Streaming Readout Workshop VII

Developing a common, community-wide standard for streaming readout

This workshop will be held as an interactive virtual event.
November 16–18, 2020

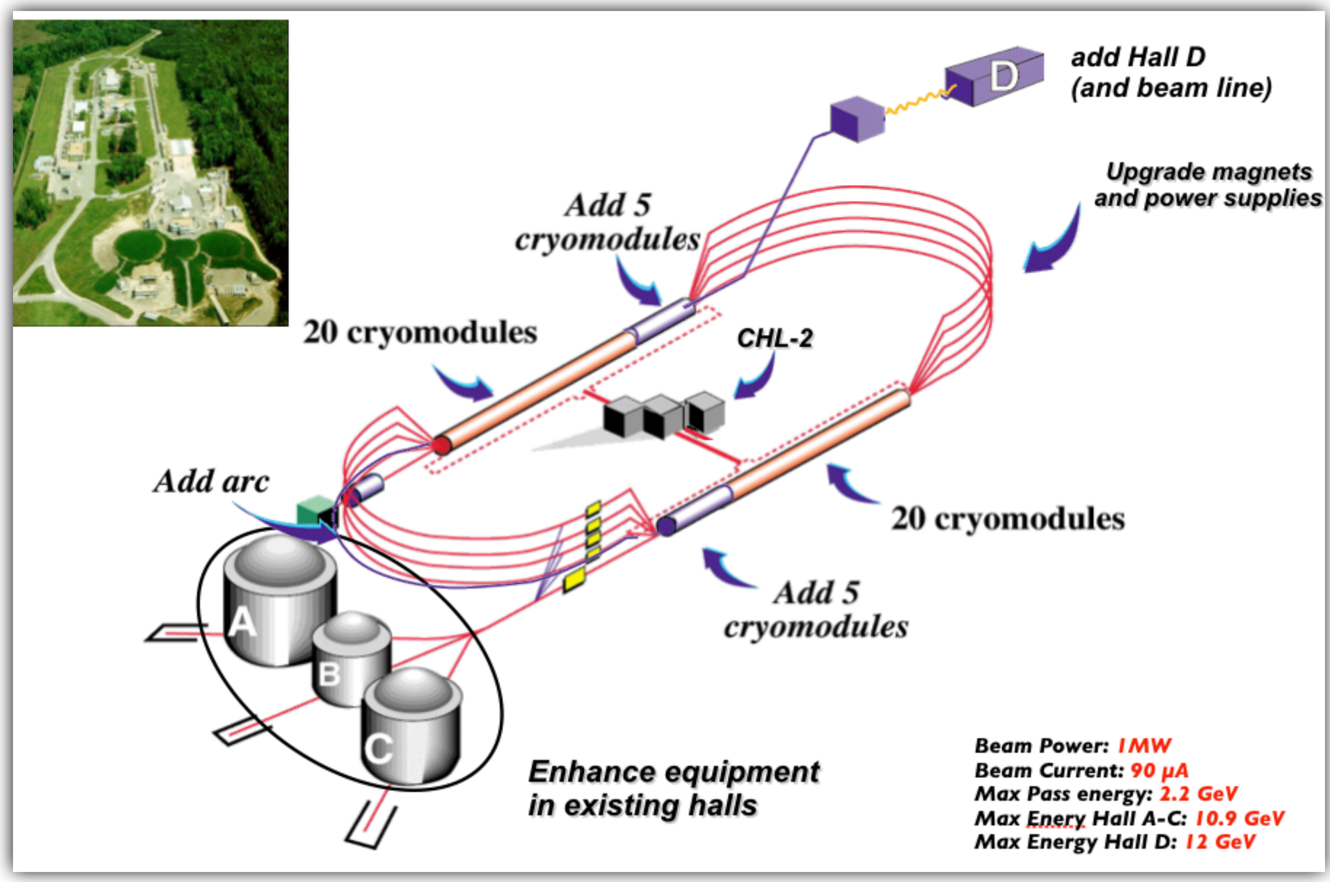
Jefferson Lab Hall-B Streaming Read-Out

Marco Battaglieri
Jefferson Lab/INFN
(for JLab SRO Team)

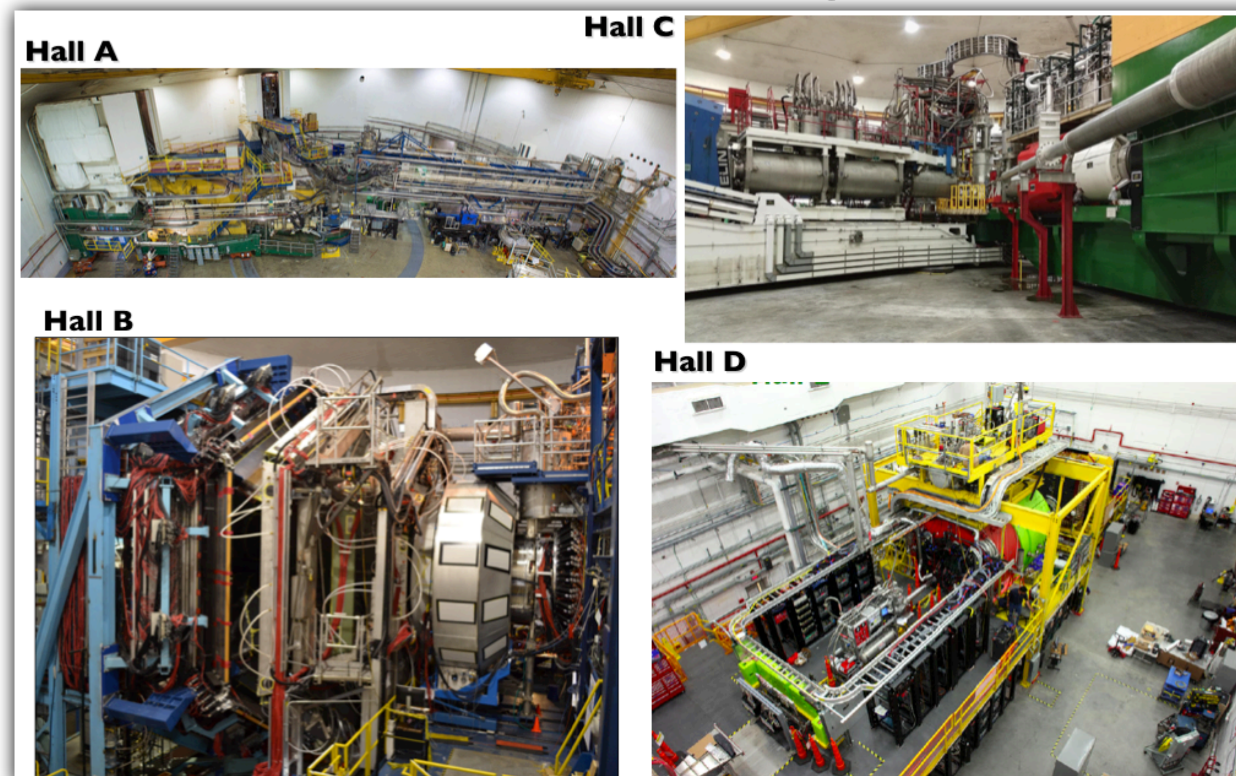
Farnesina
Ministero degli Affari Esteri e della Cooperazione Internazionale

Supported by Italian Ministry of Foreign Affairs (MAECI) as Projects of great Relevance within Italy/US Scientific and Technological Cooperation under grant n. MAE0065689 - PGR00799

Jefferson Lab



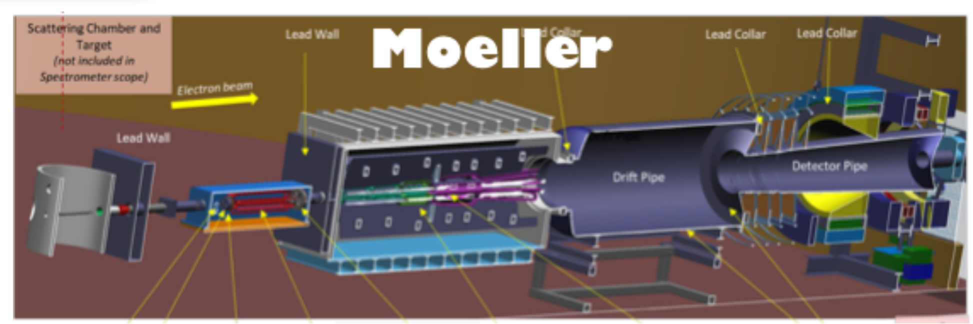
Current program

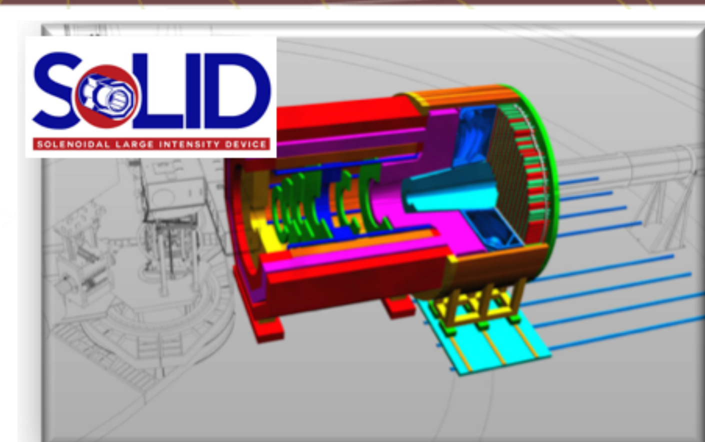


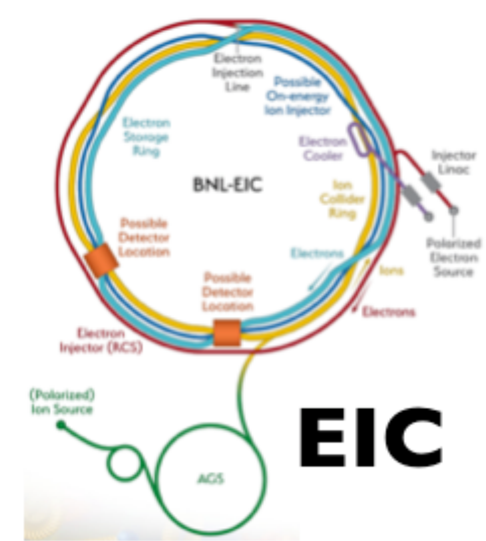
- ✳ Primary Beam: Electrons
- ✳ Beam Energy: 12 GeV
  - 10 > λ > 0.1 fm
  - nucleon → quark transition
  - baryon and meson excited states
- ✳ 100% Duty Factor (cw) Beam
  - coincidence experiments
  - Four simultaneous beams
  - Independent E and I
- ✳ Polarization
  - spin degrees of freedom
  - weak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

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

Future projects







Streaming RO

Streaming Read Out (RO) is one of the milestones of JLAB Agenda

✳ **Streaming RO is necessary for a long-term HI-LUMI upgrade of Hall-B CLAS12**

- Running CLAS12 at higher luminosity (wrt the designed $10^{35}cm^{-2}\ s^{-1}$) has been declared as a milestone for the FY20 JLab Agenda
- The appointed PhysDiv Task Force (S.Stepanyan) identified a staged approach with an increase of 2x (keeping ε_{Rec}>85%) in 2-3 years (Phase I) timeframe and a 100x in 5-7 years (Phase II)
- An update of the R1 CLAS12 DC with more dense detector (e.g. GEM) is expected in Phase I. A Streaming RO DAQ upgrade is necessary for the Phase II
- With the current triggered technology the maximum possible event acquisition rate for CLAS12 is ~100 kHz (R~30 kHz now) replacing MM (future) and CAEN TDCs (ongoing)

✳ **Streaming RO can be tested in Hall-D using the PS hodoscope**

- Hall-D PS can be used as a beam test facility (fully parasitic) for a tagged electron/positron beam

✳ **Streaming RO is recognised as the leading DAQ technology for the EIC project**

- CLAS12 can be used to test and validate detector/DAQ solutions for the EIC in a realistic on-beam conditions
- Using VTP readout CLAS12 can reuse 3/4 of existing triggered boards (fADC250) in streaming mode
- Part of a lab-wide effort (involving Hall-C and Hall-D) to test EIC calorimetry

The CLAS12 detector

Forward Detector:

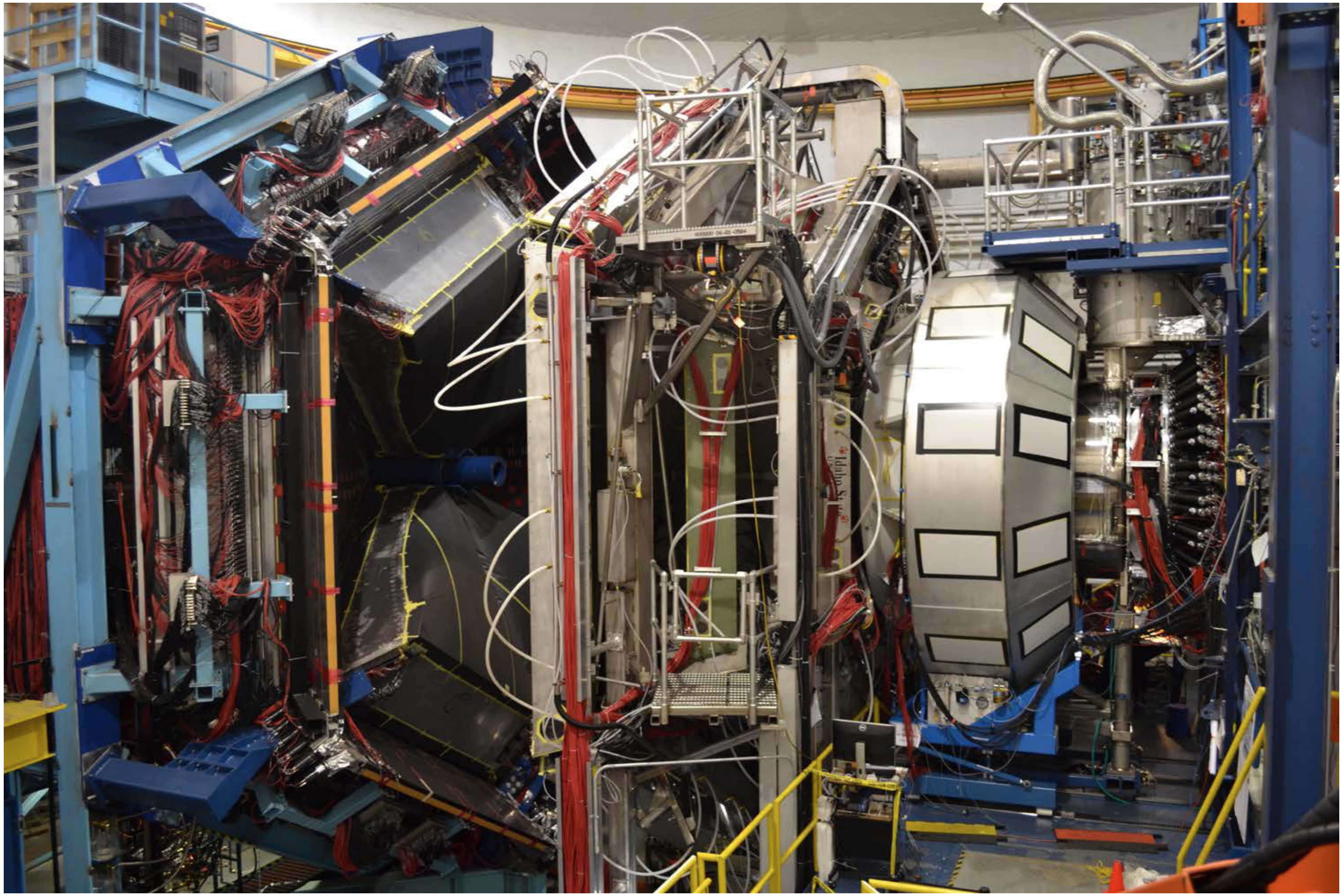
- *TORUS magnet*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*

Central Detector:

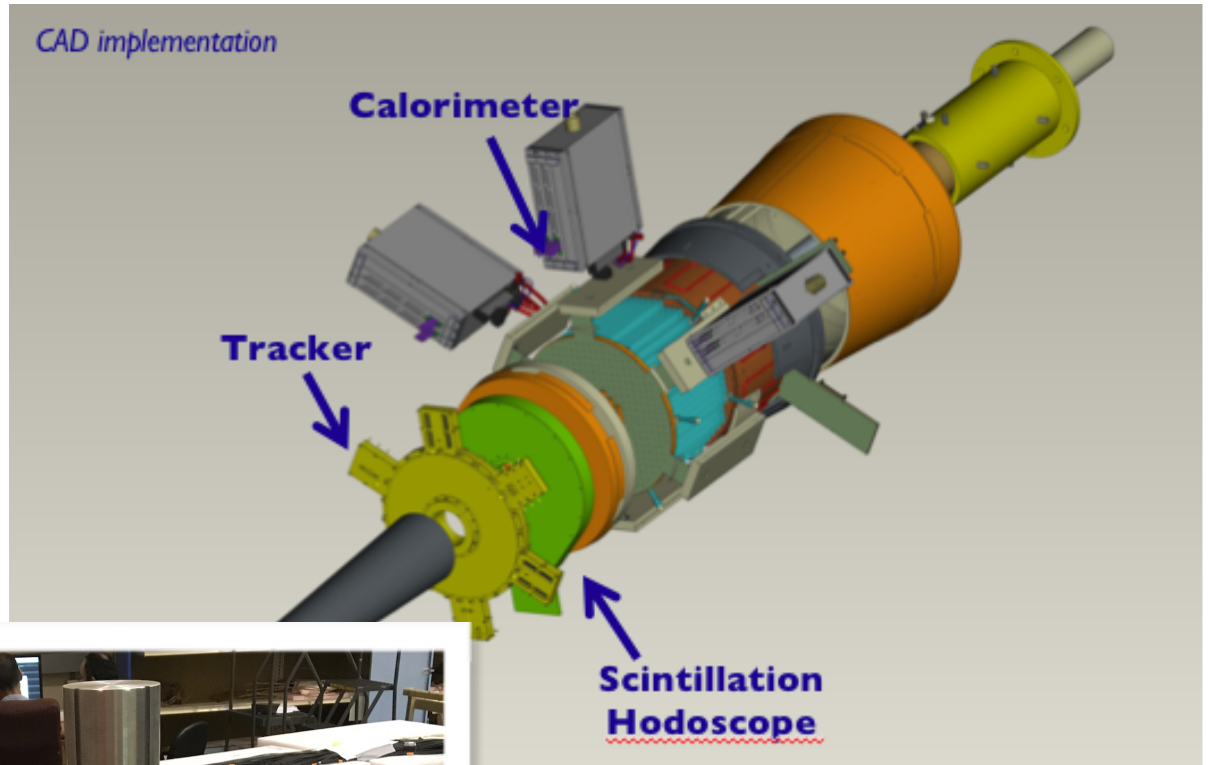
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

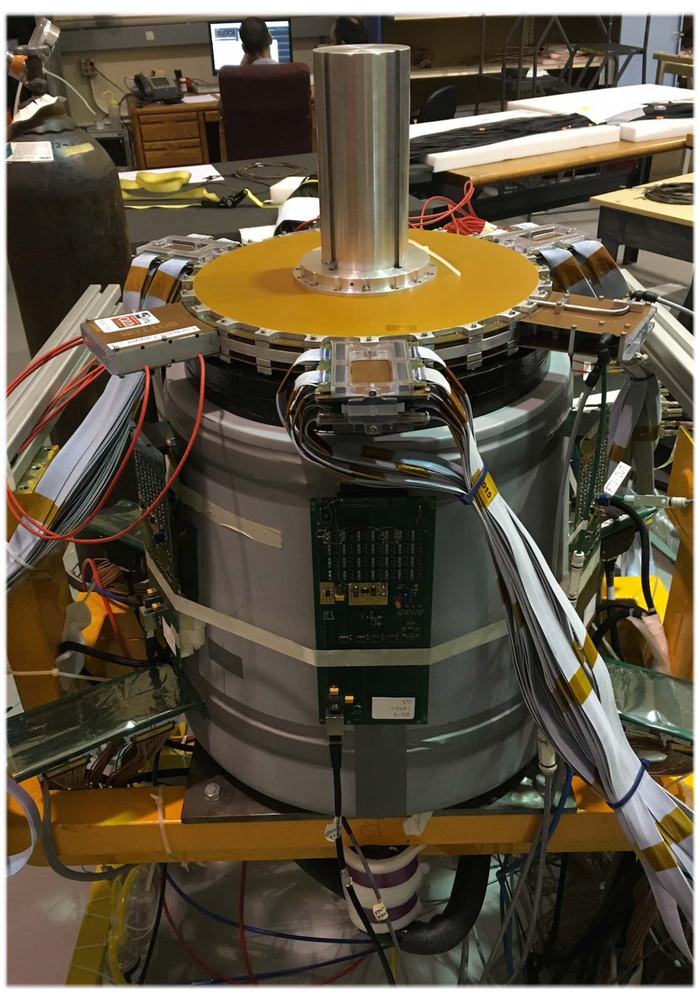
Upgrades:

- *Micromegas (CD)*
- *Neutron detector (CD)*
- *RICH detector (FD)*
- *Forward Tagger (FD)*



CLAS12 and the Forward Tagger (FT)

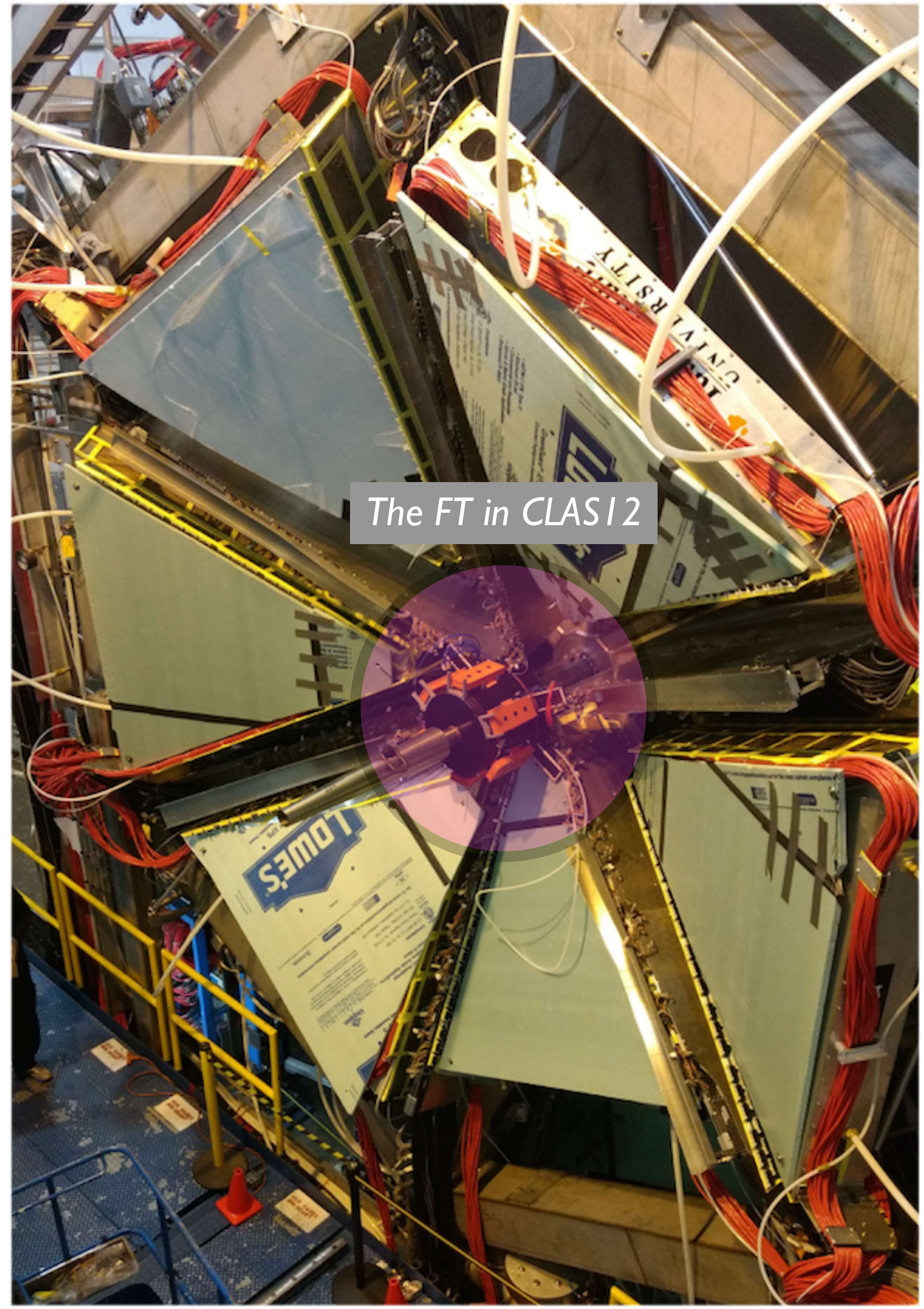




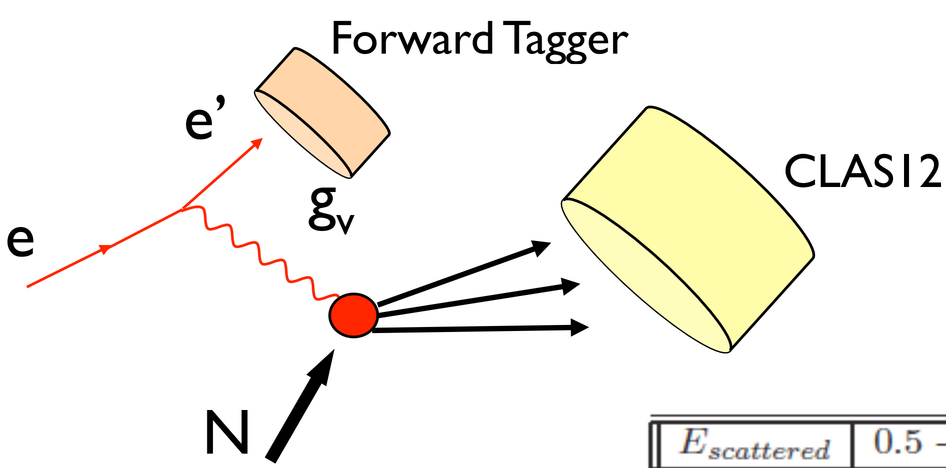
FT-Trck: MicroMegas
- electron angles and polarization plane
- 3072 chs, DREAM cheap

FT-Hodo: Scintillator tiles
- veto for photons
- Sipms, 232 ch, fADC250chs

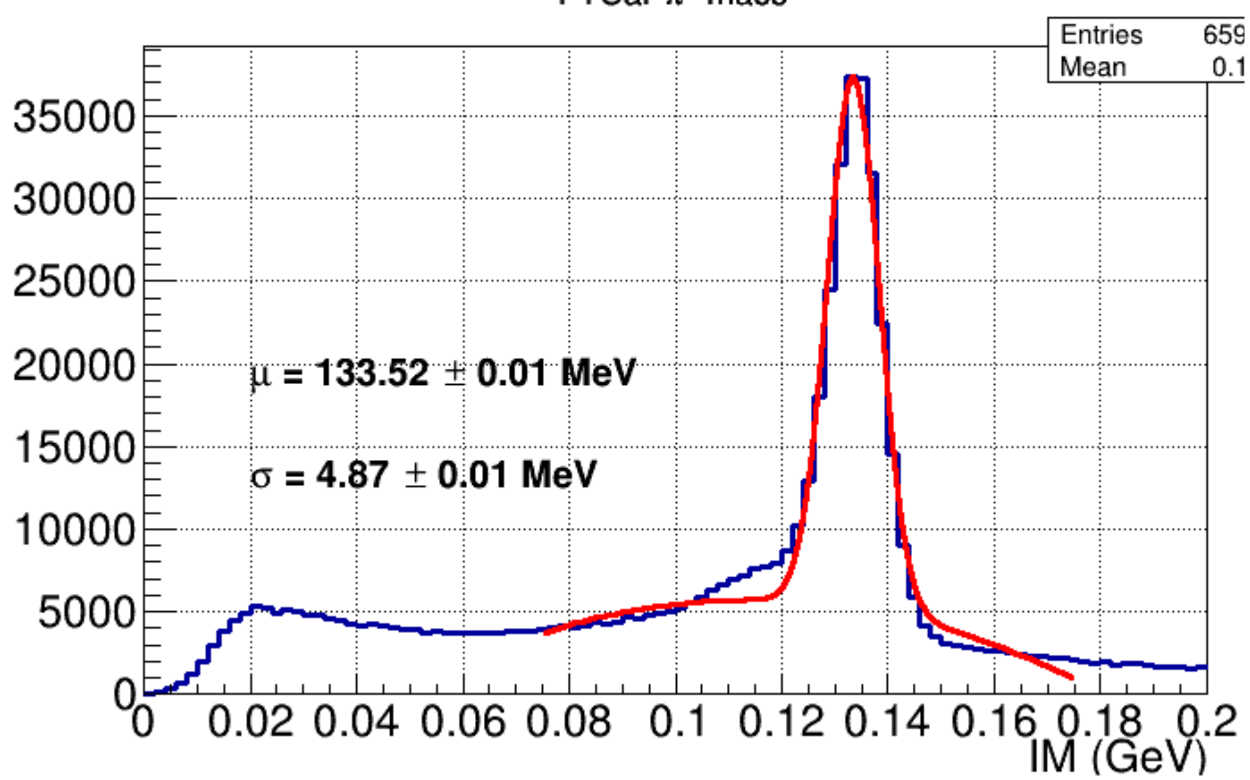
FT-Cal: $PbWO_4$ calorimeter
- electron energy/momentum
- Photon energy (ν=E-E')
- Polarization $\varepsilon^{-1} \approx 1 + \nu^2/2EE'$
- APDs, 332 chi, fADC250



FT performance

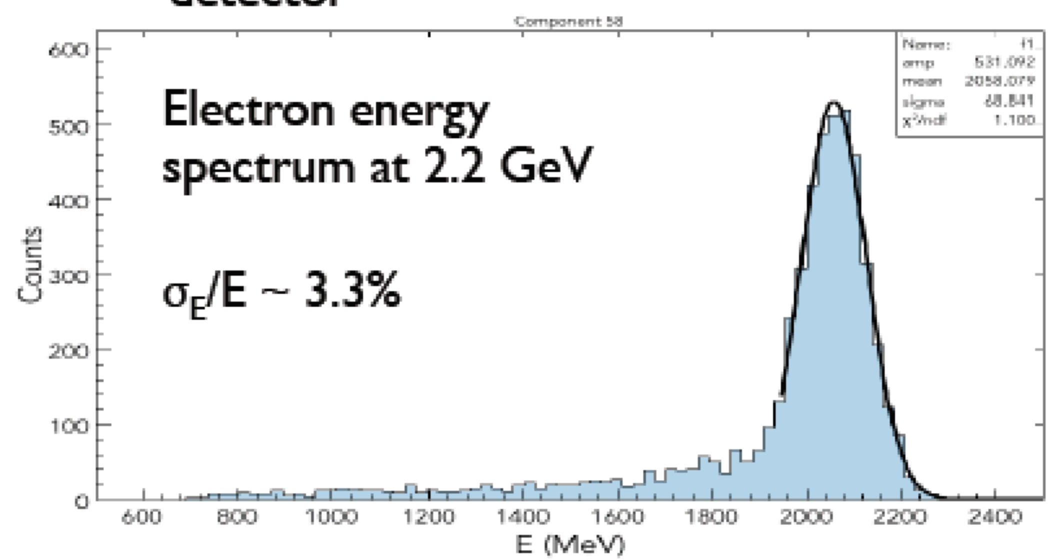


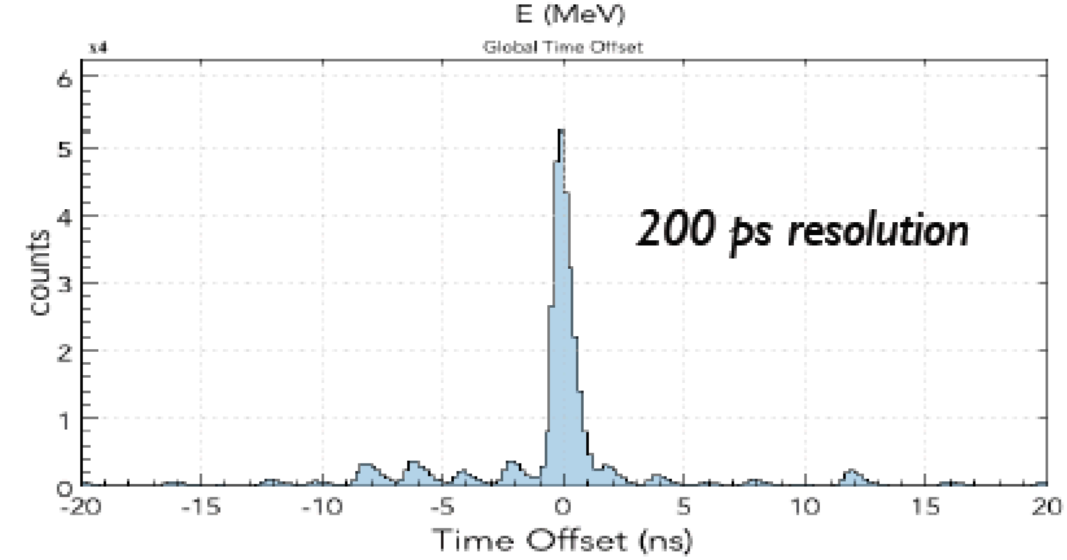
$E_{scattered}$	0.5 - 4.5 GeV
θ	2.5^o - 4.5^o
ϕ	0^o - 360^o
ν	6.5 - 10.5 GeV
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 >$ 0.1 GeV^2)
W	3.6 - 4.5 GeV



Final calorimeter calibration based on real data:

- Energy calibration based on elastic data at 2.2 GeV and 6.4 GeV
- Timing calibration based on coincidence with forward CLAS12 detector

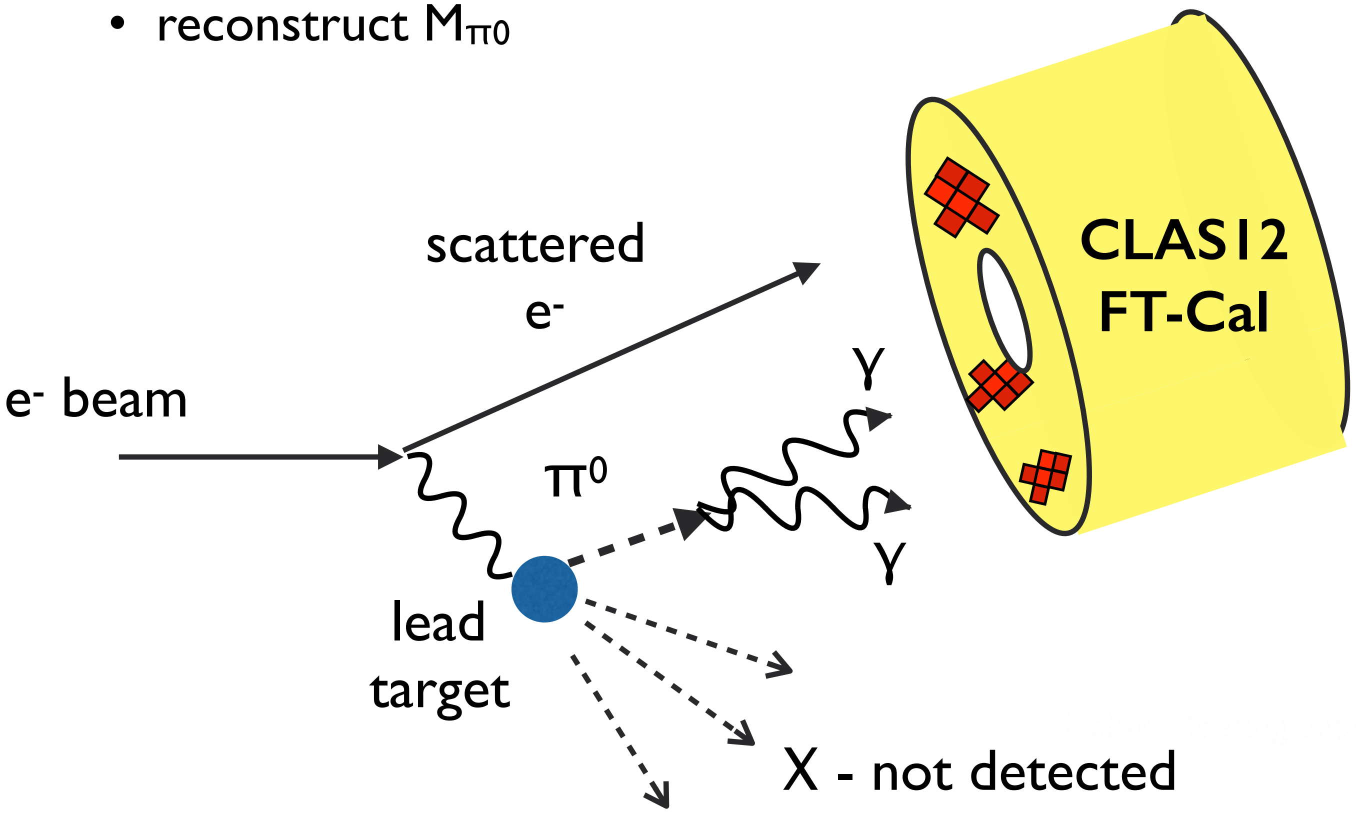




Streaming RO - CLAS12-FT tests

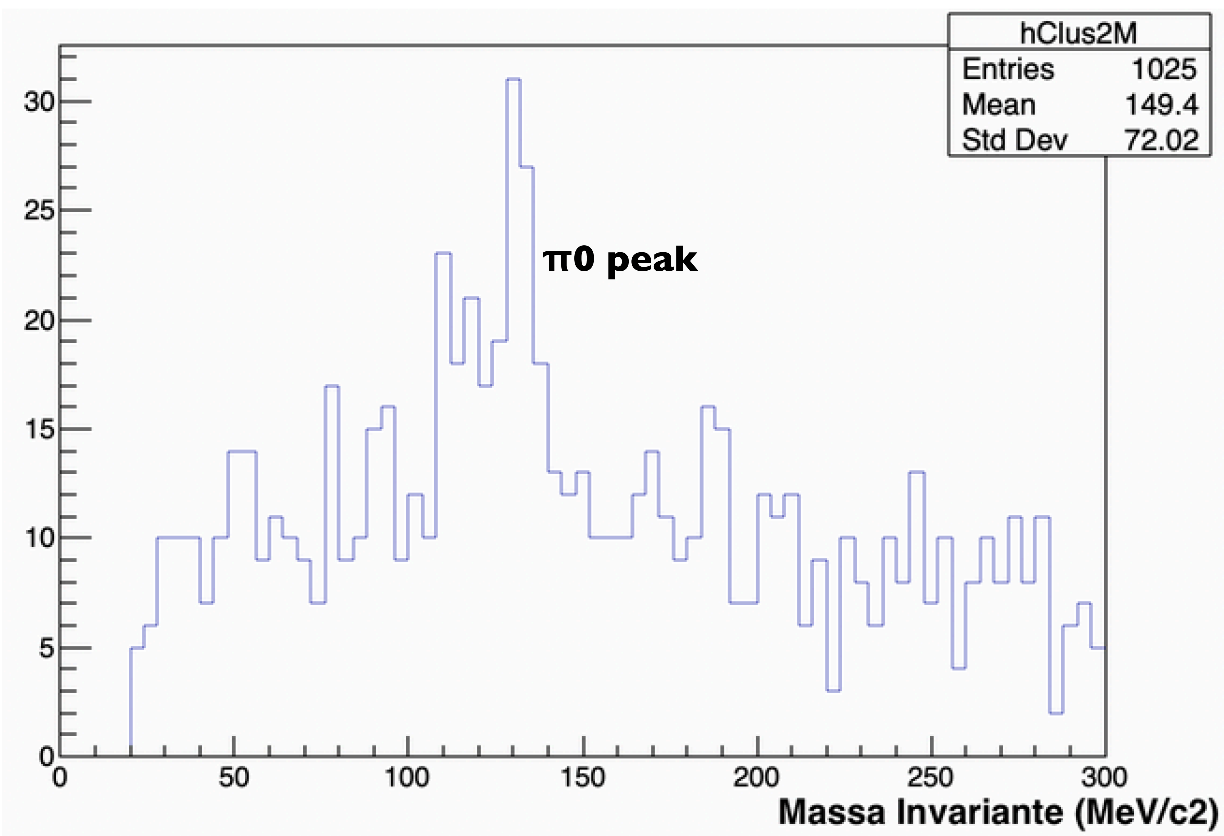
- **SRO DAQ full chain test: FE + RunControl + Streaming ROsw + Rec**
- **On-beam tests**
  - **Run1: 10.4 GeV electron beam on Pb target in Jan/Feb 2020**
  - **Run2: 10.4 GeV electron beam on H2 and D2 targets in Aug/Sept 2020**
- **Hall-B CLAS12 Forward Tagger: Calorimeter + Hodoscope + (Tracker)**

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



Test equipment
- FT-Cal: 332 PbWO crystals (APD)
- 10+12 fADC250 boards + 2 VTPs (in 2 crates/ROCs)
- FT-Hodo: 232 plastic scintillator tiles (SiPM)
- 15 fADC250 boards

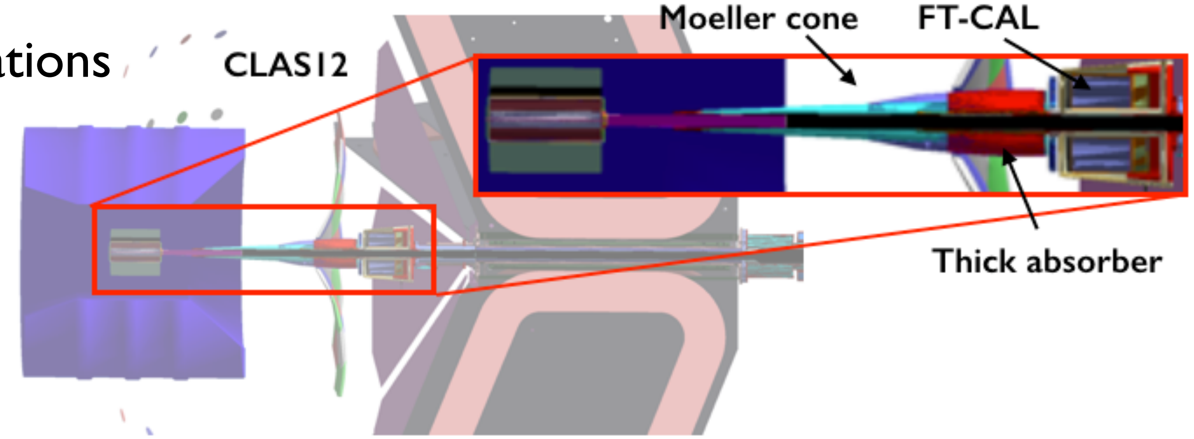
double-clusters (π0) mass obtained from FT-Cal RG-A data fed to TRIDAS



Hall-B Tests

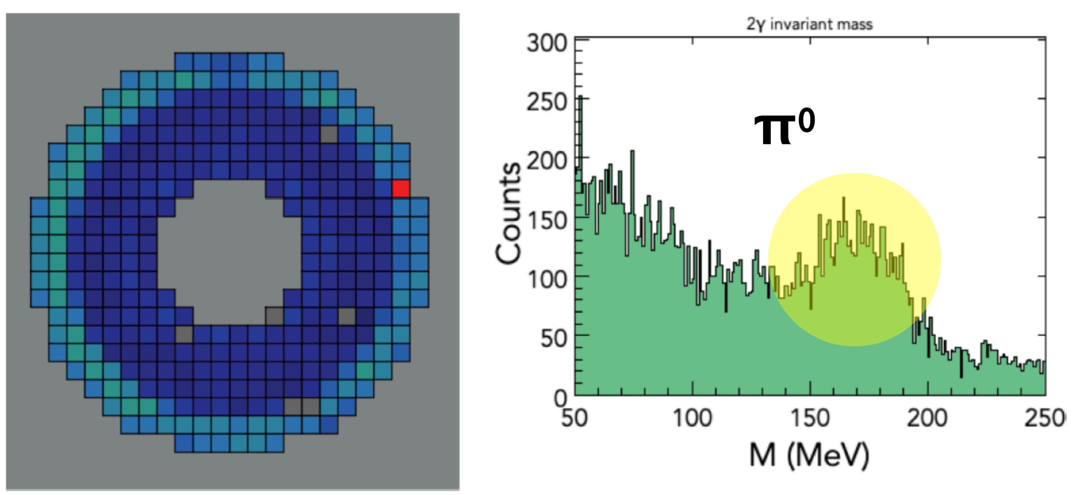
M.Bondí, S.Vallarino

- Full GEANT4 simulations for the different experimental configurations
- Run1: no Moeller cone, nuclear (thin) target
- Run2: Moeller cone, longer target



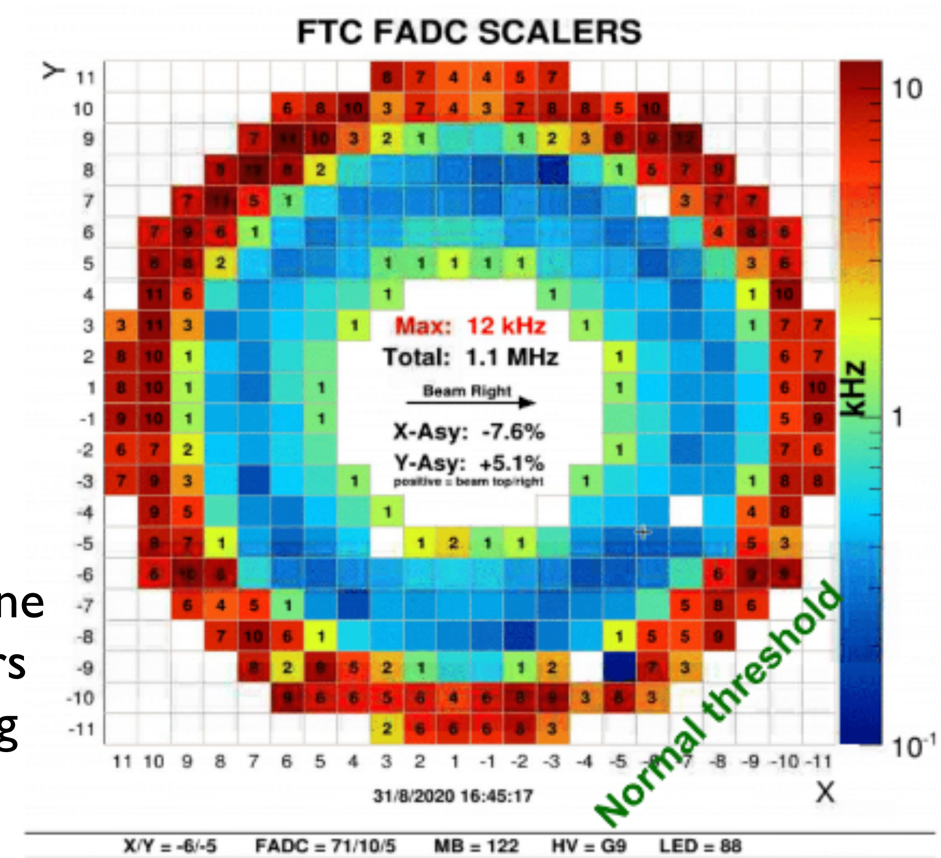
2-gamma events assuming z=-32cm

D2 target run 12509



R.De Vita

- As a reference, data taken both in 'triggered' and SRO mode



- On-line scalers during Run2

SRO mode:

- L1 "minimum-bias": at least one crystal with energy > 2 GeV
- several L2 conditions in "tagging-mode" and "filtering-mode"
  - "standard" clustering algorithm: at least 2 clusters in FT-CAL
  - cosmic tracking
  - AI clustering algorithm: at least two cluster in the FT-CAL

Goal:

- study SRO performance: memory + cpu use, trigger eff., …
- Collect data for physics analysis: pi0 production on target
- Demonstrate t SRO s outperforms vs. a triggered DAQ

Streaming RO - CLAS12-FT tests

Front-End: fADC250 VTP

SRO SW TRIDAS

Online REC JANA2

RunControl CODA

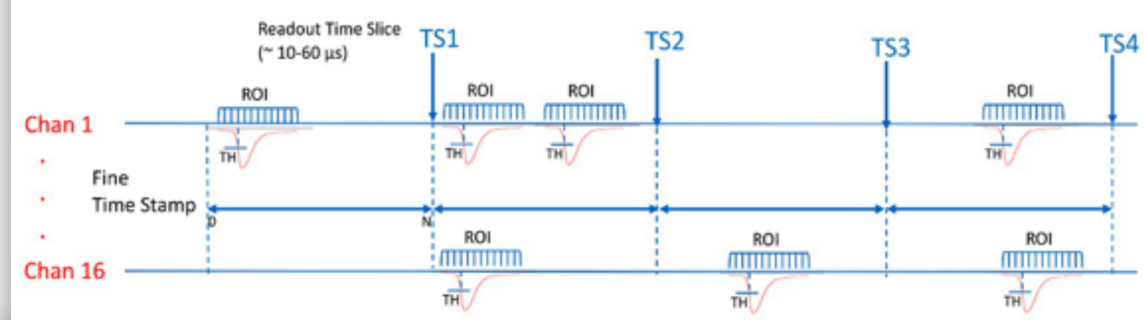
FrontEnd

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

JLAB FADC in "Streaming Mode"

Streaming data can be thought of as Triggered mode where the trigger is a fixed pulser and you keep all the data for a single channel generated from the last pulse.

A 250 MHz FADC generates a 12 bit sample every 4ns. That's 3 Gb/s for one channel. A 16 channel module is 48 Gb/s. That is over twice the available VXS bandwidth. But we don't need ALL the data.



Within the FPGA we keep only the data around a Region of Interest (ROI) from each channel, along with a fine time stamp in each time slice window.

Depending on hit rates and available bandwidth , We can keep the individual samples or just compute a sum.

Jefferson Lab

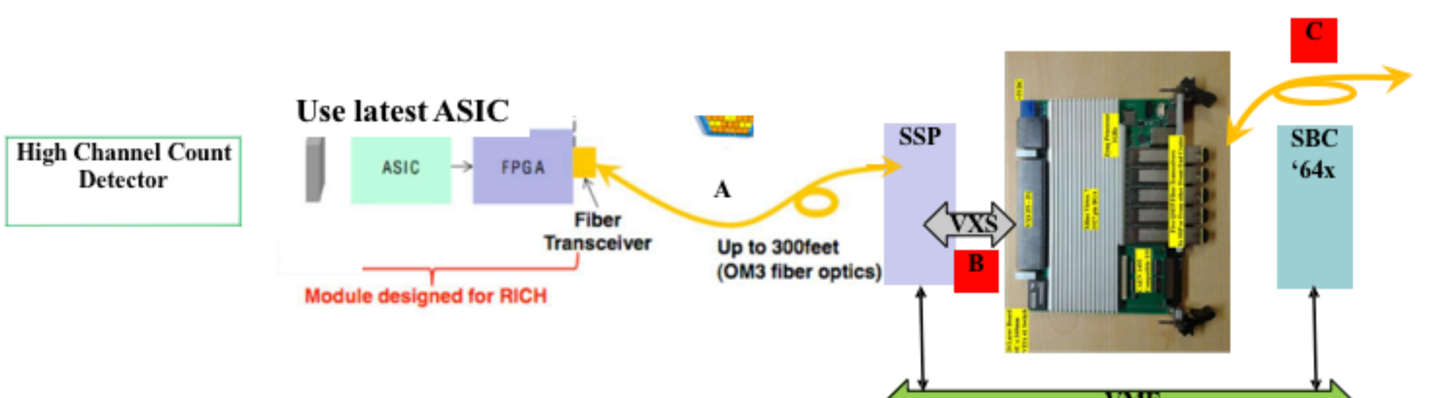
Streaming DAQ Through the VXS Trigger Processor

Bypassing '64x Example

- A 1 SSP manages 32 LC fiber @2.5Gbps
- B 16 SSP/crate @20Gbps to VTP [4 lanes/@5Gbps]
- Streaming bandwidth 320Gpbs to VTP
- 40Gbe from VTP "CODA ROC"

C VTP can perform significant data processing 192 channels for FPGA front end so, Single VXS crate could stream

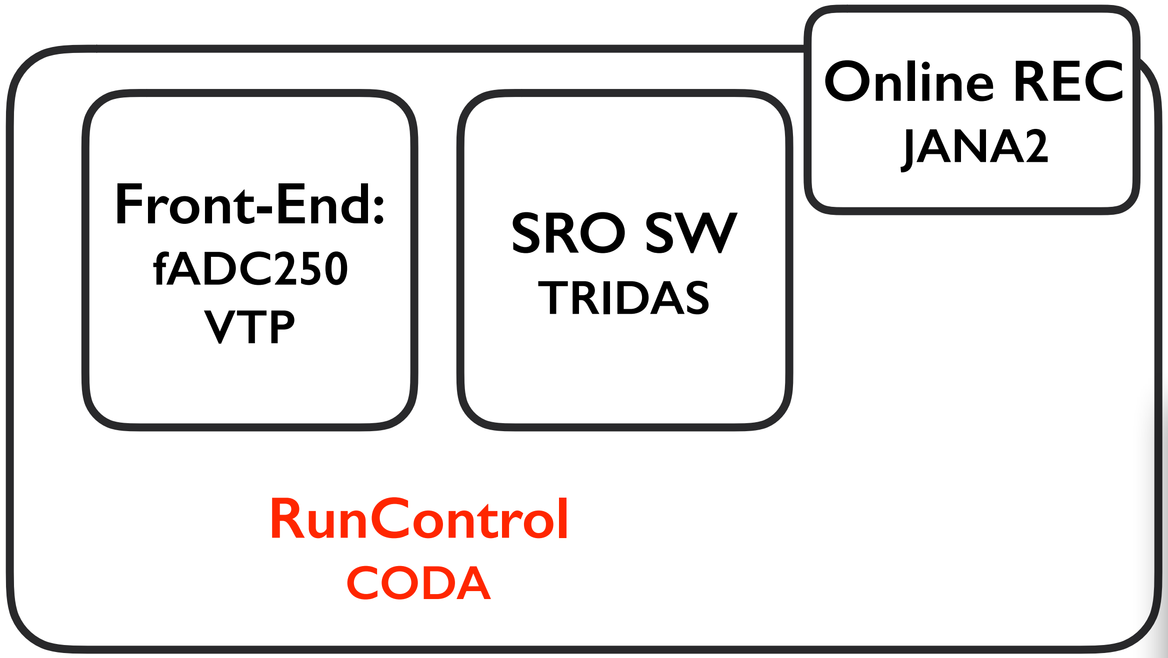
$192_{FPGA} * 32_{Links} * 16_{SSP} == 98304$ Chs



During tests:

- Peak data rates ~150MBytes total
- Current VTP limit ~2GByte/sec
- Max: 10GBytes/sec

Streaming RO - CLAS12-FT tests



CODA

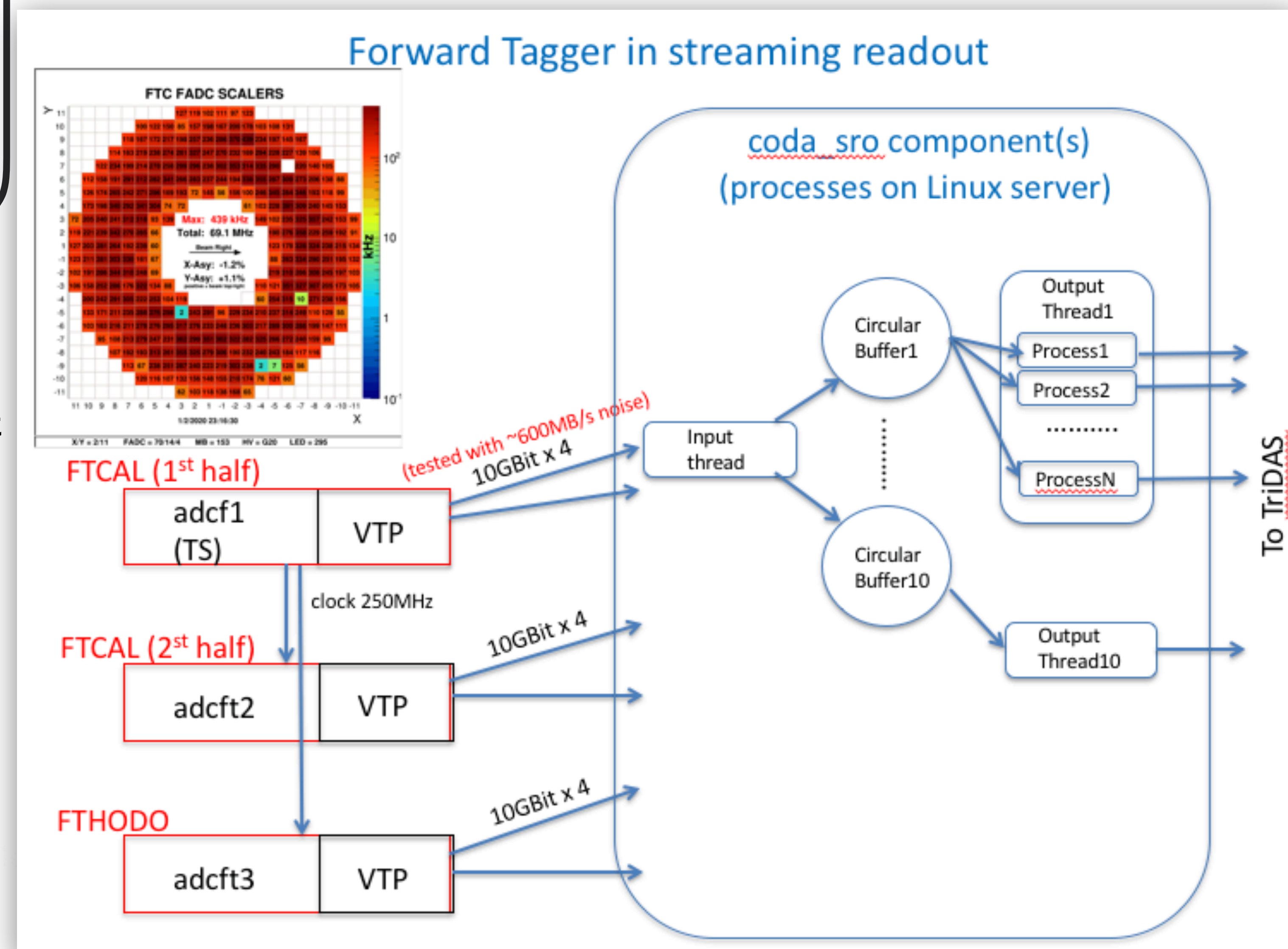
S.Boyarinov, B.Raydo, G.Heyes

Cebaf Online Data Acquisition (CODA)

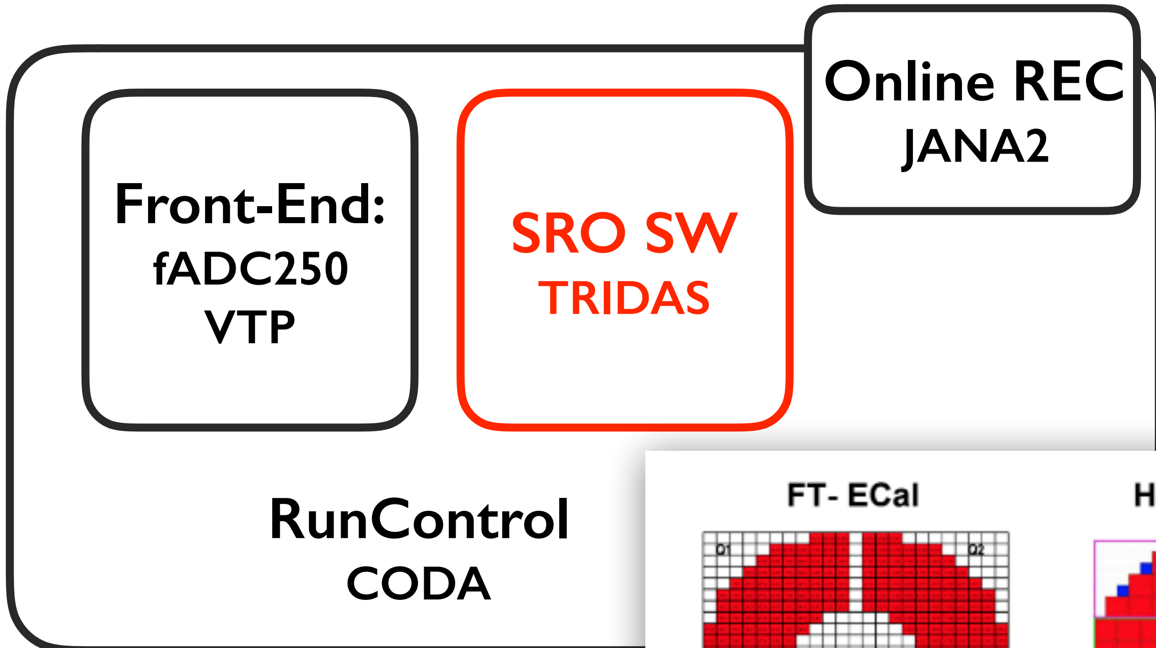
- Designed for trigger-based readout systems
- The Event Builder (EV) collects data from 100+ Readout Controllers (ROCs) and VXS Trigger Boards (VTPs)
- The Trigger Supervisor (TS) synchronies components using clock, sync, trigger and busy signals.

CODA adapted to SRO mode:

- EB replaced with new SRO component and back-end software capable of gluing ROC information based on timestamp instead of event number.
- ROCs not send data on VME bus (only initial configuration)
- Readout performed by VTP boards over serial lines
- 20GBit/s per crate (up to 40GBit/s if needed.)



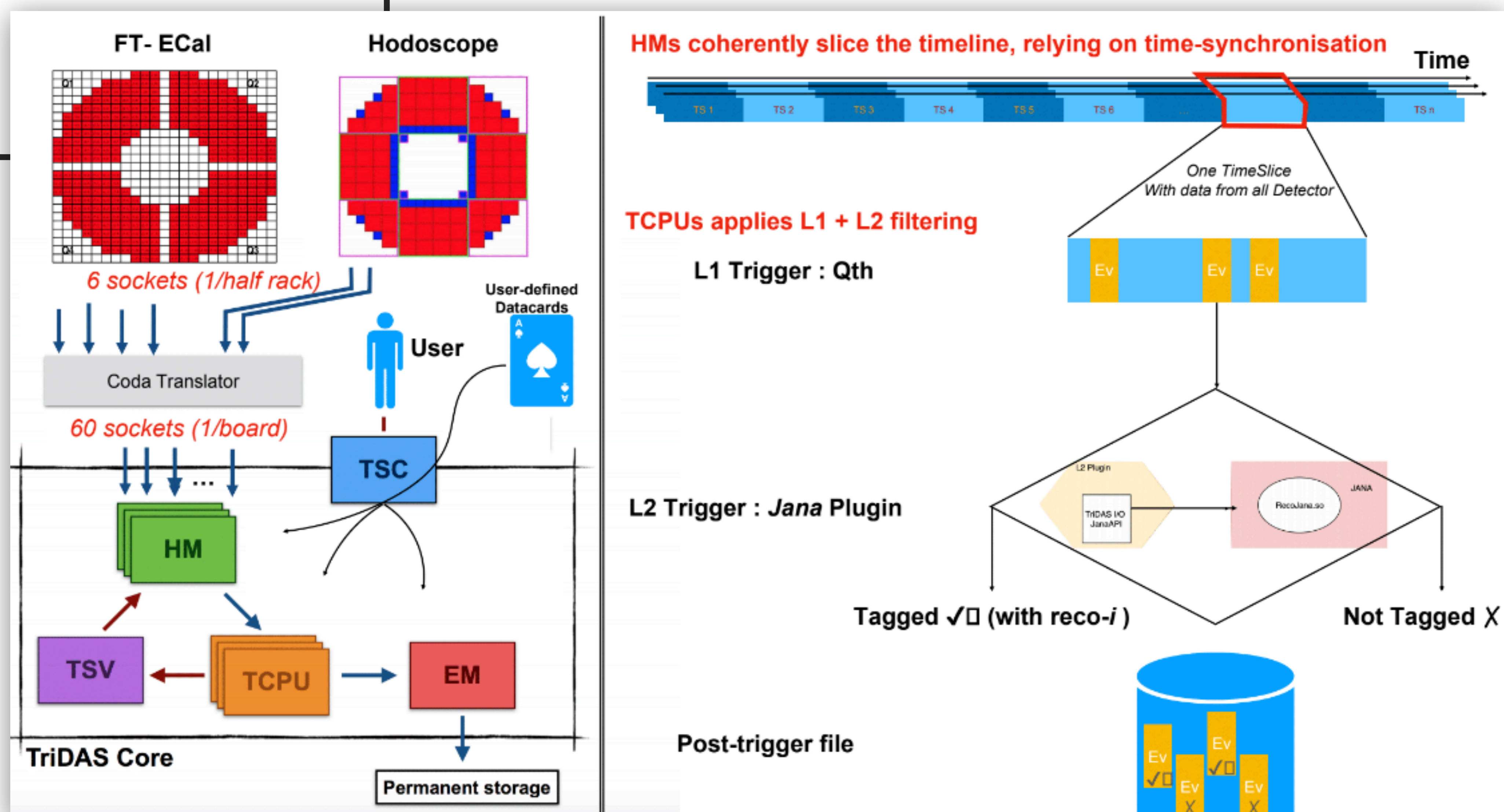
Streaming RO - CLAS12-FT tests



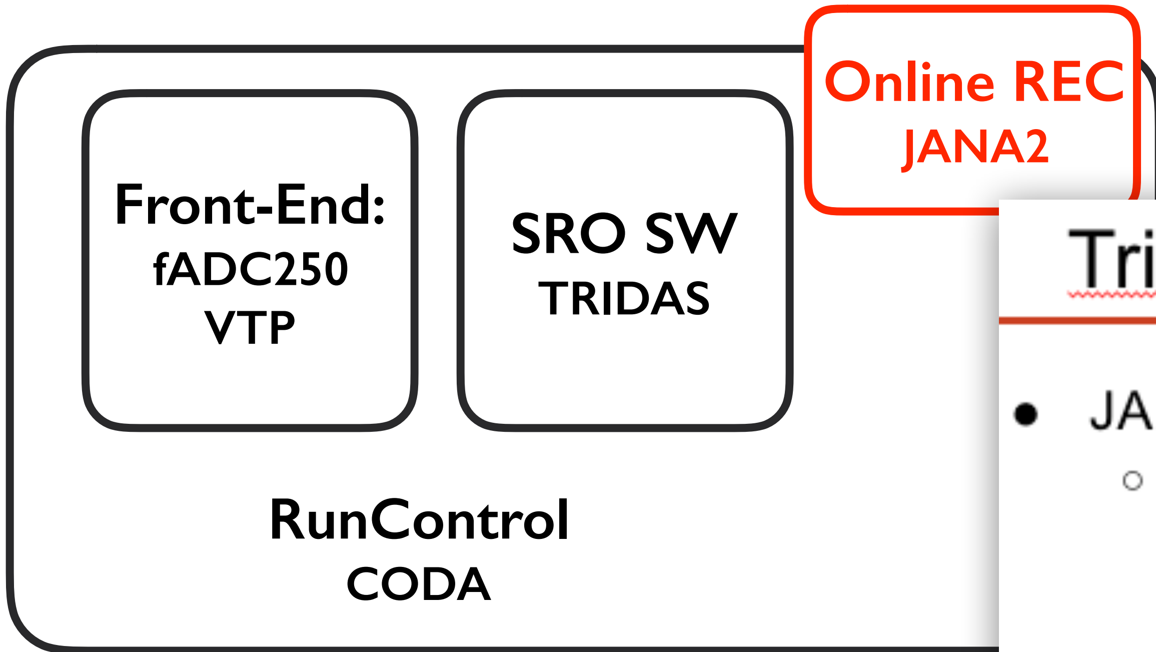
TRIDAS

T.Chiarusi, C.Pellegrino

- TriDAS: backend SRO sw framework
- developed for KM3_NET
- installed on Hall-B cluster
- Tested on multiple CPUs
- FT-Cal rate: 20-30 MHz
- Few hot-channels > 1 MHz
- Data rate ~50MB/s
- Tests performed with different parameters (thresholds, HM, TCPUs)
- Profiling and performance

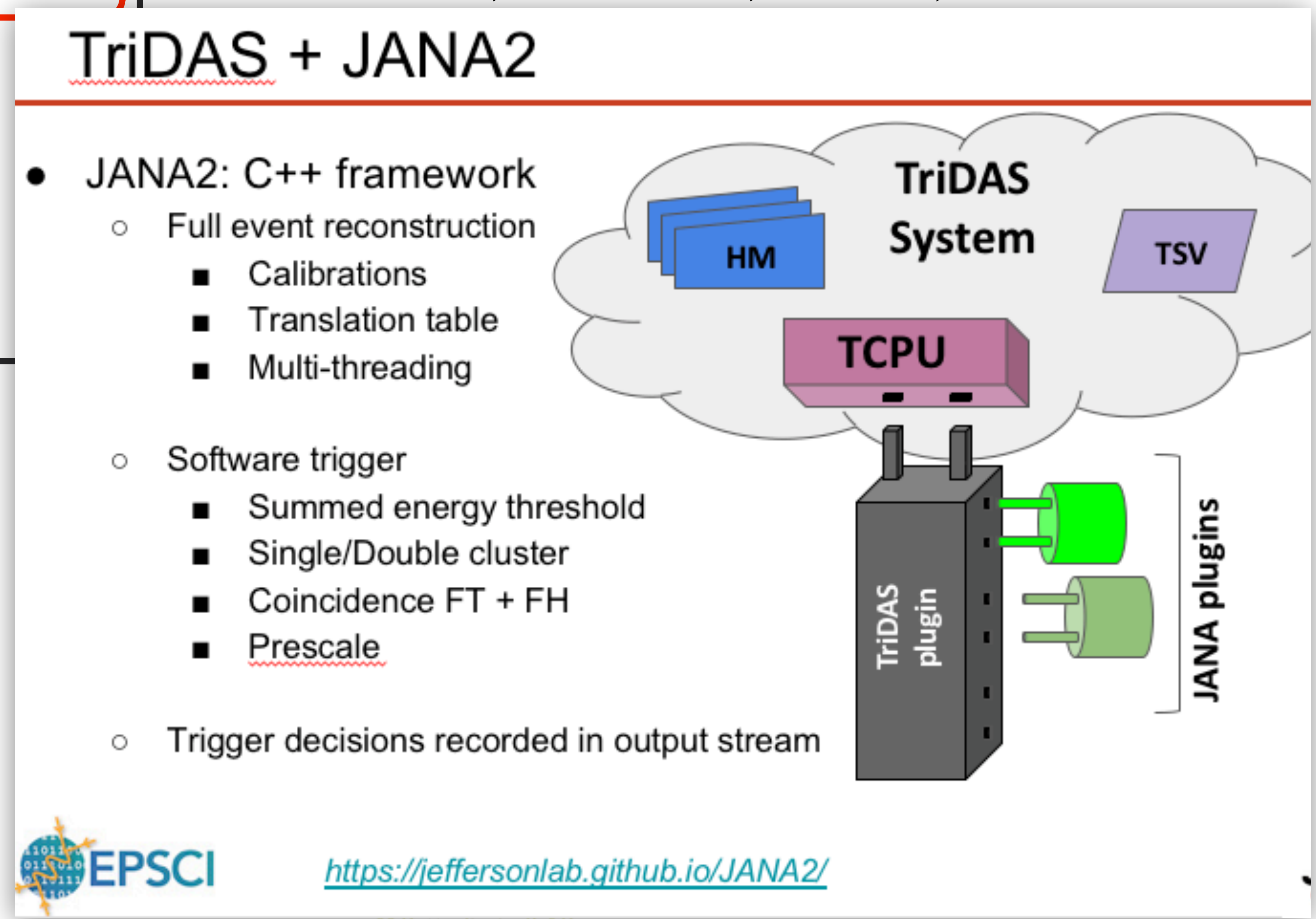


Streaming RO - CLAS12-FT tests



JANA2 + REC

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



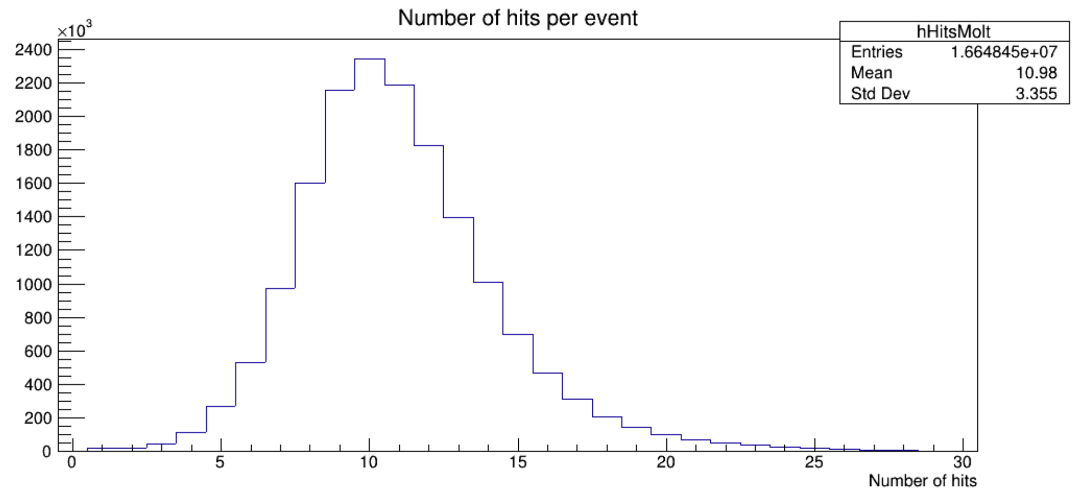
FE setup:
- FT-Cal only
- TET (on fADC250)=15/50,
- L1 threshold: 2000 (MeV)
- L1 time window: 400 ns

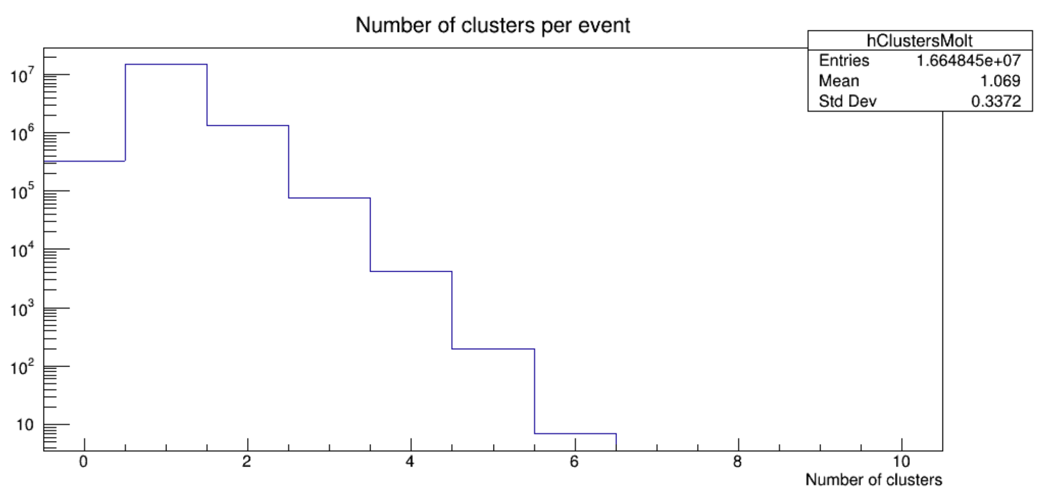
JANA2:
- L1 "minimum-bias": at least one crystal with energy > 2 GeV
- scaler (all L1 to diskS
- L2 plugins (*tagging* and *filetring*)
  - "standard" FT-CAL clustering ($N_{cluster} \geq 1, 2, 3$)
  - cosmic tracking
  - AI clustering algorithm: at least two cluster in the FT-CAL

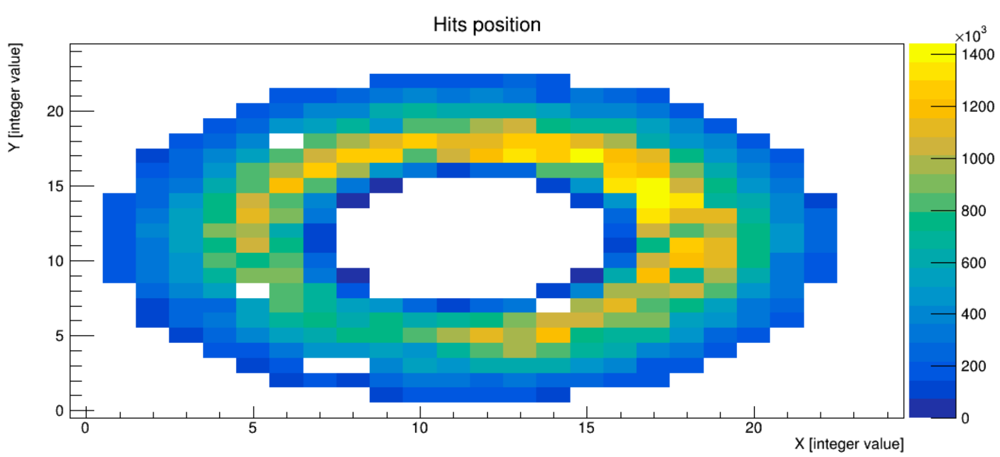
JANA Event Source plugin
- Read TriDAS file.pt files for offline analysis
- Offline algorithm development immediately available for use in Software Trigger
- Strong integration between online and offline

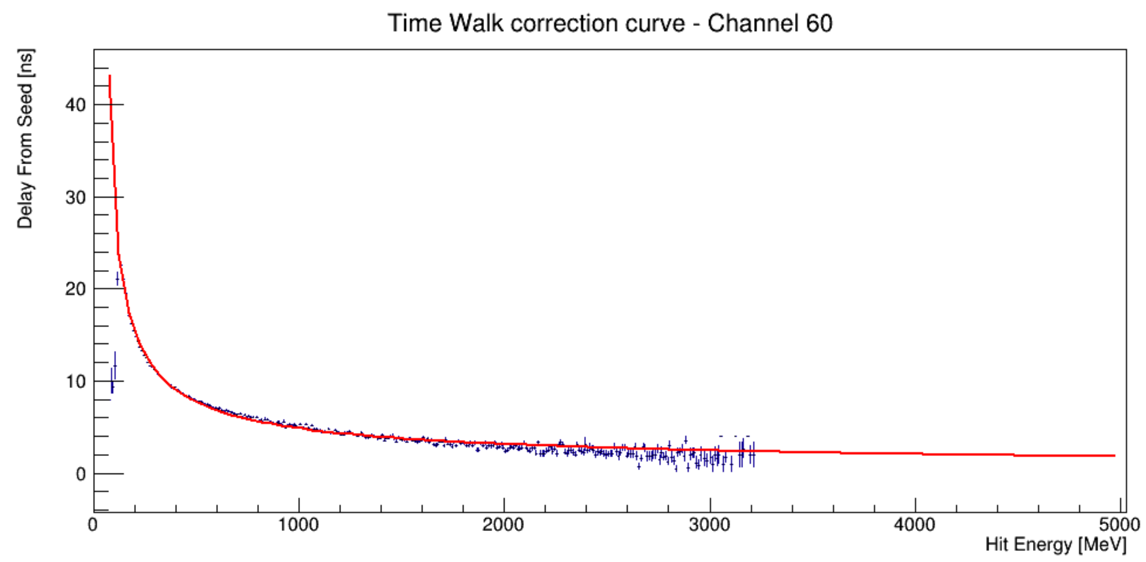
RunI Data analysis

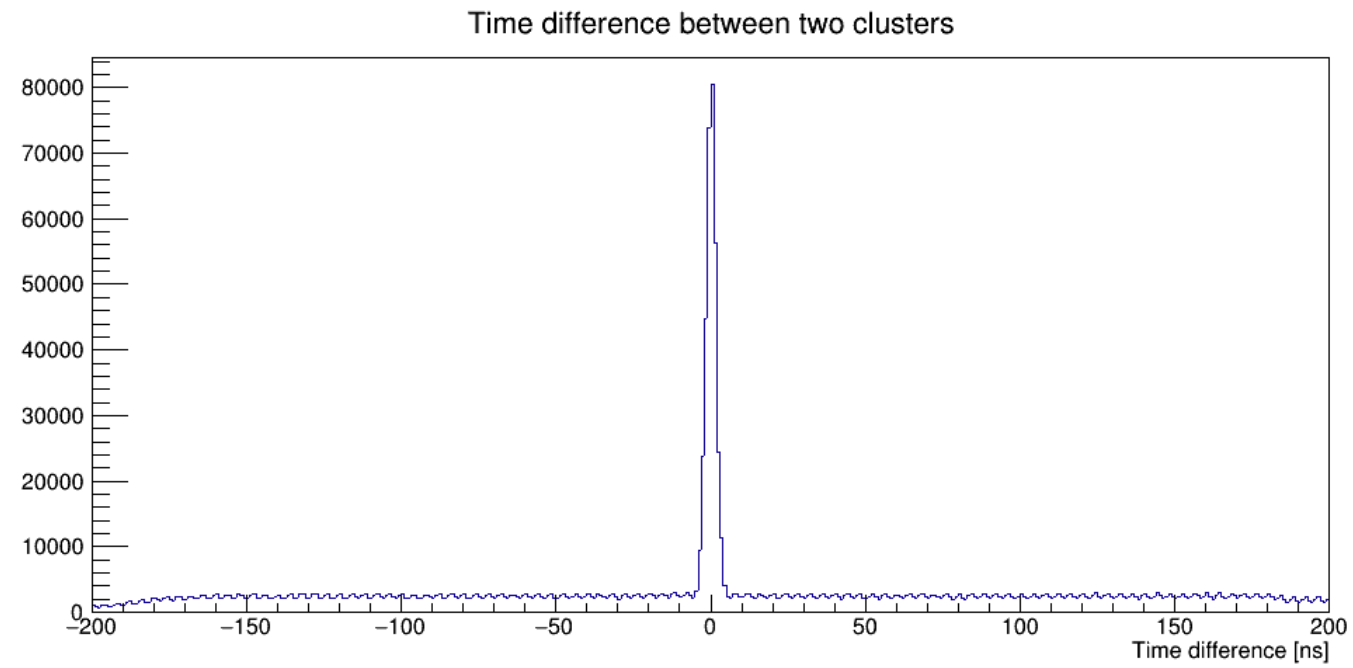
S.Vallarino, A.Celentano









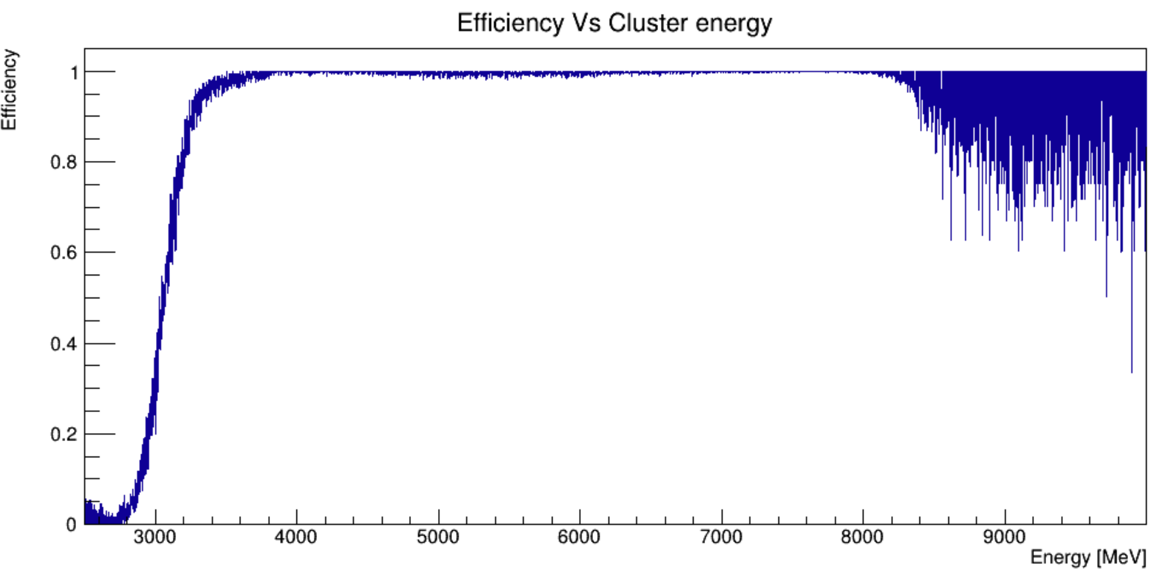


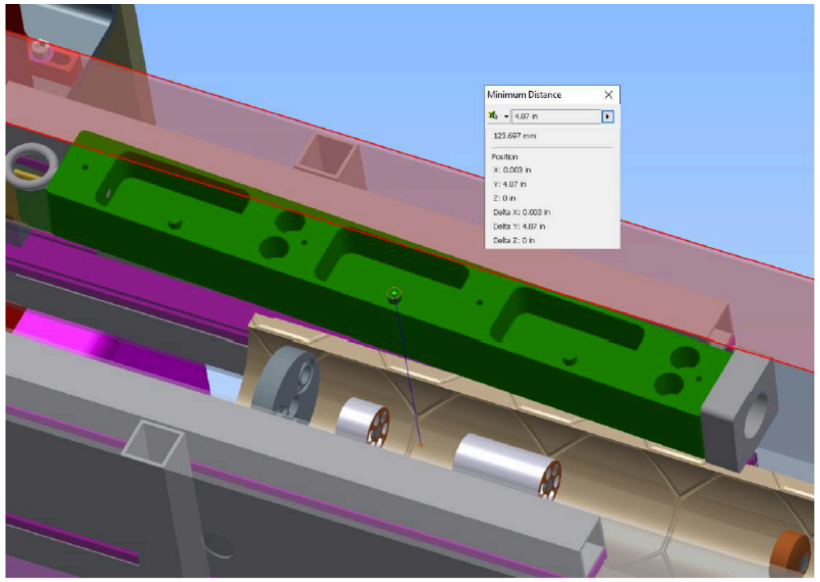
- **Time-walk (time) and calibration (energy)**
- **SRO data behaves as expected (N_{hits}, $N_{clusters}$, $XY_{cluster}$, ΔT)**

Run1 Data analysis

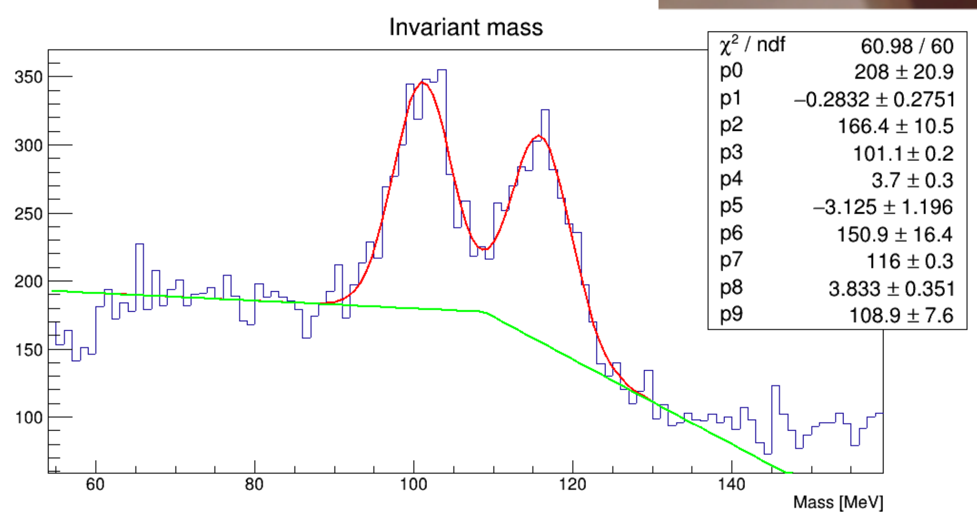
S.Vallarino, A.Celentano

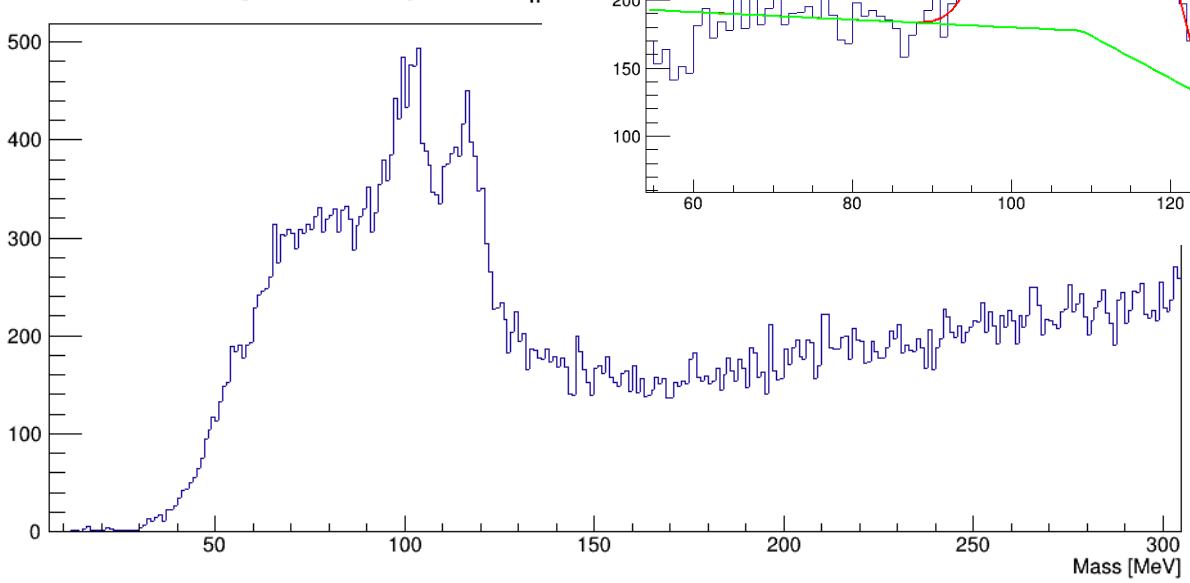
- Efficiency: comparison between online/offlin clustering

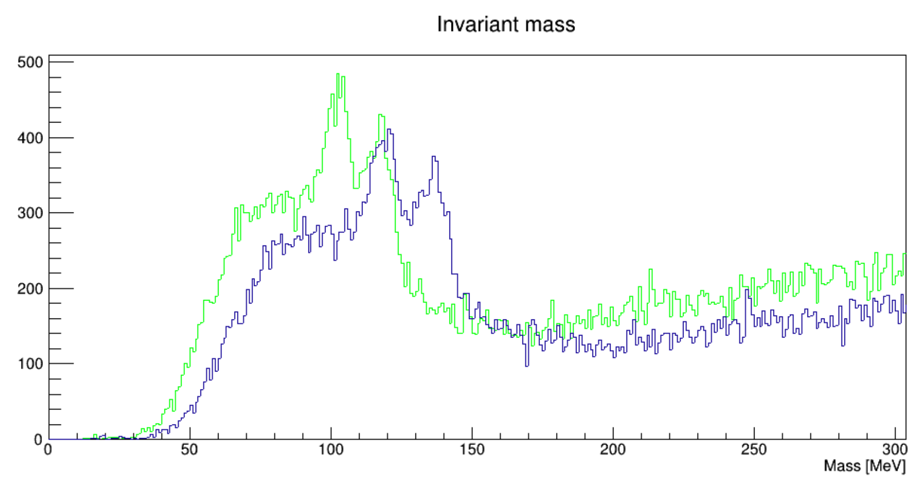




- Two pi0 peaks corresponding to two vertices (and a wrong assumption on the vortex position)







- Measured (expected) pi0 yield

  Peak1 = 1600+-40 (2700+-500)

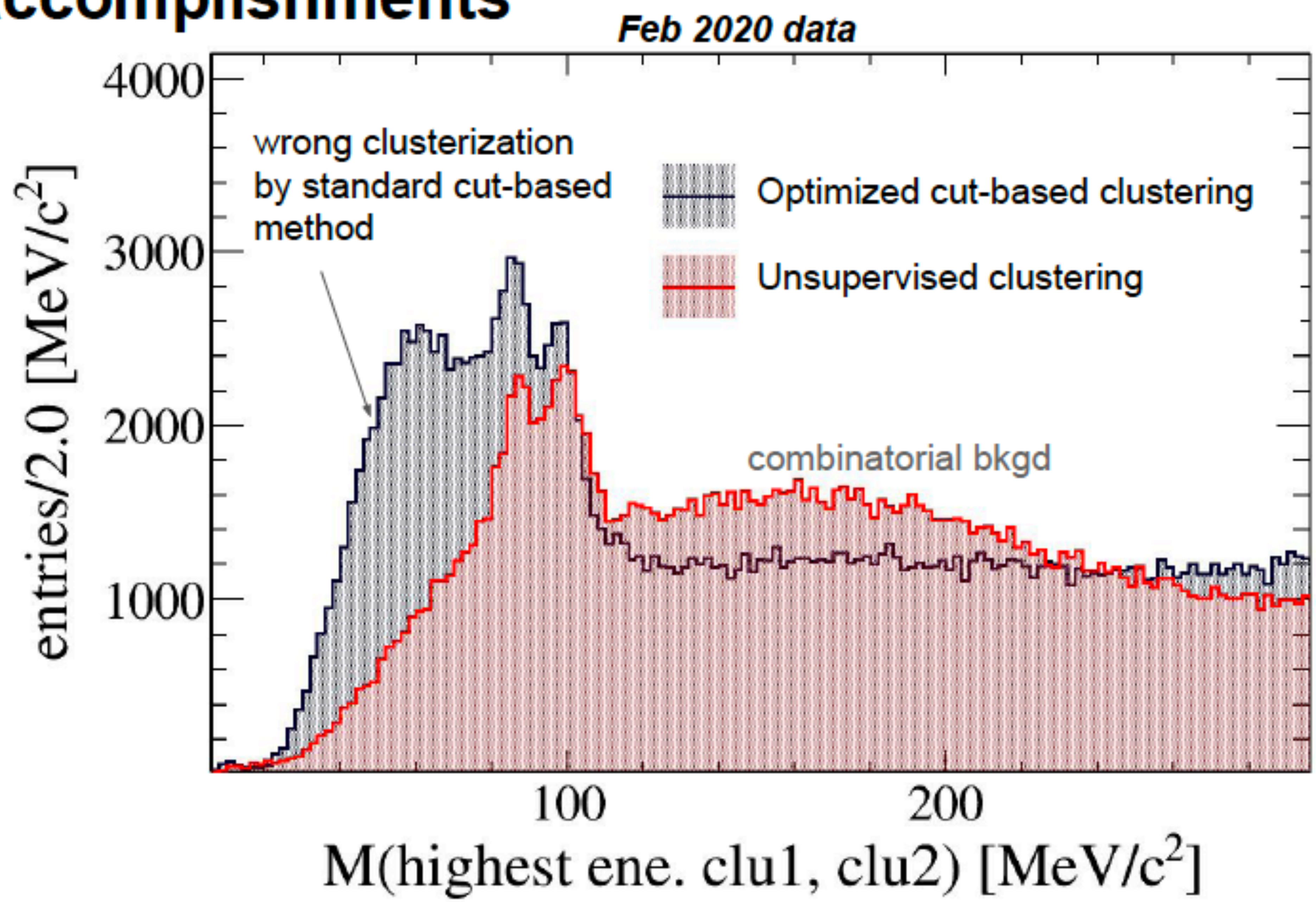
  Peak 2 = 1500+-38 (2600 +-450)

Run2 data analysis in progress

Run1 Data analysis (AI-supported)

C.Fanelli

Accomplishments



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

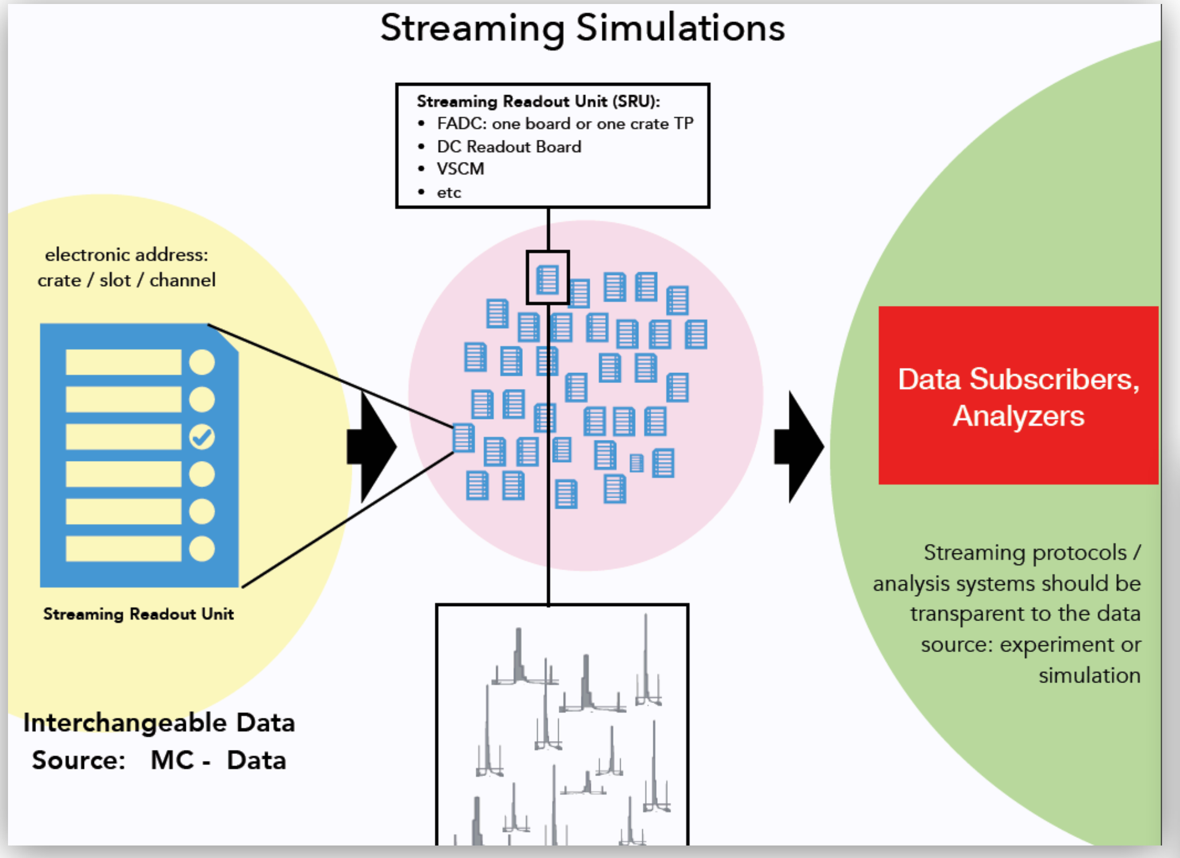
- Implementation of AI supported L2 reconstruction algorithms for SRO: offline and online tests accomplished
- Unsupervised (no cuts required) hierarchical clustering generally robust against variations in experimental conditions
- AI tolerates larger hits multiplicities

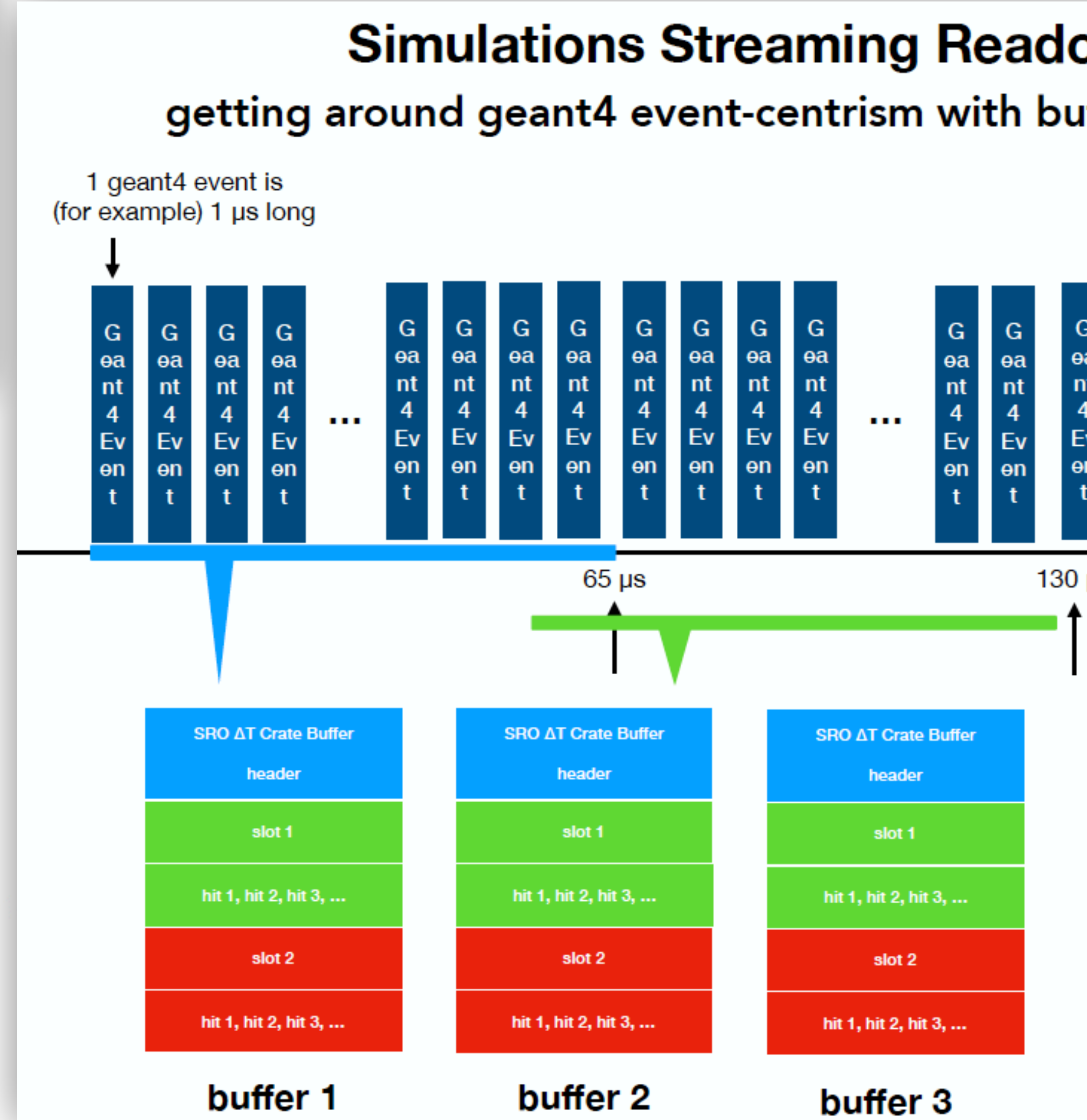
- Run1: off-line only
- Run2: real time!

Data analysis in progress

Streaming RO - GEANT4 MC

M.Ungaro





- Hits from a geant4 event can end on different buffers (propagation time, etc)
- Pile-ups are dealt naturally in this scenario

Summary

- Streaming Readout on-beam tests performed using the CLAS12-FT-Cal at JLab
- First step towards a full implementation for CLAS12 (Moeller, SOLID, EIC, …)
- The full chain (FE + SRO sw + ON-LINE REC) tested with existing hw
- Data taken in full streaming mode, analysis in progress (traditional and AI-supported)
- Parallel activity in a more controlled situation (Hall-D PS test e^-/e^+beam)
- Implementing the FT model in a SRO G4 MC to check the full chain
- Current: include it into JLab ERSAP framework (micro-services architecture)
- SRO prototype to be tested in view of a massive implementation of full CLAS12 SRO
- Built a real SRO prototype and a work team!

Many thanks to the whole JLab SRO team:
F.Ameli (INFN), MB (JLab/INFN), V.Berdnikov (CUA), S.Boyarinov (JLab) M.Bondí (INFN), N.Brei (JLab), A.Celentano (INFN), T.Chiarusi (INFN), C.Cuevas(JLab), R. De Vita (INFN), C.Fanelli (MIT), G.Heyes (JLab), T.Horn (CUA), V.Gyurjyan(JLab), D.Lawrence (JLab), L.Marsicano (INFN), P.Musico (INFN), C.Pellegrino (INFN), B.Raydo (JLab), M.Ungaro (JLab), S.Vallarino (INFN)