SciTil detector test status in Vienna

Outline

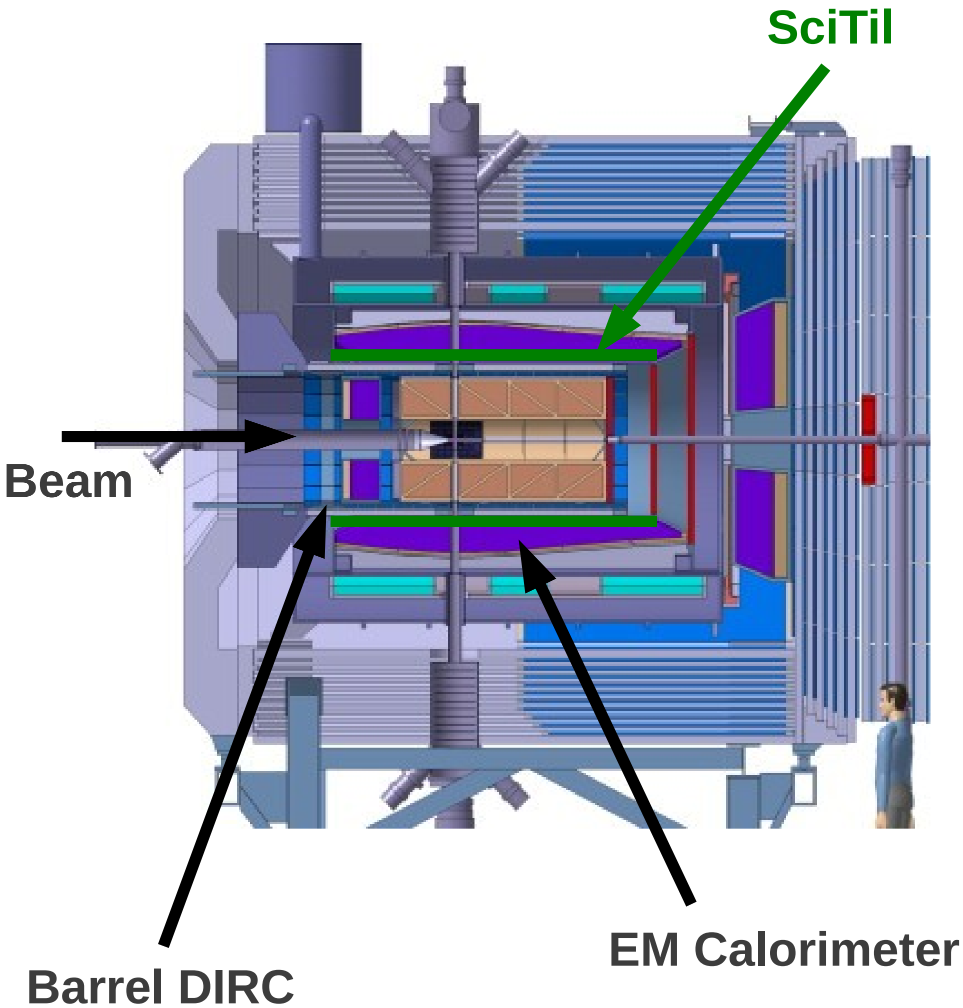
- Introduction – SciTil
- Measurements with dSiPM
- Measurements with aSiPM
- Detector optimization procedure
- Beam test plan

Introduction

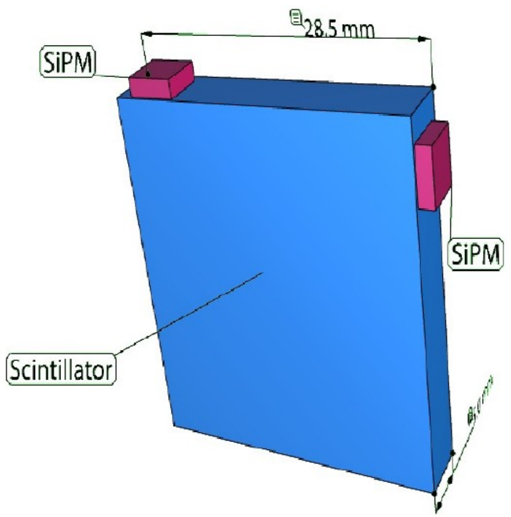
The Scintillation Tile Hodoscope (SciTil)

- **Motivation:**
  - **Particle ID**
  - **Relative timing**
  - **Event timing**
  - **Conversion detection**
  - **Charge discrimination**

- **Requirements:**
  - **Minimum material**
  - **Fast timing (σ ~ 100 ps)**



Detector layout



- **Idea**
  - **Small plastic scintillator tiles (~ 30 x 30 x 5 mm³)**
  - **Detect photons with directly attached Silicon Photomultipliers with 3 x 3 mm² sensitive area**

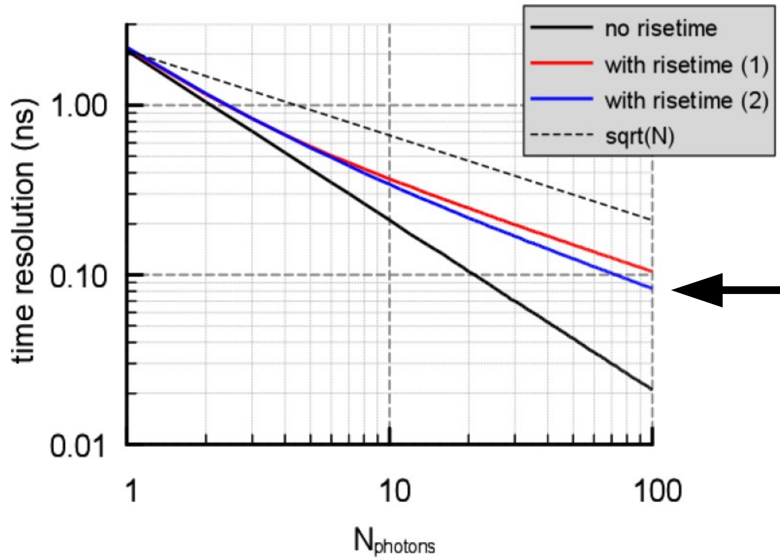
- **Plastic scintillator**
  - **Short rise/decay time**
  - **High light yield**

- **Silicon Photomultiplier (SiPM)**
  - **High PDE**
  - **Compact size**
  - **Low cost**
  - **Operation in magnetic fields**
  - **Low operating voltage**
  - **Good timing**

R&D to optimize sensor/scintillator geometry and configuration (incl. feasibility study)

Expected performance

Time resolution of BC-408 scintillator as a function of the number of measured photons (simulation):



BC-408:
τ_r = 0.9 ns
τ_d = 2.1 ns

100 photons
100 ps

Proposal for a Scintillator Tile Hodoscope for PANDA
K. Goetzen et al.

Expected photon number:

- **Minimum Ionizing Particle (MIP): ΔE (in 5 mm plastic) = 1MeV = 10^4 photons**
- **Assuming that 70% hit the rim: 7000 photons**
- **Detection area: 9 mm² (3x3 mm² SiPM), ~ 12 mm² (digital SiPM pixel)**
- **Assuming 55% PDE**
- **30 x 30 x 5 mm³ scintillator**

~ 60 photons per 3x3 mm² SiPM, ~ 75 photons per dSiPM pixel

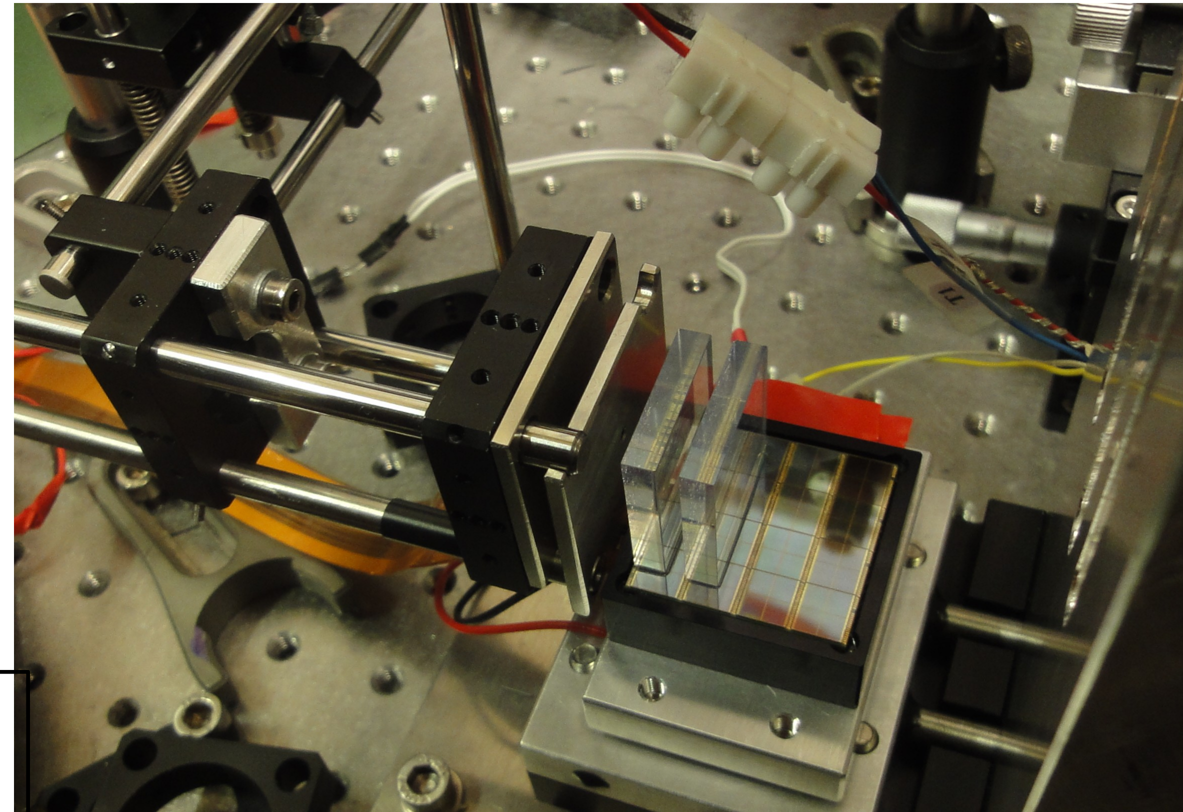
dSiPM Measurements

Experimental setup

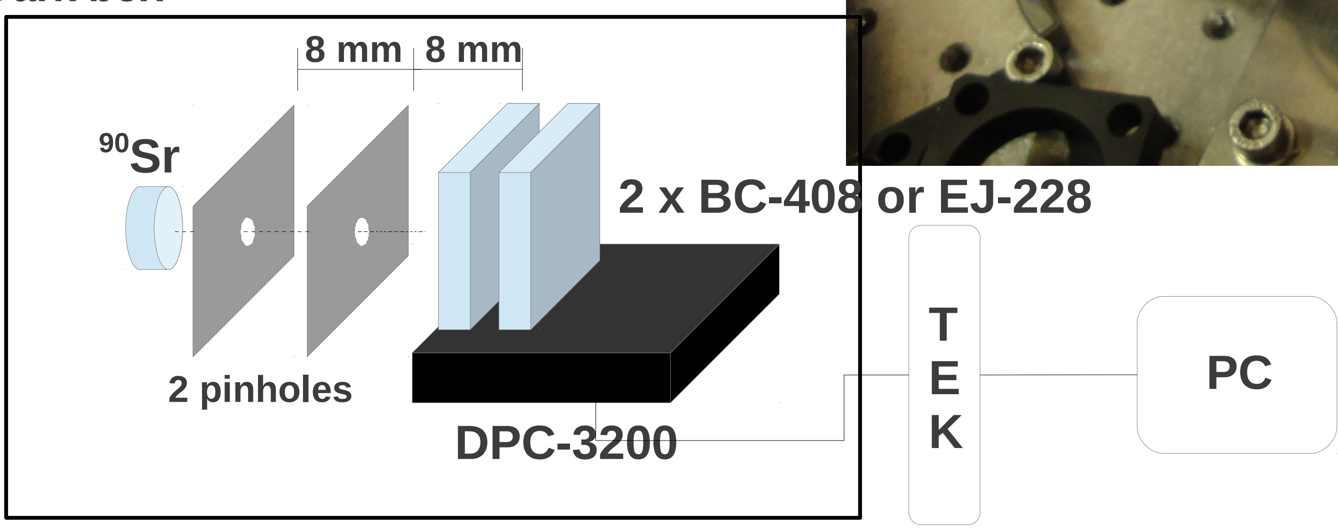
- **Coincidence using two scintillator tiles**
- **e⁻ from ^{90}Sr**

<u>Best value with EJ-228 (30 x 30 x 5 mm³):</u>

- **TOF resolution: σ = 90 ps**
- **$\sigma_{scint1} \sim \sigma_{scint2} \sim 60$ ps**



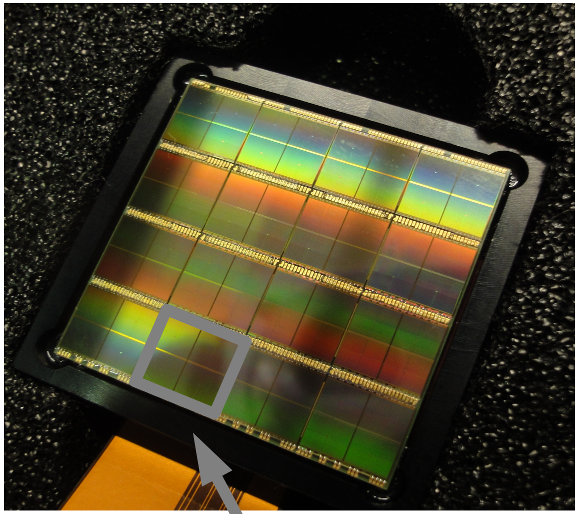
Dark box



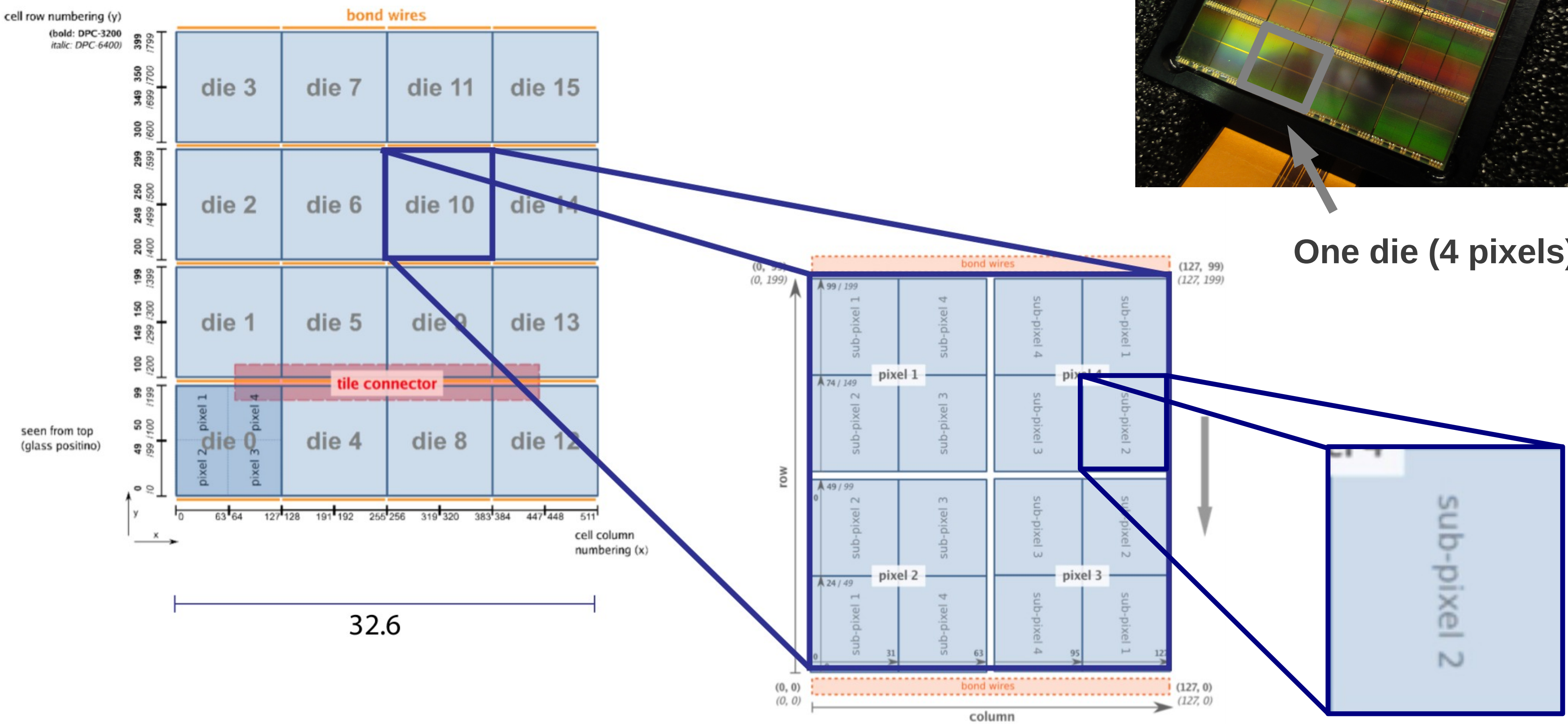
How was this value achieved?

The digital SiPM (dSiPM)

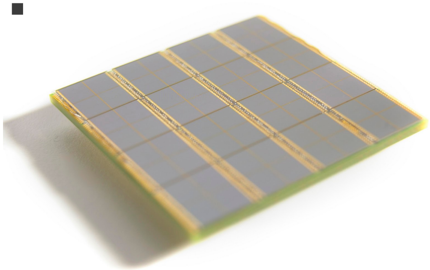
- **dSiPM consists of 16 independent die sensors (4 x 4 matrix)**
- **4 pixels each (3200 cells per pixel)**
- **One can switch on/off individual cells**



One die (4 pixels)



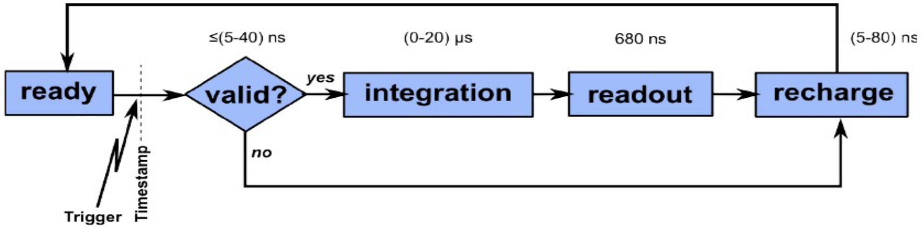
The digital SiPM – Why?



- **Try to get a feeling for time resolution of scintillator tile**
- **Big sensitive area (32.6 x 32.6 mm²)**
  - **Measure position dependence of the time resolution**
  - **Place several scintillators on one sensor**
- **Good timing (~ 20 ps sigma)**
- **Straightforward data acquisition**
  - **No additional electronics needed**
  - **Each die works as an independent sensor:**

    → Trigger threshold (set to 1 photon) → time stamp of the 1st photon

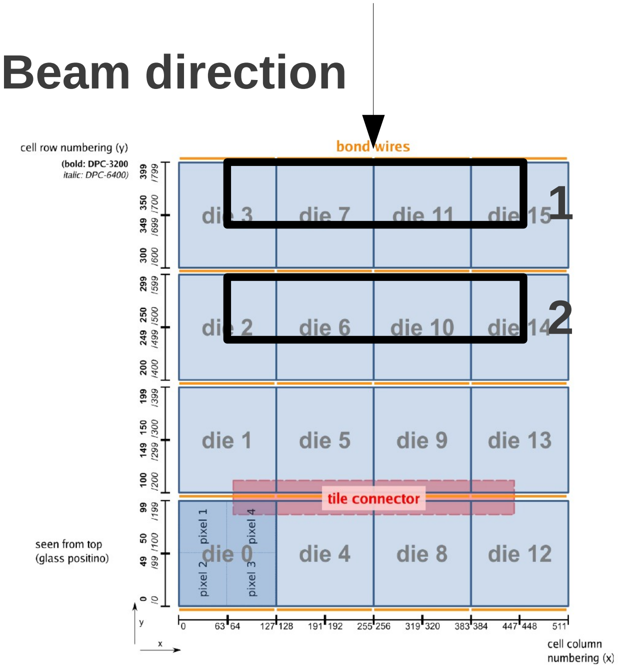
    → Validation threshold (set to 8 photons) → validates event → photon count
  - **One can decide how much area (cells) to activate per die**



dSiPM setup

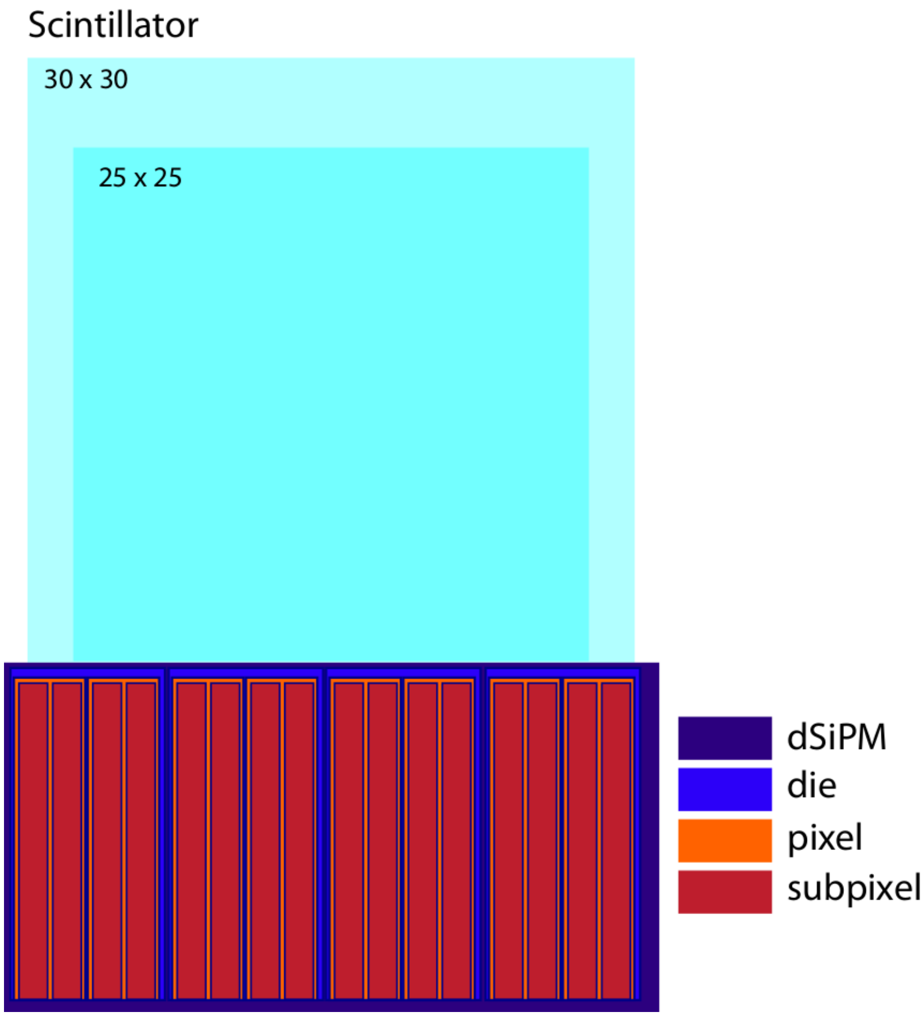
Top view

Beam direction

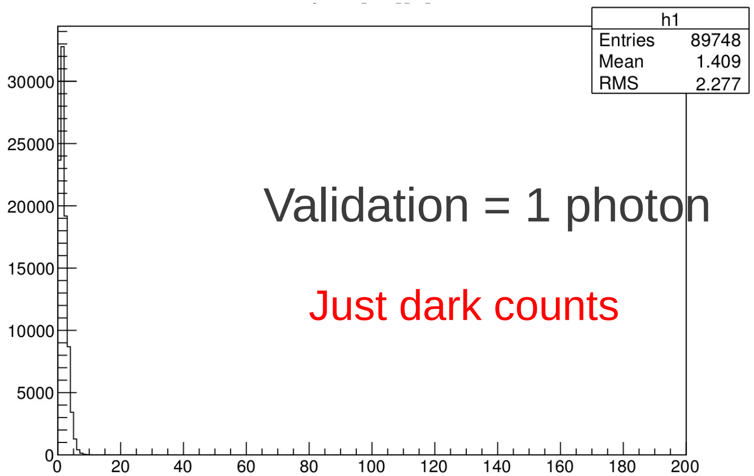


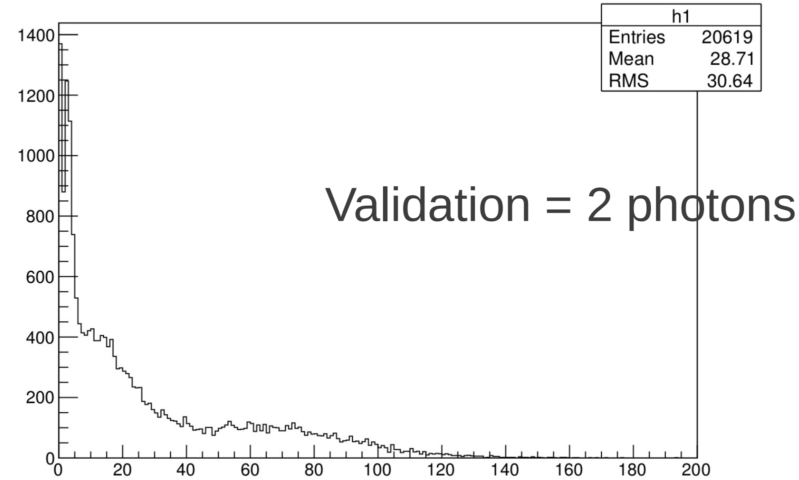
2 scintillator tiles

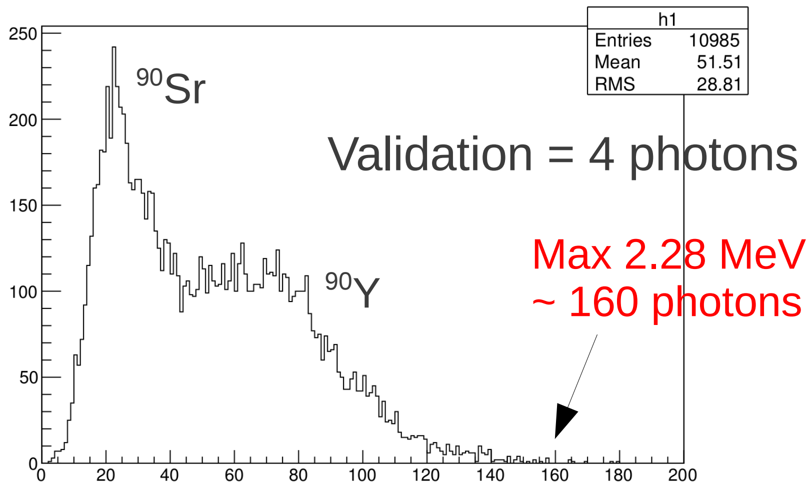
Side view

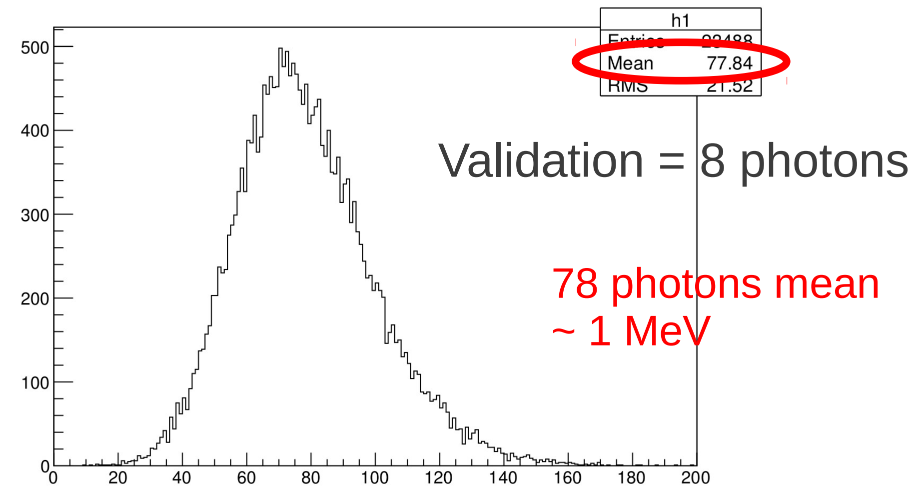


Photon spectrum









- **Validation threshold used to suppress dark count events**
- **Complicated validation logic on subpixel level**
  - **→ Threshold does not give the actual number of photons needed for validation**
  - **→ e.g. Validation = 8: on average 50 photons needed for validation**
- **Using high validation threshold results in loose cut on the energy spectrum**

Setting no. 1

2 pixels per die → 2 x 12.5 mm²
2 dies per tile → 2 x 25 mm²

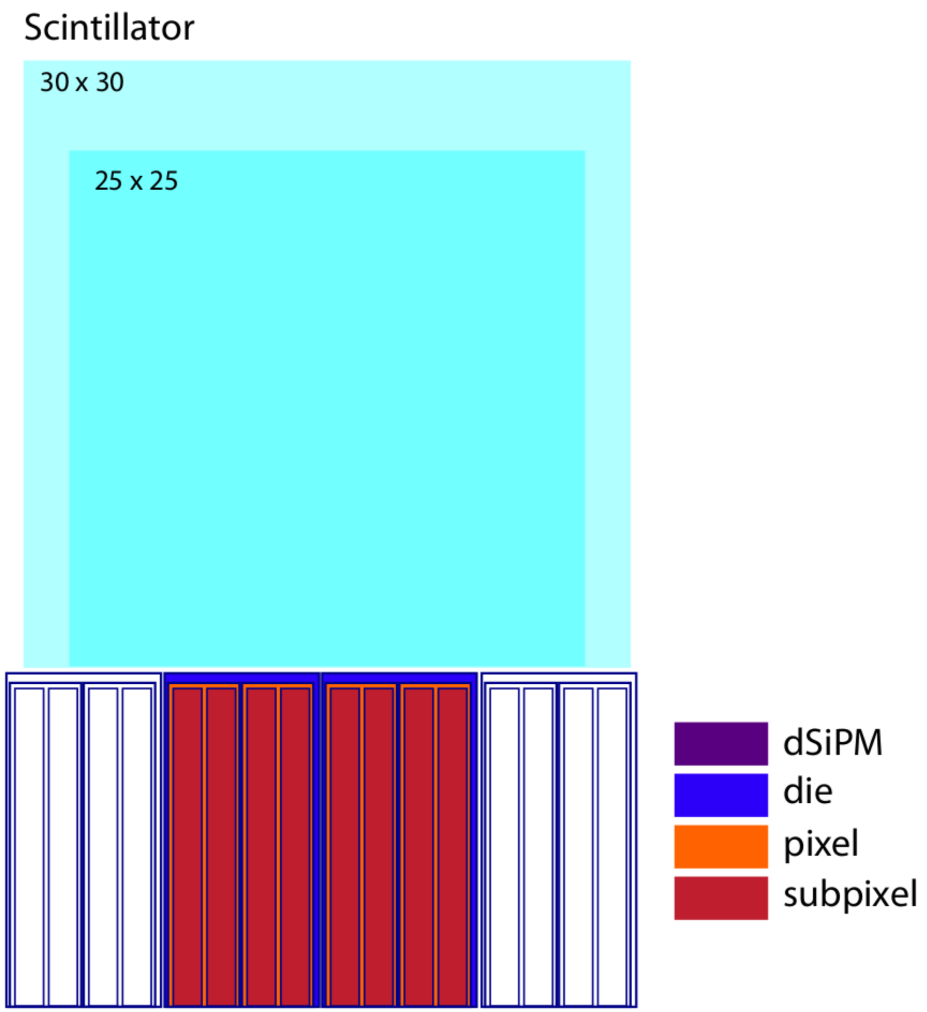
- **Total photon number:**
  - **30 x 30 x 5 mm³ (EJ-228): 2 x 145 photons**
  - **25 x 25 x 5 mm³ (BC-408): 2 x 200 photons**

  → factor 1.35 more photons for BC-408: ratio between detection area and surface area is larger

- **Timing of single tile:**
  - **30 x 30 x 5 mm³ (EJ-228): σ_{scint} = 60 ps**
  - **25 x 25 x 5 mm³ (BC-408): σ_{scint} = 85 ps**

  → BC-408 is factor 1.4 worse

EJ-228 is faster.
Shorter rise/decay time.



Setting no. 2

1 pixel per die → 1 x 12.5 mm²
2 dies per tile → 2 x 12.5 mm²

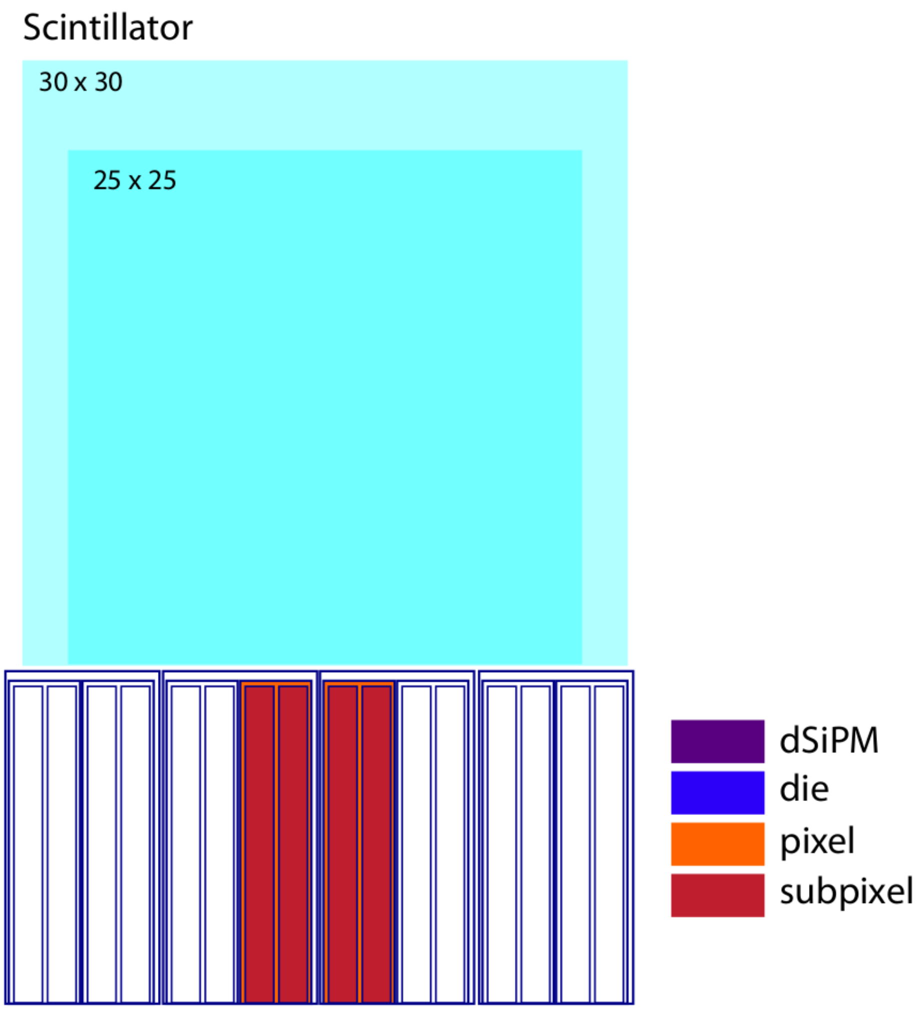
- **Total photon number:**
  - **30 x 30 x 5 mm³ (EJ-228): 2 x 70 photons**
  - **25 x 25 x 5 mm³ (BC-408): 2 x 100 photons**

    → factor 1.35 more photons for BC-408 because of smaller surface

    → factor 2 less photons compared to setting no. 1

- **Timing of single tile:**
  - **30 x 30 x 5 mm³ (EJ-228): σ_{scint} = 78 ps**
  - **25 x 25 x 5 mm³ (BC-408): σ_{scint} = 120 ps**

    → ~ factor √2 worse compared to setting no. 1 because of less photons



Setting no. 3

3x3 mm² active area per die → 1 x 9 mm²
2 dies per tile → 2 x 9 mm²

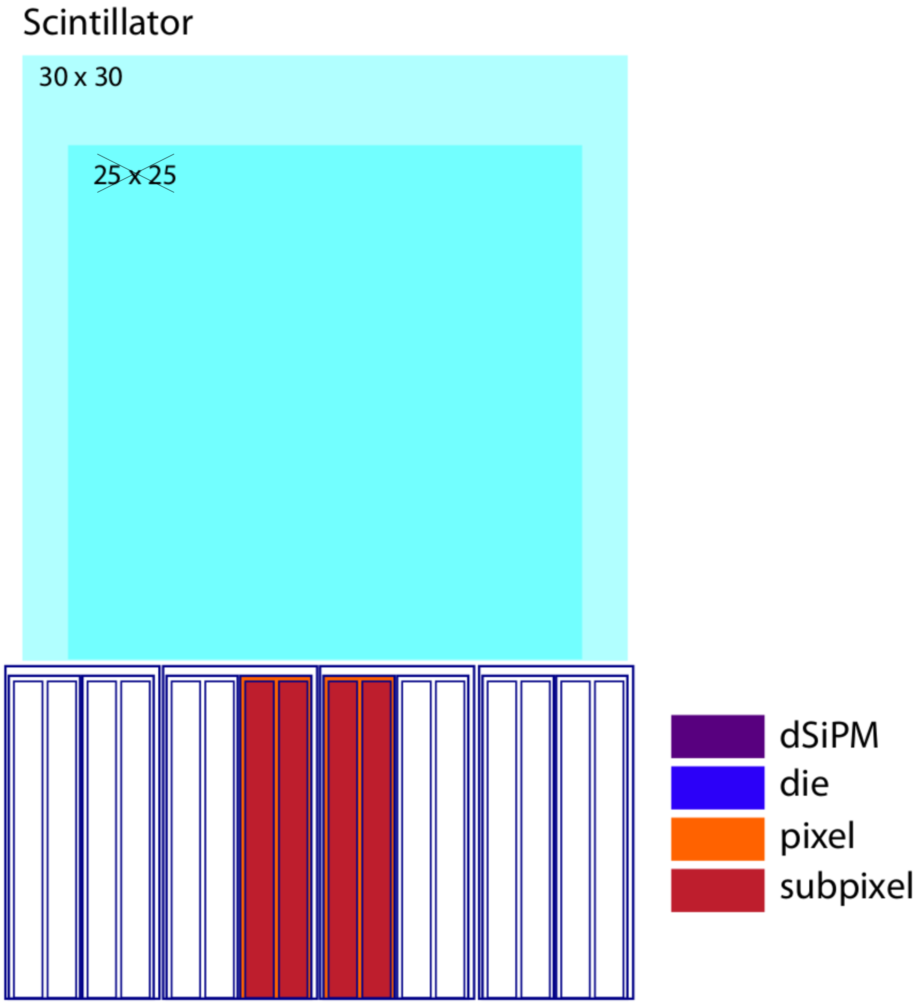
- **Total photon number:**
  - **30 x 30 x 5 mm³ (EJ-228): 2 x 55 photons**

    → ~ factor 1.4 (2*12.5/2*9) less photons compared to setting no. 2

- **Timing of single tile:**
  - **30 x 30 x 5 mm³ (EJ-228): σ_{scint} = 90 ps**

    → worse compared to setting no. 2 because of less photons

    → 100 ps reached with 2x 3x3 mm² active area



dSiPM to aSiPM

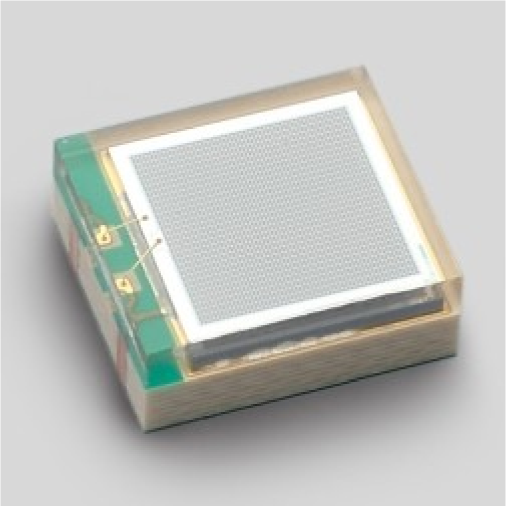
- **dSiPM unlikely to be used at SciTil**
- **First tests to get qualitative tendencies**
- **Before we go to more realistic condition using analog SiPM**

- **What can we learn:**
  - **Photon number dependent on surface area: prop. to area**
  - **Time resolution dependent on photon number: sqrt(N)**
  - **The more detection area (Nb of detectors) the better**
  - **Best value using EJ-228 (30 x 30 x 5 mm^3): 60 ps using 2 dies (2 x 25 mm^2)**
  - **90 ps using 2x 3x3 mm^2 active area (2 x 9 mm^2)**

- **Threshold settings:**
  - **Using 2 thresholds**
  - **Set validation threshold to suppress noise**
  - **Take time stamp from 1st photon (if using the dSiPM in combination with scintillator)**

aSiPM Measurements

R&D 3x3 mm² SiPM



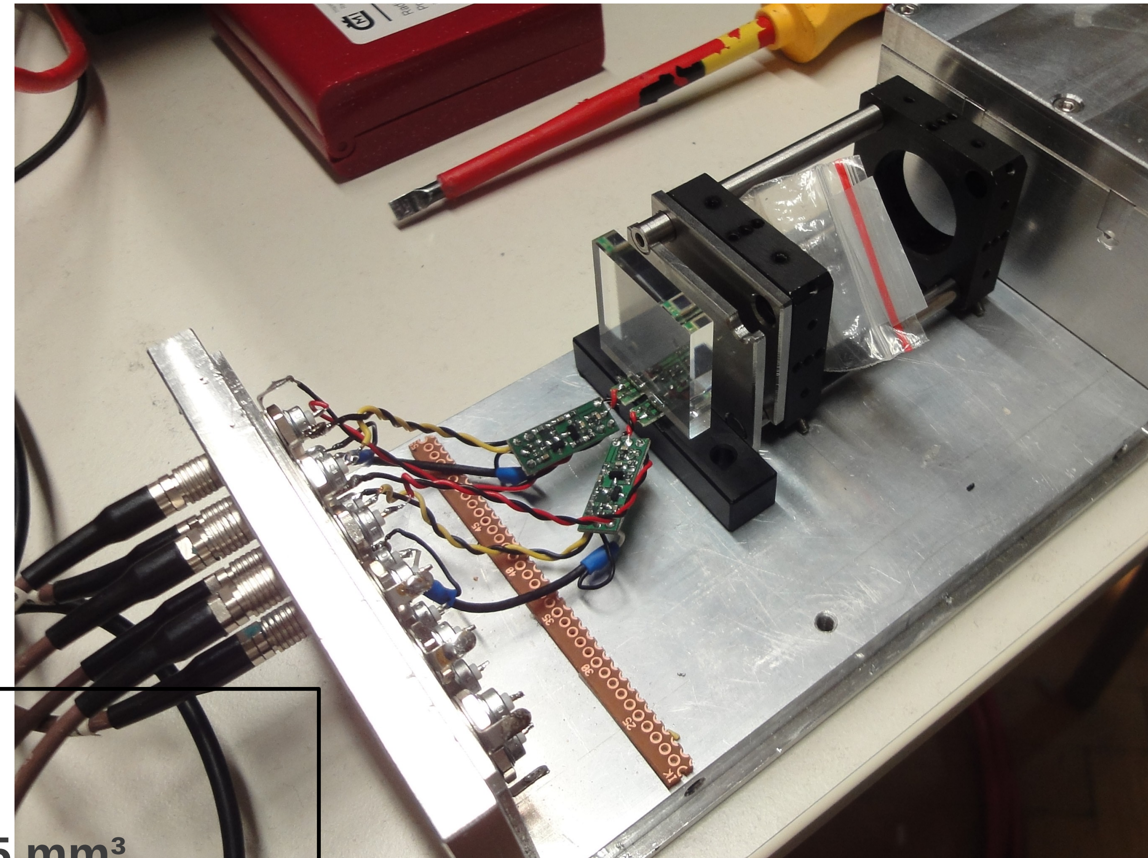
Source:
- **Strontium-90**
- **2 mm pinhole**

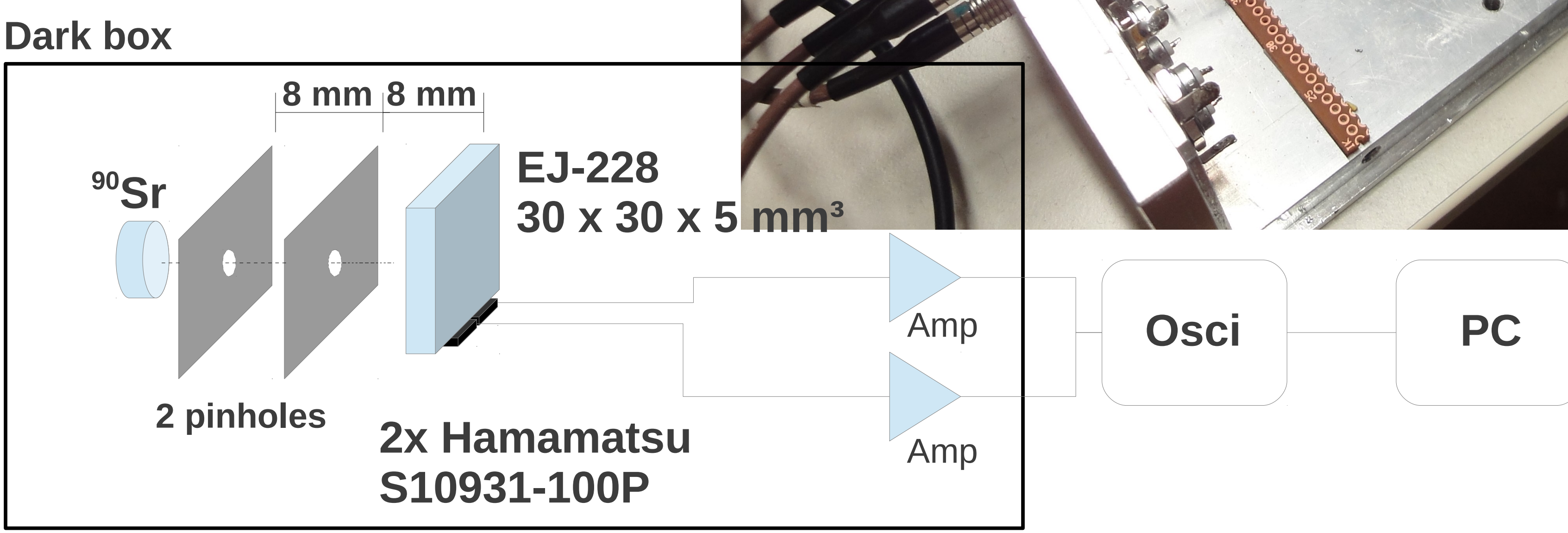
Photo sensor:
- **Hamamatsu S10931-100P**
- **3x3 mm^2 active area, 100 µm pixel size**
- **Temperature: 25 °C (room temperature)**
- **Sensor coupled to scintillator using optical grease (BC-630)**

Scintillator:
- **1 x EJ-228: 30 x 30 x 5 mm^3**

Readout and data acquisition:
- **Amp-0611 Photonique ("SMI version", slightly modified)**
- **Oscilloscope (WaveRunner 625 Zi), 40 GS/s, 2.5 GHz**
- **PC**
- **Waveform analysis**

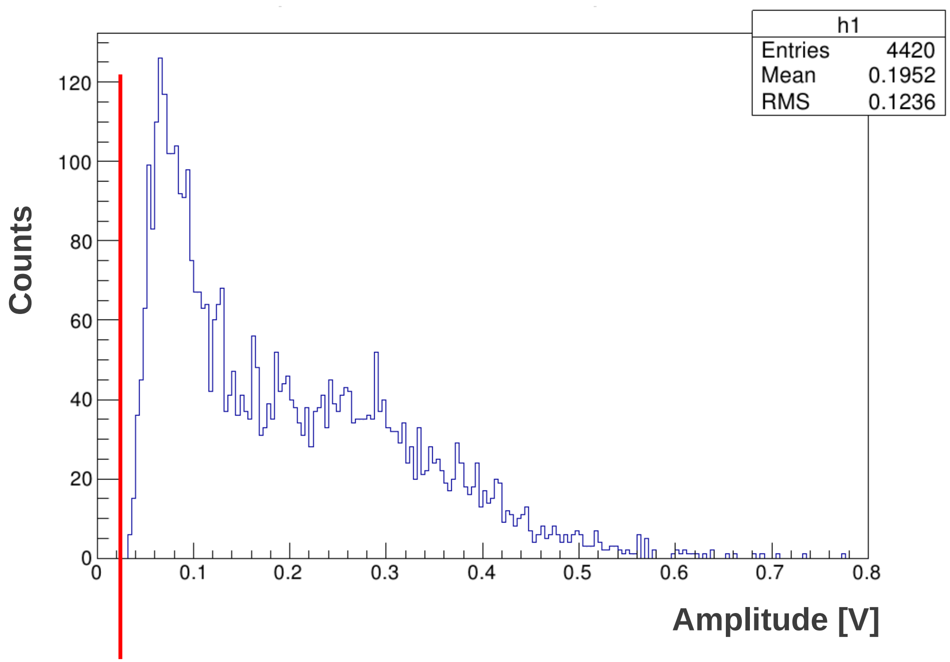
Experimental setup



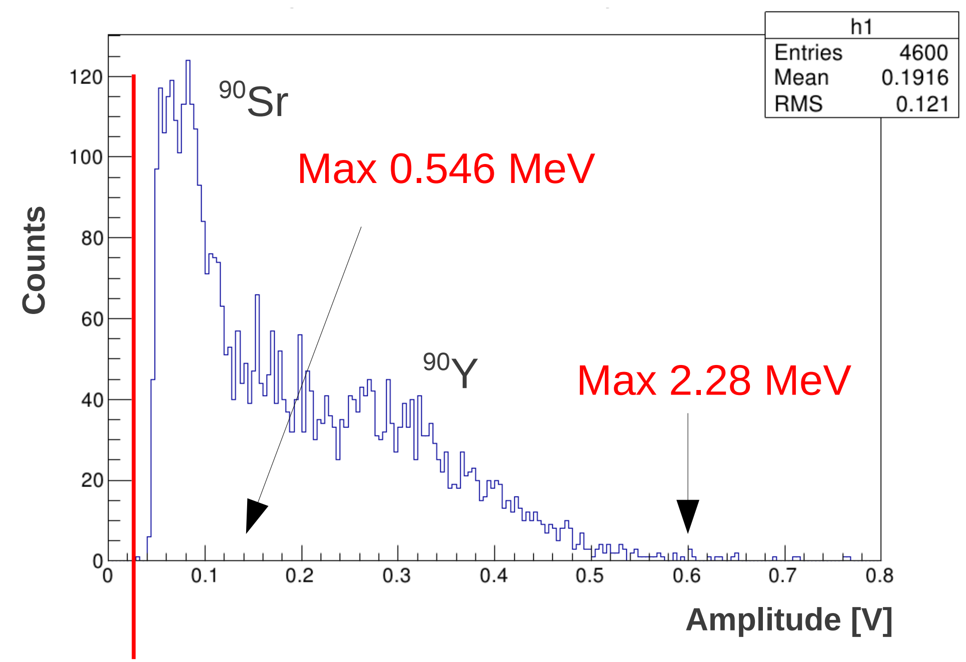


Photon number

Energy Spectrum Channel 1



Energy Spectrum Channel 2

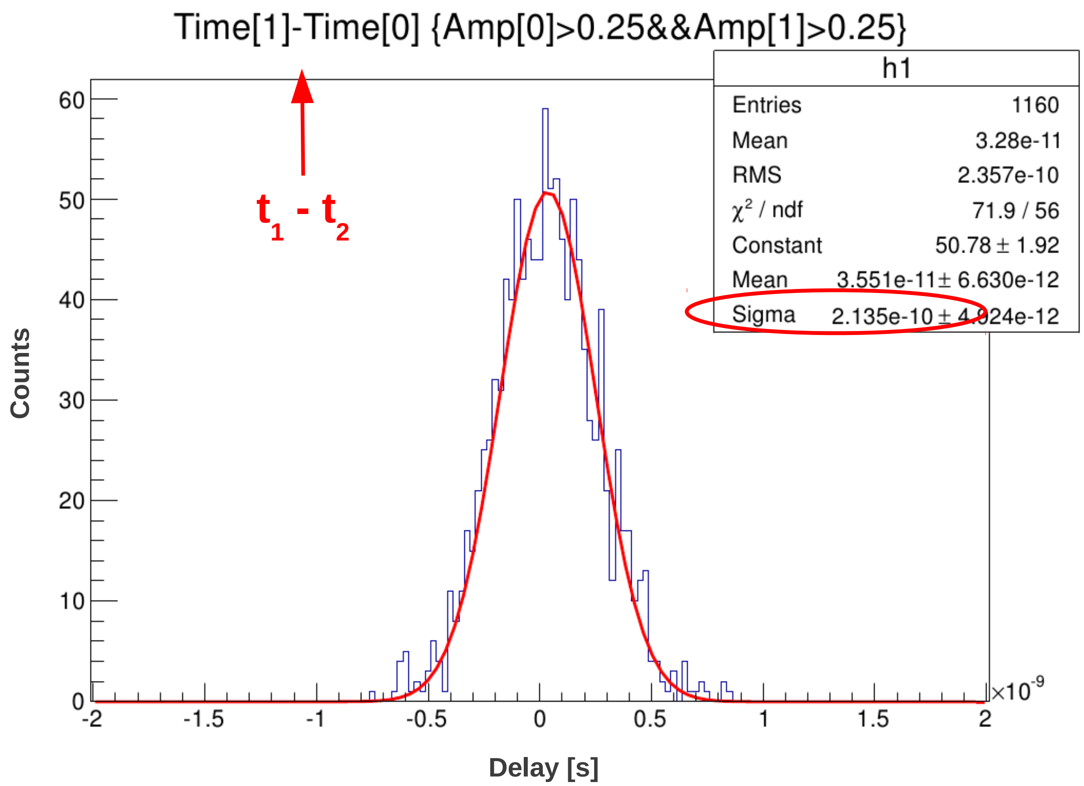


Hardware threshold
20 mV ~ 5 photons

- **^{90}Sr spectrum as expected**
- **Expected from estimation: ~ 60 photons per 3x3 mm²**
- **ΔE = 1 MeV ↔ ~ 0.25 V amplitude (= 60 photons)**
- **We see the expected number of photons**

Time resolution

Coincidence time resolution (CTR)



- **Offline waveform analysis**
- **Software threshold: 10% of the amplitude (CFD)**
- **Energy cut: ΔE > 1 MeV (MIP) (Amplitude > 0.25 V)**

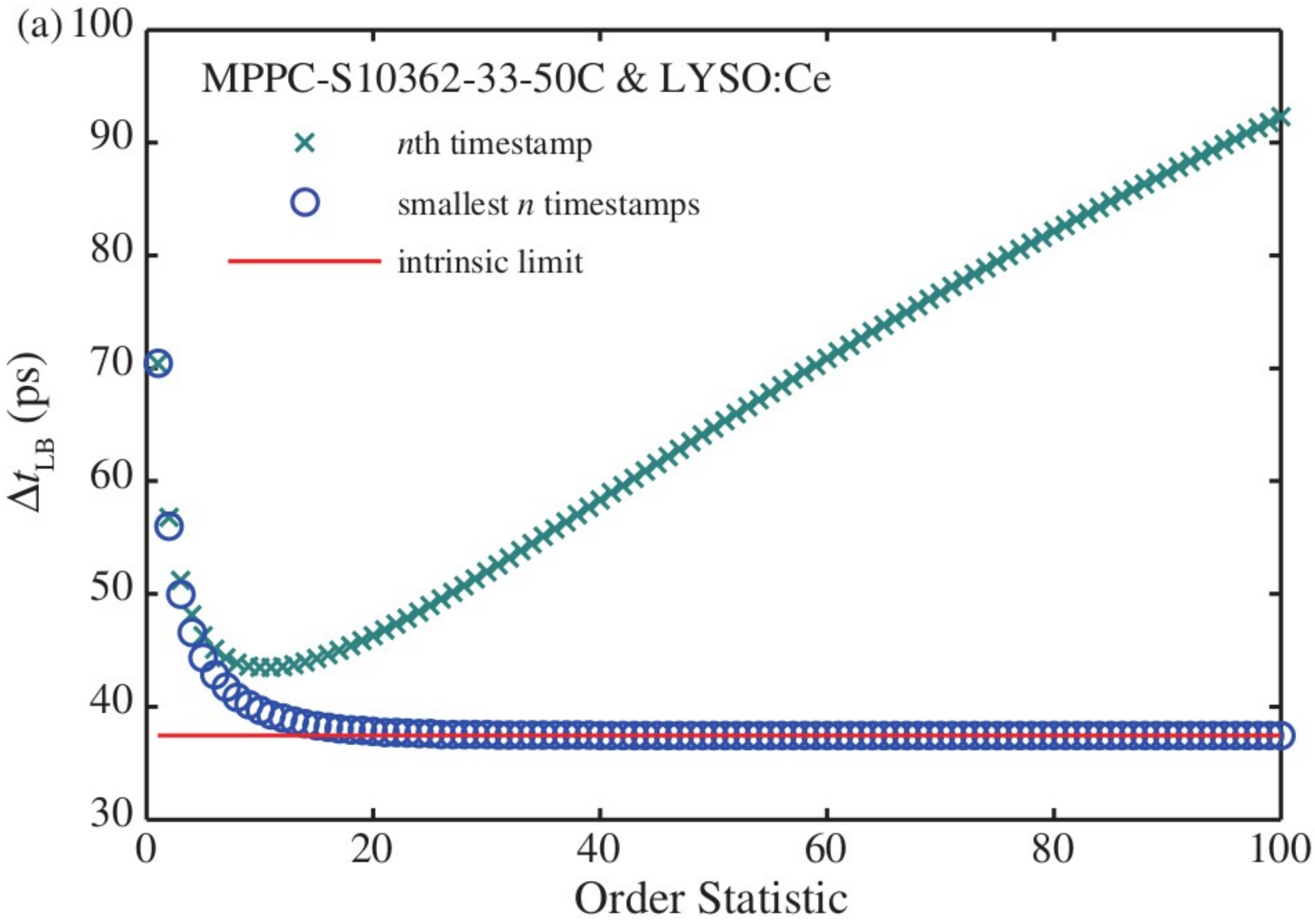
- **Time resolution of single tile readout with 2 SiPMs**

σ_{tile} ~ 150 ps

Potential for improvement (photodetector, operating conditions, …)
Threshold level needs fine tuning (triggering on the 1st photon does not necessarily give the best timing).

Threshold setting

Model calculation

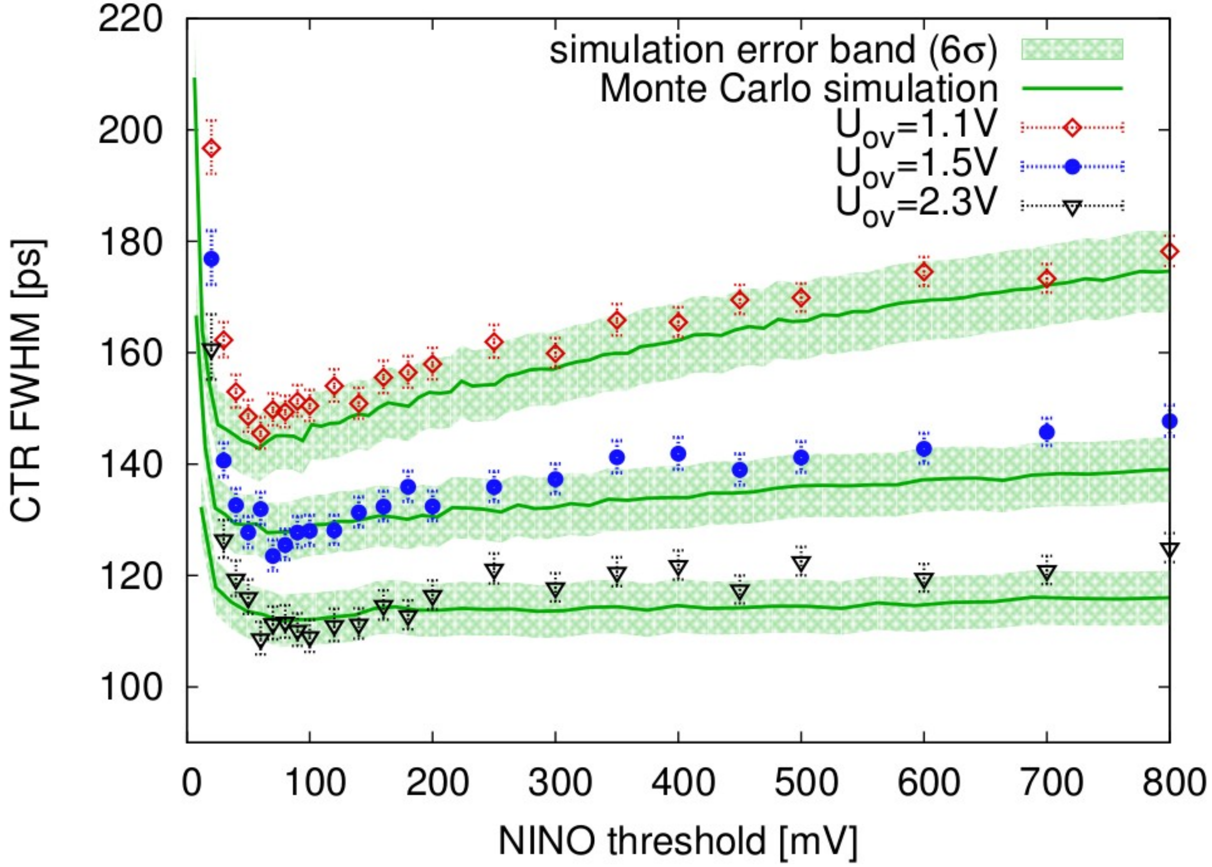


The lower bound on the timing resolution of scintillation detectors

Stefan Seifert, Herman T van Dam and Dennis R Schaart (2012)

Threshold setting

Simulation + experiment



Time of flight positron emission tomography towards 100ps resolution with L(Y)SO: an experimental and theoretical analysis
S. Gundacker at al. (2013)

Threshold setting

Simulation (Geant3)

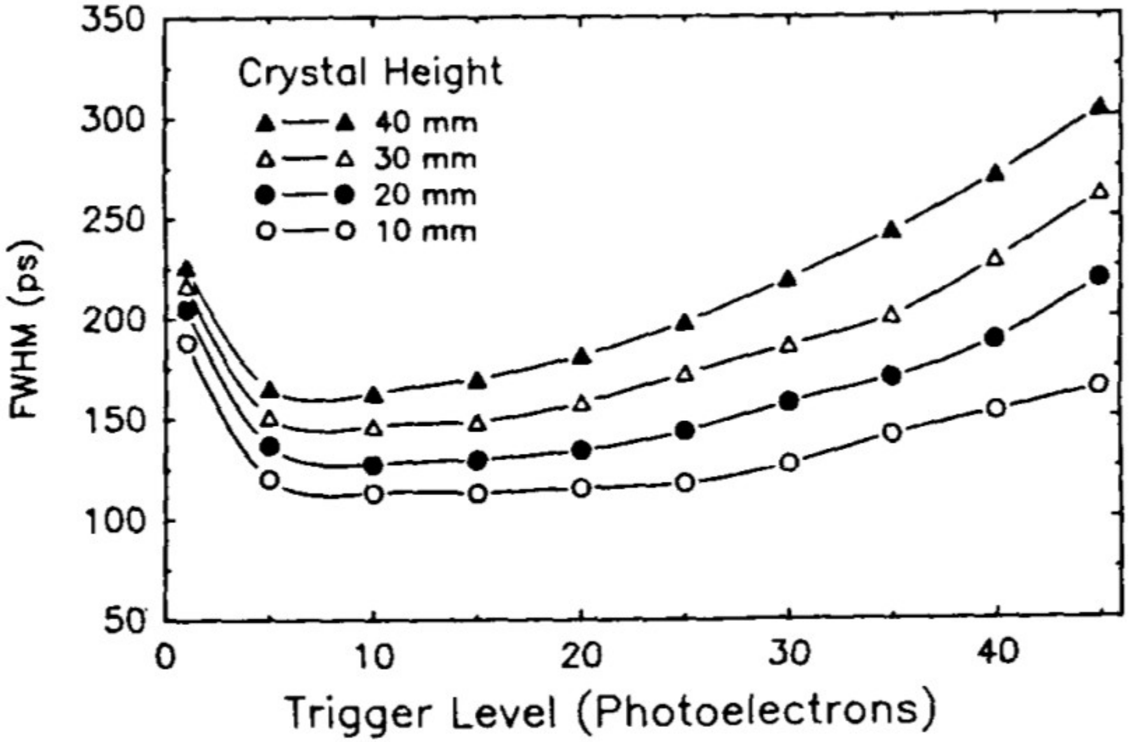


Fig. 2. Calculated width of trigger time distribution for cylindrical BaF_2 crystals with radius 15 mm, energy threshold 480 keV.

Effects of scintillation light collection on the time resolution of a time-of-flight detector for annihilation quanta
S. Ziegler at al. (1990)

Optimization

Degrees of freedom

- Photodetector
- Position of photodetector
- Number of detectors
- Scintillator material
- Scintillator geometry
- Scintillator wrapping

Degrees of freedom

- Photodetector
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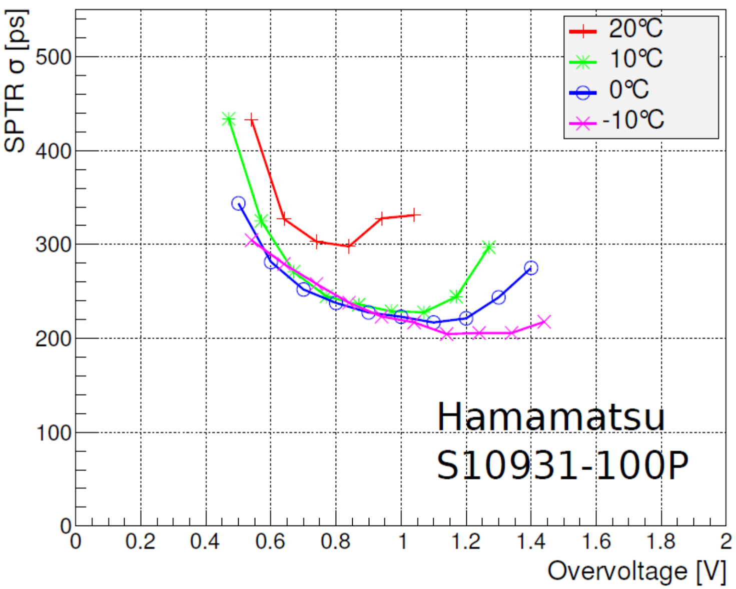
- Scintillator wrapping

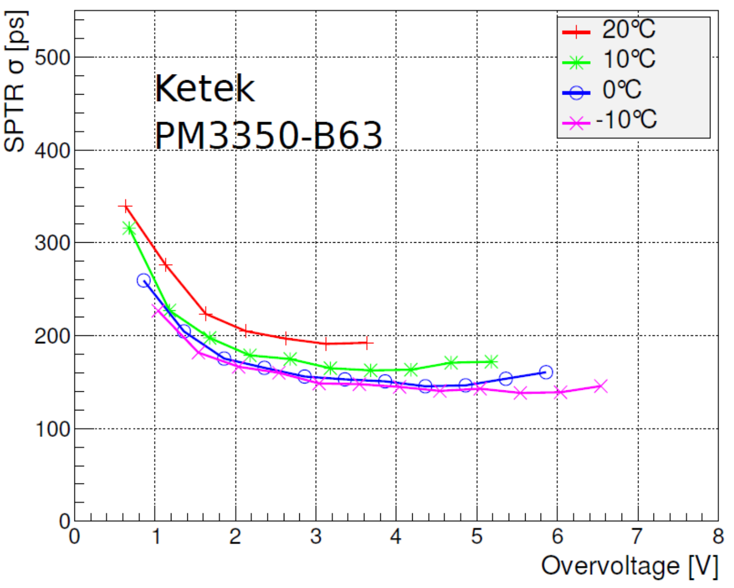
Photodetector

- dSiPM unlikely to be used for SciTil
- SiPM time resolution studies
- See talk held by S. Brunner at DIRC2013
- **2 options: Hamamatsu or Ketek (3x3 mm²)**
- Ketek PM3350-B63 shows best results:
  - optical trenches
  - 50 µm pixel size
- Hamamatsu:
  - 12572 and 12652 (new, with trenches) will be tested before beam test
  - 10931-100P or -050P
- AdvanSiD: low PDE
- SensL: not tested, also lower PDE

Time resolution follows 1/sqrt(Nb of photons)
We expect ~ 60 photons:
- Hamamatsu 100P → σ = 40 ps
- Ketek PM3350 → σ = 25 ps

Single Photon Time Resolution





Photodetector

SiPMs with 3x3 mm² active area. What do we have for testing?

	Type	Stock	Tested in lab	Comment
Hamamatsu	S10931-33-100P	> 5	x	
	S10931-33-050P	1		
	S10931-33-025P	1		
	S10362-33-100C	1		
	S10362-33-050C	1		
	S12572-010C	1		low afterpulse
	S12572-015C	1		low afterpulse
	S12572-025C	1		low afterpulse
	S12572-050C	1		low afterpulse
	S12652-050C	1		ordered
	S12652-100C	1		ordered
Ketek	PM3350-B63	1	x	low crosstalk
	PM3360-B66T75S	1	x	
	PM3375-B72	1	x	low crosstalk
AdvansID	ASD-SiPM3S-P50	> 10	x	
	ASD-SiPM3S-P-50 RGB	1		
	ASD-SiPM3S-P-50 NUV	1		
SensL	MicroFM-30050-SMT	2		

- **We need at least 2 pieces of each type we want to test.**
- **+ 1 or 2 pieces for spare.**
- **We will try to get more (at least before test beam).**

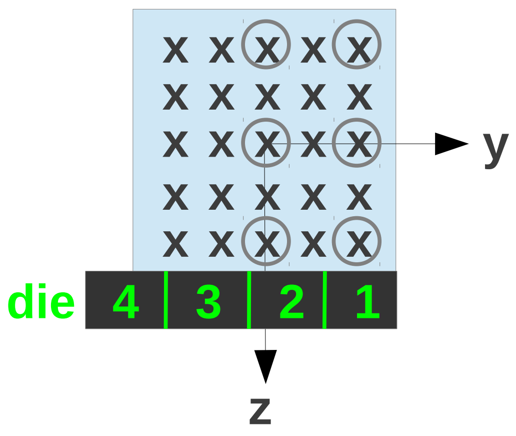
Degrees of freedom

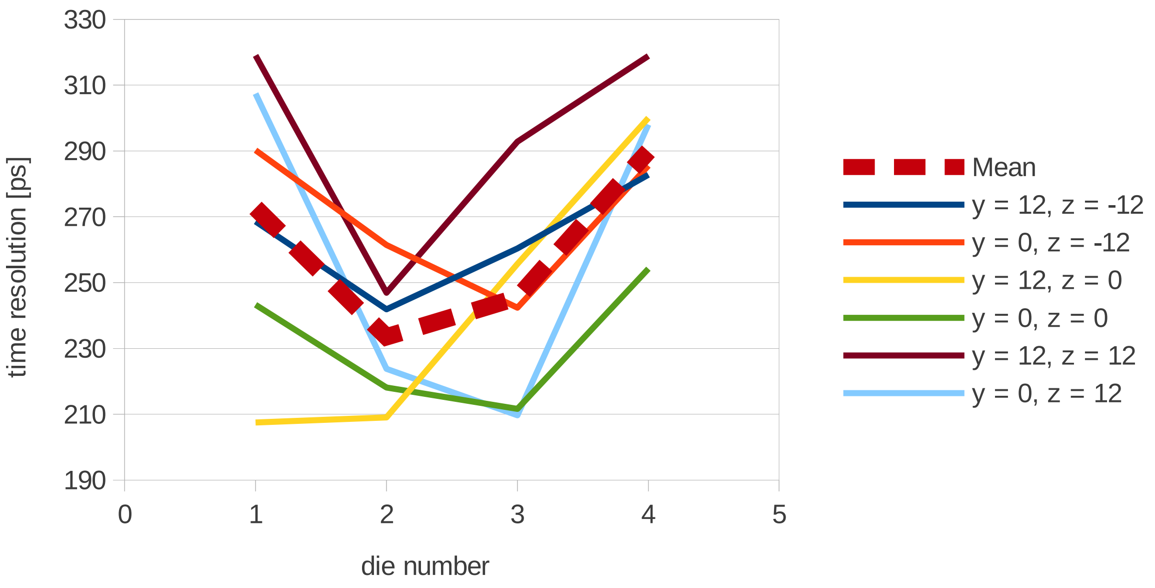
- Photodetector
- Position of photodetector
- Number of detectors
- Scintillator material
- Scintillator geometry
- Scintillator wrapping

Photodetector position

The dSiPM gives a time stamp per die at the moment of trigger occurrence (arrival of the 1st photon). One can use this time stamps to calculate arrival time difference between dies.

30 x 30 x 4 mm³ (4 dies) → 6 equations to calculate σ_i (i = 1,2,3,4)
Perform a fitting to solve equations and evaluate time resolution of single die.

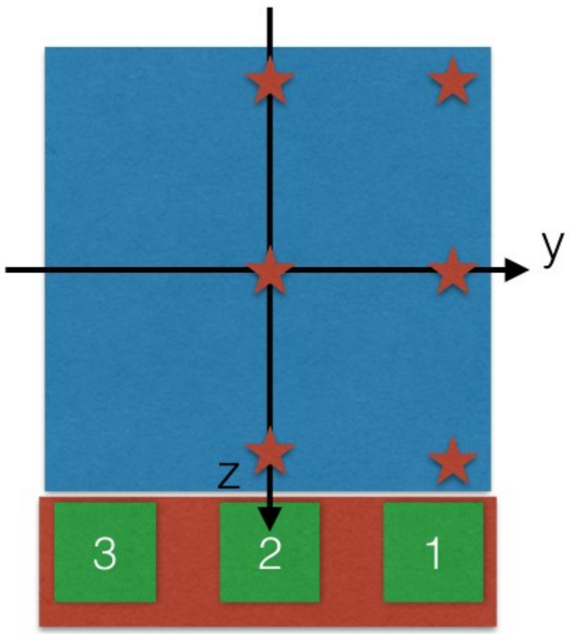




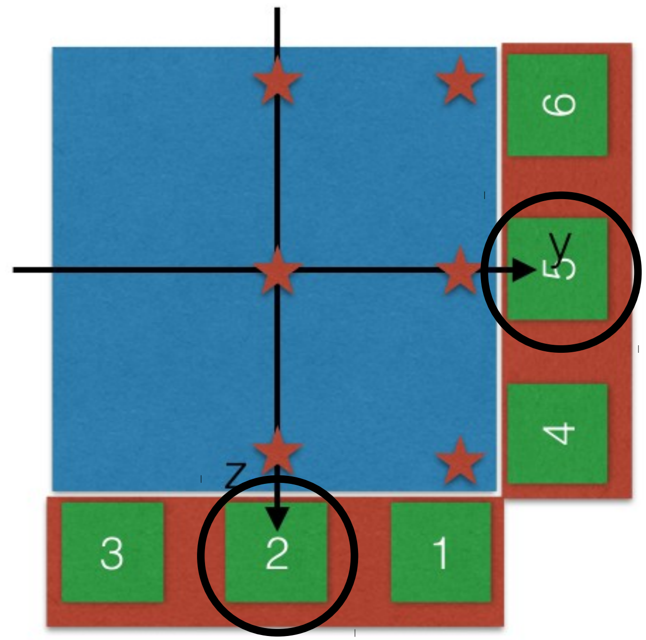
Strong position dependency !
Better time resolution for dies 2 and 3 favors central position of the sensor.

Possible Configurations

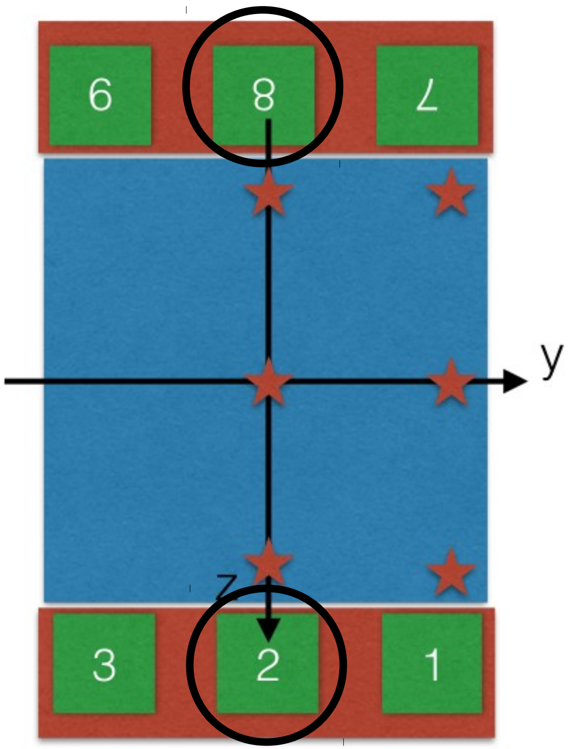
Case A:



Case B:



Case C:



- **Best time resolution:**
- **Case B: position 2 + 5**
- **Case C: position 2 + 8**

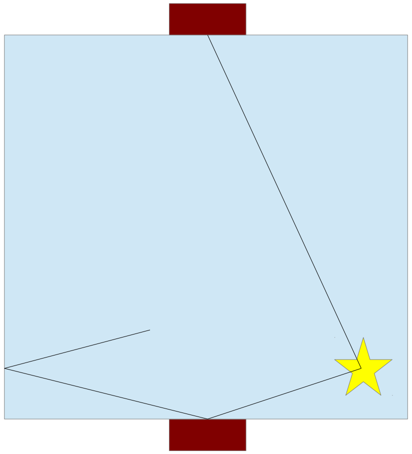
Degrees of freedom

- Photodetector
- Position of photodetector
- Number of detectors
- Scintillator material
- Scintillator geometry
- Scintillator wrapping

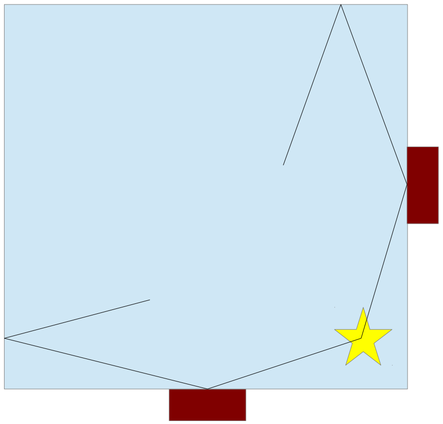
Number of detectors

- **100 ps can be expected using two detectors (3x3 mm³ each)**
- **Increasing the number of detectors N_{det}:**
  - **→ increases number of detected photons: prop. N_{det}**
  - **→ improves time resolution by $1/\sqrt{N_{det}}$**
  - **→ increases total amount of channels**

Favored positioning:



For any position of interaction, direct photons can be seen by at least one detector.



For some position of interaction, there might be no direct photons seen.

Degrees of freedom

- Photodetector
- Position of photodetector
- Number of detectors
- Scintillator material
- Scintillator geometry
- Scintillator wrapping

Scintillator material and size

What do we have for testing?

	EJ-232	EJ-228	EJ-204	EJ-200	BC-408
20 x 20 x 5 mm³		x			
25 x 25 x 5 mm³					x
28.5 x 28.5 x 5 mm³	x	x	x	x	
30 x 30 x 5 mm³		x			
40 x 40 x 5 mm³		x			

2 dim. parameter scan

	EJ-232 **NE-111A/BC-422**	**EJ-228** **Pilot-U/BC-418**	**EJ-204** **NE-104/BC-404**	**EJ-200** **Pilot-F/BC-408**	**BC408** **Pilot-F**
Light yield [% Anthracene]	55	67	68	64	64
Light yield [photons/MeV]	8,400	10,200	10,400	10,000	10,000
Rise time [ns]	0.35	0.5	0.7	0.9	0.9
Decay time [ns]	1.6	1.4	1.8	2.1	2.1
Wavelen. of Max. Emission [nm]	370	391	408	425	425

Scintillator material and size

- **BC-408 (25 x 25 x 5 mm^3) and EJ-228 (30 x 30 x 5 mm^3) tested**
- **We only considered 5 mm thickness (seems to be optimum in terms of radial space, timing, efficiency, other barrel detectors)**
- **Better results with EJ-228 – below 100 ps with dSiPM**
- **Decreasing the size:**
  - → **increases ratio between detection area (A_D) and scintillator surface (A_s)**
  - → **increases number of detected photons (N_{ph}) prop. A_D/A_s**
  - → **improves time resolution by $1/\sqrt{N_{ph}}$**
  - → **increases the total number of channels in SciTil**

- **Increasing the size:**
  - → **worsens time resolution**
  - → **decreases amount of channels**

Fine tuning needed.
Best results with EJ-228 (30 x 30 mm^2) up to now.
Tradeoff between time resolution and number of channels.

Degrees of freedom

- Photodetector
- Position of photodetector
- Number of detectors
- Scintillator material
- Scintillator geometry
- Scintillator wrapping
  - No wrapping considered up to now (100 ps reached with dSiPM)
  - Test first without wrapping

Summary

- **Using a scintillator tile (EJ-228, 30 x 30 x 5 mm³) readout with the dSiPM with an activated area of 2 x 9 mm², we measured a time resolution of σ = 90 ps.**

- **Using instead 2 Hamamatsu SiPMs (2 x 9 mm²) for readout, we achieved a time resolution of σ = 150 ps.**

- **These are rather conservative values (loose energy cuts, no time walk correction). We are very optimistic that the values can be improved and a time resolution below 100 ps sigma can be reached, also with the aSiPM.**

- **There are several parameters that can still be optimized before the test beam:**

  → type of photodetector
  → photodetector position
  → scintillator material and size
  → fine tuning of threshold settings
  → fine tuning of operating parameters
  → time walk correction

Test beam at COSY (FZ Jülich)

Schedule:

- **η' experiment test beam**
- **Primary plan: Week no. 5, 2014 (Jan 27 to Feb 2)**
- **New schedule (preliminary): Week no. 5 and 6, 2014 (Jan 27 to Feb 9)**
- **But only during night (after 9 p.m.)**
- **We are invited to join**

Purpose:

- **Test SciTil prototype in beam**
- **Measure time resolution with “most promising” setup**
- **test other SiPMs,**
- **scintillator geometry and material,**
- **electronics,**
- **...**

Test beam at COSY

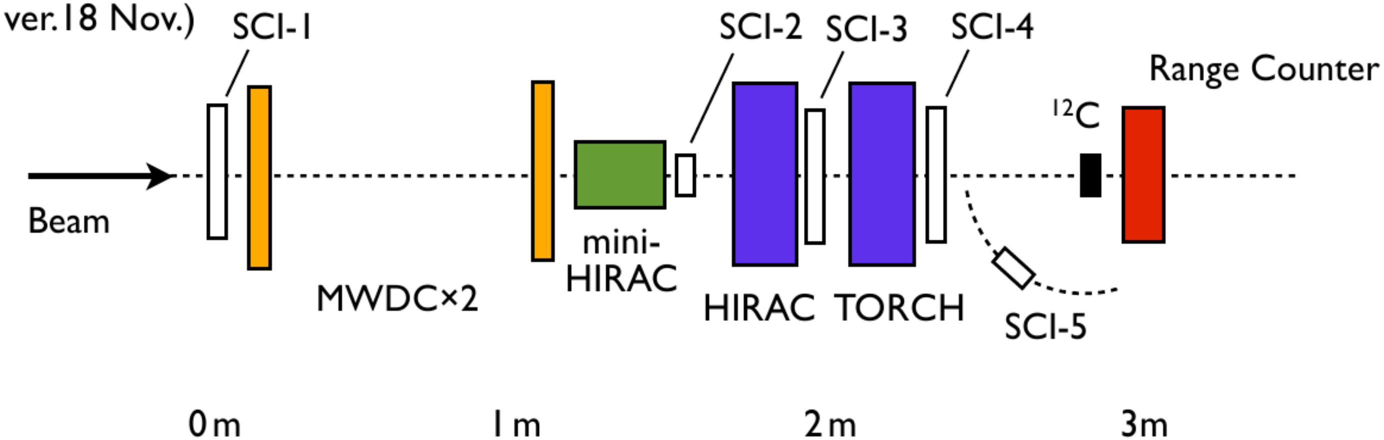
* 0.05% precision for HIRAC rejection prob. for every 5mm×5mm grid

Beam condition (in the order of priority)

(A) 2.9 GeV/c proton, defocused, 10^5-10^6/s, ~ O(10^7) trigger : (1) (2)
(B) 1.5 GeV/c proton, defocused, 10^5-10^6/s, ~ O(10^7) trigger : (1) (2)
(C) 3.3 GeV/c proton, , 10^5-10^6/s, : (3)
(D) 1.1 GeV/c proton, , 10^5-10^6/s, : (4)

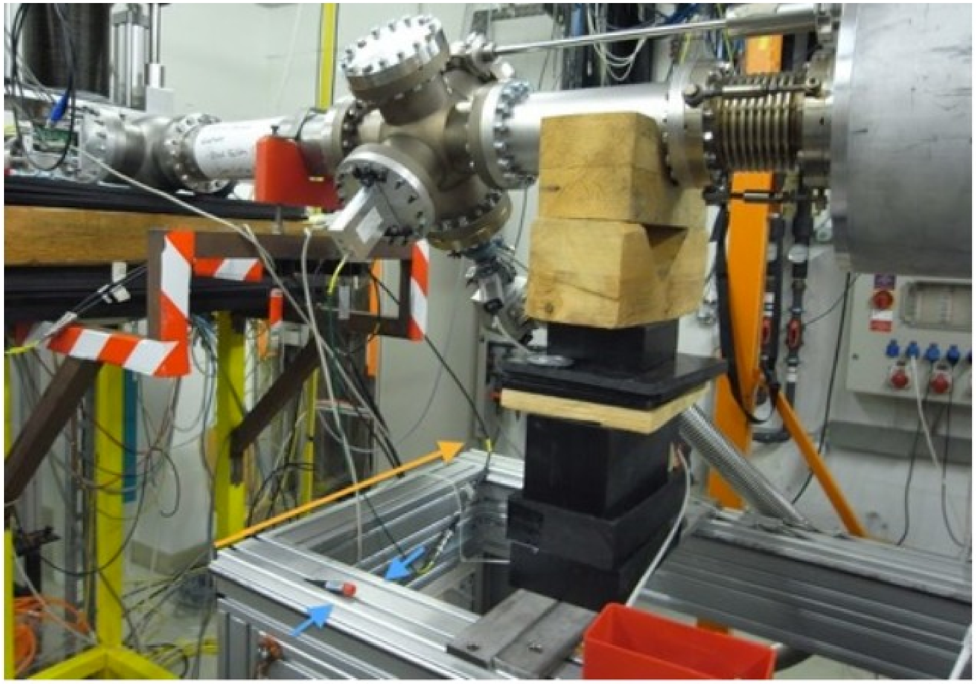
* beam intensity ~ < 10^6 Hz , spill length ~ 15 min.
* defocused beam, ~ about 5cm×5cm ?

(figure ver.18 Nov.)



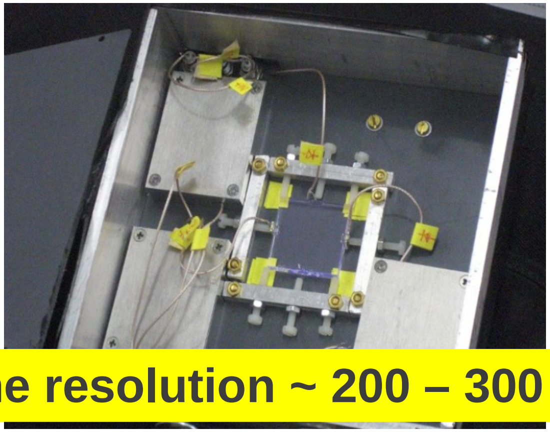
Support Structure at JESSICA

Available space for SciTil



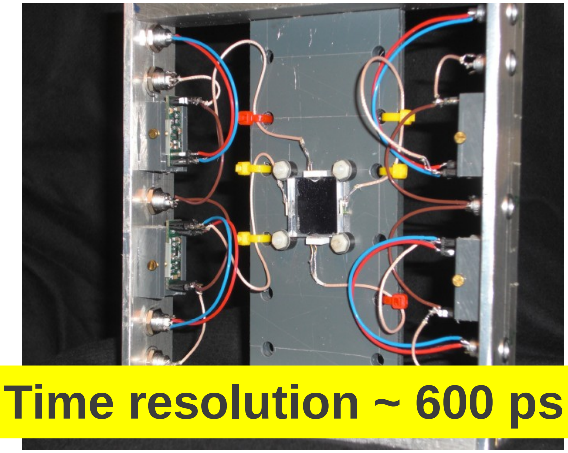
Past results

C. Schwarz
(GSI beam time, CERN, 2012)



Time resolution ~ 200 – 300 ps

C. Schwarz
(GSI beam time, CERN T9, 2011)



Time resolution ~ 600 ps

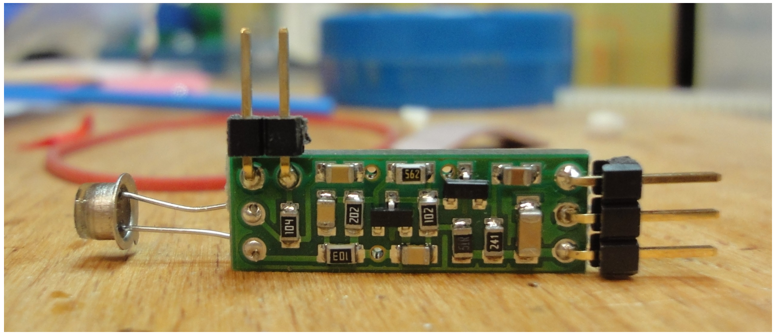
Fedor Guber, CBM beam time, CERN, 2012

Time resolution ~ 150 ps

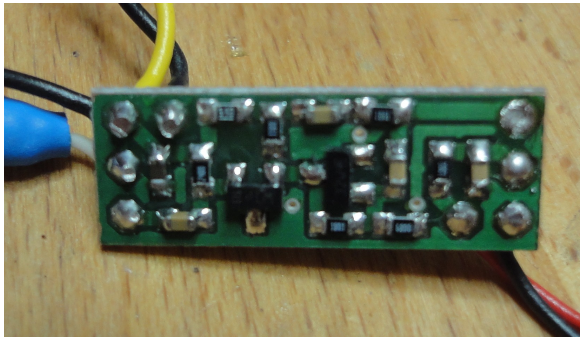
SciTil setup 2014, COSY:
- Setup is not yet finished
- We plan to use something similar as Carsten to support scintillator and SiPM
- 2 or 3 layers instead of one

Electronics

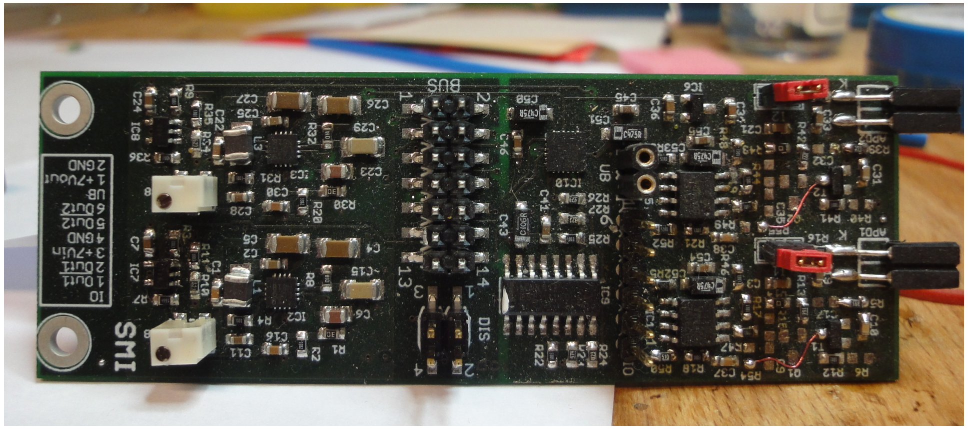
- **Photonique AMP (original version)**
- **14 spare**
- **Rise time: ~ 1 ns**
- **Gain: ~ 18**



- **Photonique “modified” (SMI version)**
- **At the moment we have 6 pieces available**
- **Lower gain**



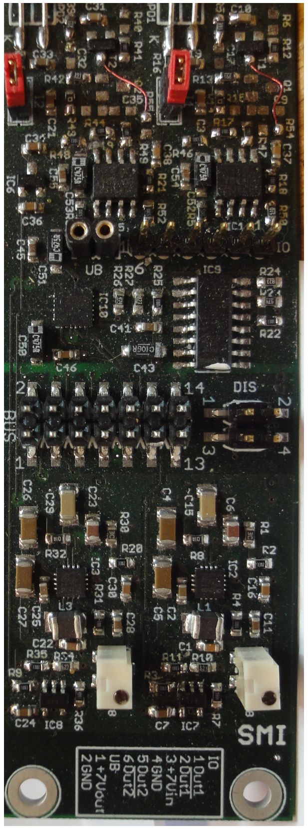
- **SMI “IFES” board**
- **New version should be ready soon**



C. Sauerzopf, H. Schneider (SMI)

IFES board

- **preamplifier board developed at SMI**
- 2 channels with full differential readout (signal from cathode and anode are used) → robust against noise
- Only one bias supply: 5 V
- Including an time over threshold discriminator
- **Bias and threshold settings of the two SiPM are controlled remotely via an Arduino Leonardo board**
- The boards can be daisy chained up two 256 channels
- Gain: 16 - 100 (by changing two resistors) → affects the rise time



- Amplifier and discriminator stage could be replaced by NINO → reduction in size
- Bias and threshold control could be done by IFES
  - → more channels on single board
  - → less power consumption
  - → full remote control

Option for PANDA SciTil?

Control & Readout