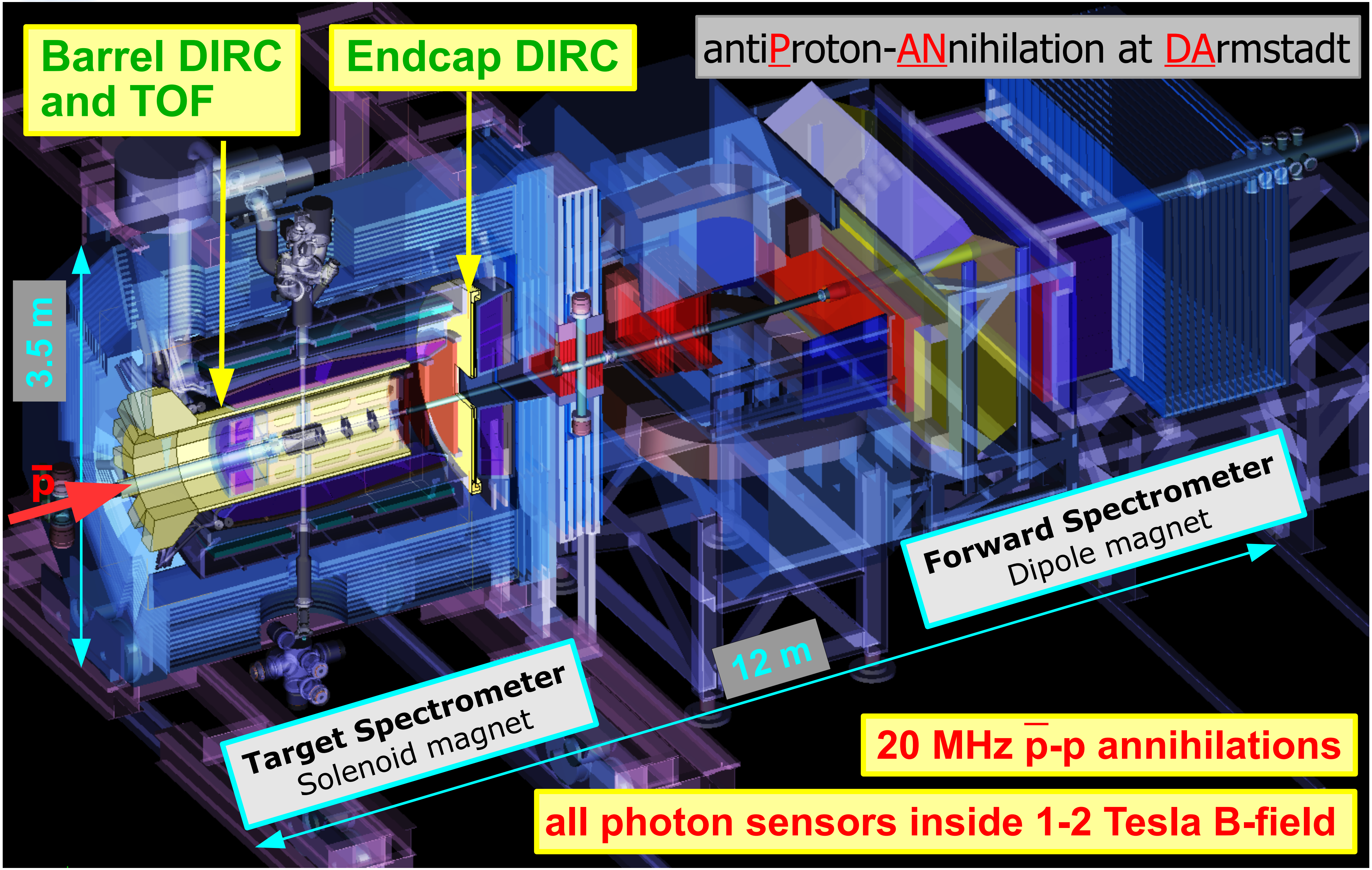
Application of SiPMs and MCP-PMTs in the PANDA PID detectors

A. Lehmann, for the PANDA TOF and Cherenkov subgroups

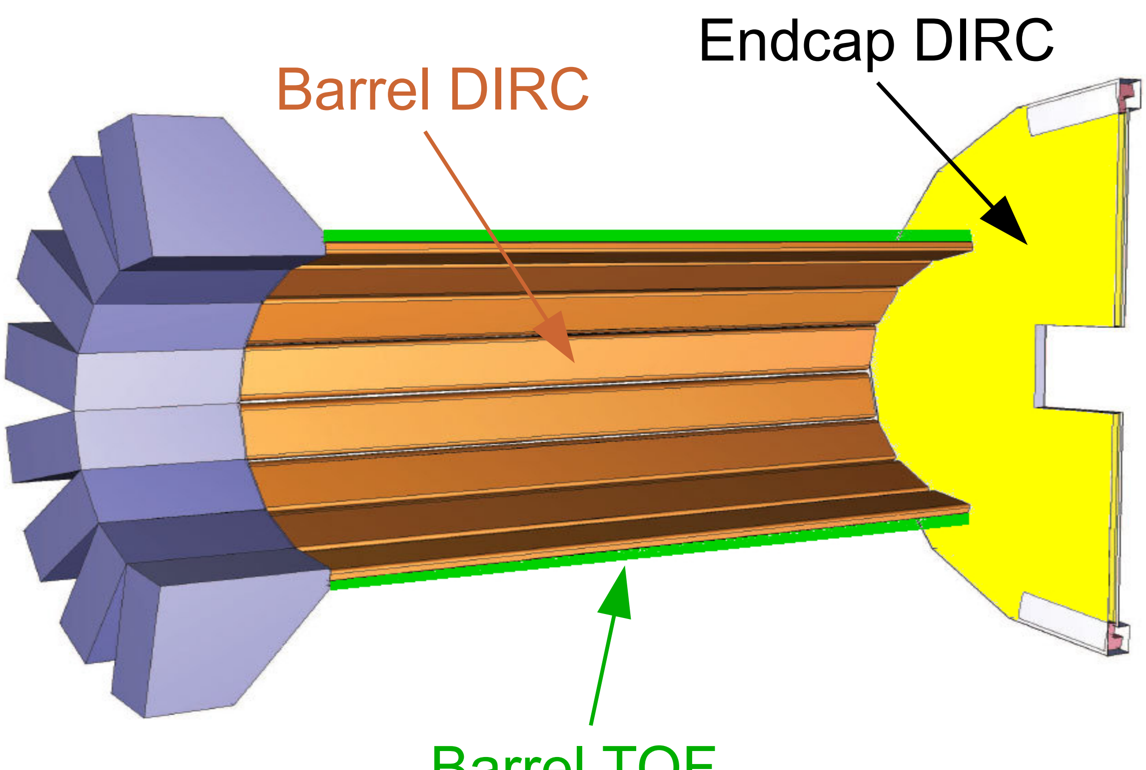
- PANDA PID detectors
- DIRC detectors and MCP-PMTs
- R&D for a high time resolution TOF detector with scintillator tiles (SciTils) and SiPMs
- Laboratory results with SciTils
- Test beam results with "MCP-TOF" counters
- Summary

$\overline{\text{P}}$ANDA Detector at FAIR



$\overline{\text{P}}$ANDA PID Detectors

- DIRC detectors
  - Identification of hadrons (π, K, …) from Cherenkov threshold to 4 GeV/c
  - Detection of 20 – 100 **single photons** distributed across a large area
  - Sensor requirements
    - >1 Tesla B-field immunity
    - <100 ps time resolution
    - **Low darkcount rate**
- Barrel TOF detector
  - PID below $\beta \approx 0.68$
  - Event timing
  - Small scintillating tiles
  - Sensor requirements
    - >1 Tesla B-field immunity
    - <<100 ps time resolution
    - Detection of **multiple scintillation photons**
    - → darkcount rate not an issue



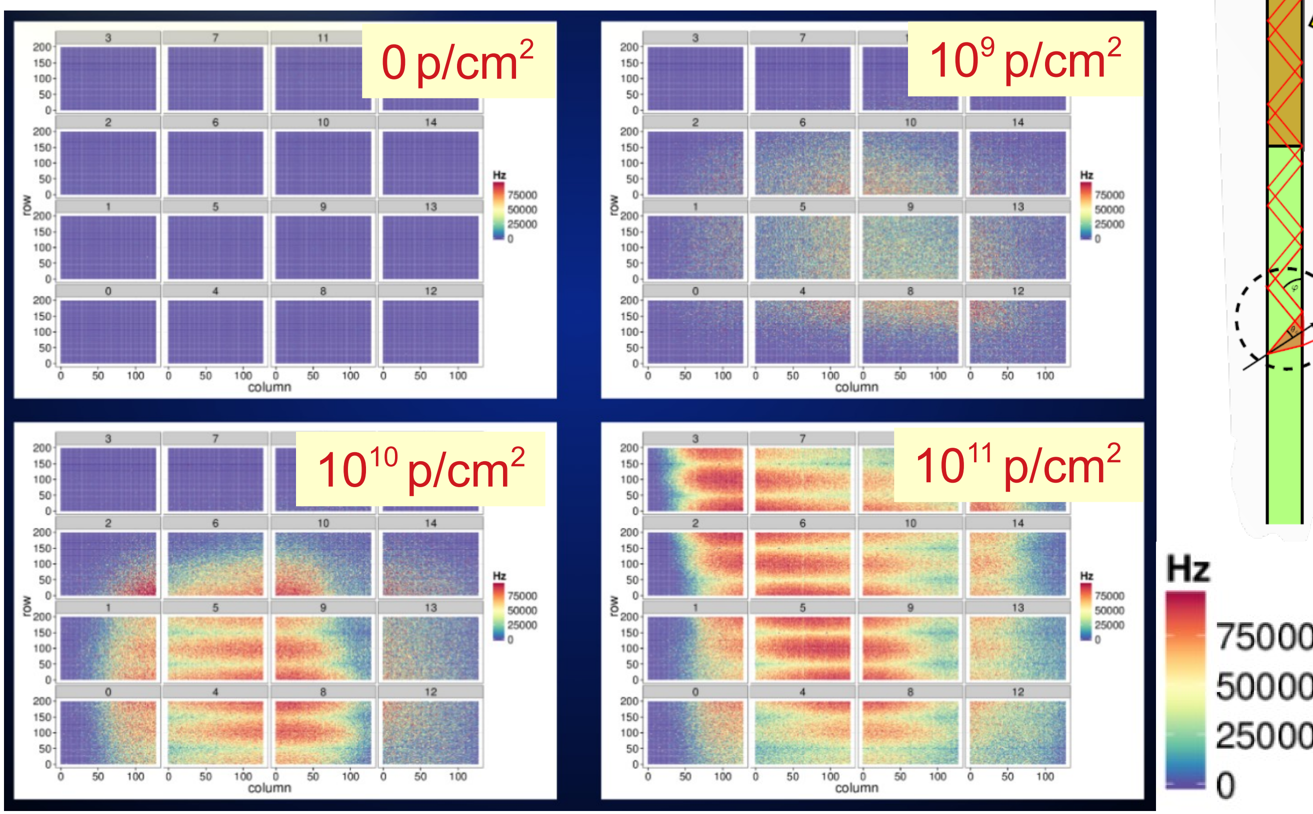
(details see yesterday's talk by Ken Suzuki)

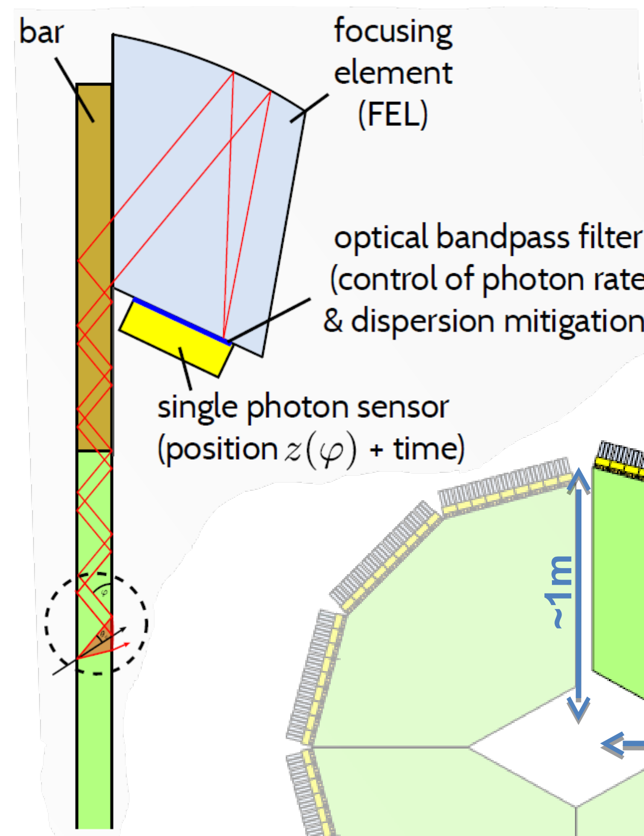
Sensors for DIRC-Detectors

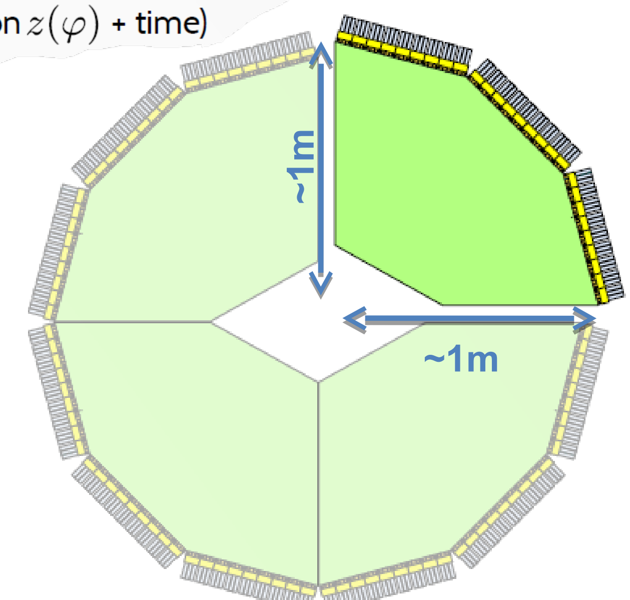
- Options
  - Multi-anode PMTs ruled out by B-field
  - Microchannel-plate (MCP) PMTs okay (but aging was a big problem)
  - SiPMs problematic for darkcount and radiation hardness reasons
- Barrel DIRC (Detection of Internally Reflected Cherenkov light)
  - Few single photons distributed across a large area → SiPMs were never seriously considered because of their huge darkcount rates
  - MCP-PMTs showed serious aging problems up to a few years ago
    - Serious photo cathode damage caused by feedback ions from the residual gas
    - Solved in recent MCP-PMT models by an ALD coating of the MCP pores
    - **Latest MCP-PMTs fulfill all sensor requirements**
- Endcap DIRC
  - Single photons distributed across a smaller area → SiPMs might be applicable with narrow time window cuts → requires intelligent logic
  - Tested Philips digital SiPMs

Philips Digital SiPMs for Endcap DIRC

- Fused silica radiator disc (2.1 m Ø; 4 independent sub-detectors)
  - 96 focusing elements (FEL) read out by MCP-PMTs or dSiPMs
- Philips Digital SiPM (DPC3200)
  - Radiation hardness not sufficient
    - Expected PANDA fluence: $10^{12}/cm^2$ 1 MeV n
    - DCR after irradiation with 14 MeV protons



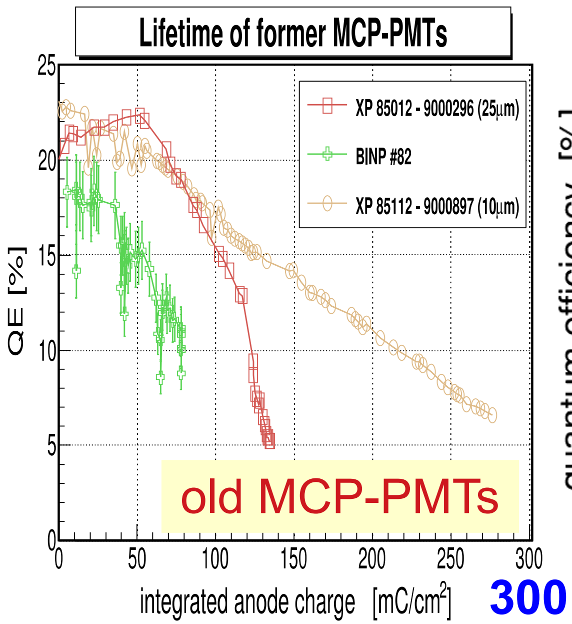


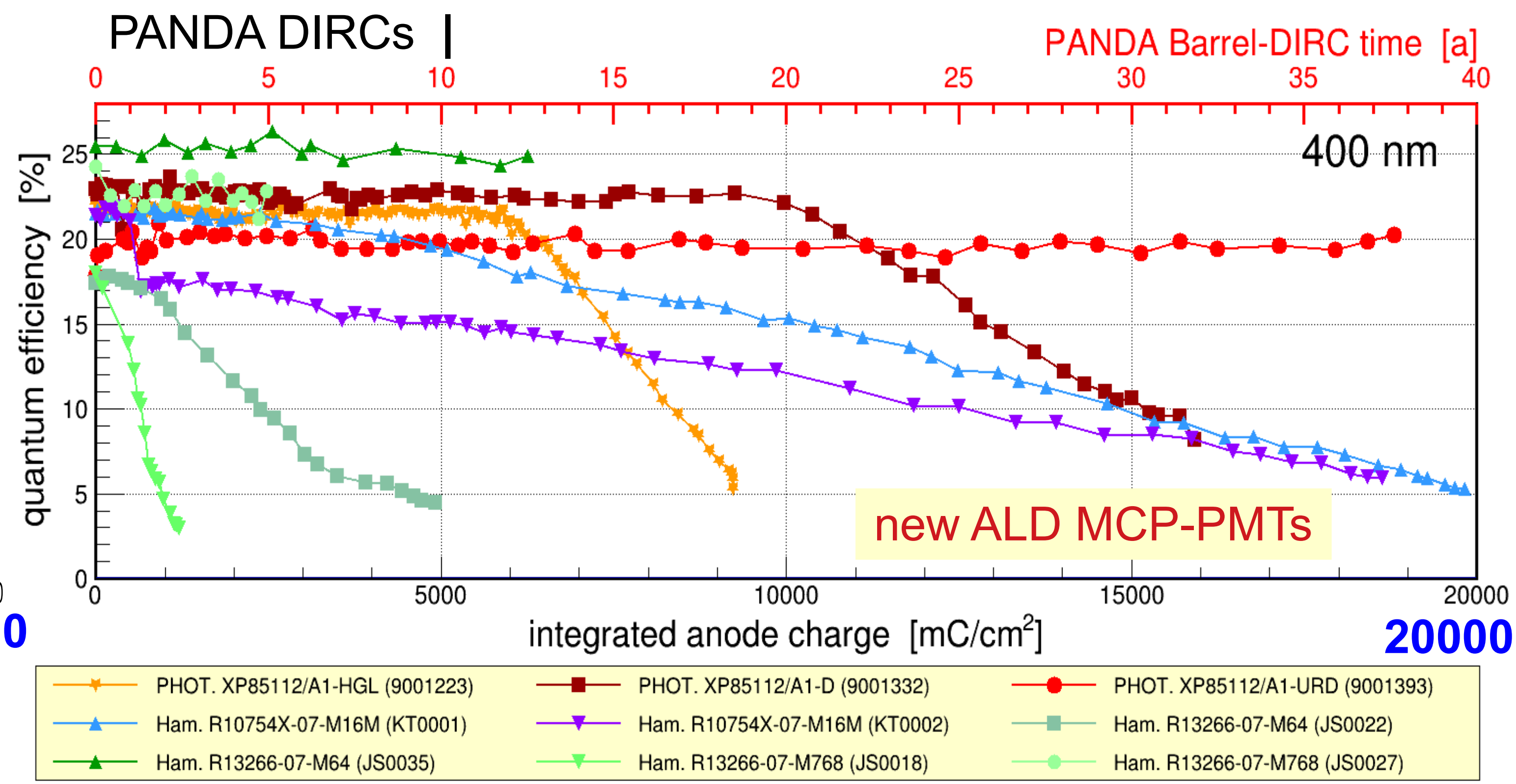


Benno Kröck, Gießen

MCP-PMT Lifetime Improvements

- ~2011: <0.2 C/cm² integrated anode charge (IAC) before destruction
- **PANDA DIRCs need >5 C/cm² IAC** for 10 years running

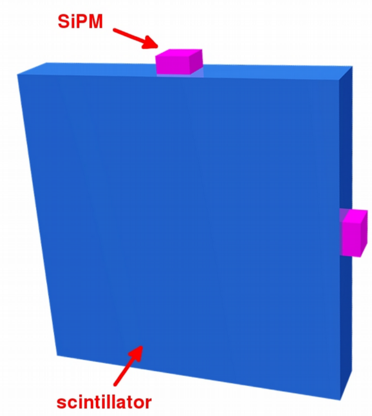




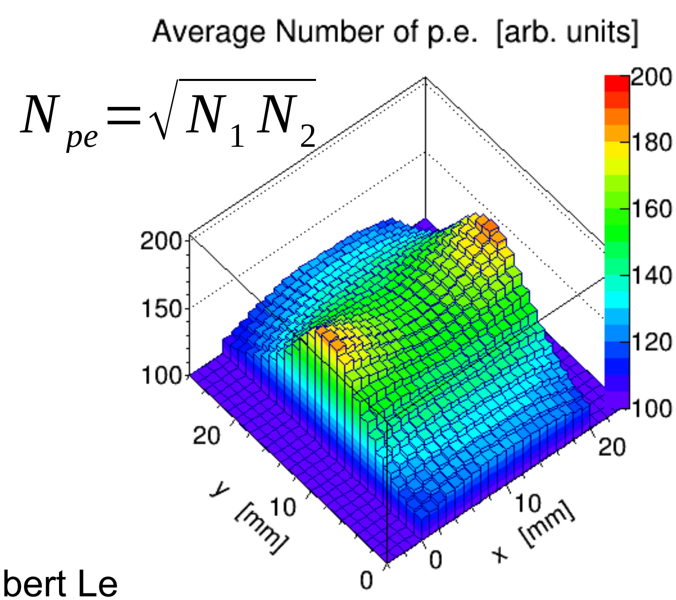
- recently: huge lifetime improvements of MCP-PMTs with ALD coating
- **no Q.E. drop up to ~20 C/cm²** → sensor of choice for both DIRCs

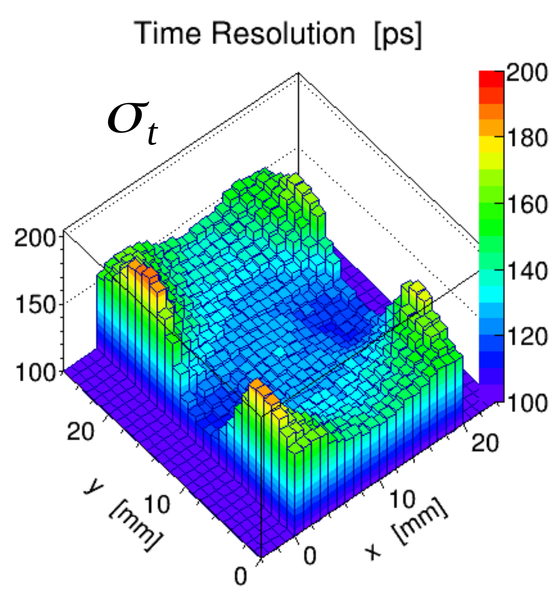
Scintillating Tiles for Barrel TOF

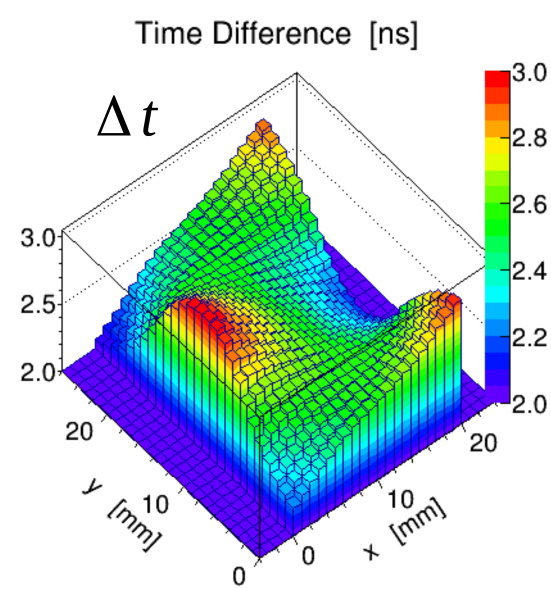
- First idea: 30x30x5 mm^3 BC408 scintillating tiles (SciTils) read out by two (opposite) 3x3 mm^2 SiPMs
  - Turned out to be not the optimum solution in terms of time resolution and light collection



- Main SciTil caveats:
  - Many reflections in all directions before photons actually hit the SiPM → only few "prompt" photons → time resolution position dependent
  - Best value: 82 ps time resolution close to SiPMs; area averaged ~130 ps





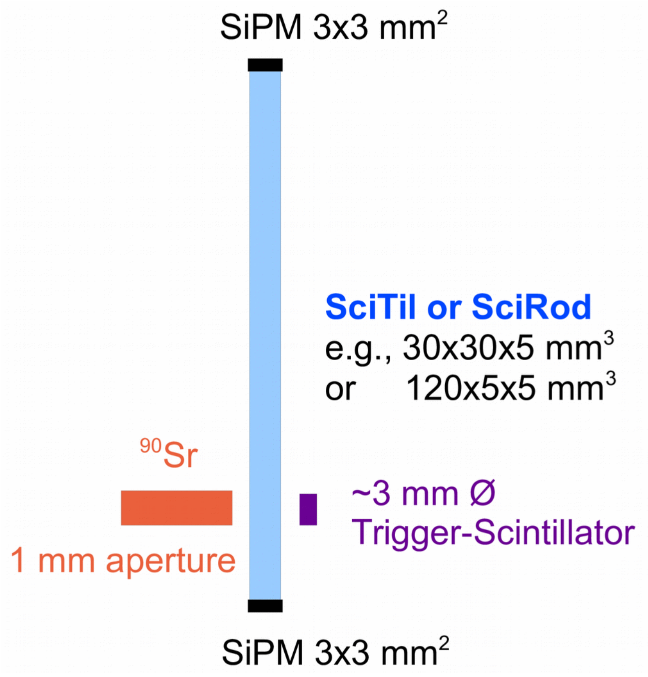


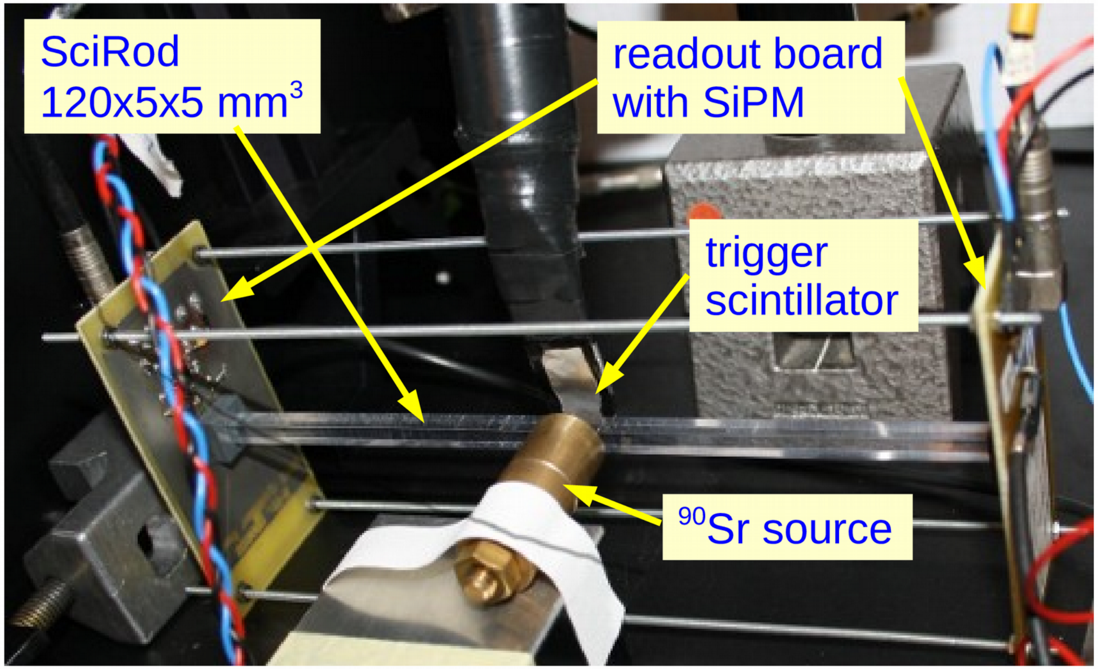
Laboratory Measurement Setup

- Scintillating tiles/rods read out at opposite sides
  - xy-position scans in 1 – 2 mm steps across scintillator surface
  - Measure pulse heights (→ number of photons)
  - Measure time difference (→ time resolution)
- Tested 3x3 mm^2 SiPMs from Hamamatsu, Ketek and SensL

Source: 1 mCi ^{90}Sr (1 mm aperture)

Trigger Scintillator: ~3 mm Ø from PS185





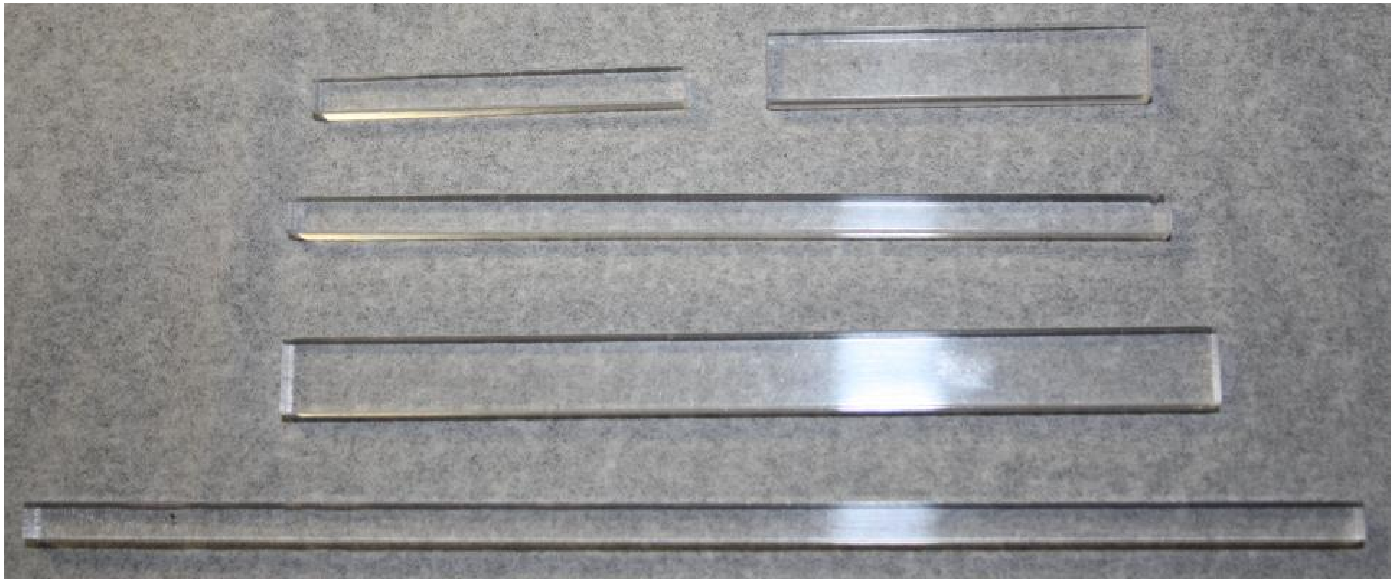
Scintillating Rods for Barrel TOF

- Advantages of scintillating rods (SciRods; e.g., 120x5x5 mm^3):
  - Read out at both scintillator ends with 3x3 mm^2 SiPMs
  - Many photons are totally reflected along scintillator rod
    → good solid angle coverage for scintillation photons
  - photons travel similar distance to SiPMs → collected photons at SiPMs arrive within a short time window → many "prompt" photons

BC408 (τ = 2.1 ns)
BC420 (τ = 1.5 ns)

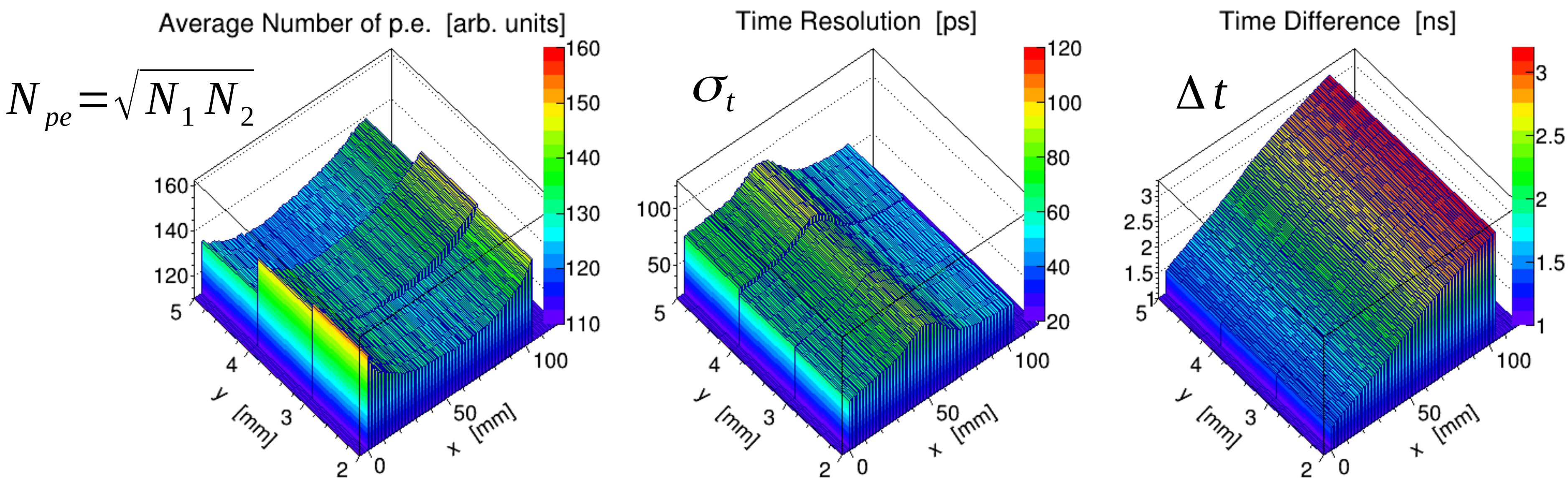
- 170 x 5 x 5 mm^3
- 120 x 5 x 5 mm^3
- 50 x 5 x 5 mm^3
- 120 x 10 x 5 mm^3
- 50 x 10 x 5 mm^3

- 30 x 30 x 5 mm^3



Results for (narrow) SciRods

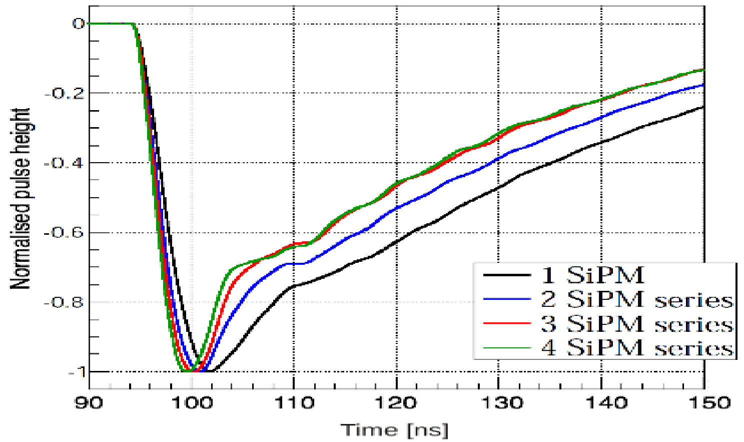
- Different-sized SciRods read out by two (opposite) 3x3 mm^2 SiPMs
  - Better time resolution (<<100 ps for BC420 scintillator) than for SciTils
  - Time resolution significantly less position dependent



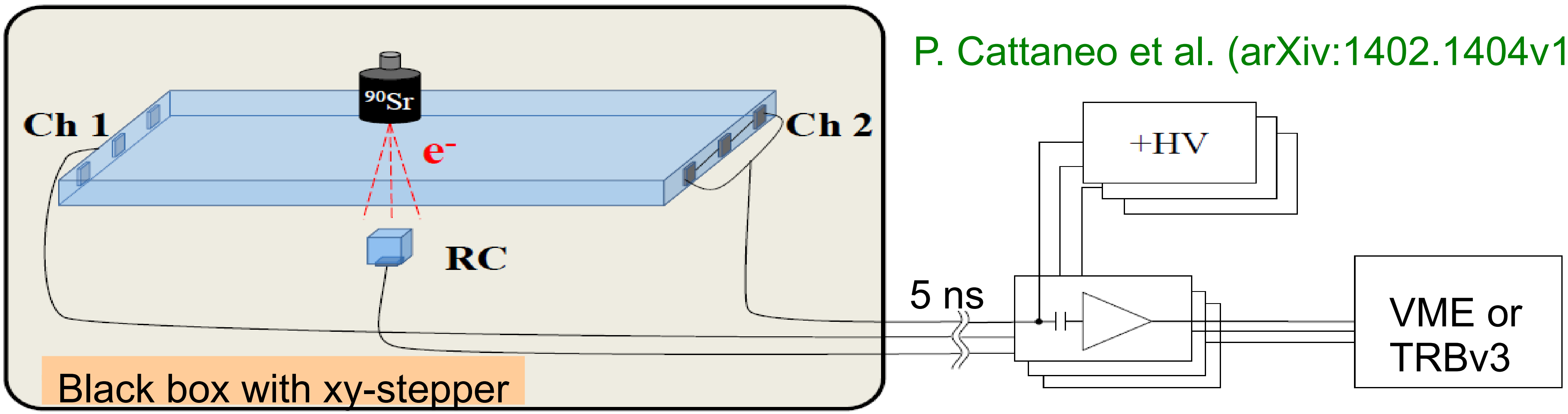
scintillator size	MPPC	BC408 $\sigma_t[ps]$	BC420
$170 \times 5 \times 5$ mm^3	S10362-050P	97 ± 19	
$120 \times 5 \times 5$ mm^3	S12652-050C	81 ± 12	68 ± 10
$50 \times 5 \times 5$ mm^3		83 ± 6	62 ± 5
$120 \times 10 \times 5$ mm^3	S10362-100P	105 ± 18	93 ± 25
$50 \times 10 \times 5$ mm^3	S12572-050P	109 ± 16	

Wide Scintillating Rods

- Disadvantages of narrow SciRods; e.g., 120x5x5 mm^3
  - reduced active area because wrapping material requires space
- Better solution: wide SciRods (e.g., 120x30x5 mm^3) read out by several SiPMs placed at opposite sides
  - Similar to MEG experiment at PSI
  - Serial connection → lower capacitance → 30% faster and 30% narrower signals
  - Better time resolution expected

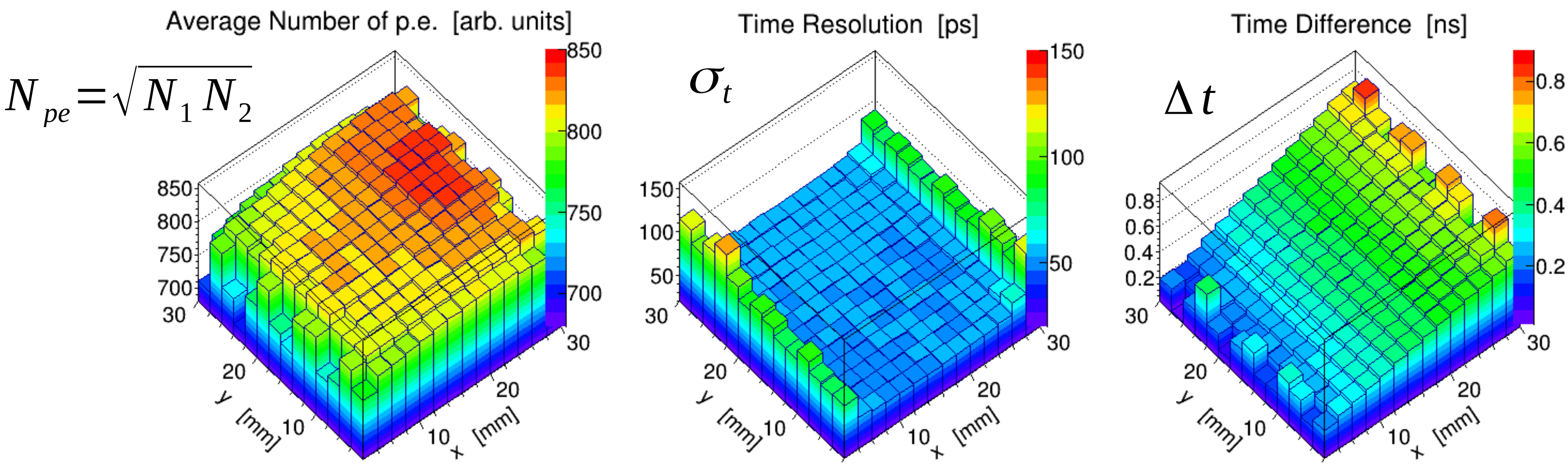


P. Cattaneo et al. (arXiv:1402.1404v1)



Results for (wide) SciRods

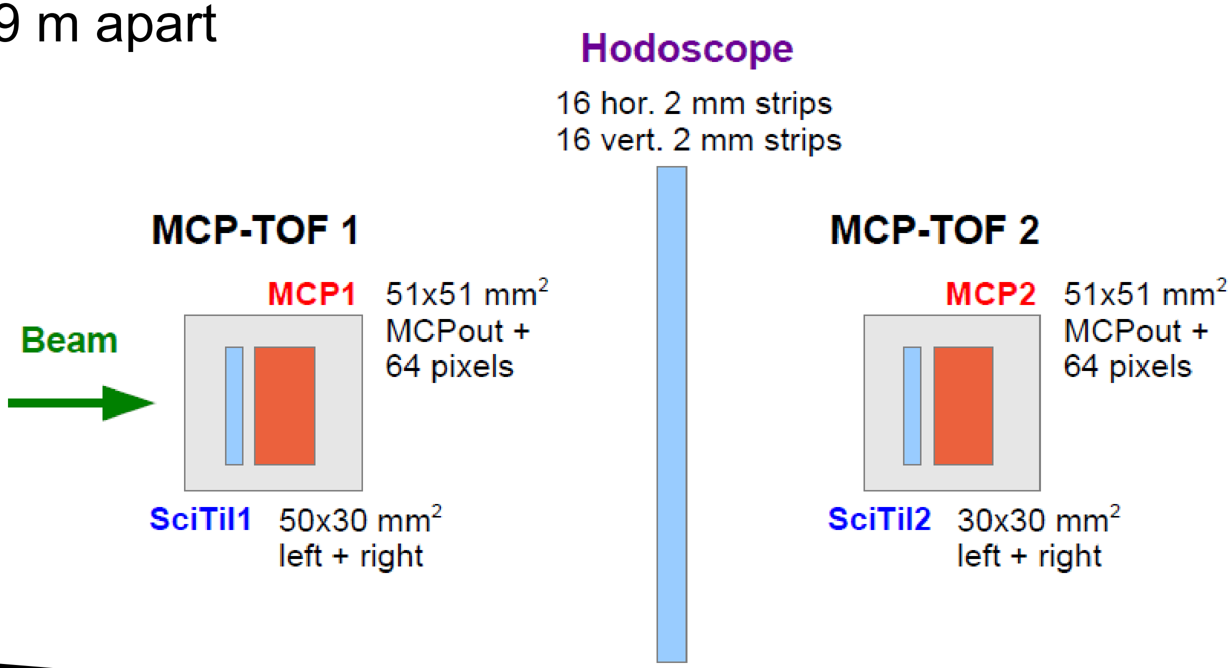
- Read out by 4 serially connected 3x3 mm^2 SiPMs at each side
  - Again better time resolution (down to <50 ps for BC418 scintillator)
  - Basically no position dependence of time resolution (better with Al-wrapping)

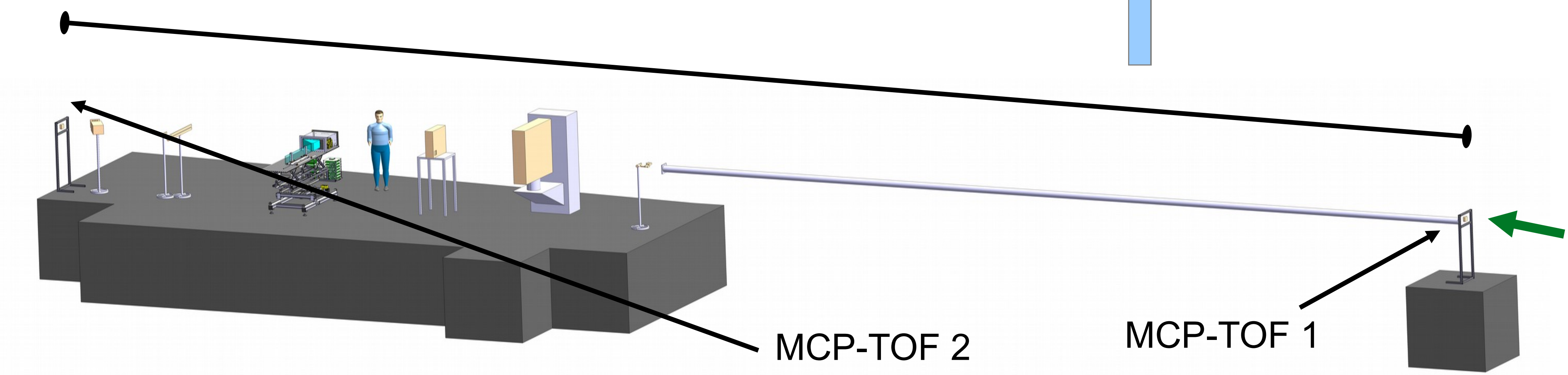


	BC420; 120 × 30 × 5 mm^3 Hamamatsu MPPC S12572-050P			BC418; 30 × 30 × 5 mm^3 KETEK SiPM PM3350TP-SB0		
wrapping	none	white paper	aluminum	none	white paper	aluminum
σ_t [ps]	83 ± 3	80 ± 2	76 ± 2	53 ± 2	48 ± 1	45 ± 1
pulse int. [chan]	658 ± 12	700 ± 15	743 ± 10	321 ± 8	420 ± 3	448 ± 1

SciTils/SciRods inside Testbeam

- Identification of beam particles by TOF at CERN T9 beamline
  - 2 – 10 GeV/c hadron-rich containing mainly protons, kaons, pions, and myons
  - Two “MCP-TOF“ stations, 29 m apart
  - Each station contains
    - one 2-inch MCP-PMT
    - one SciTil (SciRod) read out left and right by 4 SiPMs
  - → 6 independent TOF combinations to determine individual time resolutions

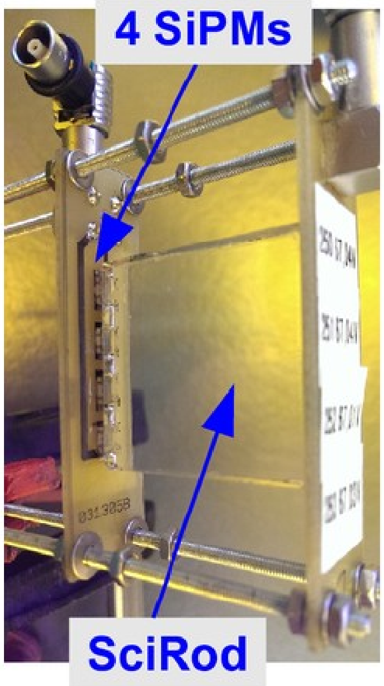


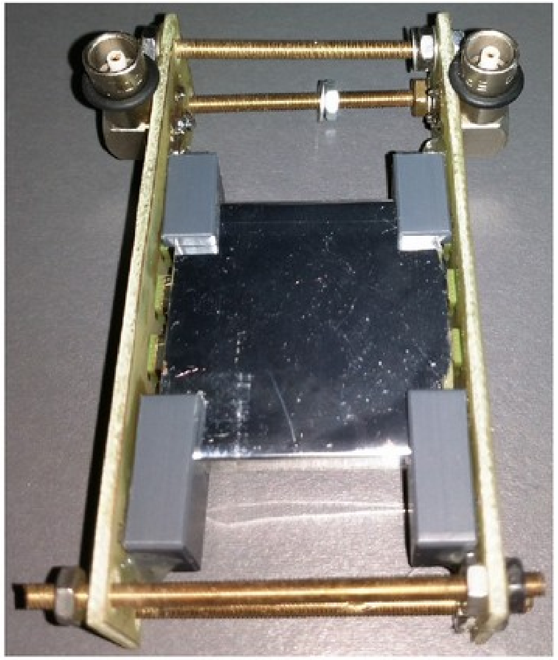


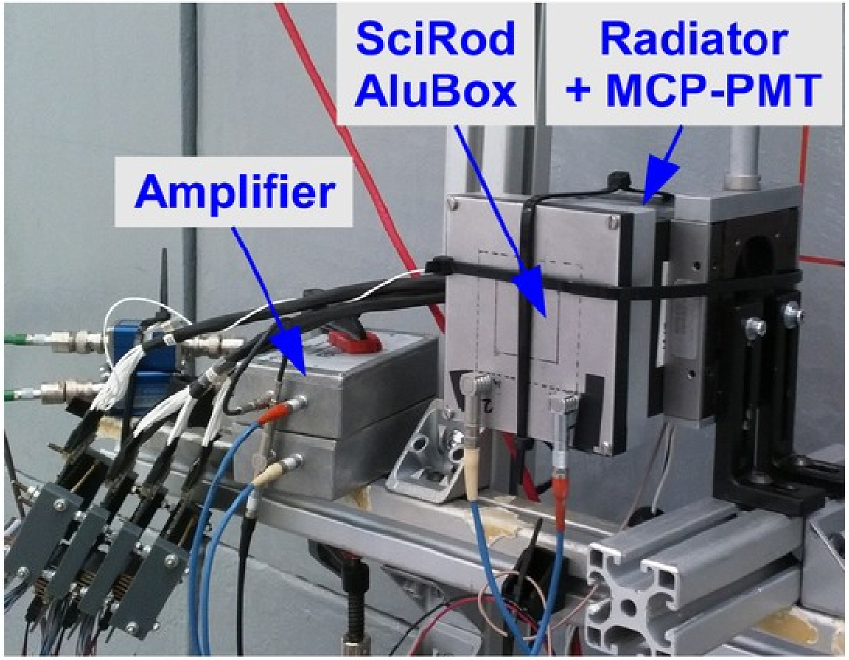
MCP-TOF Setup

- MCP-TOF station consists of 2-inch MCP-PMT and wide SciRod
  - PMMA radiator in front of MCP-PMT to produce Cherenkov radiation
  - Opposite sides of SciRod read out by 4 serially connected Ketek SiPMs
    - Aluminum wrapped scintillators
    - x10 amplifier boxes (outside aluminum box) provide bias voltage and signal shaping
    - PADIWA/TRB DAQ from GSI

M. Böhm et al., JINST 11 (2016) C05018

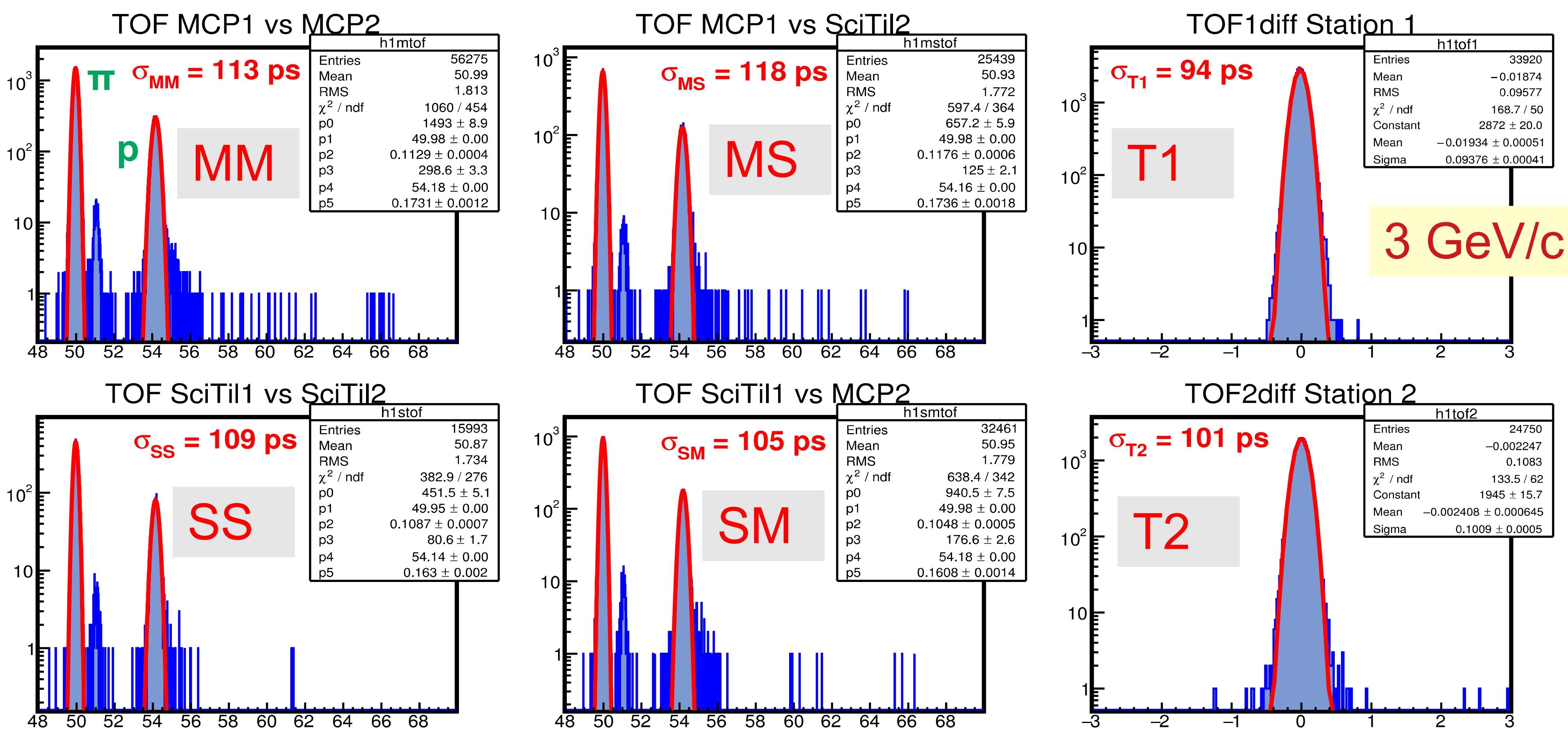






MCP-TOF Results

- 4 counters of the MCP-TOF stations provide 6 independent ways to evaluate TOF differences for pions (peak 1) and protons (peak 2)
  - MCP1 – MCP2 (MM); SciRod1 – SciRod2 (SS); MCP1 – SciRod1 (T1)
  - SciRod1 – MCP2 (SM); MCP1 – SciRod1 (MS); MCP2 – SciRod2 (T2)



Determination of Time Resolutions

$\sigma_{MM} = TOFres(MCP2 - MCP1)$

$\sigma_{SS} = TOFres(SciRod2 - SciRod1)$

$\sigma_{SM} = TOFres(MCP2 - SciRod1)$

$\sigma_{MS} = TOFres(SciRod2 - MCP1)$

$\sigma_{T1} = TOFres(MCP1 - SciRod1)$

$\sigma_{T2} = TOFres(MCP2 - SciRod2)$

$\sigma_{M1} = TimeRes(MCP1)$

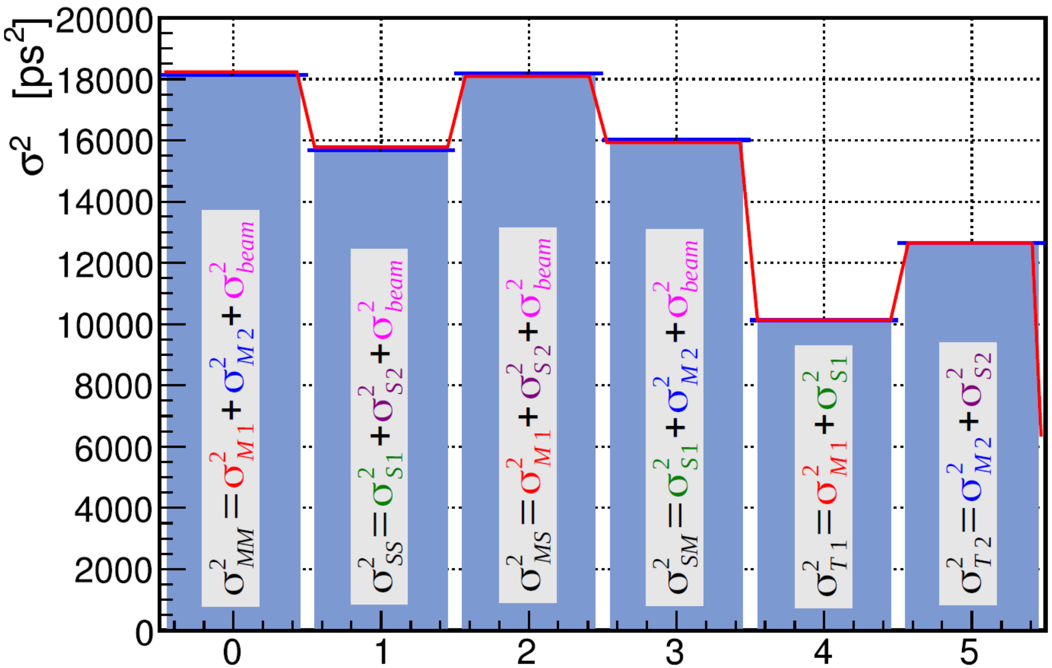
$\sigma_{M2} = TimeRes(MCP2)$

$\sigma_{S1} = TimeRes(SciRod1)$

$\sigma_{S2} = TimeRes(SciRod2)$

$\sigma_{beam} = TimeRes(Beam, Clock, \ldots)$

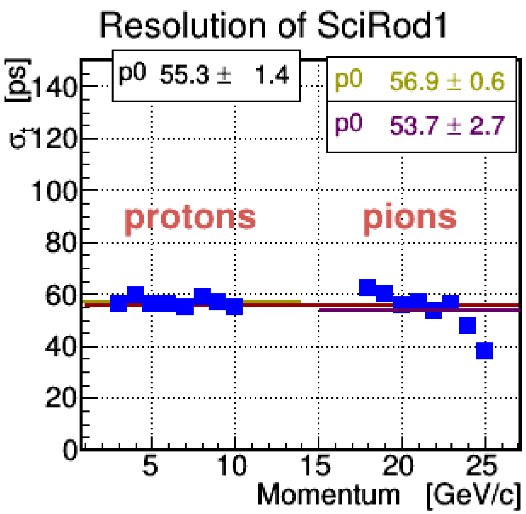
$$\sigma^2_{MM} = \sigma^2_{M1} + \sigma^2_{M2} + \sigma^2_{beam}$$
$$\sigma^2_{SS} = \sigma^2_{S1} + \sigma^2_{S2} + \sigma^2_{beam}$$
$$\sigma^2_{MS} = \sigma^2_{M1} + \sigma^2_{S2} + \sigma^2_{beam}$$
$$\sigma^2_{SM} = \sigma^2_{S1} + \sigma^2_{M2} + \sigma^2_{beam}$$
$$\sigma^2_{T1} = \sigma^2_{M1} + \sigma^2_{S1}$$
$$\sigma^2_{T2} = \sigma^2_{M2} + \sigma^2_{S2}$$

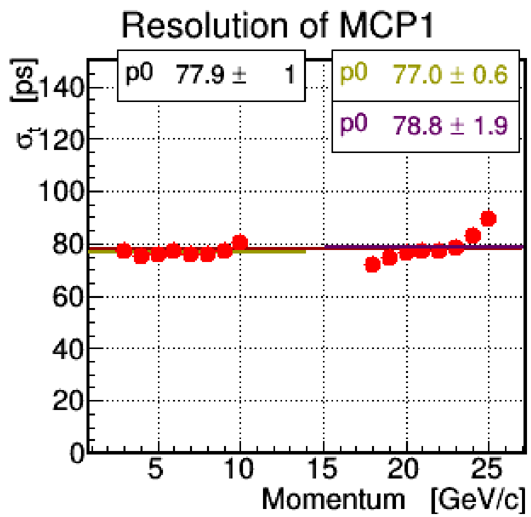


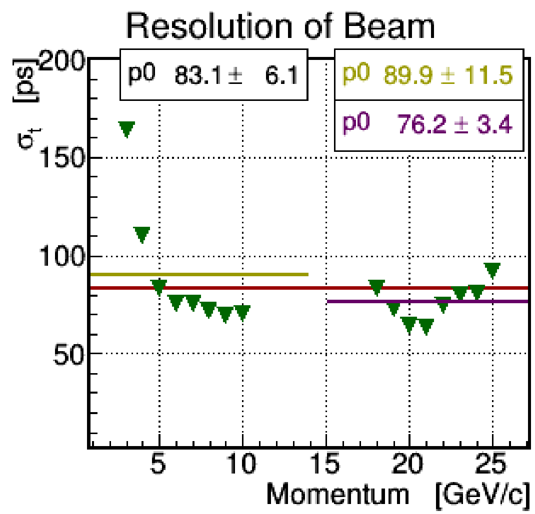
- Fit of 5 parameters to 6 equations → **time resolution for each counter**

Counter Time Resolutions

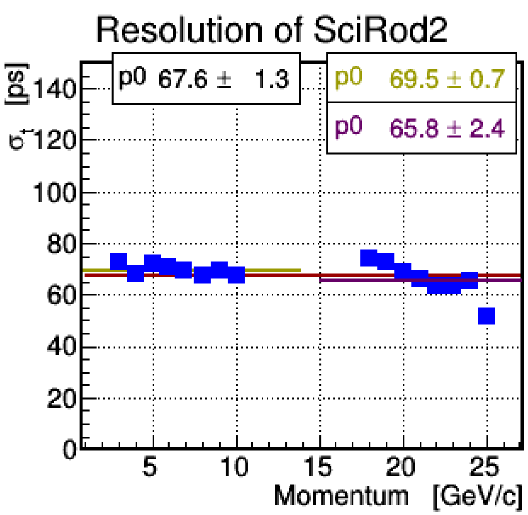
- Fitted resolutions obtained for pions and protons from 2 – 10 GeV/c
- Long run (~3 weeks) under beam conditions → stable behavior

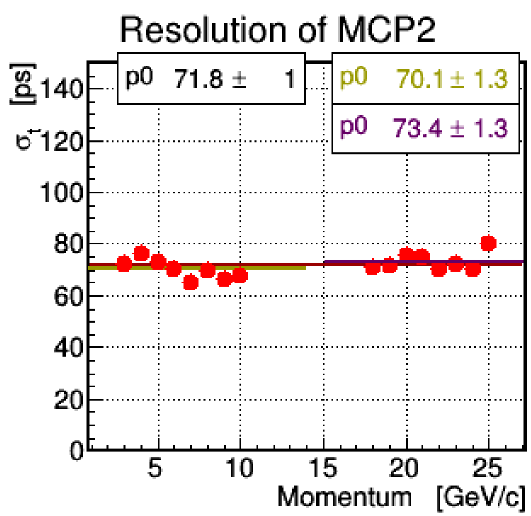






pions shifted by 15 GeV/c





$$\sigma_{M1} = (78 \pm 1)\ ps$$

$$\sigma_{M2} = (72 \pm 1)\ ps$$

$$\sigma_{S1} = (55 \pm 2)\ ps$$

$$\sigma_{S2} = (68 \pm 2)\ ps$$

$$\sigma_{beam} = (83 \pm 6)\ ps$$

Summary

- SiPMs currently not (yet) suitable for single photon detection in RICH/DIRC applications with only few photons distributed across a large area → MCP-PMTs is a better choice
- SiPMs are very good sensors for applications where many photons are expected, e.g. TOF detectors
- Best time resolutions were obtained with wide scintillating rods (SciRods) read out by serially connected SiPMs
- SciRod time resolutions obtained in the laboratory: **<50 ps**
- SciRod time resolutions obtained under running conditions in a real test experiment at CERN: 55 – 70 ps
- SiPMs are excellent sensors for multiple photon detection, but for single photons MCP-PMTs are a serious alternative now