

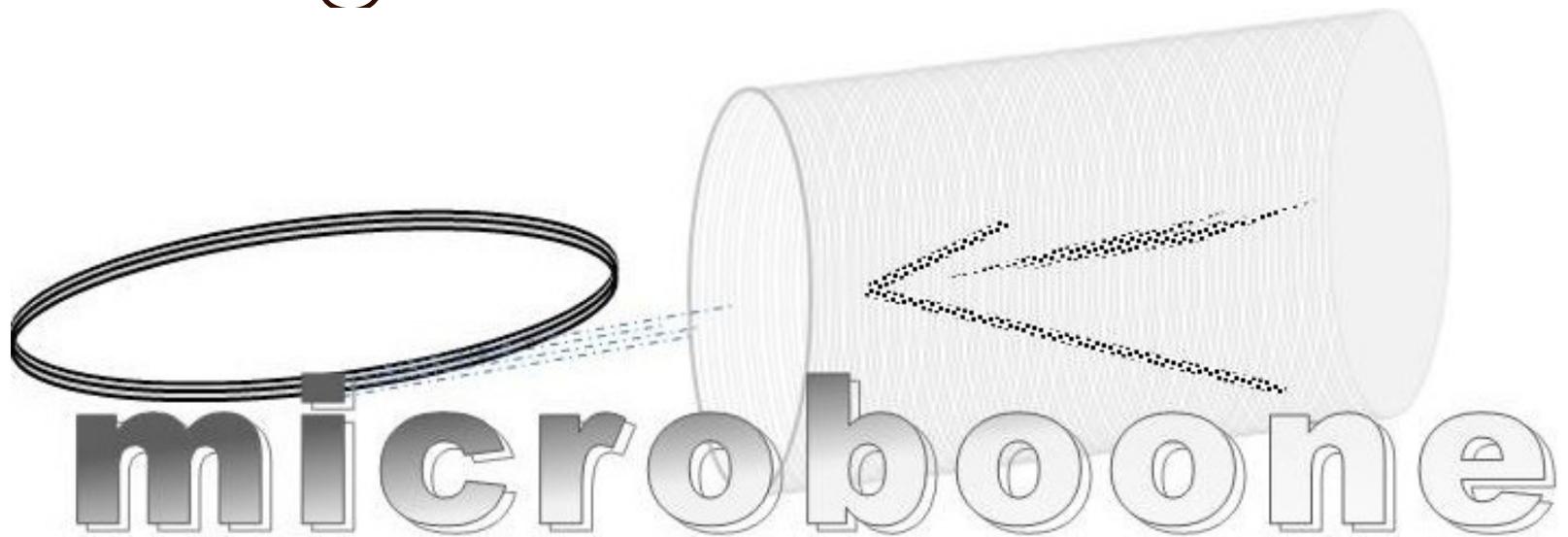
PMT Triggering and Readout for the MicroBooNE Experiment

David Kaleko (Columbia University)

for the MicroBooNE Collaboration

May 31, 2013

LIDINE @ FNAL



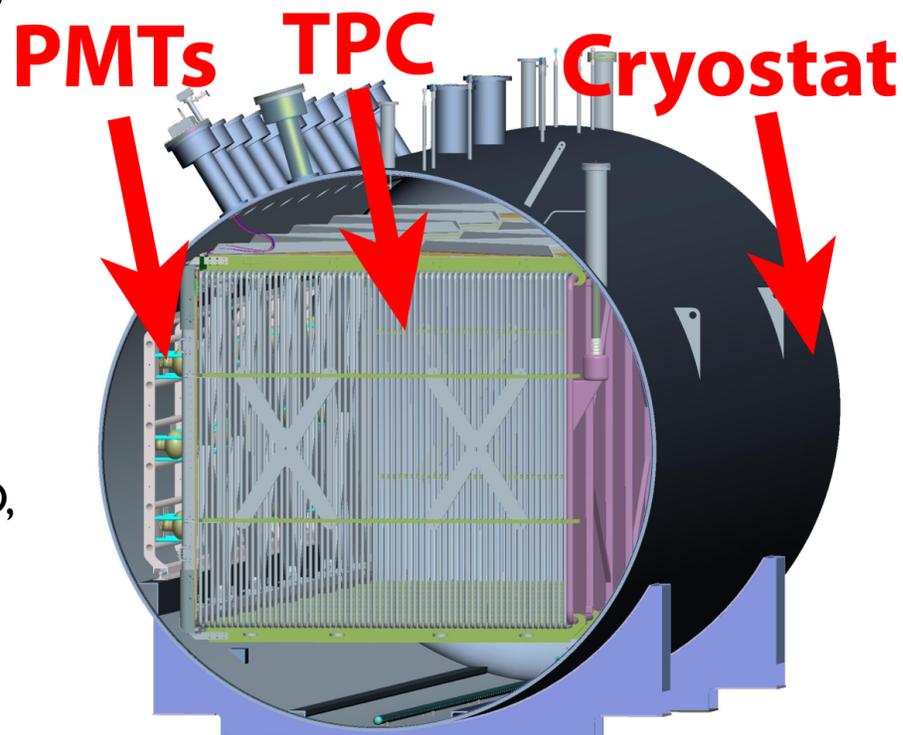


Outline

- **General MicroBooNE**
- **Goals of PMT Readout System**
- **PMT Electronics**
- **PMT Triggering**

General MicroBooNE

- Liquid Argon TPC: 170ton LAr, 86ton active
- BNB ~ 10 Hz, 1.6microsecond beam gate window (BGW)
- Located *on surface*: ~ 5 kHz cosmics (5-8 per 1.6ms drift time)
- 32 cryogenic PMTs: triggering and timing information
 - Also reconstruction, cosmic ID, etc.
 - More details: see Teppei's talk
- TPC:
 - 3mm wire spacing
 - 2.5m drift (1.6ms)
 - 3 wire readout planes (Y, U, V)





PMT Readout Goals

- We want to:
 - Identify sample of beam neutrino interactions (PMT trigger)
 - Measure timing and position of different background cosmics
 - Measure prompt and late light
 - See Michel electrons from beam events
- All while having a manageable data rate

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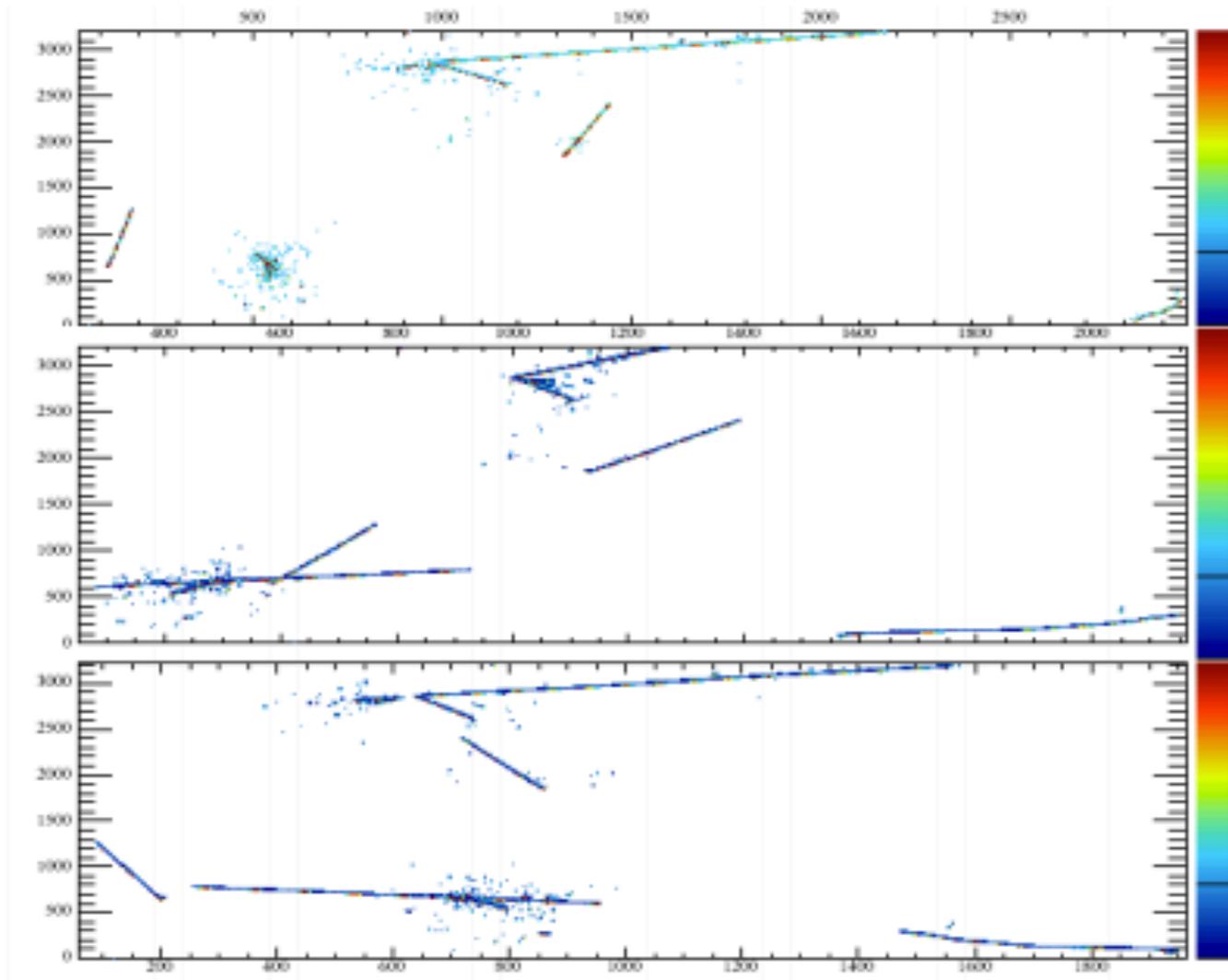
Data Volume Reduction with PMTs

- Readout with no PMT requirement:
 - 1/125 BNB events read out have cosmic in gate
 - **1/2500** BNB events read out have neutrino event (2e12ppp)
- Readout based on PMT trigger:
 - Almost all events read out have cosmic in gate
 - **1/20** BNB events read out have neutrino event

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Which of these is a Neutrino?





Tagging Cosmics

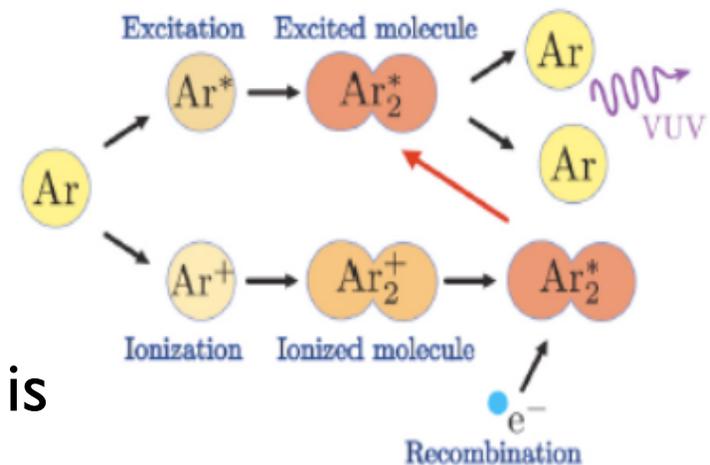
- ~Tens of cosmics in average 4.8ms TPC readout window
 - Need to reject these!
- Flash Finder (see Teppei's talk) helps isolate events in time with beam gate window
- Cosmics useful for calibrating PMTs

PMT Readout Goals

- We want to:
 - Identify sample of beam neutrino interactions (PMT trigger)
 - Measure timing and position of different backgrounds and cosines
 - Measure prompt and late light
 - See threshold for beam events
- All while having a manageable data rate

Late Light Scintillation

- Excited or ionized Ar atom may combine with ground state Ar atom to form excimer
 - This decays back into two GS atoms
 - Decay time depends on singlet or triplet state of excimer
- Prompt (singlet)
 - ~6nanosecond lifetime
- Late (triplet)
 - ~1.6microsecond lifetime
- Prompt-to-late light ratio is function of dE/dx (PID!)
- *Need to make PMT readout accommodate for seeing this*

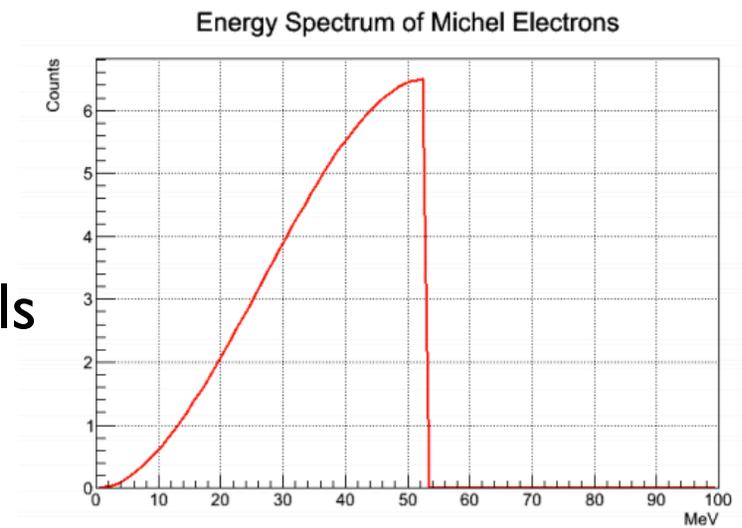
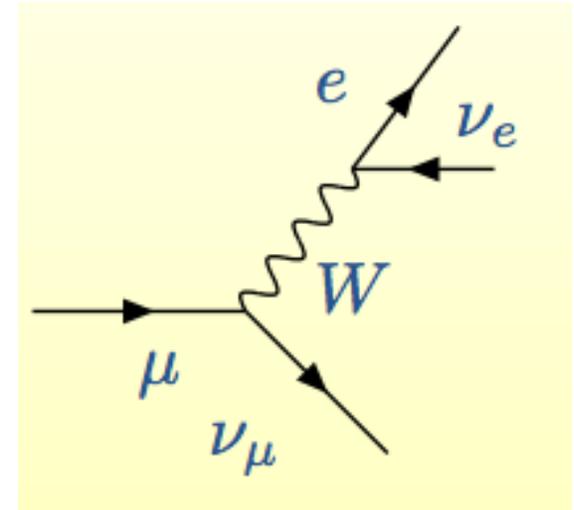


PMT Readout Goals

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Michel Electrons

- Mu lifetime of 2.2μ seconds
- Michel electron distribution useful for:
 - Identifying a final state particle as muon
 - PMT calibration (QE tube-to-tube)
 - Calibrate light yield as function of position in detector
- CCPI+ channel has two muons: possibly two Michels



PMT Readout Goals

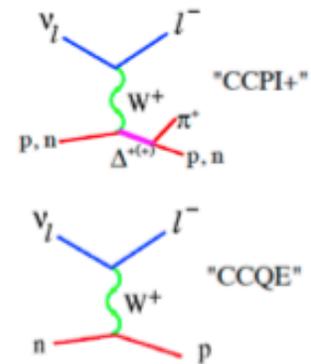
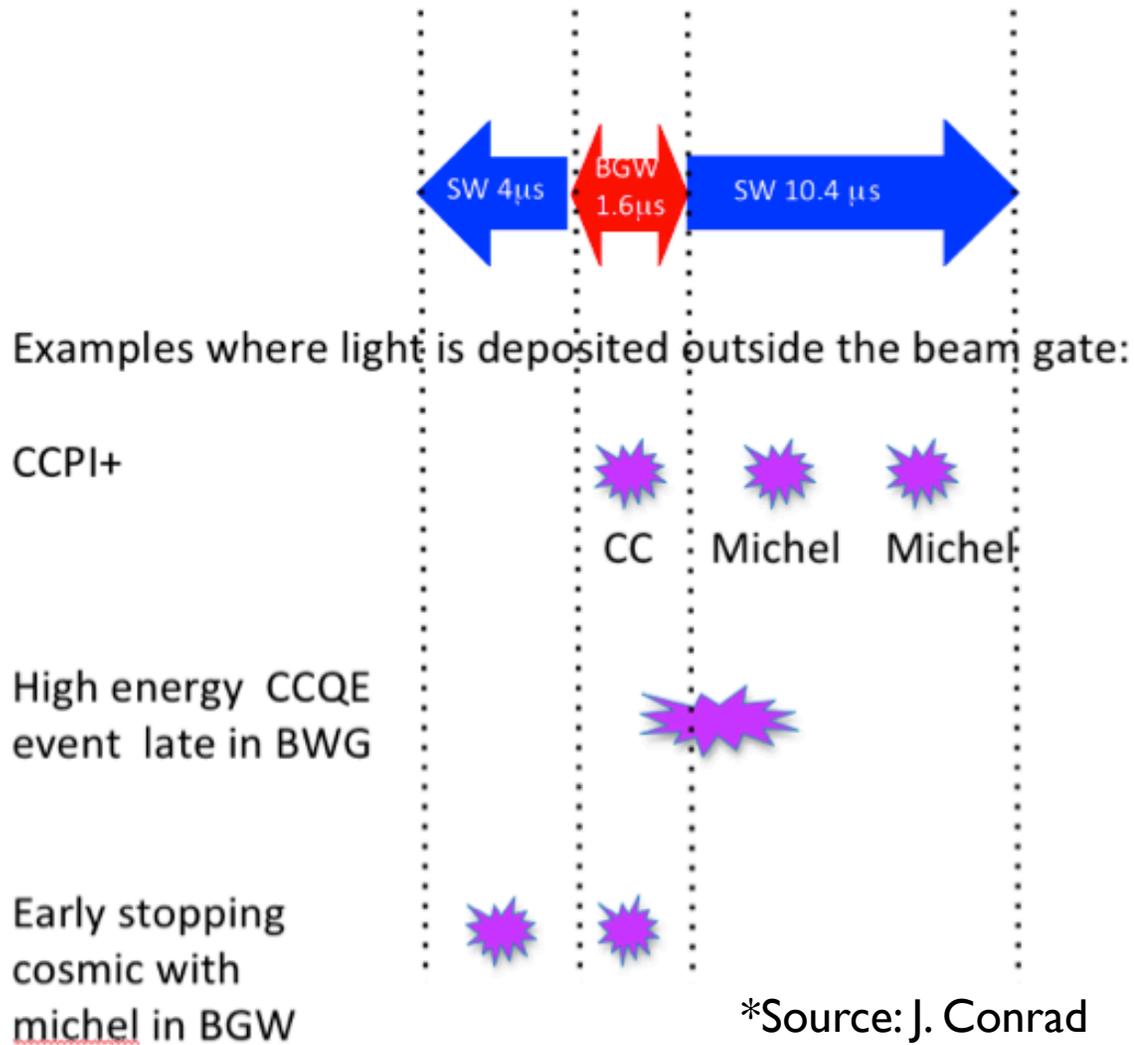
- We want to:
 - Identify sample of beam neutrino interactions (PMT trigger)
 - Measure timing and position of different background cosmics
 - Measure prompt and late light
 - See Michel electrons from beam events
- All while having a manageable data rate
 - Here's how we do it:

Readout structure

- Reading out only 1.6microsecond beam gate window (BGW) isn't insufficient
- Reading out 24/7 is unrealistic data volume
 - Need to read out a window surrounding BGW, "surrounding window" (SW)
 - 1500 digitized samples, *always read out*
 - Need to read out small windows surrounding cosmoics inside of 4.8ms TPC readout window (TPCW)



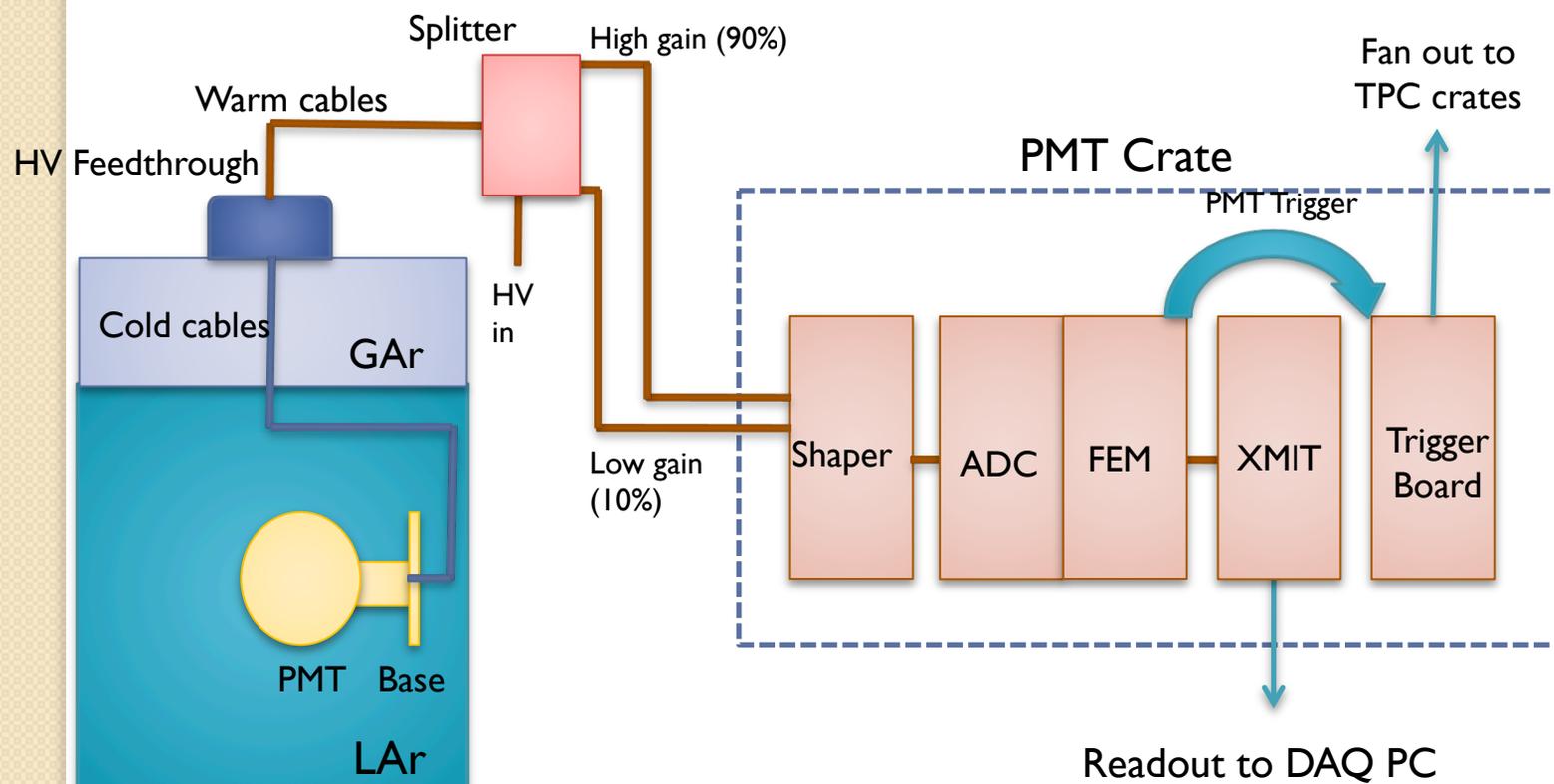
Why We Need “Surrounding Window”



*Source: J. Conrad

PMT Electronics

- Includes signal shaper boards, PMT feedthrough, HV/ signal splitters, and a trigger board
- High gain vs. low gain extends dynamic range of ADC



PMT Electronics: Shaper

- 64MHz (16ns sample) digitization
- Unipolar shaper
 - 60ns shaped rise time
 - 2-3 digitized samples on rising edge
 - Allows for accurate event start time determination
- FPGA on FEM responsible for generating PMT triggers

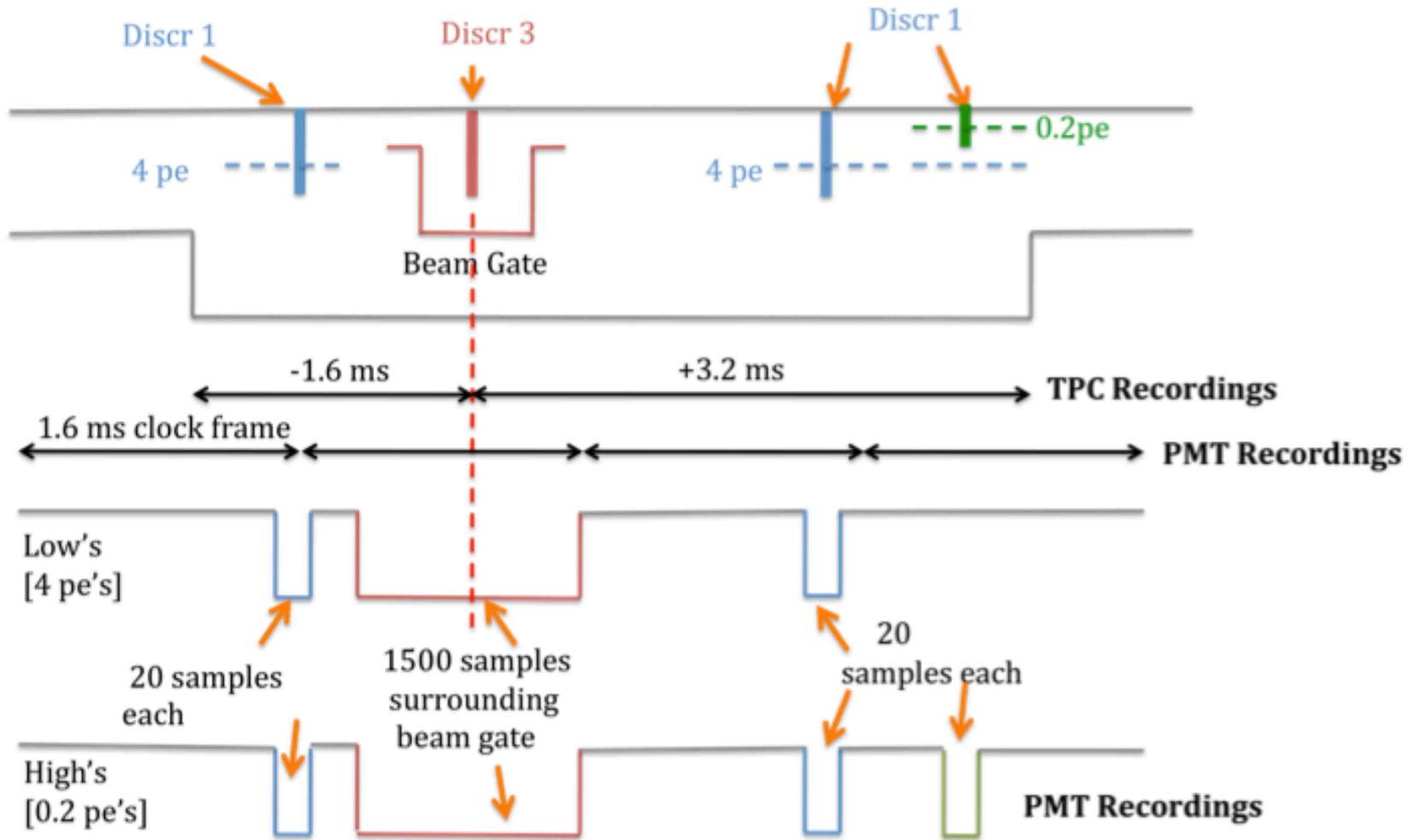


Shaped 25mV 25ns negative square pulse (differentially driven)

Conditions for PMT Readout

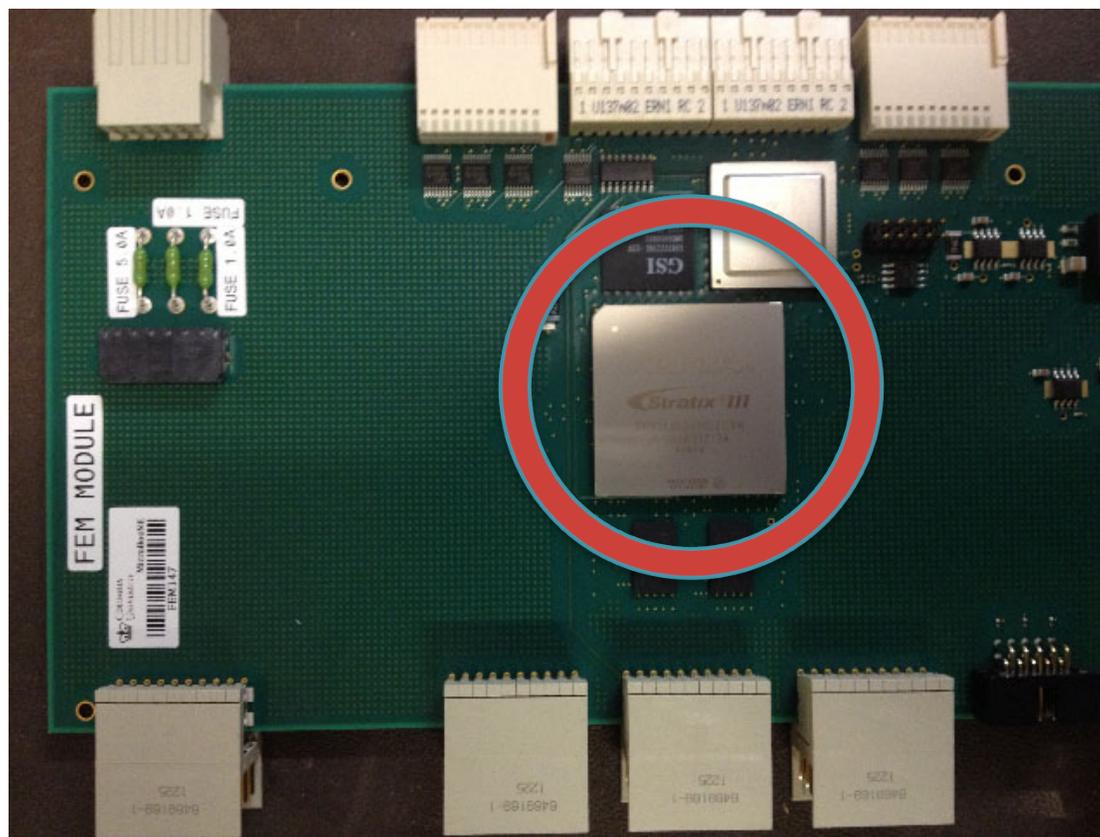
- Discriminator levels 0, 1
 - Low-threshold “Discr0” allows good timing
 - Low-threshold “Discr0” precondition for higher threshold “Discr1” outside of BGW (tagging cosmics)
- Beam gate (to read out surrounding window)
- *All parameters configurable at run-time.*

PMT recordings during Beam events



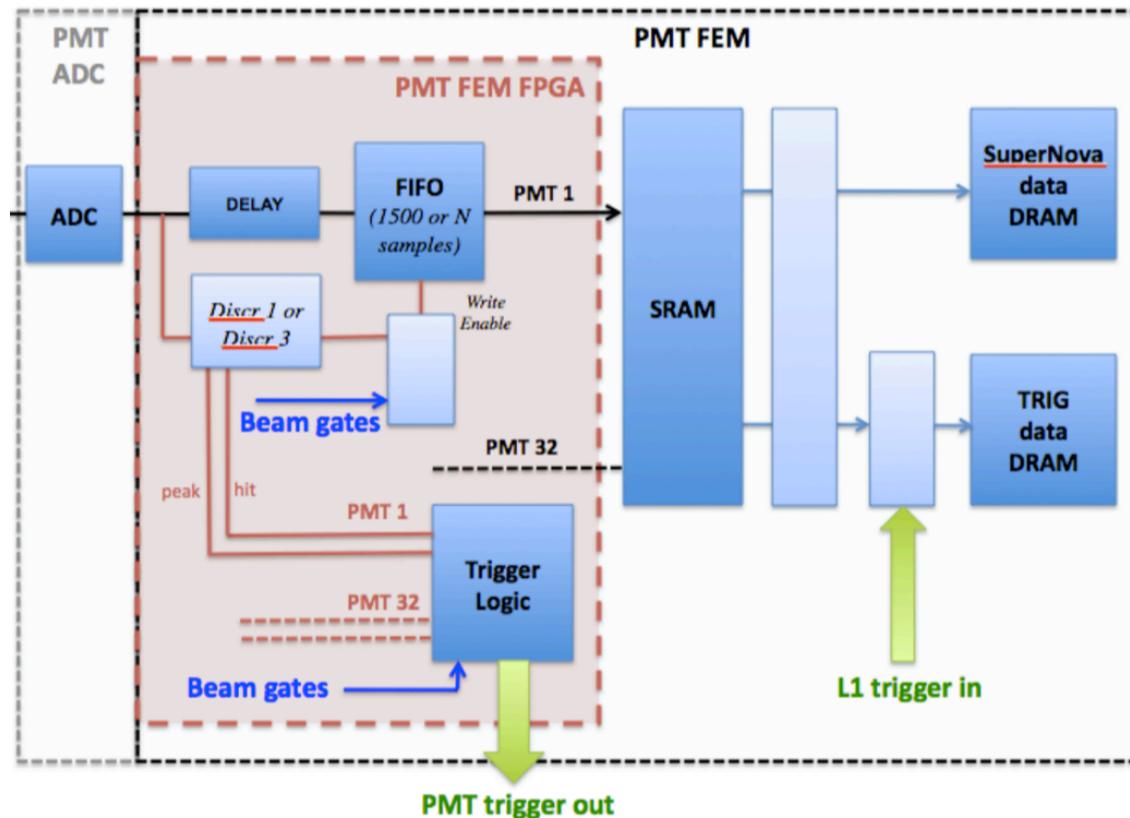
Triggering with PMTs

- Threshold/discriminator/timing conditions implemented in FPGA on PMT Front End Module.
 - Include pulse amplitude on single PMTs, summed coincidences on multiple PMTs, delayed coincidences (Michel electrons).

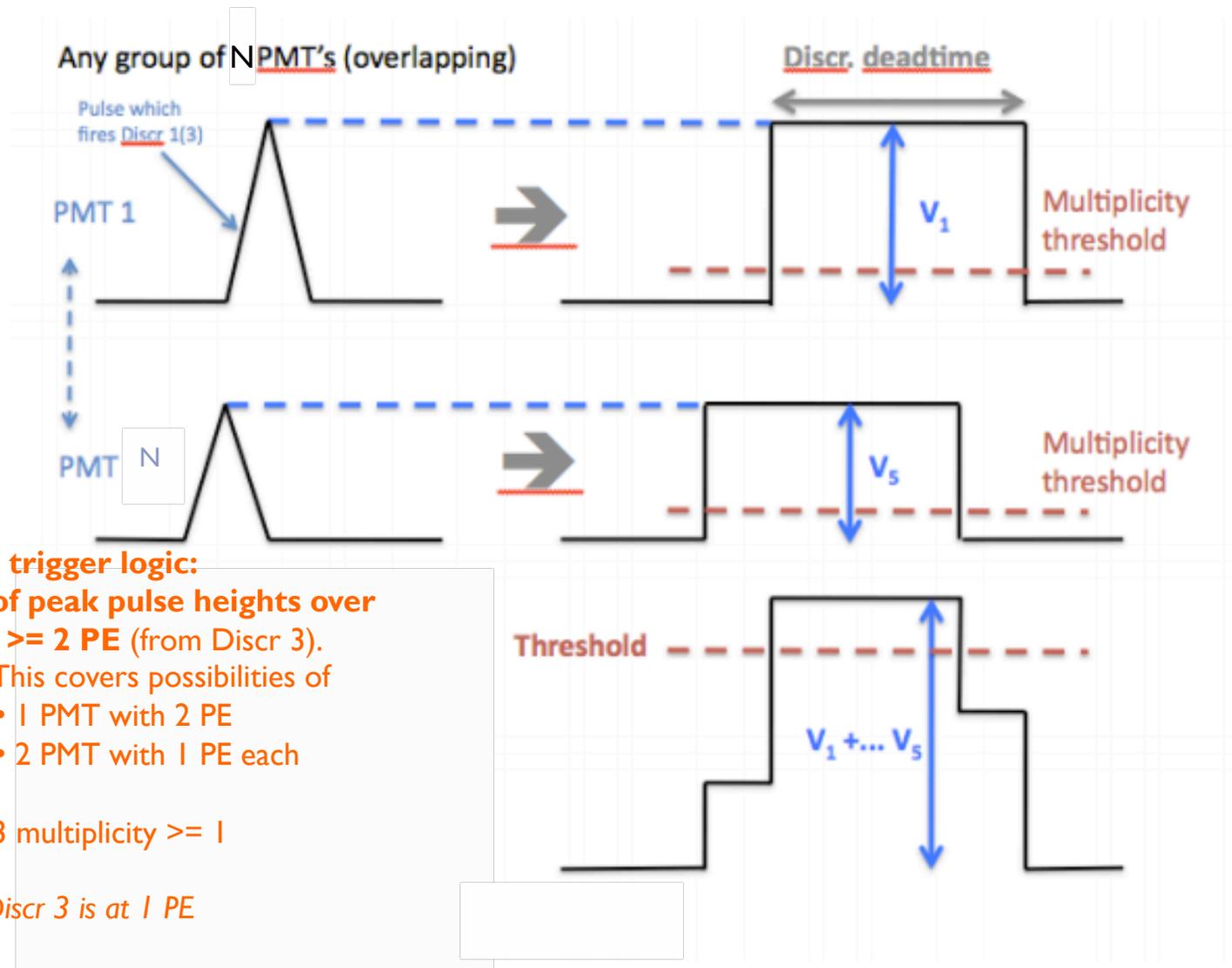


Triggering with PMTs

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Conditions for PMT Triggering



Types of Triggers Available

- Beam event trigger
 - Beam PMT trigger in coincidence with beam gate
- Cosmic PMT trigger
 - Happens in “OUTW”
- External trigger
- DAQ-issued calibration trigger
- Random trigger to study backgrounds
- All of these are mixed (“OR’d”) in trigger board



Conclusion

- PMTs capable of studying important/interesting physics, and readout structure is designed accordingly
- PMT system produces trigger signals for entire readout and DAQ system
- All triggering/readout parameters configurable at run-time
- Data taking starts beginning of 2014!

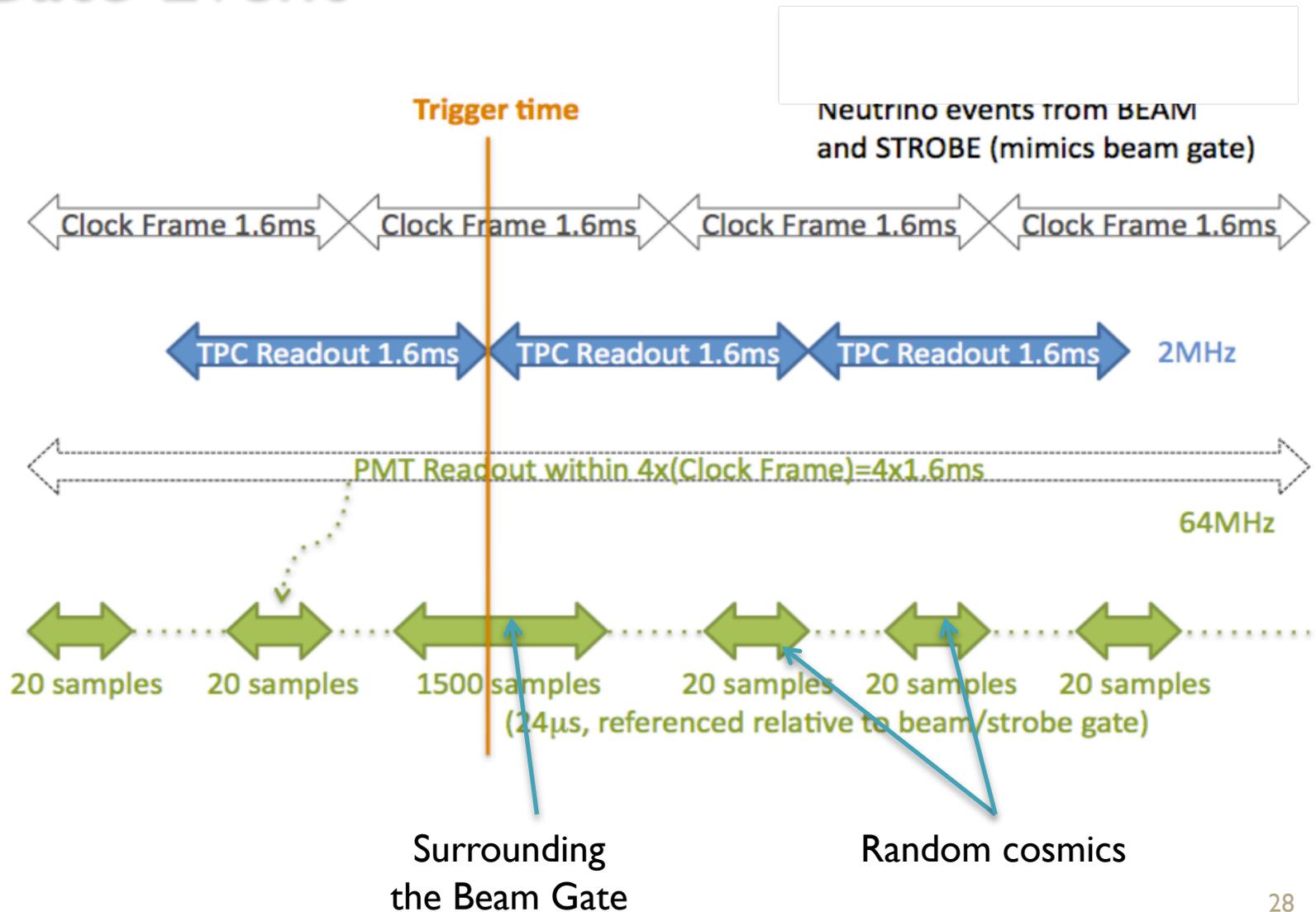
A man wearing a dark grey hoodie with 'CAROLINA 43' printed on it and khaki pants stands with his hands on his hips inside a large, circular industrial tunnel. The tunnel walls are metallic and feature various pipes, conduits, and electrical components. The lighting is dim, with a bright spot on the floor near the man. The text 'THE END' is overlaid in large, white, bold, sans-serif font across the upper middle of the image.

THE END



Backup Slides

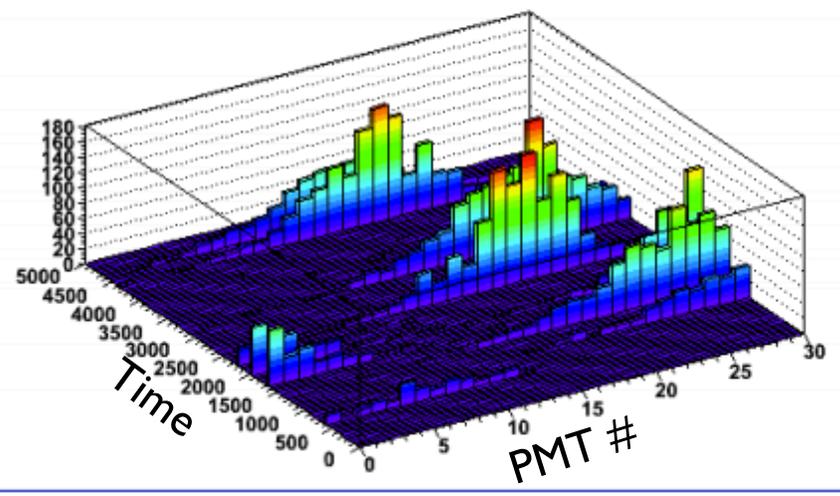
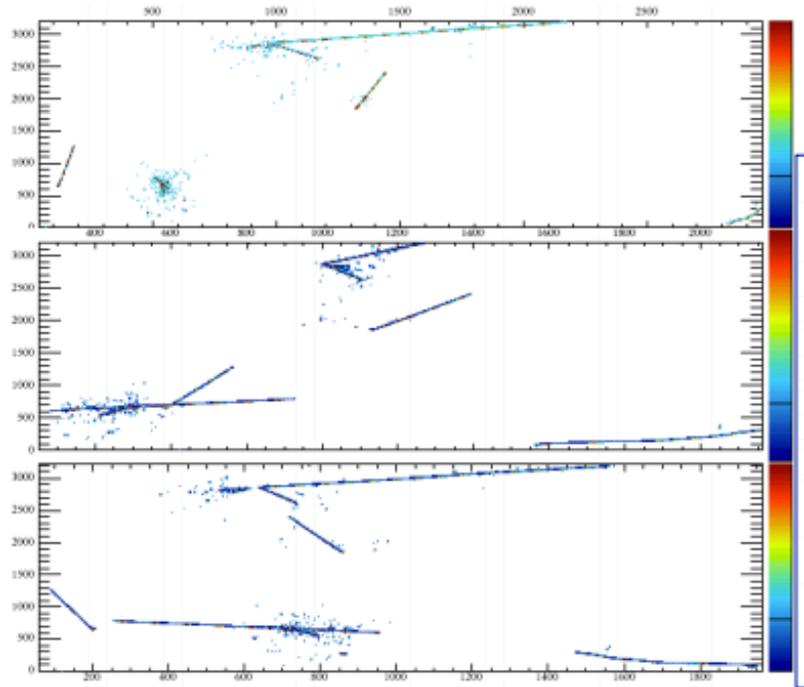
TPC + PMT Readout Data For A Beam Gate Event



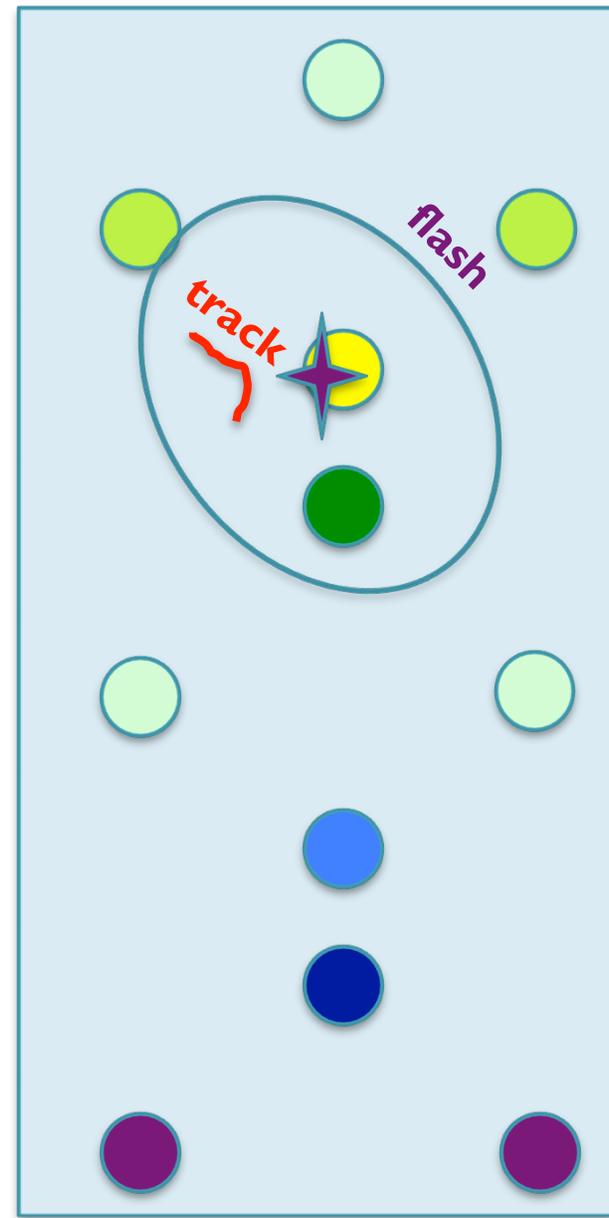


Flash Finder

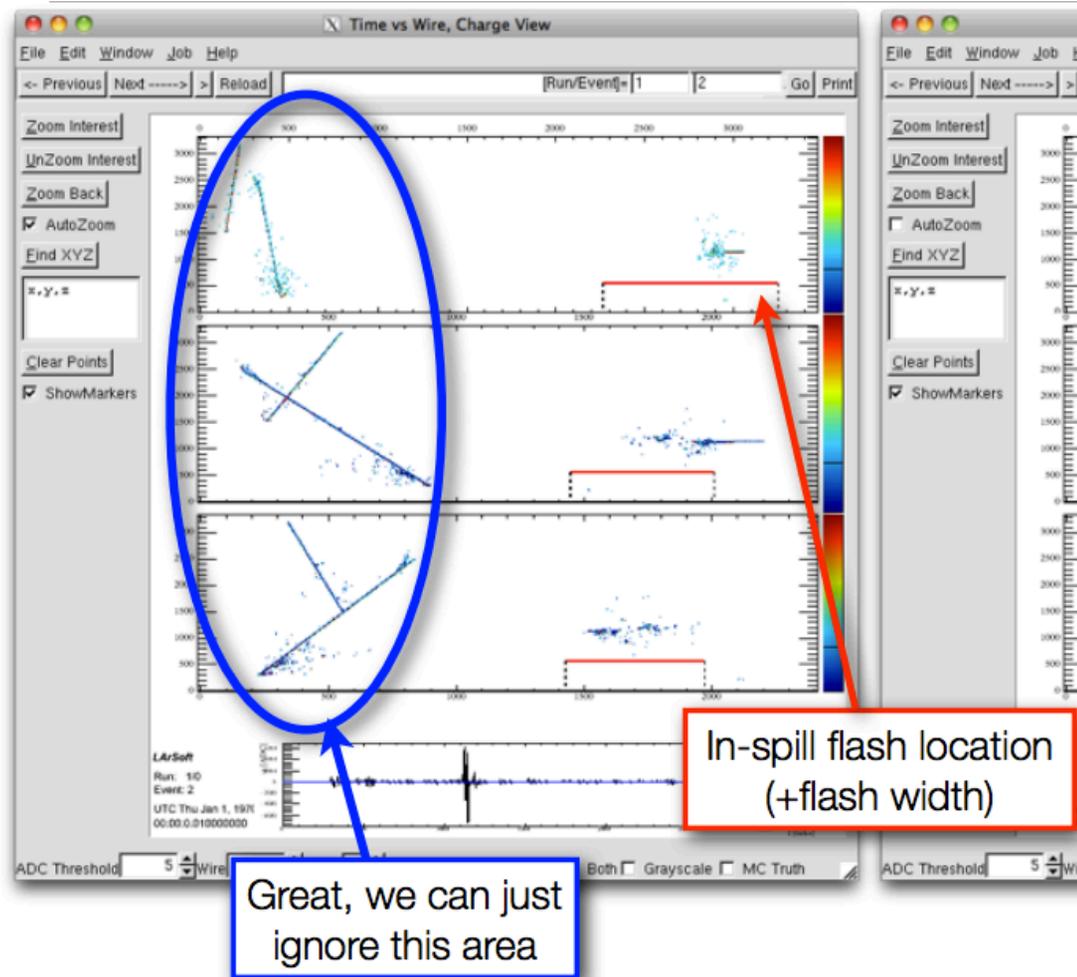
- Uses PMTs to identify subevent in time with beam (finding neutrino amidst multiple cosmics)
- **Primary goal:** Selection of real neutrino interactions amongst a large cosmic background both online (trigger) and offline (reconstruction)
- May provide info on whether to reconstruct a cosmic ray (out-of-time tracks), saving CPU time.
- Provides early to late light info for PID.



*Source: B. Jones



Flash Finder: Event Display

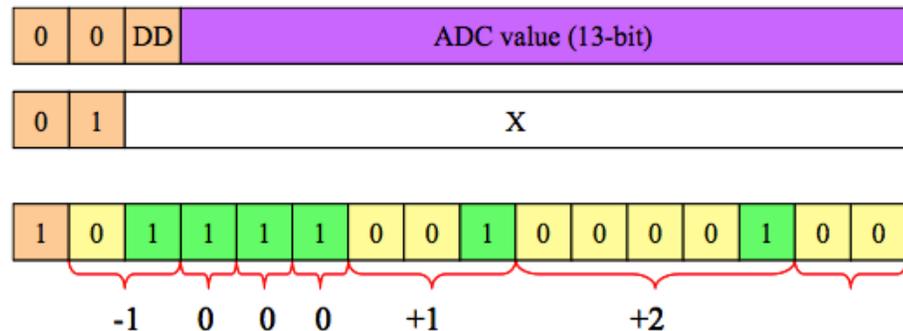


*Source: B. Jones

Huffman Coding (TPC only)

- Lossless data reduction: Huffman Coding
 - Successive data samples vary slowly in time.
 - Up to factor 10-15 reduction possible. Expected 8x.
- Average data volume further reduced by requiring PMT trigger in coincidence with beam gate.

$U(n+1)-U(n)$	Code
-4 and others	Full 16 bits word
-3	000001
-2	0001
-1	01
0	1
+1	001
+2	00001
+3	0000001



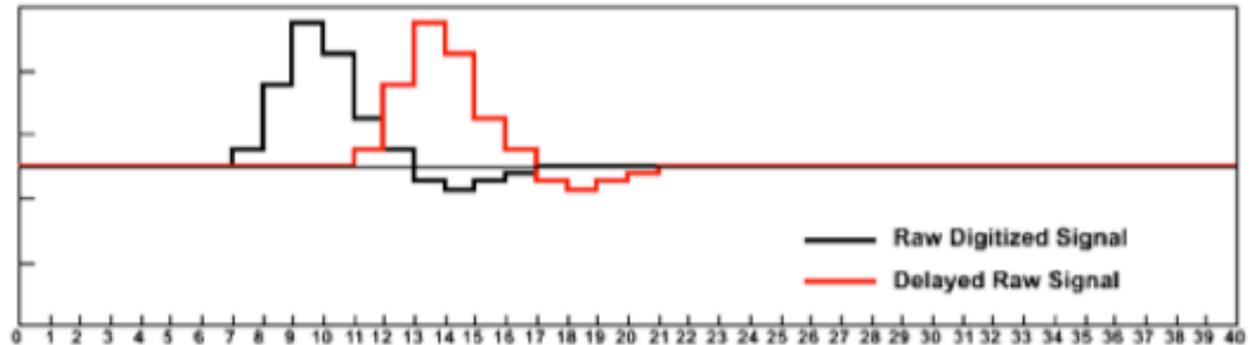
Supernova Stream

- Continuous readout with temporary data storage awaiting a SNEWS alert.
 - Stores on the order of ~a few hours.
- ~Gigabytes/sec from PMTs
- Additional “dynamic decimation” used for supernova stream
 - Not lossless. Data reduction $\sim x(1/16)$
 - Combined with Huffman to reach required 80x data size reduction.



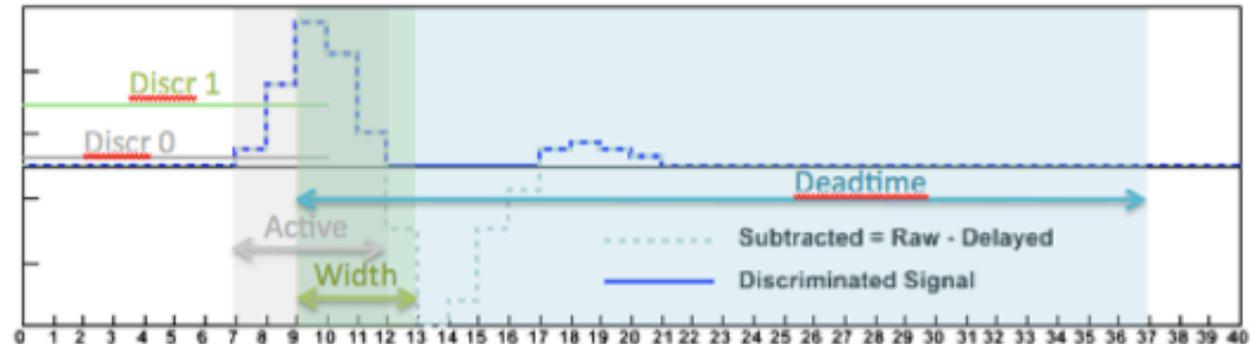
Single-channel ADC data

Same data, delayed by delay0 samples...



...and subtracted from original to form subtracted pulse. Negative values get padded to zero to for "difference".

Difference gets discriminated.



Output data:

If both Discr 0 and Discr 1 fire, a number of ADC words, N, from the raw pulse is output, along with three header words describing the frame number, channel number, and first-ADC sample number.

Relevant timing definitions:

- Discr 0 edge defines an "active" window of fixed duration, during which Discr 1 can fire.
- Discr 1 edge defines a discriminator "width" of fixed duration, during which the maximum ADC value for that particular channel is found.
- Discr 1 edge also defines a discriminator "deadtime" of fixed duration (to cover after-pulsing)





1) **Beam PMT trigger:** During any of the beam gates (BNB, NuMI, or Strobe):

High gain: Require “Beam” sum threshold $\geq 2\text{PE}$ over all tubes, and a multiplicity of ≥ 1 . The sum threshold is an active sum of peak pulse heights over 100ns using the Discr 3 level, with the Discr 3 threshold set to $\geq 1\text{ PE}$.

Notes:

This covers the possibility of 1 PMT channel with 2 PE, or 2 PMT channels with 1 PE each.

This mainly triggers on cosmics but it is efficient for neutrino-induced events.

We need to efficiently trigger on a 40 MeV proton from an NC elastic event.

2) **Cosmic PMT trigger:**

High gain: Require “Cosmic” sum threshold $> 40\text{PE}$ (or higher) in 1 (or n) tube(s) using Discr 1 level and outside of any of the four frames surrounding the beam gates.

Notes:

This provides cosmic events outside of the beam gate readouts.

It will need to be pre-scaled.



For any given subtracted pulse, **Discr 0** (timing) will fire if:

- threshold 0 is satisfied
- + the number of (64MHz) samples from the last Discr 0 firing is greater than some “precount” value (this ensures the system is in a relatively quiet state, and avoids firing on noise which reduces system efficiency)
- + threshold 0 is satisfied outside the “deadtime” of Discr 1 and Discr 3, both of which can fire after Discr 0

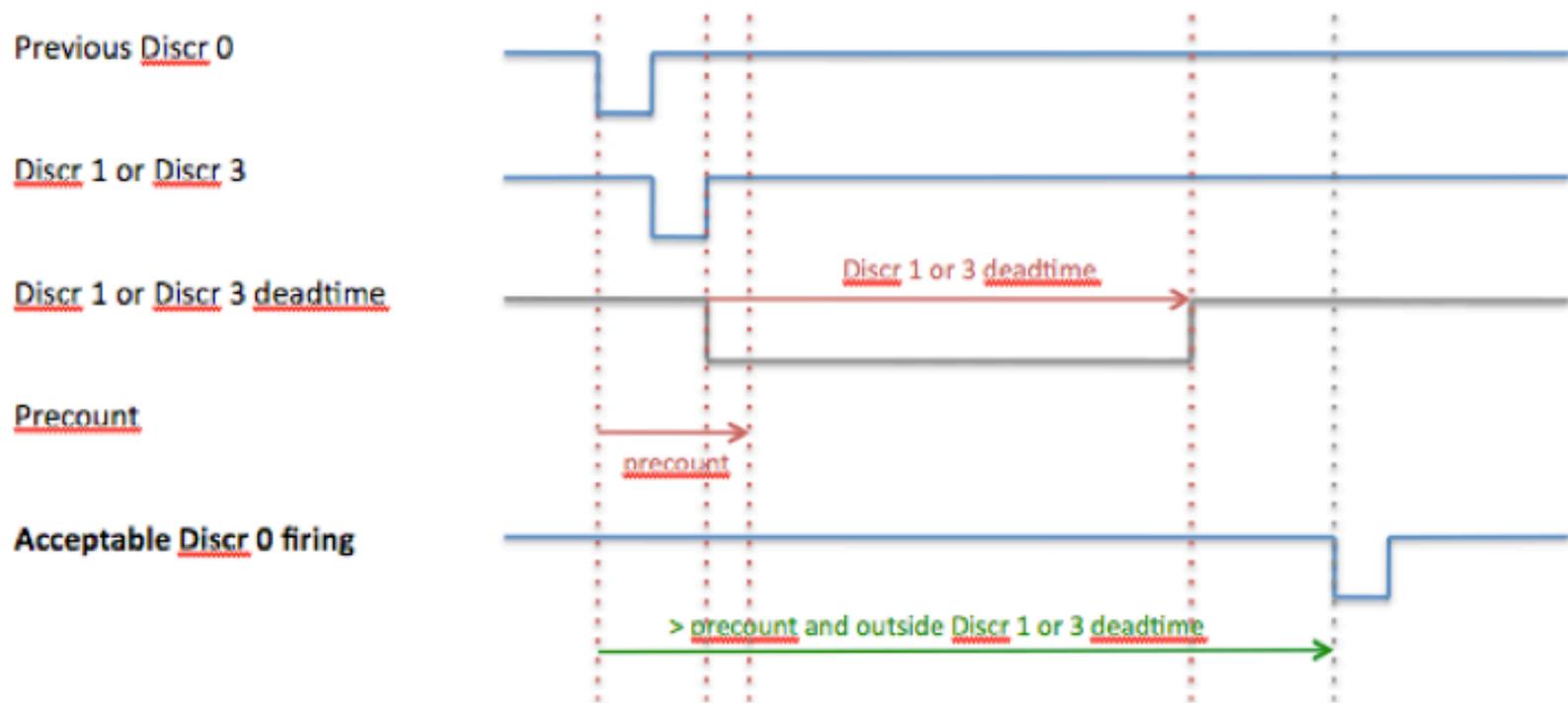


Figure 8: Discr 0 firing conditions

Discr 1 (cosmic) will fire if:

- Discr 0 has fired no more than 6-7 samples earlier (the exact number of samples is tunable at run configuration, but its value is based on the shaping time)
- + threshold 1 is satisfied
- + threshold 1 is satisfied outside the “beam window” surrounding the beam gate

Whenever Discr 1 fires, N=20 samples relative to Discr 0 firing (preceding Discr 1) will be stored in the FIFO. N is a 12-bit number, loaded at run configuration.

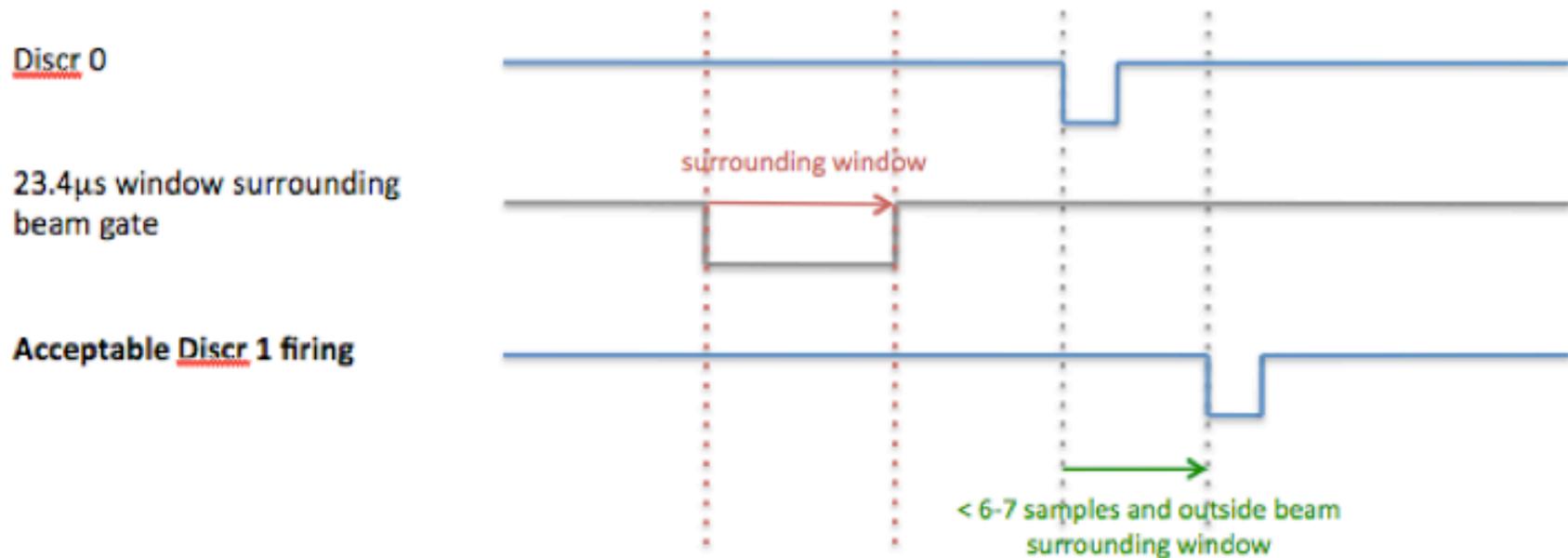
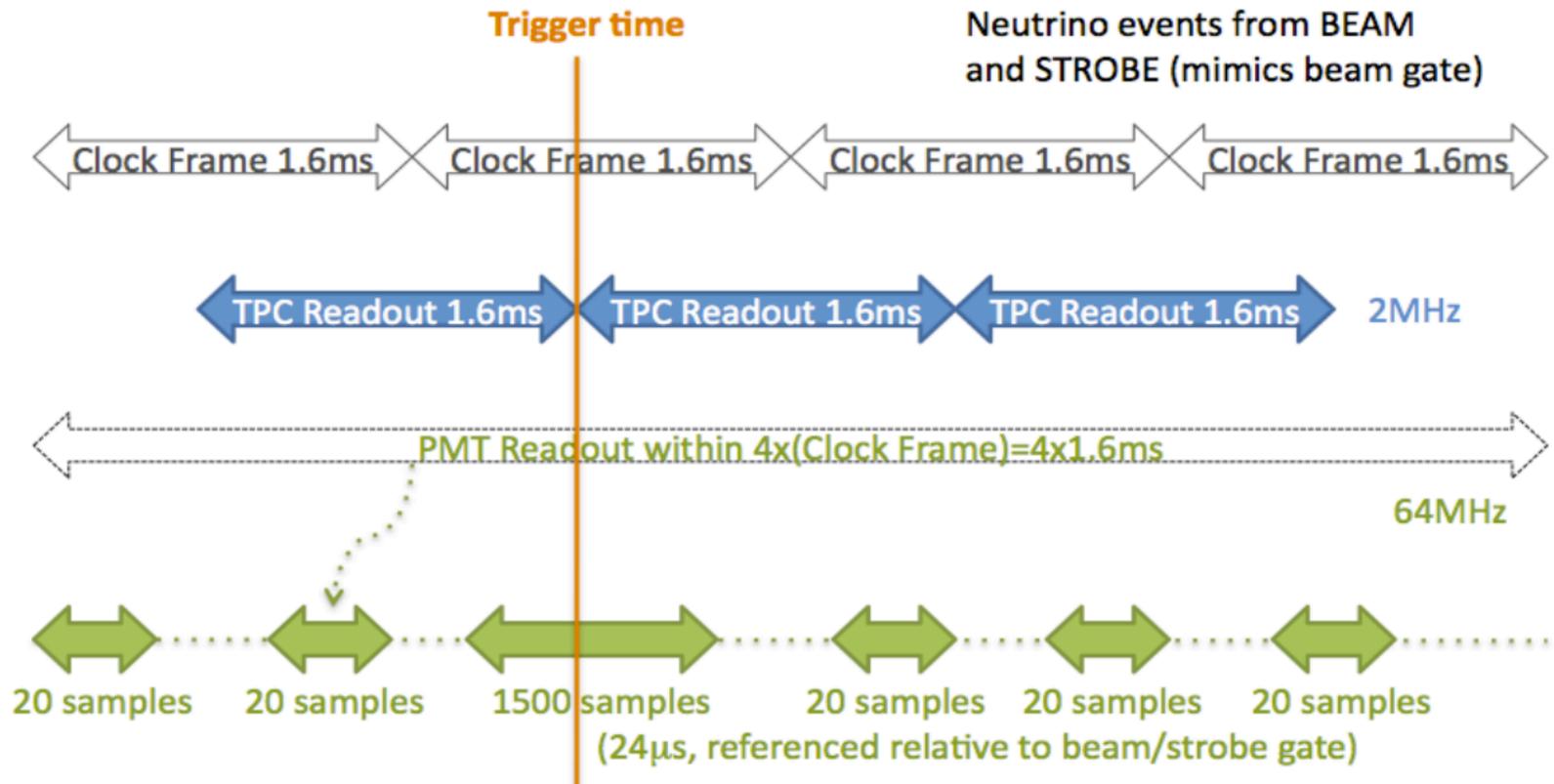


Figure 9: Discr 1 firing conditions

Supernova Stream



- Ignore the orange trigger line. All of this read out continuously and stored for ~a few hours.

Discr 3 (beam) will fire if:

- Discr 0 has fired no more than 6-7 samples earlier (the number of samples is tunable)
- + threshold 3 is satisfied
- + threshold 3 is satisfied inside the “beam gate”

Discr 0

Beam gate

Acceptable Discr 3 firing

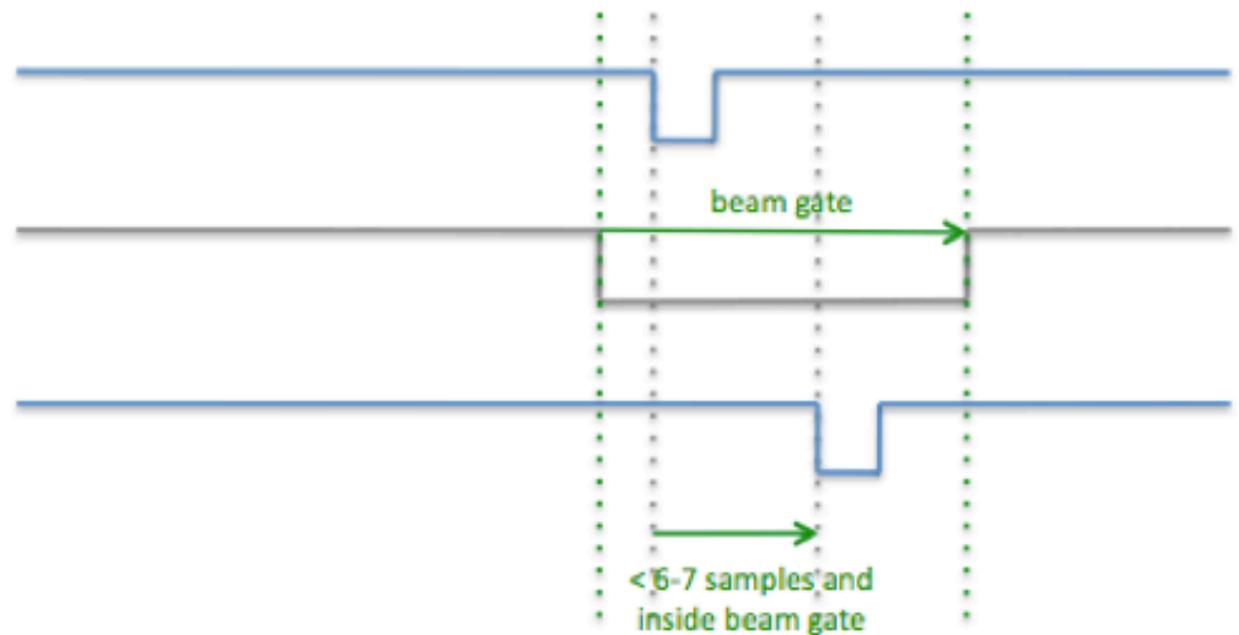


Figure 10: Discr 3 firing conditions

PMT Dead Time

Two sources of data:

- ◆ Noise: **10kHz/PMT** uncorrelated between PMT's
- ◆ Cosmic rays: **5kHz** over detector, correlated between PMT's.

Scheme:

- Set the High CR discriminator at **0.2 pe**. 4 μ s DT.
- Set the Low CR discriminator at **4 pe** No DT.

Deadtime:

- For each PMT in High gain:
- Cosmic rays: Correlated between pmt's
- $5000(\text{CR rate}) \times 4\mu\text{s} = 20,000\ \mu\text{s/s}$ or a **2.0%** deadtime.
- Noise: Uncorrelated between PMT's
- $10000(\text{noise rate}) \times 4\mu\text{s} = 40,000\ \mu\text{s/s}$ or a **4.0%** deadtime.
- **NOTE: These Dead-timed PMT's in High gain are recoverable in Low gain if their pulse height is above 4 pe's.**

References outside of uB

- <http://indico.cern.ch/getFile.py/access?contribId=s2t3&sessionId=s2&resId=0&materialId=0&confId=a053785>
 - Kirill Melnikov, UHawaii. (Michel Feynman Diagram)