Systematic uncertainties induced by SiPM non-linear response

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

Overview

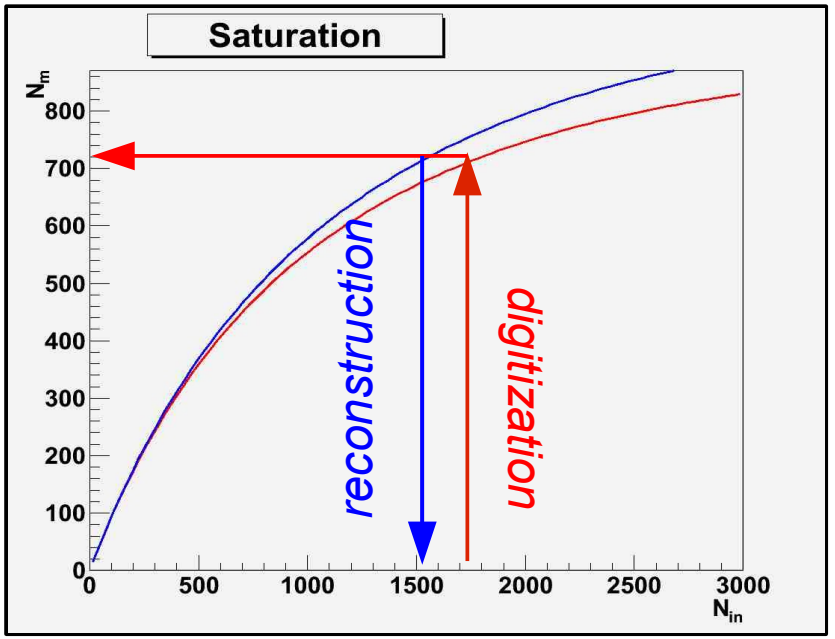
- Motivation
- General Simulation Overview
  - SiPM Saturation Simulation
- First Checks
- Conclusions

The Goal

$$E'_{\mathrm{reco}}[\mathrm{GeV}] = \frac{\sum_i E_i[\mathrm{MIP}]}{w[\mathrm{MIP/GeV}]}$$

$$E_i[\mathrm{MIP}] = \frac{A_i[\mathrm{ADC}]}{C_i^{\mathrm{MIP}}} \cdot f_{\mathrm{sat}}(A_i[\mathrm{pix}]).$$

$$N_m = A_i\,[\mathrm{pix}] = A_i\,[\mathrm{ADC}]/G_i\,[\mathrm{ADC/pix}]$$



Goal of this study:

Uncertainties due to $f_{sat}(A_i[pix])$

- Gain
- Saturation Curve shape:
  - (1)Explicit function
  - (2)SiPM simulation

Model for Saturation

(1) Use an explicit function

→ Use the **same expression** for reconstruction

→ let the parameters vary

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(2) Simulate the SiPM saturation

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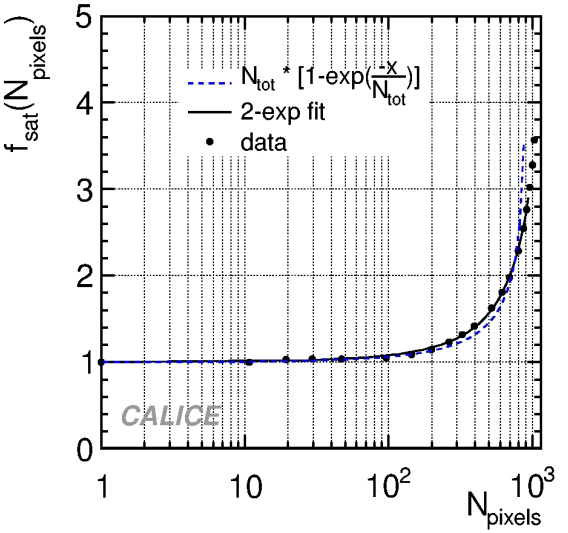
(1) An **explicit function** describing Saturation
(2) A **simulation** of the SiPM Saturation

(1) Explicit Function

$$N_{reco} = -a\, N_t \ln[(N_t - bN_m)/(N_t - N_m)] / (b - 1)$$



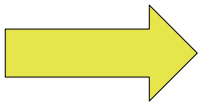
$$N_m = N_t\,(1 - e^{-a(1-b)Nin\,/\,Nt}) / (1 - be^{-a(1-b)\,Nin\,/\,Nt})$$

- $N_m \rightarrow N_t$ for $N_{in} \rightarrow +\infty$
- $N_m \rightarrow aN_{in}$ for $N_{in} \rightarrow 0$

N_t – estimation of the total active pixels

a – slope in the limit of low photons (~ 1)
b - "correction" to PDE

(2) Simulation of SiPM Saturation

For N impinging photons  N_m measured pixels

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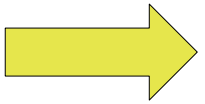
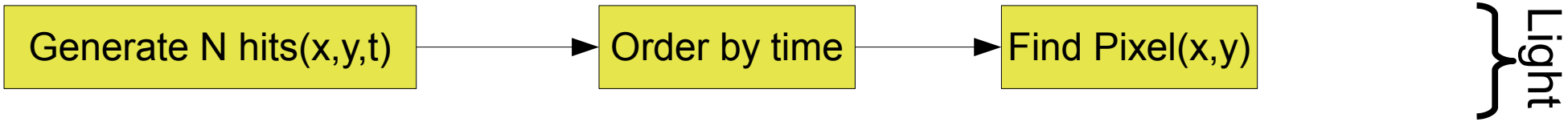
For N impinging photons  N_m measured pixels



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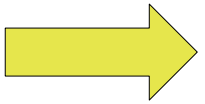
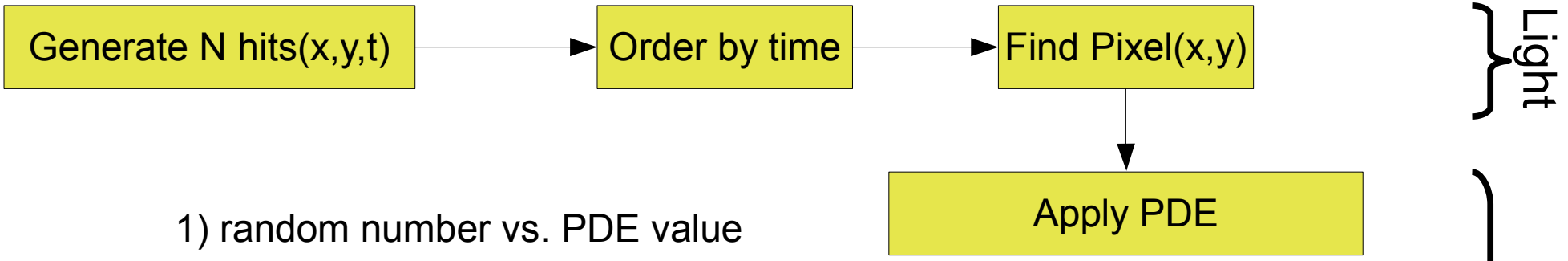
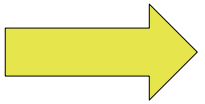
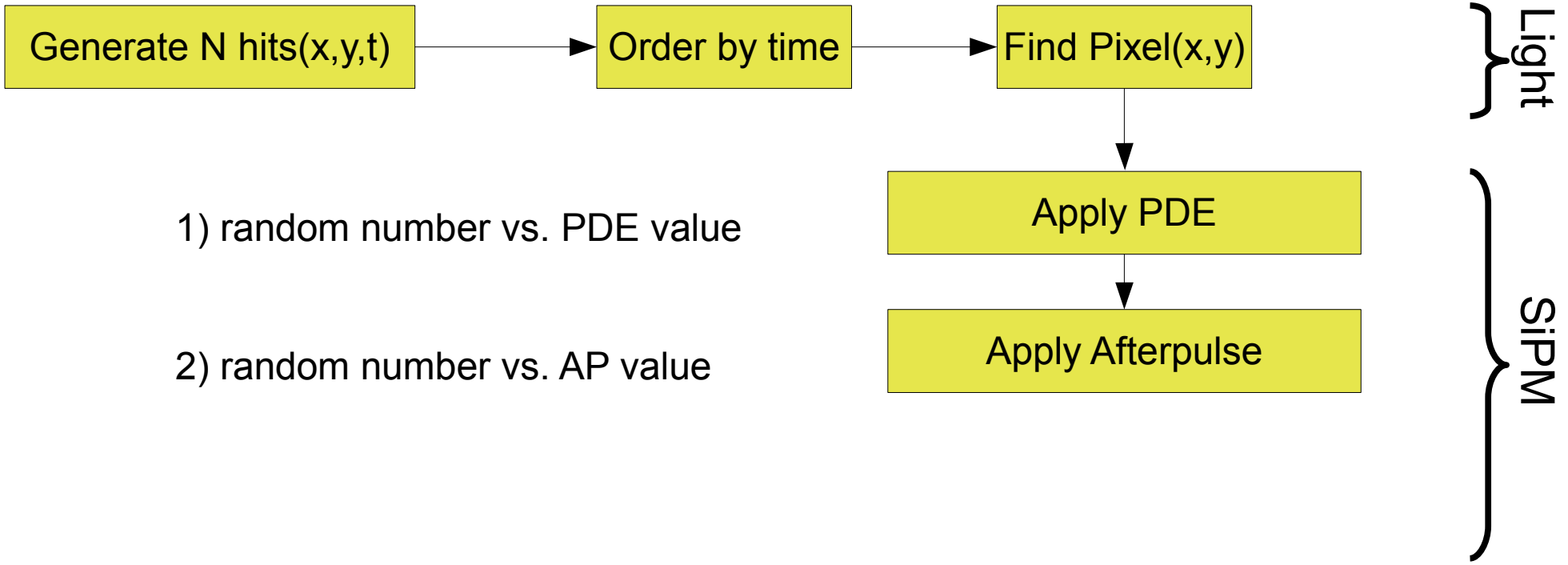
For N impinging photons  N_m measured pixels



1) random number vs. PDE value

(2) Simulation of SiPM Saturation

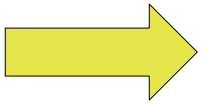
For N impinging photons  N_m measured pixels

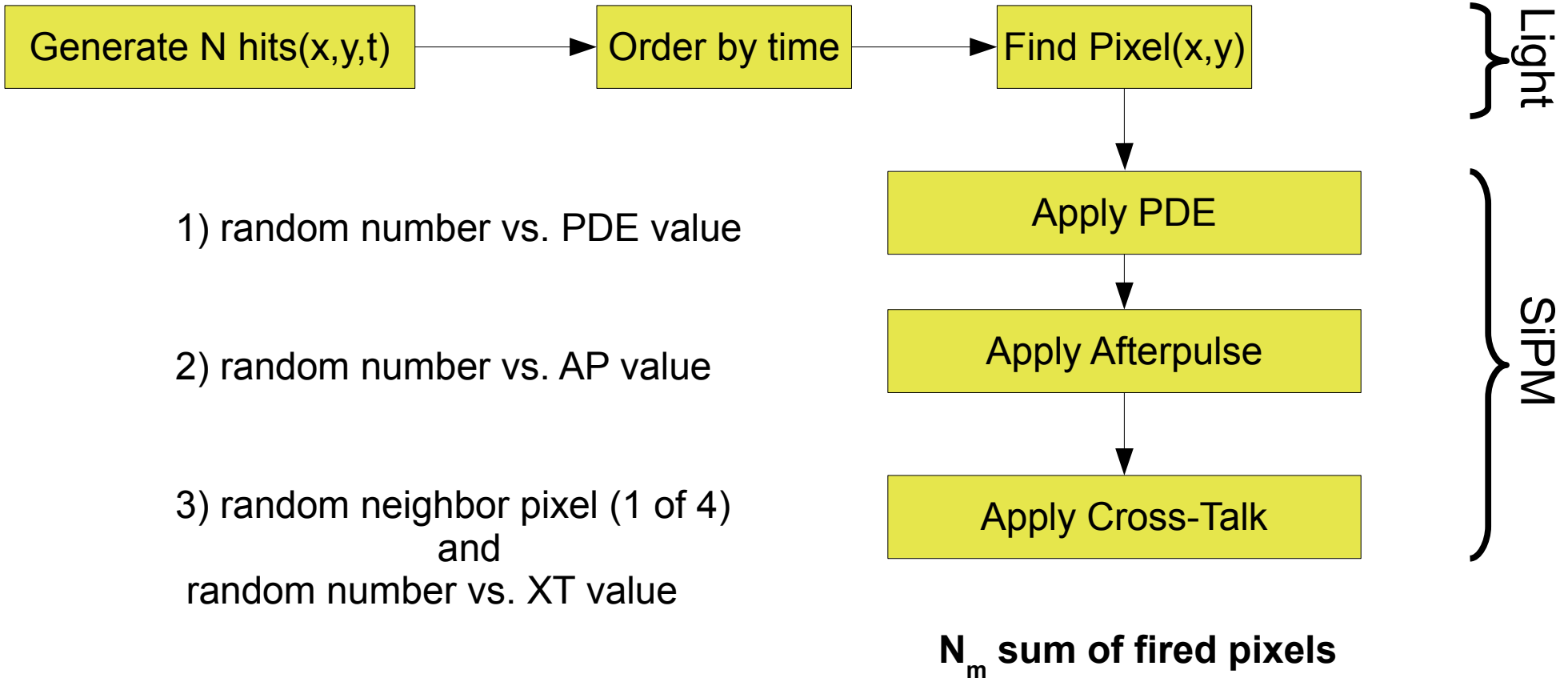


1) random number vs. PDE value

2) random number vs. AP value

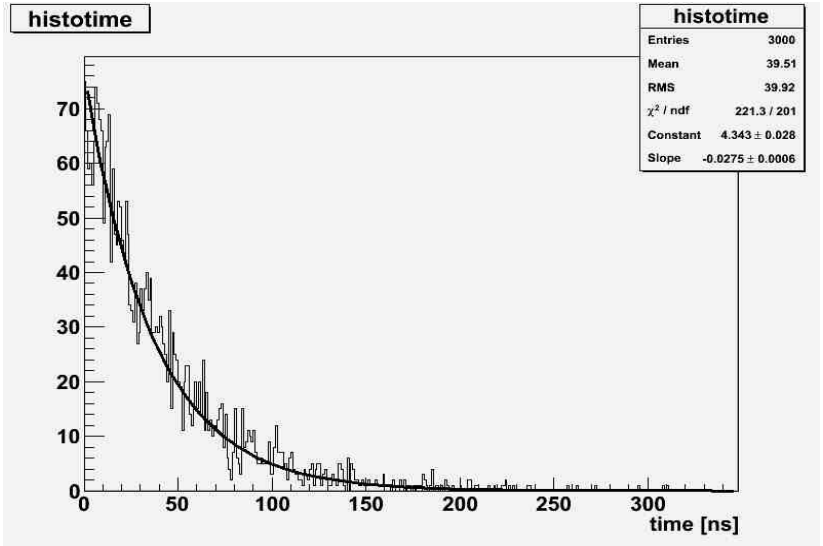
(2) Simulation of SiPM Saturation

For N impinging photons  N_m measured pixels

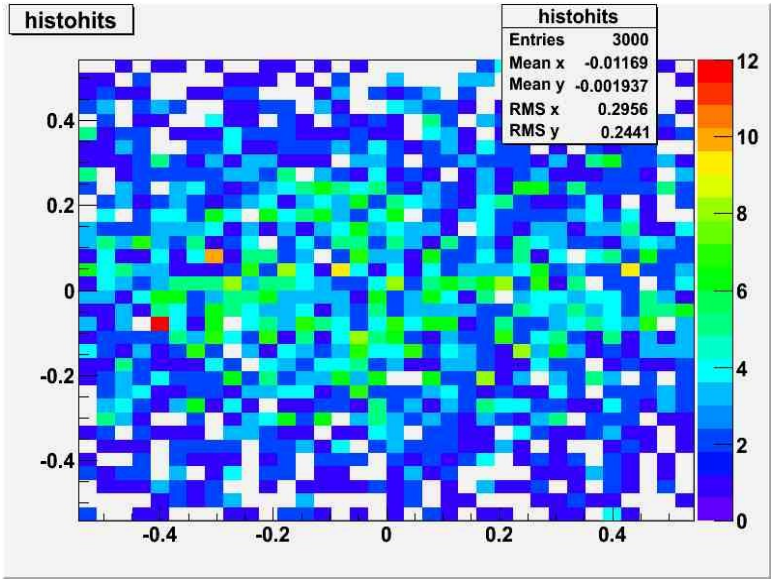


(2) SiPM simulation parameters

Temporal Distribution: double exponential
τ_{em} = 40 ns



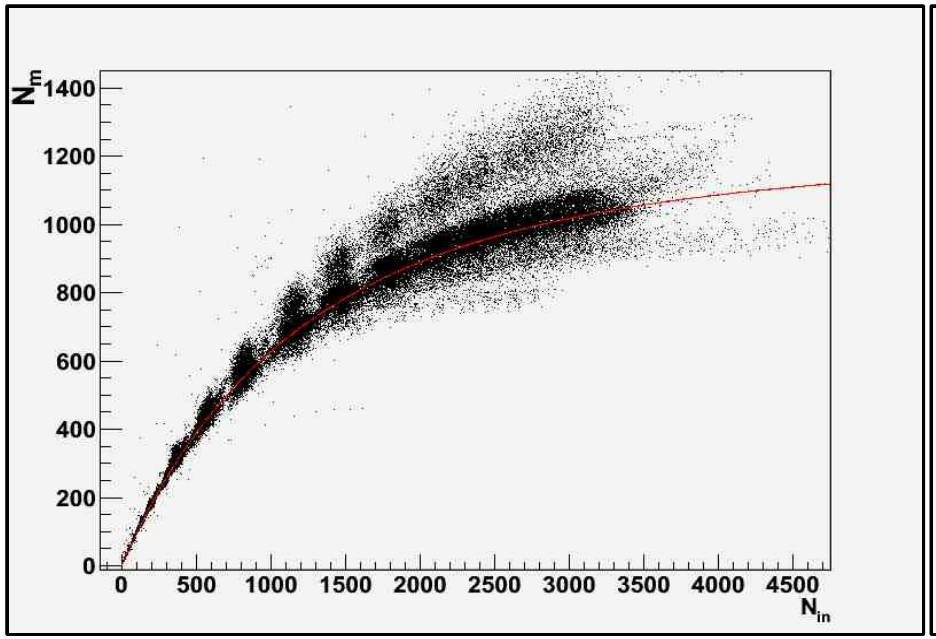
Spatial distribution:
different gaussian profiles for x and y

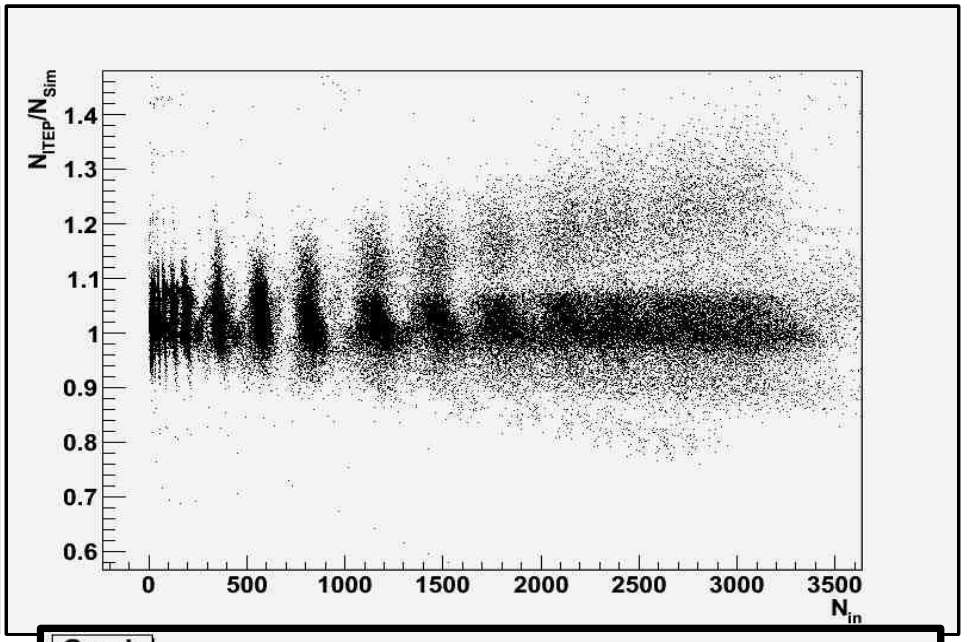


- Cell Number: 34 x 34
- Cell border = 0.032 mm
- T_{rec} = 200 ns
- PDE = 0.12
- AP probability = 0 (integration < T_{rec})
- XT probability = 0.25

✓ 1500 points between 1 and 5000 photoelectrons
✓ each point is the average of 500 iterations

(2) Comparison with ITEP curves & Best Fit



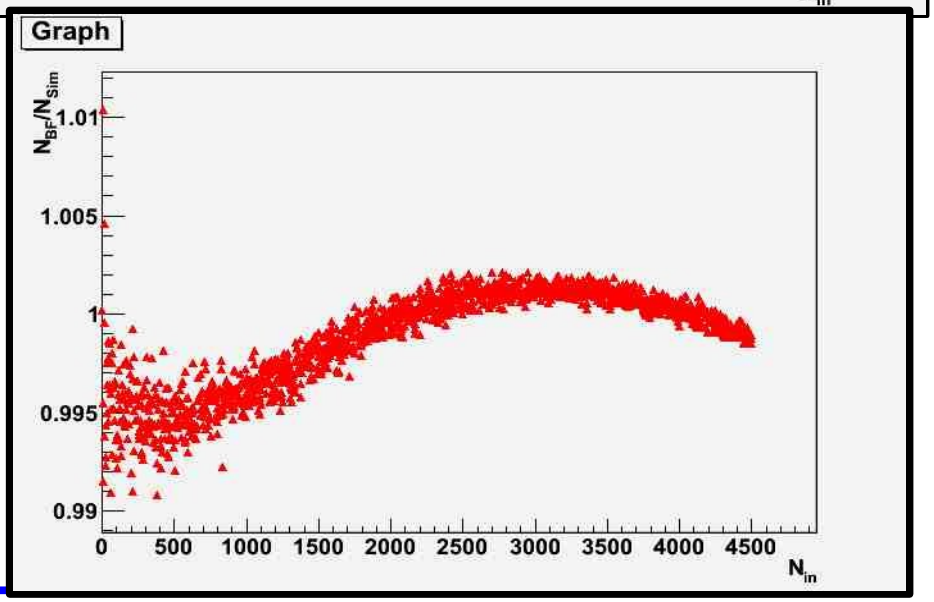


best fit

N_t = 1171

a = 1 (fixed)

b = 0.3402 (2)



Energy Reconstruction Simulation

Simulated **80 GeV pion** Run (QGSP_BERT_HP)

- Collect Energy per cell E_{hit} [MIP]
- Convert in N_{in} [p.e.] multiplying by LY
- Obtain N_m [pixels] measured pixels with normalized Saturation Function:
  - Gain & saturation parameters are fixed (mean value - NOT AS CALICE!)

digitization

- Obtain N_{reco} using the Saturation Correction:
  - Gain & Saturation parameters randomly chosen per each cell
  - Chosen cell parameter is fixed for all the Events
- Convert N_{reco} in E_{hit} [MIP] dividing by LY

recostruction

- end of Run obtain E_{reco}
- repeat 1000 times changing randomly parameters each time:
  - Uncertainty estimated as E_{reco} spread

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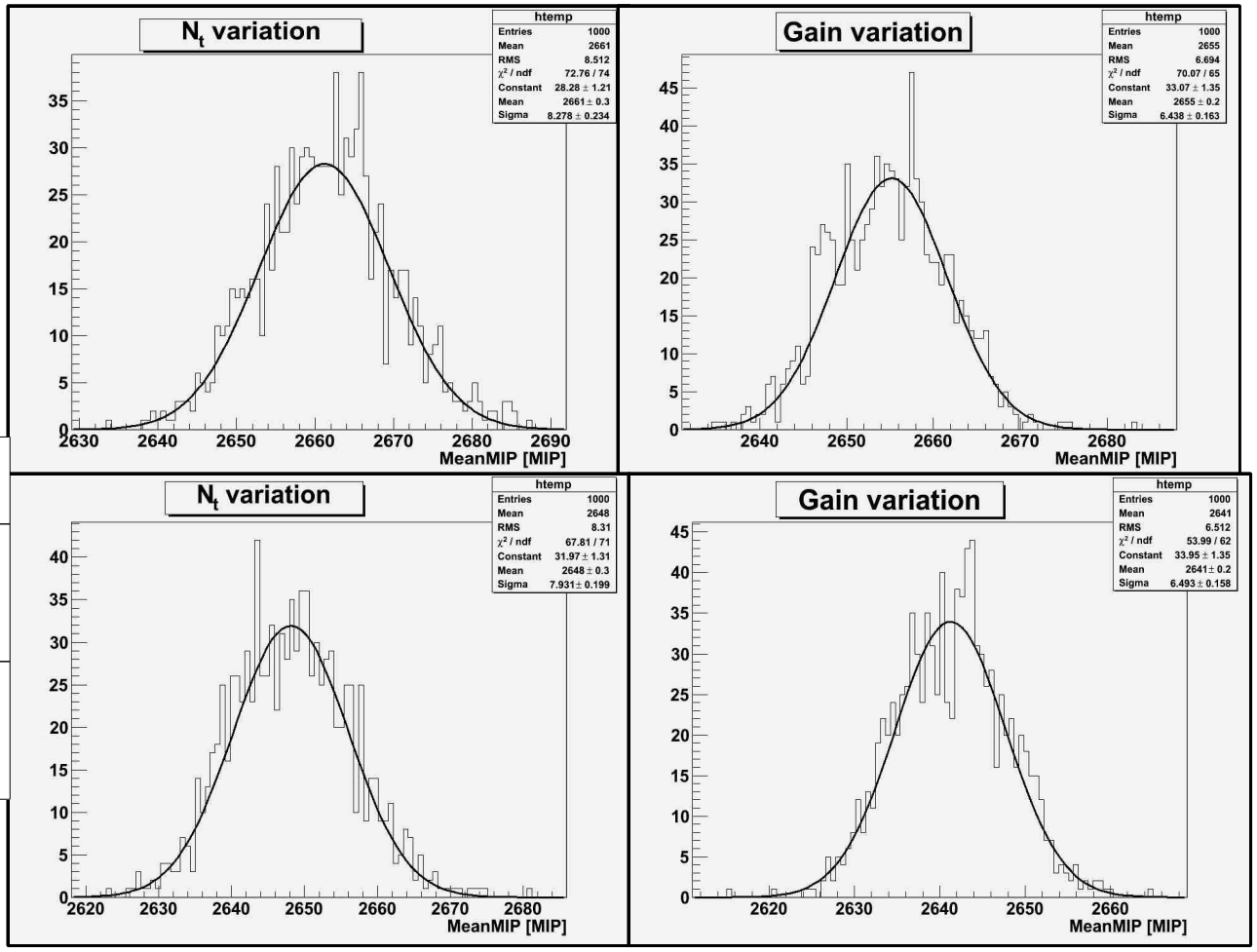
First Check

80 GeV pion
- N_t unc.: 5%
- Gain unc.: 2%

	$\delta(E)N_t$	$\delta(E)$Gain
(1)	0.31 %	0.24 %
(2)	0.30 %	0.25 %



Cross-check with positrons

50 GeV positron – AHCAL only

- N_t unc.: 10%
- Gain unc.: 2%

	$\delta(E)N_t$	$\delta(E)$ Gain
(1)	0.87 %	0.31 %
(2)	0.85 %	0.30 %
EM paper	2.4 %	1.4 %

(1)	0.74 %
(2)	0.76 %

80 GeV pion – N_t unc. 10%

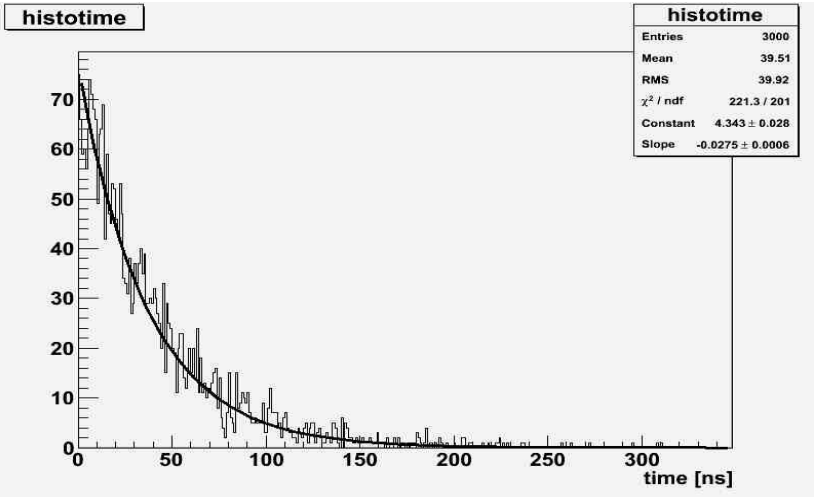
Conclusions

- Developed a code to estimate uncertainties:
  - SiPM assumed identical
  - underestimating outputs (or: identical SiPMs lead to low uncertainties)
- SiPM simulation shows consistent results:
  - double exponential
  - measured curves
- Outlook:
  - dropping the assumption of identical SiPM
  - uncertainties evaluated for different energies
  - SiPM saturation measurement setup

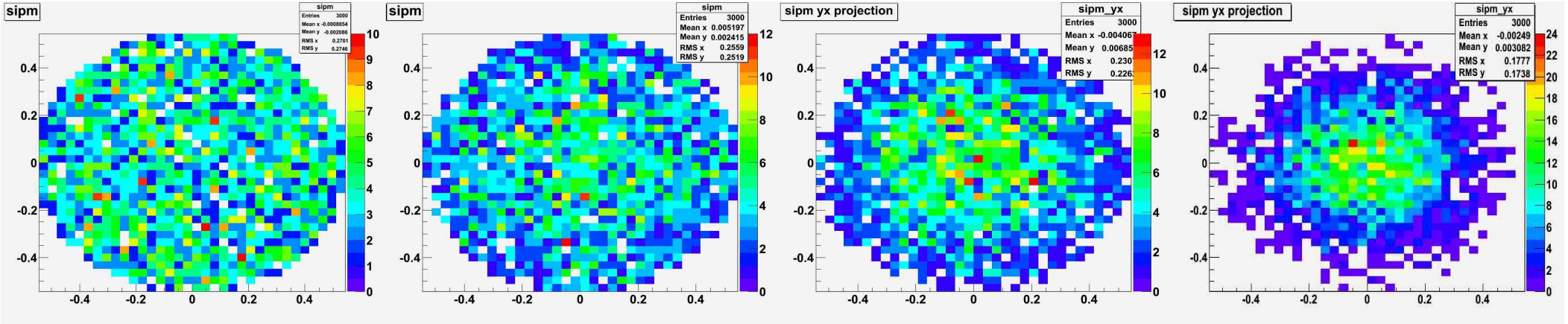
Backup Slides

Light Distributions ....

Temporal Distribution: double exponential
τ_{em} = 40 ns

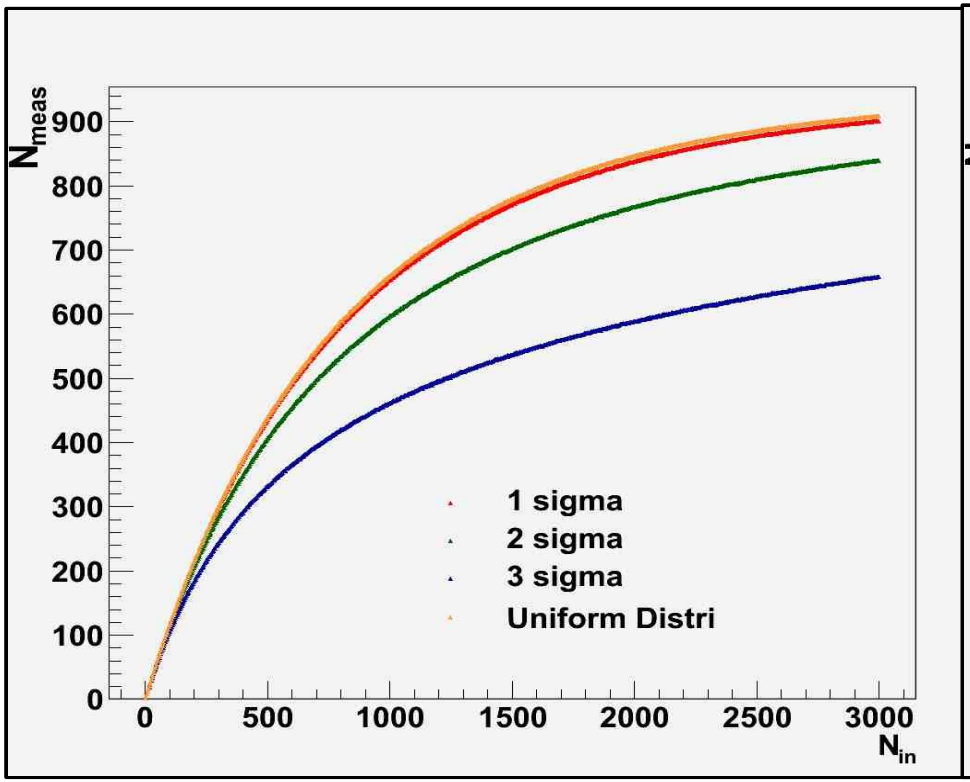


Spacial Distribution: Gaussian Profile – inscript circle

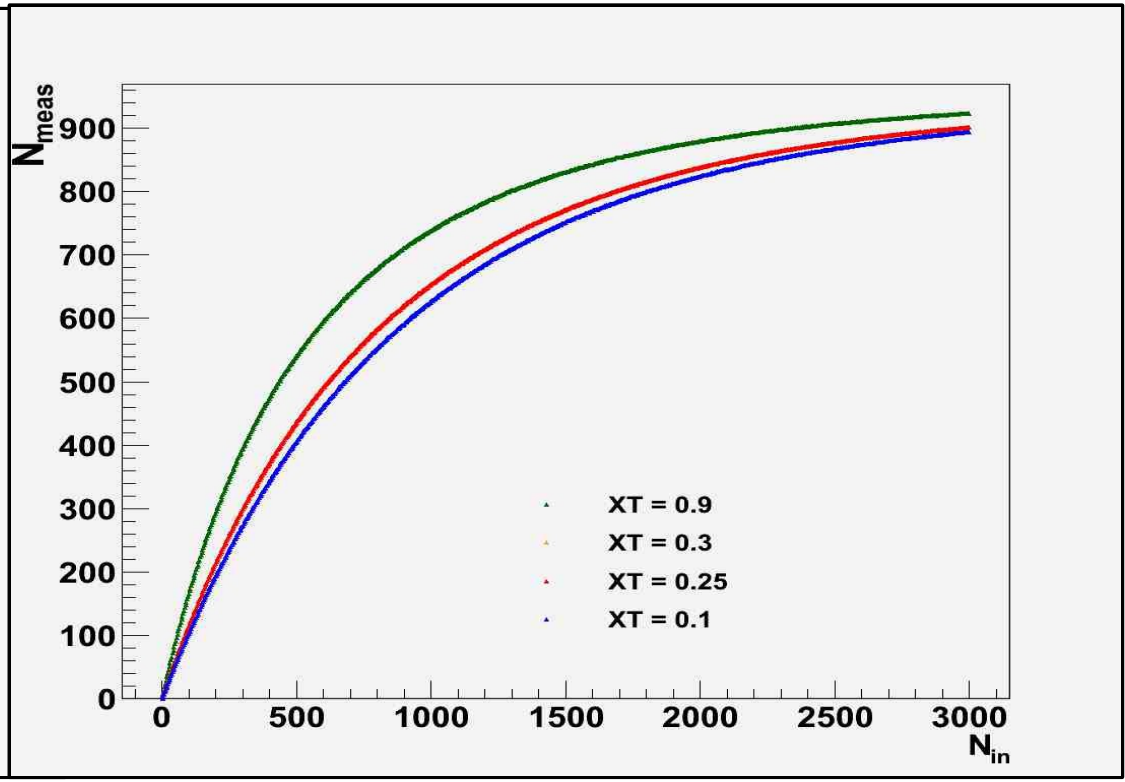


Some Curves ...

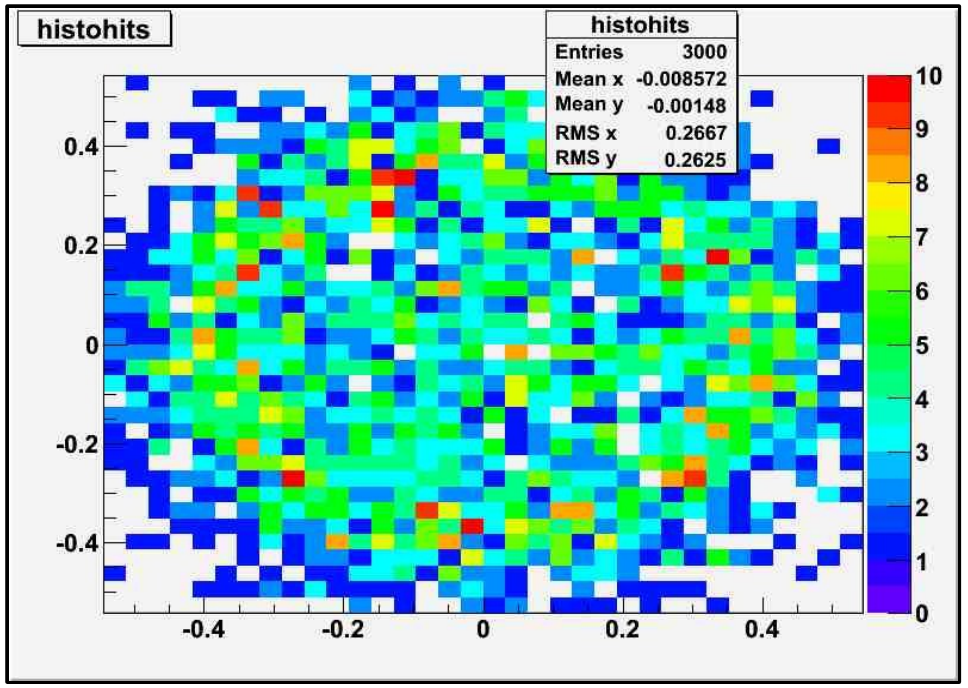
- Fixed XT = 0.25
- Varying light distribution

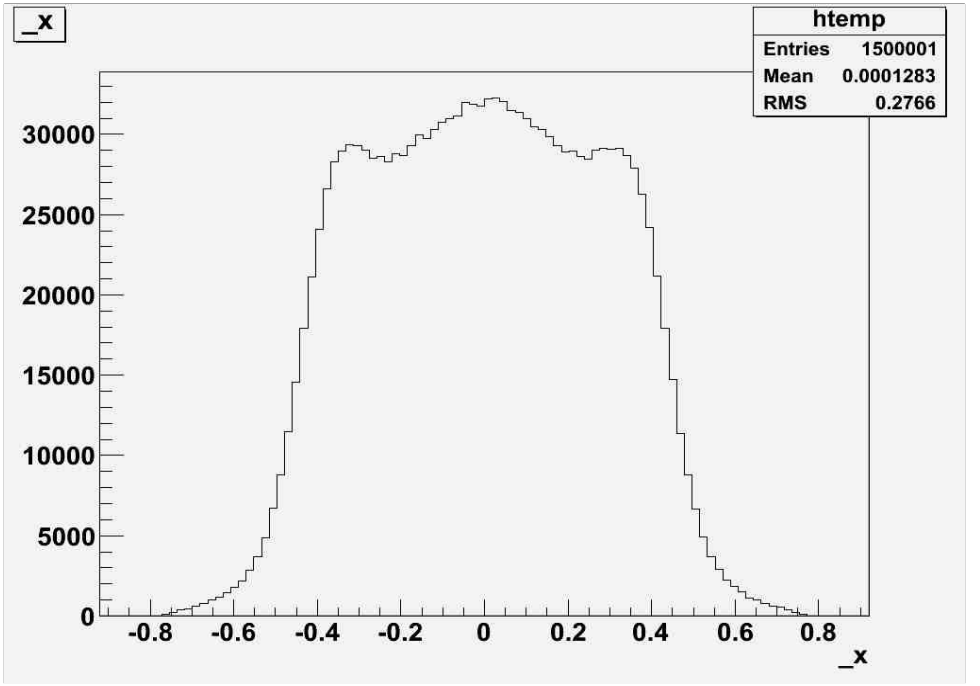


- Fixed light disatribution (rx = 1σ)
- Varying XT value;



... another light profile ....





RMS_{90} uncertainties

	$\delta(E)N_t$	$\delta(E)$Gain
(1)	3.53 %	1.55 %
(2)	3.61 %	1.63 %