Precession Frequency Analysis for Muon g-2

Kim Siang Khaw

Operational Readiness Review

Oct 02, 2017

Charge questions

Item no 4:

*Are there **robust plans** for data processing and **data analysis**? Have adequate **resources** from the laboratory and the **collaboration** been identified for **data analysis** to meet these goals?*

Outline

- Systematic table for ω_a analysis
- Basics of ω_a analysis
- ω_a analysis group structure and org chart
- Data reconstruction and analysis
- Summary

Systematic table*

*Assumed equal distribution of stat. and syst. uncertainties, and of ω_p and ω_a systematics.

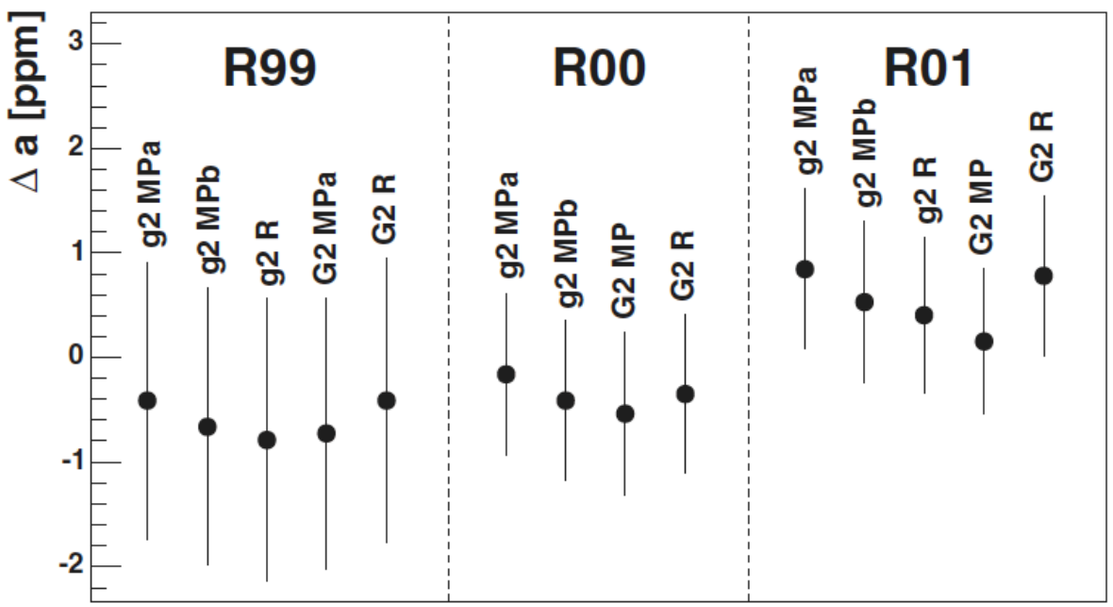
Category	E821 [ppb]	E989 Improvement Plans	E989 [ppb]
Gain changes	120	• Better laser calibration • Low-energy threshold	20
Pileup	80	• Recording low-energy samples • Segmented Calorimeters	40
Lost muons	90	• Better collimation in ring	20
CBO	70	• Higher n value • Better match of beamline to ring	< 30
E and pitch corrections	50	• Improved tracker • High precision storage ring simulation	30
Total	180	**Quadrature Sum for $\delta\omega_a$ (syst.)**	70

$$\delta\omega_a\,(\text{stat.}) \oplus \delta\omega_a\,(\text{syst.}) \oplus \delta\omega_p\,(\text{syst.}) = \delta a_\mu$$

$$100\text{ ppb} \oplus 70\text{ ppb} \oplus 70\text{ ppb} = 140\text{ ppb}$$

The spirit of ω_a analysis

- We are all working towards a single physical quantity - ω_a
  (The analysis is blinded!)
- Each analyzer will produce his/her own value of ω_a
  (Each has an unknown frequency offset!)
- Multiple analyzers expected per publication period
- Systematic uncertainties will also be estimated independently
- After reaching similar sensitivity, appropriate treatments will be applied to obtain a combined final result

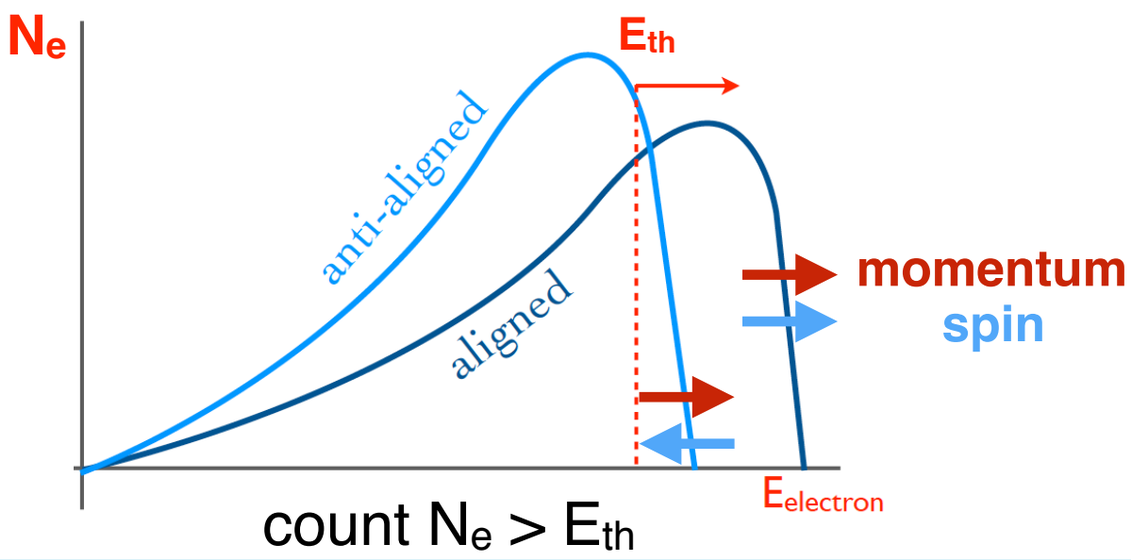


An example distribution of the values from BNL E821 experiment

Basics of ω_a analysis (Threshold)

Six basic steps in extracting ω_a:

1. Construct a histogram with **the number of high energy positron versus time**
2. **Remove pileup events** from the histogram
3. Model the **modulation in acceptance due to beam motions**
4. Model the **muon loss function** that causes the time spectrum to deviate from exponential decay
5. Fit the pileup corrected histogram incorporating models above
6. Apply **pitch** correction and **E-field** correction



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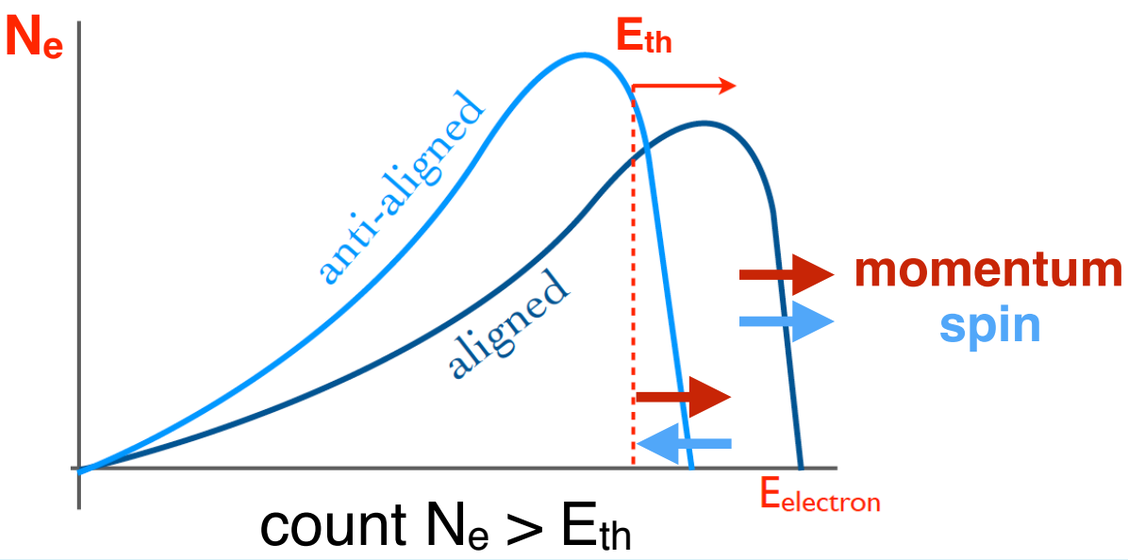

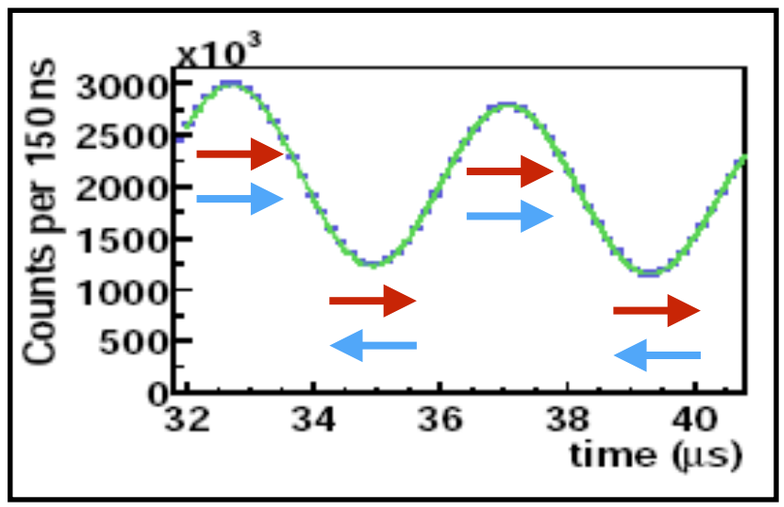

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Basics of ω_a analysis (T)

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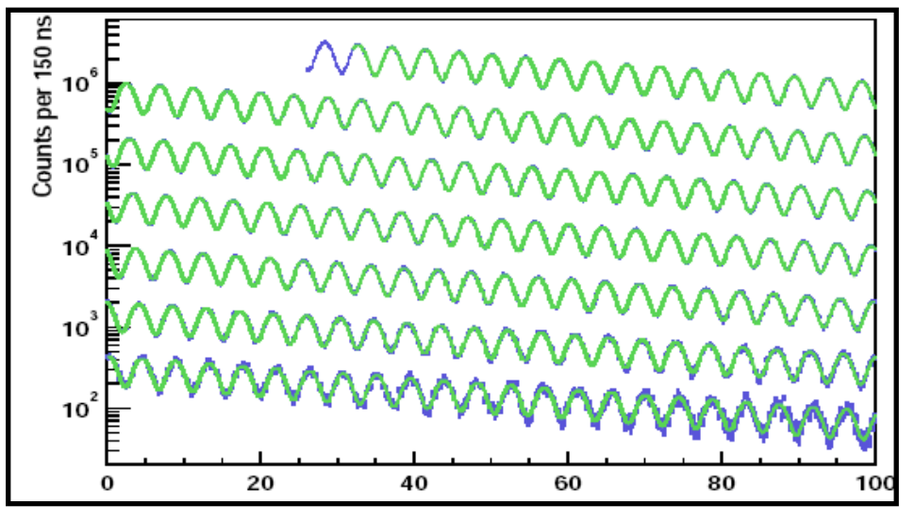

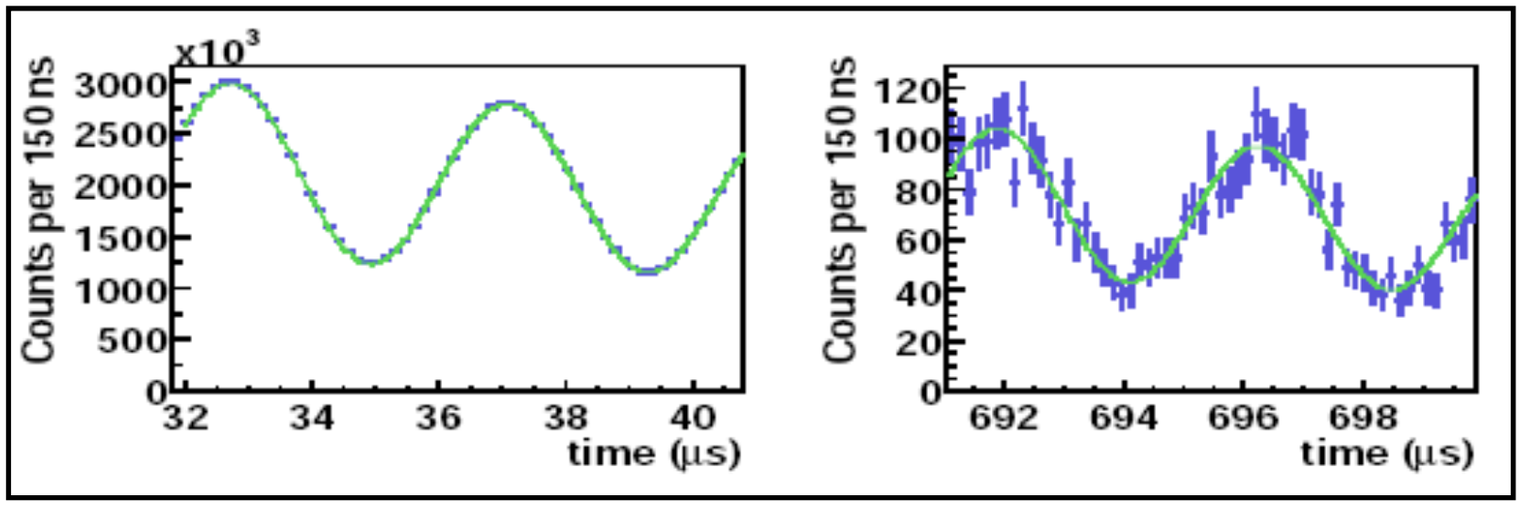

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$$\vec{\omega} = -\frac{q}{m}\left[a_\mu \vec{B} - a_\mu \frac{\gamma}{\gamma+1}(\vec{\beta}\bullet\vec{B})\vec{\beta} + (-a_\mu + \frac{1}{\gamma^2-1})\frac{\vec{\beta}\times\vec{E}}{c} \right]$$

Basics of ω_a analysis (T)

Six basic steps in extracting ω_a:

1. Construct a histogram with **the number of high energy positron versus time** **calo + laser**
2. **Remove pileup events** from the histogram **calo (tracker)**
3. Model the **modulation in acceptance due to beam motions** **calo + fiber harp**
4. Model the **muon loss function** that causes the time spectrum to deviate from exponential decay **calo + tracker**
5. Fit the pileup corrected histogram incorporating models above
6. Apply **pitch** correction and **E-field** correction **calo + fiber harp + tracker**

All detectors work together for a complete analysis!
Independent algorithms for cross checks are planned.

ω_a analysis group structure

Reconstruction groups

- Laser Calibration
- T-method Recon East
- T-method Recon West
- Q-method Recon
- Tracker Recon
- Aux. Det. Recon

ω_a analysis group structure

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Analysis groups

(strongly overlaps with above)

- Multi-Param Fitting
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- Muon Distribution
- Muon Distribution & Beam Dynamics
- Ratio Fitting
- μEDM
- CPT/LV
- Muon Losses

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Analysis groups

(strongly overlaps with above)

ω_a analysis organization chart

Co-coordinators
Khaw (UW)
Lancaster (UCL)

Recon East + A
Polly (FNAL)
Sweigart (Cornell)

- Lyon (FNAL)
- Stapleton (FNAL)
- Gibbons (Cornell)
- Duncan (Cornell)
- Schlesier (UIUC)

Recon West + A
Hertzog (UW)
Fienberg (UW)

- Khaw (UW)
- Hempstead (UW)
- Binney (UW)
- Li (L) (SJTU)
- Li (D) (SJTU)
- Li (B) (SJTU)
- Wu (UMiss)

Q-method + A
Gohn (UK)

- Gorringe (UK)
- Fatemi (UK)
- Kelton (UK)
- Han (UK)

Tracker Recon
Mott (BU)

- Walton (FNAL)
- Luca (FNAL)
- Lukicov (UCL)
- Halewood-Leagas (Liverpool)
- Boyden (NIU)
- Sathyan (BU)
- Carey (BU)
- Linehan (BU)

Muon Distribution
Tran (BU)

μEDM
Price (Liverpool)

Ratio Fitting
Roberts (BU)
Chislett (UCL)

- Kinnaird (BU)
- Mott (BU)
- Albahri (Liverpool)

Muon Losses
Ganguly (UIUC)

- Fry (UVa)

Laser Calibration + A
Venanzoni (INFN)
Incagli (INFN)

- Driutti (Udine)
- Raha (INFN)
- Luisiani (INFN)
- Smith (INFN)

CPT/LV
Quinn (UMiss)

- Bhattacharya (UMiss)

Aux. Det. Recon + A
Gray (Regis)
Chapelain (Cornell)

- Bjorkquist (Cornell)
- Kammel (UW)
- MacCoy (UW)

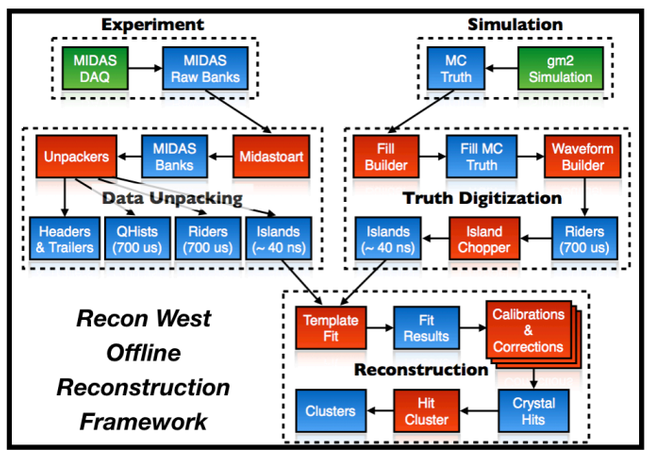
Data reconstruction & analysis chain

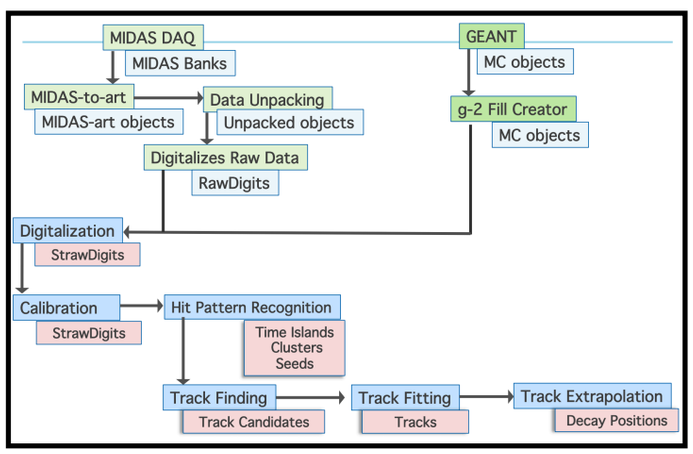
- Follow HEP-style work flow
- Adopt Fermilab's *art* framework
- High-level messages:

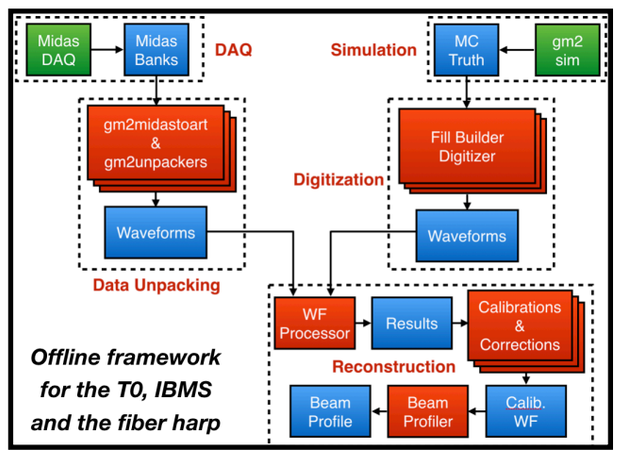
  *- **Full chain reconstruction** (from DAQ data to physics objects) established since 2+ years ago by the **tracker group***

  *- **Calorimeter and fiber harp chains** were tested rigorously at a SLAC test beam 2016 and the FY17 commissioning run*

  *- **IBMS and T0** chain were integrated into the framework during FY17 run*



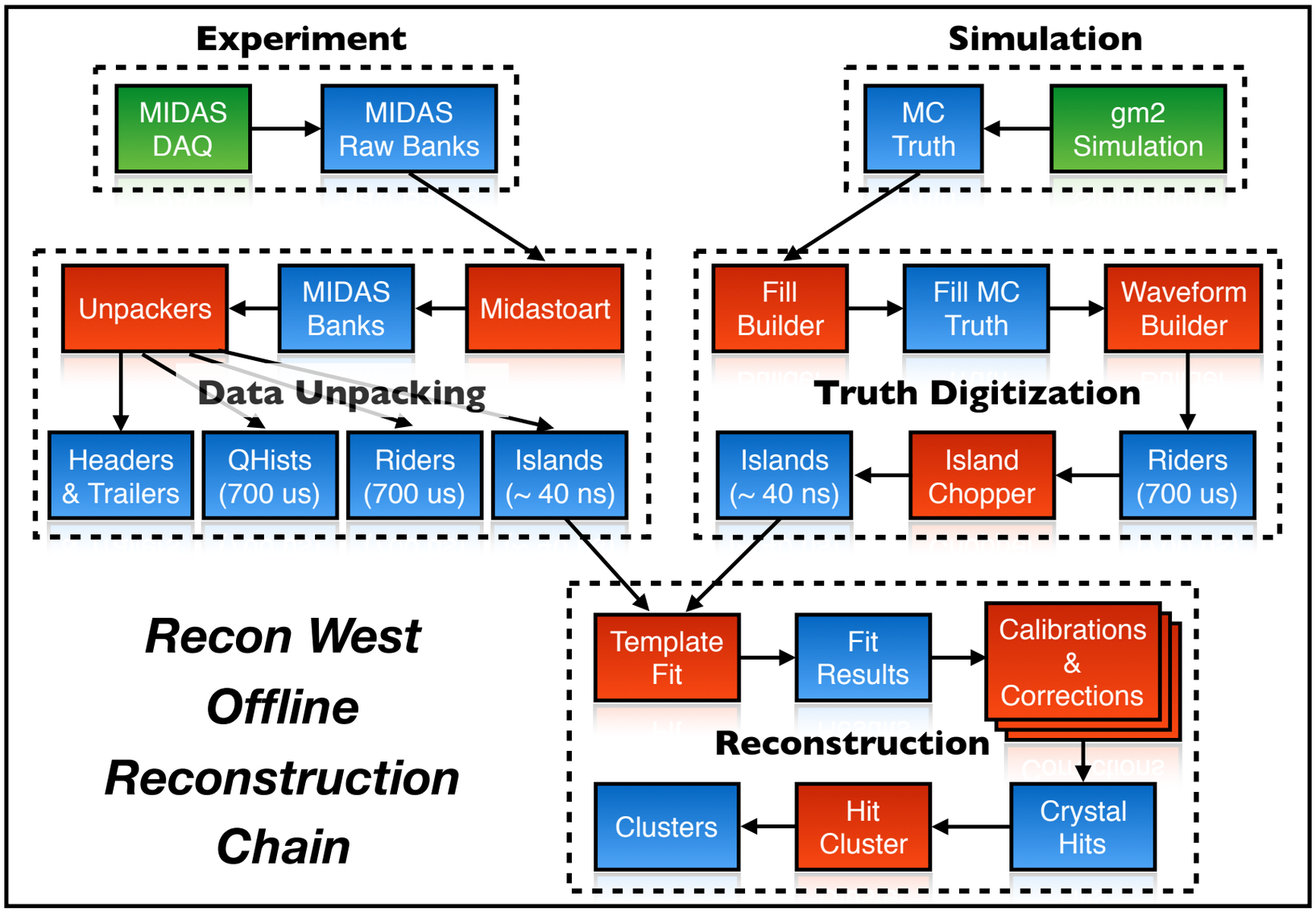




All detectors integrating into a single framework!

Data Reconstruction: Calorimeter

- Baseline plan: Standard T-method Approach (Recon West)
  - *template fitting —> energy calibration —> hit clustering —> positron candidate*
  - *well verified using mock data, SLAC test beam and commissioning run data*
  - ***ready for FY18 data reconstruction and analysis***



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- Complementary plan 1: Global T-method Approach (Recon East)
  - ***independent algorithm to compare to the Recon West approach***
  - *fitting and clustering combined into a single step to directly solve for the positron's time, energy, position, and angle*
  - ***still work in progress, to be ready for FY18 final analysis***

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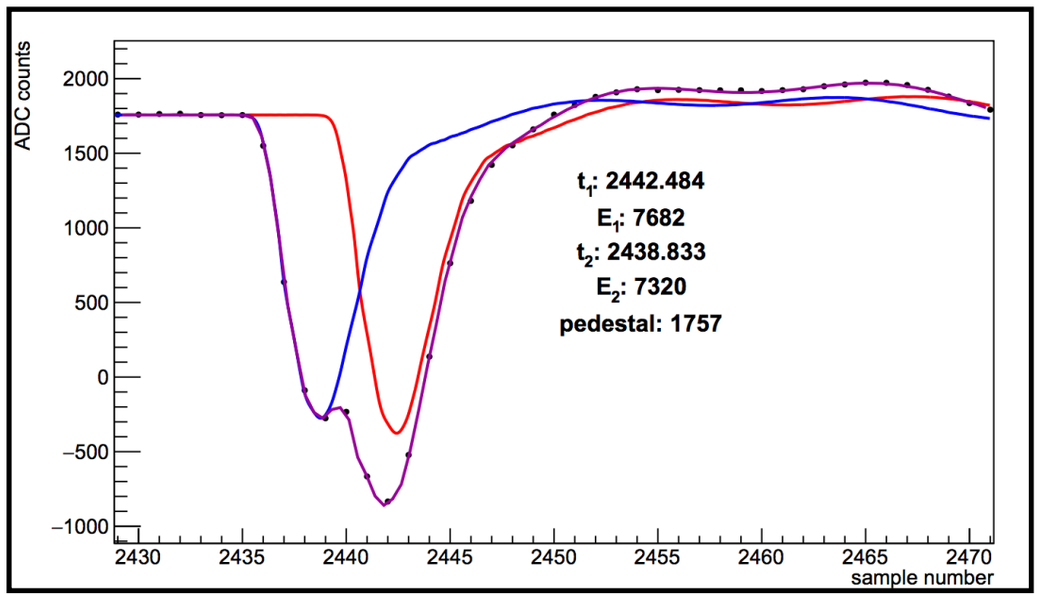
Threshold

- Complementary plan 2: Q-method reconstruction
  - ***study total decay energy as a function of time***
  - *no island chopping —> accumulate histograms of each channel*
  - *free from systematics like positron pile up*
  - ***still work in progress, to be ready for FY18 final analysis***

Charge

Data Reconstruction: Calorimeter

- Pulse fitting (*pulse —> pulse integral + time*)

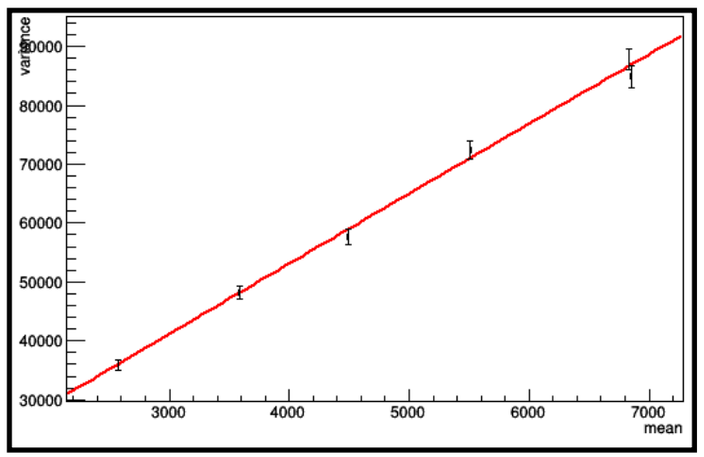


fast signal + fast digitizer +
template fit technique
= reduced pile up

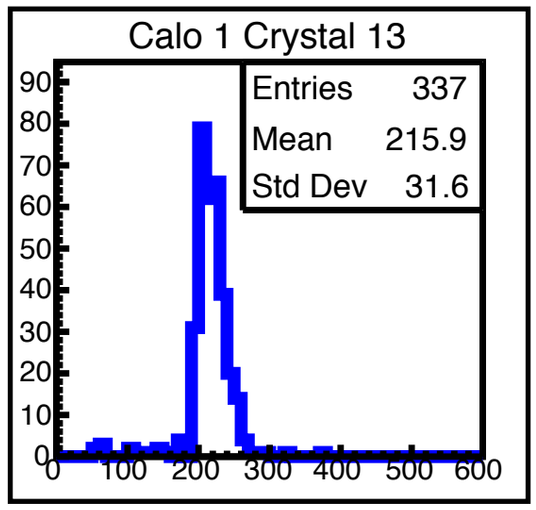
100% separation if Δt > 4 ns

Data Reconstruction: Calorimeter

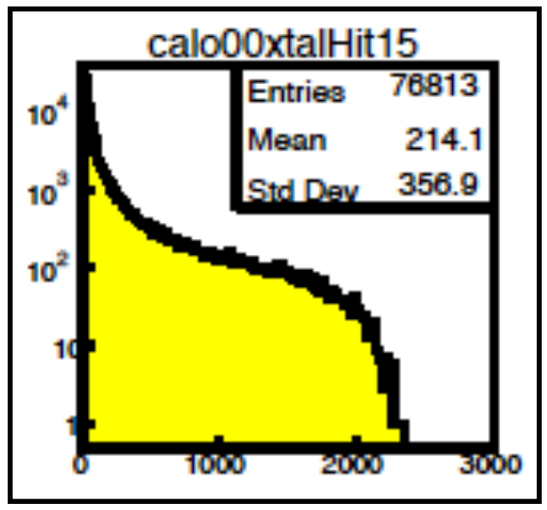
- Gain and energy calibration (*pulse integral —> #photoelectron —> MeV*)



laser calibration technique (photo-statistics)



MIP peak (loss muon)



Spectrum end-point

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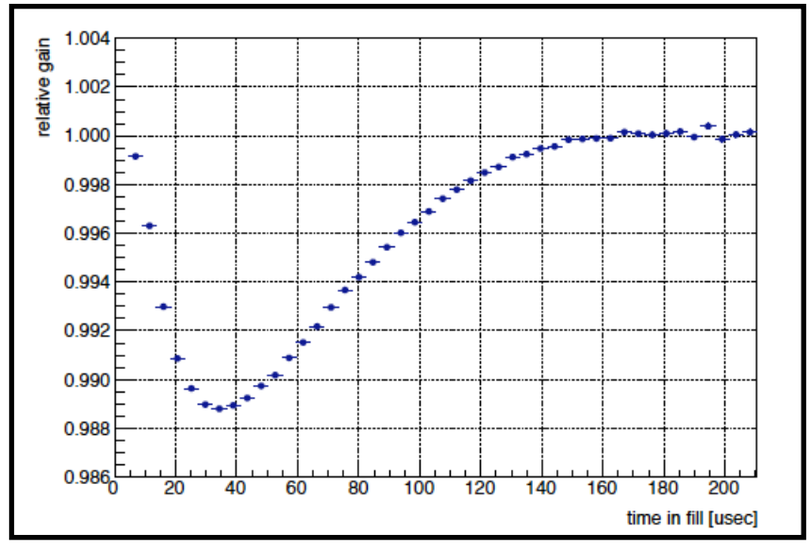
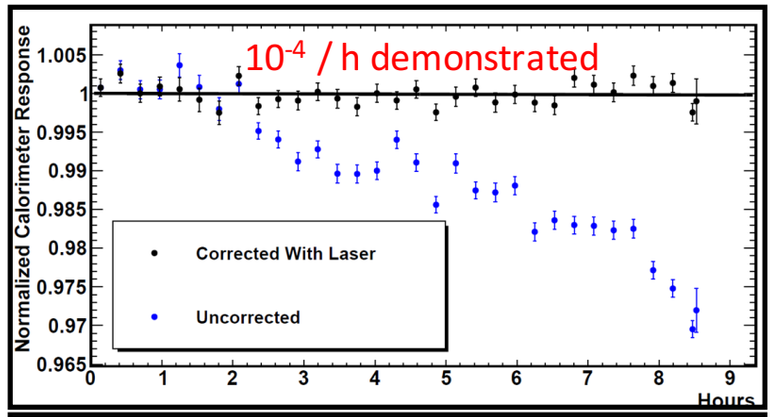
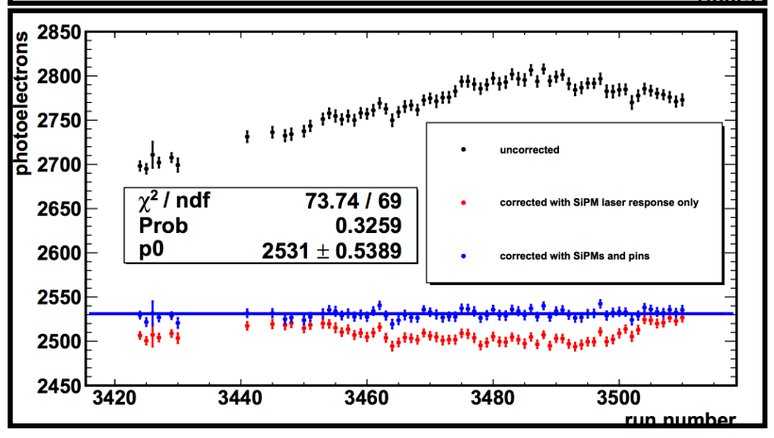
Data Reconstruction: Calorimeter

- Laser gain correction (in-fill)
  - *most important part of gain systematic*
  - *technique established at UW lab and at SLAC test beam 2016*
  - *analysis on-going for commissioning run data*
  - *robust plan in place for in-fill laser sequence*



- Laser gain correction (inter-fill)
  - *correct for long term gain drift*
  - *technique established at Frascati test beam 2016 and SLAC test beam 2016*
  - *analysis on-going for commissioning run data*
  - *robust plan in place for inter-fill laser sequence*





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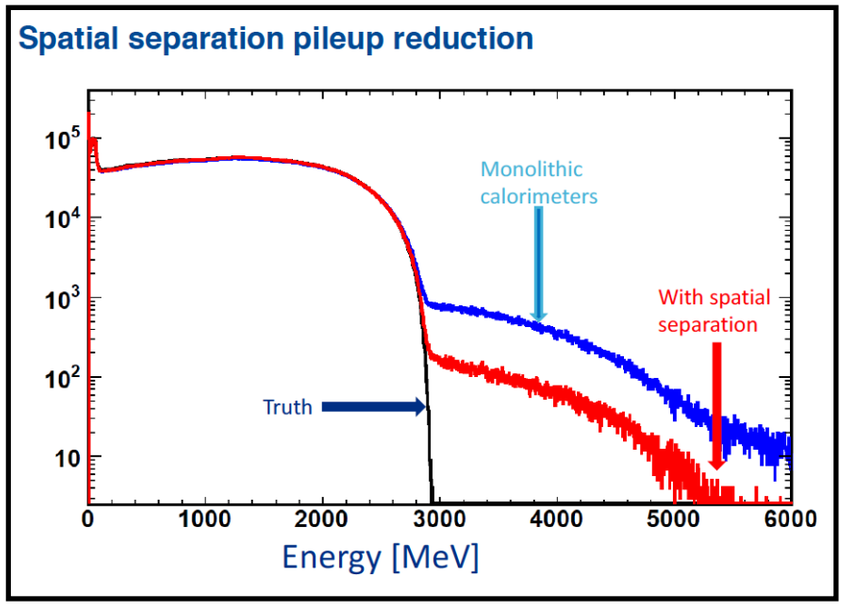
Data Reconstruction: Calorimeter

- Hit clustering: *(calibrated hits —> clusters —> positron candidate)*



A robust algorithm with timing and spatial separation —> reduced pileup

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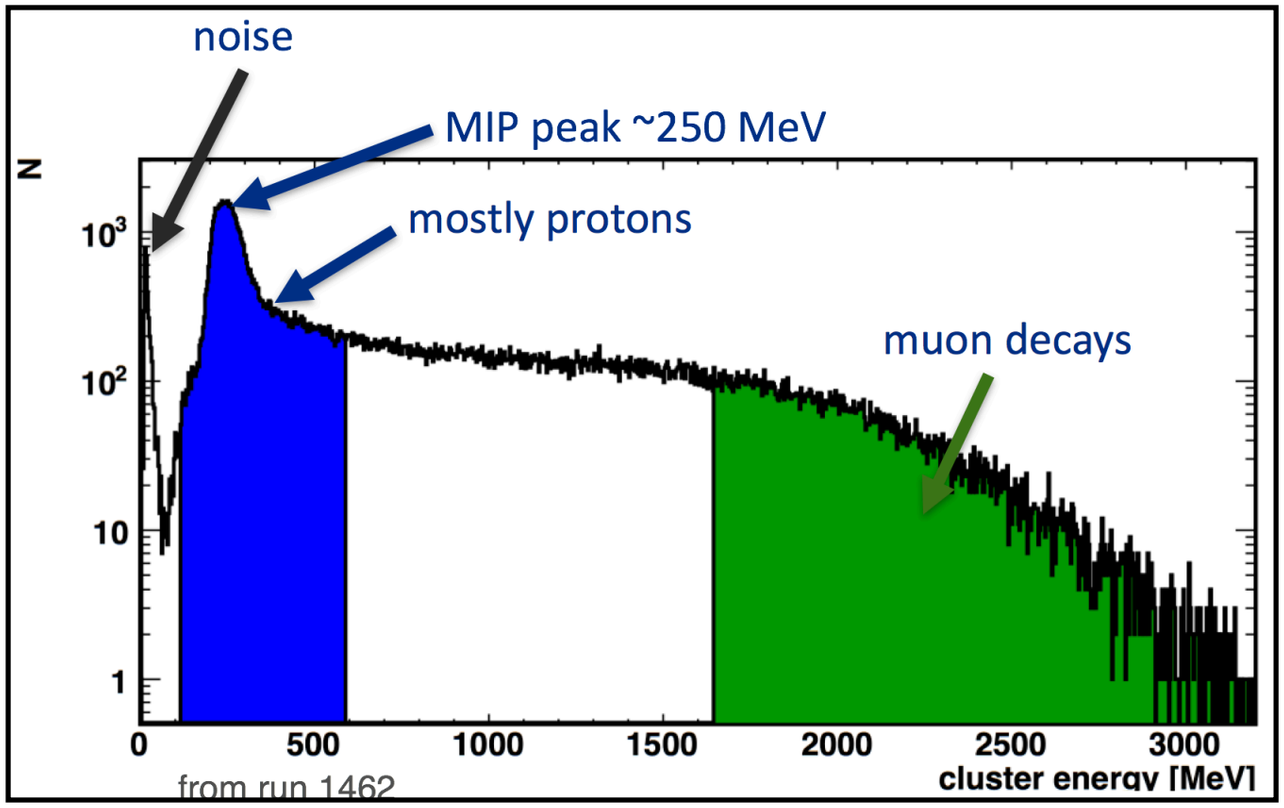
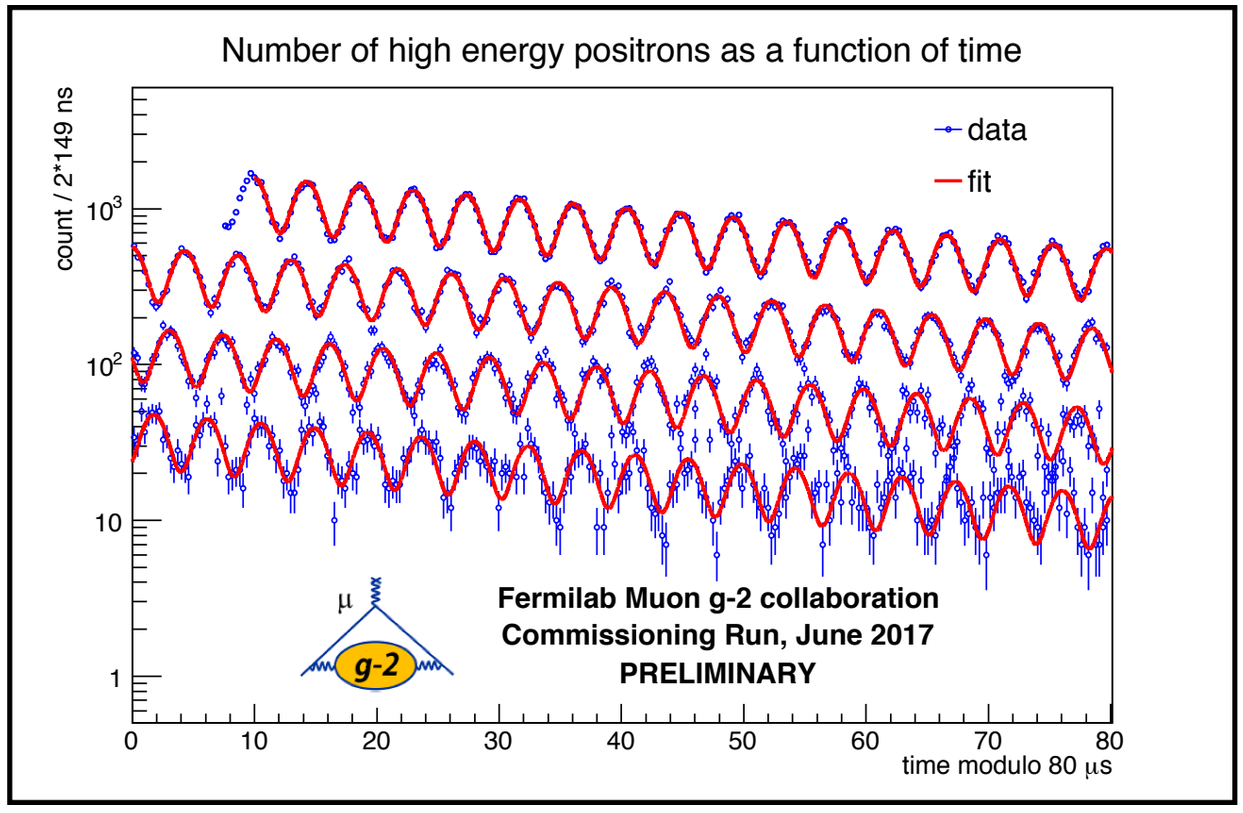


Energy spectrum from FY17



Time spectrum from FY17

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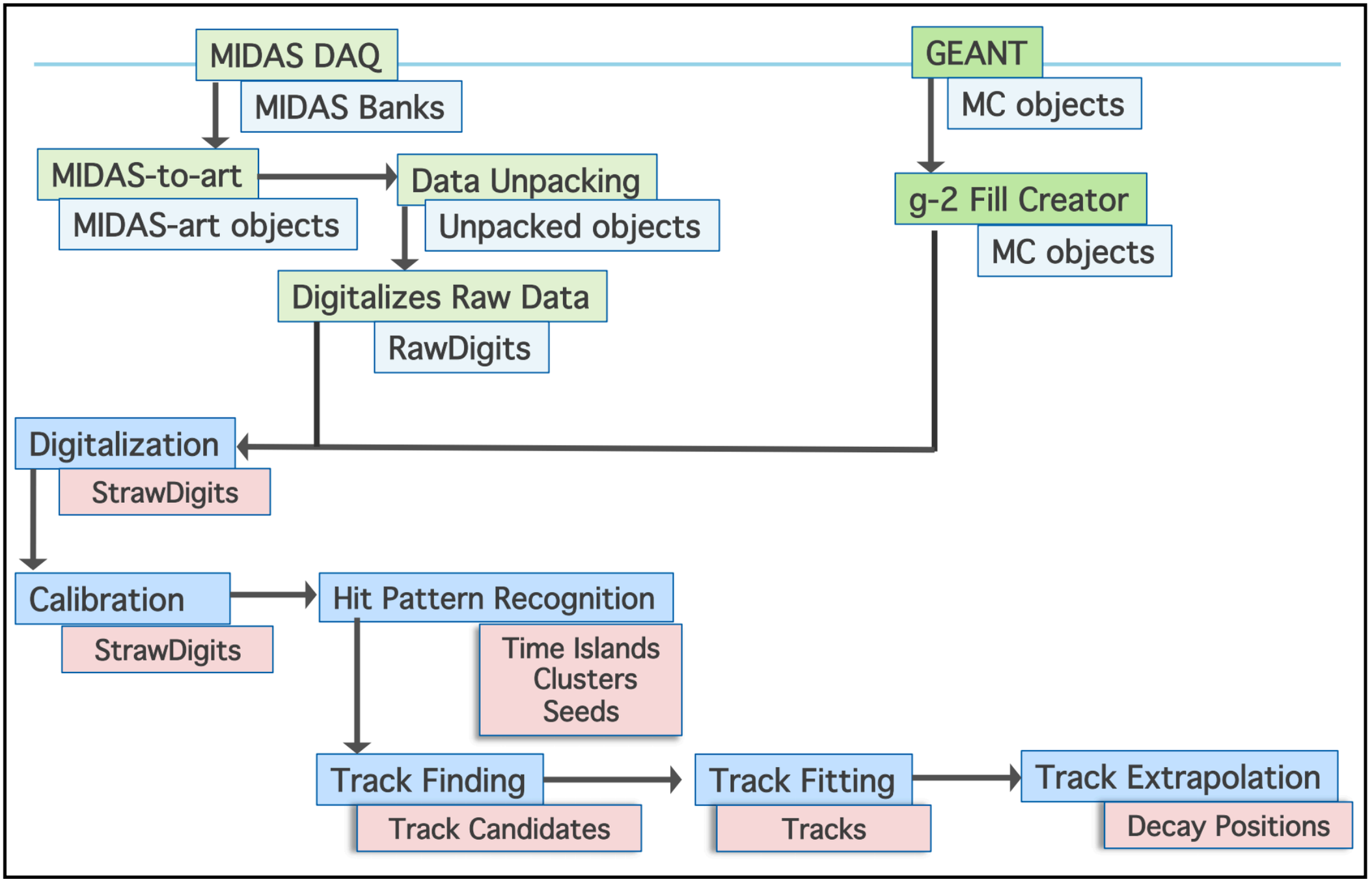
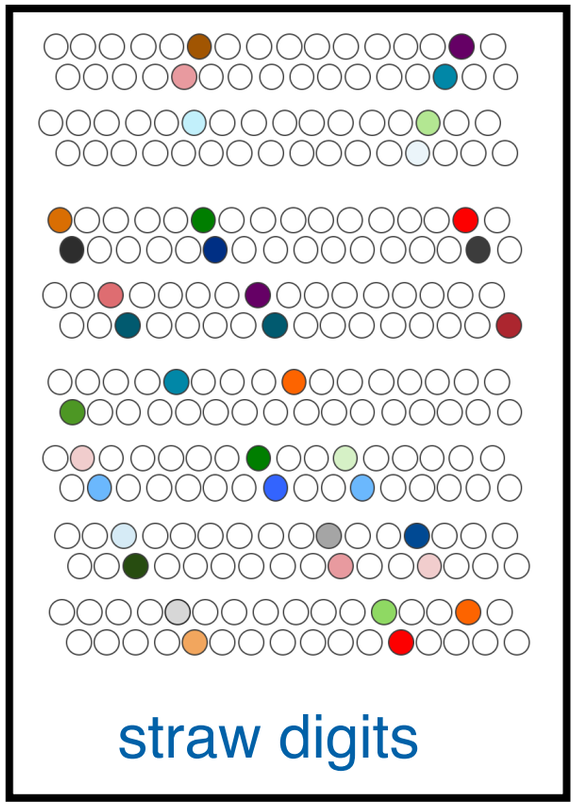
Data Reconstruction: Trackers



Data Reconstruction: Trackers

- Hit pattern recognition (*straw digits —> time islands —> clusters —> seeds)*



straw digits

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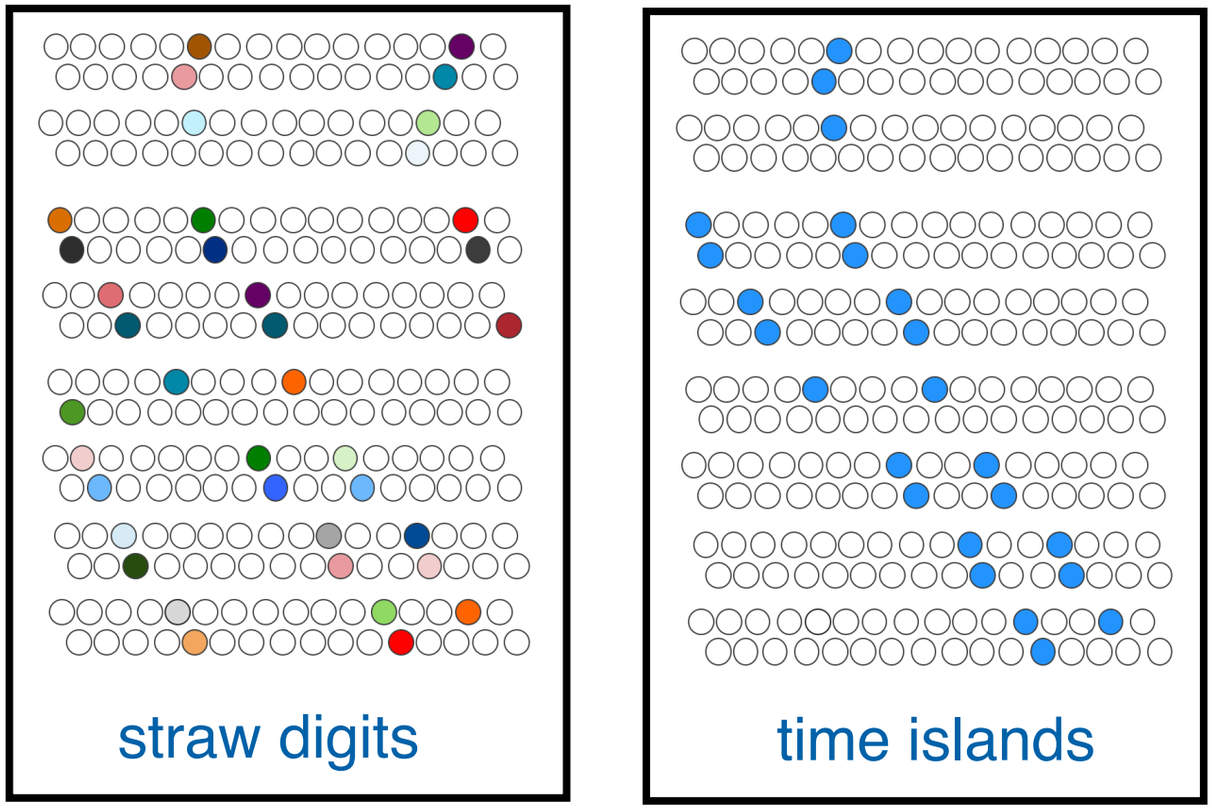

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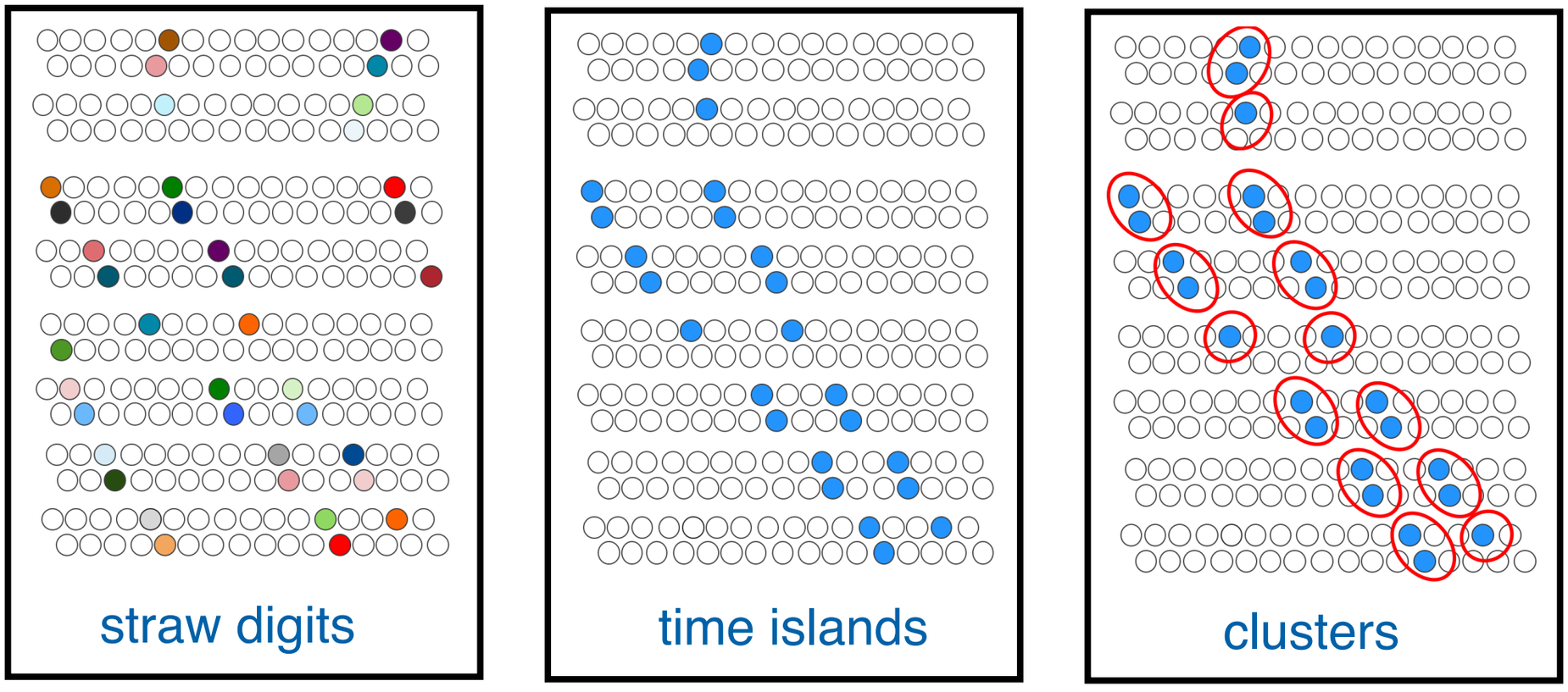

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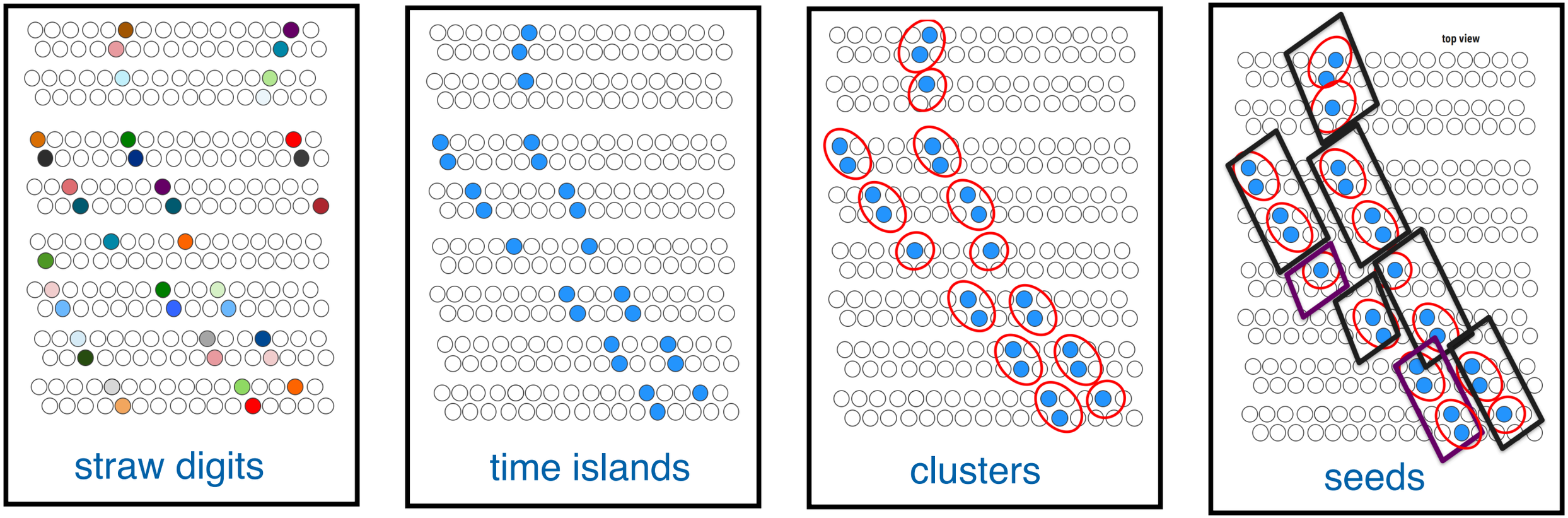
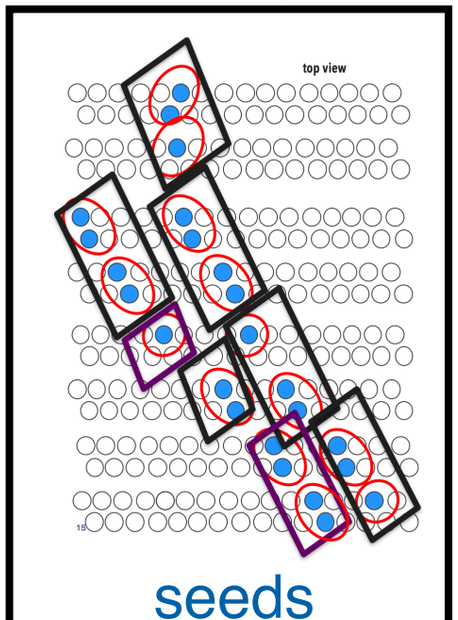
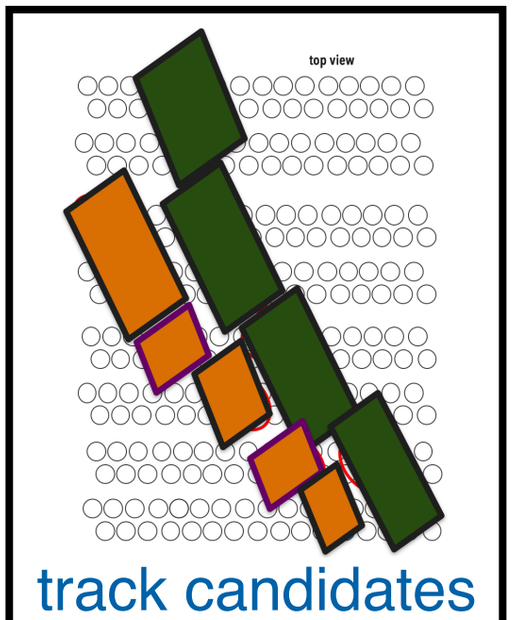


Data Reconstruction: Trackers

- Track finding (*seeds —> track candidates*)



group neighboring seeds



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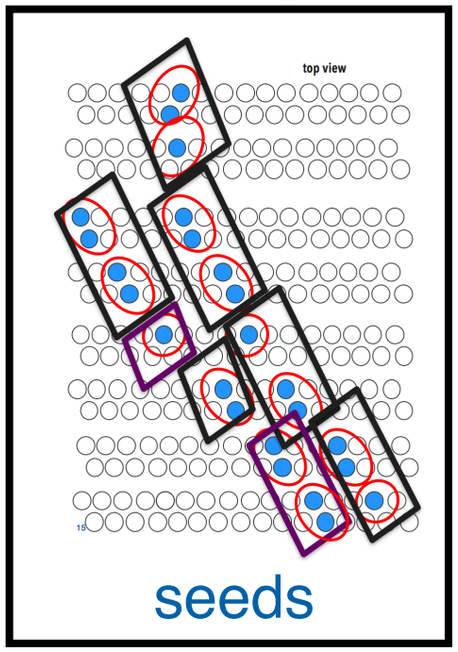

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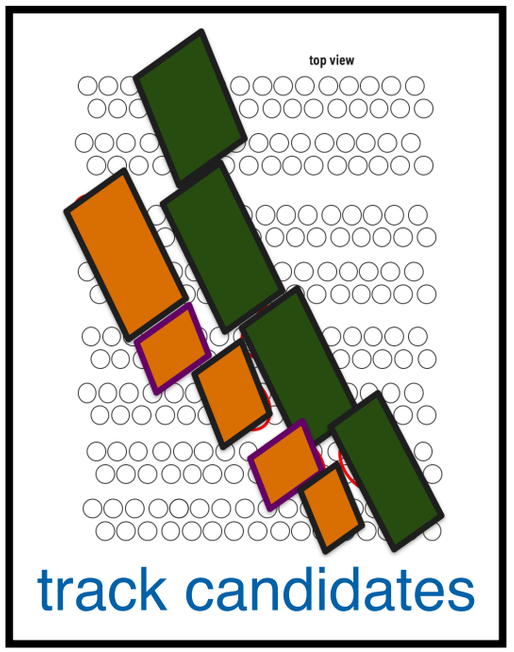
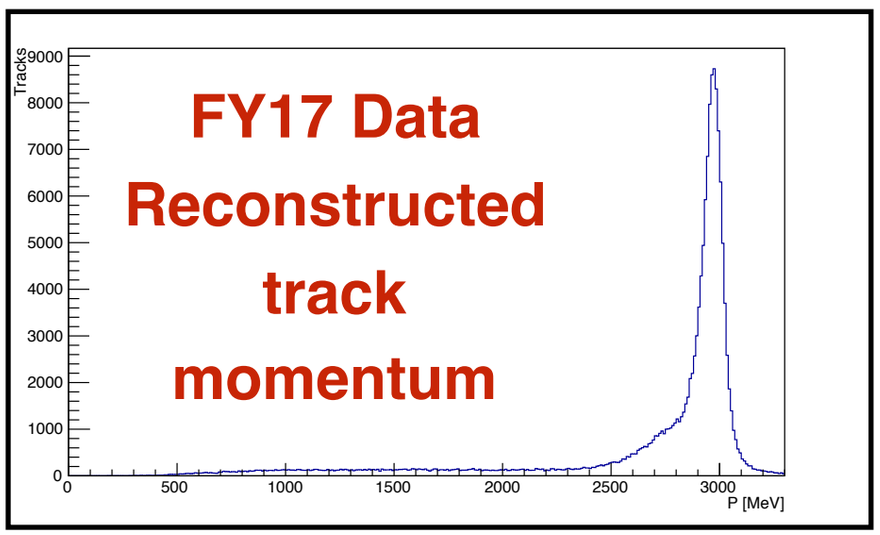
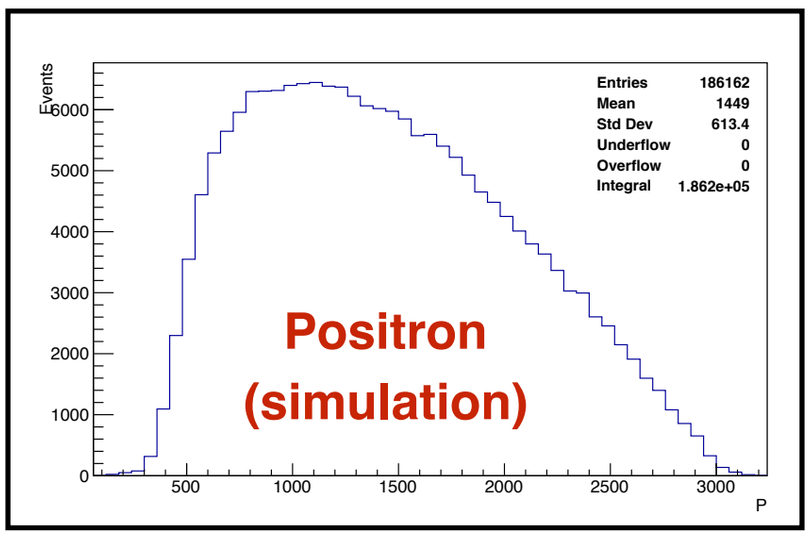
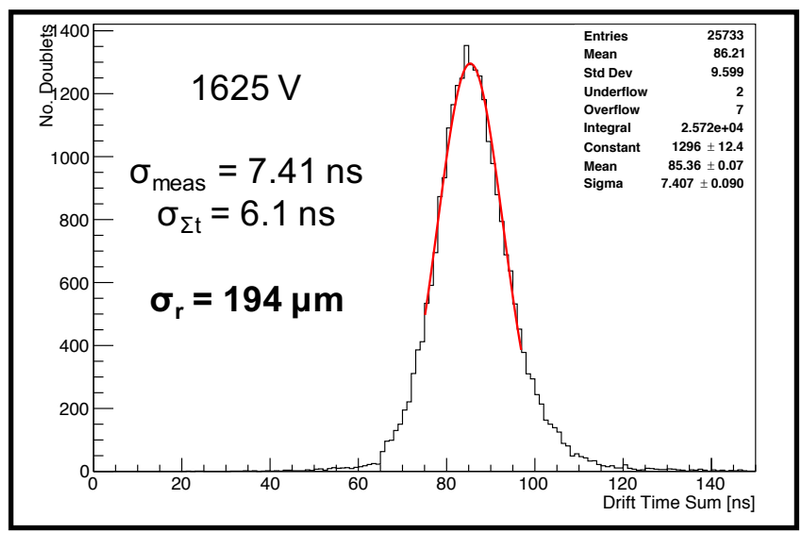


- Track fitting (*track candidates —> tracks*)
  - GEANE fitting algorithm (least squares global chi2 minimization)







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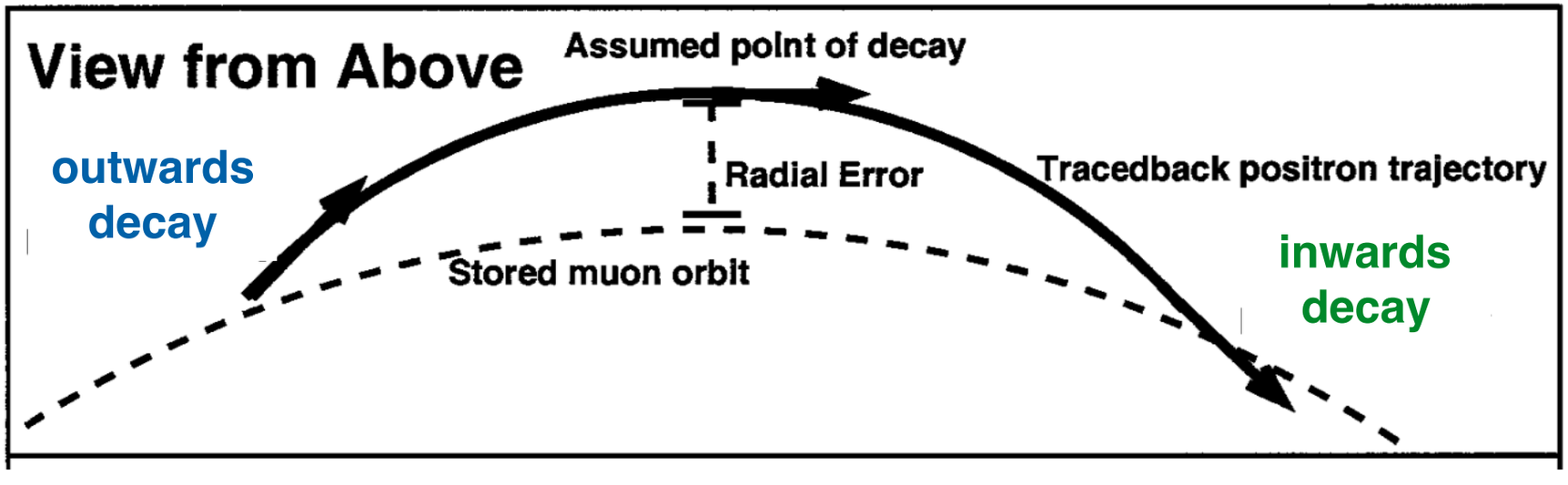
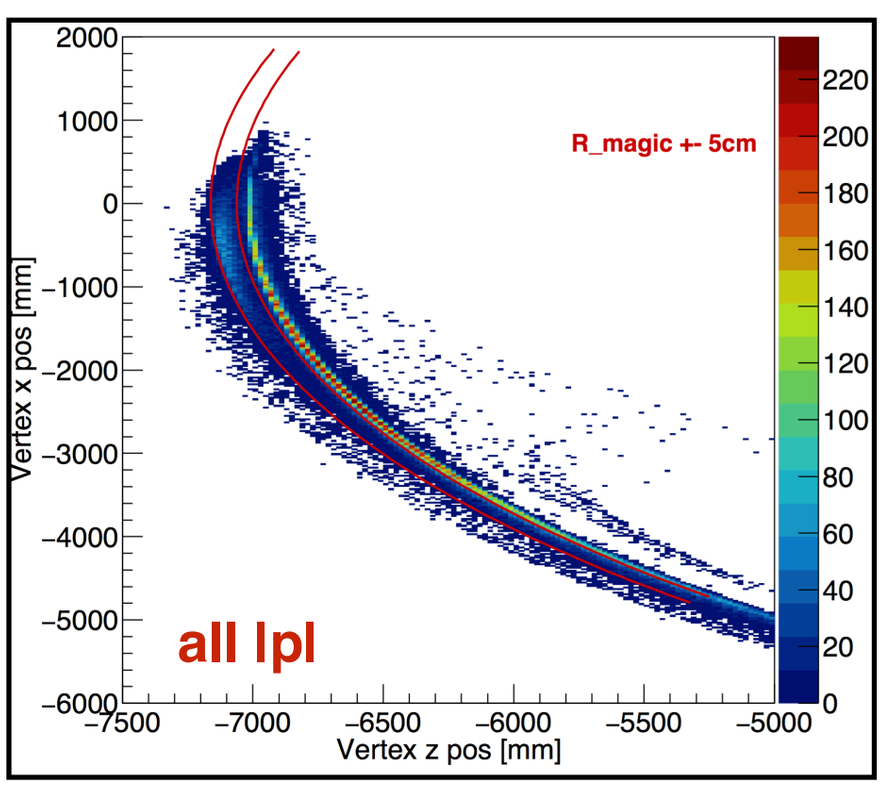
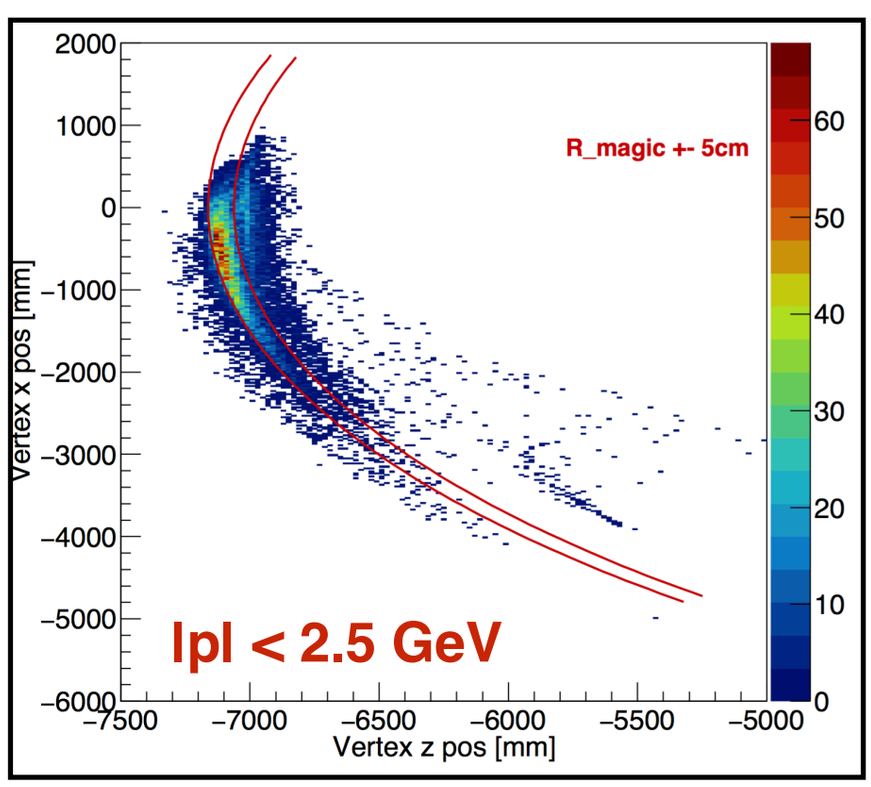
Data Reconstruction: Trackers

- Track extrapolation *(tracks —> tangency point —> decay position)*







- First pass correction from tangency point to decay position done
- Outwards and inwards decays have similar acceptance

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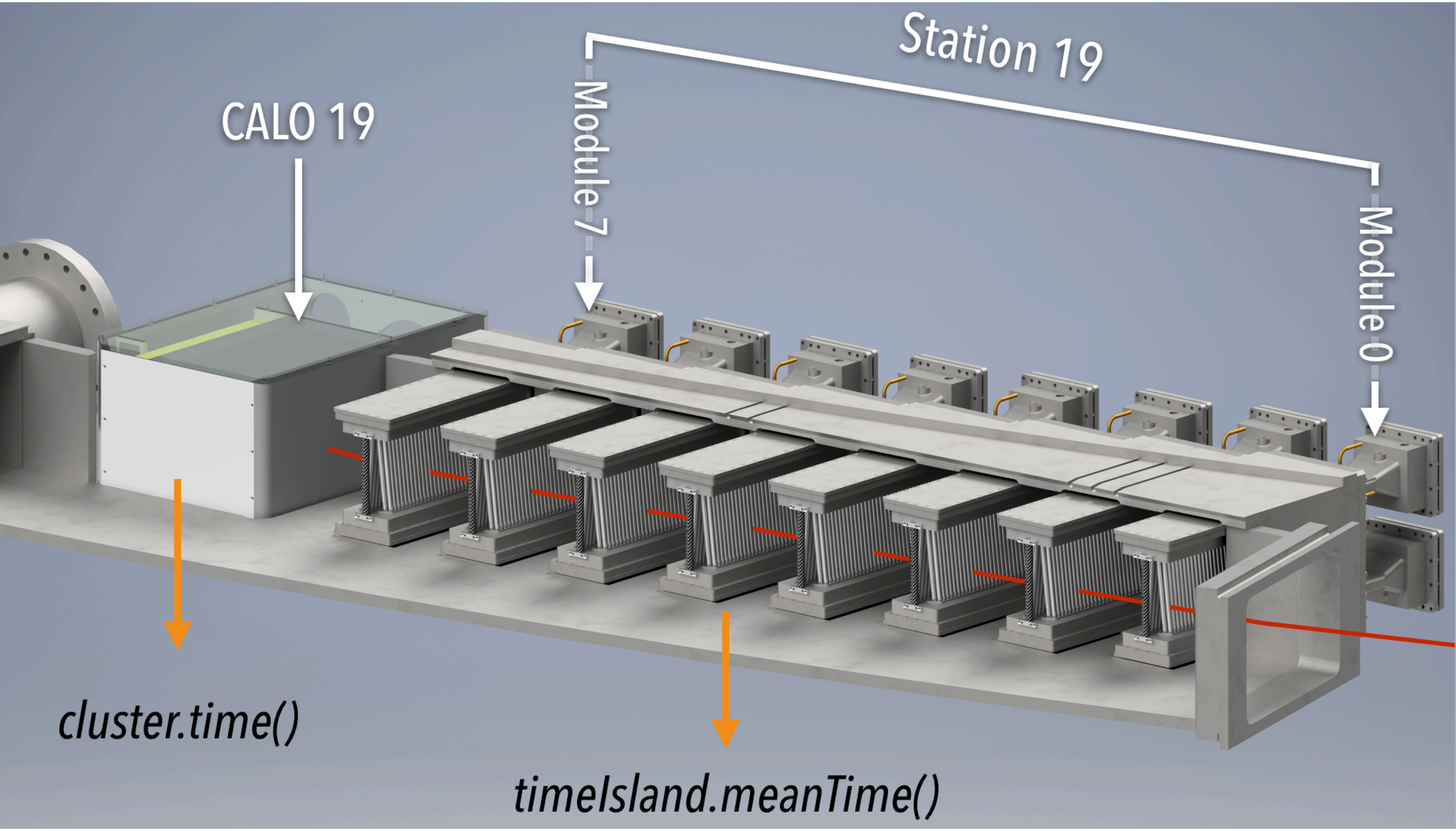
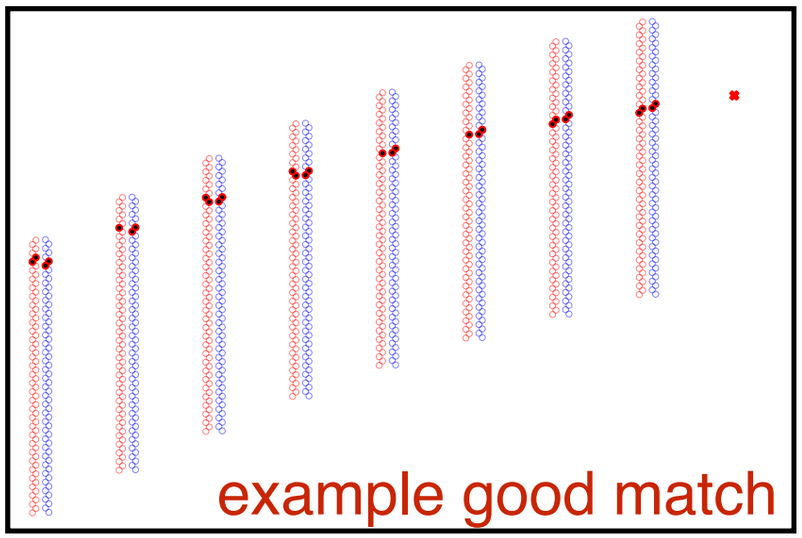
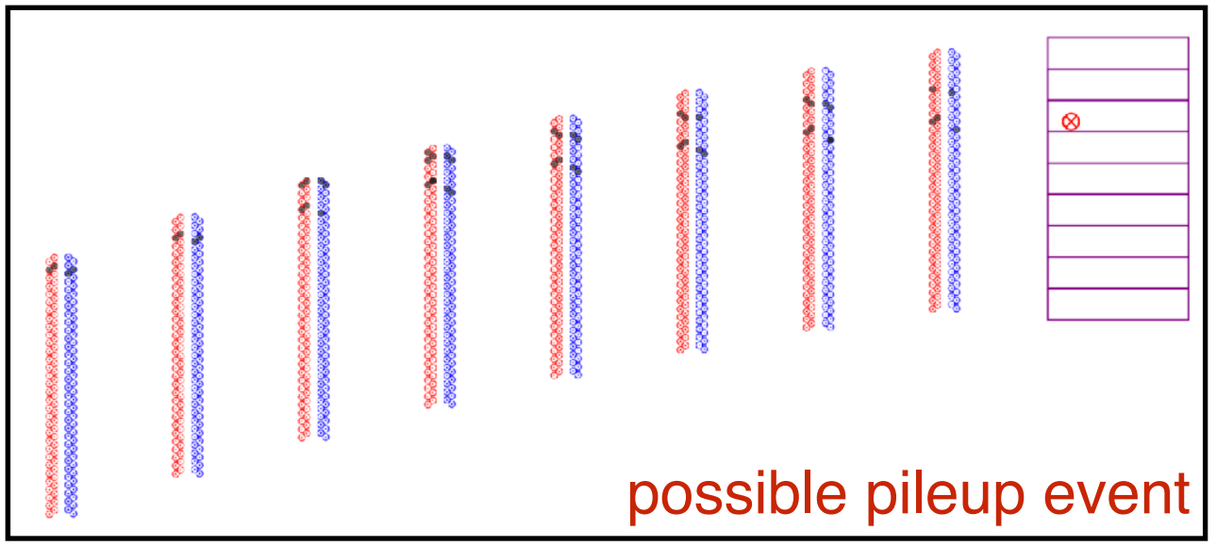
Calorimeter - tracker matching

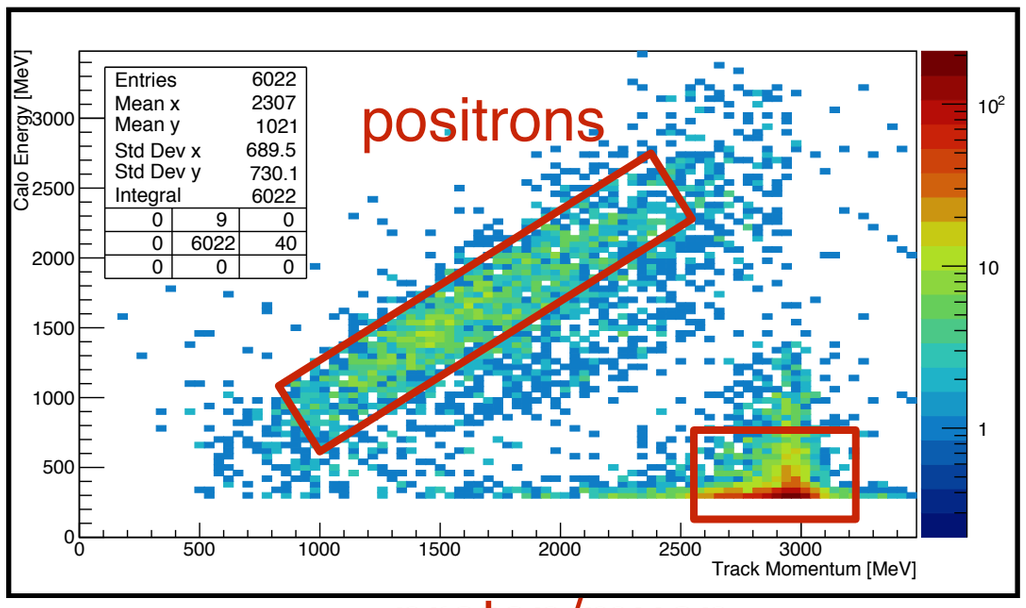


Calorimeter - tracker matching

- Cross calibration of energy and momentum
- Particle identification (muon or positron)
- Pileup identification (help understanding pileup events in calo)


example good match


possible pileup event



positrons

proton/muon

A lot of exciting works and collaboration are going on here to understand our commissioning run data!

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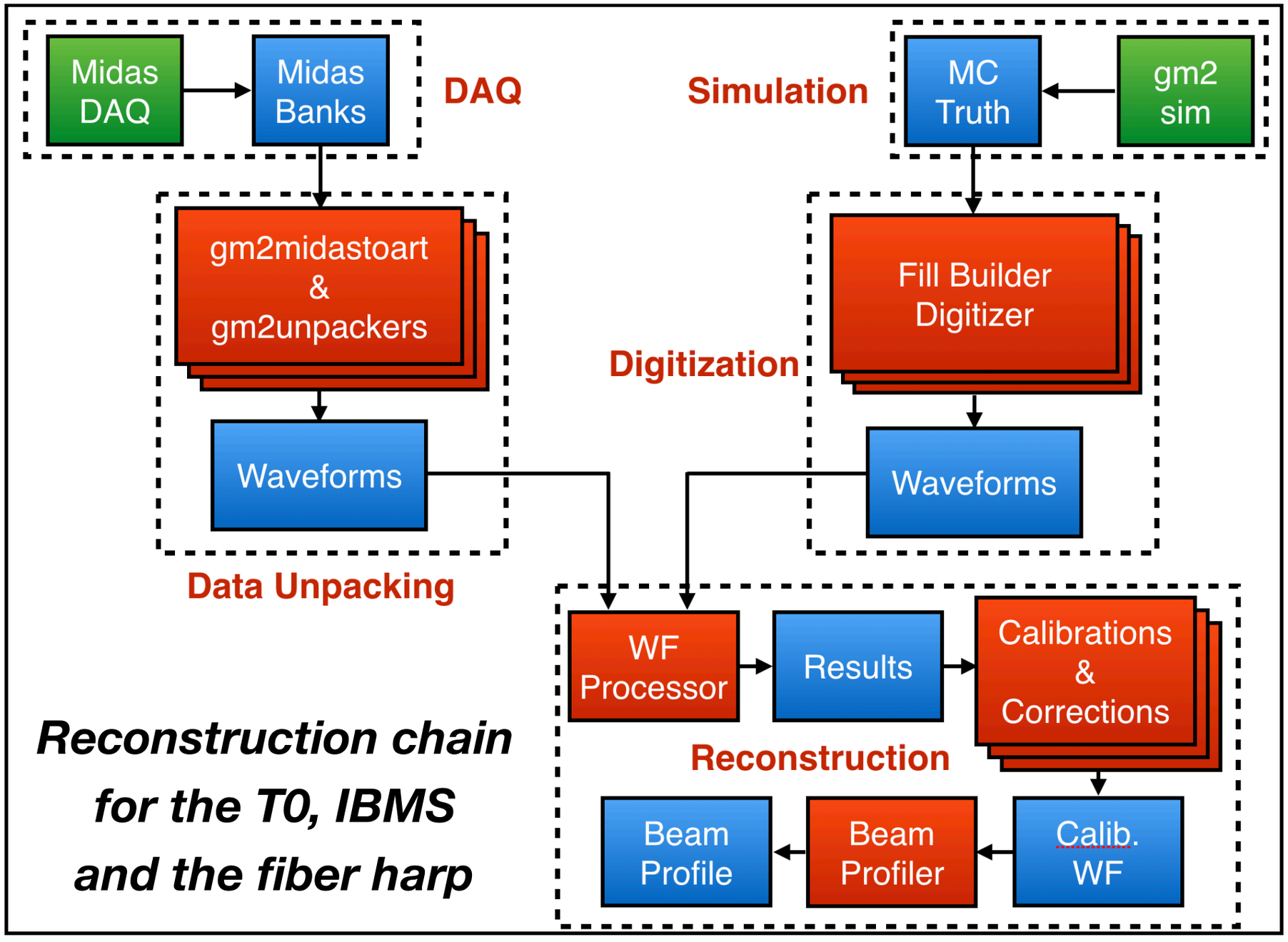
Data Reconstruction: Auxiliary Detectors (T0/IBMS/Fiber Harp)



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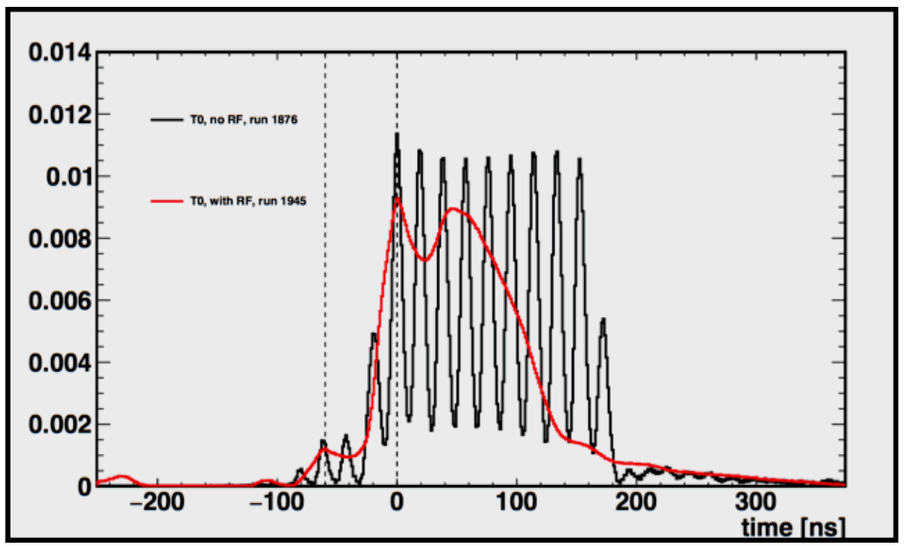
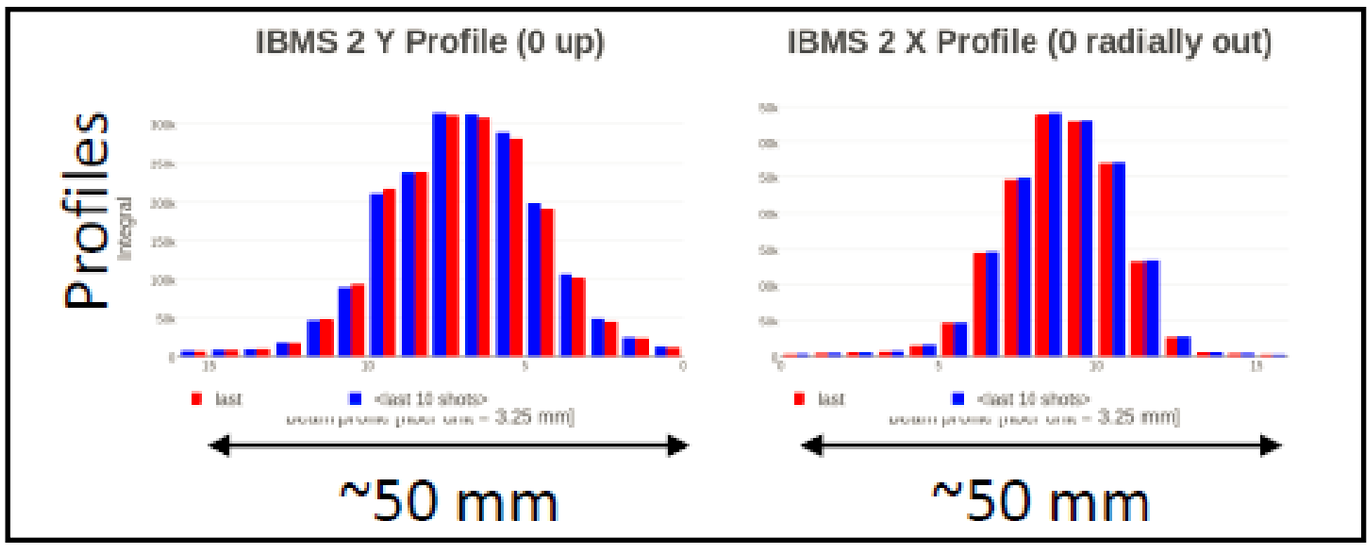
Data Reconstruction: T0 and IBMS

- T0 detector: incoming beam intensity, arrival time and time profile
  - *simple waveform analysis (integration, leading edge, etc)*
  - *first pass algorithms developed for FY17 commissioning run data*
  - ***ready for FY18 data reconstruction and analysis***

- IBMS 1 and IBMS 2: beam arrival time, spatial and time profile
  - *simple waveform analysis (integration, energy-weighted position)*
  - *first pass algorithms developed for FY17 commissioning run data*
  - ***full integration into art for FY18 data reconstruction and analysis***



T0 Beam Monitor



IBMS Beam Profile

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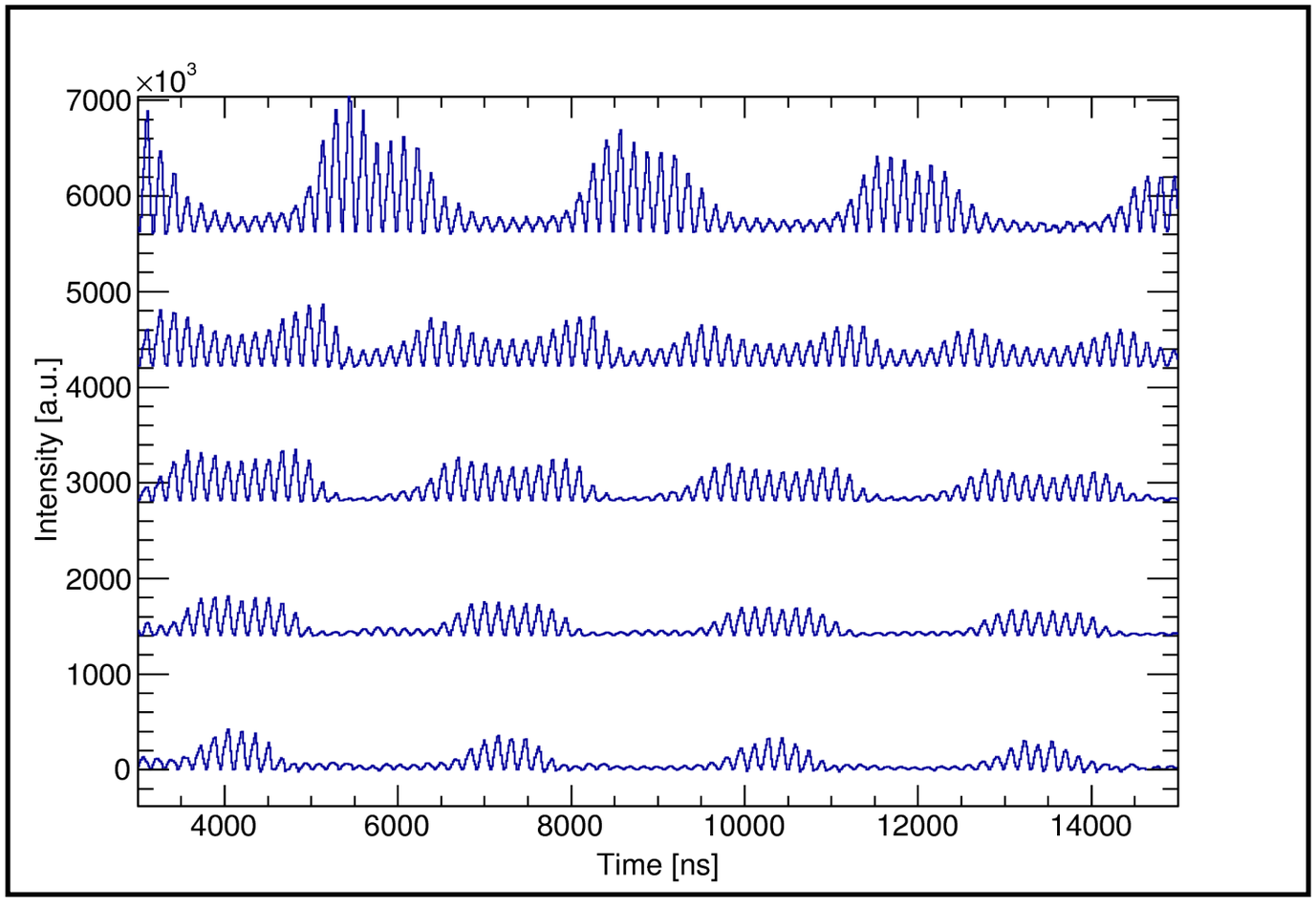
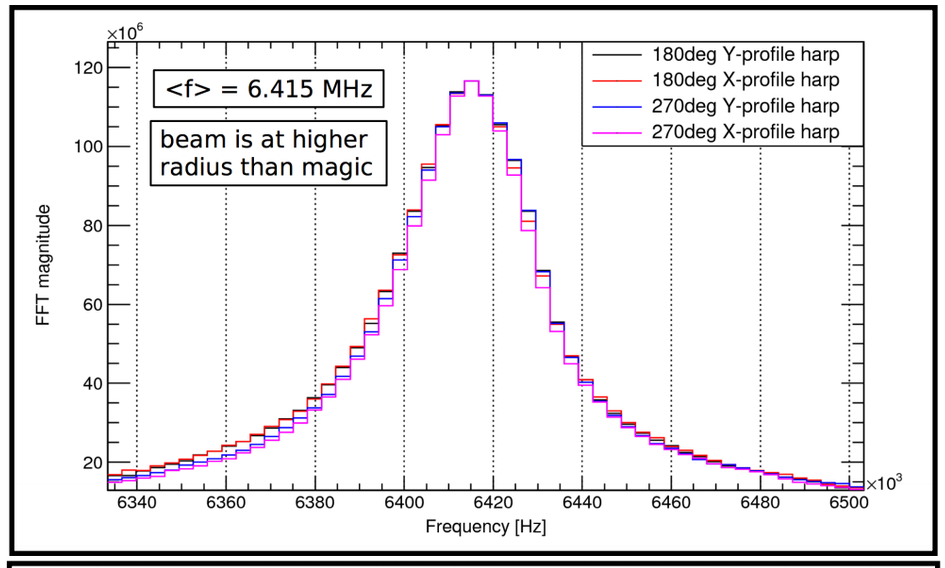
Data Reconstruction: Fiber Harp

- Fiber Harp: beam dynamics, beam profile
  - *intermediate waveform analysis (integration, FFT, baseline correction, etc)*
  - *first pass algorithms developed for FY17 commissioning run data*
  - ***ready for FY18 data reconstruction and analysis***

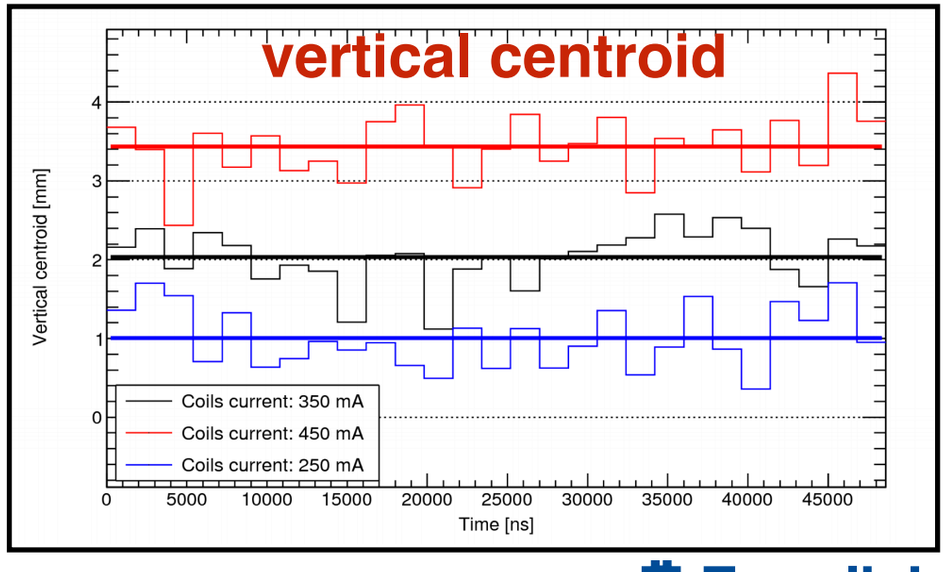


Calibrated waveforms

cyclotron frequency



vertical centroid



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Summary

- 4. Are there **robust plans** for data processing and **data analysis**? Have adequate **resources** from the laboratory and the **collaboration** been identified for **data analysis** to meet these goals?

  - We have data recon & analysis chain ready for all detectors
  - We have a list of data analysis tasks for FY17, 18 data
  - We have reconstructed and analyzed golden runs from FY17 commissioning run and produced results that help us understand our experiment
  - We have enough storage and computing resources for data analysis (Adam's talk)
  - We have enough FTE to work on data reconstruction and data analysis tasks