milliQan Simulations

2nd milliQan New York Meeting
New York University
2016/12/16

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Outline

- ✳ Resources and Documentation
- ✳ G4 Simulations: New Features
- ✳ Offline Analysis Code
- ✳ Cosmic Muons Configuration

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Resources

- **Github Link:**
  - **https://github.com/OSUmilliQan/milliQan**

milliQan/BASHScript/: run.mCP.sh, paths.mCP.sh, submit.mcp.exclusions.sh
milliQan/DataFiles/: Cross sections, Geometric Acceptances, Detector Efficiencies
milliQan/LaptopResults/: root output files for various simulation runs
milliQan/SourceFiles/: kinematic distributions for muons & mCP (for a variety of charges & masses), (*Frank Golf and Bennett Marsh, UCSB*)
milliQan/README/: README.txt, Set_Limits_milliQ_notes.pdf, milliQanDetector.pdf
milliQan/README/recipes/: Compiling instructions for variety of platforms (thanks Brian Francis)
milliQan/geant4/: Source code for G4 simulation, .cc in src/, .hh in include/

milliQan/OfflineAnalysis/
  AnalyseGeant4ROOT/: AnalyseGeant4ROOT.cc, PlotGeant4Output.nb, ConfigFiles/, Makefile, Geant4Output/, EfficiencyDataFiles/
  Sensitivities/: noWaveformSensitivities.cc, PlotSensitivities.nb, Makefile

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Resources

- **milliQan/README/**
  - **milliQanDetector.pdf**
    - Describes all classes in the G4 Simulation
    - Describes configuration files
    - Describes Offline Analysis
  - **README.txt**
    - An important guide to running, installing and compiling all the programmes
  - **KnownBugs.txt**
    - Describes (some) current limitations in the simulation
  - **Set_Limits_milliQ_notes.pdf**
    - Describes how sensitivity curves are calculated
  - **recipes/ (thanks Brian Francis)**
    - Platform specific detailed compilation instructions (even Windows!)
    - compileCommands.txt works on Unix platforms

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Resources

- **milliq/README/**
  - **milliQanDetector.pdf**

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Simulation Manual

MilliQan Simulation Manual

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(Dated: December 14, 2016)

We describe all the contents of the milliQan folder. If any bugs or outdated information is detected, please communicate them to gmagill@perimeterinstitute.ca.

I. INSTALLATION

Detailed installation instructions are located in /milliQan/README/. We give here a useful overview that you should read in addition. The first step is to install Geant4 (G4), preferably with Qt and the external Datasets (see G4 website for full details). Once that is done you can install the simulation. The link for the Github repository is `https://github.com/OSUmilliQan/milliQan`. You should clone this repo in a local directory. To install the simulation, you can do:

cd PathOutside_milliQan
mkdir BuildMilliQ
cd BuildMilliQ
cmake -DGeant4_DIR=/PATH/geant4.10.2-build/lib/Geant4-10.2.0/ PATH/milliQan/geant4/
(the first link is where the G4 build directory is installed, the second is the milliQan/geant4 source code is located)
make
./MilliQ
or you can run it from the macro:
./MilliQ PATH/milliQan/geant4/config/mcp.mac PATH/milliQan/geant4/config/default.ini
or
./MilliQ PATH/milliQan/geant4/config/mcp.mac PATH/milliQan/geant4/config/cosmicmuons.ini
In order to properly compile/run, You need to edit the file config/particles.ini or config/CosmicMuons/CMparticles.ini. You need to specify the path to the kinematic distribution .txt (it cannot be a .dat file). There is a different distribution for charges 0.001, 0.01, 0.1 and for 48 mass points. These kinematic distributions are included in milliQan/SourceFiles.

II. MILLIQAN FOLDER

A. Macro File

In /milliQan/BASHScript/, there are files called run.mCP.sh and submit.mcp.exclusions.sh. This a big bash script that cycles through masses, electric charges, particles, etc. and saves all the output. There is a setting to run on a computer cluster or a laptop. You can modify it to your architecture.
Important: be sure to specify your correct paths in /milliQan/BASHScript/paths.mCP.sh.

III. GEANT4 SIMULATION CLASSES

In the following, all the classes are prefixed by MilliQ, and suffixed by .cc. They all have a partner .hh file. The construction of the detector is a bit involved. DetectorBlockLV constructs a block (a scint + pmt). This is called by DetectorStackLV which parametrizes all the blocks into one stack (one layer of the detector) using DetectorBlockParameterisation. DetectorStackLV is called by DetectorConstruction, which parametrizes all the stacks into one detector using DetectorStackParameterisation.

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G4 Simulations

Config .ini files developed by Brian Francis

- **milliQan/geant4/config/**
  - **Boost c++ libraries!**
  - **Geometry:** # Blocks, # Stacks, Spacing between blocks, Stack Offset, Light GuideLength
  - **PMT:** PMT Dimensions, Cathode Dimensions, Photon energies and quantum efficiency spectrum, Time per digitizer sample
  - **Scintillator:** Density, Carbon/Hydrogen content, Photon emission spectrum, Refractive index, Absorption length, Scintillation yield, Resolution scale, Decay time, Rise time, Yield ratio, Birks Constant
  - **particles.ini:** Electric charge, Mass, FileName (where particle distributions are located), PathName (where FileName are located), Coincidence threshold (for online trigger)
  - **mcp.mac:** Number of events in a run

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G4 Simulations

* **milliQan/geant4/config/Geometry/default.ini**

```
; All units herein are cm, eV, ns unless otherwise noted

[DetectorGeometry]
Version = 0
NBlocks_X = 1
NBlocks_Y = 20
NBlocks_Z = 20
NStacks = 3
BetweenBlockSpacing_X = 0.
BetweenBlockSpacing_Y = 0.
BetweenBlockSpacing_Z = 0.
Offset_X = 0.
Offset_Y = 0.5
Offset_Z = 0.5

InnerShieldThickness_X = 2.
InnerShieldThickness_Y = 2.
InnerShieldThickness_Z = 2.
InnerShieldMaterial = G4_Pb
OutterShieldThickness_X = 2.
OutterShieldThickness_Y = 2.
OutterShieldThickness_Z = 2.
OutterShieldMaterial = G4_POLYETHYLENE
; If you want only 1 or no shields, make inner/outter G4_AIR with small dimensions


DetectorInnerShieldGap_X = 1.
DetectorInnerShieldGap_Y = 1.
DetectorInnerShieldGap_Z = 1.
; Make sure to put it bigger than the offset!


; Reflectance of Aluminum: Bass, M., Van Stryland, E.W. (eds.) Handbook of Optics vol. 2 (2nd ed.), McGraw-Hill (1994)
[ScintillatorGeometry]
X = 85
Y = 5
Z = 5
LightGuideLength = 10.
~
```

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G4 Simulations

- **milliQan/geant4/src/MilliQWaveform.cc**
  - **Geant4:**
    - Data available are PMT hit times given quantum efficiency
  - **Need waveforms!**
    - Discretize event into number of ADC samples
    - *For every photoelectron incident on the PMTs at time t, generate a single photo-electron waveform starting at t*
    - For all ADC samples, *generate background noise* (random small voltages)
    - For each channel, superimpose signal and background

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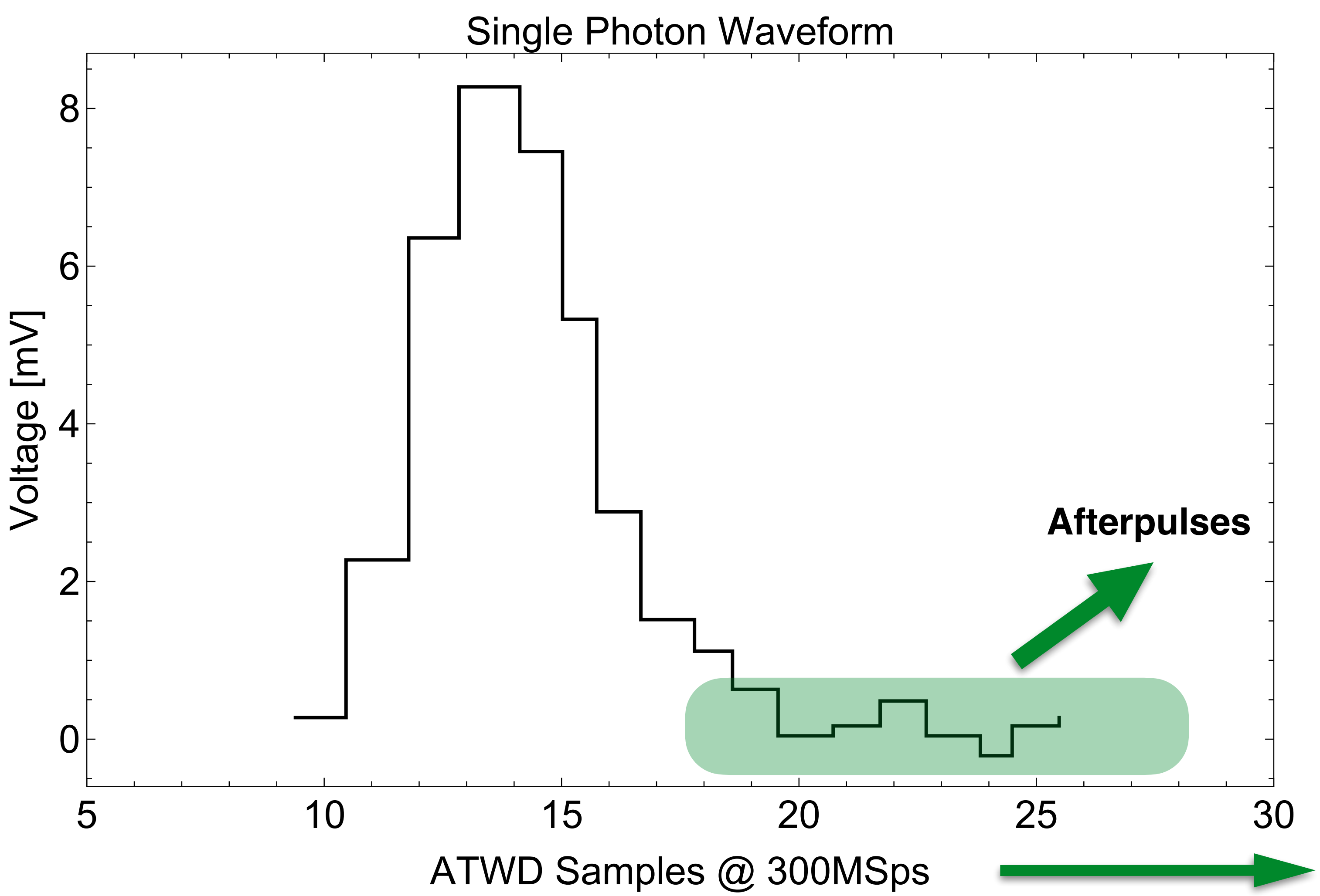
G4 Simulations

- **milliQan/geant4/src/MilliQWaveform.cc**
  - **Single Photoelectron Waveform:**
    - Currently obtained from: The IceCube data acquisition system: Signal capture, digitization, and timestamping (0810.4930)



Waveform placeholder easy to change

Photoelectron waveform to be extracted from CAEN

Plots and efficiencies shown in this talk based on 3.33ns sample period template instead of actual 0.3ns one

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G4 Simulations

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **ONLINE TRIGGERS**
    - Determines if G4 event data is output to ROOT.
    - Detector (Y x Z x NStacks): Y is the number of blocks up, Z is the number of blocks across, NStacks is the number of layers
    - Divide detector into YxZ/4 modules. Each module is a 2x2xNStacks "subdetector".
    - In each stack of a given module, a group is formed by two neighbouring PMTs along Z (with the same Y).
    - A coincidence within 150ns (configurable) in any two groups of a module activates a flag

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G4 Simulations

Output ROOT File

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **MilliQCAEN (should match CAEN digitizer output)**
    - WaveformLengthPerChannel (# channels): for each channel, output the number of recorded ADC samples
    - *WaveformVoltage*: continuous vector filled with all the voltage samples for all the channels. To be used in conjunction with WaveformLengthPerChannel, which specifies how many consecutive elements correspond to each channel. If a channel hasn't seen any activity, there will 0 samples associated with it.
    - TimePerSample: Outputs the time of one sample. This is digitizer dependent, read in from config files
    - FirstPMTTime: Some local time corresponding to first sample (first photoelectron generated) across all channels

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G4 Simulations

Output ROOT File

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **MilliQAll (pre-packaged useful truth simulation information)**
    - ActivePMT (# activePMTs): IDs of all active PMTs in event
    - PmtMedianHitTimes (# channels): Median hit times of PMT hits in a channel
    - PmtAllHitTimes (Total # PMThits): All pmt hit times for all channels
    - NumberPMTHits (# channels): # PMT hits in a channel
    - TimeOfFlight (# channels): Median PMT hit time minus scintillator first hit time in a channel
    - TotalEnergyDeposit (# channels): Total energy deposit in a scintillator channel
    - FirstHitScintillator: Channel ID of first scintillator hit by particle
    - PhotonCountAllScintillators: Total scintillator photons produced across all scintillators

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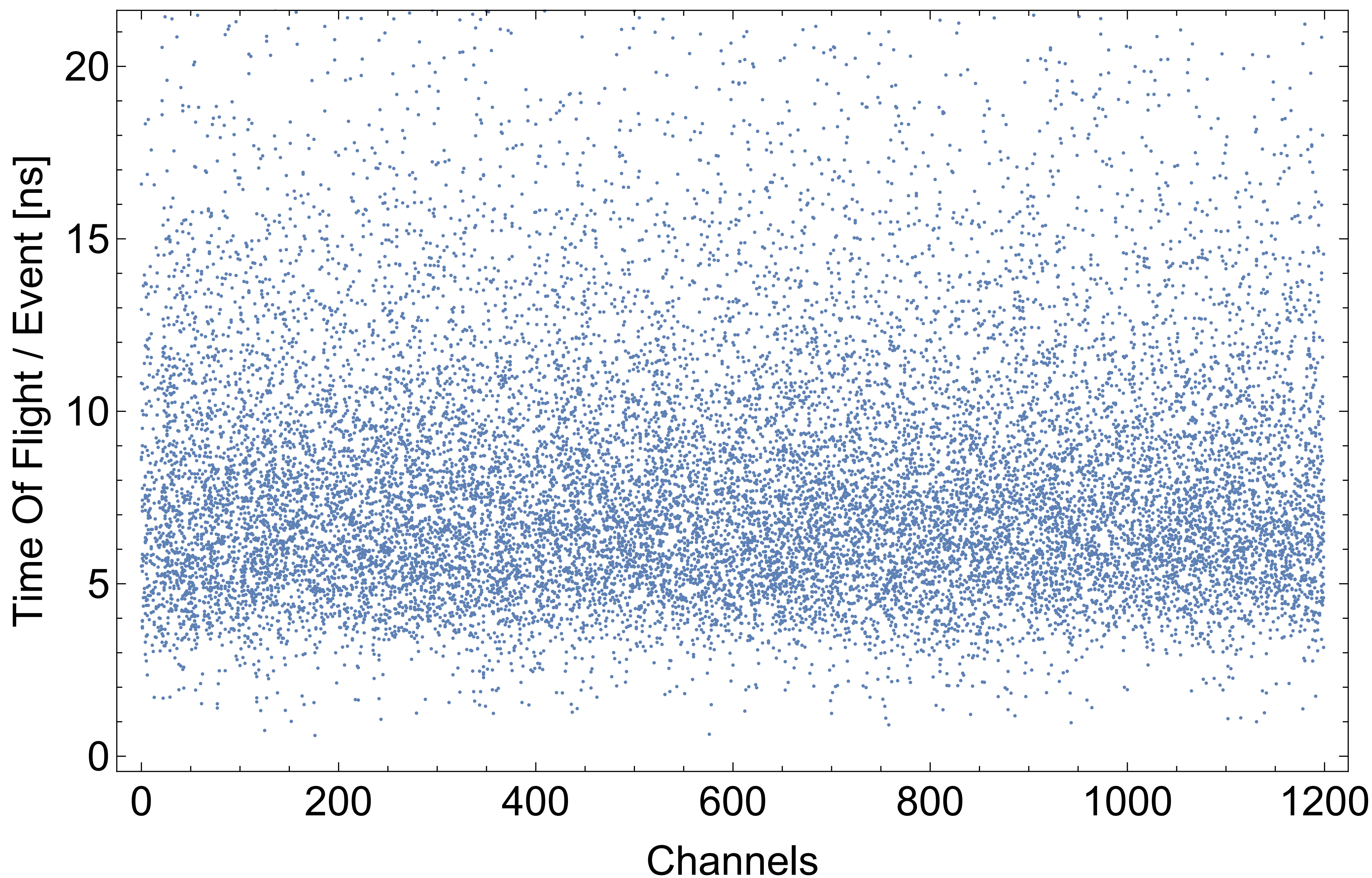
G4 Simulations

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **MilliQAll: 0.1GeV & 0.0034e**

$$6\text{ns} \times c \times \frac{1}{1.58} = 1.14\text{m}$$

Longitudinal Length: 0.85m

« Time of flight » defined as time difference between first scintillator hit and median PMT hit time in a channel



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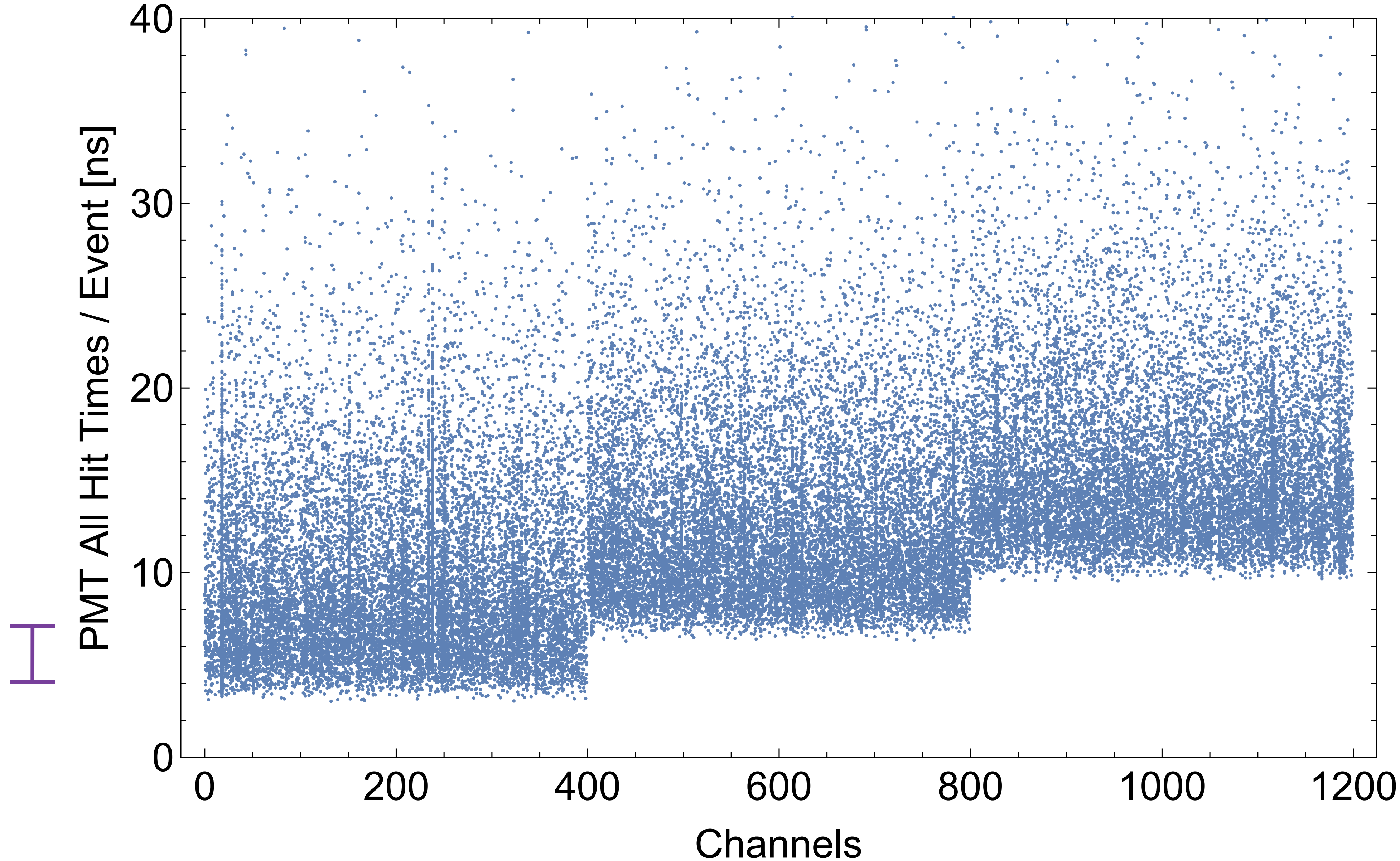
G4 Simulations

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **MilliQAll: 0.1GeV & 0.0034e**

$$3.5\text{ns} \times c = 1.05\text{m}$$

Longitudinal Length: 0.85m

3.5ns



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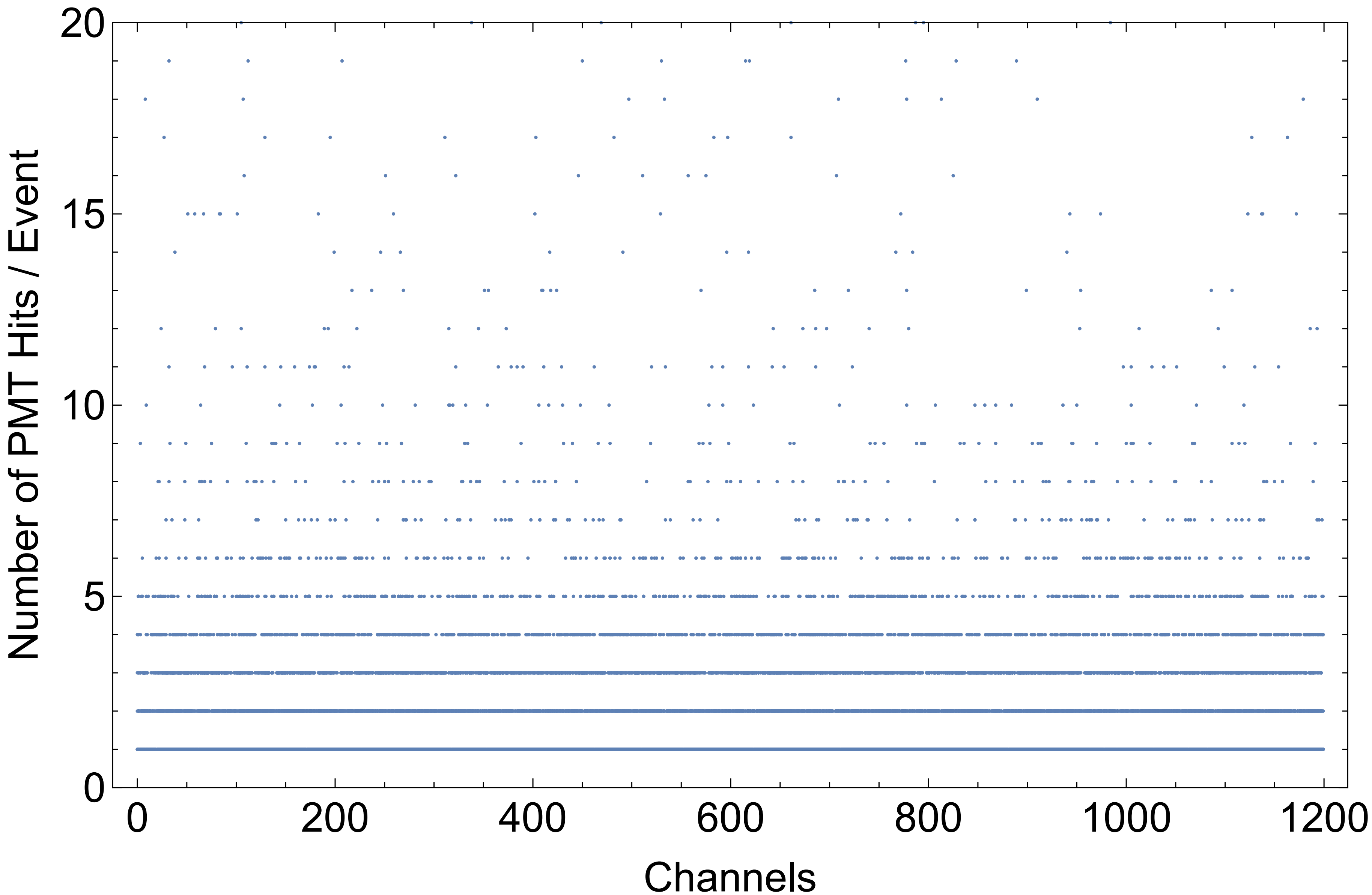
G4 Simulations

- **milliQan/geant4/src/MilliQAnalysis.cc**
  - **MilliQAll: 0.1GeV & 0.0034e**



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Offline Analysis

- **milliQan/OfflineAnalysis/AnalyseGeant4ROOT/**
  - **AnalyseGeant4ROOT.cc**
  - *Contains handles to read G4 ROOT files, calculate Offline Triggers, and output detector efficiencies to a good format*
  - Automated: reads helper file generated by bash script which specifies # events simulated, online trigger efficiencies, masses/charges of mCP in the events
  - Responsible for retrieving and writing all pre-packaged data for all plots in this talk
  - *Currently, this part of the analysis is coded to work on 3 stacks*

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Offline Analysis

- **milliQan/OfflineAnalysis/AnalyseGeant4ROOT/**
  - **AnalyseGeant4ROOT.cc**
  - *Begins by reading waveforms for each channels, delete Waveforms below cutoff, and identify peaks (ROOT::TSpectrum)*
  - Checks if there are 3 channels in different layers with 3 signal peaks in time window
  - User can choose how this is done via the options:
    - ThreeFoldAnywhere: 3 Hits anywhere. No time window.
    - AllNeighbours: Zig-zag line between neighbours. Impose time window.
    - ParticleTrajectory: Bending line (no zig-zags), neighbour steps. Impose time window.
    - BackToBack: Straight line (no bending). Impose time window.

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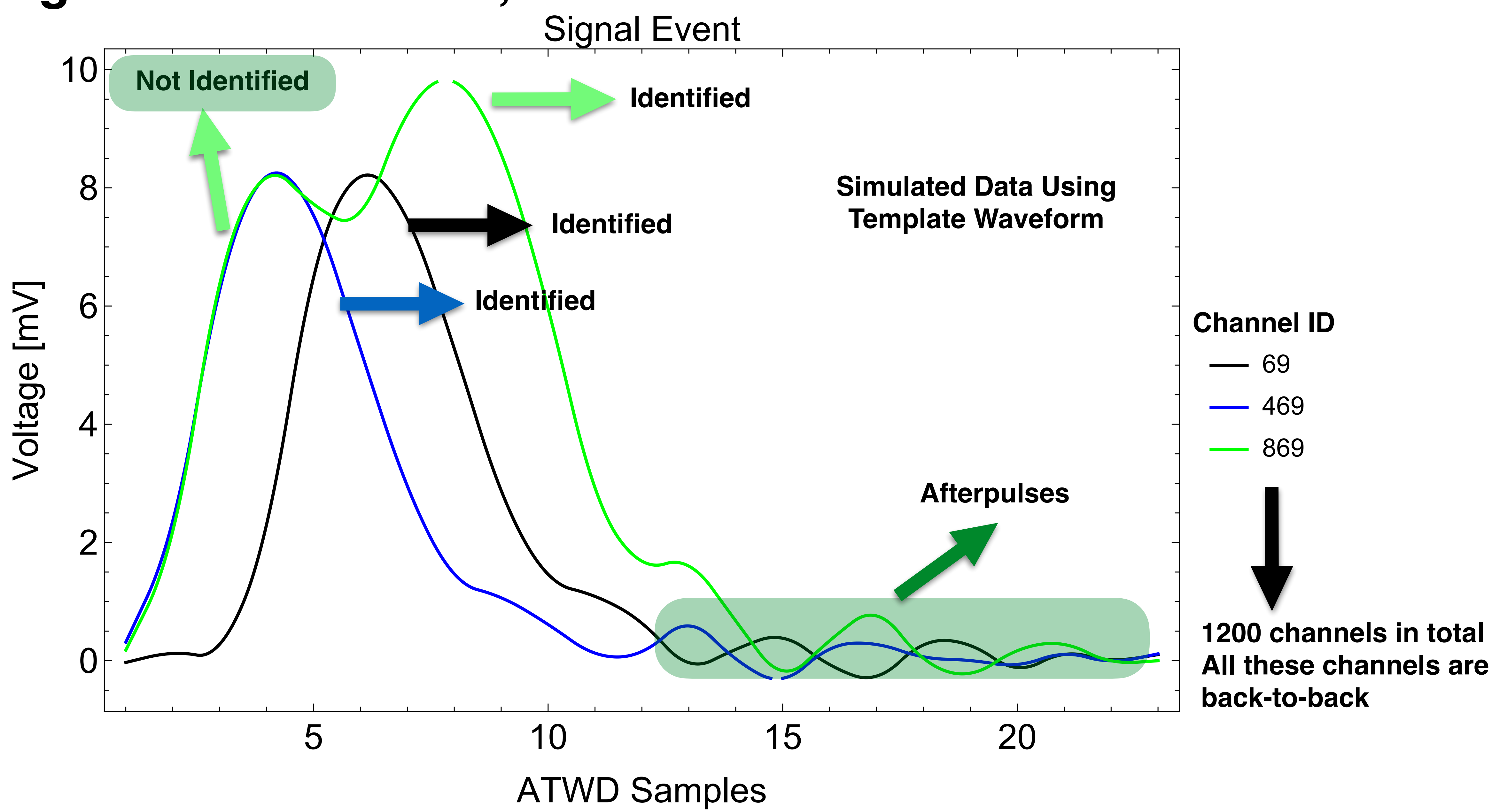
Offline Analysis

- milliQan/OfflineAnalysis/AnalyseGeant4ROOT/
  - Signal Event: 0.1GeV, 0.0034e



1200 channels in total
All these channels are back-to-back

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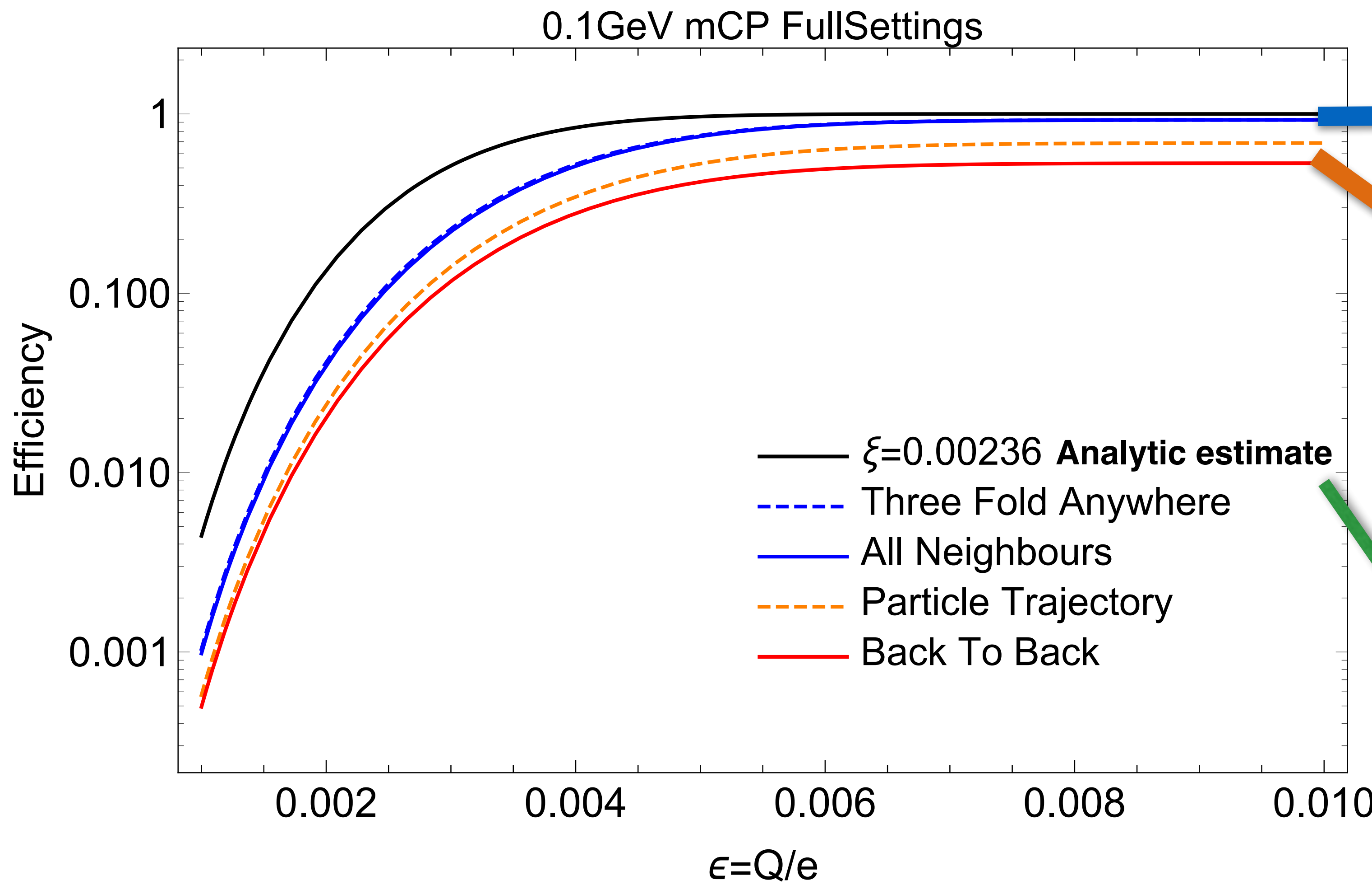
Offline Analysis

- **milliQan/OfflineAnalysis/AnalyseGeant4ROOT/**
  - **AnalyseGeant4ROOT.cc**
  - **Efficiency = #events after offline triggers / #events simulated**



Looks good, consistent with LOI

Systematic deviations in trajectory? Detector offset effects? Newly written peak finding algorithm not finding all peaks? Smaller sample period fixes this? Bug? All of the above…

Probably need to study more large charge regime, 0.1e - 1.0e

Simulated detector efficiency is fit to:

$$a^3\left(1-e^{-\frac{Q^2}{\xi^2}}\right)^3$$

0.00236 is obtained from back of envelope calculation
Other 4 curves done entirely from waveform output of Geant4

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Offline Analysis

- **milliQan/OfflineAnalysis/AnalyseGeant4ROOT/**
  - **Configuration file:**
    - Directory of ROOT files located
    - Detector details (Blocks, Stacks, names…)
    - Particle type (mCP_UFO, Y1S, Y2S, Y3S, J/Psi)
    - Coincidence threshold
    - Waveform voltage cutoff below which = noise
    - Time per digitizer sample
    - Offline trigger strategy
    - Masses, charges and particles of available ROOT files for which we want to write out MilliQAll data for plotting

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Offline Analysis

- **/milliQan/OfflineAnalysis/Sensitivities/**
  - **noWaveformSensitivities.cc**
  - *AnalyseGeant4ROOT.cc produces efficiency file*
  - *If file contains all required masses, charges & particles, noWaveformSensitivities.cc calculates Q vs M sensitivity plot*
  - # bkg events must be specified at the beginning of the file for LHC luminosities of 300 and 3000 fb^-1.
  - # bkg events will depend on offline trigger strategy, and on how well we can differentiate dark current from signal events via a waveform template matching. Currently no « systematic » script to calculate them, always done in the moment
  - Details on how sensitivities are calculated: /milliQan/README/Set_Limits_milliQ_notes.pdf (courtesy of Itay Yavin).

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Cosmic Muons

✳ Cosmic Muon Mode

- **run.mCP.sh & config files & AnalyseGeant4ROOT/**
- Settings that generate a $\cos^2\theta$ distributed cosmic muon shower
  - See geant4/config/CosmicMuons/GenerateMuonDistributions.nb

- Geometry based on David Stuart's setup
  - 1 x 32 x 16 PMTs, each of dimensions 50 x 2 x 2 mm.
- In Cosmic Muon mode, the simulation outputs the same information as in the default mode
- comicmuons run mode can be selected in the master milliQan/BASHScript/run.mCP.sh bash script
- In the past, there was a bug that caused a segmentation fault (see http://hypernews.slac.stanford.edu/HyperNews/geant4/get/opticalphotons/634.html). Reverting to an older stable geometry seems to have fixed this.

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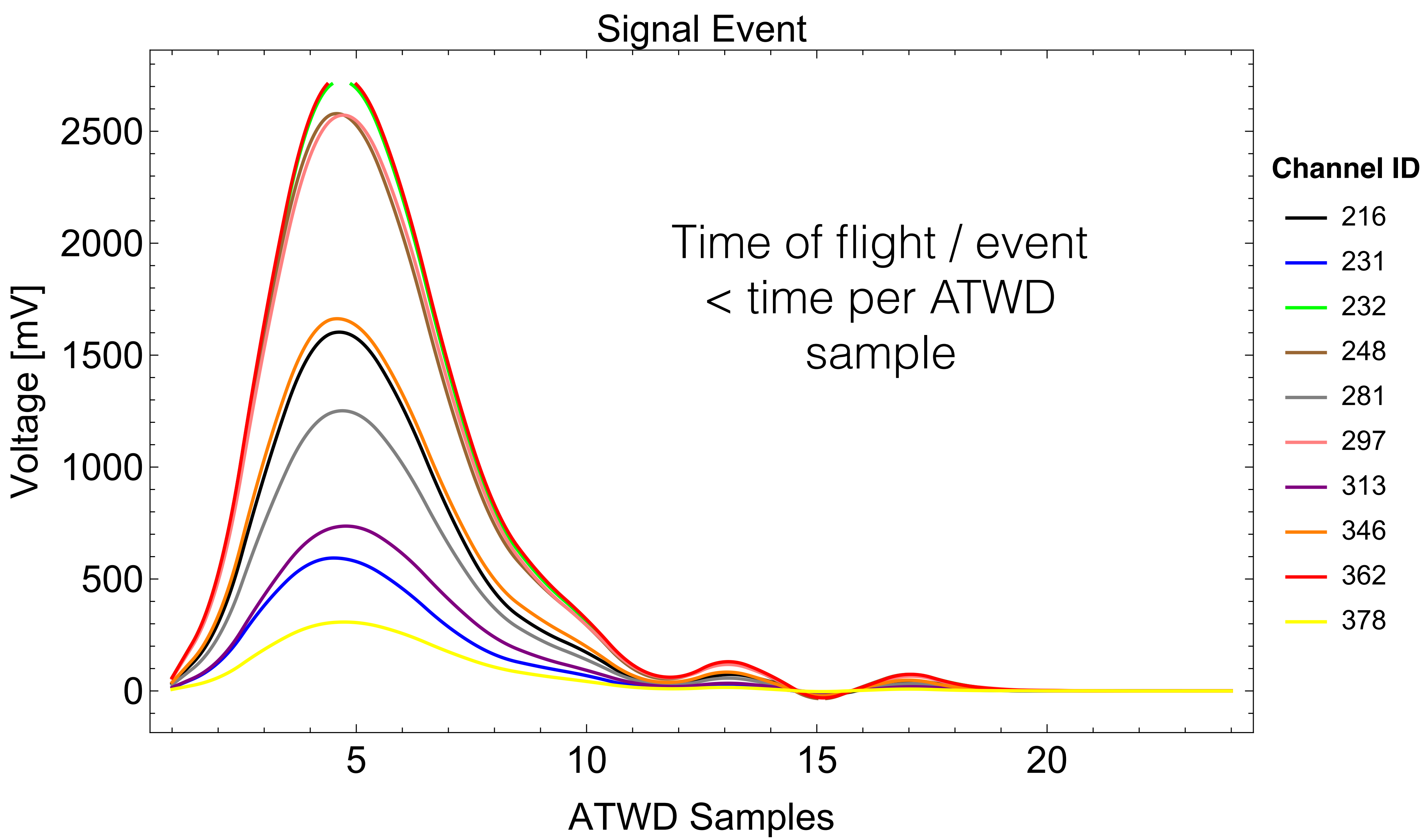
Cosmic Muons

- **Cosmic Muon Mode** Preliminary!
  - **Simulated Waveforms**



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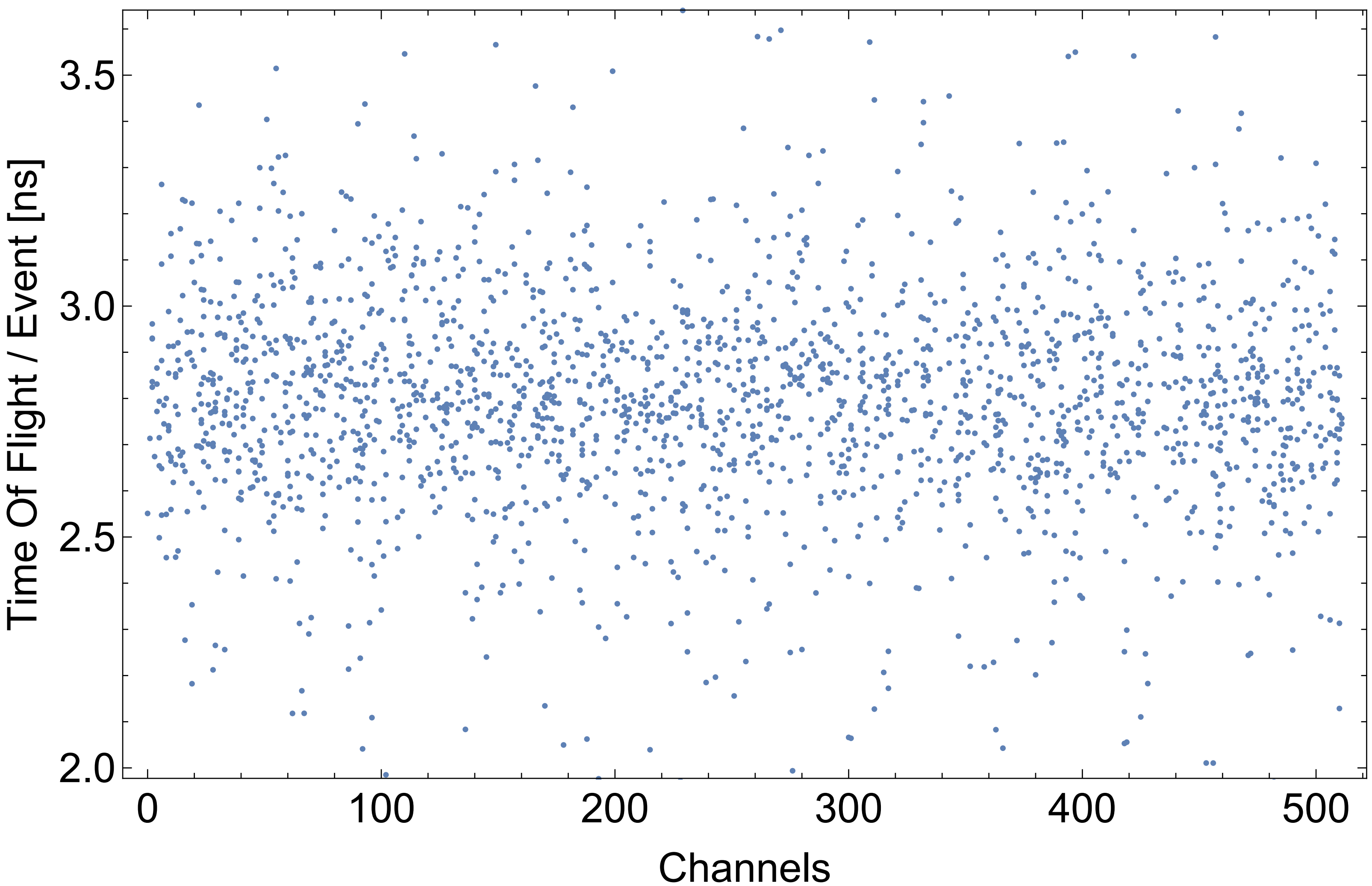
Cosmic Muons

- **Cosmic Muon Mode**
  - **Simulated Data**



Time of flight / event
< time per ATWD
sample

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Summary

Simulation more realistic

- Waveforms, peak finder
- Online triggers
- Cosmic Muon Mode
- *Currently not quite same as CAEN*

New offline analysis code

- Handles G4 ROOT files
- Calculates offline triggers
- Makes plots

A lot of documentation

- See /milliQan/README/

Try running simulation!

People can now help develop code

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