

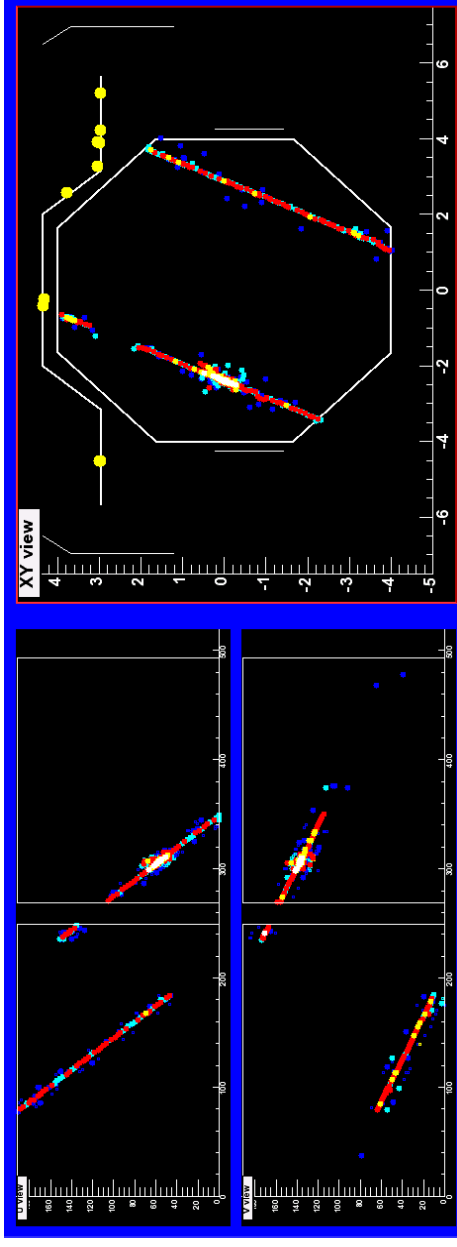
The Alternative Demultiplexer

AlgAltDemux

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Outline:

- 1 Introduction/Motivation
- 2 Method
- 3 Performance
- 4 Conclusions/Future Work



① Introduction/Motivation/Initial Goals

Motivation:

- ★ Reconstruction in MINOS is non-trivial !
- ★ Quality of DeMuxing/Tracking \Rightarrow impact physics sensitivity
particularly important for Atmospheric ν analysis
- ★ AltDeMux developed primarily for the Atmospheric Neutrino analysis
- ★ Aim for fast reconstruction (**FAST means** < DigitListModule)
- ★ Provide an alternative to the Standard Package (DeMux)
allows possibility of rejecting DeMux failures by **ANDing**
- ★ Try to keep Algorithm ‘independent’ of Standard package
adopt a significantly different approach

② Method

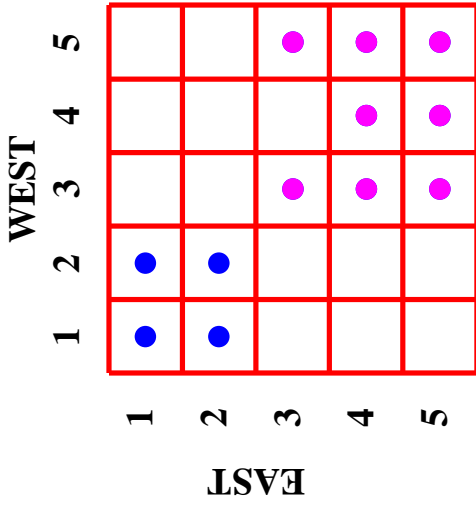
Outline of Method:

- ① Identify '**GOLDEN**' Demuxed hits on a plane-by-plane basis.
GOLDEN hits are 'unambiguous' **EAST-WEST** strip associations used as seeds for the DeMuxing
- ② **GOLDEN** hits **MAY BE** used for Event Identification used to steer demuxing strategy (not yet fully implemented)
- ③ The **GOLDEN** hits define **TARGET** regions for remaining planes.
- ④ Use target regions to search for further unambiguous **GOLDEN** hits
- ⑤ **GOLDEN** hits used to define new **TARGET** locations
- ⑥ place remaining hits close to nearest **TARGET**
- ⑦ Validate solution depending on Event Type
- ★ Now includes fairly sophisticated **Crosstalk** removal/tagging

Algorithm developed using Monte Carlo (Cosmics, Atmospheric neutrinos)

Method : Definition of Golden Hits

- ★ Iterate over planes
 - ★ Form matrix of all allowed East-West associations
- e.g. 5 East hits, 5 West Hits
- Group into unconnected groups.
 - Look for unambiguous associations

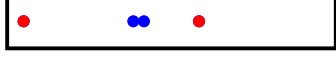


Unambiguous Associations

e.g. $2 \times 2 \Rightarrow$

2 Possible associations:

$\{ (E1, W1), (E2, W2) \}$ or $\{ (E1, W2), (E2, W1) \}$



Hits DeMuxed as **GOLDEN** if one, and only one, combination places hits 'close' together

A Few Comments:

- ① This works very well for planes with few combinations, e.g. $2 \times 2, 3 \times 3$
- ② Planes with high hit multiplicities often remain ambiguous:
large showers
steep tracks
- ③ Therefore, try to reduce combinatorics
- ④ Breaking into unconnected groups helps,
 $5 \times 5 \rightarrow (3 \times 3) + (2 \times 2)$

Clarify situation using:

- ★ Timing information (**recent IMPROVEMENTS here**)
- ★ + Charge information

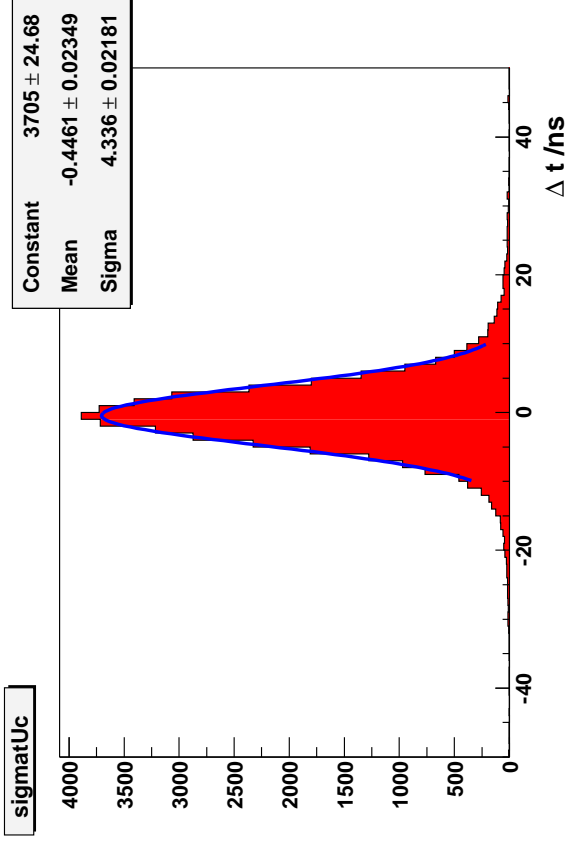
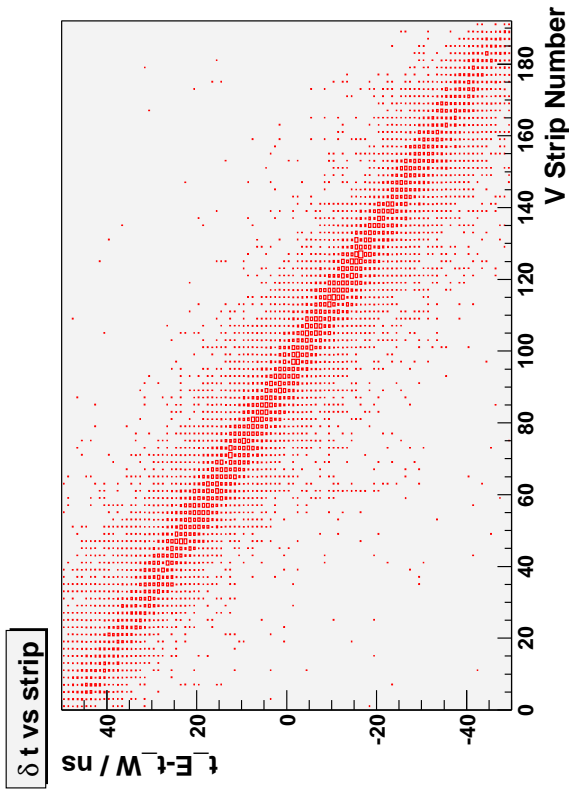
e.g. Timing - "3D DeMuxing"

Use U view times to localize event in V

e.g. U Strip



$$t_W - t_E \rightarrow V$$



$$\sigma_{\Delta t} = 4.3 \text{ ns (i.e. } \sigma_t = 3.0 \text{ ns)}$$

$$V_{strip} = 96 + \frac{\Delta t(\text{ns})}{0.505}$$

$$\sigma_{V_{strip}} = 8.6$$

$$\sigma_V = 36 \text{ cm}$$

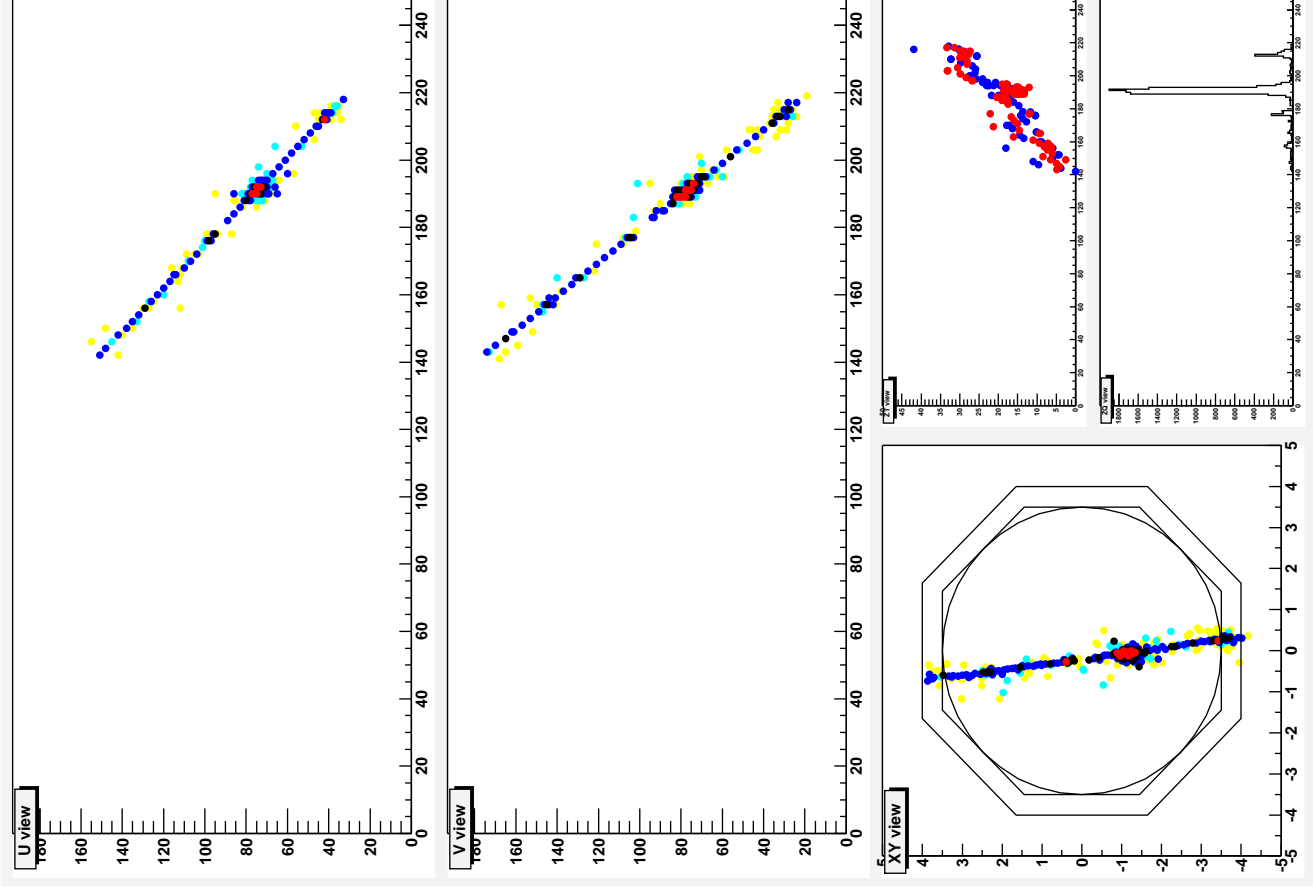
actually somewhat better now \sim
30 cm

Timing - Example Event

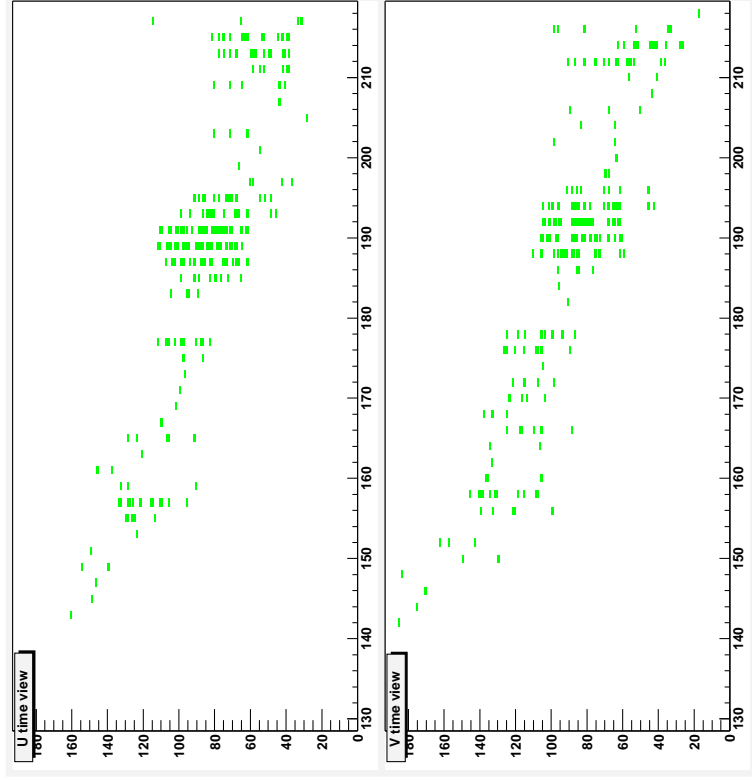
- ★ A fairly complex event - large Bremsstrahlung

Event Display (SM1 only):

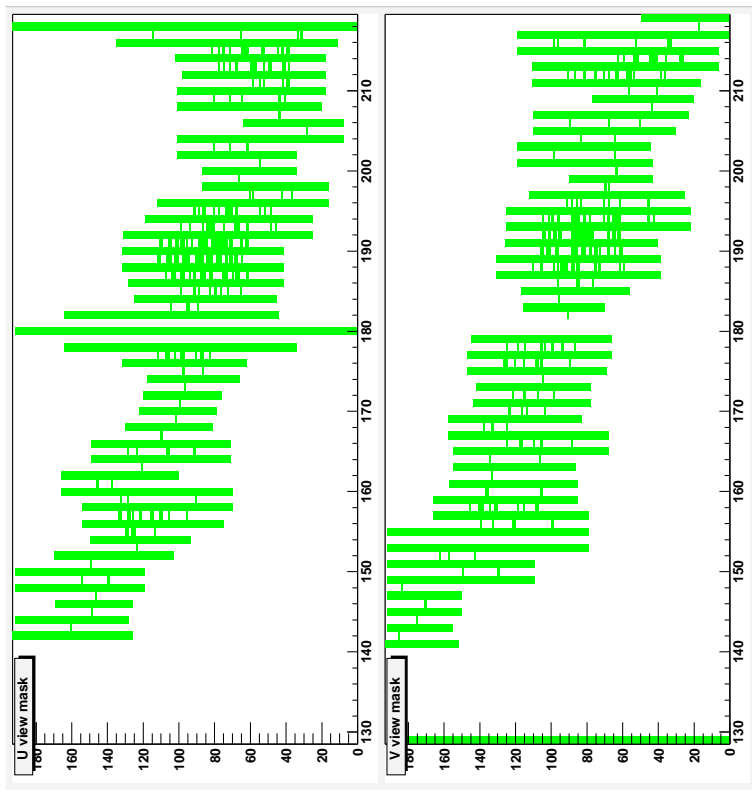
- ★ U-Plane View
- ★ V-Plane View
- ★ x - y View (no reconstruction)
- ★ time vs plane number
- ★ charge vs plane number



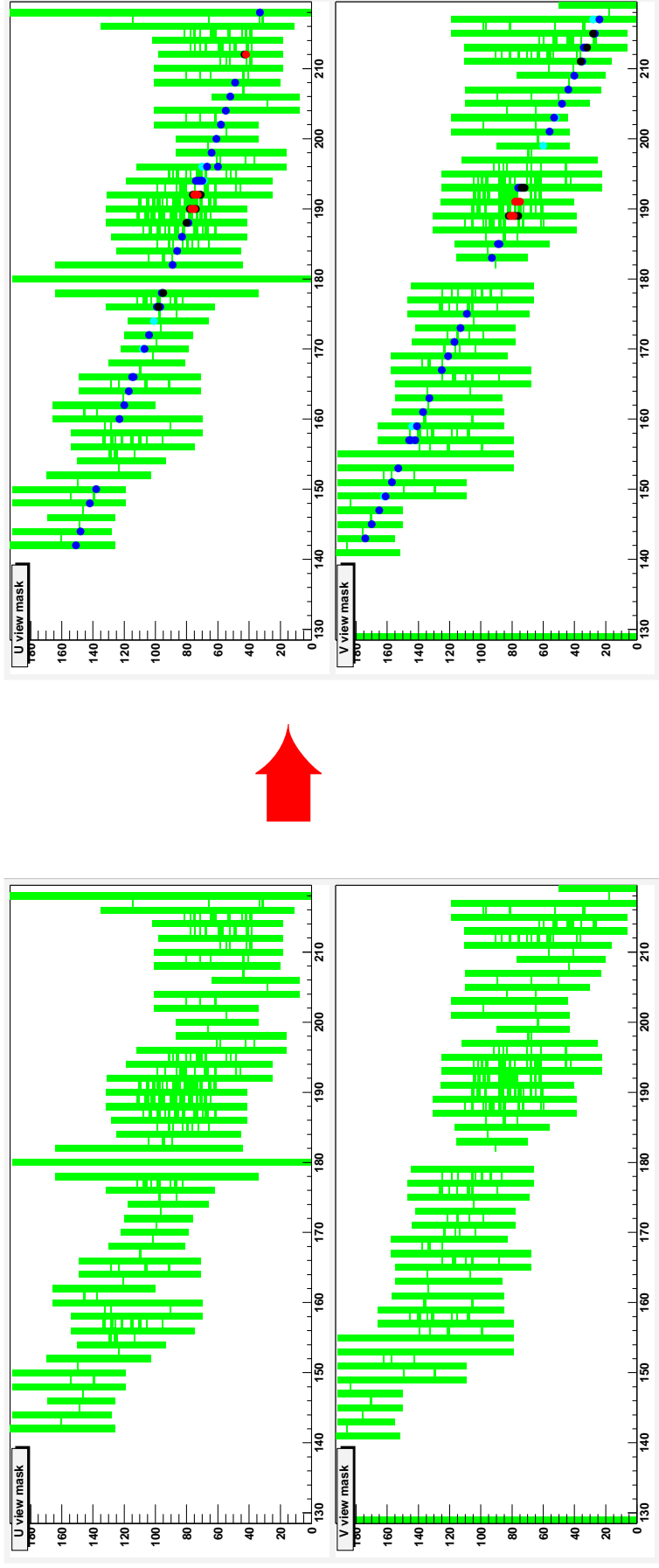
- ★ Define mask of “acceptable strips” using timing info in other view.
- ★ Many planes have > 1 East hit and > 1 West hit
- ★ Multiple combinations \rightarrow U/V positions are not determined unambiguously by timing - different fibre lengths.
- ★ **BUT** difference in fibre lengths ‘small’ compared to **16 m** !



Form “Mask”



★ The timing mask constrains locations of golden hits



GOLDEN hits used as **SEEDs** to DeMux rest of event.....

★ Note now also used for Event ID

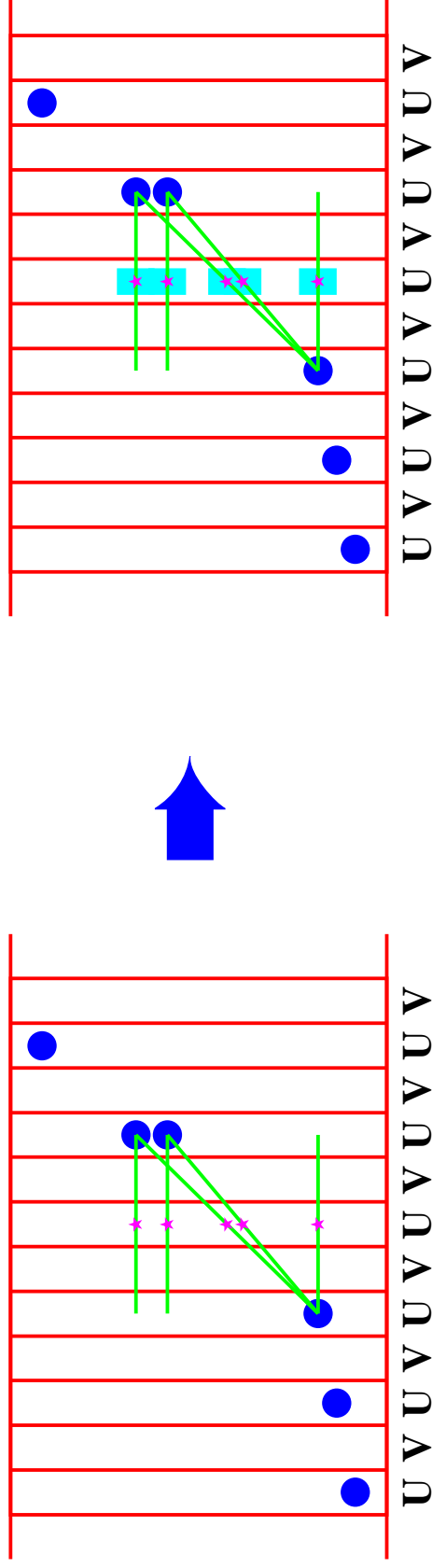
e.g. here from golden hits - looks like a single muon

SEEDs and TARGETs

SEEDs used to identify “SUITABLE” positions (**TARGETs**) to DeMux hits in other planes.

A number of possible tactics used:

- PROJECT_FORWARDS
- PROJECT_BACKWARDS
- EXTRAPOLATE_FORWARDS
- EXTRAPOLATE_BACKWARDS
- INTERPOLATE_FORWARDS
- INTERPOLATE_BACKWARDS



NEW feature: Event identification allows favoured directions to be defined.
Interpolate/Extrapolate using these directions.

Event Identification

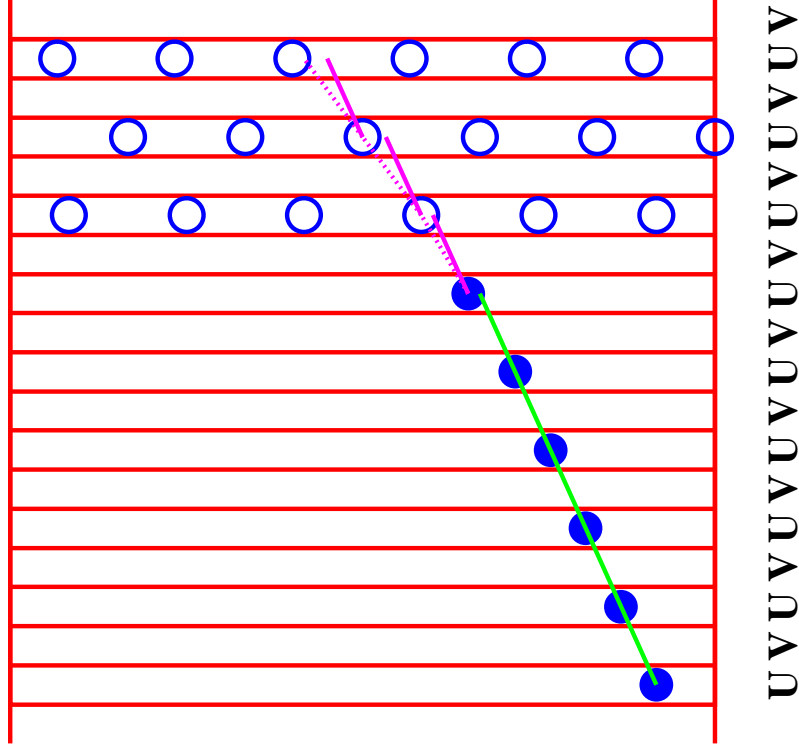
GOLDEN hits used to make first attempt at Event ID

- ★ On basis of **GOLDEN** hits - can make a good guess at event type, single cosmic, multiple muon, etc.
- ★ Use this information to steer subsequent demuxing.
 - different tactics to extrapolate/interpolate between golden hits
- ★ Identify **MULTIPLE MUON** using on U.o.M. Hough transform idea applied to GOLDEN hits
- ★ Identify **SINGLE STRAIGHT MUONS** if all(most) GOLDEN hits consistent with linear fit.
- ★ (At a later stage) Also identify **CONTAINED EVENT** candidates
- ★ Subsequent DeMuxing strategy depends on event ID
- ★ Incorrect event ID - doesn't usually result in a bad DeMux solution

e.g. Single Muon

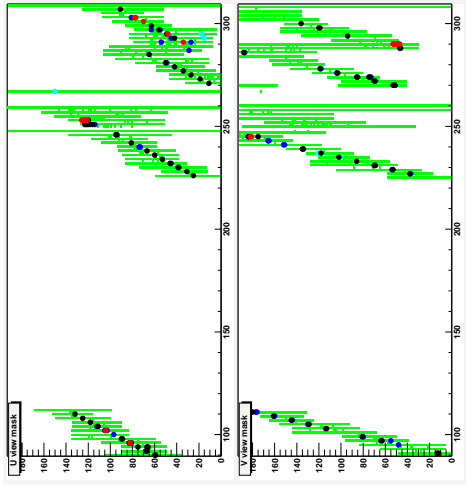
GOLDEN hits in both views give acceptable linear fits:

- ★ Tag event as probable single muon
- ★ DO NOT force subsequent hits onto line
- ★ Just modify way targets are defined.
- ★ Use linear extrapolation between hits
- ★ OR extrapolation from last hit using fitted slope

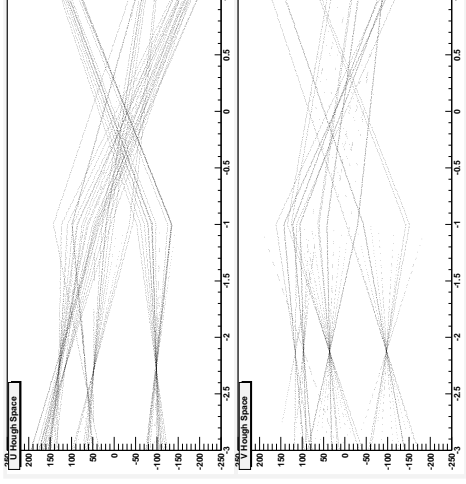


e.g. Multiple Muon Identification

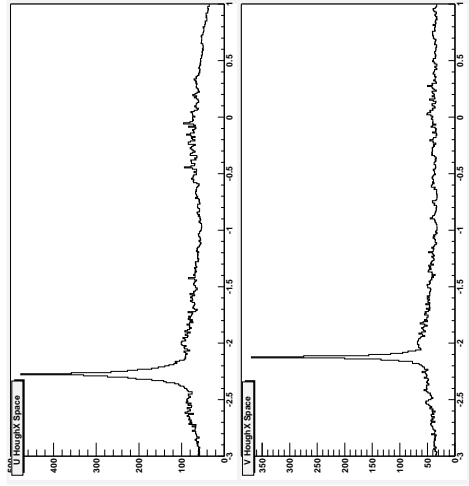
GOLDEN HITS



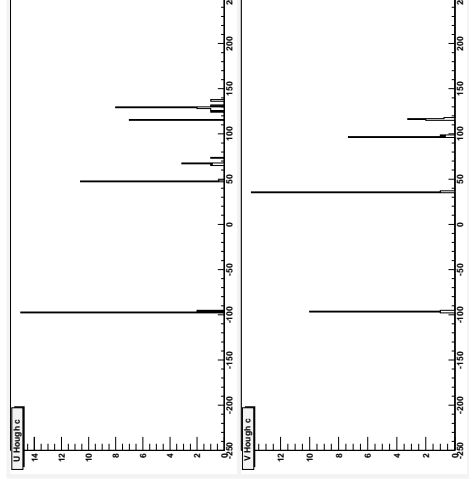
Hough Transform of GOLDEN HITS



Projection onto slope axis

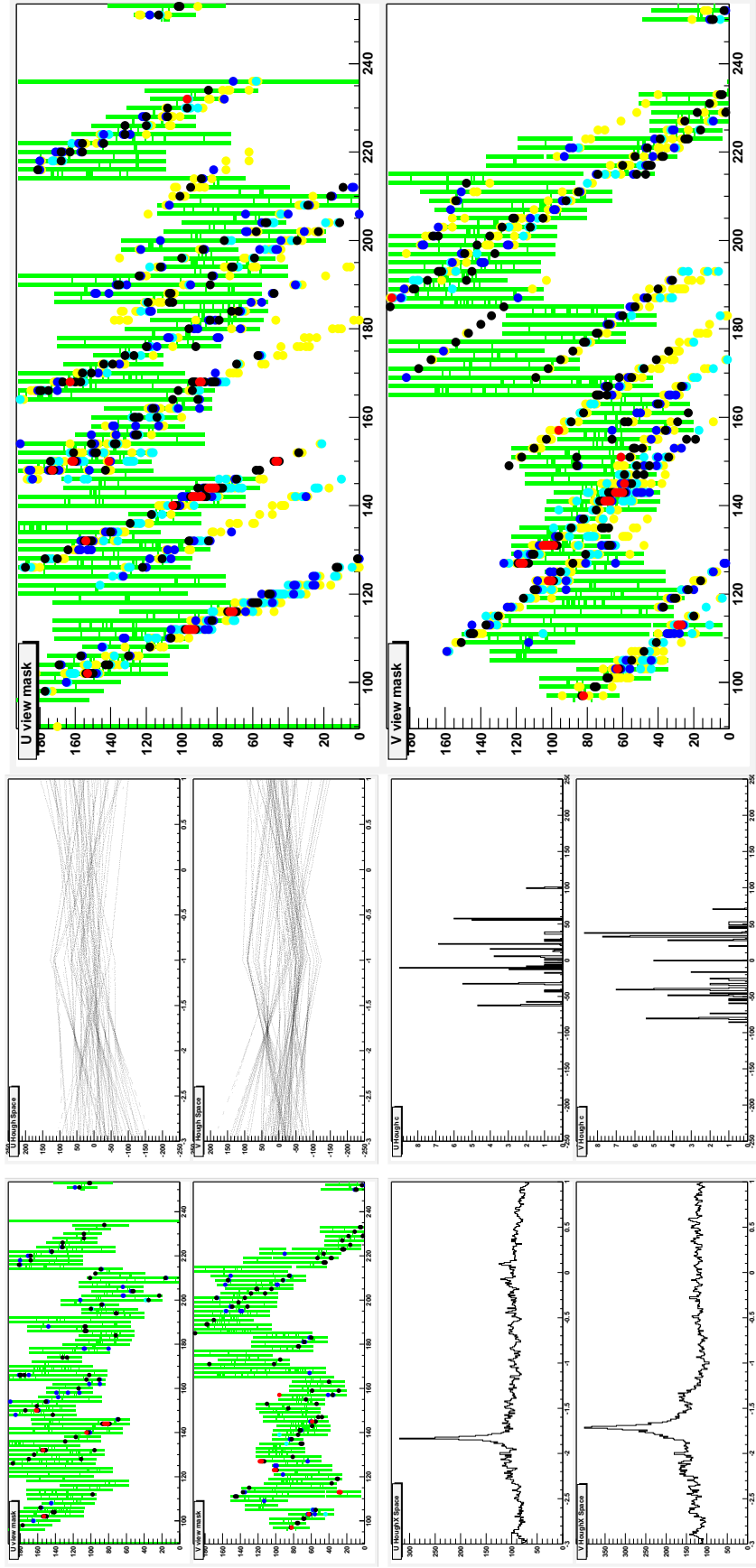


Intercept slice at favoured slope



A Complicated Example - 16(?) muons

In identified **Multiple Muon** events, Hough slope is used as basis to define **TARGETS** - improved reconstruction of multiples



★ **Multiple Muon reconstruction pretty good - but not finalised**

Overview of code

AlgAltDeMuxDevel::RunAlg() current CVS version

```

MakePixelMap(cdlh); // make map of PMT pixels for cross-talk removal
MakeAltListMap(cdlh); // fill basic data structure (NOT using Navigator class in AlgAltDeMux)
StripNoise(); // strip out any out-of-time hits
StripCrossTalk(); // remove cross-talk
GetFibreLengths(); // get the fibre lengths for this event and dump into an array - small but
significant improvement in speed
// Have now constructed basic structures - now proceed to DeMux event
MakeTimingMask(false); // First make a mask using timing information
MakeTimingMask(true); // Iterate on timing mask - bootstrap U and V view timing information
DemuxPass(0); // Now first demux pass - build a mask using loose cuts
DemuxPass(1); // Start to demux event for real - find GOLDEN HITS
Hough(); // Perform a Hough transform on Golden hits and identify Multiples
DemuxPass(2); // demux pass - look for new GOLDEN HITS
DemuxPass(3); // looser demux - still looking for double ended hits
DemuxPass(4); // demux anything that's left
AddBackCrossTalk(); // add back originally tagged as cross-talk
DemuxPass(5); // Demux hits originally tagged as cross-talk

```

③ Performance

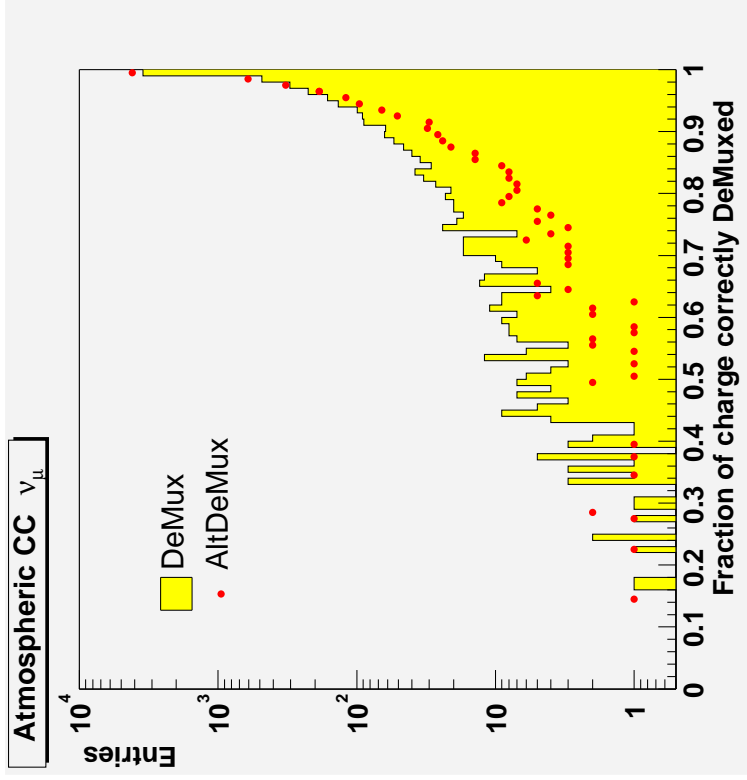
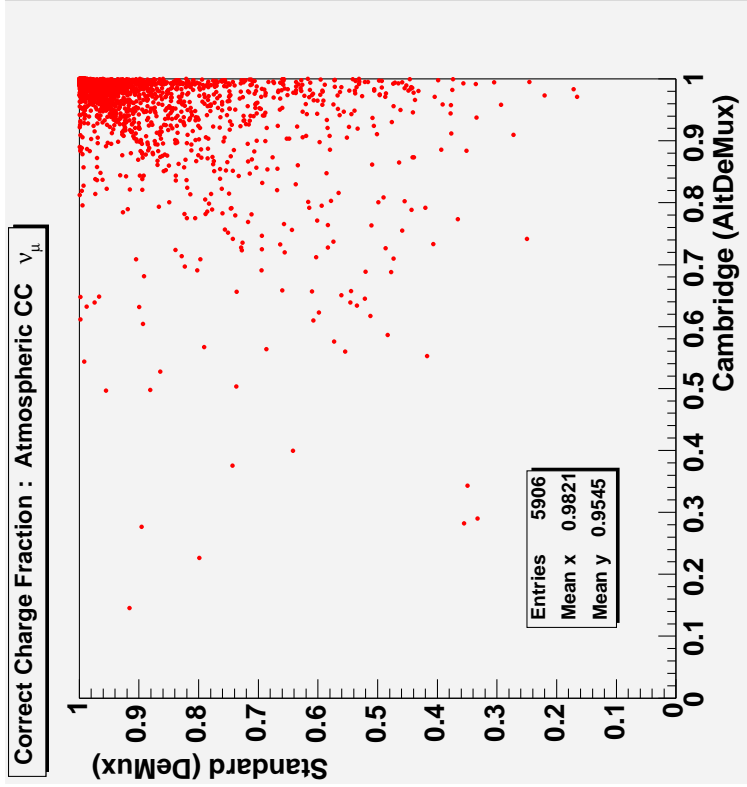
Compare AltDeMux with Standard Code (DeMux).

- ★ Monte Carlo Events with ≥ 6 planes
- ★ DetSim - include Cross-talk, etc. (thanks to Nathaniel T. and Mike K.)
- ★ For Standard Code use:
 - AlgDeMuxBeam for beam MC
 - AlgDeMuxBeam for everything else
- ★ Comparisons for all events, *i.e.* ignore flags from DeMux and AltDeMux

Look at fraction of charge DeMuxed in correct Strip, f_Q .

★ used current private version of AltDeMux - will put in CVS only when fully tested

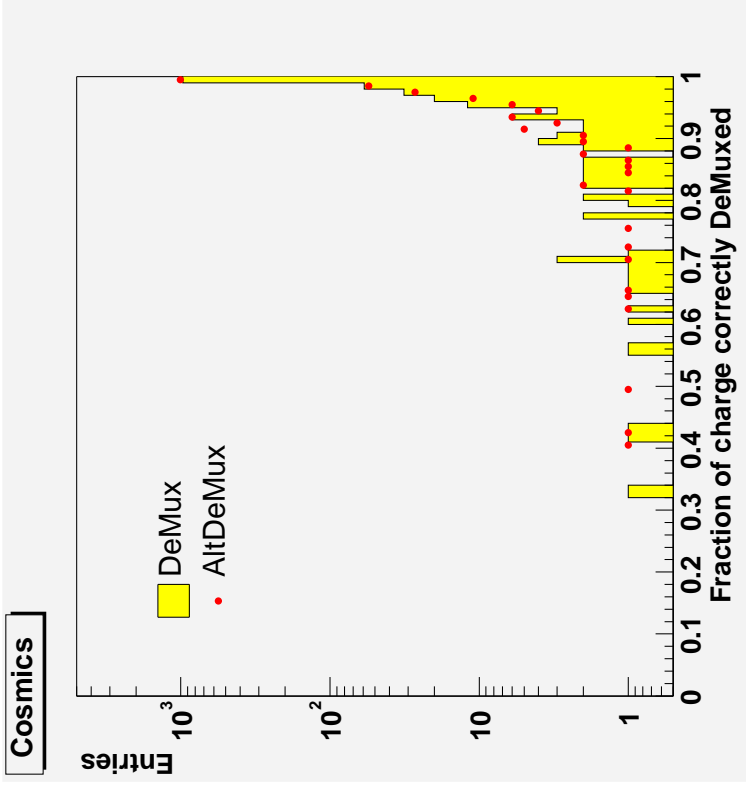
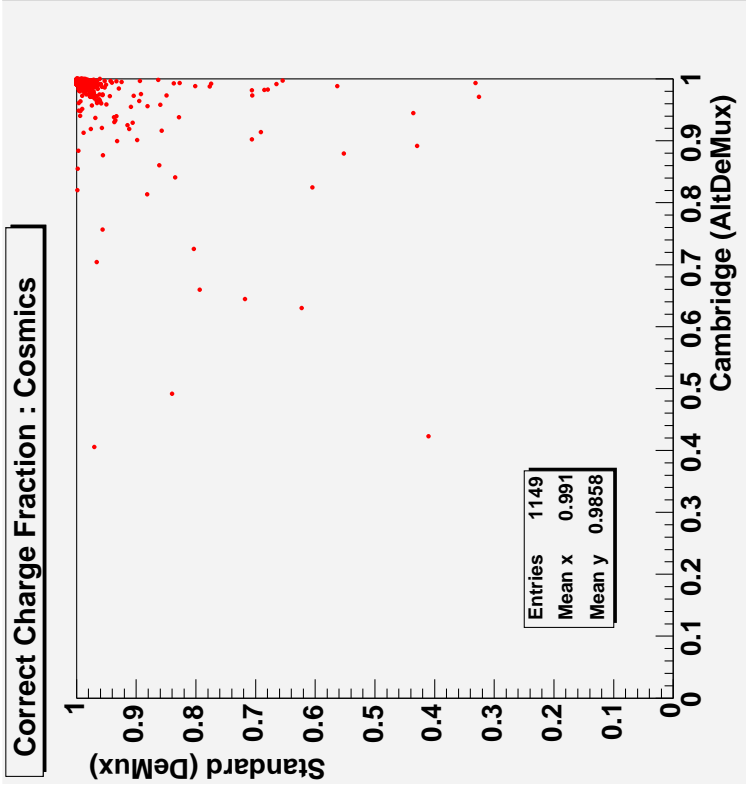
ATMOSPHERIC ν_μ CC Events



f_q	98.2%
AltDeMux	DeMux
95.5%	

- ★ **AltDeMux somewhat better**
- ★ **AltDeMux designed for Atmospheric neutrinos (less biased towards tracks)**

Single Cosmic Muons



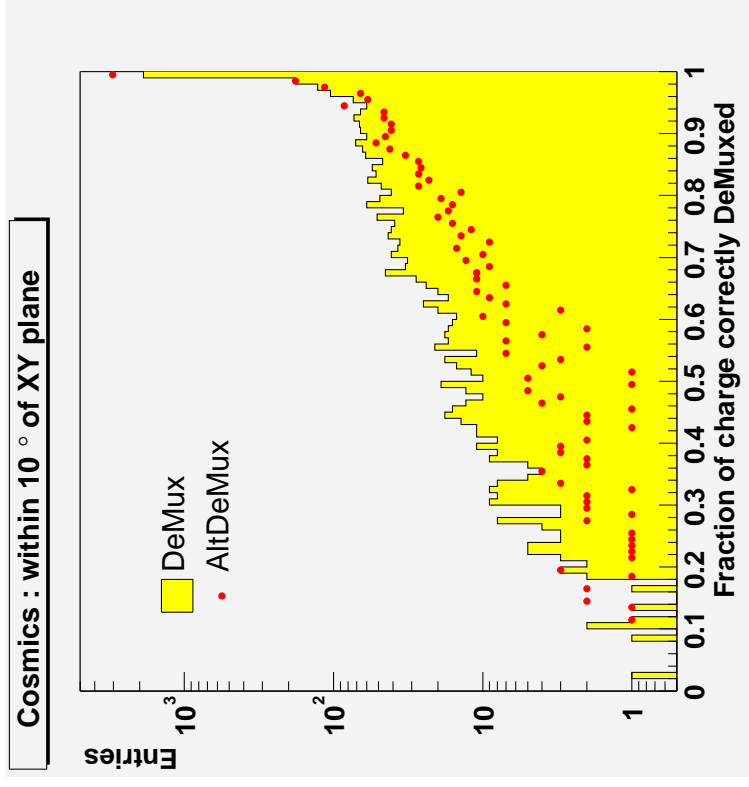
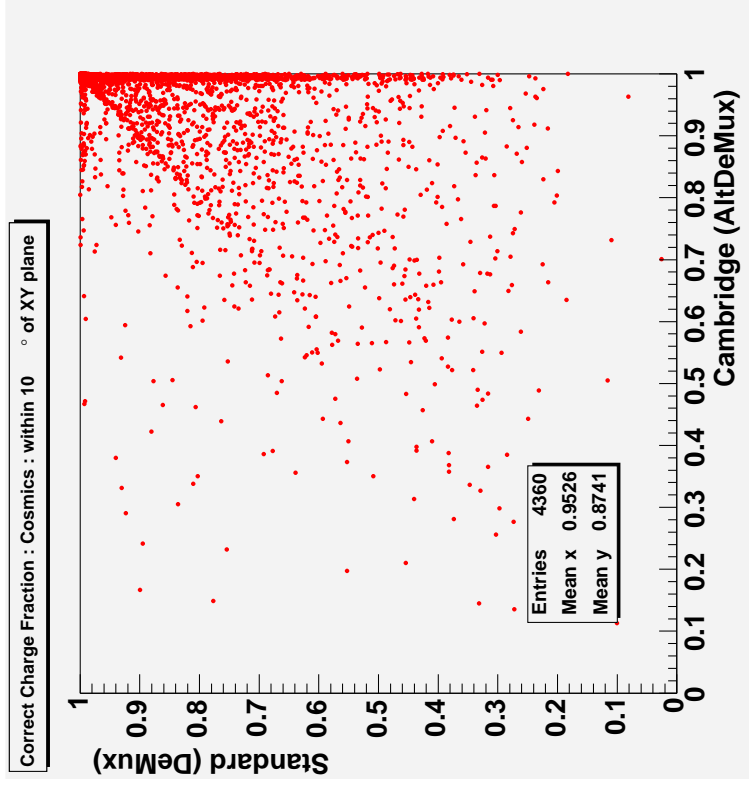
★ Very similar

	AltDeMux	DeMux
f_Q	99.1%	98.6%

★ What about potential background to atmospheric neutrinos ?

Sneaky cosmics

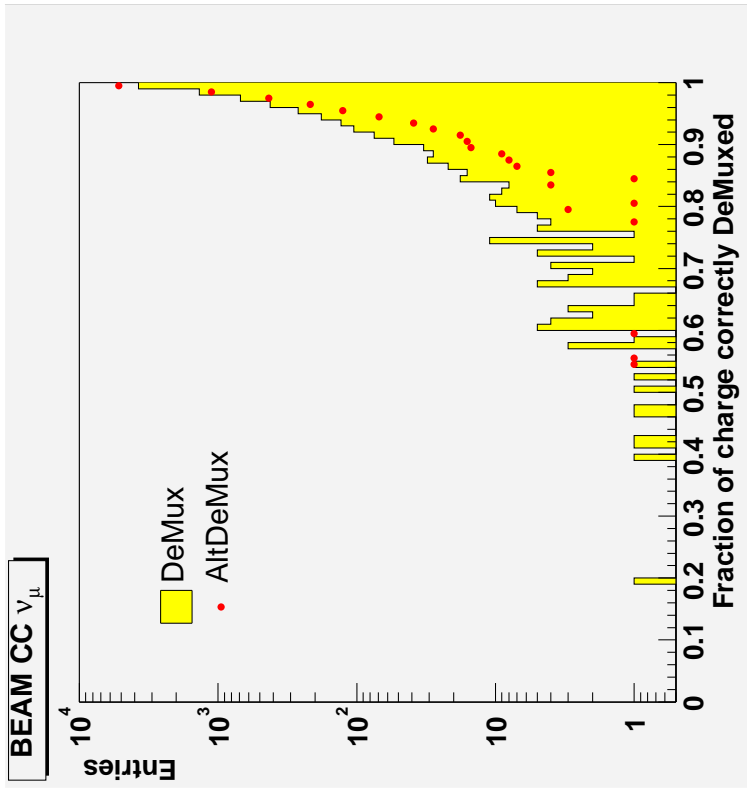
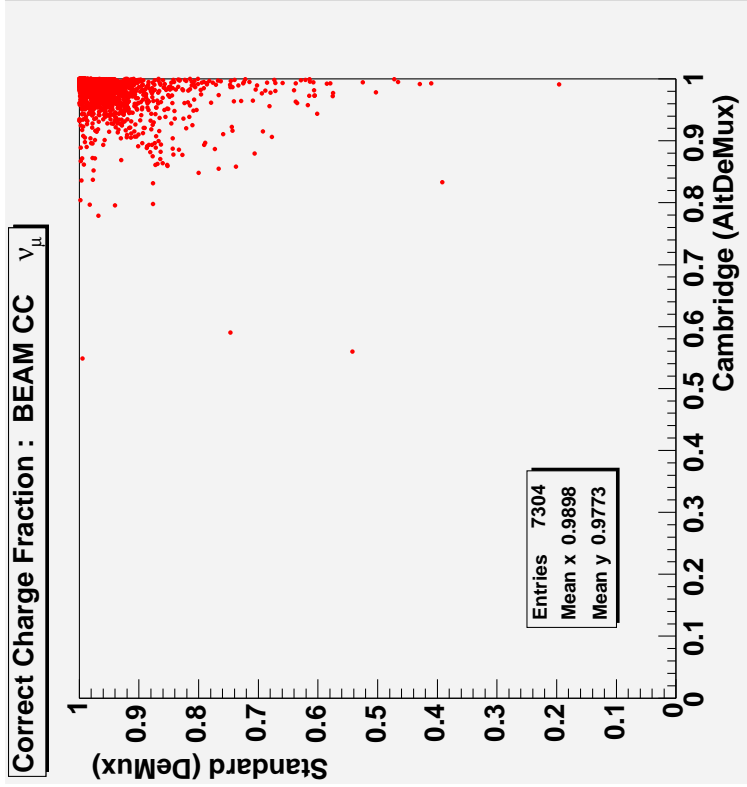
$E_\mu < 10$ GeV and within 10° of xy -plane
(dominant source of background in Atmos ν analysis)



	AltDeMux	DeMux
f_Q	95.3%	87.4%

- ★ AltDeMux performs significantly better
- ★ again less biased towards straight tracks

Beam ν_μ CC events



f_Q	AltDeMux	DeMux
	99.0%	97.7%

- ★ Similar performance
- ★ AltDeMux slightly better

Performance : Summary

	AltDeMux	DeMux	Gain
Atmospheric ν_μ CC	98.2%	95.5%	+2.7%
Atmospheric ν NC	96.1%	92.7%	+3.4%
Single Cosmic Muons	99.1%	98.6%	+0.5%
Sneaky Cosmic Muons	95.3%	87.4%	+7.9%
Beam ν_μ CC	99.0%	97.7%	+1.3%
Beam ν_μ CC $E_\nu < 5$ GeV	98.1%	97.2%	+0.9%
Beam ν_μ NC Events	98.2%	95.5%	+2.7%

- ★ AltDeMux places slightly more charge in correct place
- ★ However real test comes in relative sensitivity of physics analysis.....
- ★ + AltDeMux is ~ 20 times faster than Standard code.
 - e.g. for data : 0.075 s/cosmic c.f. 1.43 s/cosmic
- ★ + AltDeMux tags ~ 88 % of cross-talk hits
- ★ BUT much more sensitive to calibration - particularly timing

4 Conclusions and Future Work

Conclusions:

- ★ AltDeMux works well, **performance/speed**
- ★ Viable alternative to Standard code, but need to evaluate impact on physics performance
- ★ Different strengths/weaknesses
 - e.g. use DeMux for cosmics, AltDeMux for atmospherics ?
- ★ Now have **2 high quality DeMuxers !** Use in tandem to reject DeMux failures.

Future Work:

- ★ Reaching limit of approach... not much left to do
- ★ but still room for improvement - have yet to fully optimize cuts etc.
- ★ Develop a “beam neutrino” mode
- ★ Tidy up multiple muon reconstruction
- ★ New code will be in CVS soon (before October 7th)