Personal perspective of an MSCA Fellowship

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CERN CMS Collaboration

Outline

◎ Introduction

 ◆ Photon detection and detectors

  ─ Silicon Photomultiplier (SiPM)

 ◆ Dr. Vinogradov

◎ My MSCA project: "SiPM in-depth"

◎ My MSCA fellowship outcomes

◎ My lessons and advices

Flux of photons – stochastic process
Number of photons in space and time – random variable

$Pr(N = n \mid r, dt)$

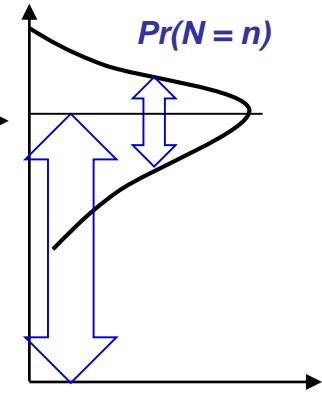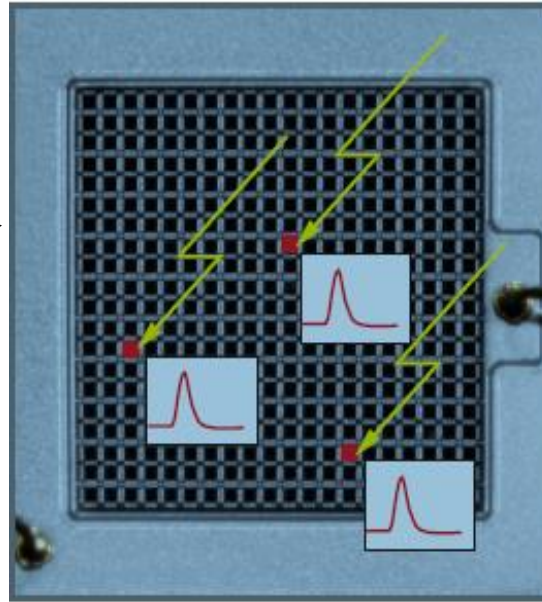**Probability distribution of number of photons in space**
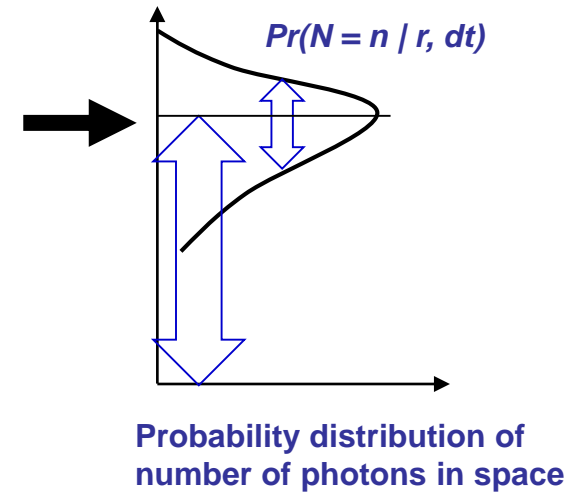
◉ Probability distribution of a random variable fully characterize the random variable

$Pr(N = n \mid dr, t)$

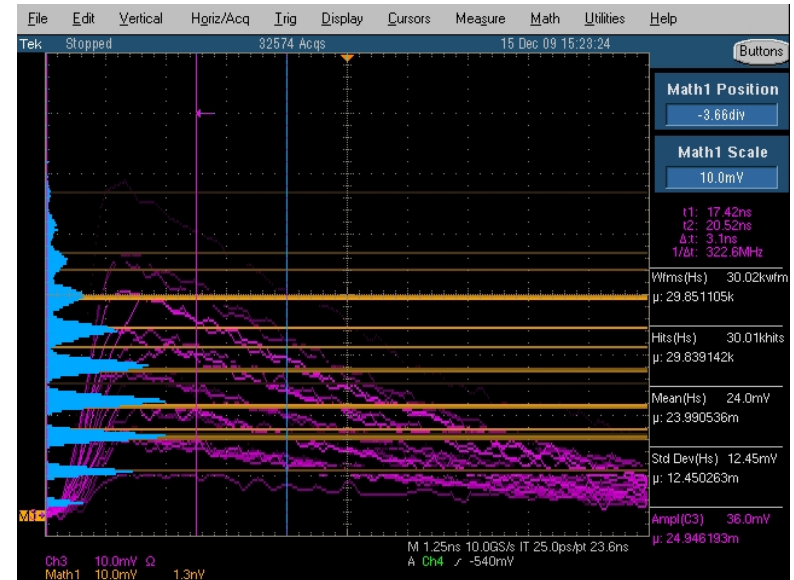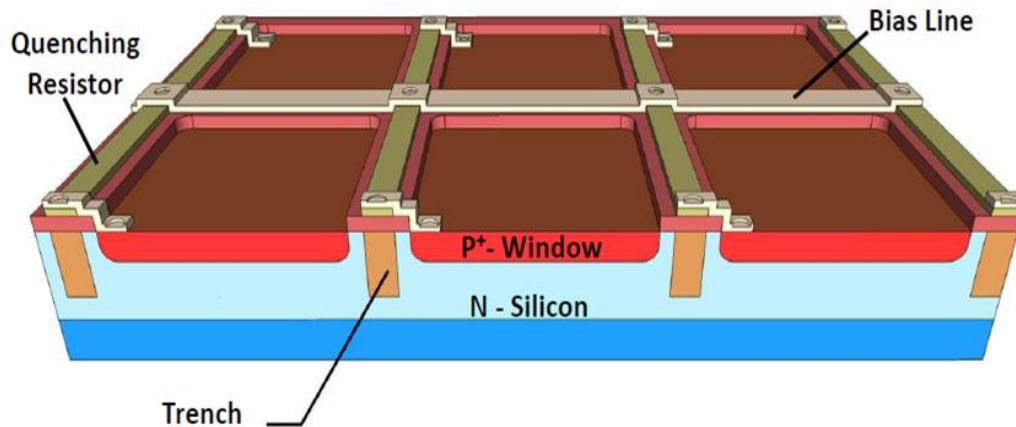**Probability distribution of number of photons in time**
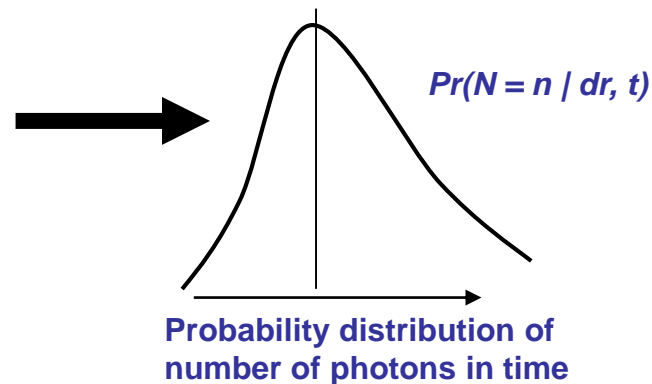
Detection of photons – stochastic process
Detector response (photoelectrons) – random variable

$Pr(N = n)$
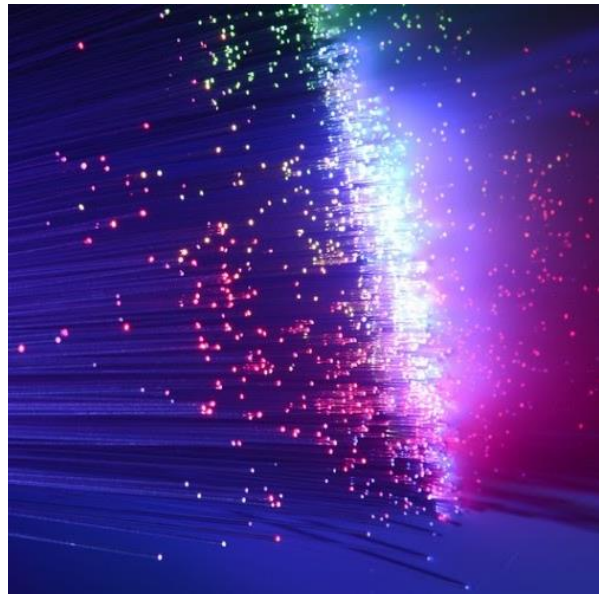
Probability distribution of detected photons

Section of KETEK SiPM Microcell

Quenching Resistor

Bias Line

P^+- Window

N - Silicon

Trench

Introduction

- Moscow State University, (MSc - 1981)

- Lebedev Physical Institute - R&D of photon detectors & SiPM (1982 – now; PhD - 1992)

- IT management "for food" – to survive in the Russian' 1990s

- Amplification Technologies – R&D of SiPM, Russian Lab (2003-2010)

- **QUASAR group – MSCA fellowship (2013-2016)**

- MEPhI - Statistics of SiPM (2016-)

- CERN CMS – Calibration of SiPM (2017-)

Dr. Sergey Vinogradov
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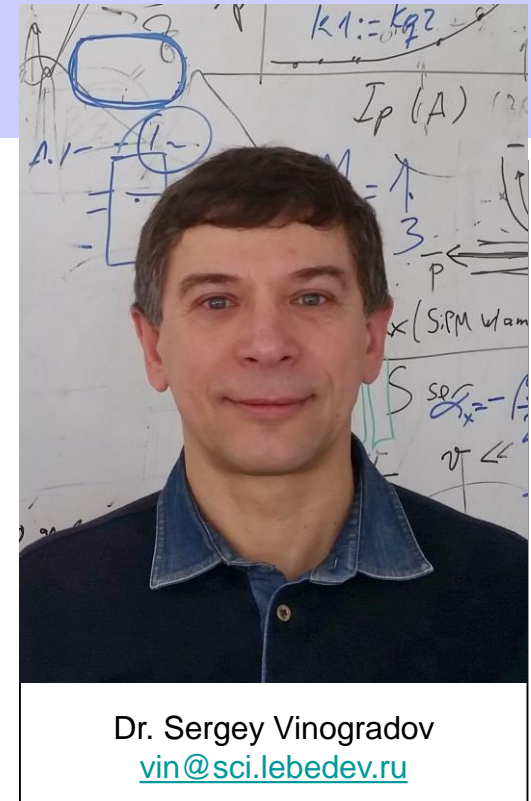
Senior Scientist

Senior SPIE member

Senior IEEE member

Senior Marie Curie fellow

Development of novel analytical and experimental approaches for an in-depth characterization and optimization of Silicon Photomultipliers

FP7-PEOPLE-2012-IIF project "SiPM in-depth"
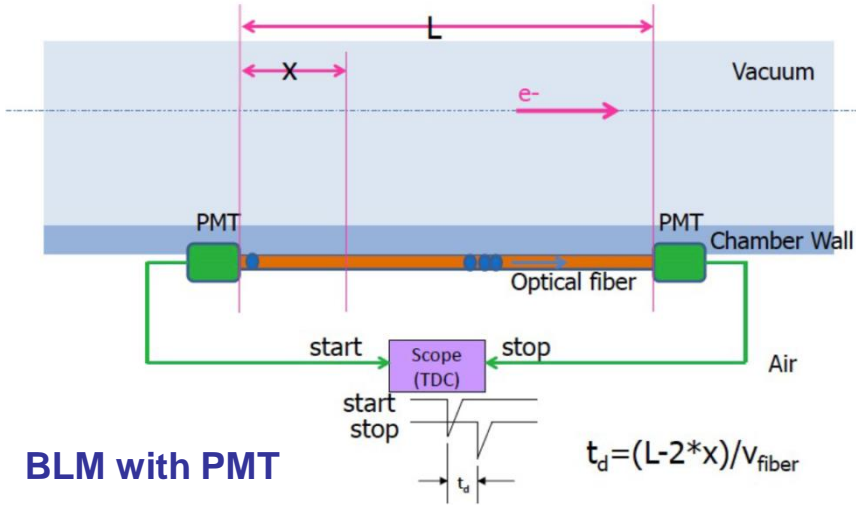**Sep. 2013 – Nov. 2016, €324K**

Main objectives

- Transfer of knowledge on SiPM technology to EU/UK host institutions,
- Advanced R&D to support SiPM-related projects in EU/UK,
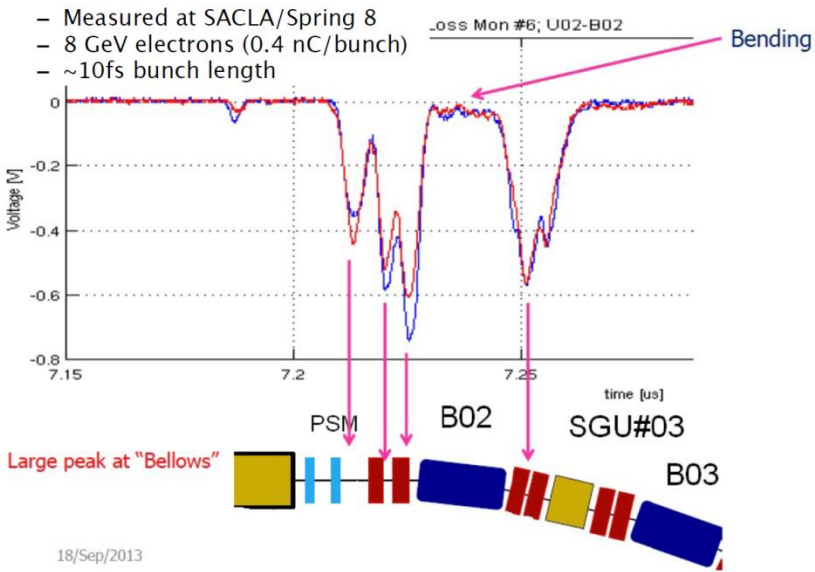- Collaboration between SiPM communities worldwide.

Main results

- Seminars in CI, MSCA schools
- Experimental Setups: CI (advanced SiPM studies) & CERN (BLM studies)
- Simulation, Modeling, Analysis
- Training on SiPM R&D
  - L. Devlin, PhD student, CI
  - M. Kastriotou, PhD student, CERN
  - Dr. E. Nebot, PDRA, CERN
- 10 papers
- 44 presentations
- 30+ events worldwide
  - SiPM BLM @AUSTRALIAN SYNCHROTRON (2016)

BLM with Cherenkov fiber

$$t_d = (L - 2 \cdot x)/v_{fiber}$$

BLM with PMT

- Measured at SACLA/Spring 8
- 8 GeV electrons (0.4 nC/bunch)
- ~10fs bunch length

Large peak at "Bellows"

18/Sep/2013

X.-M. Maréchal et al., DIPAC2009 (SACLA / SPRING 8)

BLM with SiPM

MPPC signal (left scale)
deconvolved signal (right scale)

single event
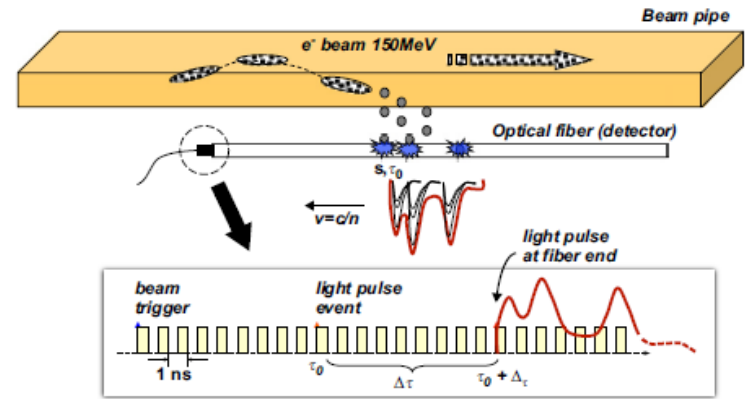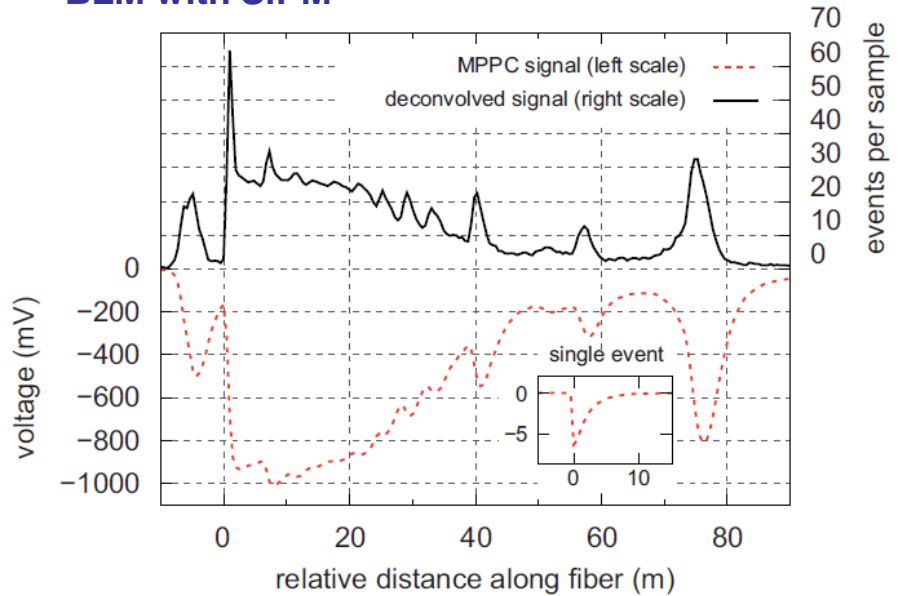
D. Di Giovenale et al., NIMA, 2011 (FERMI@Elettra, Synchrotrone Trieste)

SiPM response & performance for BLM

◎ **Information about losses to be determined**

◆ **Area of pulse → photons → particles per loss event (PNR)**

◆ **Arrival time of pulse → loss location (Time Res)**

◆ **Discrimination of losses (localized / distributed locations)**

— **Pulse pair resolution (pulse FWHM)**

— **Recovery transients (dead time ~ recovery time)**
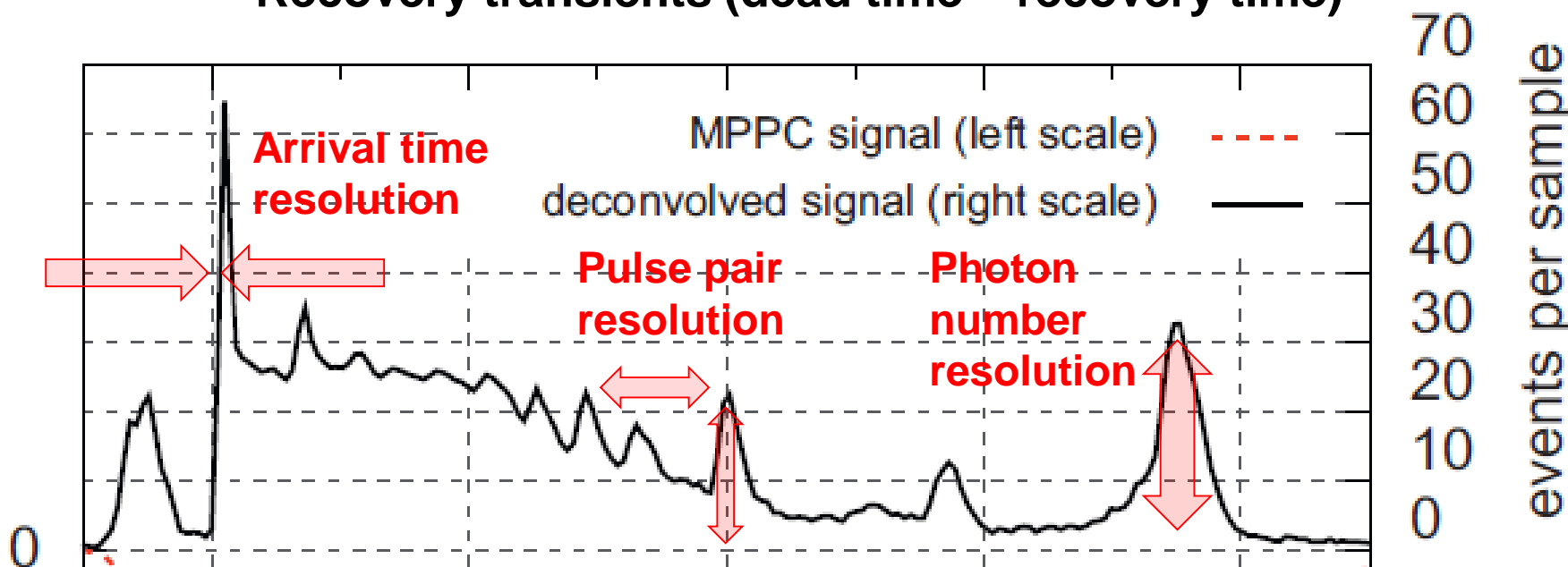
MSCA general outcomes

◉ **Professional qualification & experience of MSCA:**

  ◆ **Top-level projects, R&Ds, infrastructure**

  ◆ **International collaboration & networking**

◉ **Communications & contacts in-person (network!)**

◉ **Information on relevant projects and R&Ds**

  ◆ **Key persons**

  ◆ **Requirements**

  ◆ **Problems**

◉ **Involvement in professional communities / discussions**

◉ **Possibility to offer your expertise / ideas / solutions**

◉ **Understanding of employment situation / jobs**

My actual outcomes

- Member of Scientific Board of the LPI Solid State Physics Division

- Expert of FAST – "Fast Advanced Scintillator Timing" COST action of European Cooperation in the field of Scientific and Technical Research (2014-2018)

- Member of Expert Board of "SENSE – a roadmap for the ideal low light level sensor development" project of the EC FET-Open Horizon 2020 (2016 – 2019)

- Co-organizer/co-chair of Brainstorming Workshop on Factors influencing the timing resolution of SiPMs, Calvi, Corsica, France, May 07-08, 2015.

- Co-organizer/convener/invited expert of the (1st!) International Conference on the Advancement of Silicon Photomultipliers, 11-15 June 2018, Schwetzingen, Germany (http://icasipm.org)

- Collaboration with MEPhI on SiPM physics, statistics, metrology, and applications

- Collaboration with CERN on SiPM calibration at radiation degradation

- Collaboration with KETEK, Germany, on SiPM R&D and metrology

- Professorship at the Insubria University, Como, Italy on SiPM statistics for PhD & ESR

My advices

- ◉ We are in R&Ds to meet unknown & unresolvable =>
  - ◉ Be happy with problems and challenges!
  - ◉ Be systematic to identify a whole challenge:
    - ◉ Goal - at the edge of your performance!
    - ◉ Problem – why such a valuable goal is not achieved yet?
    - ◉ State-of-art – all about known and resolvable for that challenge

    REMARK: a lack of systematic knowledge on that is typical for PhDs

- ■ Be creative to generate new ideas and solutions
  - ▪ What if nothing happens? How to be creative?!

ADVICE: exchange the problems with your peers rather than success stories

look at "similar" problems and solutions/tools in other areas

look at synergy with your peers to resolve your challenges

REMARK to Carsten: QUASARthon => QUASAR-HAKAthon

E.g.: "Accelerator-on-chip", "Ideal photon detector", "Ideal beam profiler"...

Ultimate Low-Light Level Sensor Development

The end

Thank you for your attention!

Questions?

Objections?

Opinions?

…

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"SiPM in-depth" knowledge transfer

1. Training in form of Cockcroft Institute Seminars (Dec. 2013 - May 2014), covering all essential areas required for experimental studies, characterization, simulation, and implementation of SiPM technology:

- Silicon Photomultipliers: physics, concepts, and designs
- Silicon Photomultipliers: application areas and large projects
- Silicon Photomultipliers: measurement and characterization methodology
- Silicon Photomultipliers: probabilistic modelling and analysis
- Silicon Photomultipliers: state-of-art, challenges, and perspectives

2. Development of experimental setups for SiPM studies at the CI and CERN adapted for comprehensive characterization of SiPM performance in Beam Loss Monitoring (high intensity arbitrary waveform light signals):

- Measurements of transient SiPM response (CI Optics Lab)
- Fast timing measurements of 60 ps double pulse response (CERN BI Lab)

3. Training on SiPM measurement and characterization to the QUASAR Group members involved in R&D on Beam Loss Monitoring systems with SiPM:

- L. Devlin, PhD student, CI
- M. Kastriotou, PhD student, CERN
- Dr. E. Nebot, PDRA, CERN

4. Training on modeling of SiPM response and performance for the same QUASARs:

- Analytical probabilistic models of SiPM response based on transformation of probability distribution of random variables in stochastic processes of photodetection
- Numerical simulations of these stochastic processes
- Processing of experimental data
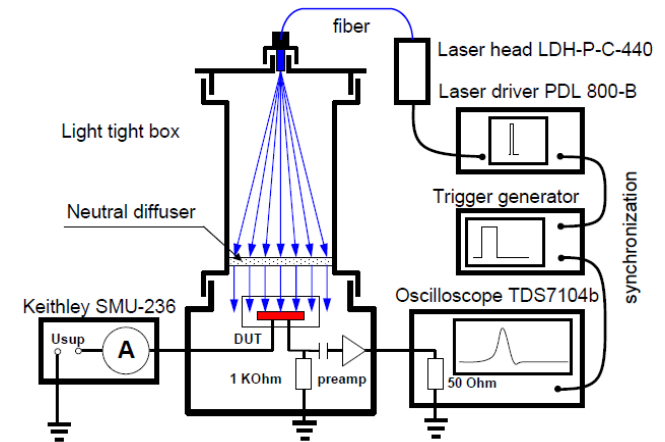
Setup for precision measurements of transient SiPM response to intense light pulses (Cockcroft Institute Optics Lab)
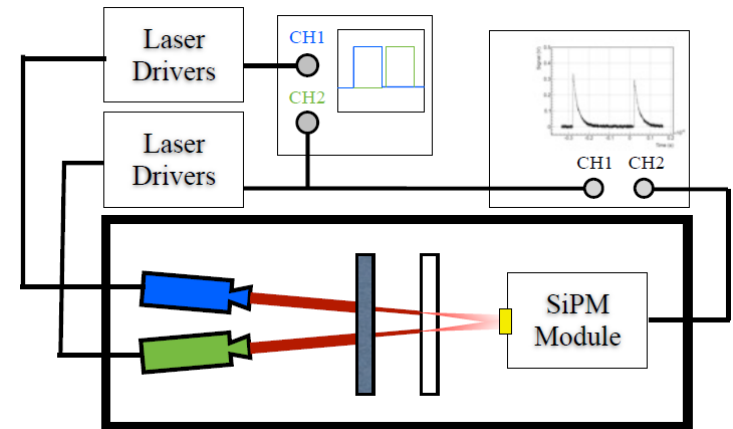
Setup for fast timing measurement of SiPM response and recovery at 60 ps double laser pulses (CERN, Beam Instrumentation Department Lab)

"SiPM in-depth" publications

1. S. Vinogradov, L. Devlin, E. Nebot del Busto, M. Kastriotou, and C. P. Welsch "Challenges of arbitrary waveform signal detection by SiPM in beam loss monitoring systems with Cherenkov fibre readout", Proc. of Science (PoS SISSA) -4 p. (accepted) Nov. 2015.

2. S. Vinogradov, "Performance of Silicon Photomultipliers in photon number and time resolution", Proc. of Science (PoS SISSA) -8 p. (submitted) Oct. 2015.

3. E. Engelmann, S. Vinogradov, E. Popova, F. Wiest, P. Iskra, W. Gebauer, S. Löbner, Ch. Dietzinger, T. Ganka, R. Fojt, and W. Hansch, "Extraction of Activation Energies from Temperature Dependence of Dark Currents of SiPM", Proc. of ICPPA-2015, -5p. (accepted) Oct. 2015.

4. S. Vinogradov, "The Silicon Photomultiplier Concept and Design Development", Astroparticle Physics European Consortium News, -4p. Apr. 2015; http://www.appec.org/index.php?view=article&id=119

5. S. Vinogradov, 'Analytical model of SiPM time resolution and order statistics with crosstalk' Nucl. Instr. Methods A (2015), pp. 229-233; http://dx.doi.org/10.1016/j.nima.2014.12.010.

6. S. Vinogradov, A. Arodzero, R.C. Lanza, and C.P. Welsch, 'SiPM response to long and intense light pulses', Nucl. Instr. Methods A (2015), pp. 148-152; http://dx.doi.org/10.1016/j.nima.2014.11.079.

7. E. Popova, P. Buzhan, A. Pleshko, S. Vinogradov, A. Stifutkin, A. Ilyin, D. Besson, and R. Mirzoyan, 'Amplitude and Timing properties of a Geiger discharge in a SiPM cell', Nucl. Instr. Methods A (2015), pp. 270-274; http://dx.doi.org/10.1016/j.nima.2014.12.050.

8. S. Vinogradov, "New approach to calibration of low gain PMTs and SiPMs using transit time histograms," Proc. of IEEE Nuclear Science Symposium and Medical Imaging Conference 2013, pp. 1–8. http://dx.doi.org/10.1109/NSSMIC.2013.6829596

9. S. Vinogradov, A. Arodzero, and R. C. Lanza, "Performance of X-ray detectors with SiPM readout in cargo accelerator-based inspection systems," Proc. of IEEE Nuclear Science Symposium and Medical Imaging Conference 2013, 2013, pp. 1–6. http://dx.doi.org/10.1109/NSSMIC.2013.6829597

10. Arodzero, A. Bolozdynya, R. C. Lanza, A. Murokh, V. Palermo, A. Pudikov, J. Rosenzweig, S. Ulin, S. Vinogradov, and A. Zimin, 'World Wide Student Laboratory: Global Educational Infrastructure for Remote Experimentation', Proc. of ICEE/ICIT-2014, -8p., 2014; http://ineer2014.rtu.lv/sites/default/files/Paper_132.pdf