First results from SciTil prototype tests at COSY beam time Jan/Feb 2014

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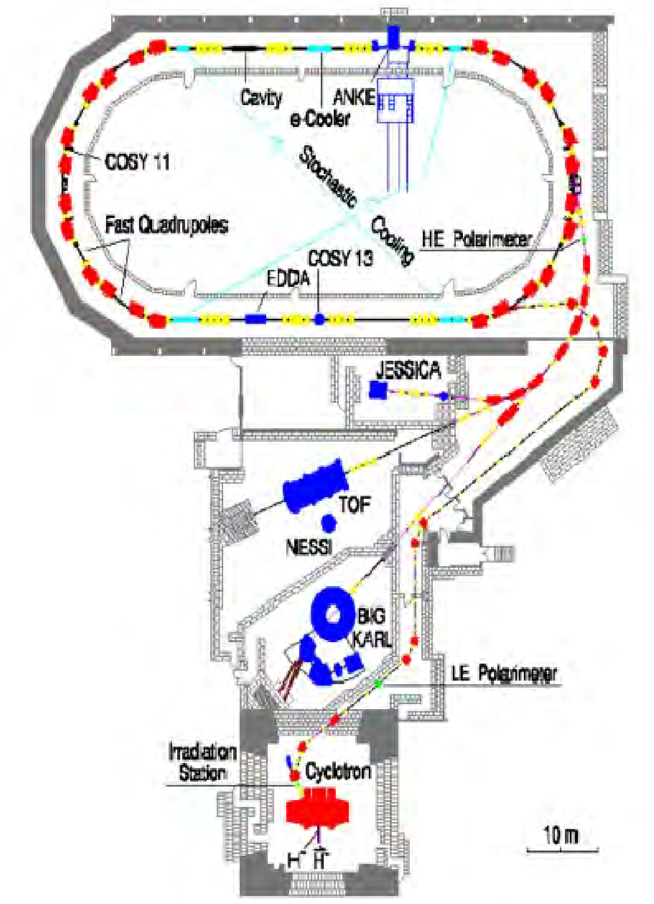
Outline

- Facts about test beam at COSY
- SciTil-SiPM prototype and setup
- Preliminary results from SciTil-SiPM
- SciTil-DPC prototype and setup
- Preliminary results from SciTil-DPC
- Radiation hardness
- New ideas for SciTil

Test beam at COSY (FZ Jülich)



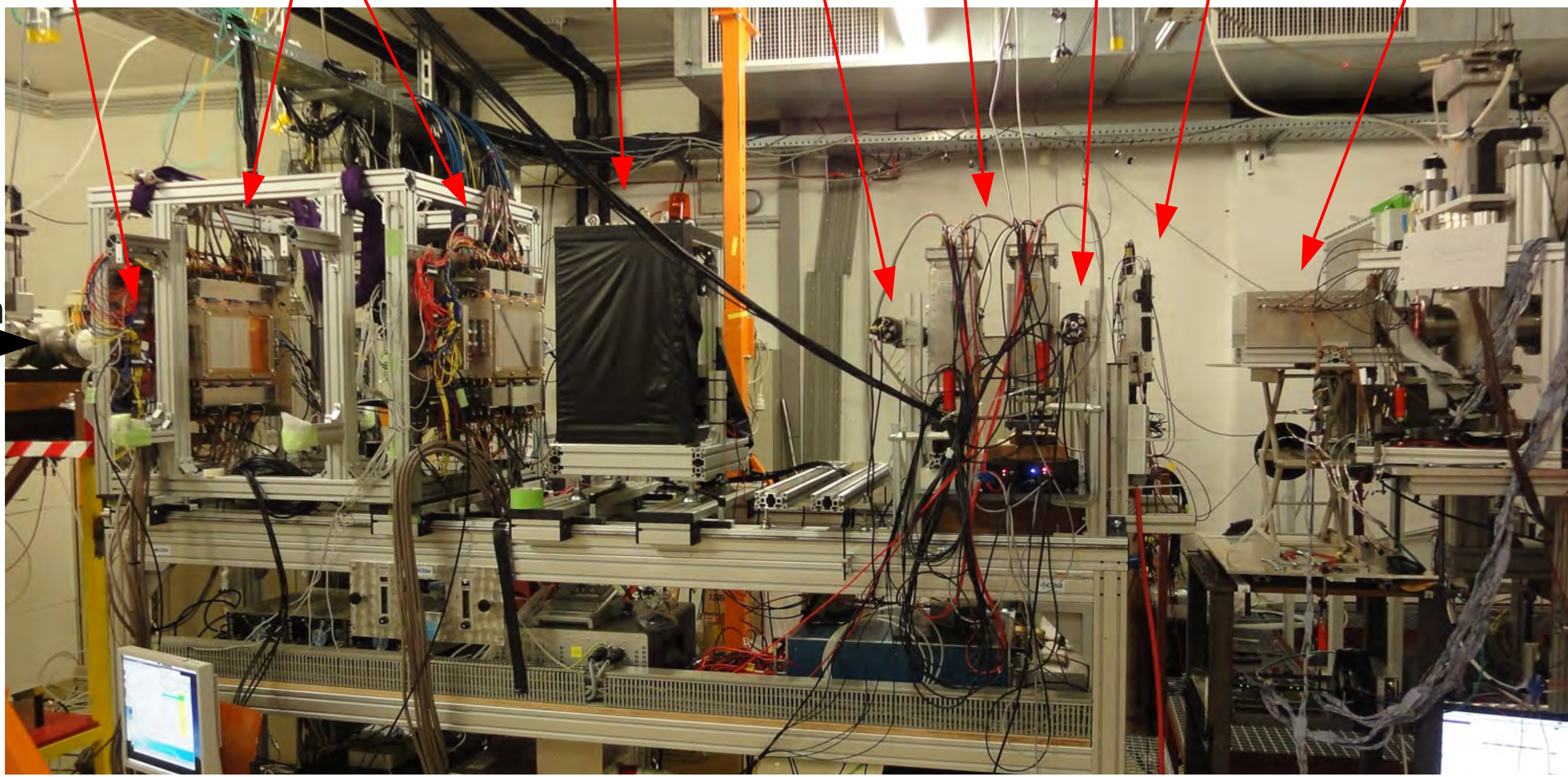
Facts:

- **FZ-Jülich, COSY-JESSICA external beam line**
- **Week no. 5 and 6, 2014 (Jan 27 to Feb 9, 2014)**
- **During week: beam during night (9 p.m. - 8 a.m.)**
- **On weekends: 24 hours**
- **Beam: 2.7 GeV/c and 1.5 GeV/c protons**
- **Intensity: ~ 10^5 – 10^6 Hz**
- **Defocused beam: ~ 5 cm x 5 cm**

Activities:

- **<u>EtaPrime Experiment (GSI):</u>**
  - **Cherenkov counters (mini-HIRAC, HIRAC, TORCH)**
  - **Multi-wire drift chambers (MWDC)**
  - **Time-projection chambers (TPC)**
  - **Plastic scintillators (SCIs)**
- **<u>3 SciTil prototypes:</u>**
  - **SMI prototype: SciTil + SiPM**
  - **SMI + Philips prototype: SciTil + DPC (Digital Photon Counter)**
  - **Erlangen prototype: SciRod + SiPM**

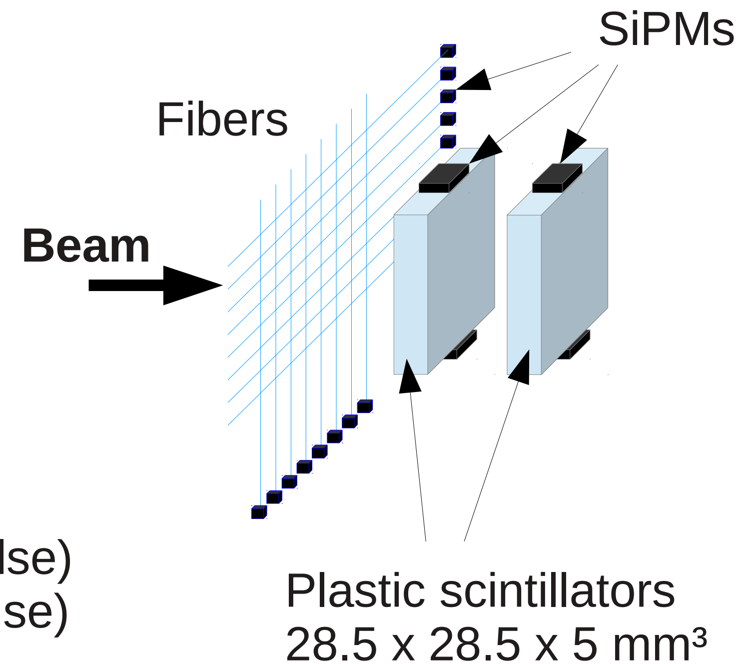
The beam line at JESSICA (1st week)



The SciTil-SiPM prototype

Setup:

- **Scintillating fiber grid for position resolution in x and y: 8 + 8 fibers, 4 mm pitch**
- **Fibers are readout with 1 x 1 mm² SiPMs: HPK MPPC S10362-11-050U**
- **2 SciTil layers: plastic scintillators readout with two 3 x 3 mm² SiPMs each**
- **No cooling: room temperature ~ 15 °C**



SiPMs tested:

HPK MPPC S12572-025C (25 µm pixel, low afterpulse)
HPK MPPC S12572-050P (50 µm pixel, low afterpulse)
Ketek PM3350 (50 µm pixel with optical trenches)
Ketek PM3360 (60 µm pixel with optical trenches)

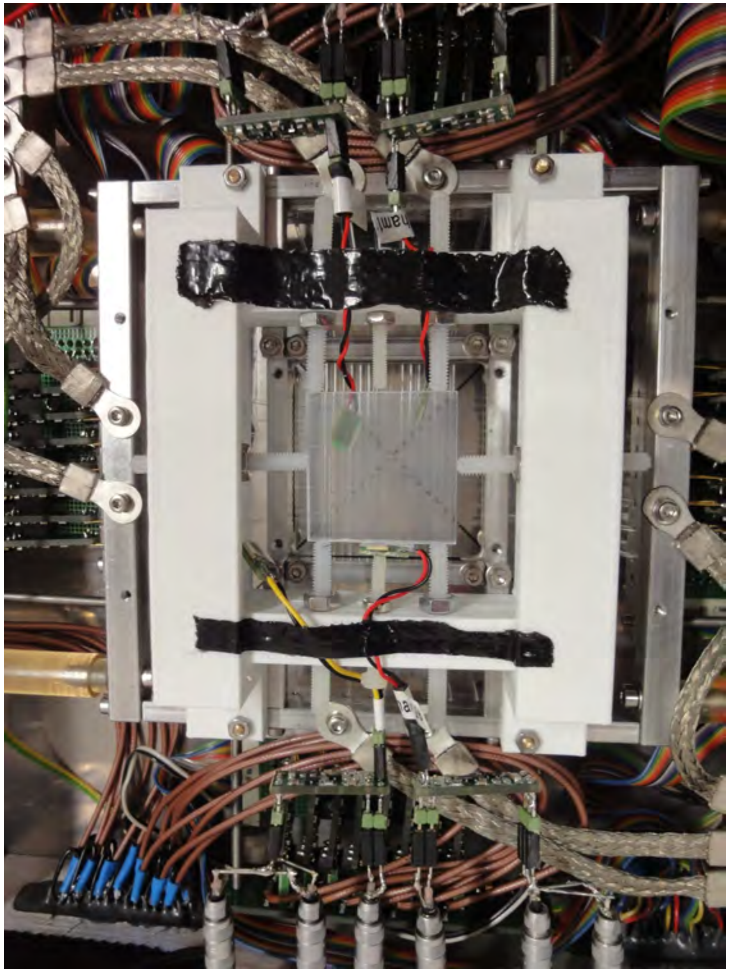
Scintillators tested:

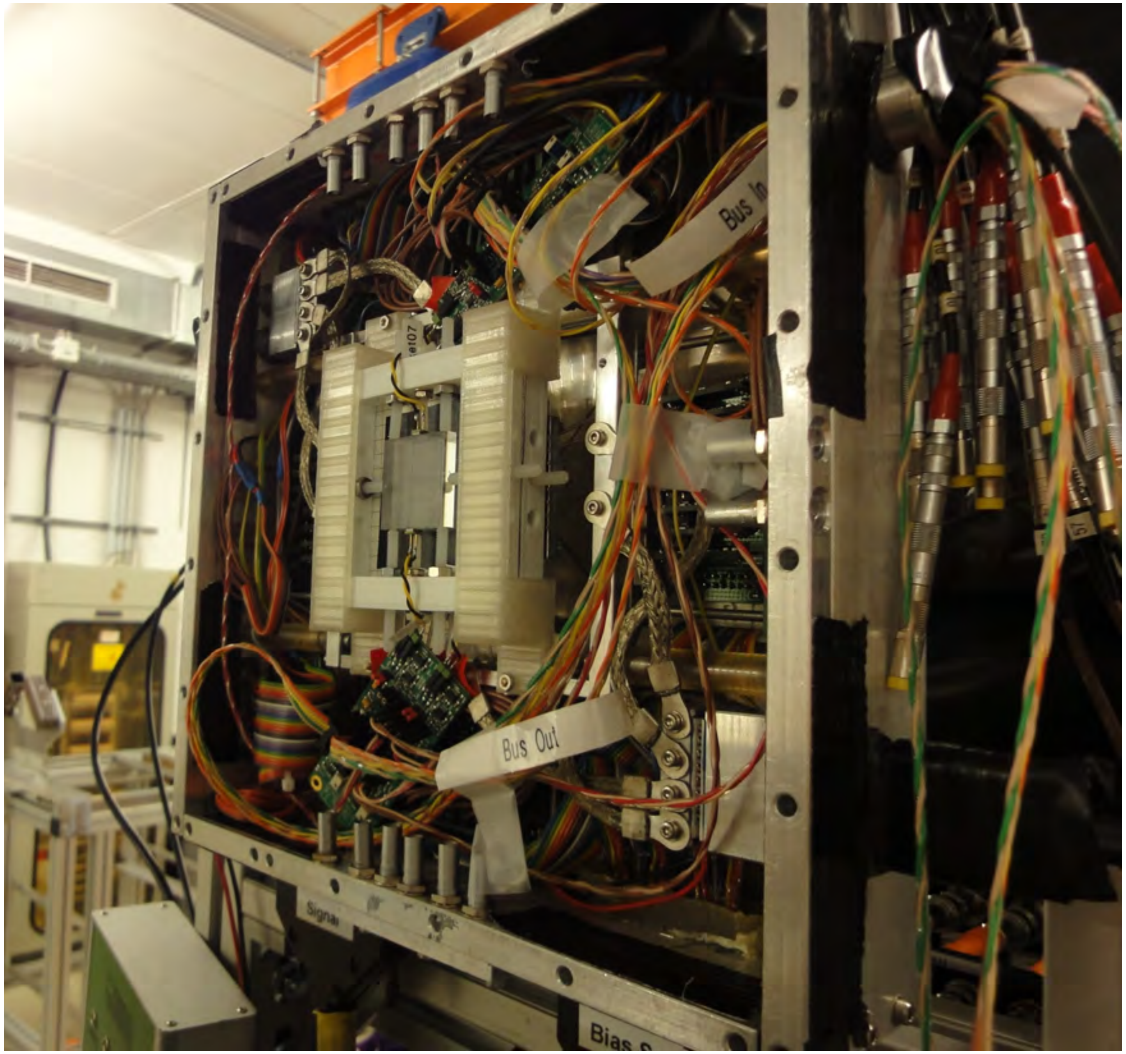
	EJ-228 Pilot-U/BC-418	EJ-232 NE-111A/BC-422
Light yield [photons/MeV]	10,200	8,400
Rise time [ns]	0.5	0.35
Decay time [ns]	1.4	1.6
Wavelen. of Max. Emission [nm]	391	370

Goal:

Time resolution of SciTil prototype: σ < 100 ps

The SciTil-SiPM prototype



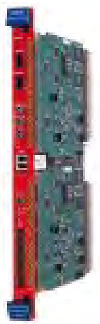


Readout electronics

Data acquisition:

- **SiPM signals are amplified using Photonique preamplifier AMP-0611**
- **The signals are then readout:**

1.) CAEN V1742 waveform digitizer: → **preliminary results**



- full waveform
- 32 Channels
- sampling rate: 5 Gs/s
- trigger: coincidence SCI1, 2 and 3 (EtaPrime)

2.) SMI "IFES" boards: → **not yet analyzed**

- test boards with fully differential readout
- analog and digital signals → V1742
- 2 channels per board
- trigger: coincidence SCI1, 2 and 3 (EtaPrime)

3.) PADIWA boards + TRBv3 board: → **not yet analyzed**

- time information: leading-, trailing edge
- time-over-threshold
- trigger: MCP (from Erlangen group)

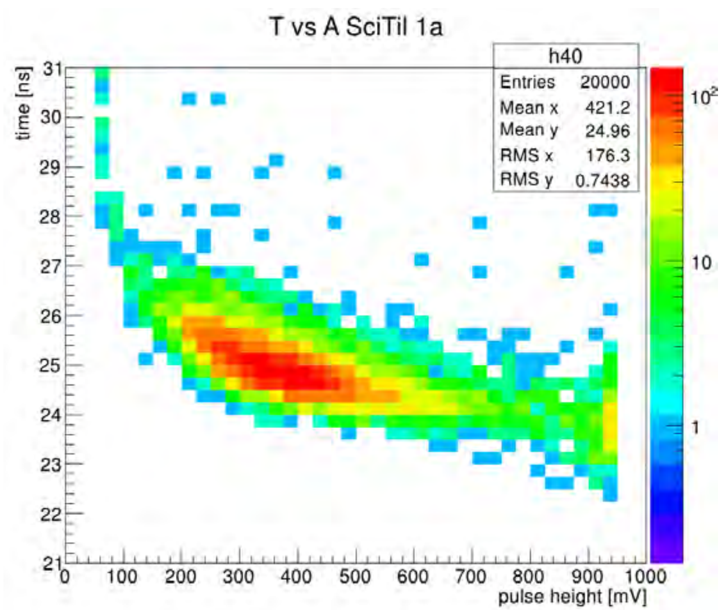
In total 5 TB of data in 2 weeks.

First results: Number of photons

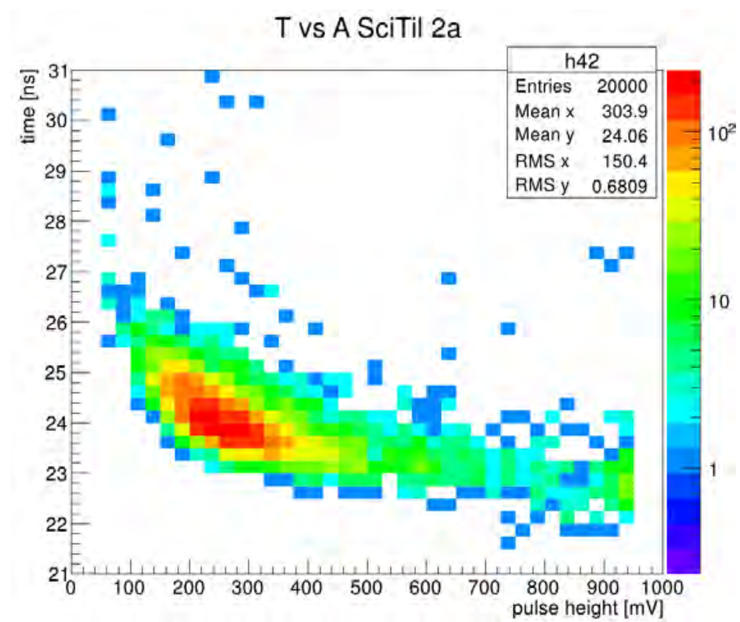
Waveform analysis (V1742):

- **Signal amplitude → number of photons**
- **Threshold crossing time: leading edge (LE) discriminator**
- **Threshold: - 50 mV ~ 10 photons**

HPK S12572-050P with EJ-228



Ketek PM3350 with EJ-232

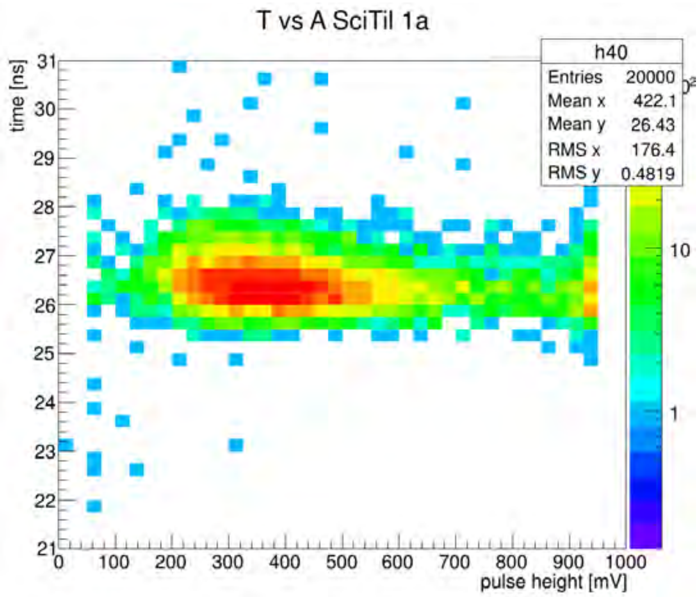


Approx. 65 – 70 photons per event per SiPM.
There is a time walk → One should correct.

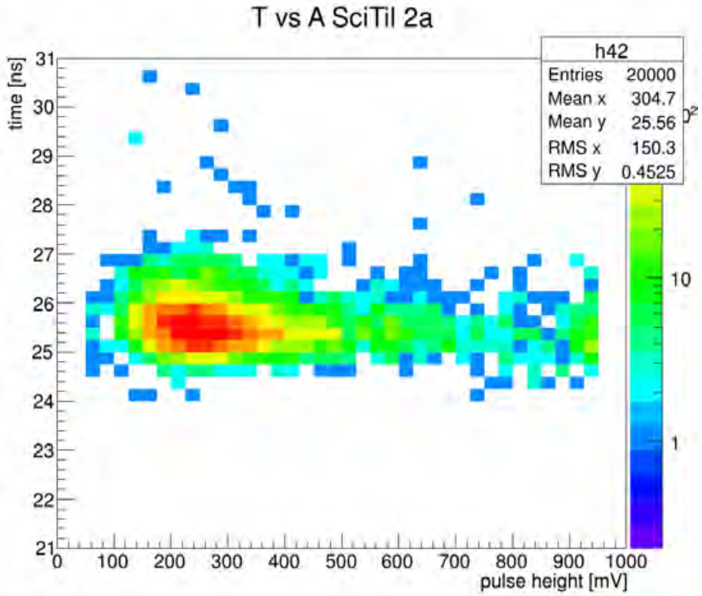
First results: time walk correction

- **We tried to correct for time walk using pulse height information**
- **It turned out that the best way is to use a constant fraction discriminator (CFD)**
- **The CFD settings (threshold, delay, attenuation) can be adjusted for different runs to get the best results**
- **Settings for this run: threshold = - 50 mV, delay = 2 ns, attenuation = 1/5**

HPK S12572-050P with EJ-228



Ketek PM3350 with EJ-232



No time walk.

First results: time resolution

- **Time resolution of a single layer can be estimated by using SCI1 from the EtaPrime group as a reference counter**
- **SCI1 is readout with 2 PMTs (L + R)**
- **Each SciTil layer is readout with 2 SiPMs (A + B)**
- **Use mean timing of all 3 counters:**

e.g. $T_{SciTil1} = (SciTil1_A + SciTil1_B)*1/2$

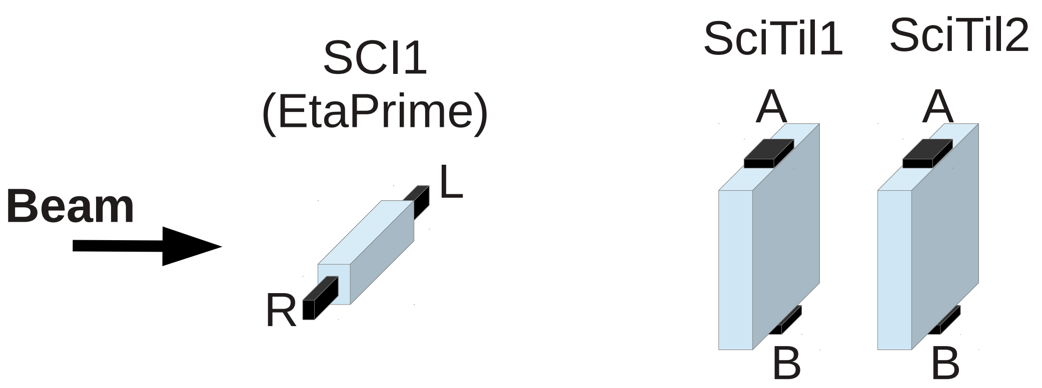
- **Determine TOF and TOF resolution between all counters:**

e.g. $TOF_{SciTil1\text{-}SciTil2} = T_{SciTil1} - T_{SciTil2}$

$\Delta TOF_{SciTil1\text{-}SciTil2} = \sqrt{(\Delta T_{SciTil1}^2 + \Delta T_{SciTil2}^2)}$

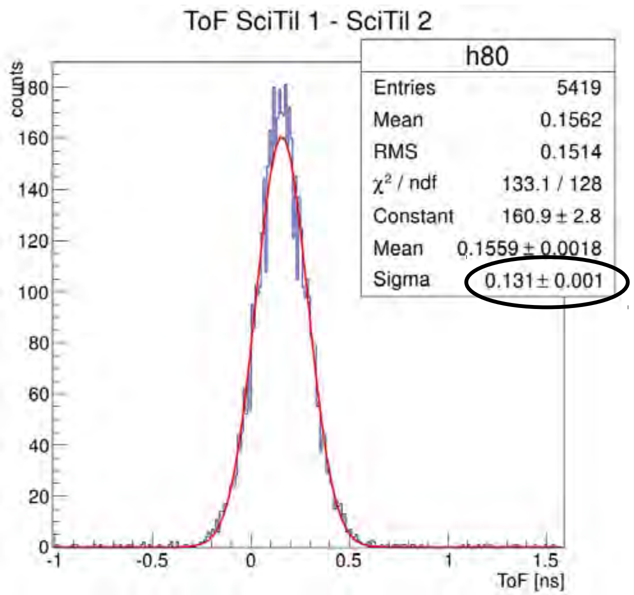
- **Calculate time resolution of individual counters:**

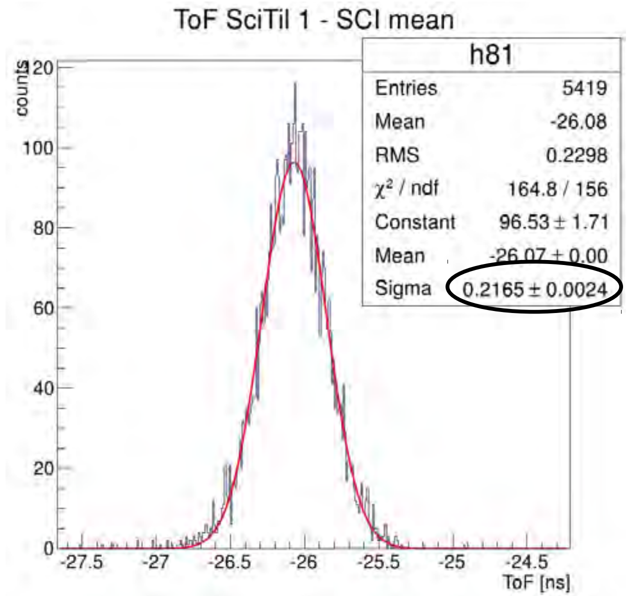
$\Delta T_{SciTil1} = \sigma_{SciTil1}, \Delta T_{SciTil2}, \Delta T_{SCI1}$

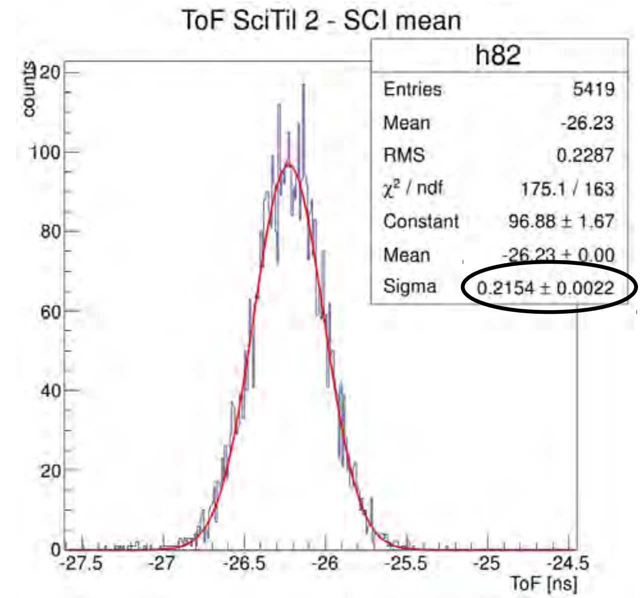


Time resolution: Example

- **SciTil1: EJ-228 readout with Hamamatsu S12572-025C**
- **SciTil2: EJ-232 readout with Ketek PM3360**
- **SCI1 readout with PMTs**







Calculate σ_i from TOF resolutions:

$\sigma_{SciTil1}$ = 93.90 ± 3.8 ps

$\sigma_{SciTil2}$ = 91.30 ± 3.9 ps

σ_{SCI1} = 195.1 ± 1.8 ps

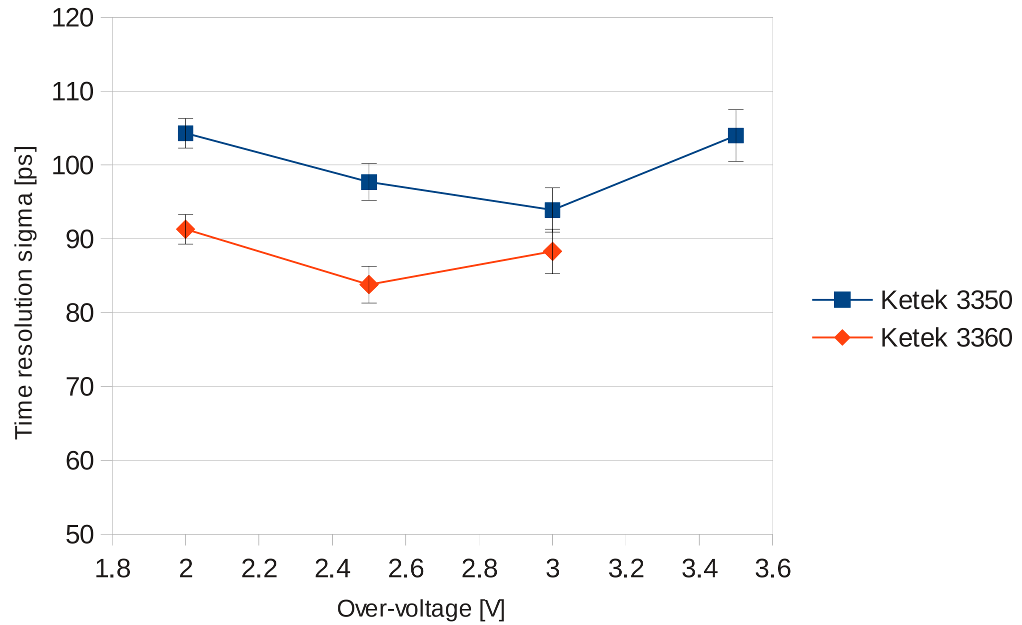
Ketek time resolution

Ketek PM 3350 with EJ-232 (V_{bd} ~ 27 V):

σ = 104.3 ± 4.8 ps @ 2.0 V over-voltage
σ = 97.70 ± 5.1 ps @ 2.5 V over-voltage
σ = 93.90 ± 8.7 ps @ 3.0 V over-voltage
σ = 104.0 ± 8.7 ps @ 3.5 V over-voltage

Ketek PM 3360 with EJ-232 (V_{bd} ~ 27 V):

σ = 91.30 ± 3.9 ps @ 2.0 V over-voltage
Best value → σ = 83.80 ± 4.3 ps @ 2.5 V over-voltage
σ = 88.30 ± 5.2 ps @ 3.0 V over-voltage



HPK time resolution

Hamamatsu S12572-050P with EJ-228 (V_{op} ~ 66.7 V):

σ = 136.5 ± 3.7 ps @ 2.0 V below V_{op}

σ = 126.8 ± 3.9 ps @ 1.5 V below V_{op}

σ = 116.6 ± 7.0 ps @ 1.0 V below V_{op}

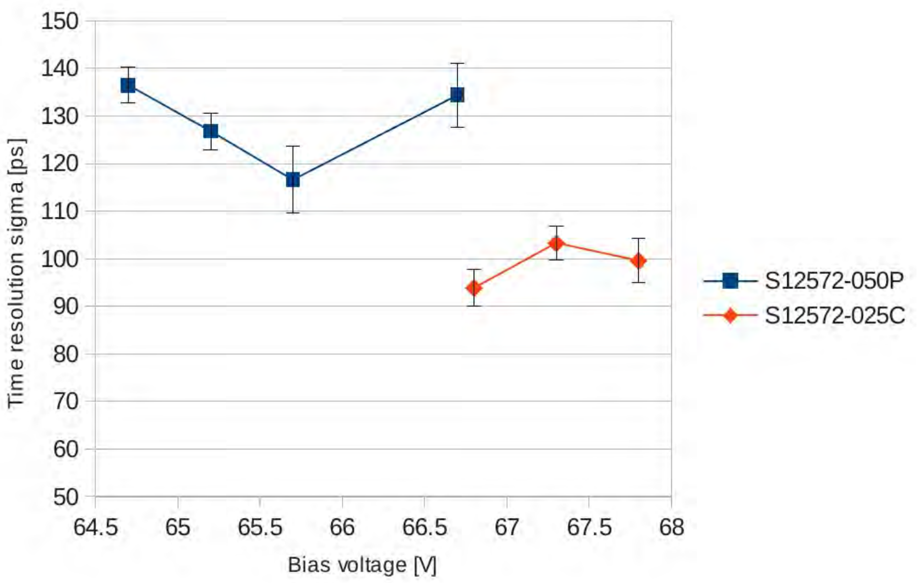
σ = 134.4 ± 6.7 ps @ V_{op}

Hamamatsu S12572-025C with EJ-228 (V_{op} ~ 67.8 V):

Best value → σ = 93.90 ± 3.8 ps @ 1.0 V below V_{op}

σ = 103.3 ± 3.5 ps @ 0.5 V below V_{op}

σ = 99.60 ± 4.6 ps @ V_{op}



Conclusion no. 1

First analysis of test beam data shows that a time resolution of the SciTil prototype below 100 ps sigma has been achieved.

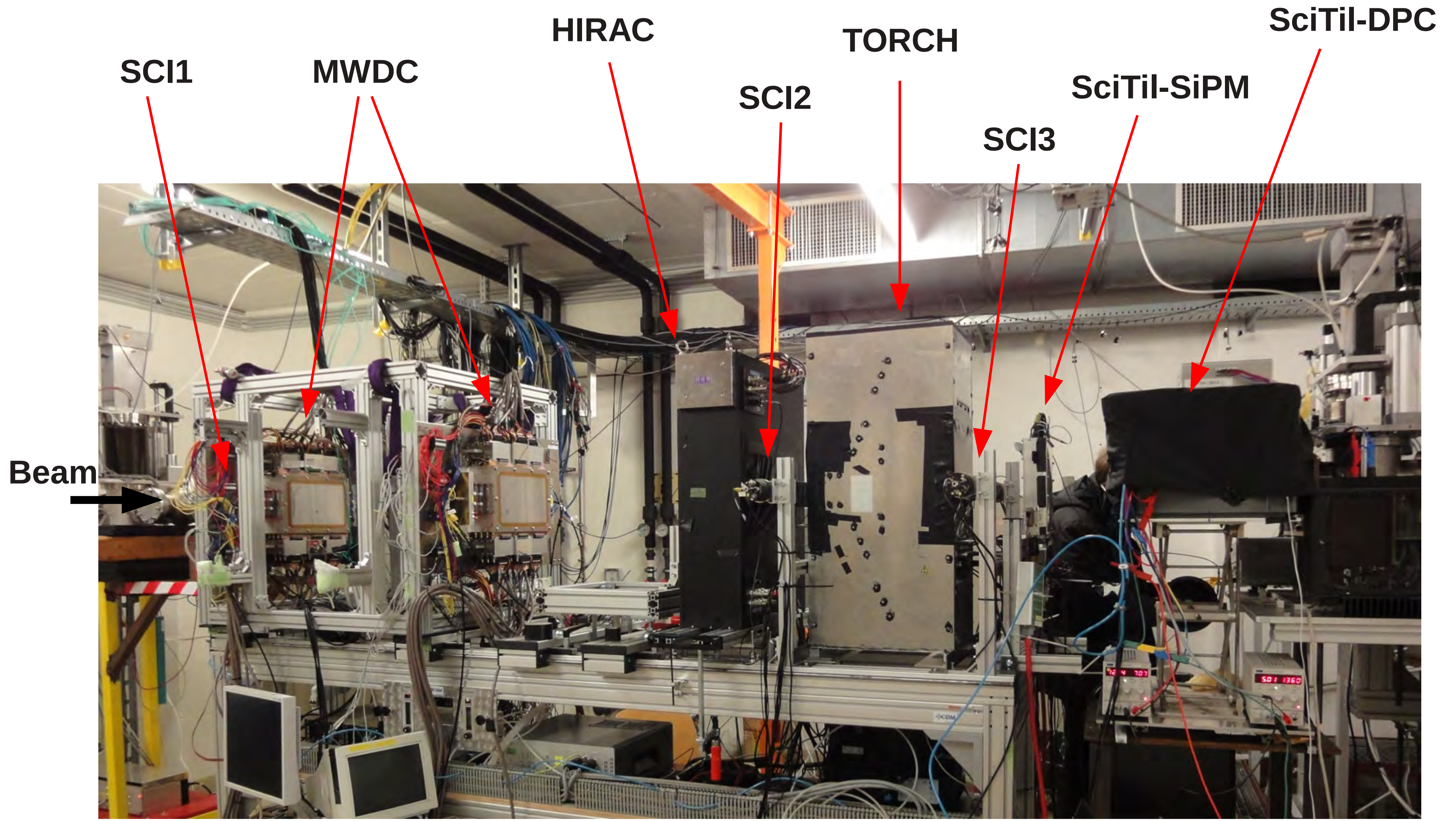
The best value achieved so far with Ketek PM3360 sensors is $\sigma \sim 84$ ps.

To achieve a time resolution below 100 ps, it is essential to use a constant fraction discriminator, in order to minimize time walk.

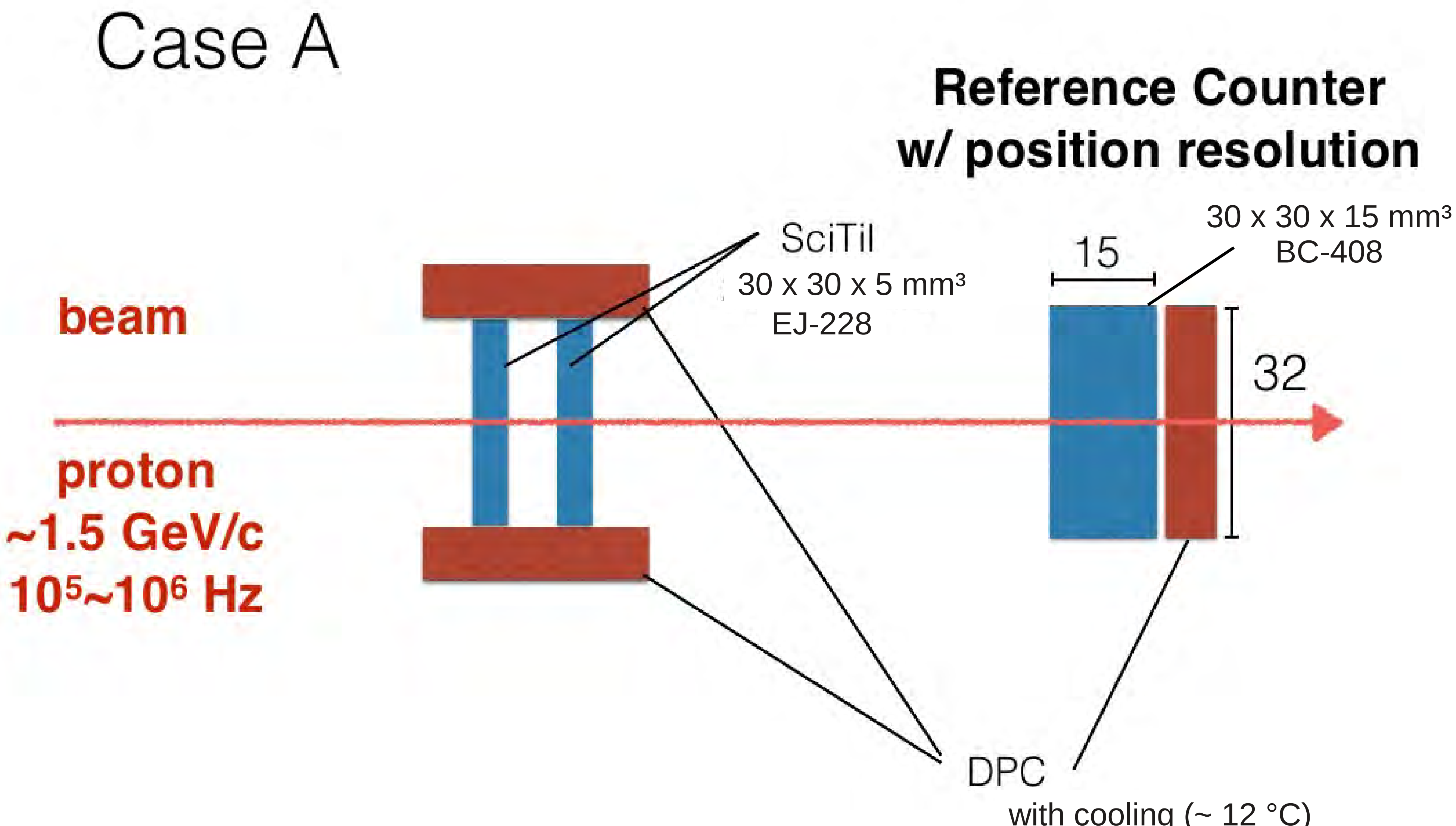
To do:

- **full analysis of V1742 data**
- **include position information from fiber tracker**
- **TRB data analysis**
- **"IFES" board data analysis**

The beam line at JESSICA (2^{nd} week)



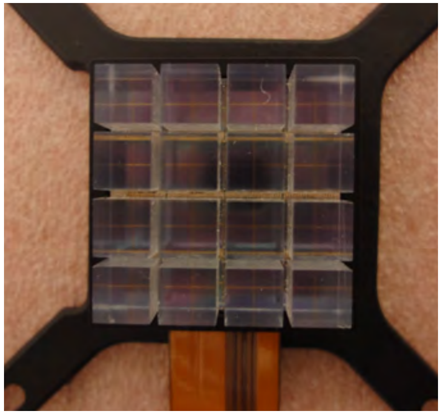
The SciTil-DPC prototype

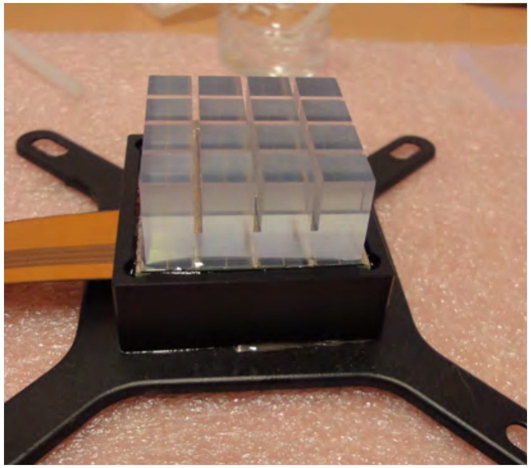


The SciTil-DPC prototype (Case A)

Reference counter readout with Philips DPC:

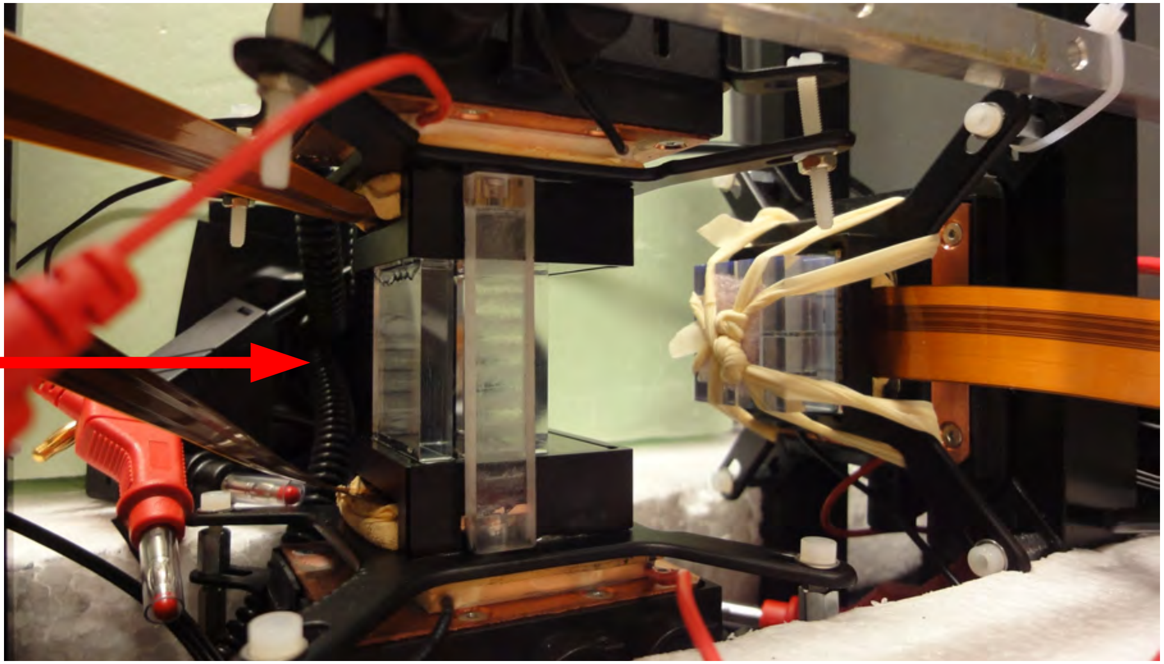
- **Thick (15 mm) scintillator to have many photons**
- **Monolithic block with slits: 1 mm wide, 10 mm deep**
- **Position information from centroid**





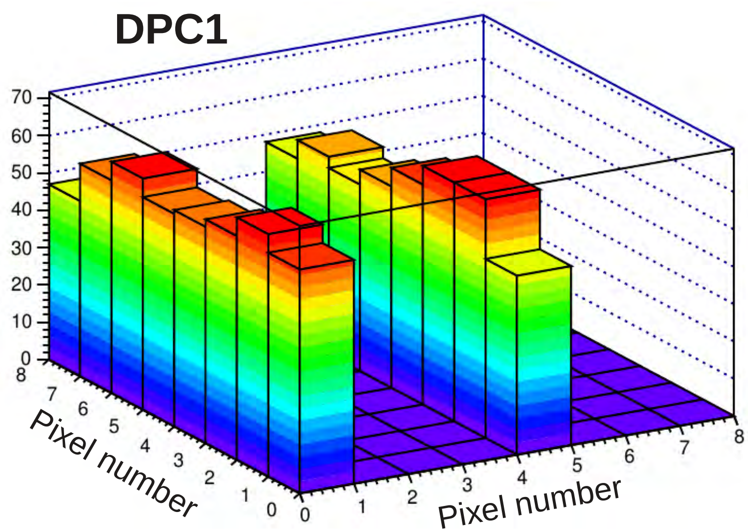
The whole setup:

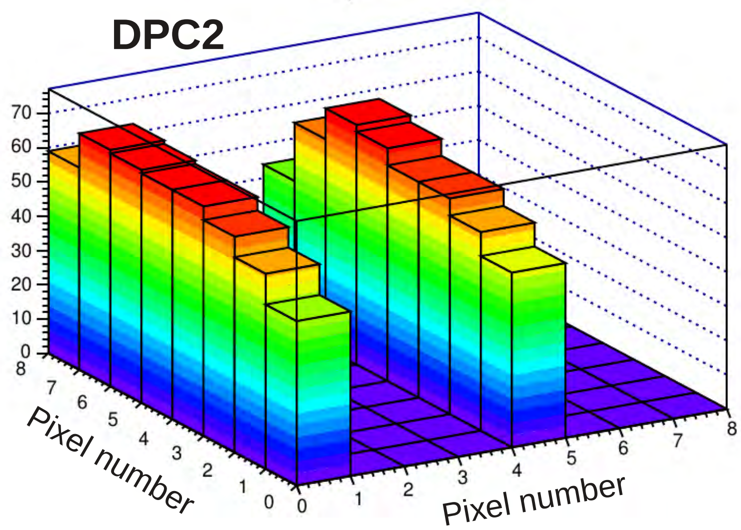
Beam

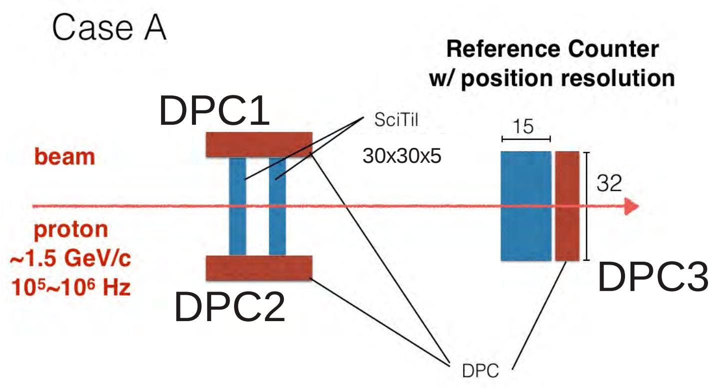


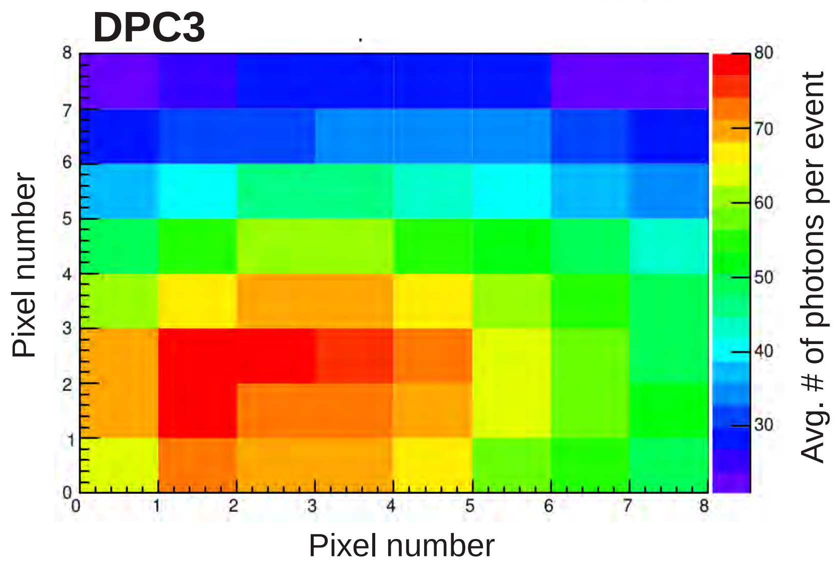
Results from case A: photon number

Avg. # of photons per event





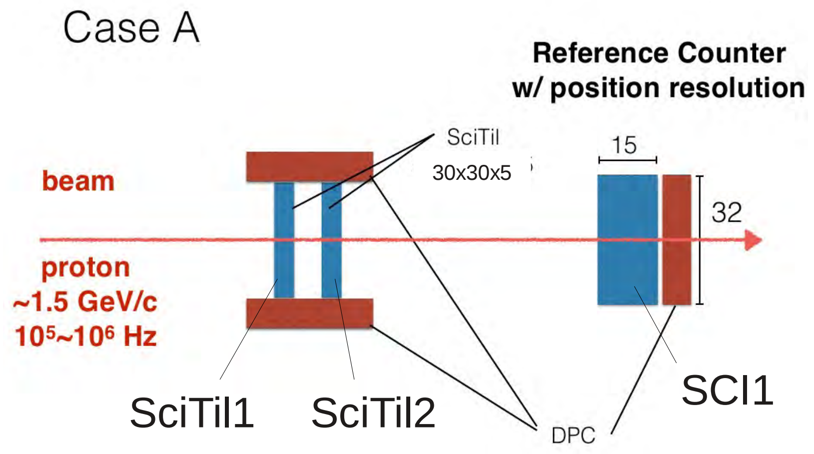




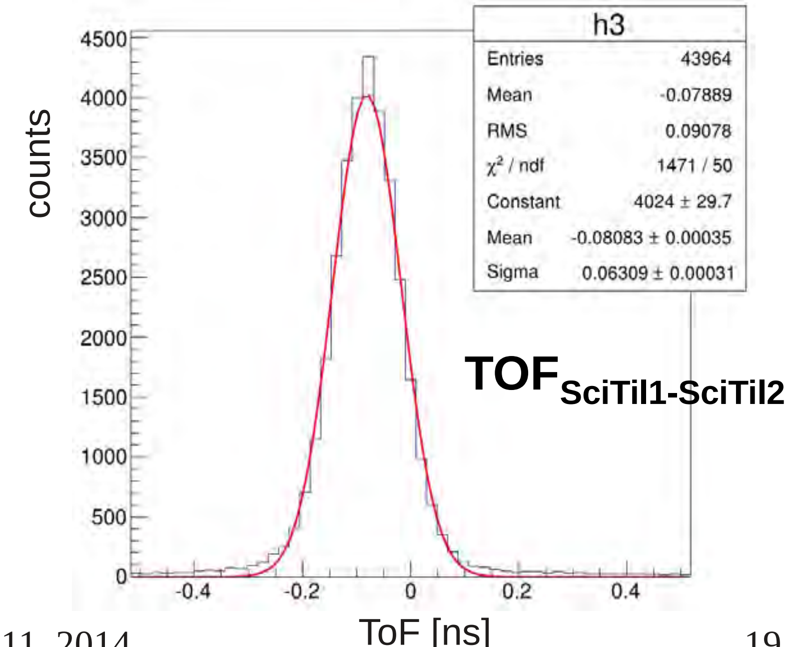
60 – 70 photons per event per DPC pixel.
Beam hitting slightly off center.

Results from case A: time resolution

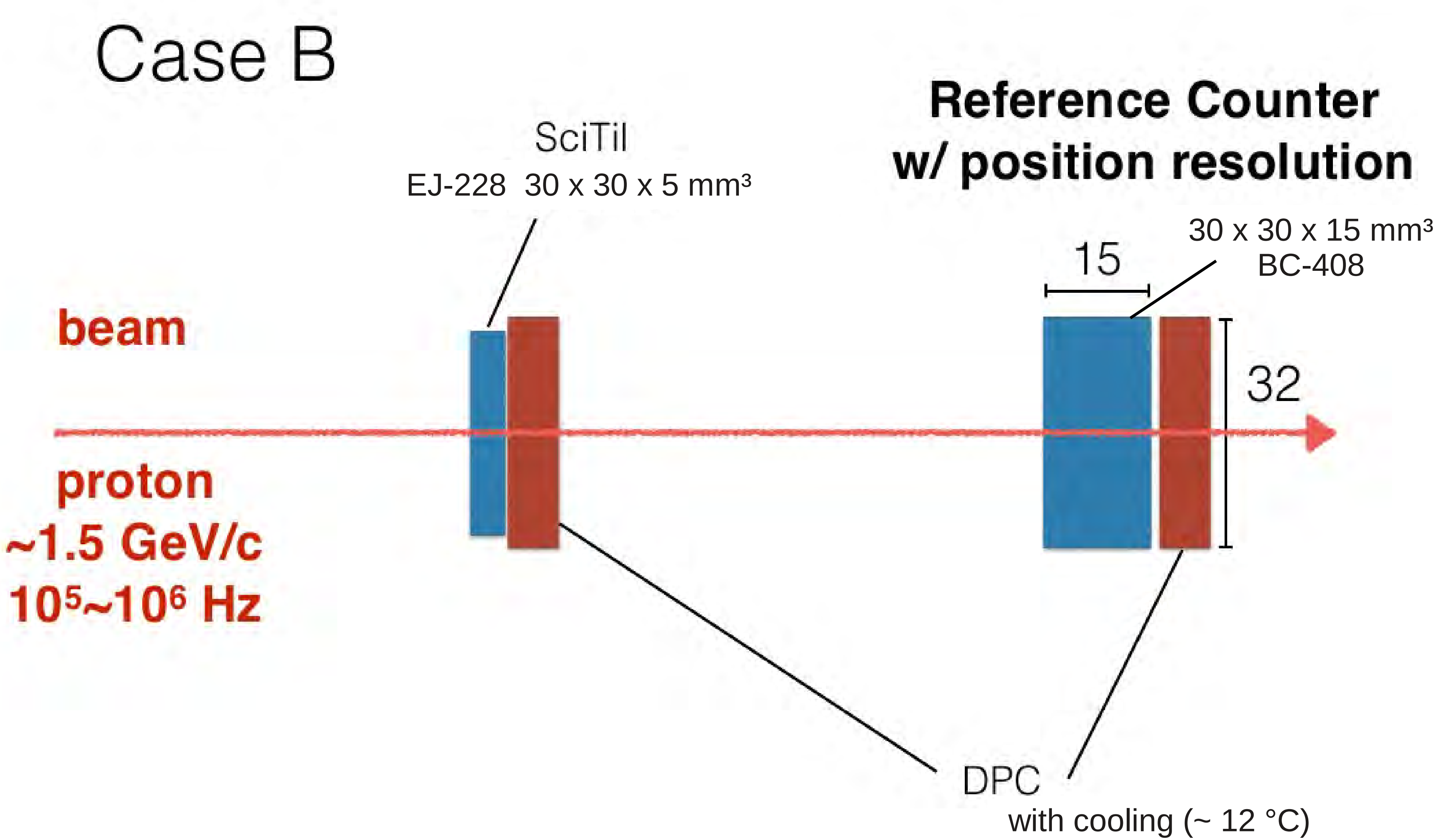
- **Performing same analysis as before**
- **SciTil1: EJ-228 readout with Philips DPC**
- **SciTil2: EJ-228 readout with Philips DPC**
- **SCI1: BC-408 readout with Philips DPC**



Calculate σ_i from TOF resolutions:
$\sigma_{SciTil1}$ = 46.9 ± 0.6 ps
$\sigma_{SciTil2}$ = 42.2 ± 0.7 ps
σ_{SCI1} = 57.0 ± 0.5 ps

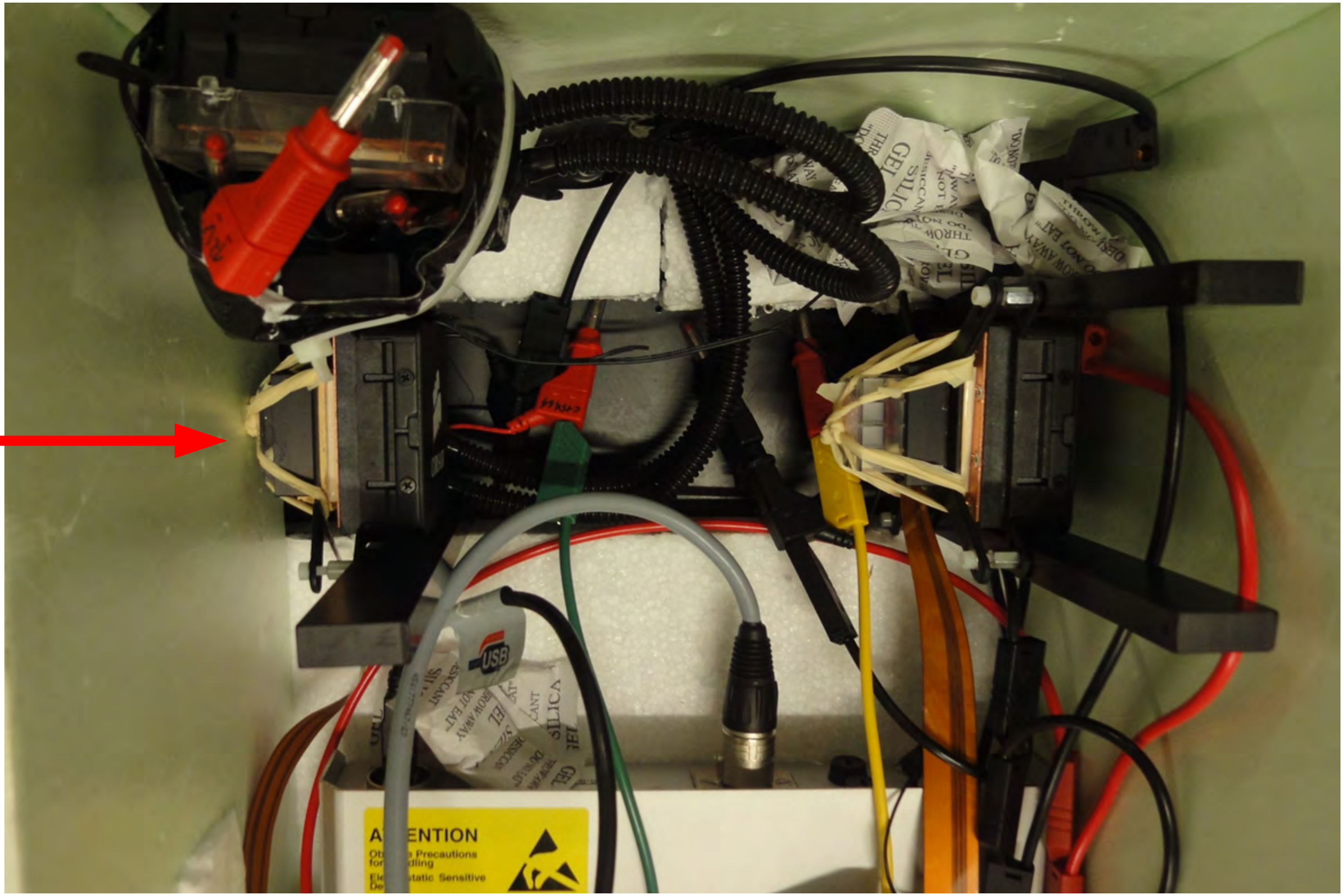


The SciTil-DPC prototype

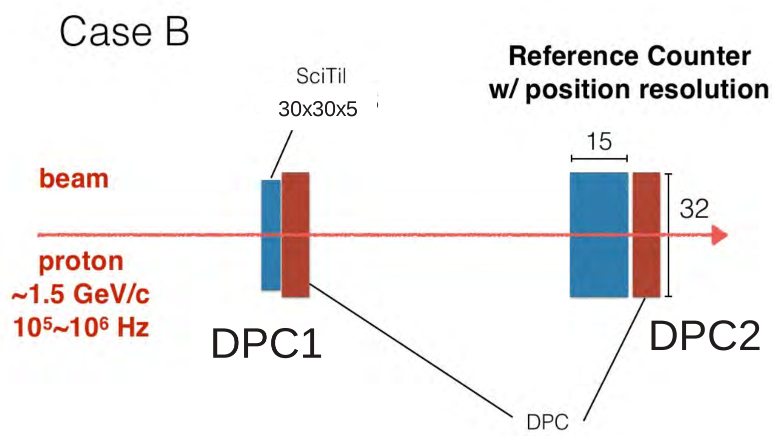


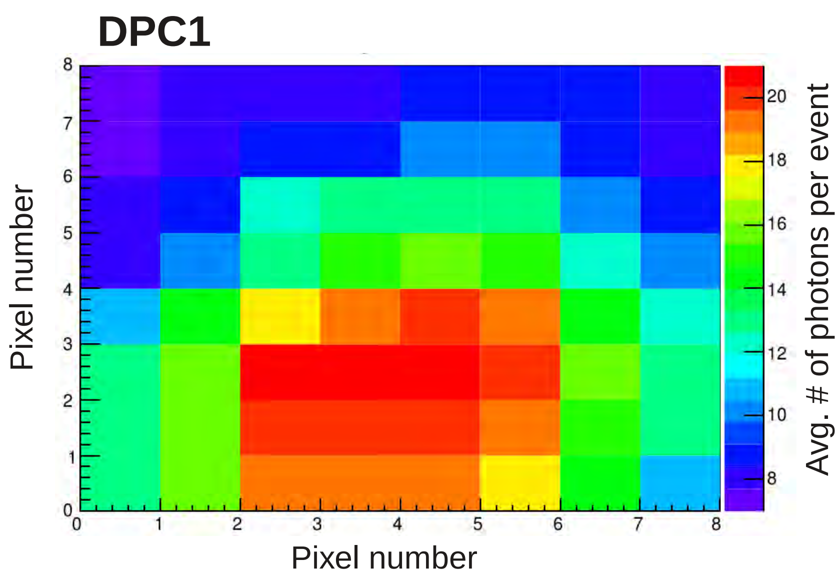
The SciTil-DPC prototype (Case B)

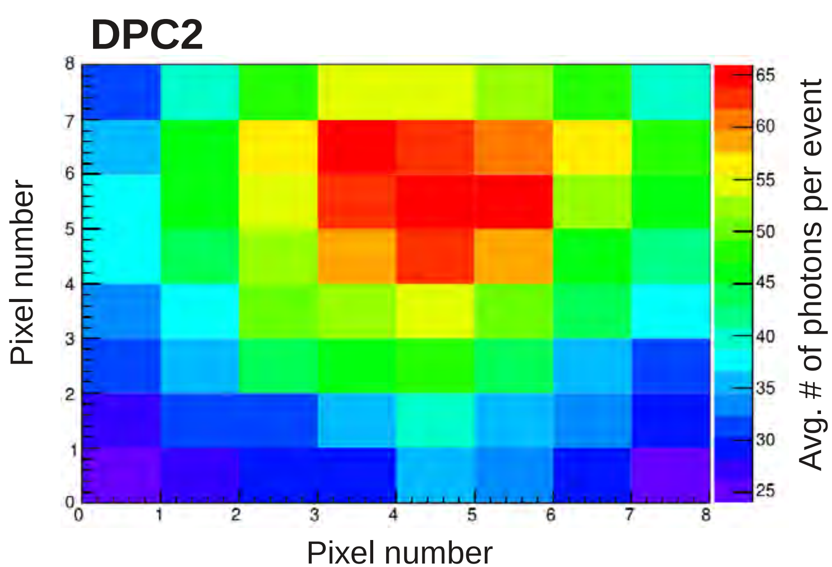
Beam



Results from case B: photon number

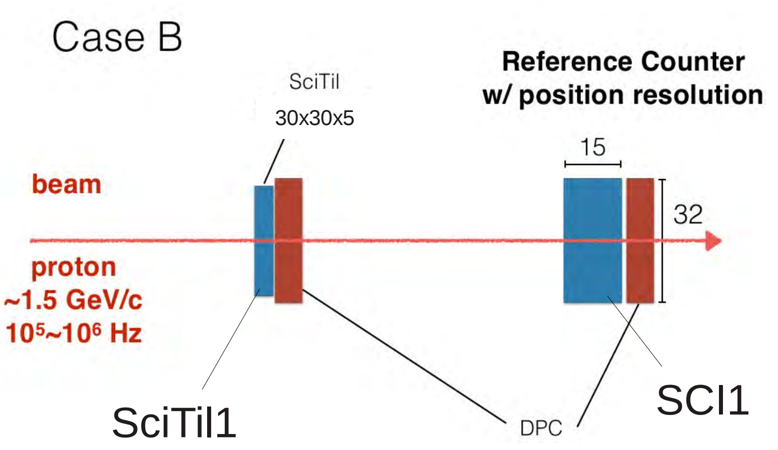






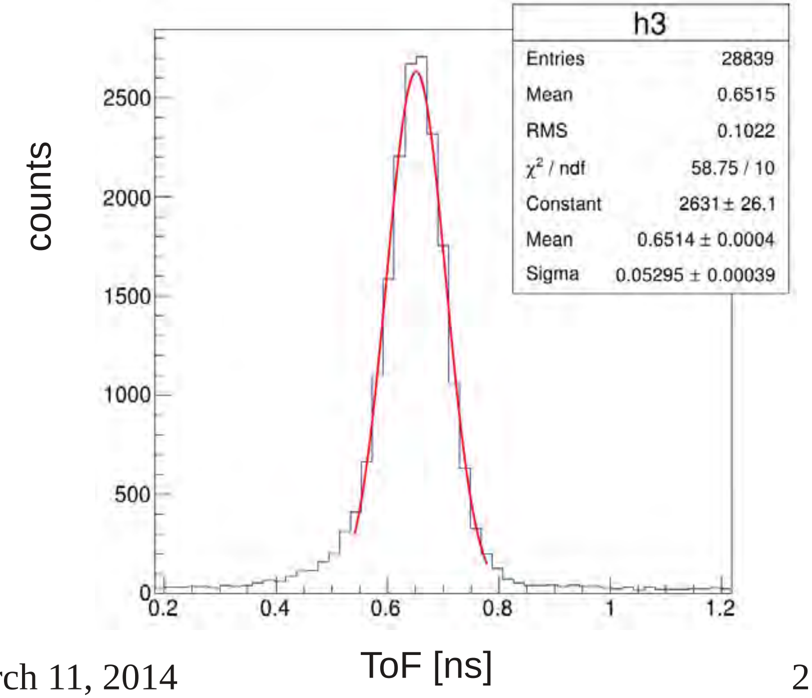
DPC2 sees 3 times more photons since scintillator is 3 times thicker.
Slightly misaligned.

Results from case B: time resolution

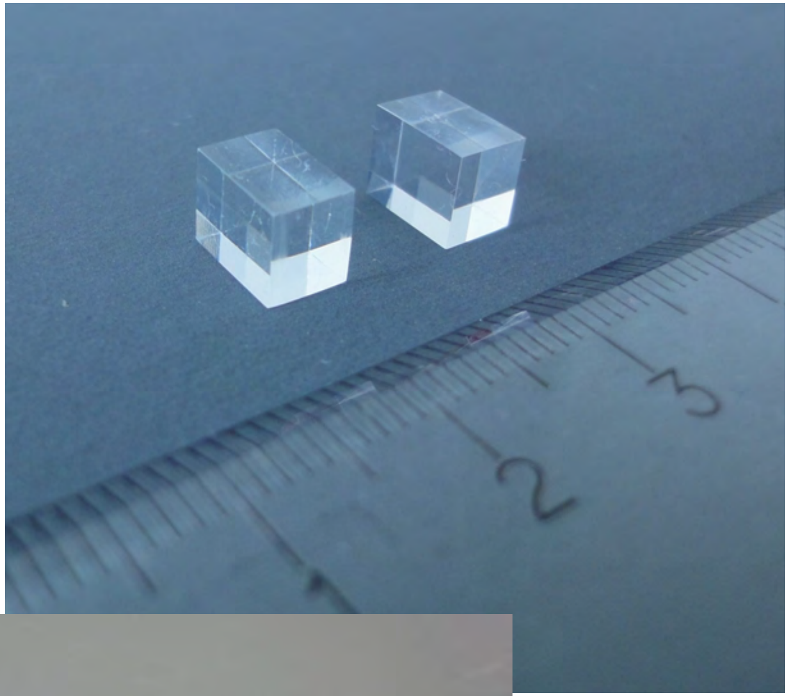


- **Performing same analysis as before**
- **SciTil1: EJ-228 readout with Philips DPC**
- **SCI1: BC-408 readout with Philips DPC**

TOF resolution:
$\sigma_{SciTil1-SCI1} = 52.9 \pm 0.4$ ps



The SciTil-DPC prototype (Case C)

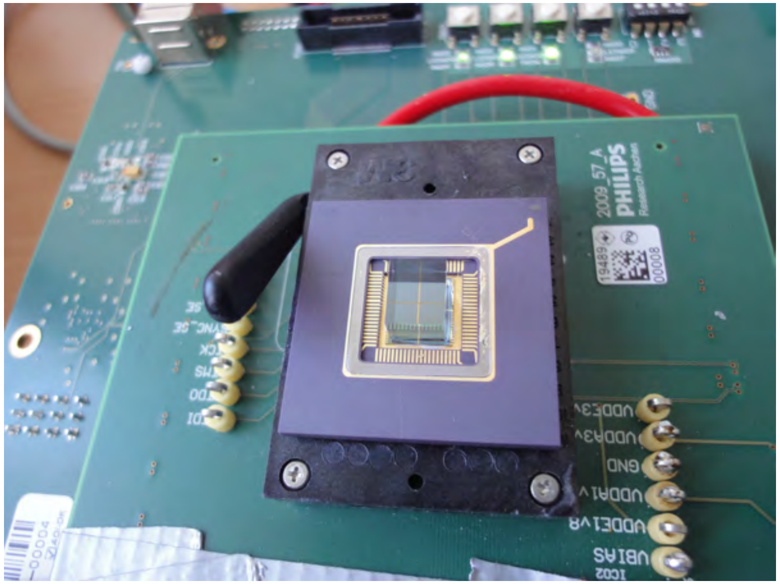


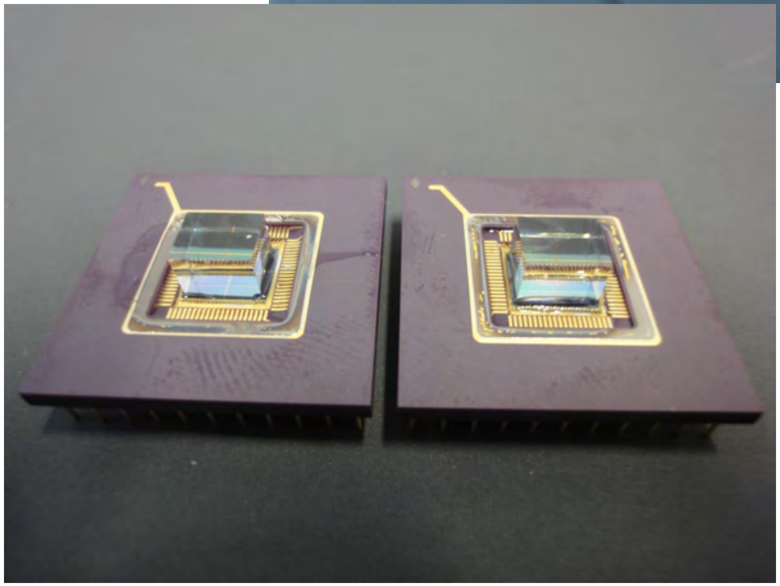
Testing of single-die DPC prototype:

- **Approx. 8 mm x 7 mm sensitive area**
- **Use only single die to avoid jitter between dies**
- **No additional time jitter from FPGA**
- **Small and fast scintillator: EJ-232 ~ 7 x 6 x 5 mm³**
- **Two modules in coincidence**

TOF resolution: σ_{TOF} ~ 40 ps

Assuming two identical detectors: $\sigma_1 = \sigma_2$ ~ 30 ps





Conclusion no. 2

First analysis of test beam data shows that a time resolution below 50 ps sigma has been achieved using the Philips DPC.

The best value achieved so far for a single SciTil scintillator tile is σ ~ 42 ps. Using a single-die DPC prototype in combination with a small scintillator, we even achieved a time resolution of σ ~ 30 ps.

Comparing with the results using the analog SiPM, the DPC is superior in terms of time resolution. However, such a comparison is not totally fair since the DPC active area is much larger.

To do:

- **full analysis of DPC data**
- **include position information using segmented reference counter**

Radiation hardness

At the moment, we cannot give numbers on the radiation hardness of the SiPM sensors from these measurements. More quantitative details after analyzing the drift chamber data.

Beam condition at JESSICA:

- **2.7 GeV/c and 1.5 GeV/c protons**
- **Intensity: ~ 10^5 – 10^6 Hz**
- **Defocused beam: ~ 5 cm x 5 cm**

However, we realized a drastic increase of SiPM dark count rates after 1-2 days of operation in beam (factor 3-4, quick measurement with oscilloscope). The gain of the SiPMs didn't change.

Afterwards, the dark count rates seem to stay constant.

This observation needs further investigation. It is necessary to have a dedicated measurement on the radiation hardness of the SiPMs sensors used for SciTil.

Very rough estimation: 1% of 10^6 for 20 hours → 7 x 10^8 particles

Revisiting SciTil Concept

Is the current design really optimum?

28.5 x 28.5 x 5 mm^3 tile with two SiPMs

RISING timing detector

- R. Hoischen et al. (RISING experiment) NIMA 654 (2011) 354.
- Octagonal shaped scintillator (ø=20cm) with 32 PMTs to achieve 10 ps time resolution
- Precise calibration and position determination
- (but for heavy ion!!)

MEG experiment ToF Tile

- More recent development with similar concept from MEG experiment
- arXiv:1402.1404v1
- 60x30x6 mm^3 BC422 plus 6 3x3 mm^2 aSiPM
- 42 ps (sigma) time resolution

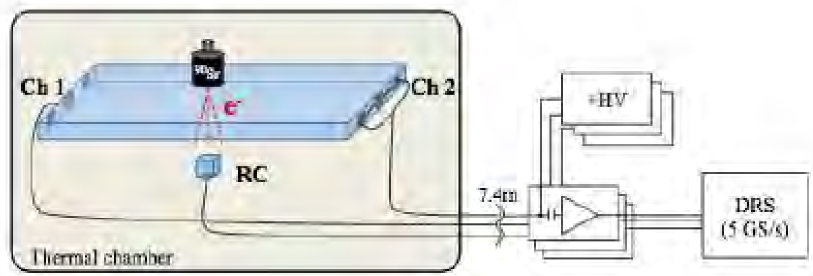
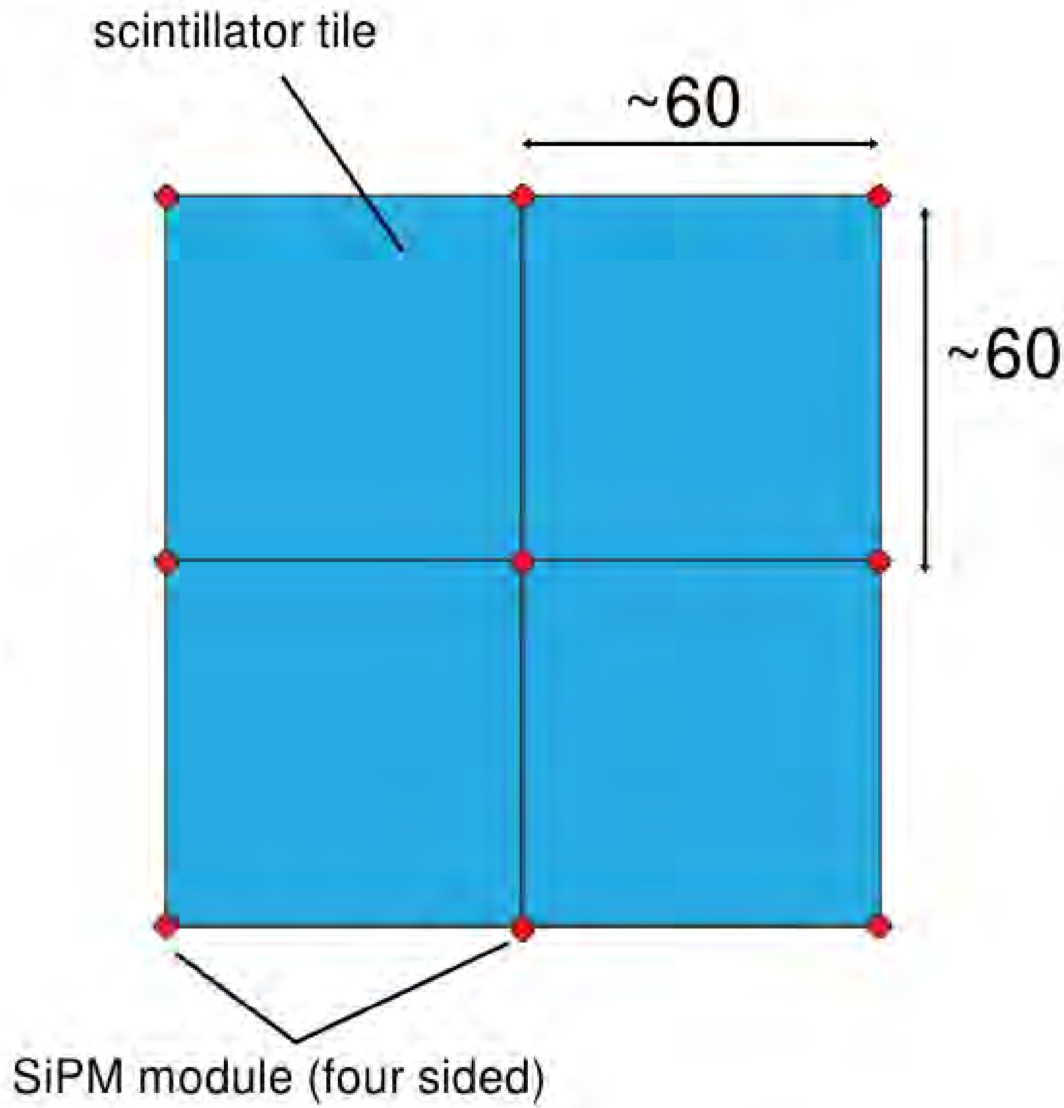


Fig. 1. Setup of the tests of counter time resolution. RC denotes the reference counter. See in the text for details.

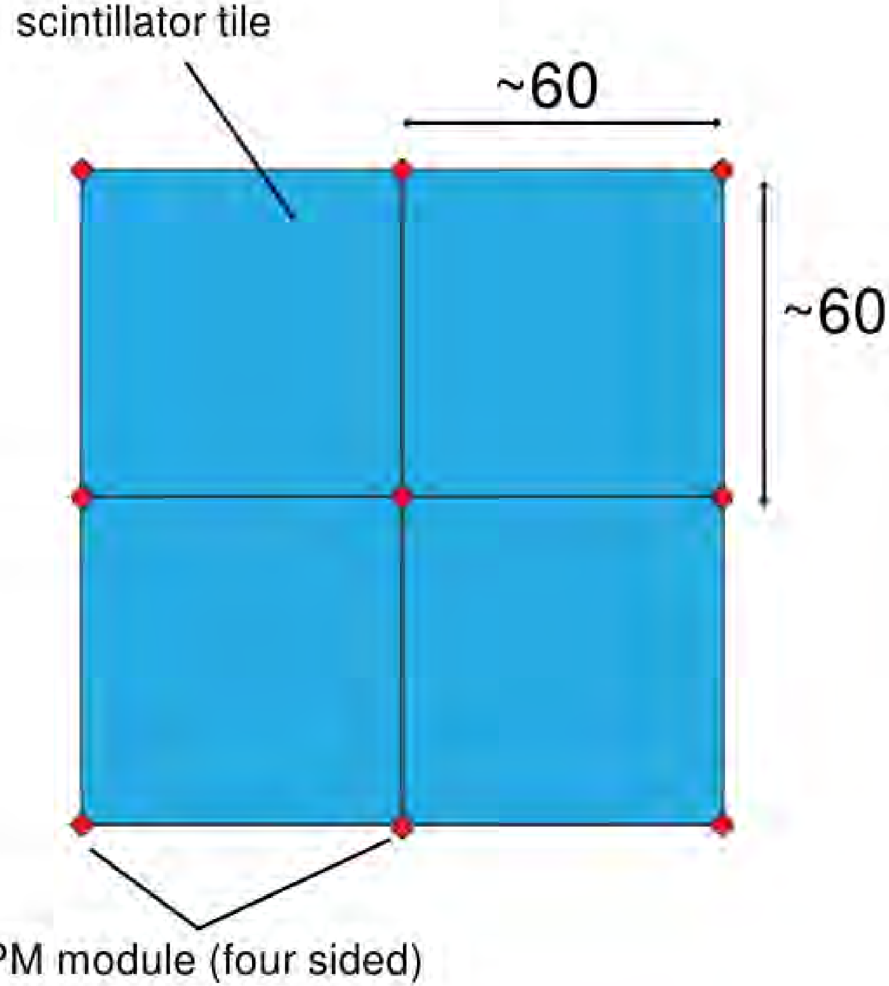
New Design Concept

- four sensors per tile
- symmetric configuration
- use charge distribution information to reconstruct the position on tile and apply a correction



Expected Advantage

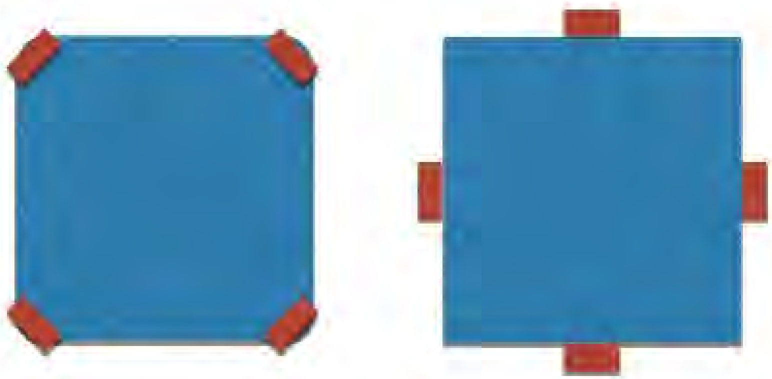
- Either the number of channels decreases with the same time resolution, or
- the number of channels stays the same, but with better time resolution
- minimize insensitive area



Questions

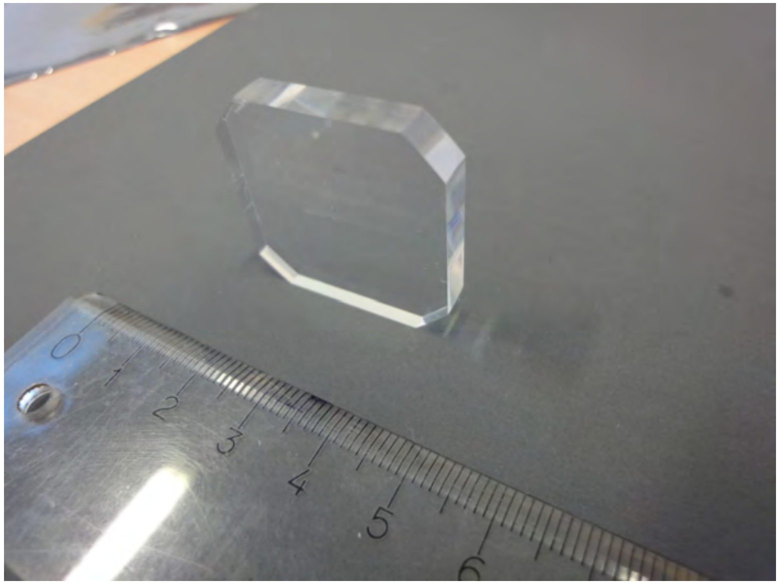
- 4 SiPMs per tile instead of 2, or even more?
- 4 centers or 4 corners?
- Position resolution skew at the corner?

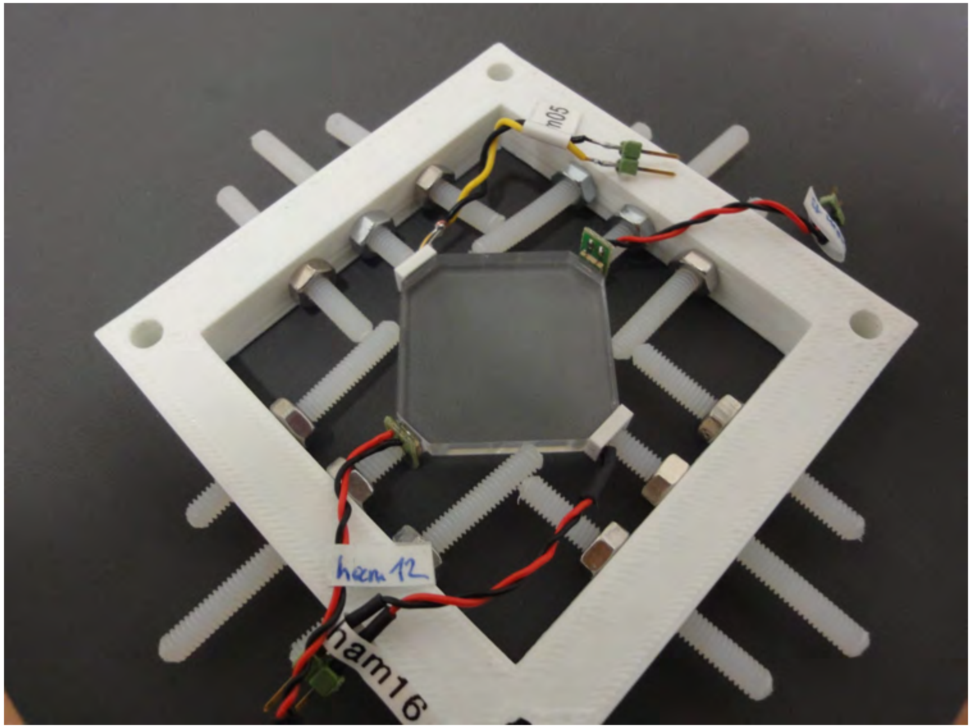
→ **SIMULATION!**



New SciTil prototype

- We prepared a scintillator (EJ-228, 28.5 x 28.5 x 5 mm³) with edges cut
- Tested during last night of test beam
- 4 Hamamatsu SiPMs (S12572-050C and -050P)
- Idea is to use the information from the charge distribution to reconstruct the position and apply a correction





Data are not yet analyzed.