Scintillation Tile Hodoscope for the PANDA Barrel Time-Of-Flight Detector

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on behalf of the PANDA/Barrel-TOF(SciTil) group

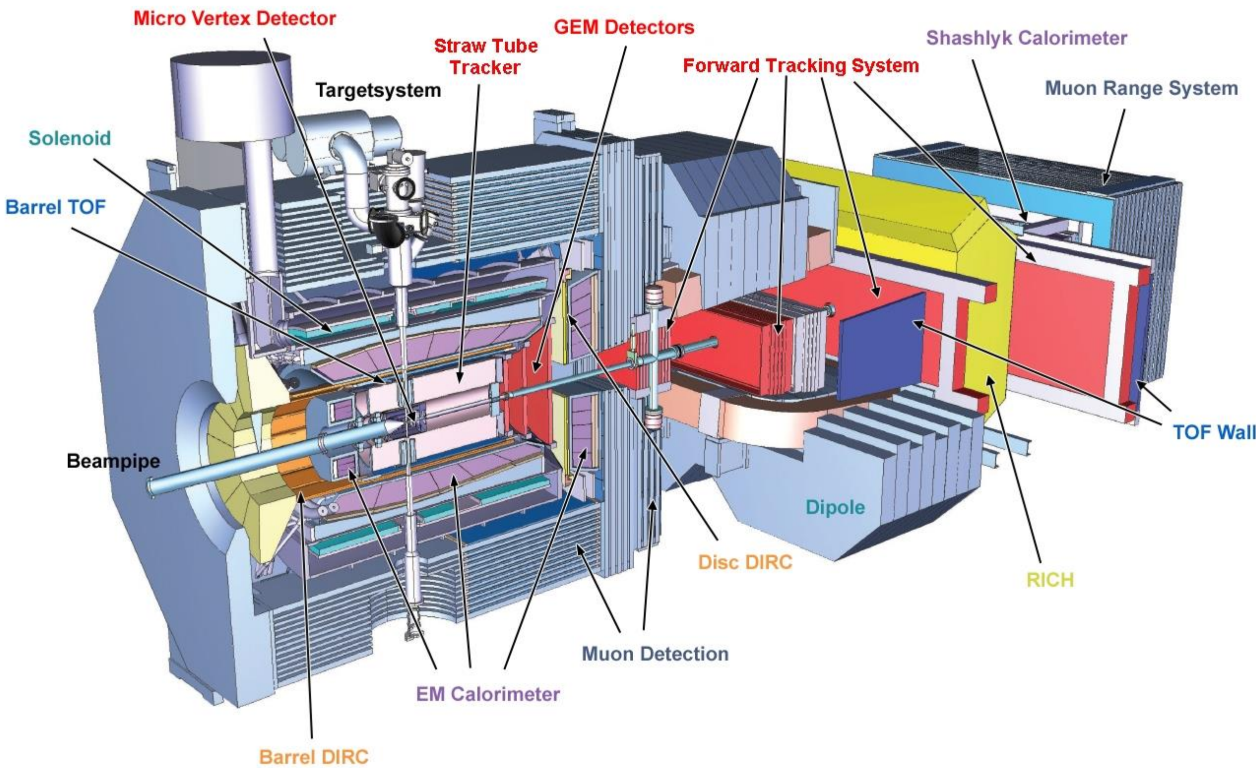
12.06.2018, ICASiPM2018

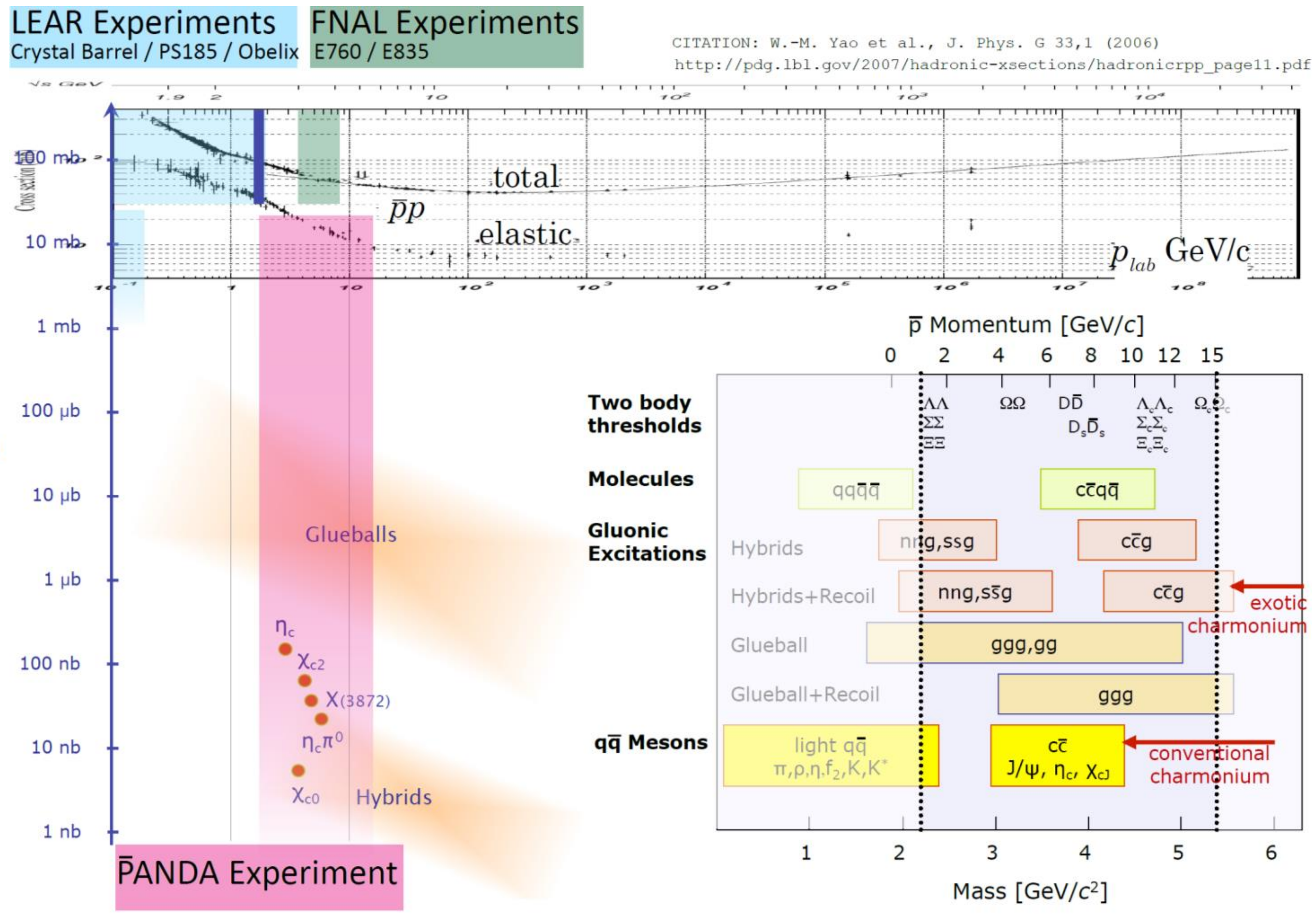
Outline

- Introduction: PANDA & FAIR
- Barrel TOF Design
- Single Tile Performance
- Larger Scale Integration

Tomorrow 11.45: Application of SiPMs and MCP-PMTs in the PANDA PID detectors - Albert Lehmann (Erlangen University)

PANDA Experiment at FAIR





MVD<STT<B-DIRC<B-TOF<EMC

Installation planned end-2021, with physics starting 2025

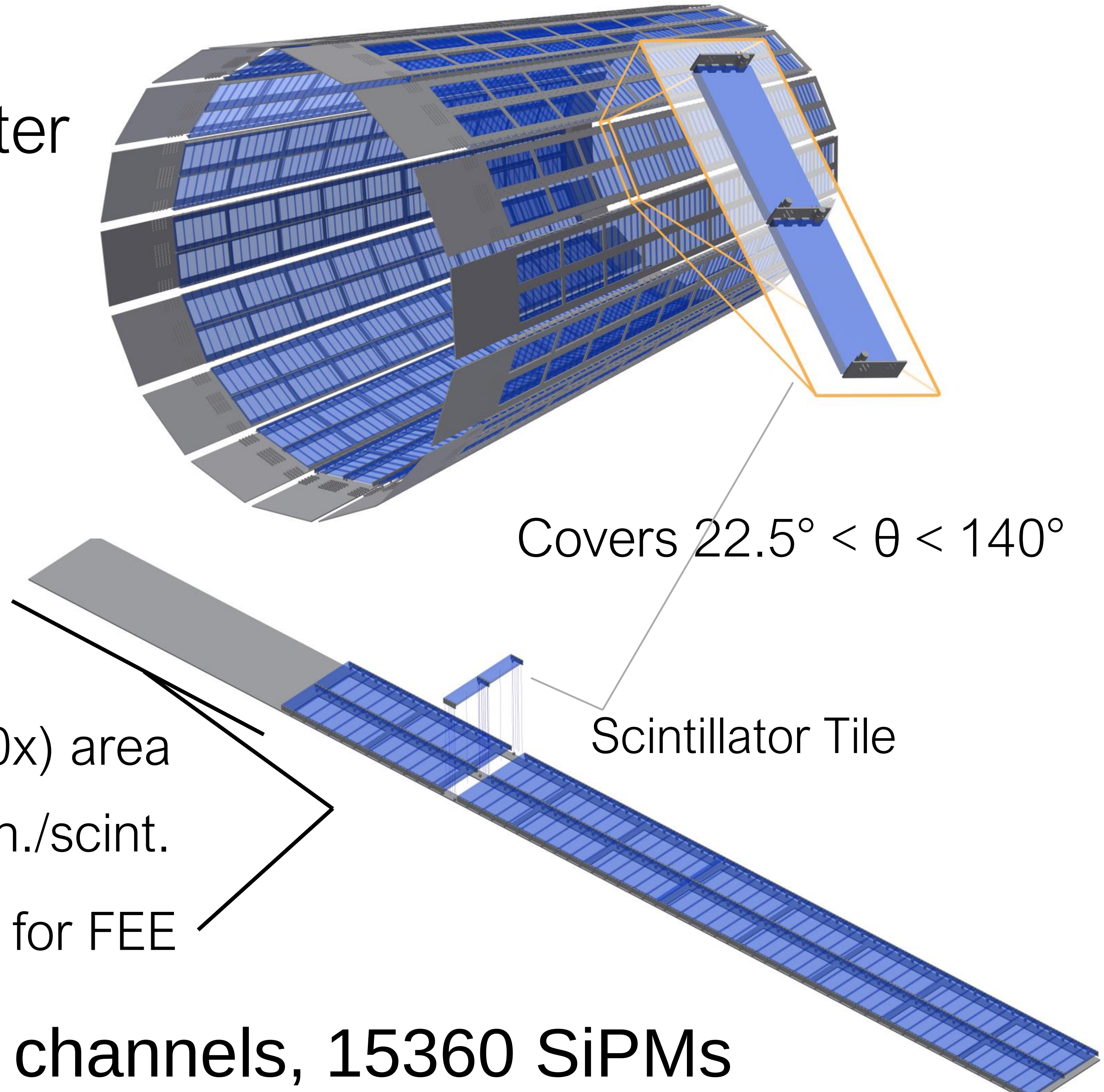
Barrel Time-of-Flight (TOF) Design

2.46m long, 1m diameter

16 Super modules

240 ch. /SM

max. 40 kHz /ch.



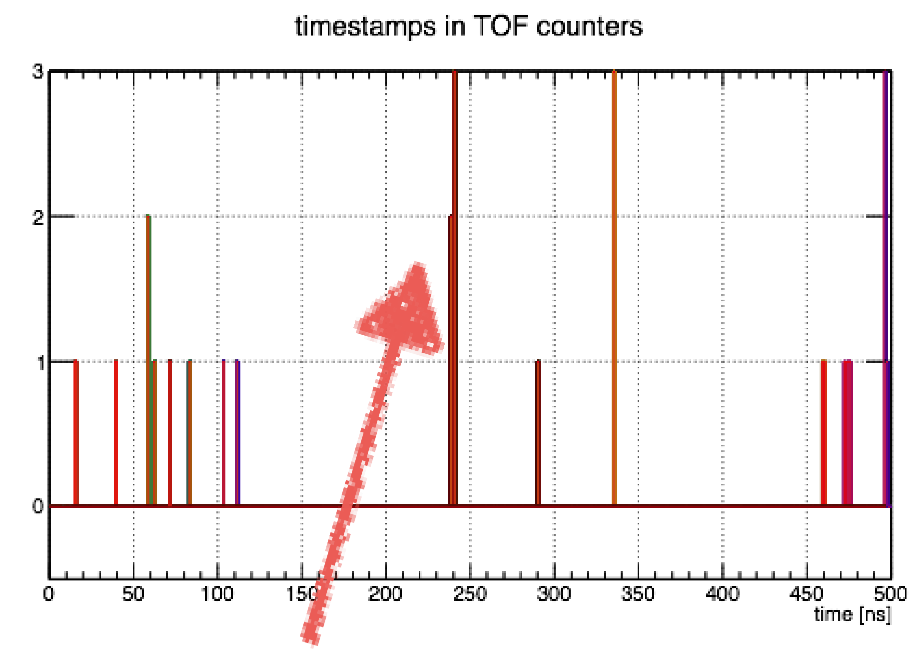
180x18 cm^2 scintillators (120x) area

2 ch./scint.

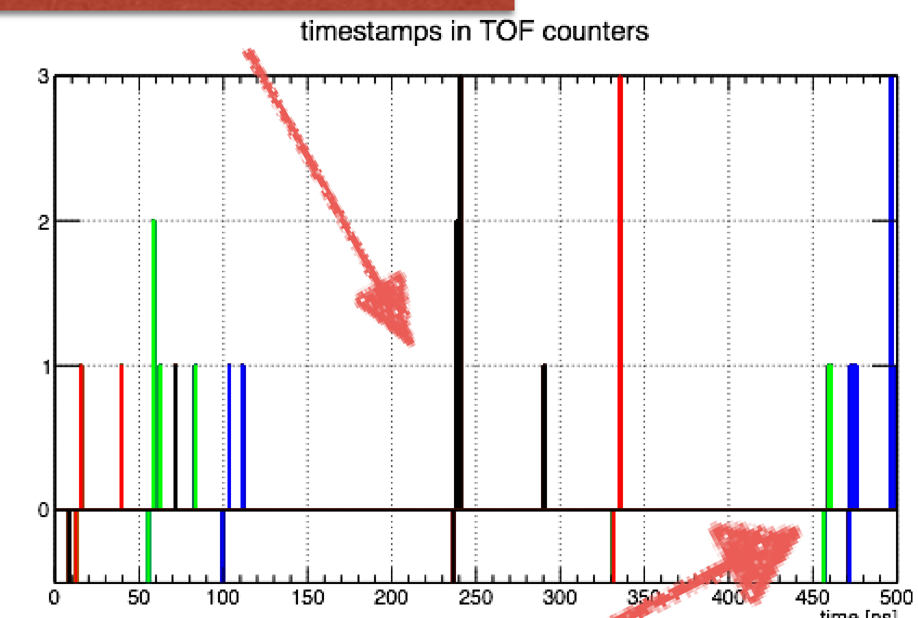
rest is left for FEE

Total: 1920 tiles, 3840 channels, 15360 SiPMs

Capabilities and Requirements

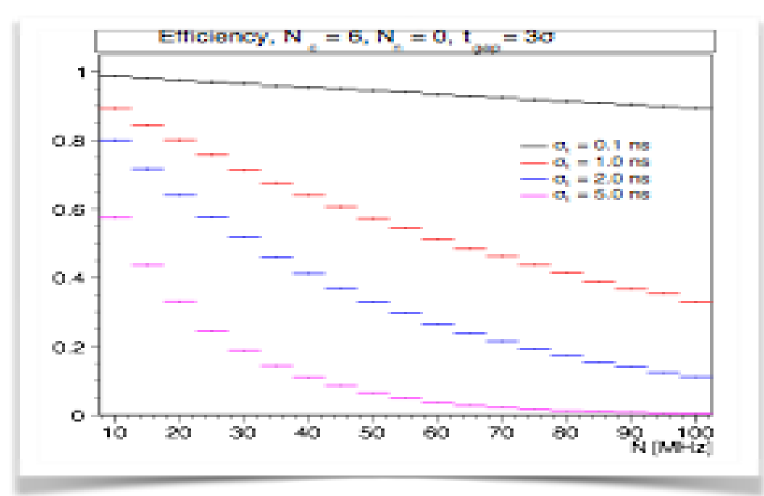


“hits” in detector



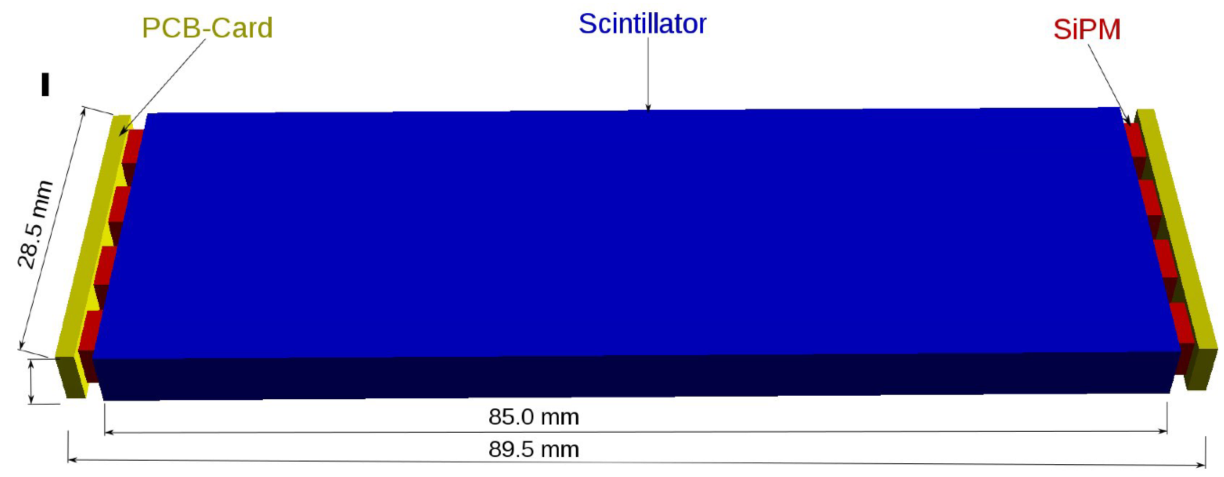
collisions

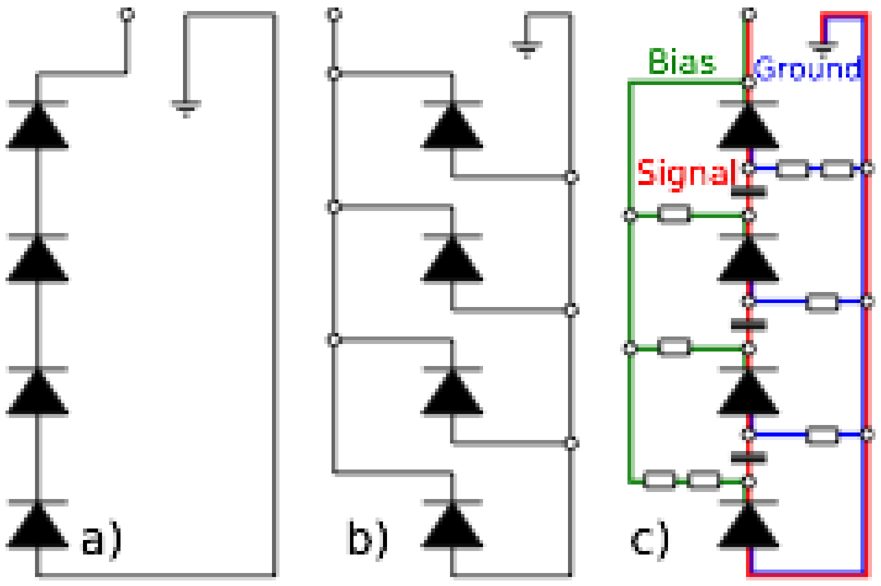
- Collision time determination
- event sorting
    - 20 MHz interaction rate
- particle identification (PID)

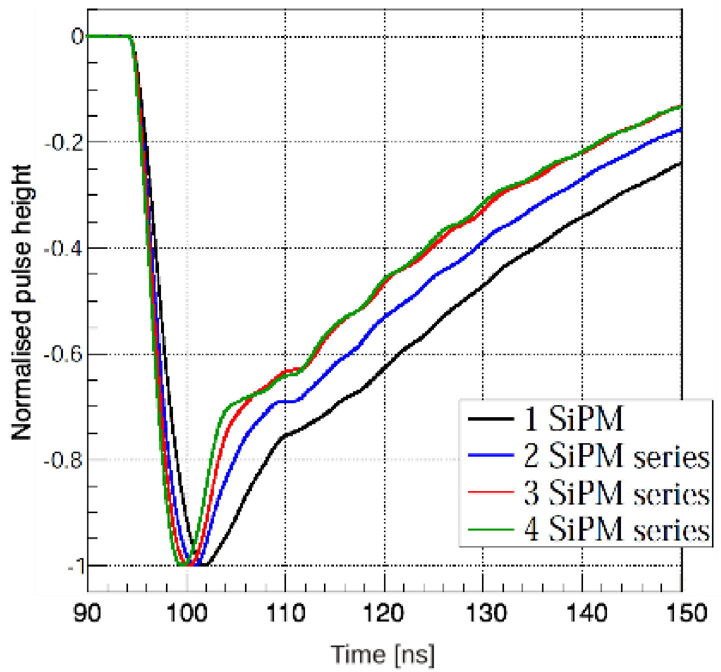


Requirement: σ_t<100 ps
to keep the efficiency loss due to event mixing in a tolerable level

Single Tile Design



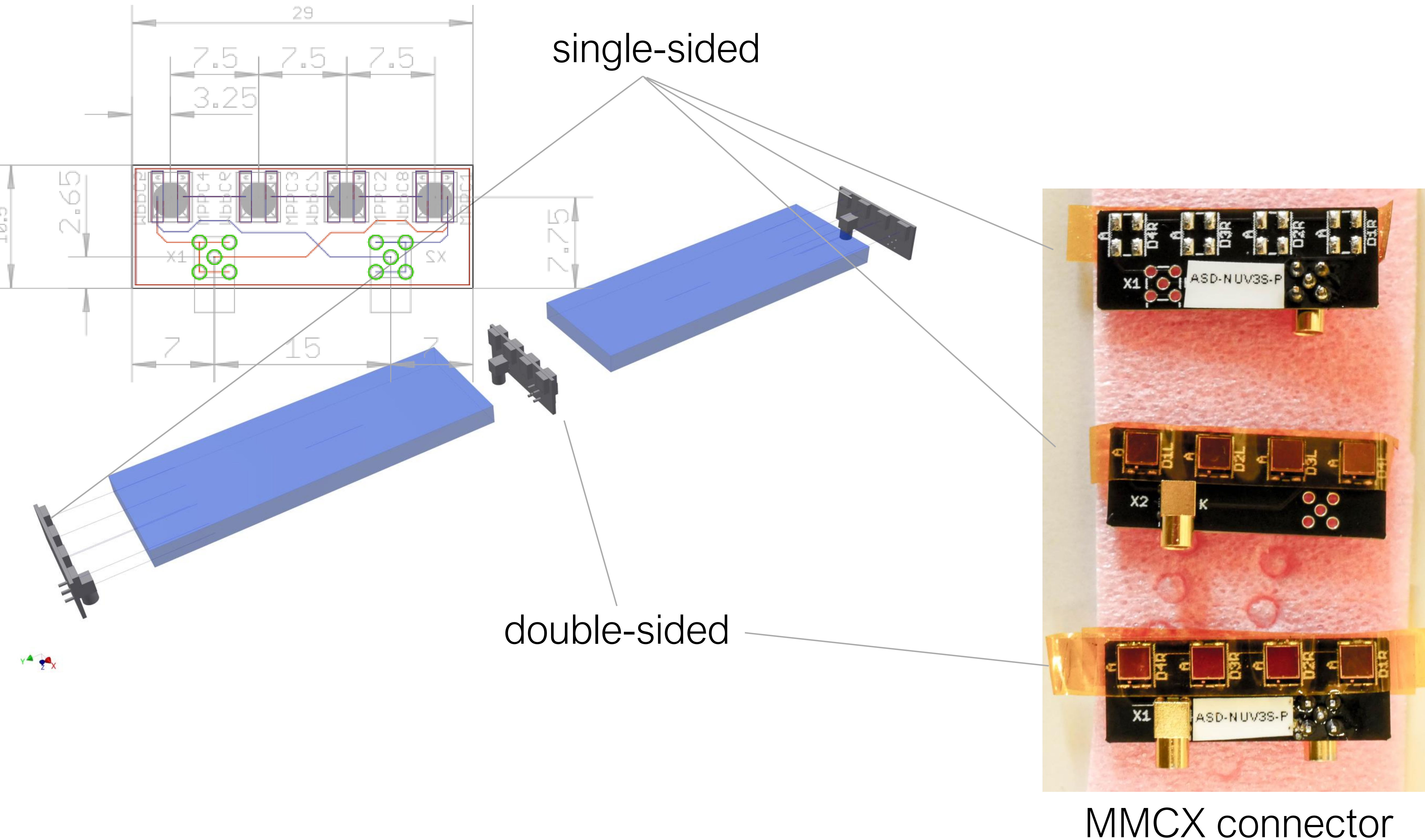




	Sensitive area	Bias Voltage	Signal shape	Gain	V_{BD} adjustment
Single	1	V_{br}+OV	-	1	-
Series	N	N×(V_{br}+OV)	faster	1/C	Yes
Parallel	N	V_{br}+OV	slower	C	No
Hybrid	N	V_{br}+OV	faster	1/C	No

Table 4.1: Comparison of series, parallel and hybrid connections of N SiPMs with reference of a single sensor.

Dual Module


single-sided
double-sided
MMCX connector
29
7.5
7.5
7.5
3.25
2.65
7.75
7
15
X1
X2
ASD-NUV3S-P
ASD-NUV3S-P

Performance - single tile

- Optimization of time-resolution

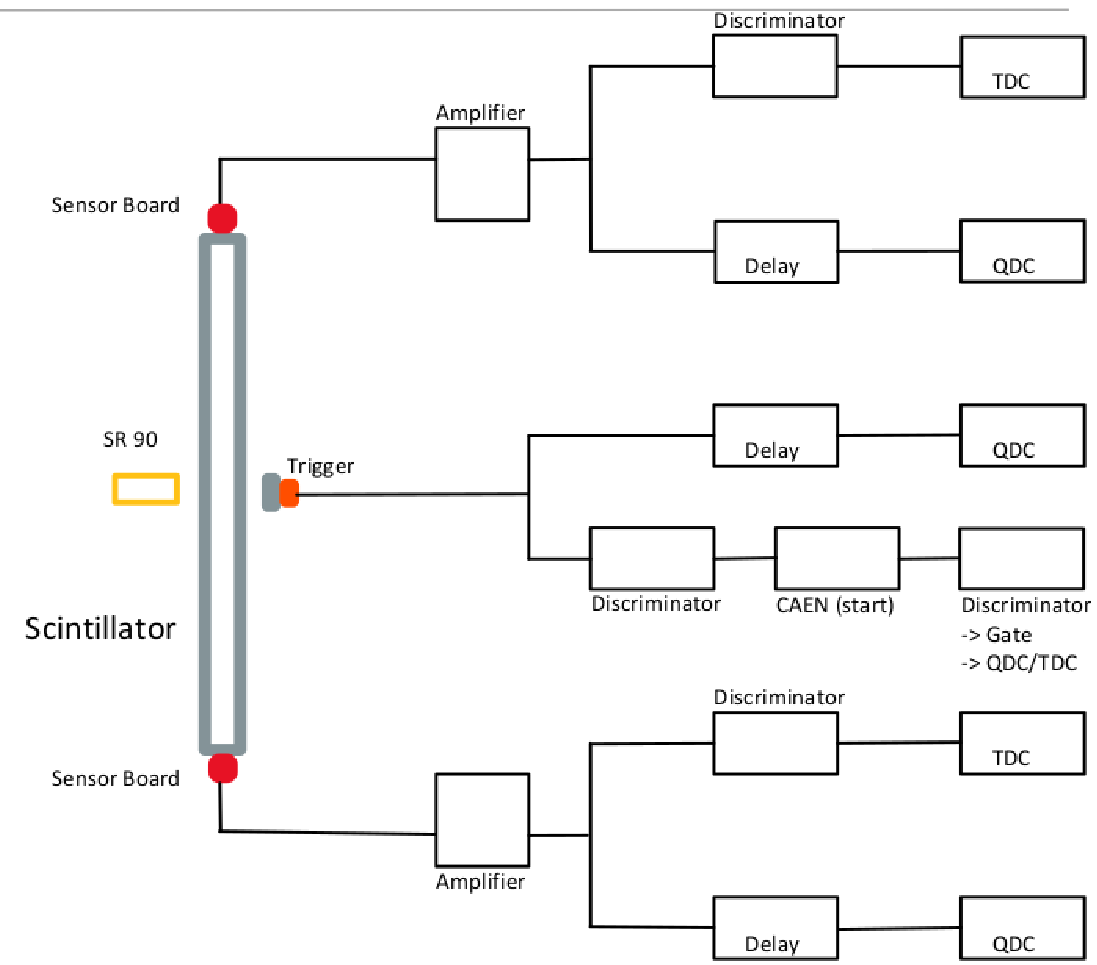
in terms of material, wrapping,

threshold, overvoltage

Wrapping material	Time resolution [ps]	Number of detected photons
No wrapping	55.0 ± 0.3	288 ± 2
Aluminised Mylar foil	52.7 ± 0.3	355 ± 2
Tyvek hardstructure 1057D	55.0 ± 0.3	394 ± 3
Enhanced specular reflector (ESR)	55.2 ± 0.3	355 ± 3
Teflon tape	59.4 ± 0.3	408 ± 4
aluminium foil	54.2 ± 0.3	344 ± 3

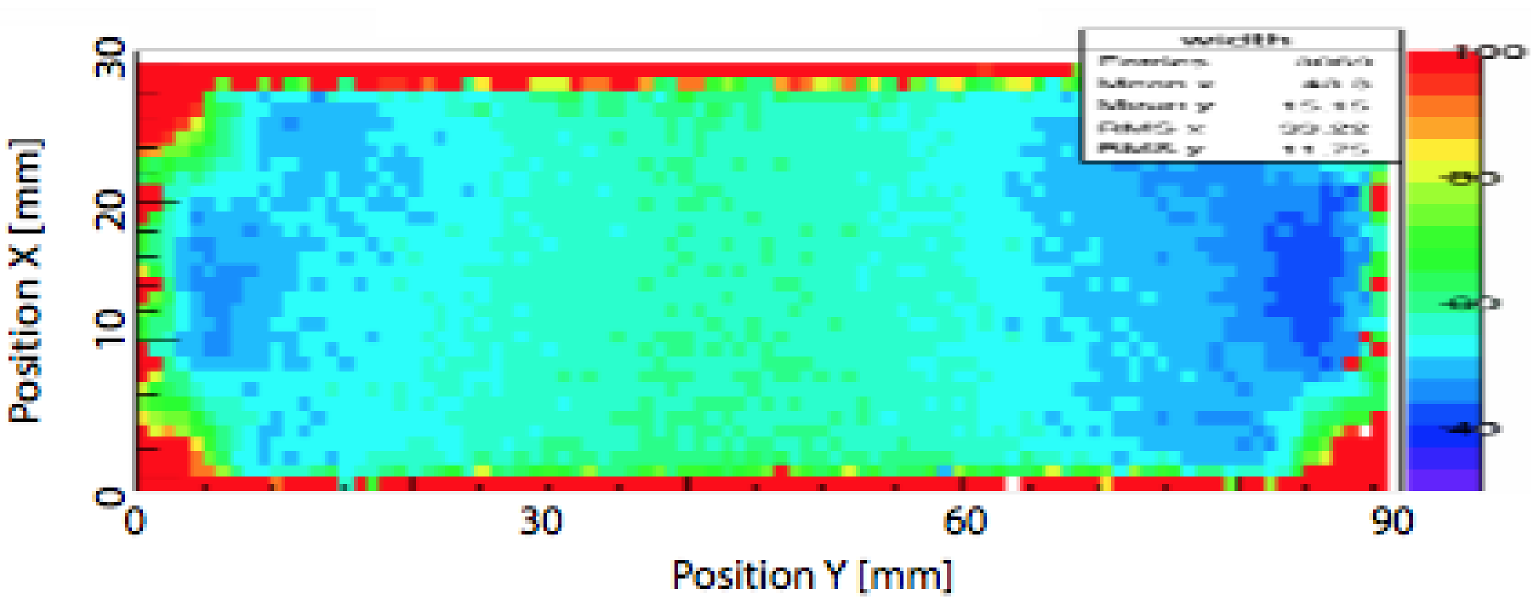
Wrapping material	Time resolution [ps]	Number of detected photons
No wrapping	61.3 ± 0.3	371 ± 2
Aluminised Mylar foil	59.7 ± 0.3	445 ± 3

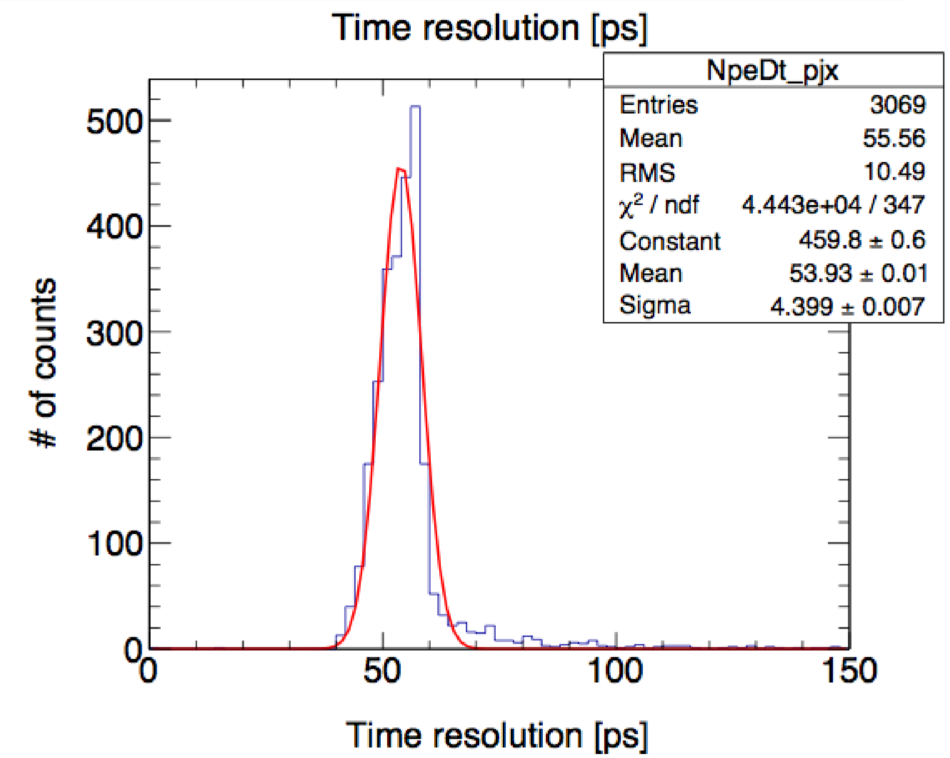
Very fine position dependence measurement of the performance with the optimised condition with well collimated ^{90}Sr source

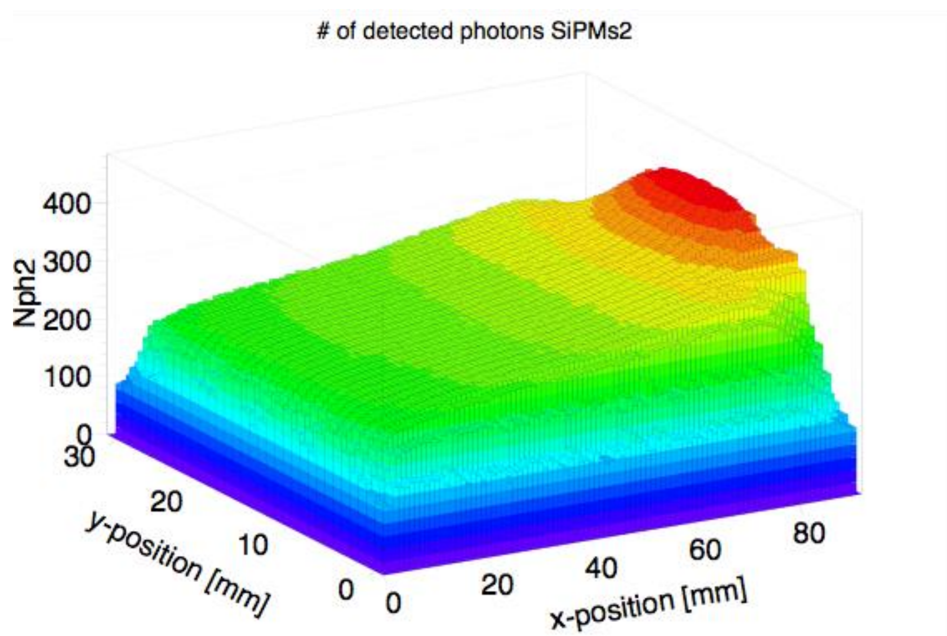


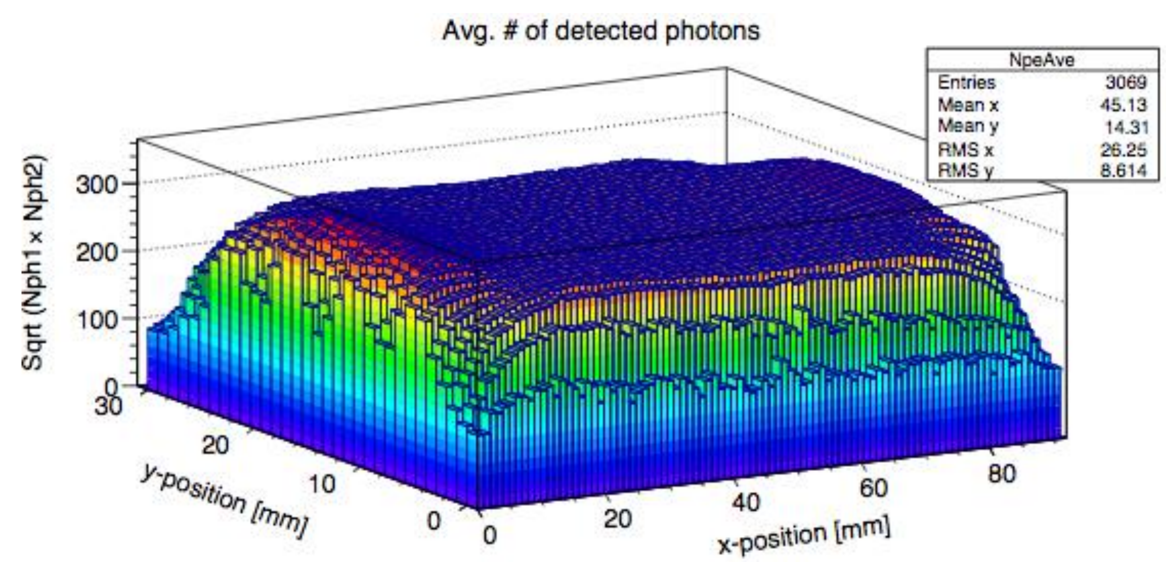
In collaboration with Erlangen

Performance - single tile









HV 240V, threshold -30 mV, 2000 events/position, 3069 positions

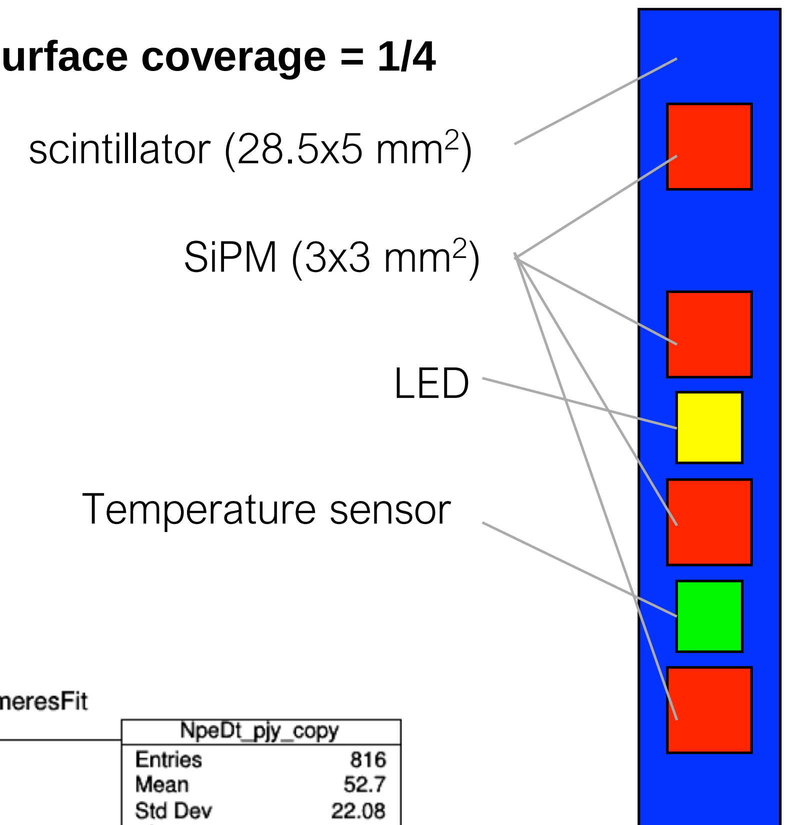
Mean time resolution σ = 53.9 ps

Performance – single Tile

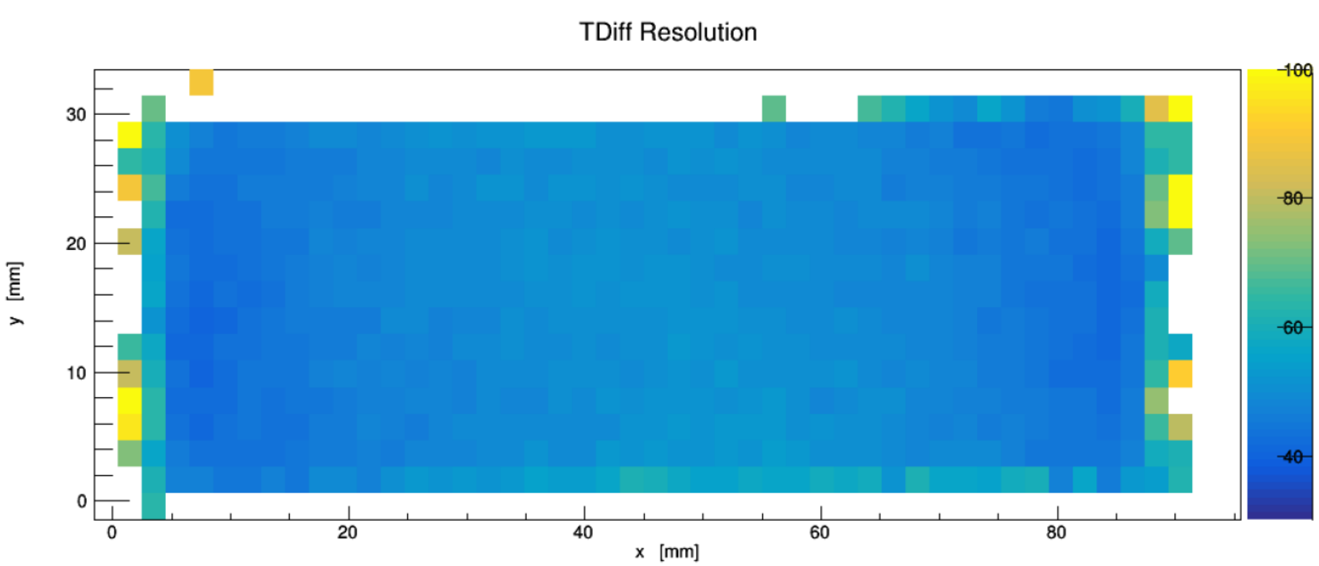
thickness		Npe1	Npe2	time-resolution (ps)
3mm		72.37	46.84	60.34
4mm		85.64	55.14	68.09
5mm		139.94	128.69	50.14
5mm polished		111.87	78.1	48.29
6mm		101.7	70.7	48.7

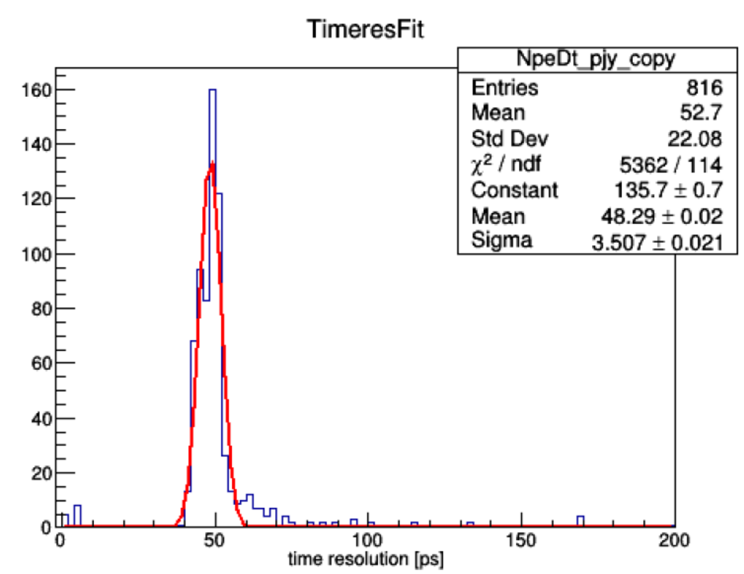
Side view of the Sensorboard

Surface coverage = 1/4

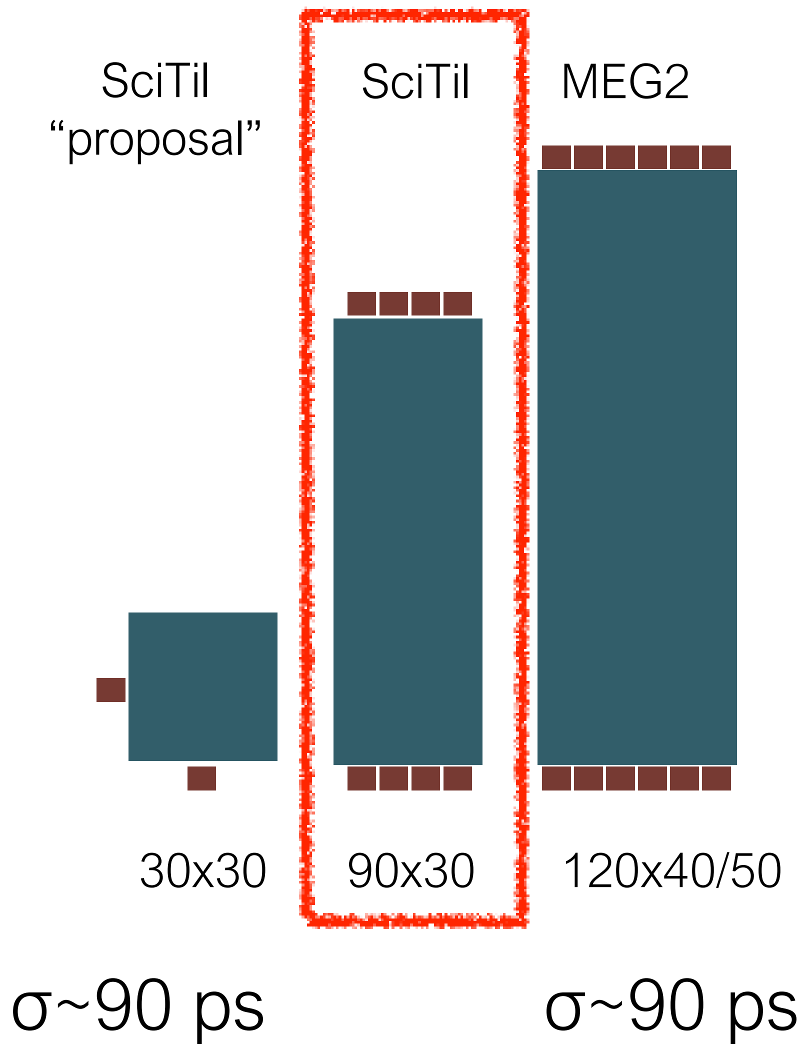


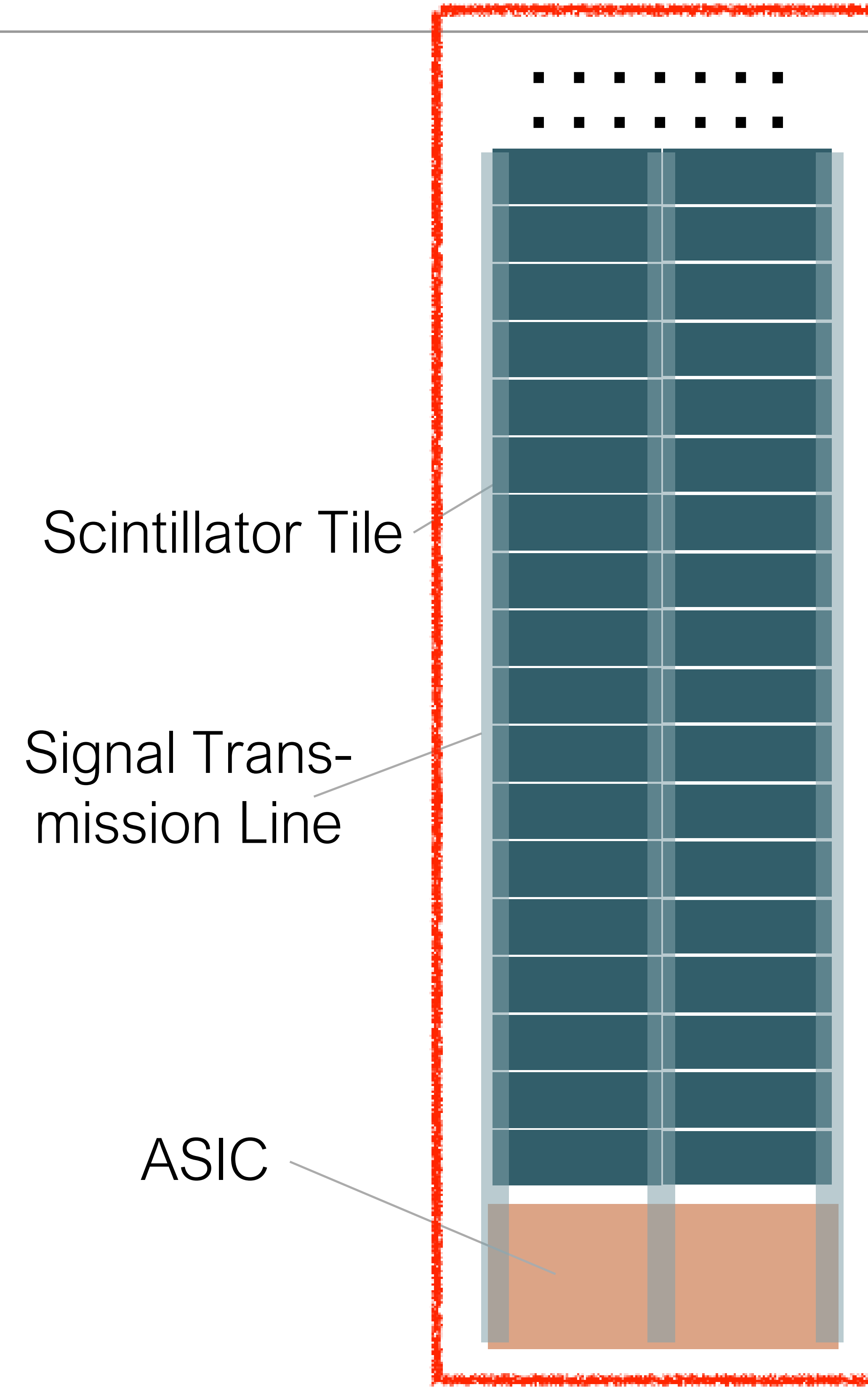
Run 47 / 5 mm polished





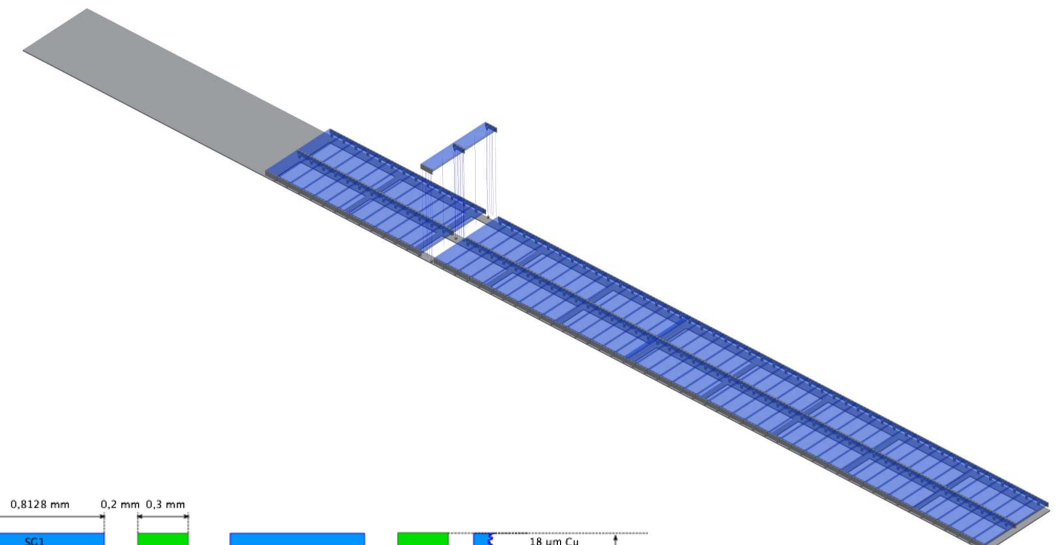
Barrel Timing Hodoscope, New Design





Micro Stripline Technique

- Coaxial-like structure to transmit signals over a PCB board, realised on a multilayer PCB board, that feature:
  - High density
  - Good shielding from external noise
  - High bandwidth
  - Low crosstalk
  - Mechanical strength

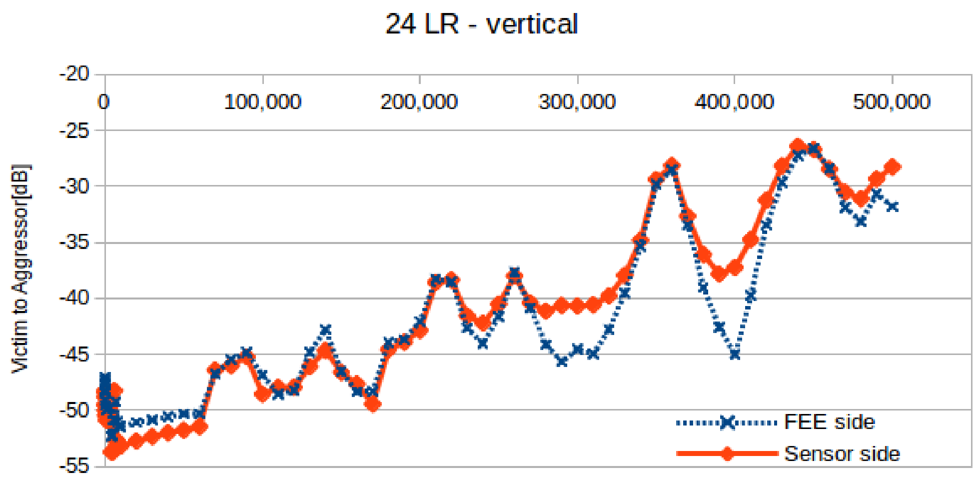


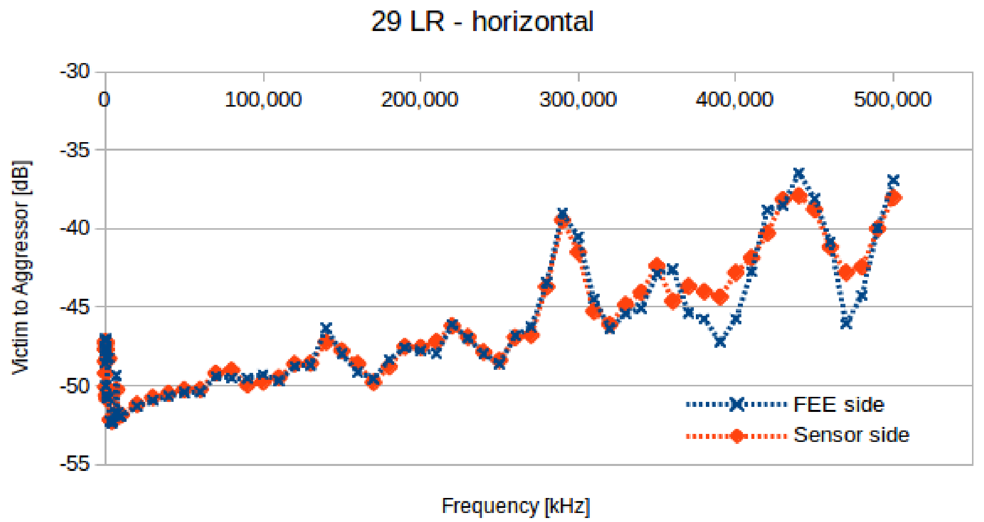
sidecut

First prototype

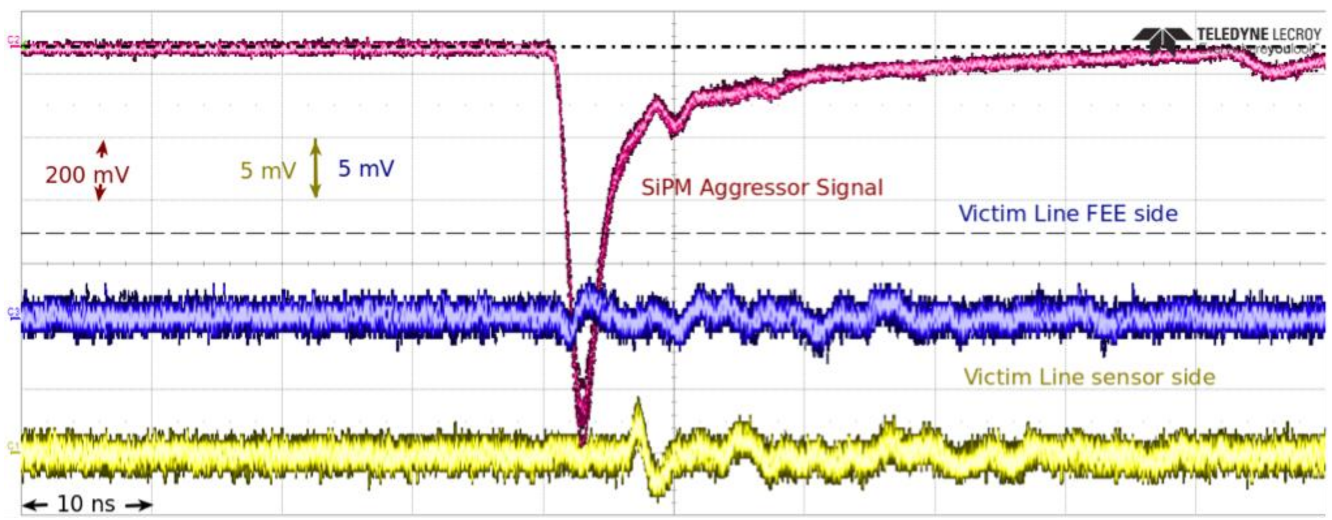
2 GND per line

Crosstalk between the Micro Striplines (Prototype n°1)





1ns rise-time = 350 MHz



Tested in realistic condition.

Crosstalks can be reduced e.g. by using “via” and/or by optimizing the channel sequence

Probable Best Design

single ground layer interconnected at the board ends

lines shuffled to minimize the distance they share as direct neighbour

design not tested yet, due to considerable manufacture delay. Delivered last week.

This design = crosstalk reduction? Less copper as prototype 1 = material budget reduction.

due to some spare space on the railboard and no extra cost, few other designs were added and will be tested for comparison

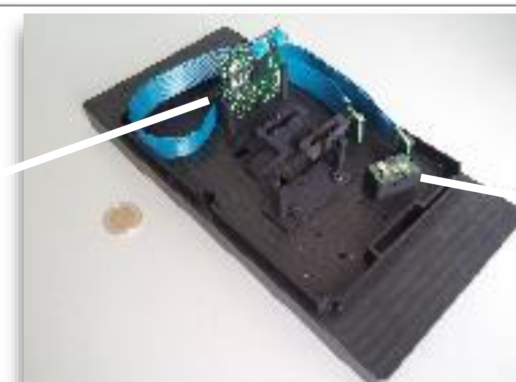
Front End Electronics

66cm allocated for FEE

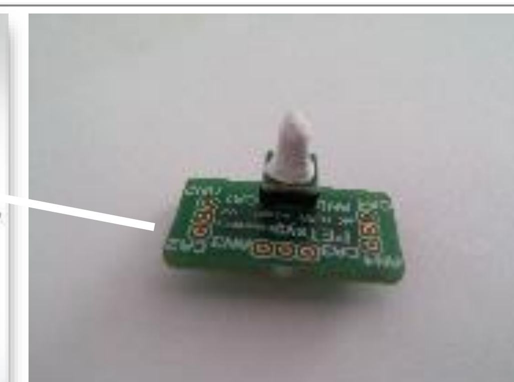
TOFPET2 ASIC readout

- Signal amplification and discrimination for each of 64 independent channels.
- Dual branch quad-buffered analogue interpolation TDCs for each channel.
- Quad-buffered charge integration for each channel.
- Dynamic range: 1500 pC.
- TDC time binning: 30 ps
- Gain adjustment per channel: 1, 1/2, 1/4, 1/8.
- SiPM family supported: positive or negative signal polarity
- Max channel hit rate: 480 kHz.
- Configurable timing, trigger and ToT thresholds.
- Fully digital output.
- Max output data rate: 2.6 Gb/s.

TOFPET2 ASIC test board (64ch)



Test assembly with SiPM and ASIC board



SiPM + LYSO crystal

Summary

- Barrel Time-of-Flight Detector for PANDA
  - 240cm long, 5m^2 sensitive area, 15.360 SiPM, 2.000 Tiles, 4.000 channels
  - series connection of 4 SiPMs
  - Cable-less design with transmission lines over PCB board
  - σ_t~50 ps, lab test. Beam test, see talk Albert Lehman (tomorrow 11:45)
  - Detector installation ~ 2022

Backup

Performance - single tile

Time resolution depend of Pole Zero Cancelation

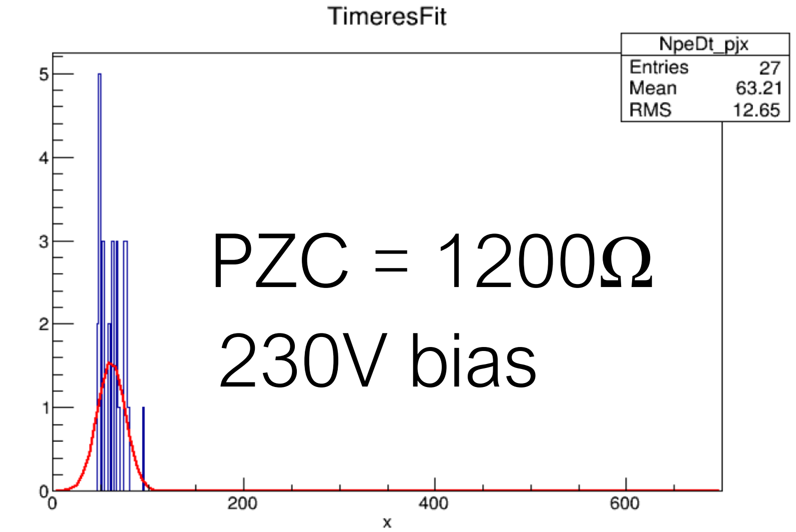
Reproduced in 2017: 63.2ps for 1200Ω
and 53.4ps for 500Ω

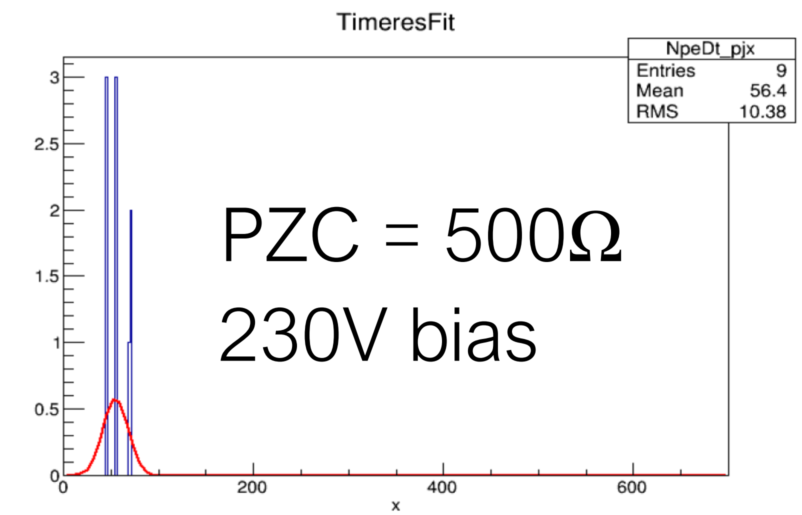
Bias voltage also has slight impact on time resolution

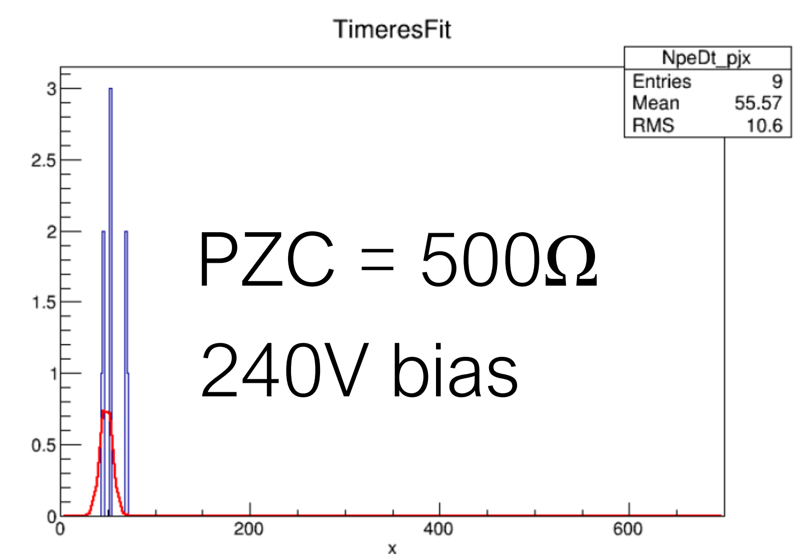
Threshold scan:

11.3mV : 49,7 +/- 1,9 ps
20mV : 47.0 +/- 2.8 ps
40mV : 48.3 +/- 3.4 ps
50mV : 50.3 +/- 5.0 ps
75mV : 50.3 +/- 3.4 ps

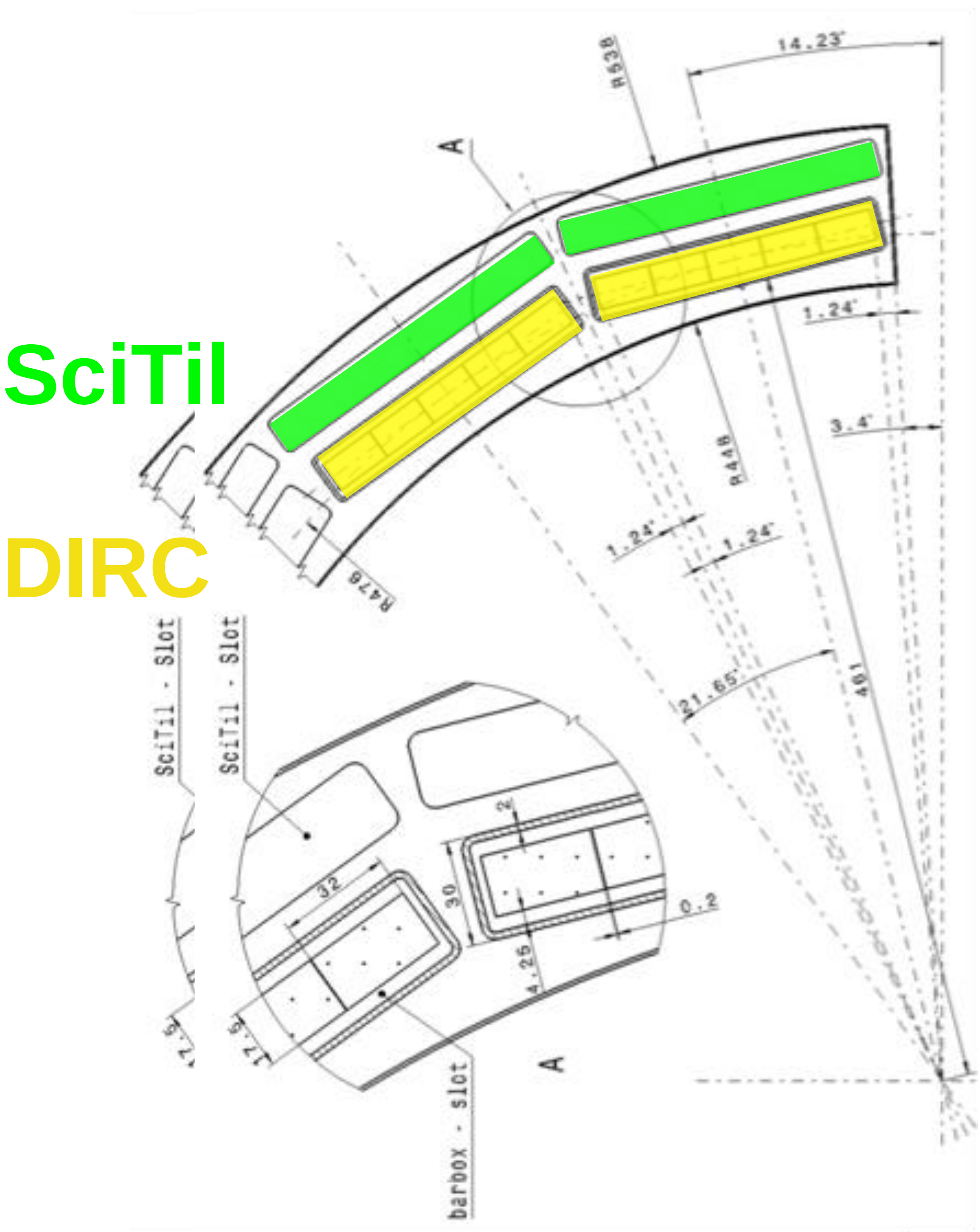
Best time-resolution for 20mV threshold



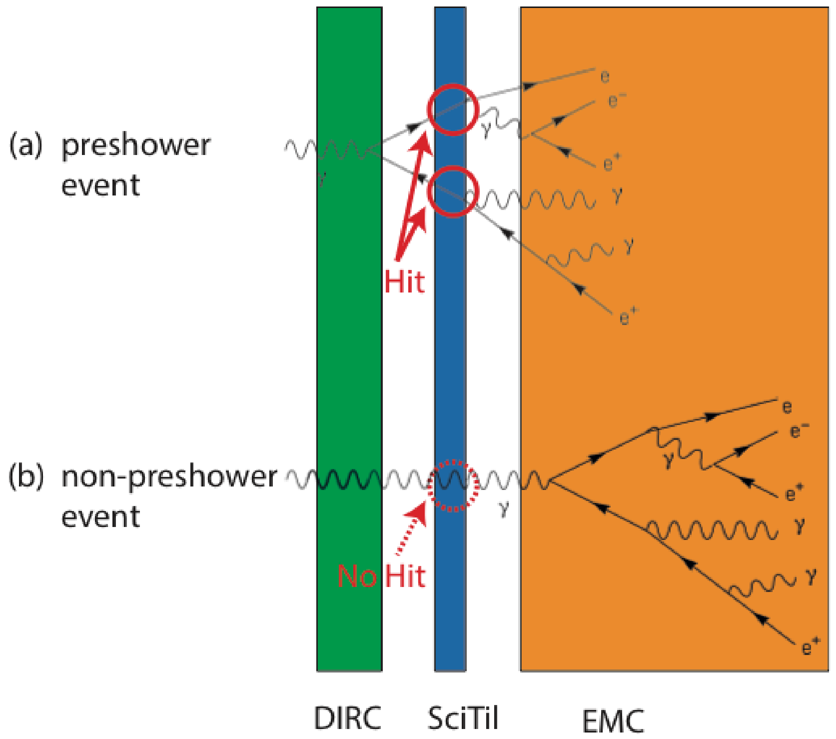




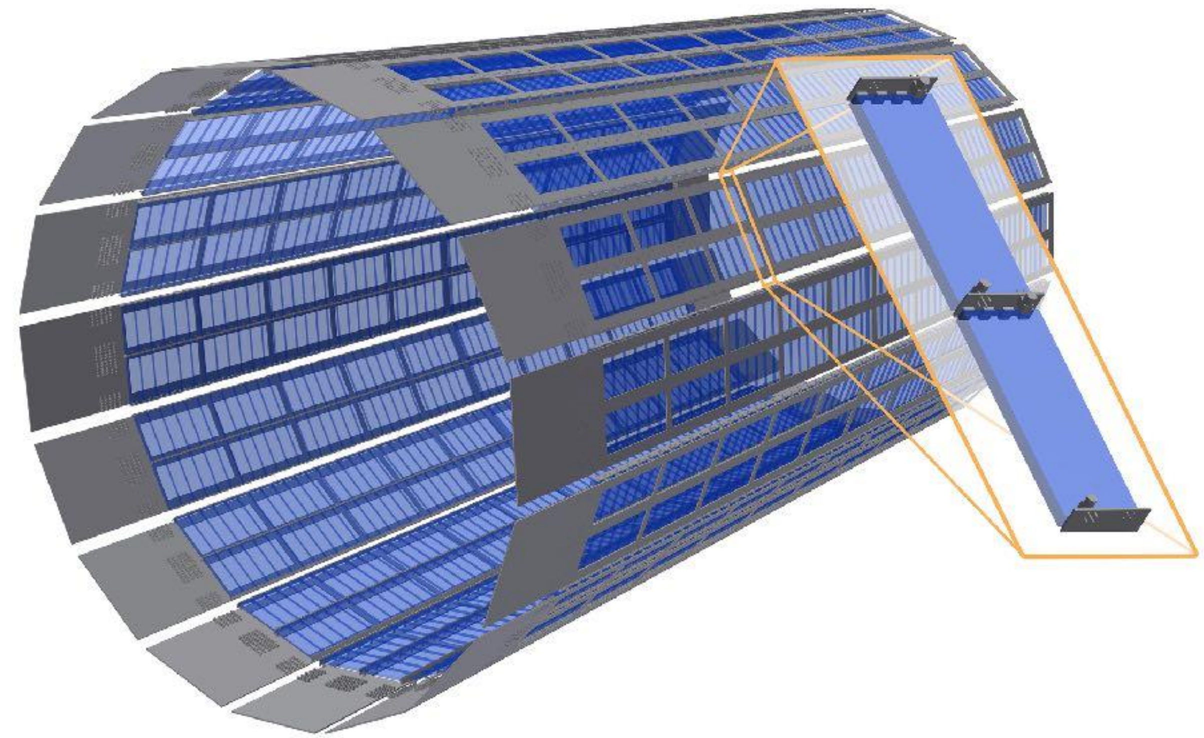
Capabilities and Requirements, and Detector Layout

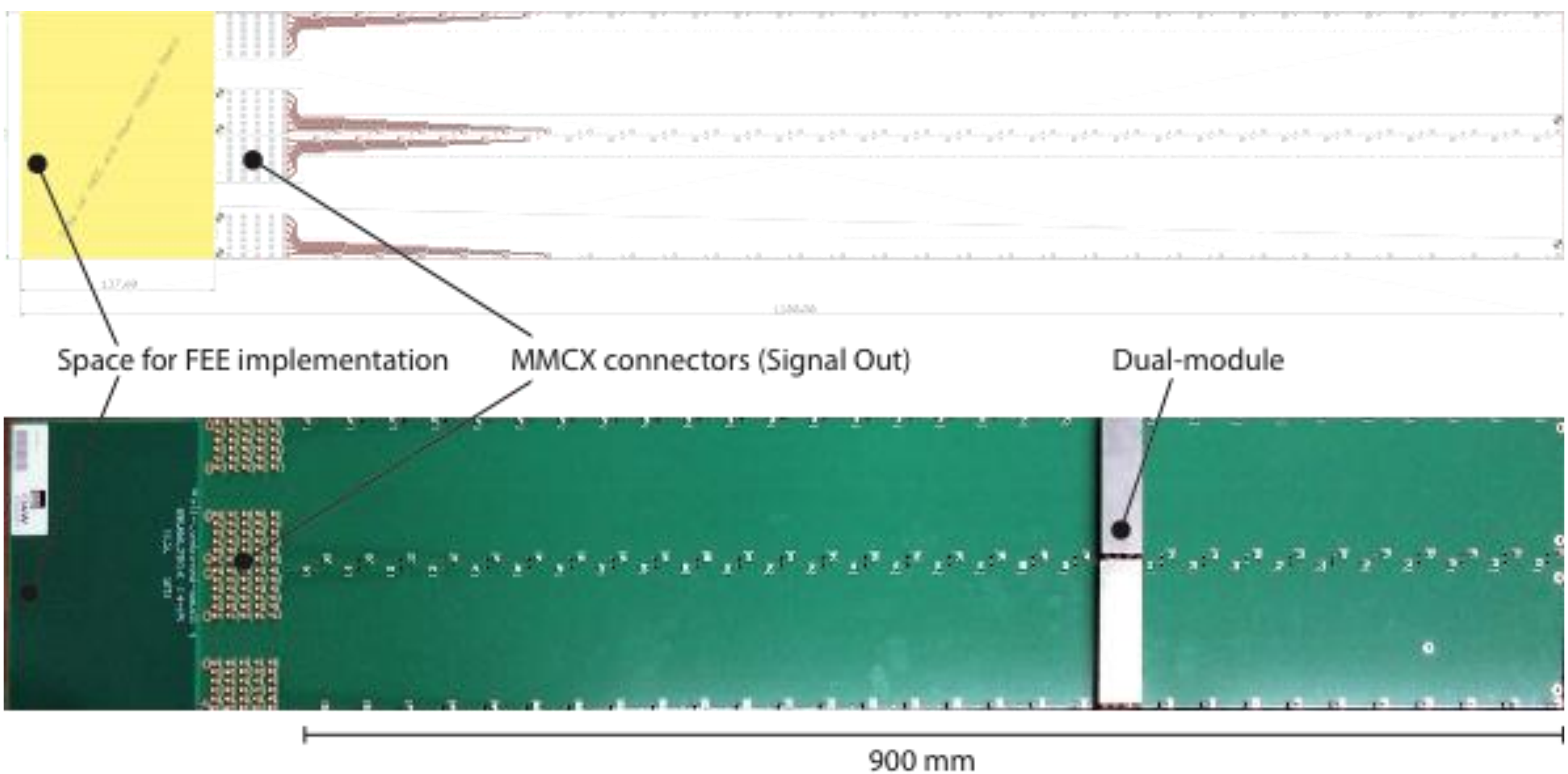


- between the Barrel DIRC and the EMC
- high efficiency to charged particles
- blind to γs

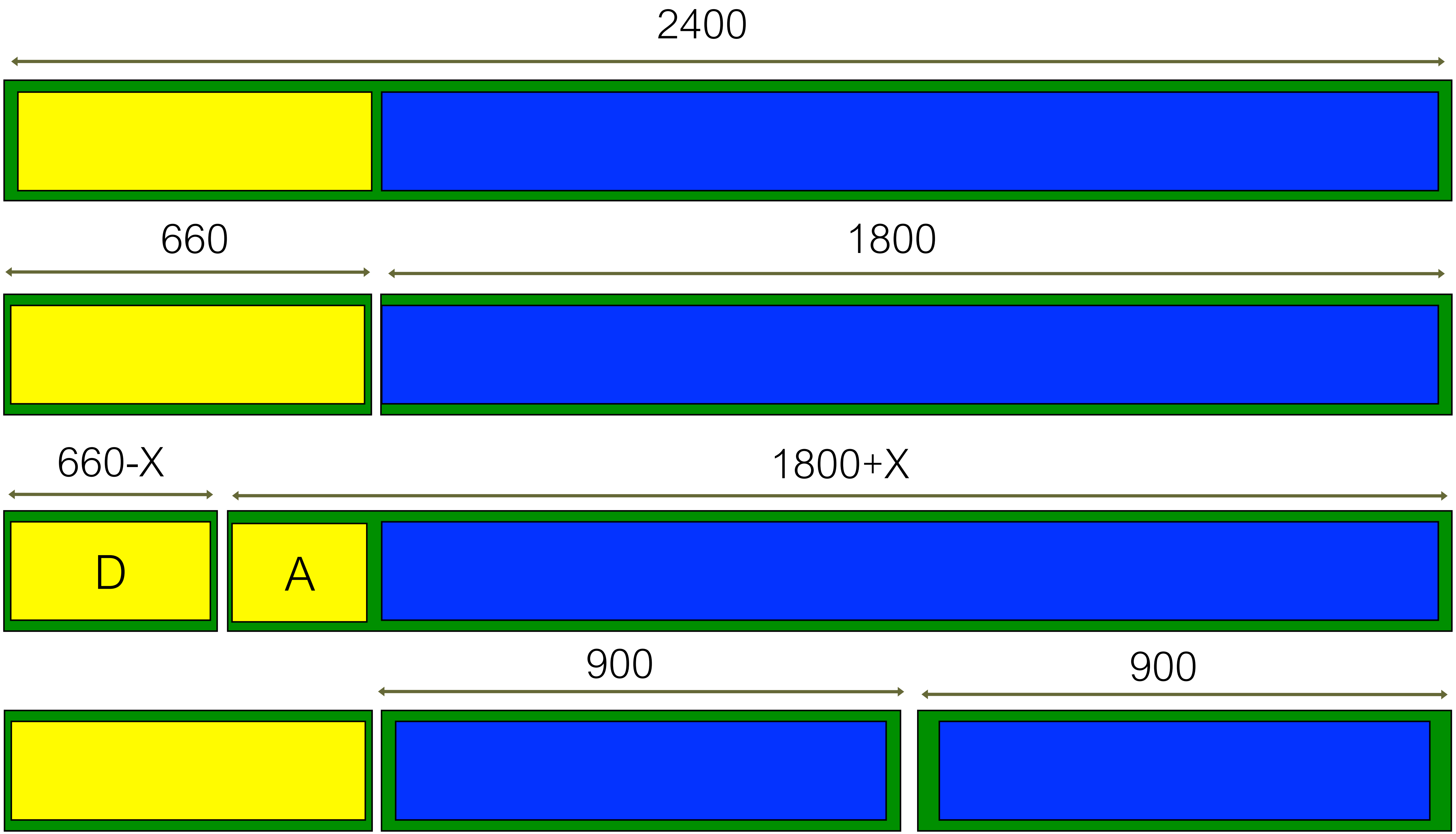


Super Module
- a half length prototype





Large PCB (railboard) production issue & Delivery Delay (3.5 months late)



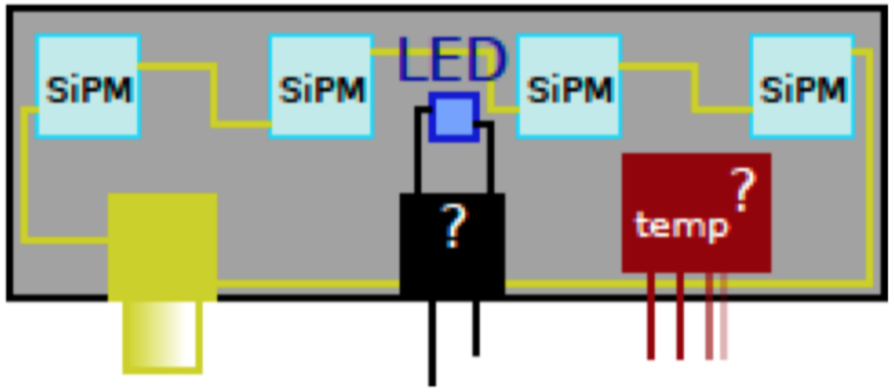
Half-length was not a problem. Full length is. Production at CERN?

Monitoring and Calibration

- Voltage and current monitoring
  - the primary parameter that influences the characteristics of SiPM
  - general health check
- Temperature
  - SMD PTC on the sensor-board
  - relative: 200 mK, absolute: 4 K
- Gain
  - DCR: 10-100 kHz/mm^2
- LED calibration system
  - SMD LED on the sensor-board

Model	V_{BD}	gain
KETEK	18 mV/K	< 0.5 %/K
Hamamatsu S13360	50 mV/K	∼ 1.3 %/K
AdvanSiD NUV	26 mV/K	< 1 %/K

Table 4.5: A short summary of temperature dependencies of SiPM characteristics. Values are taken from Ref. [10, 11, 12, 13]. The temperature dependence of break-down voltage of KETEK device is evaluated at 5 V over-voltage. Note that the absolute temperature coefficient of the gain is smaller at higher over-voltage. According to Ref. [10], the coefficient will be −0.7% at 2 V over-voltage.



SciRod (Erlangen) cont'd

More Time Resolutions (2)

Scintillator 5 x 5 x 50 mm^3

Scintillator	MPPC	left		center		right
		σ_t	σ_t	σ_t	σ_t	σ_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^3

Scintillator	MPPC	left		center		right
		σ_t	σ_t	σ_t	σ_t	σ_t
BC408	S10362-100P	113		123		92

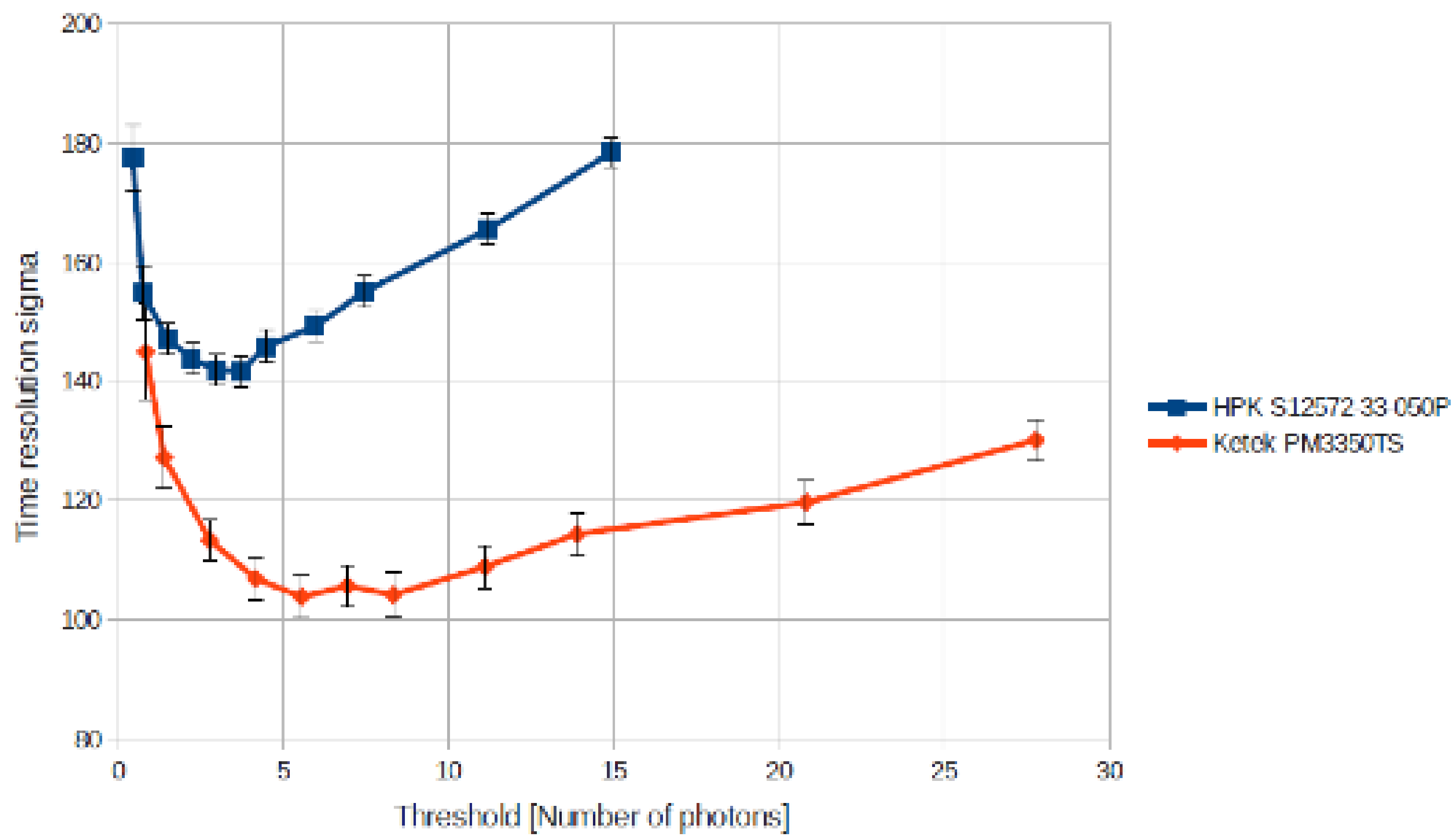
Scintillator 5 x 5 x 170 mm^3

Scintillator	MPPC	left		center		right
		σ_t	σ_t	σ_t	σ_t	σ_t
BC408	S10362-100P	88	85	129	85	99

Longer and wider rods tend to give worse time resolution

The best time precision when triggering on the first photon? Analog SiPM

Time resolution of a scintillator tile read-out with the Hamamatsu SiPMs

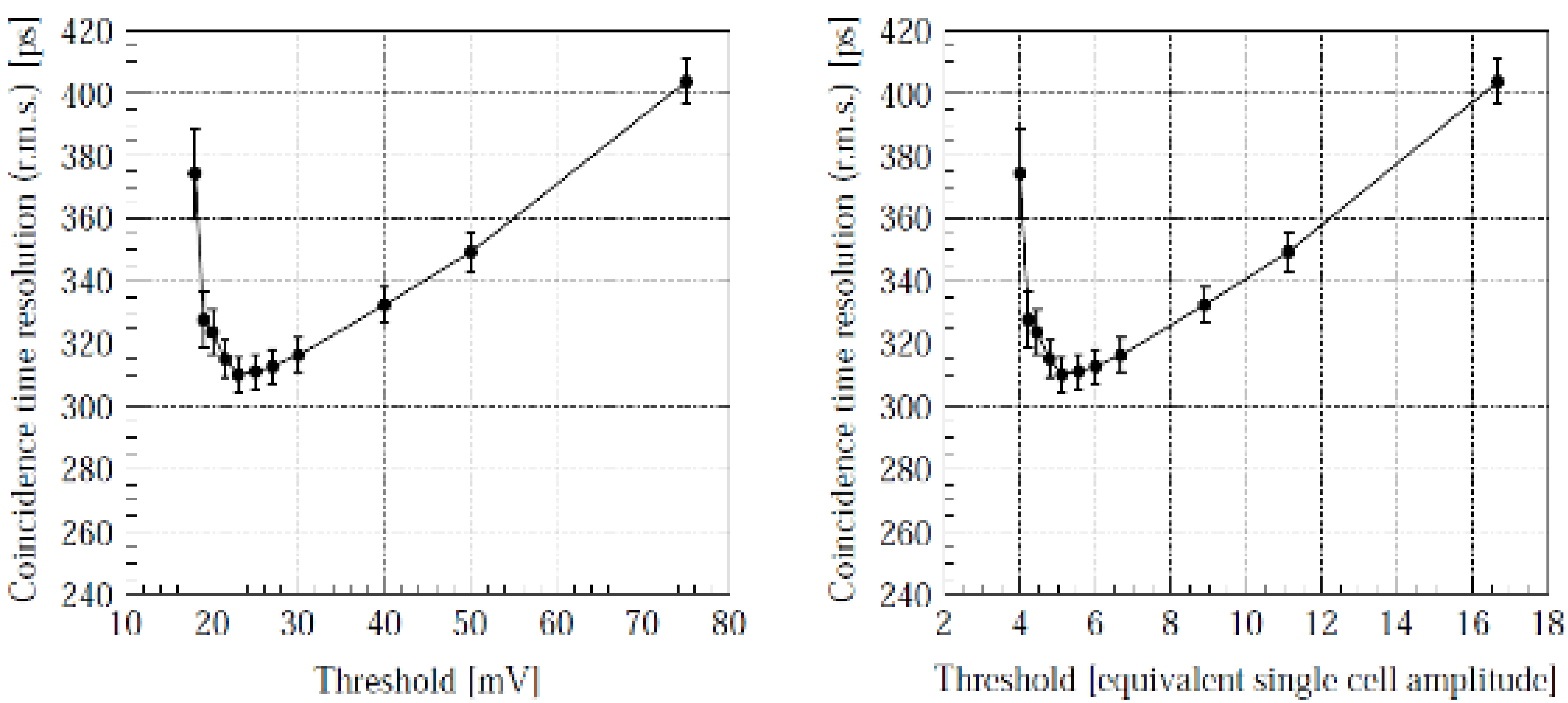


No, the trigger threshold should not be set to the first detected photon, due to electronics noise and the SPTR of the SiPM.

The best time precision when triggering on the first photon? Analog SiPM

r analog SiPMs, this behaviour is changed due to electronics noise and the SPTF

Time resolution of a scintillator tile read-out with the Hamamatsu SiPMs



No, the trigger threshold should not be set to the first detected photon

SPTR of SiPMs

2 options: Hamamatsu or Ketek (3x3 mm2)
AdvanSiD: worse timing, low PDE

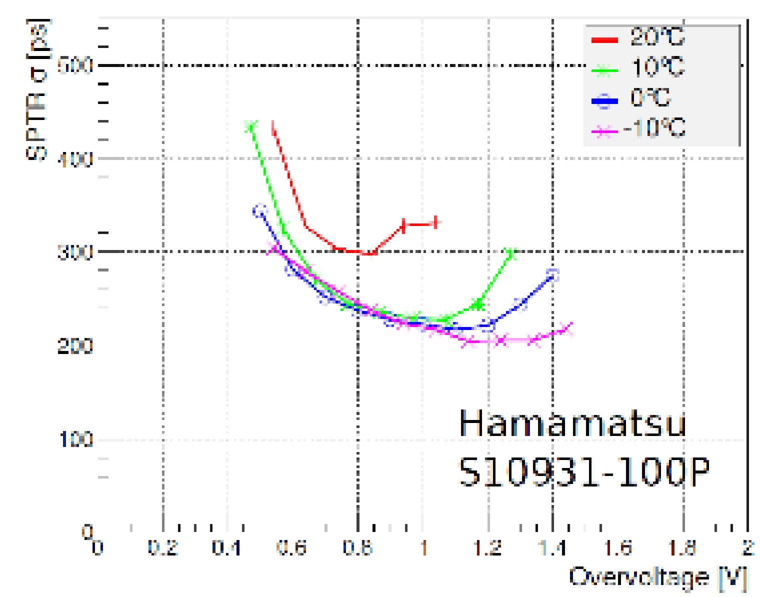
SensL: also lower PDE

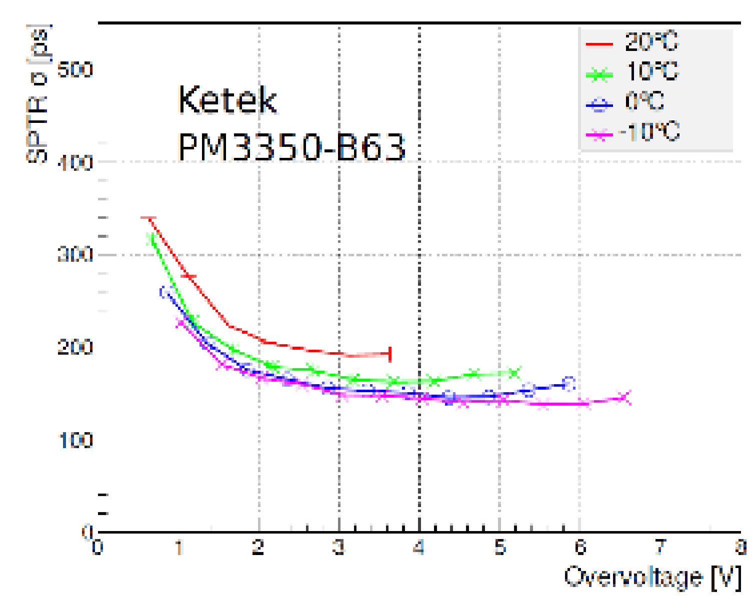
Ketek with optical trenches showed best results

Time resolution follows 1/√N

We expect ~ 60 photons per SiPM:
Hamamatsu 100P → σ ~ 40 ps
KETEK PM3350 → σ ~ 25 ps

SPTR





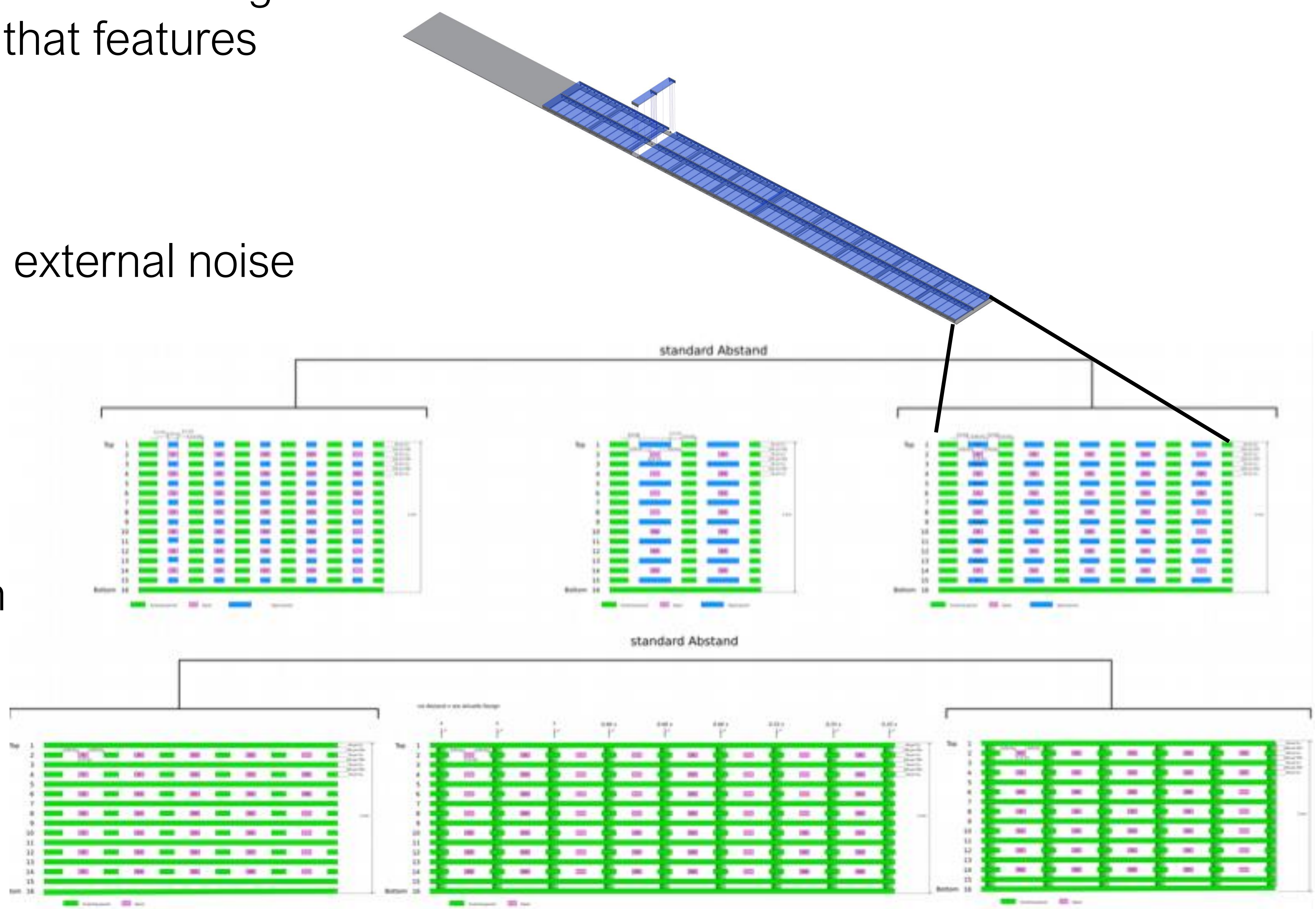
with picosecond pulsed laser (400 nm)

"Time resolution below 100 ps for the SciTil detector of PANDA employing SiPM"

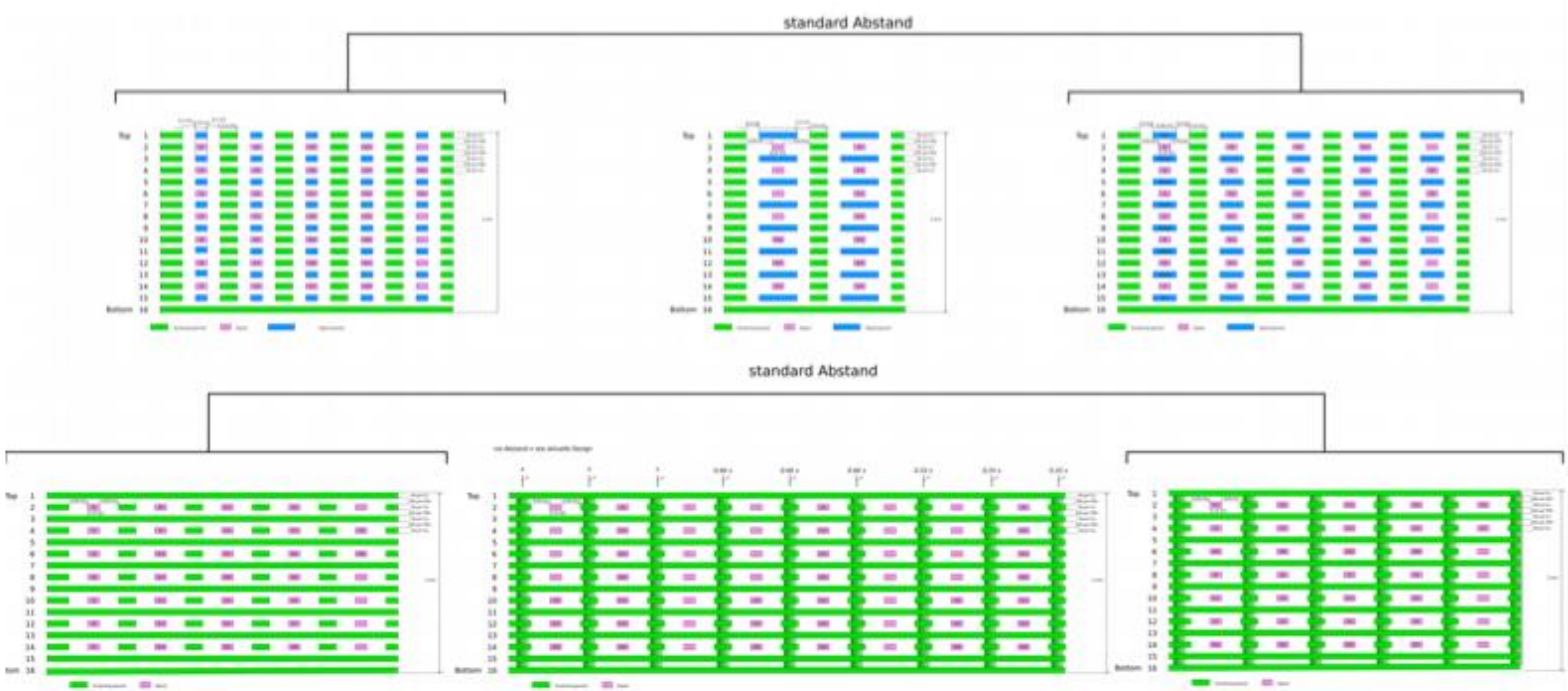
S.E. Brunner, L. Gruber, J. Marton, H. Orth, K. Suzuki

Micro Stripline Technique

- Coaxial-like structure to transmit signals over a PCB board, realised on a multilayer PCB board, that features
  - High density
  - Good shielding from external noise
  - High bandwidth
  - Low crosstalk
  - Mechanical strength

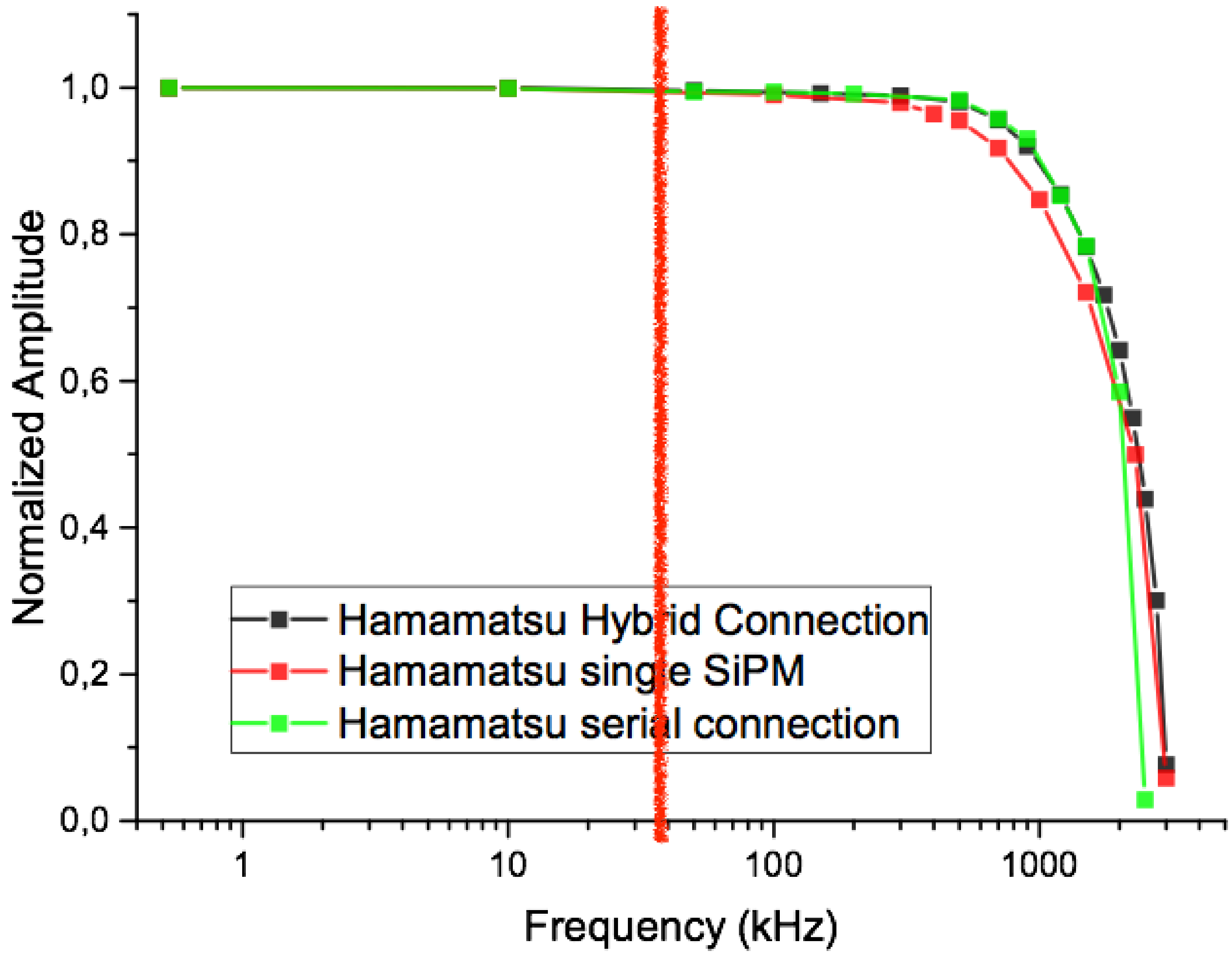


Complementary Designs Railboard v2.

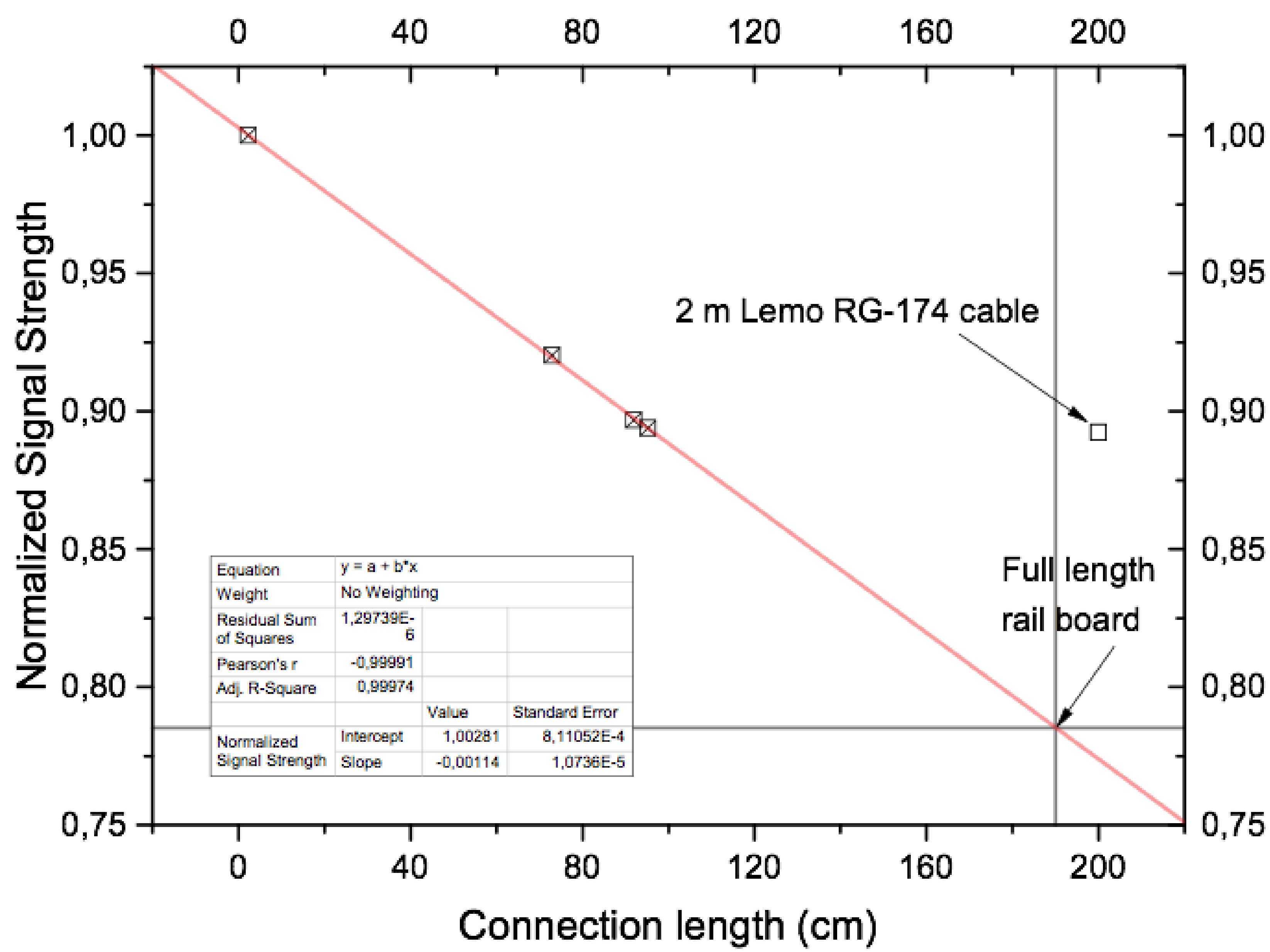


Rate Capability

Max. tile hit rate



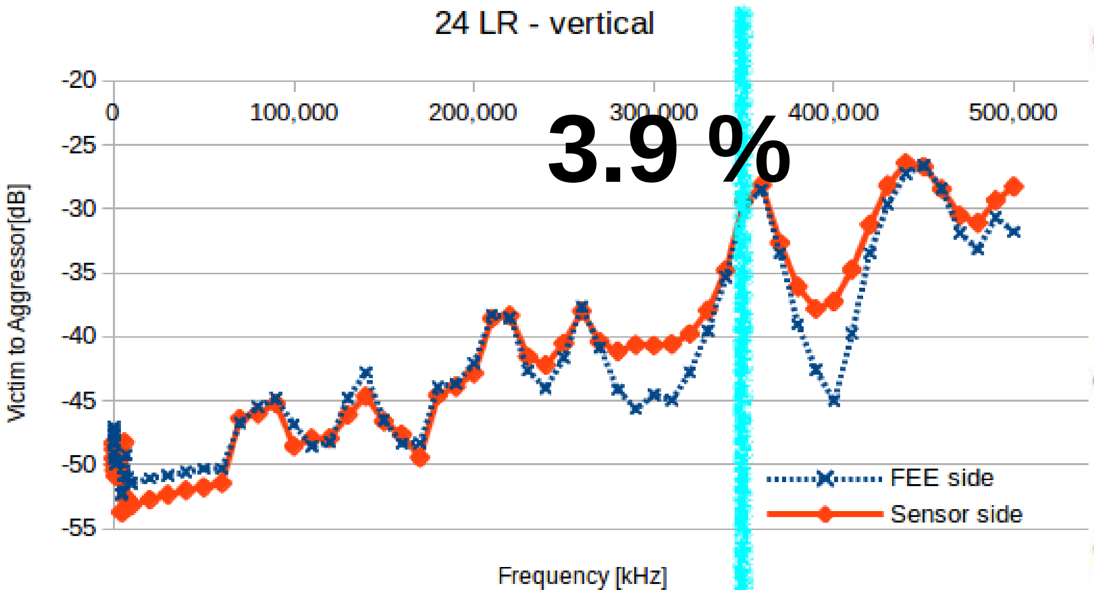
Signal Attenuation on the Micro Striplines

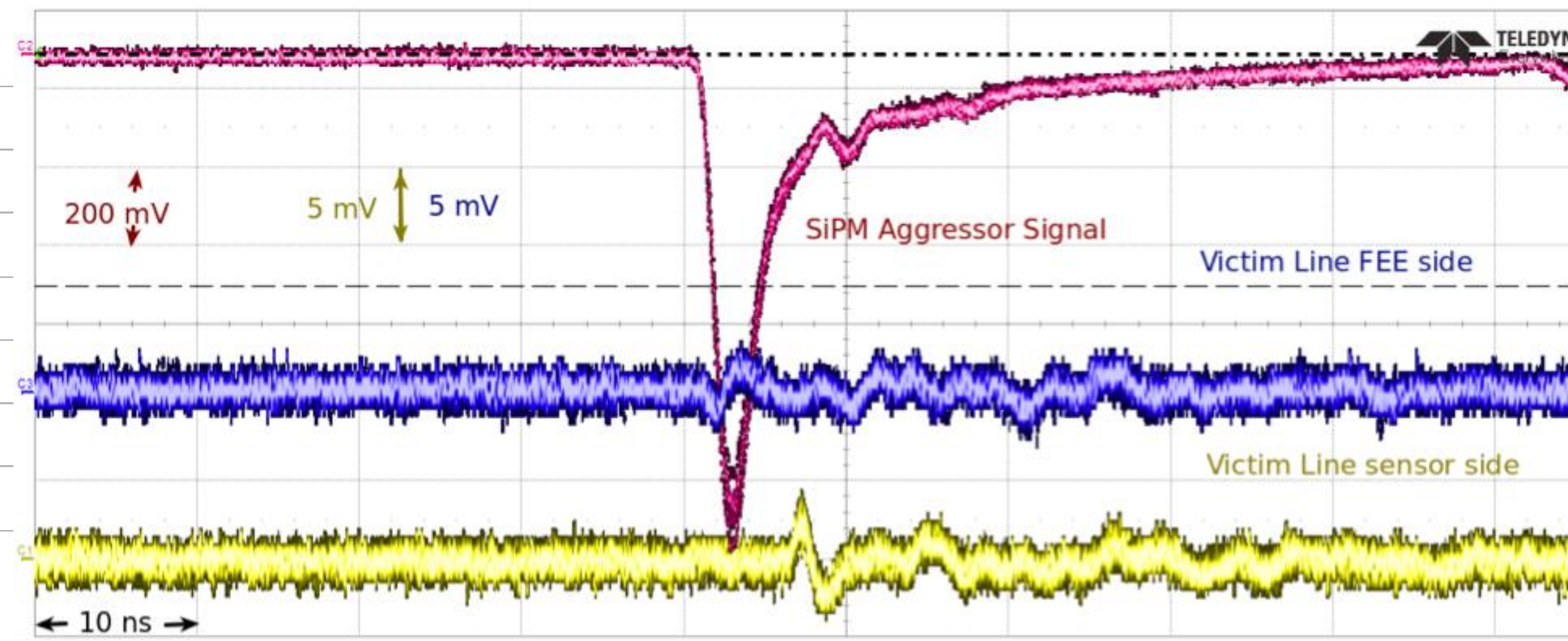


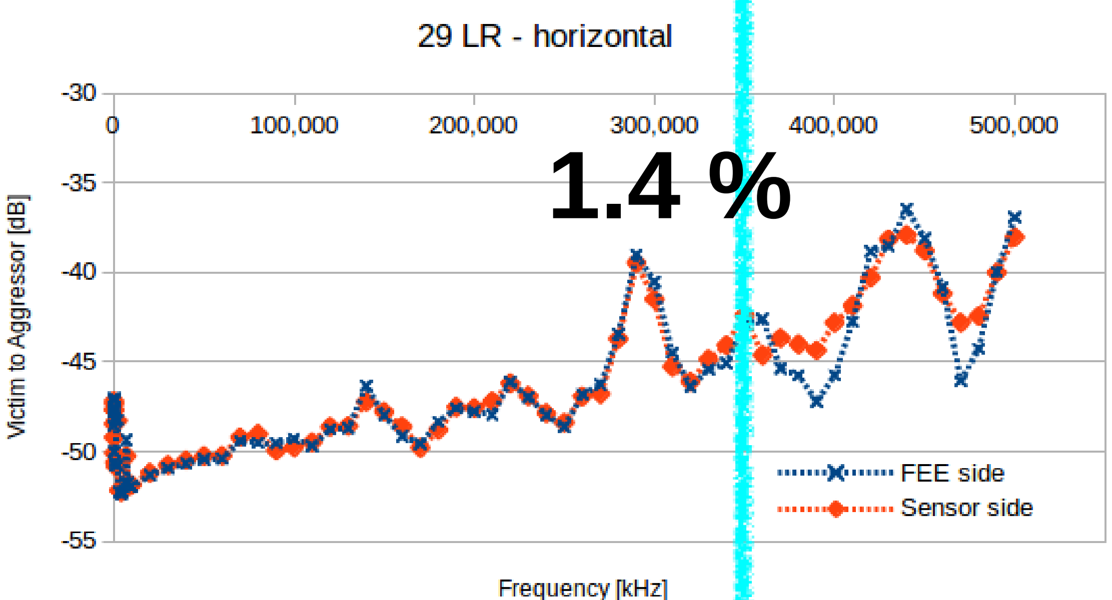
uation can be reduced by increasing the cross section of the signal

Crosstalks between Micro Striplines

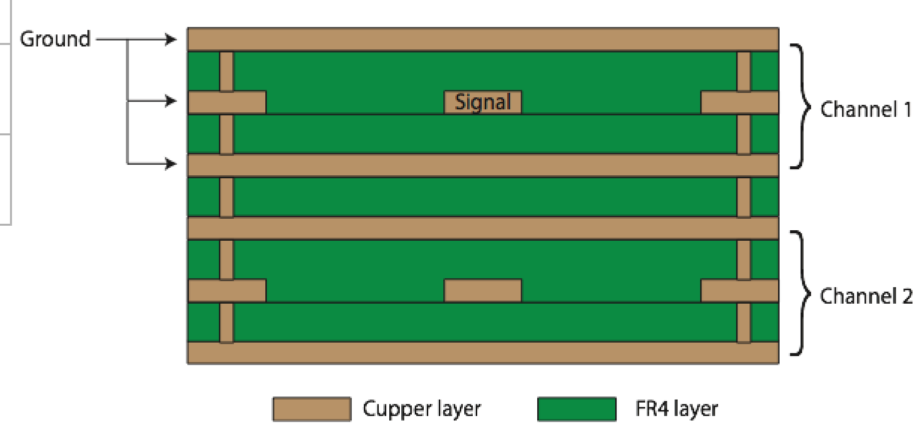
1 ns rise time







Crosstalks can be reduced e.g.
by using “via” and/or
by optimising the ch. sequence

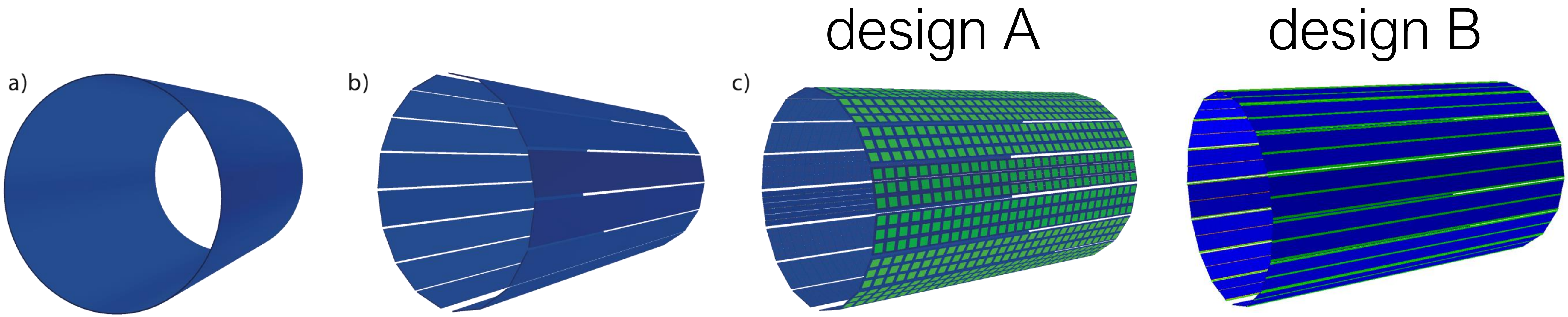


1	6	11	16	21	26
2	7	12	17	22	27
3	8	13	18	23	28
4	9	14	19	24	29
5	10	15	20	25	30

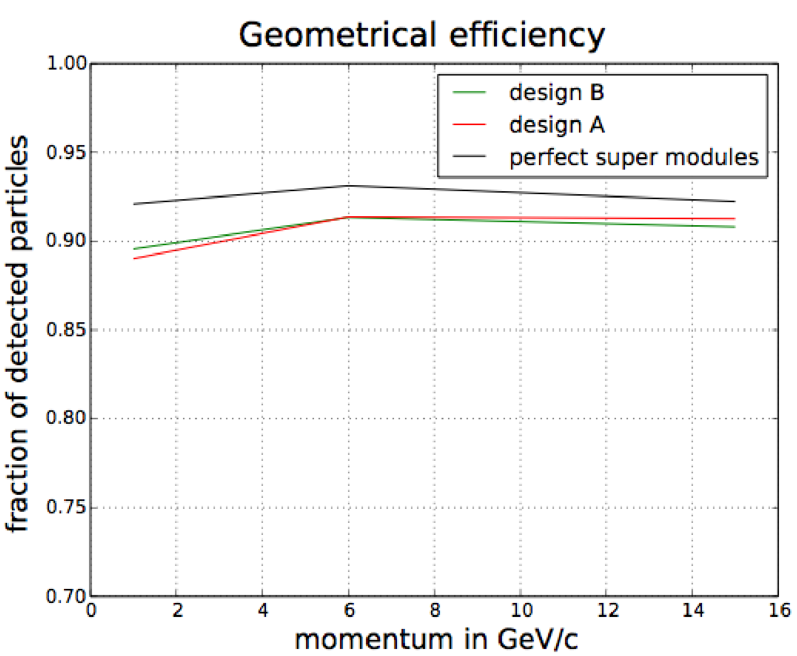
Efficiency

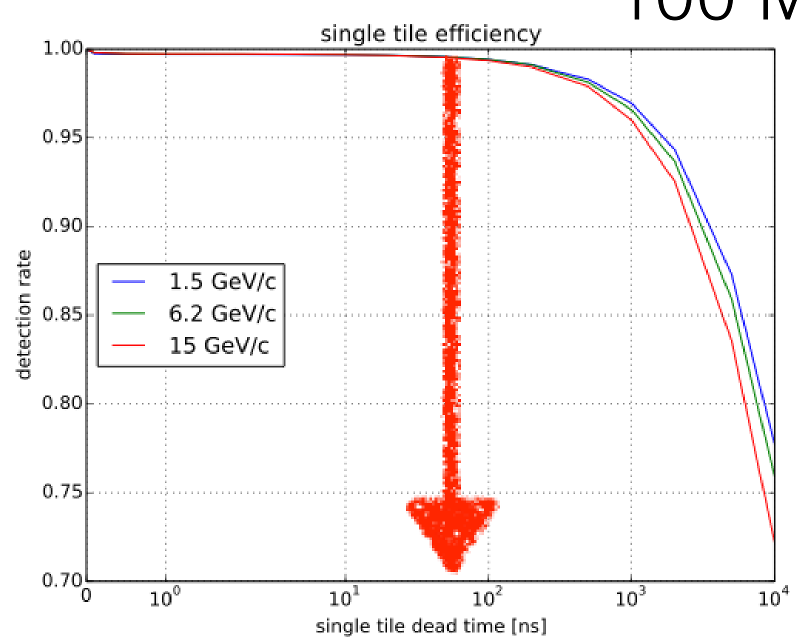
geometry	number of tiles	tile size mm^2	active area m^2	fill factor
reference	1	-	5.7	100 %
perfect super-modules	16	180×1800	5.2	91 %
design A	5760	28.5×28.5	4.7	82 %
design B	1920	86.95×29.4	4.9	86 %

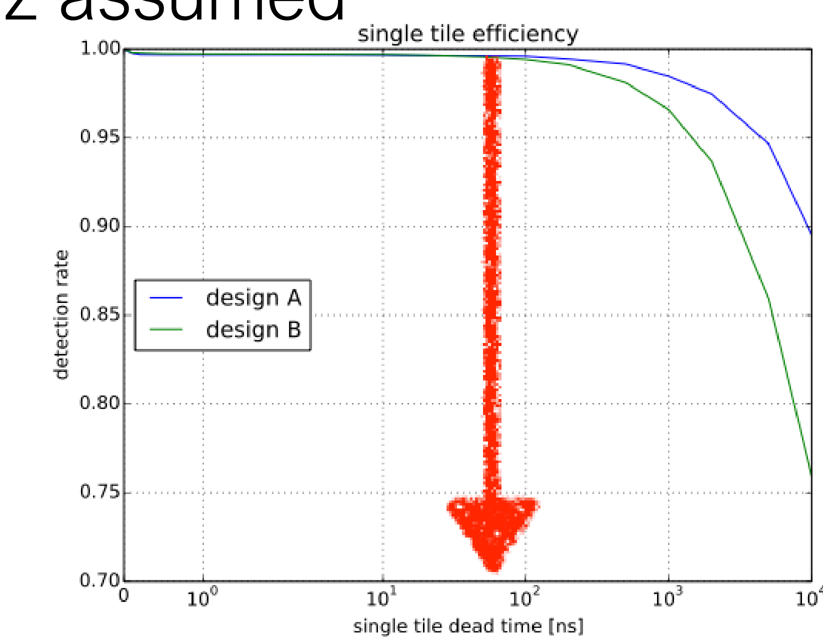
Table 5.1: Properties of the studied Barrel TOF design options.



100 MHz assumed





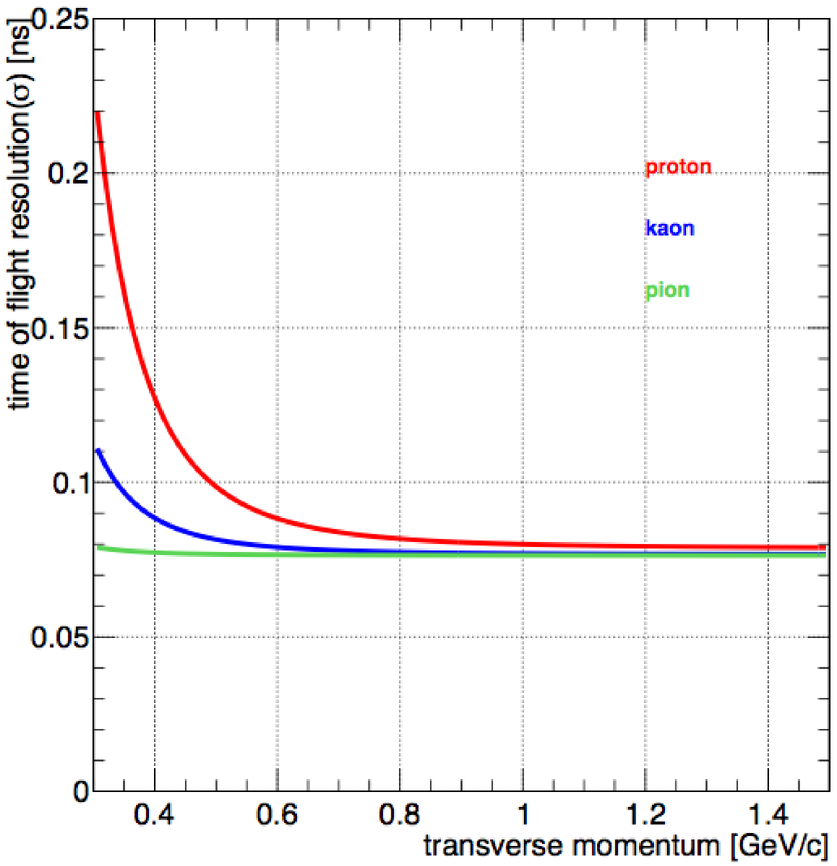


Sensor recovery time: ~50 ns, TOF-PET chip >300 kHz average through-put, Max tile hit-rate is ~40 kHz, TOF-PET chip has a buffer (4 hits) to cope with locally high-rate events

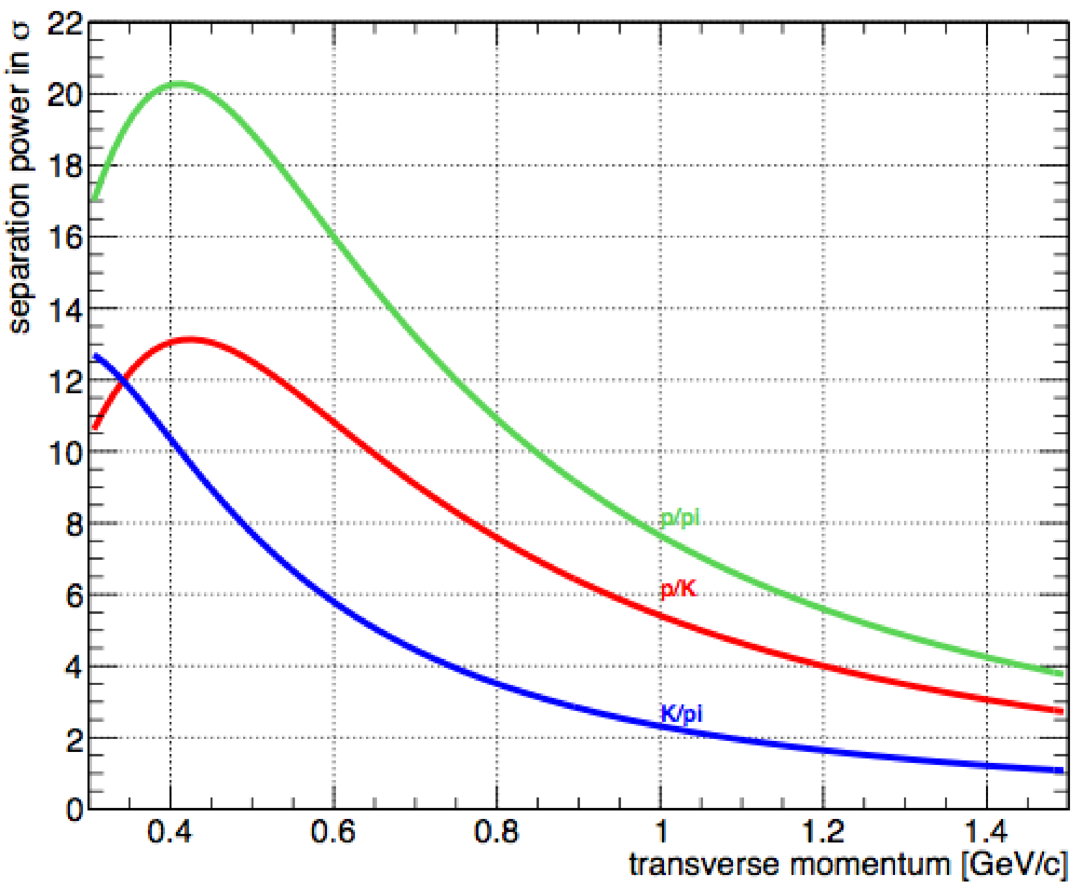
TOF-based
Particle Identification

$$n_\sigma = \frac{|tof_p - tof_K|}{max(\sigma_p, \sigma_K)}$$

time of flight resolution



separation power



from simulation

Relative TOF

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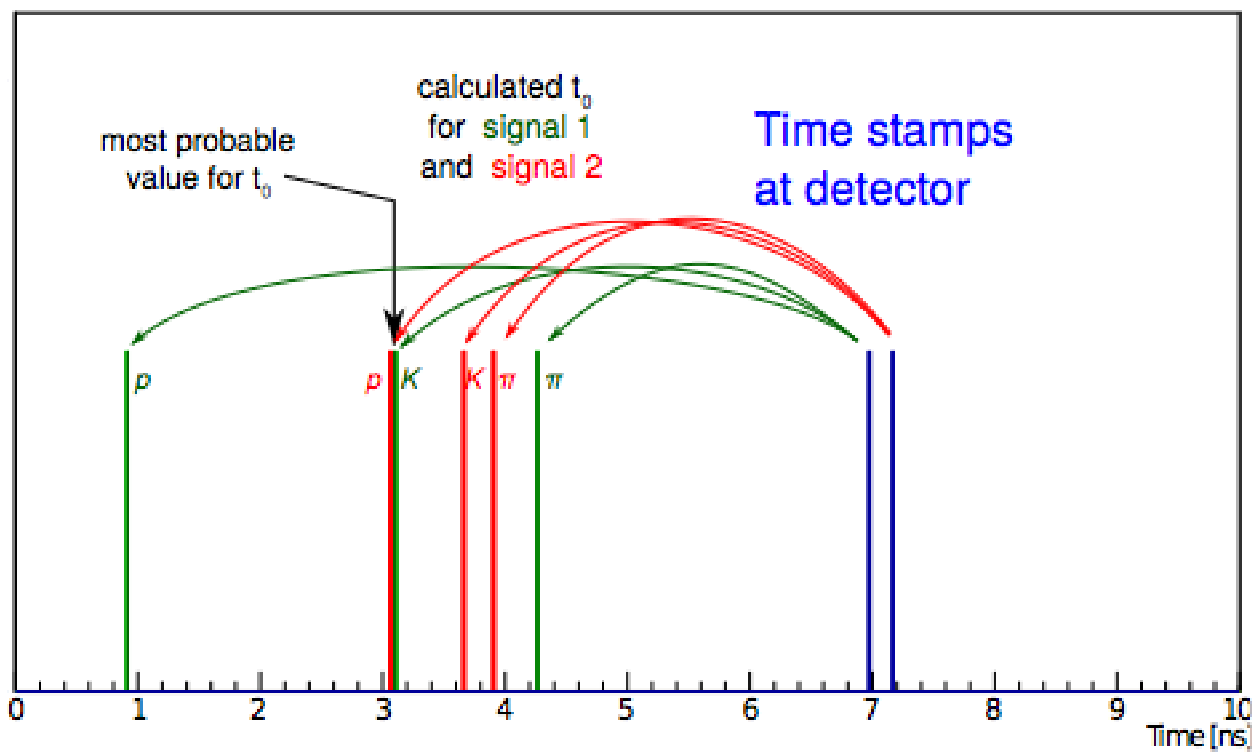
Basic principle

- Calculate t_s for all possible particle species and all N tracks
  - Using reconstructed track parameters
  - p, K, π, μ, e
- evaluate all 5^N mass configurations
  - Compare their X^2 weights
  - Select the "most probable"



Relative TOF

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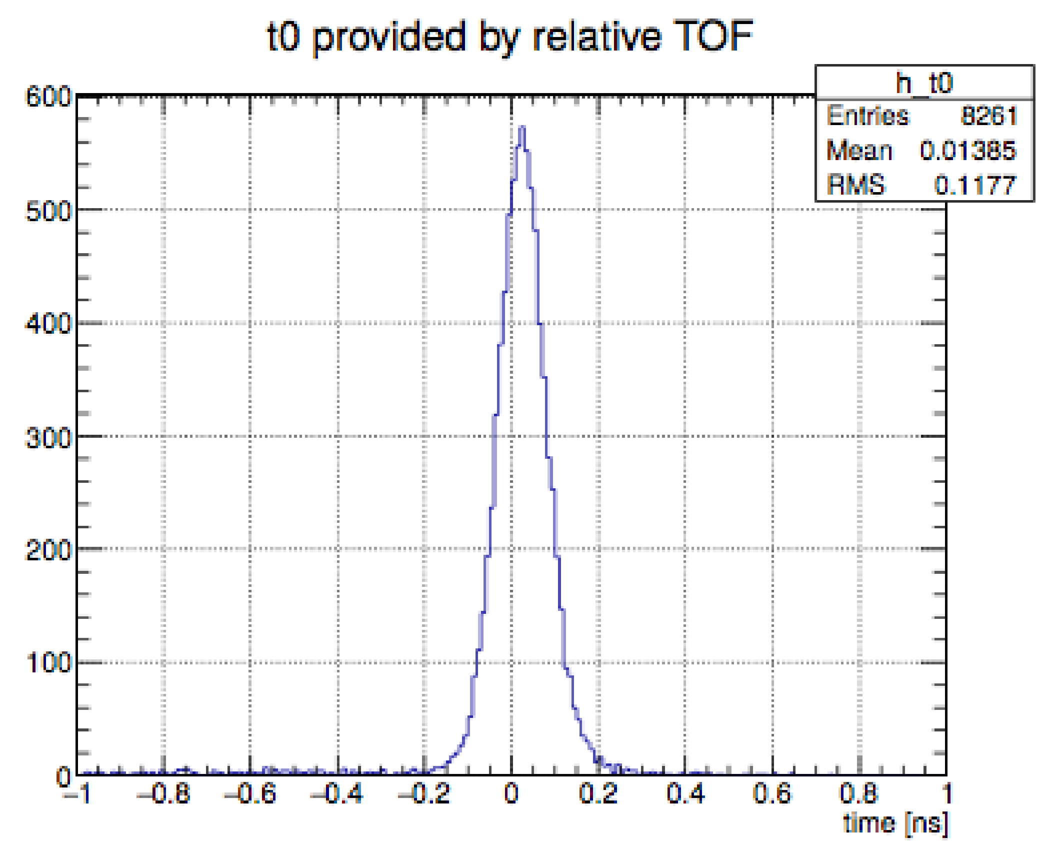
t0 determination in Pandaroot

- Relative Tof algorithm implemented in local macros
  - Pid stage
- DPM generator
- Events with N>3 primary tracks matched with SciTil
- Mismatched tracks are rejected (MC information)



Radiation Hardness of SiPMs

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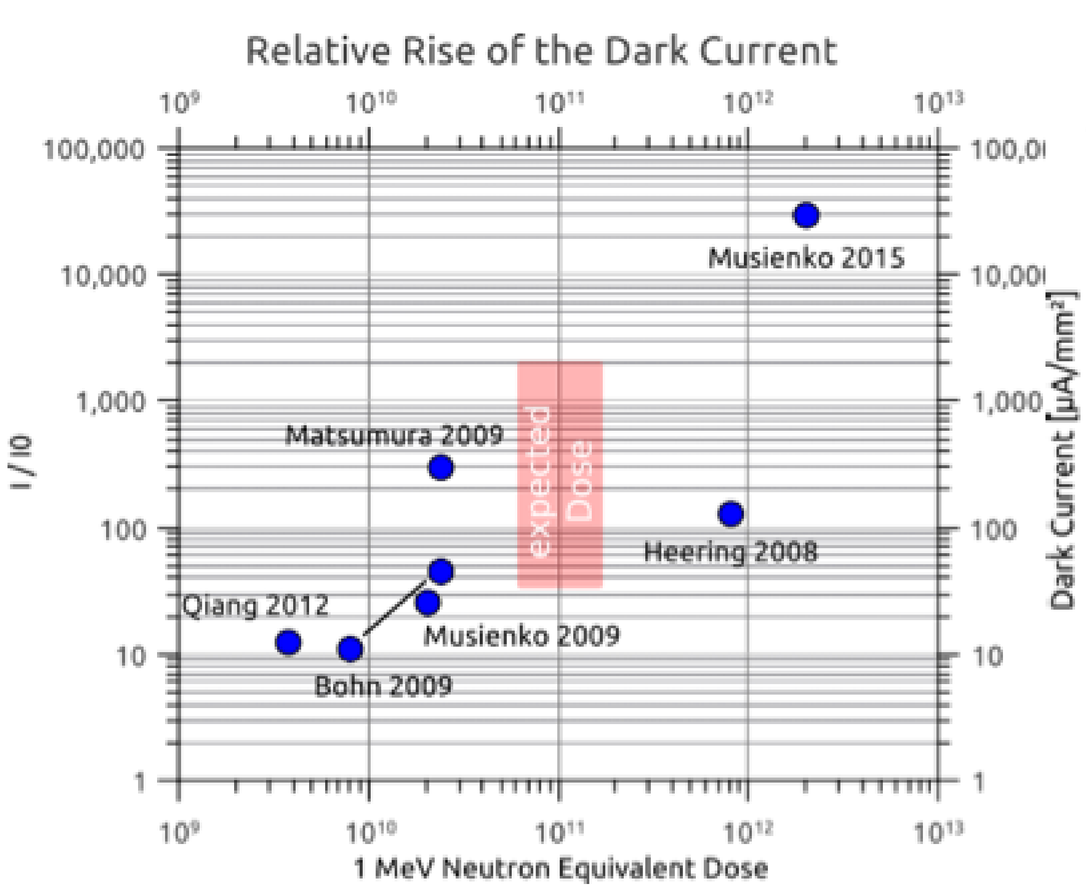
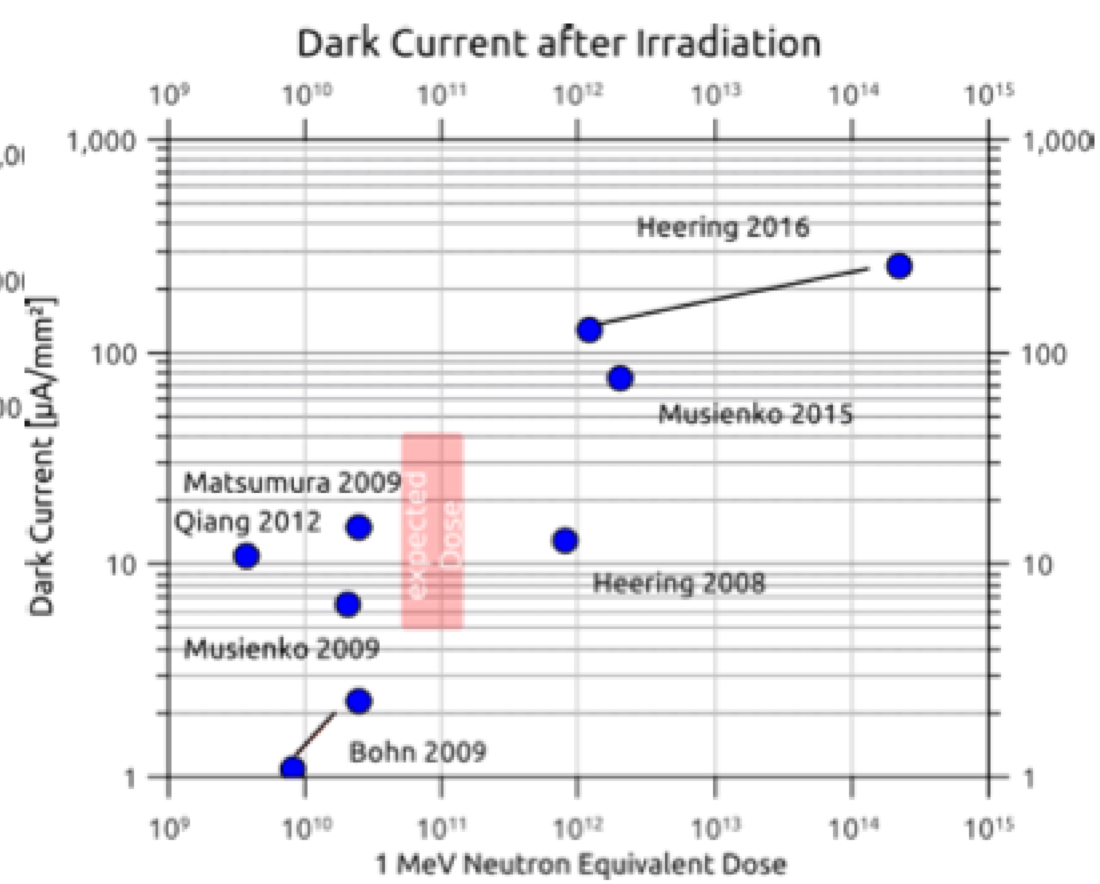
Summary of the Literature Study





Radiation Hardness of SiPMs

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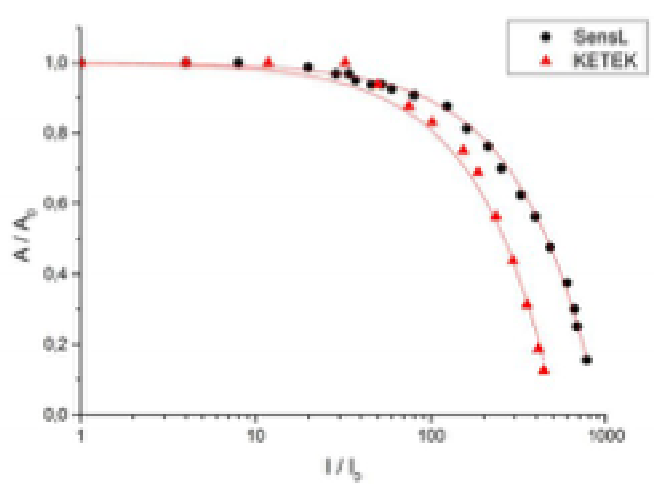
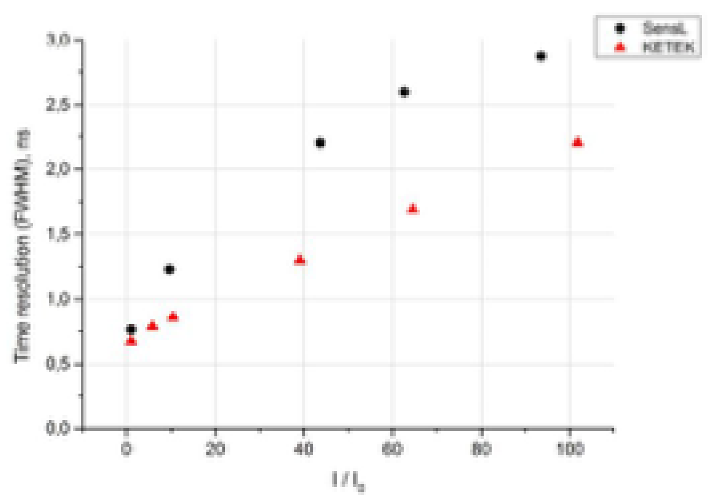
Simulation of dark current increase

- Study done by V.A. Kaplin et al., *"Time and Amplitude characteristics of large scintillation detectors with SiPM"* -2015
- Dark current increase simulated by continuous low intensity illumination by an LED





Radiation Hardness of SiPMs

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Time resolution expectation

- Expected current between 8 and 40 μA/cm²
- For 3x3 mm² sensors: up to 360 μA
- Taking the measurements of KETEK and SensL sensors as a reference we expect deterioration of the time resolution by ~30% to ~70% over 10 years
- Reduced pixel dead time should reduce the effect of the radiation
  - Hamamatsu: 50 ns, KETEK & SensL: >200 ns
- True impact however is not known

Radiation Hardness of Scintillator Material

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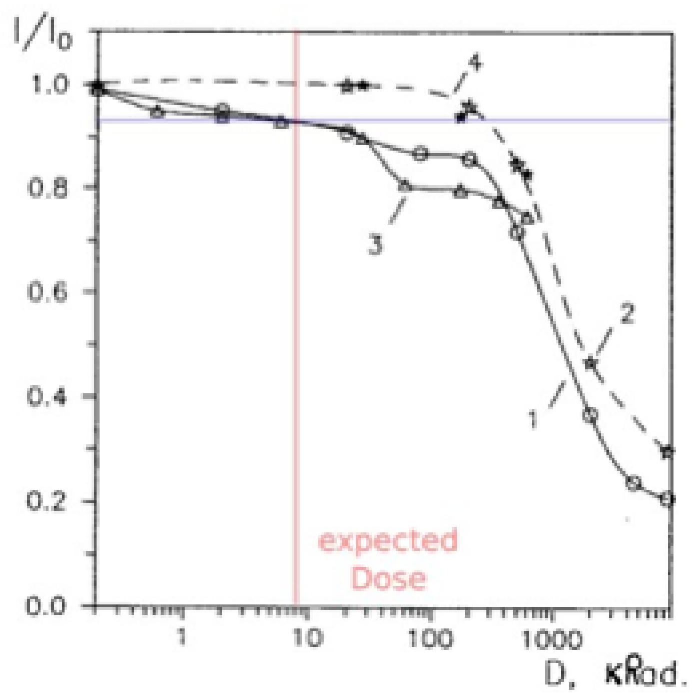
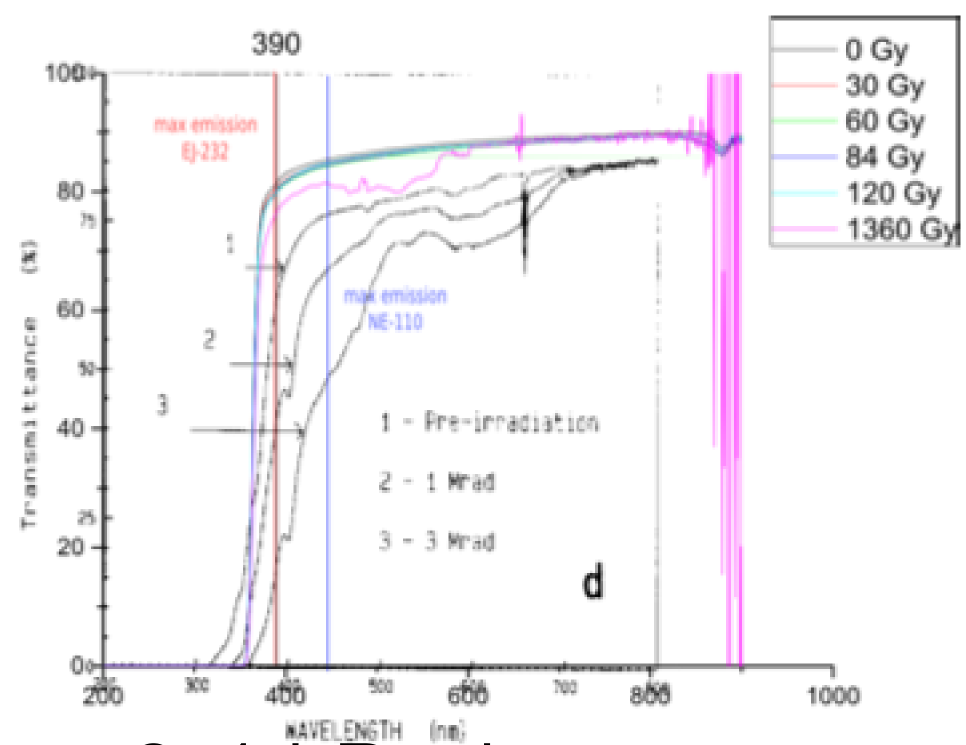
Scintillator Radiation Damage

Irradiation with Co^{60}



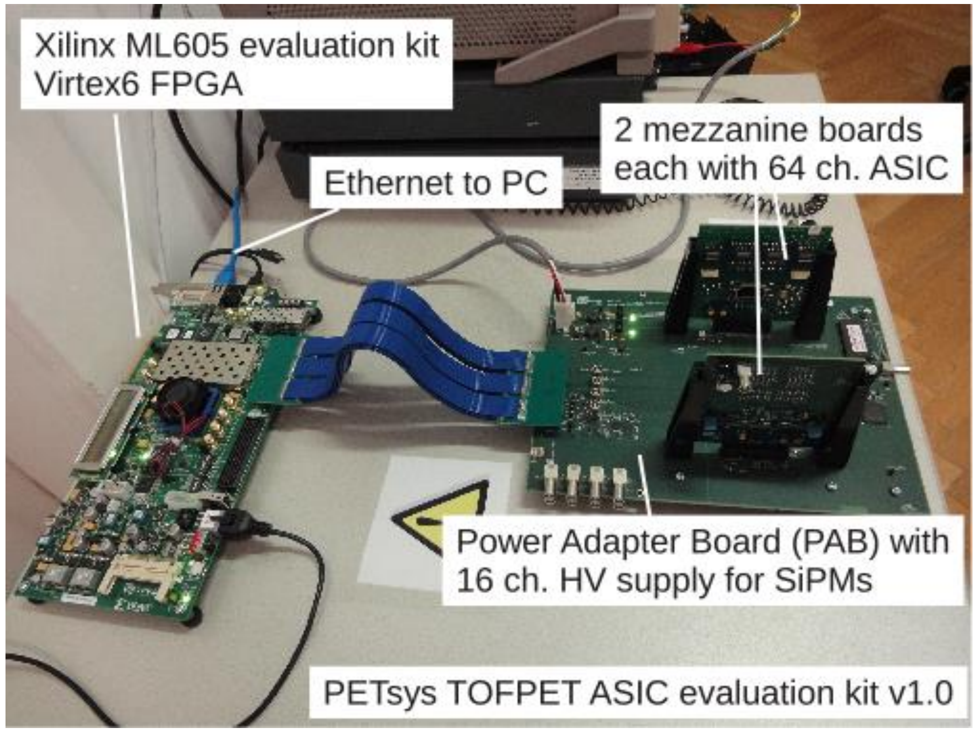


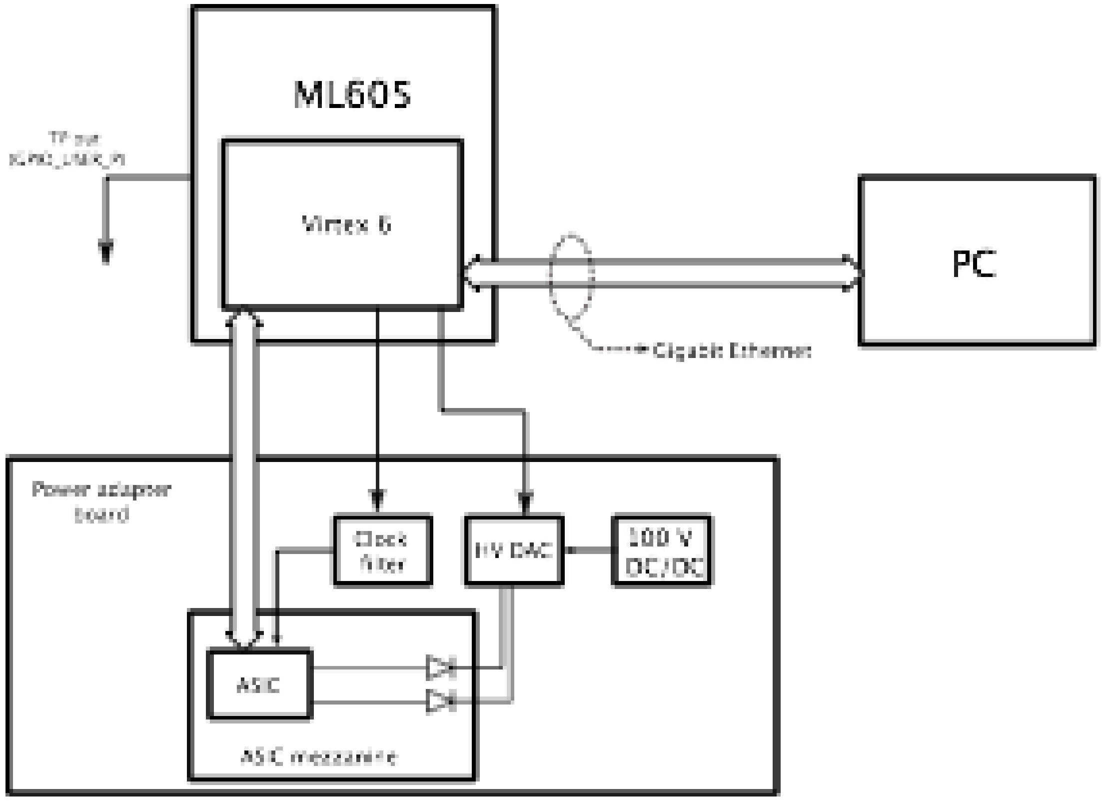
Expected dose ~8.4 kRad

Front End Electronics, DCS

TOFPET ASIC by PETsys Electronics	
number of channels	64
TDC time binning	50 ps (25 ps optional)
intrinsic time resolution	21 ps r.m.s.
charge measurement	time over threshold (ToT)
dynamic range	300 pC
SNR (Qin = 200 pF)	25 dB
coarse gain	G0, G0/2, G0/4
SiPM familiy support	positive or negative signal polarity
on-chip calibration circuit	internal pulse generator, programmable 6-bit amplitude
max channel hit rate	160 kHz
max output data rate	320 Mb/s (640 Mb/s with double data rate)
Fully digital output	2 data LVDS links, DDR compatible
operation frequency	80-160 MHz
power per channel	8-11 mW
SiPM HV fine biasing	range 500 mV

Table 4.2: Summary of the specification of the TOFPET ASIC by PETsys.





Monitoring and Calibration

- Voltage and current monitoring
  - the primary parameter that influences the characteristics of SiPM
  - general health check
- Temperature
  - SMD PTC on the sensor-board
  - relative: 200 mK, absolute: 4 K
- Gain
  - DCR: 10-100 kHz/mm^2
- LED calibration system?
  - SMD LED on the sensor-board

Model	V_{BD}	gain
KETEK	18 mV/K	< 0.5 %/K
Hamamatsu S13360	50 mV/K	~ 1.3 %/K
AdvanSiD NUV	26 mV/K	< 1 %/K

Table 4.5: A short summary of temperature dependencies of SiPM characteristics. Values are taken from Ref. [10, 11, 12, 13]. The temperature dependence of break-down voltage of KETEK device is evaluated at 5 V over-voltage. Note that the absolute temperature coefficient of the gain is smaller at higher over-voltage. According to Ref. [10], the coefficient will be −0.7% at 2 V over-voltage.