TOF detector for SPD
(plastic scintillator option)

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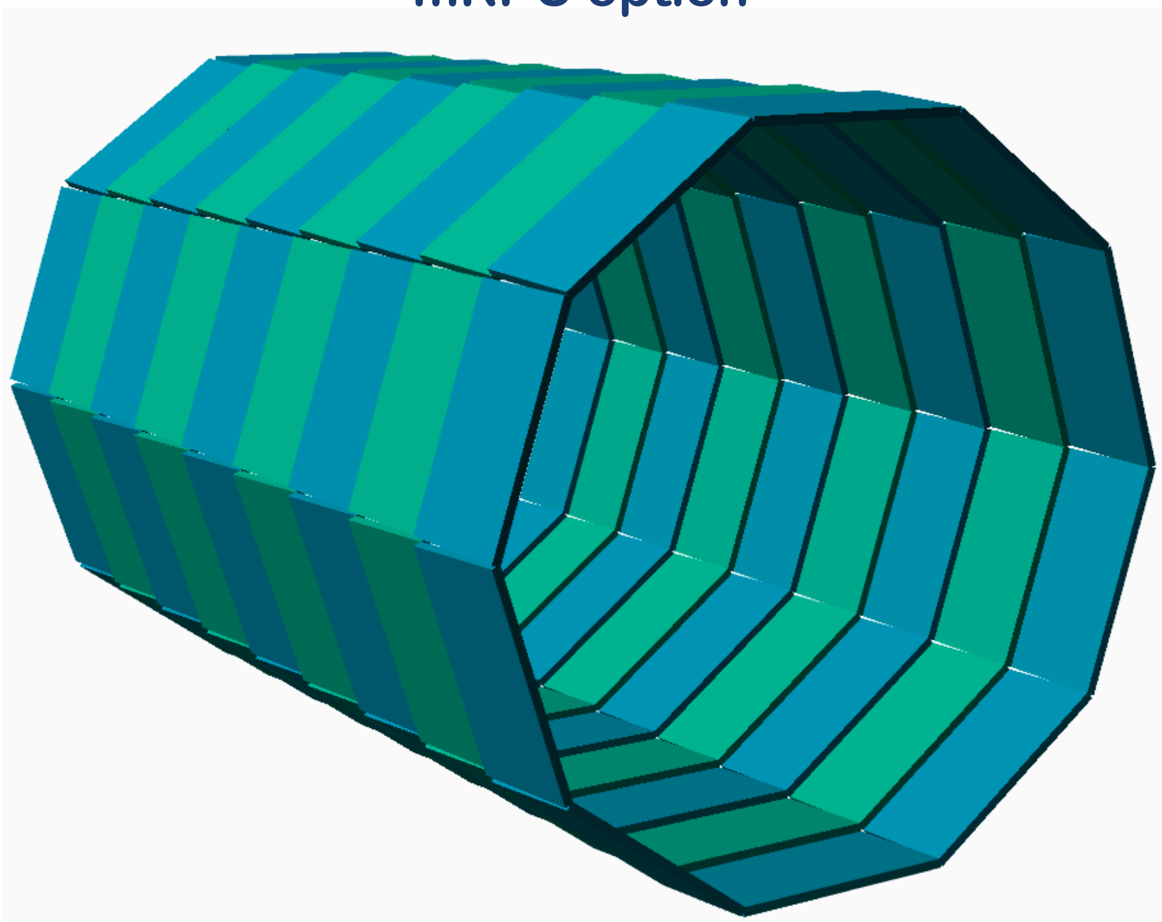
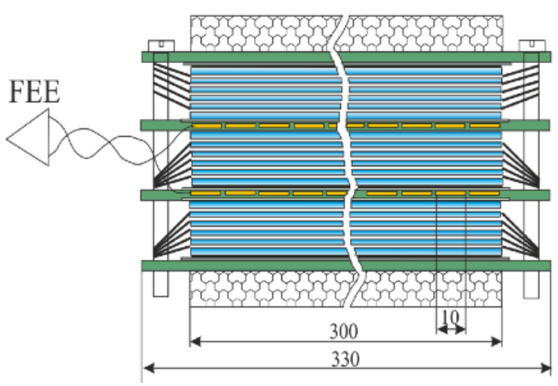
28 October 2020
SPD meeting

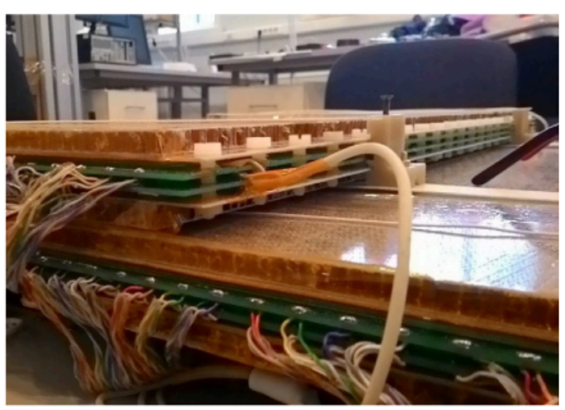
Two options for the TOF barrel of SPD

mRPC option



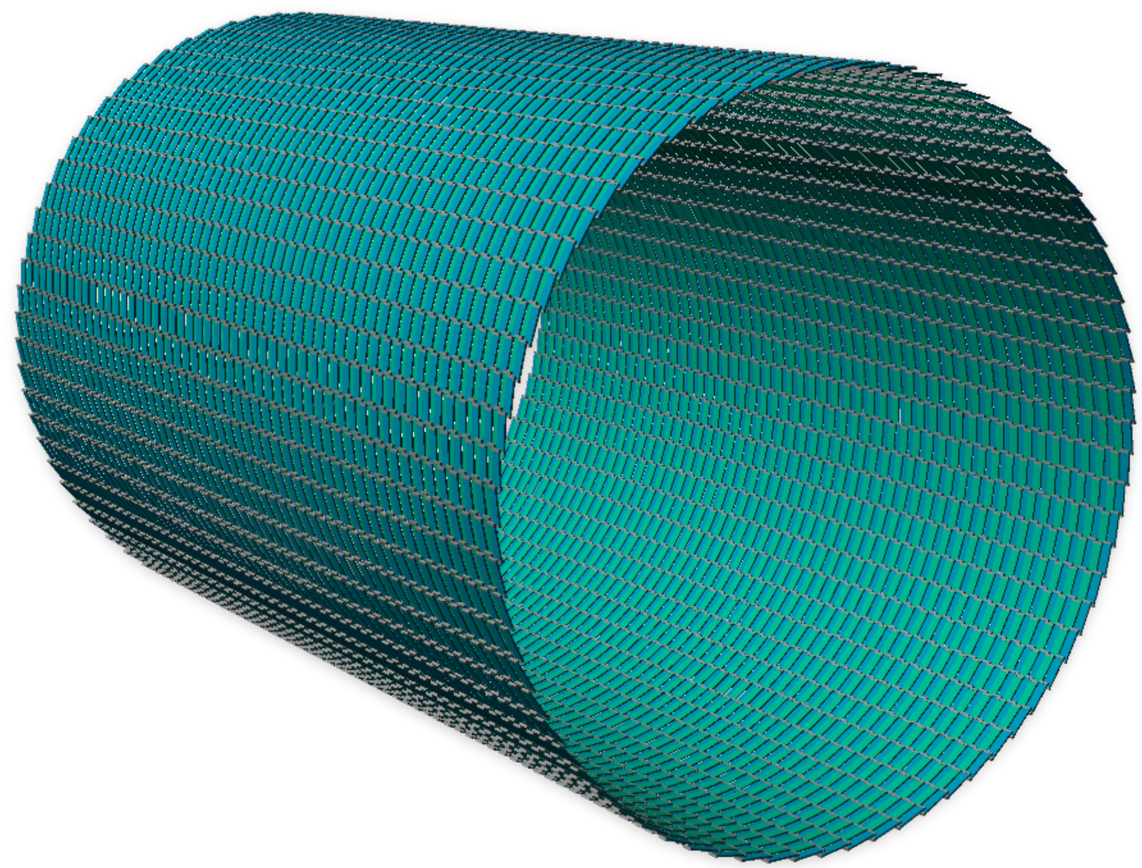
Inspired by the TOF MPD: readout PCB 24 strips,
size: 65 x 33 x 2.5 cm^3, strip: 64 x 1 cm^2



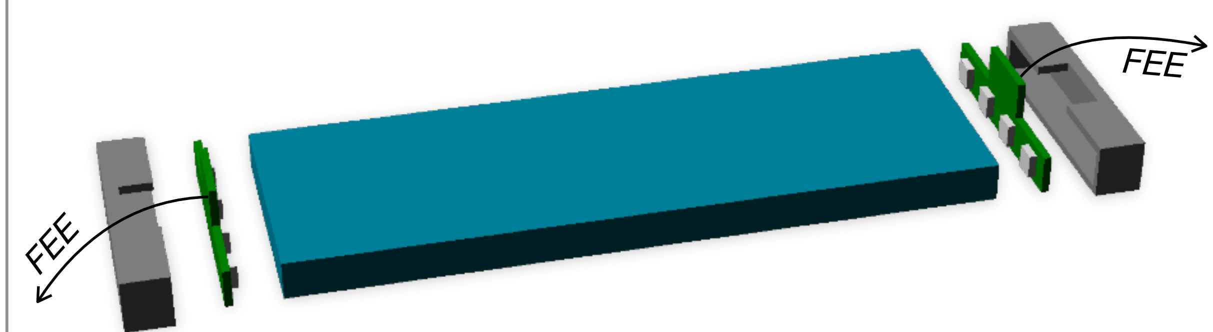


MPD NICA TDR TOF, Nov 2018, Rev 3.0

Plastic scintillator option



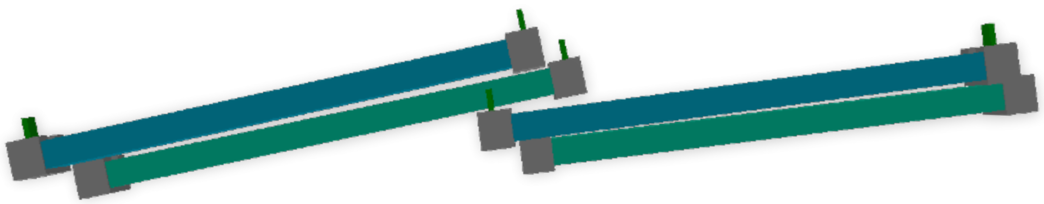
Inspired by the TOF of PANDA:
tile size: 9 x 3 x 0.5 cm^3, 4 SiPMs (3 x 3 mm^2) at each end



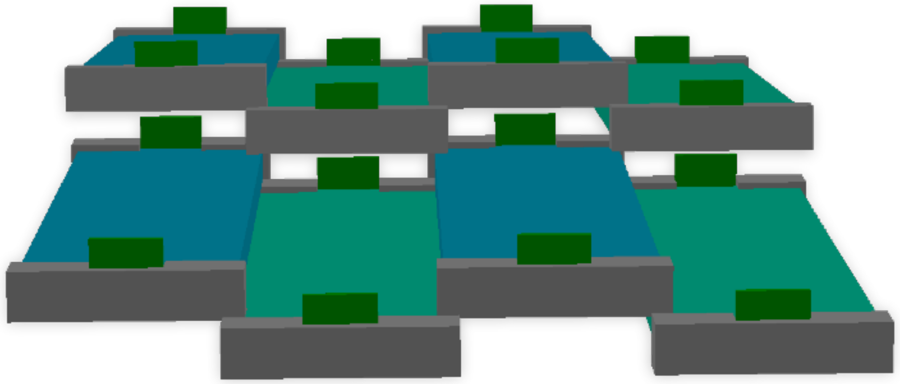
TDR for the PANDA Barrel TOF, July 4, 2018

Layout of tiles without dead zones

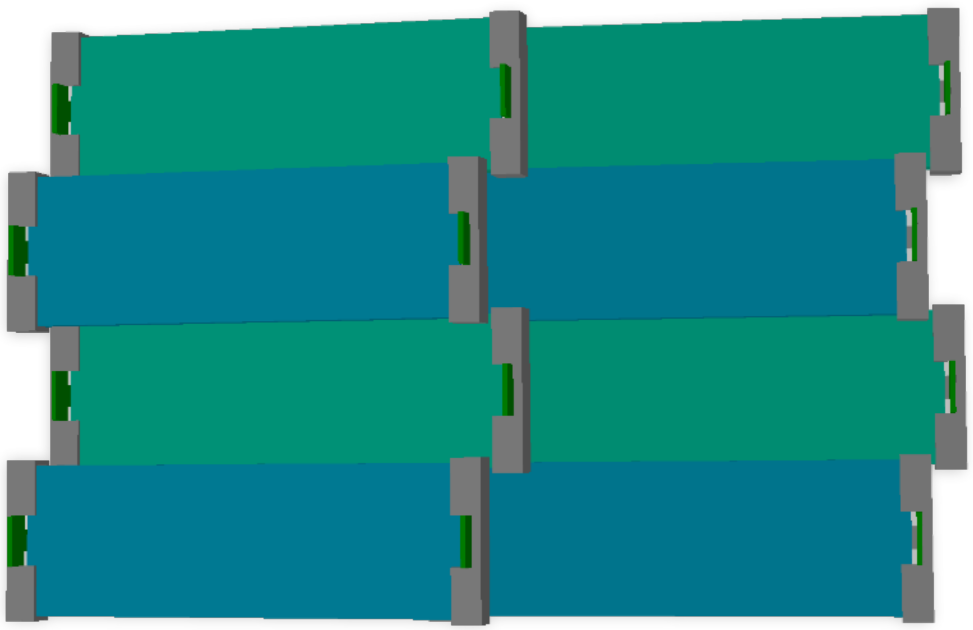
side view



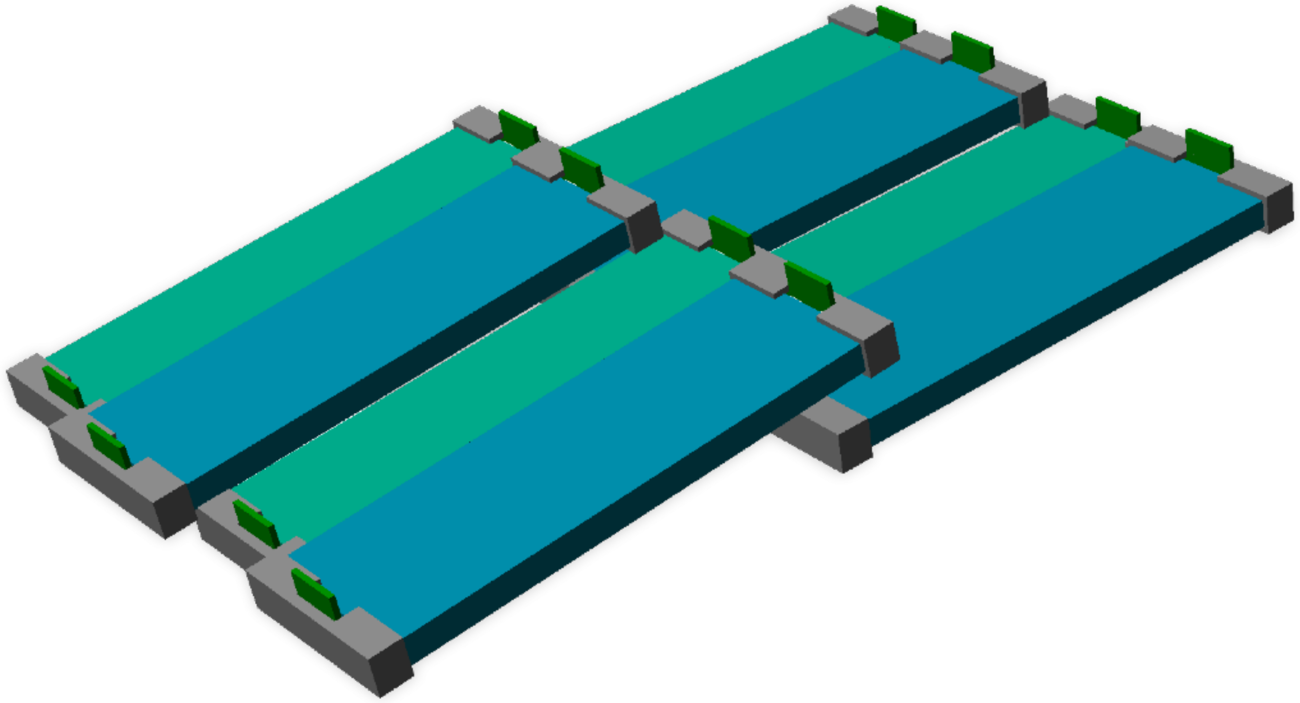
front view



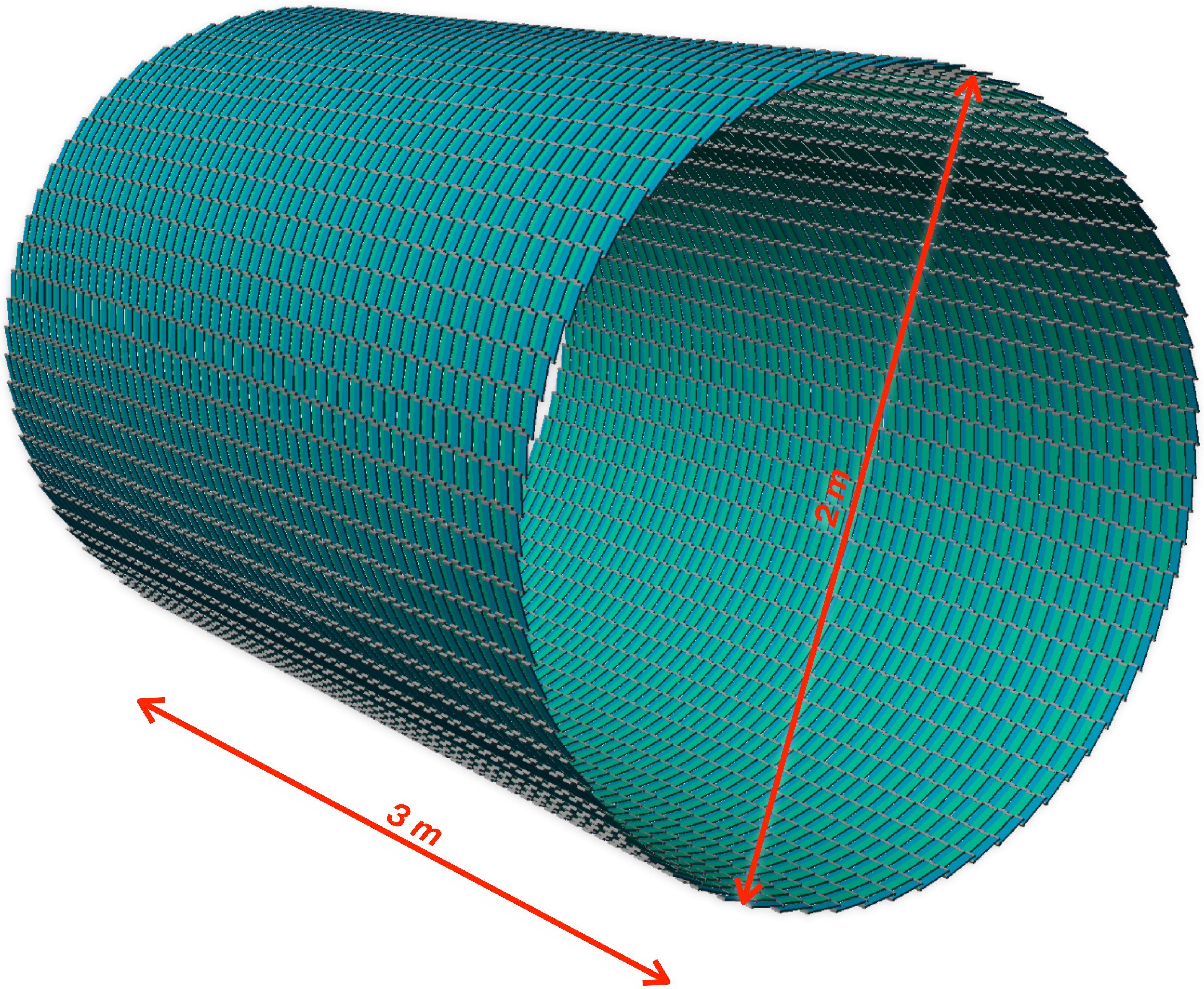
top view



rotated view



TOF barrel of SPD (plastic scintillator)

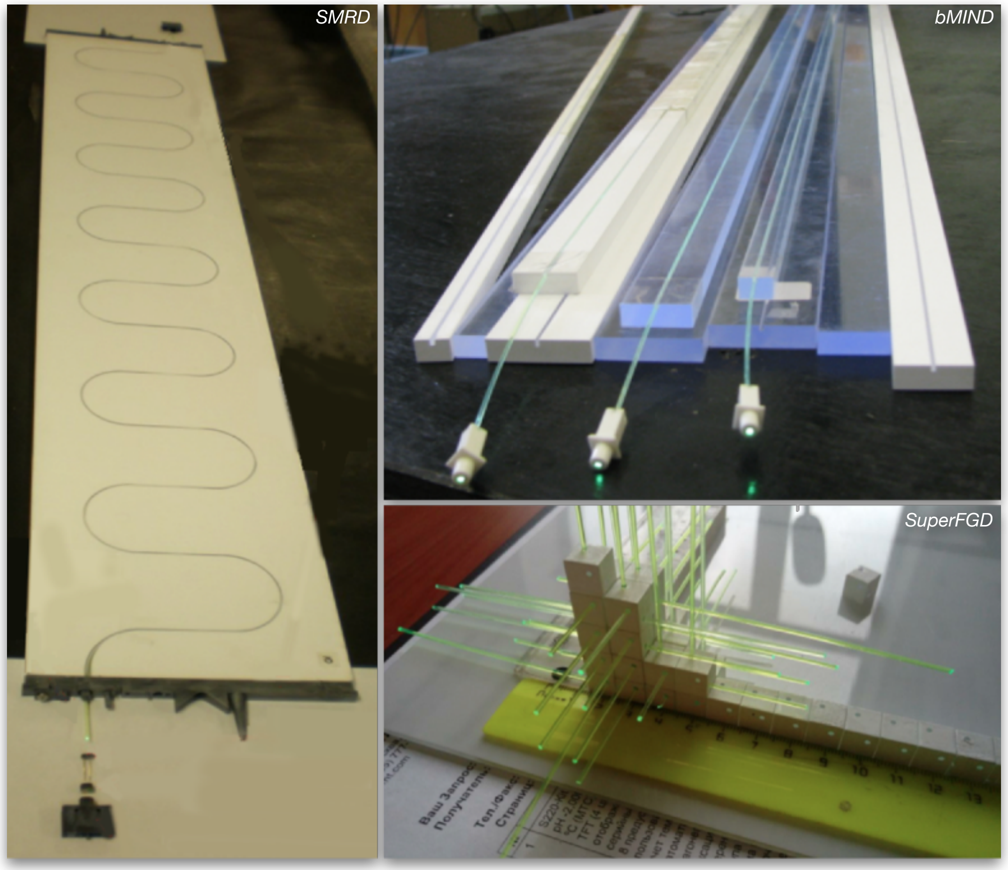


- Size of one tile: 9x3x0.5 cm^3
- Overlap of tiles: 1mm
- Number of tiles
  - along the beam = 103
  - circumferentially = 74
  - Total = 103 x 74 = 7622
- Number of DAQ channels assuming 2-side readout = 15244
- Number of SiPMs assuming 4 pcs per side = 60976
- Total weight of plastic = 107 kg

Goal of this study

- Estimate the time resolution of a single tile basing on the previous experience (TOF detector of ND280/T2K)
  - Compare to PANDA's study
- Estimate the cost of main components: SiPMs + Plastic scintillator

Two common approaches for readout of scintillator bar



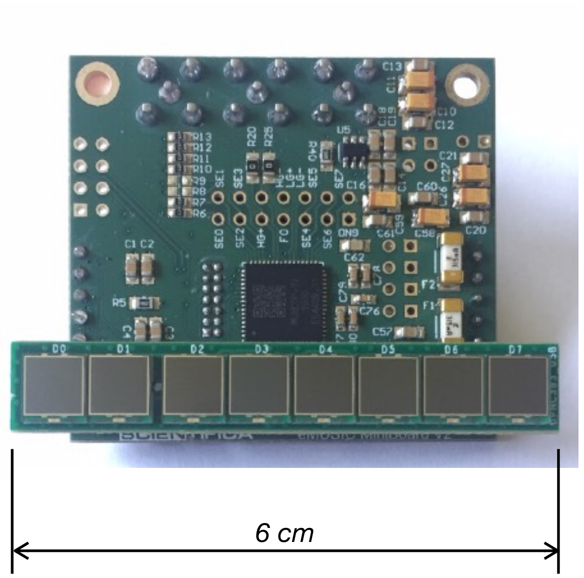
- Extruded plastic, polystyrene based
- Diffuse reflectance coating (chemical etching)
- WLS fiber: NUV → Green light
    - increase of time constant
- Small SiPM (1x1 mm^2) for light collection
- Typical light yield is few dozens p.e.
- Typical time uncertainty ≈1ns

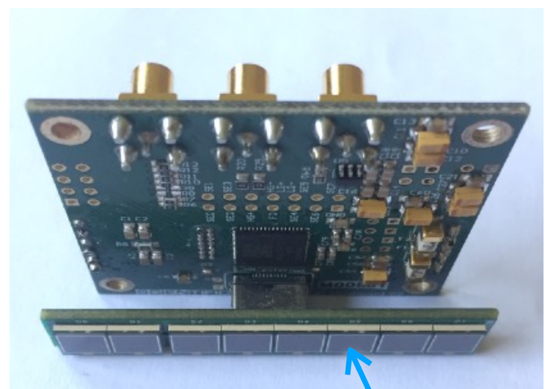
- Cast plastic scintillator, PVT based
- γ transfer is governed by total internal reflection
- Direct light readout by
    - Light-guide + PMT w/ magnetic shielding
    - Array of large-area SiPMs (6x6 mm^2)
- More expensive than the WLS-fiber option
- Typical light yield is few hundreds p.e.
- Typical time uncertainty ≈0.1ns

Readout circuit for the TOF SiPM-array

A *large SiPM capacitance* increases the rise time and width of the signal ⇒ worsens the time resolution. A reduction of the capacitance can be achieved by using an *independent sensor readout* and amplification to isolate the sensor capacitances from each other. Signals are summed up at the end.

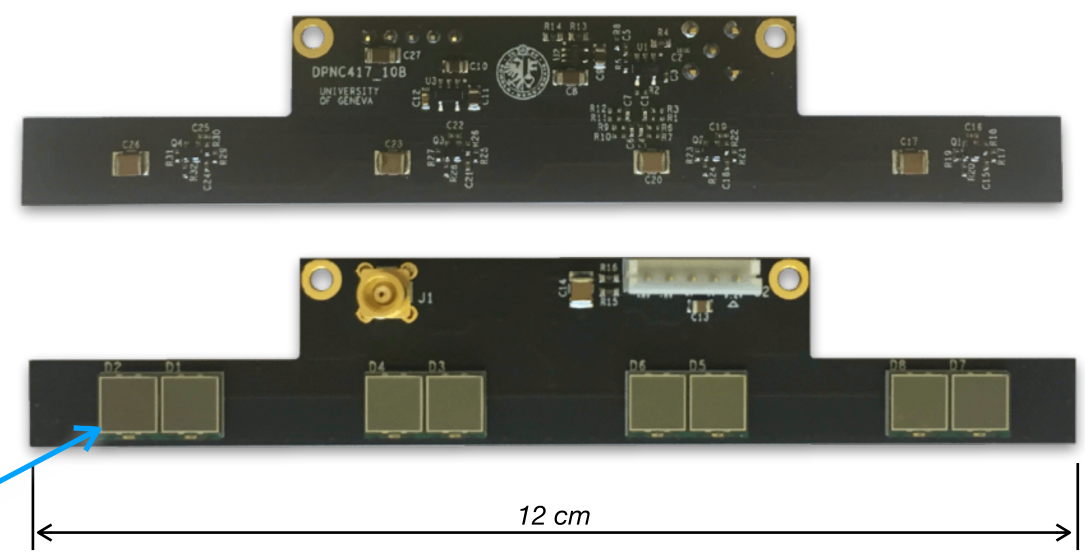
Integrated circuit (ASIC)





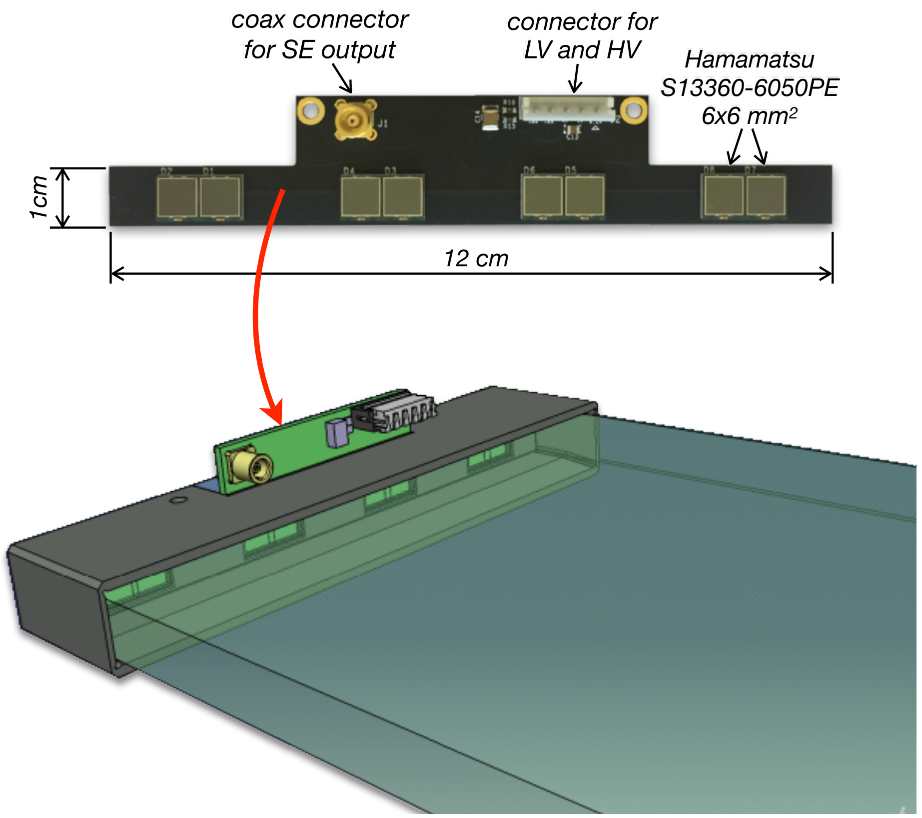
- eMUSIC: Multiple Use Sipm IC (for CTA)
- Input: 8 SiPMs of any size
- Output: sum or individual
- SPI control: pole-zero cancelation, individual offsets, gain control, discriminated output
- External controller is mandatory

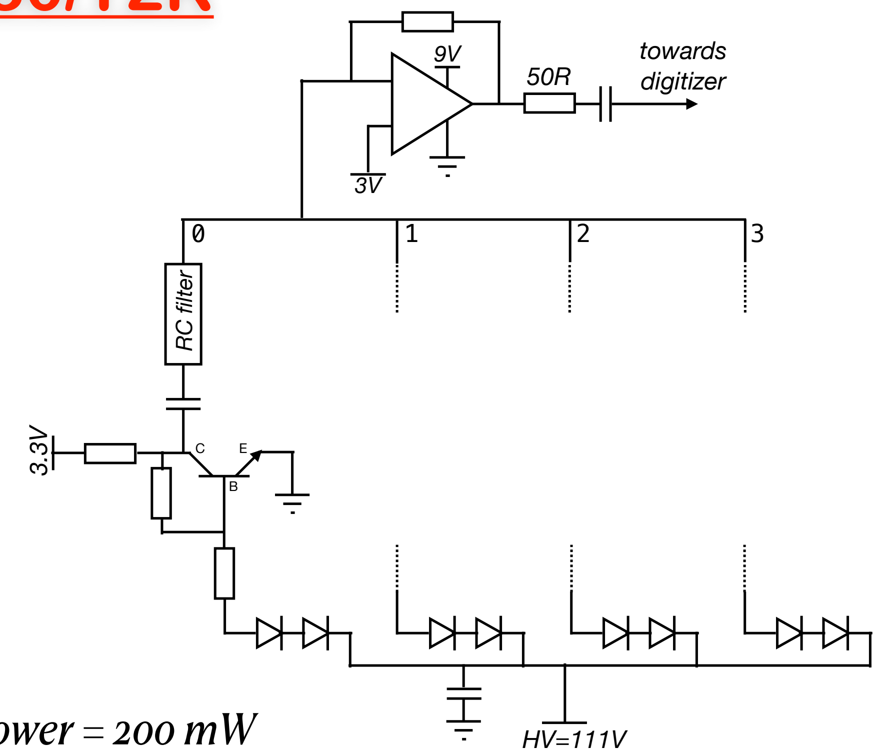
Discrete circuit



- All parameters (shaper, gain, dynamic range and so on) have been adjusted with testbeam data and fixed
- Problem of individual SiPM offsets is solved by sorting SiPMs
- About an order of magnitude cheaper

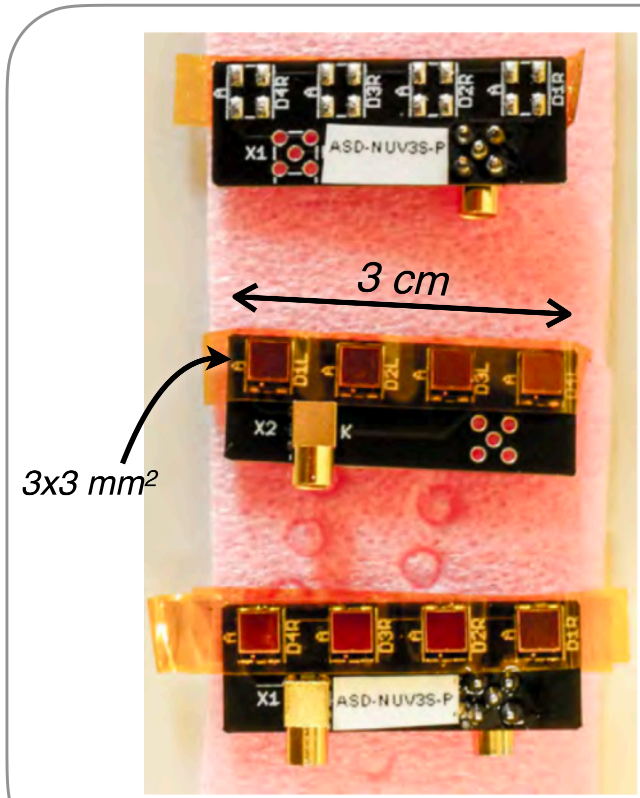
TOF for ND280/T2K





Power = 200 *mW*

TOF for PANDA



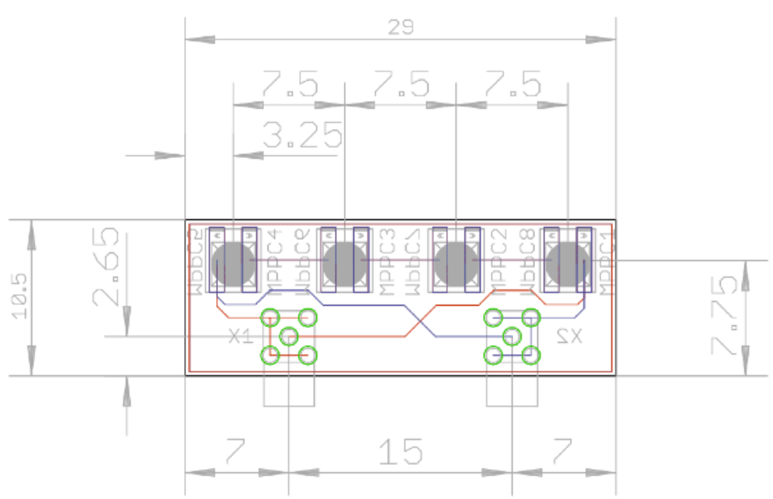
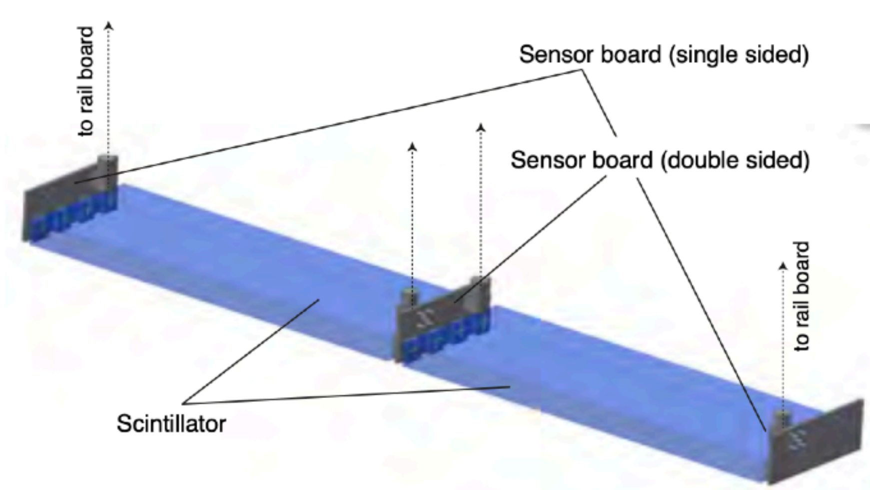


Figure 4.7: The layout of the sensor-board. 4 SMD-type SiPMs are soldered on one side. If the sensor board is to be used in the middle of two scintillators, the SiPMs are soldered on both sides. See also Fig. 4.10.



PLASTIC SCINTILLATOR PRODUCTS

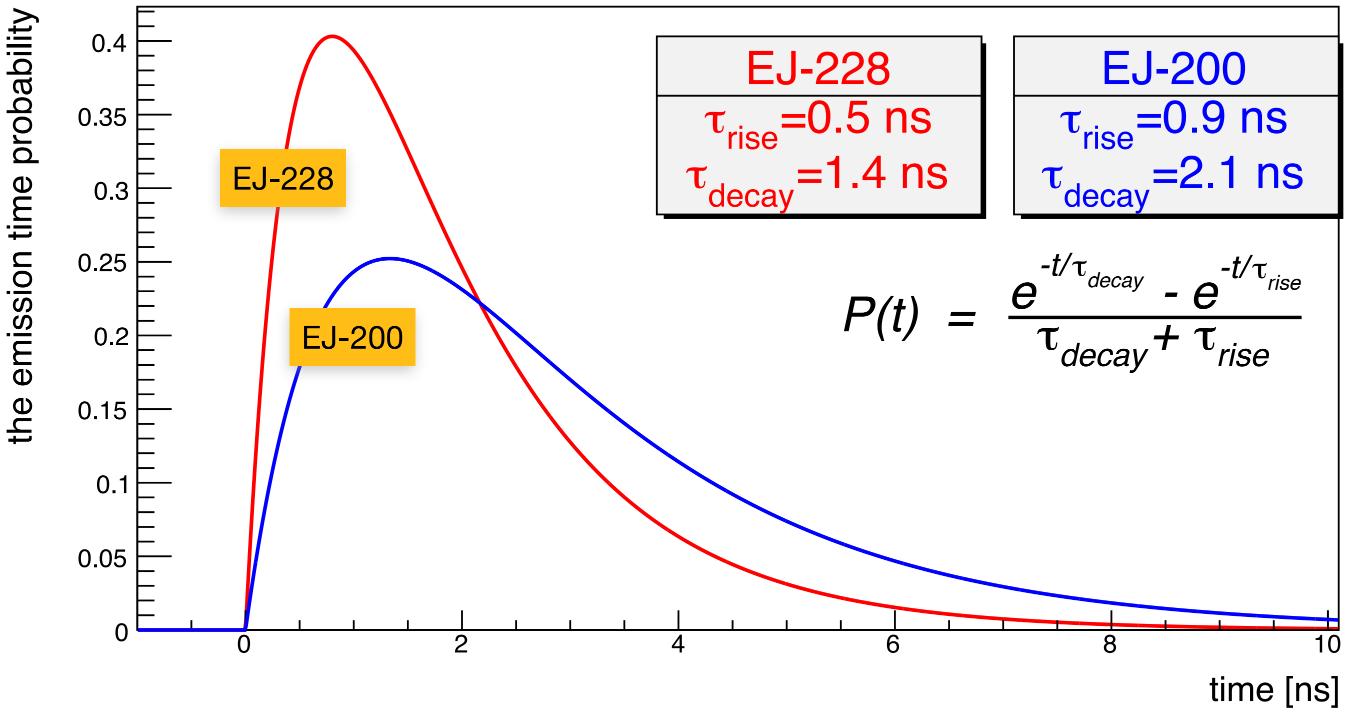
Material	Description/Application	Commercial Equivalents	
		NE	S-G
EJ-200	Best overall general properties	Pilot F	BC-408
EJ-204	Good general properties, Use with green WLS	NE-104	BC-404
EJ-208	Good general properties, High attenuation length	NE-110	BC-412
EJ-212	Good general properties, Thin films	NE-102A	BC-400
EJ-214	Ultra-thin films (25 μm), Formerly EJ-299-07	–	–
EJ-228	Very fast timing, High pulse pair resolution, Small sizes (<10cm)	Pilot U	BC-418
EJ-230	Variant of EJ-228, Used for detector dimensions exceeding 10cm	Pilot U2	BC-420
EJ-232	Very fast timing, Use with blue WLS, Small sizes (<10cm)	NE-111A	BC-422
EJ-232Q	Variant of EJ-232, Quenched for ultra-fast timing	–	BC-422Q

typical material for ~2m TOF bars (EJ-200)

~10cm long tiles (EJ-228, EJ-230, EJ-232, EJ-232Q)

https://eljentechnology.com/index.php/products/plastic-scintillators

Chois of scintillator material

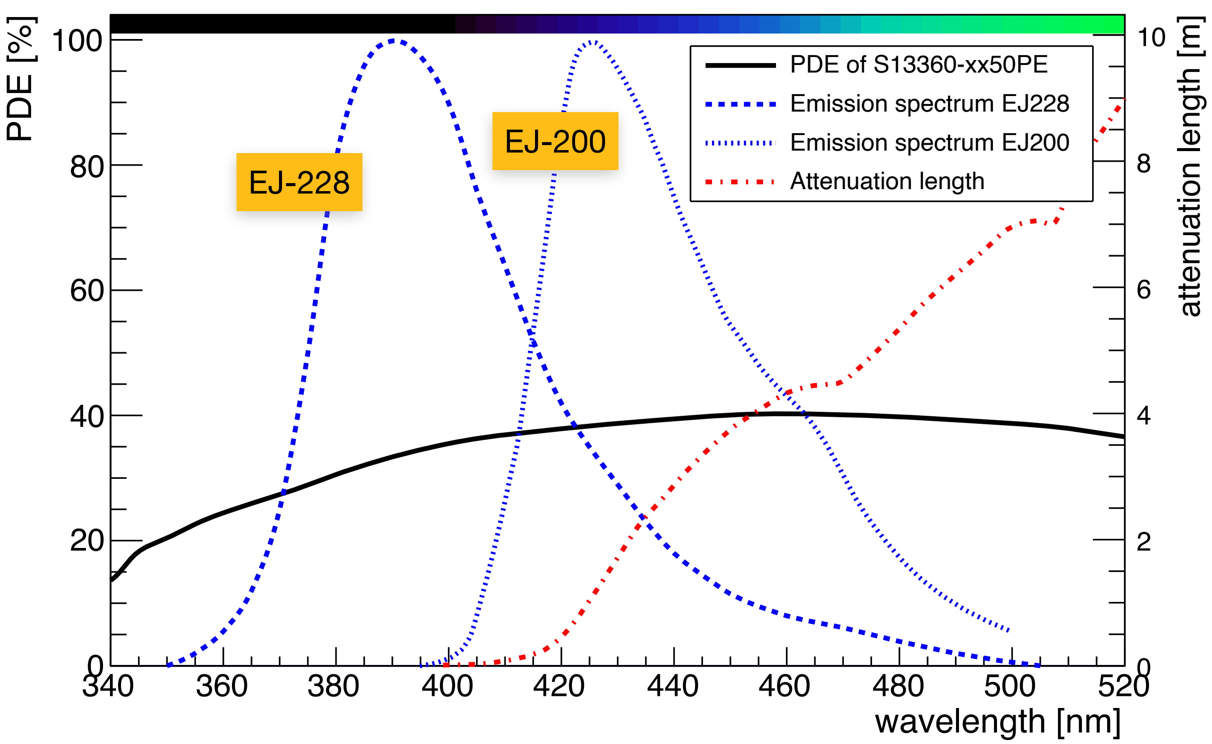


- Time resolution is inversely proportional to the slope of the rising edge

$$\sigma_t^2 = \left(\frac{\sigma_u}{du/dt}\right)^2 + Const$$

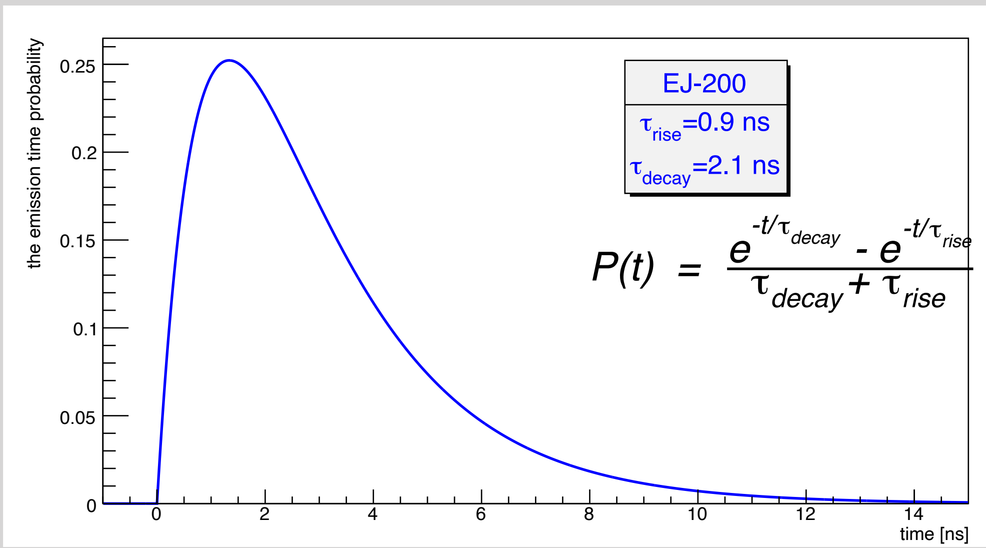
- the shorter the rise time, τ_{rise}, the better the precision, σ_t.

- Faster light emission in UV region
- UV region is stronger absorbed by plastic than the visible light
- 'Faster' scintillator has shorter attenuation length, 'slower' scintillator has longer attenuation length

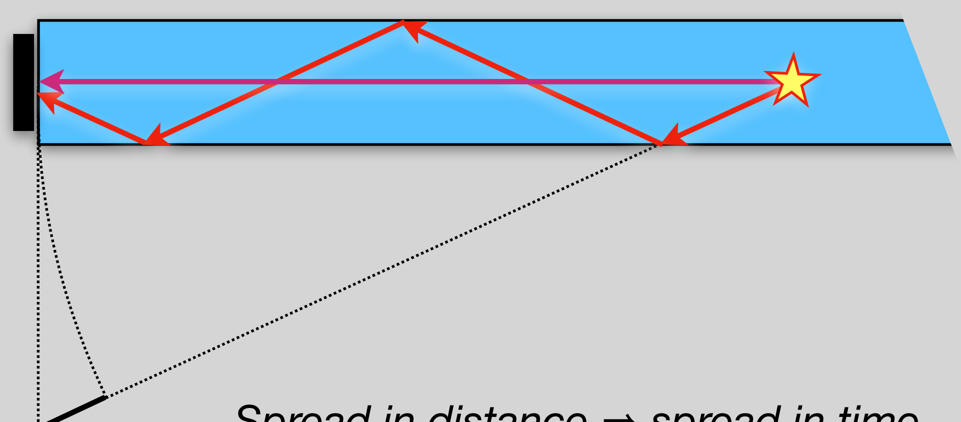


Time spread due to the photo-emission and photo-sensor

- Rise time of SiPM signals is ~2.5 ns (10% to 90%)
- Another τ definition for light emission in plastic



Time spread due to the light transmission



Spread in distance ⇒ spread in time.
increases linearly with distance

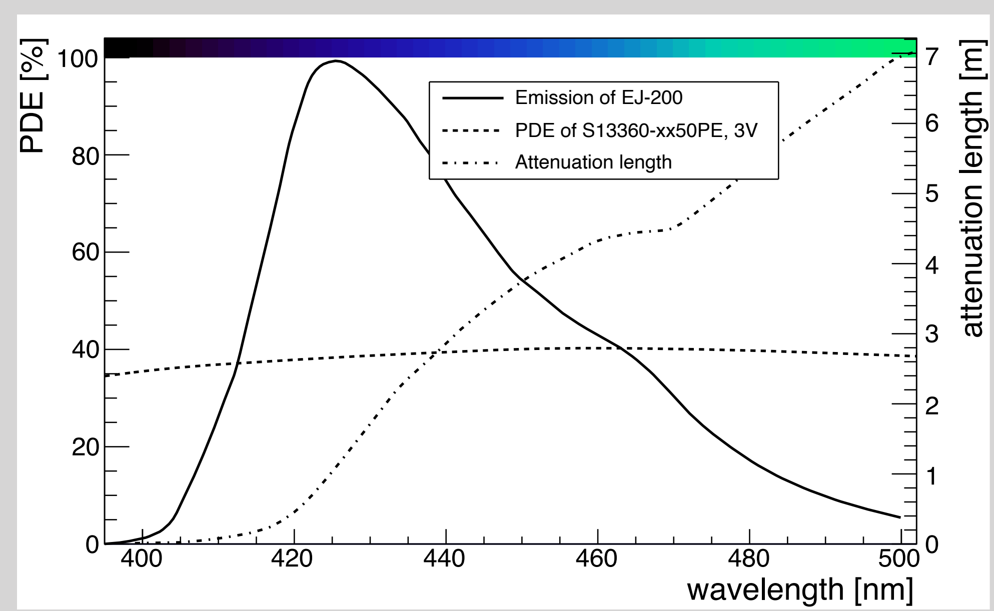
Time resolution σ_t vs light propagation x

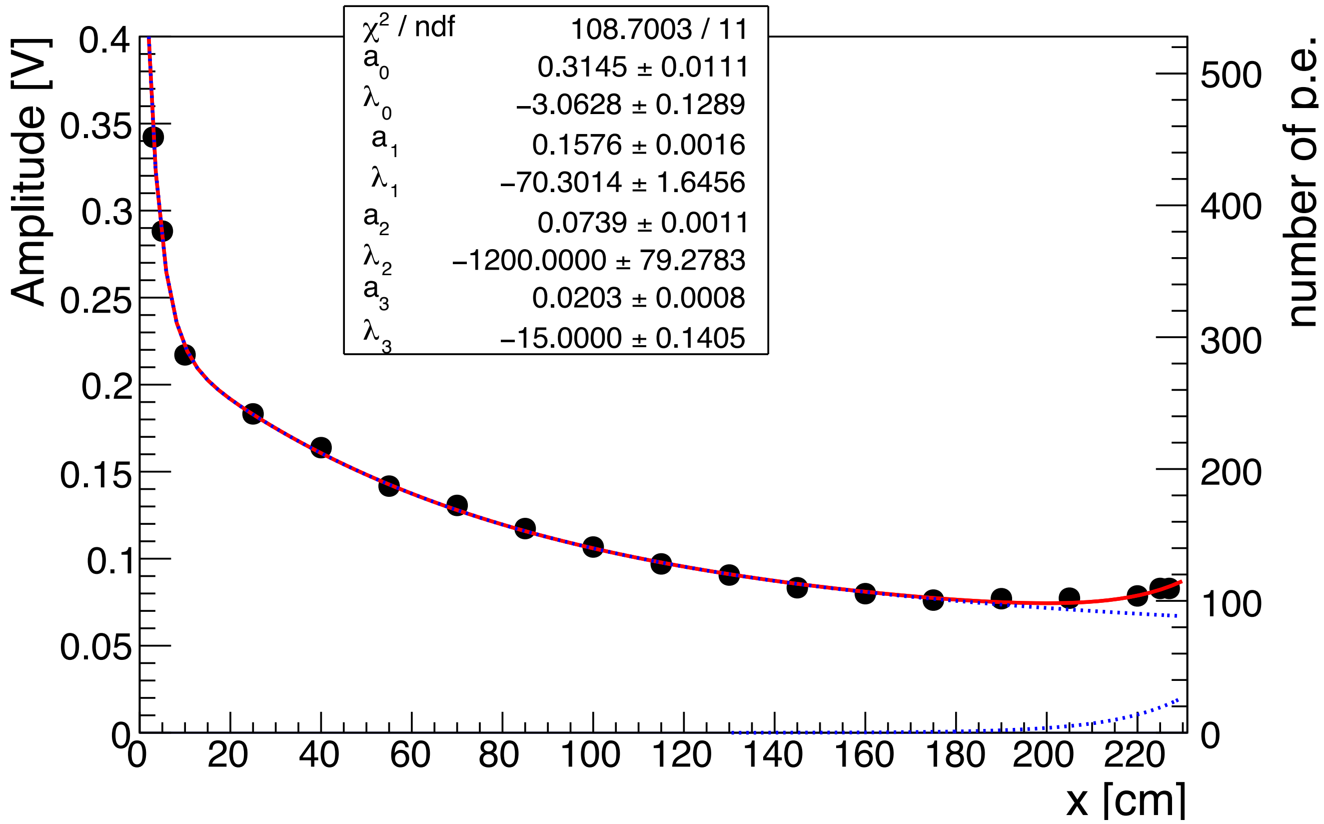
$$\sigma_t(x) = \sqrt{\frac{\sigma^2_{sci+SiPM}}{N(x)} + \frac{(\sigma_{length}\cdot x)^2}{N(x)} + \sigma^2_{el}}$$

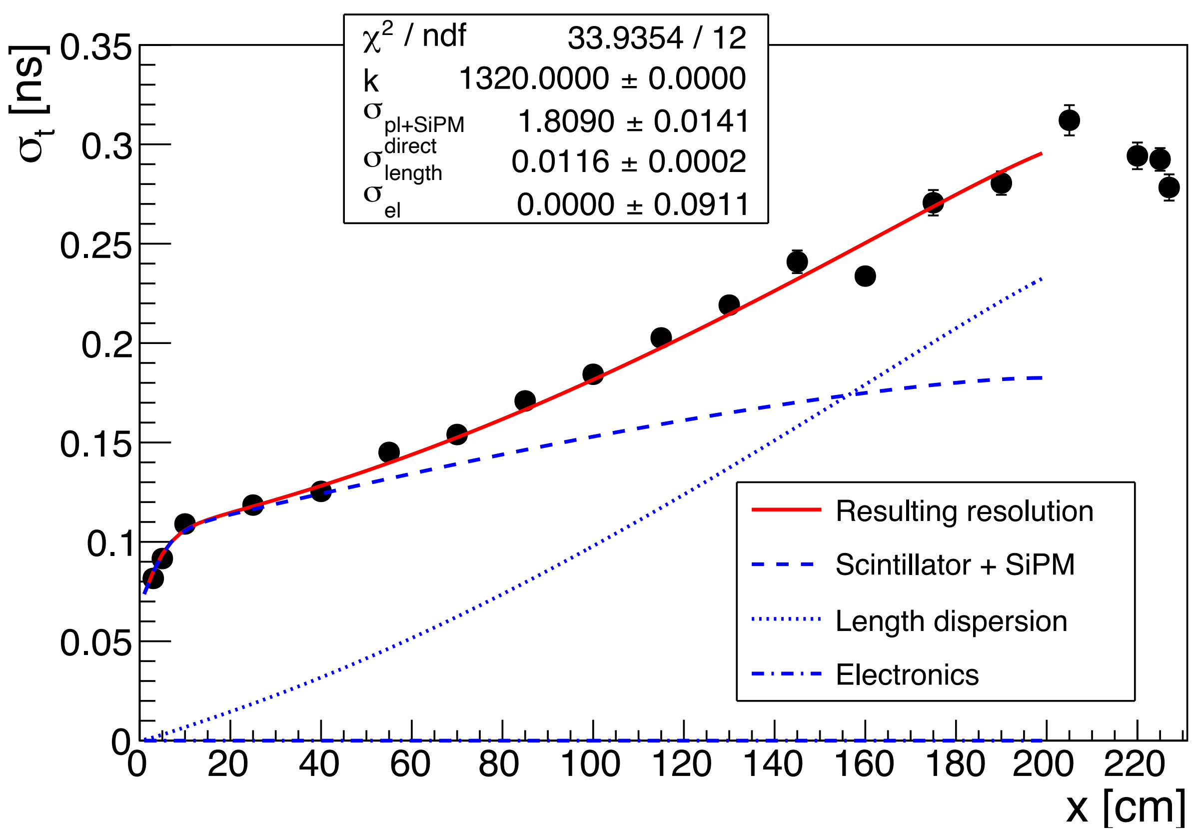
- Resolution and noise of electronics.
- Independent of x

Number of photo-electrons

- Decreases exponentially with distance for a fixed wavelength: $N(x) = N_0\, e^{-x/\lambda}$
- Different wavelengths have different attenuation length



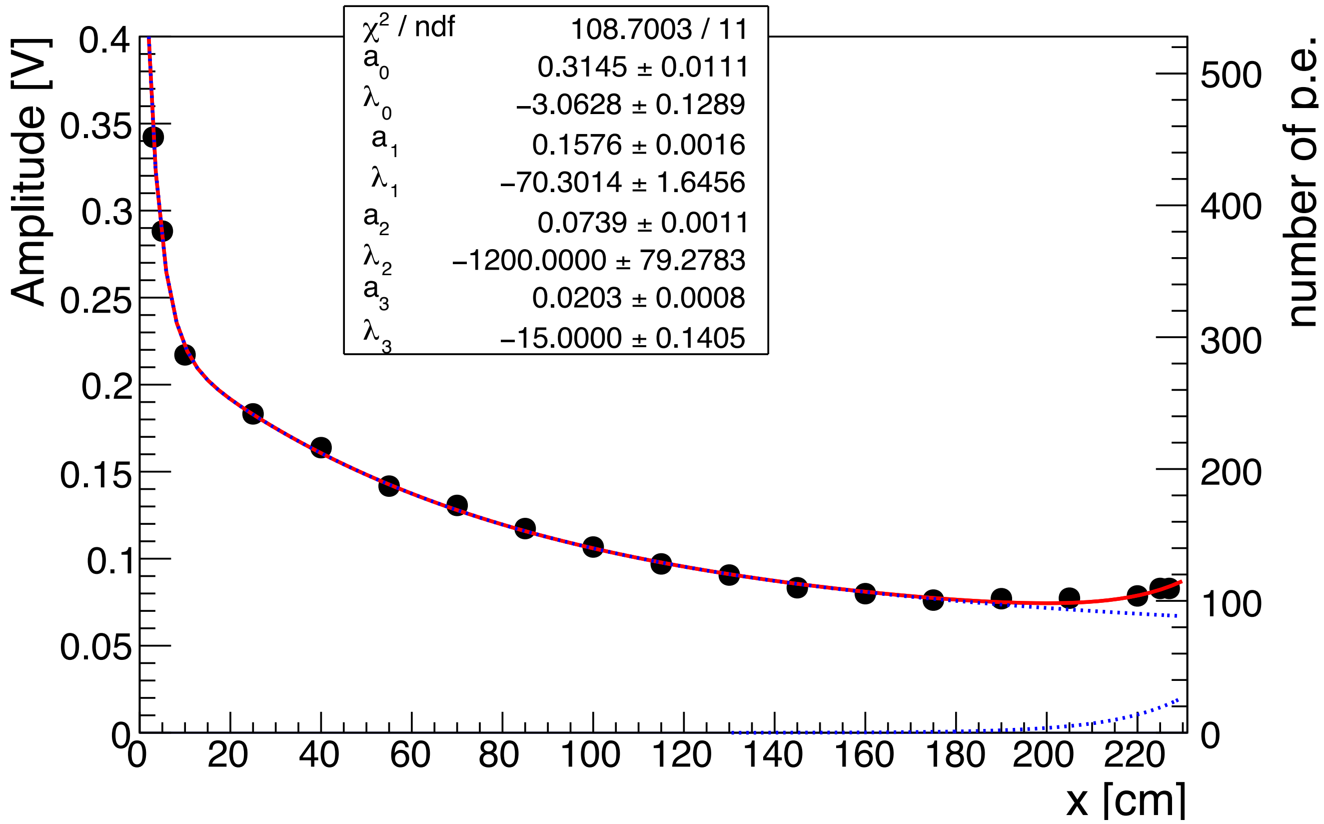




Phenomenological analysis for the time resolution *(L_{bar} = 2.3 m)*

$$\sigma_t(x) = \sqrt{\frac{\sigma^2_{sci+SiPM}}{N(x)} + \frac{(\sigma_{length} \cdot x)^2}{N(x)} + \sigma^2_{el}}$$

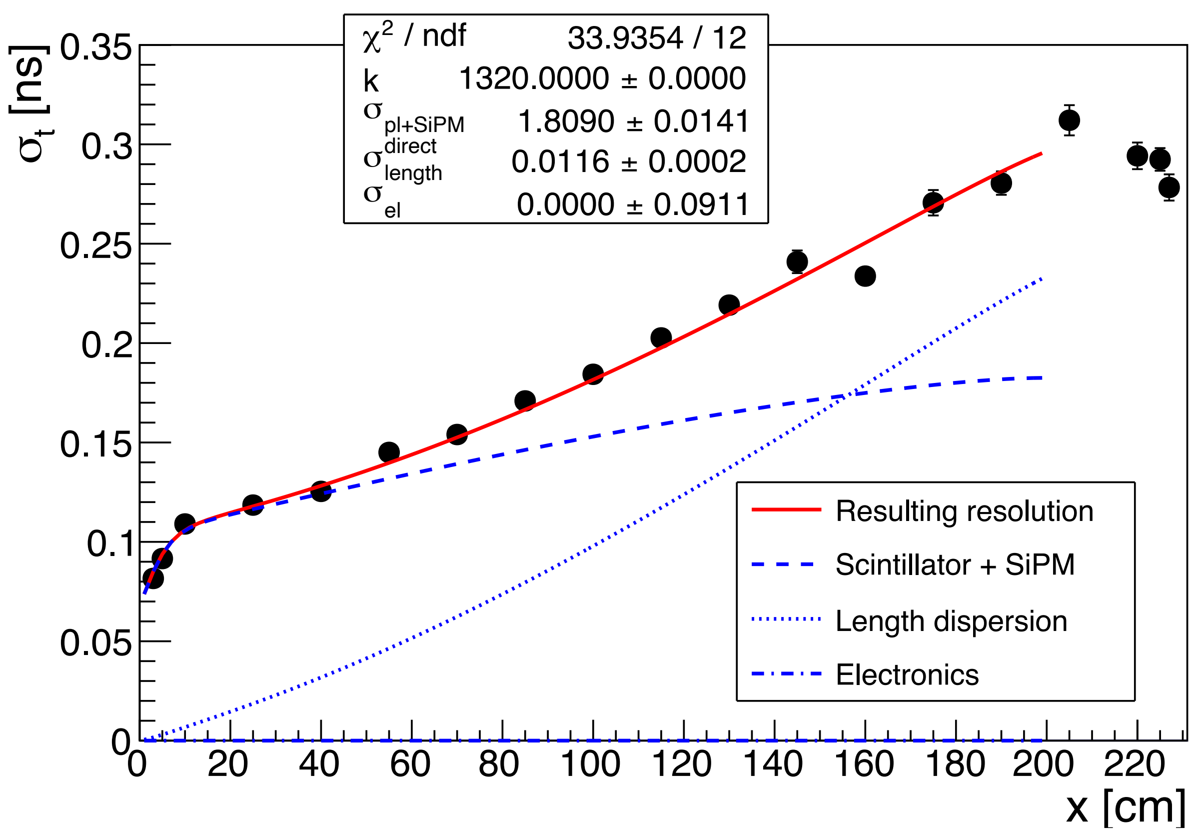
- Assumption: number of photons is proportional to the signal amplitude: $N(x) = kA(x)$
- k to be defined from dedicated measurements

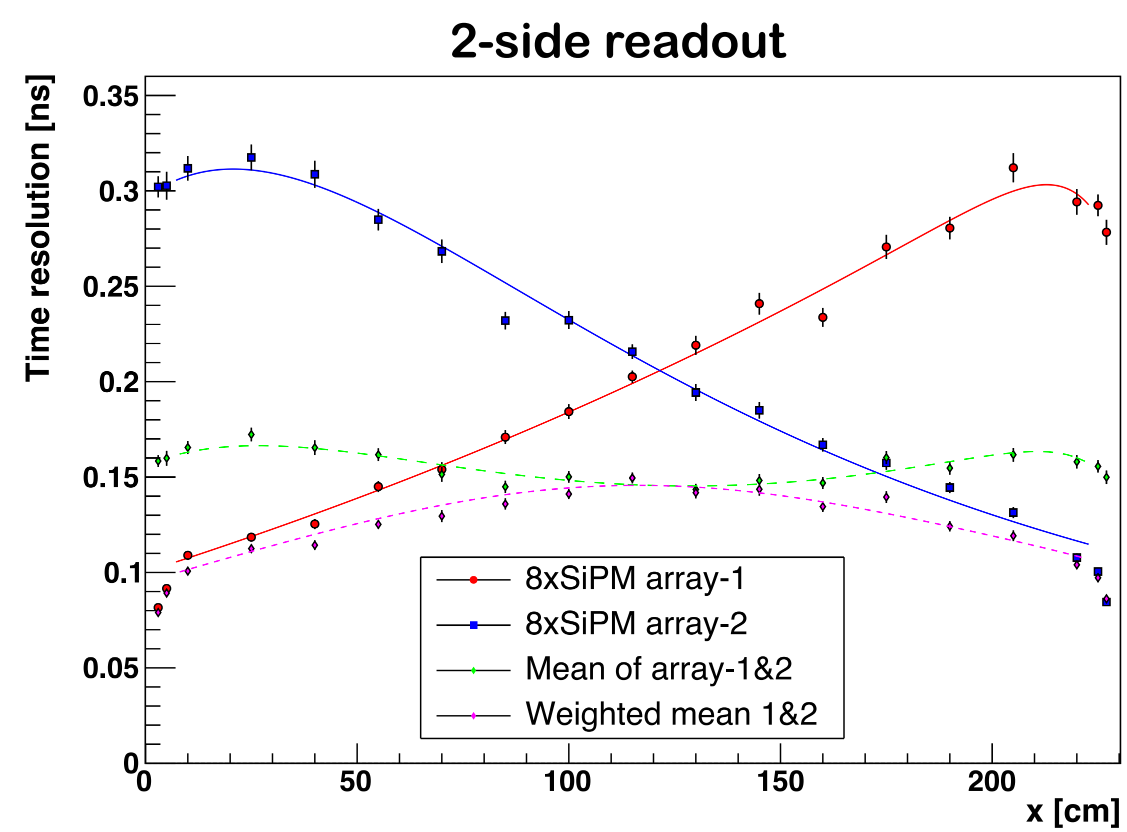


Phenomenological analysis for the time resolution *(L_{bar} = 2.2 m)*

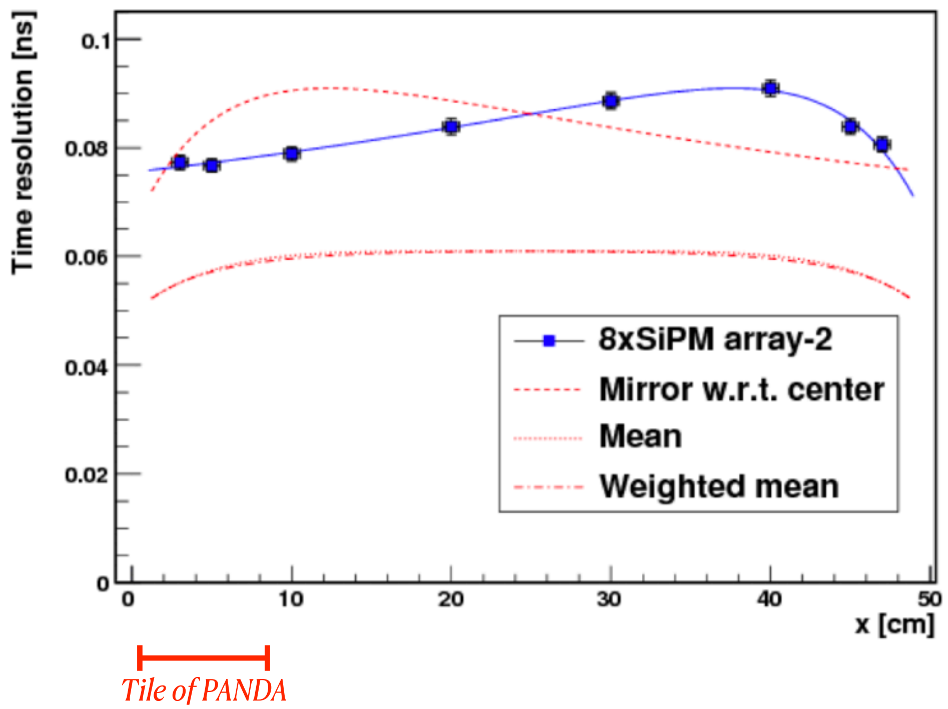
$$\sigma_t(x) = \sqrt{\frac{\sigma^2_{sci+SiPM}}{N(x)} + \frac{(\sigma_{length} \cdot x)^2}{N(x)} + \sigma^2_{el}}$$

- Assumption: number of photons is proportional to the signal amplitude: $N(x) = kA(x)$
- k to be defined from dedicated measurements





<u>50 cm</u> bar, EJ204, one-side readout



- Bar cross section is 60x10 mm^2
- 8 SiPMs 6x6 mm^2 each
- Fraction of light detected
  - (8x6x6)/(60x10) = 48%
- The resolution is ~60 ps, shorter bar would make possibly ~50ps
- No silicone grease was applied between SiPM and plastic

- TOF of PANDA
- Tile cross section is 30x5 mm^2
- 4 SiPMs 3x3 mm^2 each
- Fraction of light detected
  - (4x3x3)/(30x5) = 24%
- The resolution is 50 - 100 ps

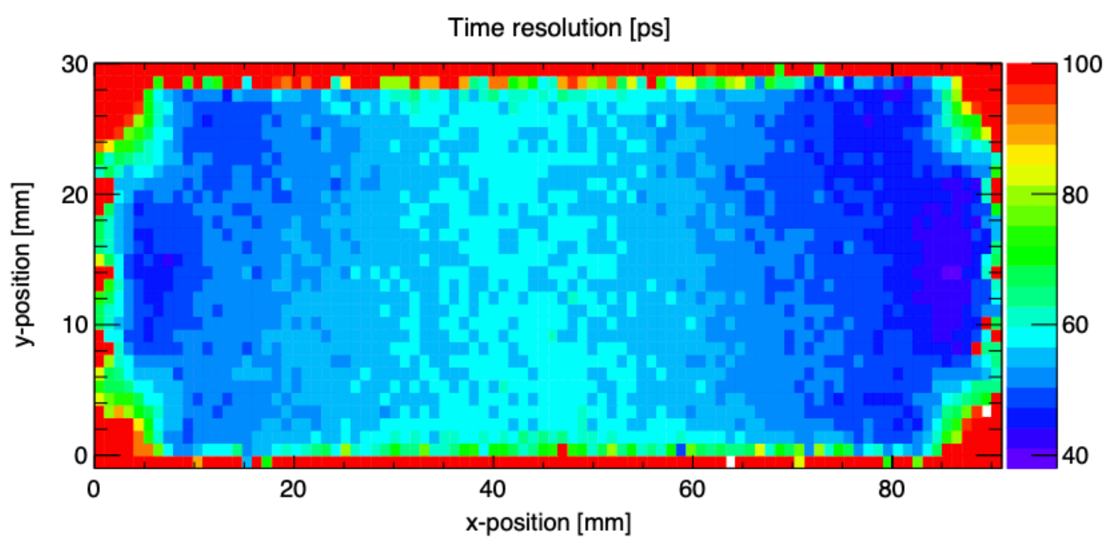
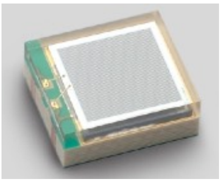


Figure 6.13: Time resolution obtained from a position scan of a 90×30×5 mm^3 EJ-232 scintillator tile readout by Hamamatsu SiPMs attached to opposite sides (y-axis), 4 SiPMs in series per side.

SiPMs from Hamamatsu

S13360-3050PE: 3x3mm², 50μm pixel

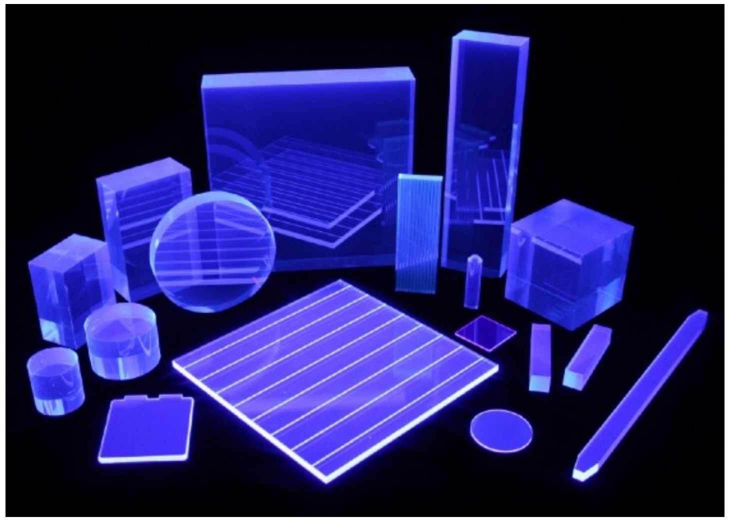
Quotation date: 14.05.2019



Pos	Part No. Description	Quantity (pcs)	Unit Price JPY	Net Amount JPY
1.1	S13360-3050PE MPPC RoHS conform	40000	1'340.00 =12.81 USD	53'600'000.00
1.2	S13360-3050PE MPPC RoHS conform	50000	1'210.00 =11.57 USD	60'500'000.00 =578.5 kUSD

Possible option for optimization (~10% of cost):
to oder the array directly, cost of NRE (non-recurring engineering) ~6 kUSD

Plastic scintillator



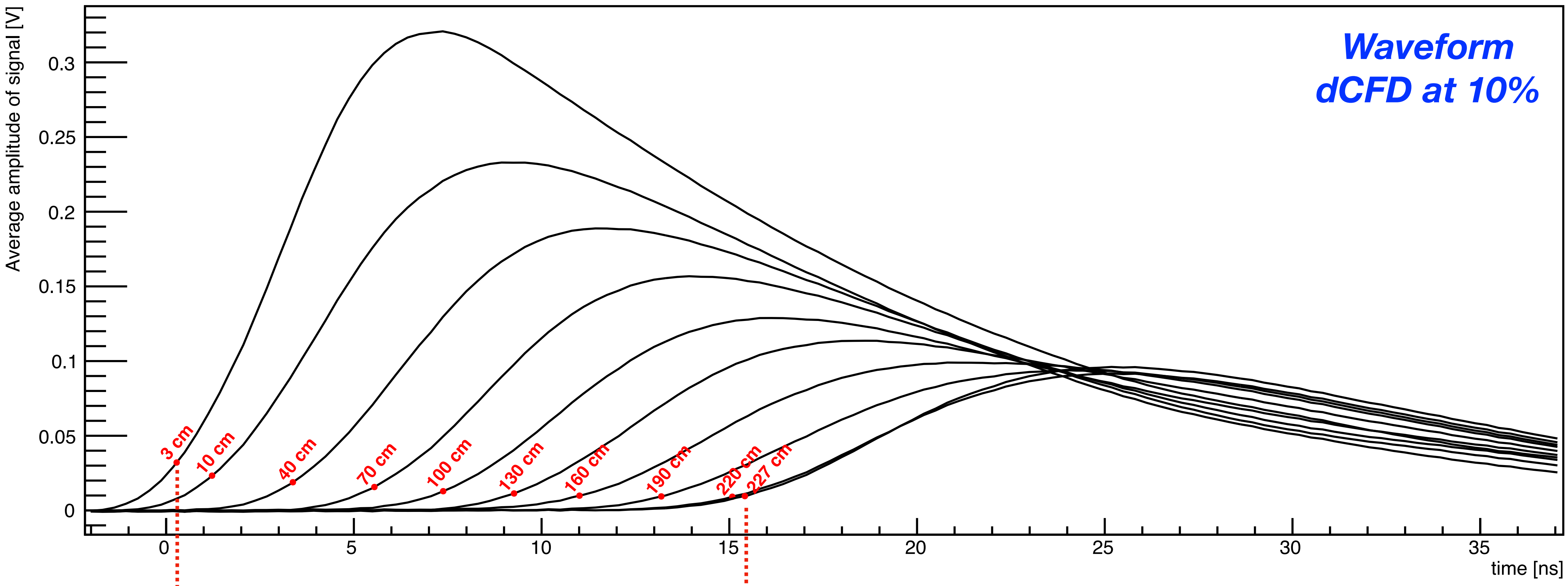
- UV or NUV scintillator from EJ or BC (or Uniplast/Vladimir?)
- Typical cost is ~200 USD/kg but shaping can be expensive
- Requesting quotation to be sure

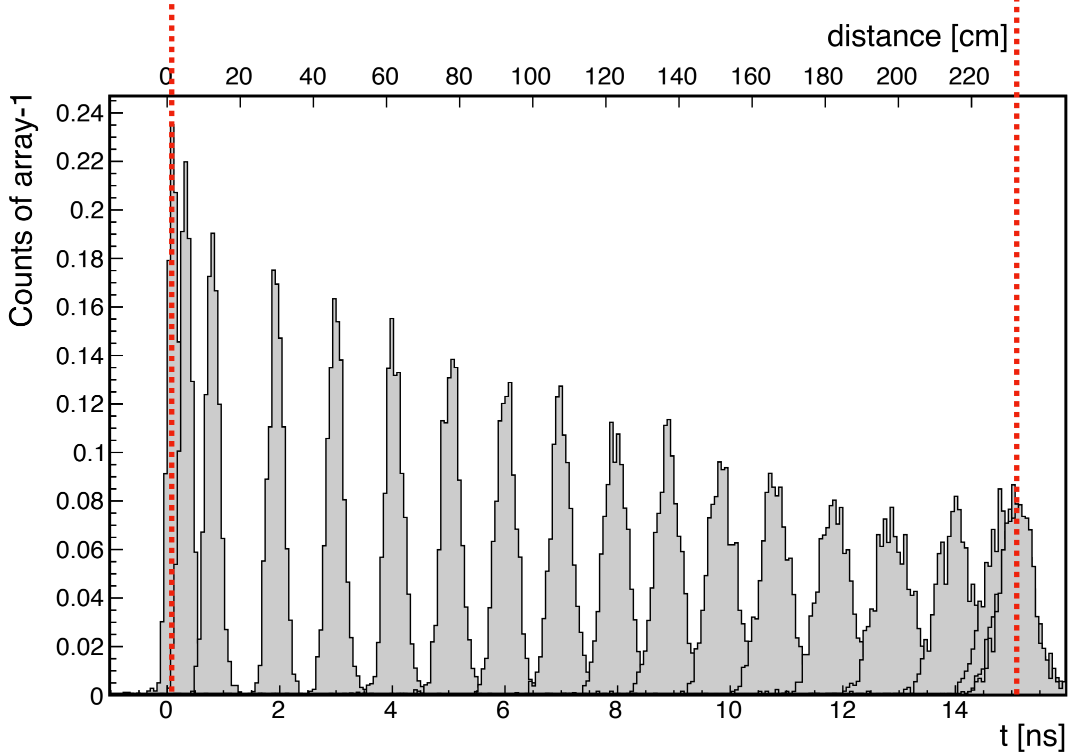
Conclusions

- Two possible options for TOF of SPD
  - *mRPC*: well established approach (production in JINR & Protvino)
  - *Plastic scintillator*: much lighter in terms of material, less demanding in terms of long-term support but requires R&D
  - Only analog part is different. Time resolution is 50 -100 ps
- It was *not* covered in this talk
  - End-cap parts of TOF
  - Discriminator + ToT (for instance NINO in MPD)
  - Time-to-digital conversion (for instance TDC72VHL with sampling 24.4ps in MPD)
  - Power supply and slow control
  - Mechanics: support frame, holding brackets, cabling guides

backup slides

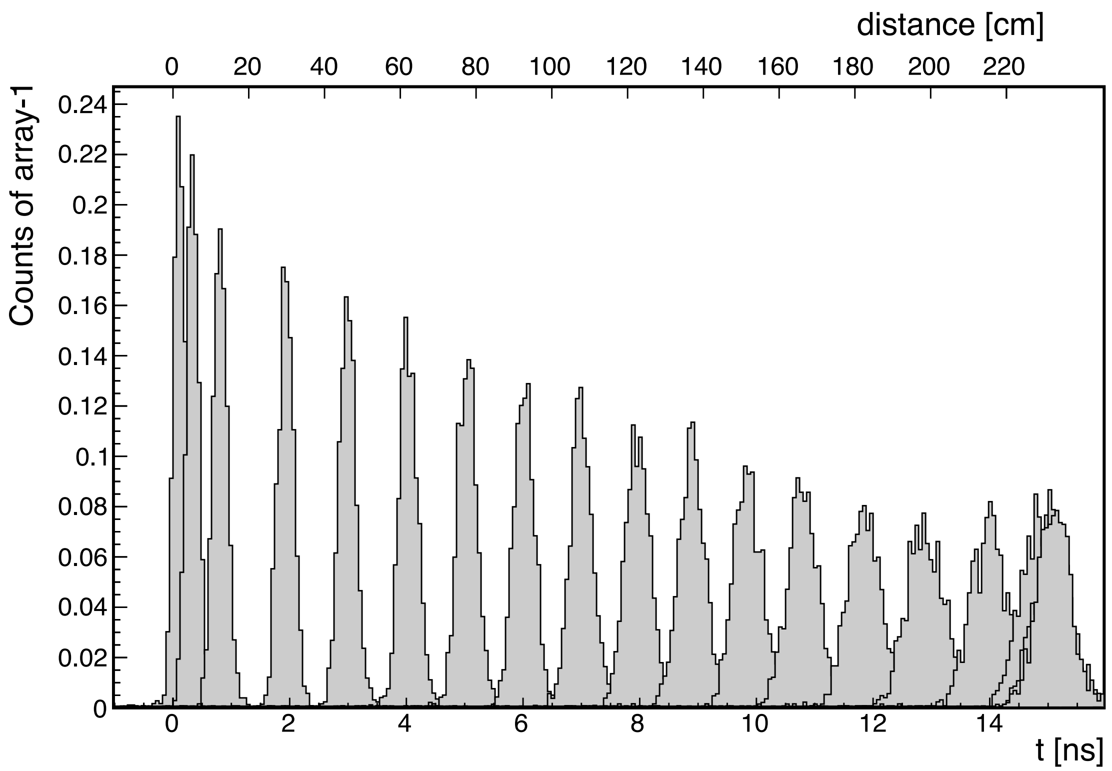
A single bar analysis (testbeam of 2018)

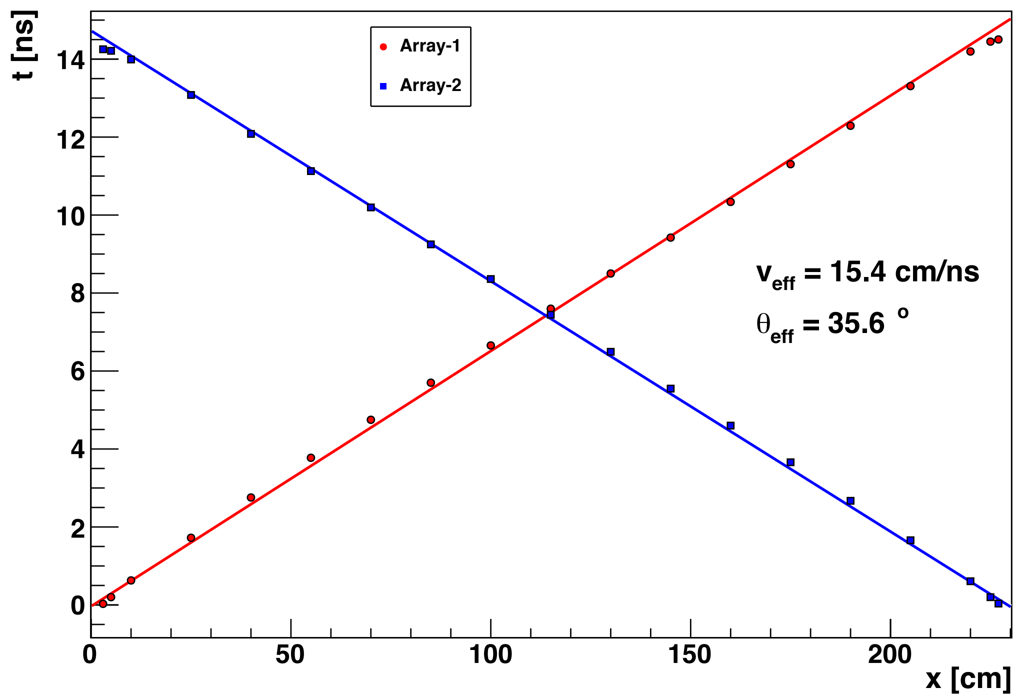


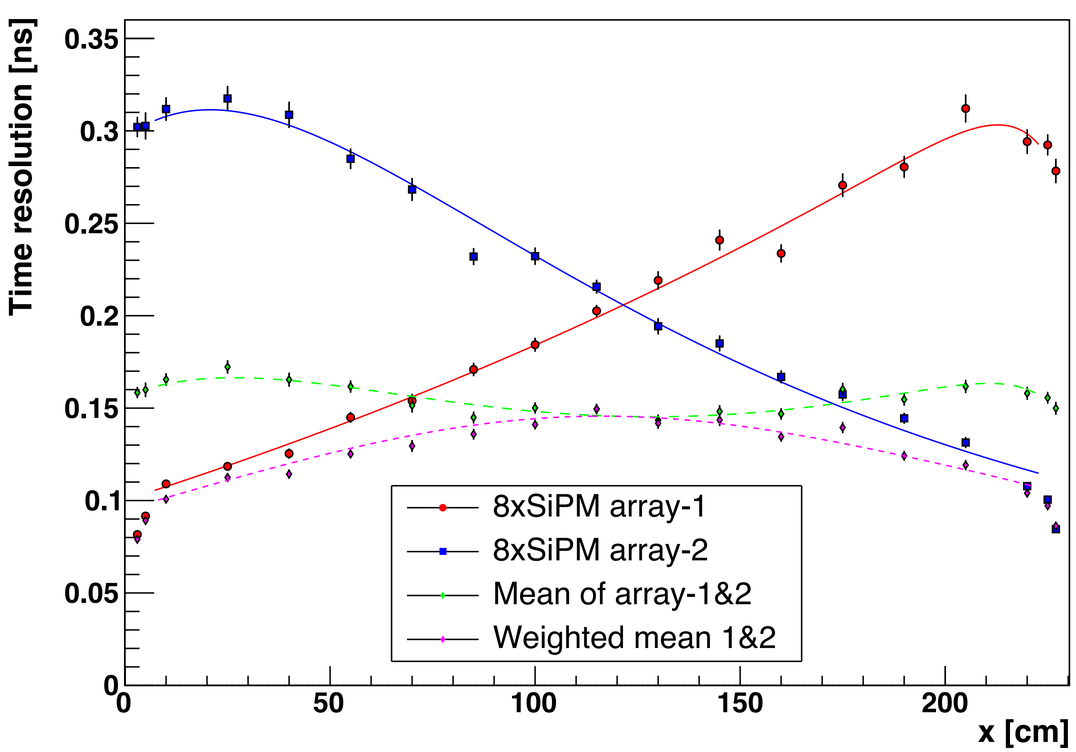


- Testbeam in T10 of CERN PS in summer 2018
  - 6 GeV proton beam
- EJ200 bar with size of 230 x 12 x 1 cm^3 (10 cm longer than the one of TOF-ND280)
- SiPM-array readout by ASIC (eMUSIC)
  - resolution is compatible with discrete circuit (check for few points with cosmics)
- Timing reference by 2 beam counters right located up- and downstream of the EJ200 bar

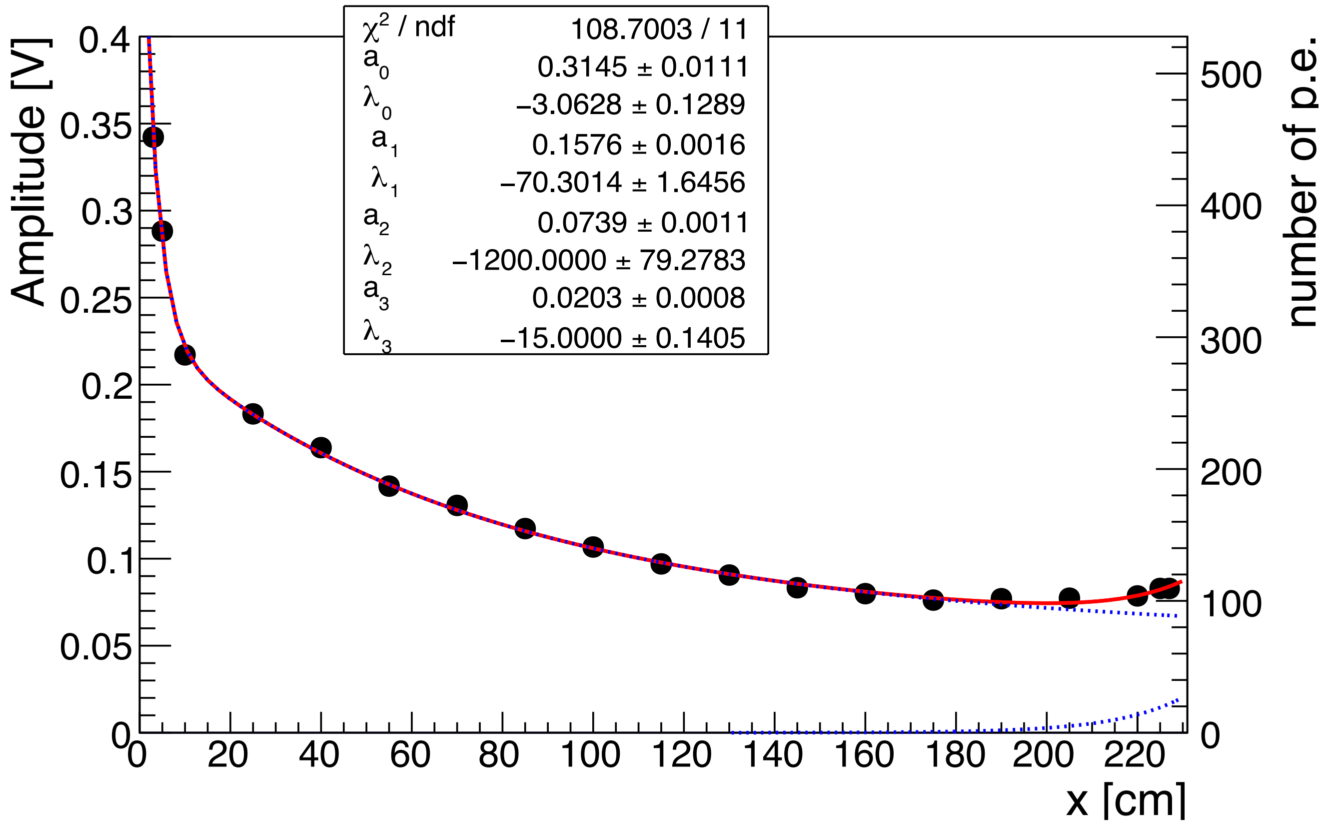
A single bar analysis (testbeam of 2018)

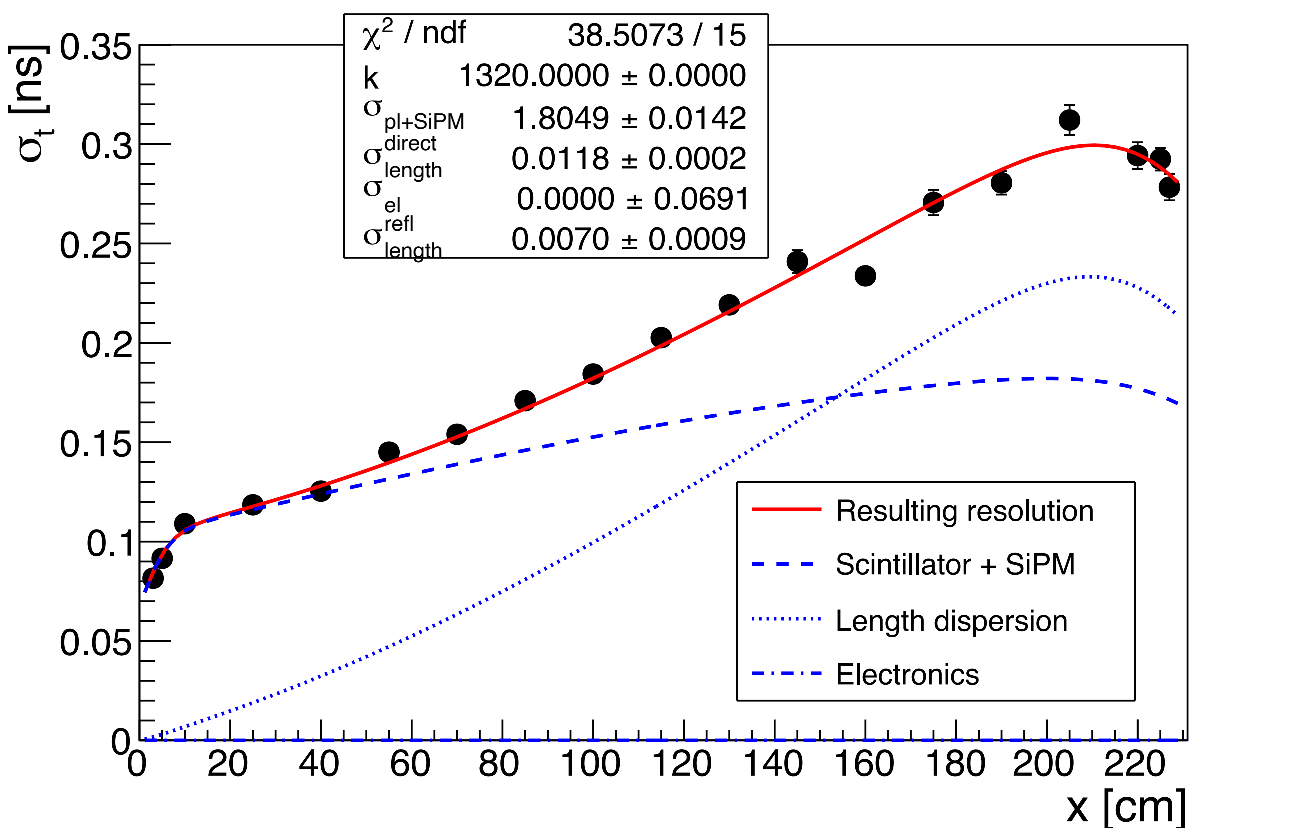






- Reference (trigger) time resolution is much better thus not not subtracted
- Gaussian fit
  - Sigma gives the time resolution
  - Mean value gives the position
- The cross time is defined by both arrays as a mean or weighted mean time





Phenomenological analysis for the time resolution

$$\sigma_t^{direct}(x) = \sqrt{\frac{\sigma^2_{sci+SiPM}}{N^{direct}(x)} + \frac{(\sigma^{direct}_{length} \cdot x)^2}{N^{direct}(x)} + \sigma^2_{el}}$$

$$\sigma_t^{refl}(x) = \sqrt{\frac{\sigma^2_{sci+SiPM}}{N^{refl}(x)} + \frac{(\sigma^{refl}_{length} \cdot x)^2}{N^{refl}(x)} + \sigma^2_{el}}$$

$$\sigma_t(x) = \frac{1}{\sqrt{\frac{1}{\sigma_t^{direct}(x)^2} + \frac{1}{\sigma_t^{refl}(x)^2}}}$$