The NOvA Upward Going Muon Trigger

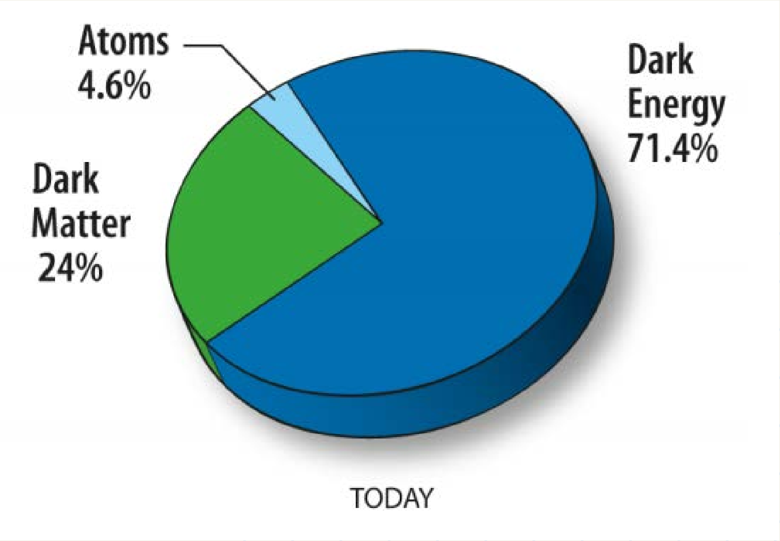
Eric Culbertson - University of Virginia

The NOvA Experiment

- NOvA (**N**uMi **O**ff-axis **ν_e** **A**ppearance) is a neutrino oscillation experiment with a smaller near detector at FermiLab, and a larger far detector in Minnesota
- The same qualities that make it great for measuring neutrino oscillations also make it useful for a variety of other projects
- One of these projects is an indirect dark matter search

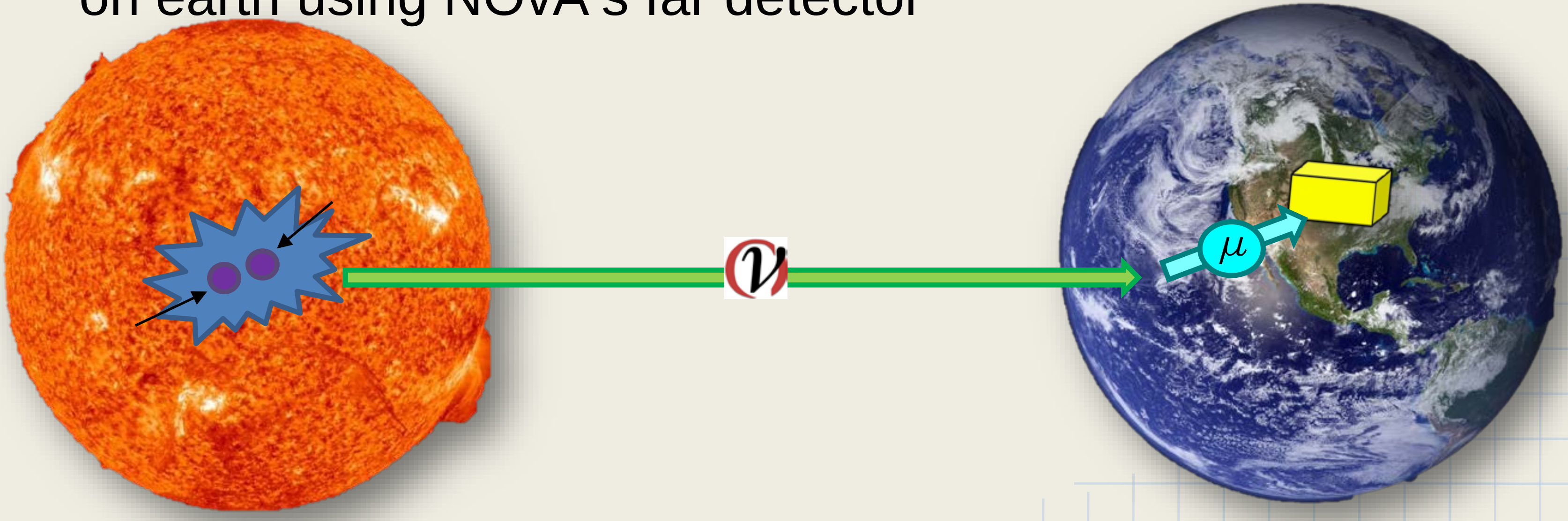
Dark Matter

- Regular matter cannot alone account for observed gravitational effects in the universe.
- Dark matter is the proposed solution for this missing “stuff” in the universe



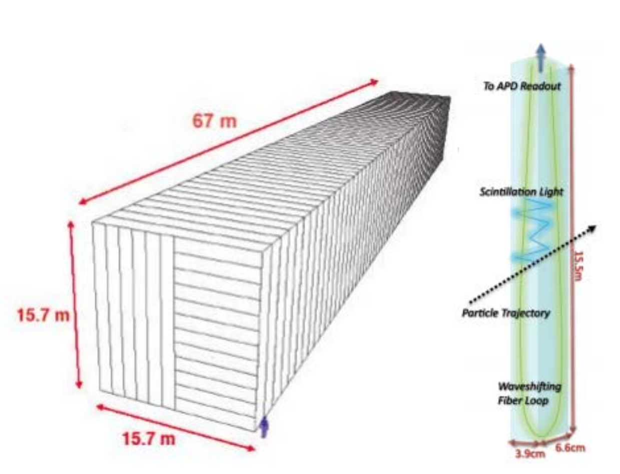
WIMPs

- A leading theoretical description of dark matter is the weakly interacting massive particle (WIMP)
- As the sun orbits the galactic center, it can entrap WIMPs within its gravitational well. These trapped WIMPs then annihilate at the sun's center
- Particle's produced from these annihilations can be detected on earth using NOvA's far detector

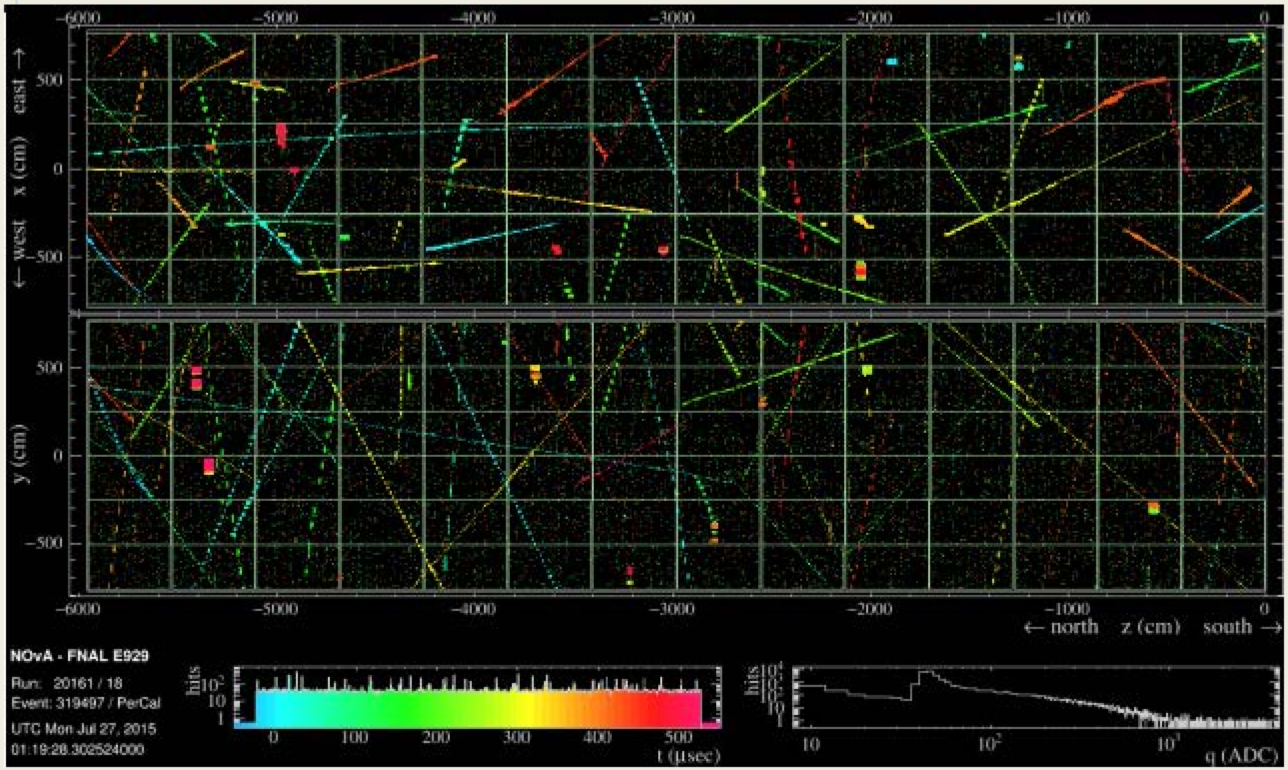


The NOvA Far Detector

- Located in Ash River, MN
- 14 kTon finely grained, scintillating tracking calorimeter
- Over 300,000 active channels allow for high rate of data collection
- Excellent for tracking muons



The NOvA Event Display



Data collected by the far detector within a 550 μsec exposure window

- Rate of downward going muons is huge! (~ 100kHz)
- We take our data at night and look for the upward going muon signal
- Let earth act as a shield from almost all cosmic upward going muons

Upward Going Muons

- Need a way to isolate upward going muons (background to signal ratio is over 10^{10})
- We have two different “upmu triggers” that use hit time information to find upward going muons
- This trigger fires at ~1Hz and looks for long, linear tracks, that are not necessarily contained within the detector

The UpMu Trigger

The UpMu Trigger employs several cuts to isolate the "good" muon interactions within the detector:

- **Quality of tracks** – longer tracks with more hits can provide more certainty on track directionality
- **Timing –** the NOvA far detector has a small enough resolution to use the timing of hits in a track to determine track directionality

UpMu Sample

- I trigger has run for a while now, and we need to analyze data gathered by the through-going UpMu trigger
- The trigger alone reduces background by ~5 orders of magnititude, but a greater reduction is needed to say anything about the signal

Determining Upward Going Muon Candidates

- To isolate possible candidate tracks, a suite of cleanup and directionality cuts are applied

Base "Clean Up" Cuts

Length > 500 cm
$\Delta X > 5$ cells
$\Delta Y > 10$ cells
$\Delta Z > 5$ planes
$R^2X > .99$
$R^2Y > .99$
Number of X-View Hits > 15
Number of y-Yiew Hits > 15
Number of Total Hits > 60

Physics Cuts

Timing based cuts:
LLR > 10
LLRX > 5
LLRY > 5
$0 < \beta < 2$
$X^2 < 1.5$

Elevation angle > 10^o

Efficiency of Candidate Cuts

- Unfortunately, these cuts lower the efficiency of finding upward going muons in addition to cutting out background

- Need to test if current cuts have the optimal balance of background rejection and signal efficiency

- I tested the signal efficiency of our cuts using an Atmospheric Monte Carlo sample

Efficiency of Cuts

In my MC sample there is at most 1 upward going muon of significant energy in each event

I defined "efficiency %" as

$$\frac{\#\,Good\ Muon\ Events\ With\ Passed\ Upward\ Muon\ Track/}{\#\ Good\ Muon\ Events}$$

Where a "Good Muon Event" is an event with a clearly upward going and detectable muon found using truth info (Elevation angle > 10^{o}, Energy deposited > .5 GeV, Length > 5m)

Efficiency of Cuts

```
Efficiency % With No Cuts:                  98.3146
Efficiency % with all Cuts:                 48.5955
----------------N-1 Test-----------------------
Efficiency % with all but Length Cut:       53.3708
Efficiency % with all but ΔX Cut:           48.5955
Efficiency % with all but ΔY Cut:           48.5955
Efficiency % with all but ΔZ Cut:           48.5955
Efficiency % with all but R2X Cut:          50.2809
Efficiency % with all but R2Y Cut:          66.0112
Efficiency % with all but nHitsX Cut:       48.5955
Efficiency % with all but nHitsY Cut:       48.5955
Efficiency % with all but nHits Cut:        49.4382
Efficiency % with all but eleAngle Cut:     48.8764
```

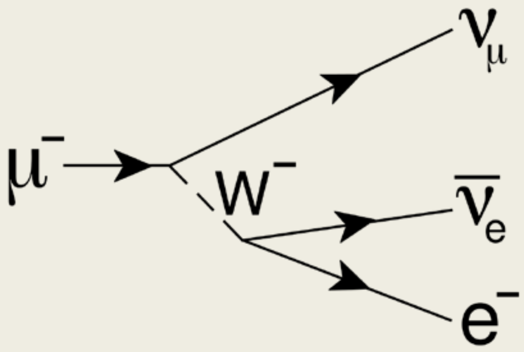
- Efficiency of timing cuts were not yet able to be tested
- R2Y cut has a larger effect on signal effiecy than expected

Michel Electrons

- It would be beneficial to identify a subsample with higher signal purity

- Michel electrons are produced by muon decay at the end of muon tracks

- finding Michel electrons in a tracks that stop in the detector can be a clear indicator of directionality



Michel Efficiency

- Looked into both an upward going atmospheric sample and a cosmic Monte Carlo sample

- In both samples, I looked at muon tracks that ended in the detector, and checked to see if these tracks produced a Michel

Michel Efficiency

Sample	Stopped μ- Tracks	Stopped μ+ Tracks	% μ- Tracks With a Michel	% μ+ Tracks With a Michel	% μ– Michel's found	% μ+ Michel's found
Cosmic	1227	1232	76.3	91.8	21.1	19.3
Atmospheric	821	380	74.5	90.5	20.9	19.1

For the future

- Need to test how our cuts affect background rejection

- See if using Michel clusters created in reconstruction can improve our ratio of signal to background

- Experiment with changing candidate cuts to see if a more optimal set of cuts can be determined

Acknowledgements

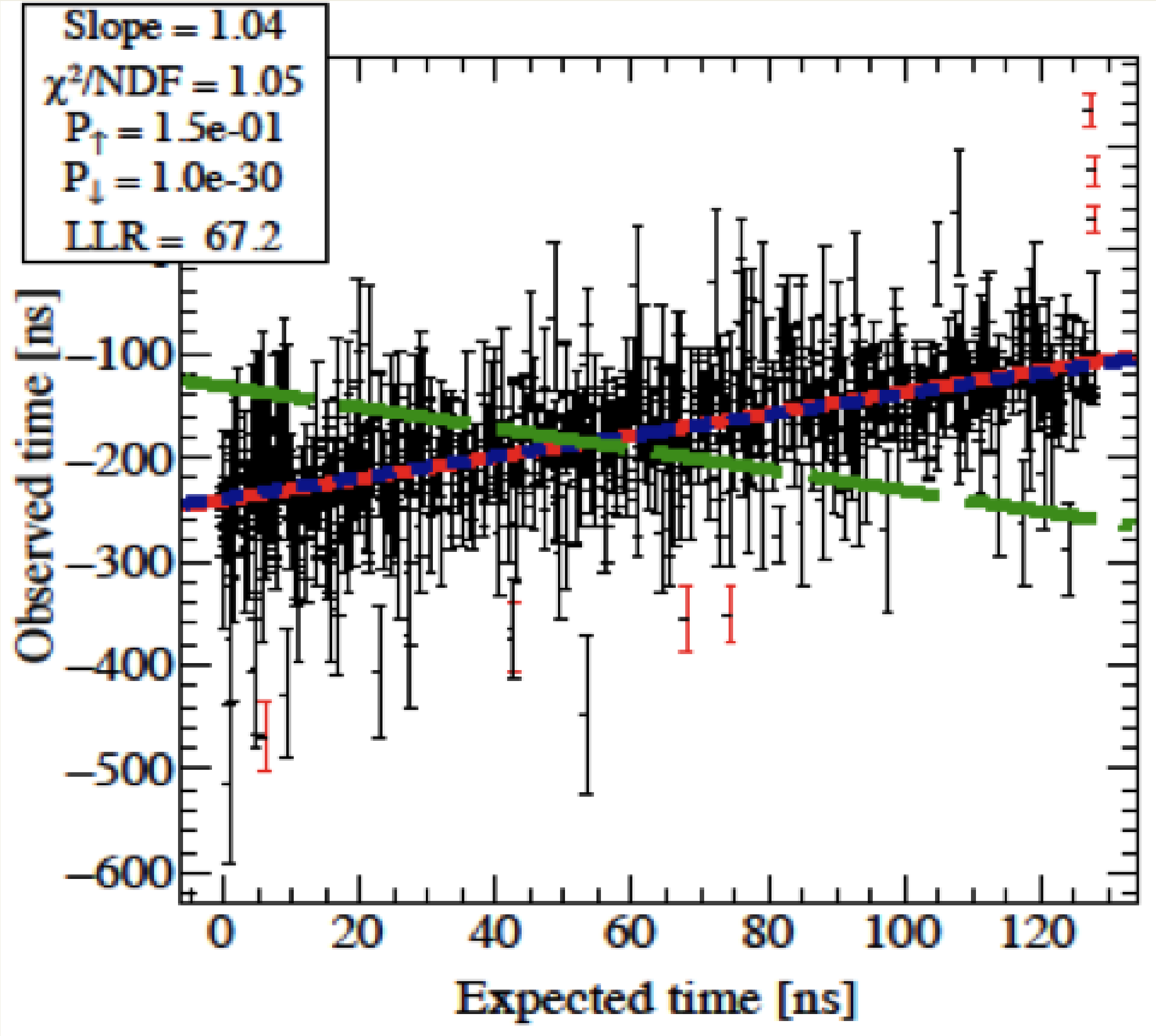
- Professor Craig Group
- Rob Mina (check out his poster!)

Slope (β)

To determine directionality, we calculate a speed β for each track, normalized by c. 1.0 means upward-going and -1.0 means downward-going.

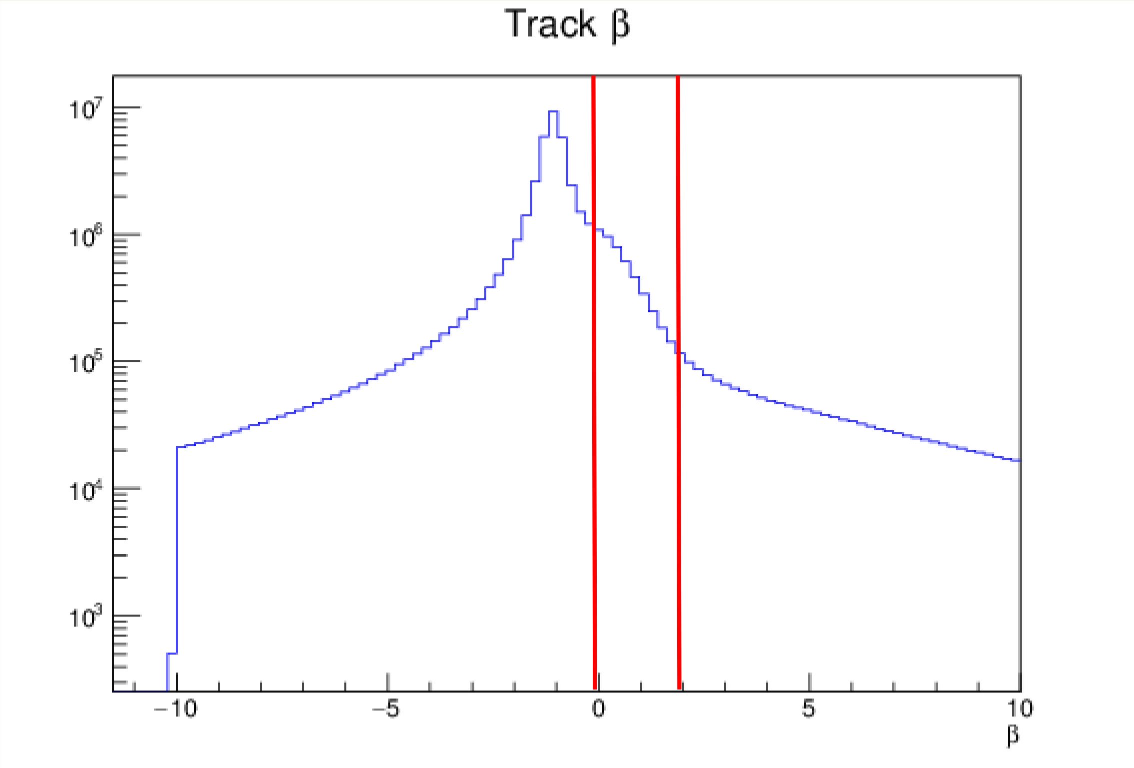
This is simply the slope from a linear fit to the measured times of the track cell hits vs the expected times assuming an upward-going relativistic particle.

Slope (β)



Slope = 1.04
χ²/NDF = 1.05
P↑ = 1.5e-01
P↓ = 1.0e-30
LLR = 67.2
Observed time [ns]
−100
−200
−300
−400
−500
−600
0
20
40
60
80
100
120
Expected time [ns]

Track β



- 40.0 % of tracks fail this cut

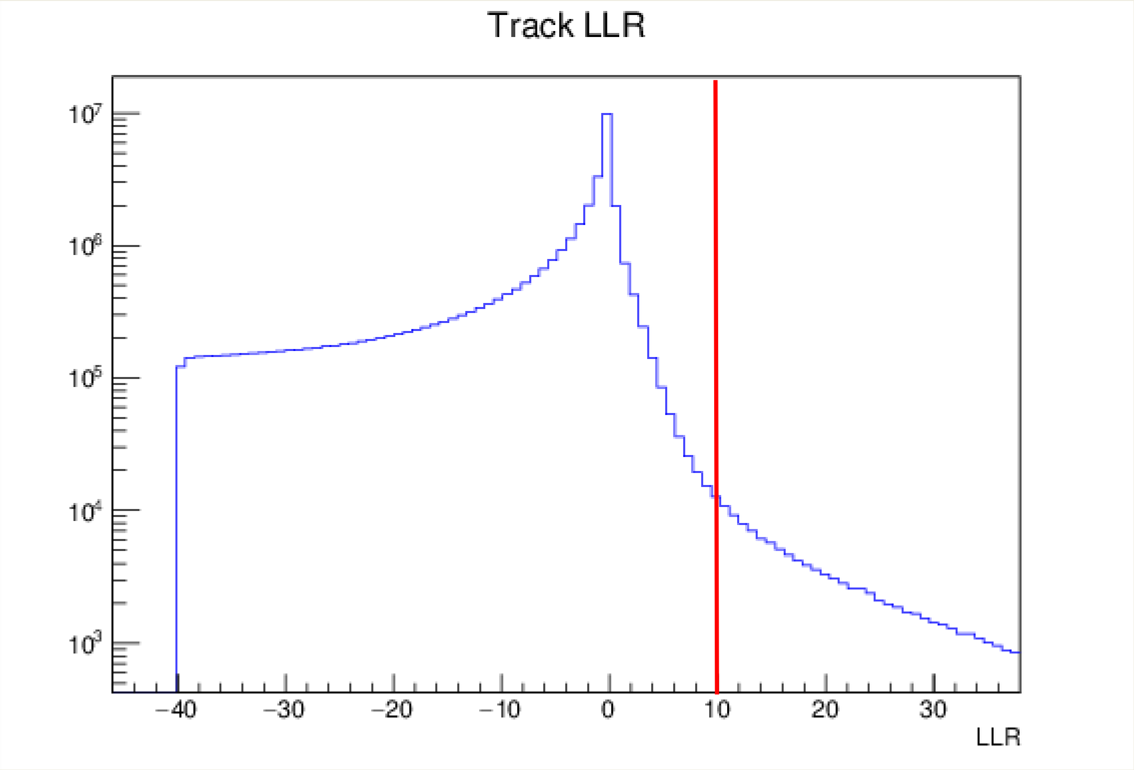
LLR (Courtesy of Rob Mina)

If a track is not perfectly horizontal (it isn't - we cut on the absolute value of ΔY), then the true value of β is either 1 or -1.

We leverage this simplifying constraint using the LLR:

- Perform a linear fit to the measured vs expected times with a fixed slope of 1
- Perform another fit with a fixed slope of -1
- Calculate the probability of each fit using the χ^2. Set a nonzero minimum for the probabilities (10^{-30}).
- $LLR = \ln(Prob_{up} / Prob_{dn})$
- LLR close to 0 means the track was neither conclusively upward- nor downward-going.

Track LLR



- 99.7 % of tracks fail this cut