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The UHH SiPM group:

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Model the SiPM response function

DRD6 AHCAL "Marzipan" Meeting

Hamburg, 11.12.2024

Introduction

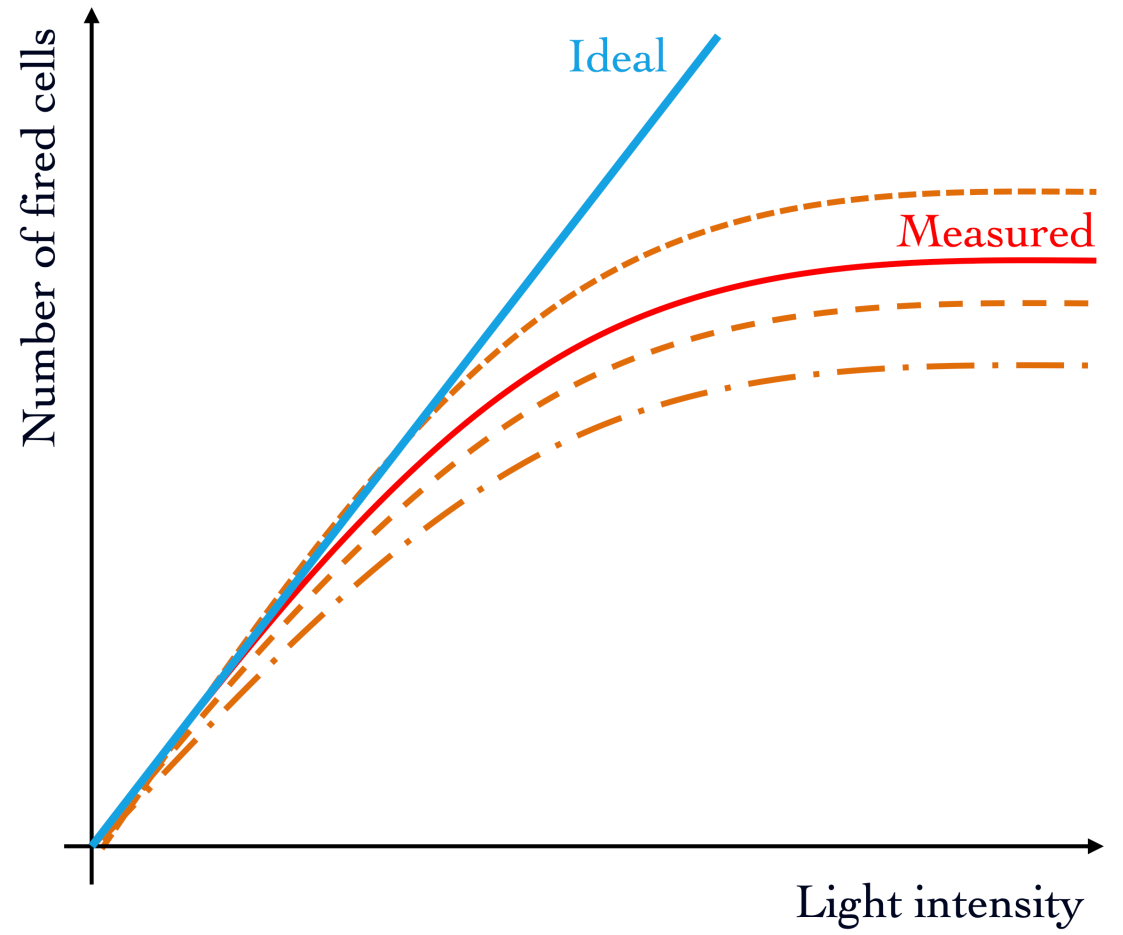
The SiPM non-linear response

> The dependence of the SiPM response from **multiple parameters** needs to be evaluated with systematic studies.

- **Light source** type (laser, LED, scintillator, Cherenkov, etc.):
  Spatial distribution (uniform, Gaussian, from tile, fiber, etc.)
  Time spread (instantaneous, Gaussian, exponential, etc.)
  Wavelength.

- **SiPM** key parameters:
  Geometry, V_{OV}, Temperature, etc.
  Stochastic effects (DCR, PDE, AP, OCT, etc.)

- **Other** effects (environment, readout, etc.):
  Fluence (DCR increase, trapping and SNR degradation, etc.)
  Readout electronic, etc.



✓ Can be corrected

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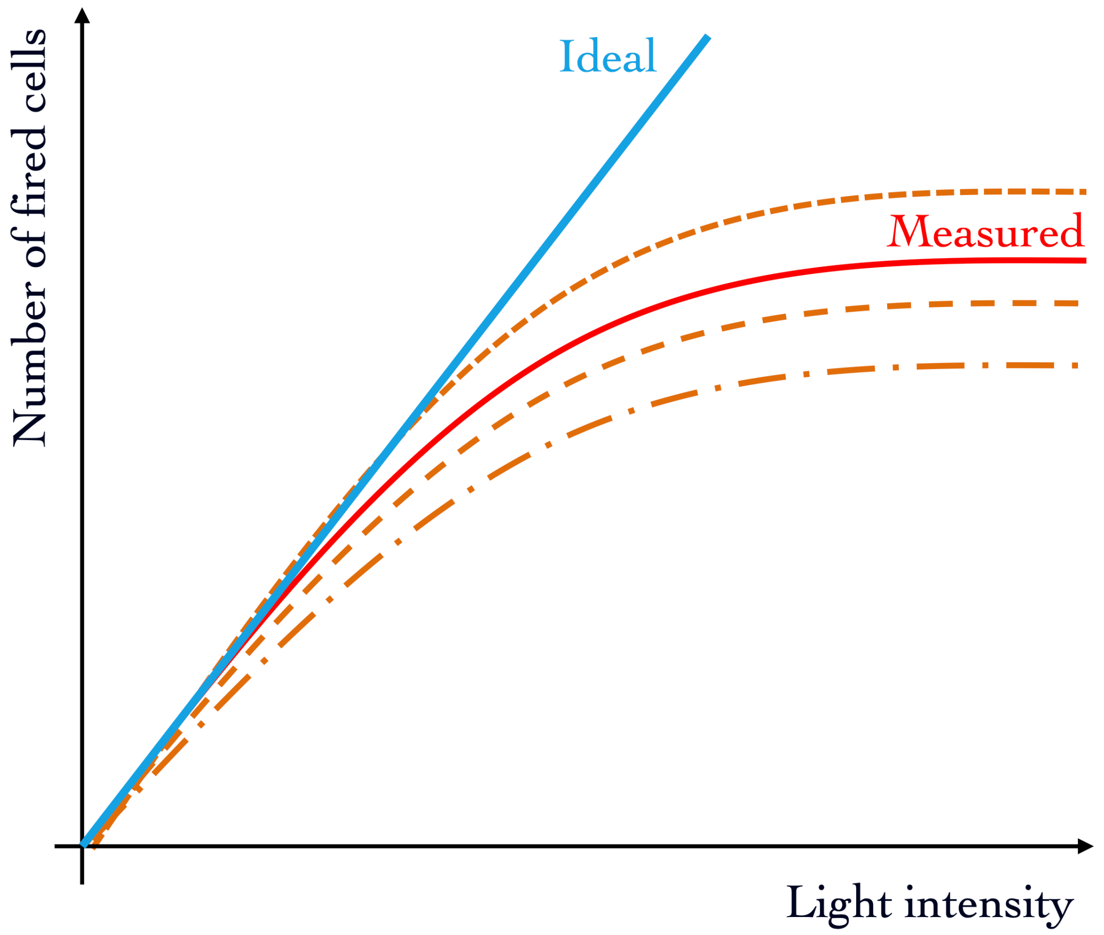


✓ Can be corrected

- A **new measurement** and correction function for each set of parameters may be required.
- For many applications, **continuous variation** of some of these parameters is expected.
- In many cases, **direct measurement** of every possible "configuration" of these parameters is **not possible**.

Introduction

Our goal

> Develop a tool to enable **fast simulation of SiPM response** based on knowledge of basic SiPM parameters.

> The tool has to be:

01. Fast

To allow **systematic studies** on SiPM response variations.

Benchmark (8 core macbook pro M1):

- **~85 sec for a light spectrum**
- 10k events with <μ> = 10k photons
- 1 MHz DCR, 20% OCT, 10% AP
- 100 x 100 cells

02. Flexible

To include different **time and space distributions** of photons.

- simulate scintillator response
- coupling to SiPM
- etc.

03. Complete

To be able to include effects of **digitization**.

- non-linearity
- spreads in electronics
- etc.

SUM

Three inputs, one output

- A comprehensive model that describes SiPM operational physics while bridging the gap between **low and high light response regimes**.
- A **modular and extensible framework** for SiPM simulation, optimization, and characterization.

01. **Single cell signal**
Real data, electric circuit simulation, physical models

02. **SiPM key parameters**
N_{cells}, PDE, T, G, DCR, OCT, AP, V_{ov}, etc.

03. **Light source**
Source type, photons arrival time and spatial distributions

SUM
SiPM Unified Model

SiPM response

- The “Geiger Array” (GA).
  For every event and Geiger discharge:
  - Time of arrival.
  - Signal amplitude.
  - Cell ID.
  - Type (light, DCR, OCT, AP).
- Transient for every event (from GA).

The action plan

Step 1: Extract the SiPM key parameters

✓ Completed
J.Rolph's PhD thesis

01.
Light spectrum

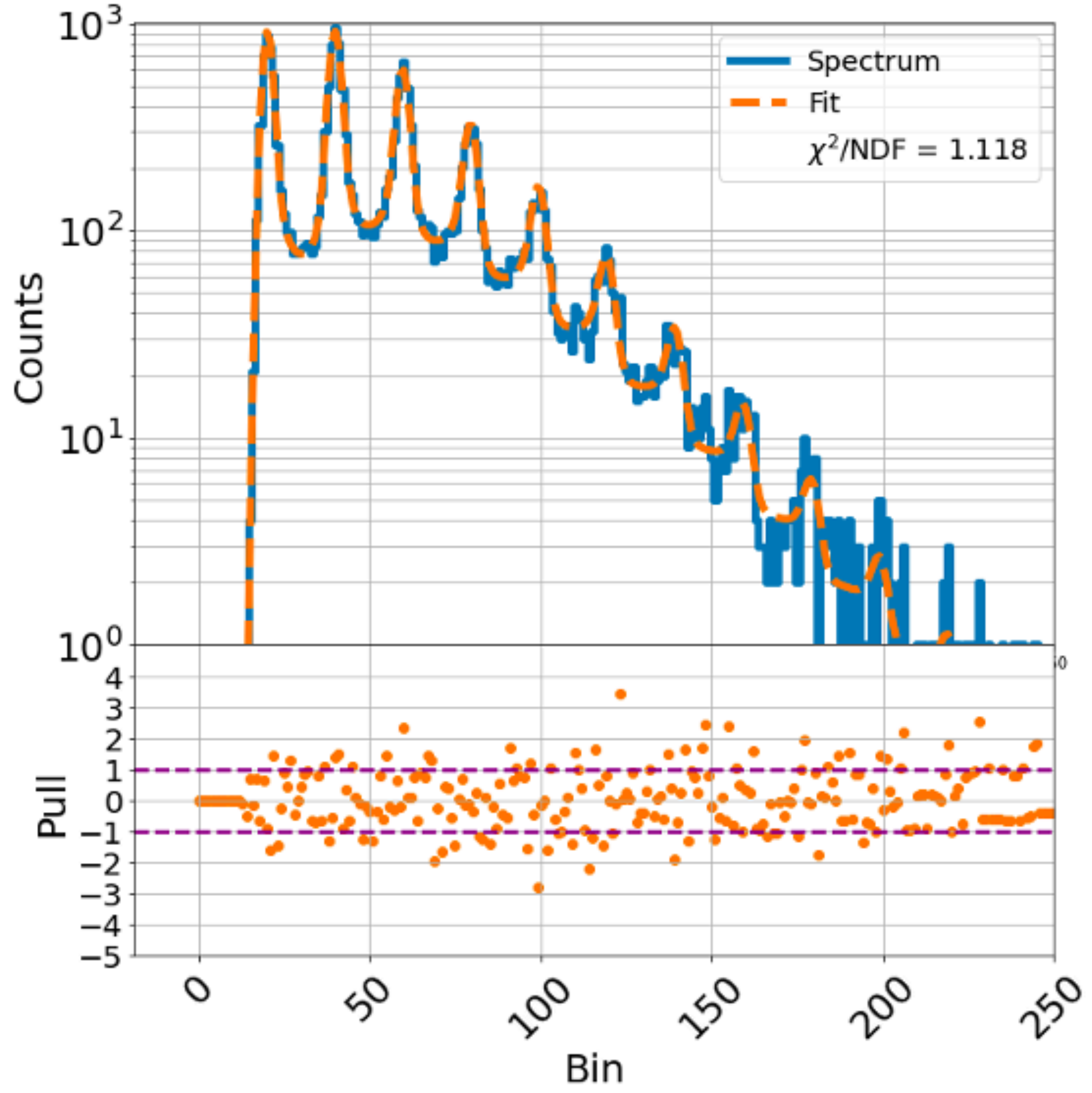
Acquire high-statistics spectrum with low-intensity light

02.
Fit with PeakOTron

- DOI:10.1016/j.nima.2023.168544
- DOI:10.5281/zenodo.10014537

03.
Extract the SiPM parameters

G, DCR, OCT, AP, etc.



The action plan

Step 2: Verify the model for low light intensity

✓ Completed
J.Rolph's PhD thesis

01.
Simulations

Simulate low light intensity spectrum using the key parameters extracted in step 1

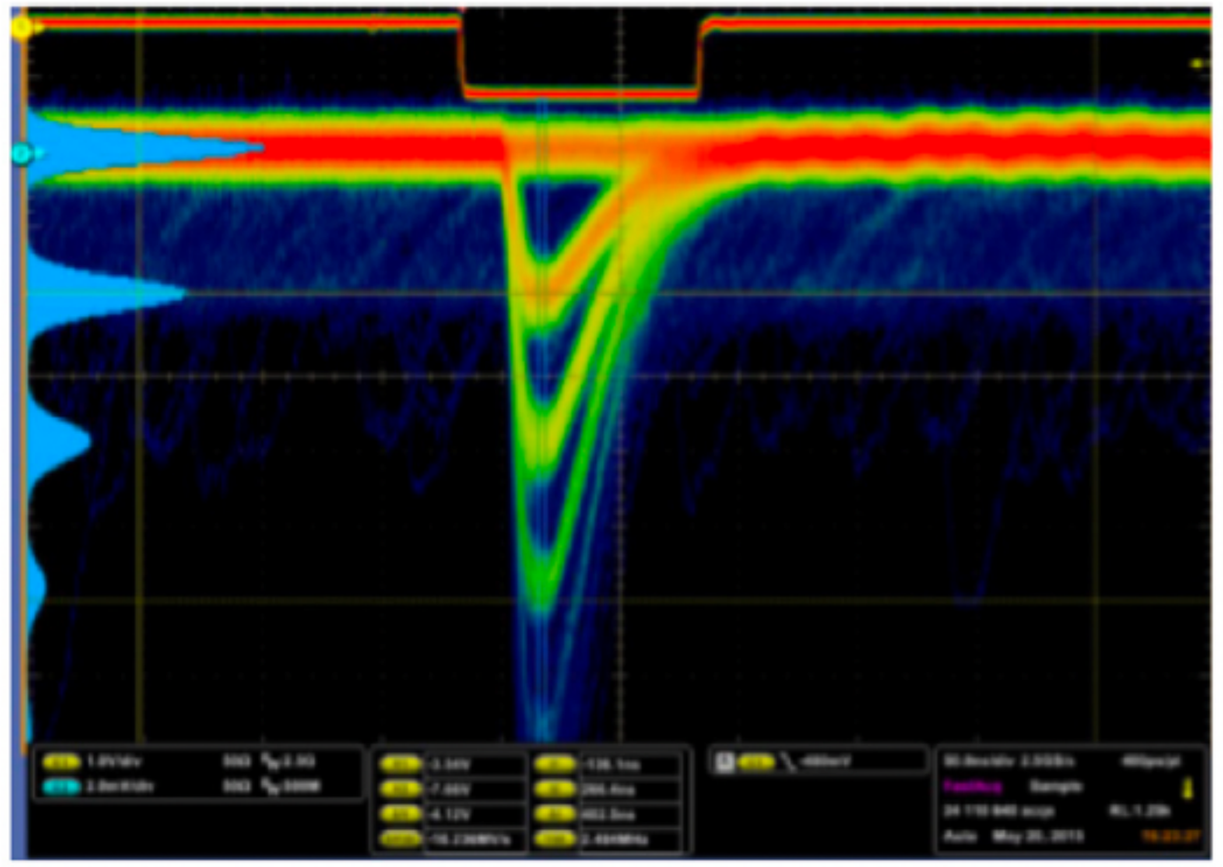
02.
LightSimtastic ✓

In progress
also for SUM

- DOI:10.1016/j.nima.2021.165853
- DOI:10.5281/zenodo.10019687

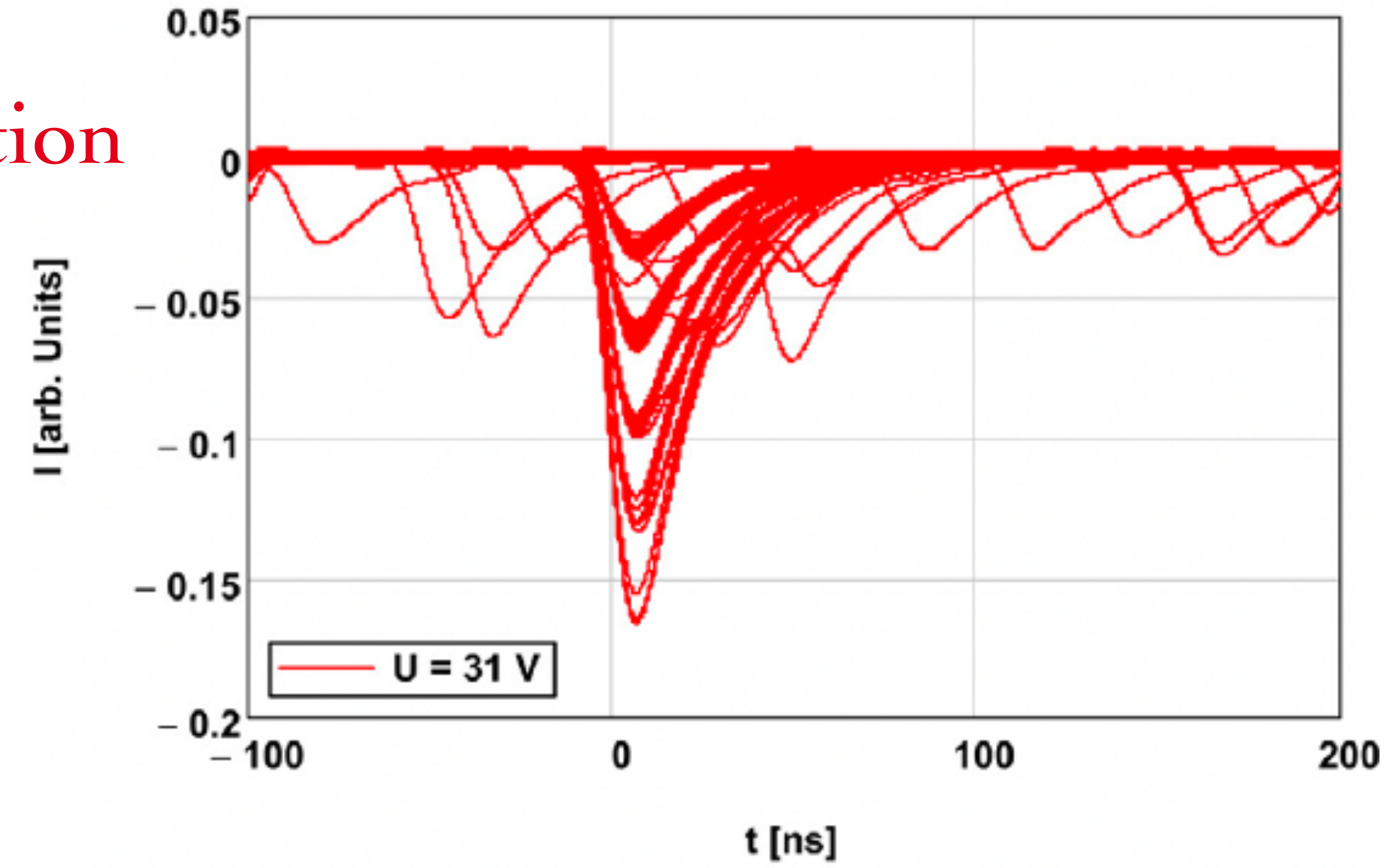
03.
Validation

Compare measured and simulated spectra



Data

Simulation



The action plan

Step 3: Validate the full SiPM response function on measurements

In progress
L.Brinkmann's PhD thesis

01.
Simulation (SUM)

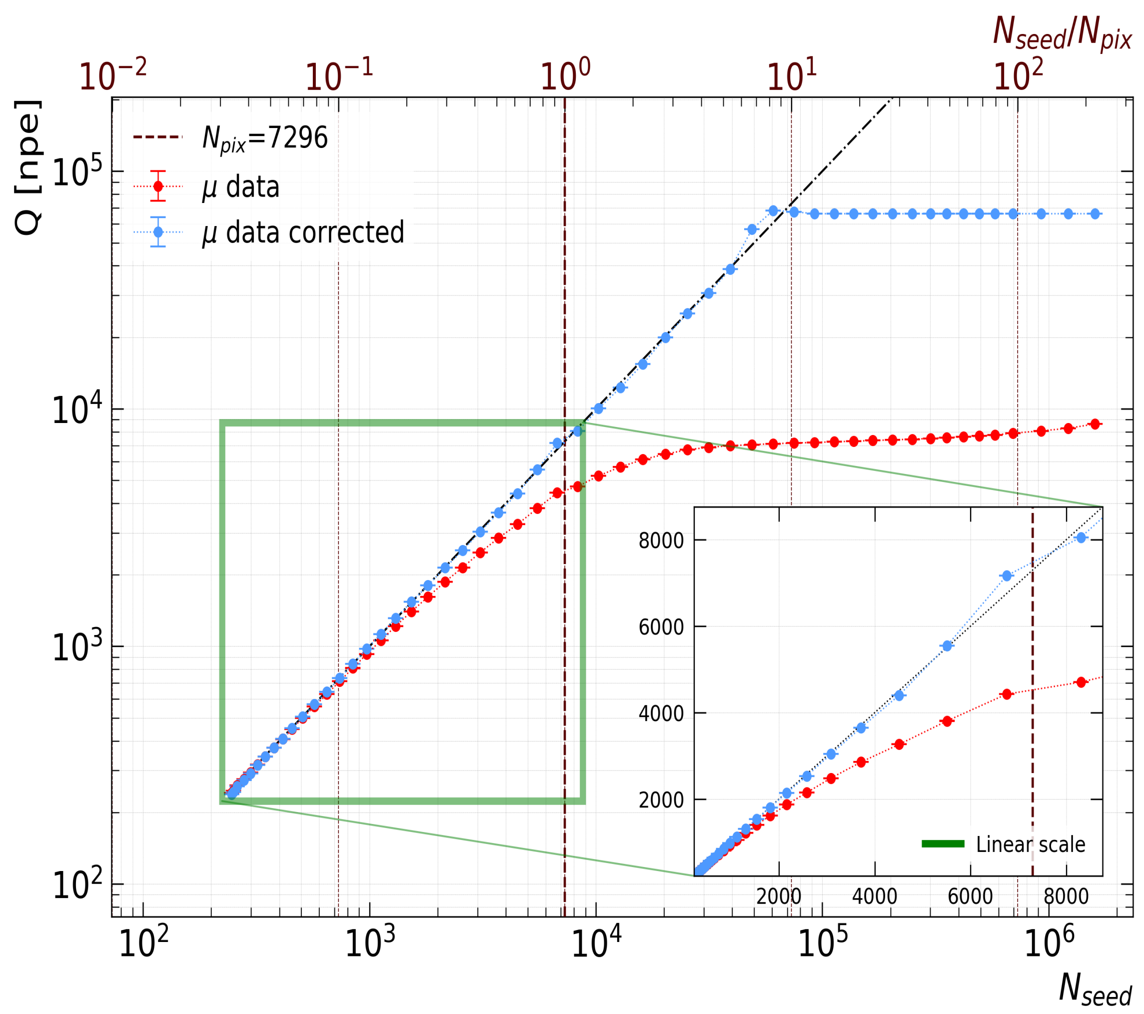
Simulate the SiPM response function and the **high light** intensity spectrum with SUM

02.
Validation

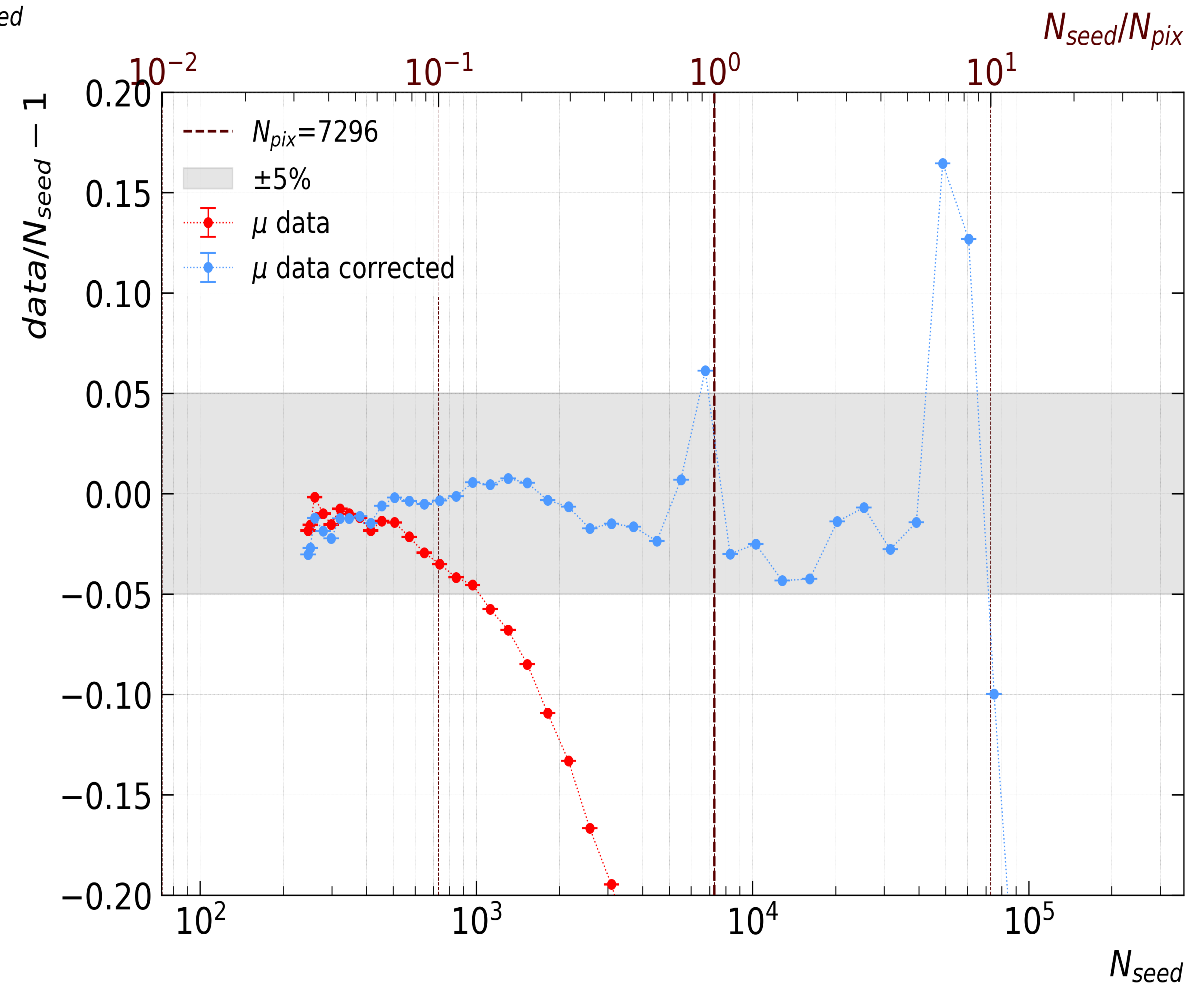
Compare measured and simulated data for **instantaneous/homogeneous light**
> DOI:[10.3390/s24051671](https://doi.org/10.3390/s24051671)

03.
Fine tuning of SUM

Tune and improve SUM based on the validation results



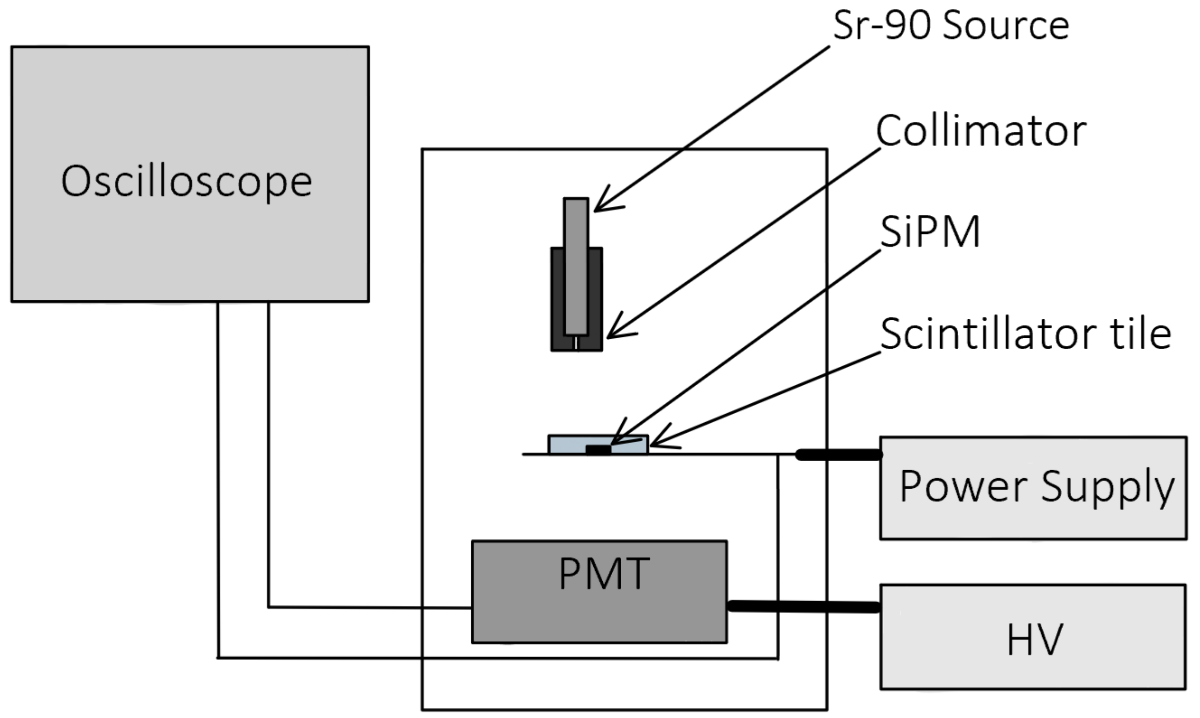
More info in L.Brinkmann talk



The action plan

Step 4: Qualify the light distribution property

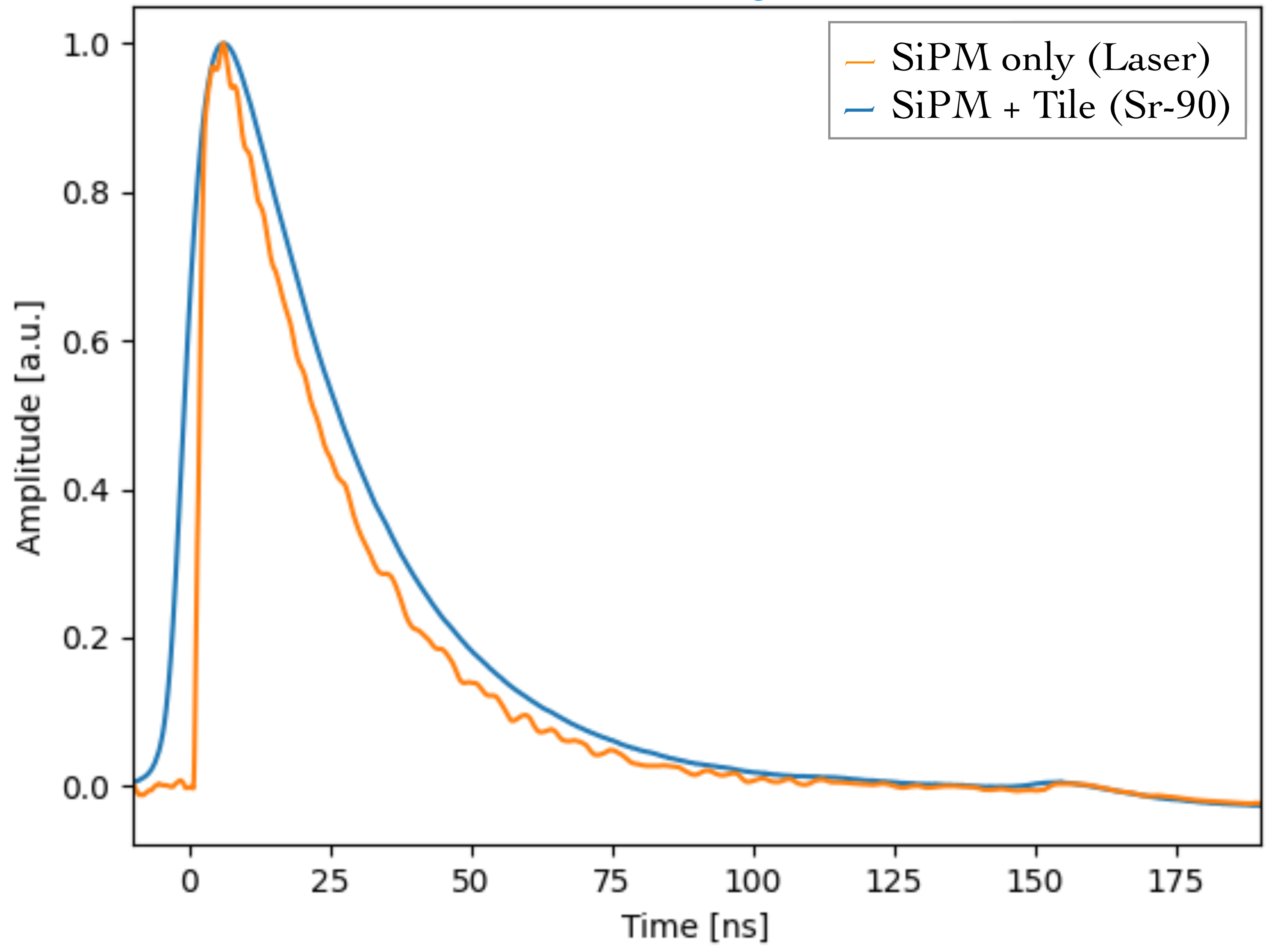
In progress
K.Neumann's Master thesis



01.
Simulation (SUM)

Reproduce MIP response with SUM

Preliminary data



02.
Light time and spatial distributions

Determine/tune the time and spatial distributions of photons from **scintillator** on SiPM

The action plan

Step 5: Add the effect of digitization

01.

Readout

Simulate the readout noise and its non-linearity in SUM

02.

A dedicated module

Implement a module similar to what done for Allpix Squared (Link)

The action plan

Step 6: Simulate the SiPM response and its systematics

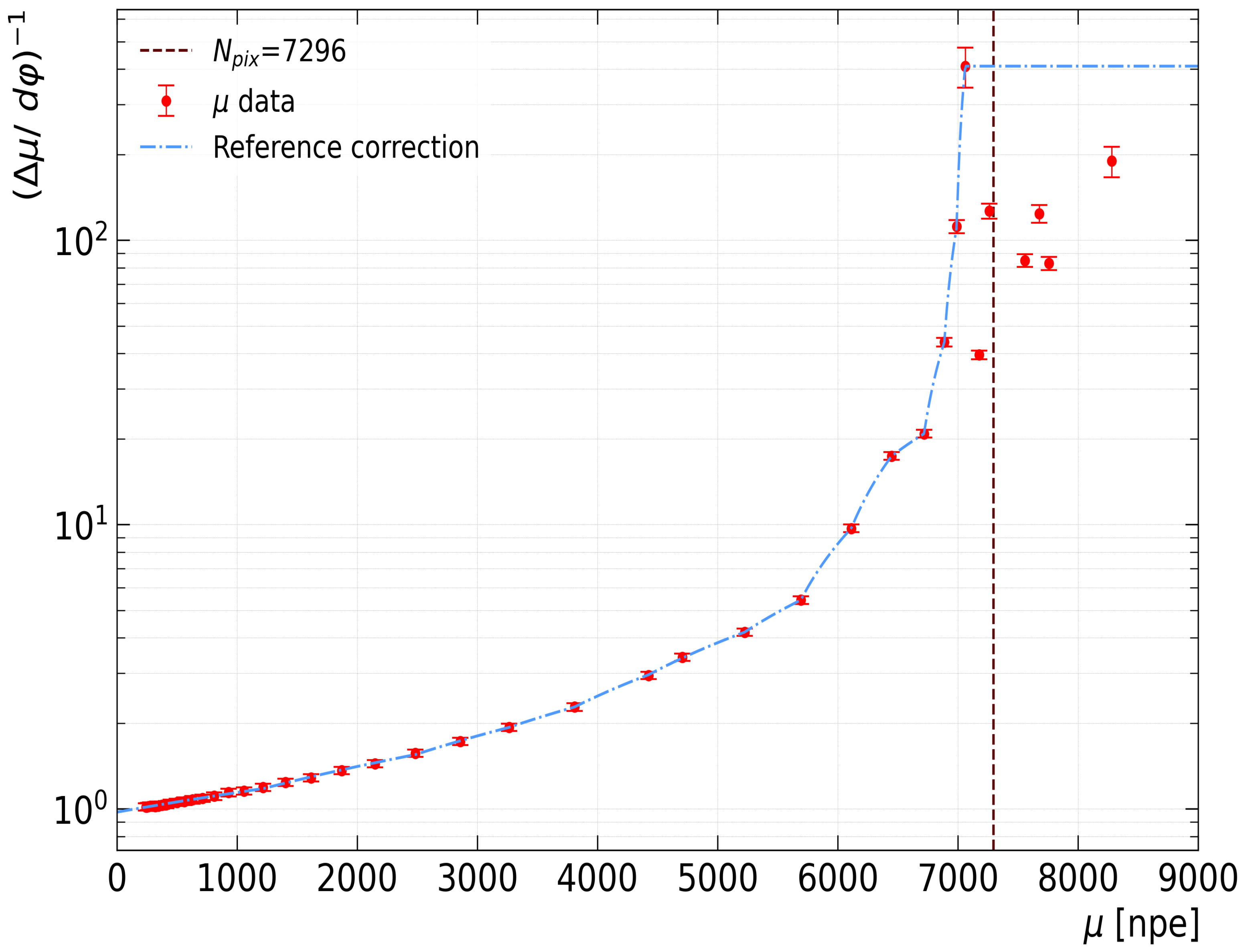
New project
Lead by M.Antonello

01.
SUM

Simulate the SiPM full response with SUM (validated)

02.
Systematic studies

Study the systematic effects from variations in SiPM parameters (especially when direct measurement is not possible)



Work in progress

and next steps

01.
Non-linear response and saturation

Perform **systematic studies** on the non-linear response correction as:
> T and V dependence.
> Fluence dependence.
> Variation across SiPMs.
> Etc.

02.
SiPM response with scintillation light

Obtain a **non-linear response correction combining SiPM** precise lab calibration **and light** emission spectrum from scintillator using SUM (validated).

03.
SUM model and framework

Develop the framework in Julia and make it ready also for further **system optimisation studies**.

Thank you

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From a model to a framework

The main structure

SW infrastructure and core

The main part of the code including the GUI, the source, and the entire structure of the framework.

The core module is a **fast simulation** based on SUM, validated with real data for different regimes and systematic studies.

Built-in utilities and modules

The core module can interface with **various "modules"** developed from the group's know-how, which will complete and extend the simulation.

Each module will be designed to work **independently or in combination** with others.

Extensibility and user's modules

Each user will be able to implement and make available to the community their **own specific modules**.

Useful for adding other device designs such as Digital SiPMs or TAPDs, etc..