INFN CATANIA

Imaging Cosmic And Rare Underground Signals

Fermilab

Analysis and Validation of PMT’s Waveforms in ICARUS LArTPC Using Monte Carlo Simulations

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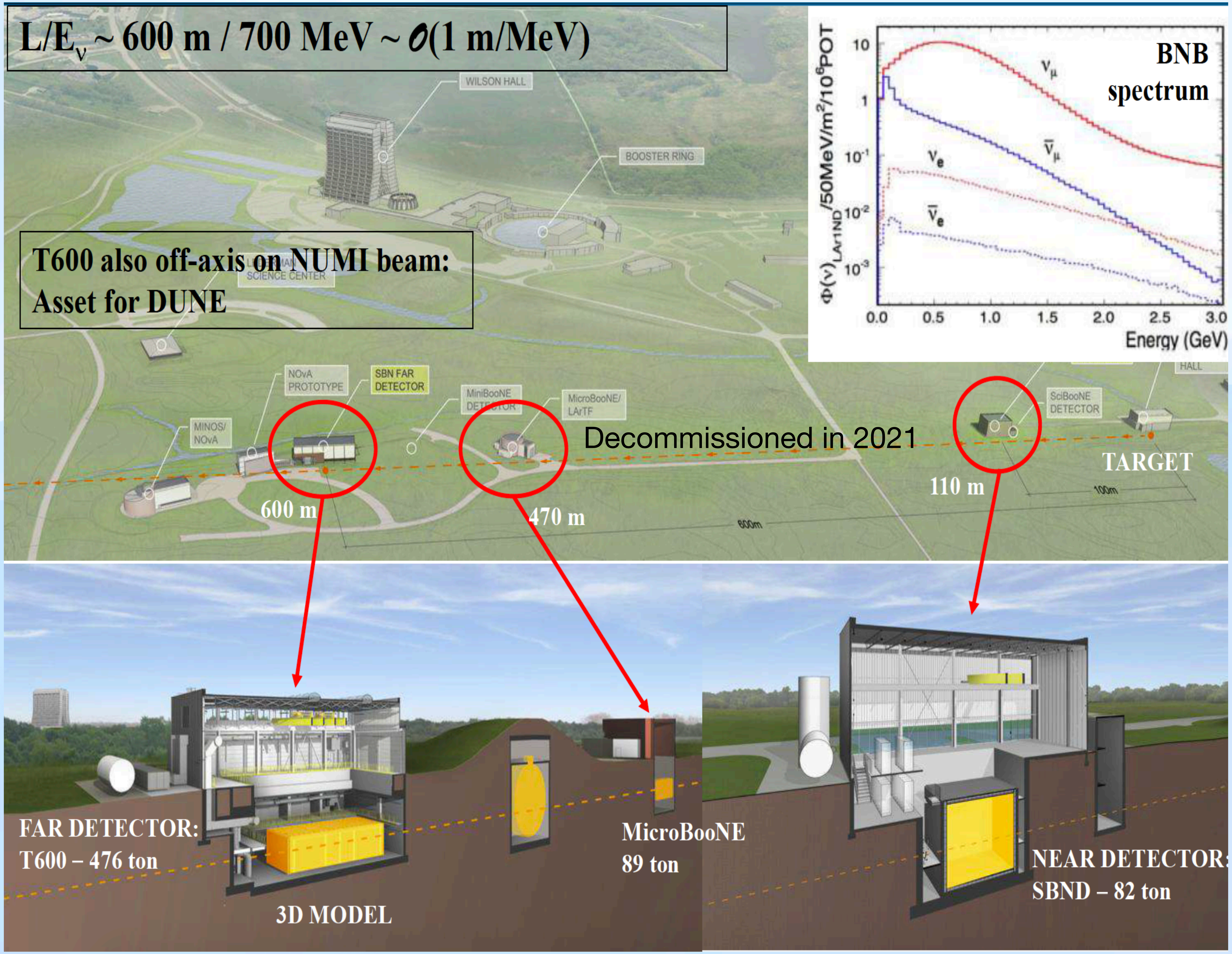
SBN Experiment Overview



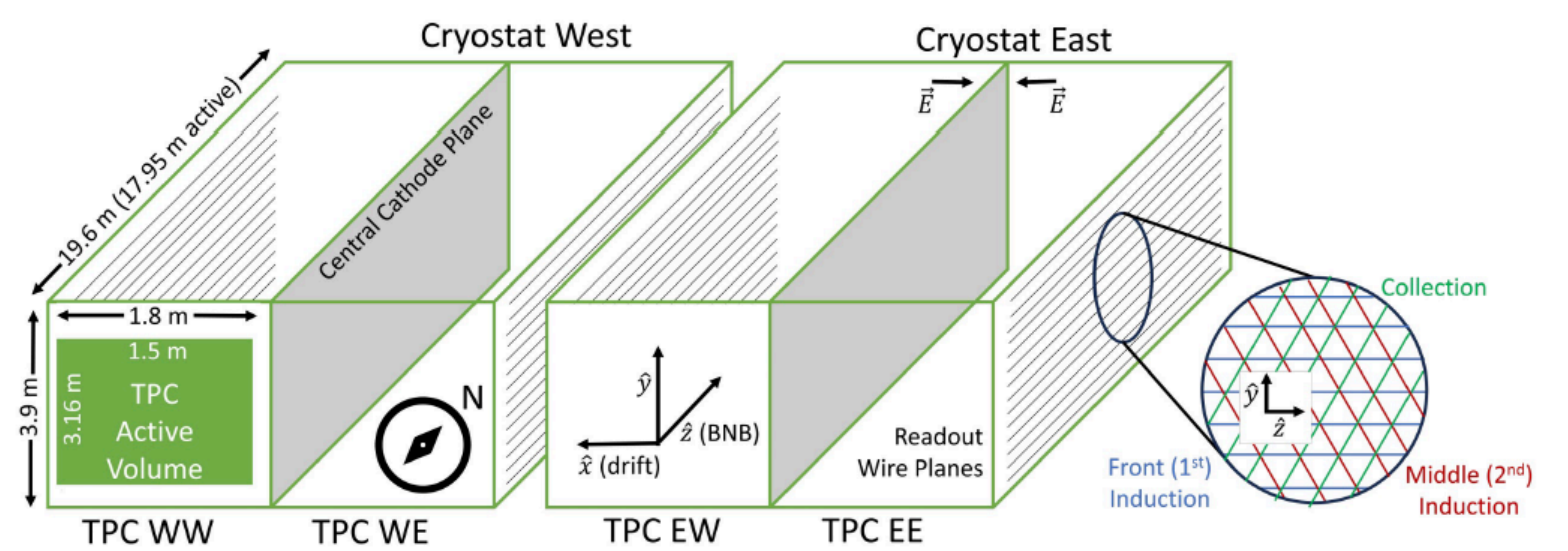
Short Baseline Neutrino (SBN)

use, along the line of neutrino beam (Booster Neutrino Beamline) of three detectors:

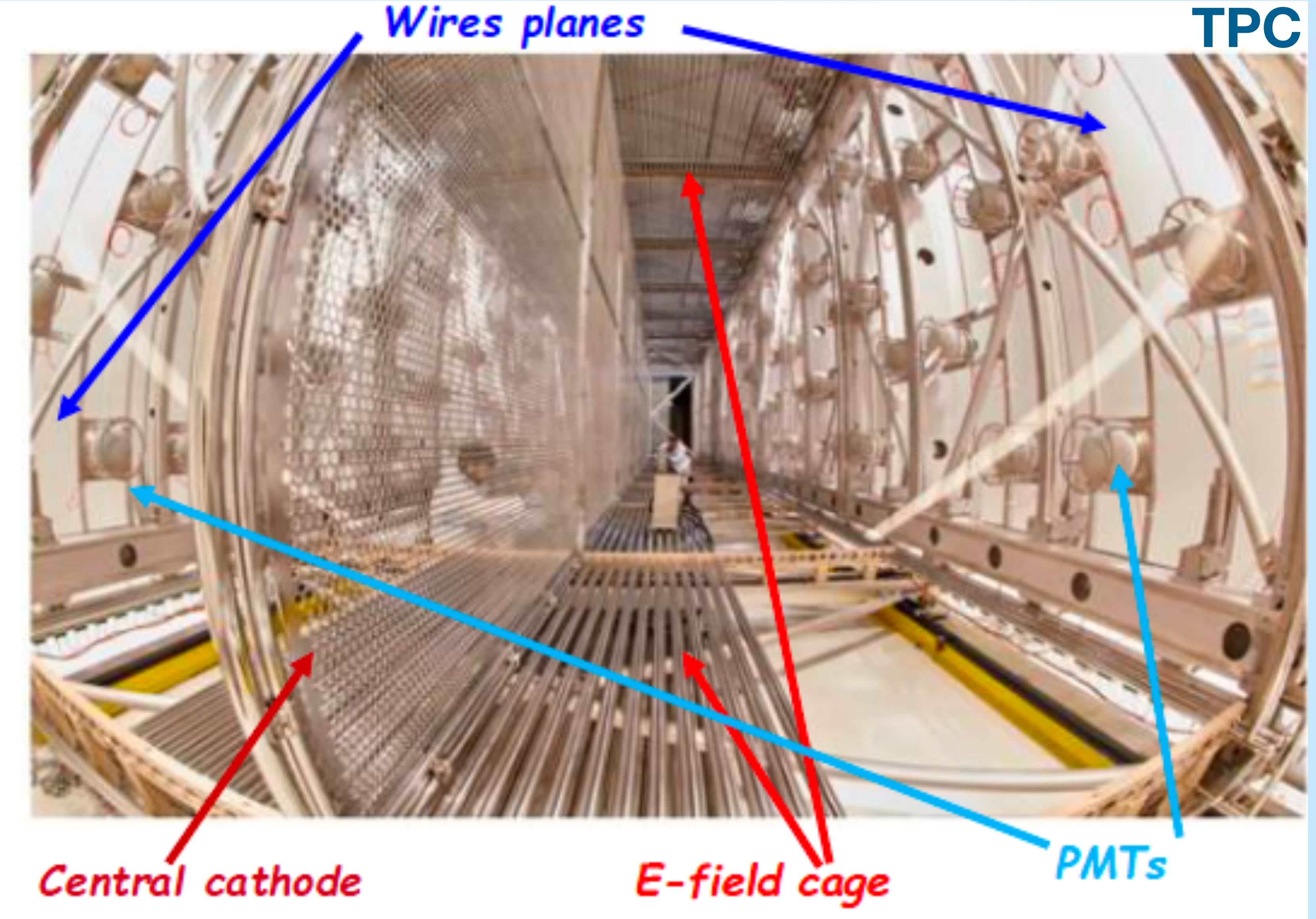
- The ***Short Baseline Near Detector (SBND)***, located ~ 110 meters from the source;
- ***MicroBooNE***, ~ 470 meters from the neutrino source;
- ***ICARUS***, ~ 600 meters from the neutrino source.

ICARUS Detector - SBN FD

- ICARUS is the largest liquid argon detector currently in operation (~476 active tons).



- Two identical cryostats, filled with about 760 t of ultra-pure liquid argon at 89 K ± 1K , 1.5 m drift, ED= 0.5 kV/cm;
- Each cryostat houses two TPCs with 1.5m maximum drift path, sharing a common central cathode.
- Anode: 3 parallel wire planes; ab0ut 54000 wires;



The information of the ionization track occurrence time, combined with the electron drift velocity provides the event coordinate in the drift direction.

The composition of the three views from the TPC wires yields the track projection on the anode plane.

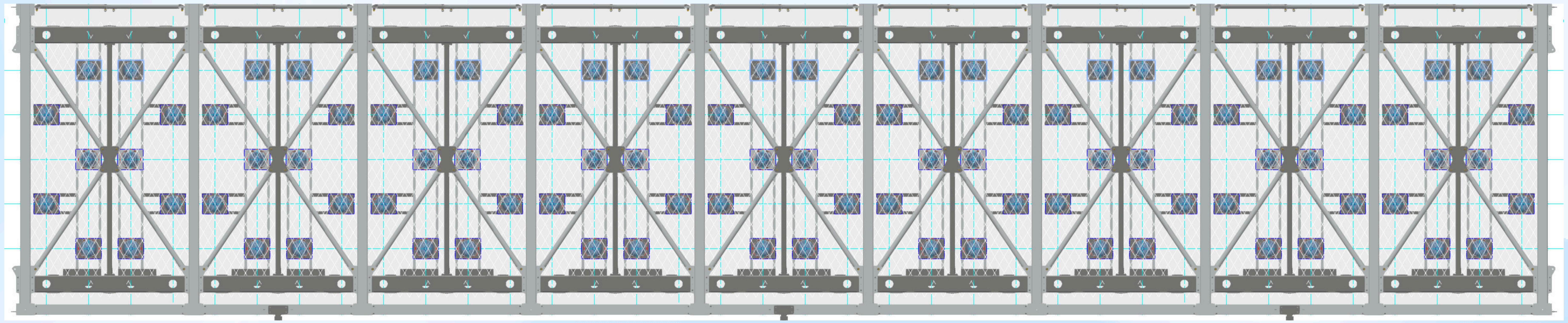
This information allows obtaining a **full 3D reconstruction of the tracks, with a spatial resolution of about 1mm³.**

ICARUS PMTs System

360 Hamamatsu R5912-MOD 8" PMTs mounted behind the anode wires.

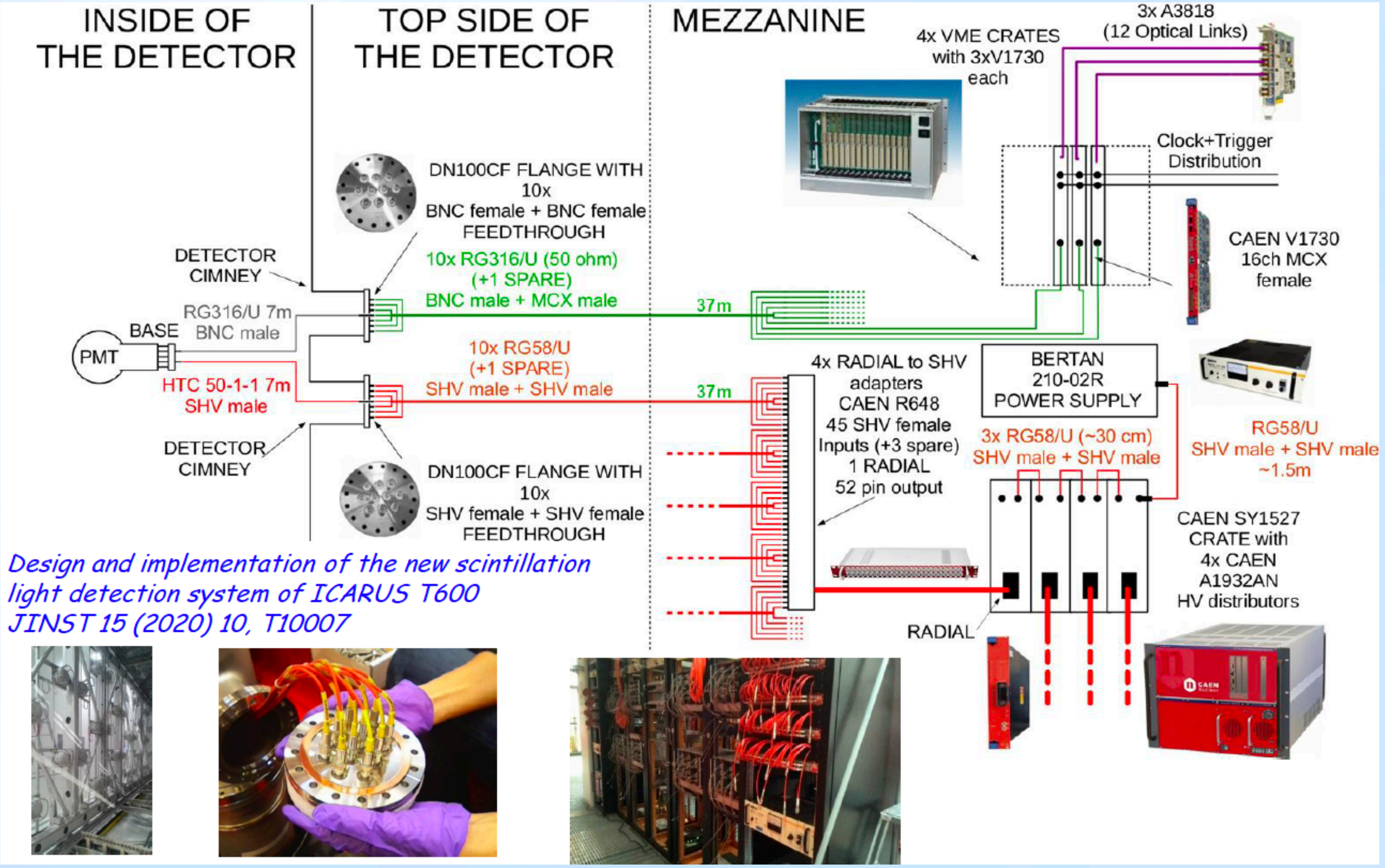
Gain about 10^7 .

~18m



~3.6m

The new ICARUS PMTs mounted behind the wires of one TPC



Design and implementation of the new scintillation light detection system of ICARUS T600
JINST 15 (2020) 10, T10007

- Placed in a **"honeycomb" structure** on the four TPC "walls" (90 per TPC wall, 180 per module);
- **TPB coating** for 128nm sensitivity;
- 24 **CAEN V1730B** digitizers (500 MSa/s), 15 PMTs + 1 spare channel per board.

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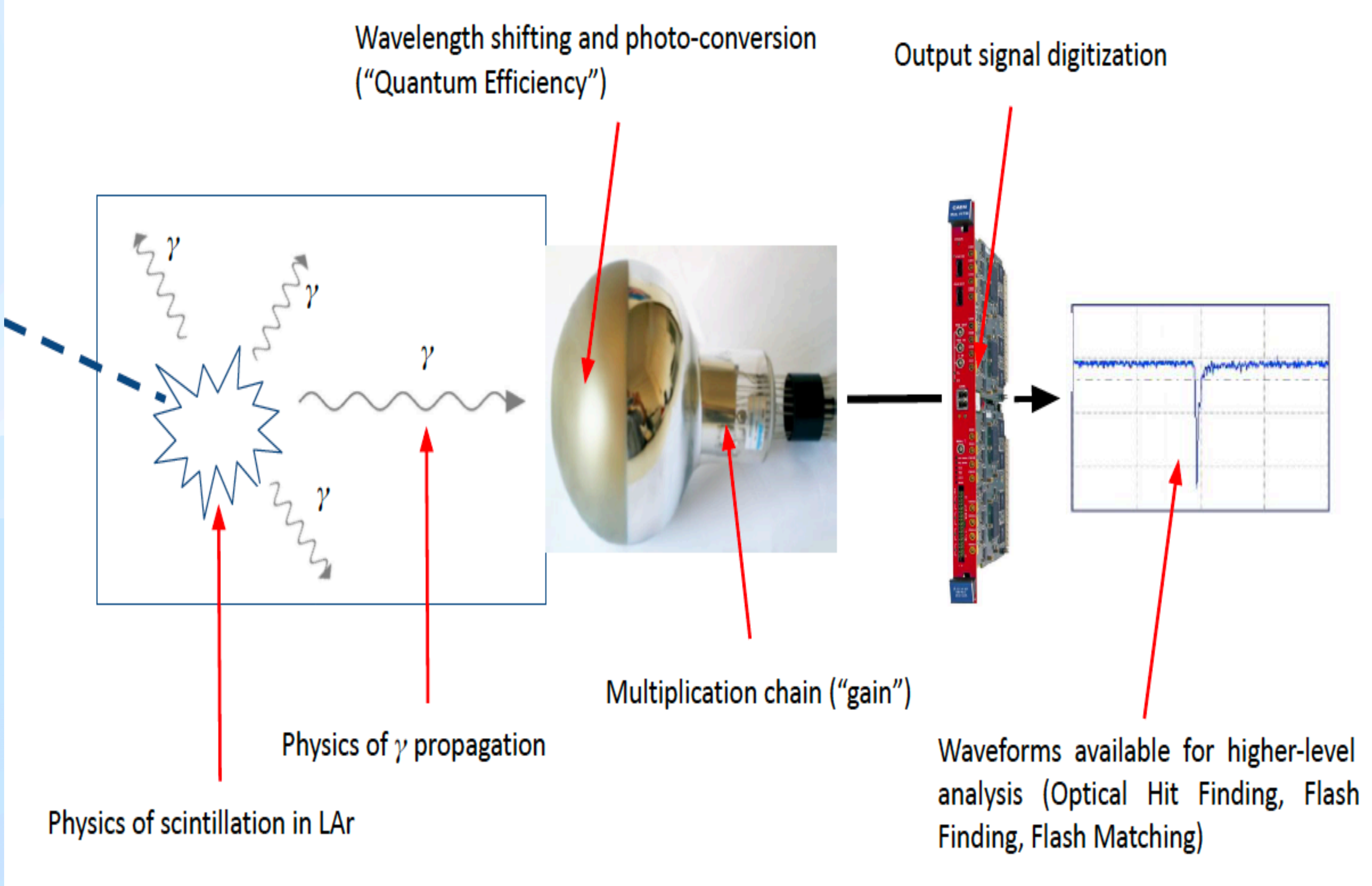
Light Reconstruction Chain



Scintillation light in LAr:

- Light yield ~ few 10,000's of photons per MeV;
- Wavelength of emission is 128 nm.

- Light with two characteristic time constants:
- **fast component,** 6-7 ns;
- **slow component**,1500- 1600 ns;

- Percentage of light for electrons and photons:
- fast light: 25-30% ;
- slow light: 70-75% .

With a timing resolution of about 1 ns, the PMTs enable precise event time tagging, crucial for distinguishing closely spaced neutrino events.

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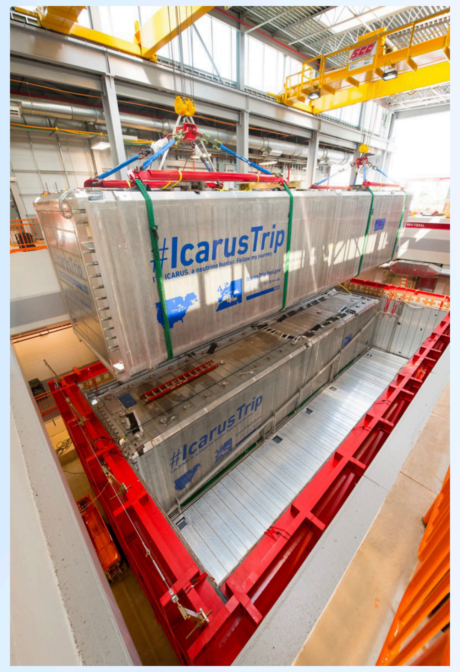
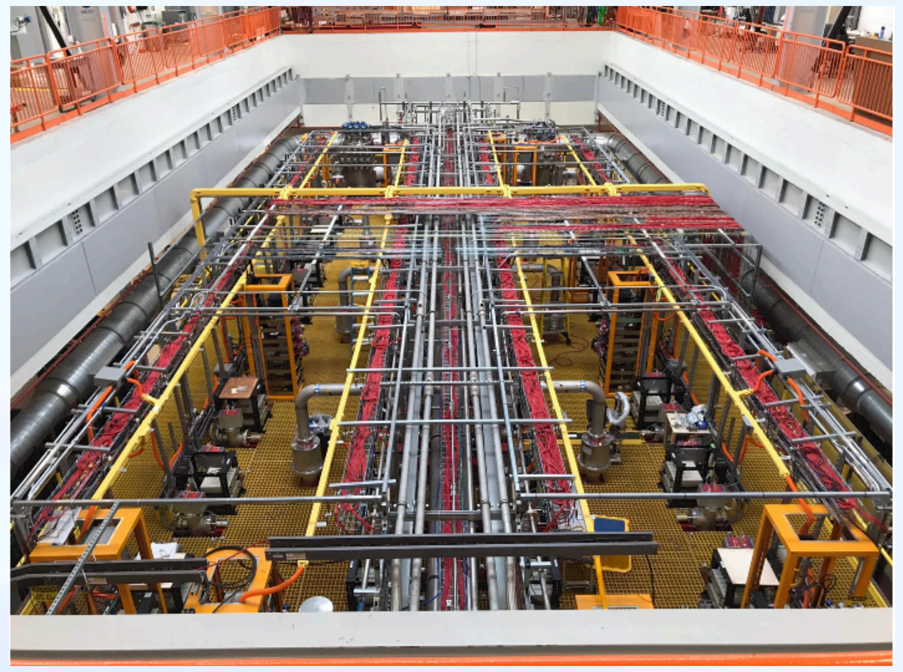
ICARUS Data Taking

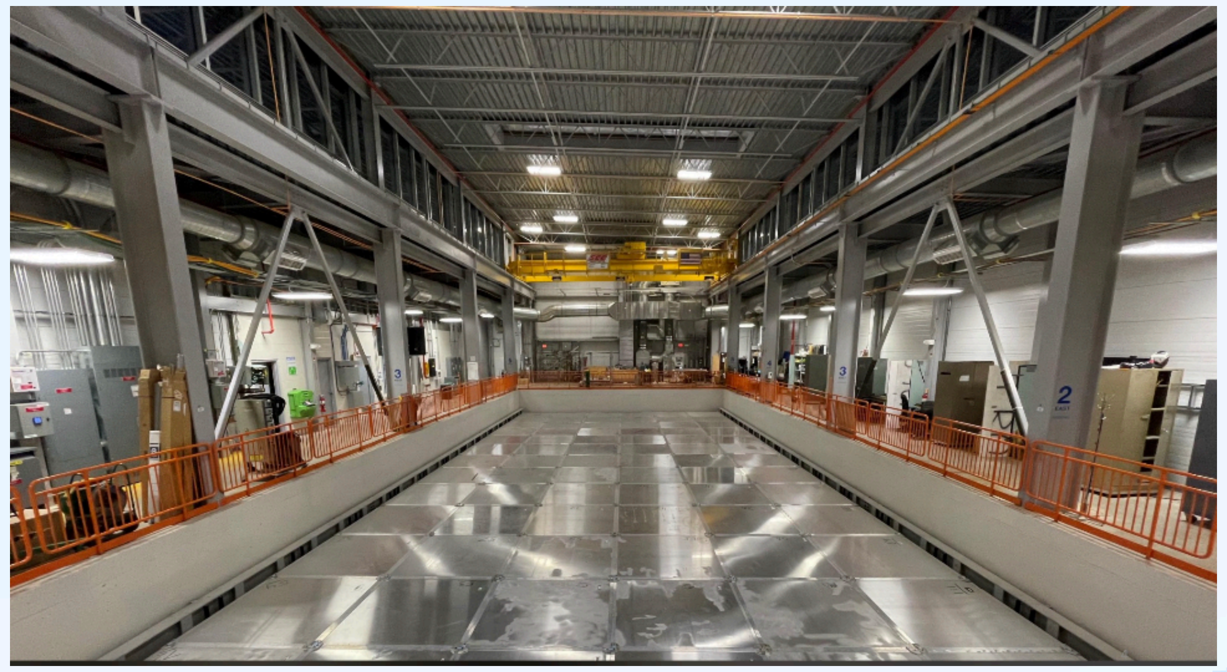


2018
from CERN
to Fermilab

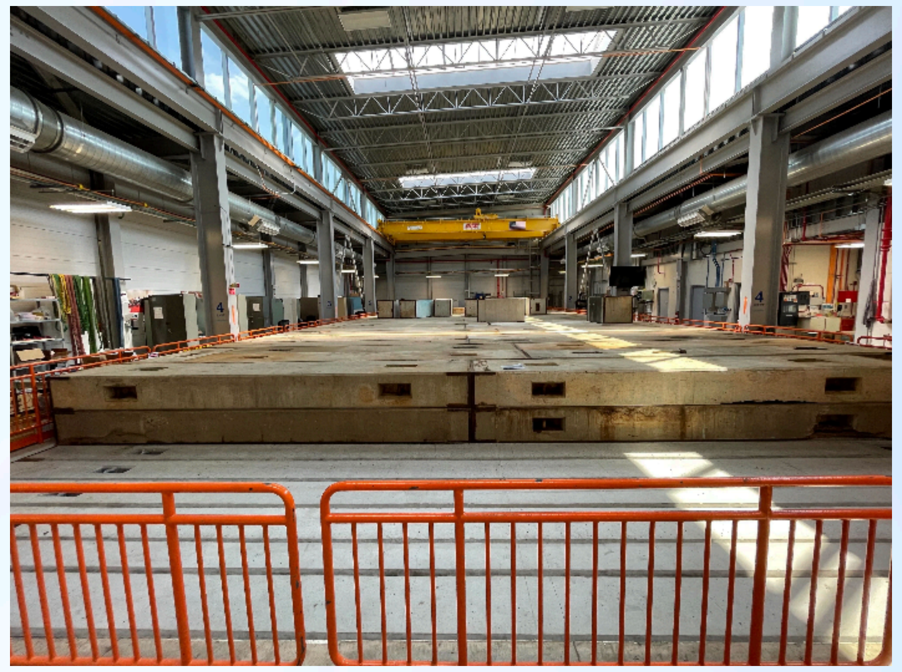


2020
Begin of
commissioning
activities.

End 2021
Installation of the
Cosmic Ray Tagger



May 2022
Begin of Physics runs



ICARUS electron Lifetime

Used in my analysis

Run3 -> New PMTs cables

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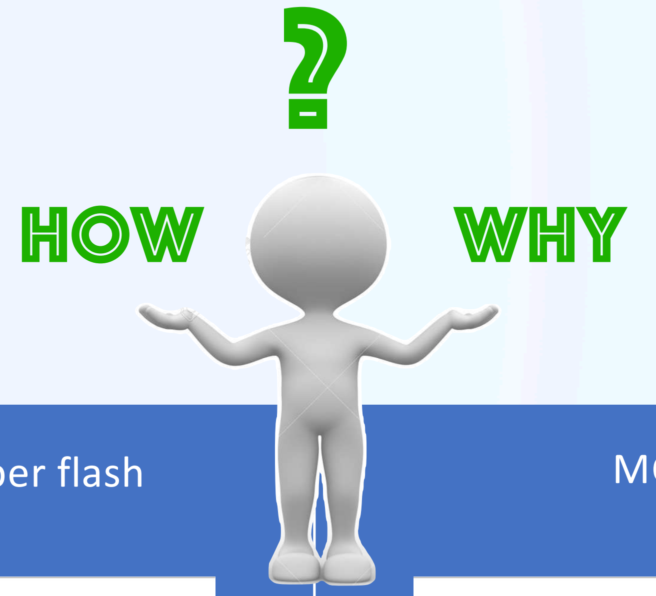
Datasets and analysis method

2 different Datasets:

Data -> Run 2 _ 9435

Mc -> Run 2



Study of the average waveform from Data and MC

Selection Data Parameters:

1. cathode crossing tracks with abs(t0) < 300us
2. vertical:
   - y_start > 125cm & y_stop <-175cm
   - abs(x_stop - x_start) < 70cm
   - abs(z_stop - z_start) < 70cm
3. coinc track-flash:
   - abs(z_bary_track – z_bary_flash) < 30cm
   - t_track – t_flash = [1.3, 9.5] for data and MC

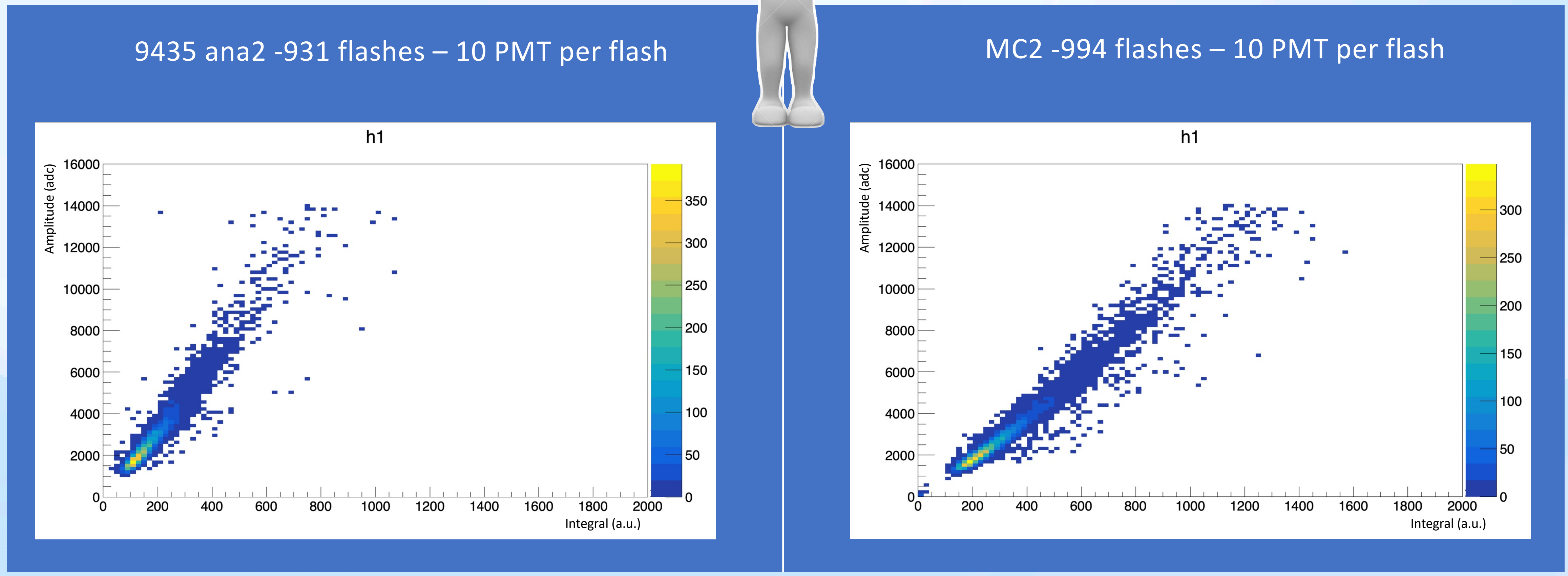
Selection MC Parameters:

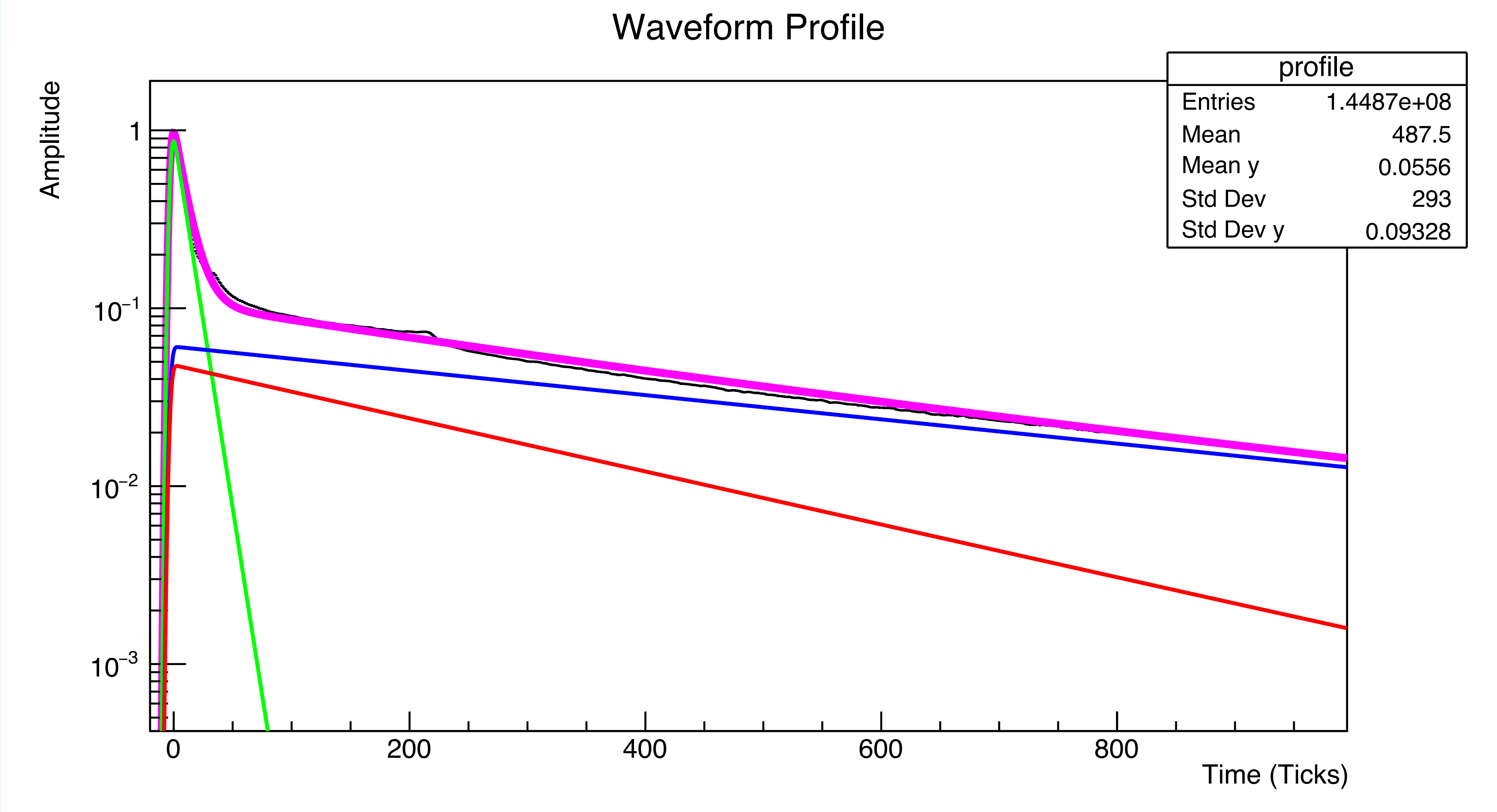
1. Vertical tracks
2. QE 7.3%
3. Gain= 7.5 e+06

- Selection of the 12 brightest pmts for each flash;
- Alignment of all waveforms at t0=0;
- Normalization of the aligned waveforms;
- Study of the average waveform;
- Fit function of average waveform:

$$f(t) = \sum_{j=f,i,s} \frac{A_j}{2\tau_j} \exp\left[\frac{1}{2}\left(\frac{\sigma}{\tau_j}\right)^2 - \left(\frac{t-t_m}{\tau_j}\right)\right]\left[1 - \mathrm{erf}\left(\frac{1}{\sqrt{2}}\left(\frac{\sigma}{\tau_j} - \frac{(t-t_m)}{\sigma}\right)\right)\right]$$

- Comparison Data - MC.

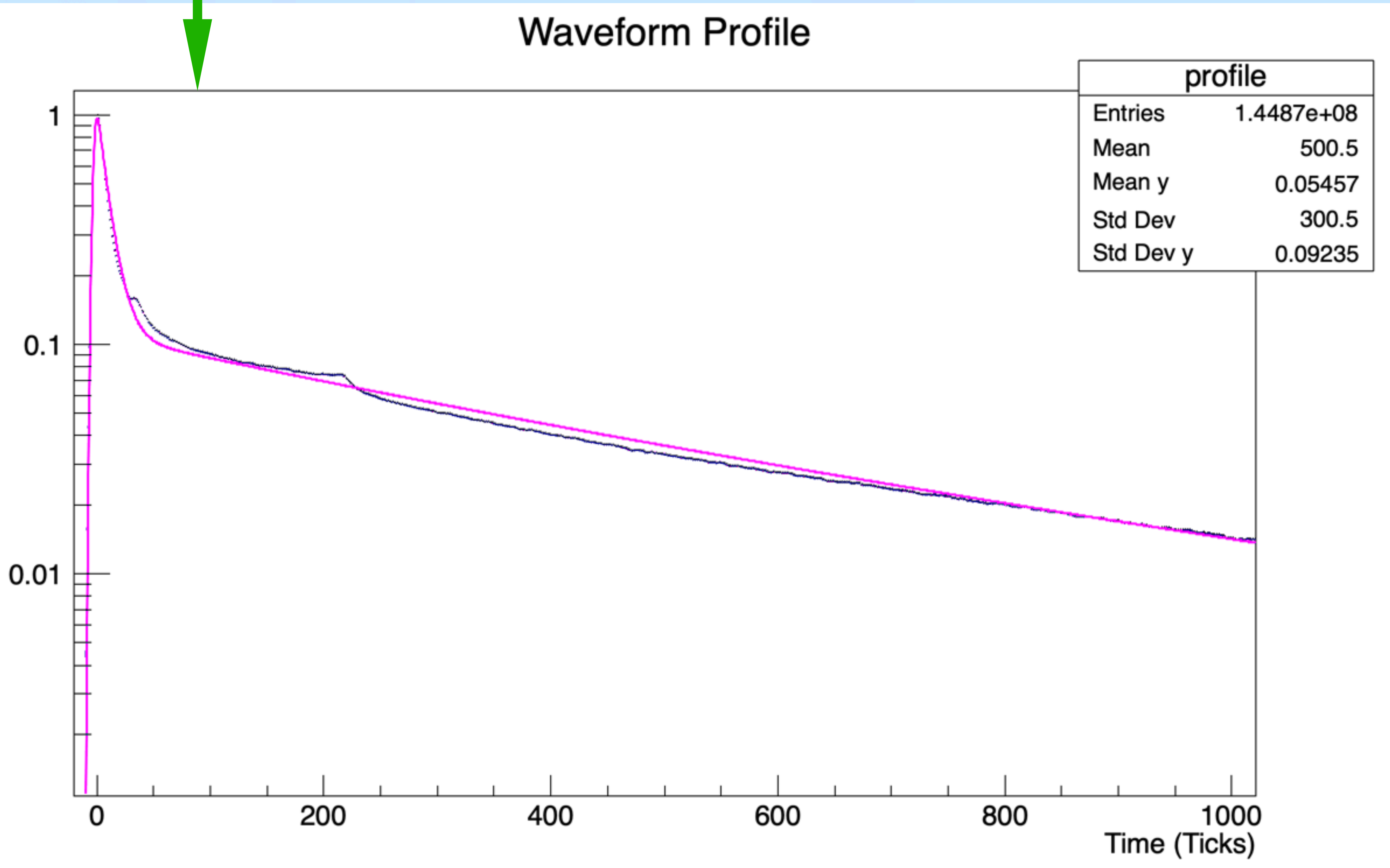


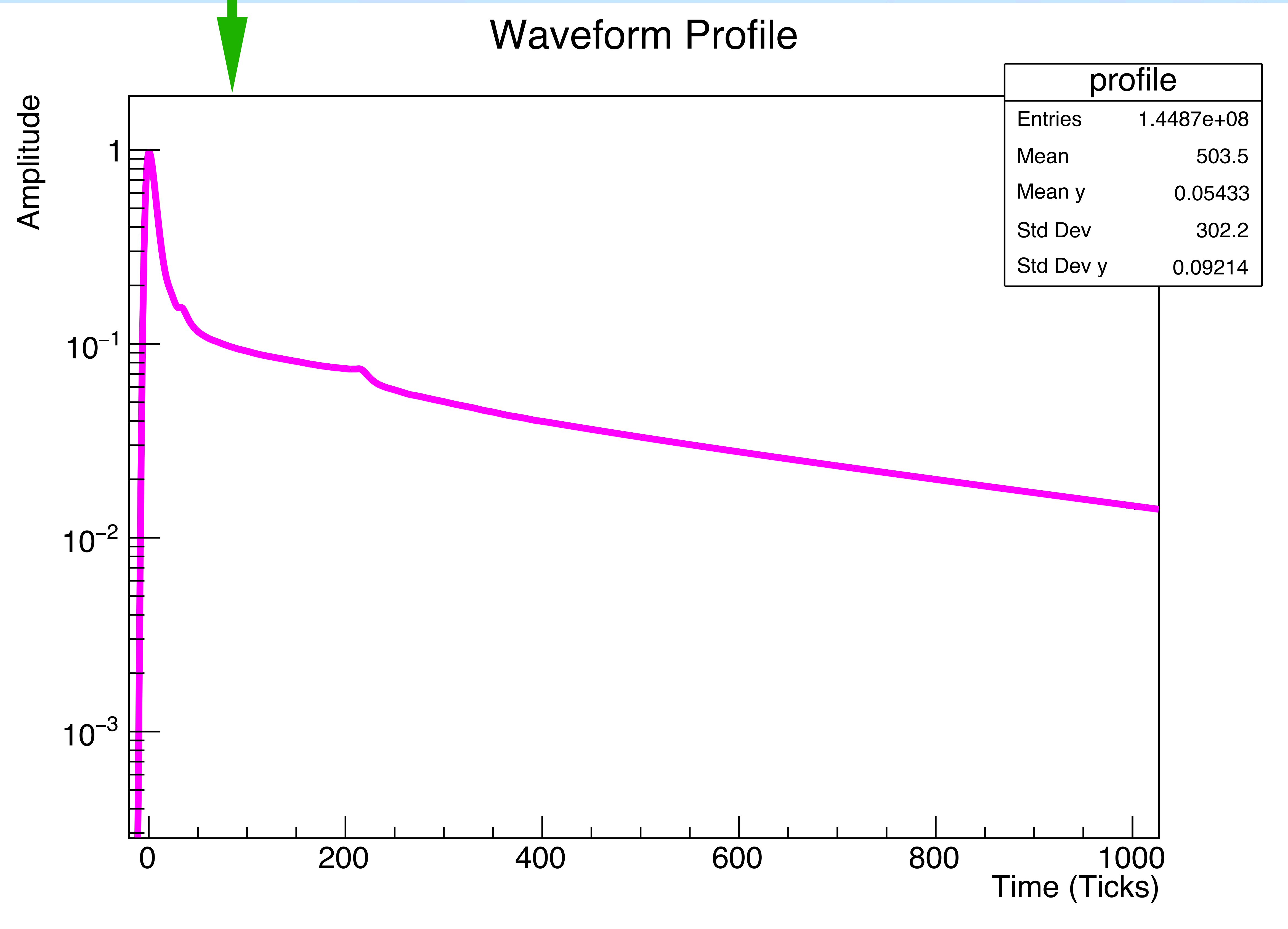


Data - Run 2

Old fit function = $$f(t) = \sum_{j=f,i,s} \frac{A_j}{2\tau_j} \exp\left[\frac{1}{2}\left(\frac{\sigma}{\tau_j}\right)^2 - \left(\frac{t-t_m}{\tau_j}\right)\right]\left[1 - \mathrm{erf}\left(\frac{1}{\sqrt{2}}\left(\frac{\sigma}{\tau_j} - \frac{(t-t_m)}{\sigma}\right)\right)\right]$$

New fit function = Old fit function+ SPR convolution





T Fast [ns]	T Interm [ns]	T Slow [ns]	% Fast	% Slow+ Interm
19 ± 0,5	555 ± 10	1275 ± 1	20%	80%

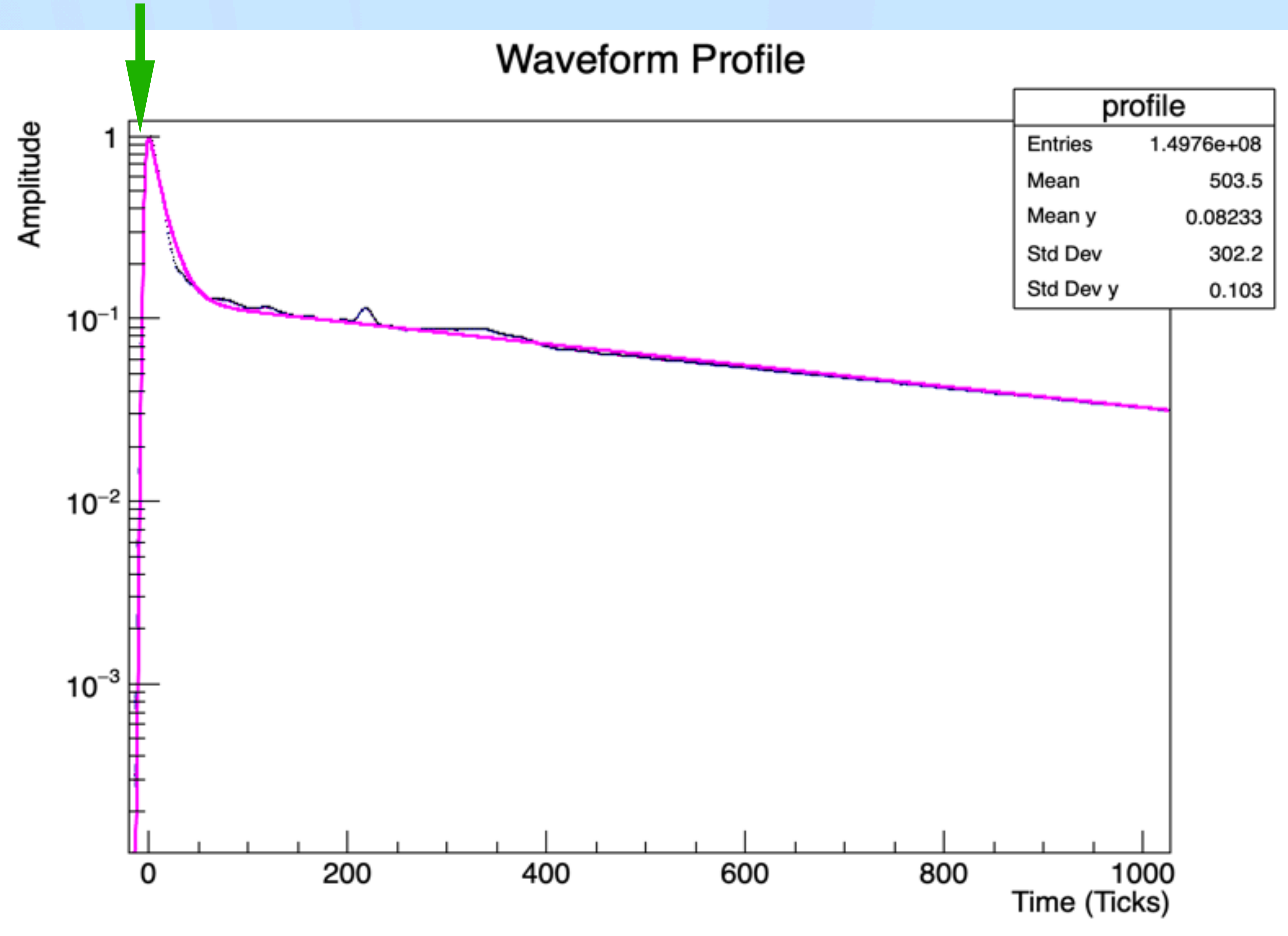
T Fast [ns]	T Interm [ns]	T Slow [ns]	% Fast	% Slow	%Interm
10 ± 0,1	310 ± 1	1314 ± 0,4	28.8%	62.7%	8.5%

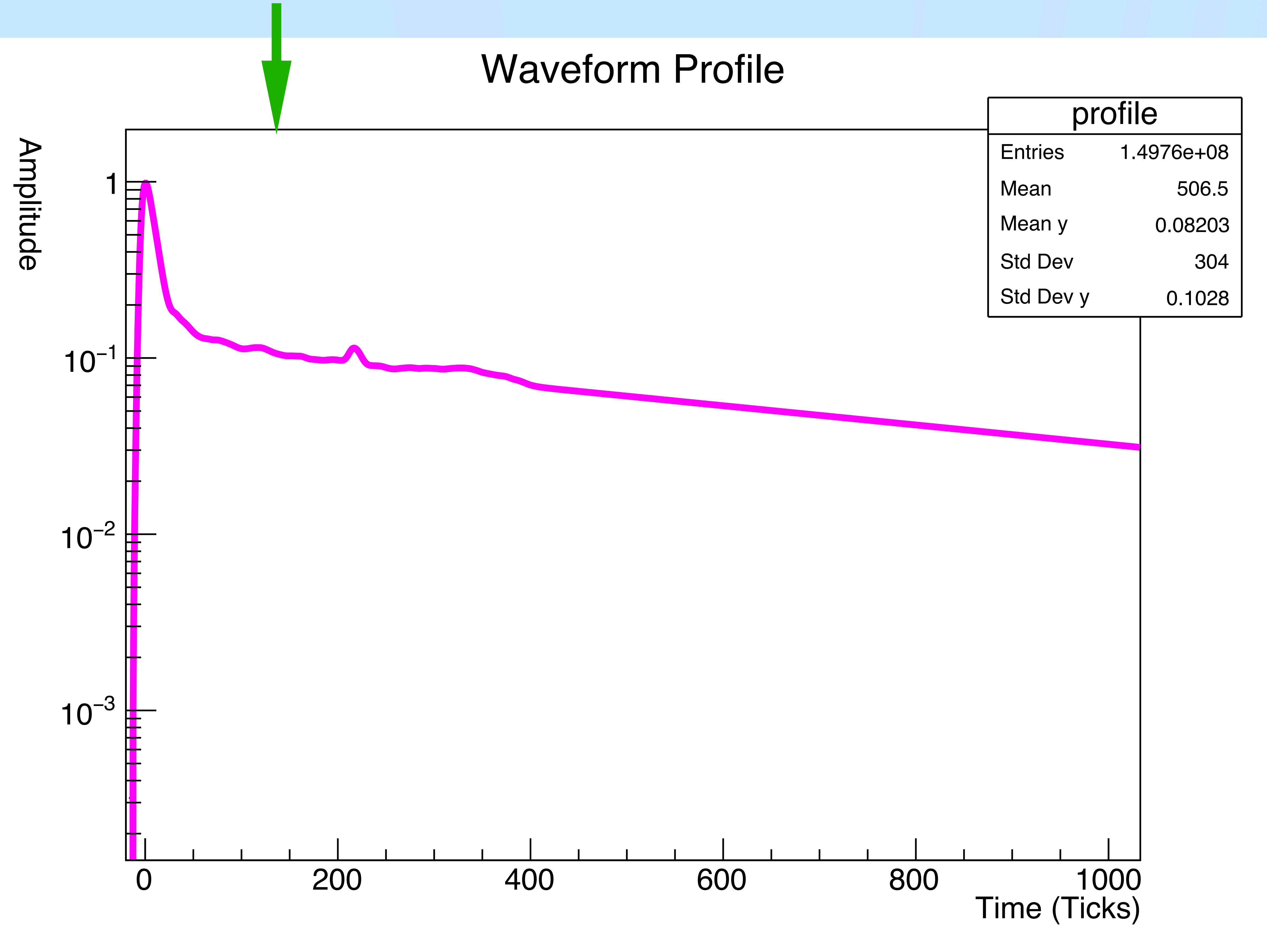
MC - Run 2

Old fit function =

$$f(t) = \sum_{j=f,i,s} \frac{A_j}{2\tau_j} \exp\left[\frac{1}{2}\left(\frac{\sigma}{\tau_j}\right)^2 - \left(\frac{t-t_m}{\tau_j}\right)\right]\left[1 - \text{erf}\left(\frac{1}{\sqrt{2}}\left(\frac{\sigma}{\tau_j} - \frac{(t-t_m)}{\sigma}\right)\right)\right]$$

New fit function = Old fit function+ SPR convolution





T Fast [ns]	T Interm [ns]	T Slow[ns]	% Fast	% Slow+ Interm
28 ± 0,2	979 ± 22	1592 ± 0,3	15%	85%

T Fast [ns]	T Interm [ns]	T Slow[ns]	% Fast	% Slow	%Interm
14,6 ± 0,1	494 ± 0,5	1589 ± 0,2	23.9%	76%	0.1%

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Conclusion

IC ARUS PMTs System

- **Excellent PMT Performance**:
  - The Hamamatsu R5912-MOD PMTs used in the ICARUS experiment provide a gain of approximately **10^7**, enabling high-efficiency scintillation detection.
- **Advanced Sensitivity**:
  - Capability to detect low-energy events, with a sensitivity threshold of **100 MeV**, making the PMTs crucial for identifying neutrino interactions.
- **Timing Resolution**:
  - With a timing resolution of about **1 ns**, the PMTs ensure precise event time registration, essential for distinguishing closely spaced neutrino events.
- **Contribution to Future Research**:
  - The innovative light detection system enhances ICARUS's ability to tackle experimental challenges, including reducing cosmic background and optimizing neutrino oscillation measurements.

Light Analysis study:

- **Data - Run2**
  - New fit: tau fast closer to the expected value of 6 ns. Slow/fast ratio closer to 3.
  - Tau slow smaller than 1.6 us though. Intermediate component small, but present.
- **MC2**
  - New fit: MC tau fast improved, but still larger than data. Slow/fast ratio closer to 3.
  - Tau slow ~ 1.6 us as expected and no interm. component: this is consistent since we do not simulate it!
- **Next Steps**:
  - Continue optimizing Monte Carlo models to improve data accuracy.
  - Expand the analysis to Run3.

Thank you for your attention!

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