simulation parameters revisited

EPICAL-2 project

15.09.2021
mTower meeting

Tim Rogoschinski
Institut für Kernphysik
Goethe Universität Frankfurt
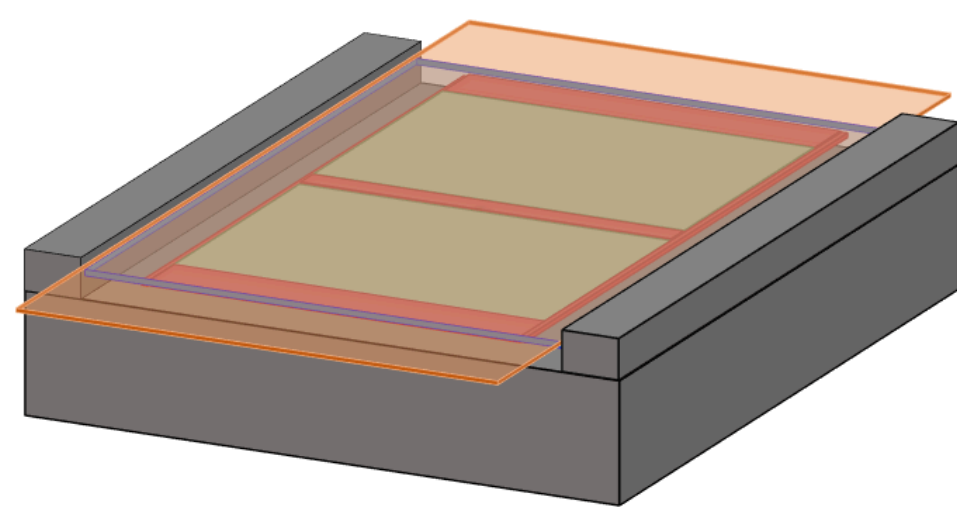
GOETHE
UNIVERSITÄT
FRANKFURT AM MAIN

HGS-HIRe *for FAIR*
Helmholtz Graduate School for Hadron and Ion Research

EPICAL-2 simulation utilising Allpix² ▮

A Monte Carlo Simulation tool for silicon pixel detectors
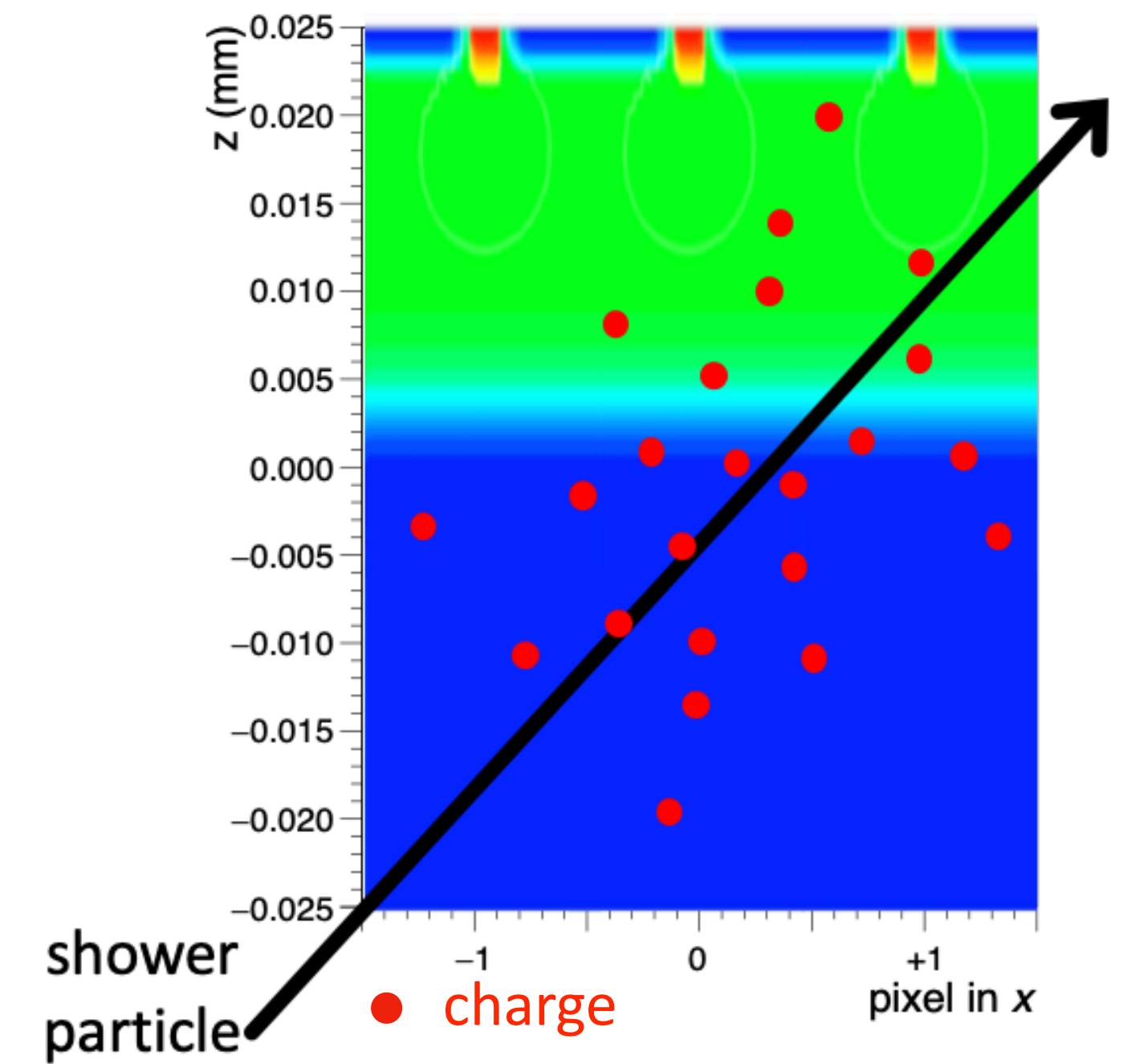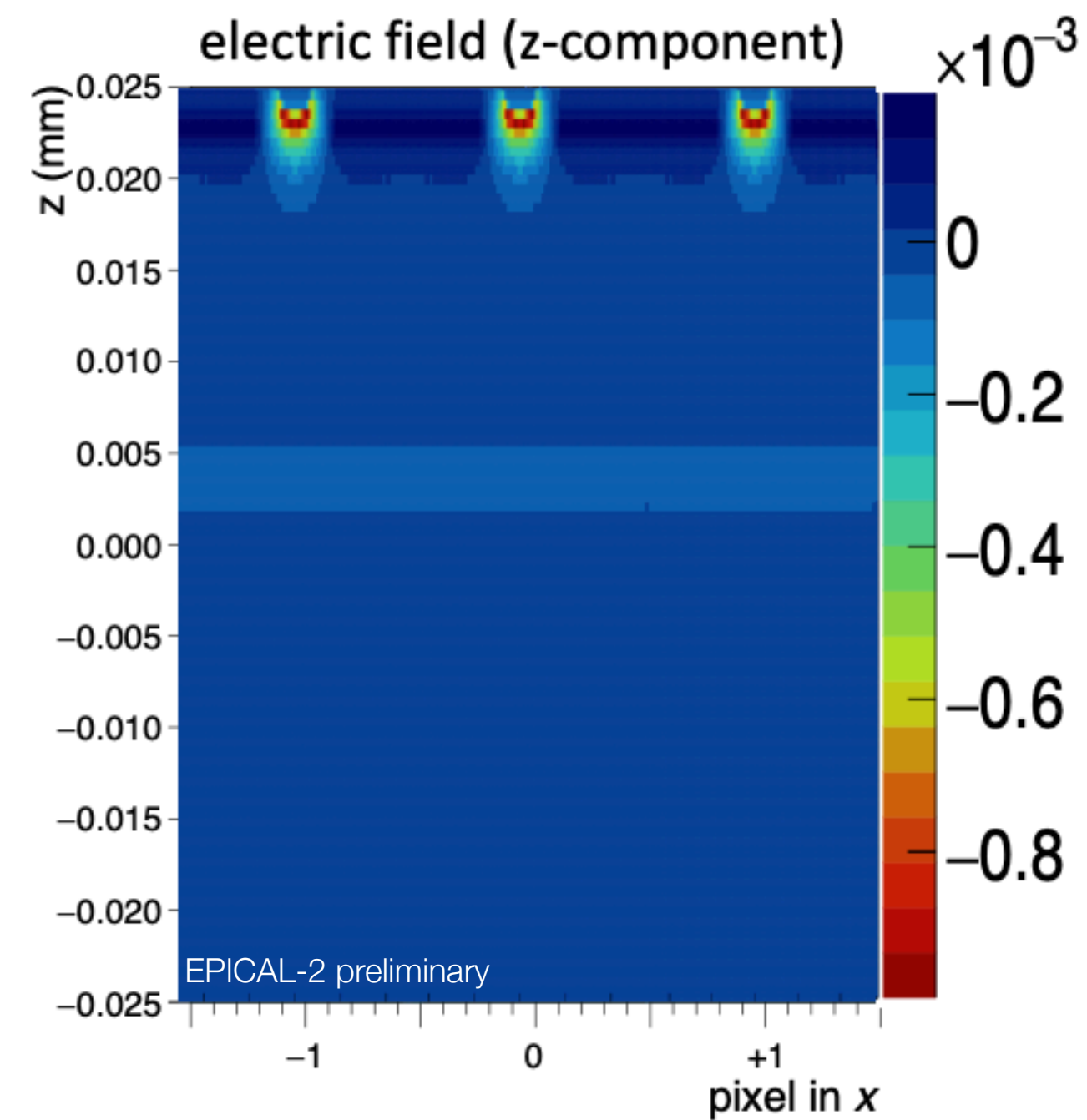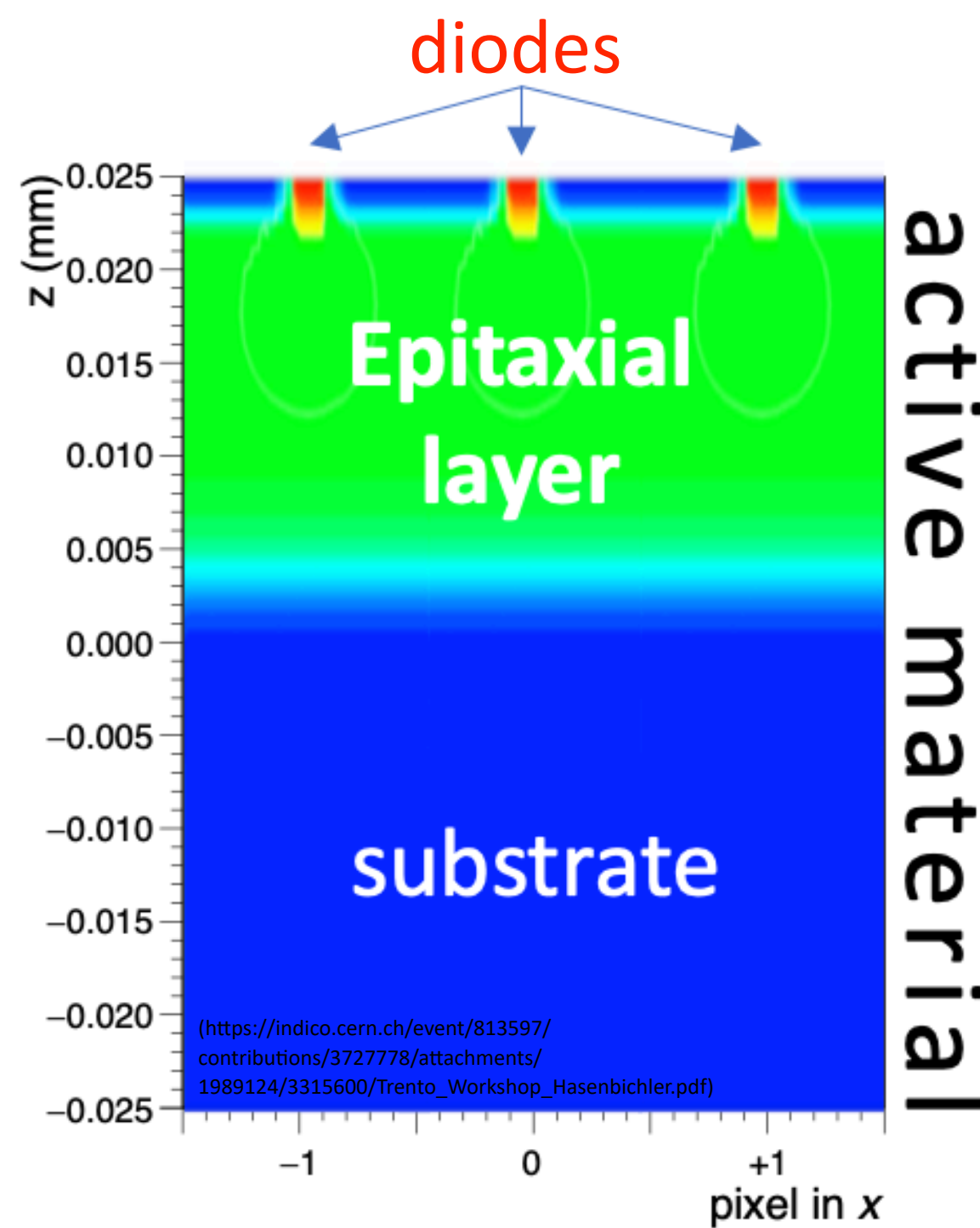From incoming particle(s) to readout

simulation chain:

| geometry builder | → | electric field initialisation | → | energy deposition | → |

electric field initialisation:
- ▸ electric field obtained from **TCAD** simulation by Jan Hasenbichler
- ▸ total reverse bias voltage $V_{RB} = 1.4$ V

energy deposition:
- ▸ beam utilising GPS
- ▸ particle transport and deposition of charges in active materials
  - FFTP_BERT_EMZ

diodes

Epitaxial layer

substrate

active material

(https://indico.cern.ch/event/813597/contributions/3727778/attachments/1989124/3315600/Trento_Workshop_Hasenbichler.pdf)

electric field (z-component) ×10⁻³

EPICAL-2 preliminary

shower particle

● charge

variation: TCAD simulation
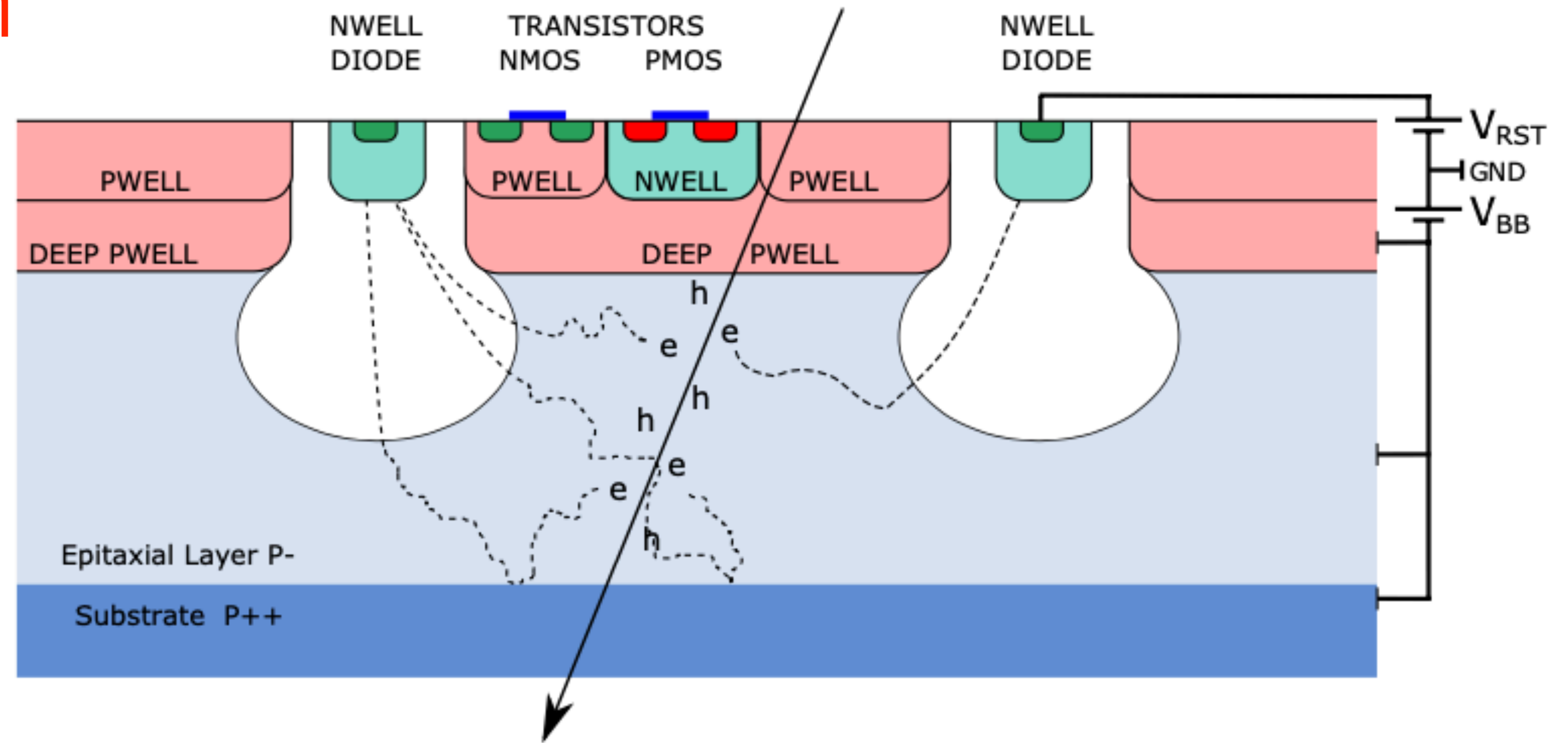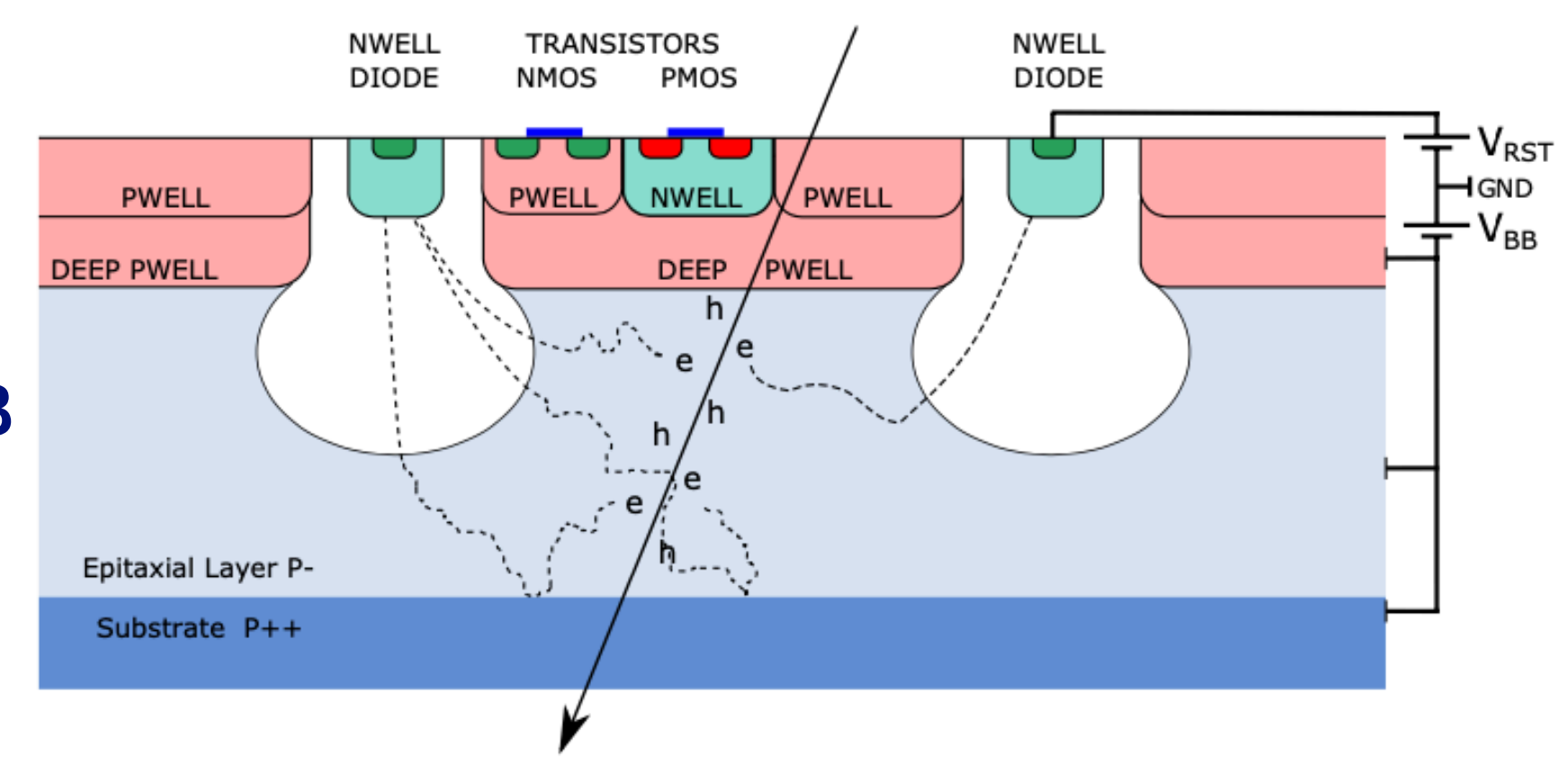
reminder:

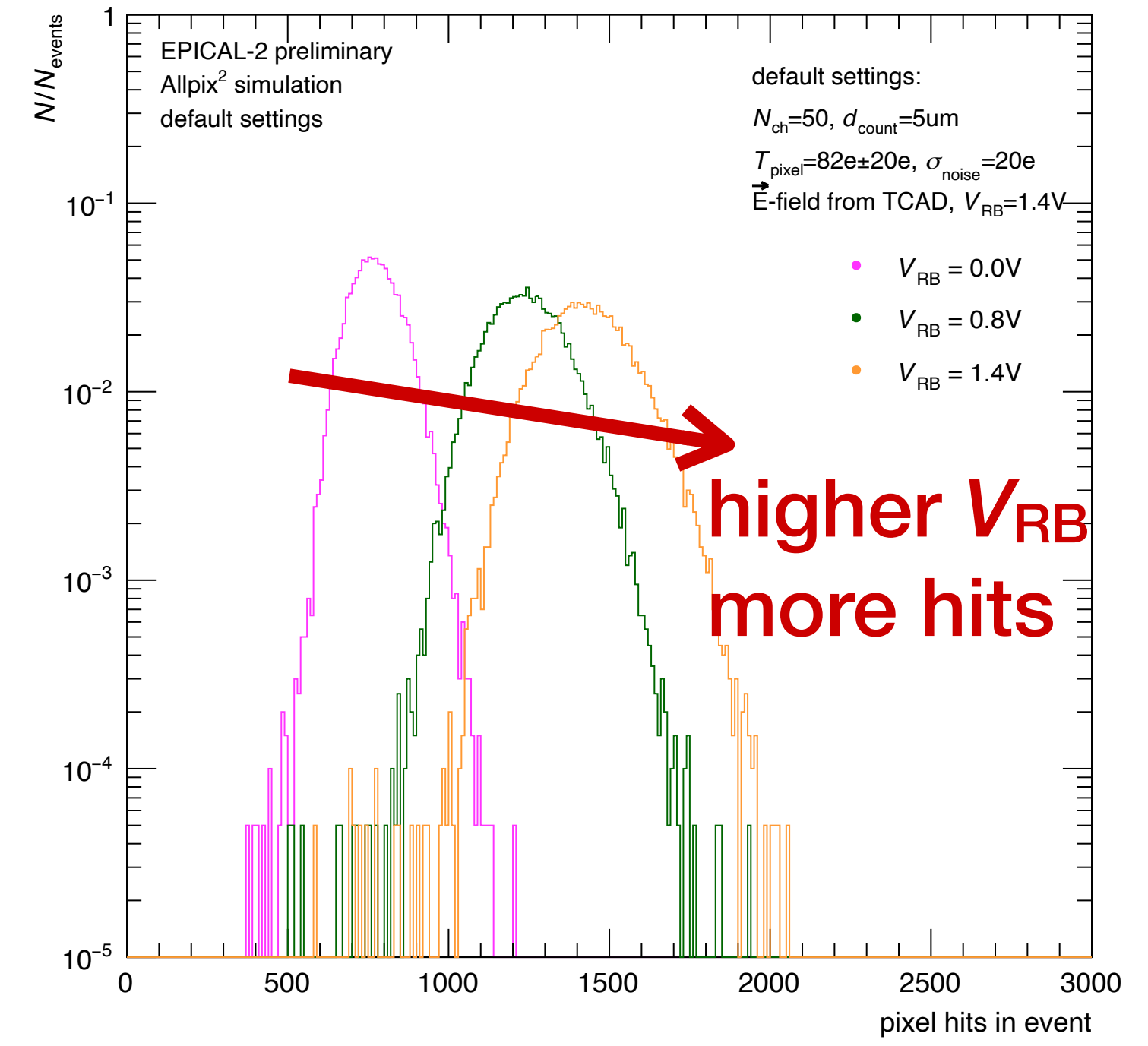total reverse bias voltage V_{RB}

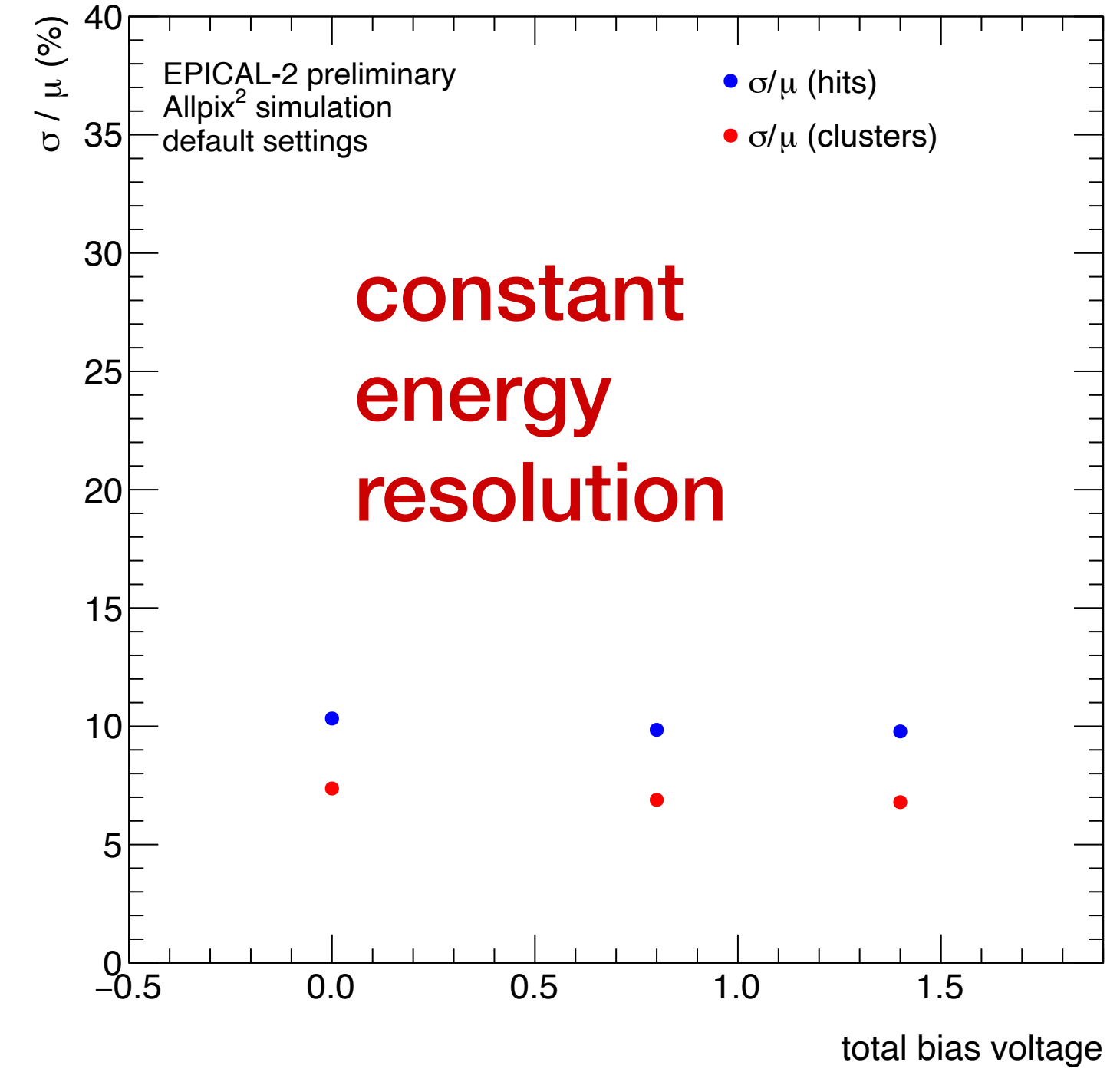▸ $V_{RB} \approx V_{RST} + V_{BB}$

V_{RST} : pixel reset voltage

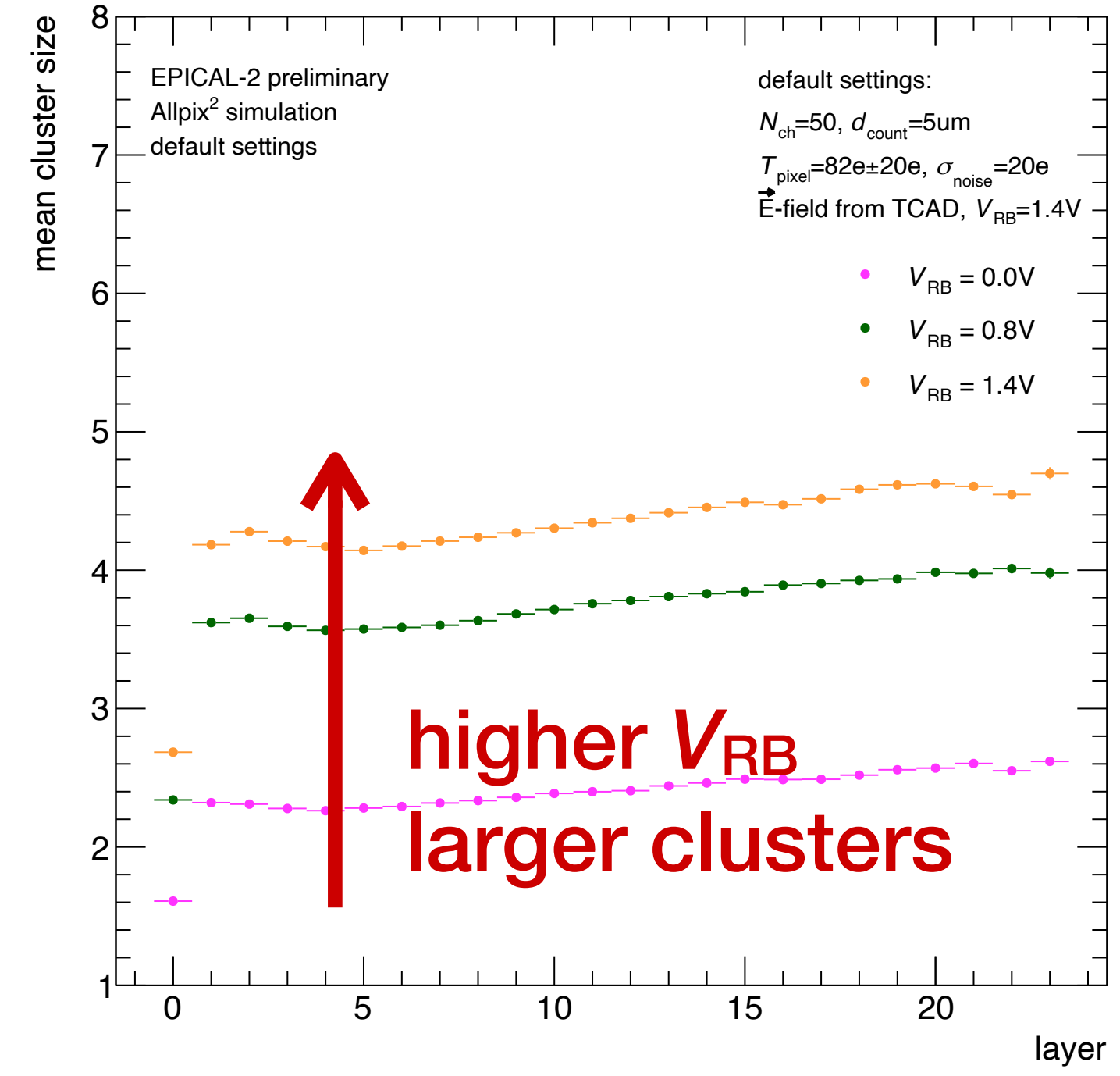V_{BB} : reverse substrate bias voltage

variation: TCAD simulation

hits

reminder:

total reverse bias voltage **V_{RB}**

▸ **$V_{RB} \approx V_{RST} + V_{BB}$**

V_{RST} : pixel reset voltage

V_{BB} : reverse substrate bias voltage

EPICAL-2 preliminary
Allpix^2 simulation
default settings

default settings:
N_{ch}=50, d_{count}=5um
T_{pixel}=82e±20e, σ_{noise}=20e
$\vec{E}$-field from TCAD, V_{RB}=1.4V

- V_{RB} = 0.0V
- V_{RB} = 0.8V
- V_{RB} = 1.4V

higher V_{RB} more hits

resolution

EPICAL-2 preliminary
Allpix^2 simulation
default settings

- σ/μ (hits)
- σ/μ (clusters)

constant energy resolution

mean cluster size

EPICAL-2 preliminary
Allpix^2 simulation
default settings

default settings:
N_{ch}=50, d_{count}=5um
T_{pixel}=82e±20e, σ_{noise}=20e
$\vec{E}$-field from TCAD, V_{RB}=1.4V

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higher V_{RB} larger clusters

clusters

EPICAL-2 preliminary
Allpix^2 simulation
default settings

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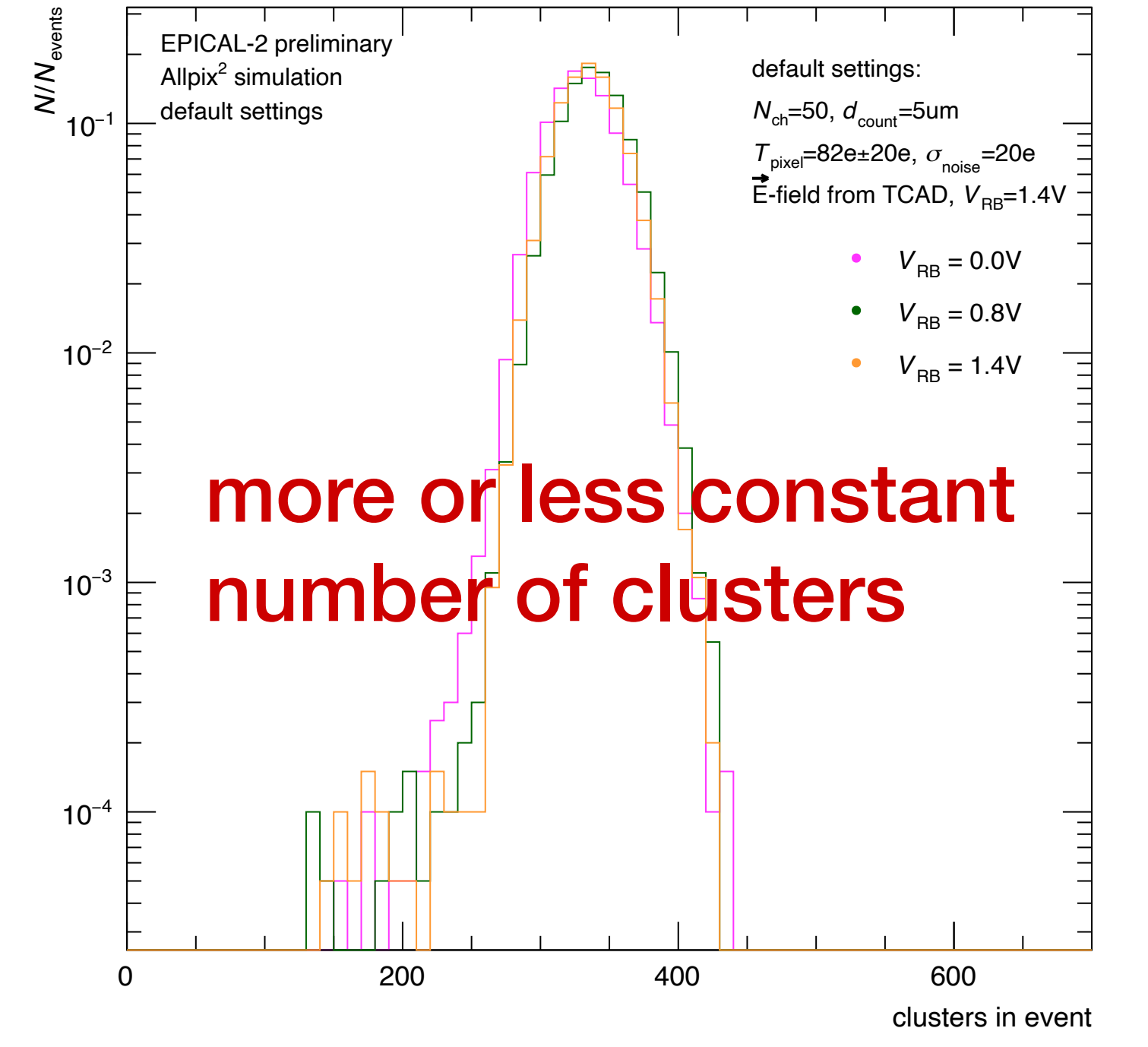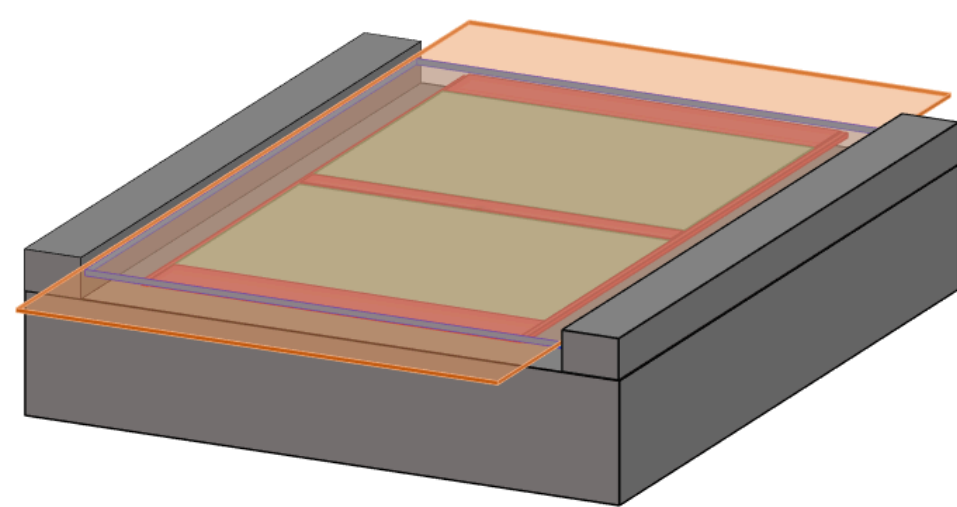**more or less constant number of clusters**

EPICAL-2 simulation utilising Allpix² ▮

A Monte Carlo Simulation tool for silicon pixel detectors
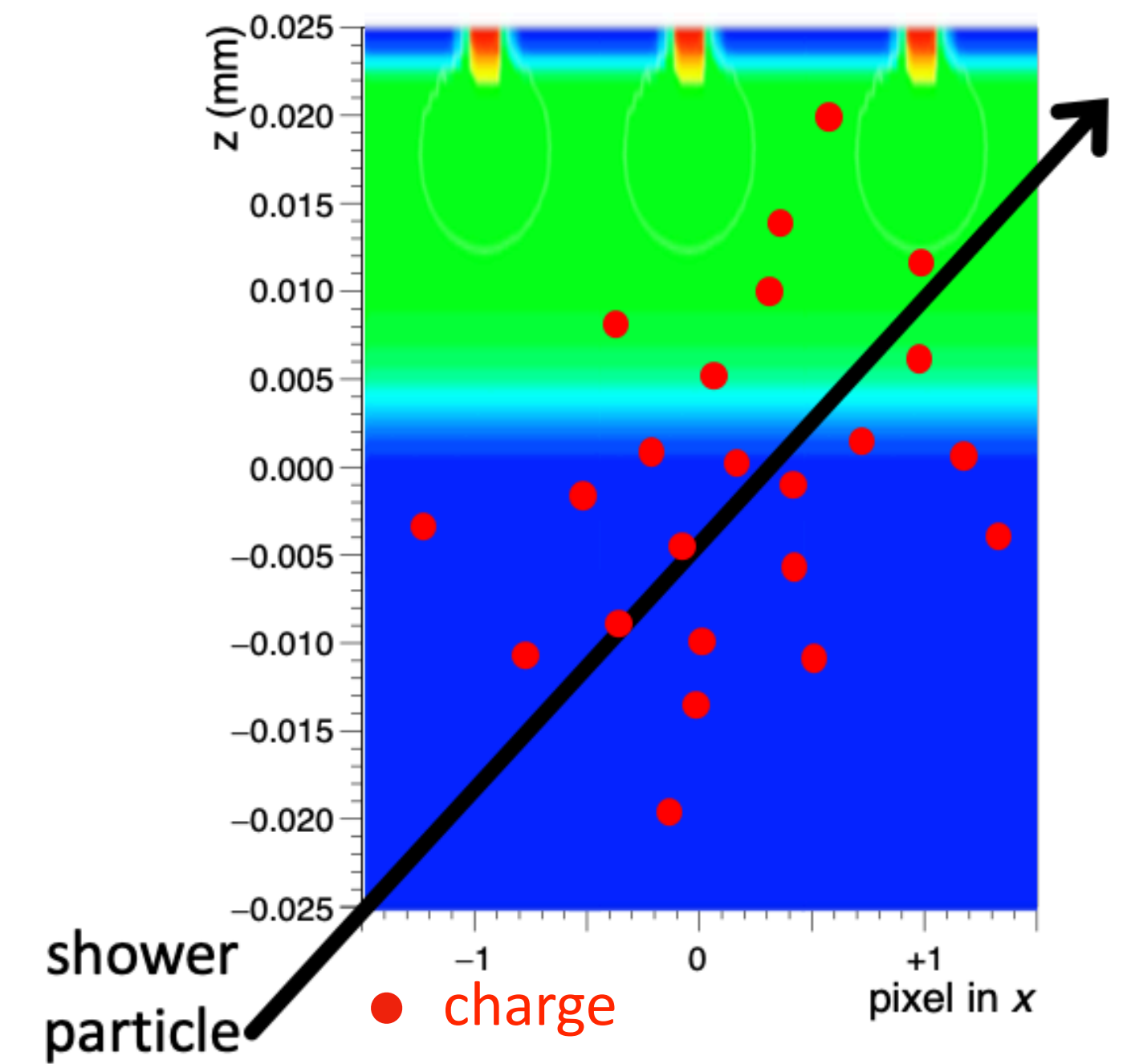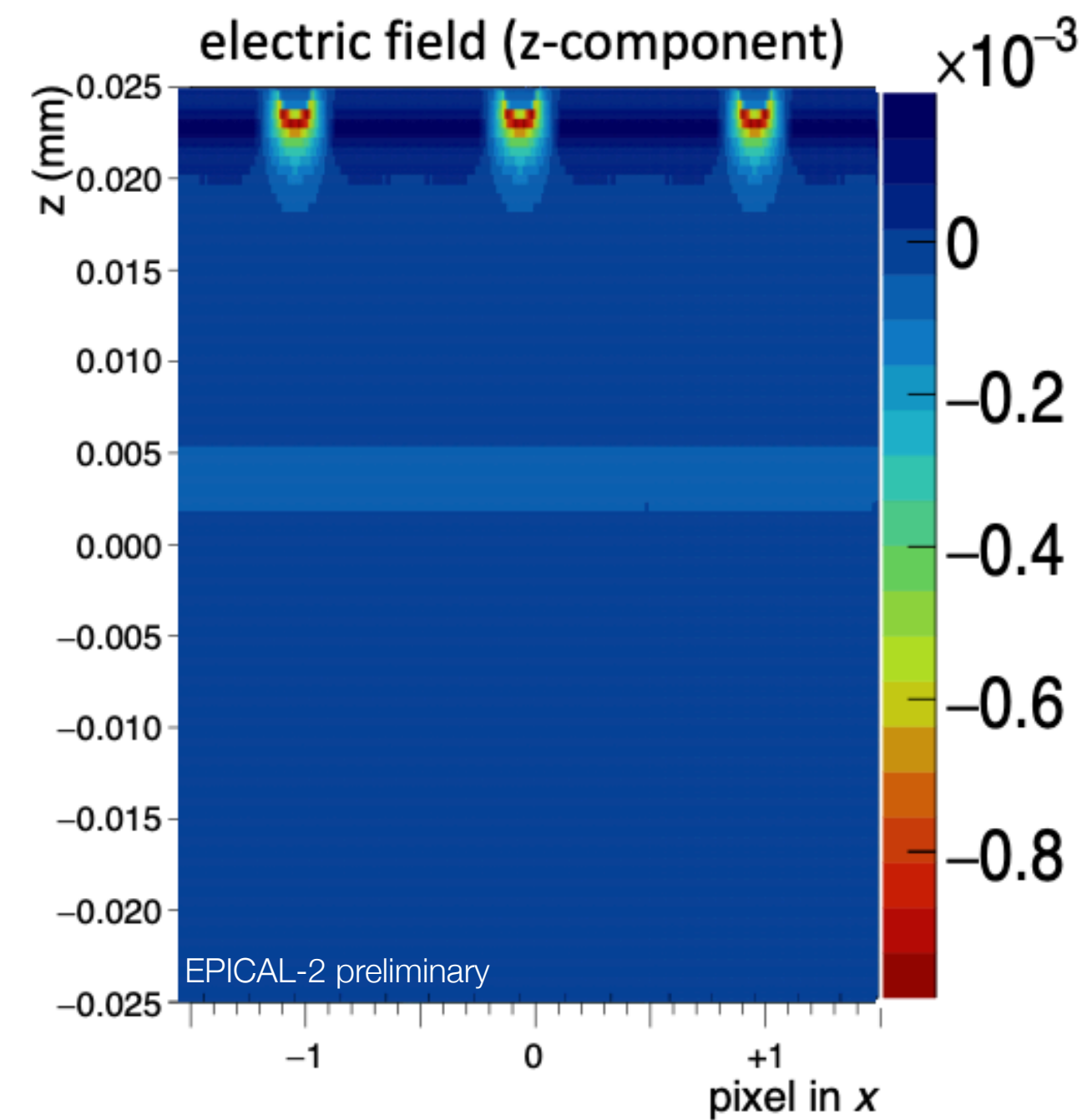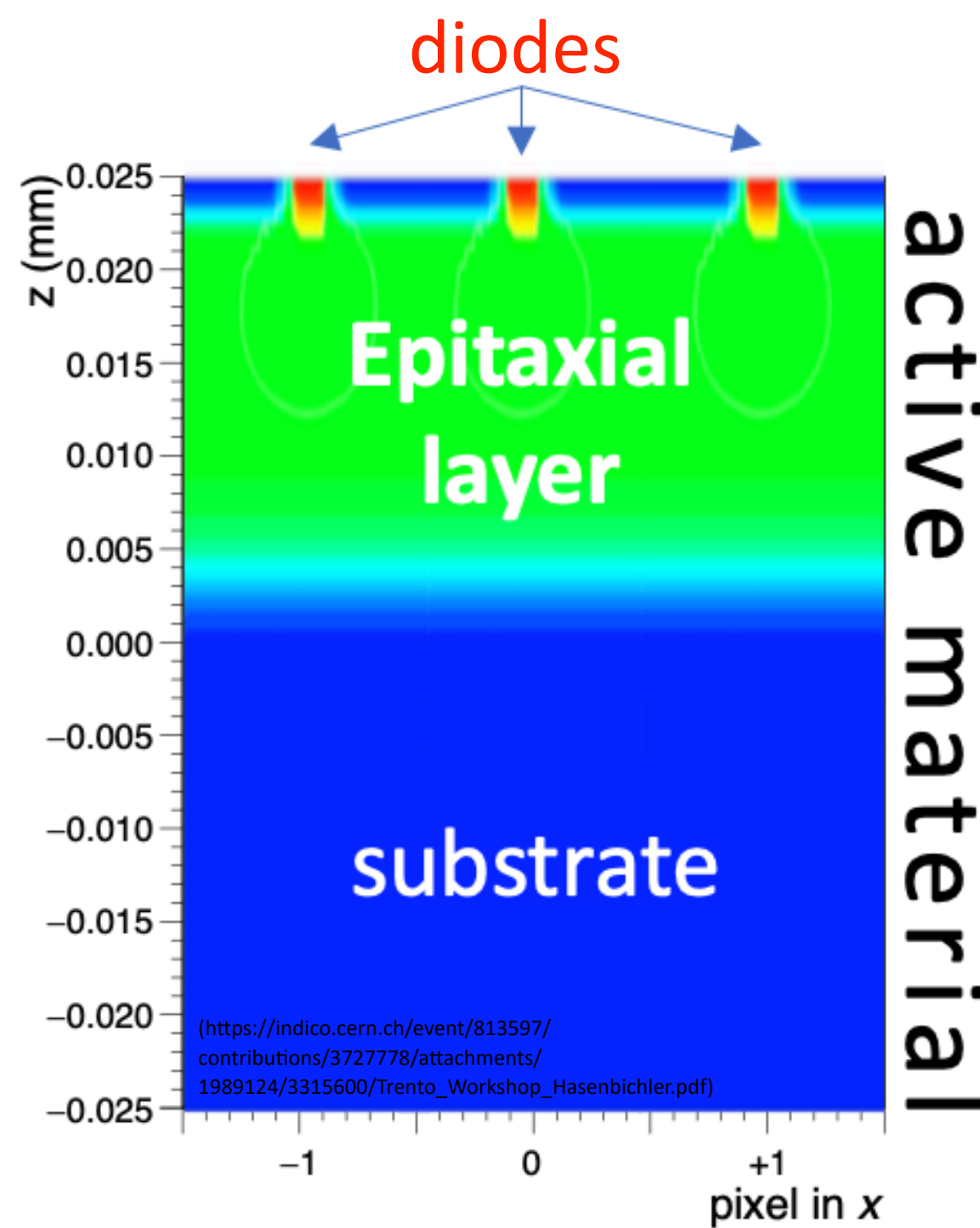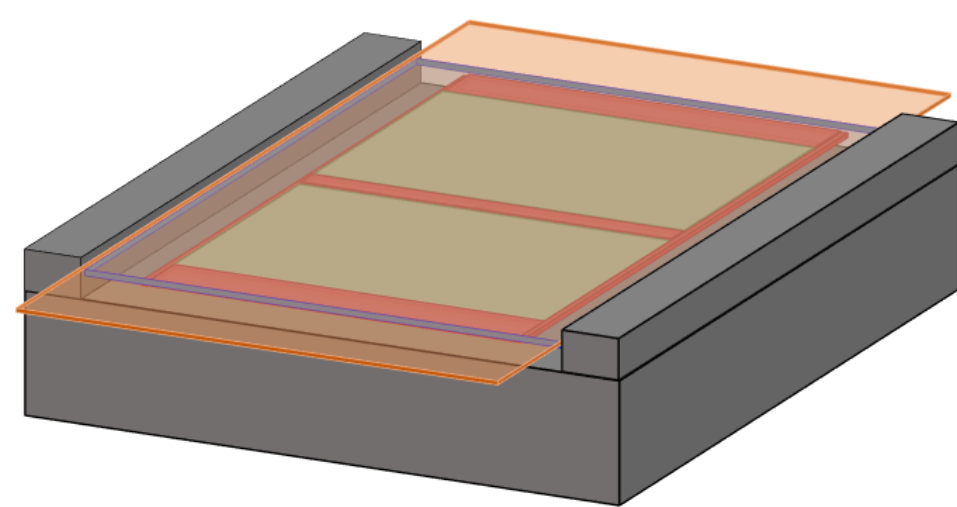From incoming particle(s) to readout

simulation chain:

geometry builder	→	electric field initialisation	→	energy deposition	→

diodes

▸ electric field obtained from **TCAD** simulation by Jan Hasenbichler
▸ total reverse bias voltage V_{RB} = 1.4 V

▸ beam utilising GPS
▸ particle transport and deposition of charges in active materials
  • FFTP_BERT_EMZ

EPICAL-2 simulation utilising Allpix² ▌

A Monte Carlo Simulation tool for silicon pixel detectors
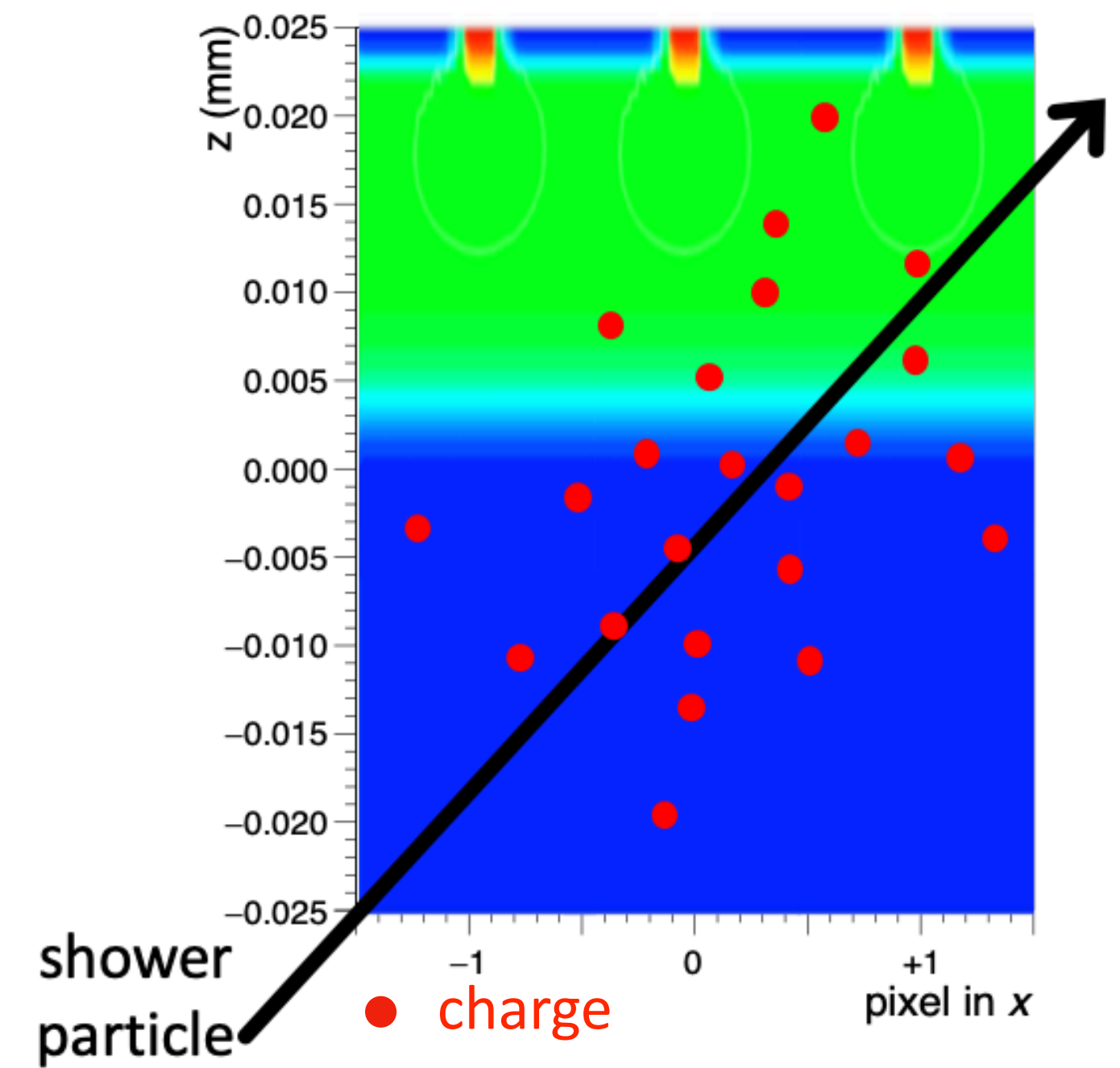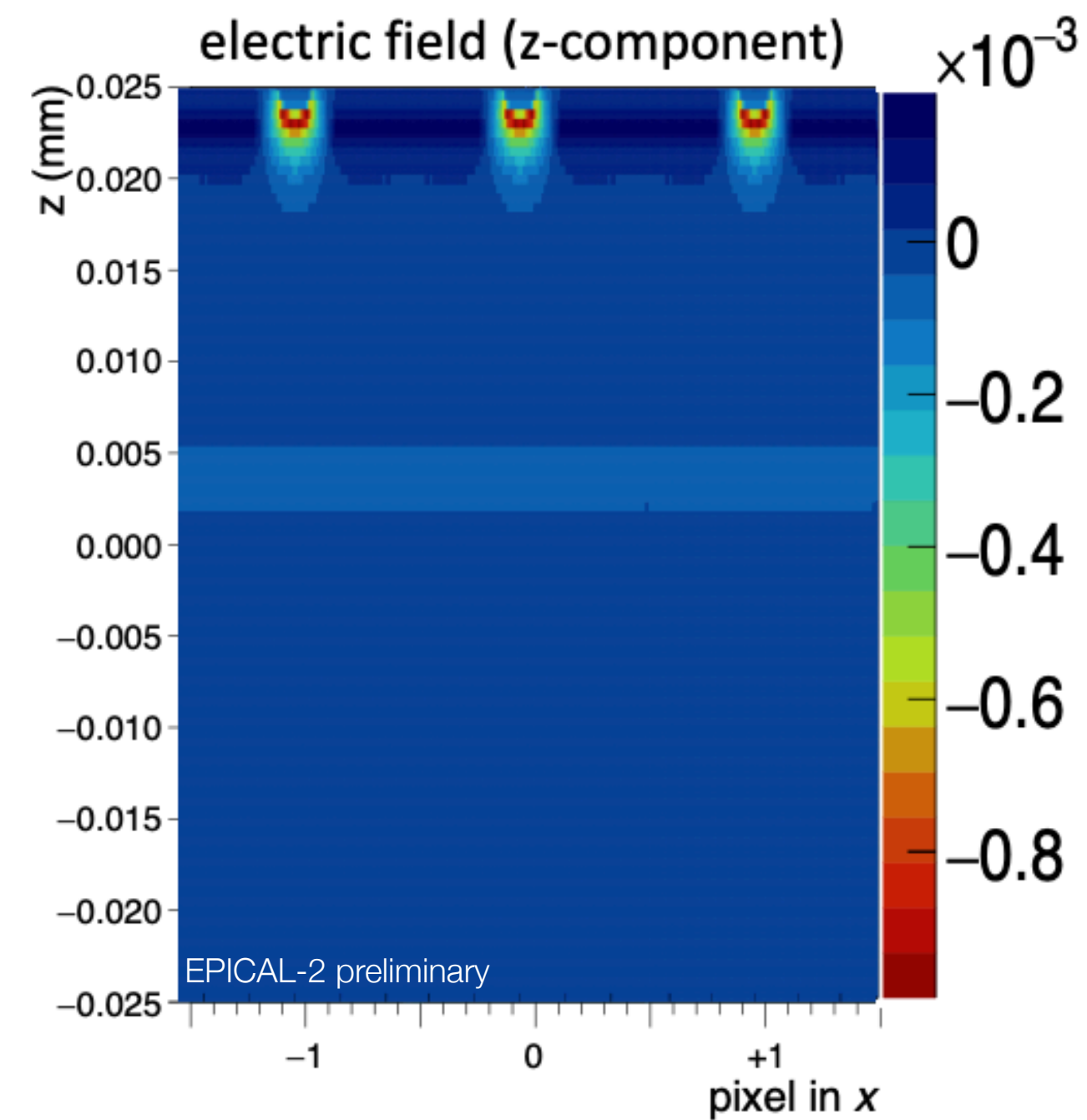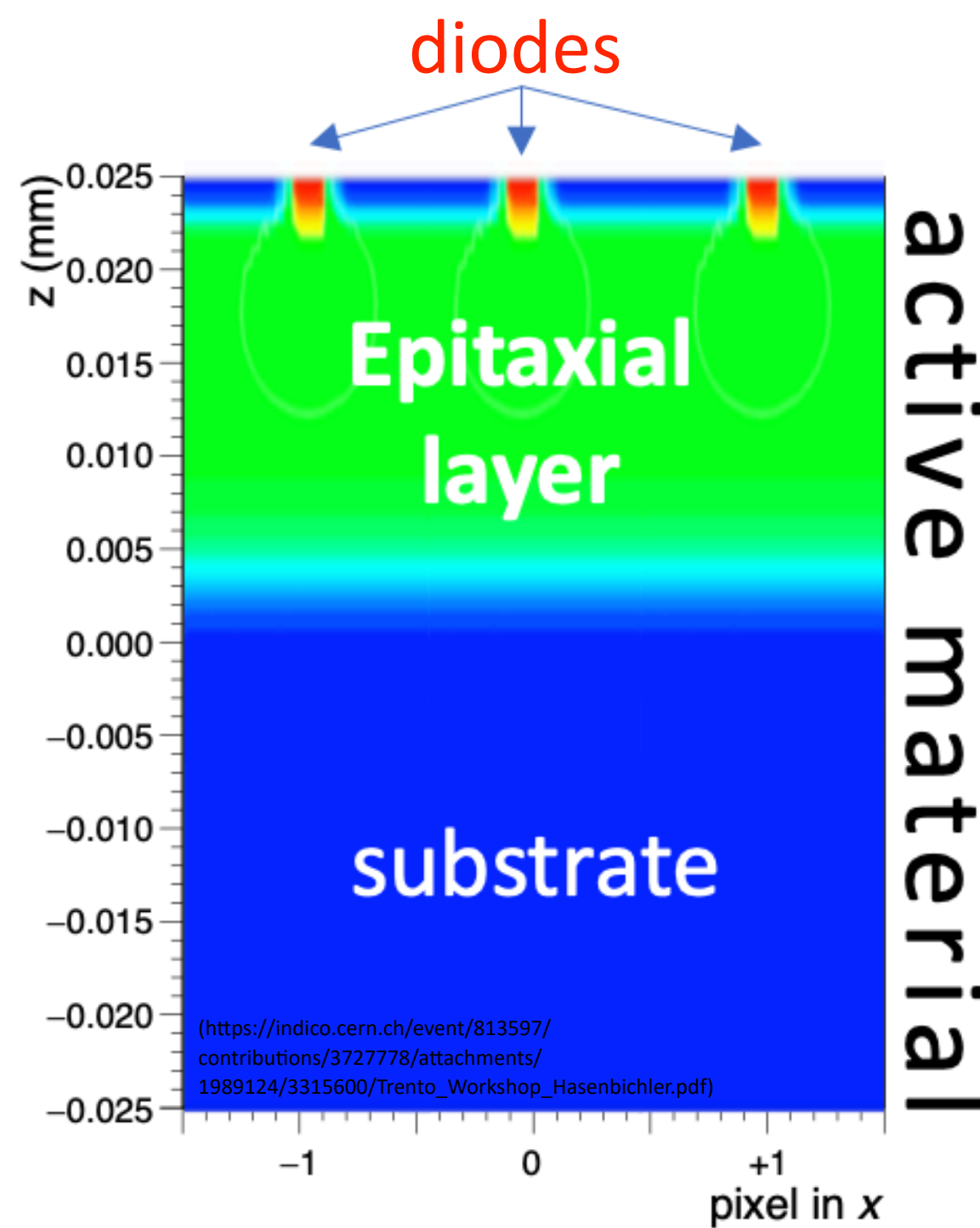From incoming particle(s) to readout

simulation chain:

| geometry builder | → | electric field initialisation | → | energy deposition | →

geometry builder

diodes

electric field initialisation

▸ electric field obtained from **TCAD** simulation by Jan Hasenbichler
▸ total reverse bias voltage V_{RB} = 1.4 V

electric field (z-component)

EPICAL-2 preliminary

energy deposition

▸ beam utilising GPS
▸ particle transport and deposition of charges in active materials
  • FFTP_BERT_EMZ

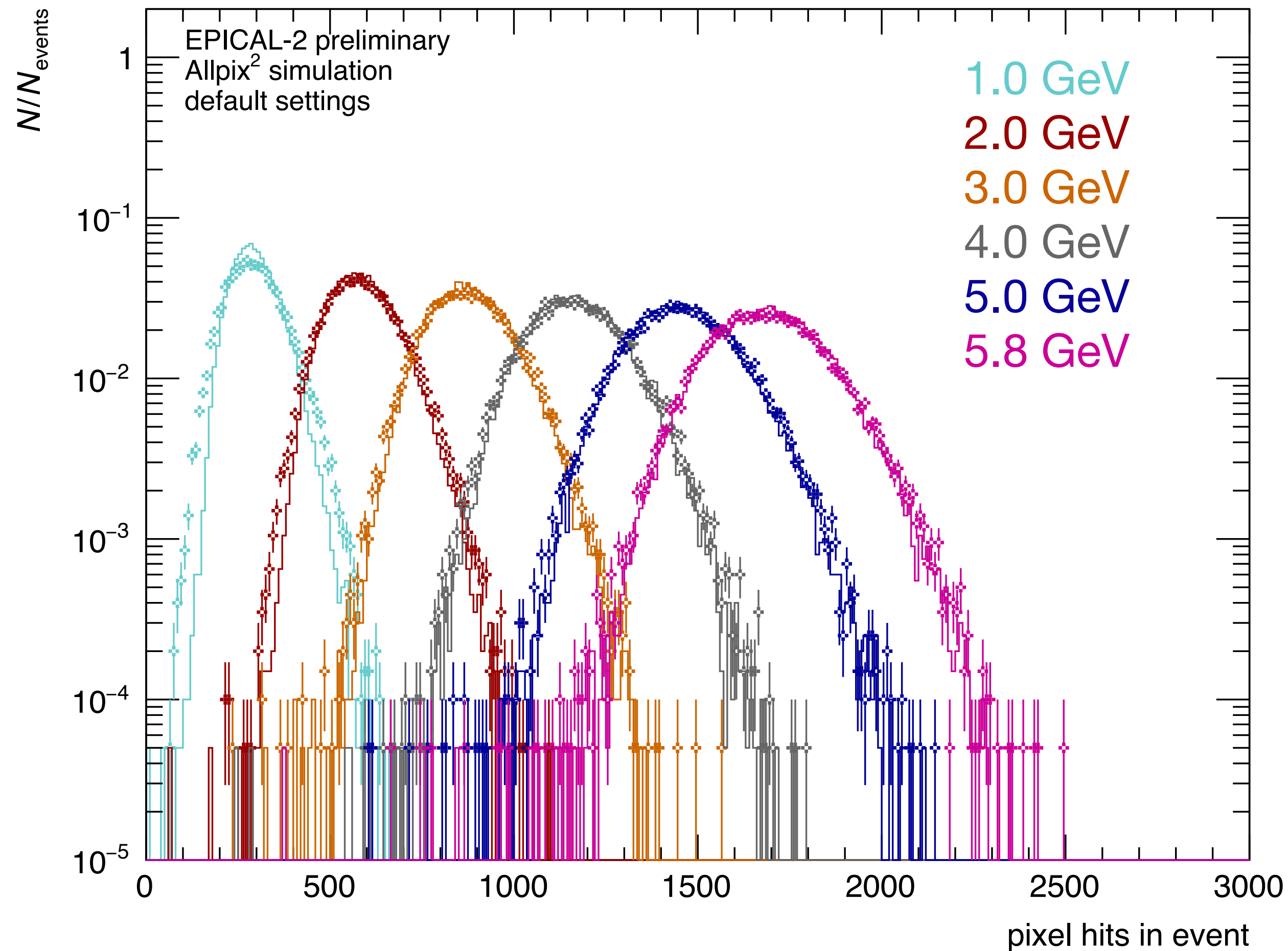
shower particle
● charge

Gaussian beam-energy spread

— solid line
0 GeV spread of beam energy
all chips with threshold 82e ± 20e

✚ crosses
0.158 GeV spread of beam energy
all chips with threshold 82e ± 20e

→ broadening of the distributions
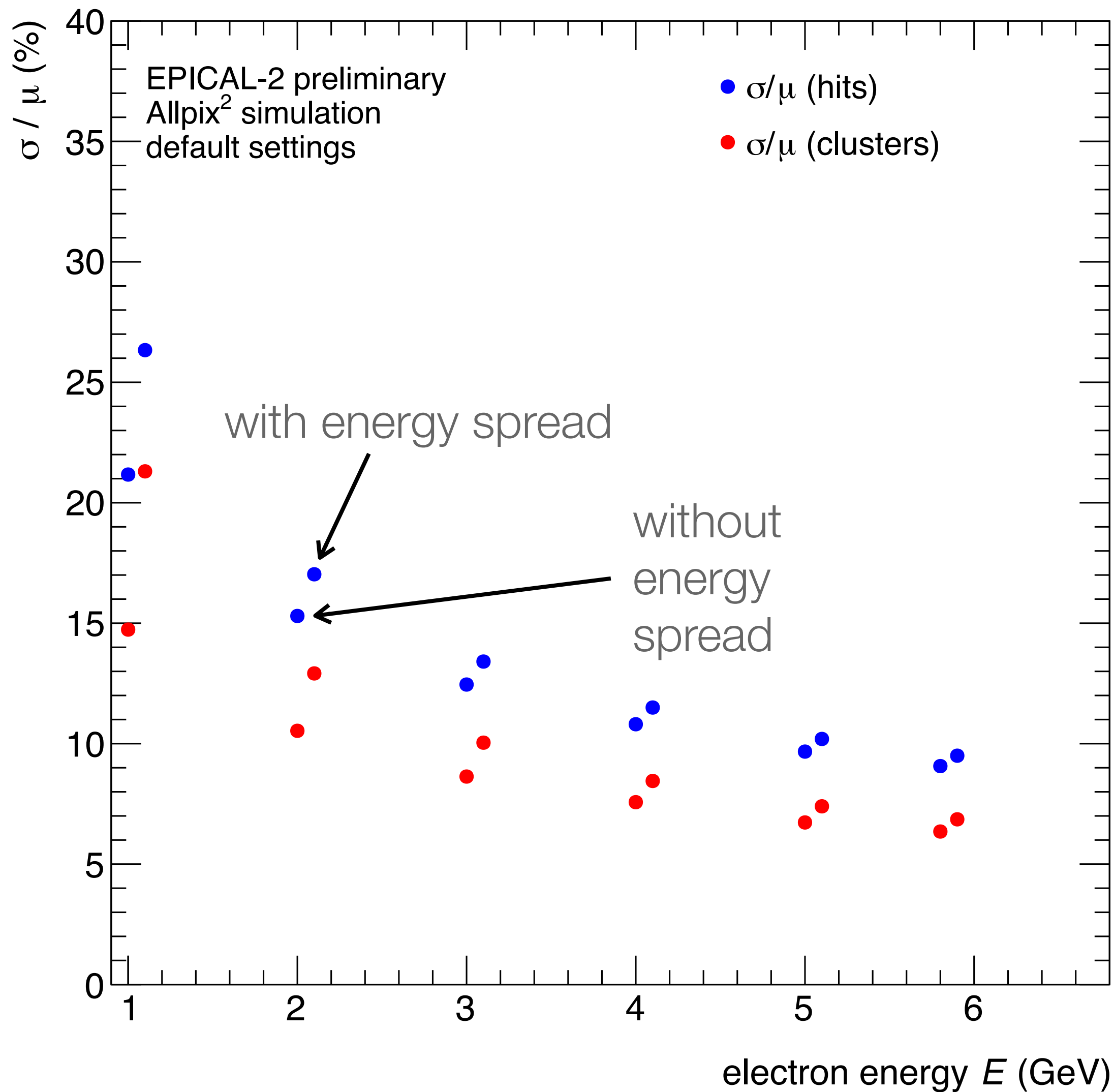
→ stronger influence of beam energy spread
   on the distributions for lower energies

number of pixel hits

EPICAL-2 preliminary
Allpix^2 simulation
default settings

1.0 GeV
2.0 GeV
3.0 GeV
4.0 GeV
5.0 GeV
5.8 GeV

N/N_{events}

pixel hits in event

number of clusters

EPICAL-2 preliminary
Allpix^2 simulation
default settings

1.0 GeV
2.0 GeV
3.0 GeV
4.0 GeV
5.0 GeV
5.8 GeV

N/N_{events}

clusters in event
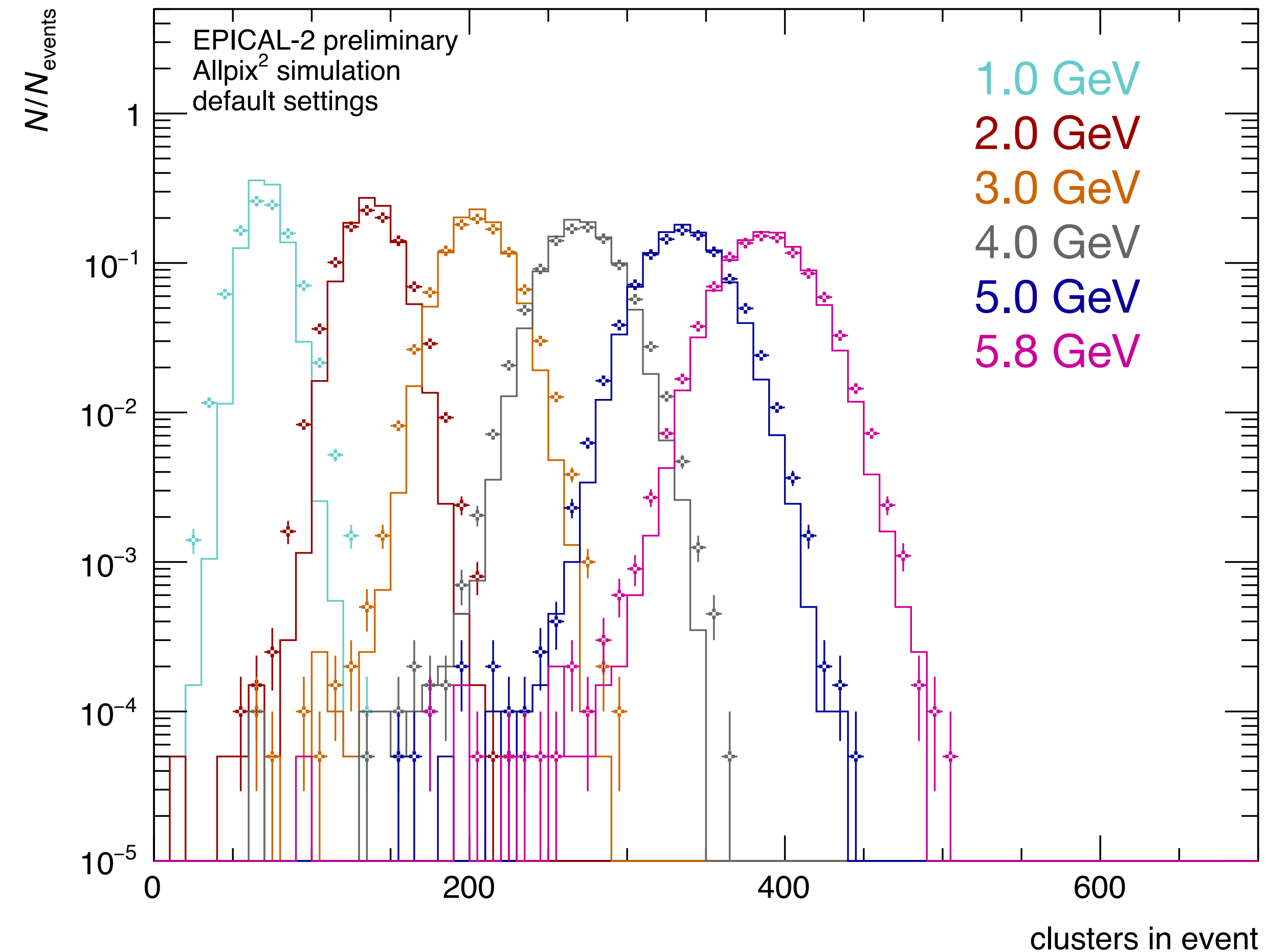
energy resolution

→ worsening of the energy resolution

— solid line
0 GeV spread of beam energy
all chips with threshold 82e ± 20e

✚ crosses
0.158 GeV spread of beam energy
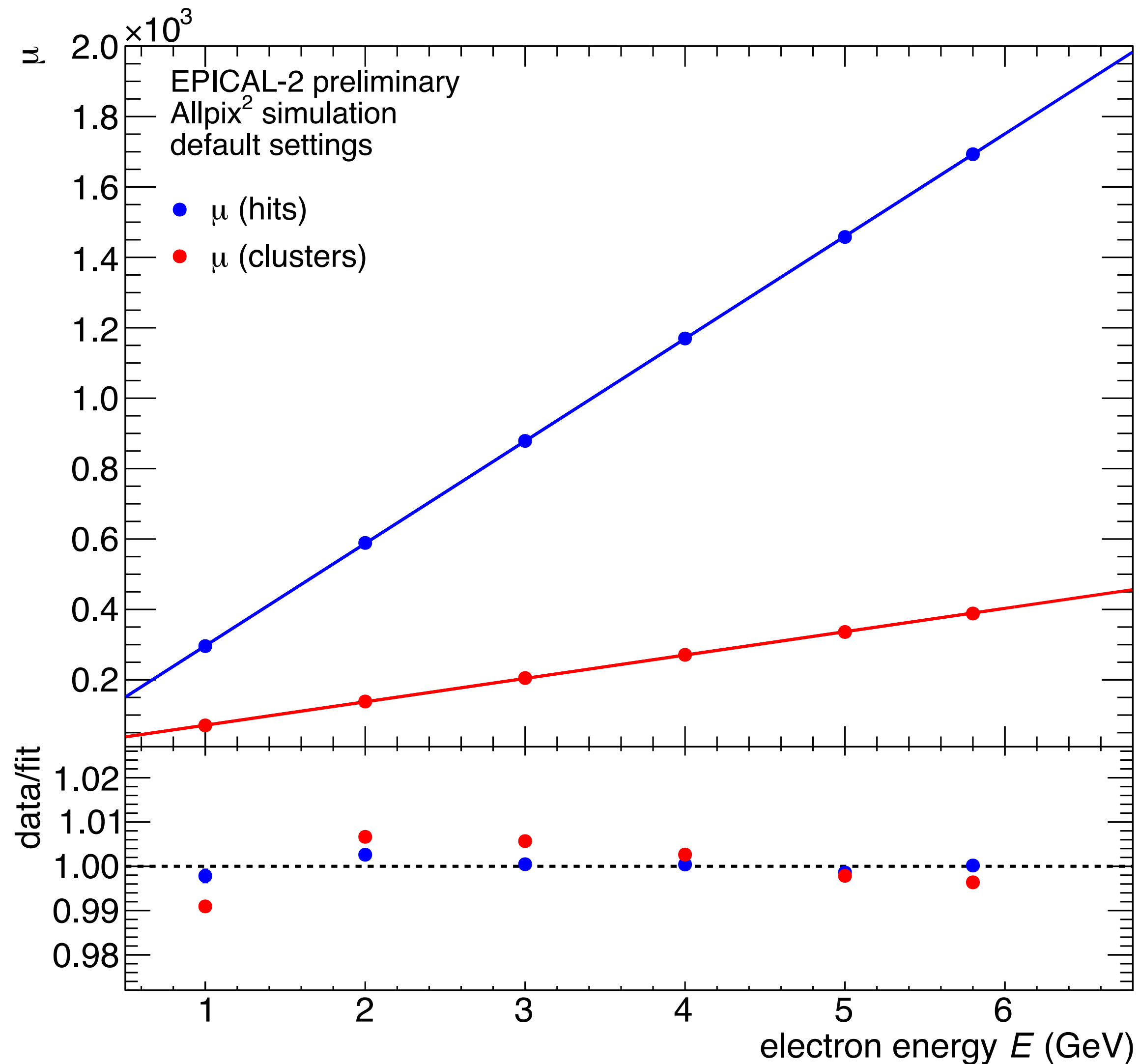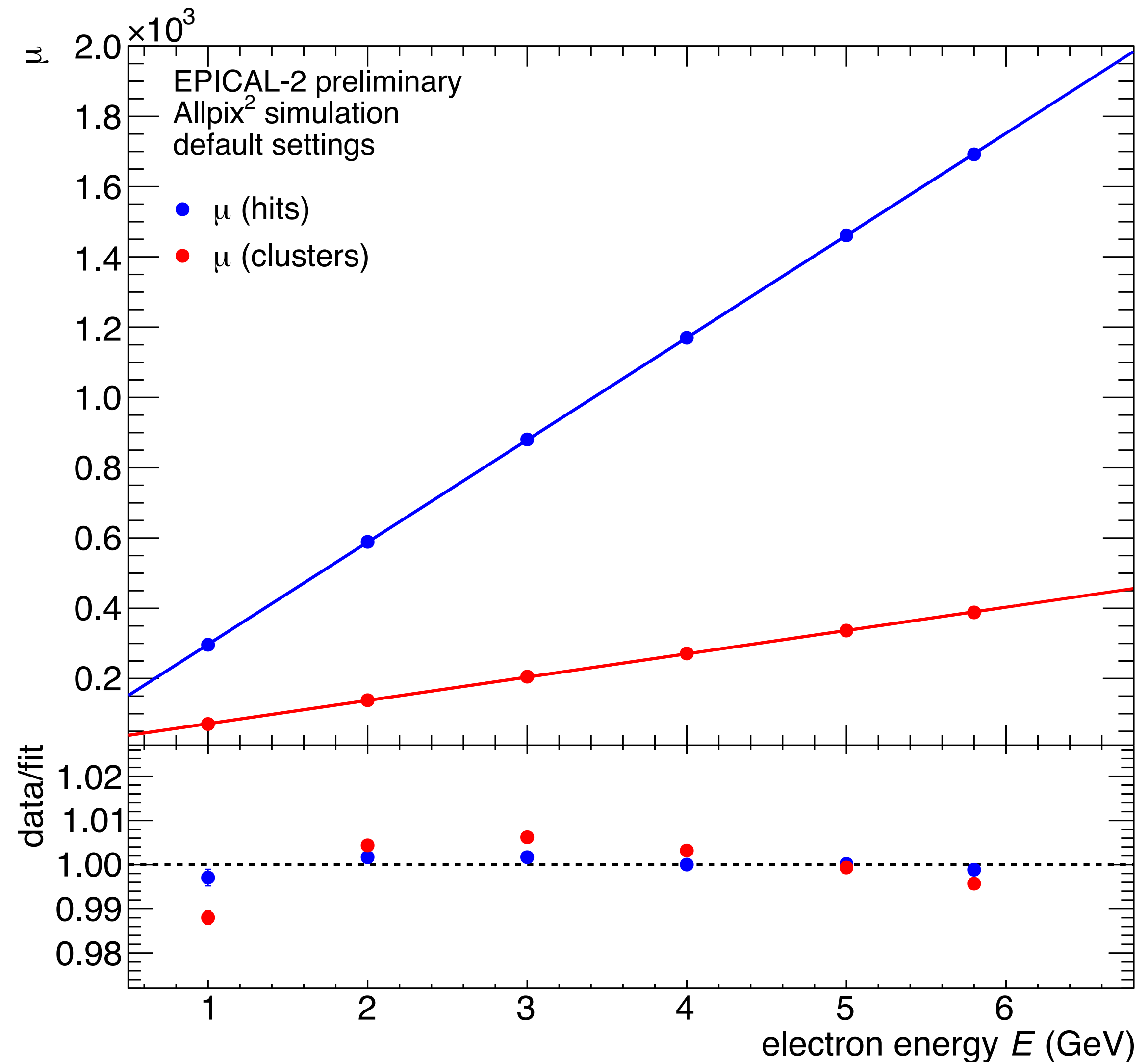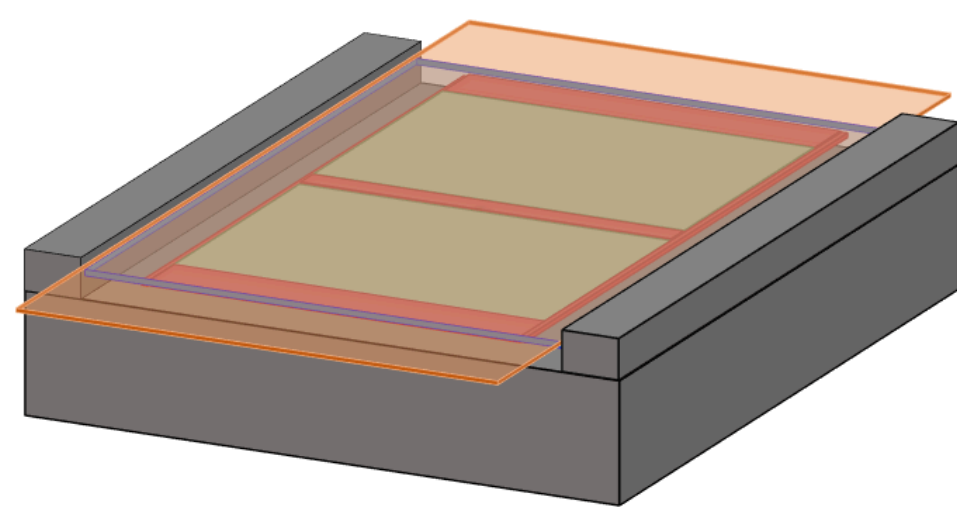all chips with threshold 82e ± 20e

dots at energies
x.1 GeV
from simulation with beam energy spread

EPICAL-2 preliminary
Allpix^2 simulation
default settings

- σ/μ (hits)
- σ/μ (clusters)

with energy spread

without energy spread

σ / μ (%)

electron energy E (GeV)

energy response: linearity

Gaussian beam energy spread

▸ no influence on the deviation between
μ and the linear parametrisation

left:
0 GeV spread of beam energy
all chips with threshold 82e ± 20e

right:
0.158 GeV spread of beam energy
all chips with threshold 82e ± 20e

EPICAL-2 preliminary
Allpix^2 simulation
default settings

- ● μ (hits)
- ● μ (clusters)

μ ×10^3

data/fit

electron energy E (GeV)

EPICAL-2 simulation utilising Allpix² ▮

A Monte Carlo Simulation tool for silicon pixel detectors
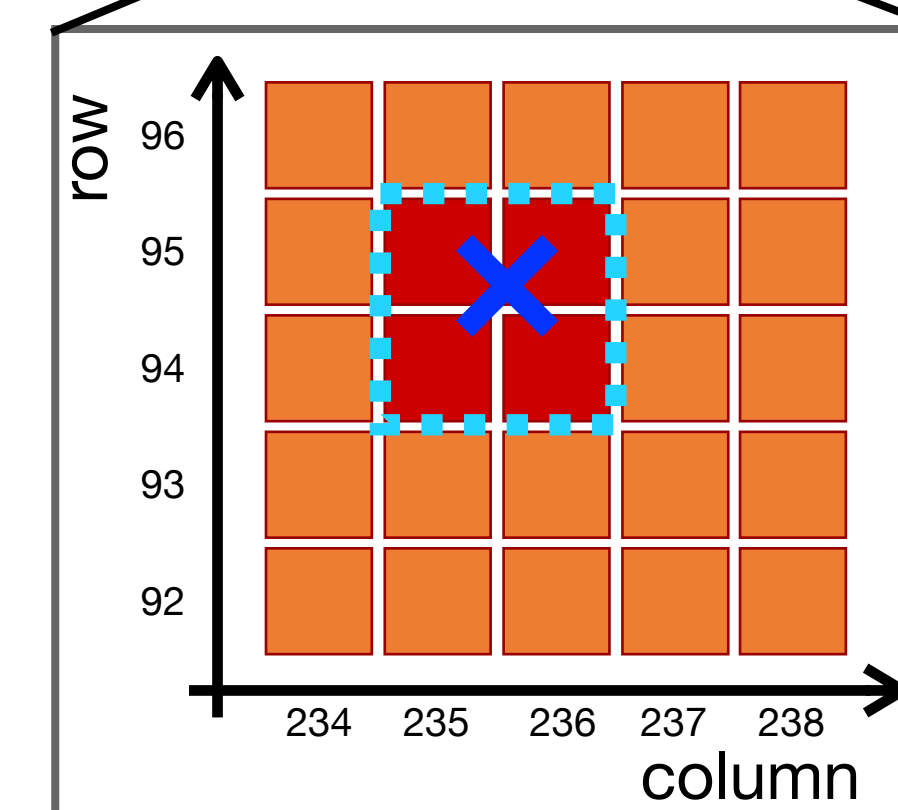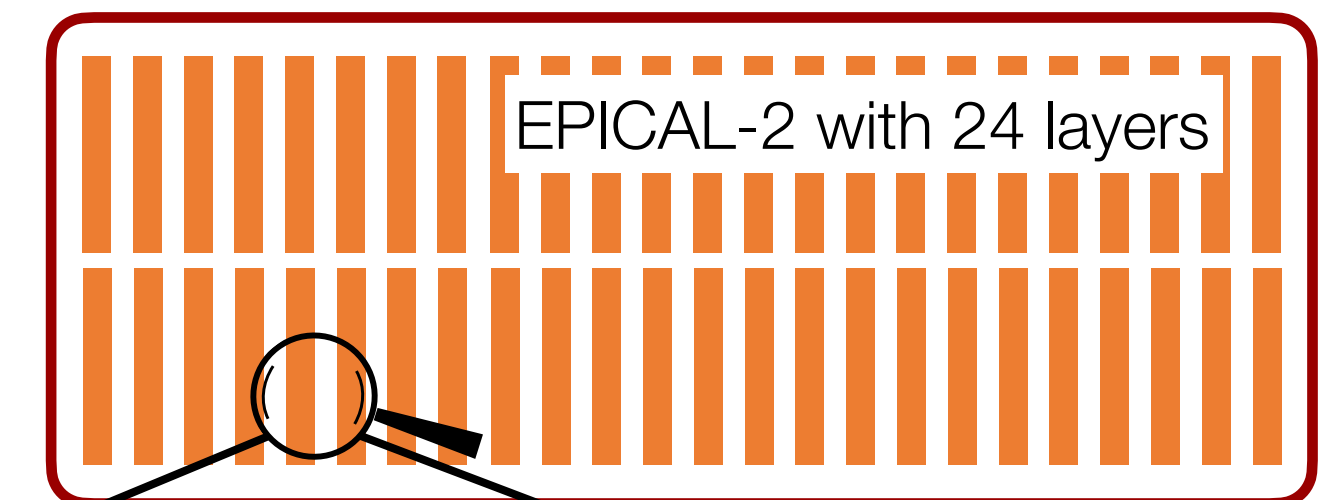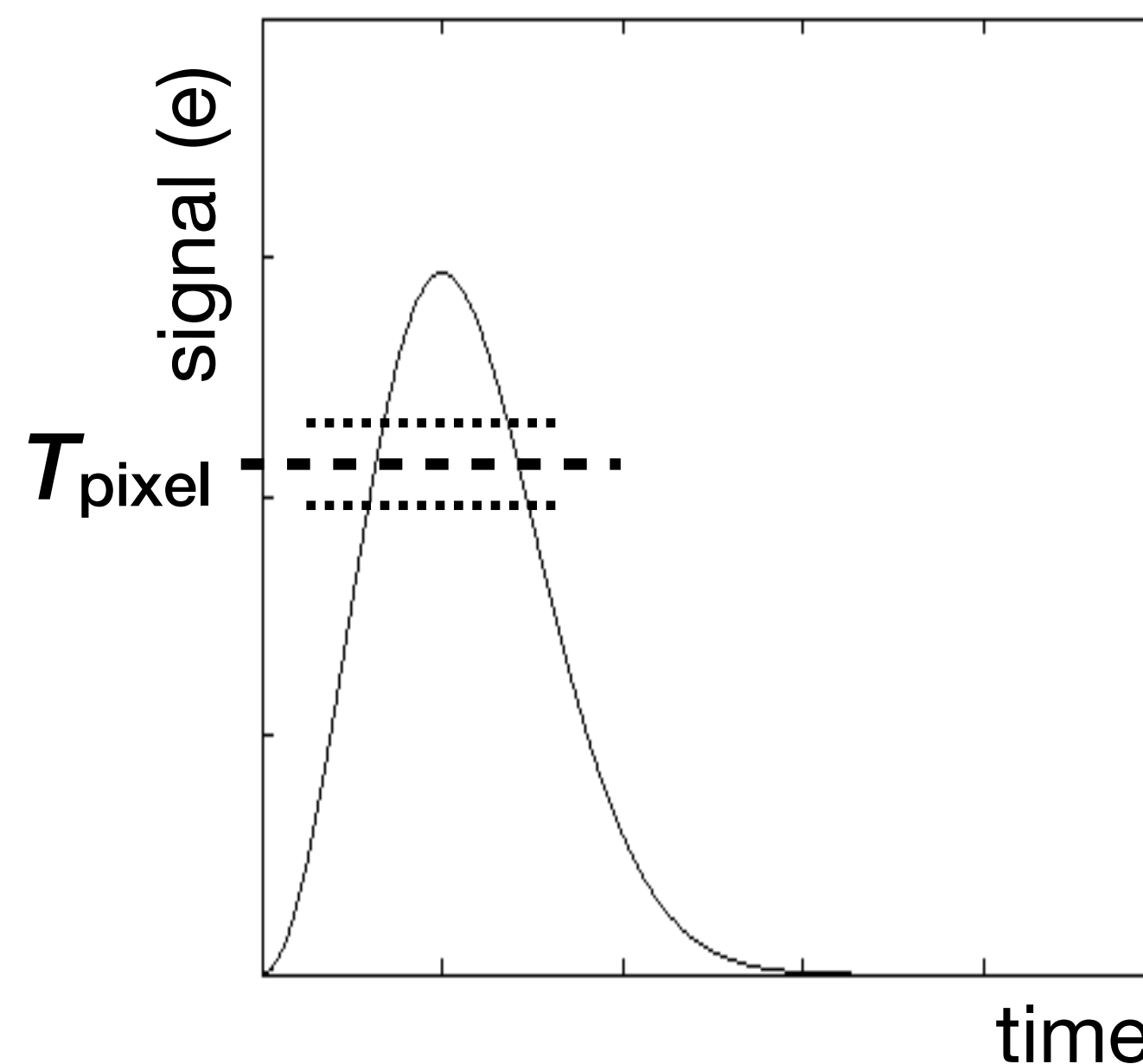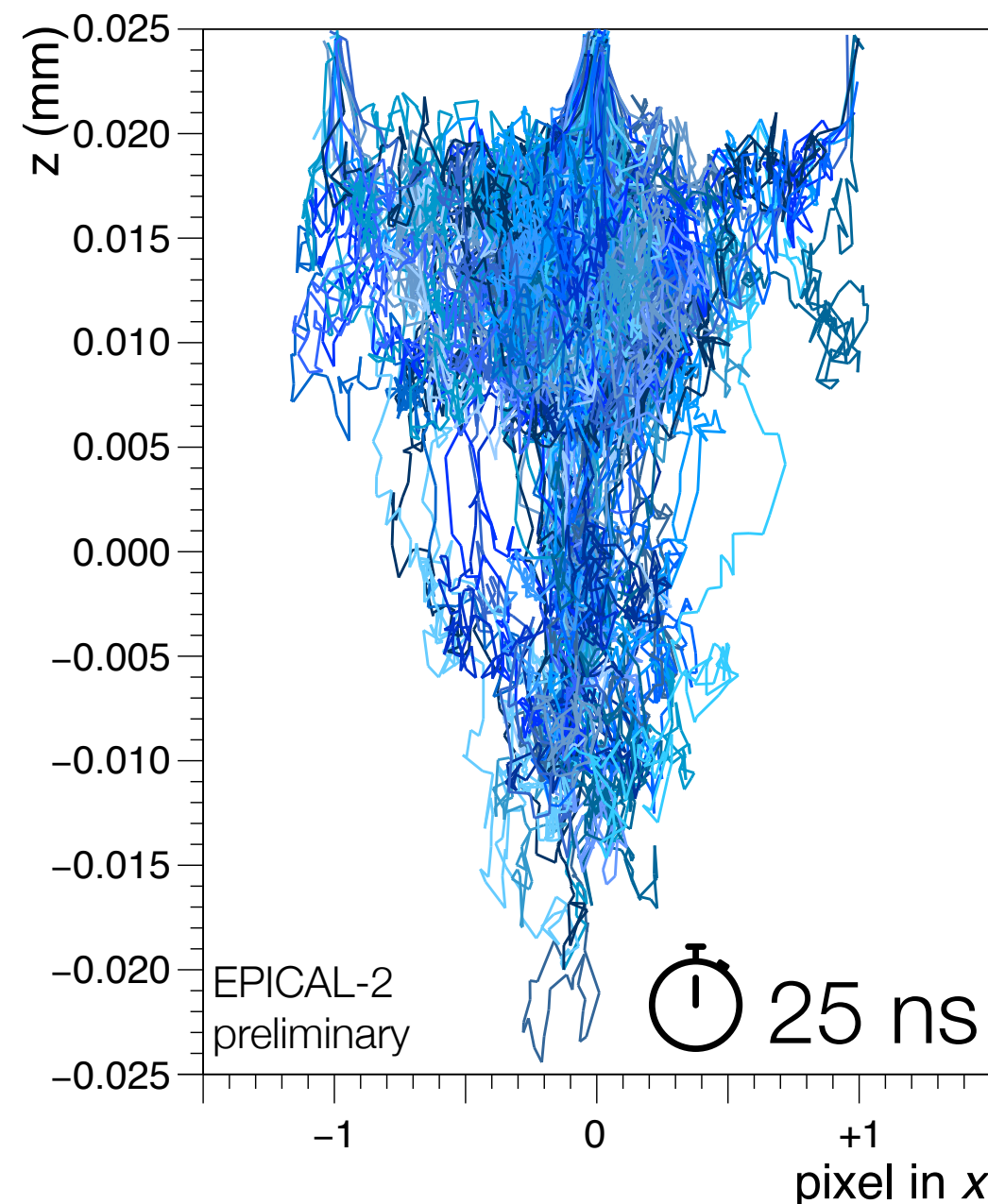From incoming particle(s) to readout

simulation chain:

geometry builder	electric field initialisation	energy deposition

geometry builder

diodes

electric field initialisation

▸ electric field obtained from **TCAD** simulation by Jan Hasenbichler
▸ total reverse bias voltage V_{RB} = 1.4 V

energy deposition

▸ beam utilising GPS
▸ particle transport and deposition of charges in active materials
  • FFTP_BERT_EMZ

EPICAL-2 simulation utilising Allpix^2 ▌▌

A Monte Carlo Simulation tool for silicon pixel detectors
From incoming particle(s) to readout

simulation chain:

| propagation and transfer | digitisation | output |

propagation and transfer

▸ propagation of **charge carrier groups** (50 charges)

▸ diffusion and drift within **integration time** t_{int} = 25 ns

▸ pixel assignment of charges

EPICAL-2 preliminary ⏱ 25 ns

digitisation

▸ **Gaussian noise** with width σ_{noise} = 20 e

▸ pixel hit: charge surpasses **threshold value** T_{pixel} = 82 ± 20 e

T_{pixel}

signal (e)

time

output

▸ 2D information of hits per layer
  • column and row

EPICAL-2 with 24 layers

measurement:

▸ number N_{hits} of pixel hits

▸ number $N_{clusters}$ of clusters

✕ shower particle   ⬚ cluster
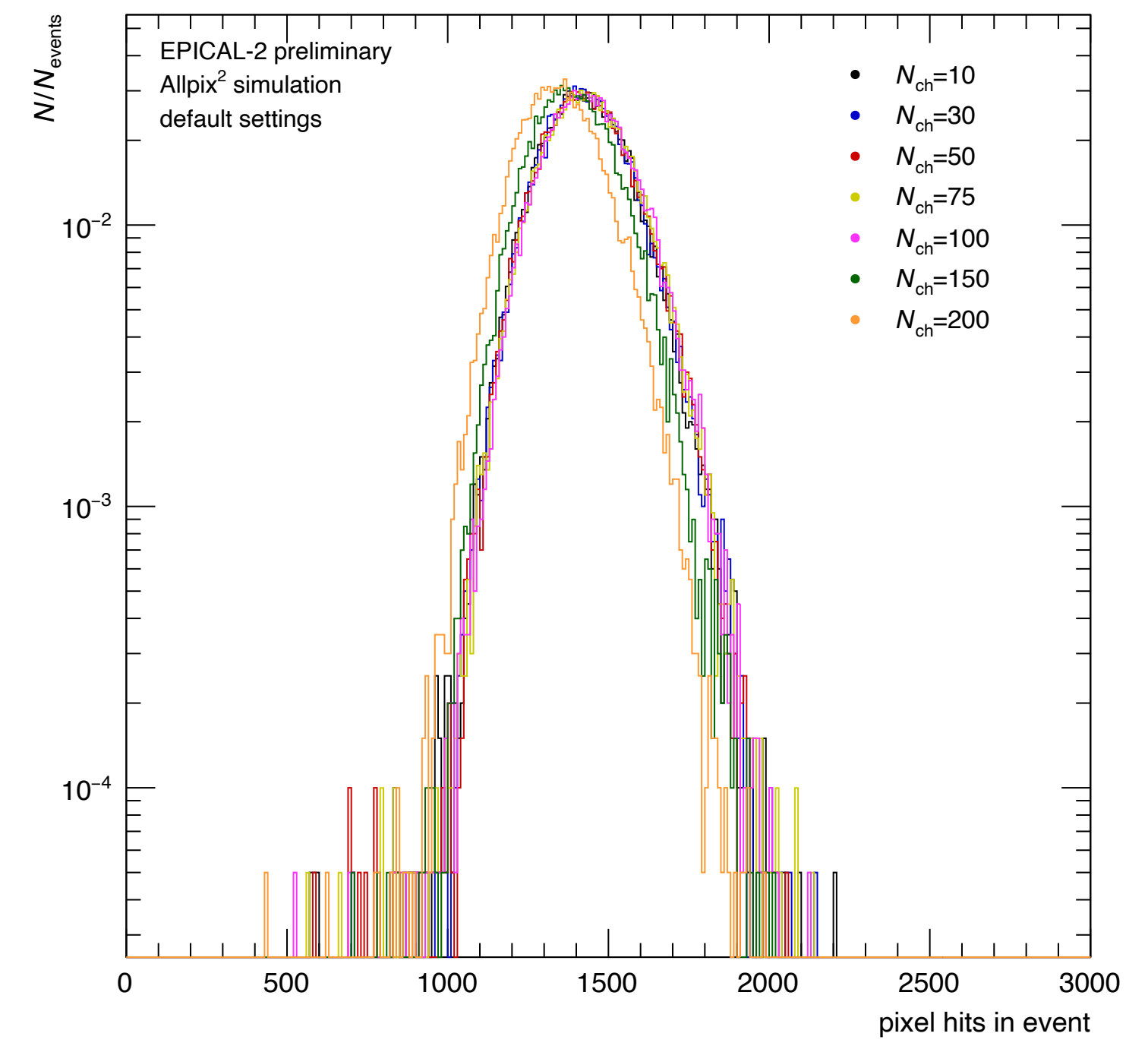🟥 pixel with hit   🟧 pixel without hit

variation: charge carriers in a group
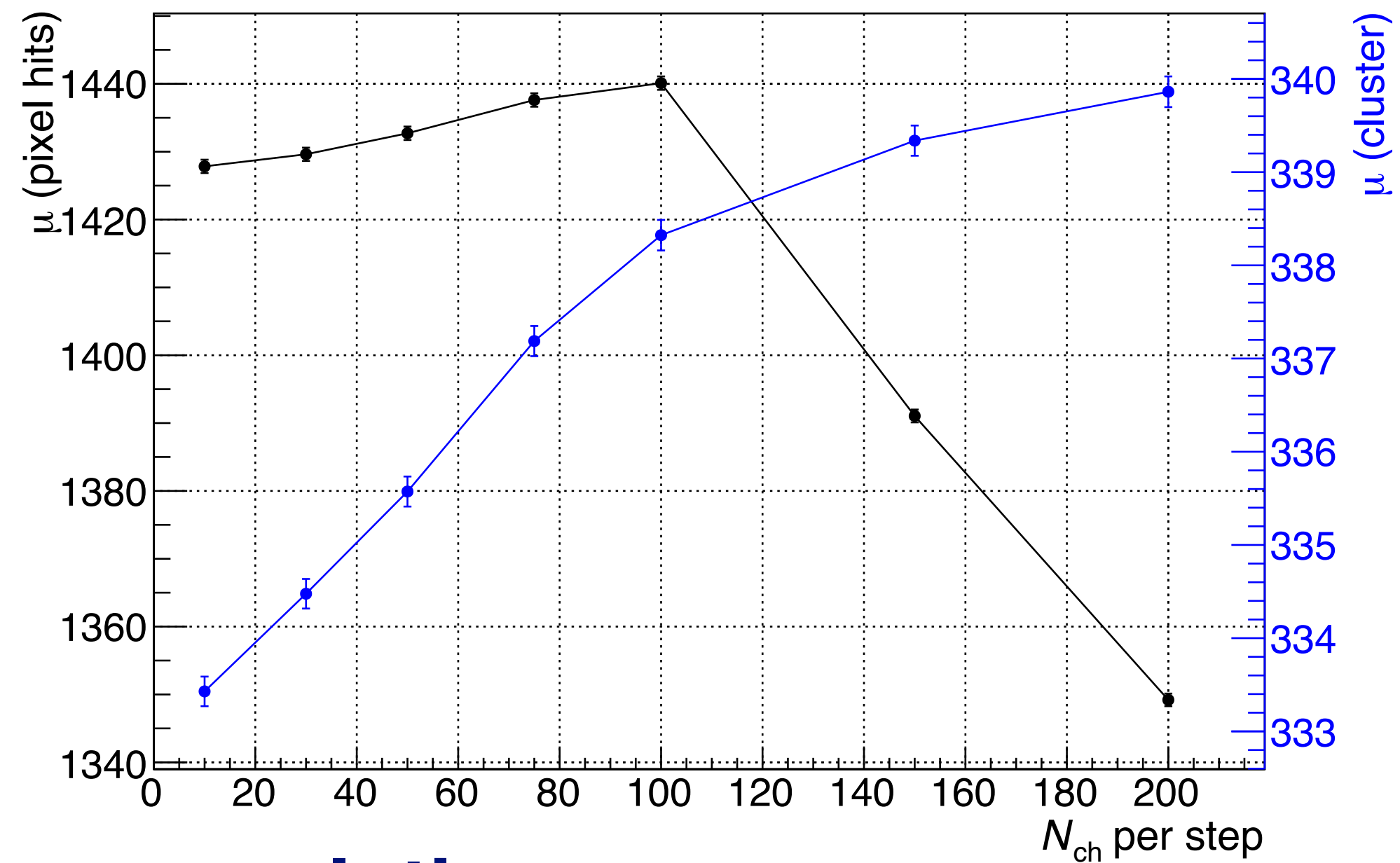
hits

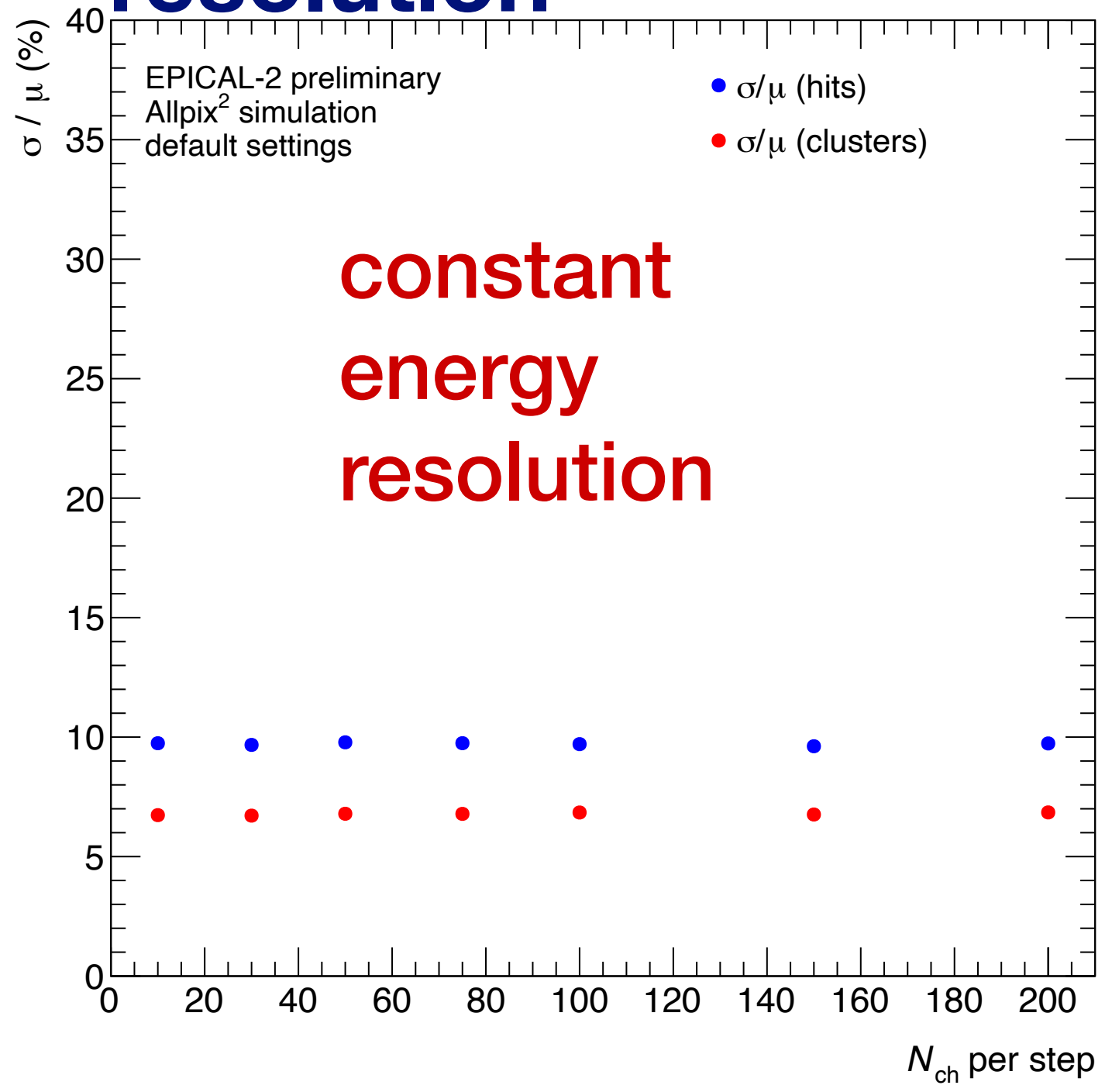for $N_{ch} < 100$:
rising mean of
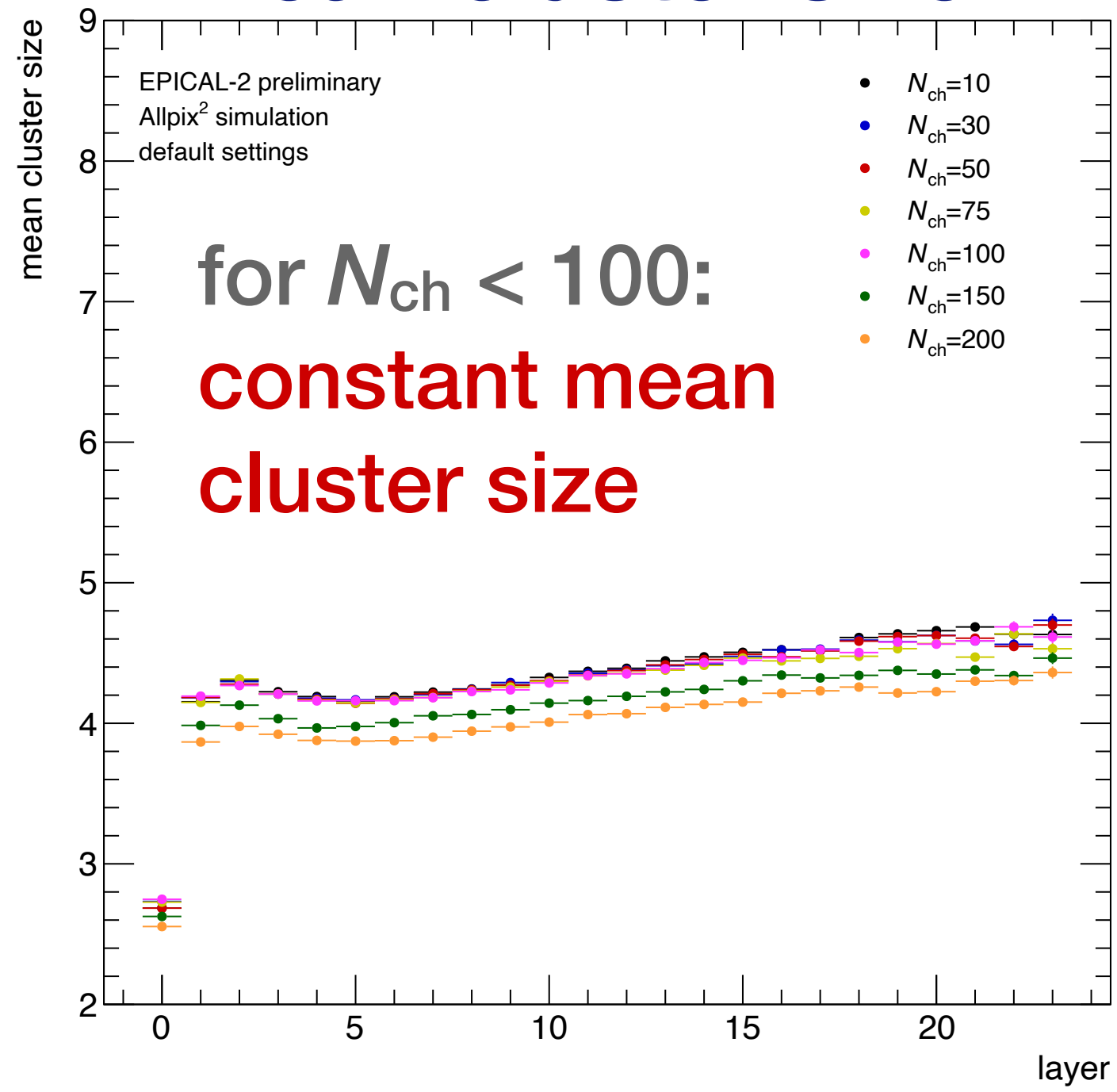pixel hits and clusters
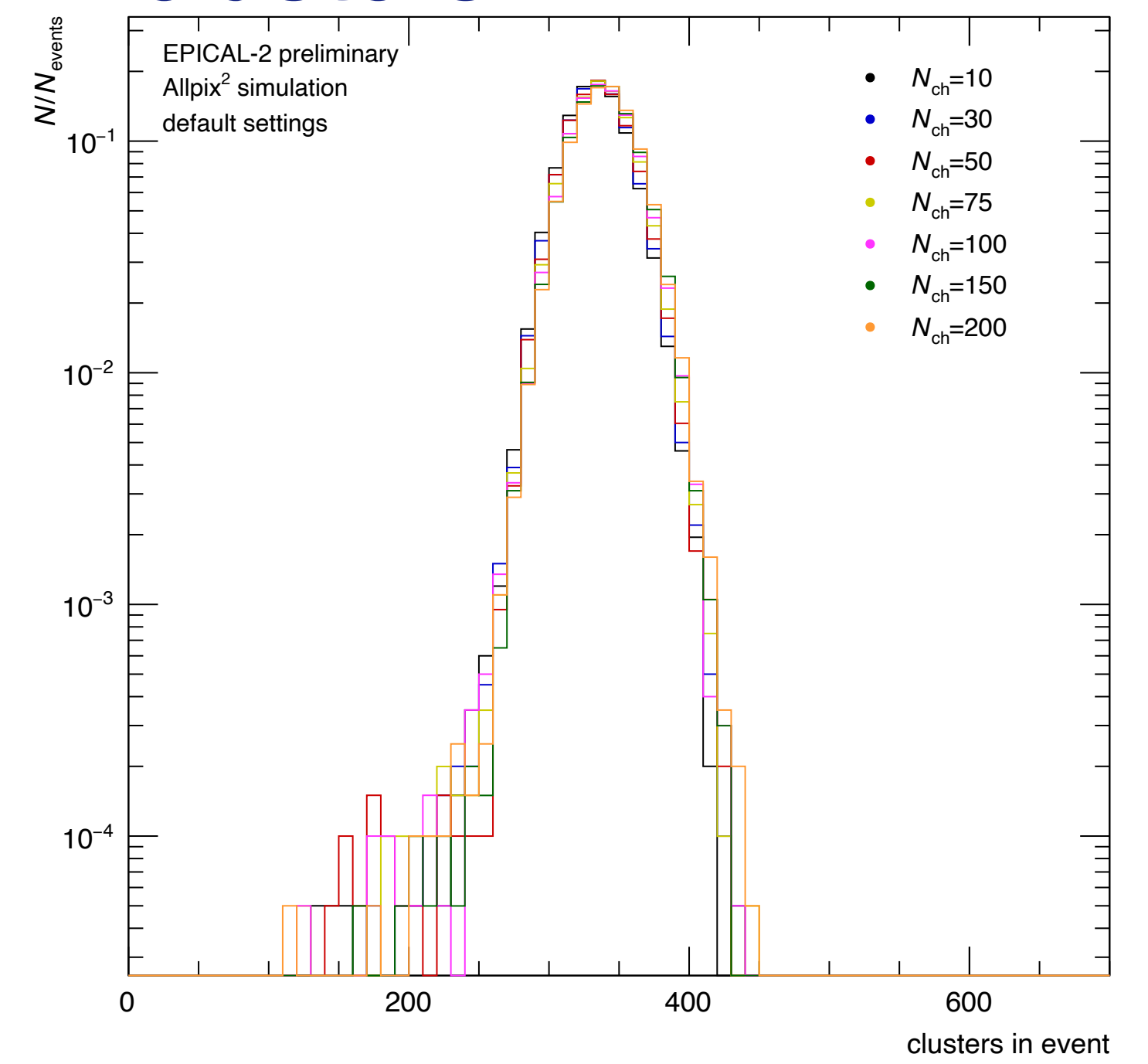for $N_{ch} > 100$:
sudden drop of
mean of pixel hits

resolution

constant
energy
resolution

mean cluster size

for $N_{ch} < 100$:
constant mean
cluster size

clusters

EPICAL-2 simulation utilising Allpix² ❚❚

A Monte Carlo Simulation tool for silicon pixel detectors
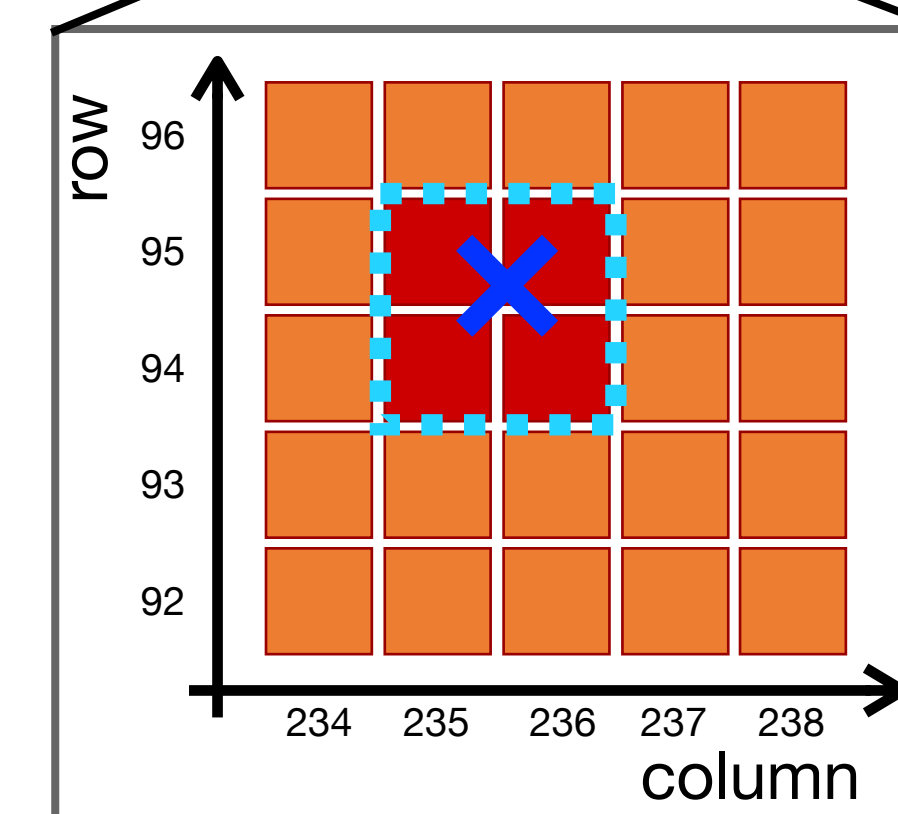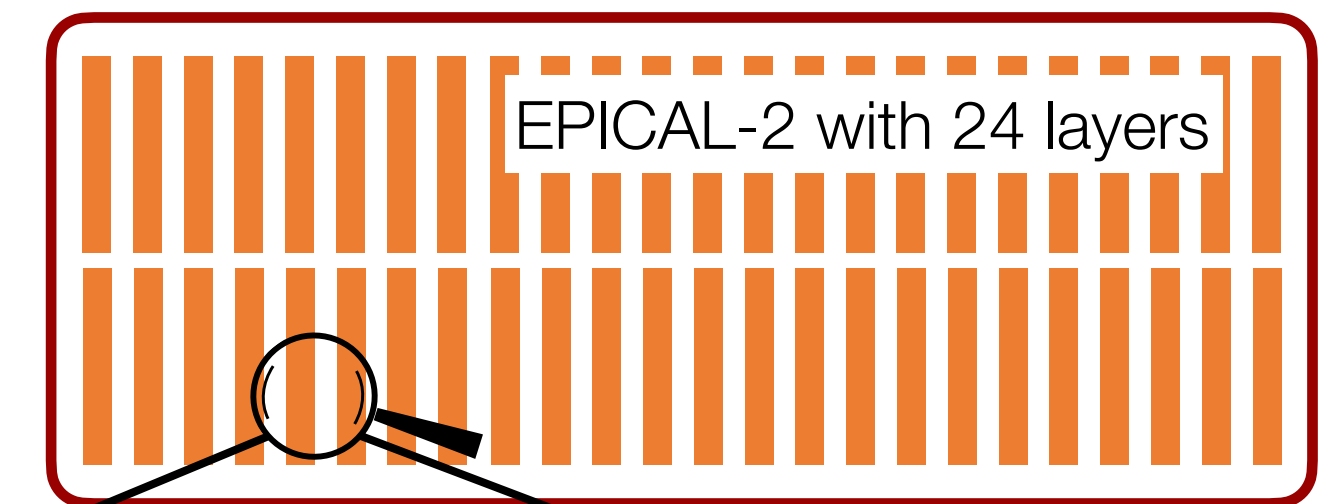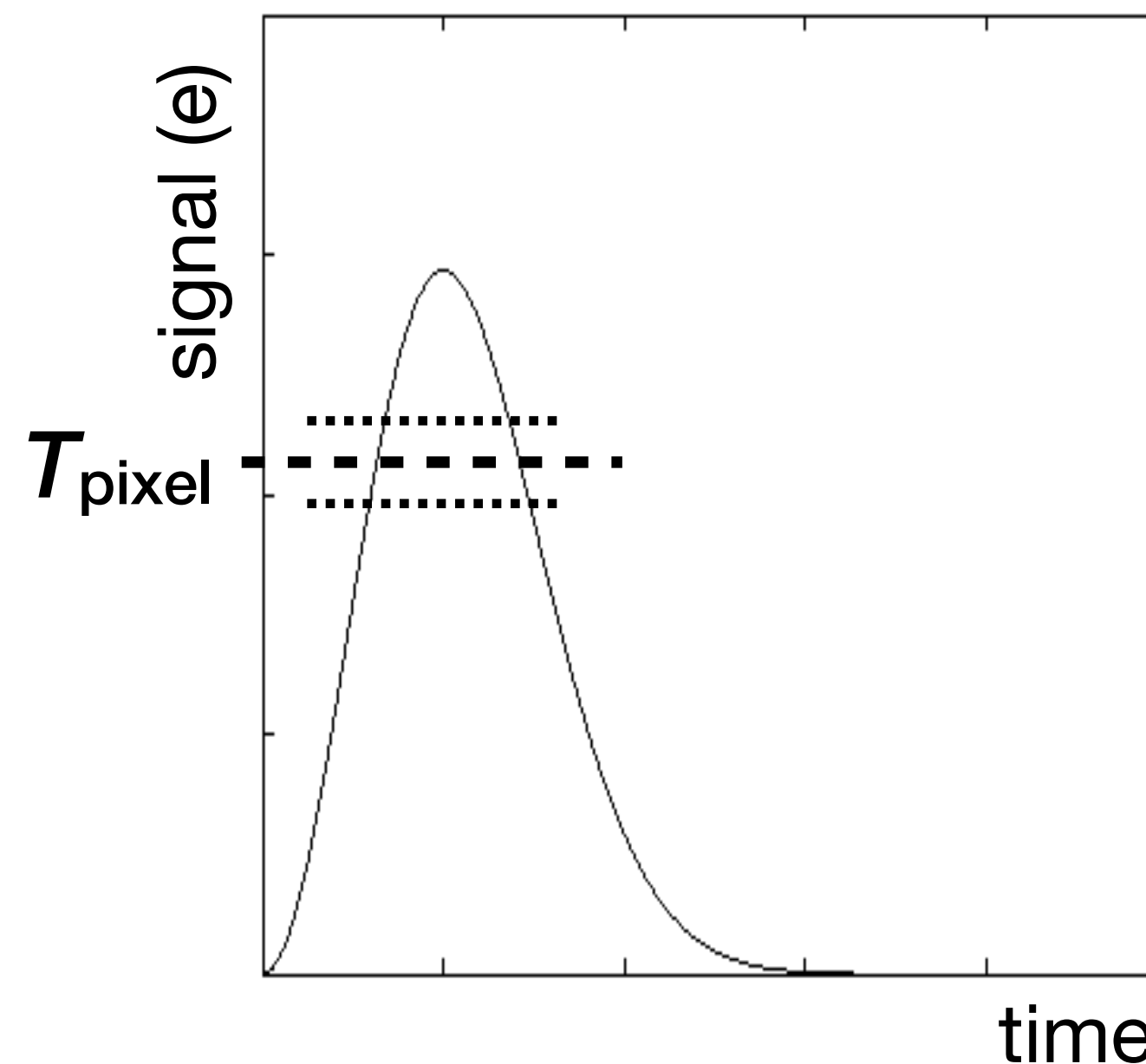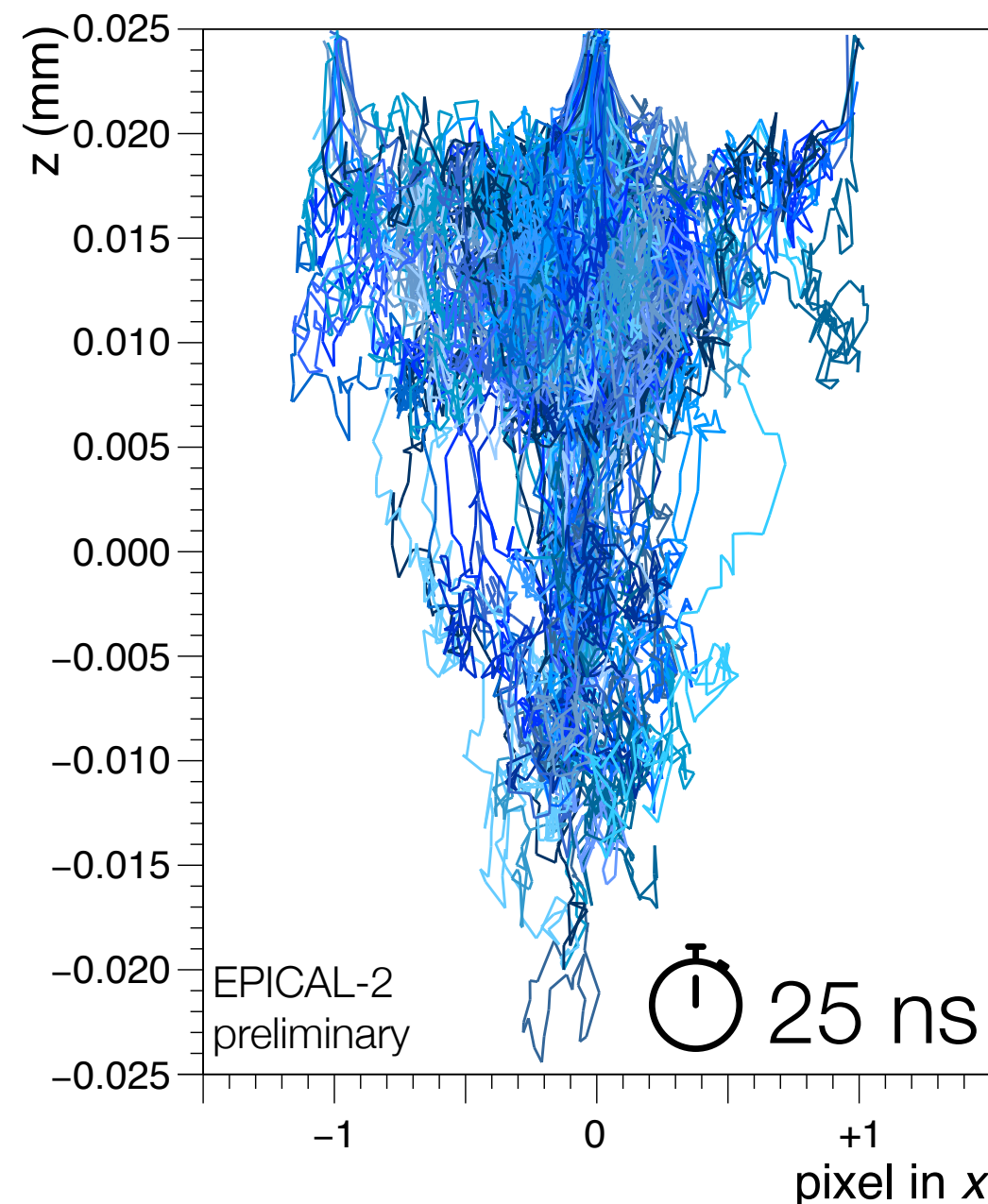From incoming particle(s) to readout

ap² allpix squared

GEANT4 A SIMULATION TOOLKIT

ROOT Data Analysis Framework

simulation chain:

propagation and transfer - - - ▶ **digitisation** - - - ▶ **output**

▸ propagation of **charge carrier groups** (50 charges)
▸ diffusion and drift within **integration time t_{int} = 25 ns**
▸ pixel assignment of charges

▸ **Gaussian noise** with width σ_{noise} = **20 e**
▸ pixel hit: charge surpasses **threshold value T_{pixel} = 82 ± 20 e**

▸ 2D information of hits per layer
  • column and row

EPICAL-2 with 24 layers

z (mm) ... EPICAL-2 preliminary ⏱ 25 ns ... pixel in x

signal (e) ... T_{pixel} ... time

row 96 95 94 93 92 ... column 234 235 236 237 238

measurement:
▸ number N_{hits} of pixel hits
▸ number $N_{clusters}$ of clusters

✖ shower particle ┊ cluster
🟥 pixel with hit 🟧 pixel without hit

EPICAL-2 simulation utilising Allpix^2 ▮▮

A Monte Carlo Simulation tool for silicon pixel detectors
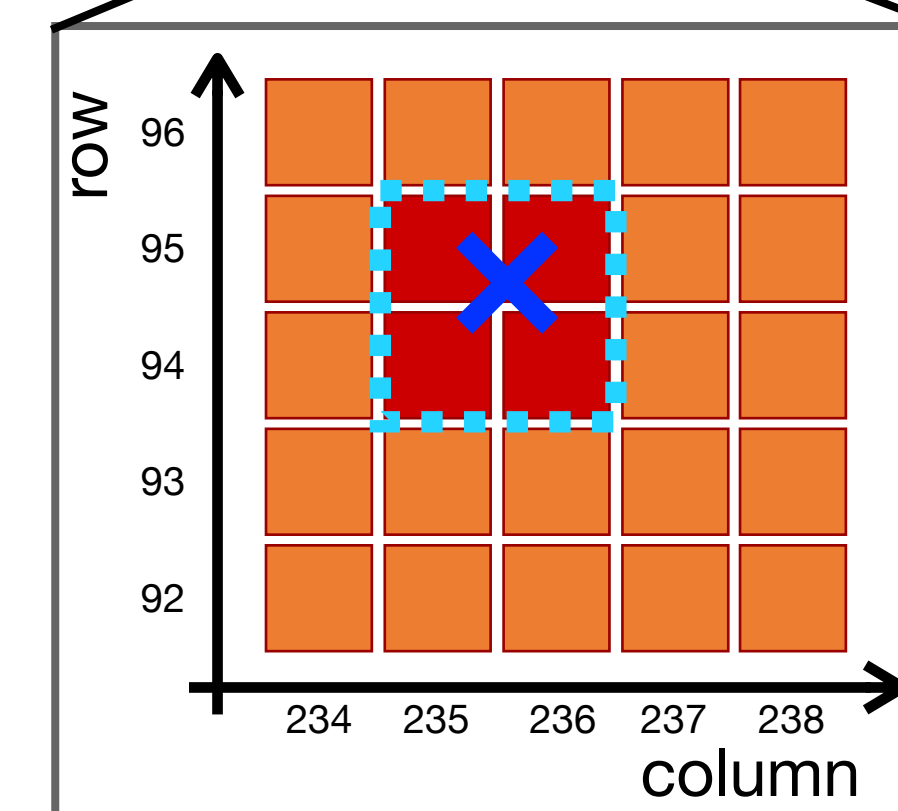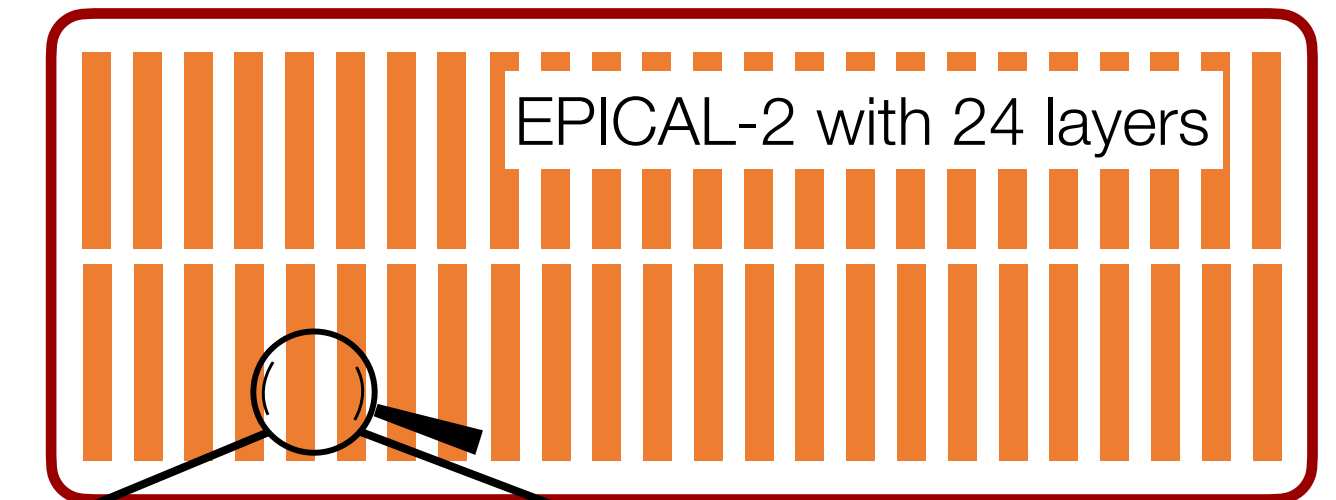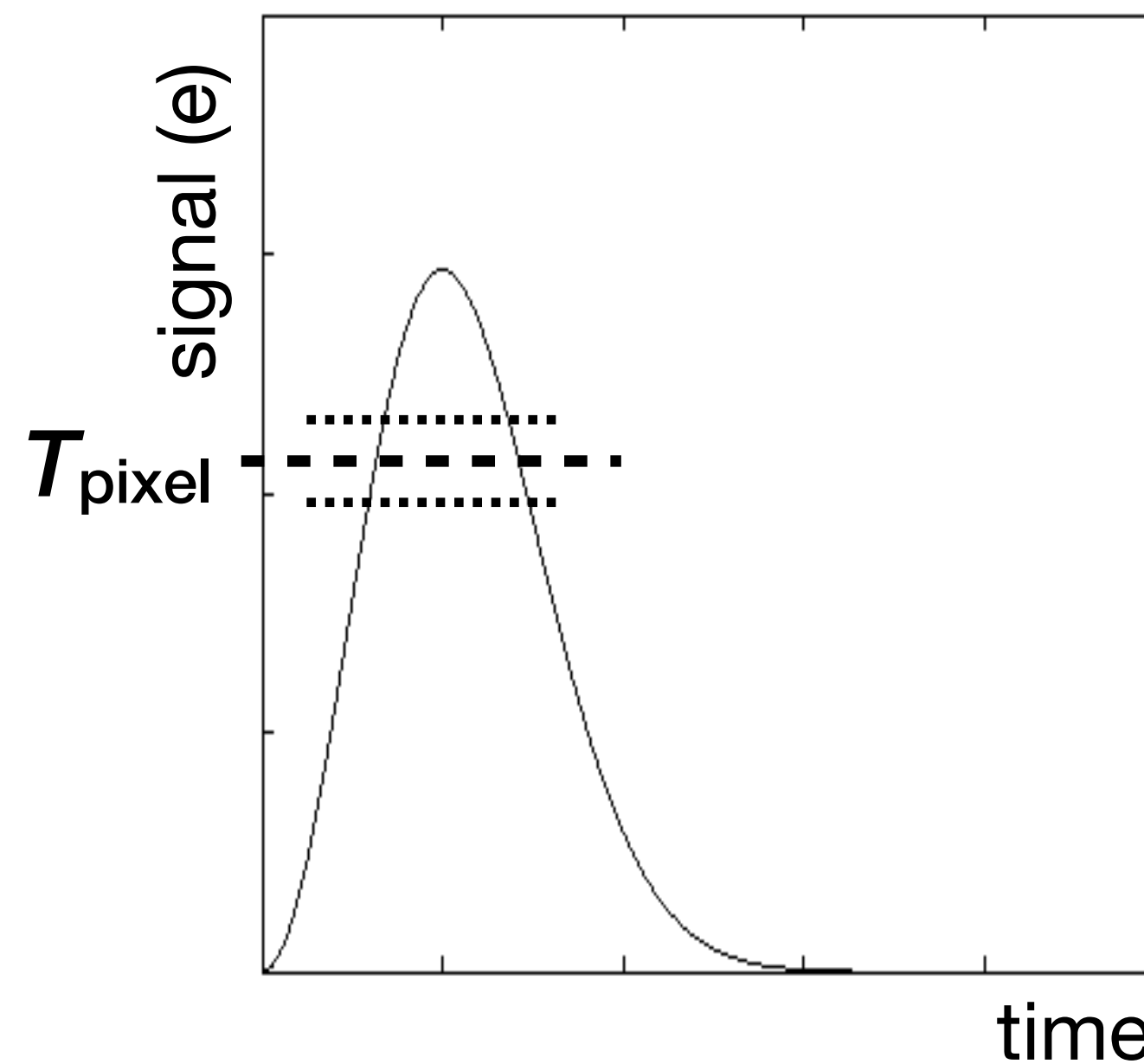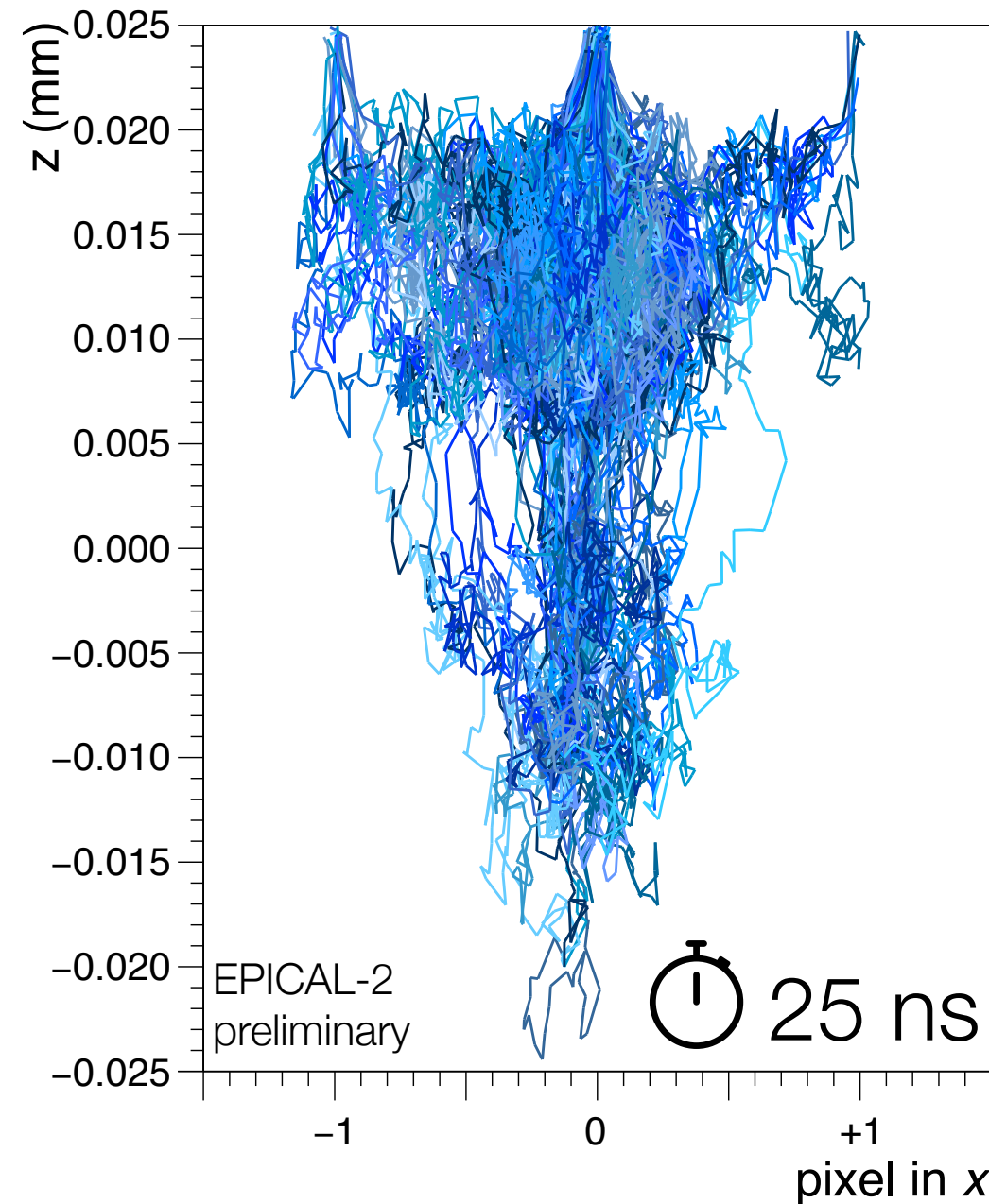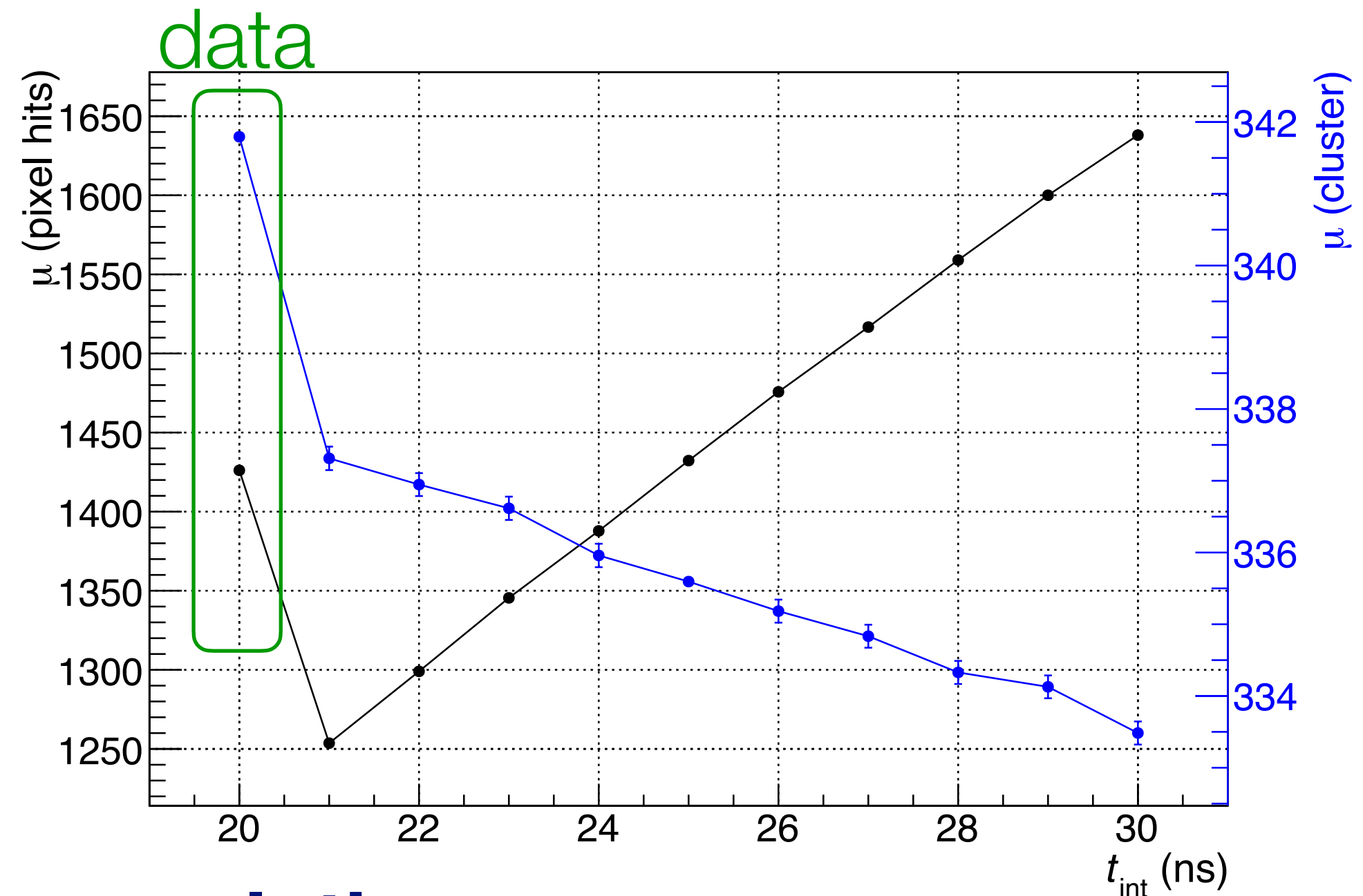From incoming particle(s) to readout

simulation chain:

```
- - -▶  propagation and transfer  - - - -▶  digitisation  - - - -▶  output
```

▸ propagation of **charge carrier groups** (50 charges)

▸ diffusion and drift within **integration time** t_{int} = **25 ns**

▸ pixel assignment of charges

▸ **Gaussian noise** with width σ_{noise} = **20 e**

▸ pixel hit: charge surpasses **threshold value** T_{pixel} = **82 ± 20 e**

▸ 2D information of hits per layer
  • column and row

EPICAL-2 with 24 layers

EPICAL-2 preliminary ⏱ 25 ns

T_{pixel}

signal (e)

time

row

96
95
94
93
92

234 235 236 237 238
column

measurement:
▸ number N_{hits} of pixel hits
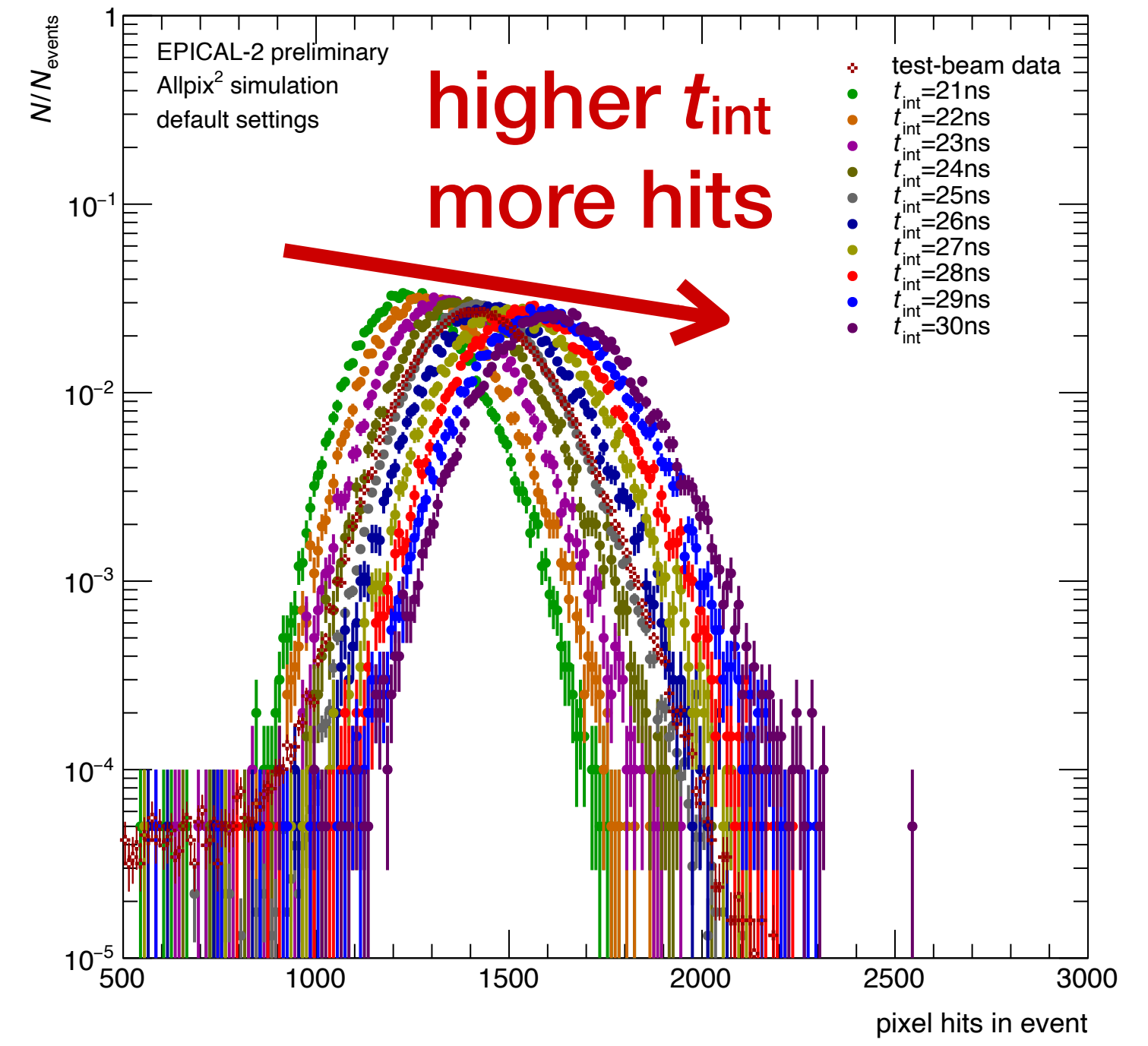▸ number $N_{clusters}$ of clusters

✕ shower particle ⬚ cluster
■ pixel with hit ■ pixel without hit
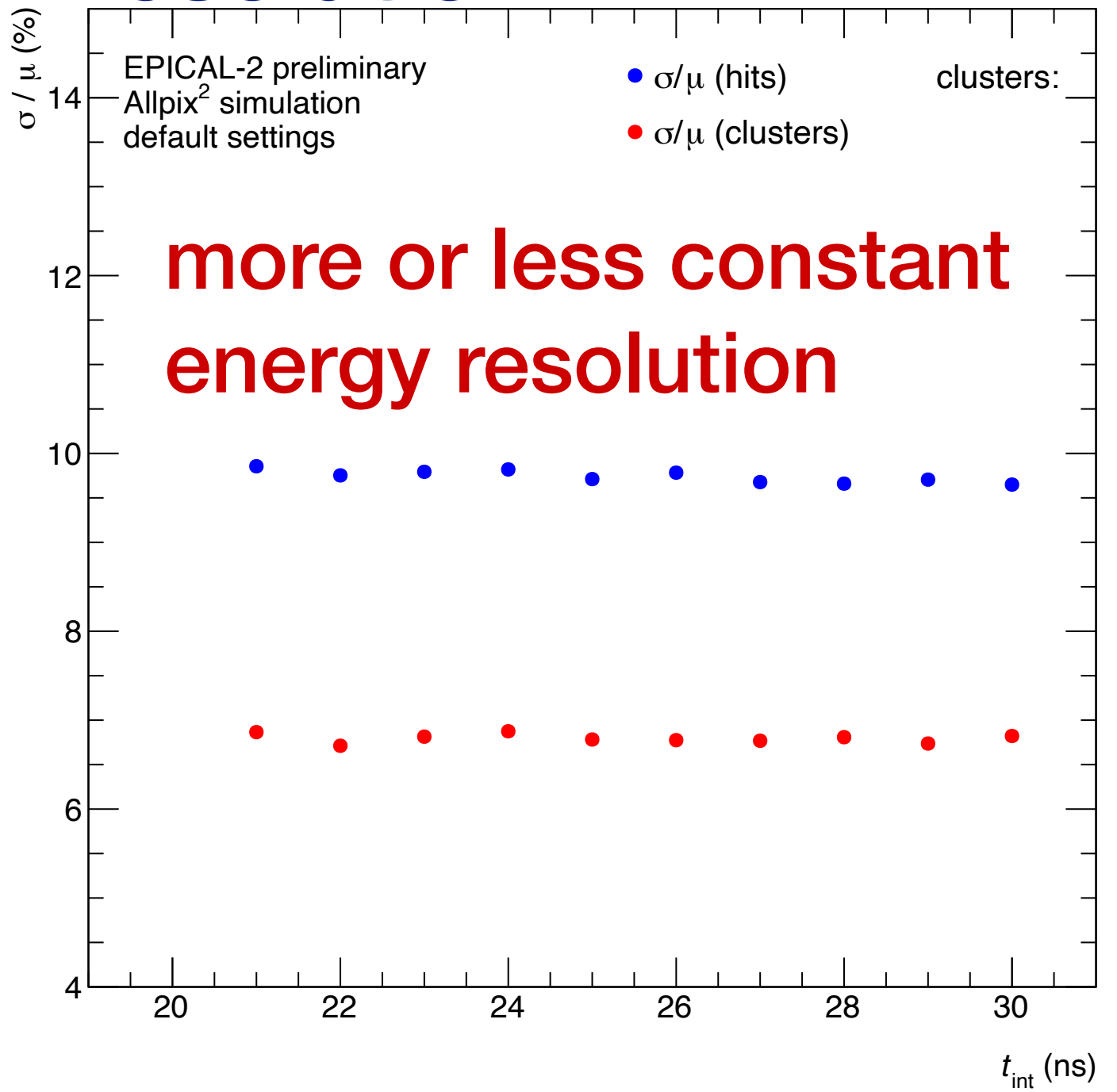
variation: integration time t_{int}

hits

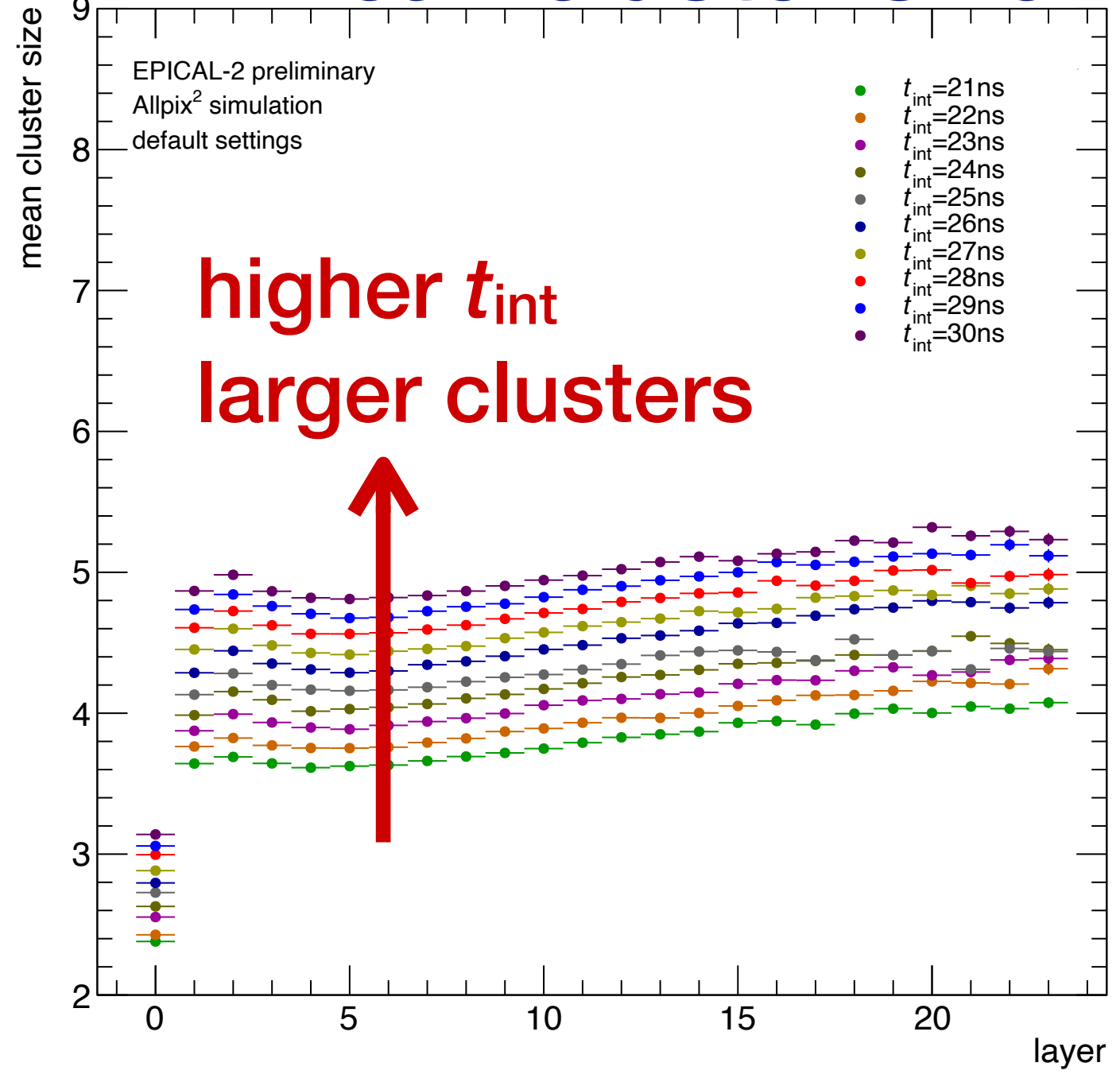higher t_{int}:

linear rise (decrease)
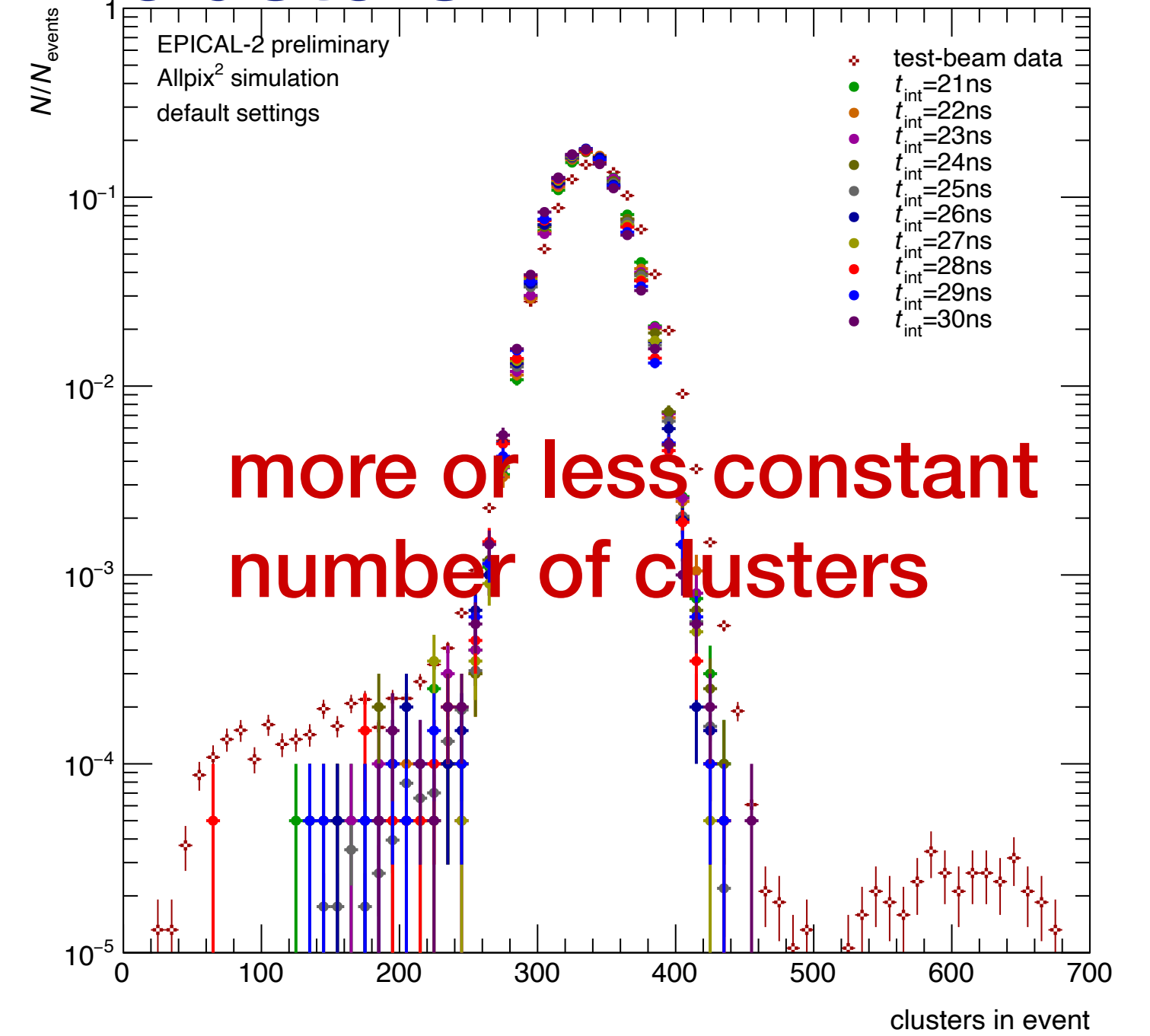for hits (clusters)

higher t_{int}
more hits

data

resolution

more or less constant
energy resolution

mean cluster size

higher t_{int}
larger clusters

clusters

more or less constant
number of clusters

EPICAL-2 simulation utilising Allpix^2 ❚❚

A Monte Carlo Simulation tool for silicon pixel detectors
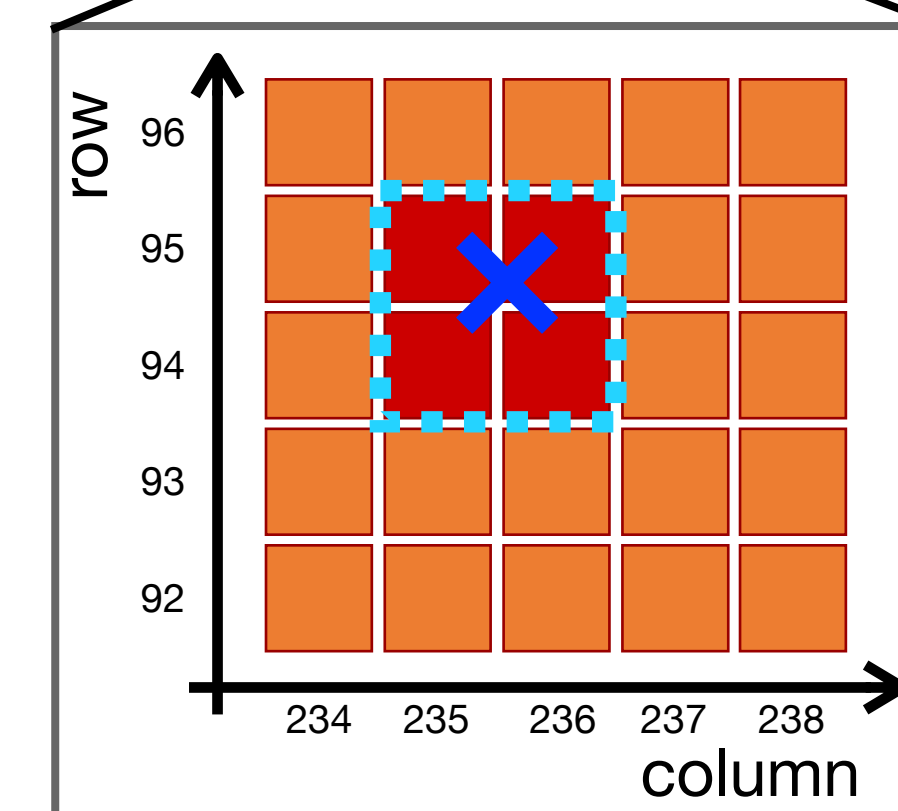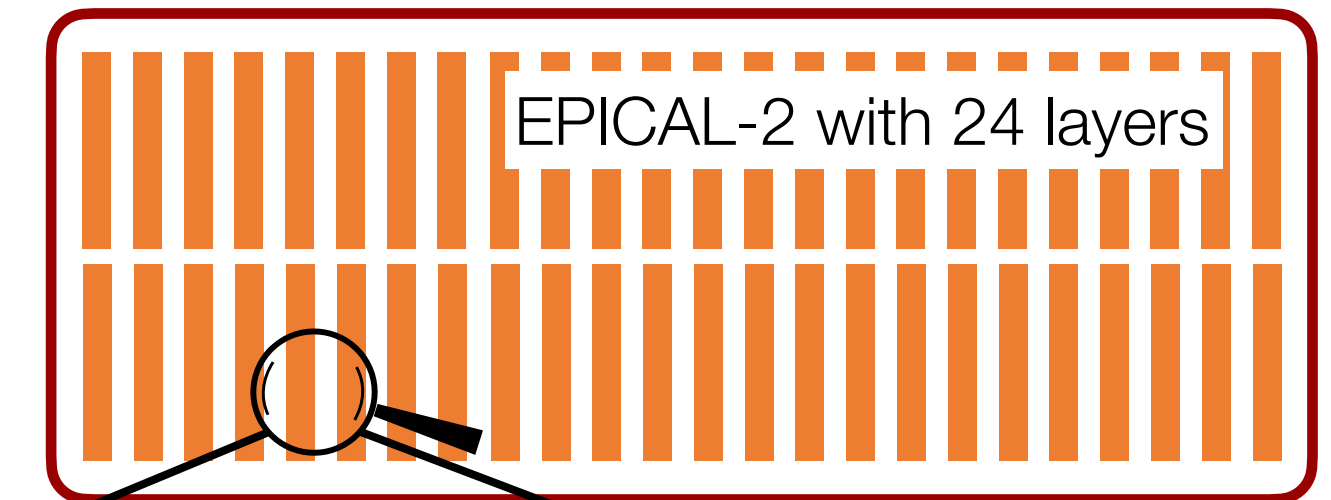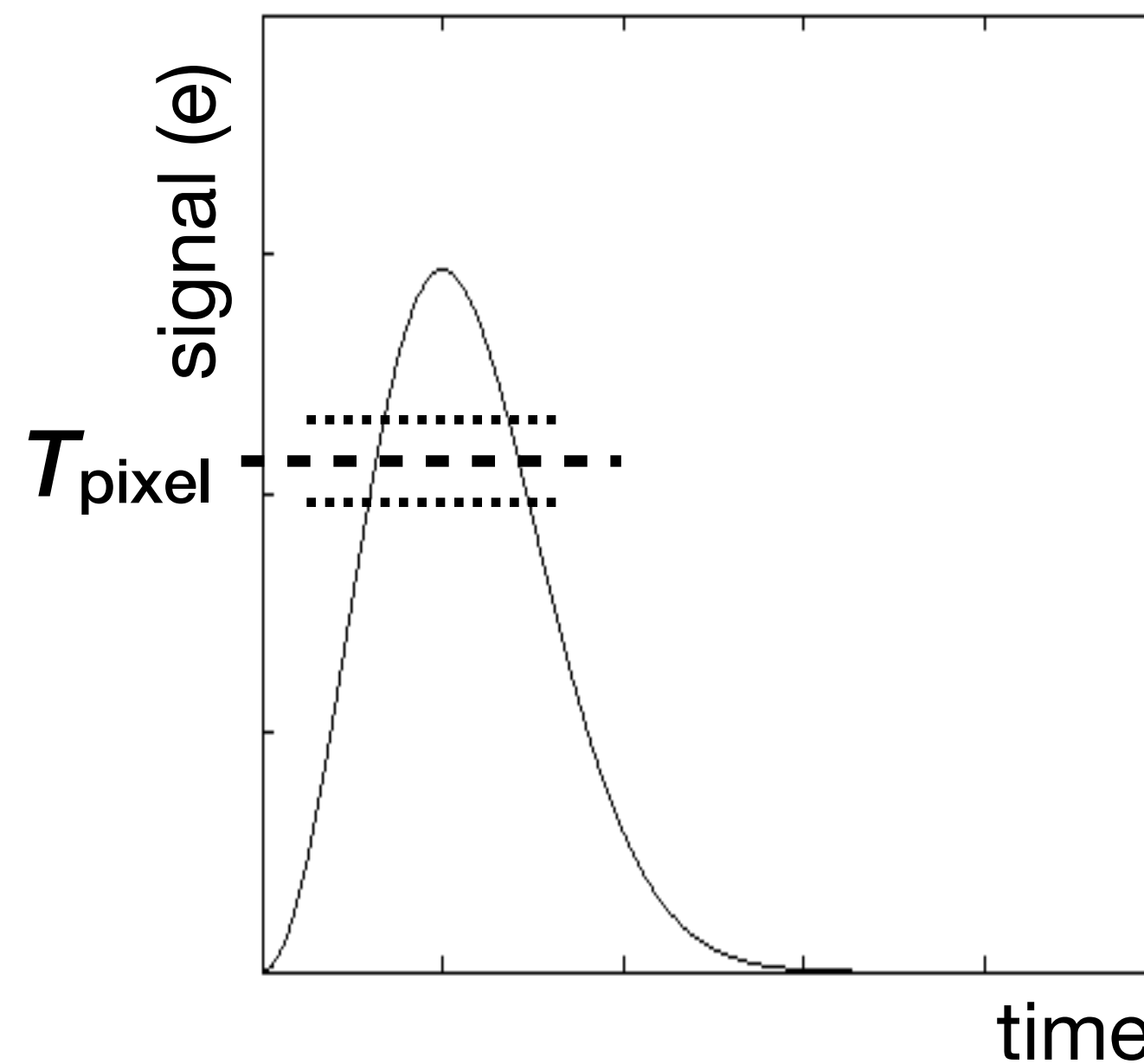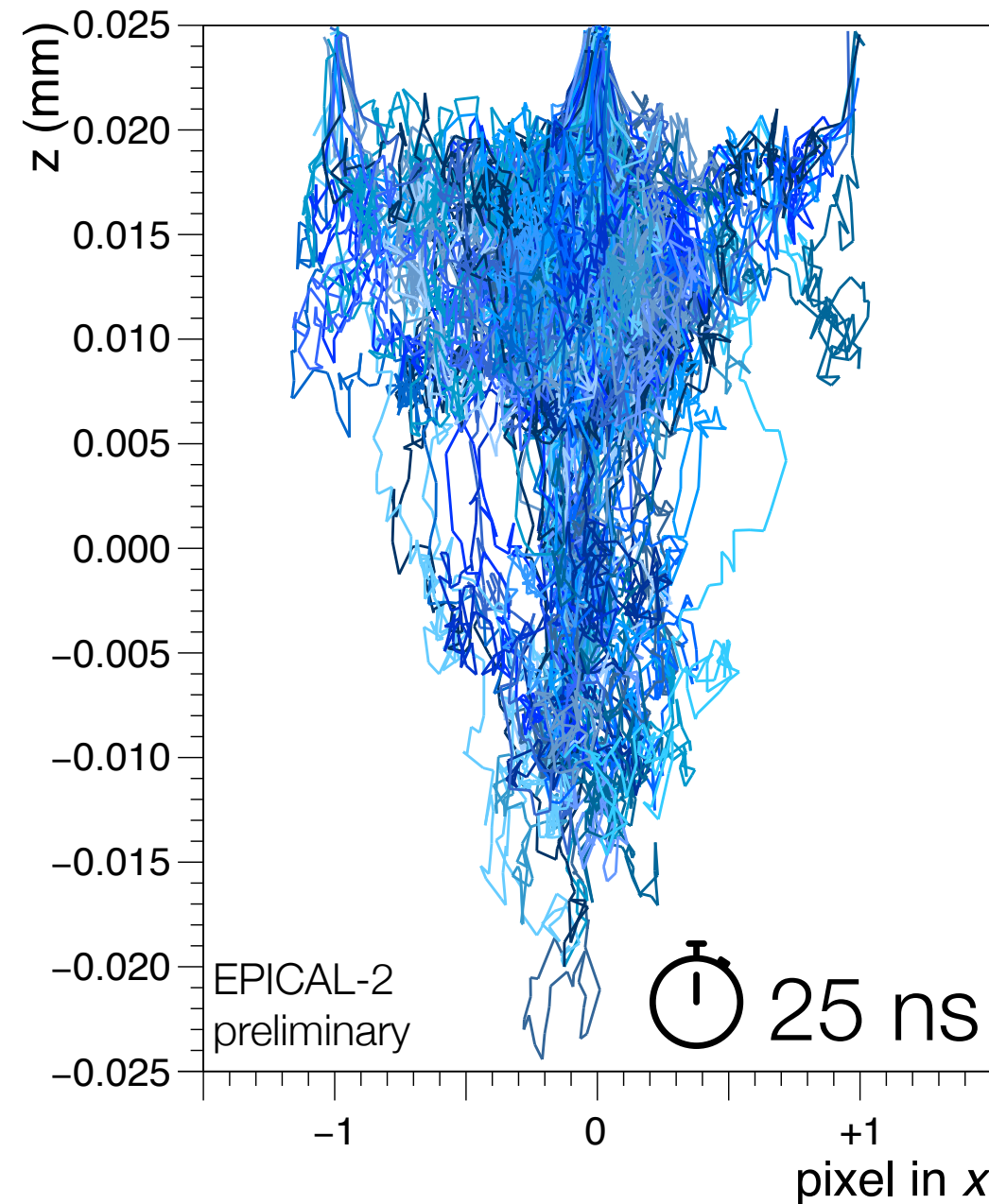From incoming particle(s) to readout

simulation chain:

```
- - -> propagation and transfer  - - - ->  digitisation  - - - ->  output
```

▸ propagation of **charge carrier groups** (50 charges)

▸ diffusion and drift within **integration time** t_{int} = **25 ns**

▸ pixel assignment of charges

▸ **Gaussian noise** with width σ_{noise} = **20 e**

▸ pixel hit:
charge surpasses **threshold value** T_{pixel} = **82 ± 20 e**

▸ 2D information of hits per layer
  • column and row

EPICAL-2 with 24 layers

measurement:
▸ number N_{hits} of pixel hits
▸ number $N_{clusters}$ of clusters

EPICAL-2 preliminary

⏱ 25 ns

T_{pixel}

signal (e)

time

row

column

✖ shower particle ⬚ cluster
🟥 pixel with hit 🟧 pixel without hit

EPICAL-2 simulation utilising Allpix² ▮▮

A Monte Carlo Simulation tool for silicon pixel detectors
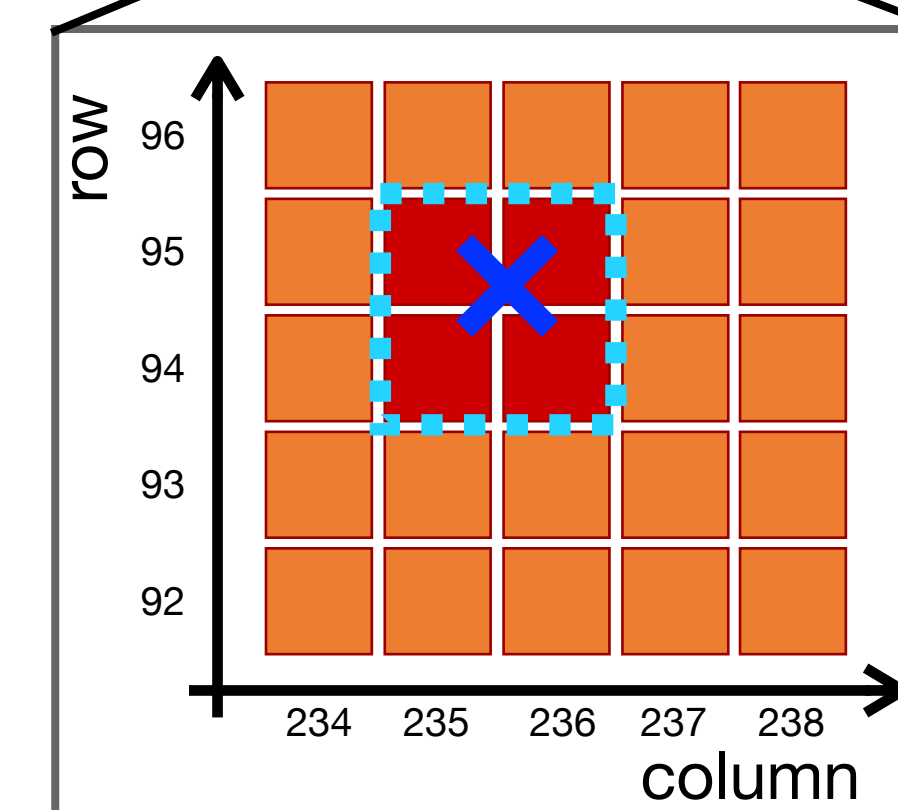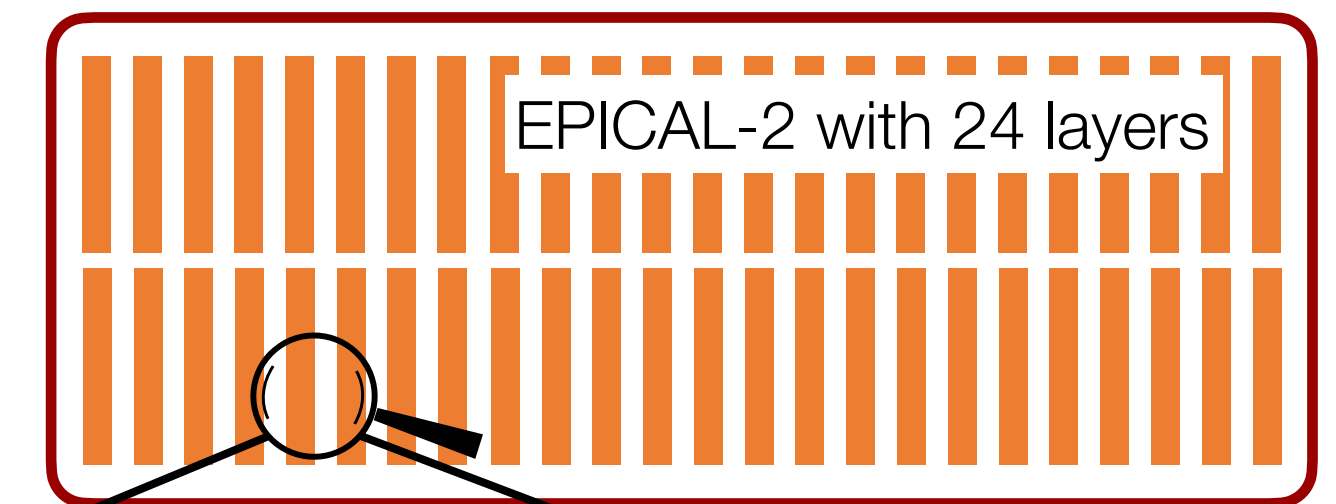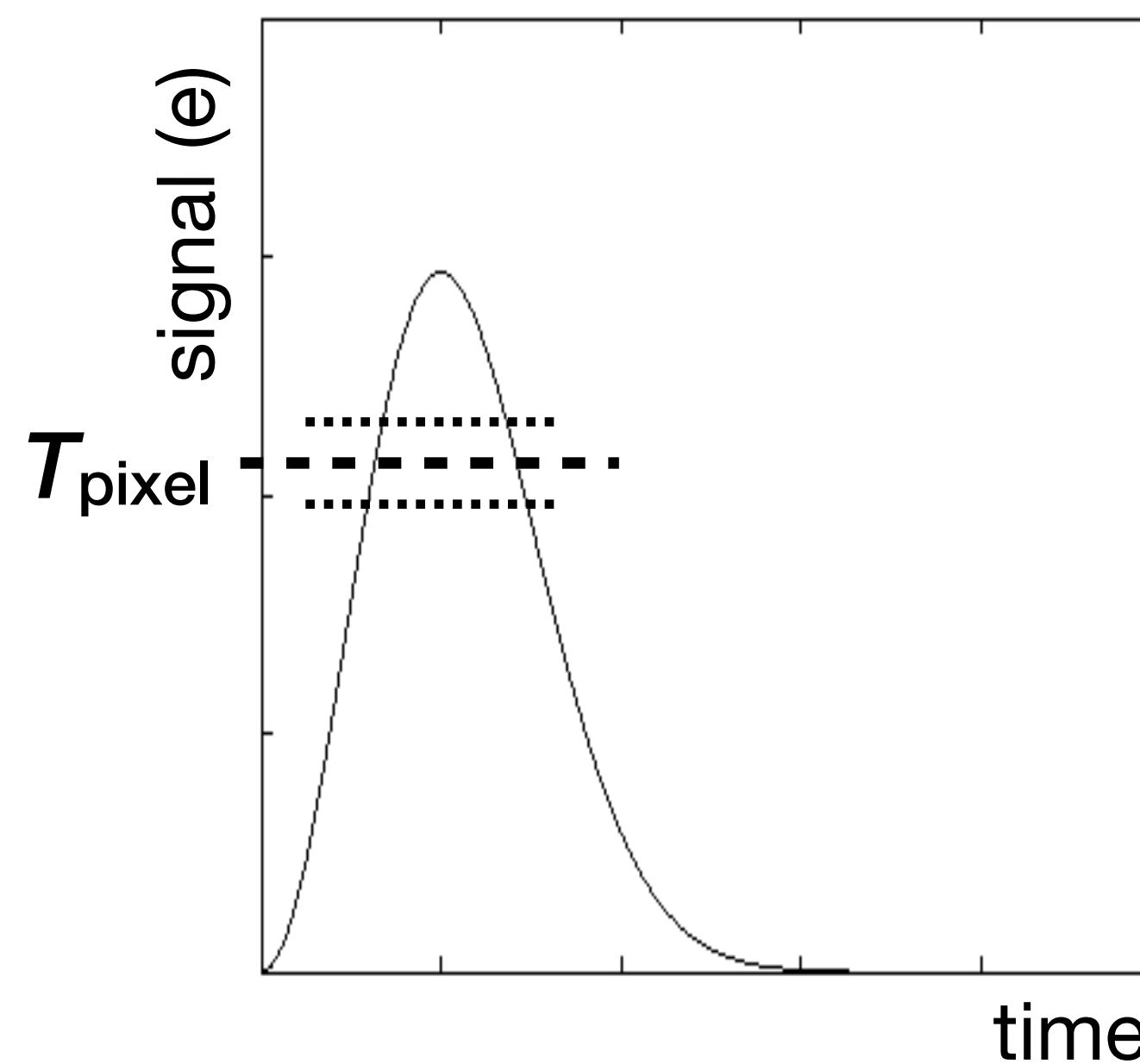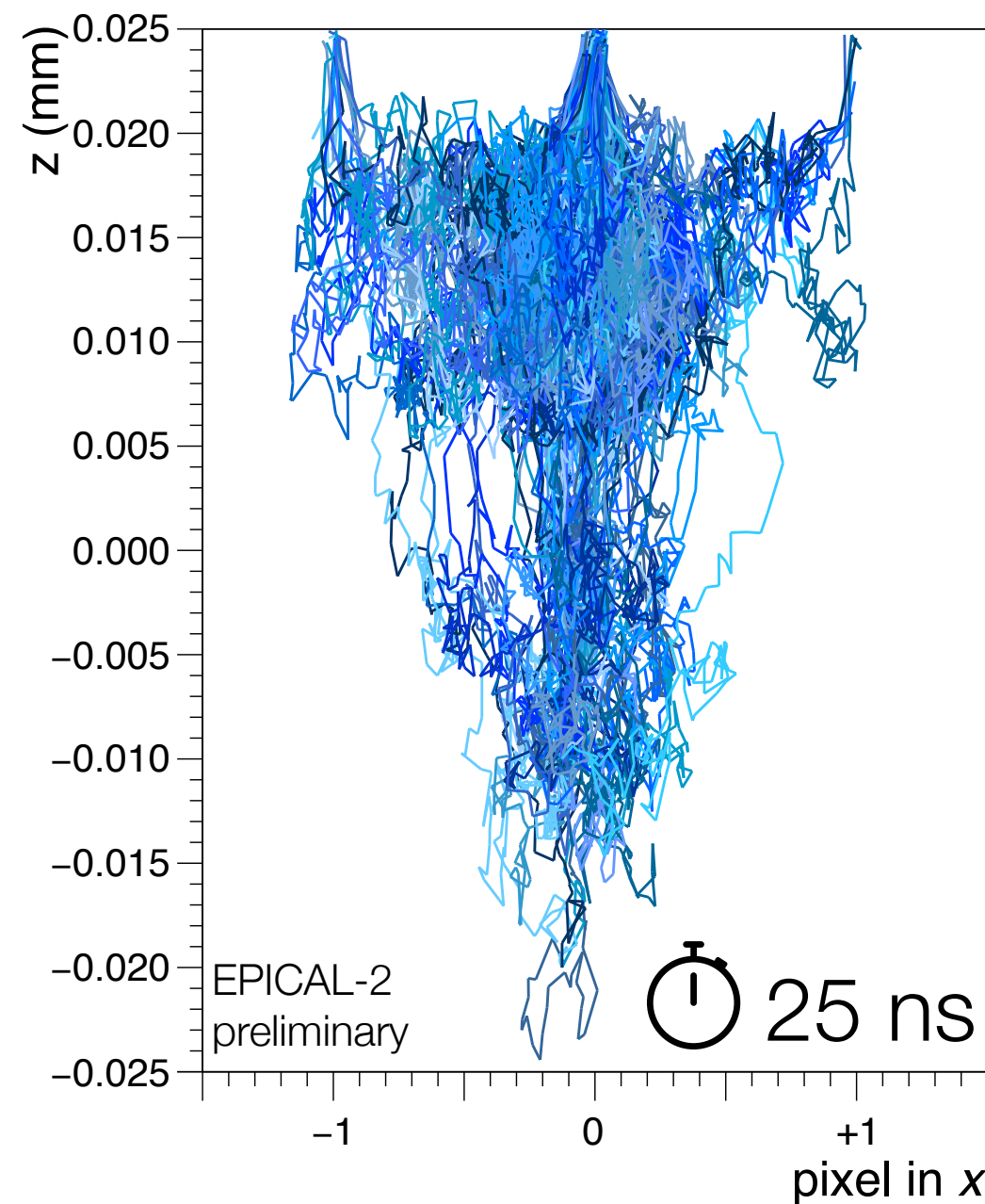From incoming particle(s) to readout

simulation chain:

```
┄┄▶ [ propagation and transfer ] ┄┄┄▶ [ digitisation ] ┄┄┄▶ [ output ]
```

- ▸ propagation of **charge carrier groups** (50 charges)
- ▸ diffusion and drift within **integration time** t_{int} **= 25 ns**
- ▸ pixel assignment of charges

- ▸ **Gaussian noise** with width σ_{noise} **= 20 e**
- ▸ pixel hit: charge surpasses **threshold value** T_{pixel} **= 82 ± 20 e**

- ▸ 2D information of hits per layer
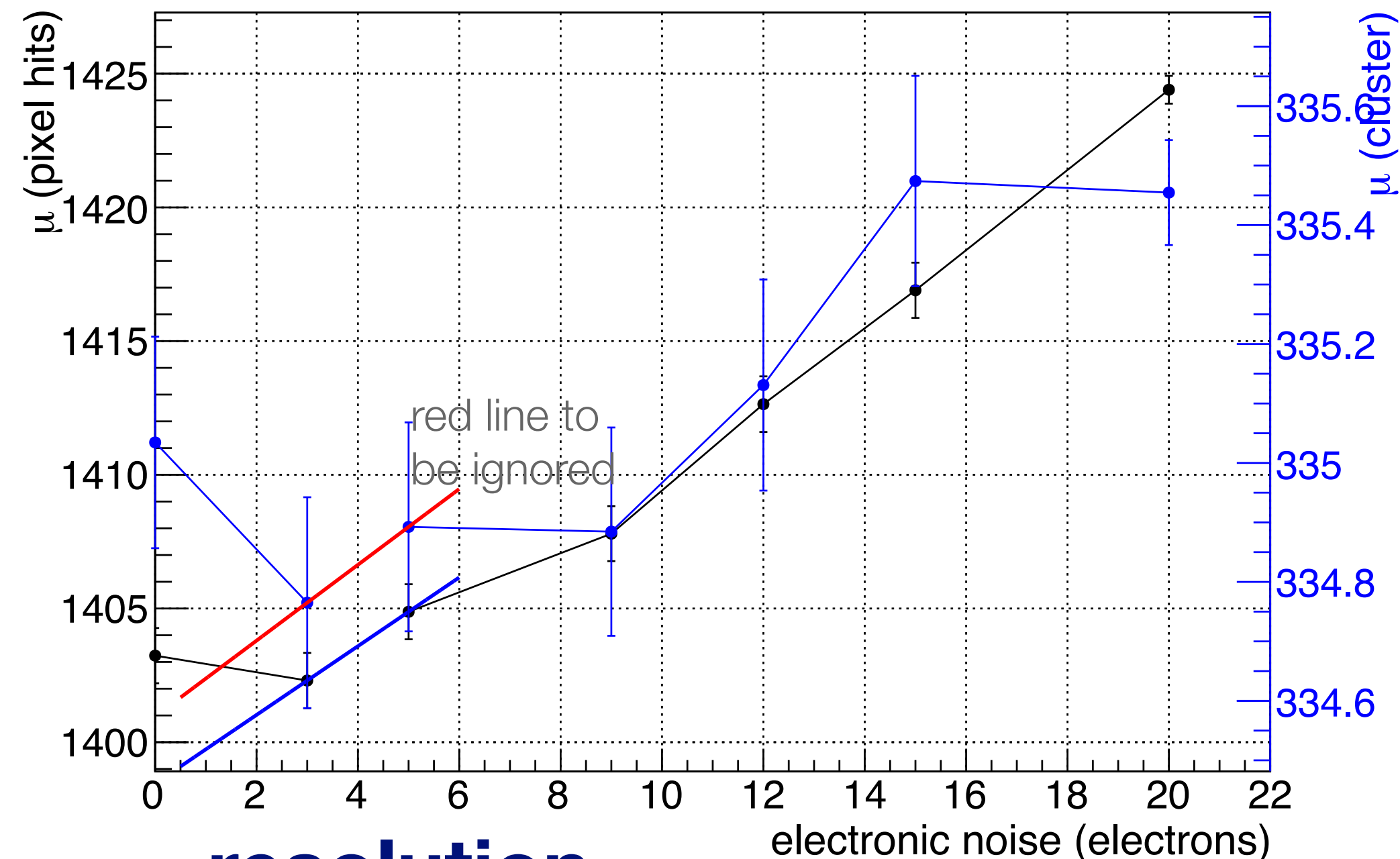 - column and row

EPICAL-2 with 24 layers

measurement:
- ▸ number N_{hits} of pixel hits
- ▸ number $N_{clusters}$ of clusters

✖ shower particle ⬚ cluster
🟥 pixel with hit 🟧 pixel without hit

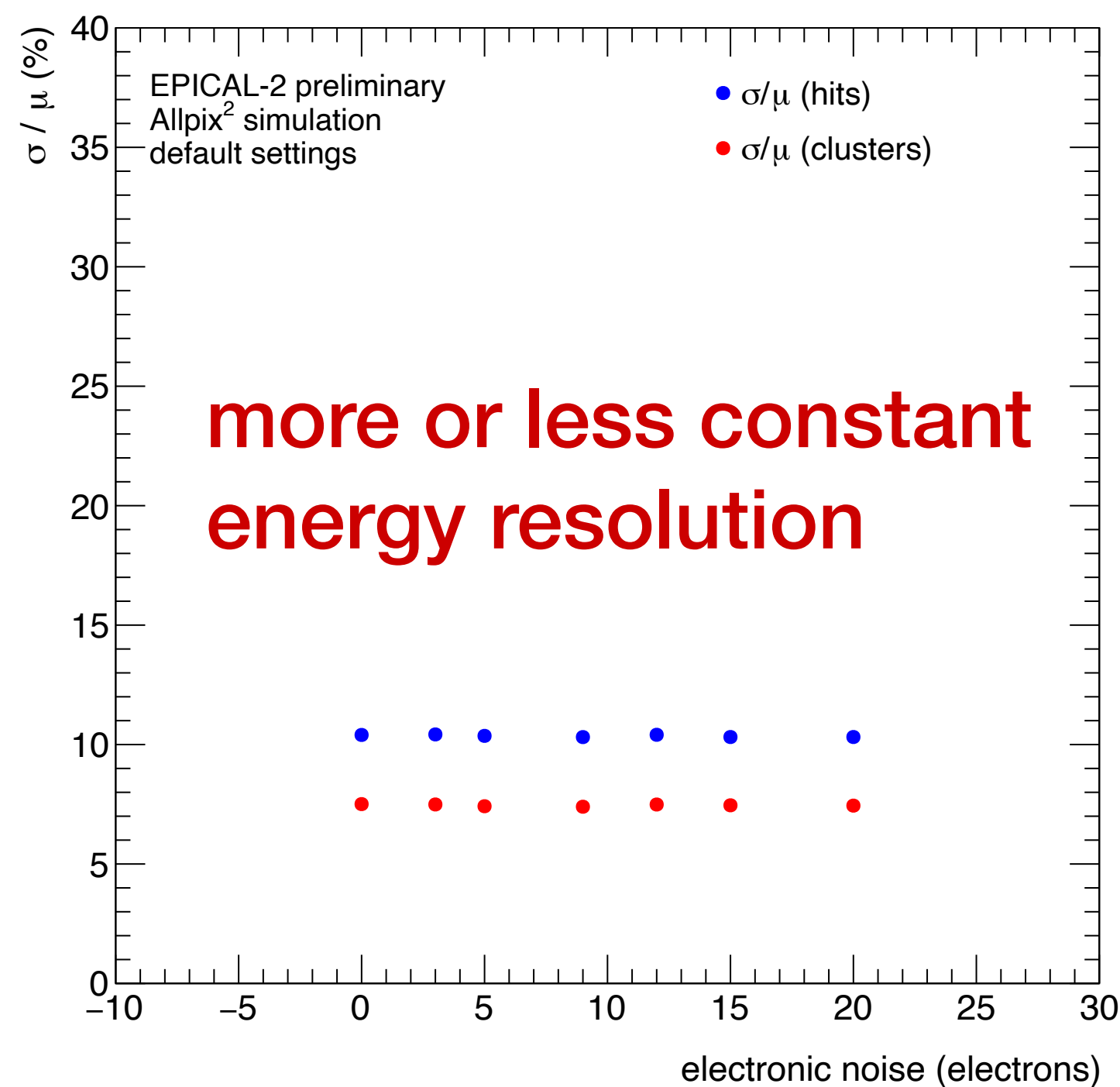EPICAL-2 preliminary ⏱ 25 ns

z (mm) vs pixel in x

T_{pixel} — signal (e) vs time

row 92–96, column 234–238

variation: Gaussian noise

hits

higher *noise*:

slightly rising mean
of hits and clusters

resolution
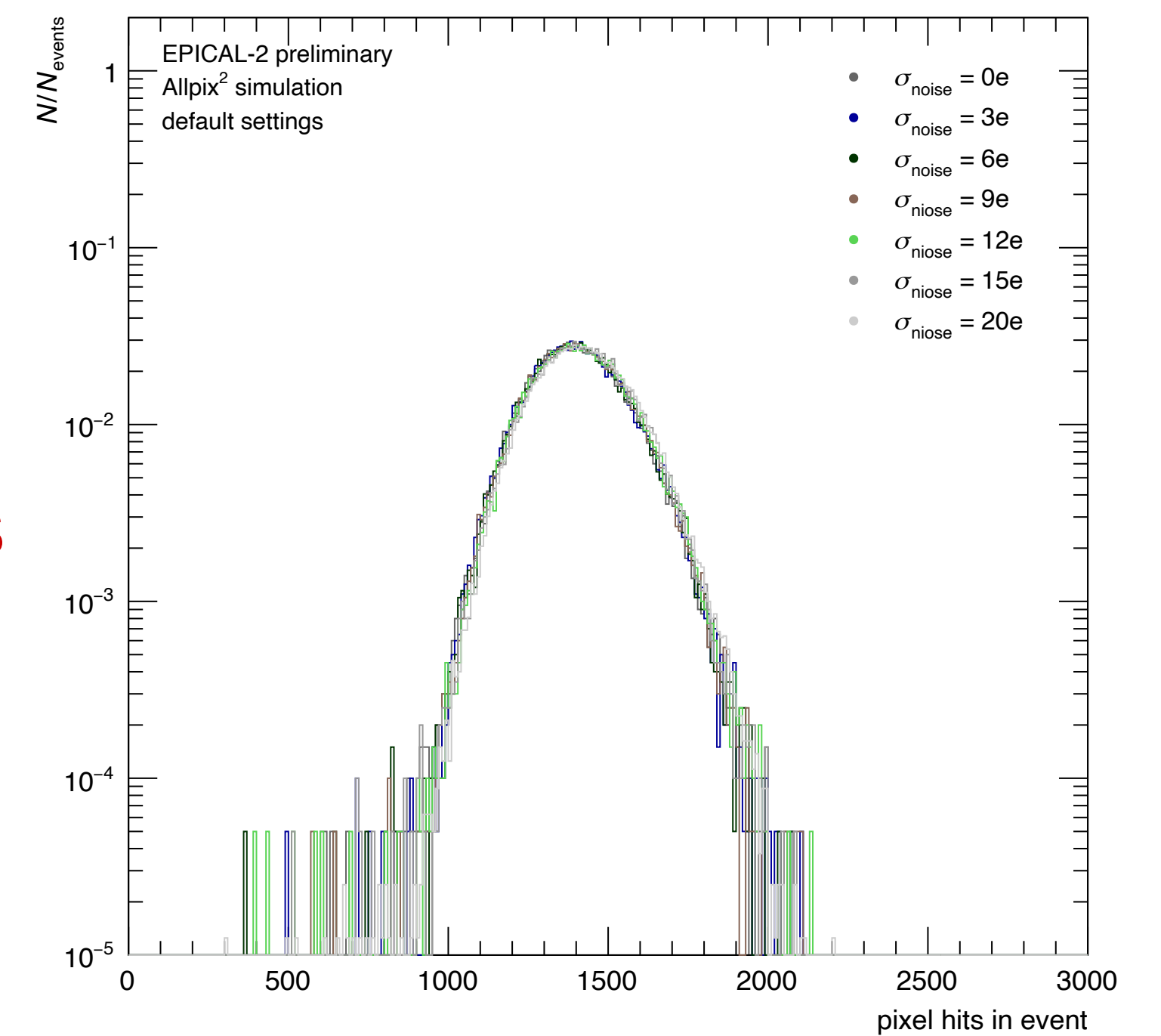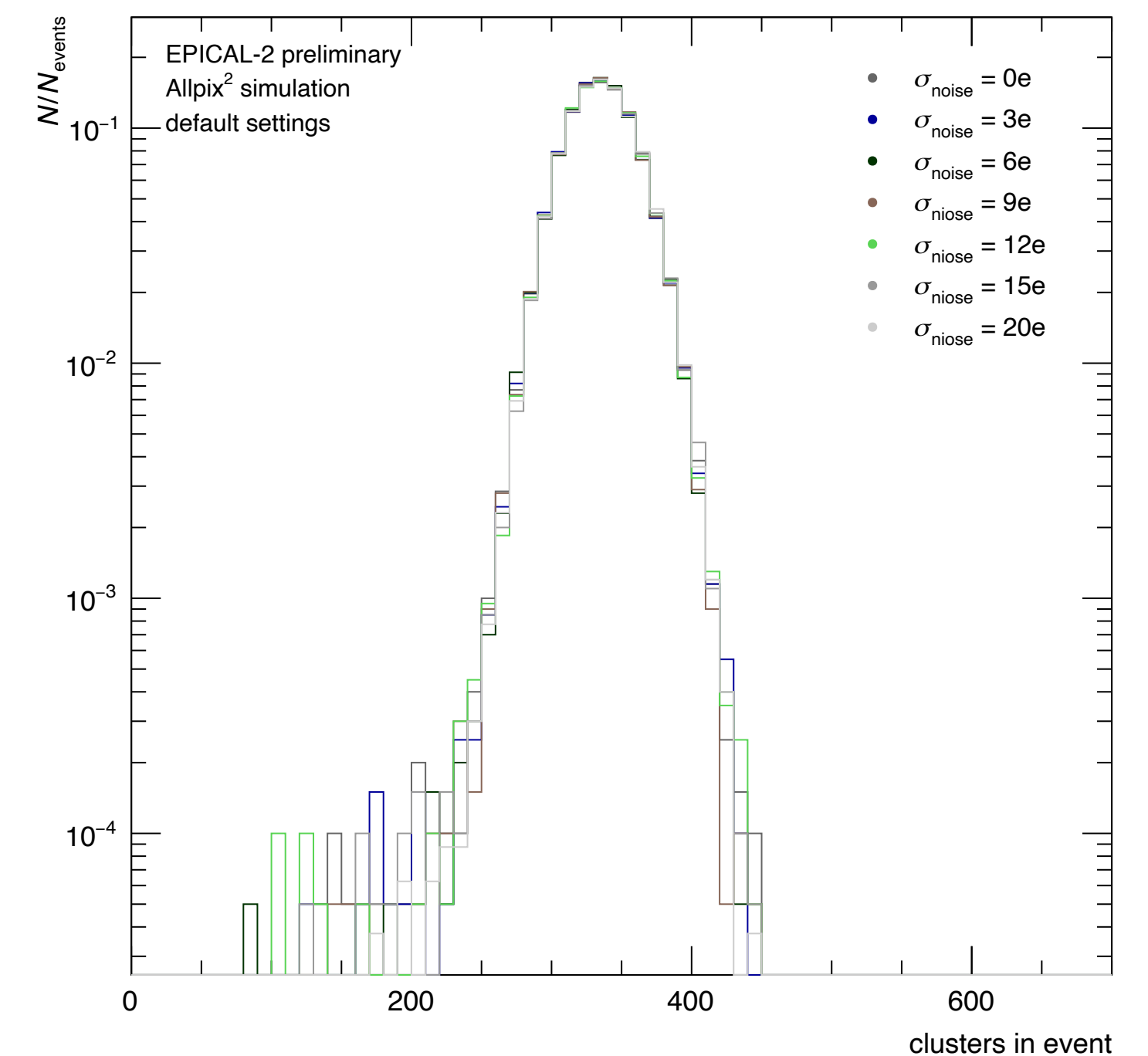
more or less constant
energy resolution

clusters

EPICAL-2 simulation utilising Allpix^2 ‖

A Monte Carlo Simulation tool for silicon pixel detectors
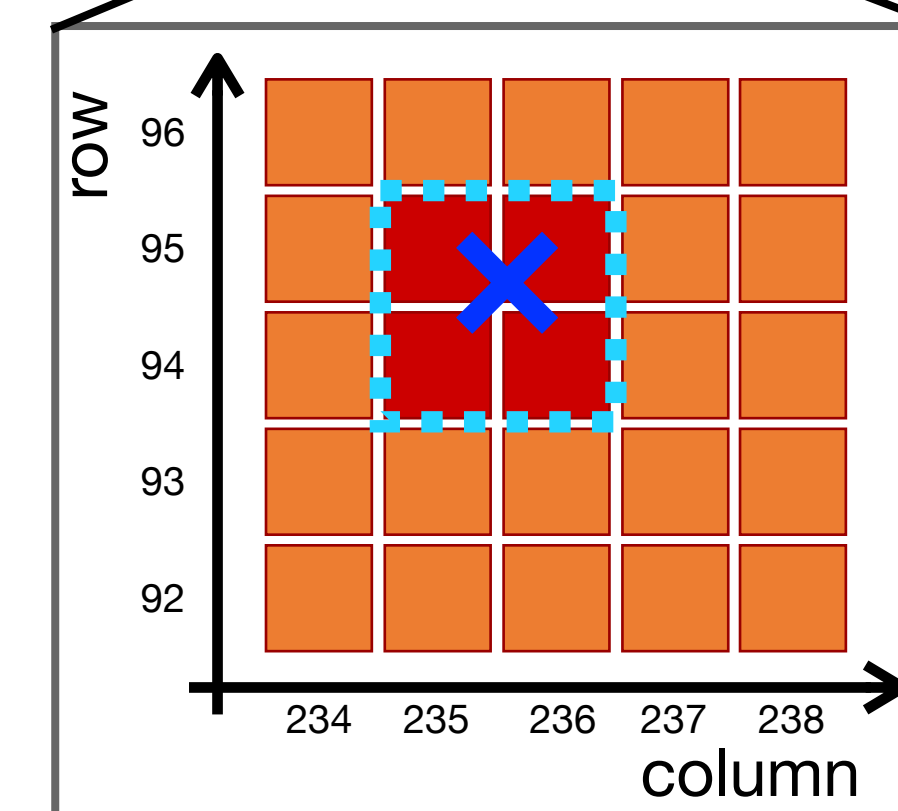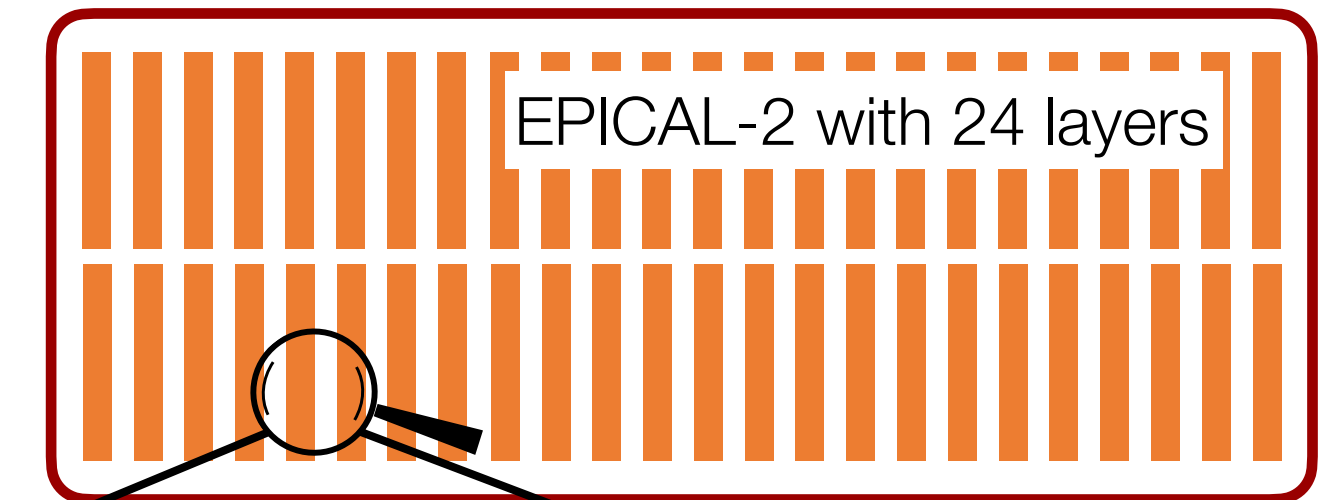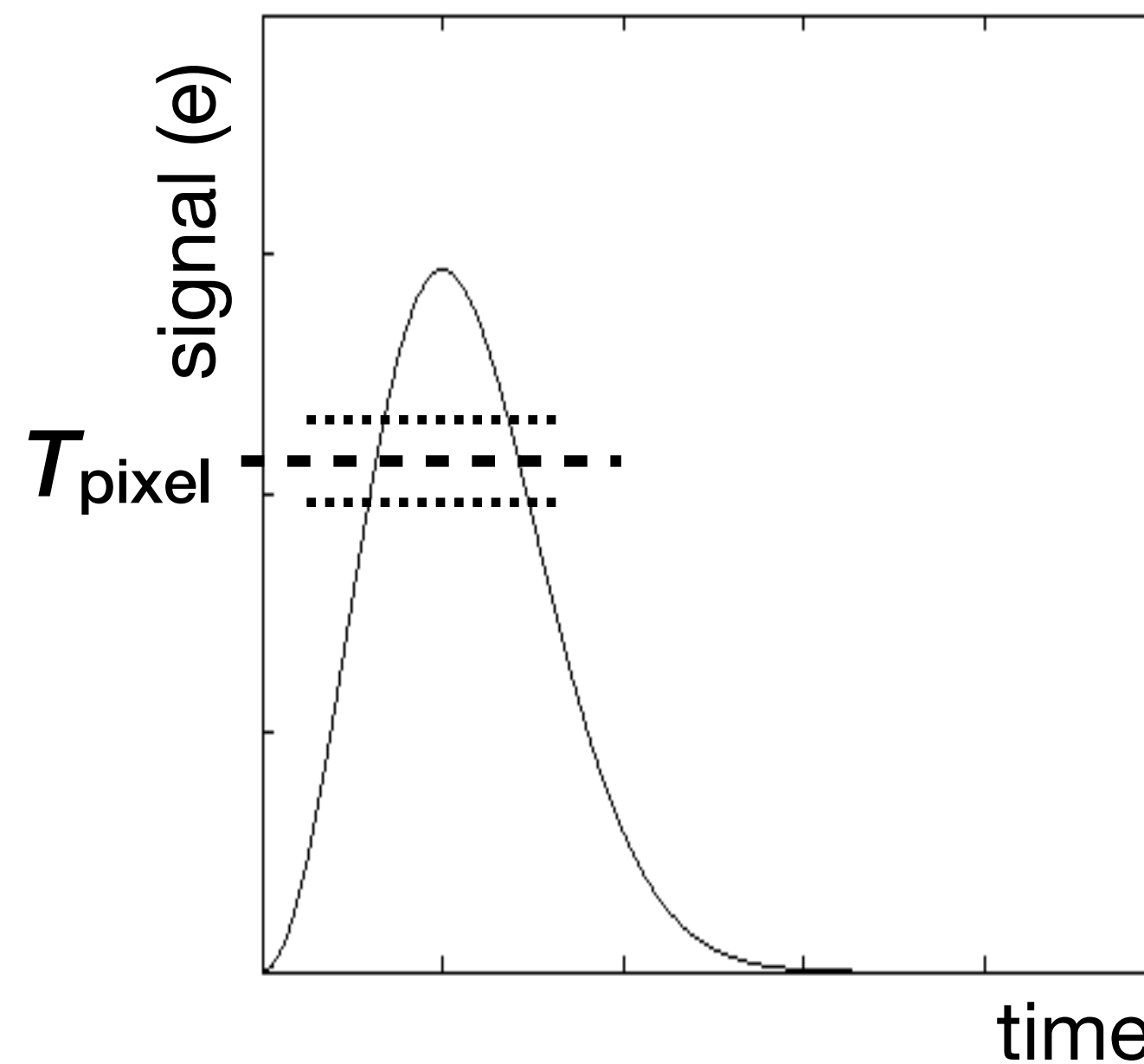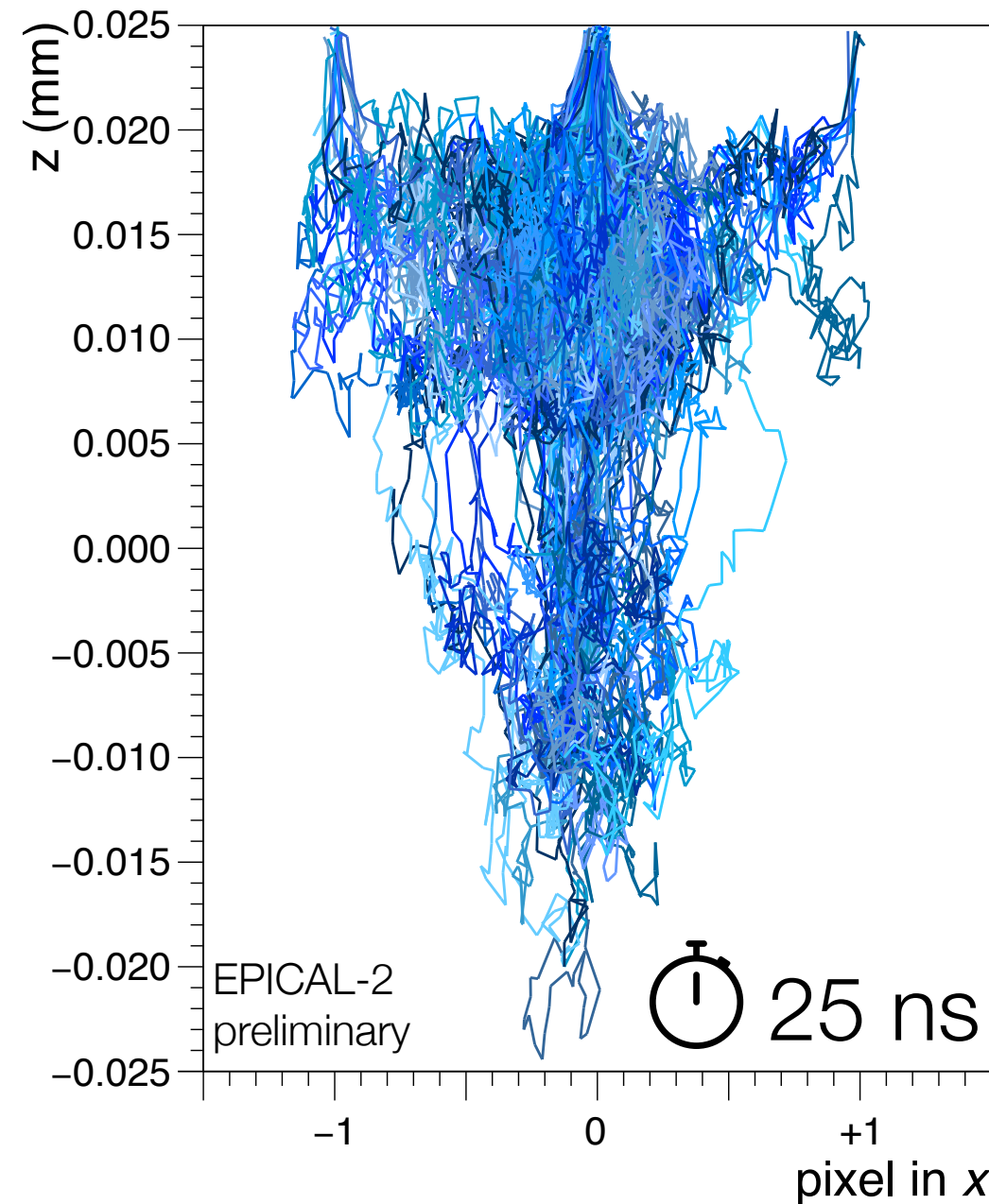From incoming particle(s) to readout

simulation chain:

propagation and transfer	digitisation	output

propagation and transfer

▸ propagation of **charge carrier groups** (50 charges)
▸ diffusion and drift within **integration time t_{int} = 25 ns**
▸ pixel assignment of charges

EPICAL-2 preliminary   ⏱ 25 ns

digitisation

▸ **Gaussian noise** with width σ_{noise} = 20 e
▸ pixel hit:
charge surpasses **threshold value T_{pixel} = 82 ± 20 e**

T_{pixel}

signal (e) — time

output

▸ 2D information of hits per layer
  • column and row

EPICAL-2 with 24 layers

measurement:
▸ number N_{hits} of pixel hits
▸ number $N_{clusters}$ of clusters

✖ shower particle   ┈ cluster
■ pixel with hit   ■ pixel without hit

EPICAL-2 simulation utilising Allpix^2 ▮▮

A Monte Carlo Simulation tool for silicon pixel detectors
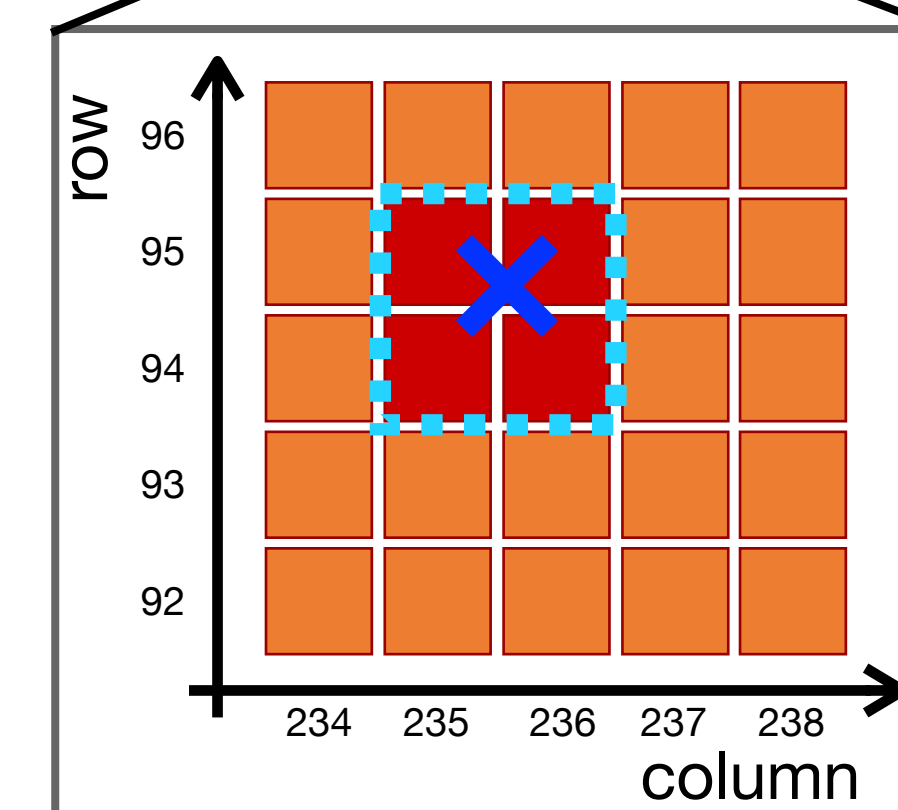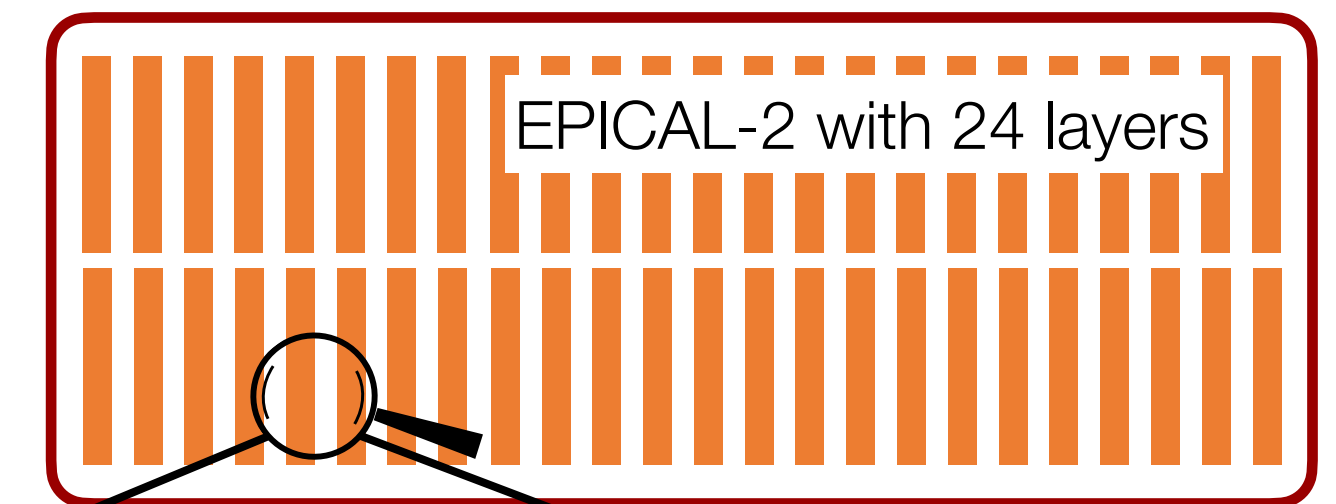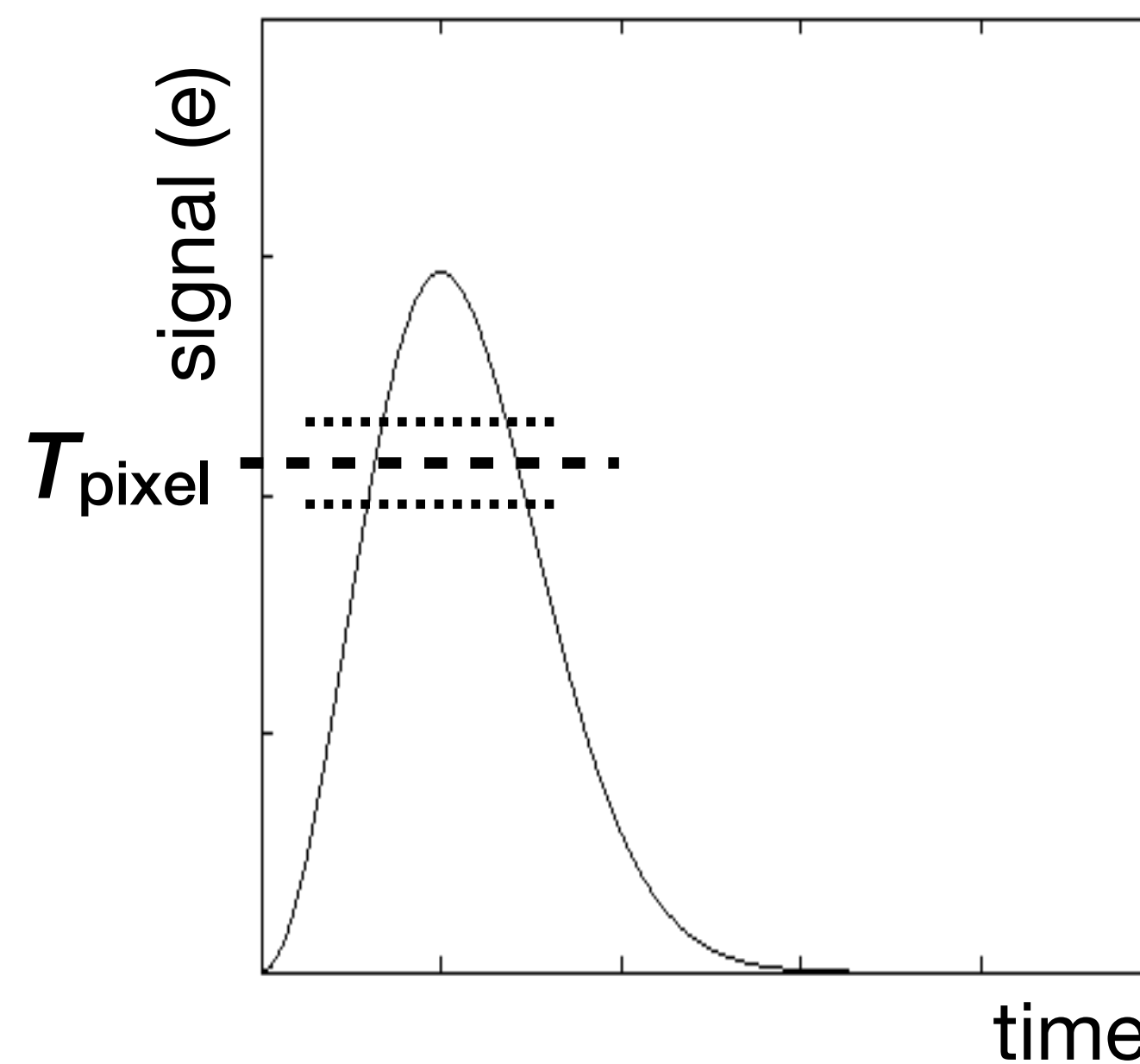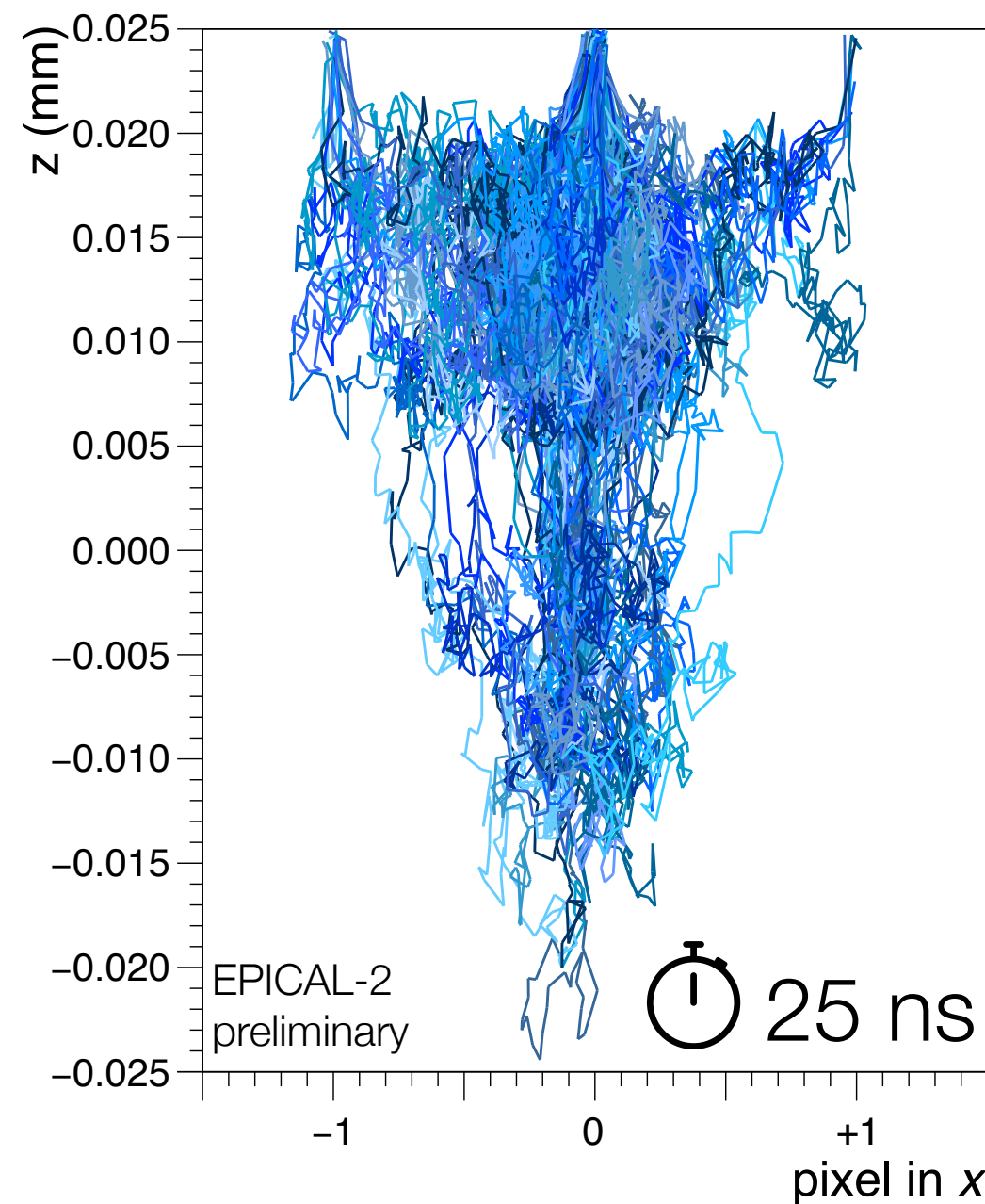From incoming particle(s) to readout

simulation chain:

propagation and transfer - - - ▶ **digitisation** - - - ▶ **output**

▸ propagation of **charge carrier groups** (50 charges)
▸ diffusion and drift within **integration time** t_{int} = 25 ns
▸ pixel assignment of charges

▸ **Gaussian noise** with width σ_{noise} = 20 e
▸ pixel hit:
charge surpasses **threshold value** T_{pixel} = 82 ± 20 e

▸ 2D information of hits per layer
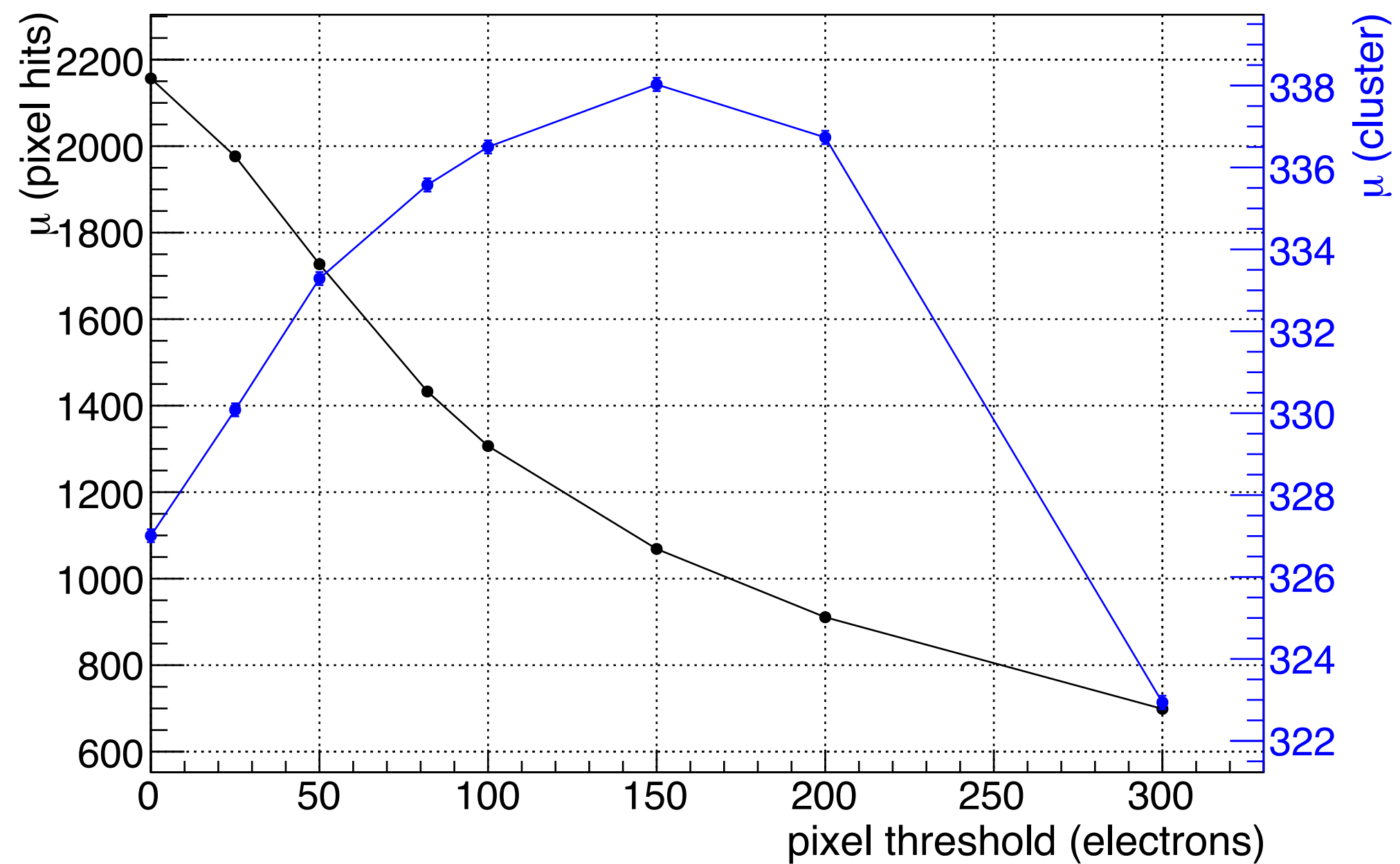 • column and row

EPICAL-2 with 24 layers

measurement:
▸ number N_{hits} of pixel hits
▸ number $N_{clusters}$ of clusters

✖ shower particle ⬚ cluster
■ pixel with hit ■ pixel without hit

EPICAL-2 preliminary ⏱ 25 ns

T_{pixel}

signal (e)

time

variation: pixel threshold

hits

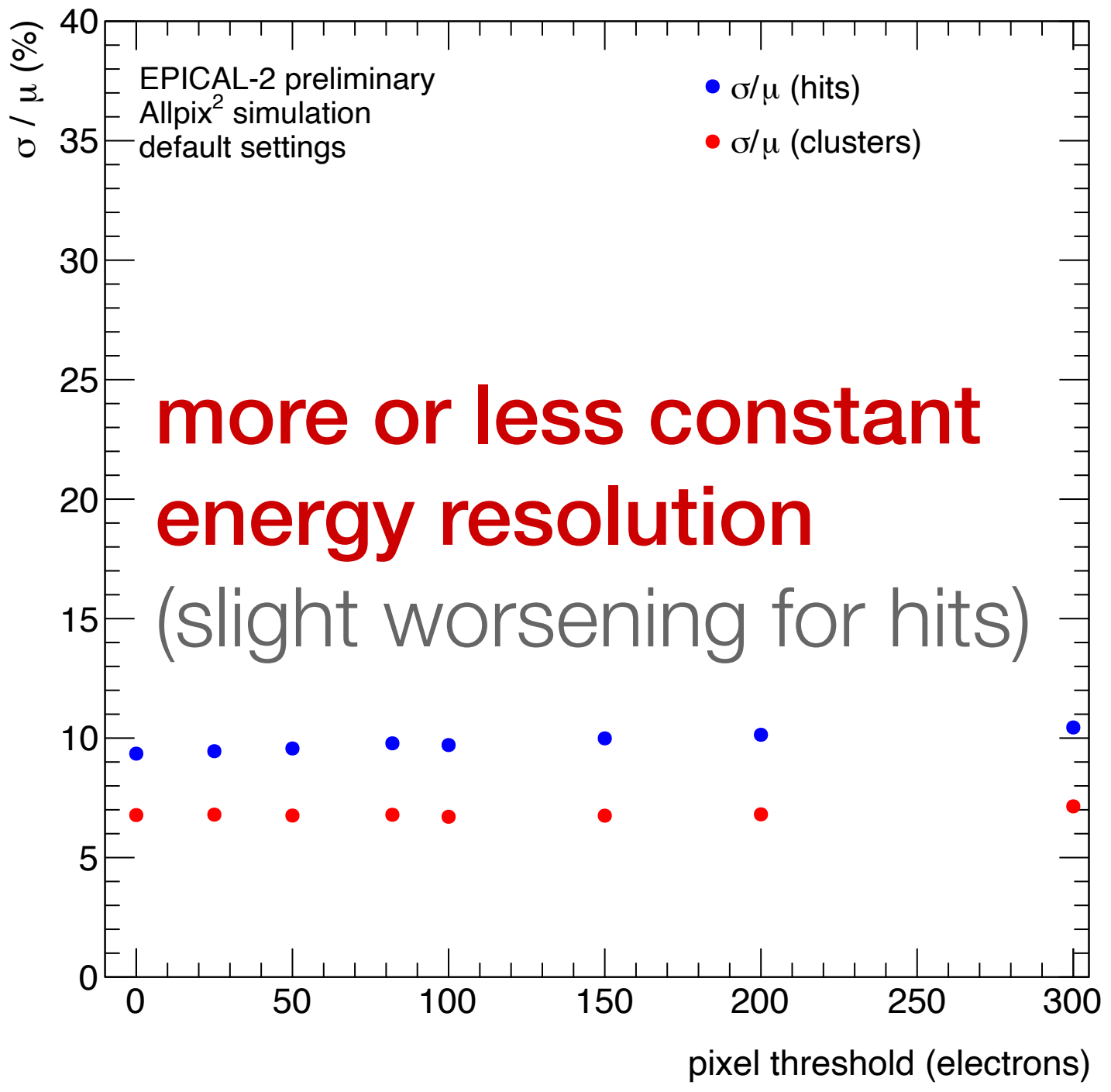treshold < 150:
less hits but
slightly more clusters
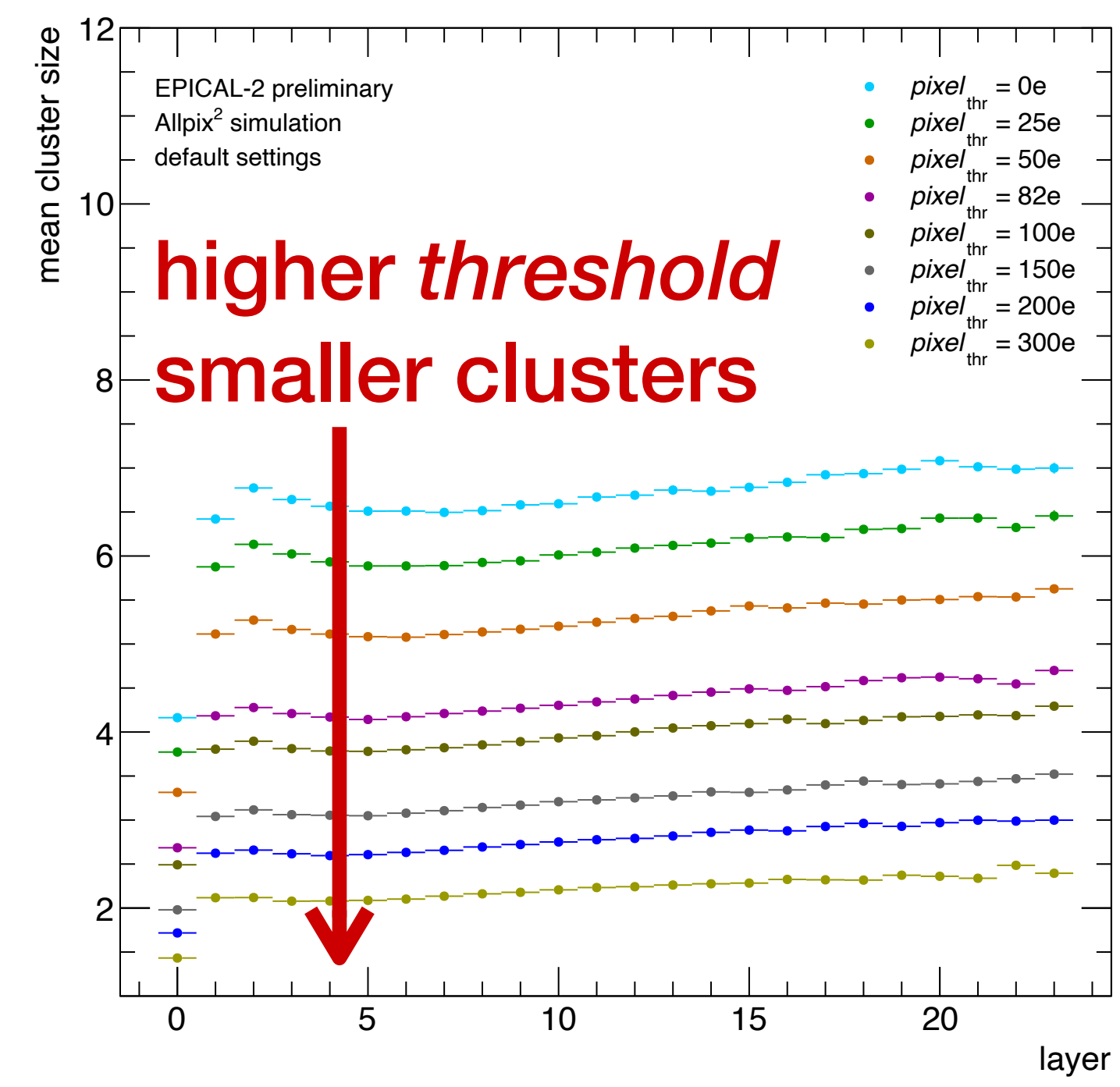treshold > 150:
less hits and
clusters
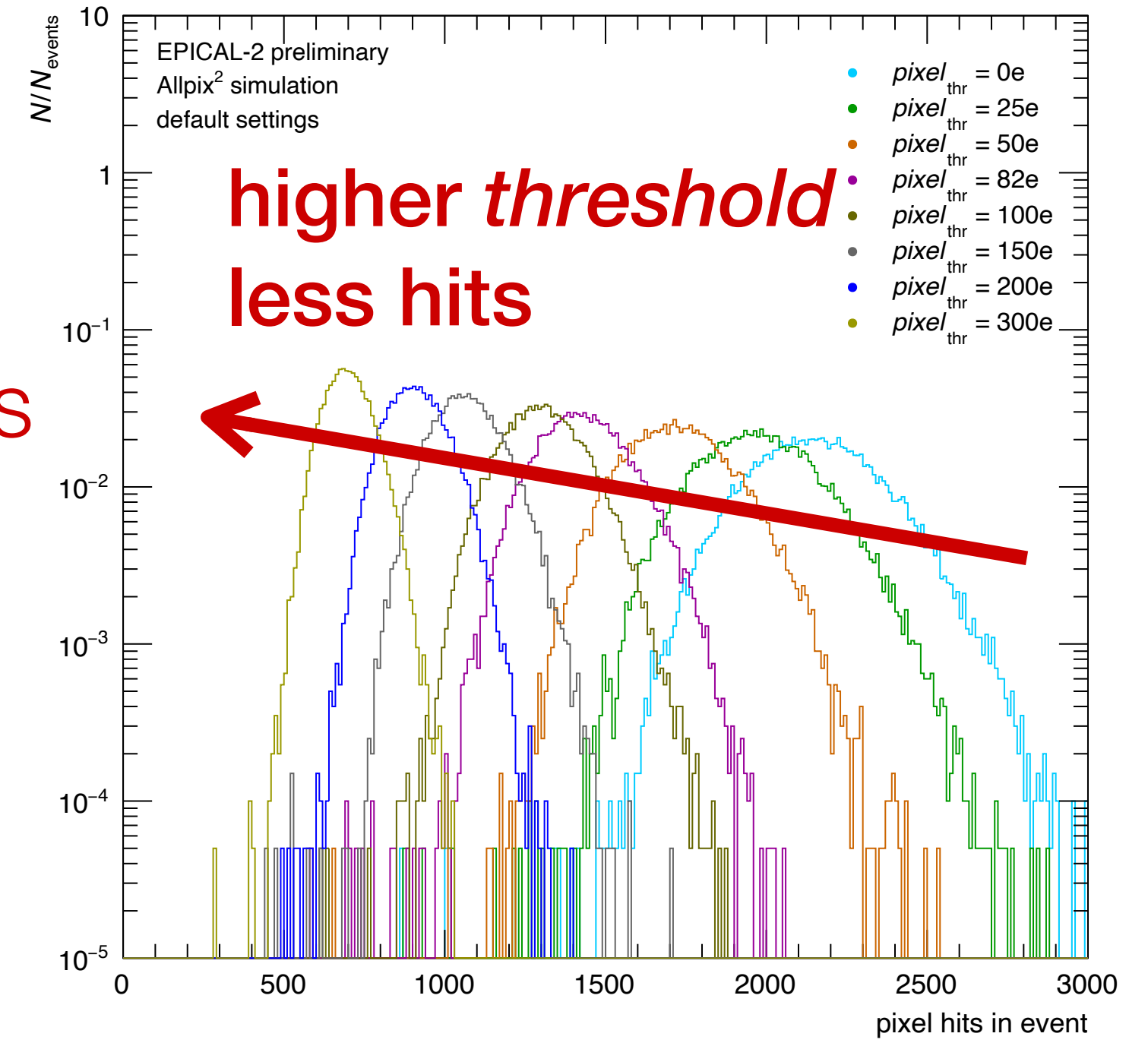
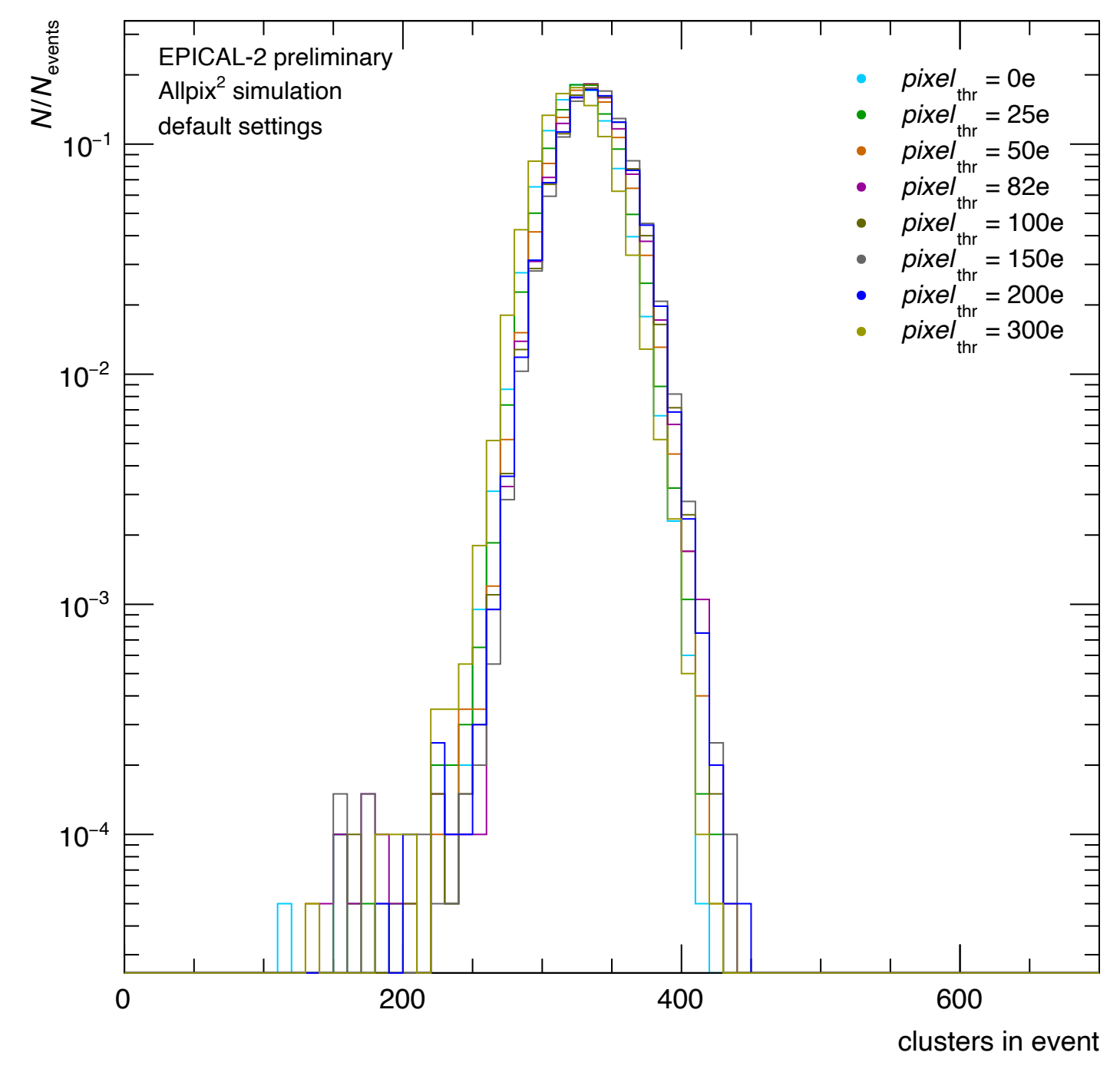**higher *threshold* less hits**

resolution

more or less constant
energy resolution
(slight worsening for hits)
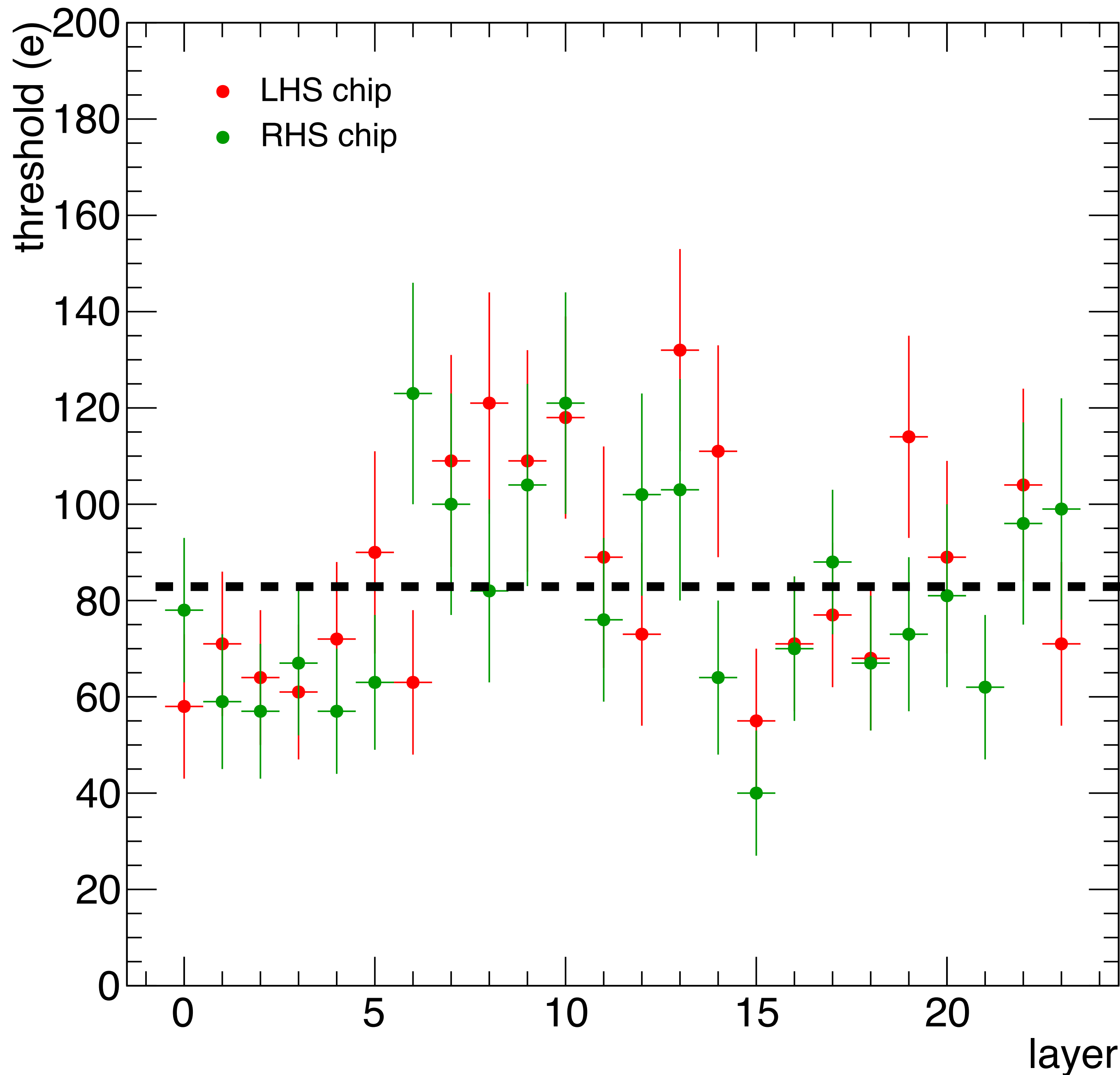
mean cluster size

higher *threshold* smaller clusters

clusters

variation: individual pixel-threshold setting for each chip

▸ chip-by-chip threshold as depicted

  ● Gaussian threshold

▸ $T_{\text{pixel}} = 82 \pm 20$ e (mean of al thresholds)
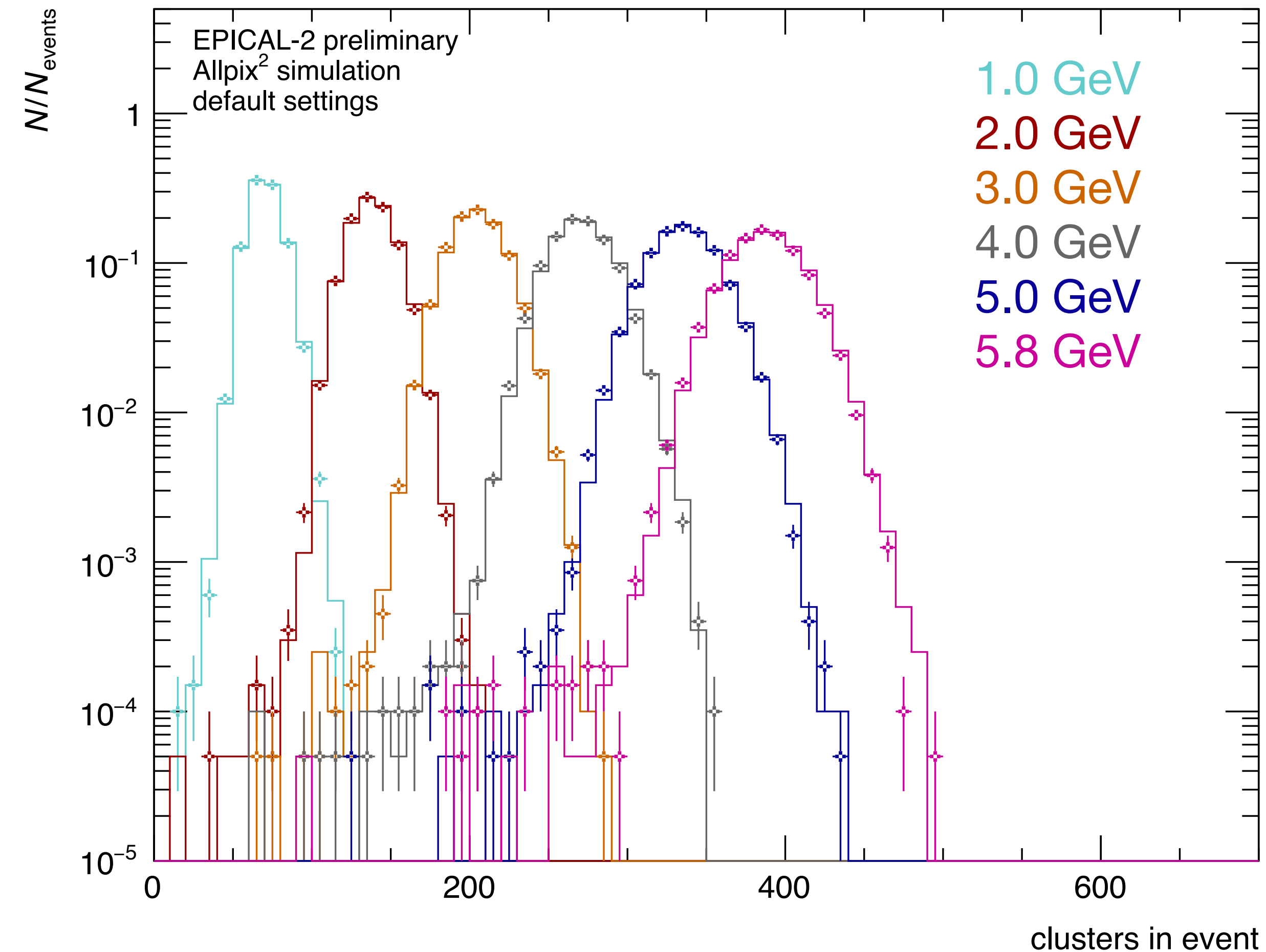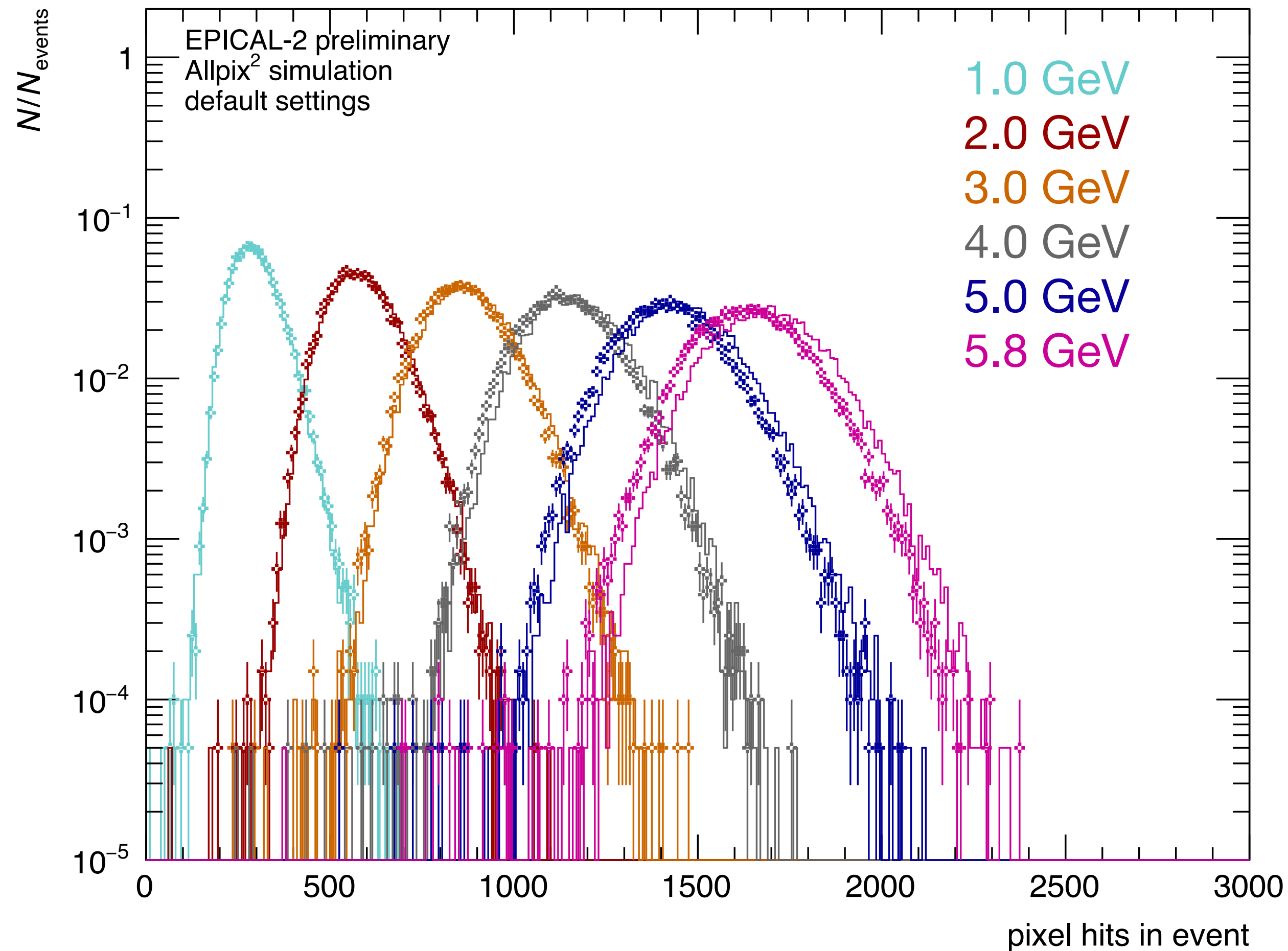
number of hits and clusters

→ chip-by-chip threshold does not influence the shape of the distribution

→ mean at lower number of hits for higher energies

— solid line
0 GeV spread of beam energy
all chips with threshold **82e ± 20e**

✚ crosses
0 GeV spread of beam energy
chips with **individual threshold**

EPICAL-2 preliminary
Allpix^2 simulation
default settings

1.0 GeV
2.0 GeV
3.0 GeV
4.0 GeV
5.0 GeV
5.8 GeV

pixel hits in event

EPICAL-2 preliminary
Allpix^2 simulation
default settings

1.0 GeV
2.0 GeV
3.0 GeV
4.0 GeV
5.0 GeV
5.8 GeV

clusters in event

energy resolution
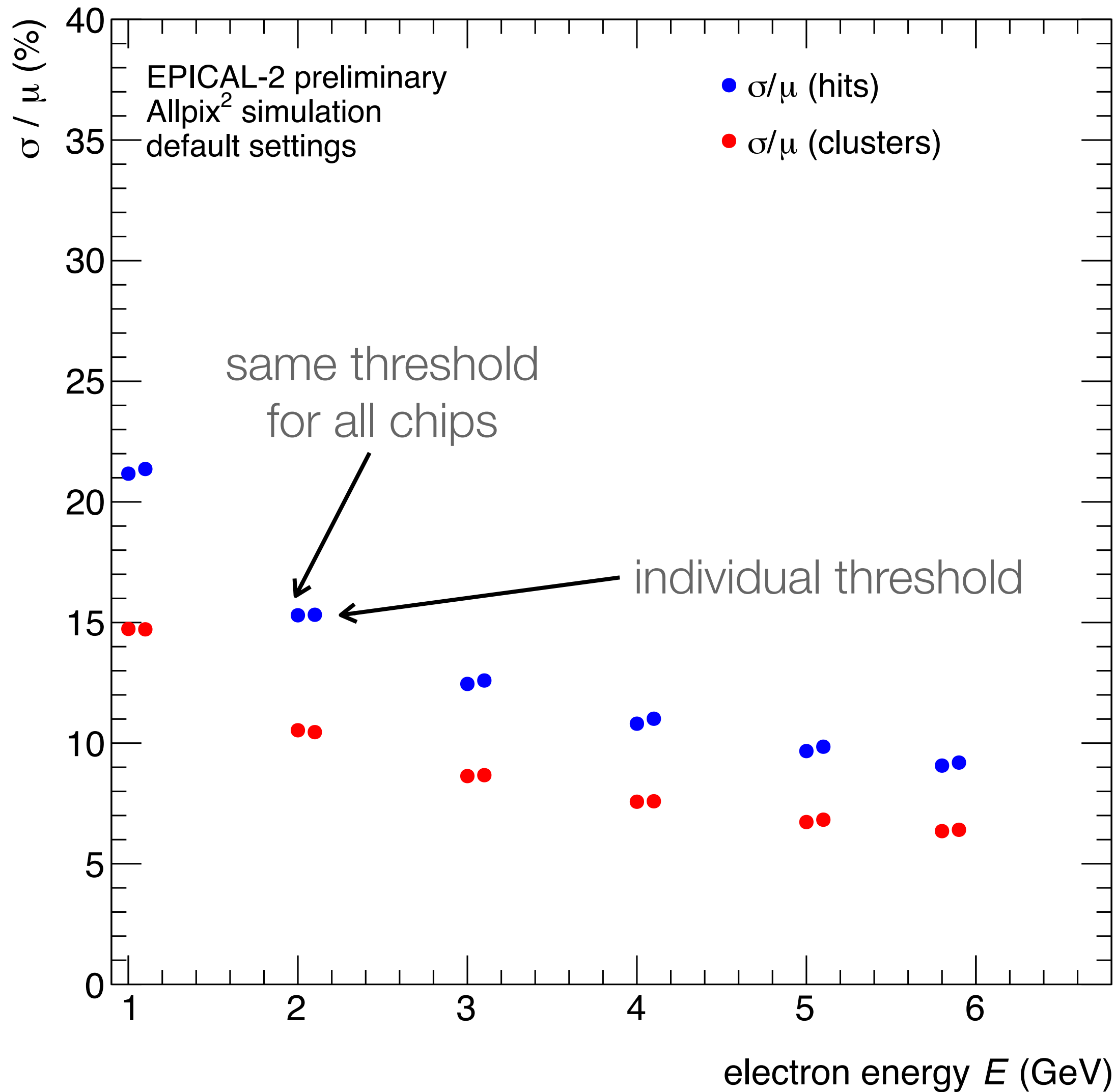
— solid line
0 GeV spread of beam energy
all chips with threshold **82e ± 20e**

✚ crosses
0 GeV spread of beam energy
chips with **individual threshold**

→ small influence on energy resolution

EPICAL-2 preliminary
Allpix^2 simulation
default settings

● σ/μ (hits)
● σ/μ (clusters)

same threshold
for all chips

individual threshold

σ / μ (%)

electron energy E (GeV)

dots at energies
x.1 GeV
from simulation with individual threshold

energy response: linearity

individual chip threshold:

▸ slightly greater deviation between
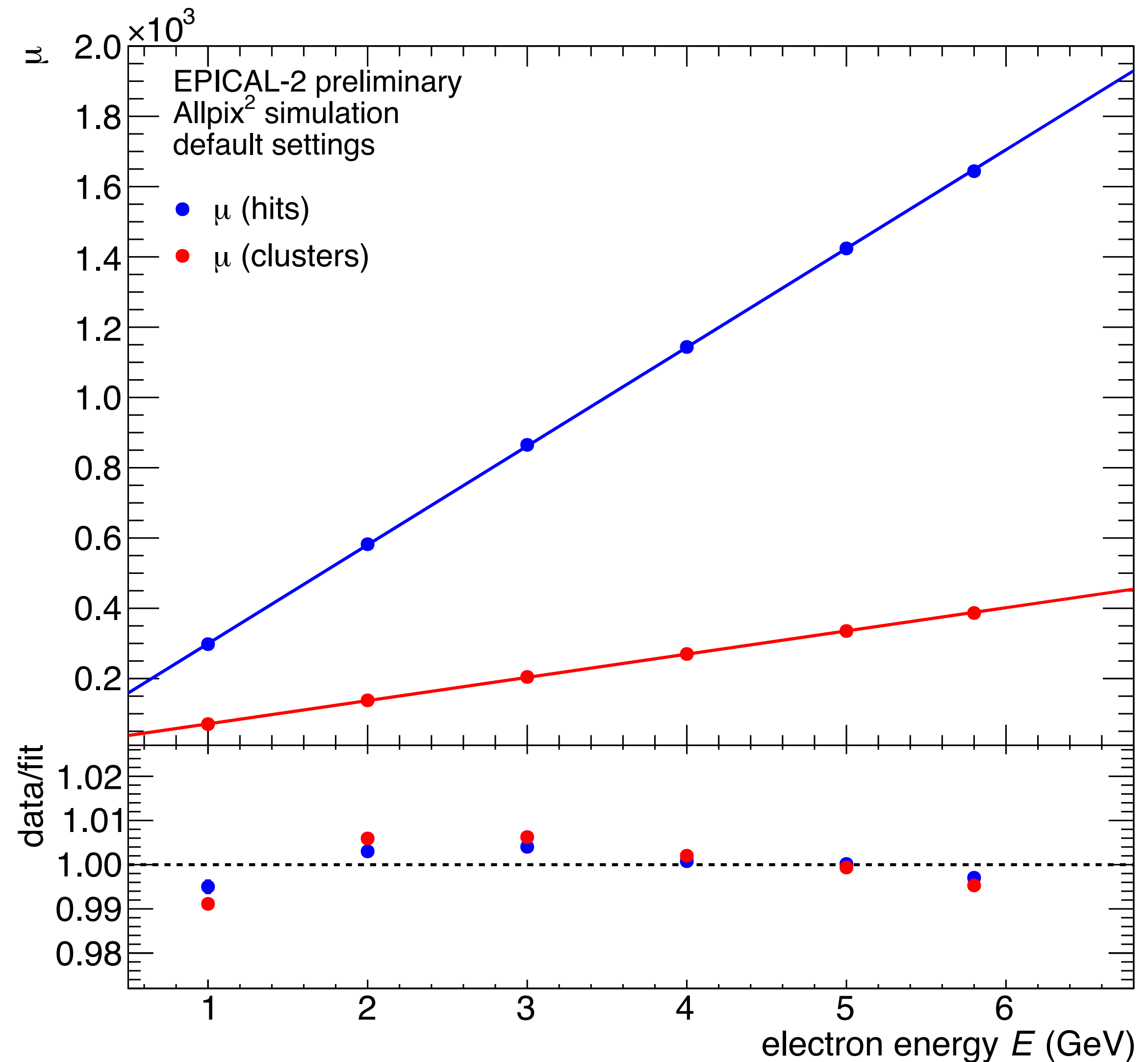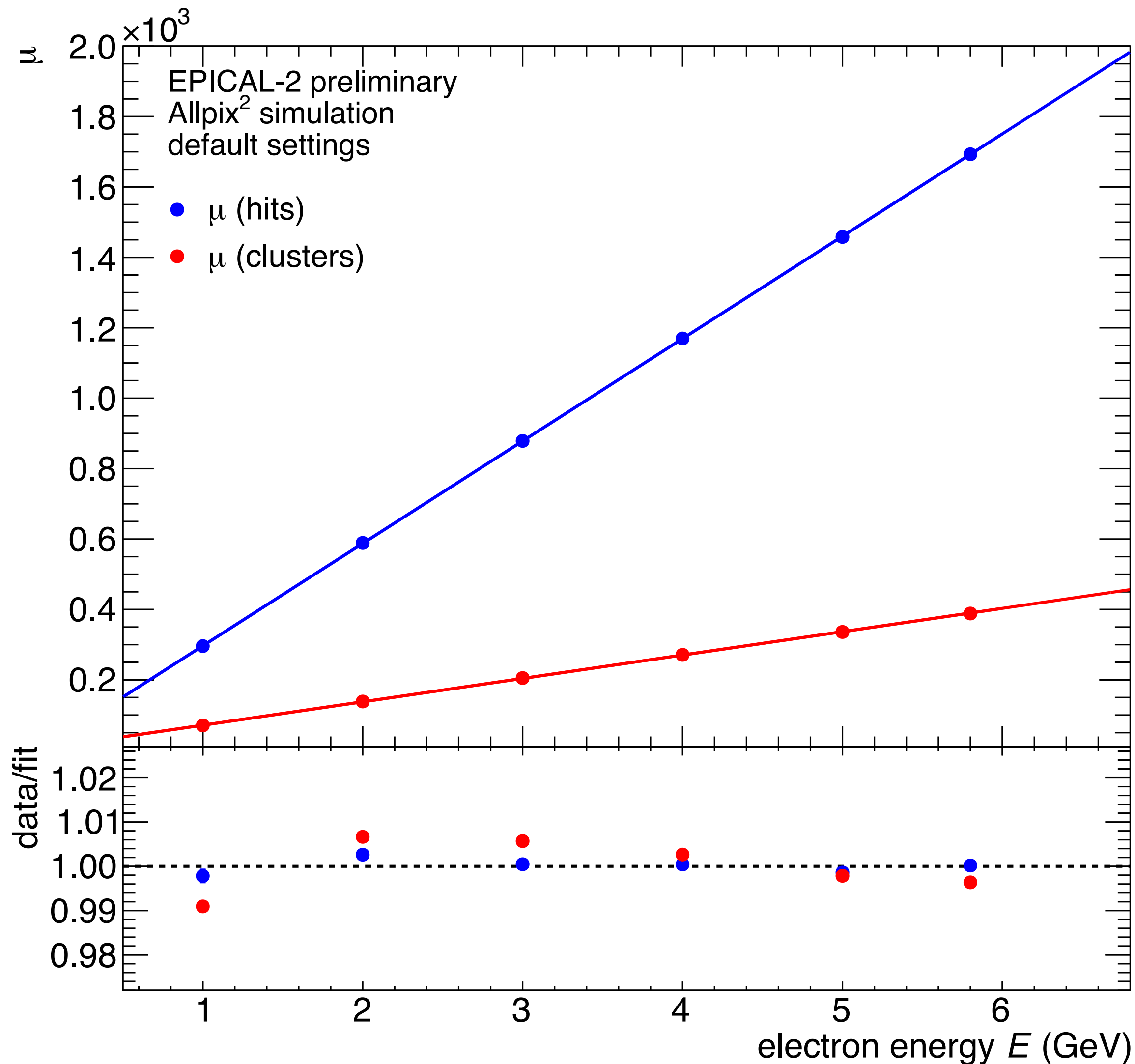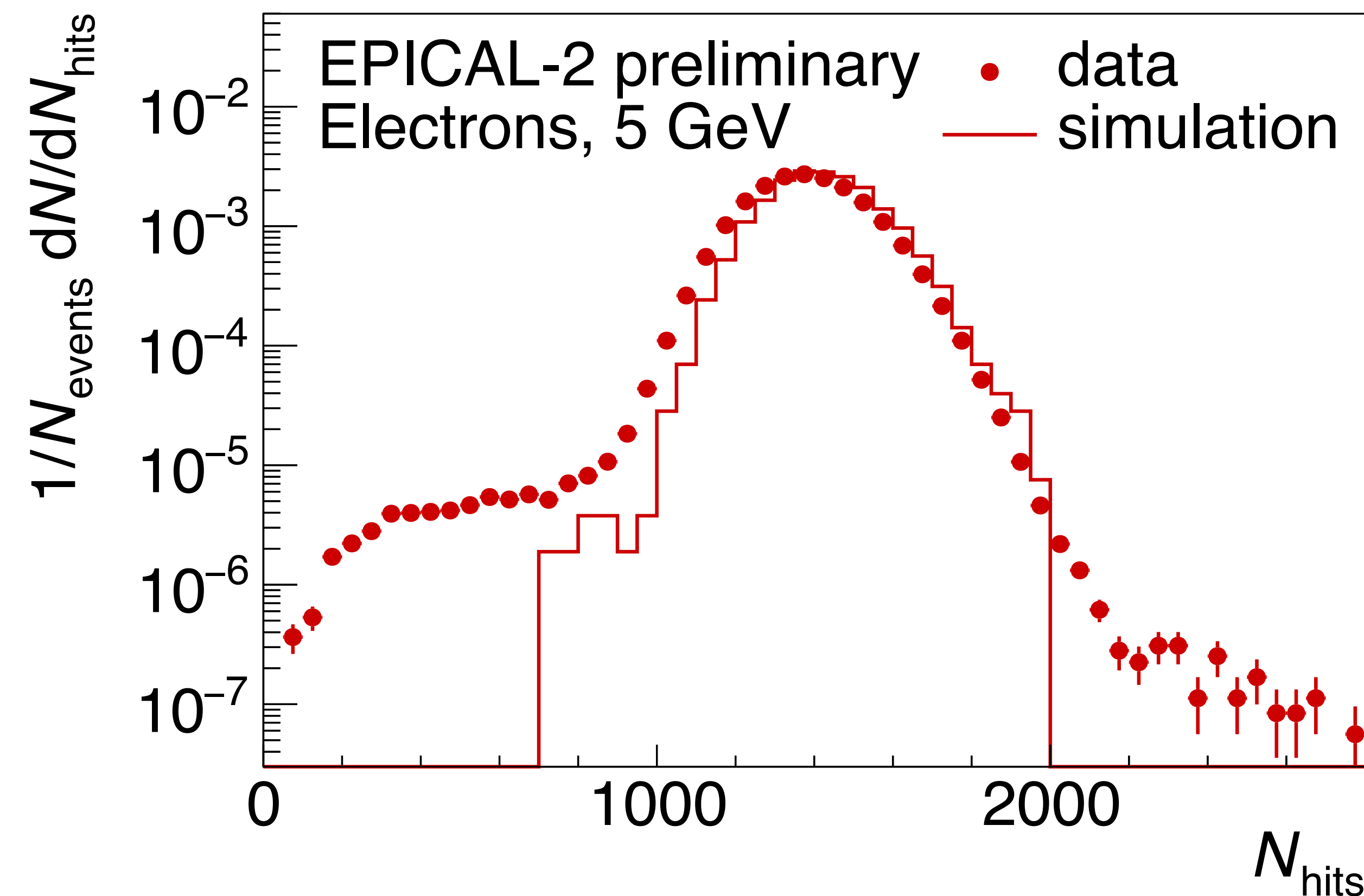 μ and the linear parametrisation
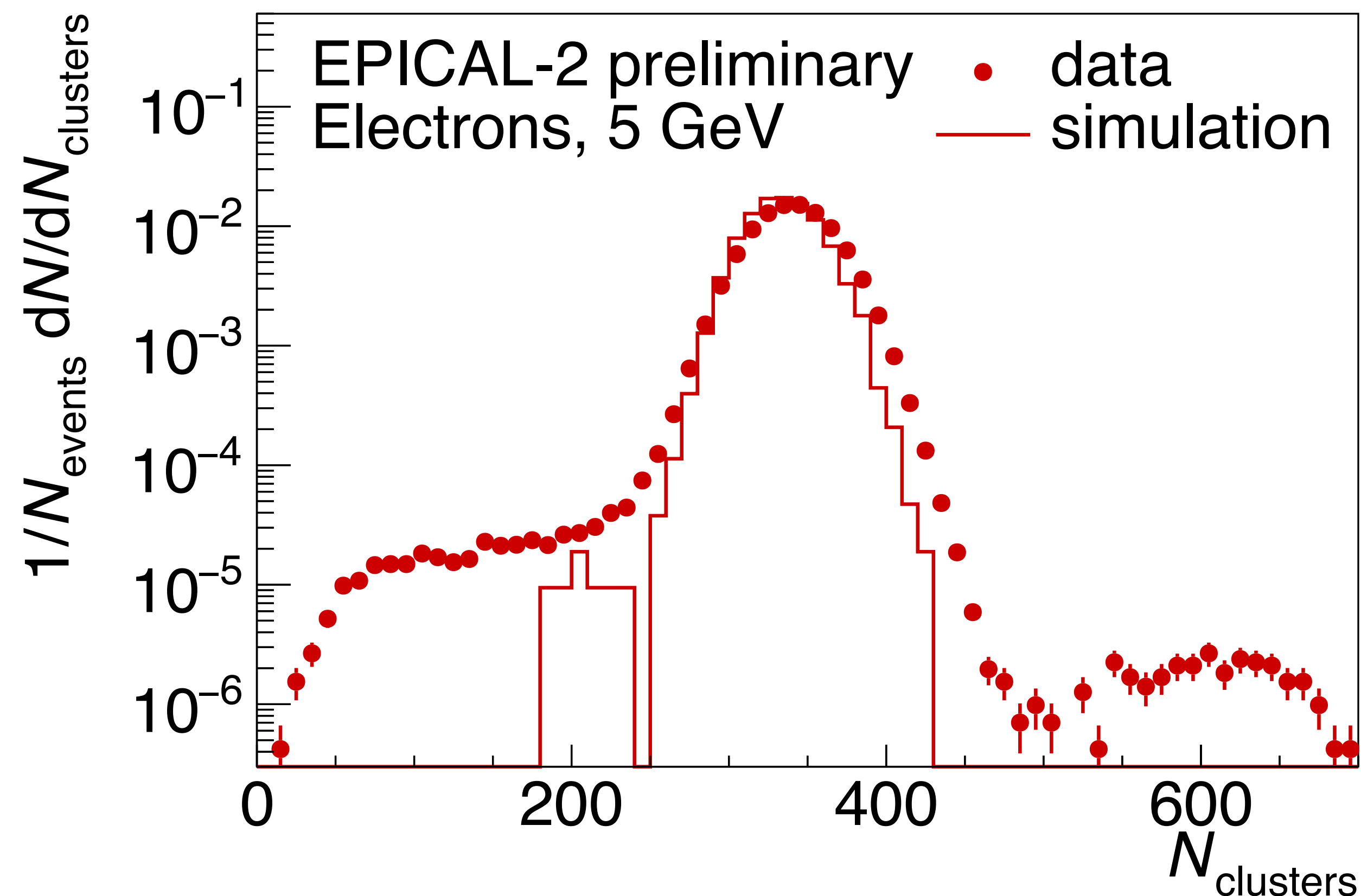
left:
0 GeV spread of beam energy
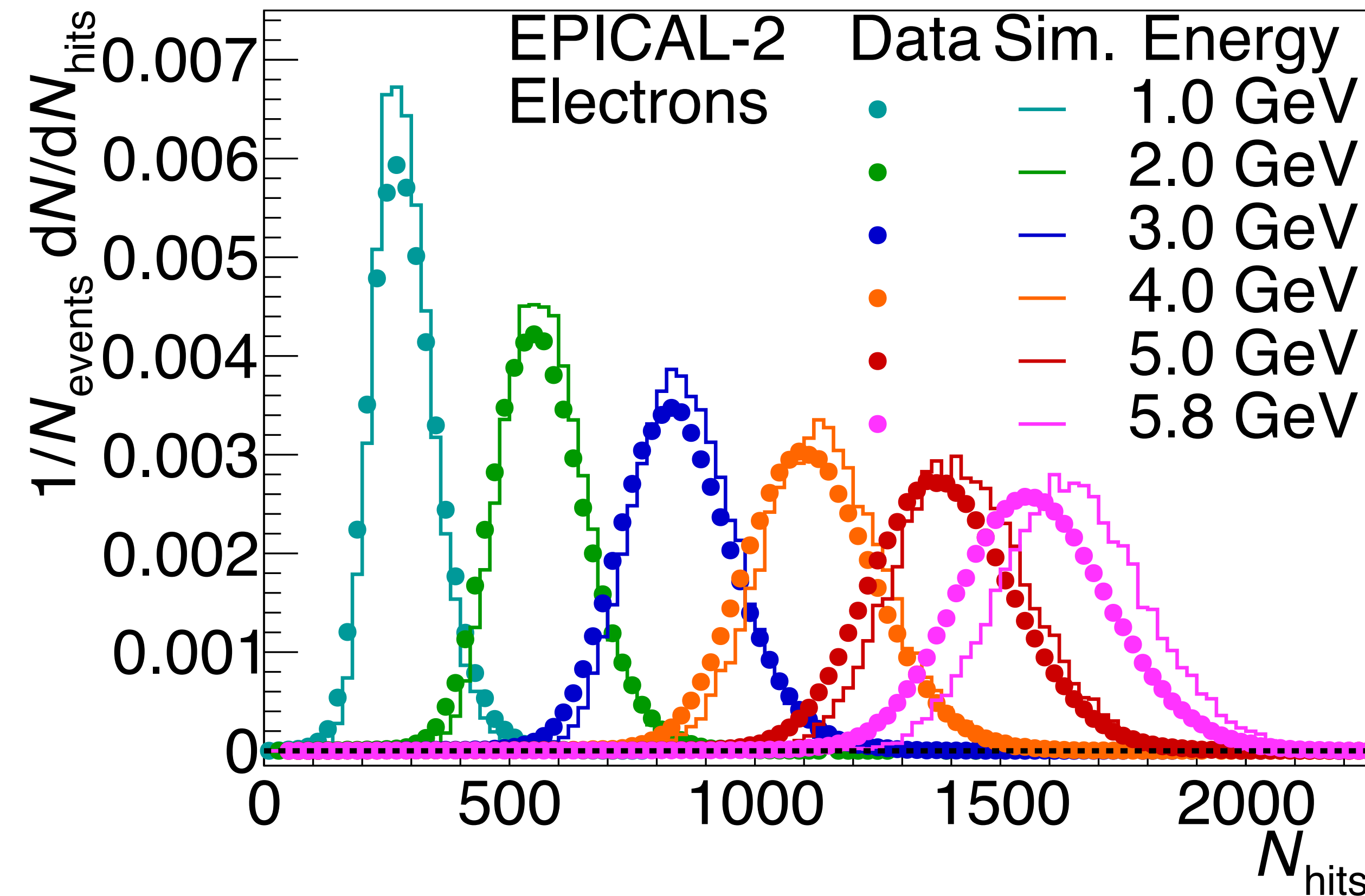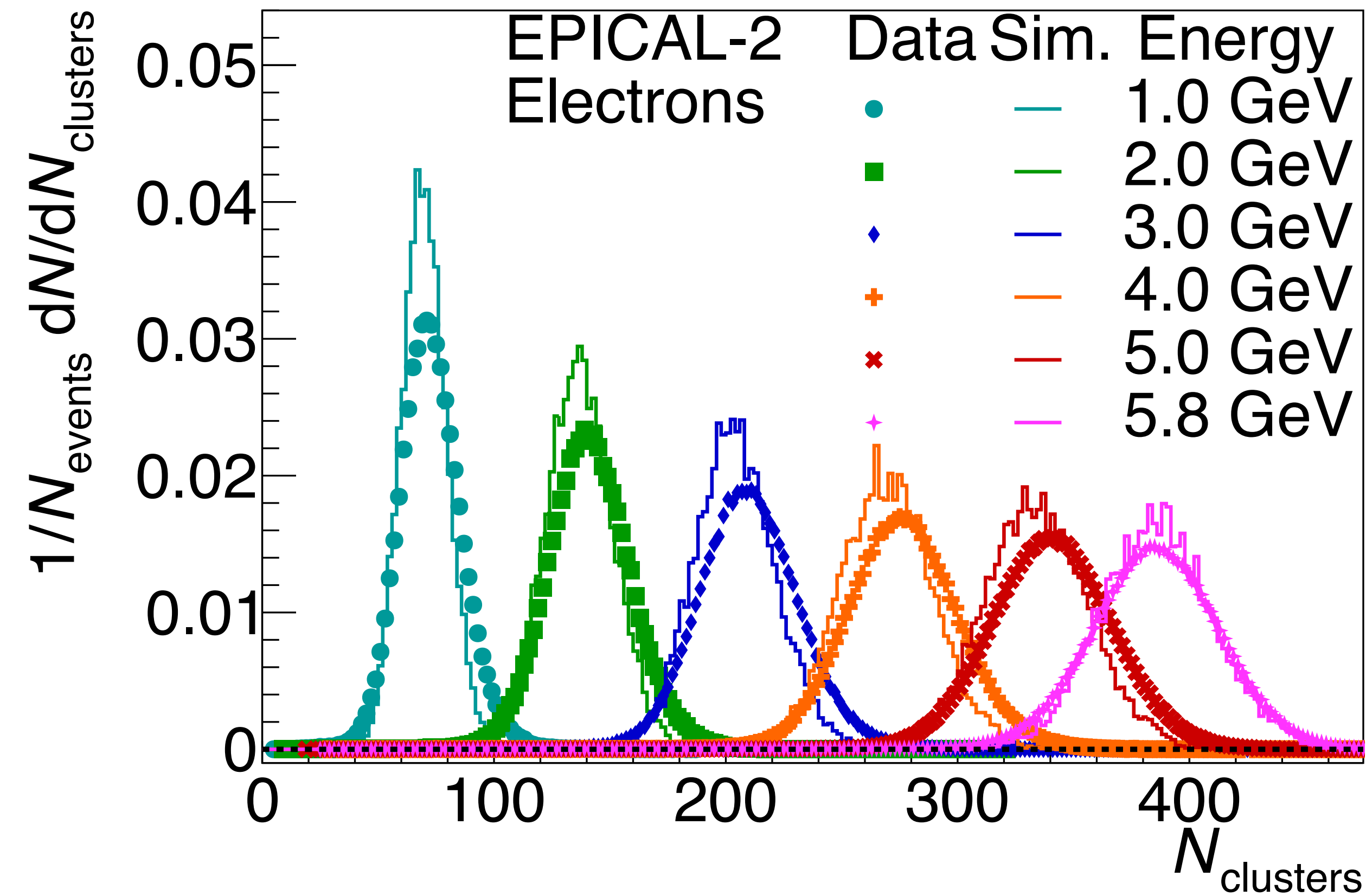all chips with **threshold 82e ± 20e**

right:
0 GeV spread of beam energy
chips with **individual threshold**

latest version of the EPICAL-2 simulation showed at DPG and CALICE meeting

latest version: signal distributions

total number of **hits**

EPICAL-2 preliminary
Electrons, 5 GeV

- data
- simulation

$\frac{1}{N_{events}} \, dN/dN_{hits}$

N_{hits}

total number of **clusters**

EPICAL-2 preliminary
Electrons, 5 GeV

- data
- simulation

$\frac{1}{N_{events}} \, dN/dN_{clusters}$

$N_{clusters}$

▸ electron beam from box (10 mm x 10 mm), isotropic

▸ no beam-energy spread

▸ all chips are working with the same threshold of 82e ± 20e (Gaussian) and Gaussian *noise* of 20e
expect one chip in layer 21 (which was not working during TB)

▸ integration time t_{int} = 25ns

▸ 50 charges per step

▸ event selection and pixel mask applied

latest version: signal distributions

total number of **hits**

total number of **clusters**

▸ electron beam from box (10 mm x 10 mm), isotropic
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