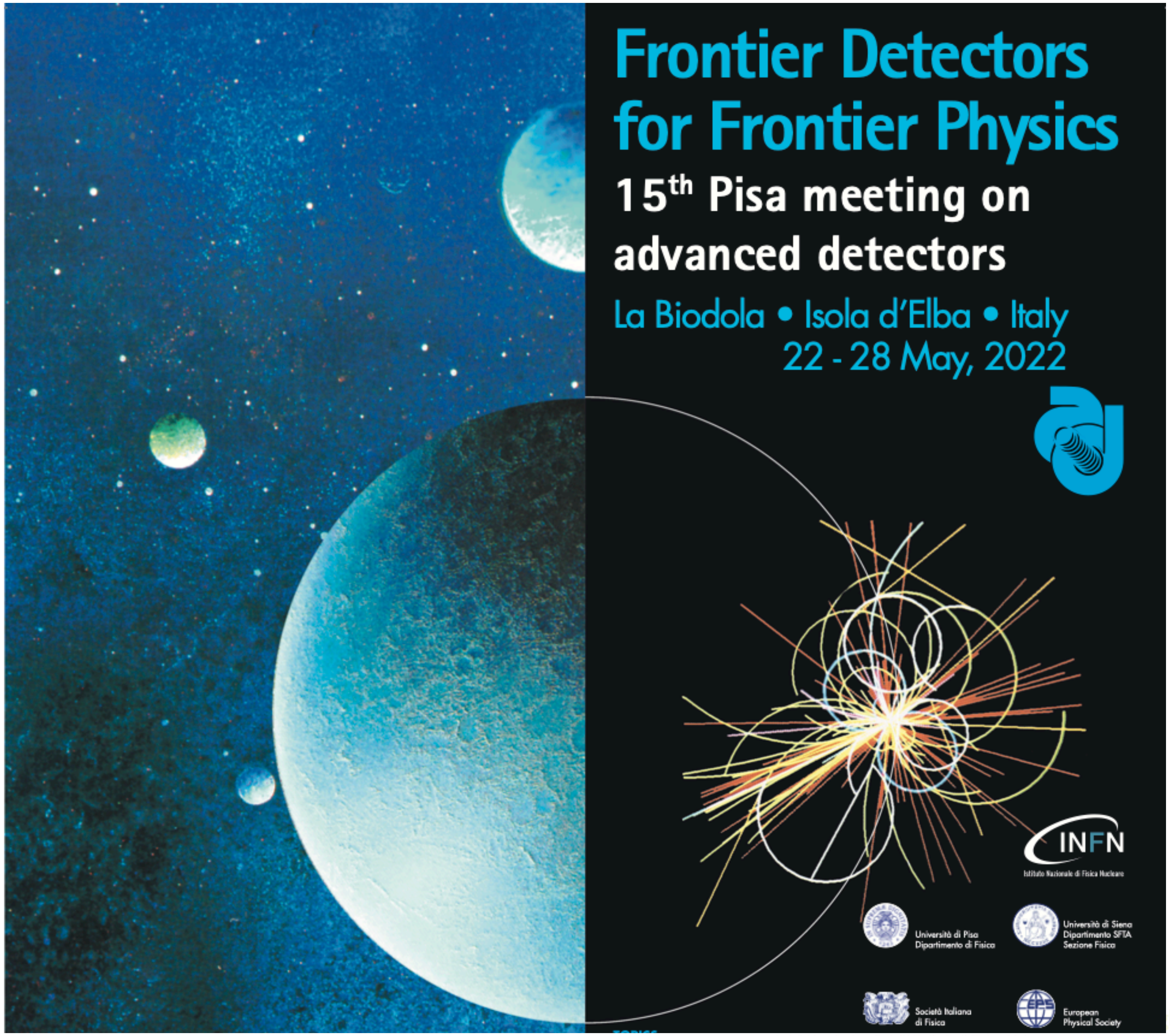


Streaming data acquisition system for electron scattering experiments

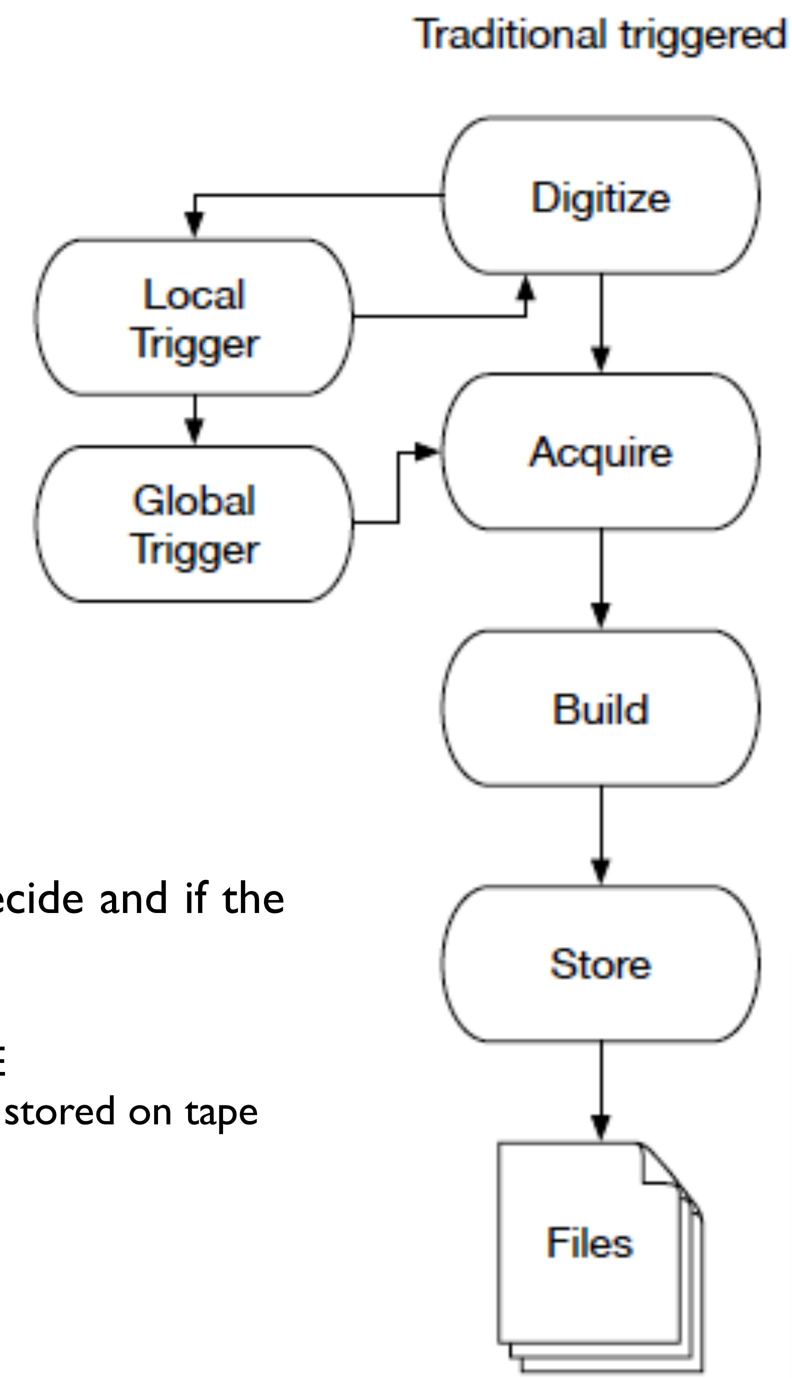
Marco Battaglieri
INFN

Farnesina
Ministero degli Affari Esteri
e della Cooperazione Internazionale

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

Streaming RO

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:

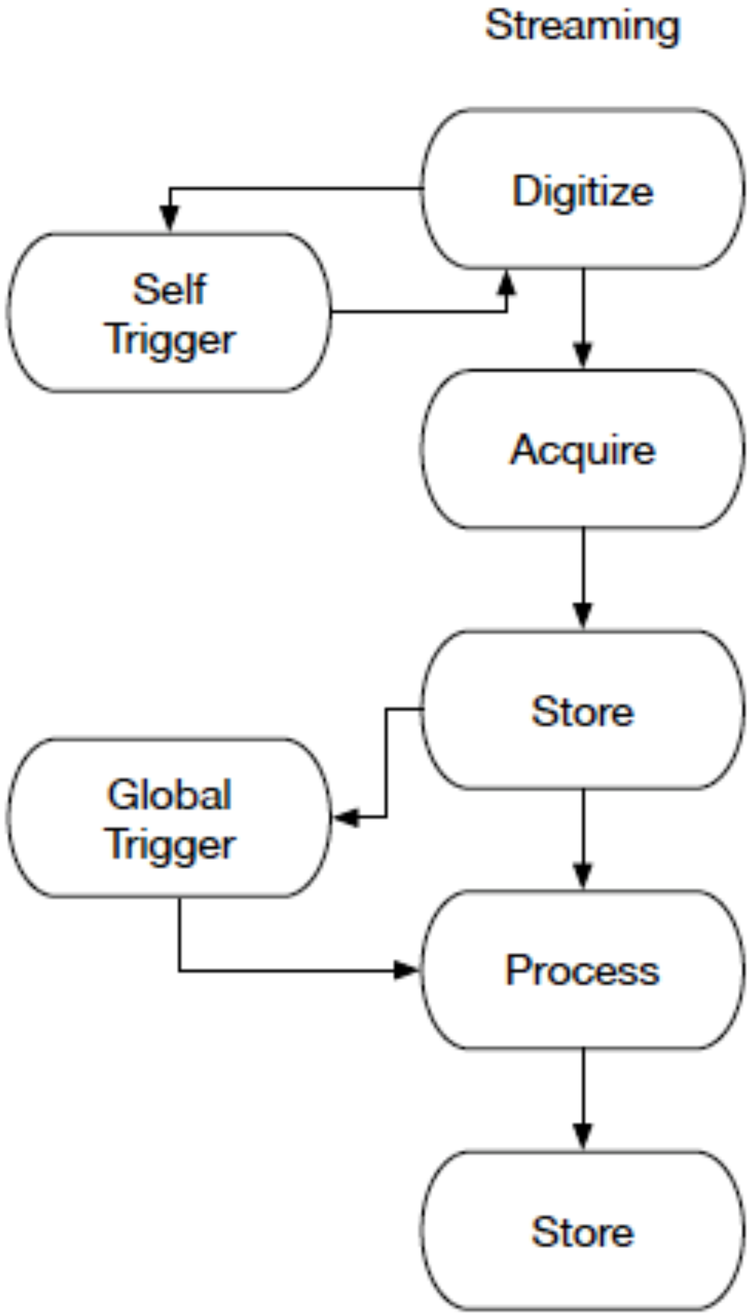
- a new 'event' is defined
- trigger signal back to the FEE
- data read from memory and stored on tape

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 RO

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?

- **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

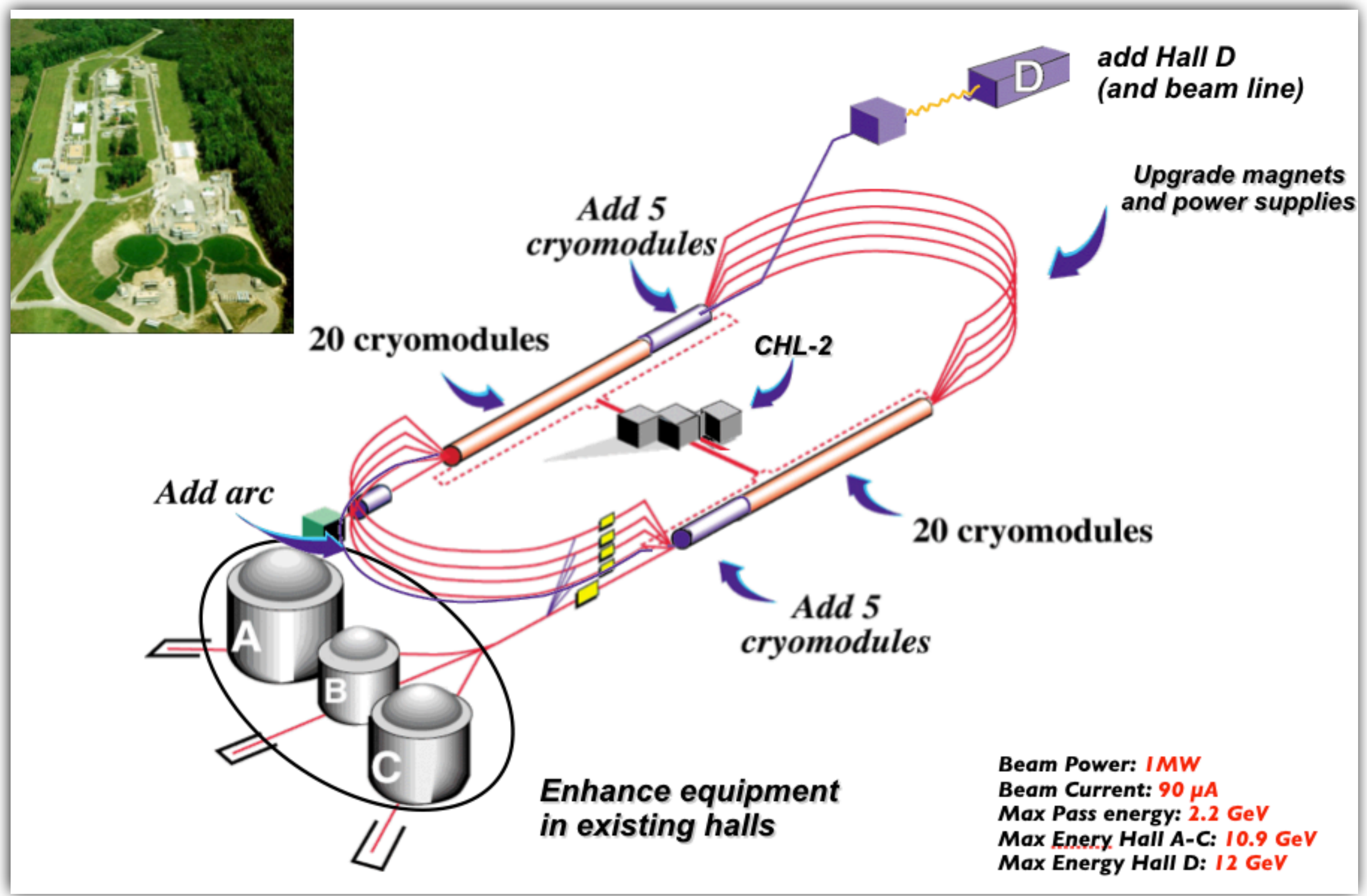
Many NP and HEP experiments adopt the SRO scheme (with different solutions):

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

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

Present & future

Jefferson Lab



- ✳Primary Beam: Electrons
- ✳ Beam Energy: 12 GeV
  - 10 > λ > 0.1 fm
  - nucleon → quark transition
  - baryon and meson excited states
- ✳100% Duty Factor (cw) Beam
  - coincidence experiments
  - Four simultaneous beams
  - Independent E and I
- ✳ Polarization
  - spin degrees of freedom
  - weak neutral currents

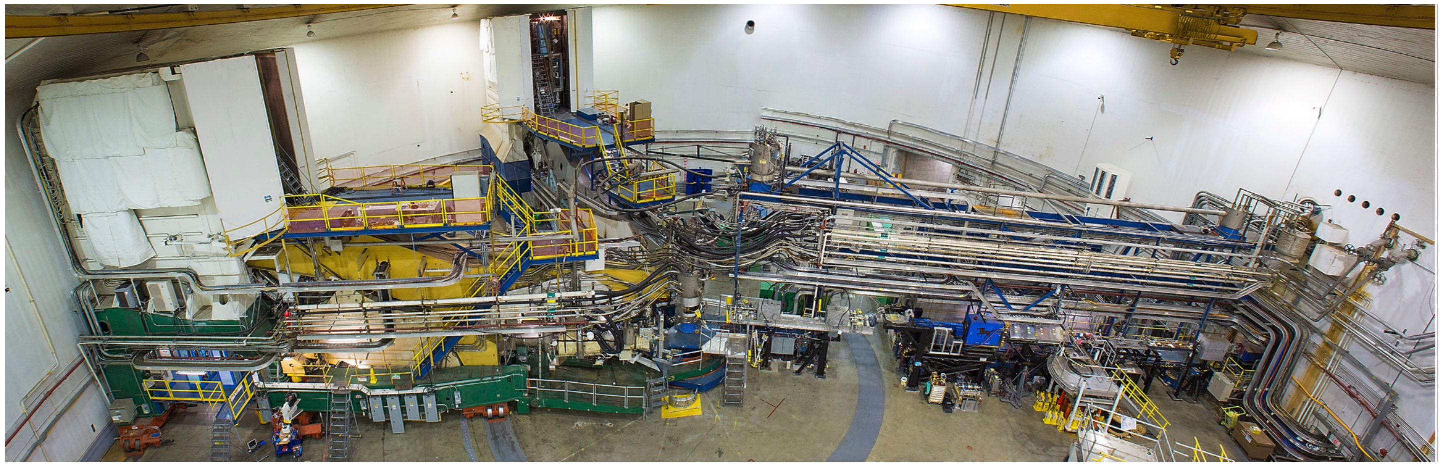
Luminosity > 10^7 -10^8 x SLAC at the time of the original DIS experiments!

- ✳ **Streaming RO is necessary for a long-term HI-LUMI upgrade of CLAS12**
  - Current triggered DAQ max rate < 100 kHz (R~30 kHz now)

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

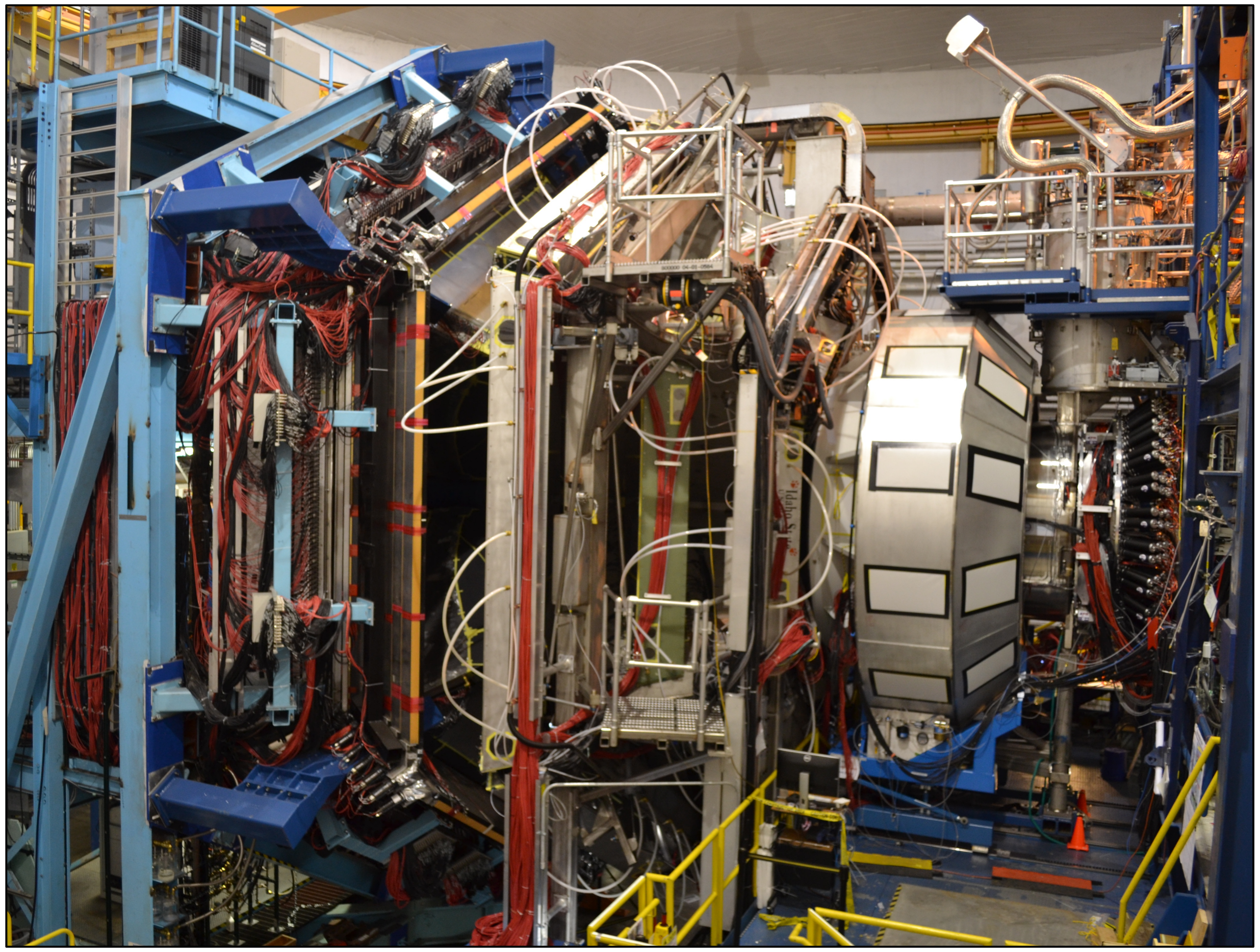
Present & future

Hall A

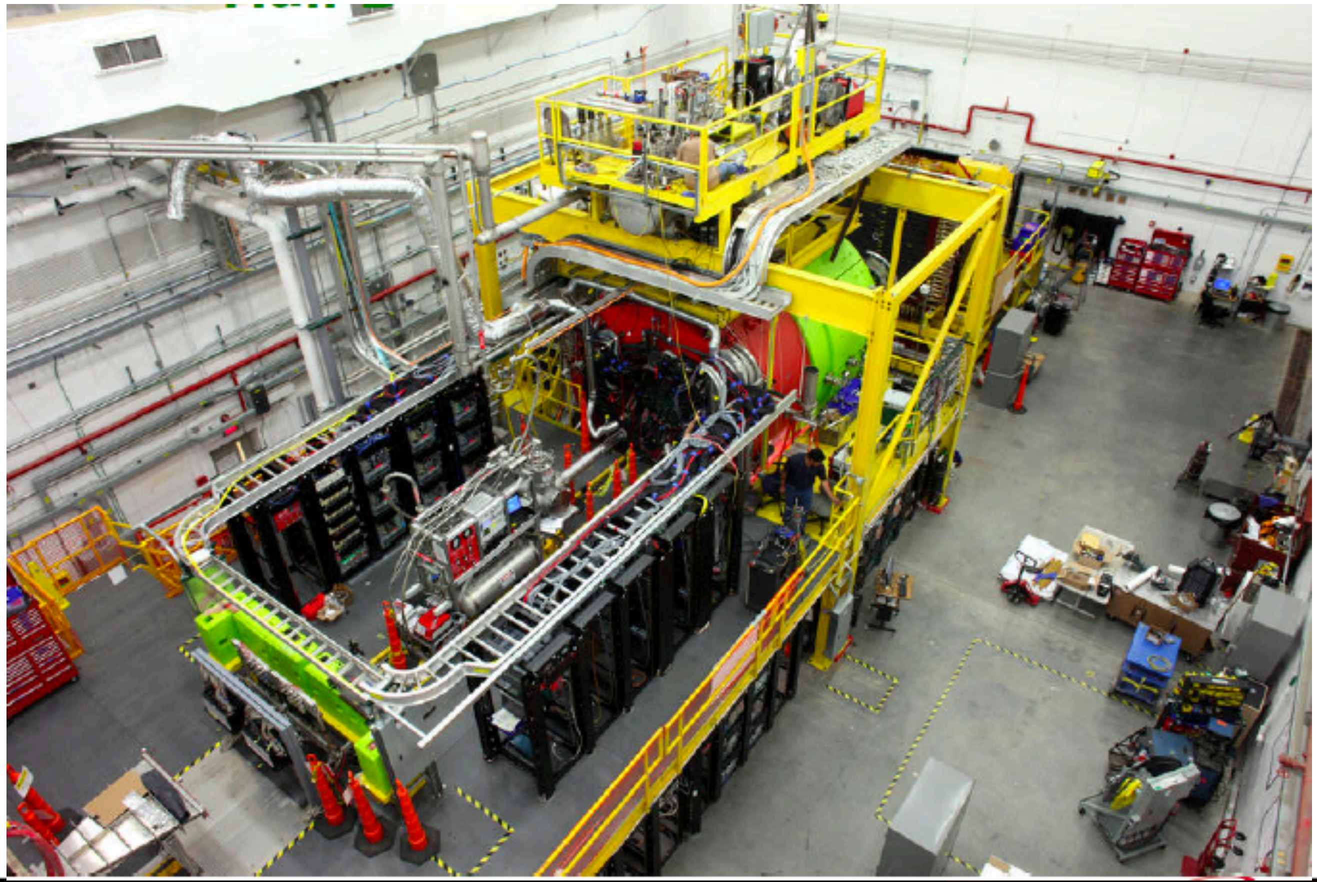


Hall C

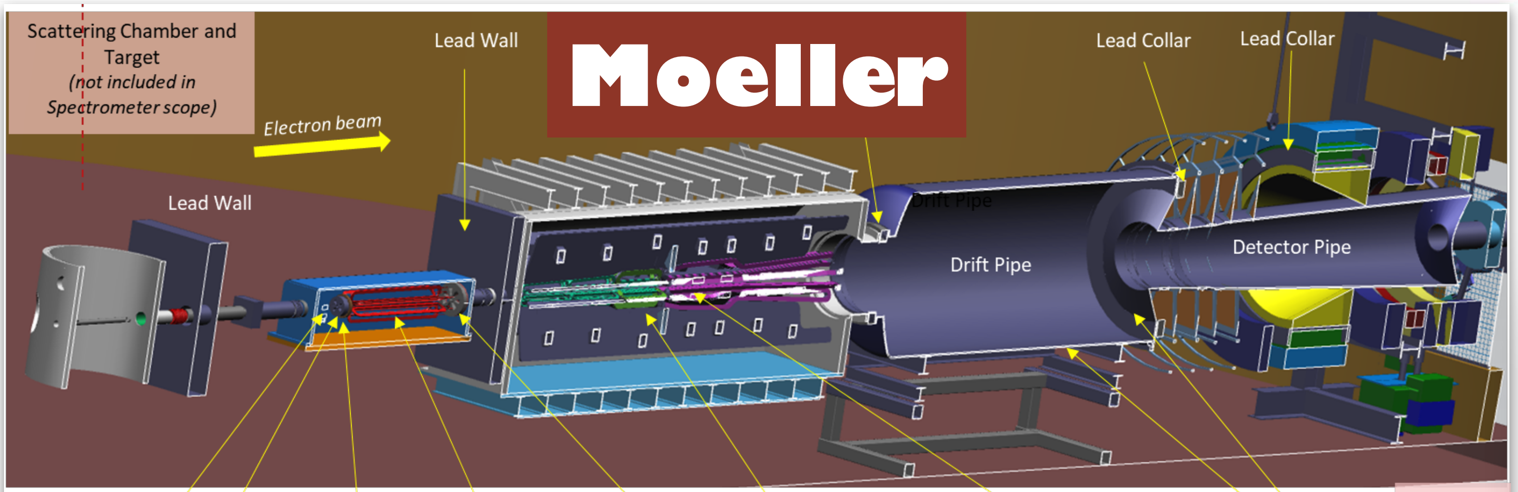
Hall B



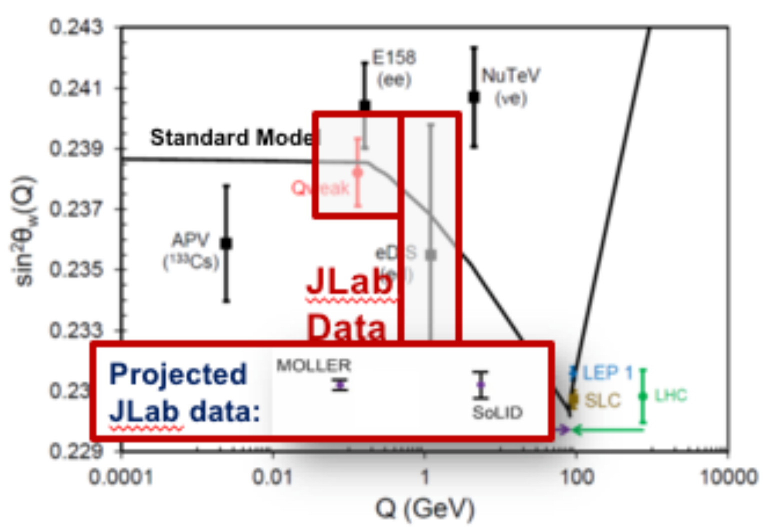
Hall D



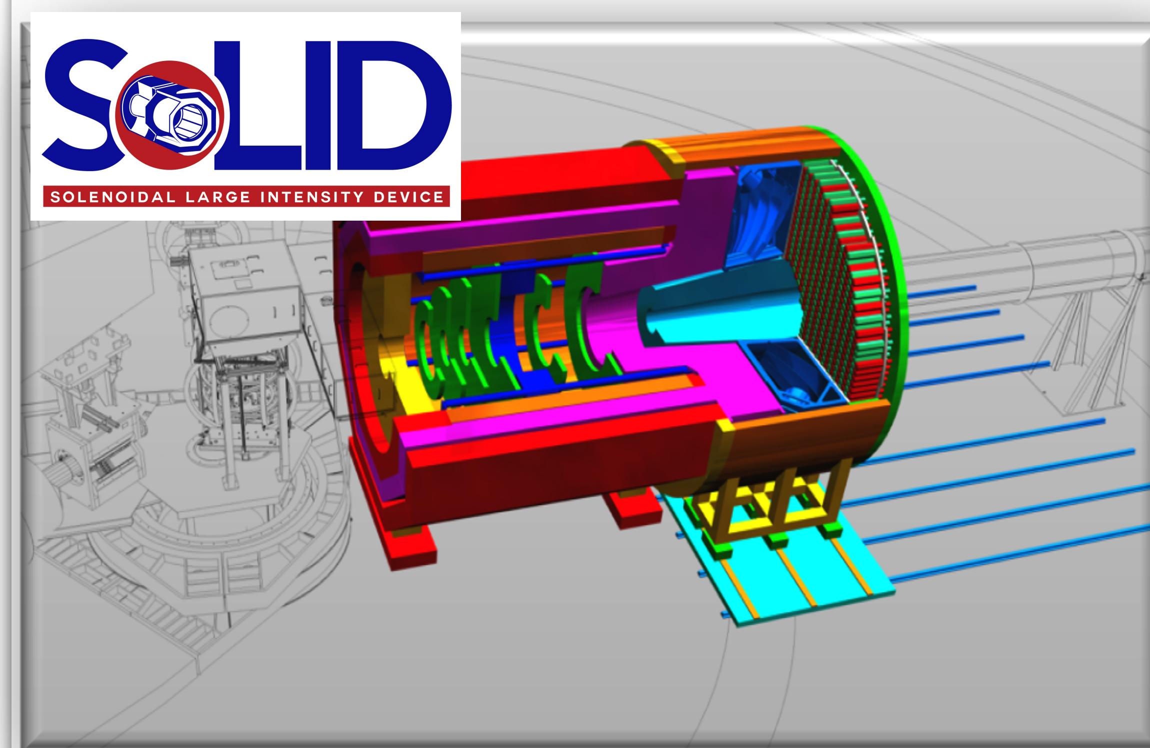
Present & future

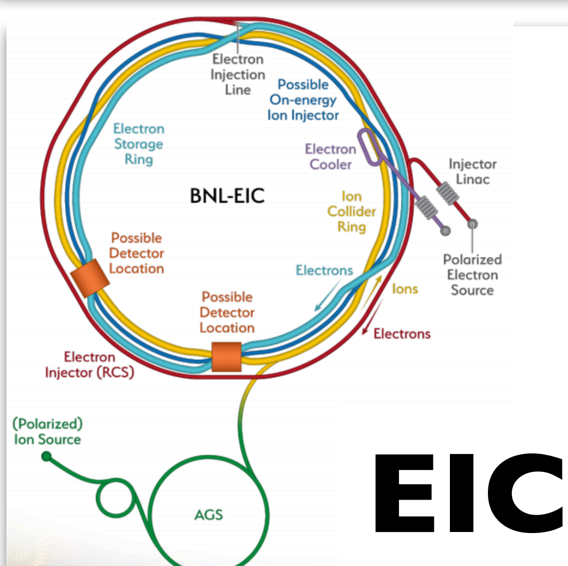


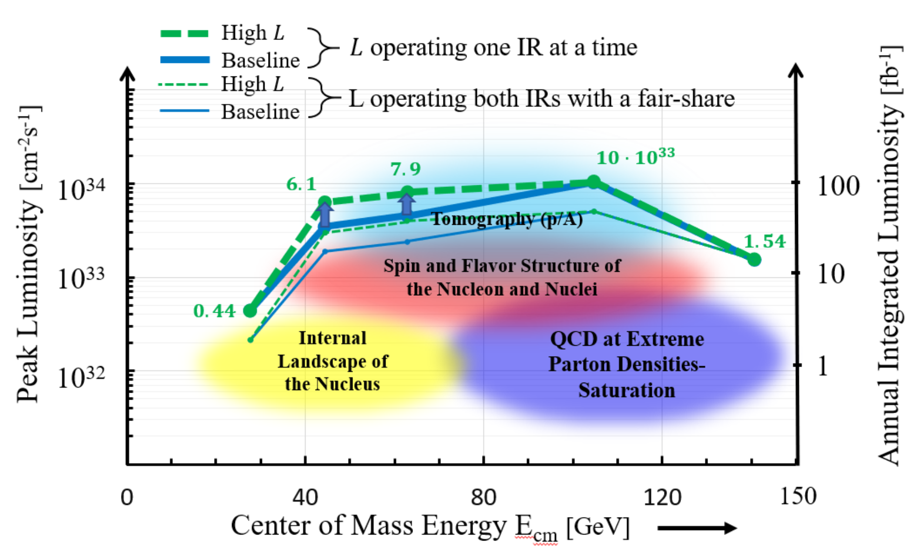
- Unique discovery space for new physics up to 38 TeV mass scale, with a purely leptonic probe
- CD-1 approved Dec 2020
- Expected to operate in FY26



- **SO**lenoidal **L**arge **I**ntensity **D**evice – new multipurpose detector facility optimized for high luminosity ($10^{37\text{-}39}$ cm^{-2} s^{-1}) and large acceptance





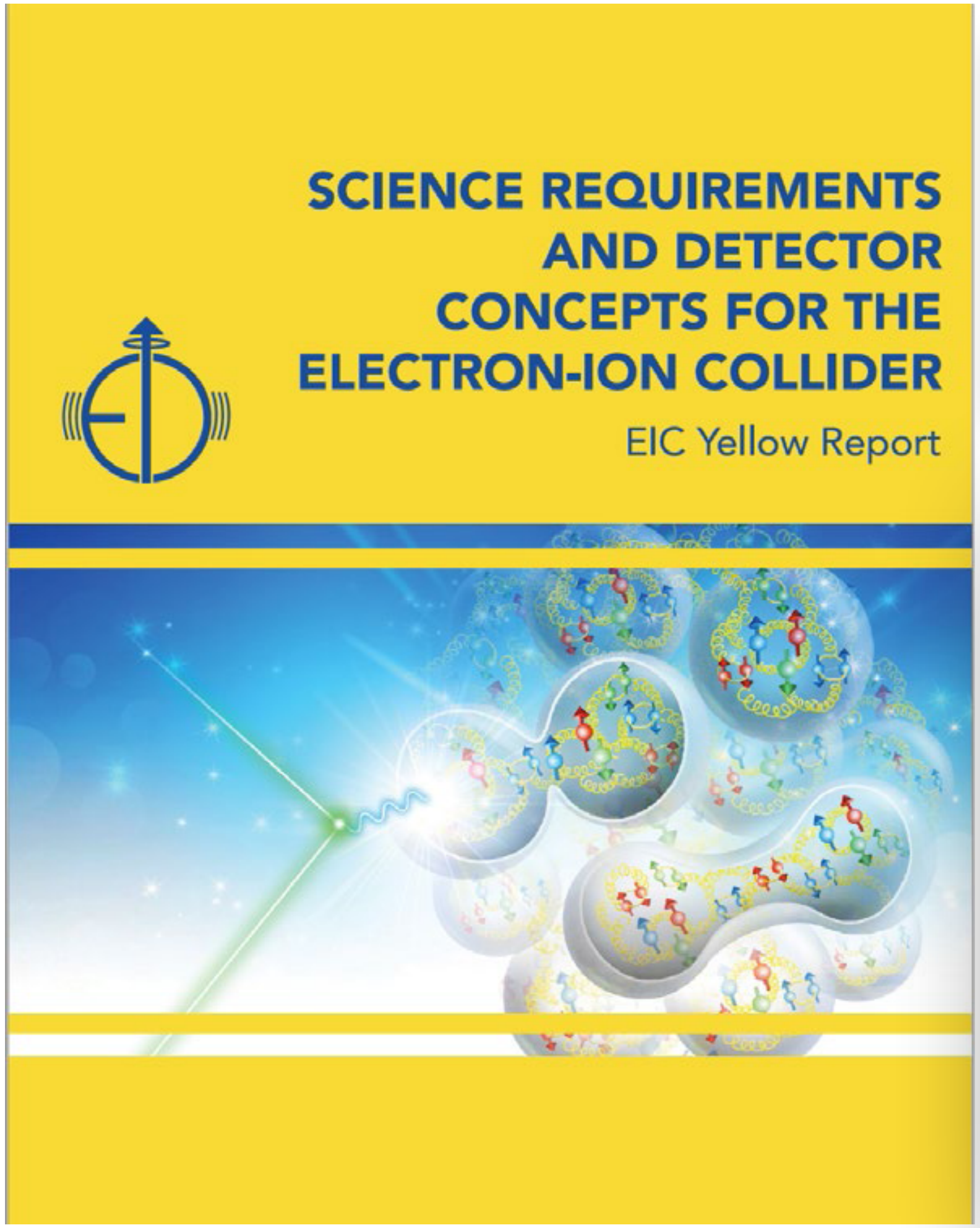


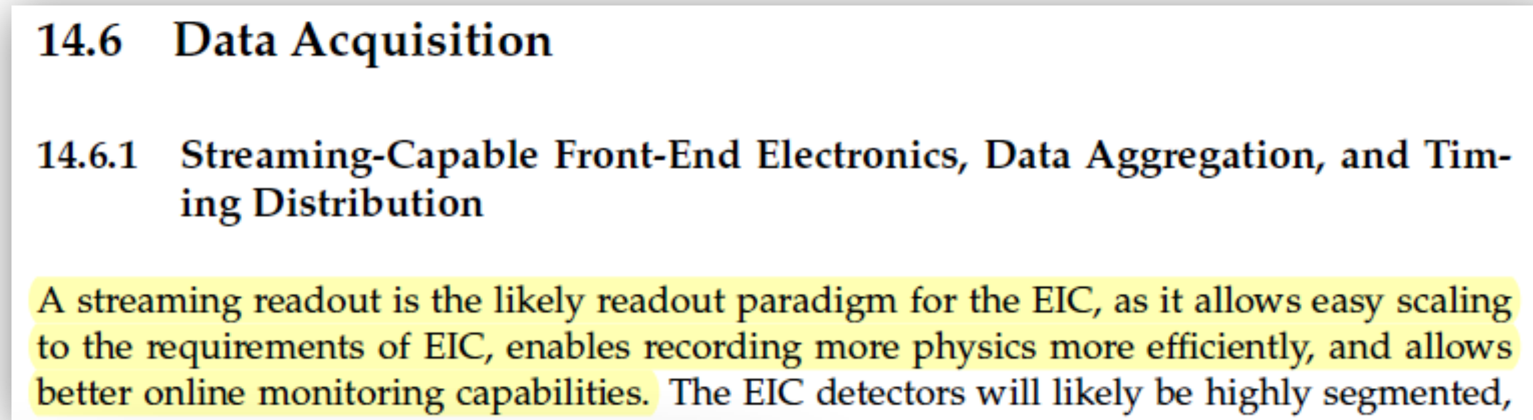
- Luminosity 100-1000 times that of HERA
- Polarized protons and light nuclear beams
- Nuclear beams of all A (p→U)
- Center mass variability with minimal loss of luminosity

- Large acceptance
- Frwrd/Bckw angles

- Precise vertexing
- HRes Tracking
- Excellent PID

SRO for EIC

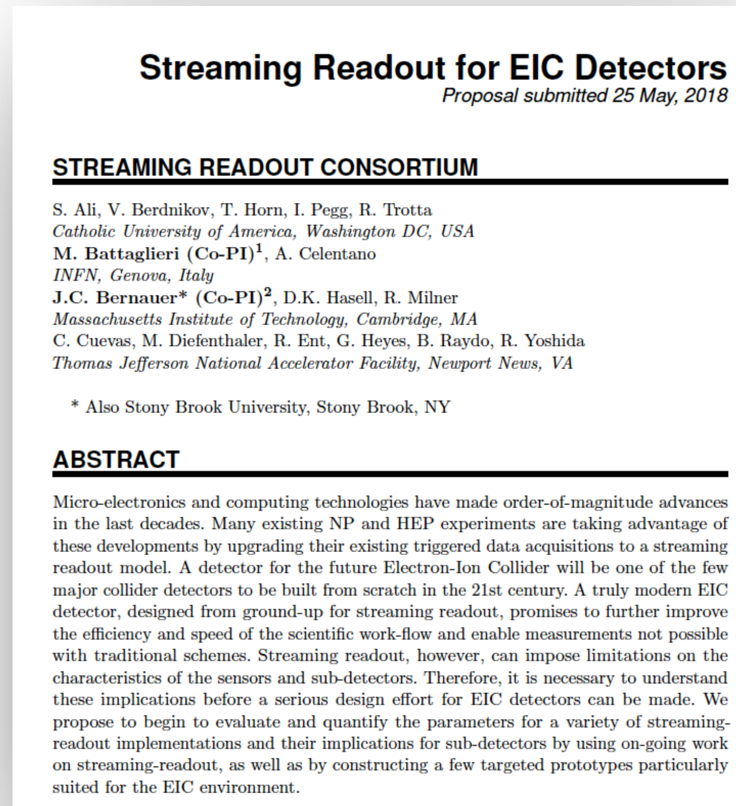




14.6 Data Acquisition

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,



Streaming Readout for EIC Detectors

Proposal submitted 25 May, 2018

STREAMING READOUT CONSORTIUM

S. Ali, V. Berdnikov, T. Horn, I. Pegg, R. Trotta
Catholic University of America, Washington DC, USA
M. Battaglieri (Co-PI)[1], A. Celentano
INFN, Genova, Italy
J.C. Bernauer* (Co-PI)[2], D.K. Hasell, R. Milner
Massachusetts Institute of Technology, Cambridge, MA
C. Cuevas, M. Diefenthaler, R. Ent, G. Heyes, B. Raydo, R. Yoshida
Thomas Jefferson National Accelerator Facility, Newport News, VA

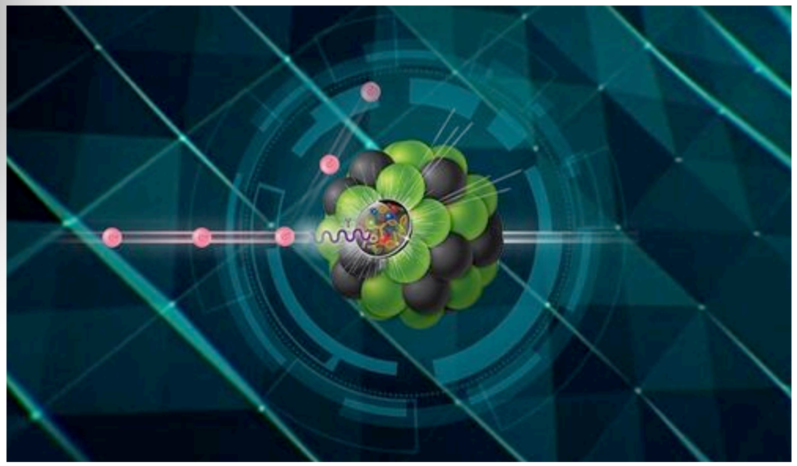
* Also Stony Brook University, Stony Brook, NY

ABSTRACT

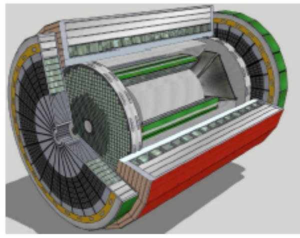
Micro-electronics and computing technologies have made order-of-magnitude advances in the last decades. Many existing NP and HEP experiments are taking advantage of these developments by upgrading their existing triggered data acquisitions to a streaming readout model. A detector for the future Electron-Ion 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.

EIC R&D
Streaming Readout
Consortium
eRD23

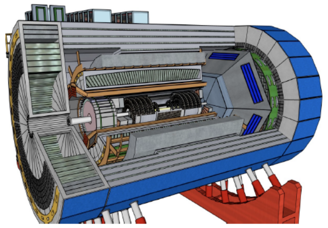
Streaming RO - X
- Organized by JLab
- May 17-19 2022



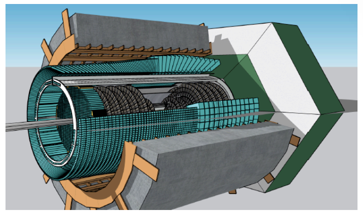
ECCE



ATHENA

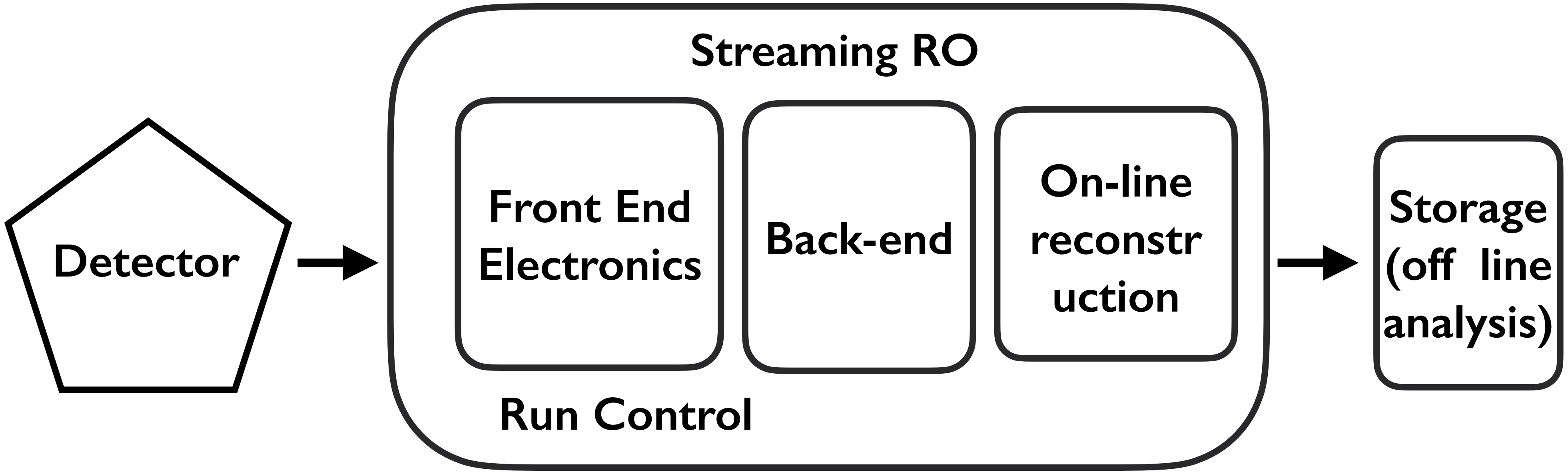


CORE



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

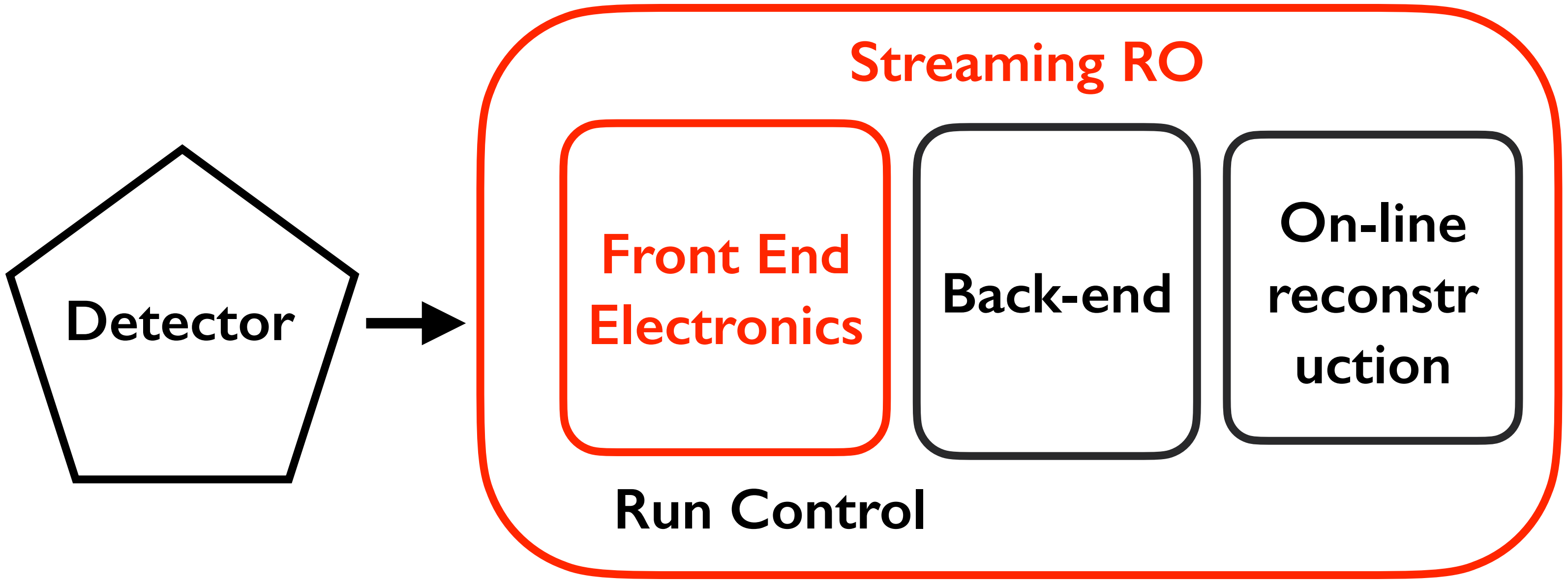
Streaming RO components



SRO concept validation

1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

Streaming RO components



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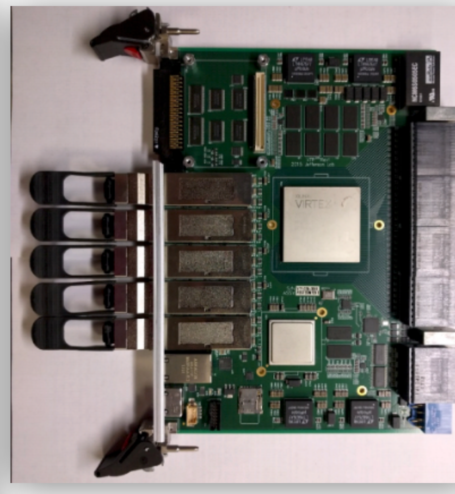


FrontEnd

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

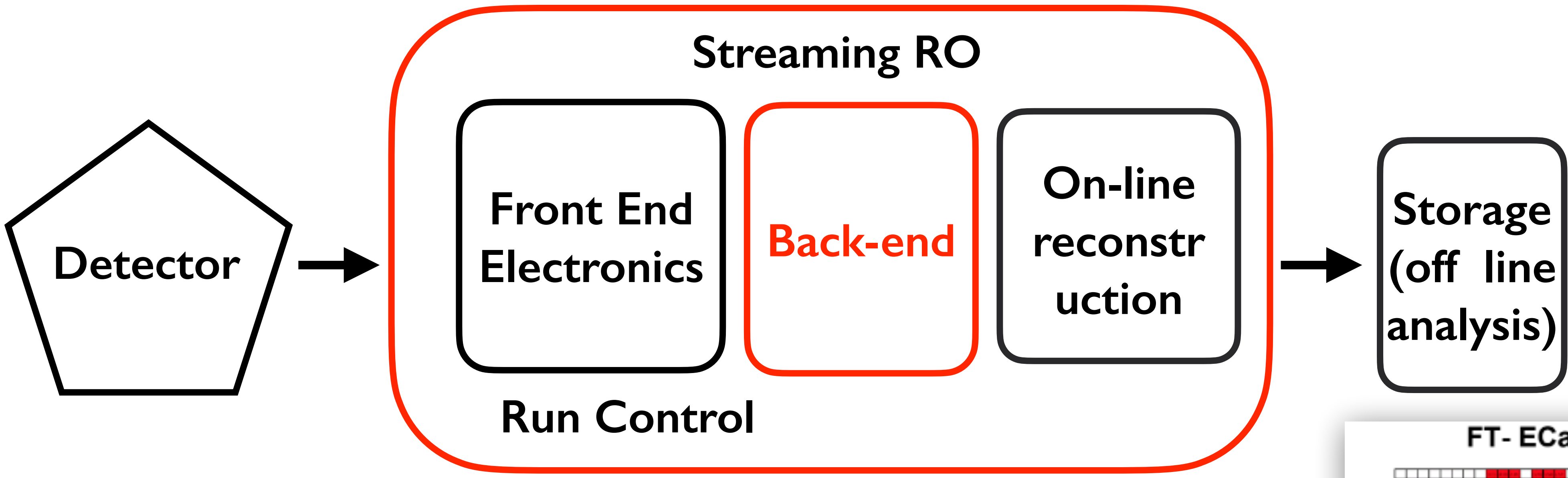
✳ **JLab fADC250 + VTP bord**

- 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

✳ **INFN WaveBoard**

- SRO dedicated INFN 250 MHz flash ADC digitizer

Streaming RO components



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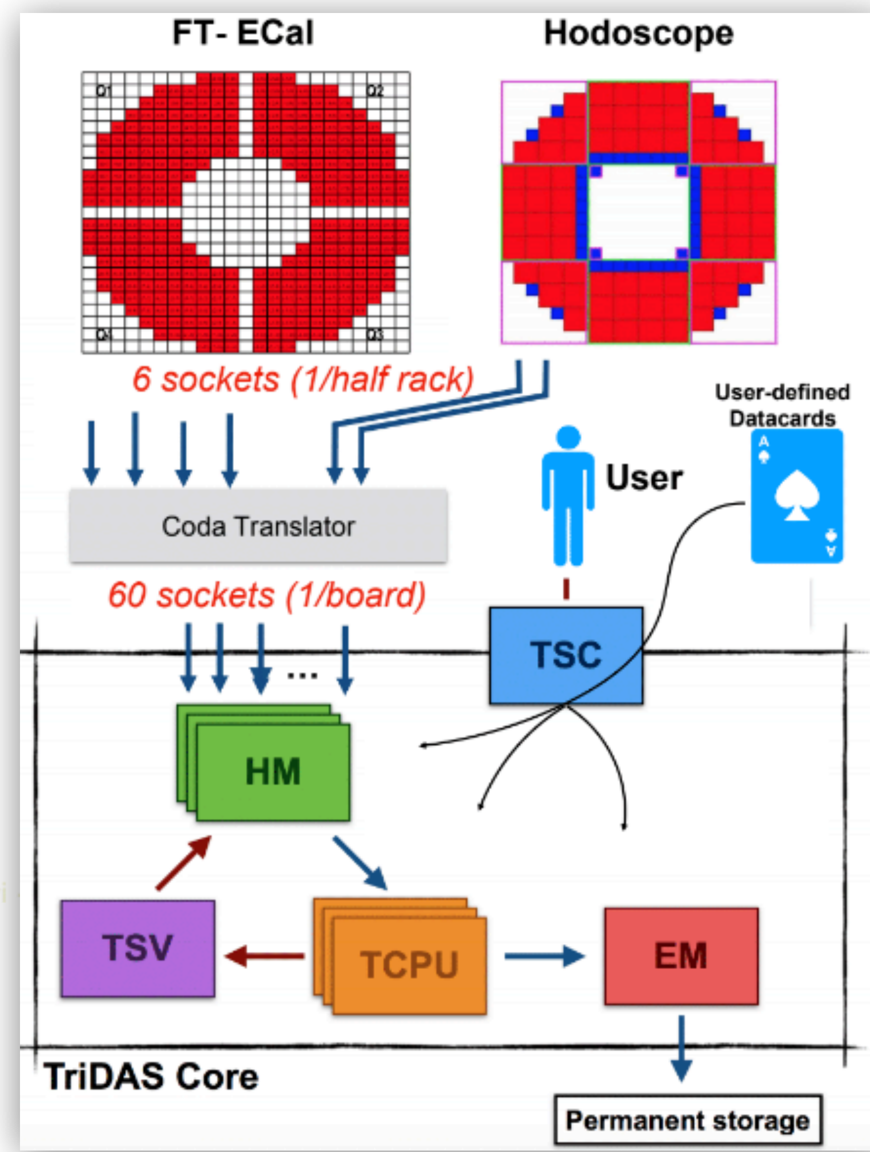
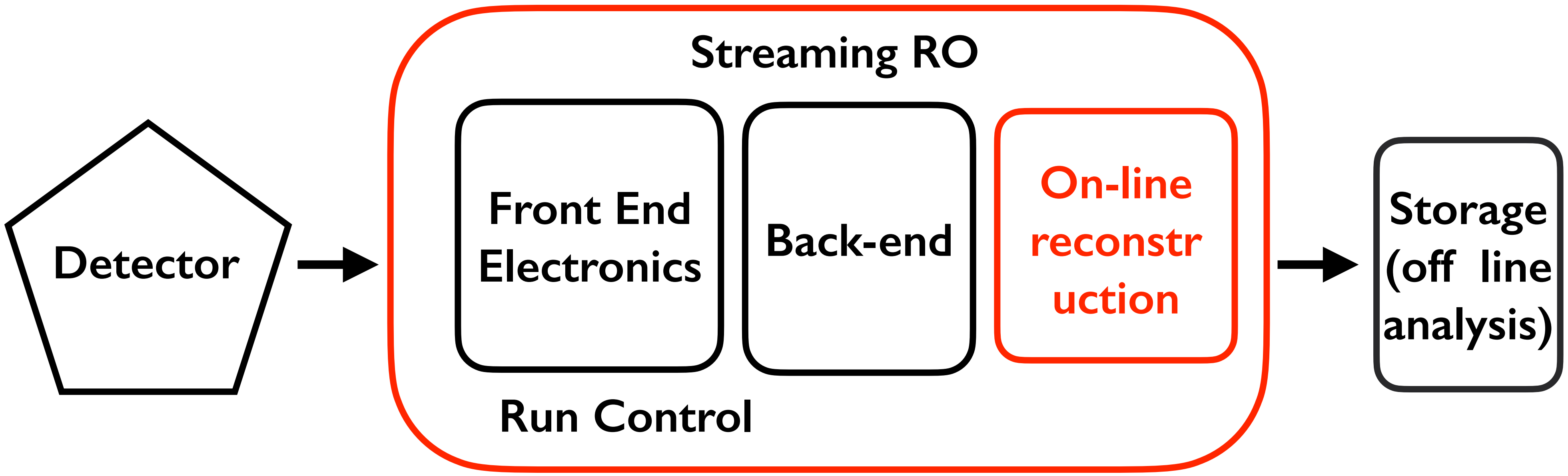
BackEnd

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 components



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1) Assemble SRO components
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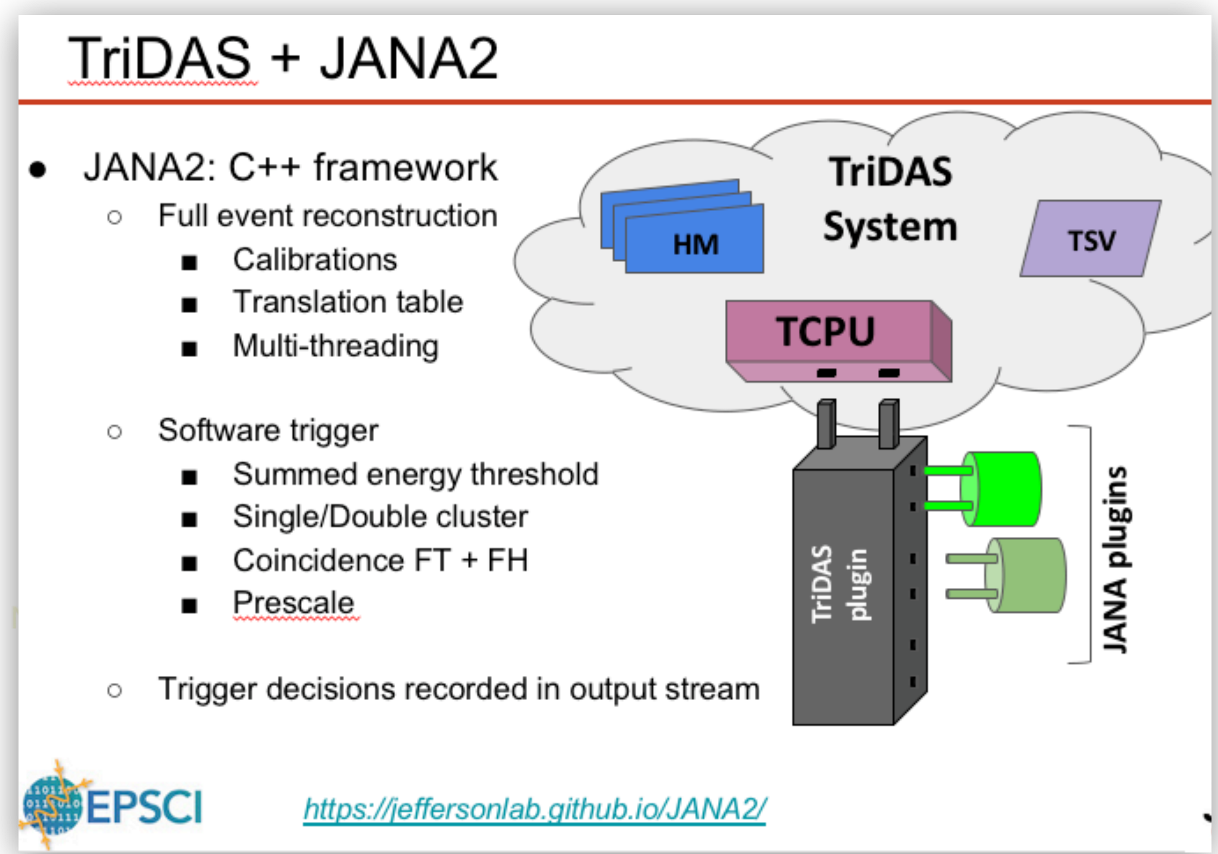
3) Test SRO DAQ on-beam

Jana2 + reconstruction

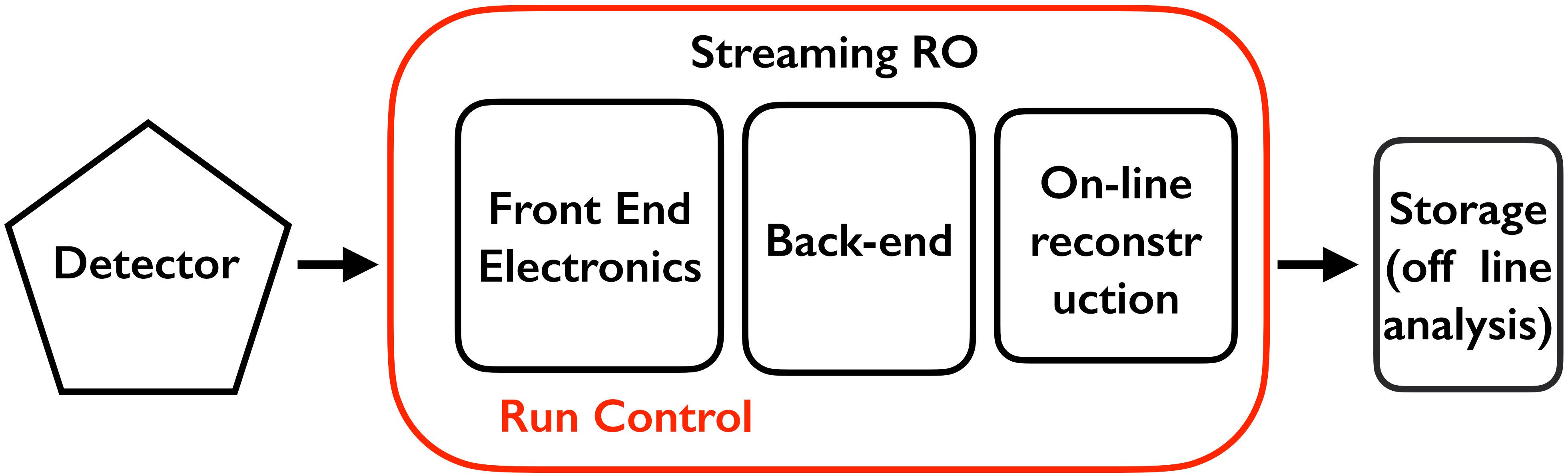
N.Brei, D.Lawrence,
M.Bondi', A.Celentano, C.Fanelli, S.Vallarino

✳ 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 ($N_{cluster}$≥1, 2, 3)
  - cosmic tracking
  - AI clustering algorithm: at least two cluster in the FT-CAL



Streaming RO components



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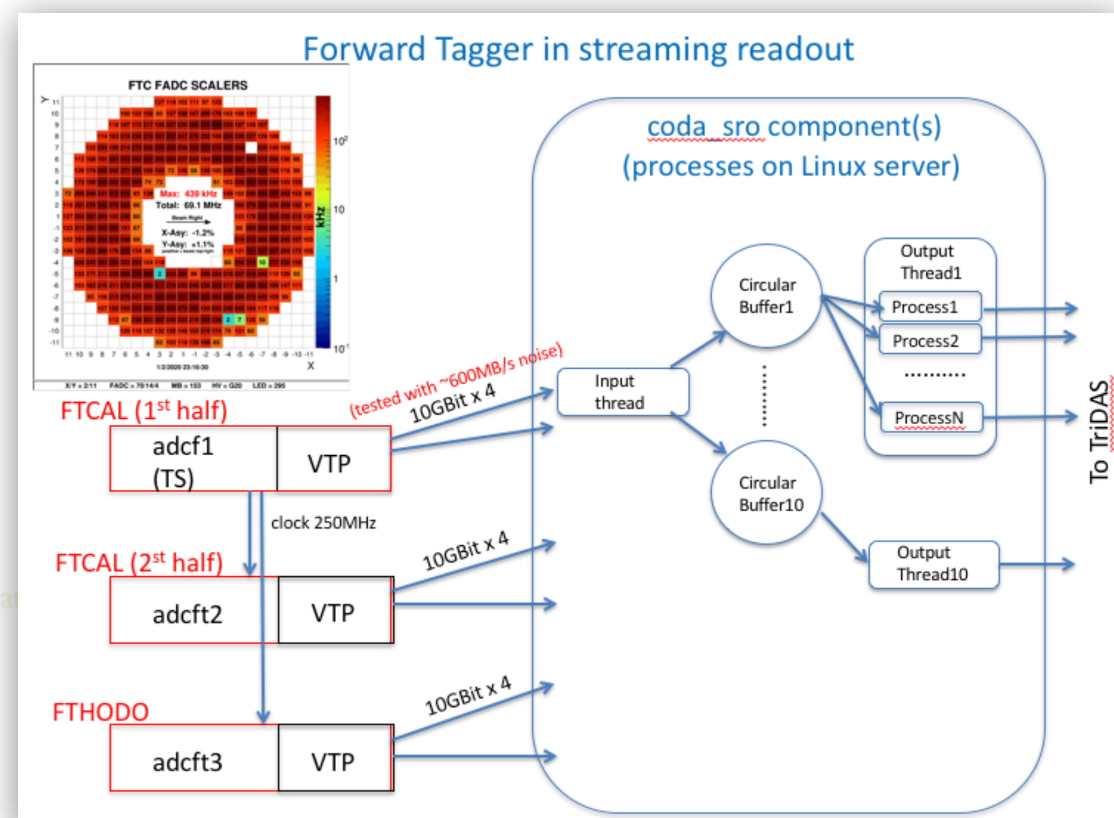
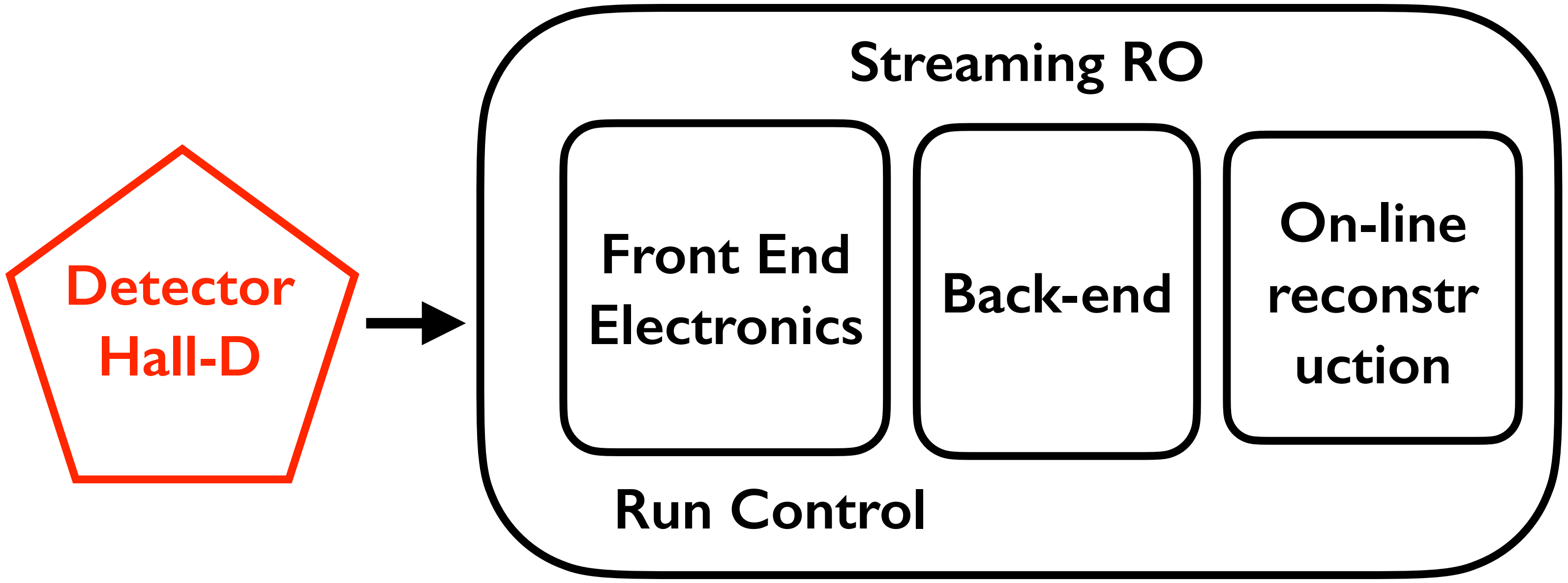
Cebaf Online Data Acquisition (CODA)

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)



Streaming RO components



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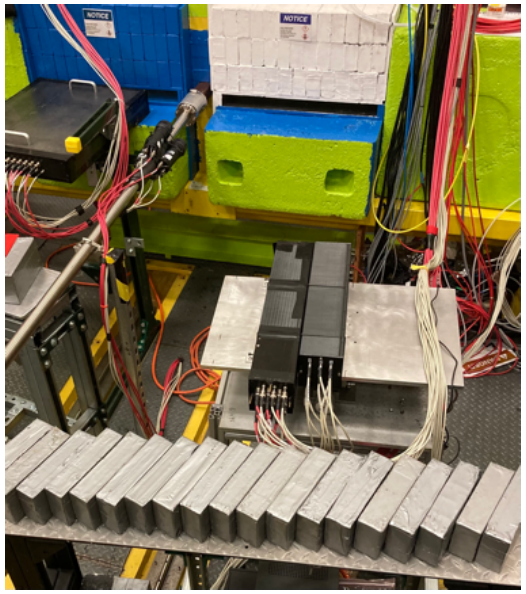
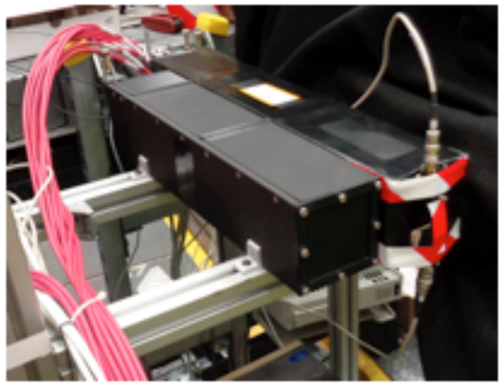
JLab SRO validation

V.Berdnikov, T.Horn



✳ **EIC ECal PbWO prototype**

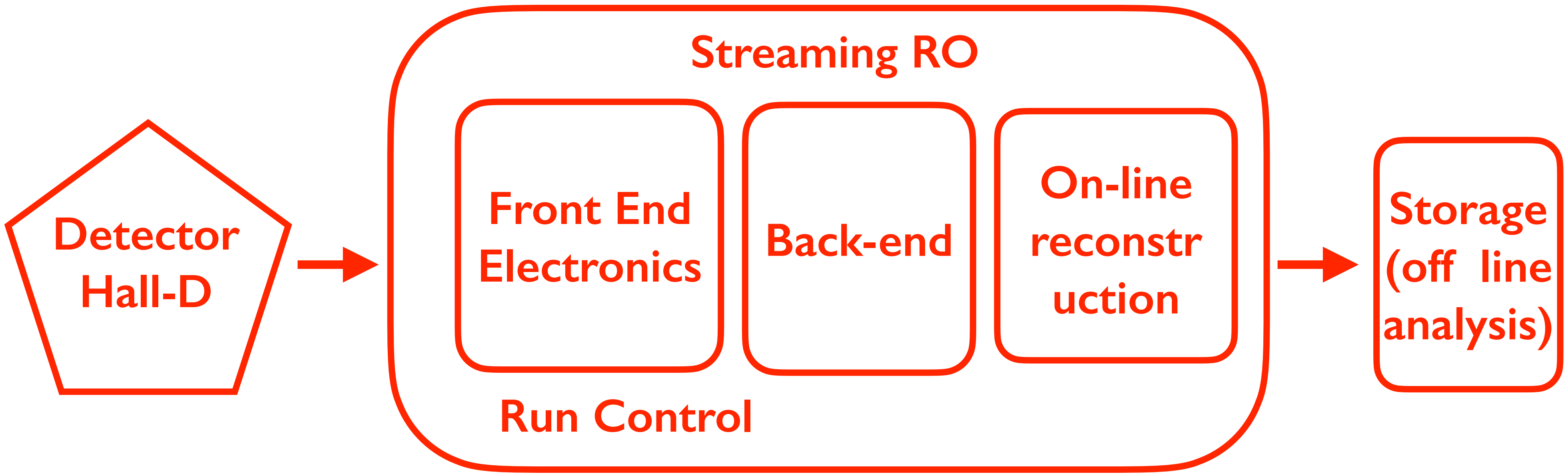
- Use the Hall-D Pair Spectrometer setup
- Secondary e+/e- beam: E range (3-6) GeV
- Simple setup to compare TRIGGERED to TRIGGERLESS
- 3x3 PbWO crystals, PMT and SiPM readout
- fADC250+VTP and WaveBoard front end



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

Waveboard

Streaming RO components



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JLab SRO test

V.Berdnikov, T.Horn

Preliminary test results

✳ **EIC ECal PbWO prototype**

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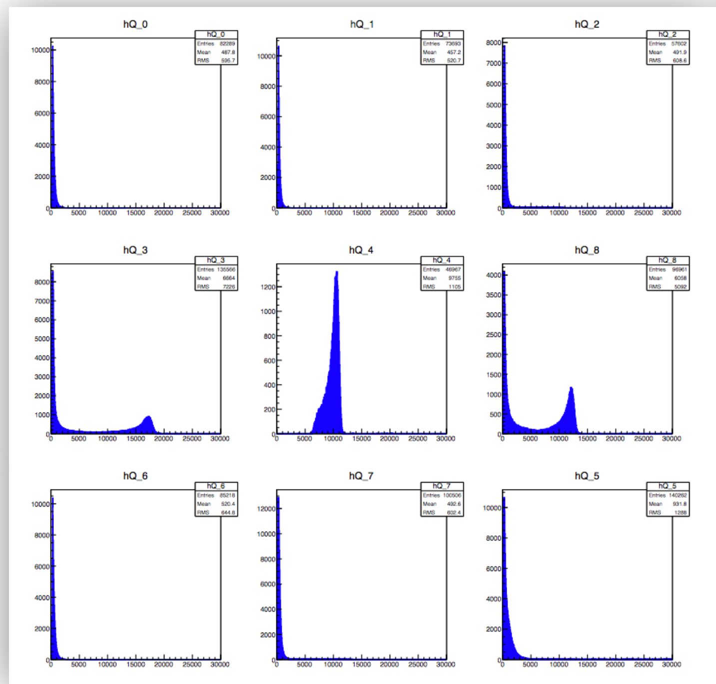
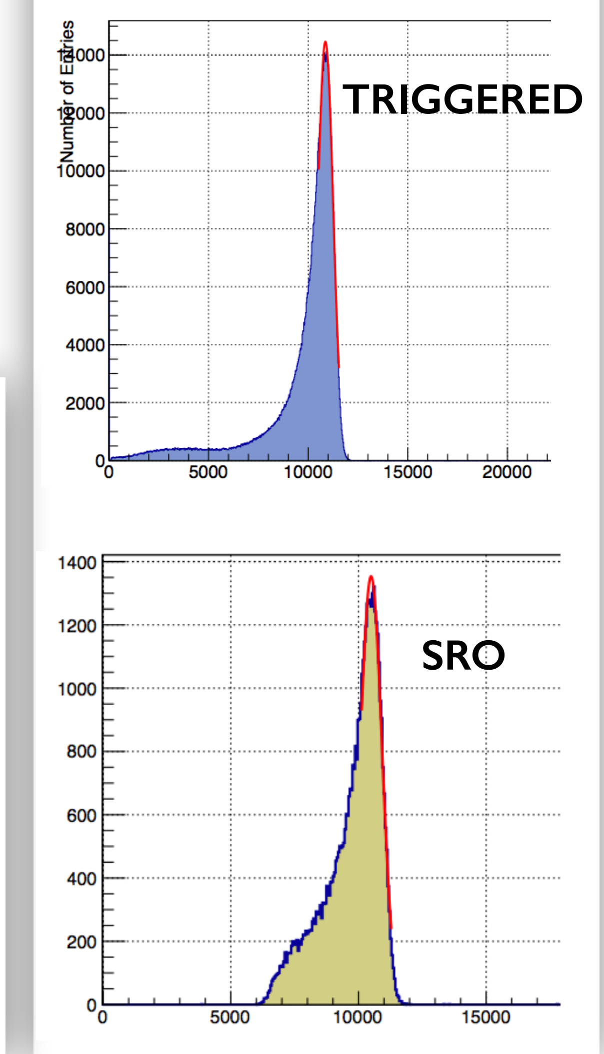
- Secondary e+/e- beam: E range (3-6) GeV
- Simple setup to compare TRIGGERED to TRIGGERLESS
- 3x3 PbWO crystals, PMT and SiPM readout
- fADC250 and WaveBoard front end

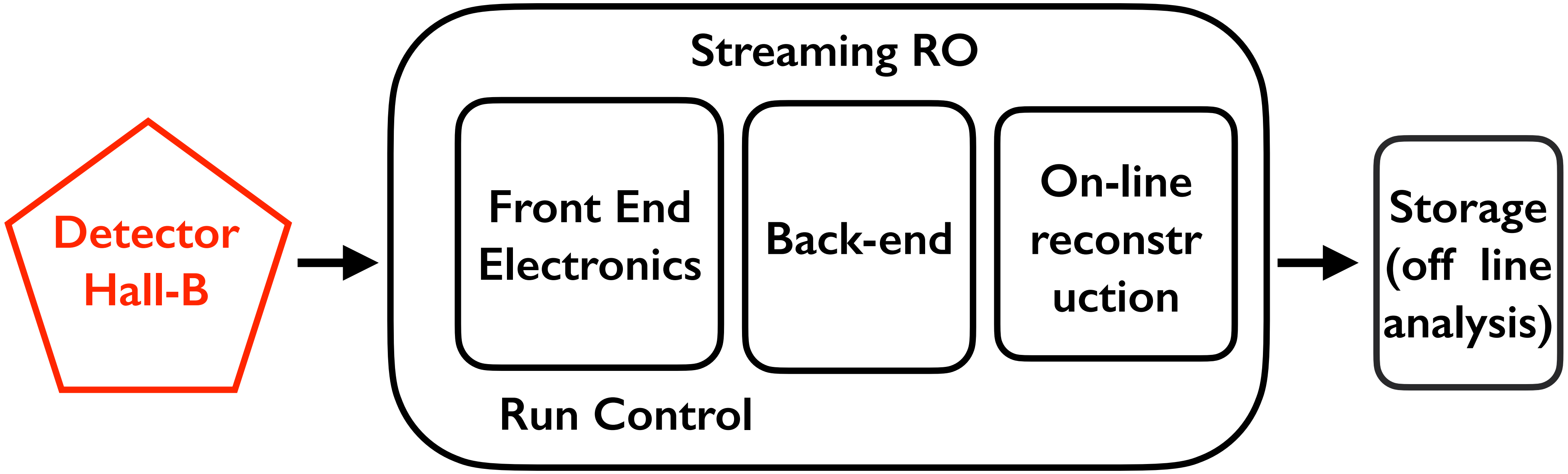
ECAL proto: 9ch SRO-mode



EM shower seed



Streaming RO components



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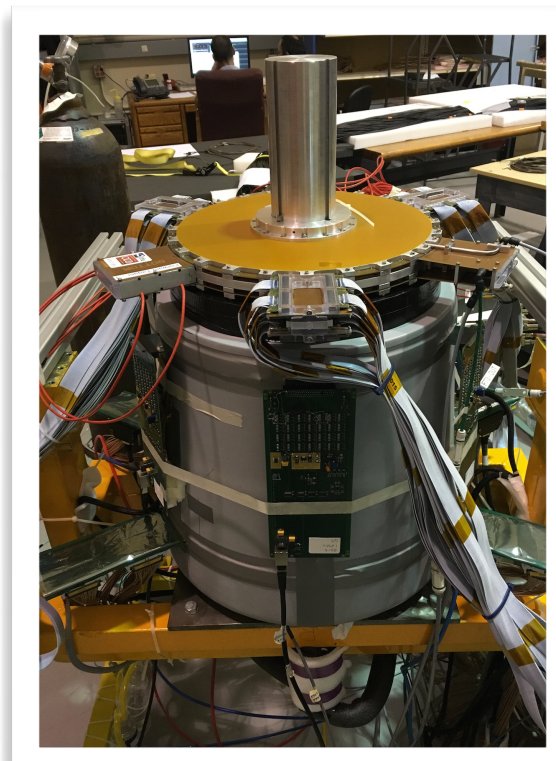
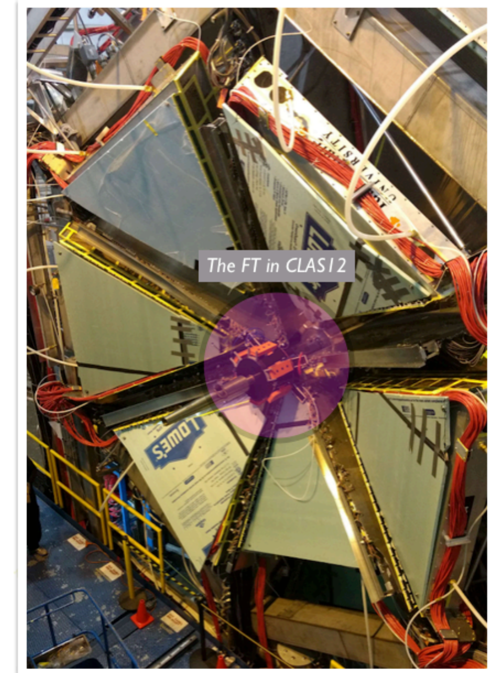


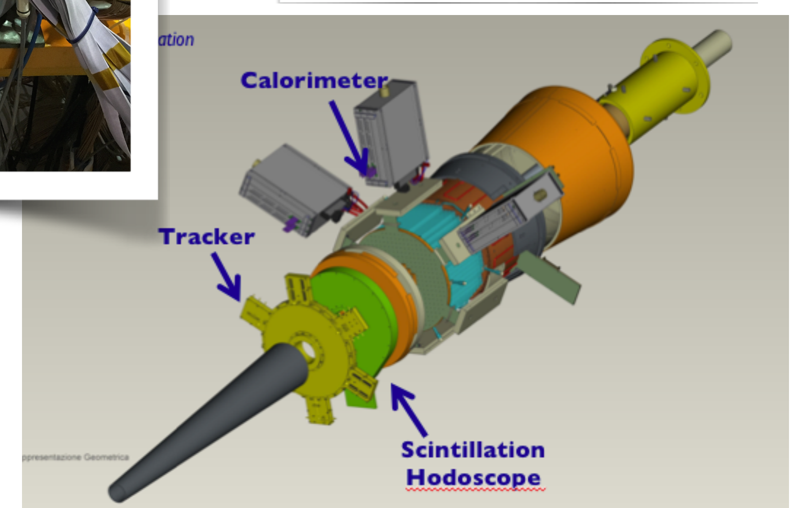


JLab SRO validation

M.Bondi, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

✳ **CLAS12 Forward Tagger**

- Complete system that include calorimetry, PiD, Traking in a simpler (than CLAS12) set up
- FT-ECAL: 332 PbWO crystals, APD readout
- FT-HODO: 224 plastic scintillator tiles, SiPM readout
- FT-TRK: ~3000 channels, MicroMegas
- fADC250 digitizers + DREAMs for MM



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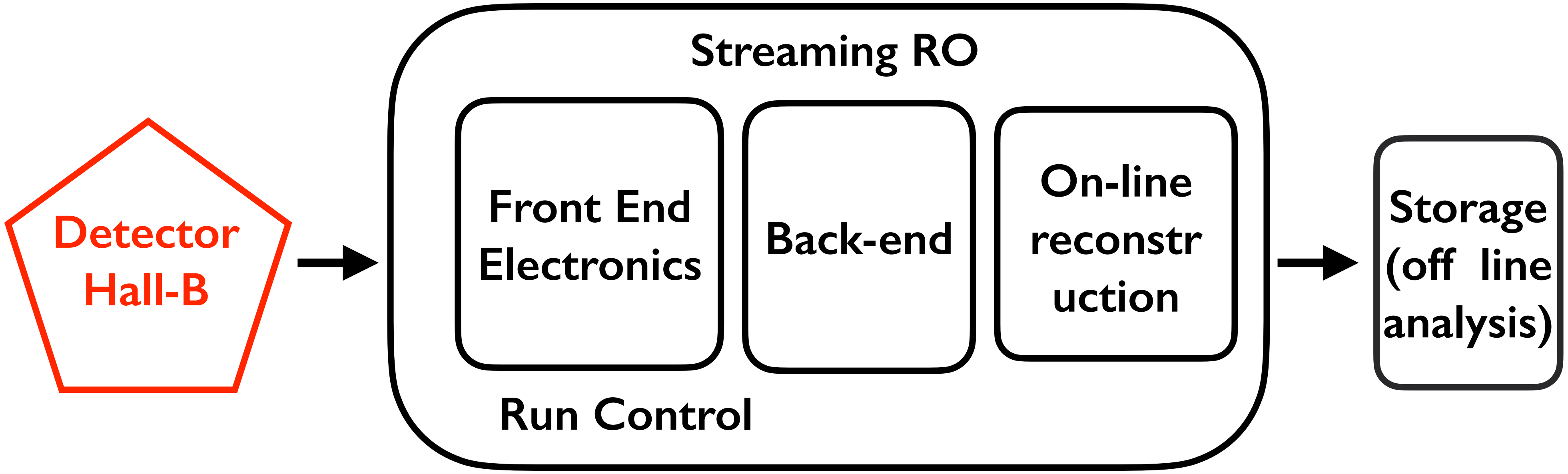

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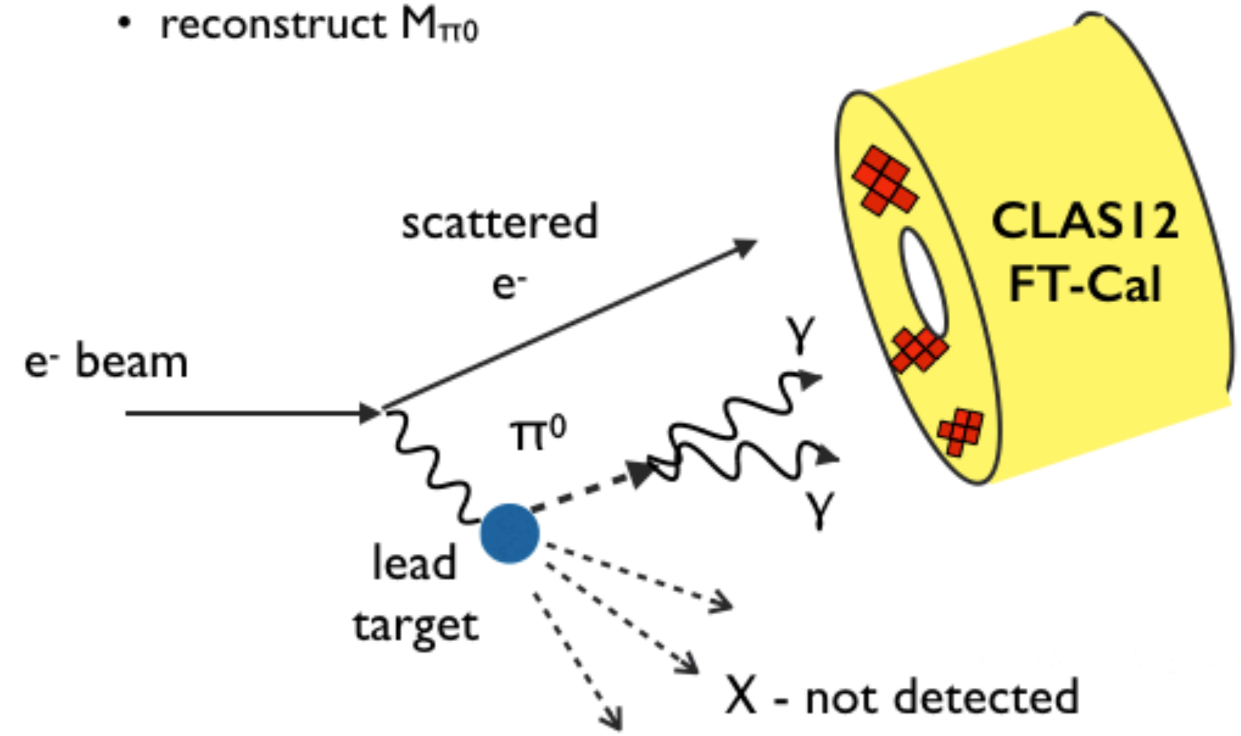
JLab SRO validation

M.Bondi, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

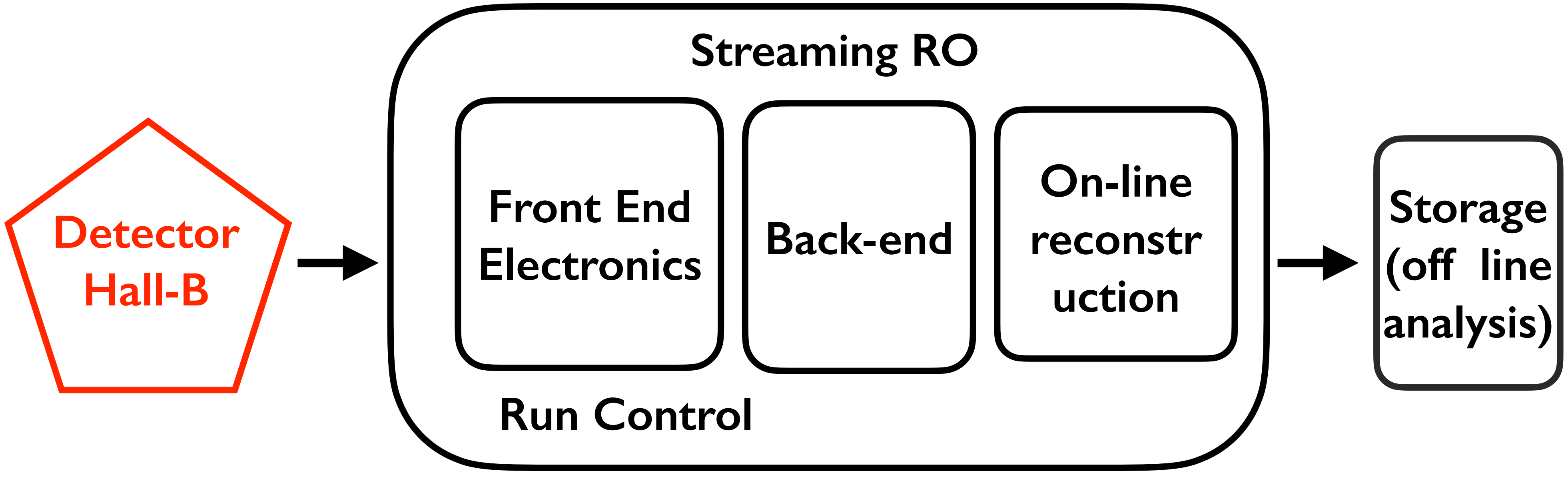
- collect data with 1-2-3 clusters in FT-CAL
- Identify the reaction
  e H/D2/Al/Pb → (X) e' π^0 →(X) e' γ γ
- reconstruct $M_{\pi 0}$

✳ **CLAS12 Forward Tagger**

- Inclusive pi0 electroproduction
- Two gammas detected into FT-CAL
- EM clusters identification, anti coincidence with FT-Hodo
- Self-calibration reaction (pi0 mass)



Streaming RO components



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JLab SRO validation

M.Bondi, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

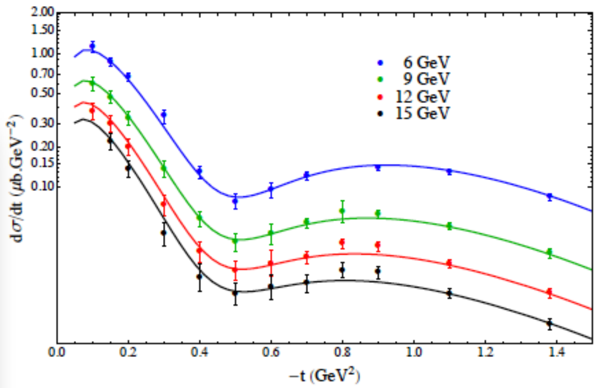
✳ **CLAS12 Forward Tagger**

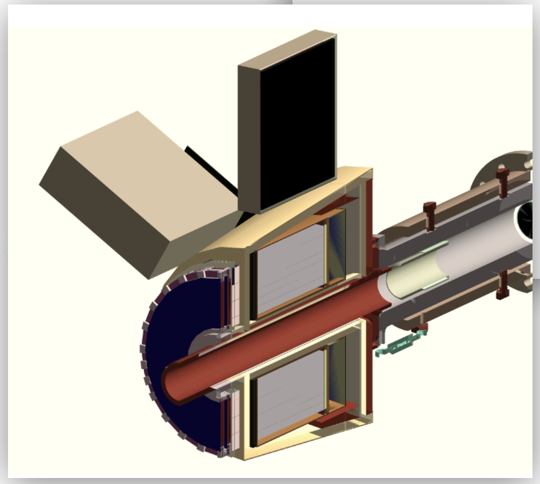
- Realistic exclusive pi0 electroproduction provided by JPAC
- Realistic GEANT4 model of the FT detector
- Contributions considered: electro-photoproduction byPb and Al targets

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

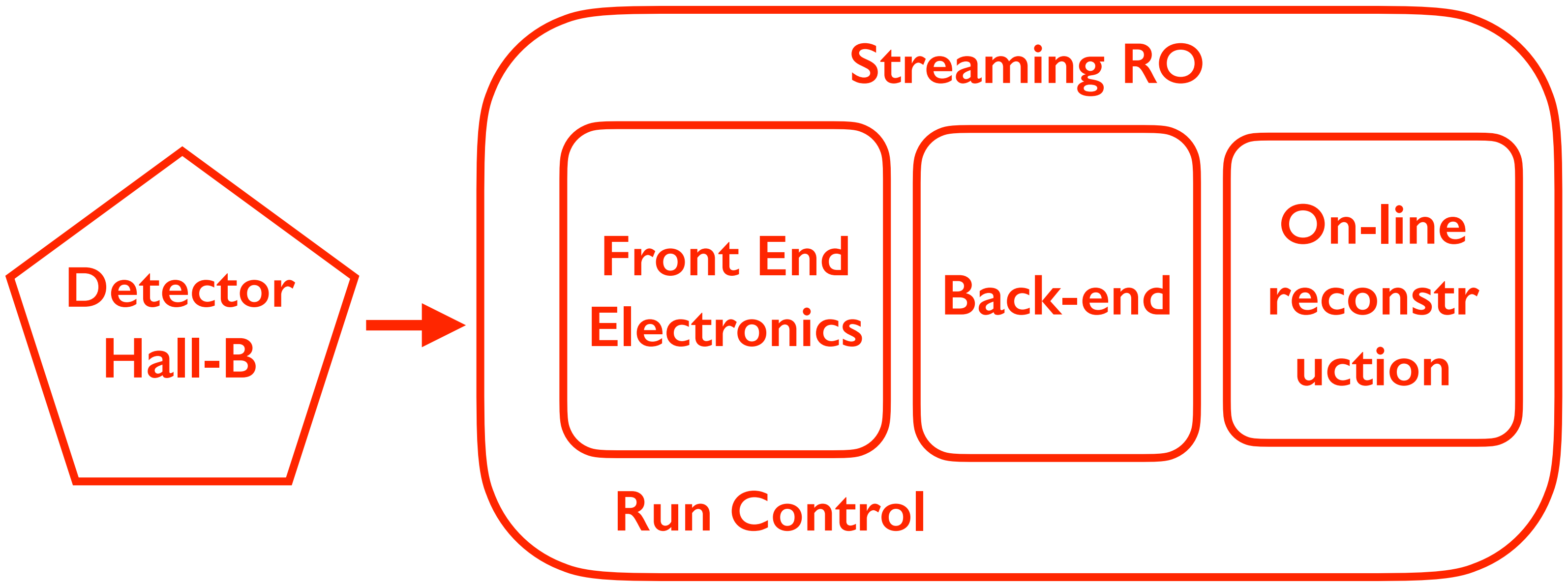
- From Lead ~1800
- From 160μm Al+glue ~420

- 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





Streaming RO components



SRO concept validation

1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

JLab SRO test

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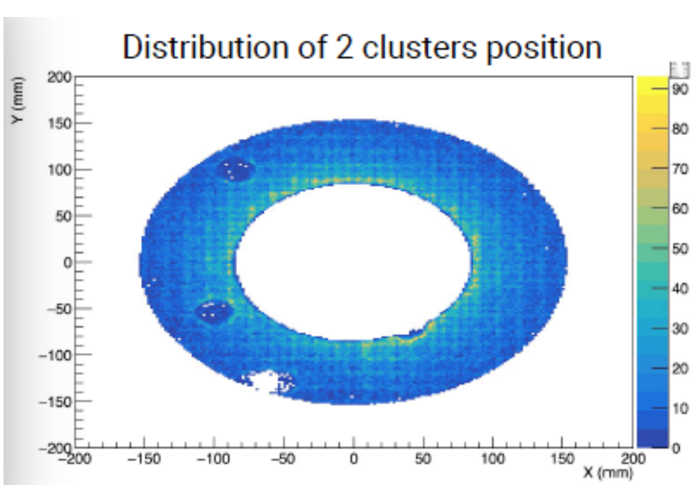
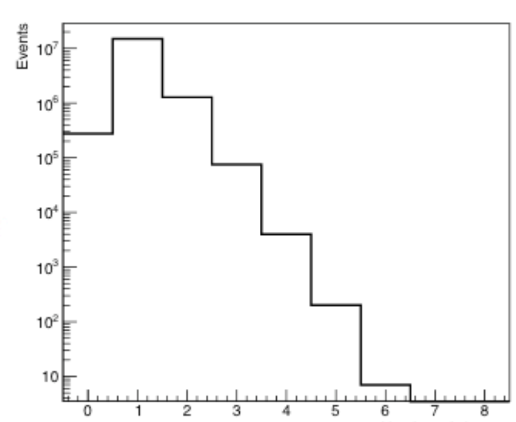
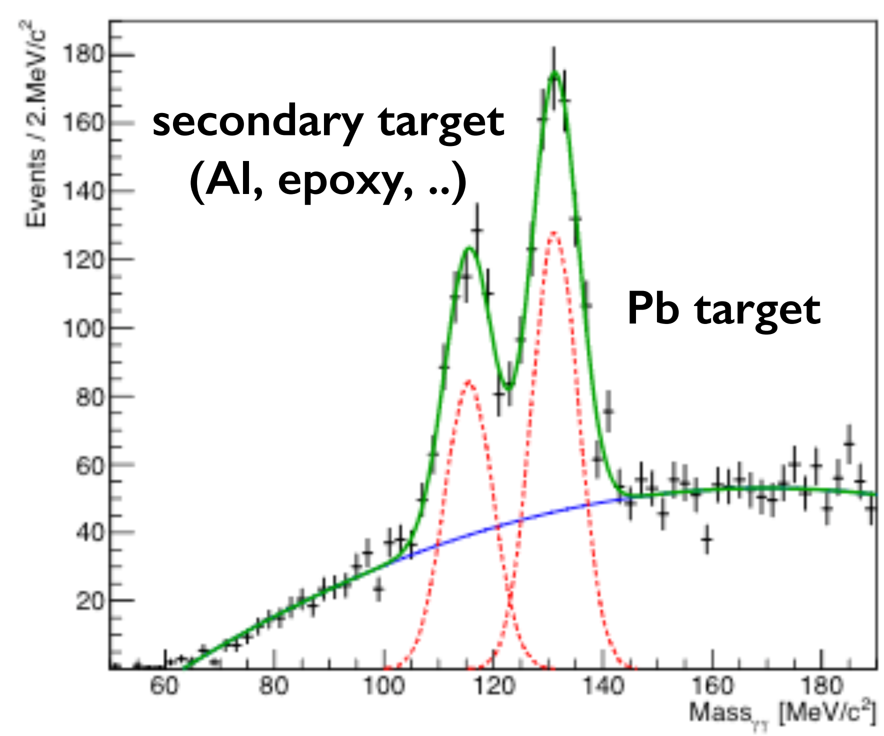
✳ **CLAS12 Forward Tagger**

- Data corrected for time walk effect and energy calibrated
- Two targets: Pb (primary) + Al scattering chamber window
- Two pi0 peaks (correct/wrong assumption on vertex)





Preliminary test results



- **Measured (expected) pi0 yield**

  Peak1 = 1365+-140 (~1800)

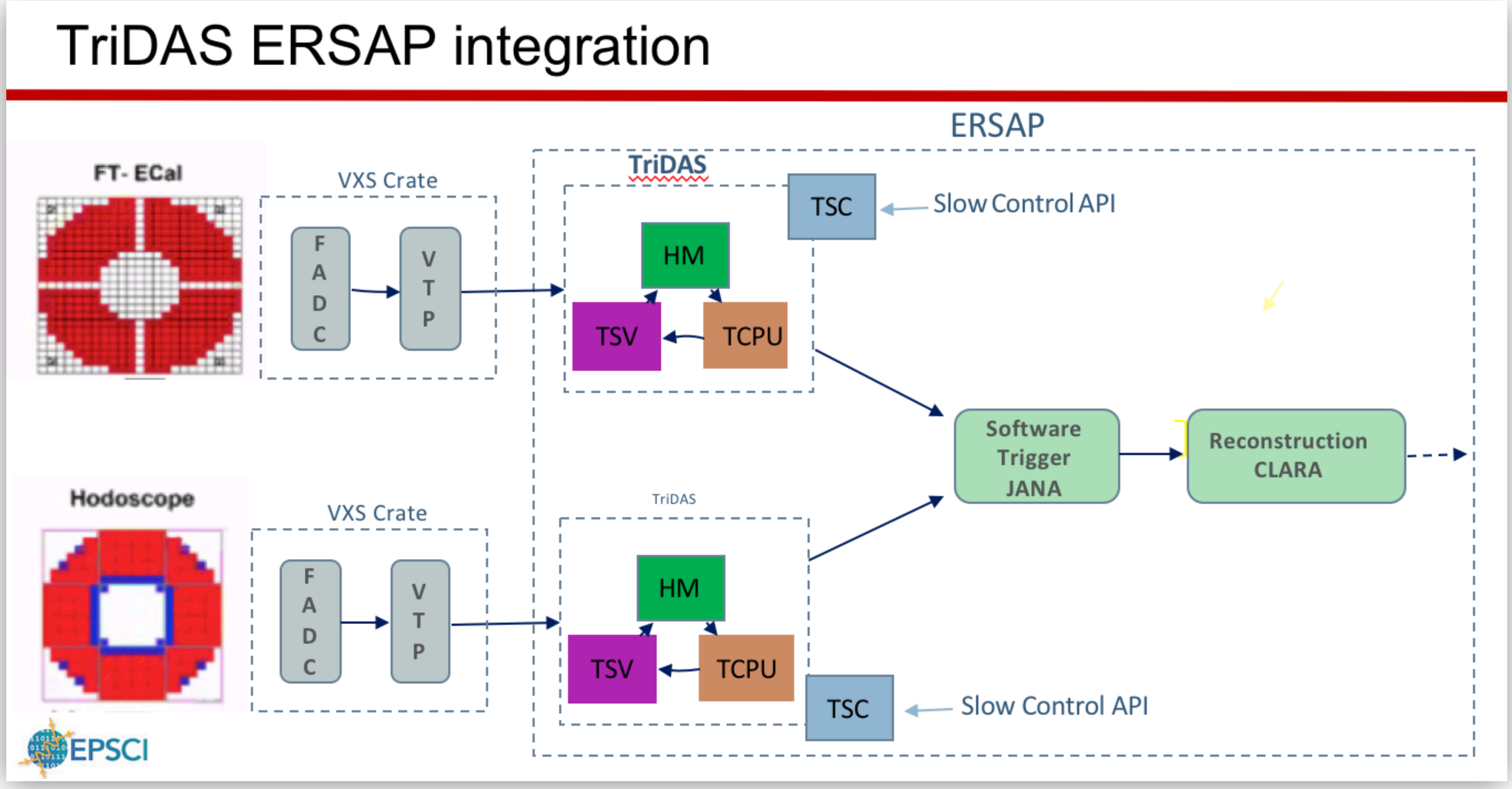
  Peak 2 = 930+-100 (~420)

JLab current SRO effort

- Hall-D and Hall-B test results demonstrated the first JLab SRO DAQ system
- What next:
  - Integration of different components in n optimised SRO framework

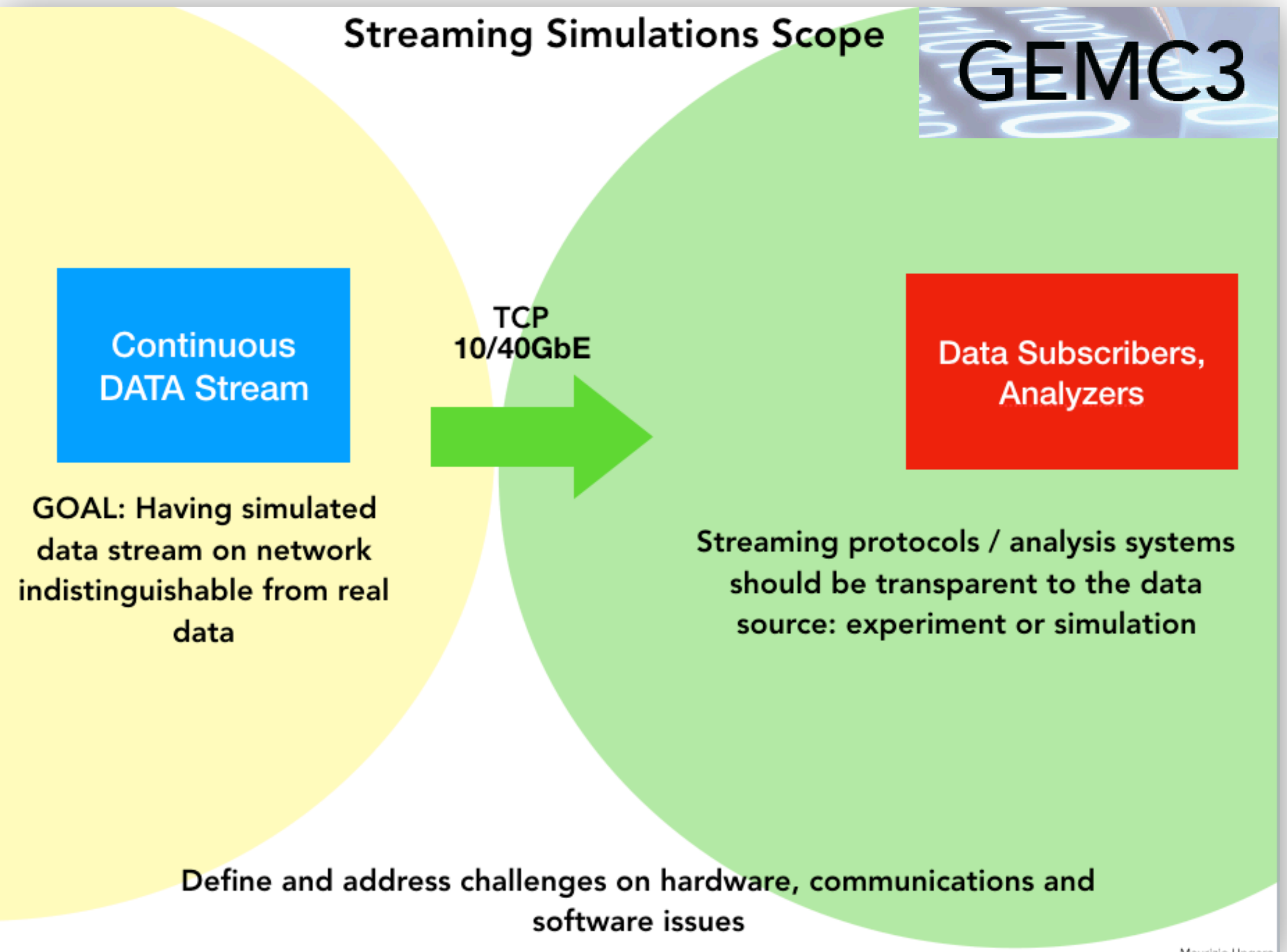
ERSAP

- 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

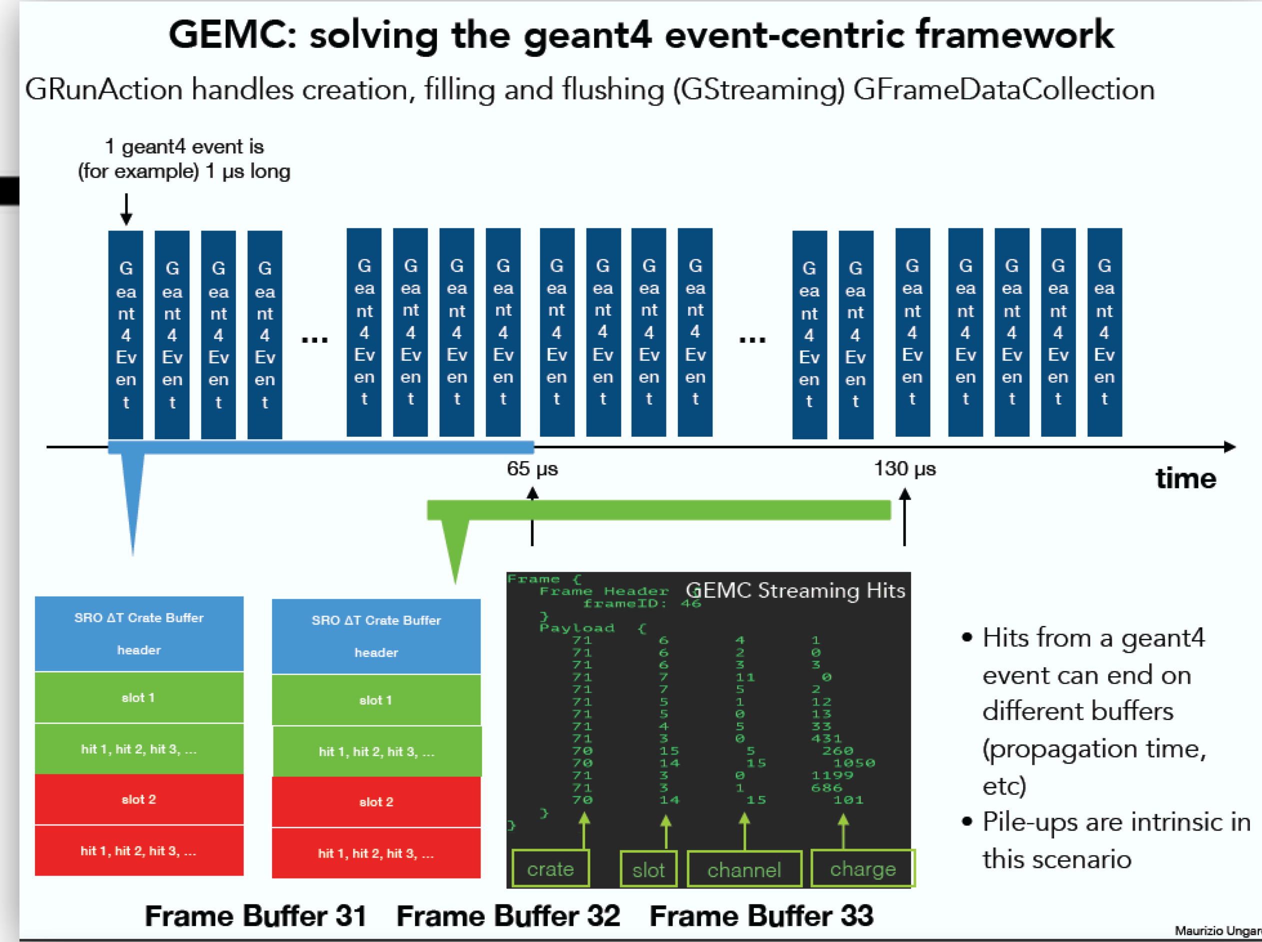


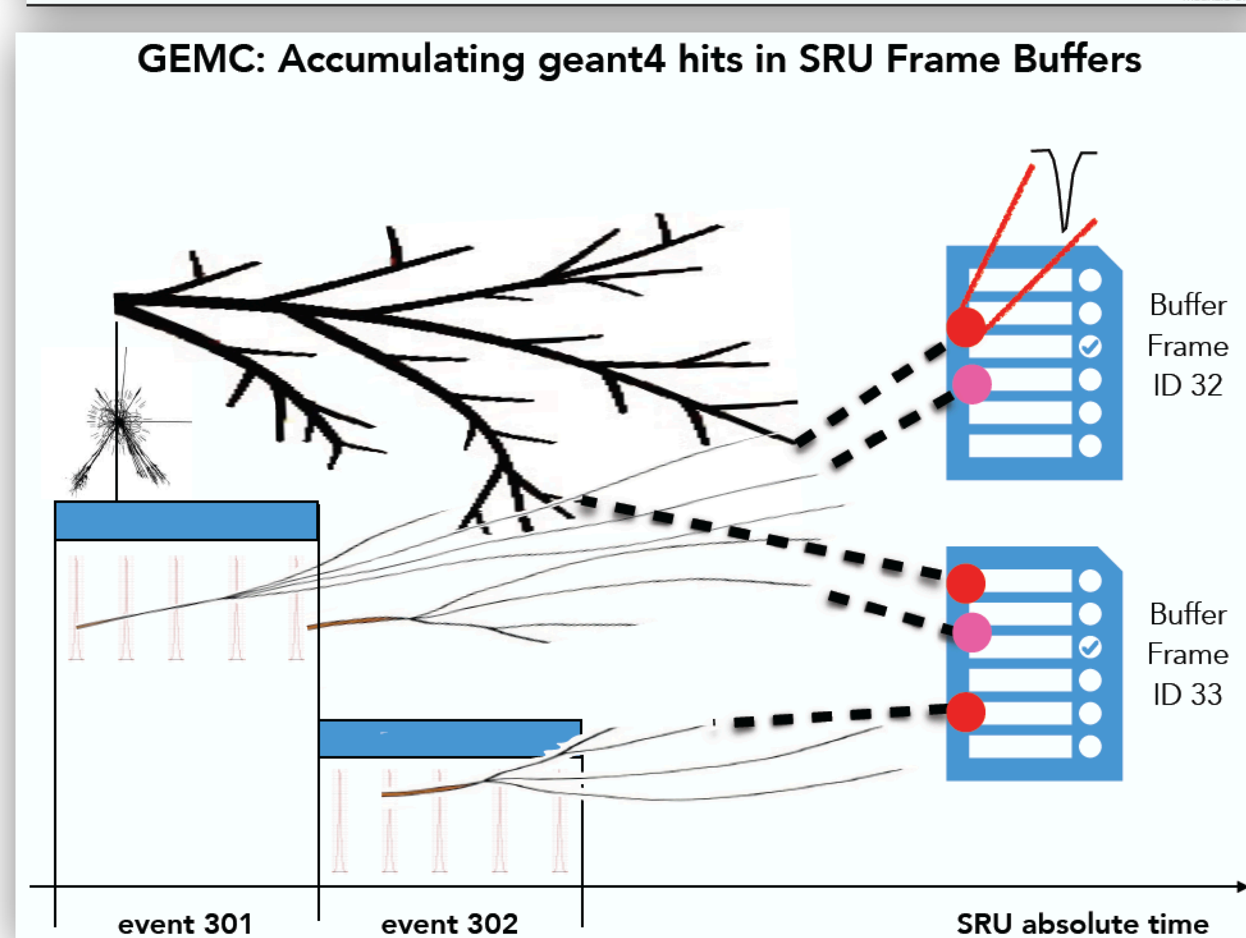
GEMC3: SRO GEANT4 MC

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





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Summary

- Streaming RO is 'THE' option for future electron beam experiments
- 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)
- Built a working SRO prototype and a work team!

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