Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

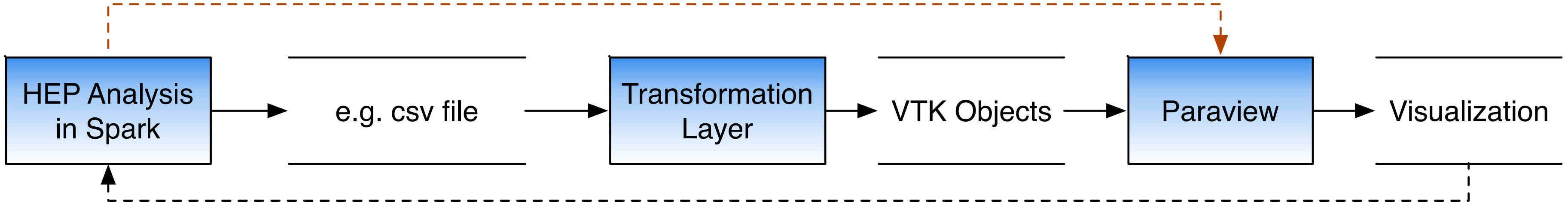
Visual Evaluation of an HEP Algorithm Using Spark and Paraview

Saba Sehrish, Jim Kowalkowski and Marc Paterno

SC DOE Booth Demo

11/17/2015

Using Spark and Paraview



HEP Problem Background

Neutrino Physics

- "The neutrino is an elementary particle which holds no electrical charge, travels at nearly the speed of light, and passes through ordinary matter with virtually no interaction."
  - The mass is so small that it is not detectable with our technology
- Neutrinos are among the most abundant particles in the universe.
  - Every second trillions of neutrinos from the sun pass through your body.
- There are three flavors of neutrino: electron, muon and tau.
  - As a neutrino travels along, it may switch back and forth between the flavors. These flavor "oscillations" confounded physicists for decades.

Neutrino Unknowns

- The NOvA experiment is constructed to answer the following important questions about neutrinos:
  - What are the heaviest and lightest of neutrinos?
  - Do neutrinos change flavor? (muon neutrino changing to an electron neutrino)
  - Do neutrinos violate matter/anti-matter symmetry?
- NOvA - NuMI Off-Axis Electron Neutrino Appearance
  - NuMI - Neutrinos from the Main Injector

The NOvA Experiment

- Fermilab's accelerator complex produces the most intense neutrino beam in the world and sends it straight through the earth to northern Minnesota, no tunnel required. Neutrinos rarely interact with matter.
- Moving at close to the speed of light, the neutrinos make the 500-mile journey in less than three milliseconds.
- When a neutrino smashes into an atom in the NOvA detector in Minnesota, it creates distinctive particle tracks.
  - Scientists explore these particle interactions to better understand the transition of muon neutrinos into electron neutrinos.

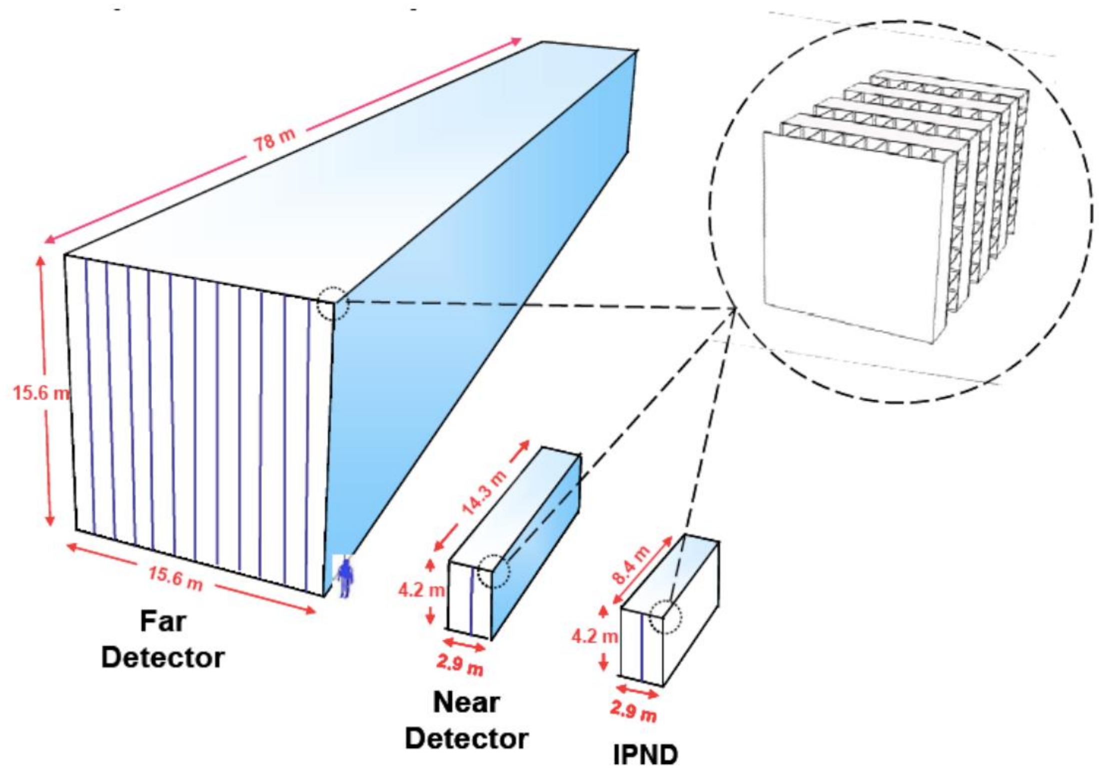
The NOvA Detector

Two functionally identical detectors, optimized for electron neutrino identification

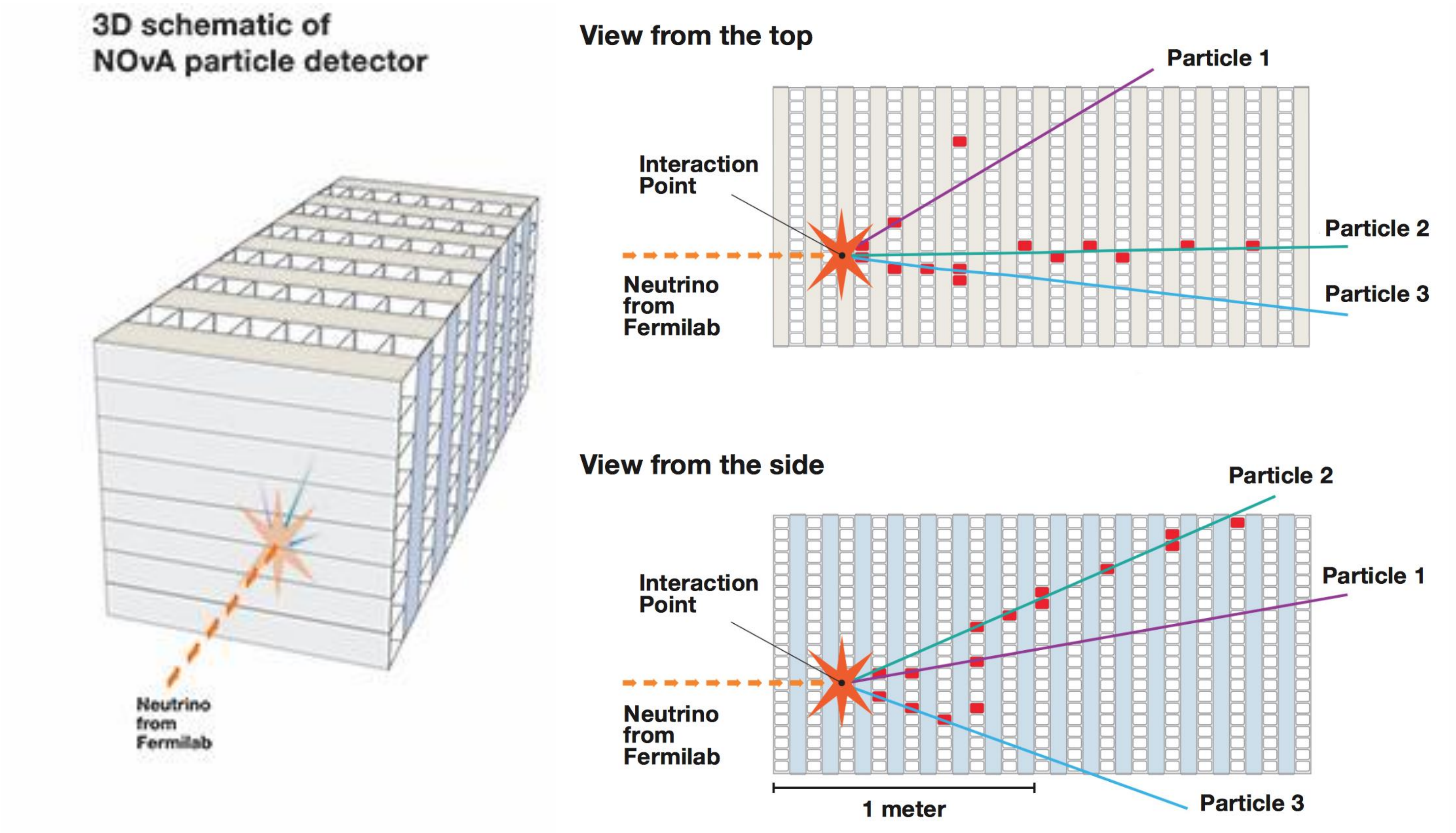
- 14 kt liquid scintillator Far Detector on the surface at Ash River
- A ~300 ton Near Detector (~100m underground) at Fermilab, 1 km from source

The NOvA detectors are constructed from planes of PVC modules alternating between vertical and horizontal orientations.

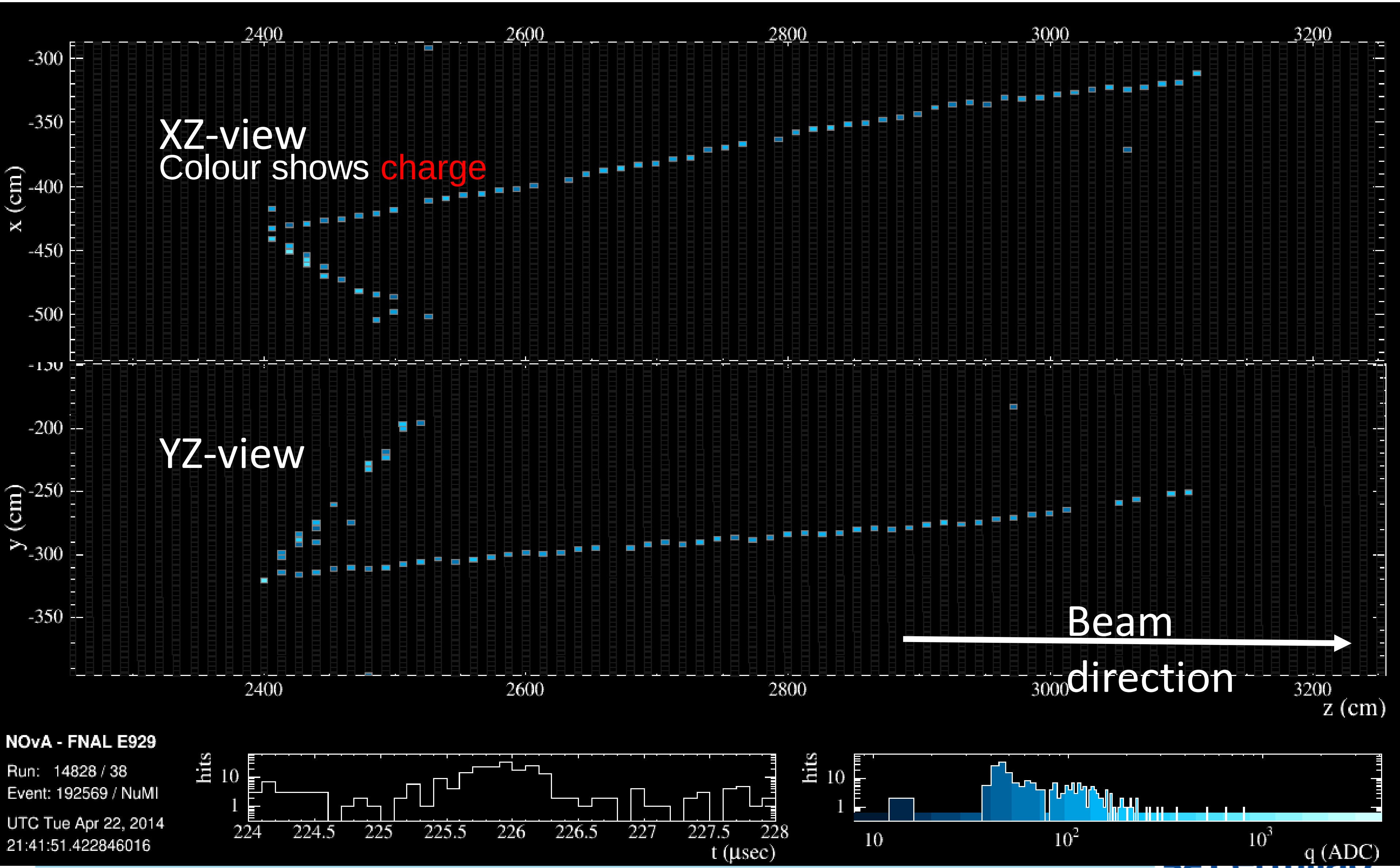
- they form about 1000 planes of 50ft stacked tubes, each about 3x5cm



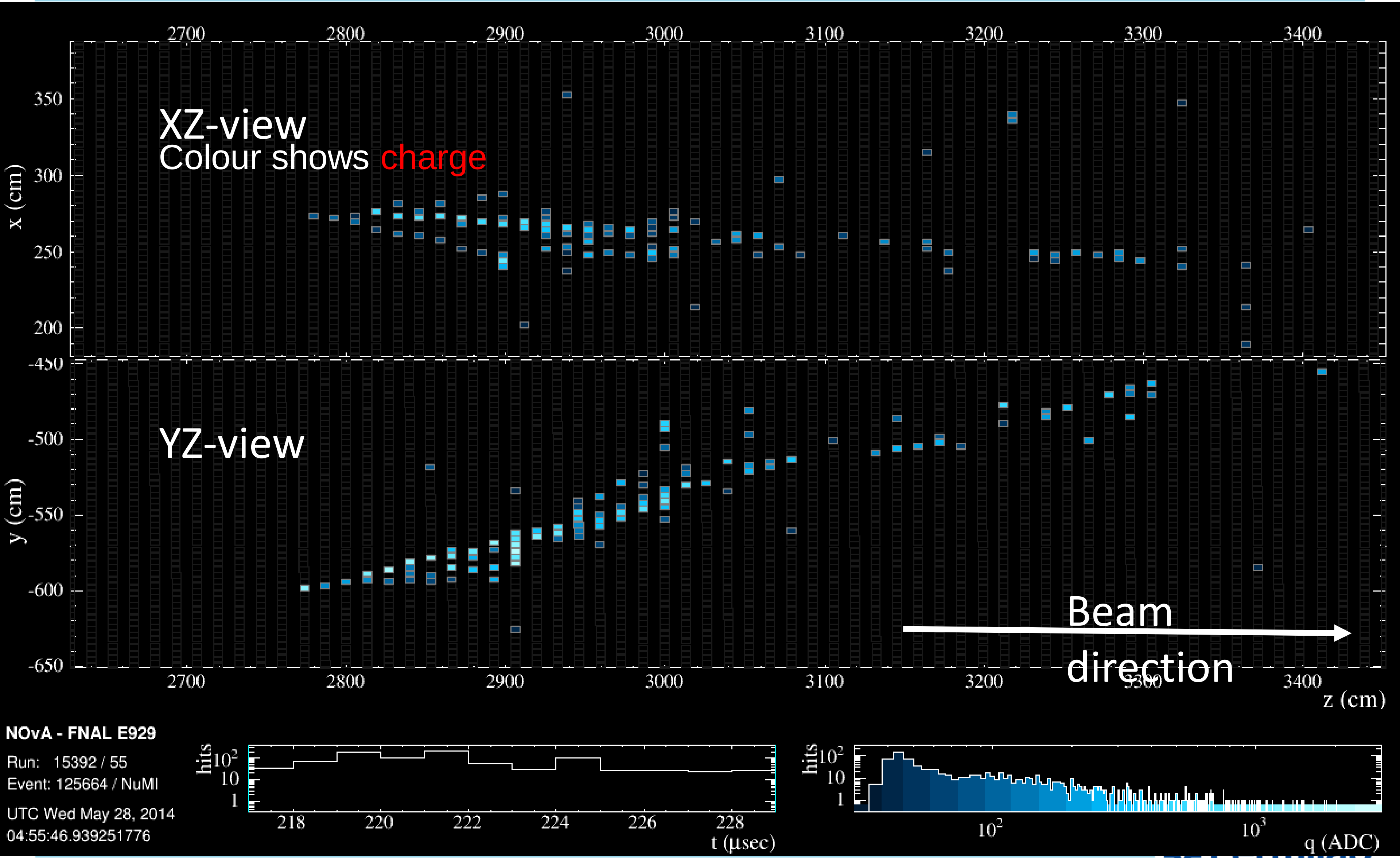
Neutrino interactions recorded by NOvA



Muon-neutrino Charged-Current Candidate (Far Detector)



Electron-neutrino Charged-Current Candidate (Far Detector)



Physics problem

- Classify types of interactions based on patterns found in the detector:
  - Is it a muon or electron neutrino?
  - Is it a charged current or neutral current?

Library Event Matching Algorithm

- Classify a detector event by comparing its cell energy pattern to a library of 77M simulated events cell energy patterns, choosing 10K that are “most similar”
  – Compare the pattern of energy (hit) deposited in the cells of one event with the pattern in another event.
- The “most similar” metric is motivated by an electrostatic analogy: energy comparison for two systems of point charges laid on top of each other

Algorithm 1: Algorithm to calculate electrostatic energy, this function accepts an event and a template, each event and template has the following information per hit: cells (c), planes (p) and energy (e), and the number of hits (N).

```
function calcEEnergy (A, B);
Input  : Event A and template B;
N= the number of hits in the event to be classified;
p_i, c_i, e_i= plane and cell coordinates and energy of hit i in
the event to be classified; i ∈ N − 1;
N_k= the number of hits in the template k;
p_{k,i}, c_{k,i}, e_{k,i}= plane and cell coordinates and energy of hit
i in the template k; i ∈ N_k − 1;
Output: The metric value for measuring the closeness of
        template k to the event.
β = 0.5;
T =function of the distance (motivated by the electrostatic
analogy) between the hits; see [4] for details;
E_AB = Σ_{i=0}^{N−1} Σ_{j=0}^{N_k−1} e_i^β e_{k,j}^β T(p_i − p_{k,j}, c_i − c_{k,j});
return E_AB;
```

$$E = \frac{1}{2}E_{AA} + \frac{1}{2}E_{BB} - E_{AB}.$$

Fermilab

Is Spark a good technology for this problem?

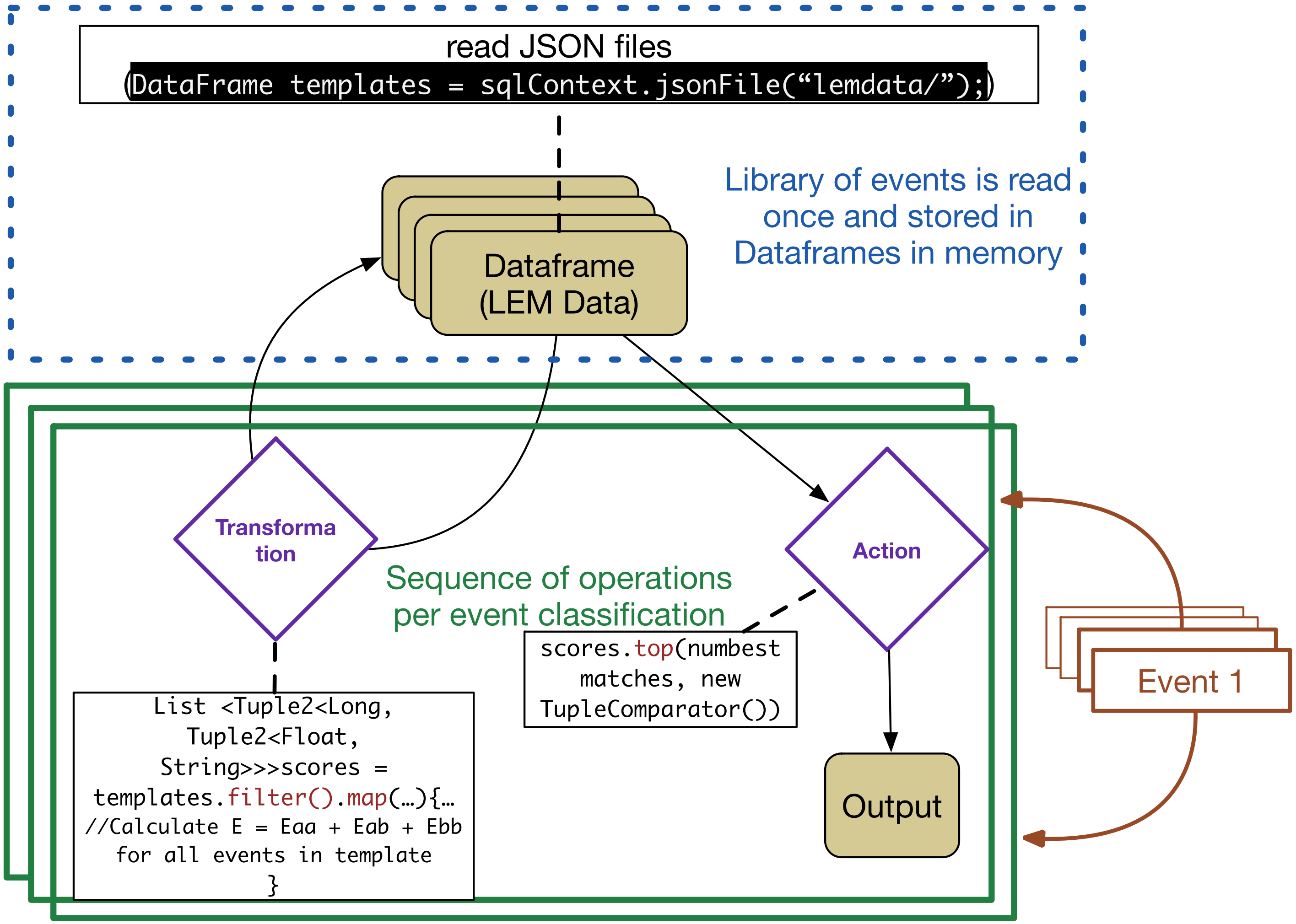
- Goal is to to classify 100 detector events per second
  - In the worst case this equates to 7.7B similarity metric calculations per second using the 77M event library!
  - NOvA is thinking about increasing the library size to 1B events to improve the accuracy
- Spark has attractive features
  - In-memory large-scale distributed processing
  - Uses distributed file system such as HDFS, which supports automatic data distribution across computing resources
  - Language supports the operations needed to implement the algorithm
  - Good for similar repeated analysis performed on the same large data sets

Spark Implementation

Implementation in Spark

- Used Spark's DataFrame API (Java)
- Input data - used JSON format (read once)
- Transformation – create a new data set from an existing one
  - `Filter`
    - Return a new dataset formed by selecting those elements of the source on which *func* returns true.
  - `Map`
    - Return a new distributed dataset formed by passing each element of the source through a function *func*.
- Action – return a value to the driver program after running a computation on the dataset
  - `top`
    - Return the first *n* elements of the RDD using either their natural order or a custom comparator.

Flow of operations and data in Spark



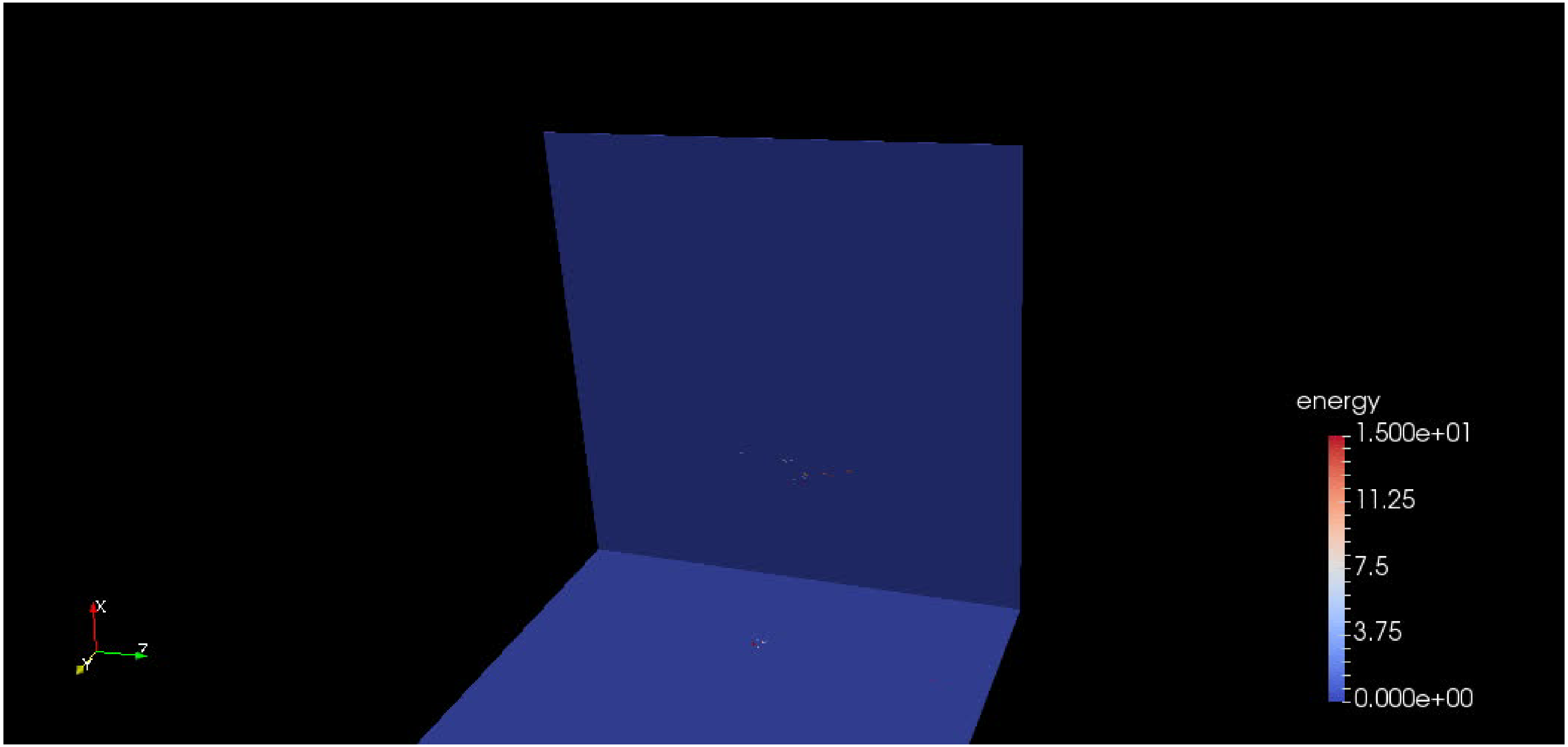
Results on Edison (Spark 1.5.0)

- 8260 tasks (~32MB block size)
- ~ 35 sec to classify an event using 360 cores
- Caching and filtering
- ~ 0.02 event per second
  - Far from 100 events per second
- Not sure if using more cores will help: ~37 sec to classify an event using 696 cores
- History Server on Edison

http://128.55.72.31:18080/history/app-20151019095019-0000/jobs/

ParaView Visualization

Paraview Visualization to compare two events


energy
1.500e+01
11.25
7.5
3.75
0.000e+00
X
Y
Z

Comments about Spark

- Adding a new column to the spark DataFrame from a different DataFrame is not supported
  - Our data was read in to two different DataFrames
- Performance of *join* operation is extremely slow
- Getting data out of DataFrame by column name is not supported
  - Inconvenient to use if your DataFrame has many columns
- Multi-line JSON format is not supported
  - Each line must contain a separate, self-contained valid JSON object.

Comments about Spark

- All the transformations in Spark are lazy
  - It was hard to isolate slow performing tasks
- Many operations are available through wrapped types (Java)
  - A lot of time was spent in boxing and unboxing
  - Better performance if DataFrames used primitive types
- Slow performance for repetitive numerical computations
- It is hard to tune a Spark system
  - How many tasks per node?
  - How much memory per node?
  - How many physical disks per node?

Comments about Spark

- Interactive environment is good for rapid development
  - Test functionality using Python or Scala shell
- Rapid Evolution of this product
  - More than 4 versions since we started developing
  - Introduction of DataFrame interface, which helped to improve the expression of the problem we are solving
- Prelim implementation C++ MPI 100 cores
  - 1-2 events per second
  - Not load-balanced

References

1. A Fermilab Today article
   – Nine weird facts about neutrinos by Tia Miceli, Fermilab (http://www.fnal.gov/pub/today/archive/archive_2014/today14-11-06.html)
2. Public presentations on Fermilab NOvA
   – The Status of NOvA by Gavin Davies, Indiana University (http://www-nova.fnal.gov/presentations.html)
3. Fermilab NOvA webpage
   1. http://www-nova.fnal.gov
   2. http://www-nova.fnal.gov/NOvA_FactSheet.pdf
4. Library Event Matching event classification algorithm for electron neutrino interactions in the NOvA detectors
   – http://arxiv.org/abs/1501.00968