The PANDA Barrel-TOF Detector

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On behalf of the Panda Barrel-TOF group
Vienna

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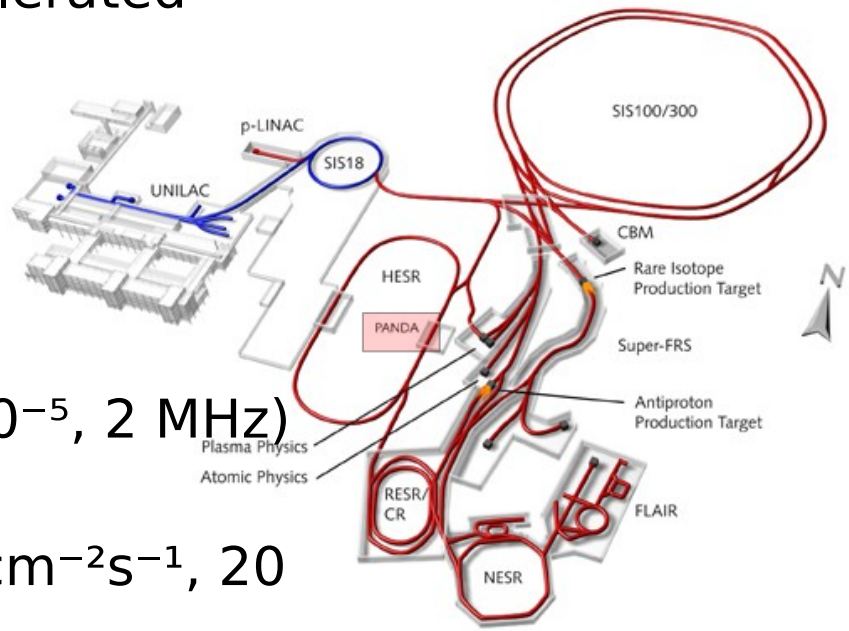
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Outline

- The PANDA experiment
- Overview of the Barrel-TOF
- Submodules
- SiPM configuration
- Time resolution
- Capabilities of the detector
  - Event time determination
  - Event sorting
  - Particle Identification

The PANDA Experiment

- One of four flagship experiments at FAIR
- Fixed target experiment with accelerated ani-protons on protons
  - Momentum range of 1.5 GeV/c to 15 GeV/c
- Two operation modes of the High Energy Storage Ring (HESR):
  - High resolution mode ($\Delta p/p \leq 10^{-5}$, 2 MHz) electron cooling
  - High luminosity mode ($2 \cdot 10^{32}$ cm^{-2}s^{-1}, 20 MHz)



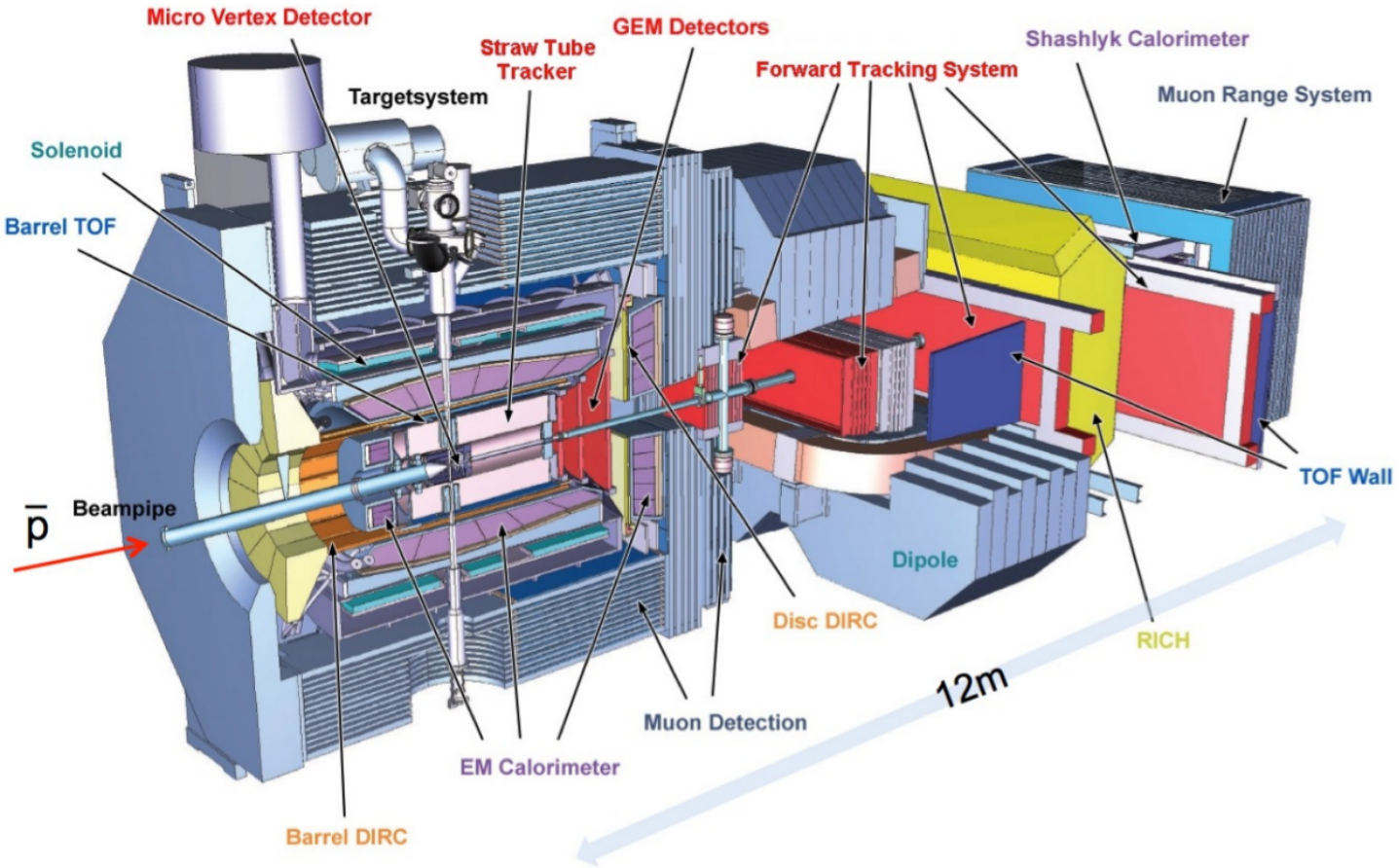
Experimental Challenges

- The PANDA detector will be a trigger-less system
- Data rate in the Order of 200 GB/s
  - Needs to be reduced by a factor of 1000
- The barrel time of flight detector plays a vital role in this regard

- The Barrel TOF provides:
  - Interaction time
  - Particle identification
  - Event selection

  all important for data reduction

The PANDA Detector



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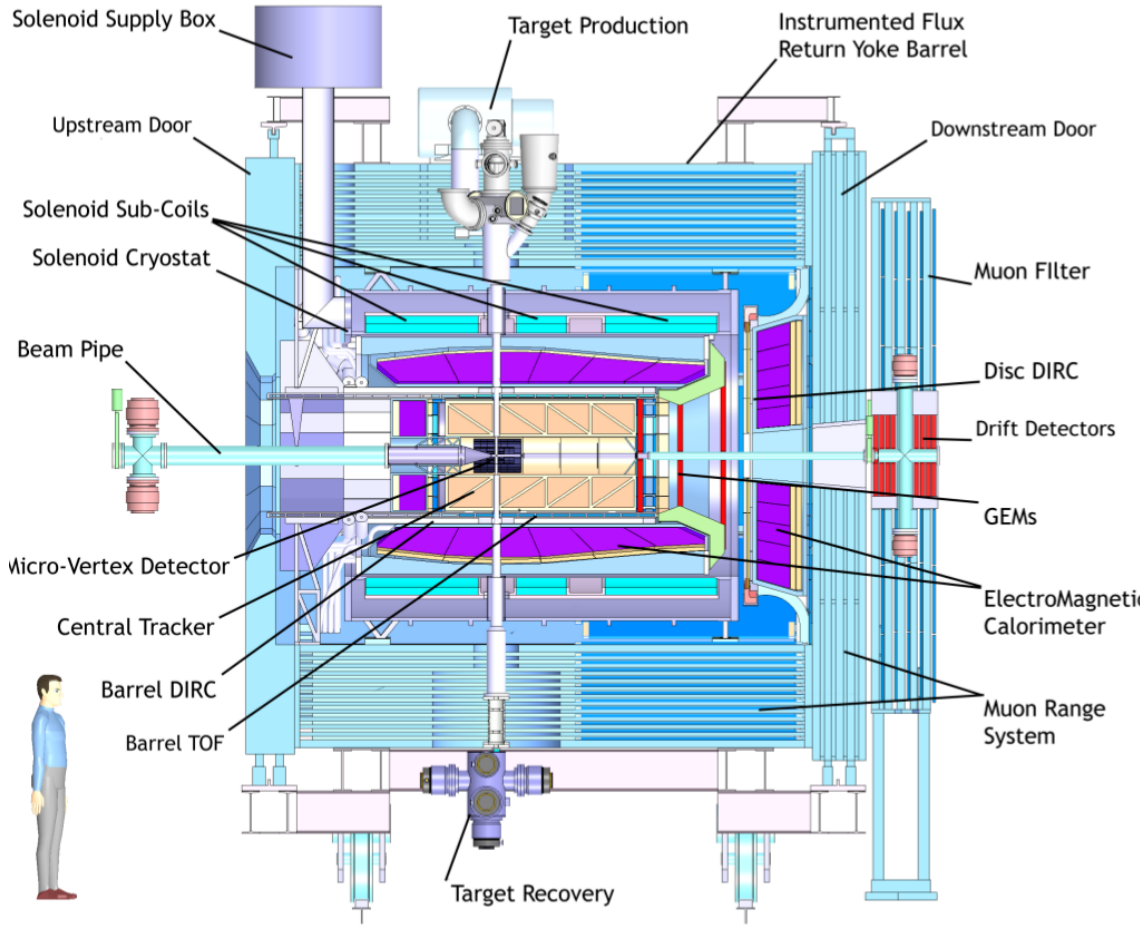
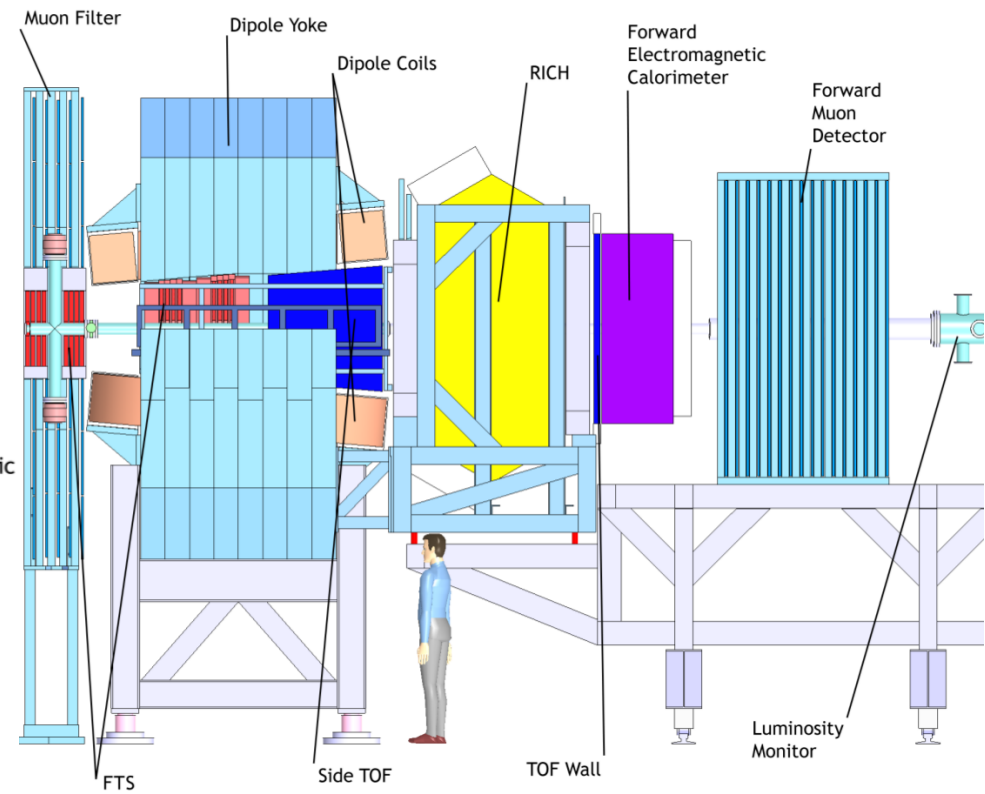
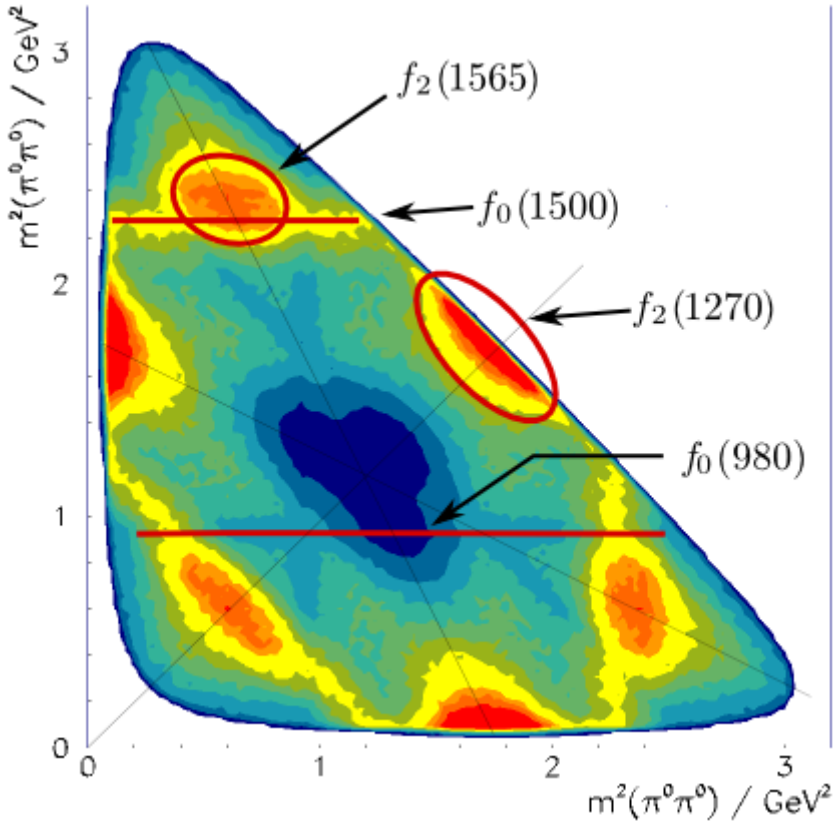




The PANDA Physics Program

- Hadron Spectroscopy and Exotic Hadrons
  - Search for Gluonic Excitations
  - Charmonium/D-Meson/Baryon Spectroscopy
- Hadrons in Matter
- Nucleon Structure
- Hypernuclei

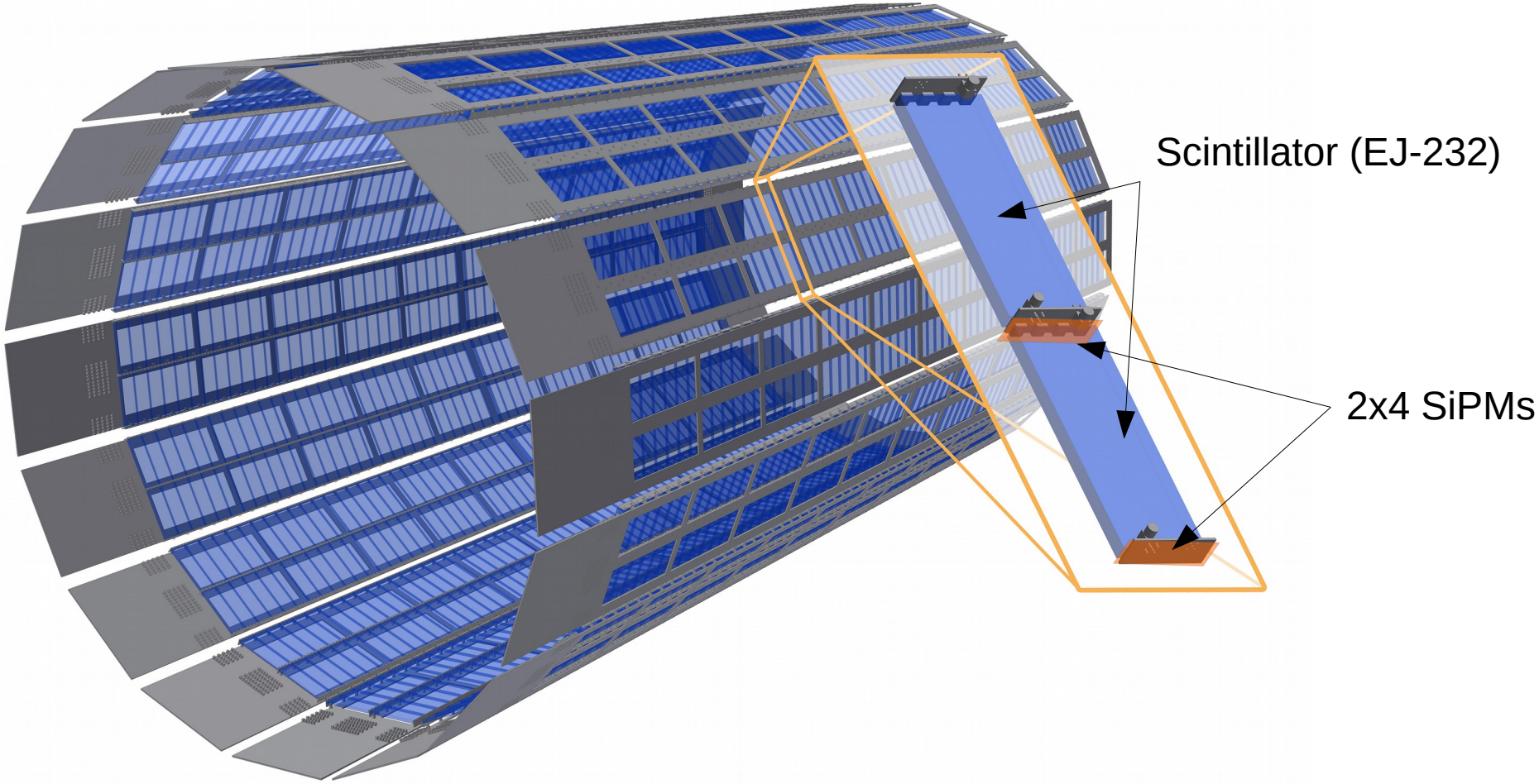


Production Stage of the Detector

- TDR internal review process ongoing
  - Submission to FAIR in 2017
- 2017-2018: development of FEE
- 2019: industrial fabrication of components
- 2020: Assembly of mechanical components
- 2021: Installation in PANDA

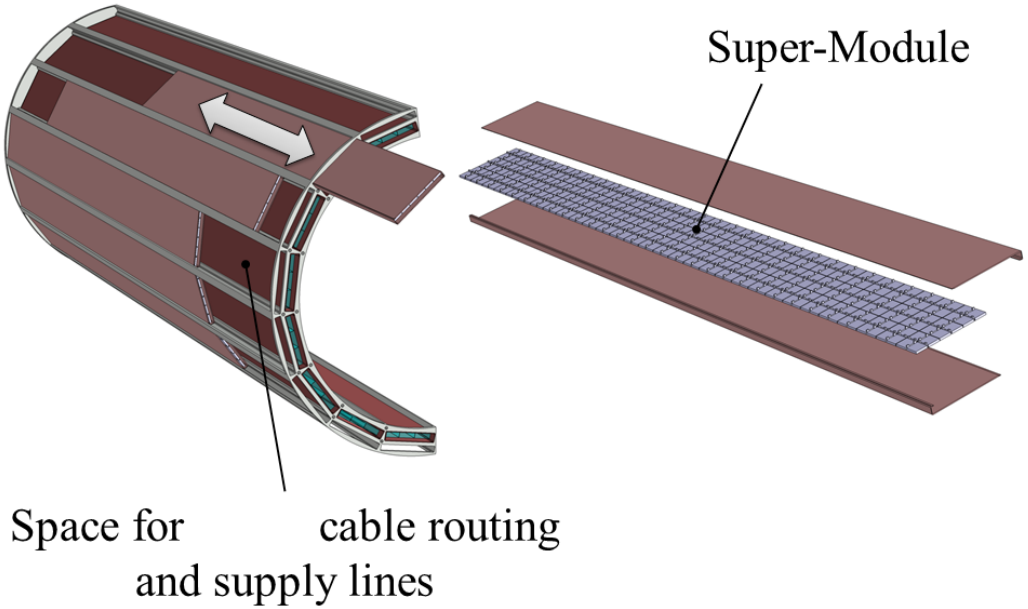
- First data taking runs should start 2022 with start-up version

The BarrelTOF



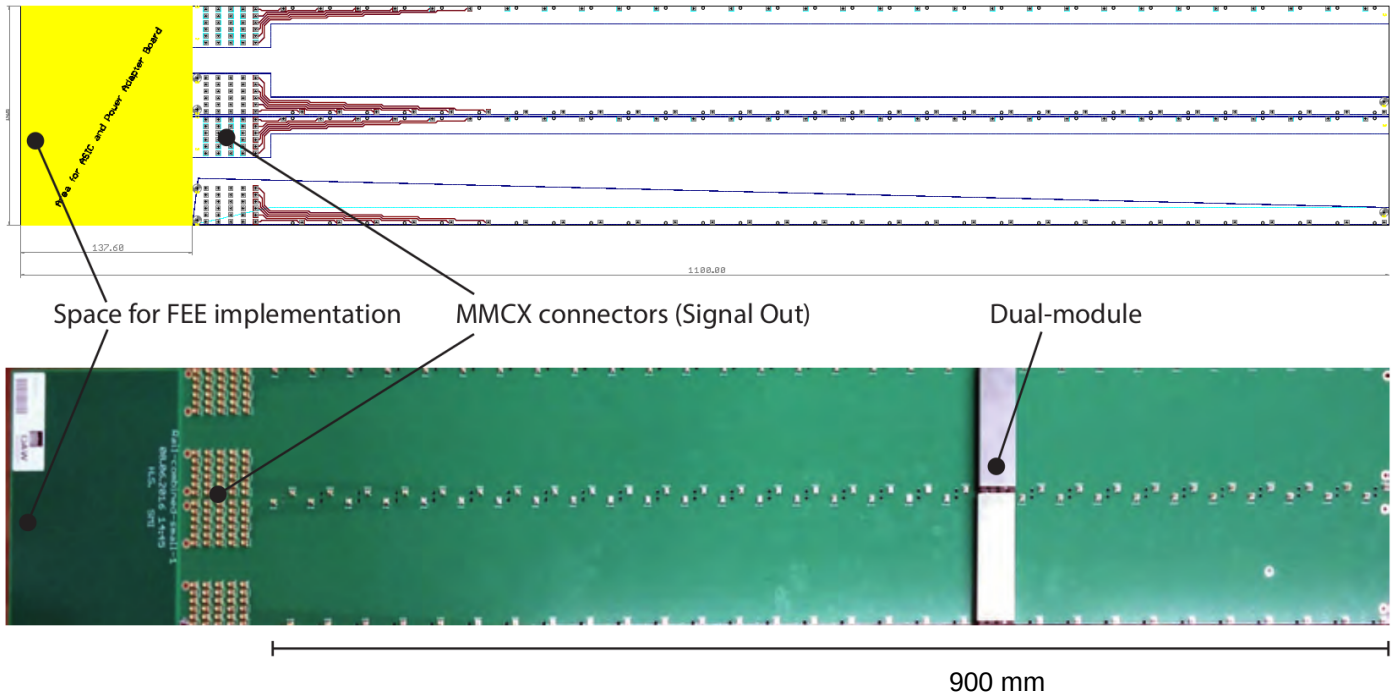
The BarrelTOF

- 16 segments (supermodule)
- 2x60 scintillating tiles per supermodule (dual module)
- Scintillator read out on two sid 4 SiPMs each
  - 4x4 SiPMs per dual module
- FEE on each supermodule
  - TOF PET ASIC from PETsys electronics
- Scintillator: EJ-232 or EJ-228 (BC-422 / BC-418)
- SiPM: 3x3 mm^2 Hamamatsu



Supermodule

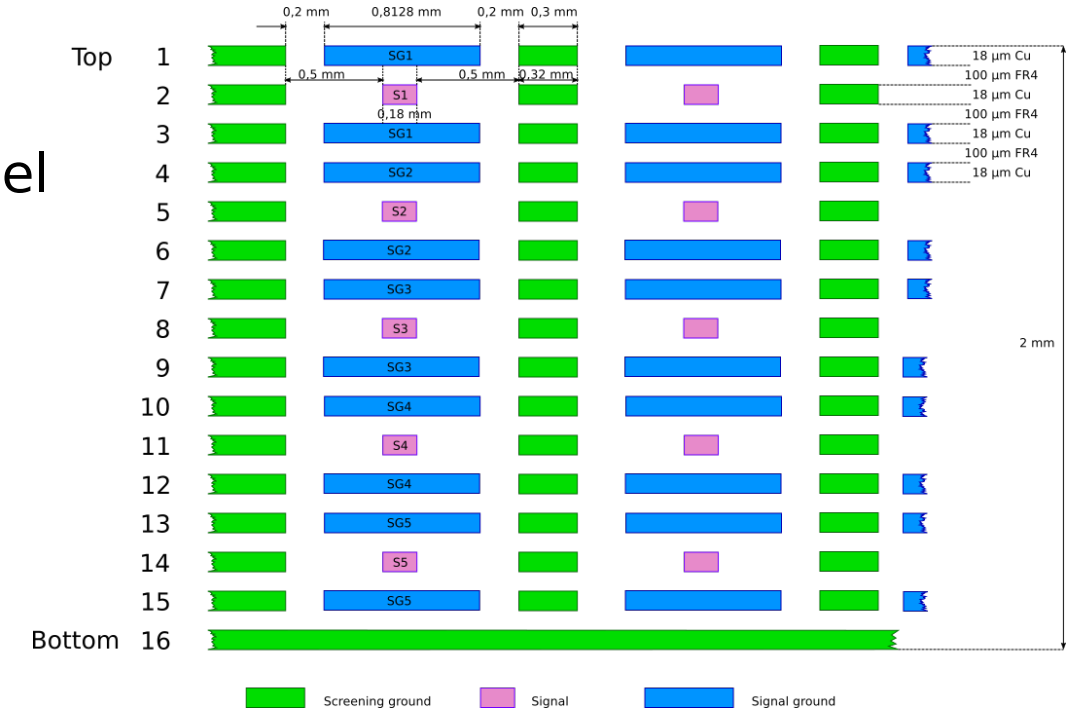
- Railboard[1] + Dualmodule + FEE
- Multilayer PCB board (currently 16 layer design)
- Mechanical support for scintillators and housing for 4x60 signal lines
- Connects 60 channels along the 1800 mm active area
- FEE embedded in the backward side of the board



[1] inspired by MEGII: arXiv:1301.7225

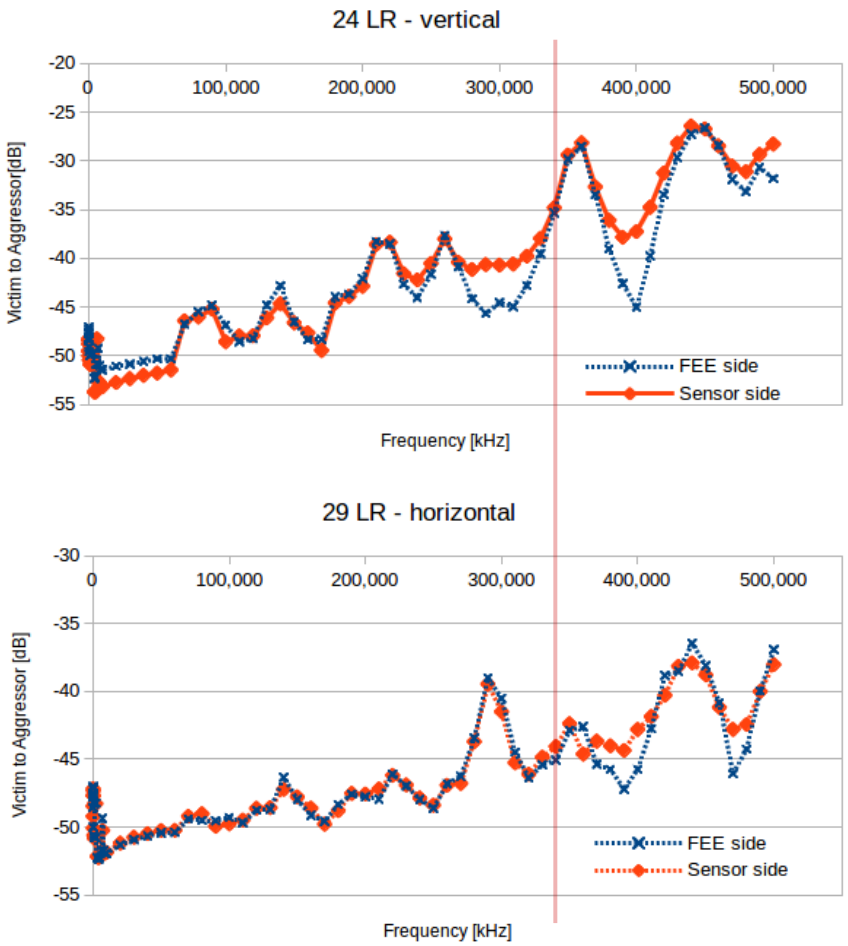
Railboard Crossection

- Screening ground lines (green) interconnected
- Signal shielding above and below signal line
  - Separate for each channel
- Line thickness of 18 µm
- Separated by 100 µm FR4



Crosstalk

- Using sinusoidal signal
- SiPM Signal risetime in order of 1 ns
  - > corresponds to 350 MHz
  - Approx. 2.5% crosstalk level
- Crosstalk level higher for vertical neighbours
- With a real signal crosstalk only appears with >1V amplitudes (above expectation)
  - At a approx. -53 dB (0.2 %) level for 1.5 V



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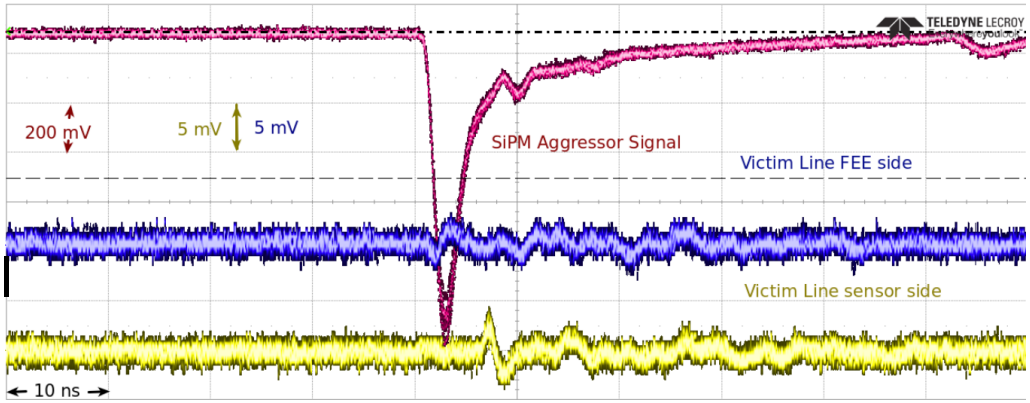
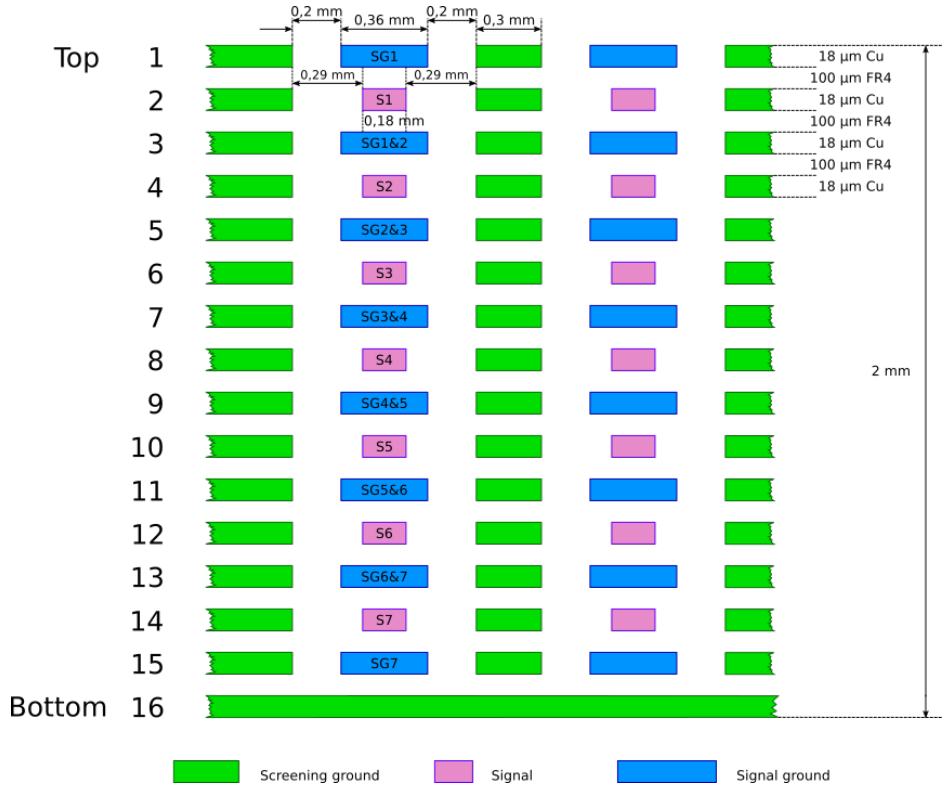


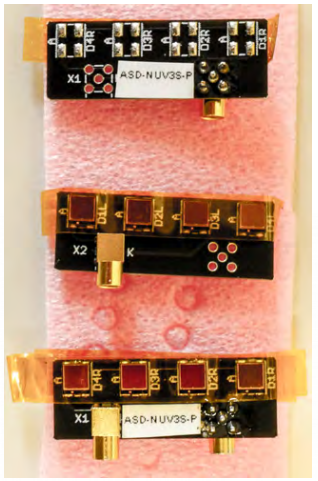
New Design

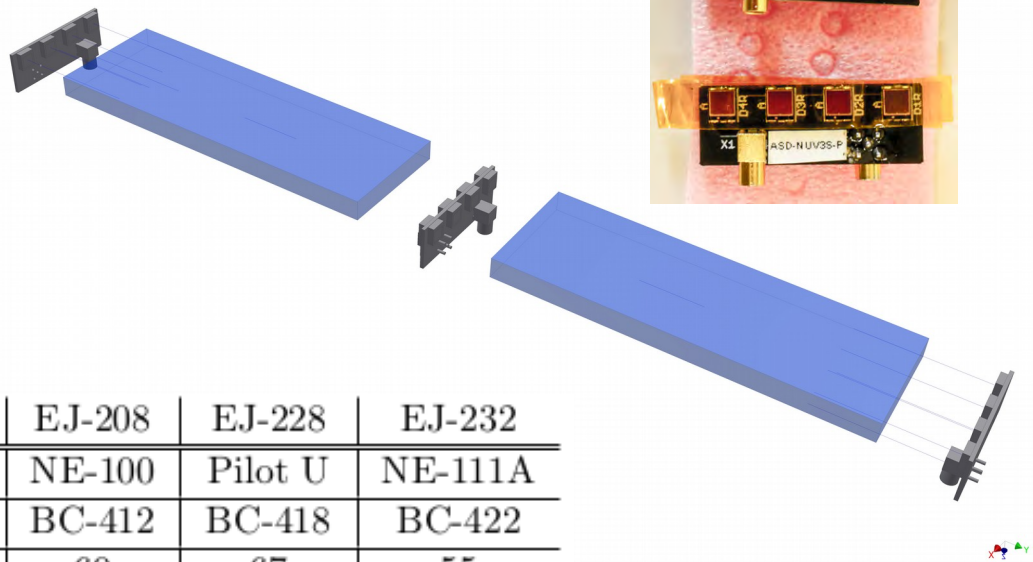
- Signal shields merged and width reduced
- Potential thickness increase to 35 µm
- Width of area occupied by connections reduced
  → material budget reduced
  - Previously approx. 2.4% X_0



Dual Module

- Two scintillating tiles read out on two sides each
  - Dimensions: 87x29.4x5 mm³
- Readout by Hamamatsu SiPM ar

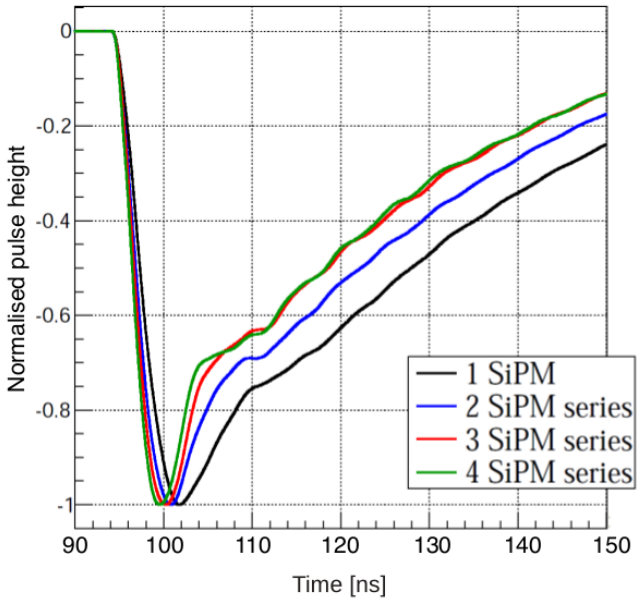


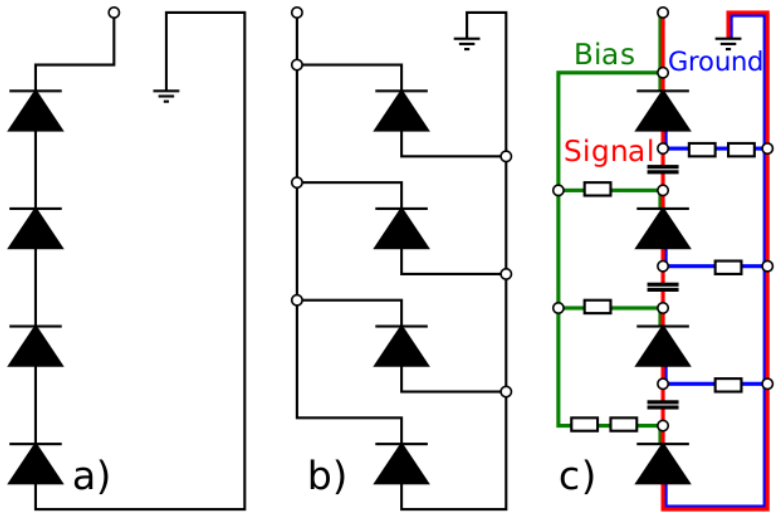


	EJ-200	EJ-208	EJ-228	EJ-232
Equivalent product by NE	Pilot F	NE-100	Pilot U	NE-111A
Equivalent product by Saint-Gobain/Bicron	BC-408	BC-412	BC-418	BC-422
Light Output (% Anthracene)	64	60	67	55
Scintillation Efficiency (photons/ 1 MeV e^-)	10,000	9,200	10,200	8,400
Wavelength of Maximum Emission (nm)	425	435	391	370
Light Attenuation Length (cm)	380	400	- (120?)	10
Rise TIme (ns)	0.9	1.0	0.5	0.35
Decay Time (ns)	2.1	3.3	1.4	1.6
Pulse Width, FWHM (ns)	2.5	4.2	1.2	1.3

SiPM Configuration

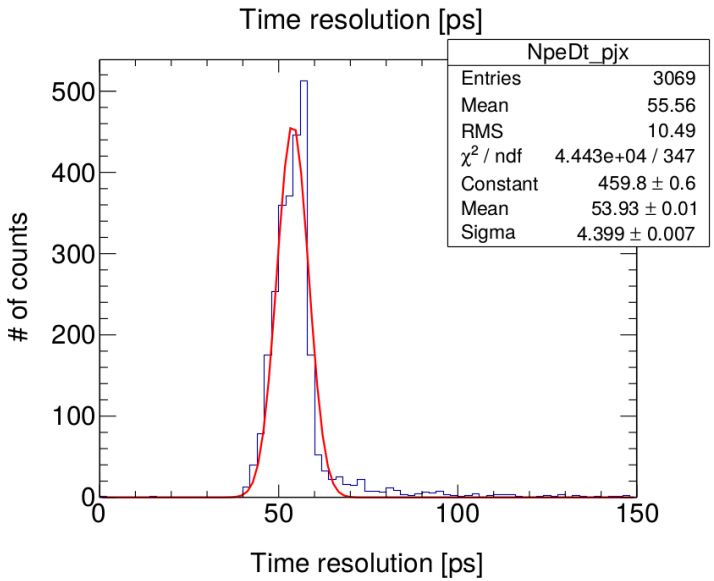
- SiPMs will be connected in series or in hybrid[1] configuration (insert image right)
- Simplifies readout (1 channel for 4 SiPMs)
- Serial connection improves signal rise time
- Hybrid connection can only provide one voltage value to all 4 SiPMs

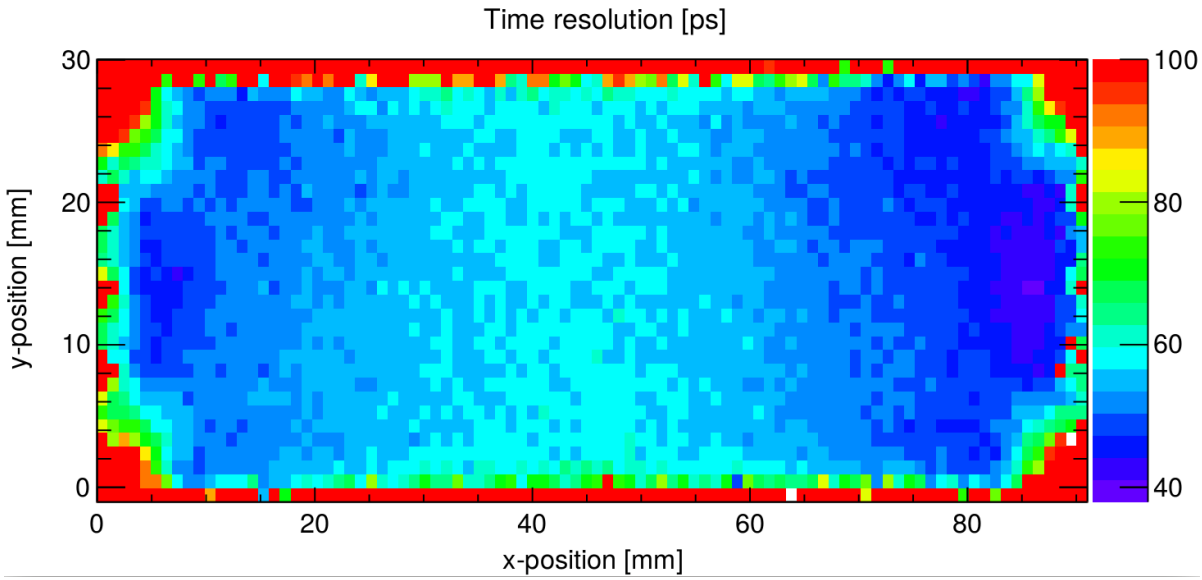




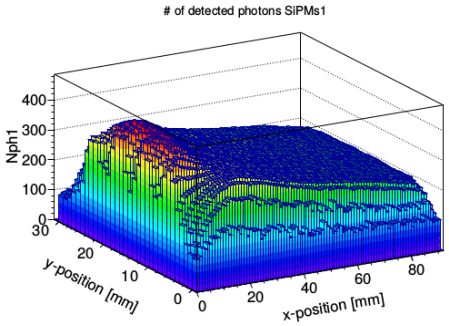
[1] Inspired by MEGII: arXiv:1301.7225

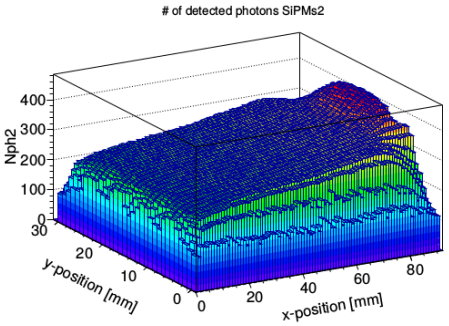
Measurement Results

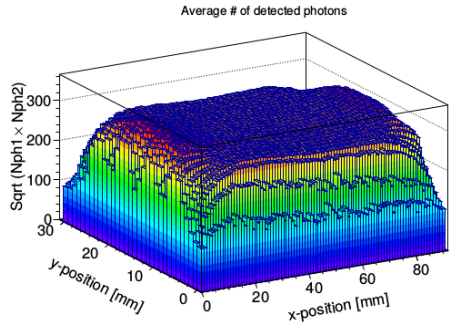




Measured with EJ-232
(90x30x5 mm³),
4 x HPK S13360-3050-PE







Measurement Results

- Wrapping material has impact on time resolution
  - More photons =! better time resolution
- Position resolution form timing differences
  - Sigma = 5.5 mm in x direction

EJ-232

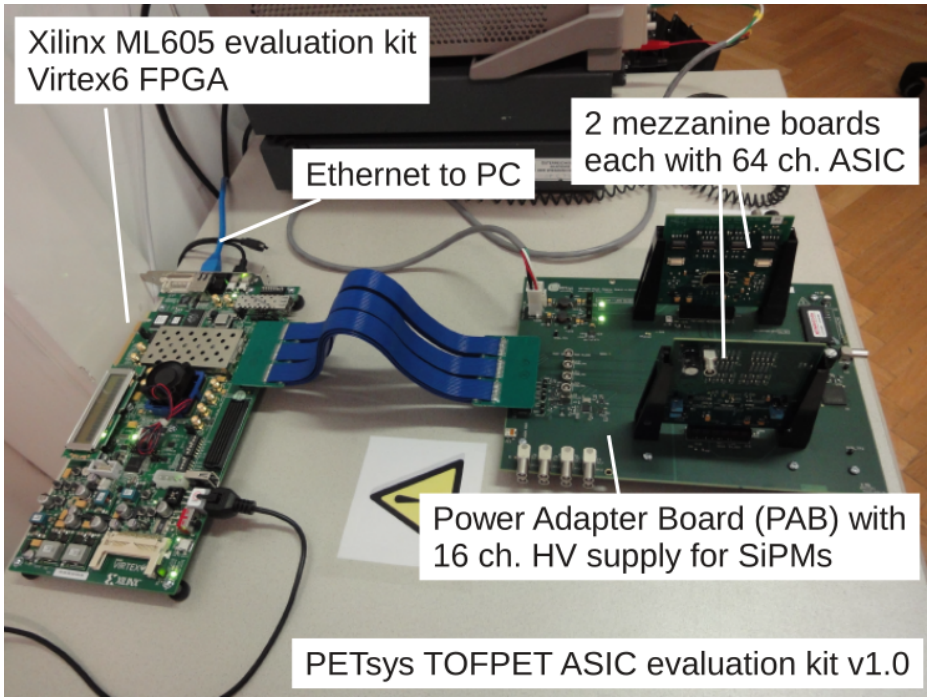
Wrapping material	Time resolution [ps]	Number of detected photons
No wrapping	55.0 ± 0.3	288 ± 2
Aluminised Mylar foil	52.7 ± 0.3	355 ± 2
Tyvek hardstructure 1057D	55.0 ± 0.3	394 ± 3
Enhanced specular reflector (ESR)	55.2 ± 0.3	355 ± 3
Teflon tape	59.4 ± 0.3	408 ± 4
aluminium foil	54.2 ± 0.3	344 ± 3

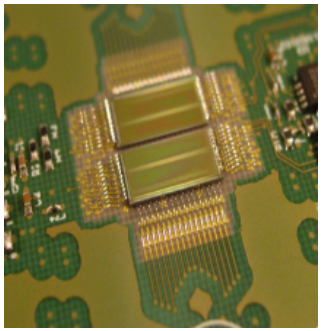
EJ-228

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

Front End Electronics (FEE)

- Data will be processed by the TOF PET ASIC produced by the company PETsys Electronics

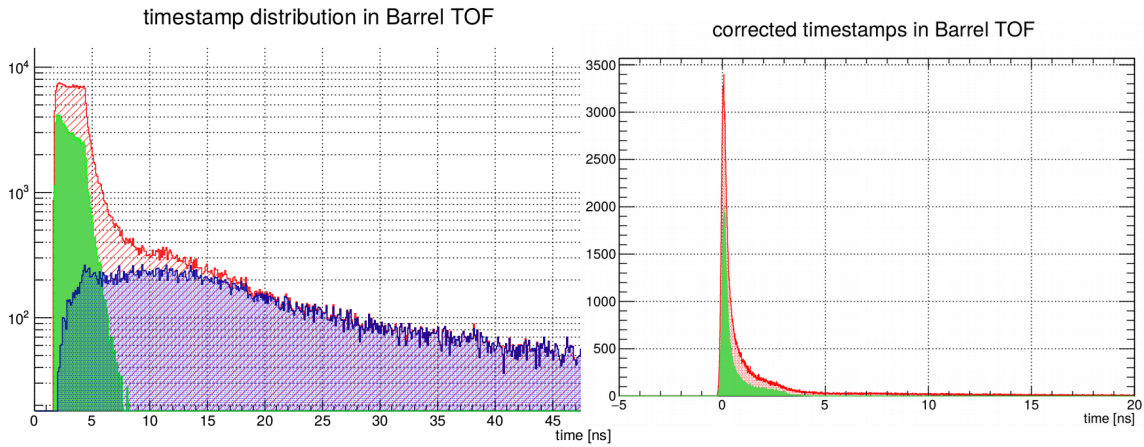




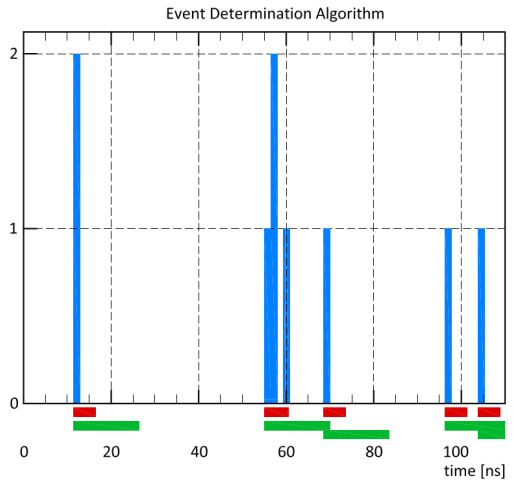
TOFPET ASIC by PETsys Electronics	
number of channels	64
TDC time binning	50 ps (25 ps optional)
intrinsic time resolution	21 ps r.m.s.
charge measurement	time over threshold (ToT)
dynamic range	300 pC
SNR (Qin = 200 pF)	25 dB
coarse gain	G0, G0/2, G0/4
SiPM familiy support	positive or negative signal 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

Event Sorting

- PANDA is a trigger-less system
- Event rates up to 20 MHz
  → occasional overlap of events
- Challenge is to find all events and save all interactions with minimum of doubled data
- Simple speed of light correction applied
- 99% of primaries and 75% of all arrive in 4 ns



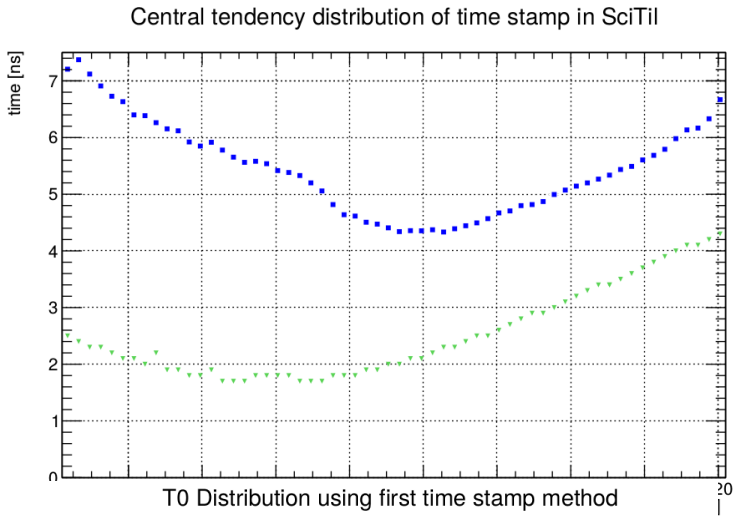
Long tail due to neutrons and neutron secondaries



event rate	$\#t_0$ candidates/ $\#t_0$(MC)	#correctly identified/ $\#t_0$(MC)	#missed events/ $\#t_0$(MC)	#ghosts/ $\#t_0$(MC)
2 MHz	1.73	0.93 (0.935)	0.065	0.8
20 MHz	1.55	0.89 (0.93)	0.07	0.66
20 MHz with ghost reduction	1.12	0.83 (0.87)	0.12	0.29

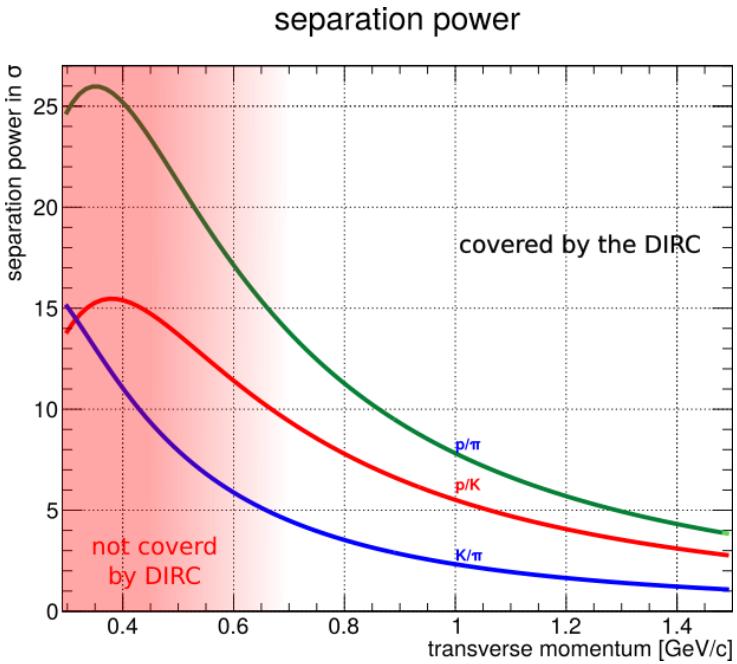
Event time Determination

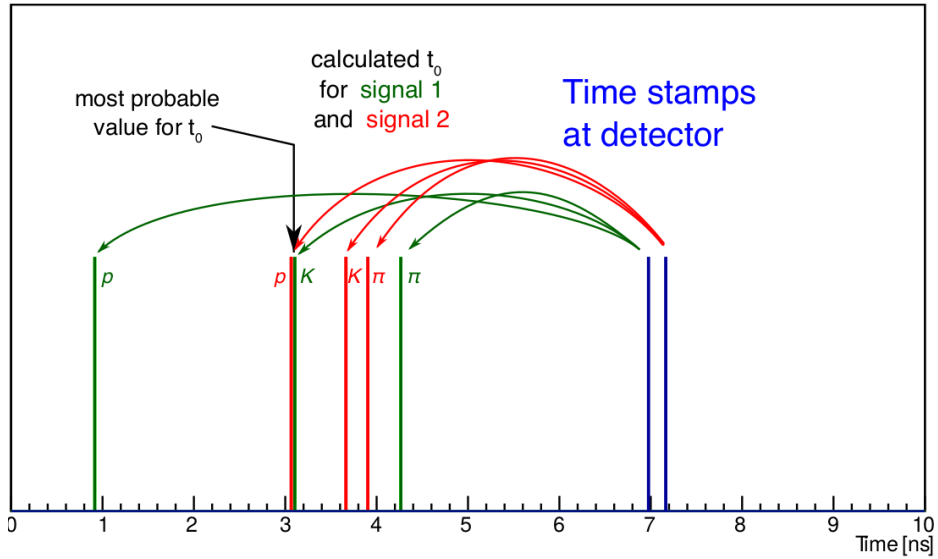
- t_0 = collision time of event
- Done by using track reconstruction and momentum information of other subdetectors
- Not possible for online t_0 determination
- Angle dependent average travel times are used for online reconstruction
- Simulations produce distribution with sharp peak but long tail
- Resolution for different algorithms:
  - 2.3 ns for peak correction (green)
- More events → better resolution (10 hits, 0.4 ns)
- Average of 4 hits per event



Particle Identification (PID)

- Different particle masses are assumed and corresponding t_0 calculated from track and momentum information





- Time resolution for 3 or more track of 167 ps
- Very good separation power for particles with low momentum
  - Important for particles below the Cherenkov threshold

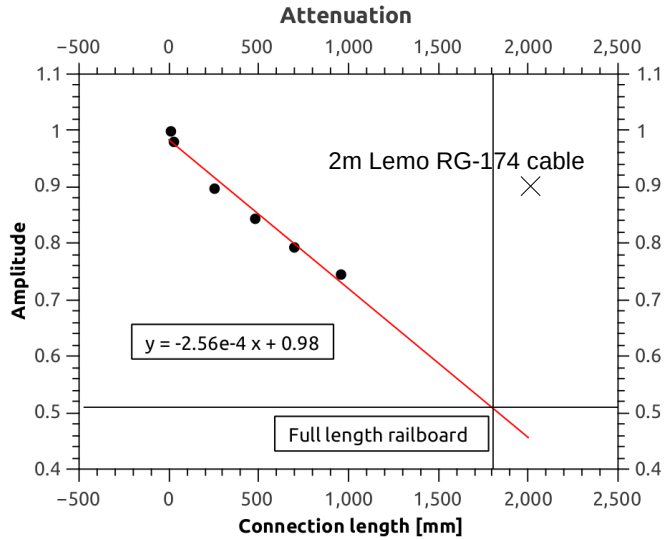
Summary

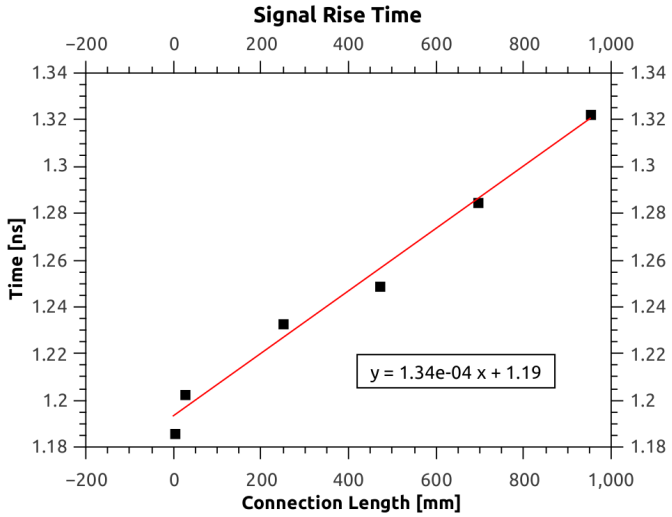
- Detector TDR is being reviewed internally
- Installation planned for 2021
- PCB in coaxial structure for mechanical tile support as well as signal transmission and FEE housing
- 90x30x5 mm³ palstic scintillating tiles (EJ-232 or EJ-228)
- Time resolution of 55.5 ps achieved
- Online t_0 determination with 2.3 ns resolution
- Offline t_0 determination with 168 ps for 3 or more hits
- Separation power below DIRC threshold is at high values above 15 sigma

Thank you for your attention

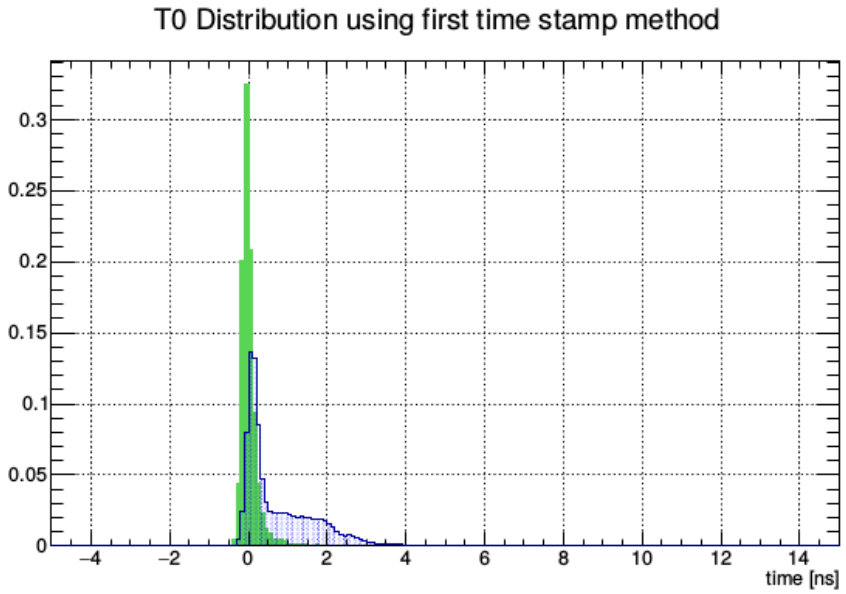
Attenuation

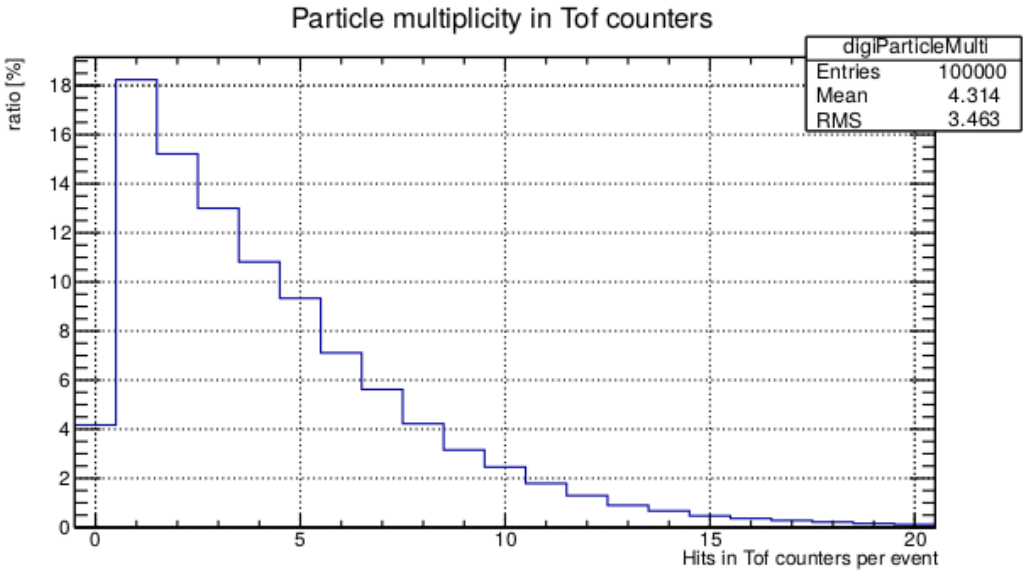
- Attenuation measured with SiPM pulses
  - Extrapolated to full length board
- Linear loss of 26% of maximum amplitude per meter
- Rise time increases by 0.13 ns per meter



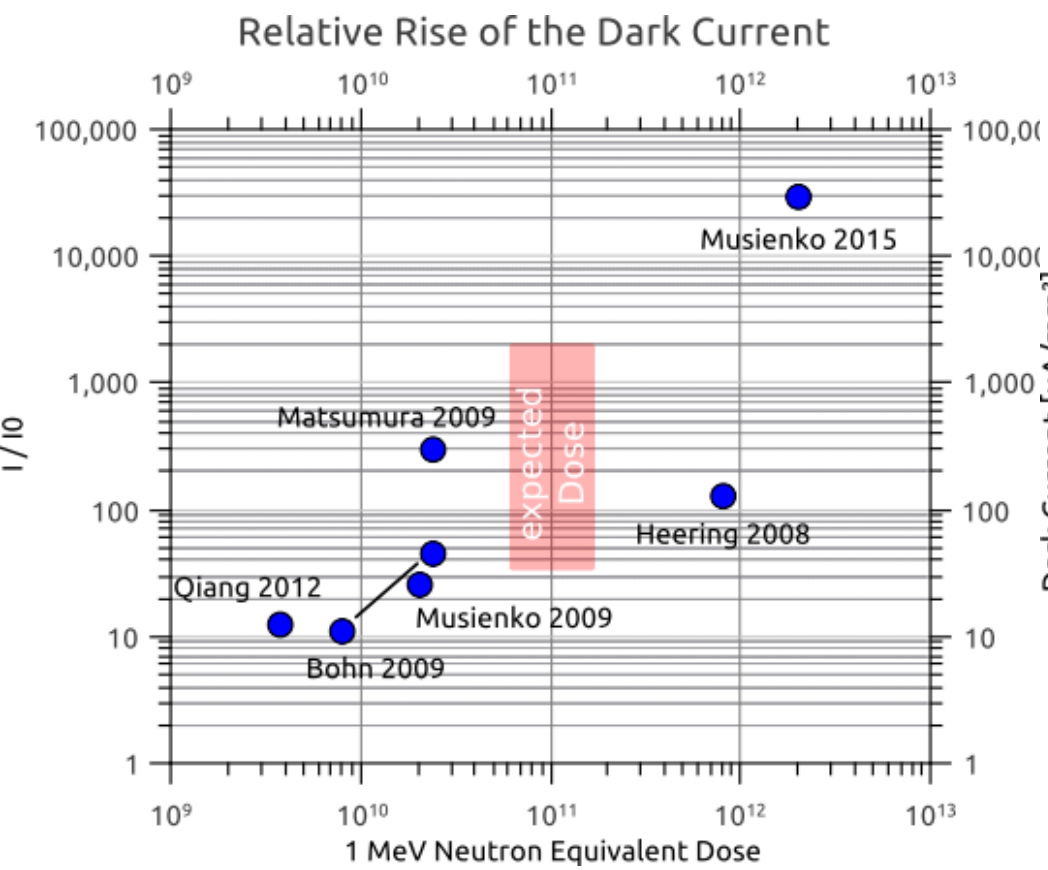


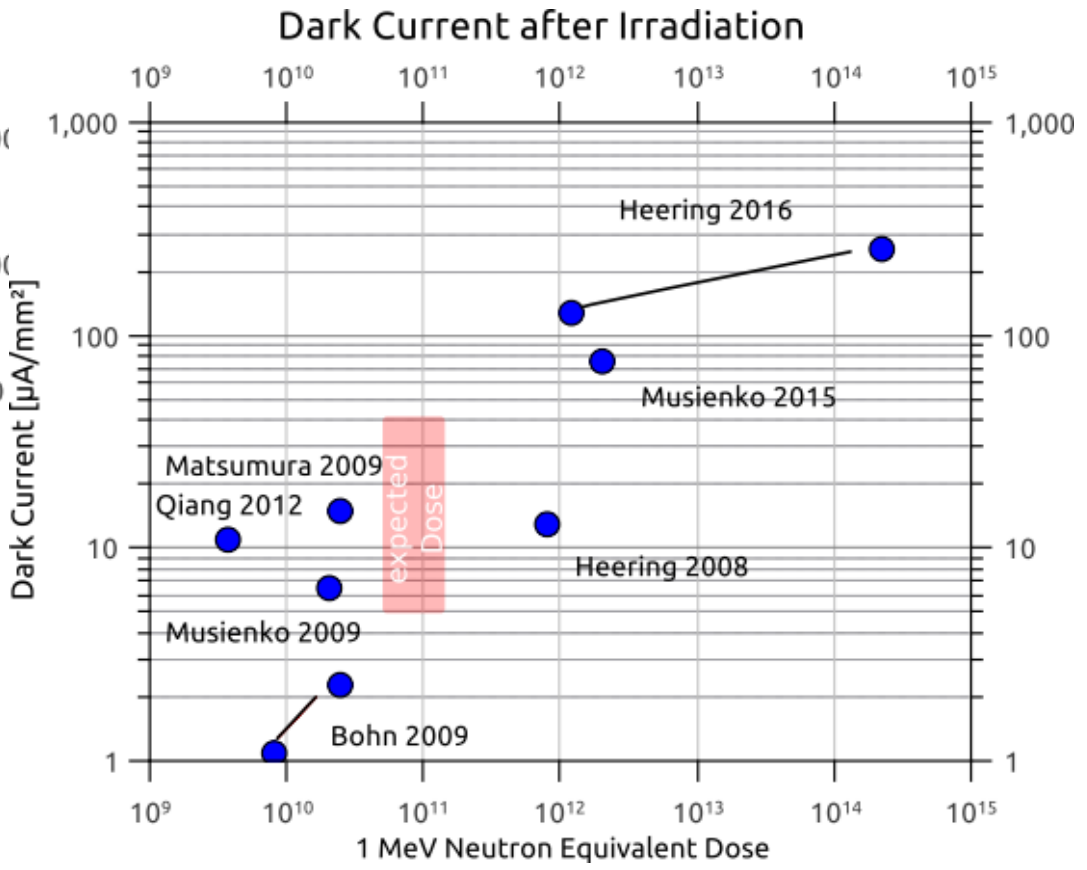
Backup


T0 Distribution using first time stamp method
0.3
0.25
0.2
0.15
0.1
0.05
0
−4
−2
0
2
4
6
8
10
12
14
time [ns]


Particle multiplicity in Tof counters
digiParticleMulti
Entries 100000
Mean 4.314
RMS 3.463
ratio [%]
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
Hits in Tof counters per event

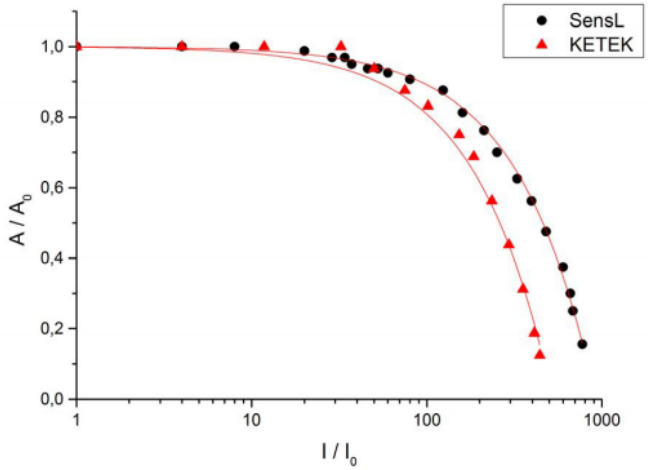
Summary of the Literature Study

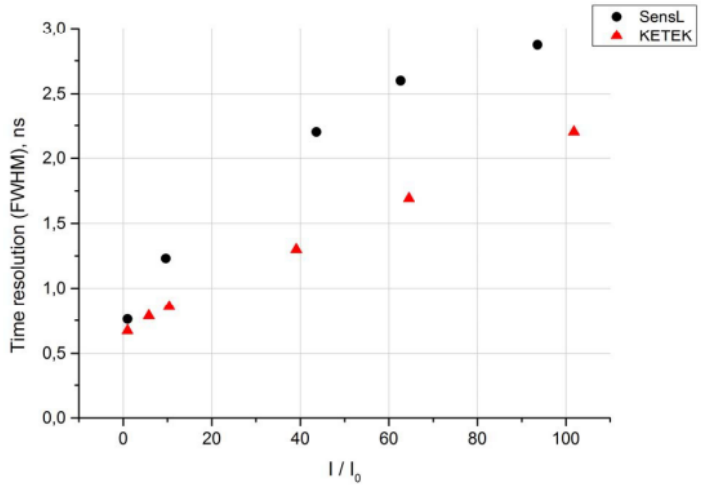




Simulation of dark current increase

- 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





Time resolution expectation

- Expected current between 8 and 40 μA/cm^2
- For 3x3 mm^2 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

Scintillator Radiation Damage

Irradiation with Co^{60}