Digital Silicon Photomultiplier Design Flow

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High Energy Physics: particle detection

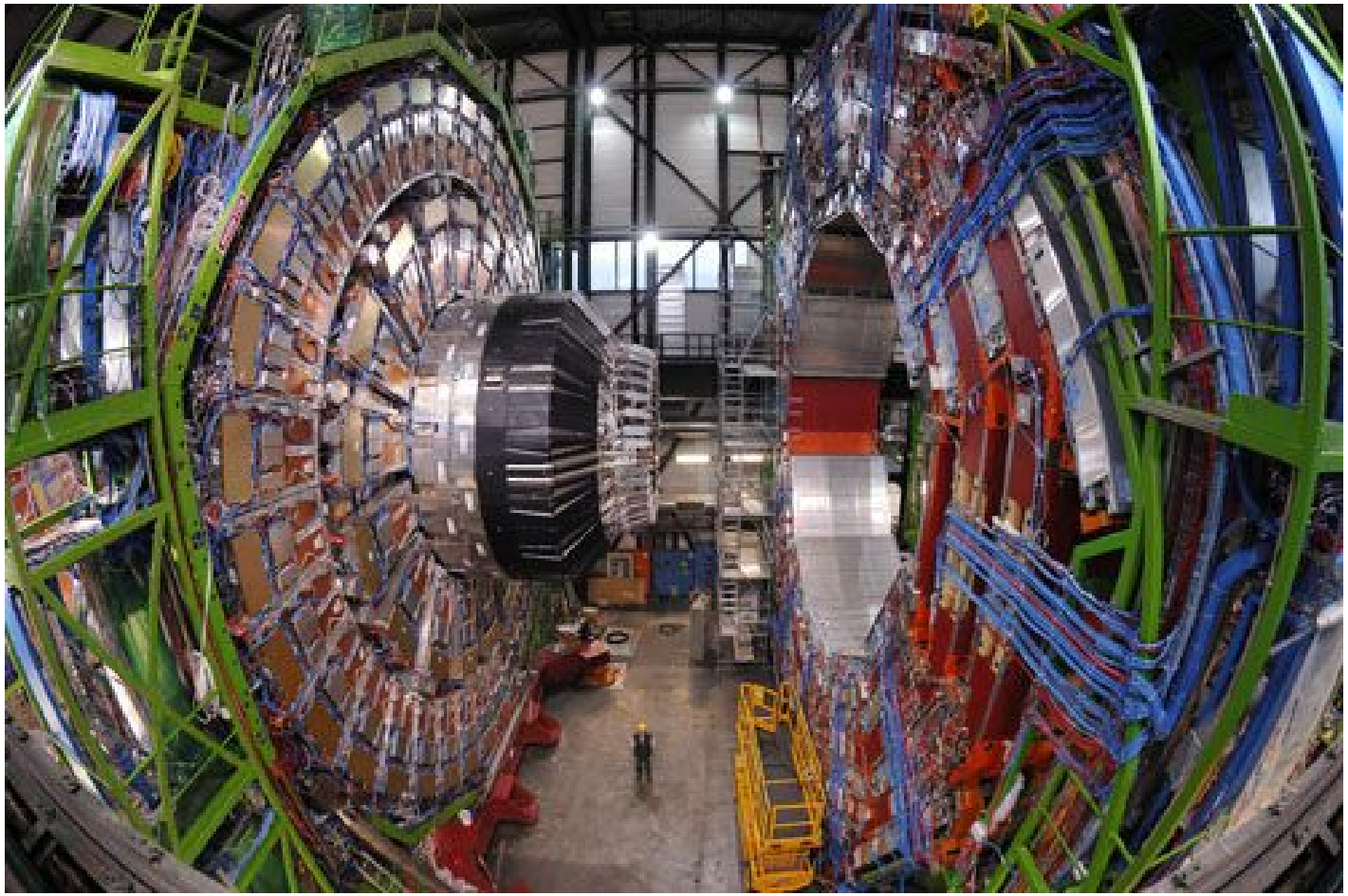


Figure: (cc) CMS detector at Large Hadron Collider (CERN).

Bio-medicine: FLIM and PET.

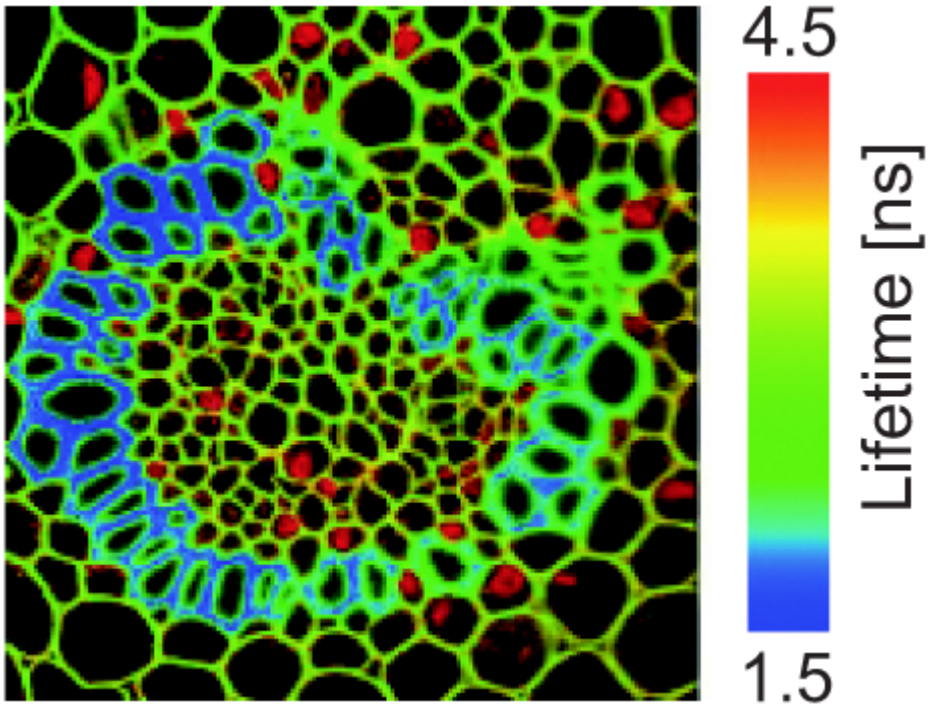


Figure: ©FLIM: Pico Quant.

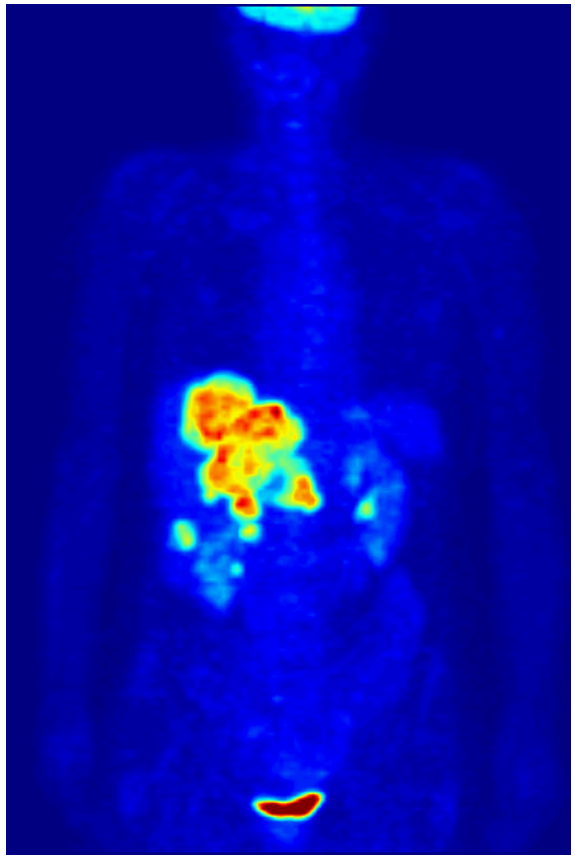


Figure: (cc) PET from liver metastases of a colorectar tumor (I, Jens Maus).

Detection block

Each detector block is composed of a scintillator crystal and a photodetector).

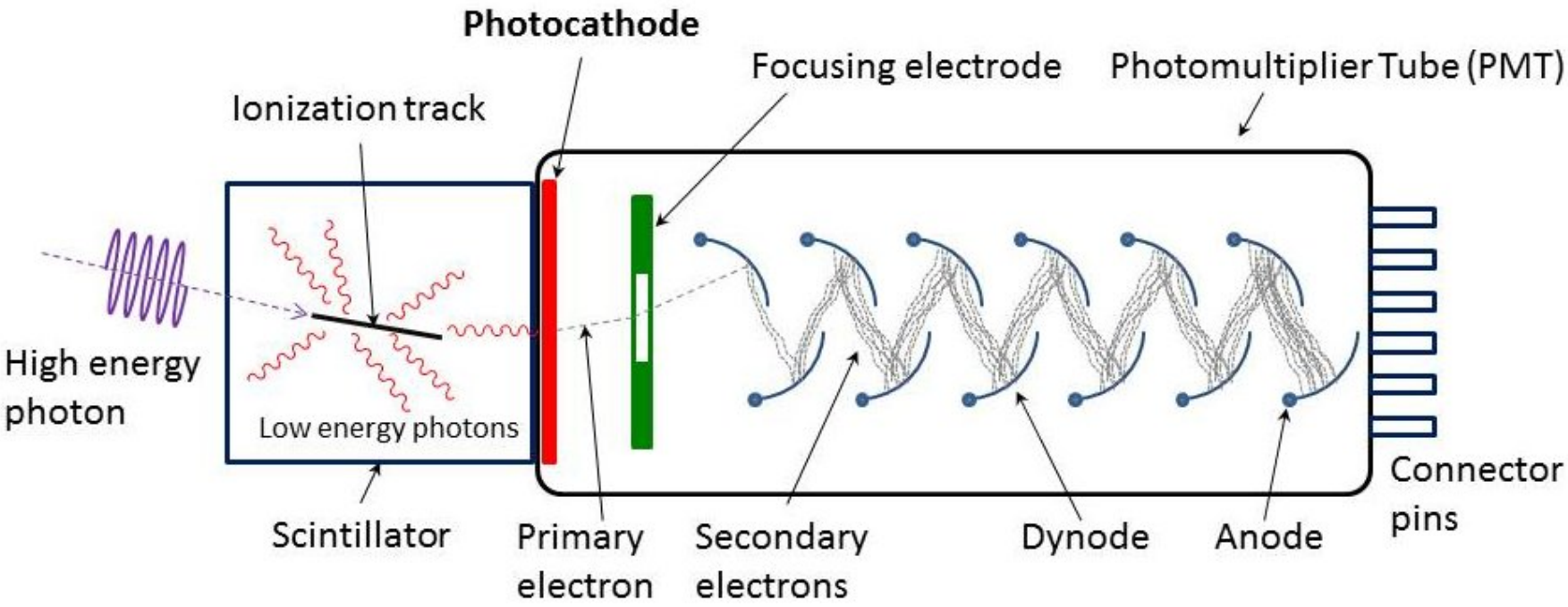


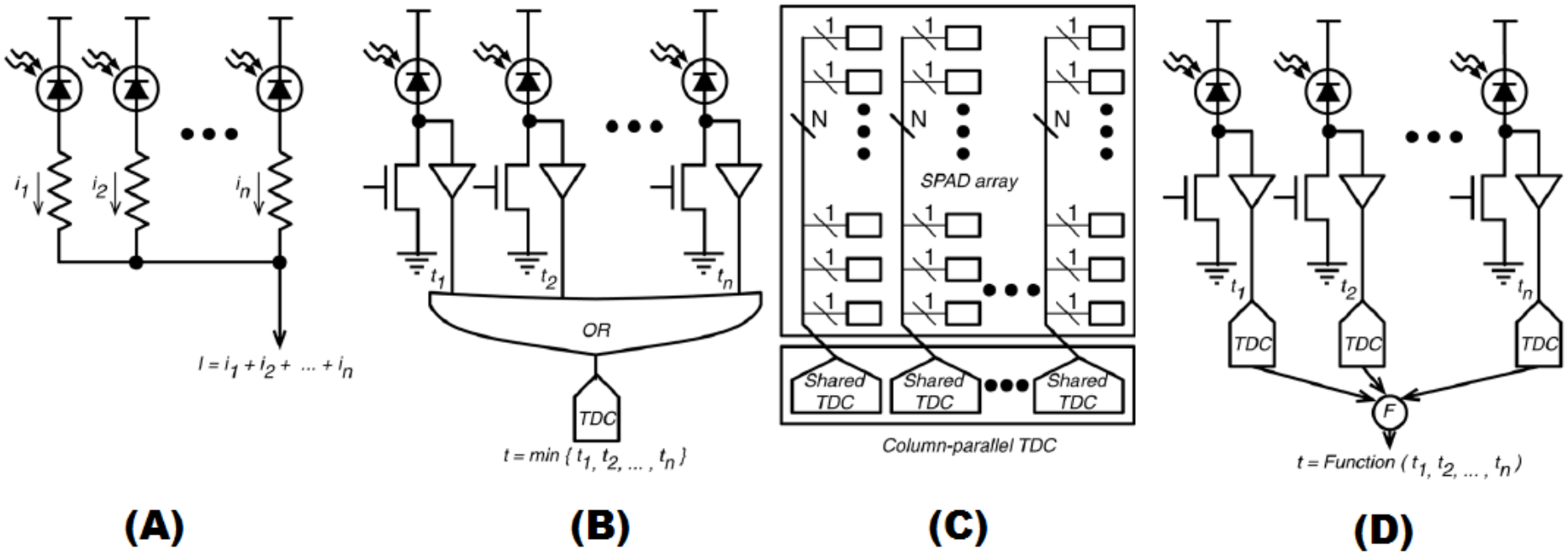
Figure: (cc) Qwerty123uiop.

Benefits of SiPMs over PMTs

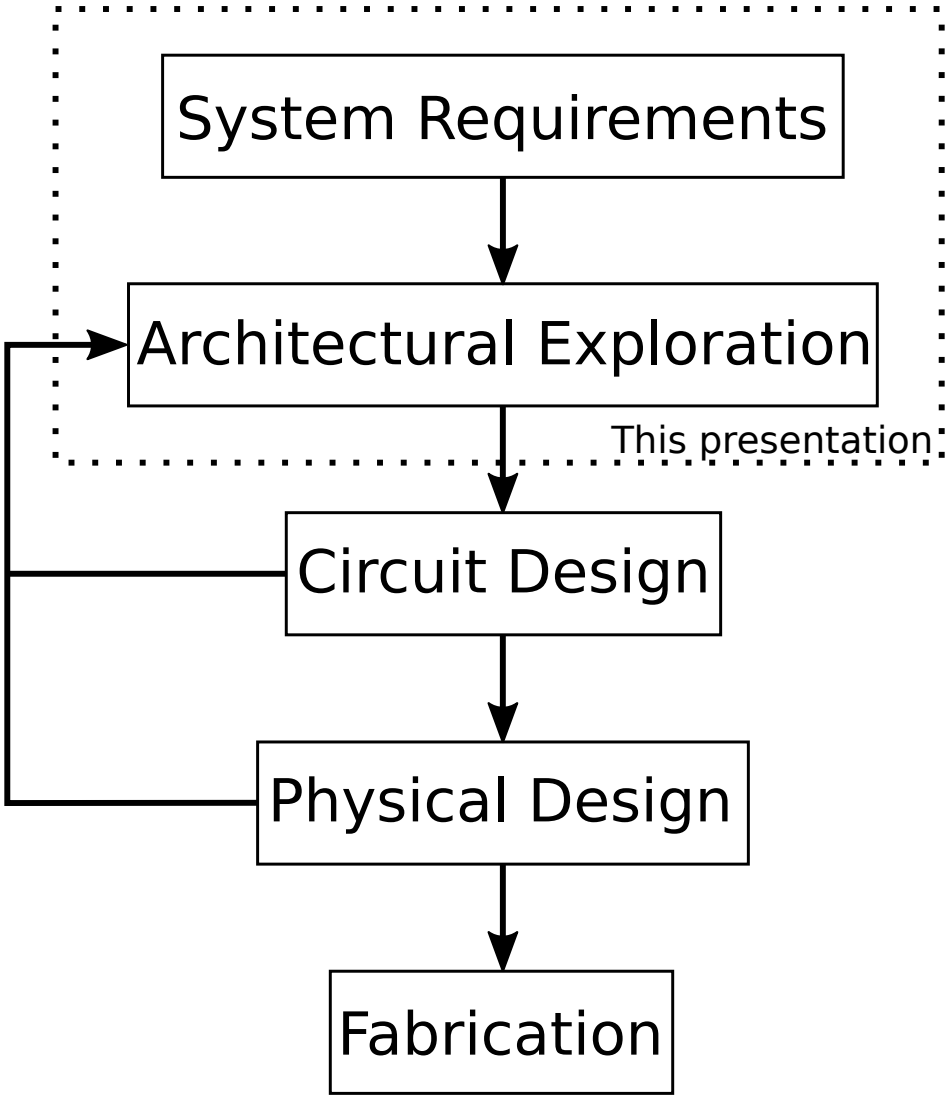
	PMT	SiPM
Power	✗	✓
Low bias voltage	✗	✓
Compactness	✗	✓
Spatial resolution	✗	✓
High gain	✓	✓
Magnetic field compatible	✗	✓
In-pixel detection processing	✗	✓
Cost/unit	✗	✓

Digital Silicon Photomultiplier

Digital Silicon Photomultipliers (d-SiPMs) can provide two measurements: the arrival time of particles to the scintillator crystal and the amount of energy involved at the interaction (counted photons).



Design Flow


System Requirements
Architectural Exploration
This presentation
Circuit Design
Physical Design
Fabrication

System Requirements

- Low light density ($D_{ph} = 450(1 - e^{-T_{clk}/\tau})$).
- Smart pixels:
  - FSM to detect scintillation events.
  - TDC to allow PET-TOF.
  - Large number of SPADs to keep linearity.
- Pixel size: 1.5x1.5mm^2 to increase spatial resolution and distinguish Compton and Photoelectric interactions.

Pixel Architectural Exploration

During the architectural exploration, the characteristics of a SiPM based on the level of shared logic can be determined.

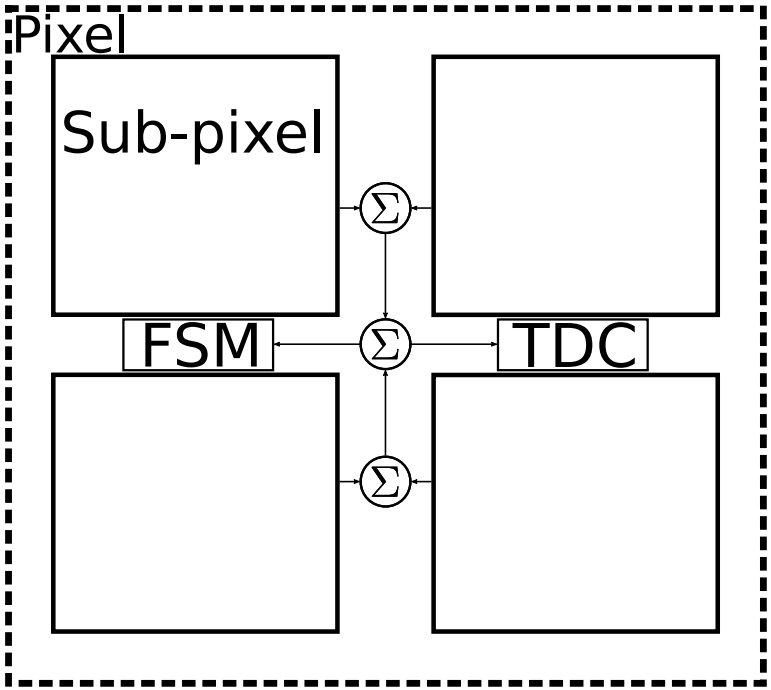


Figure: Diagram of digital SiPM.

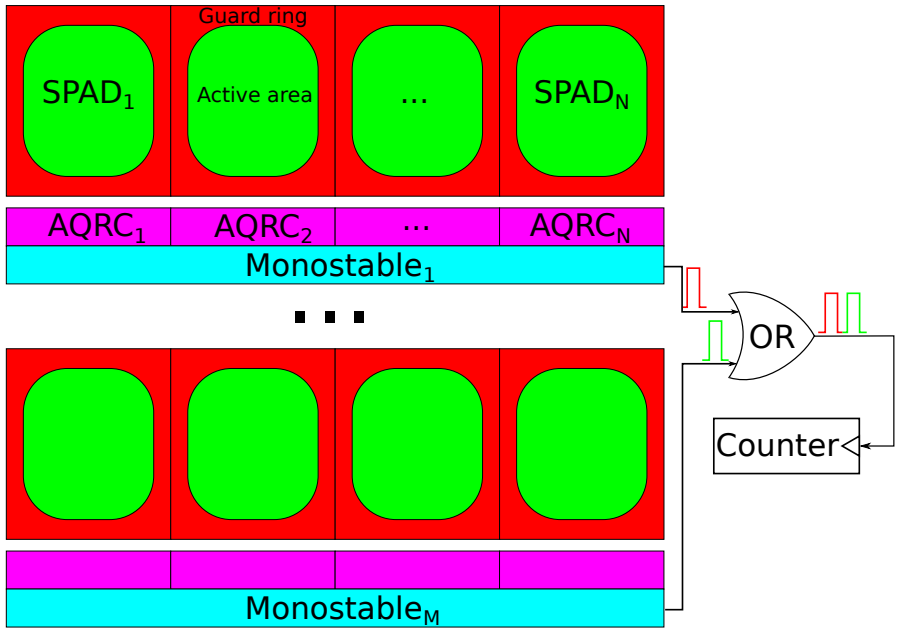


Figure: Diagram of sub-pixel.

Consideration for Architectural Exploration

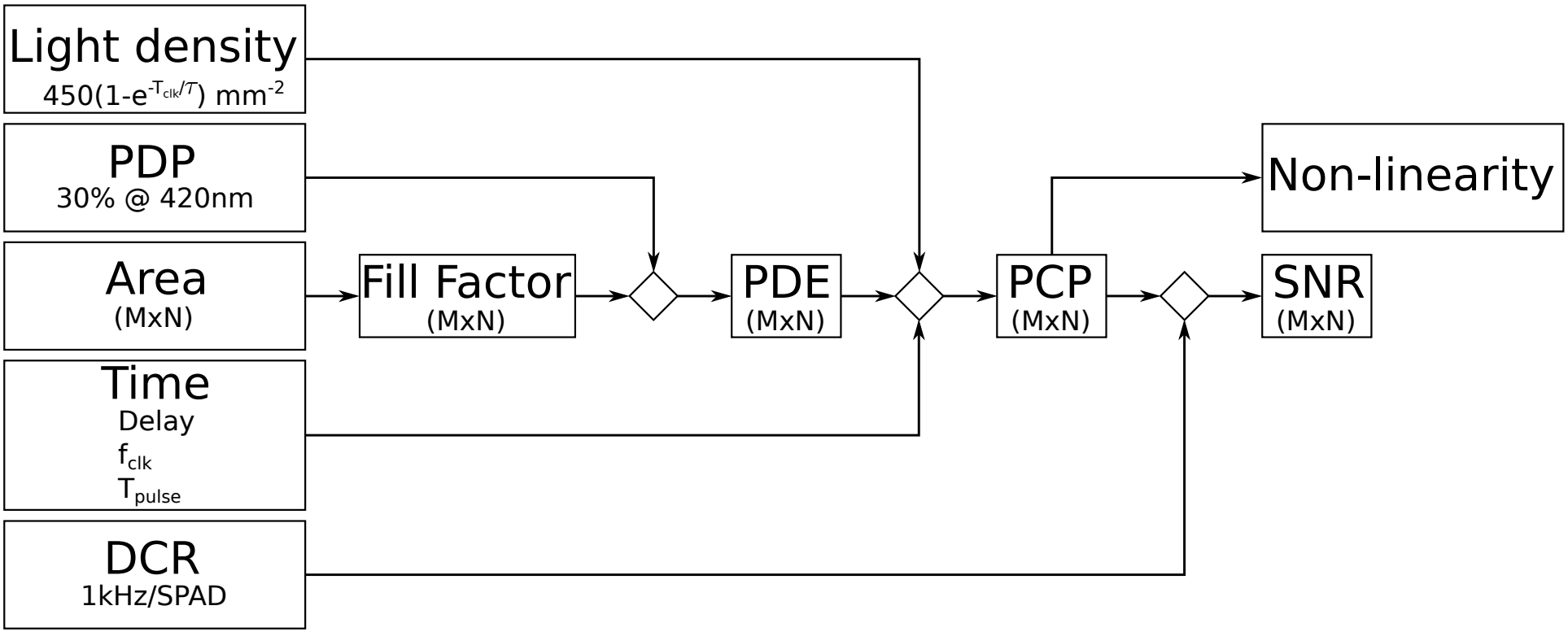


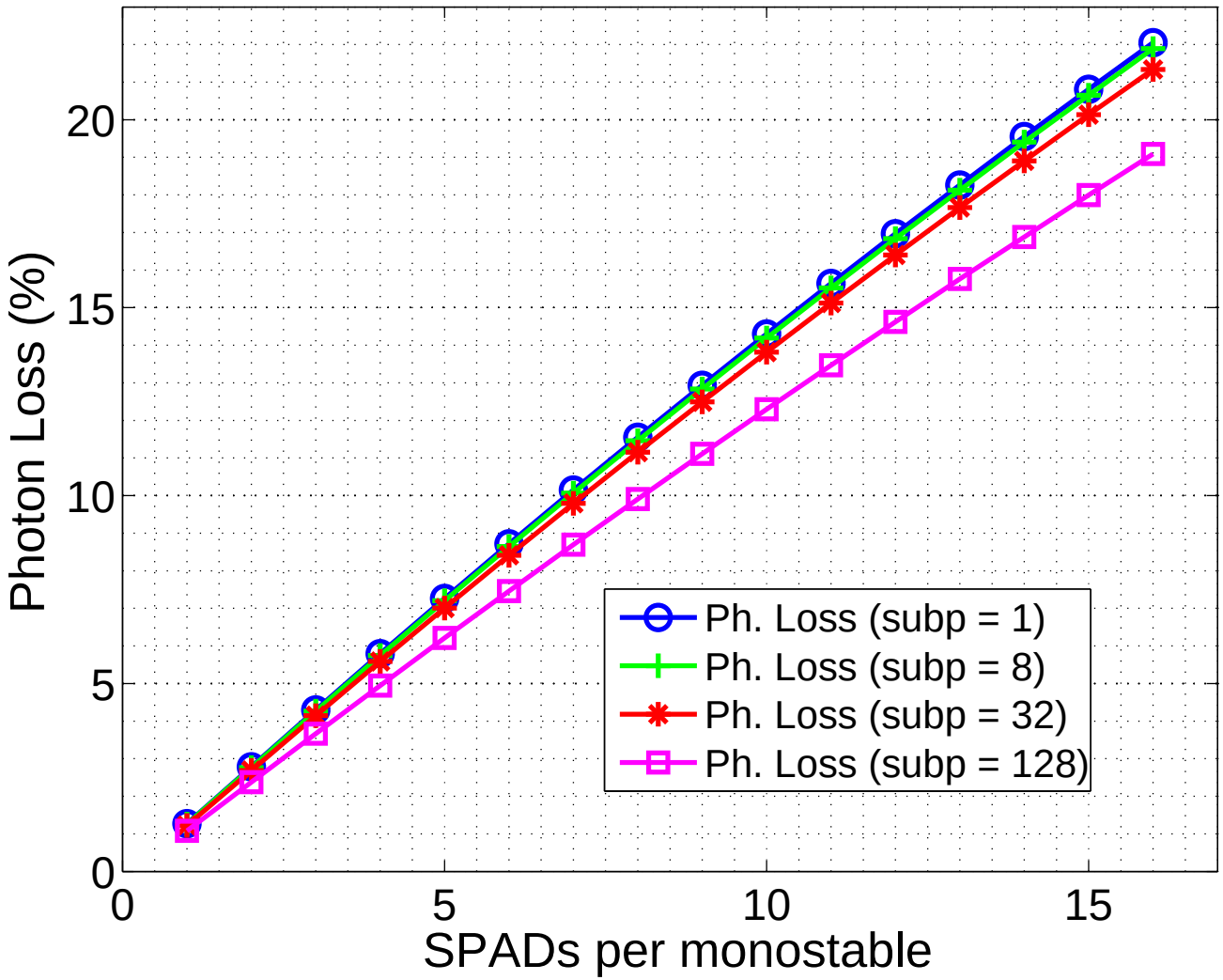
Figure: M is the number of sub-pixels/pixel and N is the number of SPADs/monostable.

Photon Counting Probability

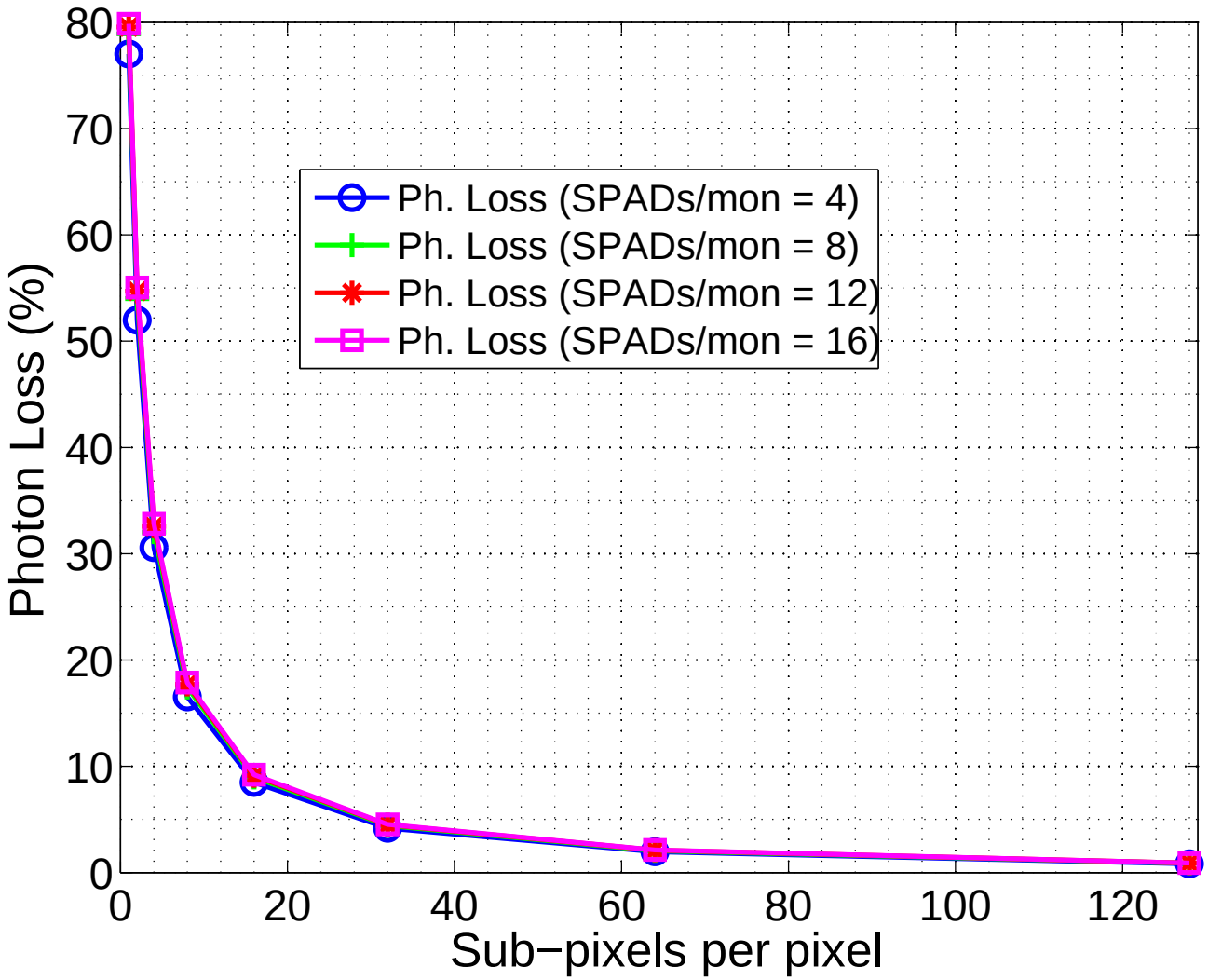
The photon losses due to spatial and temporal compression (P_{sp} and P_{tp}) [Braga 2011 IEEE NSS] are needed to determine the Photon Counting Probability (PCP):

$$\begin{aligned} PCP &= PDE \cdot (1 - P_{sp}) \cdot (1 - P_{tp}) \\ P_{sp} &= 1 - e^{-N_{SPAD} \cdot PDE \cdot D_{ph} \cdot A_{SPAD}} \\ P_{tp} &= 1 - e^{-\frac{N_{SPAD}}{M_{spxl}} \cdot PDE \cdot D_{ph} \cdot A_{SPAD} \cdot T_{pulse} \cdot f_{clk}} \end{aligned} \tag{1}$$

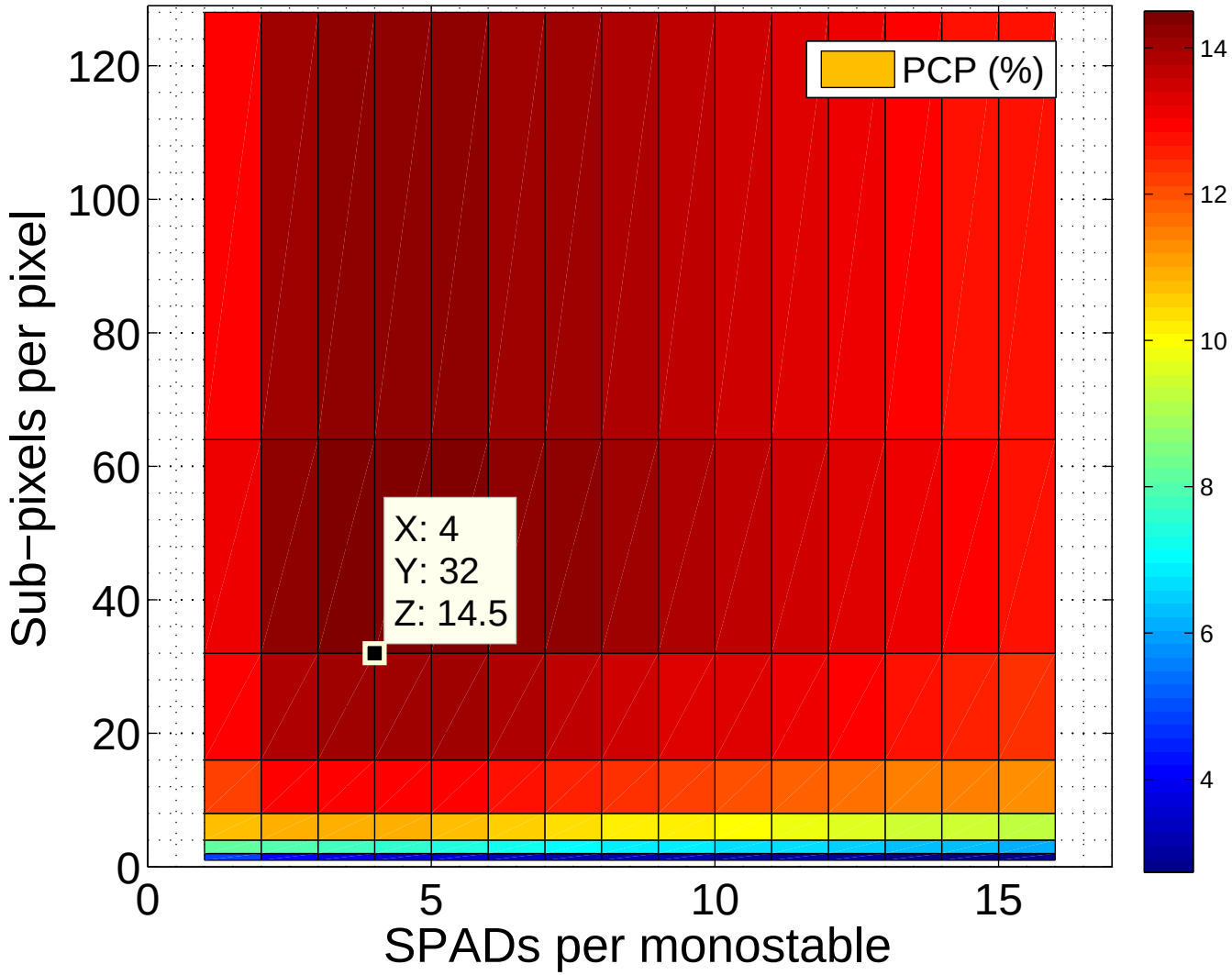
Photon loss due to spatial compression



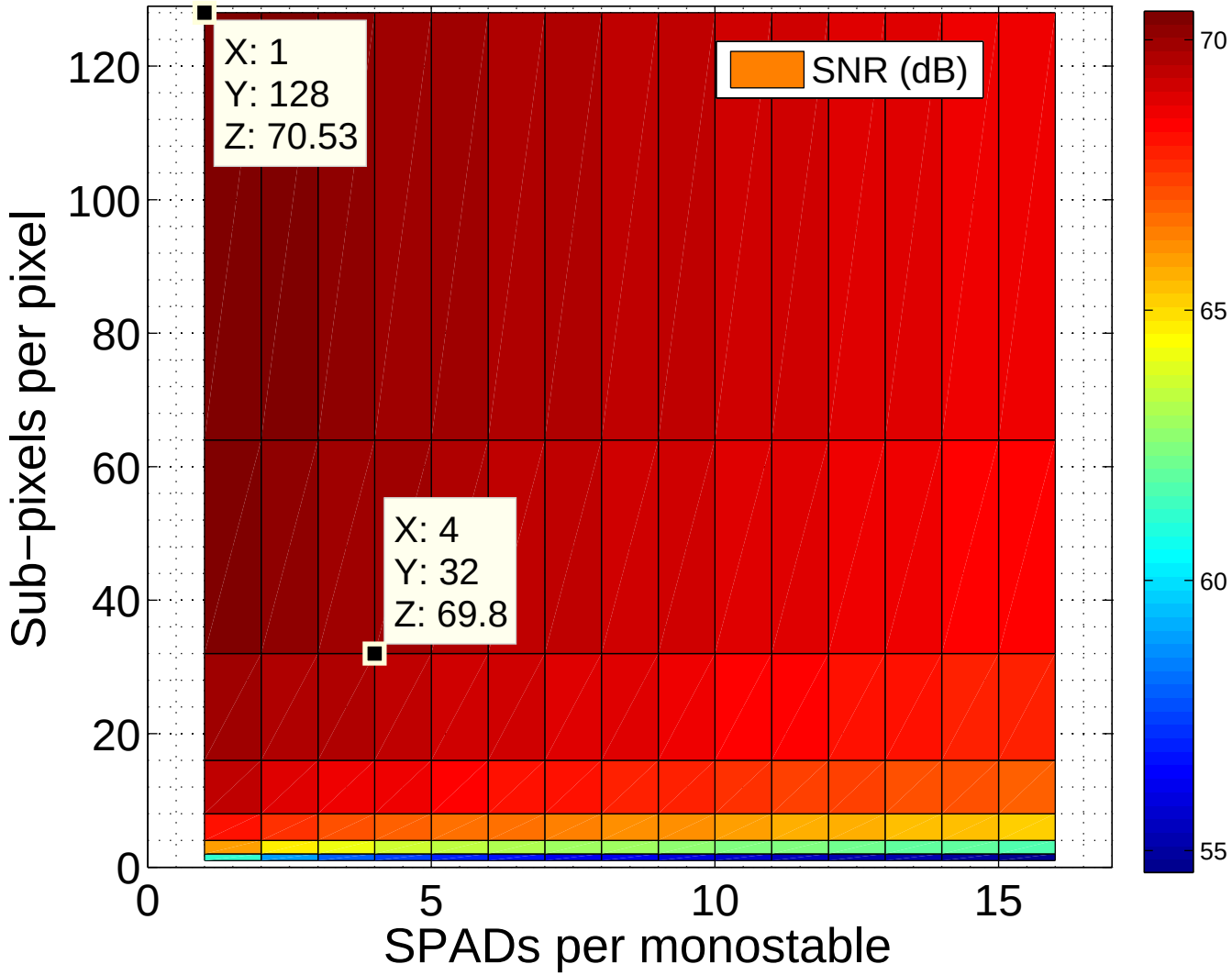
Photon loss due to temporal compression



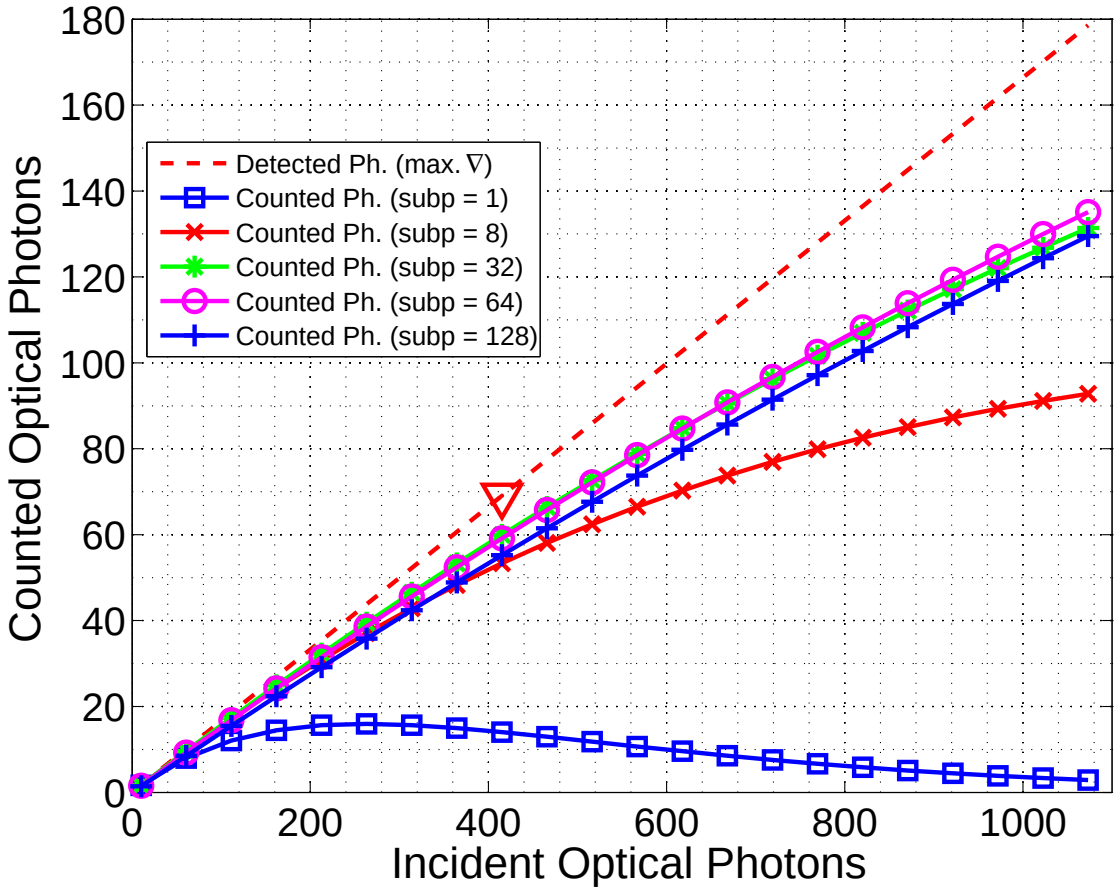
PCP vs sub-pixels/pixel and SPADs/monostable



SNR vs sub-pixels/pixel and SPADs/monostable



Linearity



M_{spxl}	Non-linearity (%)
1	1226.5
2	116.8
4	41.6
8	19.9
16	11.4
32	7.5
64	5.5
128	4.3

Figure: Counted photons as a functions of the detected photons with 4 SPADs per monostable.

Conclusions

- The proposed method allows the estimation of PCP, SNR and non-linearity.
- A maximum of PCP is found at 32 sub-pixels/pixel and 4 SPADs/monostable.
- No maximum is found for SNR.

Future work

- SiPM's opto-electrical characterization.
- SiPM's energy resolution and coincidence resolving time characterization.
- Design the second prototype that will include FSM, PLL...

Acknowledgments

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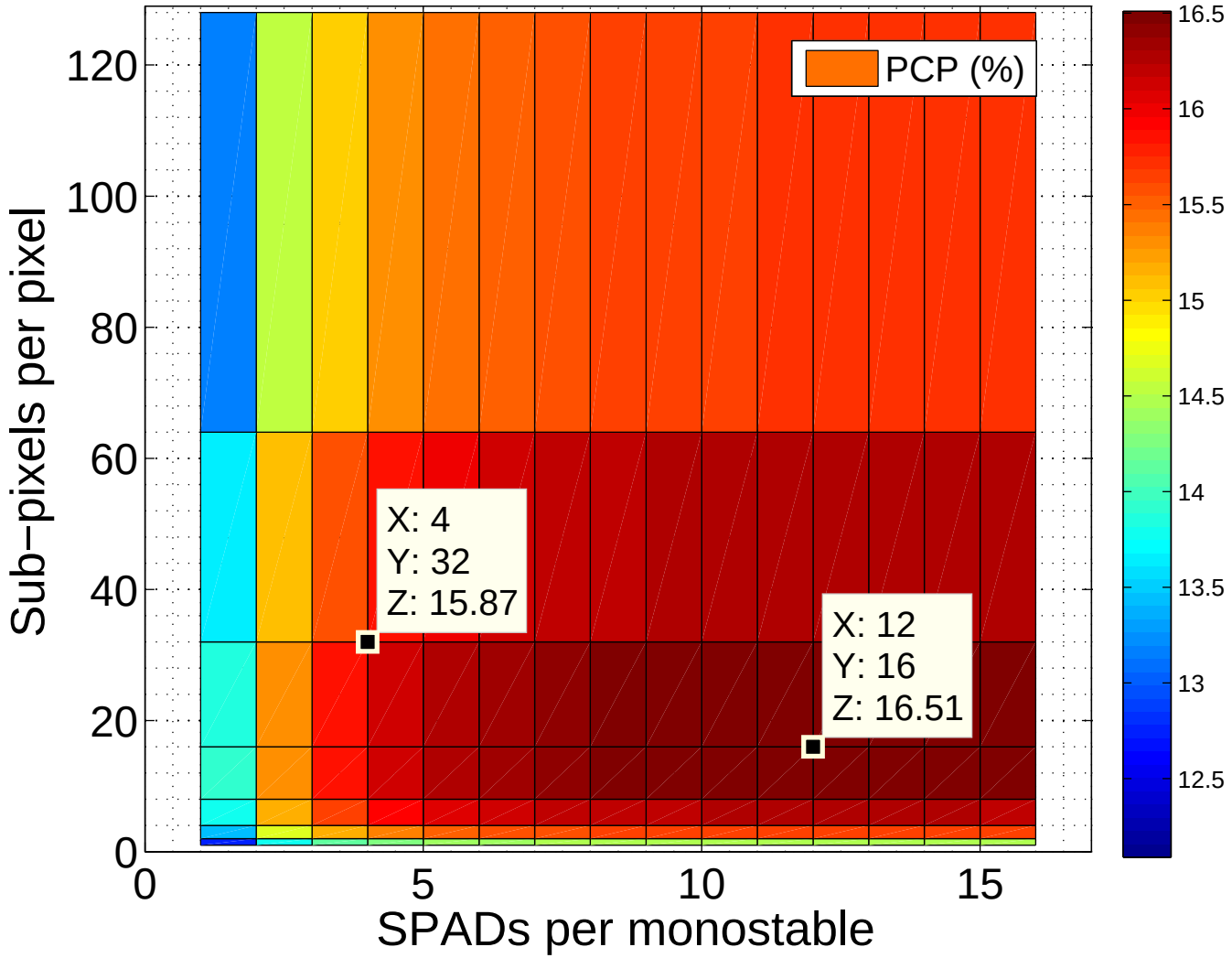
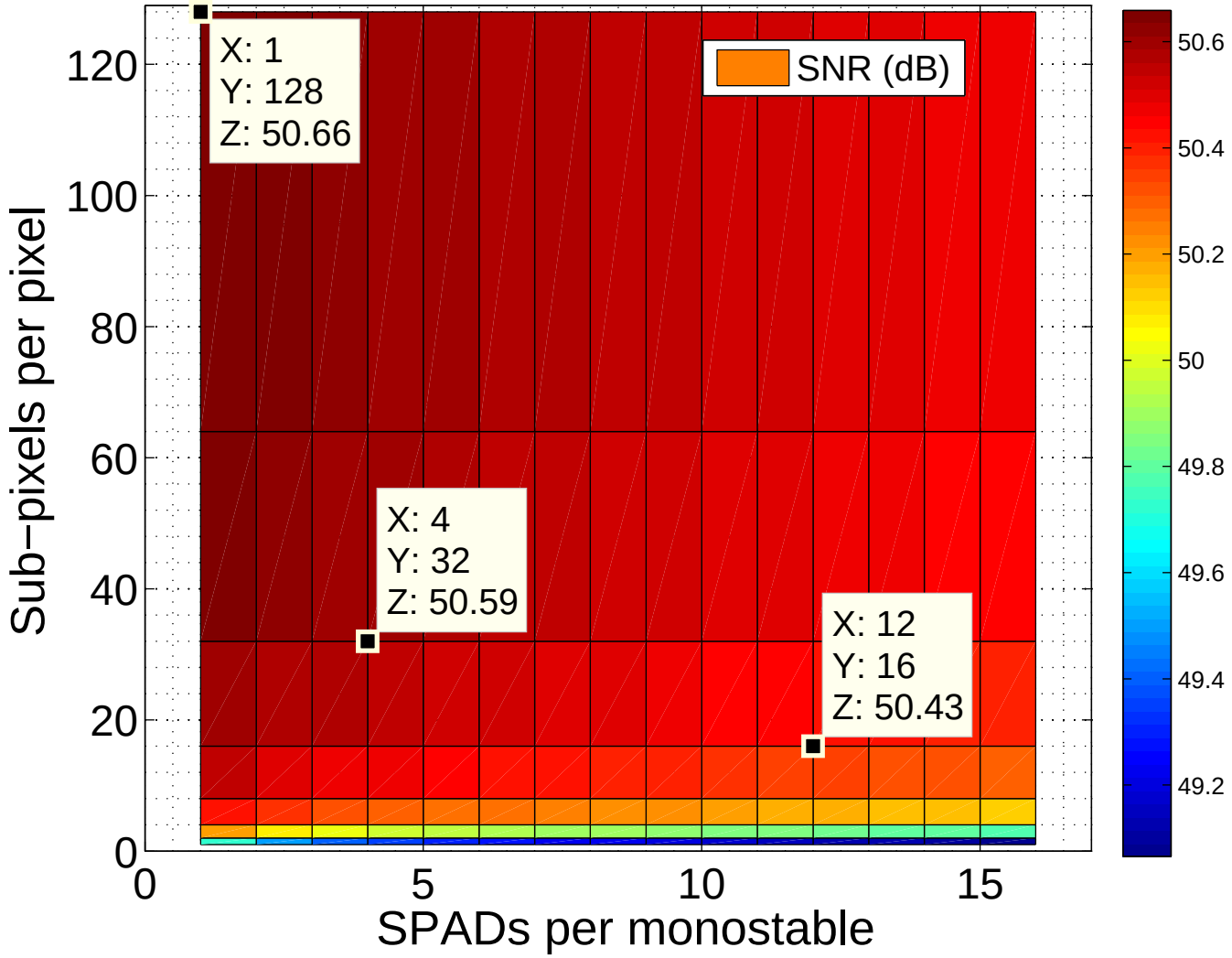
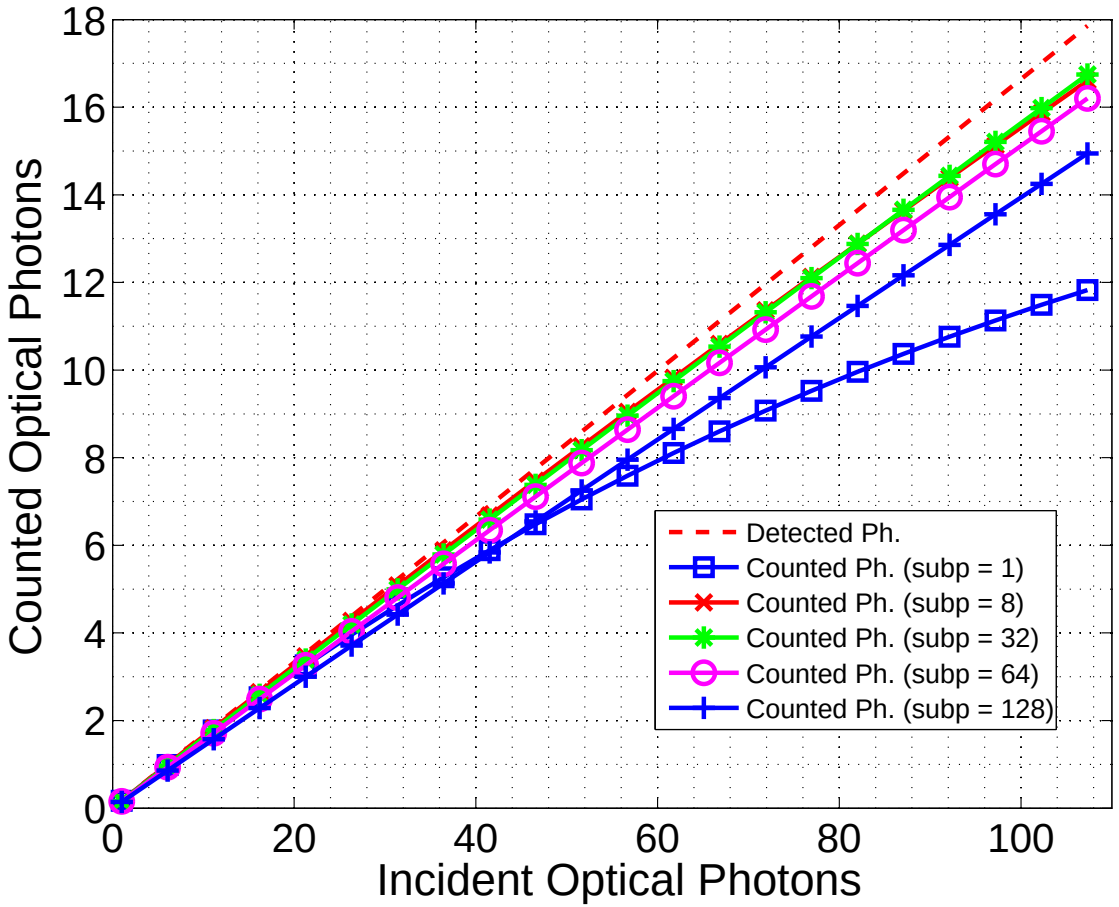
PCP vs sub-pixels/pixel and SPADs/monostable $D_{ph} = 45(1 - e^{-T/\tau})$



SNR vs sub-pixels/pixel and SPADs/monostable $D_{ph} = 45(1 - e^{-t/\tau})$



Linearity $D_{ph} = 45(1 - e^{-t/\tau})$



M_{spxl}	Non-linearity (%)
1	11.9
2	5.8
4	3.0
8	1.7
16	1.0
32	0.7
64	0.5
128	0.4

Figure: Counted photons as a functions of the detected photons with 4 SPADs per monostable.