Performance Test of the SAMIDARE Board with Mini-TPC using heavy-Ion Beams

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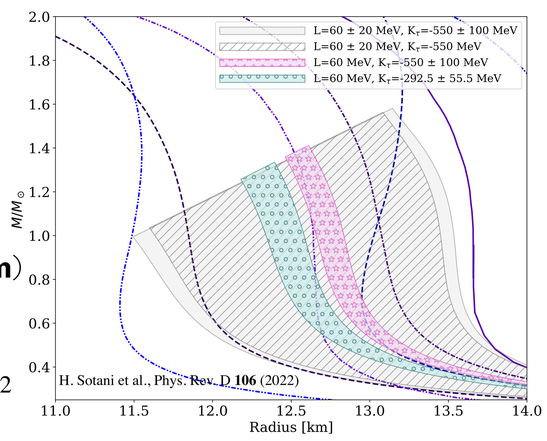
1. Physics Case

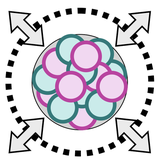
Nuclear Matter Equation of State

$$\mathscr{E}(\rho,\alpha) = \epsilon_0 + J\alpha^2 + \frac{1}{2}\left[K_0^\infty + K_\tau^\infty \alpha^2\right]\bar{x}_0^2 \cdots$$

Incompressibility (Isospin dependent term)



Isoscalar Giant Monopole Resonance

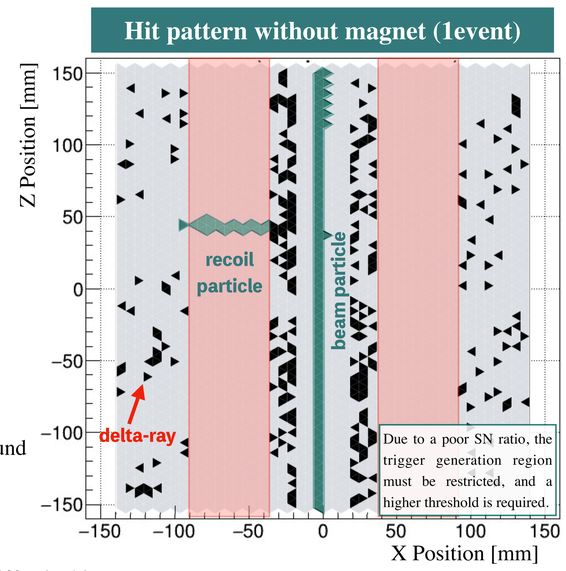


$$E_{\mathrm{ISGMR}} = \hbar\left(K_{\mathrm{A}}/m\langle r^2\rangle\right)^{1/2}$$

$$K_{\mathrm{A}} - K_C Z^2 \mathrm{A}^{-4/3} = K_0\left(1 + cA^{-1/3}\right) + K_\tau\left(\frac{N-Z}{A}\right)^2$$

2. Motivation

- Time Projection Chambers (TPCs) measure multi-particle trajectories.
- TPCs require waveform readout for tracking and particle identification.
- General Electronics for TPCs (GET) system has been widely used as a standard TPC DAQ system.



Current Problem

- Common threshold for **zero suppression** and **trigger**
  - δ-rays come from heavy-ion beams cause serious background
- DAQ efficiency: ~60%
- Discontinuation of the AGET chip
  - It makes future development and long-term maintenance difficult chip
- Many TPC projects in Japan share a common concern about the future of TPC DAQ systems

Detector	Channel	Sampling rate	Particles	Energy
CAT	4200	12.5 MHz	p, d, He, Sn…	0.1~20MeV, 100 MeV/u
Maiko	1700	12.5 MHz	He	0.1~5 MeV
E16 & E88	14000	20 MHz	K, p, π, e	0.1~10 GeV
TRIP TPC	3200	10 or 20 MHz	He, Sn…	0.1~20MeV, 100 MeV/u
Hyp TPC	5800	12.5 MHz	K, Λ, p, π	0.1~10 GeV
SRiRIT	12000	25 MHz	p, d, He	~100 MeV
LEPS2	10000	45 MHz		
Korea	1000	20 MHz	He	10 MeV

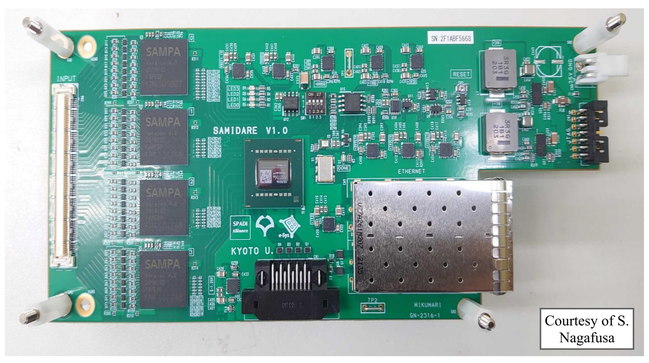
GET DAQ is becoming difficult to develop and maintain; new waveform-readout system is needed.

3. SPADI Alliance and SAMIDARE

- Common need for a standard, scalable, and streaming DAQ platform has emerged in Japanese communities.
- SPADI Alliance was launched as a collaborative development community by researchers sharing this motivation.
- SAMIDARE is one of the waveform digitizer developments within SPADI, targeting streaming readout for TPC.

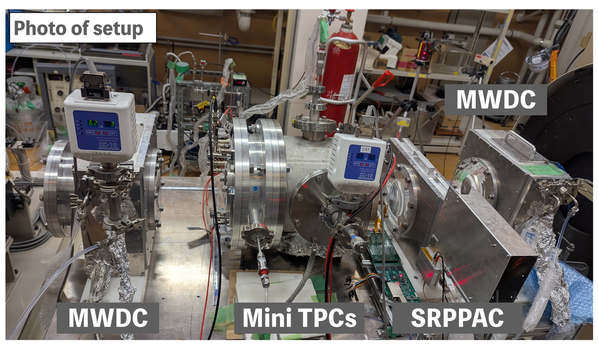
SAMpa based high Integrated DAta REadout (SAMIDARE)

- Input channels: 128 ch
- ASIC: SAMPA_v4 (32 ch / chip)
  - ADC Resolution: 10-bit
  - Sampling rate: 5 / 10 / 20 MHz
  - Acquisition mode: DAS / DSP
  - Serial link clock: 80 / 160 / 320 MHz
- Network interface: SFP+ port x2
- FPGA: Artix UltraScale+



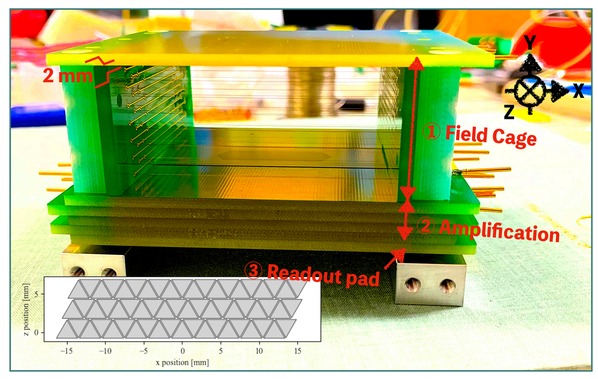
4. Experimental Setup (heavy ion beam test)

- Verify SAMIDARE prototype operation with Mini-TPCs under heavy-ion beam irradiation
- Evaluate timestamp-based data integration between SAMIDARE and an independent reference DAQ system
- Facility: HIMAC (Synchrotron)
- Beam information:
  - ^{132}Xe @ 200 MeV/u,
  - Average beam intensity: < 1 kHz
- 2 Mini-TPCs read out by SAMIDARE
  - Hydrogen gas @ 40kPa
  - 60 readout pad / TPC
- 2 MWDCs + 1 SRPPAC read out by Other DAQ system



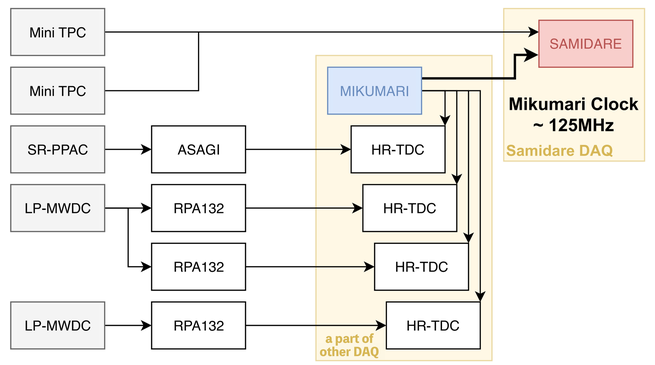
Mini TPC

- Field cage: 70 x 30 x 60 mm³
- Active volume: 30 x 30 x 10 mm³ (x, y, z)
- Drift region: 13 electrodes/side & 20 wires/ side
- Amplification region:
  - THGEM hole / pitch / thickness → ϕ200, 300, 400μm
  - Stack THGEM using PCB spacer
- Readout pad : Equilateral triangle @ 3mm x 60



5. DAQ Concept

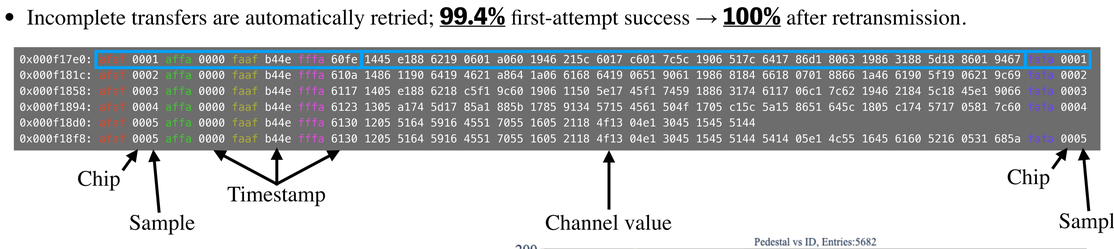
- Clock synchronization is provided by the clock distribution module (MIKUMARI) for the DAQ system used with the reference detector.
- SAMIDARE independently counts the MIKUMARI clock and embeds the counter value as a timestamp, providing a timing bridge to the reference DAQ.
- SAMIDARE setting:
  - Samples: 64 samples (16 pre-sample)
  - Conversion gain: 4 mV/fC
  - Shaping time: 300 ns



6. Result

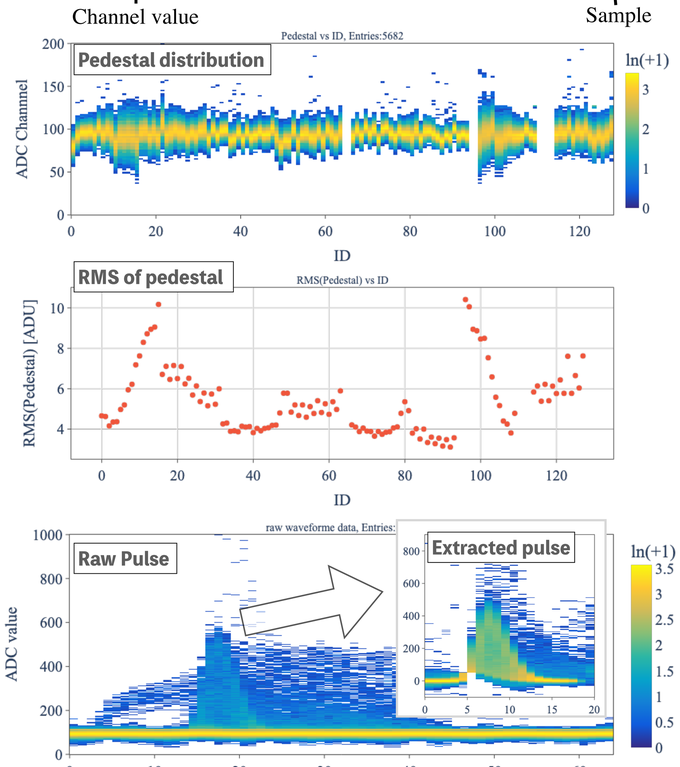
Raw data format

- Consists of a 128-bit header, 320-bit channel data, and a 32-bit footer (Total 60 Byte/Sample).
- Header information identifies the SAMPA chip, sampling number, and timestamp.
- Incomplete transfers are automatically retried; **99.4%** first-attempt success → **100%** after retransmission.



Pedestal and baseline RMS

- Upper panel shows the pedestal distribution for each channel ID.
- Lower panel shows the RMS of the pedestal distribution for each channel ID.
- Channel ID: Chip No. × 32 + Channel No.
- Pedestal levels around **80-120 ADC channels**.
- Typical baseline RMS **4–10 ADC units.**
  - Consist with H. Hernández et al.,
  - RMS ~ 5 (Baseline - ADCounts).

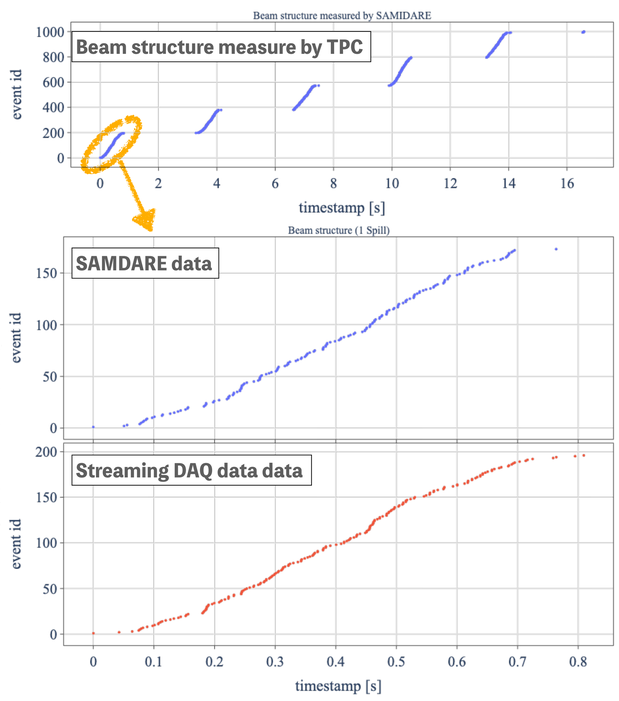


Waveform analysis

- Baseline subtraction:
  - Calculate from first 10 samples
- Pulse finding:
  - Rising/falling threshold: 50 ADC counts
  - Pre-sample / post sample: 5 / 8 samples

Timing correlation

- Top panel shows the beam structure measured by Mini TPC (SAMIDARE)
- Beam structure was built by grouping waveform hits within a time window of $\Delta t = \pm 3$ μs from first incoming pulse.
- Spill structure **consistent with** beam setting
  - 3.3-s synchrotron operation cycle.
  - beam intensity: < 1 kHz.
- Middle and bottom panels show examples of beam structures within one spill, measured by the Mini-TPC and by the SRPPAC anode with an independent streaming DAQ, respectively.
- Beam structures show **overall consistency** between the SAMIDARE data and another independent streaming DAQ data.



7. Future / outlook

- Timing-resolution and position-resolution analysis.
- MIKUMARI protocol implementation for clock synchronization.
- DSP-mode implementation and 10GbE data transportation for streaming data processing.