Time resolution studies for the PANDA Scintillation Tile Hodoscope using the Philips digital SiPM

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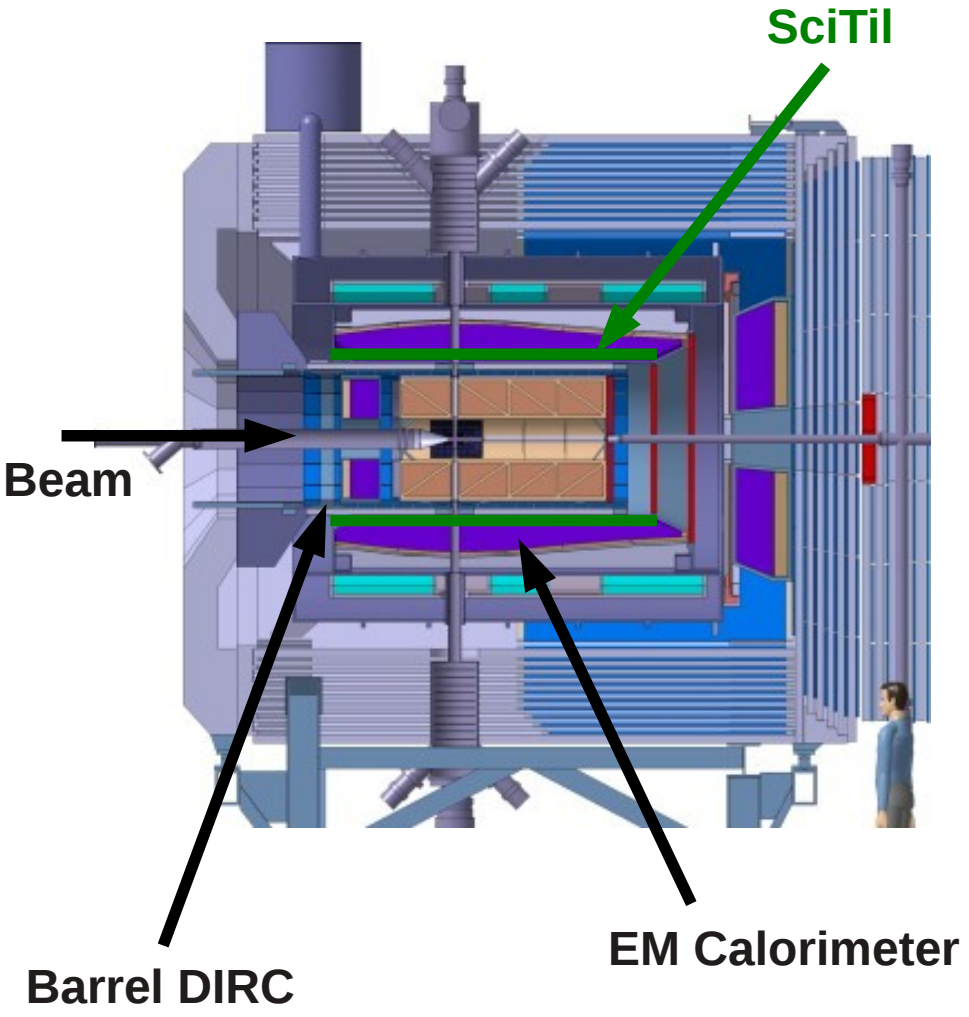
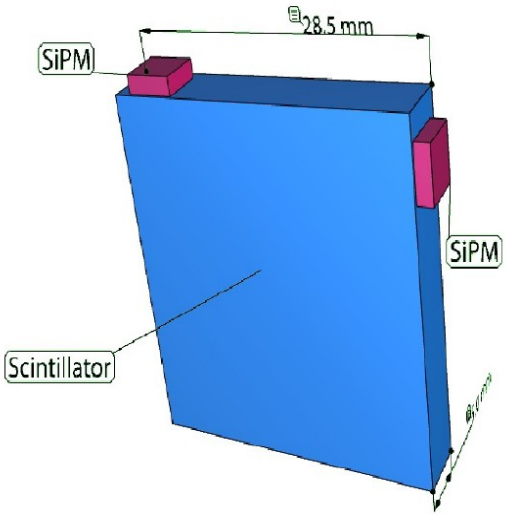
The Scintillation Tile Hodoscope (SciTil)

- **Motivation:**
  - **Particle ID**
  - **Relative timing**
  - **Event timing**
  - **Conversion detection**
  - **Charge discrimination**
- **Requirements:**
  - **Minimum material**
  - **Fast timing (σ ~ 100 ps)**



Detector layout



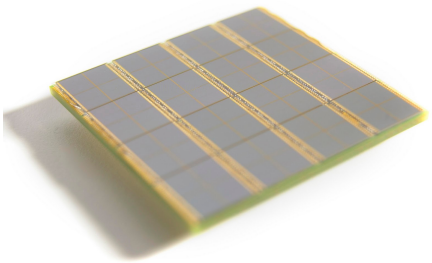
- **Idea**
  - **Small plastic scintillator tiles (~ 30 x 30 x 5 mm³)**
  - **Detect photons with directly attached Silicon Photomultipliers with 3 x 3 mm² sensitive area**

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

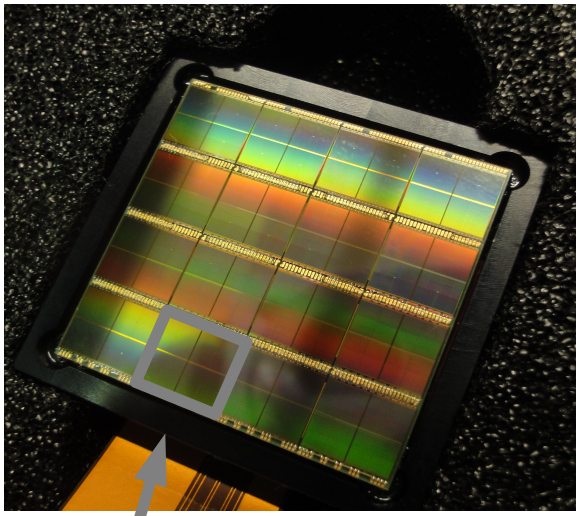
- **Silicon Photomultiplier (SiPM)**
  - **High PDE**
  - **Compact size**
  - **Low cost**
  - **Operation in magnetic fields**
  - **Low operating voltage**
  - **Good timing**

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

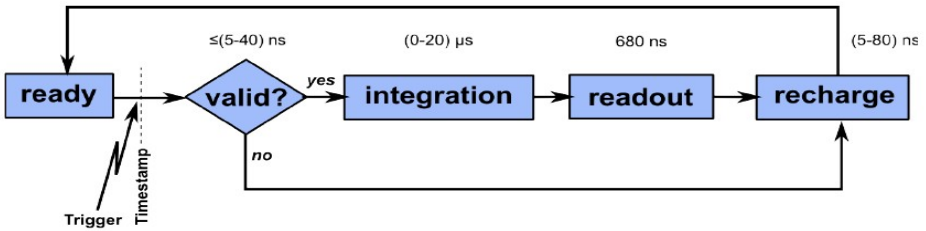
The digital SiPM



- Tile consists of 16 independent die sensors with 4 pixels each
- Two types: DPC-3200, DPC-6400 (gives the cell number per pixel)
- Big sensitive area (32.6 x 32.6 mm²) +
  - Cover the whole surface of scintillator and measure the photon distribution and time resolution as a function of the position
  - Place several scintillators on one sensor
- Good timing (~ 50 ps FWHM) +
- Straightforward data acquisition +
  - No additional electronics needed
  - One can set a trigger threshold (>= 1 ph.) per die and validation threshold (>= 4 ph.) per die
  - Time stamp per die at trigger occurrence
  - Number of photons (breakdowns)



One die consists of 4 pixels
The whole tile has 16 dies



Experimental setup

Source:

- **Strontium-90 (moveable with step motor and µm stage)**
- **2 mm pinhole**

Photo sensor:

- **Philips dSiPM: DPC-6400 and DPC-3200**
- **Voltage: 3 V over-voltage (default)**
- **Trigger threshold: 1st photon**
- **Temperature: 20 °C (Water and Peltier cooling)**
- **Sensor coupled to scintillator using optical grease (BC-630)**

Scintillator:

- **1 x BC-408: 30 x 30 x 4 mm³**
- **2 x BC-408: 25 x 25 x 5 mm³**
- **2 x EJ-228: 30 x 30 x 5 mm³**

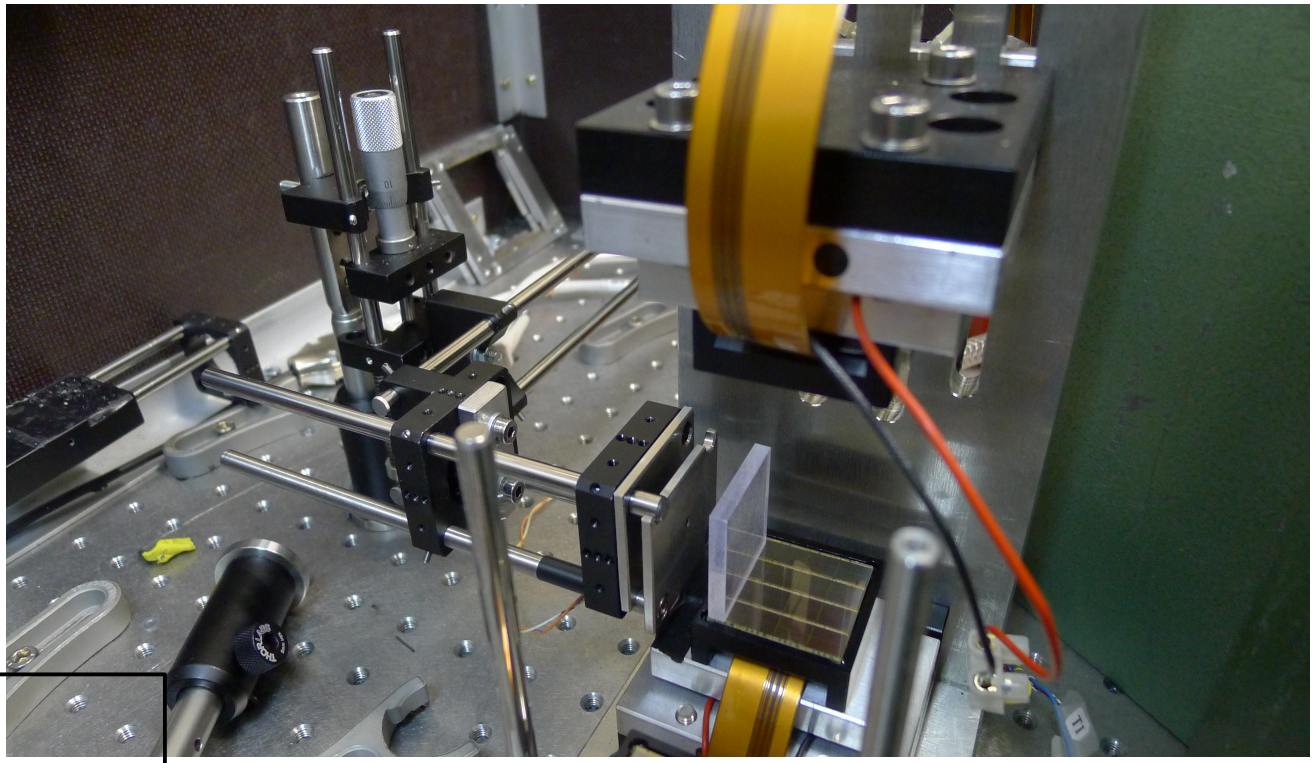
Data acquisition:

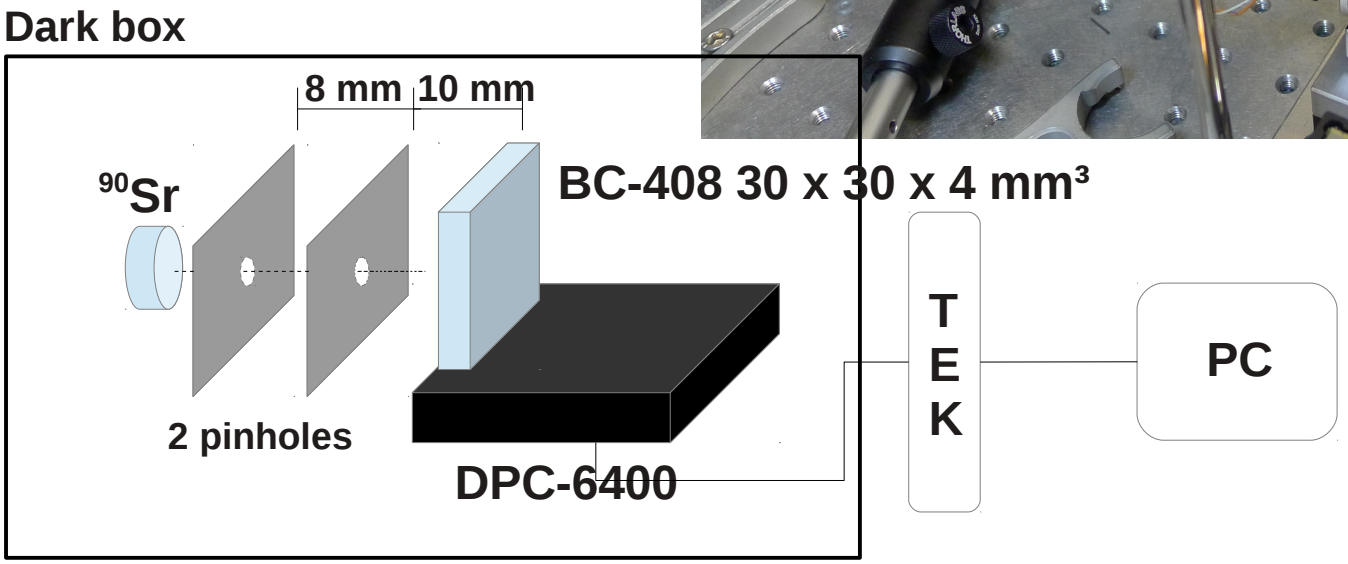
- **PDPC-TEK unit + PC**

	BC-408	**EJ-228** **Pilot-U/BC-418**
Light yield [% Anthracene]	64	67
Light yield [photons/MeV]	10,000	10,200
Rise time [ns]	0.9	0.5
Decay time [ns]	2.1	1.4
Wavelen. of Max. Emission [nm]	425	391

http://www.eljentechnology.com

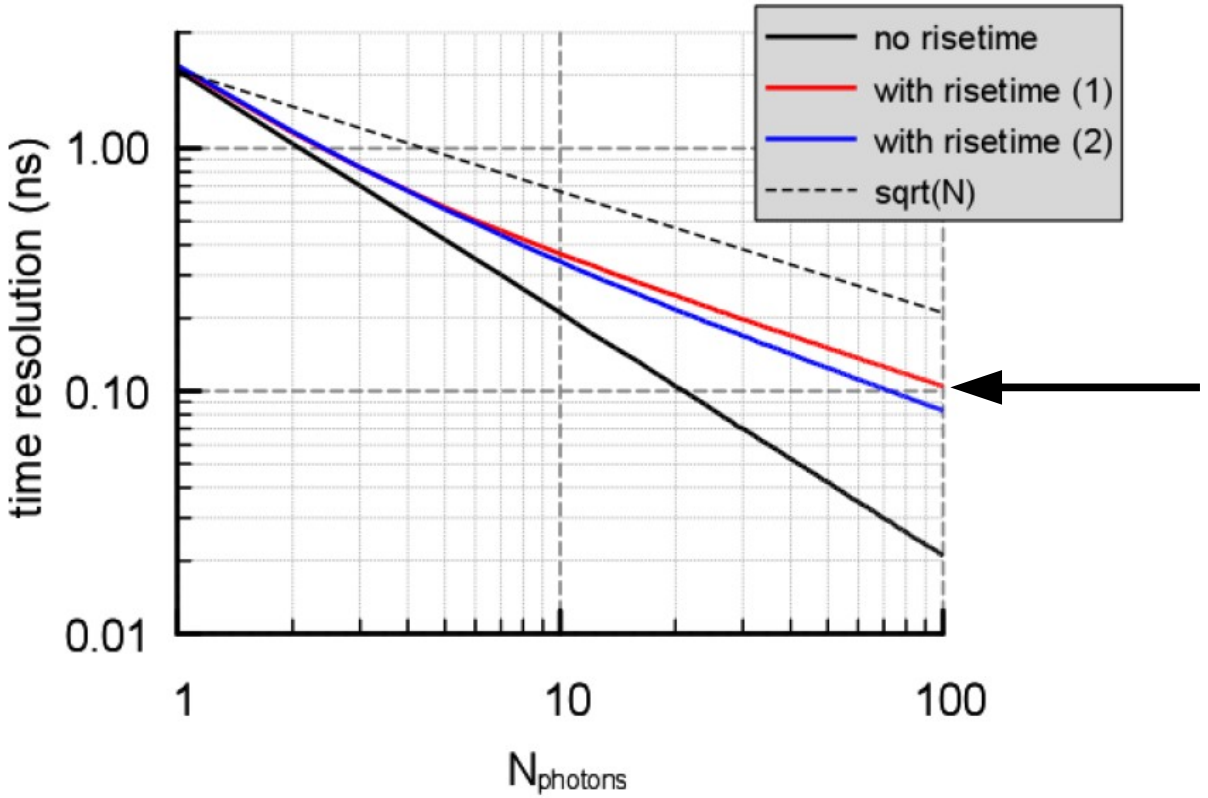
1st experimental setup





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

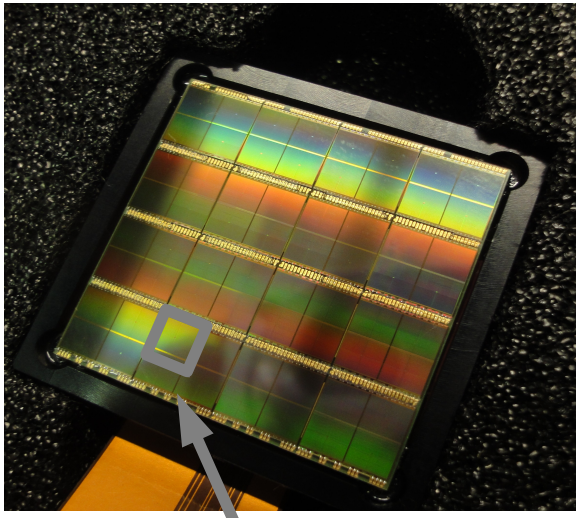
100 photons
100 ps

Proposal for a Scintillator Tile Hodoscope for PANDA
K. Goetzen, H. Orth, G. Schepers, L. Schmitt, C. Schwarz, A. Wilms

Expected photon number

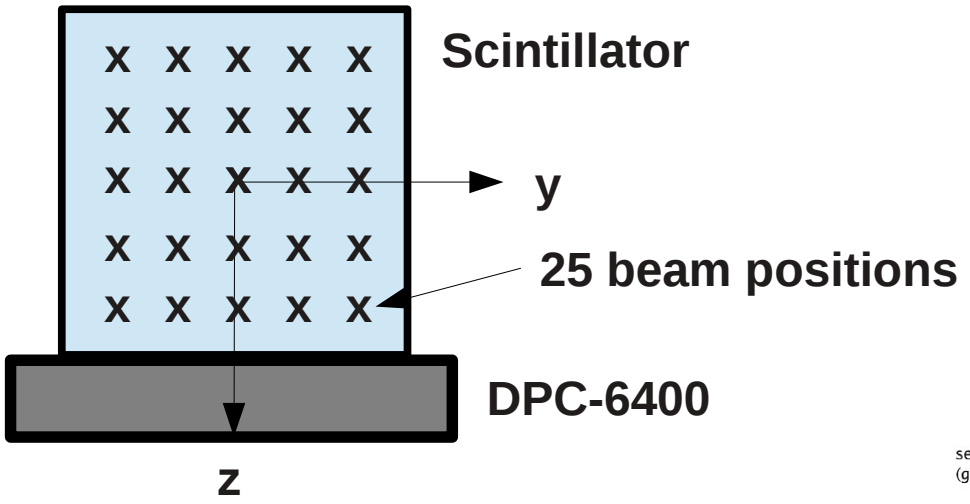
- **Minimum Ionizing Particle (MIP): ΔE (in 5 mm plastic) = 1MeV = 10^4 photons**
- **Assuming that 70% hit the rim: 7000 photons**
- **Detection area of dSiPM: 1 pixel ~ 12 mm² (~ 3 x 3 mm² SiPM)**
- **Assuming 50% PDE for DPC-3200, 30% for DPC-6400**
- **DPC-6400:**
  - **30 x 30 x 5 mm³ → ~ 45 photons per pixel**
  - **25 x 25 x 5 mm³ → ~ 50 photons per pixel**
- **DPC-3200**
  - **30 x 30 x 5 mm³ → ~ 70 photons per pixel**
  - **25 x 25 x 5 mm³ → ~ 90 photons per pixel**

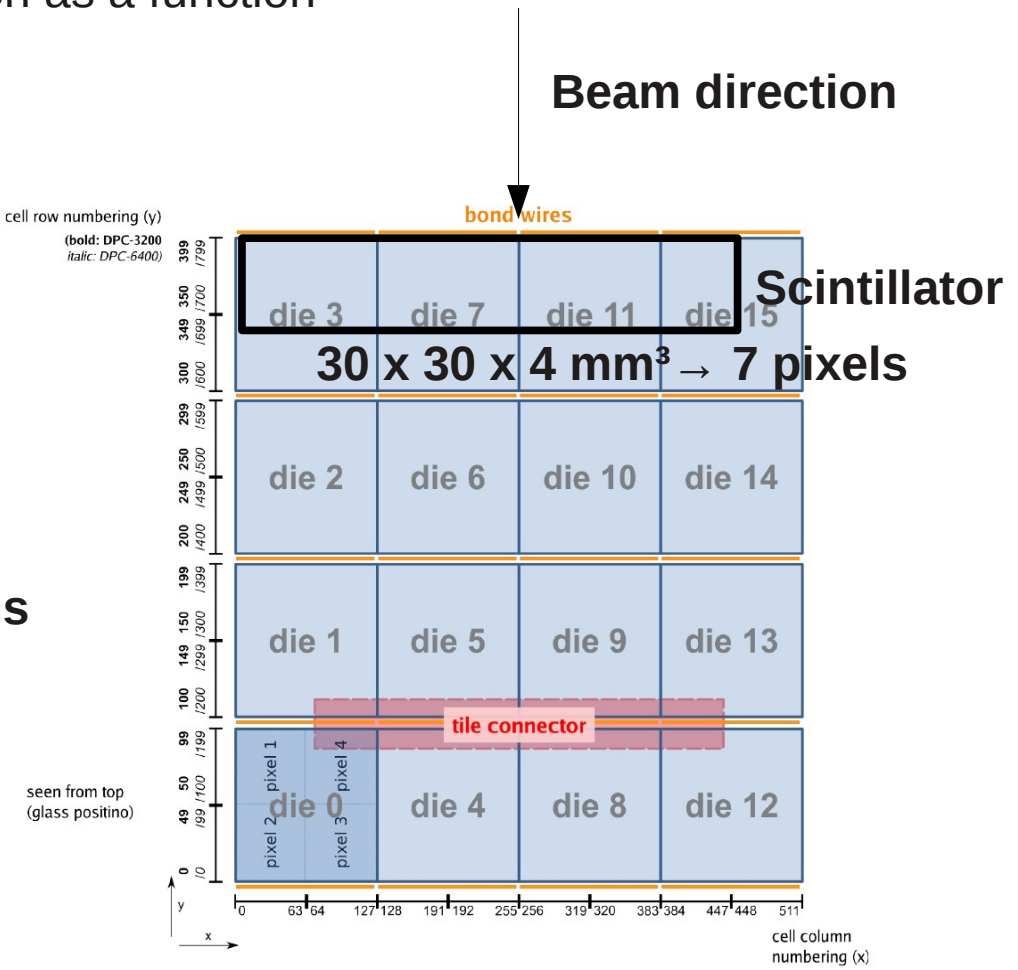
Using 2 pixels one can expect > 100 photons



Measurement procedure

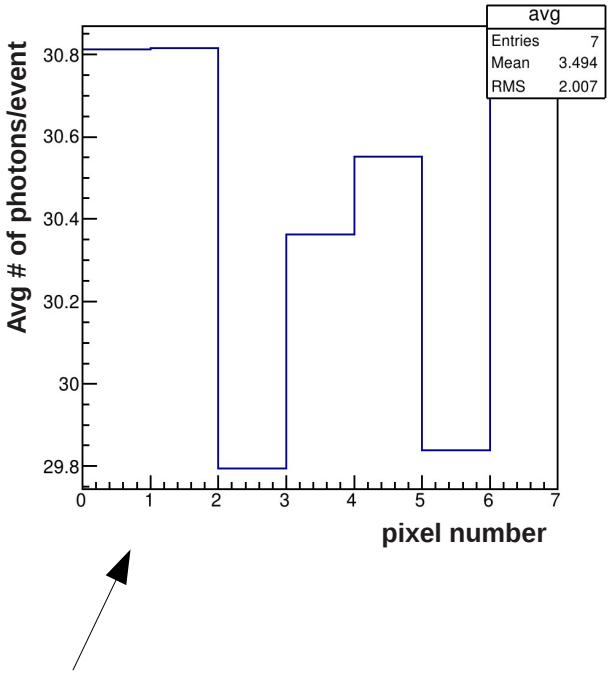
Idea: Scan the scintillator in 2 dimensions and measure the photon number and time resolution as a function of the beam position.





Photon number

BC-408 30 x 30 x 4 mm³
DPC-6400



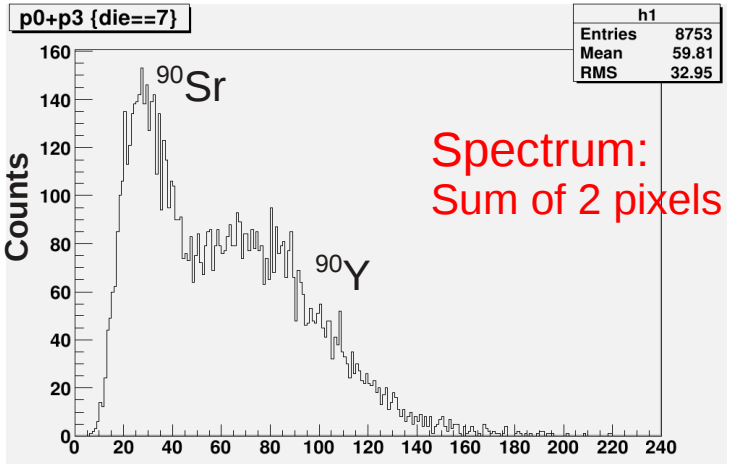
~ 30 photons per pixel per event

Expected from estimation: ~ 50 photons

But: ΔE < 1 MeV on average because all events are considered:

$^{90}Sr \rightarrow {}^{90}Y$ (max 0.546 MeV) and
$^{90}Y \rightarrow {}^{90}Zr$ (max 2.28 MeV)

- **Plot shows the average values of 25 measurements (25 beam positions)**
- **No position dependency**
- **Photons distributed equally**

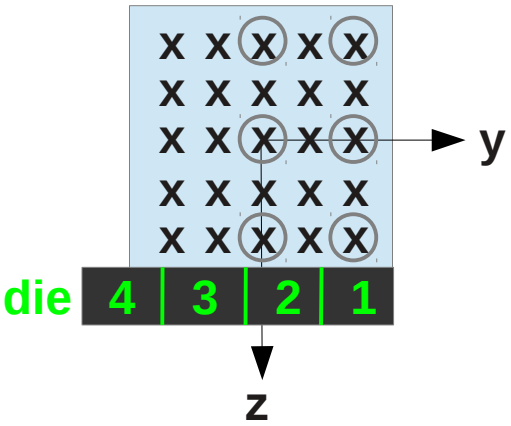


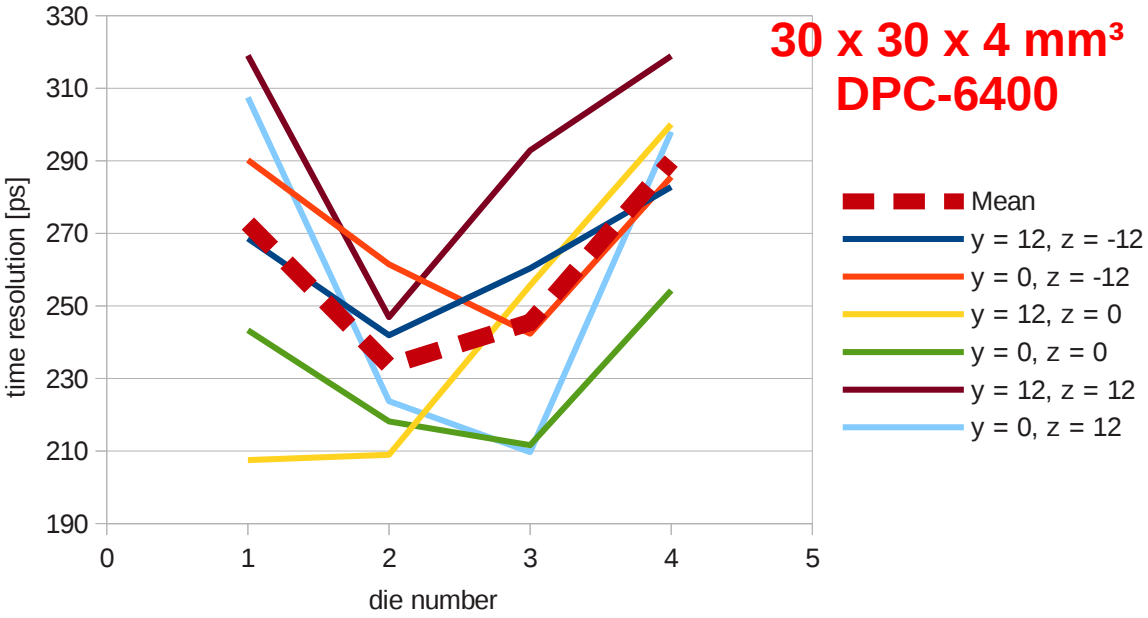
Time resolution

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.



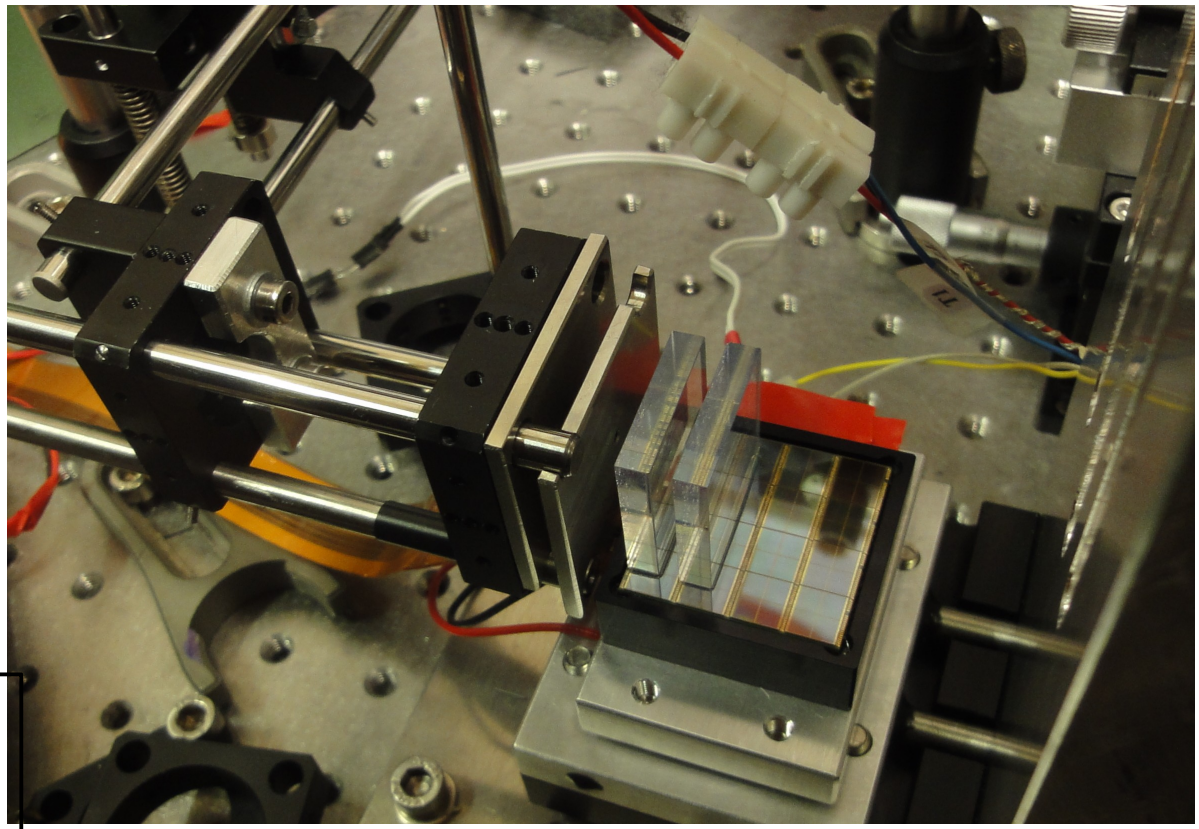


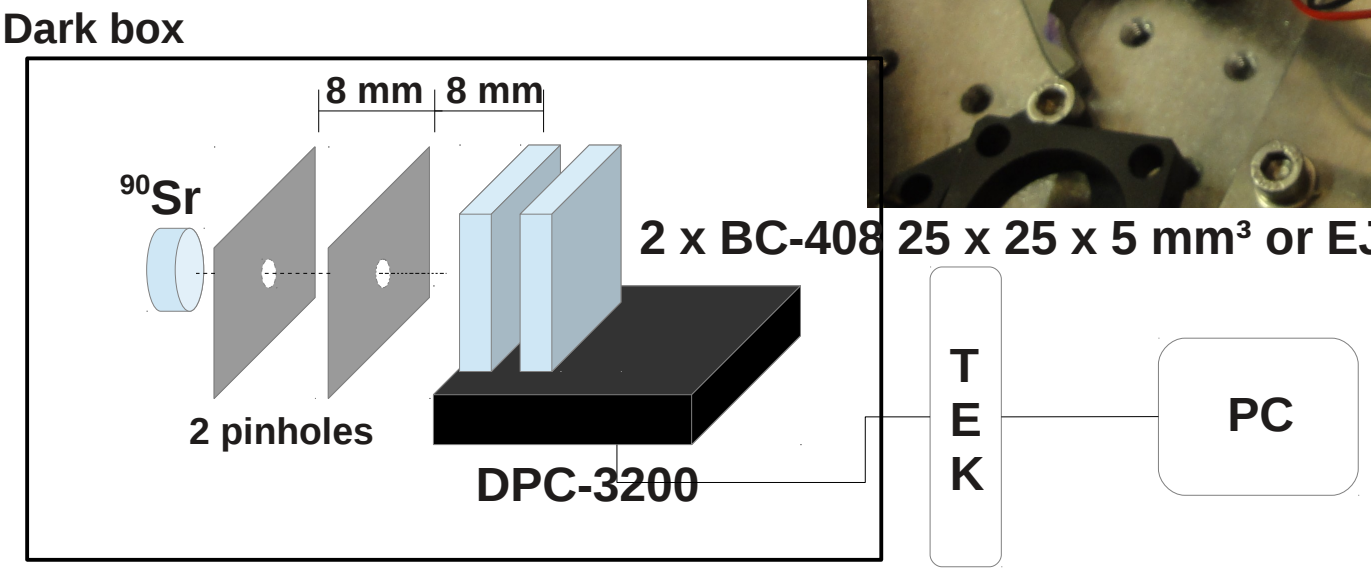
Strong position dependency !
Better time resolution for dies 2 and 3 favors central position of the sensor.

2nd experimental setup

- **Coincidence using two scintillators on a single tile**
- **e^- from ^{90}Sr decay should be stopped in first scintillator → collect only ^{90}Y events**
- **Use DPC-3200 → higher PDE**

3200 cells/pix ↔ we expect ~ 100 ph./pix

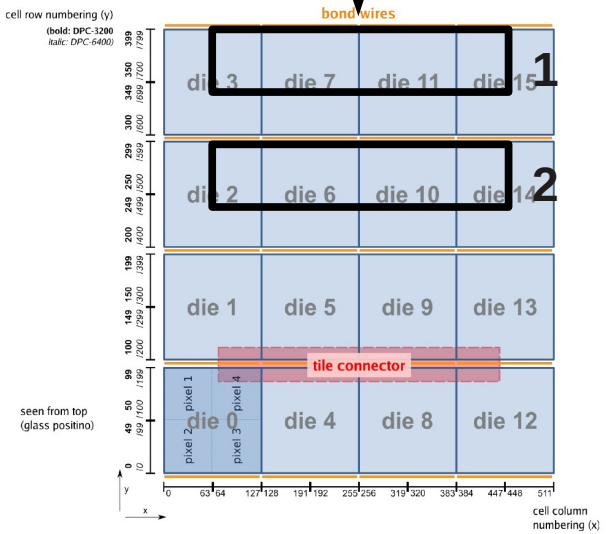


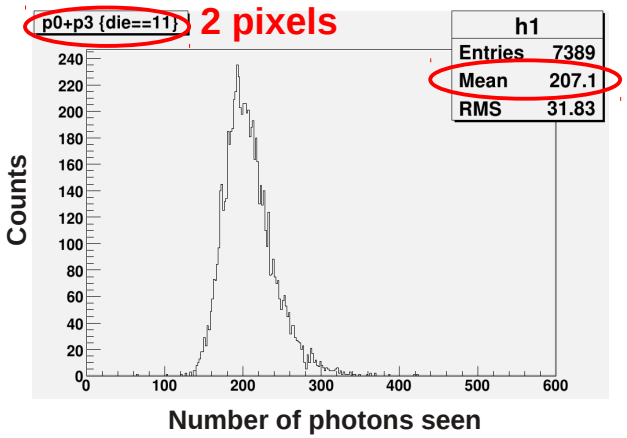


Photon number

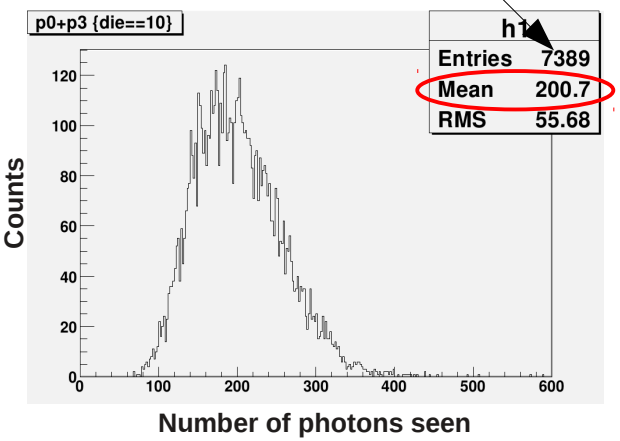
DPC-3200
2 x BC-408 25 x 25 x 5 mm³

Beam direction





Event rate ~ 5 Hz

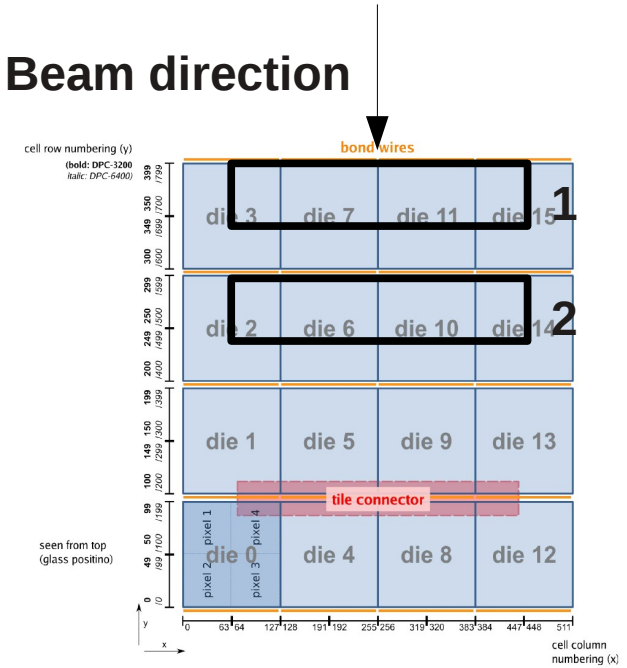


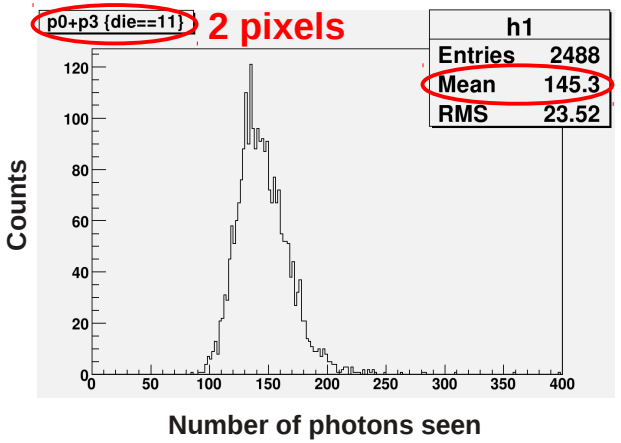
- **2 scintillators in coincidence (BC-408)**
- **First peak from ^{90}Sr disappears**
- **Expected: ~ 180 photons (90 per pixel)**
- **We see the expected number of photons**

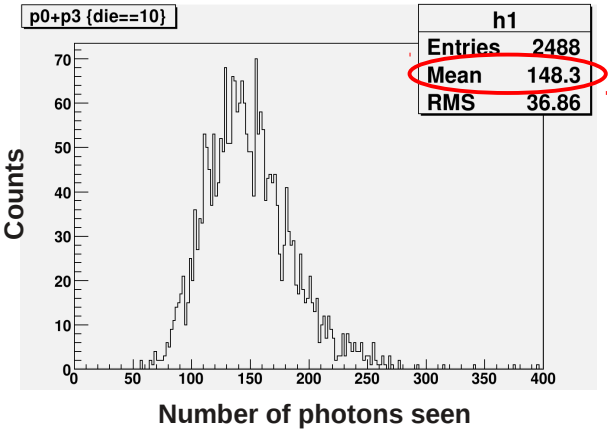
Photon number

DPC-3200

2 x EJ-228 30 x 30 x 5 mm³





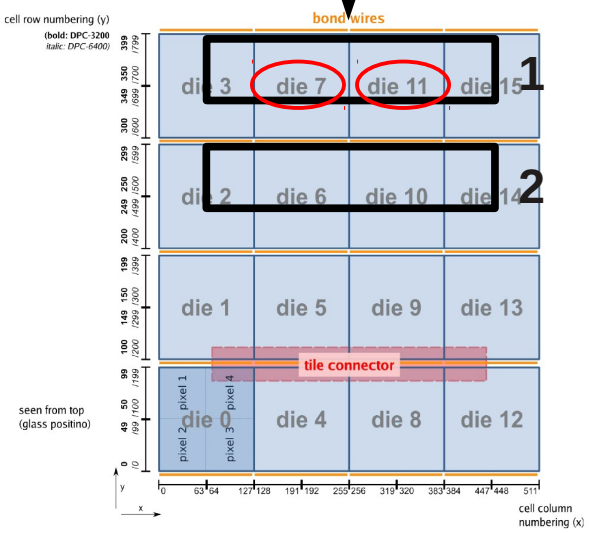


- **2 scintillators in coincidence (EJ-228)**
- **First peak from ^{90}Sr disappears**
- **Expected: ~ 140 photons (70 per pixel)**
- **We see the expected number of photons**

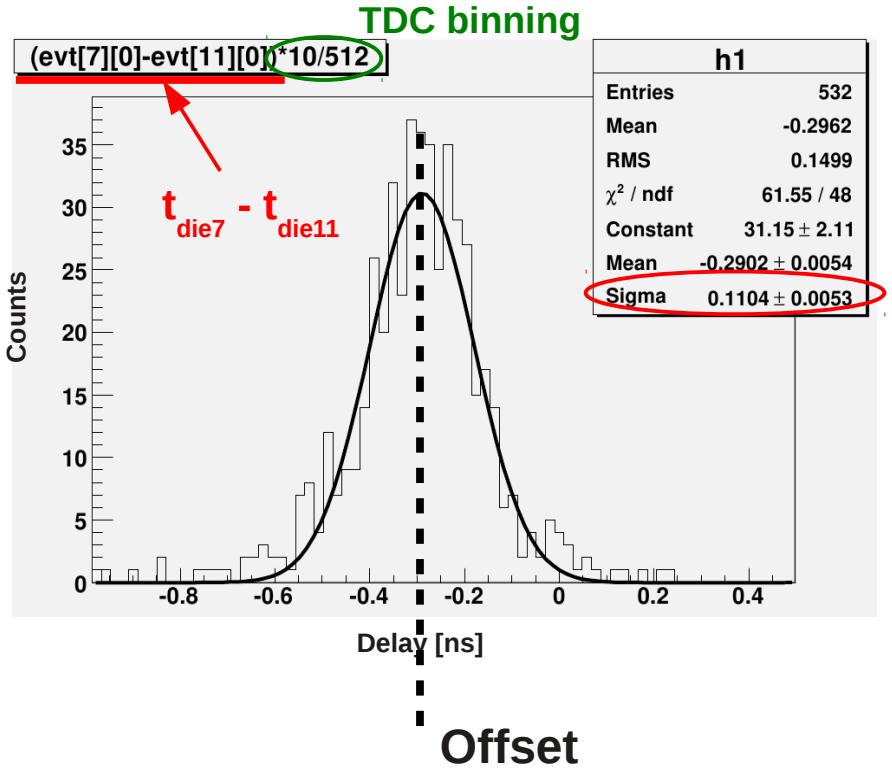
Time resolution

BC-408 25 x 25 x 5 mm³

Beam direction



Coincidence timing: die 7 and die 11



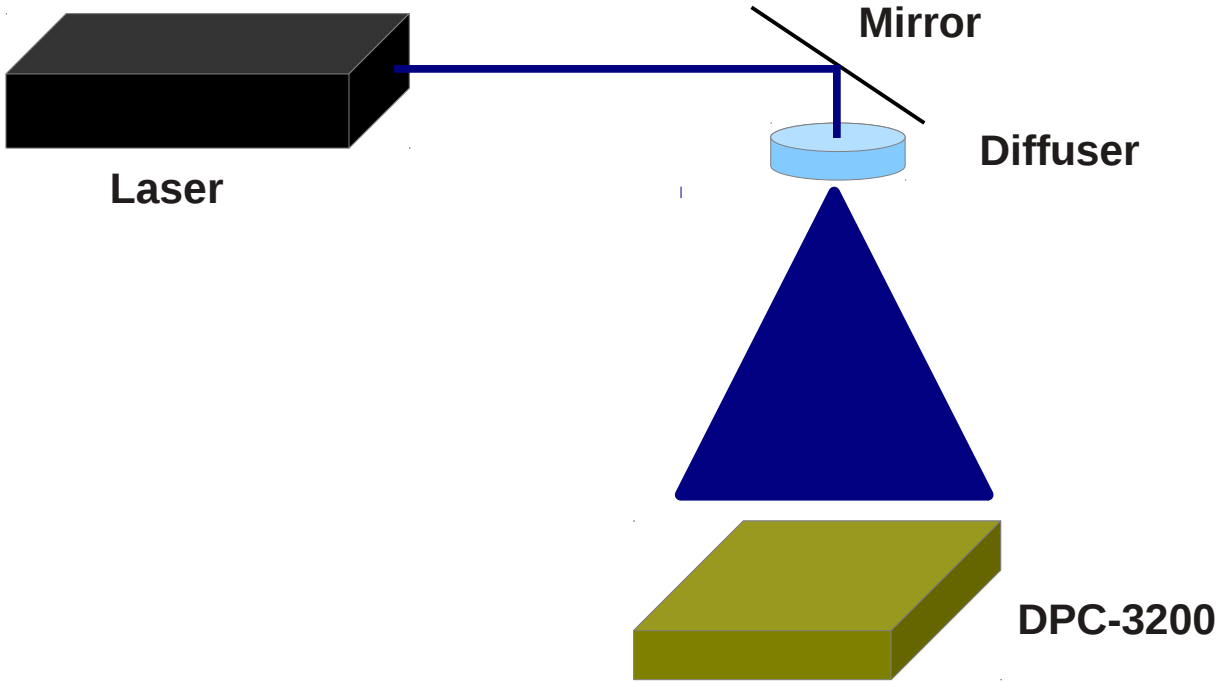
- **Offset in delay spectrum**
- **Skew between dies → one should correct**

- **Timing: σ = 110 ps**
- **Assuming two identical dies:**

$$\sigma_{die7} \sim \sigma_{die11} \sim 78 \text{ ps}$$

Skew correction

- **Perform skew correction using pulsed laser (~ 30 ps pulse width, repetition rate 1 kHz)**
- **Measure delay between dies and correct for offset**

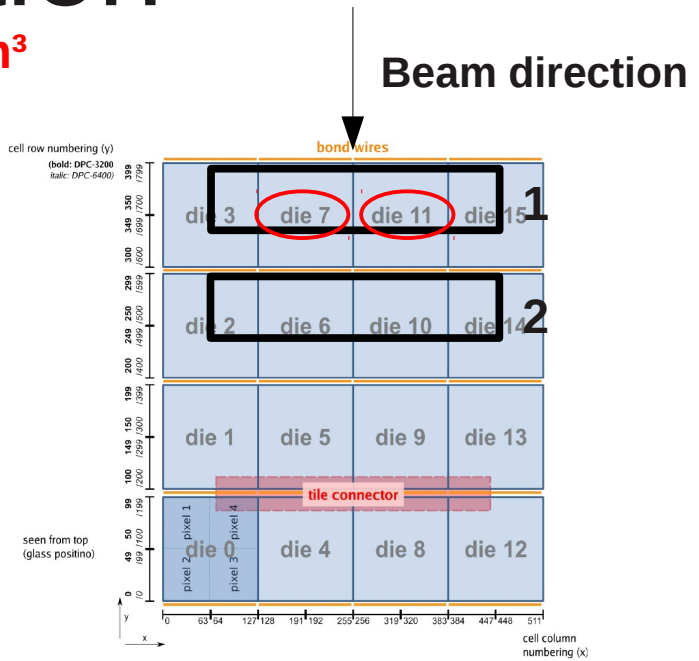


Die number	Skew correction [TDC bins]
0	+14
1	+15
2	+42
3	+39
4	+7
5	+9
6	+15
7	+15
8	+10
9	+19
10	+4
11	+0
12	+16
13	+16
14	+20
15	+16

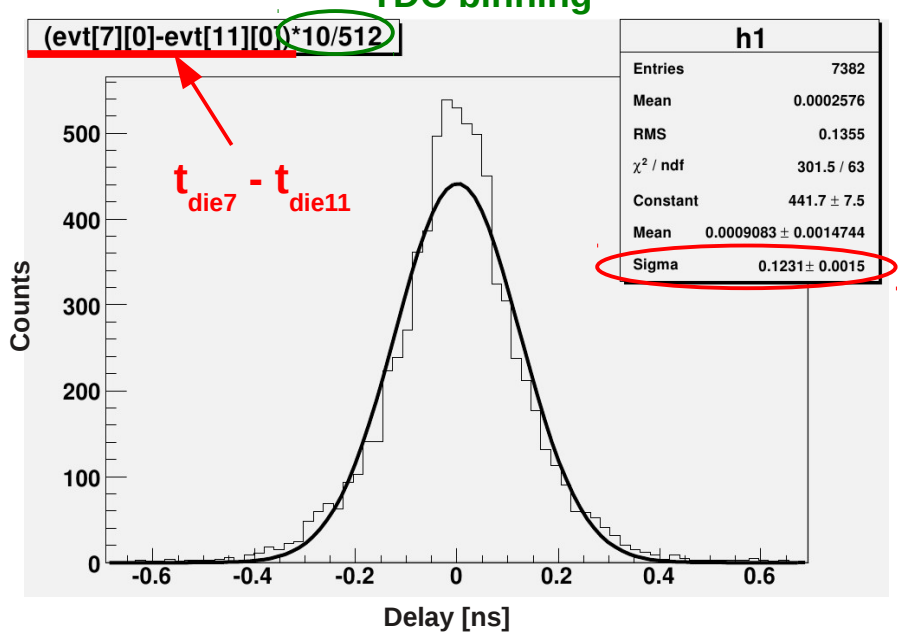
Time resolution

BC-408 25 x 25 x 5 mm³
Skew corrected

Coincidence timing: die 7 and die 11



TDC binning



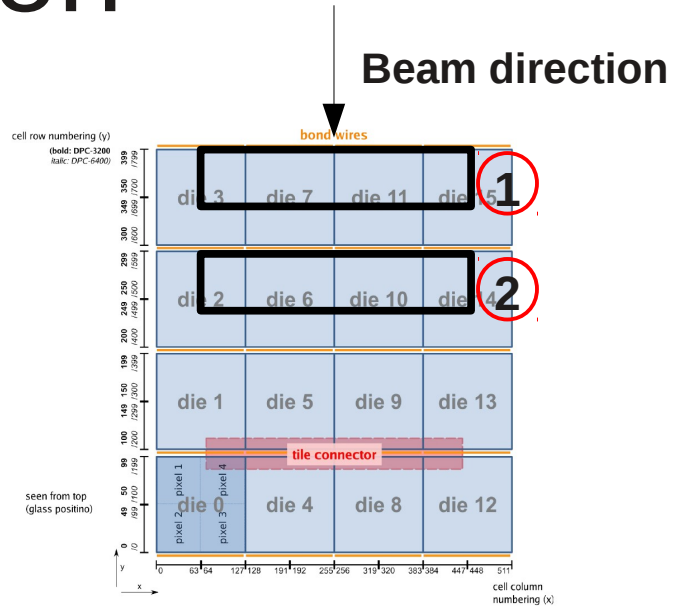
- **Delay spectrum now centered at Δt = 0**
- **Coincidence timing: σ = 123 ps**
- **Assuming two identical dies:**

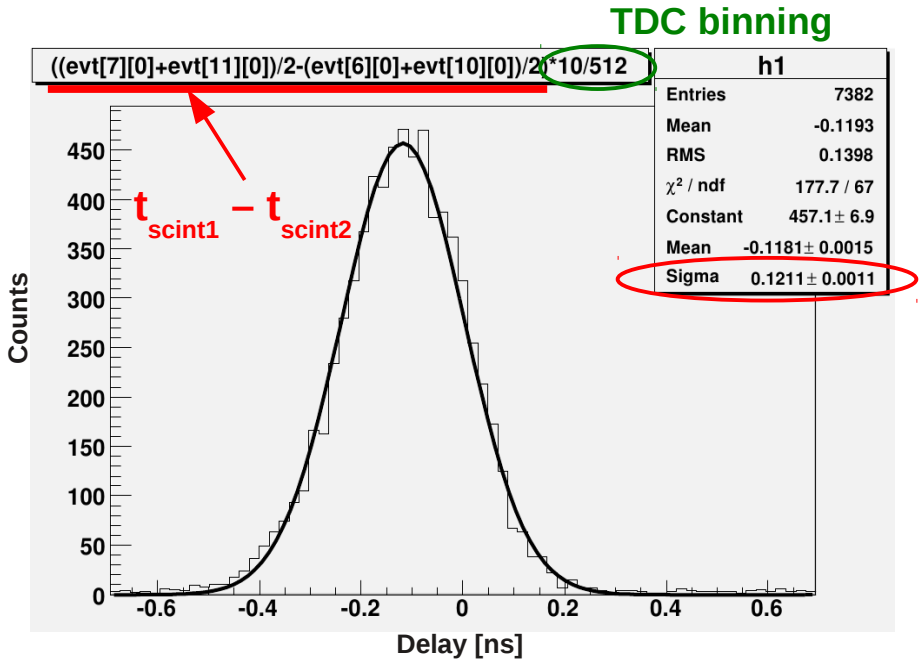
  $\sigma_{die7} \sim \sigma_{die11} \sim 85$ ps

- **In agreement with previous measurement from slide 15**

TOF resolution

- **Use scintillator 1 as start counter to evaluate TOF resolution**
- **Since we have 2 dies per scintillator, we can use mean timing of these two channels**





BC-408 (25 x 25 x 5 mm³):

- **TOF resolution: σ = 121 ps**
- **Assuming two identical layers:**

$\sigma_{scint1} \sim \sigma_{scint2} \sim 85$ ps

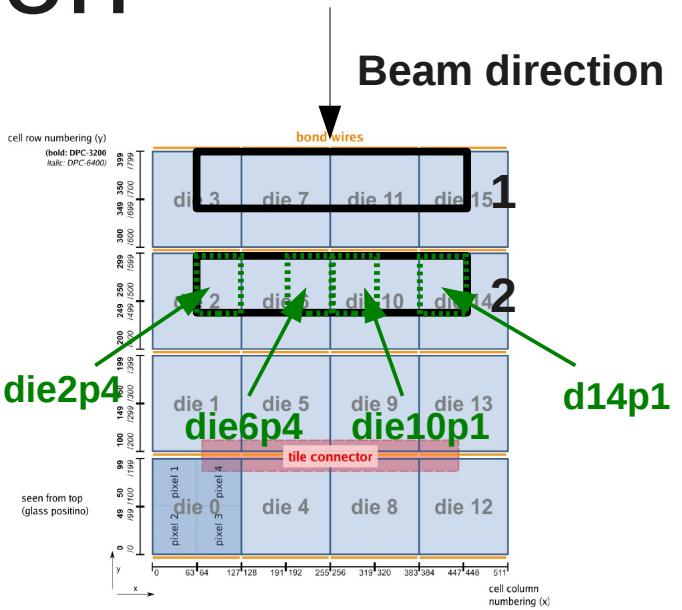
EJ-228 (30 x 30 x 5 mm³):

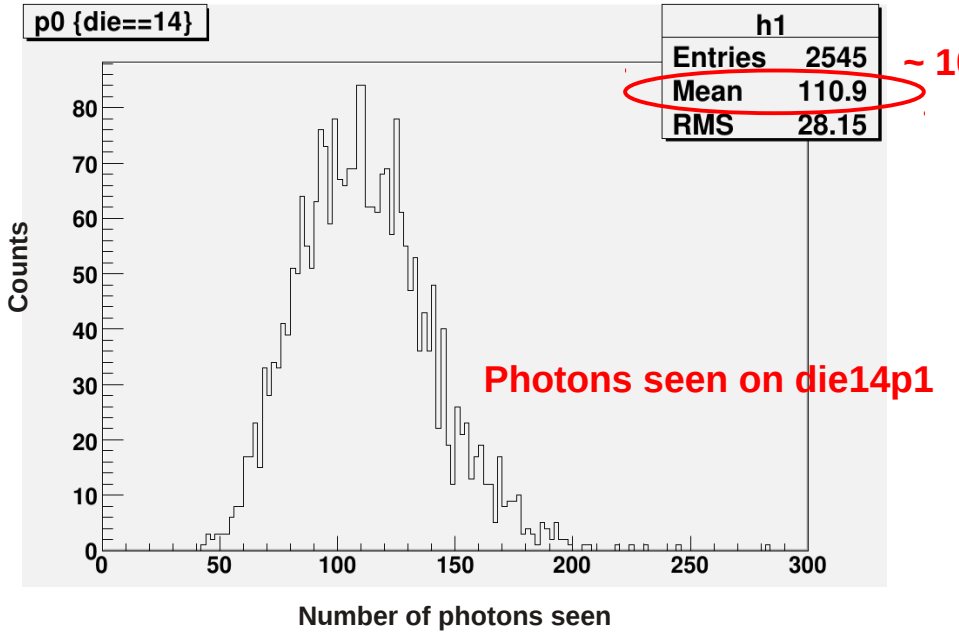
- **TOF resolution: σ = 90 ps**
- $\sigma_{scint1} \sim \sigma_{scint2} \sim 60$ ps

Time resolution

BC-408 25 x 25 x 5 mm³

- **Use scintillator 1 as start counter**
- **Try to evaluate time resolution of scintillator 2 readout by a single pixel → active area is comparable to a single 3 x 3 mm² SiPM**





~ 100 photons per pixel

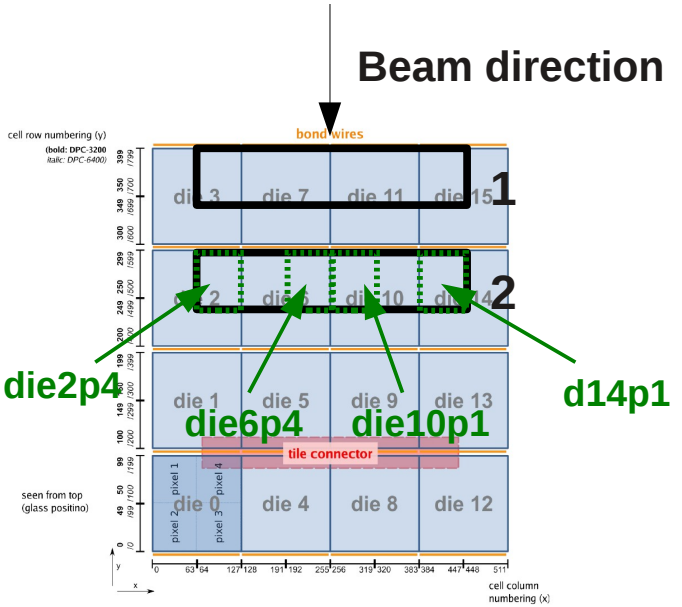
Pixel	Time resolution (σ_{scint2})
die14p1	165 ps
die10p1	155 ps
die6p4	150 ps
die2p4	170 ps

Better timing using central pixels

Time resolution

BC-408 25 x 25 x 5 mm³

- **Use scintillator 1 as start counter to evaluate TOF resolution**
- **Try to evaluate time resolution of scintillator 2 readout by 2 pixels → active area comparable to two 3 x 3 mm² SiPMs**
- **Take either mean timing of 2 pixels (e.g. die6p4 and die10p1) or first time stamp of 2 pixels**



	TOF resolution (σ)	σ_{scint2}
Mean timing	150 ps	120 ps
1st timing	145 ps	115 ps

Expect σ_{scint2} < 100 ps using EJ-228 !!!

BC-408 vs. EJ-228 (BC-418)

- **Photon number:**
  - **EJ-228: less photons because larger (30 x 30 x 5 mm³)**
    ~ 75 photons per pixel (~ size of 3 x 3 mm² SiPM)
  - **BC-408: factor 1.3 – 1.4 more photons (25 x 25 x 5 mm³)**
- **Timing:**
  - **Scintillator read out with 2 dies:**
    - **EJ-228: σ_{scint2} = 60 ps**
    - **BC-408: σ_{scint2} = 85 ps → factor 1.4 worse**
  - **Scintillator read out with 2 pixels (~ two 3 x 3 mm² SiPMs):**
    - **BC-408: σ_{scint2} = 115 ps**
    - **EJ-228: σ_{scint2} < 100 ps expected**
- **Rise time:**
  - **EJ-228: τ_R = 500 ps**
  - **BC-408: τ_R = 900 ps**

EJ-228: faster rise time although larger and less photons – EJ-228 gives better timing

Outlook

- **Systematic measurements:**
  - **Several scintillators have been ordered (EJ-200 (BC-408), EJ-204 (BC-404), EJ-228 (BC-418), EJ-232 (BC-422))**
  - **Just arrived**
  - **Study influence of rise time, light yield, geometry, wrapping, …**

- **Use conventional 3 x 3 mm² SiPMs:**
  - **Time resolution measurements are ongoing (see next talk by S. Brunner)**
  - **Ketek, Hamamatsu (new S12572 !), AdvanSiD, SensL**

- **Simulation**
  - **Geant4 simulation, code almost ready**
  - **Comparison with measurement**
  - **Optimization of the setup**