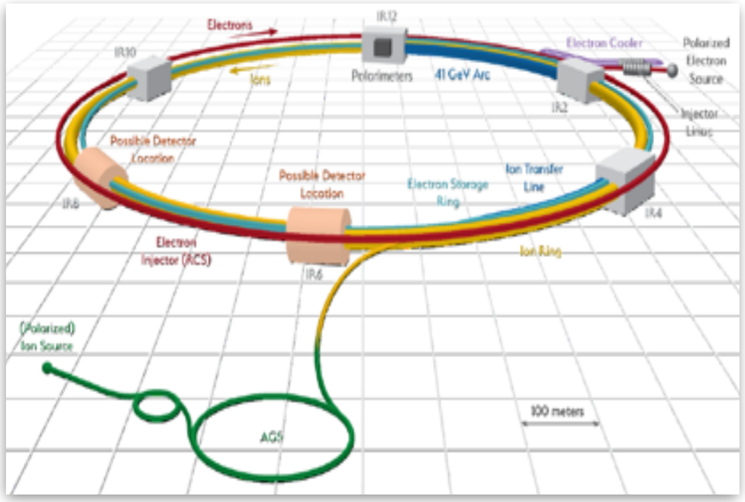
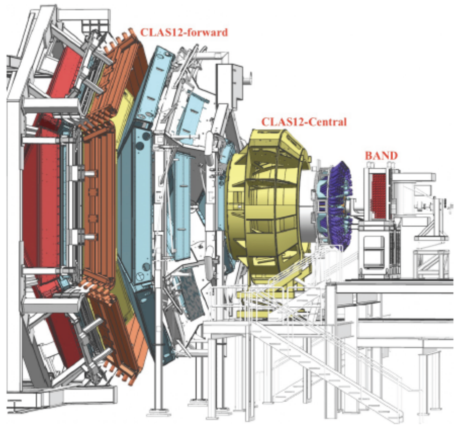
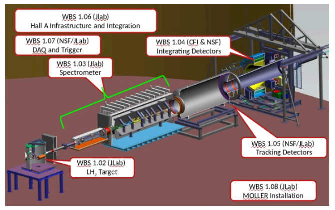
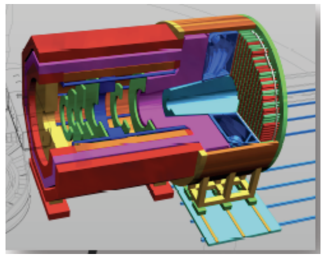
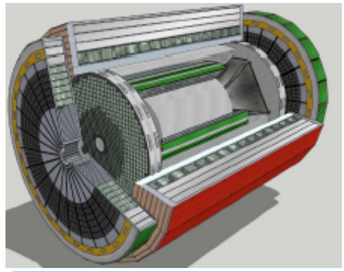
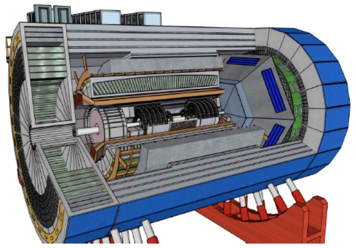


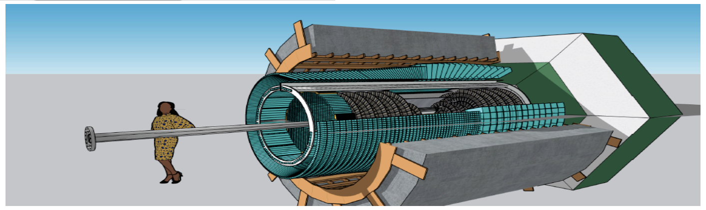












Farnesina Ministero degli Affari Esteri e della Cooperazione Internazionale

e-JLab12 clas CEBAF Large Acceptance Spectrometer Jefferson Lab INFN

Streaming Readout @EIC

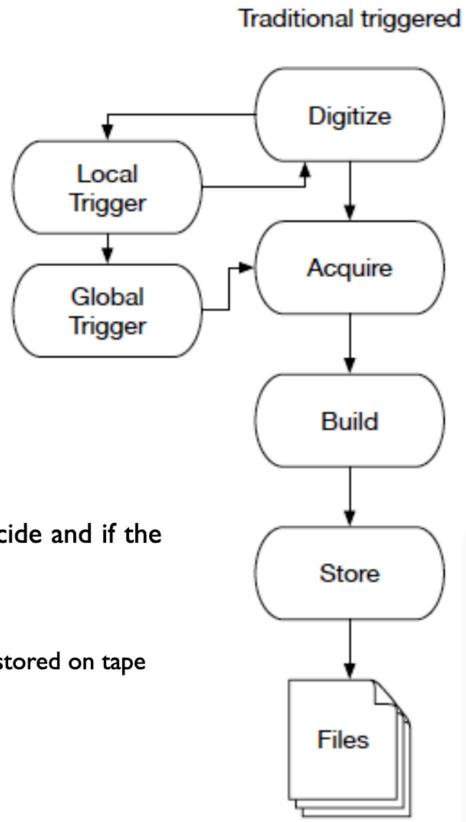
Marco Battaglieri
INFN

M.Battaglieri - JLAB

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



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

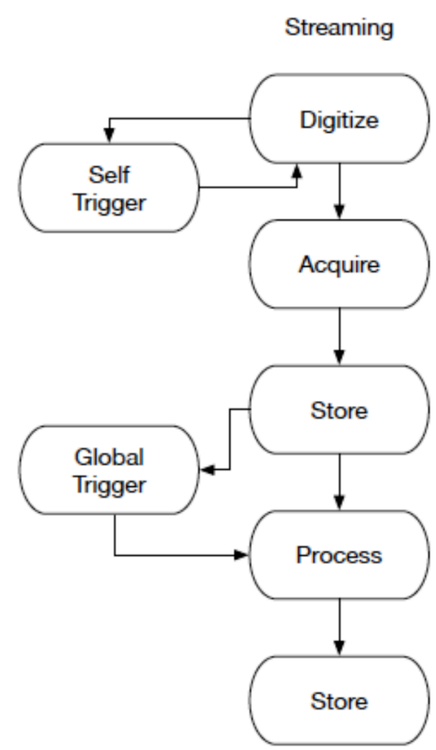
* All channels continuously measured, hits stored in short term memory

* 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?

✳ **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

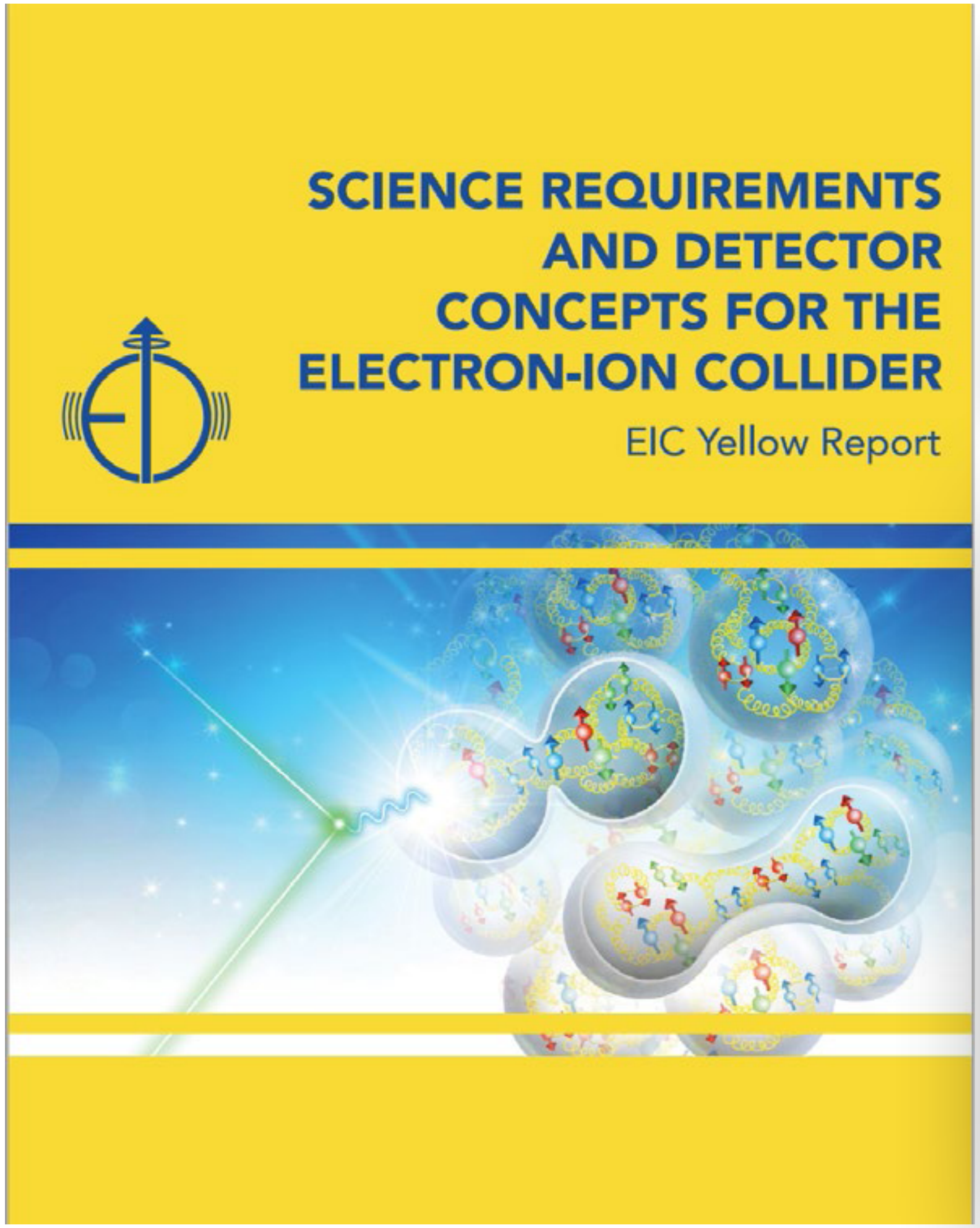
✳ **Scaling**
- Easier to add new detectors in the DAQ pipeline
- Easier to scale
- Easier to upgrade

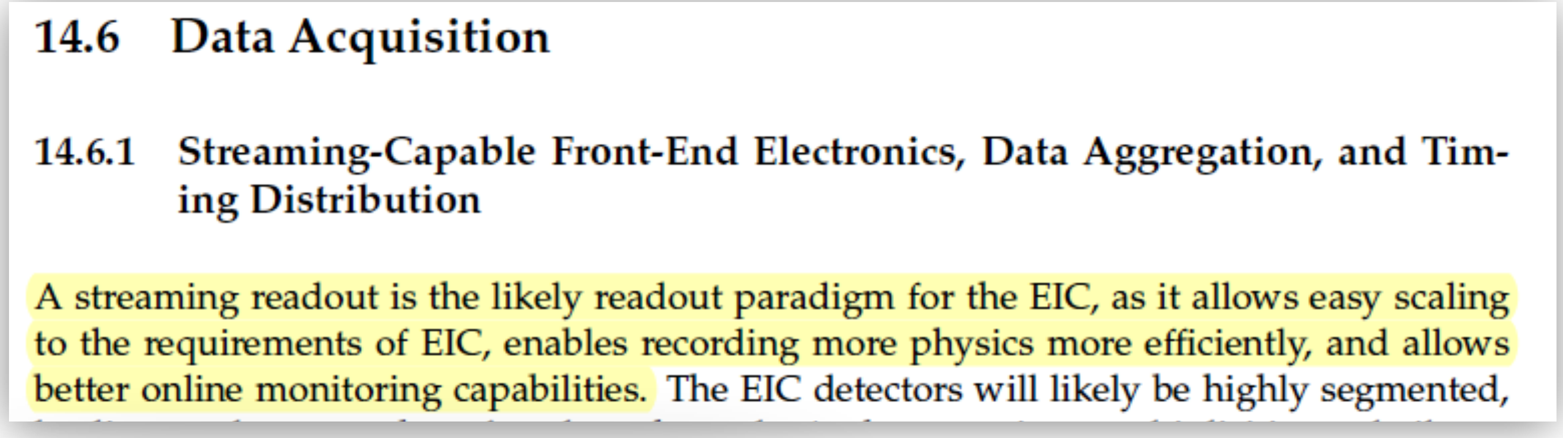
Many NP and HEP experiments adopt the SRO scheme (with different solutions):

- 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

SRO for EIC

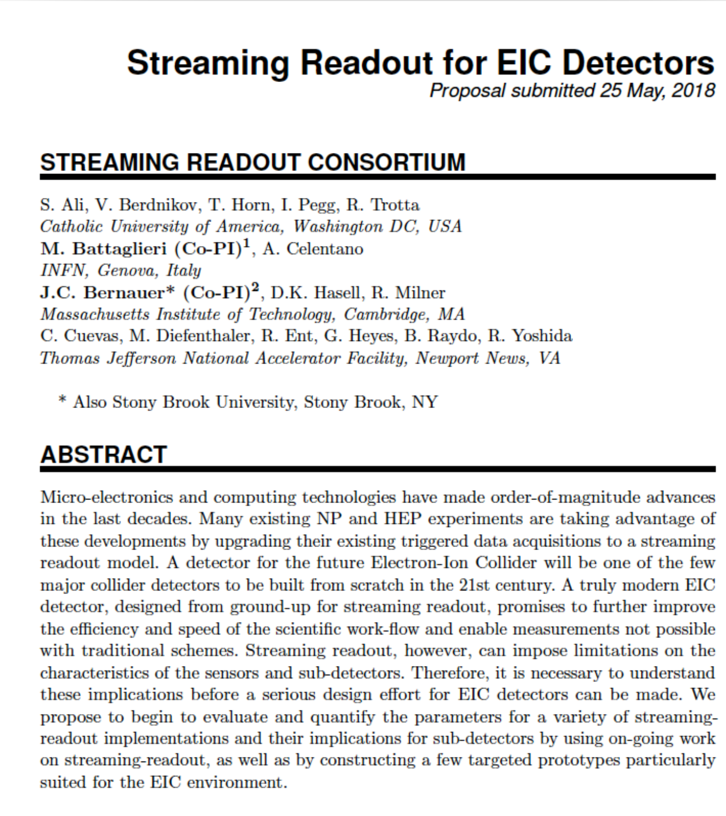




14.6 Data Acquisition

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

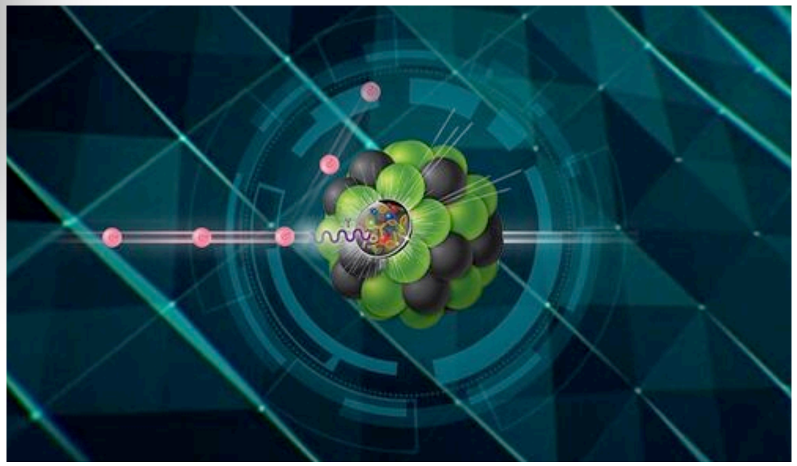
* Also Stony Brook University, Stony Brook, NY

ABSTRACT

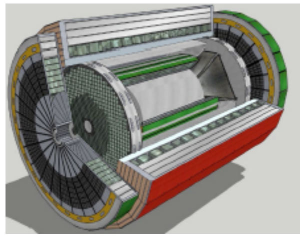
Micro-electronics and computing technologies have made order-of-magnitude advances in the last decades. Many existing NP and HEP experiments are taking advantage of these developments by upgrading their existing triggered data acquisitions to a streaming readout model. A detector for the future Electron-Ion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

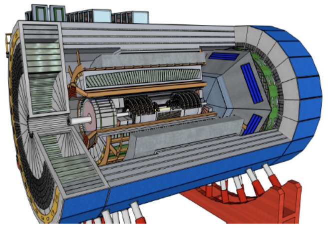
Streaming RO - X
- Organized by JLab
- May 17-19 2022



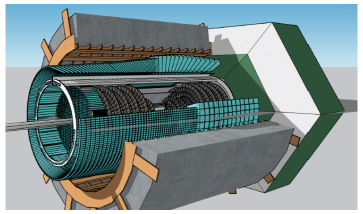
ECCE



ATHENA

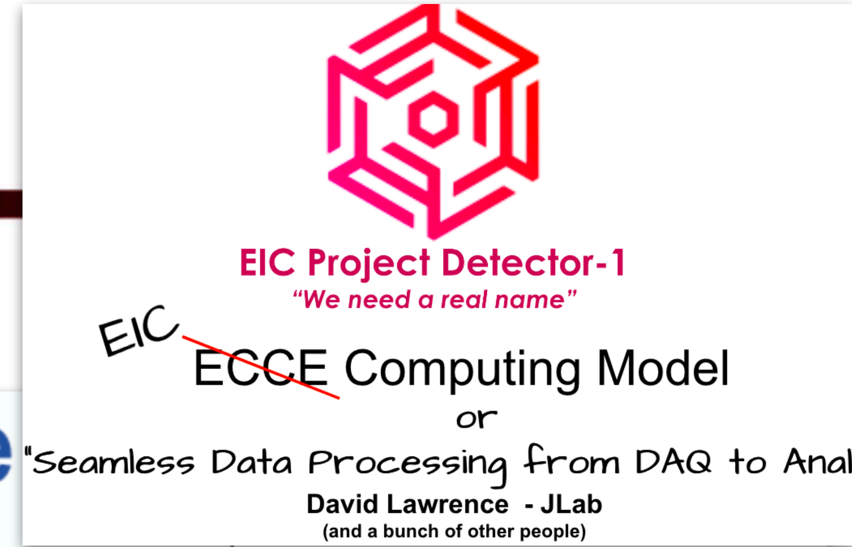


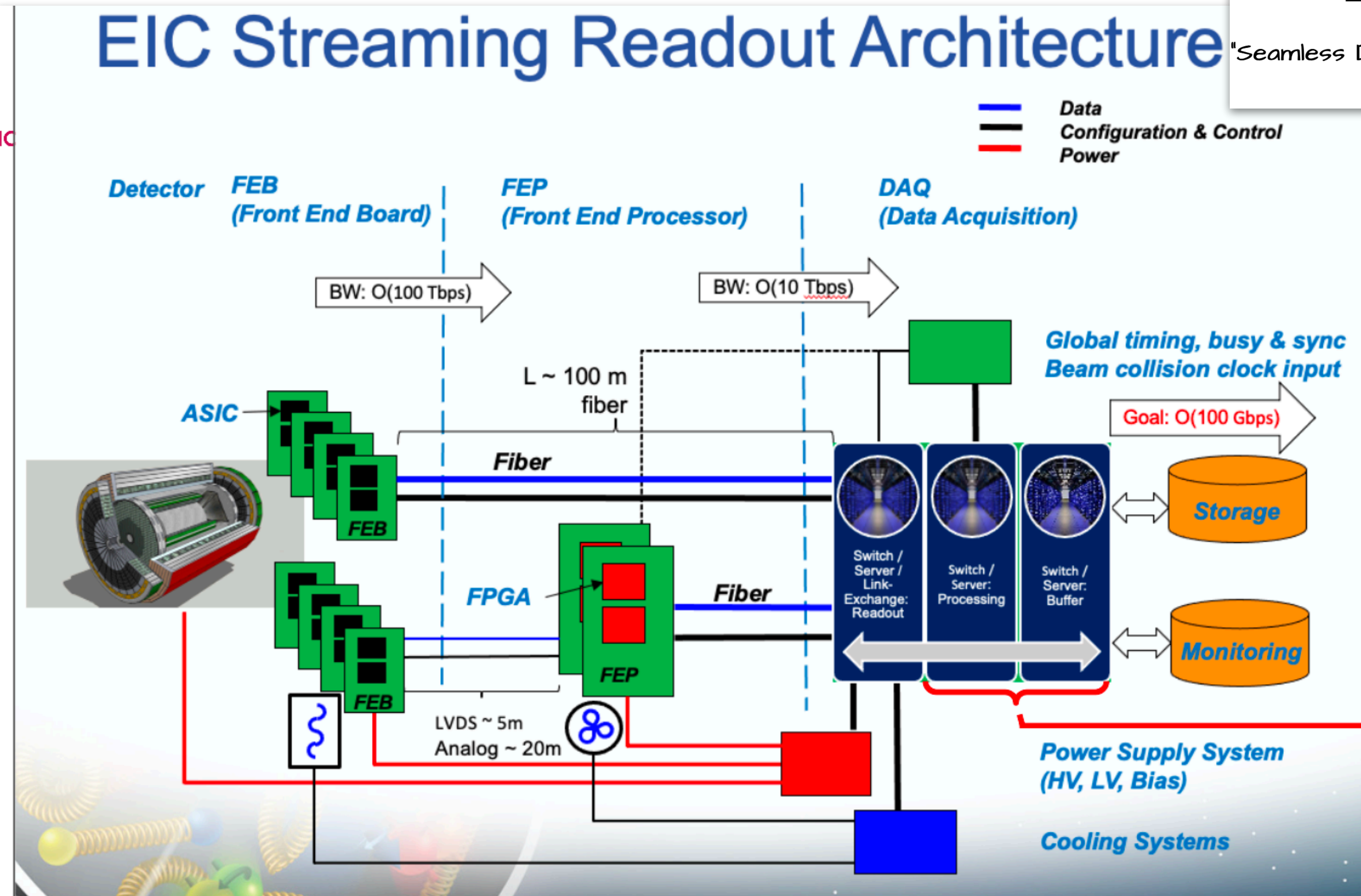
CORE



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

SRO for EIC





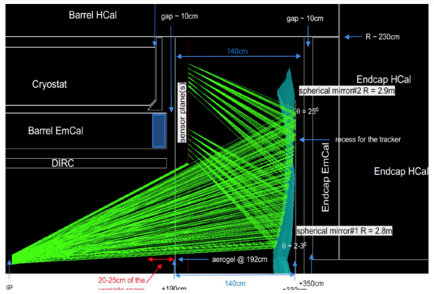
factor of 100 in data reduction

EIC Streaming Readout (From Fernando Barbosa's talk at AI4EIC Sep. 9, 2021)

David Lawrence -- Seamless Data Processing from DAQ to Analysis -- May 17, 2022 -- Streaming Readout X

4 / 13

dRICH



- Collider parameters:
  - ~500KHz of collisions
  - ~60-100Gbps zero suppressed data
  - ~15 KB/event
  - ~100 bytes/bunch crossing

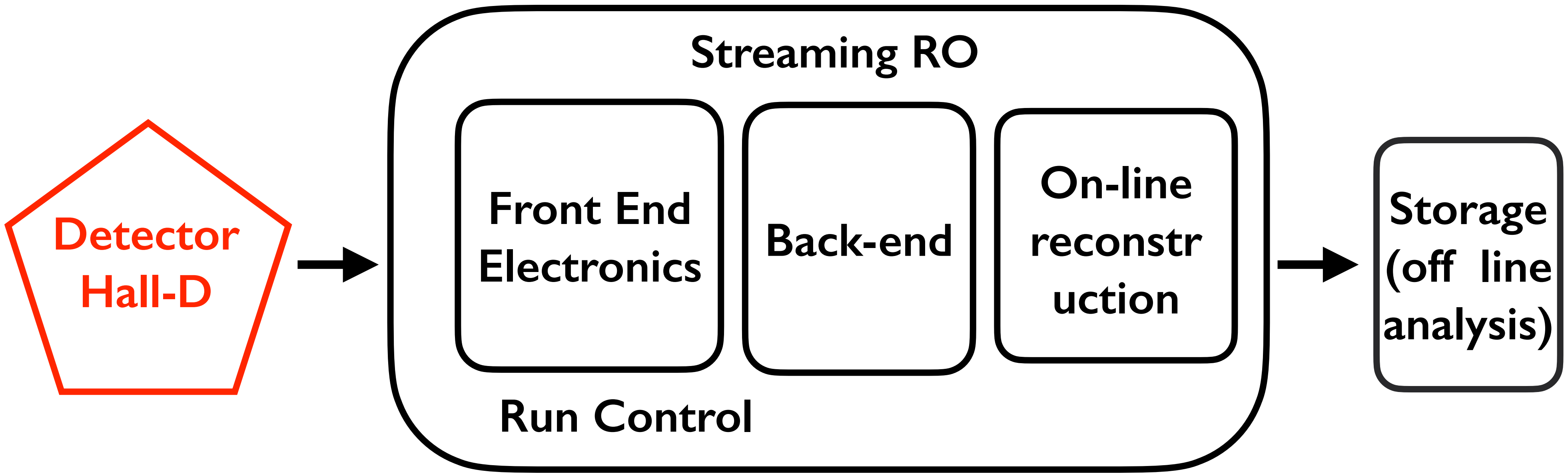
Detector	Channels	DAQ Input(Gbps)	DAQ Output(Gbps)
B0 Si	400M	<1	<1
B0 ac-lgad	500k	<1	<1
RP+Offm+ZDC	700k	<1	<1
FB Cal	4k	80	1
eCal	34k	5	5
hCal	39k	5.5	5.5
imCal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
uRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Totals		3400	61

- Sensors are inside the 3T magnetic field,
  - SiPM sensors are envisioned.
  - Thresholds must be sensitive to single photons
- Dark Currents at this threshold ~3Khz / channel increasing to ~300Khz / channel after several years after which annealing will be performed
  - Mitigate by ~3 by applying timing window with respect to bunch crossing
  - Read up to 3.3Tbps into the DAQ computers but filter using
    - Software trigger
    - Potentially ML/AI if turns out practical
  - Software trigger reduces dark current volume to ~<15.5Gbps
  - As a potential mitigation the timing system & FELIX could be adopted to supply hardware trigger.

Streaming RO R&D

M.Battaglieri - JLAB

Streaming RO R&D status

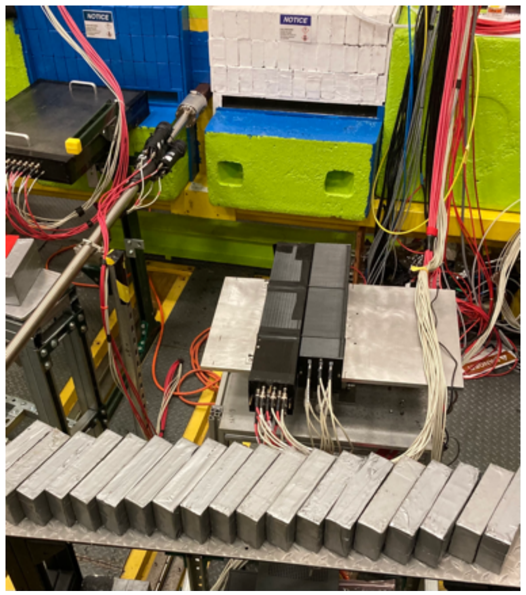


SRO concept validation

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

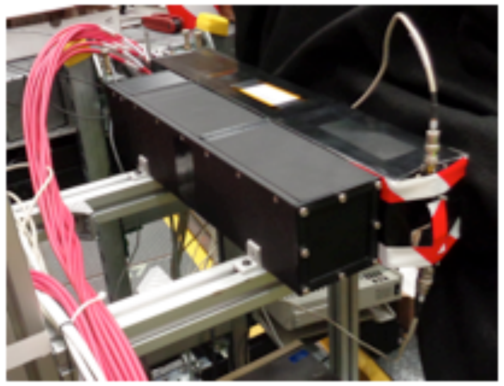
SRO validation @ JLab

V.Berdnikov, T.Horn



✳ **EIC ECal PbWO prototype**

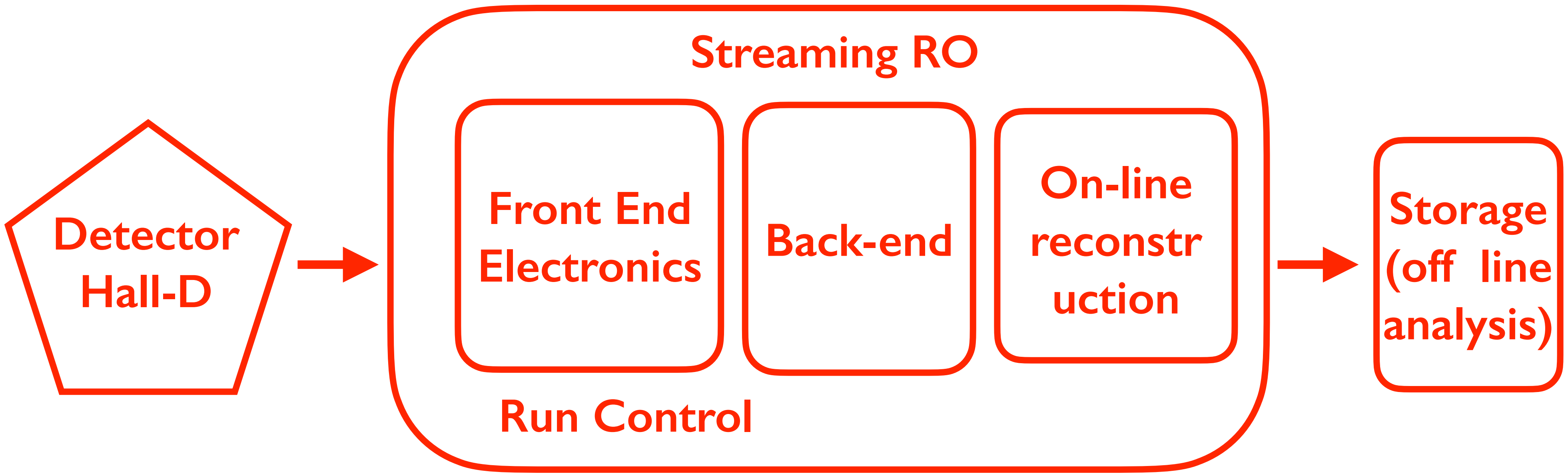
- Use the Hall-D Pair Spectrometer setup
- Secondary e+/e- beam: E range (3-6) GeV
- Simple setup to compare TRIGGERED to TRIGGERLESS
- 3x3 PbWO crystals, PMT and SiPM readout
- fADC250+VTP and WaveBoard front end



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

Waveboard

Streaming RO R&D status



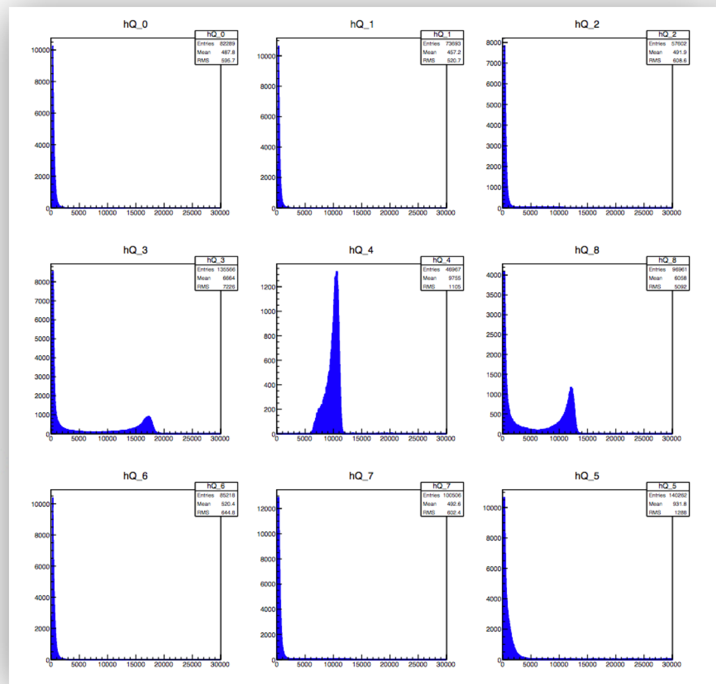
SRO concept validation

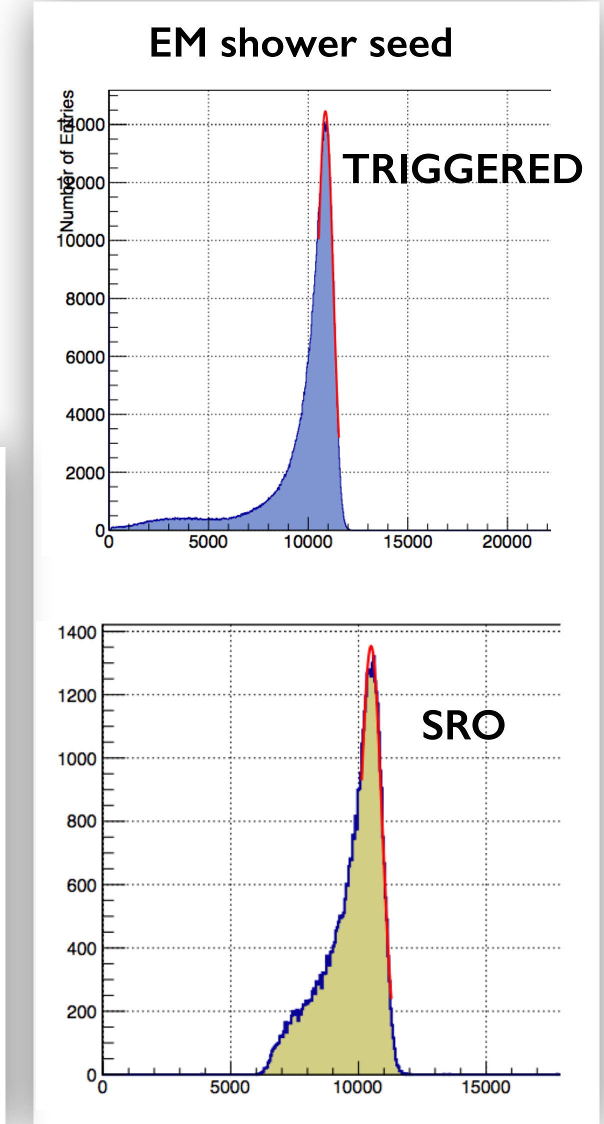
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

SRO test @ JLab

V.Berdnikov, T.Horn

ECAL proto: 9ch SRO-mode

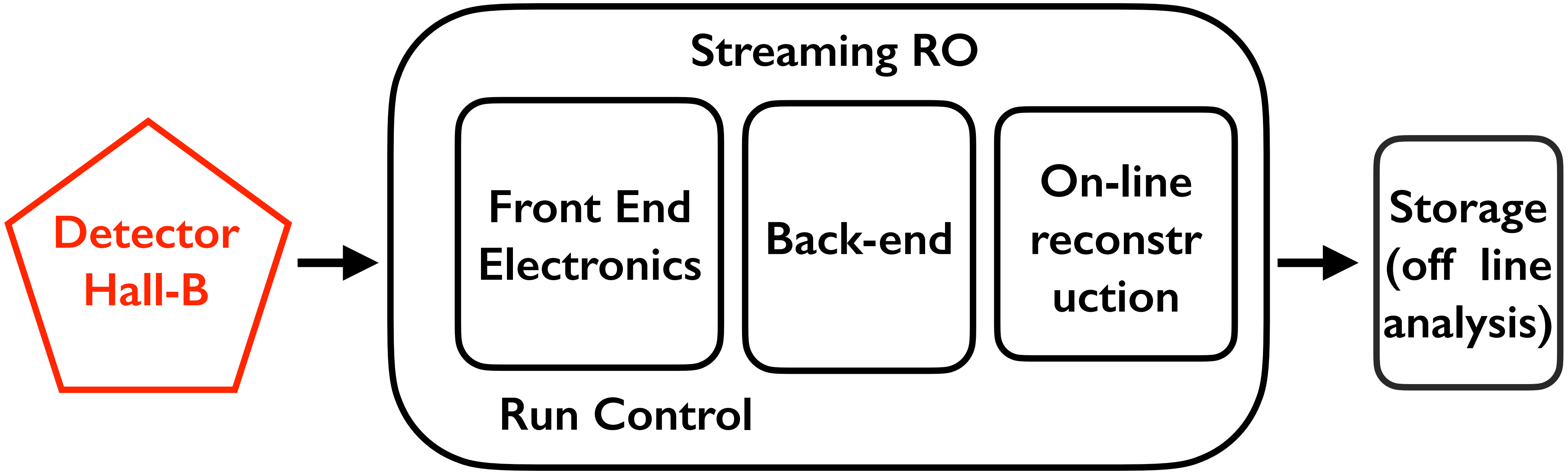




✳ **EIC ECal PbWO prototype**

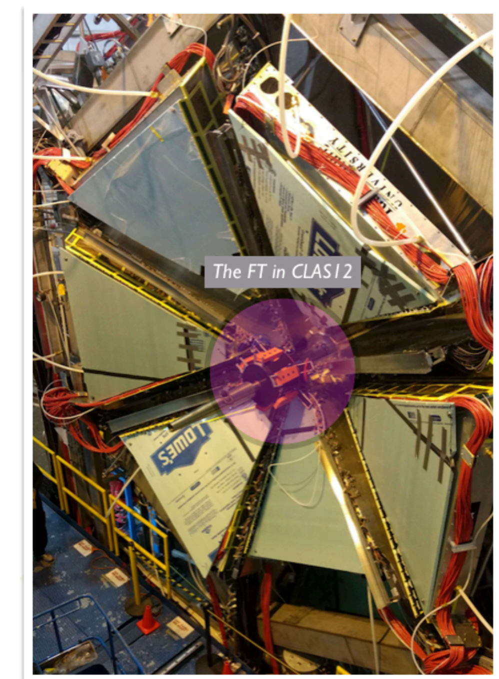
- Use the Hall-D Pair Spectrometer setup
- Secondary e+/e- beam: E range (3-6) GeV
- Simple setup to compare TRIGGERED to TRIGGERLESS
- 3x3 PbWO crystals, PMT and SiPM readout
- fADC250 and WaveBoard front end

Streaming RO R&D status



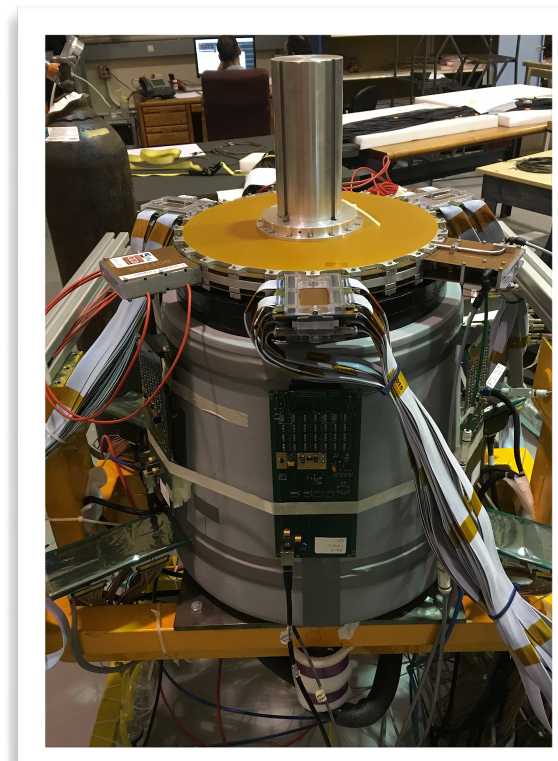
SRO concept validation

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



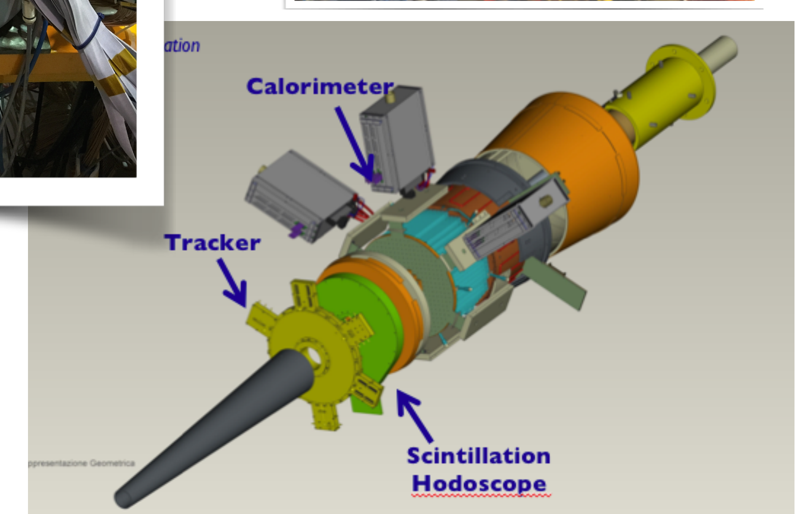
SRO validation @ JLab

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

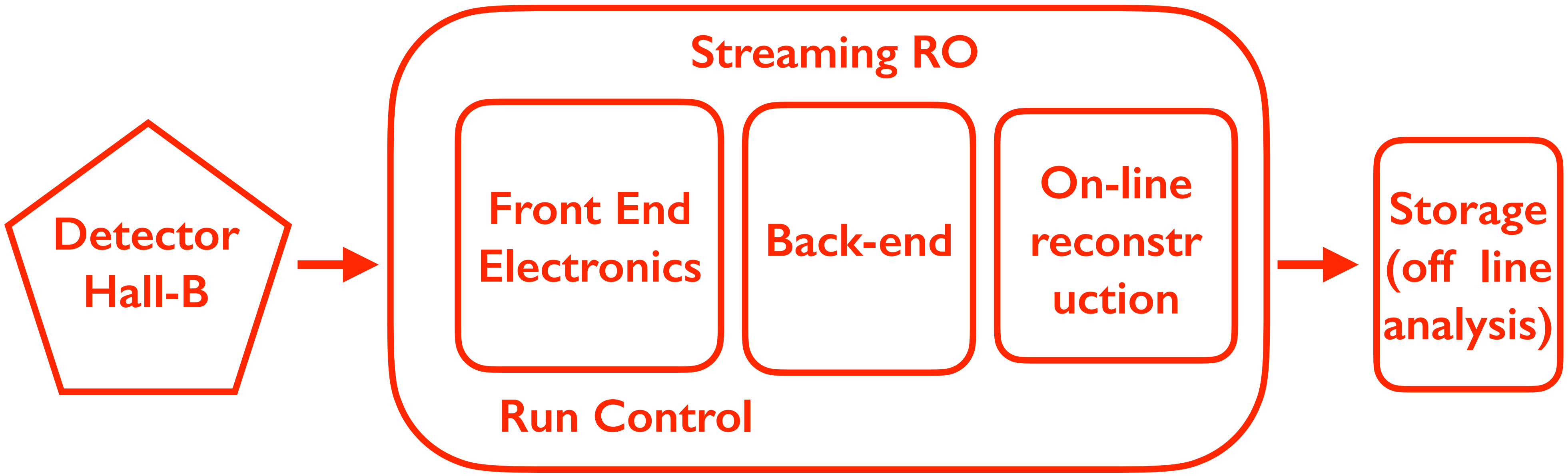


✴ **CLAS12 Forward Tagger**

- 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



Streaming RO R&D status



SRO concept validation

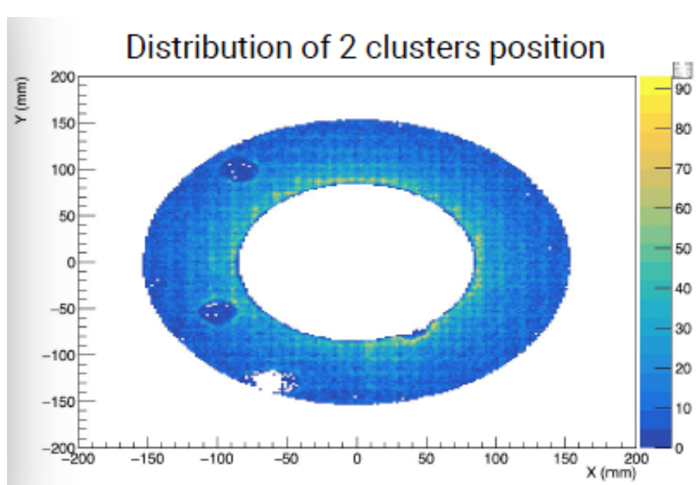
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

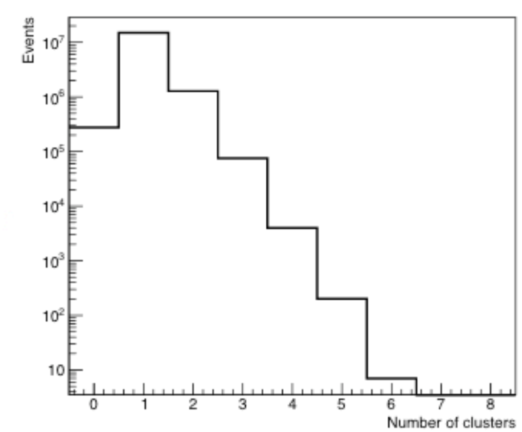
SRO test @ JLab

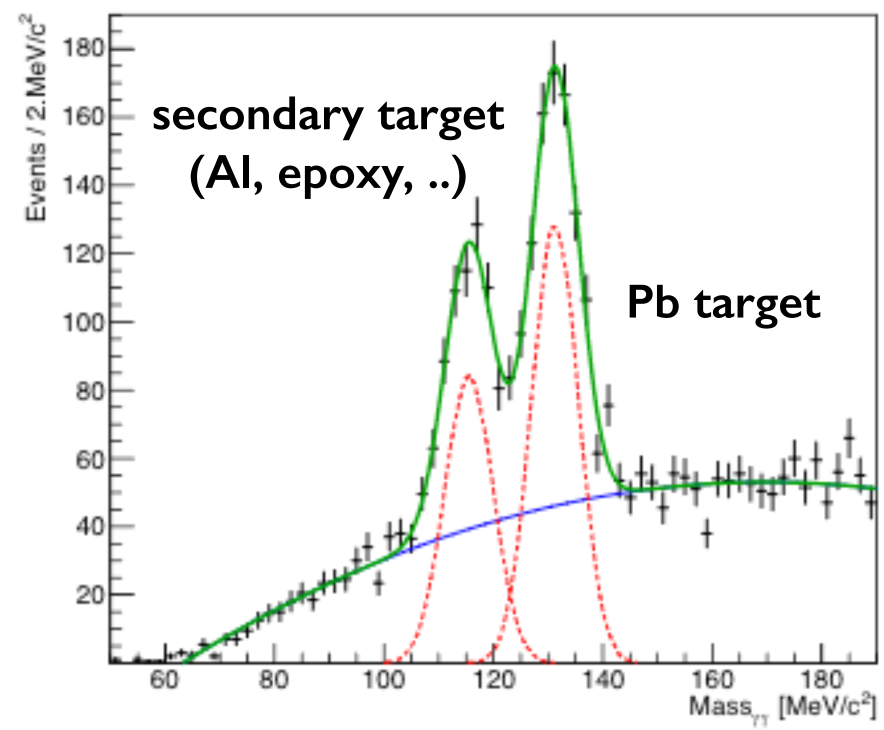
M.Bondi, S.Vallarino, A.Celentano, A.Pilloni, P.Moran

✳ **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)







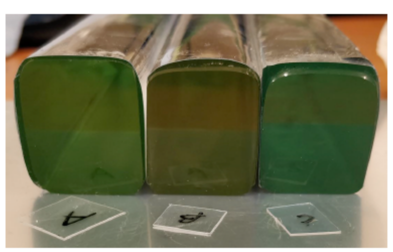
- **Measured (expected) pi0 yield**

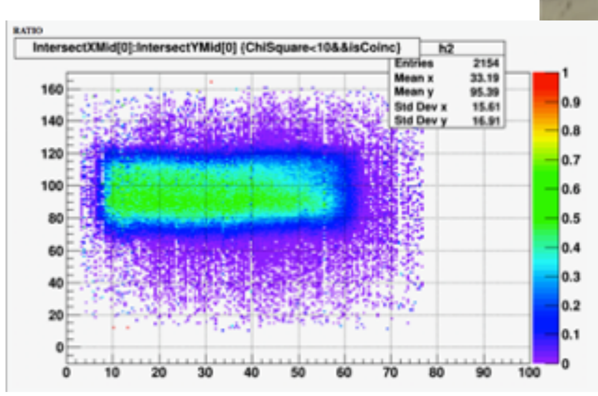
  Peak1 = 1365+-140 (~1800)

  Peak 2 = 930+-100 (~420)

Streaming RO R&D results

- Test results just published on Eur. Phys. J. Plus (2022)137:958 https://doi.org/10.1140/epjp/s13360-022-03146-z)
- Scheduled a new beam test campaign with EIC PbWO Calorimeter prototype in Fall22/Spring23
- New prototype will use SCIGLASS (currently under tests in Genova as part of eRD105 activity)





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

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

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)

Published online: 24 August 2022

Springer

Streaming RO R&D plans

✳ **Synergic activities:**

- External funds: A streaming RO for EIC MAECI (Progetto di grande rilevanza nell'ambito della Collaborazione Scientifica-tecnologica Italia-USA)

  funds available for 2018-2022 period, personnel and equipment

- EIC eRD105 - SRO for EIC calorimetry

  dedicated R&D for EIC Calorimetry, SRO DAQ

- EIC Generic R&D (previous eRD23): A streaming RO for EIC detectors

  proposal to coordinate the SRO activity in EIC

- JLAB12: SRO tests at Jefferson Lab

  on-beam tests withEIC Cal prototype using service architecture of EIC SRO framework (ERSAP)

- APE Group in RM-TV for AI on FPGA implementation

  started a collaboration with experts of AI implementation on FPGA

✳ **dRICH SRO to start**

- postdoc position tom be awarded in Fall22 (*AI for real-time applications*), candidate identified, call preparation
- the candidate will spend 6m in RM-TV and 6m in GE
- implementation of AI algorithms on FPGAs with a specific target of reducing dRICH rate
- work with dRICH electronic group to use ALCOR in streaming mode
- possible use in EIC Cal (similar sipm readout)

Streaming RO R&D plans

✳ **Goals for 2023:**

- SRO set up in Genova based on WB+Tridas+Jana2
- Cosmic and on-beam (JLab) tests of EIC Cal prototype with AI-supported tagging/filtering (implemented in Jana2)
- Existing solutions assessment for multiple channels readout (eg ALCOR ASIC)
- Smart tagging/filtering algorithms on GPU/CPU farms (off-line)
- Smart tagging/filtering algorithms on FPGA (real-time)

✳ **Funding requests:**

GE: INV	6k	WaveBoard per il sistema Streaming Readout
GE: CON	1k	cavetteria, connettori, accessori
RM2: INV	4.5k	VCK5000-AIE-ADK Versal Development Card for AI Inference

VCK5000 Versal Development Card

by: Xilinx, Inc

XILINX

The Xilinx VCK5000 Versal development card is built on the Xilinx 7nm Versal® ACAP architecture and is designed for (AI) Engine development with Vitis end-to-end flow and AI Inference development with partner solutions. * Limited to AI Engine only. For full Vivado® flow and device customization, please contact sales.