26 March 2021

SDHCAL STABILITY STUDIES

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LPC

AIM OF THE STUDY

- Predict & quantify the stability of the SDHCAL response
- Implement the dependence of the simulation to some parameters (gap width, Temperature, Pressure, Magnetic Field, Gaz mixture, ionising particle type, ...)
- Consider amplification effects only:
  - Variations coming from readout or signal induction not considered
  - Method: Combine avalanche simulation with digitiser

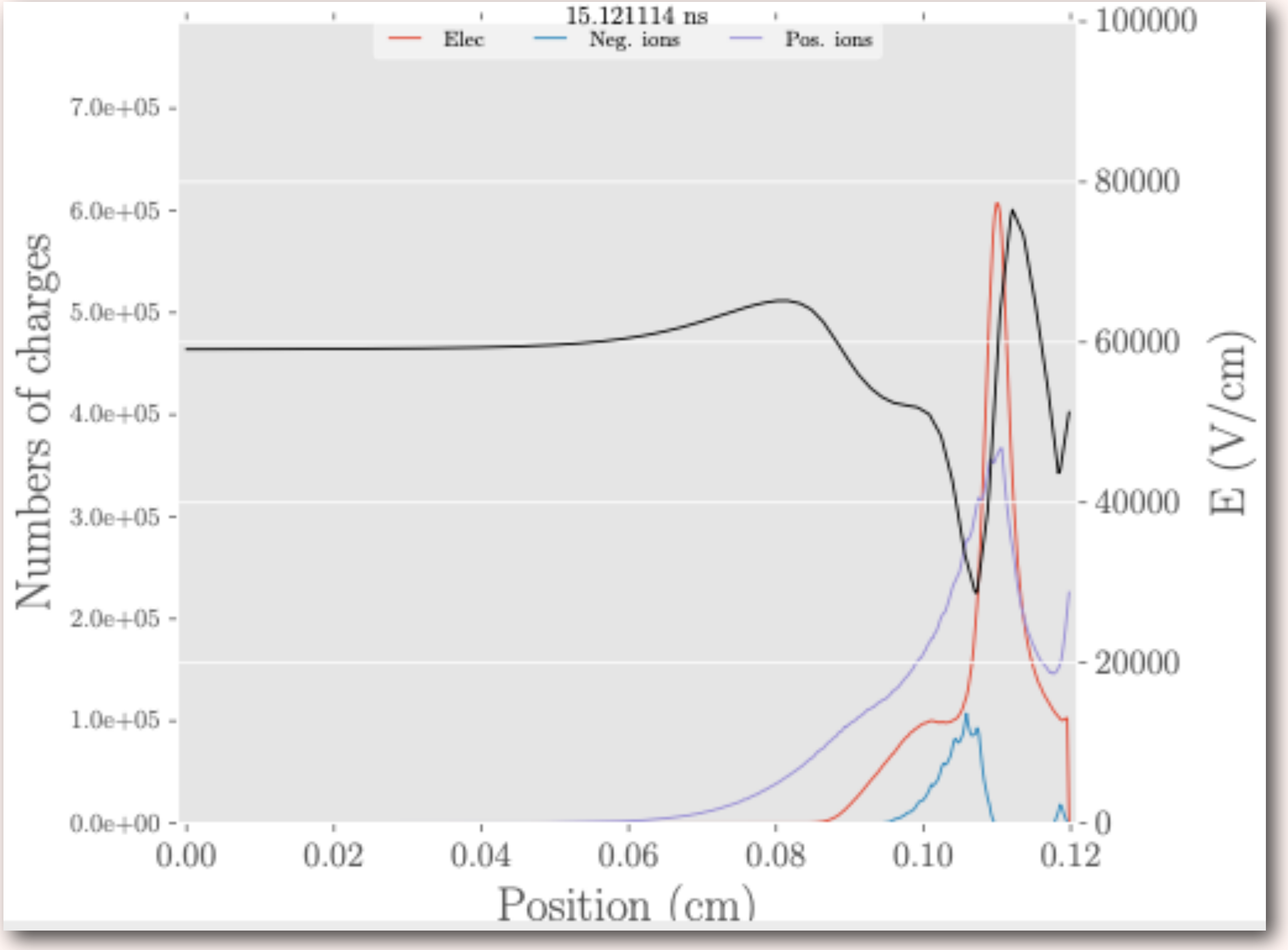
OUTLINE

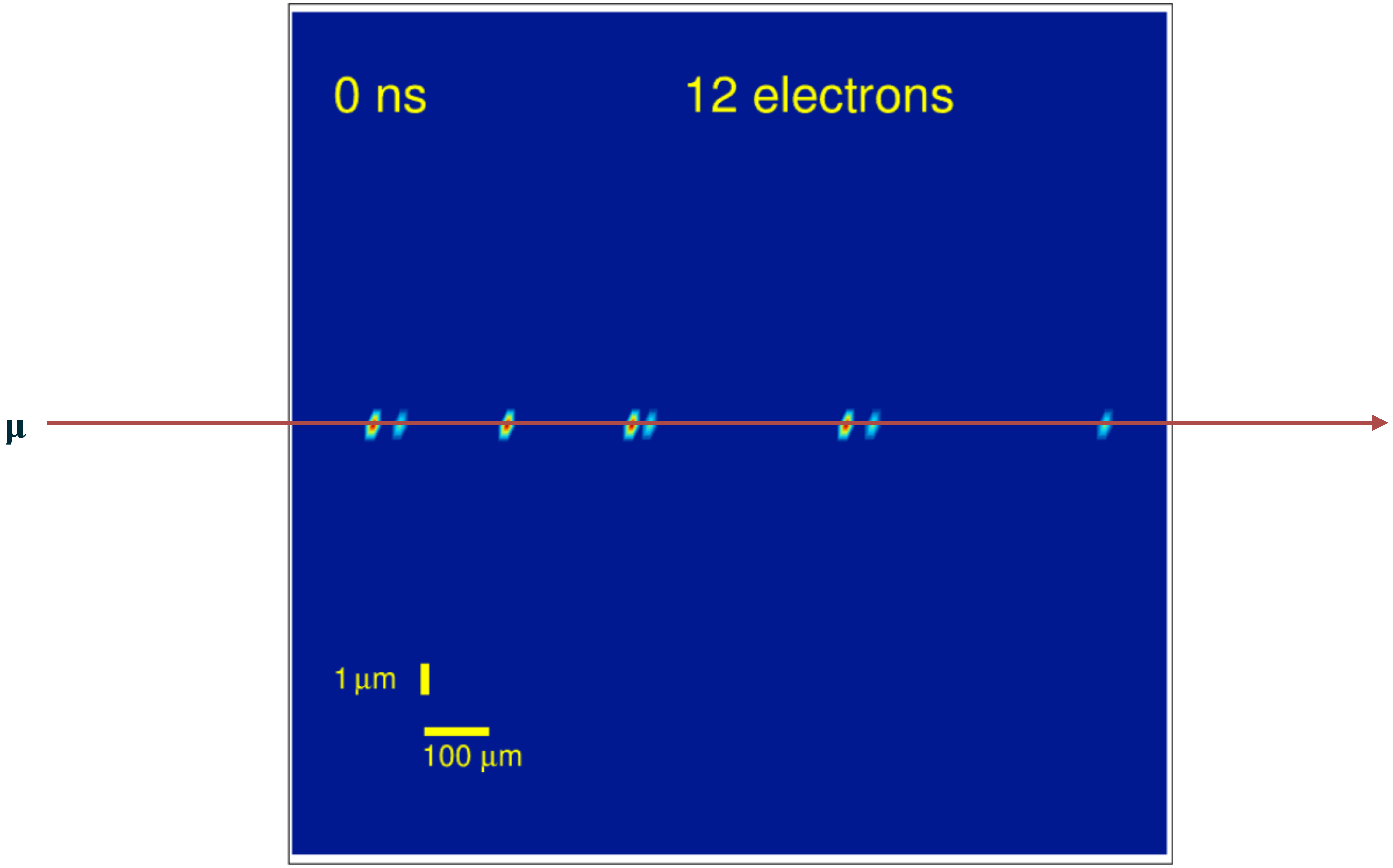
1. Avalanche simulation and modeling
2. SDHCAL simulation: Digitizer
3. Results: predicted stability of SDHCAL output
4. 2015 Test Beam Data

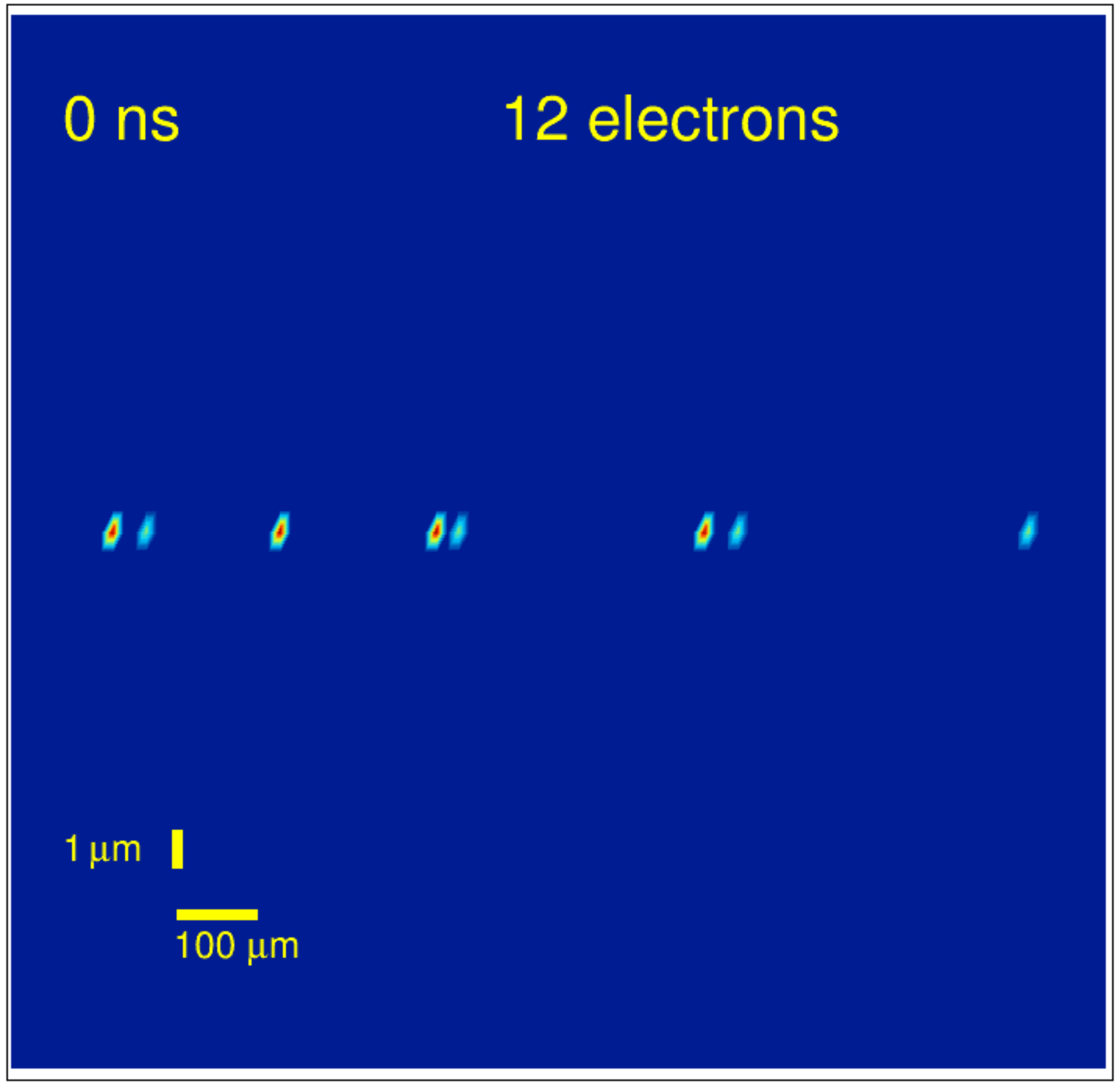
1- AVALANCHE SIMULATION

INGREDIENT: AMPLIFICATION MODELLING

- **Monte Carle simulation of the avalanche:**
  - **Follow the evolution of the number of electrons and ions as a function of time and position**
  - **Take into account the changes in the magnetic field**
- **Simulation account for:**
  - **Multiplication and absorption probabilities**
  - **Diffusion**
  - **Space charge effect: computing the influence of the avalanche on the electric field at each position & time**
  - **Induced charge**




0 ns
12 electrons
μ
1 μm
100 μm


0 ns
12 electrons
1 µm
100 µm

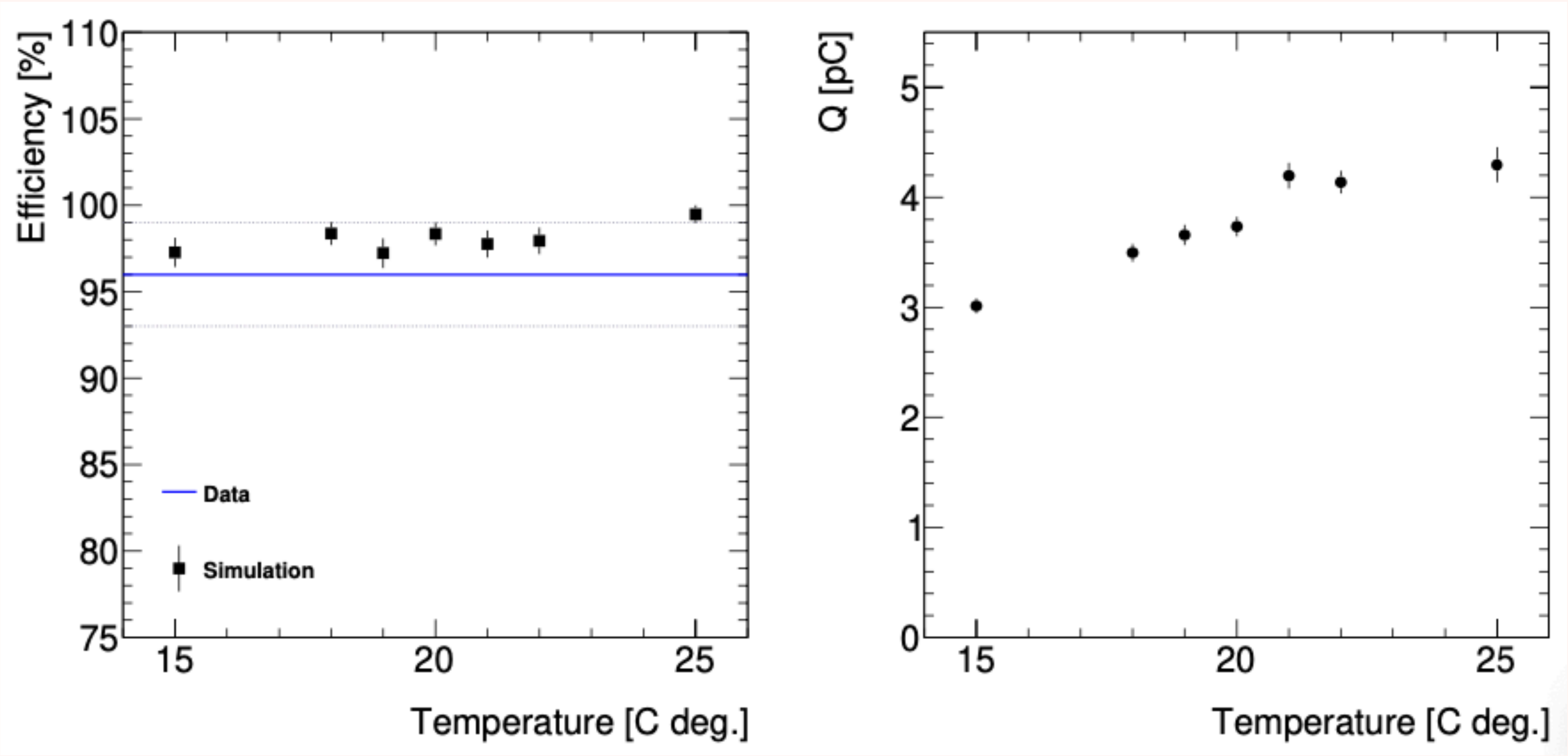
SIMULATION INPUT & OUTPUTS

Parameter		Value
Width	Gap	0.12 cm
	Anode	0.07 cm
	Cathode	0.11 cm
Permitivity	Anode	$7\epsilon_0$
	Cathode	$7\epsilon_0$
Gas Mixture	$C_2H_2F_6$	93%
	SF_6	2%
	CO_2	5%
Electric Field		$57500\ \mathrm{Vcm}^{-1}$
Temperature		$293.15\ K$
Pressure		1 atm

- **Outputs:**
  - **Induced signal (in pC)**
  - **Efficiency** (fraction of avalanches that survive and whose signal reach the first threshold)
  - **Large charge probability** (~ streamer proba.)
  - **Time of hit, time resolution**

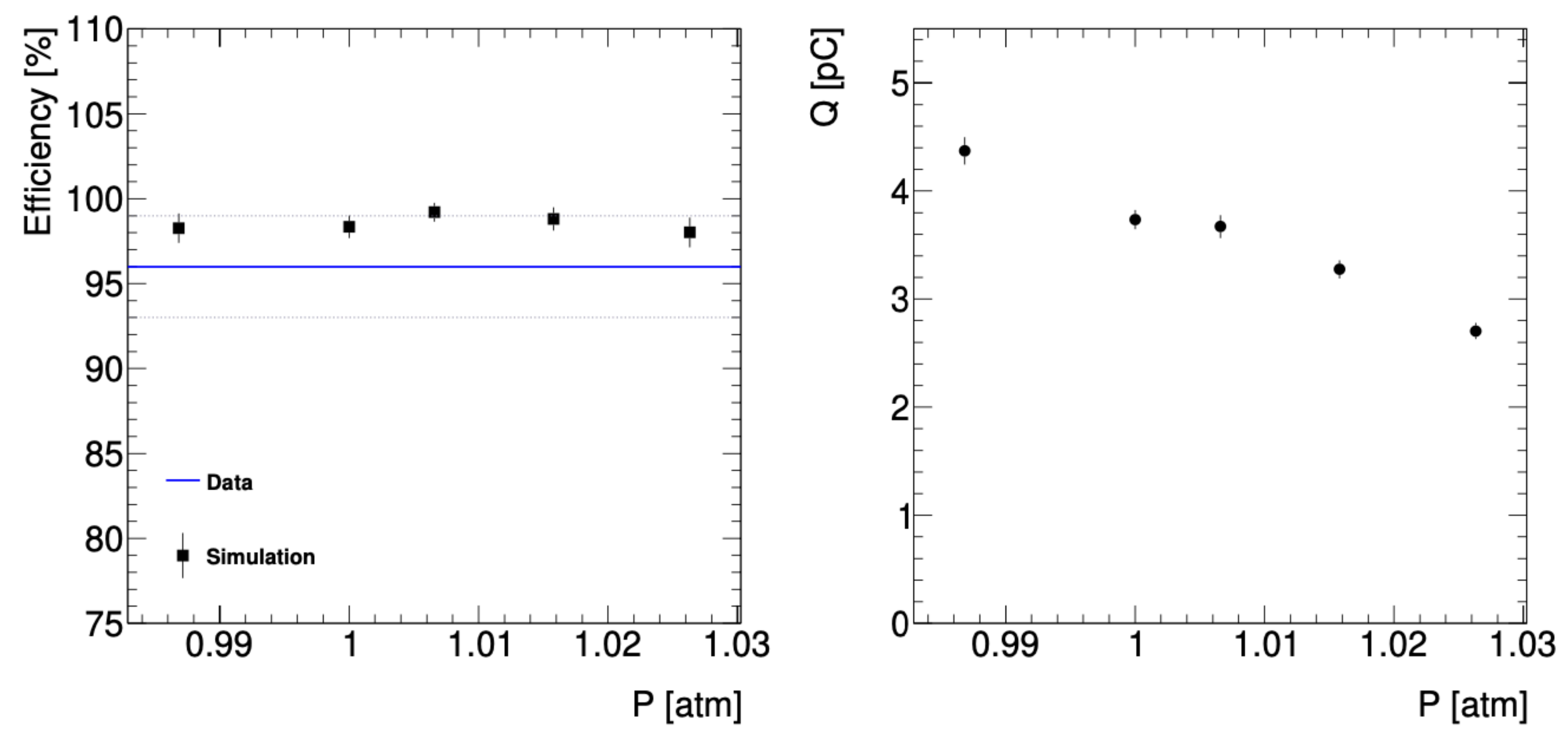
RPC SIGNAL VS TEMPERATURE

- **Avalanches induced by 100 GeV muons are simulated at different temperatures**
- **$\Delta Q/\Delta T \simeq +0.15$ pC/Degree**
- **$\Delta\varepsilon/\Delta T \simeq +0.2$ %/Degree**
- **$\Delta Q(\Delta T)$, $\Delta\varepsilon(\Delta T)$ are modelled**



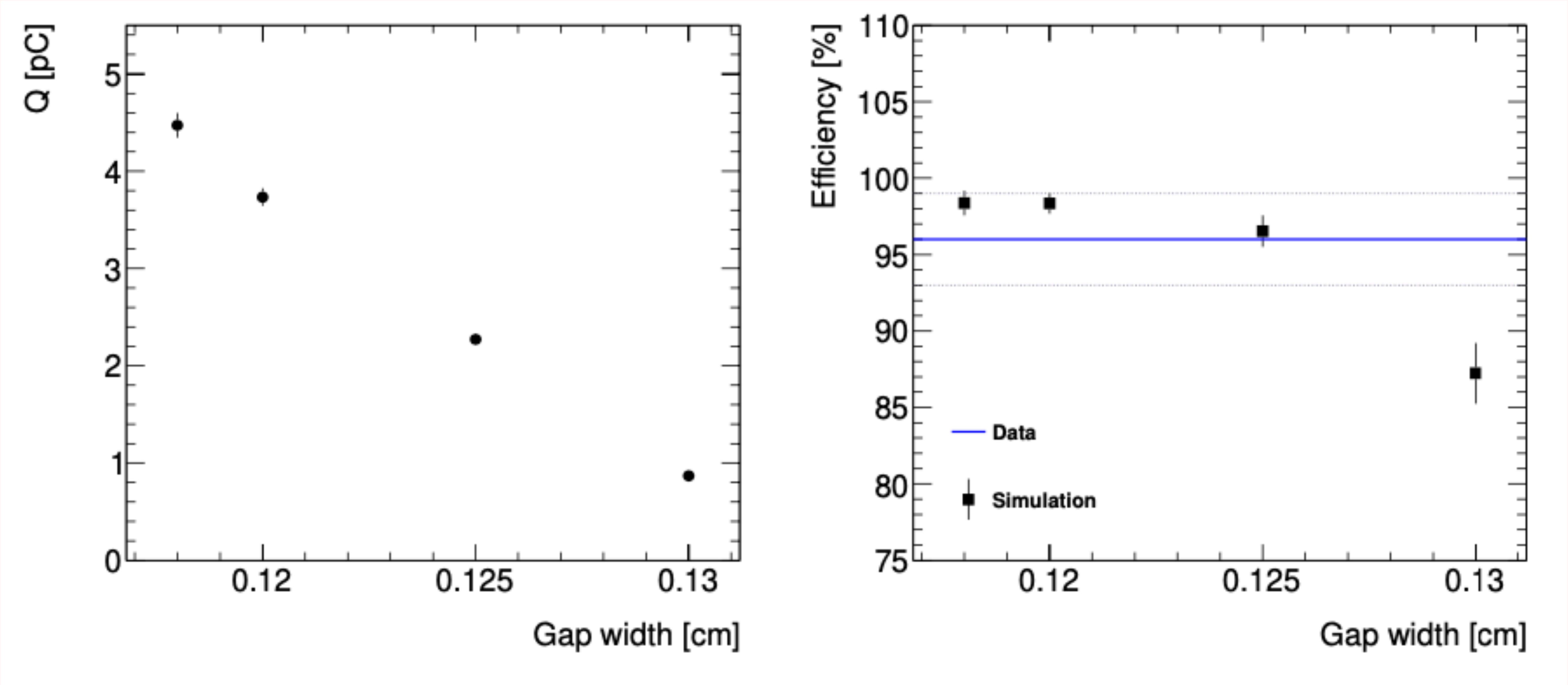
RPC SIGNAL VS PRESSURE

- **Avalanches induced by 100 GeV muons are simulated at different gas pressures**
- **$\Delta Q/\Delta P \simeq -0.04$ pC/mbar**
- **$\Delta Q(\Delta P)$, $\Delta\varepsilon(\Delta P)$ are modelled**



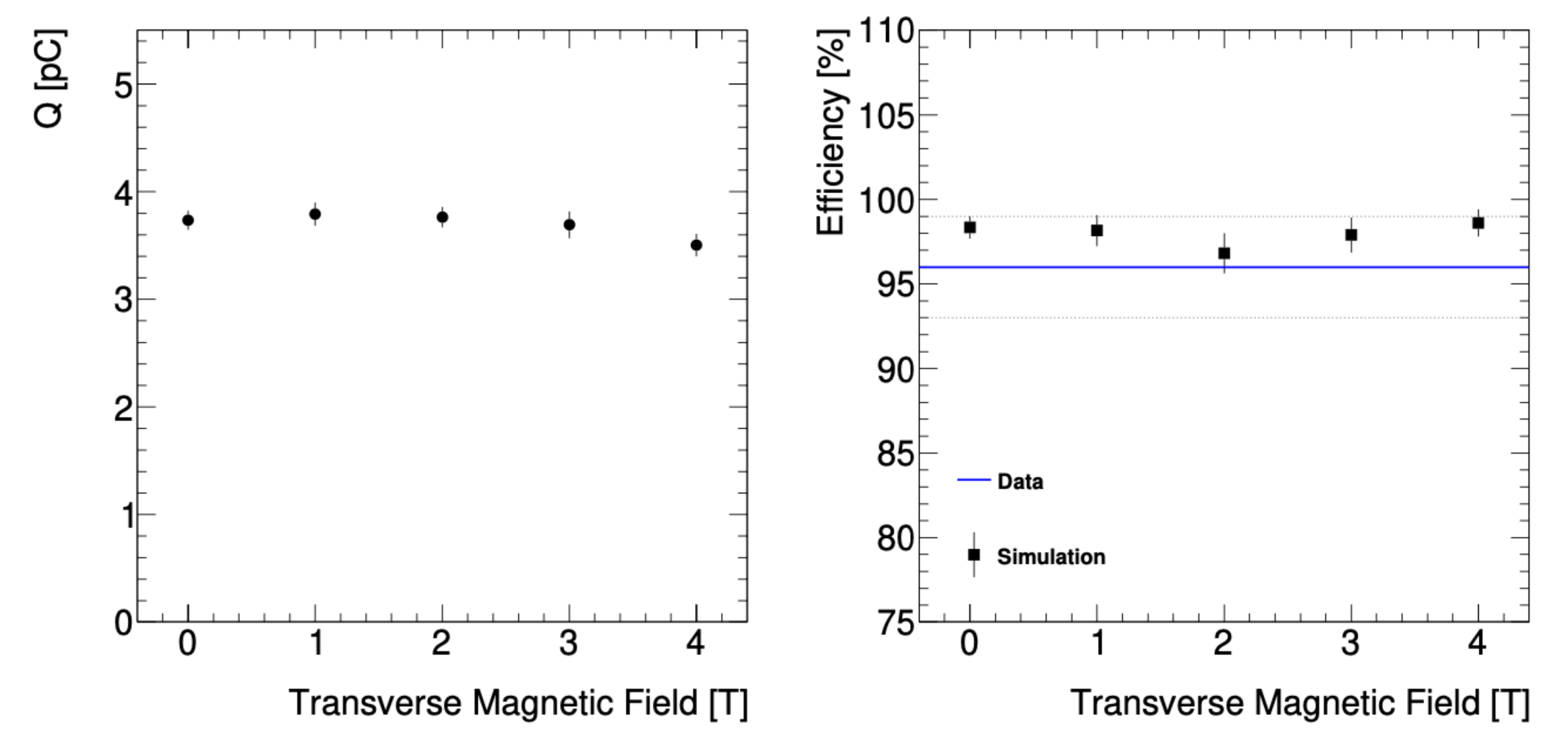
RPC SIGNAL VS GAP WIDTH

- **Avalanches induced by 100 GeV muons are simulated are different gap widths**
- **Assuming stable HV (⇒ Electric Field changes)**
- **$\Delta Q/\Delta D \simeq -0.028$ pC/μm**
- **$\Delta Q(\Delta D)$, $\Delta\varepsilon(\Delta D)$ are modelled**



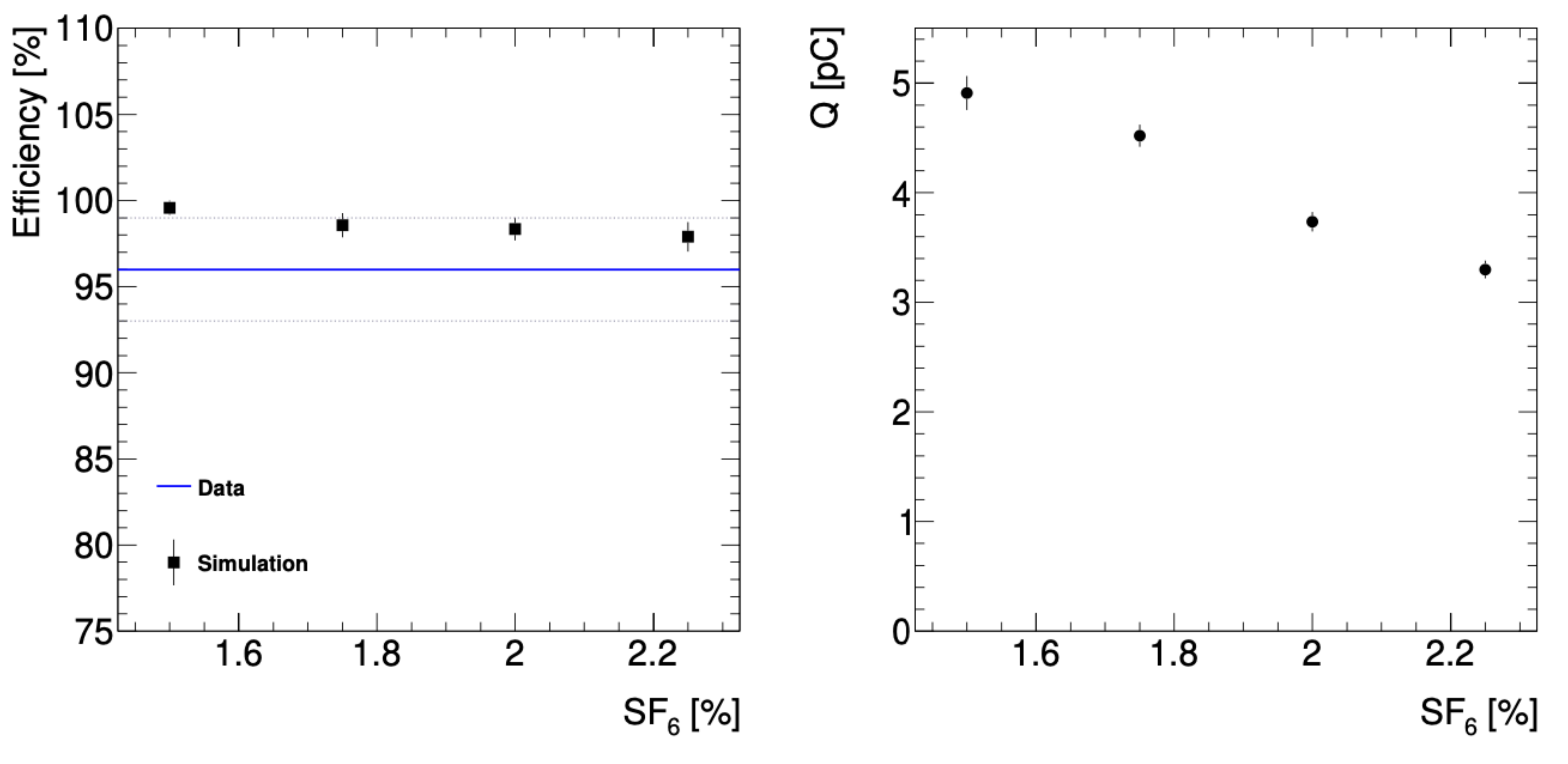
RPC SIGNAL VS MAGNETIC FIELD

- **Avalanches induced by 100 GeV muons are simulated using different Magnetic Field amplitudes and configurations**
- **Longitudinal and Transverse**
- **No sizeable effect was seen**



EFFECT OF THE GAS MIXTURE VARIATION

- Avalanches induced by 100 GeV muons are simulated using different SF6 fractions (C_{sf6})
- $\Delta Q \simeq -0.22$ pC if ΔC_{sf6} : 2.0%→2.1%
- $\Delta Q(\Delta C_{sf6})$, $\Delta\varepsilon(\Delta C_{sf6})$ are modelled
- Variation in CO2 less easy to interpret (secondary avalanches, that appear if CO2 fraction reduced, not modelled)



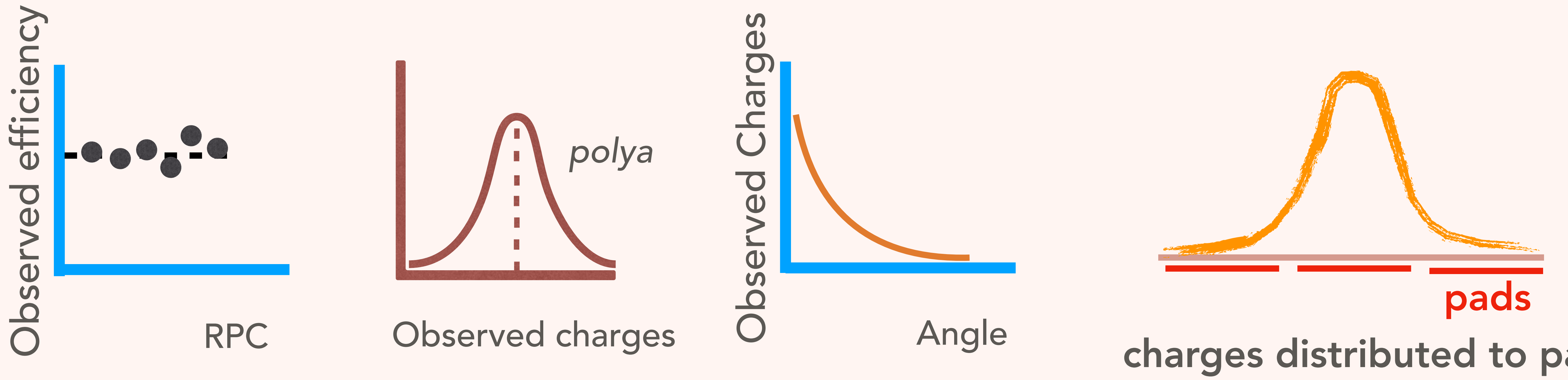
2- DIGITIZER

SDHCAL DIGITIZER

Particle± cross RPC Type/βγ → ionisation → Initial Charges → avalanche → Charges → induction, threshold → Induced signal Distribution to pads

G4 Step preselection

x



charges distributed to pads: hits

SDHCAL DIGITIZER

Particle± cross RPC
Type/βγ

ionisation

Initial
Charges

avalanche

Charges

induction, threshold

Induced signal
Distribution to pads

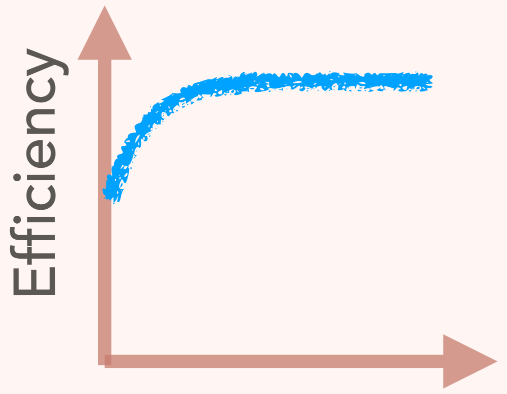
G4 Step
preselection

x

charges distributed to pads:hits

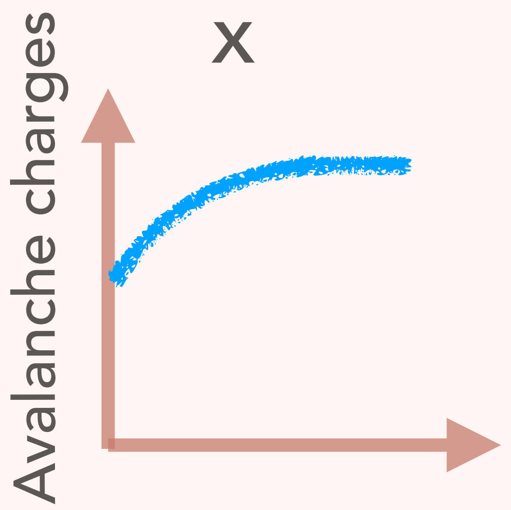
Modelling from
avalanche simulation

x



N initial electrons
ΔT, ΔP, ΔD, ΔC_{sf6}

x



N initial electrons
ΔT, ΔP, ΔD, ΔC_{sf6}

Analytical functions that
summarise Avalanche
simulations
(10^4 CPU hours)

SDHCAL DIGITIZER

```xml
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 <execute>
  <processor name="MyAIDAProcessor"/>
  <processor name="MySimDigital"/>
  <processor name="MySimDigitalLinkToParticles"/>
  <processor name="MyLCIOOutputProcessor"/>
 </execute>

 <global>
  <parameter name="LCIOInputFiles">
    ../../SDHCALSim/script/pi-_5GeV.slcio
  </parameter>
  <!-- limit the number of processed records (run+evt): -->
  <parameter name="MaxRecordNumber" value="0" />

  <parameter name="SkipNEvents" value="0" />
  <parameter name="SupressCheck" value="false" />
  <parameter name="Verbosity" options="DEBUG0-4,MESSAGE0-4,WARNING0-4,ERROR0-4,SILENT"> MESSAGE </parameter>
  <parameter name="RandomSeed" value="1234567890" />
 </global>
```

```xml
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        <parameter name="tempVariation" type="float"> 0 </parameter>
        <parameter name="pressVariation" type="float"> 0 </parameter>

        <parameter name="widthVariation" type="float"> -1 </parameter>

        <parameter name="widthVariations" type="FloatVec"> 48 16 12 33 15 32 8 2 37 44 39 7 38 40 42 4 34 29 27 29 30 9 48 23 45 49 5 8 46 18 0 21 30 12
10 45 5 18 34 43 40 38 0 14 5 28 48 15 </parameter>
```

(Use of N initial electrons), ΔT, ΔP, ΔD, ΔC_{sf6} Parameters of the digitiser

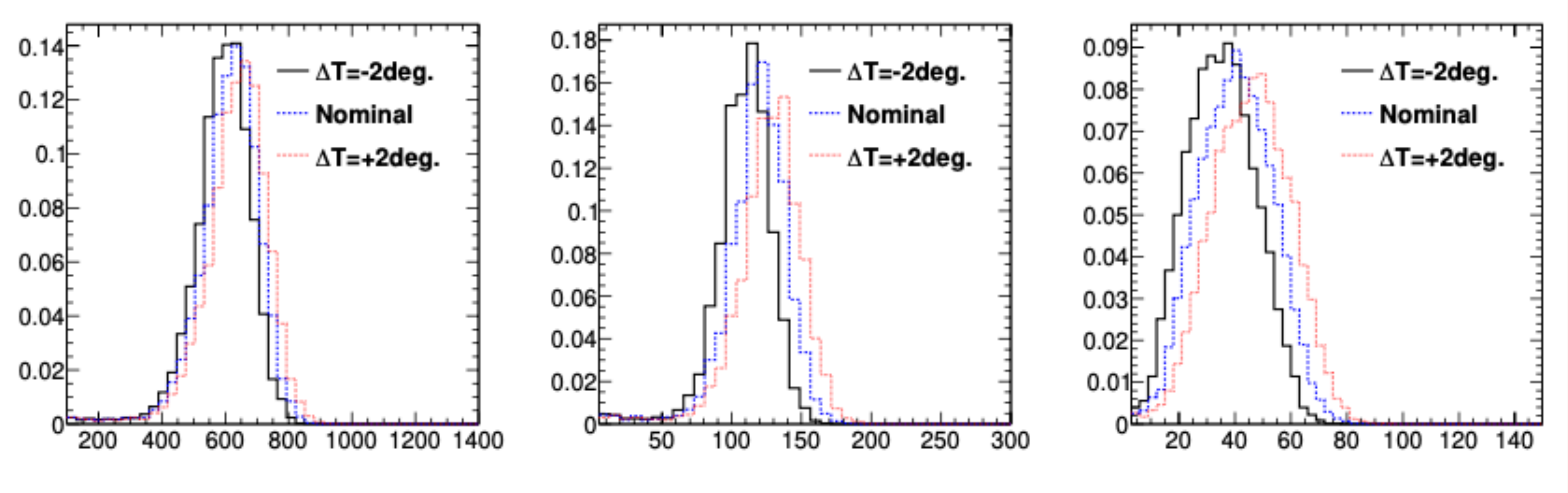
- **Full simulation function of different parameters, from Geant 4 to final detector output: hits**

3- RESULTS

GAP WIDTH VARIATIONS: HITS

- **Events simulated with 2 temperature variations:**
  - **+ and -2℃ (homogeneous)**
  - **Number of Hits vary by: 3% (Total), 9%(2nd thr.) and 15% (3rd thr.) for +2℃**

40 GeV Pions

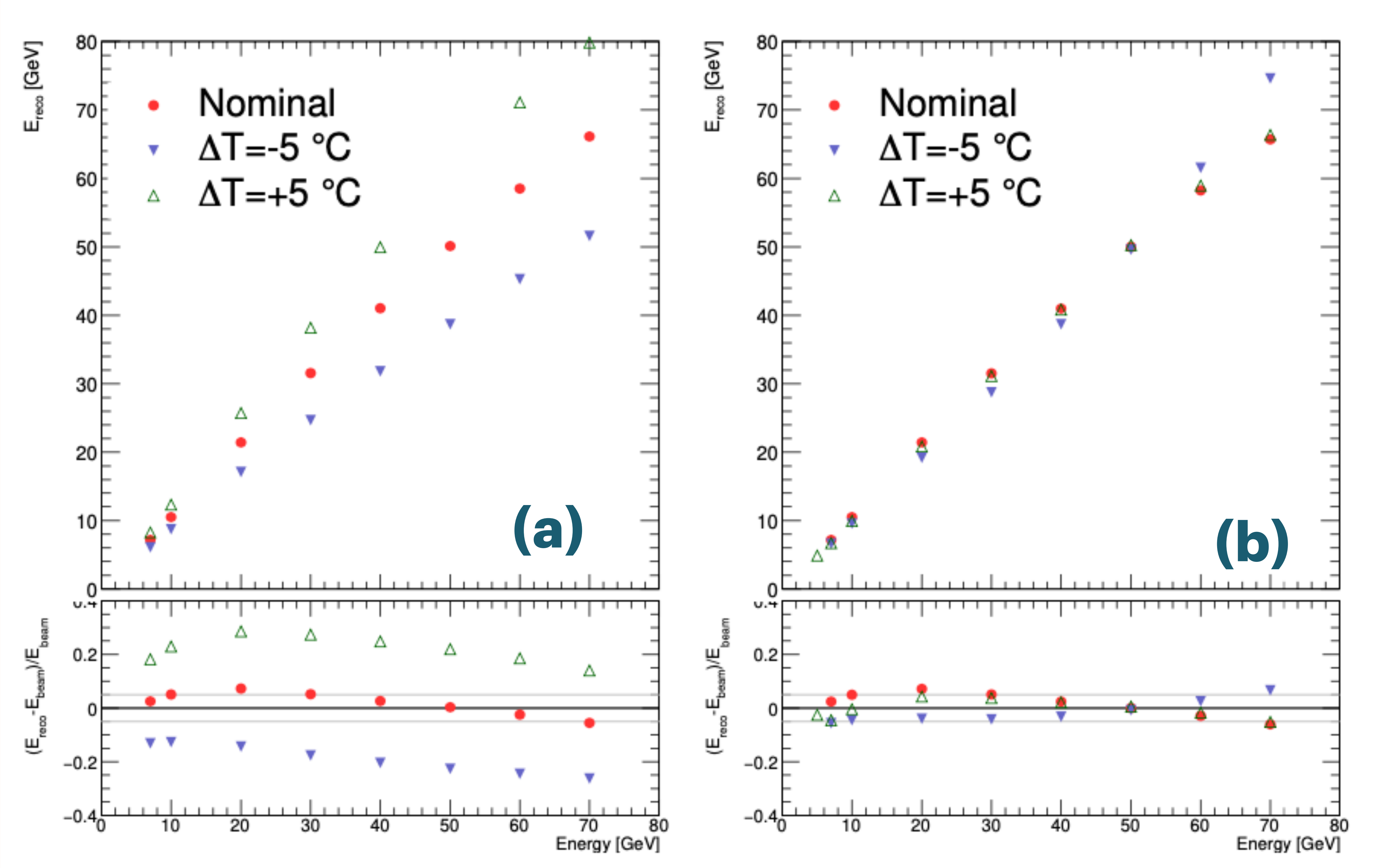


GAP WIDTH VARIATIONS: ENERGY

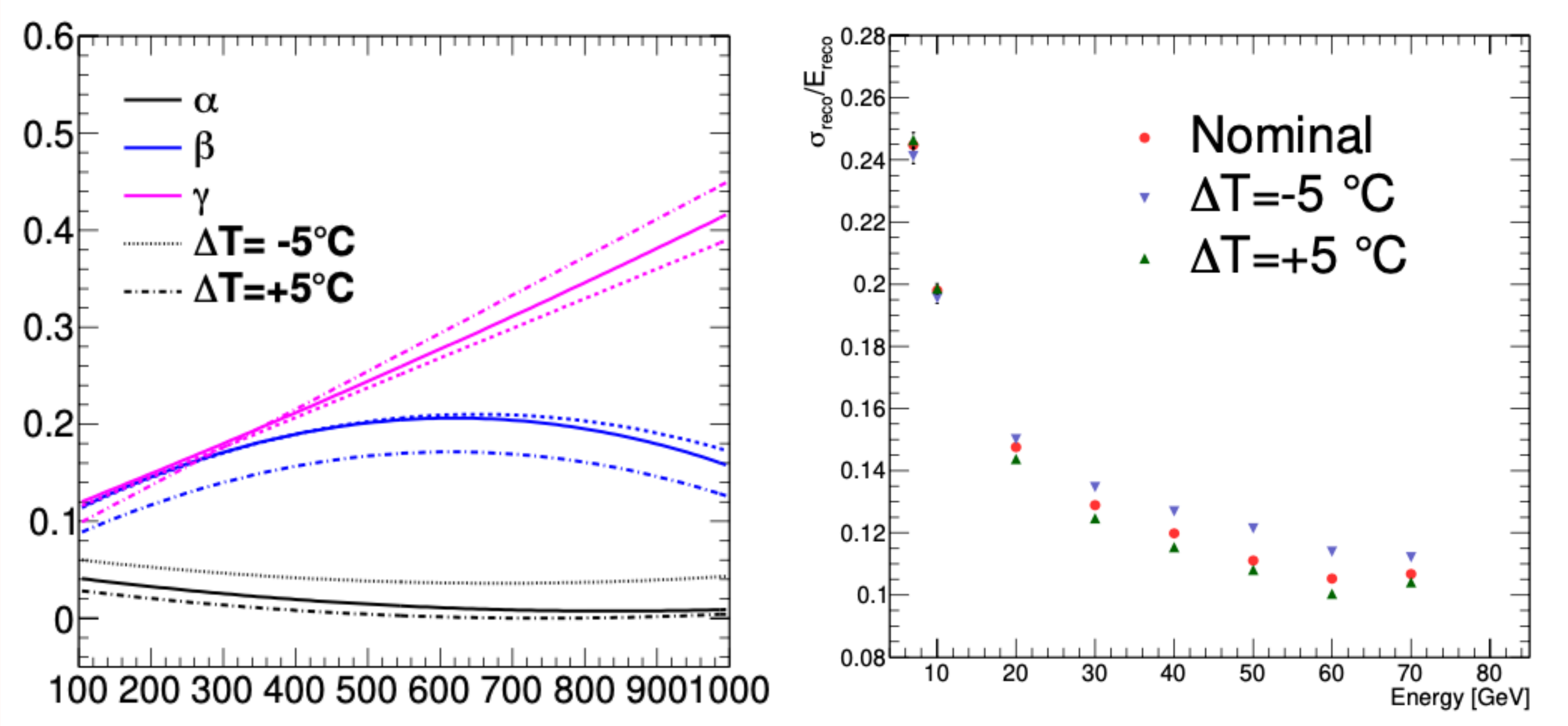
- **Reconstructed energy:**

$$E_{\text{reco}} = \alpha(N_{\text{tot}}) \times N_1 + \beta(N_{\text{tot}}) \times N_2 + \gamma(N_{\text{tot}}) \times N_3$$

- **2 scenarios:**
  - pessimistic: temperature change after the definition of the energy scale (α,β,γ) **(a)**
  - optimistic: constant temperature, energy is recalibrated, (α,β,γ) are defined for each situation, the new parameters absorb the variations in number of hits **(b)**



GAP WIDTH VARIATIONS: ENERGY



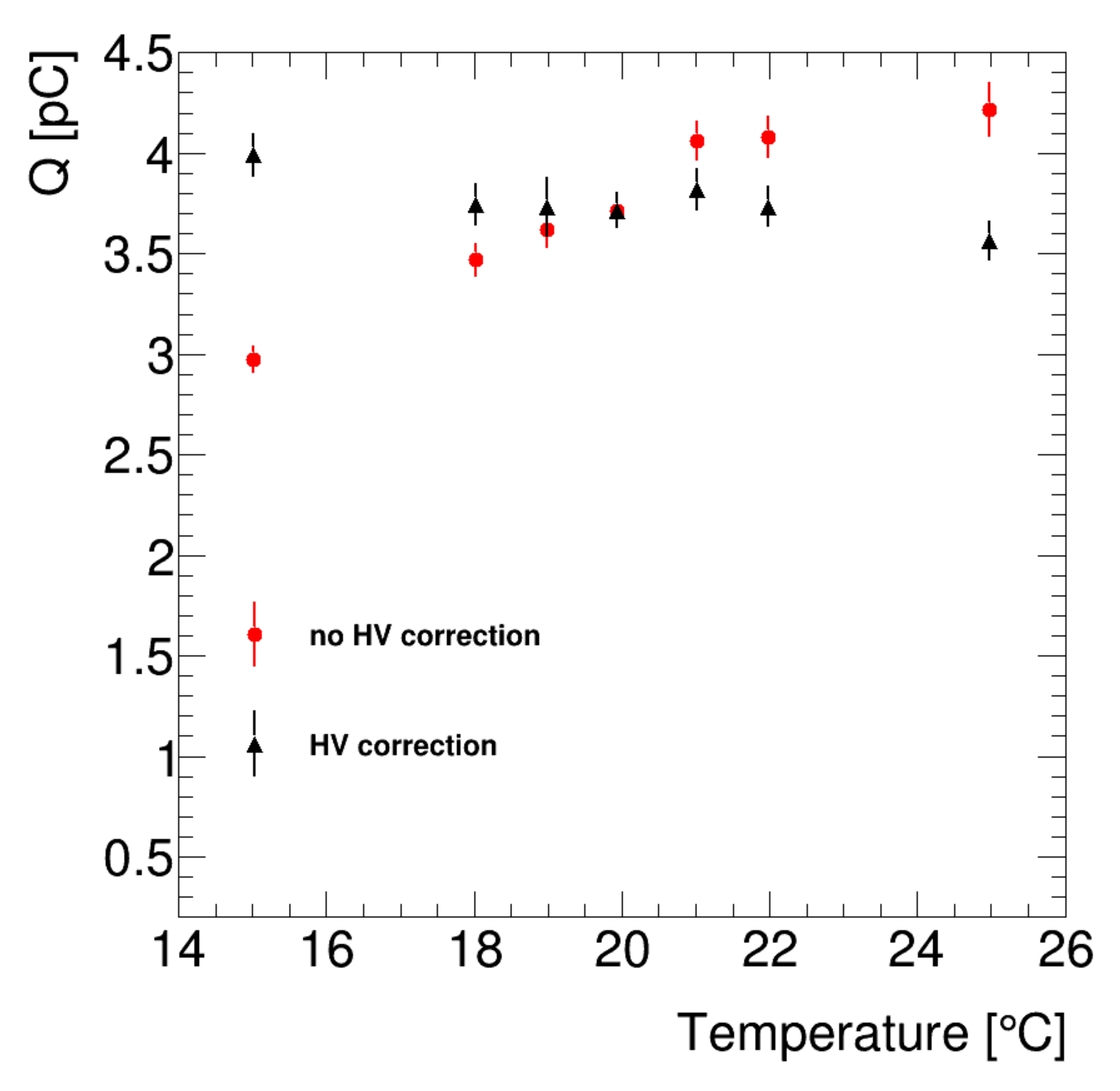
- (α,β,γ) optimisation restore the linearity with some resolution loss in the case of a temperature decrease

DETECTOR BASED CORRECTIONS

- **Assumed stable HV. In many runs online corrections used.**
- **HV was rescaled following T/P:**

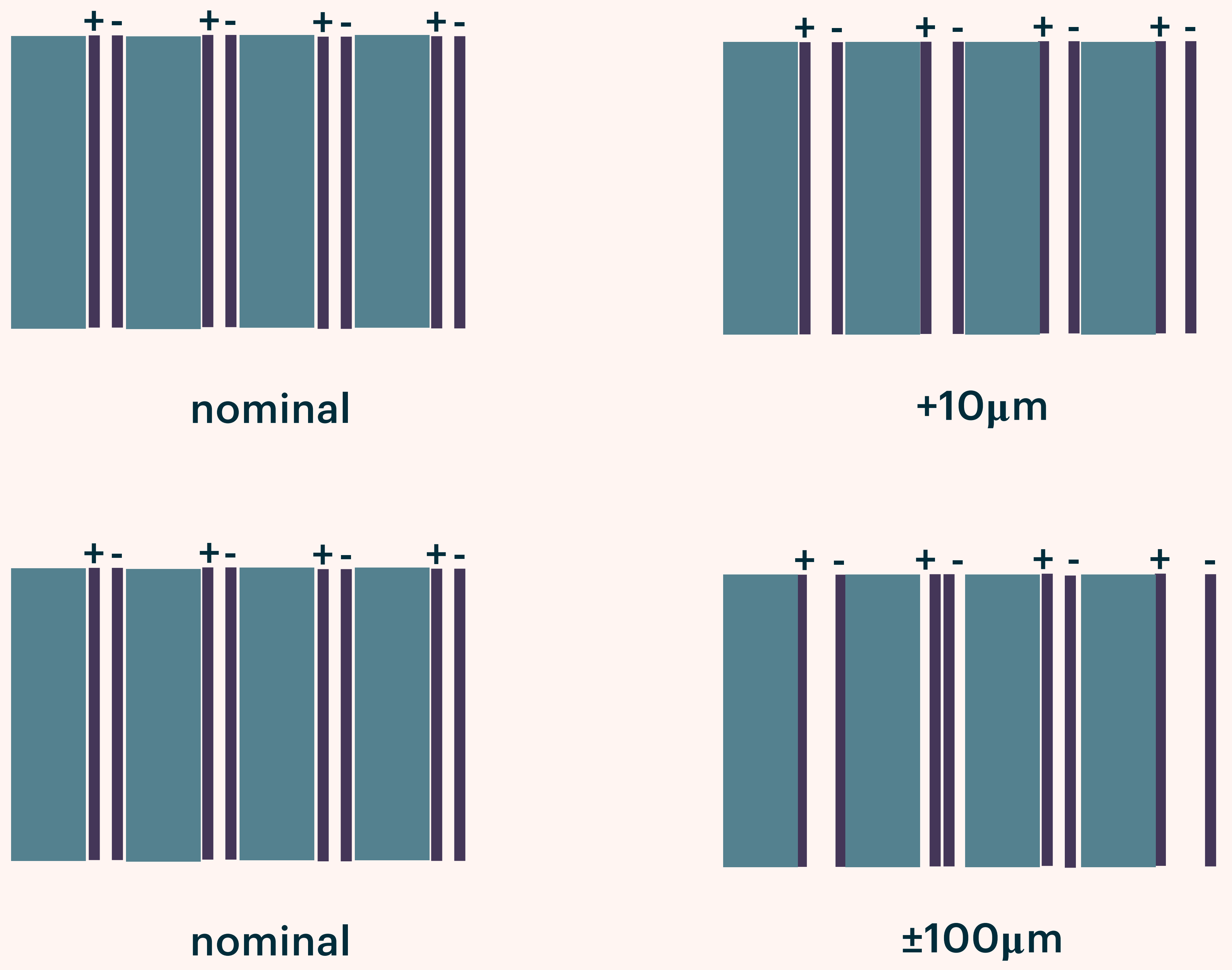
  $HV(T,P) = (P/T)\ HV_{nom}(T_{nom}/P_{nom})$

- **Dedicated simulation where T was varied and HV was varied as 1/T**
  - **Rescaling HV as 1/T absorbs most of the temperature effect**
  - **Tends to overcorrect: +0.15pC/Degree (no correction) → -0.05pC/Degree (HV correction)**
- **Temperature effect is divided by ~3 when detector based corrections are applied**



GAP WIDTH VARIATIONS: HITS

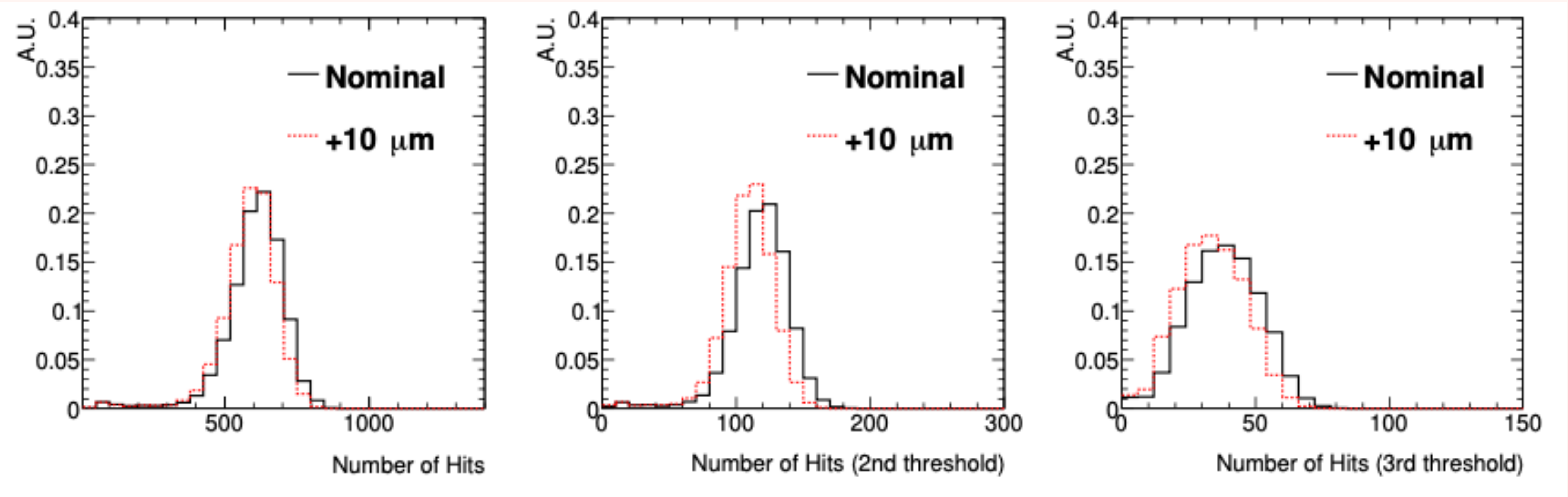
- **Events simulated with 2 geometries**
- **2 déformations:**
  - +10µm (homogeneous)
  - ±100µm (smearing following a flat distribution): models an intrinsic non-uniformity with a tolerance of 50µm from each side of the chambre



GAP WIDTH VARIATIONS: HITS

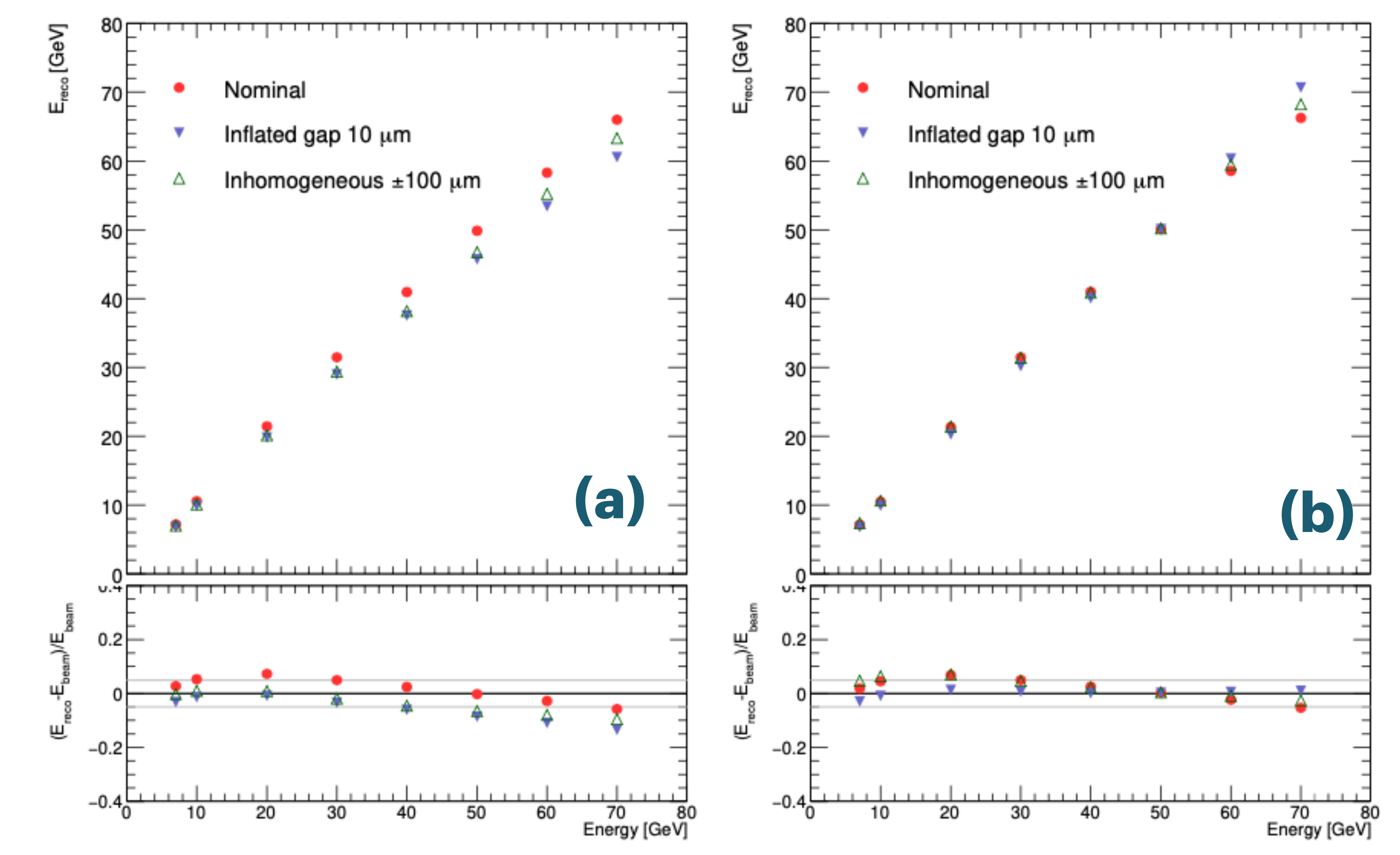
- **Events simulated with 2 geometries**
- **2 déformations:**
  - +10µm (homogeneous)
  - ±100µm (smearing following a flat distribution): models an intrinsic non-uniformity with a tolerance of 50µm from each side of the chambre
- **Number of Hits vary by: 4% (Total), 8%(2nd thr.) and 12% (3rd thr.) for +10µm**

40 GeV Pions

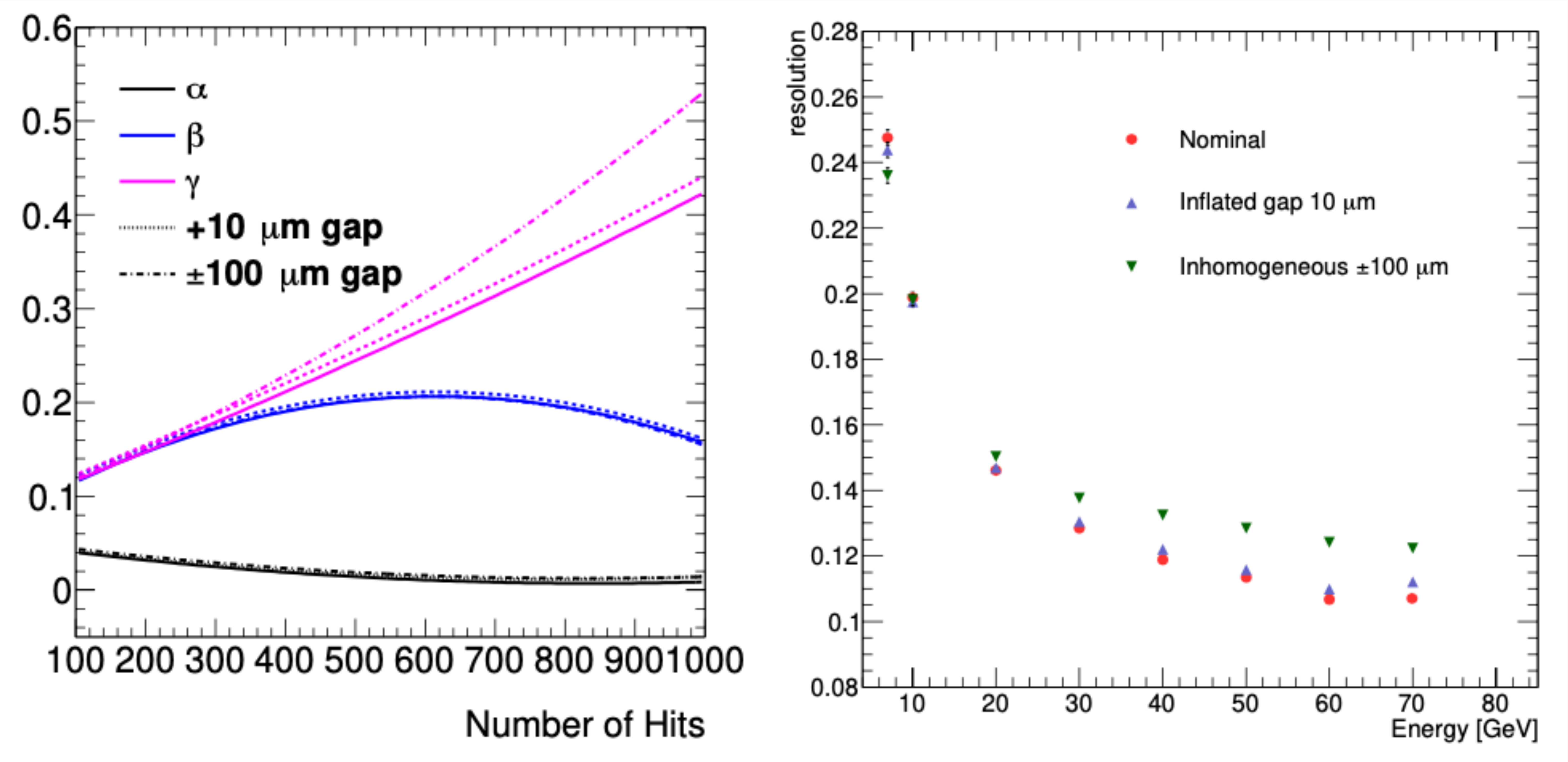


GAP WIDTH VARIATIONS: ENERGY

- **2 scenarios:**
  - pessimistic: deformation of the gap after the definition of the energy scale (α,β,γ) **(a)**
  - optimistic: frozen deformation, energy is recalibrated, (α,β,γ) are defined for each situation, the new parameters absorb the variations in number of hits **(b)**



GAP WIDTH VARIATIONS: ENERGY



- (α,β,γ) optimisation restore the linearity with some resolution loss in the case of a gap width smearing

SIMULATION SUMMARY

40 GeV pions

		$\Delta Q/Q$ [%]	$\Delta N_{tot}/N_{tot}$ [%]	$\Delta N_2/N_2$ [%]	$\Delta N_3/N_3$[%]	Energy Bias [%]
Gap	$+10\ \mu m$	-7.2 ± 0.3	-3.5 ± 0.2	-8.0 ± 0.3	-12.3 ± 0.5	-8.6 ± 0.5
	$\pm 100\ \mu m$		-7.9 ± 0.2	-13.7 ± 1.8	-19.2 ± 0.2	-6.9 ± 0.2
T	$+1°$ C	4.1 ± 0.4	1.9 ± 0.2	4.3 ± 0.4	7.5 ± 0.7	4.2 ± 1.1
P	$+1$ mbar	-1.09 ± 0.11	-0.5 ± 0.1	-1.2 ± 0.2	-1.9 ± 0.2	-1.17 ± 0.13

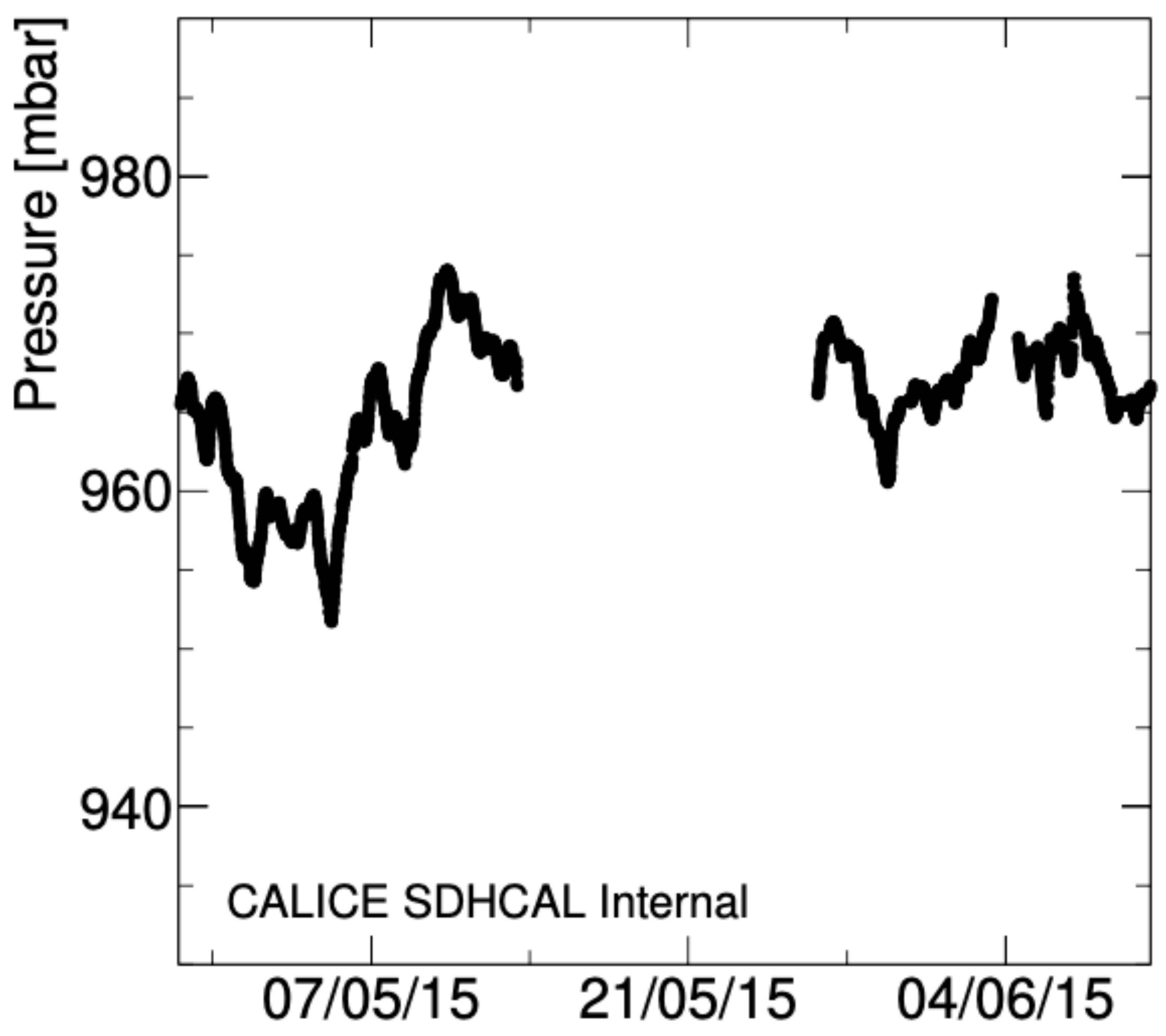
Energy bias in the pessimistic scenario

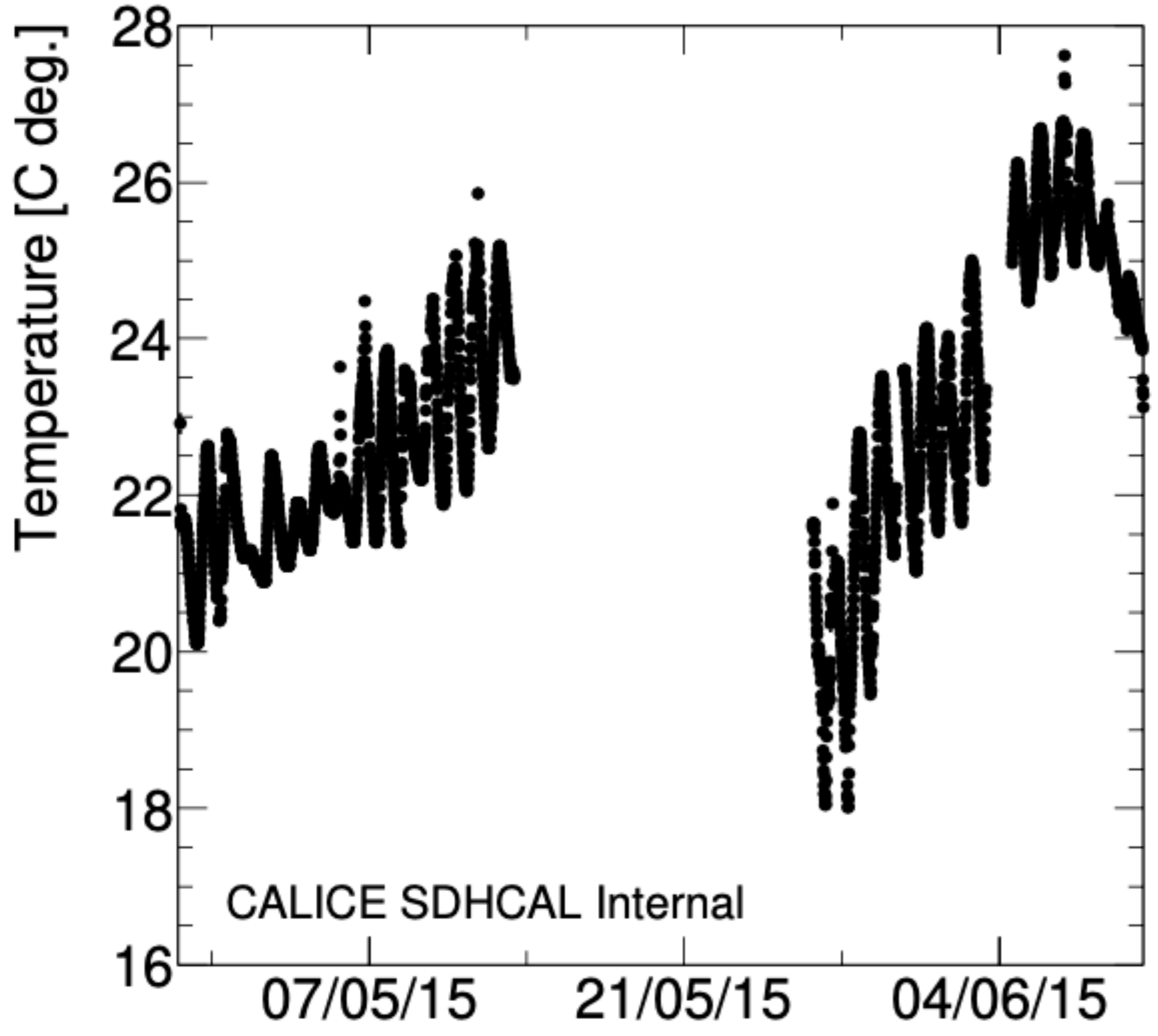
- **2 messages:**
  - **Simulation outputs depend on data taking conditions: assume the detector stable, or that variations are compensated (eg. HV versus T/P)**
  - **Predicts a detector response stability**

4- TEST BEAM DATA

SLOW CONTROL DATA

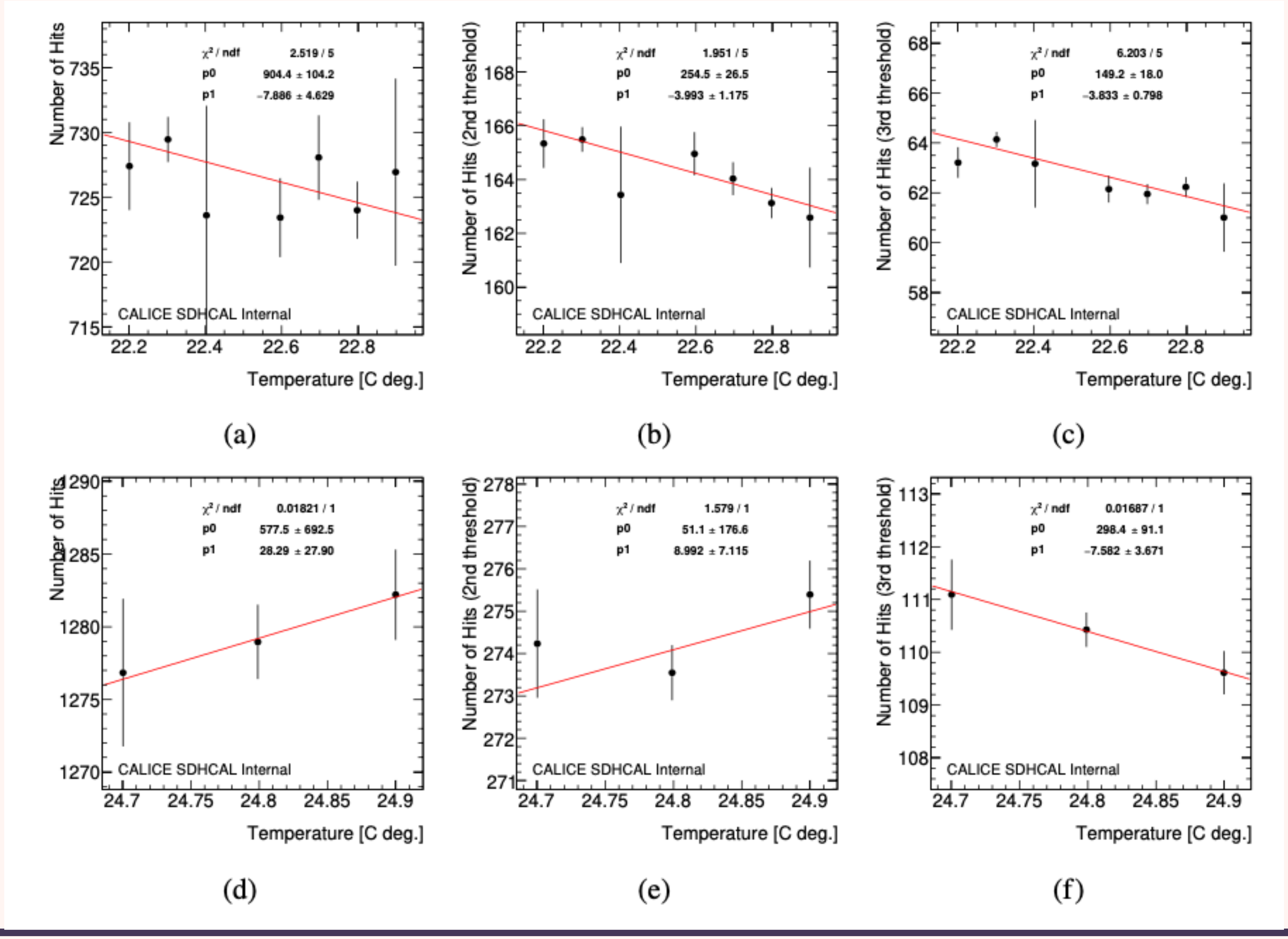
- **Slow control data extracted and associated to each TB event**
- **Day/Night variations in Temperature observed despite cooling**
- **In many runs HV was rescaled following adapted to T/P**
- **Selected a 48 period where HV was not changed**





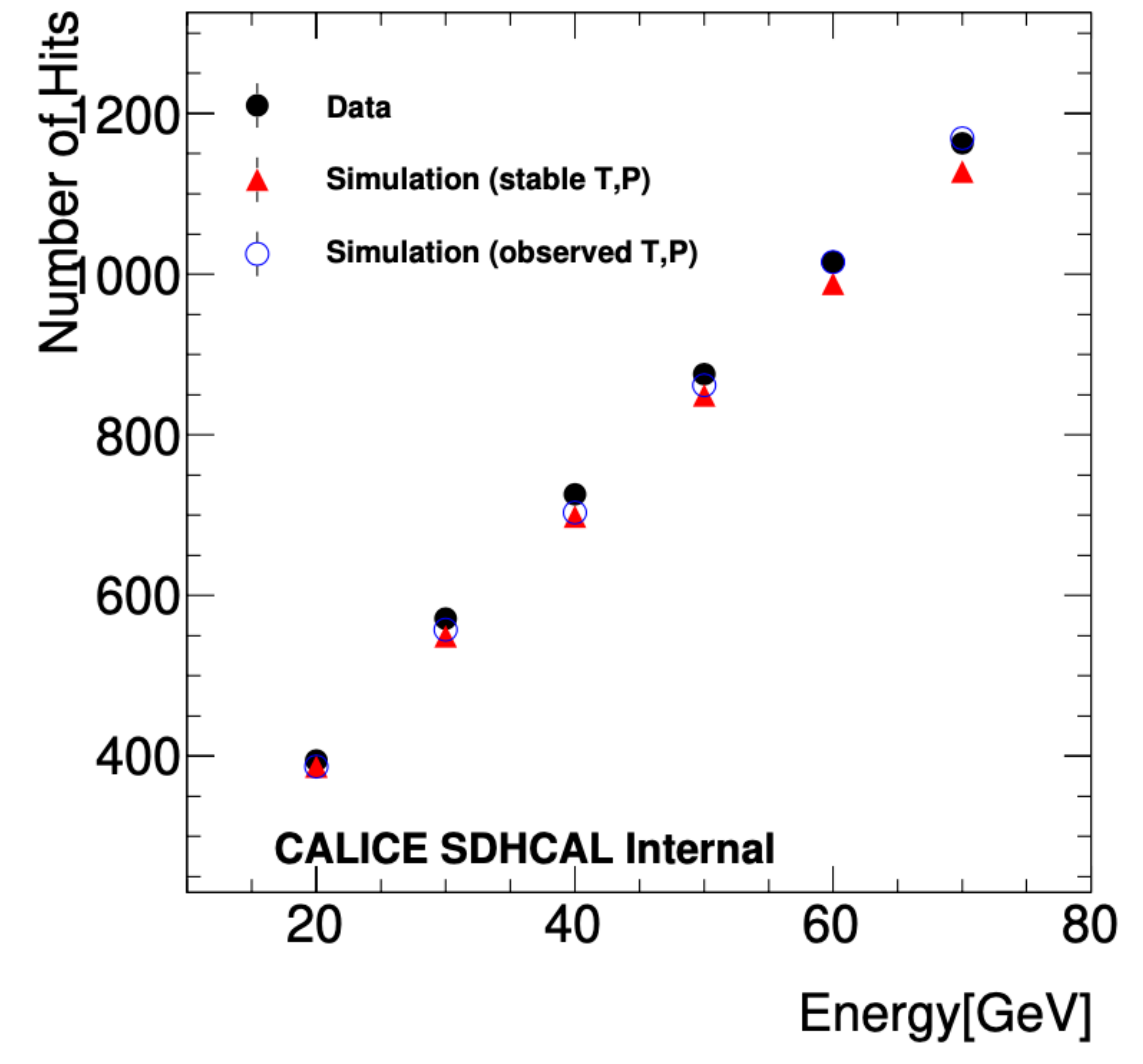
IN RUN STABILITY

- **Runs tased at different energies cannot be compared**
- **Analysing N_{hits} versus T and P in individual runs**
- **Different trends observed, some in contradiction**
- **other sources of variation in the runs (beam intensity variation + saturations ?)**



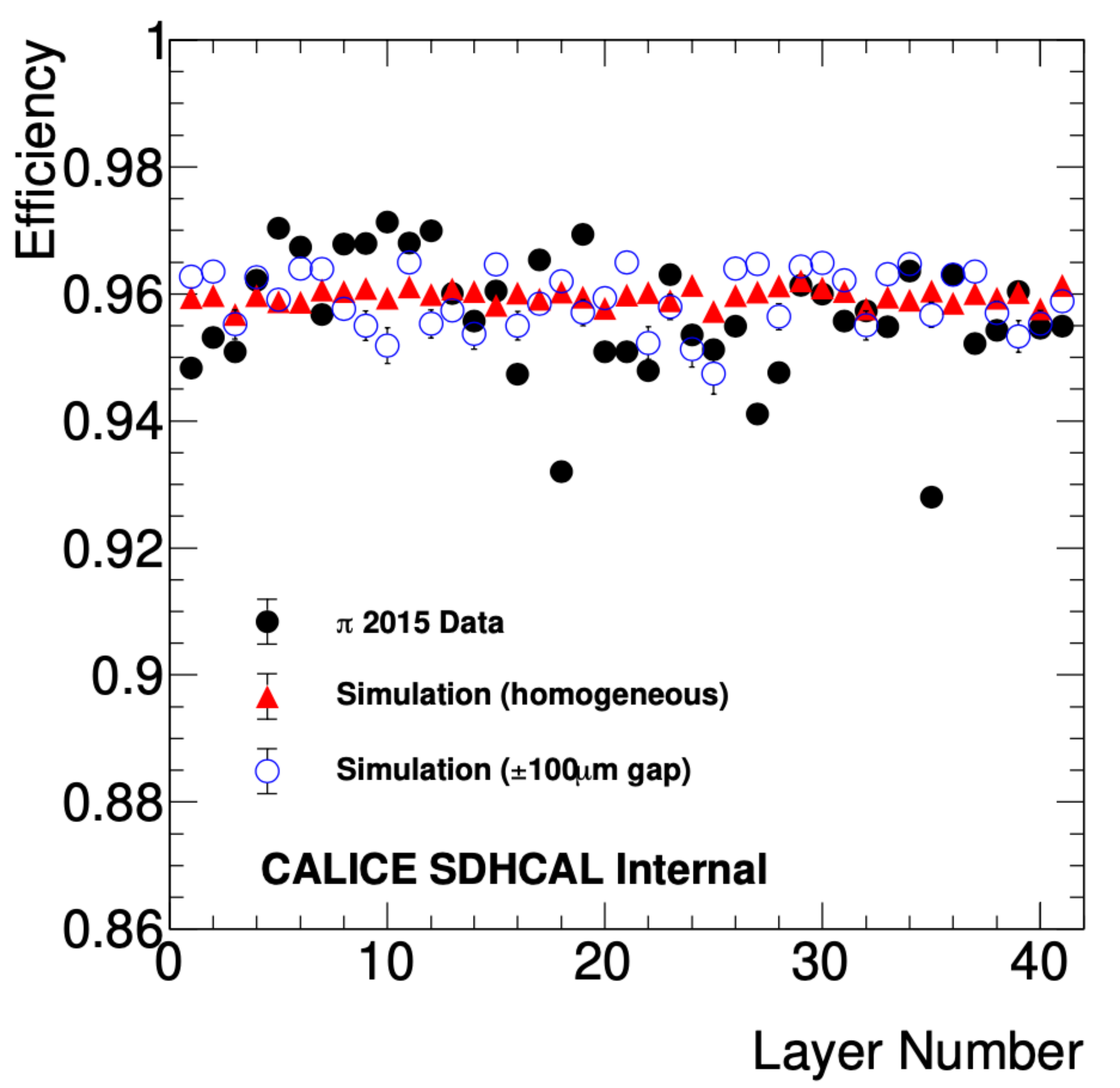
DATA/SIMULATION

- **Data/Monte Carlo comparison**
- **Producing two simulations:**
  - **Simulation with constant Q**
  - **Simulation where for each run the observed ΔT, ΔP are injected**



DATA/SIMULATION

- Data/Monte Carlo comparison
- Producing two simulations:
  - Simulation with constant gap width
  - Simulation injecting a gap width variation (layer to layer ±100µm)



SUMMARY

- Digitizer extended to account for various effects using avalanche modelling (10^4 CPU hours)
- Full simulation used to predict detector stability
- At Digitial level (inclusive hits) detector is rather stable: typically at $< 5\%$ level
- Semi-digital information (thresholds) more sensitive to the various effects, typically 10% level
  - can be partially compensated at detector level or software level
- Based on data, other sources of instabilities in beam tests (saturations, readout, etc)

WORK DOCUMENTED

Description and stability of a RPC-based calorimeter in electromagnetic and hadronic shower environements

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Abstract: The CALICE Semi-Digital Hadron Calorimeter technological prototype that was completed in 2011 is a sampling calorimeter using Glass Resistive Plate Chamber detectors as the active medium. This technology is one of the two options proposed for the hadron calorimeter of the International Large Detector for the International Linear Collider. The prototype was exposed in 2015 to beams of muons, electrons and pions of different energies at the CERN Super Proton Synchrotron.

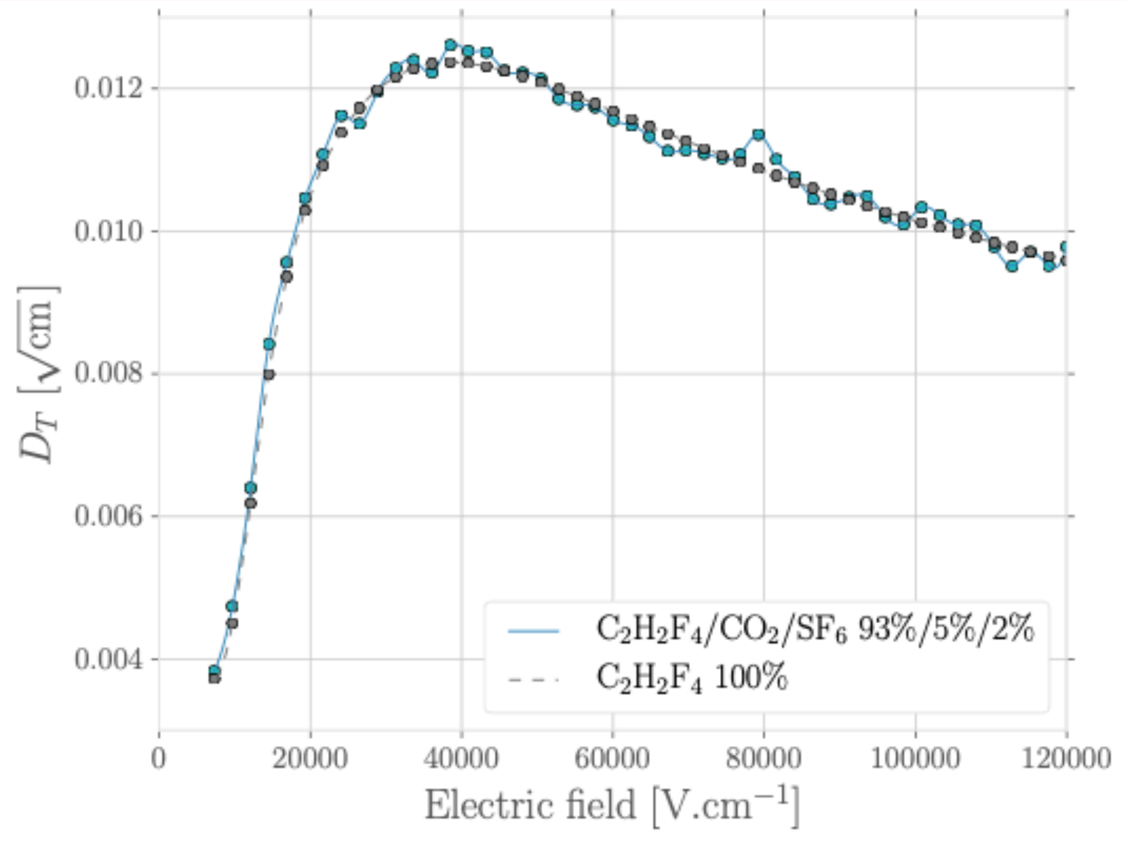
The use of this technology for future experiments requires a reliable simulation of its response that can predict its stability. The prototype is simulated using GEANT4 and a custom digitisation algorithm. It describes the full path of the signal: showering, gas avalanches, charge induction and hit triggering. The simulation was tuned using muon tracks and electromagnetic showers in order to account for detector inhomogeneity and tested on hadronic showers collected in test beam. Initial digitisation algorithm was described in JINST 11 (2016) 6 P06014. Further developments of the algorithm are described and used to predict the stability of the detector performances against various changes in the data taking conditions like temperature, magnetic field, gap width variations, etc. These predictions are confronted with test beam data and provide an attempt to explain some of the detector behaviors. The detector efficiency is found to be rather stable regarding to data taking conditions like temperature and potential detector inhomogeneities while the density measurements are more affected.

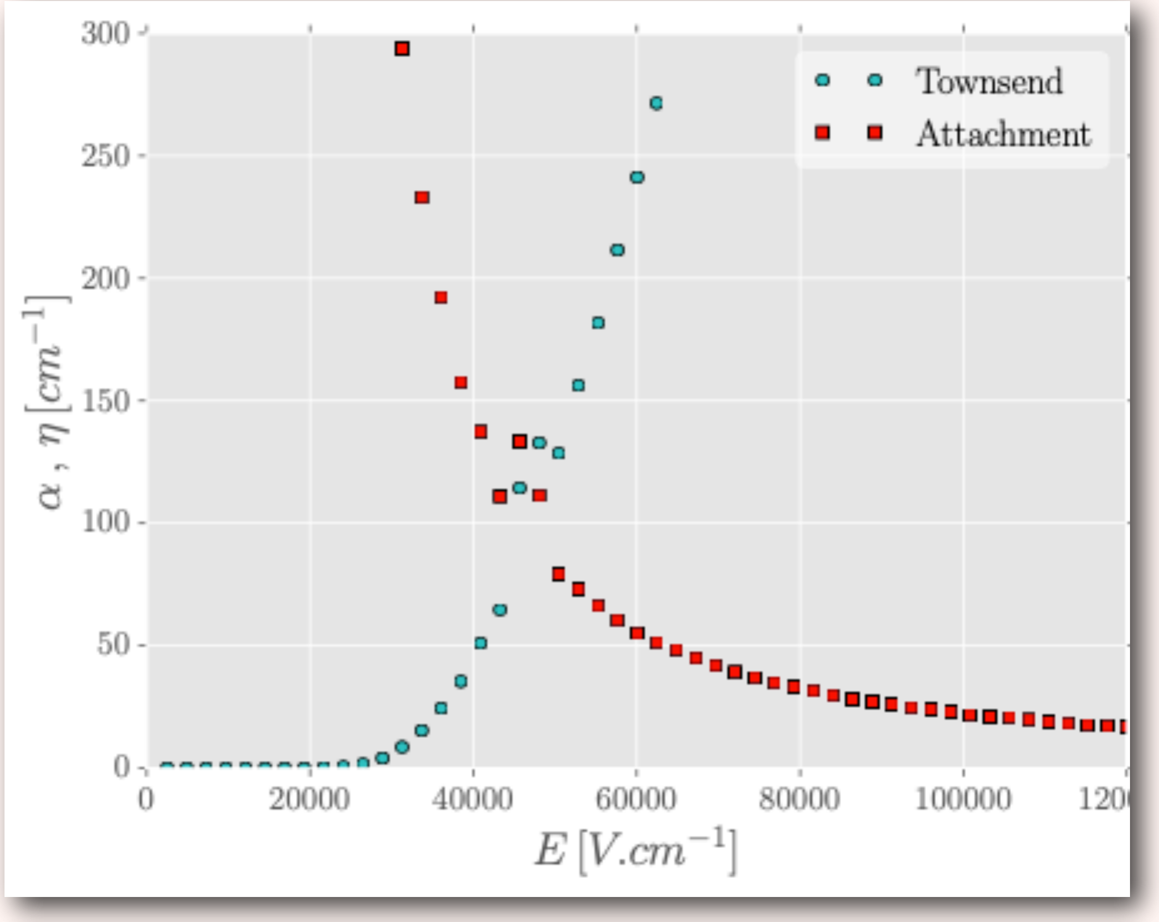
Contents

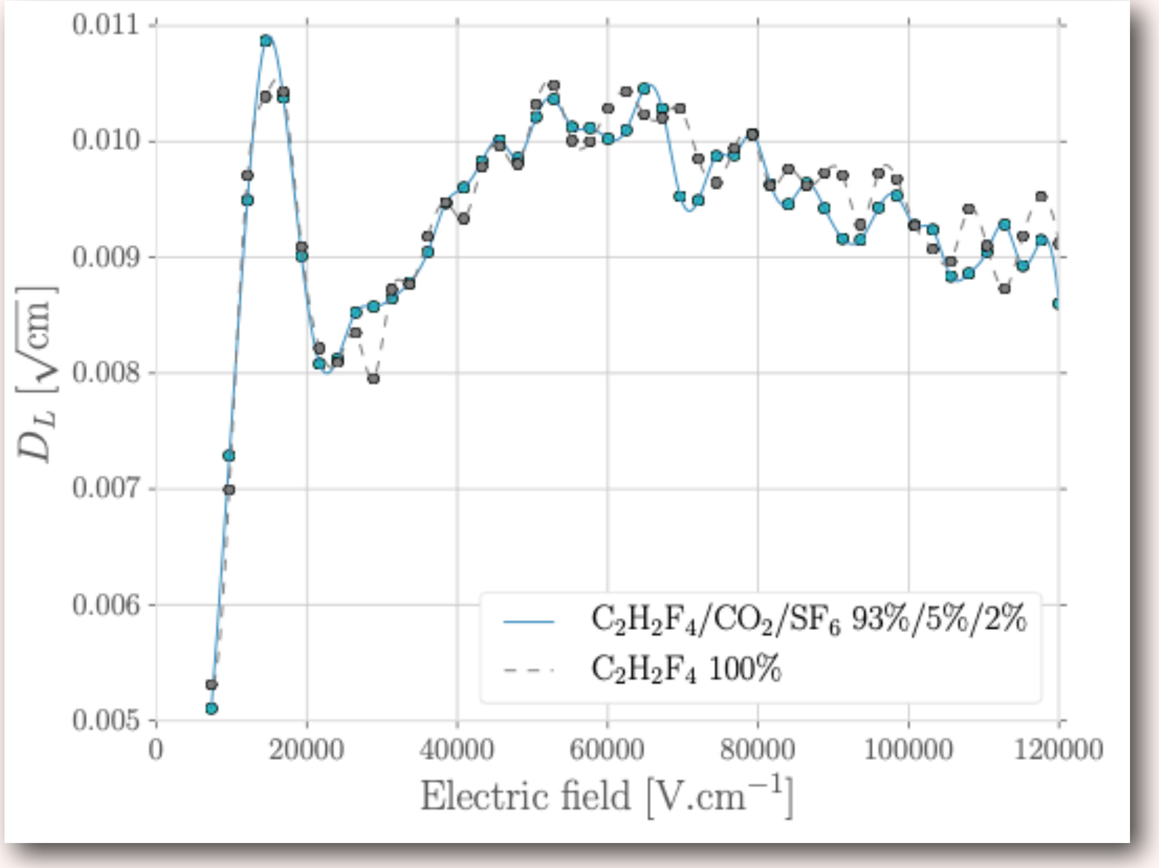
BACKUP

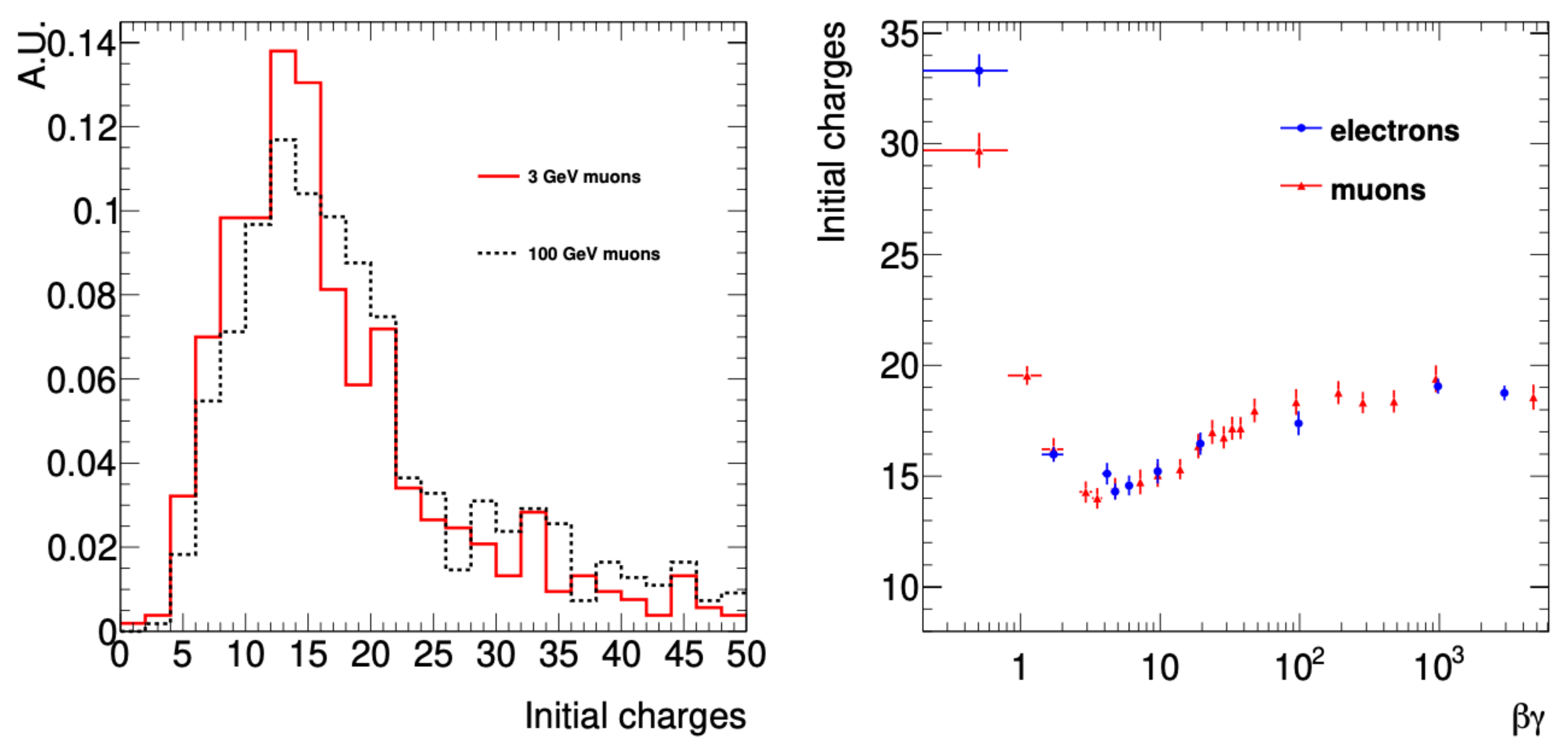
AVALANCHE SIMULATION

- **Monte Carle simulation of the avalanche:**
  - **Follow the evolution of the number of electrons and ions as a function of time and position**
  - **Take into account the changes in the magnetic field**
- **Simulation account for:**
  - **Multiplication and absorption probabilities from Magboltz**
  - **Diffusion**
  - **Space charge effect**
  - **Induced charge**



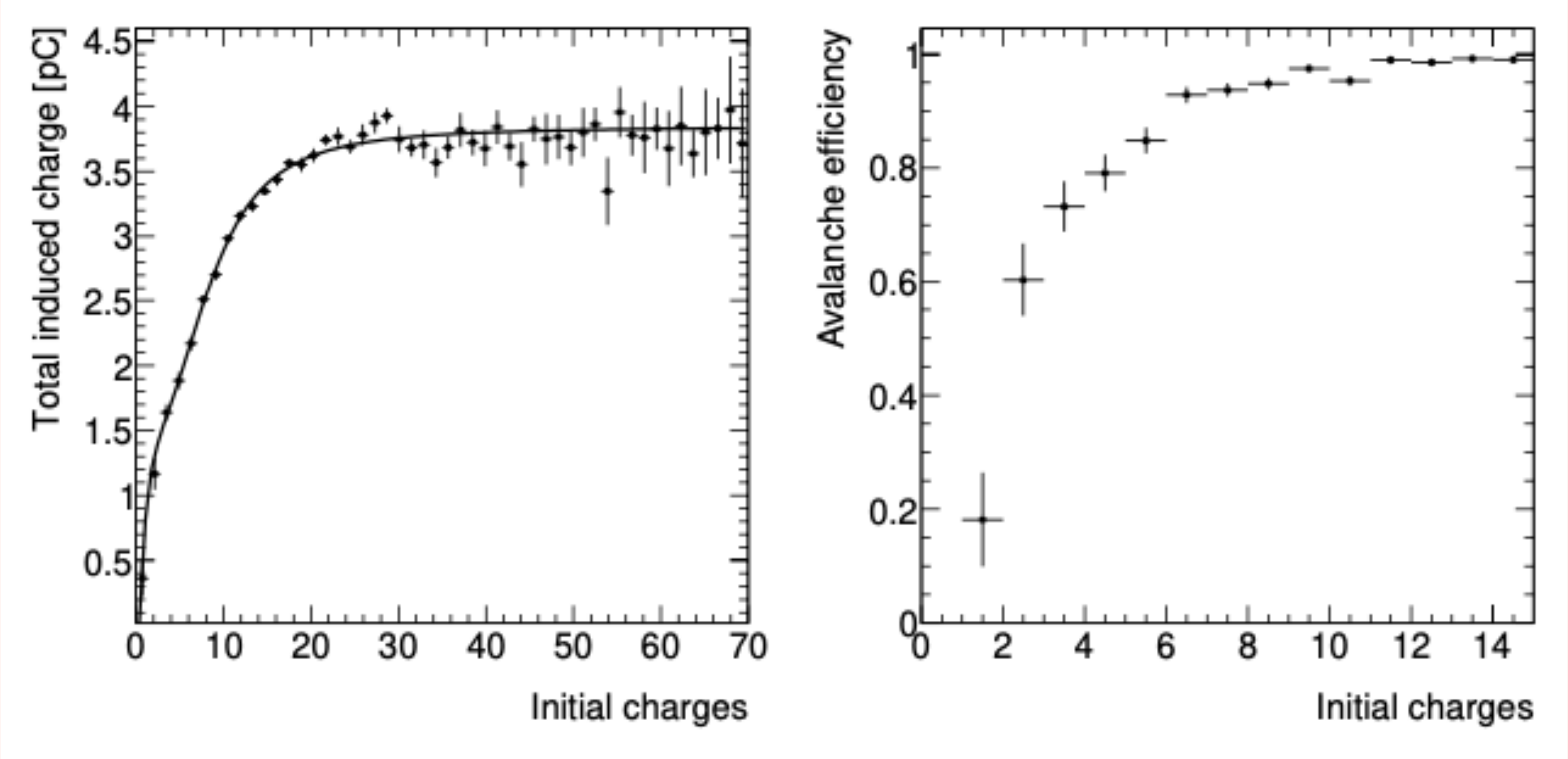





A.U.
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 5 10 15 20 25 30 35 40 45 50
Initial charges
3 GeV muons
100 GeV muons
Initial charges
35
30
25
20
15
10
1 10 10^2 10^3
βγ
electrons
muons

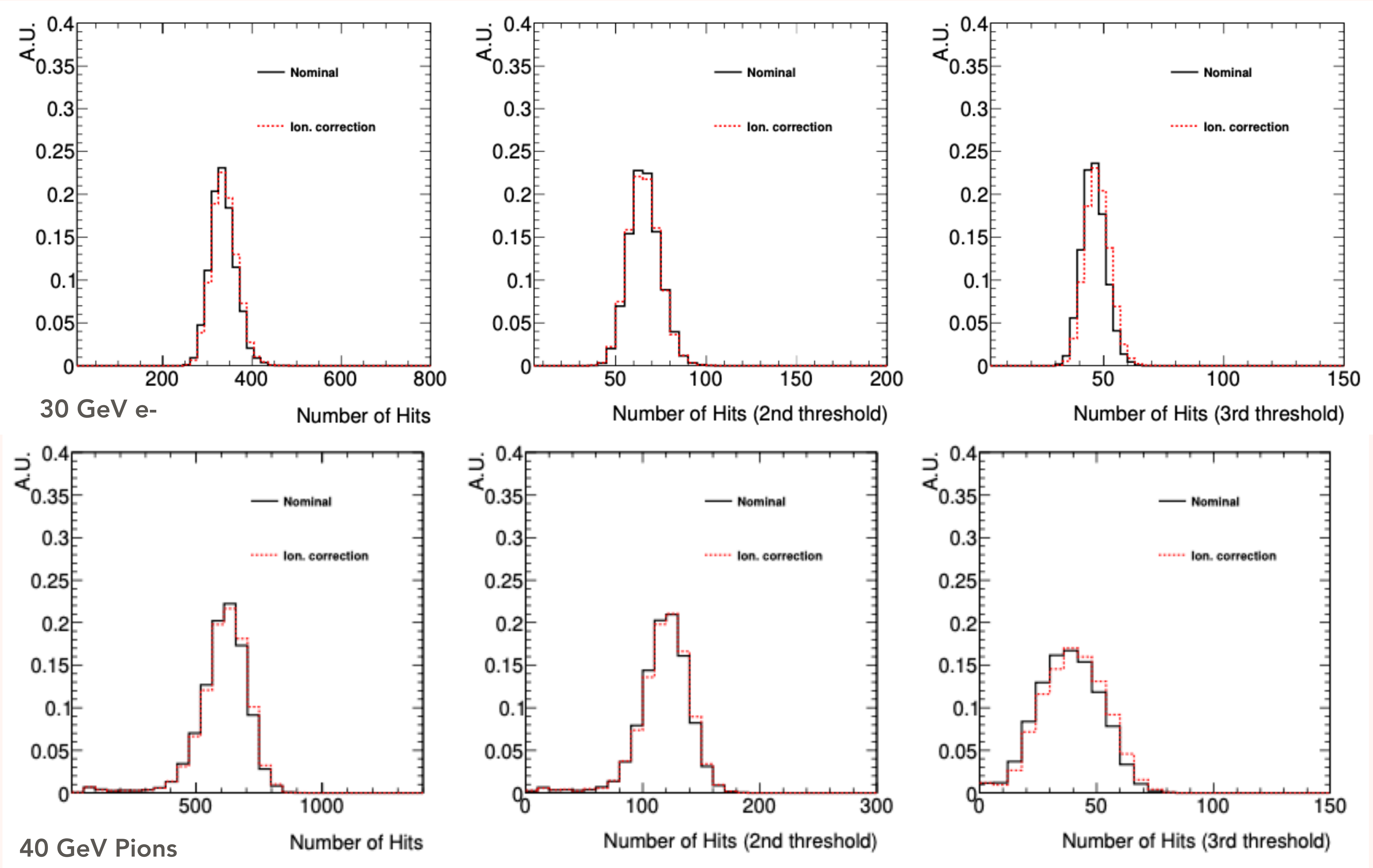
ADDING DEPENDENCE TO THE ENERGY DEPOSIT

- **Digitizer Polya defined with 100 GeV muons, many particles in a shower are not MIPs**
- **Avalanches induced by 700 keV—500 GeV muons and electrons are simulated**
- **Q**($N_{charges}$)**/Q(**μ100GeV**), ε(**$N_{charges}$**) / ε(**μ100GeV**) are modelled**
- $N_{charges}$ **given by Geant4 (deposited energy/29 eV)**

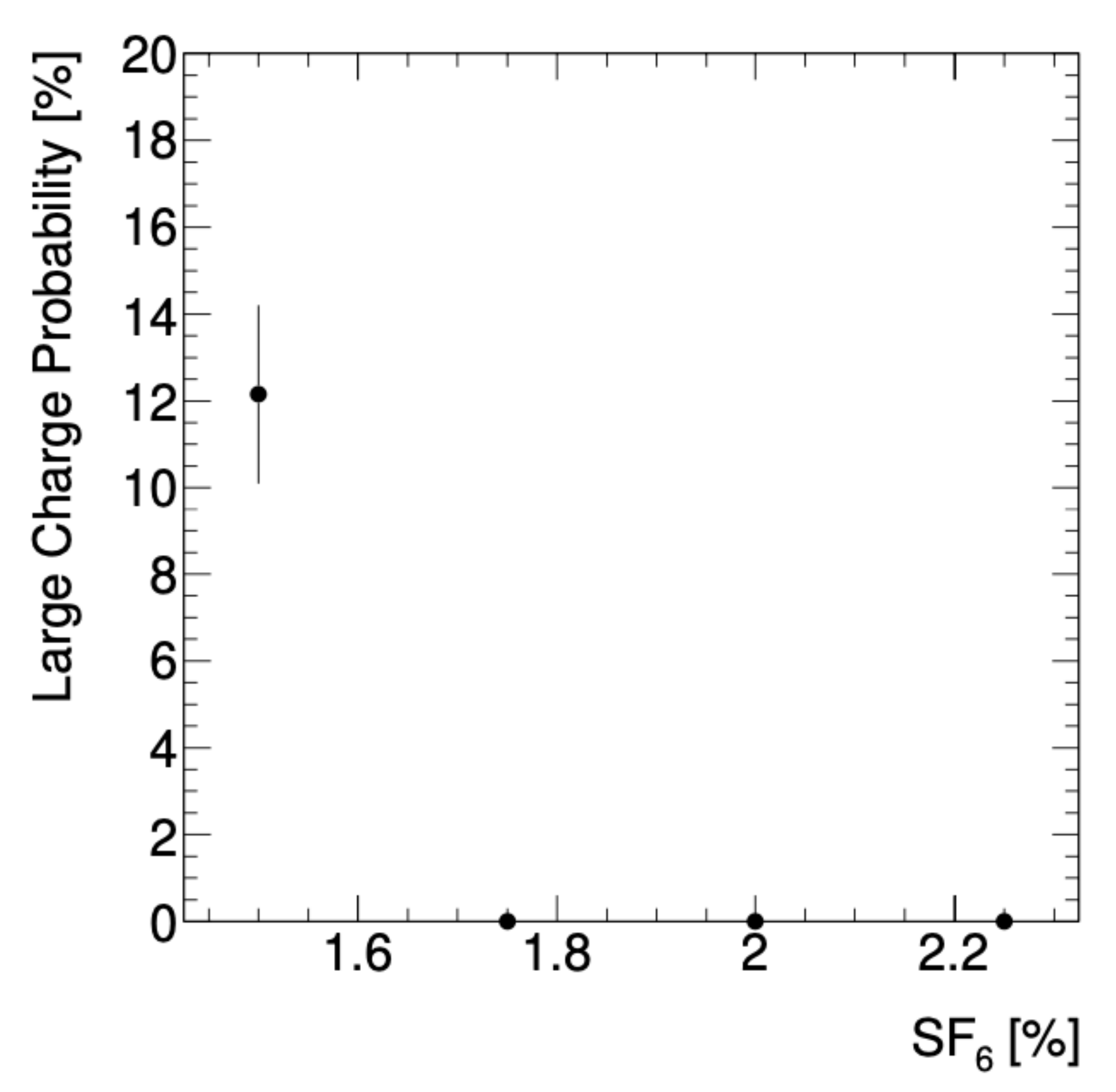


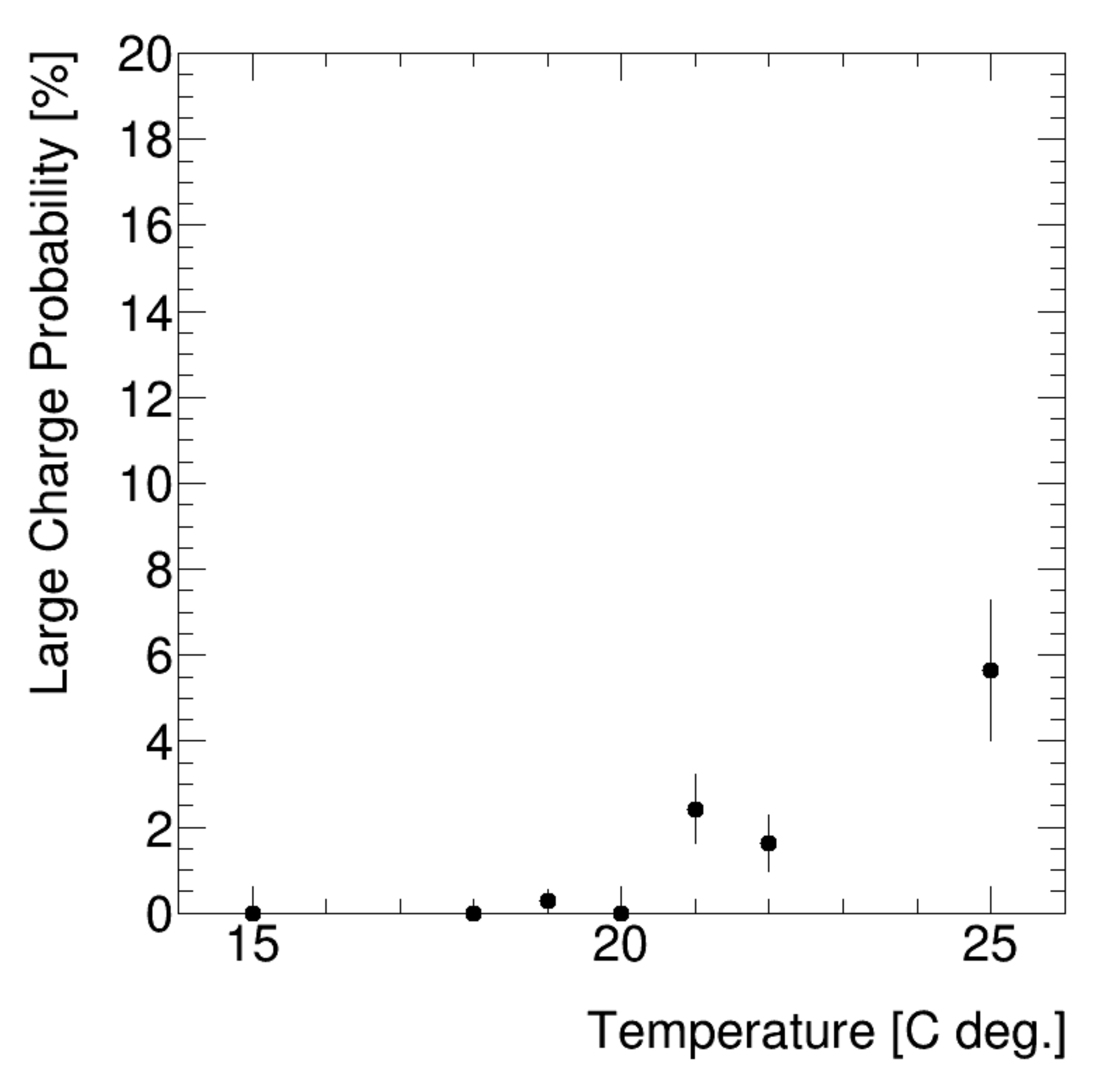
DEPENDENCE TO ENERGY DEPOSIT

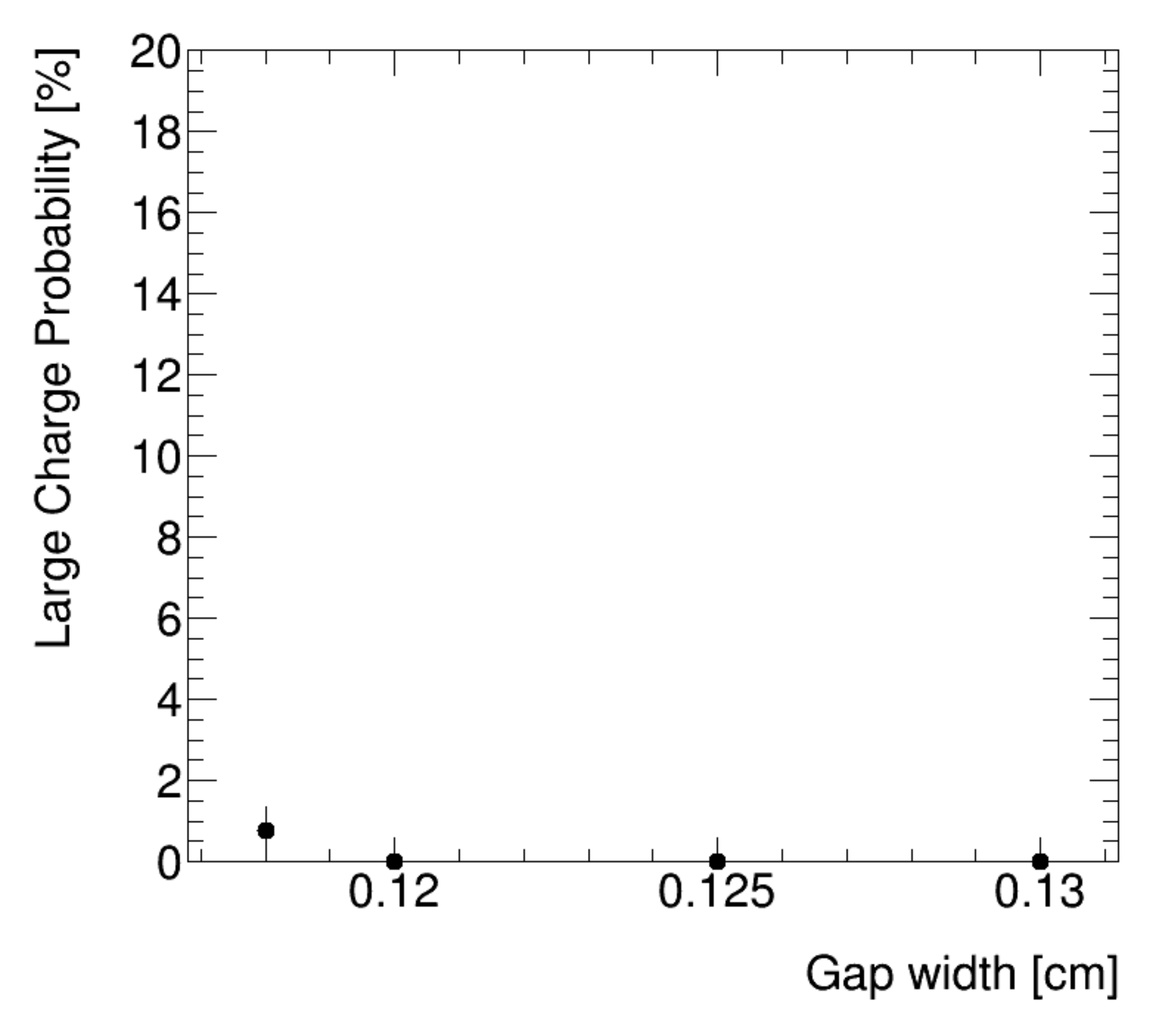
- Difference between using a constant Polya (independent from energy deposit in the gas) and a Polya that is rescaled as a function of energy deposit
- Affects mainly 3rd threshold (3% for 30 GeV electrons, 5% for 40 GeV pions)
- In the following, dependence is kept by default



STREAMERS



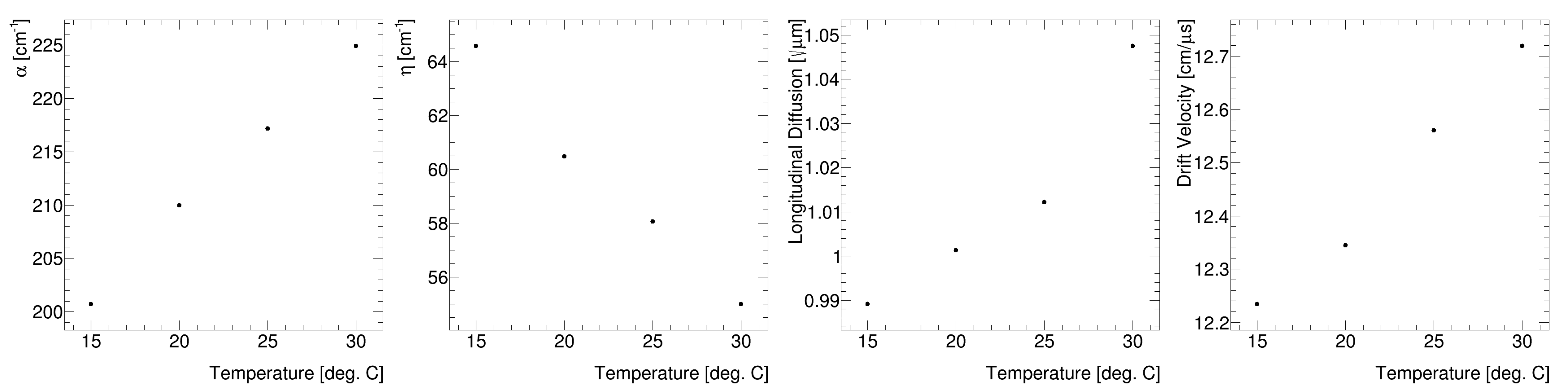




- **Trends in Large Charge Probability give an indication about streamers**

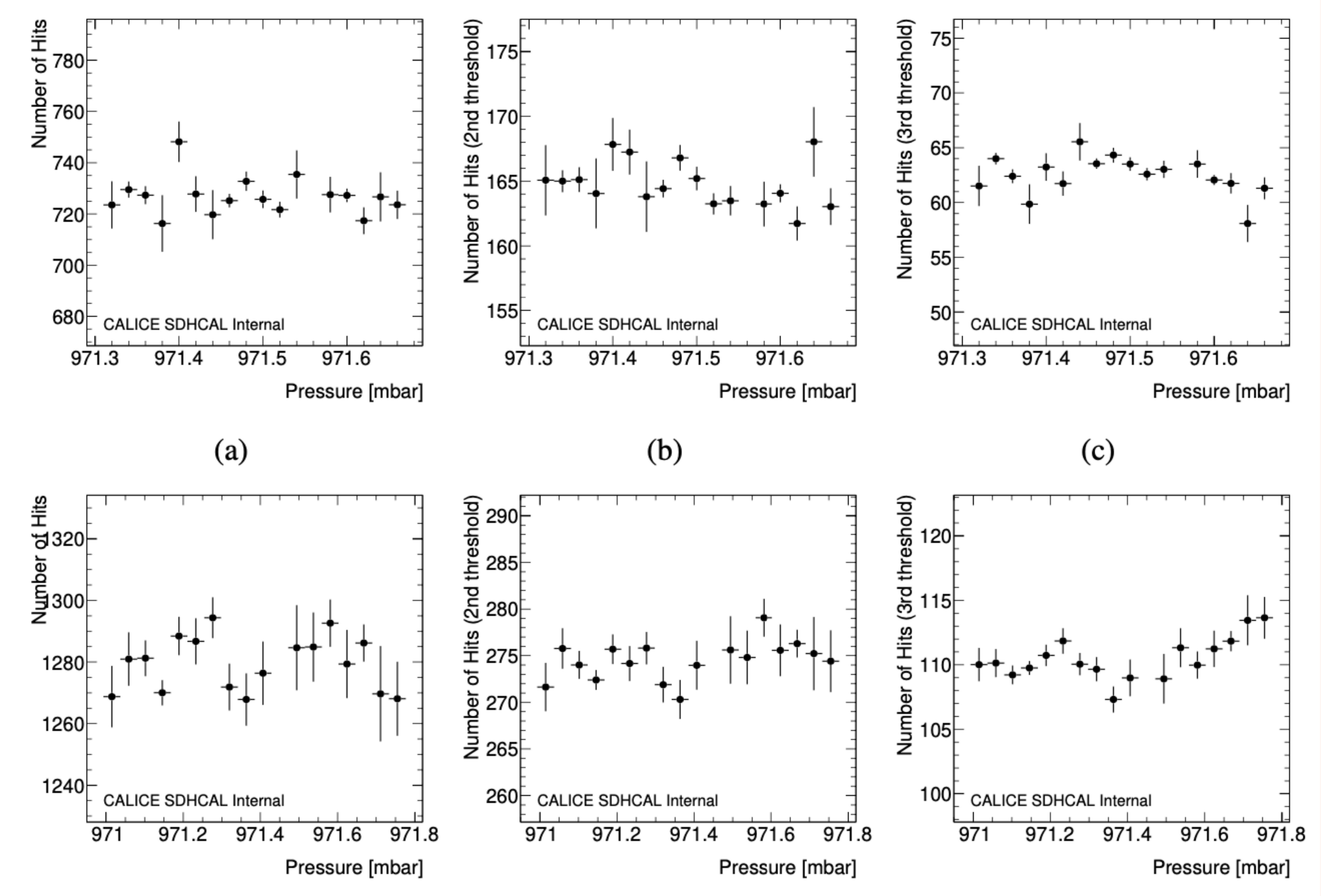
PARAMÈTRES VS TEMPERATURE

multiplication absorption diffusion velocity



- **multiplication (+12%) Absorption (-14%) Diffusion longit. (+5%) Diffusion transv. (+2%) Velocity (+4%)**

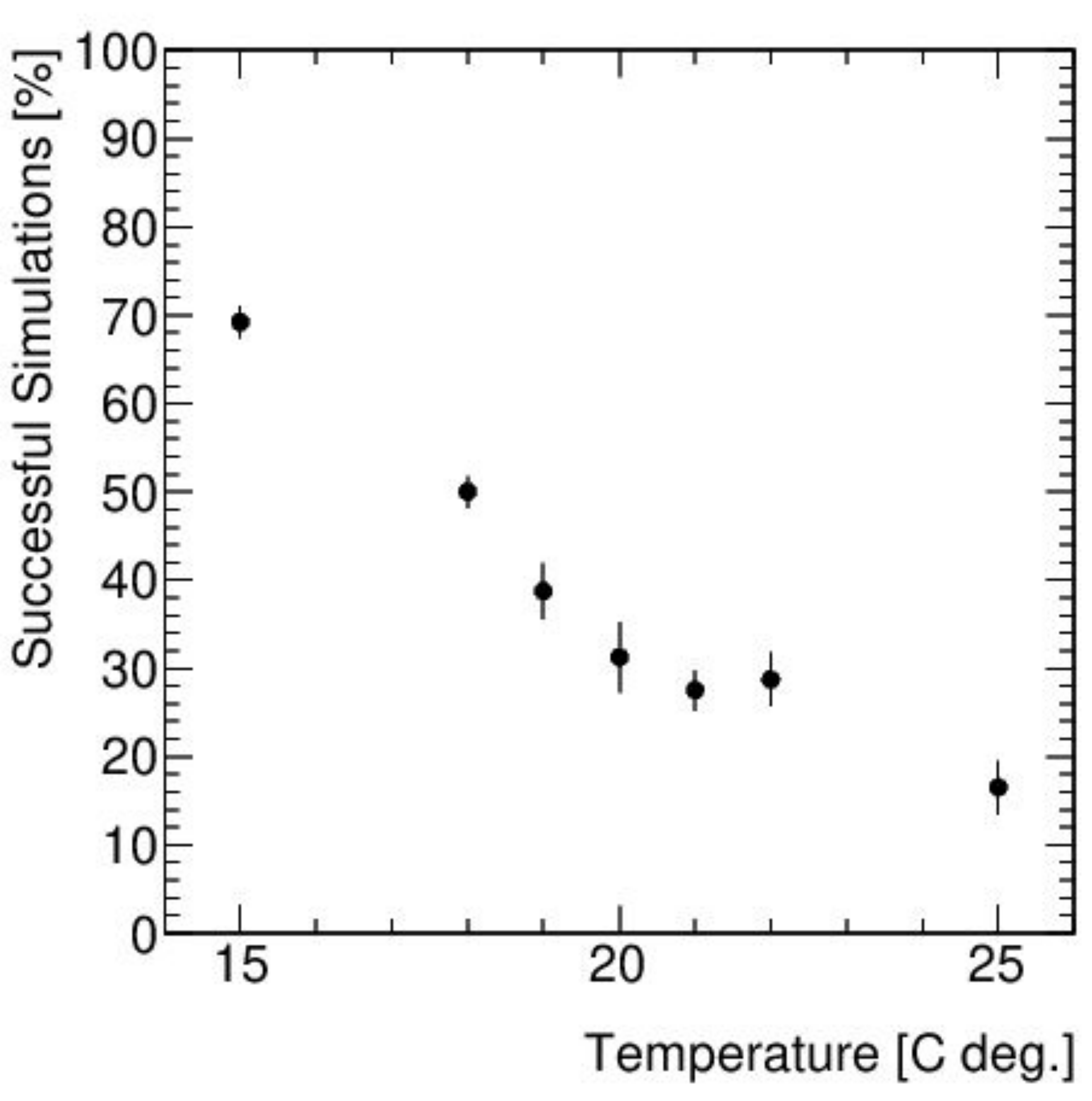
- **Runs tased at different energies cannot be compared**
- **Analysing N_{hits} versus T and P in individual runs**
- **Different trends observed, some in contradiction**
- **other sources of variation in the runs (beam intensity variation + saturations ?)**



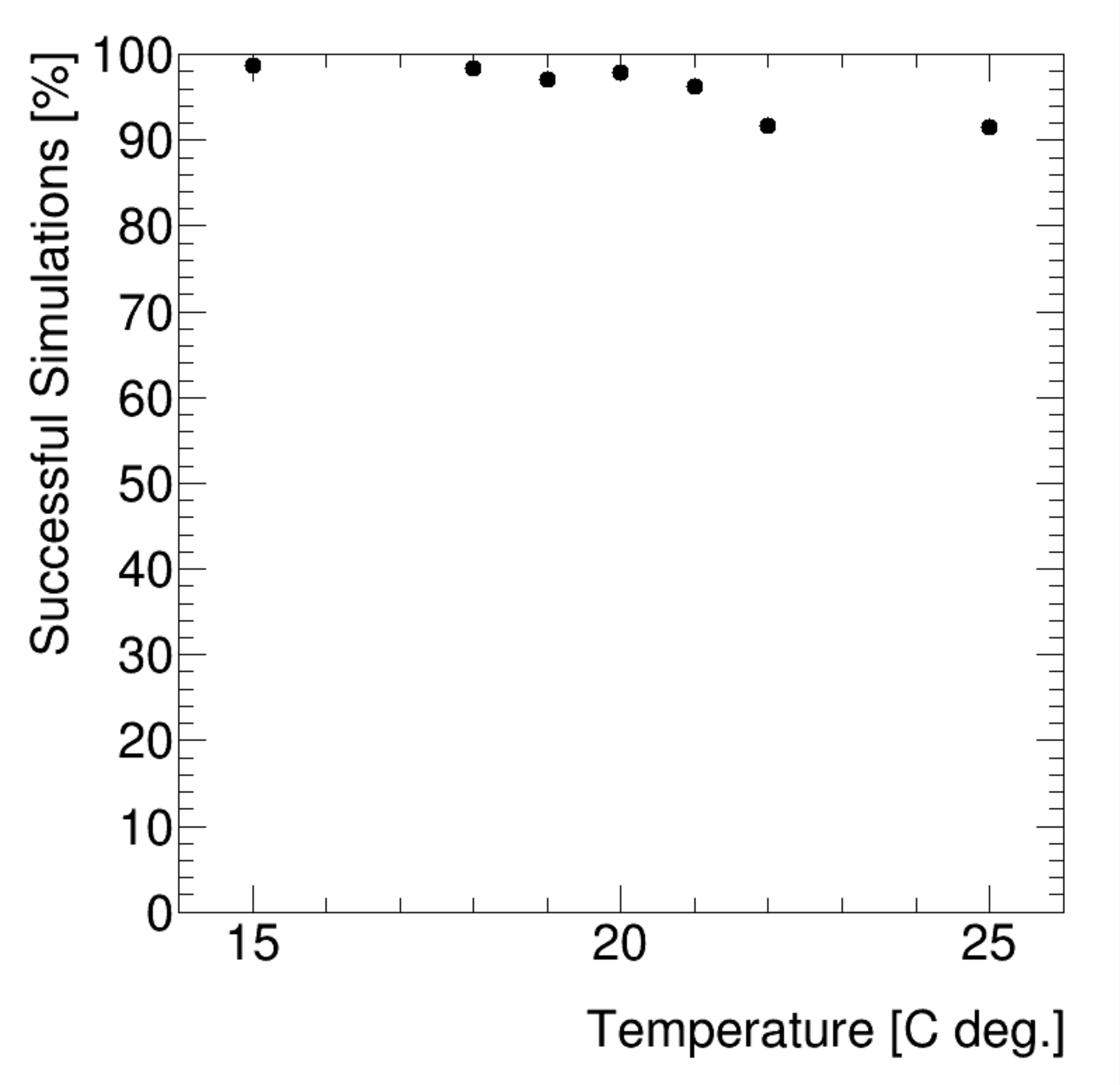
(a) (b) (c)

FIX: DIVERGENCES VERSUS TEMPERATURE

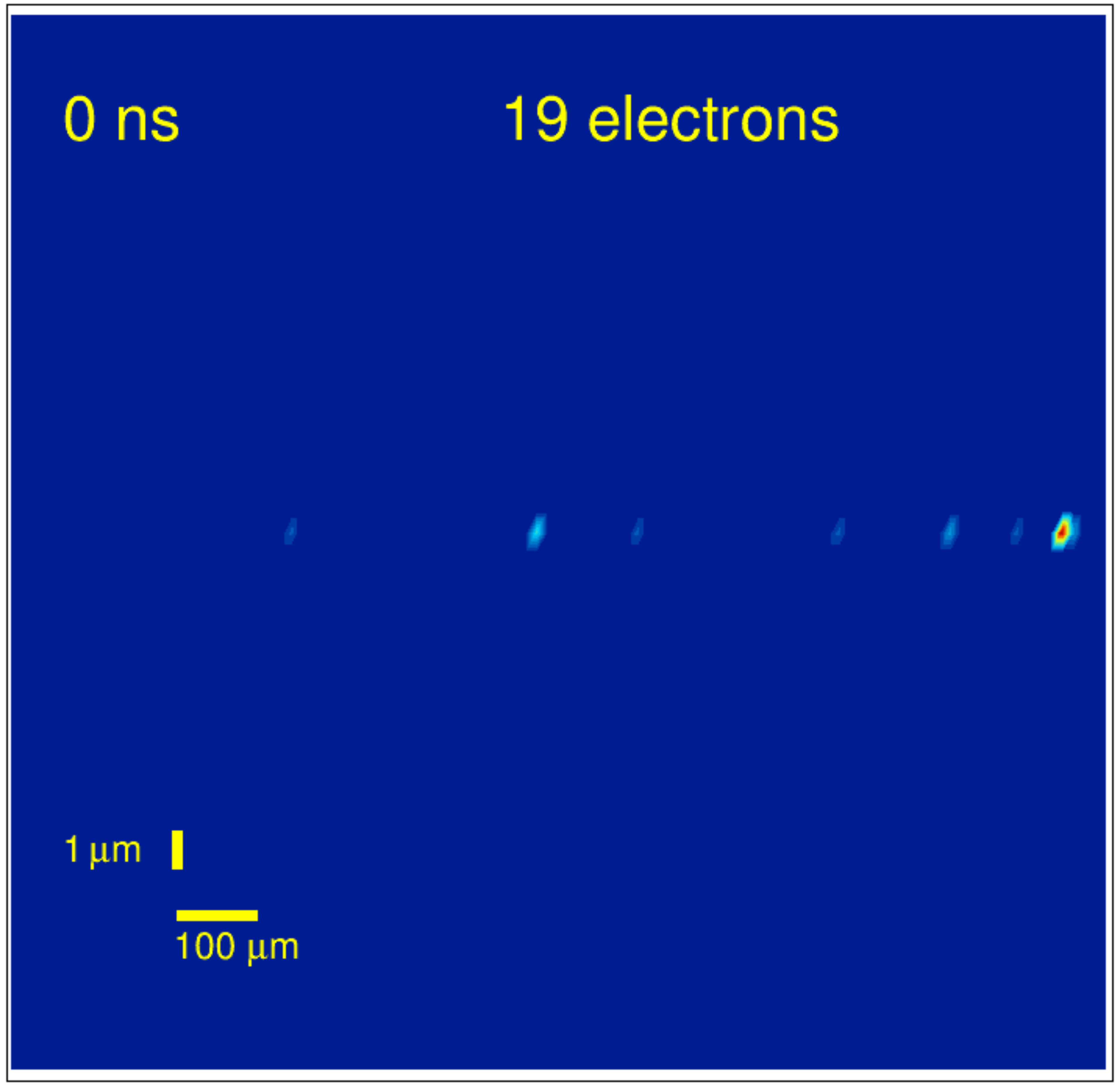
old version



new version



- **old version : only a small event fraction of the events was used ⇒ tend to reject events with many charges ⇒ biased subsample was used**
- **Now fixed**


0 ns
19 electrons
1 µm
100 µm