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Development of a New Data Acquisition System for the SUPER Experiment

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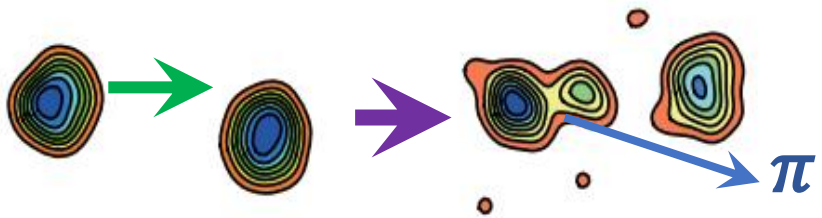
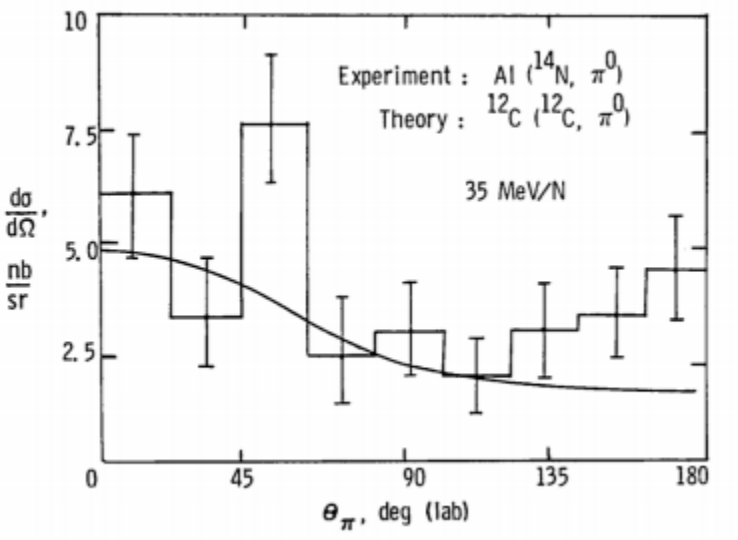
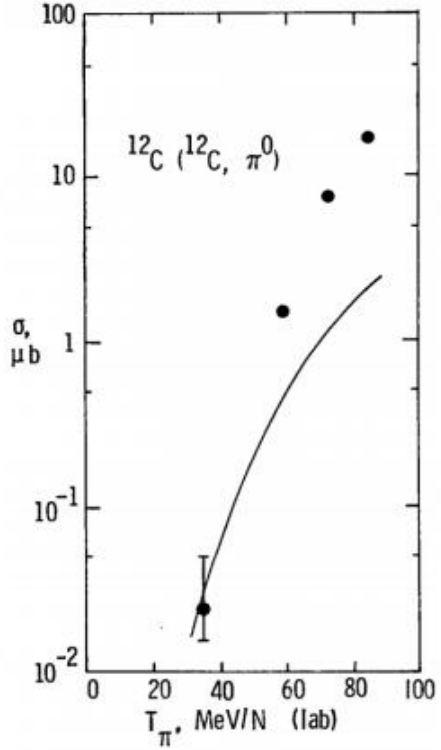
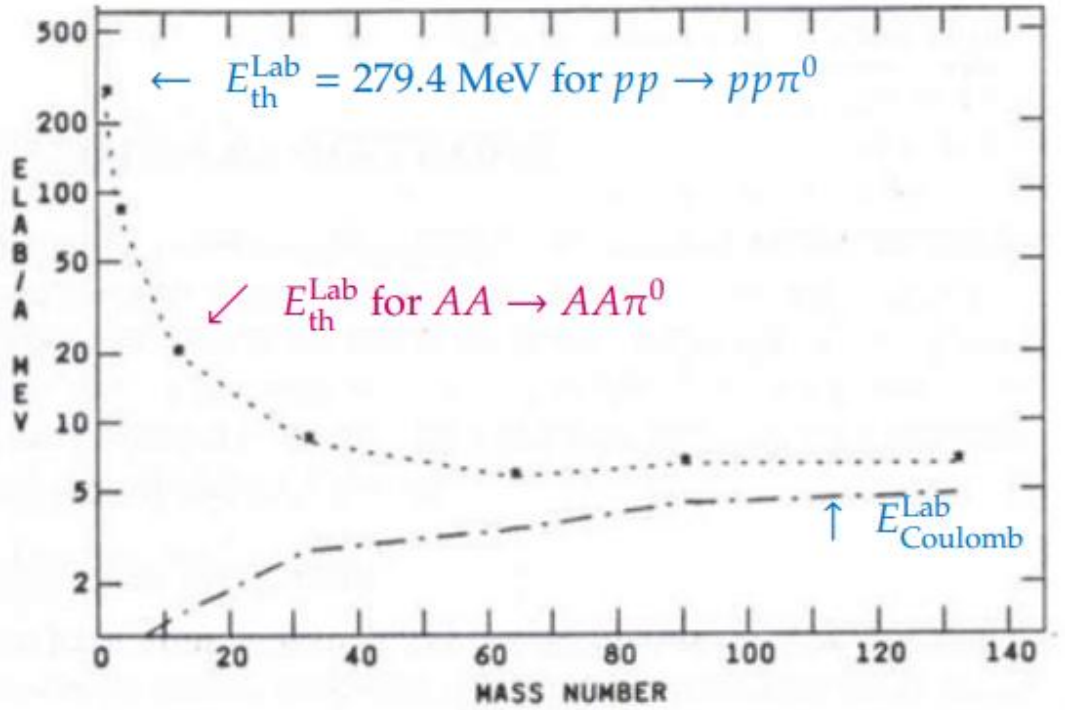
Subthreshold Pion Production Experiment at RAON (SUPER)

- SUPER explores deep subthreshold pion production in heavy-ion collisions in the energy range of 20 to 50 MeV/nucleon.





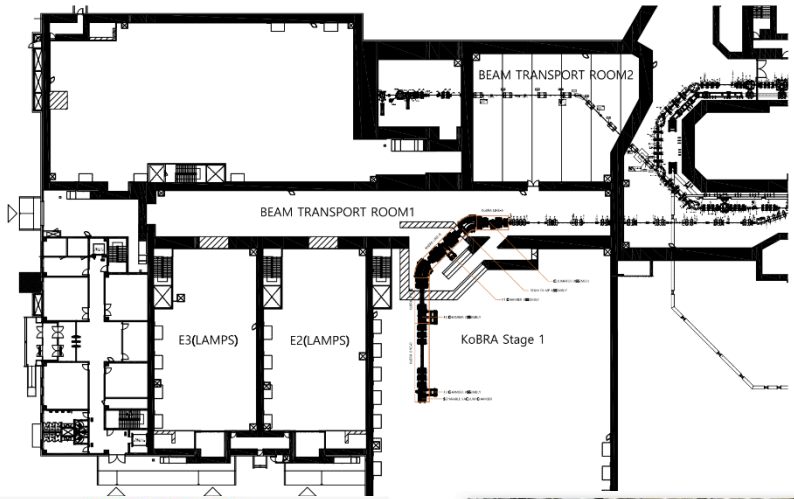


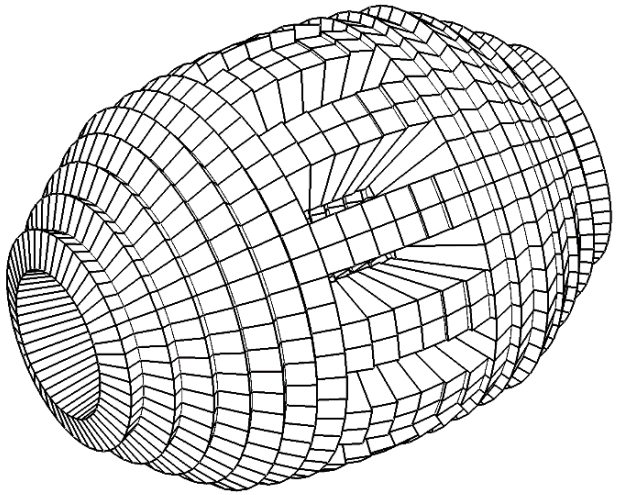


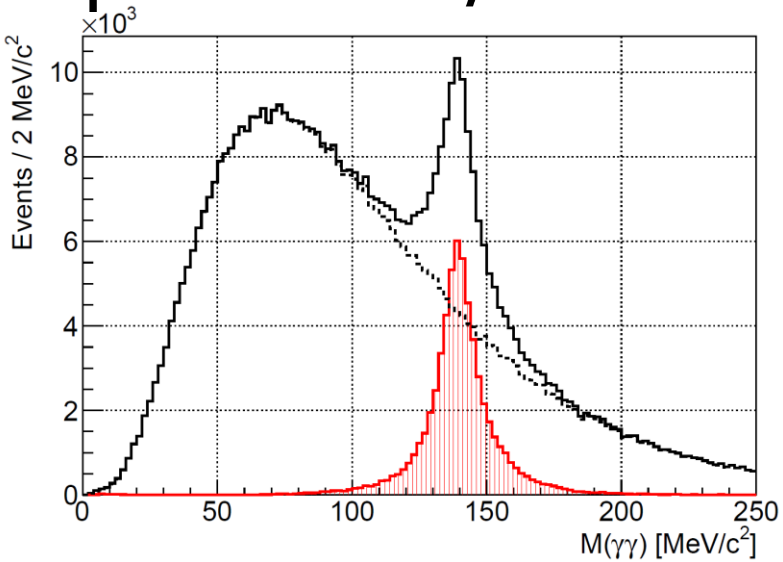
- Nucleon Fermi motion, multi-nucleon cooperative effects
- It requires precise measurement of low-yield π^0 production

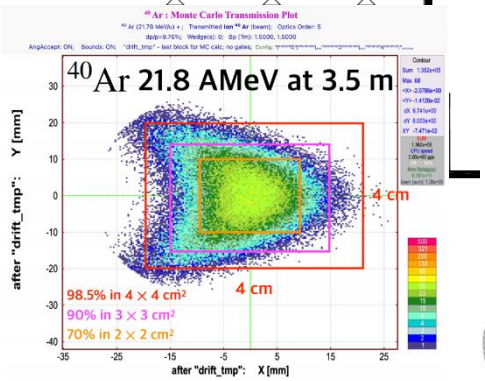
Subthreshold Pion Production Experiment at RAON (SUPER)

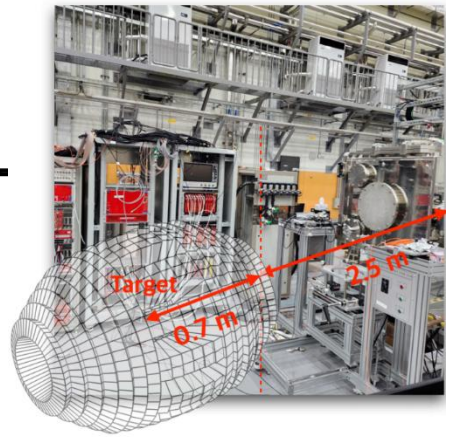
- RAON currently delivers (un)stable ion beams up to 20 MeV/nucleon.











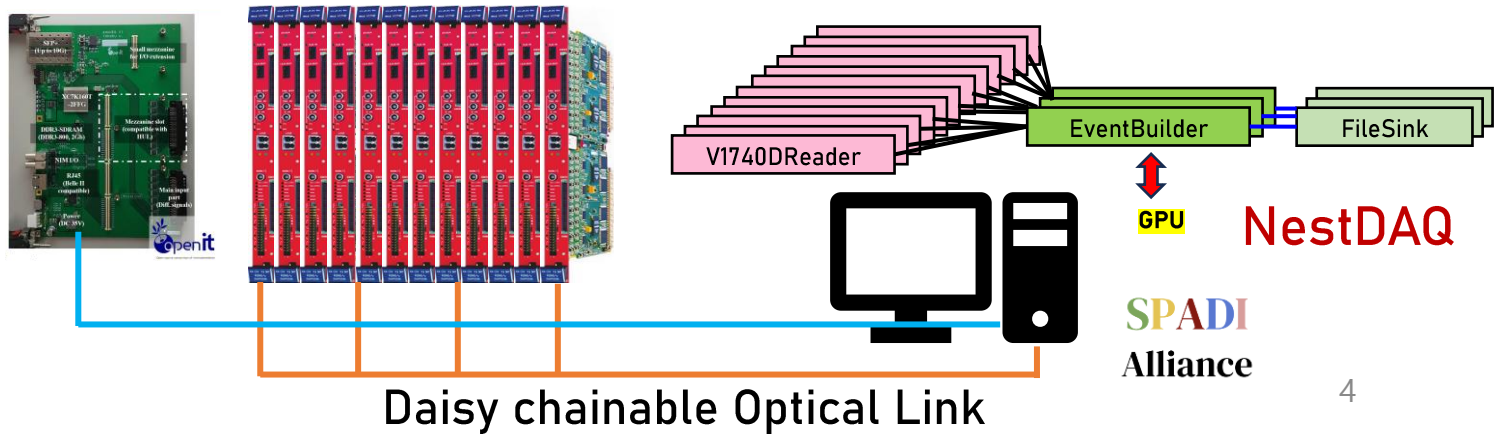
- The SUPER detector consists of 768 CsI(Tl) crystals, covering 75% of 4π
- It is designed to detect photons from $\pi^0 \rightarrow \gamma\gamma$ decays with large acceptance.
- Each crystal is 25 long, corresponding to $13.5X_0$

RAON is Korea's heavy-ion accelerator facility for rare isotope science.

Development of DAQ System for SUPER Experiment

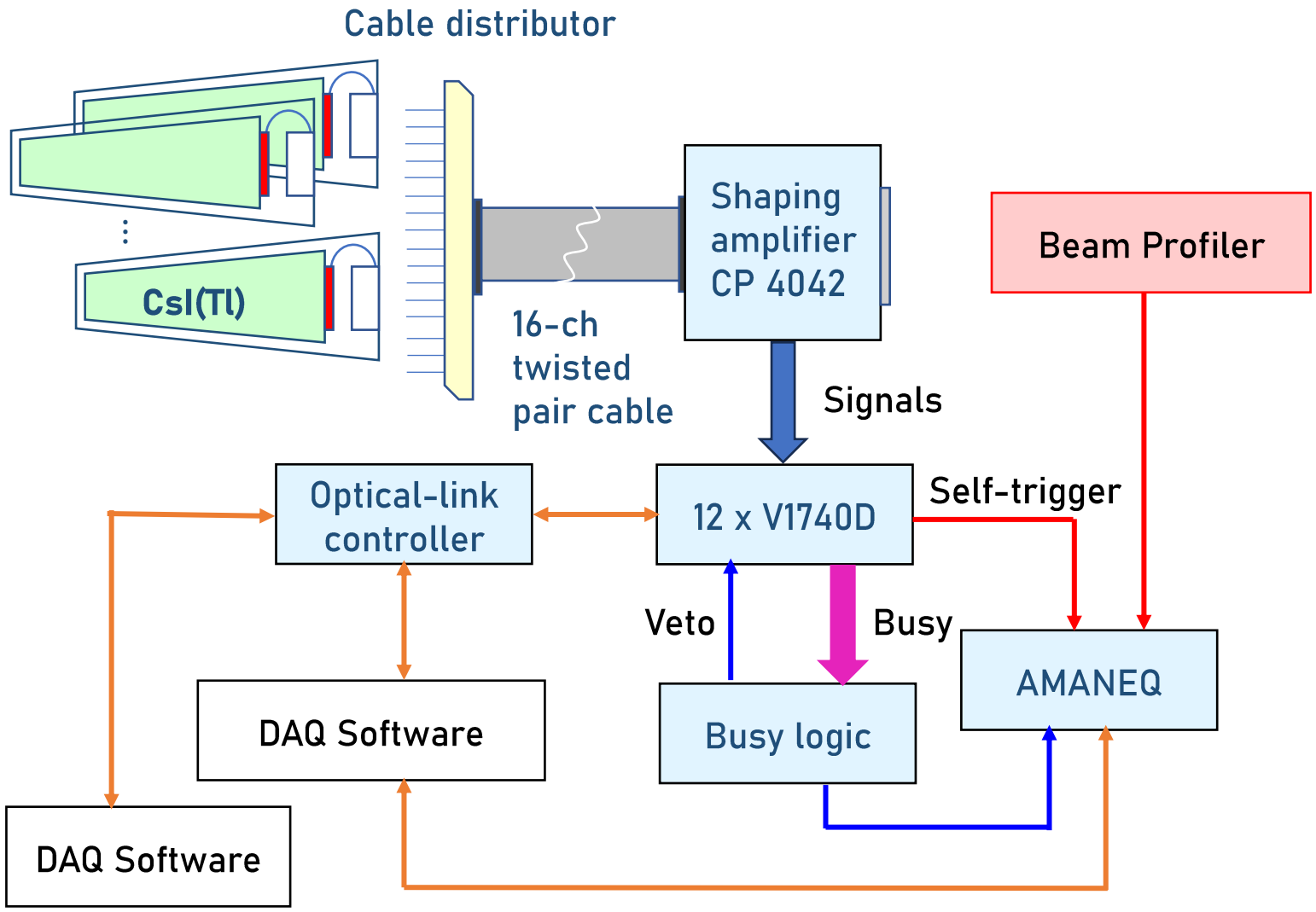
Subthreshold Pion Production Experiment

Experimental need	DAQ requirement
768 CsI(Tl) channels	Scalable multi-channel readout
High photon background/rates	Stable operation at high photon hit rates
Need beam flux and trigger monitoring	Synchronized acquisition of detector and beam monitor
Pileup in CsI waveforms	Waveform digitization
Future experiments at multiple facilities	Flexible, extensible architecture



Development of DAQ System for SUPER Experiment

Subthreshold Pion Production Experiment



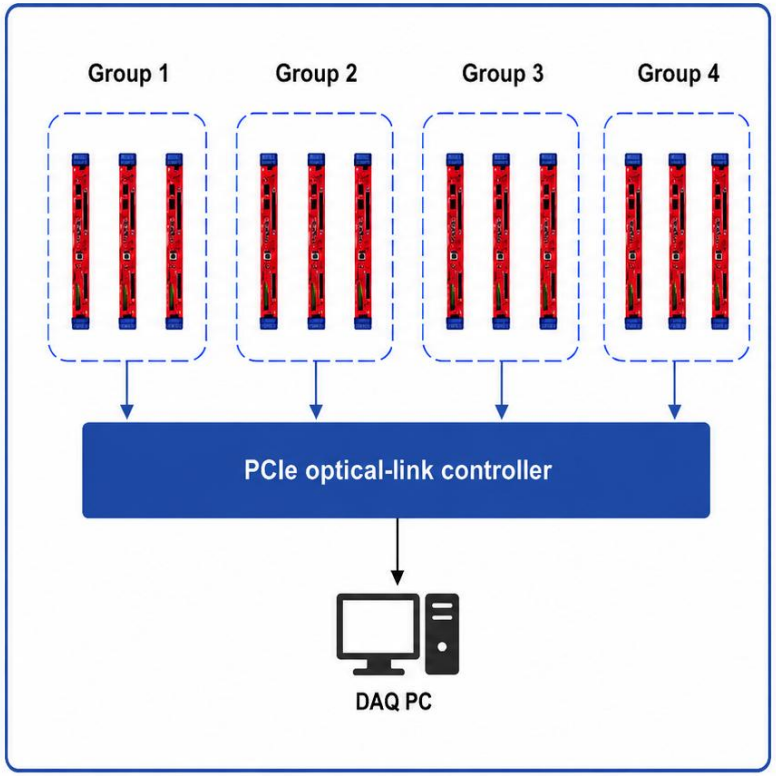
- Waveforms from 768 CsI(Tl) crystals are digitized by 12 V1740D
- Beam-monitor signals are recorded by AMANEQ HR-TDC in streaming mode.
- The CsI waveform data and the beam-related data are recorded in parallel.

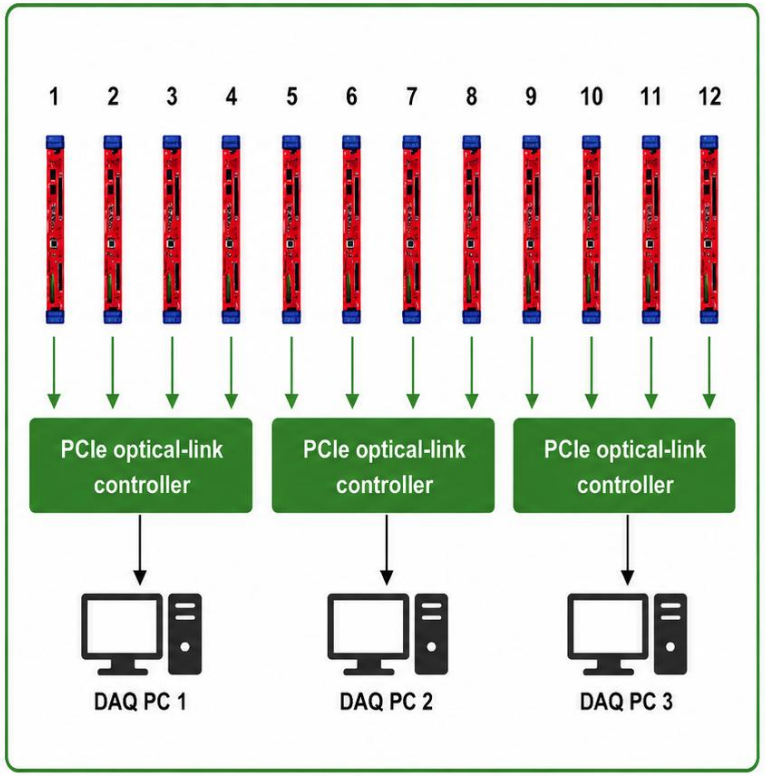
Waveform Digitizer for CsI(Tl) Readout: CAEN V1740D

V1740D Waveform Digitizer

- 64 channels / module
- 12-bit ADC resolution
- 62.5 MS/s sampling rate: 16 ns/sample
- 2 Vpp single-end input range
- Optical-link readout via CONET2 (CAEN's optical readout interface)

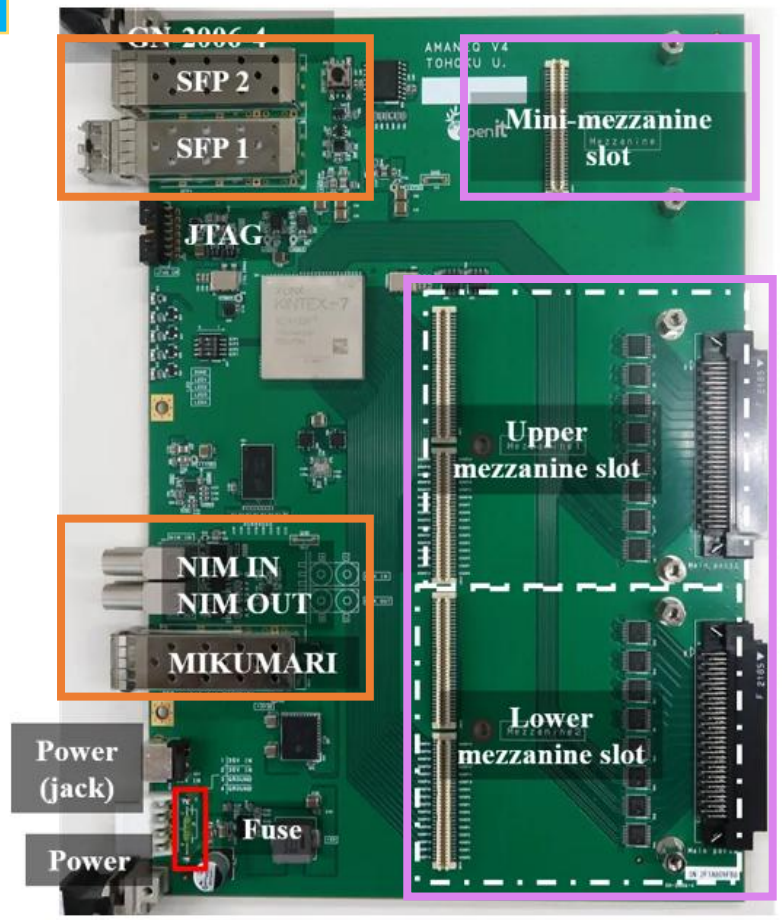
Possible Readout architecture



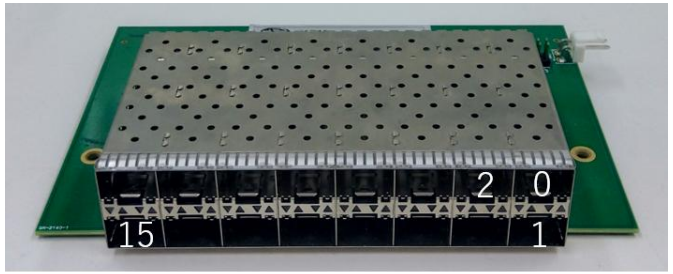


PCIe optical-link controller

AMANEQ HR-TDC Readout for Beam Monitoring



Signal input



Clock-Data-Distributer Optical (CDD-OPT)

32 ch tapped-delay-line (TDL) based HR-TDC

- Input IO std.: LVDS (ECL is not supported)
- Both leading/trailing edges
- Intrinsic resolution: 15 ps (σ)

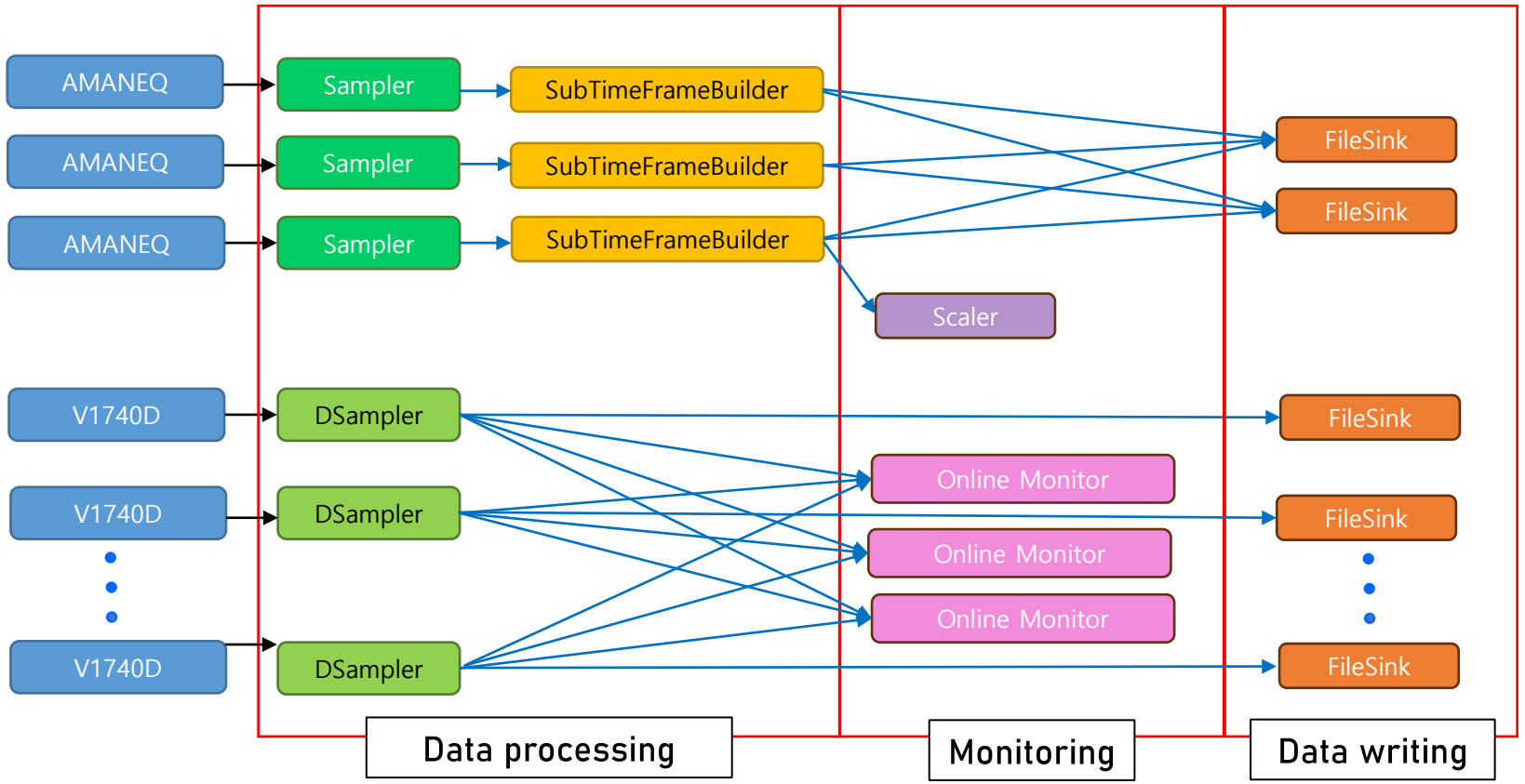
AMANEQ

- High-speed trigger-less DAQ design
- Multiple I/O interfaces on front and rear panels
- 2 Gb DDR3 memory for buffering continuous data streams

Software architecture

Network-based Streaming DAQ

The system can be easily adapted to different experiments and requirements



- NestDAQ enables a network-based streaming DAQ architecture
- FairMQ provides flexible message-based communication among distributed DAQ processes
- Redis manages configuration parameters and run-control information through a key-value database.

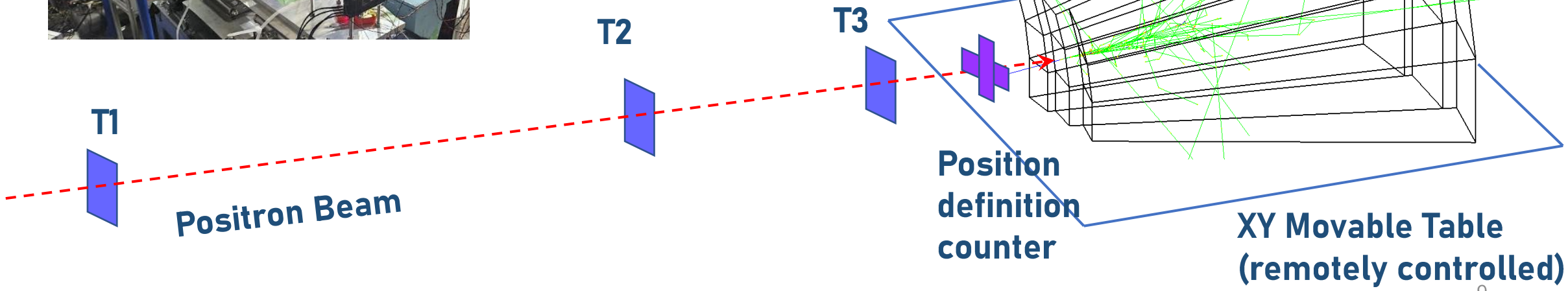
FairRootGroup/
FairMQ
C++ Message Queuing Library and Framework

redis

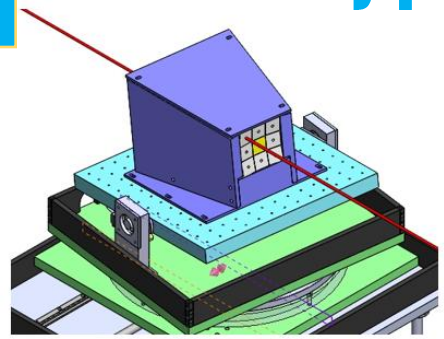
Prototype Beam Commissioning Setup

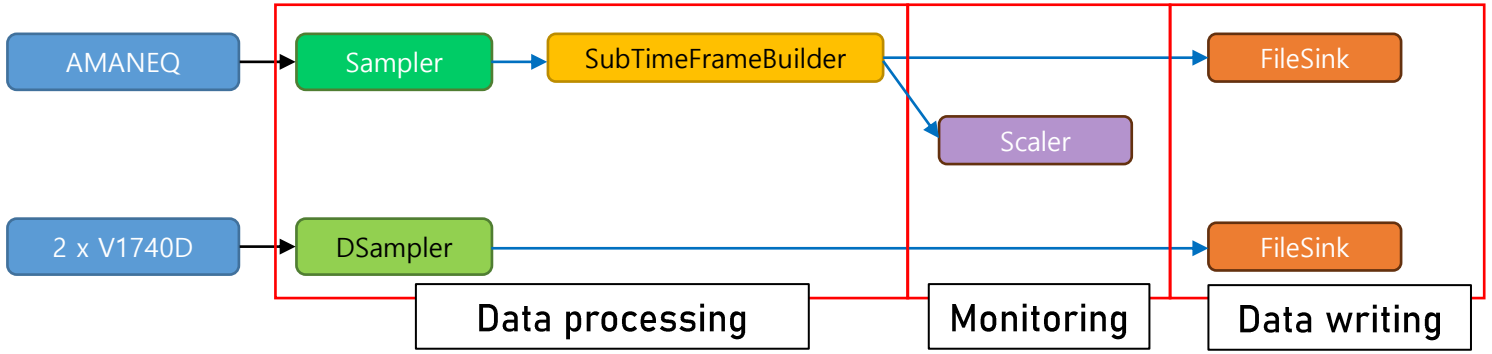
RARIS, Tohoku University

- Positron beams will be exposed to the front face of the 3x3 CsI(Tl) array. Three scintillator trigger counters will define the beam entrance position.



Prototype Beam Commissioning Setup

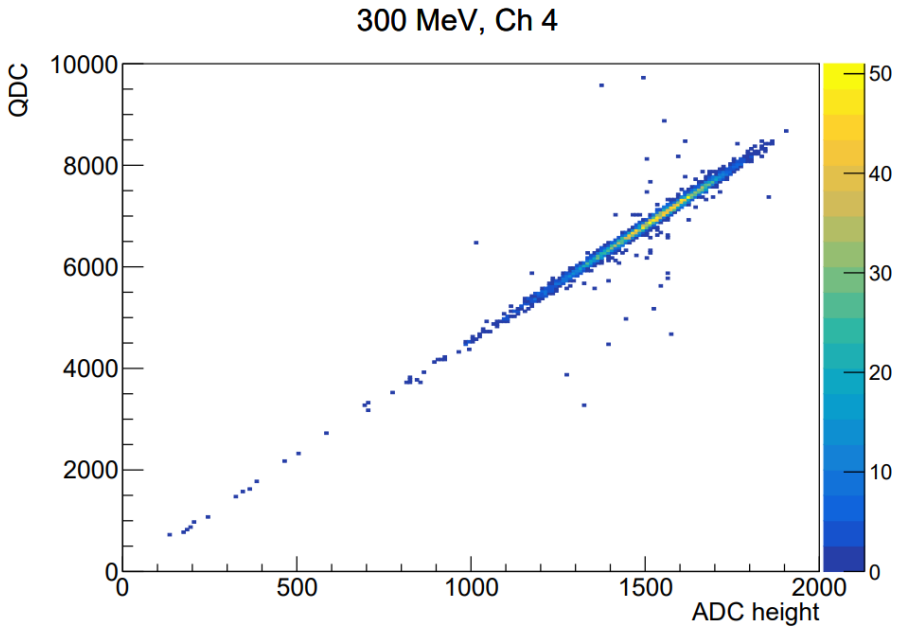


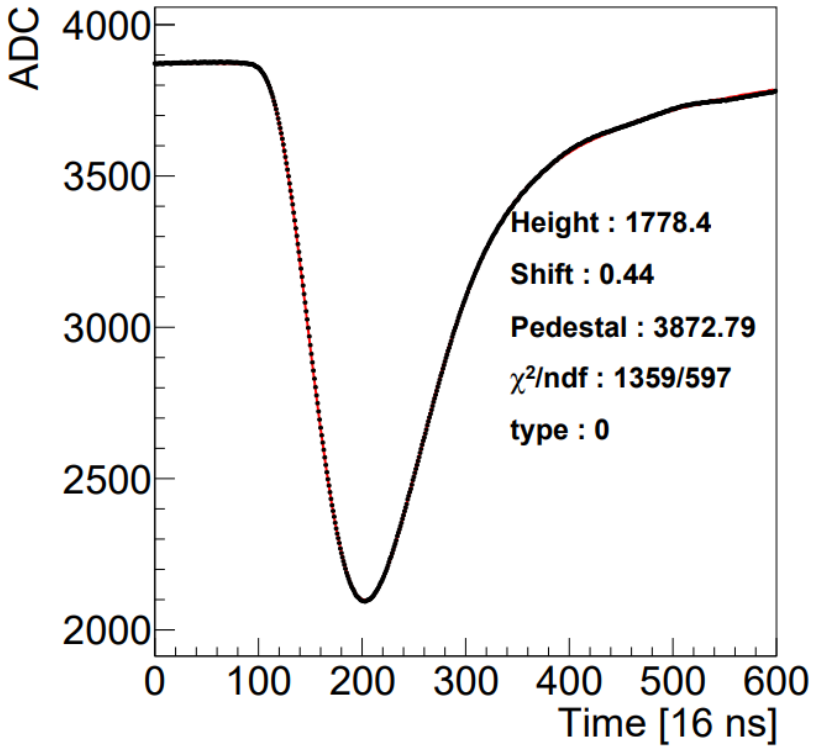


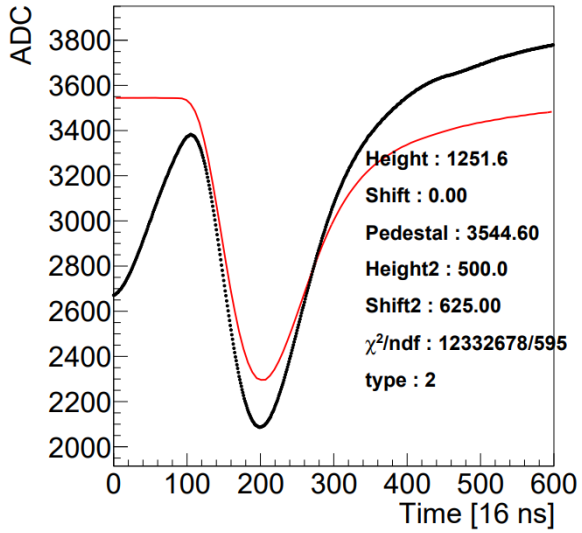
- Waveform from 3x3 CsI(Tl) prototype were recorded by two V1740D digitizers.
- Signals from the beam-defining plastic scintillators were sent to AMANEQ HR-TDC.
- This setup enables a direct comparison between triggered and streaming readout.

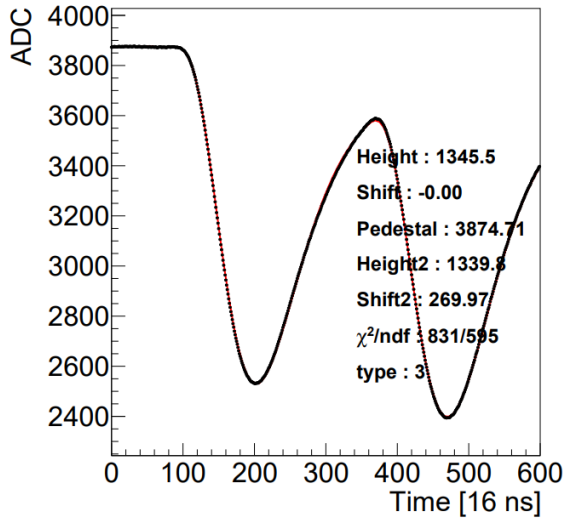
Waveform Readout for Pulse-Shape and Pile-up Analysis

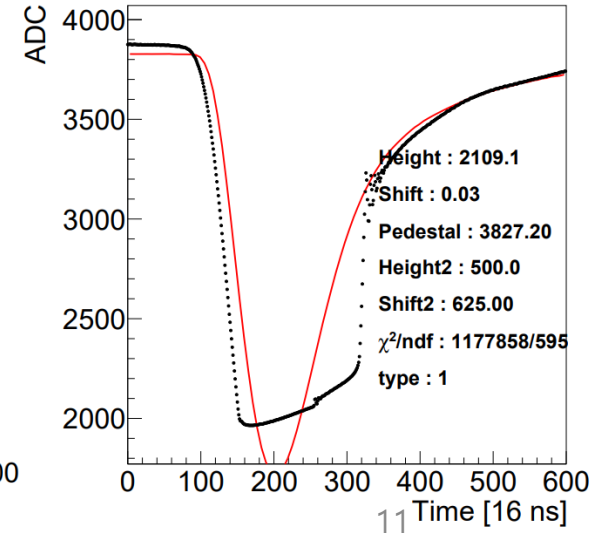
- Waveform digitization enabled pulse-shape/pile-up analysis.
- Pile-up rates are approximately 3% to 5% for 300 MeV and 800 MeV, respectively.





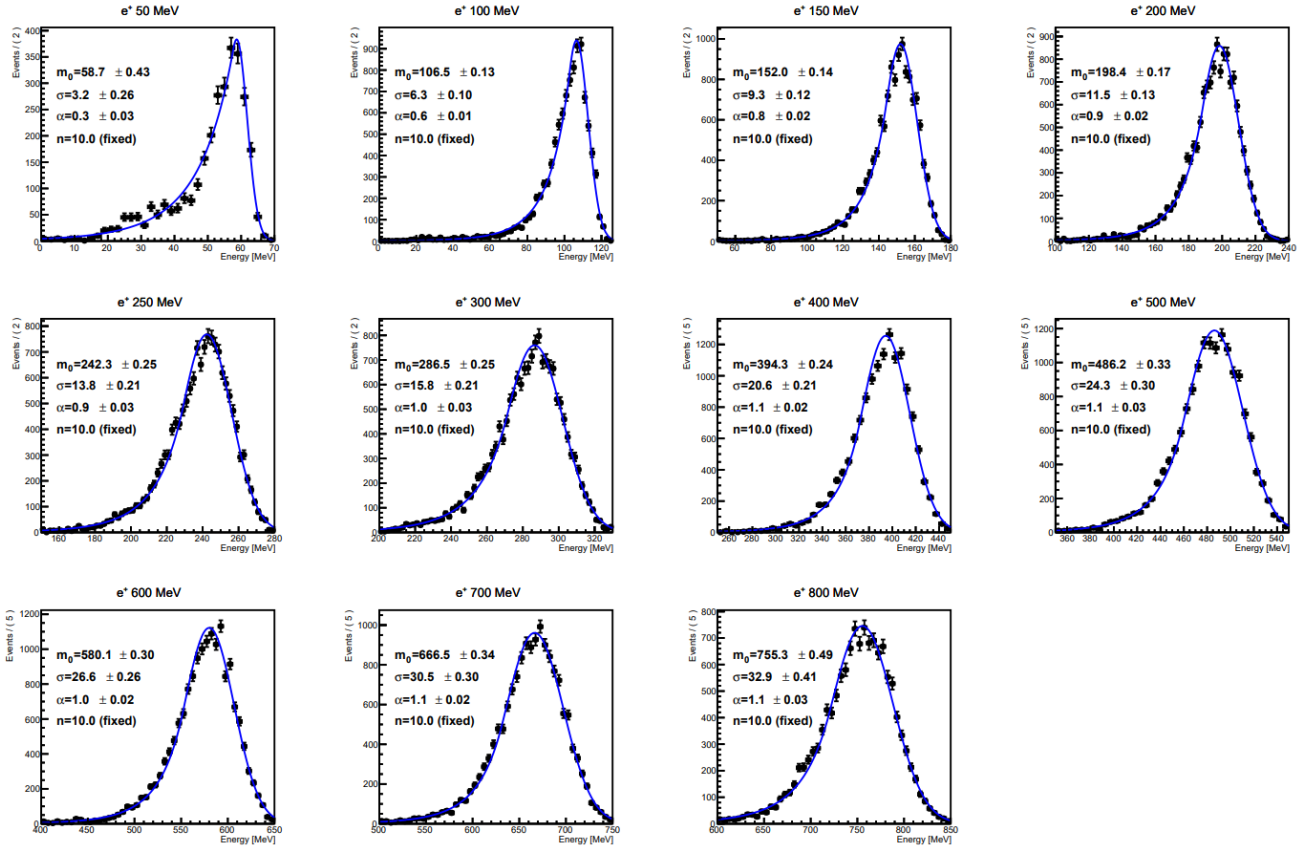


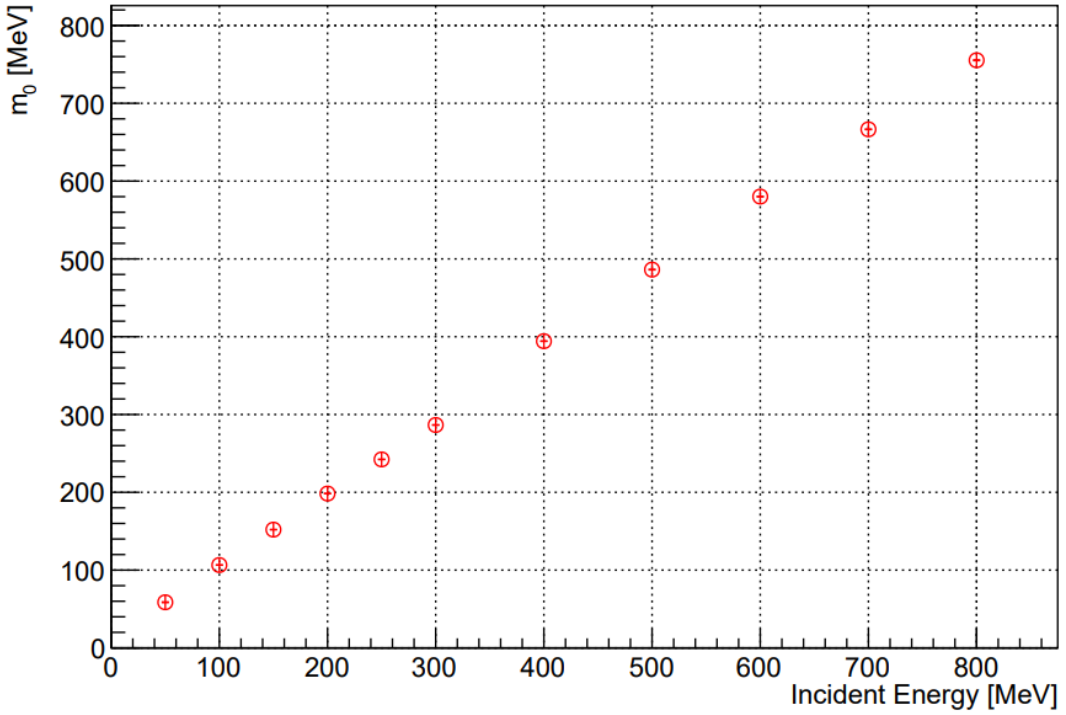




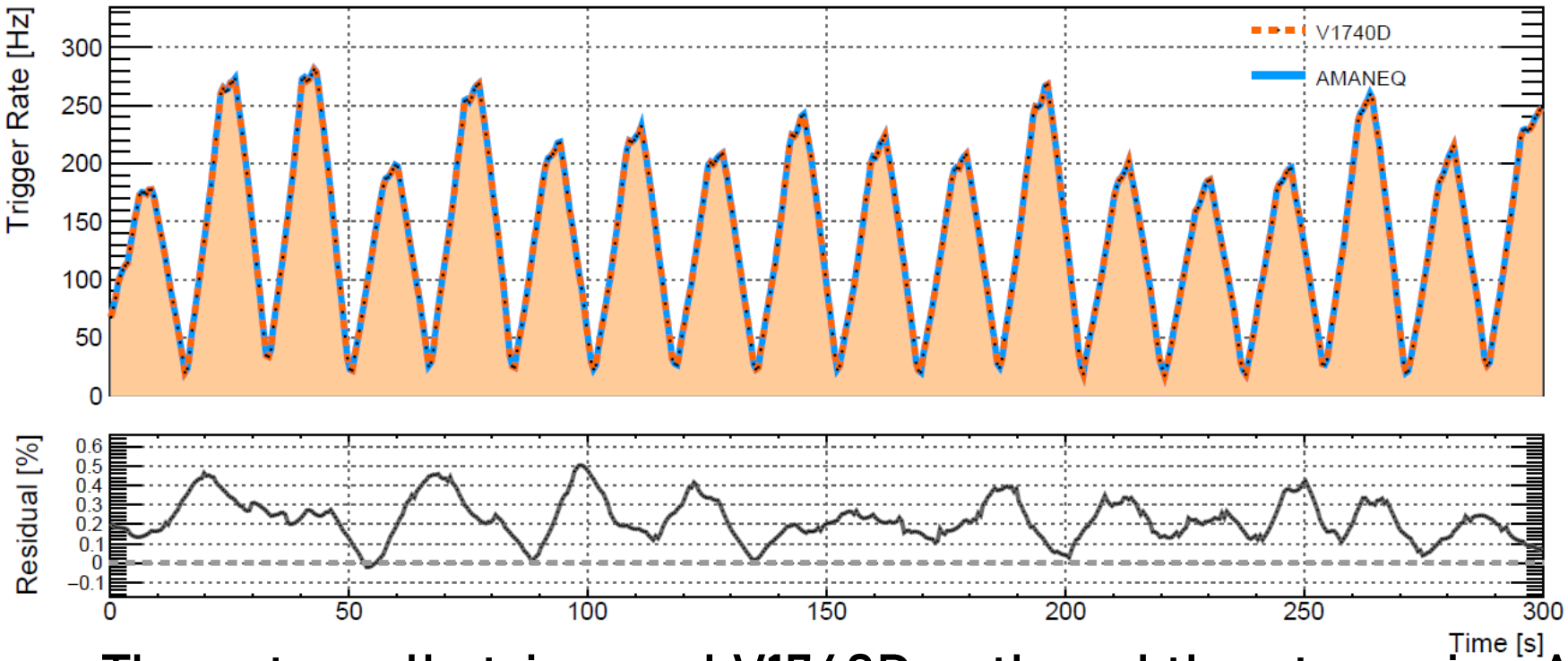
Energy Reconstruction from V1740D Waveform Readout

- Energy spectra were reconstructed from waveforms recorded by the V1740D digitizers.
- Preliminary results show an energy resolution of about 6% to 4% for the 3x3 CsI(Tl) array over 50-800 MeV.





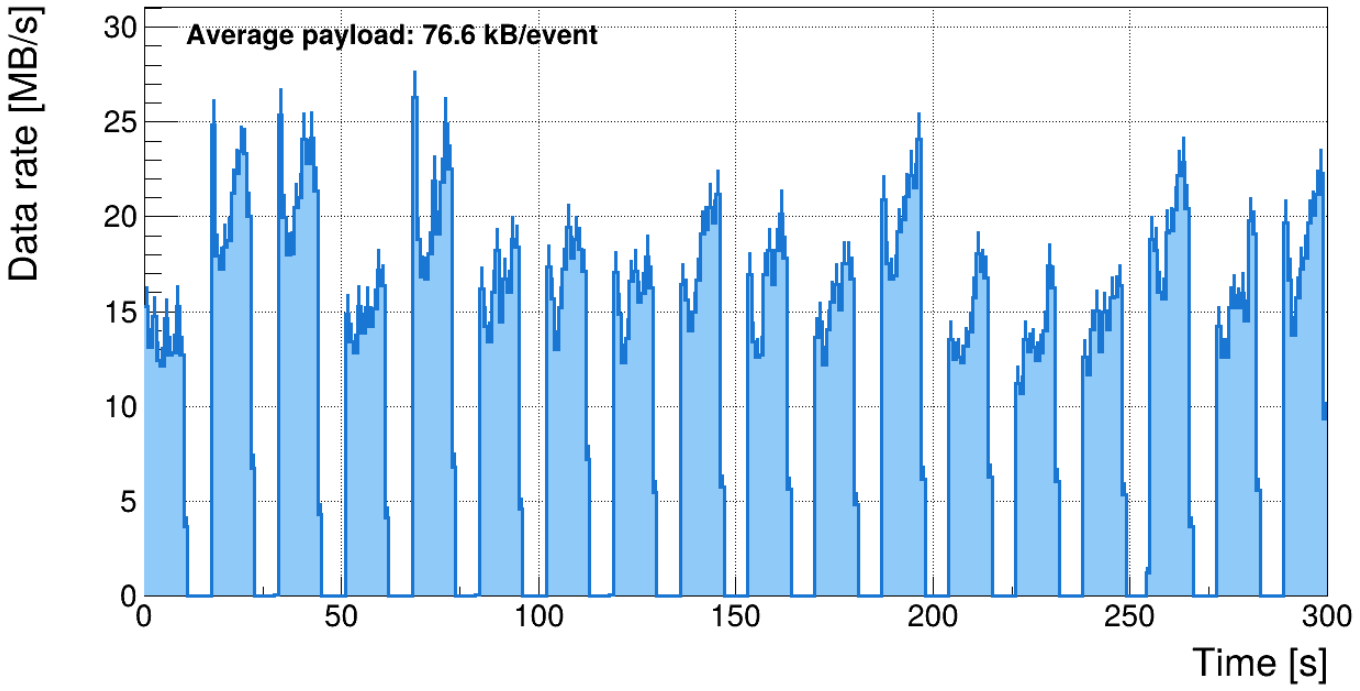
Beam-Rate Consistency between Dual Readout Paths



$$\text{Residual [\%]} = \frac{AMANEQ - \text{V1740D}}{\text{V1740D}} \times 100$$

- The externally triggered V1740D path and the streaming AMANEQ path reproduced the same beam-rate structure.
- The rate difference remained within 0.5% over the beam-test period.
- This beam test validated the consistency of the two readout paths in the prototype DAQ.
- Higher-rate operation will be evaluated toward the full SUPER experiment.

Digitizer Throughput and Scaling toward SUPER



- Measured payload: 76.6 kB/event for the 32-channel prototype readout, full 600-sample waveforms were stored for all active channels, although 9 channels carried detector signal.
- Peak beam-test throughput is approximately 25 MB/s.
- Toward SUPER, efficient waveform acquisition is essential for precision π^0 measurements with manageable data volume.

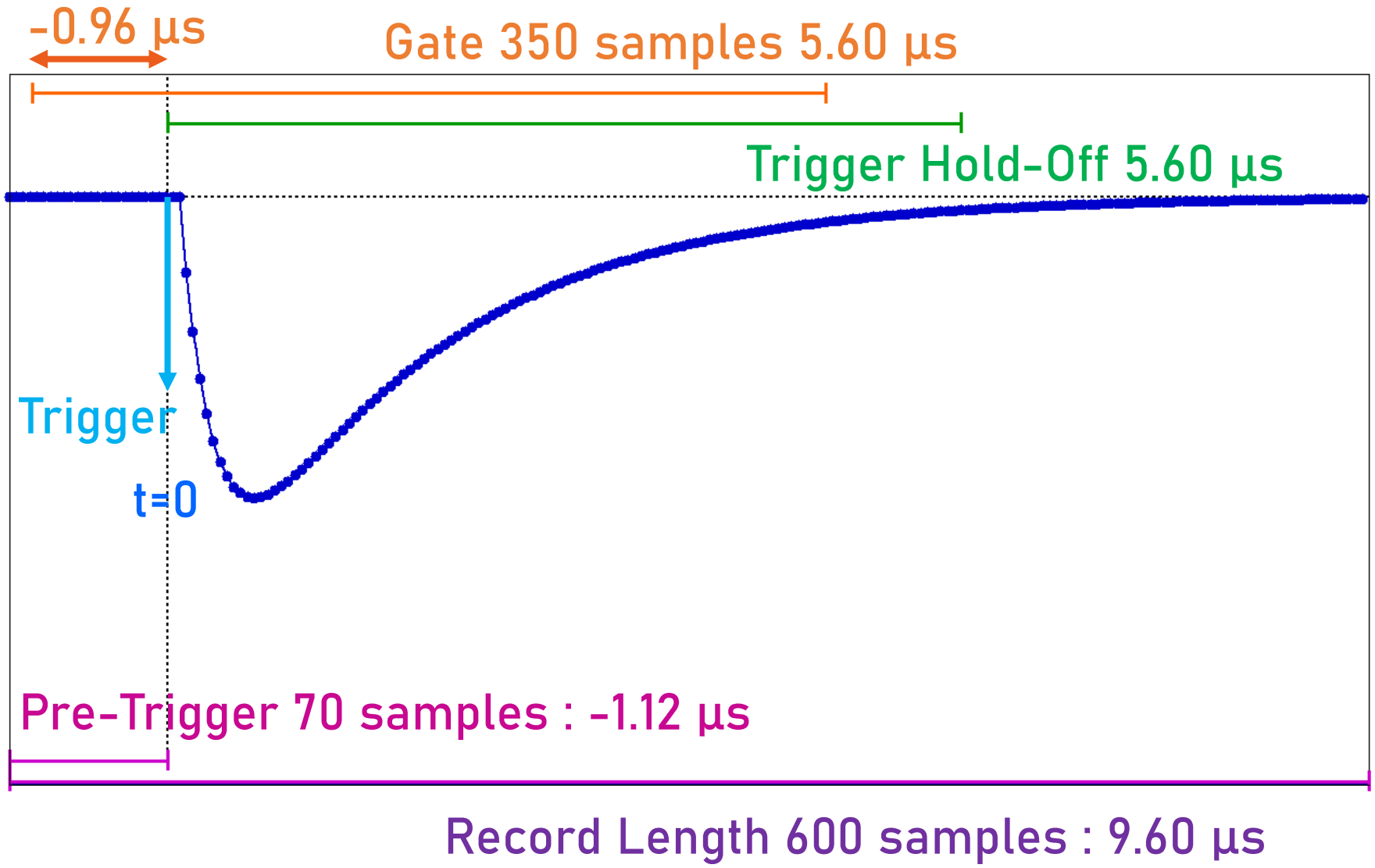
- High-rate DAQ operation (~50 kHz) and data-reduction strategies will be tested at RCNP using self-triggered signal readout, optimized waveform recording, and distributed data collection

Beam Structure Monitoring with Dual Readout Paths

- A new DAQ system is being developed for the SUPER experiment combining self-triggered waveform readout for the CsI(Tl) calorimeter and streaming time-stamped readout for beam signals and module-level self-trigger signals.
- A prototype beam test was performed with a 3x3 CsI(Tl) array at RARIS.
- The beam test verified the consistency between externally triggered V1740D readout and AMANEQ streaming monitoring, reproducing the same beam-rate structure within 0.5%
- These results provide the first experimental validation of the DAQ concept for SUPER. The next step is to implement and evaluate the full-scale DAQ for the 768-channel detector.

Backup

Digitizer Settings for the RARIS Beam Test

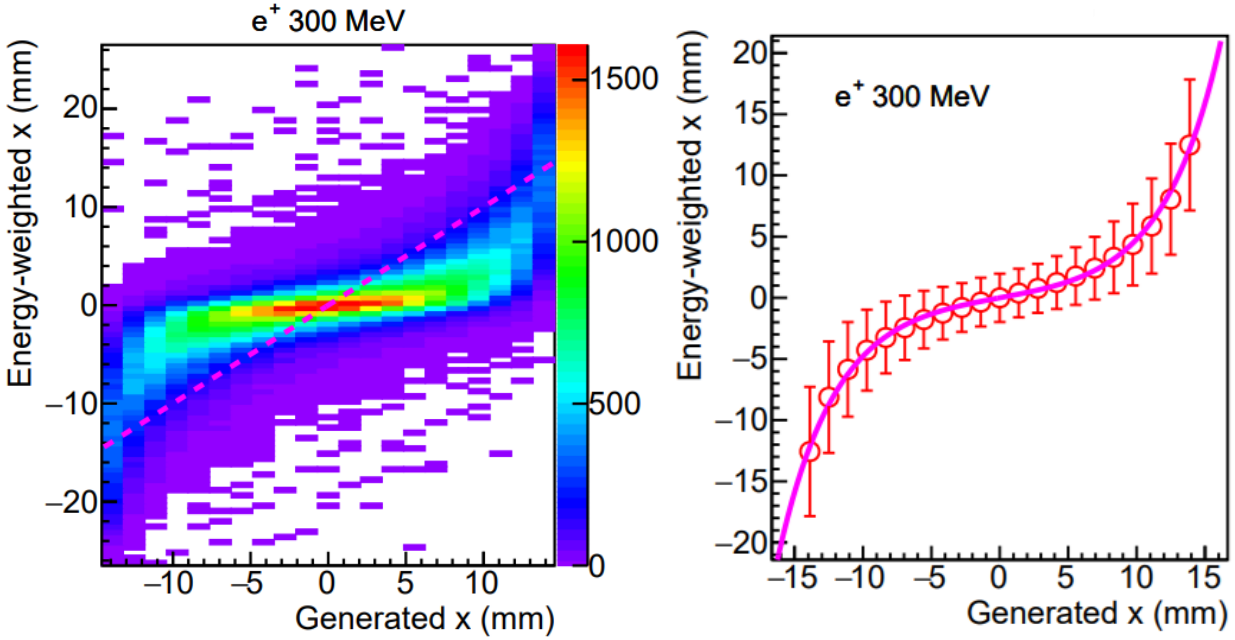


The V1740D was operated with an external beam trigger, recorded both waveform and charge information.

This setting provided waveform data for pulse-shape, pile-up and energy-reconstruction studies.

Position Reconstruction from Digitized Waveforms

- The digitized waveform data also enabled position reconstruction of the prototype response.
- The reconstructed position dependence was consistent with the detector-response expectation.



Geant4 simulation on the CsI(Tl) array response to positrons in the momentum range from 50 to 300 MeV/c.