Barrel time-of-flight detector for the PANDA experiment at FAIR

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on behalf of the PANDA TOF Group

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The PANDA experiment at FAIR

The PANDA experiment [1] is going to be installed at the Facility for Antiproton and Ion Research (FAIR) [2], which is currently under construction as an expansion of the GSI Helmholtz Centre. Upon completion the facility will be one of the largest accelerator facilities in the world (Fig. 1).

The PANDA detector is located at the High Energy Storage Ring (HESR) of FAIR. The experiment will address fundamental questions of QCD, studying interactions between antiprotons and fixed target protons and nuclei. PANDA will be able to deliver high statistics and unprecedented precision by providing the following features:

- High yield of antiproton induced reactions (gluon rich)
- Very high precision for mass and width measurements
- Momentum range: 1.5 GeV/c to 15 GeV/c
- High luminosity: up to L = 2 × 10^{32} $cm^{-2}s^{-1}$
- High momentum resolution: $\delta p/p \approx 10^{-5}$
- Versatile detector with large acceptance (Fig. 2)

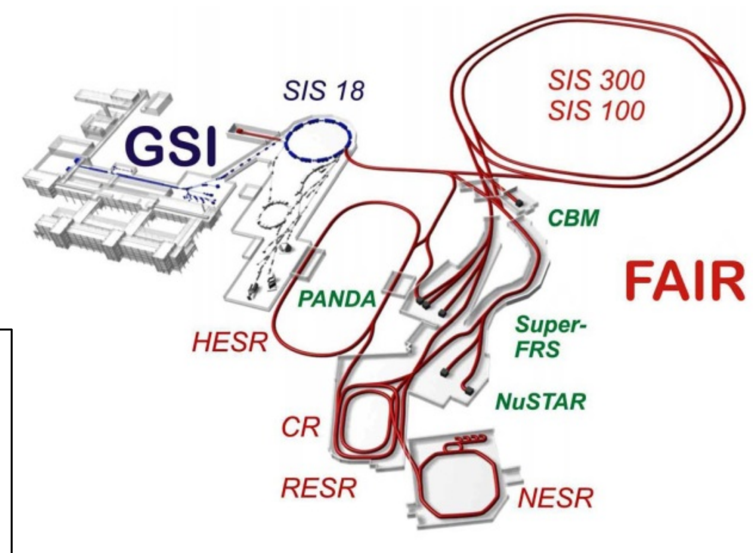
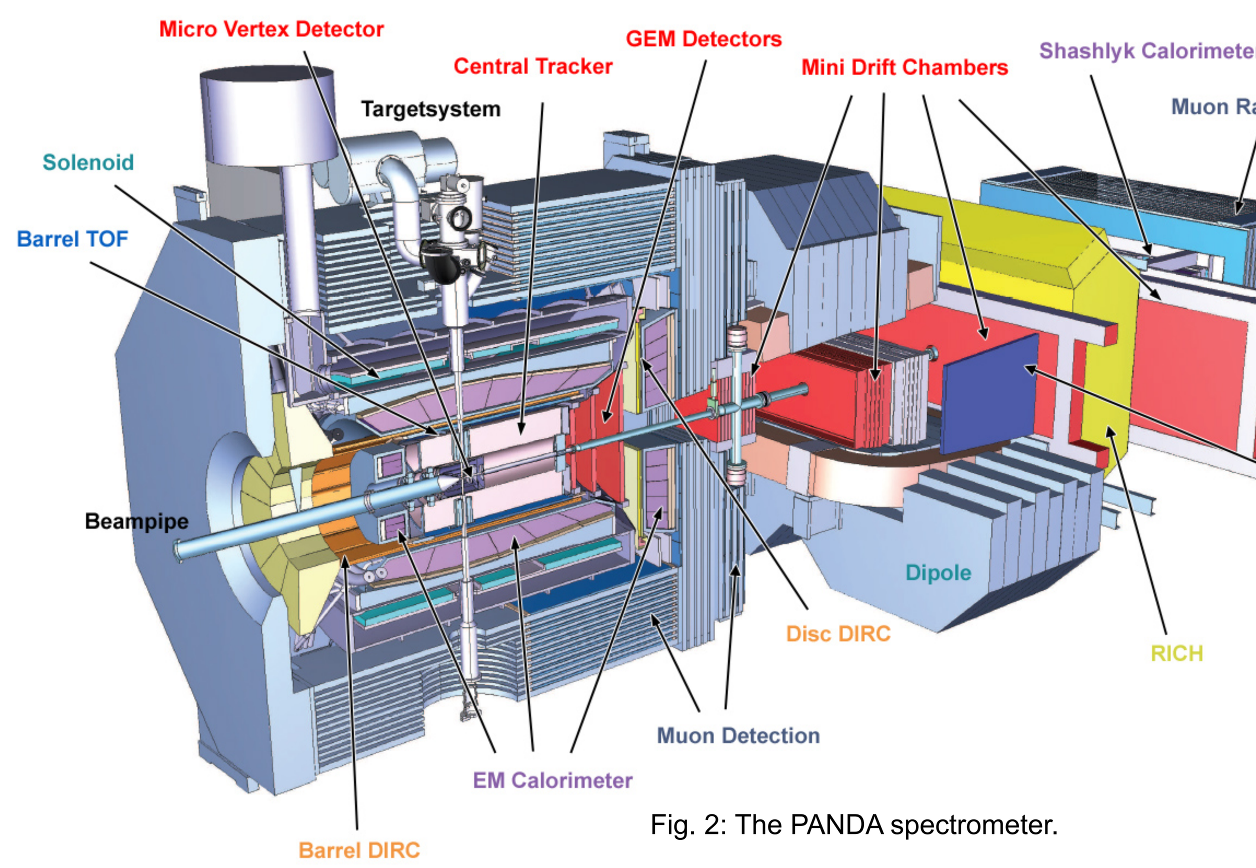


Fig. 1: The FAIR accelerator complex.



TOF Wall

Fig. 2: The PANDA spectrometer.

PANDA physics program:

- Hadron spectroscopy
- Exotic hadrons
- Hadrons in nuclear matter
- Hypernuclear research
- Hadron structure
- …

The PANDA barrel time-of-flight detector

The barrel time-of-flight (TOF) detector has to provide important input to event building and software triggering at high collision rates with N_{avg} = 20 MHz. Apart from that it is beneficial for the overall particle identification (PID) of the PANDA experiment and can deliver unique input for other detector systems, such as the Electromagnetic Calorimeter (EMC).

Motivation:

- Event timing: no trigger in PANDA
- Event building: separation of events (see Fig. 3)
- Relative time-of-flight together with FTOF
- PID below DIRC momentum threshold (Fig. 4)
- Charge discrimination and conversion detection

Requirements:

- Minimum material
  - 2% of a radiation length
  - 2 cm radial thickness
- Good time resolution: σ < 100 ps
- Large angular acceptance (22° ≤ θ ≤ 140°)

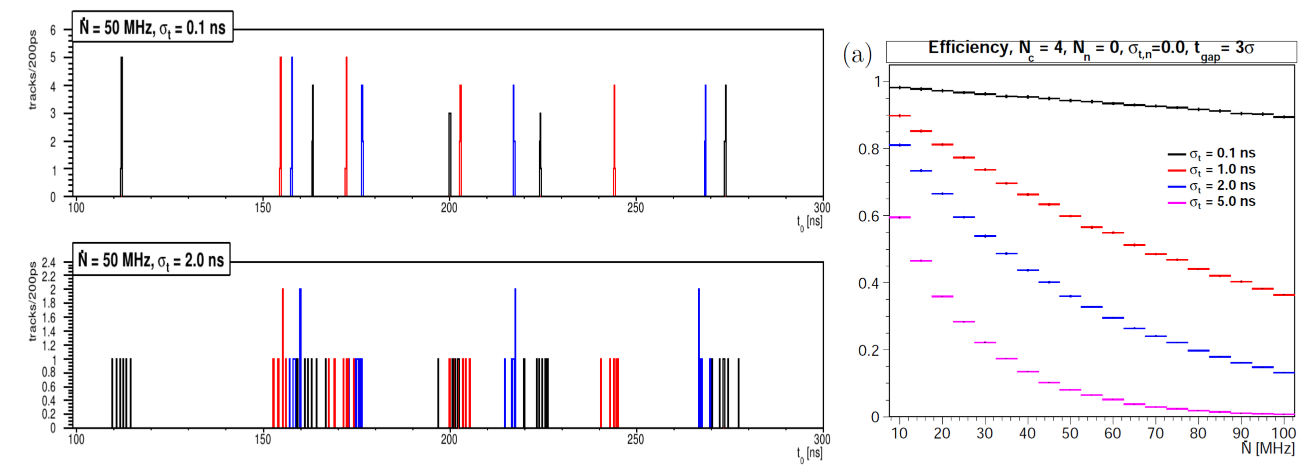


Fig. 3: Particle creation times (left) and event building efficiency (right) for different time resolutions [3].

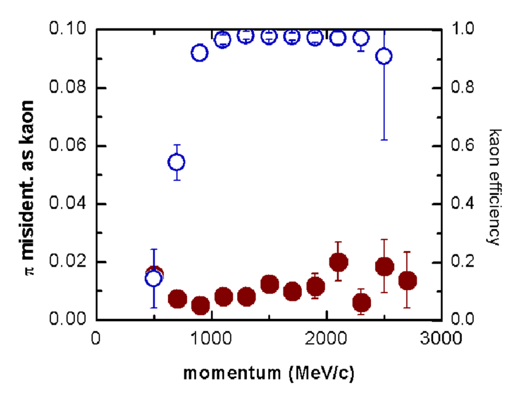


Fig. 4: Misidentification probability (red) and efficiency (blue) of the DIRC [4].

The barrel time-of-flight detector is planned as a Scintillator Tile (SciTil) Hodoscope [5], consisting of small plastic scintillator tiles readout with directly attached Silicon Photomultipliers (SiPMs), as shown in Fig. 5. The whole system is composed of 5760 scintillator tiles covering an area of about 5.2 m^2.

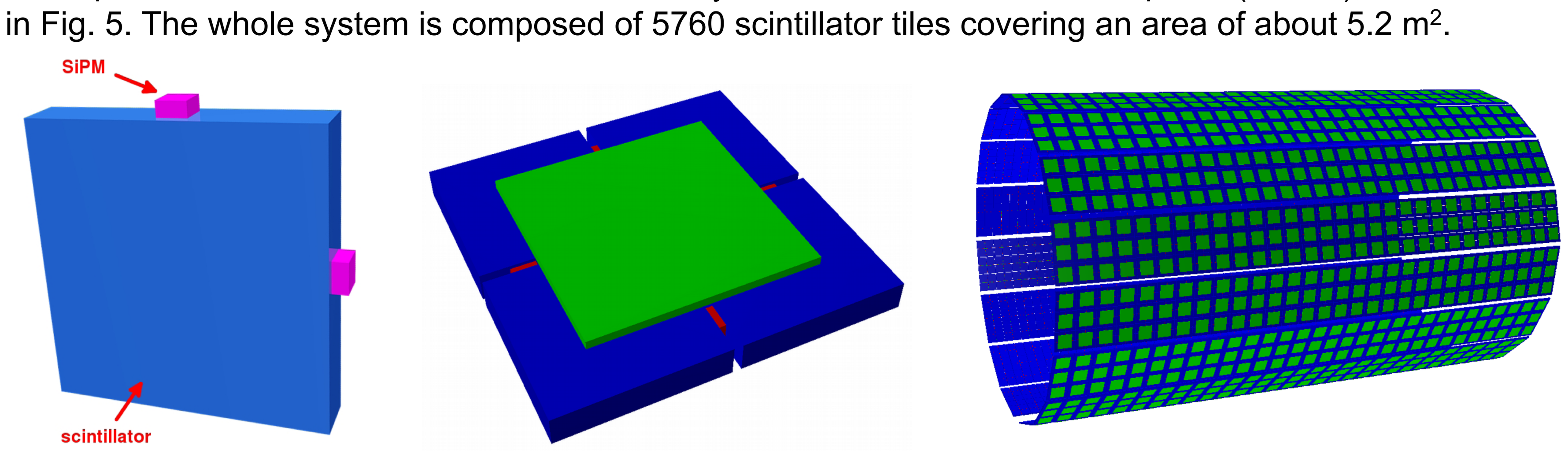


Fig. 5: From left to right: Scintillator tile (~ 30 × 30 × 5 mm^3) with SiPMs, basic module consisting of 4 tiles, SciTil barrel with r ~ 50 cm.

SciTil detector optimization

In order to reach the required time resolution of σ < 100 ps, research and development on the detector design is needed. The achievable time resolution is influenced by several parts, namely the plastic scintillator, the photodetector and the read-out electronics. The optimization has been done by performing laboratory tests using radioactive sources and lasers, test beam experiments and Monte Carlo simulations.

Photodetector: We consider analog and digital SiPMs (Fig. 6). The main advantages are:

- Good timing properties (see Fig. 7)
- Insensitivity to magnetic fields
- Low operating voltage and power consumption
- High Photon Detection Efficiency
- High gain
- Compact size

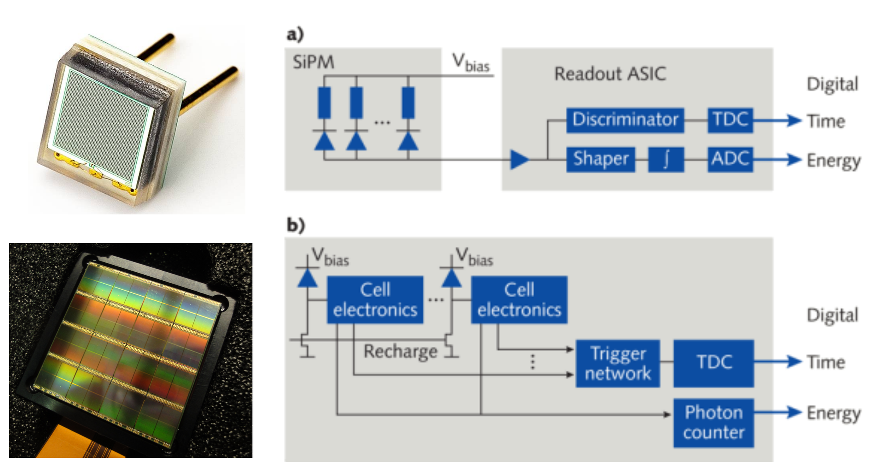


Fig. 6: Top: Analog SiPM from KETEK with schematic layout. Bottom: Digital Photon Counter (DPC) from Philips.

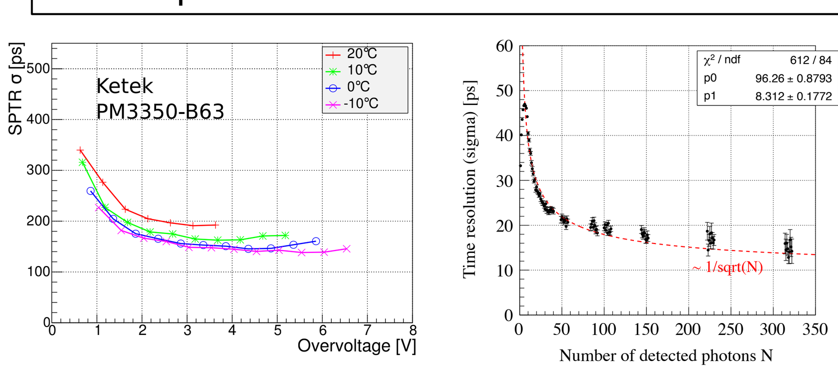


Fig. 7: Left: Single photon time resolution of a KETEK SiPM [6]. Right: Time resolution of the Philips DPC. Measured with a pulsed laser.

Scintillator: The scintillator time resolution is limited by photon counting statistics and photon propagation. Triggering on the first photon gives the best time precision (not considering the photodetector response). The optimal scintillator should have shortest rise- and decay times and highest light output (see Fig. 8).

Table 1: Plastic scintillators for fast timing applications from ELJEN.

Scintillator	EJ-232	EJ-228	EJ-204	EJ-200
Light yield [photons/MeV]	8,400	10,200	10,400	10,000
Rise time [ns]	0.35	0.5	0.7	0.9
Decay time [ns]	1.6	1.4	1.8	2.1
Wavelength of max. emission [nm]	370	391	408	425

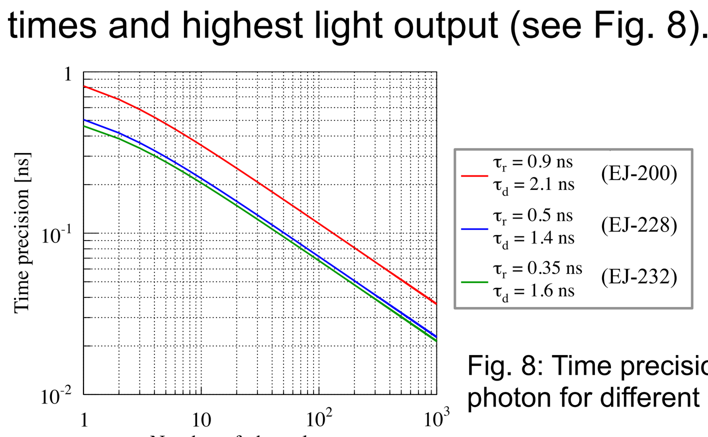


Fig. 8: Time precision of the first photon for different scintillators.

Prototyping: best time resolution reached with Philips DPC and EJ-228:

σ ~ 60 ps

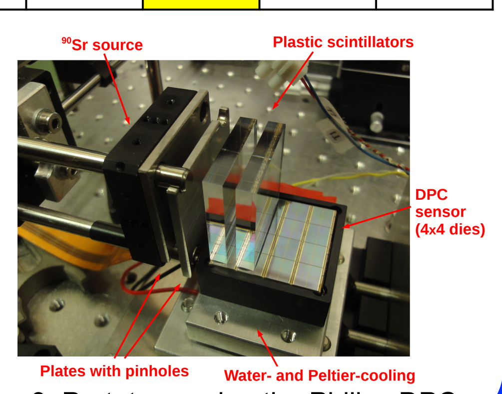


Fig. 9: Prototype using the Philips DPC.

Latest test beam results and outlook

Based on the optimization studies, a SciTil prototype has been built and tested in a proton beam at Forschungszentrum Jülich to check if a time resolution below 100 ps sigma can be achieved also in a test beam environment.

- JESSICA external beam line at COSY (Fig. 10)
- Beam: max. 2.7 GeV/c protons
- Intensity: ~ 10^4 to 10^5
- Defocused beam: ~ 5 cm × 5 cm
- 2 SciTil prototypes:
  - SciTil + SiPM (Hamamatsu and KETEK)
  - SciTil + Philips DPC

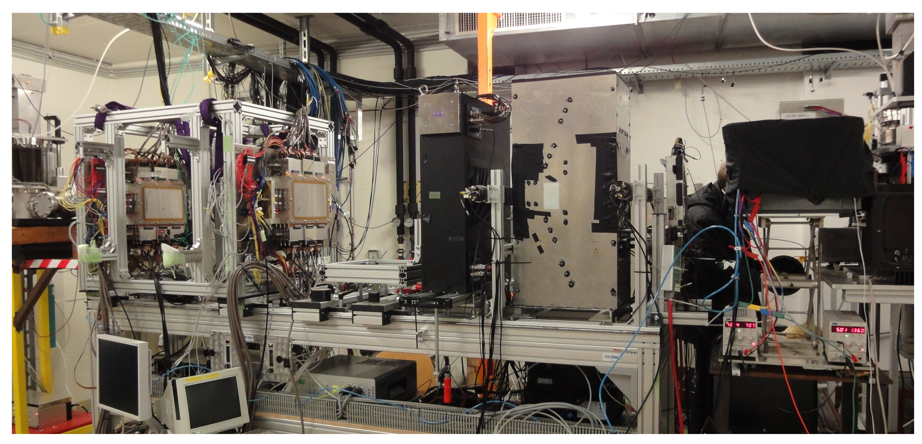


Fig. 10: The actual beam line at JESSICA. Beam is entering from the left.

SciTil-SiPM prototype:

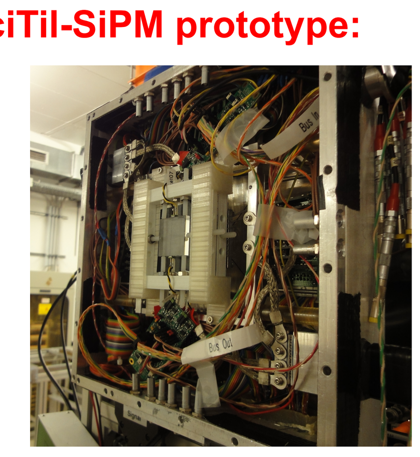


Fig. 11: The SciTil-SiPM detector.

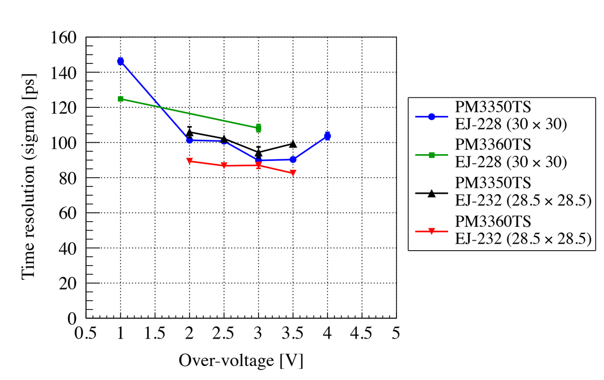


Fig. 12: Time resolution with KETEK SiPMs and ELJEN scintillators.

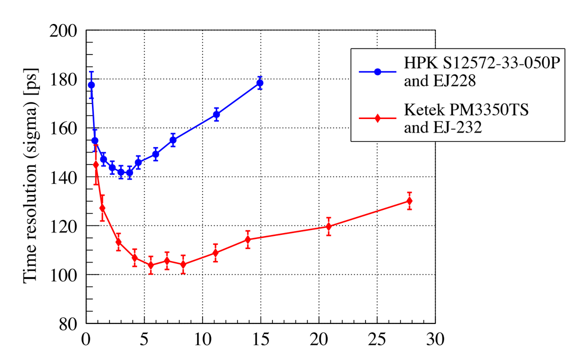


Fig. 13: Time resolution as a function of the applied threshold.

The best time resolution obtained with KETEK SiPMs: **σ = 82.5 ± 1.7 ps** (Hamamatsu: σ ~ 95 ps)
The time resolution depends on SiPM type, scintillator, voltage and threshold (1st photon not the best).

SciTil-DPC prototype:

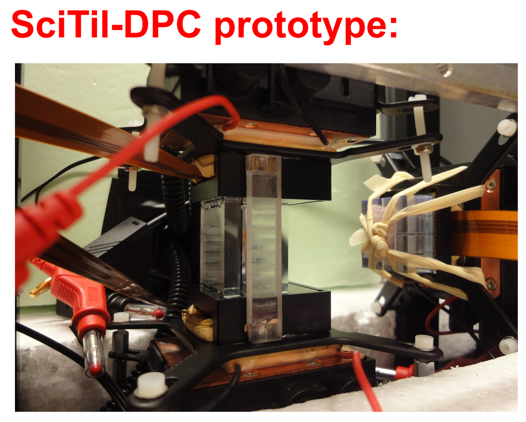


Fig. 14: The SciTil-DPC detector.

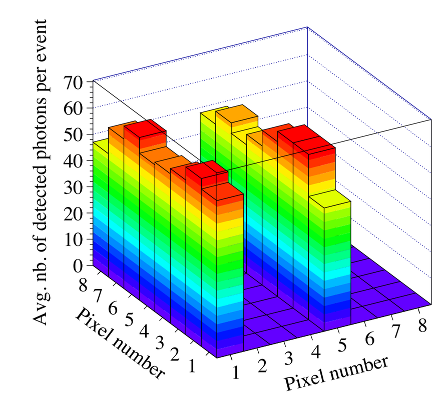


Fig. 15: Photon count per DPC pixel.

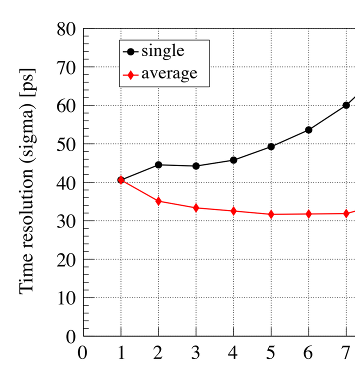


Fig. 16: Time resolution as a function of the number of used time stamps.

σ ~ 32 ps using a multiple time stamp approach.

Outlook: layout optimization (simulation), electronics R&D, PANDA Root, radiation tests, TDR, …

[1] PANDA Collaboration, *Physics Performance Report for PANDA*, PANDA Physics Report, arXiv:0903.3905 [hep-ex], Mar. 2009.
[2] H. H. Gutbrod, *FAIR – Baseline Technical Report*, Volume 1, Executive Summary, ISBN 3-9811298-0-6, Sept. 2006.
[3] K. Goetzen, *Influence of Particle Timing on Event Building*, PANDA Note, Mar. 2011.
[4] C. Schwarz, *Development of the PANDA barrel DIRC*, JINST 4 (2009) P12016.
[5] K. Goetzen et al., *Proposal for a Scintillator Tile Hodoscope for PANDA*, PANDA Note, Version 1.1, Mar. 2011.
[6] S. E. Brunner et al., *Time resolution below 100 ps for the SciTil detector of PANDA employing SiPM*, JINST 9 (2014) C03010.