

SELECTION ALGORITHMS DEVELOPMENT FOR ATMOSPHERIC NEUTRINO DETECTION IN THE NOVA EXPERIMENT



Neutrino 2026

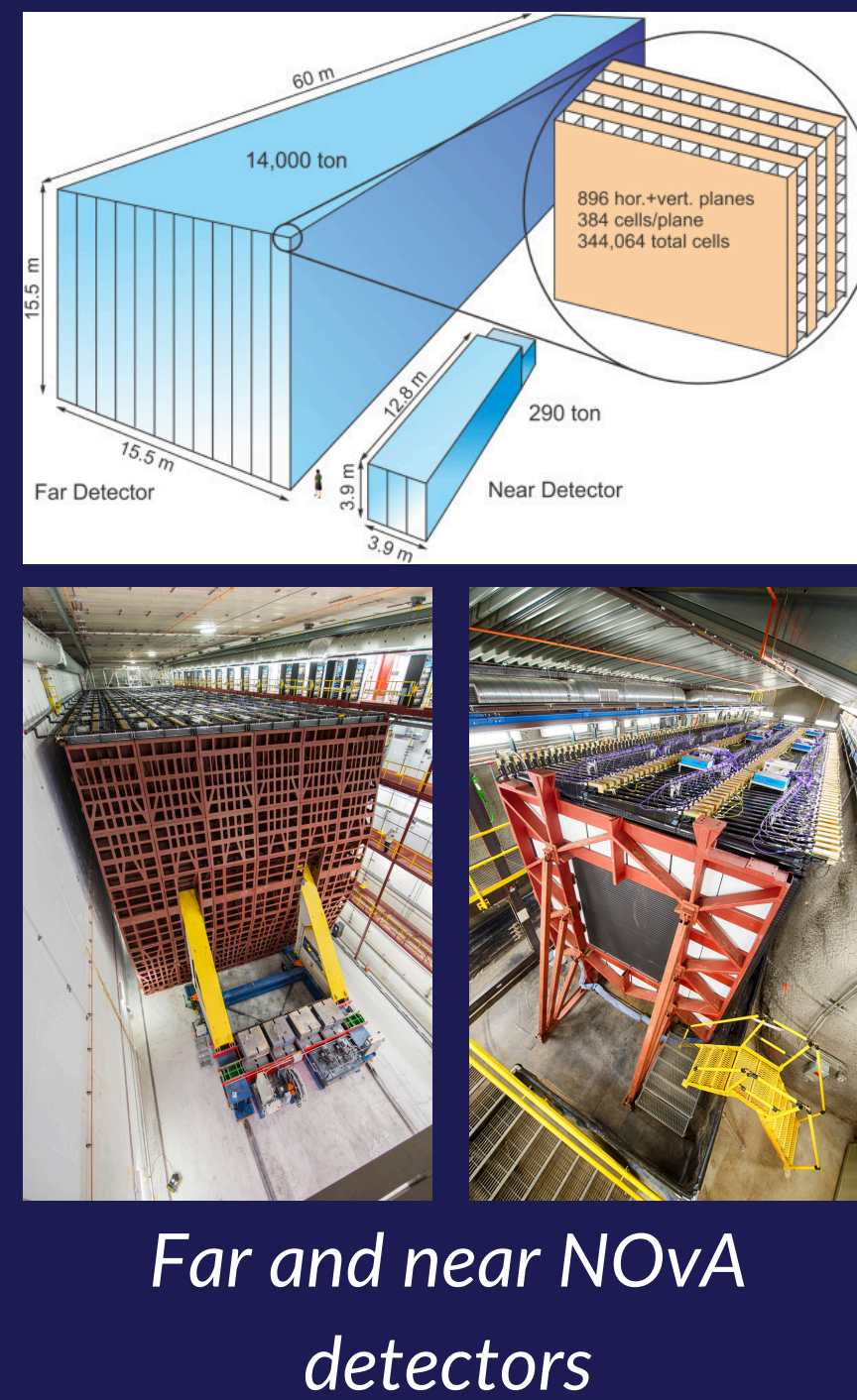
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1. NOvA Experiment. Data Acquisition System

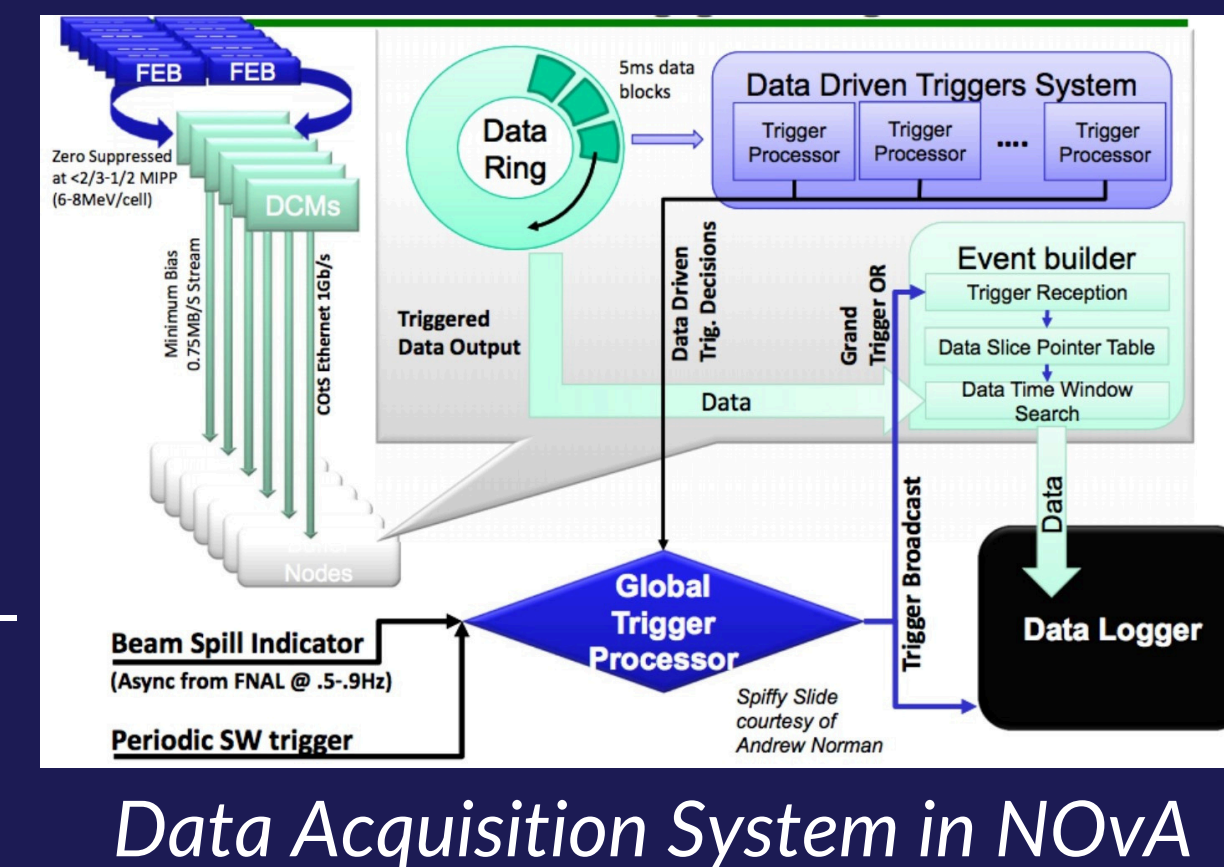
The NOvA experiment:

- Measure ν_e appearance in a narrow-band beam of ν_μ peaked at 2 GeV
- PVC tubes filled with liquid scintillator based on mineral oil
- Two detectors:
 - Near detector (ND, 300 tons) at a distance of 1 km from the ν source at Fermilab
 - Far detector (FD, 14 kilotons) at a distance of 810 km, in the state of Minnesota



Software Trigger System

- Main analysis selects events that are time-coincident with the beam
- For other physics tasks, a software trigger system – **Data Driven Triggers (DDT)** – is used
- All data are written to a circular buffer and processed by algorithms that save the necessary events for offline analysis



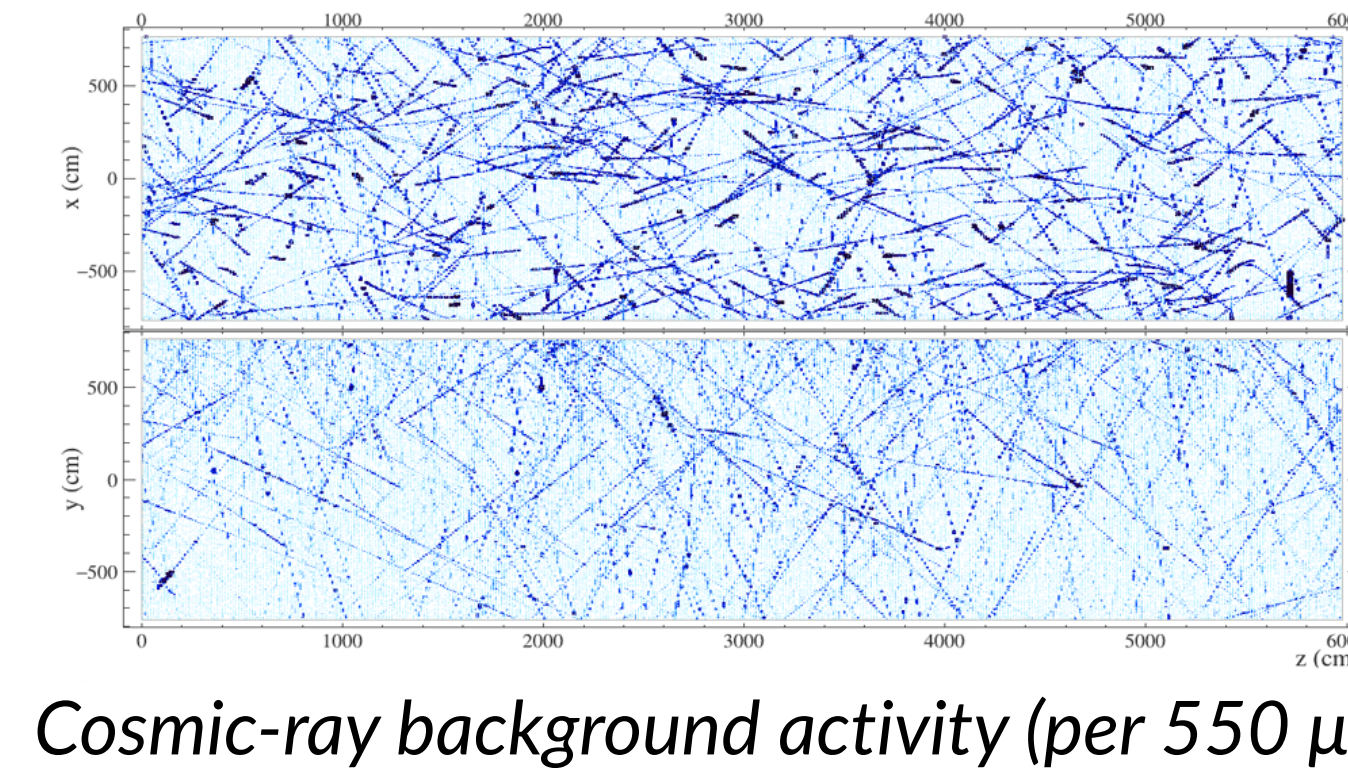
However, NOvA did not have a dedicated trigger for atmospheric ν selection.

NOvA physics goals:

- Determination of the neutrino mass hierarchy
- Determination of the θ_{23} octant and refinement of θ_{13}
- Constraining the CP-violating phase δ_{cp}
- Measurement of neutrino cross-sections

There are also many “exotic” tasks, in particular, the detection of **Atmospheric Neutrinos (AtmoNu)**.

2. Development of AtmoNu Selection Algorithms



Cosmic-ray background activity (per 550 μ s)

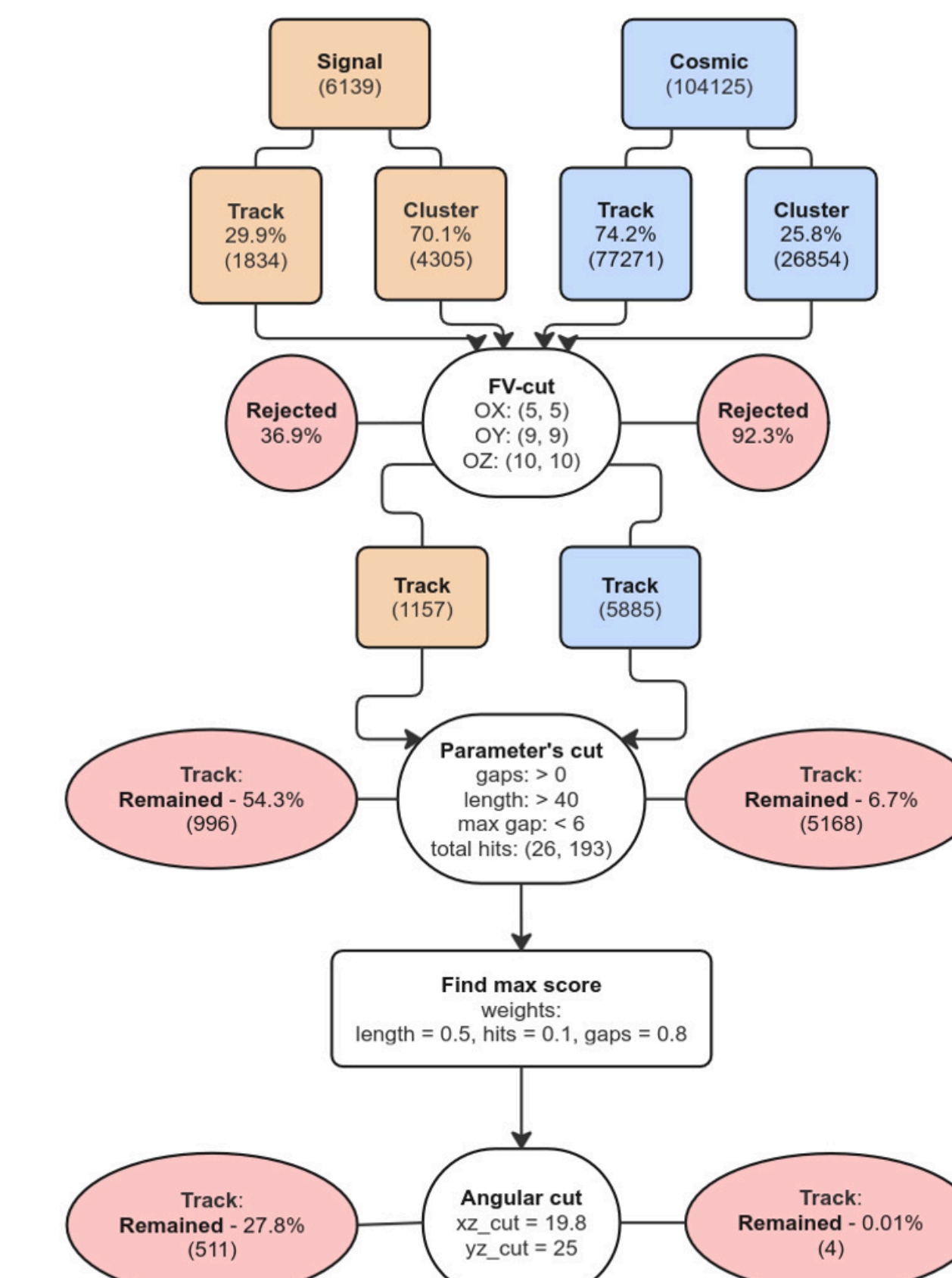
- **Goal:** Develop a dedicated trigger to increase statistics and enable real data analysis
- NOvA main data-taking period is planned to **conclude in 2027**
- **Main challenge:** Remove the secondary cosmic-ray background (~150k muons per second in FD)
- **Expected ν rate:** only 12 events per day

3. Track Selection Procedure

- Track events are most often **muons**
- The procedure includes:
 - **Fiducial Volume (FV)** – interactions within the detector
 - Selection criteria on **parameters:** number of **gaps** in a track, **track length**, **maximum gap** between hits, **hits total number**
 - Selection the **best track** in an event using the ***Score**:
 - Assigning weights to length, hits, and gaps
 - Selecting the maximum score
- **Angular selection** – background events are mostly vertical

$$\text{Score} = \text{length_weight} \cdot \text{norm_length} + \text{hits_weight} \cdot \text{norm_hits} + \text{gaps_weight} \cdot \text{norm_gaps}$$

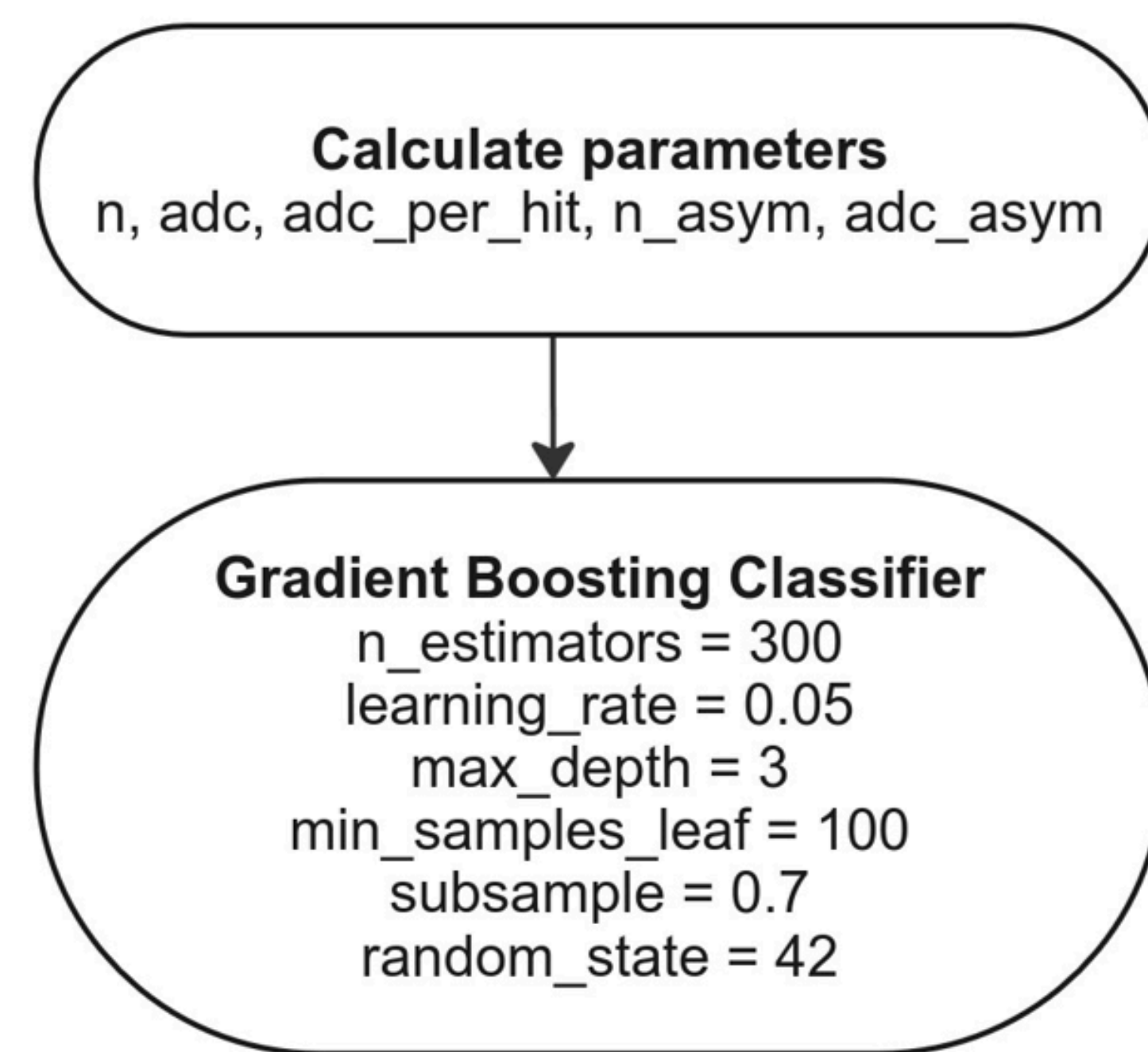
*Score parameter calculation:



Stages of track event selection: track – track events, cluster – non-track

4. Non-Track Selection Procedure

- Examples of **non-track** events are electromagnetic showers, as well as neutral current (NC) events
- Selection procedure consists of:
 - **Fiducial Volume (FV)** selection – interactions only within the detector
 - **Computing parameters:**
 - n – hits number
 - adc – total signal amplitudes
 - adc per hits – average signal amplitudes
 - n_ asym (x-y hit asymmetry)*
 - adc_ asym (x-y signal asymmetry)*
 - Applying the **Gradient Boosting Classifier** algorithm [1] to the computed values



$$*n_asym = (n_x - n_y) / (n_x + n_y)$$

$$*adc_asym = (adc_x - adc_y) / (adc_x + adc_y)$$

[1] J.H. Friedman, Ann. Statist., vol. 29, no. 5, pp. 1189–1232 (2001).

5. Selection Efficiencies

- The selection procedure was applied to the **signal simulation (sg)** – AtmoNu, and **background (bg)** – cosmics, and previously collected experimental data (Minimum Bias)
- On April 27th this year, **it was run on the detector!**

AtmoNu Trigger Rates:

Procedure	Signal simulation	Background simulation	Minimum Bias data	AtmoNu trigger rate
Track procedure	27.8%	4 Hz	8 Hz	~15 Hz
Non-track procedure	Sg – 21%	Bg – 12 Hz	Min Bias – 36 Hz	AtmoNu ~32 Hz

Expected number of events by the end of 2026 after trigger and reconstruction procedure ~300 events

Rate monitor on the detector

6. Summary

- Results:**
- Dedicated algorithm for selecting atmonu (both track and non-track events) has been developed and implemented within the NOvA software framework
 - Expected number of atmonu events using this algorithm is ~300 events for 8 months

- Plans:**
- Perform post-selection of trigger events
 - Build an energy spectrum
 - Apply the procedure to calculate neutrino oscillation parameters