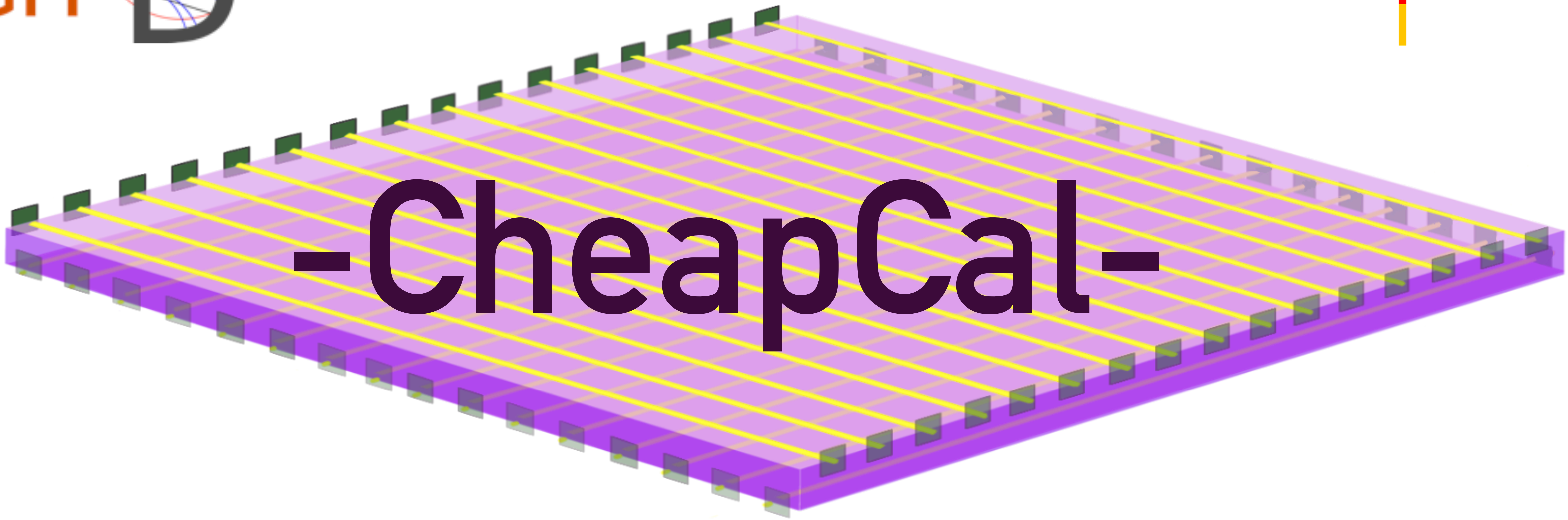


-CheapCal-

Time resolution of the second wavelength-shifting fiber structured plastic scintillator detector prototype

Lea Baumgartner, Alessia Brignoli, Valery Dormenev, Christian Dreisbach, Karl Eichhorn, Jan Friedrich, Martin J. Losekamm, Heiko Markus Lacker, Anupama Reghunath , Christian Scharf, Ben Skodda, Valerian von Nicolai , Hans-Georg Zaunick

Ida Wöstheinrich
Master Student

Humboldt Universität zu Berlin

High-D Consortium Meeting
20th - 21st February 2024

Technical University of Munich

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Bundesministerium für Bildung und Forschung

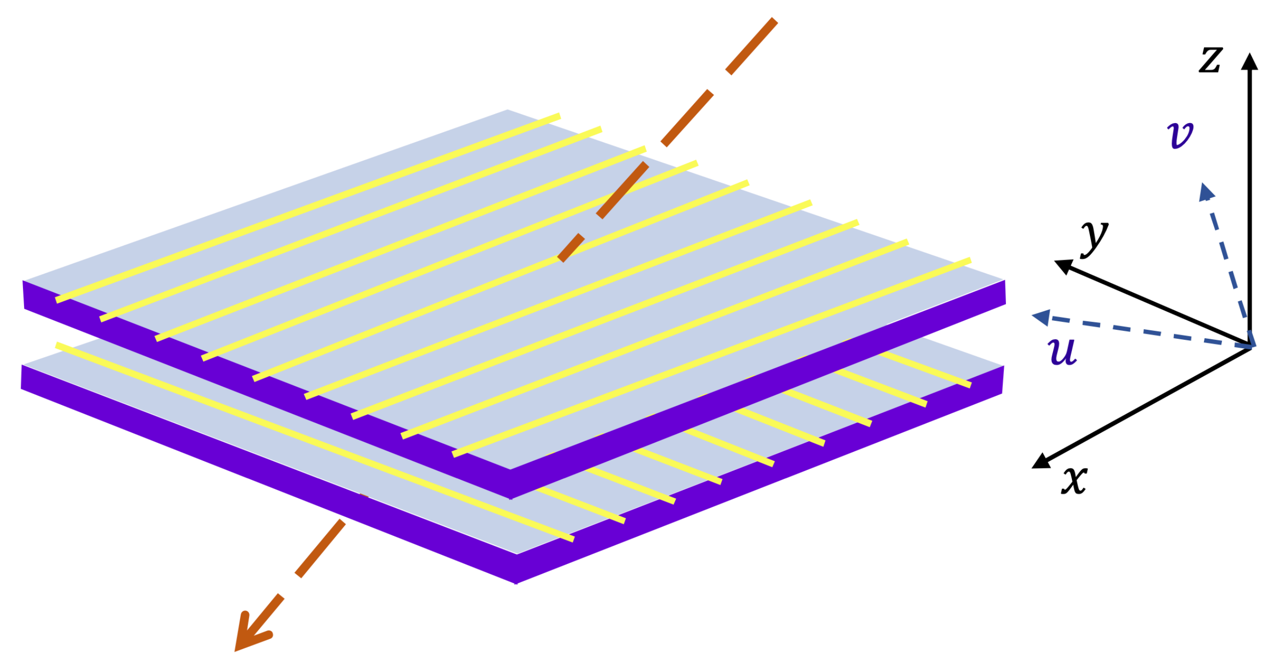
GOAL AND PREVIOUS WORK

CheapCal Project:

- constructing an affordable and easy-to-built detector capable of identifying minimum ionizing particles
- spatial resolution < 1 cm
- fiber-structured extruded plastic scintillator plate
    - cost-effective alternative to cast plastic scintillators in sampling calorimeters

Last Prototype:

- shows proof-of-principle of spatial reconstruction of a traveling particle
- optimized parameters to achieve the highest possible light yield
- time resolution between 3.4 ns and 4.1 ns

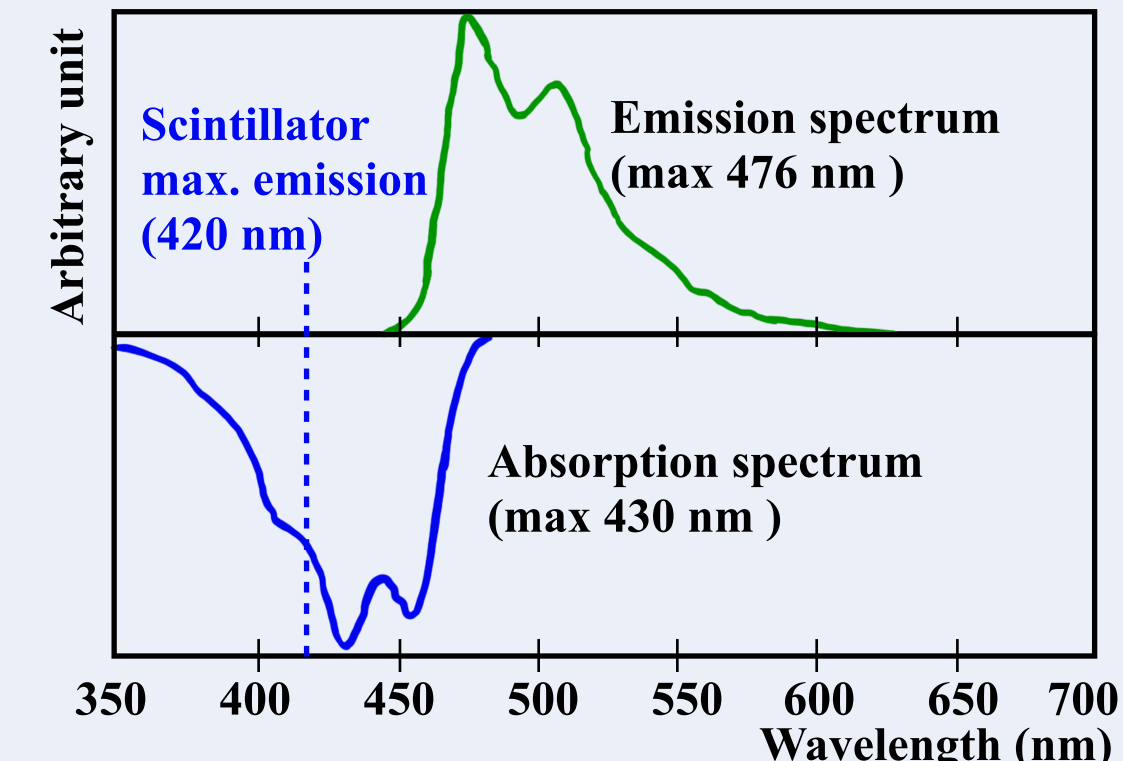


21-02-2022 – A. Brignoli – Humboldt University of Berlin

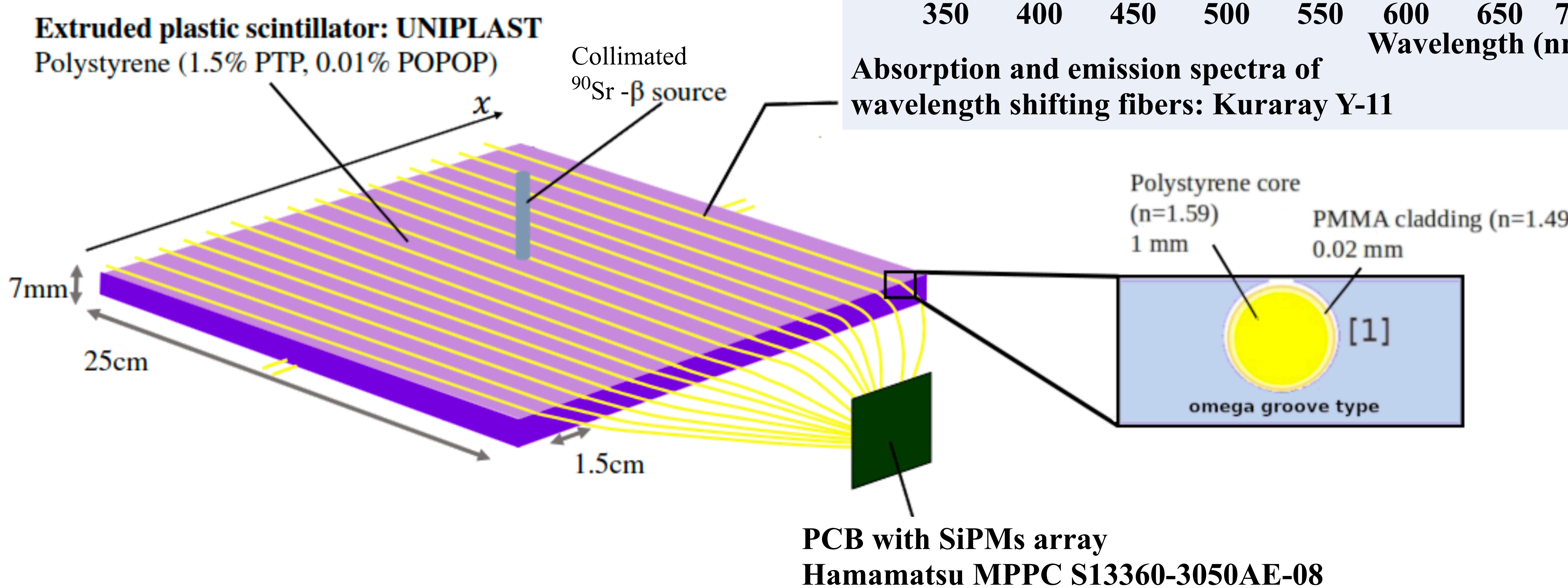
STRUCTURE OF THE DETECTOR – FIRST PROTOTYPE

Main components:

- extruded plastic scintillator material characterized by a short light attenuation length (25x25x0.7 cm)
- 16 parallel wavelength-shifting fibers with a uniform distance of 1.5 cm and a decay time of about 7 ns



Absorption and emission spectra of wavelength shifting fibers: Kuraray Y-11



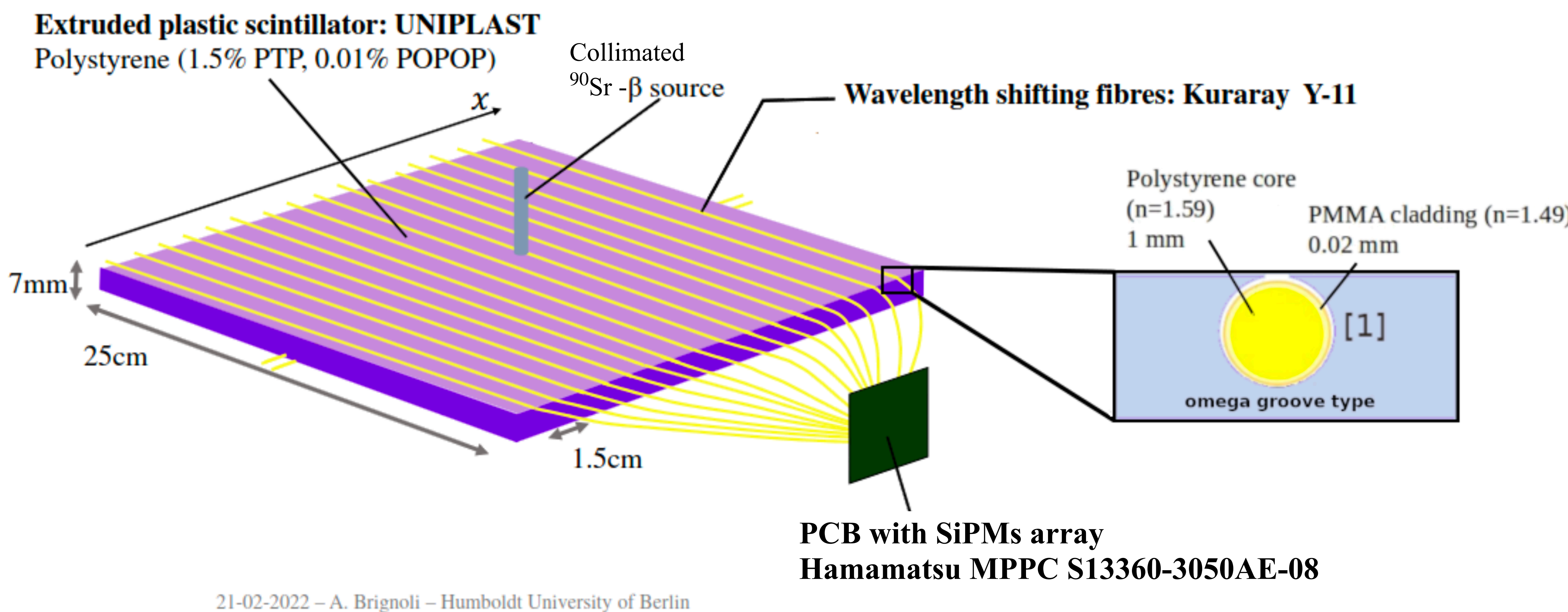
STRUCTURE OF THE DETECTOR – FIRST PROTOTYPE

Main components:

- extruded plastic scintillator material characterized by a short light attenuation length (25x25x0.7 cm)
- 16 parallel wavelength-shifting fibers with a uniform distance of 1.5 cm and a decay time of about 7 ns

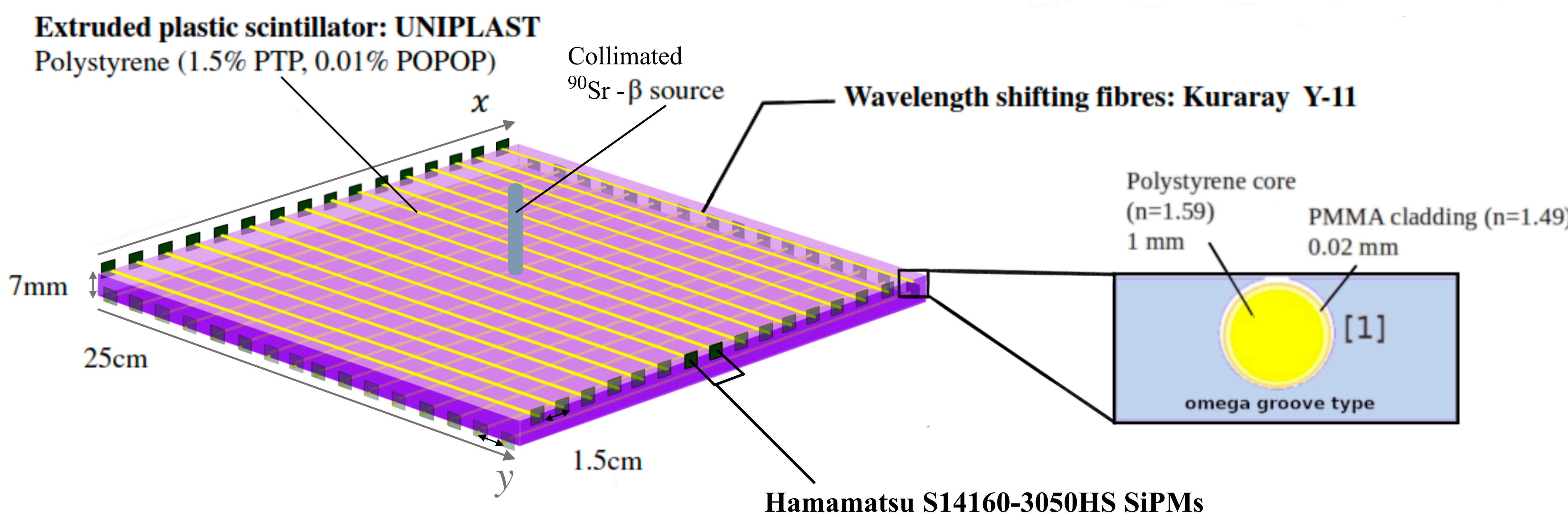
Optimized for higher light yield:

- Omega groove type
- Plastic scintillator wrapped in Dupont™ Tyvek® 1073D foil
- Optical coupling between fibers and the SiPMs by Silicon pads



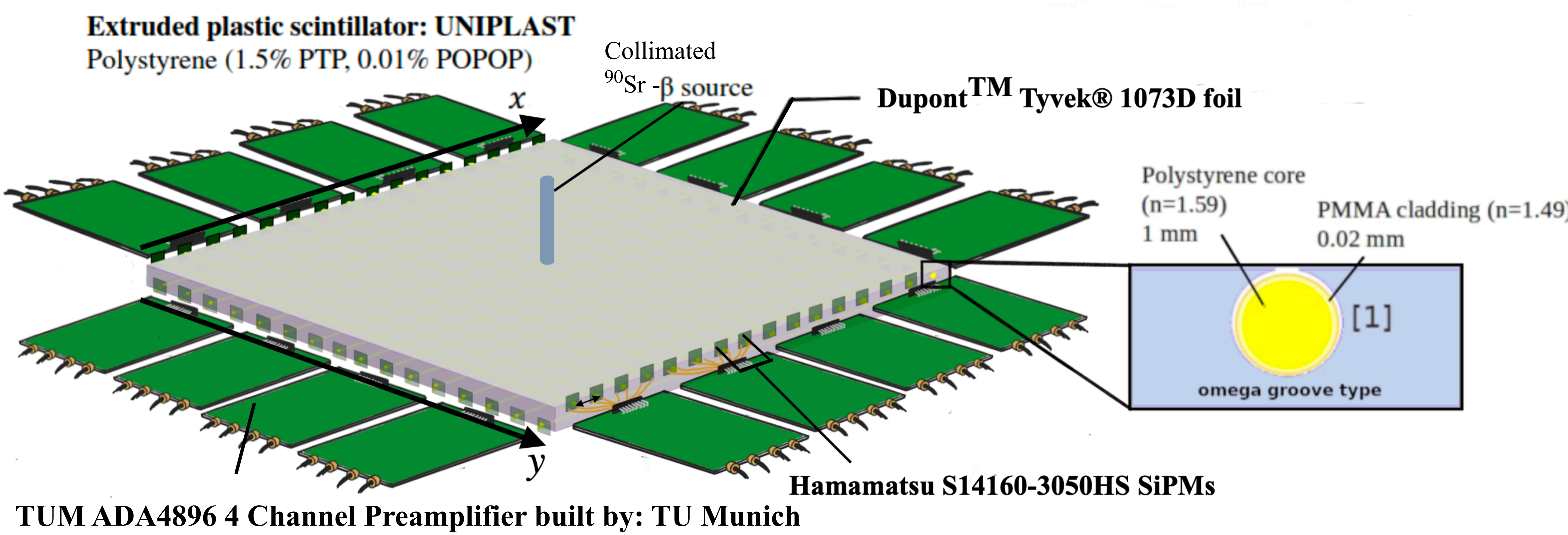
STRUCTURE OF THE DETECTOR – SECOND PROTOTYPE

- Changes to further improve light yield and position reconstruction:
  - 32 fibers in two dimensions shortened to dimensions of the detector plate (25 cm)
  - SiPMs on both sides of each fiber (64 in total)



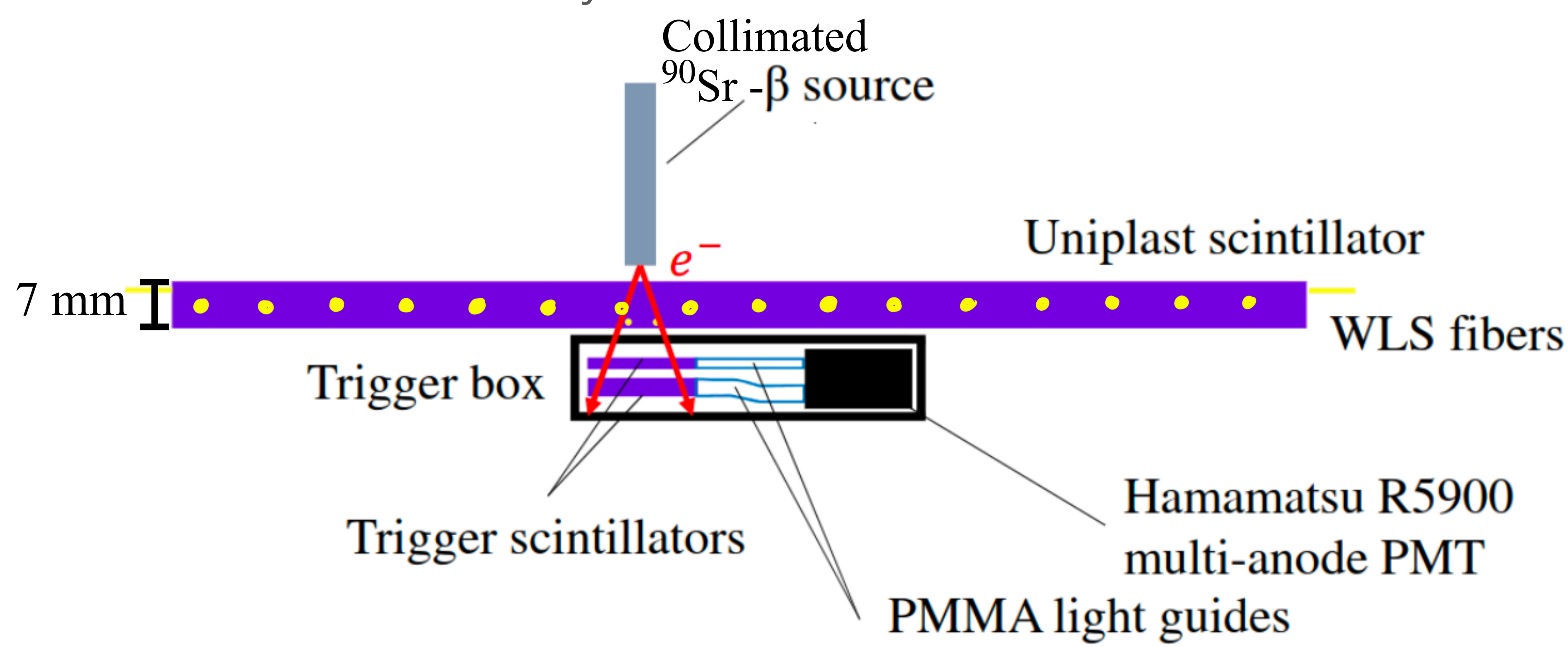
STRUCTURE OF THE DETECTOR – SECOND PROTOTYPE

- Changes to further improve light yield and position reconstruction:
  - 32 fibers in two dimensions shortened to dimensions of detector plate (25 cm)
  - SiPMs on both sides of each fiber (64 in total)
  - Again wrapped reflective Dupont™ Tyvek® 1073D foil
  - 16 shaping preamplifiers



TIME RESOLUTION AND RESPONSE MEASUREMENTS – LAB SETUP

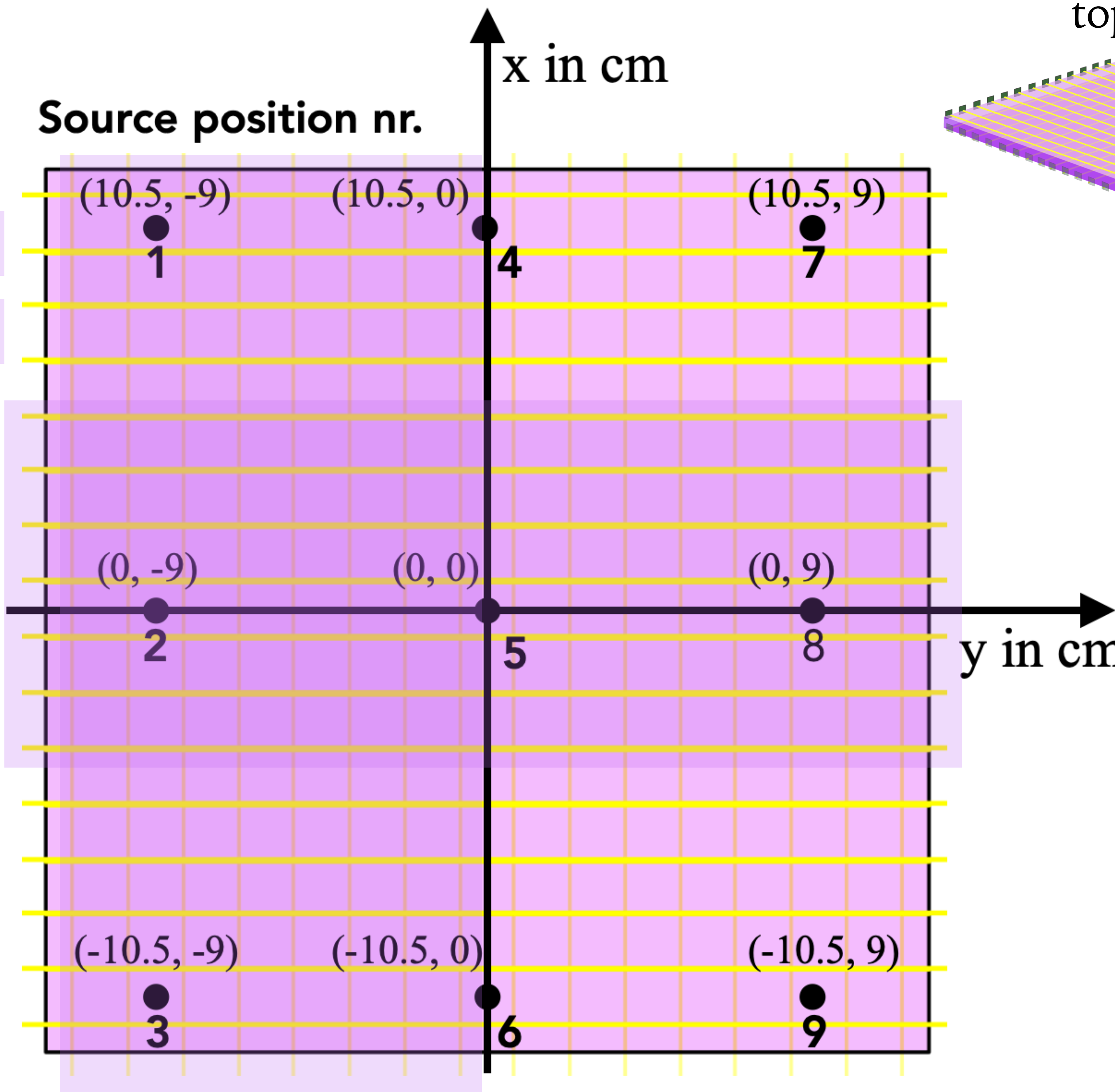
- The whole setup is located in a dark box
- Readout: WaveCatcher digitizer (with 32 channels) and WaveCatcher Data Analysis Software ReadRun based on ROOT Cern C++ framework
- Triggerbox built by: U Hamburg ,DESY Zeuthen
- Collimated beta source - daughter nucleus of Strontium emits electrons with an energy ≈ 2 MeV,
- Measured rate of events in this analysis ≈ 10 Hz

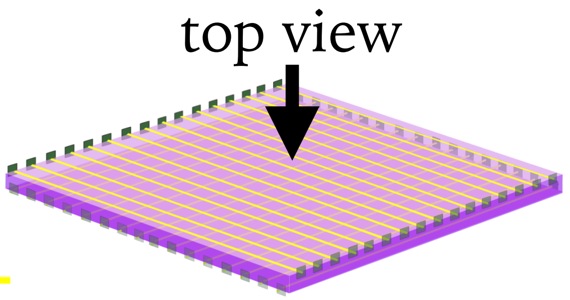


TIME RESOLUTION AND RESPONSE MEASURMENTS – SOURCE POSITIONS

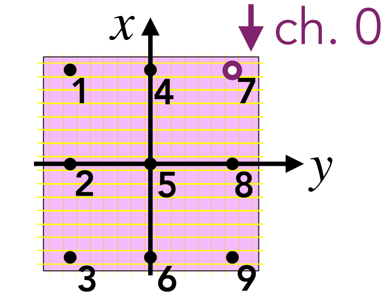
Considered 8 fibers in y

Considered 7 fibers in x



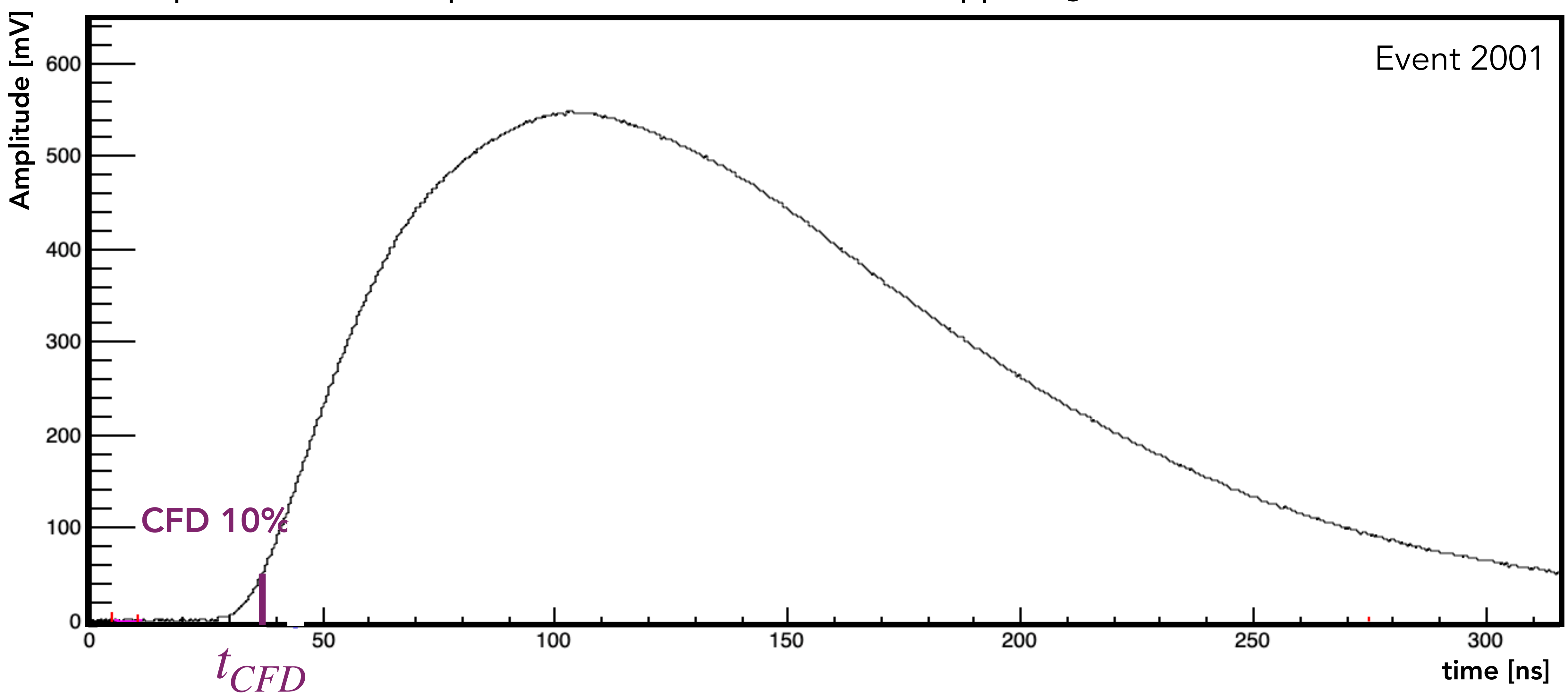


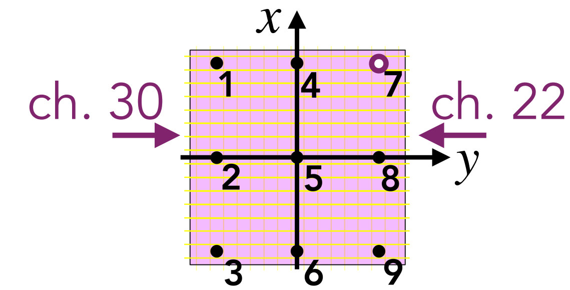
CONSTANT FRACTION DISCRIMINATION



- From the SiPM signal, extract timing information as a function of source position using constant fraction discrimination (CFD, 10%)
- t_{CDF} is the timing acquired from the waveform of the SiPM signal

Example waveform for position 7 and channel 0 in the upper right corner of the detector





TIME RESPONSE - SIGNAL ARRIVAL TIME

Getting the time signals of :

➤ 64 SiPMs

$$t_{\text{SiPM}} := t_{CFD} - t_{\text{upper trigger}}$$

➤ 32 fibers mean of the SiPM signals from both ends of the fiber.

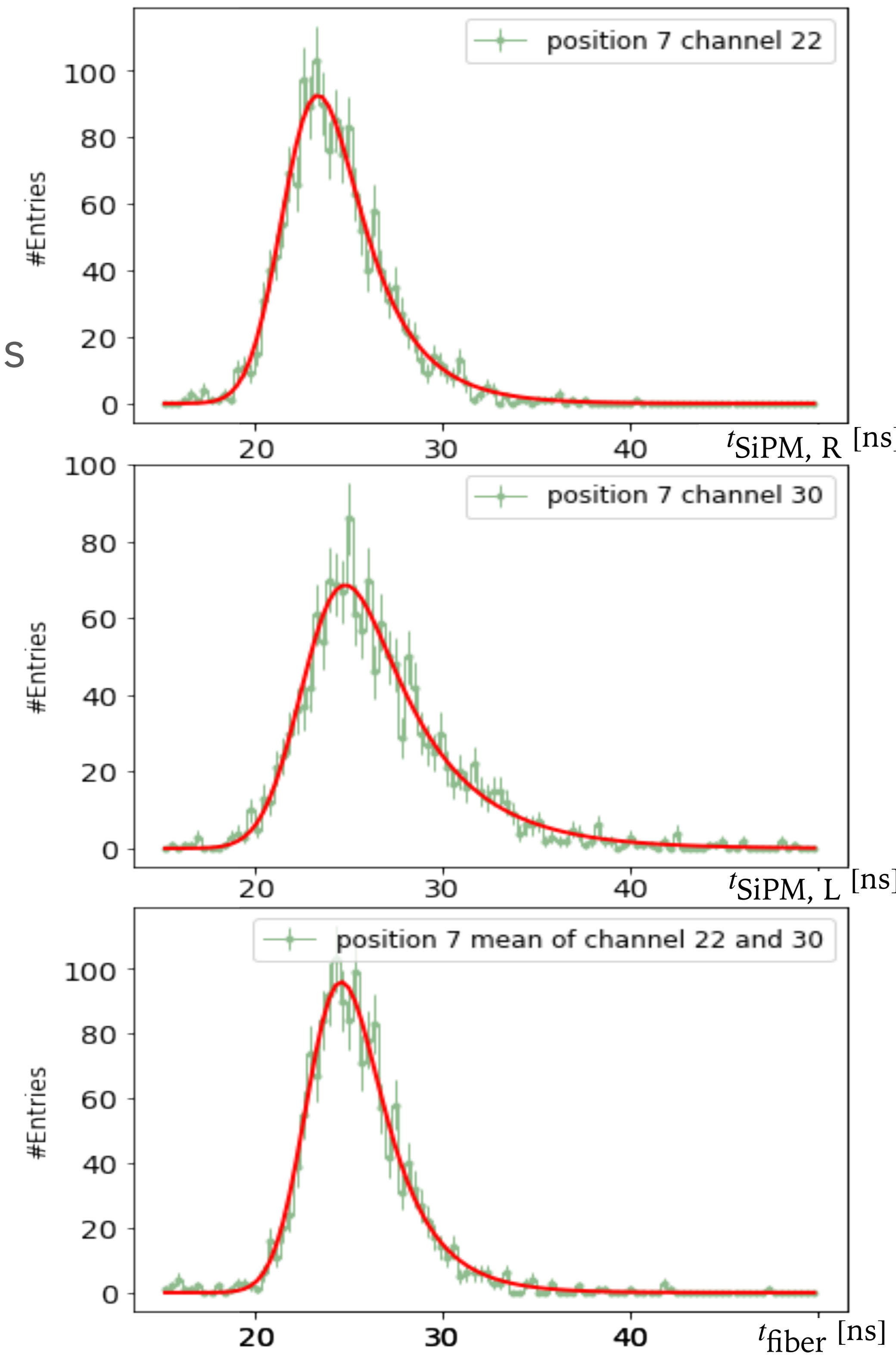
$$t_{\text{fiber}} = \frac{(t_{\text{SiPM, L}} + t_{\text{SiPM, R}})}{2}$$

➤ Shape of the signal affected by different arrival times of photons

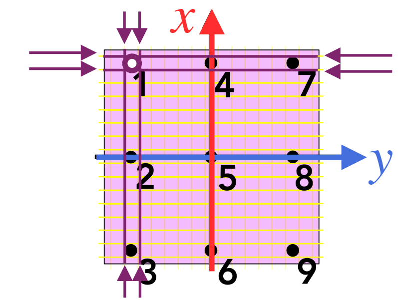
➤ Convolution of a Gaussian with an exponential distribution $f * g$ as fit function, where

$$f \propto \exp\left(\frac{-(x-t_0)^2}{2\sigma^2}\right) \text{ and } g \propto \exp\left(-\frac{x}{\tau}\right)$$

Examples of time signals

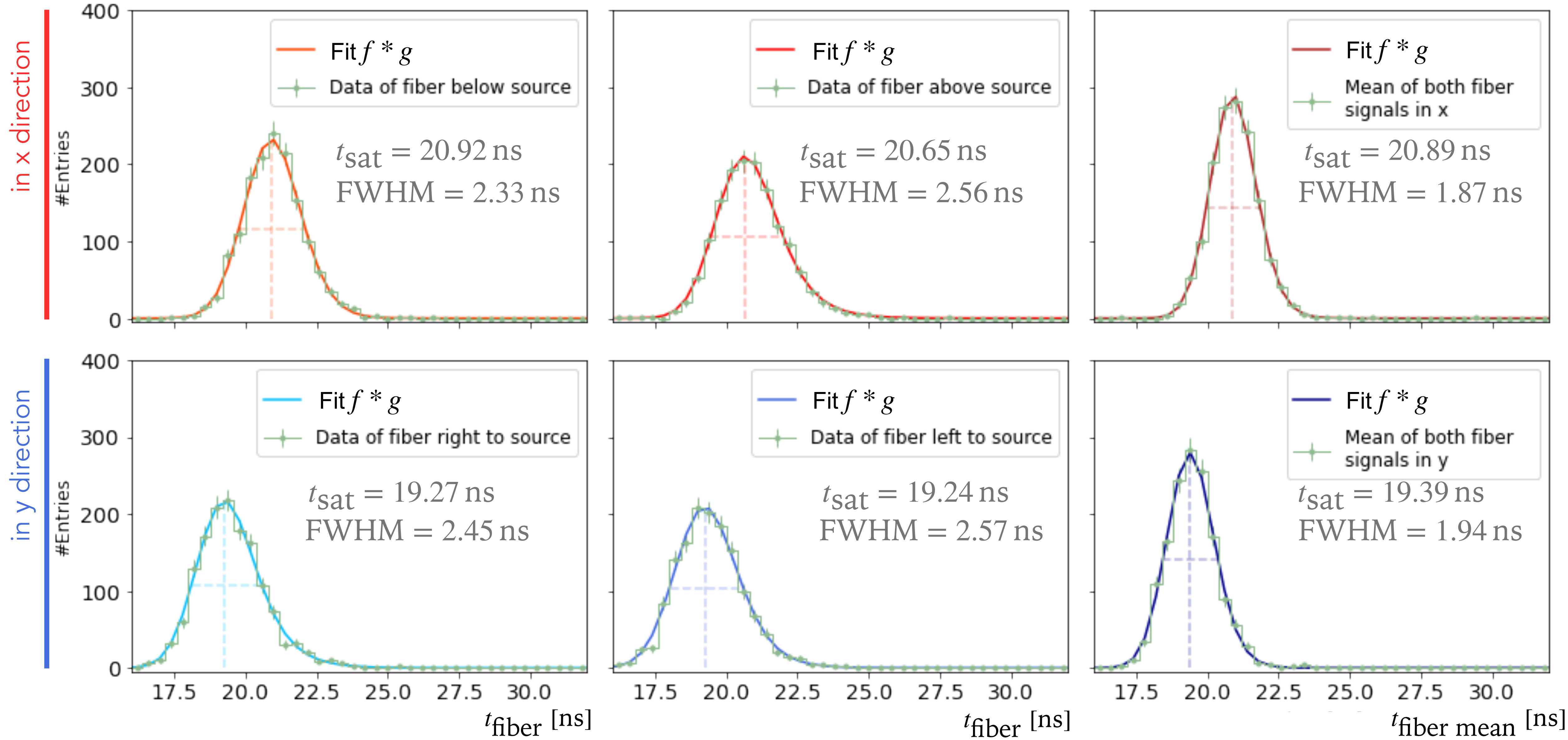


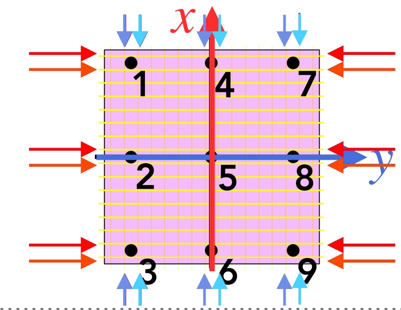
ESTIMATION OF TIME RESPONSE AND RESOLUTION



- Estimating the time resolution of the detector by the signal in the 4 fibers closest to source position
- Fit maximum interpreted as signal arrival time t_{sat}
- Fit FWHM interpreted as time resolution

Example: time signal of closest fiber to source position in the upper left corner of the detector

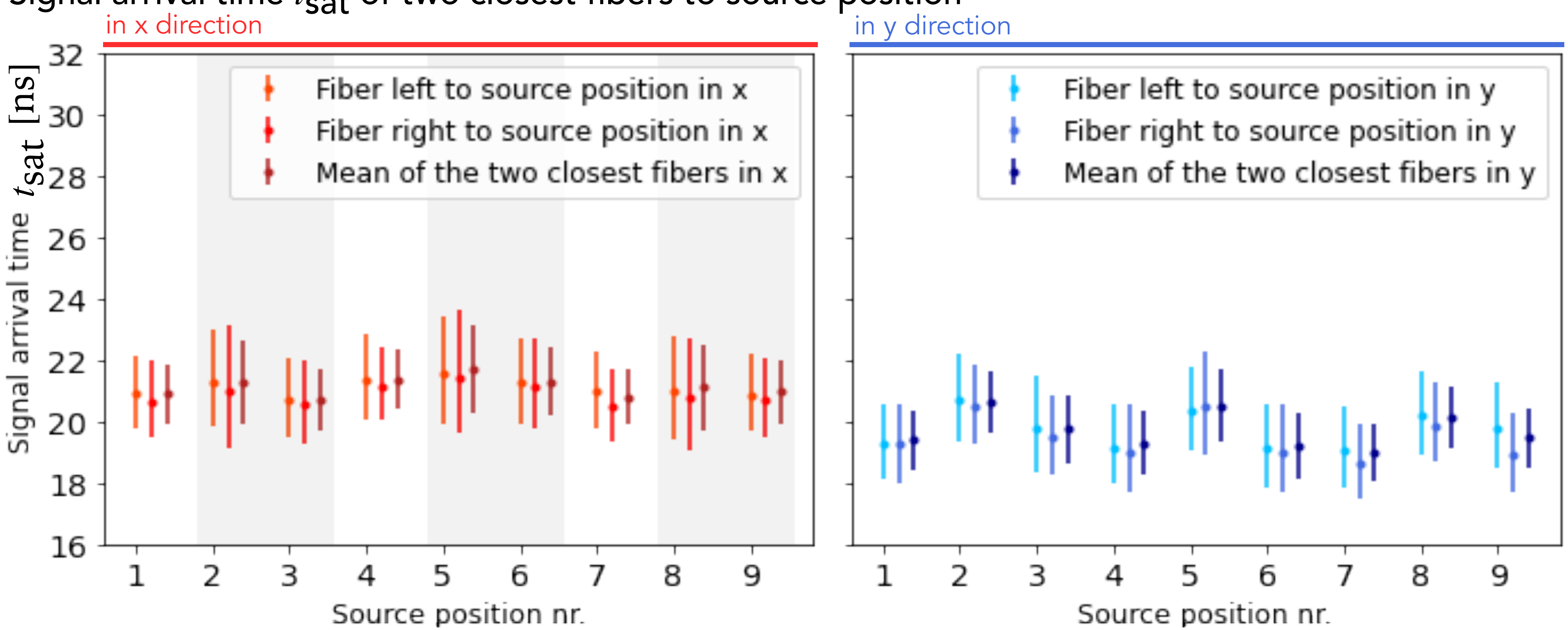




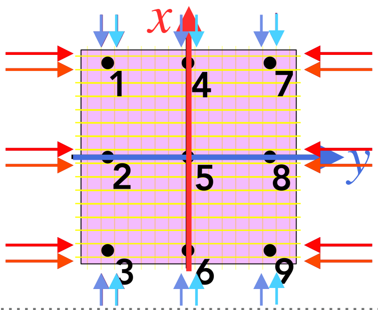
TIME RESPONSE – SIGNAL ARRIVAL TIME

- For positions 2, 3, 5, 6, 8, and 9 delay in signal arrival time t_{sat} due to 64 cm longer cables in x
  - 3.2 ns later response
  - subtracted from the timing data
- Errors too big to use t_{sat} to improve position reconstruction
- SiPMs 1.5 cm closer to source positions 1, 3, 4, 6, 7, and 9 in y - shorter t_{sat}

Signal arrival time t_{sat} of two closest fibers to source position

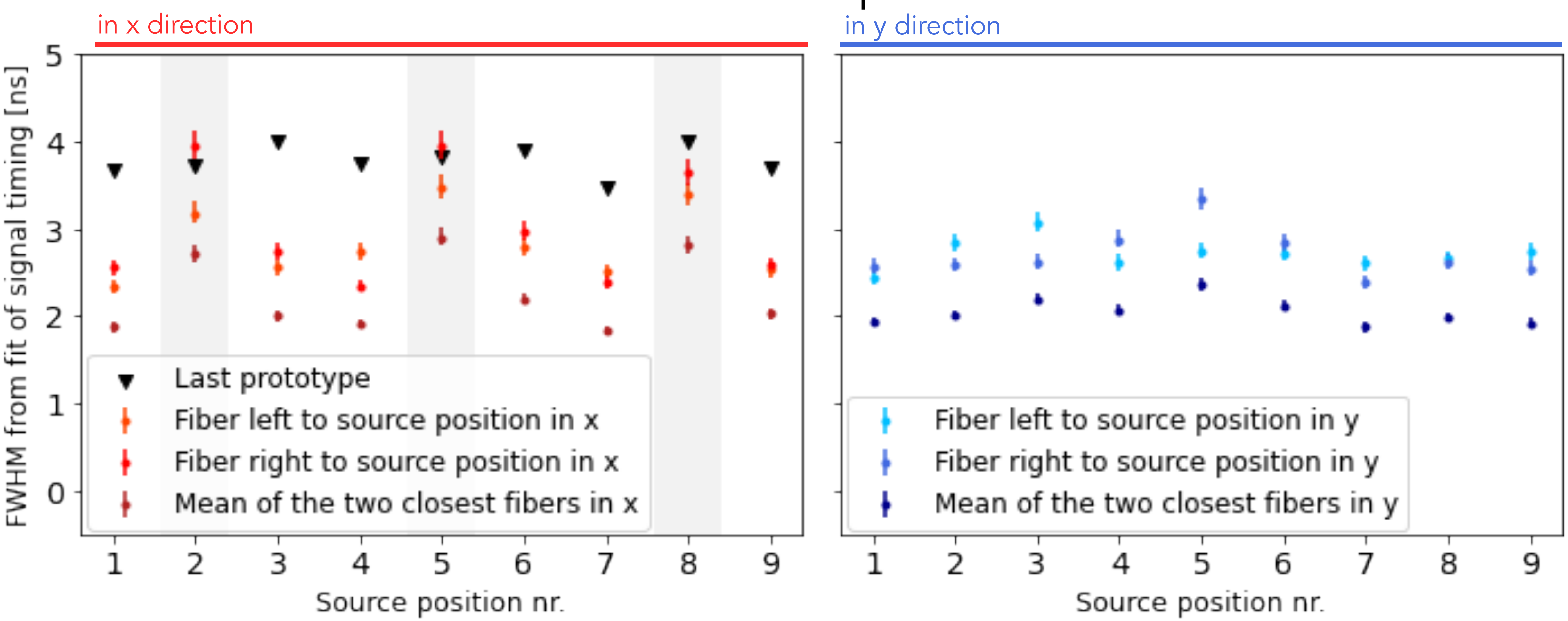


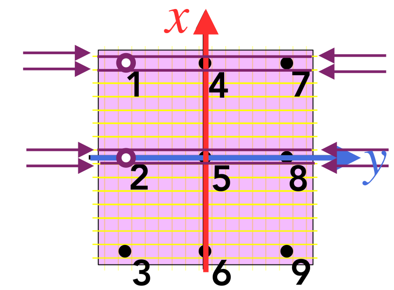
TIME RESOLUTION IN X AND Y DIRECTION



- Improved resolution for six positions by a factor of about 2 compared to the last prototype
- FWHM is larger for positions 2,5 and 8, which is due to a lower light yield measured for these positions

Time resolutions FWHM of two closest fibers to source position

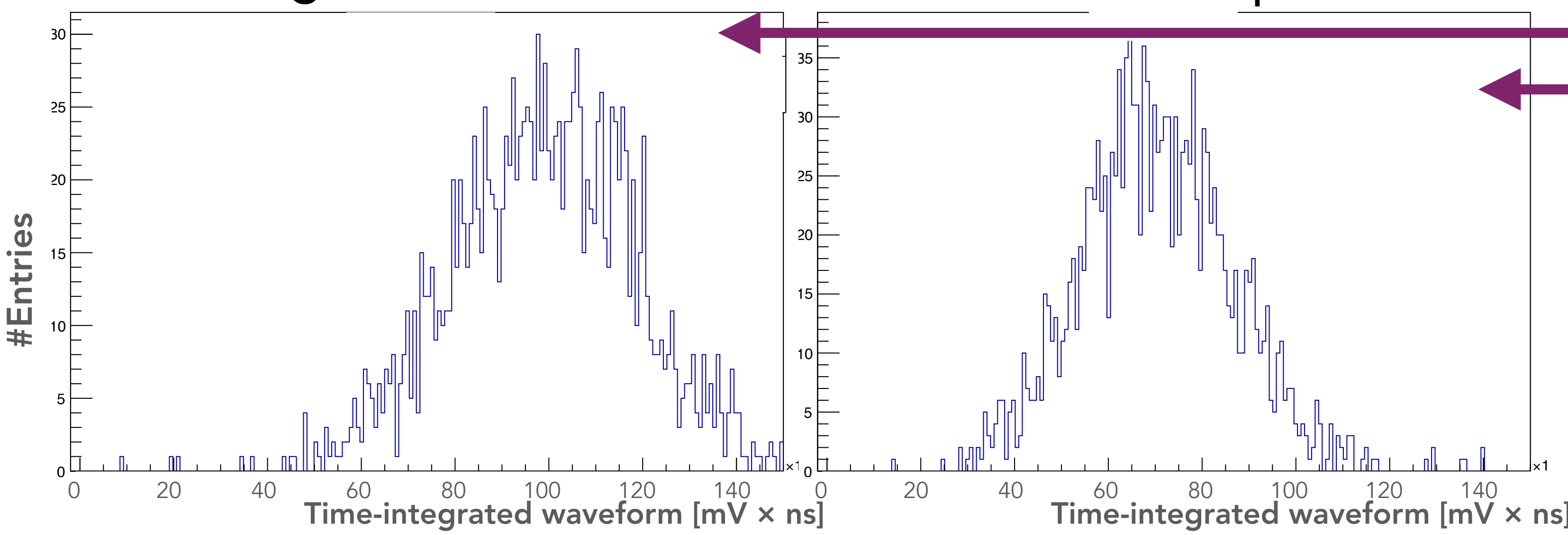




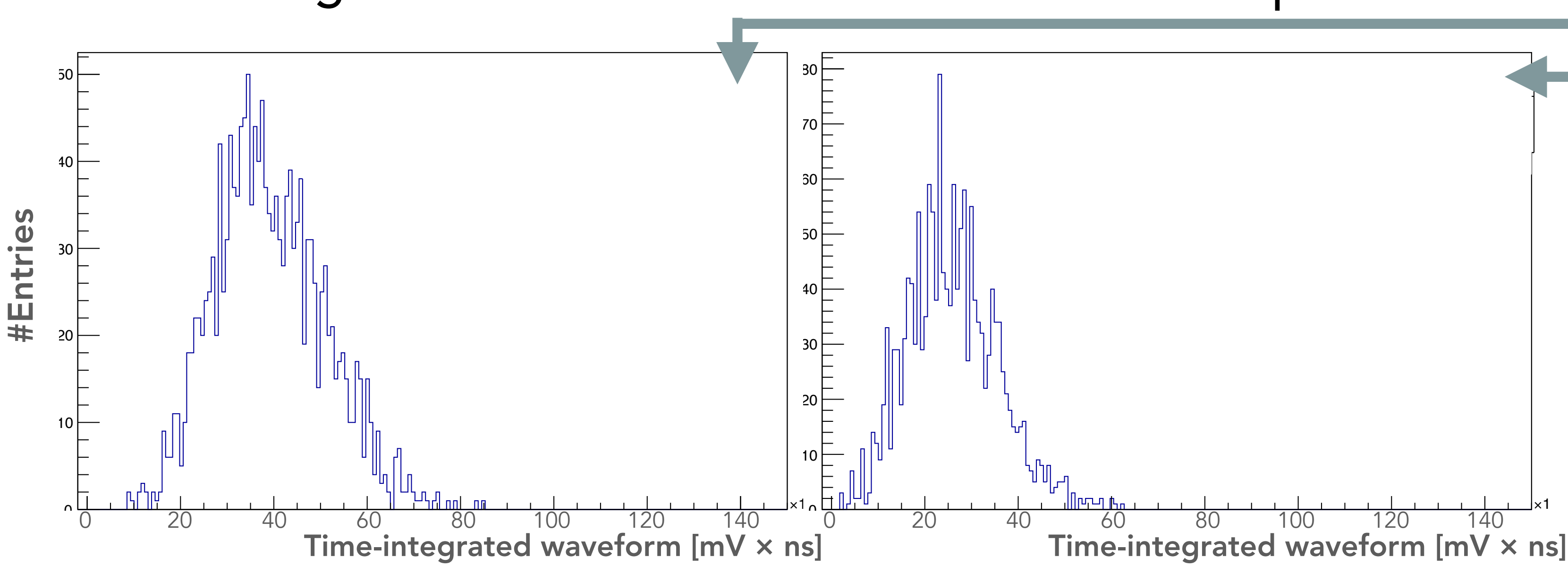
LOWER SIGNAL IN CHANNELS 2, 5 AND 8

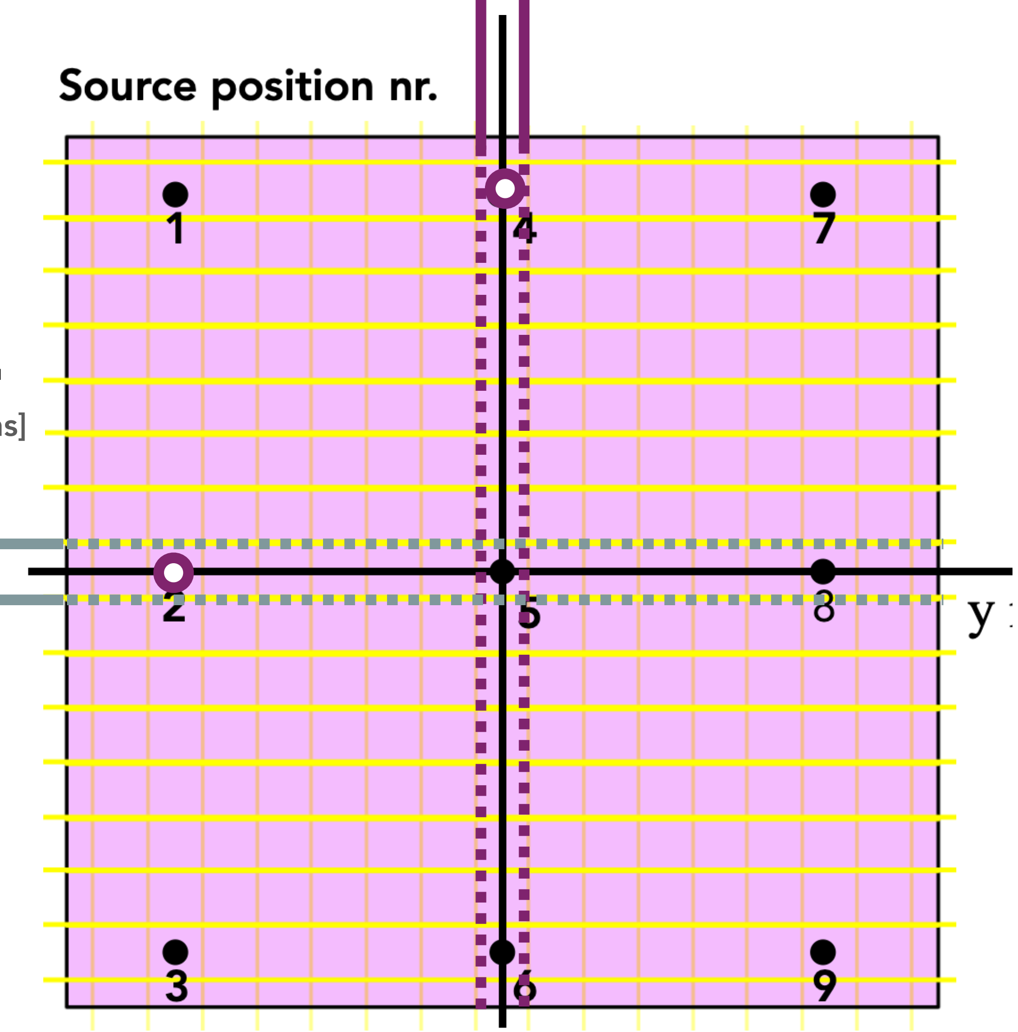
- Time-integrated waveforms much lower for the SiPMs closest to positions 2, 5, and 8
  - Possible causes: still to be found

Time integrated waveform closest SiPMs to source position 4

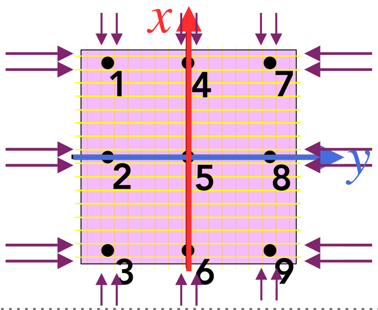


Time integrated waveform closest SiPMs to source position 2





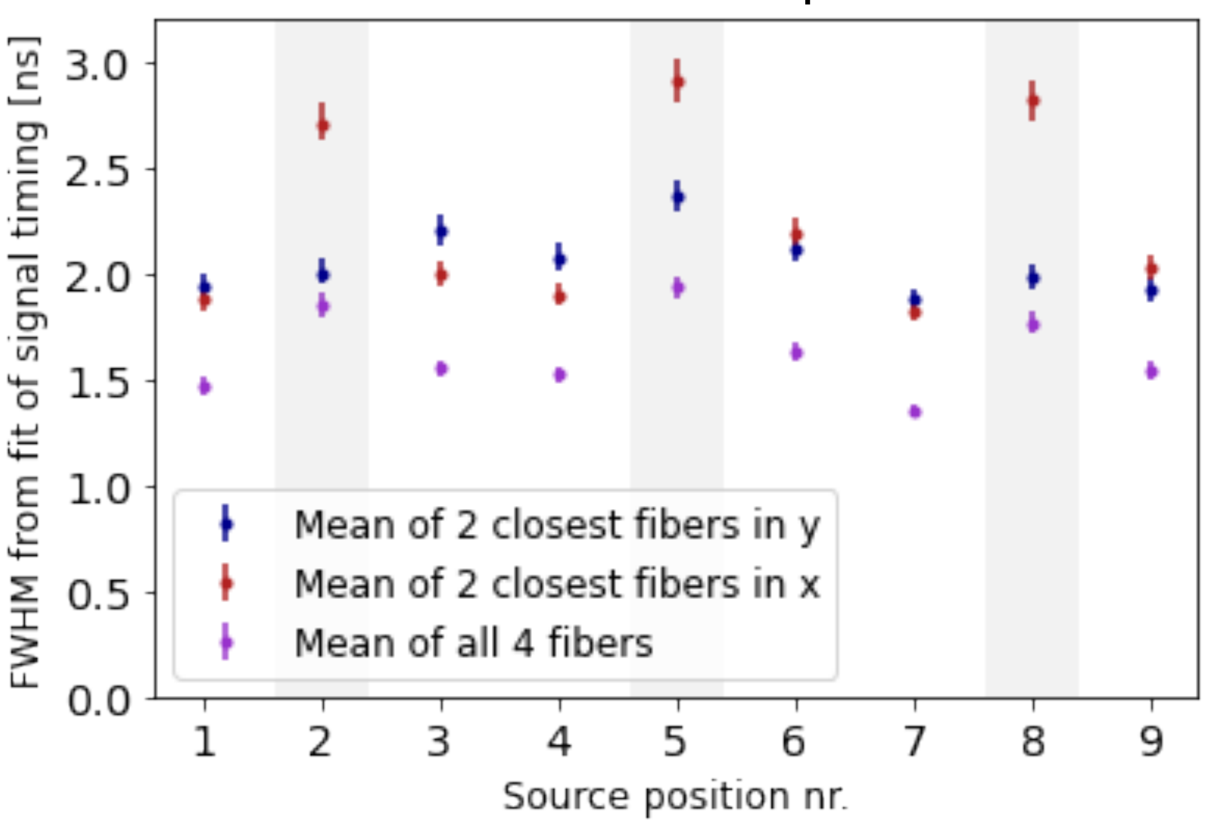
TIME RESOLUTION



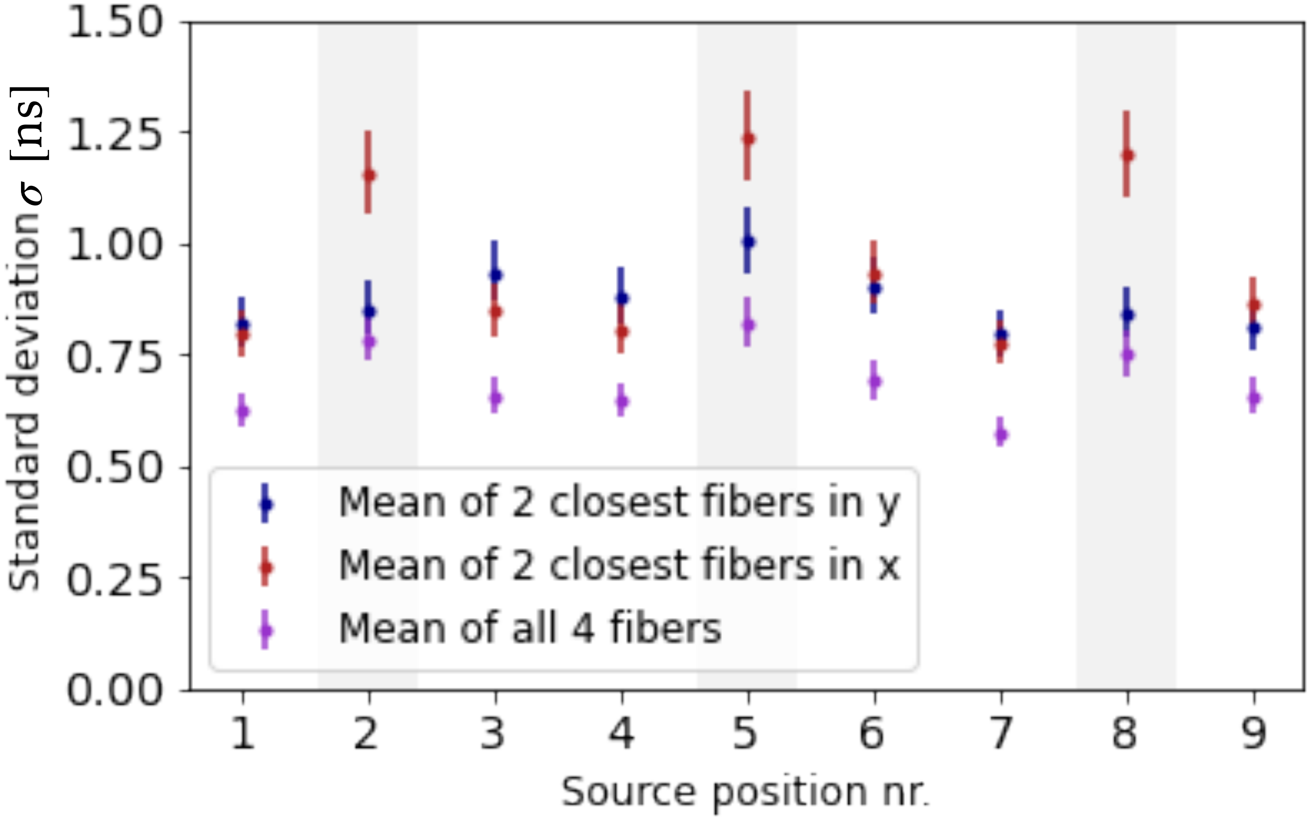
- Further improvement of the resolution by averaging over the signal of all four closest fibers to source position (in x and in y)
- The distribution of these means can also be fitted by Gaussian distribution with standard deviation.

$$\sigma \approx \frac{1}{2.355}\mathrm{FWHM}$$

FWHM
of four closest fibers to source position



Standard deviation σ
of four closest fibers to source position

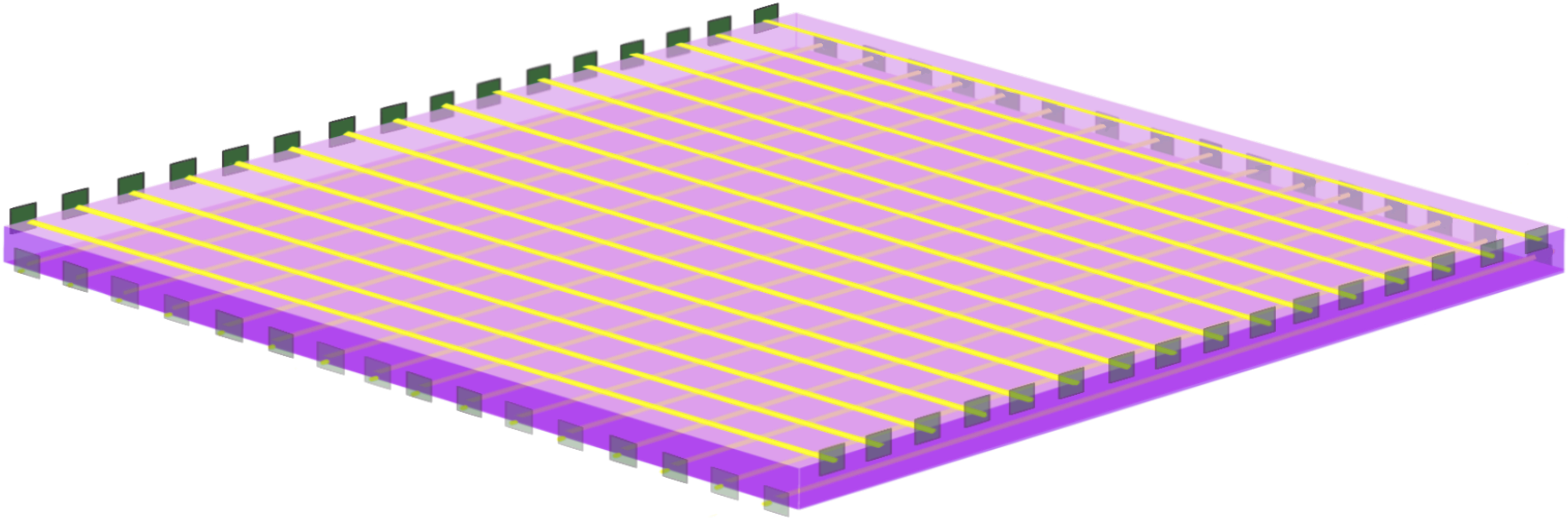


CONCLUSION AND OUTLOOK

- Construction of a new prototype with wavelength-shifting fibers in both directions for a 2D position reconstruction was successful
- Estimate of the signal arrival time $t_{\mathrm{sat}} \in [18, 24]$ ns between and the FWHM $\in [1.3, 2.0]$ ns $\rightarrow \sigma \in [0.6, 0.8]$ ns

Next steps:

- Intercalibration and taking measurements with other source positions
- Fix the problem of the lower light yield measured for positions 2, 5, and 8
- Preamplifiers optimized for time measurements
- Fibers with an even shorter decay time



THANK YOU FOR YOUR ATTENTION!