Event Reconstruction Goals and Challenges at Jefferson Lab

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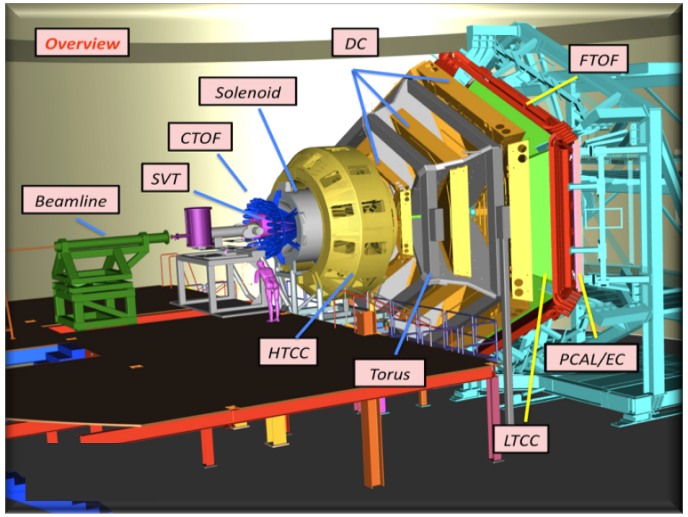
Event Reconstruction at JLab Common Goals and Challenges

- Overall goal to **publish quality physics results in a timely fashion** (many approved experiments targeting different physics, e.g. GPDs, spectroscopy, exotic hadrons searches, etc…)
- **Complex detector systems** with multiple tracking devices (CLAS12 in Hall B, GlueX in Hall D)
  - **Commonalities** in tracking complexities and background handling in reconstruction
  - Talk will **focus on CLAS12**

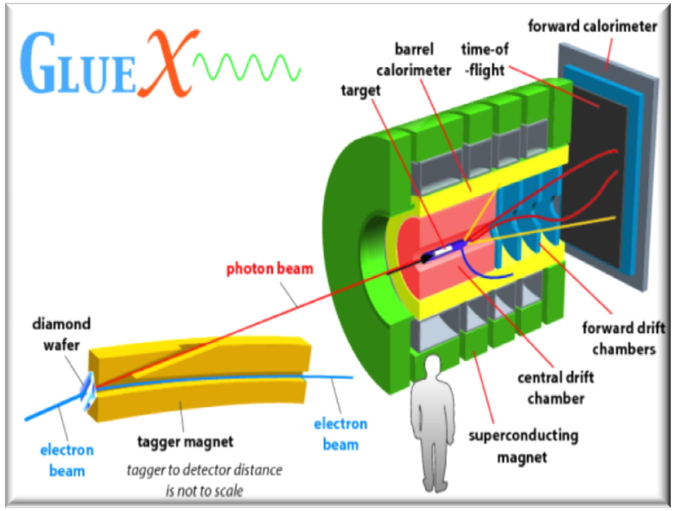
Goals and Challenges

- Data processing to keep up with **data rates**
  - Data volumes, data formats
  - Use of farm resources & workflow
  - Data distribution and use of off-site resources
- Event reconstruction challenges
  - **Large backgrounds** when running at ~design luminosity
  - **Tracking efficiency & accuracy** to meet physics specs
  - Accurate model of inefficiencies (malfunctions, dead times, intrinsic detector component inefficiencies)
  - **Realistic simulations** (detector responses & event generators)
  - **Reconstruction speed** (most time spent swimming tracks through torus magnetic field in forward detector)
  - **Alignment** (CLAS12 2-system detector: central & forward)
  - Magnetic **field mapping** (CLAS12 torus & solenoid magnets)
  - **Calibrations**
  - **Database management and tools** appropriate for fairly rapidly changing conditions (added/removed detector components for various run groups)

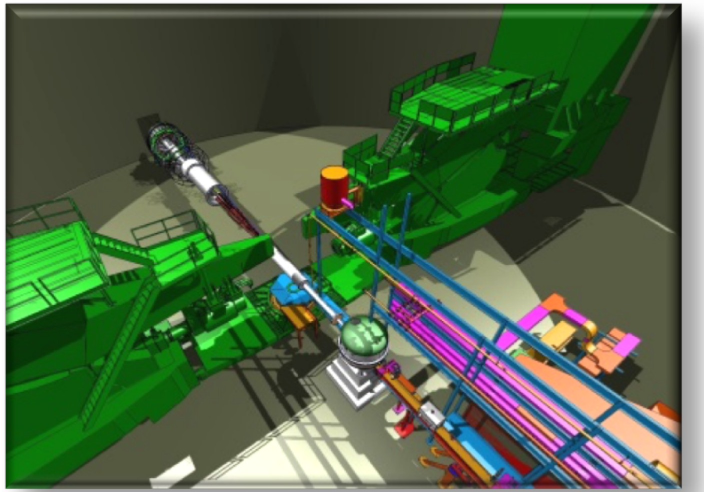
Experimental Halls at Jefferson Lab



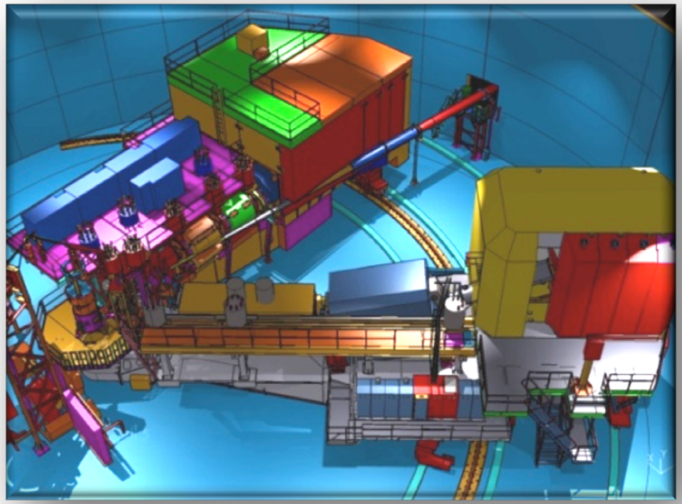
Hall B – understanding of the "mechanics" underlying nucleon structure via Generalized Parton Distributions and Transverse Momentum-dependent Distributions



Hall D – exploring origin of confinement by studying exotic mesons



Hall A –
form factors, future new experiments (e.g., SoLID and MOLLER)



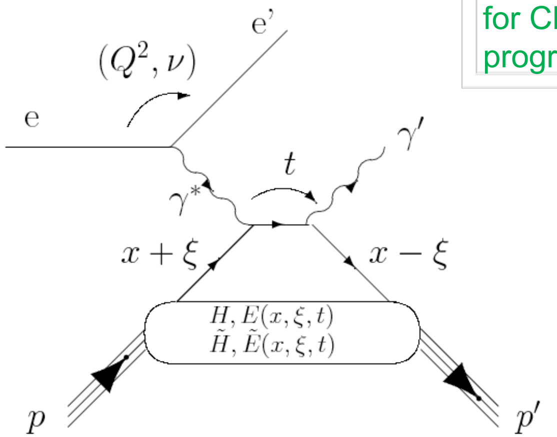
Hall C – precision determination of valence quark properties in nucleons /nuclei

Jefferson Lab

Hall B – CLAS12: toward High Impact science

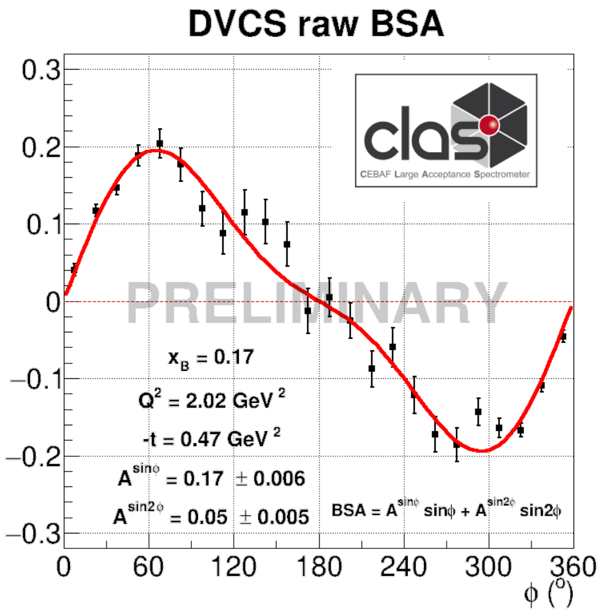
Deeply **V**irtual **C**ompton **S**cattering ep → e' p' γ

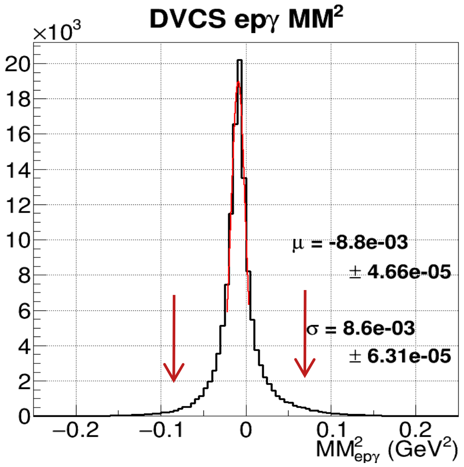
Accessing Generalized Parton Distributions



Flagship experiment for CLAS12 physics program

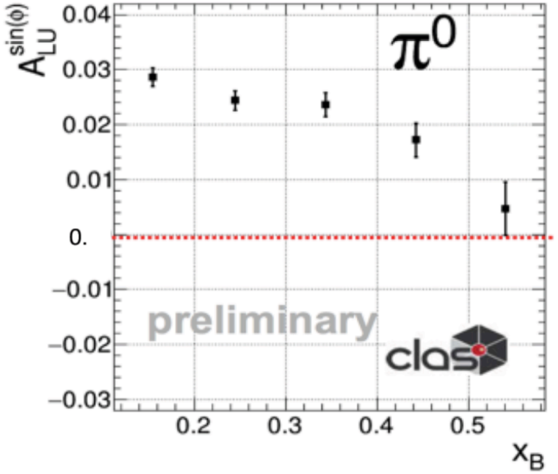
Understanding nucleon and hadron structure via electro-production of inclusive, semi-inclusive and exclusive final states



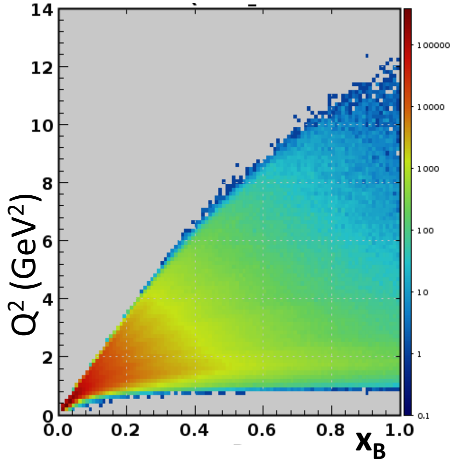


~ 10% of data collected from 11 GeV run (Spring 2018)

Semi-**I**nclusive **D**eeping **I**nelastic **S**cattering ep → e' h, (h= π)



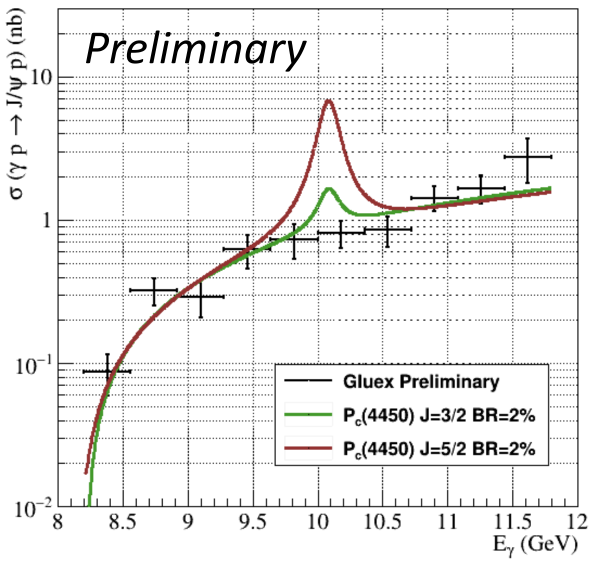
Kinematic reach at 10.6 GeV



electron kinematics at 10.6GeV beam energy, covering the range 1.2 ≤ Q^2 ≤ 13 GeV^2 for elastic ep kinematics at x_B = 1

Hall D: analysis as of Fall 2018

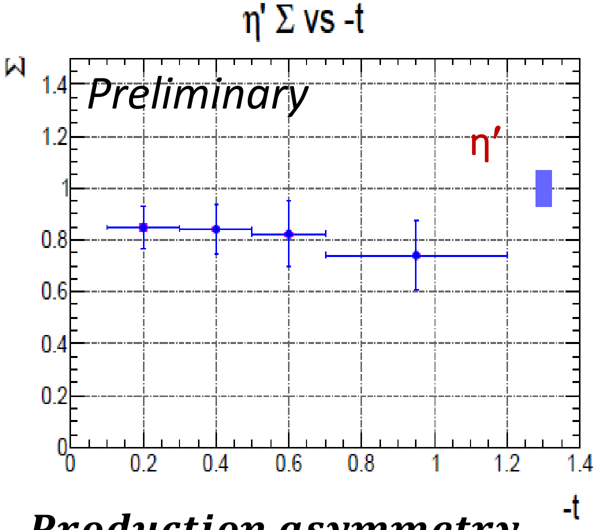
J/ψ production at threshold



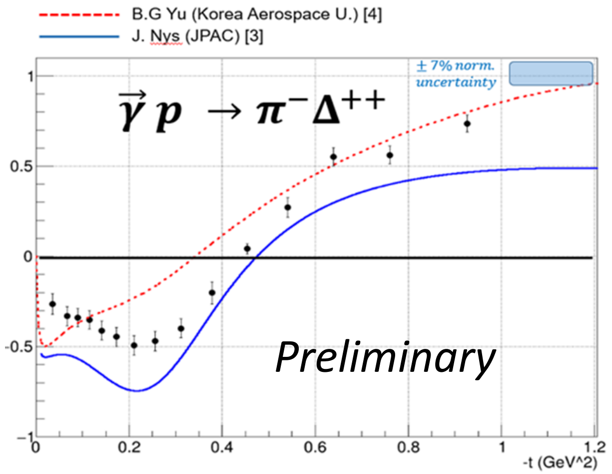
J/ψ cross section at threshold and limit on charm pentaquark photoproduction
(manuscript in preparation)

- GlueX-I is complete
- 25% of data analyzed, 3 papers in preparation
- Getting ready for Primex-η and GlueX-II (with **DIRC**)

Production Asymmetries

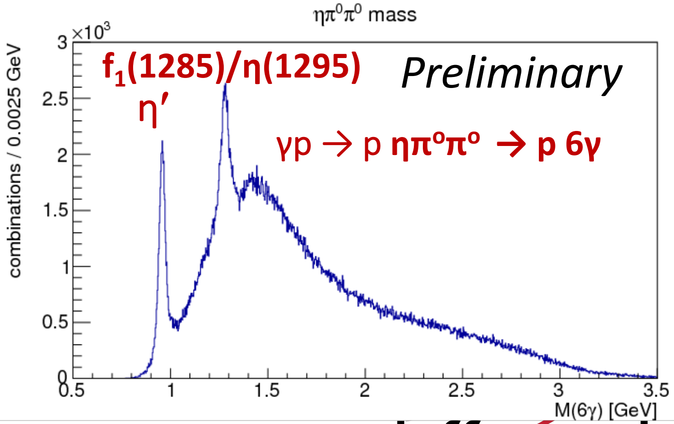


Production asymmetry of the reaction γp → p η′
Preparing for internal review



Production asymmetry of the reaction γp → π^- Δ^{++}
Preparing for internal review

Exploring the origin of quark-gluon confinement by studying meson photo-production and searching for exotics



Jefferson Lab

Forward Detector (FD)

- TORUS magnet (6 coils)
- HT Cherenkov Counter
- Drift Chamber system
- LT Cherenkov Counter
- Forward ToF system
- Pre-shower Calorimeter
- E.M. Calorimeter

Central Detector (CD)

- SOLENOID magnet
- Silicon Vertex Tracker
- Central ToF system

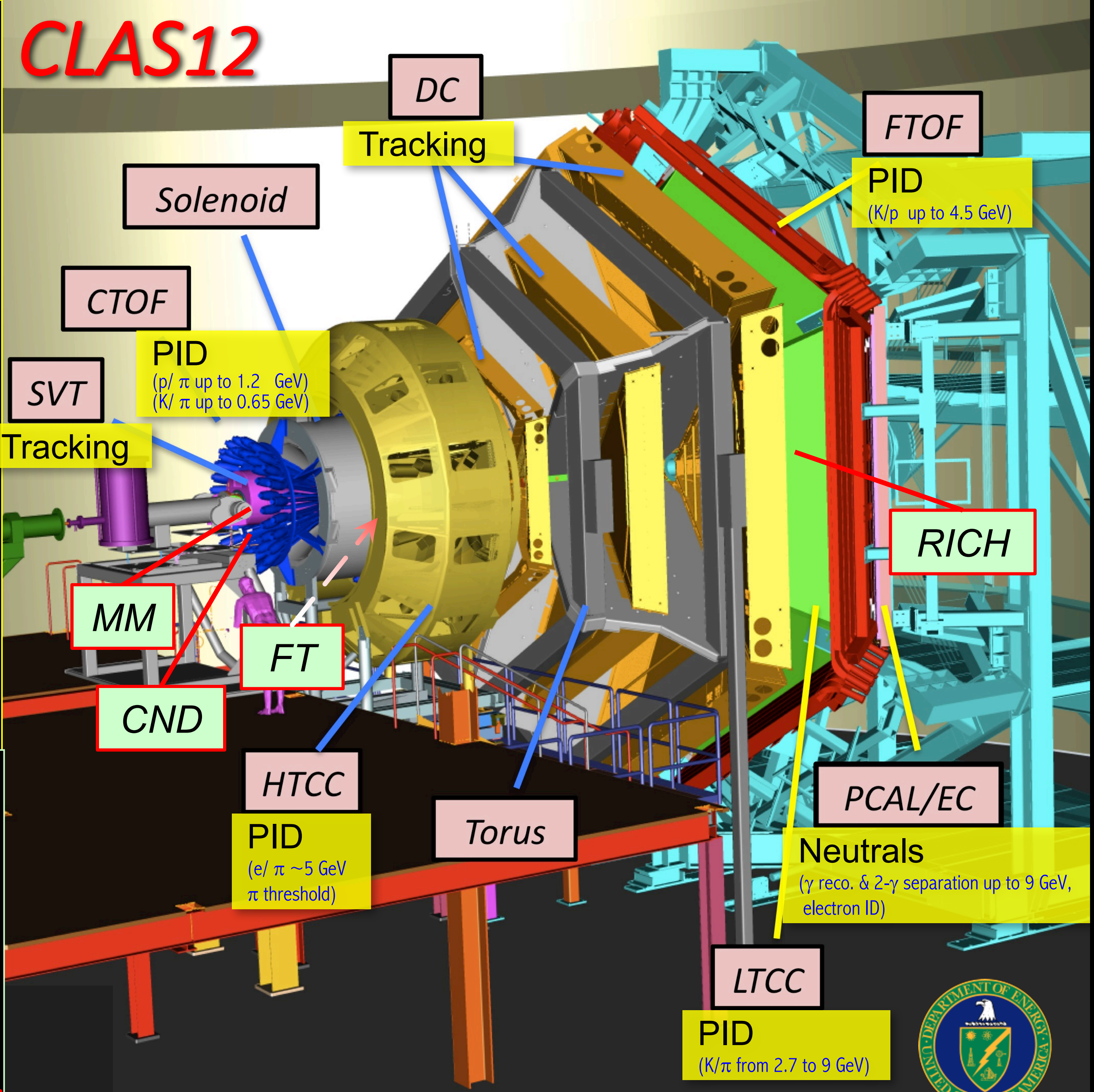
Beamline

- Targets
- Moller polarimeter

User provided equipment

- MicroMegas
- Central Neutron Detector
- Forward Tagger
- RICH detector (1 sector)
- Polarized target (long.)

http://www.jlab.org/Hall-B/clas12-web/



18 sub-detectors, >100k readout channels

CLAS12 Data Processing Challenges and Progress

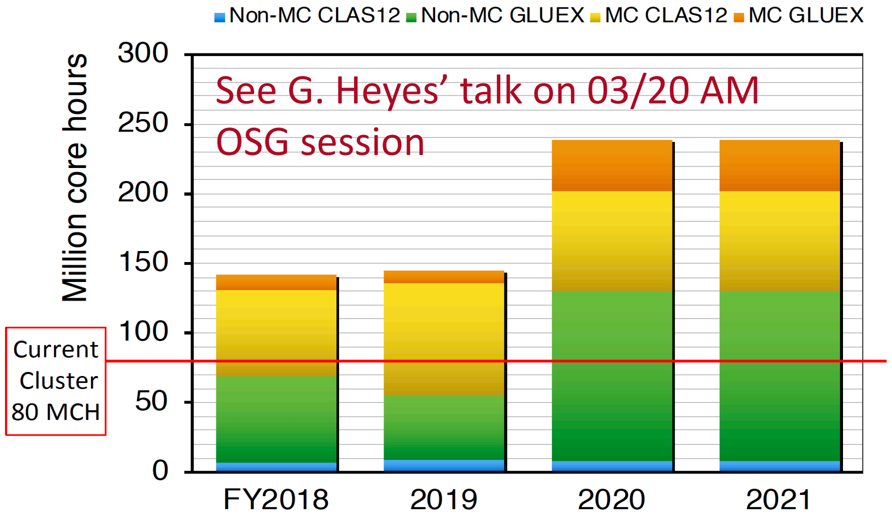
- Data Volumes
  - Highly **selective** trigger (FPGA-based) → **most events recorded are Physics events**
  - Trigger rate **~15 kHz**
  - DAQ event size reduced from 42 kB/event to **25 kB/event**
    - Implemented bit-packing for FADC pulses
    - Improved trigger purity by about **30%** using tracking trigger
- Data formats
  - CLAS12 data format designed for:
    - **Compression** is needed for large scale data
    - Fast random read data format
  - Bucket/Record **Tagging** ability for big data ➔ significant improvement on IOPS while reading from JLAB file system.
  - **Event categorization and tagging** in reconstruction process reduces disk access for analysis.
  - Introduction of collaborative data processing work-flow for data analysis and calibration, **analysis TRAINS**, allows multi-skim output depending on event topology, facilitated by tagging in data format.
- Offline software
  - Java based toolset (I/O, geometry, calibration, analysis, …) and reconstruction packages
  - **CLA**S12 **R**econstruction and **A**nalysis Framework (CLARA) glues together **isolated, independent micro-services** with reactive resource allocation and **multithreading** capability.

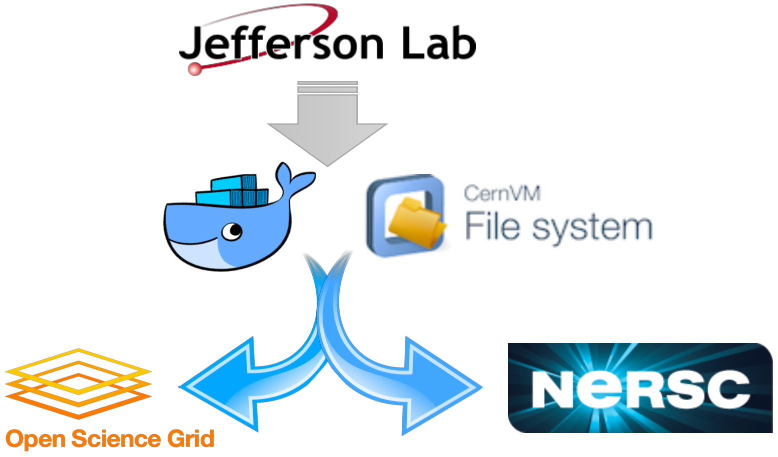
See G. Heyes' talk on 03/18 AM plenary session

CLAS12 Physics data taking started in Spring 2018:
First run on hydrogen target in 2018
*(**13 parallel physics proposals**)*
Currently running on deuterium

Data Processing Challenges and Progress

- Leveraging **offsite** resources:
  - Simulations:
    - Open Science Grid (OSG)
    - MIT computing farm (CLAS12)
  - Reconstruction:
    - **Significant allocation** at National Energy Research Scientific Computing Center (NERSC) for GlueX and CLAS12
  - Software distribution:
    - **Docker container** transformed into singularity image
    - Share via CernVM File System (CVMFS)

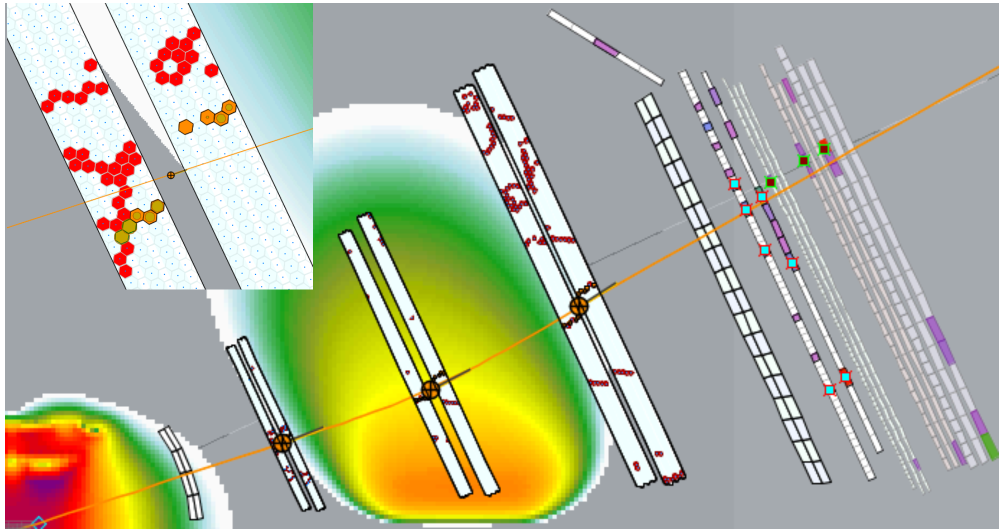


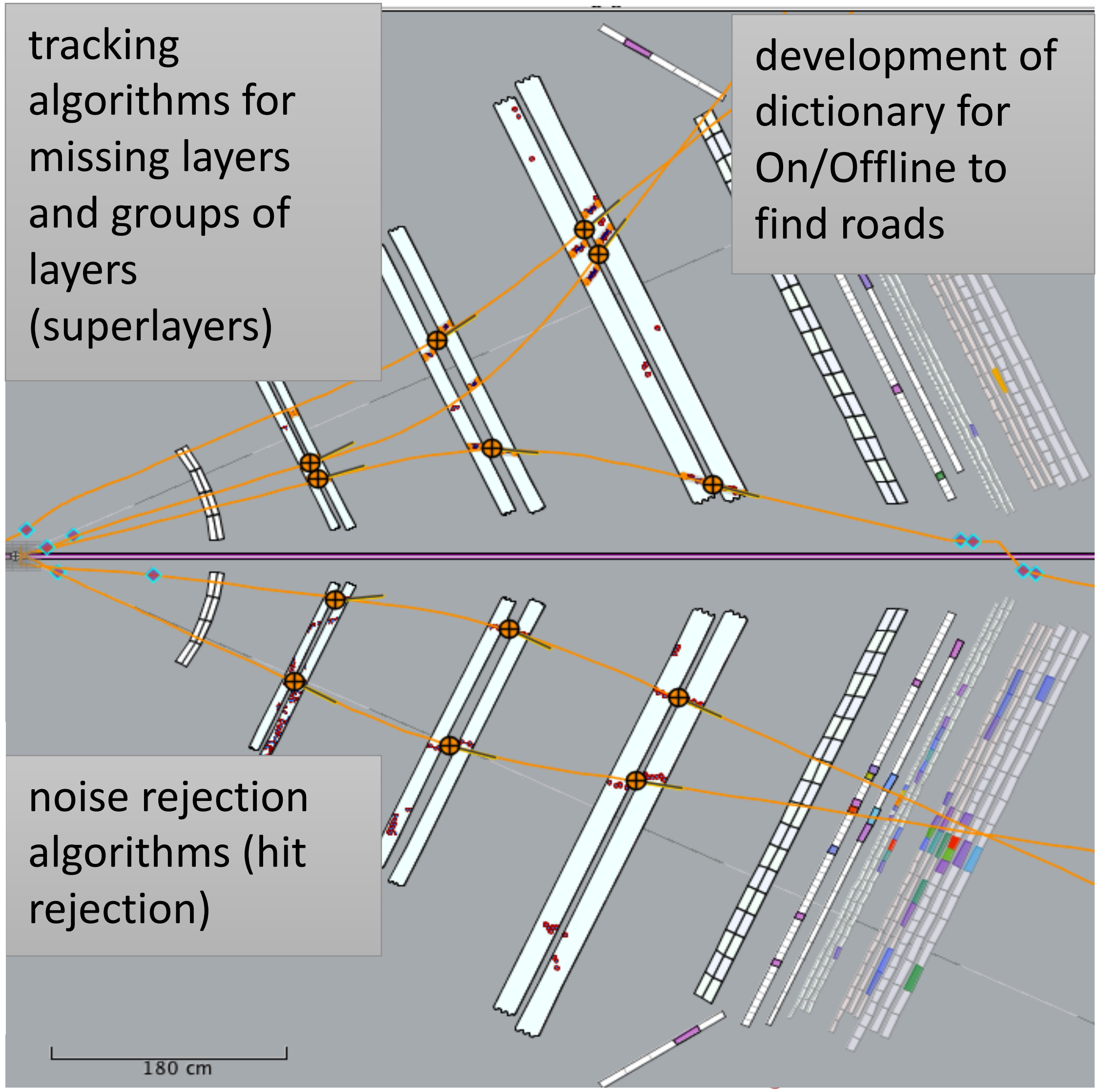


Event reconstruction challenges

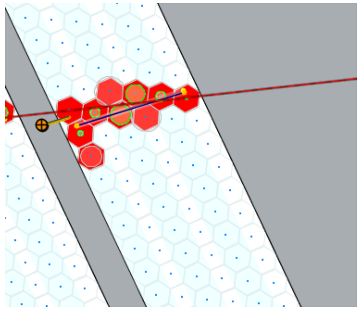
– Large backgrounds when running at ~design luminosity

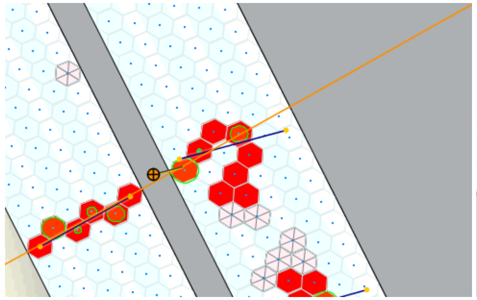
Typical noise pattern in CLAS12 Drift Chambers (loopers)





DC noise patterns in CLAS12

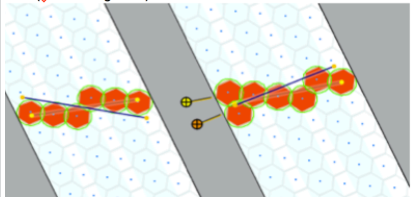




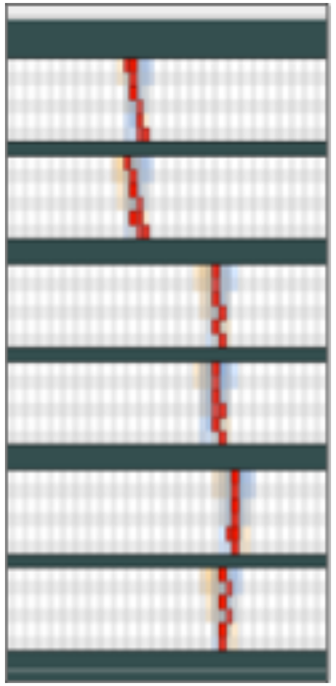
Out-of-time-hits rejection

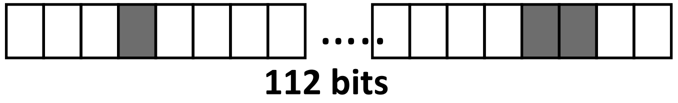
Out-of-timers signature

$\Sigma_{i(i:\text{ hit in segment})}$ doca ~ Σ_i cell-size



CLAS12 Drift Chambers Fast Pattern Recognition

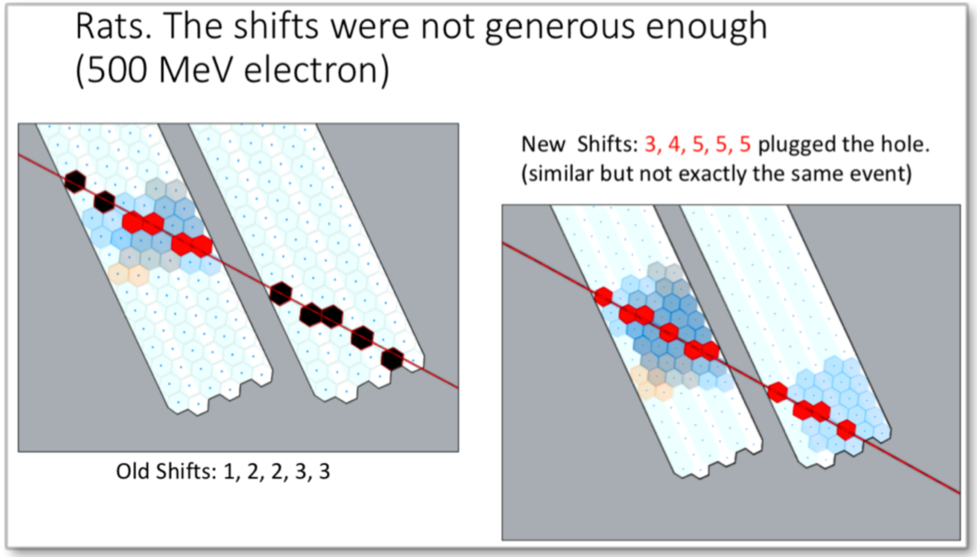




Bit-shifting algorithm finds DC noise

Algorithm further developed for Pattern Recognition

- *key-value* pairs (FastMC) dictionary
- **Very fast** …
  - Dictionary retrieval time (including encoding key and decoding value back to track parameters) ~**2 microsec** (if found.)
- Working on fast "nearest key" if not found. Current dictionary finds ~80%.



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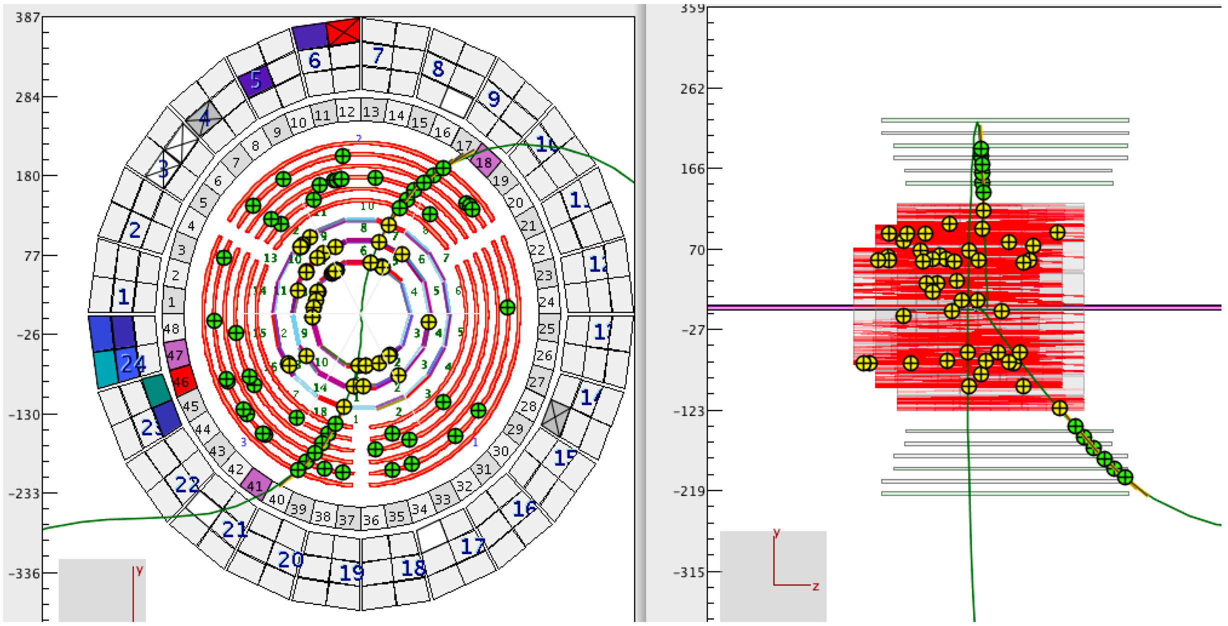
Event reconstruction challenges

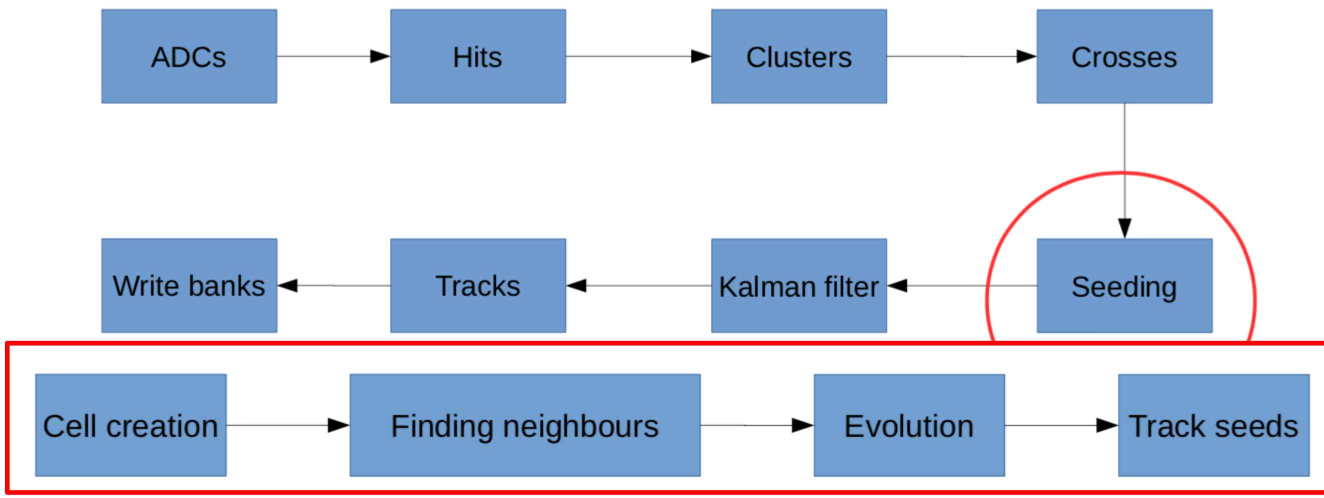
– **Tracking algorithms tuned to reject backgrounds** when running at ~design luminosity

Central Tracker (RGB [deuterium target] 50 nA beam current)



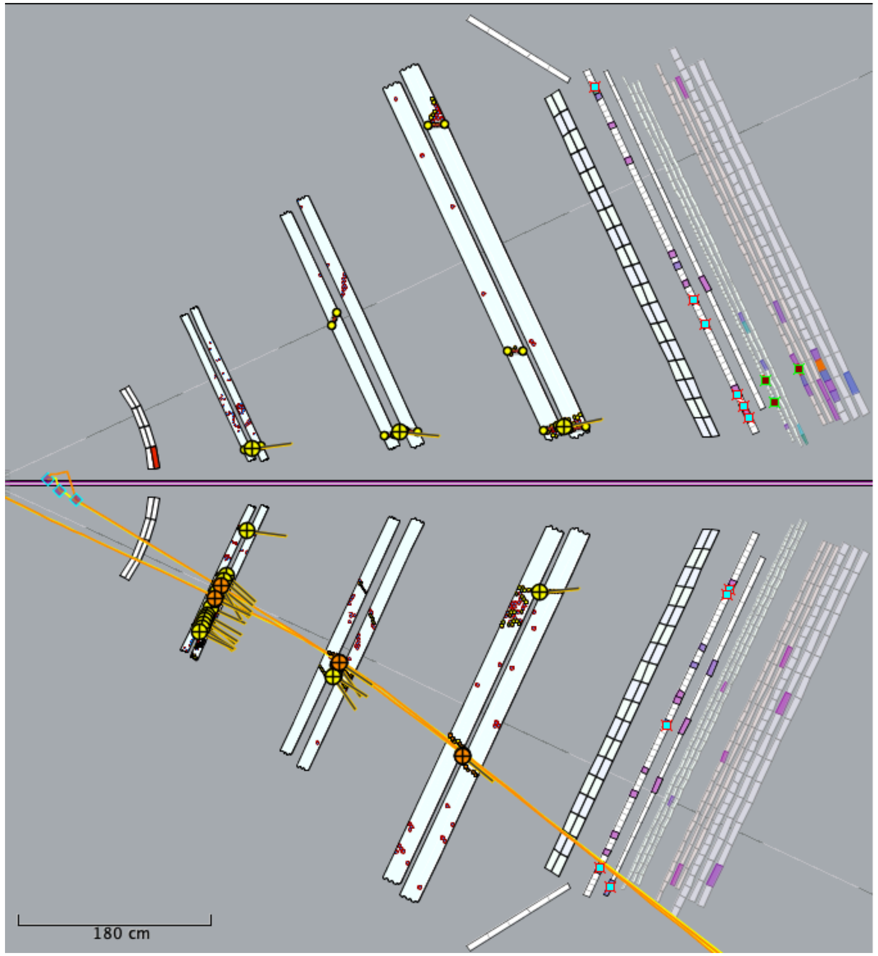
Track seeding

- New track seeding algorithm based on cellular automata
- Inspired to the Hera-B CATS algorithm (NIM A 498 (2002))



Event reconstruction challenges

– Understanding tracking **inefficiencies**



- Seeding failures
  - Noise hits close to track causing first stage Pattern Recognition to fail
  - Not enough hits to estimate track parameters (e.g. missing layers in reconstruction due to malfunctions …)
- Tracking failures
  - Seed parameters too far for fit to converge
- Ghost tracks

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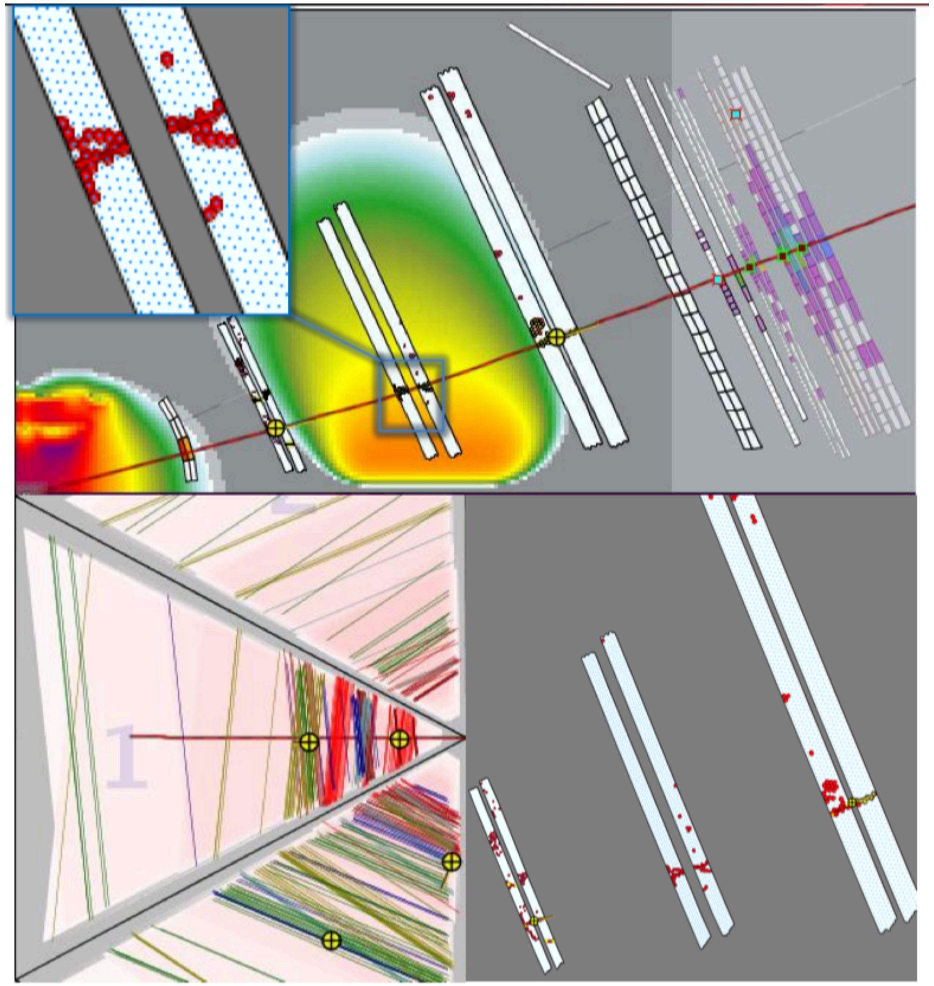
Analysis of Efficiency as a function of Beam Backgrounds

- Generation with background **too compute intensive**
- Realistic representation of beam-related background using **signal/background merging**
- Background merging ready provides **realistic measure of tracking efficiency as a function of beam current** & tool to analyze **tracking performance** and validation algorithm improvements
    - **Signal MC track** (parametrized wire intrinsic inefficiency) merged with random trigger data.
    - **Low beam background data** merged with random trigger data
    - ADC and TDC raw lists from data and MC combined.



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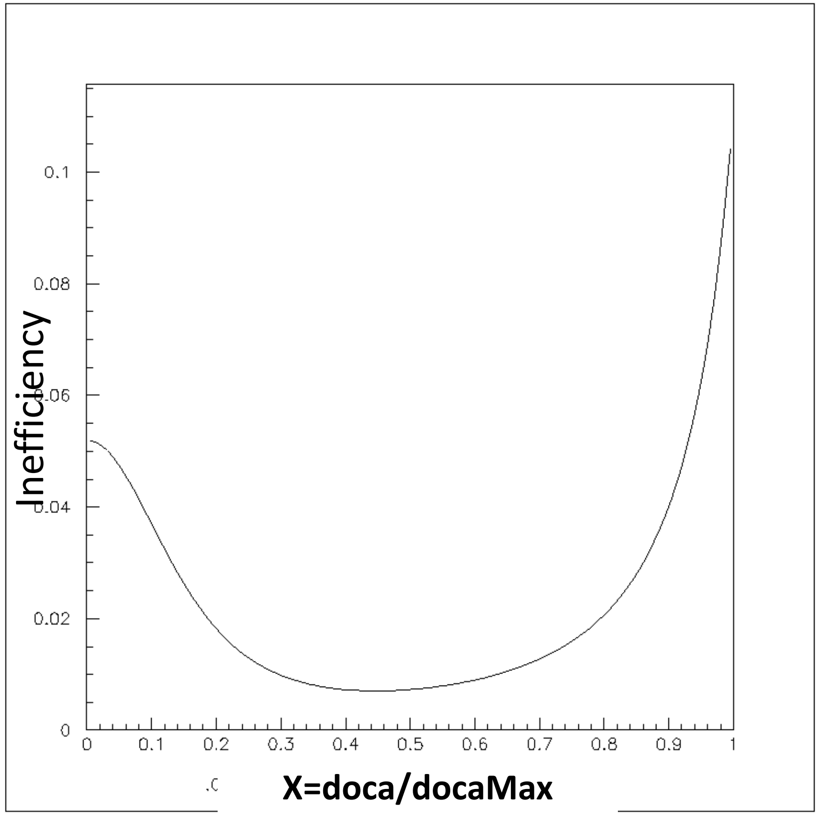
Event reconstruction challenges

– Accurate model of inefficiencies (**malfunctions, dead times, intrinsic detector component inefficiencies**)

- Three sources of inefficiency in CLAS12 Drift Chambers :
  - **Intrinsic** (applies to all wires) – cells don't always fire,
  - Equipment **malfunction-related** (applies to specific wires),
  - **Background-related** (unavoidable knock-on electrons)

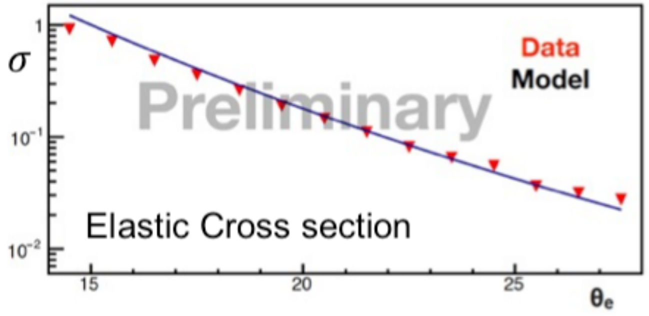


- Drift Chamber hit times generated by simulation digitization routine **smeared by intrinsic inefficiency function** (parameters extracted from data).
- Same inefficiency function and parameters are used by the track reconstruction software to form error matrix in the fit.

Need to understand and model detector efficiency, geometrical acceptance and backgrounds well

Detector efficiency and geometrical acceptance

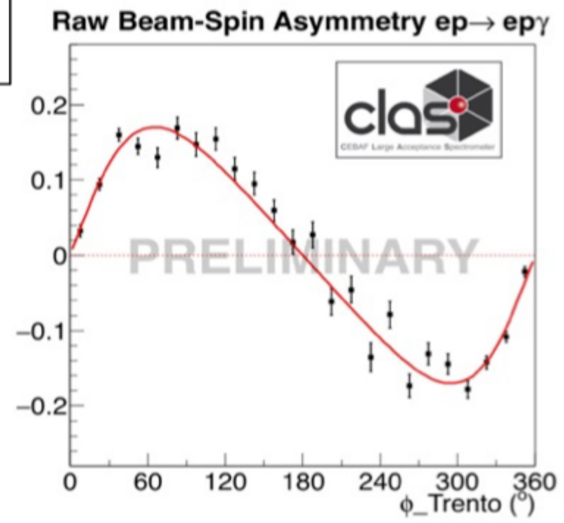
Integrated luminosity (includes beam charge & target thickness)



$$\sigma \sim N/(\epsilon\mathcal{L})$$

Cross sections

Number of identified physics events at each B/T spin state

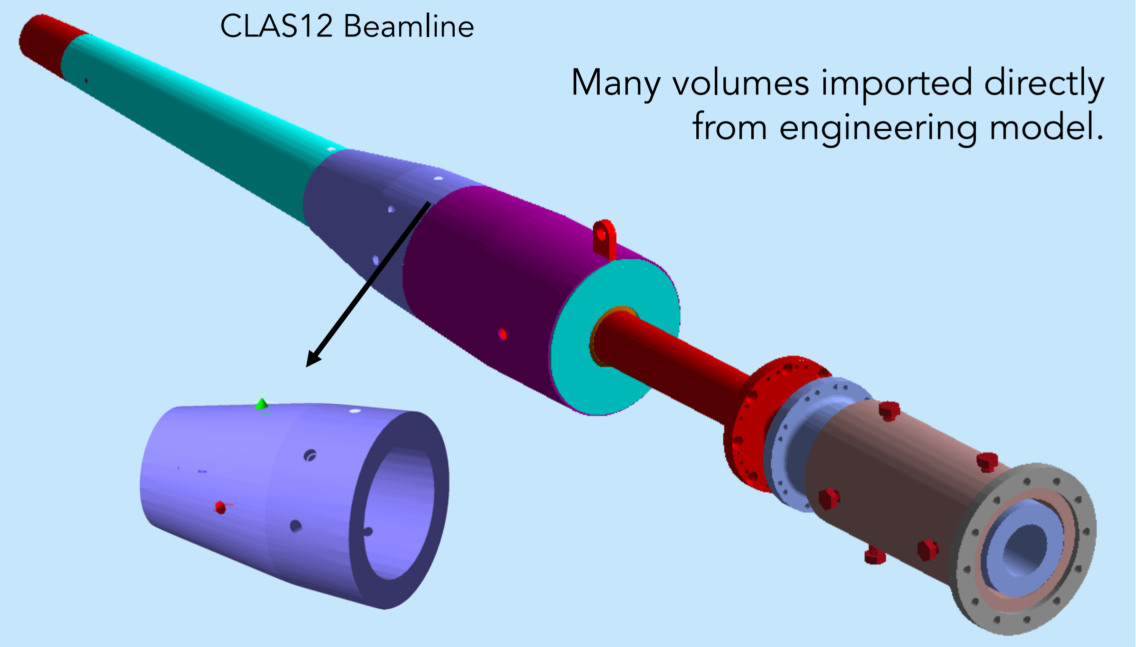


Spin (beam and/or target) asymmetries

$$A_{B(T)} \sim \frac{1}{P_{B(T)}} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

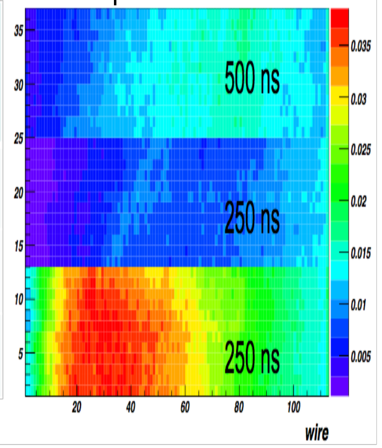
Beam (target) polarization

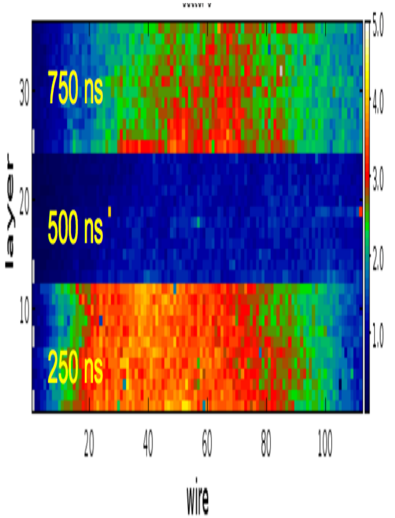
CLAS 12 Geant-4 MC: Years of optimizing beam line, shielding, studies of rates on many detectors, simulation validated with real data



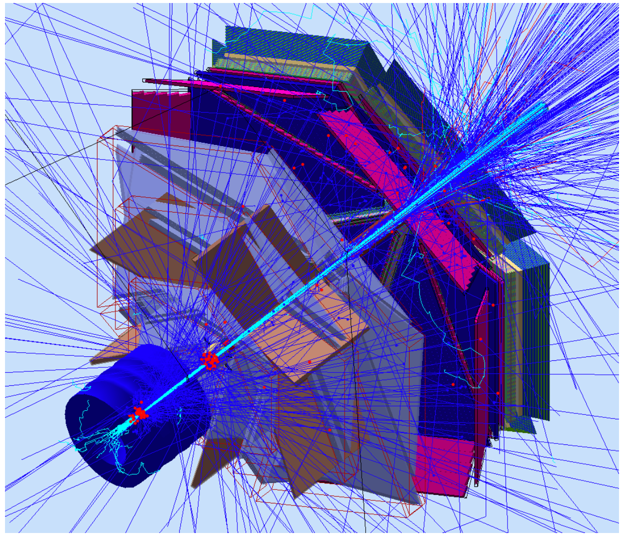
Simulation / Data Comparison

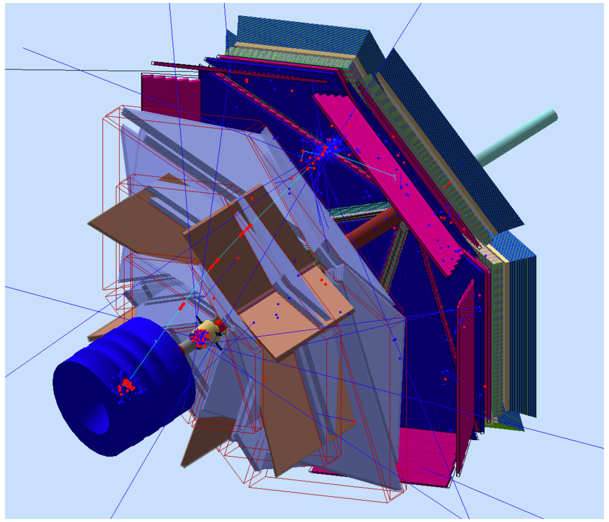
	Data (rescaled)	GEMC
R1	2.8 %	2.68 %
R2	0.6 %	0.76 %
R3	1.5 %	1.18 %

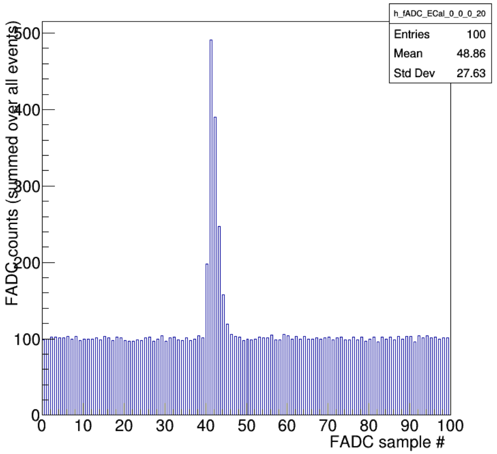




Background Generation







- **Validation** from data: extensive background studies and analysis of detector responses
- FADC output used for trigger studies

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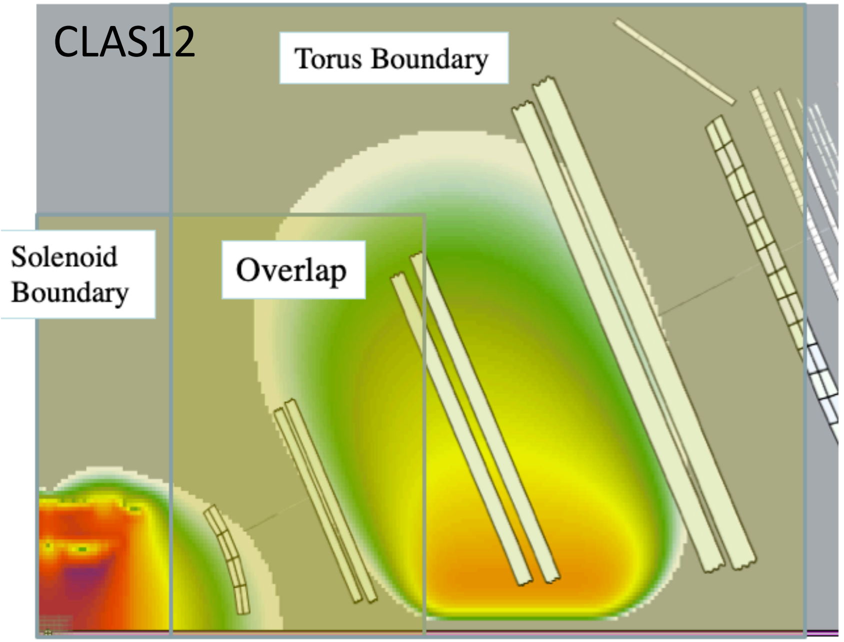
Event reconstruction challenges

Reconstruction speed (most time spent swimming tracks through torus magnetic field in forward detector)

– Improvements
  - **Swimming algorithms:** improvements (numerical methods in transport of state vector and covariance matrix, adaptive step size, field caching, …)
  - **Magnetic Fields Handling**: dedicated service to load and handle the fields (solenoid + torus in 2 different frames) with ability to cache field coordinates (probes).
  - **Code cleanup**: memory usage (objects reuse, List<Object> instead of Arrays, etc., un-necessary loops, etc.)

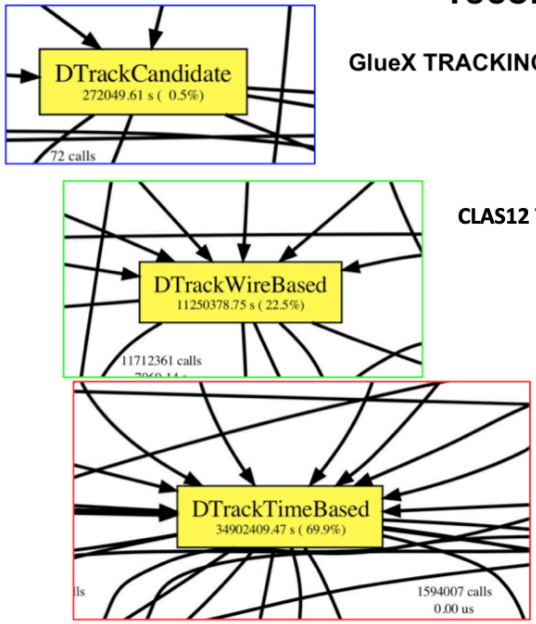
– Overall speed improvements *however* tracking still remains **biggest CPU time** consumer…



Machine Learning Initiative at JLab

Motivation:

The largest CPU resource driver for event reconstruction is charged particle tracking



GlueX TRACKING CPU Usage:

DTrackCandidate: ~2.0%
DTrackWireBased: 22.5%
DTrackTimeBased: 69.9%

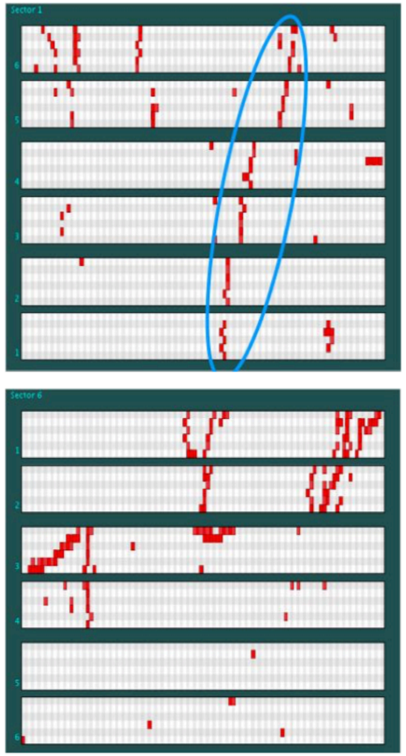
Tracking Total: 94.4%

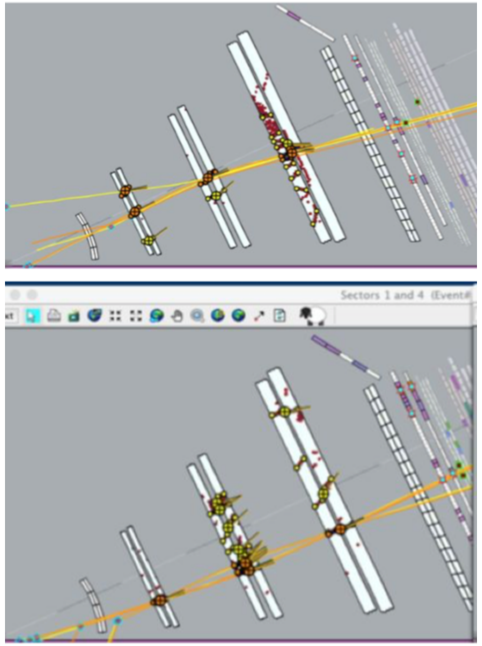
CLAS12 TRACKING CPU Usage:

DCPatternRec	~2%
HitBasedTracking	58%
TimeBasedTracking	37%
Tracking Total:	97%

Targeted Areas of Improvement for CLAS12

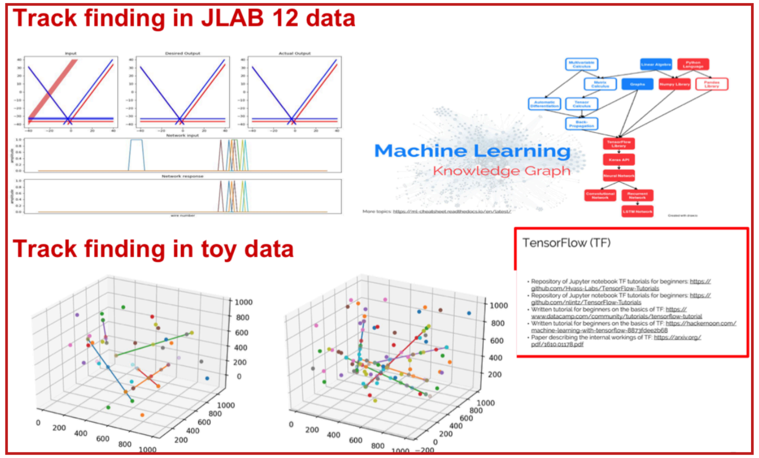
- Processing **speed**
  - More efficient noise rejection
  - Combinatorics (ghost tracks)

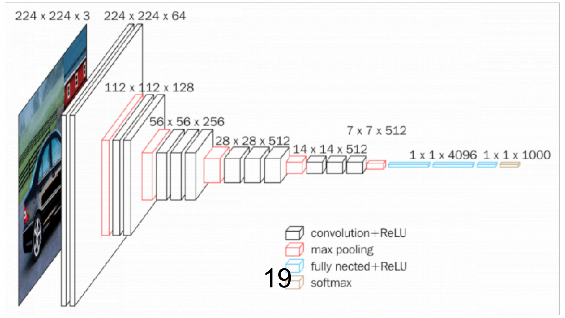




Pilot project
We can start with pre-trained **VGG16** architecture to identify tracks in our drift chambers; reduce the data sample that tracking has to work with.
Using Adversarial Neural Network we can clean up the hits that belong to the tracks: reducing number of combinatorics.
Extension:
Use regression network on the top to calculate track parameters and pass it to tracking code to minimize Kalman-Filter iterations.

JLab ML Initiative





Jefferson Lab

Summary

- 12 GeV physics program with **4-Halls operation ongoing**

- Keeping up with data rates and processing data and MC events in **timely fashion** to avoid back-log is a challenge to all experiments producing **large data volumes**
  - Leveraging **off-site resources** (OSG, NERSC) and **deployment approach** (Docker, CVMFS)
  - Explore and invest in **leading edge technologies such as machine learning** to speed up reconstruction time

- Publishing physics quality results contingent on having a **reliable Monte Carlo** and **good reconstruction resolution**
  - Challenge to model the data **geometry** (& distortions), **inefficiencies** (tracking, PID, detector intrinsic, etc.)
  - Reliable **event generators** (radiative corrections)
  - Quality reconstruction (many reconstruction packages requiring detailed validations)

BACKUP

Approved experiments

Experimental Program Planned for the Next Ten Years
All Halls have collected 12 GeV Data and have operational experience

Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD	0	2	1	3	0	**6**
The transverse structure of the hadrons	6	3	3	1	0	**13**
The longitudinal structure of the hadrons	2	3	6	0	0	**11**
The 3D structure of the hadrons	5	9	6	0	0	**20**
Hadrons and cold nuclear matter	8	5	7	0	1	**21**
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1	0	1	2	**7**
Total	**24**	**23**	**23**	**5**	**3**	**78**
Total Experiments Completed	**4.6**	**2.7**	**2.1**	**0.8**	**0**	**10.2**
Total Experiments Remaining	**19.4**	**20.3**	**20.9**	**4.2**	**3.0**	**67.8**

CLAS12 reconstruction framework

Reconstruction Framework

- **CLA**S12 **R**econstruction and **A**nalysis Framework
- glues together isolated, independent micro-services with reactive resource allocation
- each service runs a unique algorithm, communicating with each other through a message passing mechanism (data banks) to serve data processing goals
- provides multithreading with horizontal and vertical scaling, error propagation and fault recovery
- provides relevant live performance measures
- supports CLAS12 on JLab batch farm, multicore environments, future diverse hardware
- https://claraweb.jlab.org/clara/

CLAS12 reconstruction tools

- common tools, e.g. I/O interfaces, geometry framework, analysis utilities
- reconstruction engines, monitoring and analysis services as plugins to ClaRA
- https://github.com/jeffersonlab/clas12-offline-software
  - master/development branches for organization
  - issue tracking, automatic Travis build with real validation tests

CLAS12 data format

- random access, on-the-fly high/fast LZ4 compression, no size limit
- internal dictionary describing data structures
- provides for easy bank filtering and event tagging mechanism (DST making and reading)

Hall D/GlueX

JANA:

- Multithreaded, factory based, plugin driven C++ framework for reconstruction and analysis

AmpTools:

- C++ libraries for Partial Wave Analysis (PWA), i.e. unbinned maximum likelihood fits to data using user-provided sets of interfering amplitudes
- Multi-core, multi-machine support, GPU-enabled

Data format:

- EVIO and REST data formats for raw and reconstructed (DST) data formats

	Low Intensity	**High Intensity**
Beam	2.4 x 10^7 γ /s	5 x 10^7 γ /s
Trigger	42 kHz	90 kHz
Front End	0.5 GB/s	1.2 GB/s
Disk	0.5 GB/s	600 MB/s
Tape	4.2 PB/yr	5.8 PB/yr

CLAS12 Calibration & Monitoring

Common Calibration Framework

- used for all CLAS12 detectors
- provides GUI fitting, plotting, display utilities
- for extracting and checking calibration parameters, along each stage of the calibration sequence
- generates the final calibration tables formatted for Hall D/B common database (ccdb)

Procedures

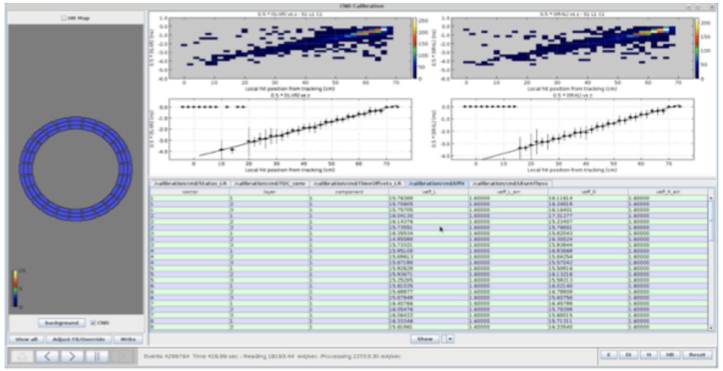
- workflow and dependencies well understood and tested, first through calibration challenges and now with real data
- detectors' calibrations are mostly decoupled after rough, initial calibrations

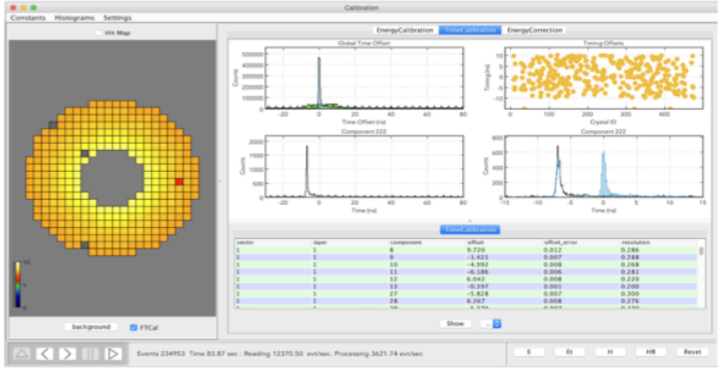
CLAS12 data filtering

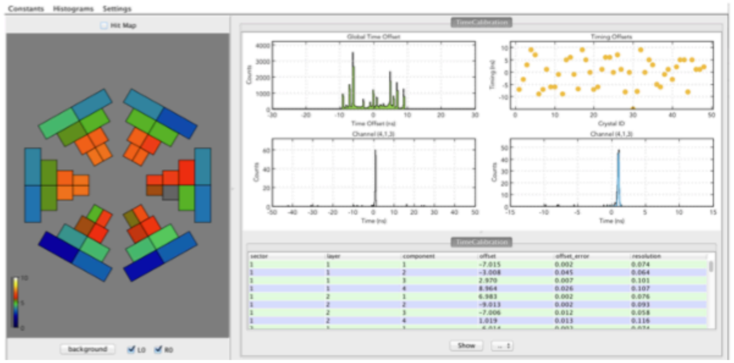
- easily generate slim skims and bank filters, at least 100X reduction, for each detector's specific calibration needs

Service Orientation

- for fast iterations to support individual detector's iterations, e.g. reprocessing single service



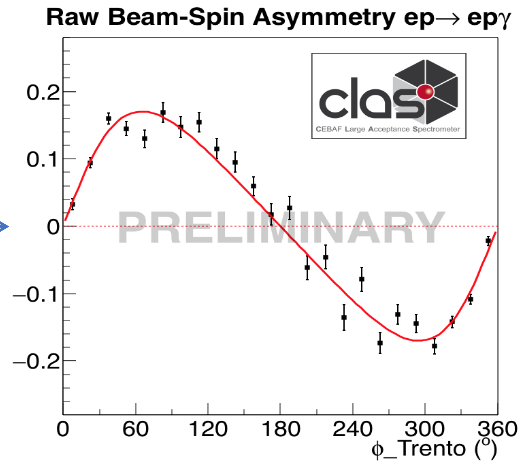


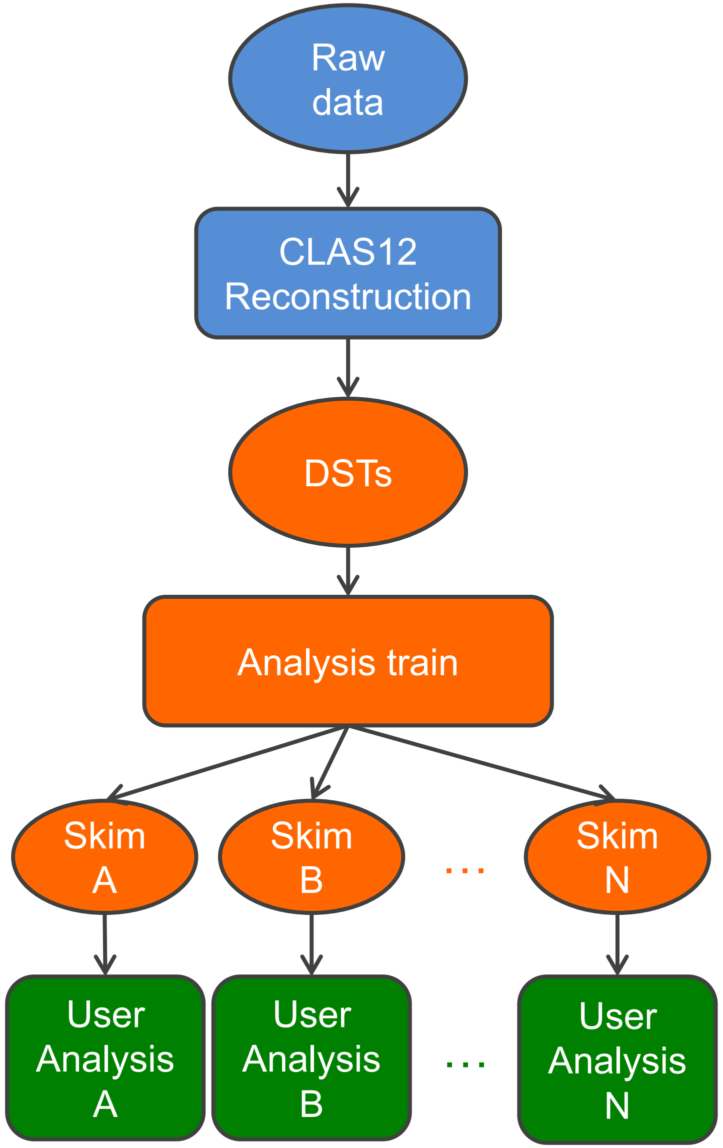


Data processing workflow

- Input: raw event files from DAQ
- Decoding to CLAS12 data format files, implementing translation tables and fADC pulse analysis
- Event reconstruction using detector-specific packages running in CLARA and producing DSTs (4-vectors, PID)
- Use analysis trains to skim different event topologies and produce separate reconstructed event files
- Skimmed files distributed to users for physics analysis

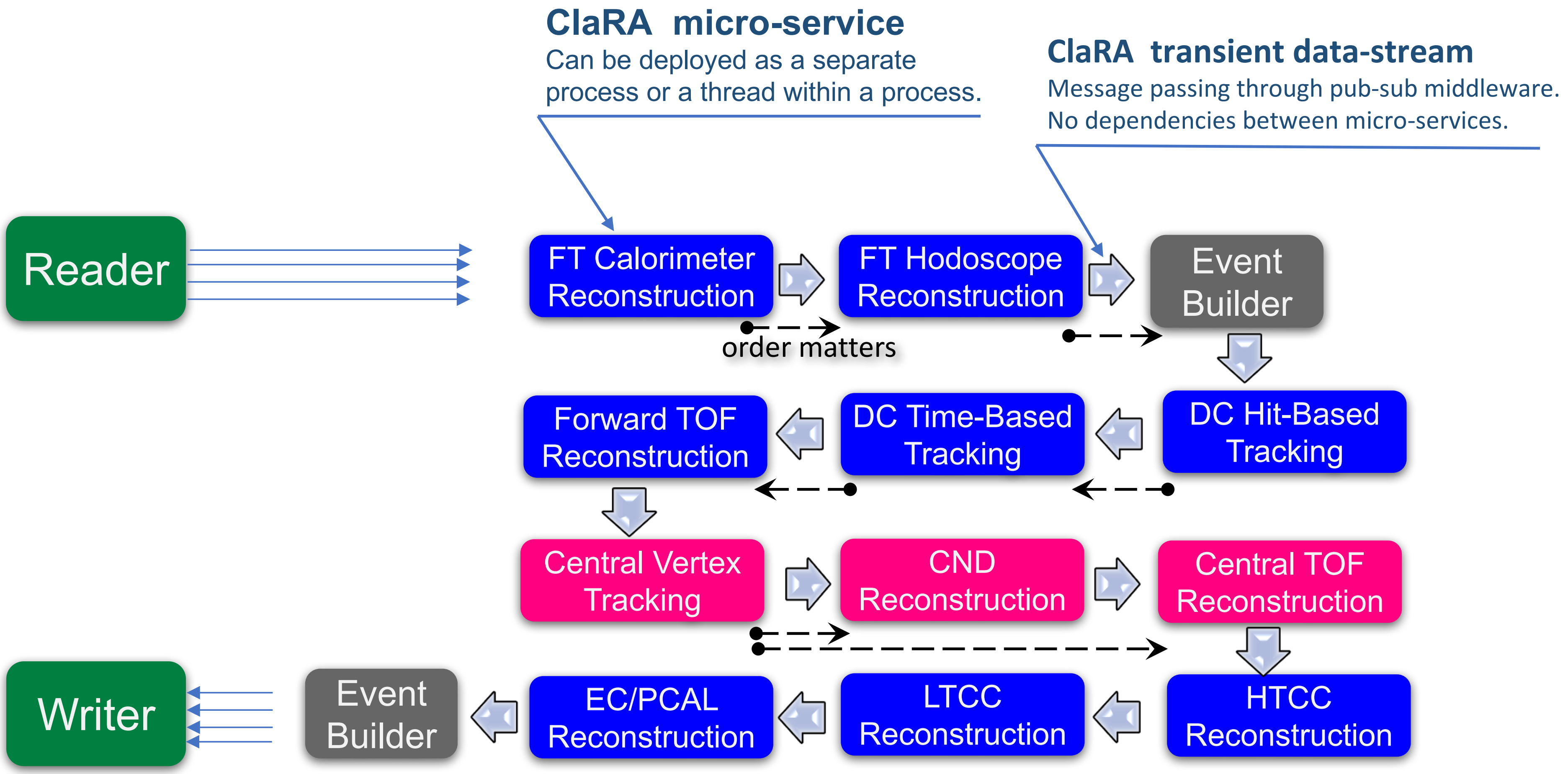
Exercised for DNP



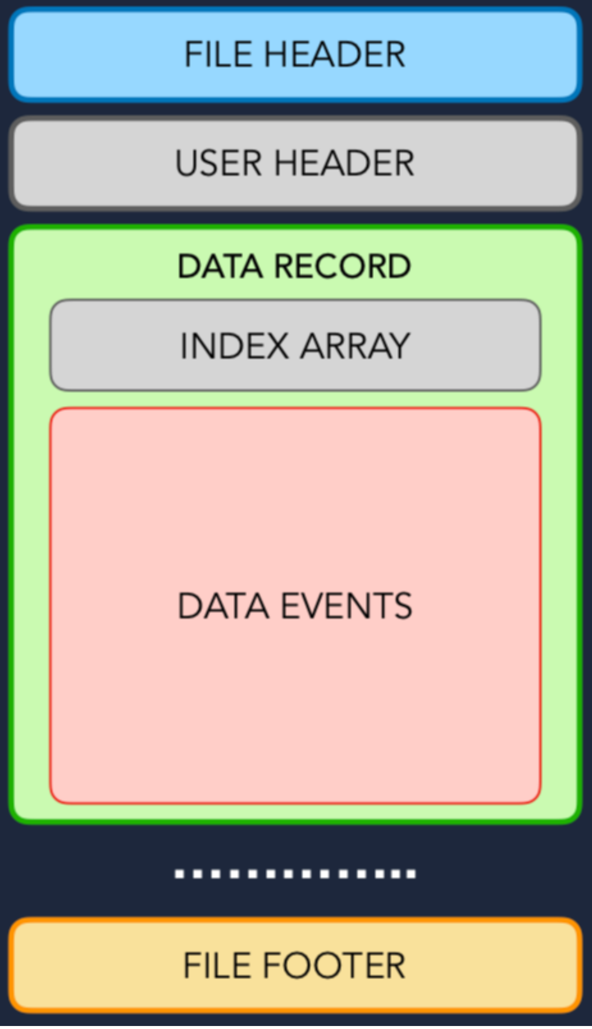


CLAS12 Event Reconstruction Service Composition

- Each detector reconstruction component is a **ClaRA** service.
- Event building services (EB) combines info from individual services output banks to reconstruct particle candidate.



CLAS12 Data Format



User Header

Contains information about the record dictionary, format. User specified parameters related to conditions of the experiment.

Data Record

Compressed buffer of data consisting of events and index. Record header provides number of events and the TAG for the record. Data records are typically ~8 MB.

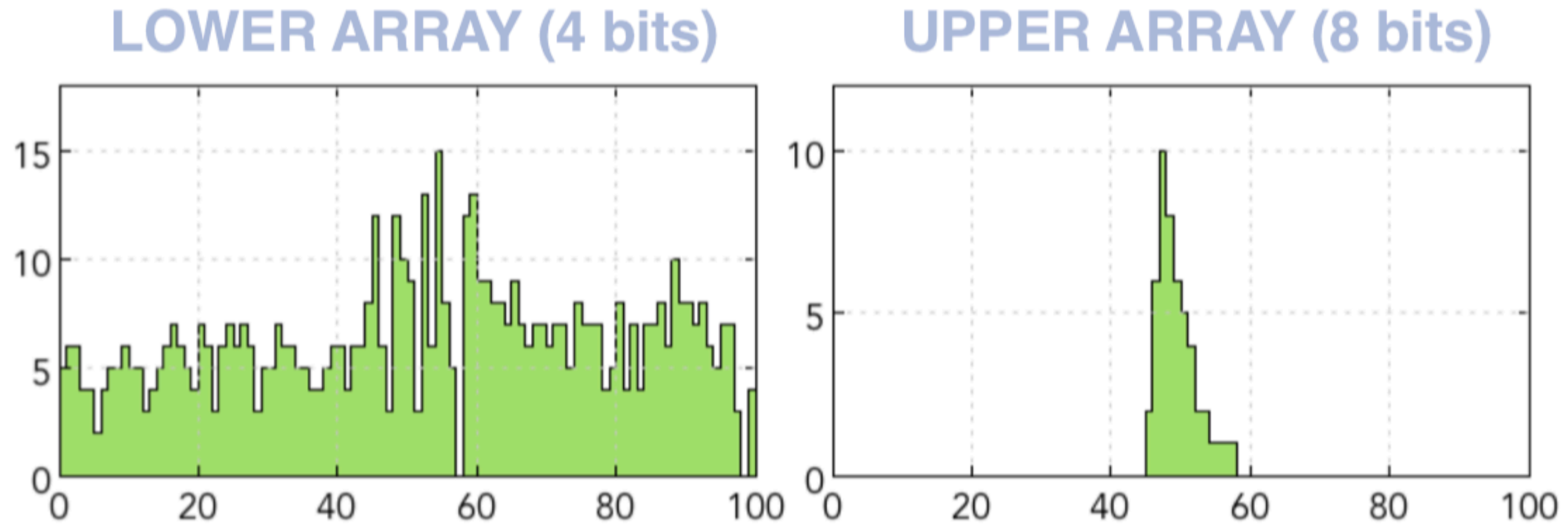
Index Array

Array of event offsets inside the event buffer. Dynamically creates event random access table.

FILE FOOTER

Contains positions of every record in the file with number of events for fast random access. Also has tags for each Data Record.

How bit-packing works



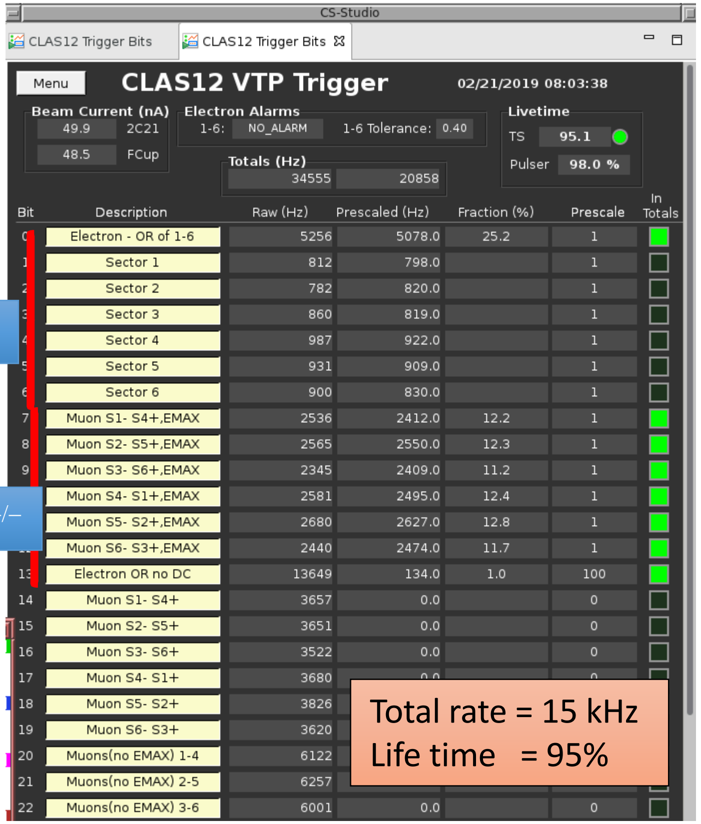
- The fADCs are 12-bits yet the upper 8 bits are zero for most samples.
- Split upper 8 and lower 4 bits into two arrays :
- First, encodes in **52** bytes lower 4 bits of samples:
  - **2** bytes for pedestal height
  - **50** bytes for **100** samples of **4** bits
- Second array is encoded into series of bytes
  - leading and trailing zeros are suppressed
  - **1** byte is index of first non-zero byte
  - **N** following bytes are the top section of the pulse.

Current Example:
63 bytes used
52 for lower
10 bytes for high bits
1 byte for first non-zero

CLAS12 Run Group B

A dictionary based segment finder in each of 6 superlayers; every superlayer has 6 layers, trigger requires at least 4 layers to have hits. Road finder gives extra 10-12% event rate decrease for inbending electrons.

Trigger	Rate	Tr. Conditions
Electron	5 kHz	DC negative roads PCU space correlation
Muons	10 kHz	+/- Roads FTOF-PCALU space correlation


CS-Studio

CLAS12 Trigger Bits | CLAS12 Trigger Bits

Menu **CLAS12 VTP Trigger** 02/21/2019 08:03:38

Beam Current (nA): 49.9 2C21; 48.5 FCup

Electron Alarms: 1-6: NO_ALARM 1-6 Tolerance: 0.40

Totals (Hz): 34555 20858

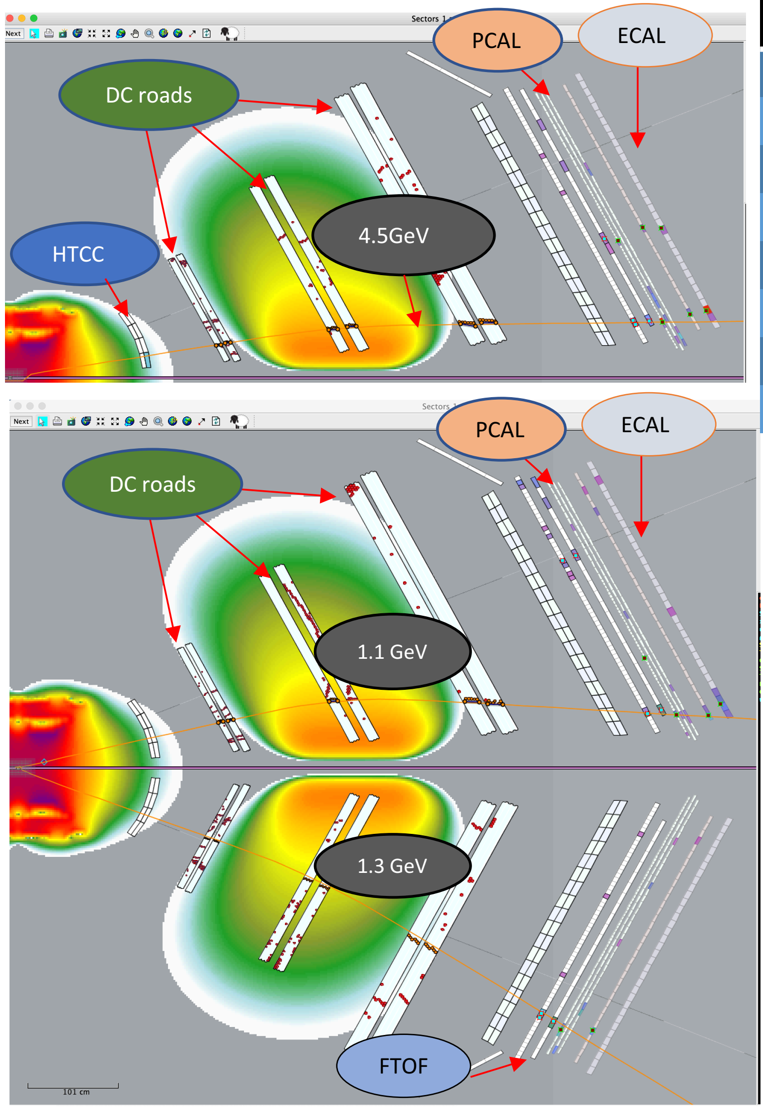
Livetime: TS 95.1; Pulser 98.0 %

Bit	Description	Raw (Hz)	Prescaled (Hz)	Fraction (%)	Prescale	In Totals
0	Electron - OR of 1-6	5256	5078.0	25.2	1	
1	Sector 1	812	798.0		1	
2	Sector 2	782	820.0		1	
3	Sector 3	860	819.0		1	
4	Sector 4	987	922.0		1	
5	Sector 5	931	909.0		1	
6	Sector 6	900	830.0		1	
7	Muon S1- S4+,EMAX	2536	2412.0	12.2	1	
8	Muon S2- S5+,EMAX	2565	2550.0	12.3	1	
9	Muon S3- S6+,EMAX	2345	2409.0	11.2	1	
	Muon S4- S1+,EMAX	2581	2495.0	12.4	1	
	Muon S5- S2+,EMAX	2680	2627.0	12.8	1	
	Muon S6- S3+,EMAX	2440	2474.0	11.7	1	
13	Electron OR no DC	13649	134.0	1.0	100	
14	Muon S1- S4+	3657	0.0		0	
15	Muon S2- S5+	3651	0.0		0	
16	Muon S3- S6+	3522	0.0		0	
17	Muon S4- S1+	3680	0.0		0	
18	Muon S5- S2+	3826				
19	Muon S6- S3+	3620				
20	Muons(no EMAX) 1-4	6122				
21	Muons(no EMAX) 2-5	6257				
22	Muons(no EMAX) 3-6	6001	0.0		0	

e-

$\mu^{+/-}$

Total rate = 15 kHz
Life time = 95%

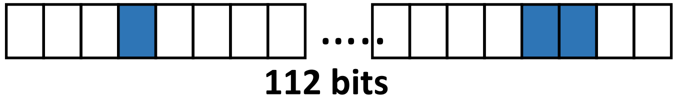


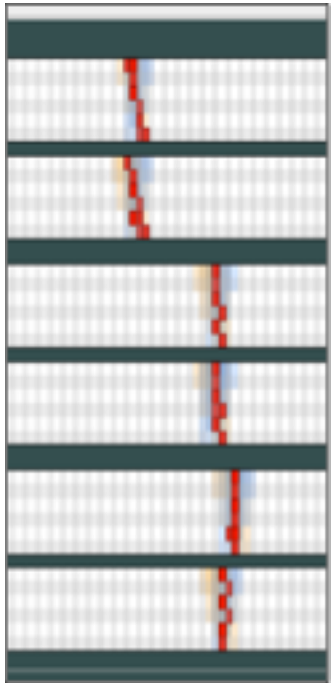
Trigger is 99% efficient

Target	LD2
HTCC	> 2 phe
ECAL+PCAL	> 300 MeV
DC ROAD	Data based
Track-PCAL-U	Space corr.
Sign of track	Negative
Trigger purity	**54%**
Current	50 nA
Rate @50 nA	5 kHz

Target	LD2
PCAL	> 10 MeV
ECAL	40<E<120 MeV
FTOF-PCALU	Space correlation
DC ROAD	GEMC based
Sign of track	pos and -negative
Trigger purity	**25%** of events w/ 2 recon TB tracks
Current	50 nA
Rate @50 nA	10 kHz

CLAS12 Drift Chambers Fast Pattern Recognition Details



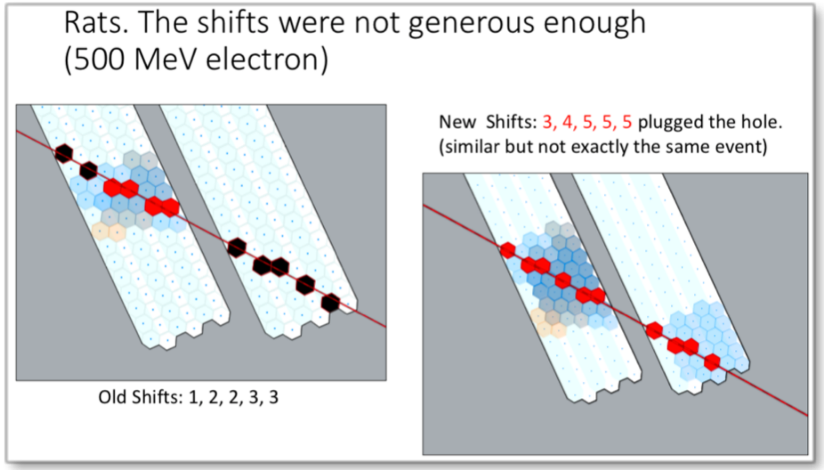


Bit-shifting algorithm finds DC noise

- Finds segments (and noise) superlayer by superlayer using Big Words (128 bits) and bitwise operations
- Fast (works in parallel using bit operations)
- Bullet proof within its programmable parameters: number of missing layers allowed and the layer by layer wire number difference (shift) with layer 1

• Default values:
  - 2 missing layers per superlayer
  - Spread if 1,2,2,3,3

• Output: 6x2 Big Words. Each word has bits set where algorithm finds that a segment might originate in layer 1 of that superlayer



Pattern Recognition algorithm (in development)

- DC 6 superlayers, combined into one massive 672 bit word. Encoded in base 36 = *key*. Multiplied track parameters (x, y, z, p, θ, ϕ) by 100, rounded them, included charge and encoded in base 36. That became the *value.* Trained (with FastMC) dictionary → 381k *key-value* pairs; Dictionary size = 32 MB.
- Dictionary retrieval time (including encoding key and decoding value back to track parameters) ~**2 microsec** (if found.) Working on fast “nearest key” if not found. Current dictionary finds ~80%.

Hall-B Run Groups Summary

Run Groups	Number of experiments	Beam time (PAC-days)	Luminosity (per nucleon)	Triggers
A	13	139 (100)	$10^{35} cm^{-2} s^{-1}$	$e^-, 2\mu, e^-_{FT} 2H$
B	7	90	$10^{35} cm^{-2} s^{-1}$	$e^-, 2\mu$
C	6	180	$2{\times}10^{35} cm^{-2} s^{-1}$	e^-
D	1	60	$2{\times}10^{35} cm^{-2} s^{-1}$	e^-
E	1	60	$2{\times}10^{35} cm^{-2} s^{-1}$	e^-
F	1	42	$4{\times}10^{34} cm^{-2} s^{-1}$	e^-
G	1	55	$2{\times}10^{35} cm^{-2} s^{-1}$	e^-
H	3	110	$10^{34} cm^{-2} s^{-1}$	e^-
I¶	1	180	$10^{34} cm^{-2} s^{-1}$	$e^+ e^-$
K	3	100	$10^{35} cm^{-2} s^{-1}$	e^-
L	4	55	$10^{35} cm^{-2} s^{-1}$	e^-
M	2	45	$2{\times}10^{34} cm^{-2} s^{-1}$	e^-

¶ - Heavy Photon Search, non-CLAS12 experiment

- The experiment in RG-J (PRad) has been completed

- e^- is 50% of RG-A trigger rate (data volume)
- RG-A will have 22% of data volume of currently approved all CLAS12 experiments combined

$$f.m. = days \times Lum \times trigg$$

Hall B/CLAS12 Data Rates and Event Size

Run		rate kHz	Billions of events	Event size (kB)	Data size (pB)
RG- A Spring 2018	2018 Spring	13	23	42	0.945
RG-A Fall 2018	2018 Fall	13	33	26	0.858
RG-K	2019	13	10	26	0.260
RG-B	2019	7.8	33	26	0.858
RG-A Spring 2019	2019	13	16	26	0.416

CLAS12 Reconstruction Readiness Reviews

Test of the full reconstruction chain:

Validations on MC:

- Use calibration challenge data sample and kinematic-specific samples.
- Verify reconstruction resolutions and efficiencies.

Single track resolution and multi-track event reconstruction well within specs

Average Specs:

- $\sigma(\Delta p/p) < 1\%$
- $\sigma(\theta) < 1$ mrad
- $\sigma(\phi) < 3$ mrad

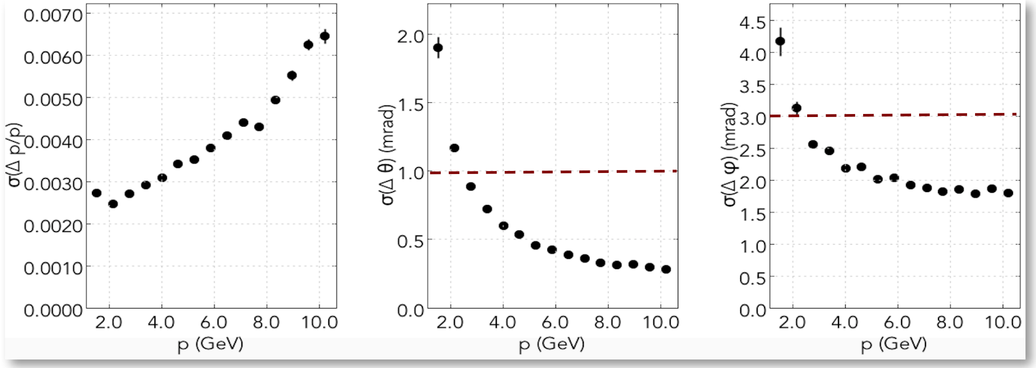
Tracking Efficiency:

$10^o<\theta<35^o$, $p>1$ GeV/c — DC

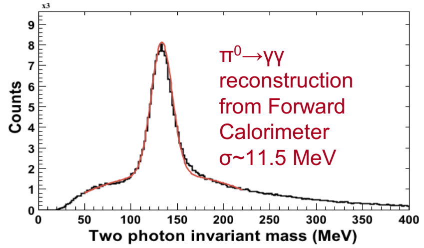
$\varepsilon > 97$ %

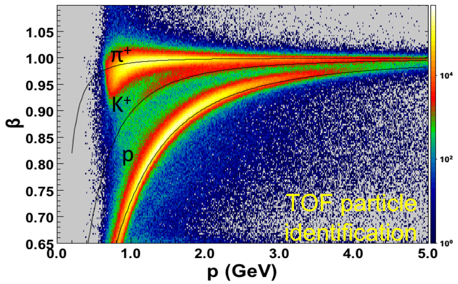
$45^o<\theta<110^o$, $0.5<p<2$ GeV/c — SVT

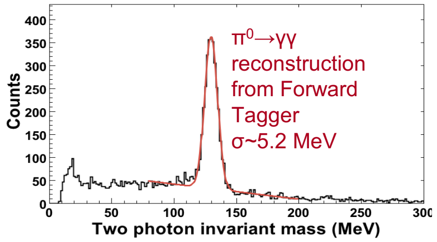
$\varepsilon > 96$ %

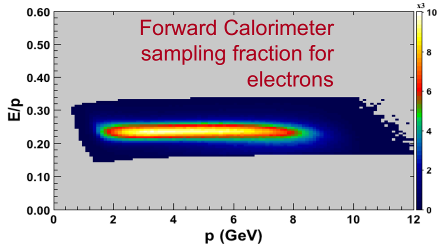


Performance plots (from CLAS12 run 4013)

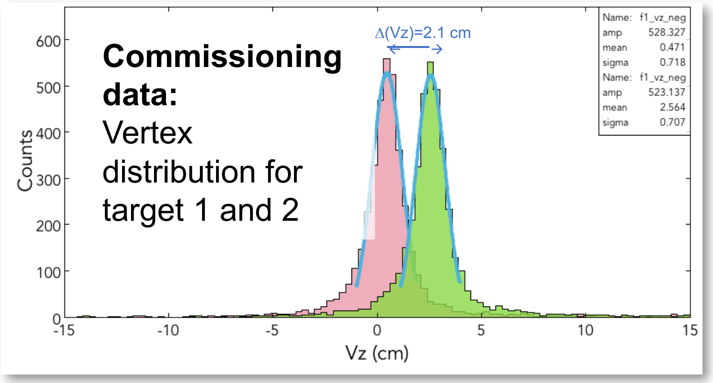








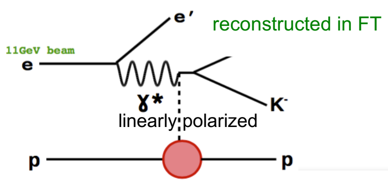
Targets: two 0.5 mm ^{12}C wires mounted 2.1 cm apart along the beamline (Vz)



CLAS12 Analysis Example

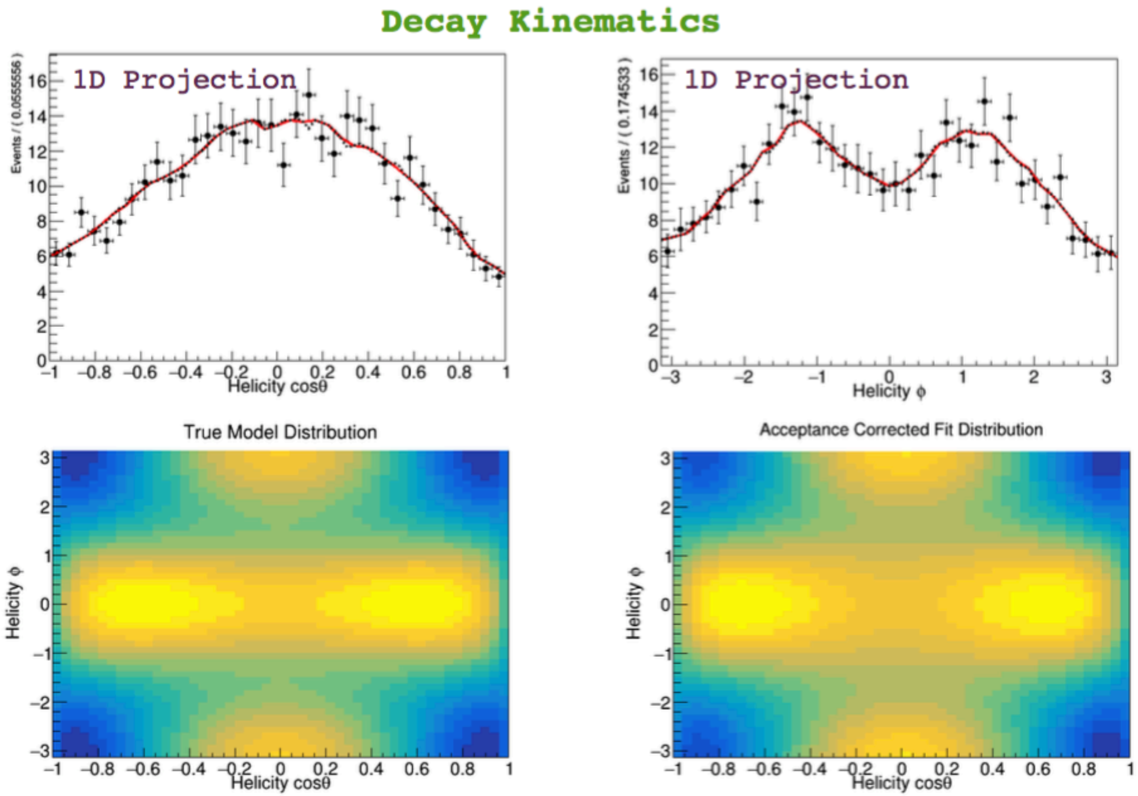
Reaction channel :

ep → e' p' K^+ K^-



- **Analysis**:
  - Data generated as phase space and weighted according to model (t-slope=1 GeV^{-2}, photon asymmetry=0.8, non-zero Y_{LM} moments).
  - Reconstruct & filter events for each topology (exclusive or missing hadron).
  - Convert to *analysis* data format and calculate fit variables.

Extended Maximum Likelihood fits to reconstructed simulated data after acceptance correction



CLAS12 Analysis Example

Reaction channel* :

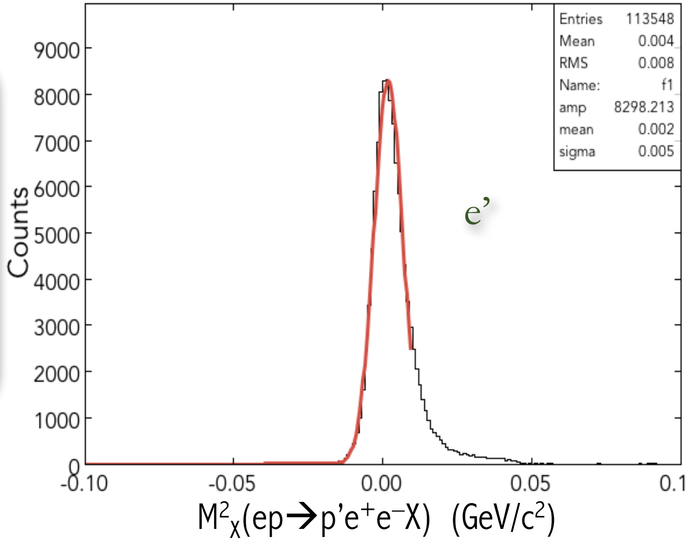
ep → e' J/ψ p; J/ψ → $e^+ e^-$

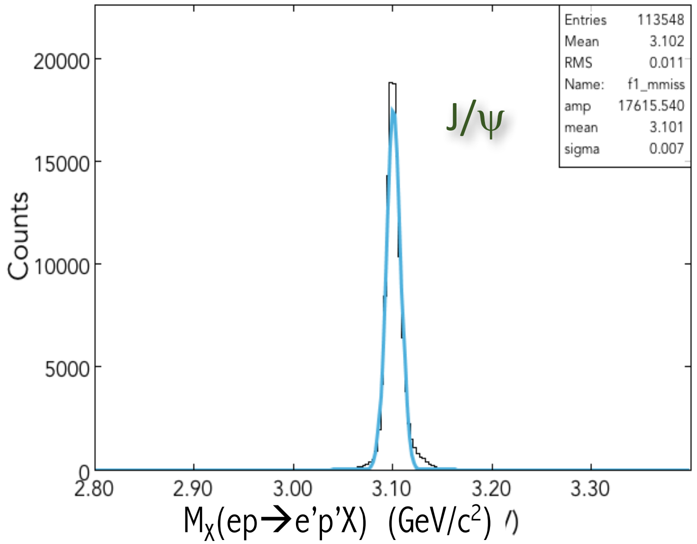
*Search for Hidden-Charm Pentaquark ep → e' Pc → e' J/ψ p

Reconstructed Masses by Missing Mass Technique

Forward going e- in Forward Tagger

e' M_X resolution important for pentaquark search in ep→ e'Pc reaction

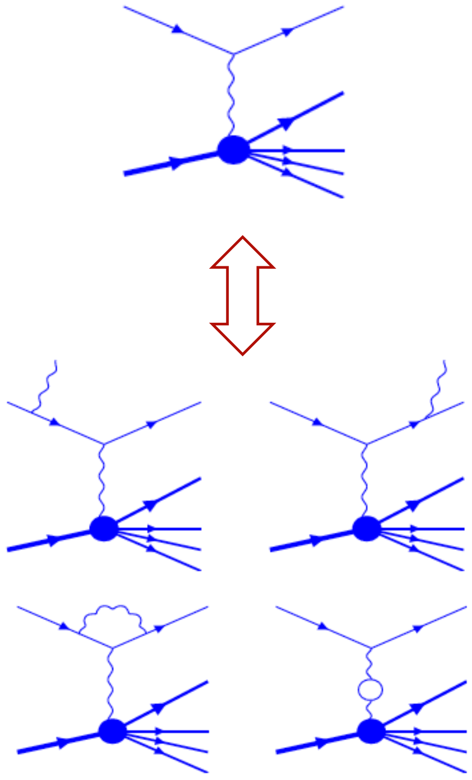




Radiative Corrections

Needed to account for distortion of measured observables (cross section and asymmetries) induced by radiation:

- distortion of observable magnitude
- modulation of angular distributions



Use and extension of algorithms and codes developed for 6 GeV program:

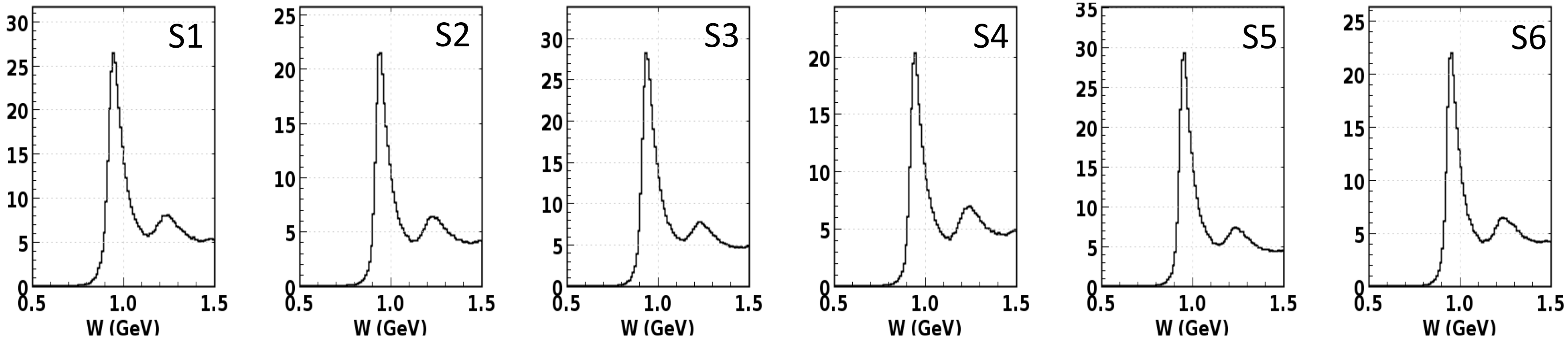
- RadGen for inclusive/DIS processes
- ExcluRad for single meson production
- Dvcsgen for DVCS
- HapRad and SidisGen for SIDIS
- …

Dedicated Workshop at JLab in May 2016:

1. Set of precision calculations of radiative corrections for different processes including the full set differential cross section
2. Development of generators including the radiative photon emission

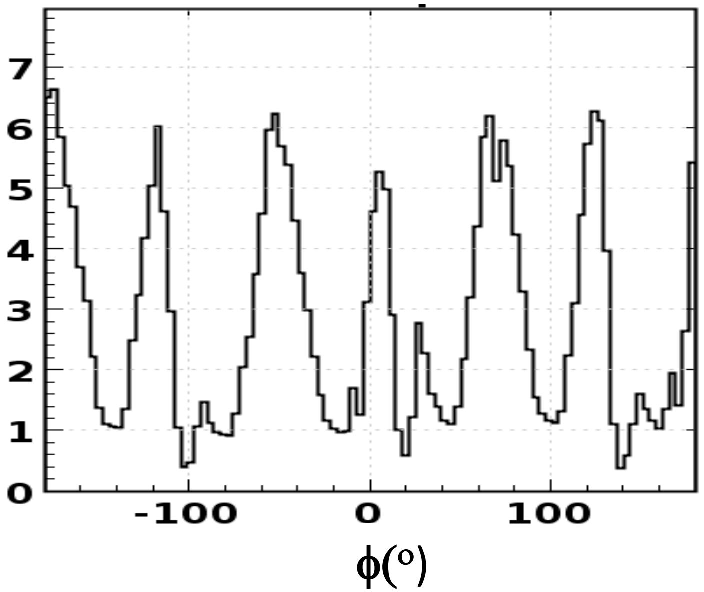
CLAS12 Acceptance Limitations

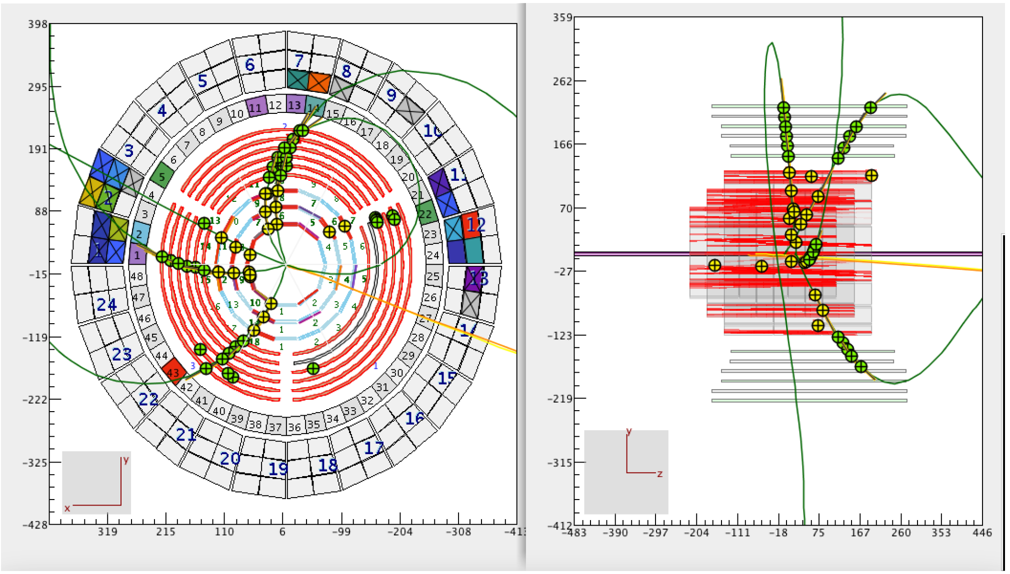
Elastic electrons in FD



Elastic protons in CD matched to electron sector + 180°. Fine structure due to acceptance…

- Need for accurate efficiency correction of the data

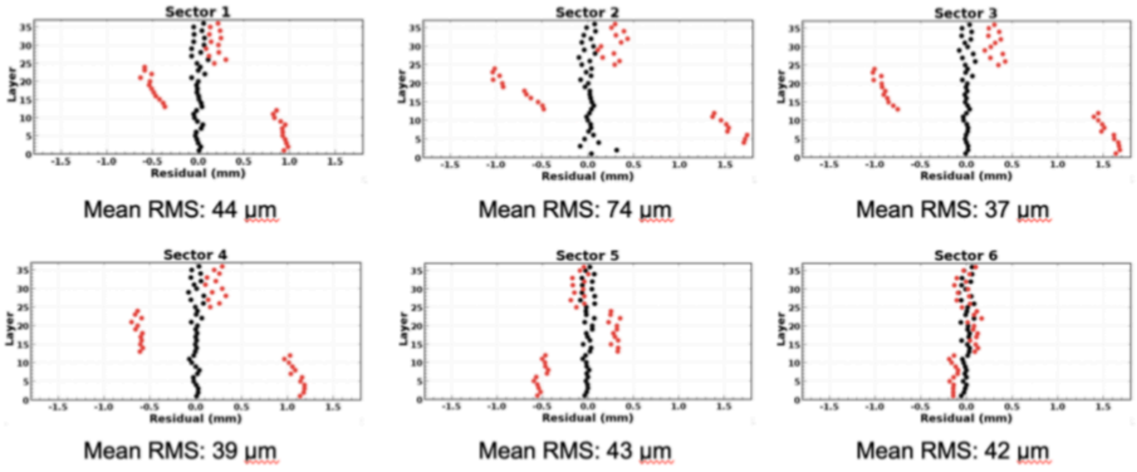


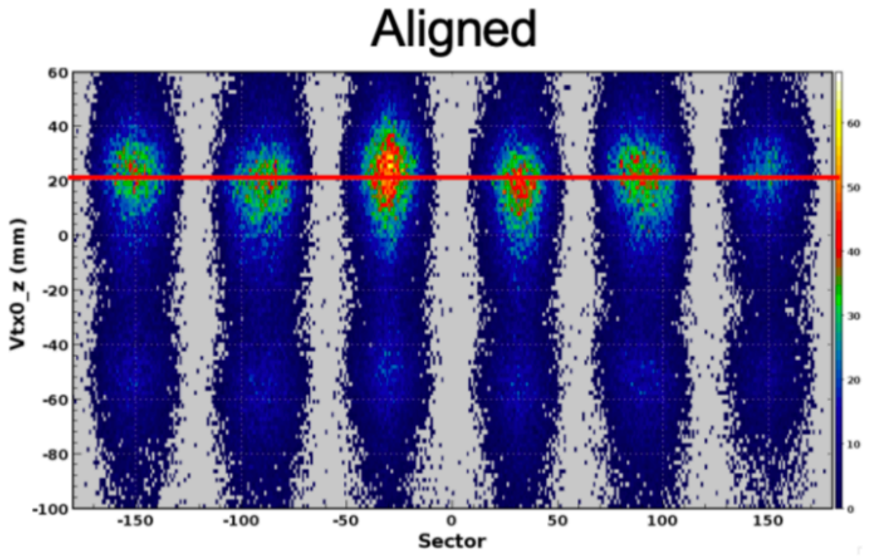


Tracking inefficiency from acceptance limitations

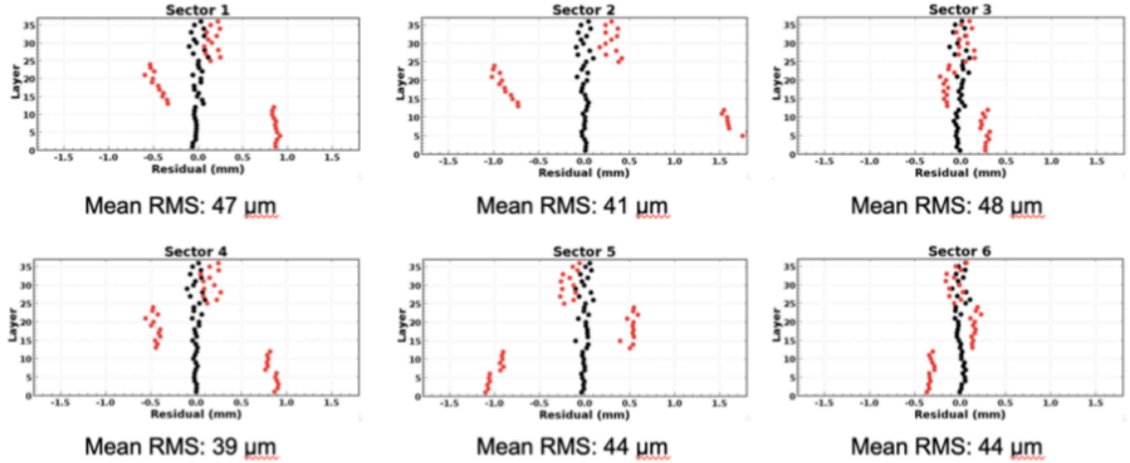
CLAS12 Drift Chambers Alignment

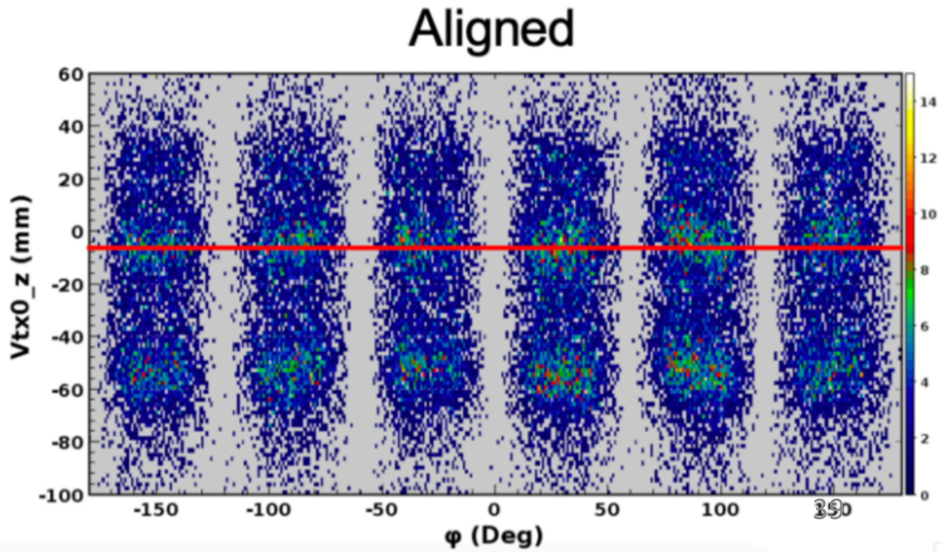
run 2467, Spring Alignment Residuals





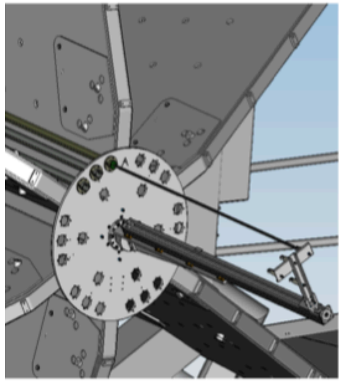
run 5297, Fall Alignment Residuals





CLAS12 Torus Field Mapping

- Measure all components of the TORUS field at 24 positions in the XY plane along 40 positions along the z-axis and calculate the “distortion field”
- Minimize a chi-squared function that compares the measured and modeled “distortion fields” caused by the anticipated movements of the six coils



Visual model of the Hall probe being pushed by a motor along the beam axis inside a non-magnetic Carbon tube

$$\chi^2 = \sum_{pts=1}^{24} \sum_{dim=1}^{3} \left(\frac{\Delta B_{meas}(dim, pts) - \Delta B_{calc}(dim, pts)}{\delta B(dim)} \right)^2$$

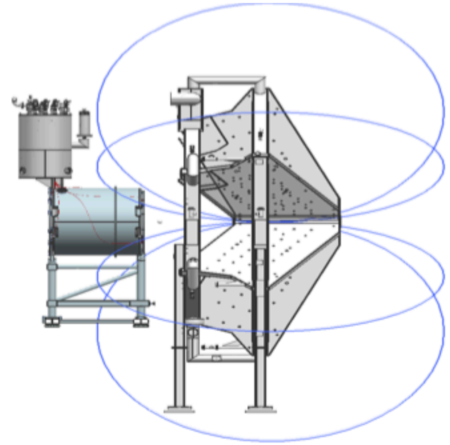
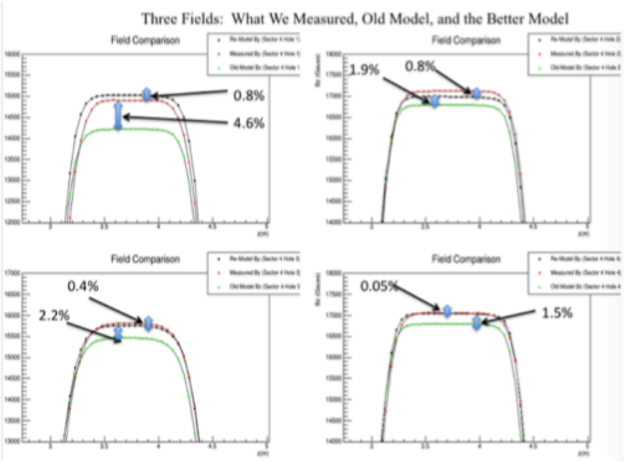


Fig. 1. Schematic of TORUS magnet and direction of the field lines

- Measured data was compared to pre-calculated fields where coils were intentionally moved by a unit distance laterally offset, downstream, and radially outward from the bore.
- Using MINUIT, the coil movements from the designed position are determined by calculating the unit coefficients within the chi-squared function

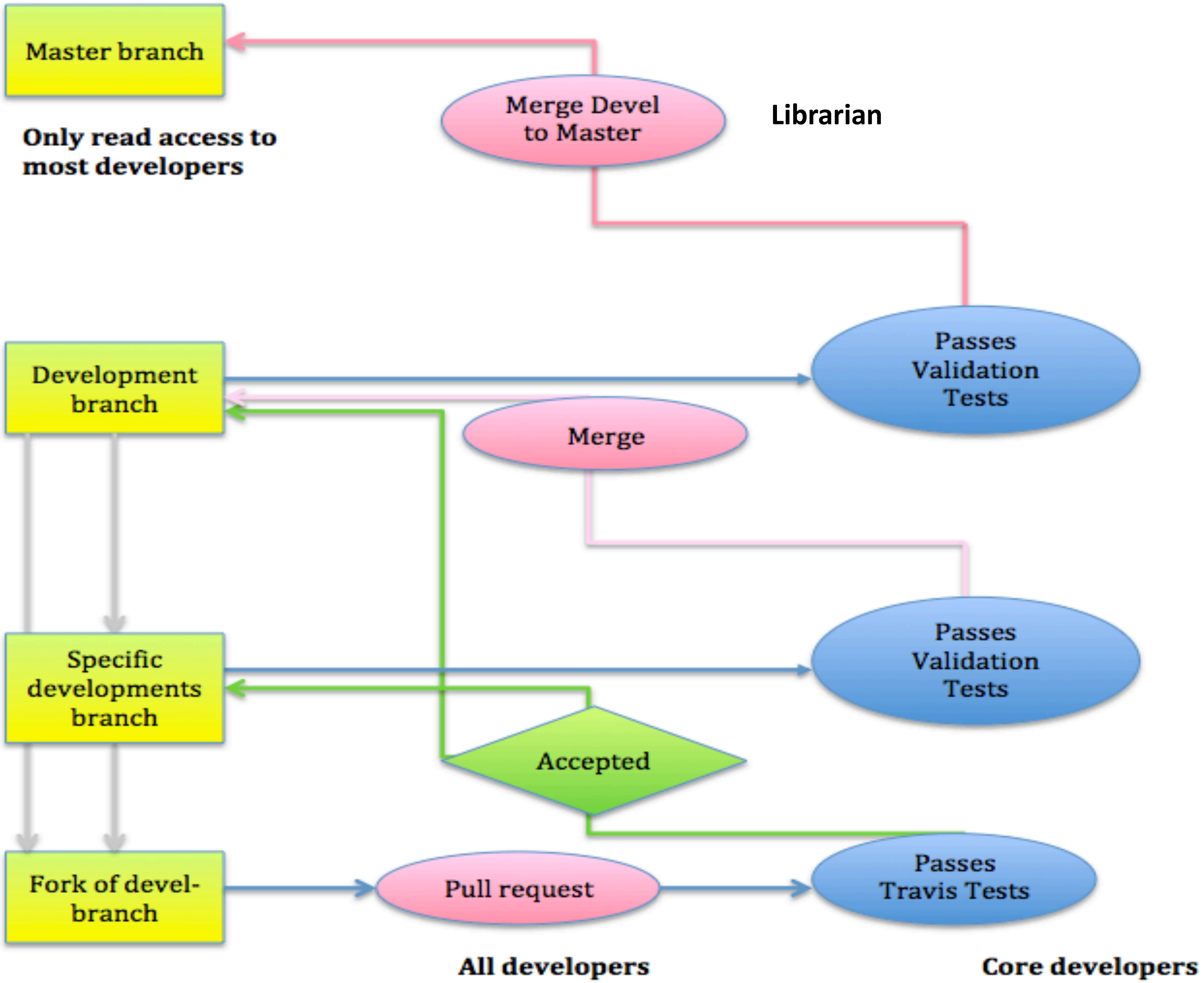


Improvement of new field map (January 2018)

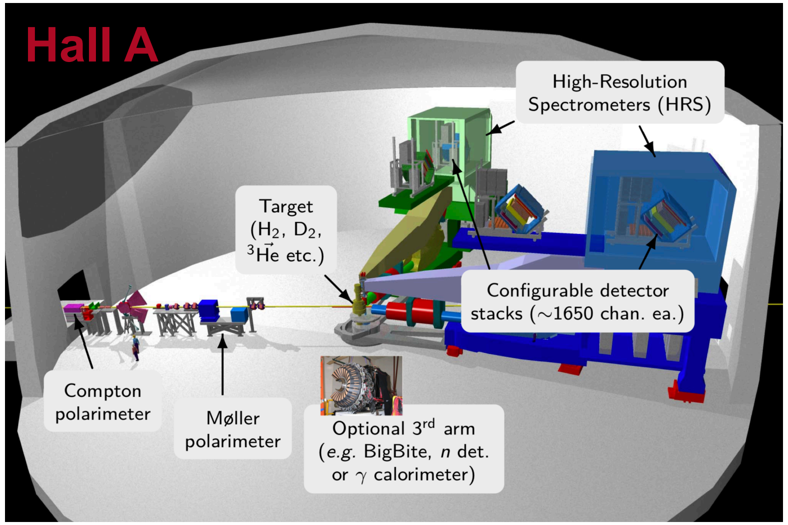
Fit procedure to determine deviations of the coil positions and angular orientations due to manufacturing and installation process

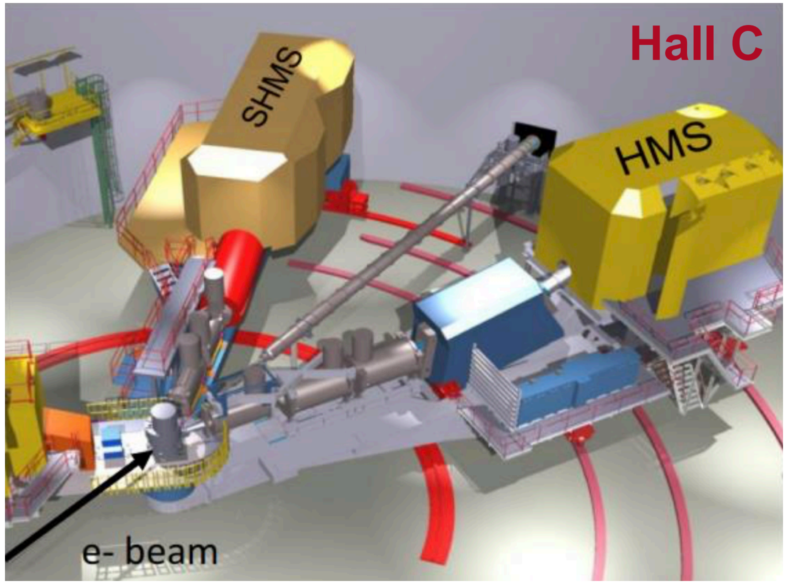
Software Development Management

- clas12-offline software kept under github repository
- Code validation (validation suites, bug finding tool spotBugs) included in Travis build system
- Code development and release tagging scheme
  - release notes
  - issue reporting



Hall A&C





Precision measurements on nucleon structure, form factor, … , and BSM physics:

- High resolution magnetic spectrometers
- Dedicated, experiment-dependent equipment and configuration
- Space for large installation
- Future facilities (Moller, SOLID)

Software and computing:

- Relatively small event size and rate, will grow with future upgrades
- Flexible, plugin-based C++ reconstruction, calibration and analysis framework
  - Highly modular and run-time configurable
  - Large application libraries
  - User-friendly to support large user community and diverse physics goals