DESY
MAX-PLANCK-GESELLSCHAFT
KIT Karlsruhe Institute of Technology

Ultimate Low-Light Level Sensor Development

SENSE

WP2: Results & Outlook

Teresa Montaruli, Andrii Nagai,

Domenico della Volpe, Matthieu Heller

18/10/2017

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Tasks of WP2: R&D Cooperation

2.1 Agreement on R&D cooperation between research groups and industry for advancing LLL sensors

2.2 Linking to other European initiatives (strong connection with APPEC, ATTRACT and IdeaSquare@CERN, not yet with Photonics21) ← Today we are here

2.3 Fostering the exchange between academia and industry

Cooperation agreement:

- University of Geneva, DPNC
- Max-Planck-Institute für Physik
- KIT-Centrum Elementarteilchen und Astroteilchenphysik
- DESY-Zeuthen
- INAF-Osservatorio Astrofisico di Catania
- Institute for Space-Earth Environmental Research, Nagoya University
- MPI - Heidelberg

→ SENSE Consortium

Currently signed by 3 partners, other signatures on the way

Ultimate Low-Light Level Sensor Development

Cooperation Agreement for providing a framework for the testing and performance studies of photosensors

12 October 2017

Preamble

Considering that:

various Institutions and industrial partners, have expressed their interest in carrying out together a *long-term detector R&D for future ultimate photo-sensor*, which also includes an educational and technology training component.

These activities, referred to as **SENSE Cooperation Agreement**, comprise detector testing and prototyping, electronics design, computer simulations, end-user need analysis and more, are to be performed in the partner laboratories and at the CERN IdeaSquare testing facility on SiPM.

These experimental activities aim at exploring new detector technologies for physics experiments and industrial applications, while engaging students from different fields and school levels and industrial partners.

Exploring new technologies with validated test benches

Open access publications

The partners of this Agreement communicate through the Technology Exchange Platform

Working plan for WP2:

1. Define & contact research groups with experience in LLL
2. Prepare cooperation agreement
3. Validate different set-up and result consistency
4. Establish the measurements/analysis procedure
5. Contact LLL producers for cooperation agreement
6. Ask the producers for their latest devices ← Today we are here

Future work:

2.2 Linking to other European initiatives

2.3 Fostering the exchange between academia and industry

Cooperation agreement between research institutes & industry:

- Contact the producers for their latest devices:
  - Characterize their currennt best SiPM products
  - Discuss output and most attractive features to work on in the future
  - Minimize duplication efforts in characterizing sensors and establish precision on measured quantities
  - Publication of results
  - Create a database with SiPM & their main characteristics

Experimental setups: Setup @ Ideasquare/Unige

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

continuous light

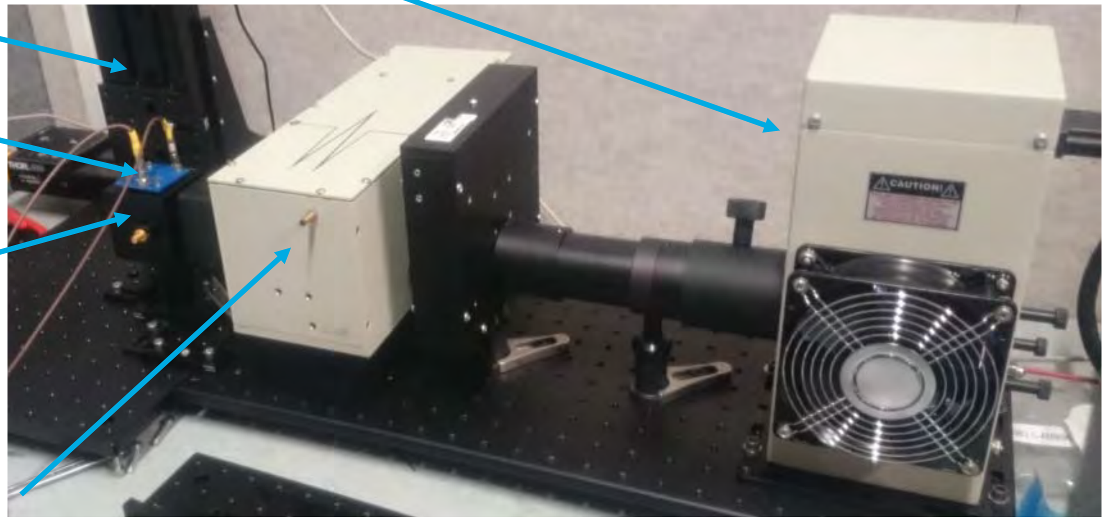
Translation stage

Photodiode (S1337-1010BQ)

Integration sphere

Monochromator

Xe 75 W lamp: 250nm to 1800 nm



pulsed light

Motorized wheel with 12 filters + Diffuser (transmission from 81.3% to 0.01%)

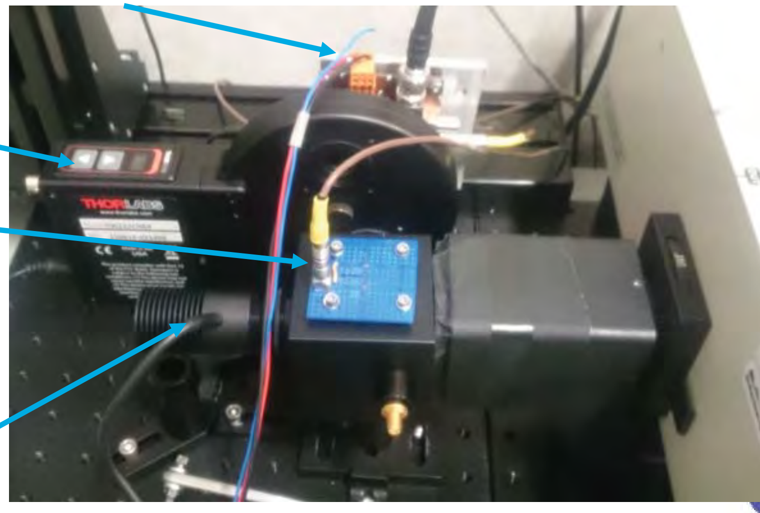
Photodiode 10x10 mm^2 (S1337-1010BQ)

LED`s :

280, 340, 375, 405,
420, 455, 470, 505,
525, 530, 565 & 572 nm

LED

SiPM

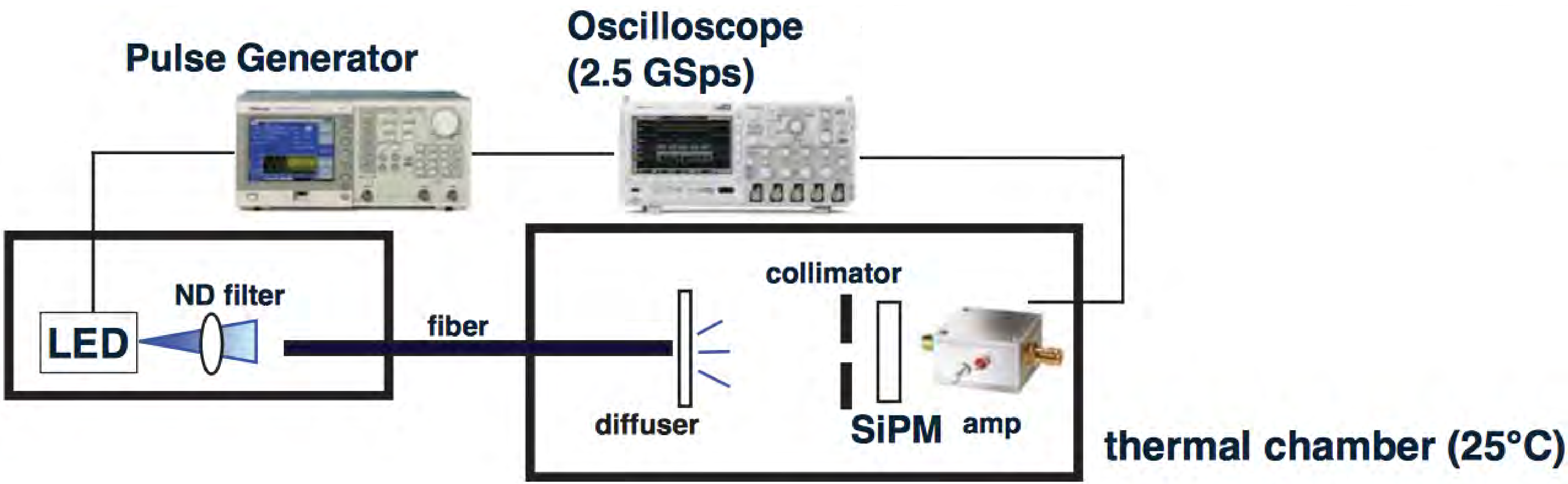


SENSE

Experimental setups: Setup @ Nagoya

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Schematic:



Offline data analysis:
- Digital filter
- Pulse analysis

Light output is monitored by reference SiPM

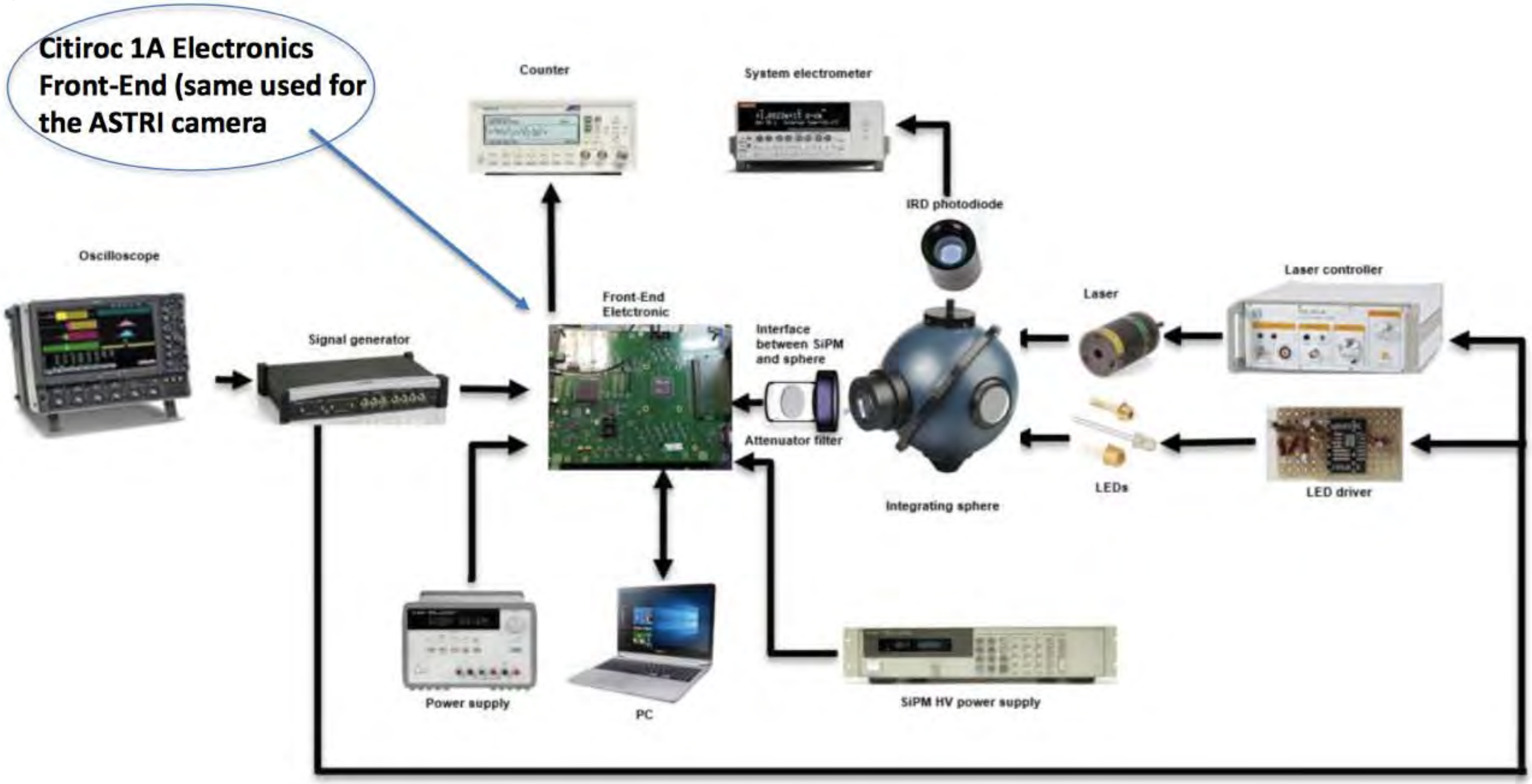
Measured at UCSC — Measured at Nagoya

$$PDE(DOI) = PDE(REF\text{-}3050, OV{=}3) \frac{\mu(DOI)}{\mu(REF\text{-}3050, OV{=}3)}$$

SENSE

Experimental setups: Setup @ Catania

Schematic:



- Calibrated photodiode + integrating sphre is used;
- ASTRI electronics to process SiPM signals;

Measurements done in Climatic chamber (0 - 25 ^{0}C)

LED`s: 285, 315, 341, 385, 405, 430, 450, 465, 496, 505, 525, 570, 591, 635, 660, 680, 780 & 851 nm

PDE vs. ΔV: Calculation

Poisson distribution:

$$P(n_{p.e.}) = \frac{(k)^{n_{p.e.}}}{n_{p.e.}!} \cdot e^{\ k}$$

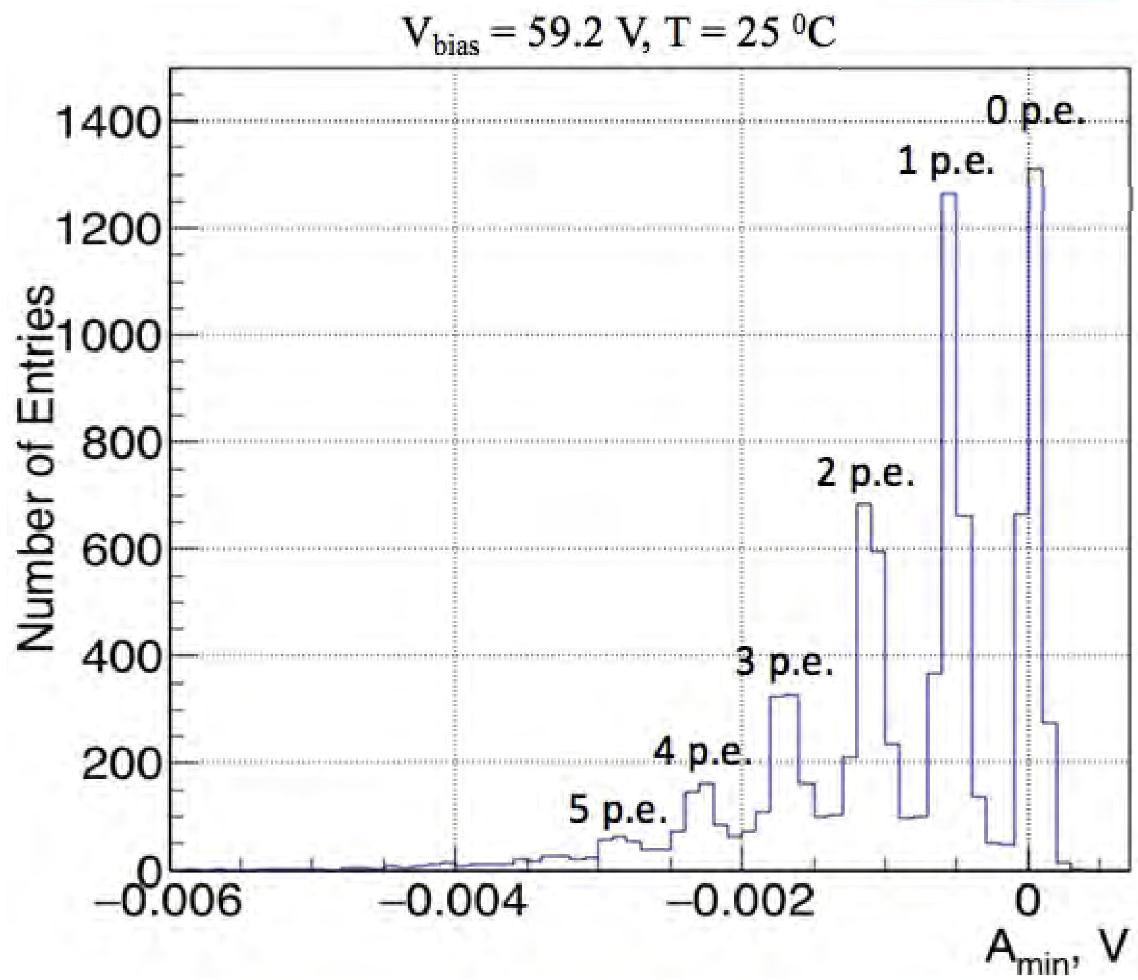
Probability to detect 0 p.e. :

$$P(0) = e^{\ k} = \frac{N(0)}{N(total)}$$

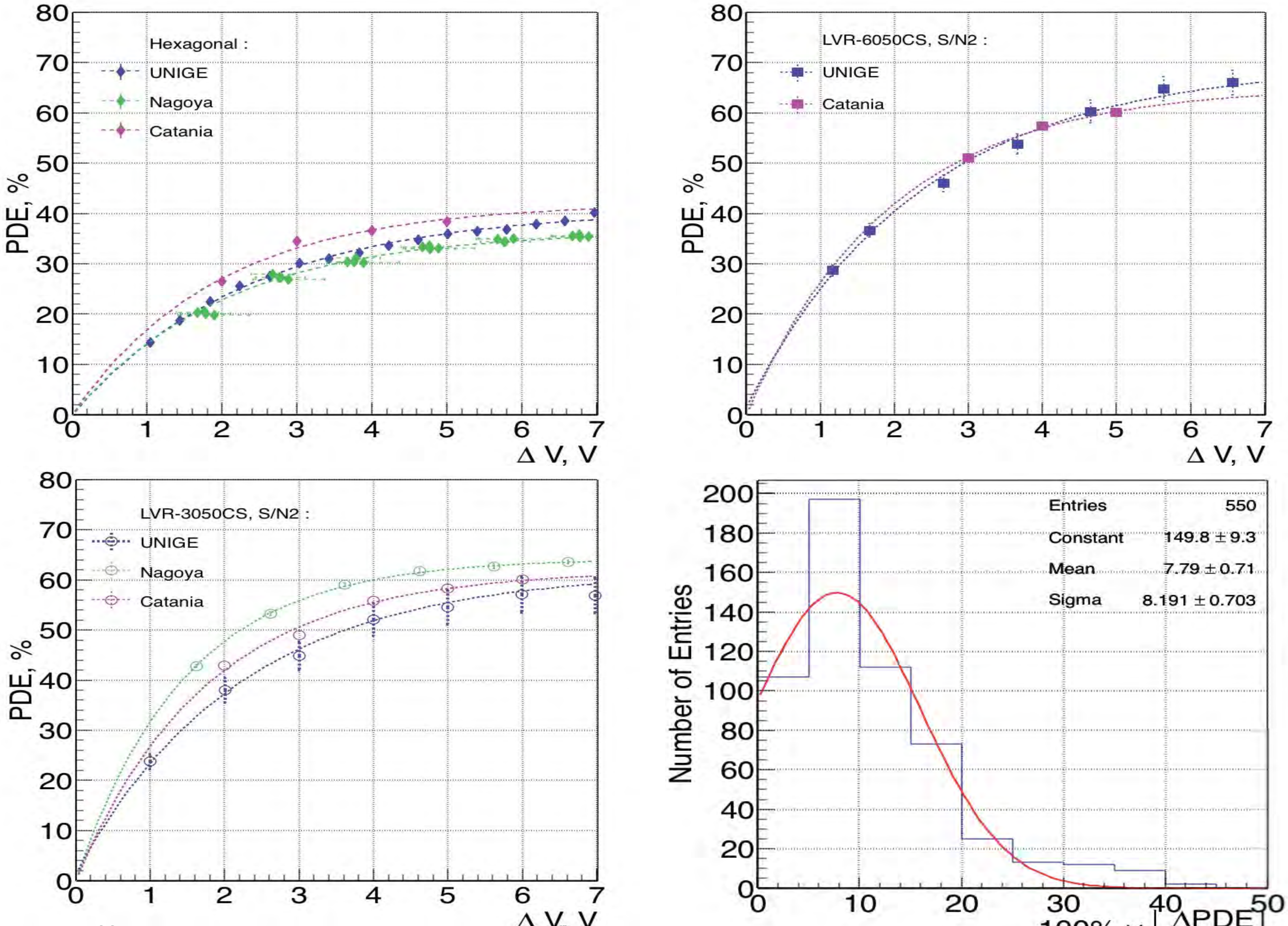
Average number of detected photons:

$$k = -\ln(P(0)_{LED}) + \ln(P(0)_{dark})$$

$$PDE = \frac{k}{N_{photons}} = \frac{k \times QE \times e^{-} \times R}{I_{Photodiod}}$$



PDE vs. ΔV @ 405 nm: Comparison



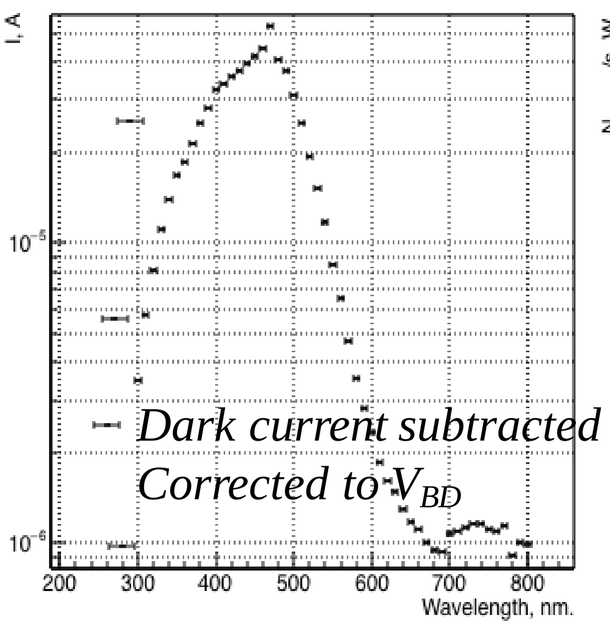
7.8% difference in average between PDE from three partners

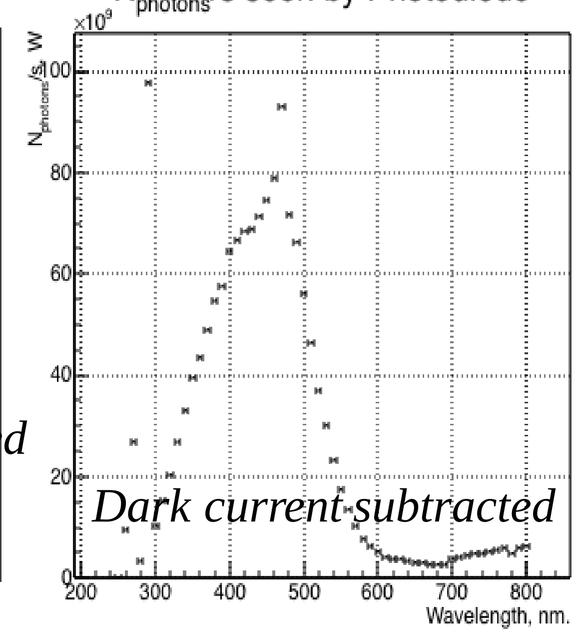
PDE vs. λ: Calculation

$$PDE = \frac{I_{SiPM}}{N_{photons} \cdot e \cdot G_{eff}}$$

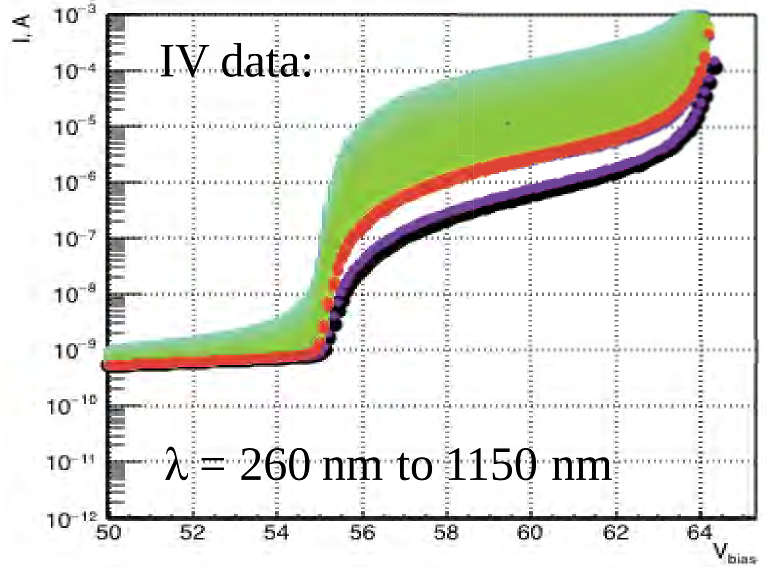
$$N_{photons} = \frac{I_{photodiode}}{QE \cdot e}$$

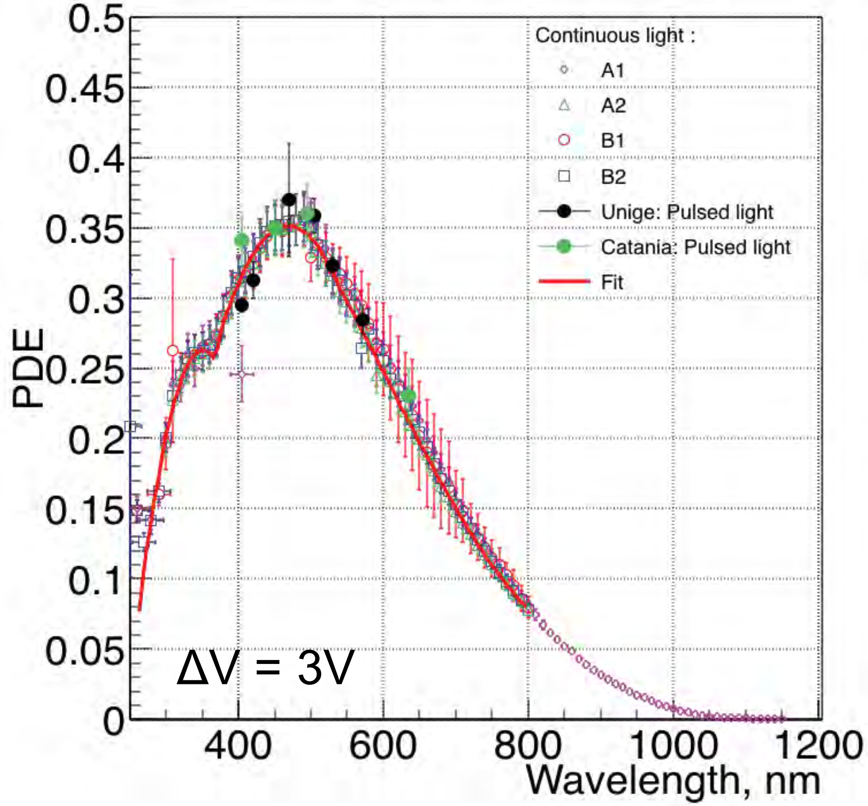
$$PDE \sim \frac{I_{SiPM}}{I_{photodiode}} \cdot QE$$





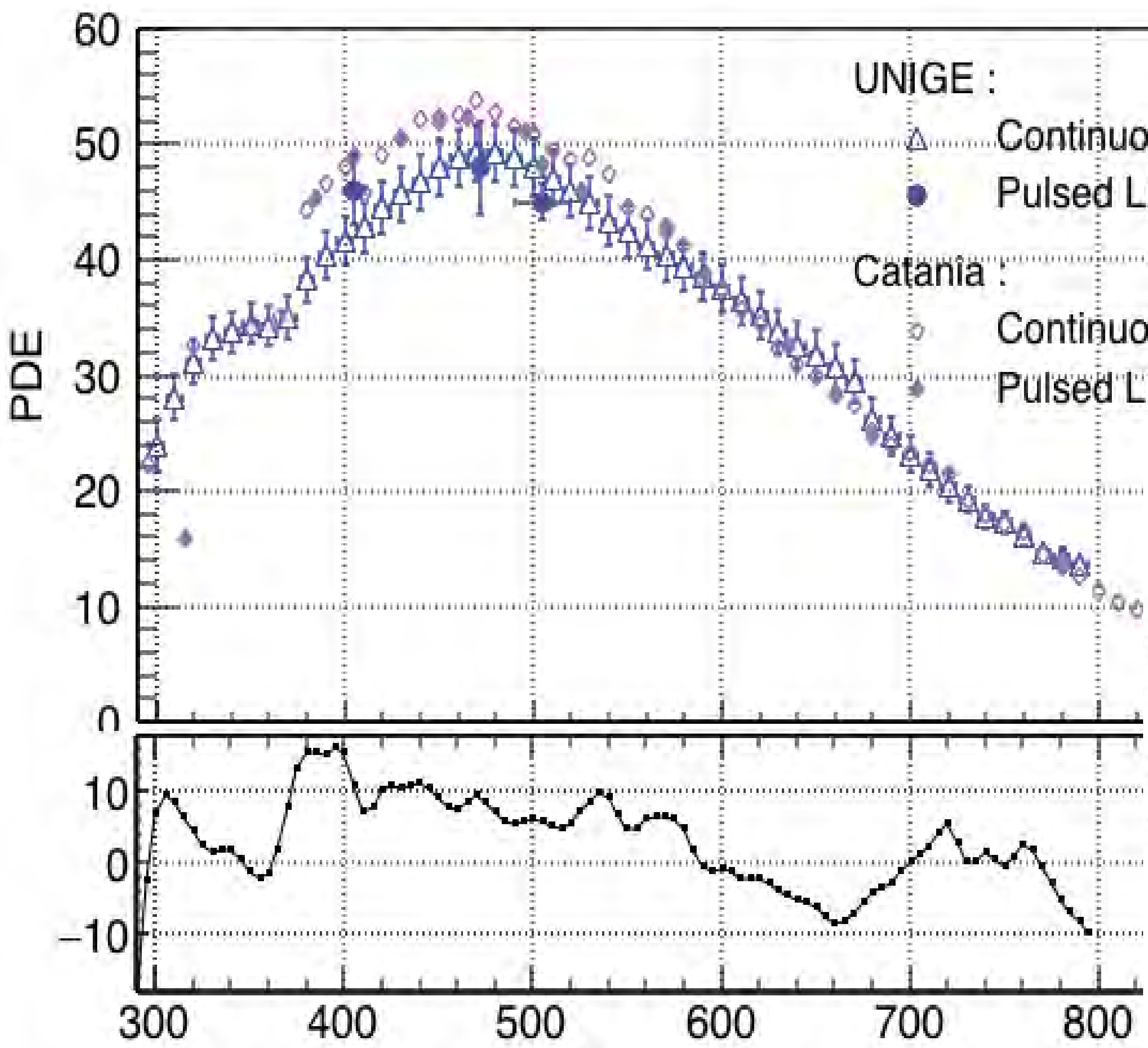
$$100\% \times \frac{PDE_{Catania} - PDE_{Unige}}{PDE_{Unige}} < 2\%$$

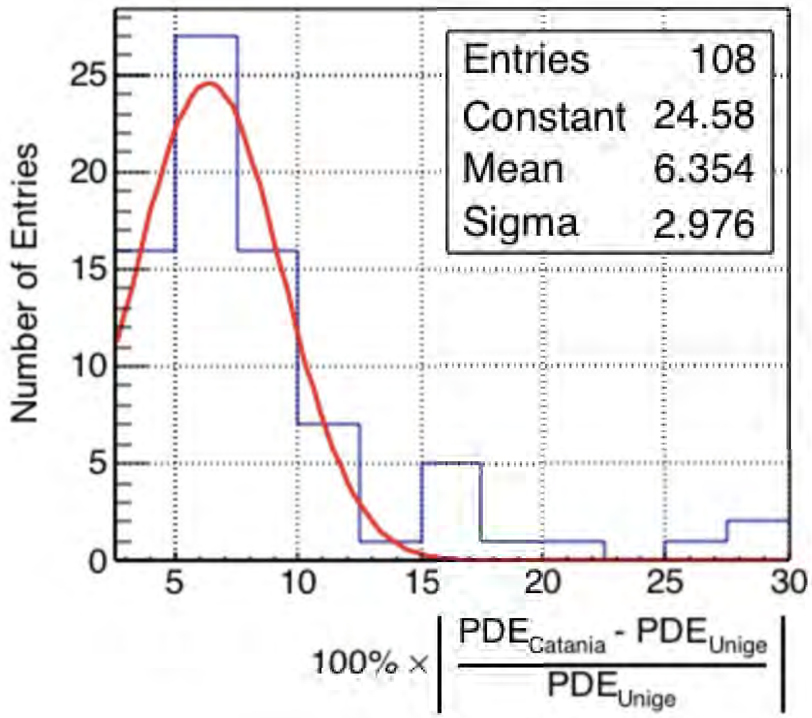




PDE vs. λ : Comparison

Hamamatsu: LVR-3050 @ ΔV = 3V



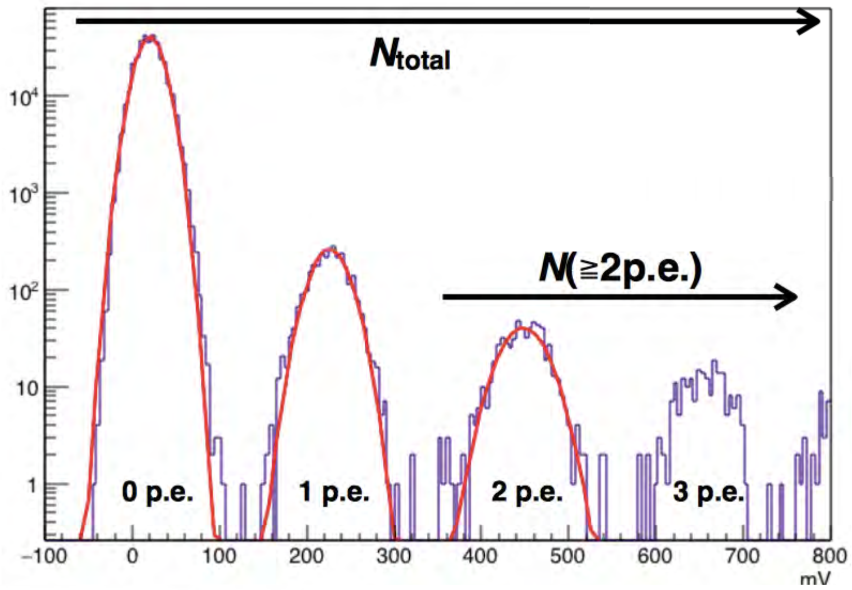


PDE vs. λ measured within 6.4 %

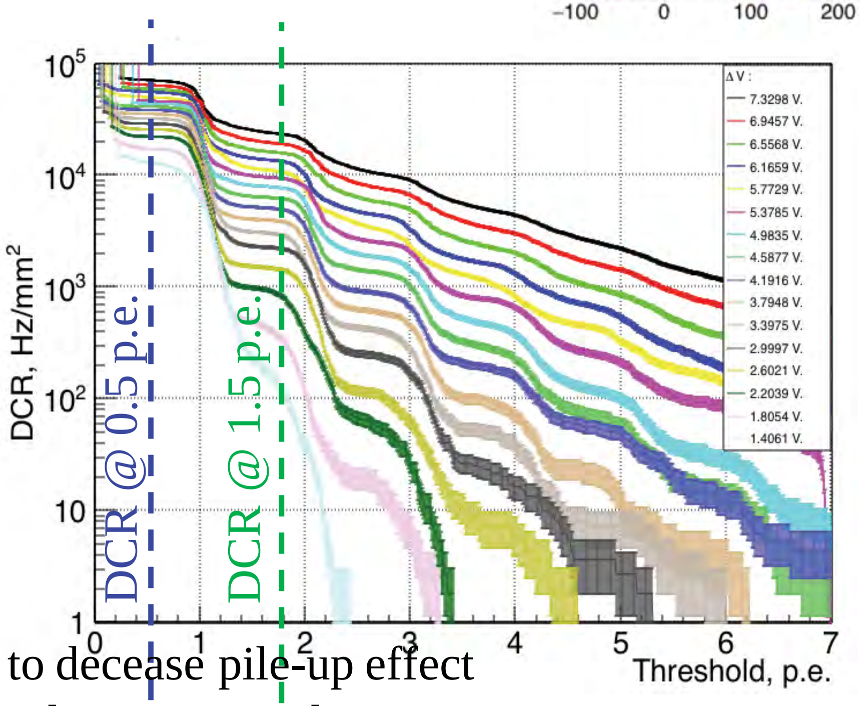
P_{XT} calculation:

Nagoya method:

$$\frac{N(\geq 2\,\text{p.e.})}{N_{\text{total}}} = P(1)R_{\text{OCT}} + P(2) + P(3) + \cdots$$
$$\approx P(1)R_{\text{OCT}} + P(2) + P(3),$$
$$P(1) = \mu P(0),$$
$$P(2) = \frac{\mu^2}{2}P(0),$$
$$P(3) = \frac{\mu^3}{6}P(0),$$
$$R_{\text{OCT}} \approx \frac{N(\geq 2\,\text{p.e.})}{\mu P(0) N_{\text{total}}} - \frac{\mu}{2} - \frac{\mu^2}{6}$$

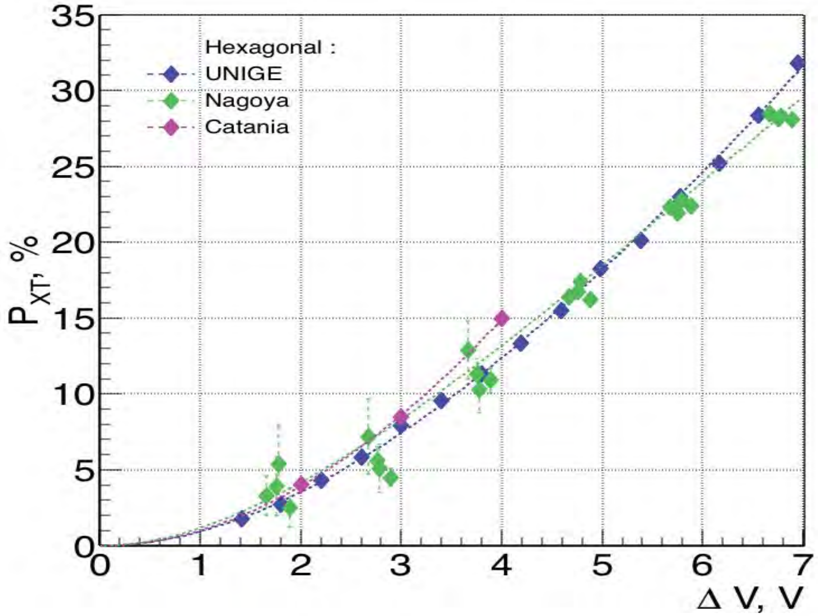


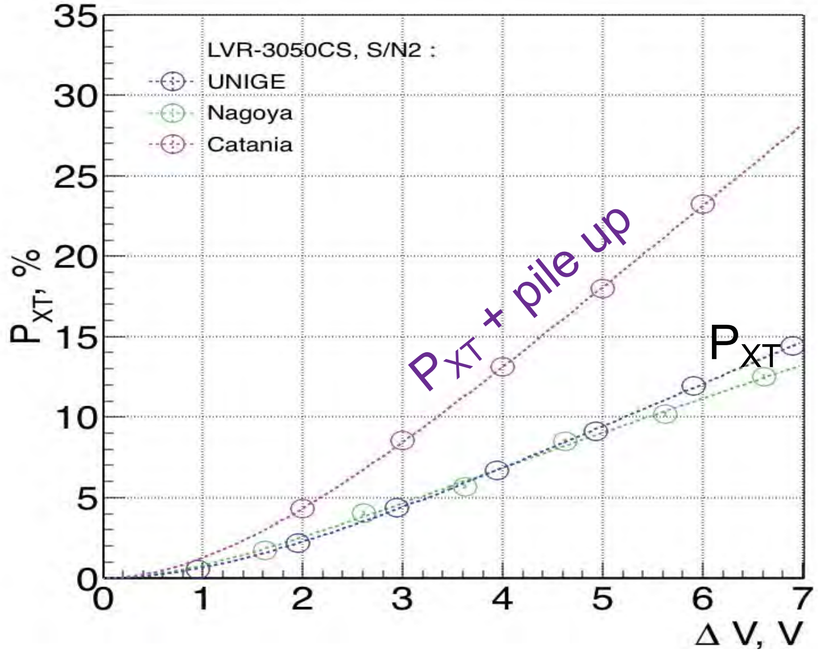
Catania & Unige:

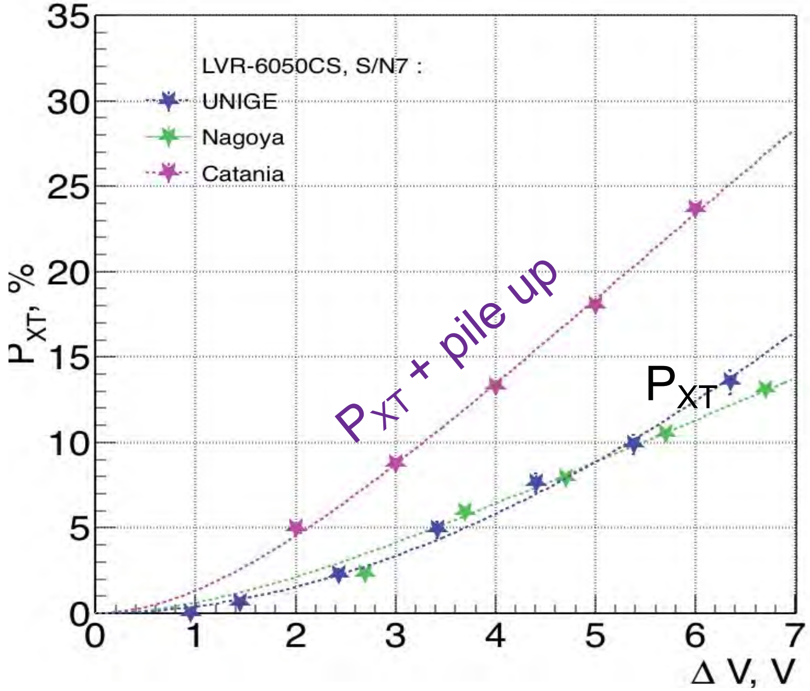


@ Catania measurements at 2 ^{0}C to decease pile-up effect
@ Unige correcting to 2 thermal pulses in coincidence

P_{XT} vs. ΔV: Comparison







Fit:

$$P_{XT}(\Delta V) = P_{hv} \cdot P_{Geiger}(\Delta V) \cdot Gain(\Delta V)$$

Difference in P_{XT} inside error bars up to $\Delta V < 6V$

Results from Task 2.1:

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

- Cooperation agreement between 5 partners signed
- 4 SiPM devices were measured by 3 partners:
  - Three LVR devices;
  - Hexagonal LCT2 device for CTA experiments;
- Validated 3 set-ups and result consistency:

Parameter	PDE vs ΔV	PDE vs λ	P_{XT} vs ΔV
Result consistency	7.8 %	6.4 %	inside error bars up to $\Delta V < 6V$

Future work:

2.2 Linking to other European initiatives

2.3 Fostering the exchange between academia and industry

SENSE

Cooperation agreement between research institutes & industry:

- Contact the producers for their latest devices:
  - Characterize SiPM devices
  - Minimize duplication efforts in characterizing sensors and establish precision on measured quantities
  - Publication of results
  - Create a database with SiPM & their main characteristics