ART (Algebraic Reconstruction Technique) for Electron Shower Reconstruction

Jaewon Park
University of Rochester

Overview

- Electron Final States
- MINERvA Detector
- EM Calorimetry
- What is ART?
- Simple ART Demos with X-Y and Hex Image Array
- Angular resolution using ART

Electron Final States

$$\nu_e n \rightarrow e^- p$$
$$\bar{\nu}_e p \rightarrow e^+ n$$

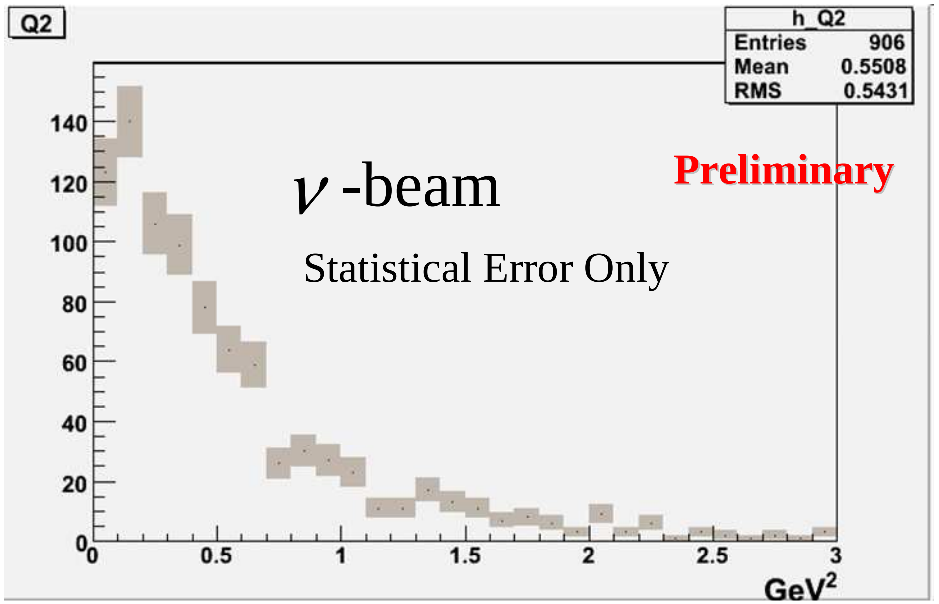
- Fraction of electron neutrino in the neutrino beam is small (~1%)
- Proton and neutrino may not be visible when it has too low energy
- Q^2 (4-momentum square) distribution has not been measured

$$\nu_\mu + e \rightarrow \nu_\mu + e$$
$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$

- Well-known cross section
- Very small cross section
- Very forward electron
- Measurement can give loose constrain to flux

- Background has not been studied yet

$\nu_e, \bar{\nu}_e$ CCQE Q^2 Distribution



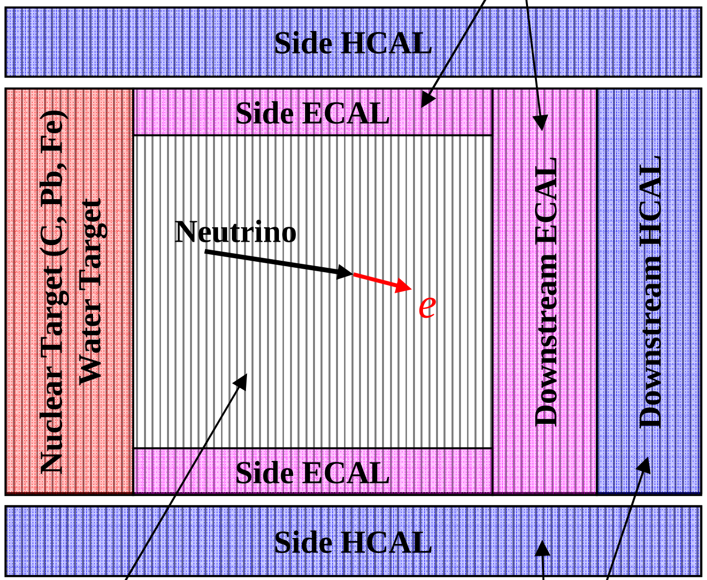
$$E_\nu = \frac{m_n E_e - m_e^2/2}{m_n - E_e + p_e \cos\theta}$$

$$Q^2 = 2M_n(E_\nu - E_e)$$

- This is GENIE MC prediction

Minerva Detector

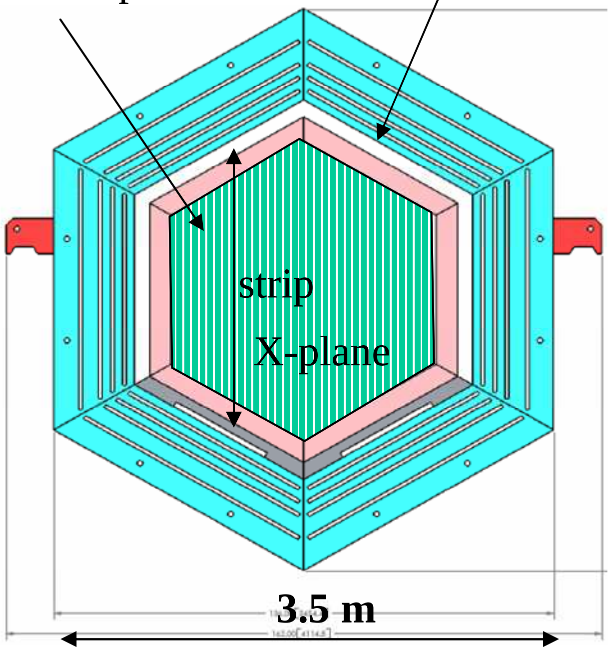
ECAL: Scintillator + lead sampling calorimeter

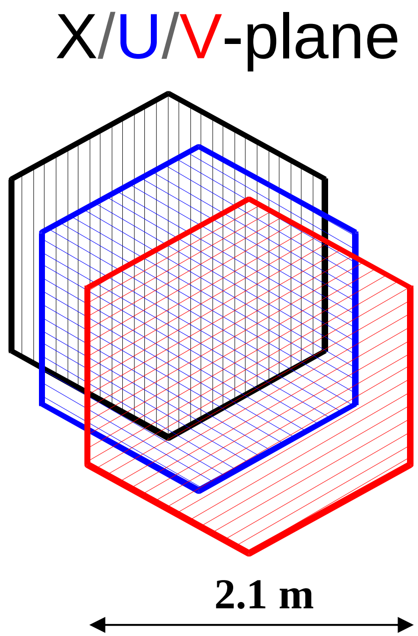


Tracker serves as target (CH)

One module has two scintillator planes.
Module Type: XU module, XV module

127 strips

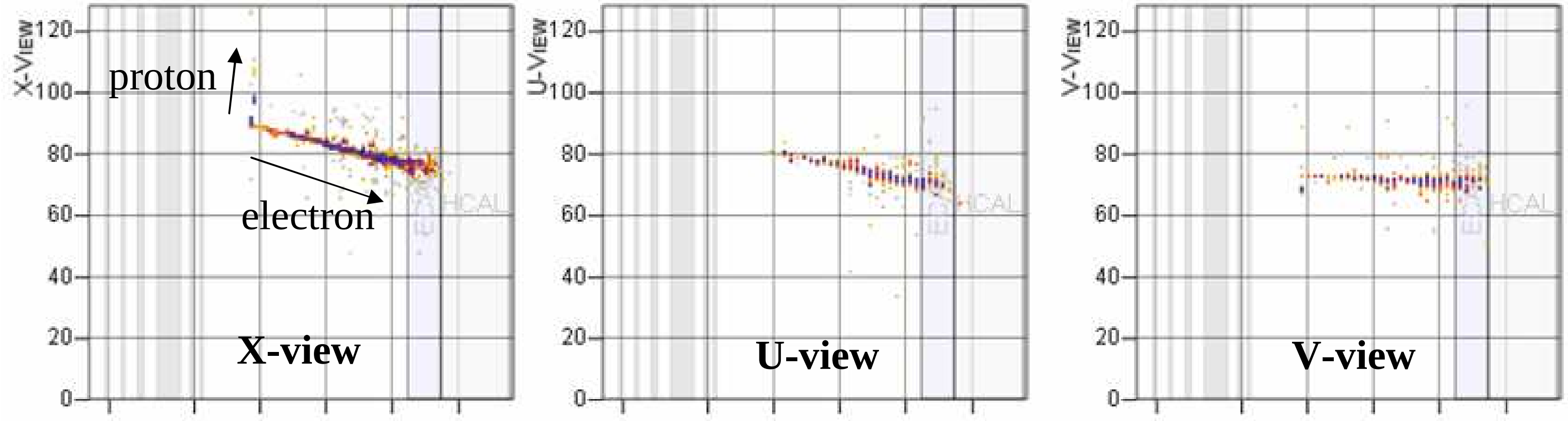




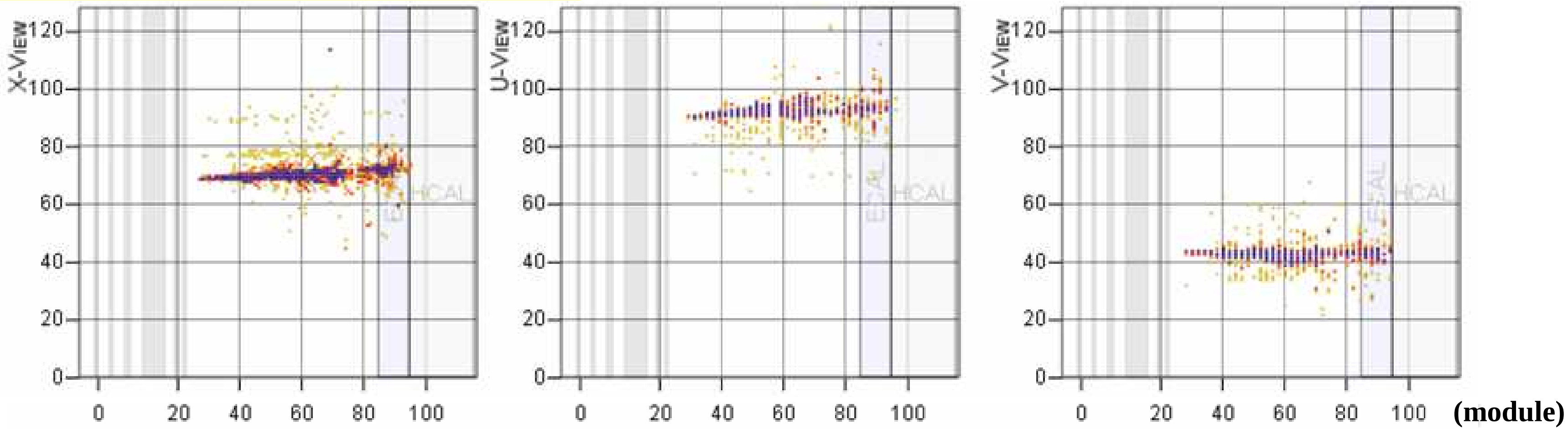
HCAL: Scintillator + steel sampling calorimeter

Event Display
(Real Data)

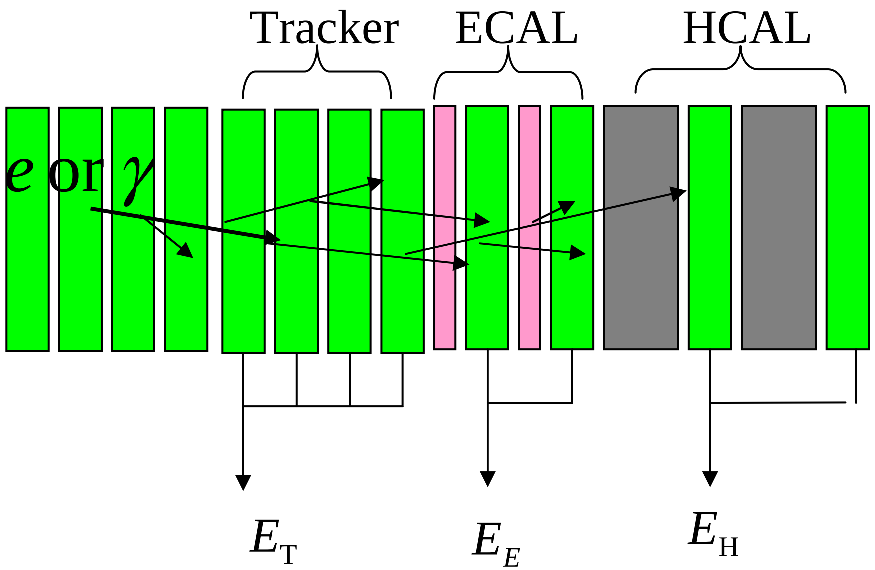
$\nu_e n \to e^- p$ candidate event



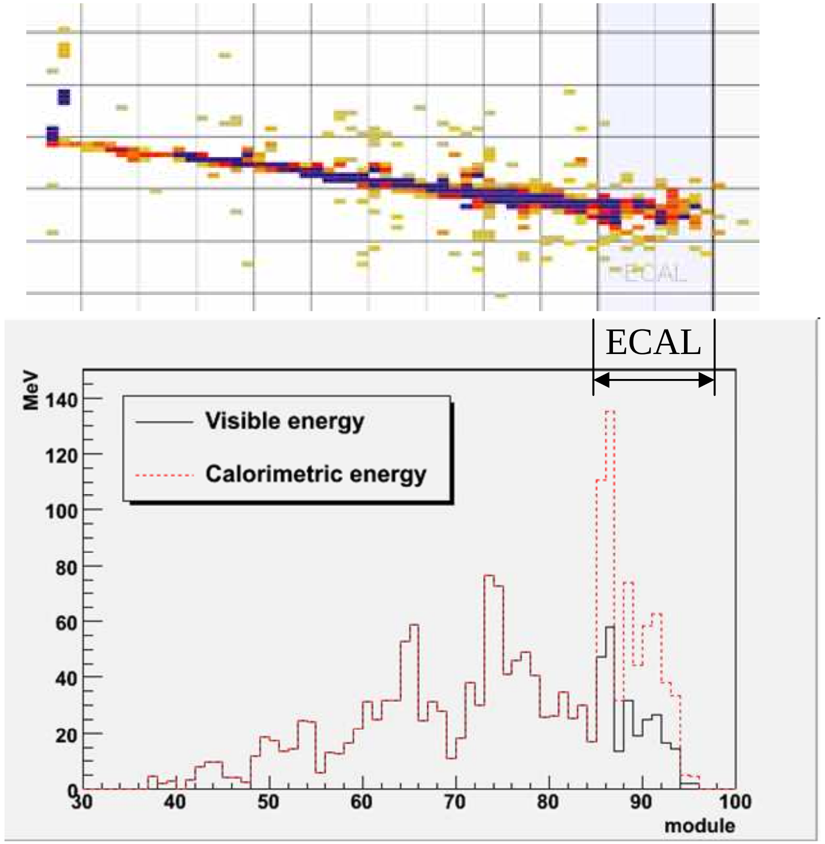
$\nu_\mu e^- \to \nu_\mu e^-$ candidate event



Calorimetric Energy



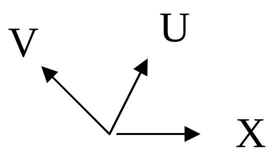
$$E = \alpha(E_T + k_E E_E + k_H E_H)$$

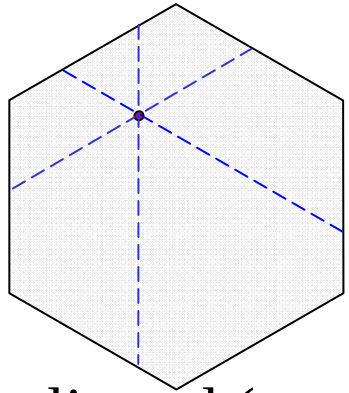


- Typical sampling calorimeter has structure of alternating absorbers (lead or steel) and active mediums (scintillator).
- In calorimetric energy calculation, we need to compensate energy loss in absorber.

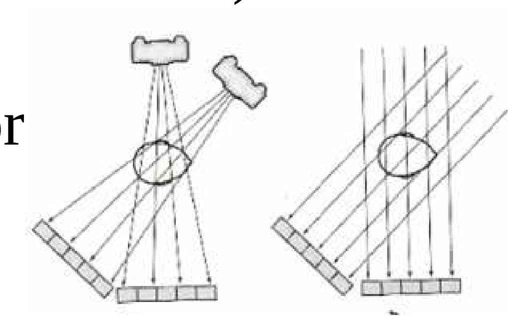
ART

- Current tracking algorithm reconstructs thin track well.
  - It uses X=U+V matching condition.





- It's not easy for shower event or complicated (multi-track) event.
- Finding 3D coordinates from 3 different views (or projections) is very similar to problem solving in Computed Tomography (CT).
- Among several methods, algebraic reconstruction technique (ART*) is adopted.

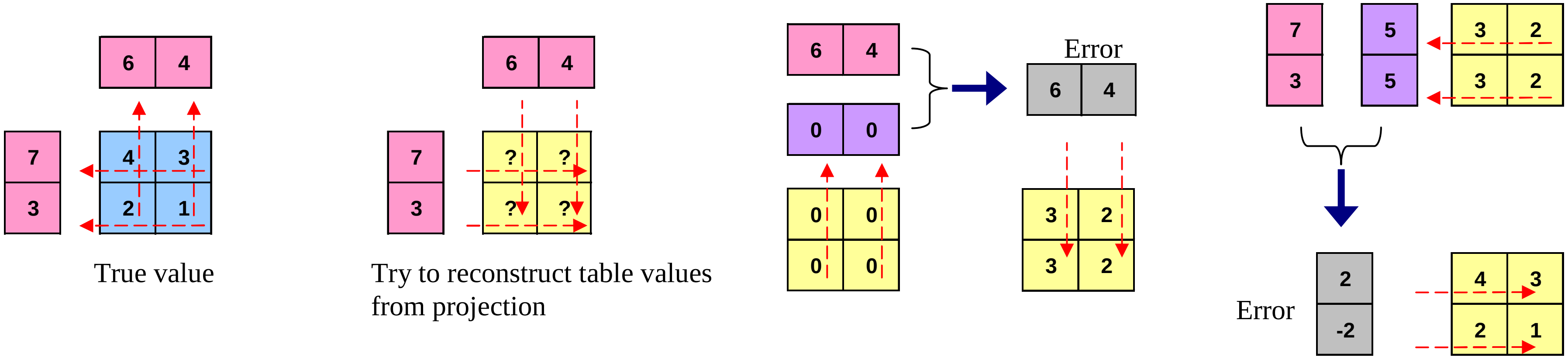


CT Scan

*** Stefaan Vandenberghe et al, Phys. Med. Biol. 51 (2006) 3105 http://iopscience.iop.org/0031-9155/51/12/008**

Algebraic Reconstruction Technique (ART) Example

- Example of reconstructing 2D position from x and y projections



True value

Try to reconstruct table values from projection

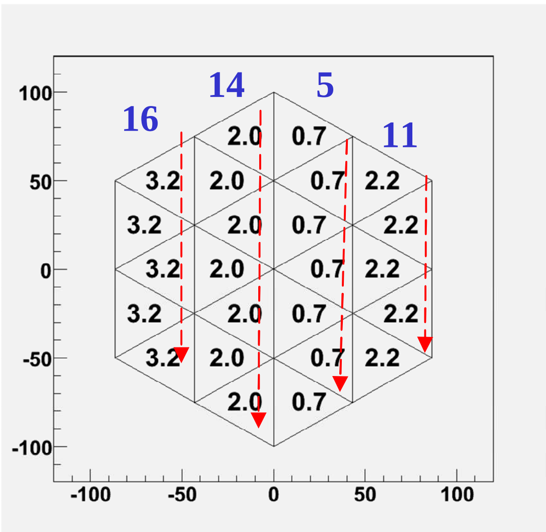
(a) (b) (c) (d)

- This is an iterative algorithm

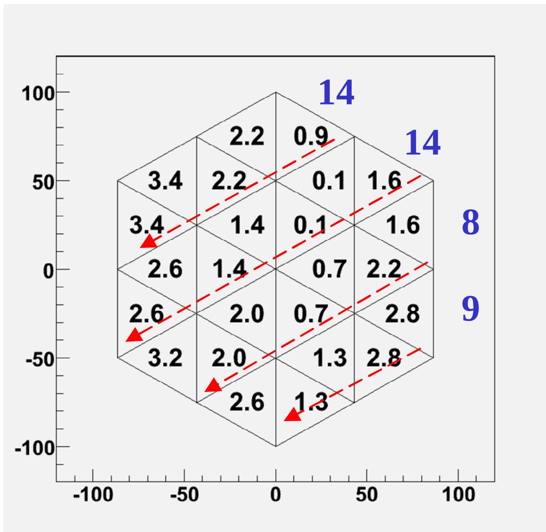
2D image from XUV projection

- MINERvA has hexagonal planes and three views.
- Triangular image grid is used for easy applying three views' projection.
  - X-Y grid to XUV grid.

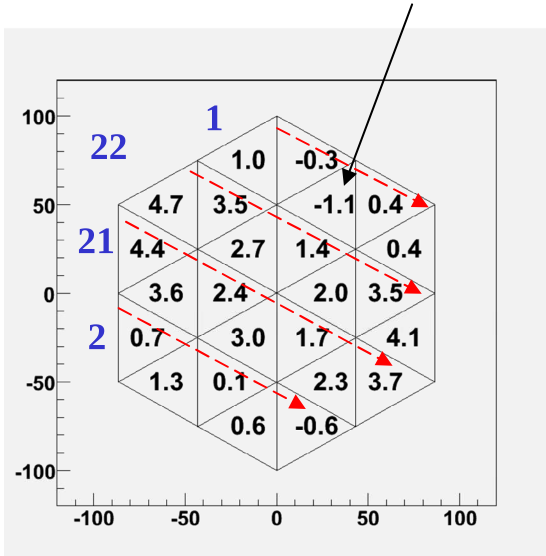
Negative number is unphysical (Use constraint to be positive)



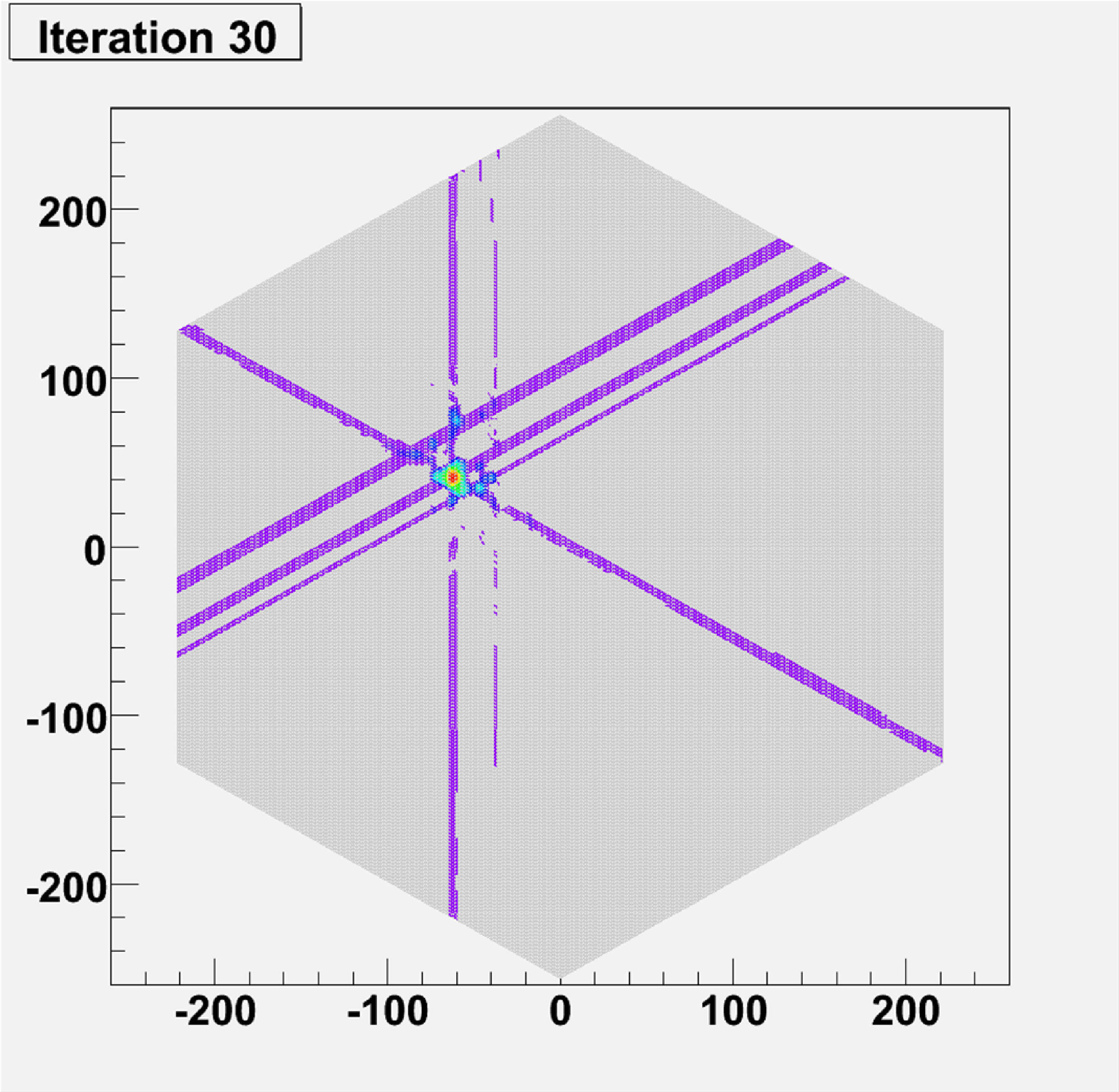
Iteration for X



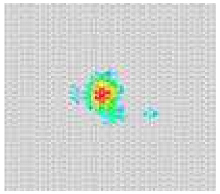
Iteration for V



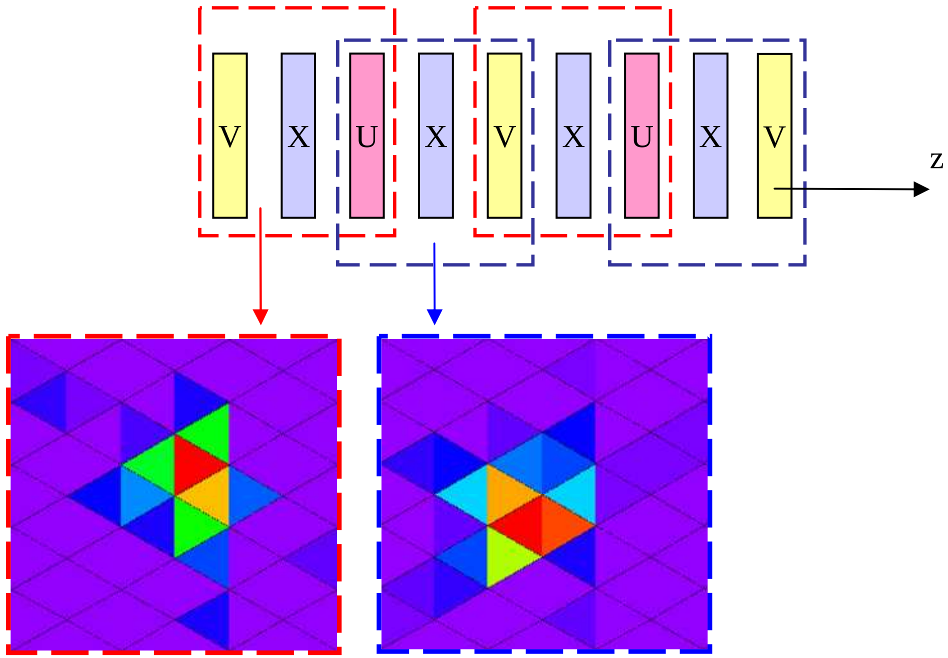
Iteration for U

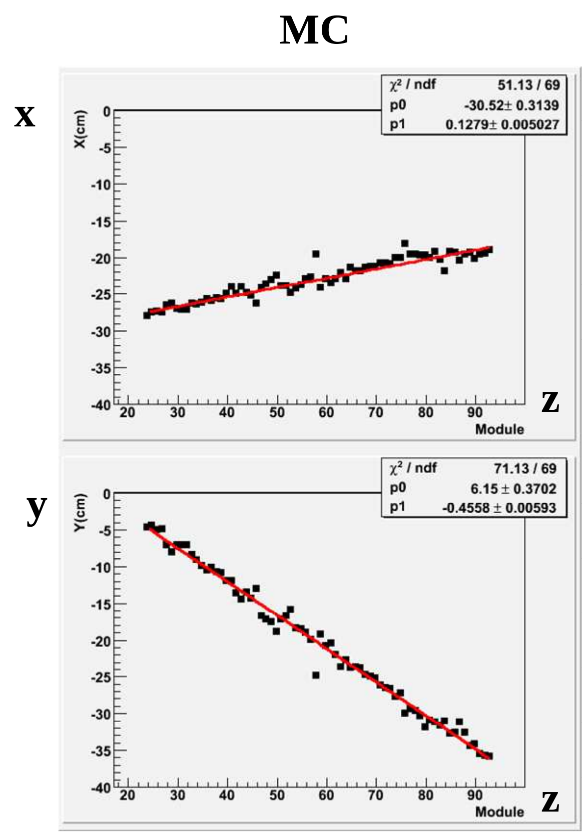


Actual reco uses minimum energy cut



2D coordinates → 3D track





- Can take VXU or UXV module set to apply ART from VXUX module pattern.
- x, y positions are based on energy weighted mean position of cells.

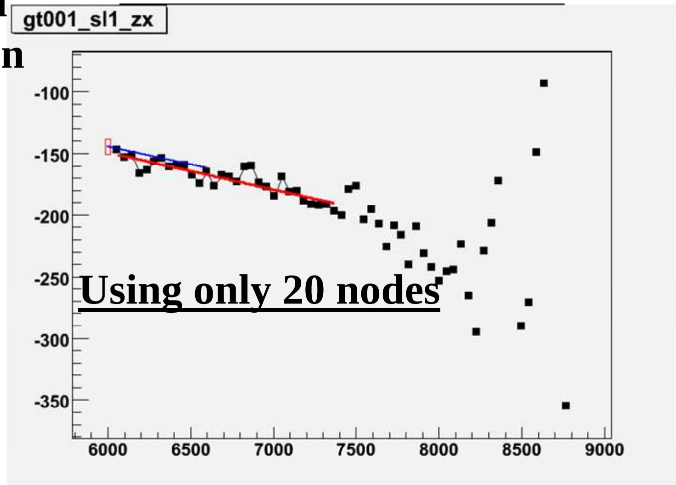
$$x = \frac{1}{\text{Total Cell Energy}} \sum_k (\text{Cell position x})_k \cdot (\text{Cell energy})_k$$

$$y = \frac{1}{\text{Total Cell Energy}} \sum_k (\text{Cell position y})_k \cdot (\text{Cell energy})_k$$

Electron Direction Fit using MC sample

Fitting only beginning of shower gives better angle resolultion

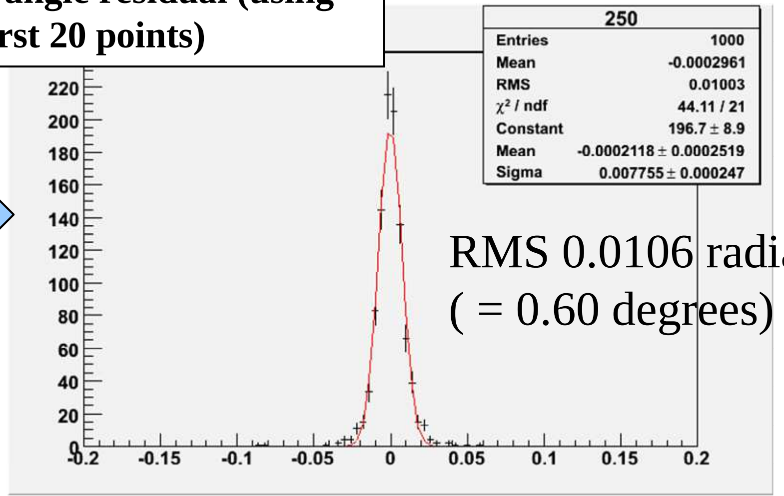
Centroid x-position (mm)



Using only 20 nodes

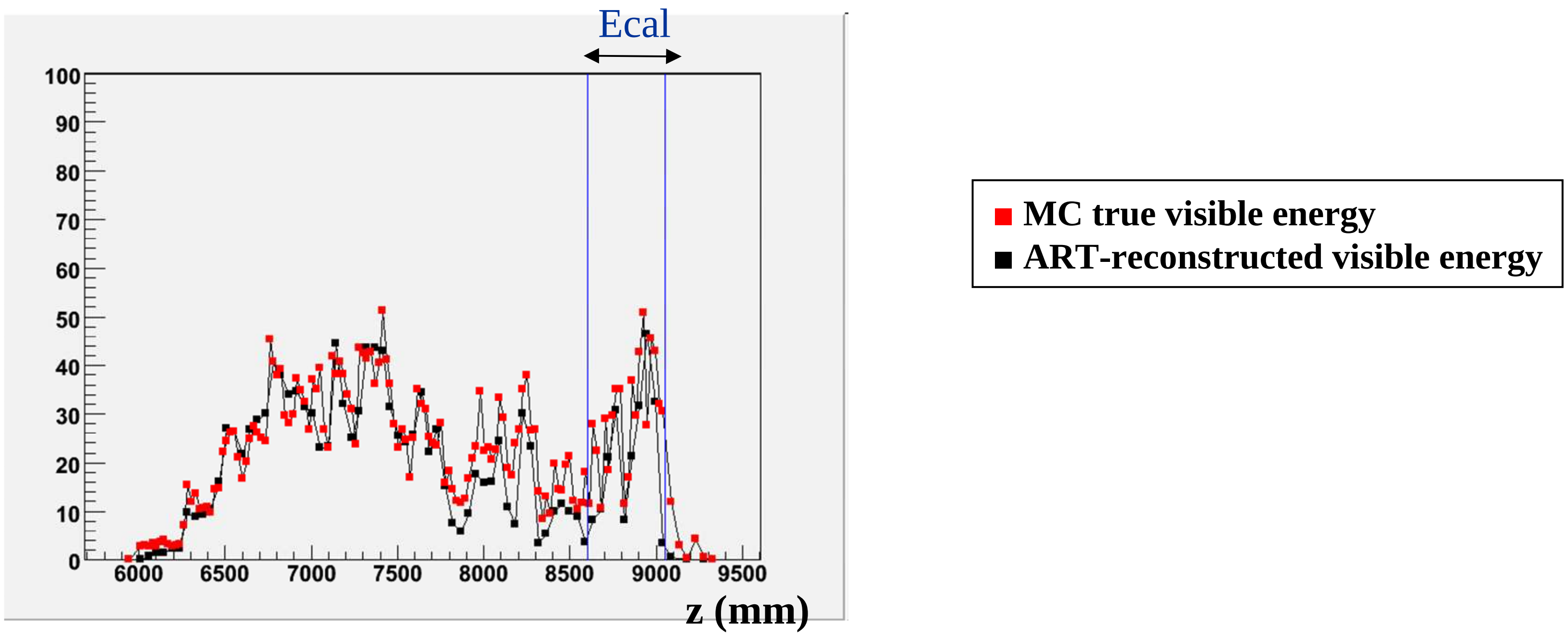
z (mm)

x-angle residual (using first 20 points)



RMS 0.0106 radian
(= 0.60 degrees)

Longitudinal Energy Profile



- ART reconstructs longitudinal energy profile reasonably well

Conclusion

- ART gives good angular resolution for electron shower
- ART reconstructs longitudinal energy profile pretty well
- ART is currently slow ~19 seconds/event but
  - Current code is not optimized on performance yet
  - ART can be used with pre-filter
- ART is a very powerful reconstruction technique for electron shower

(Backup Slides)

Data Sample and Event Sample Size

- Data sample to be used
  - Frozen detector, $\bar{\nu}$-beam, 8×10^{19} POT
  - Minerva detector, ν-beam, 1.28×10^{20} POT
  - Minerva detector, $\bar{\nu}$-beam, 1.5×10^{20} POT
- Event Sample size (After fiducial cut, E_e>0.8GeV)

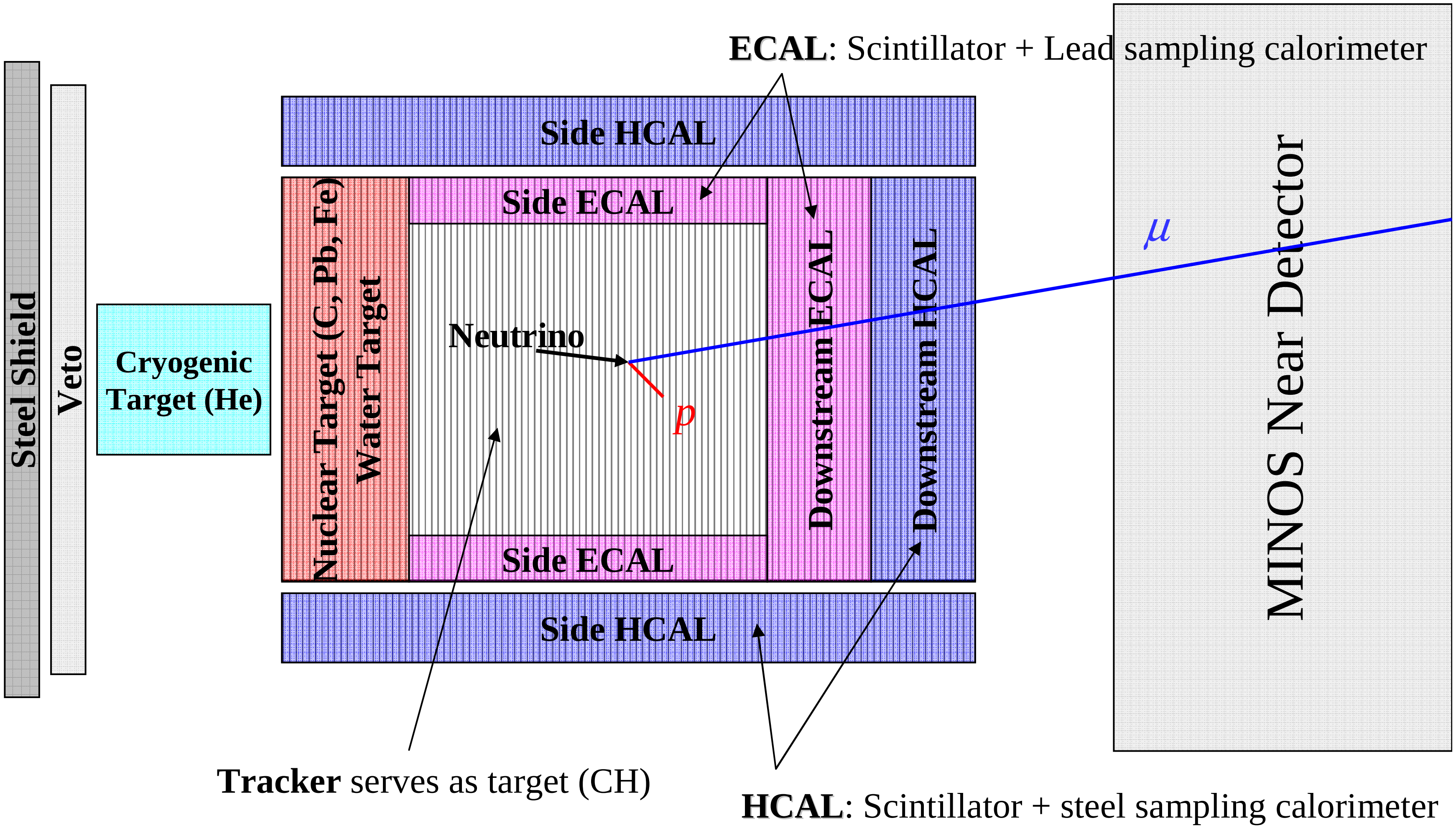
ν-beam

ν_e CCQE	816
$\bar{\nu}_e$ CCQE	90
$\nu_\mu e$, $\bar{\nu}_\mu e$	46

$\bar{\nu}$ -beam

ν_e CCQE	231
$\bar{\nu}_e$ CCQE	597
$\nu_\mu e$, $\bar{\nu}_\mu e$	52

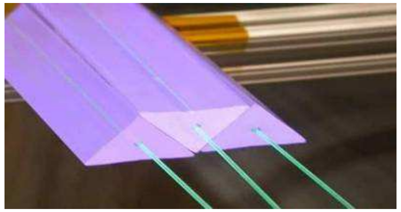
Minerva Detector

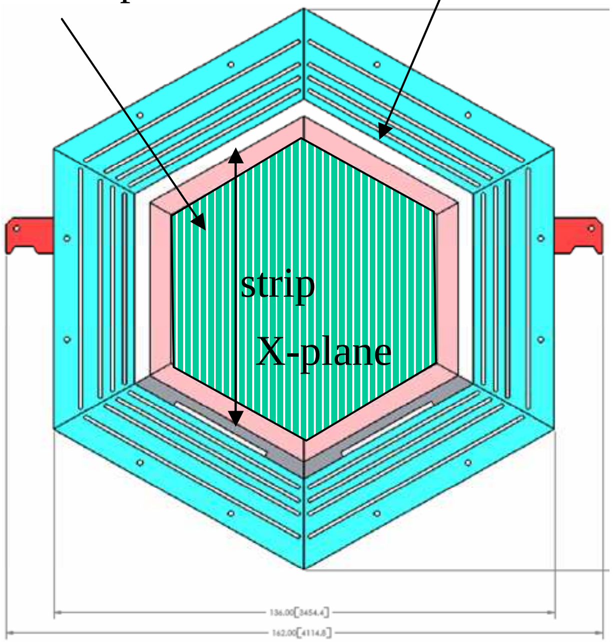


Detector Technology

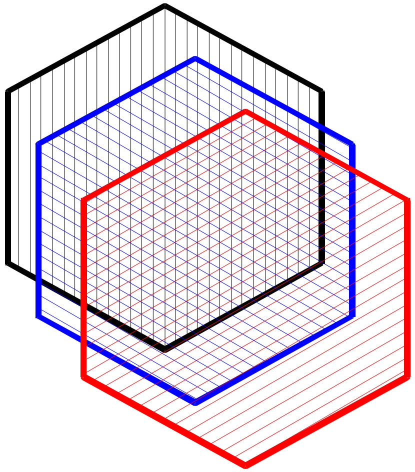
One module has two scintillator planes.
Module Type: XU module, XV module

127 strips

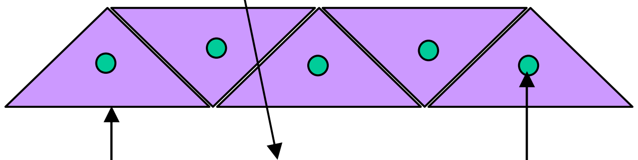




X/U/V-plane



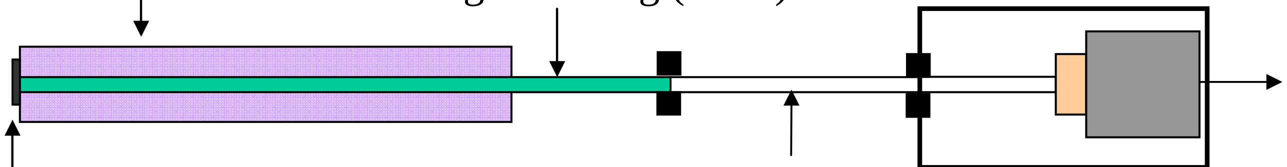
Particle



Scintillator strip

Wavelength shifting (WLS) fiber

PMT Box



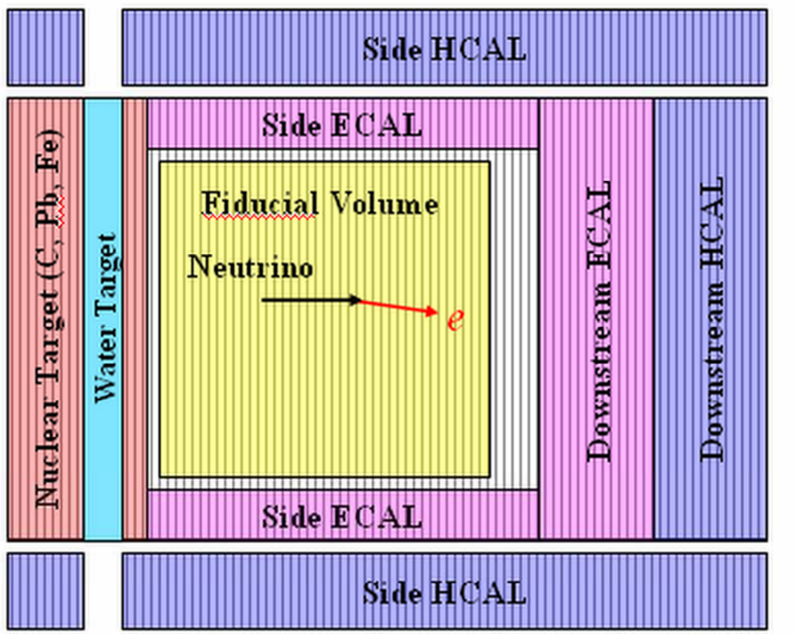
Readout

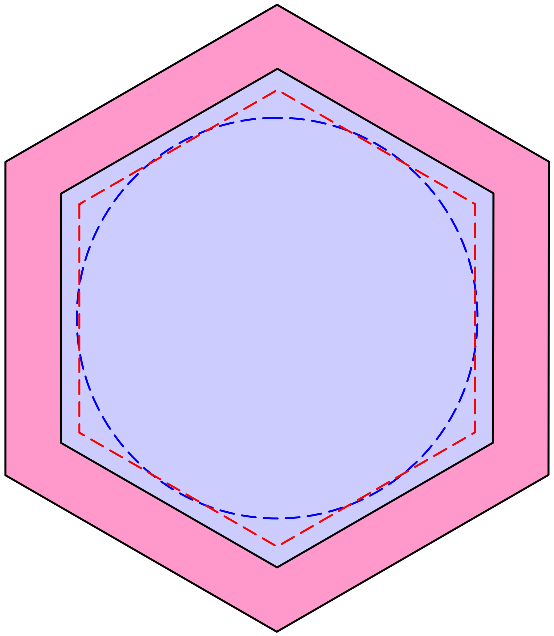
Clear fiber

64 channel Multi-anode PMT accepts 64 fibers

Mirror

Fiducial Volume





- First module is not used to veto nuclear target events
- The last four modules are not used to get electron direction
- Hexagonal fiducial volume to maximize fiducial volume

X=U+V

$$U = X\cos 60^\circ - Y\sin 60^\circ$$

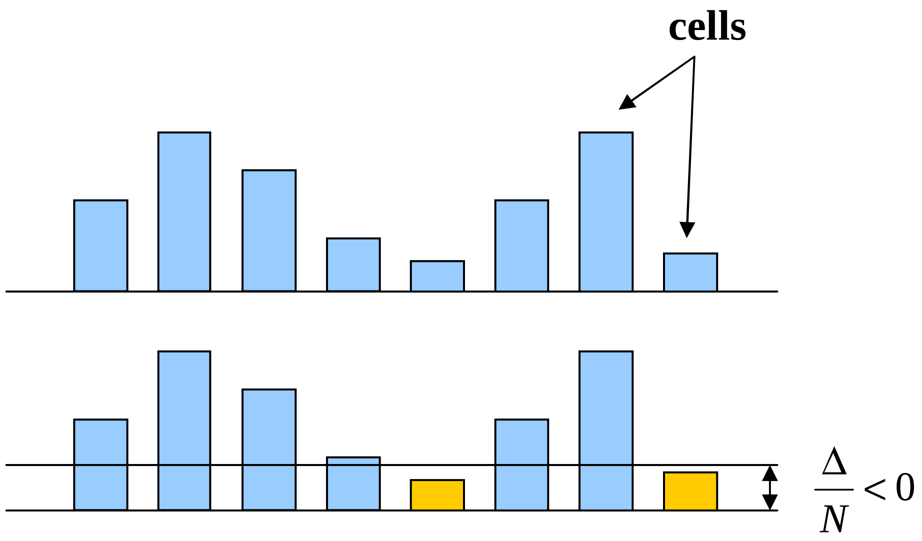
$$V = X\cos 60^\circ + Y\sin 60^\circ$$

$$U + V = 2X\cos 60^\circ = X$$

$$V - U = 2Y\sin 60^\circ = \sqrt{3}Y$$

Preventing Negative Cell Value

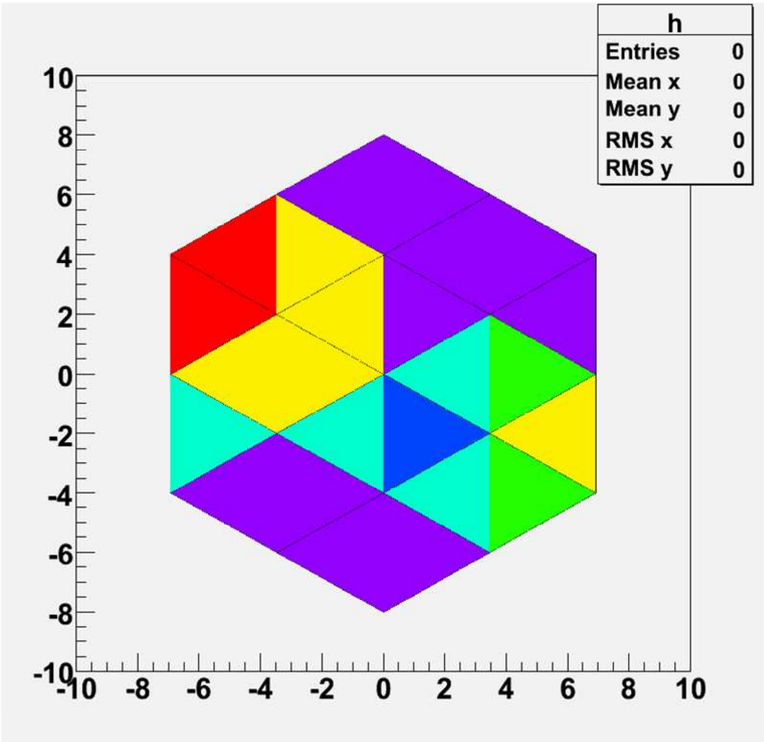
$$x_i' = x_i + \frac{\Delta}{N}$$



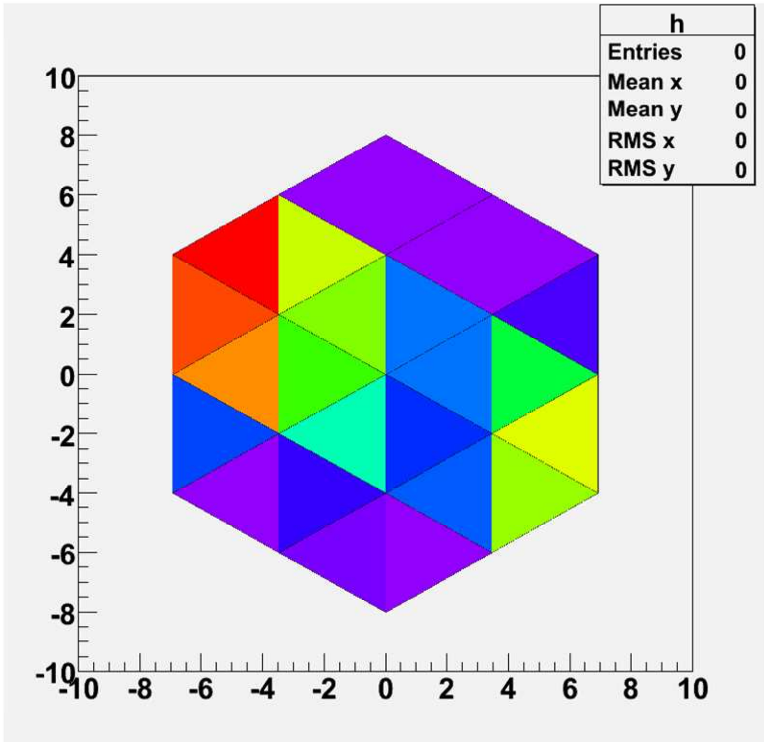
- Negative cell values are unphysical
- The iteration skips correction on some cells if corrected cell becomes negative.
- If we don't do this, iteration sometimes diverges.
  - Amplitude of the negative cell becomes bigger and bigger for each iteration

ART demo with Small Hex

True value

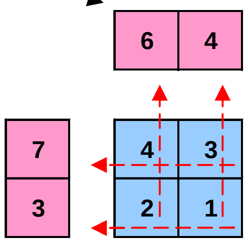


Reconstructed



Energy Scale in ART

These x and y-projections are in same z position

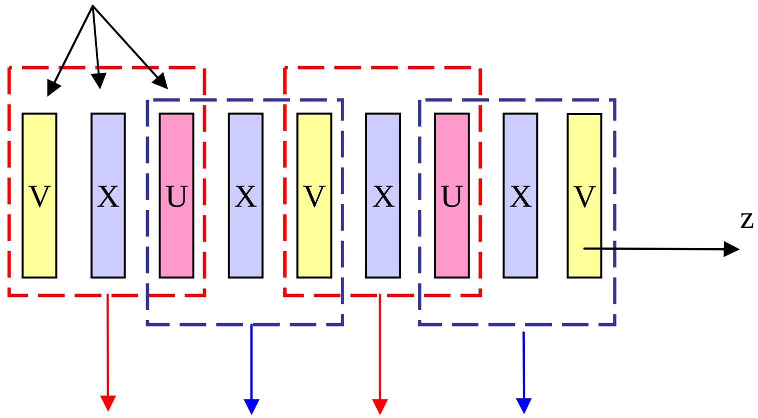


True value

E sum in ART: 10=1+2+3+4

E sum in projection: 20=7+3+6+4

These x, u and v-projections are in different z positions



$$\frac{1}{3}X+\frac{2}{3}V(\text{or }U)=\frac{1}{3}\frac{1}{2}+\frac{2}{3}\frac{1}{2}=\frac{1}{2}$$

1/3 = three views are used for one z-node

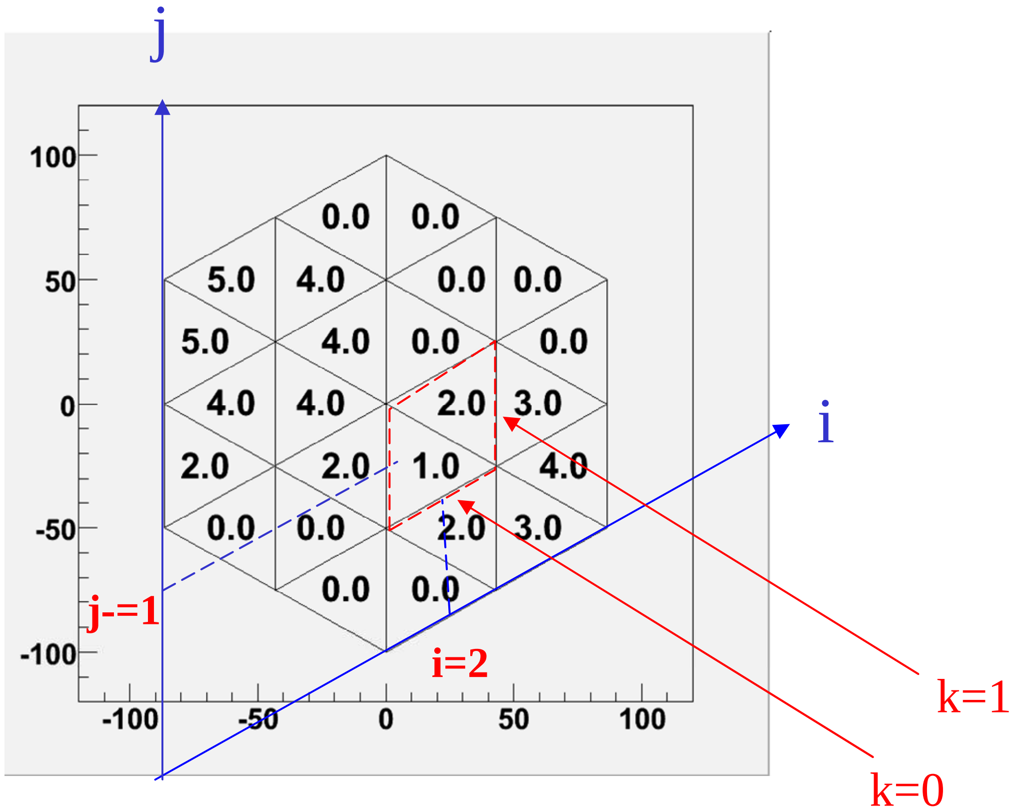
Factor 2 is added because V (or U) is used twice

Factor ½: z-node is per two planes

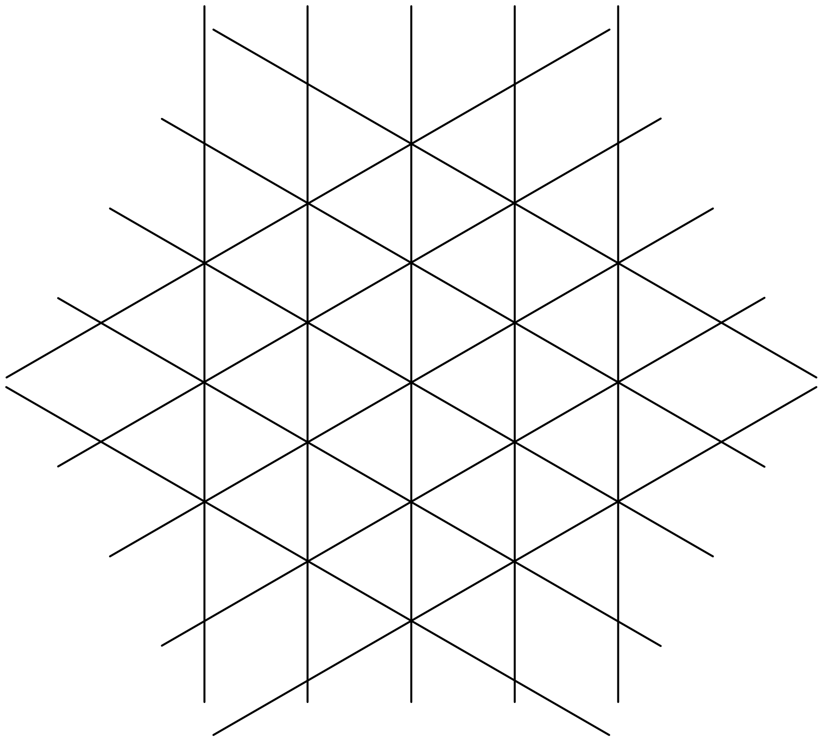
- Energy sum of ART energy cell ~ ½*(simple energy sum)
- ART energy is scaled up by factor 2

Data Structure

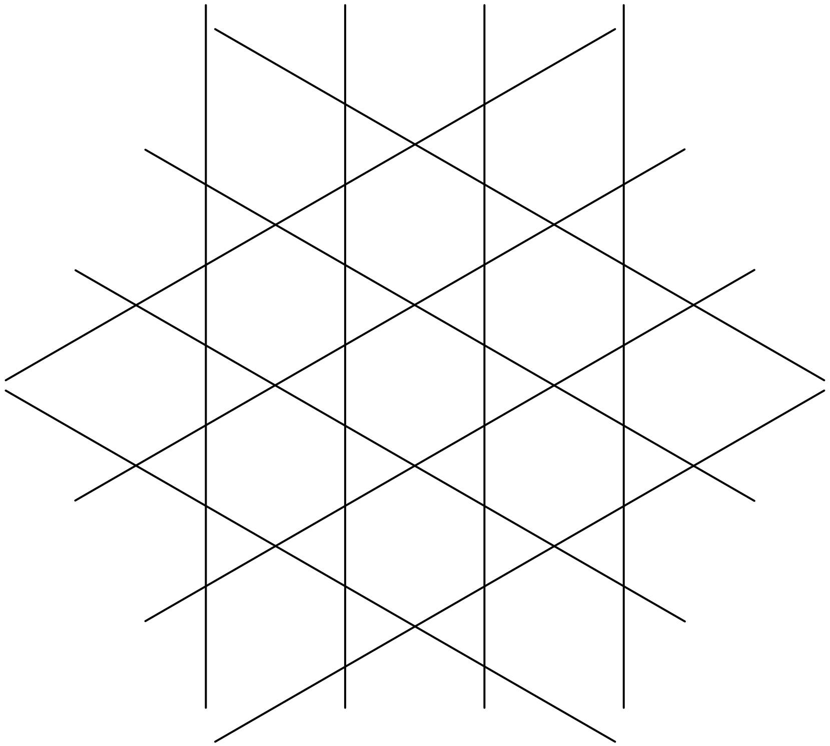
- M[i][j][k]
  - i=0, nstrips-1
  - j=0, nstrips-1
  - k=0 or 1



Event Number of Strip Vs. Odd Number of Strips



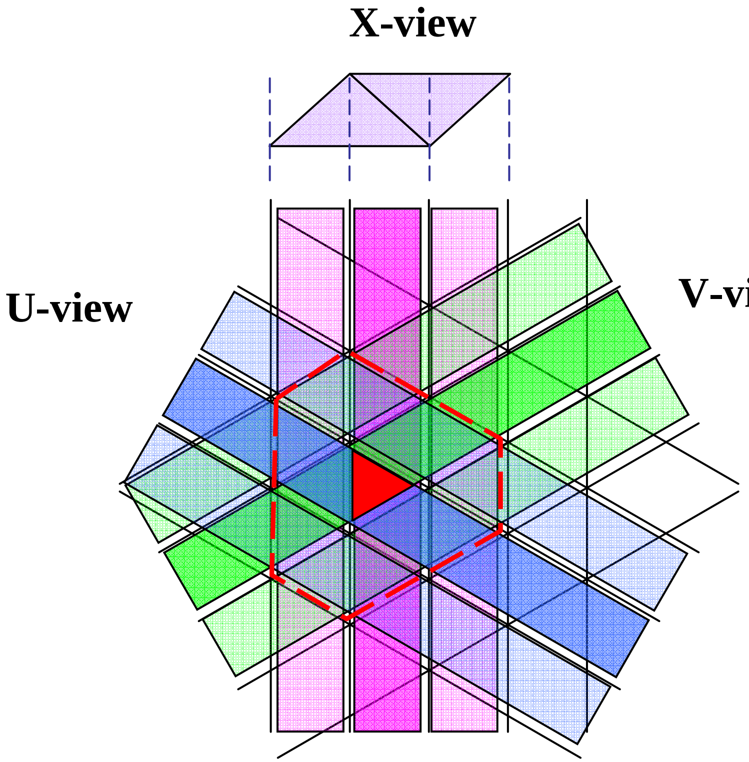
Event number of strips



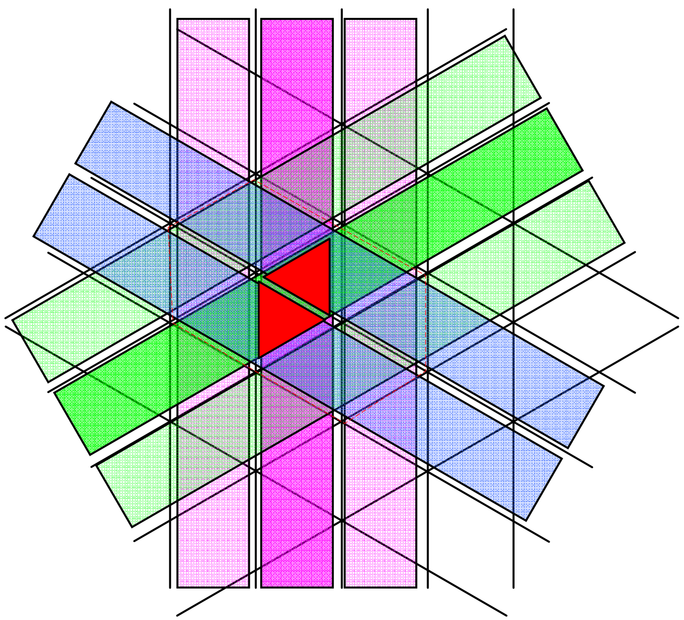
Odd number of strips

Shapes of XUV Intersection

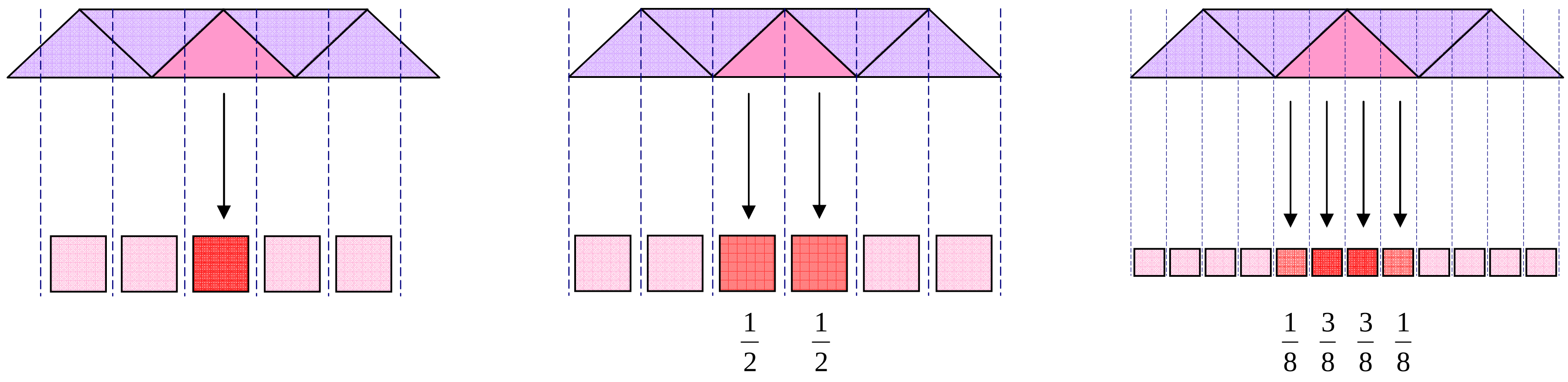
Doublet in three views



Doublet in two views and Singlet in one view



Smaller Cell



(a) (b) (c)

- Initially 128 columns are used.
  - Symmetry of cell is only available in even number of columns.
  - Actual number of strips are 127.
- ART implies X=U+V matching condition implicitly.
  - Slight mis-matching XUV hits are suppressed.
- To loosen XUV matching condition, one strip is projected to two columns.
  - It also solves odd number of column problem.
- Further smaller cell mimics charge sharing between adjacent strips