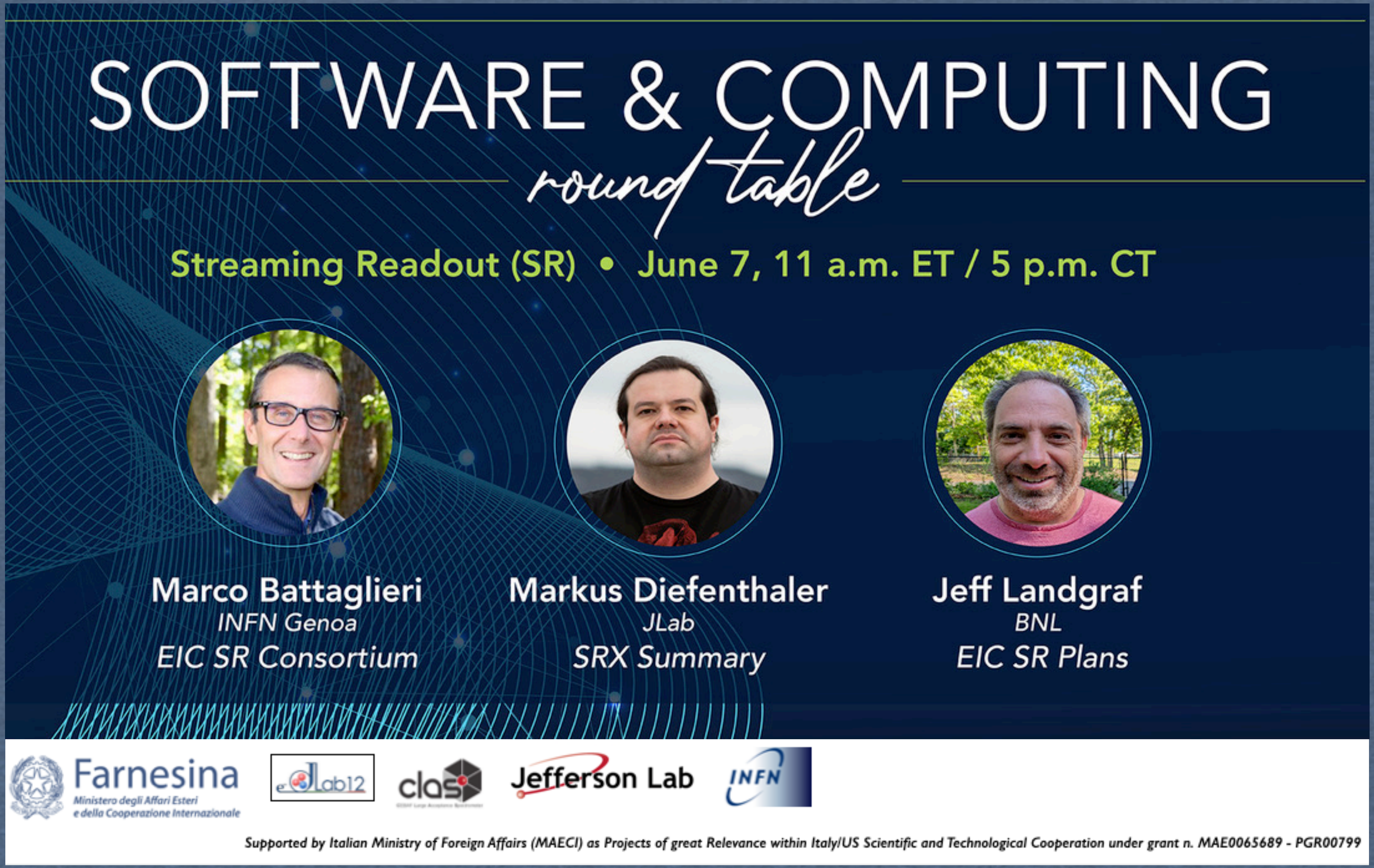

EIC Streaming Readout Consortium

M.Battaglieri ***(INFN) and J.Bernauer (SBU)***

eRD23 Consortium Proposal (EIC generic R&D)

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.

Streaming Readout for EIC Detectors

Douglas Hasell
for the
Streaming Readout Consortium

EIC Detector R&D Meeting
Catholic University of America
July 26, 2018

... back to July 2018

Introduction | Streaming Readout Consortium

Streaming Readout Consortium

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Thomas Jefferson National Accelerator Facility, Newport News, VA

New members welcome !

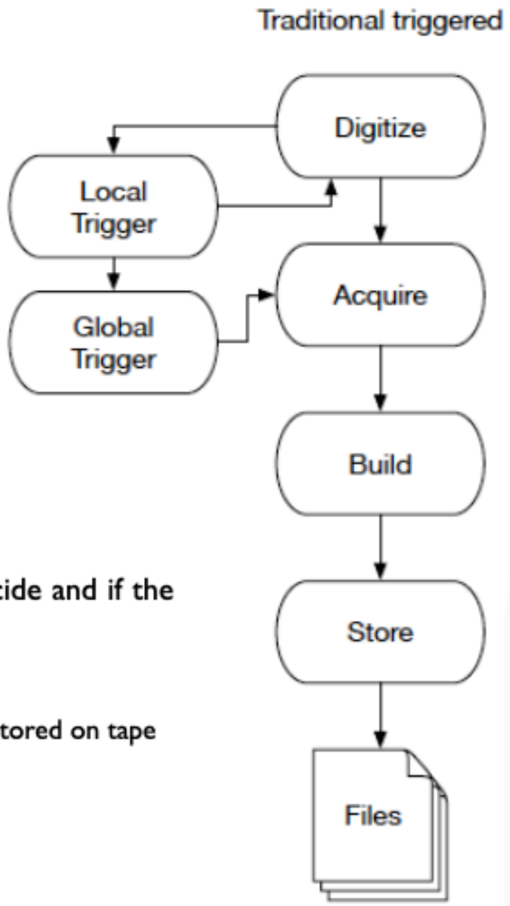
Yulia Furletova (JLab) and GEM-TRD/T group will collaborate.

† at Stony Brook University beginning September, 2018

D.K. Hasell | EIC Streaming Readout | July 26, 2018 | 2 / 24

Streaming RO: the project

Traditional (triggered) DAQ



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

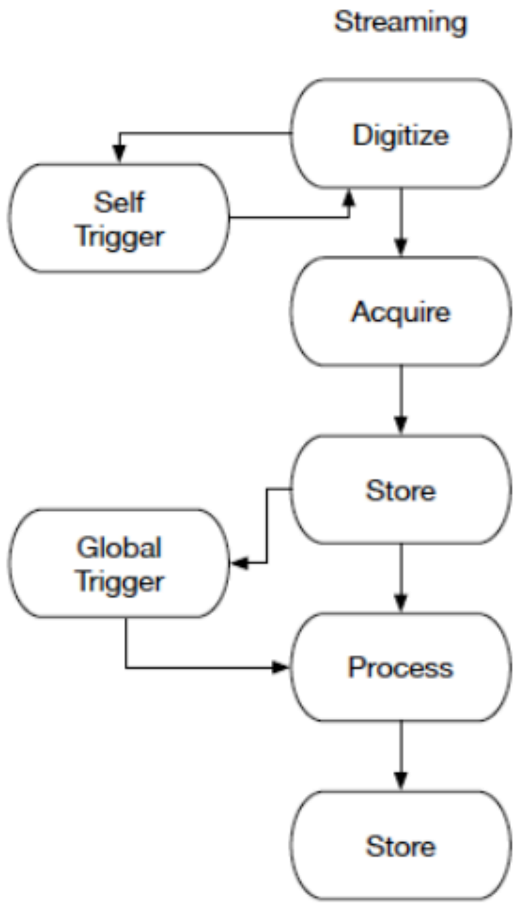
* All channels continuously measured, hits stored in short term memory

* 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):

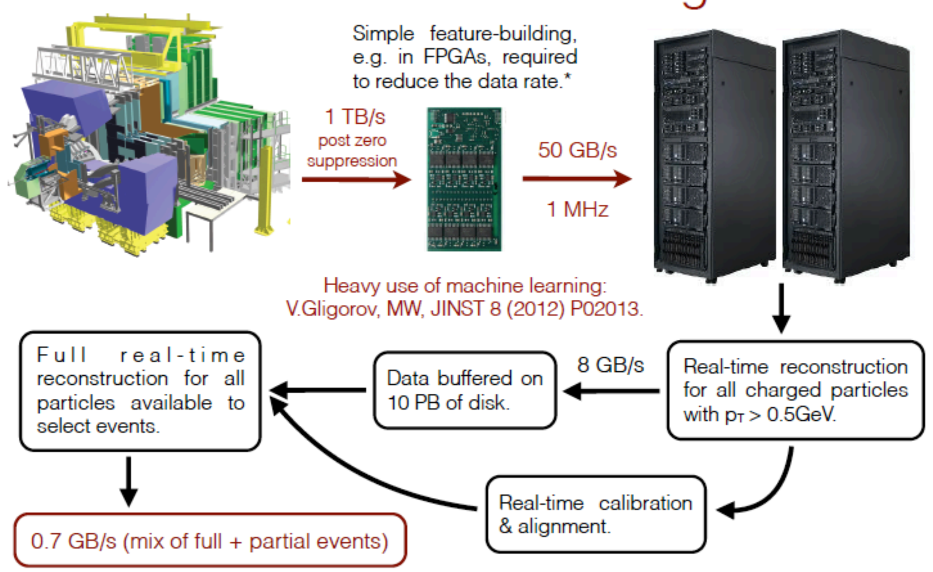
- CERN: LHCb, ALICE, AMBER
- FAIR: CBM
- DESY: TPEX
- BNL: sPHENIX, STAR, EIC
- JLAB: SOLID, BDX, CLAS12, …

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

Readout Scheme at LHCb

JINST 8 (2013) P04022

Real-Time Processing

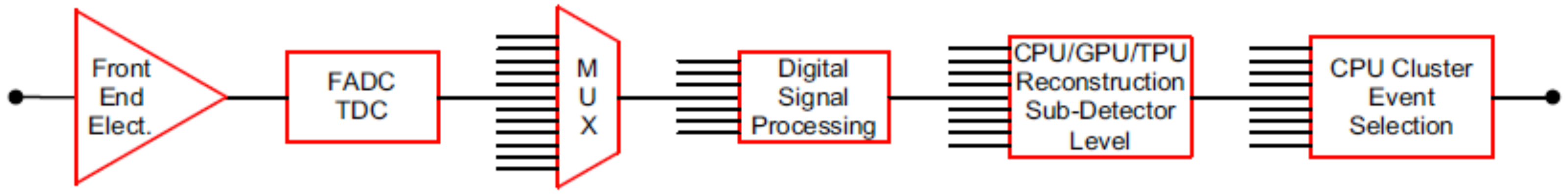


*LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

Slide provided by Mike Williams (MIT)

✳ LHCb HI-LUMI as a reference

Streaming Readout Scheme



Goal: Do as much as possible on-line and save everything that is useful

- extract relevant parameters for all channels
- extract time, position, momenta, angles, energy, . . .
- discard noise and background hits when possible
- save high-level information, not hits !
- combine data in sub-detector or sectors to form event segments
- option to organised into events or not !
- all detector information available for making decisions

Consequences for detectors, electronics, software, and analysis !

Streaming Readout is Possible

For the EIC we need to start working towards this goal now !

- implications for the detectors, electronics, software, and analysis
- the whole chain needs coordination and standardisation

Leverage advances and falling costs of electronics, computers, storage, . . .

- ASICs → multiplexed ADC/TDC chips, rad. hard, low power, . . .
- FPGAs → affordable, multi-channel, digital signal processing
  - now with UNIX OS to simplified programming
- high bandwidth copper and optical fibre networking solutions
- affordable, multi-core CPU clusters to analyse data in real time
- reconstruction algorithms: neural networks, machine learning, . . .
- TPU chips - artificial intelligence accelerator ASIC

Many experiments already moving toward streaming readout !

✳ Prophetical view (4y ago!)

✳ Ambitious program:

- Front End electronics
- Backend software
- Detector interface

Develop the whole framework!

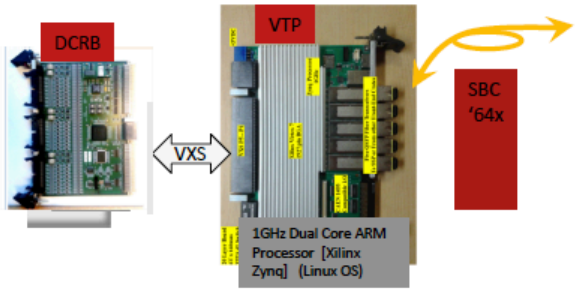
✳ **Main players:**
- BNL
- JLab
- CUA/MIT/INFN/SBU

R&D Proposal — JLab

Plan for Work at JLab

Streaming readout studies using the TDIS GEM readout for the rTPC

- use rTPC test stand being assembled at JLab
- components and software based on the ALICE DAQ upgrade
- gain experience to guide design of streaming readout



Crate-less streaming readout

- alternative to standard VME
- use VXS
- 250 MHz FADC and DCRB
- VXS trigger processor 20 Gb
- 4GB buffering

No funding request for this part of the proposal

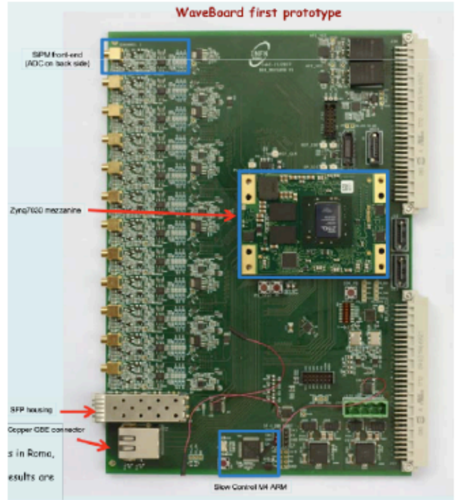
D.K. Hasell — EIC Streaming Readout — July 26, 2018 — 18 / 24

R&D Proposal — Genova and CUA

Plan for Work at INFN Genova and CUA

Streaming readout scheme for electromagnetic calorimetry

- investigate technologies suitable for various calorimeters
- SiPM, APD, PMT readout
- $PbWO_4$ calorimeters



Digitiser board at INFN-Genova

- 12 channels
- 250 MHz, 14 bit
- FEE matched to SiPM readout
- Zynq7030 FPGA dual core ARM
- copper and fiber output
- VME for power only

15 k$ requested both CUA and INFN Genova

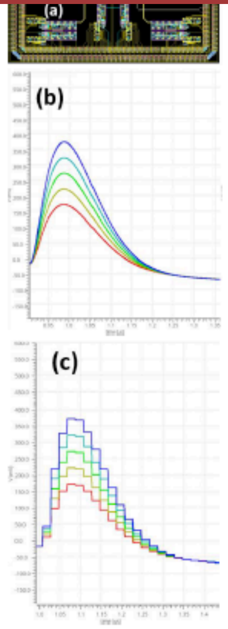
D.K. Hasell — EIC Streaming Readout — July 26, 2018 — 20 / 24

R&D Proposal — MIT

Plan for Work at MIT

Work on design of on-detector electronics

- front-end electronics
- ASIC chips in collaboration with Alphacore
  - preamplifiers, charge sensitive, shaper
  - 300-1300× gain for 0-300 pF
  - FADC 10-12 bit, 100-200 MSPS
- output matched to FPGA test boards
- various prototype detectors SiPM
  - SiPM connected to scintillating strip
  - GEM detectors
  - $PbWO_4$ with SiPM, APD or PMT together with INFN Genova



No funding request for this part of the proposal

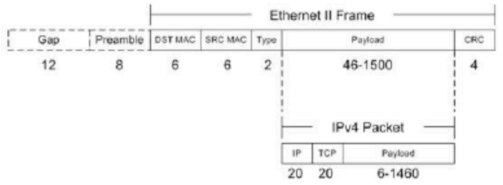
D.K. Hasell — EIC Streaming Readout — July 26, 2018 — 19 / 24

R&D Proposal — SBU

Plan for Work at Stony Brook University

Propose to investigate data transport architectures for streaming readout

- study different protocols: IP, TCP, UDP, Ethernet, . . .
- develop application layer solutions for data, slow control, . . .
- framework for online data processing
- study architectures for CPU clusters to best use resources



20 k$ requested for this part of the proposal

D.K. Hasell — EIC Streaming Readout — July 26, 2018 — 21 / 24

Streaming readout consortium for EIC detectors

A Streaming readout scheme for EIC requires:
- to identify and quantify relevant streaming-readout parameters
- to be implemented in realistic study cases
- to compare performances with traditional DAQ
- to evaluate the impact on EIC detector design

→ **Streaming Readout Consortium**

Deliverable: document/publication

NO funding requests

- **TPC in streaming readout at JLab**
  - Implementation of a streaming readout rTPC for Tagged-DIS in Hall-A
- **Crateless-Streaming ast JLab**
  - Use of FADC250 boards with VTP-readout in streaming and buffered mode
- **FEE and circuit design for streaming readout at MIT**
  - Dedicated ASIC (Alphacore) (preamps + ADC) as bases for a EIC multi-detector FEE

WITH funding requests
$15k travel + $35k equipment

- **Streaming readout for EIC ECal at INFN-GE and CUA**
  - Setting up a test bench with traditional and streaming readout using 2x2 PbWO2 crystals and compare results
- **Multilayered Architecture for streaming readout at StonyBrook**
  - Prototype for layered architecture for streaming data transport network (firmware, communication protocols, middleware and CPU managing)

Requested $50k for FY19 → granted $7.5k for travels only …

August 28, 2018

M. Battaglieri (INFN, Genova)
J.C. Bernauer (MIT)
Project: NewProposal/eRD23

Dear Jan and Marco,

I am writing in response to your proposal for EIC Detector R&D funds entitled "*Streaming Readout for EIC Detectors*", presented by Douglas Hassell at the July meeting of the Detector R&D Advisory Committee at the Catholic University of America in Washington D.C.

This is to inform you that the proposal was accepted, although with considerable reduced funding. The new R&D Identifier for your project is **eRD23**. Please refer to this number in all follow-up correspondence.

The Committee submitted their report and the referring recommendations. As you know, the Committee had an exceptionally difficult task given the large amount of proposals and flat budgets. The complete final report is attached.

The Committee provided the following recommendation:
The committee recommends limited travel support for the proponents to further develop the proposal. The proponents are asked to compare streaming solutions with a well-designed conventional triggered system and show where a conventional trigger fails but a streaming readout is plausible.

In accordance with the Committee's priorities and recommendations **$7,500** are awarded to eRD23 for FY19.

The funding will be transmitted via one or more R&D subcontracts with BNL. Please be in touch with Liz Mogavero (mogavero@bnl.gov) and provide her with a list of institutions to which funds are to be directed, the amounts for each, and a business contact for each institution with whom we can initiate the necessary documentation.

Note that due to character of the funding (contracts not grants), we have to follow travel rules dictated by DOE. This implies that international travel or travel to large conferences has to be

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Requested $20k (travels+ws organization) for FY20 → granted $14k

2019 July EIC Detector Advisory Committee Meeting

eRD23: Streaming Readout

J. Bernauer reporting

An interesting beginning of a cost-benefit analysis of possible readout architectures focusing on minimizing custom trigger hardware and relying, as much as possible, on commercial computing for data selection has been presented. Without any particular set of requirements from a particular set of detector subsystems it is not clear that one can yet make any firm conclusions on where an optimum design might lie. It should be noted that all the variants mentioned assumed on-detector zero suppression and so some level of local "triggering". This topic will be of increasing interest as detector ideas converge and as real detector design communities emerge.

Recommendation:
Modest funding is suggested to continue to encourage discussions of options and development of the means of completing a detailed cost benefit analysis once more is known about the EIC detector(s).

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Requested $20k for FY21→ not funded …

eRD Program ended in FY21…

2020 July EIC Detector Advisory Committee Meeting

eRD23: Streaming Readout

J. Bernauer reporting

The collaboration organized a successful virtual workshop on streaming readout in May. The workshop covered a number of technical topics and somewhat narrowed the focus of the toolsets that are likely to be useful in an EIC detector. The collaboration has also started to define some general principles to guide the design of any DAQ system. Some progress has been made in operating various test systems that may provide useful information on future EIC DAQ designs. The collaboration plans additional workshops this fall and next year. The collaboration has been using some ERD funding to support travel for undergraduate and graduate student work on DAQ problems.

While the statement of general principles is helpful, it is probably necessary to wait until the detectors are better defined and there are clear physics driven requirements before attempting to define a DAQ design in any detail.

It is clearly useful that some of the problems and opportunities in an EIC DAQ system are being examined in the workshops and meetings that the collaboration has organized, and this should continue.

It is, however, a little unclear exactly what the collaboration means by SRO – in some parts of the proposal explicit triggers are mentioned and zero suppression is certainly discussed. It would probably be good to open up the discussion some to understand what data is and is not important, how one separates the two, what data sources are similar and what sources imply very different methods for determining what to keep and what to discard. This DAQ centric effort should probably also reach back into the "front end" designs to understand what information is actually needed to define a "hit" and what is extraneous. An EIC detector can be a rich source of physics and clearly one should not exclude some class of physics data because of an ill-considered "trigger", but such a detector is also a potential source of TB of data per second and not all of it can be saved forever and much of it can't even be passed on to some next processing stage. The technology may exist for doing almost anything, but the funds certainly do not. Whether the pruning process is via a hardware object or a sophisticated calculation on a general-purpose computing platform is, surely, a matter of sophisticated optimization and where the real challenges lie. The group noted that their budget had a large carry-over, partly due to the pandemic.

Recommendations:

Continue to meet and discuss the challenges and opportunities presented by EIC. Continue to involve graduate and undergraduate students in the effort. Modest support for centrally held travel funds to be used to support students at test beams is suggested.

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- ✳ Very limited funds: ~$22k in 4 years from eRD23
- ✳ Very limited scope: travel + ws organisation (no personnel, no hardware, no test beam)
- ✳ The Review Committee rational: *DAQ should come after detectors. Premature to fund SRO w/o the detector design*
- ✳ … but EIC sub-detectors <u>should know in advance limit/requirements of a possible SRO DAQ</u>
- ✳ not convincing enough to show the trigger(less) paradigm change

Requested $50k for FY19 → granted $7.5k for travels only …

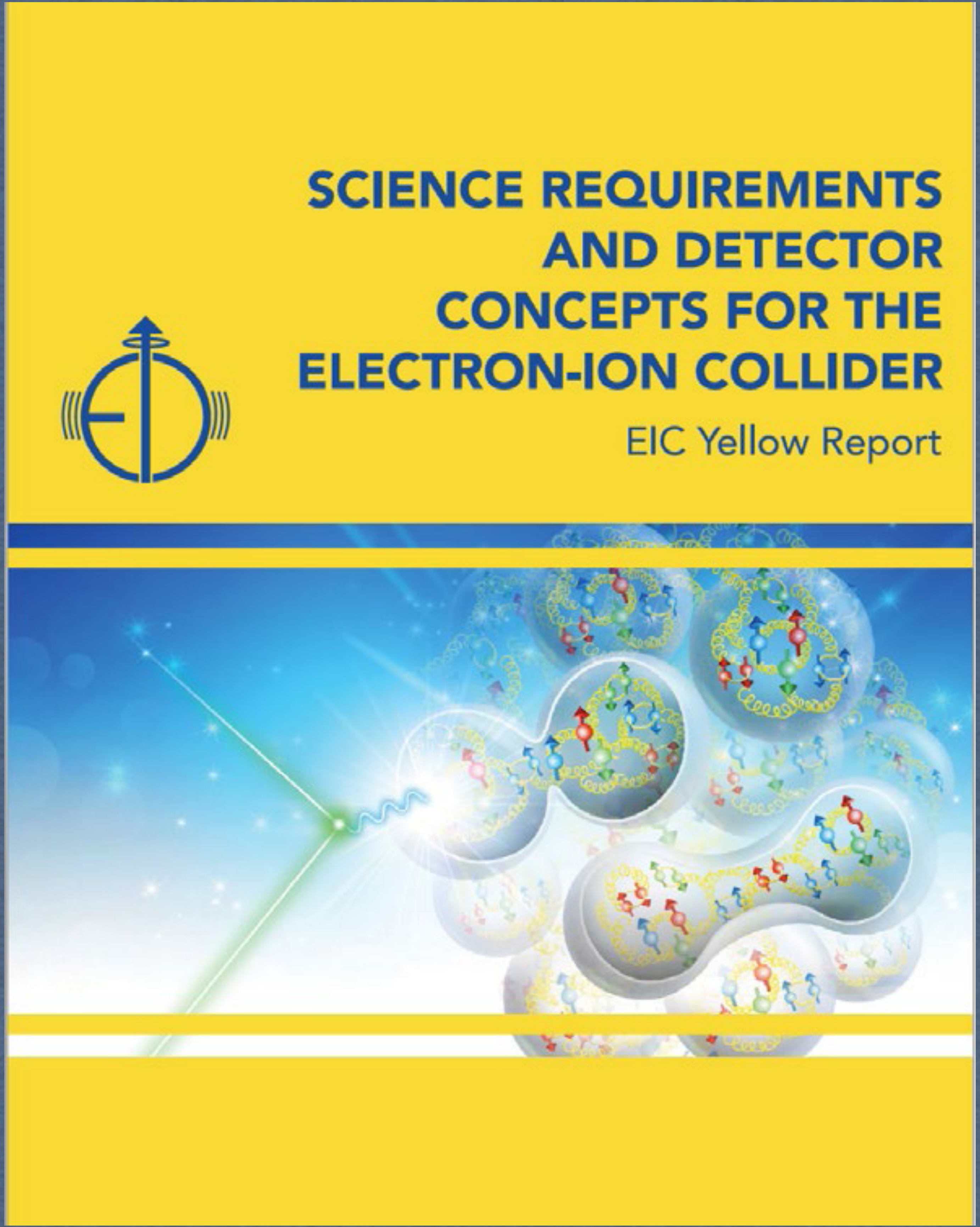
Requested $20k (travels+ws organization) for FY20 → granted $14k

Requested $20k for FY21→ not funded …

eRD Program ended in FY21…

eRD23

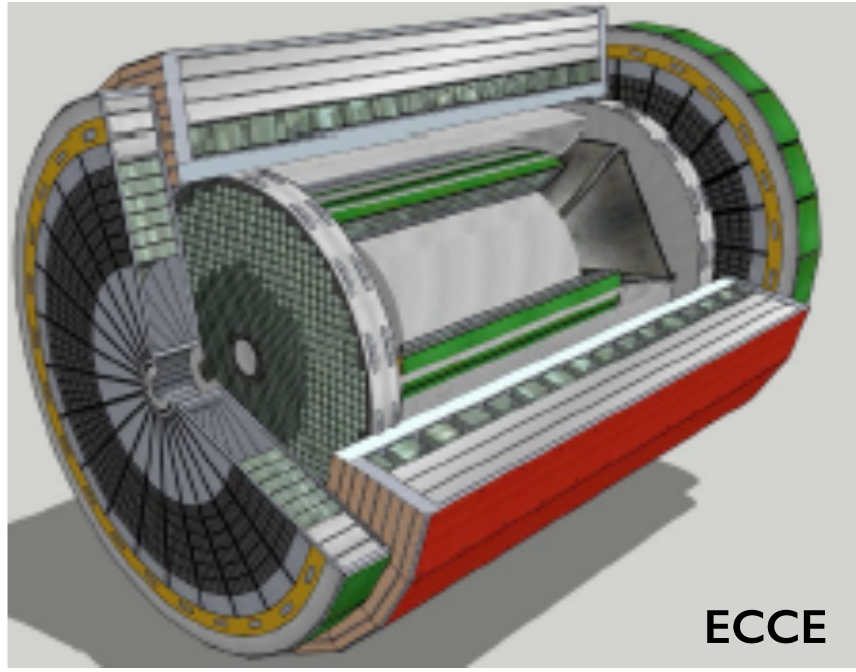
- ✳ Organize SRO workshops twice per year from SRO III to X (I and II were MIT-managed focused on DarkLight experiment)
- ✳ Create a global community (including CERN, FAIR, DESY, …) proving SRO as a valuable solution
- ✳ Transfer this knowledge to the EIC YR

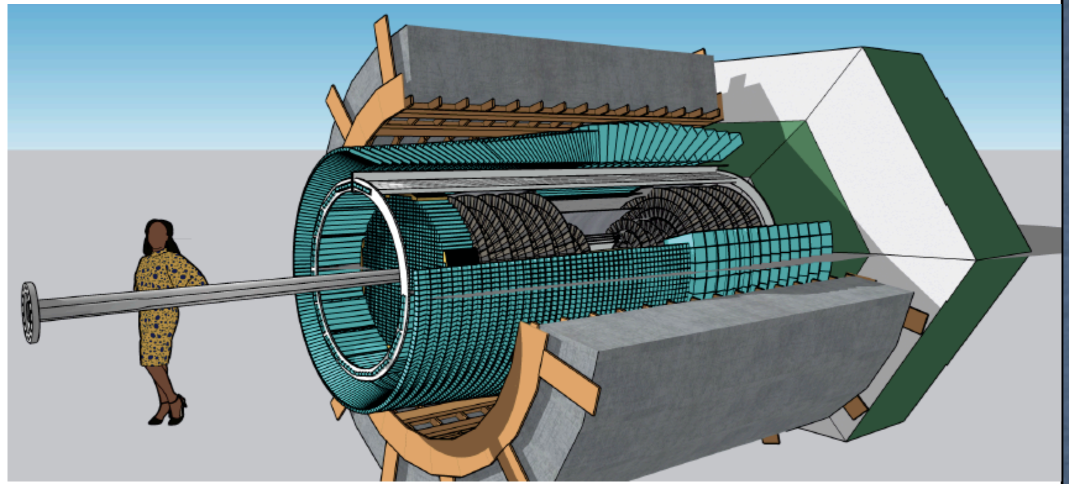


14.6 Data Acquisition

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,





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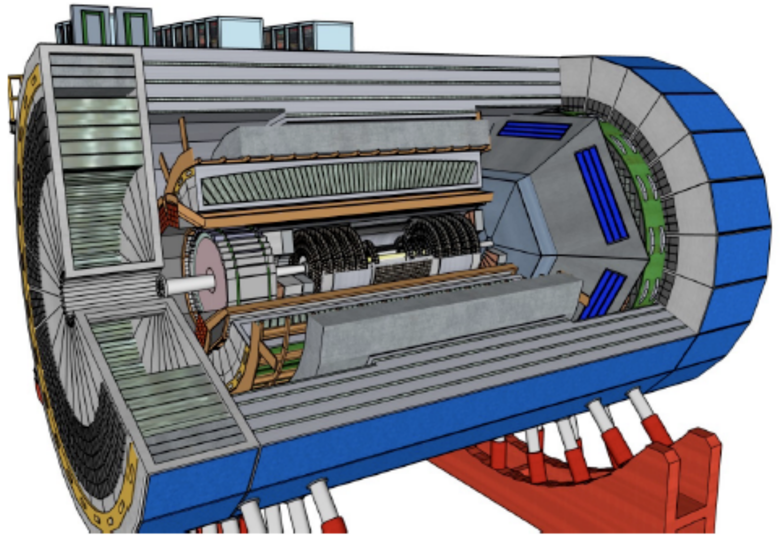


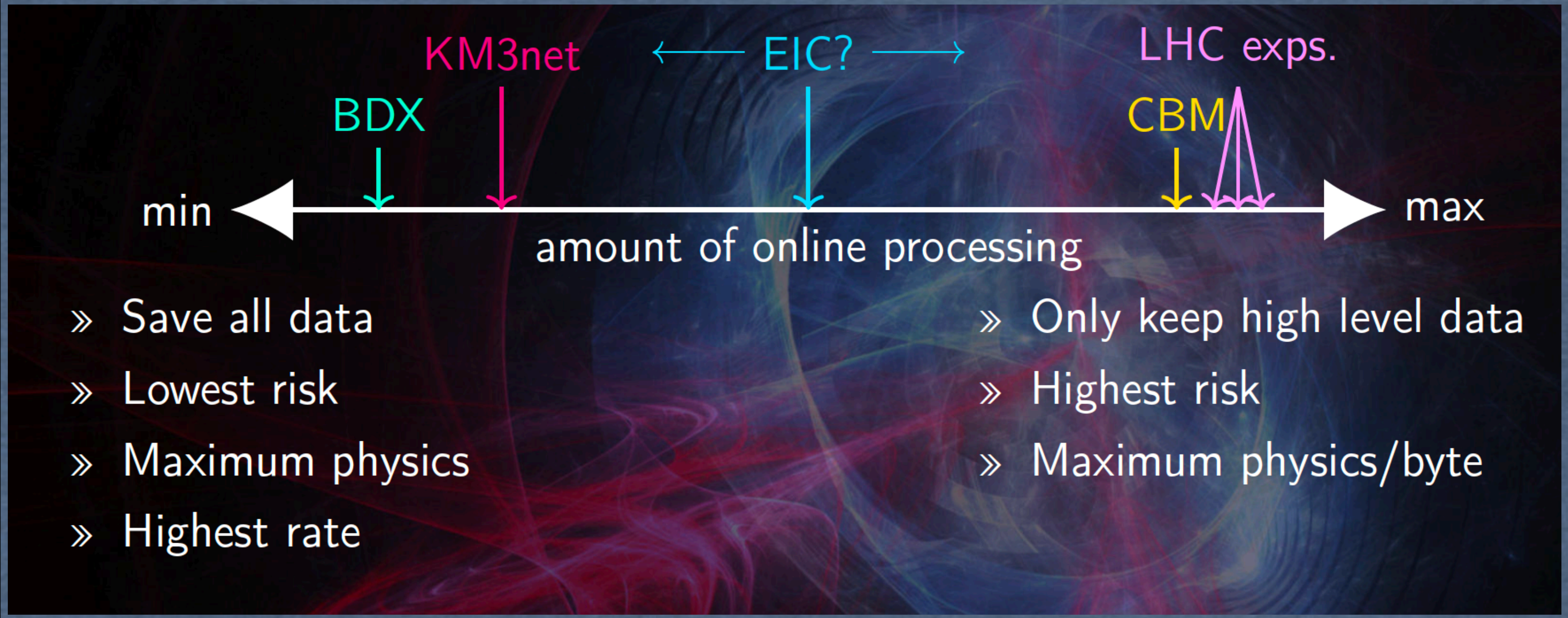
ATHENA

- The three projects shared the same SRO concept

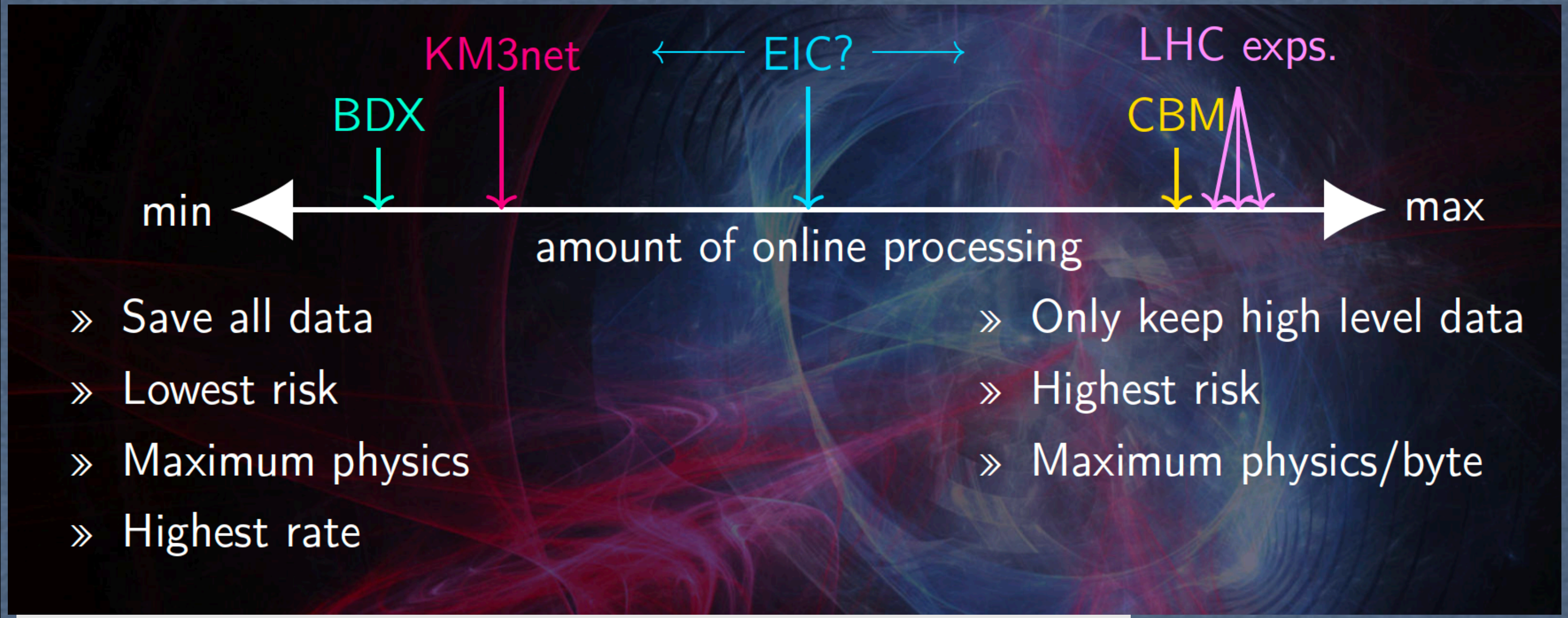
eRD23 activities
(only partially funded by eRD23!)

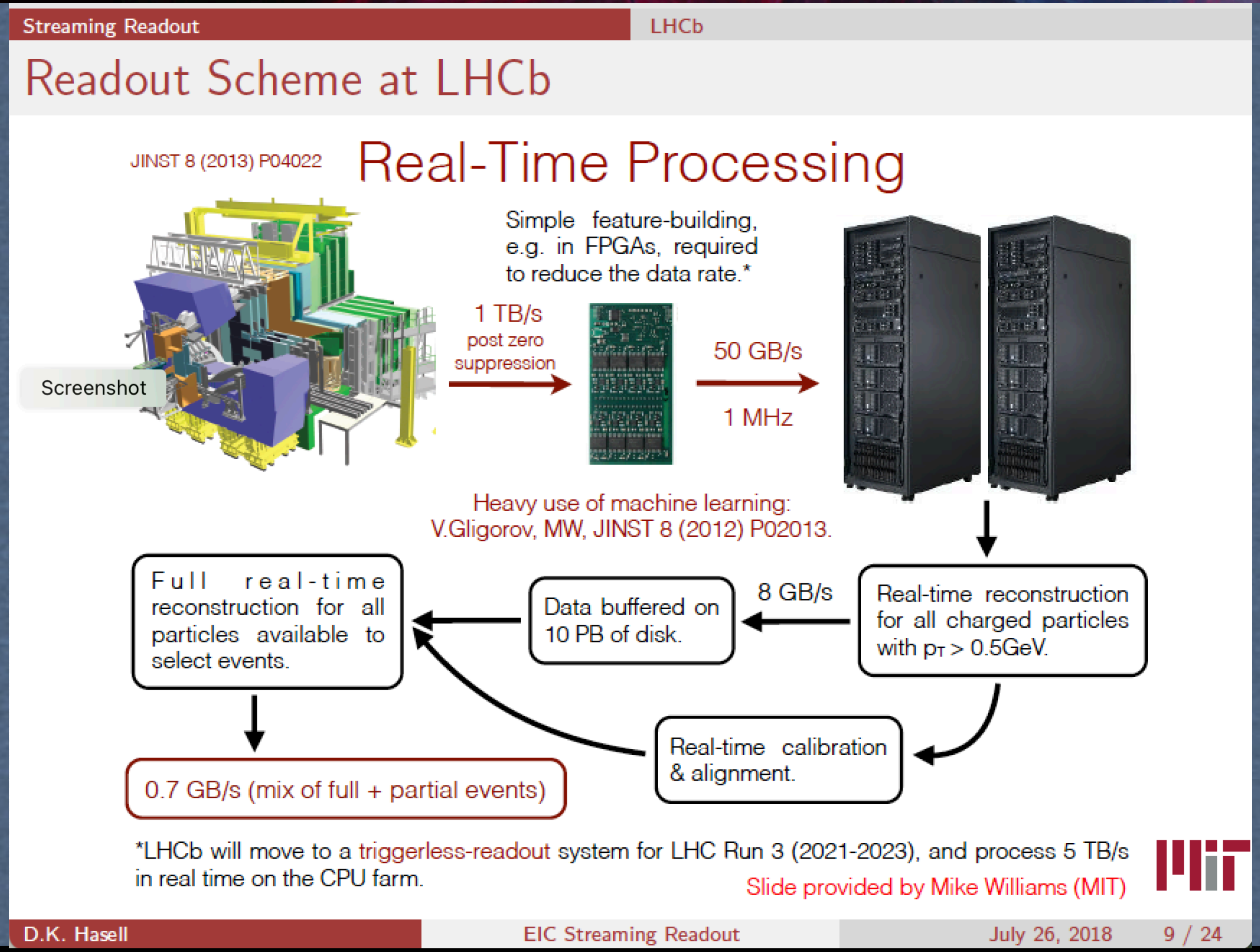
- use of SRO DAQ in other experiments
- Progress in FrontEnd electronics and BackEnd software and integration
- Test SRO prototypes at BNL and JLab (+DESY TPEX experiment)
- [Connection with EIC detector groups to develop an EIC SRO framework integrated in EIC detectors]

eRD23 activities
SRO progress

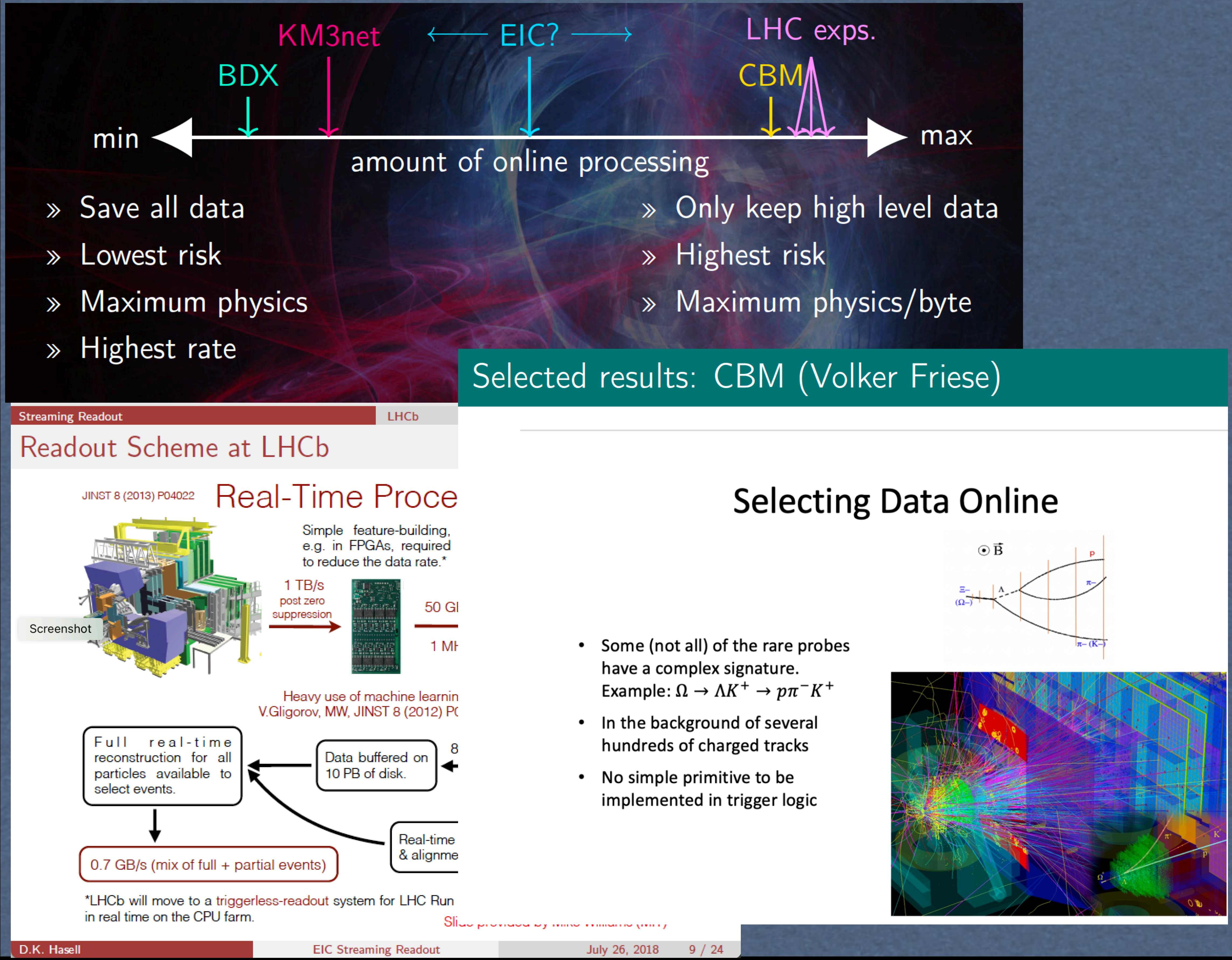


eRD23 activities
SRO progress





eRD23 activities
SRO progress



eRD23 activities
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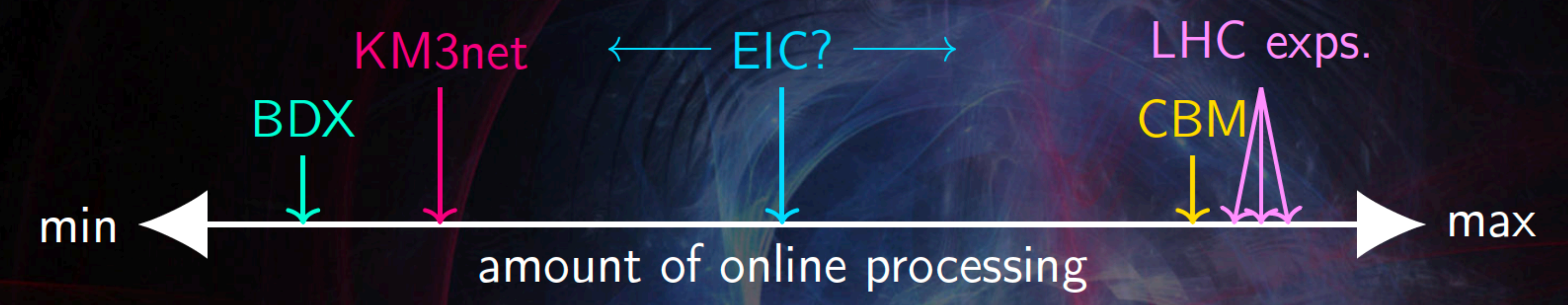
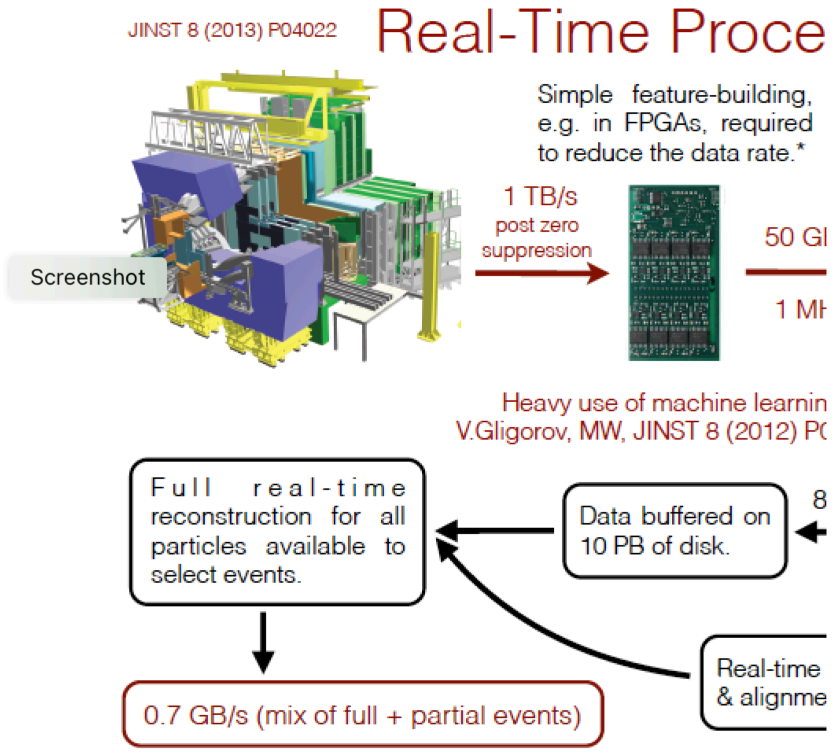


» Save all data
» Lowest risk
» Maximum physics
» Highest rate

» Only keep high level data
» Highest risk
» Maximum physics/byte

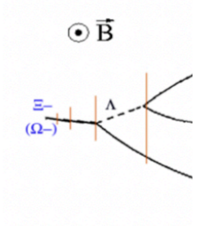
Readout Scheme at LHCb



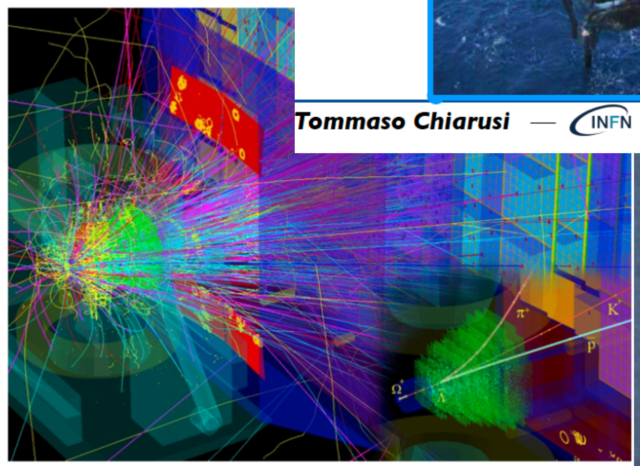
*LHCb will move to a triggerless-readout system for LHC Run in real time on the CPU farm.

Selected results: CBM (Volker Friese)

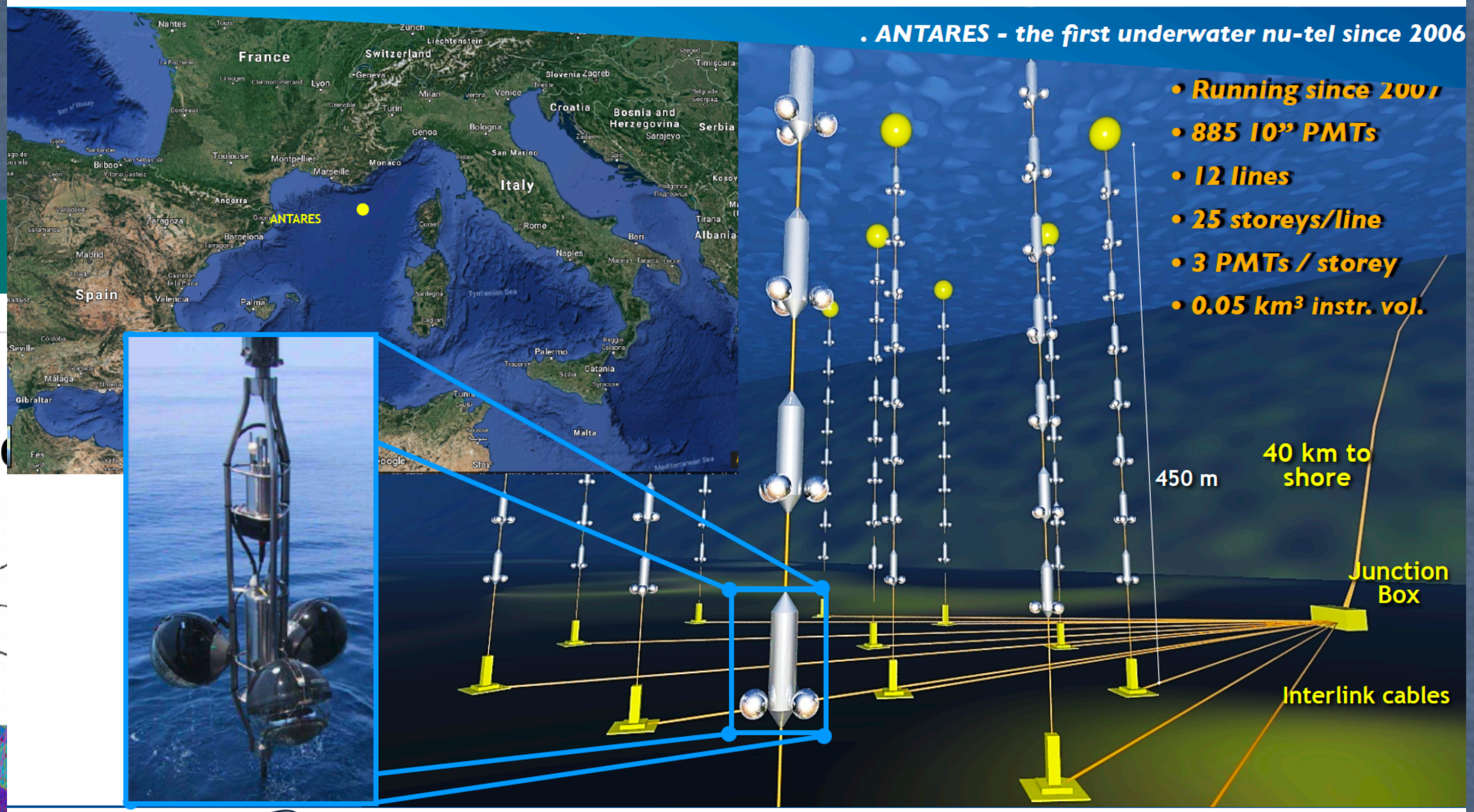
Selecting Data Onlin



- Some (not all) of the rare probes have a complex signature. Example: $\Omega \to \Lambda K^+ \to p\pi^- K^+$
- In the background of several hundreds of charged tracks
- No simple primitive to be implemented in trigger logic



TRIDAS/KM3net (T. Chiarusi)



eRD23 activities
SRO progress

KM3net ⟵ EIC? ⟶ LHC exps.
BDX
CBM
min ⟵ amount of online processing ⟶ max

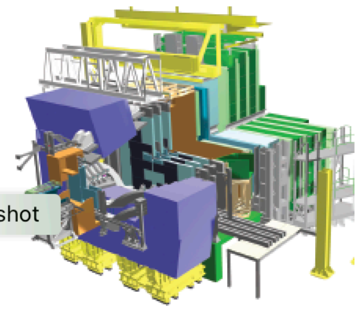
» Save all data
» Lowest risk
» Maximum physics
» Highest rate

» Only keep high level data
» Highest risk
» Maximum physics/byte

Readout Scheme at LHCb

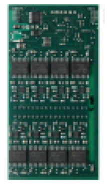
JINST 8 (2013) P04022

Real-Time Proce



Simple feature-building, e.g. in FPGAs, required to reduce the data rate.*

1 TB/s
post zero suppression



50 GI

1 MH

Heavy use of machine learnin
V.Gligorov, MW, JINST 8 (2012) P(

Full real-time reconstruction for all particles available to select events.

Data buffered on 10 PB of disk.

8

Real-time & alignme

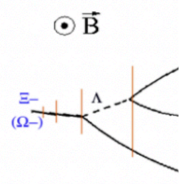
0.7 GB/s (mix of full + partial events)

*LHCb will move to a triggerless-readout system for LHC Run in real time on the CPU farm.

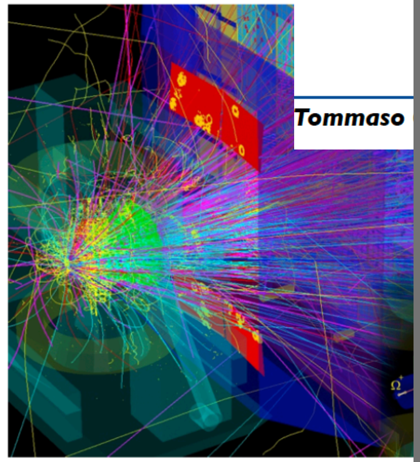
Slide provided by Mike Williams (MIT)

Selected results: CBM (Volker Friese)

Selecting Data Onlin

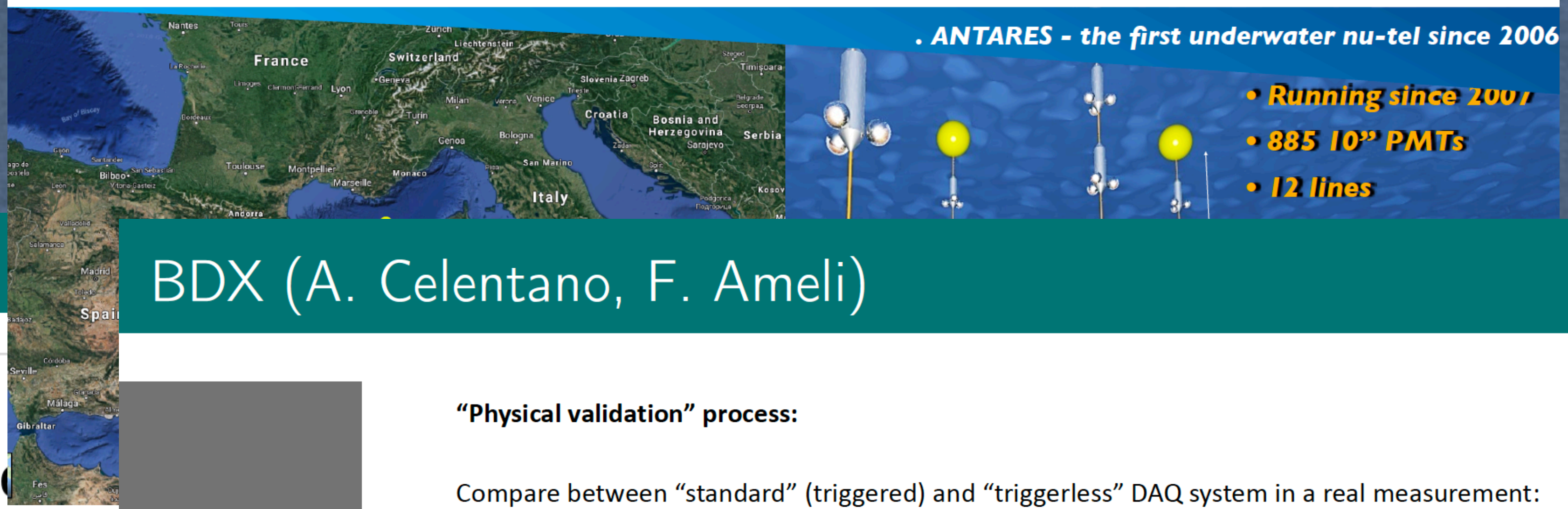


- Some (not all) of the rare probes have a complex signature. Example: $\Omega \to \Lambda K^+ \to p\pi^- K^+$
- In the background of several hundreds of charged tracks
- No simple primitive to be implemented in trigger logic



Tommaso

TRIDAS/KM3net (T. Chiarusi)



BDX (A. Celentano, F. Ameli)

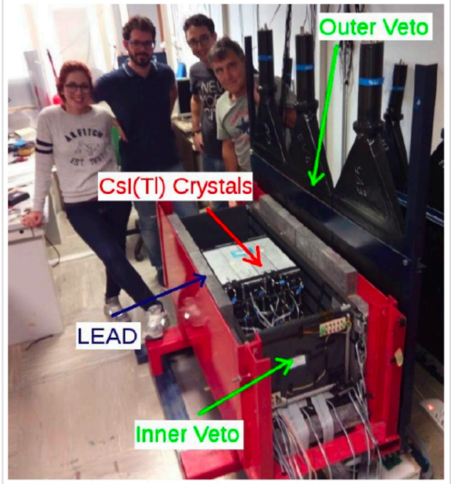
BDX DAQ system validation

"Physical validation" process:

Compare between "standard" (triggered) and "triggerless" DAQ system in a real measurement: perform the analysis of the **same observable** in the two cases and **compare results**

BDX-proto measurement @ JLab:

- Place a small scale prototype of one BDX module in a setup with similar overburden configuration as in the final setup
- Measure cosmogenic rate and evaluate foreseen backgrounds



BDX-proto detector:

- 16x CsI(Tl) crystals, SiPM readout
- 2 plastic scintillator veto layers, SiPM readout
- Setup to be modified to be compatible (cabling, …) with wave-brd readout

Tests foreseen in 2019

eRD23 activities
FE(hw)/BE(sw) progress

Alphacore (Ph. Bikkina, D. Mazidi)

Summary

Robust High Performance Microelectronics
ALPHACORE

- Alphacore presented the current status of detector readout IC development including rad-hard preamplifiers, ADCs and combined ROICs.
- Large tapeout was completed and IC testing will start in January 2019.

Questions for the audience?

- **Is there a need for a "Combined ROIC", i.e. a chip that has both preamplifiers and ADCs, or can they be on separate chips?**
- **What are the target experiments, their schedule, channel counts, and readout specifications?**
- **Radiation hardness requirements?**
- **Integration level requirements (IP? Wafers? Packaged chips? Packaged and tested chips? Evaluation boards? Ready-made readout boards with FPGAs ?)**

 12/3/2018 14

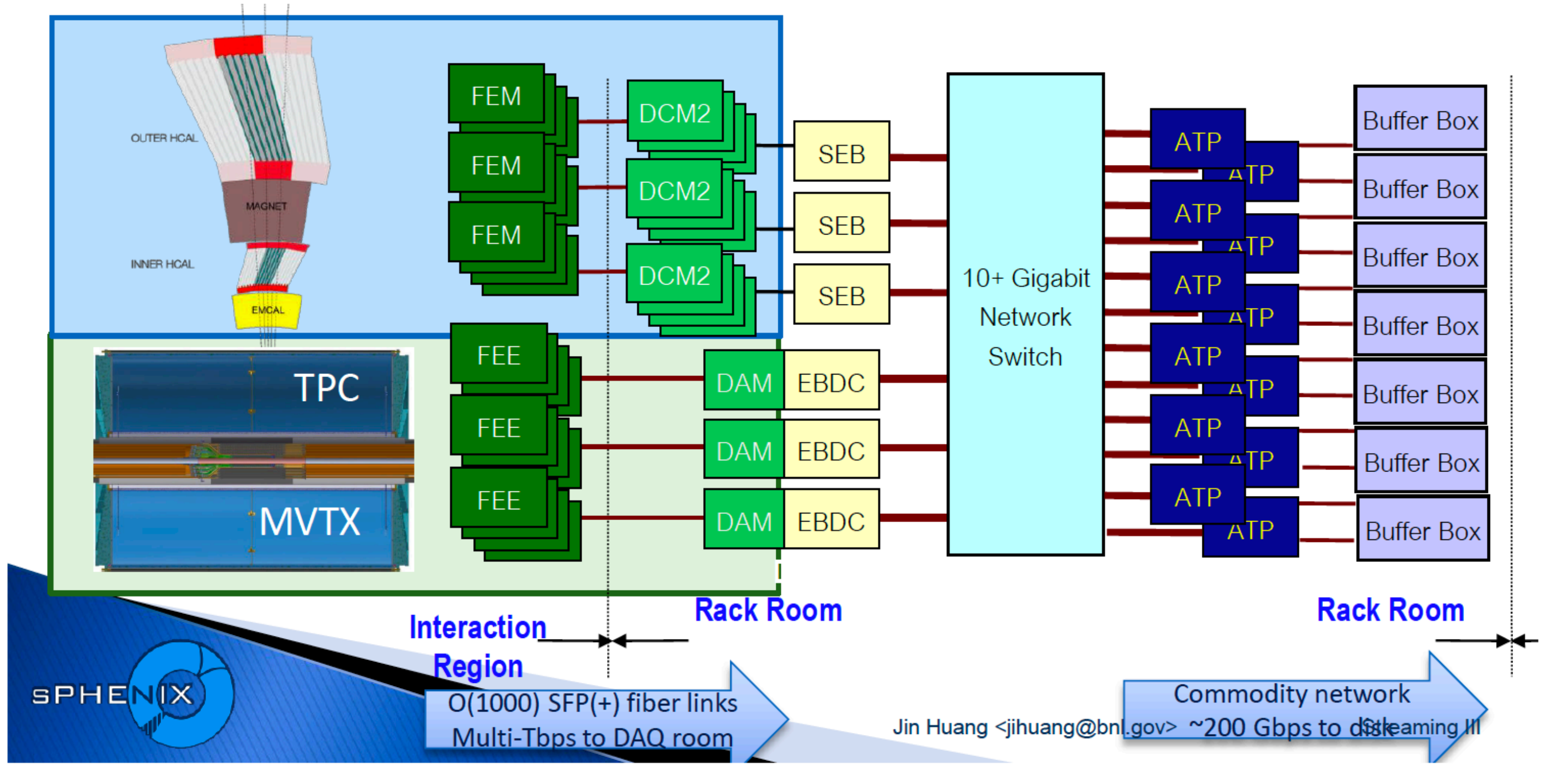
19

eRD23 activities
FE(hw)/BE(sw) progress

Alphacore (Ph. Bikkina, D. Mazidi)

SPHENIX and EIC-SPHENIX (J. Huang)

- **For calorimeter triggered FEE,**
  (signal collision rate 15kHz x signal span 200ns) << 1:
  No need for streaming readout which significantly reduce front-end transmission rate
- **For TPC and MVTX tracker FEE supports full streaming:**
  (signal collision rate 15kHz x integration time 10-20us) ~ 1:
  Streaming readout fits this scenario. Consider late stage data reduction by trigger-basec



20

eRD23 activities
FE(hw)/BE(sw) progress

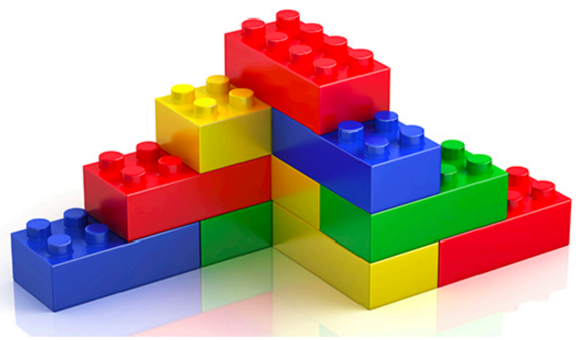
Alphacore (Ph. Bikkina, D. Mazidi)

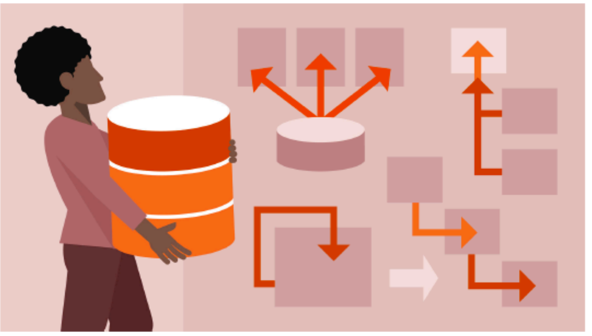
SPHENIX and EIC-SPHENIX (J. Huang)

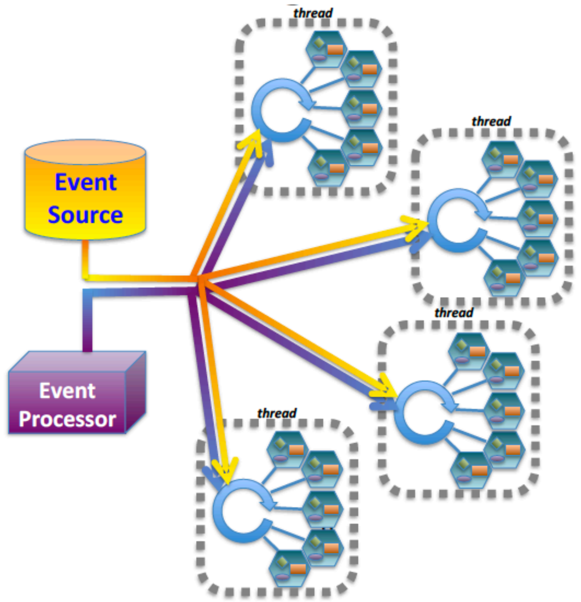
Network and Software aspects (M. Diefenthaler, J.C. Bernauer, D. Blyth)

Streaming readout software requirements

Modular design	Common data model (conceptual logical and physical), instead of common framework	Common parallelizer







Streaming Readout III, December 4 11 Jefferson Lab

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eRD23 activities
FE(hw)/BE(sw) progress

Alphacore (Ph. Bikkina, D. Mazidi)

SPHENIX and EIC-SPHENIX (J. Huang)

Network and Software aspects (M. Diefenthaler, J.C. Bernauer, D. Blyth)

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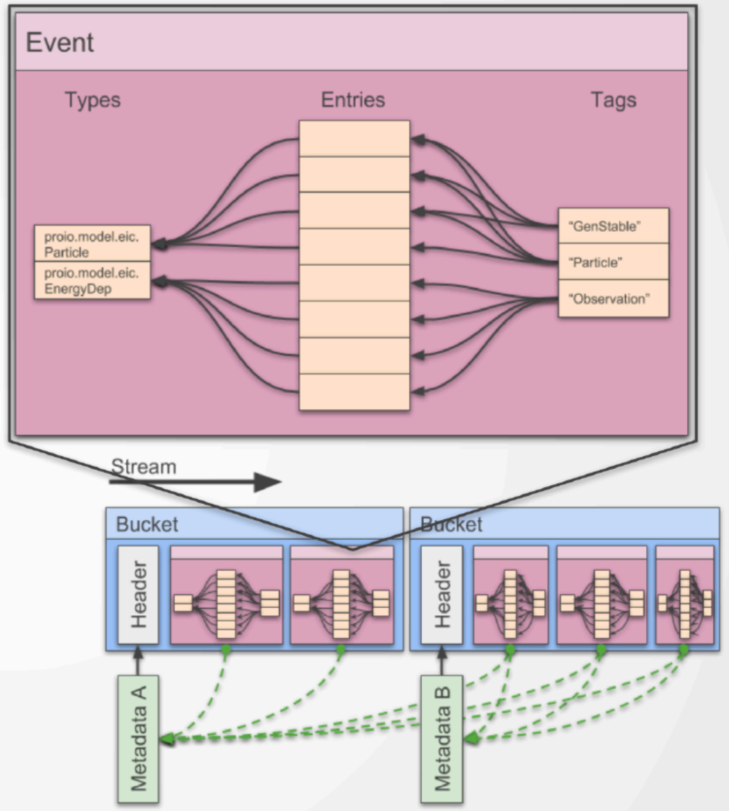
ProIO

- project for utilizing protobuf for HEP/NP in a language-neutral way
  - C++, Python, Go, and Java native libraries already implemented*
- supported by ANL LDRD and eRD20 (multi-lab EIC Software Consortium)
- based on pioneering work by Sergei Chekanov (ProMC) and Alexander Kiselev (EicMC)
- https://github.com/proio-org
- preprint available end of this week (contact me at dblyth@anl.gov for copy)



*Java implementation is currently incomplete, but read functionality is there

eRD23 activities
FE(hw)/BE(sw) progress

Alphacore (Ph. Bikkina, D. Mazidi)

SPHENIX and EIC-SPHENIX (J. Huang)

Network and Software aspects (M
Bernauer, D. Blyth)

Streami

Streaming Read

Network and Software aspect
Bernauer, D. Blyth)

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Collaboration with the software consortium

Identified overlaps on both ends of the software stack:

» Aim to find general data format for exchange

» MC frameworks organized around time instead of events ⇔ i.e. what is required for pileup simulations.

» Since analysis and DAQ converges: Problem of orchestration of DAQ/Analysis cluster similar

eRD23 activities
SRO prototype tests

Progress: sPHENIX (BNL, SBU)

- V5 of SAMPA with 80ns shaping, 20 MHz digitization
- Better suited for EIC
- Engineering run delivered, 25 wafer production started
- Work stopped by COVID. sPHENIX will have three streaming detectors (full tracking system)

eRD23 activities
SRO prototype tests

Progress: sPHENIX (BNL, SBU)

Progress: Timing Module (BNL)

- New timing system prototype
- Test if PLL lock can be maintained during RF sweeps of RHIC operation
- Measure jitter
- Tests planned as soon as BNL reopens.

eRD23 activities
SRO prototype tests

Progress: sPHENIX (BNL, SBU)

Progress: Timing Module (BNL)

Progress: RFSoC (BNL)

- Xilinux UltraScale+ RFSoC include multi-gigasamples ADC/DAC
- Via analog-multiplexing/digital-demultiplexing in frequency domain, can read multiple channels with single ADC
- Possibility to increase channel-density and reduce analog cable requirements

eRD23 activities
SRO prototype tests

Progress: sPHENIX (BNL, SBU)

Progress: Timing Module (BNL)

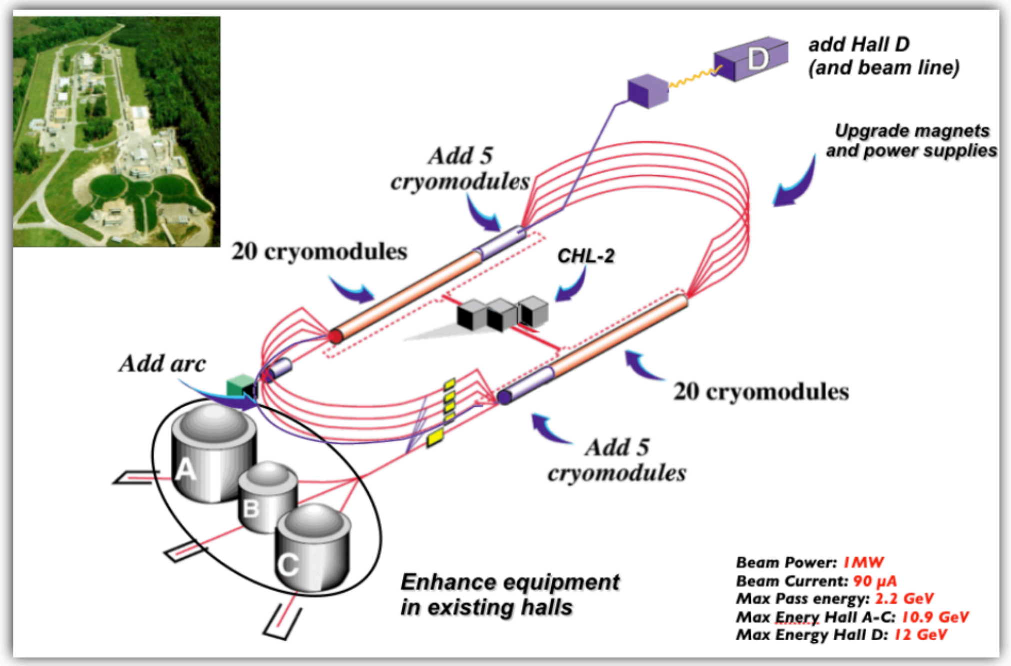
Progress: RFSoC (BNL)

Progress: TPEX/DESY test beam (CUA, INFN, JLAB, MIT, SBU)

- Test beam postponed because of COVID.
- Analysis of older data is progressing.
- Will aim to have test beam at JLAB to offset COVID delays.

eRD23 activities
SRO prototype tests

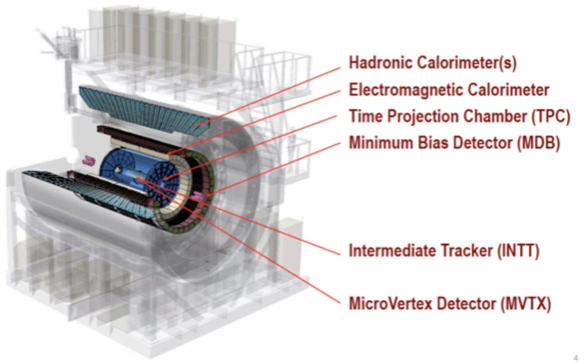
Jefferson Lab: CLAS12

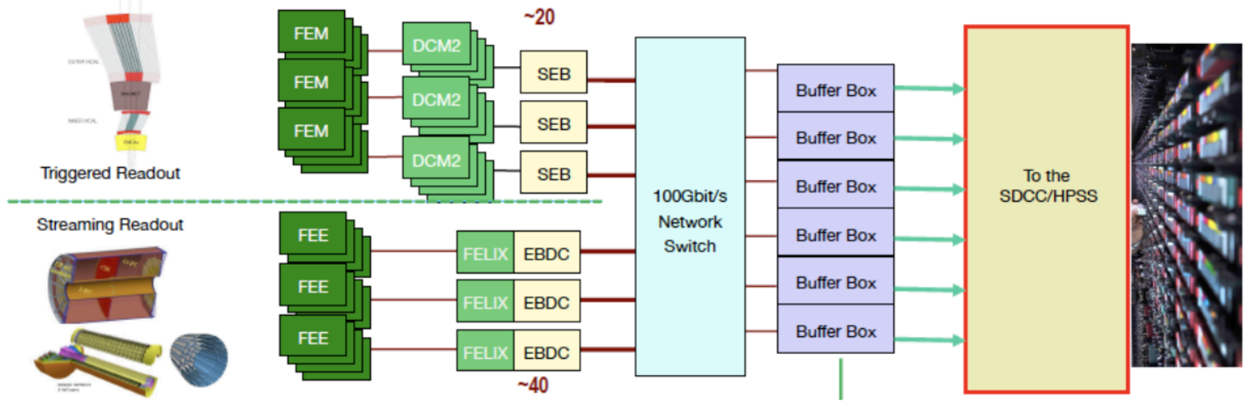


- ✳Primary Beam: Electrons
- ✳ Beam Energy: 12 GeV
  - 10 > λ > 0.1 fm
  - nucleon → quark transition
  - baryon and meson excited states
- ✳100% Duty Factor (cw) Beam
  - coincidence experiments
  - Four simultaneous beams
  - Independent E and I
- ✳ Polarization
  - spin degrees of freedom
  - weak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

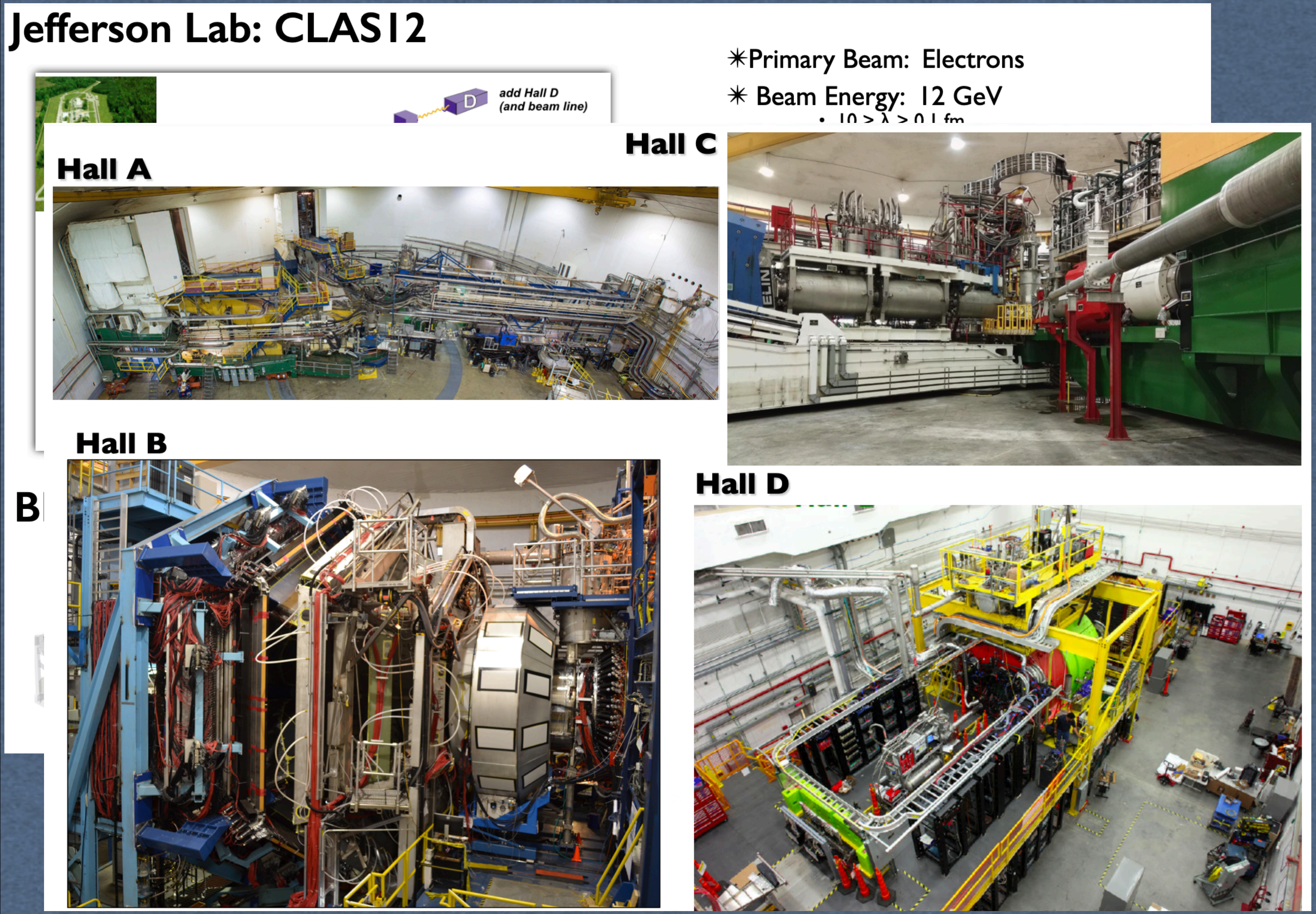
Luminosity > 10^7 -10^8 x SLAC
at the time of the original DIS experiments!

BNL: sPHENIX





eRD23 activities
SRO prototype tests



eRD23 activities
SRO prototype tests

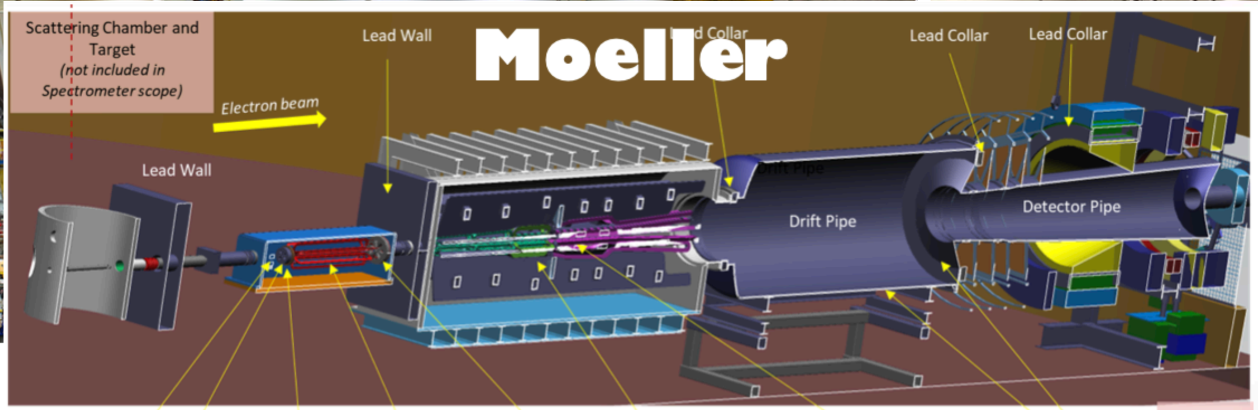
Jefferson Lab: CLAS12

✳Primary Beam: Electrons
✳ Beam Energy: 12 GeV

Hall A

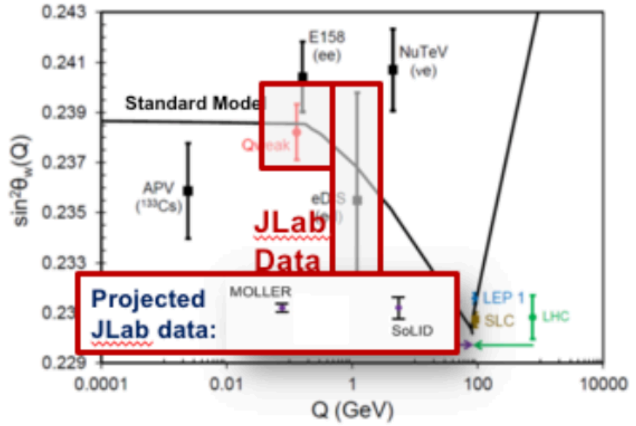
Hall C

Moeller

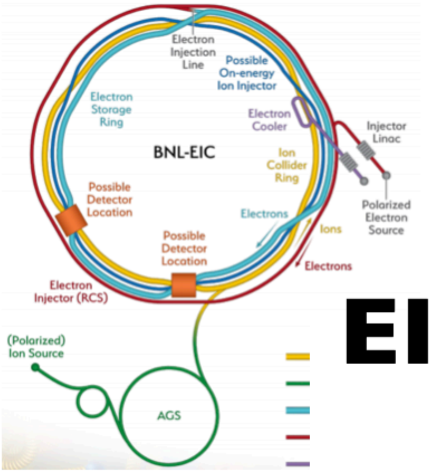


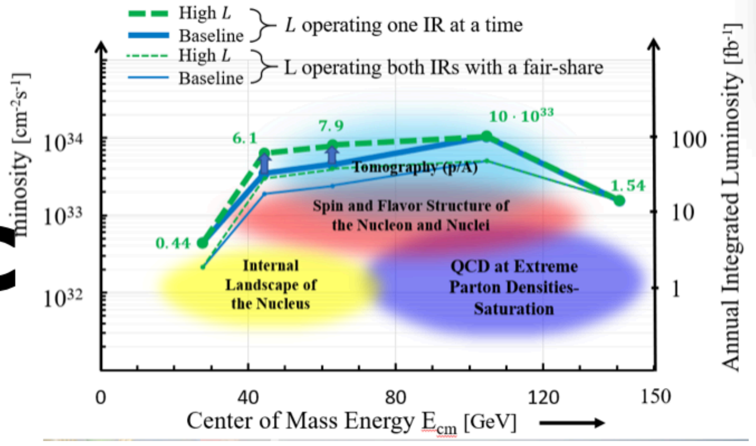
Hall B

- 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

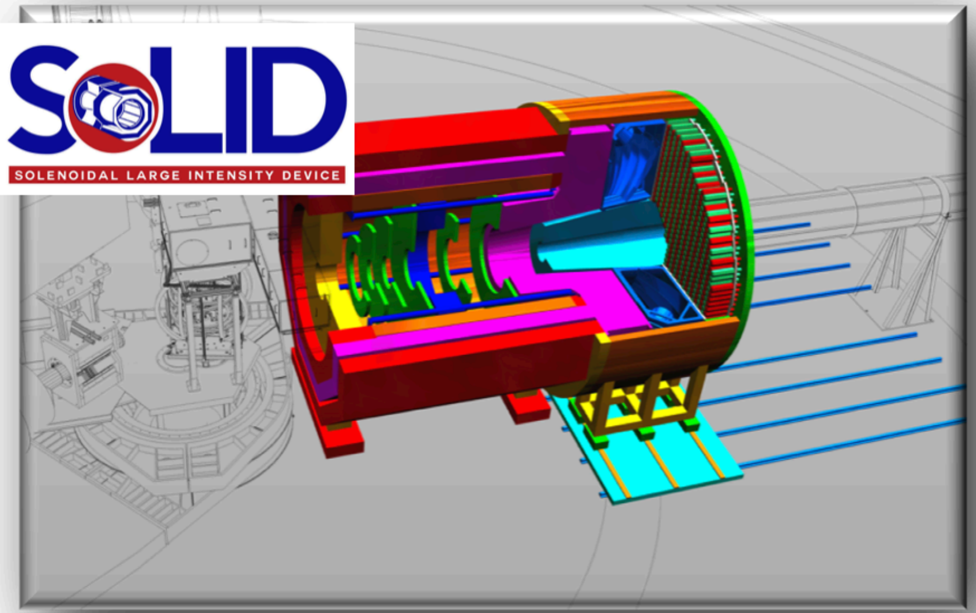


EIC





- Solenoidal Large Intensity Device – new multipurpose detector facility optimized for high luminosity and large acceptance, enabling very broad scientific program
- Unique capability combining high luminosity ($10^{37\text{-}39}$ / cm^2/s) (more than 1000 times the EIC) and large acceptance, with full ϕ coverage to maximize the science return of the 12-GeV CEBAF upgrade

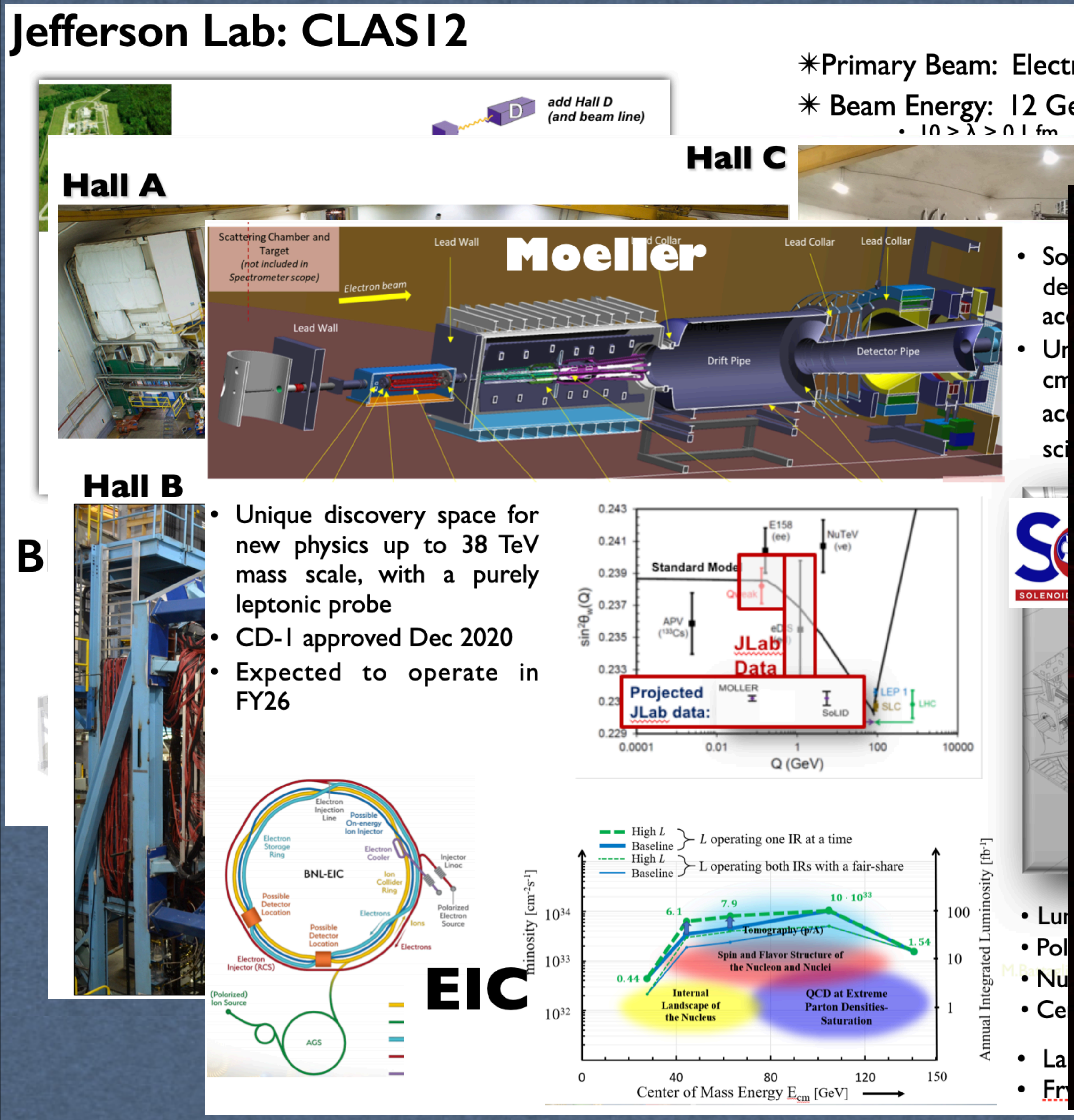


- Luminosity 100-1000 times that of HERA
- Polarized protons and light nuclear beams
- Nuclear beams of all A (p→U)
- Center mass variability with minimal loss of luminosity

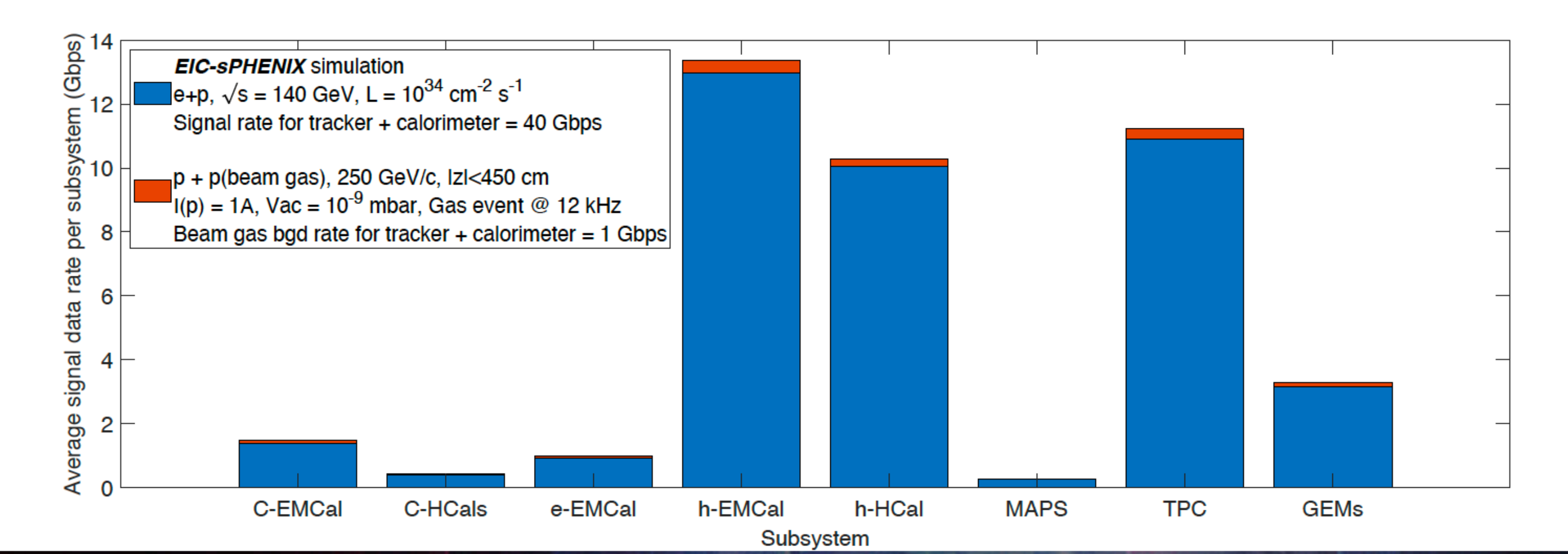
- Large acceptance
- Frwrd/Bckw angles

- Precise vertexing
- HRes Tracking
- Excellent PID

eRD23 activities
SRO prototype tests



A rate study: sPHENIX based EIC detector (Jin Huang)



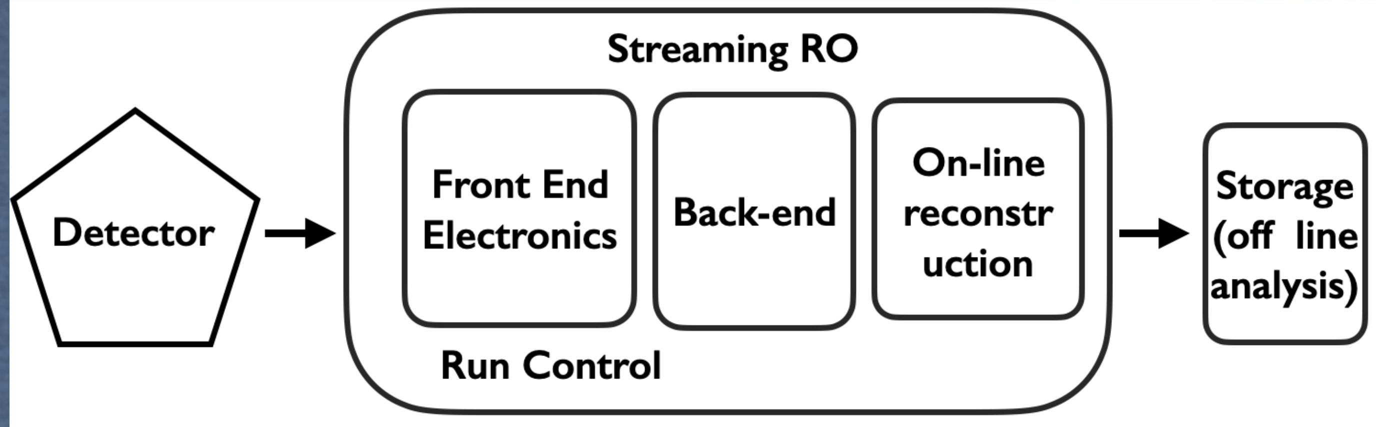
Total rate around 100 GBit/s. This is 1/2 the rate of sPHENIX!

» Rates are very well doable for sPHENIX, will be trivial for EIC time frame.
» EIC SRO is on the safe side of the spectrum!
» BeAST: similar rate
» JLEIC: First estimate: 250 GByte/s for vertex detector. Need streaming, ROI/noise suppression.

(Different detectors might give different rates, especially if channel count is drastically larger.)

eRD23 activities
SRO prototype tests

Streaming RO components

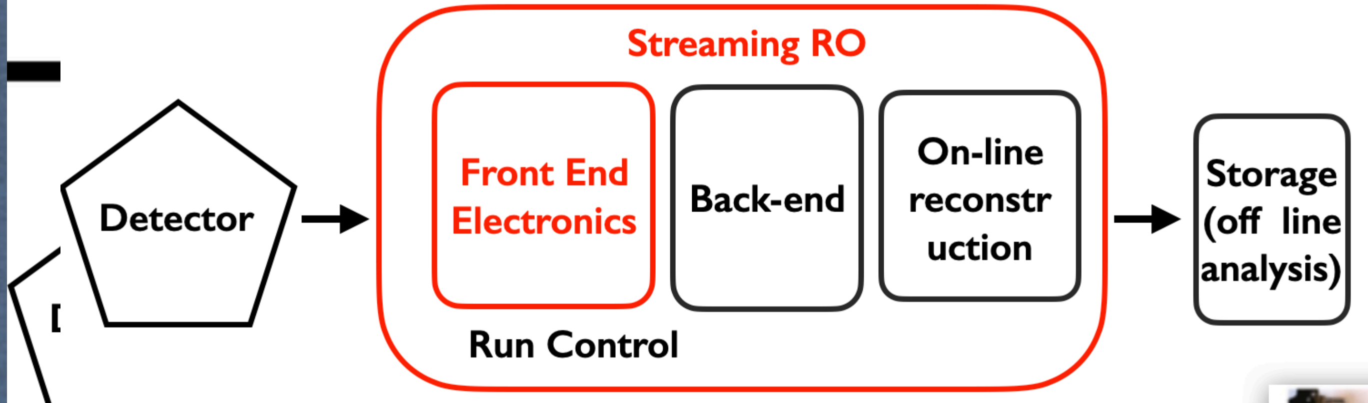


SRO concept validation

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

eRD23 activities
SRO prototype tests

Streaming RO components



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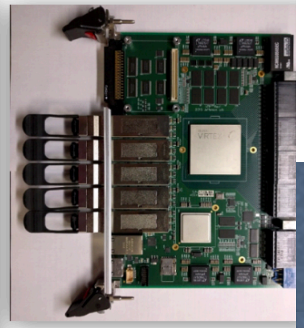
3) Test SRO DAQ on-beam

FrontEnd

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

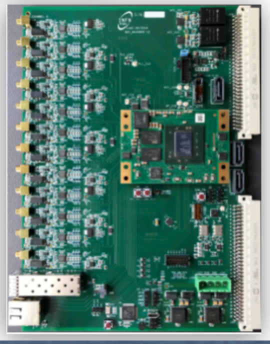



✳ **JLab fADC250 + VTP bord**

- 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**

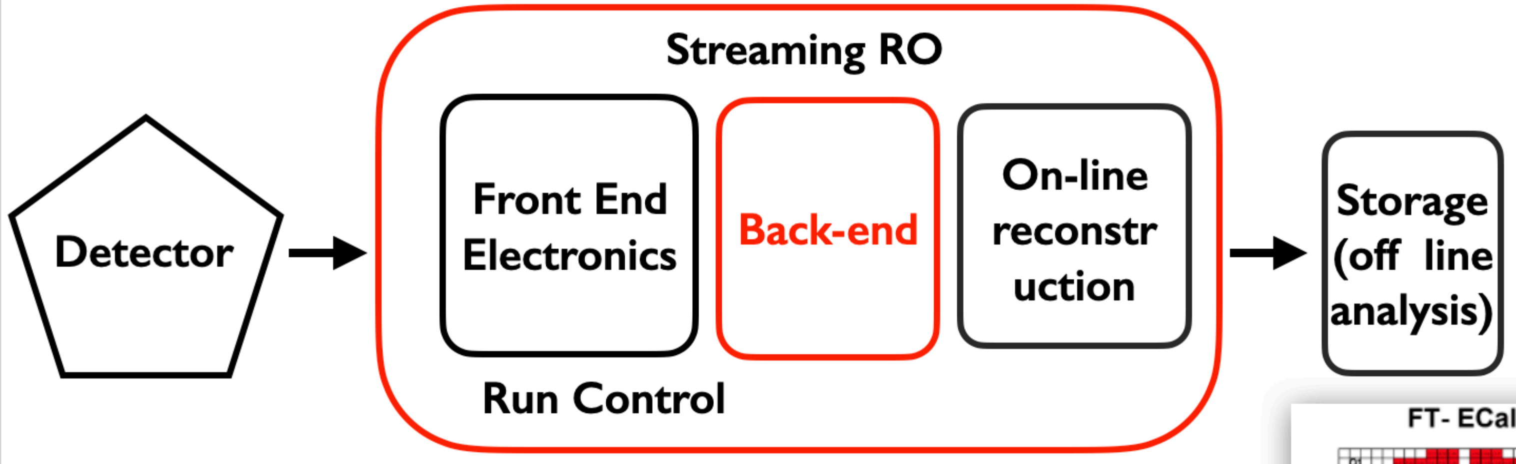
- SRO dedicated INFN 250 MHz flash ADC digitizer



eRD23 activities
SRO prototype tests

Streaming RO components

Streaming RO



SRO concept validation

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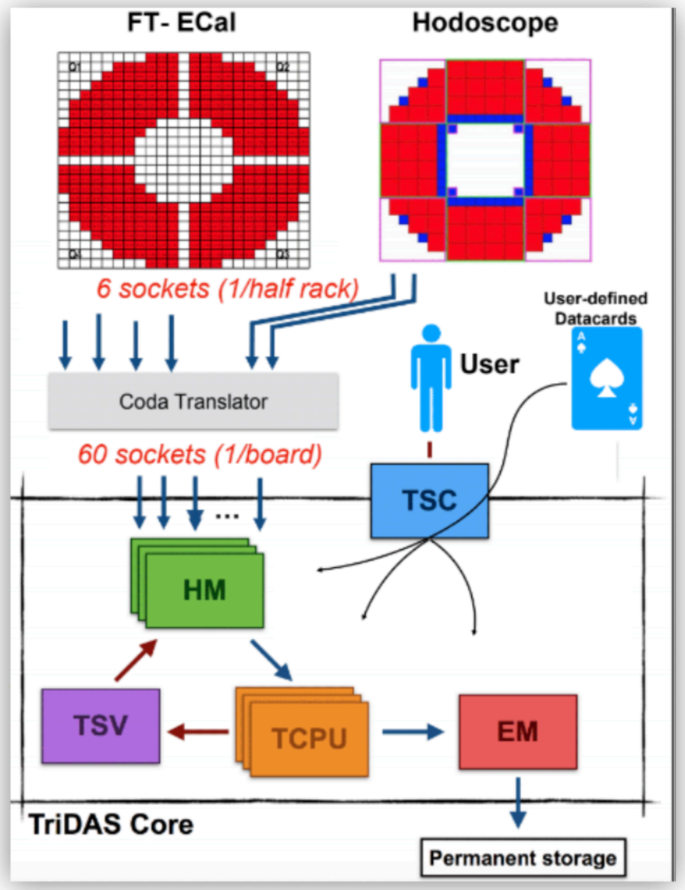
3) Test SRO DAQ on-beam

BackEnd

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

✳ TRIggerless Data Acquisition System (TriDAS)

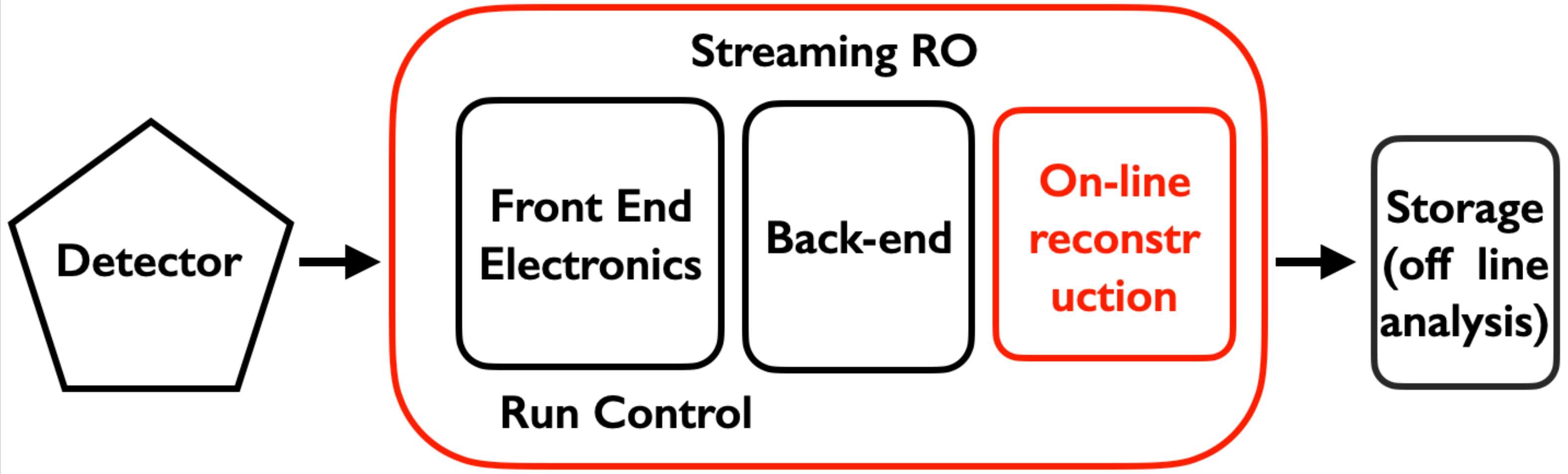
- Developed for KM_3NET
- Installed on Hall-B DAQ cluster
- Multi CPUs, rate up to 20-30 MHz



✳ JLal

Det

eRD23 activities
SRO prototype tests



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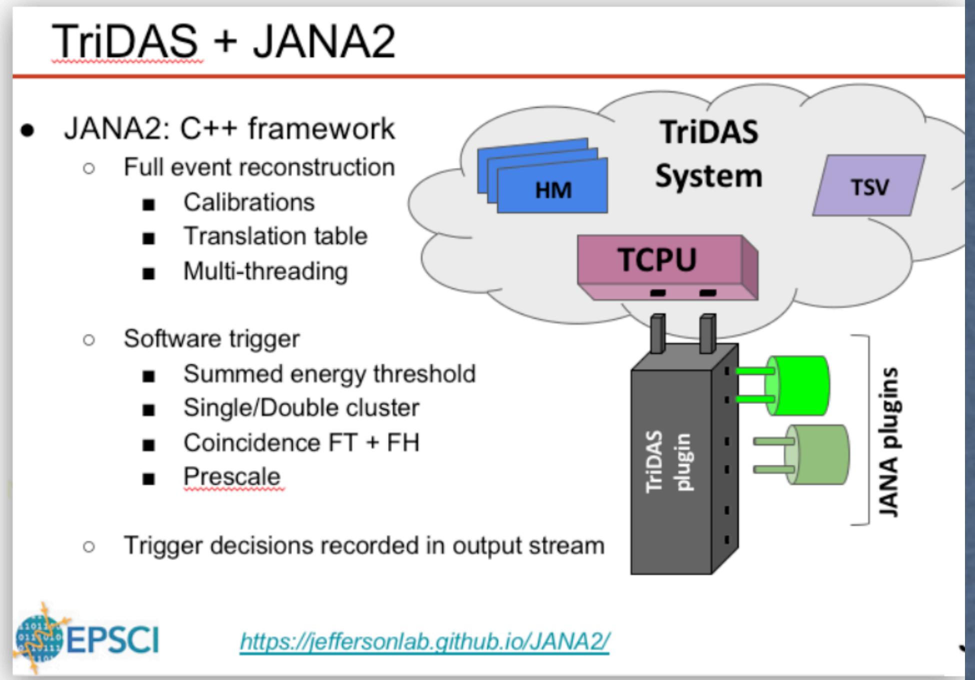
3) Test SRO DAQ on-beam

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



eRD23 activities
SRO prototype tests

Streaming RO

Detector → [Front End Electronics | Back-end | On-line reconstruction] → Storage (off line analysis)

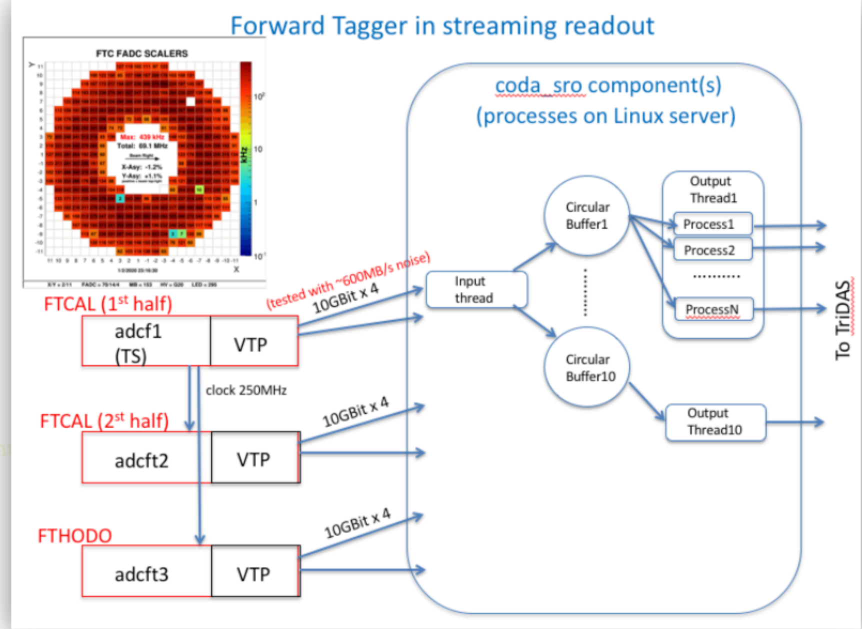
Run Control

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

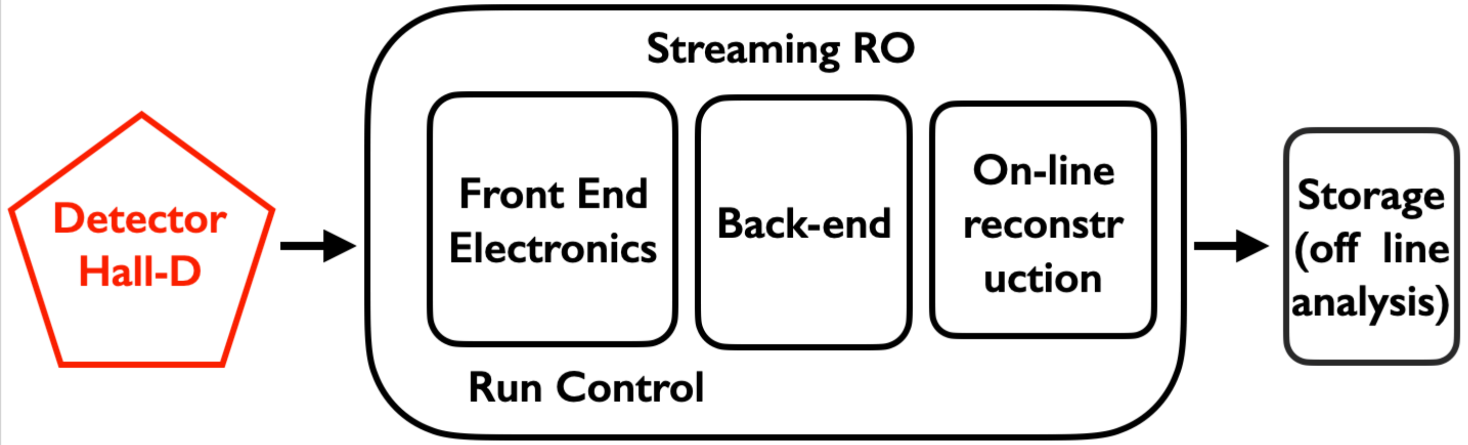
Cebaf Online Data Acquisition (CODA)

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)



eRD23 activities
SRO prototype tests



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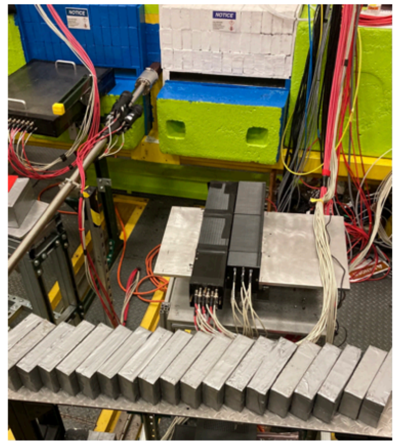
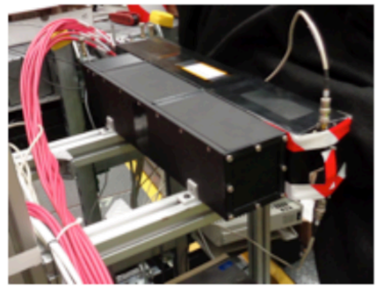
3) Test SRO DAQ on-beam

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

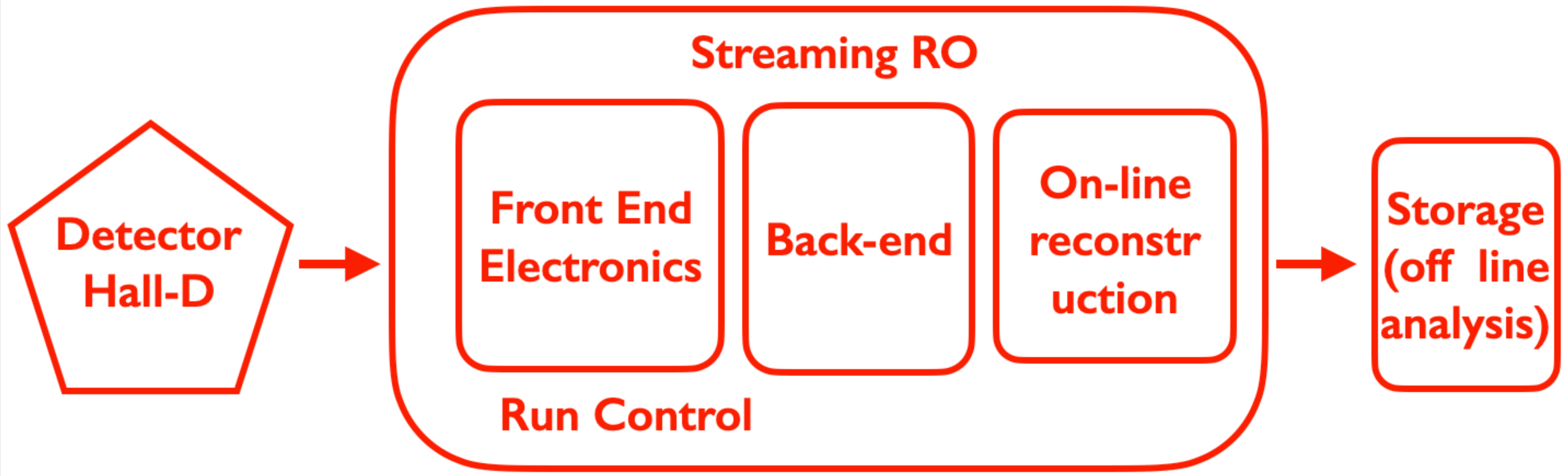



SiPM(left) & PMT(right) cal. prot.


Waveboard

eRD23 activities
SRO prototype tests

Streaming RO components



SRO concept validation

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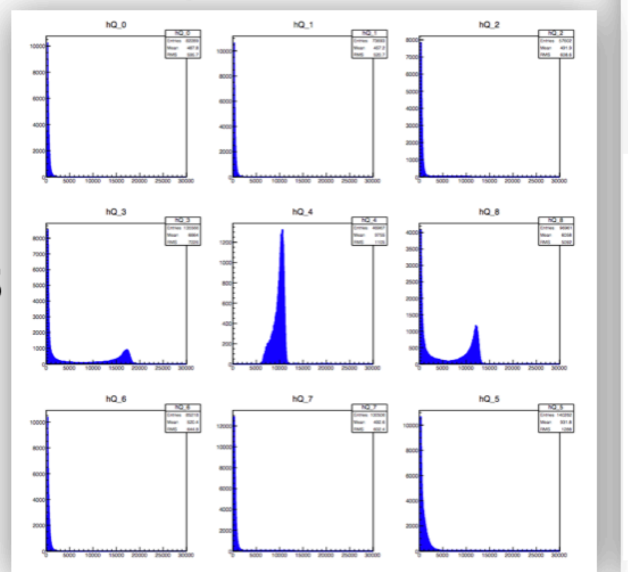
JLab SRO test

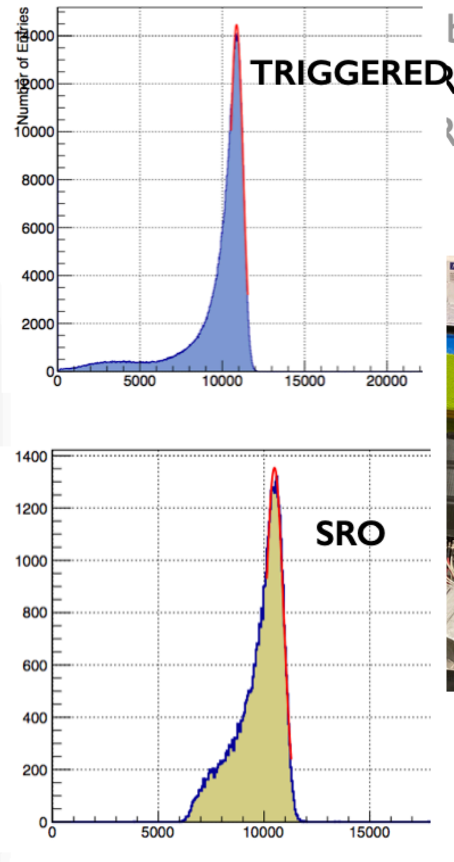
V.Berdnikov, T.Horn

Preliminary test results

ECAL proto: 9ch SRO-mode



EM shower seed



oncept validation
ble SRO components
RO DAQ in lab
RO DAQ on-beam

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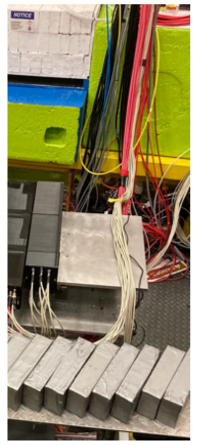

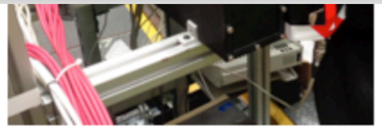

SiPM(left) & PMT(right) cal. prot.

Waveboard

eRD23 activities
SRO prototype tests

Streaming RO

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

JLab SRO test
V.Berdnikov, T.Horn

Preliminary test results

SRO concept validation
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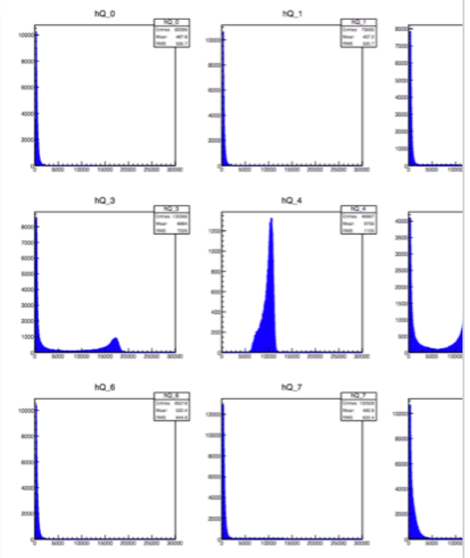
- fADC250 and WaveBoard front end

ECAL proto: 9ch SRO-m



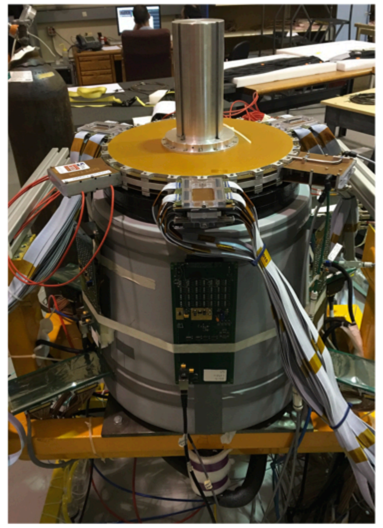
Streaming RO

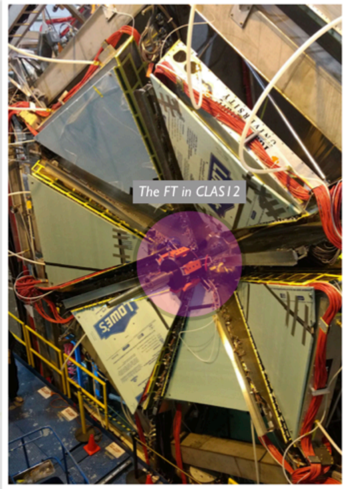
Detector Hall-B → [Front End Electronics | Back-end | On-line reconstruction] (Run Control) → Storage (off line analysis)

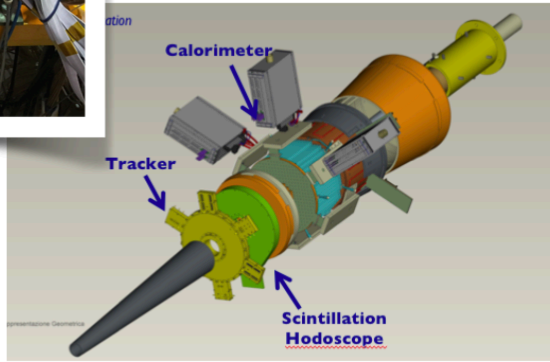
SRO concept validation
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

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

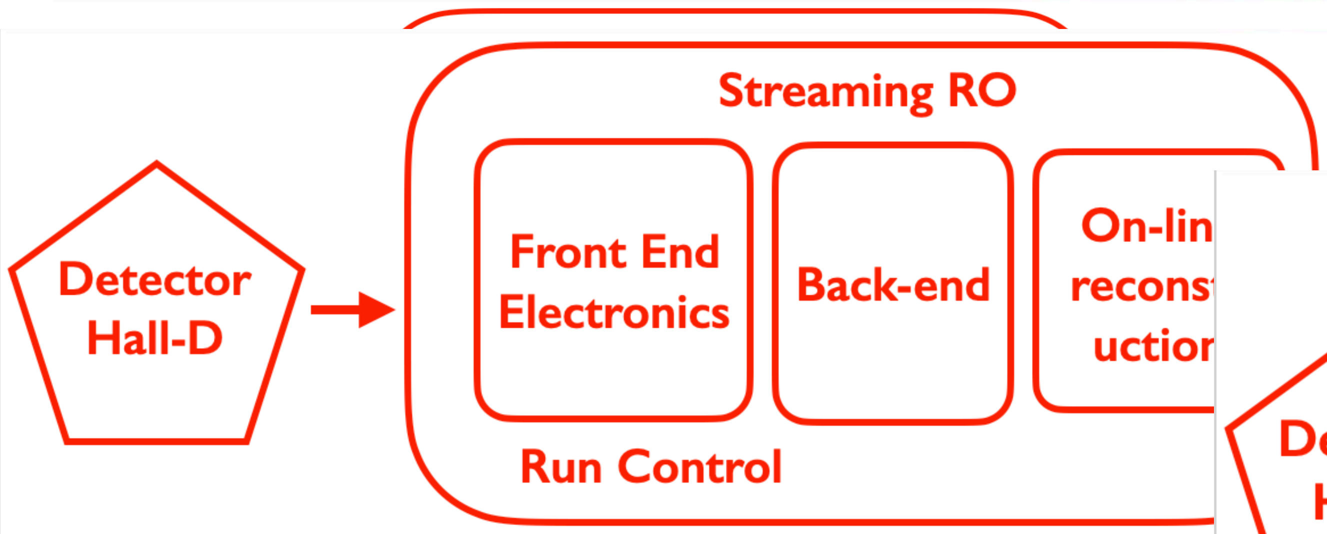






eRD23 activities
SRO prototype tests

Streaming RO components



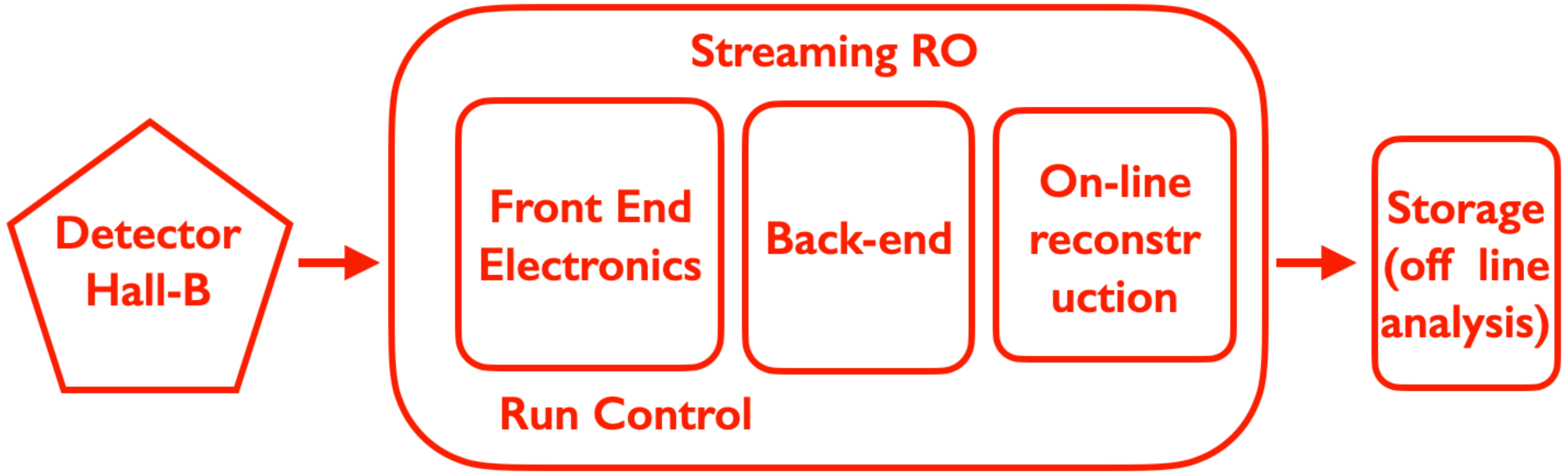
JLab SRO test

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 and WaveBoard front end

- Al
- fADC250+VTP and WaveBoard



SRO concept validation

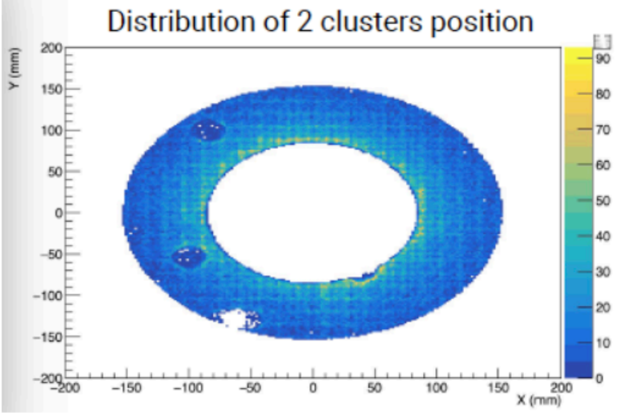
1) Assemble SRO components
2) Test SRO DAQ in lab
3) Test SRO DAQ on-beam

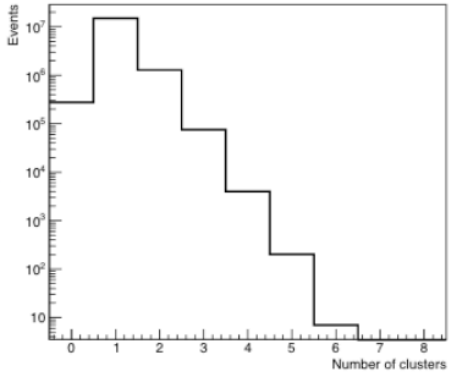
JLab SRO test

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

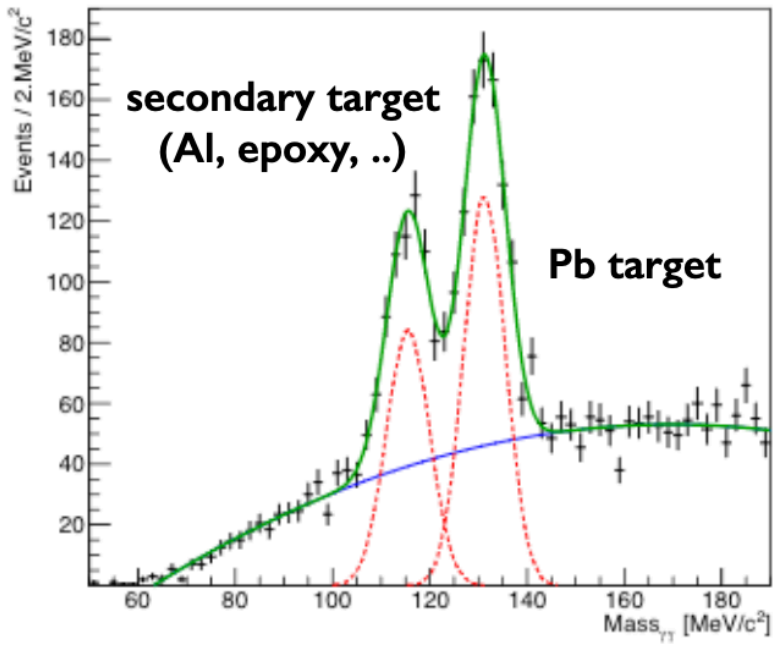
✳ CLAS12 Forward Tagger

- 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)

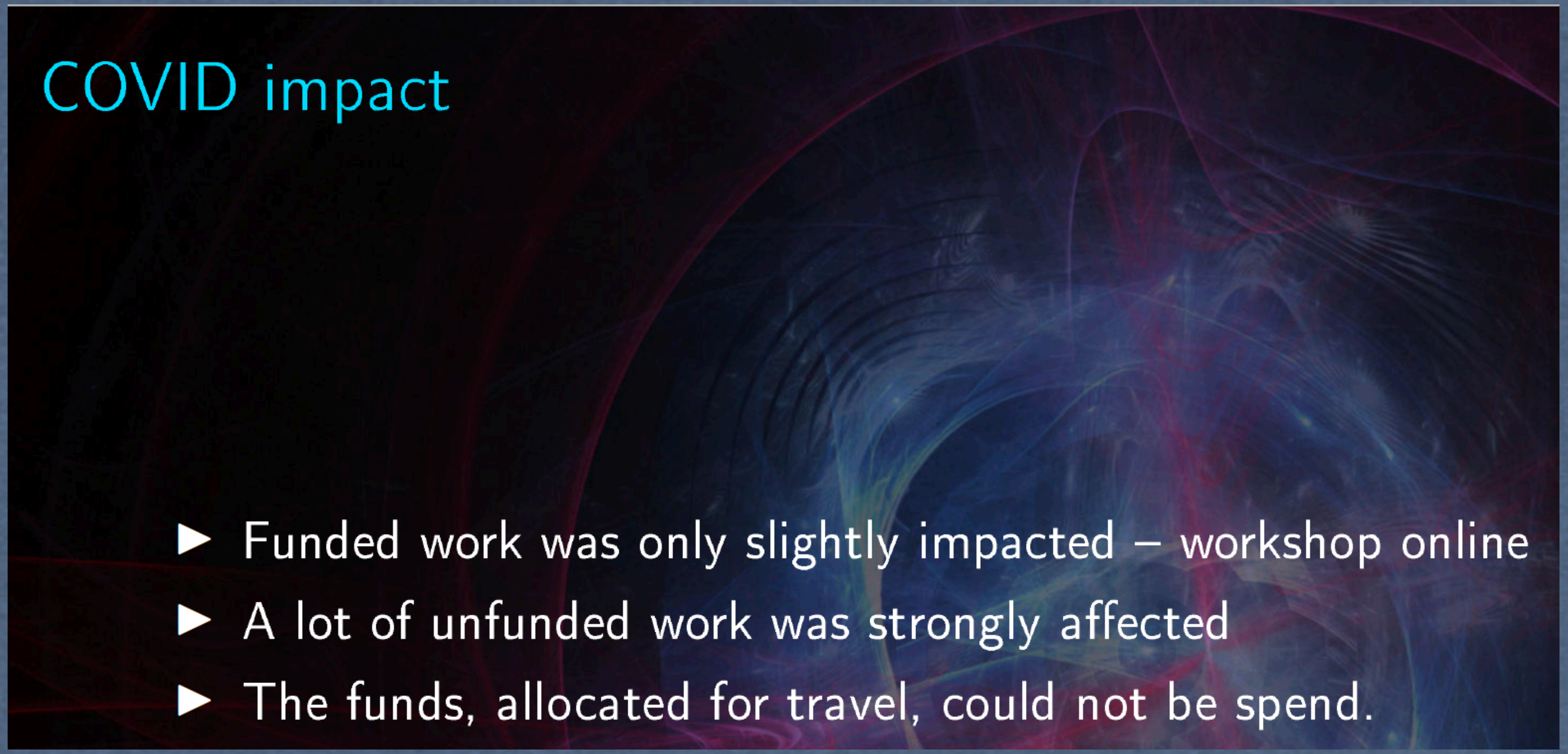
eRD23 activities
(not funded by eRD23!)

Successfully progress!

- ✳ SRO DAQ for other experiments
- ✳ Progress in FrontEnd electronics and backed software and integration
- ✳ Test SRO prototypes at BNL and JLab (+DESY TPEX experiment)
- ✳ Connection with EIC detector groups to develop an EIC SRO framework integrated in EIC detectors

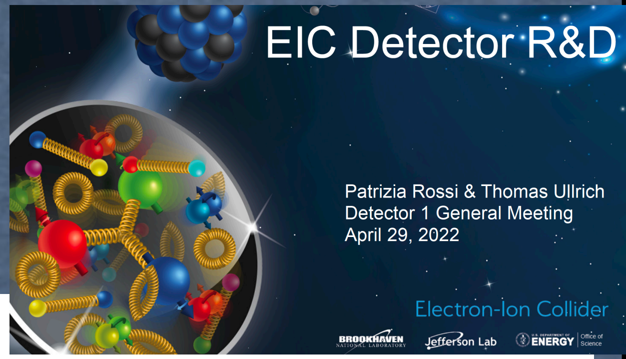
eRD stops:

- COVID-19
- EIC project evolved in multiple detector concepts (not finalised yet)



eRD23: the future

- eRD23 demonstrated, with facts, that SRO is THE solution for EIC DAQ
- It was not easy to convince the EIC community (and EIC eRD Committee!)
- SRO workshops serie gathers a growing community interested in SRO within EIC (but not only)
- Results visible in EIC YR, but not able to coordinate enough with ECCE, ATHENA and CORE (COVID)
- Keep testing SRO frameworks at BNL, JLab and other institutions (SBU, MIT, INFN, ORNL, …)
- DETECTOR1 FEE/DAQ WG will merge the different proposals resetting
- Coordination with detector WG is expected (ASIC/FEE, timing requirements)
- Establish a strong connection with eRD109 consortium ASICS/Electronics
- Not clear if another round of 'generic' RD will include DAQ/SRO: directions needed from EIC community
- Strengthen the connections and coordination with sub-detector groups to show limitations and opportunities
- Keep going with regular meetings (SRO-XI, XII, …) to learn, discuss and plan



eRD109: ASICs/Electronics

- Substantial R&D will be need for the development of Front-End Electronics: ASIC, Front-End Board (FEB), and Front-End Processor (FEP)
- The choice of using streaming read-out for the EIC excludes several existing ASIC chips.
- ASICs exist for the Si-Vertex detector (the current ALICE ITS chips meet EIC requirements).
- ASICs for the readout of LGADs/AC-LGADS is contained in the LGAD R&D.
- Estimate the need for 3 ASICs : (i) SiPM (calorimetry), (ii) MCP-PMT/PMT (PID), and MMG/GEM2/μRWell (tracking). This will require 3 FEB and likely 1-2 FEP.
- Timeline: ASIC development takes 4-5 years. Developments of the various parts will likely have to occur concurrently. Final requirements can only be established once the detector technologies are finalized
- eRD109: Put on hold since we don't have enough details to start ASIC development yet