

Tile Simulation

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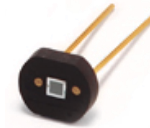
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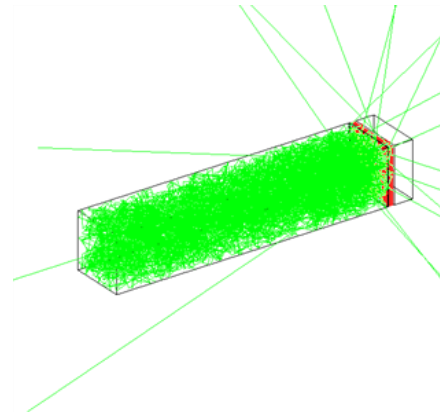
Outline

- SiPM Simulation



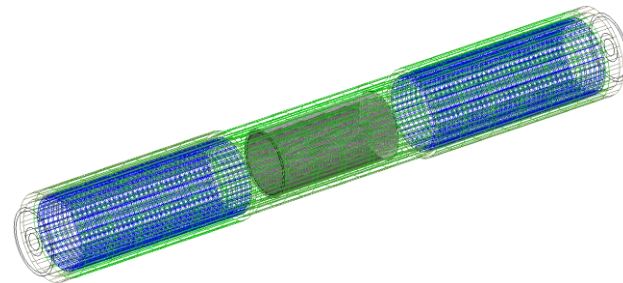
- SiPM - Tile Simulation Studies

- Scintillator Comparison
- SiPM Comparison
- Timing Performance



- Full Tile Detector

- SiPM Digitization
- Geometry Optimization

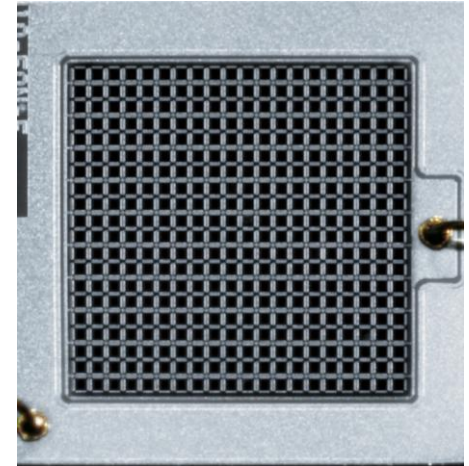


- Summary & Outlook

SiPM Simulation

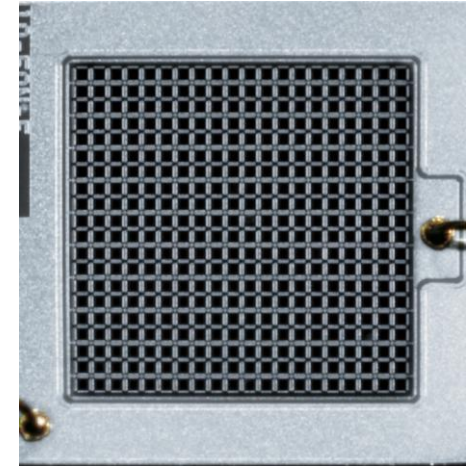
Silicon Photomultipliers

- Array of Geiger-mode APDs
(typ. 100 – 2000 Pixels / mm²)
- Pixel signal independent of number of photons
- Pixels connected to common output
- SiPM signal = sum of all pixel signals

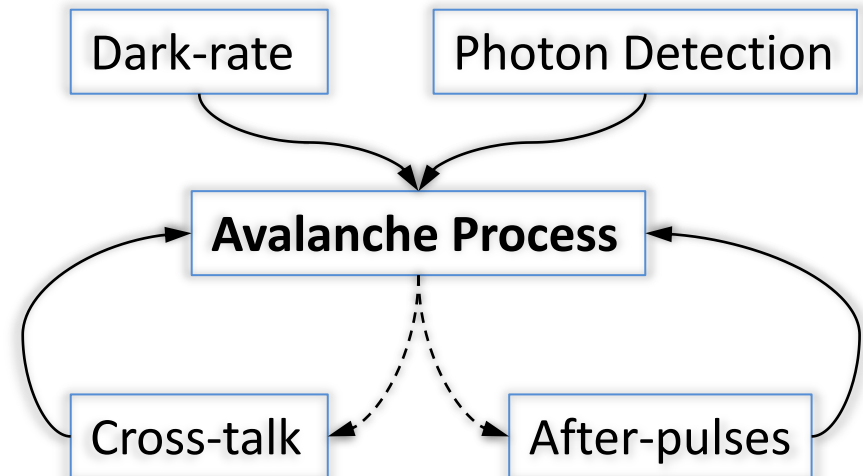


SiPM Response

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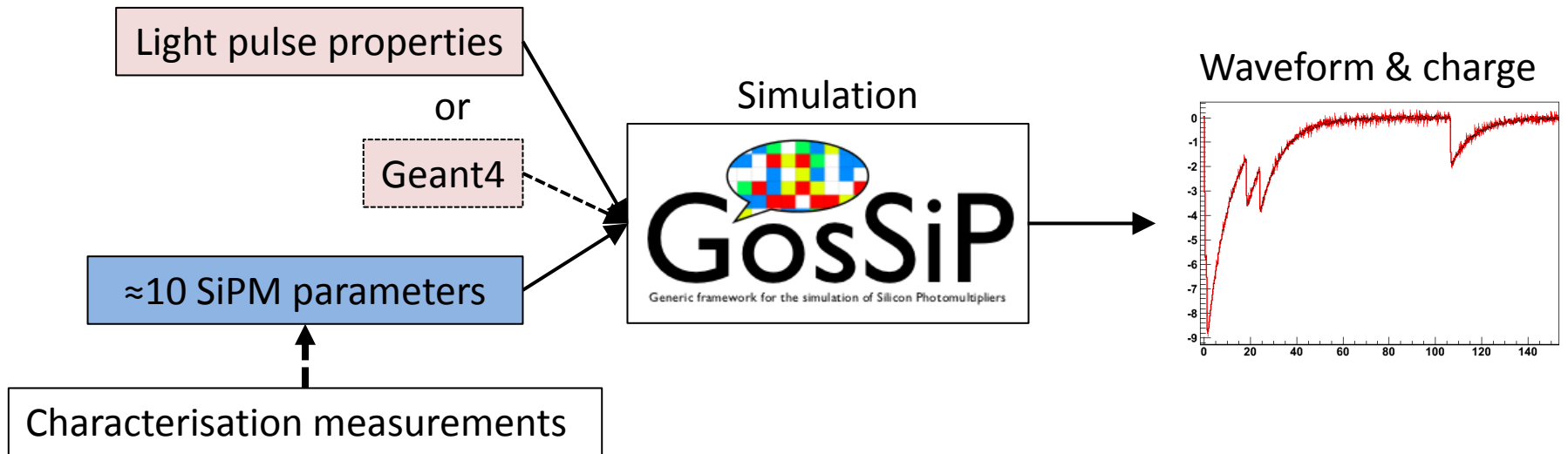


- SiPM response is complex:
 - Depends on light pulse properties
 - Correlated and uncorrelated noise
 - Recovery effects
- ⇒ **Monte Carlo simulation**

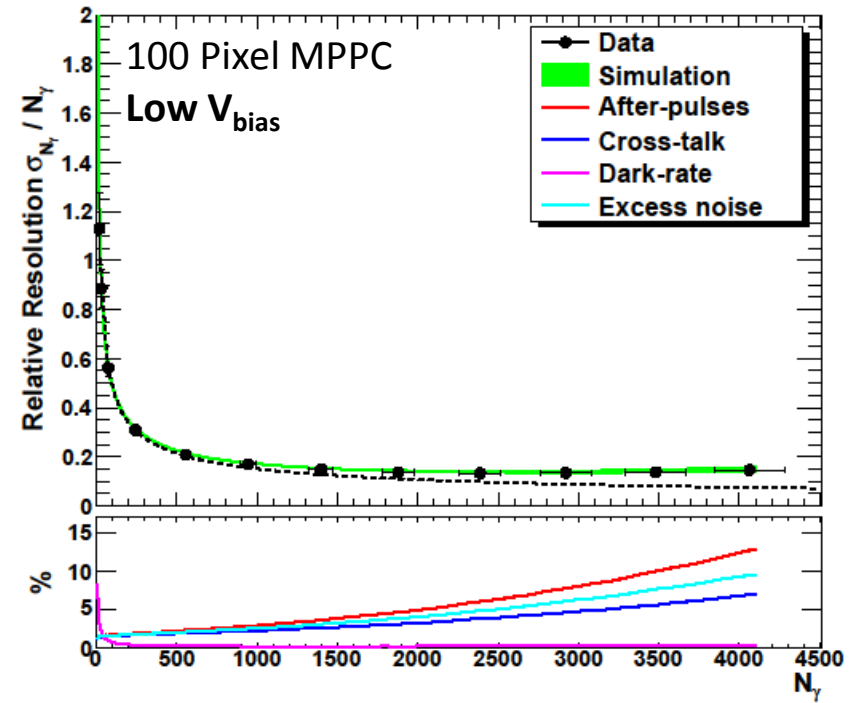
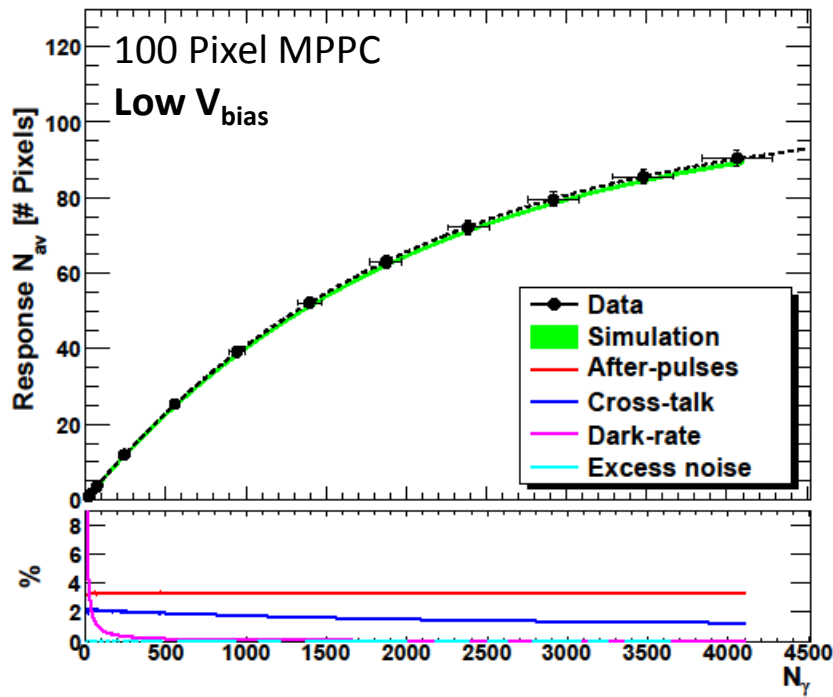


SiPM Simulation Framework - GosSiP

- Detailed model of SiPM response for arbitrary operation conditions
- Customizable SiPM properties
- Input parameters from basic characterization measurements
- Can be integrated into external software (e.g. Geant4)

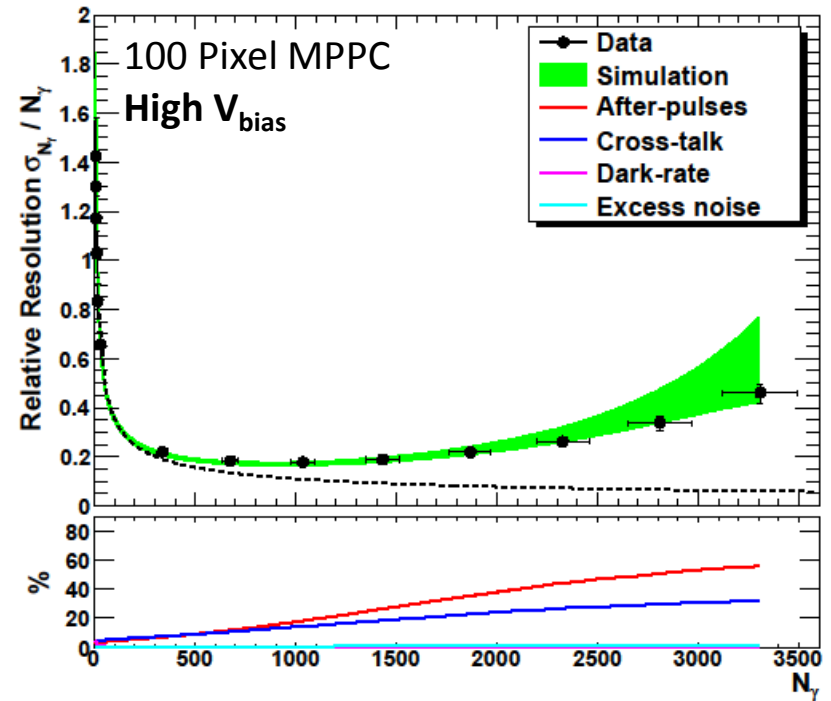
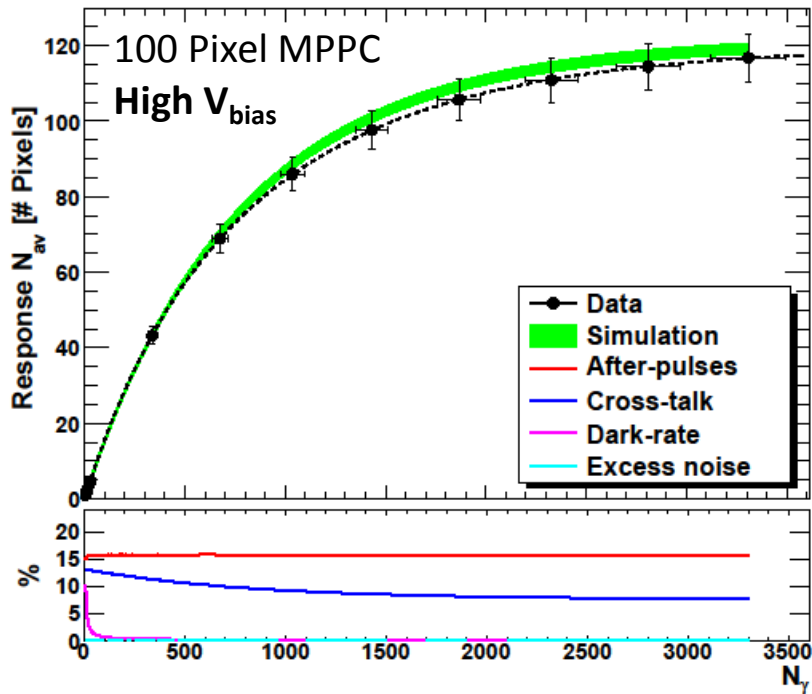


SiPM Simulation Framework - GosSiP



- Excellent model for the SiPM response in full dynamic range
- Not yet verified for time response – but should yield similar accuracy!

SiPM Simulation Framework - GosSiP

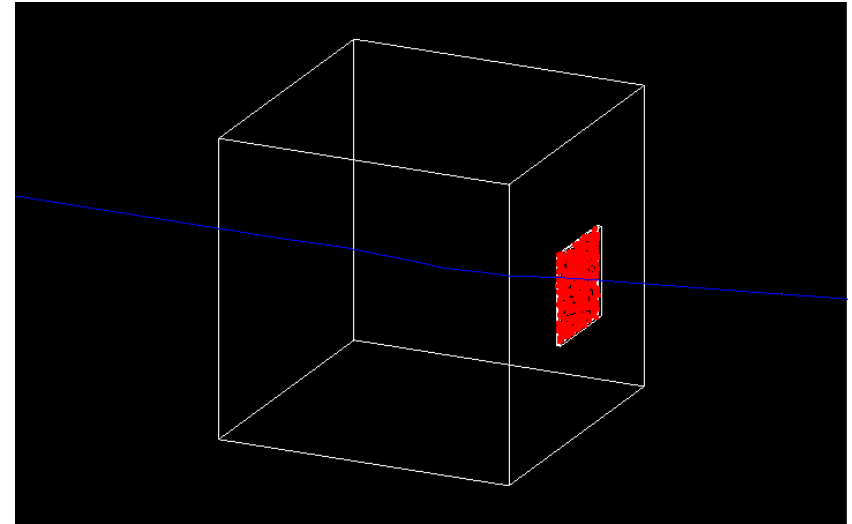


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SiPM – Tile Simulation

Simulation Setup

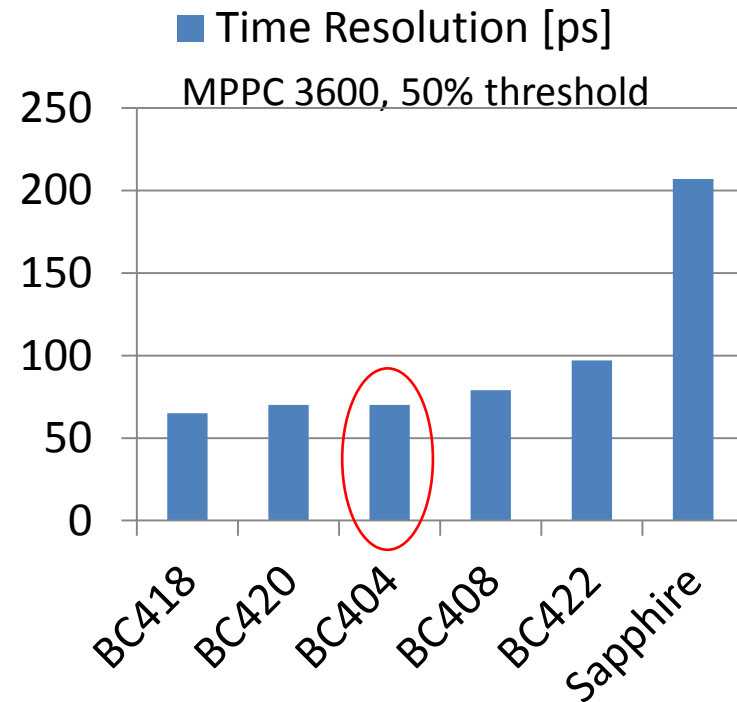
- 15MeV e+
- Tile:
 - 1x1x1 cm³
 - Light yield: ca. 10 photons/keV
 - Polished surface ($\sigma_{\alpha} = 0.01$)
 - Reflective foil (98% reflectivity)
- SiPM:
 - 3x3mm², 1x1 mm², 6x6 mm²
 - 25 μ m, 50 μ m, 100 μ m pixel size



•The following results are preliminary estimations and have to be verified in measurements!!!

Scintillator Comparison

- Requirements:
 - Fast rise time
 - Large light yield
 - Wavelength has to match sensitivity of SiPM
- Similar performance for BC404 – BC420
- Cherenkov crystal (Sapphire) not competitive
- Best performance/cost: BC404



SiPM Comparison

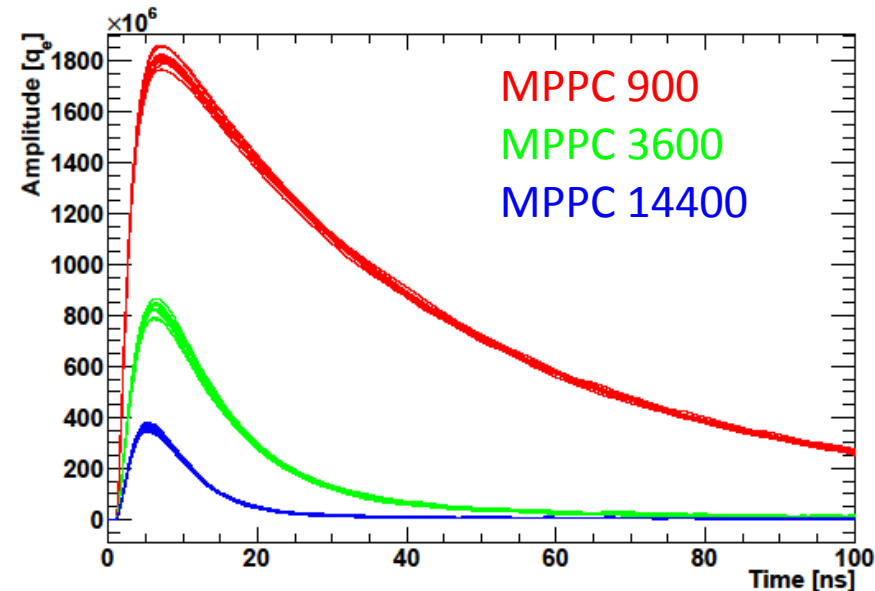
- Requirements:
 - High detection efficiency
 - Fast signal / decay time
- Sensor size:
 - 1x1 mm²: ~1700 photons
 - **3x3 mm²: ~5900 photons**
 - 6x6 mm²: ~6100 photons
- Pixel size:
 - Trade-off between timing & rate

Hamamatsu MPPCs (Npixels)

Pitch/Size	100mu	50mu	25mu
1x1mm ²	100	400	1600
3x3mm ²	900	3600	14400
6x6mm ²	3600	14400	42300

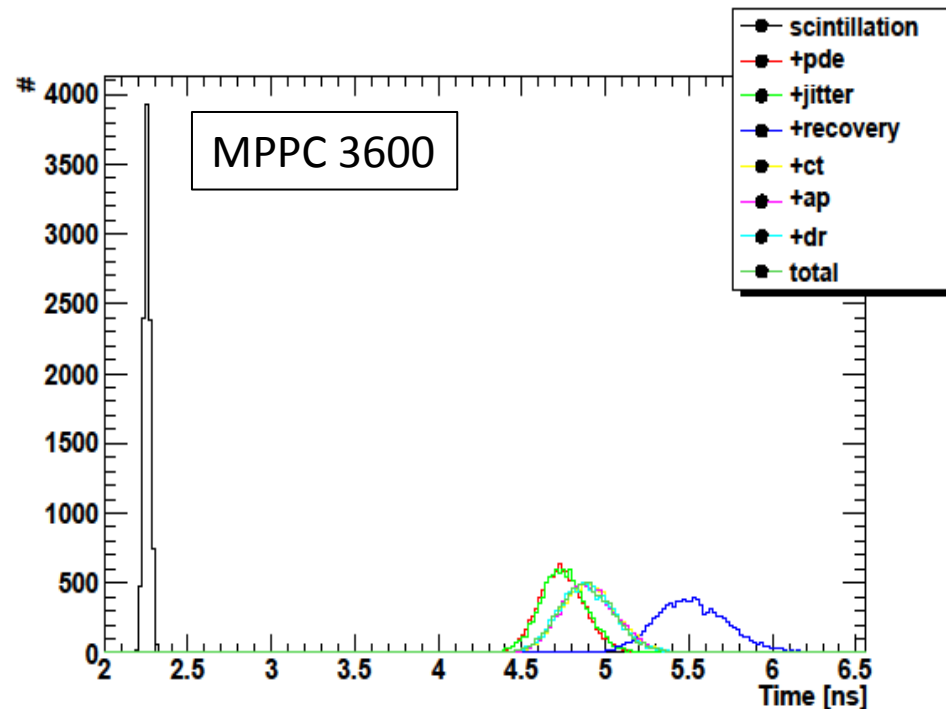
Timing

Rate



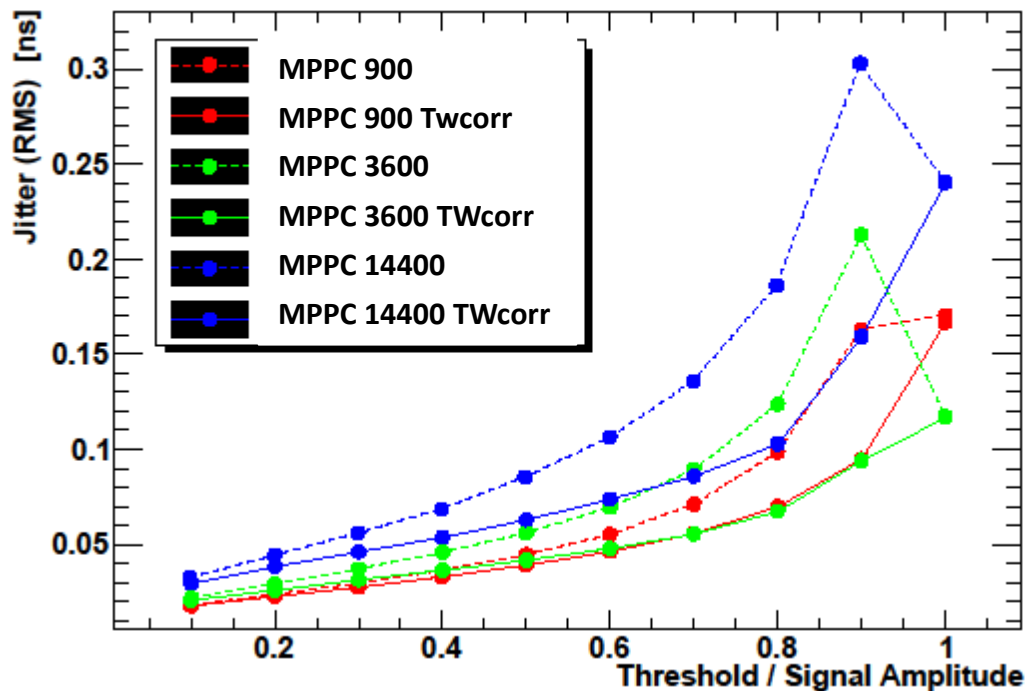
Timing – SiPM Contributions

- Jitter from scintillation process / light collection is small
- Jitter from SiPM:
 - Dominated by PDE & saturation
 - Cross-talk helps
 - Other effects negligible



Jitter vs Threshold

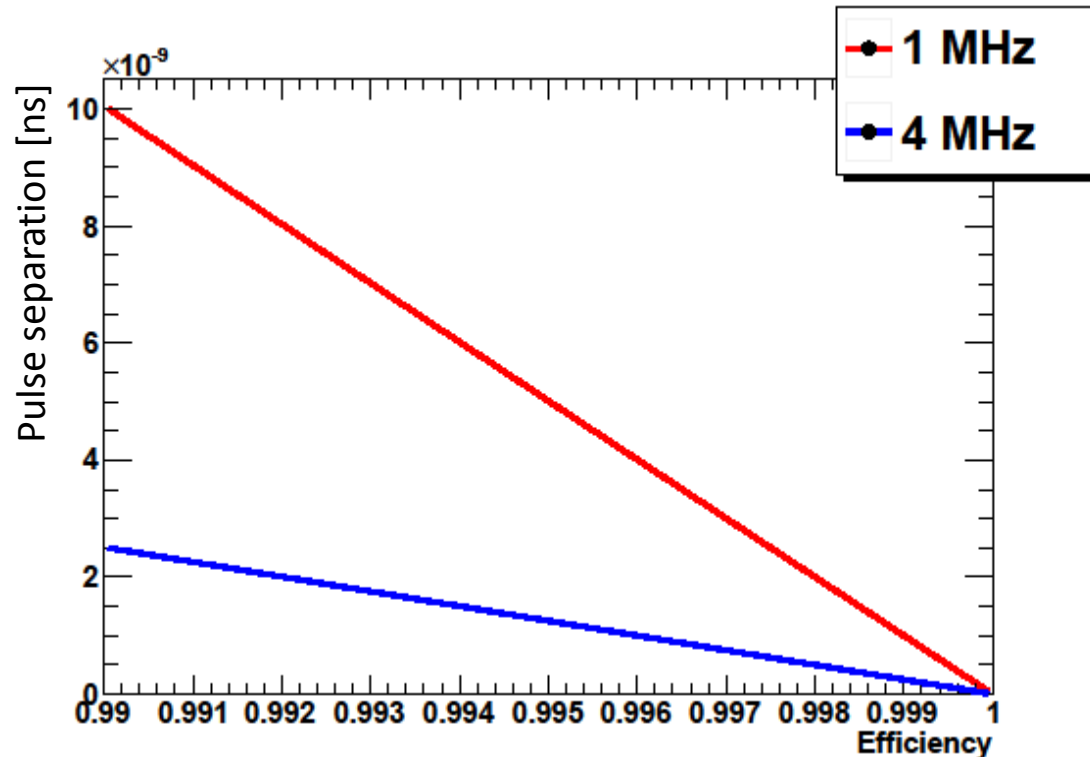
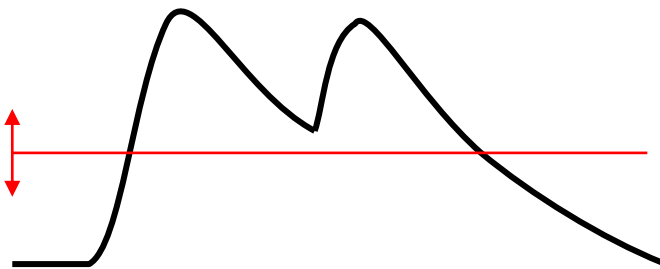
- Jitter < 50ps (RMS) for low threshold
- Timewalk correction is important (especially for varying energy deposits!)



- Dashed: w/o timewalk correction
- Solid: with (perfect) timewalk correction
- Threshold = 1: time stamp from signal peak (fitted)

Pileup & Efficiency

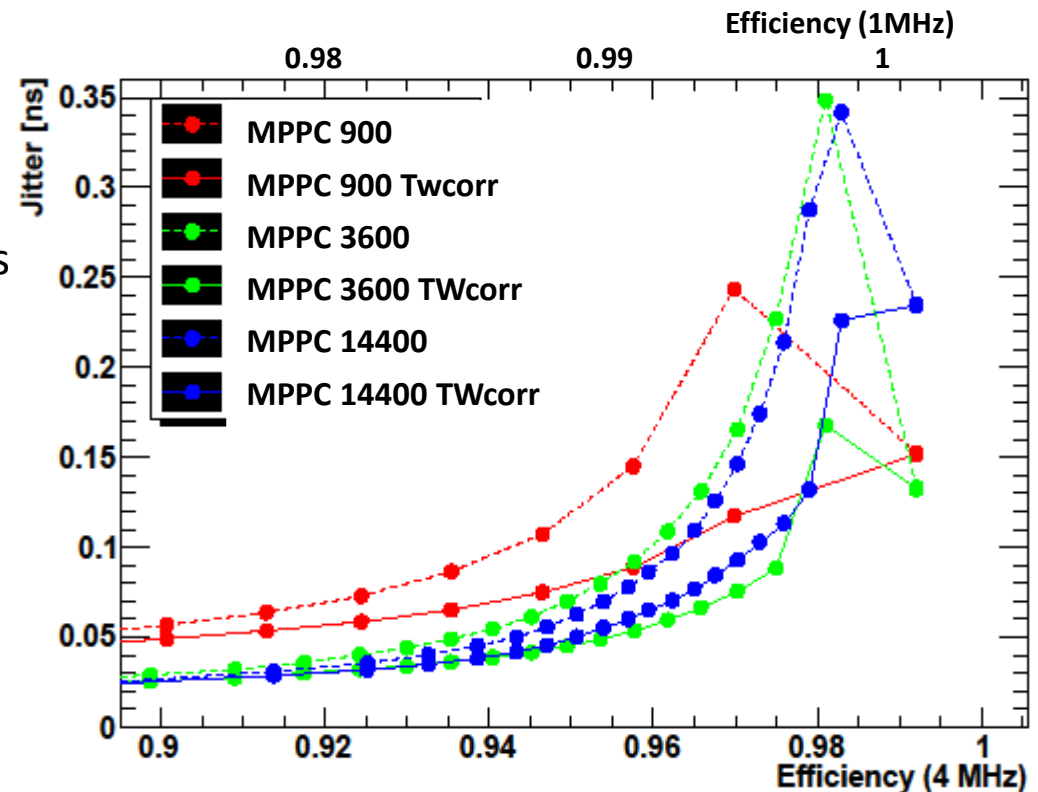
- Expected rate: 1-4 MHz/cm² → Signal Pileup
⇒ High efficiency requires high threshold for pulse separation
- Trade-off: timing vs efficiency



Jitter vs. Efficiency

- 100ps resolution (RMS!) seems possible with an efficiency of ca. 97%
- Best suited sensor: MPPC with 3600 pixels
- Idealized system!
 - Tracks only in one tile
 - Fixed electron energies
 - No jitter from readout electronics!
 - Simple time stamping

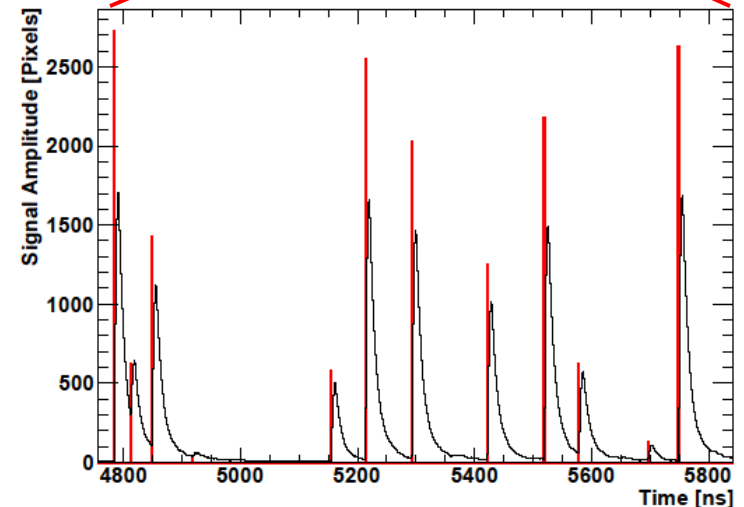
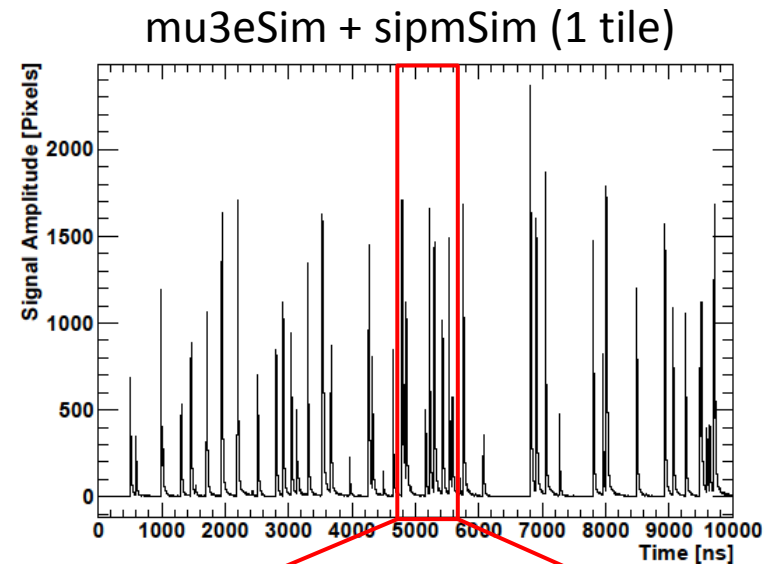
⇒ Go to full detector simulation



Full Tile Detector

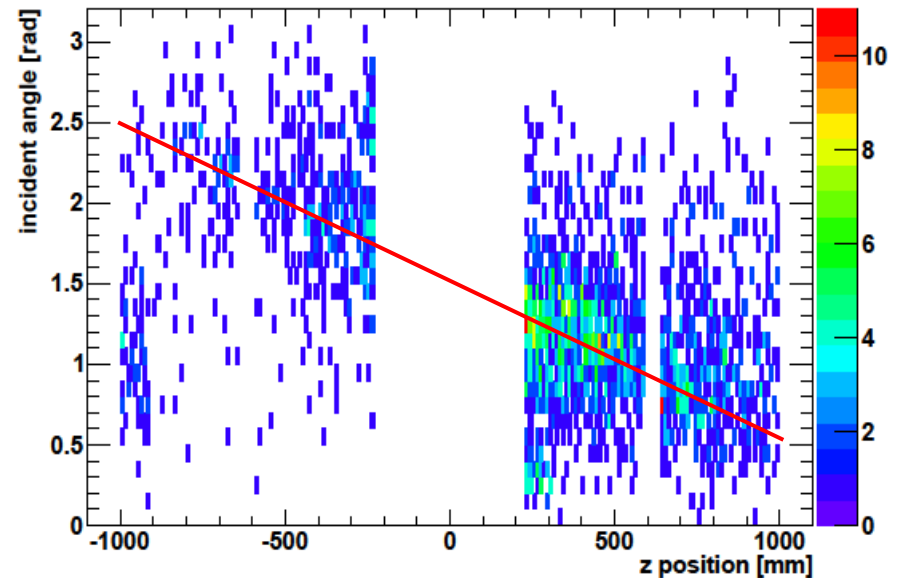
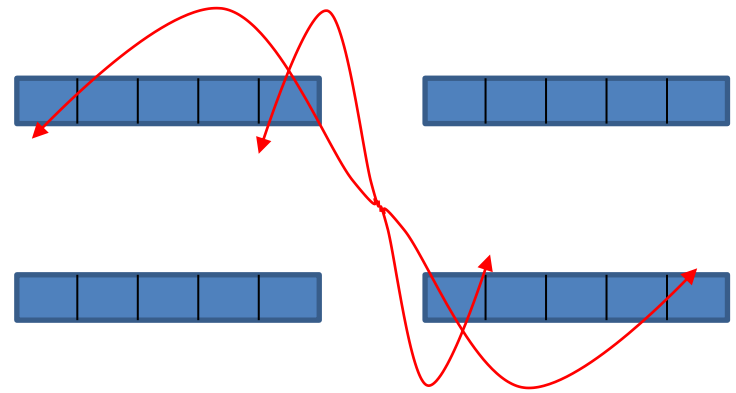
SiPM Digitization

- Digitization of tile hits in Mu3eSim
- As good as ready...
- Input:
 - ROOT data file from Mu3eSim
 - Photons per dE/dx
 - Light pulse shape (rise/decay time)
 - SiPM parameters
- Output:
 - Signal waveforms
 - Raw (truth) data
- Can be used for tiles and fibres
- Long computing time ($O(1h)$ for 100 frames)
- ⇒ Find good parameterization
- ⇒ Test different time stamping methods



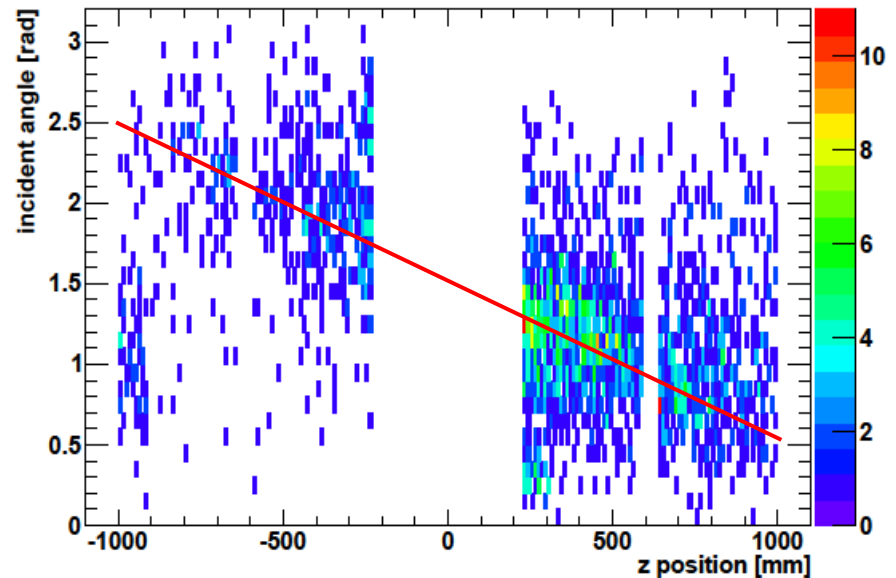
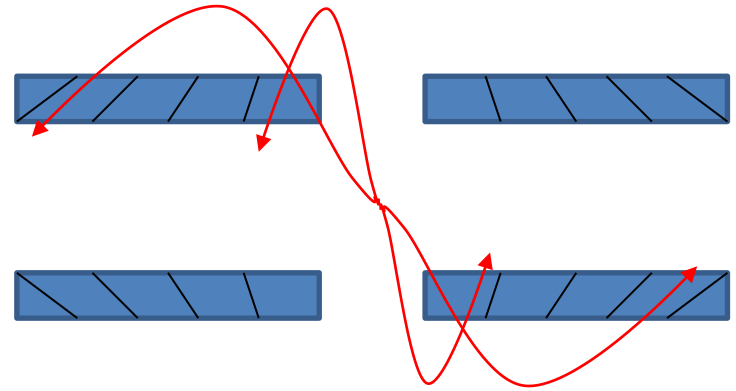
Tile Detector Geometry

- Electrons have certain incident angle depending on z
- Current geometry:
 - Tracks can pass two or more tiles
 - ⇒ Less light yield / more pile-up
- Improved geometry:
 - Tilt tiles (z dependent)
 - ⇒ Tracks contained in one tile!



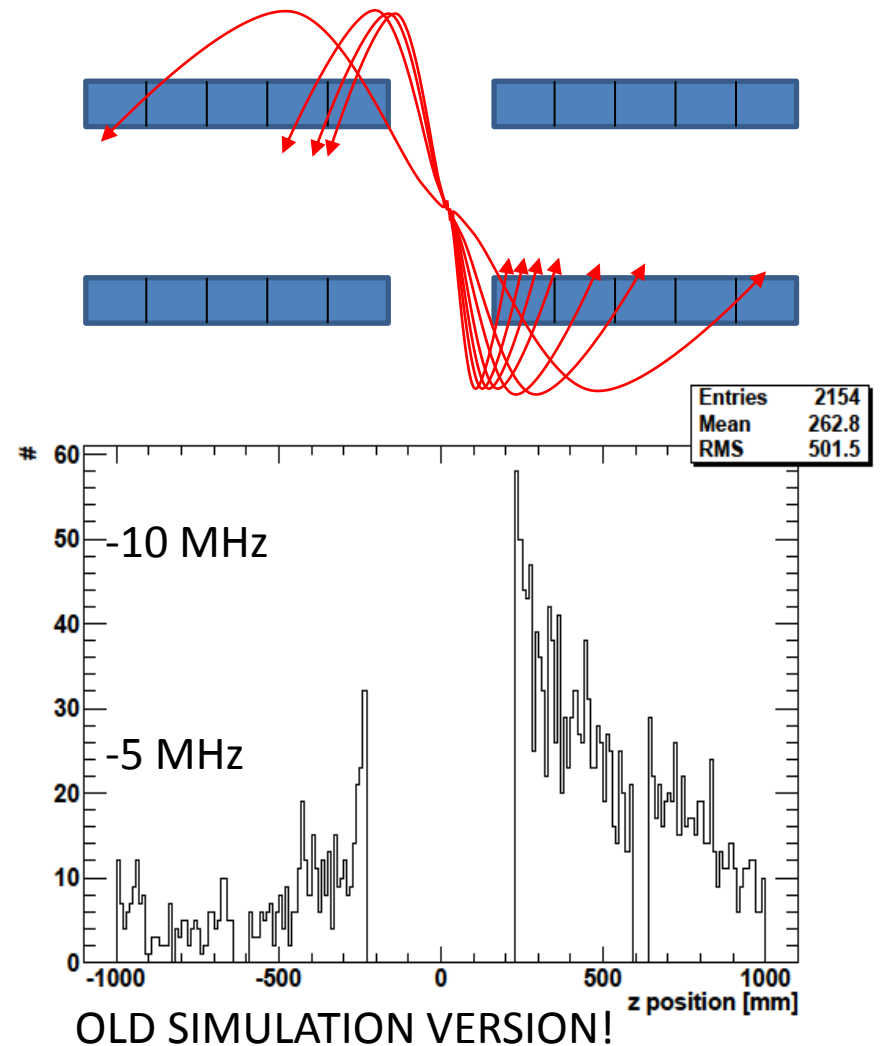
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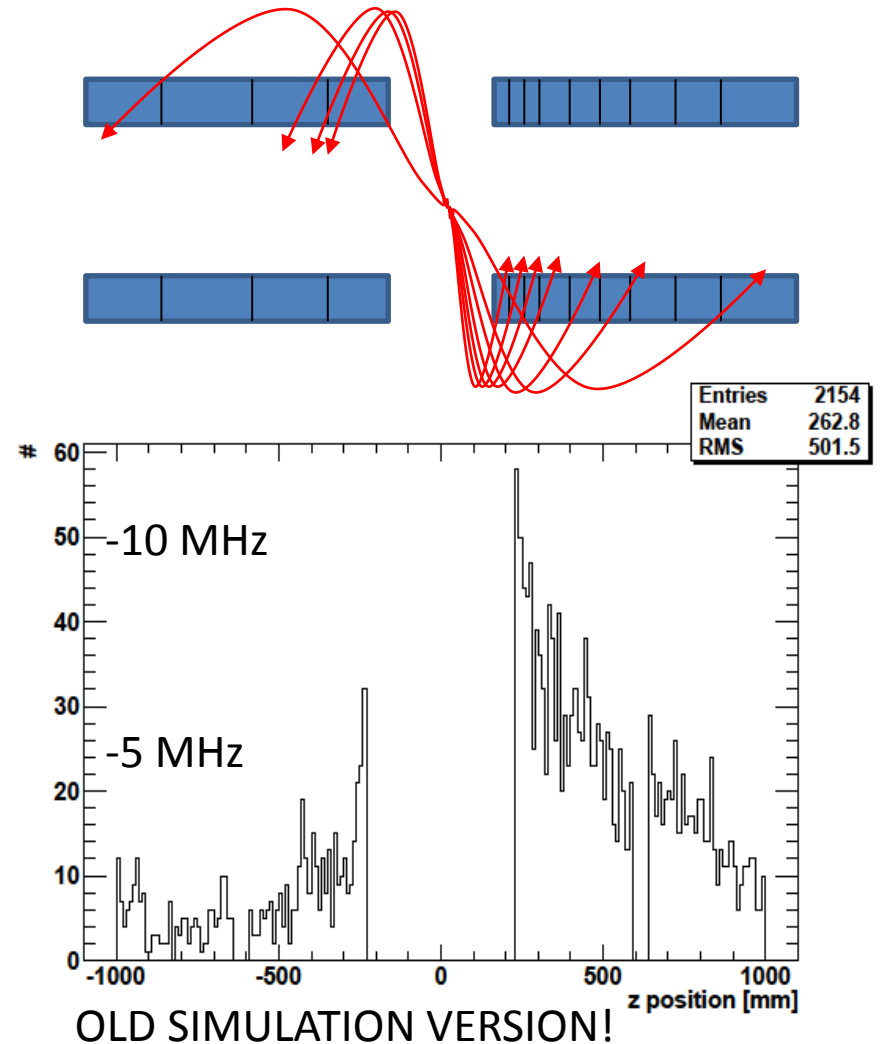
Tile Detector Geometry

- Rate depends on z position
- Current geometry:
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- Improved geometry:
 - Adjust granularity according to rate
 - ⇒Same rate for every tile
 - ⇒Reduces costs

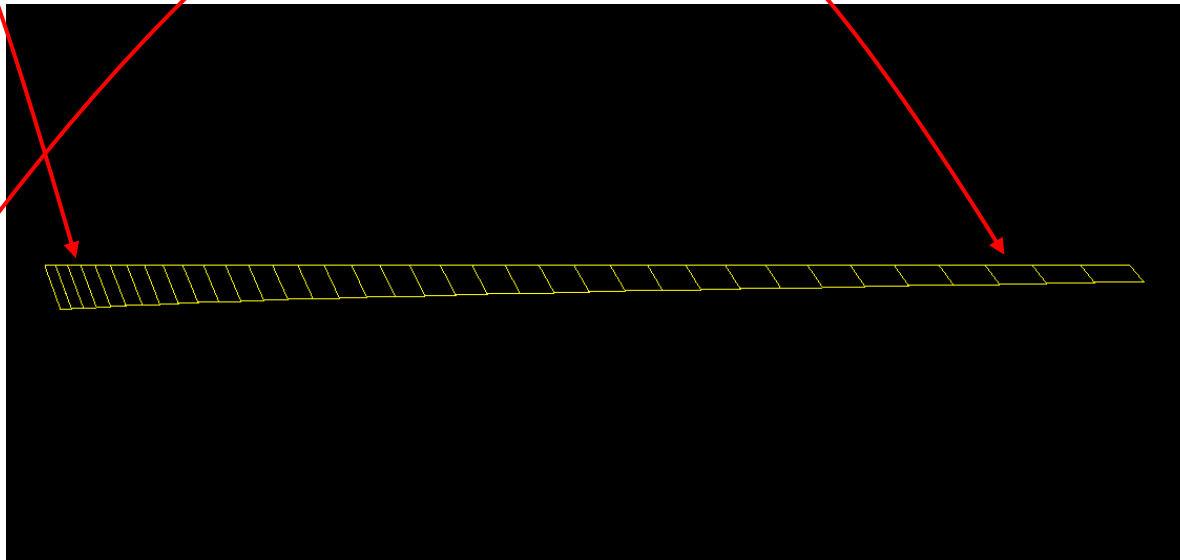


Tile Detector Geometry

- Rate depends on z position
- Current geometry:
 - Pile-up depends on z
- Improved geometry:
 - Adjust granularity according to rate
 - ⇒Same rate in every tile
 - ⇒Reduces costs
- Same light yield / timing for every tile
 - ⇒Adjust tile thickness



Detector Geometry



...just a sketch

- Exact (ideal) geometry is currently implemented in Mu3eSim

Summary & Outlook

- Summary :

- Trade-off between time resolution and efficiency
- Ca. 100ps RMS resolution with 97% efficiency
- SiPM digitization for Mu3eSim
- Optimization of tile geometry ongoing

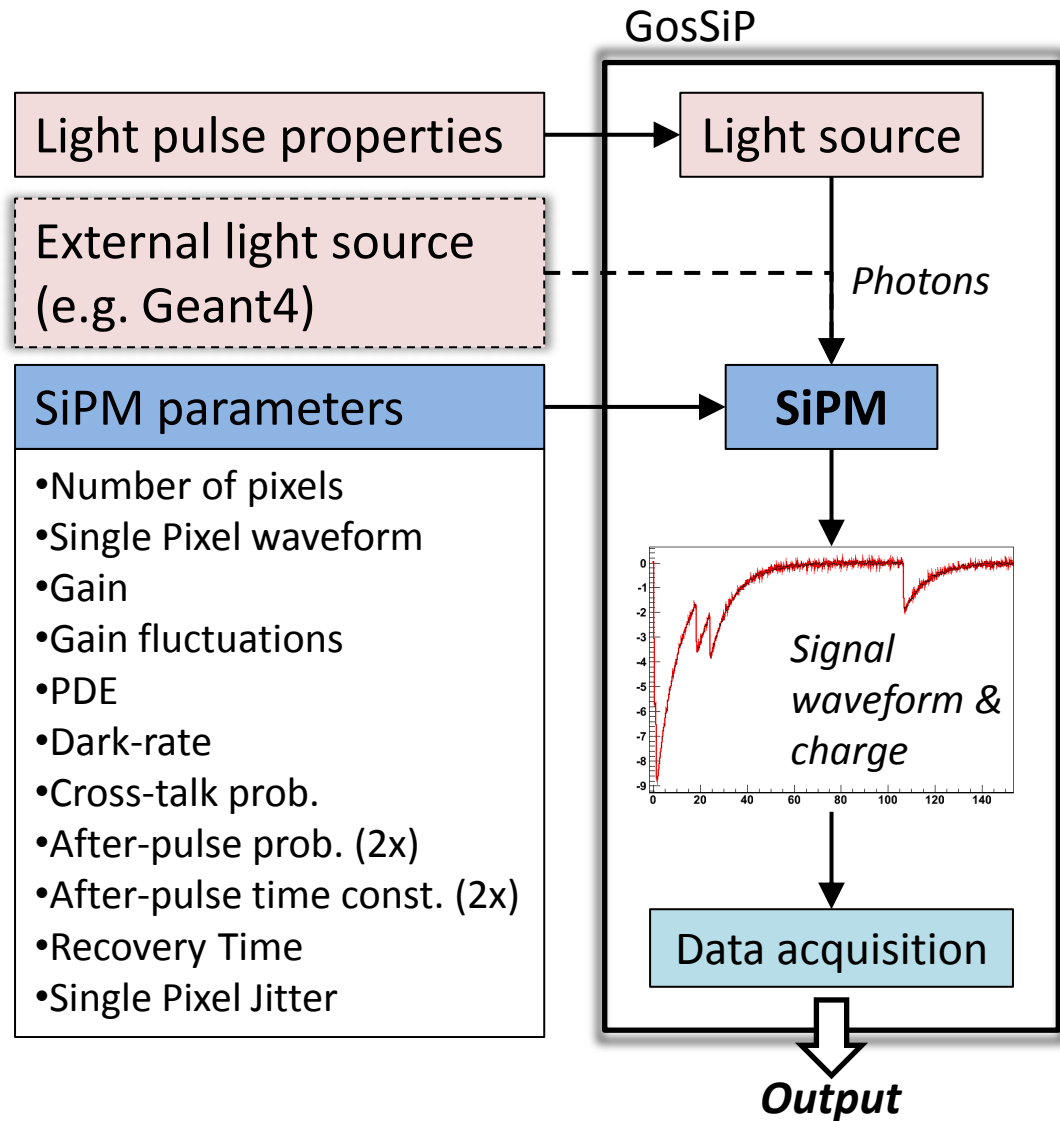
- ToDo:

- Simulate timing performance with complete detector setup
- Measure time resolution for single tile+SiPM
- Readout & time-stamping?
- Calibration system?!

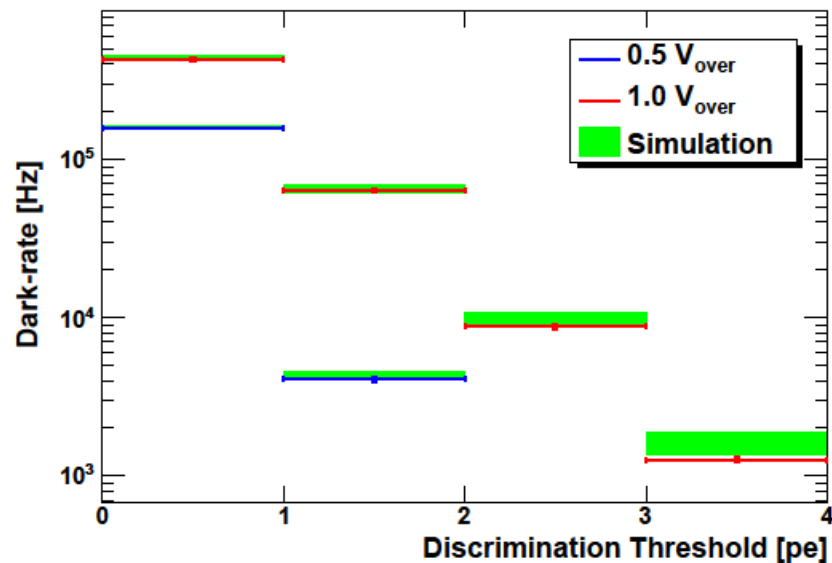
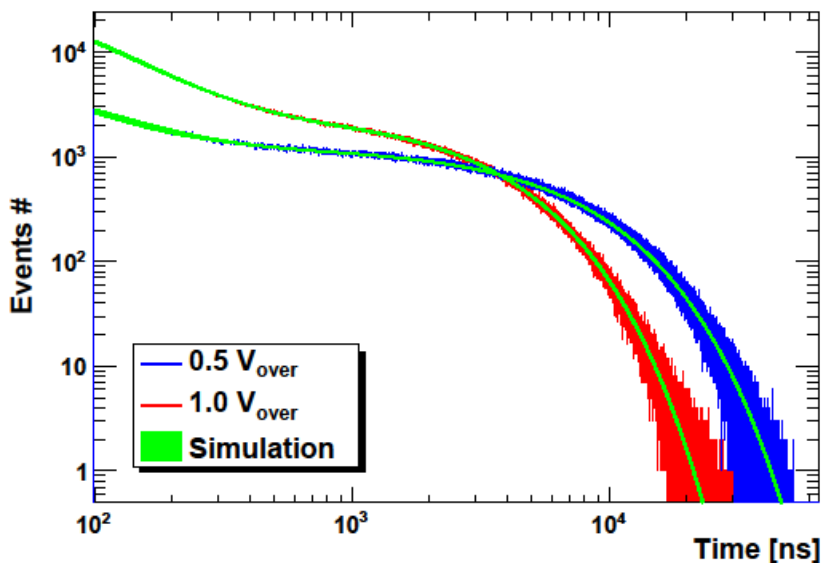
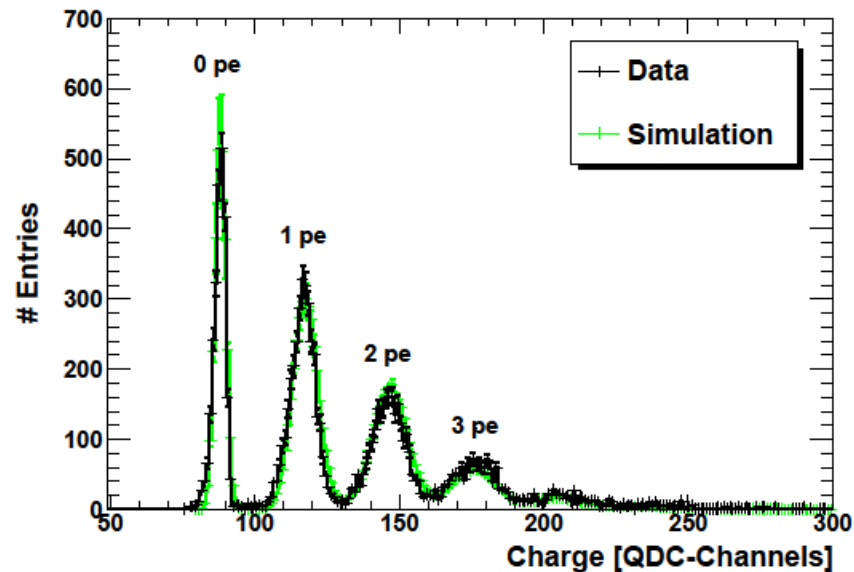
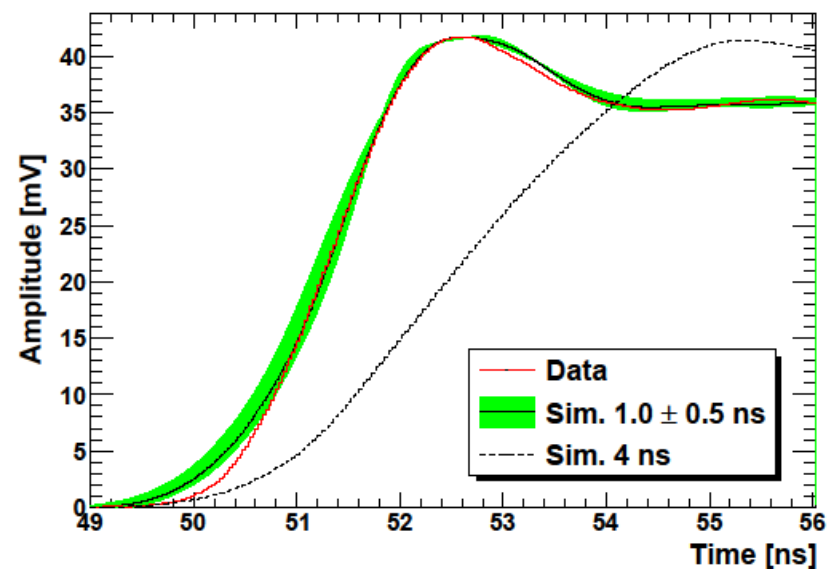
Backup

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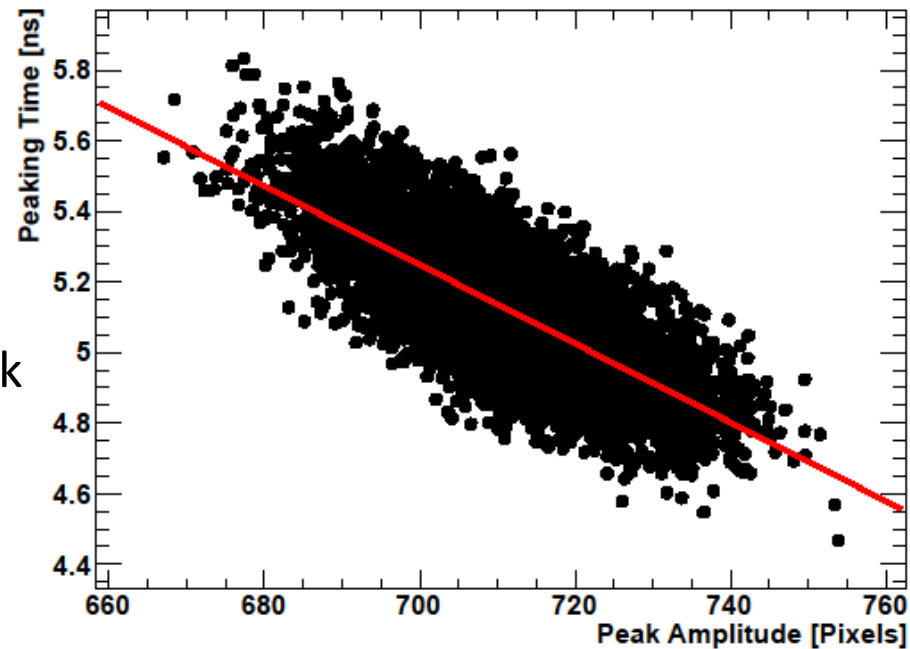
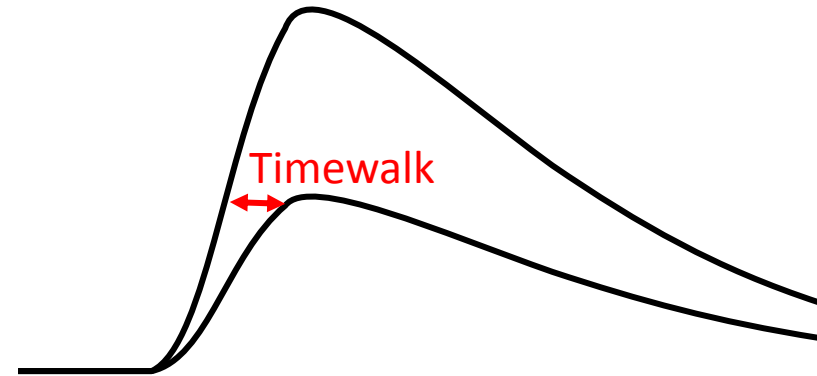


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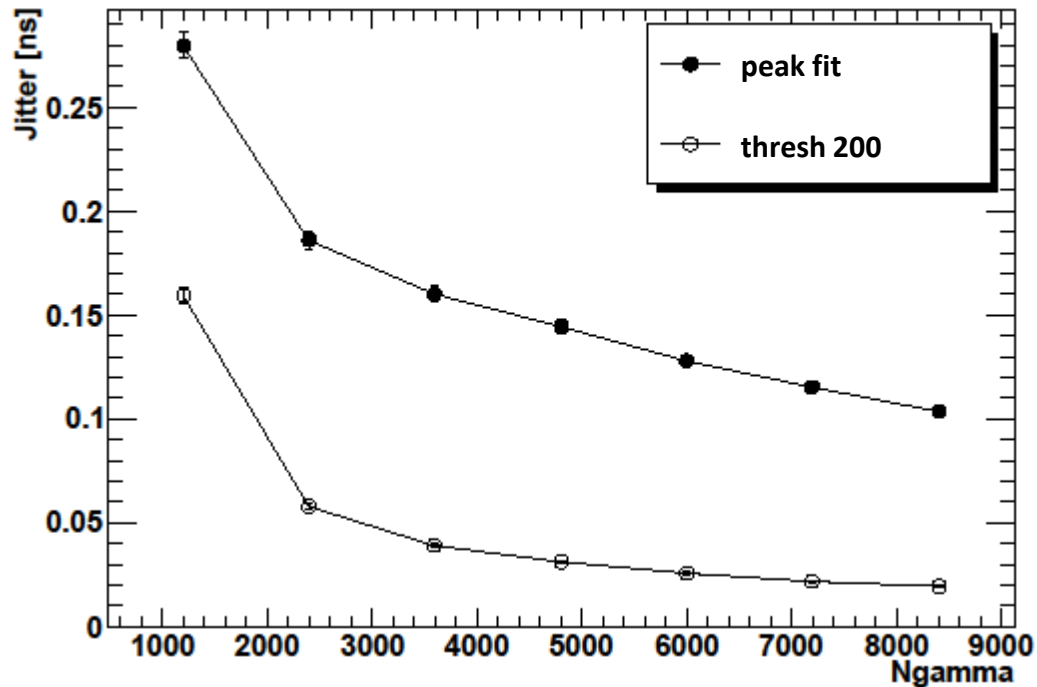


Timewalk Correction

- Timewalk due to varying signal amplitudes
- Contributes significantly to jitter
- But can be corrected!
- Correction in general not linear
- In the following:
 - Fixed particle energy
⇒ Timewalk small
⇒ Linear correction proportional to peak amplitude



Jitter vs Ngamma



- MPPC 3600
- Timing from peak fit and fixed threshold @ 200 pixels