Update on the design of the lens based optical detector for GRAIN

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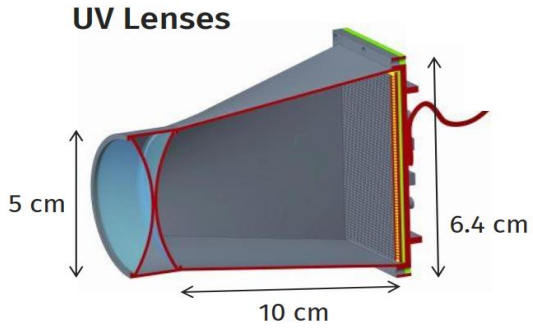
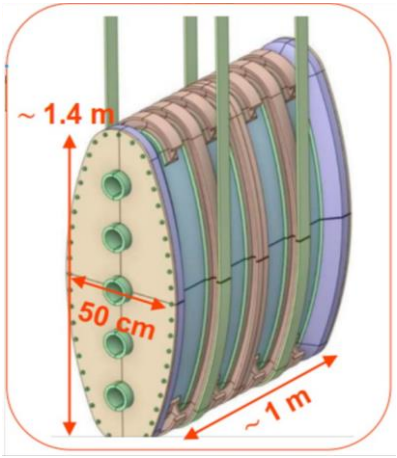
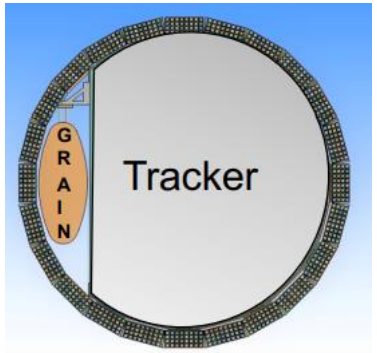
Università di Genova
INFN Istituto Nazionale di Fisica Nucleare

Lens-based configuration

- For the optical system for GRAIN, one of the two possible options is a lens-based optical detector







- **2 mm side** SiPM 32x32 matrices
- A **unique ASIC** specifically designed for **GRAIN**

Simulation and tests

- **Tests**

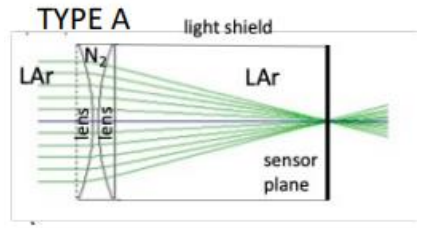
Goal: Test and calibrate the acquisition board using an artificial light source

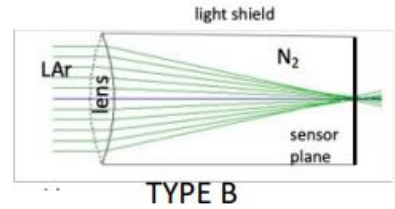
- **Simulations**

Goal: Validation of the proposed design for the ASIC. A dedicated analysis on Monte Carlo data has been performed

First prototypes

- 2 types of **optical system**:
  - **Type A**: two plane-convex lenses → gas between the two lenses
  - **Type B**: single bi-convex lens → gas between the lens and the sensor





- 2 different **materials**:
  - SILO Corning® HPFS 8655 glass → needs Xenon doping
  - MgF_2 → does not need Xenon doping

Both material samples successfully tested in LN_2

First prototypes

Type A

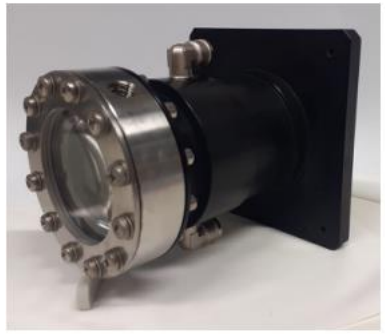
Material: Corning® HPFS 8655 glass

Focal length: 89 mm

Ready

1. **Smaller diameter**: 50 mm

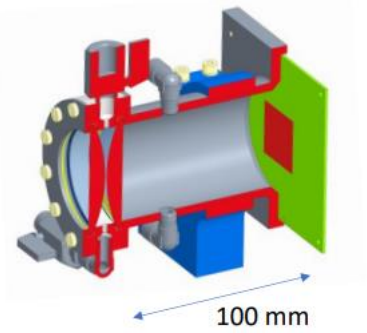
   Thickness: 12 mm



To be assembled

2. **Bigger diameter**: 60 mm

   Thickness: 20 mm



In construction

Material: MgF_2

Diameter: 66 mm

Radius of curvature: 60 mm

Type B

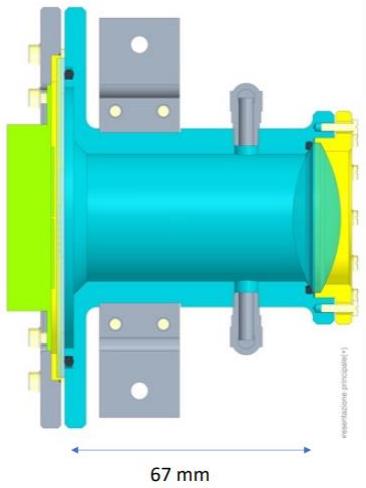
Material: Corning® HPFS 8655 glass

Focal length: 64 mm

Diameter: 50 mm

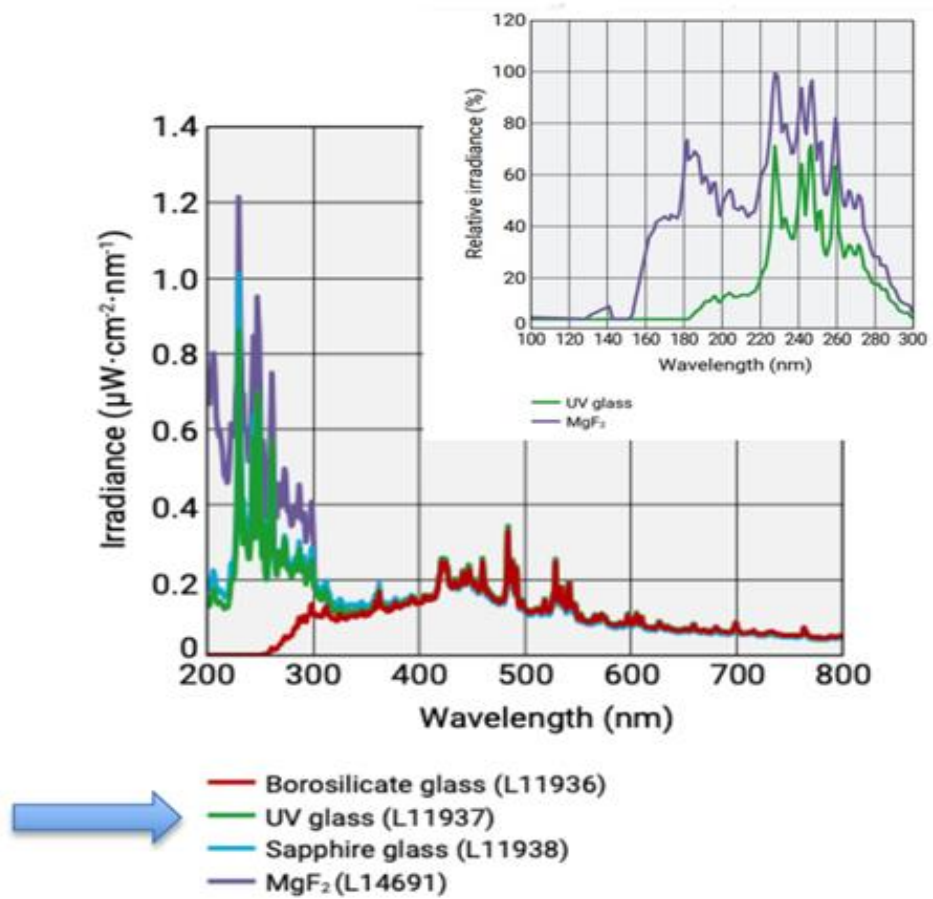
Thickness: 18 mm

Pieces in the workshop



Set up: the artificial light source

The source light system is made up of a Xe pulsed lamp at 5 W made by HAMAMATSU, to which is connected a monochromator that gives us the possibility to select a specific wavelength.



Set up and readout

- **Sensors:**

Matrix with 16x16 SiPM:

  – Different sizes: 1 mm or 3 mm (2 mm almost ready)

  – With or without TPB deposition (wavelength shifter)

The SiPM matrix is acquired by 8 Alcor chips

For each channel, we can record:

- Time of the over-threshold (TDC time)
- TOT (Time Over Threshold)

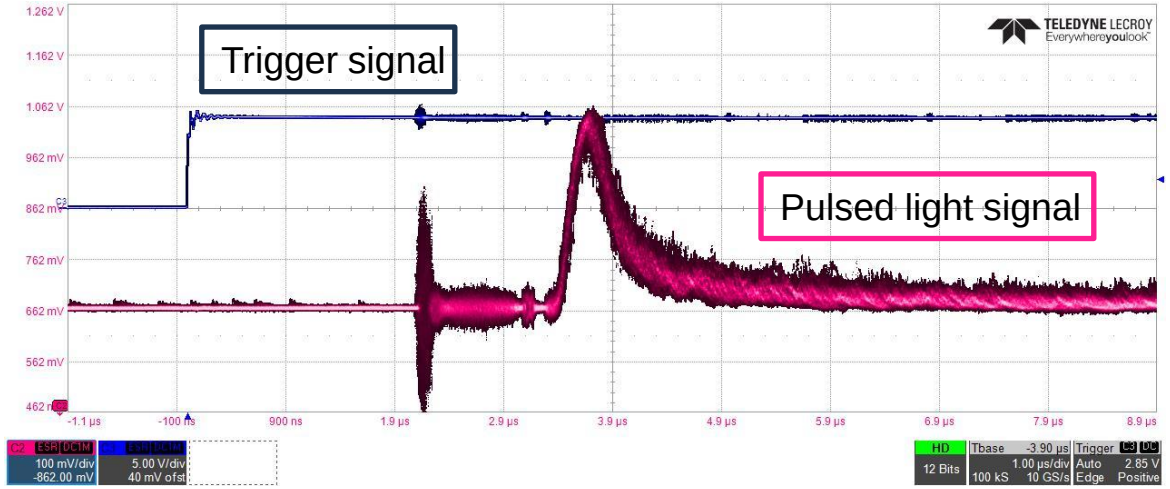
We have to optimize threshold and gain for each channel

To interface the Alcor chips, an FPGA is used

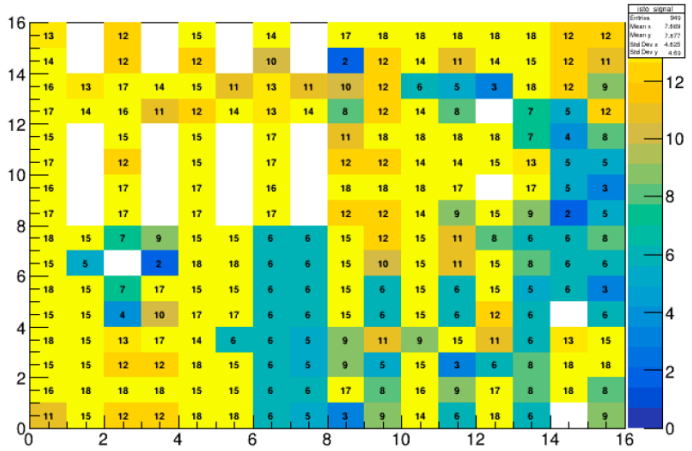
- **Tests performed both at room temperature and in Liquid Nitrogen**

The pulsed light signal on the whole matrix

Matrix: 3mm x 3 mm without TPB



Full spectrum – no specific wavelength selected

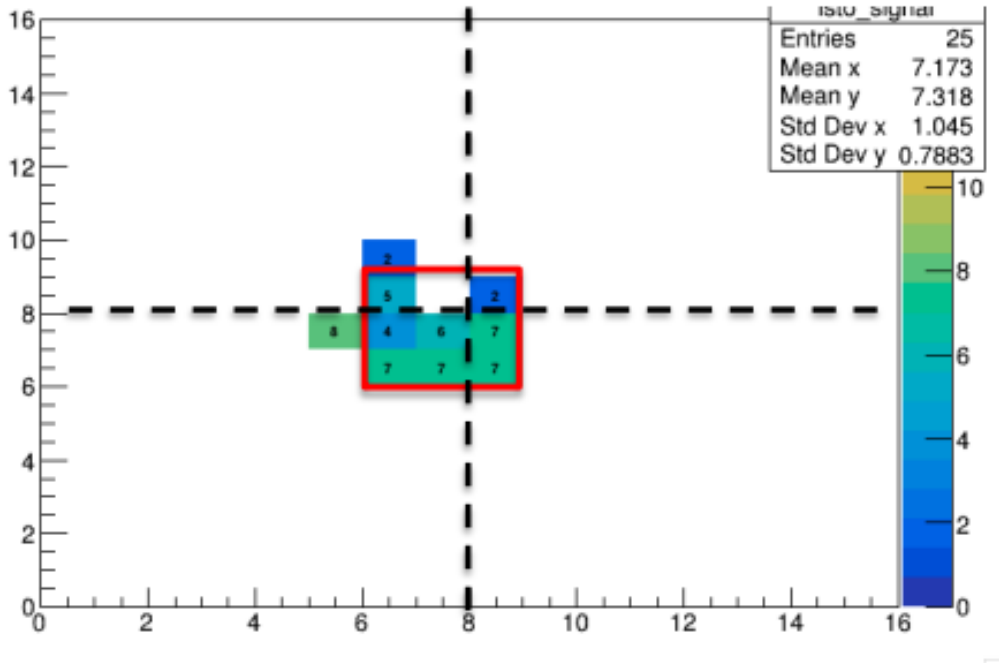


- 18 counts are expected for each channel
- Thresholds not completely optimized
- Some problematic channels
- CHIP U7 temporarily broken
- Light is detected on the whole matrix

Pulsed light signal on few channels

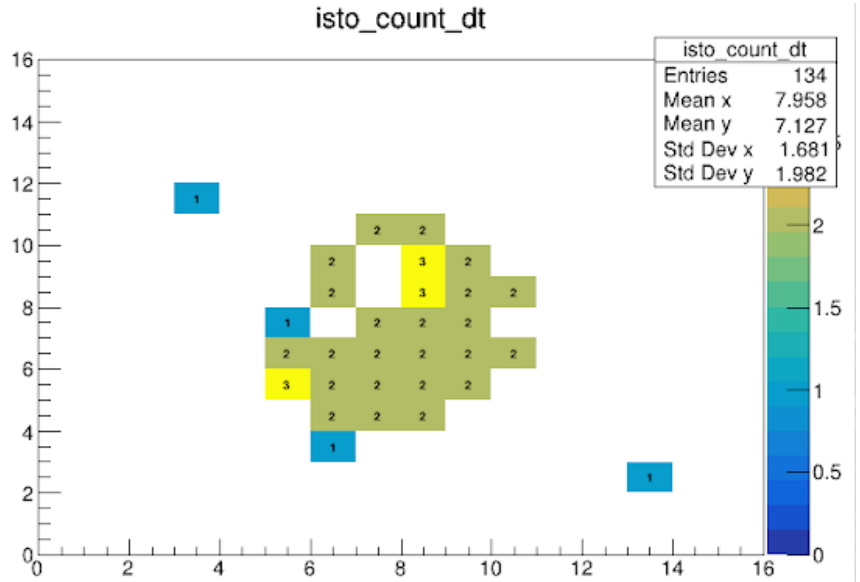
- By using a shield the light impinged only few channels

Threshold 55



- 8 counts are expected for each channel

Less intense pulsed light



- 2 counts are expected for each channel

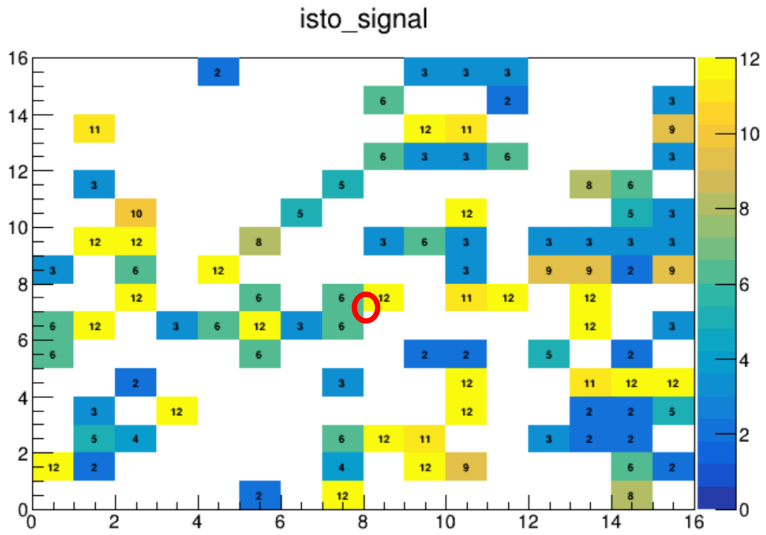
- The light signal is well detected only in the center
- A few channels are still problematic

A problem with the TPB deposition

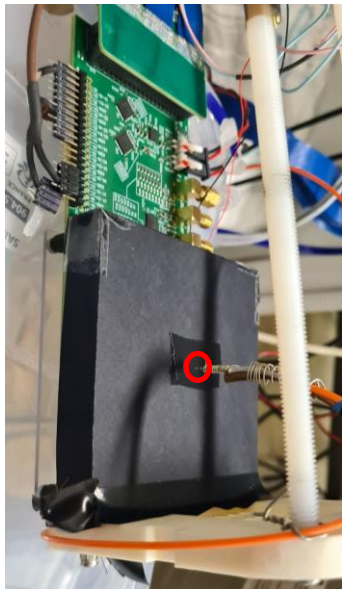
Pulsed light signal on the whole matrix:

Matrix: 1 mm x 1 mm with TPB

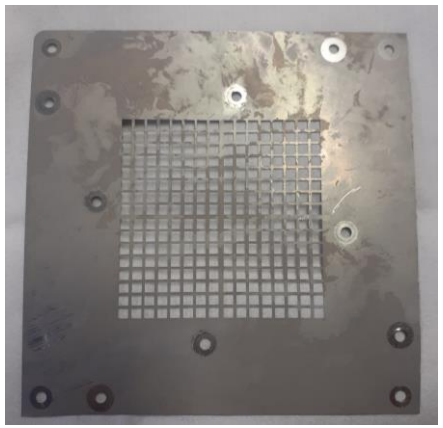
- If we point the light on a single SiPM, the light is detected everywhere

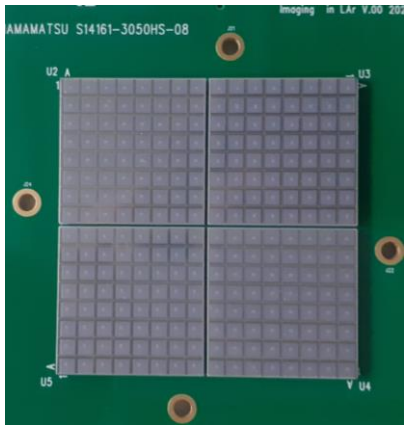


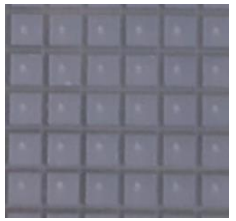
This is due to the uniform layer of deposited TPB



Very small hole!
0.7 mm







- In October at LNGS N. Canci deposited TPB by using a grid
- We will test it soon!

Conclusions

- Having optimized threshold and gain for each channel, the signal is correctly acquired

- We have to perform other tests with SiPM of 3 mm side matrix with the new TPB deposition

- After final threshold optimization, we will proceed with tests of the lens prototypes

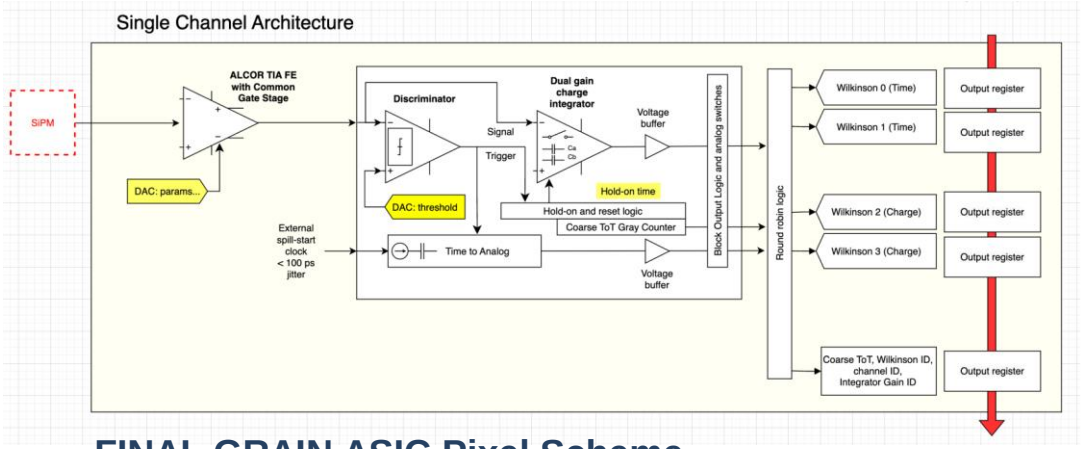
Validation of the proposed ASIC design

Starting point: ALCOR (**A** **L**ow-power **C**hip for **O**ptical sensors **R**eadout)

- Developed by INFN Section of Torino
- **32** channels
- **Single-photon time tagging** mode or **time and charge measurement**

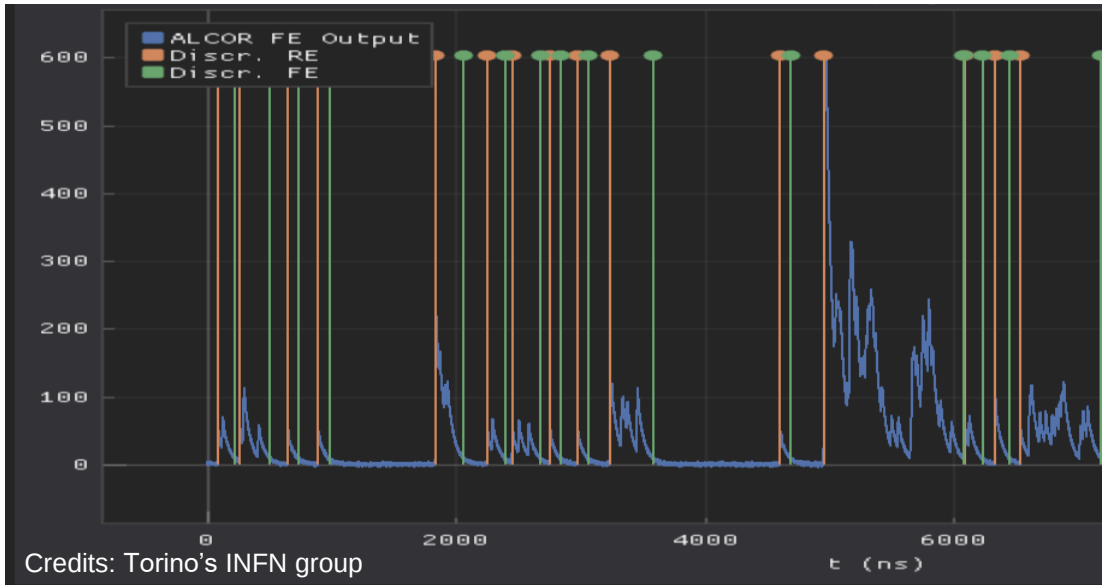
Final configuration: GRAIN ASIC

- **1024** channels
- Integration window:
  - rising edge with a timing resolution of 100 ps
  - falling edge with a timing resolution of few ns
  - charge integrator
- Power consumption **< 5 mW/ch**



FINAL GRAIN ASIC Pixel Scheme

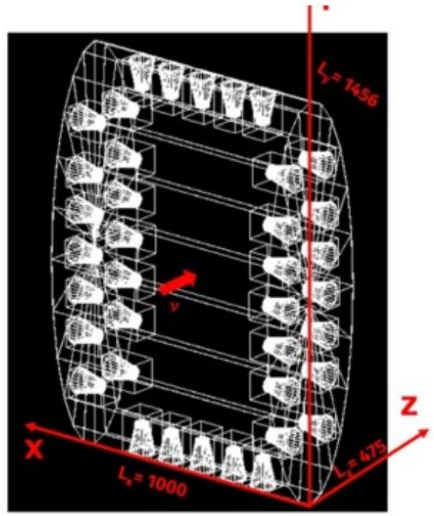
Credits: Torino's INFN group

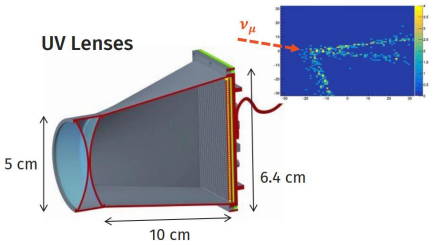


Credits: Torino's INFN group

Monte Carlo simulations

- **Simulated data**: neutrino interactions in SAND during a spill time
- **Geometry:** 53 cameras, 1024 channels (SiPMs 2x2 mm^2 each)
- Simulations consist of photon scintillation emission both in pure Liquid Argon and in Xenon-doped liquid Argon
- **Simulation output**: position and time of photons detected by each camera, quantum efficiency included
- **ASIC simulation output:** integrated charge (reconstructed photons), number of integration windows for each spill, opening and closing time of each integration window





By studying the ASIC simulation output we want to validate the ASIC design with respect to the physics requirements

Physics goals & ASIC requirements

- **Track** reconstruction

- **Calorimetric** reconstruction

- Distinguish **multiple events in the same spill**

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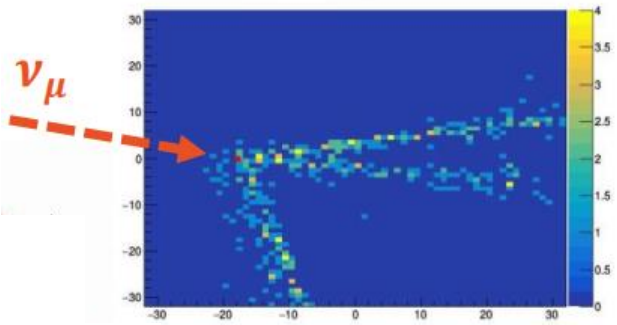


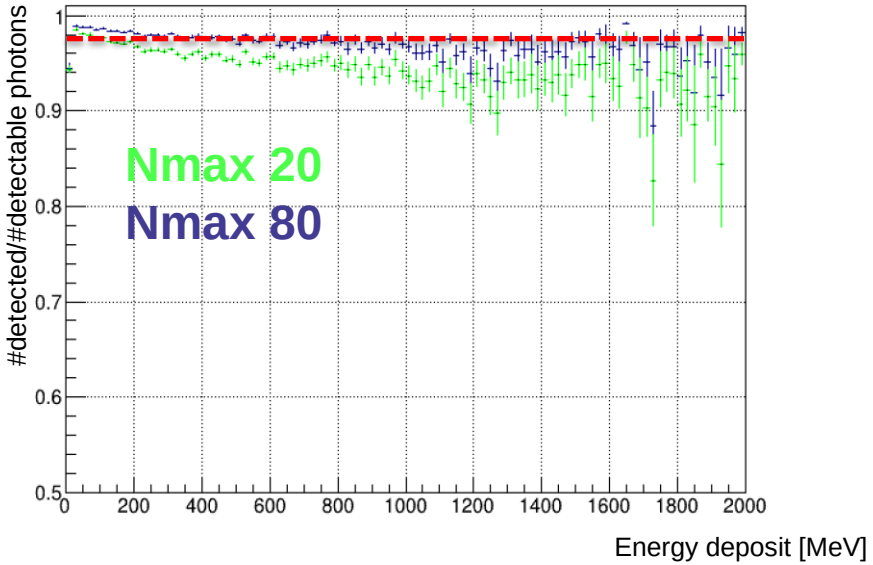
Typical image for lenses

Capability to accurately detect few photons (0-10 photons) per channel

Physics goals & ASIC requirements

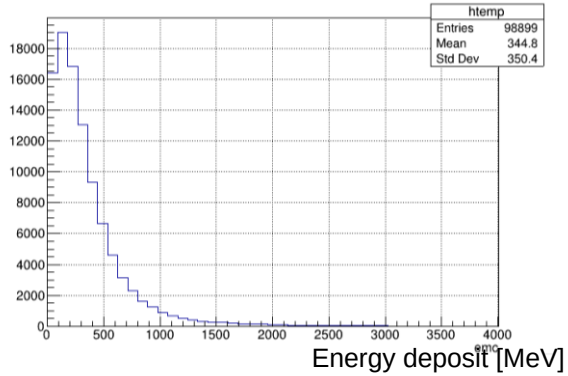
- **Track** reconstruction
- **Calorimetric** reconstruction
- Distinguish **multiple events in the same spill**

Efficiency vs energy deposit for different saturation values



Saturation over 100 photons for each integration window

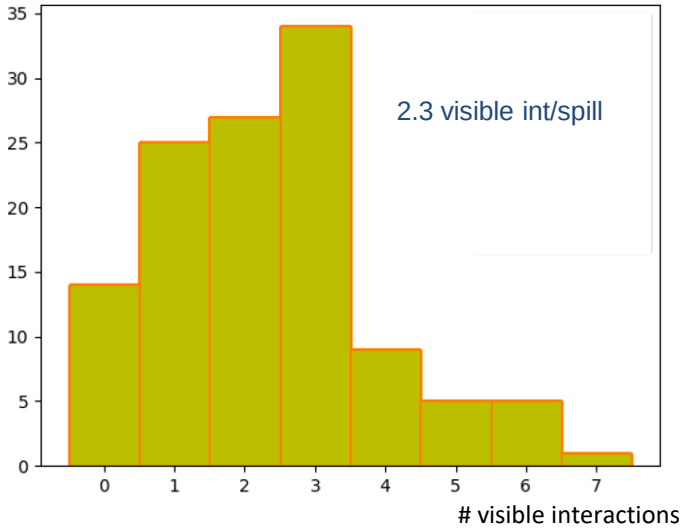
Distribution of the energy deposit by track in each interaction GRAIN



Physics goals & ASIC requirements

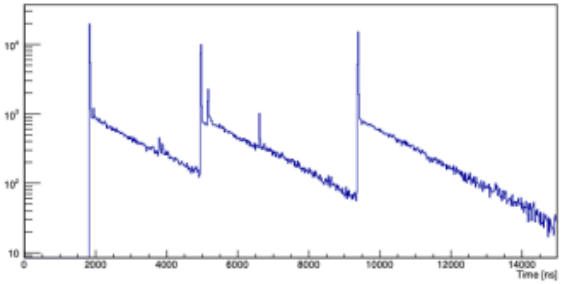
- **Track** reconstruction
- **Calorimetric** reconstruction
- Distinguish **multiple events in the same spill**

Distribution of the number of visible interactions in each channel



Good reconstruction of the time of the first photons of each interaction (100 ps for neutrino interaction)

Photon distribution in a spill time by integrating on all cameras



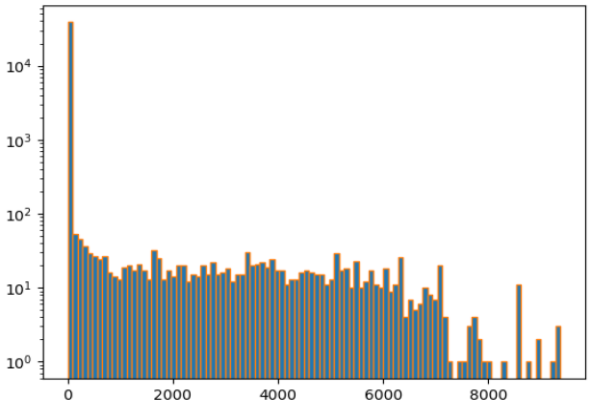
Study for the time reconstruction of the first photon in each channel for each interaction

Method:

- For each channel:
  - ❑ Search for the time of the first photon for each interaction t_{int}
  - ❑ Calculate dt as the time interval between t_{int} and the previous photon in that channel

NOT AN ISSUE for both cases

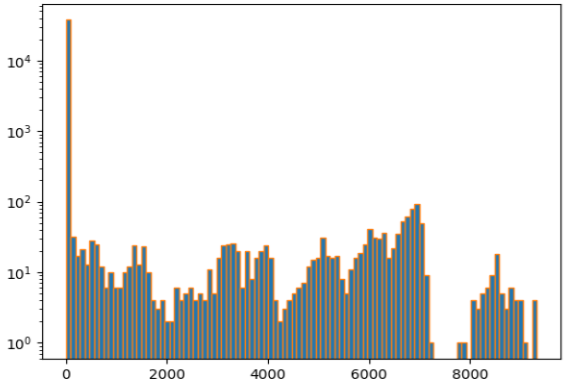
dt distribution in pure liquid Ar t_{slow} = 1600 ns



Channels which detect only 1 interaction = 40193
dt<500 ns ⟶ 0.6%

Less than 1% of the channels have a dt<500 ns

dt distribution in Xenon-doped Ar t_{slow} = 160 ns



Channels which detect only 1 interaction = 39136
dt<500 ns ⟶ 0.4%

0.4% of the channels have a dt<500 ns

Studies with lens configuration

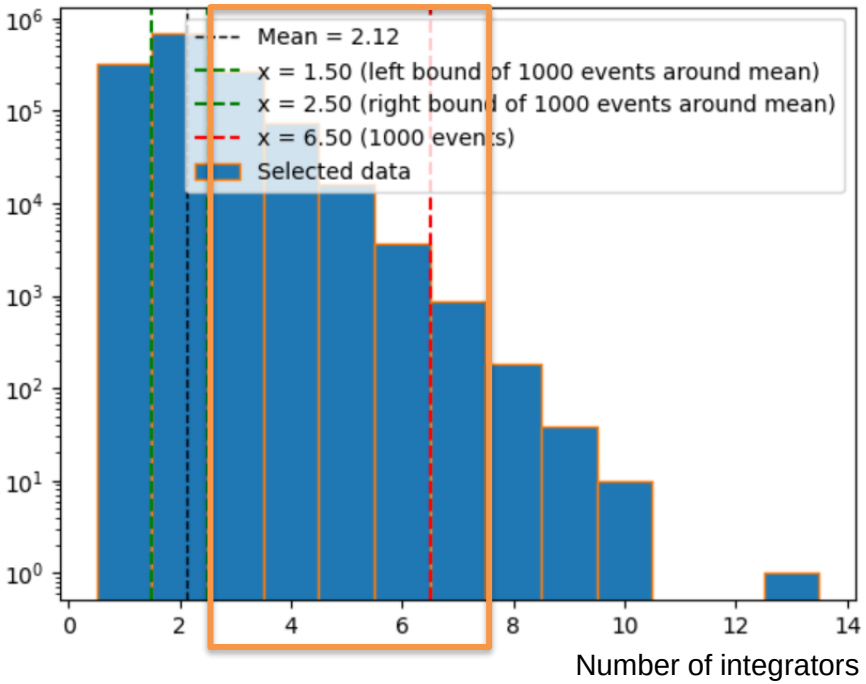
We have considered simulations in **Xenon-doped liquid Argon**
Simulated data: 720 spills

We select three samples by considering:

1. Number of integration windows
2. Number of photons within an integration window
3. Number of photons arriving in 20 ns after the interaction time

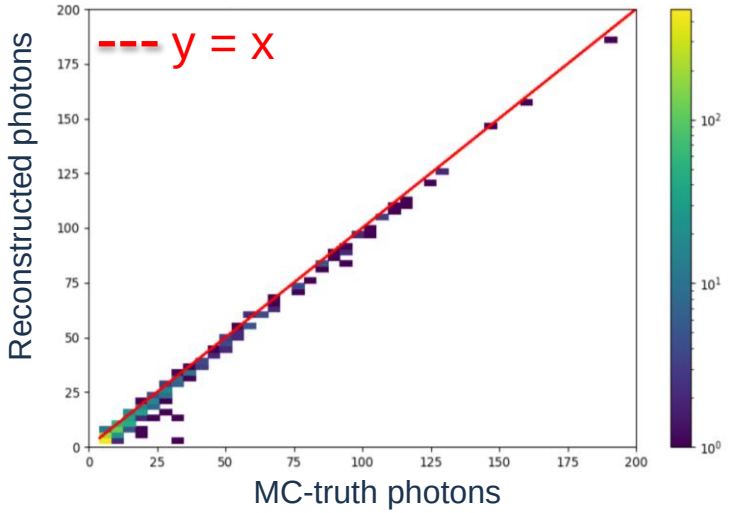
Number of integration windows

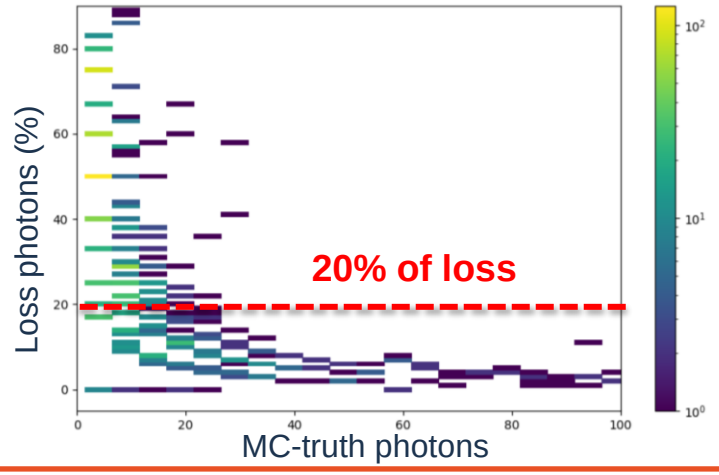
Xenon-doped Ar
720 spills



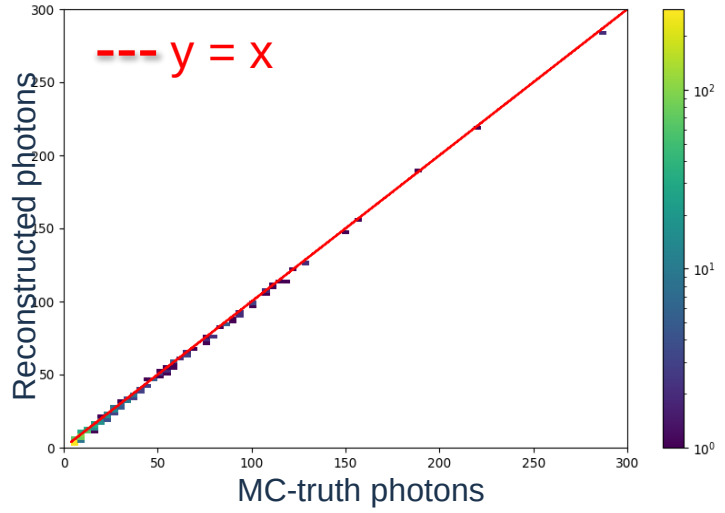
Reconstructed photons vs MC-truth photons

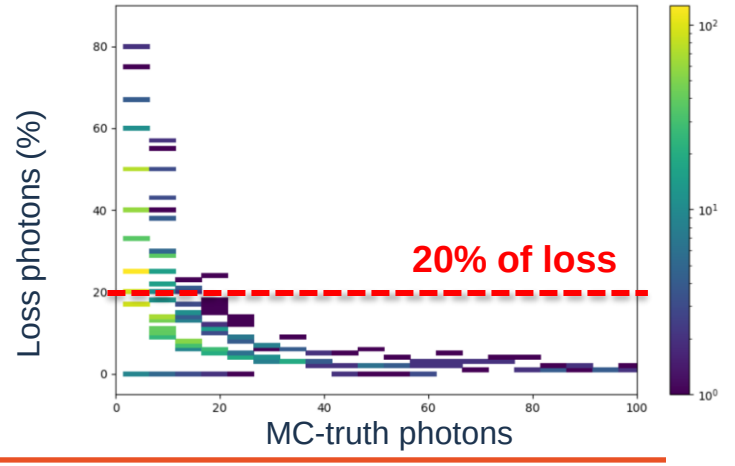
Clock period = 3.333 ns





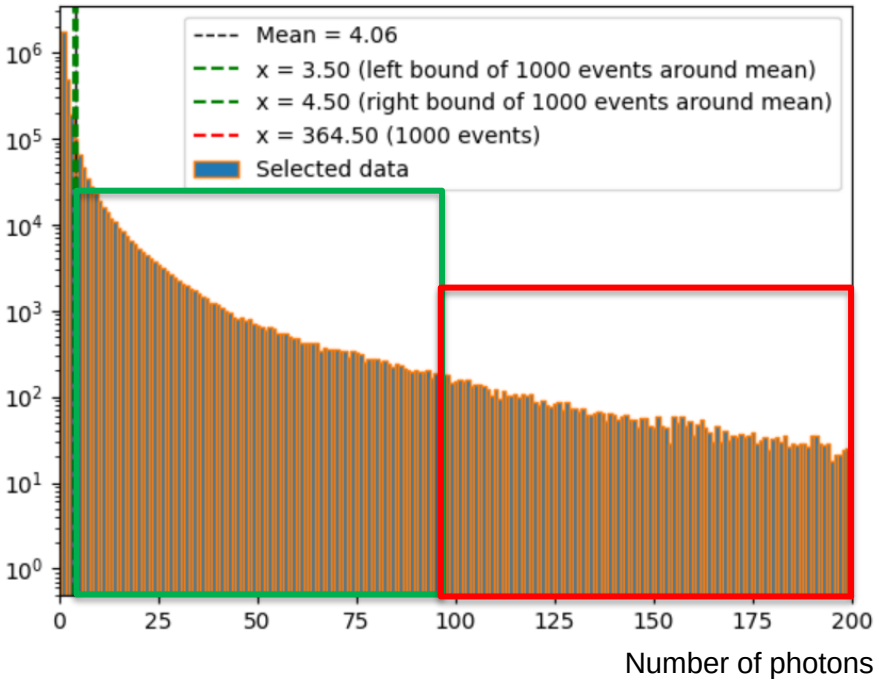
Clock period ¼ = 0.833 ns



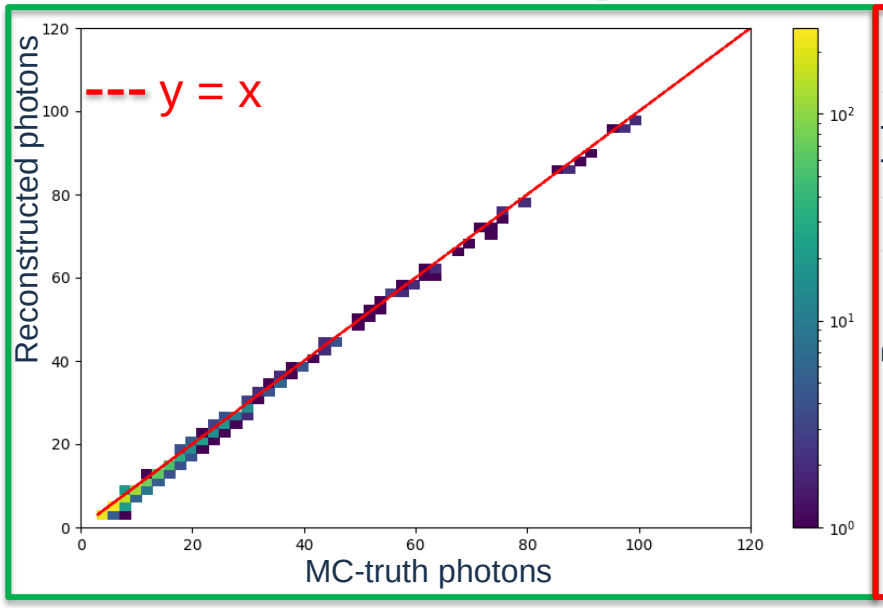


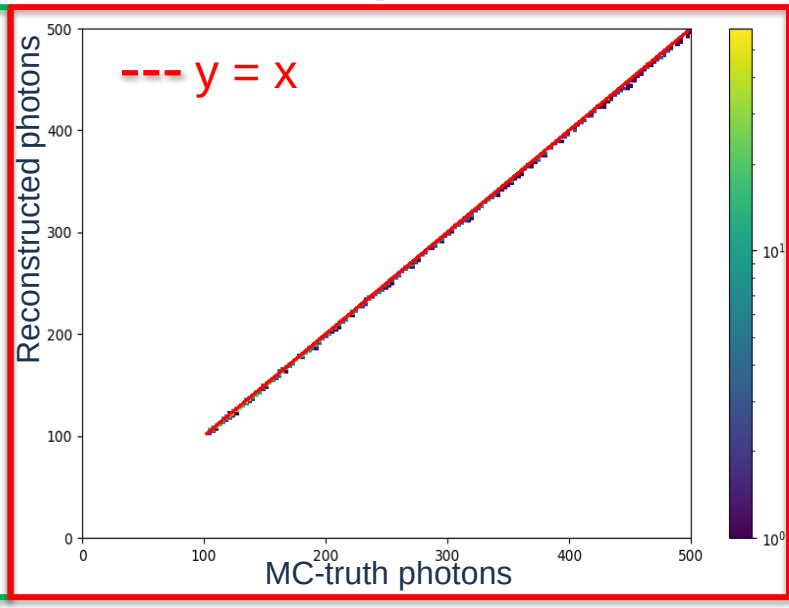
Number of photons within an integration window

Xenon-doped Ar
720 spills



2d histograms
Reconstructed photons vs MC-truth photons





We select 2 regions:

1. Green region: we require a very good reconstruction
2. Red region: only for check

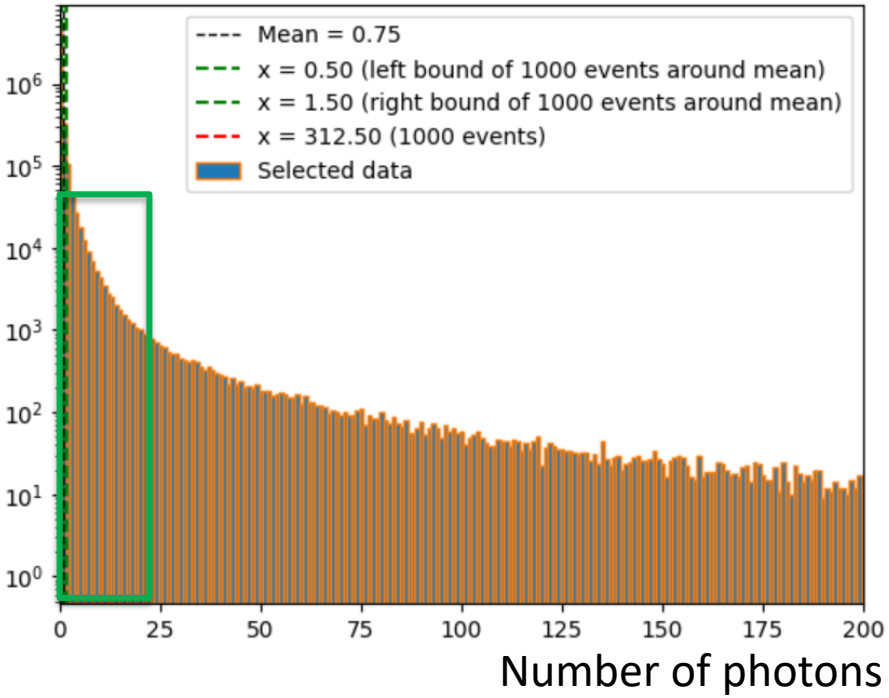
2 < N° of photons within a single integration window < 100

N° of photons within a single integration window > 100

The reconstruction is **good up to 500 photons**. From 500 photons there is saturation and the number of reconstructed photons is always 500

Number of photons arriving in 20 ns after the interaction time

Xenon-doped Ar
720 spills



- This is the distribution of the number of photons per channels within 20 ns from the true interaction time
- The true interaction time is given by true information from Monte Carlo, if a peak of at least 3 photons is detected in the channel

- For a big fraction of events we have ≈ 20-25 piled photons
- This will be taken into account for the Front End amplifier design

Conclusions

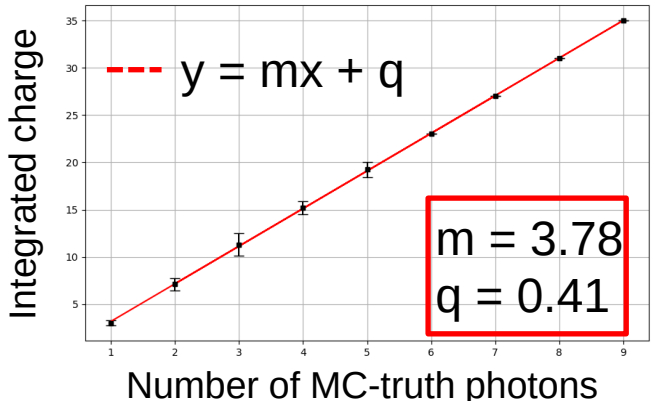
- The preliminary ASIC design satisfies the requirements
- We are able to properly reconstruct the interaction time
- We have defined the important parameter for the electronics design: clock period, ADC dynamic range and Front End saturation
- These studies are almost completed and the ASIC design has already started

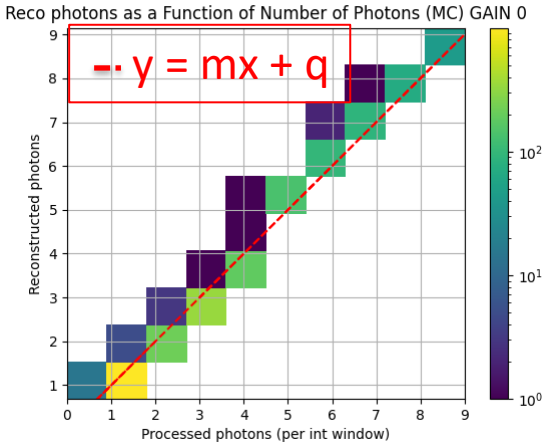
THANK YOU FOR YOUR ATTENTION

Charge calibration

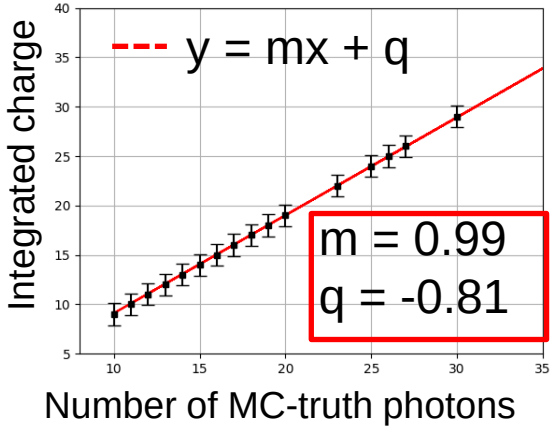
- Since the architecture simulation gives us the integrated charge, it is necessary to do a charge calibration to understand what is the relationship between integrated charge and number of photons

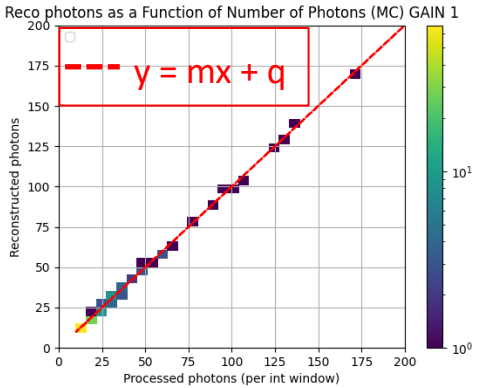
GAIN = 0

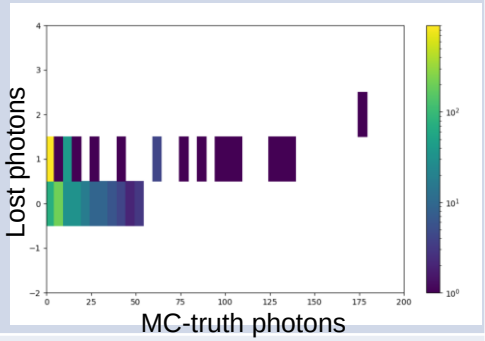
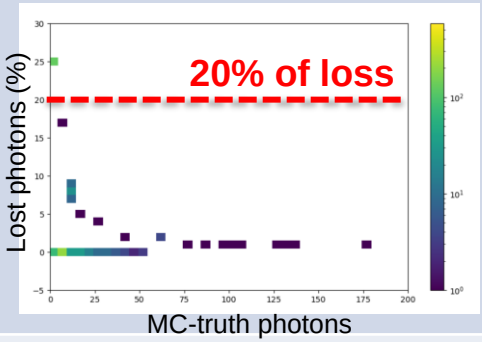
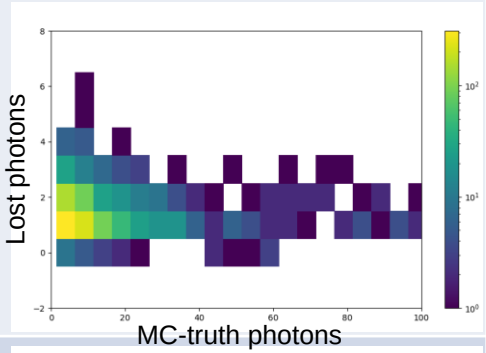
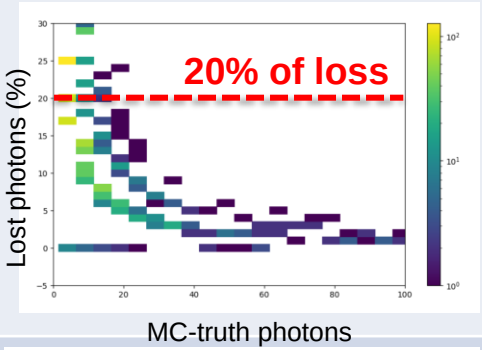
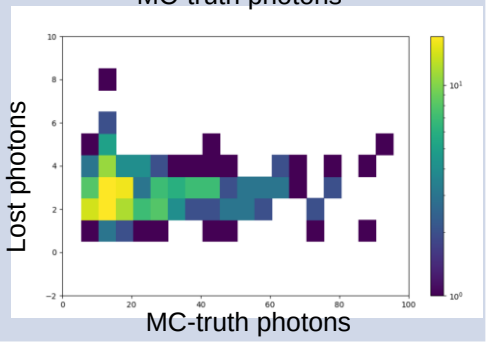
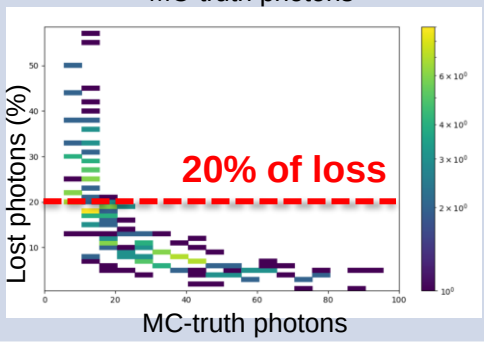


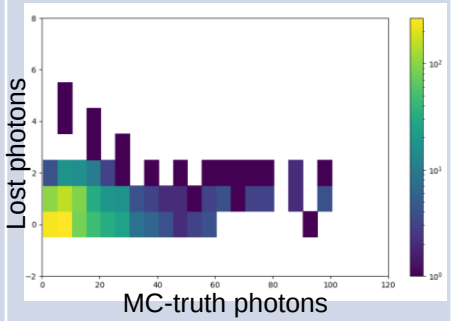
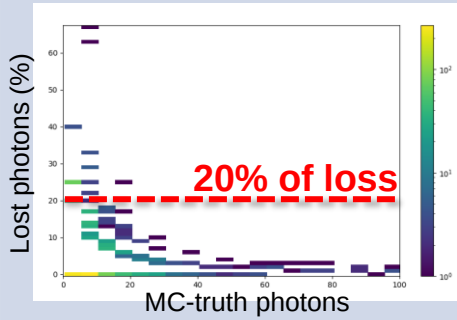
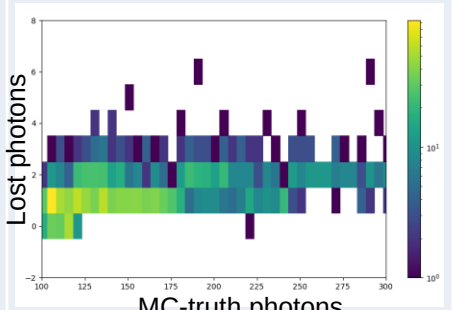
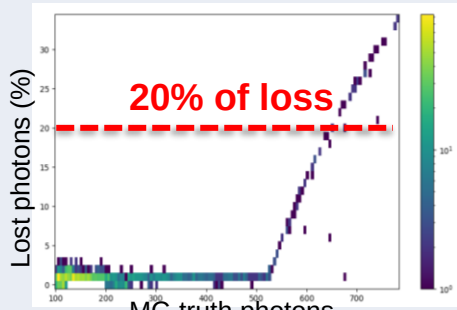


GAIN = 1





Selected sample	Requirement	Loss of photons	Loss of photons (%)	Satisfied
# of integrators = 2 (**GREEN REGION**)	Very good reconstruction of the number of photons			**YES**
3 < # of integrators < 7 (**ORANGE REGION**)	Good reconstruction of the number of photons			**YES**
# of integrators > 7 (**RED REGION**)	Only for check			**YES**

Selected sample	Requirement	Loss of photons	Loss of photons (%)	Satisfied
2 < Nph in a single integration window < 100 (**GREEN REGION**)	Very good reconstruction of the number of photons			**YES**
Nph in a single integration window > 100 (**RED REGION**)	Only for check			**YES**