Simulation status UHH

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Introduction

Simulation of the pulse shape of radiation damaged, segmented (pixel,strip) sensors with and without B-field + effects of readout electronics

- For the prediction of:

1. Time and spatial resolution
2. Signal-to-noise ratio
3. Efficiency

- And:

4. For the optimisation of reconstruction algorithms
5. Templates for detailed Monte Carlo simulation of the tracker

- Why? Going from LHC to SLHC

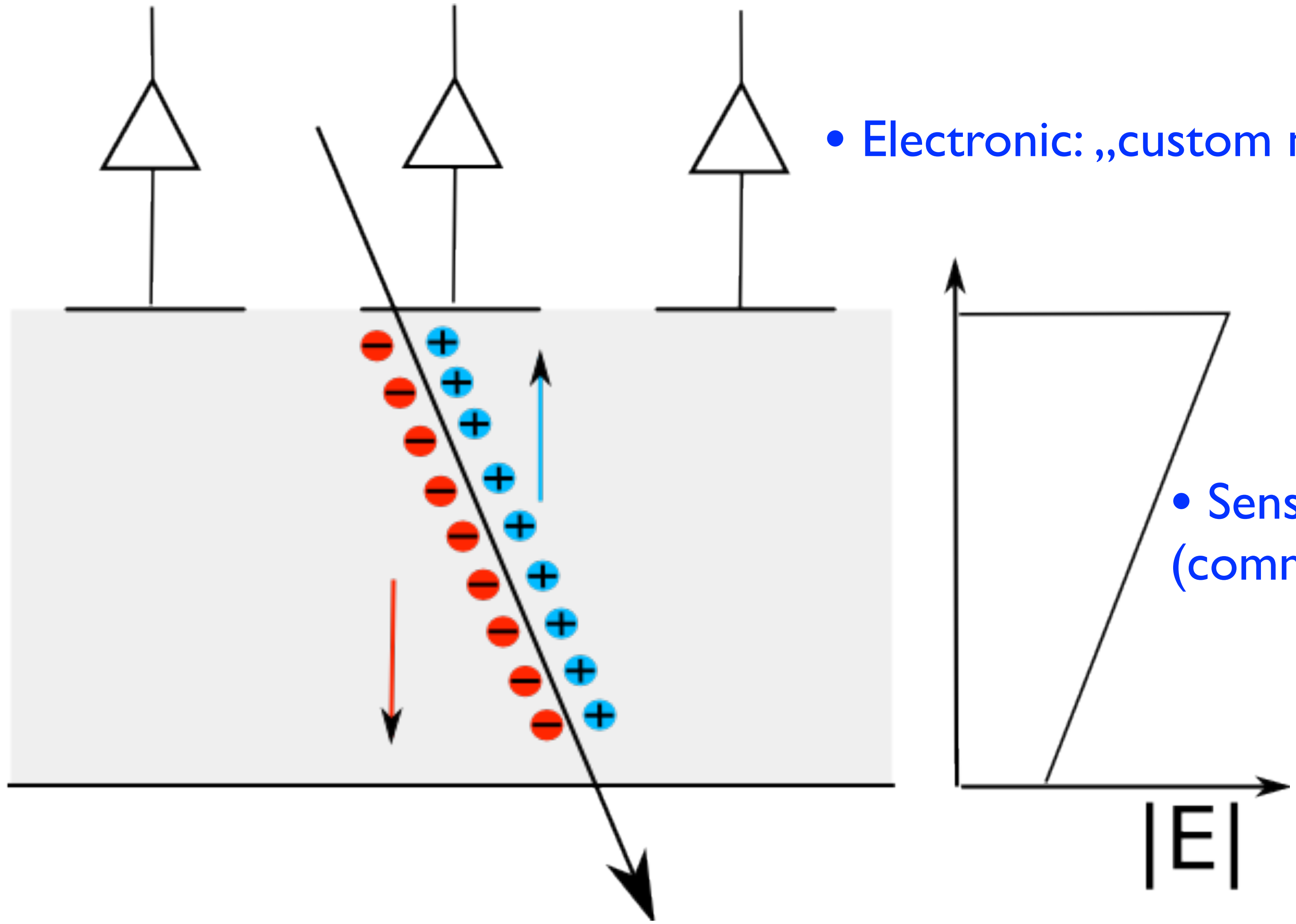
Luminosity: 10^{34} cm^{-2} s^{-1} → 10^{35} cm^{-2} s^{-1}

Fluence Φ_{equ} (r=4 cm): 3×10^{15} cm^{-2} → 1.6×10^{16} cm^{-2}

⇒ Optimise sensor design for radiation hardness

Simulation overview

• Signal shape: further development of „PIXELAV“ (M. Swartz) (M. Swartz CMS-Note 2002/027, M. Swartz et.al. arXiv:physics/0409049v2)



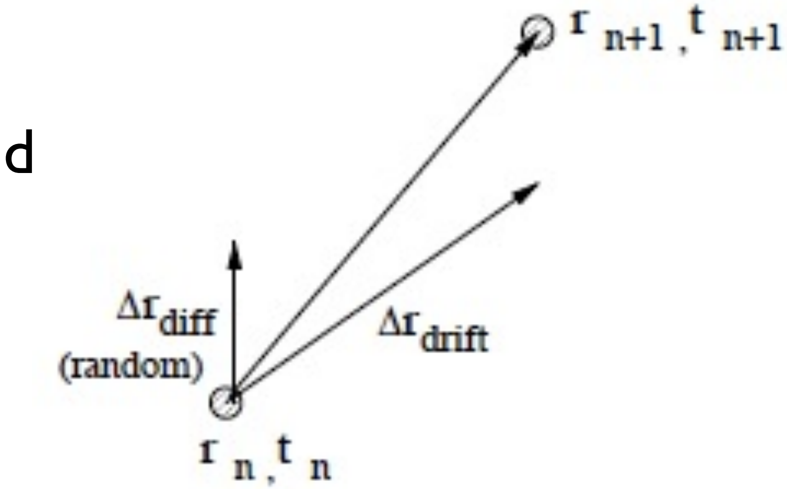
• Electronic: „custom made“ program

• Sensor (static): TCAD (commercial program)

• Charge carrier generation:
 1) PIXELAV (pions)
 2) Monte-Carlo-simulation (N. Mazziotta and H. Bichsel) (NIM A533 (2004) 432)

Simulation I

- Electric field: TCAD simulation (so far const. doping)
- Charge deposition: realistic generation of the e/h-pairs (with δ-electrons)
- Charge transport:



Drift: general classical formula for charge carries in E- and B-field

$$\Delta\vec{r} = \frac{\mu\left[\vec{E} + \mu r_H \vec{E}\times\vec{B} + \mu^2 r_H^2 (\vec{E}\cdot\vec{B})\vec{B}\right]}{1 + \mu^2 r_H^2 |\vec{B}|^2}\Delta t$$

with:

$\mu(E)$ mobility: saturation of velocity for high E-field is considered

r_H Hall-factor: $r_H = \mu_H/\mu$ μ_H Hall-mobility

Diffusion: random distribution (Gauss) $\sigma_x^2 = \sigma_y^2 = \sigma_z^2 = 2D\Delta t$

D from „Einstein-relation“ $D = \frac{kT}{e}\mu$

Trapping: $\Delta P_{trap} = \frac{\Delta t}{\tau_{eff}}$ (Monte Carlo) ΔP_{trap} trapping probability

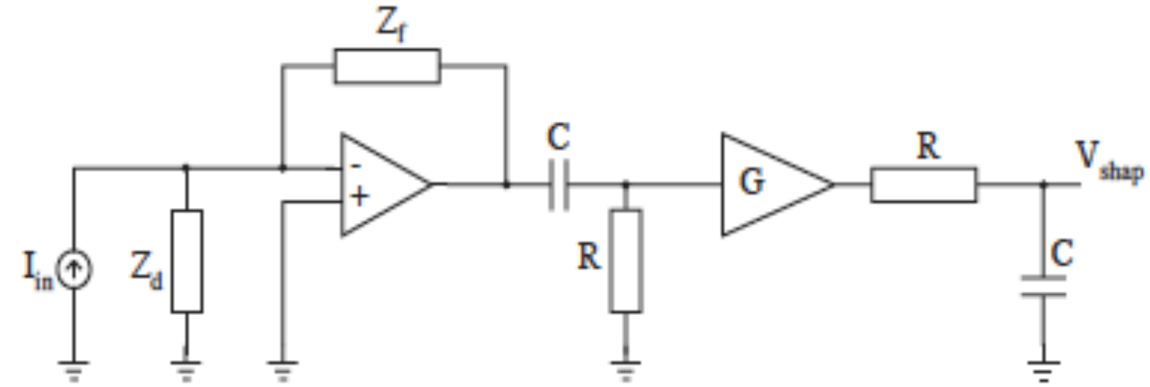
τ_{eff} effective trapping time

- Charge collection: induced signal calculated by „method of mirror charges“
- Coupling capacitance („crosstalk“): transfer matrix (values taken from measurements)

Simulation II

- APV 25: is simulated as an ideal Op amp and CR-RC shaper + peak / deconvolution mode and 8 bit ADC
  - preamp transfer function:

$$H_p(s) = \frac{1}{C_f}\frac{1}{\frac{1}{\tau_f}+s} \qquad C_f = 0.15pF \quad \tau_f = C_f R_f$$

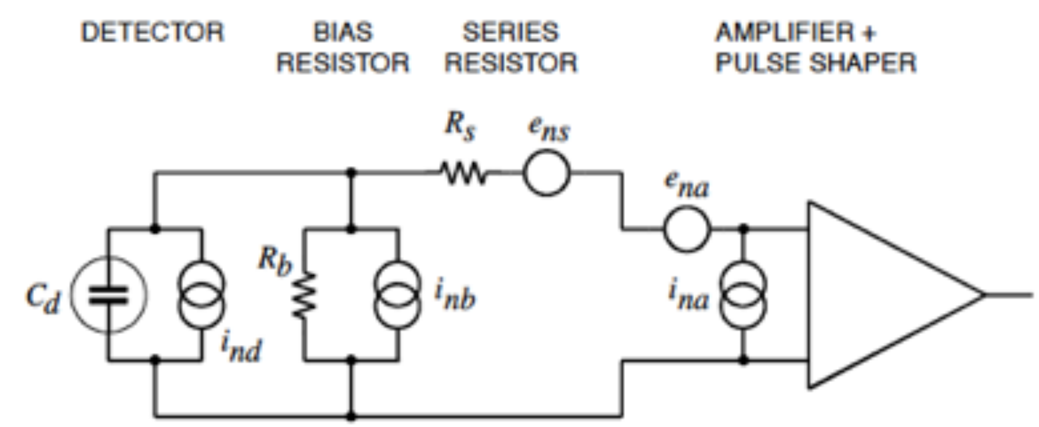


Equivalent electronic readout chain

  - shaper transfer function:

$$H_{sh}(s) = \frac{s\tau}{(1+s\tau)^2} \qquad \tau = 50ns$$

- Noise simulation:
  - parallel: leakage current: $i^2_{nd} = 2eI_d$
    bias resistor: $i^2_{nb} = \frac{4kT}{R_b}$
  - seriell: serial resistor: $e^2_{ns} = 4kTR_s$
    amplifier: $e^2_{na} = \frac{8}{3}\frac{kT}{g_m}$



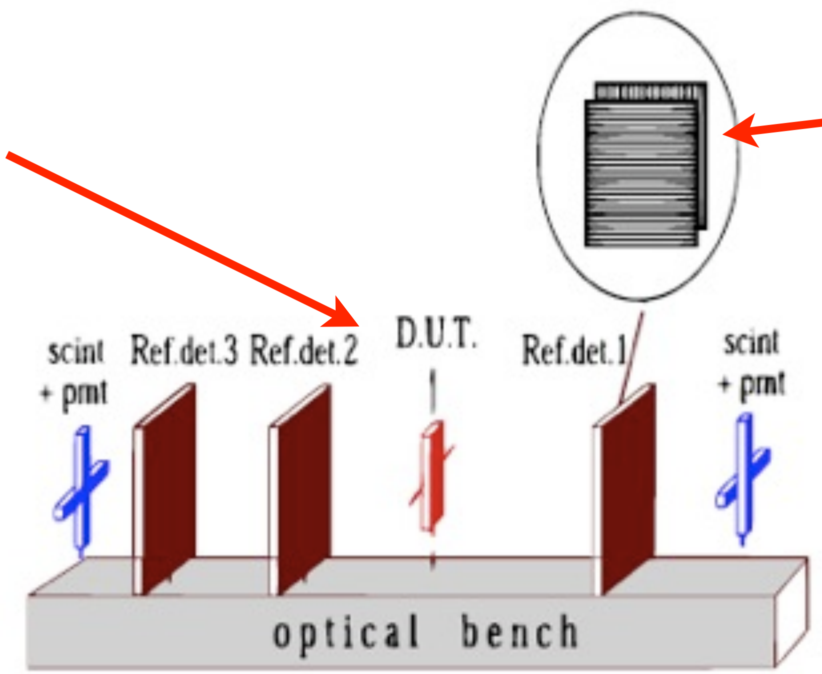
Noise equivalent electronic circuit

  - no1/f noise in the simulation!
  - Noise current and voltage pulses are generated according to: $X(t) = \Sigma_i A_i \delta(t - iT_s)$
    Where T_s is the sampling time and A_i is take from a gaussian distribution with: $\sigma_p = \sqrt{i^2_{nd} + i^2_{nb}}/\sqrt{2T_s}$ (parallel) and $\sigma_s = \sqrt{e^2_{ns} + e^2_{na}}/\sqrt{2T_s}$ (seriell)
  - The noise pulses are processed by the preamplifier and then added to the signal

Testbeam experiment

- Where carried out at DESY II synchrotron with electron beam energy of 1-6 GeV
- Non-irradiated modules from different parts of the CMS silicon strip tracker have been investigated (angle dependent 0°-60°)
- Prediction at DUT: ~10 µm at 6 GeV (dominated by multiple scattering)

test module



2 strip sensors, rotated by 90° against each other

- The test module used for comparison:

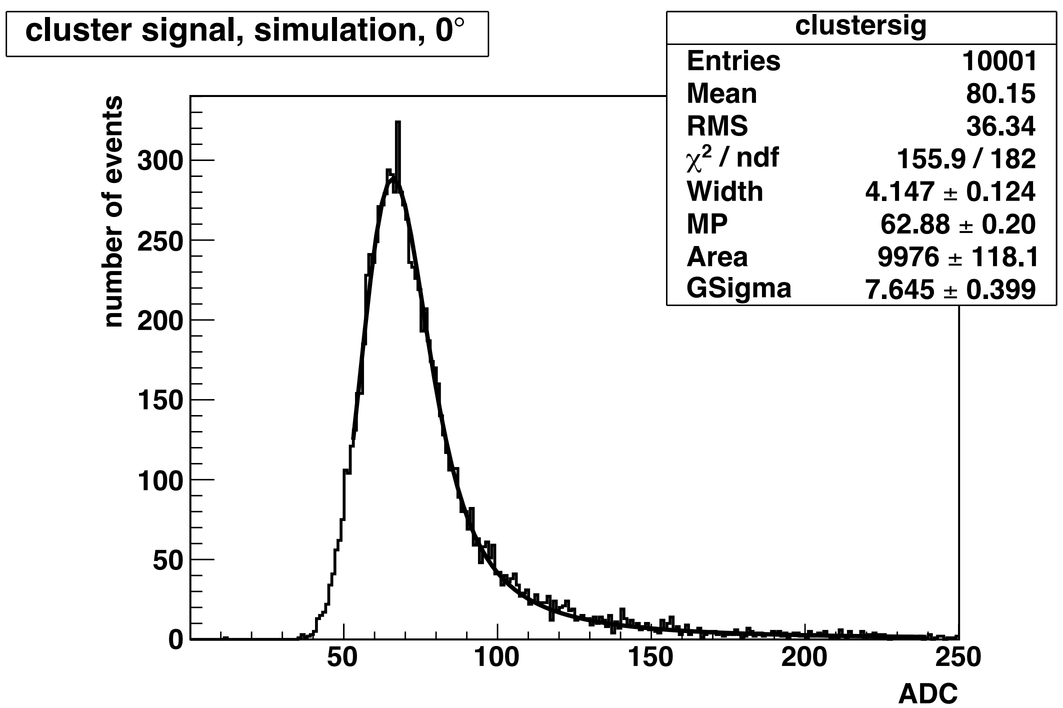
  non-irradiated, n-Typ, Outer Barrel 1, pitch = 122 µm, thickness = 500 µm

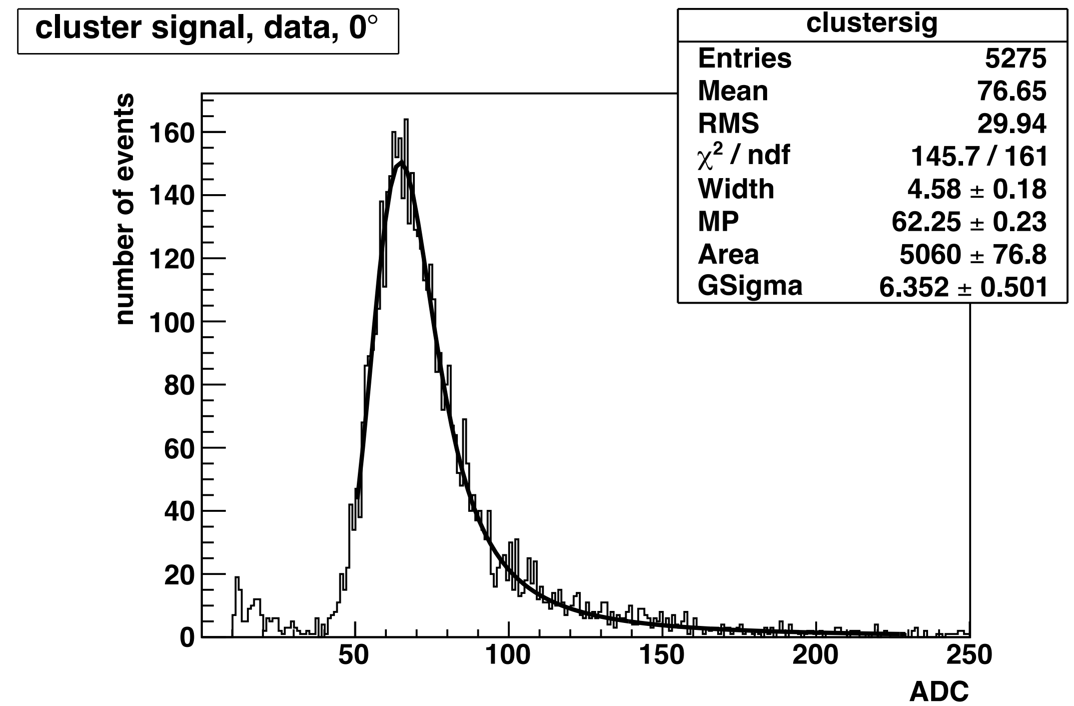
- Measurement parameters:

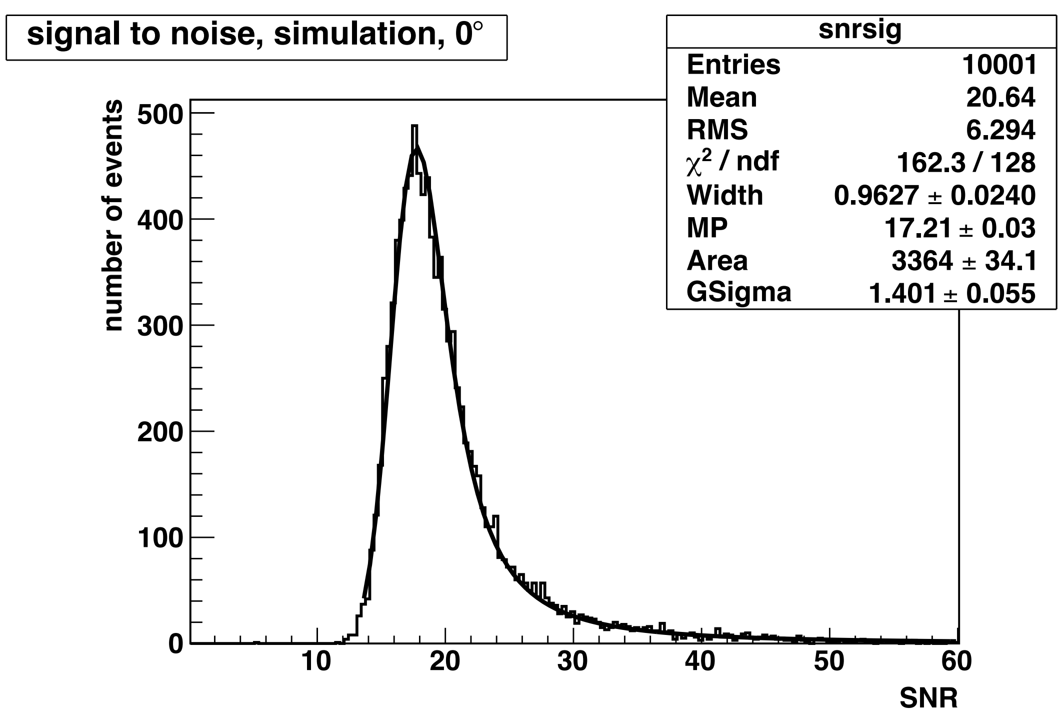
  T = -15° C, V_{FD} = 180 V , V_{bias} = 450 V

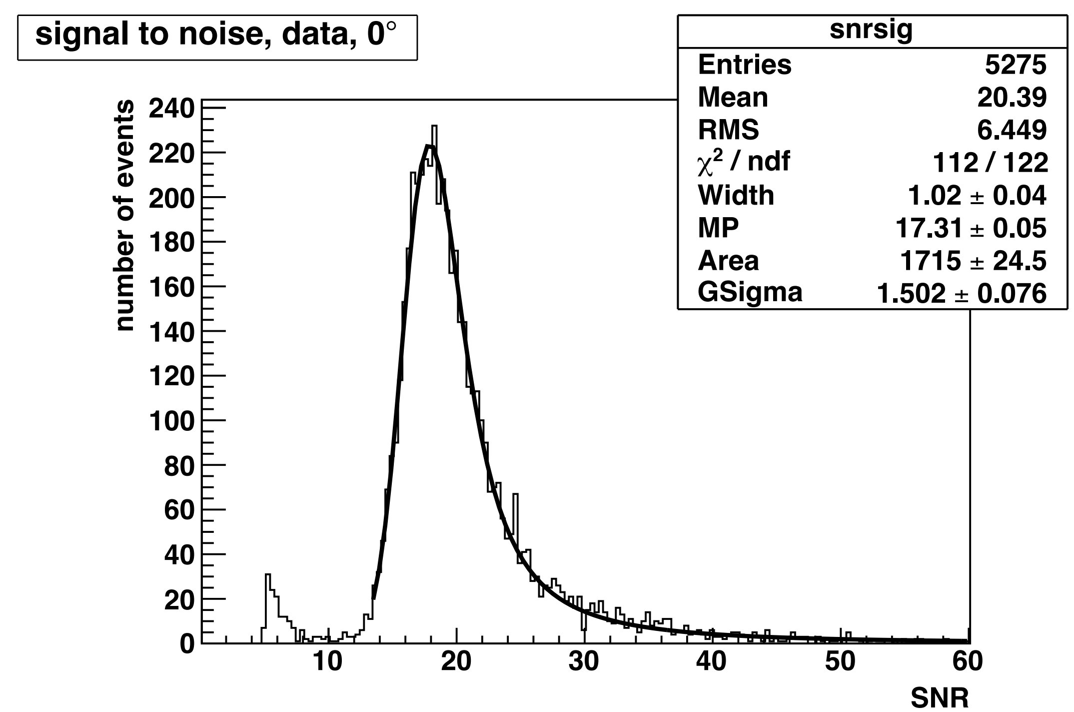
Cluster signal and SNR

- Cluster signal: 3-threshold algorithms (cuts: signal: S/N>2, seed: S/N>3, cluster: S/N>5)
- In simulation adjusted: Amplifier gain and noise





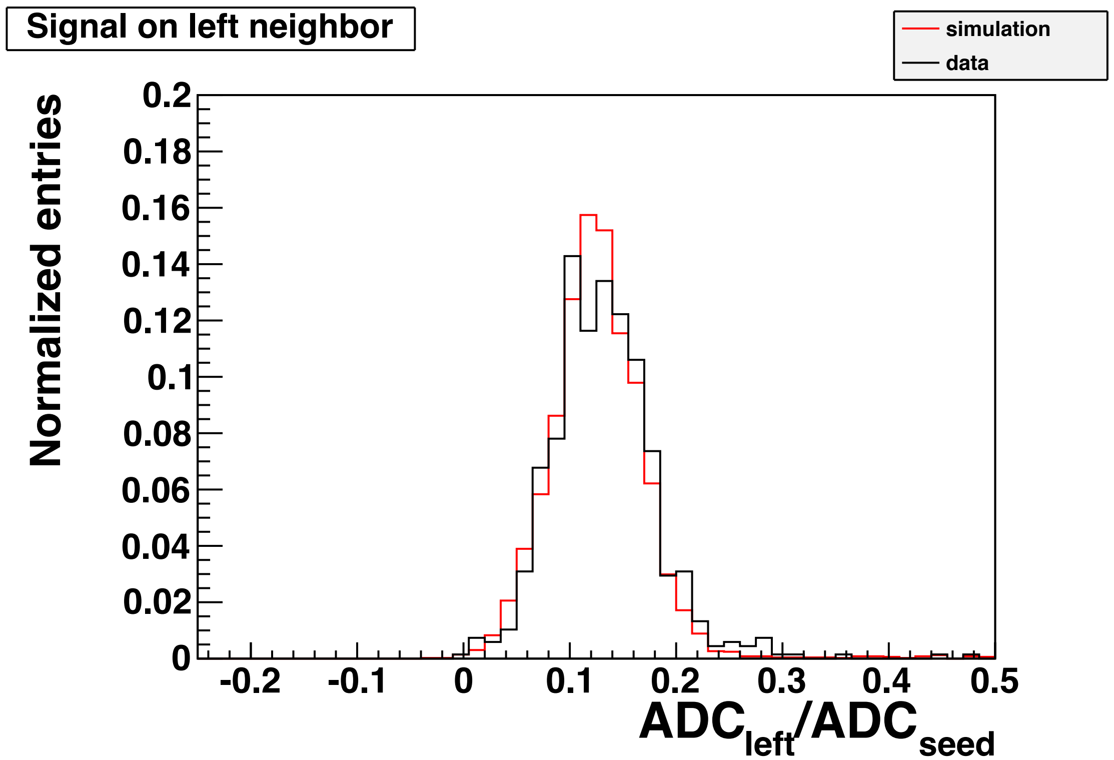


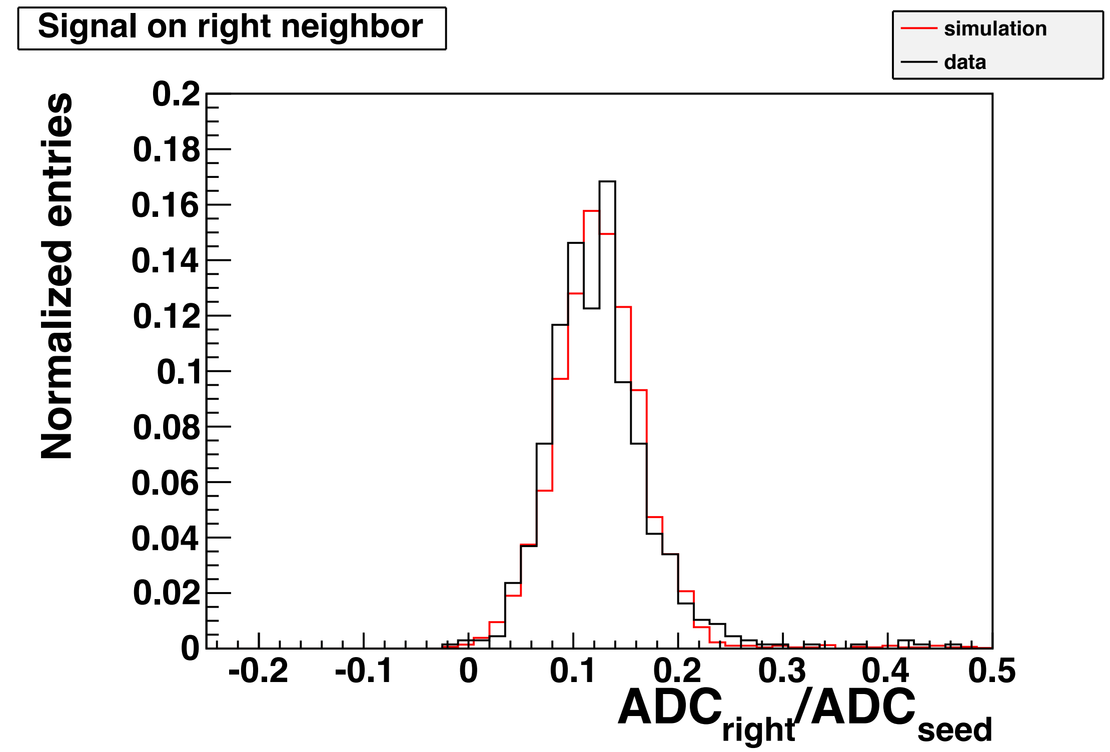


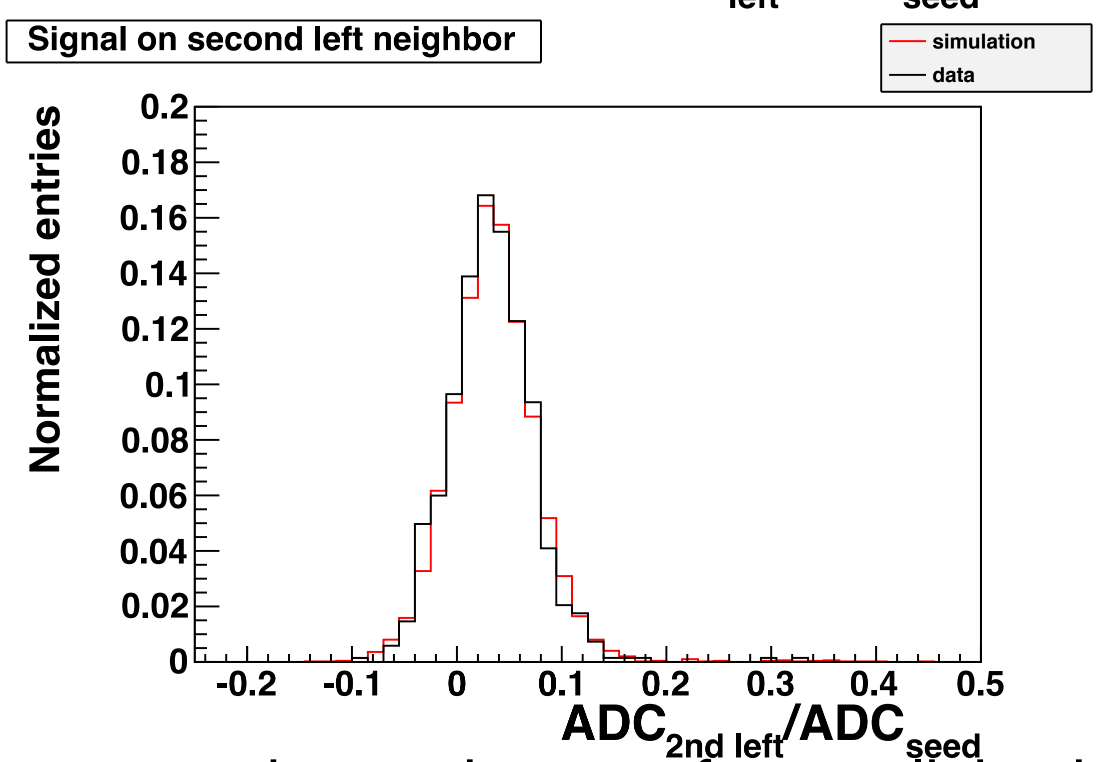
- good agreement of MP, width and GSigma

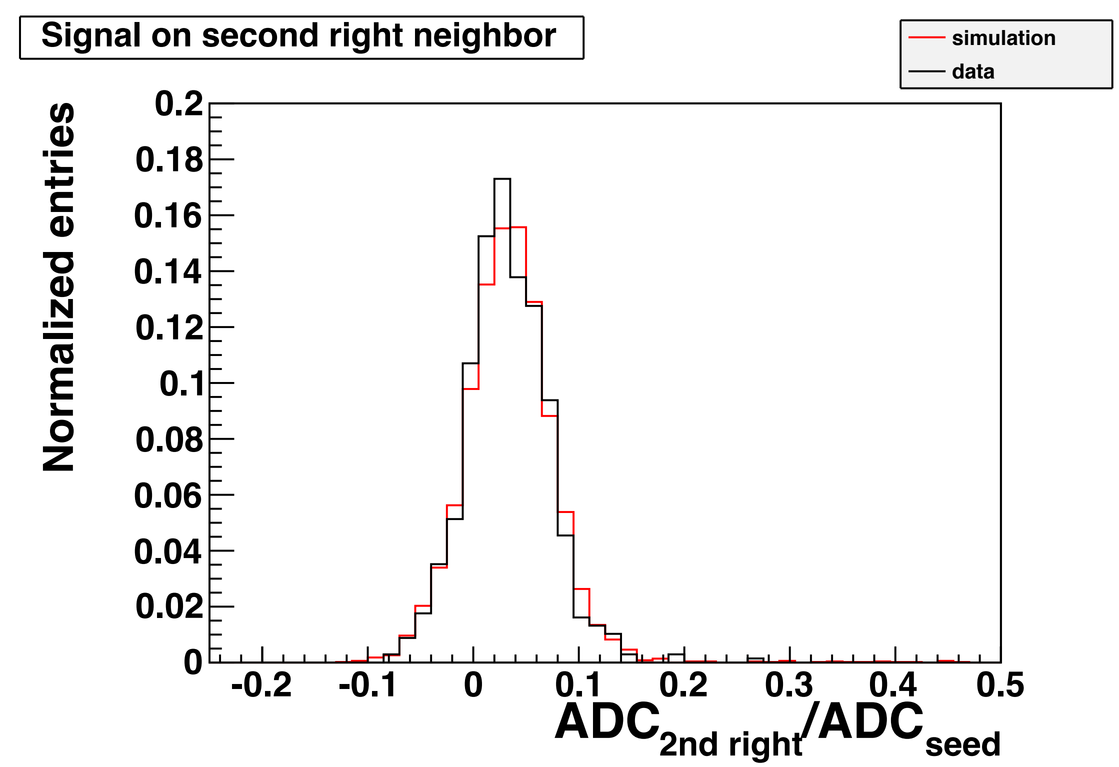
Crosstalk

- Crosstalk taken from data for 3 strips r./l. ⇒ in simulation inserted (transfer matrix)





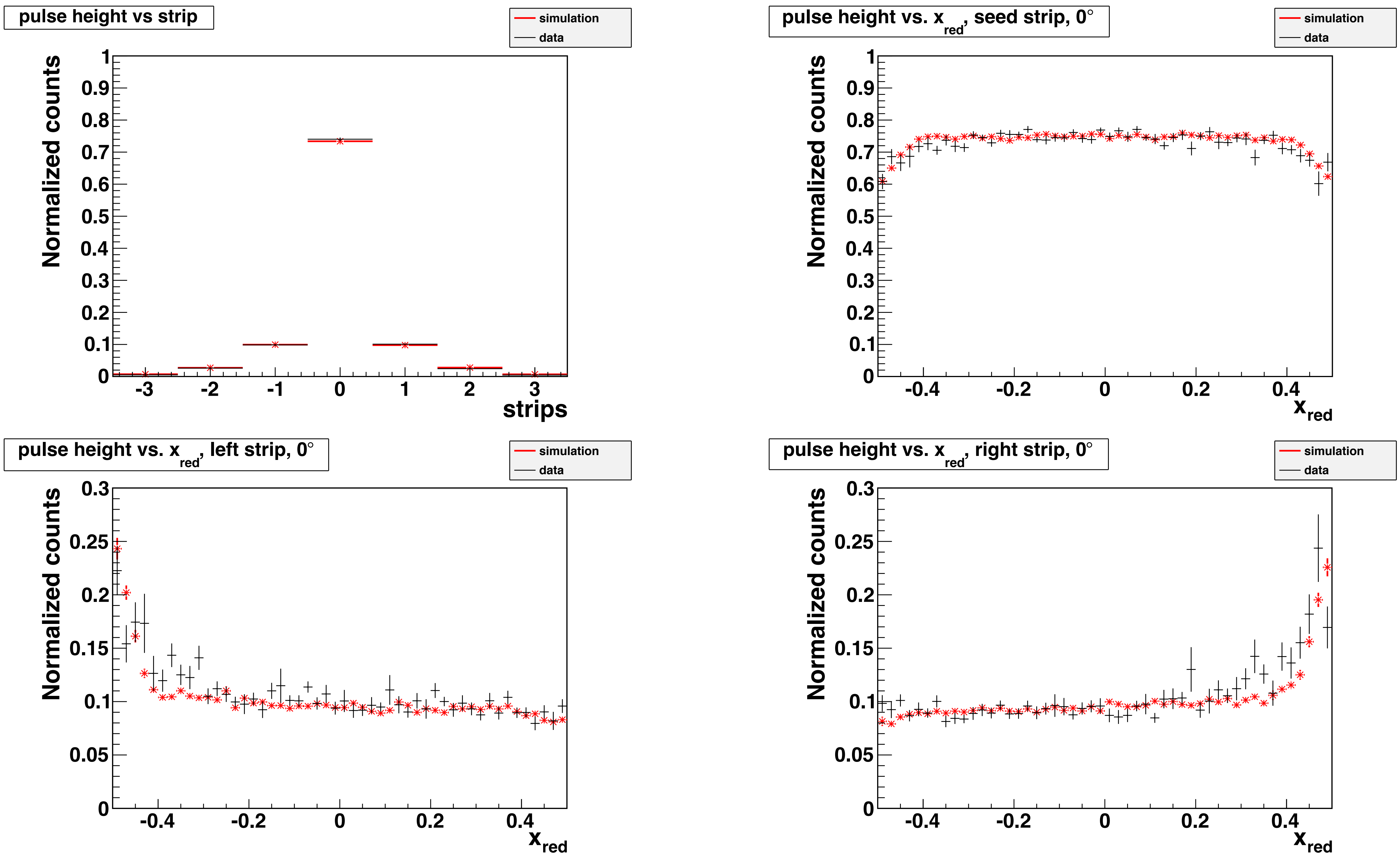




- good reproduction of crosstalk by the simulation

Pulse height distrbution

x_{red} position on the strip (0 centre); depends on the prediction of the telescope

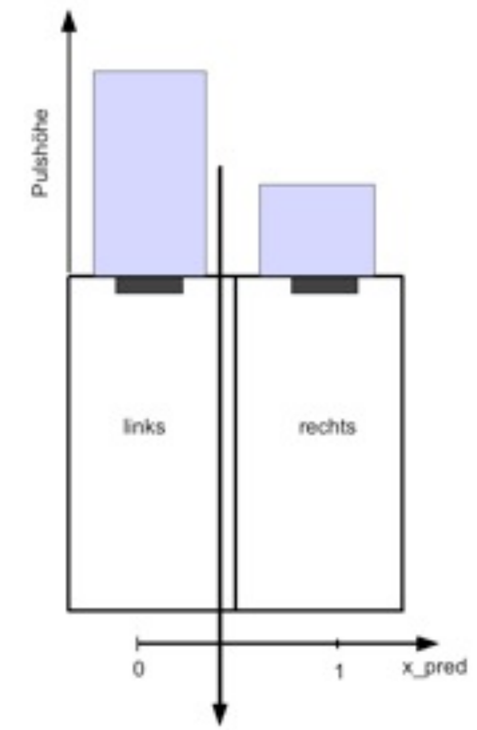


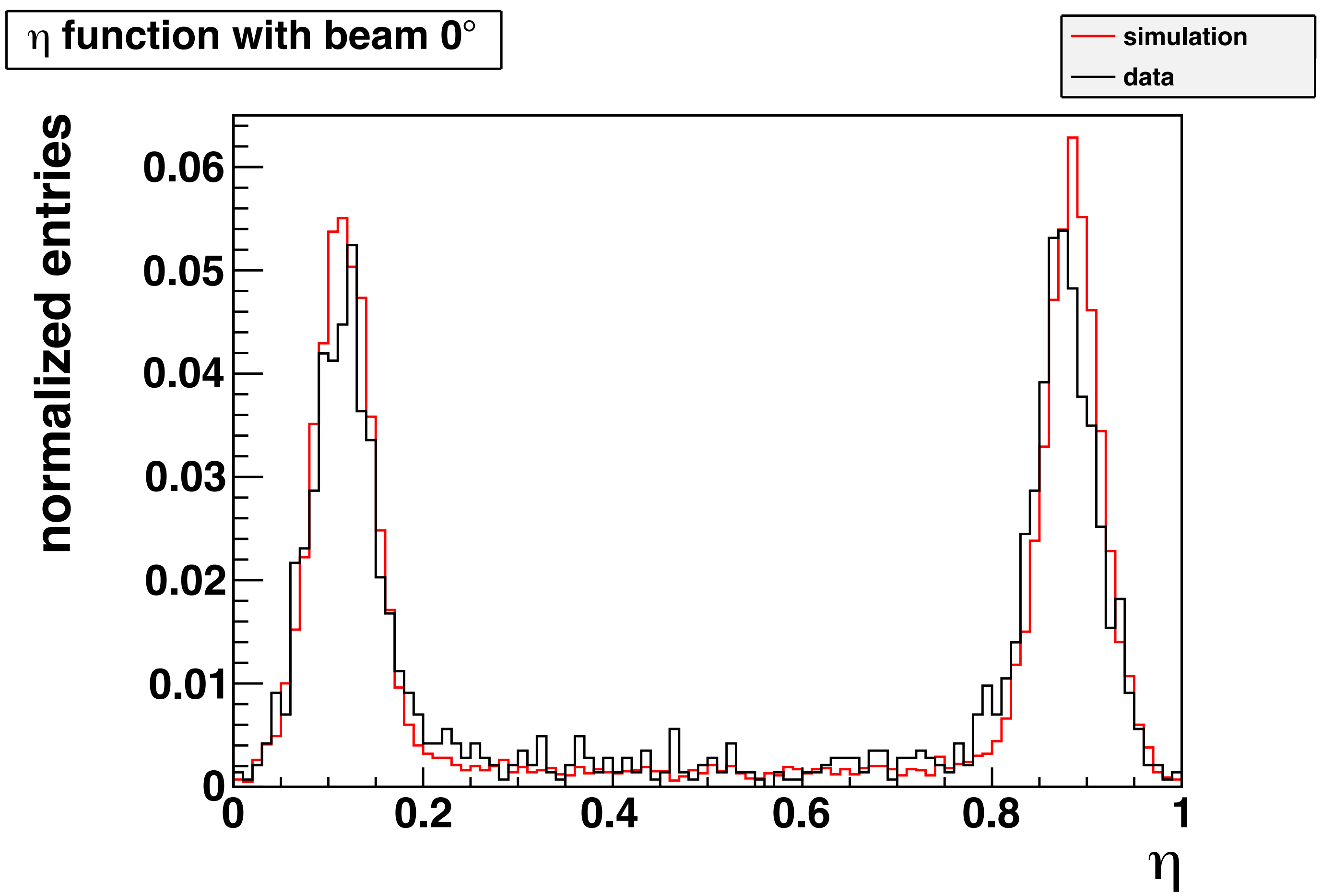
- mean pulse height: relative deviation seed: <1%, neighbour: <3%

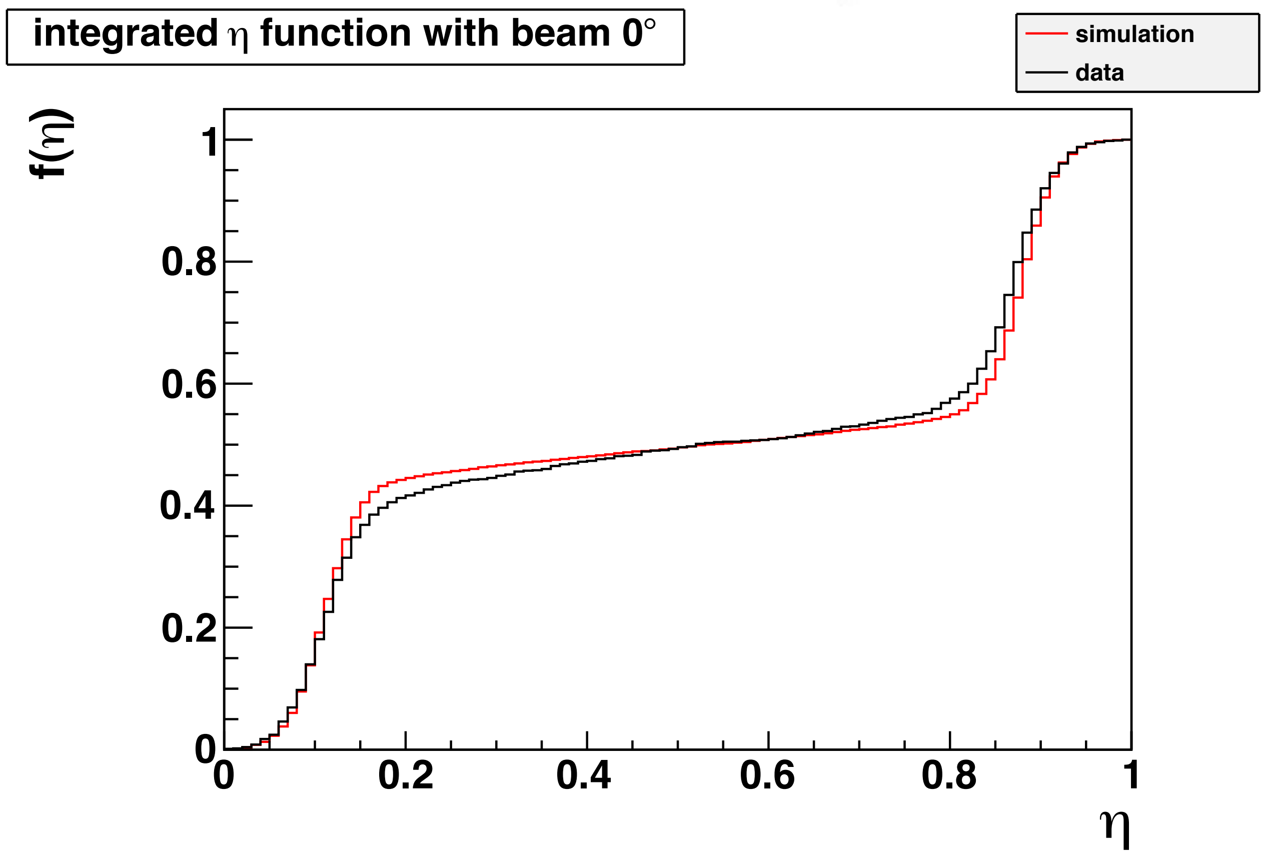
η-function I

PH(i) pulse height of strip i ⟶ $\eta = \frac{PH(R)}{PH(R)+PH(L)}$

integrated η-function: $f(\eta) = \frac{\int_0^{\eta} \frac{dN}{d\tilde{\eta}} d\tilde{\eta}}{\int_0^{1} \frac{dN}{d\tilde{\eta}} d\tilde{\eta}}$

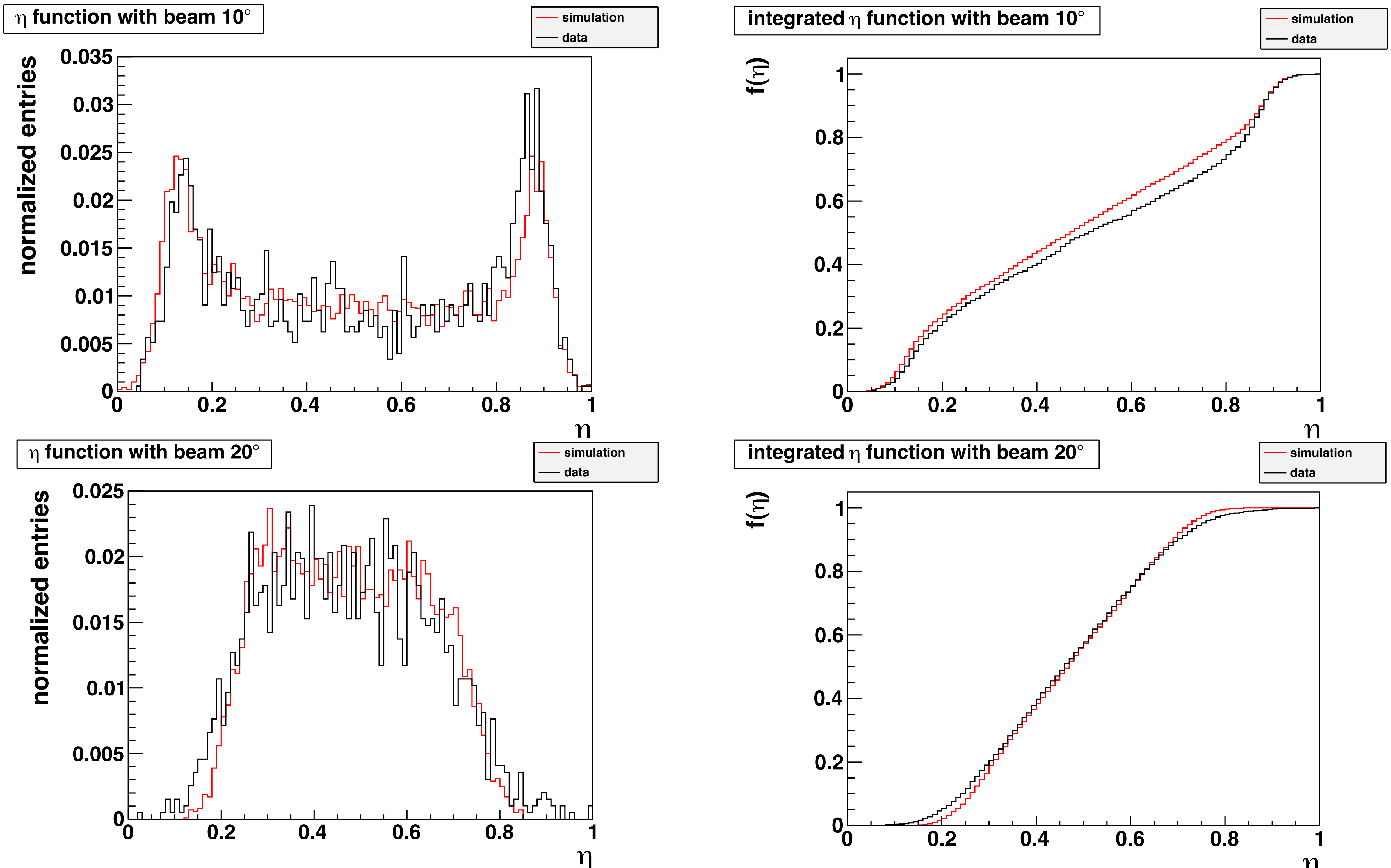






η-Function II

- η-Function at 10° and 20° , charge sharing

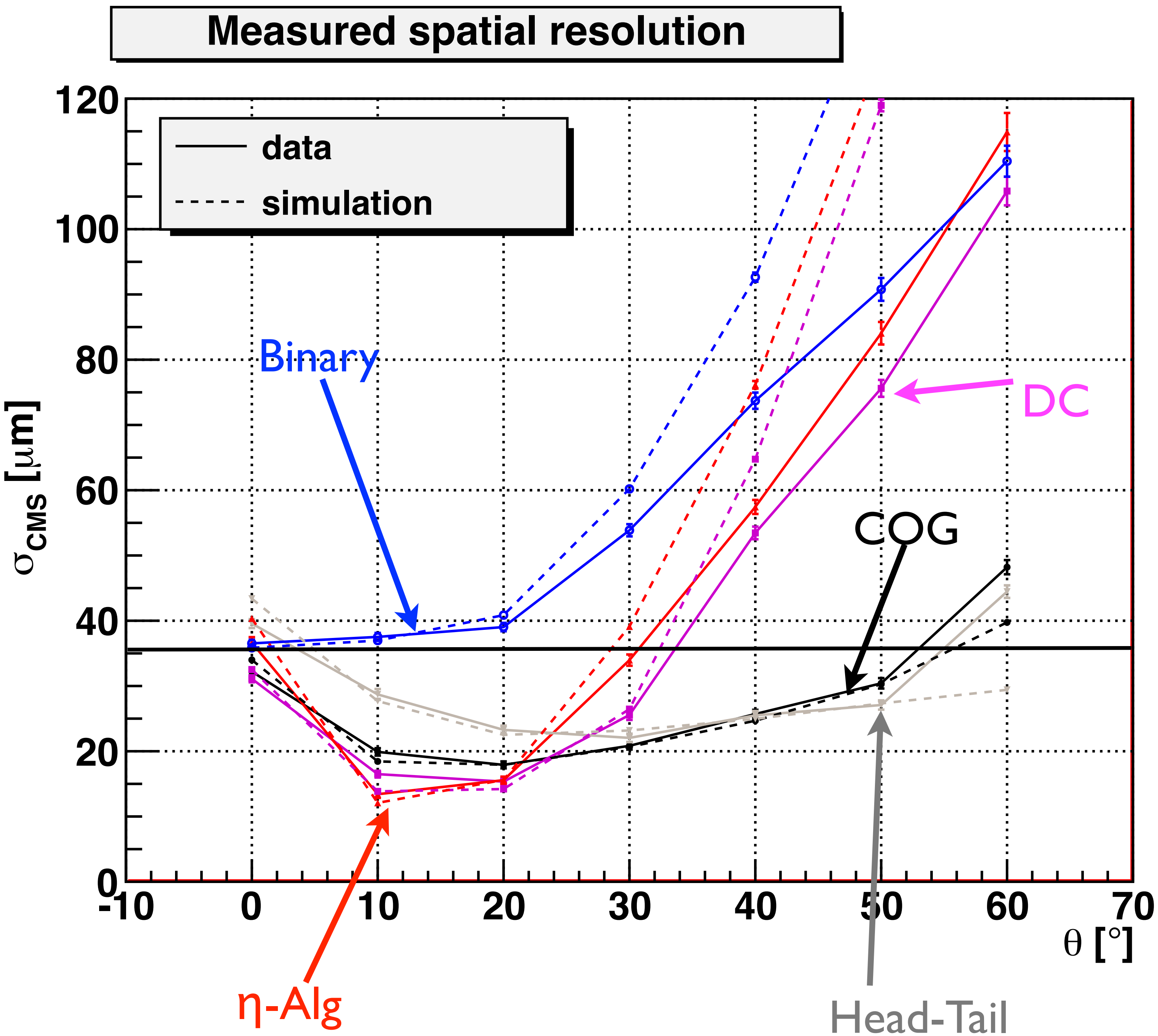


- deviation at 10°, good agreement at 20°

Spatial resolution

- Data: Corrected for multiple scattering and effective telescope resolution:

$$\sigma_{DUT}^{intr\;2} = (\sigma_{DUT}^{raw})^2(E \to \infty) - k_2 \cdot \sigma_{tel}^{eff\;2}$$



- Reconstruction algorithms:

Centre-of-Gravity:

$$x_{COG} = \frac{\sum_{cluster} S_i x_i}{\sum_{cluster} S_i}$$

η-Alg:

$$x_\eta = x_l + f(\eta) \cdot p$$

Double centroid:

$$x_{DC} = \frac{C_{left}/dr + C_{right}/dl}{dr + dl}$$

with $dl = \frac{S_{left}}{S_{right}} = 1/dr$

C_{left} COG of left and seed

Binary:

Head-Tail:

$$x_{HT} = \frac{x_H + x_T}{2} + \frac{S_H - S_T}{2S_{avg}} \cdot p$$

Summary & Next steps

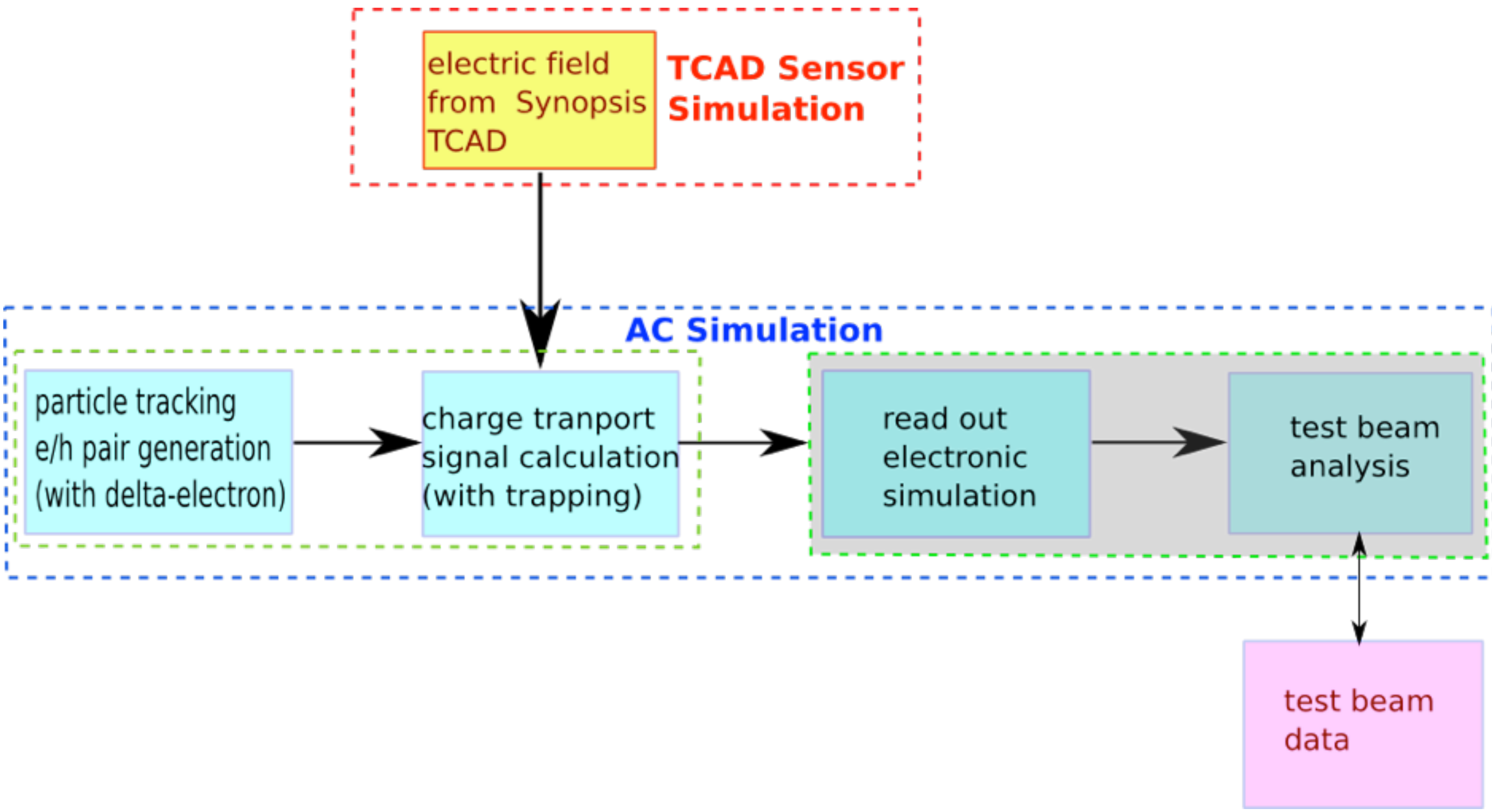
•Summary:

- For the development of radiation hard silicon sensors a simulation program is needed, which allow one to simulate the pulse shape of irradiated sensors.
- Based on TCAD, PIXELAV and other tools we are developing such program.
- Comparison of simulation and non-irradiated CMS sensors are in good agreement.

•Next steps:

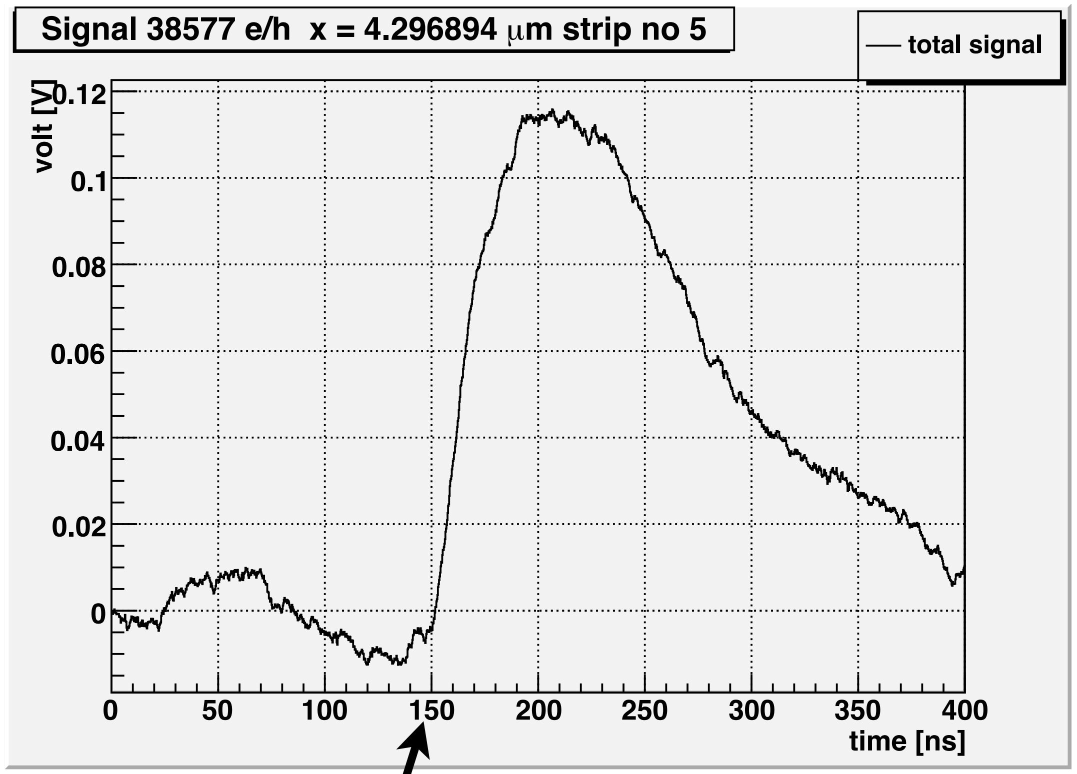
- Implementing of the „weighting field“ method
- TCAD simulation of irradiated sensors

Backup

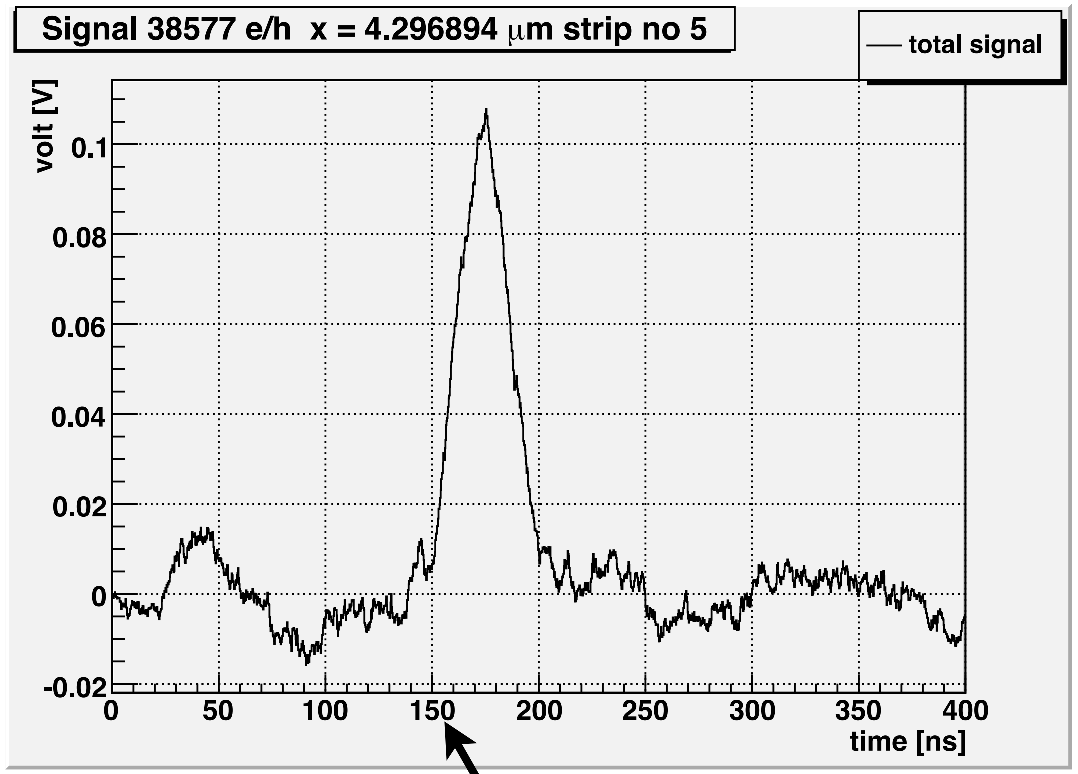

electric field
from Synopsis
TCAD
TCAD Sensor
Simulation
AC Simulation
particle tracking
e/h pair generation
(with delta-electron)
charge tranport
signal calculation
(with trapping)
read out
electronic
simulation
test beam
analysis
test beam
data

Example of pulse shape

- Simulated signal: peak mode



- Simulated signal: deconvolution mode



Signal starts at 150ns

Signal starts at 150ns

Signal from on-chip test pulse

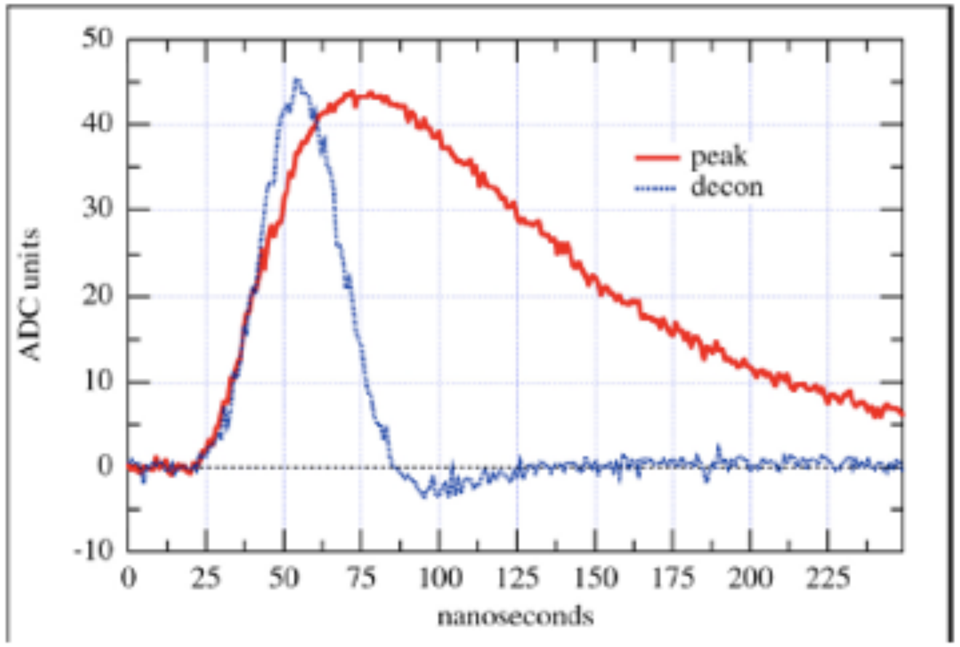


Figure 14. Measured APV25 Pulse shapes.