# DUNE Triggering

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LBNC Review

May 5, 2021

Penn
University of Pennsylvania

DUNE

# Outline

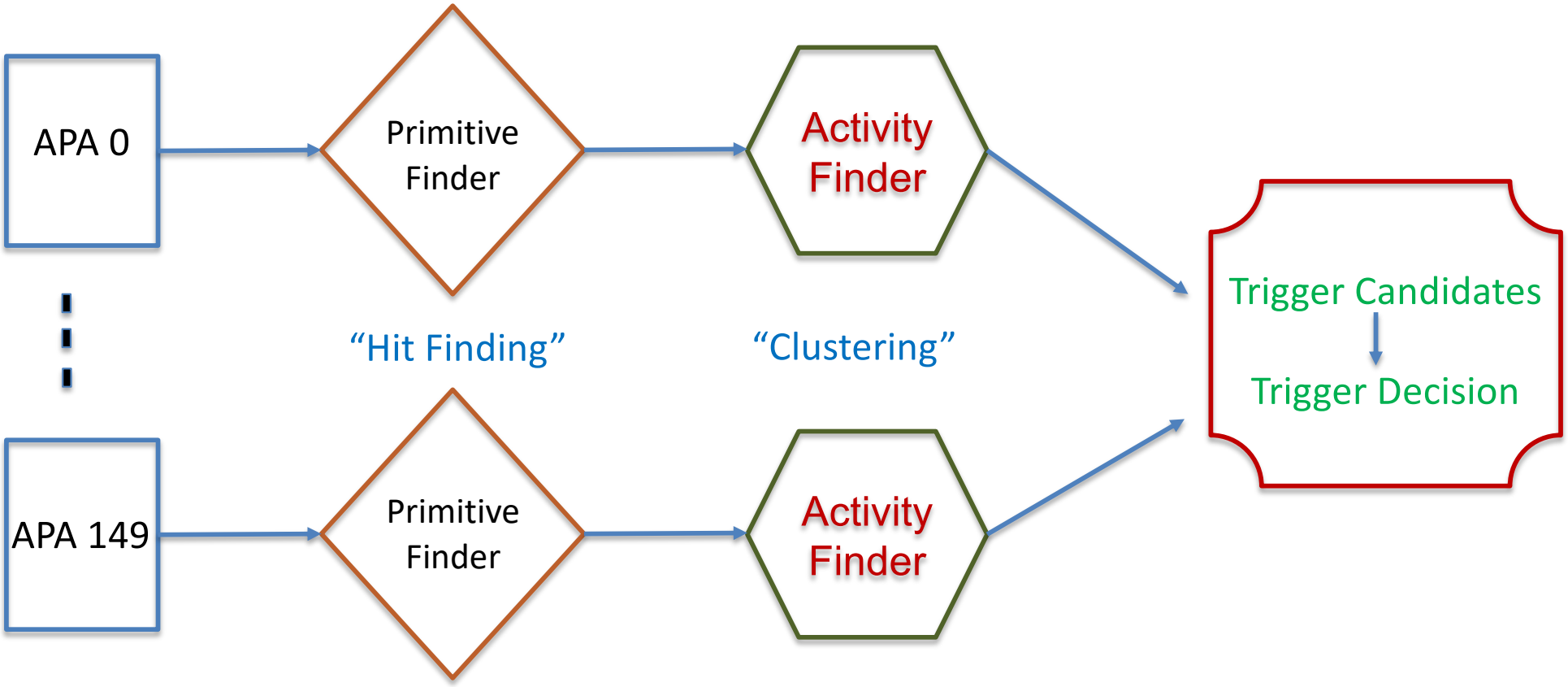
- DUNE Trigger Basics
- Physics and Other Limitations
- Demonstrations to Date
- Moving Lower in Energy
- Future Paths Forward

# DUNE Trigger Basics

- Primary detector system (TPC) is very slow, data buffered for 10 s
- Leaves plenty of time to exploit TPC topology in trigger
- PDS system can also be used to trigger independently or w/ TPC
- (Calibrations and other auxiliary systems can also trigger)
- System intended to be as *inclusive* as possible
  - e.g., everything with E > threshold
  - Constraint here will be from low-energy backgrounds (later)
- Event readout can be:
  - All channels for some time window ~ drift
  - A narrow region of interest (ROI) in channel and time space
  - A very long time window (for supernovas) up to 100 s for all channels

# TPC Triggering

## Basics




- Activity Finders = Low Energy, High Energy, Exclusive channels…
- Candidate Finder = SN bursts, High E event, beam event, etc.

# TPC Triggering

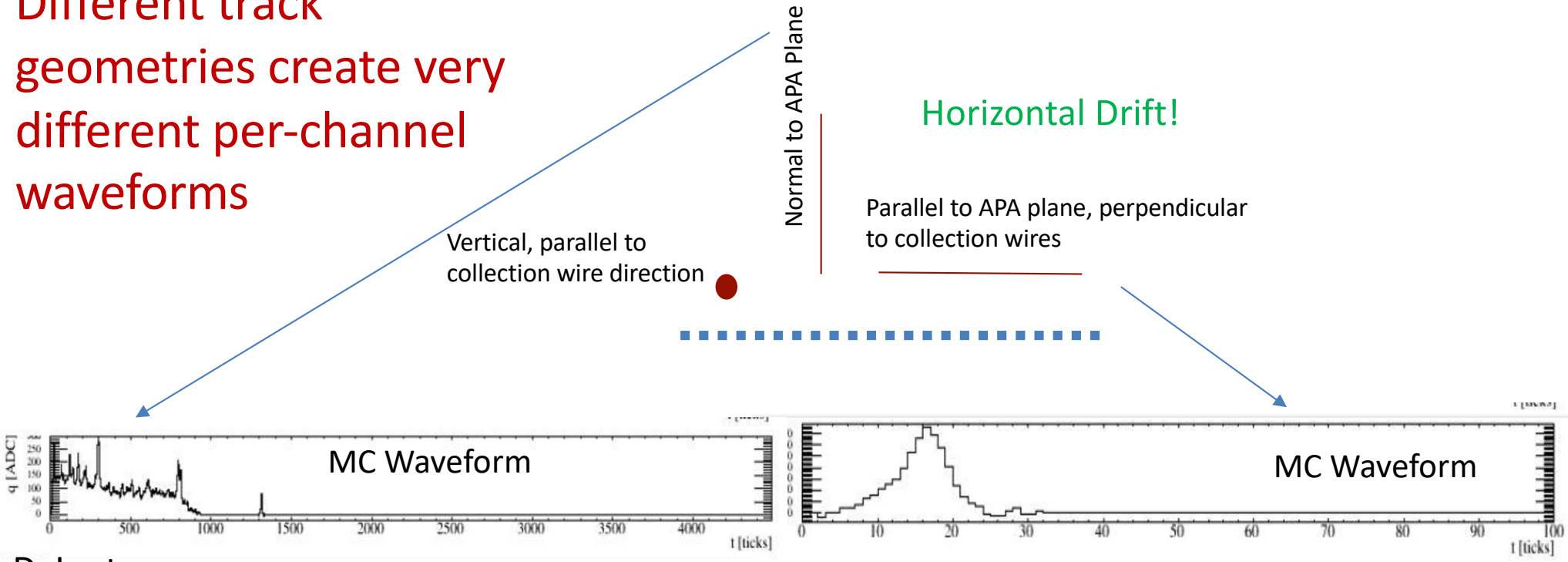
Basics

A quick note about the word “threshold”….

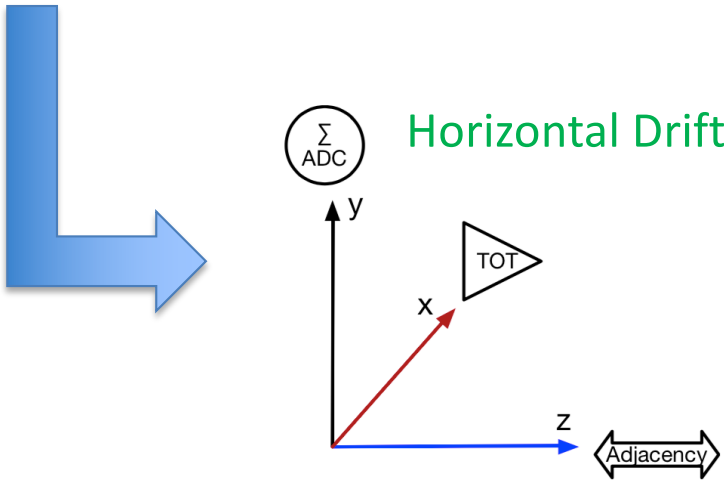
- Trigger Primitives have a “hit” threshold
- Trigger Decision based on various “event” thresholds
- Supernova Bursts have a “burst threshold”
  - Once a burst is triggered, the data is acquired with zero threshold for 100 s

# Trigger Primitives (TPs)

Different track geometries create very different per-channel waveforms




D. Last




Horizontal Drift!

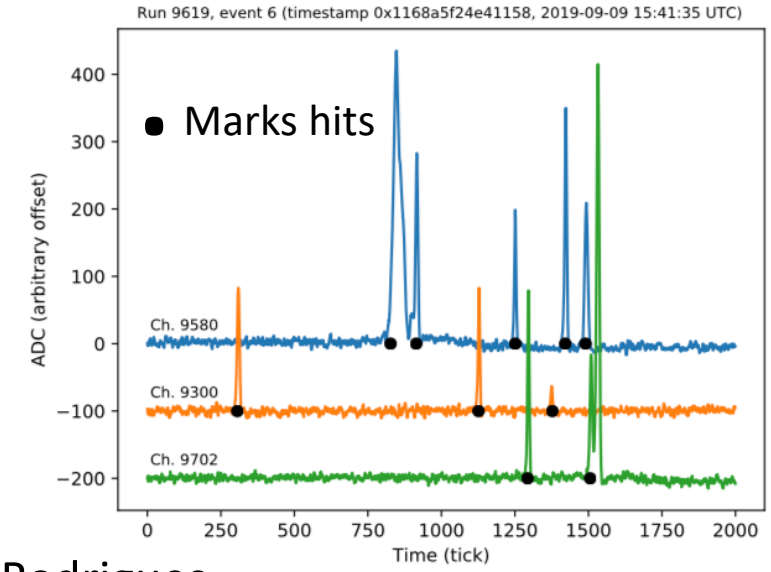
TPs include “orthogonal” basis of information
(collection wires only so far)

D. Rivera

# Trigger Primitives (TPs)

## Hit finding

## Example from ProtoDUNE-SP

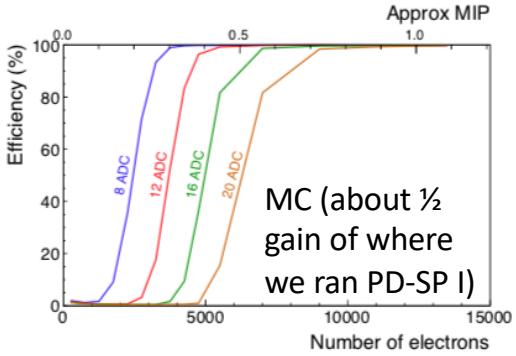


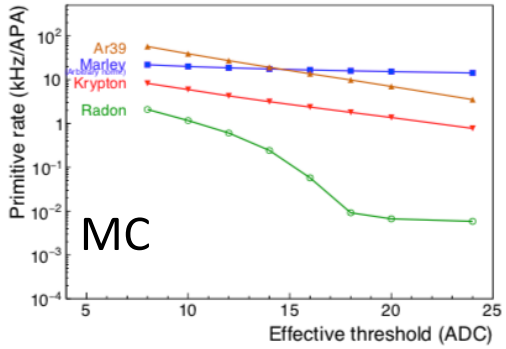

P. Rodrigues

TP threshold was around 1/4 MIP-equivalent, or around 250 $keV_{ME}$ (per wire)

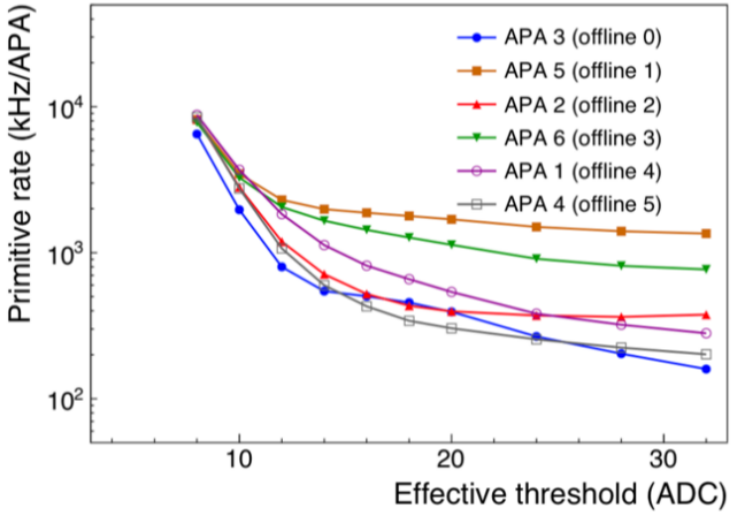
Need to study this for VD strips instead of HD wires

Raw noise in ENC at PD I was ~600 e (collection)



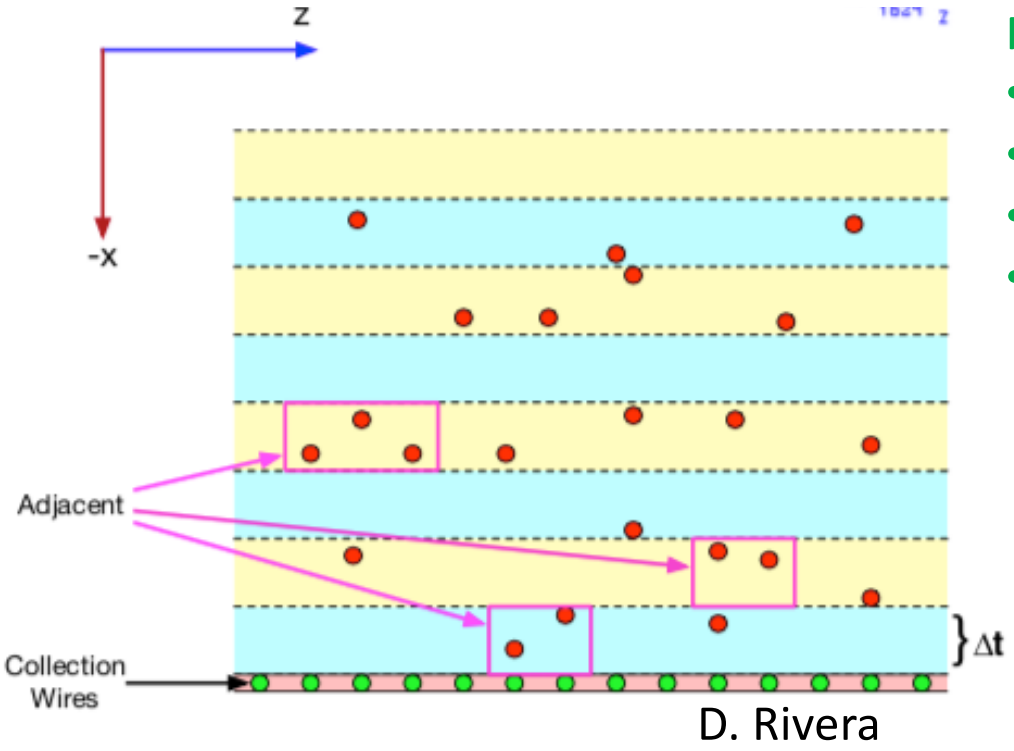




Raw noise RMS in PD I was 3-4 ADC above pedestal



# Trigger Activity
## Clustering and Cutting

Cannot simply sum up all charge---in 10 ktonnes and a full drift, this is about a GeV of charge.

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Need some kind of clustering as first stage of triggering

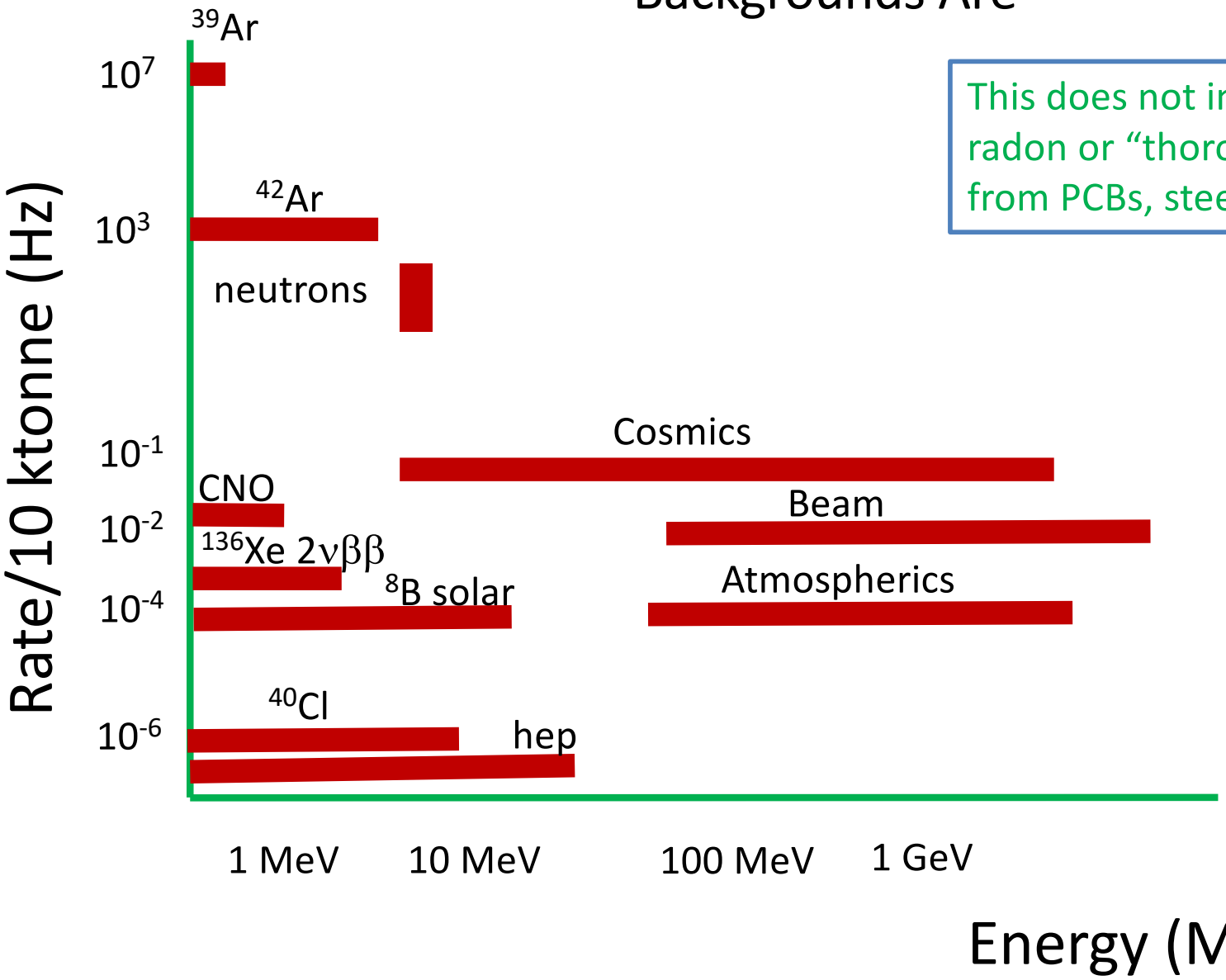
Radiological rate acceptable* with:

- $N_{adj}$ >= 8 wires
- Cluster charge sum > 7000 ADC counts
- Max integrated wire charge > 6500 counts
- Max time-over-threshold >= 45 ticks

***acceptable rate was so that 5.4 ms readout of all channels had data rate < 25% of cosmic data rate**

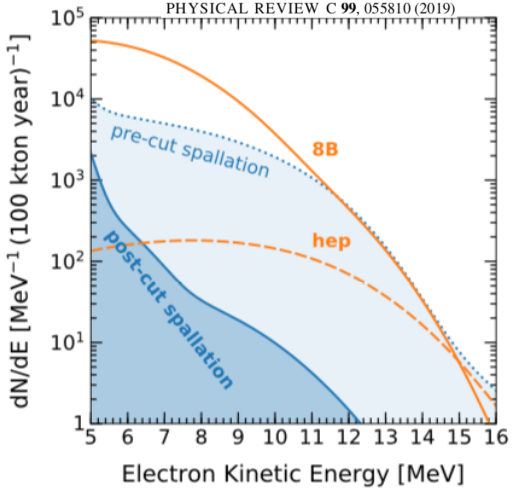
# Triggering is Not the Challenge

## Backgrounds Are



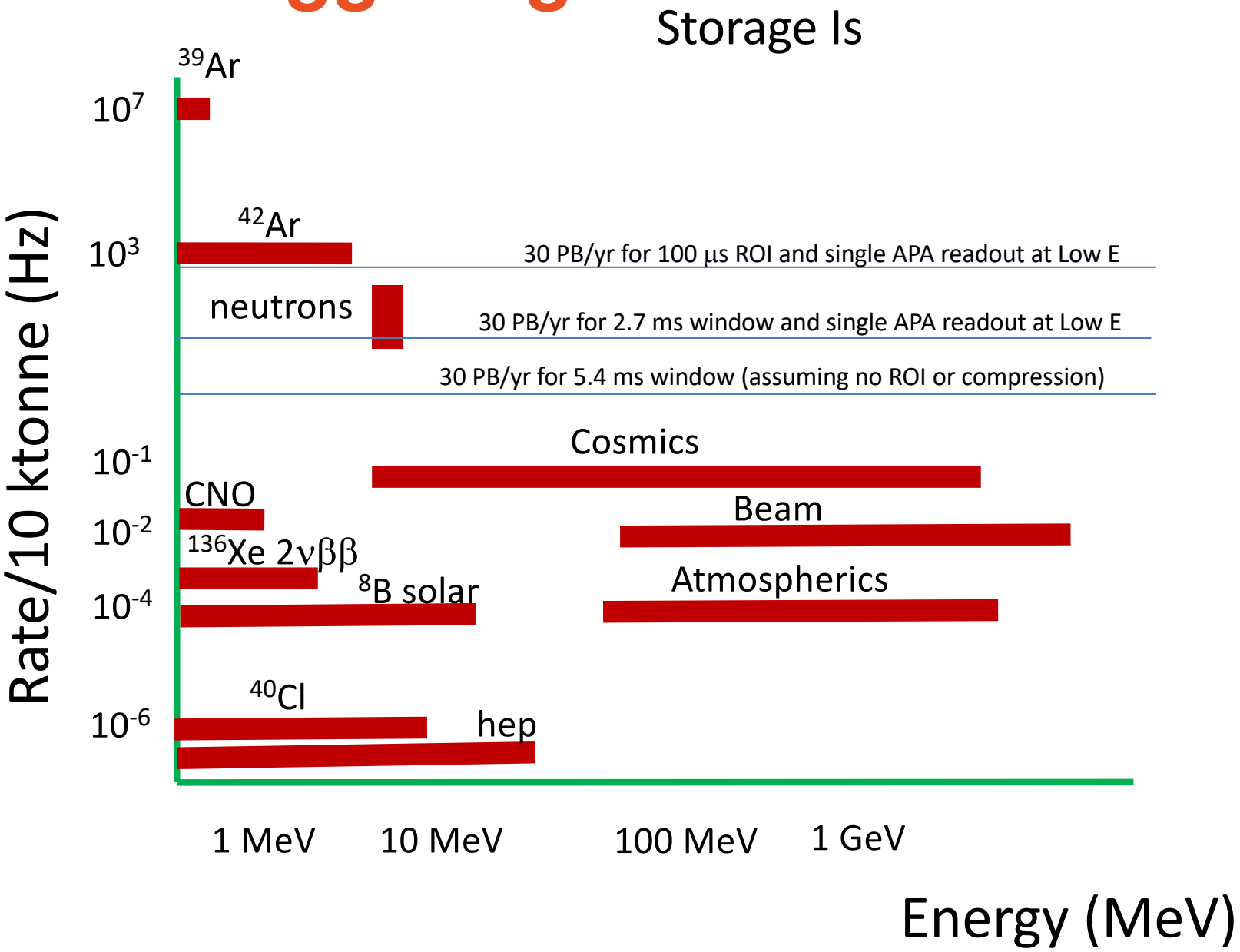

This does not include unsupported radon or "thoron," or U/Th gammas from PCBs, steel, APAs, or $^{40}$Ar($\alpha$,$\gamma$)

Zhu, Li, Beacom

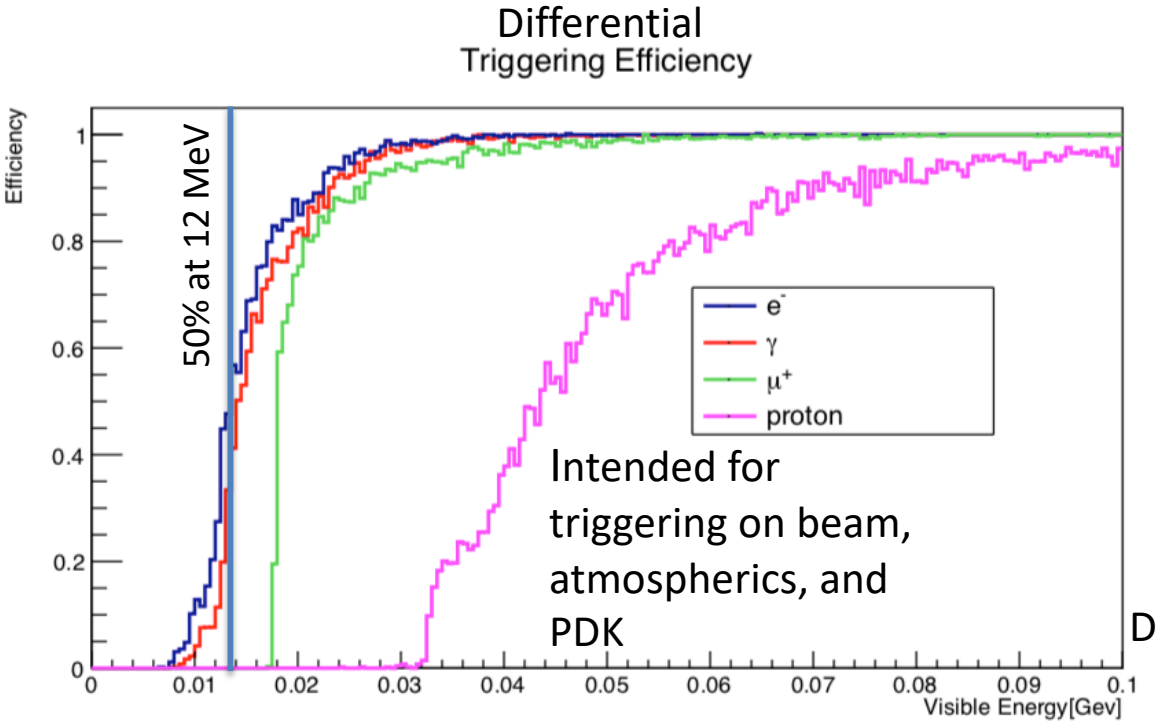



Or spallation

# Triggering is Not the Challenge



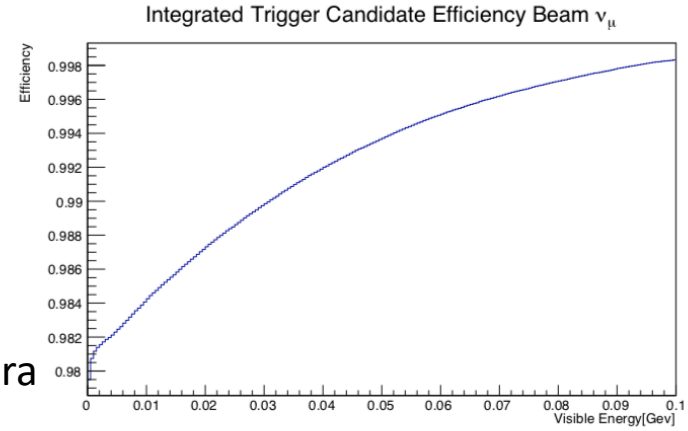
# High-Energy Trigger Efficiency




Intended for triggering on beam, atmospherics, and PDK

- Integrated efficiency $\epsilon_I$ is given by :

$$\epsilon_I(E_{vis}) = \frac{\int_{E_{vis}}^{\infty} n_{trig}(E)dE}{\int_{E_{vis}}^{\infty} n_{evt}(E)dE}$$



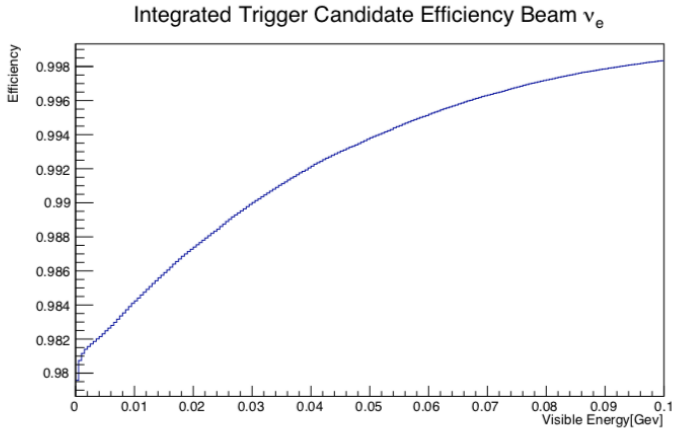

D. Rivera

**Threshold is set by background rate!**

Moving to ROI readout allows a lower threshold

The trigger is intentionally *inclusive*

but different species have different topologies and thus different efficiencies

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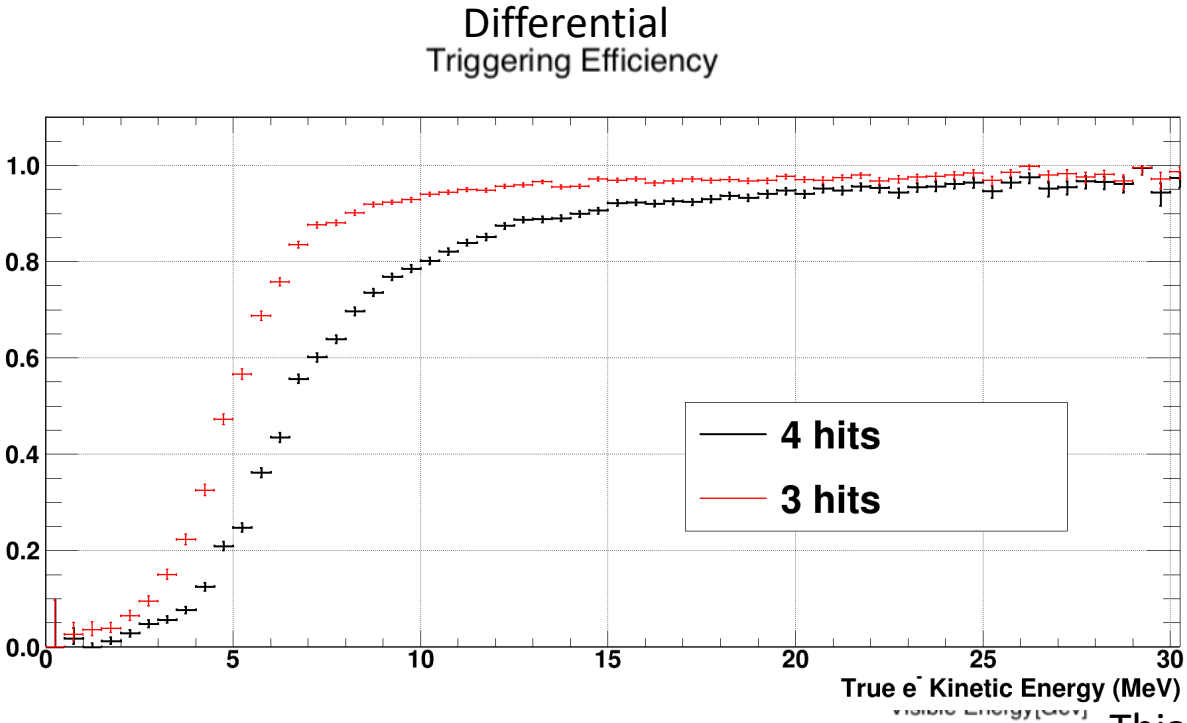


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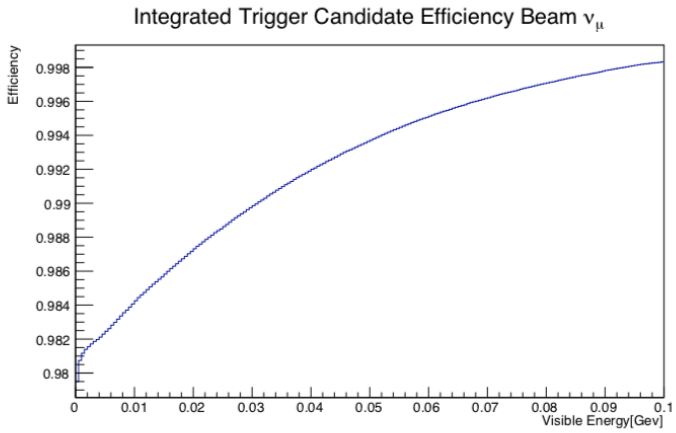


Thiago Bezerra

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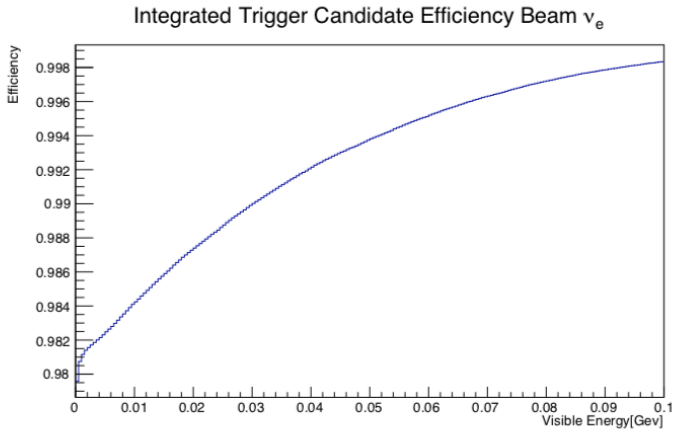


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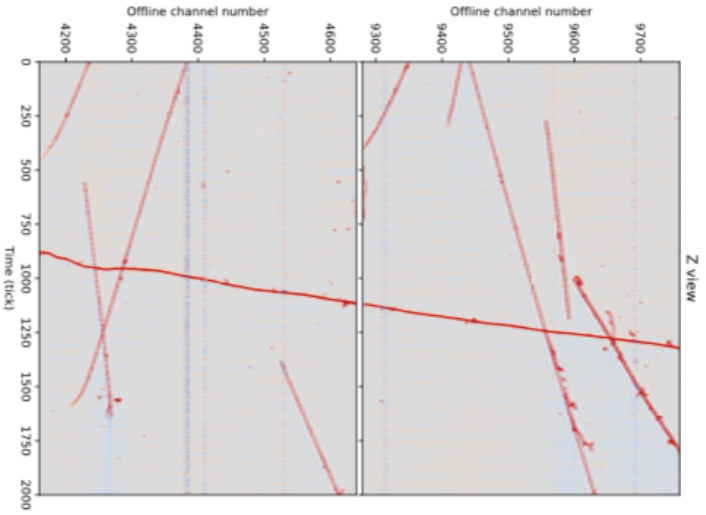
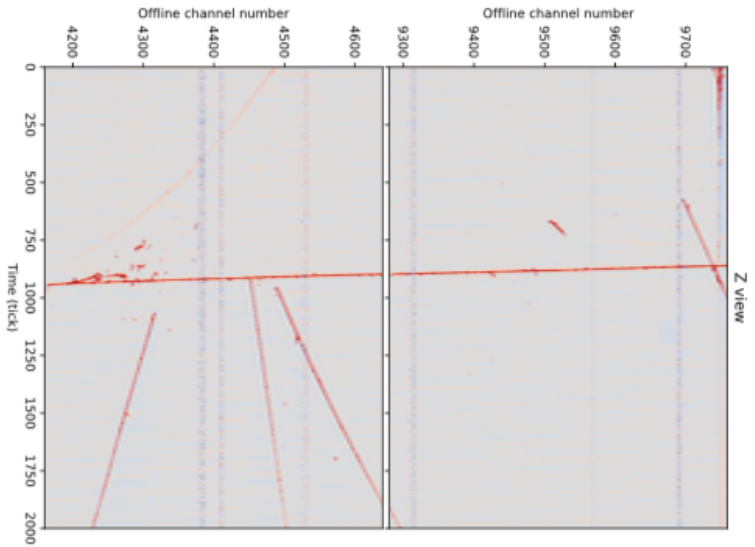
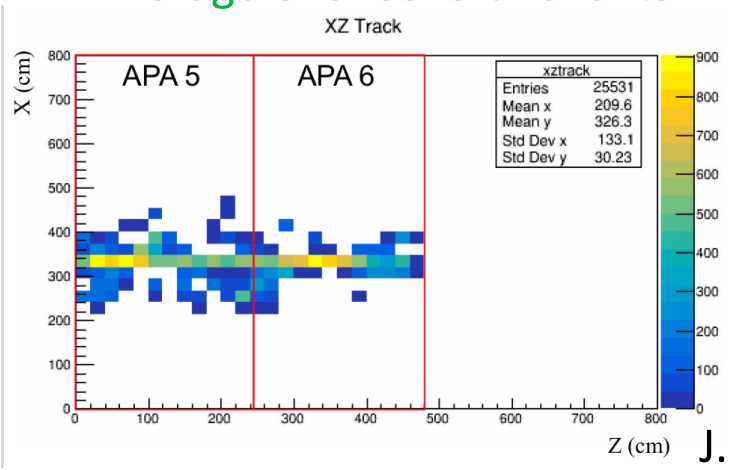
# Performance at PD-SP 1

Horiztonal Muon Trigger (exclusive)

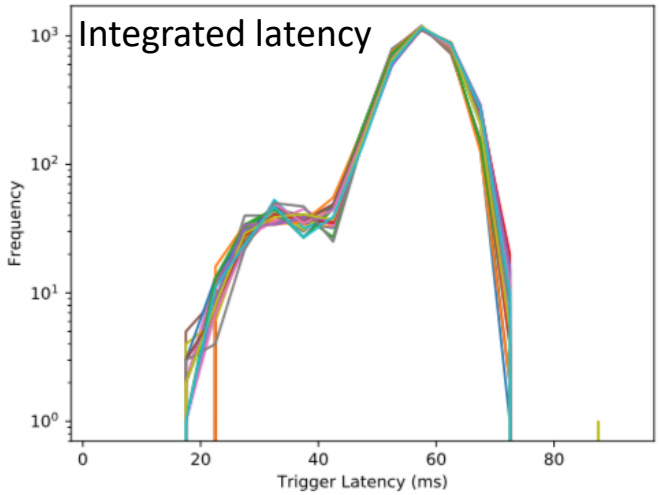



Average over several events




J. Sensenig




Time from data arriving at FELIX to Trigger Decision

Buffer depth was 1 second

# Moving Lower in E

## Region-of-Interest (ROI) Readout

Can have a higher trigger rate if data/trigger is smaller size:

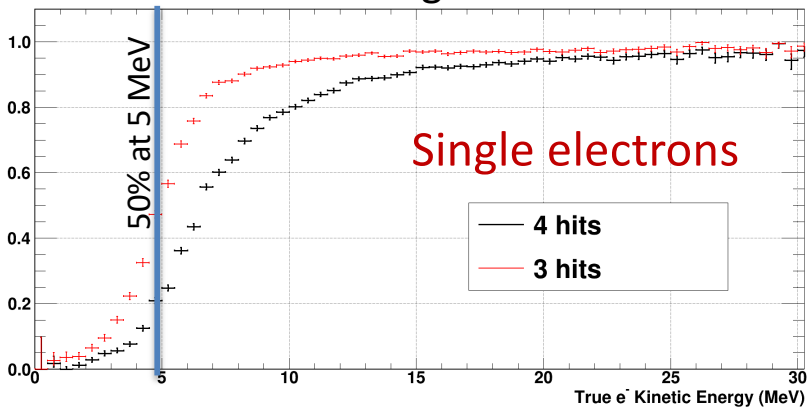
1. Halve readout window
2. Write out only APAs with trigger activity (TA)
3. Use a much narrower readout (100 μs) window around hits ("zero suppression")
4. Fully localize TA and use 100 μs window for readout

Table 2:

| Data Reduction Approach | Event Size (Uncompressed) | Max Trigger Rate | Enabled Physics |
|---|---|---|---|
| Nominal | 6.075 GB | 0.078 Hz | Beam, NDK, Atm. |
| 2.7 ms Readout Snapshot | 3.3075 GB | 0.156 Hz | Unknown |
| APA-Localization (Cosmics) | 0.243 GB | 1.95 Hz | *hep* solar $\nu$ |
| APA-Localization (Low-E) | 0.041 GB | 11.7 Hz | $^{8}$B solar $\nu$, neutrons,Rn |
| Zero Suppression | 0.040 GB | 12.0 Hz | $^{8}$B solar $\nu$, neutrons,Rn |
| TC[illegible] TA lization +Z ppression | 14.6 kB | 32.5 kHz | $^{42}$Ar, $^{40}$Cl, *pep* solar $\nu$? |

Of course, ROI can depend on type of Trigger Candidate

Threshold set so background rate ~ 10 Hz

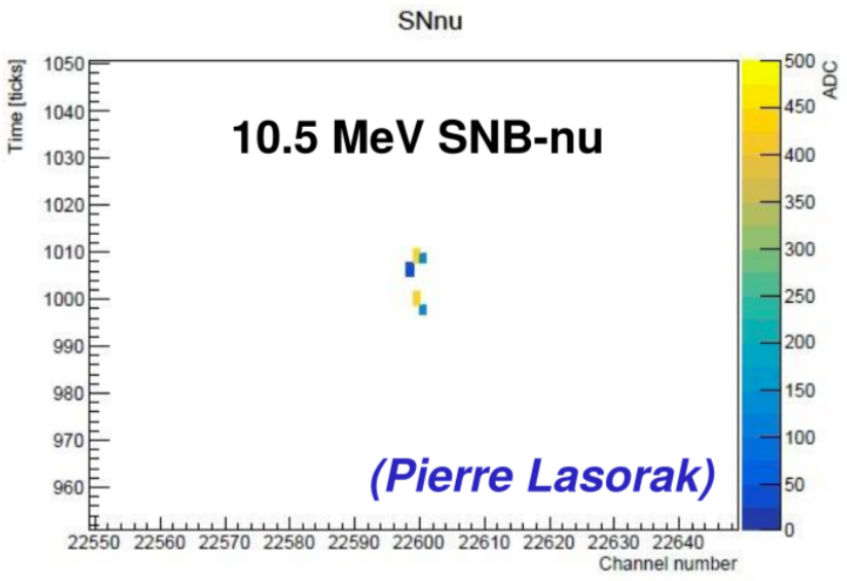


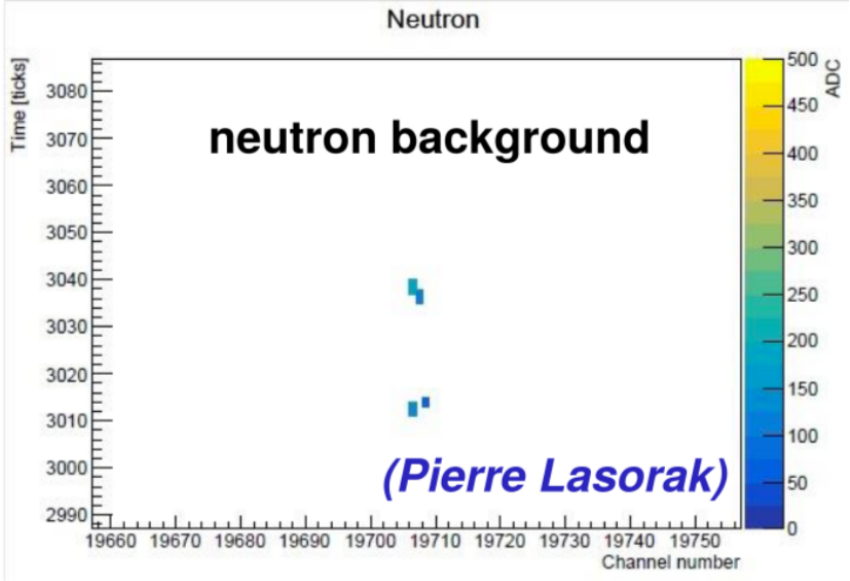

Thiago Bezerra

# Moving Lower in E

What if we want to reduce neutrons?

Neutrons produce a $\gamma$ cascade when they capture, electrons are more track-like
(But solar and SN neutrinos include de-excitation $\gamma$s):



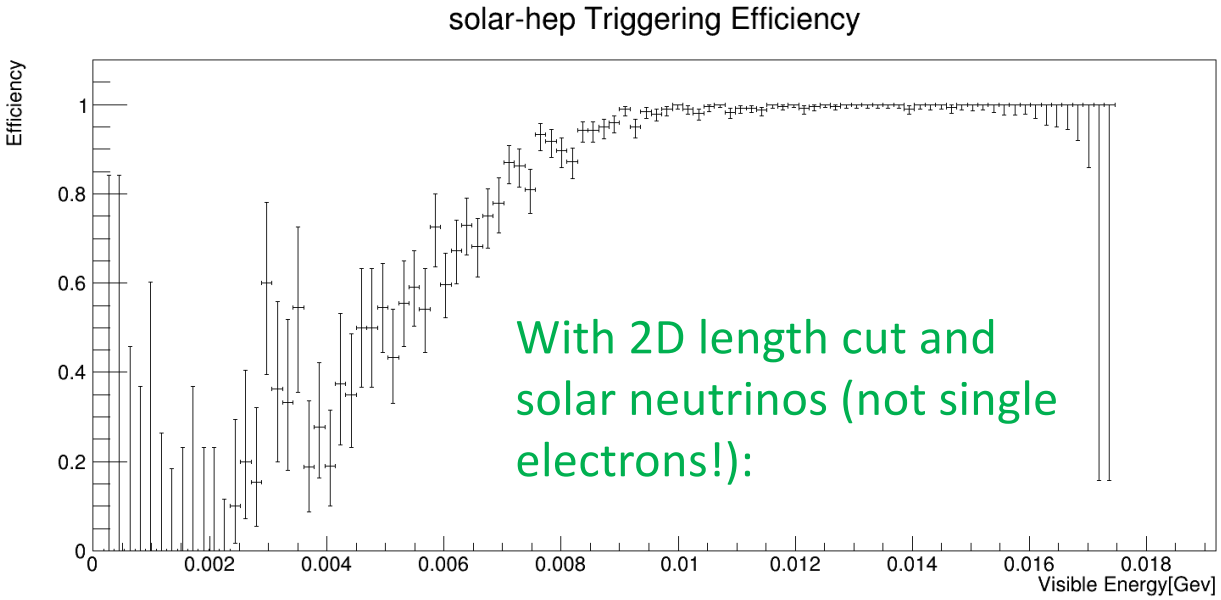



# Moving Lower in E

Can exploit topology of TPC:

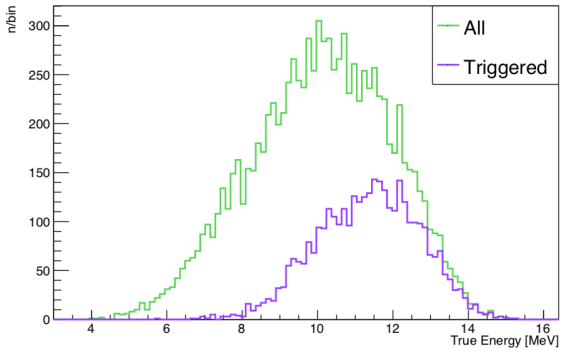
Use (collection-wire) primitives to create a “2D track length cut”

$$\mathcal{L} = \sqrt{(adj_{max} * 5mm)^2 + (TOT_{max} \times v_{drift})^2}$$

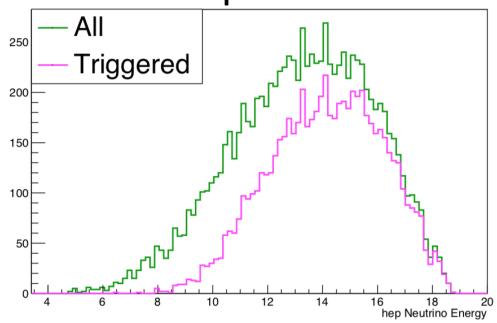



Trigger rate is ~ 100 Hz from backgrounds

$^8$B solar




hep solar



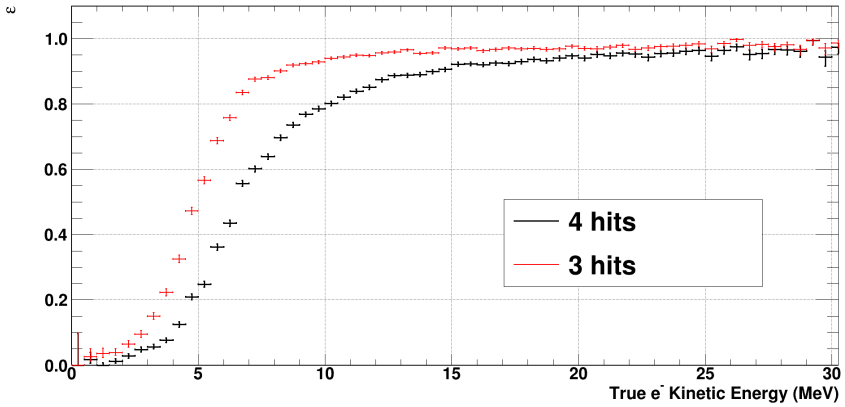

D. Rivera

# Moving Even Lower in E

- Include u/v wire trigger primitives
- (Very little pulse shape information at low energies)
- Write all of them continuously
- Threshold is ~250 keV
- Can run “offline” algorithms as sophisticated as desired
- Data will be overwhelmingly $^{39}$Ar

# Supernova Bursts

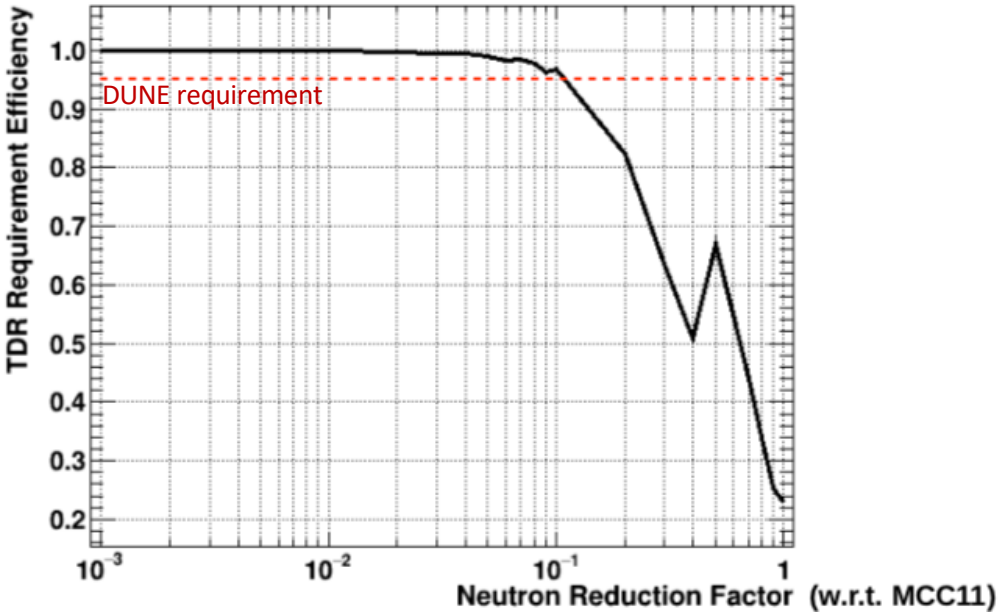
## Additional handle: Time and energy profile




T. Bezerra

Can accommodate more aggressive ”trigger activity” threshold but lowering single-interaction threshold hurts without energy-weighting

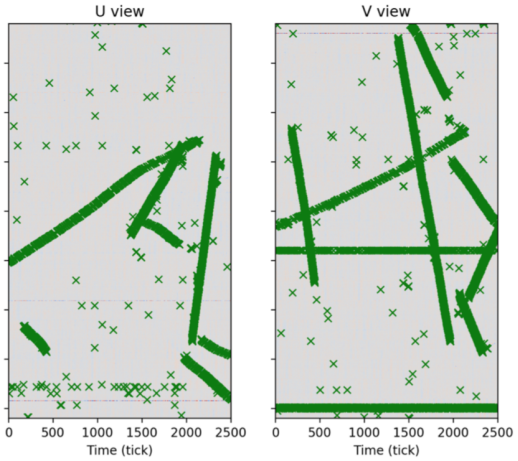
Not including energy profile




Note: we read out ***everything*** for 100 s if we detect a burst---event efficiency does not matter (much) except outside of that window

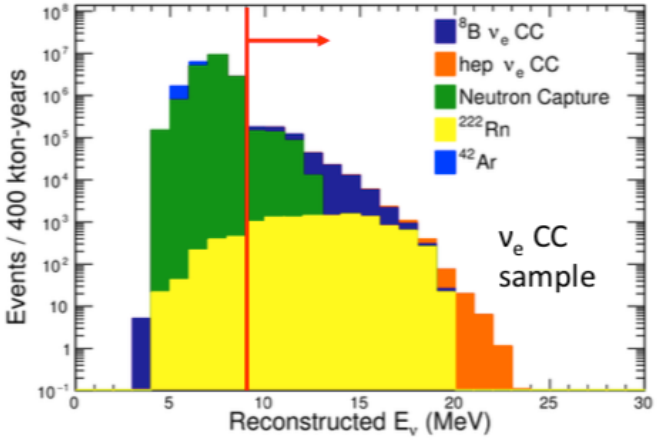
# Further Plans

- Induction wire TPs will help with neutron/electron discrimination




But noise level is about 20-30% higher than collection

But helps in using topology




D. Pershey

More complete “reconstruction” can be done in High-Level Filter

# Further Plans

- Including PDS
  - Naturally inclusive trigger (e.g., Npe>threshold)
  - Efficiency likely easy(-ier) to model and measure
  - Can be fast
  - Can reduce background rates via fiducialization---maybe in high-level filter
  - Noise uncorrelated with TPC
  - In principle singlet/triplet PID can reject $\alpha$s for very low-E program with u/g Ar

Careful study of background rates needed---in progress

# Summary

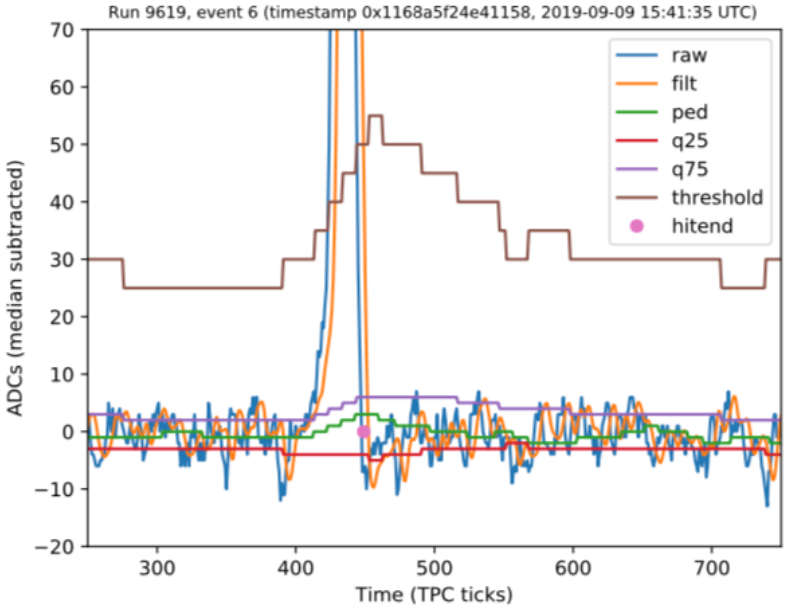
- Primary DUNE trigger uses TPC information to satisfy requirements
- Low-energy program can also be accommodated with tighter ROI for readout
- Fiducialization with PDS may help reduce external backgrounds and provide redundant path for additional efficiency
  - Need to understand background rates
- But nevertheless background rates limit usefulness of low-E data without shielding and/or underground argon

# Backups

# Trigger Primitives (TPs)
## Hit finding

At ProtoDUNE-SP I tried two approaches:

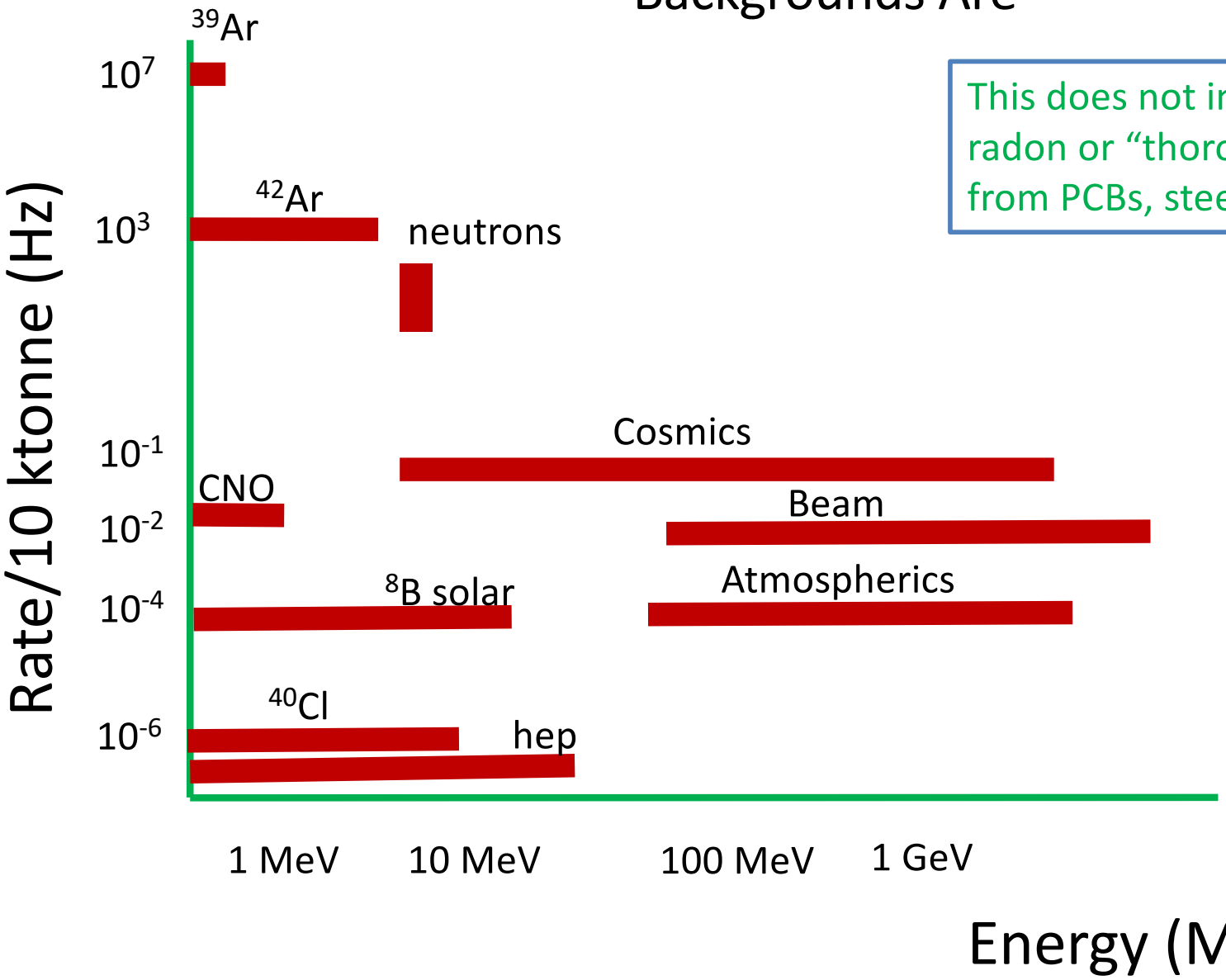
2. Noise RMS-dependent threshold
   - Find baseline and rms via “frugal streaming” (arXiv:1407.1121)
   - Filter (7-tap FTIR)
   - Apply threshold in noise sigma (5σ for PD-SP I)




P. Rodrigues

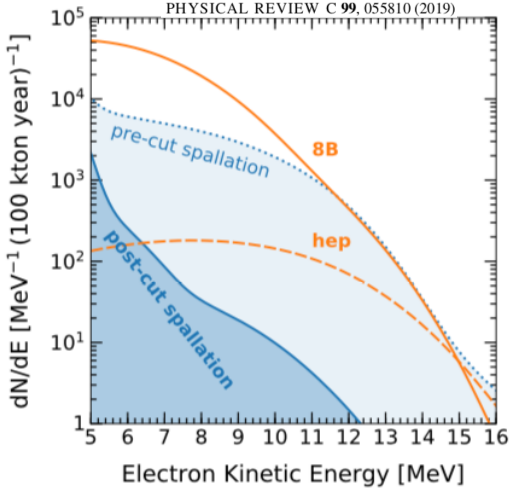
# Triggering is Not the Challenge

## Backgrounds Are




This does not include unsupported radon or "thoron," or U/Th gammas from PCBs, steel, APAs, or $^{40}$Ar($\alpha$,$\gamma$)

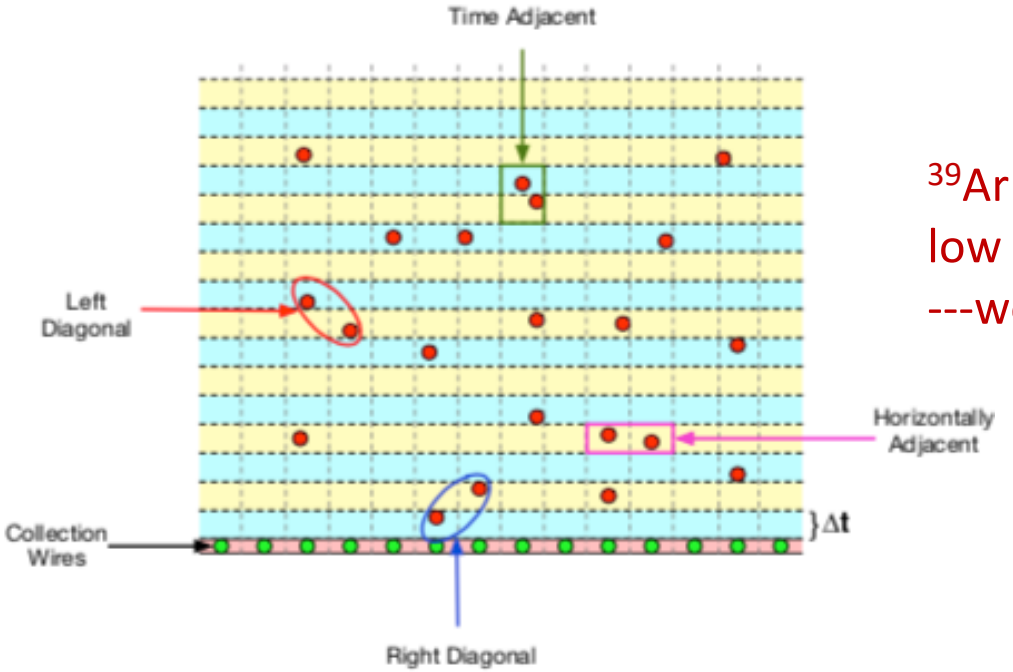
Zhu, Li, Beacom




Or spallation

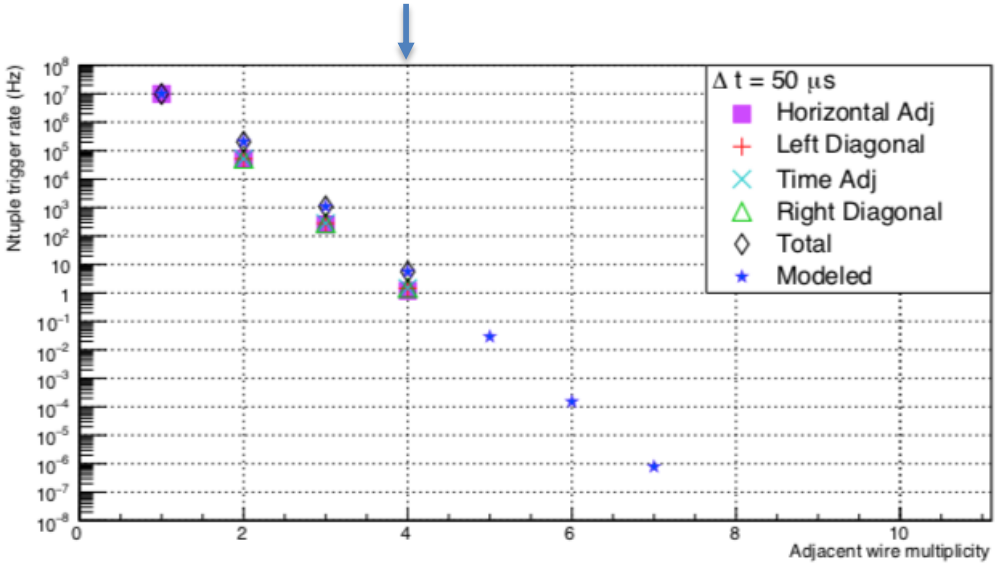
# Triggering is Not the Challenge

## Timing Is




$^{39}$Ar is such a high rate that pileup can create low E track-like events in slow drift medium ---worse for longer drift volumes.

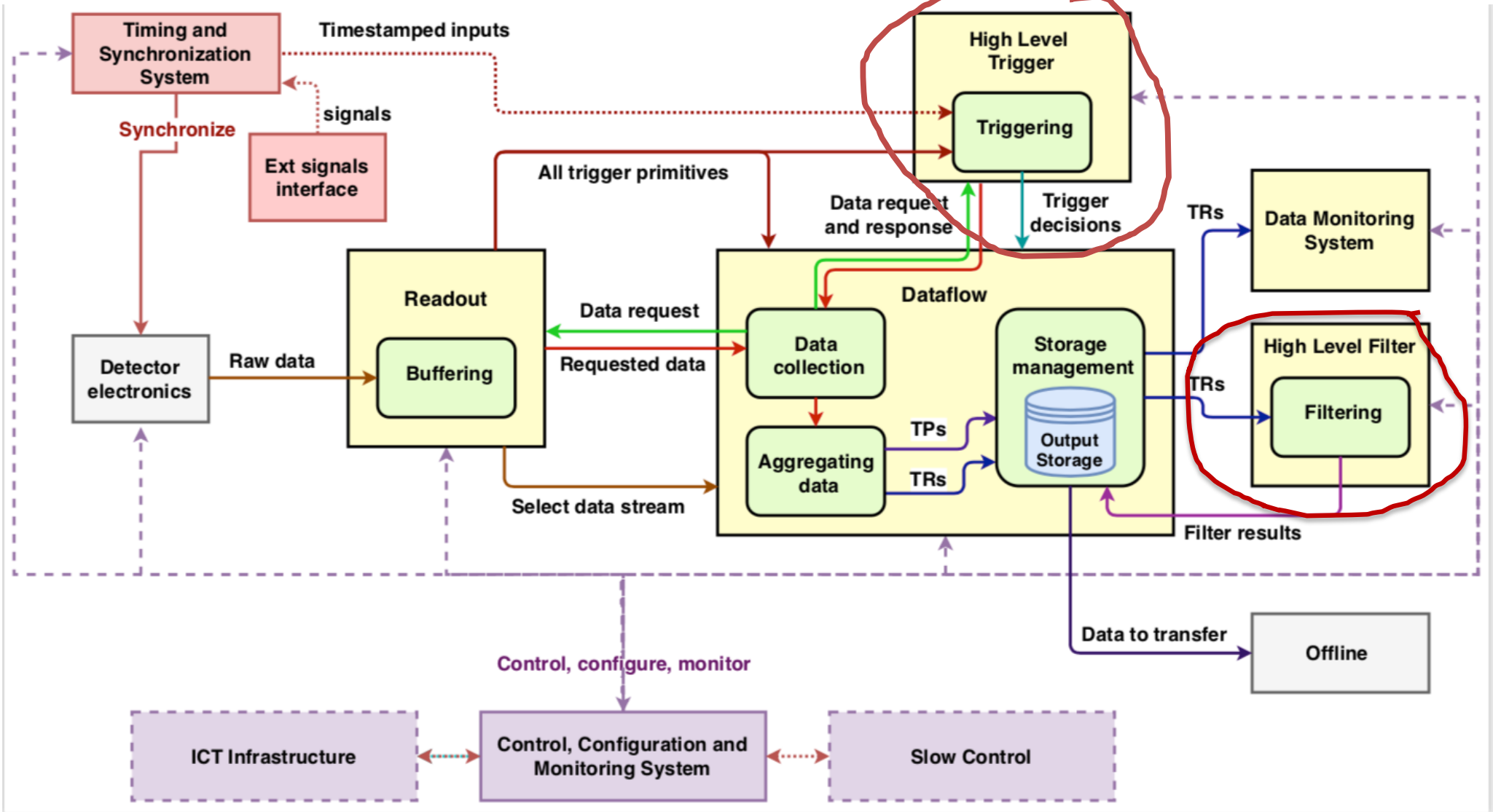
About 4 MeV MIP-equiv




D. Rivera

# TPC Triggering

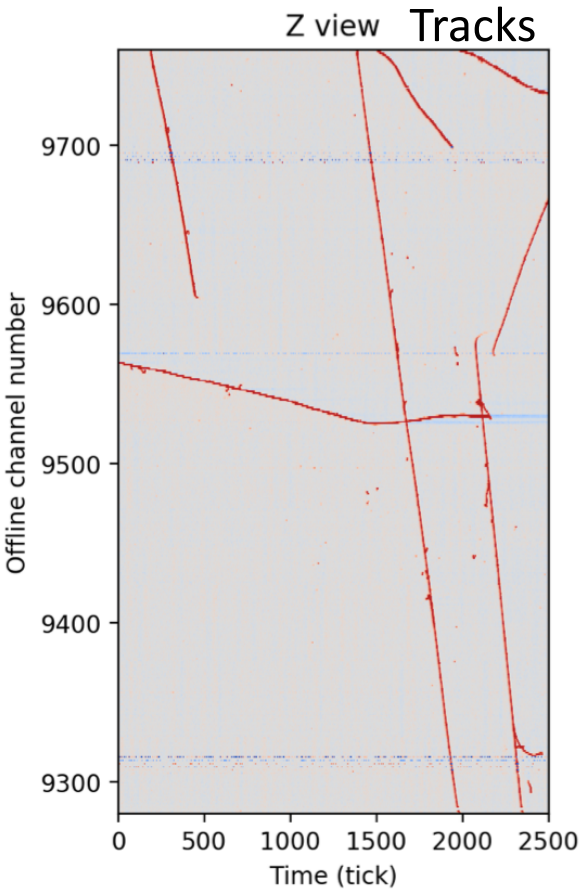
## More Complete Diagram

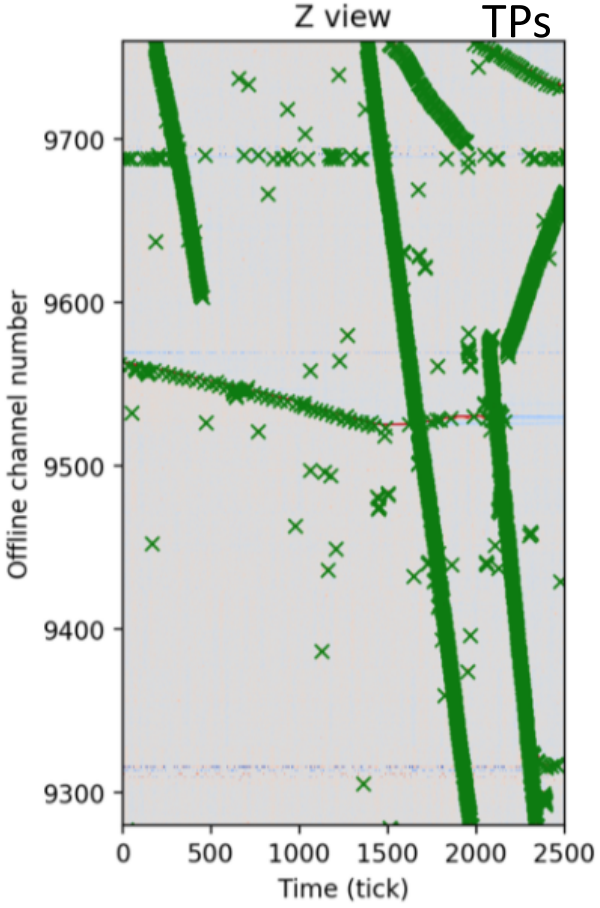


# Trigger Primitives (TPs)

## Hit finding

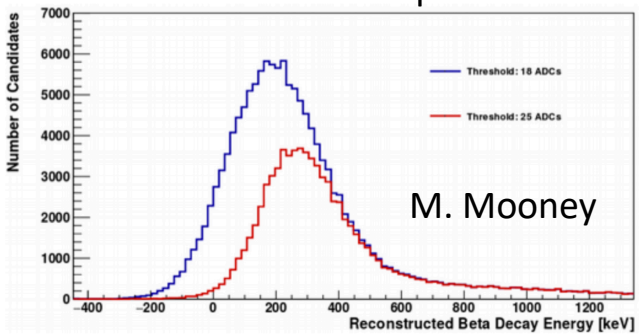
Run 11044, event 5 (timestamp 0x11955baa4c000a0, 2020-03-09 17:22:51 UTC)



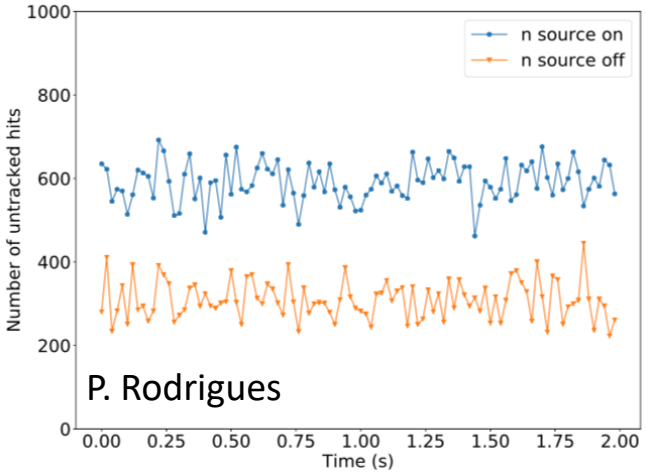




TP threshold was around 1/4 MIP-equivalent, or around 250 $keV_{ME}$ (per wire)

ProtoDUNE-SP $^{39}Ar$ spectrum



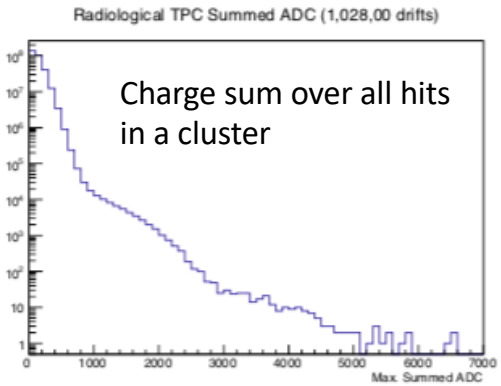

Some efficiency for neutrons

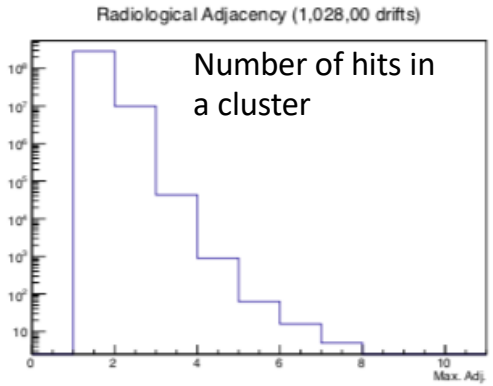


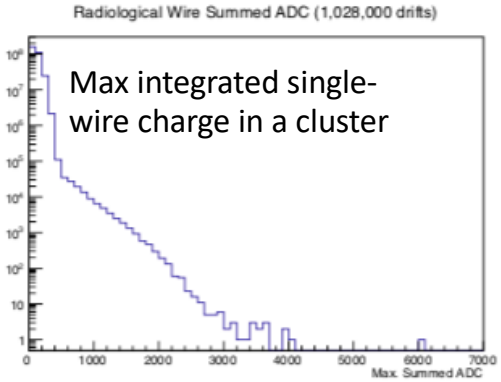

P. Rodrigues

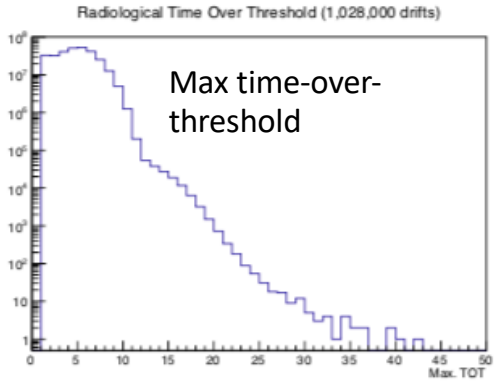
# Trigger Candidates

## Cutting




Rivera and Last

Radiological rate acceptable* with:

- $N_{adj}$ >= 8 wires
- Cluster charge sum > 7000 ADC counts
- Max integrated wire charge > 6500 counts
- Max time-over-threshold >= 45 ticks

***acceptable rate was so that 5.4 ms readout of all channels had data rate < 25% of cosmic data rate**

# Moving Lower in E

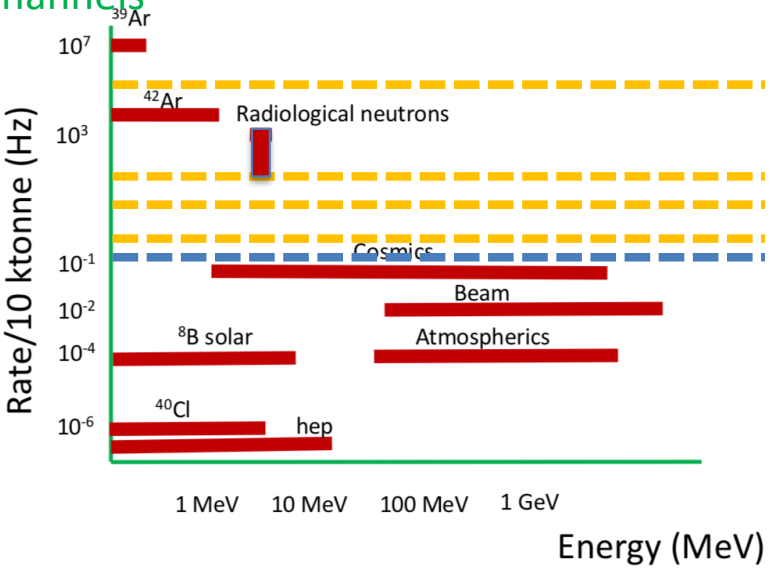
## Region-of-Interest (ROI) Readout

Can have a higher trigger rate if data/trigger is smaller size:

1. Halve readout window
   - "Free" because for low E events there is no trigger ambiguity
2. Write out only APAs with trigger activity (TA)
   - At low E, pretty safe and big reduction
   - Cosmics require ~6 APAs on average
3. Use a much narrower readout (100 μs) window around hits ("zero suppression")
   - Big enough for any deconvolution in processing
   - Will definitely do this for laser calibrations
4. Fully localize TA and use 100 μs window for readout
   - Most aggressive; need to read out "box" around hit channels

Table 2:

| Data Reduction Approach | Event Size (Uncompressed) | Max Trigger Rate | Enabled Physics |
|---|---|---|---|
| Nominal | 6.075 GB | 0.078 Hz | Beam, NDK, Atm. |
| 2.7 ms Readout Snapshot | 3.3075 GB | 0.156 Hz | Unknown |
| APA-Localization (Cosmics) | 0.243 GB | 1.95 Hz | *hep* solar $\nu$ |
| APA-Localization (Low-E) | 0.041 GB | 11.7 Hz | $^{8}$B solar $\nu$, neutrons,Rn |
| Zero Suppression | 0.040 GB | 12.0 Hz | $^{8}$B solar $\nu$, neutrons,Rn |
| TA Localization +Zero Suppression | 14.6 kB | 32.5 kHz | $^{42}$Ar, $^{40}$Cl, *pep* solar $\nu$? |



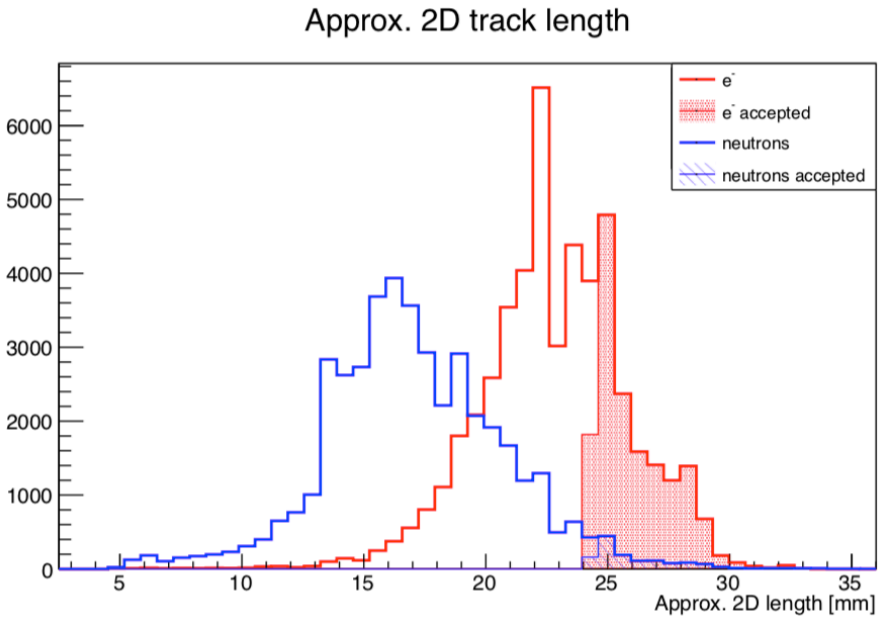

Of course, ROI can depend on type of Trigger Candidate

# Moving Lower in E

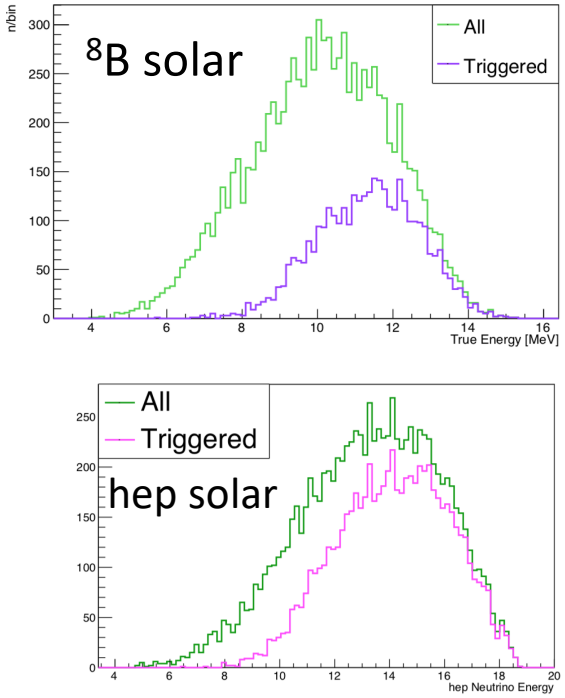
Can exploit topology of TPC:

Use (colletion-wire) primitives to create a “2D track length cut”

$$\mathcal{L} = \sqrt{(adj_{max} * 5mm)^2 + (TOT_{max} \times v_{drift})^2}$$




D. Rivera

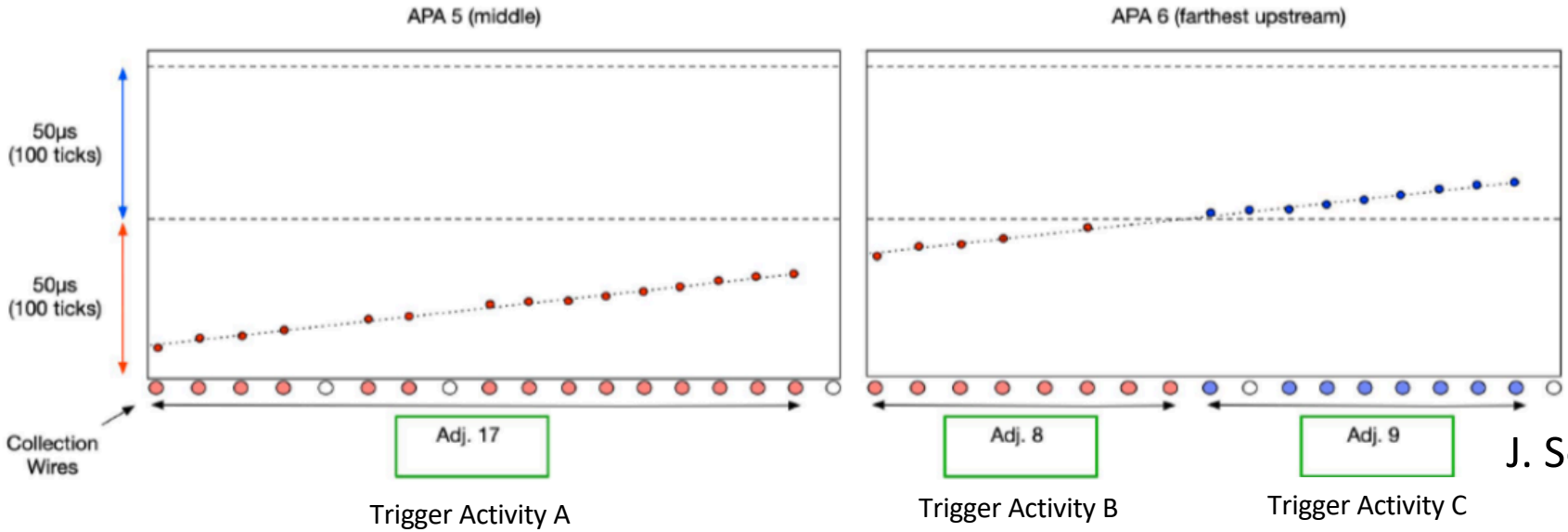


# Further Plans

- Including PDS
  - Naturally inclusive trigger (e.g., Npe>threshold)
    - Trigger threshold maps to energy pretty cleanly and simply
    - But that also means higher background rates
    - Also will depend on channel-level thresholds
    - And depends strongly on light yield and uniformity
  - Efficiency likely easy(-ier) to model
    - Can be calibrated and measured relatively easily
  - Can be fast
    - Helps reduce spallation-induced fake supernova bursts
    - But readout buffers are so big (10 s) that speed not critical for trigger decision
  - Can reduce background rates via fiducialization---even better for VD!
    - External neutrons and $\gamma$s will capture/convert near edges of volume
    - Can get lower trigger rates for low-energy physics
    - Might do this in High-Level Filter
  - Noise uncorrelated with TPC
    - Can help reject unexpected triggers from noisy wires
  - In principle singlet/triplet PID can reject $\alpha$s for very low-E program with u/g Ar
    - Xenon loading is an interesting opportunity/complication
    - Will need to require nitrogen (and other) contamination to be very low

# Implementation at PD-SP 1

- Cosmic rate too high for an inclusive trigger
- Picked reasonably low-rate exclusive channel---horizontal muons
- Allowed us to exercise entire TP→TA→TC chain




J. Sensenig

Trigger activity from individual APAs stitched together to form Trigger Candidates
(Gaps of up to 4 wires allowed in Trigger Activity cluster)