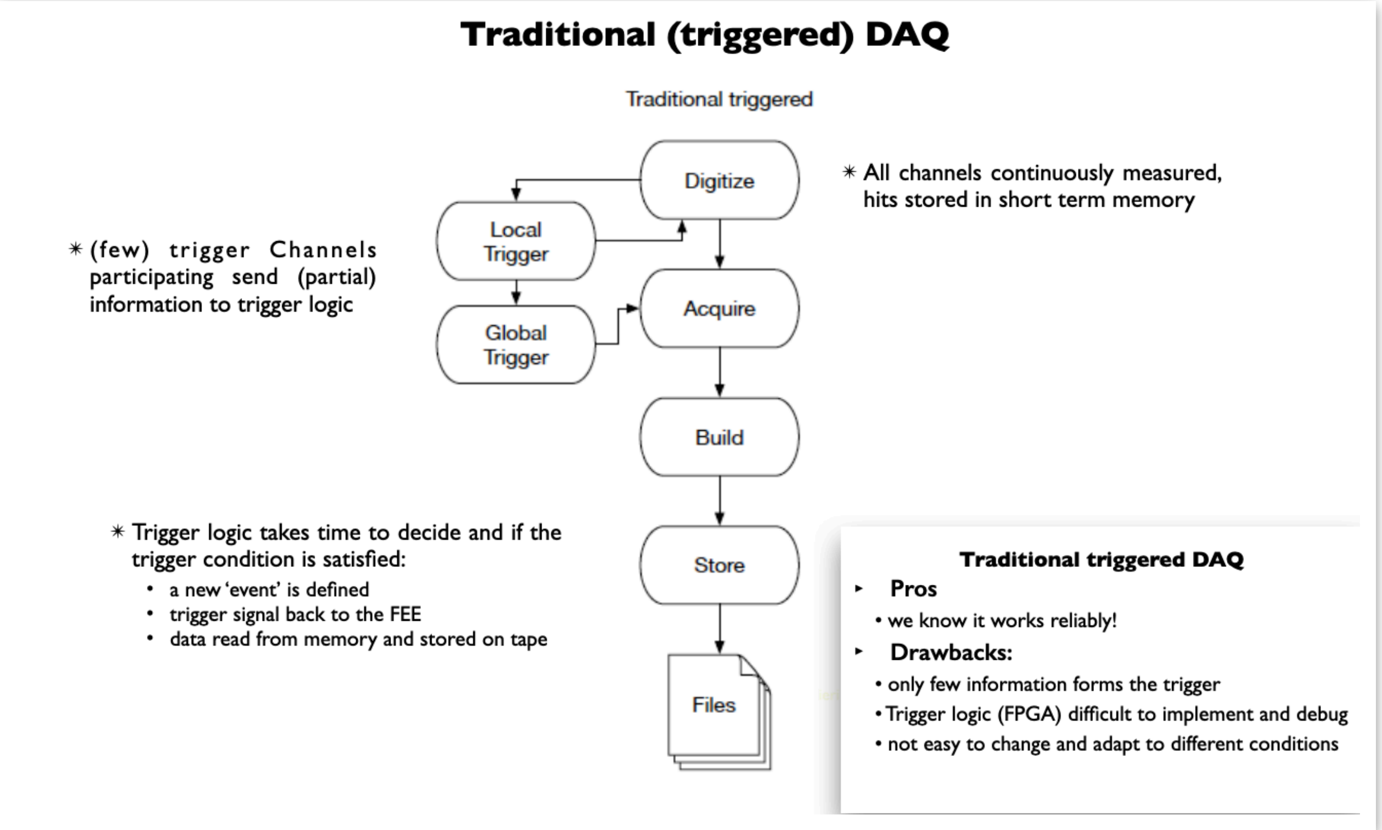
Streaming Readout tests @ JLAB

Mariangela Bondì
INFN - Sezione di Catania

M.Battaglieri - JLAB

Streaming Readout Workshop SRO-XI

Streaming readout VS triggered DAQ



Traditional (triggered) DAQ

✳ All channels continuously measured, hits stored in short term memory

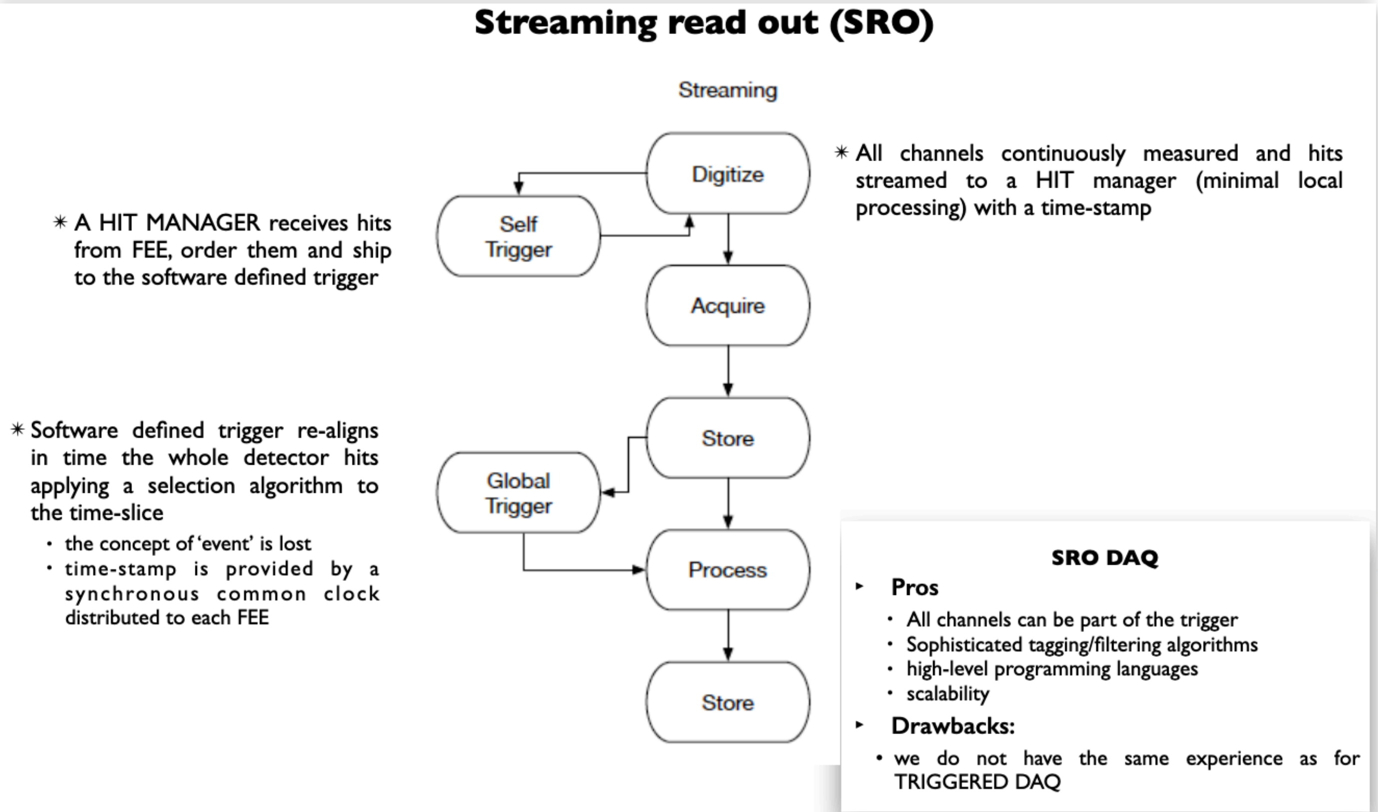
✳ (few) trigger Channels participating send (partial) information to trigger logic

✳ Trigger logic takes time to decide and if the trigger condition is satisfied:

- a new 'event' is defined
- trigger signal back to the FEE
- data read from memory and stored on tape

Traditional triggered DAQ

- **Pros**
  - we know it works reliably!
- **Drawbacks:**
  - only few information forms the trigger
  - Trigger logic (FPGA) difficult to implement and debug
  - not easy to change and adapt to different conditions



Streaming read out (SRO)

✳ All channels continuously measured and hits streamed to a HIT manager (minimal local processing) with a time-stamp

✳ A HIT MANAGER receives hits from FEE, order them and ship to the software defined trigger

✳ Software defined trigger re-aligns in time the whole detector hits applying a selection algorithm to the time-slice

- the concept of 'event' is lost
- time-stamp is provided by a synchronous common clock distributed to each FEE

SRO DAQ

- **Pros**
  - All channels can be part of the trigger
  - Sophisticated tagging/filtering algorithms
  - high-level programming languages
  - scalability
- **Drawbacks:**
  - we do not have the same experience as for TRIGGERED DAQ

Why SRO is so important?

SRO is a must if we want to fully unlock the scientific potential of experiments

✳ **High luminosity experiments**

- Current experiments are limited in DAQ bandwidth
- Reduce stored data size in a smart way (reducing time for off-line processing)

✳ **Shifting data tagging/filtering from the front-end (hw) to the back-end (sw)**

- Optimize real-time rare/exclusive channels selection
- Use of high level programming languages
- Use of existing/ad-hoc CPU/GPU farms
- Use of available AI/ML tools
- (future) use of quantum-computing

✳ **Scaling**

- Easier to add new detectors in the DAQ pipeline
- Easier to scale
- Easier to upgrade

Many NP and HEP experiments adopt the SRO scheme (with different solutions):

- CERN: LHCb, ALICE, AMBER
- FAIR: CBM
- DESY: TPEX
- BNL: sPHENIX, STAR
- JLAB: SOLID, BDX, CLAS12, …

SRO advantages are evident but it needs to be demonstrated by the use in real experimental conditions

Testing SRO @ JLAB

- 2020-21 test **results published** on Eur. Phys. J. Plus (2022)137:958 https://doi.org/10.1140/epjp/s13360-022-03146-z)
  - Setups:
    - On-beam test in HALL B @ JLAB: CLAS12 Forward tagger
  - Goals:
    - SRO framework assembling
    - Physics channel identification: pi0 production

- New tests in spring 2023 **to test the SRO framework using a 3x3 and a 5x5 SciGlass EIC-EM**
  - Setups:
    - Cosmic rays (Hall-B): commissioning of SRO DAQ
    - EM shower (Hall-D): EM shower in SciGlass
  - Goals:
    - Real-time AI-supported algorithms (clustering, calibration, …)
    - Data collected in ‘dump-’, ‘tagging-’ and ’filtering-’ mode
    - JLab SRO system performance profiling

Eur. Phys. J. Plus (2022) 137:958
https://doi.org/10.1140/epjp/s13360-022-03146-z

THE EUROPEAN
PHYSICAL JOURNAL PLUS

Regular Article

Check for updates

Streaming readout for next generation electron scattering experiments

Fabrizio Ameli[1], Marco Battaglieri[2,3], Vladimir V. Berdnikov[4], Mariangela Bondi[3,a], Sergey Boyarinov[2], Nathan Brei[2], Andrea Celentano[3], Laura Cappelli[5], Tommaso Chiarusi[6], Raffaella De Vita[3], Cristiano Fanelli[7,8], Vardan Gyurjyan[2], David Lawrence[2], Patrick Moran[7], Paolo Musico[3], Carmelo Pellegrino[5], Alessandro Pilloni[9,10], Ben Raydo[2], Carl Timmer[2], Maurizio Ungaro[2], Simone Vallarino[11]

[1] Sezione di Roma, Istituto Nazionale di Fisica Nucleare, 00185 Roma, Italy
[2] Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
[3] Sezione di Genova, Istituto Nazionale di Fisica Nucleare, 16146 Genova, Italy
[4] Catholic University of America, Washington, DC 20064, USA
[5] Istituto Nazionale di Fisica Nucleare, CNAF, 40127 Bologna, Italy
[6] Sezione di Bologna, Istituto Nazionale di Fisica Nucleare, 40127 Bologna, Italy
[7] Massachusetts Institute of Technology, Cambridge, MA 02139-4307, USA
[8] The NSF AI Institute for Artificial Intelligence and Fundamental Interactions, Cambridge, MA 02139-4307, USA
[9] Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università degli Studi di Messina, 98166 Messina, Italy
[10] Sezione di Catania, Istituto Nazionale di Fisica Nucleare, 95123 Catania, Italy
[11] Sezione di Ferrara, Istituto Nazionale di Fisica Nucleare, 44122 Ferrara, Italy

Received: 3 February 2022 / Accepted: 4 August 2022

Abstract Current and future experiments at the high-intensity frontier are expected to produce an enormous amount of data that needs to be collected and stored for offline analysis. Thanks to the continuous progress in computing and networking technology, it is now possible to replace the standard ‘triggered’ data acquisition systems with a new, simplified and outperforming scheme. ‘Streaming readout’ (SRO) DAQ aims to replace the hardware-based trigger with a much more powerful and flexible software-based one, that considers the whole detector information for efficient real-time data tagging and selection. Considering the crucial role of DAQ in an experiment, validation with on-field tests is required to demonstrate SRO performance. In this paper, we report results of the on-beam validation of the Jefferson Lab SRO framework. We exposed different detectors (PbWO-based electromagnetic calorimeters and a plastic scintillator hodoscope) to the Hall-D electron-positron secondary beam and to the Hall-B production electron beam, with increasingly complex experimental conditions. By comparing the data collected with the SRO system against the traditional DAQ, we demonstrate that the SRO performs as expected. Furthermore, we provide evidence of its superiority in implementing sophisticated AI-supported algorithms for real-time data analysis and reconstruction.

1 Introduction

A new generation of electron scattering experiments is underway at the world-leading QCD facilities such as Brookhaven National Lab (BNL) and Jefferson Lab (JLab). New projects include the Electron Ion Collider (EIC) [1] at BNL, SOLID [2] and Moller [3] at JLab, and upgrades of the existing detectors in the two labs, sPHENIX [4] and CLAS12 [5], respectively.

All these experiments are characterized by modern detectors with millions of active readout channels and by an unprecedented data rate produced by high-luminosity operations of the accelerators. The ambitious scientific program at the *intensity frontier* of nuclear physics calls for a data acquisition system (DAQ) that can record the interesting events and filter out the unnecessary background. Advances in data manipulation algorithms, e.g., artificial intelligence (AI) and machine learning, open up new possibilities for (quasi-)real-time data processing, by providing an efficient tool to calibrate the detector while running and at the same time intelligently select and reconstruct the final state particles. To fully exploit this progress, it is necessary to leave the triggered DAQ paradigm and move toward a more flexible software-based framework. In this scheme, all data is streamed from the detector to a data center where the entire detector’s information can be analyzed and used for efficient data tagging and filtering. This framework is called *triggerless* or *streaming readout (SRO)* DAQ.

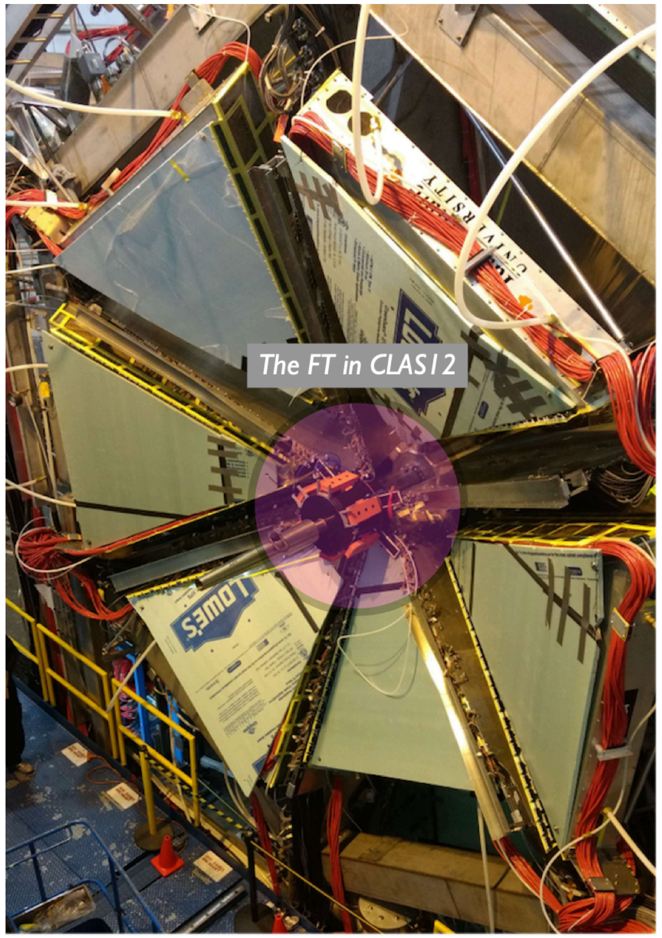
---

[a] e-mail: mariangela.bondi@ge.infn.it (corresponding author)

Springer

2020-21 SRO test @ JLAB - HALL B

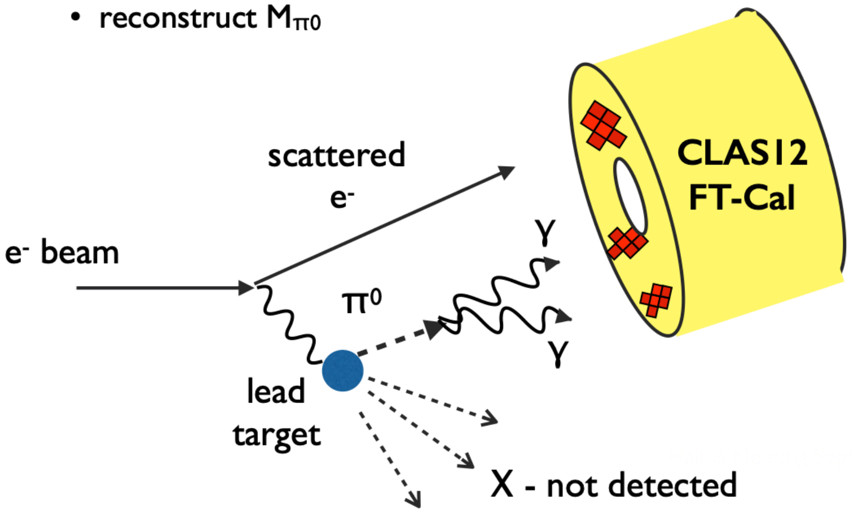
- ✳ **On-beam tests:**
  - 10.4 GeV electron beam on thin Pb/Al target
- ✳ **Hall-B CLAS12 Forward Tagger: Calorimeter + Hodoscope**
  - FT-CAL: 332 PbWO4 crystals (APD)
    - 10 +12 FADC250 boards + 2VTPs (in 2 crates/ROCs)
  - FT-HODO: 232 scintillator tiles (SiPM)
    - 15 FADC250 boards
- ✳ **SRO DAQ full chain: JLAB-FADC250, TRIDAS, JANA2**



GOAL:

- ✳ **DAQ implementation and preliminary performance study**
- ✳ **First AI application in SRO on real data tested online**
- ✳ **Physics channel identification: pi0 production**
  - e + Pb/Al ->(X) eπ0-> (X)eγγ
    - Two gammas detected in FT-CAL

- reconstruct M_{π^0}



SRO DAQ

FrontEnd

D.Abbott, F.Ameli, C.Cuevas, P. Musico, B.Raydo

✷ **JLab fADC250 + VTP bord**

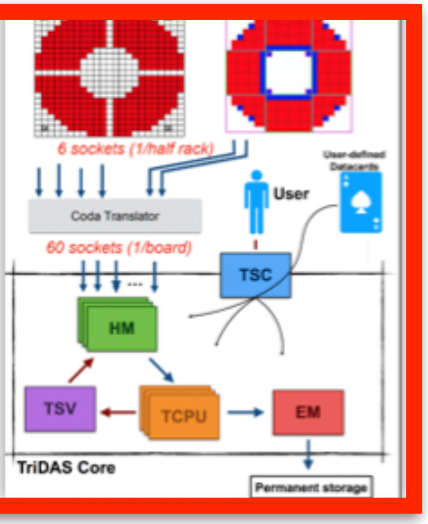
- JLab 250 MHz flash ADC digitizer currently used in many experiments
- Overcome VXS limitations (<24 Gb/s) using JLab VTP board (<40 Gb/s)
- Not optimised but reuse of existing boards: ready-to-go solution while waiting for fADC250.v2

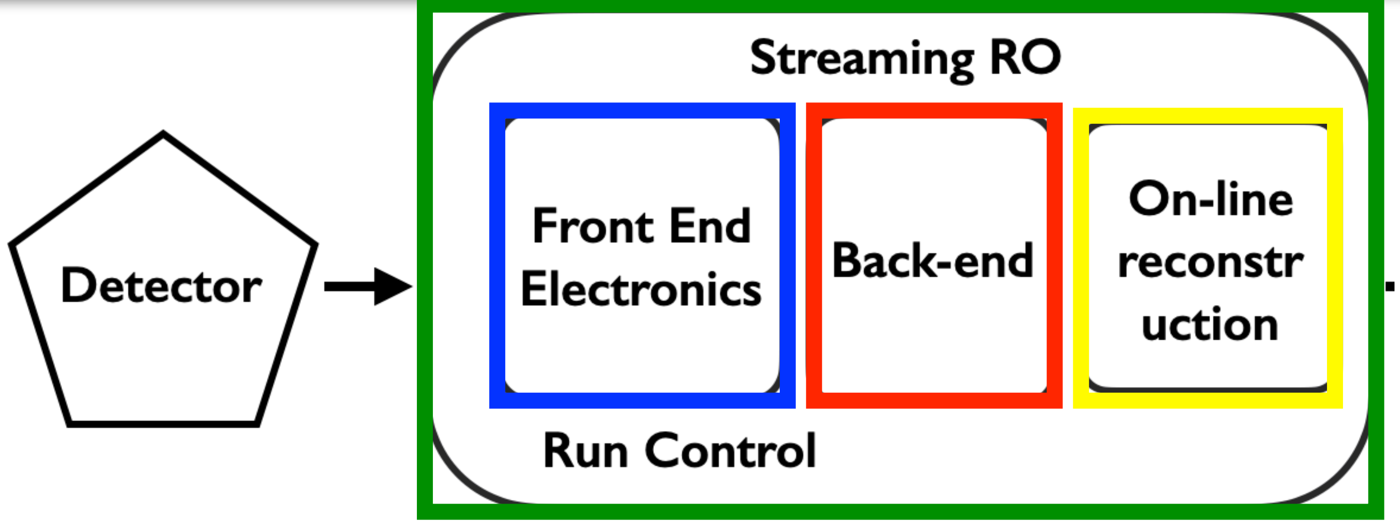
BackEnd

L.Cappelli, T.Chiarusi, F.Giacomini, C.Pellegrino

✷ **TRIggerless Data Acquisition System (TriDAS)**

- Developed for KM_3NET
- Installed on Hall-B DAQ cluster
- Multi CPUs, rate up to 20-30 MHz





Streaming RO

Detector

Front End Electronics

Back-end

On-line reconstruction

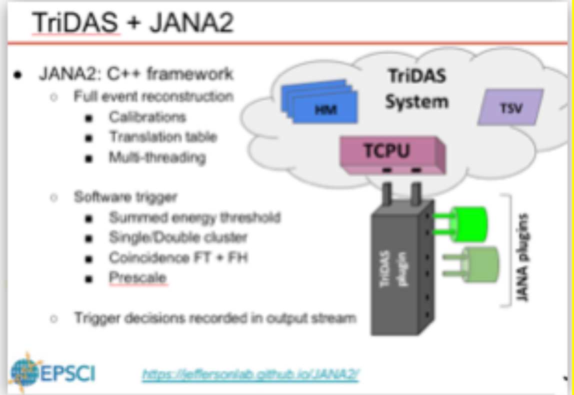
Run Control

Jana2 + reconstruction

N.Brei, D.Lawrence,
M.Bondi', C.Fanelli, A. Fulci, M.Spreafico

✷ **JANA2 + TriDAS**

- Integration between On-line and off-line
- Real-time tagging/filtering data
- Offline algorithm development immediately available for use in Software Trigger
- Level 1 "minimum-bias": at least one crystal with E> 2 GeV
- Level 2 plugins (*tagging* and *filtering*)
  - "standard" FT-CAL clustering ($N_{cluster} \geq 1, 2, 3$)
  - cosmic tracking
  - AI clustering algorithm: at least two cluster in the FT-CAL



TriDAS + JANA2

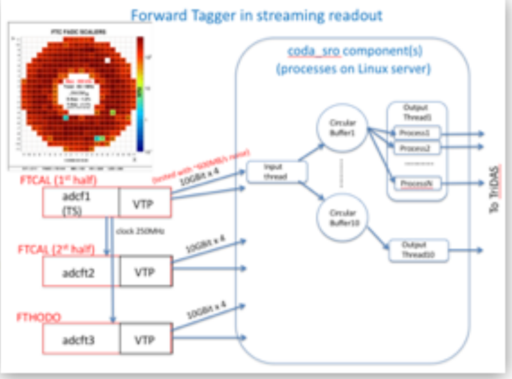
- JANA2: C++ framework
  - Full event reconstruction
    - Calibrations
    - Translation table
    - Multi-threading
  - Software trigger
    - Summed energy threshold
    - Single/Double cluster
    - Coincidence FT + FH
    - Prescale
  - Trigger decisions recorded in output stream

https://jeffersonlab.github.io/JANA2/

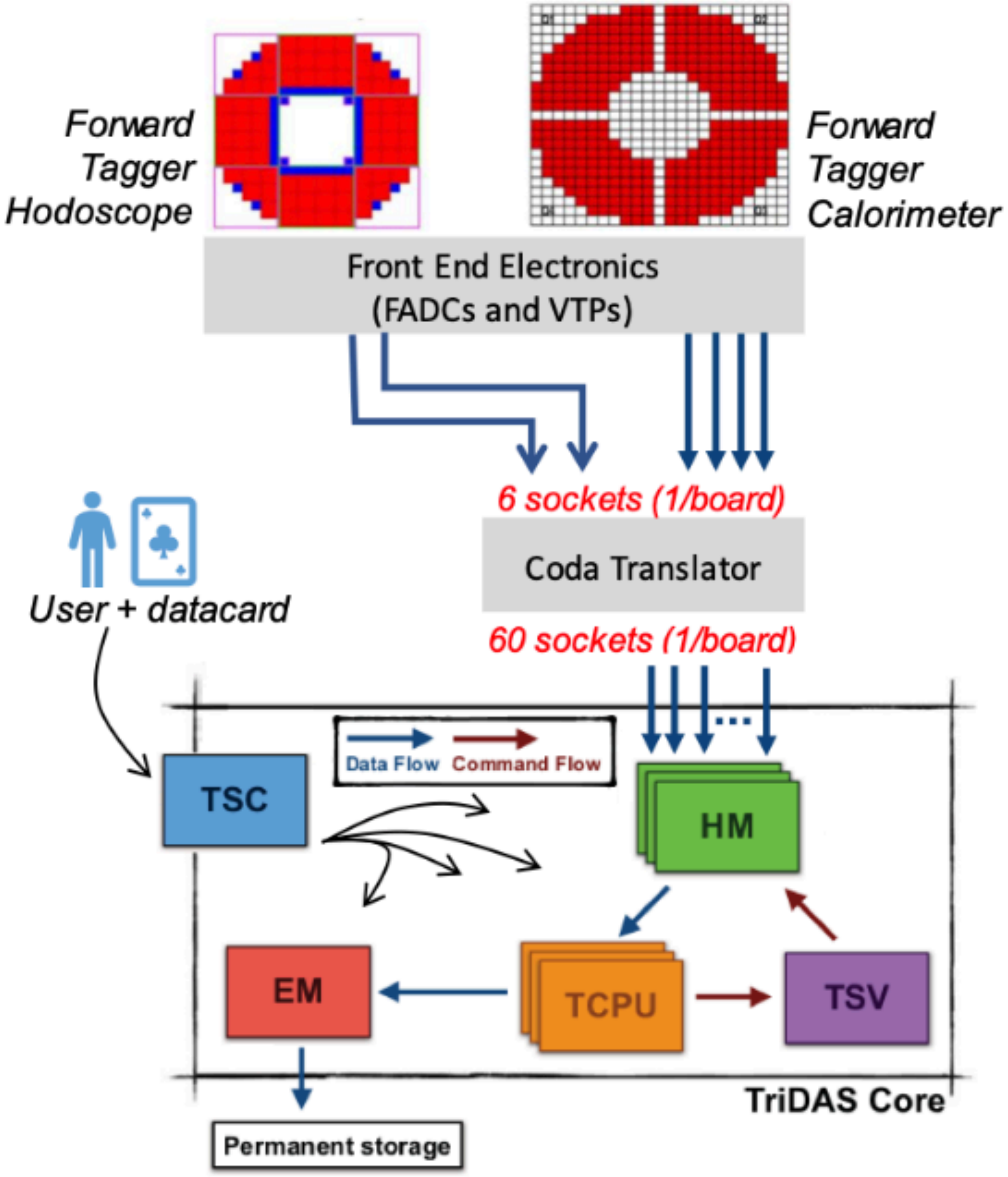
Cebaf Online Data Acquisition (CODA)

S.Boyarinov, B.Raydo, G.Heyes

- Originally designed for trigger-based readout systems
- Controllers (ROCs) and VXS Trigger Boards (VTPs)
- The Trigger Supervisor (TS) synchronizes components using clock, sync, trigger and busy signals.-time tagging/ filtering data
- CODA adapeted to the SRO
  - Replaced EB to use timestamp)
  - ROC communication via VTP (not VXS bus)



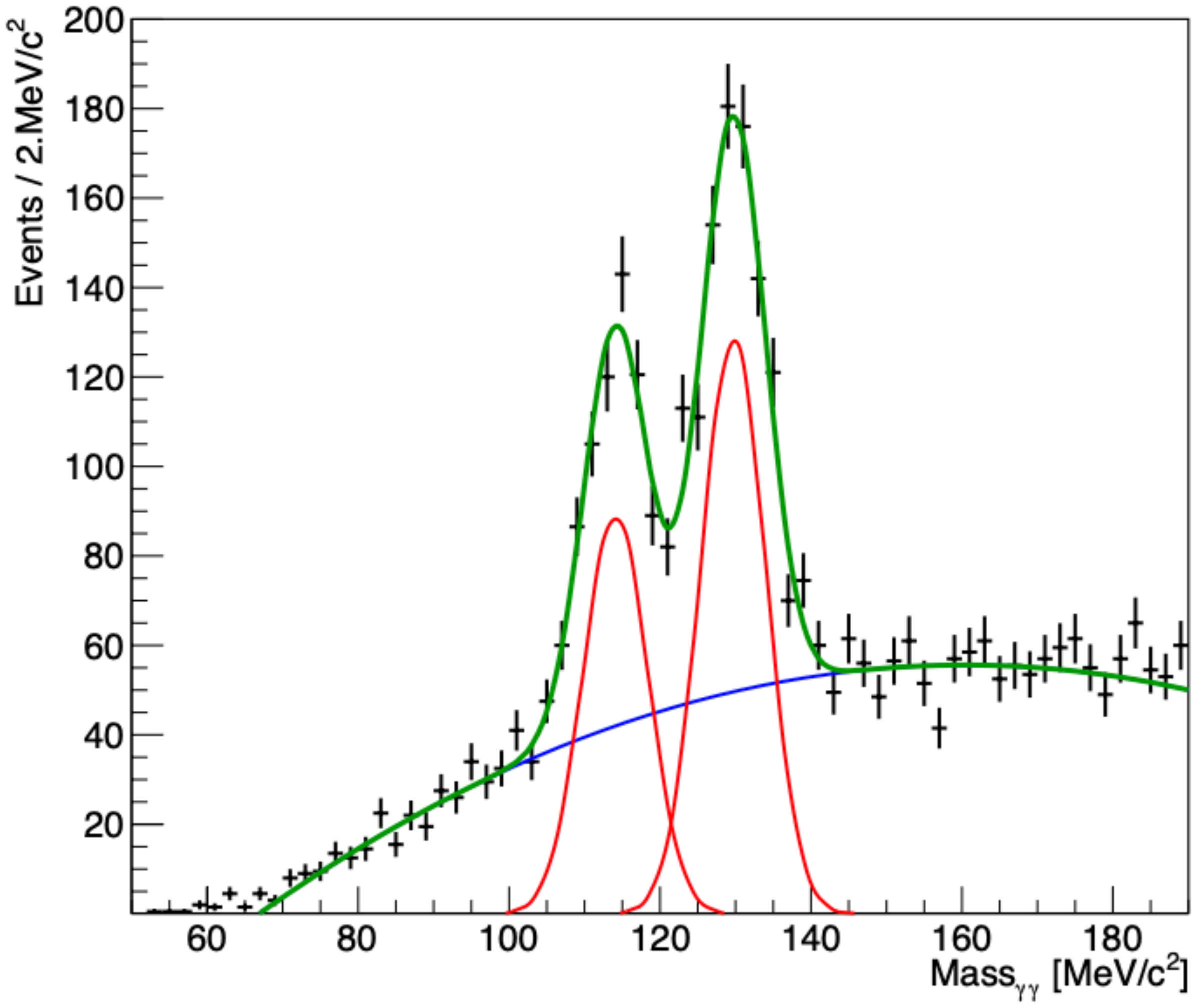
2020-21 SRO test: DAQ performance



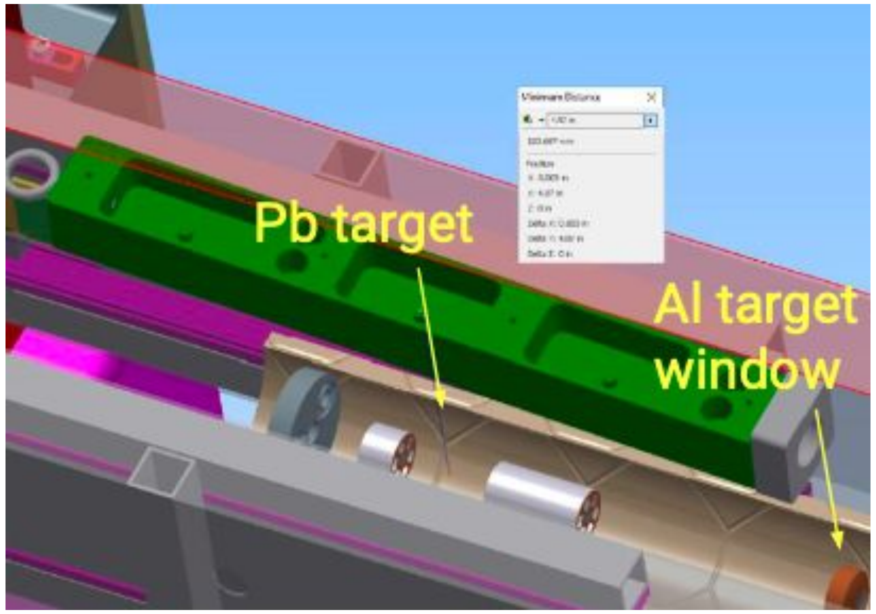
- **Data Rate from the FEE**
  - High zero suppression threshold: ~50 MeV in the ECAL; ~ 1 MeV in the HODO
  - 3VXS crates with 6 fiber uplinks: 4GB/s (~800MB/s per uplink)
  - No data frame dropping
- **Linux servers used:**
  - 48 Cores, 1GHz each, 64 GB RAM
  - 3 servers used for all modules
- **HM instances:**
  - CPU consumption linear with number of instances (500% - 1600%)
  - Memory occupancy constant (12-13 GB per run)
- **TCPUs instances: 10 instances on 2 servers => 20 instances**
  - 5 time slices at the same time on each instance
  - Trigger: JANA2 plugins
  - CPU consumption: depending on the trigger algorithms: 400% (traditional cluster trigger) - 1600% (AI-based cluster trigger)
  - Memory occupancy: 20-24 GB

2020-21 SRO test: DAQ

- **Physics channel identification: pi0 production**
  - e + Pb/Al ->(X) eπ0 -> (X)eγγ
    - Two gammas detected in FT-CAL



Two pi0 peaks corresponding to two vertices (and a wrong assumption on the vertex position)



- **Measured (expected) pi0 yield**
  - **Peak 1 : 1365 +/- 140 (~1800)**
  - **Peak 2: 930 +/- 100 (~420)**
- **Good agreement provides a significant validation of the SRO DAQ performance**

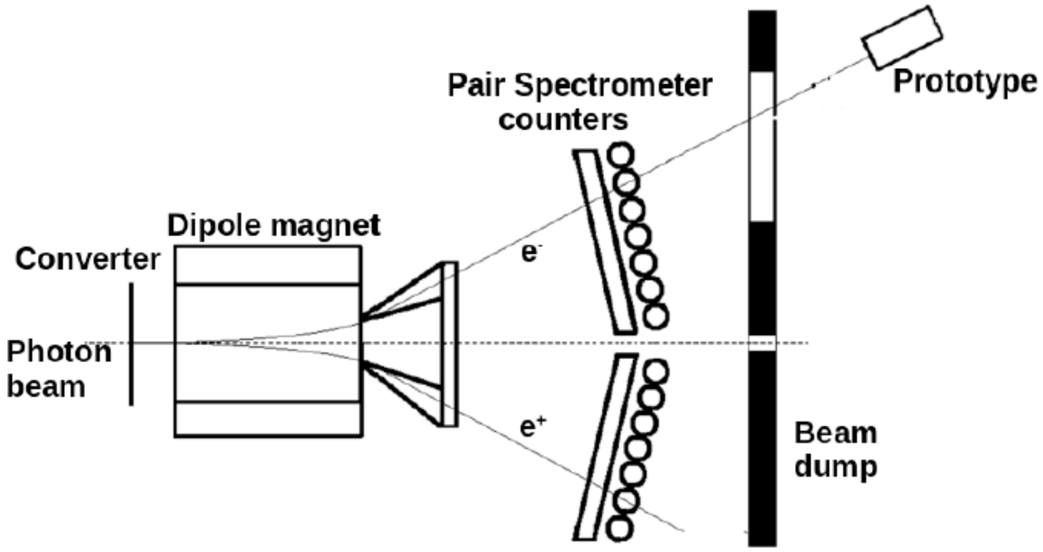
M.Battaglieri - JLAB

2023 SRO test @ JLAB - HALL D

M. Battaglieri, V.Berdnikov, S.Boiarinov, M.Bondi, J. Chrafts, C. Fanelli, A. Fulci, Y. Ghandilyan, D. Lawrence, S. Grazzi, T.Horn, A. Somov, M.Spreafico

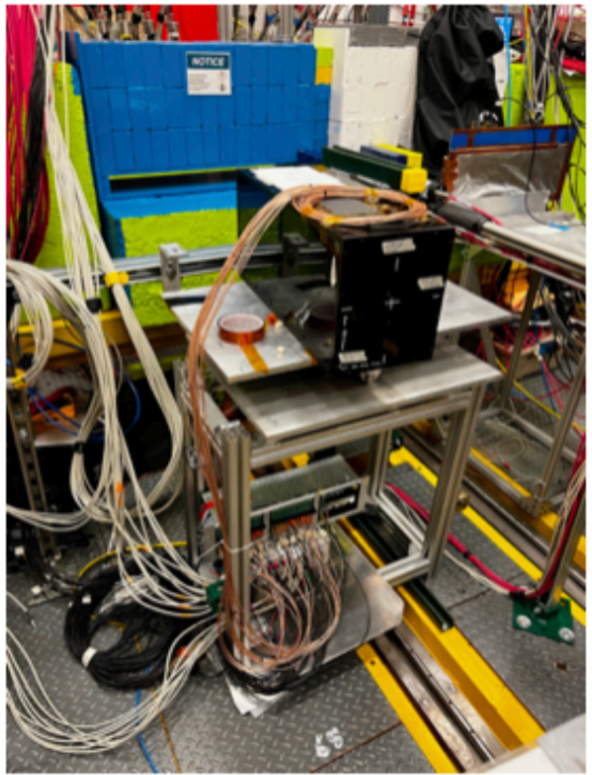
✳ **EIC EM bCal Sciglass prototype**

- Use the Hall-D Pair Spectrometer setup
- Secondary e+/e- beam: E range (3-6) GeV
- 5x5 Sciglass blocks, SiPM readout
- fADC250+VTP front end
- Detector read in the same time by three DAQ
    - Triggered GLUEX DAQ
    - SRO-DAQ
    - Alternative SRO-DAQ



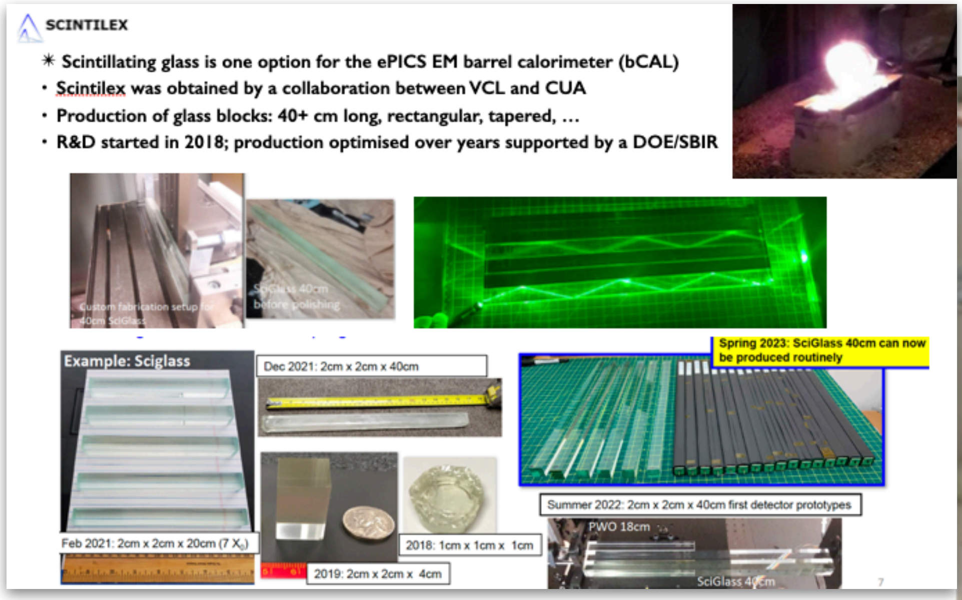
✳ **Goals:**

- **JLab SRO system performance profiling**
- **Real-time AI-supported algorithms (clustering, calibration, ...)**
- **Data collected in 'dump-', 'tagging-' and 'filtering-' mode**



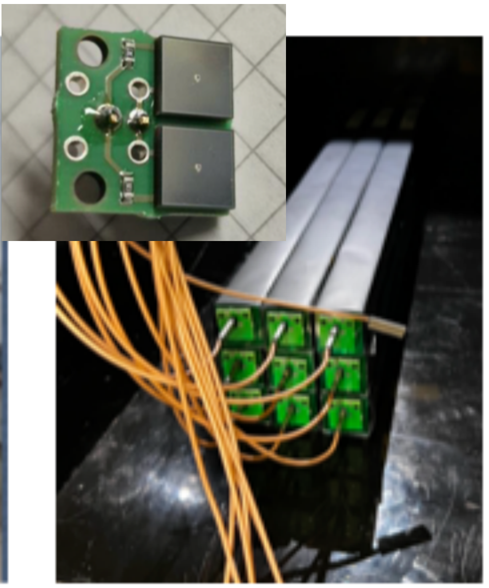
The detector: scintillating glasses

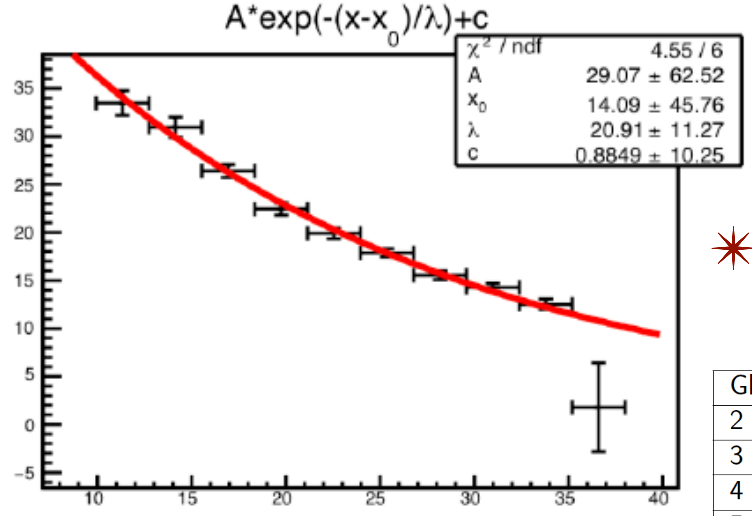
Credit to: M. Spreafico, S. Grazzi, M. Battaglieri



SCINTILEX

- ✳ Scintillating glass is one option for the ePICS EM barrel calorimeter (bCAL)
- Scintilex was obtained by a collaboration between VCL and CUA
- Production of glass blocks: 40+ cm long, rectangular, tapered, …
- R&D started in 2018; production optimised over years supported by a DOE/SBIR





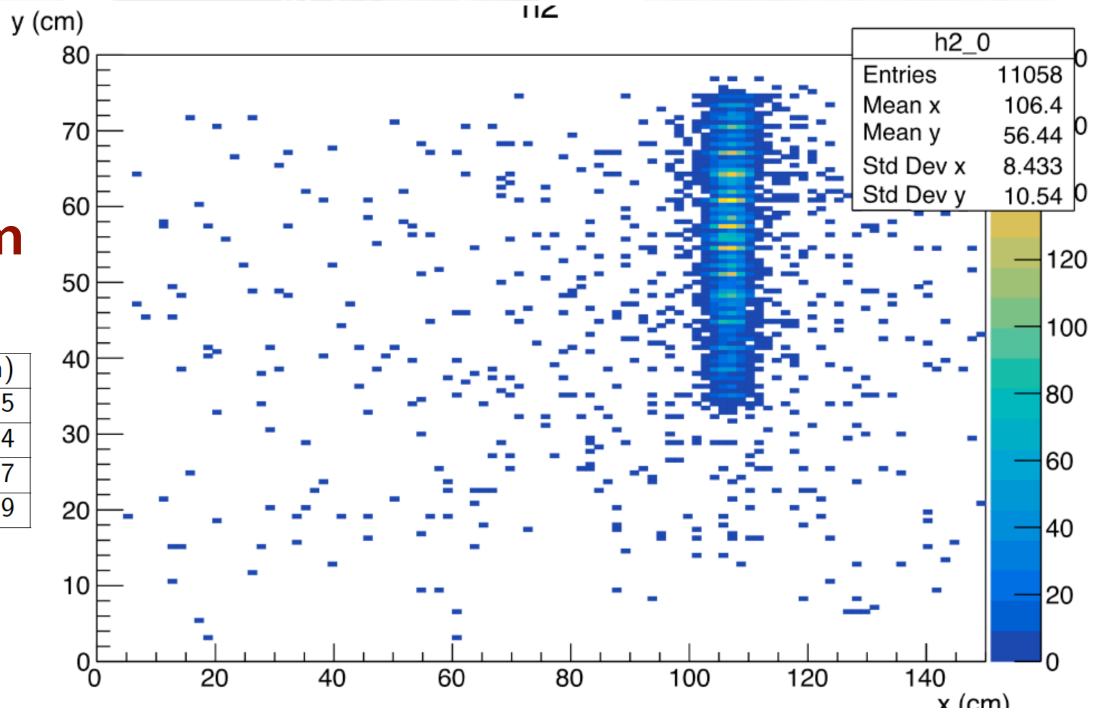
✳ **Attenuation length ~ (15± 5) cm**

Glass	λ (cm)
2	19 ± 7
3	14 ± 4
4	18 ± 6
5	21 ± 11

Glass	λ (cm)
6	16 ± 4
7	16 ± 6
8	20 ± 7
9	10 ± 2

Glass	λ (cm)
10	12 ± 3
11	14 ± 4
13	
14	13 ± 6

Glass	λ (cm)
15	18 ± 5
16	13 ± 4
18	17 ± 7
19	22 ± 9



✳ **LY ~ (4 ± 0.5) pe/MeV**

Glass	LY (pe/MeV)
2	$4.29^{+0.425}_{-0.3}$
3	$4.07^{+0.447}_{-0.3}$
4	$3.6^{+0.446}_{-0.3}$
5	$3.92^{+0.47}_{-0.4}$

Glass	LY
6	$3.46^{+0.408}_{-0.3}$
7	$4.05^{+0.534}_{-0.4}$
8	$3.64^{+0.403}_{-0.3}$
9	$4.25^{+0.7}_{-0.5}$

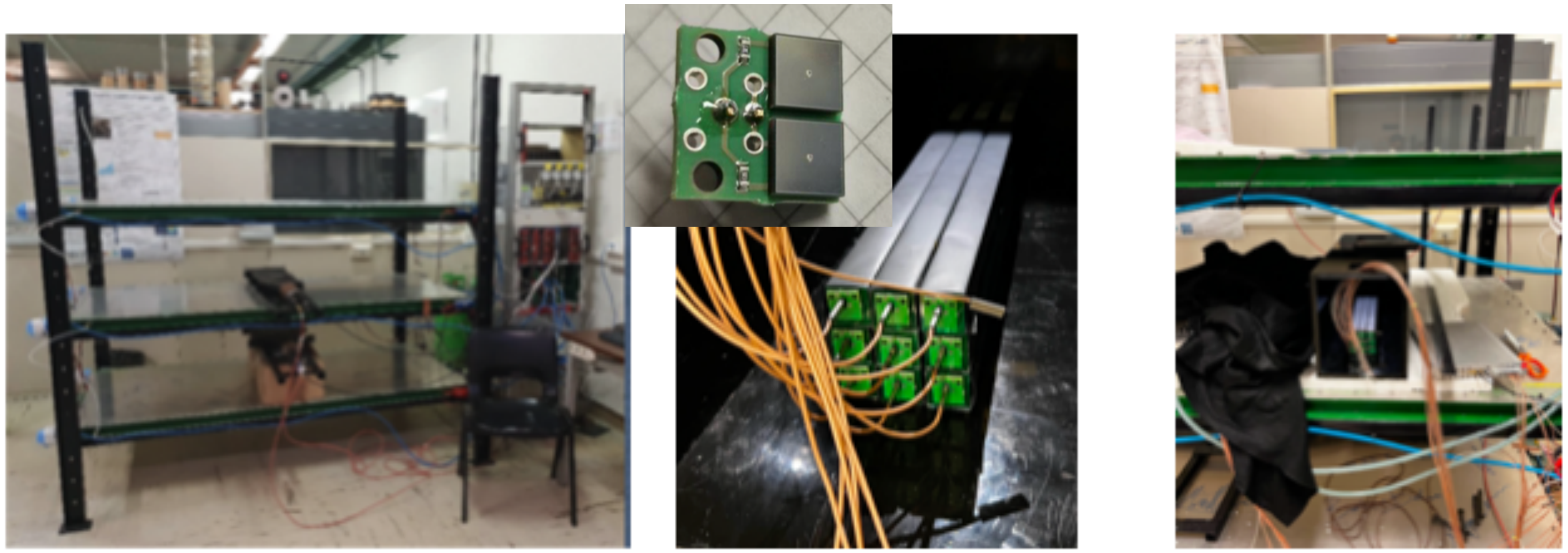
Glass	LY
10	$4.32^{+1}_{-0.8}$
11	$4.34^{+0.5}_{-0.4}$
13	$3.76^{+0.5}_{-0.3}$
14	$3.41^{+0.5}_{-0.4}$

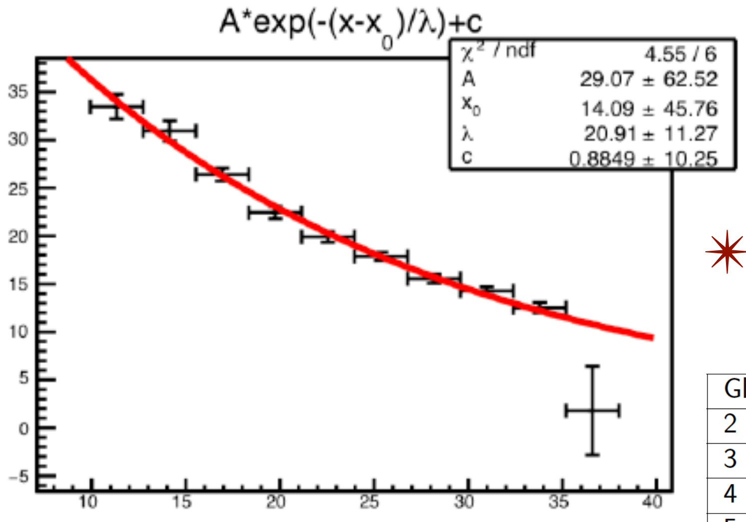
Glass	LY
15	Not measured
16	$4.19^{+0.4}_{-0.3}$
18	$3.28^{+0.3}_{-0.3}$
19	$3.13^{+0.3}_{-0.3}$

The detector: scintillating glasses

Credit to: M. Spreafico, S. Grazzi, M. Battaglieri

- ✳ 25 Glasses (2x2x40 cm3) read by 2 SiPM (Hamamatsu S14160-6050HS)
- ✳ Scintillating glass characterization at INFN-GE
- A telescope of three large area (80x150 cm2) RPCs (ALICE-TOF like) to measure the att. length





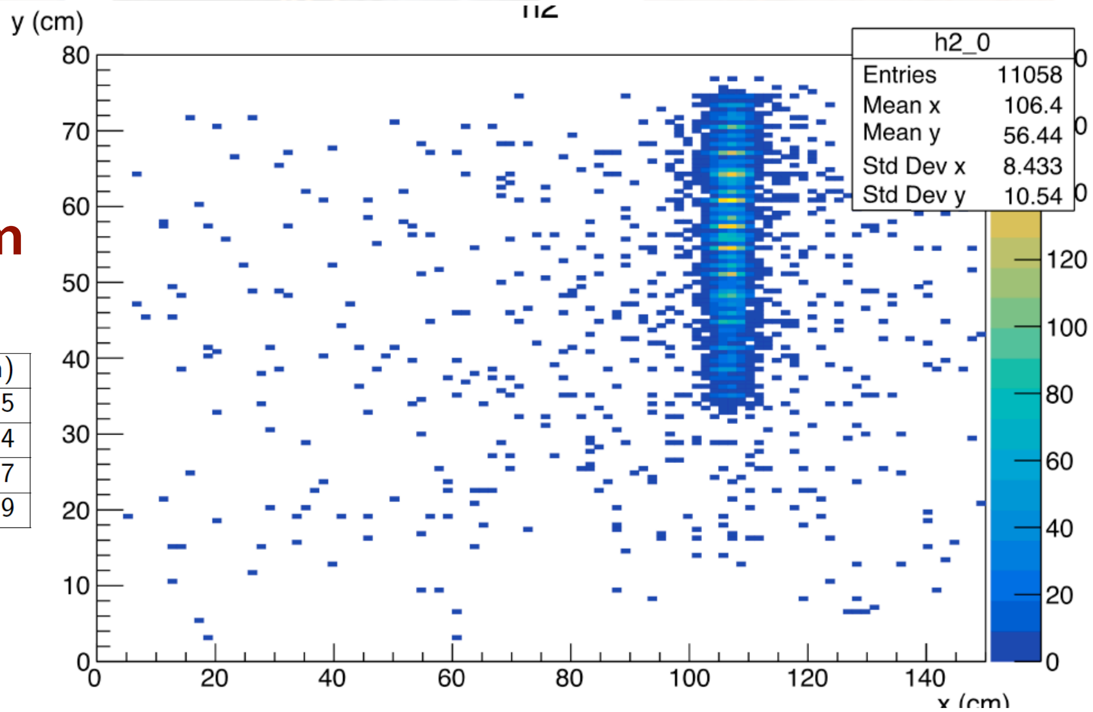
✳ **Attenuation length ~ (15± 5) cm**

Glass	λ (cm)
2	19 ± 7
3	14 ± 4
4	18 ± 6
5	21 ± 11

Glass	λ (cm)
6	16 ± 4
7	16 ± 6
8	20 ± 7
9	10 ± 2

Glass	λ (cm)
10	12 ± 3
11	14 ± 4
13	
14	13 ± 6

Glass	λ (cm)
15	18 ± 5
16	13 ± 4
18	17 ± 7
19	22 ± 9



✳ **LY ~ (4 ± 0.5) pe/MeV**

Glass	LY (pe/MeV)
2	$4.29^{+0.425}_{-0.3}$
3	$4.07^{+0.447}_{-0.3}$
4	$3.6^{+0.446}_{-0.3}$
5	$3.92^{+0.47}_{-0.4}$

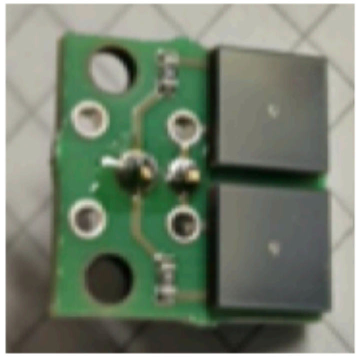
Glass	LY
6	$3.46^{+0.408}_{-0.3}$
7	$4.05^{+0.534}_{-0.4}$
8	$3.64^{+0.403}_{-0.3}$
9	$4.25^{+0.7}_{-0.5}$

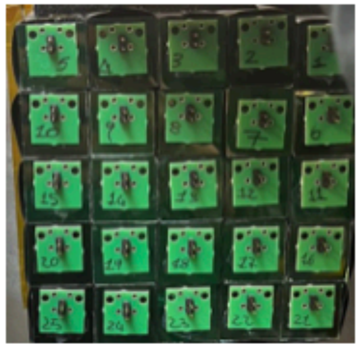
Glass	LY
10	$4.32^{+1}_{-0.8}$
11	$4.34^{+0.5}_{-0.4}$
13	$3.76^{+0.5}_{-0.3}$
14	$3.41^{+0.5}_{-0.4}$

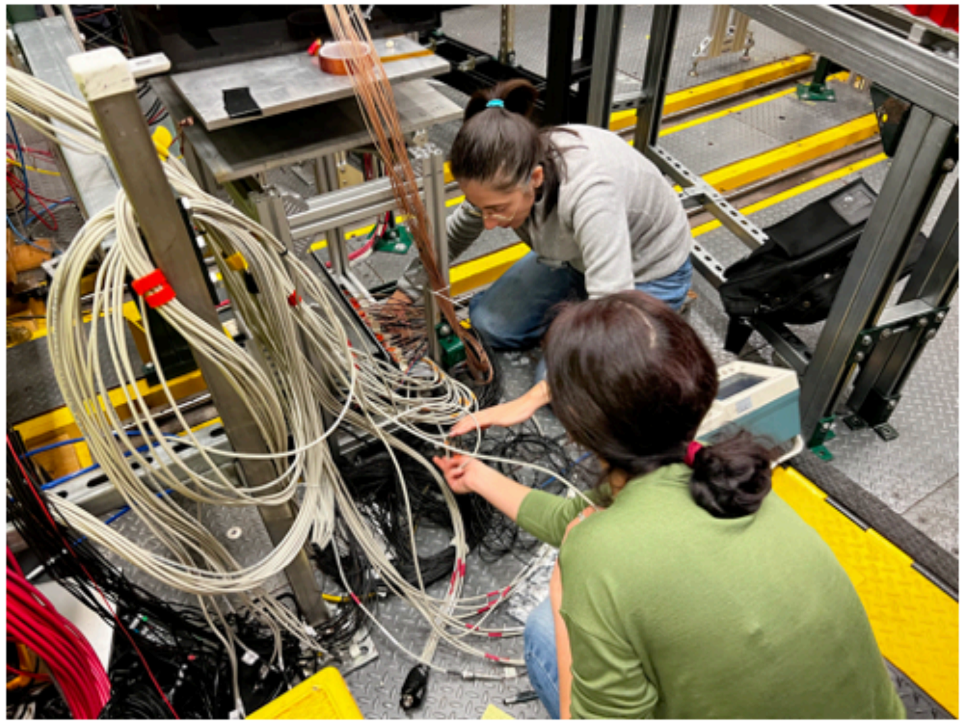
Glass	LY
15	Not measured
16	$4.19^{+0.4}_{-0.3}$
18	$3.28^{+0.3}_{-0.3}$
19	$3.13^{+0.3}_{-0.3}$

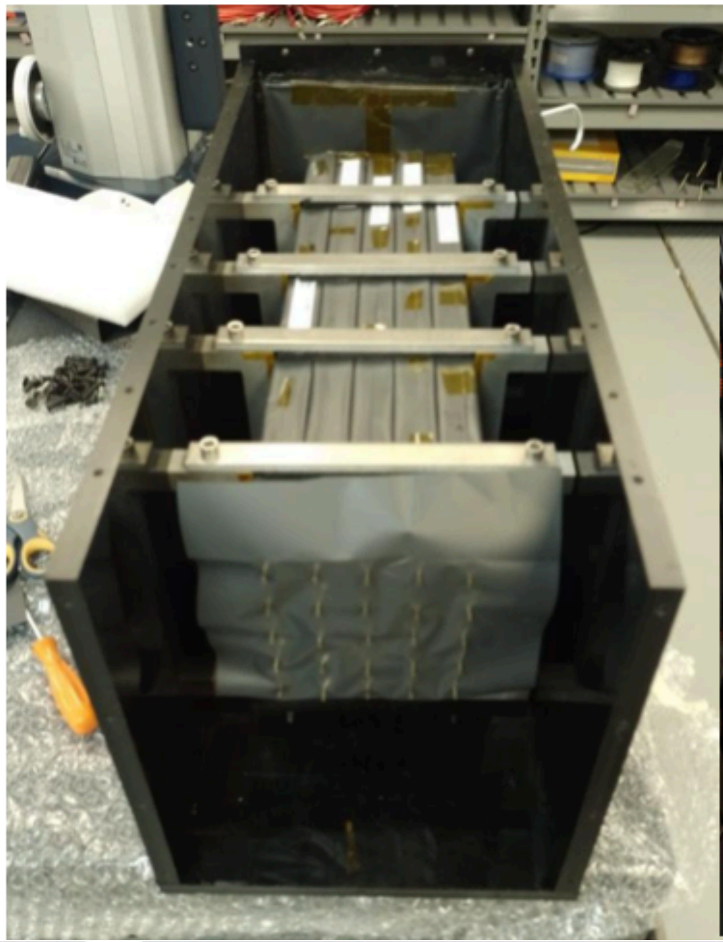
2023 SRO test @ JLAB - HALL D: set-up

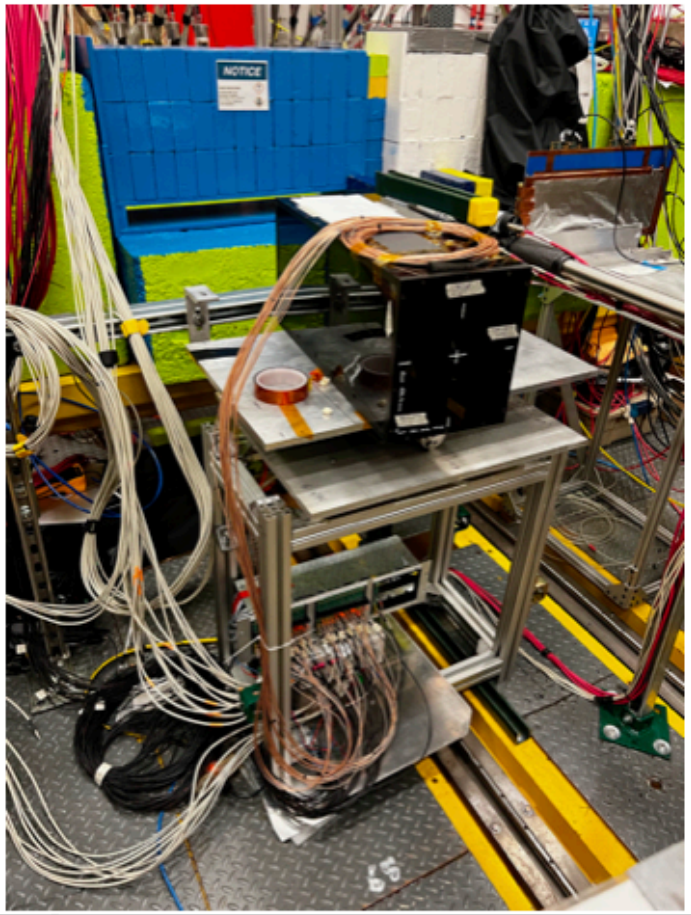
- 5x5 2x2x40 cm3 blocks
- SiPM: 2x 6x6 mm2, 50um, Hamamatsu, mounted on a PCB
- Prototype irradiated with 4 GeV Hall-D PS e+ beam
- DAQ:
  - SRO-DAQ
  - Triggered DAQ: GLUEX DAQ

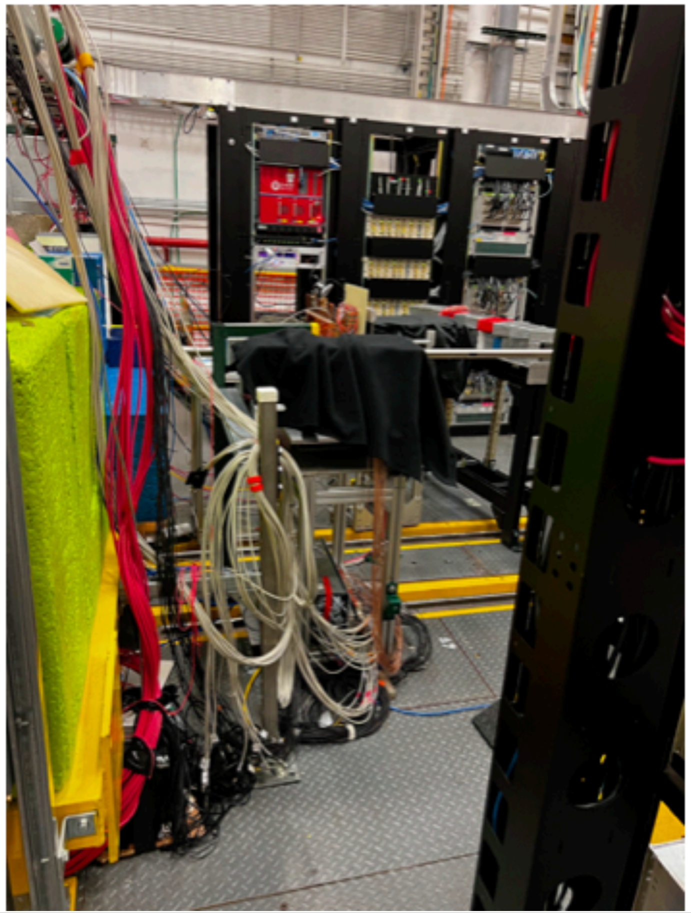






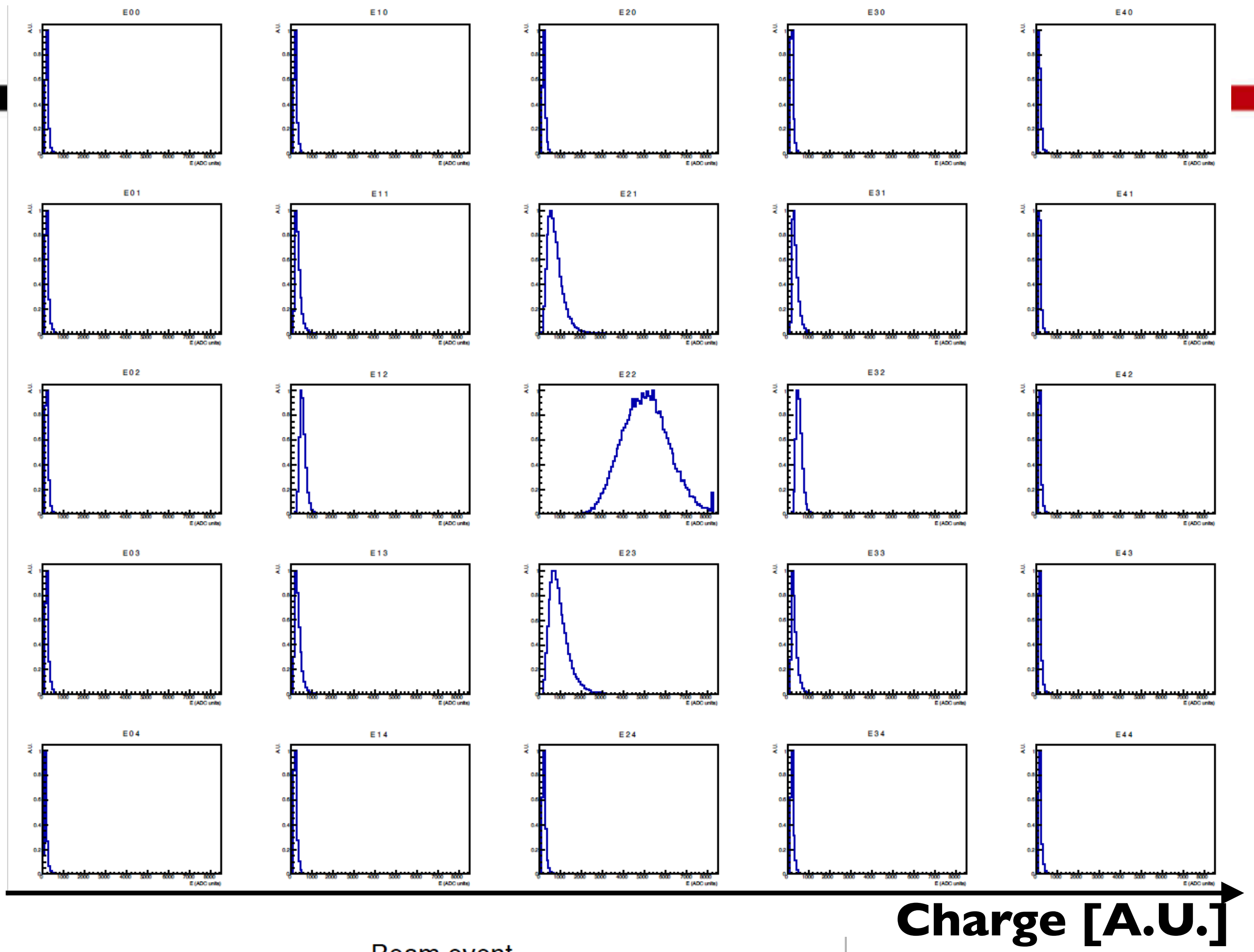




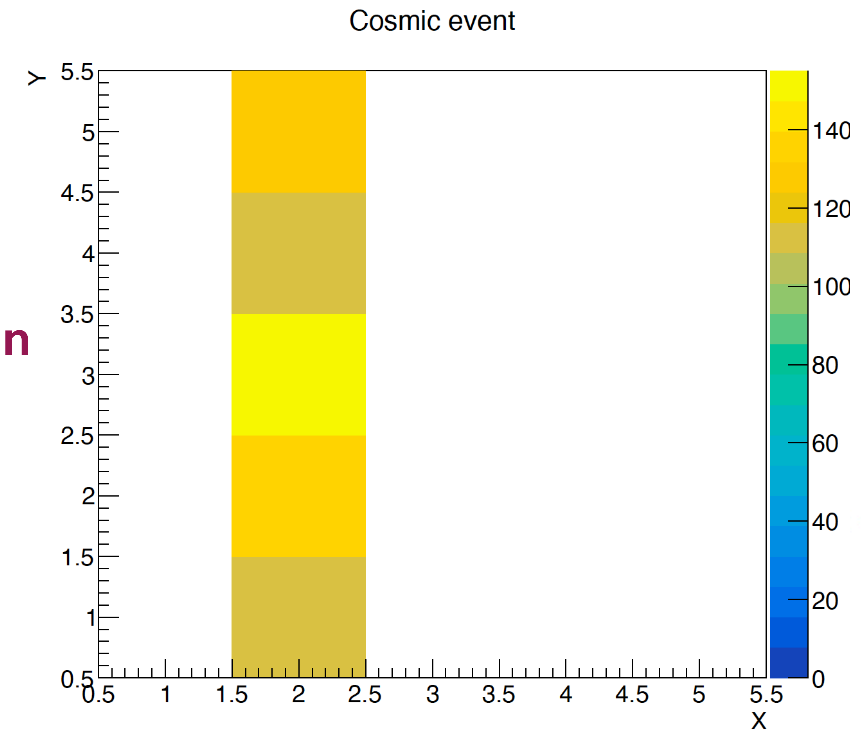


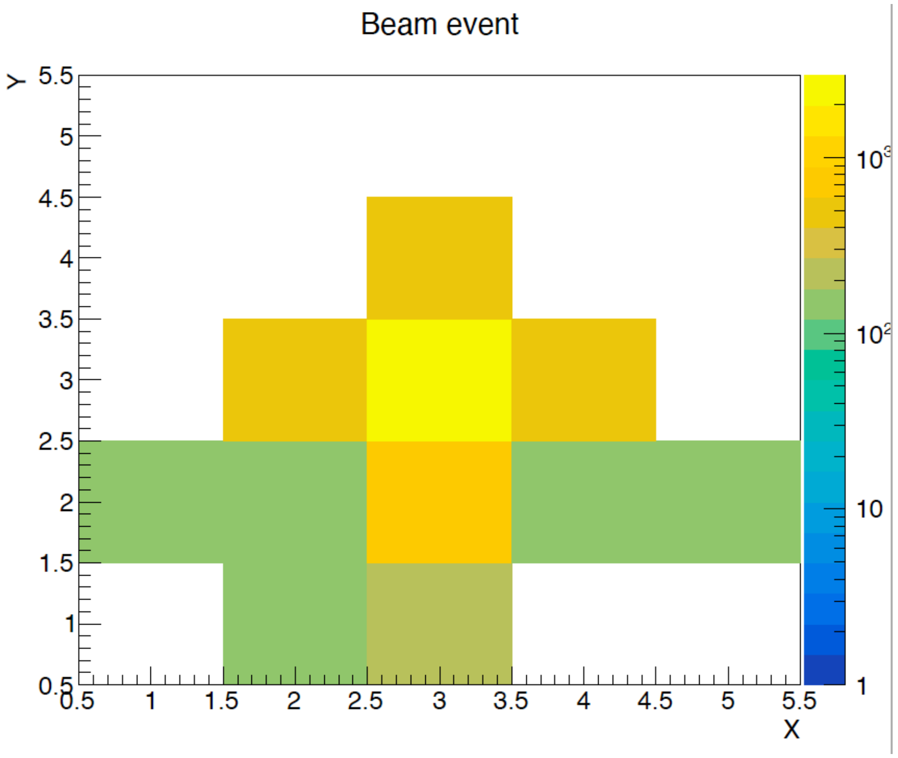
Test results - SRO DAQ

- **TRIDAS + JANA**
  - Same reconstruction algorithms (software triggers) for both on-line and off-line analysis
    - Cluster identification with standard/ML algorithm
    - Cosmic ray tracking
  - Real time tagging/filtering data
  - On-line monitor system



JANA2 plugin cosmic


Cosmic event

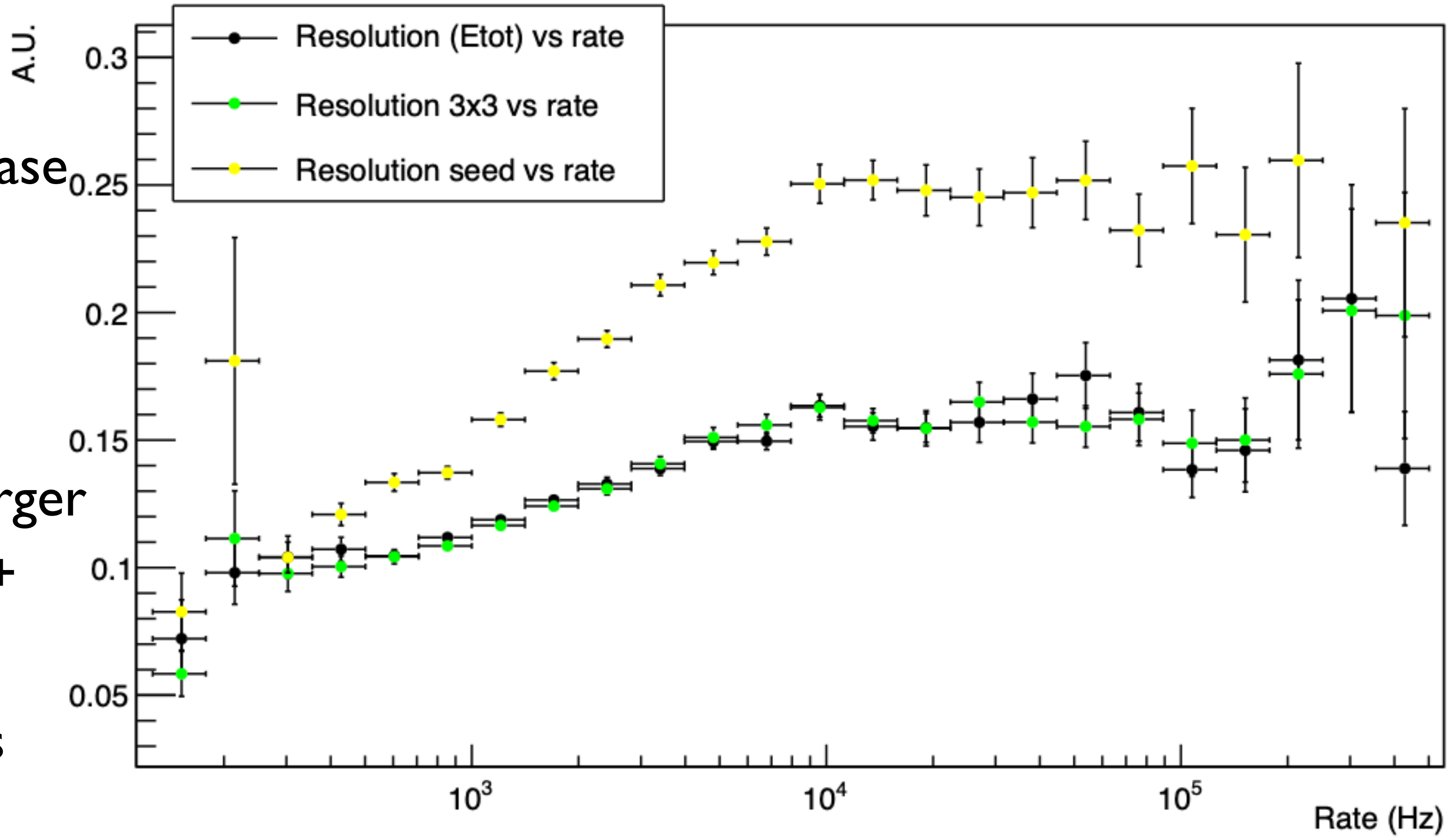

Beam event

JANA2 plugin clustering

Credit to: M.Spreafico

Test results - SRO DAQ

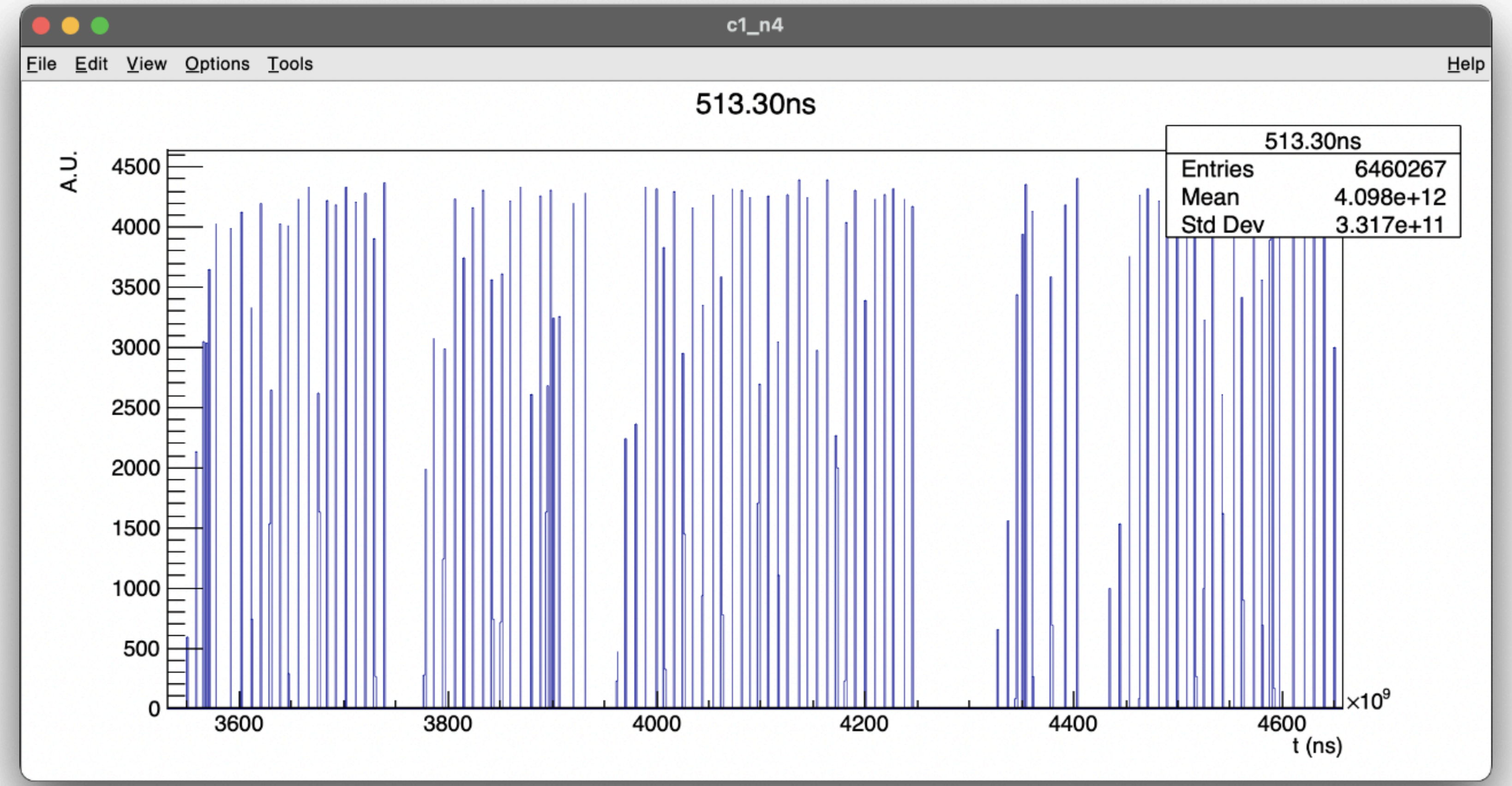
- Calorimeter response depends by the rate
  - Resolution worsening with rate increase
  - SiPM response alternated by the high charge and high rate due to gain variation (G)
    - Current drained by the SiPM gets larger and biasing circuitry (power supply + biasing) doesn't make it.
    - VBias reduces and the G drops (as well as the PDE)
    - This issue observed in several FEE not only Genova board.



Credit to: M.Spreafico, M. Bondi

Test results - SRO DAQ

- **TRIDAS lost data**
  - Stress-test: low zero-suppression thresholds
  - Hit manager not passing timeframes to TCPU
  - No-data windows depend on the run parameters (mainly PMT-buffer)
- TRIDAS needs to be updated
  - originally designed for a neutrino telescope, where all detection elements produce almost the same data throughput, providing a well distributed and balanced load to the HM.



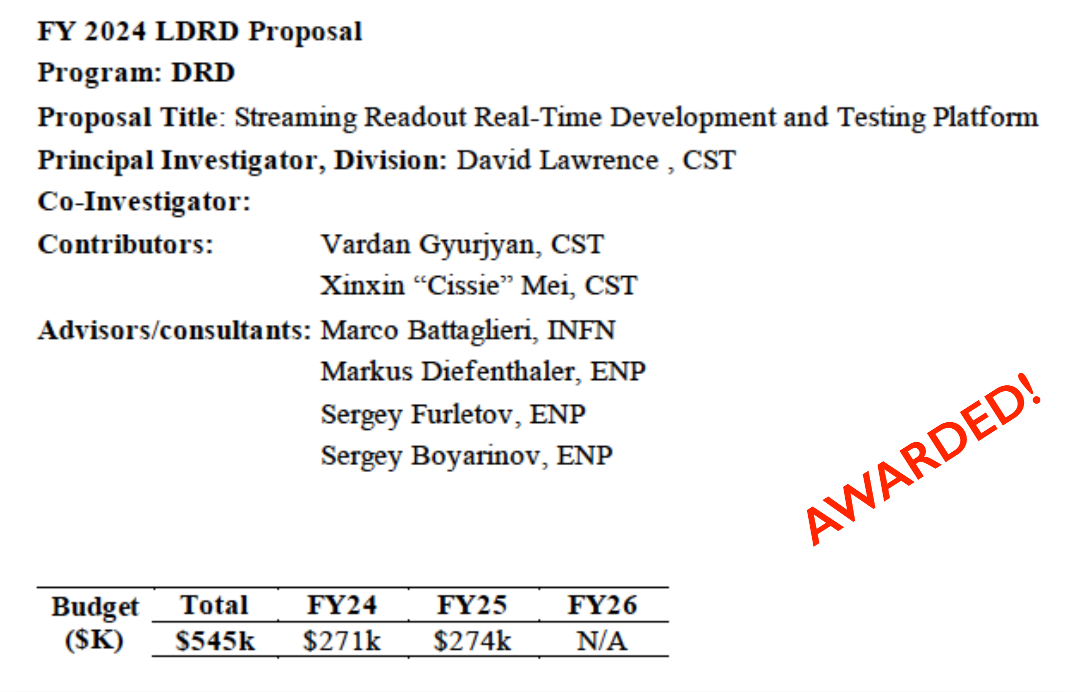
Lesson learned: **No a single central system but a multi-components (HW or SW) framework. Each component is devoted to a specific and simple task. => ERSAP**

See Vardan talk!

Credit to: M.Spreafico, M. Bondi

Toward the JLAB - SRO Data acquisition system

- JLAB12: SRO tests at Jefferson Lab and FY 2024 LDRD
  - *Streaming Readout Real-Time Development and Testing Platform*



FY 2024 LDRD Proposal
Program: DRD
Proposal Title: Streaming Readout Real-Time Development and Testing Platform
Principal Investigator, Division: David Lawrence , CST
Co-Investigator:

Contributors:	Vardan Gyurjyan, CST Xinxin "Cissie" Mei, CST
Advisors/consultants:	Marco Battaglieri, INFN Markus Diefenthaler, ENP Sergey Furletov, ENP Sergey Boyarinov, ENP

Budget ($K)	Total	FY24	FY25	FY26
	$545k	$271k	$274k	N/A

AWARDED!

- ✳ Develop a fully working SRO system able to manage future JLAB experiments
  - ✳ Leveraging on the the existing systems developed at JLab (HW and SW) and developing the ones that are missing.

See Chris talk!

See Vardan talk!

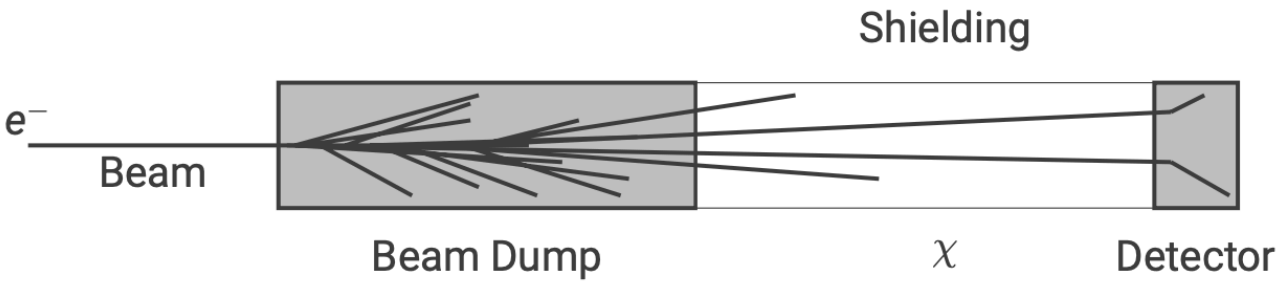
- ✳ CLAS12 can be used to test and validate SRO-DAQ solutions in a realistic on-beam condition
  - ✳ Using VTP readout CLAS12 can reuse 3/4 of existing triggered boards (fADC250) in streaming mode

See Sergey talk!

M.Battaglieri - JLAB

The Beam Dump eXperiment BDX - SRO DAQ

BDX : Light Dark matter (1-100 MeV mass range) production and detection in a e- beam, fixed target setup



- BDX will run behind Hall-A beam dump in a new dedicated infrastructure
- Will make use of high current (~65 uA) 11GeV e- beam
- Fully parasitic wrt Hall-A physics program (Moeller experiment)

BDX will adopt the JLAB - Streaming Readout DAQ system for the whole detector system

- BDX Detector:
  - State-of-the art EM calorimeter: **800** CsI(Tl) crystals with SiPM-based readout
  - Dual active-veto layers, made of plastic scintillator counters with SiPM readouts
  - JLAB FEE : FADCs + VTPs

- Number of channels and rates
  - EM-CAL: 800 crystals: Rate: ~5Hz per channel, ~3kB/s
  - VETOs: 224 readout channels: Rate: 4KHz per channel ~ 2MB/s

M.Battaglieri - JLAB

Outlook

- Streaming Readout is a must if we want to fully unlock the scientific potential of experiments
- So many advantages: performance, flexibility, scaling… but has to demonstrate to be as effective (or more!) than triggered systems
- SRO is recognized as the leading DAQ technology for the EIC project
- JLAB is the appropriate place to develop and test SRO-DAQ in real condition thanks the current physics program and the number of scheduled experiments
- SRO-DAQ prototype: JLAB FEE + TRIDAS + JANA2 used in successful on-beam tests
- Last tests showed the current TRIDAS version drops data at high-rate
- A significant effort led by EPSCI group and supported by all experimental halls staff to develop a fully working SRO system