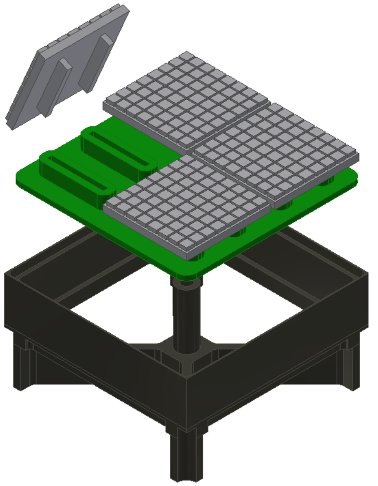
SiPMs for the space-based fluorescence telescope JEM-EUSO

School for Astroparticle Physics | Obertrubach | October 2015

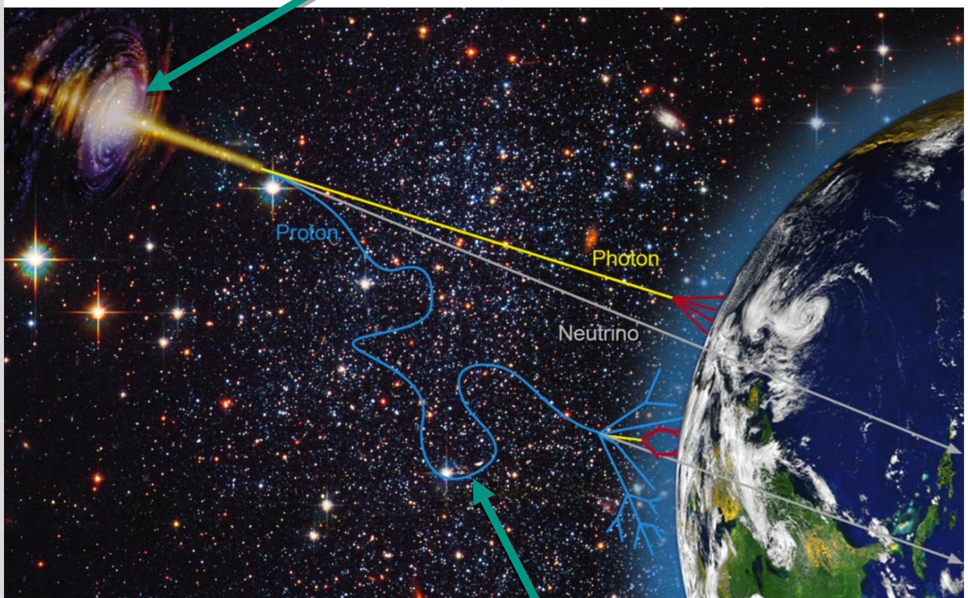
Thomas Huber | Karlsruhe Institute of Technology | Institute of Experimental Nuclear Physics (IEKP)

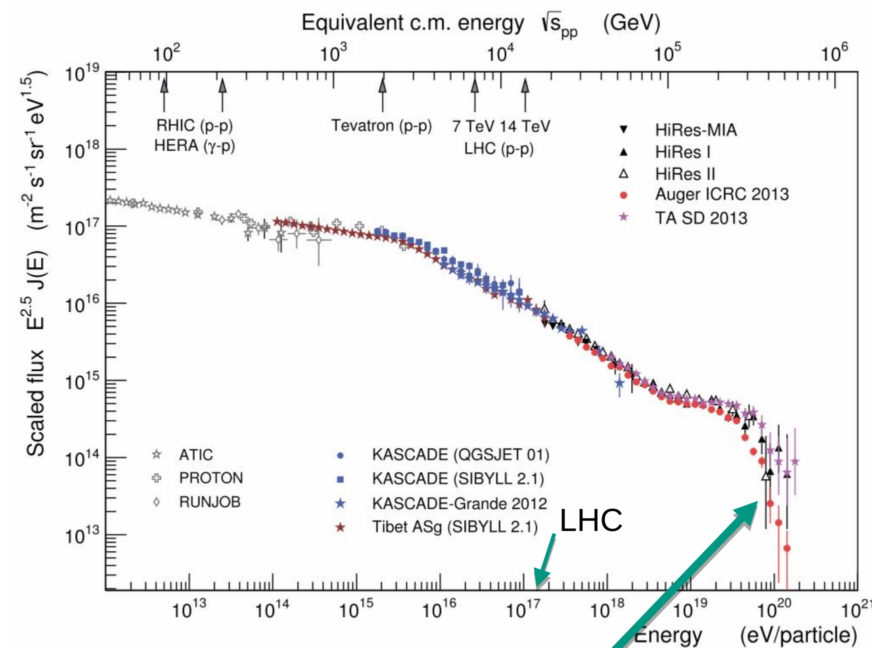


KIT – University of the State of Baden-Wuerttemberg and
National Research Center of the Helmholtz Association

Cosmic Rays

Sources?
Accelerators?





LHC

Protons? Nucleons?
Composition?

$$1 \cdot \frac{1}{km^2 \cdot year}$$

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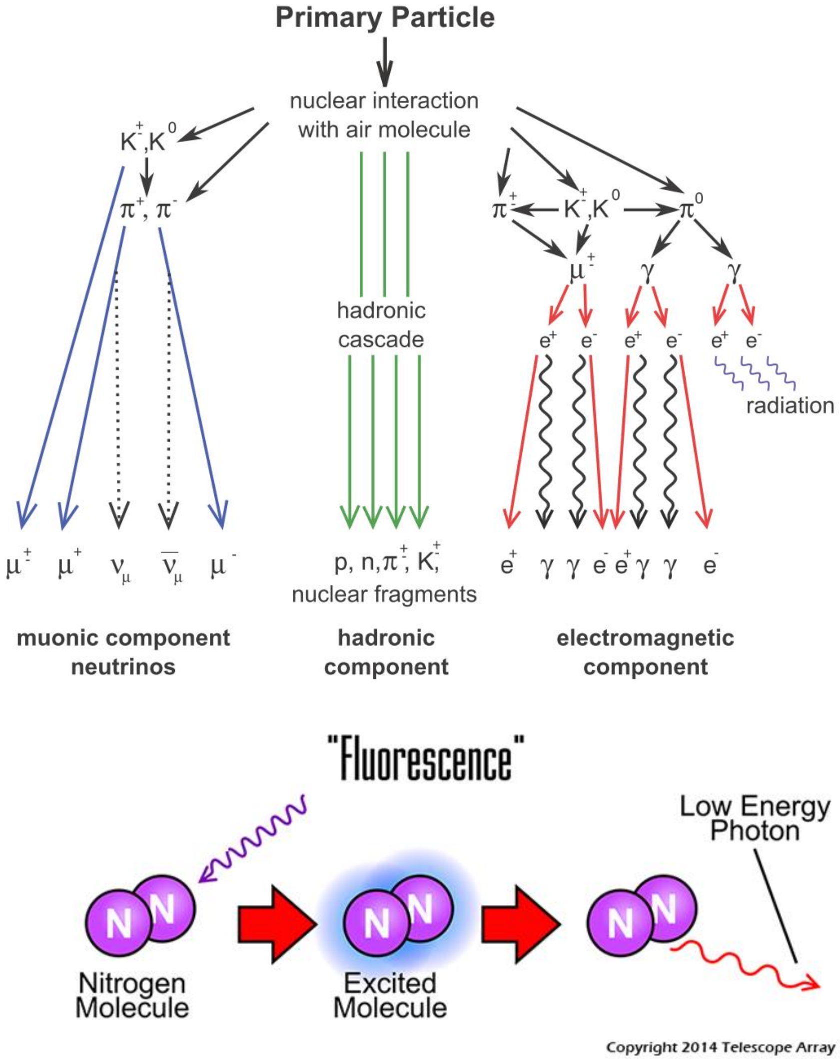
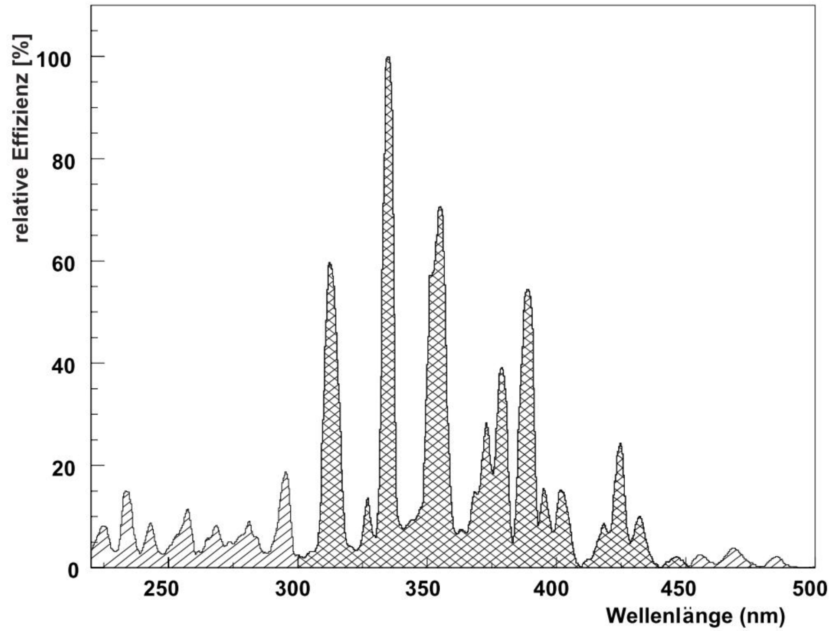
How to measure? Fluorescence light





Spectrum from AUGER Design Report 1997

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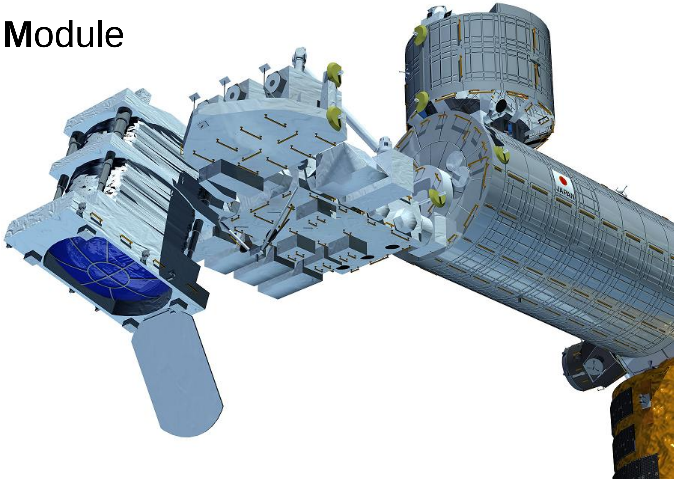
JEM-EUSO

Extreme **U**niverse **S**pace **O**bservatory onboard **J**apanese **E**xperiment **M**odule

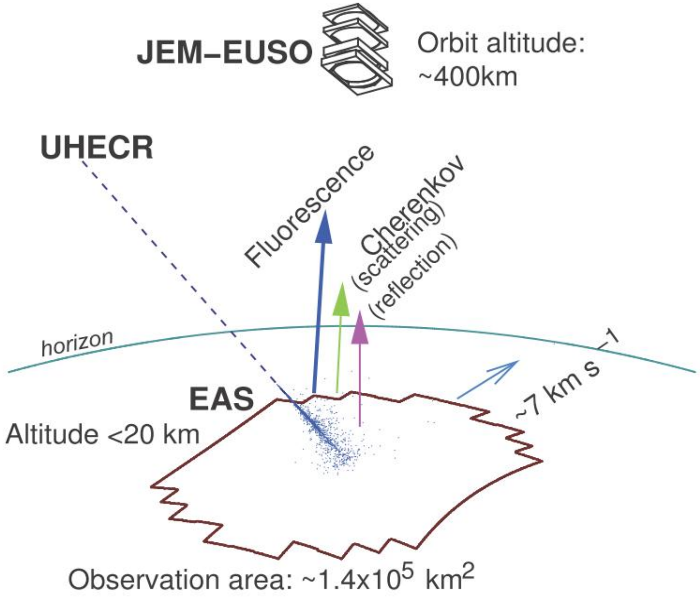


Reconstruction:

- Arrival directions better than 2.5 deg.
- Energy resolution better than 30%

Obvservation Area:

- TA, Utah (700 km²)
- AUGER, Malargüe (3.000 km²)
- JEM-EUSO, ISS (140.000 km²)



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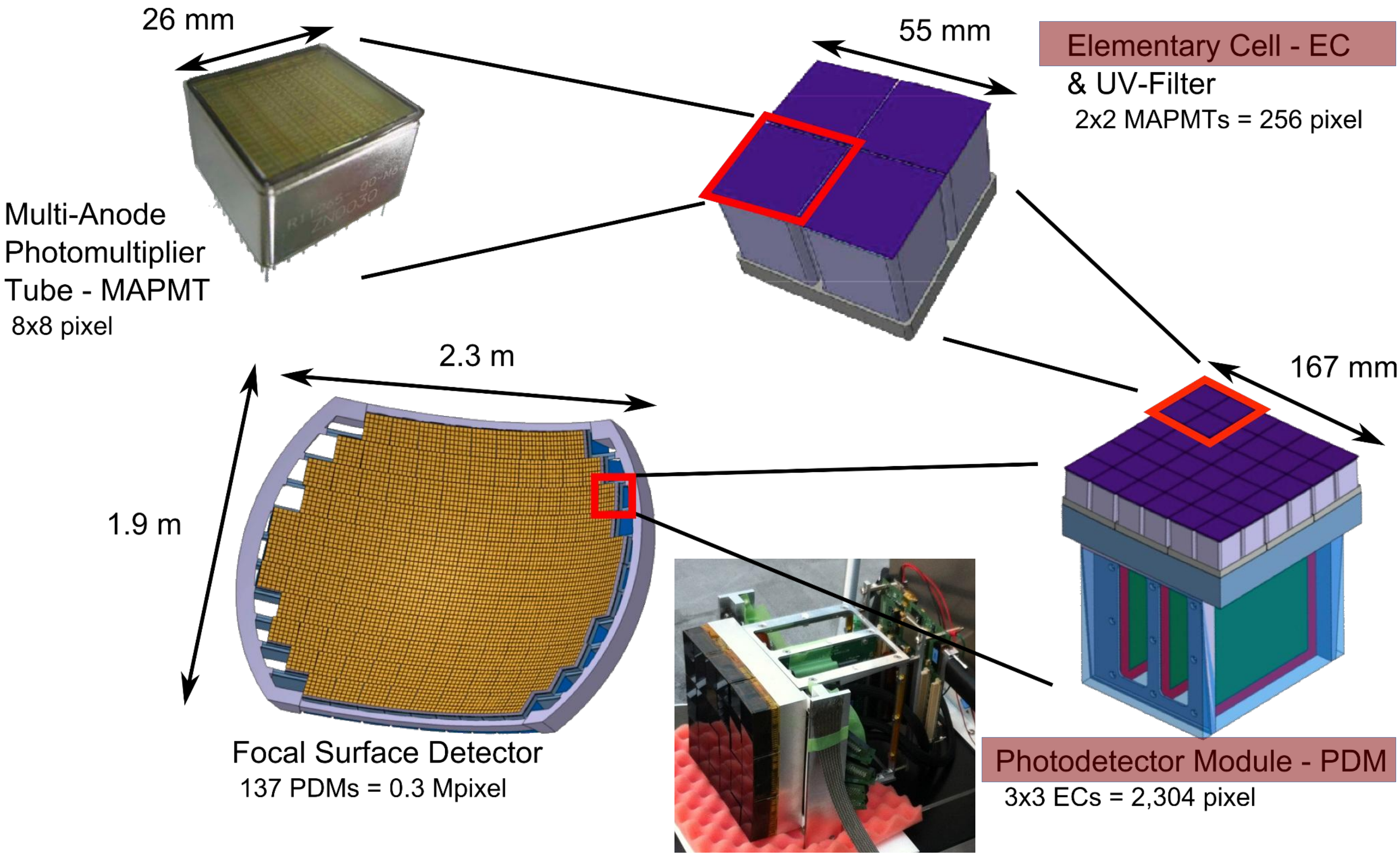
JEM-EUSO – baseline design (MAPMTs)



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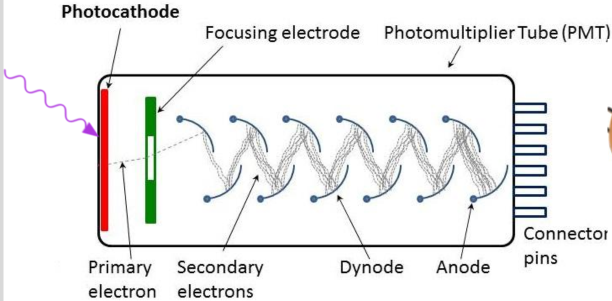
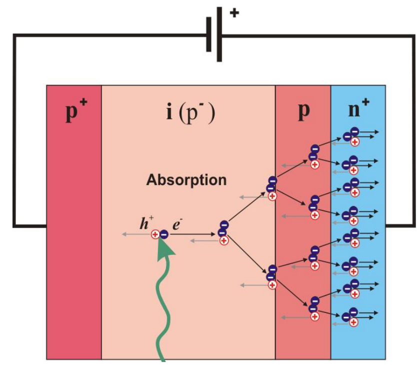
Silicon Photomultiplier (SiPM)

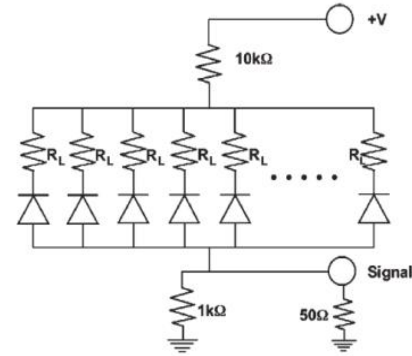
PMT



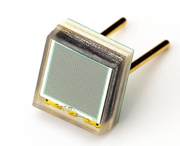
APD

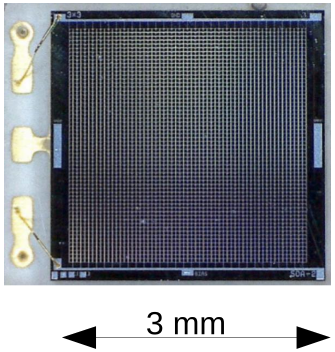


SiPM



	PMT	SiPM
Photo Detection Efficency PDE	20-40%	20-60%
Gain	10^6	10^6
TTS (Transit Time Spread)	~1 ns	~1 ns
Dynamic range	10^6	10^3
Dark noise rate	~Hz ☺	~MHz ☹
Behavior in magnetic fields	☹	☺
Operation Voltage	1000+ V ☹	50-70 V ☺
Temperature sensitivity	☺	☹
Robustness and compactness	☹	☺





$$\text{PDE} = \frac{\text{Number of detected photons}}{\text{Number of incident photons}}$$

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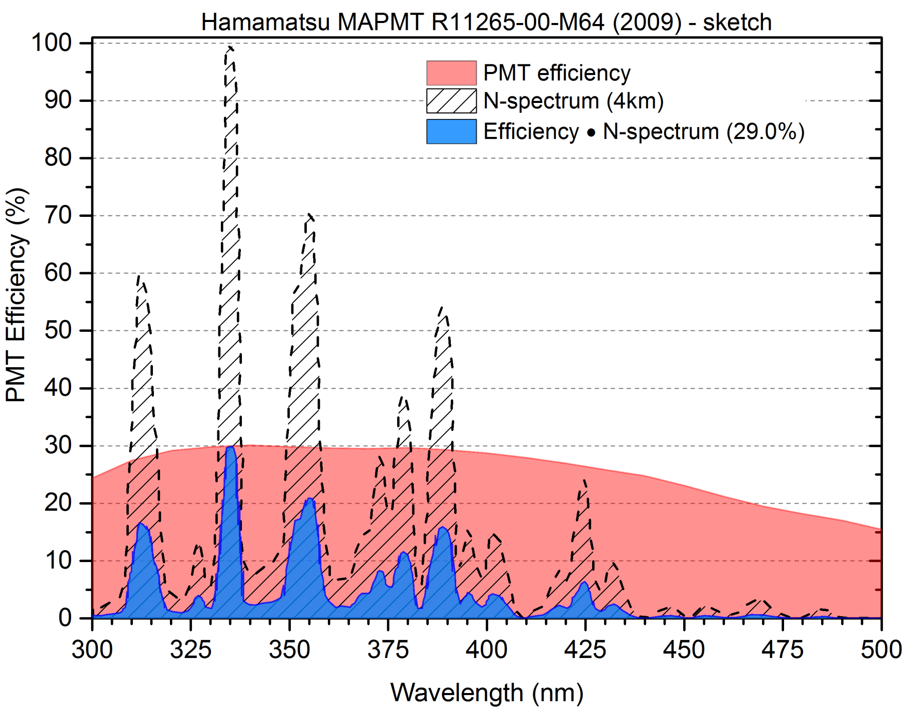
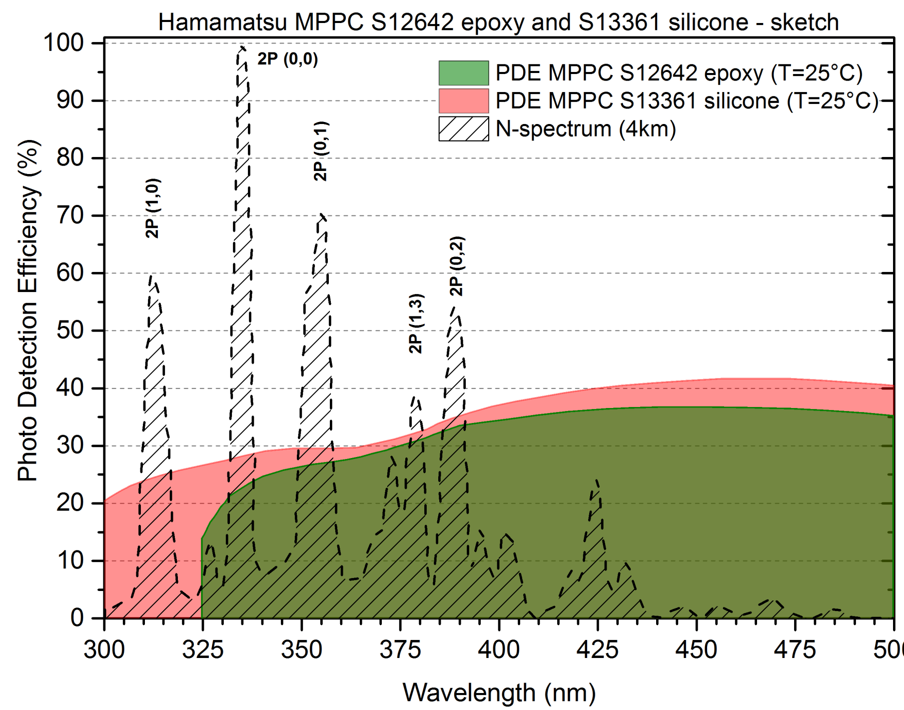
Motivation: MAPMT vs. SiPM





Ratio of MAPMT/SiPM area and nitrogen spectrum area:

MAPMT:
~29%

SiPM:
~31%

Spectrum from AUGER Design Report 1997

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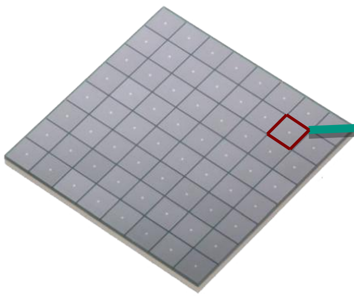
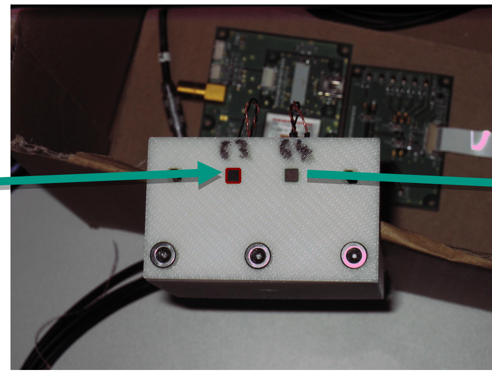
Our Candidate:

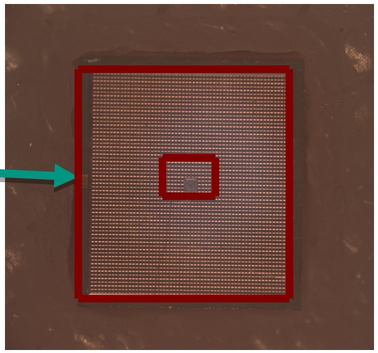
Candidate:
Hamamatsu
64 Pixel
SiPM TSV-Array



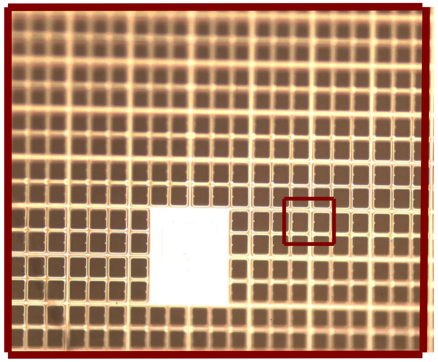
1 Pixel from the
TSV Array



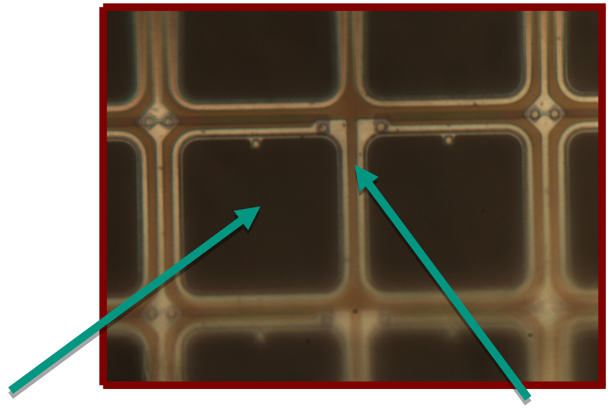
2.5x Zoom into 1 Pixel



10x Zoom



100x Zoom



1 Avalanche Photodiode
(of est. 3600 @ 1 pixel)

Crosstalk-reducing
Isolator

Hamamatsu S13361-3050

Gain:	$\sim 10^6$
Low Bias Voltage:	~53V
Number of APDs:	~3600
Darkcountrate:	~1 Mcps
Crosstalk	~3%

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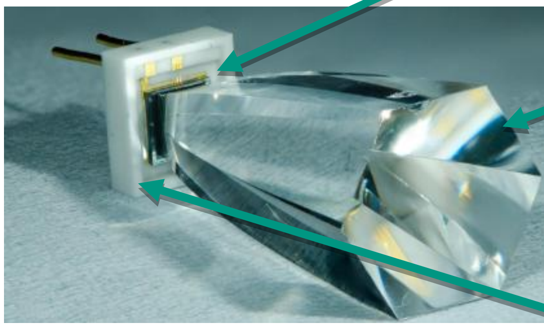
Our Candidate:

FACT / FAMOUS:

3 mm Gap
between 2 pixels



Winston cone

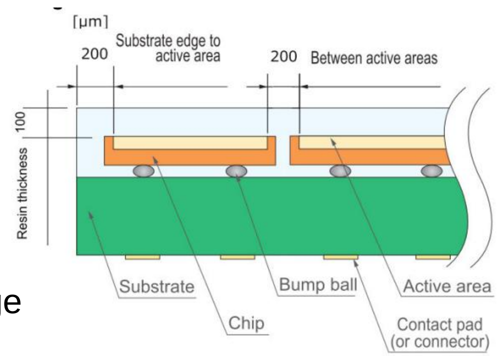
Hamamatsu SiPM
MPPC ceramic package

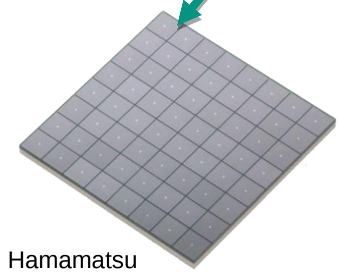
Daniela Dorner HAP Workshop Zeuthen 2014

New TSV-MPPCs SiPM :

TSV = Trough Silicon Via

0.2 mm Gap
between 2 pixels





Hamamatsu

Absolute maximum ratings

Parameter	Symbol	S12		
		-025C	-050C	-100C
Operating temperature*1	Topr	-20 to +40		
Storage temperature*1	Tstg	-20 to +60		

Hamamatsu Datasheet

...for operating outdoor

Absolute maximum ratings

Parameters	Symbol	S12642 -0404PA-50	S12642 -0808PA-50	S12642 -1616PA-50
Operating temperature	Topr	0 to +40		
Storage temperature	Tstg	-20 to +60		

Hamamatsu Datasheet

???

- structural problems?
- fear of condensed water?
- loss of performance?

Check for thermal induced changes in

- PDE
- Bias-Voltage
- Darkcounts
- Structural changes

Investigation with AFM
before/after cooling

TSV- SiPM

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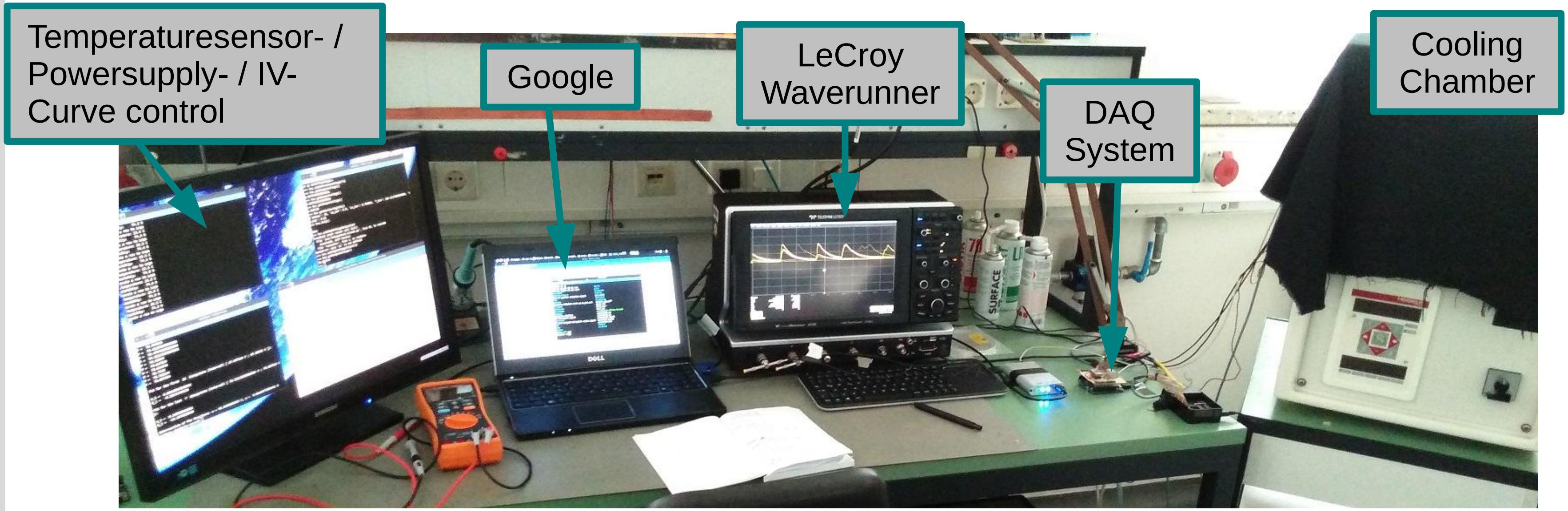
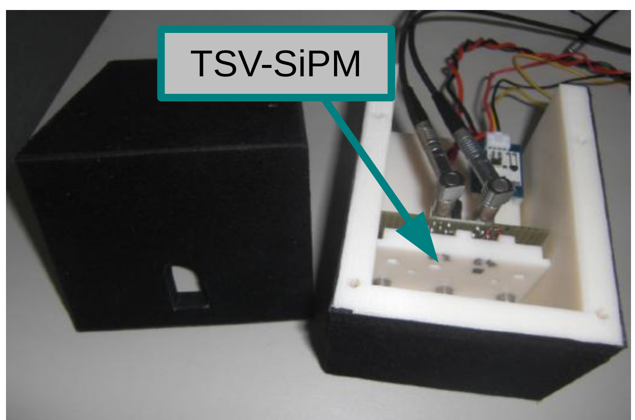
Experimental Setup for Bias-Voltage / Darkcounts





- TSV-SiPM testing device with attached temperature/humidity sensor and one part of the readout electronics
- 2x 3mm², 1x 2mm², 1x 6mm² TSV SiPM sockets to compare them simultaneously
- Photon shielding is overlapping the corners.

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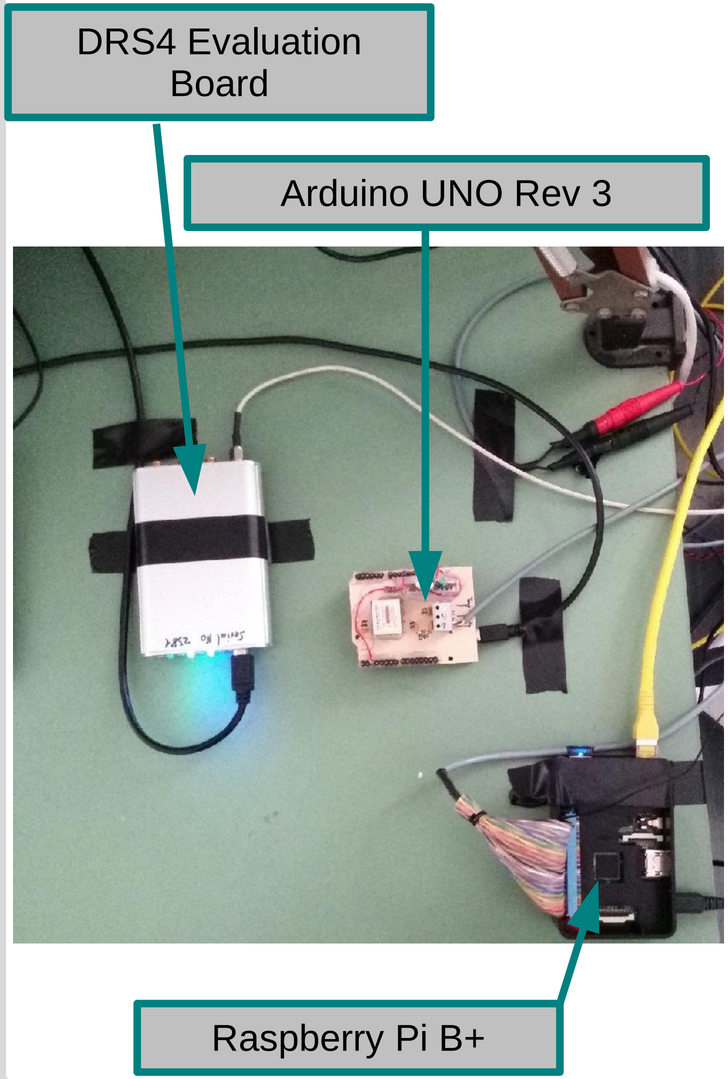
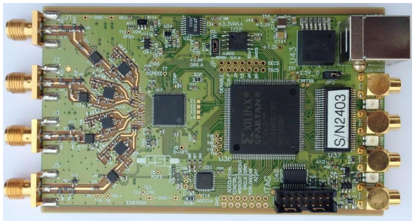
Experimental Setup for Bias-Voltage / Darkcounts



DRS4 Evaluation Board:
- Up to 5 GS/s
- DAQ SiPM Signals



4 Channel ADC

Arduino UNO Rev 3:
- Mounted with Hamamatsu SiPM Power Supply
- Control of Bias-Voltage via Python interface
- Current Monitor

C11204-01
Output Voltage:
50V to 90V

Raspberry Pi B+
- Connected via GPIO to temperature sensor
- Monitoring temperature. Written in Python; Controlled via SSH; Saving data via SQL to a local webserver

AM2303
± 2% of humidity level
± 0.3°C temperature

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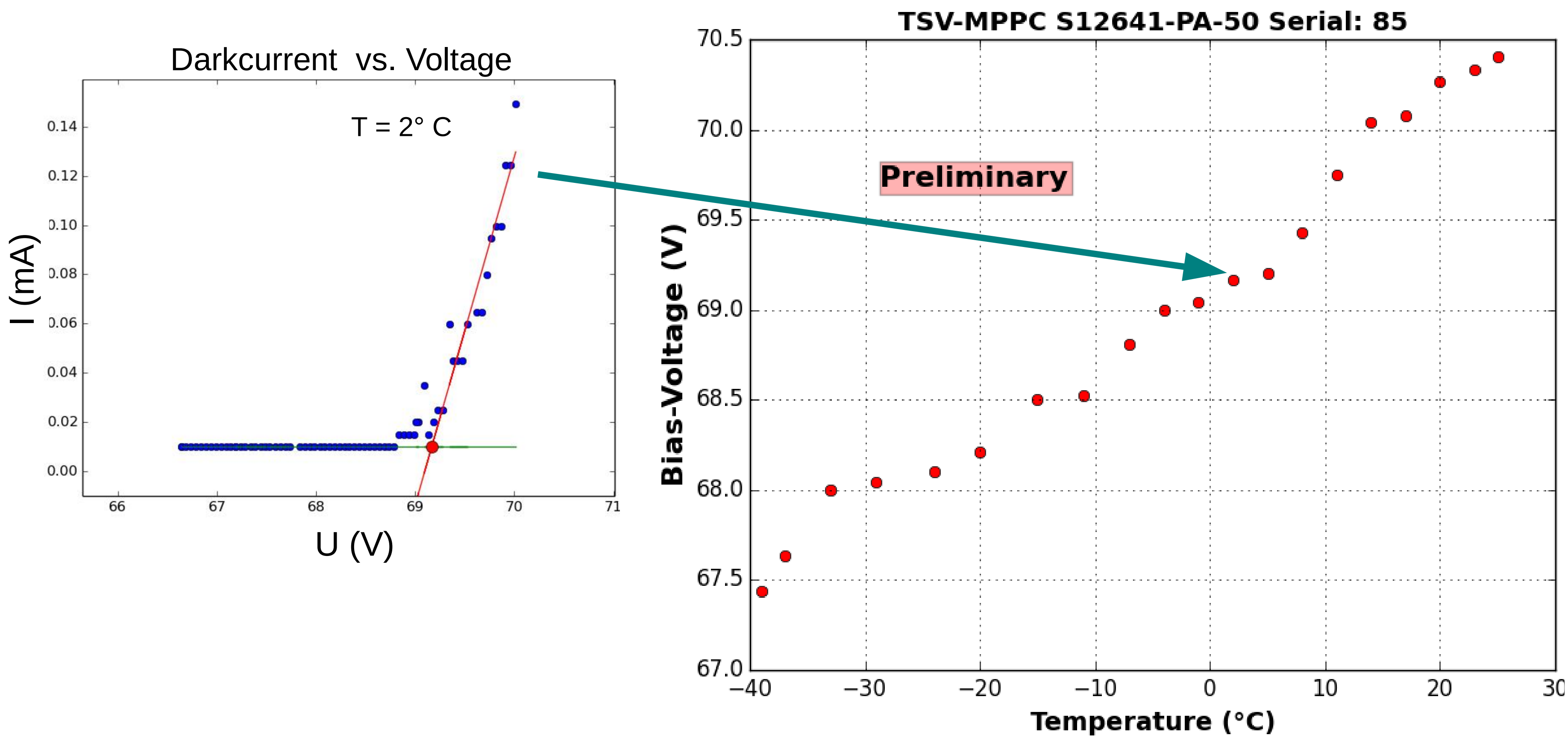
Temperature dependency of Bias-Voltage



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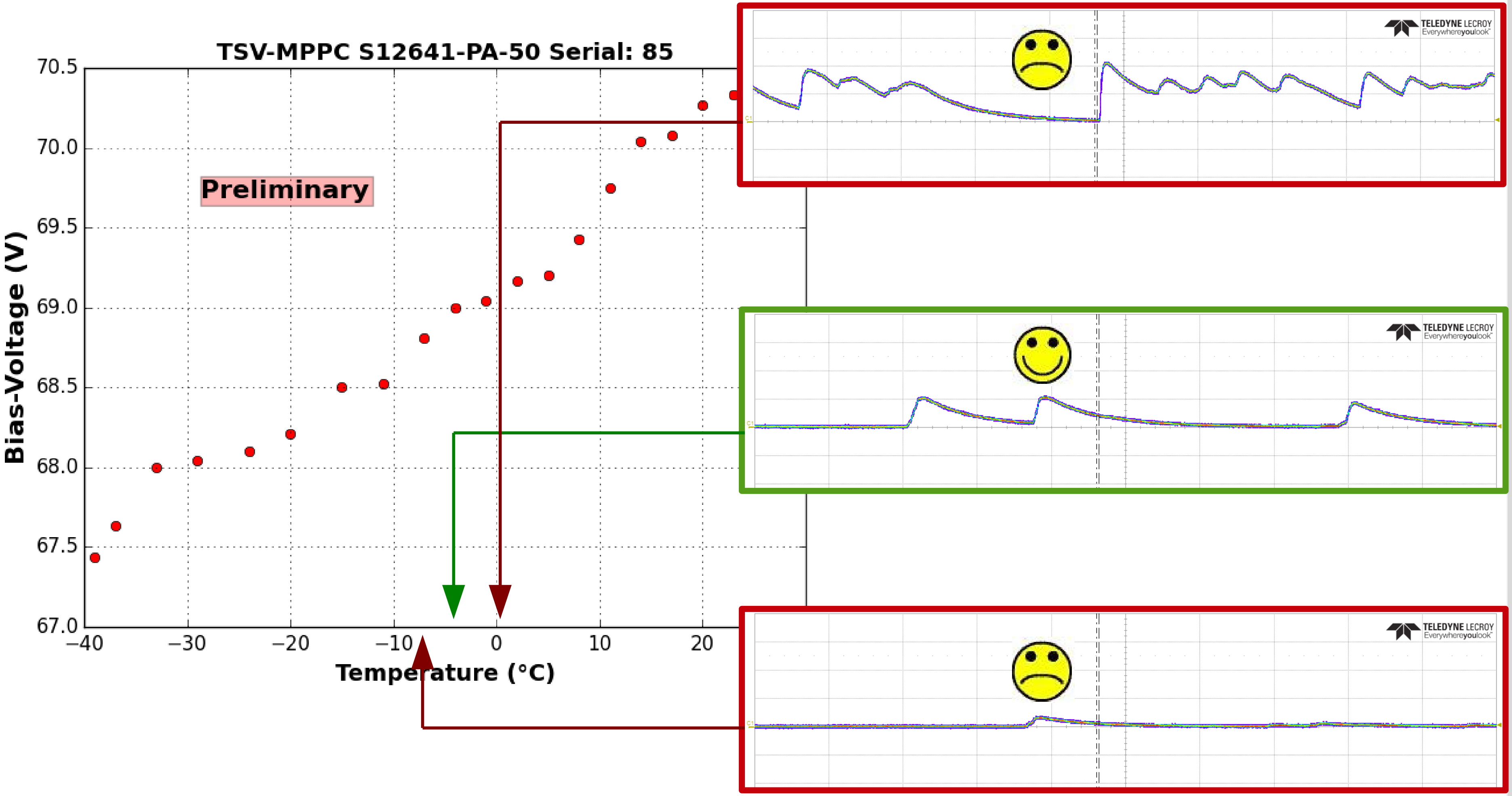
Consequence of not adjusting the Bias-Voltage

With a constant Bias-Voltage:



V: 50mV/div Timebase: 500ns/div

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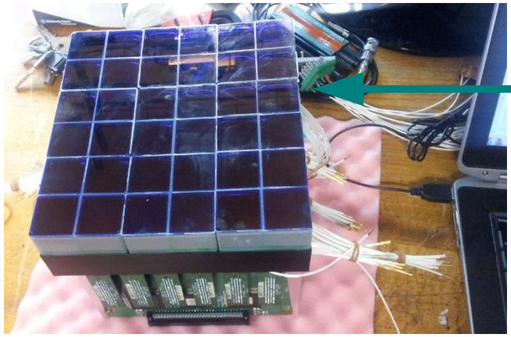
Pathfinder Mission: NASA SPB Flight 2017

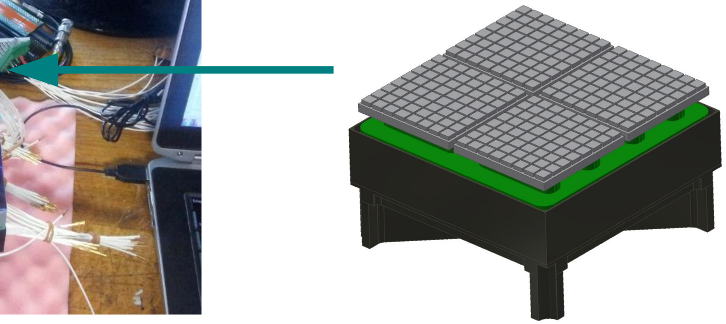
Karlsruhe Institute of Technology

- Payload 1000kg of science instruments
- Sustained flight altitude: ~33km
- ~ 1,5km altitude variation during flight
- Flight duration ~ 100 days

MAPMT PDM



SiPM EC



Delivery to NASA: July 2016

Possibly flight in spring 2017 from Wanaka, NZ

NASA's first Super Pressure Balloon flight, March 2015, Wanaka, NZ:
- Flight duration 32 Days

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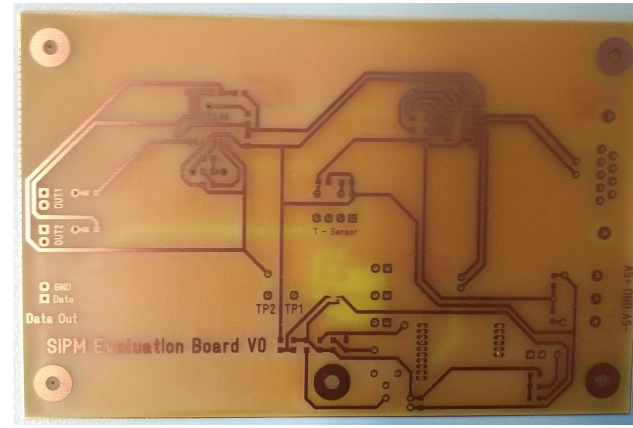
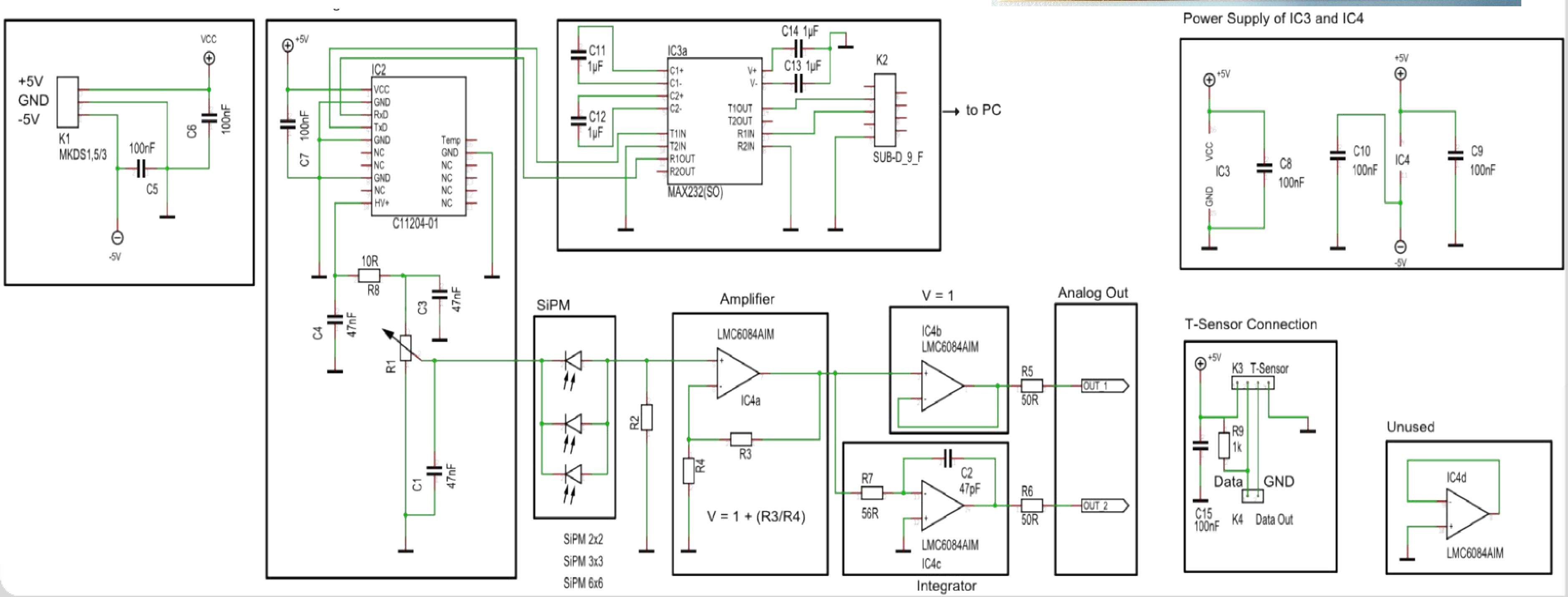
First step: TSV-SiPM Readout board

- For PDE / Gain Measurement
- Integrated amplifier (via OP)
- Temperature sensor
- Voltage adjustment
- Fast readout for investigate time resolution
- Integrated readout for charge measurements





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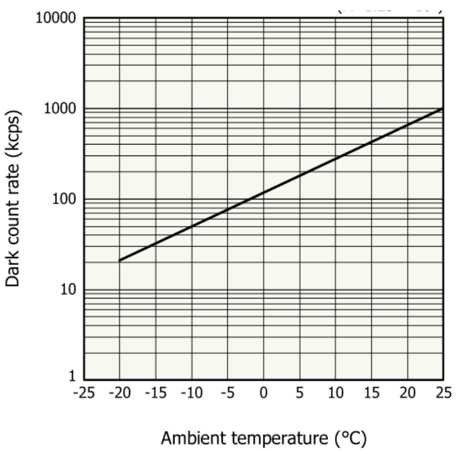
Outlook

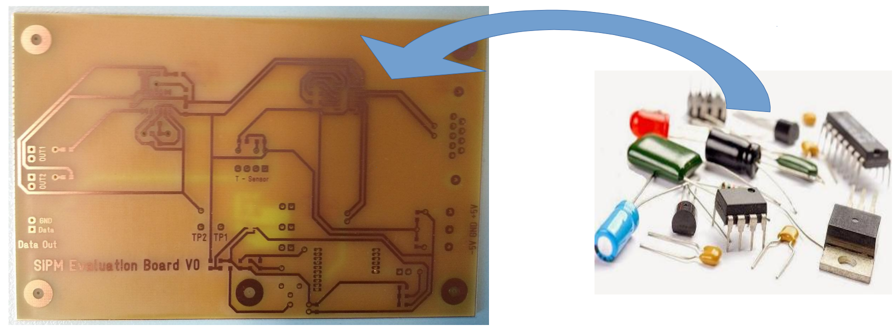
Darkcounts of TSV-SiPMs:

3mm² Area, pitch 50µm, typical example

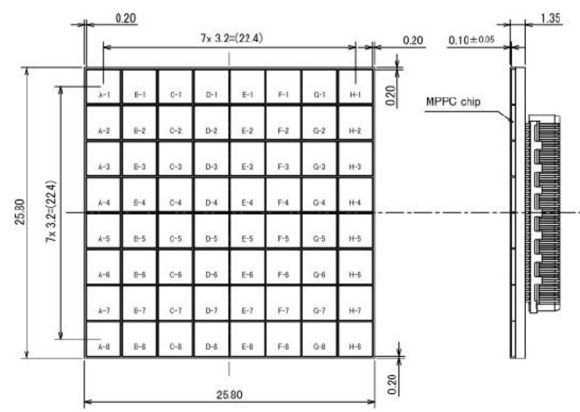


$$N_{DC} \approx T^{\frac{3}{2}} \cdot e^{\frac{E_g}{2kT}}$$

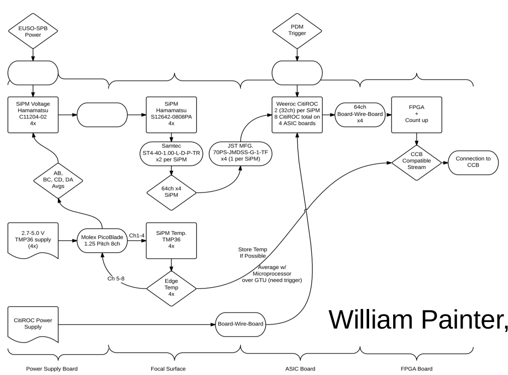
Assembling the readout-board:



Is Hamamatsu able to produce a uniform array?



DAQ-System of the SiPM-EC (256 Channels):



William Painter, KIT

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Thanks for listening.

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BACKUP

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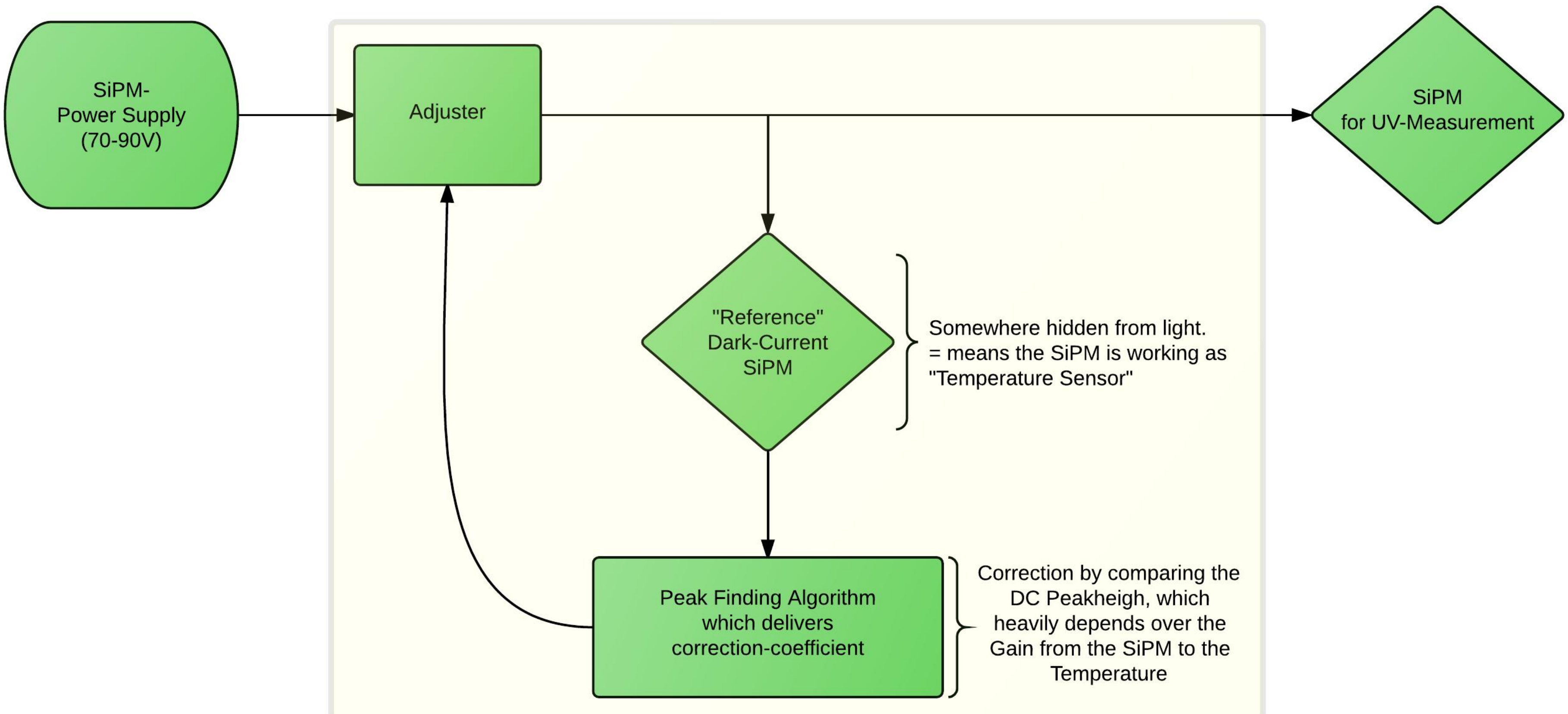
Possible Way to handle this?: Temperature-Correction-Coefficient α

$$\mathrm{Gain} = \frac{C_{Pixel} \cdot \Delta V}{e}$$

$$\mathrm{V}_{Bias} = \alpha \cdot T$$

$$\alpha \approx \frac{60\ mV}{^\circ C} \longrightarrow \Delta T = 2K \longrightarrow \Delta\mathrm{Gain} \doteq 33\%\,!!$$



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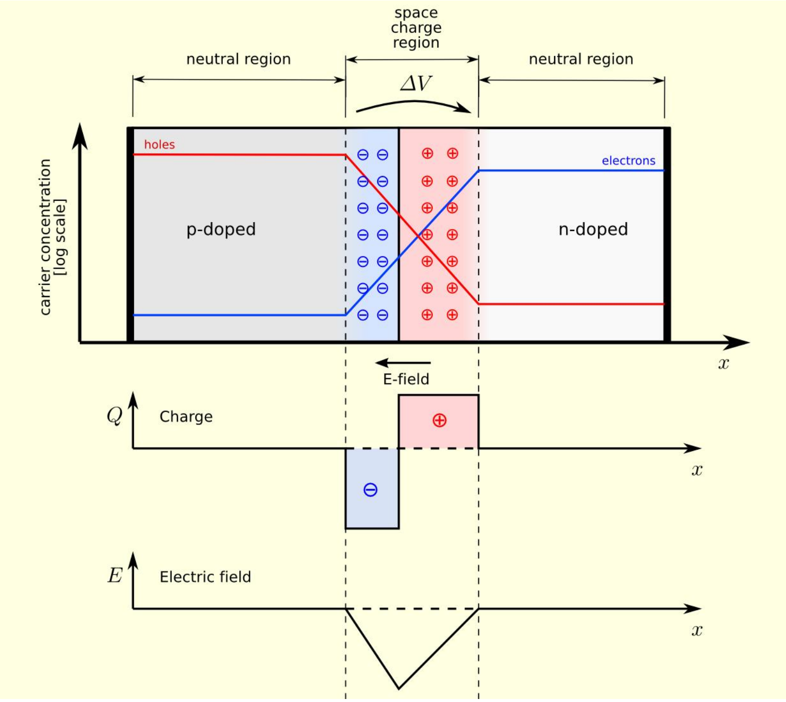
Working principle Avalanche Photodiode

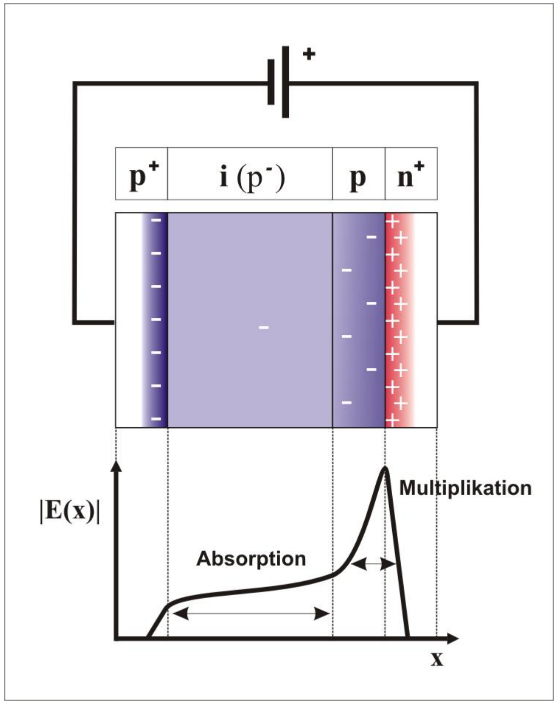
They are using:
- Photoelectric effect
- Avalanche multiplication

$$G = \frac{Q_{pixel}}{e} = \frac{C_{pixel} \cdot (U_{bias} - U_{breakdown})}{e}$$
$$C_{pixel} \approx 100 \text{ fF}$$

Normal diode



APD



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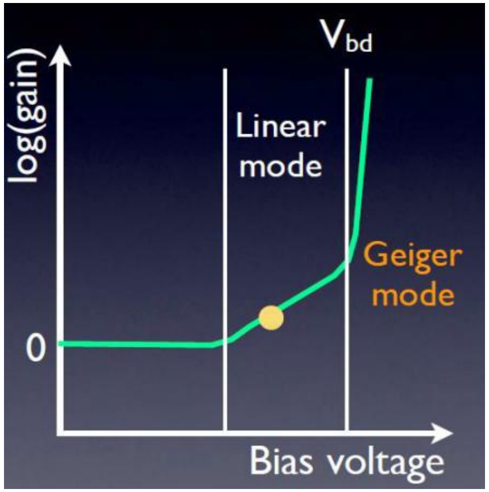
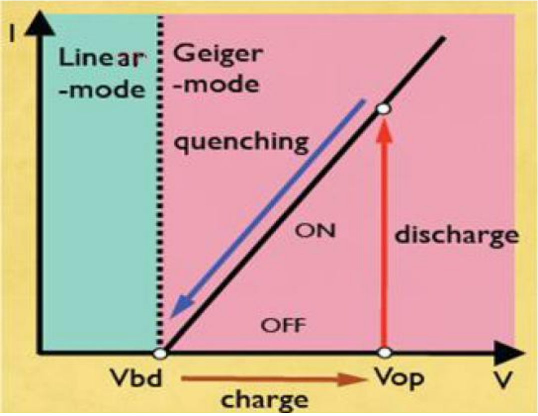
Geiger-Mode





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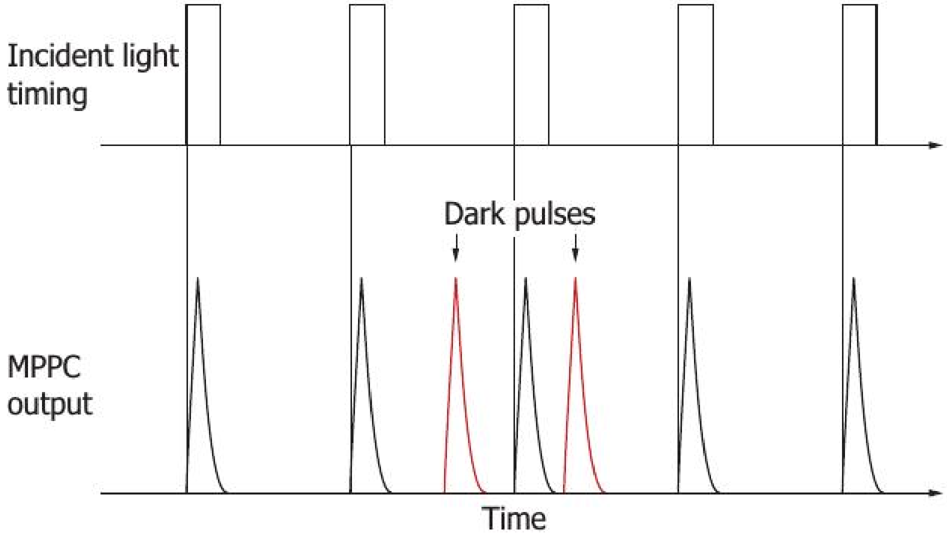
Darkcounts

$$N_{0.5\,p.e.}(T) \approx AT^{\frac{3}{2}} \exp\left[\frac{Eg}{2k\,T}\right] \cdots\cdots\cdots (4)$$

T : absolute temperature [K]
A : arbitrary constant
Eg: band gap energy [eV]
k : Boltzmann's constant [eV/K]



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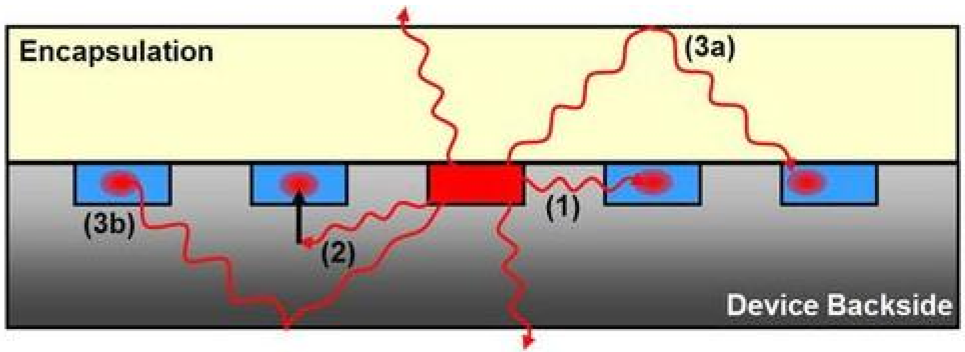
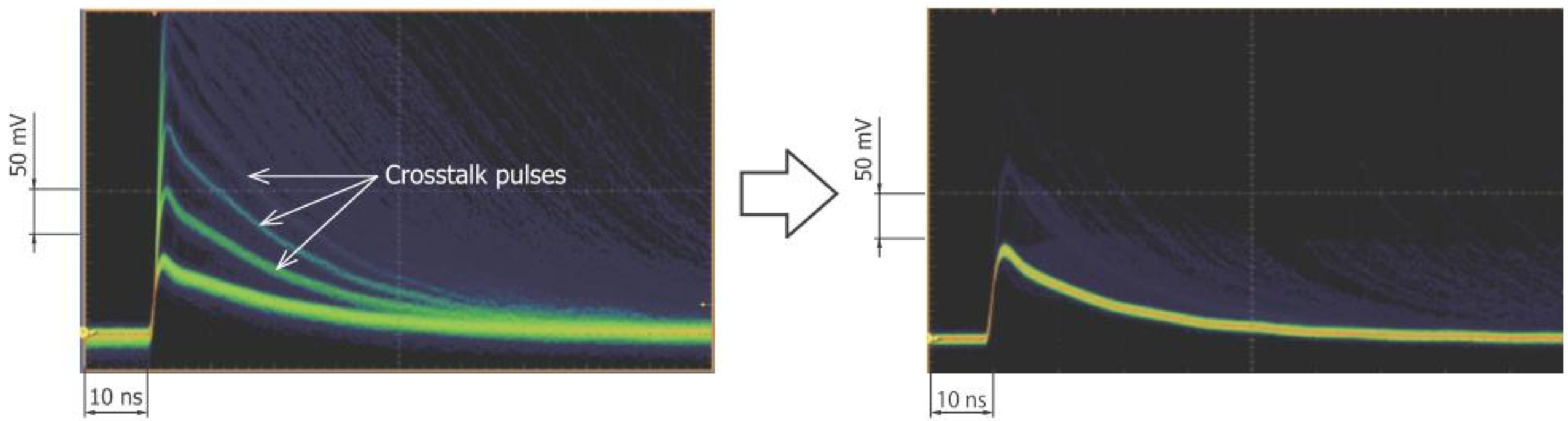
Crosstalk





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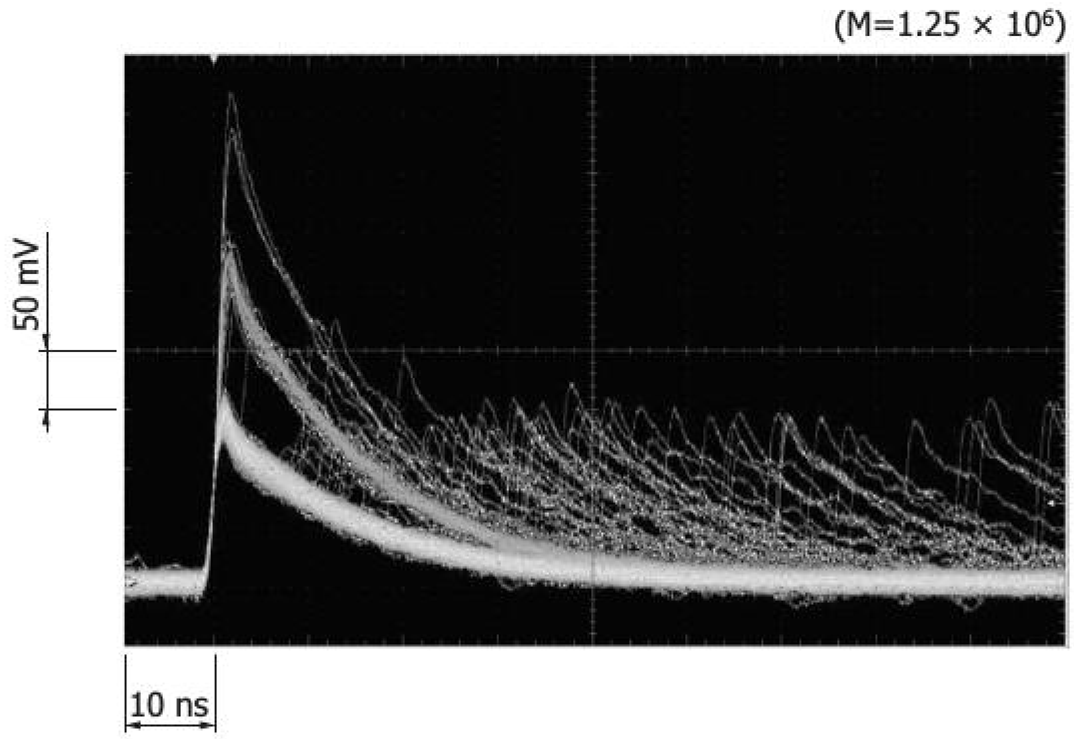
Afterpulse



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SiPM specialized peak finding algorithm

- Time Calibration via samplerate

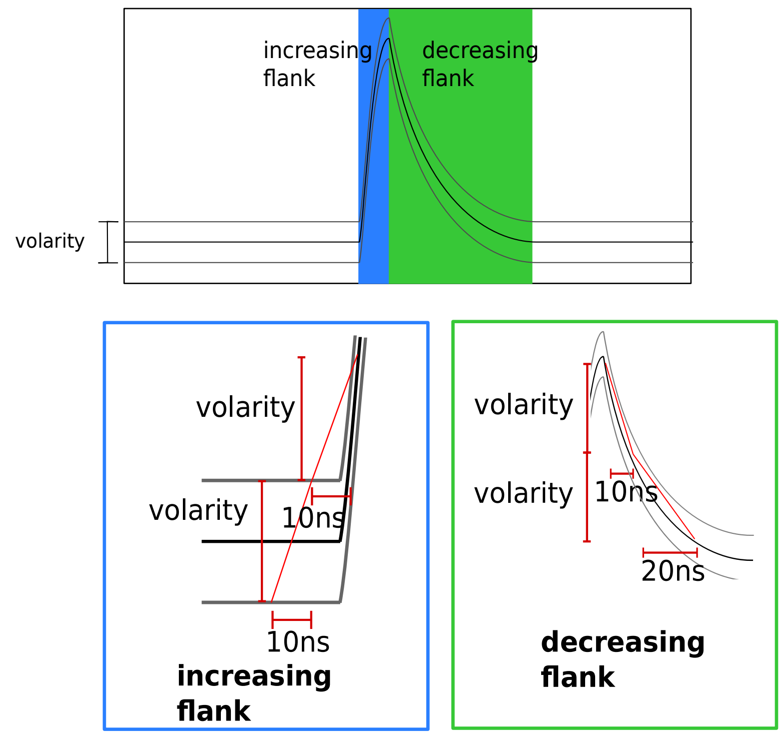
Find increasing flank:

- difference between 10ns must be bigger than volarity (default 0.01, uncertainty of measurment)
- difference between 10ns must be bigger than volarity and direct afer first condition

Find decreasing flank:

- for a peak, a decreasing flank must be after an increasing flank
- between 20ns the difference must be bigger than volarity (first gradient is higher than second because of exponential decrease)
- direct after 2. condition: between 10ns the difference must be bigger than volarity
- no other decreasing flank found since a increasing flank (no double counting)

```
tom@tom:~/code/peakfinding$ ./amp_peak_counter -h
help:
        --file          inputfile
         --threshold             set threshold in (V)
         -o      --output        set file for maximum value of peak (default: output.txt)
         --volarity              set volarity in (V)
         --10GHz                 set sample rate to 10GHz (default)
         --1GHz                  set sample rate to 1GHz
```



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DRS4 Data Acquisition: „get_data“

```
File  Edit  View  Search  Terminal  Help
tom@tom-Vostro-V131:~$ get_data -h
get_data - DRS4 acquisition Rev. 1393

Usage: get_data [OPTIONS]

Record settings
  -c CH1[,CH2,...] Set one or more readout channel numbers (default = 1)
  -n NUM_FRAMES    Number of frames to record
  -a               Free-running mode (no trigger)
  -T [CH_NUM|ext]  Trigger on channel CH_NUM or 'ext' for external trigger
  -t TrigTrheshV   Set the trigger threshold in Volts. Default = -0.05V
  -P               Trigger on positive edge [default NEGATIVE]
  -D delay         Trigger Delay in percent
  -F f_SAMPLE      Sampling frequency in GSp/s, range ~0.68-5, default 0.68GSp/s
  -p               Short for '-r 0.5', sets the input range to [0 .. 1V]
  -r CenterVolt    Set the center input voltage. Quantisation is done in
                   the CenterVolt-0.5 .. CenterVolt+0.5 voltage range.
                   Default = 0

Data Format
  -f FORMAT        Set the format of the recorded data.
                   FORMAT is one of MULTIFILE, MULTIFILE_BIN, TEXT, BIN, YAML or ROOT.
  -d               Output directory for MULTIFILE output (will create one file per frame!)
  -o               Name of the output file(s). The correct file extension will be
                   appended automaticaly, so there is no need to specify it. If the
                   wrong extension is specified, the correct one is appended, too!
  -C               Enable zlib compression (only works with single text file).
  -l LVL           Set compression level (default 9). Only used if -c is set
  -H user_header   Add a line to the user header

Temperature Control
  -U socket        UNIX domain socket for detector control.
                   Default: /tmp/detector_control.unix
  -s T_soll        Enable temperature stabilized measurement.
                   Value in Kelvin if suffixed by K, other wise
                   it is interpreted as degree Celsius

Miscellaneous Options
  -v               Show version information
  -X               Stand-alone, embedded mode.
                   Outputs certain information in a machine-readable JSON. Each piece
                   of information is written line by line to stdout in JSON format; errors
                   are written to stderr in verbose format.
                   The advantage of this output mode  is simple processing,
                   e.g. for GUI embedding with progrssbars, while maintaining
                   full flexibility and extensibility.
```

- Very creative name :-D
- Alpha Status
  - Working, but a lot of work to do!
  - Already a lot of functions (see below)

- Functions:
- adjustable trigger threshold
- Multiple Channel Readout at once
- Important to do: boolean algebra

- Binary Output (buggy) and also ROOT Format (working)
- Zlib compression

- First attempts to implement temperature stabilized data acquisition

Licensing:
get_data is distributed under the GPL3 license

FindROOT.make by F.Uhlig@gsi.de http://fairroot.gsi.de
FindLibUSB.cmake by Michal Cihar, michal@cihar.com

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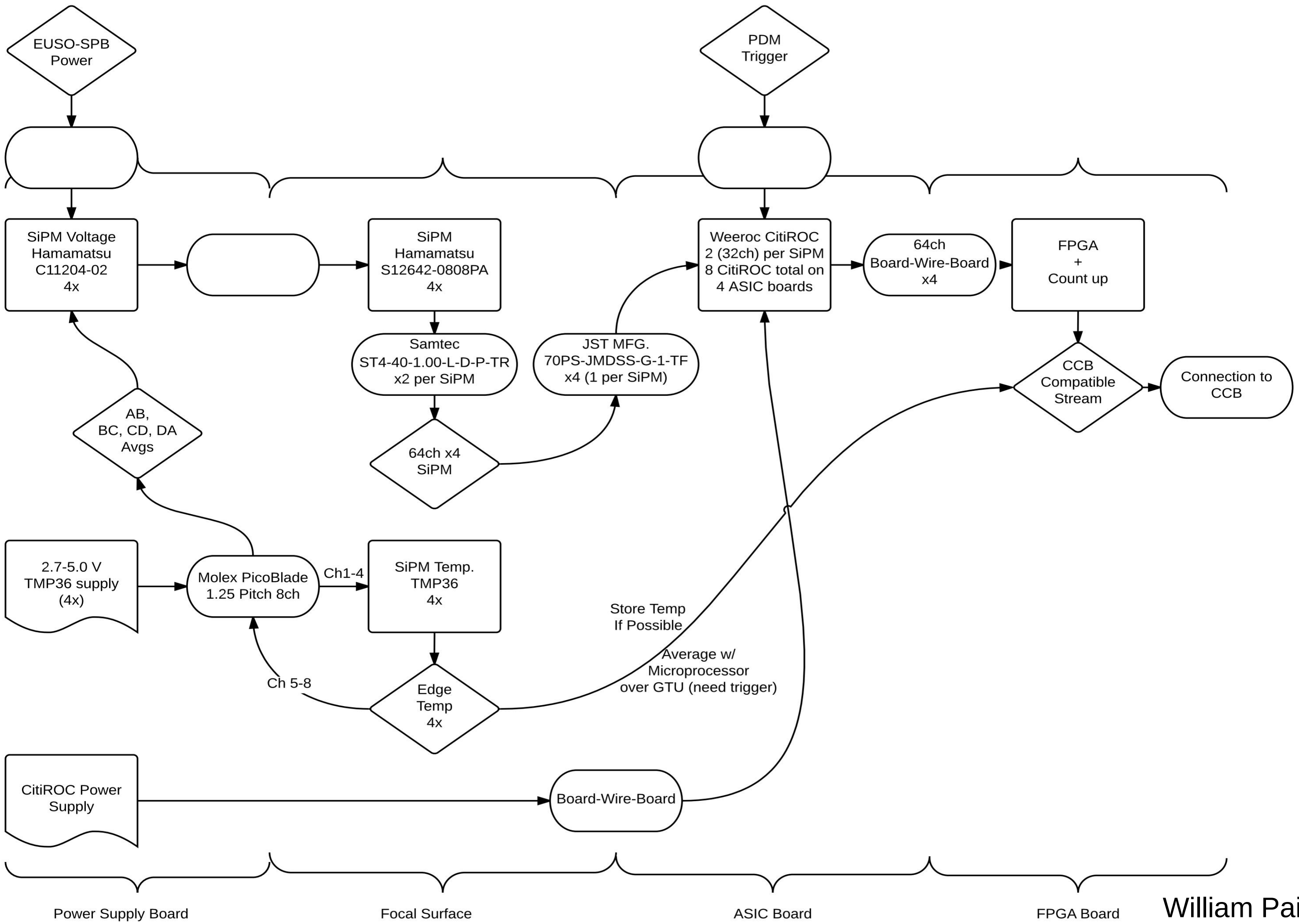
thomas.huber@student.kit.edu

DAQ-System of the SiPM-EC (256 Channels)



William Painter, KIT

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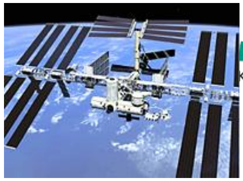
The near future of JEM-EUSO



Karlsruhe Institute of Technology

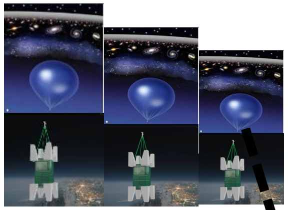
SPB-EUSO

2014 2017 2024

JEM-EUSO EUSO

2020 2024

TA-EUSO



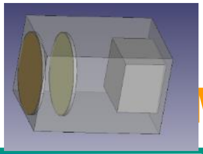
EUSO-Balloon

AO from NASA in 2014?

SiPM-PDM?

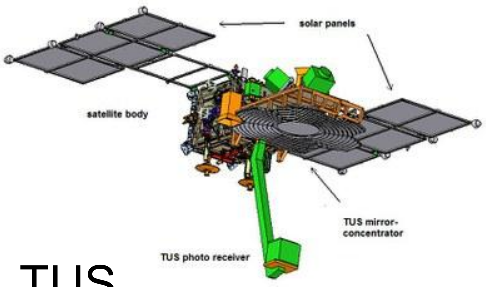
M4 mission
Free flyer?

esa European Space Agency

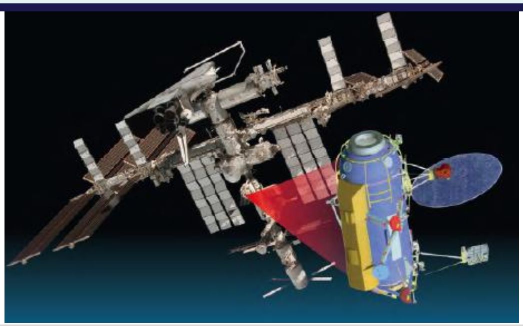


Mini-EUSO

Collaboration with a Russian project, KLYPVE



TUS



"K-EUSO"

Backup

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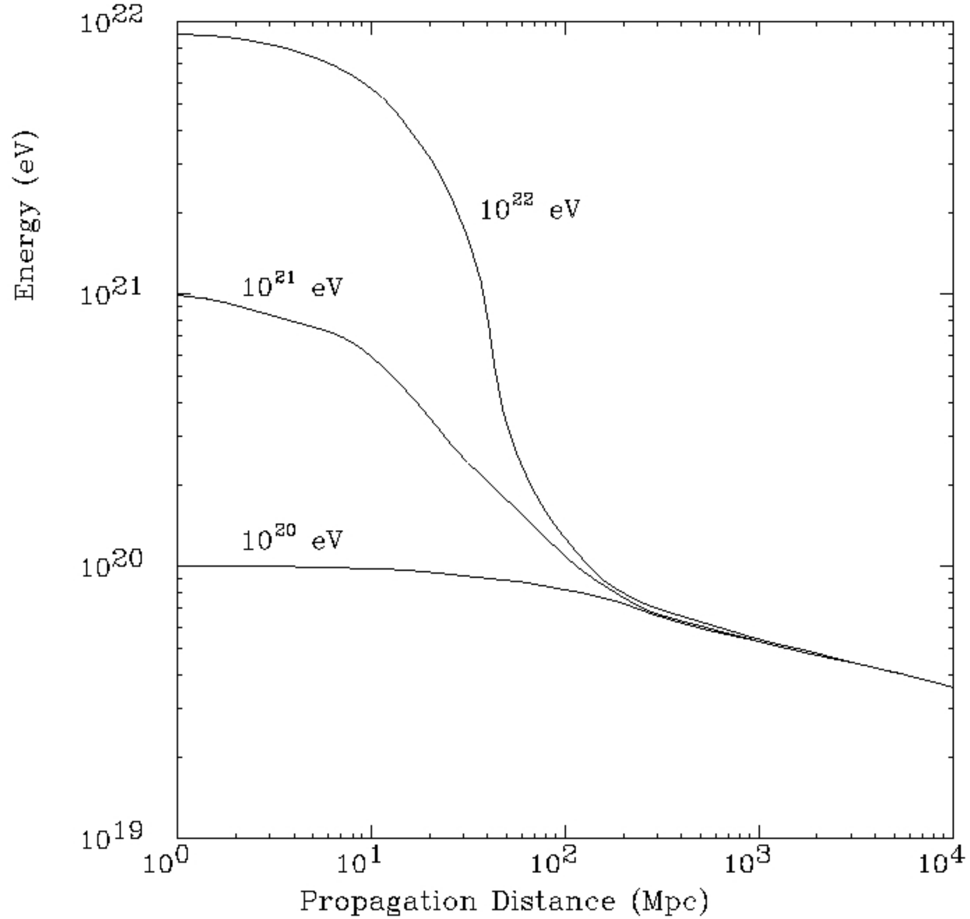
GZK-Cutoff

$$p + \gamma_{3K} \longrightarrow \Delta^{+} \longrightarrow p + \pi_0$$



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PDE from PMTs and SiPMs

SiPM

$$PDE(\lambda,V) = QE(\lambda)\cdot\varepsilon(V)\cdot GE$$

QE	*Quantum Efficiency*
ε	*Geiger Efficiency*
GE	*Geometrical Efficiency*
λ	*Wavelength*
V	*Bias*

PMT

$$PDE = QE_{(\lambda)}\cdot CE$$

QE	Quantum Efficiency
CE	Collection Efficiency

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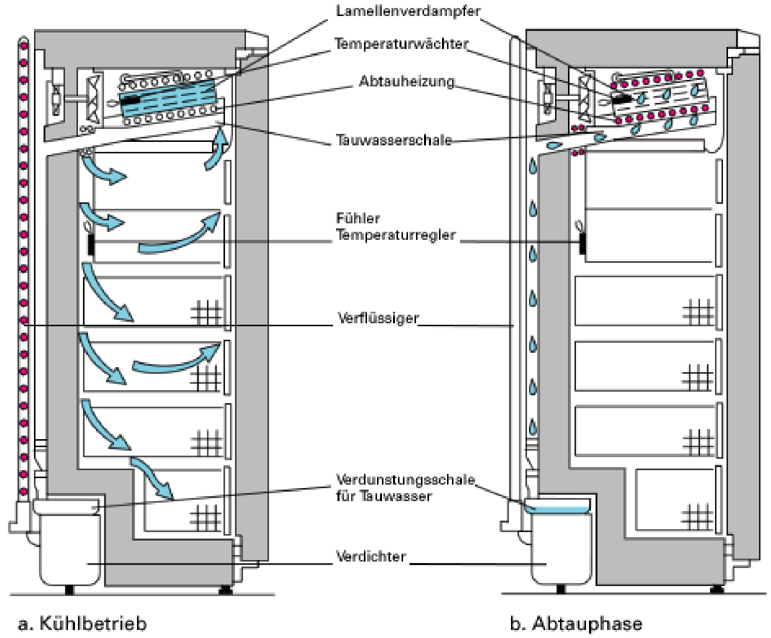
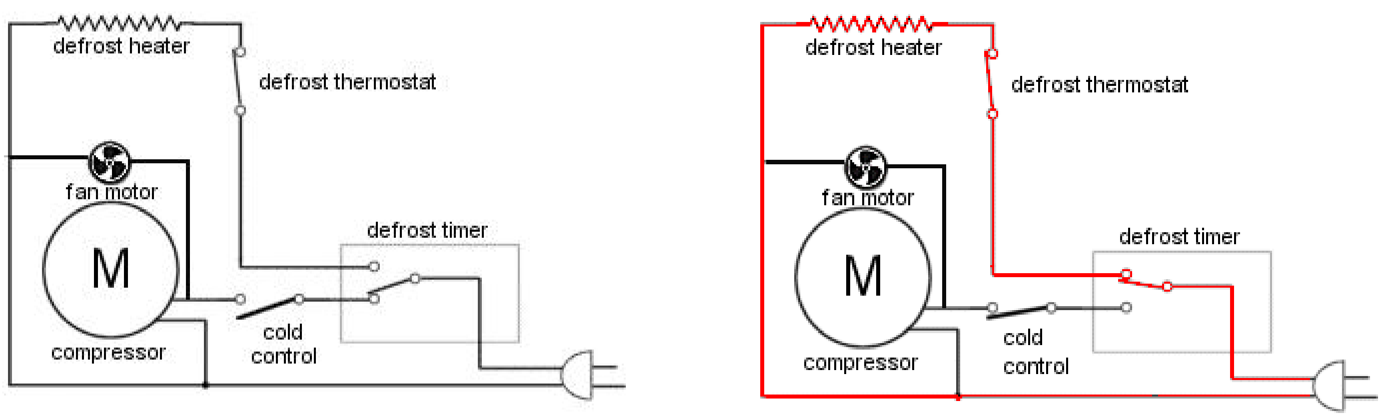
Defrost System





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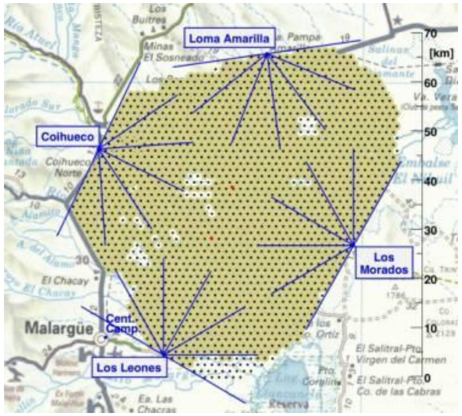
JEM-EUSO Performance

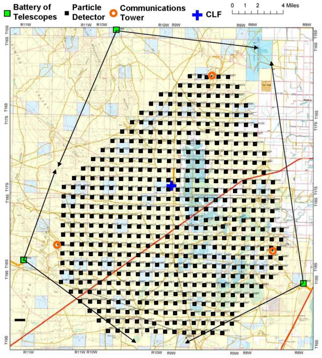
How many UHECR with E > $6 \cdot 10^{19} eV$?

AUGER, Malargüe (3.000 km²)



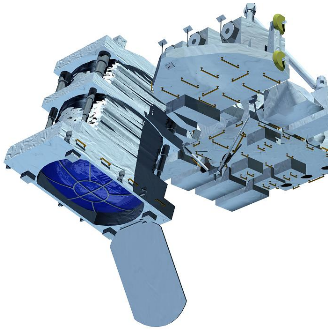
~ 20 Events each Year

TA, Utah (700 km²)



~ 5 Events each Year

JEM-EUSO, in Space (140.000 km²)



~ 200 Events each Year

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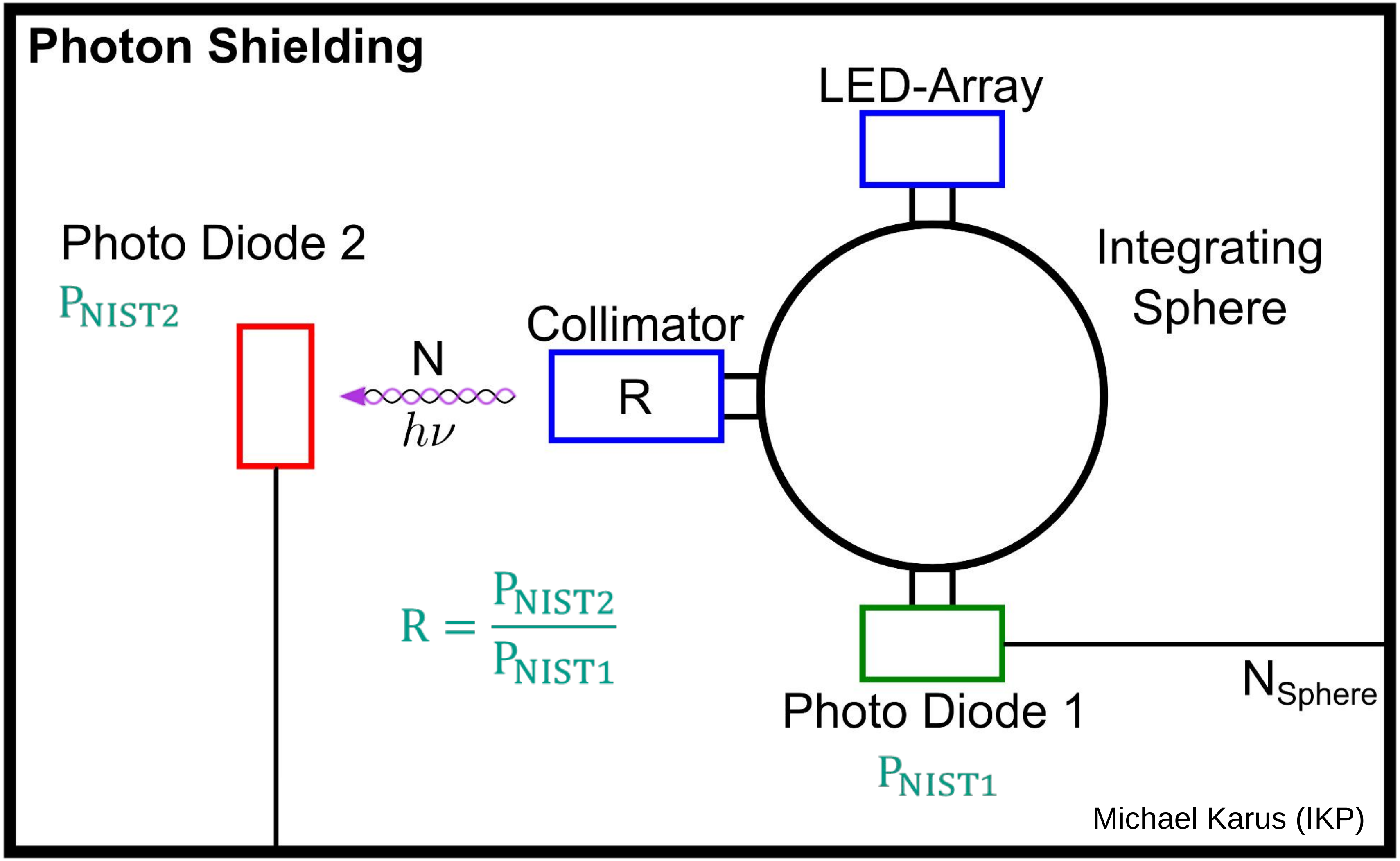
Calibration set-up



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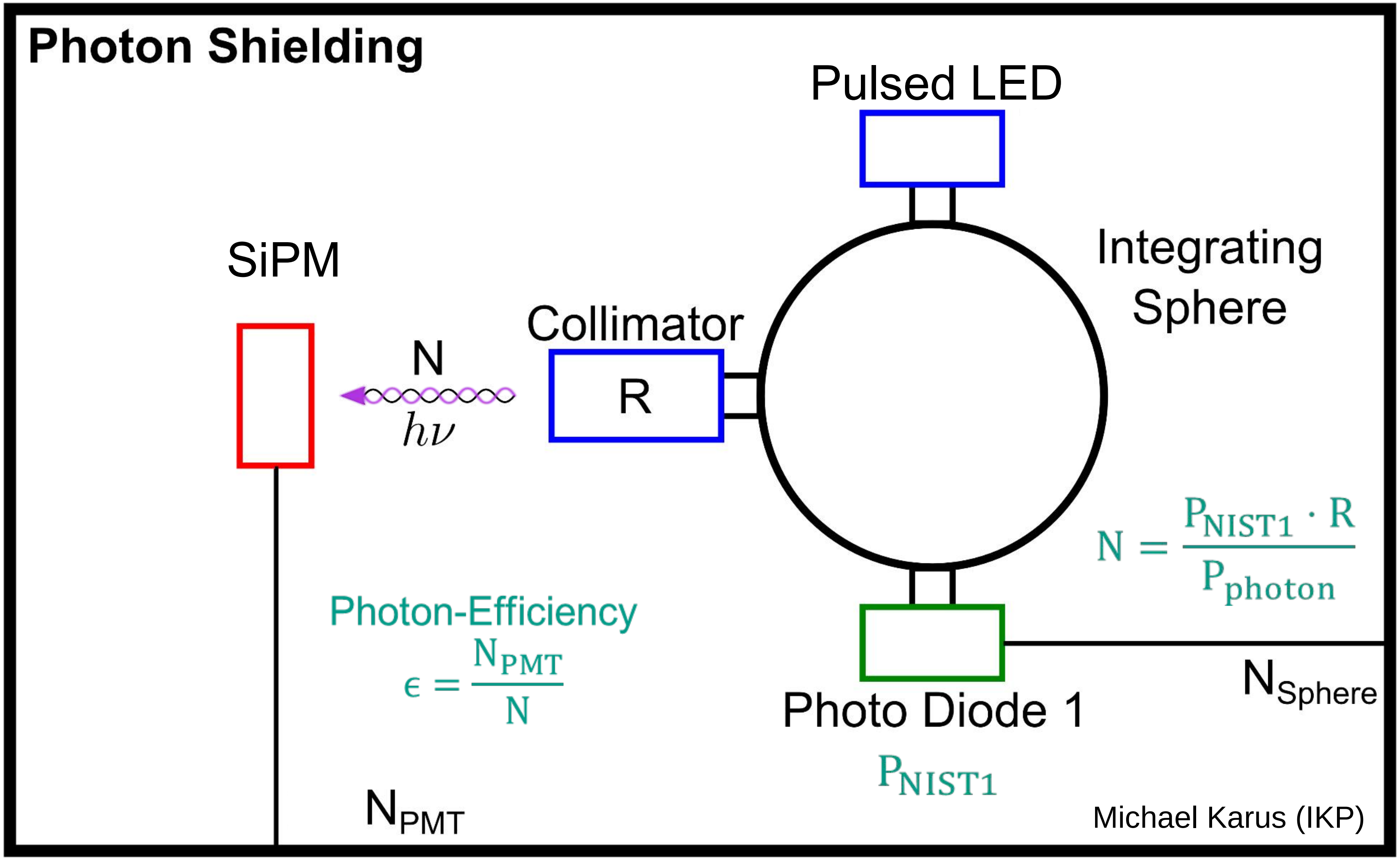
Calibration set-up



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