Toward Streaming Readout @ EIC

Supported by Italian Ministry of Foreign Affairs (MAECI) as Projects of great Relevance within Italy/US Scientific and Technological Cooperation under grant n. MAE0065689 - PGR00799

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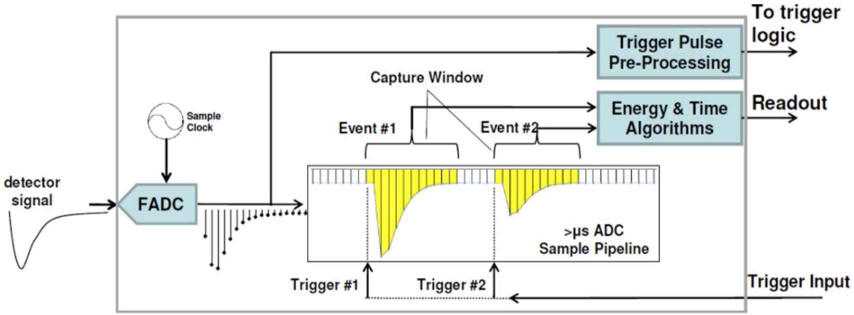
Jefferson Lab

Giornata Nazionale EIC-NET 2022

Traditional (Triggered) DAQ

- Data path is different from trigger path
  - All channels continuously measured and hits stored in short term memory by the FEE
  - Channels participating to the trigger send (partial) information to the trigger logic
- Trigger decision based on a limited information
- Trigger logic takes time to decide and if the trigger condition is satisfied:
  - trigger signal back to the FEE
  - a new event is defined
  - data read from memory and stored on tape

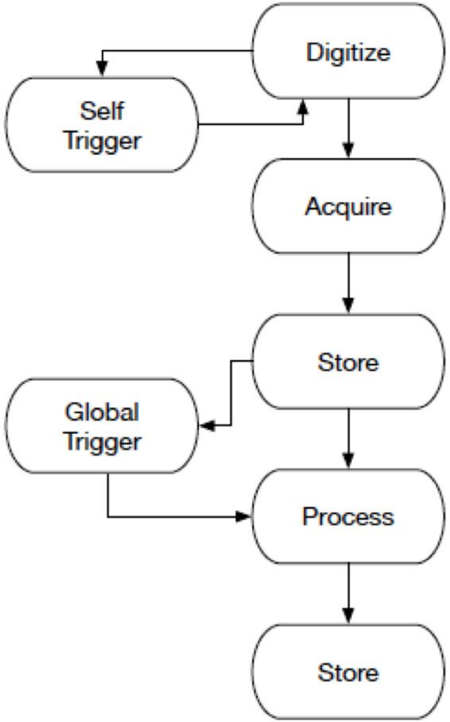


- **Pros**
  - we know it works reliably!
- **Drawbacks**:
  - only few information form the trigger
  - Trigger logic (FPGA) difficult to implement and debug
  - not easy to change and adapt to different conditions

Streaming DAQ

- Data path equal to trigger path
    - each channel that exceeds a threshold (as implemented on the front-end board) is labeled with a time-stamp and then transferred to an on-line CPU farm.
- Trigger decision based on complete detector information, possibly with the same reconstruction software used offline
- “Event” defined at software level

- **Pros**
    - All channels can be part of the trigger
    - Sophisticated tagging/filtering algorithms
    - scalability
- **Drawbacks**:
    - we don’t have the same experience as for Triggered DAQ



Why SRO is so important?

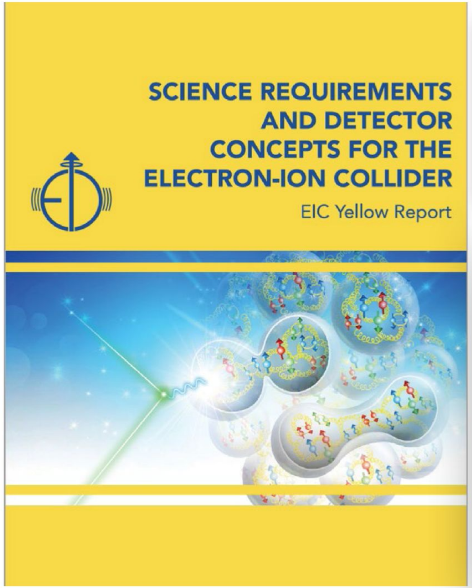
- High luminosity experiments
  - Current experiments are limited in DAQ bandwidth
  - Reduce stored data size in a smart way (reducing time for off-line processing)

- Shifting data tagging/filtering from the FEE (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 AL/MI tools

- Scaling
  - Easier to add new detectors in 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,EIC
  - JLAB: SOLID, BDX, CLAS12,...
  - …
  -

SRO for EIC



Streaming Readout for EIC Detectors
Proposal submitted 25 May, 2018

STREAMING READOUT CONSORTIUM

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ABSTRACT

Micro-electronics and computing technologies have made order-of-magnitude advances in the last decades. Many existing NP and HEP experiments are taking advantage of these developments by upgrading their existing triggered data acquisitions to a streaming readout model. A detector for the future Electron-Ion Collider will be one of the few major collider detectors to be built from scratch in the 21st century. A truly modern EIC detector, designed from ground-up for streaming readout, promises to further improve the efficiency and speed of the scientific work-flow and enable measurements not possible with traditional schemes. Streaming readout, however, can impose limitations on the characteristics of the sensors and sub-detectors. Therefore, it is necessary to understand these implications before a serious design effort for EIC detectors can be made. We propose to begin to evaluate and quantify the parameters for a variety of streaming-readout implementations and their implications for sub-detectors by using on-going work on streaming-readout, as well as by constructing a few targeted prototypes particularly suited for the EIC environment.

14.6 Data Acquisition

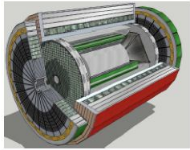
14.6.1 Streaming-Capable Front-End Electronics, Data Aggregation, and Timing Distribution

A streaming readout is the likely readout paradigm for the EIC, as it allows easy scaling to the requirements of EIC, enables recording more physics more efficiently, and allows better online monitoring capabilities. The EIC detectors will likely be highly segmented,

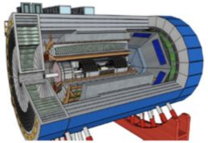
EIC R&D

Streaming Readout Consortium eRD23

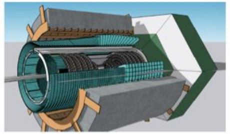
ECCE



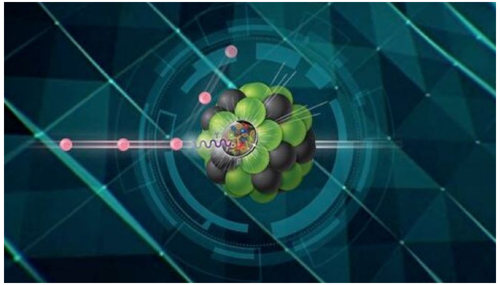
ATHENA



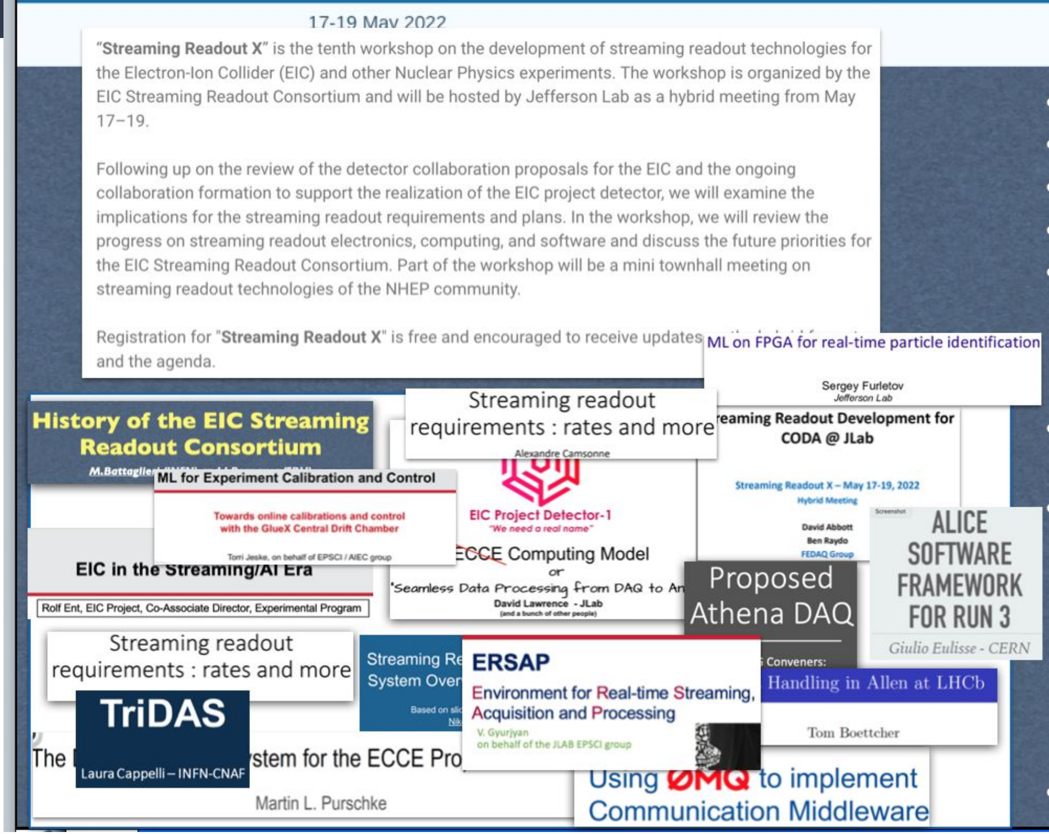
CORE



The three projects shared the same SRO concept → **DETECTOR I**



SRO for EIC



SRO-X in a nutshell

- First 'in person' (hybrid) meeting in years!
- 3 days of 20mn presentations (21) and discussion
- Live notes + ws report (in preparation)
- 74 registered participants
- organised in collaboration with conveners/ representatives of DAQ/electronics/software of EIC (former) collaborations, detectors, R&D programs …
- Goal: report about the current status and prepare the ground for the next steps
- Six sessions:
  - SRO Status
  - SRO DAQ
  - SRO Data
  - SRO Electronics
  - SRO in NHEP
  - SRO Community
- Per each talk/topic: past/present/future

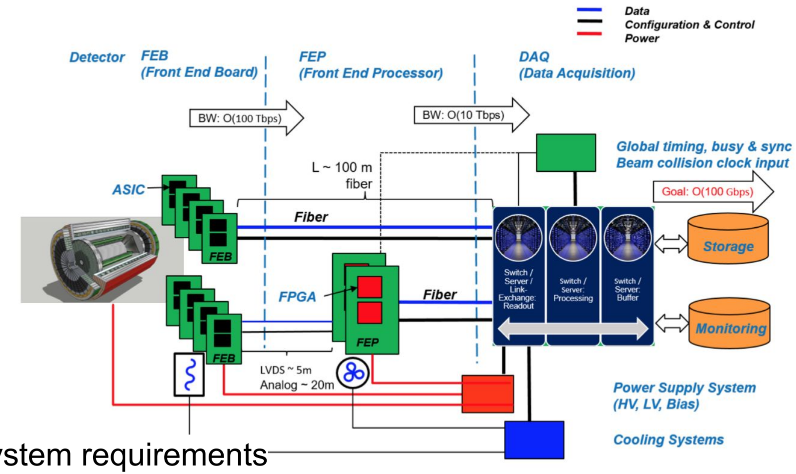
SRO for EIC

➢ Machine parameters
- Luminosity up to 10^{34} $cm^{-2}s^{-1}$
- Highly polarized (~70%) electron and nucleon beams
- Center of mass energy: from 40GeV to 140GeV

➢ Detector requirements:
- Large acceptance
- Precise vertexing
- Frwrd/Bckw angles
- HRes Tracking
- Excellent PID

➢ Three detector project shared the same SRO concept
- Number of channels O(2M)

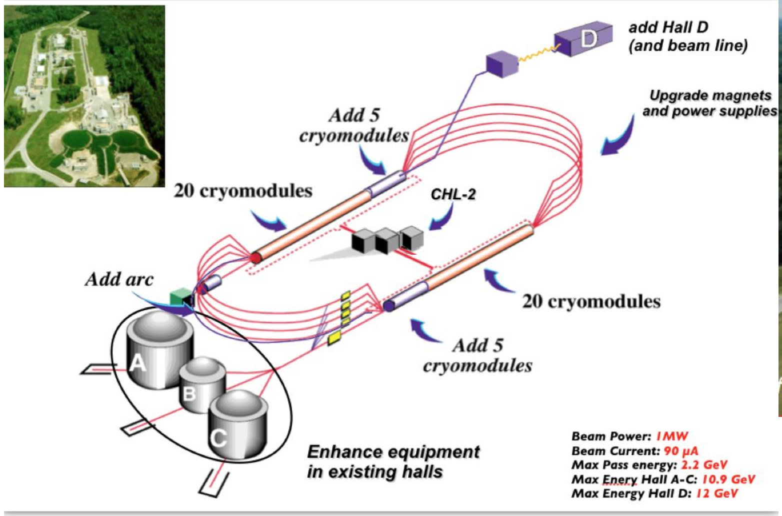
Yellow report streaming DAQ design



DAQ system requirements

- Collider
  - EIC will deliver beam in up to 1160 bunches (~100MHz)
  - Expected physics rate ~500KHz
- Detector
  - Streaming Design
    - Physics requires min-bias data
    - High collision rates
    - low detector occupancy
  - O(100Gbps) output rates

Jefferson LAB



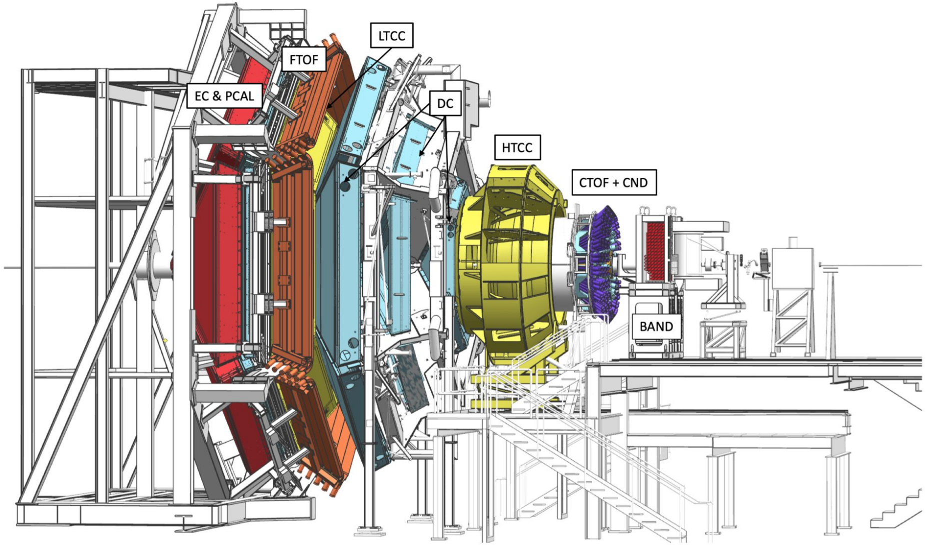
- Primary beam: Electron
- Beam energy: 12 GeV
- 4 Experimental Halls running simultaneously (independent E and I)
- Polarization
- High intensity beam - (up to O(100uA))

- The principle goal of JLAB is nuclear physics research
- But a program related to BSM physics is also present (APEX, HPS, BDX..)

Unique opportunity of testing solutions in real (on-beam) conditions

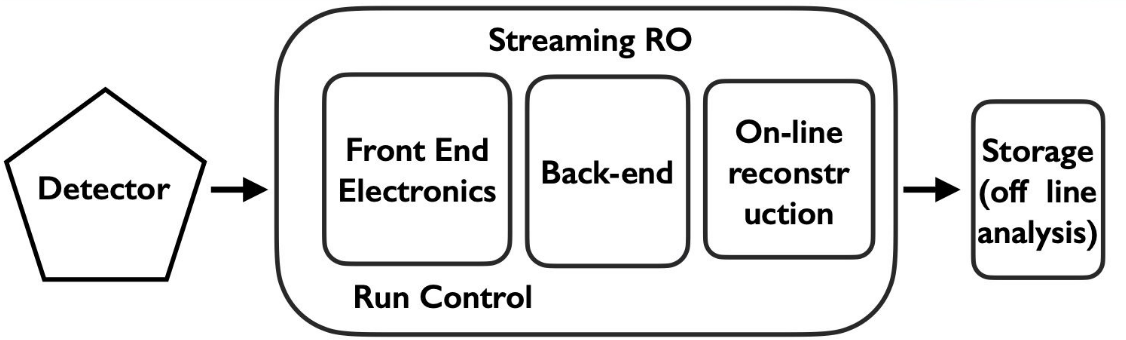
SRO for CLAS12

- ➢ Installed at Jefferson Lab's experimental HALL-B
- ➢ Expansive program of physics topics:
  - investigation of the structure of the proton and neutron both in their ground state, as well as their many excited states
  - searches for exotic meson and baryon configuration
  - …
  - ….



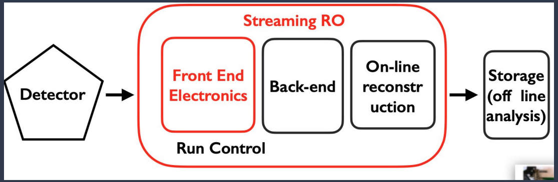
- Luminosity : $10^{35} cm^{-2} s^{-1}$
- Standard DAQ system
  - Event rate: 15-30kHz
  - Data rate: 500-1000 MByte/s
- Upgrade in luminosity: x2 in 2-3 years (Phase 1) and x100 in 5-7 years (Phase2)
- With the current triggered technology the maximum possible event acquisition rate for CLAS12 is ~100 kHz
- Streaming RO is necessary for a long-term HI-LUMI upgrade of CLAS12

Streaming RO- Components



- SRO advantages are evident buy it needs to be demonstrated by the use in real experimental conditions
- To validate SRO concept:
    - Assemble SRO components
    - Test SRO DAQ
- **JLAB-INFN collaboration to develop a prototype SRO DAQ**

Streaming RO prototype- FEE
JLAB FADC250 digitizer and VTP board

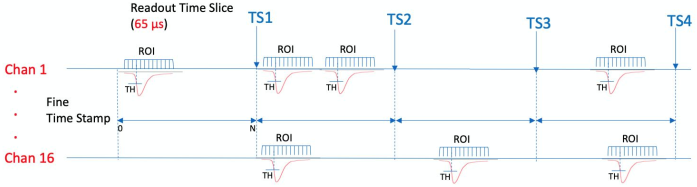


D.Abbott, C.Cuevas, B.Raydo, S. Boyarinov

JLAB FADC – Streaming mode

A 250 MHz FADC generates a 12 bit sample every 4ns. That's 3 Gb/s for one channel. 16 channels is 48 Gb/s. Currently, we identify a threshold crossing (hit) and integrate charge over a ROI and send only a sum and timestamp for each hit.

Available bandwidth will allow for 1 hit every 32ns from all channels.
A data frame (Time Slice) for all available hits is generated in the VTP every 65µs



The next revision to the firmware will have an option for full ROI wave forms to be streamed, but this will allow possible dropped hits due to bandwidth limitations

The FADC can still simultaneously operate in triggered mode with an 8µs pipeline and 2µs readout window.

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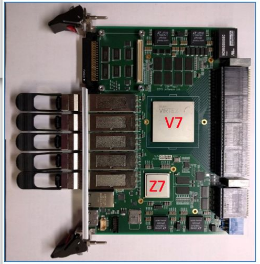
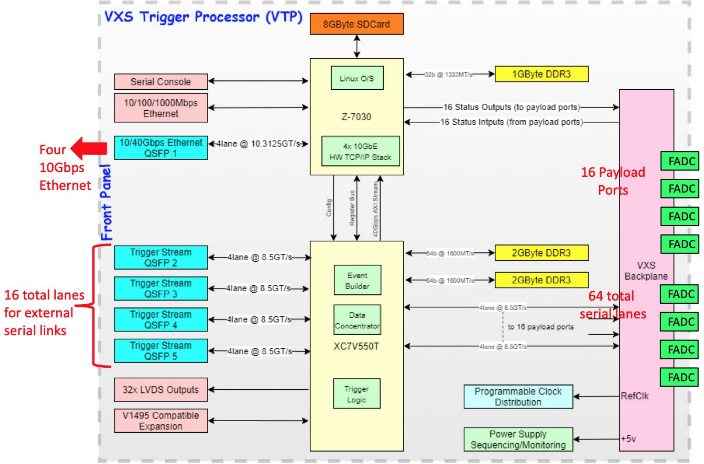
JLAB – VTP Board

Linux OS on the Zync-7030 SoC
(2-core ARM 7L , 1GB DDR3)
10/40Gbps Ethernet option
(runs the CODA ROC)

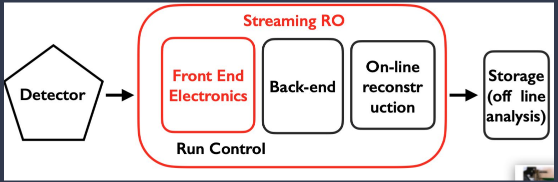
Xilinx Virtex 7 FPGA
Serial Lanes from both the VXS backplane and the Front panel
4GB DDR3 RAM





Jefferson Lab

Streaming RO prototype– FEE INFN - WaveBoard

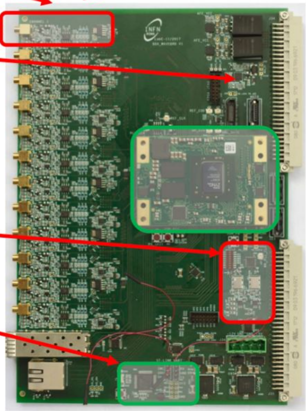


F.Ameli, P. Musico

The *WaveBoard* digitizer board

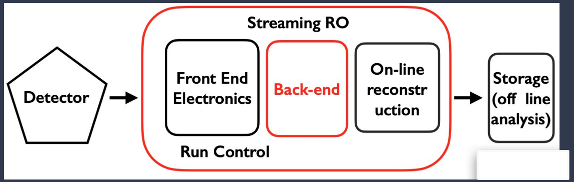
- The board is based on a Commercial-Off-The-Shelf (COTS) System On Module (SOM) mezzanine card hosting a **Zynq-7030**
- There are 12 analog front end channels
  - 6 dual-channel ultra low-power ADCs (**12/14** bit up to **250MHz**)
  - Pre-amplifier on board: **selectable gain** (either 2 or 50)
  - **HV** provided and monitored on-board
  - pedestal set by DAC
- Timing interfaces:
  - PLL to clean, generate, and distribute clocks
  - External clock and reference signals
  - White Rabbit enabled board
- ARM-M4 controls on-board peripherals (ADCs, DACs, PLL, …)
- On board peripherals:
  - High speed: GbE, SFP, USB OTG
  - Low Speed: serial, I2C, temperature monitor

Single Channel Front End w/ High Voltage



credit to F. Ameli

Streaming RO prototype– Backend TRIDAS software



T. Chiarusi, C. Pellegrino, L. Cappelli

- Designed for the astrophysical neutrino detector prototype NEMO

The TriDAS framework

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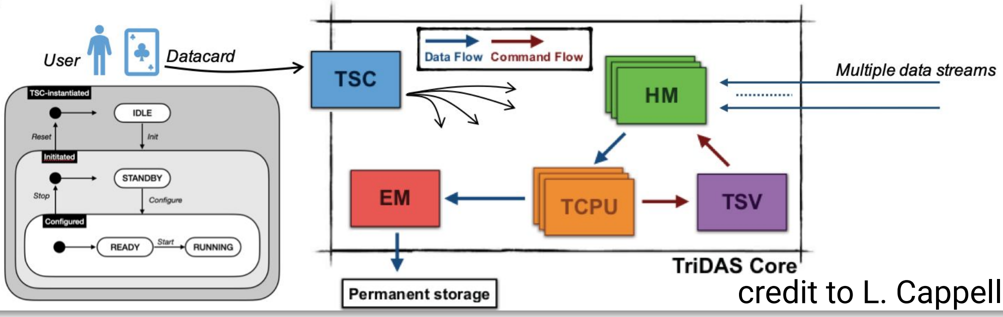
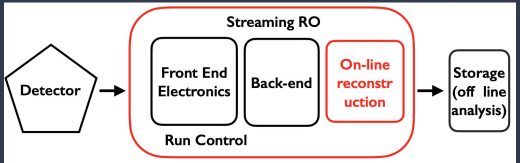
- TriDAS characteristics:
  - C++17 multithreaded software framework
  - Dependencies: CMake, ZeroMQ, Boost
  - State machine driven process
  - Flexible design:
    - Configurable via datacard (e.g. detector geometry)
    - L2 trigger algorithms in standalone plugins
    - Data format
- Composed by 5 modules:
  - HM (*Hit Manager*)
  - TCPU (*Trigger CPU*)
  - TSV (*TriDAS SuperVisor*)
  - EM (*Event Manager*)
  - TSC (*TriDAS System Controller*)
- The TriDAS code is available [here]



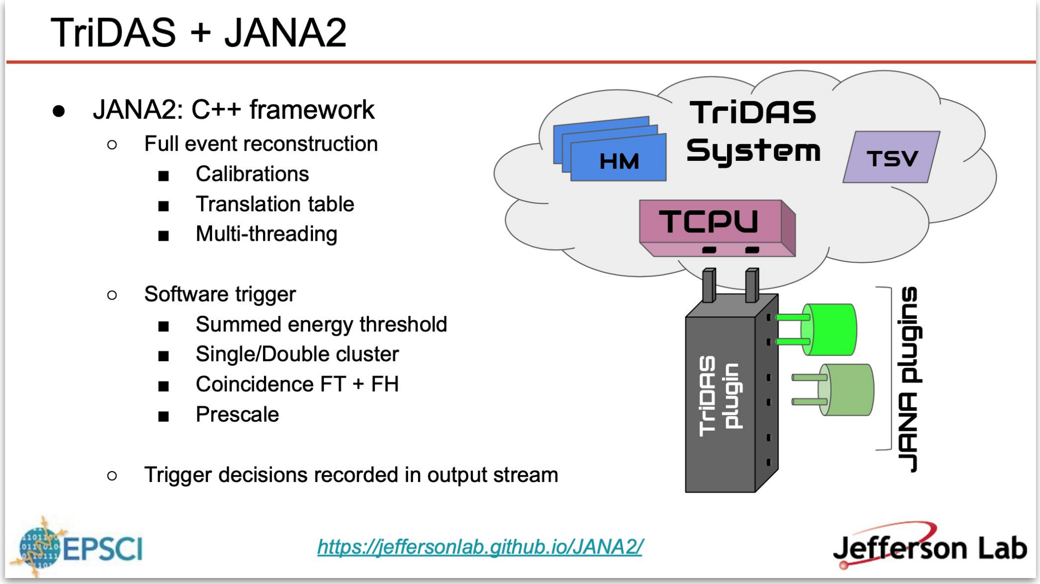
credit to L. Cappelli

Streaming RO prototype- Online-reco JANA2 software



N.Brei, D.Lawrence

- Same reconstruction algorithms (software trigger) for both online and offline analysis
- Real-time tagging/filtering data
- Offline algorithm development immediately available for use in Software Trigger



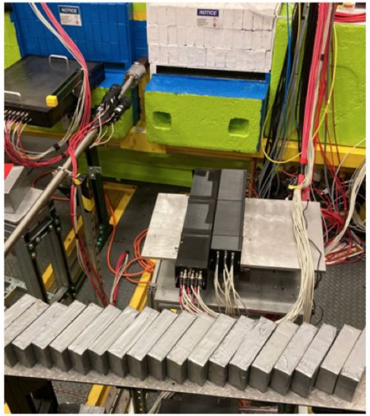
JLAB SRO validation – HALL D test

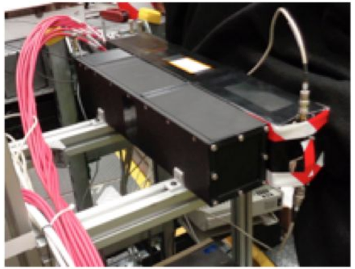
V. Berdnikov, T. Horn, M. Battaglieri

- **EIC ECAL PbWO prototype**
  - Use the Hall D Pair Spectrometer setup
  - Prototype irradiated with a 4.7 GeV e- beam
  - Simple setup to compare TRIGGERED to TRIGGER-LESS
  - 3x3 PbWO crystals, PMT and SiPM readout

- **SRO - DAQ setup:**
  - FEE: Waveboard
  - Back-end software: TRIDAS
    - L1 event: threshold equivalent to 2GeV
  - Reconstruction: JANA2

GOAL: compare TRIGGERED to TRIGGER-LESS





SiPM(left) & PMT(right) cal. prot.

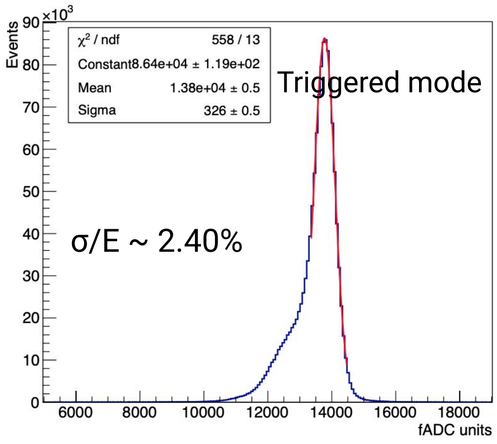
Waveboard

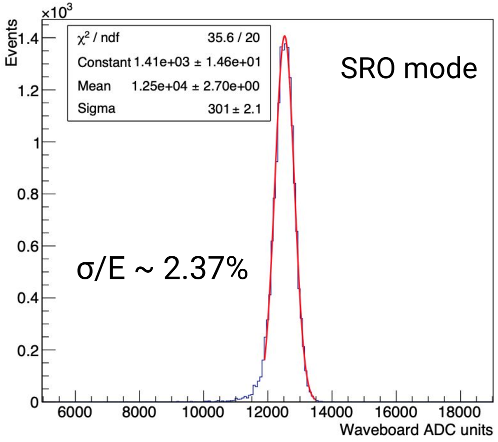
JLAB SRO validation – HALL D test

V. Berdnikov, T. Horn, M. Battaglieri

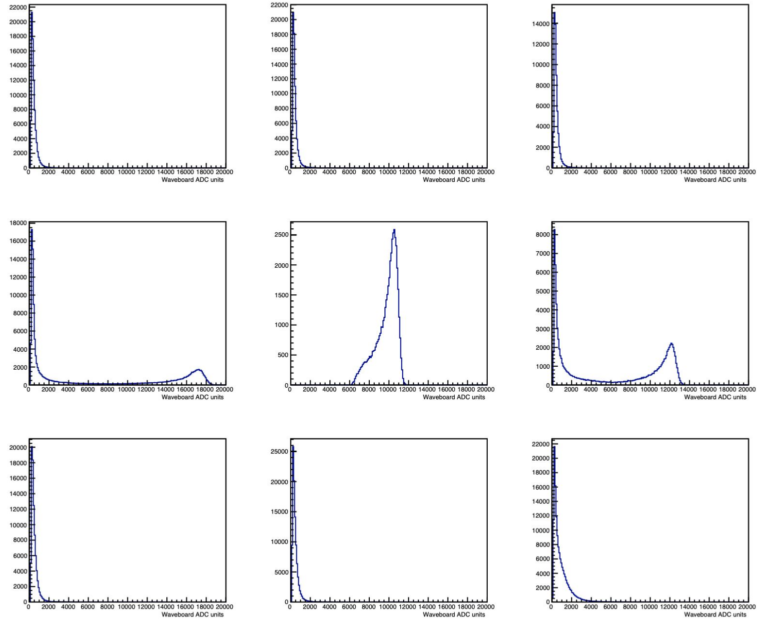
- Comparison between E-resolution obtained in trigger and SRO moc

Reconstructed cluster energy





ECAL proto 9 Channels - SRO mode



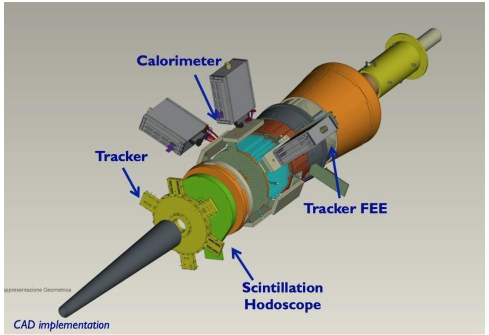
Streaming RO - CLAS12 FT test:

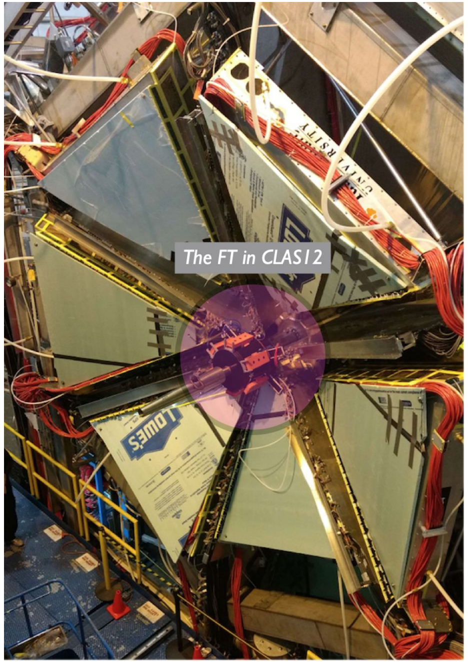
M. Battaglieri, M.Bondi, R. De Vita, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

- **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
    - FT-Tracker: MicroMegas
- **SRO DAQ full chain: JLAB-FADC250, TRIDAS, JANA2**

GOAL:

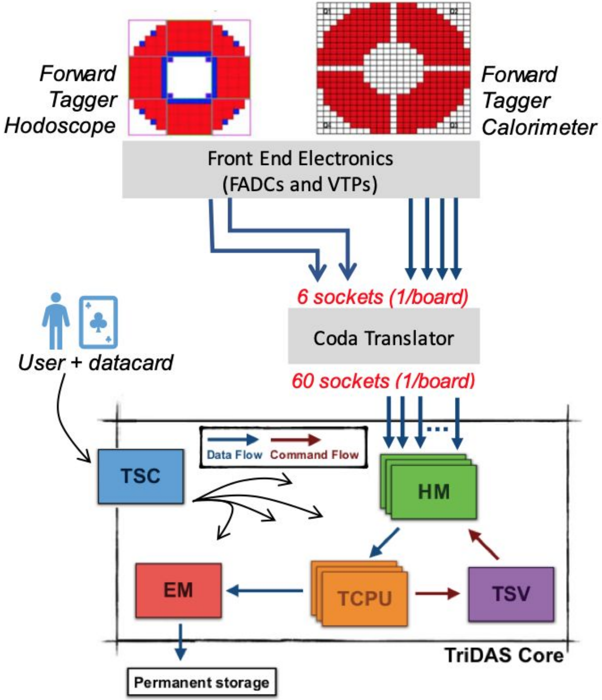
- DAQ system performance
- Physics channel identification: pi0 production



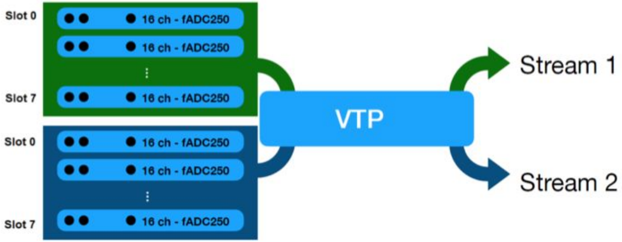


Streaming RO – CLAS12 FT tests: Setup

T. Chiarusi, C. Pellegrino, L. Cappelli, D.Abbott, C.Cuevas, B.Raydo, S. Boyarinov



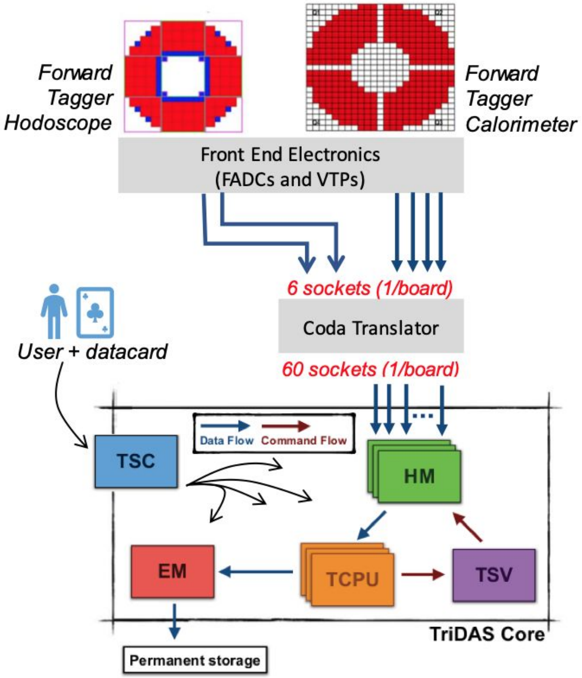
- System tested on the Forward Tagger sub-detectors
  - 6 streams: 2 streams from 3 VXS Trigger Processors (**VTP**)
    - Throughput: max 4 GBps per stream, set from few tens of MBps to 100 MBps
  - 16 Flash ADCs 250 (**FADC**) per VTP, 8 per stream
  - 16 channels per FADC
  - Total channels: 768 (16 ch * 8 FADC * 2 streams * 3 VTP)



- Between the front-end electronics and TriDAS there was the **CODA translator** layer

Streaming RO - CLAS12 FT tests: Setup

T. Chiarusi, C. Pellegrino, L. Cappelli, D.Abbott, C.Cuevas, B.Raydo, S. Boyarinov



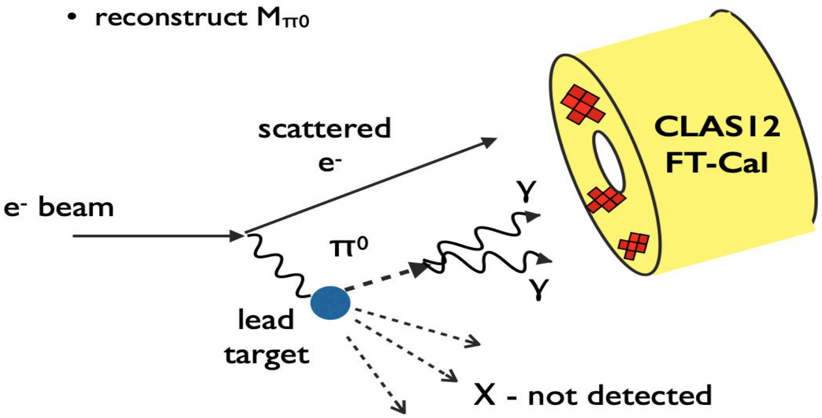
- Linux servers used:
  - 48 cores, 1GHz each, 64 GB RAM
  - 3 servers used for all modules
- HM instances: from 5 to 20
  - CPU consumption linear with the number of instances (500% – 1600%)
  - Memory occupancy constant (12-13 GB per run)
- TCPUs instances: 10 instances on 2 servers = 20 instances
  - 5 Time Slices at the same time on each instance
  - Trigger: **Jana2 plugin** (rudimental reconstructions and clustering)
  - CPU consumption: depending on the trigger algorithms (400% – 1600%)
  - Memory occupancy: 20-24 GB

From:
F. Ameli et al. "Streaming readout for next generation electron scattering experiments". arXiv: 2202.03085

Streaming RO - CLAS12 FT test:

M. Battaglieri, M.Bondi, R. De Vita, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

- **On-beam tests:**
  - 10.4 GeV electron beam on thin Pb/Al target
  - Inclusive pi0 production
    - e + Pb/Al ->(X) eπ^0 -> (X)e$\gamma\gamma$
  - Two gammas detected in FT-CAL
  - EM clusters identification, anti-coincidente with FT-Hodo

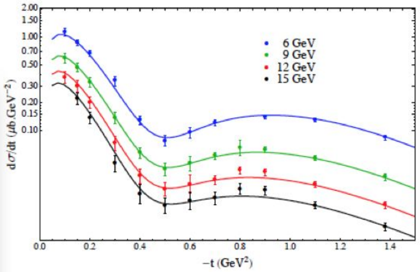


Streaming RO - CLAS12 FT test:

M. Battaglieri, M.Bondi, R. De Vita, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

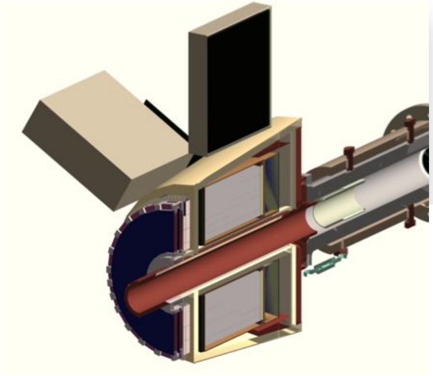
- **Realistic simulations:**
  - Realistic exclusive pi0 electro-production provided by JPAC
  - Realistic GEANT4 model of the FT detector
  - Contributions considered: electro-photoproduction by Pb

- Physics model of π^0 real photoproduction from JPAC (arXiv:1505.02321)
- Electroproduction simulated as quasi-real ph.prod. as in Tsai
- $2 < k_\gamma < 10$ GeV
- Acceptance $2° < \theta_{\pi^0} < 6°$, quite larger than the real one;
- Real acceptance (different for each target) from GEANT
- Other cuts from GEANT



Expected yield (20mn run L=1e^{35} cm^{-2} s^{-1})

- From Lead ~1800
- From 160μm Al+glue ~420

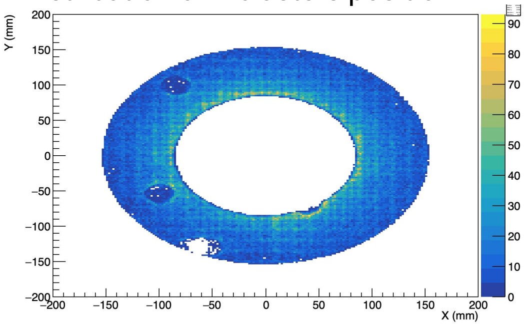


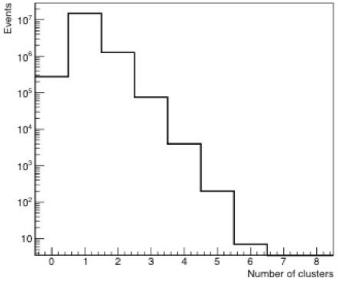
Streaming RO - CLAS12 FT test:

M. Battaglieri, M.Bondi, R. De Vita, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

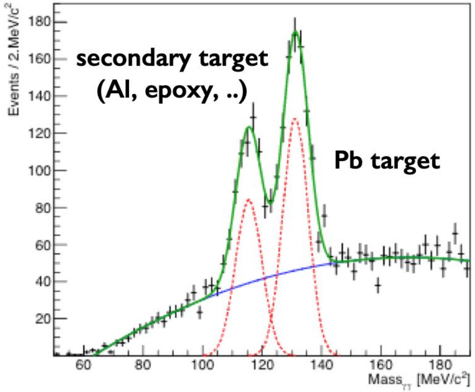
- off-line data analysis:
  - same full suite of reconstruction algorithm used in the on-line analysis
  - energy-calibration and time-walk correction
  - two targets: Pb(primary) + Al scattering chamber window
    - lower invariant mass due to the assumption that the vertex is located at the ... en calculating the invariant mass.

Distribution of 2 clusters position





Preliminary test results



- **Measured (expected) pi0 yield**

  Peak1 = 1365+-140 (~1800)

  Peak 2 = 930+-100 (~420)

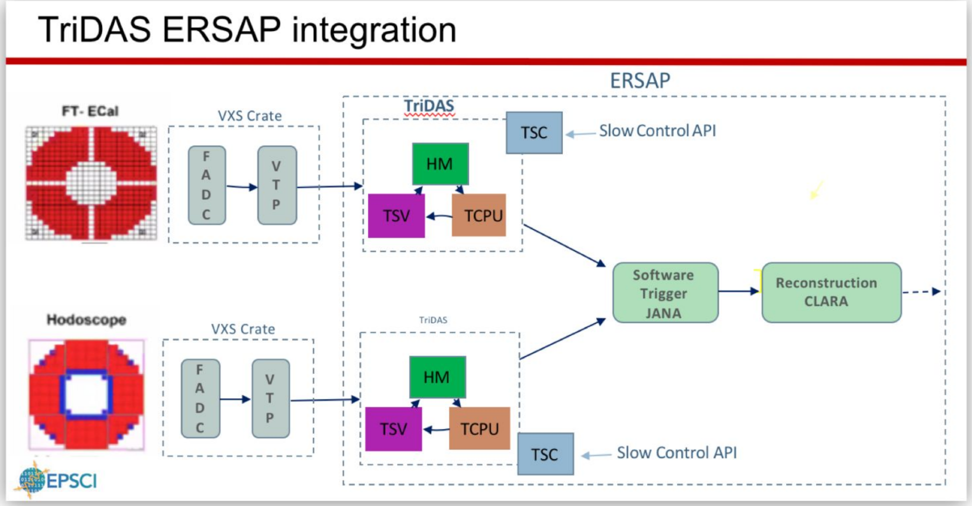
JLAB current SRO effort

V. Gyurjyan

- Hall-D and Hall-B test results demonstrated the first JLAB SRO DAQ system
- What next
  - Integration of different components in an optimized SRO framework

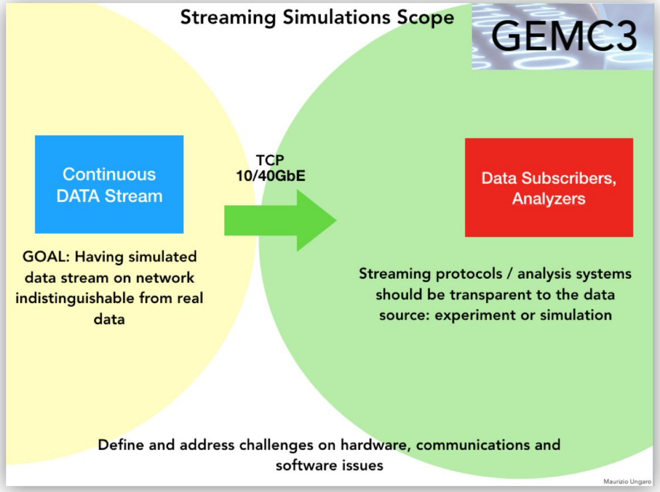
ERSAP

- Reactive, event-driven data-stream processing framework that implements micro-services architecture
- Provides basic stream handling services (stream aggregators, stream splitters, etc.)
- Adopts design choices and lessons learned from TRIDAS, JANA, CODA and CLARA



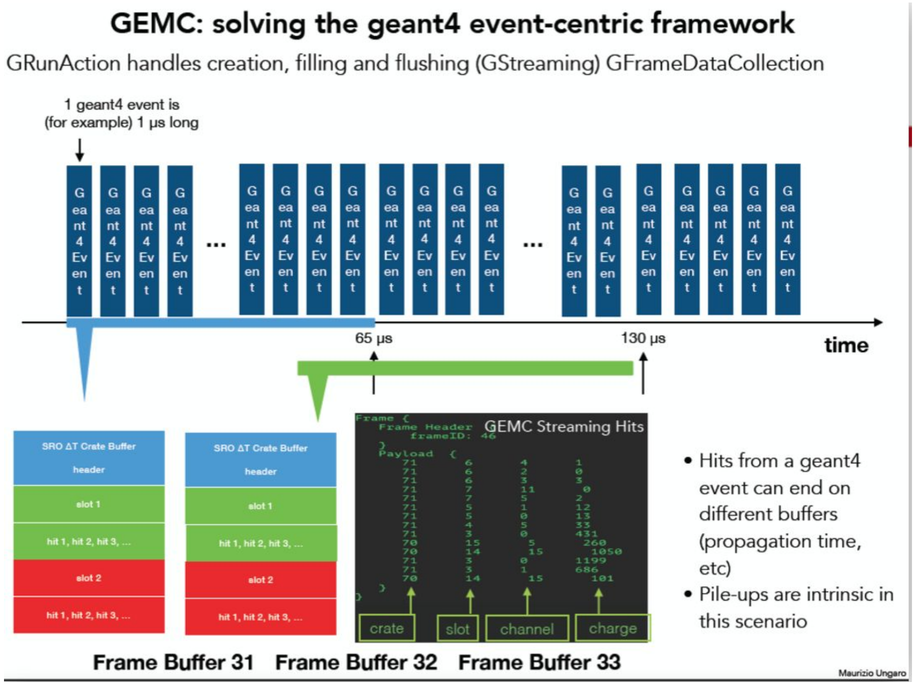
GEMC3: SRO GEANT4 MC

Development of a MC GEANT-based toolkit to implement SRO in detector simulations



- Transform event-based to stream-based G4 logic
- Develop libraries share same on-line data format
- Emulate TCP output to feed to ERSAP
- Milestone Nov 2021, FT Calorimeter streaming

M. Ungaro, P. Moran, L. Cappelli



Summary

- SRO is the option for future EIC
- Take advantage of the full detector's information for an optimal (smart) tagging/filtering
- So many advantages: performance, flexibility, scaling, upgrading ...
  ... but, has to demonstrate to be as effective (or more!) than triggered systems
- Streaming Readout on-beam tests performed in Hall-D and Hall-B at JLab
- First SRO chain (FE + SRO sw + ON-LINE REC) tested with existing hardware
- Deployment of JLab SRO framework based on micro-services architecture (ERSAP)
- Taking advantage of current JLab operations for on-beam tests
- Development of a SRO G4 MC (GEMC3)

Many thanks to the whole JLAB SRO team: F.Ameli (INFN), M. Battaglieri (INFN), V.Berdnikov (CUA), S.Boyarinov (JLab) M.B. (INFN), N.Brei (JLab), A.Celentano (INFN), T.Chiarusi (INFN), C.Cuevas(JLab), R. De Vita (INFN), C.Fanelli (MIT), G.Heyes (JLab), T.Horn (CUA), V.Gyurjyan(JLab), D.Lawrence (JLab), L.Marsicano (INFN), P.Musico (INFN), C.Pellegrino (INFN), B.Raydo (JLab), M.Ungaro (JLab), S.Vallarino (INFN)

Many thanks to CLAS12 collaboration as well as JLAB technical staff for their accommodation and support of this effort