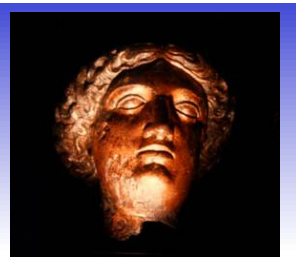


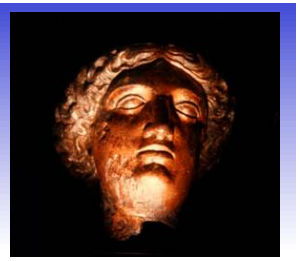
MINERvA Data Reconstruction:

past, history, MINERvA, math!, extra, fin.

Neutrino University Session VII – 7/29/2010

benjamin p. ziemer

Neutrino 'University'



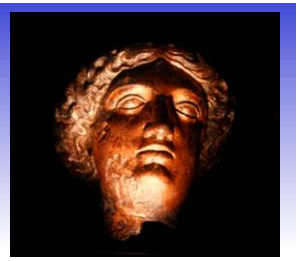
- Previous sessions included talks on history of the neutrino, neutrino production, interaction rates and results from specific experiments.

- Keeping with the theme, this talk will be on neutrino data processing, specifically on event reconstruction. There is a long path between a running experimental apparatus and physics results.

- Data reconstruction techniques specific to MINERνA will be presented (this is my job, after all), but the goal is a greater understanding of certain methods of a particle physics experiment.

Experimental Neutrino Particle Physics

(a.k.a. finding out about the world)



- What? – Nature presents a problem. People think about it and then decide how to solve it.

- Who? – You.

- When? – As soon as the funding arises and people get motivated.

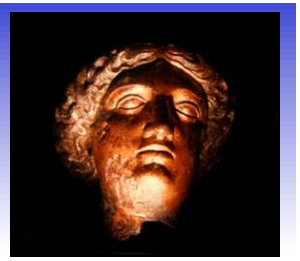
- **How? – Build a neat detector, get some data and figure it out.**

  note: simply analyzing a data is only a part of this

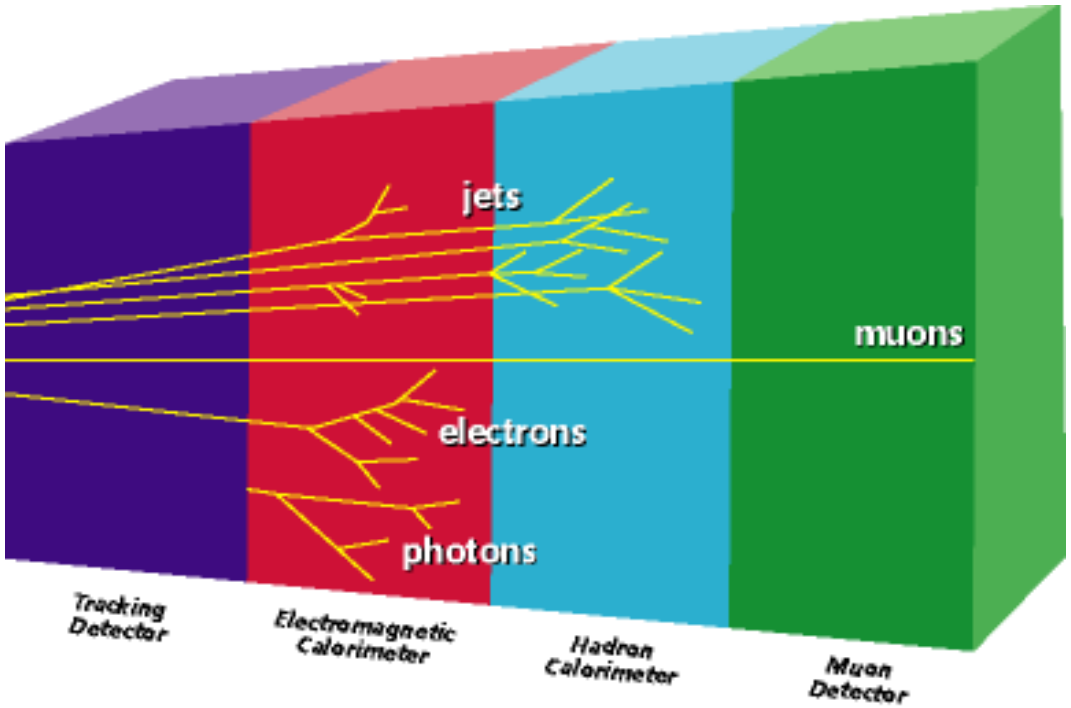
- Why? – *because we want to know, because it is there . . .*

  . . . . because we can.

‘Standard’ Particle Physics Detector

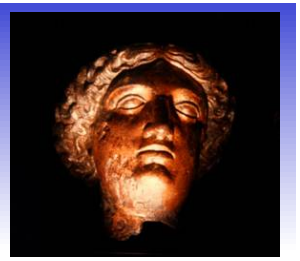


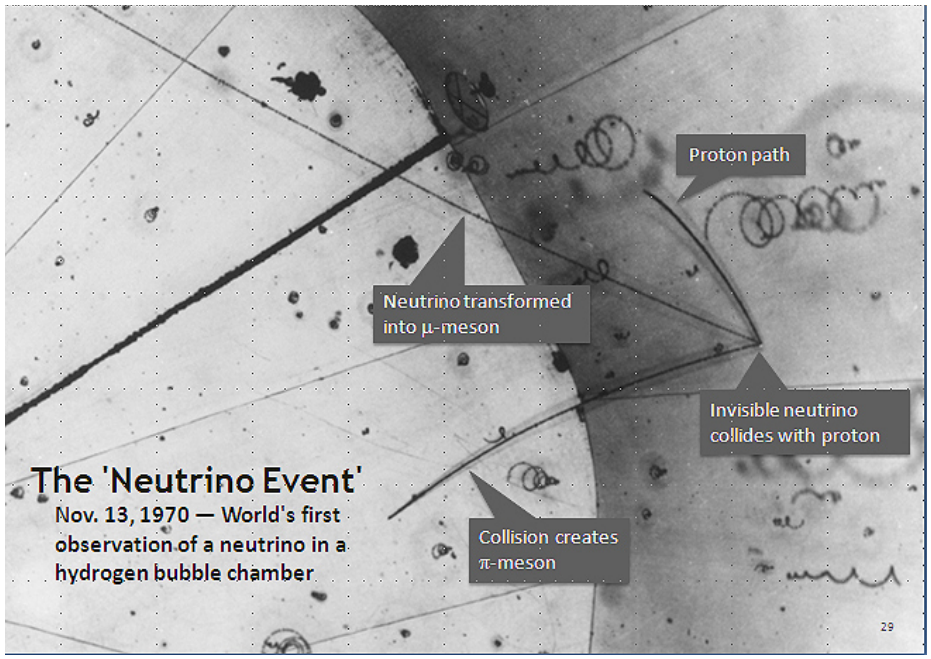
- A particle physics detector is a large block of matter in a beam of particles designed to force interactions.
  - matter: H_2O, Si, CH, C, Pb, Fe, U, etc.
  - particles: electrons, protons, pions, neutrinos, etc.
  - detector composition: depends on the nature of the experiment

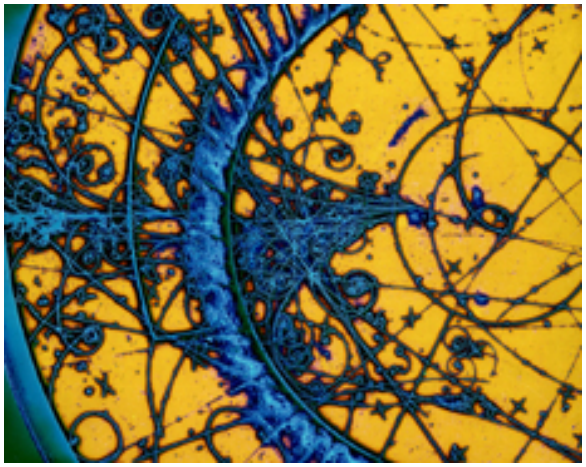


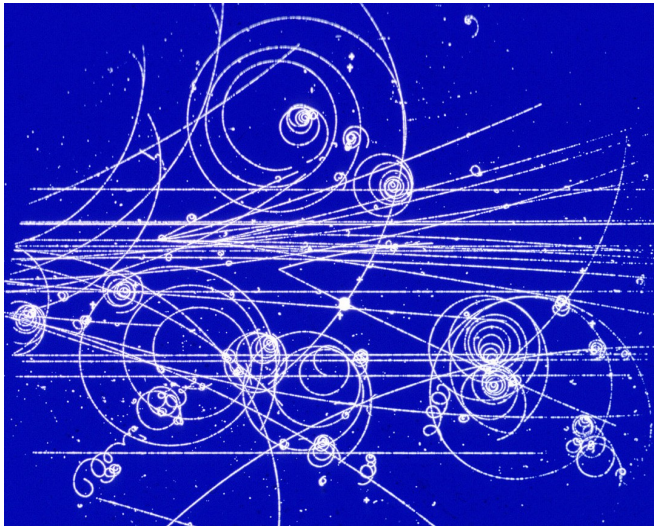
detectors come in many different varieties

Bubble/Gas Chamber Experiments



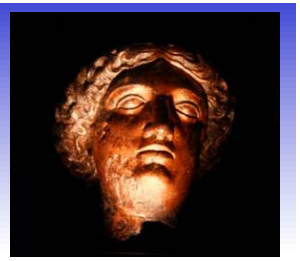


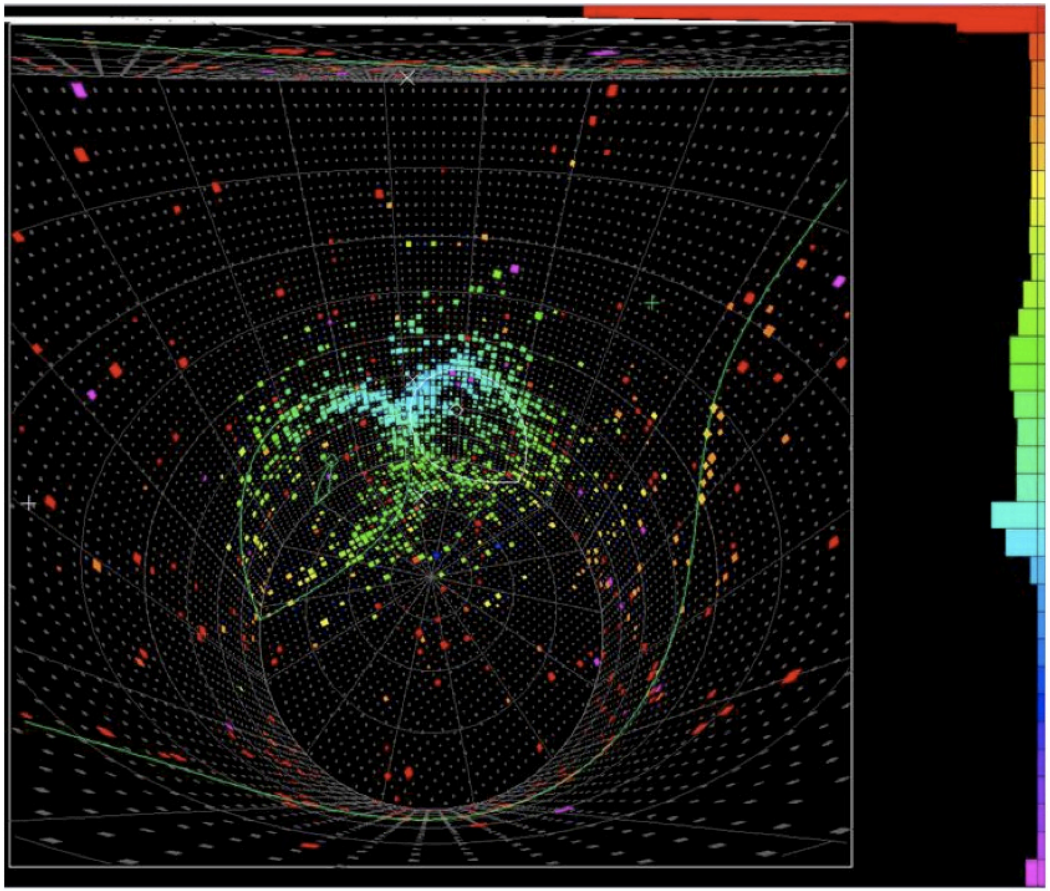


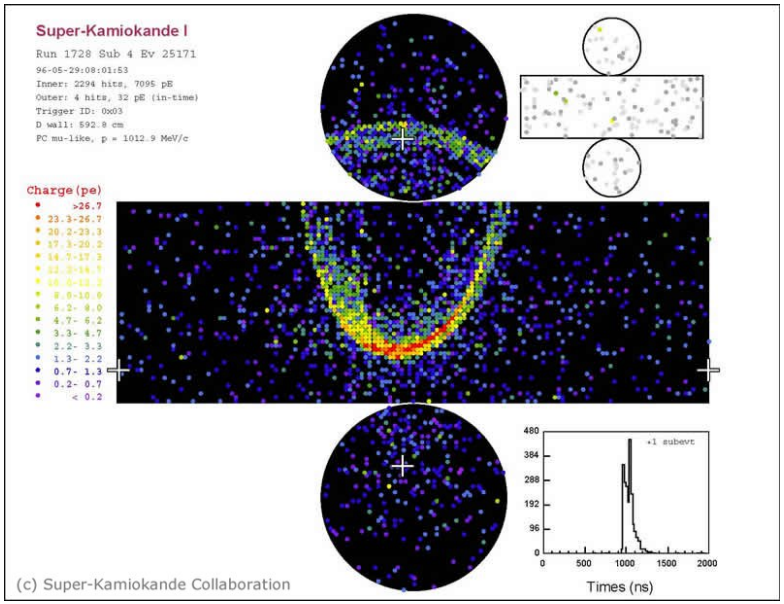


- Some of current neutrino cross section knowledge is from bubble chamber data.
- Very good resolution, poor statistics
- Mysterious origin? **1960 NOBEL - D.GLASER**

Super Kamiokande Experiment

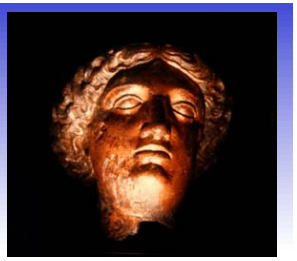


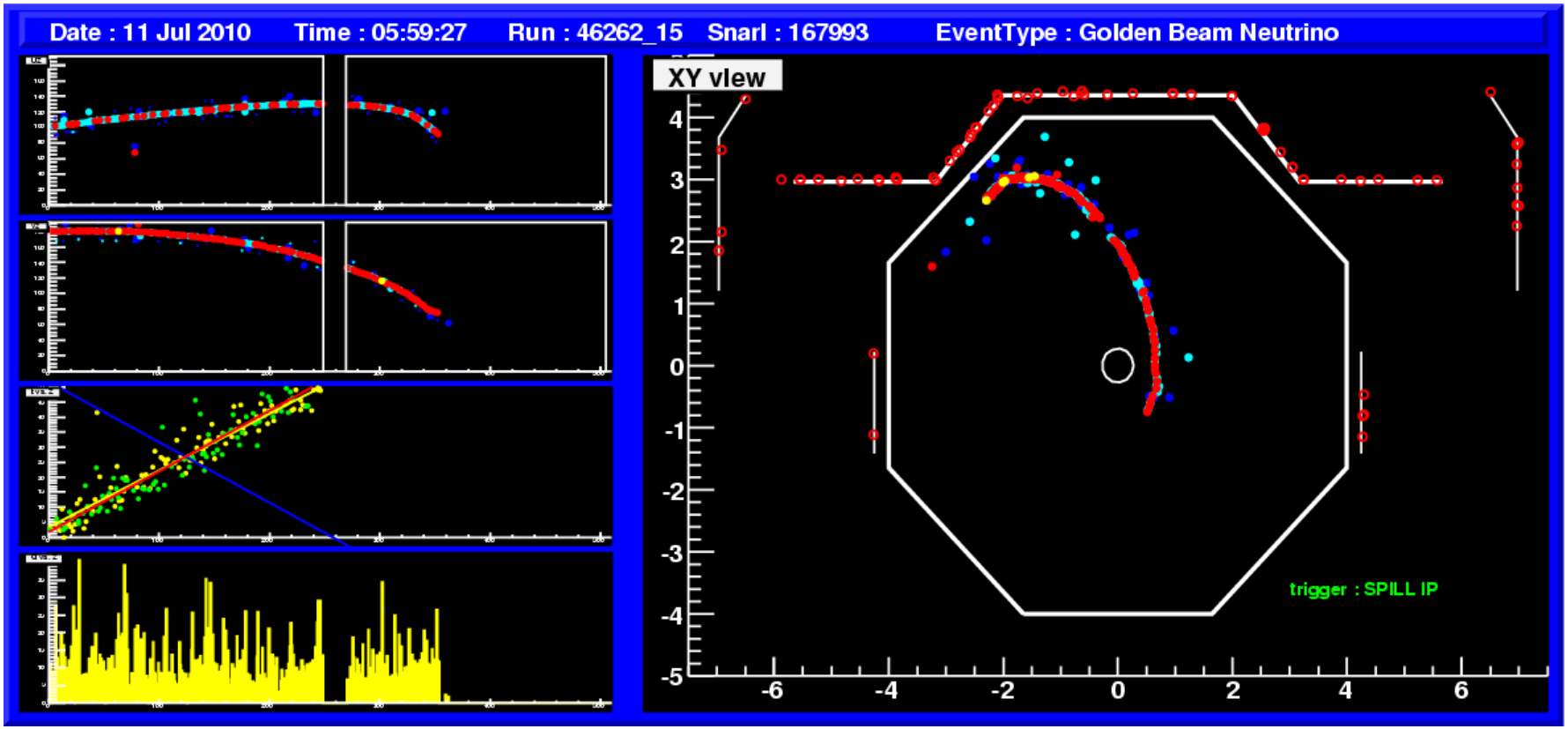




- Cherenkov light detection
- Not a tracking detector
- Energy and position data obtained from light patterns
- Similar to MiniBooNE

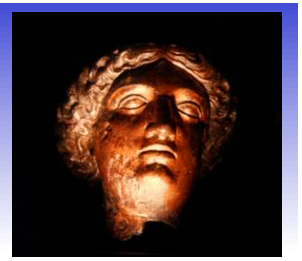
MINOS Experiment

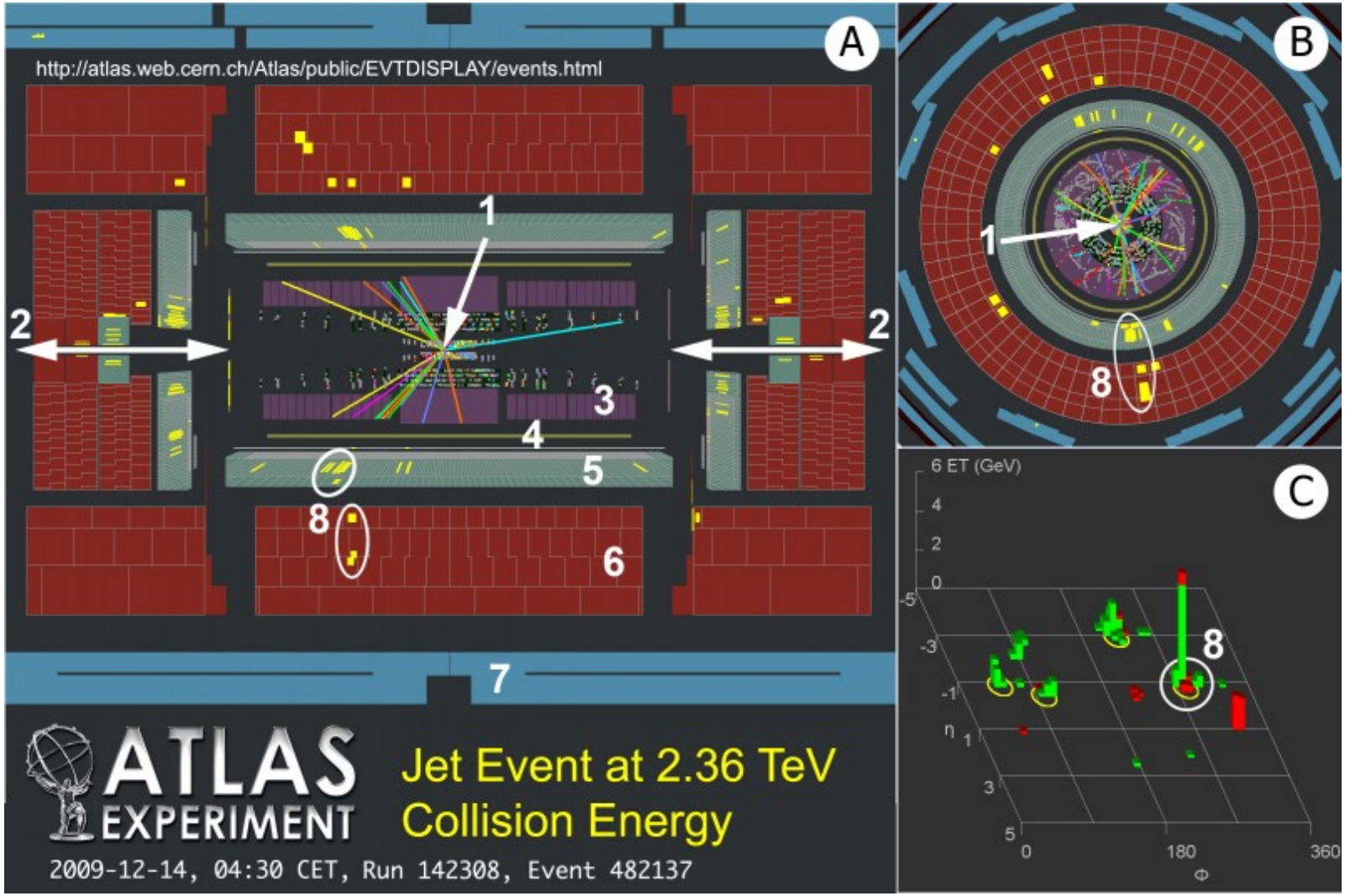




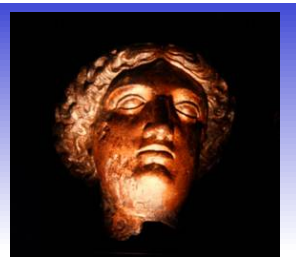
- Magnetized Steel/Scintillator
- Tracking/Calorimeter detector
- Energy and position data from light and curvature

Other Experimental Apparatuses





MINERνA

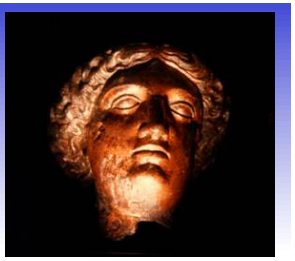


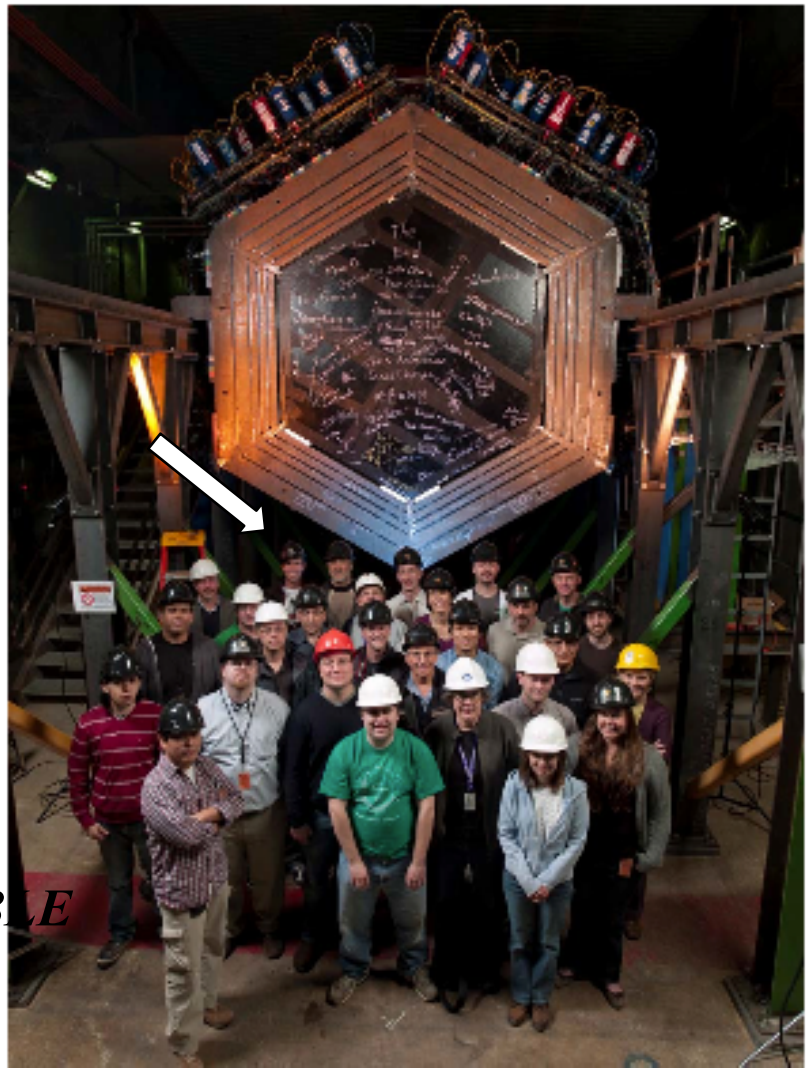
- The Main Injector Experiment ν–A (E938) is a high statistics neutrino scattering experiment at Fermi National Accelerator Laboratory. It will study neutrino–matter interactions. K.McFarland

- MINERνA takes advantage of the Intensity Frontier offered by the NuMI beam line. This intensity is coupled with a versatility of multiple different neutrino energy configurations in the 1-20(ish) GeV range. D.Harris

MINERνA Makes History

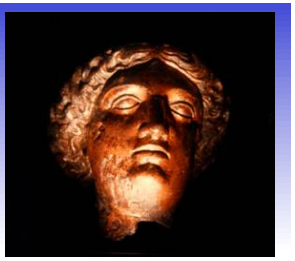
(i.e. event rates)

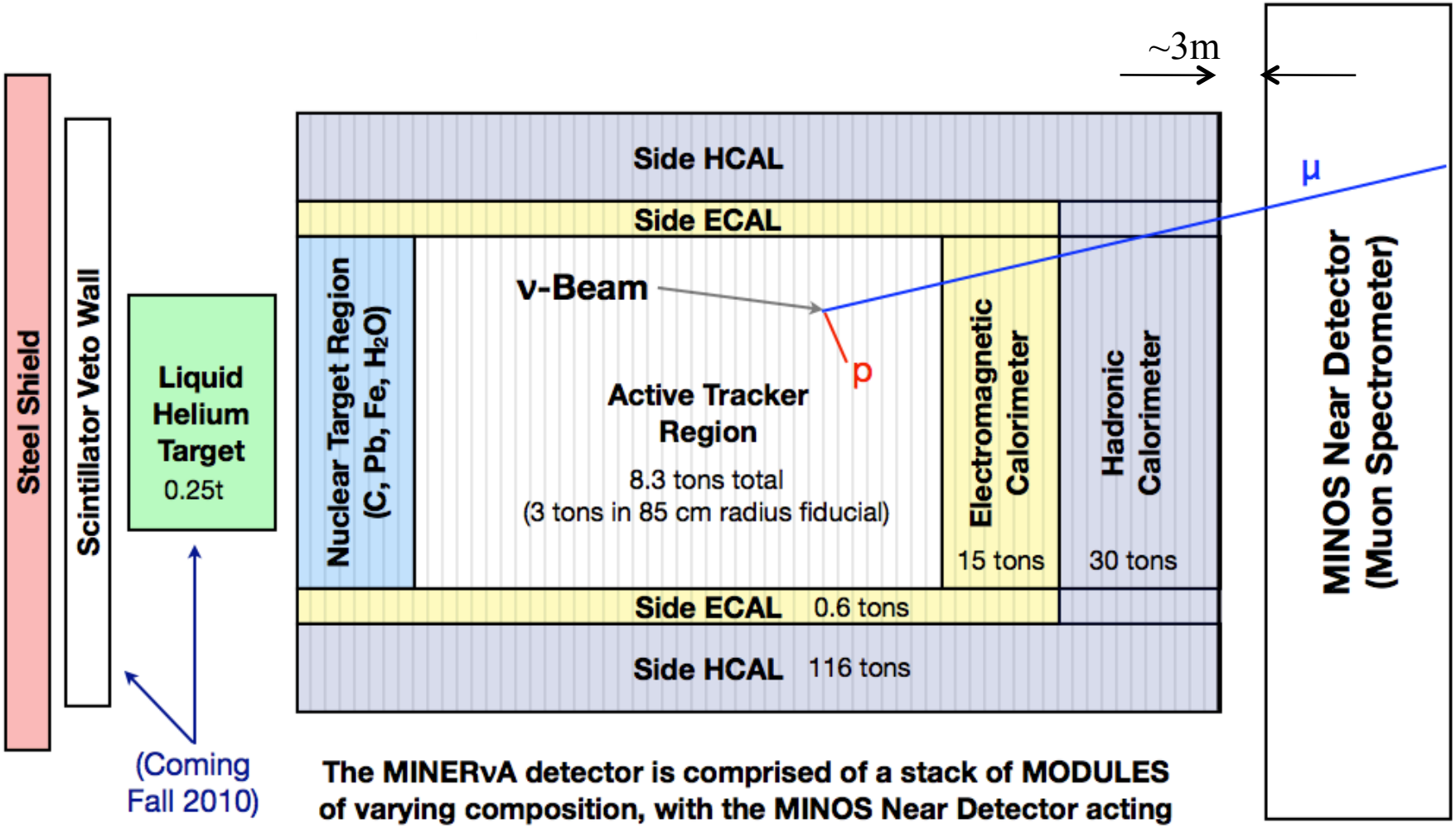




- 6.3M CC events in He,C,H_2O,Fe,Pb
- 9M CC events in CH – tracking volume
- ***240K COMPLETELY RECONSTRUCTABLE STRANGE AND CHARM EVENTS***

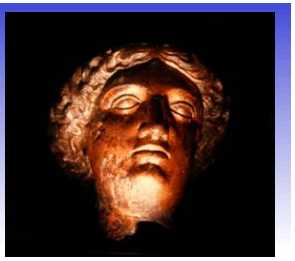
MINERvA Detector

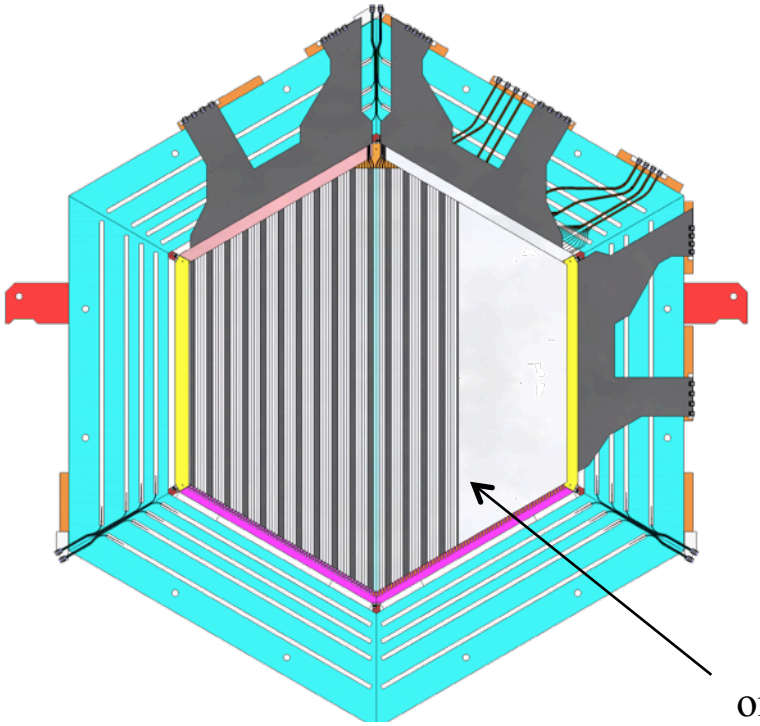




The MINERvA detector is comprised of a stack of MODULES of varying composition, with the MINOS Near Detector acting as a muon spectrometer. Finely segmented (~32 k channels) with multiple nuclear targets (C, CH, Fe, Pb, He, H_2O).

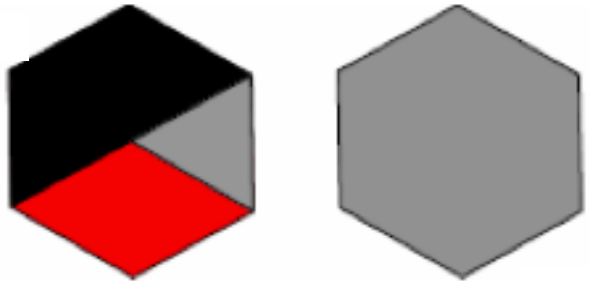
MINERvA Modular Structure

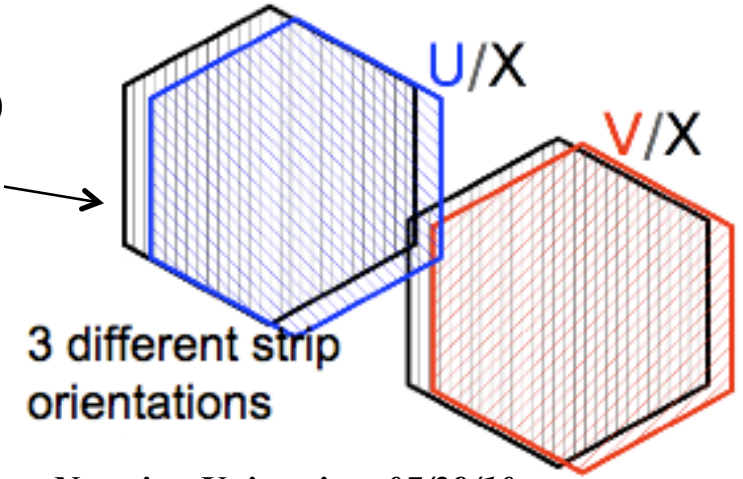




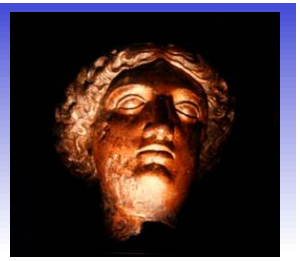
- The (full) MINERA detector consists of 208 hexagonal planes surrounded by a steel frame.
- Planes are either pure scintillator or have Pb, Fe absorber depending on the plane location. Heavy targets exist at the upstream end of the detector.
- There are three different views of the planes to aid in 3D reconstruction.

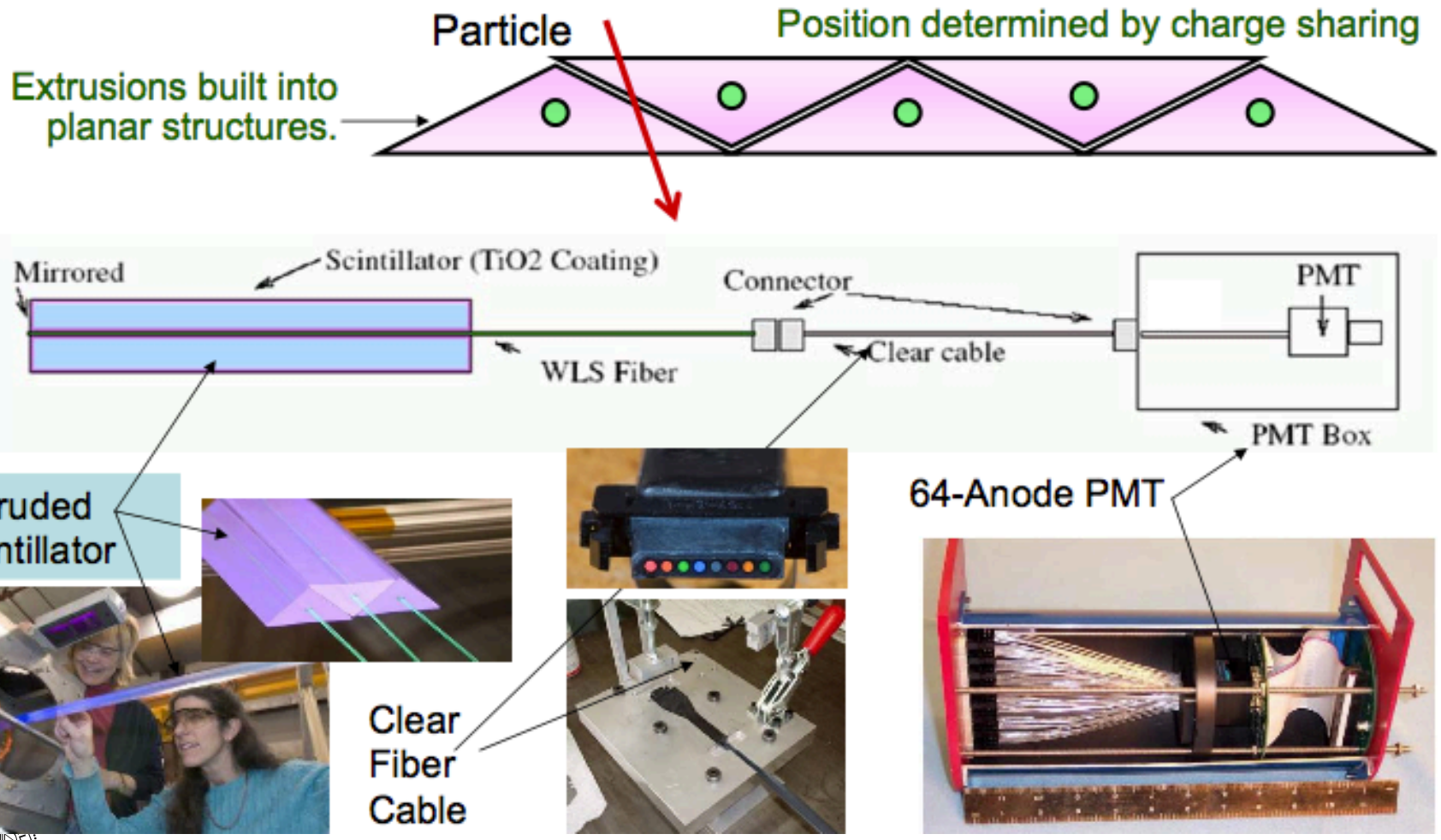
only get ($\mathbf{W_T}$,**Z**) from each plane



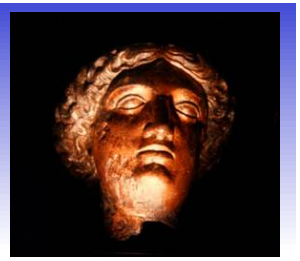


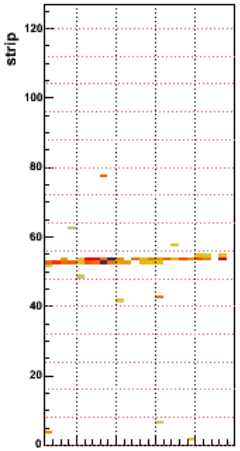
MINERvA Optical Elements



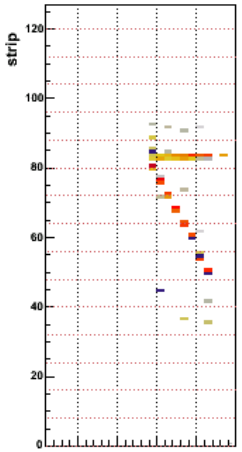


MINERvA Detector Data

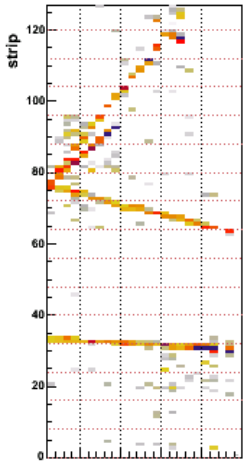




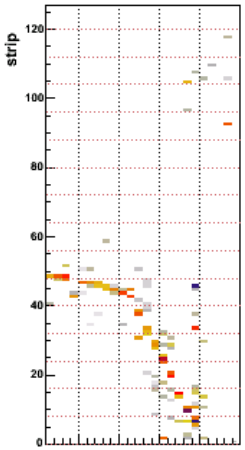
straight tracks



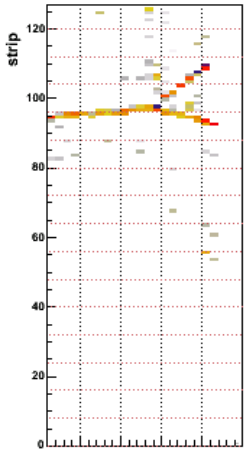
two track multiplicity



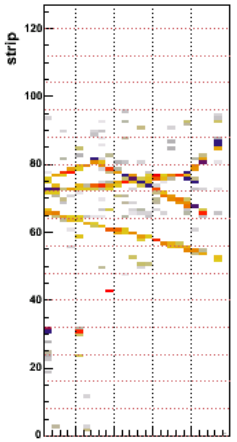
higher multiplicity



kinked tracks

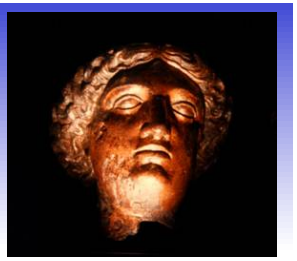


downstream interactions



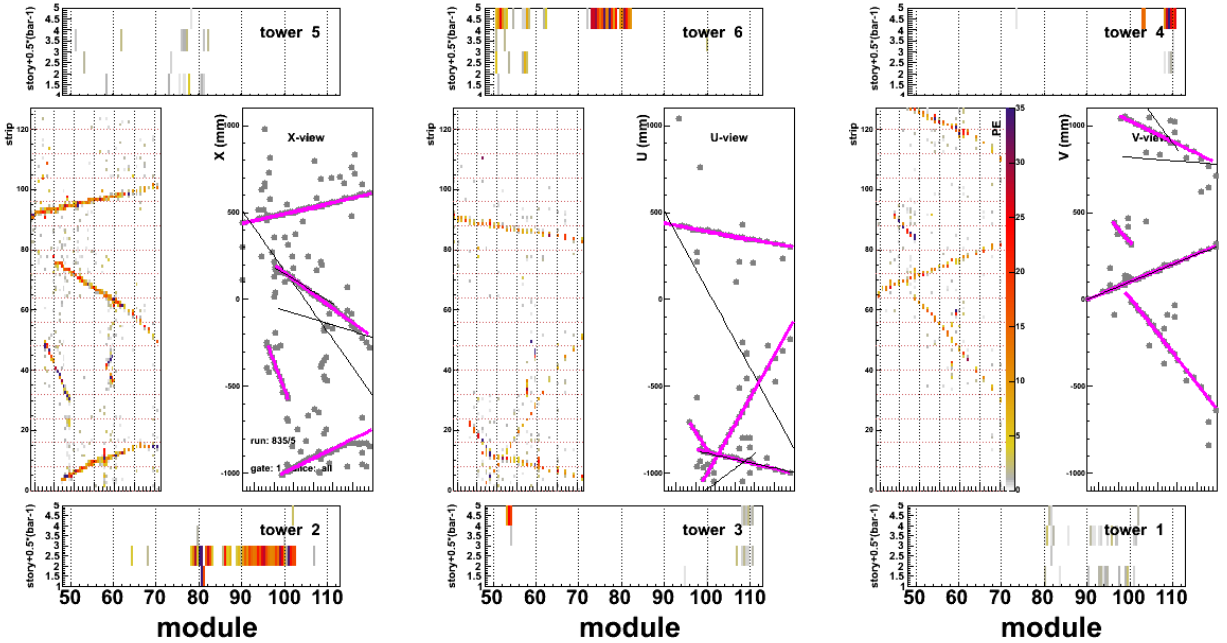
crossing tracks

First Reconstruction Task?

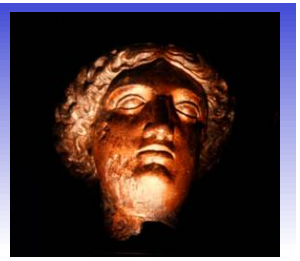


- Physics distributions are shown at conferences; reconstruction is concerned with each individual interaction.

- So, let's assume that we have built a neutrino detector and we have a data set. What is the first step in the reconstruction?

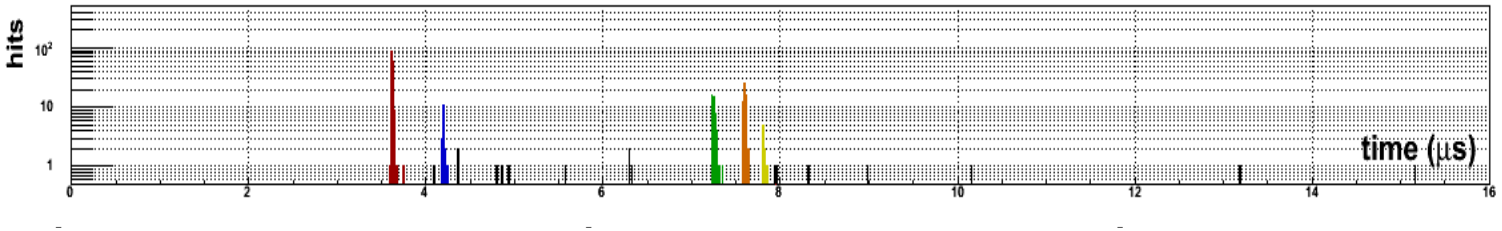


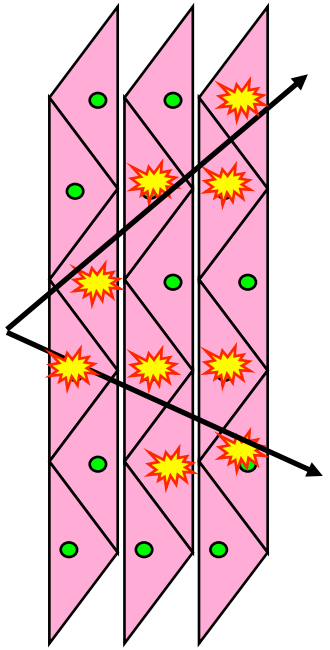
Stages of Data Processing



✌ Data directly from a detector needs to be first translated and have various calibrations applied before it is ready for reconstruction.

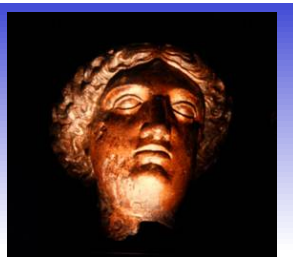
✌ The NuMI beam delivers bunches of neutrinos: a 10μs bunch of neutrinos every 2 seconds. The data needs to be scanned and data signals (detector hits) grouped in time.





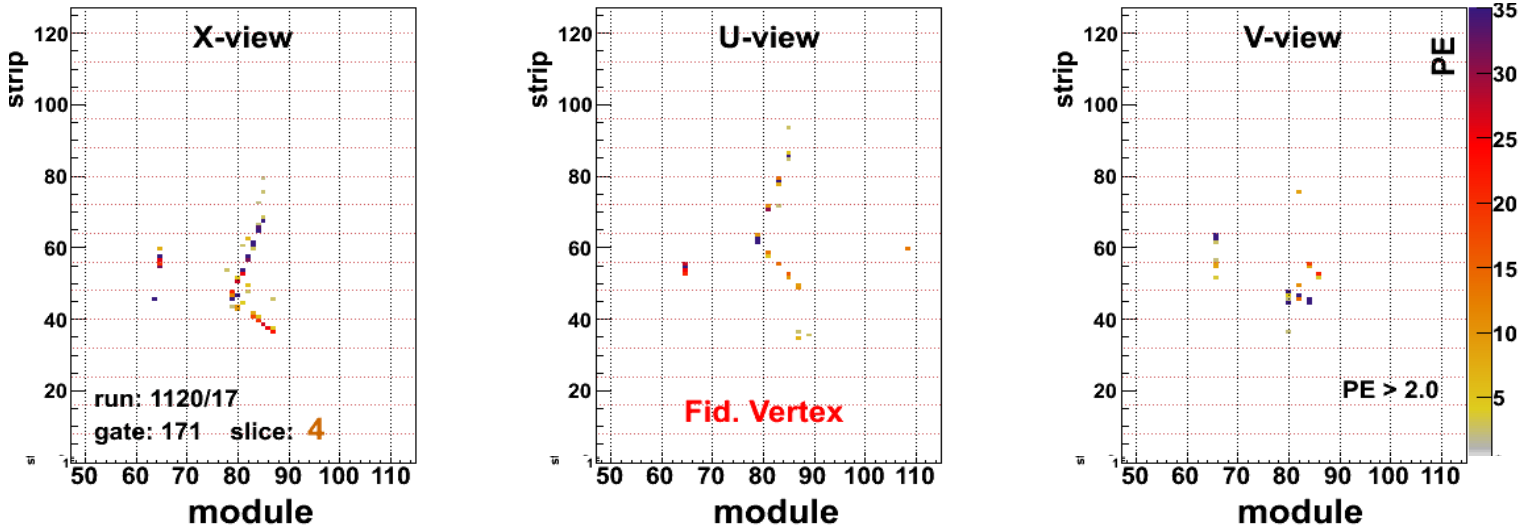
✌ Detector signals also need to be spatially grouped. One track can leave multiple hits – vertex regions are areas of difficulty/headaches . . .

Individual Event Processing

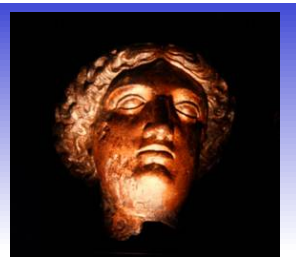


✌ Now we have (hopefully) a collection of hits in the detector that are closely spaced in time. This may or may not correspond to a single neutrino interaction – event overlap is possible.

✌ The tracks are obvious to the eye (in two views). How does one 'teach' software to do the task that the brain does quite well?

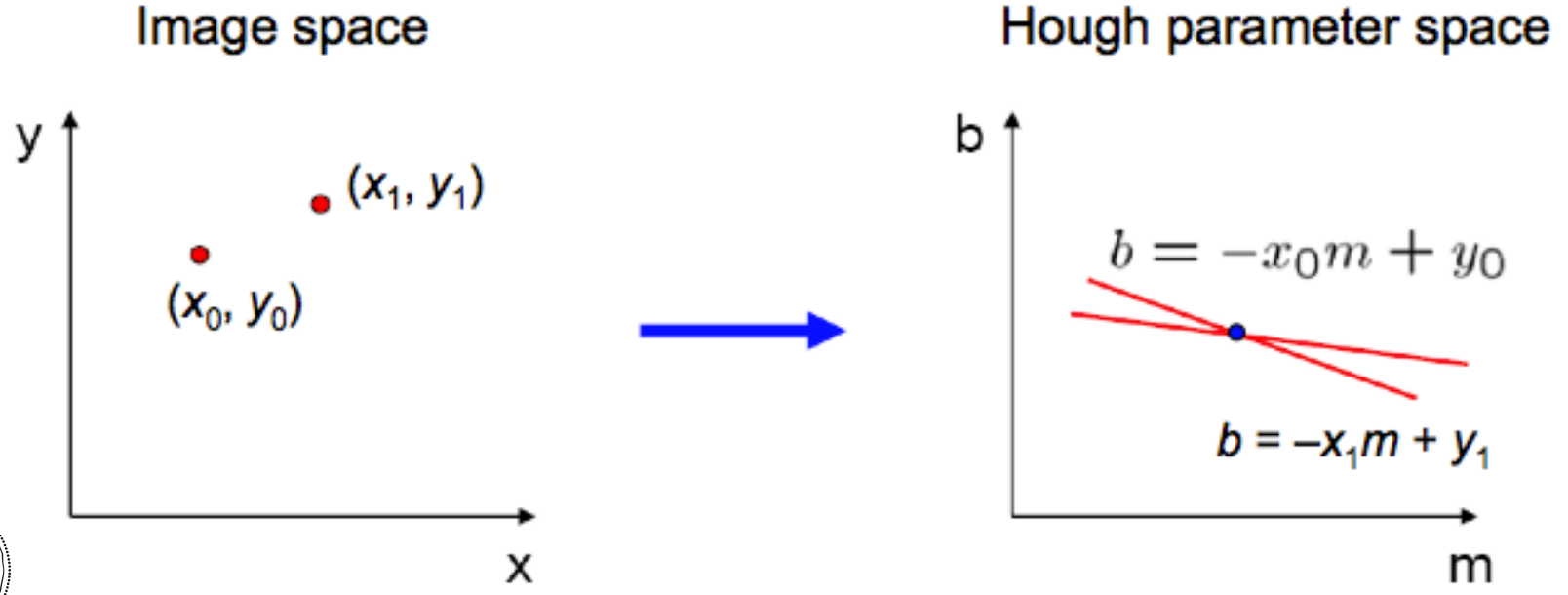


Pattern Recognition

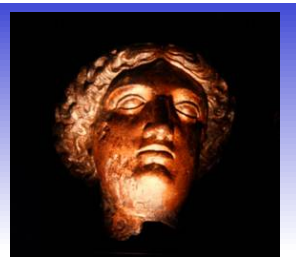


- We now do what Google (Bing, etc.) does – pattern recognition.

- Pattern recognition is the transformation from one space to another where patterns are more readily discernable; a common straight line transform is (X,Y)➔(m,b). The complexity of the transform varies.

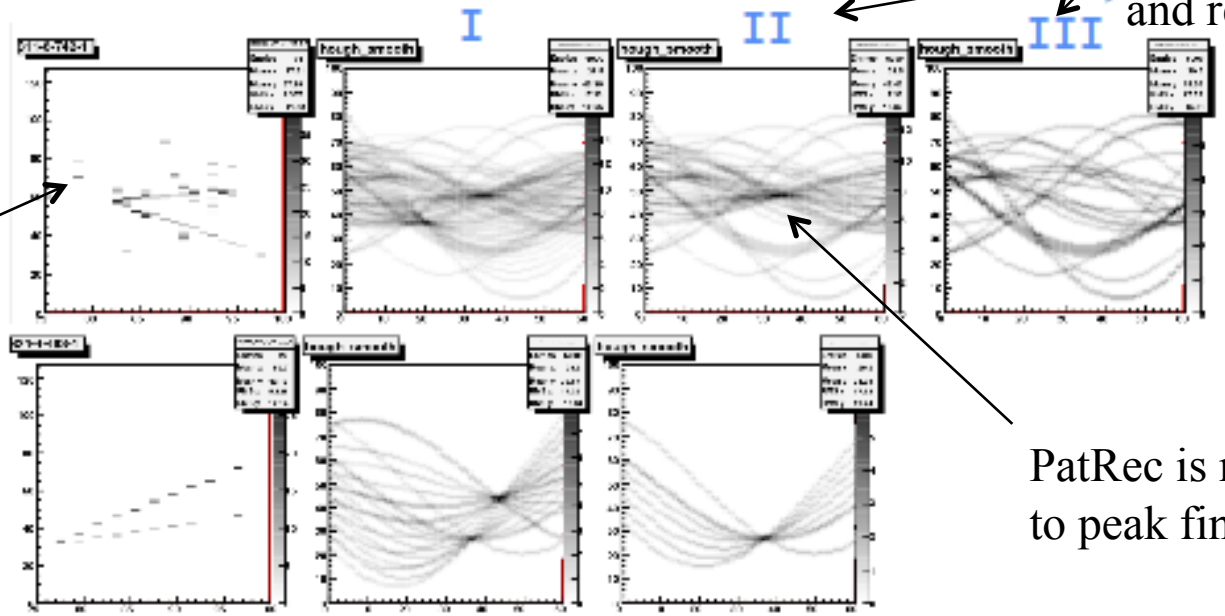


Hough Transform



- Another transform is (X,Y)➔(R,θ). We take every point and calculate an R = Xcosθ + Ysinθ - a loop over θ is implied.

- The transform takes points into sinusoids. Areas of heavy density correspond to the parameters of the line.

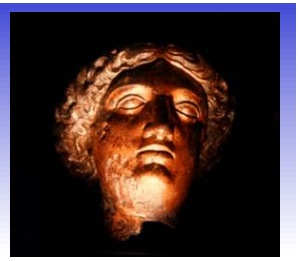


remove data and repeat

noise complicates things

PatRec is reduced to peak finding

Standing on Shoulders . . .

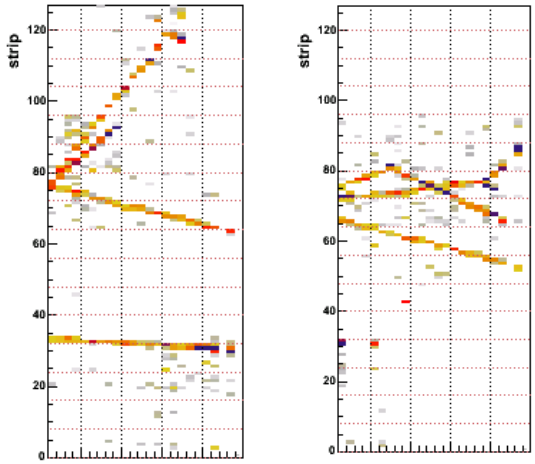


- The Hough transform is a common tool in the field. This algorithm has certain limitations.

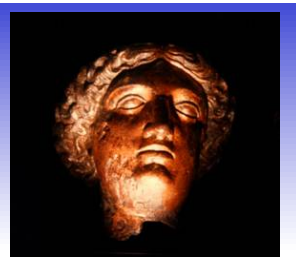
- This approach is considered 'global' pattern recognition (i.e. throw all data at the algorithm and cross your fingers). A local approach is ideal when there are richer structures than simple lines.

- We need to use a little cunning instead of blindly going forward with what has been done in the past . . . make you mark!

. . . . "If I have seen further it is only by standing on the shoulders of giants"



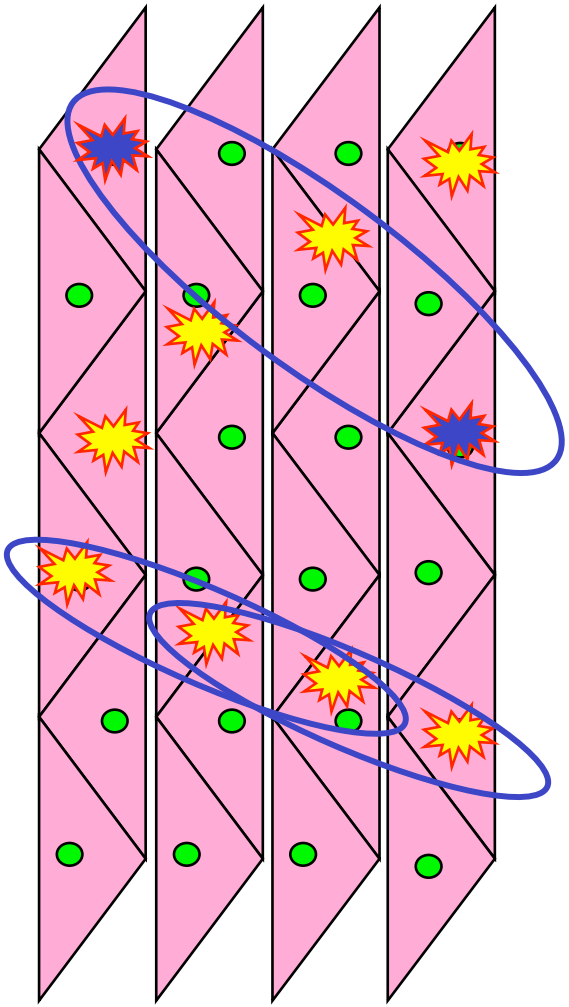
Local Pattern Recognition



- Start in the downstream region of the detector, collect groups of three hits in each view and fit them to a line with a least-squares method.

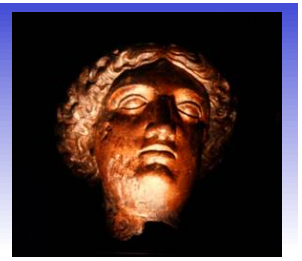
- This approach can reject noise hits and also reduces the number of objects to be used in the reconstruction.

- Now we have transformed the data from N hits in X,Y space into M groups of three hits (M<N) in m,b space. Peak finding (HT) or a simple merging can be done to reduce the data and collect tracks.



specific Z-length required

Three Dimensional Track Formation



✌ Currently have one track in three views: match tracks

End goal for tracking: $\{X, Y, Z, \alpha_X, \alpha_Y\}$ – state vector

Z is known from plane!

From view tracking:

- $X(Z) = \alpha_x Z + \beta_x$
- $U(Z) = \alpha_u Z + \beta_u$
- $V(Z) = \alpha_v Z + \beta_v$

Know:

$U = X\cos\theta - Y\sin\theta$

$V = X\cos\theta + Y\sin\theta$

Also:

$X = (2\cos\theta)^{-1}(U + V)$

$Y = (2\sin\theta)^{-1}(V - U)$

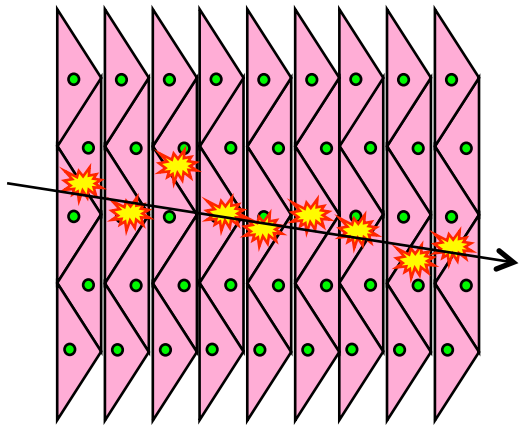
Math on a white board later:

- $\alpha_x = (2\cos\theta)^{-1}(\alpha_u + \alpha_v)$
- $\beta_x = (2\cos\theta)^{-1}(\beta_u + \beta_v)$

Get for free: seed for track fitter

$\alpha_Y = (2\sin\theta)^{-1}(\alpha_u - \alpha_v)$

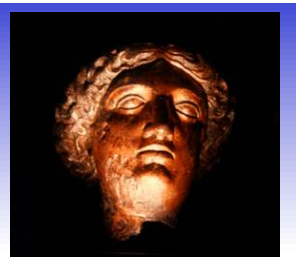
$\beta_Y = (2\sin\theta)^{-1}(\beta_u - \beta_v)$

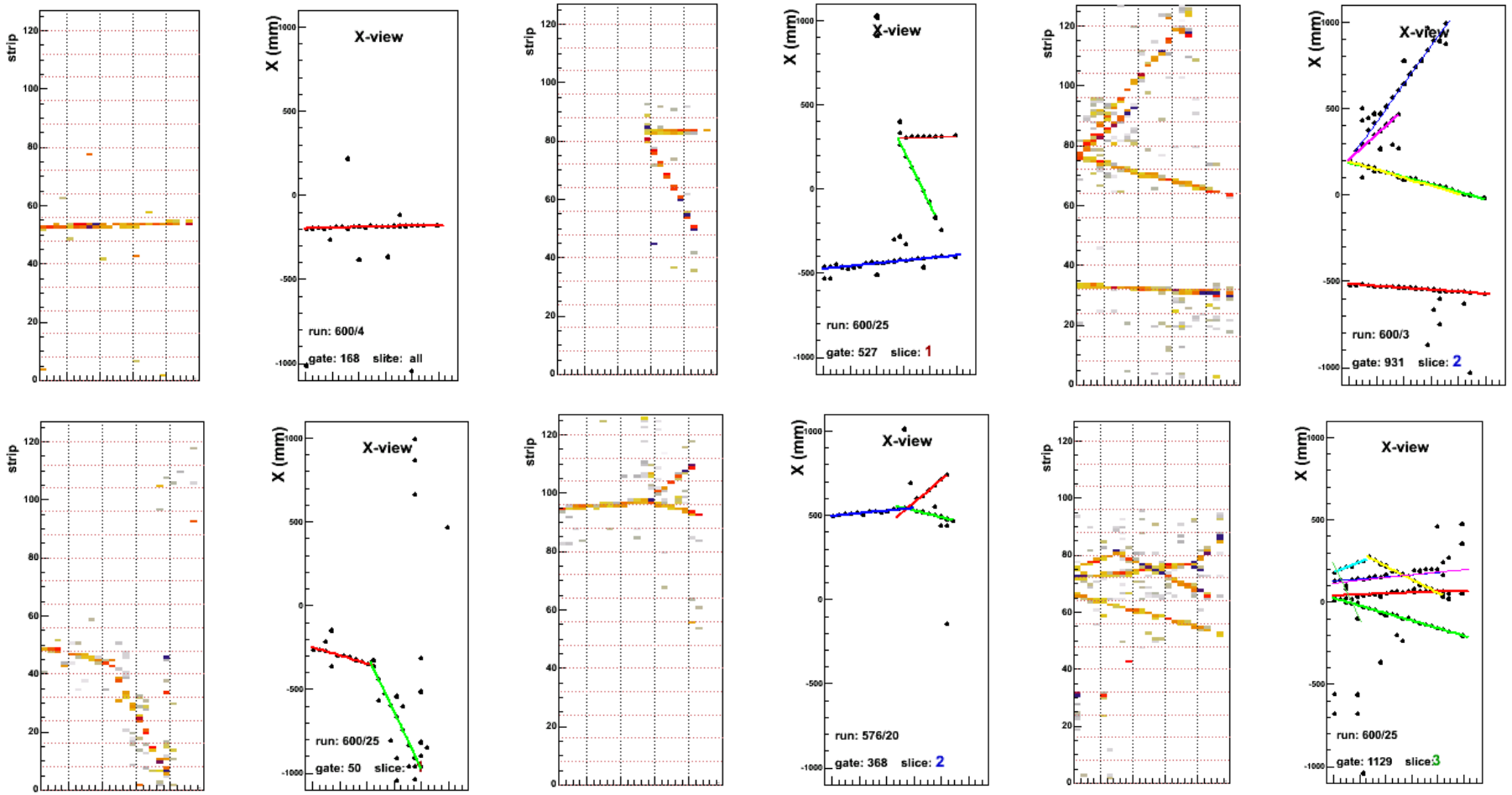


Form and cut on:

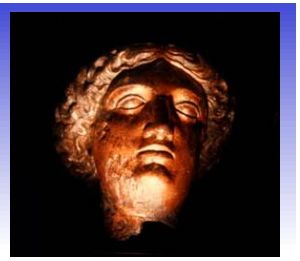
- $\chi^2 \sim \Sigma \{ X(Z) - [U(Z) + V(Z)] \}^2 +$ ("Y-term")^2
- overlap parameters

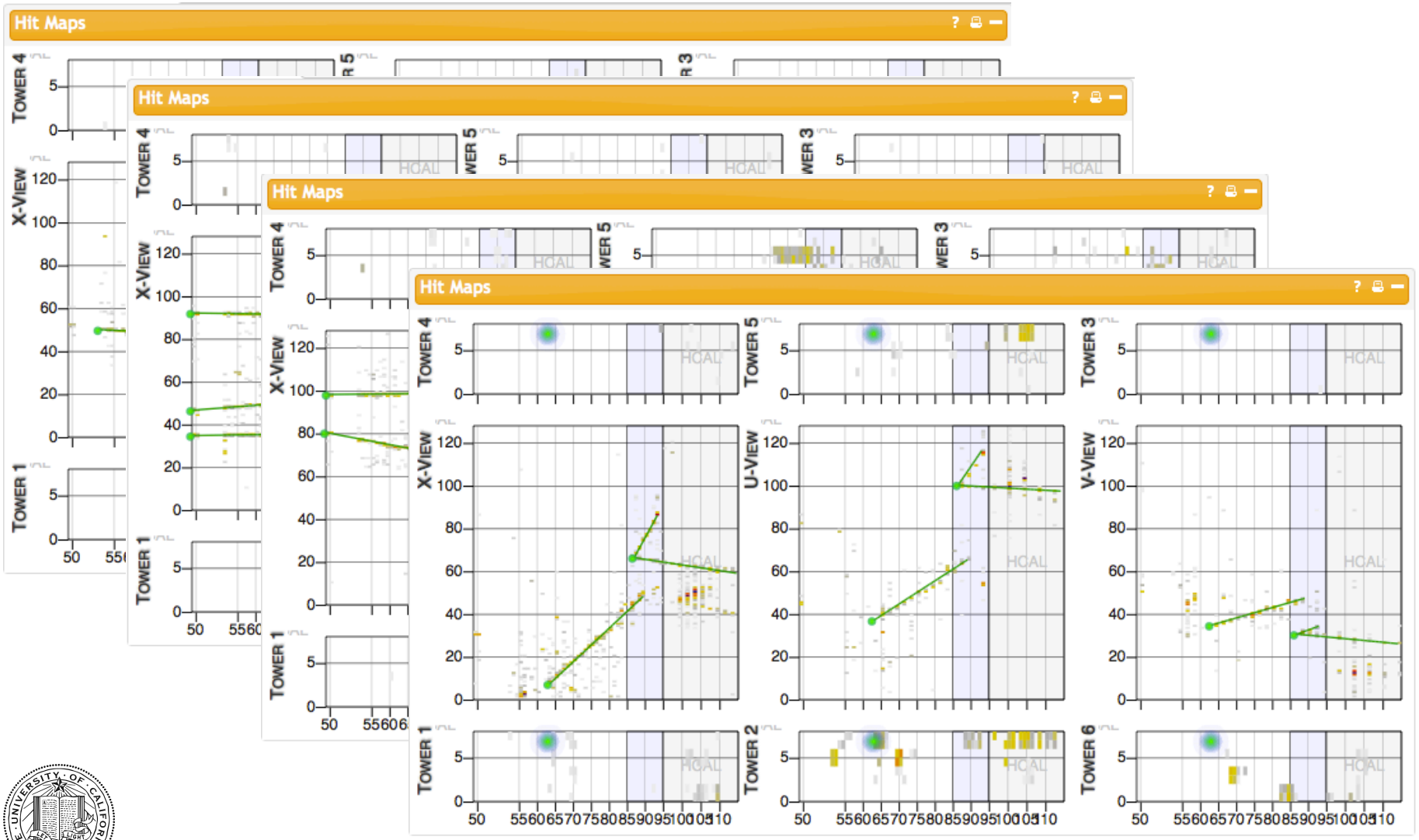
MINERvA Detector Data



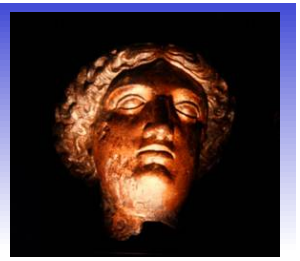


Hungry for More . . . ?

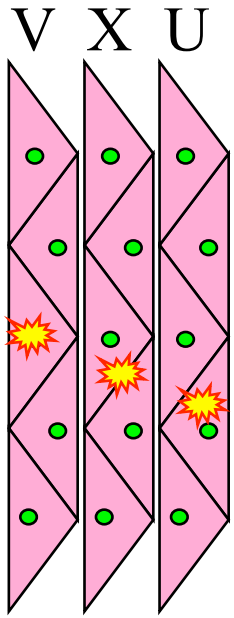




Further Reconstruction Tasks



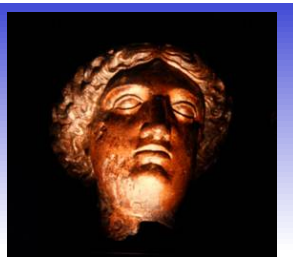
- The pattern recognition scheme we developed requires a certain length to work. We can also use the geometric connection between hits to create a ShortPR.

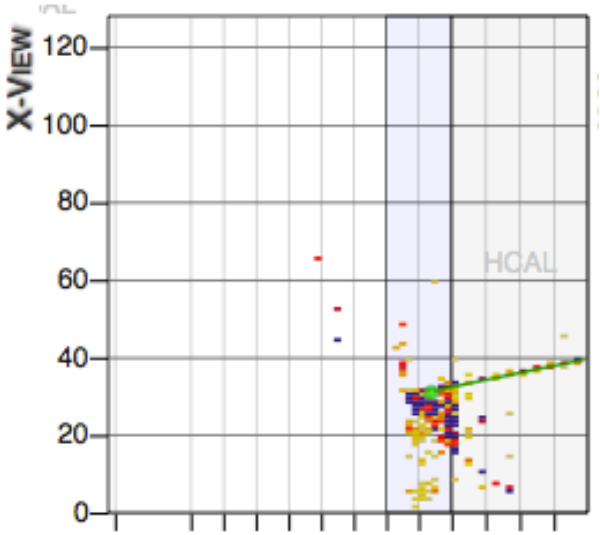


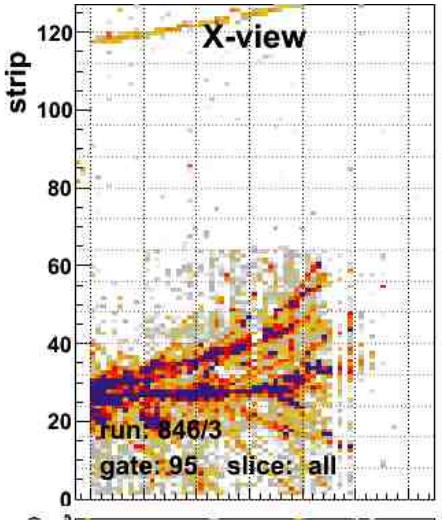
- Have (V,Z_1), (X,Z_2),(U,Z_3) and again need to form a state vector: $\{X_0, Y_0, Z_0, \alpha_{X_0}, \alpha_{Y_0}\}$

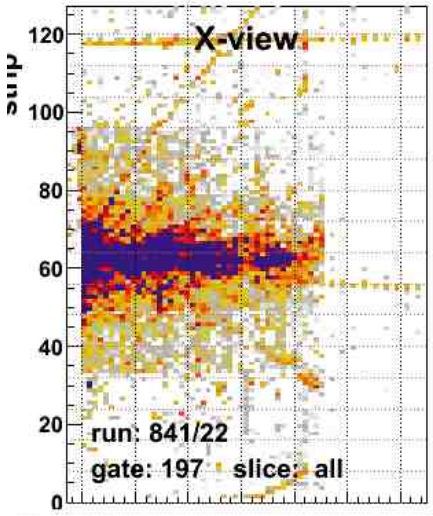
- Form match (just as in 3D case):
  - $\chi^2 \sim X - (U + V)$: this can vary for angled track
  - $Y_{UV} = 3^{-½}(V - U)$, $Y_{XU} = 3^{-½}(X - 2U)$, $Y_{XV} = 3^{-½}(2V - X)$
  - use these to get an initial guess of α_X and α_Y
  - iterate to get final parameters
  - higher error in shorter tracks due to less information used in the fitting

Particle Showers: Simple, Complex





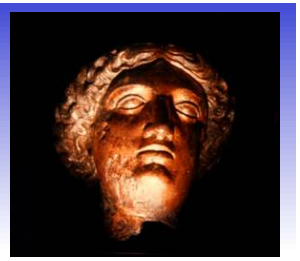




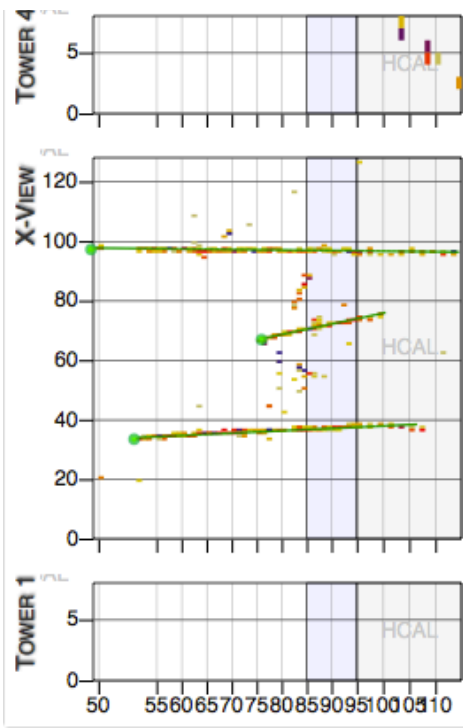
- A shower PatRec is also needed. Showers don't require same resolution as tracks – but much depends on the topology.

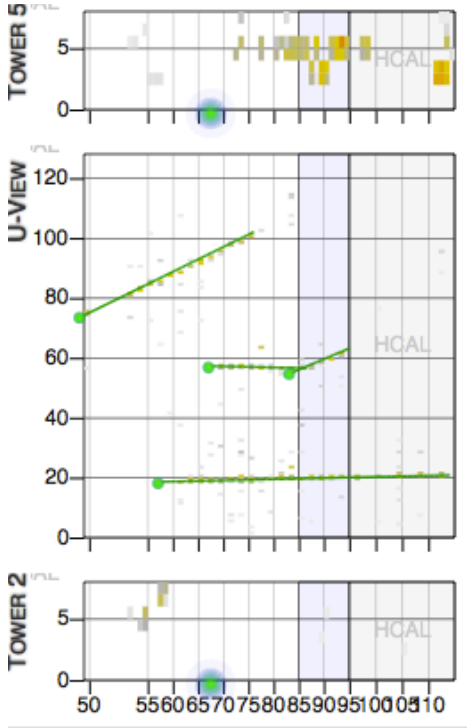
- Shower signals can be in addition to tracks or in place of them.

Tasks To Do After The Task Is Done

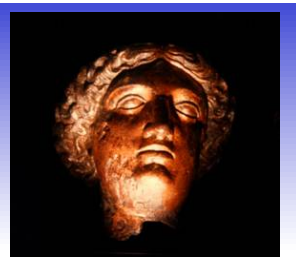


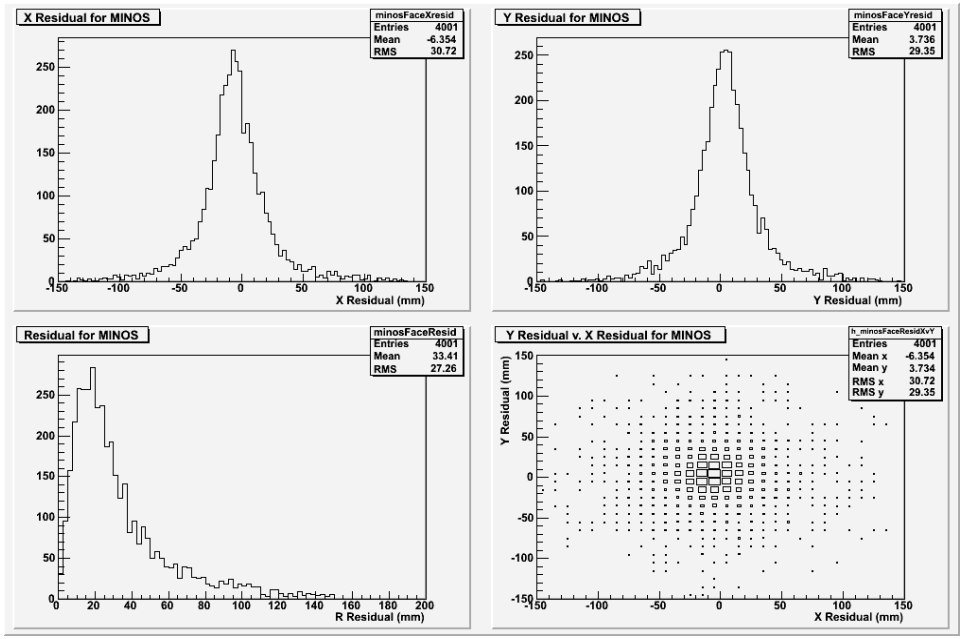
✌ Post-tracking tasks include: track merging, vertexing, re-fitting with momentum, identifying re-interactions, hit removal for further data processing, coordinate refinement due to known angle . . .





MINOS Track Matching

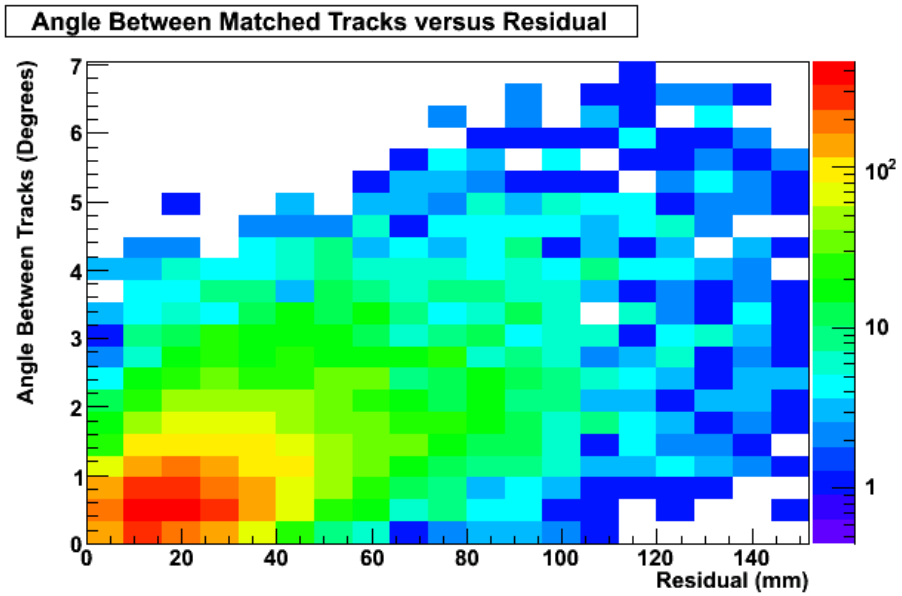




~3cm matching residuals

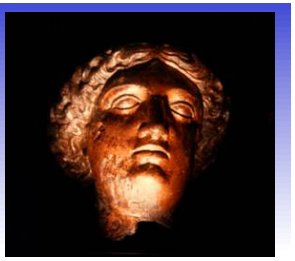
- Matching residuals are approximately 3cm before any inter-detector alignment has been attempted.

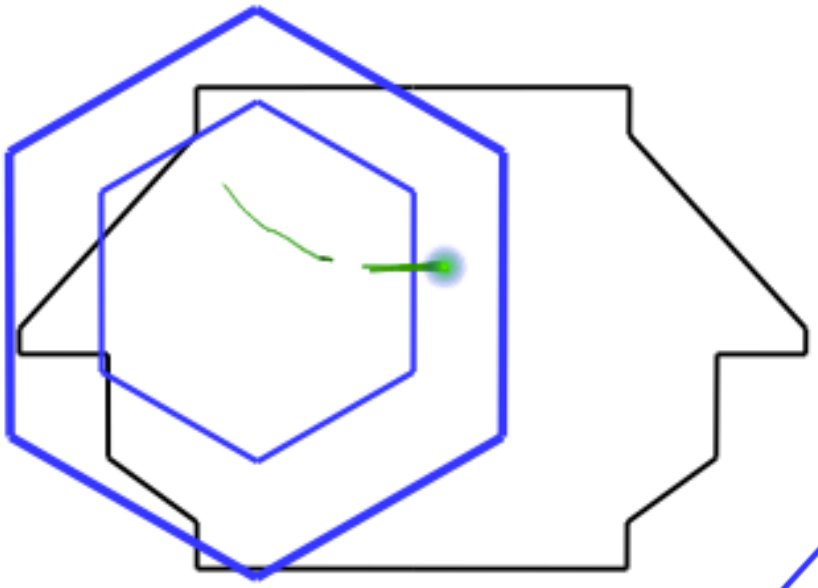
- Tracks exiting MINERvA are matched to momentum analyzed MINOS tracks. MINERA has no magnetic field and therefore heavily reliant on MINOS.



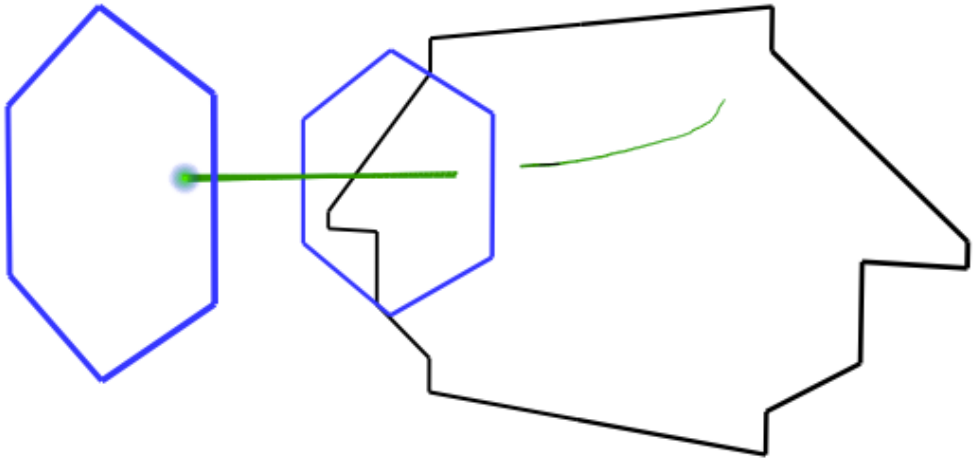
MINOS Track Matching

(visualized)

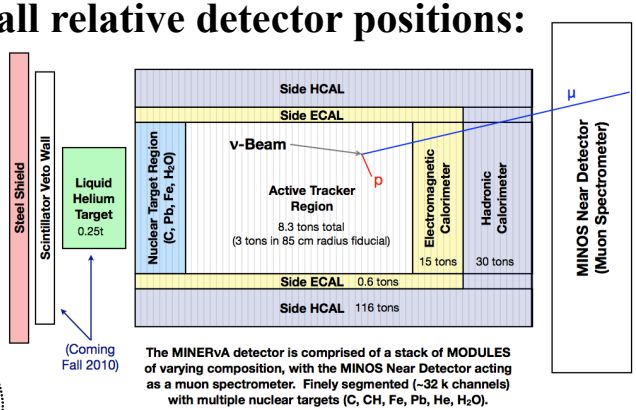




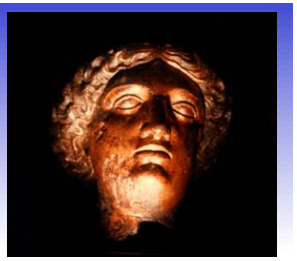
- Tracks exiting MINERvA are matched to momentum analyzed MINOS tracks. MINERA has no magnetic field and therefore heavily reliant on MINOS.



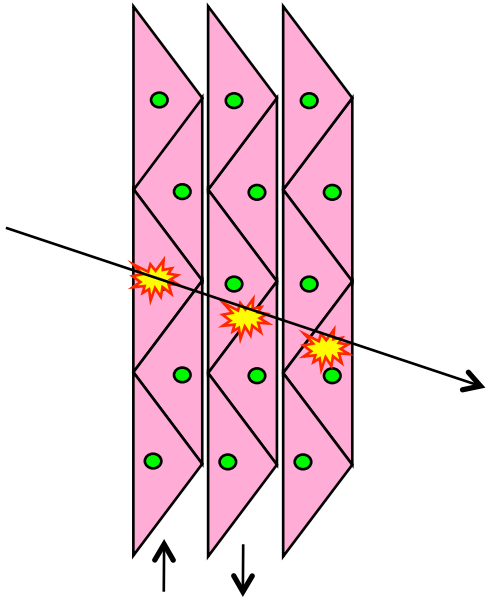
Recall relative detector positions:



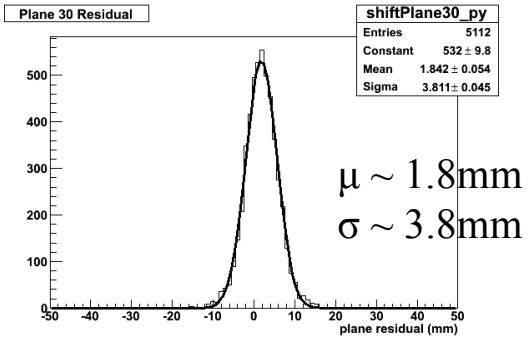
Track-Based Alignment



- Misalignments between detector planes are introduced during the construction of the detector. Reconstruction can aid in this task.

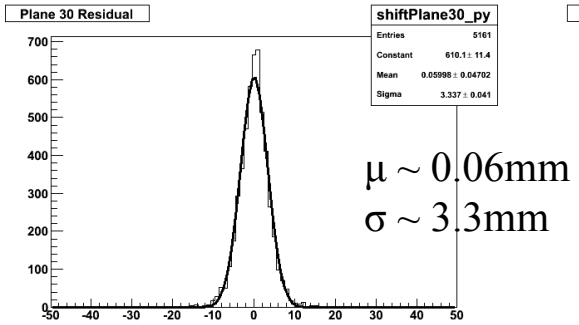


- These residuals are removed via minimization of planar residuals.
  - parameterized via Δw_i (shift), $\Delta \theta_i$ (rotation) {i = plane}



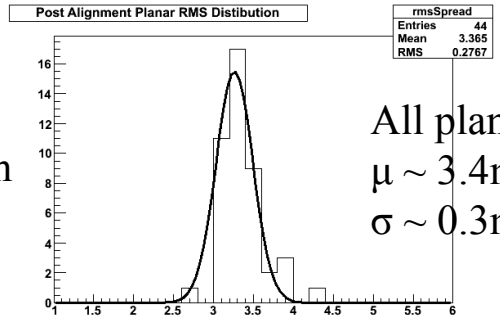
$\mu \sim 1.8$mm
$\sigma \sim 3.8$mm

pre-aligned



$\mu \sim 0.06$mm
$\sigma \sim 3.3$mm

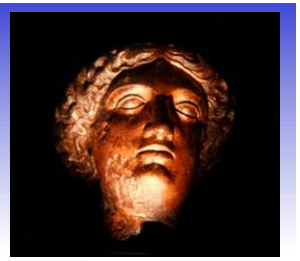
post-aligned



All planes:
$\mu \sim 3.4$mm
$\sigma \sim 0.3$mm

PRELIMINARY ALIGNMENT

Go Forth, Do Physics and Be Merry

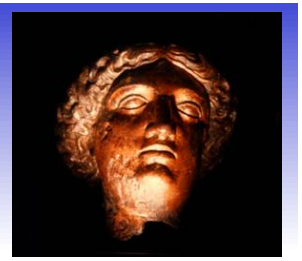


✌ Data processing is crucial to extracting physics and distributions from particle detectors. There are many stages of processing, each as important as the last.

✌ Pattern recognition/track fitting is the 'art' of taking detector signals and producing particle signatures. The methods depend heavily on the detector technology used, but fresh ideas are essential.

✌ We mainly focused on how to get tracks. But, reconstructed tracks are then used for momentum reconstruction, event building, alignment, etc.

✌ Be Merry.



Thanks for attending.