The spatial dependence of MCP-PMTs timing performance and its usability as a t0-reference detector

@

7th Beam Telescopes and Test Beams Workshop

Lukas SOHL

16.01.2019

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

UNIVERSITÉ PARIS SUD
Comprendre le monde, construire l'avenir

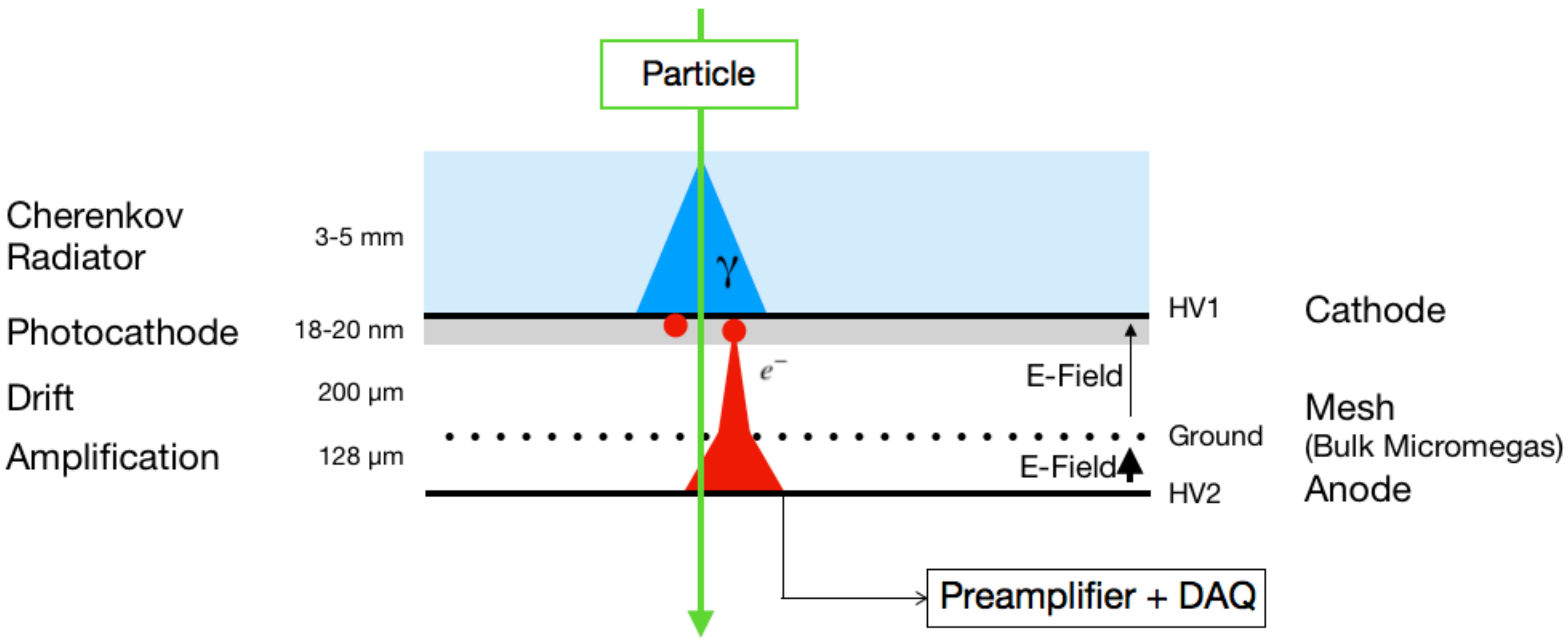
université PARIS-SACLAY

École Doctorale PHENIICS Doctoral School

Outline

- PICOSEC Micromegas Project
- Beam Measurements
- DAQ and Analysis (Software CFD)
- Time Resolution
- Charge Distribution
- Spatial Time Resolution
- Initial Number of Photoelectrons

PICOSEC Micromegas a RD51 Project



- **Particle produce Cherenkov radiation**
- **Electrons are emitted by the radiation in a photocathode**
- **All primary ionised electrons are localised on the photocathode**
- **Due to high electric field, time jitter before first amplification minimised**

To measure the time resolution a t0 reference detector is needed

-> MCP-PMT

DE LA RECHERCHE À L'INDUSTRIE cea

CERN

1958 University of Science and Technology of China

ΔΗΜΟΚΡΙΤΟΣ

IGFAE

HELSINKI INSTITUTE OF PHYSICS

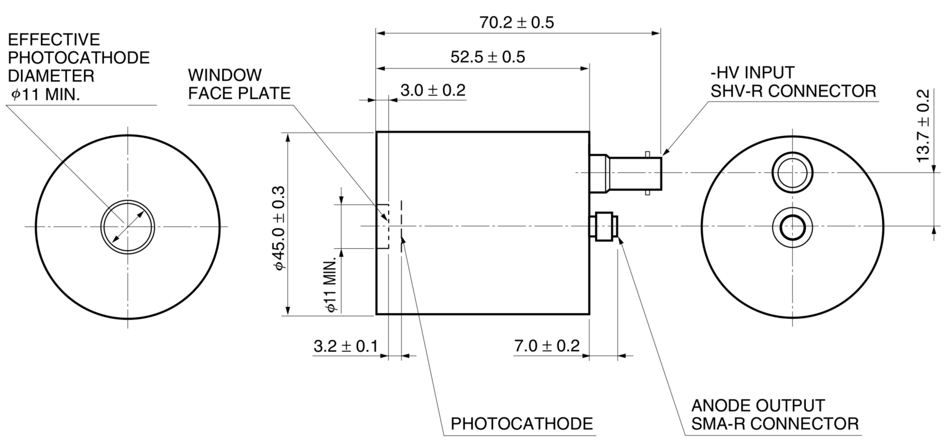
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, INOVAÇÃO E DO ENSINO SUPERIOR

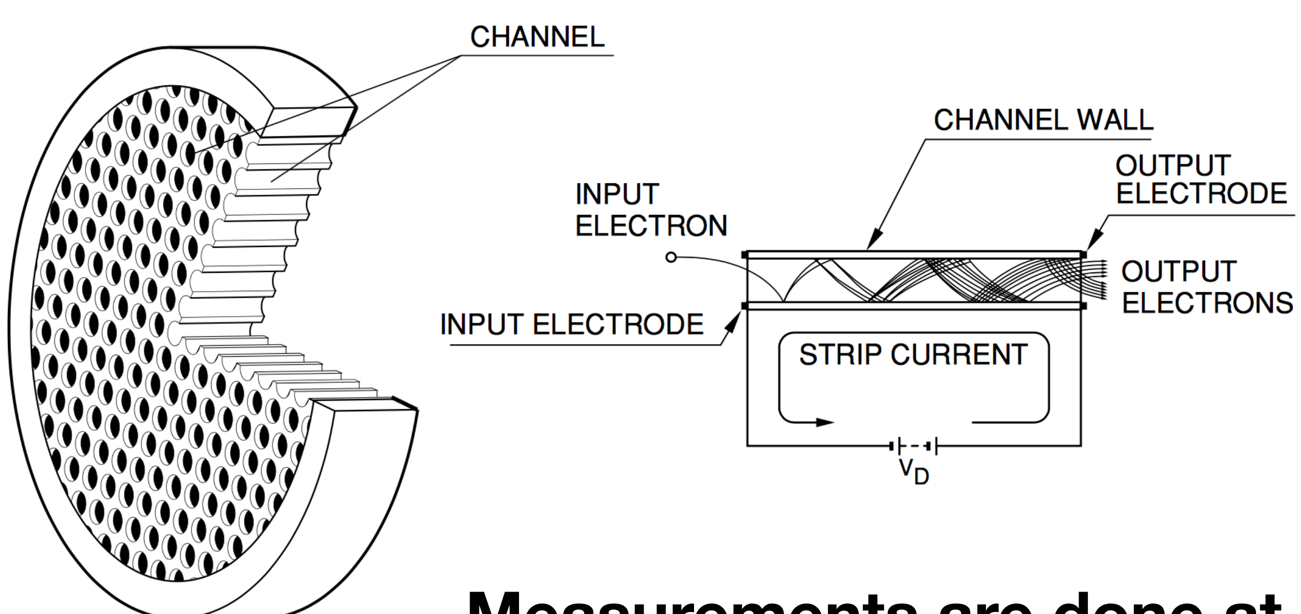
UNIVERSITY of VIRGINIA

HELLENIC REPUBLIC
ARISTOTLE UNIVERSITY OF THESSALONIKI

PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector, Nucl. Instrum. Meth. A903 (2018) 317-325. doi:10.1016/j.nima.2018.04.033.

MCP-PMT: Hamamatsu R3809U-50



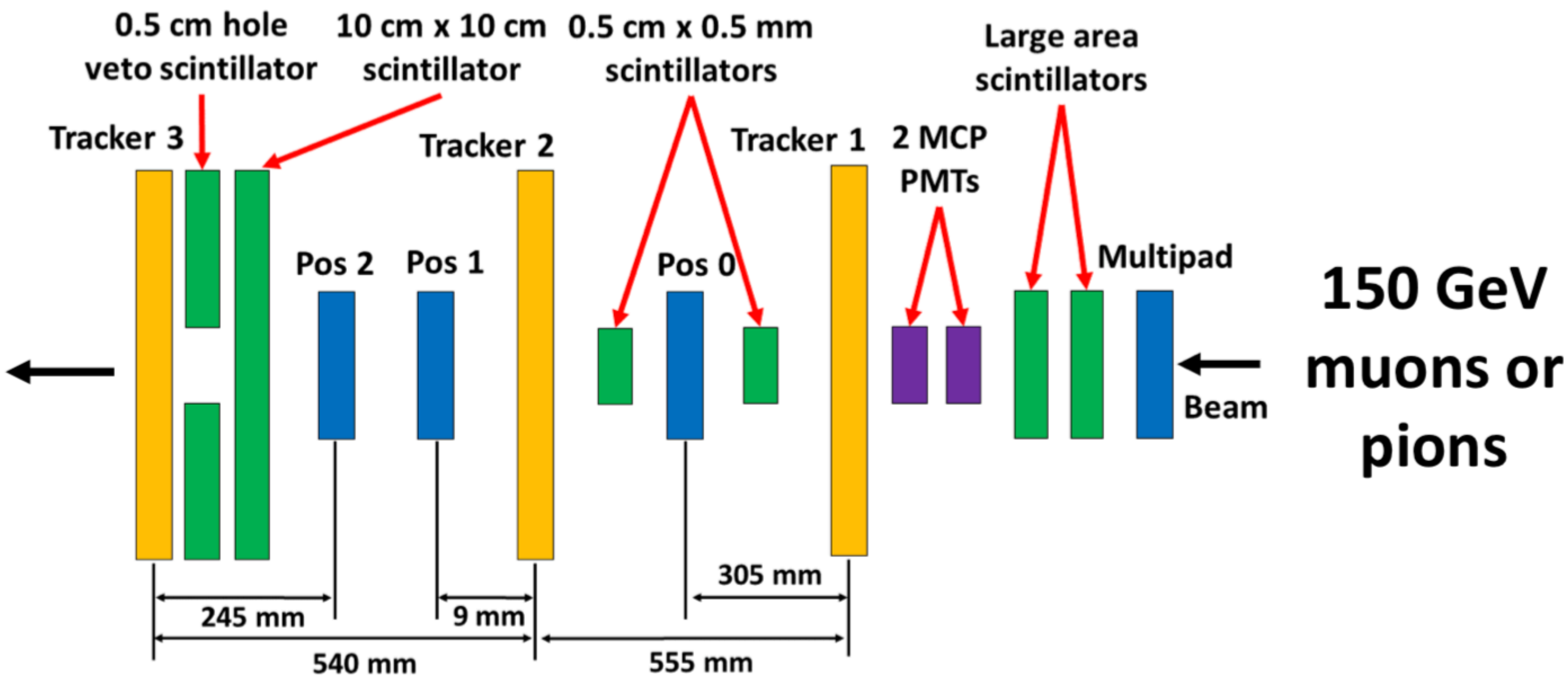


- **Signal creation similiar to PICOSEC Micromegas:**
  - **Particle are passing a Cherenkov radiator**
  - **Electrons are emitted by a photocathode**
- **Signals are amplified in a Micro Channel Plate**
  - **Electrons are accelerated by a high Voltage**
  - **More electrons are emitted along the channel walls**

Measurements are done at an operating Voltage of <u>2800 V</u>

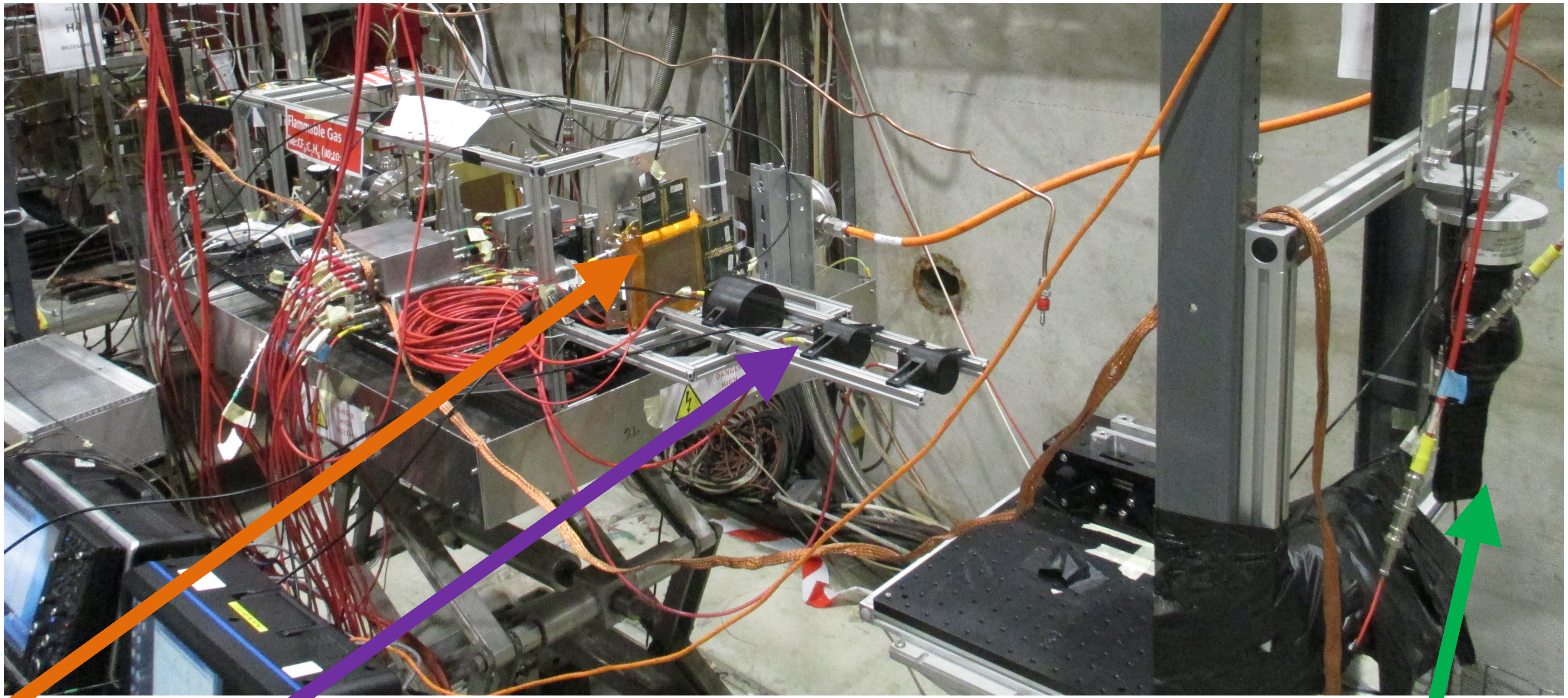
R3809U-50 SERIES Hamamatsu PHOTONICS K. K. (2015). <https : / / www . hamamatsu.com/resources/pdf/etd/R3809U-50_TPMH1067E.pdf>.

MIP Beam Test



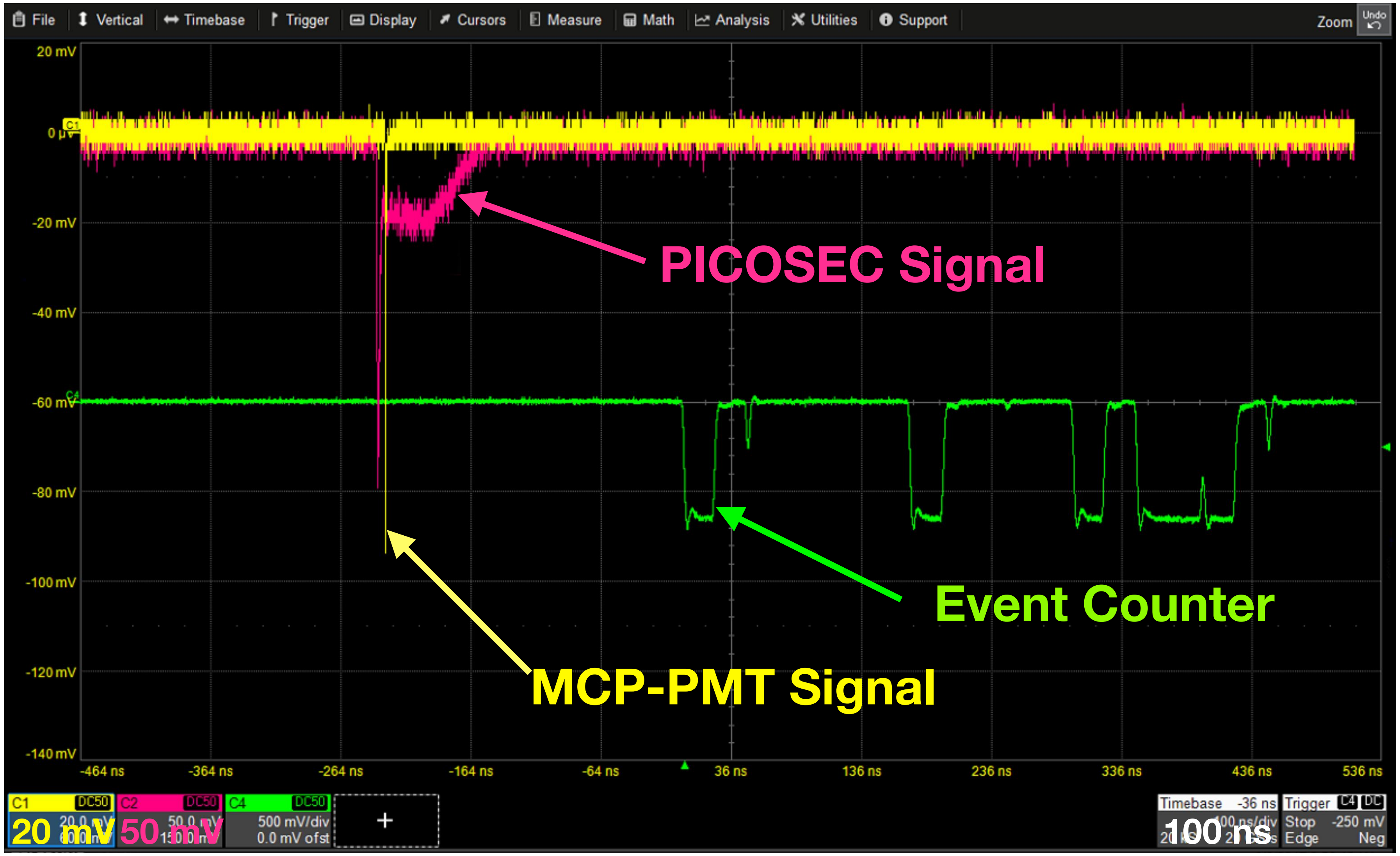
- **Time reference:** two MCP-PMTs (**<5 ps** resolution).
- **Tracking system:** 3 triple-GEMs (**40 µm** precision).
- **Scintillators**: used to select tracks & to avoid showers.
- **Electronics:** CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

Beam Telescope @ CERN SPS H4



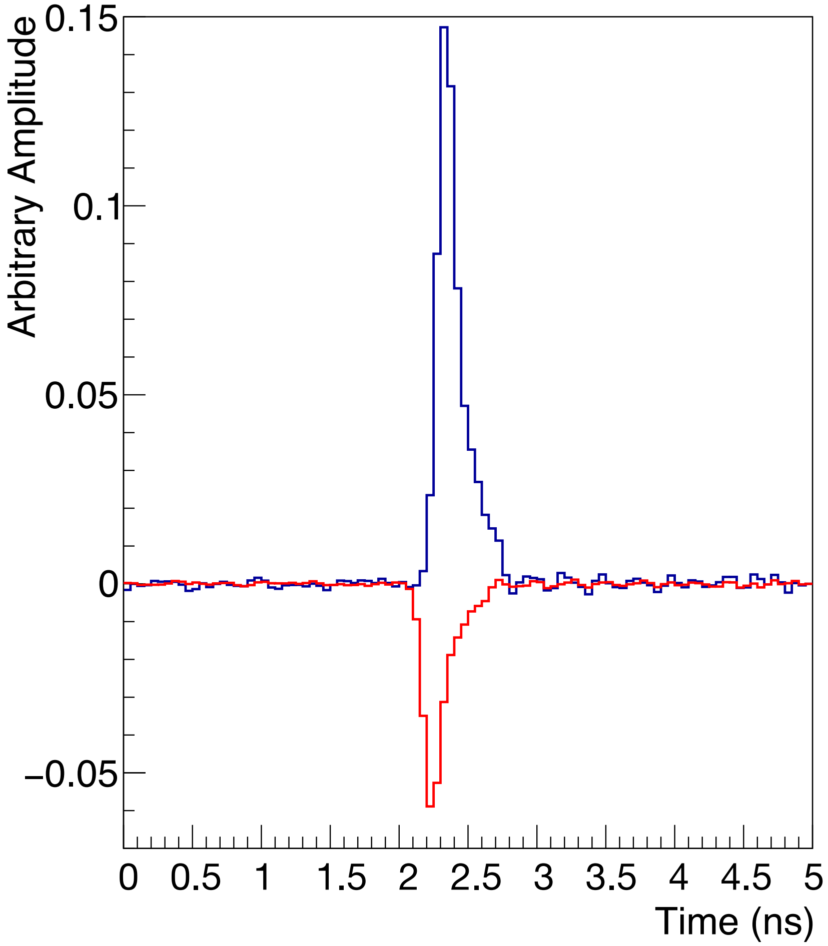
- **Time reference:** two MCP-PMTs (**<u><5 ps</u>** resolution).
- **Tracking system:** 3 triple-GEMs (**<u>40 µm</u>** precision).
- **Scintillators**: used to select tracks & to avoid showers.
- **Electronics:** CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

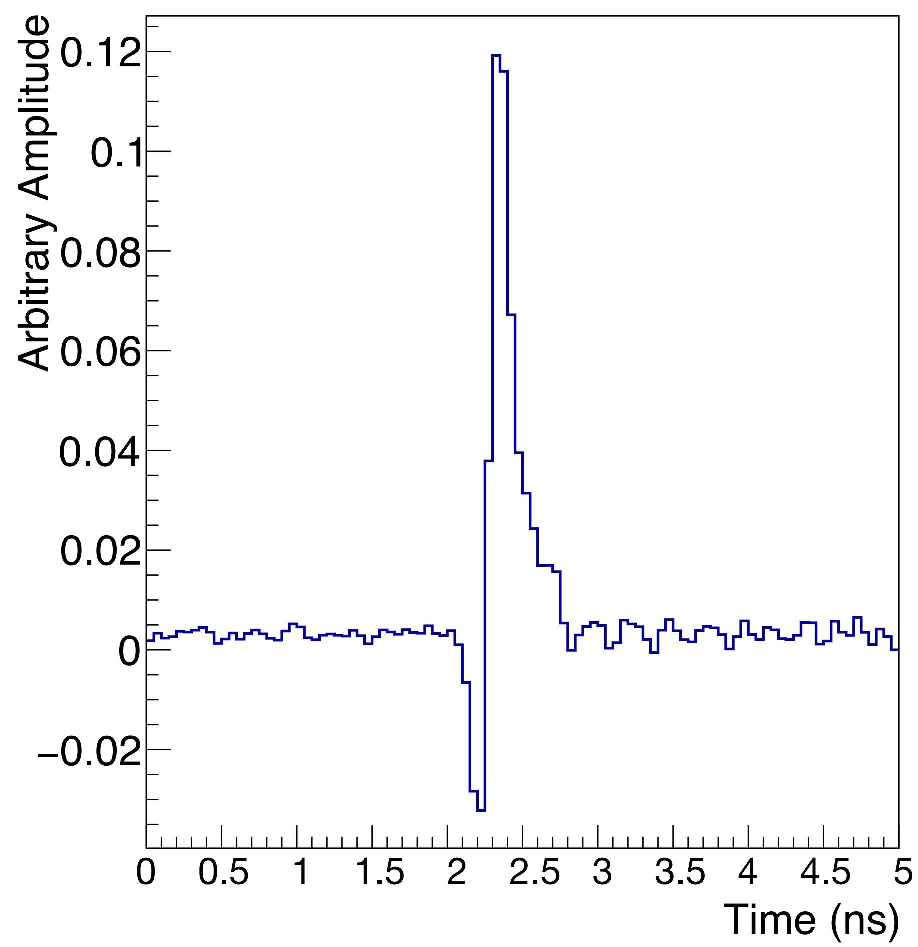
DAQ



- **Waveforms are acquired with 20 GS/s oscilloscopes**
- **MCP-PMT and DUTs are sampled in the same acquisition window**
- **Tracking software provides an event counter to match with the signals**

CFD Algorithm





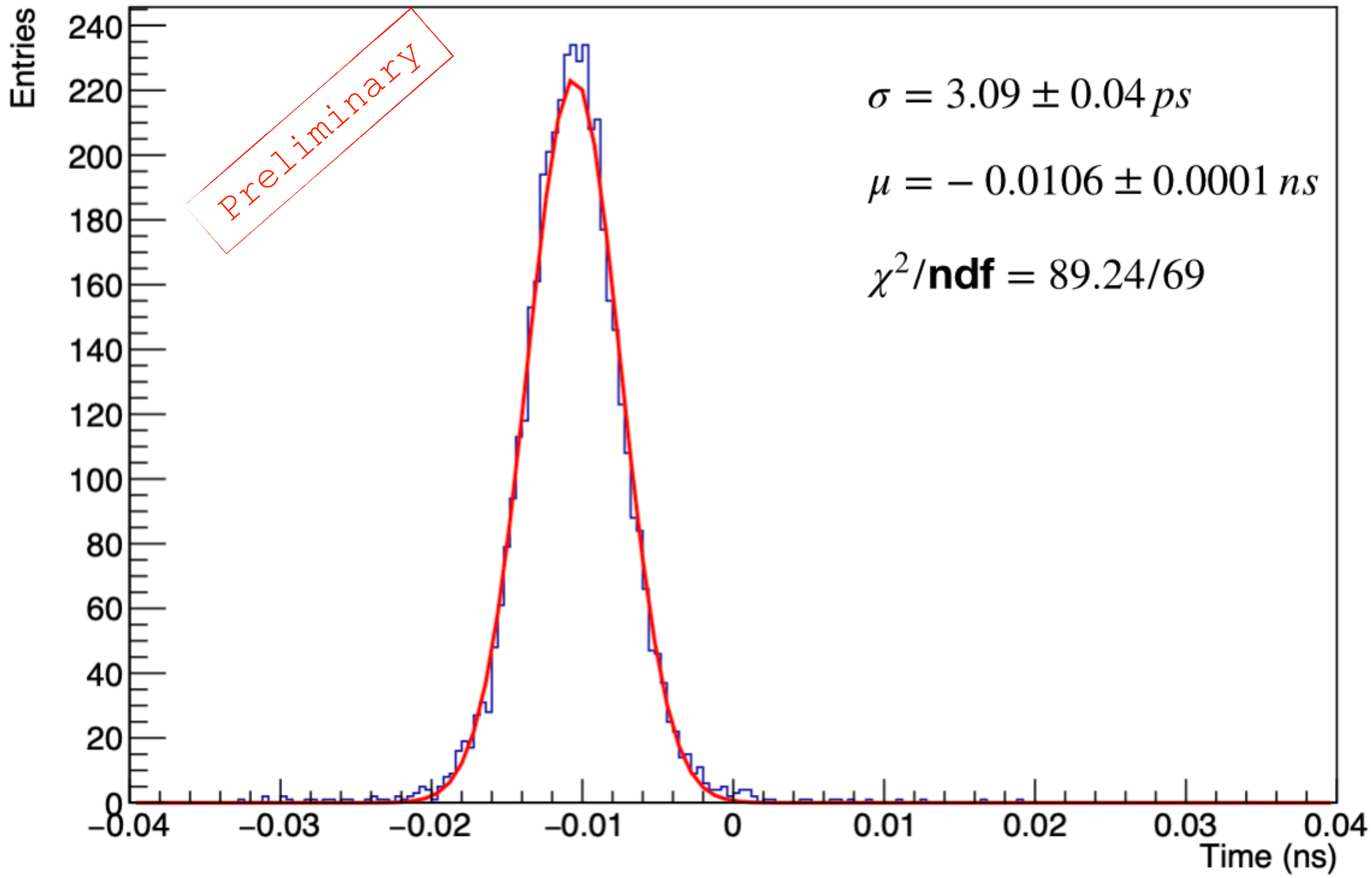
- **Software CFD algorithm is used to extract signal arrival time from the full signal waveform**
- **Algorithm in the style of a hardware CFD circuit**
- **CFD can be calculated without information about the amplitude**

  ➡Advantage at fewer sampling points

Time delay and attenuation of the duplicated waveform depends on the demanded fraction of the amplitude:

$$t_\mathrm{d} = t_\mathrm{r} \cdot (1 - 0.4)$$

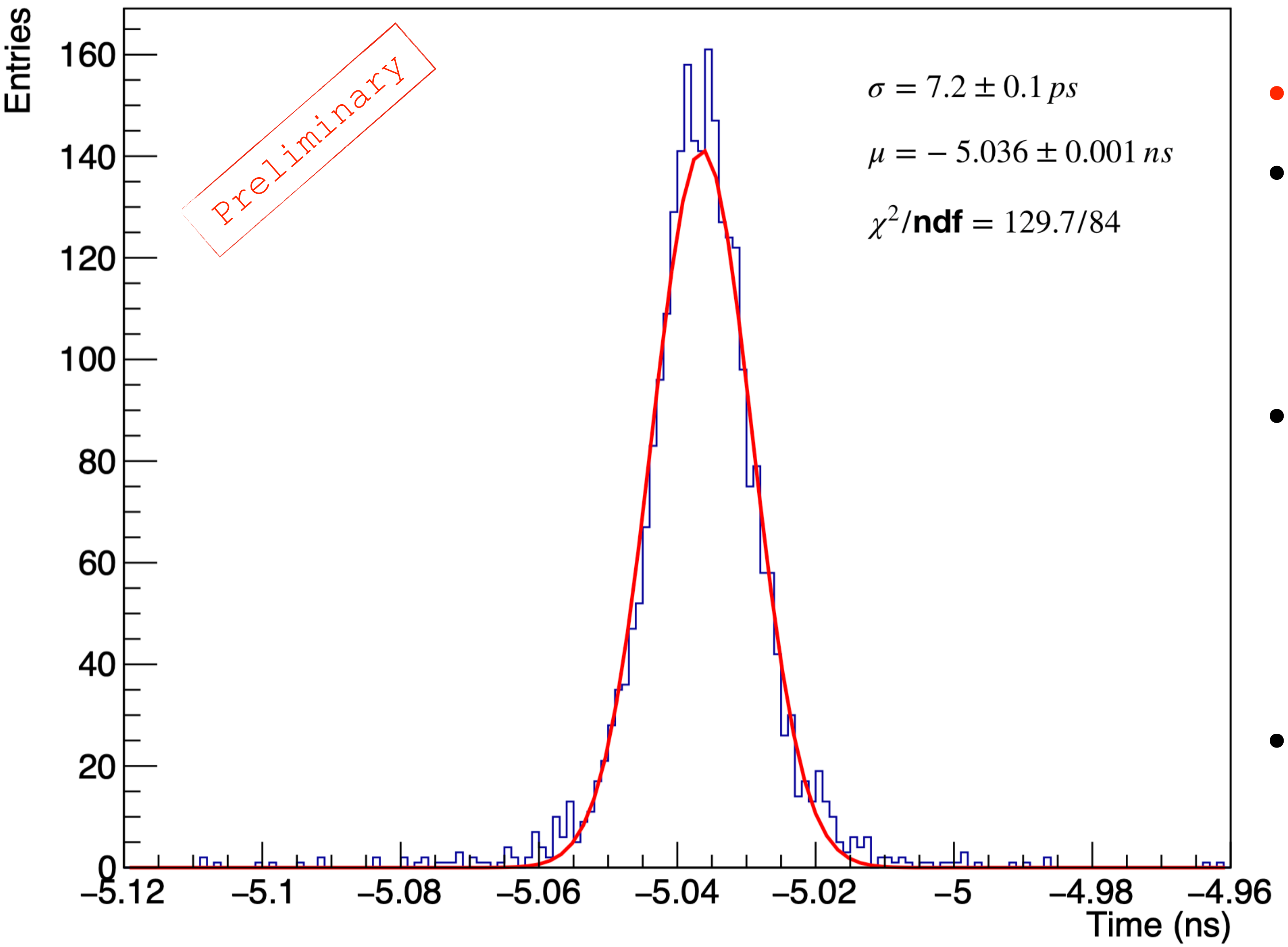
DAQ Uncertainty



- **The combined systematic uncertainty of the sampling rate and the CFD algorithm has been evaluated**
- **Signal of the same MCP-PMT has been splitted and aquired in two channels of the oscilloscope**

$$\sigma_{\mathrm{DAQ}} = \frac{(3.09 \pm 0.04)\ \mathrm{ps}}{\sqrt{2}} = (2.18 \pm 0.03)\ \mathrm{ps}$$

Time Resolution



- **Two MCP-PMTs are used**
- **Time difference between both signals has been calculated**
- **Distribution gives combined time resolution of both MCP-PMTs and the DAQ uncertainty**
- **Operating Voltage 2800 V**

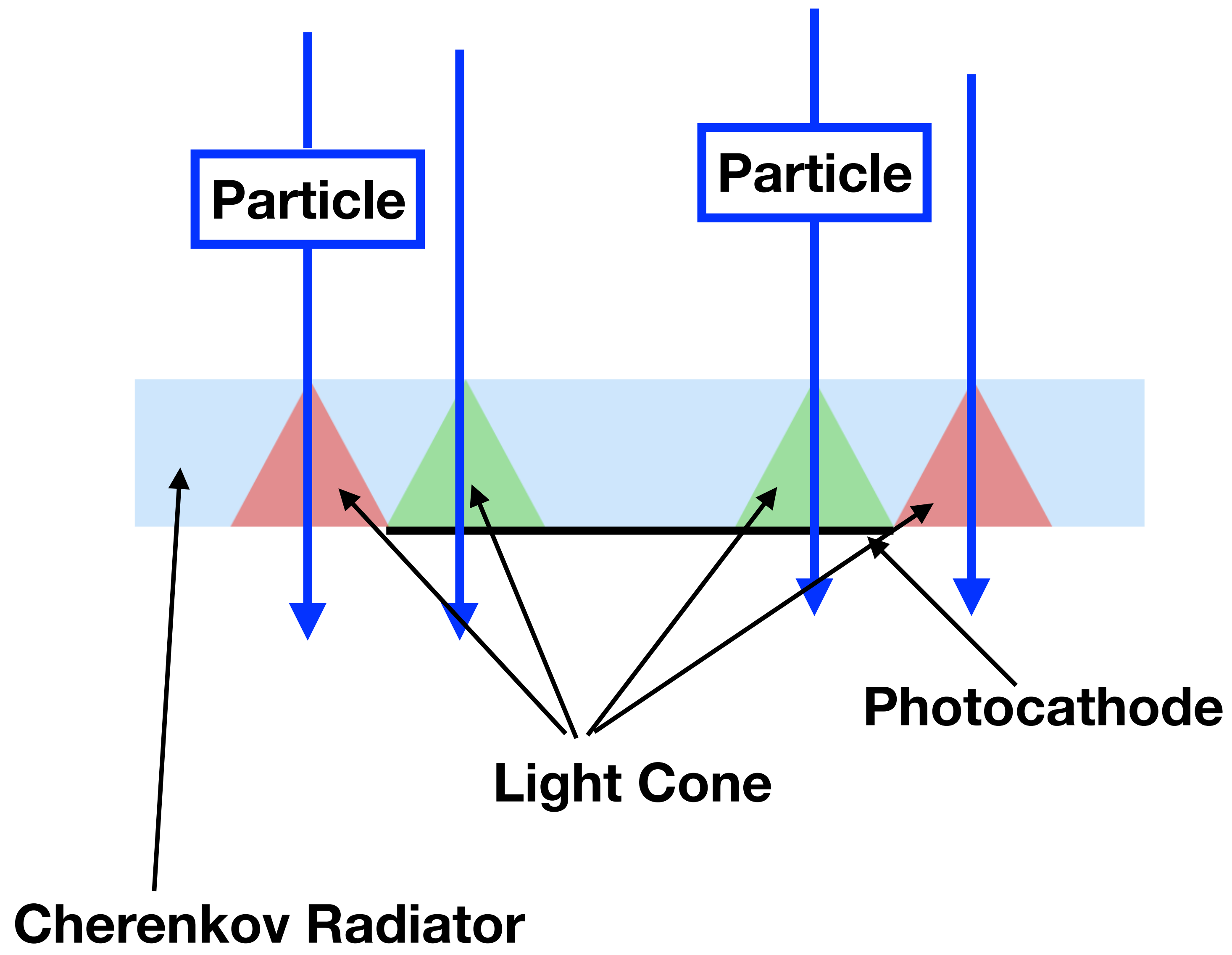
$$\sigma_{\text{mes}} = \sqrt{2\sigma^2_{\text{MCP}} + \sigma^2_{\text{DAQ}}}$$

All particles hitting the useful active area (r < 5.5 mm*) are taken into account

$$\Rightarrow \sigma_{\text{MCP}} = \sqrt{\frac{\sigma^2_{\text{mes}} - \sigma^2_{\text{DAQ}}}{2}} = (4.87 \pm 0.32)\ \text{ps}$$

*) *R3809U-50 SERIES* Hamamatsu PHOTONICS K. K. (2015). <https : / / www . hamamatsu.com/resources/pdf/etd/R3809U-50_TPMH1067E.pdf>.

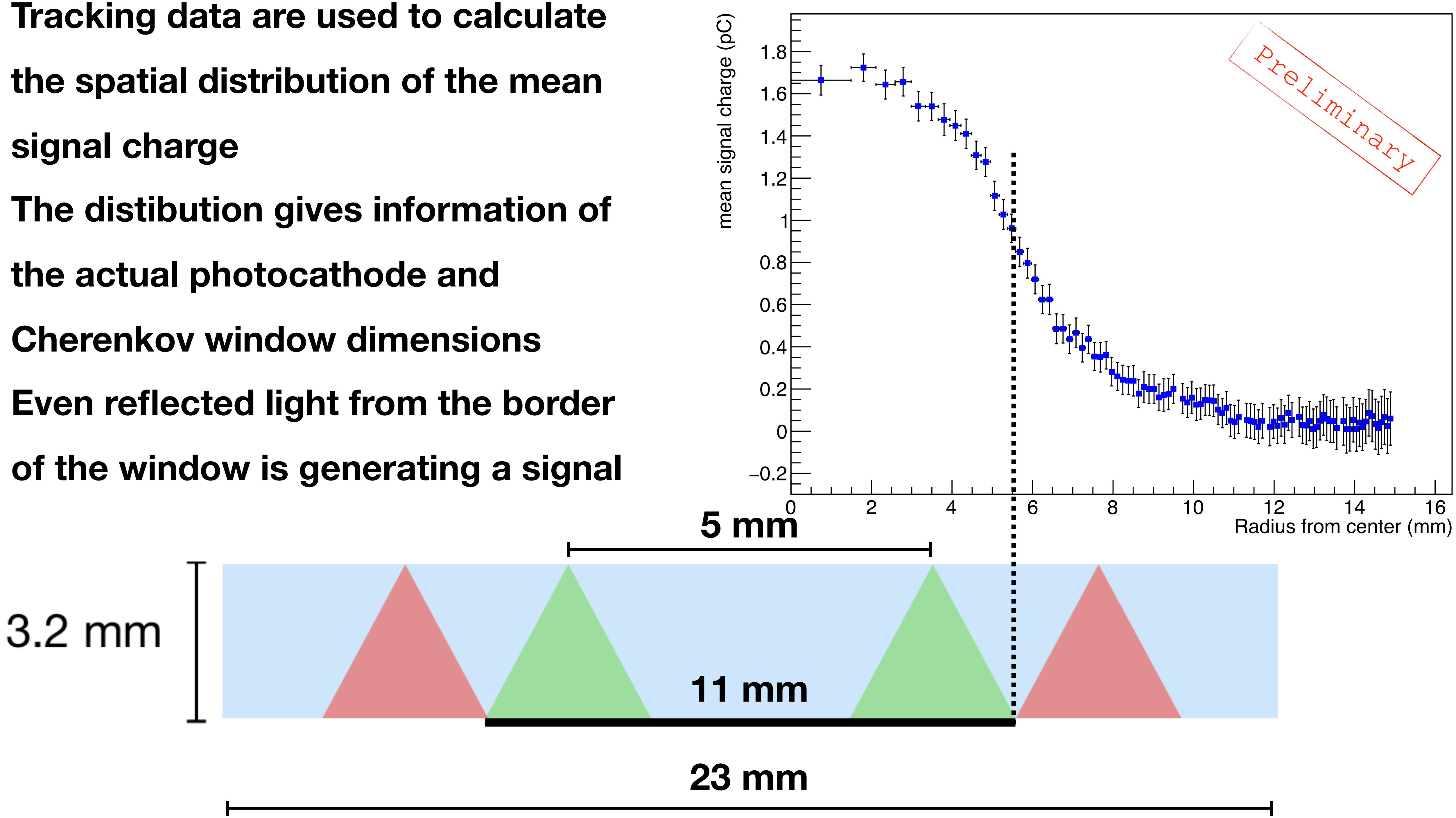
Cherenkov Light Propagation

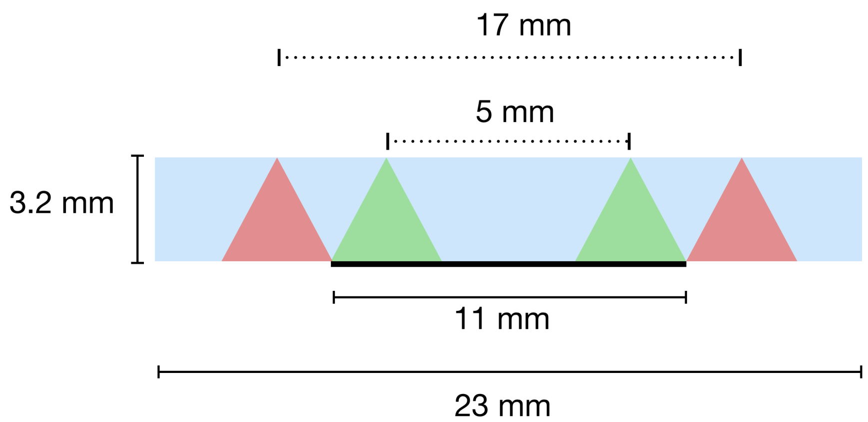


- **MIPs are detected in a Cherenkov radiator in front of the MCP-PMT**
- **Number of photoelectrons are depending on amount of light reaching the photocathode**
- **Smaller signals are expected for MIPs detected further outside of the centre**
- **Actual dimensions are not given in the datasheet**

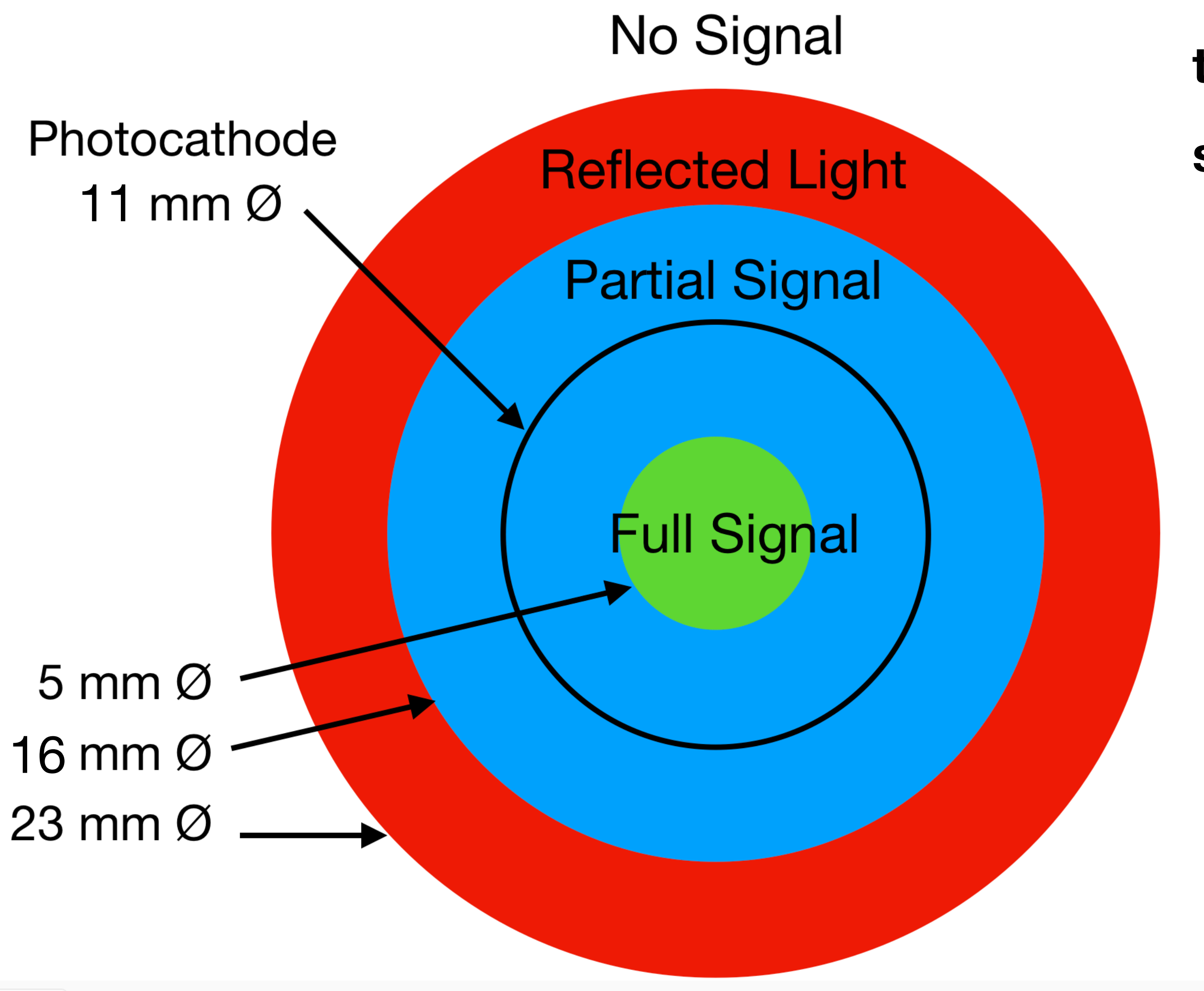
Charge Distribution

- Tracking data are used to calculate the spatial distribution of the mean signal charge
- The distibution gives information of the actual photocathode and Cherenkov window dimensions
- Even reflected light from the border of the window is generating a signal



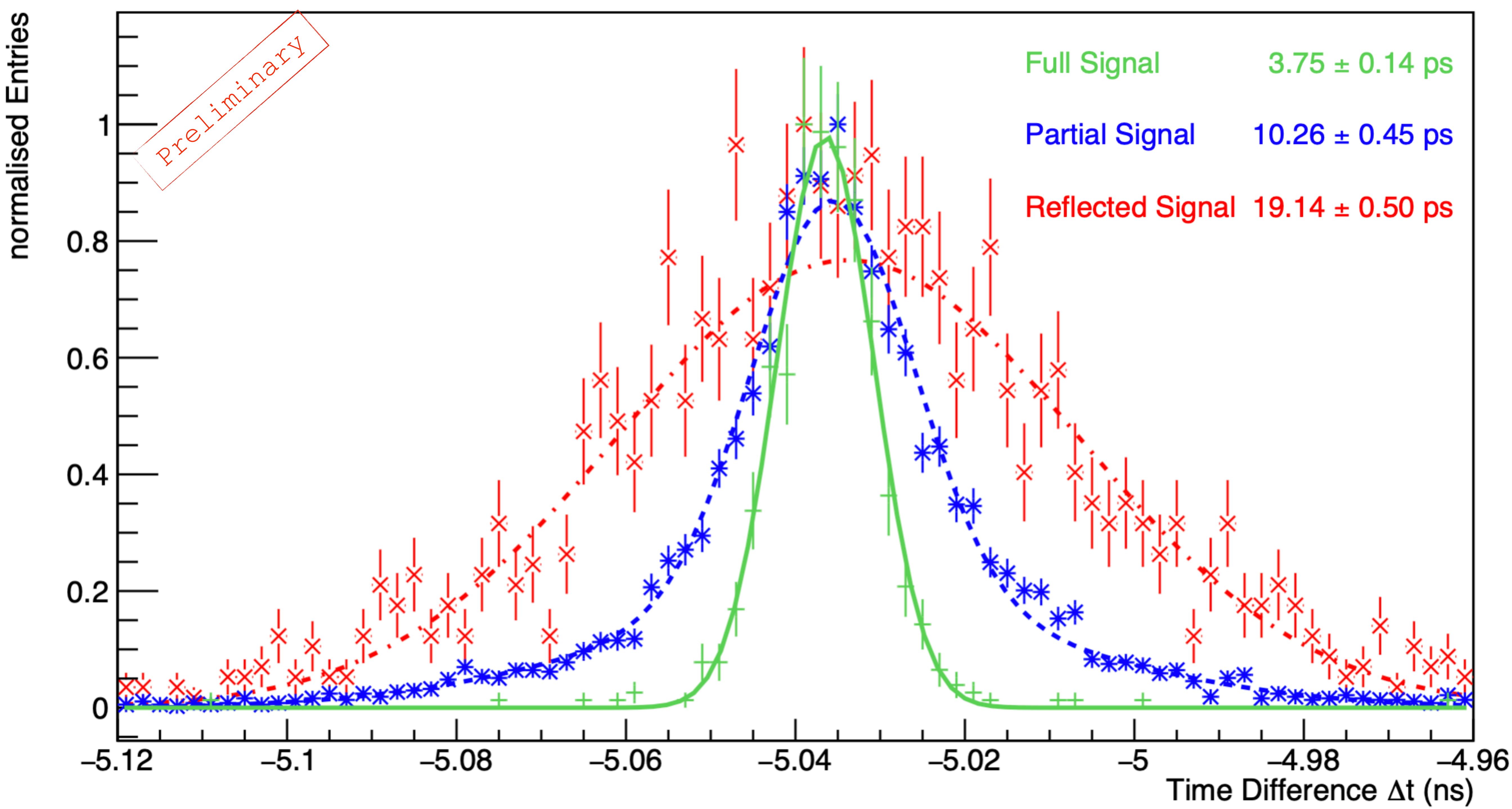


ROIs

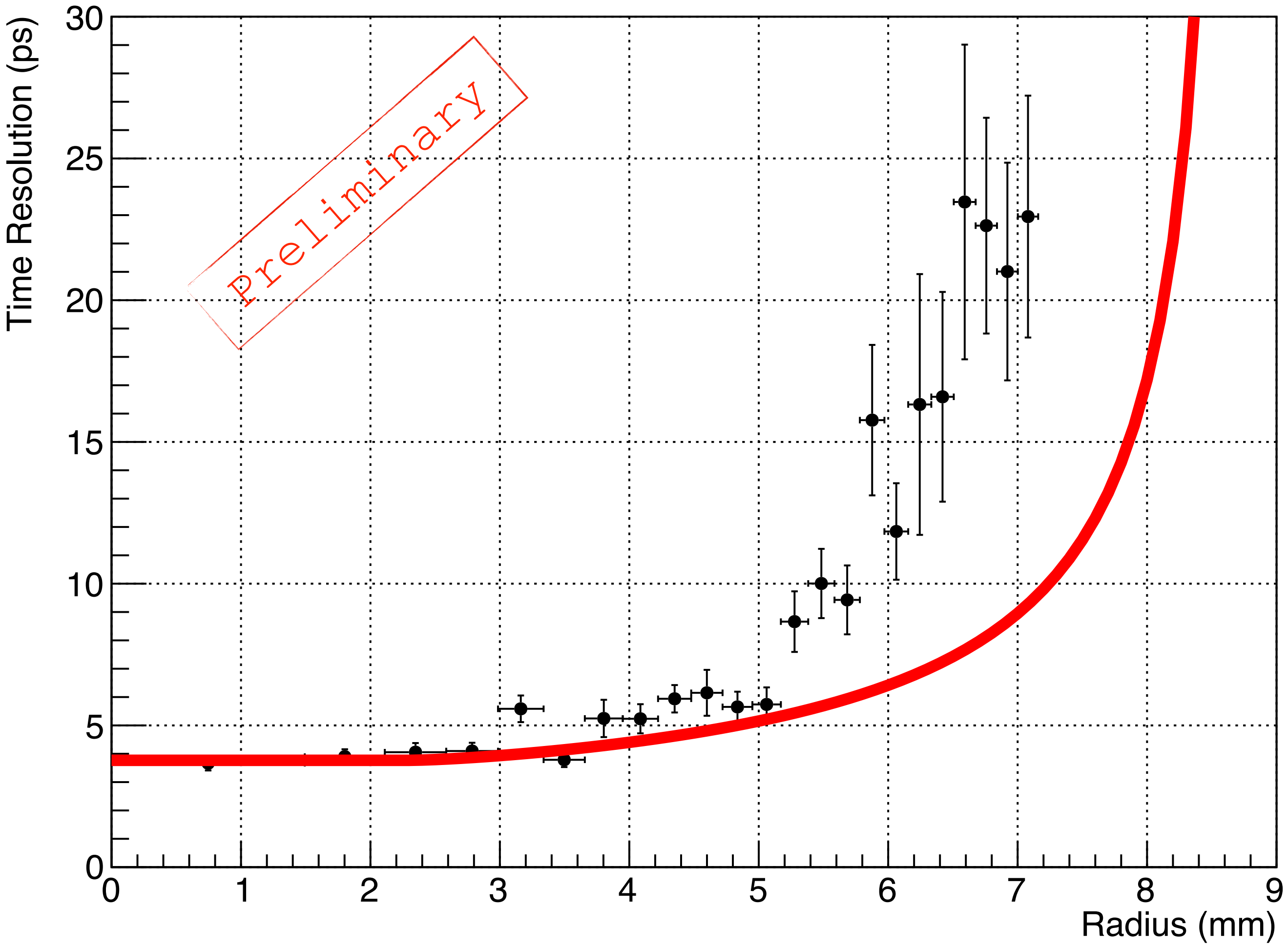


- **Based on the charge distribution observations, three ROIs of the MCP-PMT signals can be defined:**
  1. **The full Cherenkov cone is projected on the photocathode**
  2. **The Chernekov cone is partially projected onto the photocathode**
  3. **Only (diffus) reflected light is reaching the photocathode**

Time Resolution of the ROIs



Number of Photoelectrons



- **The time resolution can be estimated with the transit time spread (TTS) for a single photoelectron and the number of photoelectrons given by the Cherenkov light:**

$$\sigma_{\mathrm{MCP}} \approx \frac{\sigma_{\mathrm{TTS}}}{\sqrt{N_{\mathrm{p.e.}}}}$$

- **TTS is given with 25 ps which results in 44 ± 2 p.e. in the centre of the MCP-PMT**
- **The time resolution based on the N.p.e. has been calculated geometrically**
- **The trend of the model shows an agreement with the data**
- **Especially in the outer parts the high contribution of the reflected light is not included in the model**

Conclusion

- **A time resolution of up to 3.75 ± 0.14 ps has been measured with R3809U-50 MCP-PMTs operating at 2800 V**
- **The full active area (Ø 11 mm, as given by the manufacturer) can be used as a time reference with a time resolution < 10 ps**
- **Several conclusions can be made for fast timing photodetectors with a Cherenkov window (like the PICOSEC Micromegas):**
  - **The initial number of photoelectrons shows in general a 1/sqrt dependancy on the time resolution**
  - **The geometry of the photocathode in relation to the projection of the Cherenkov cone is important to define the active area of the detector**

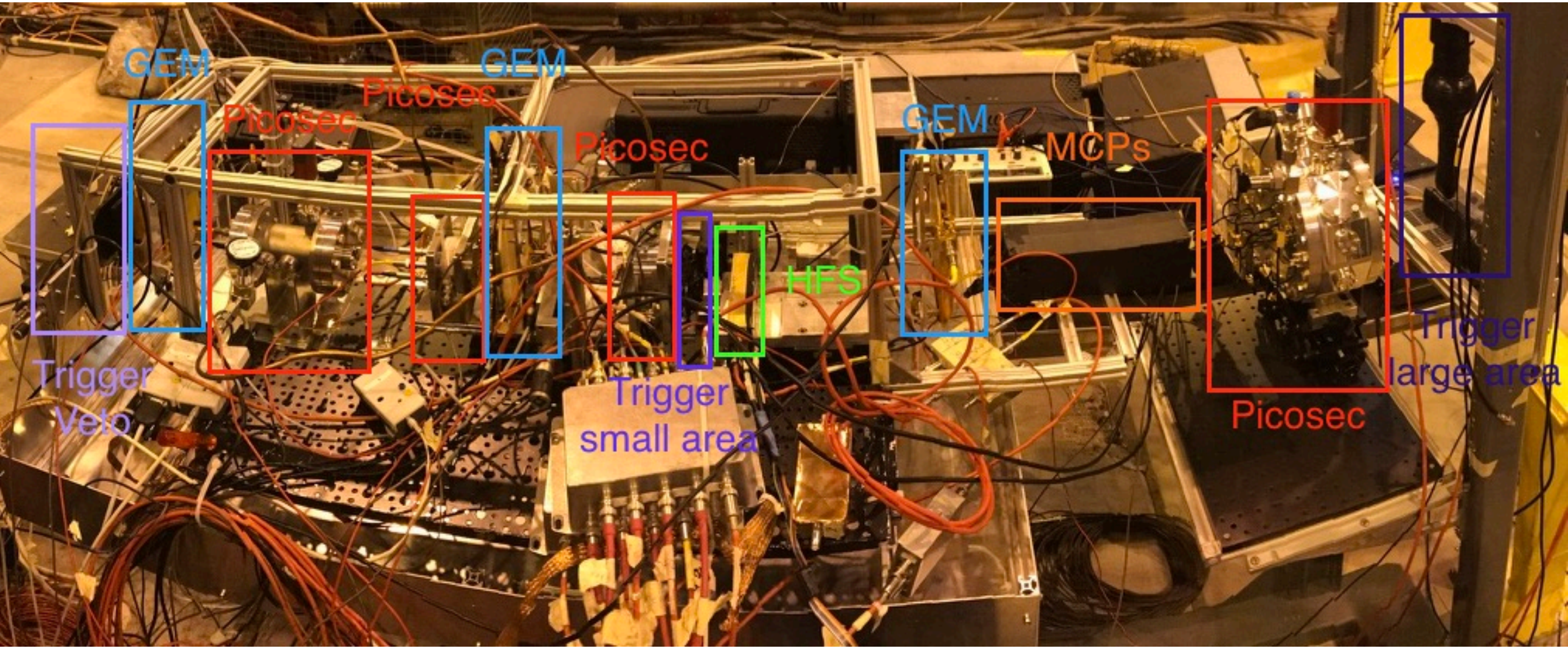
Conclusion

- **A time resolution of up to 3.75 ± 0.14 ps has been measured with R3809U-50 MCP-PMTs operating at 2800 V**
- **The full active area (Ø 11 mm, as given by the manufacturer) can be used as a time reference with a time resolution < 10 ps**
- **Several conclusions can be made for fast timing photodetectors with a Cherenkov window (like the PICOSEC Micromegas):**
  - **The initial number of photoelectrons shows in general a 1/sqrt dependancy on the time resolution**
  - **The geometry of the photocathode in relation to the projection of the Cherenkov cone is important to define the active area of the detector**

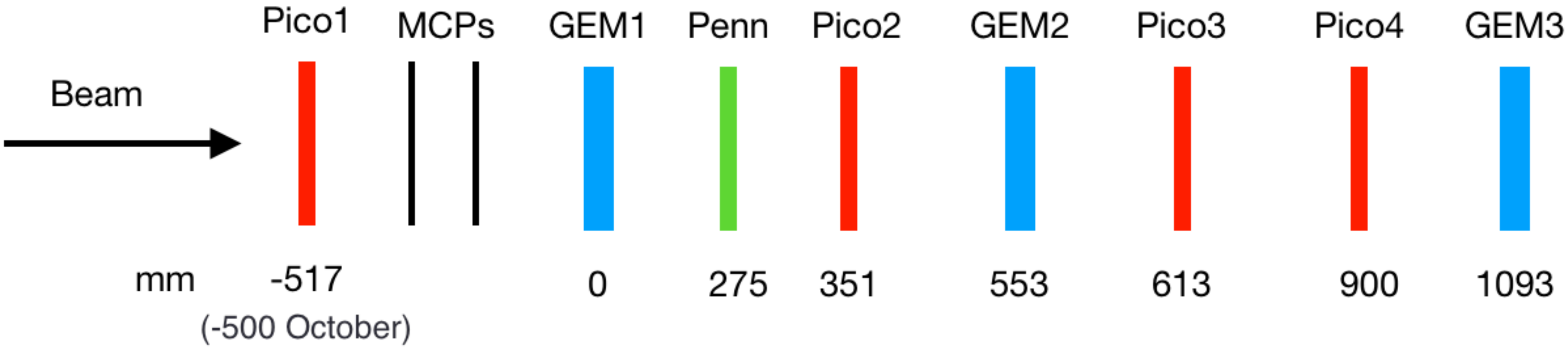
Thanks for your attention & Stay Tuned

Backup

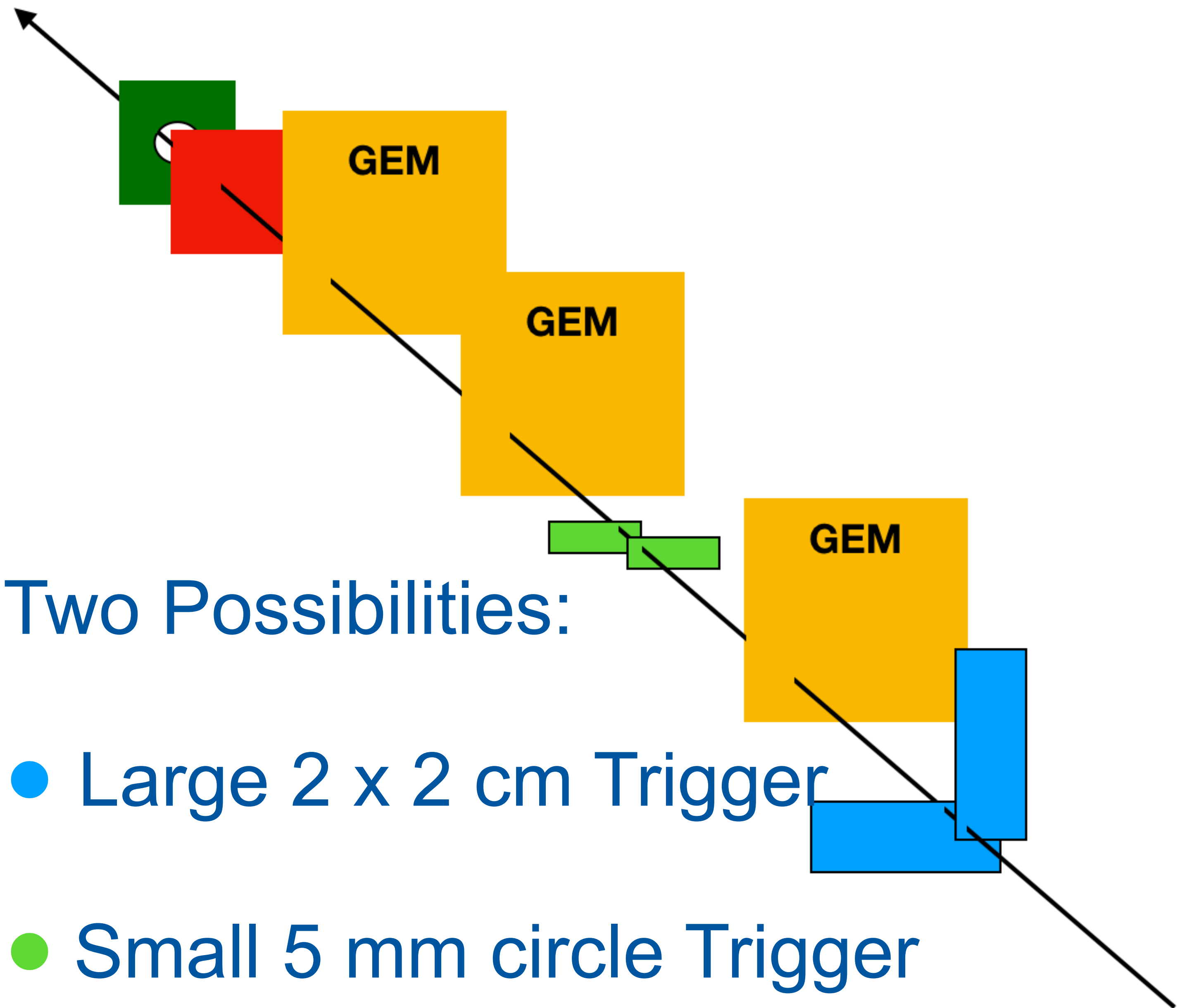
Beam Telescope @ CERN SPS H4



Detector Position in the Beam Telescope



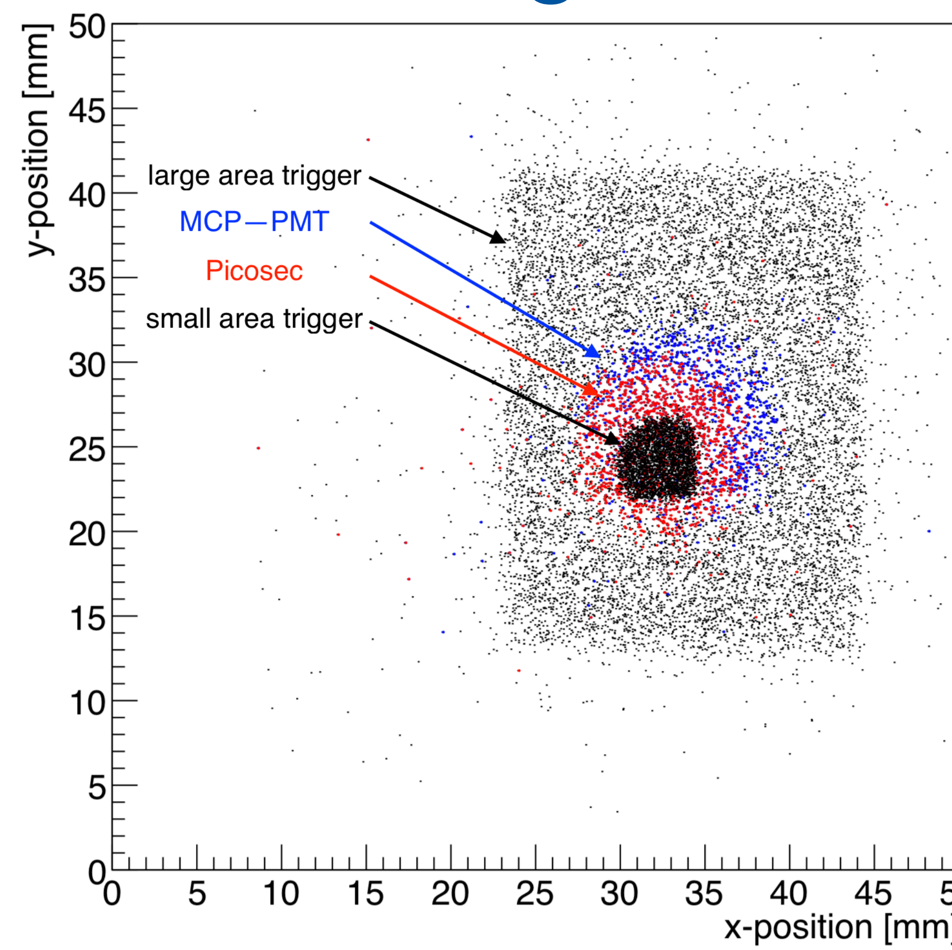
Trigger Configuration



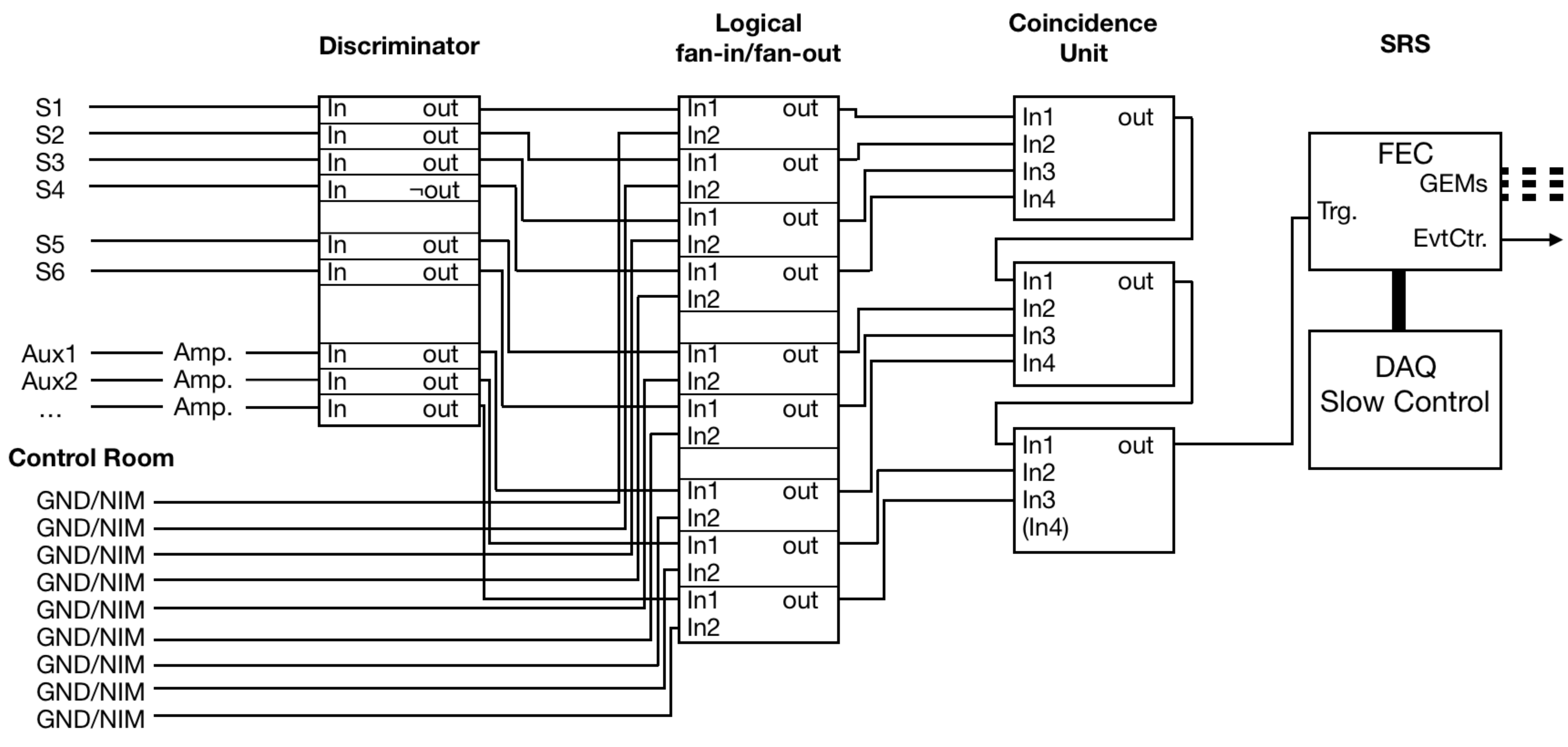
Two Possibilities:

- Large 2 x 2 cm Trigger
- Small 5 mm circle Trigger

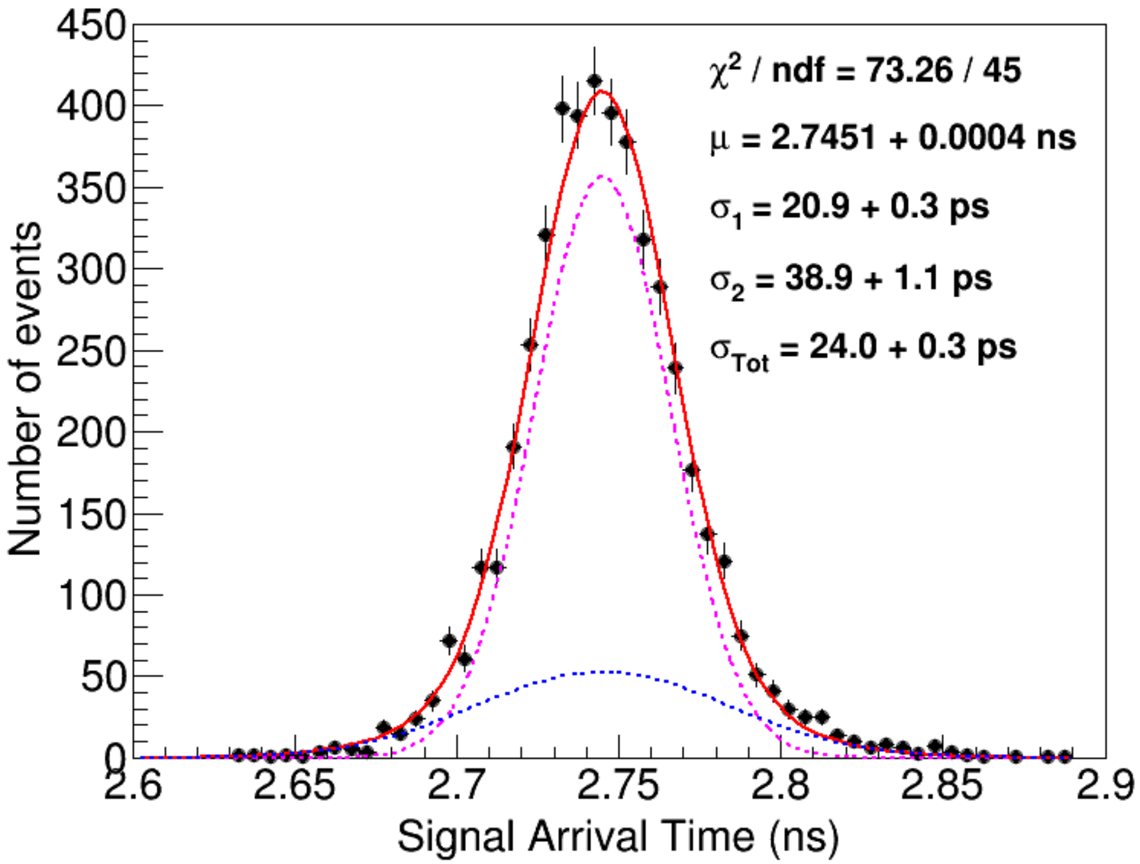
Beam Alignment

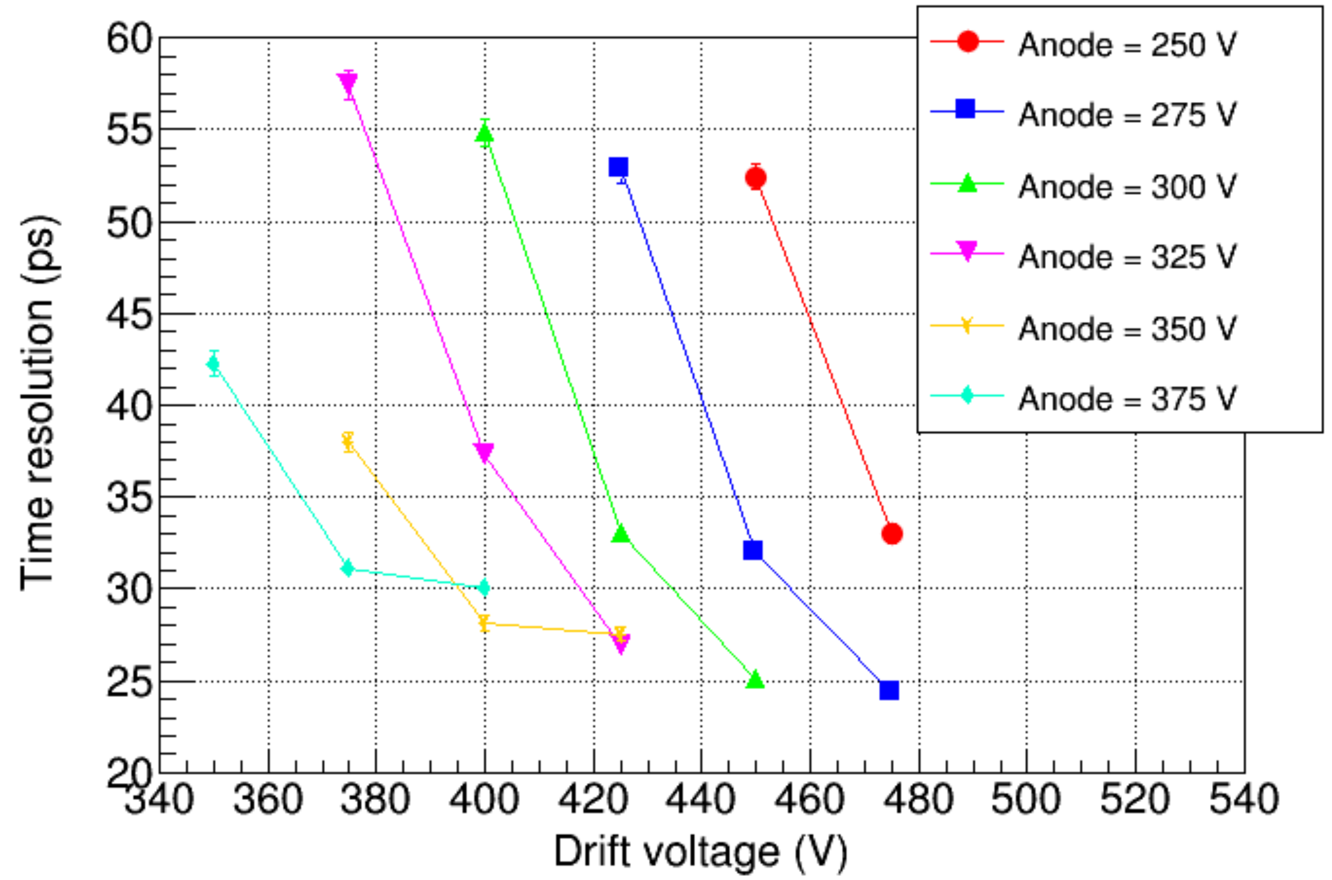


Hardware trigger selection from the Control Room



PICOSEC Time Resolution

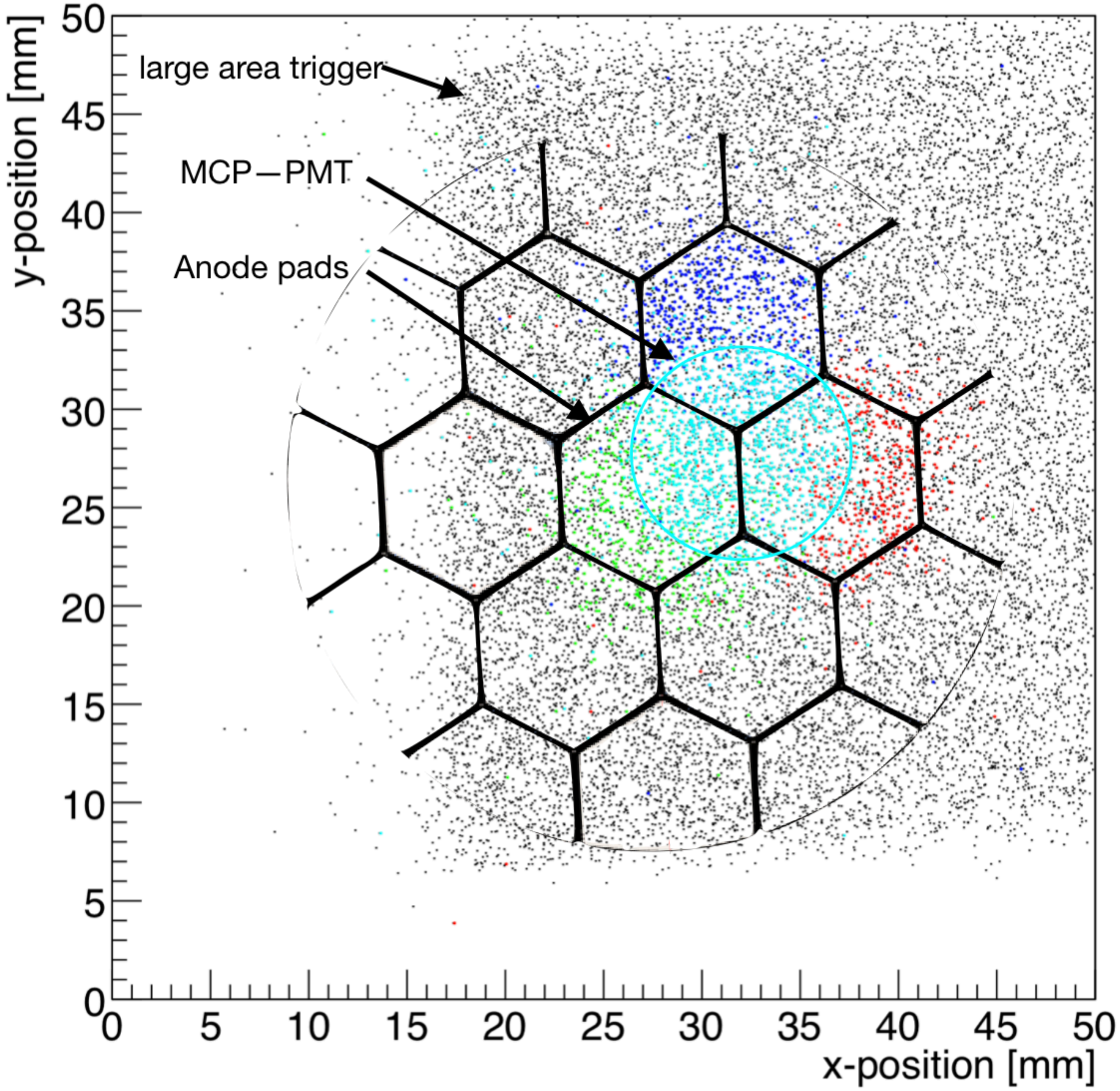




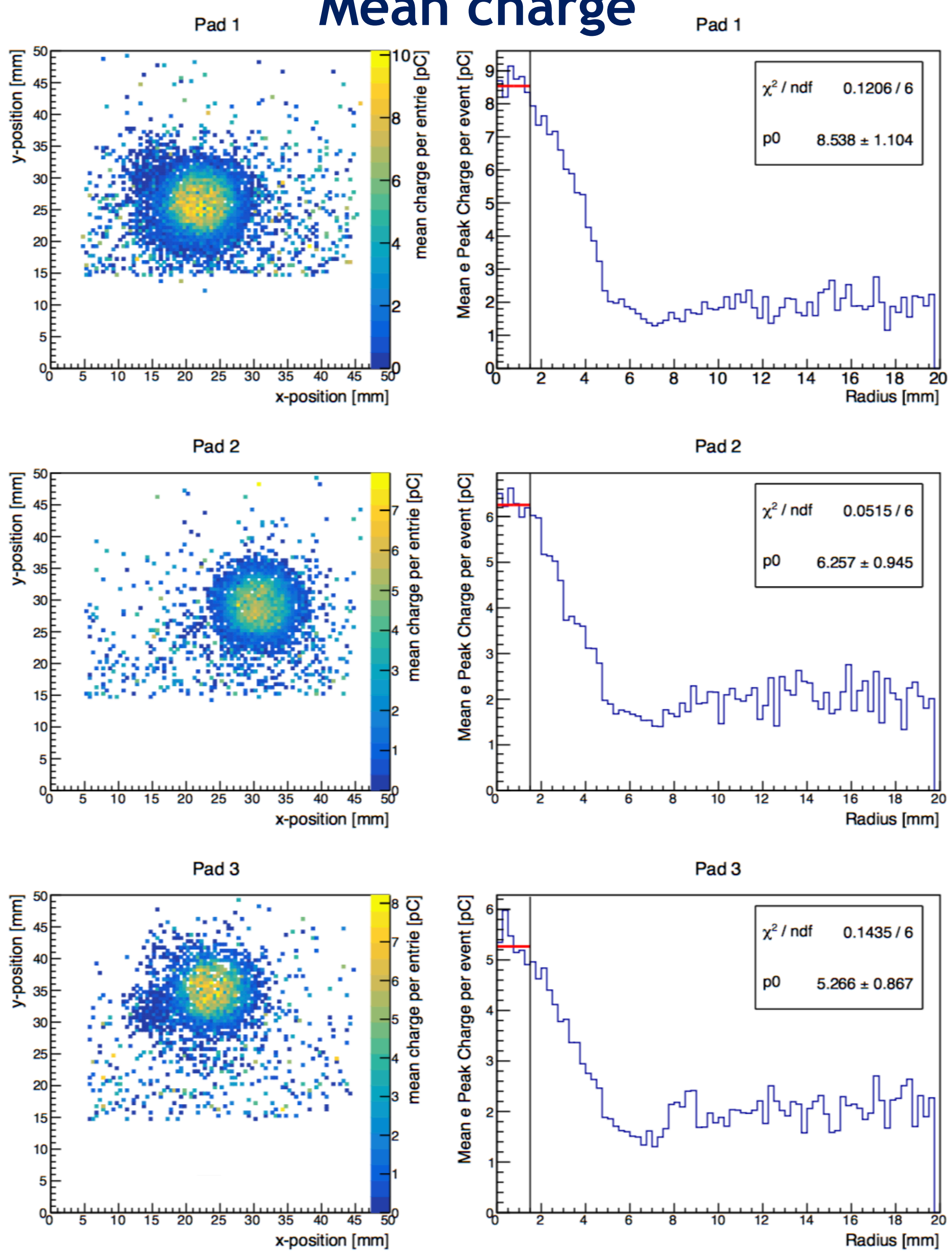
- **Bulk Micromegas with:**
  3 mm MgF2 window and 5.5 nm Cr + 18 nm CsI Photocathode
- **COMPASS Gas mixture: 0.8 Ne + 0.1 iC4H10 + 0.1 CF4**
- **Optimal operation point at: Amplification +275 V, Drift -475 V**
- **Mean number of photoelectrons: 10.4 ± 0.4**
- **Time resolution for 150 GeV Muons: 24.0 ± 0.3 ps**

To calculate the combined time resolution of several pads the exact position and gain of each participating pads needs to be evaluated

Pad alignment



Mean charge



PICOSEC Outlook

- Analysis of large Multipad datasets with four Pads
- Continuing measurements with different photocathode materials
- Ageing studies of promising photocathode samples
- Development of a resistive multipad Picosec chamber

- (Embedded) electronic necessary for segmented readout

- Comprehensive simulation and analysis at AUTH
- DLC and S.E. Production at USTC and CEA
- New cosmic muons bench at Saclay
- Asset photocathode test chamber at CERN
- At least 6 weeks of Laser time at Saclay
- Participation at MIP beam tests all over Europe