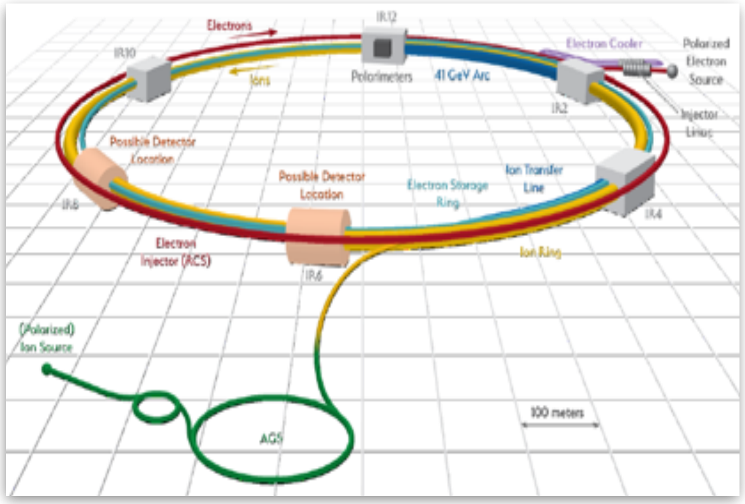
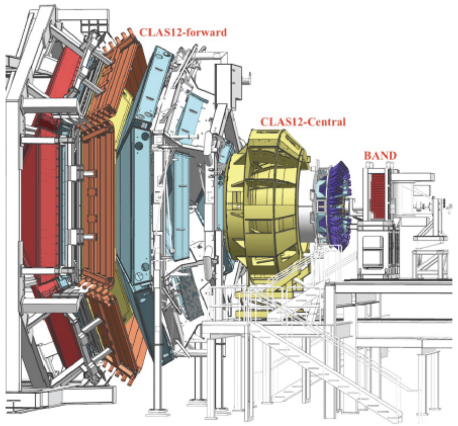
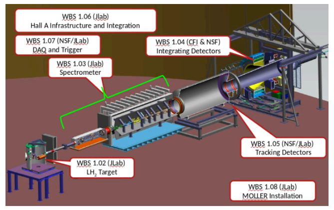
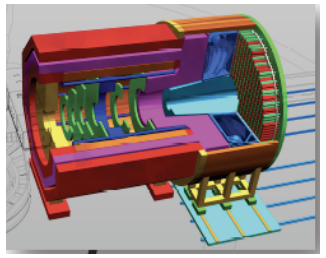
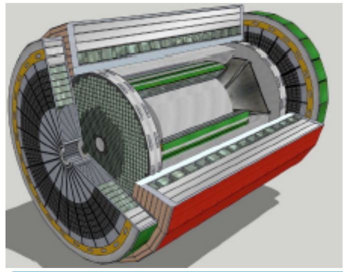
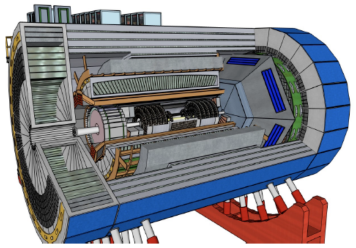


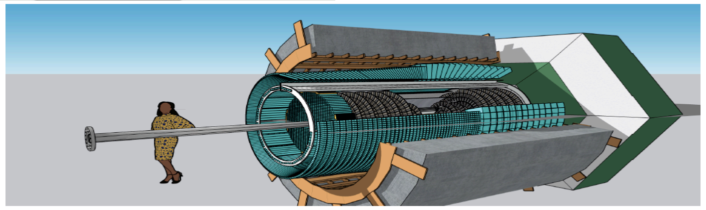












Farnesina
Ministero degli Affari Esteri e della Cooperazione Internazionale

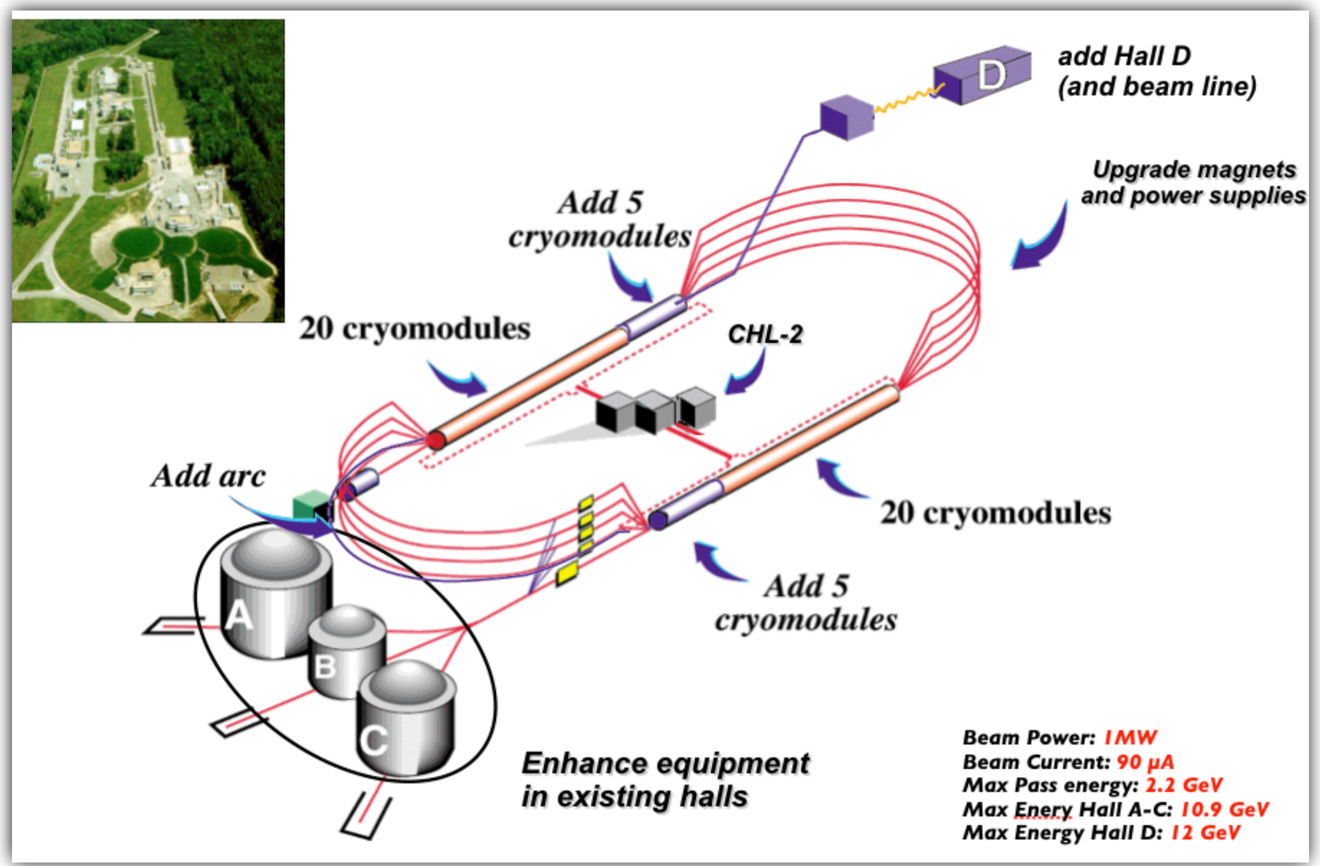
Streaming Readout

Marco Battaglieri
Jefferson Lab/INFN

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

Present & future

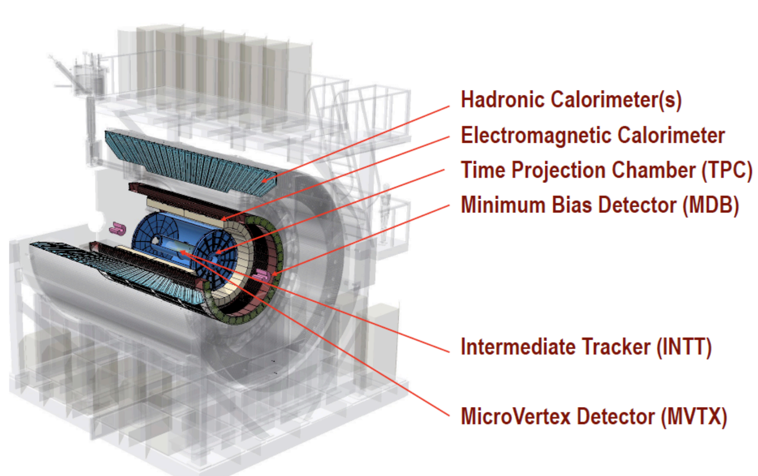
Jefferson Lab: CLAS12

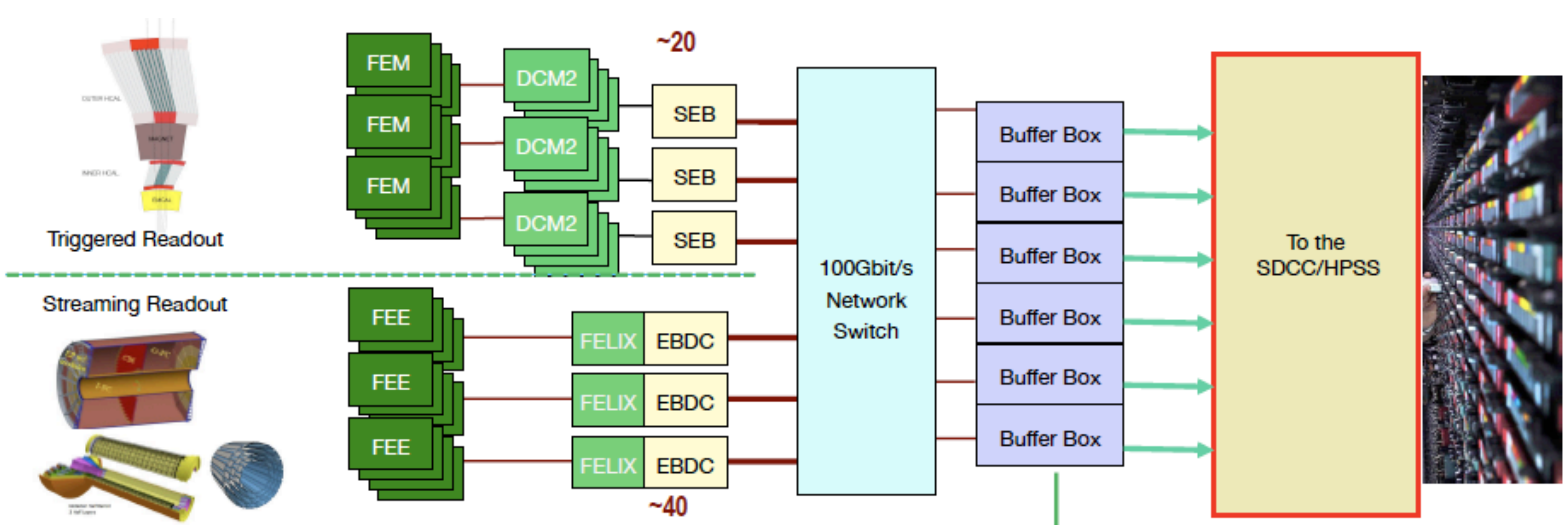


- ✳Primary Beam: Electrons
- ✳ Beam Energy: 12 GeV
  - 10 > λ > 0.1 fm
  - nucleon → quark transition
  - baryon and meson excited states
- ✳100% Duty Factor (cw) Beam
  - coincidence experiments
  - Four simultaneous beams
  - Independent E and I
- ✳ Polarization
  - spin degrees of freedom
  - weak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

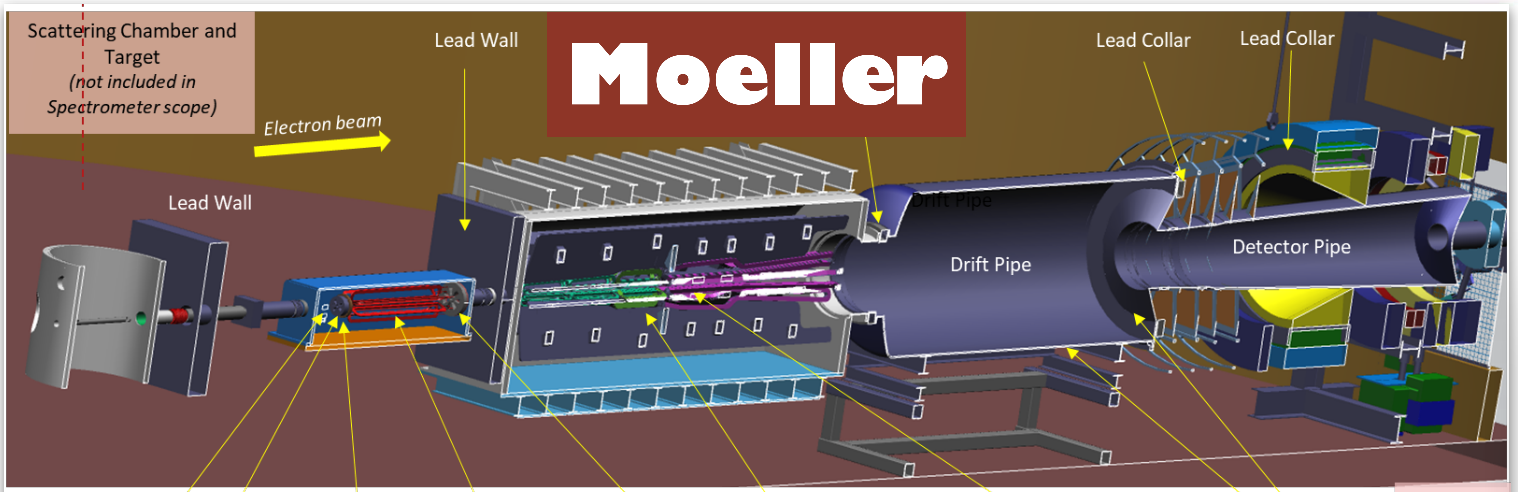
Luminosity > 10^7 -10^8 x SLAC at the time of the original DIS experiments!

BNL: sPHENIX

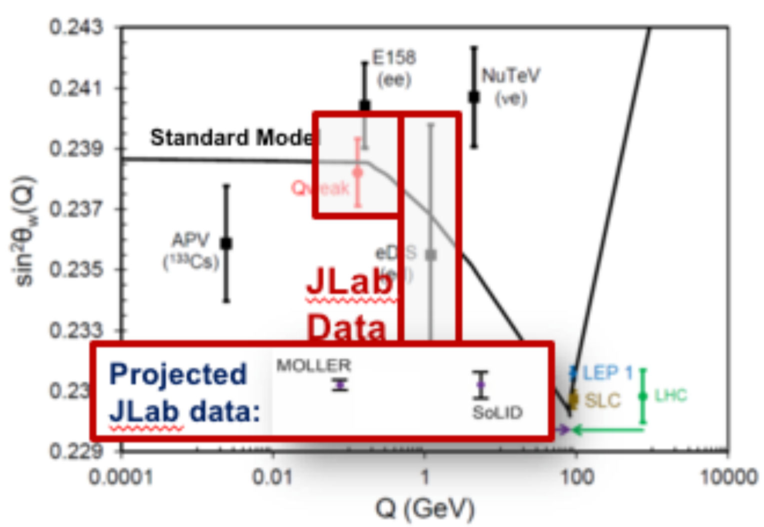




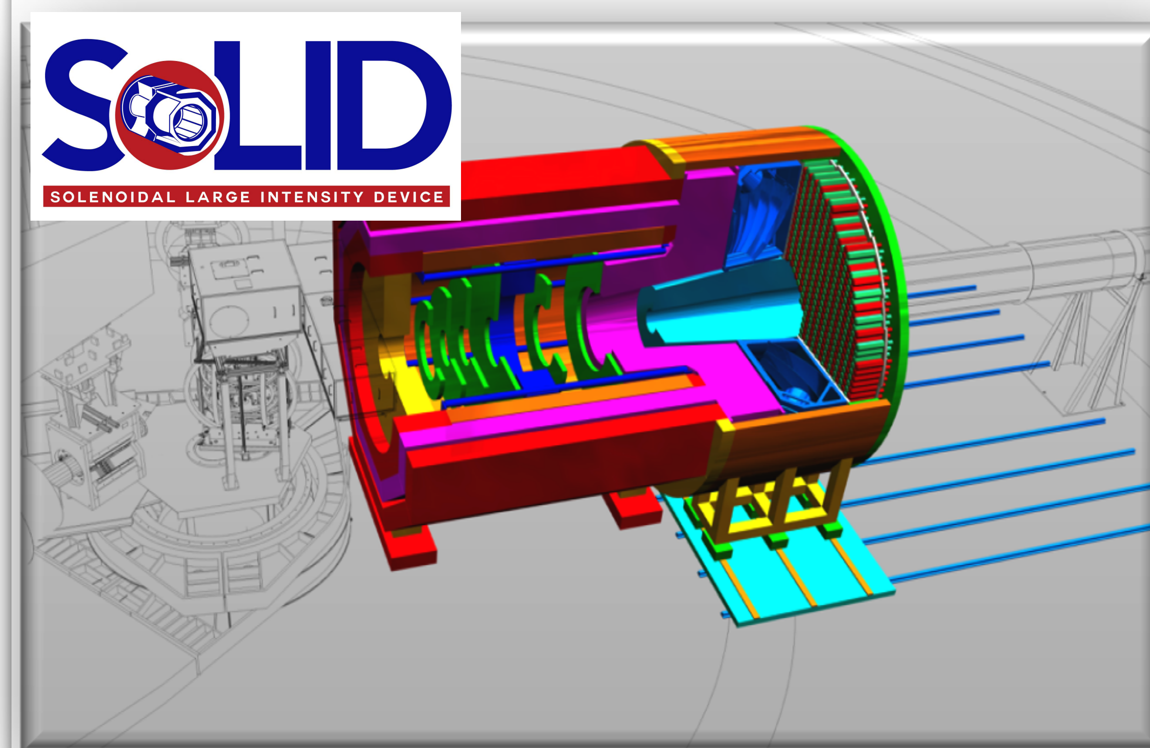
Present & future

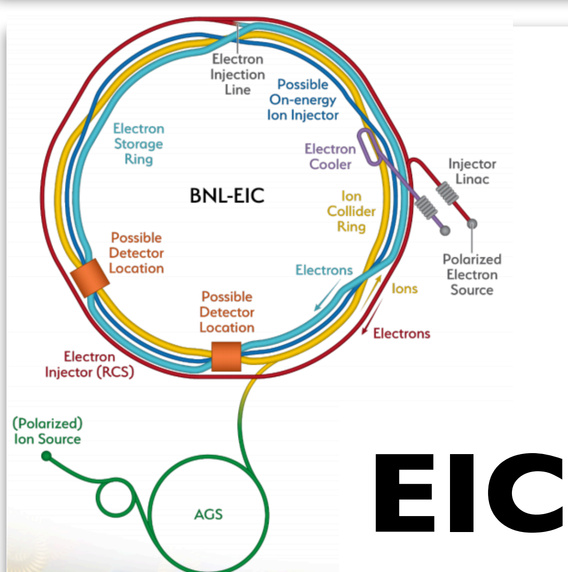


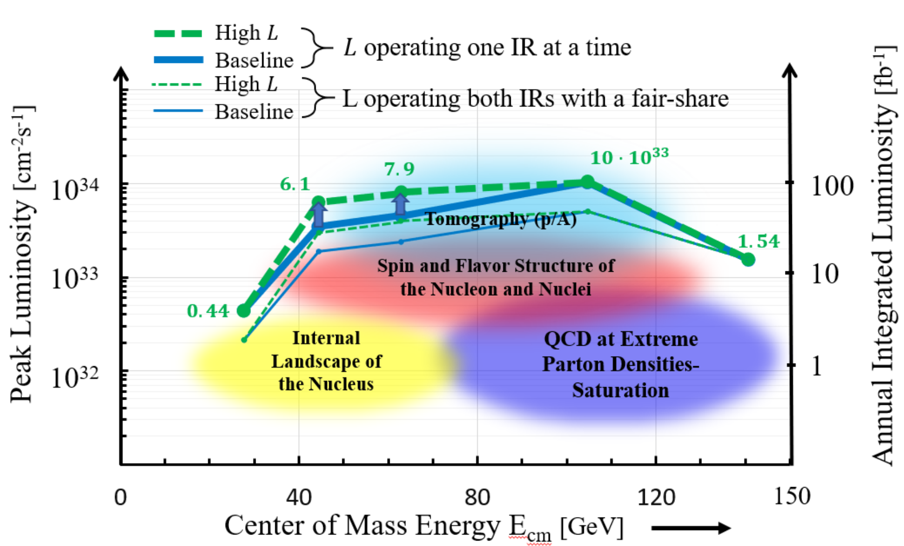
- Unique discovery space for new physics up to 38 TeV mass scale, with a purely leptonic probe
- CD-1 approved Dec 2020
- Expected to operate in FY26



- **SO**lenoidal **L**arge **I**ntensity **D**evice – new multipurpose detector facility optimized for high luminosity (10^{37-39} 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

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

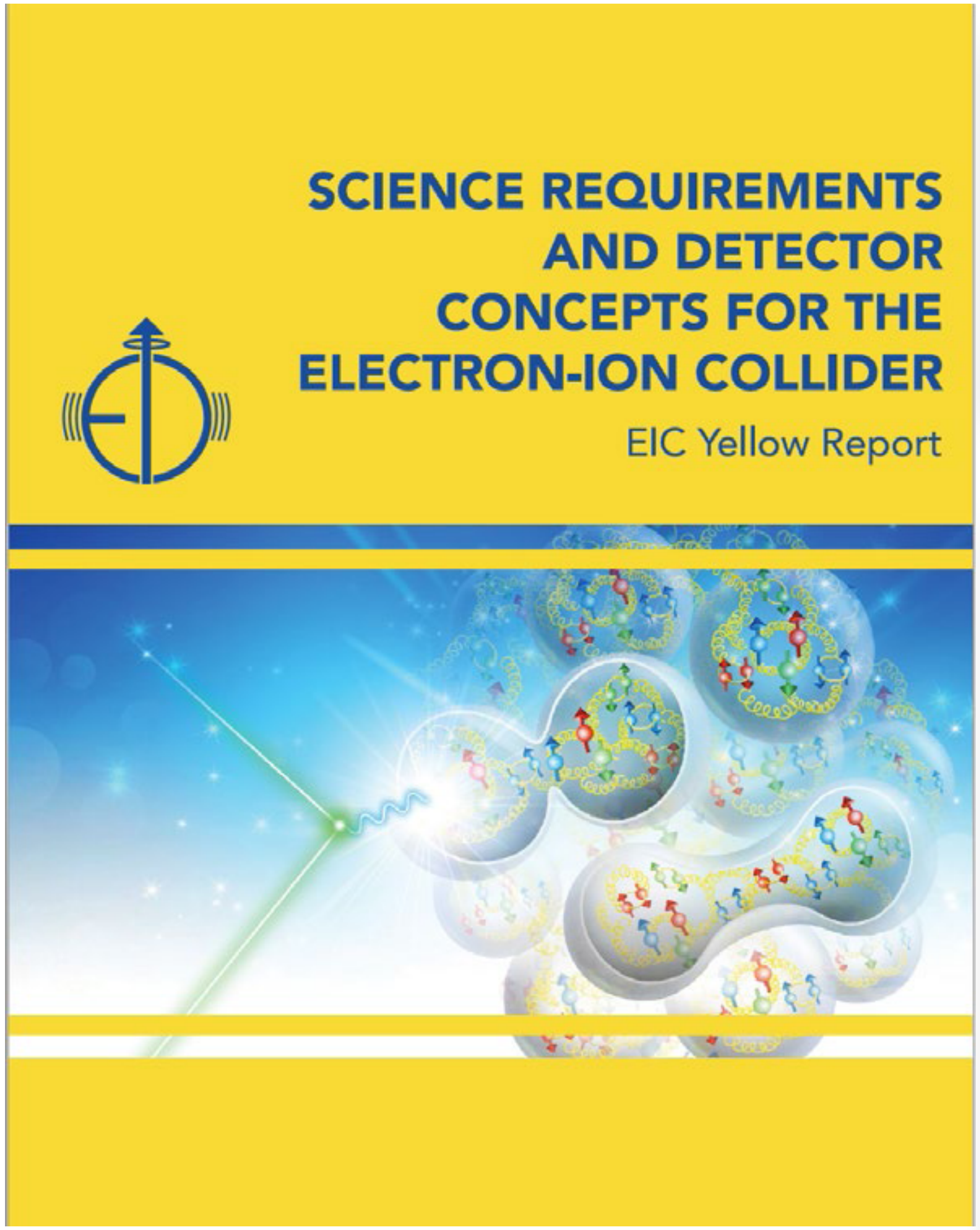
Many NP and HEP experiments adopt the SRO scheme (with different solutions):

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

M.Battaglieri - JLAB

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,

Date: Mar 05, 2021

EIC Detector R&D Proposal and Progress Report

Project ID: eRD23
Project Name: Streaming readout for EIC detectors
Period Reported: from 6/26/2020 to 2/28/2021
Project Leader: M. Battaglieri and J. C. Bernauer
Contact Person: M. Battaglieri and J. C. Bernauer
Project members

J. Huang, M.L. Purschke
Brookhaven National Laboratory, Uptown, NY

S. Ali, V. Berdnikov, T. Horn, M. Muhoza, I. Pegg, R. Trotta
Catholic University of America, Washington DC

M. Battaglieri, M. Bondí, A. Celentano, L. Marsicano, P. Musico
INFN, Genova, Italy

F. Ameli
INFN, Roma La Sapienza, Italy

L. Cappelli, T. Chiarusi, F. Giacomini, C. Pellegrino
INFN, Bologna, Italy

D. K. Hasell, C. Fanelli, I. Friščić, R. Milner
Massachusetts Institute of Technology, Cambridge, MA

J. C. Bernauer
Stony Brook University, Stony Brook, NY and Riken BNL Research Center, Upton, NY

E. Cline
Stony Brook University, Stony Brook, NY

S. Boyarinov, C. Cuevas, M. Diefenthaler, R. Ent, Y. Furletova, V. Gyurjyan, G. Heyes, D. Lawrence, B. Raydo
Thomas Jefferson National Accelerator Facility, Newport News, VA

Abstract

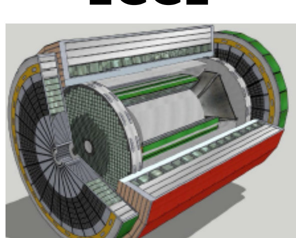
The detectors foreseen for the future Electron-Ion Collider will be some of the few major collider detectors to be built from scratch in the 21st century. A truly modern EIC detector design must be complemented with an integrated, 21st century readout scheme that supports the scientific opportunities of the machine, improves time-to-analysis, and maximizes the scientific output. A fully streaming readout (SRO)

M.Battaglieri - JLAB

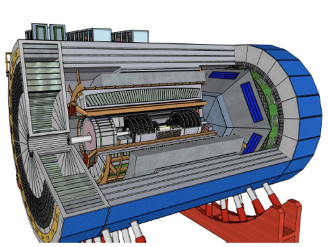
EIC R&D
Streaming Readout Consortium
eRD23

Last workshop
- Organized by ORNL
- virtual, Dec 8-10 2021

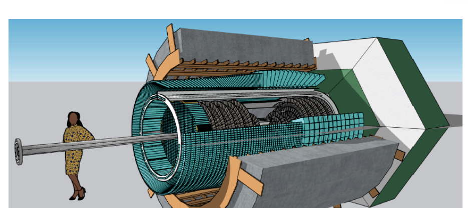
ECCE



ATHENA



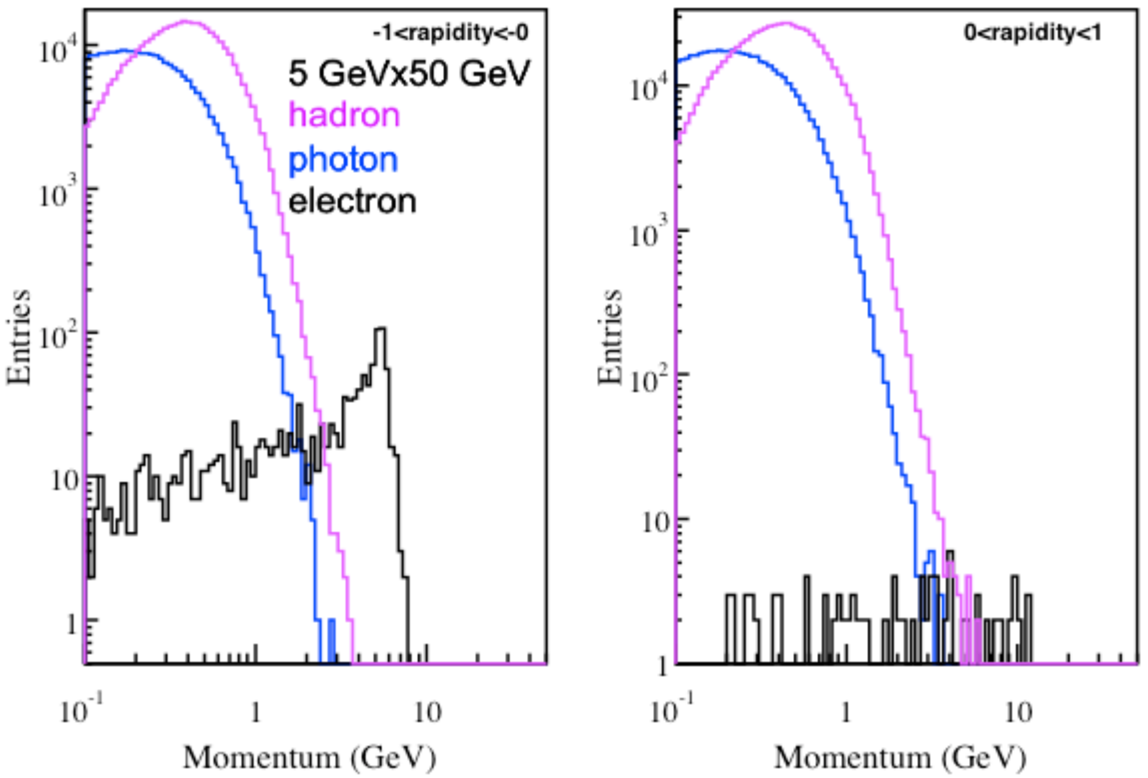
CORE



Some examples ...

Streaming readout for EIC

A triggerless DAQ provides advantages for all EIC reaction channels



Inclusive channel

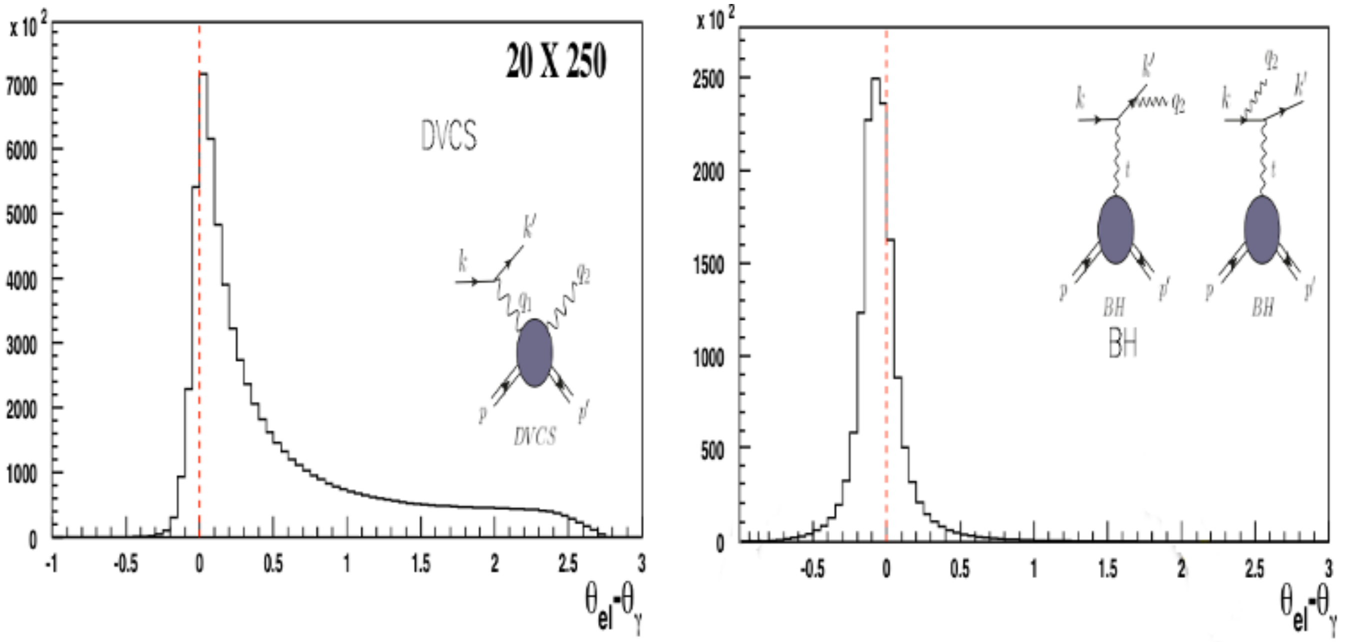
- Excellent e/h and e/γ discrimination
- At large η (large Q^2), low-momentum electrons are overwhelmed by hadrons background

Triggerless DAQ system allows a sophisticated electron selection, making use of advanced algorithms applied to the full information from detectors

Exclusive channels

Several trigger conditions tailored to physics Eg. DVCS

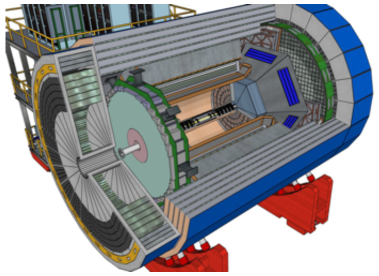
- DVCS benefits by the measurement of the hard photon together with the scattered electron
- The dominant BH background can be rejected by reconstructing θ_e and θ_γ and cutting on (θ_e-θ_γ)

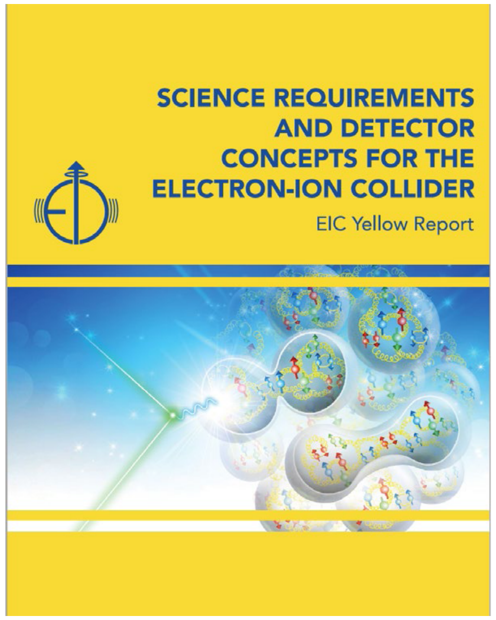


Large flexibility to add new triggers for different physics cases!

Some examples ...

Alexandre Camsonne, Jeffery Landgraf

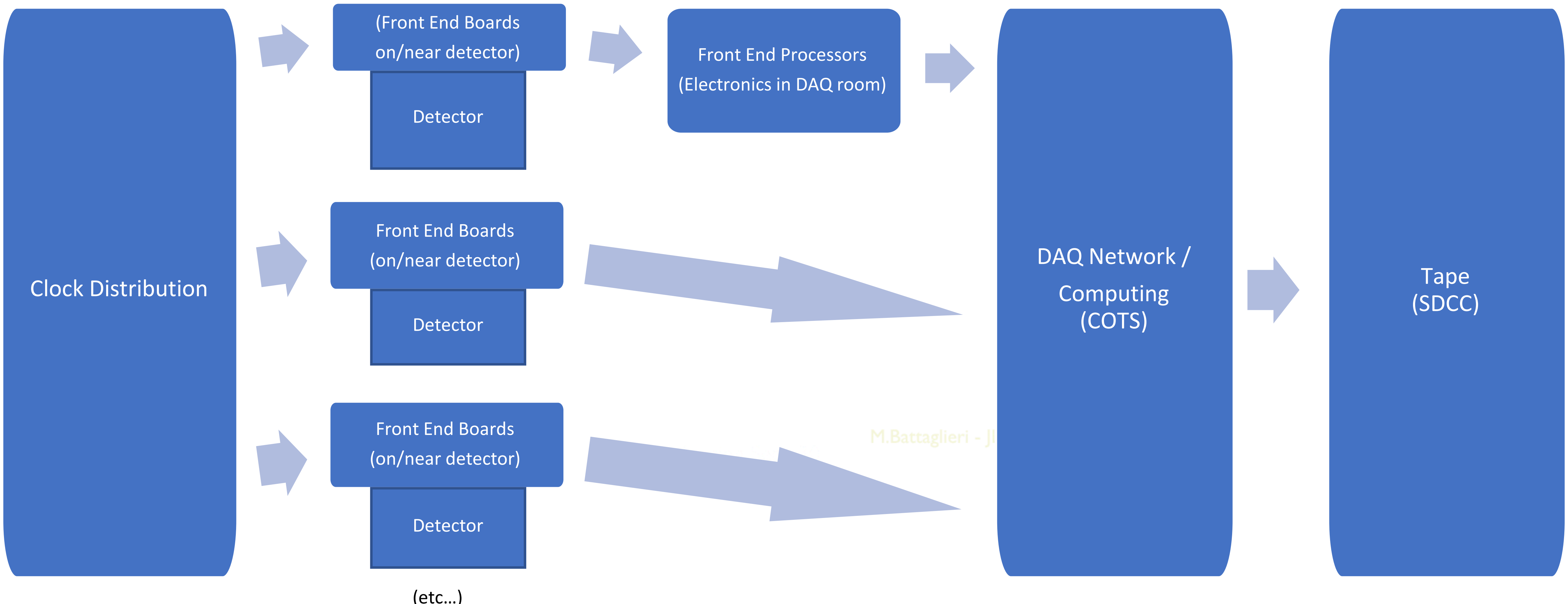




ATHENA

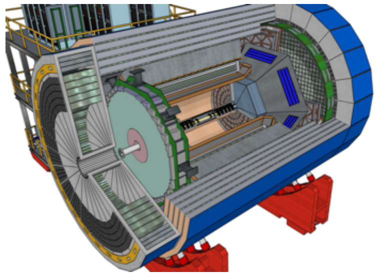
We envision a triggerless streaming DAQ system following the outline described in the Yellow Report

- *Gets rid of many latency constraints*
- *Gets of the need for a hardware trigger*
- *Amplifies the need for robust zero-suppression / data compression*
- *No trigger allows for any physics process studies off-line*

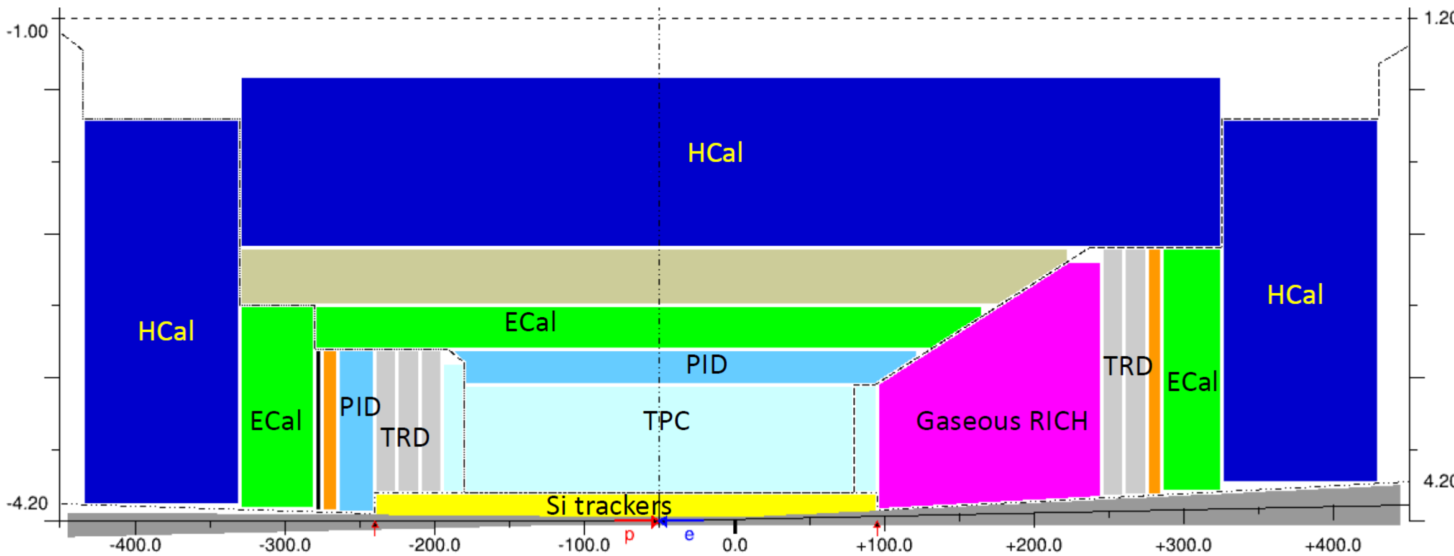


Some examples …

Alexandre Camsonne, Jeffery Landgraf



ATHENA

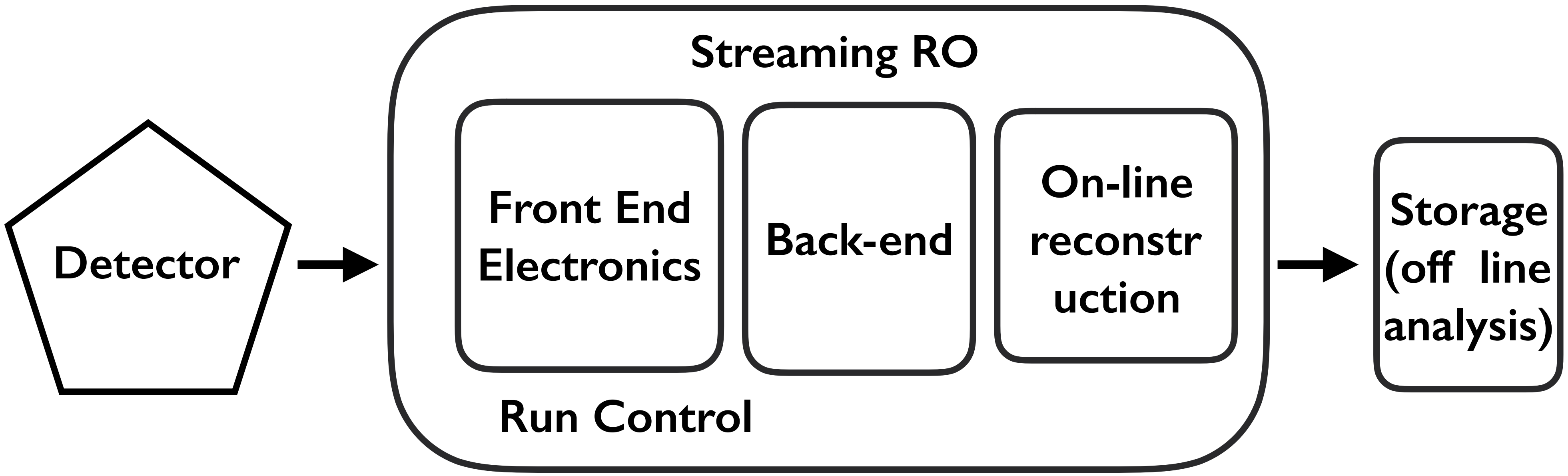


- Tracking: GEM + MPGD
- eCal-FW: PBWO + W_{powder} sci/fi, SiFi
- eCal-BR: SiFi
- hCal: Fe/Sci
- pId: mRICH, DIRC, DRICH
- pId: TOF LGAD
- FarFW: ZDC, RomanPot

- Collider parameters:
  - ~500KHz of collisions
  - ~60-100Gbps zero suppressed data
  - ~15 KB/event
  - ~100 bytes/bunch crossing
- Significant number of channels
- Challenging data compression scheme
  - Noise reduction
  - Zero suppression
  - Background elimination
- Keeping option of data selection before going to tape in case data volume too large to record all the streams

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
HCAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

Streaming RO components

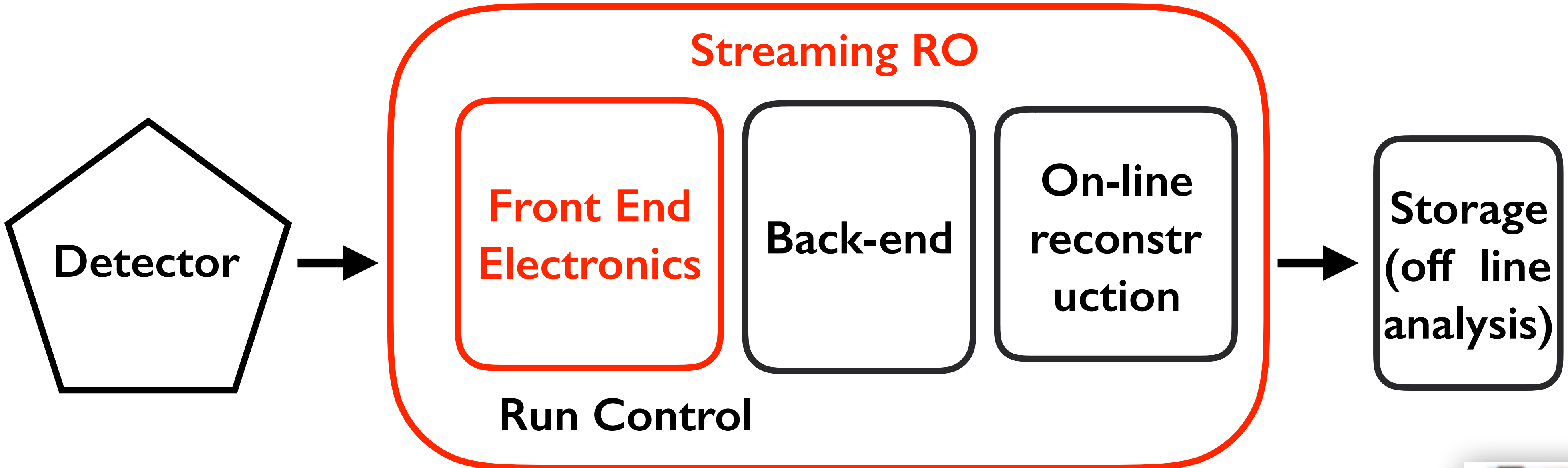


SRO concept validation

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

M.Battaglieri - JLAB

Streaming RO components



SRO concept validation
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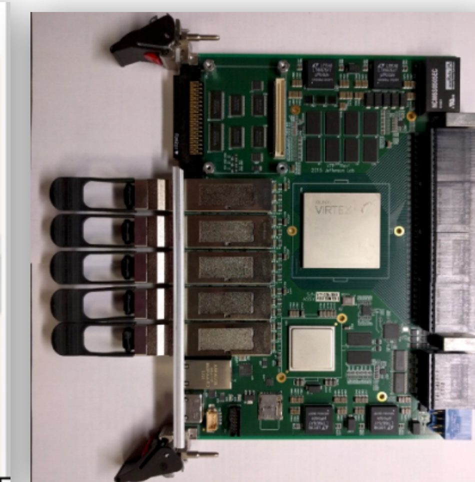
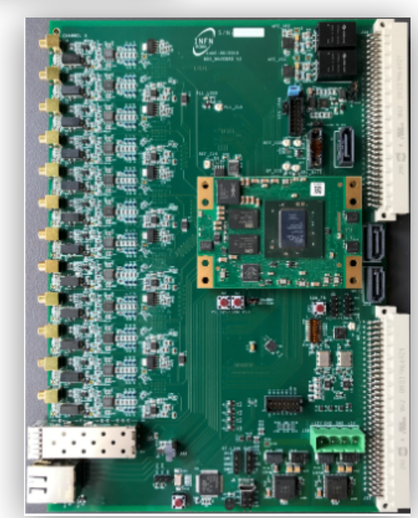
FrontEnd

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

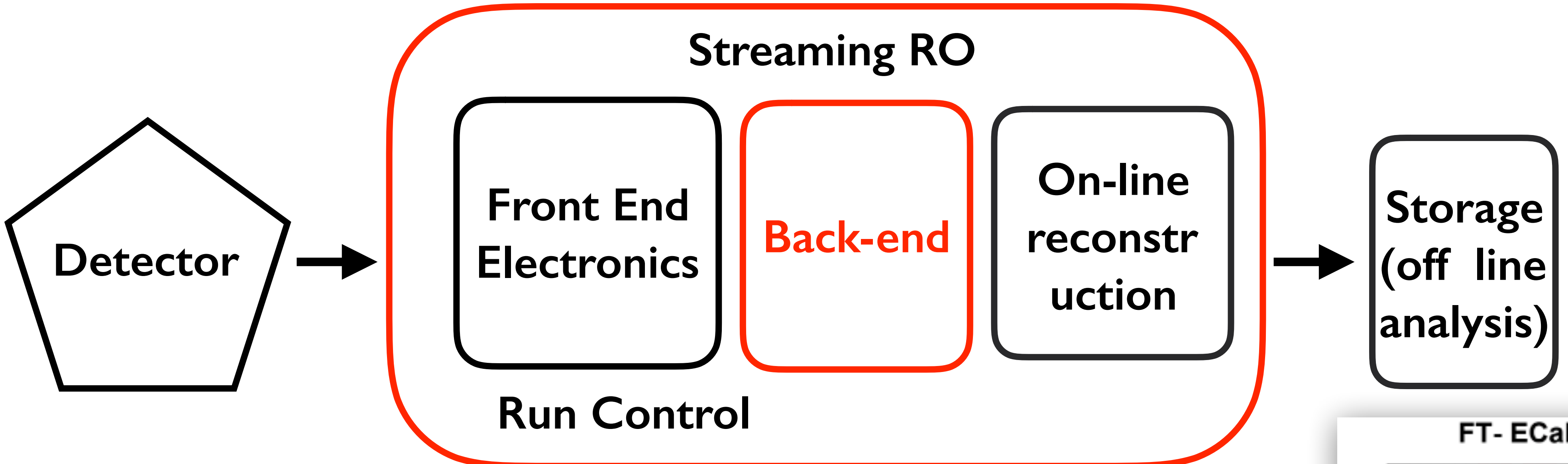


M.Battaglieri - JLAB

✳ **INFN WaveBoard**

- SRO dedicated INFN 250 MHz flash ADC digitizer

Streaming RO components



SRO concept validation
1) Assemble SRO components
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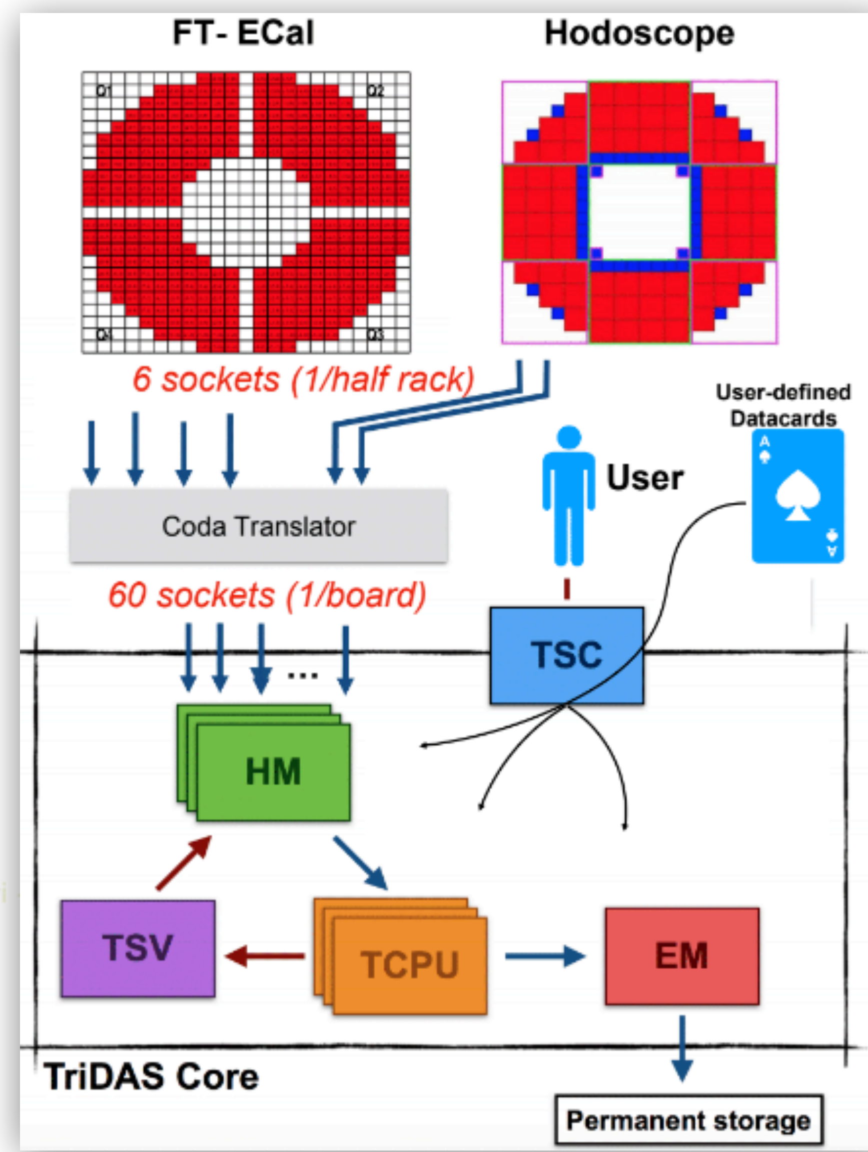
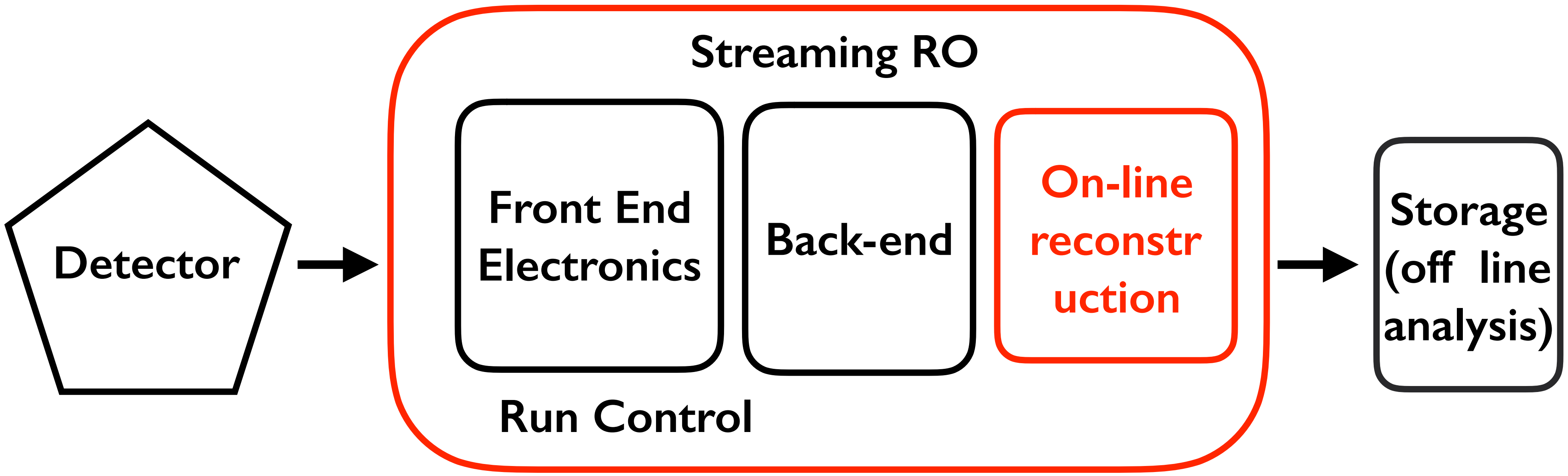
BackEnd

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



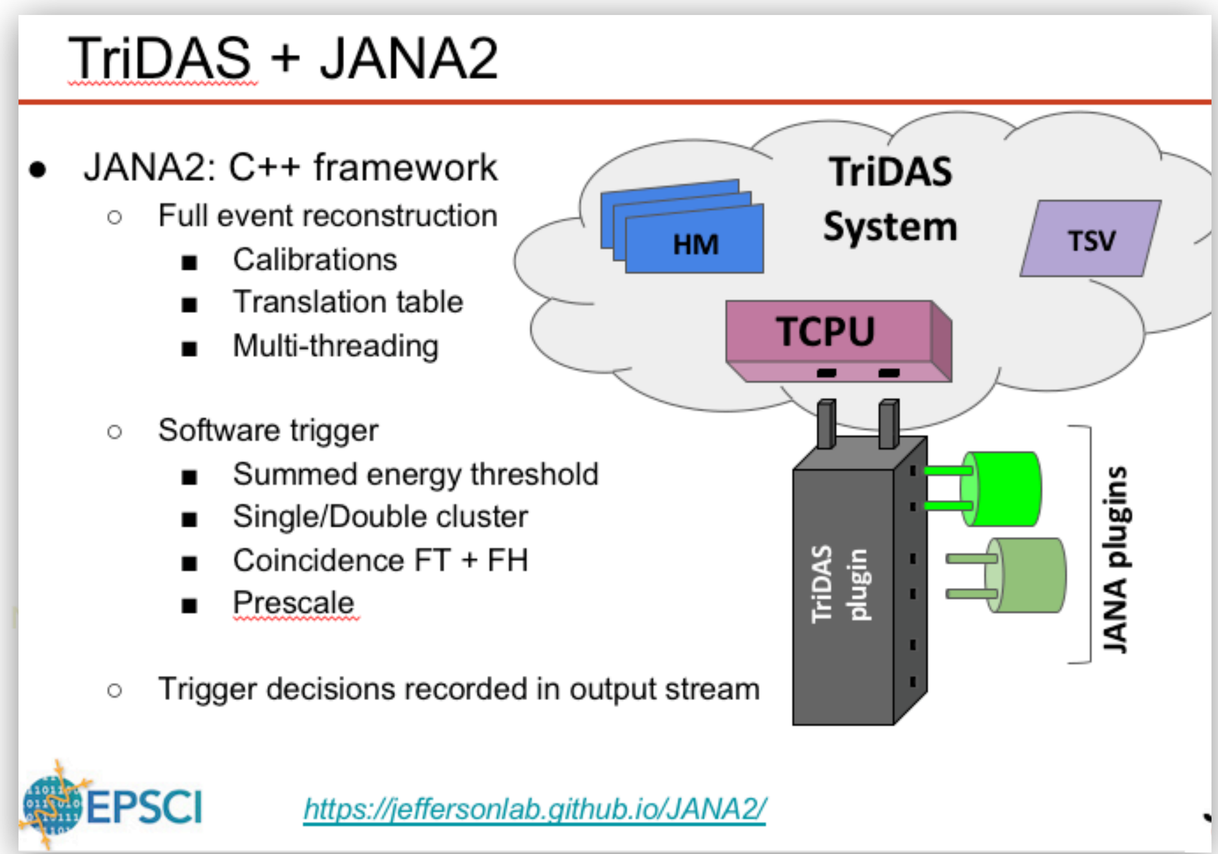
SRO concept validation
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

Jana2 + reconstruction

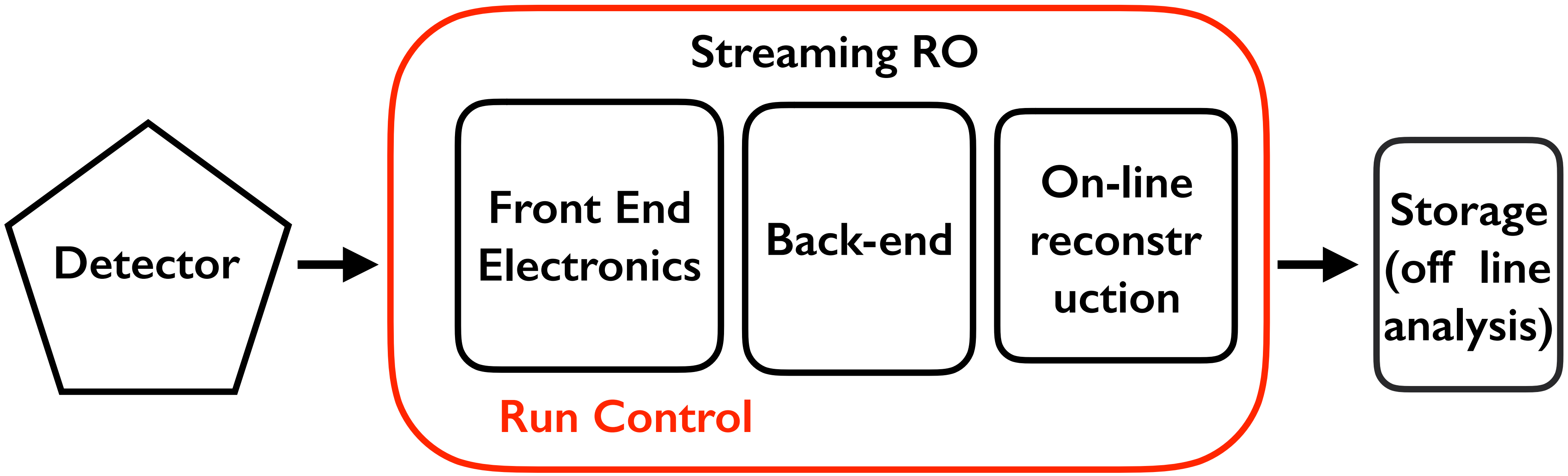
N.Brei, D.Lawrence,
M.Bondi', A.Celentano, C.Fanelli, S.Vallarino

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



Streaming RO components



SRO concept validation

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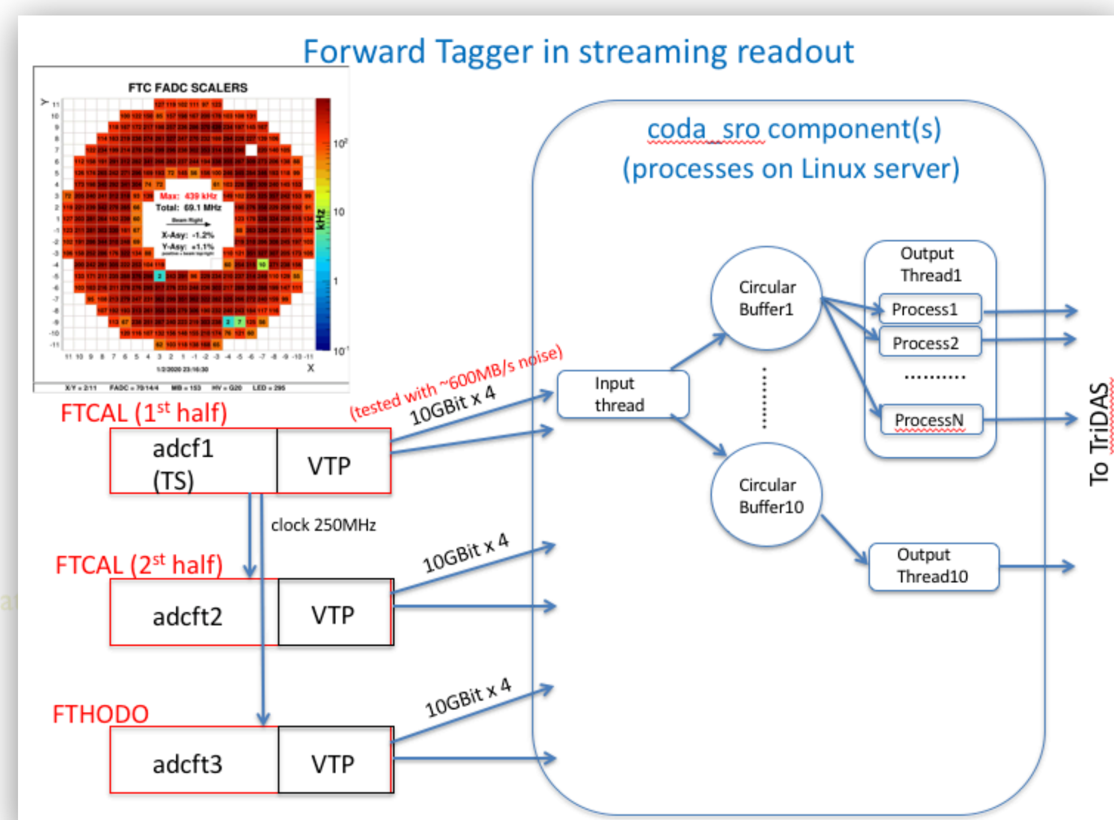
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

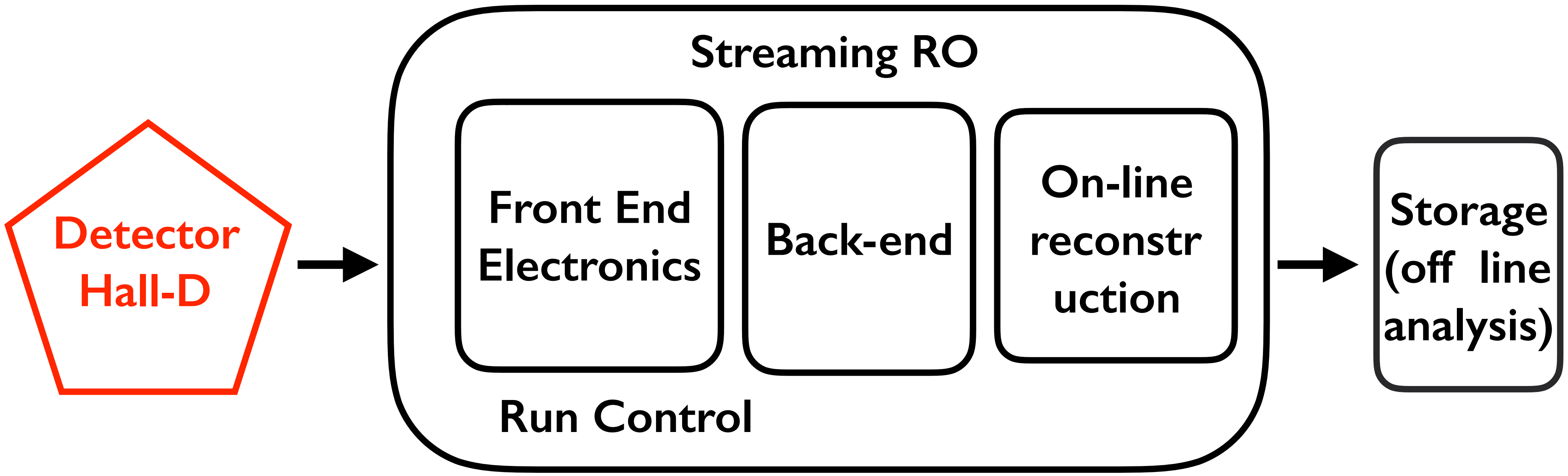
Cebaf Online Data Acquisition (CODA)

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



SRO concept validation

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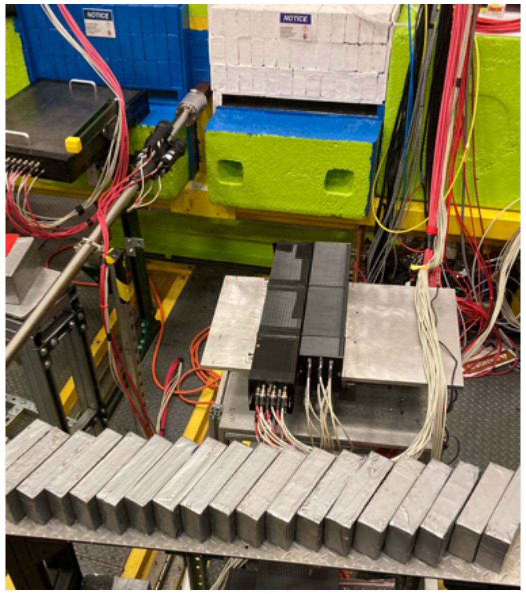
JLab SRO validation

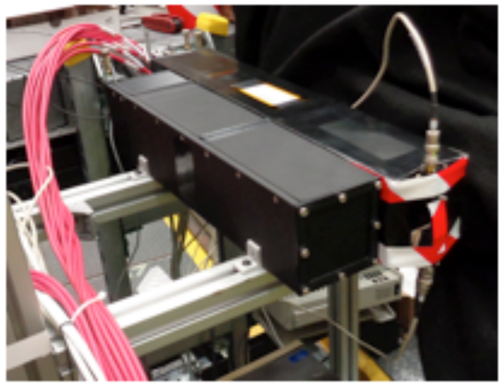
V.Berdnikov, T.Horn



✳ 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

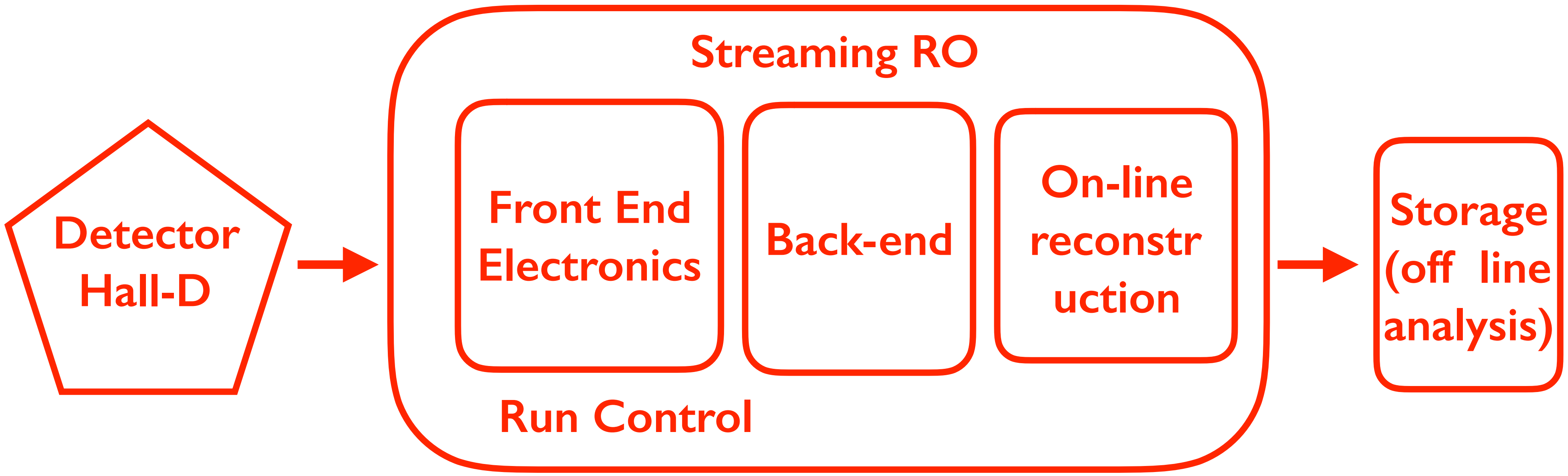
M.Battaglieri -



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

Waveboard

Streaming RO components



SRO concept validation

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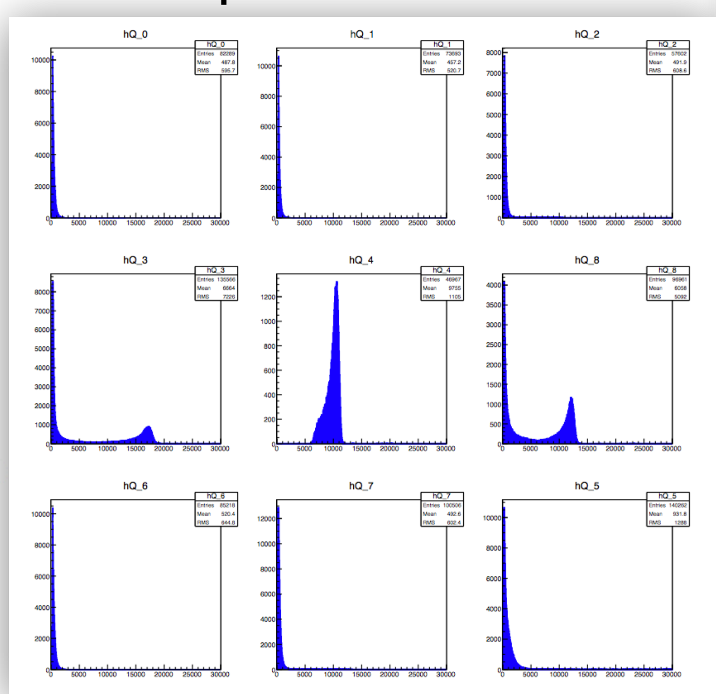
3) Test SRO DAQ on-beam

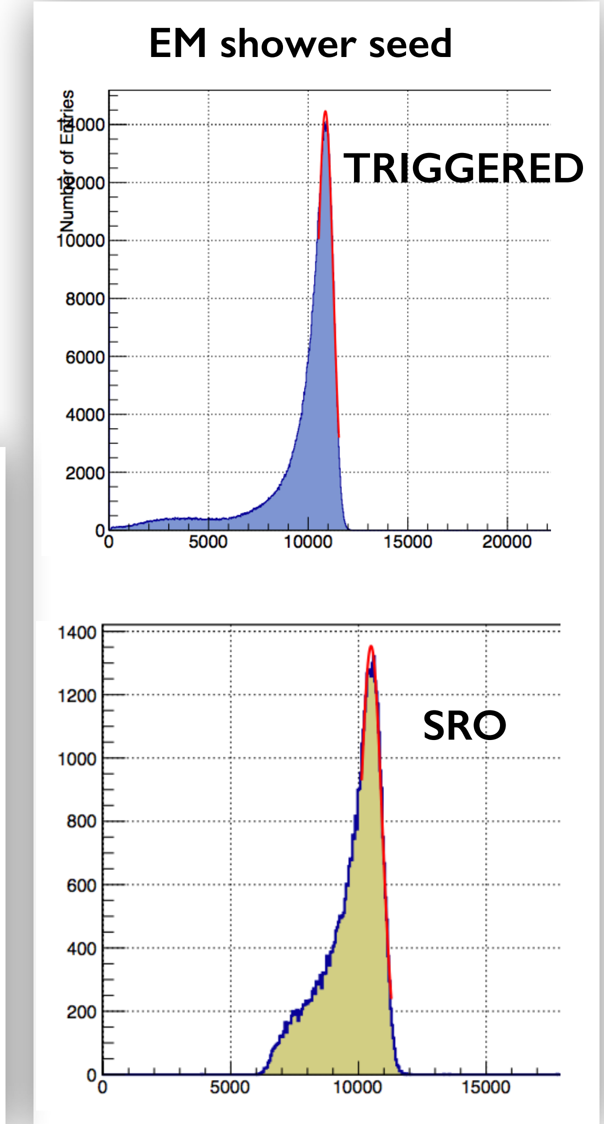
JLab SRO test

V.Berdnikov, T.Horn

Preliminary test results

ECAL proto: 9ch SRO-mode





✳ **EIC ECal PbWO prototype**

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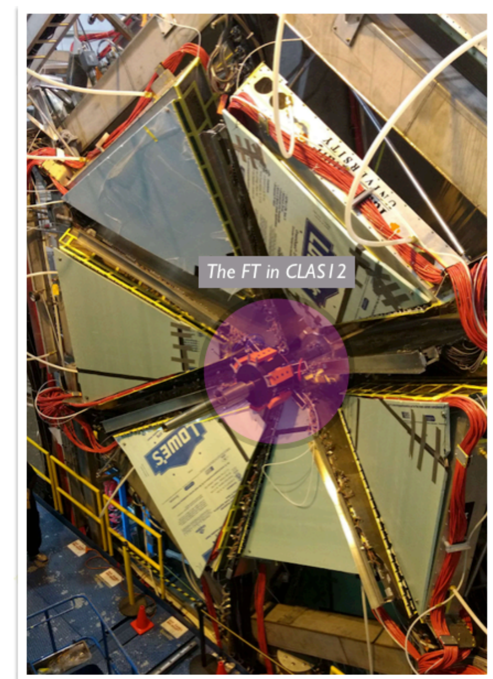
- Simple setup to compare TRIGGERED to TRIGGERLESS
- 3x3 PbWO crystals, PMT and SiPM readout
- fADC250 and WaveBoard front end

Streaming RO components

Detector Hall-B → **Streaming RO** [Front End Electronics | Back-end | On-line reconstruction] Run Control → Storage (off line analysis)

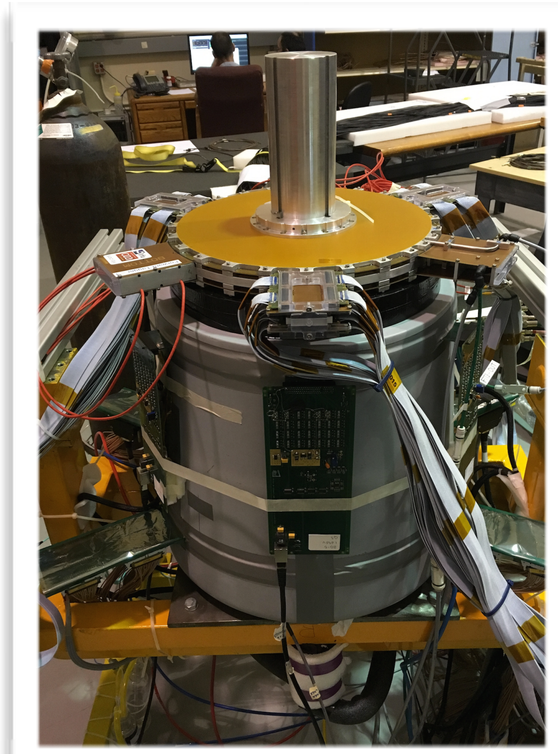
SRO concept validation

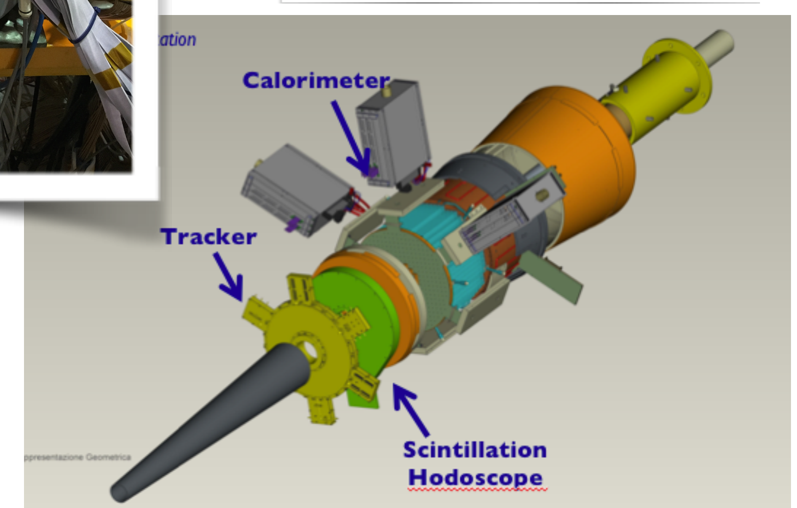
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam



JLab SRO validation

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



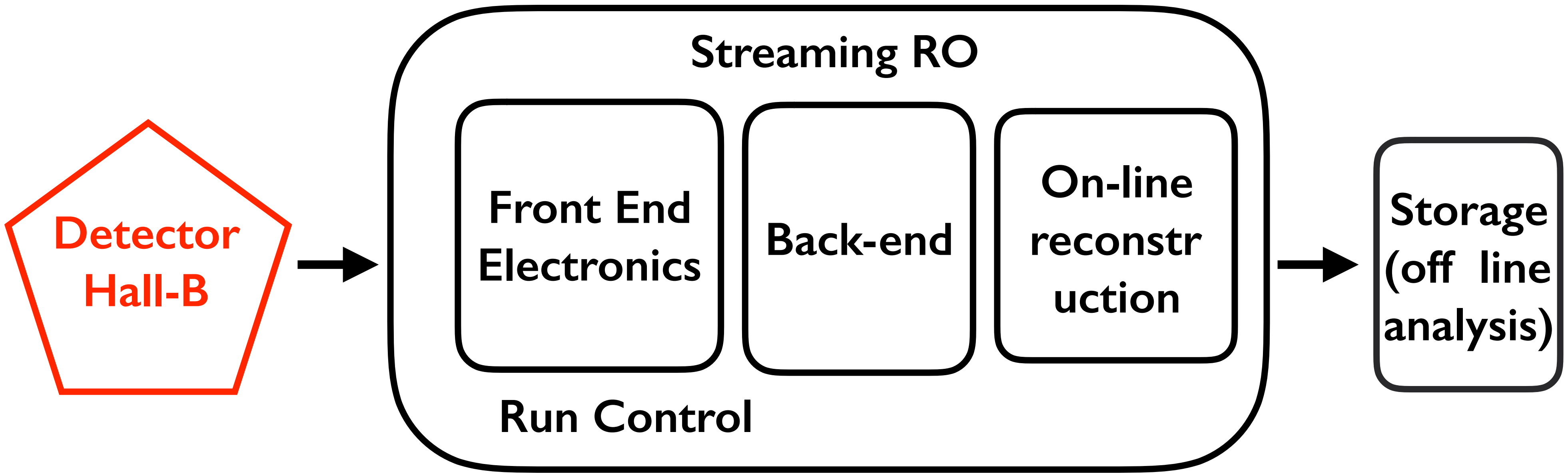


✳ **CLAS12 Forward Tagger**

- 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

M.Battaglieri - JLAB

Streaming RO components



SRO concept validation

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

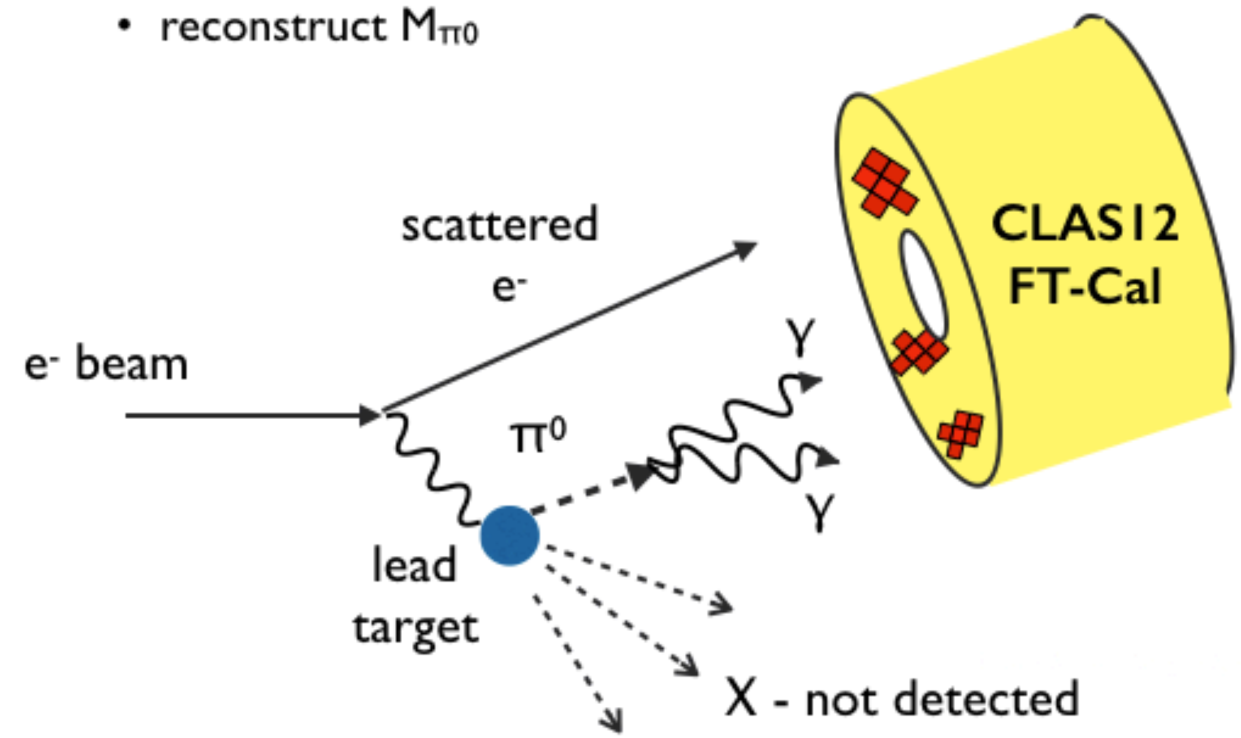
JLab SRO validation

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

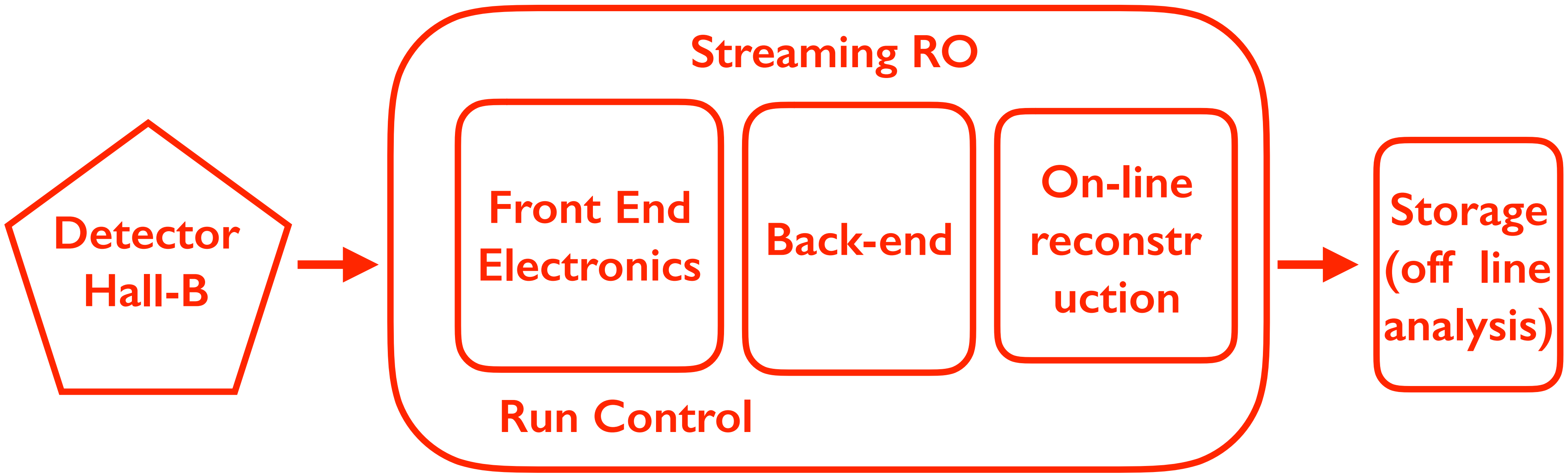
- collect data with 1-2-3 clusters in FT-CAL
- Identify the reaction
  e H/D2/Al/Pb $\rightarrow$ (X) e' π^0 $\rightarrow$ (X) e' γ γ
- reconstruct $M_{\pi 0}$

✳ **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



SRO concept validation

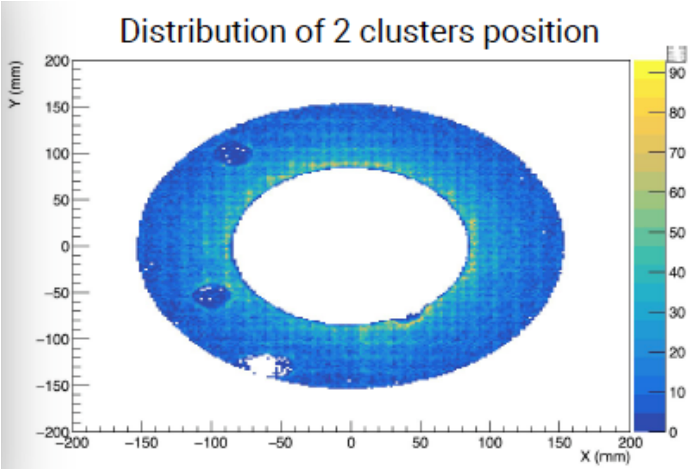
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

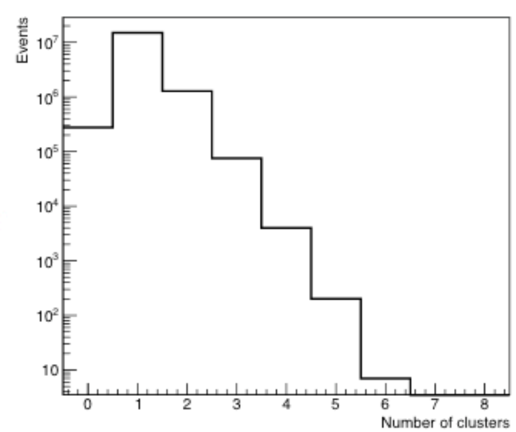
JLab SRO test

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

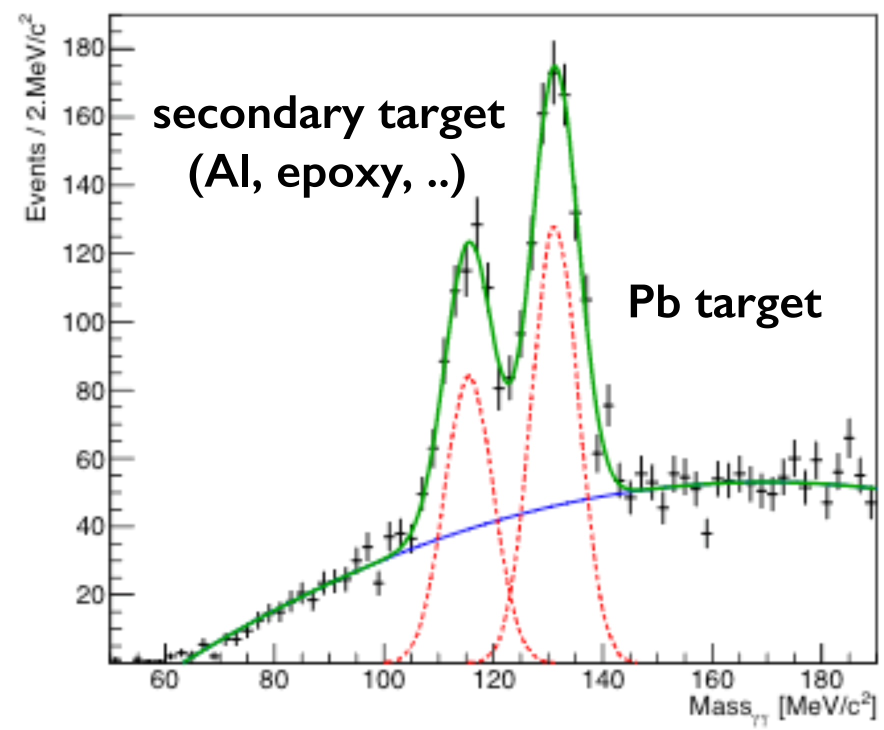
✳ **CLAS12 Forward Tagger**

- 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)





Preliminary test results



- **Measured (expected) pi0 yield**

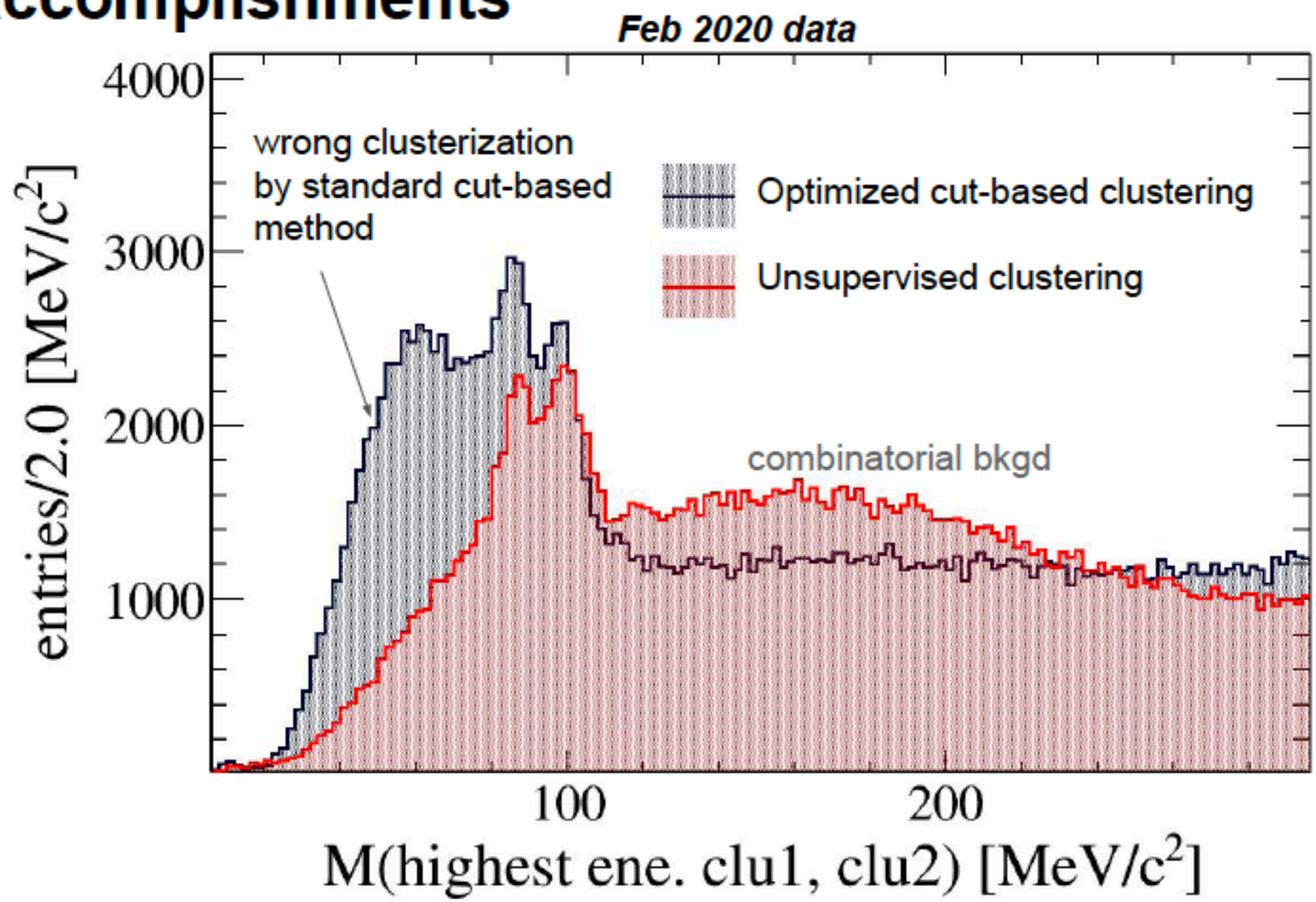
  Peak1 = 1365+-140 (~1800)

  Peak 2 = 930+-100 (~420)

Run1 Data analysis (AI-supported)

C.Fanelli

Accomplishments



*The cut-based clustering seems to assign more hits to the highest energy seed cluster.

- Implementation of AI supported L2 reconstruction algorithms for SRO: offline and online tests accomplished
- Unsupervised (no cuts required) hierarchical clustering generally robust against variations in experimental conditions
- AI tolerates larger hits multiplicities

- Run1: off-line only
- Run2: real time!

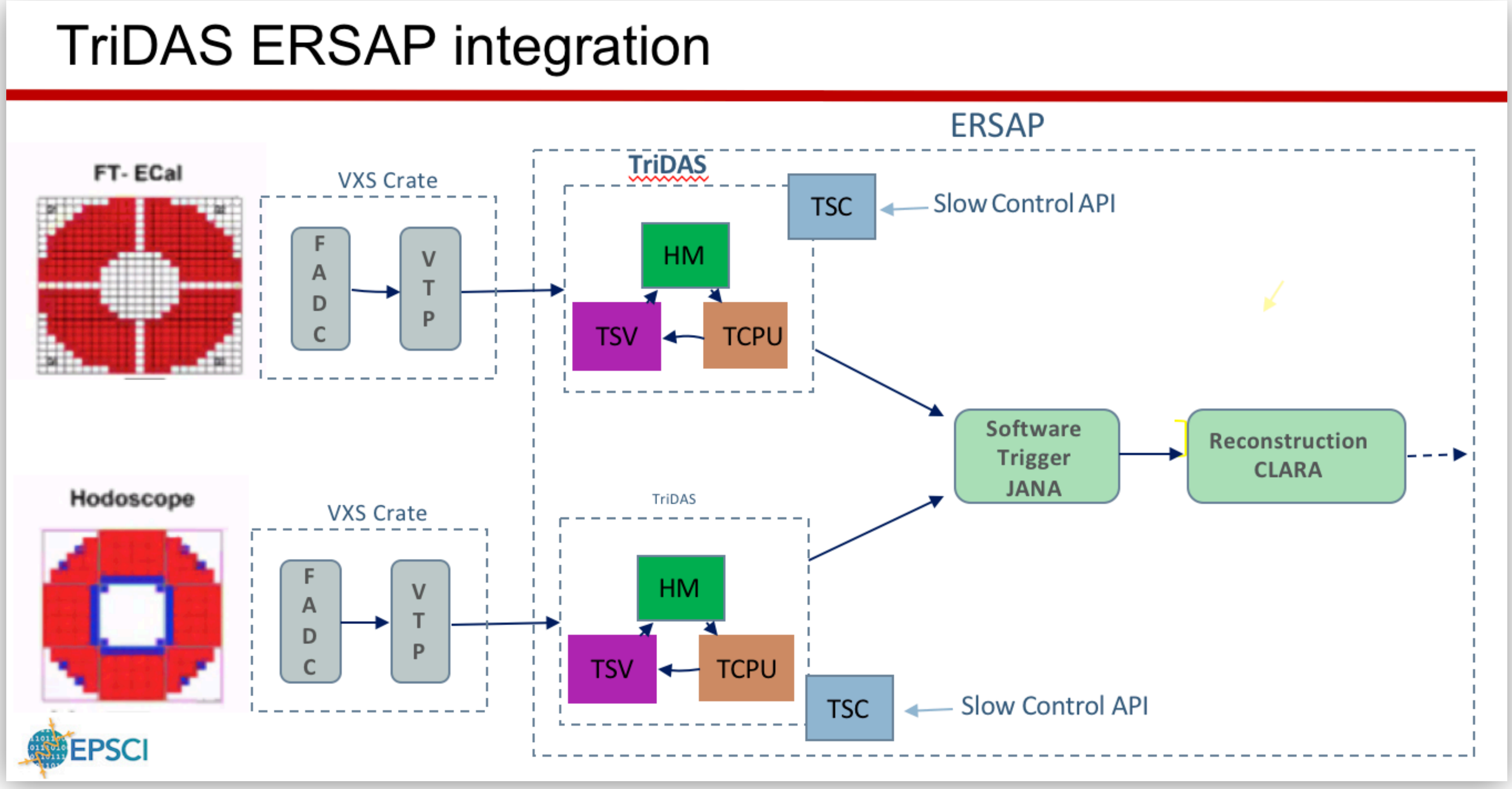
Data analysis in progress

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



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Next steps

- We built SRO DAQ working system (FE+TRIDAS+JANA) with a join effort INFN/JLAB
- Tested on EIC cal prototype (PbWO)
- Tested in on-beam tests at Jefferson Lab (CLAS12-FT)
- Tested some AI-supported algorithms (off-line) for clustering

Workplan 2022

- Secure resources for 1y postdoc from MAECI grant to hire for dedicated effort
  - Scintillating glass tests with cosmic rays (INFN-GE)
  - dRICH data
- Implementation of AI/ML-supported algorithms at both front-end and back-end
- FE: implementation on FPGA boards? filtering?
- BE: high level analysis: raw data (clustering, tracking, …) and beyond