



# Performance Comparison of SciRods and SciTils

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- Motivation for “SciRods”
- Setups for Time Resolution Measurements
- Results with  $^{90}\text{Sr}$  source
- Results with proton beam





# Motivation for “SciRods”

- 30x30x5 mm<sup>3</sup> SciTils read out by two 3x3 mm<sup>2</sup> MPPCs are certainly not the optimum solution in terms of
  - Time resolution
  - Light collection
- SciTil caveats:
  - Many reflections in all directions before photons hit MPPC
  - Detected photons are distributed over a rather wide time interval
  - Only few “prompt” photons → time resolution position dependent
- Advantages of SciRods (e.g., 5x5x120 mm<sup>3</sup>):
  - Use only photons totally reflected along scintillator rod  
→ collected photons at MPPCs arrive within a short time window
  - Read out at both scintillator ends with 3x3 mm<sup>2</sup> MPPCs  
→ good solid angle coverage for scintillation photons  
→ many photons travel same distance to MPPC → many “prompt” photons



# Scintillator Samples

## BC408 ( $\tau = 2.1$ ns)

- $5 \times 5 \times 170$  mm<sup>3</sup>
- $5 \times 5 \times 120$  mm<sup>3</sup>
- $5 \times 5 \times 50$  mm<sup>3</sup>
- $5 \times 10 \times 120$  mm<sup>3</sup>
- $5 \times 10 \times 50$  mm<sup>3</sup>
- $5 \times 30 \times 30$  mm<sup>3</sup>

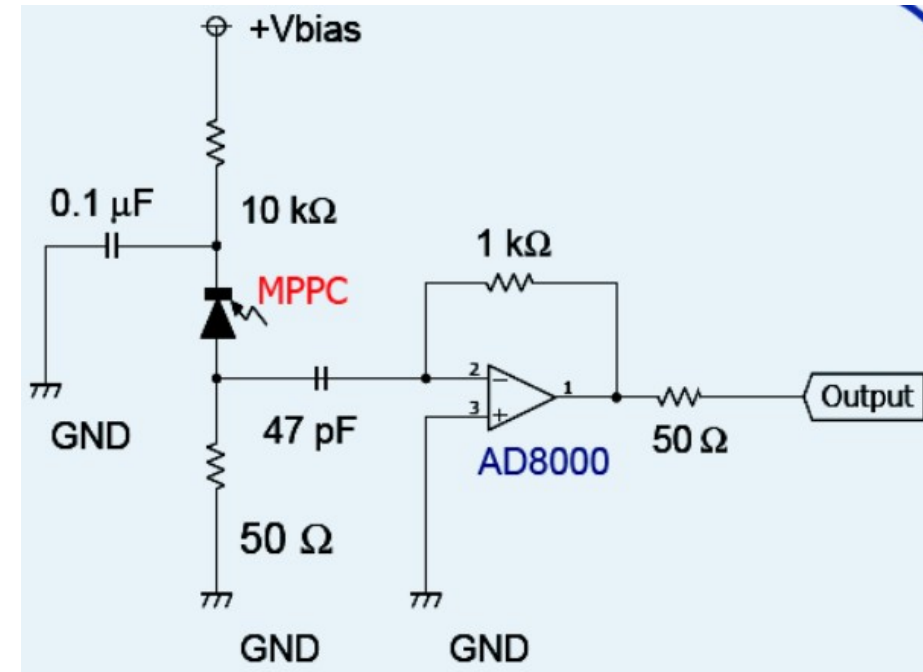
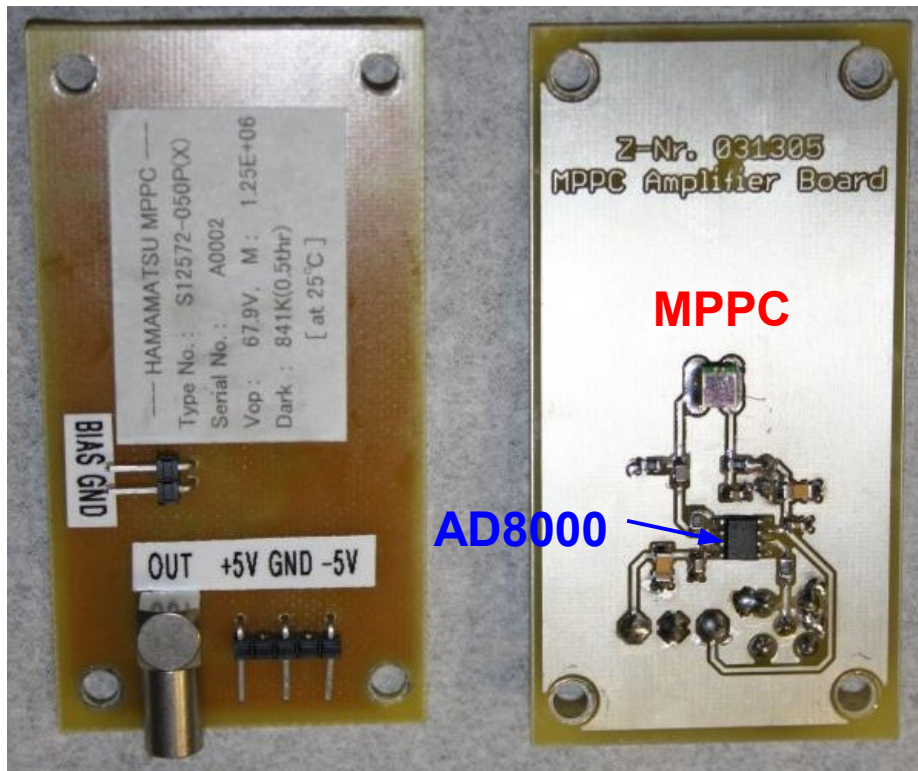


## BC420 ( $\tau = 1.5$ ns)

- $5 \times 5 \times 120$  mm<sup>3</sup>
- $5 \times 5 \times 50$  mm<sup>3</sup>
- $5 \times 5 \times 30$  mm<sup>3</sup>
- $5 \times 10 \times 120$  mm<sup>3</sup>
- $5 \times 10 \times 50$  mm<sup>3</sup>
- $5 \times 10 \times 30$  mm<sup>3</sup>

# Readout

- Readout circuit taken from a talk of H. Kanda given at PhotoDet 2012
  - Inverting amplifier circuit with **AD8000** high speed chip (1.5 GHz)
  - Capacitive coupling with 47 pF



- Used MPPCs ( $3 \times 3 \text{ mm}^2$ )
  - Hamamatsu standard
    - S10362-33
  - Hamamatsu improved
    - S12572-33 (lower afterpulsing)
    - S12652-33 (with trenches)

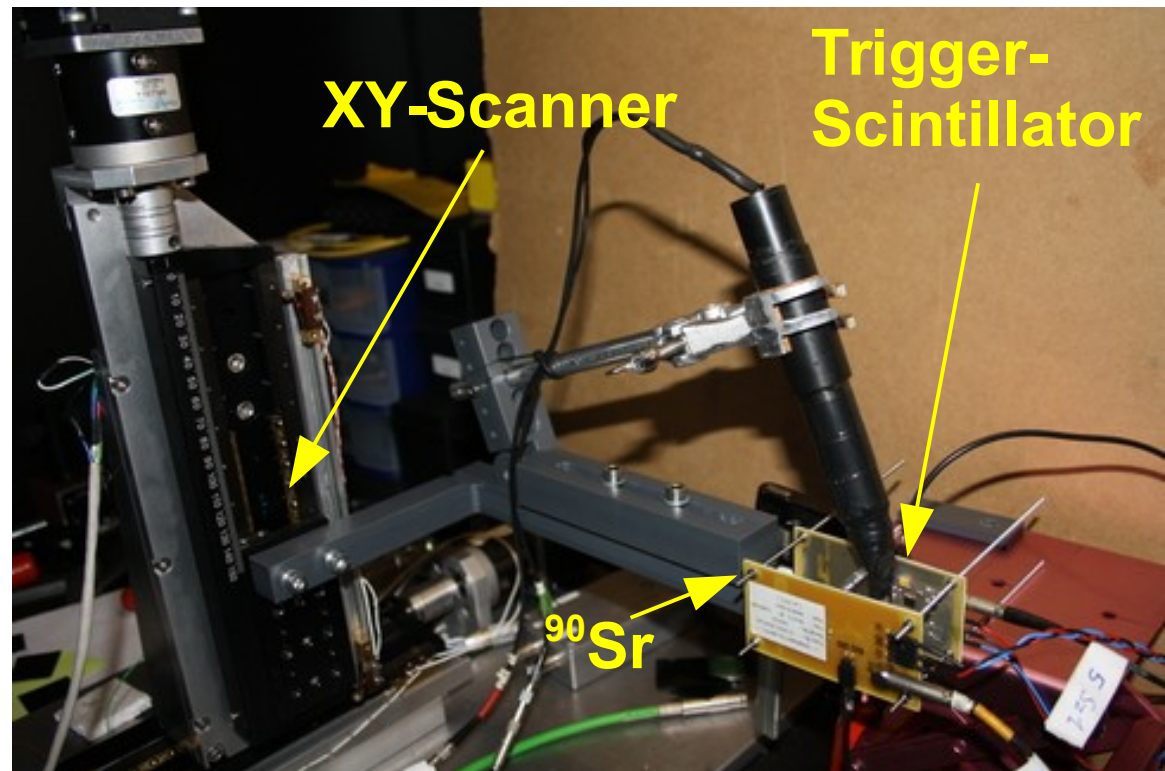
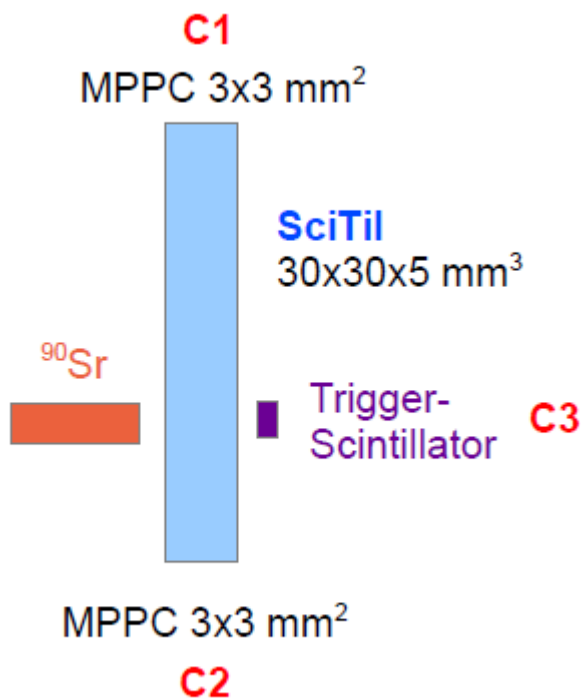


# Measurement Setup

- Scintillator rods/tiles read out at opposite sides
  - No aluminum wrapping (→ collect only totally reflected photons)
  - Measure pulse heights (→ number of photons)
  - Measure time difference (→ time resolution)

**Source:** 1 mCi  $^{90}\text{Sr}$  with 1 mm aperture

**Trigger Scintillator:** ~3 mm  $\varnothing$  from PS185

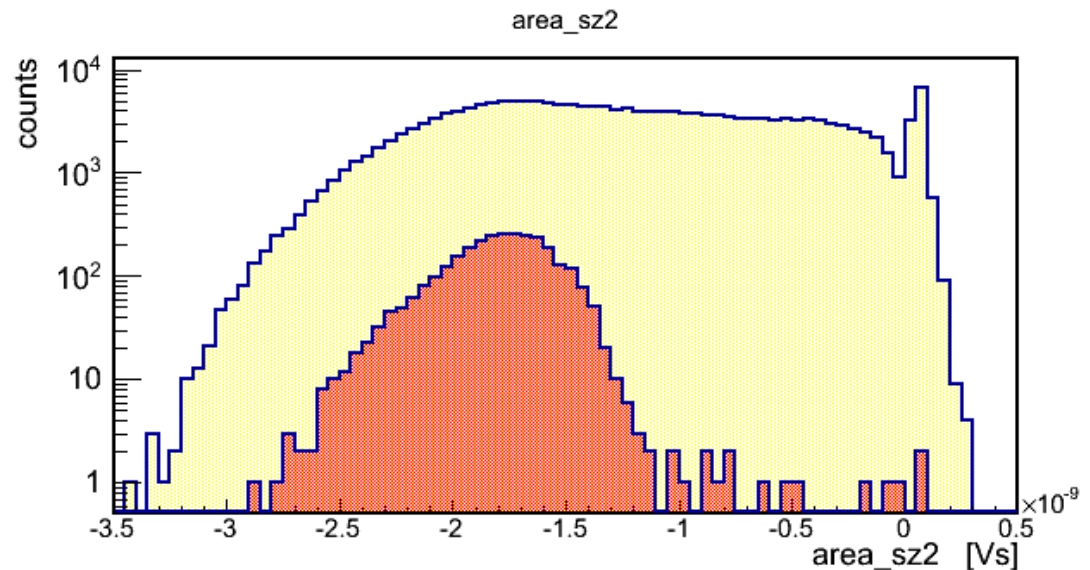
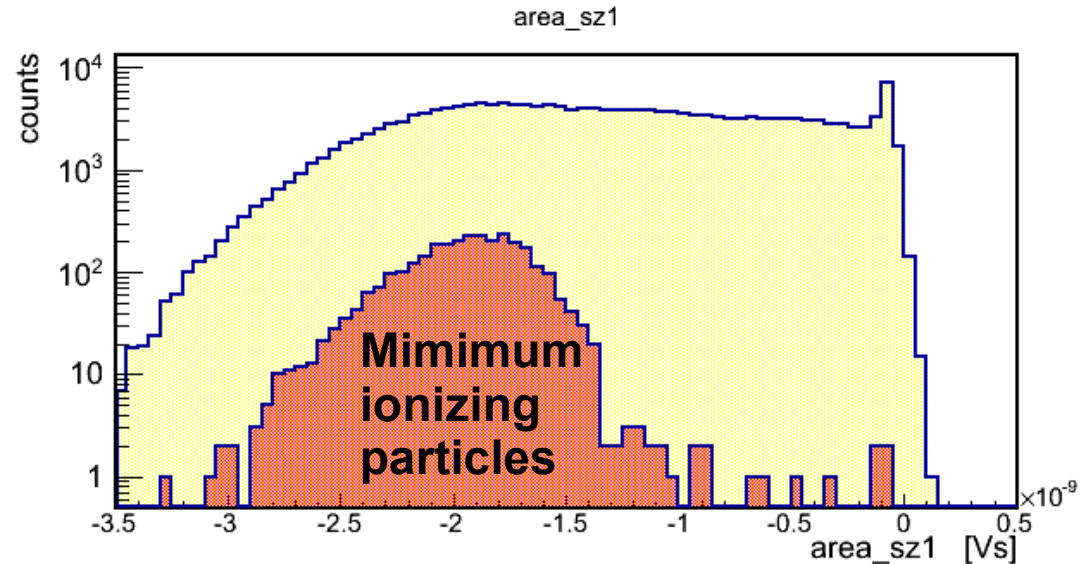




# Expected Number of Photons

- Beta electrons simulate minimum ionizing particle
  - Energy loss in 5 mm thick scintillator (e.g. 5x5x120 mm<sup>3</sup>)
    - **~1 MeV** (0.92 MeV exact)
  - Number of photons created in 5 mm BC408 scintillator
    - **~9000**
- Number of photons at 3x3 mm<sup>2</sup> MPPCs
  - e.g., with 5x5 cm<sup>2</sup> SciRods
  - Assuming **PDE of 25%** and totally reflected photons
  - **~150 detected photons** at each side expected

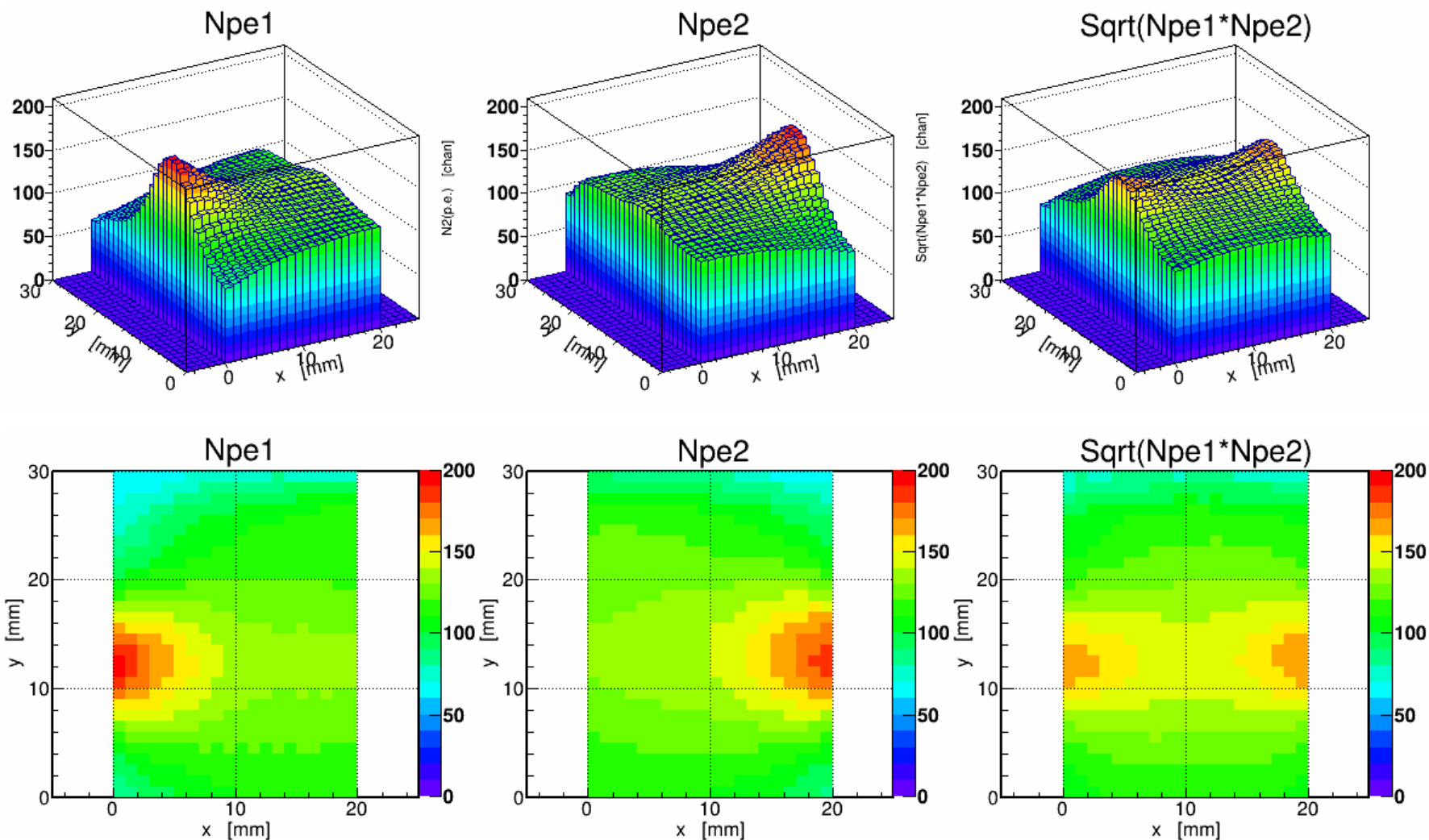
Event rate at trigger: ~100 Hz





# Number of Photons from SciTiL

Scintillator BC408  
MPPC S12652-050C

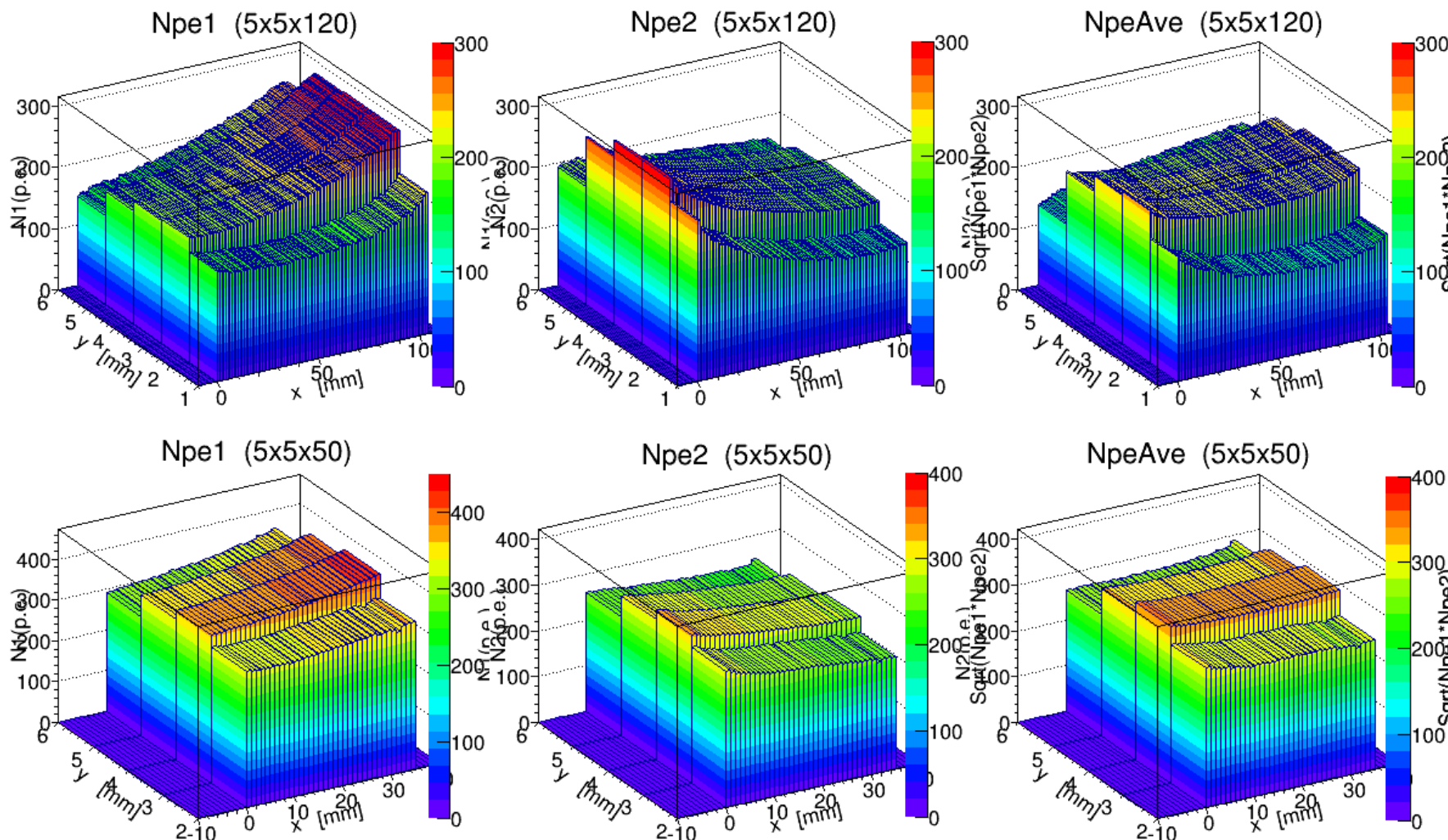


- In average  $\sim 120$  photons detected (?? calibration correct ??)
- Highest close to MPPC and significantly fewer far away from MPPC



# Number of Photons from SciRods

Scintillator BC420  
MPPC S12652-050C



- Detect in average 220 (5x5x120 cm<sup>3</sup>) and 310 (5x5x50 cm<sup>3</sup>) photons
- Highest close to MPPC (~exponential decrease as expected)

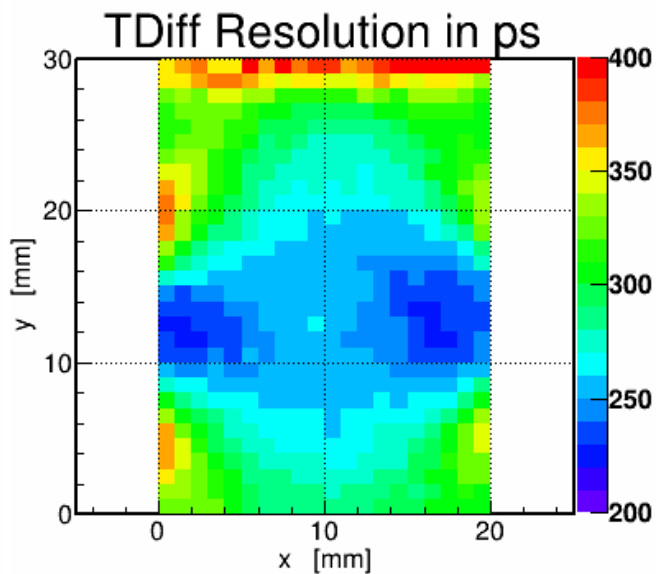
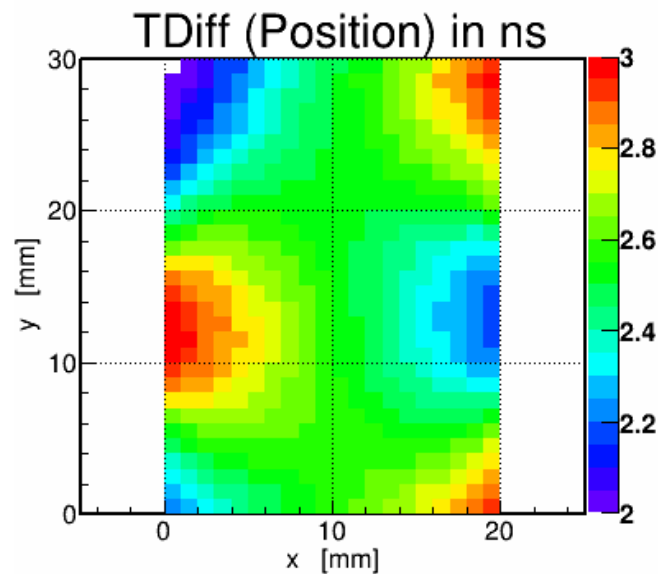
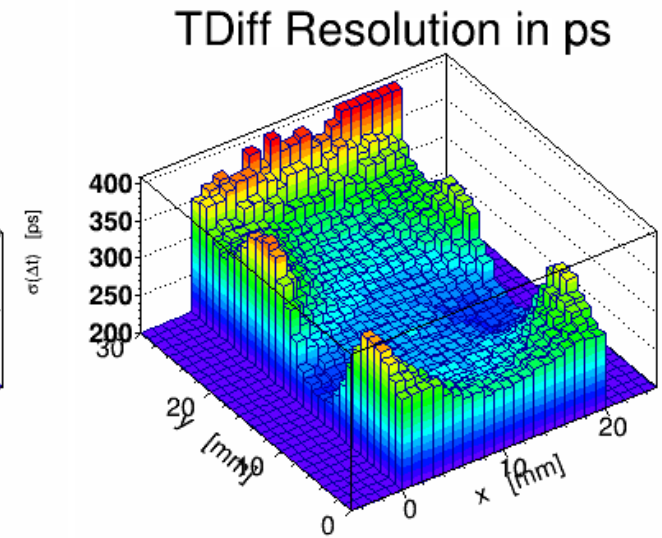
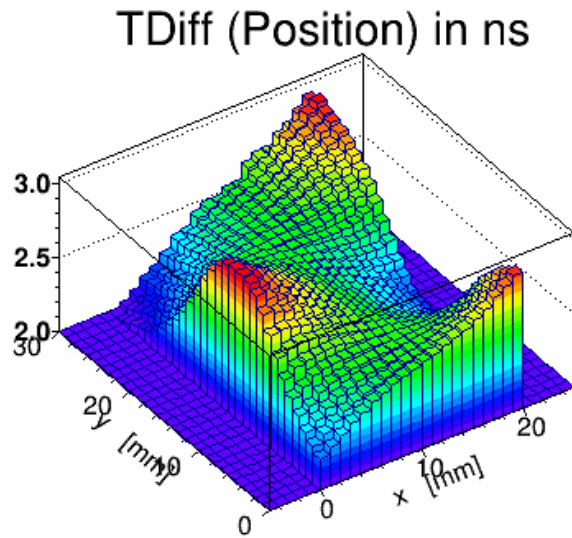




# Time Resolution of SciTil

MPPC S12652-050C  
Scintillator: BC408  
with alu wrapping

- Time difference
  - varies by almost 1 ns
  - resolution between 240 and 380 ps
- Time resolution
  - varies between 120 and 190 ps across surface
  - best resolution close to sensors



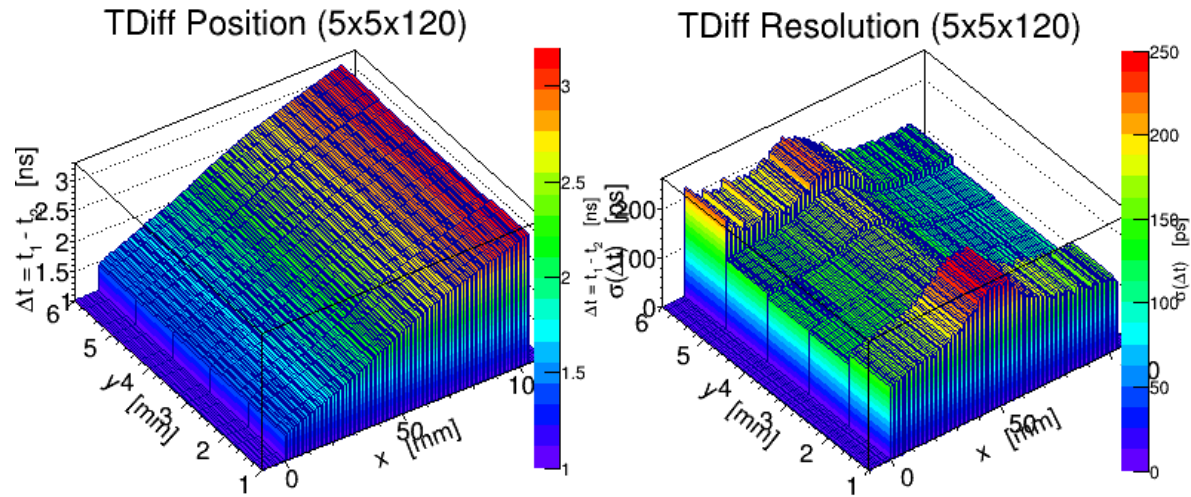


# Time Resolution of SciRods

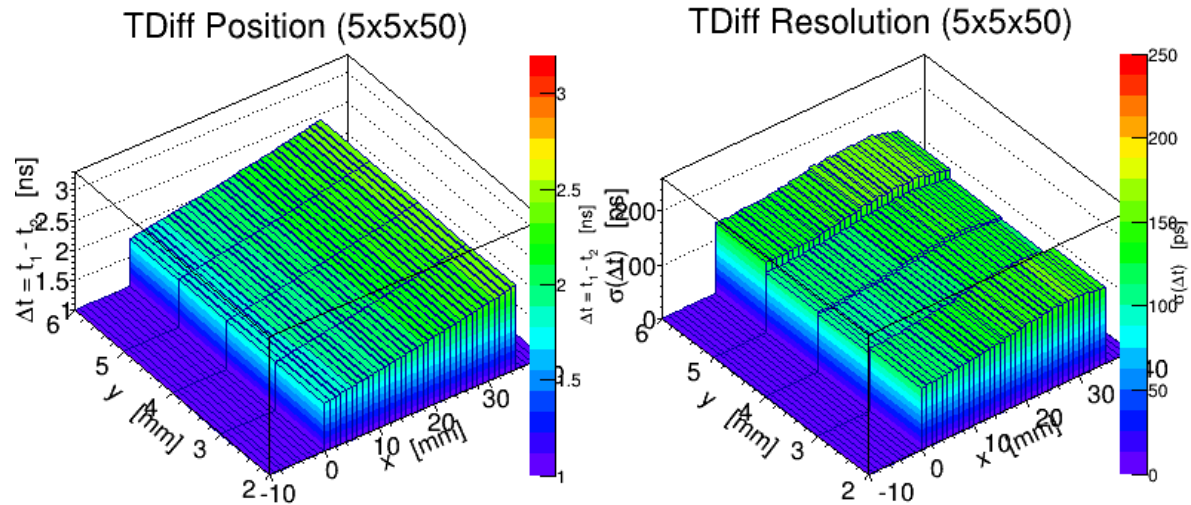
MPPC S12652-050C  
Scintillator: BC420

- Time difference
  - smooth slope
  - determine x-position !
- Time resolution
  - best resolution directly at sensors
  - little worse in rod center
  - varies from ~50 to ~75 ps and back
  - slightly better for 5x5x50 cm<sup>3</sup> SciRod

Only amplification with AD8000



Mean  $\sigma(\Delta t) = 135$  ps



Mean  $\sigma(\Delta t) = 128$  ps



# SciRod Time Difference Resolutions

Scintillator  $5 \times 5 \times 120 \text{ mm}^3$

MPPC	BC408		BC420	
	Mean $\sigma(t1-t2)$	Best $\sigma(t1-t2)$	Mean $\sigma(t1-t2)$	Best $\sigma(t1-t2)$
S10931-100P	$166 \pm 21$	120	$131 \pm 17$	98
S10931-050P	$190 \pm 15$	170	$141 \pm 18$	114
S12572-050P			$124 \pm 20$	104
S12572-015P	$202 \pm 26$	151	$169 \pm 22$	132
S12652-050C	$161 \pm 24$	125	$136 \pm 19$	101

Scintillator  $5 \times 5 \times 50 \text{ mm}^3$

MPPC	BC408		BC420	
	Mean $\sigma(t1-t2)$	Best $\sigma(t1-t2)$	Mean $\sigma(t1-t2)$	Best $\sigma(t1-t2)$
S10931-100P	$173 \pm 11$	143	$127 \pm 8$	112
S12652-050C	$165 \pm 11$	144	$123 \pm 9$	106

- Only moderate dependence on scintillator length
- Best results for BC420 scint. and S12572-050P/S12652-050C MPPC



# SciRod Time Resolutions

● Time resolution  $\sigma_t == \sigma(t1-t2) / 2$

Scintillator 5 x 5 x 120 mm<sup>3</sup>

MPPC	BC408		BC420	
	Time resol. ( $\sigma_t$ )	Best time resol.	Time resol. ( $\sigma_t$ )	Best time resol.
S10931-100P	83 ± 11	60	66 ± 9	49
S10931-050P	95 ± 8	85	71 ± 9	57
S12572-050P			62 ± 10	52
S12572-015P	101 ± 13	76	85 ± 11	66
S12652-050C	81 ± 12	63	68 ± 10	51

Scintillator 5 x 5 x 50 mm<sup>3</sup>

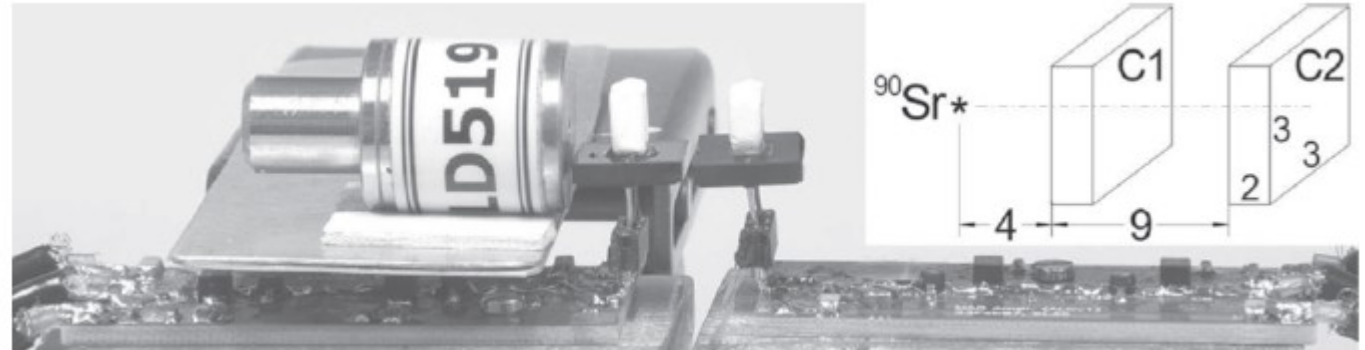
MPPC	BC408		BC420	
	Time resol. ( $\sigma_t$ )	Best time resol.	Time resol. ( $\sigma_t$ )	Best time resol.
S10931-100P	87 ± 6	72	64 ± 4	56
S12652-050C	83 ± 6	72	62 ± 5	53



# Estimation of Time Resolution

A. Stoykov, et al.; NIM A695 (2012) 202-205; “A time resolution study with a plastic scintillator read out by a Geiger-mode Avalanche Photodiode”

Setup uses 2 samples of BC422 (3 x 3 x 2 mm<sup>3</sup>) read out by Hamamatsu MPPCs 10362-33-050



Time resolution measured:

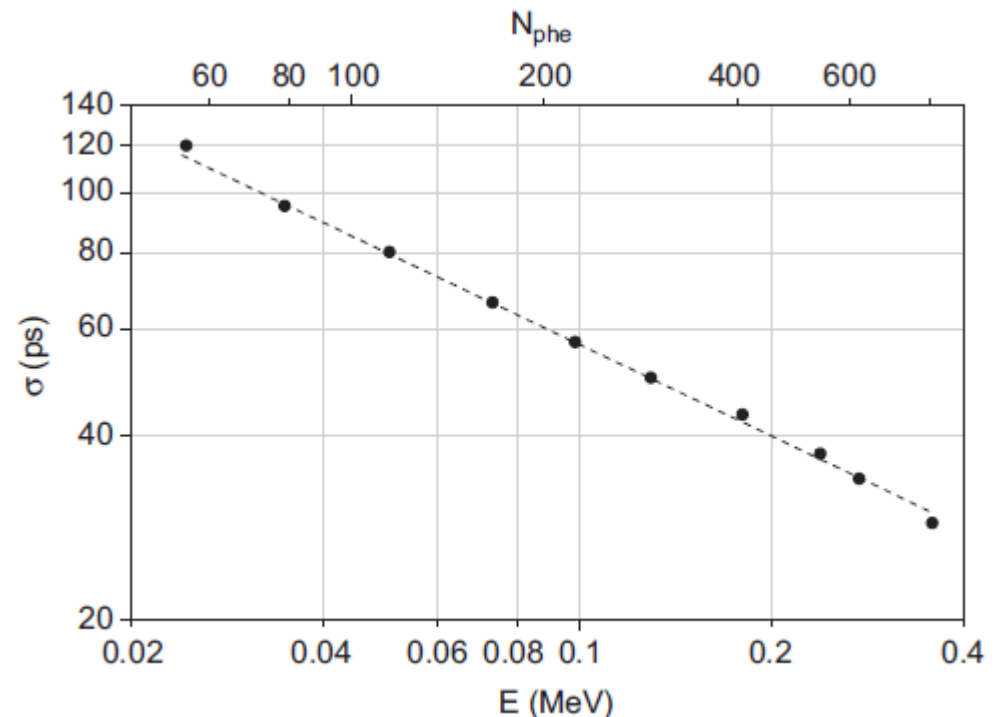
$$\sigma_t = 18 \text{ ps} \cdot \text{MeV}^{0.5}$$

This roughly corresponds to

100 ps with 80 photo electrons

70 ps with 150 photo electrons

50 ps with 300 photo electrons





# More Time Resolutions (1)

Scintillator 5 x 5 x 120 mm<sup>3</sup>

Scintillator	MPPC	left		center		right
		$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$
BC408	S10362-100P	88		94		101
	S10362-100P(x10)	71		77		74
	S12572-050P	72		77		74
BC420	S12572-015P	60		108		63
	S12572-050P	50	79	74	57	52

Scintillator 5 x 10 x 120 mm<sup>3</sup>

Scintillator	MPPC	left		center		right
		$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$
BC408	S10362-100P	88	116	132	98	93
BC420	S10362-100P	75		121		82

**BC420 scintillator provides better results than BC408**



# More Time Resolutions (2)

Scintillator 5 x 5 x 50 mm<sup>3</sup>

Scintillator	MPPC	left		center		right
		$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$
BC408	S10362-100P	68		103		74
	S12572-050P	74		67		68
BC420	S12572-050P	78		64		51

Scintillator 5 x 10 x 50 mm<sup>3</sup>

Scintillator	MPPC	left		center		right
		$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$
BC408	S10362-100P	113		123		92

Scintillator 5 x 5 x 170 mm<sup>3</sup>

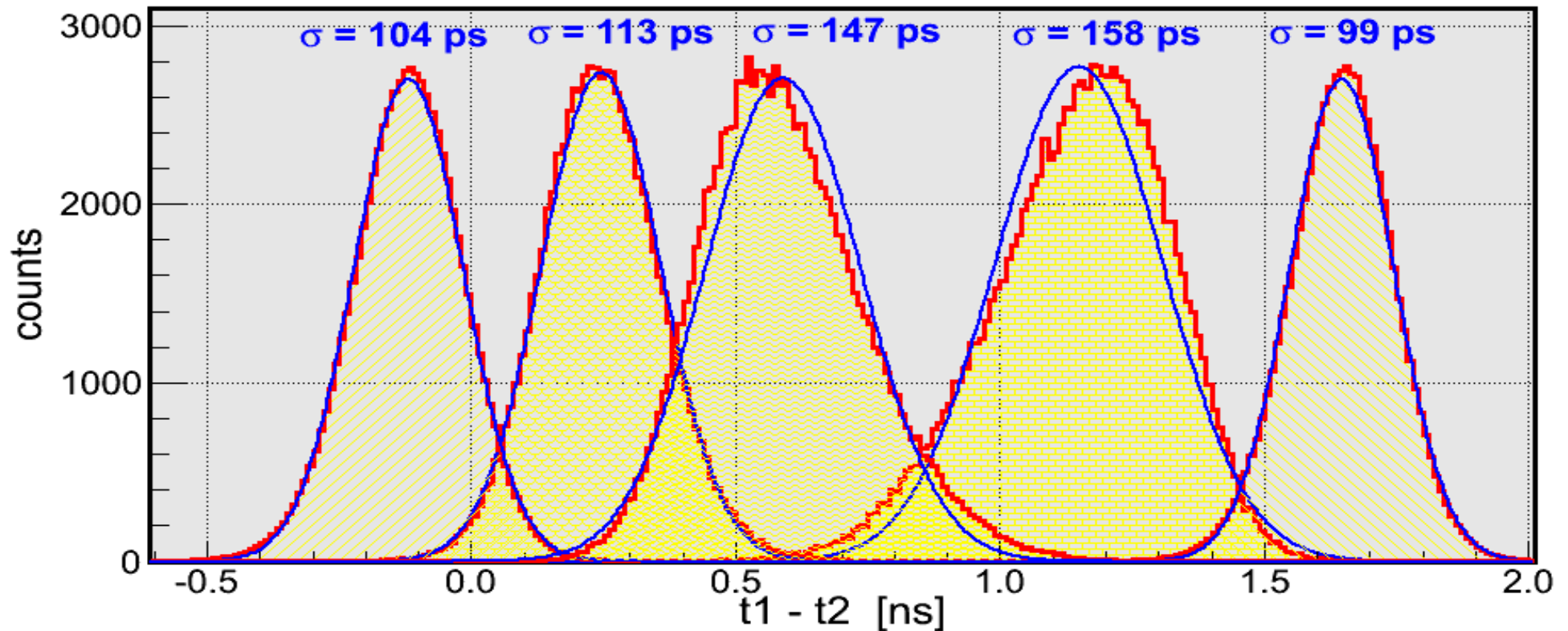
Scintillator	MPPC	left		center		right
		$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$	$\sigma_t$
BC408	S10362-100P	88	85	129	85	99

**Longer and wider rods tend to give worse time resolution**



# Position Resolution

MPPC S12572-33-050P (t1 - t2) uncorrected of BC420 5x5x120 mm<sup>3</sup>



● Position resolution with  $\sigma(t1-t2) = 100$  ps:

$$\Delta x(\text{FWHM}) = 100 \text{ mm} * 235 \text{ ps} / 1770 \text{ ps} = 13 \text{ mm}$$



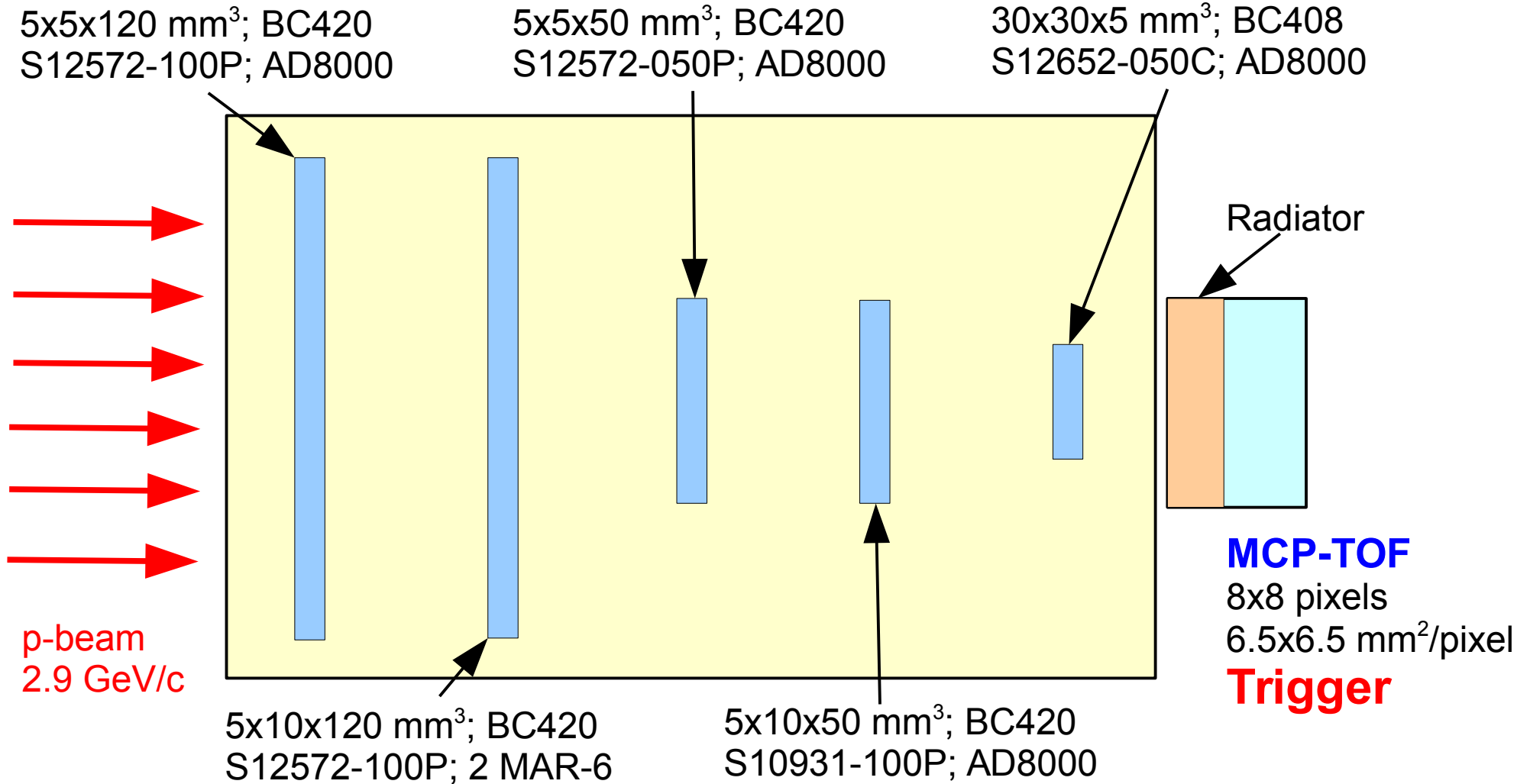


# SciRod Test at Julich Proton Beam

- SciTil/SciRod time resolution tests at 2.9 GeV/c COSY proton beam
  - 27 Jan – 3 Feb 2014
- 5 scintillator/SiPM configurations measured simultaneously [enclosed in aluminium box]
  - 5x5x120 mm<sup>3</sup> BC420; MPPC S12572-100P; AD8000
  - 5x10x120 mm<sup>3</sup> BC420; MPPC S12572-100P; 2 MAR-6
  - 5x5x50 mm<sup>3</sup> BC420; MPPC S12572-050P; AD8000
  - 5x10x50 mm<sup>3</sup> BC420; MPPC S10931-100P; AD8000 [did not work]
  - 30x30x5 mm<sup>3</sup> BC408; MPPC S12652-050C; AD8000
- Rough tracking with 8x8 pixel MCP-TOF behind alubox
- TRBv3 data acquisition with PADIWA boards (10x amplifier)
- Several threshold scans of time differences (resolutions) done

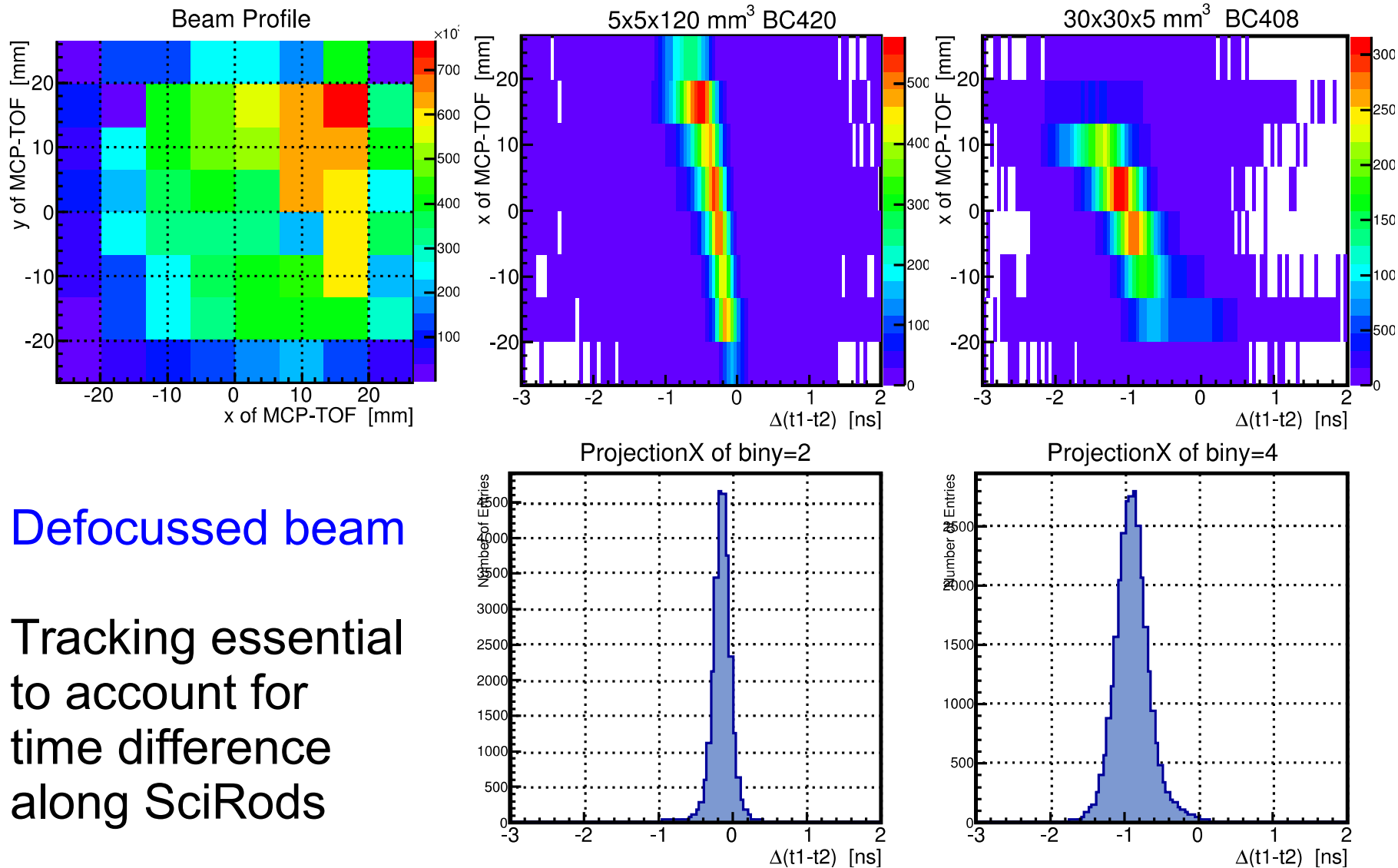


# Setup in Julich





# Tracking with MCP-TOF



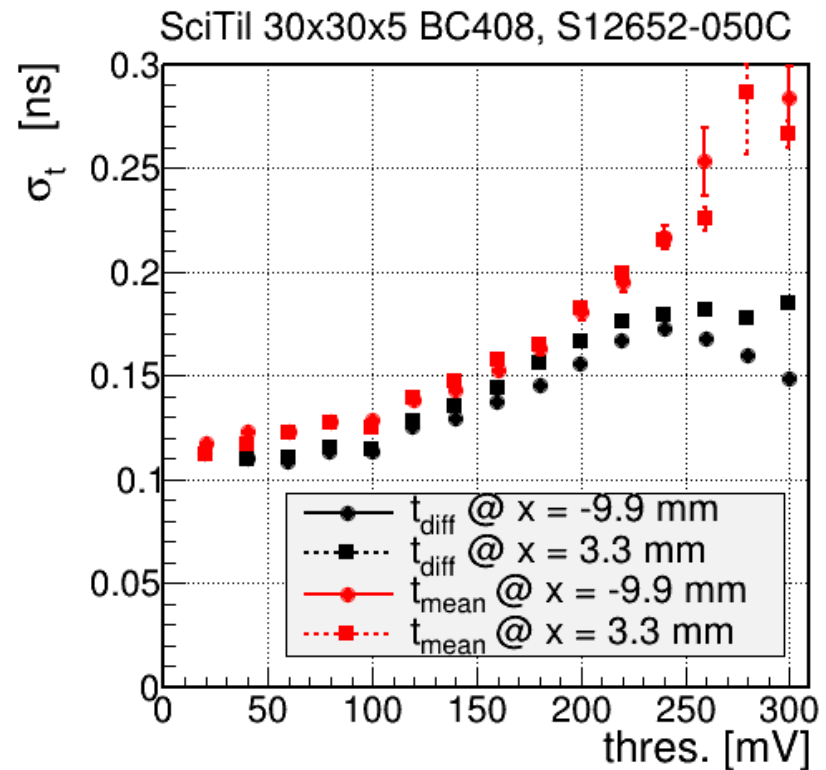
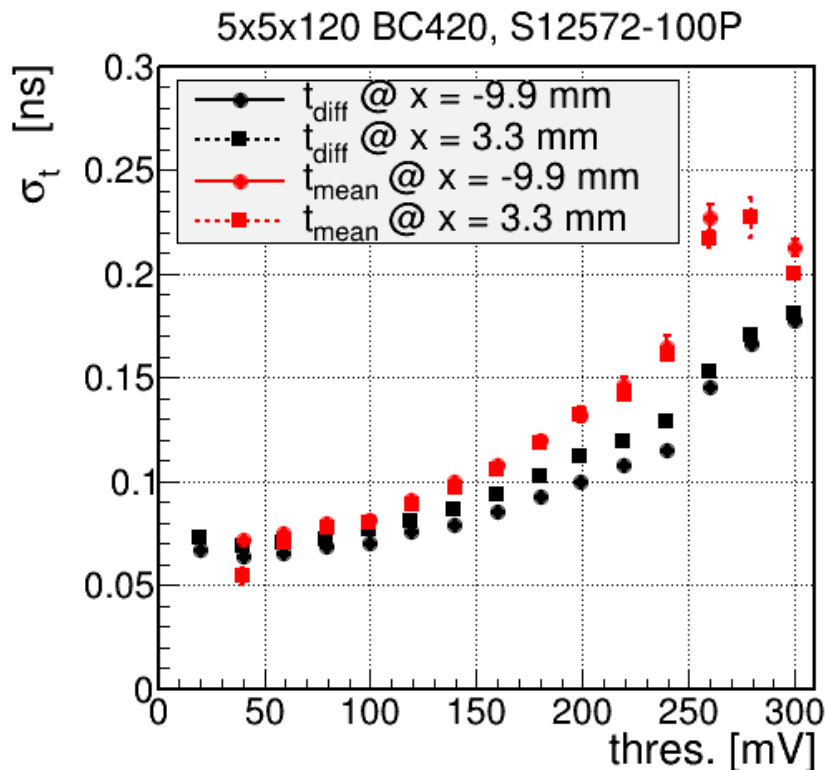
Defocussed beam

Tracking essential  
to account for  
time difference  
along SciRods

# Time Resolutions with Proton Beam

$t_{diff}$ : time resolution from time difference of 2 opposite MPPCs at 1 SciRod  
 $t_{mean}$ : time resolution determined with 3 SciRods

SciRod BC420  
MPPC S12572-100P



SciTil BC408  
MPPC S12652-050C

- Time resolution of SciRod better than SciTil (but BC408)
- Best time resolution at low thresholds (**60-70 ps**)



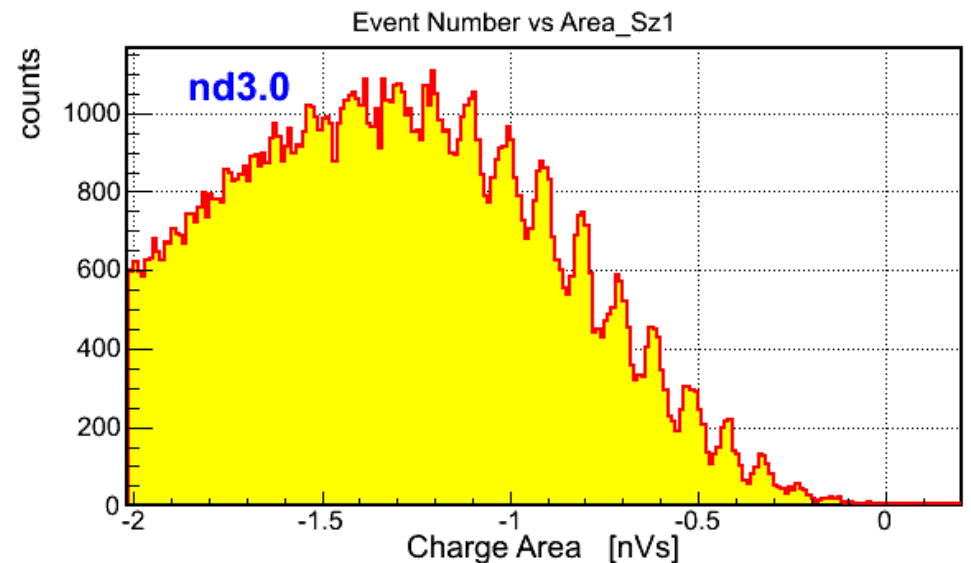
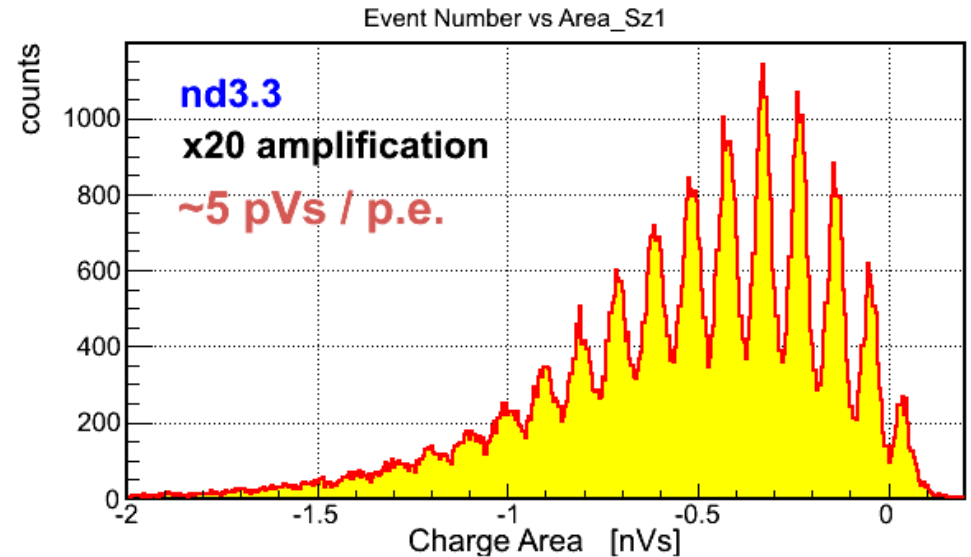
# Summary and Outlook

- Various sizes of SciRods/SciTils and different MPPCs tested
- Tests with SciRods show very promising results
  - Uniformity of collected photons and time resolution much better for SciRods than for SciTils
  - time resolution  $\sigma_t$  varies between 50 and 100 ps
    - **Dependent upon size (length, width) of SciRod**
    - better than SciTils because of more collected photons
    - position resolution (FWHM) down to 13 mm
- Time resolutions obtained with proton beam and TRBv3 DAQ are consistent with those measured with  $^{90}\text{Sr}$  source
- Outlook:
  - Tests of 120x30x5 mm<sup>3</sup> SciRods read out by 4 MPPCs at each side
  - Tests with Ketek SiPMs



# Pulse Height Calibration

- Calibration was done with pulsed laser light (372 nm) on MPPCs (also possible with darkcount)
- Whole charge scale calibrated by using different ND filters
  - S10362-33-100P at  $V_{op} = 72.5$  V
  - AD8000 + PS775 (x20) amplifiers
- Each peak corresponds to one photon:
  - ~5 pVs / p.e.
  - charge scale linear up to several hundred photo electrons
  - tested with different ND filters (nd3.3 to nd2.0)





# Time Resolution with Laser

- laser light (372 nm) into center of  $5 \times 10 \times 50 \text{ mm}^3$  BC408 scintillator
- -1 nVs corresponds to  $\sim 200$  Npe
  - expected for minimum ionising particle
  - $\sigma_{\Delta t} \approx 70\text{-}130 \text{ ps}$

