Computing Round Table (2019)

from Tuesday, 12 February 2019 at **10:00** to Tuesday, 10 December 2019 at **16:00** (US/Eastern)
at **CEBAF Center**

Streaming Consortium Project: **Electromagnetic Calorimeter Streaming Readout**

M.Battaglieri
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Date: 6/20/19

EIC Calorimeter R&D Proposal and Progress Report

Project ID: eRD1
Project Name: Development of EIC Calorimeter Technology
Period Reported: from 1/1/19 to 06/30/19
Project Coordinators: H.Huang and C.Woody
Contact Persons: O.Tsai, T.Horn, C.Woody, S.Kuleshov, E.Kistenev

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eRD1

eRD23

Date: 06/20/2019

EIC Detector R&D Progress Report

Project ID: eRD23
Project Name: Streaming readout for EIC detectors
Period Reported: from 01/01/2019 to 6/30/2019
Project Leaders: M. Battaglieri and J. C. Bernauer
Contact Person: M. Battaglieri and J. C. Bernauer

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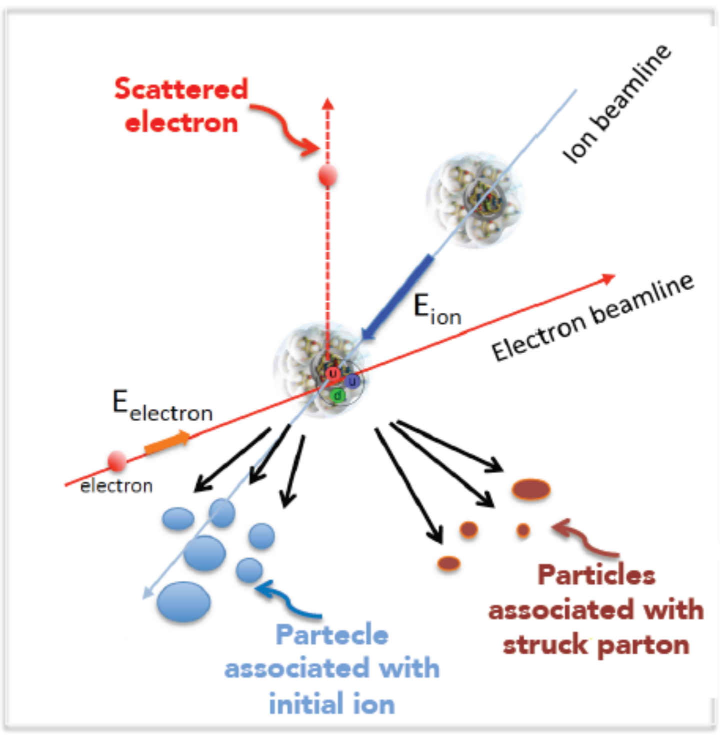
Abstract

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 design must be complemented with an integrated, up-to-date readout scheme that supports the scientific opportunities of the machine, improves time-to-analysis, and maximizes the scientific output. A fully Streaming Read Out (SRO) design delivers on these promises, however, it can also impose limitations on the characteristics of the sensors and sub-detectors. The streaming readout consortium will research the design space by evaluating and quantifying 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.



✳ Resolve partons in nucleons
- high beam energies and luminosities
- Q2 up to ~1000 GeV^2

✳ Resolve (k_t, b_t) of the order a few hundred MeV in the proton
- High Granularity, wide dynamic range

✳ Detect all types of remnants to seek for correlations:
- scattered electron
- particles associated with initial ion
- particles associated with struck parton

EIC detectors

- Large acceptance
- Frw/Bckw angles
- Precise vertexing
- HRes Tracking
- Excellent PID

Options for EIC readout

Traditional (triggered) DAQ

✳ All channels continuously measured and hits stored in short term memory by the FEE

✳ Channels participating to the trigger send (partial) information to the trigger logic

✳ Trigger 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

✳ **Drawbacks:**
- only few information form the trigger
- Trigger logic (FPGA) difficult to implement and debug
- not easy to change and adapt to different conditions

Streaming readout

✳ All channels continuously measured and hits streamed to a HIT manager (minimal local processing) with a time-stamp

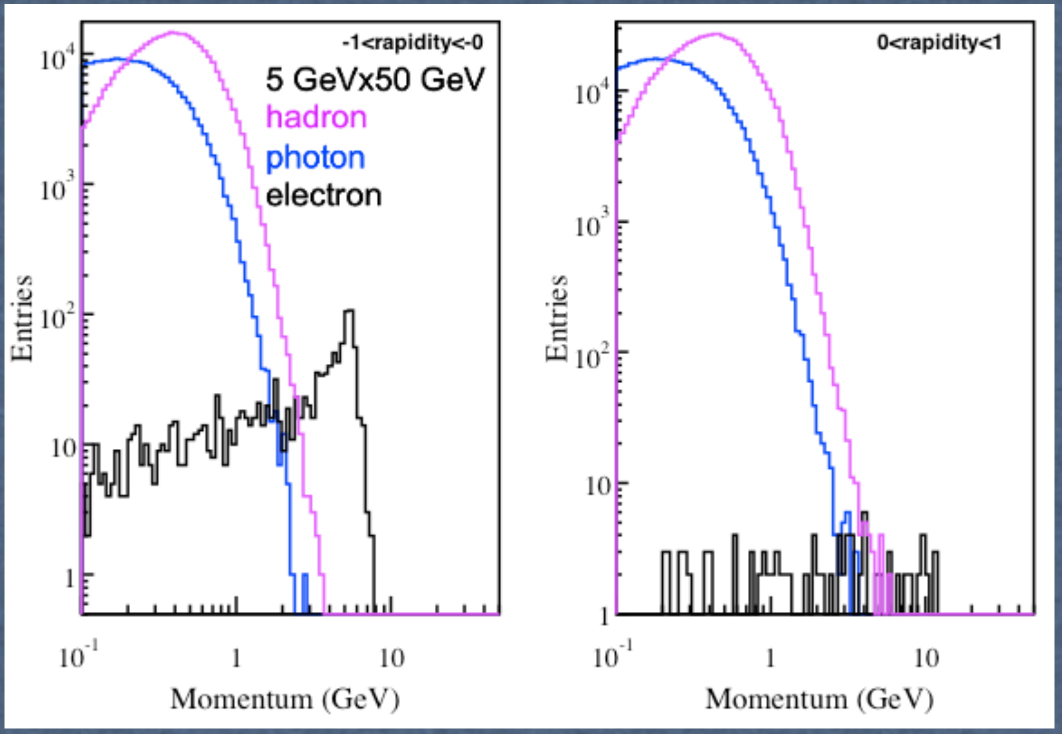
✳ A HIT MANAGER receives hits from FEE, order them and ship to the software defined trigger

✳ 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

✳ **Advantages:**
- Trigger decision based on high level reconstructed information
- easy to implement and debug sophisticated algorithms
- high-level programming languages
- scalability

Streaming readout for EIC

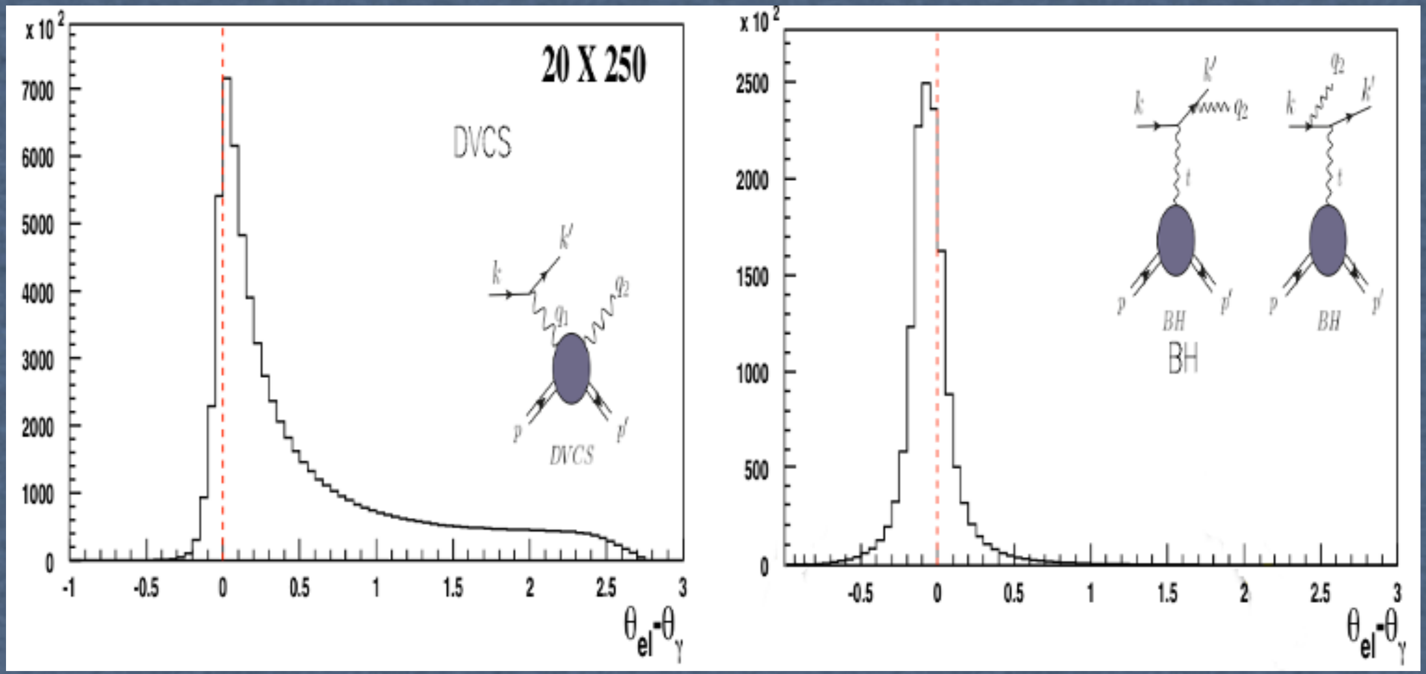
A triggerless DAQ provides advantages for all EIC reaction channels



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

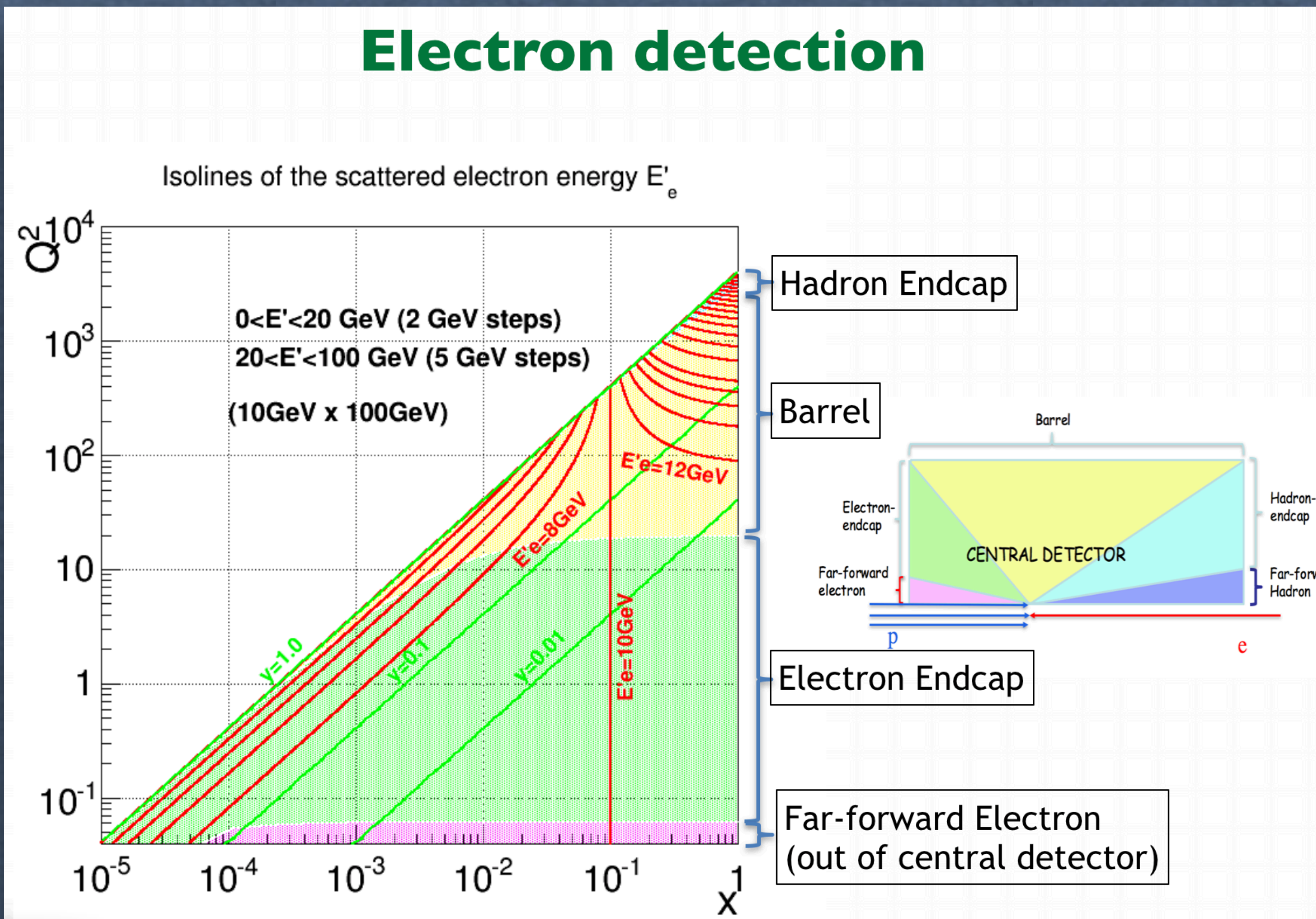
- DVCS benefits by the measurement of the hard photon together with the scattered electron
- The dominant BH background can be rejected by reconstructing θ_e and θ_γ and cutting on (θ_e-θ_γ)

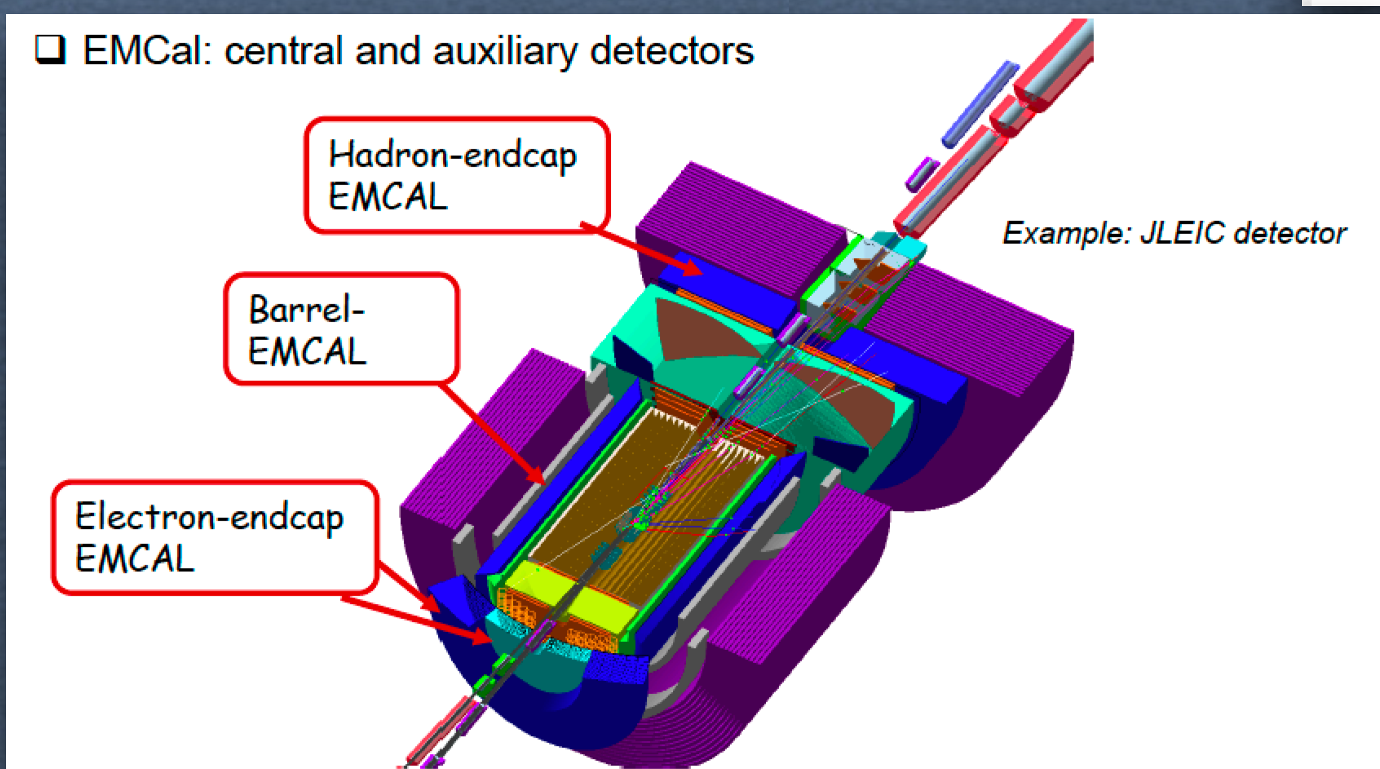
Large flexibility to add new triggers for different physics cases!

Calorimeters @ EIC

- *Particle IDentification:*
  discriminating single photons from, e.g., π^0 decay and e/p
- *Particle Reconstruction:*
  reconstruct four-momentum of scattered electrons at small angles, where the momentum (or energy) resolution from the tracker is poor

Tracker momentum resolution rapidly degrades at η< -2 because of the vanishing B*dl integral of the solenoid field; this definitely affects {x,Q2} reconstruction quality





EM Inner Calorimeter Requirements

- Good resolution in angle to at least 1° to distinguish between clusters
- Energy resolution to a few %/√E for measurements of cluster energy
- Ability to withstand radiation down to at least 1° wrt beam line

EM calorimeters

eRD1: Develop calorimeters that meet the requirements of physics measurements at an EIC –including all regions of the detector

- ★ **radiation hardness**
  can sustains a high dose (small angles coverage)
- ★ **small em radiation length and reduced Moliere radius**
  compact, longitudinal and transverse size, position resolution
- ★ **fast**
  high rates, good timing, triggering
- ★ **large LY**
  high energy and time resolution

	X_0 [cm]	E_c [MeV]	R_M [cm]
Pb	0.56	7.2	1.6
Scintillator (Sz)	34.7	80	9.1
Fe	1.76	21	1.8
Ar (liquid)	14	31	9.5
BGO	1.12	10.1	2.3
Sz/Pb	3.1	12.6	5.2
PB glass (SF5)	2.4	11.8	4.3

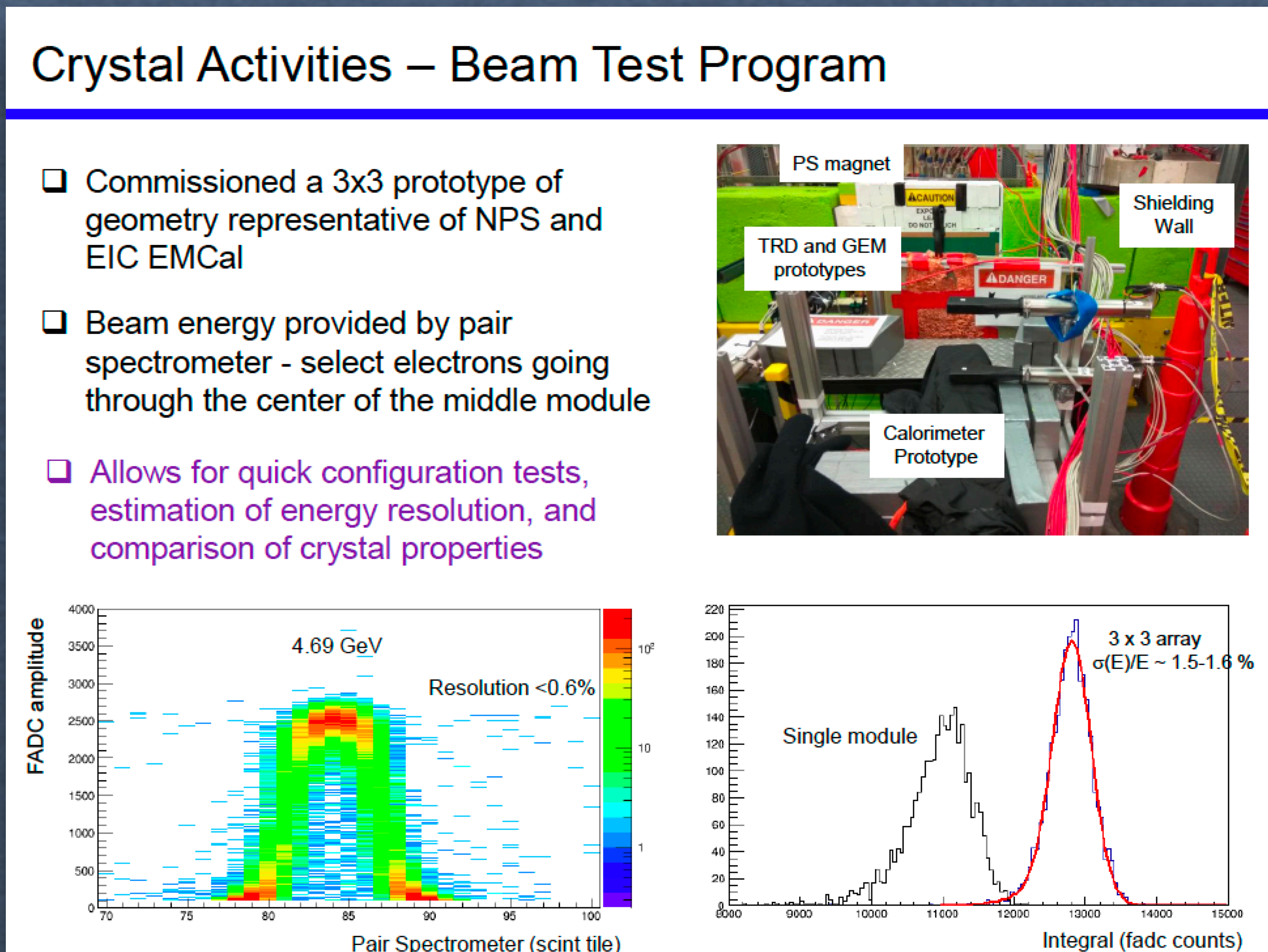
Best option:
homogeneous calorimeter (crystals)

$PbWO_4$ is the leading option for EIC calorimeters
(CMS, PANDA, FT-CAL, DVCS, …)

Testing the current technology (SICCAS, CRYTUR, …)

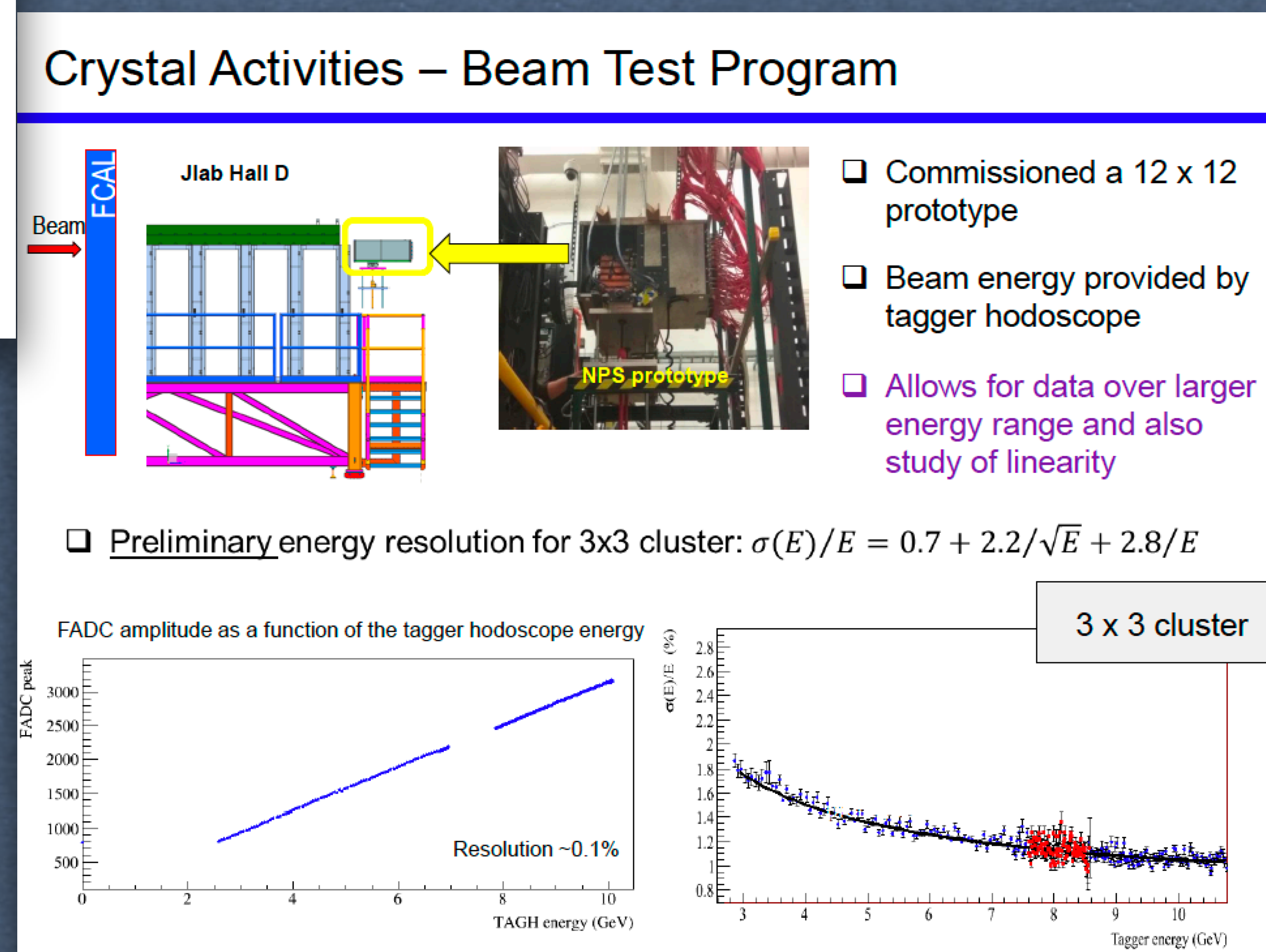
Developing new scintillating materials (e.g. ceramic-glasses)

$PbWO_4$ ECal Beam test at JLab



Crystal Activities – Beam Test Program

- ❑ Commissioned a 3x3 prototype of geometry representative of NPS and EIC EMCal
- ❑ Beam energy provided by pair spectrometer - select electrons going through the center of the middle module
- ❑ Allows for quick configuration tests, estimation of energy resolution, and comparison of crystal properties



Crystal Activities – Beam Test Program

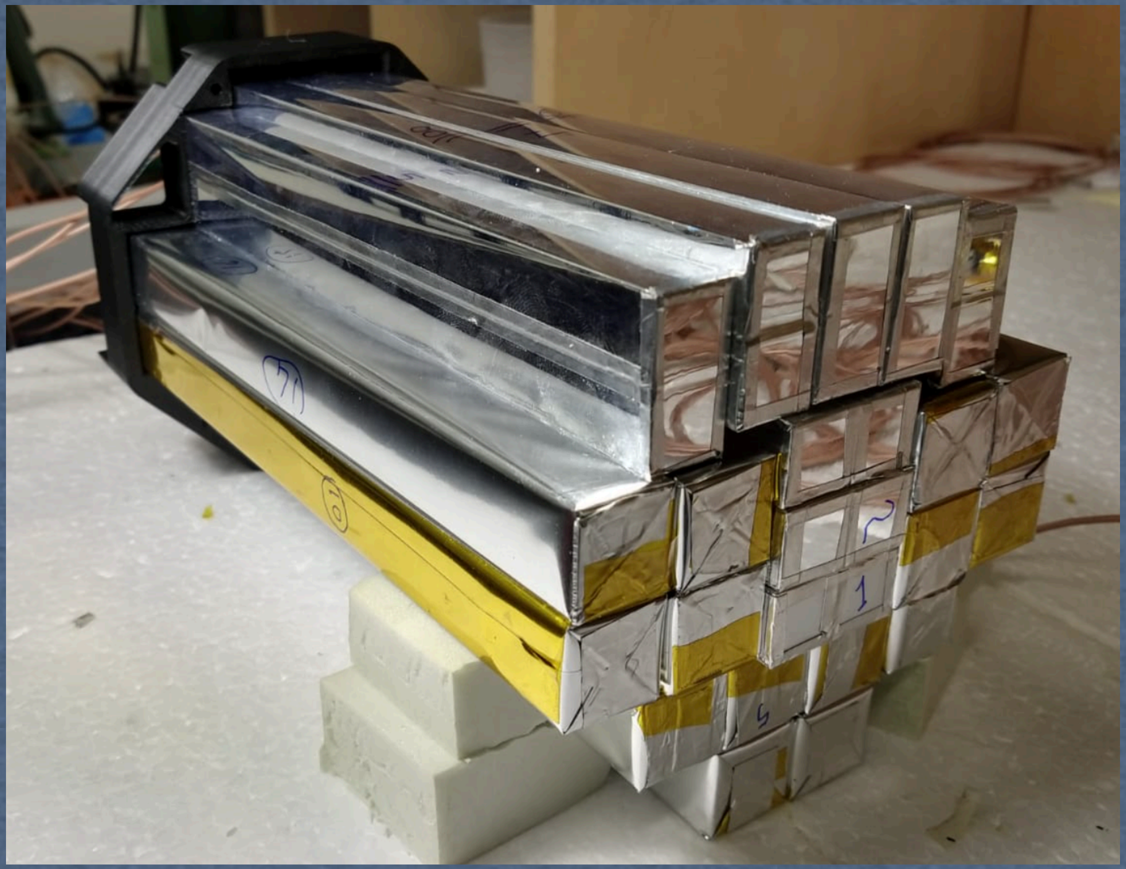
- ❑ Commissioned a 12 x 12 prototype
- ❑ Beam energy provided by tagger hodoscope
- ❑ Allows for data over larger energy range and also study of linearity

❑ Preliminary energy resolution for 3x3 cluster: $\sigma(E)/E = 0.7 + 2.2/\sqrt{E} + 2.8/E$

- 12x12 (3x3) PbWO4 + PMT
- So far tested with traditional DAQ
- Good resolution

Credit to T.Horn

Streaming RO test at JLab



- ★ Ecal of BDX-MINI experiment at JLab
- ★ 48x PbWO4 matrix of SICCAS (FT-Cal) and BTCP (PANDA) crystals
- ★ Light sensor: 6x6 mm^2 Hamamatsu SiPM, 25µm, 57.6k cells, trenched, pde=25%
- ★Custom preamp FE (modified version used for HPS and CLAS12-FT_Cal APDs)
- ★ Triggered DAQ based on CAEN fADC + FPGA
- ★ Currently running downstream of Hall-A dump
- ★ Cosmic rays

Streaming RO test at JLab

DAQ architecture and front-end inherited from **KM3NeT** experiment

Trigger-less front-end system WaveBoard:

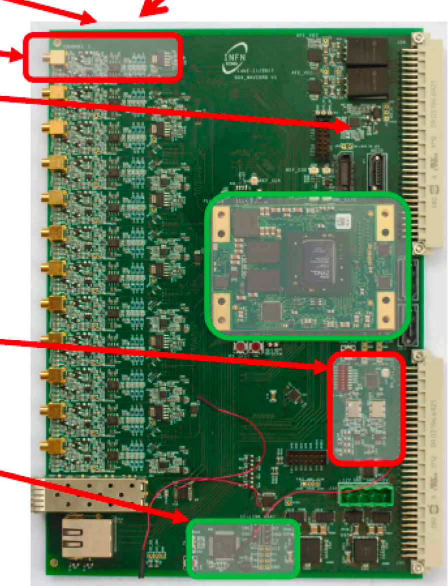
- ADC sampling (14 bit, 250MHz)
- **zero-suppression** (L0 trigger) @ 0.3 p.e. threshold
- sampling window is **time-variable**
- all non-zero data forwarded (**all data to CPU-farm**)

The *WaveBoard* digitizer board

INFN

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

Single Channel Front End w/ High Voltage



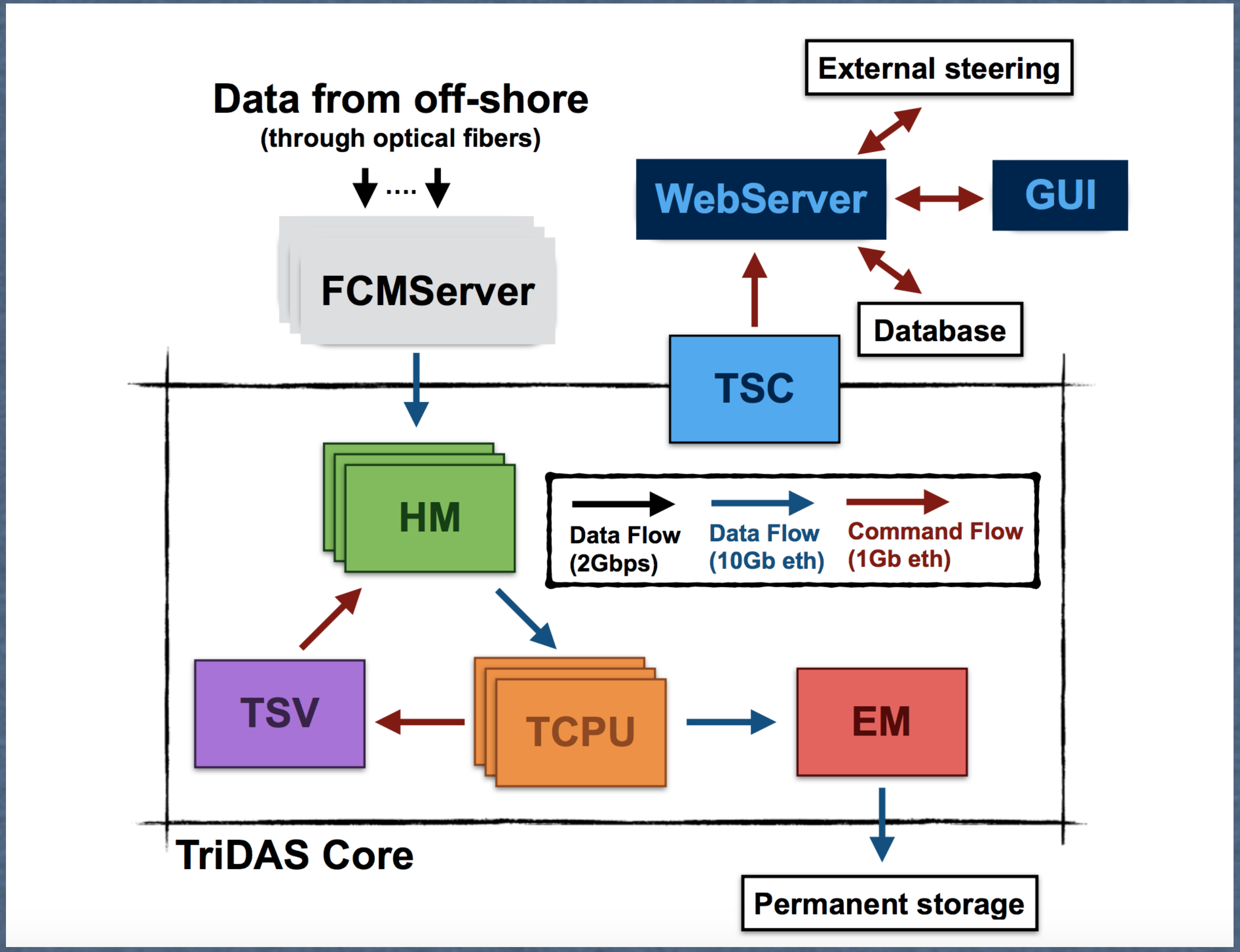
Credit to F.Ameli

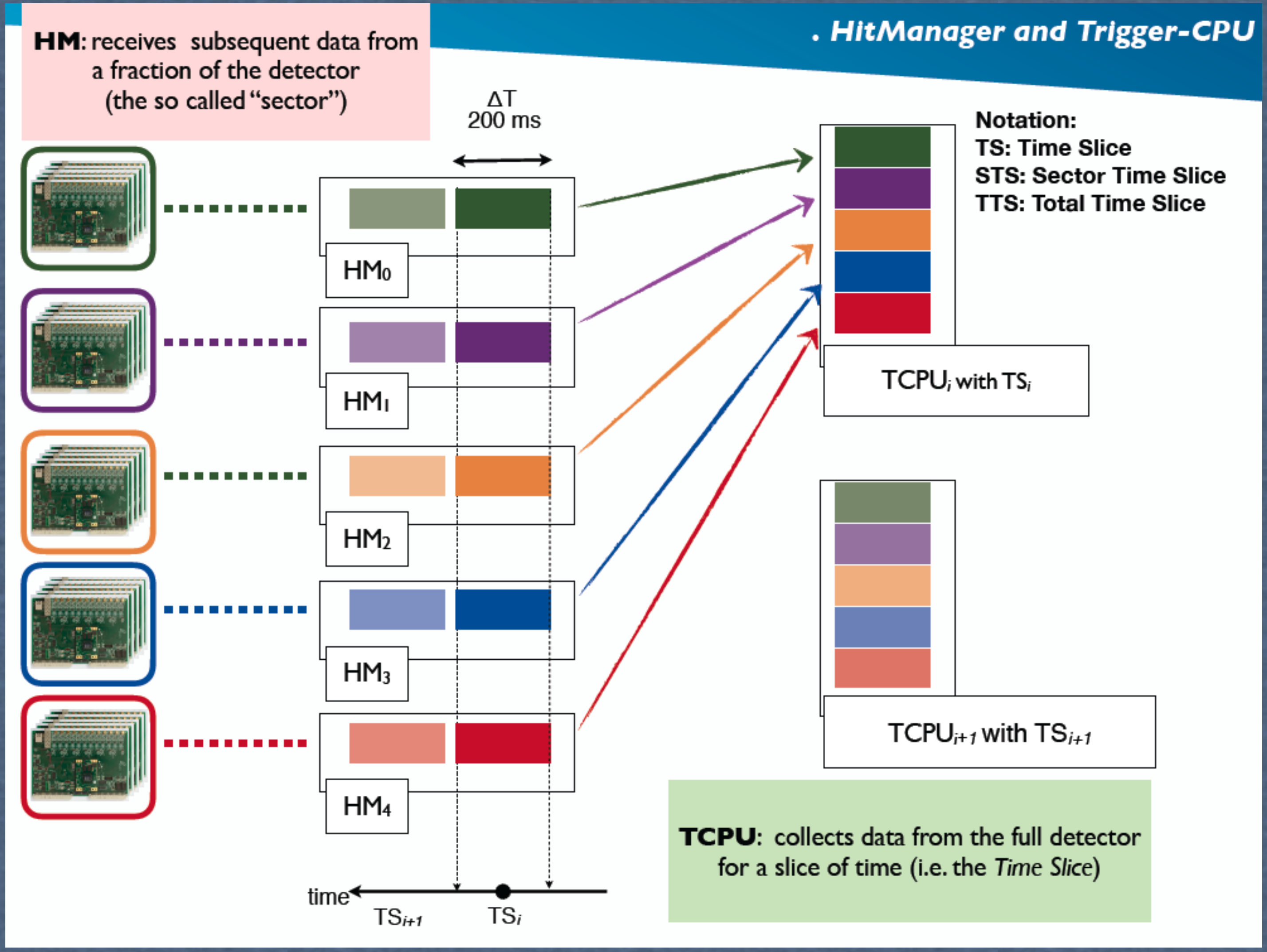
Streaming RO test at JLab

DAQ architecture and front-end inherited from **KM3NeT** experiment

Trigger-less Data Acquisition System (TriDAS)

- **Scalable** Event Building architecture
- DAQ scalability relies on **network** scalability





Credit to T.Chiarusi

Streaming RO validation at JLab

Triggerless DAQ Chain – wave board + TriDAS

I. Only signals over the wave-board hardware threshold are processed (Hits)

II. Event definition and construction by **Level 1 (L1)** low level software selection algorithm (e.g. OR of crystals Hits)

III. Event selection and tagging by **Level 2 (L2)** algorithm (e.g. clustering, trajectories selection)

Triggered DAQ Chain – Jlab FADC + CODA

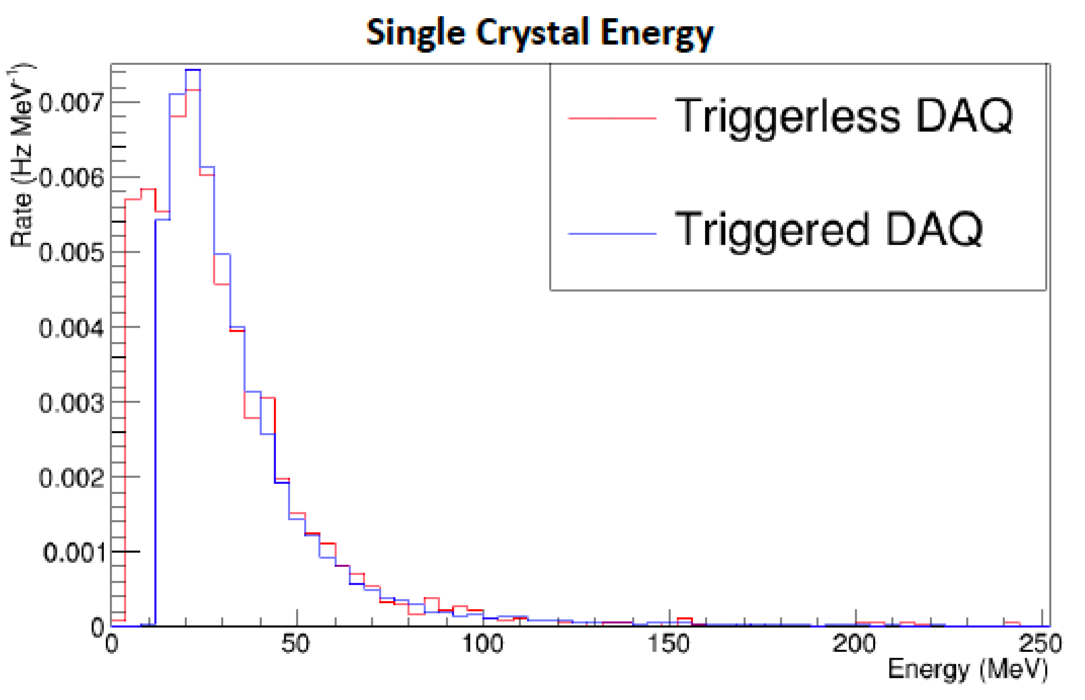
I. All channels are passed to discriminators

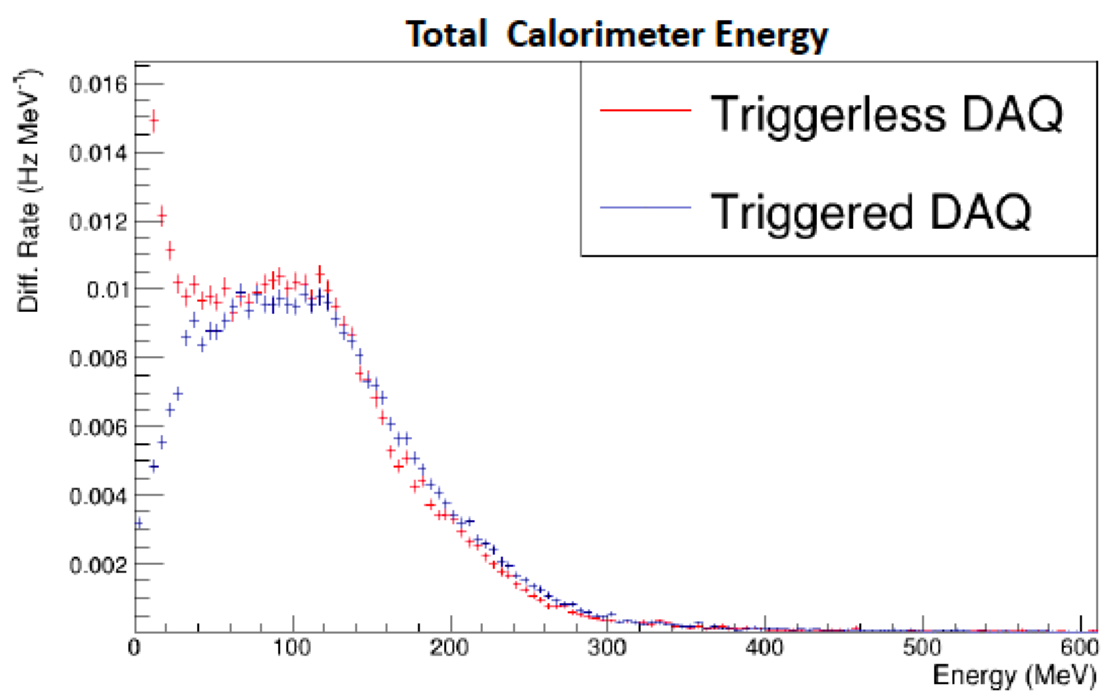
II. Discriminator output passed to coincidence module for event definition (OR of crystals)

III. All channels waveforms acquired and saved for each trigger

Comparison between triggered and triggerless data

- Rates
  - Tot energy: slight discrepancy due to the different thresholds





Credit to A.Celentano, L.Marsicano

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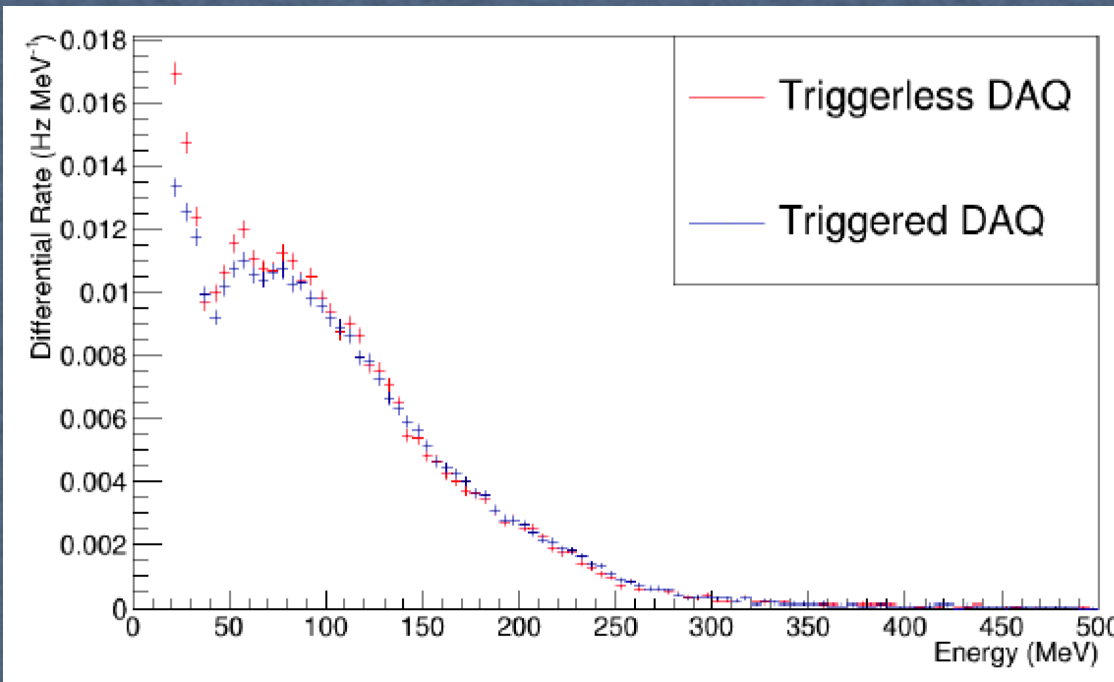
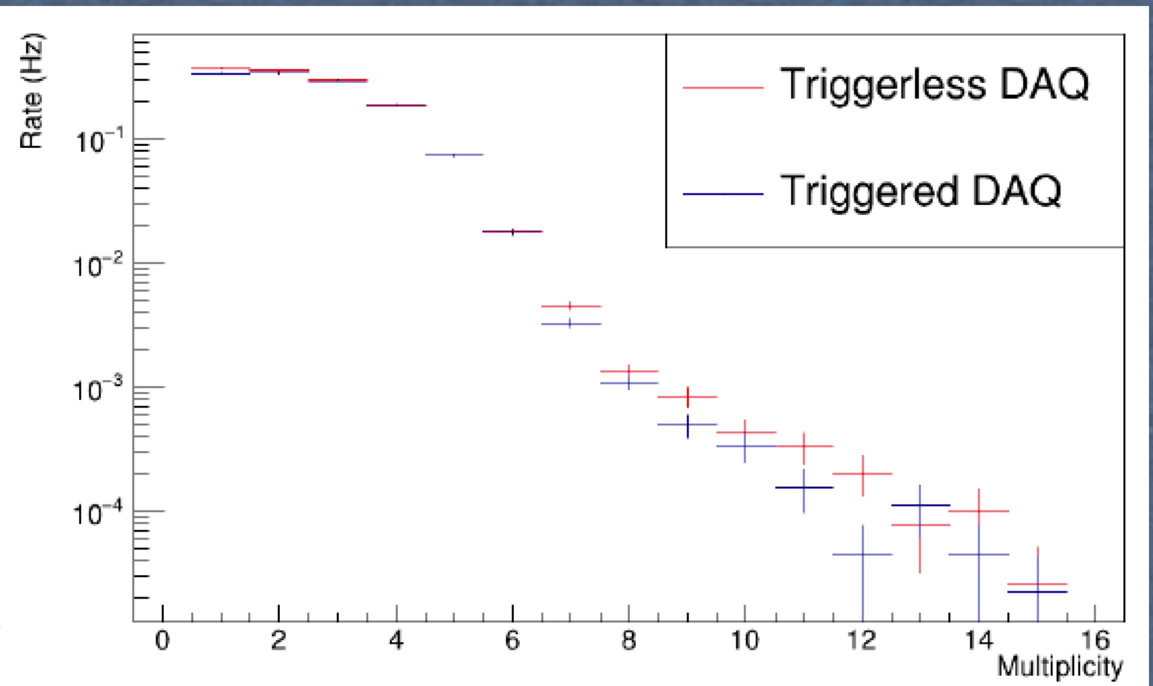
Comparison between triggered and triggerless data

- Multiplicity

- Confirmed by multiplicity distribution





Credit to A.Celentano, L.Marsicano

Streaming RO validation at JLab

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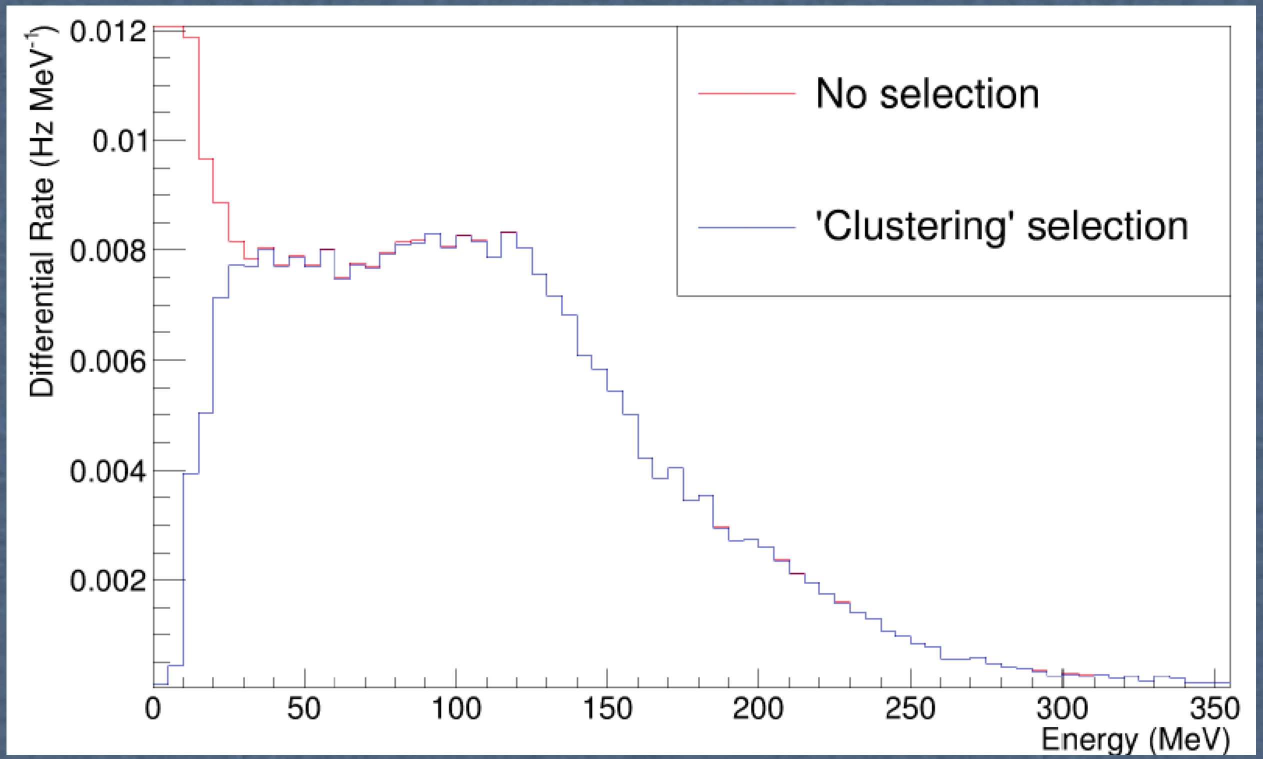
Comparison between triggered and triggerless data

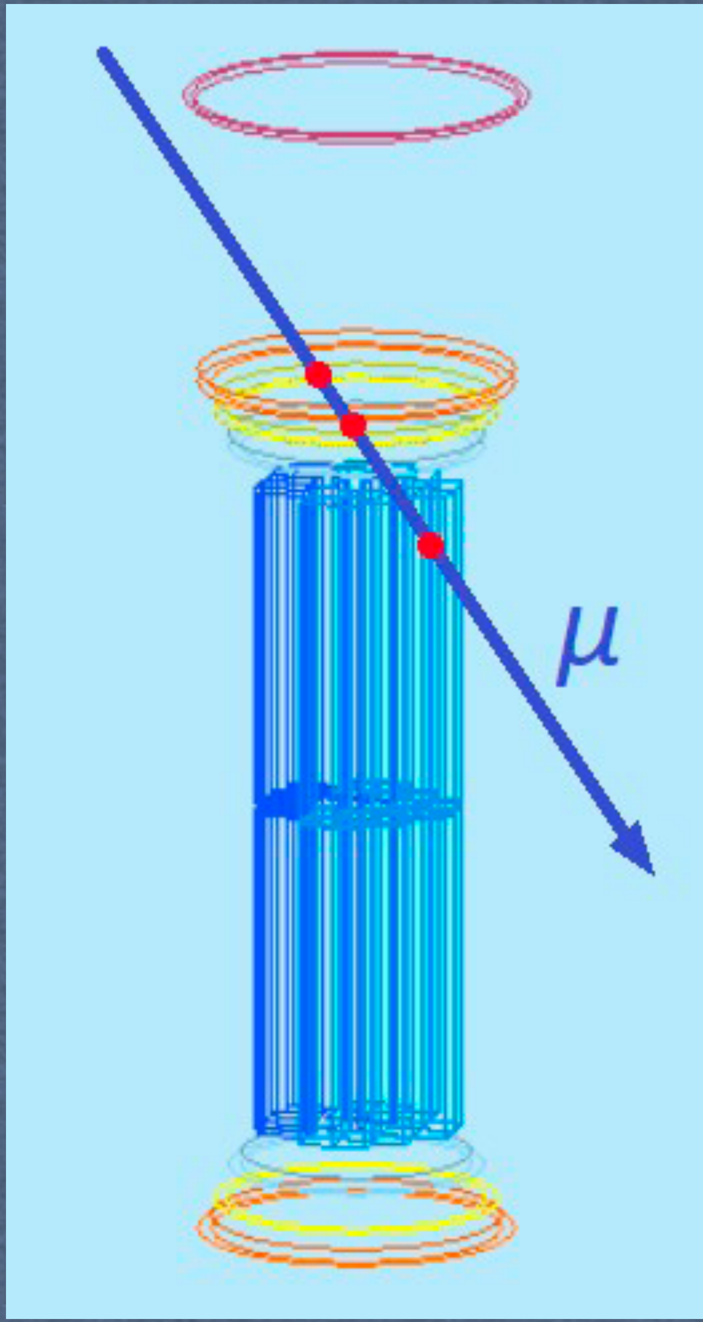
- Clustering
  - L2 "clustering" selection trigger
  - Online: few MeV thresholds on E_{tot} and E_{seed}
  - Same cuts applied offline to unselected events
  - Trigger efficiency found to be ~100 %



Credit to A.Celentano, L.Marsicano

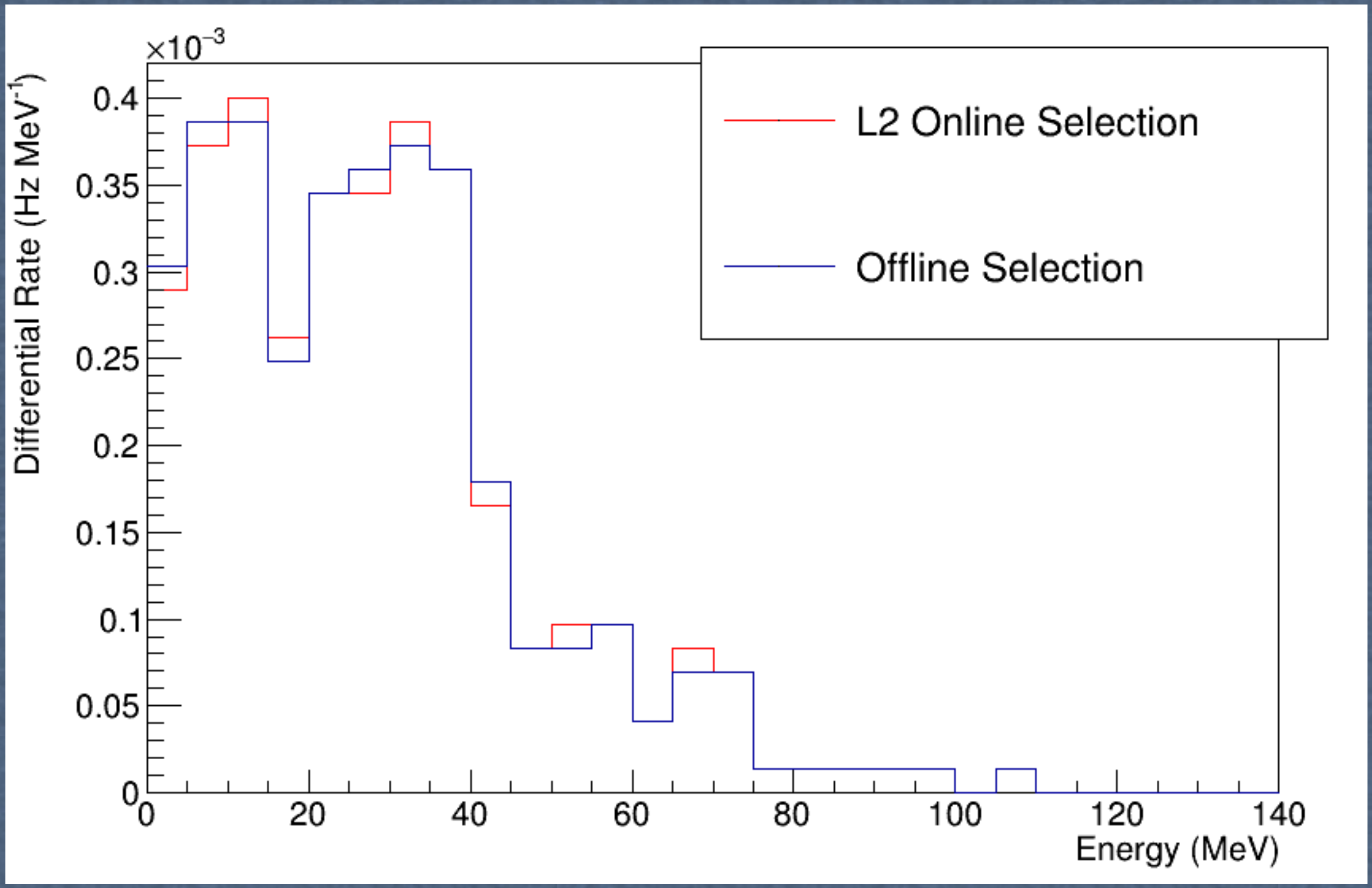
Streaming RO validation at JLab

- Cosmic track selection



Select events with hits in well defined positions of the vetos can be used to identify cosmic muons trajectories (useful for crystals calibration)

- Online trajectory selection trigger
- Conditions on veto topology and SiPM charge distribution
- Online selection has comparable efficiency to offline analysis



Credit to A.Celentano, L.Marsicano

Plans and Conclusions

- ✳ EIC detectors require/deserve a modern DAQ technology
- ✳ Streaming Read-Out presents many advantages when compared to the triggered DAQ
- ✳ If adopted, the streaming RO will affect all EIC detectors
- ✳ Streaming RO needs to be validated against triggered DAQ
  - it works as well
  - overperfoms
- ✳ EM calorimeters are a crucial component in EIC and traditionally the key-element in trigger formation
- ✳ PbWO4 is the leading technology for EIC EM Cal (many parallel efforts too)
- ✳ Beam tests of EMCal prototypes are on-going to assess performance (triggered DAQ)
- ✳ PbWO4 Streaming RO validated using cosmic ray
- ✳ Next step: streaming RO on-beam validation to demonstrate:
  - on-line calibration,
  - cluster-findin,
  - sophisticate trigger algorithms
  - over-performance in energy and time resolution