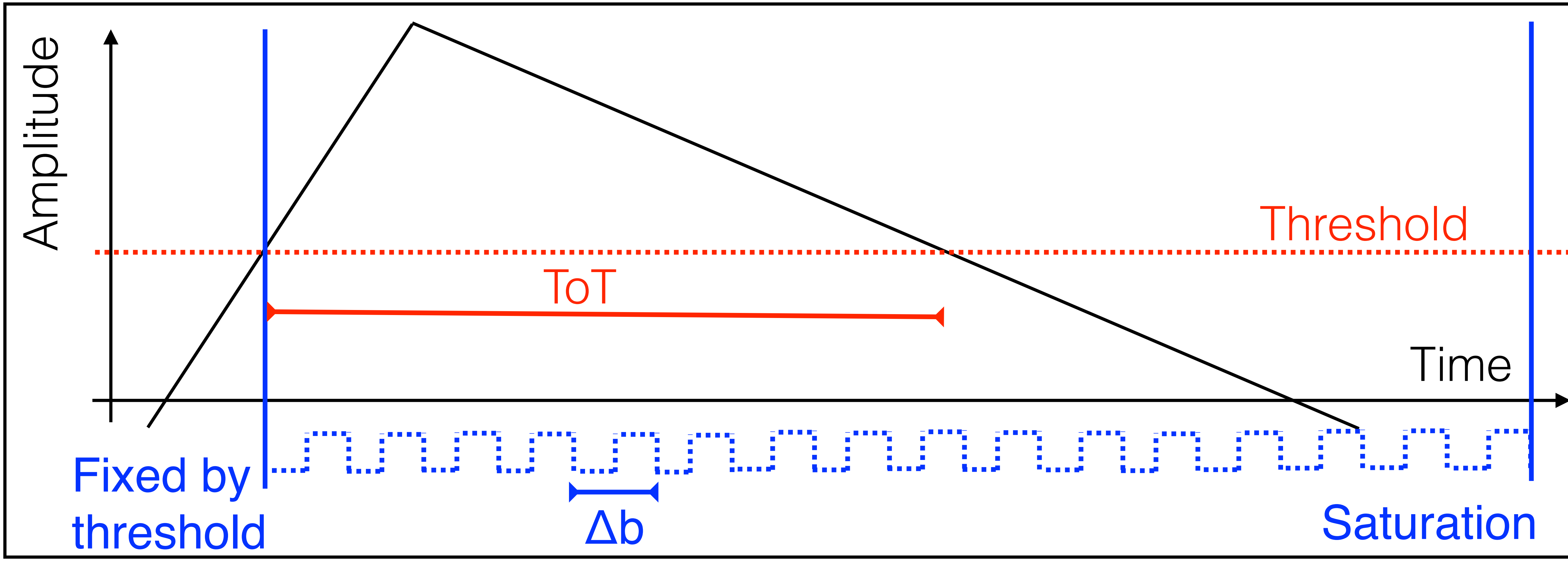
- 200 MHz clock, ToT-readout

→ **Frequency = 200 MHz / (clock-division + 1)**

→ Scan of clock-division during data taking corresponds to **shift of saturation and precision due to fixed number of 4 bits**:



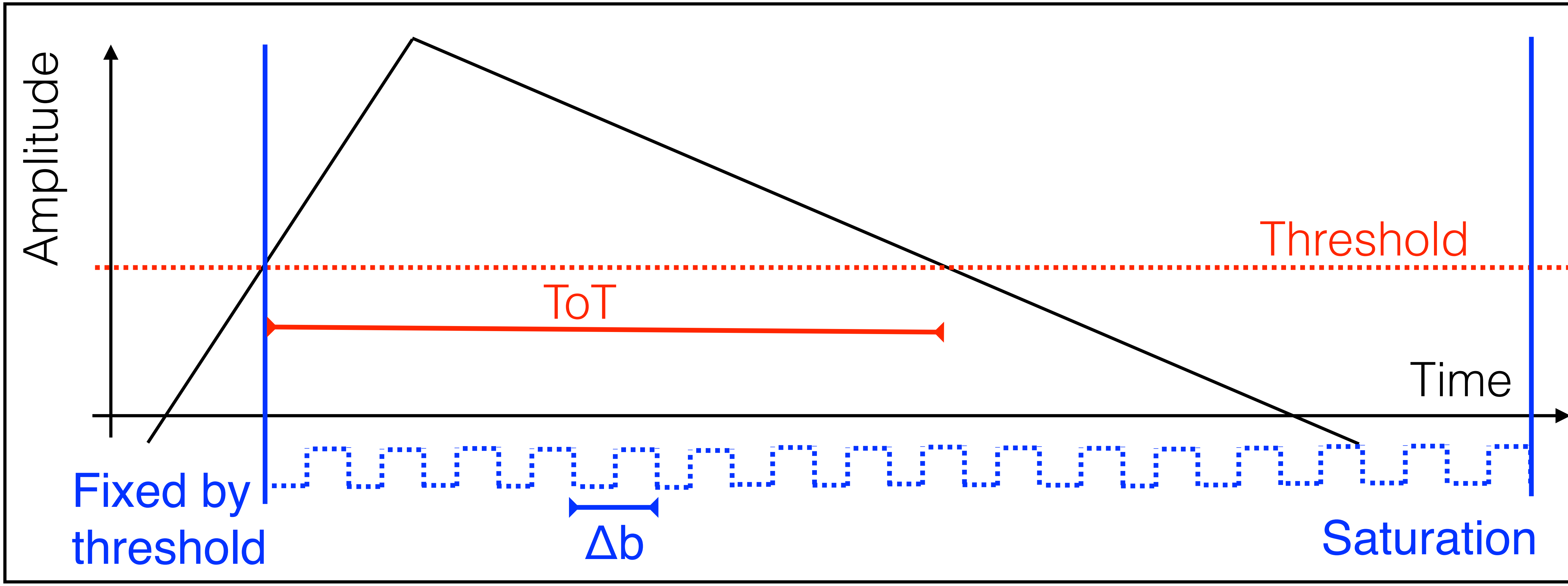
# Digitalisation / comparison of CLICpix data to simulation




Need to convert the clock-division factor to an electron scale to compare clock-scan to simulation:

- Landau of cluster signal in units of Δb
- Select clock-division of 20 which does not saturate the signal
- Fit Landau ⊗ Gauss ➝ MPV [Δb(clock-division=20)]

# Digitalisation / comparison of CLICpix data to simulation



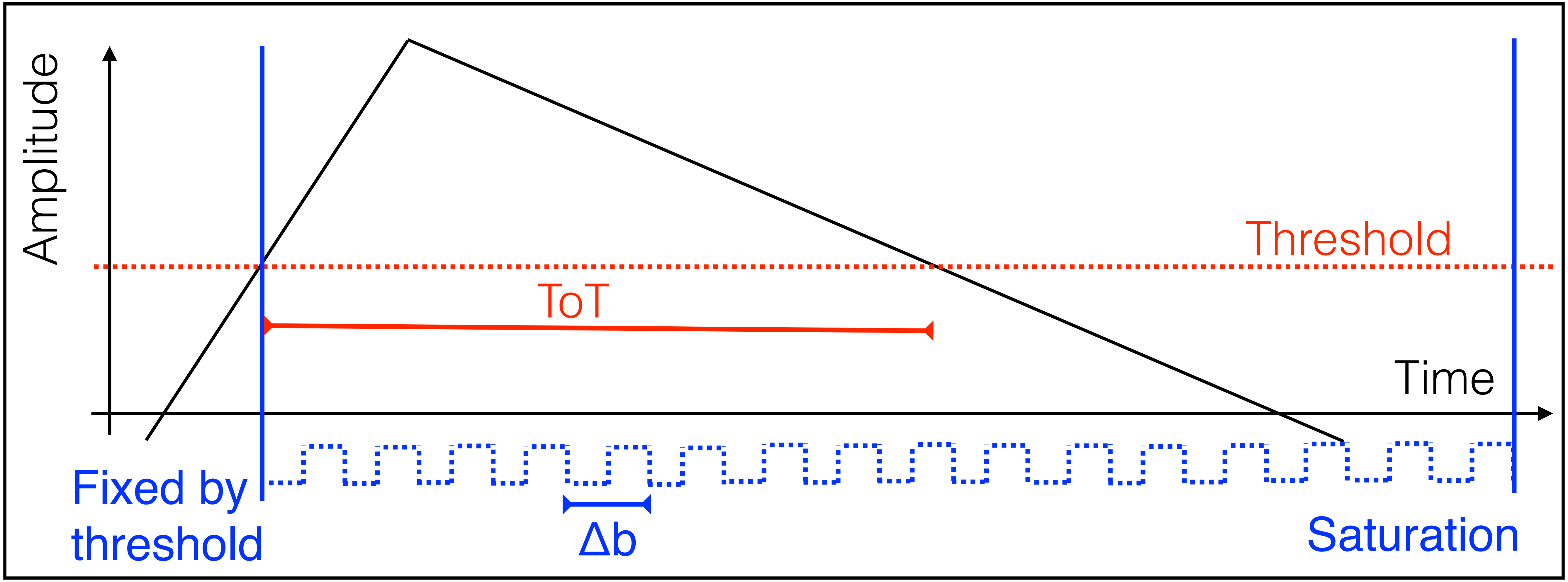

- Fit Landau ⊗ Gauss → MPV [Δb(clock-division = 20)]
- Sensor thickness of 200 μm → MPV [Δb(clock-division = 20)] = 16000 $e^-$

→ Δb(clock-division = 20) [$e^-$ ] = 16000 $e^-$ / MPV

→ Fixed number of 4 bits:

Saturation(clock-division = 20) [$e^-$ ] = $2^4$ x Δb(clock-division = 20) [$e^-$ ]

# Digitalisation / comparison of CLICpix data to simulation




For arbitrary clock-division:

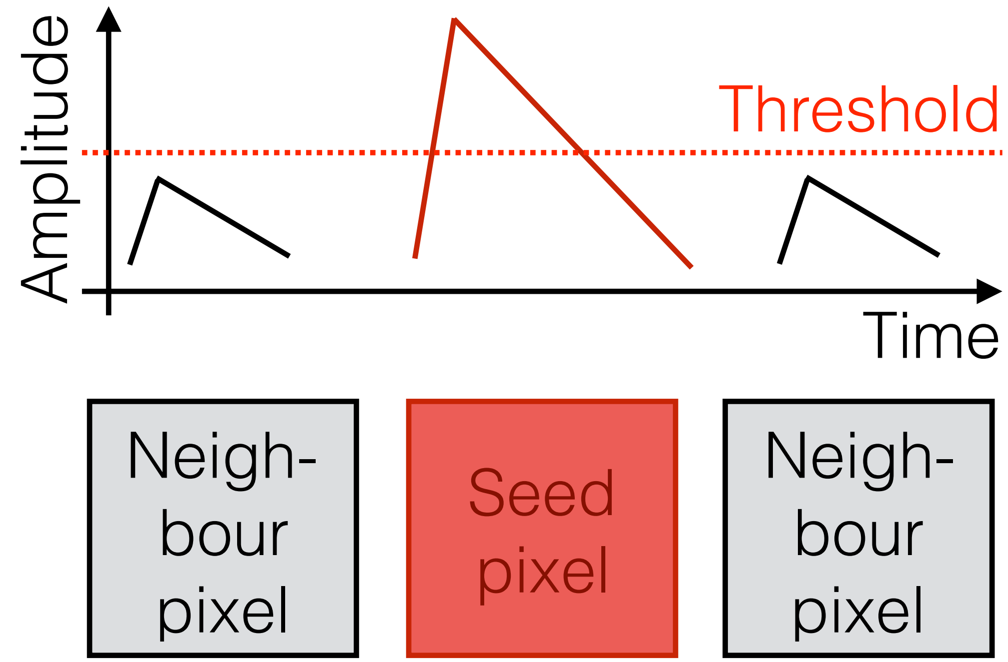
Δb(clock-devision) [$e^-$ ] = (16000 / MPV) x (clock-division + 1) / (20+ 1)

Saturation(cd) [$e^-$ ] = $2^4$ x Δb(clock-division) [$e^-$ ]

This can be used now to convert any clock-devision in saturation [$e^-$ ] for the simulation

# Landau ⊗ Gauss fit / cut on sensor center

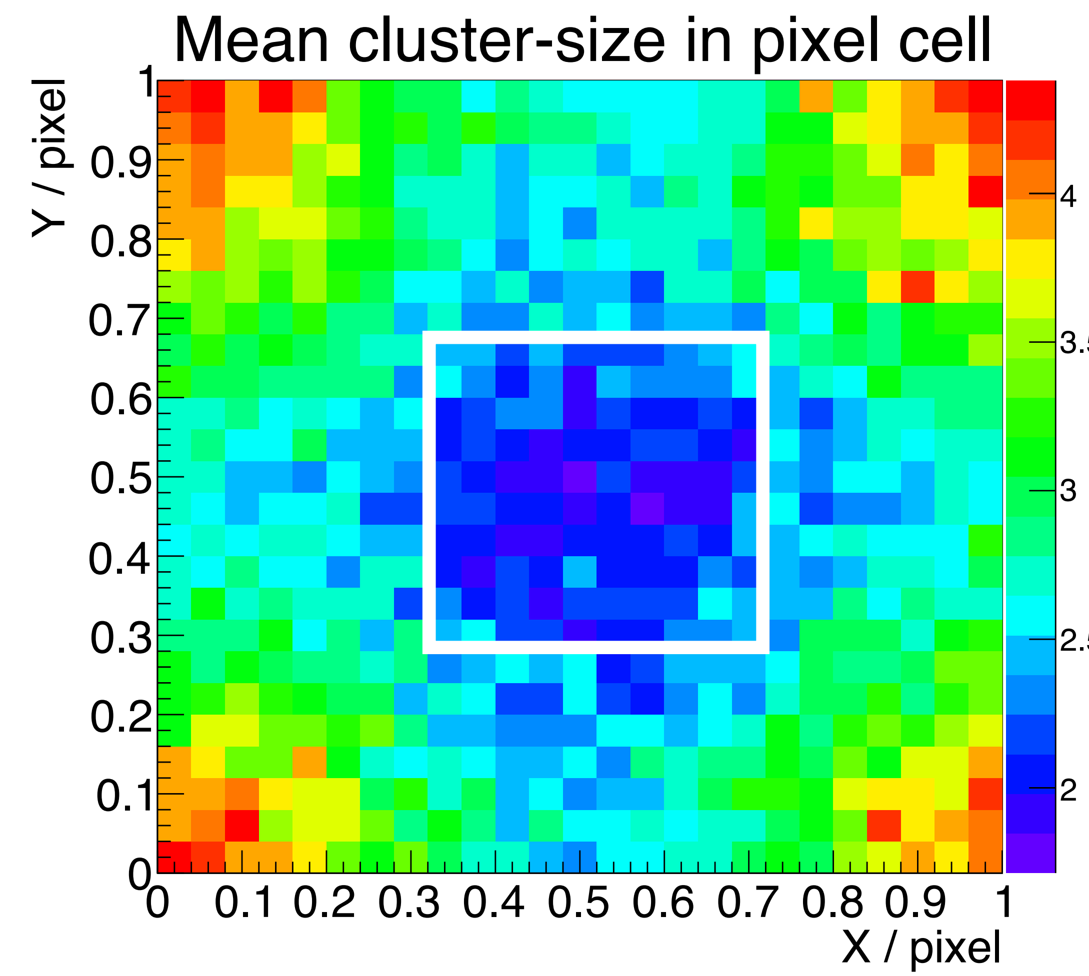
- → Charge sharing
- → Neighbour pixels might be below threshold
- → Distortion of cluster-signal
- → Need to avoid charge sharing



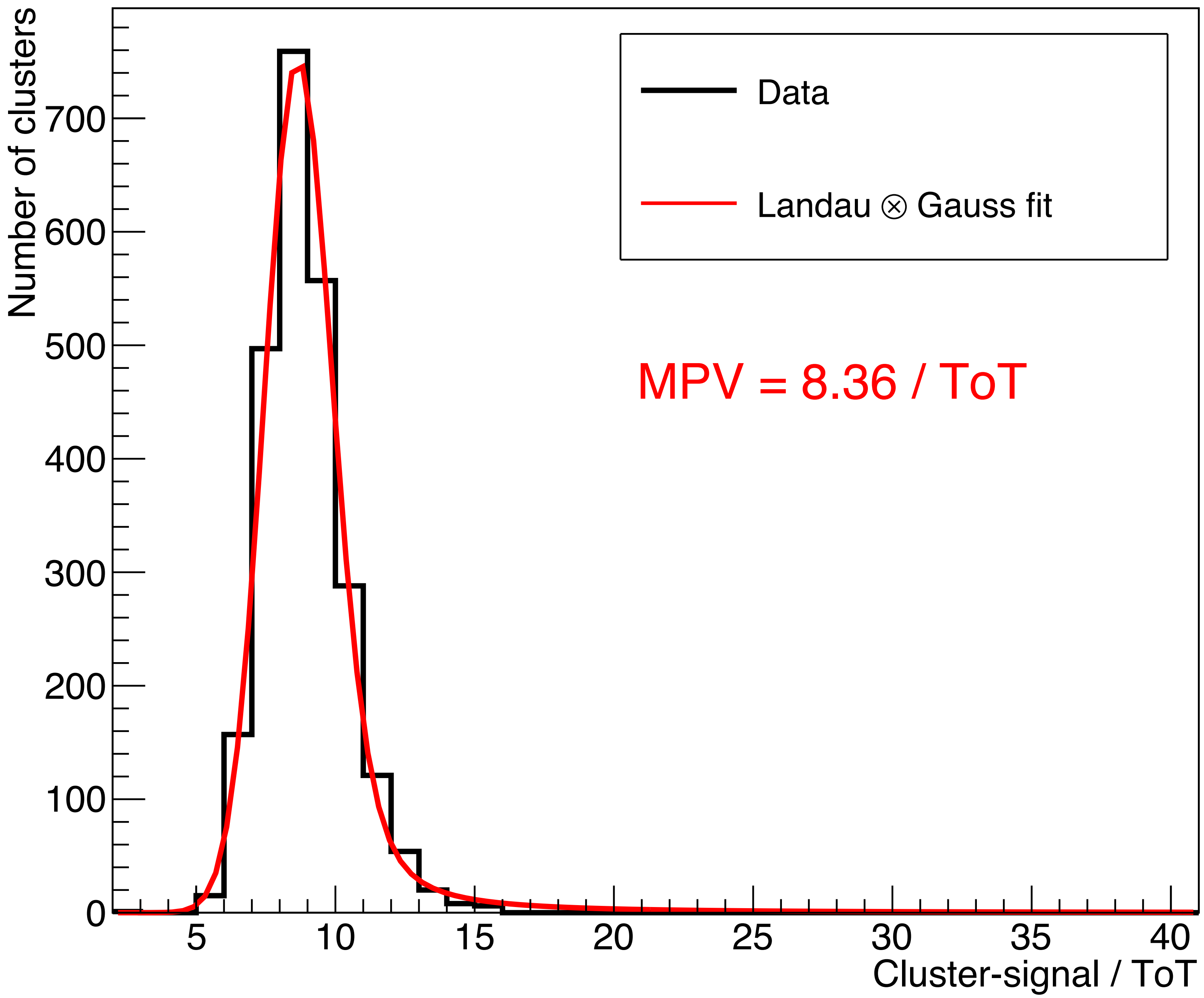

Avoid charge sharing by requiring cluster-size of 1 and cutting on sensor center

↓

**Select only hits in white box which have a cluster-size of 1**



# Landau ⊗ Gauss fit / results for even columns




$\Delta b$(clock-devision) [$e^-$] = (16000 / MPV) x (clock-division + 1) / (20+ 1)

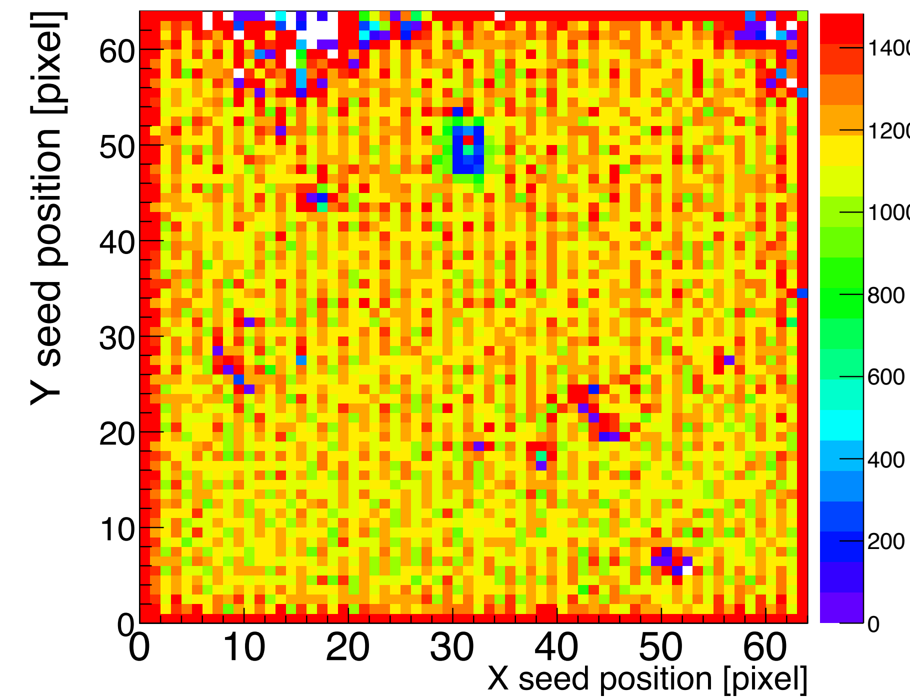
Saturation(cd) [$e^-$] = $2^4$ x $\Delta b$(clock-division) [$e^-$]

# Cuts in the test-beam analysis

## Why?:

Different response of odd and even columns in x-dimension because of known CLICpix issue:

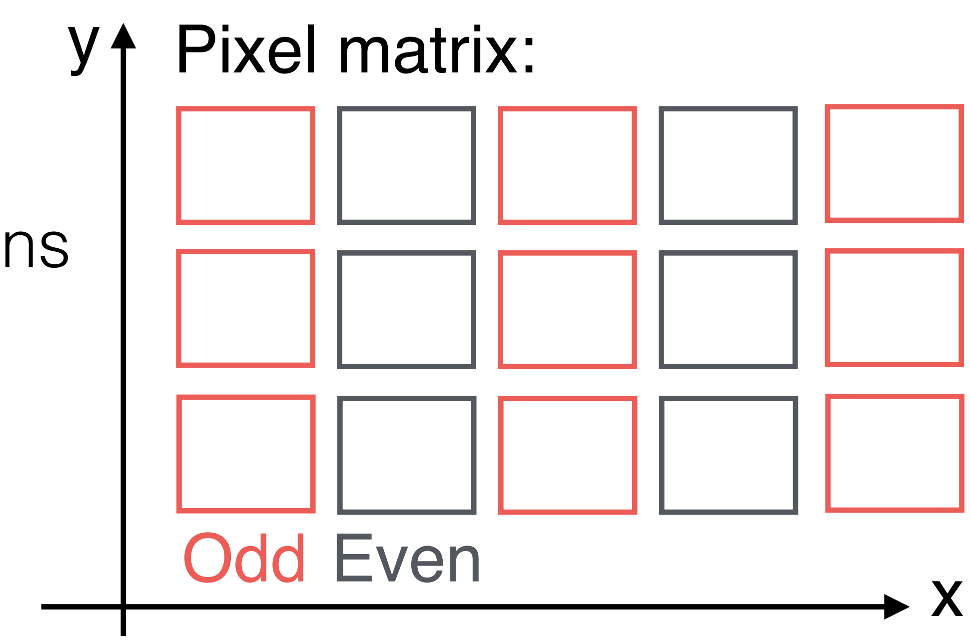
- Crosstalk from discriminator output to preamplifier
- Different for even and odd columns because of pixel layout




## How?:

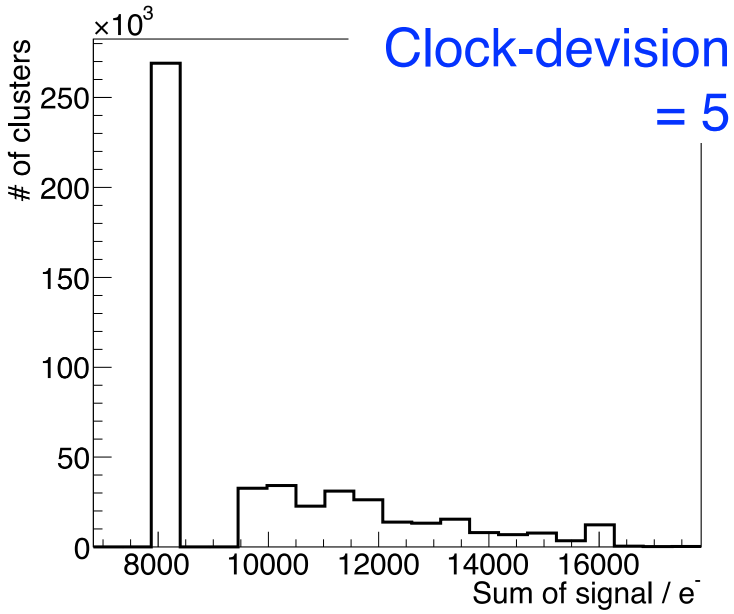
Force cluster size in x-dimension to 1 & cut on sensor center:

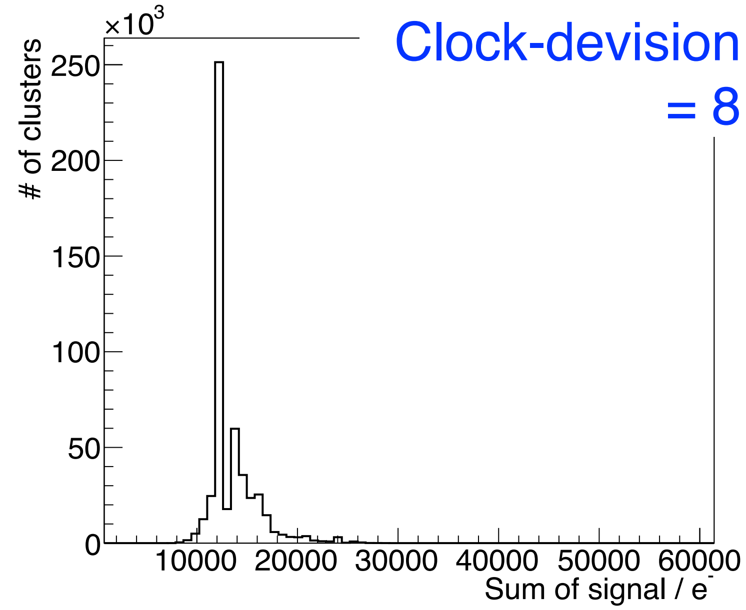
- Reduce charge sharing between odd & even columns
- Study odd & even columns separately
- Study observables in y-dimension
- Show only results for even columns

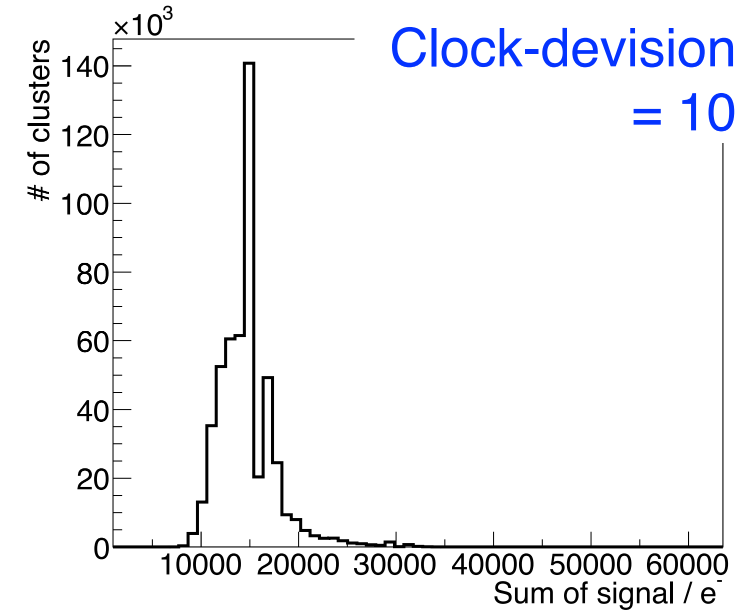


# Landau for different clock devisions

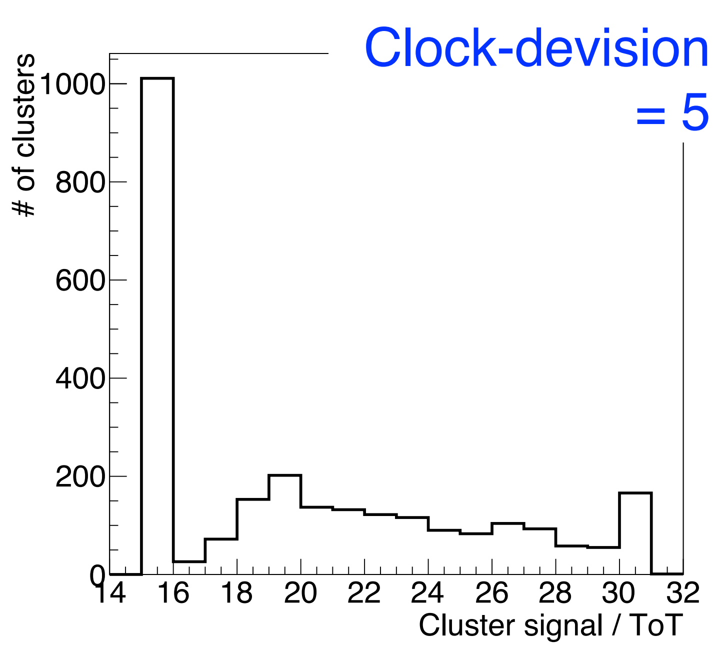
Simulation:

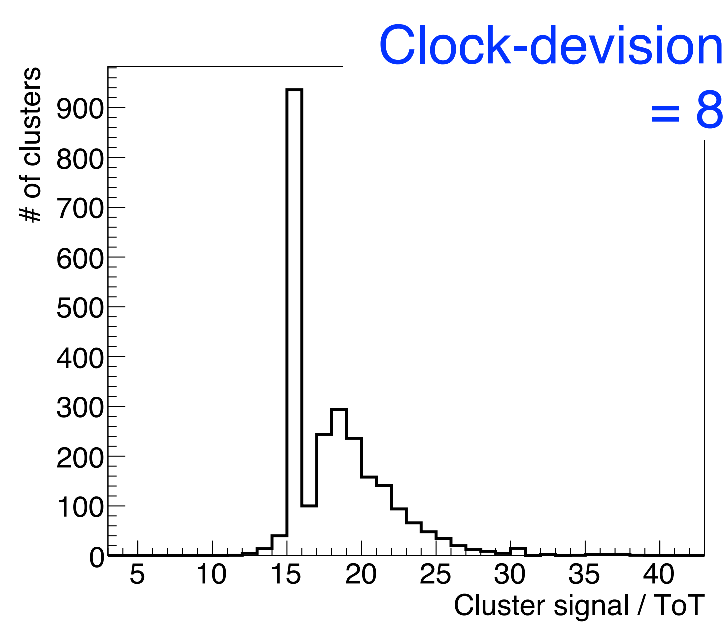


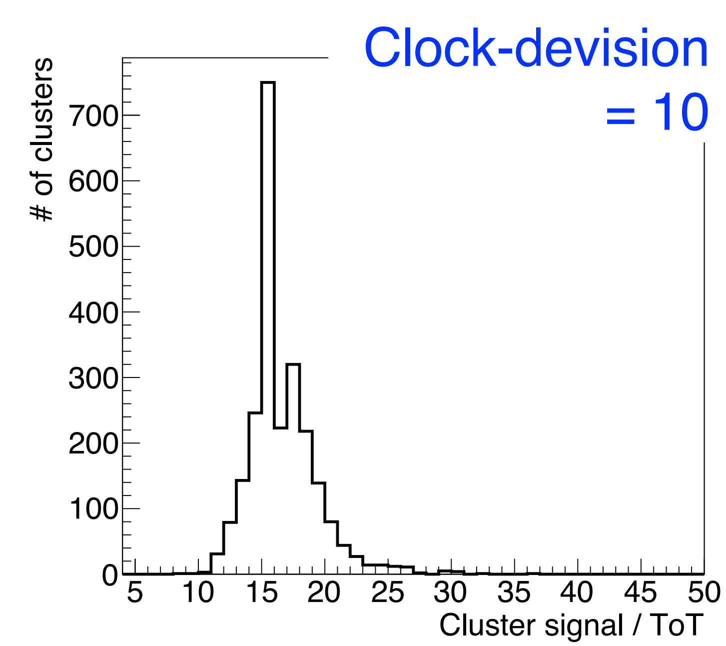




Data:



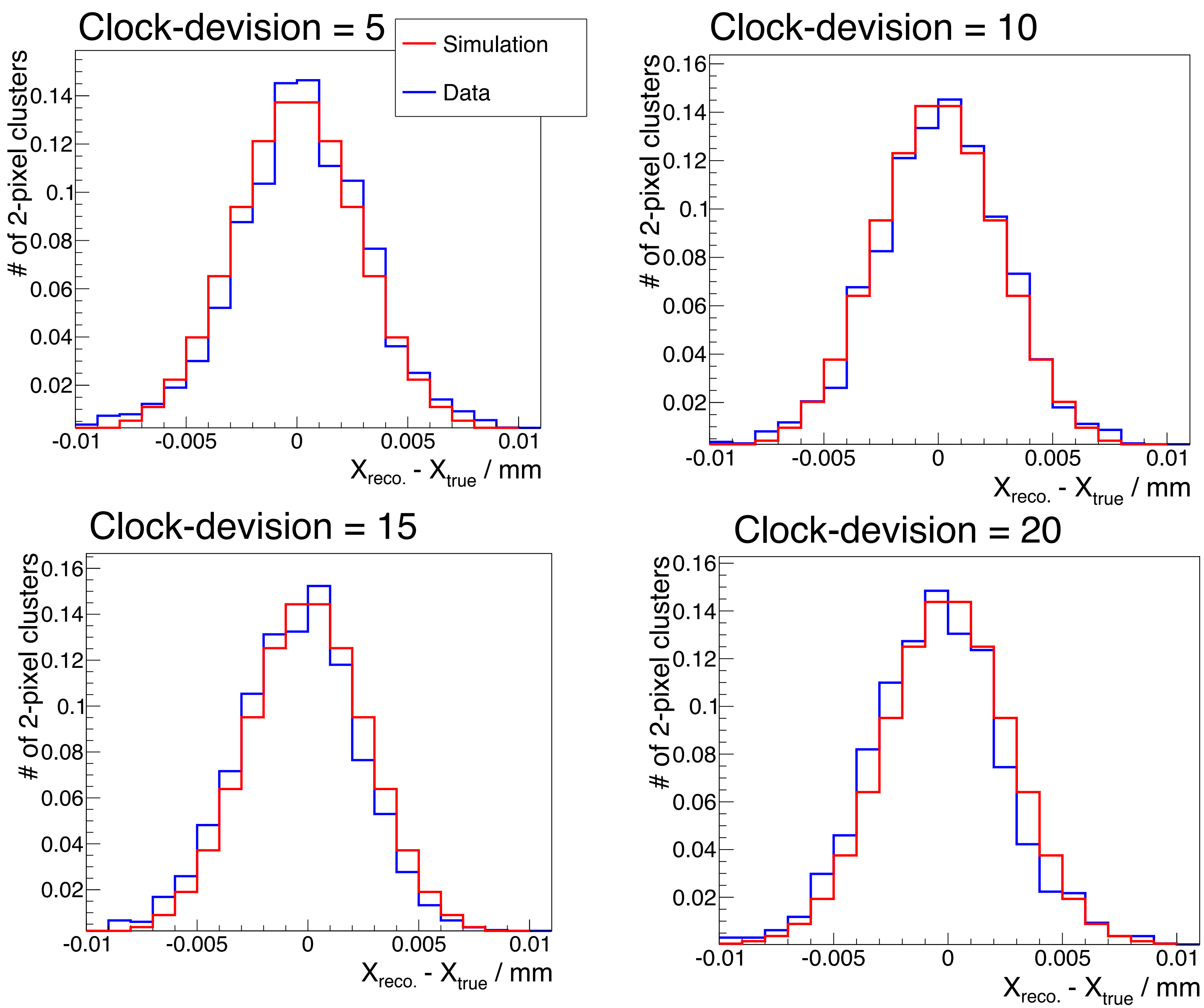




Good agreement!

# Resolution versus clock division

- Single pixel cluster resolution always binary, independent from digitalisation

↳ Study **2-pixel cluster resolution for different clock divisions**:




Simulation:

- $\sigma_{Telescope}$ = 2.5 μm
- $\sigma_{Noise}$ = 150 $e^-$
- $\sigma_{Threshold}$ = 22 $e^-$

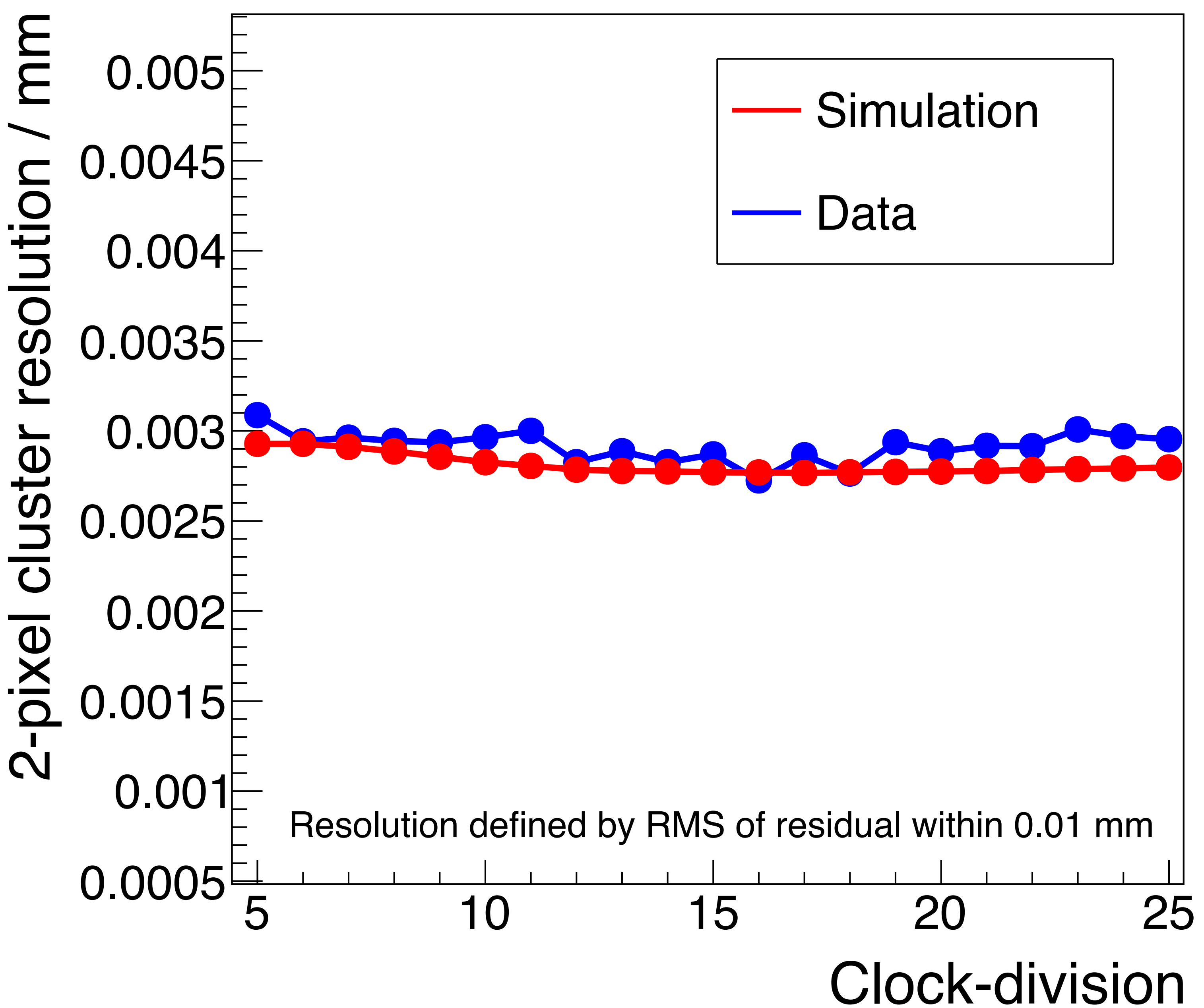
**Excellent agreement.**

# Resolution versus clock division

**Expectation:**

- Very small clock division → saturation of signal → resolution gets worse
- Very large clock division → loss of precision → resolution gets worse

**Observation:**




No agreement between expectation & observation

But agreement between data & simulation in Landau distributions & 2-pixel cluster resolution

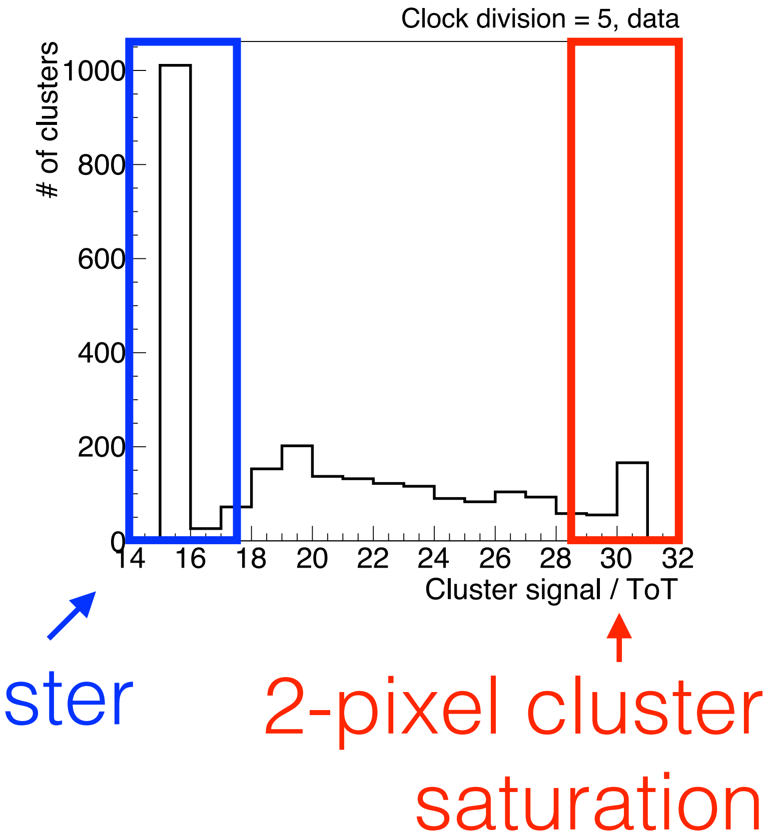
↓ ↓ ↓

Use the simulation to understand discrepancy between expectation & observation

# Resolution versus clock division / even

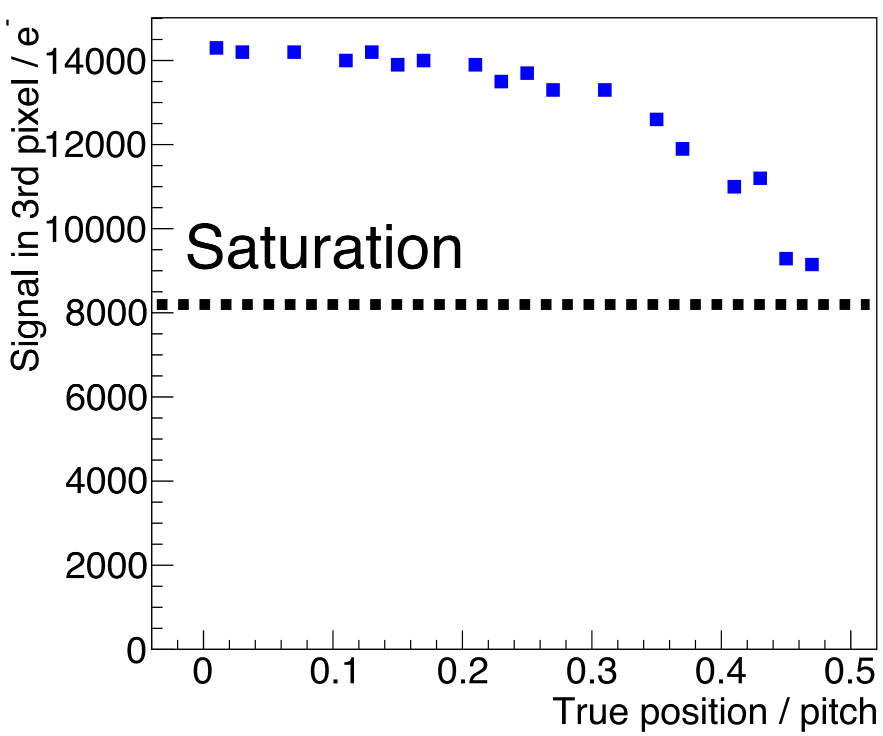
**Why does the resolution not gets worse for small clock-divisions?:**

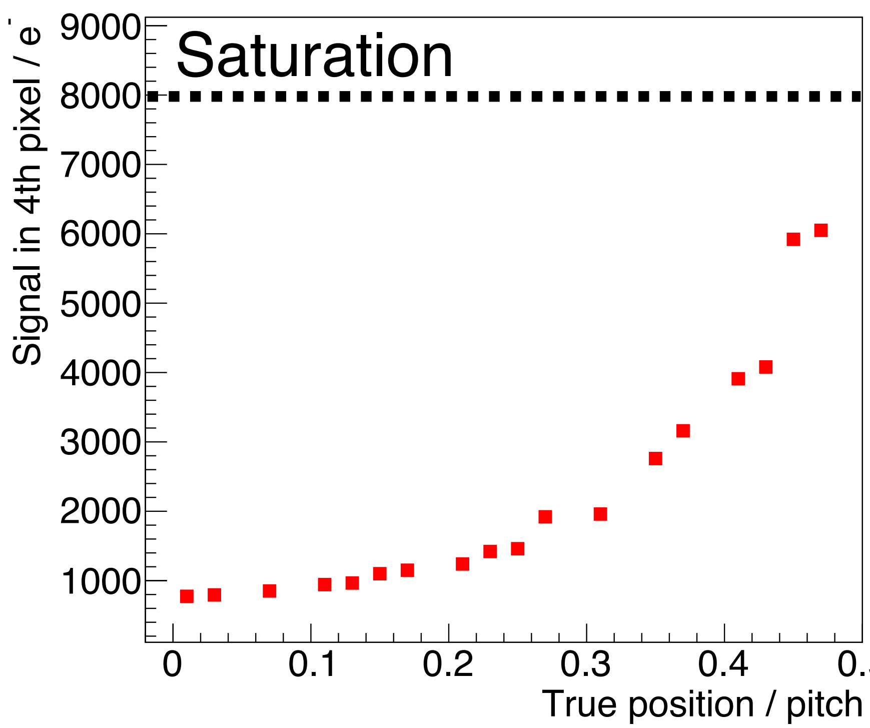
- For a clock division of 5 one still gets multi-pixel cluster Landau distribution




Check in simulation:

- One strip/pixel always saturated
- One strip/pixel mostly non-saturated



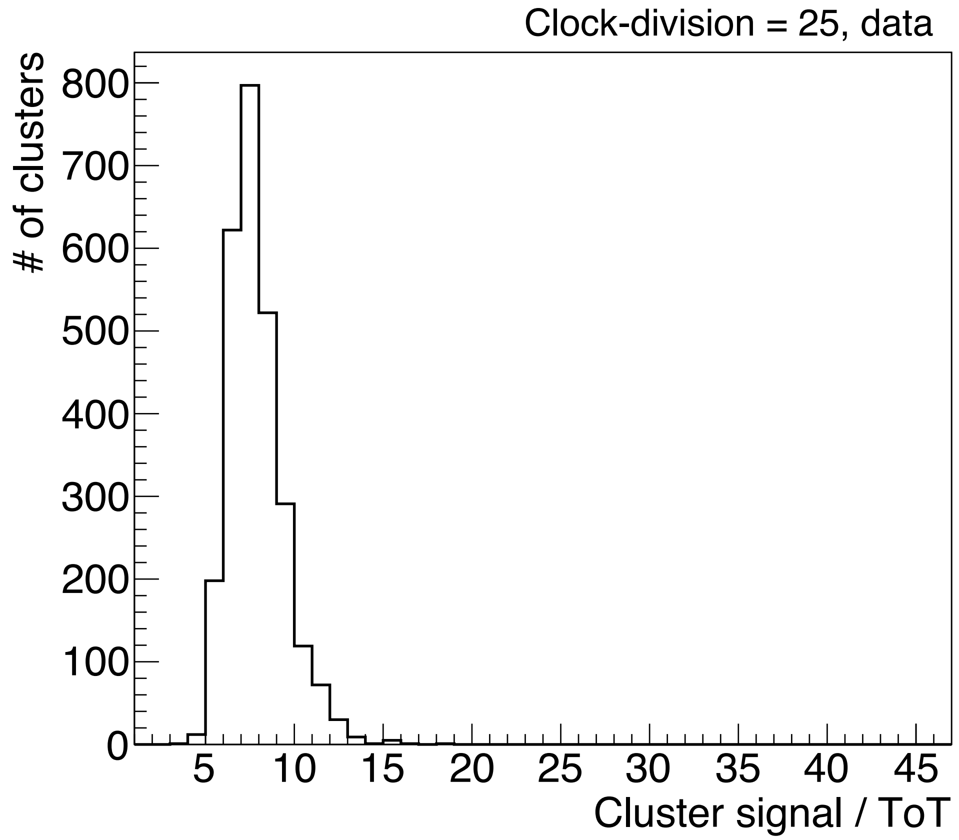




↳ Distortion of CoG
But eta-correction corrects for non all linearities

# Resolution versus clock division / even

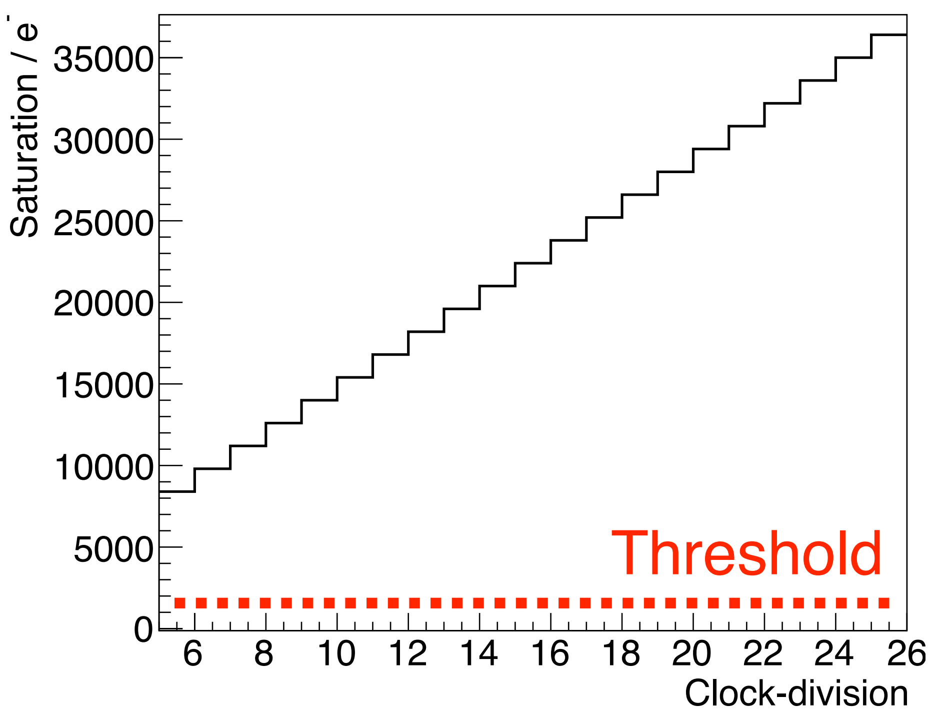
**Why does the resolution not gets worse for large clock-divisions?:**

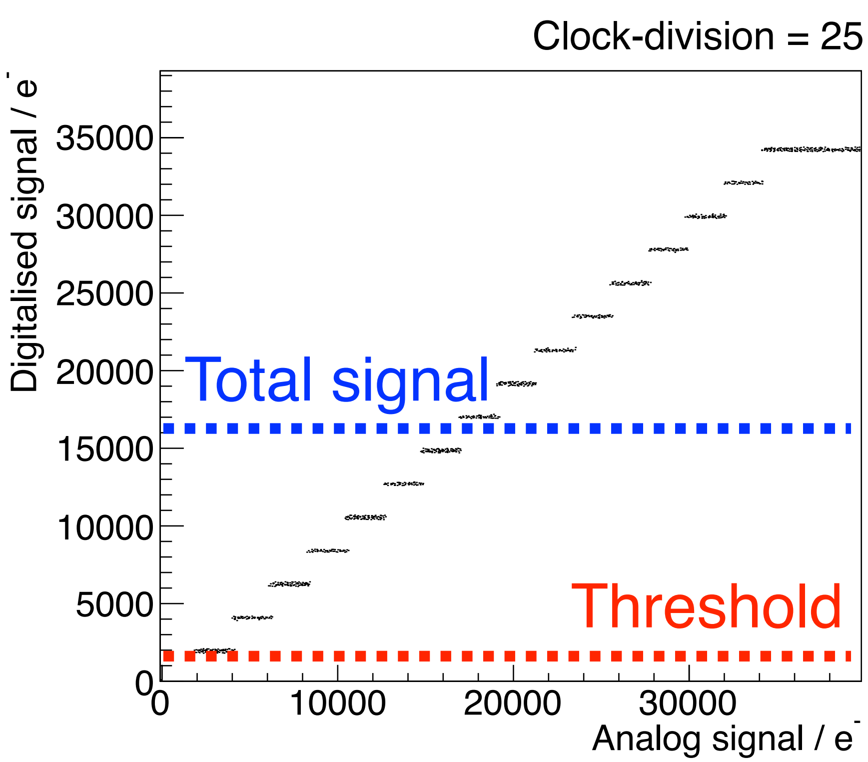
- For a clock division of 25 one still gets precise enough Landau distribution




Check in simulation:

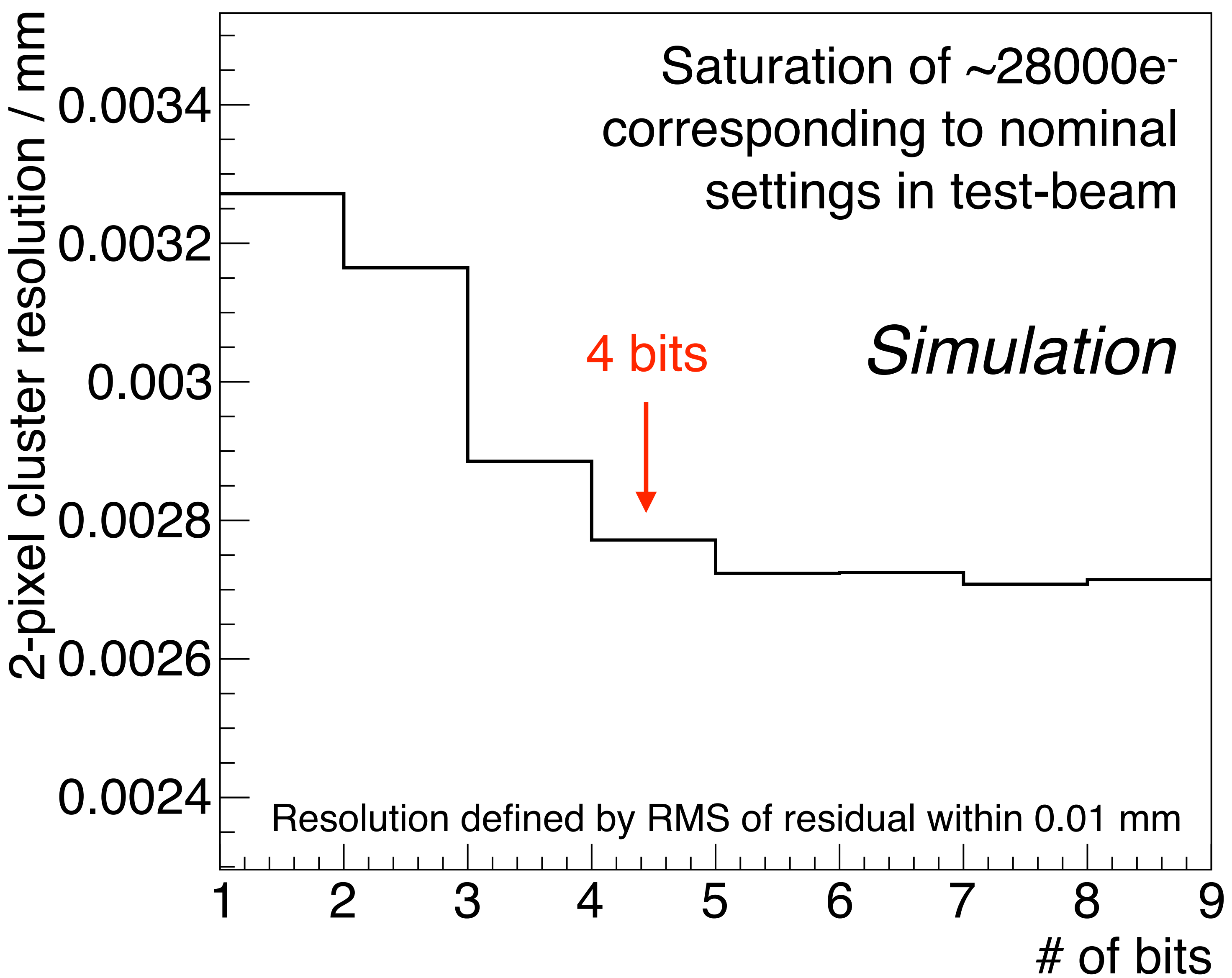
Do we need 4-bits or are less bits sufficient?



# Resolution versus number of bits / simulation

**First look** to answer the questions how many bits are optimal:




↳ For the clock-devision and the sensor used in the test-beam
4 bits seem to be kind of optimal

# Summary & outlook

Simulation of digitalisation implemented and validated:

↳ Good agreement with test-beam data from CLICpix planar-sensor clock-scan for:

- Landau distributions
- Resolution

↳ Simulation helps to understand results

Simulation framework validated for:

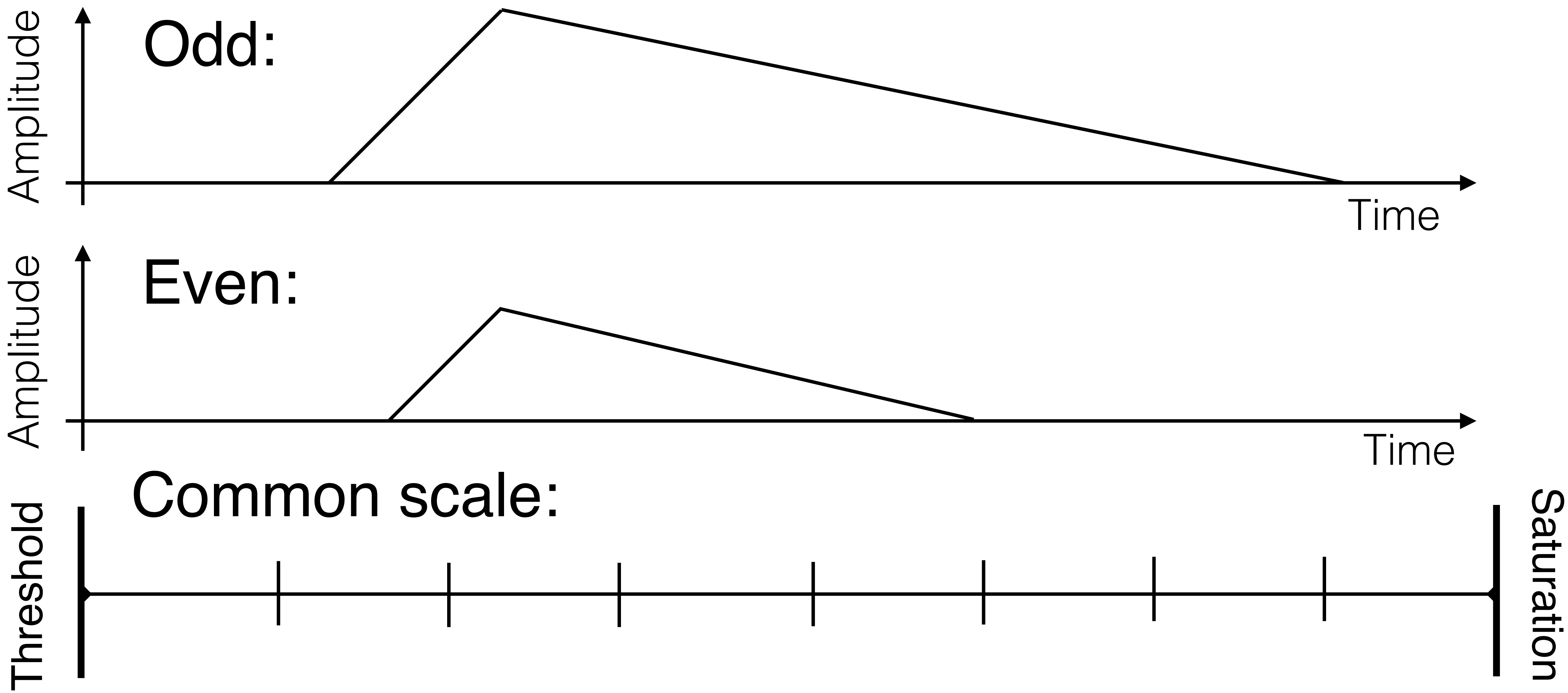
- Different chips (TimepixI & CLICpix)
- Different sensor thicknesses
- Different incident angle
- Magnetic field
- Different thresholds
- Digitalisation

Framework finally fully validated

Can use the framework now to study performance of different designs

BACKUP

# Effect of difference in even & odd columns

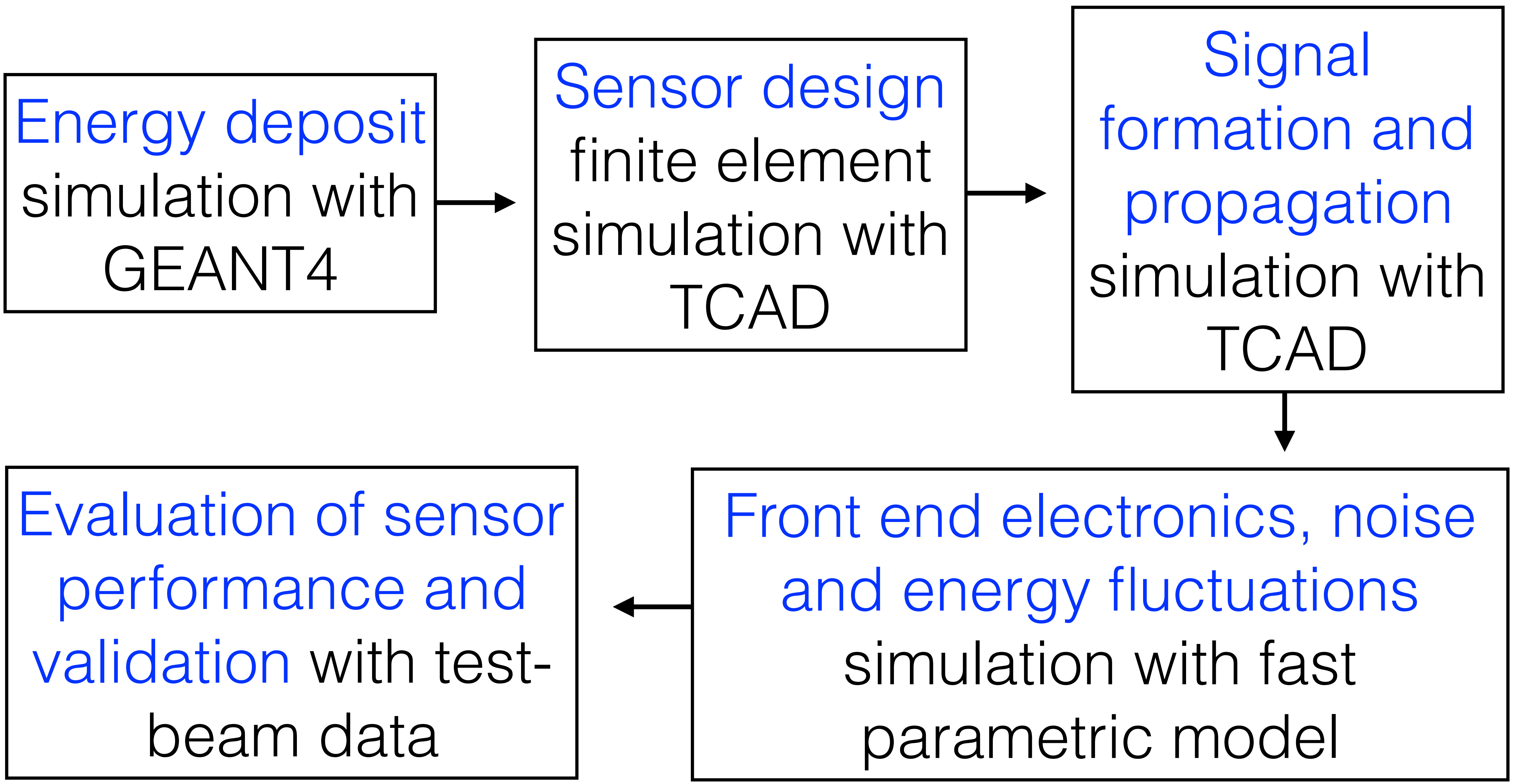



- Even (low charge) refers to nominal condition (without additional charge injected)
- Odd refers to additional injected charge

→ This is just a change of the pulse form and **leaves the parameter of Threshold & Saturation unchanged**

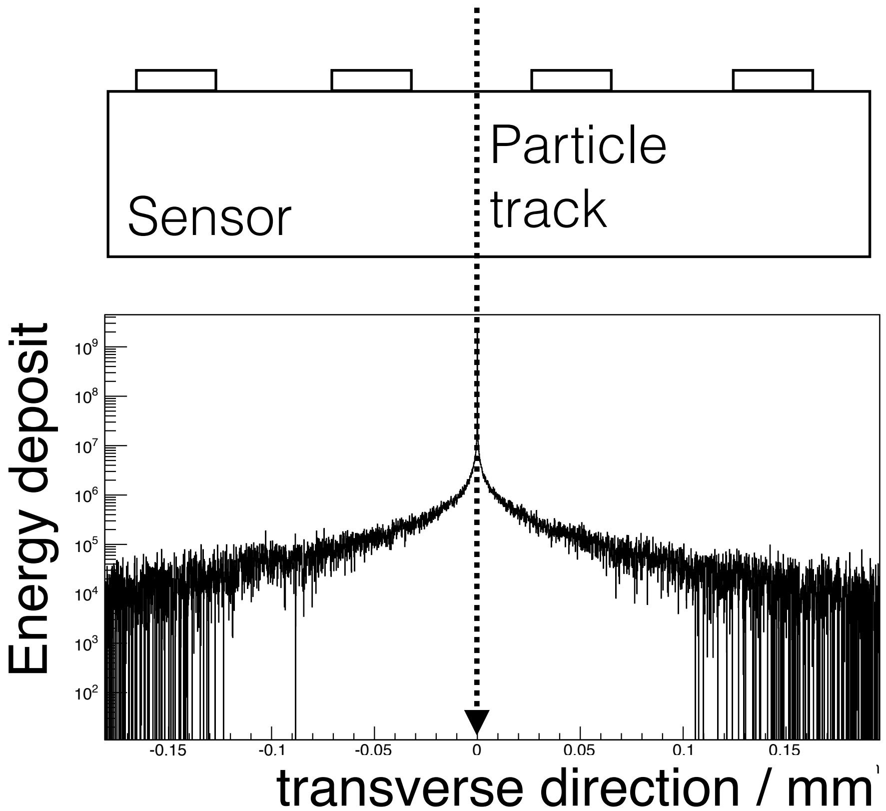
→ Calibrate digitalisation scale to even columns and inject charge before threshold application in simulation to compare to odd columns

# My workflow for the simulation of tracking sensors

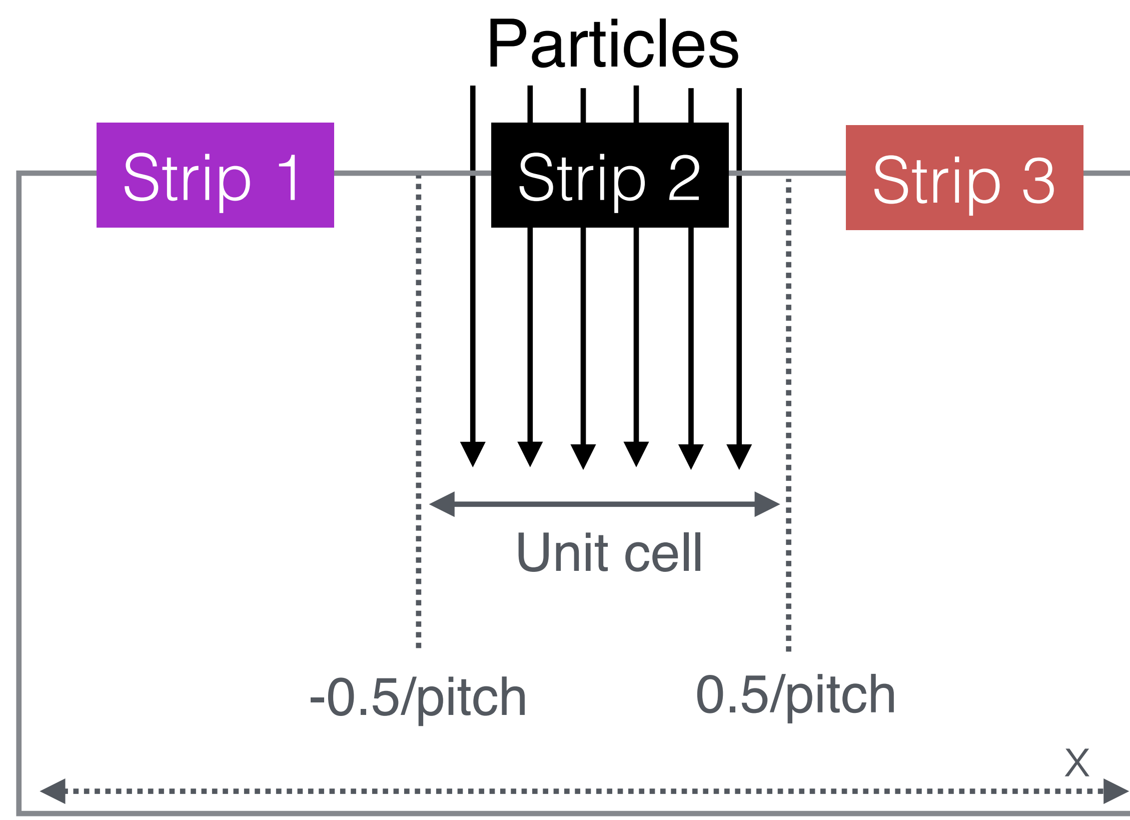


# Simulation of particle signal in sensor

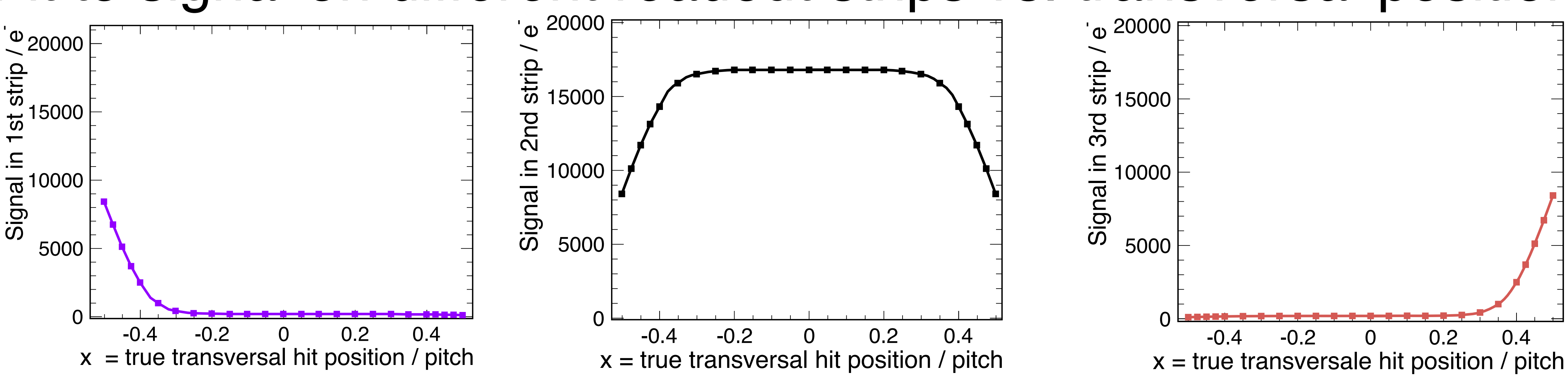
GEANT4 simulation of energy deposit in silicon sensor:




Finite element simulation of sensor with T-CAD:

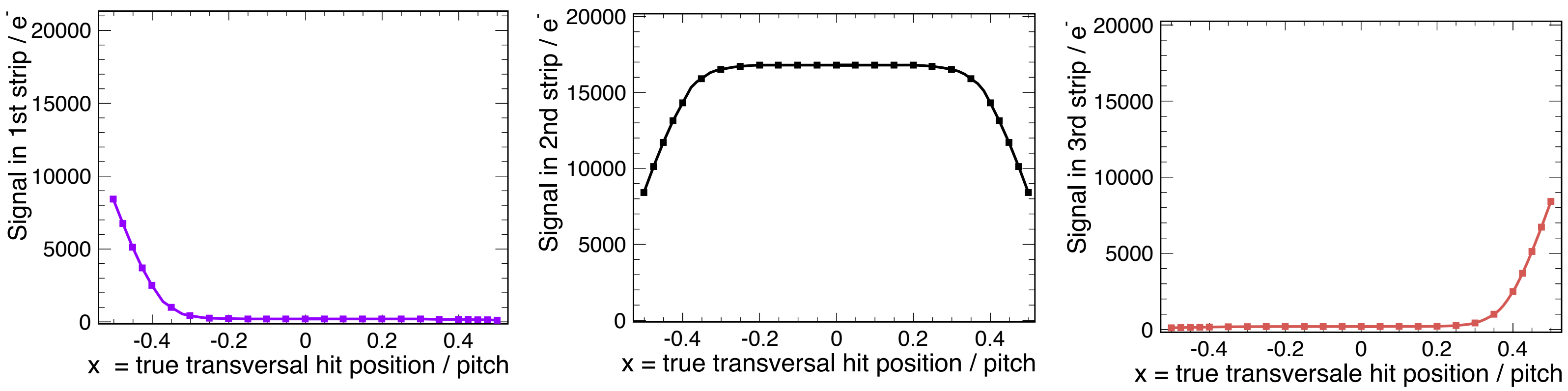



Fit to signal on different readout strips vs. transversal position x:



# Fast parametric model of front end electronics, energy fluctuations and noise

- Start with fit to **signal on readout strips**




- **Scan x** with small step size, perform for each position:

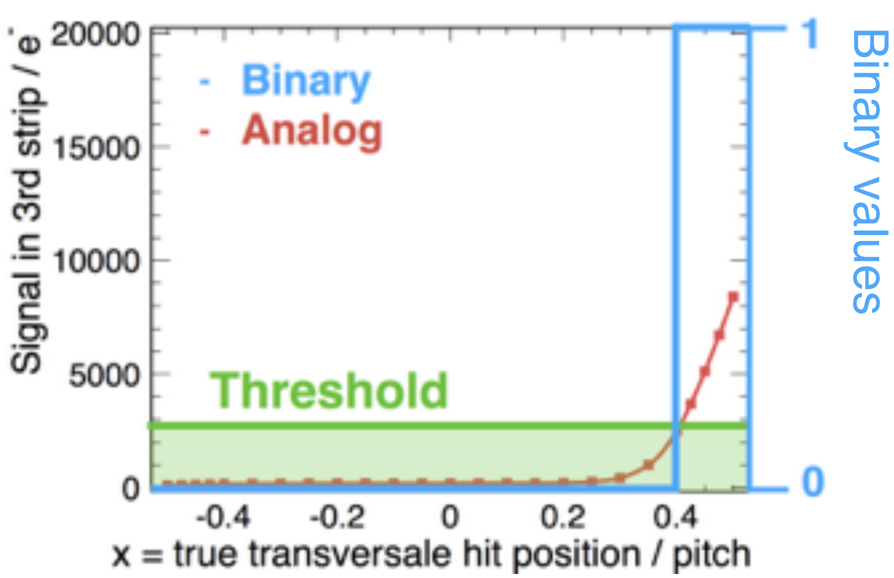
1.) **Landau smearing** of sum of signal (energy fluctuations)
(Use Landau distribution from GEANT4 simulation)

2.) **Gauss smearing** of single strip signal (electronic noise)

3.) **Threshold application**

4.) **Digitalisation**

- Analog
- Digital, adjust # of bits & saturation
- Binary, just two bit-states (1 bit)



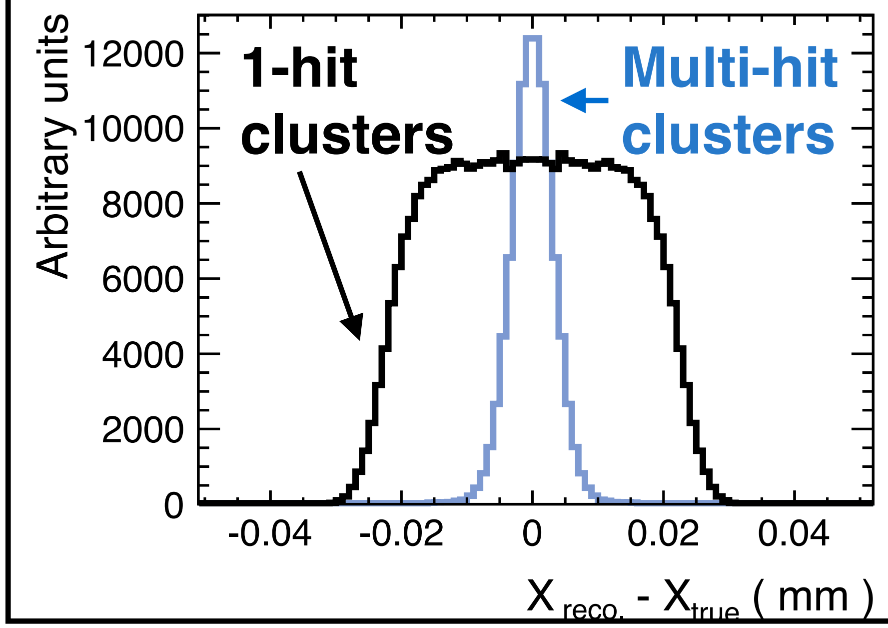
# Position reconstruction

Start with **C**enter **o**f **G**ravity (CoG):

$$\mathrm{CoG} = \sum_{i \in \{strips\}} \mathrm{position}_i \cdot \mathrm{signal}_i \Big/ \sum_{i \in \{strips\}} \mathrm{signal}_i$$

Binary:
- Nothing more -

CoG-corrected residual:




Analog or digital:

- CoG-correction: