

# Cryogenic Target Event Reconstruction in MINERvA

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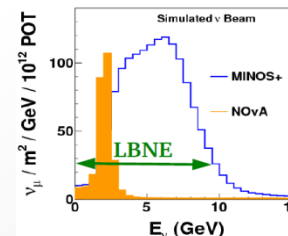
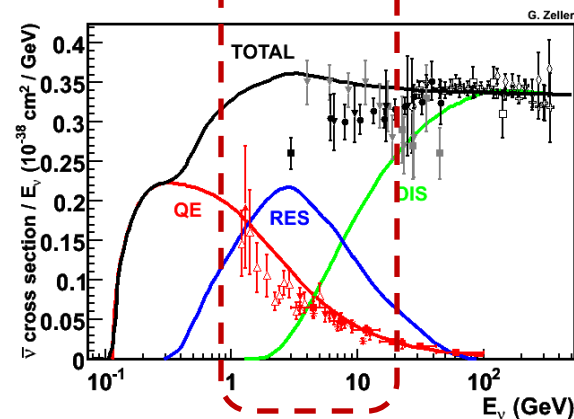
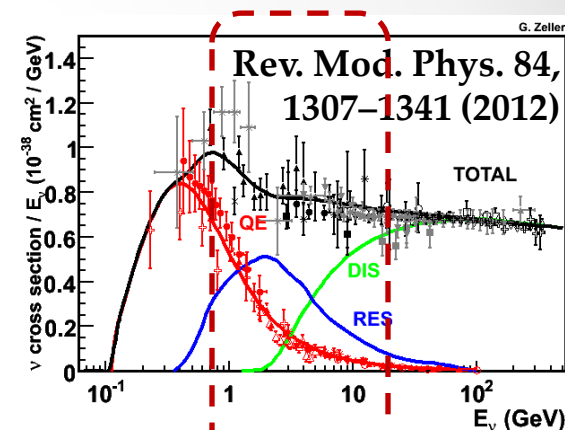
# Outline

- Physics Motivation
- Neutrino beam and flux
- The MINERvA detector
- Event reconstruction for He-target
  - Vertex two tracks from cryogenic target region.
  - Data and Monte Carlo (MC) comparison of vertex distributions
  - Comparison between data with full He-target and empty target
- Summary

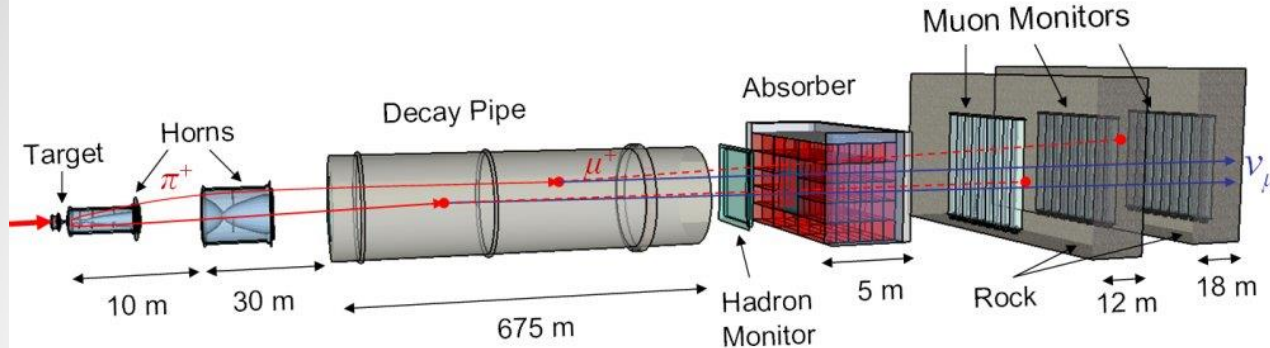
# Physics Goals for MINERvA



- Low Energy (LE) Beam
  - Precision measurement of inclusive and exclusive interaction rates for neutrinos and anti-neutrinos in the 1-20 GeV energy range
  - Study the nuclear (A) dependence of neutrino interactions with various target (He, C, Fe, Pb)
  - Precision determination of cross sections for  $\nu$  and anti- $\nu$  interactions in nuclear matter in 1-10 GeV energy range is crucial for current and upcoming neutrino oscillation experiments
- Medium Energy (ME) Beam in NOvA era
  - Structure Functions on various nuclei

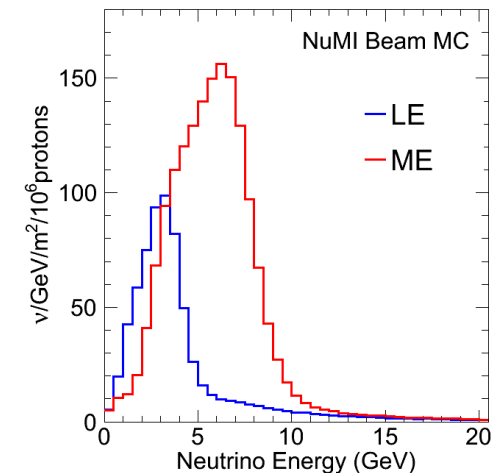


# Neutrinos at the Main Injector



MINOS  
Near  
Detector

- Magnetic horns focus pions and kaons, which decay into muons and neutrinos
- $\nu$  or  $\bar{\nu}$  predominant beam based on horn current polarity. The energy spectrum can be adjusted by moving the target and magnetic horns
- Low energy (LE) mode: 280-350 kW beam power, 10  $\mu$ s beam spill every 2.2 sec
- MINERvA LE run: March 2010 to April 2012
- Medium energy (ME) running starting in 2013
  - Upgrade the beam power to 700 kW and reduce the cycle time to 1.33 sec

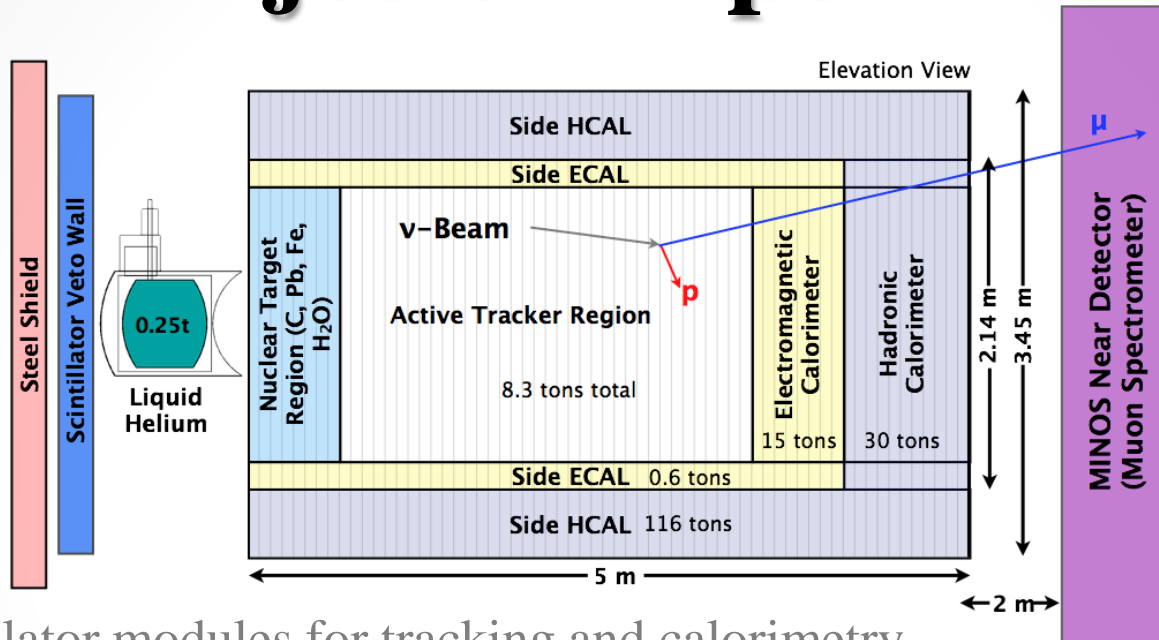


**LE neutrino mode:**  
 **$3.98 \times 10^{20}$  protons on target (POT)**  
**LE anti-neutrino mode**  
 **$1.7 \times 10^{20}$  POT**

# MINERvA



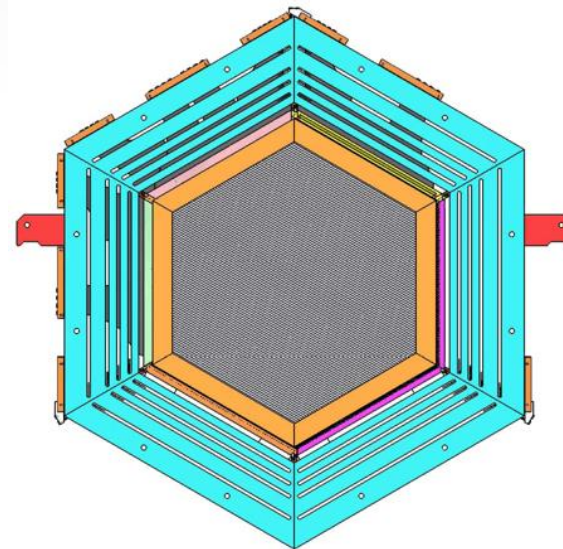
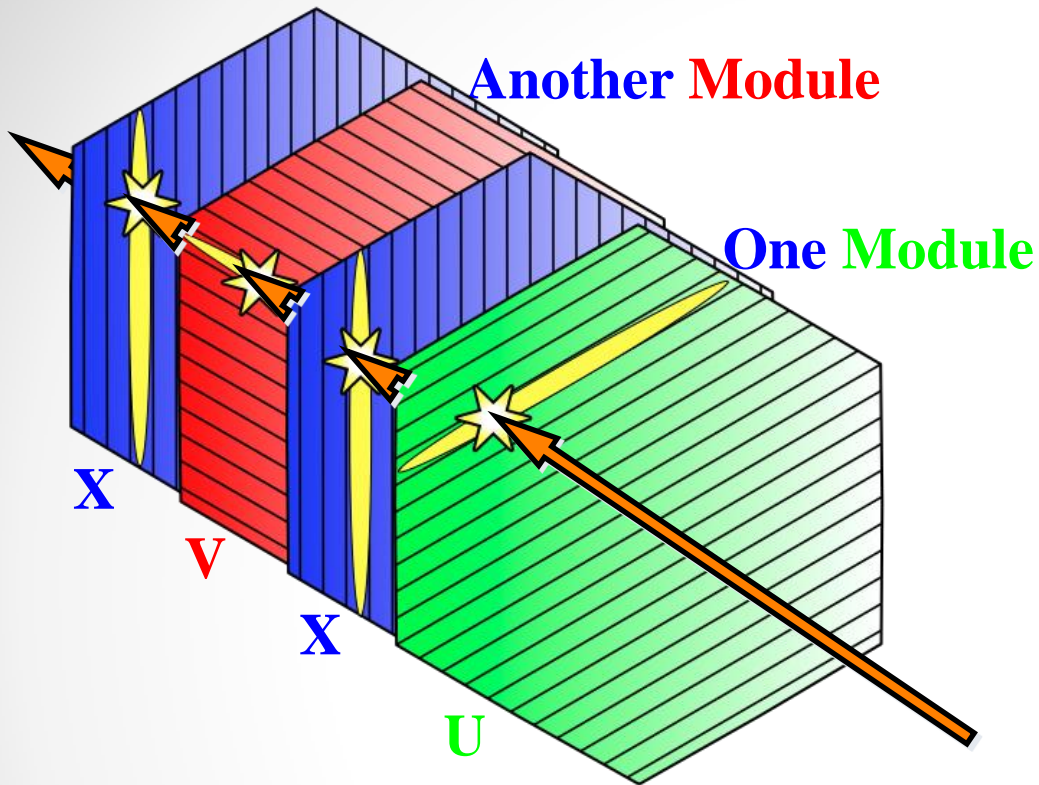
## Main INjector ExpeRiment v-A



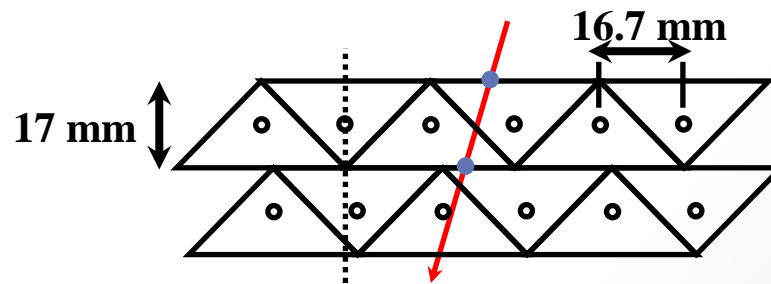
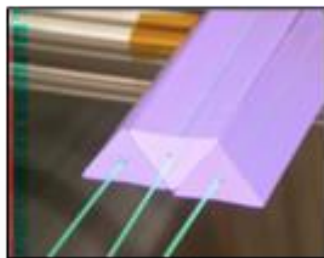
- 120 scintillator modules for tracking and calorimetry (~32k readout channels).
- MINOS Near Detector serves as muon spectrometer
- Construction completed Spring 2010.
- Helium and Water added in 2011
  - About half of the POT in neutrino mode taken with Helium and water targets
- M. Datta, Hampton U.

Target	Fiducial Mass (tons)	$\nu_\mu$ CC Events in 1.0e20 POT
Plastic	6.43	313k
Helium	0.25	14k
Carbon	0.17	9.0k
Water	0.39	20k
Iron	0.97	54k
Lead	0.98	57k

# MINERvA

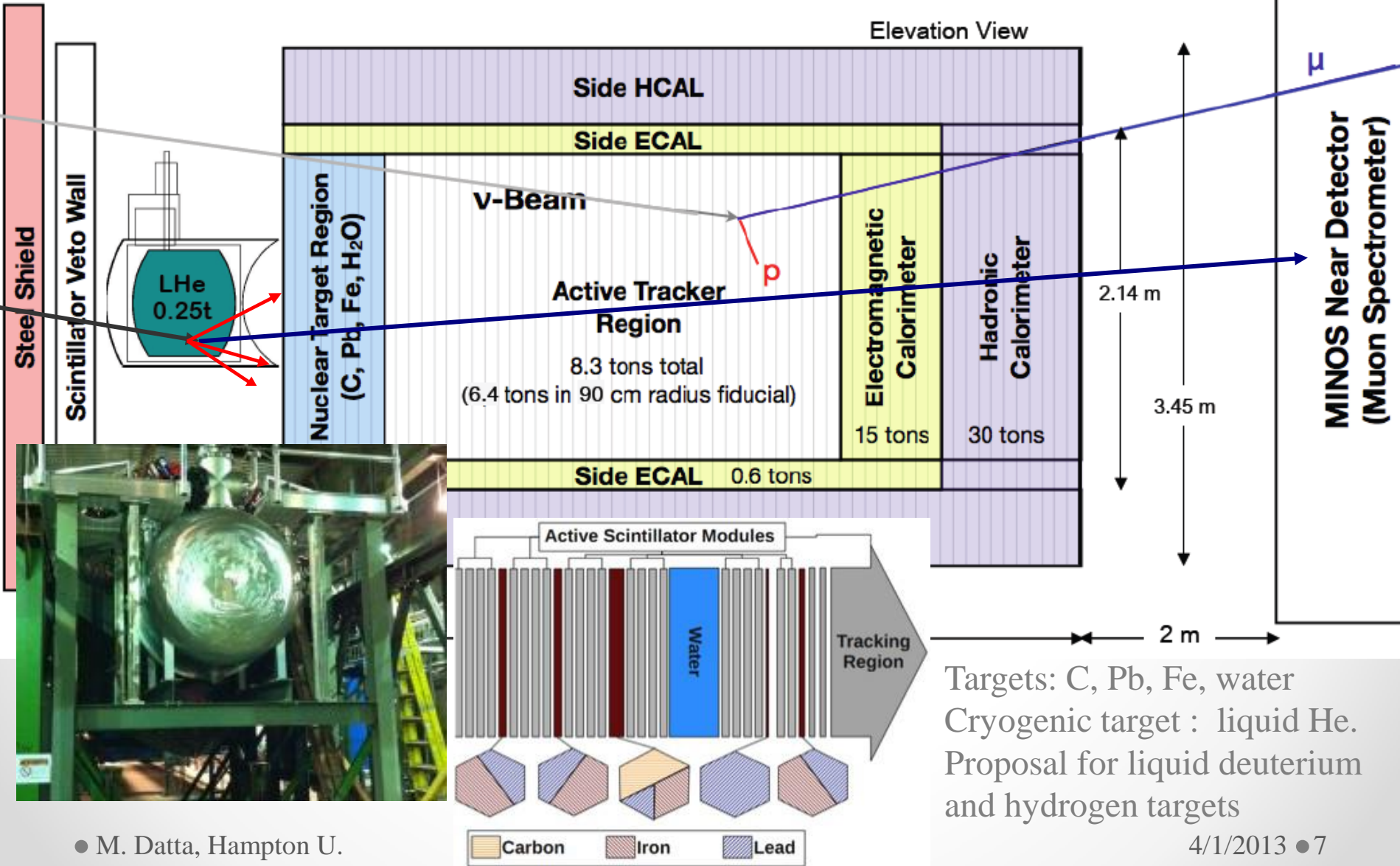


Scintillator - tracking  
Lead - EM calorimetry  
Steel - hadronic calorimetry



Charge sharing for improved position resolution ( $<3$  mm) and alignment

# Target Region



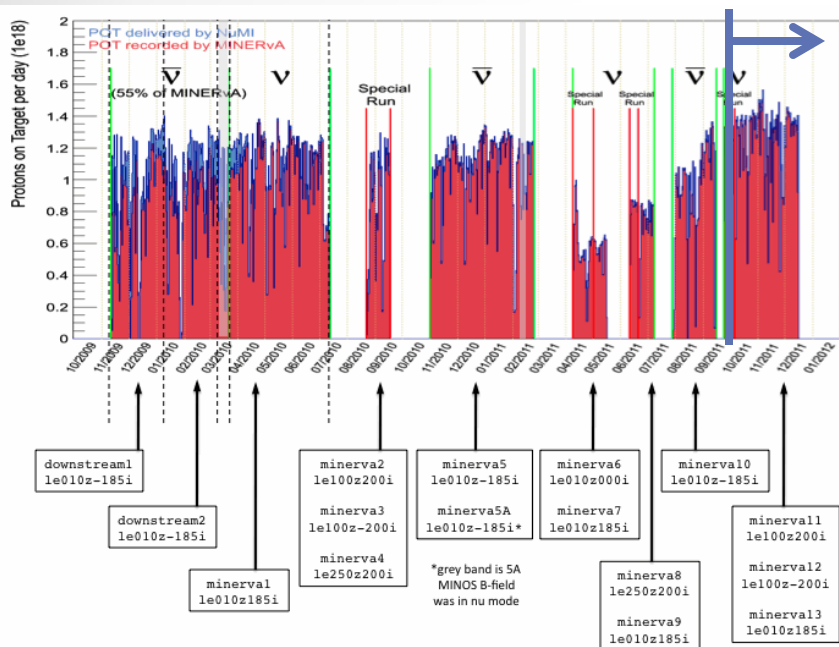
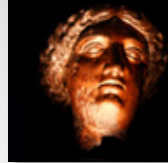
# Brief Overview



- Cryo-target event reconstruction looked at by Eric and Lingyan
  - LOI to include Deuterium target (Minerva-doc-6194-v8)
  - Physics motivation
    - Determining the quark content of Nucleon Structure function : PDFs
    - Nuclear medium modifications of nucleon structure
      - The nuclear EMC effect
      - Nuclear effects on neutrino scattering
      - A/D ratio with neutrino and anti-neutrino beams
    - Charge Symmetry violation at the quark level
- Current Minerva software framework was not available for the previous studies
- Current studies based on Minerva current software release (v10r6)
  - Compared to software/code used for previous studies, significant development in tracking and vertex-reconstruction
  - First look at data taken with Cryogenic target



# He-target Runs



- Target installed in July 2011
- Filled with He in late September 2011
- Neutrino beam exposure beginning in October 2011
  - **Playlist 13 (LE  $\nu$ ): ~1.9e20 POT, 18-10-2011 to 30-04-2012**
  - Playlist 11 (pseudo ME  $\nu$ ) : 24-09-2011 to 30-09-2011

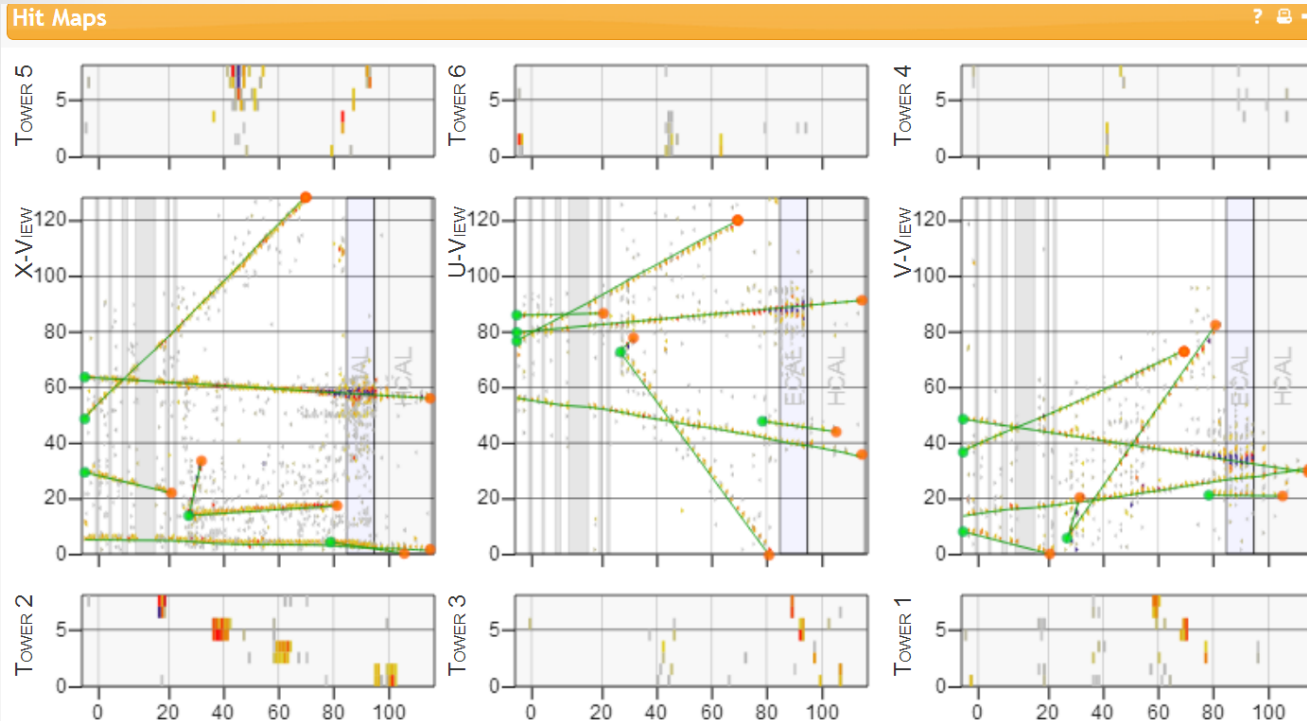
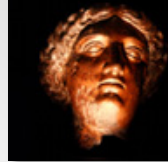
Playlist	Run period	Status	POT
13A (LE $\nu$ )	05-10-2011 to 18-10-2011	NoH20_FullHe	1.28e+19
13B (LE $\nu$ )	18-10-2011 to 17-11-2011	NoH20_FullHe	1.65e+19
<b>13C (LE <math>\nu</math>)</b>	<b>17-11-2011 to 12-03-2012</b>	<b>FullH20_FullHe</b>	<b>1.22e+20</b>
13D (LE $\nu$ )	12-03-2012 to 17-03-2012	FullH20_EmptyingHe	6.68e+18
<b>13E (LE <math>\nu</math>)</b>	<b>17-03-2012 to 30-04-2012</b>	<b>FullH20_EmptyHe</b>	<b>5.22e+19</b>

# Ana-stage Vertex Reconstruction



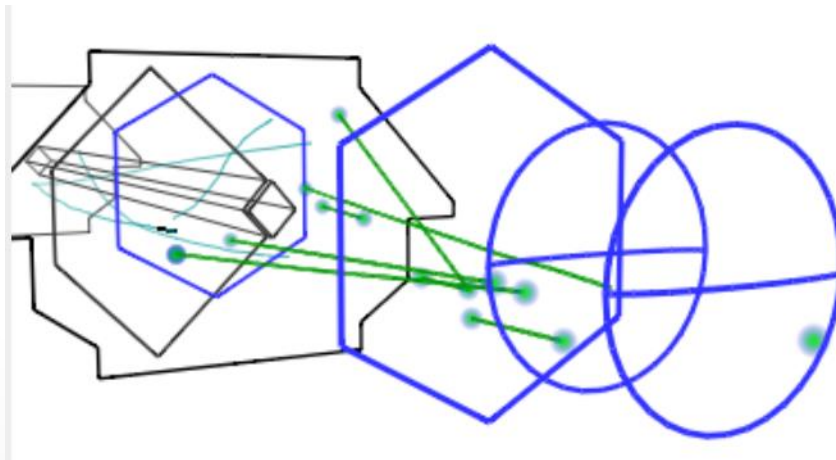
- Select events containing at least one track (from single vertex), from the front of the detector.
  - Two or more reconstructed long tracks from the front of the detector
  - One reconstructed long track from the front of the detector
    - Use “LongAnchoredTrack”-ing and “AnchoredShortTracker”-ing to look for the second track
- Requirements :
  - Long and/or anchor track(s) with most upstream Z-vertex position  $< 4446.33$  mm (before the first nuclear target)
  - Calculate the distance of closest approach (crossing point) between upstream track(s) and/or anchor track
    - If the Z-position of the crossing point  $< 4293.04$ mm (first plane location), then those tracks together with the anchor track is passed to the vertex fitting algorithm

# Two Reconstructed Long Tracks

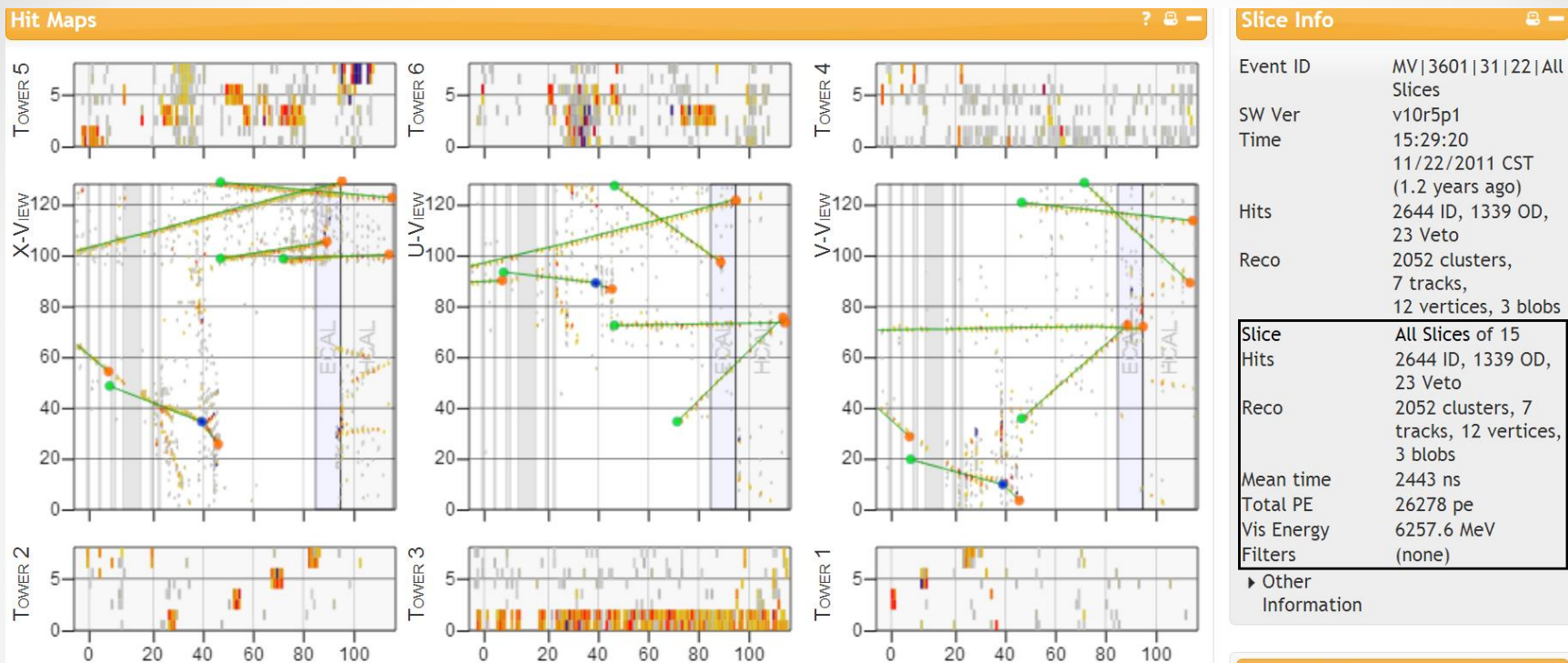
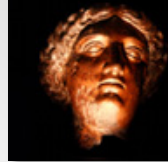


Slice Info	
Event ID	MV 3601 57 12 All Slices
SW Ver	v10r5p1
Time	23:15:39 11/22/2011 CST (1.2 years ago)
Hits	3200 ID, 223 OD, 27 Veto
Reco	2462 clusters, 7 tracks, 15 vertices, 10 blobs
Slice	All Slices of 9
Hits	3200 ID, 223 OD, 27 Veto
Reco	2462 clusters, 7 tracks, 15 vertices, 10 blobs
Mean time	3357 ns
Total PE	20975 pe
Vis Energy	5125.7 MeV
Filters	(none)
▶ Other Information	

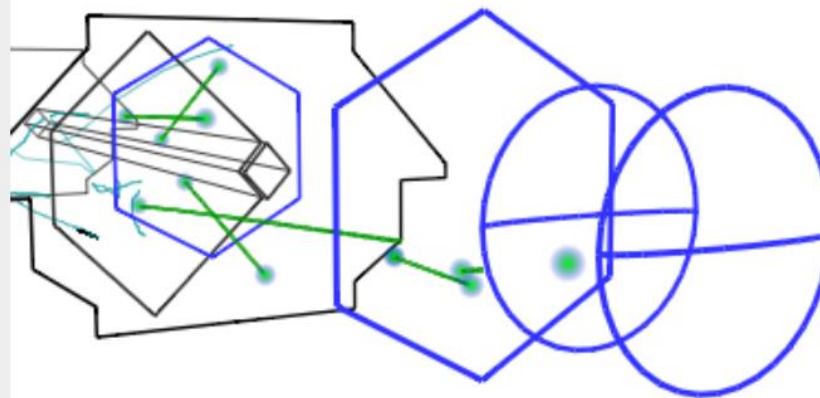
Run-Subrun-Gate  
3601-57-12  
Playlist :  
Minerva 13C



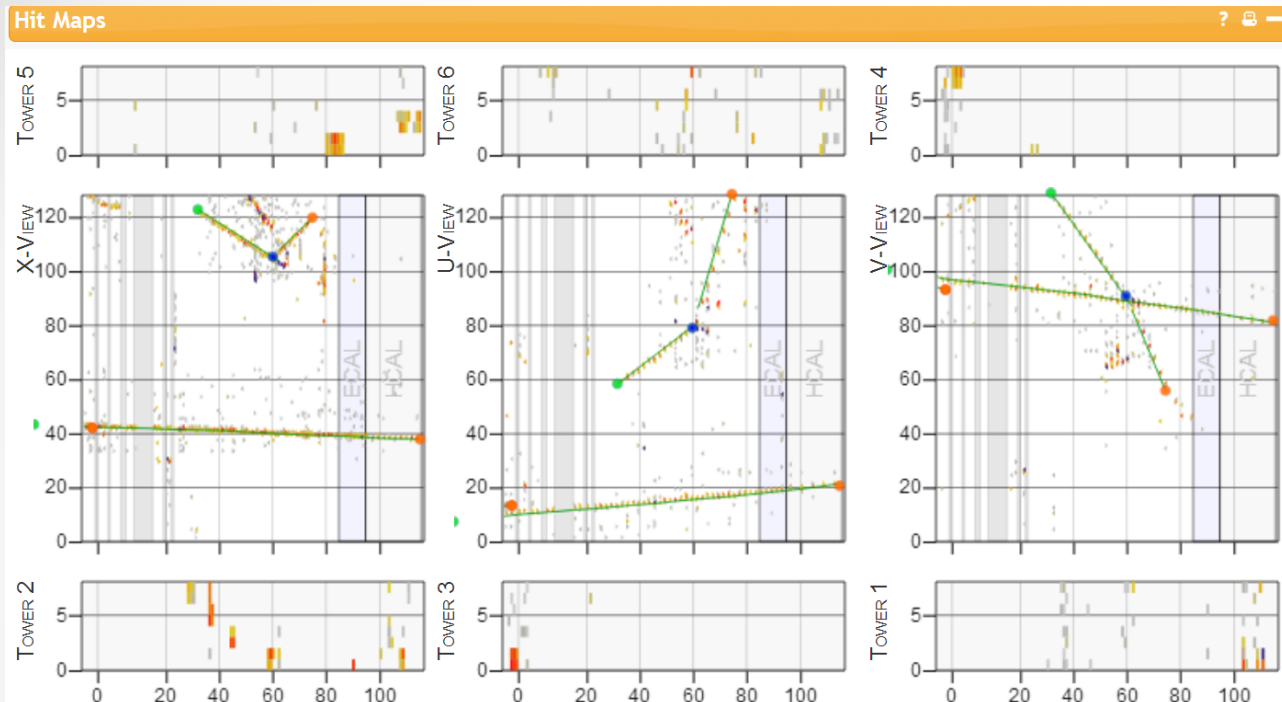
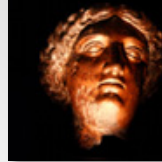
# Long Anchor Track



Run-Subrun-Gate  
3601-31-22  
Playlist :  
Minerva 13C

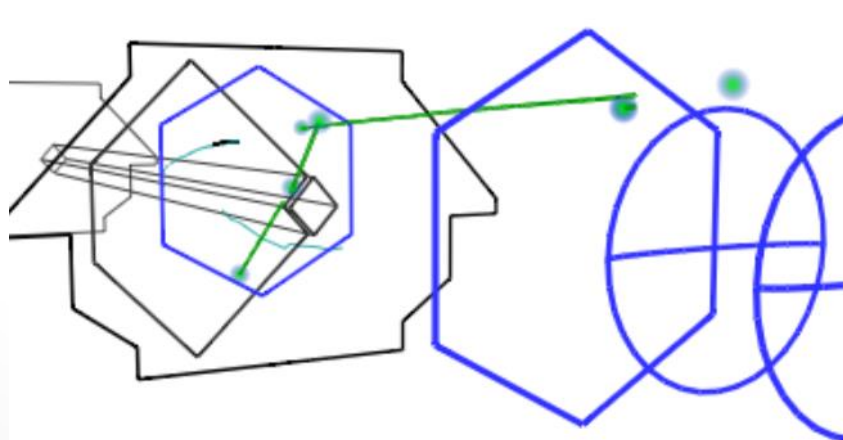


# Short Anchor Track



Slice Info	
Event ID	MV 3601 24 156 All Slices
SW Ver	v10r5p1
Time	12:22:55 11/22/2011 CST (1.2 years ago)
Hits	1600 ID, 204 OD, 20 Veto
Reco	1252 clusters, 4 tracks, 7 vertices, 4 blobs
Slice	All Slices of 9
Hits	1600 ID, 204 OD, 20 Veto
Reco	1252 clusters, 4 tracks, 7 vertices, 4 blobs
Mean time	3928 ns
Total PE	12088 pe
Vis Energy	2716.0 MeV
Filters	(none)
▶ Other Information	

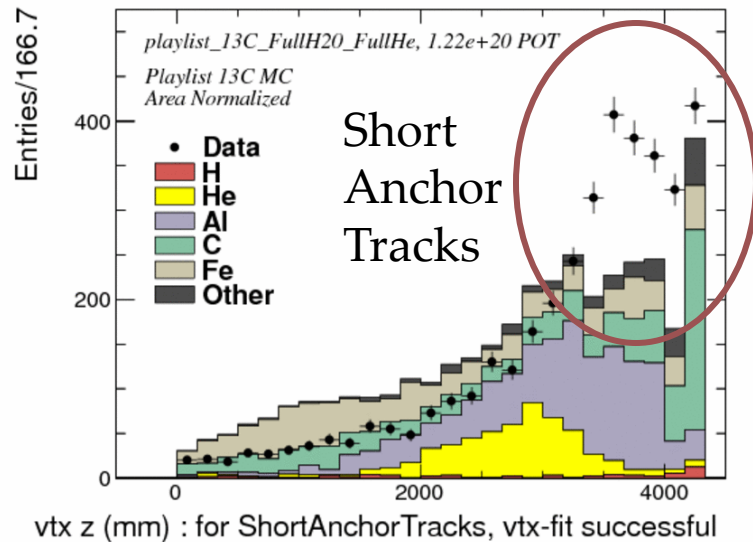
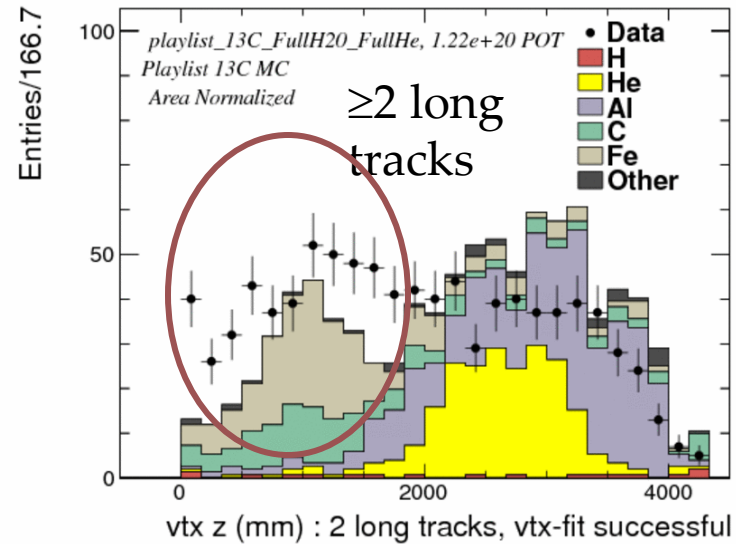
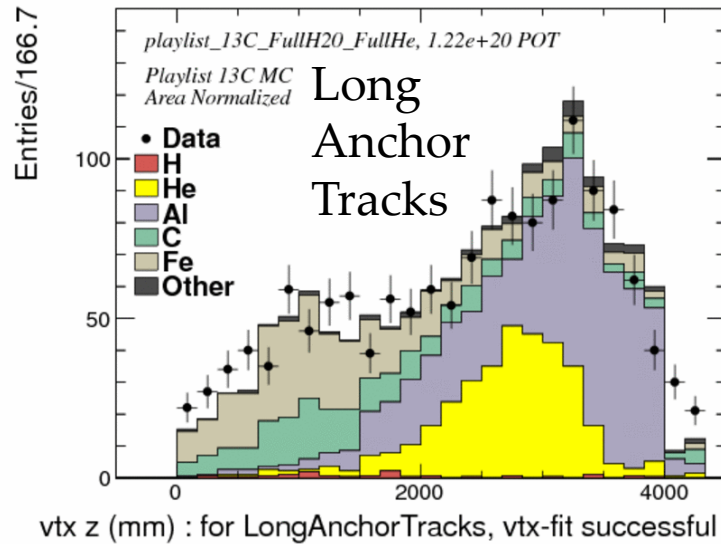
Run-Subrun-Gate  
3601-24-56  
Playlist :  
Minerva 13C



# Data-MC Comparison

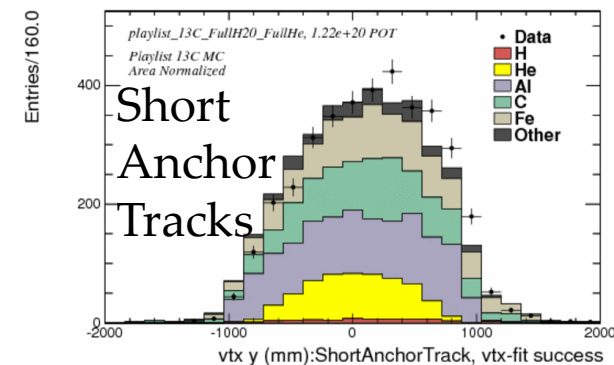
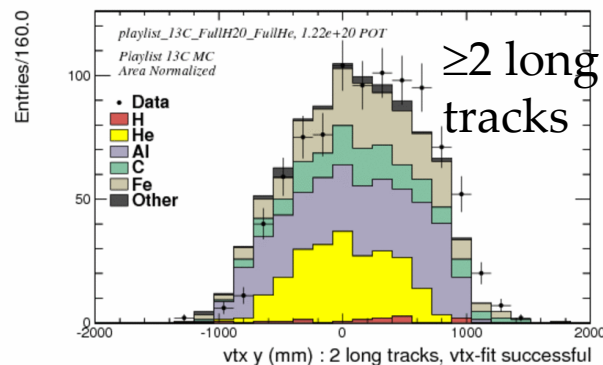
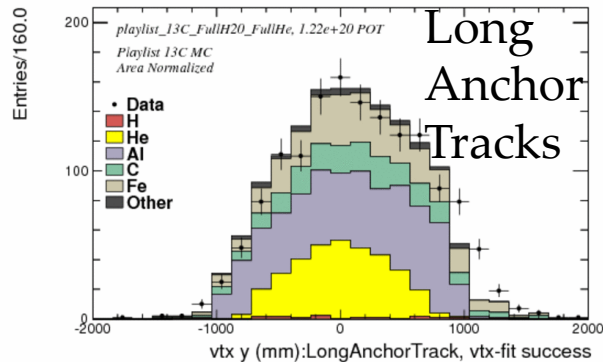
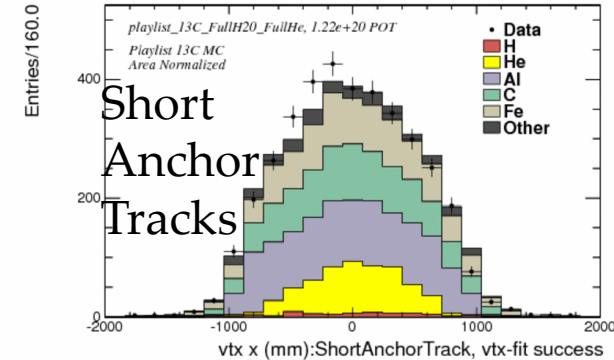
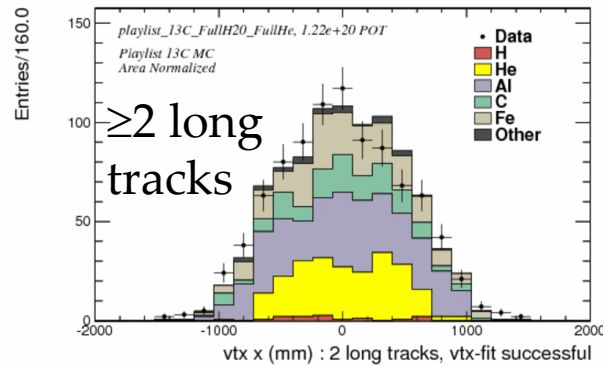
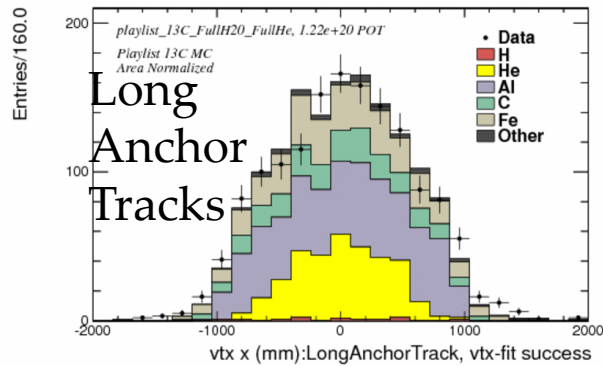
...

# Reconstructed Z-vertex



- Agreement is better for “LongAnchorTrack” events
- Work in progress to understand the data-MC difference

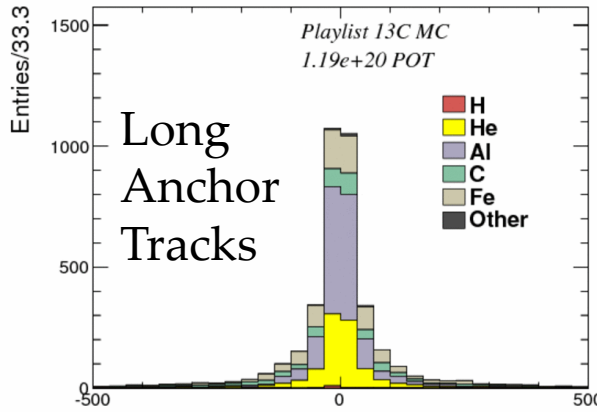
# Reconstructed vertex-X and vertex-Y



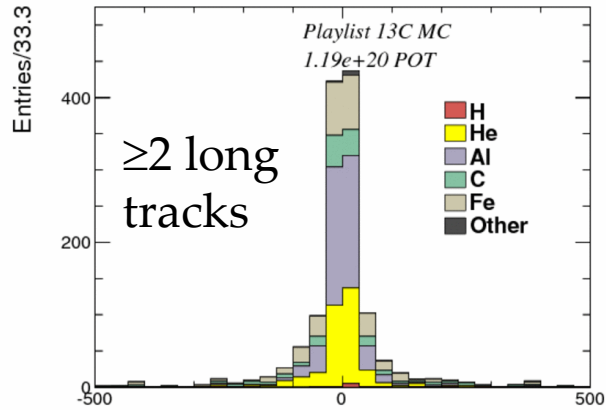




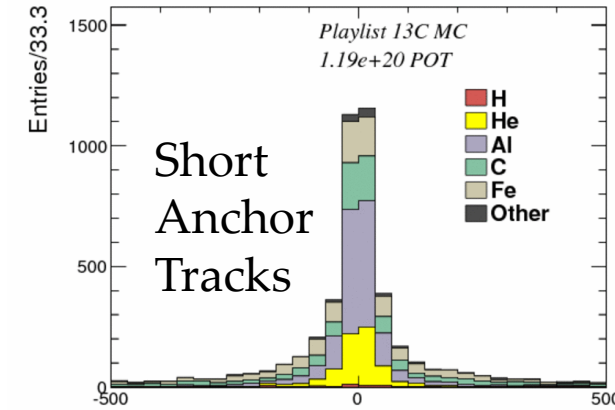
# Vertex-X Resolution



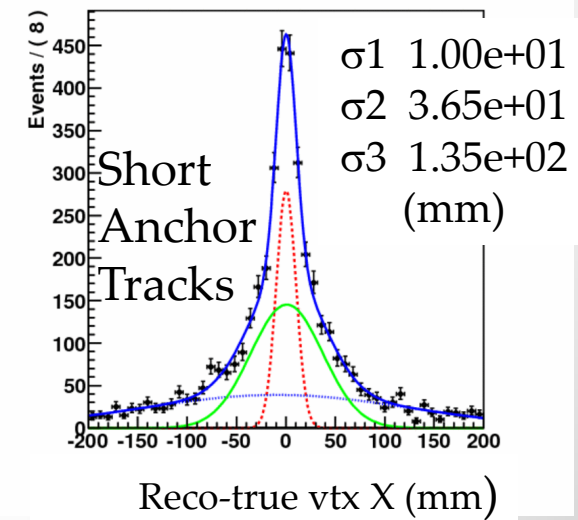
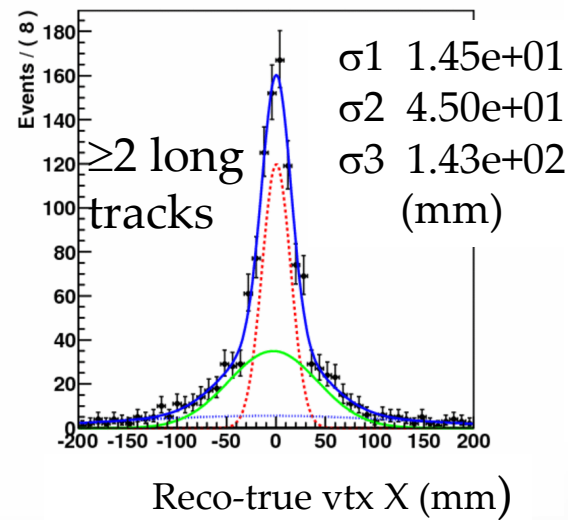
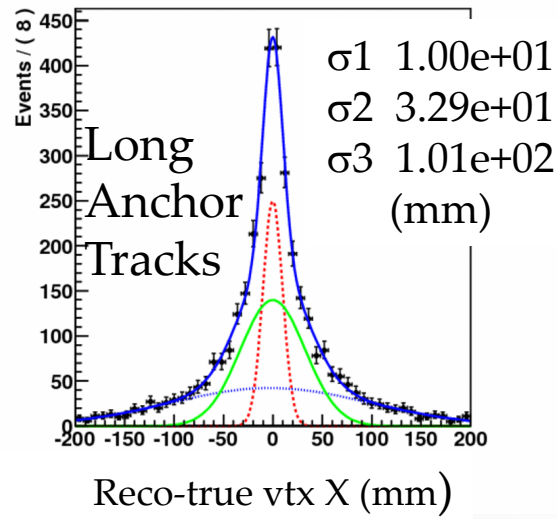
reco-true vtx x (mm):LongAnchorTrack, vtx-fit success

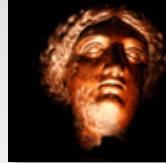


reco-true vtx x (mm) : 2 long tracks, vtx-fit successful

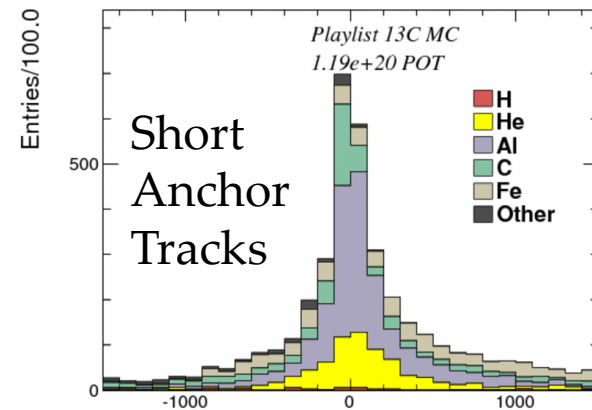
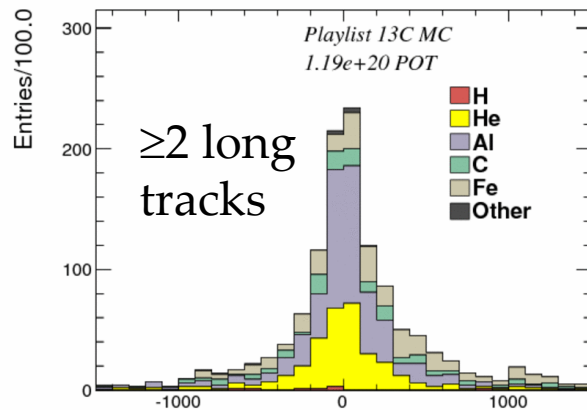
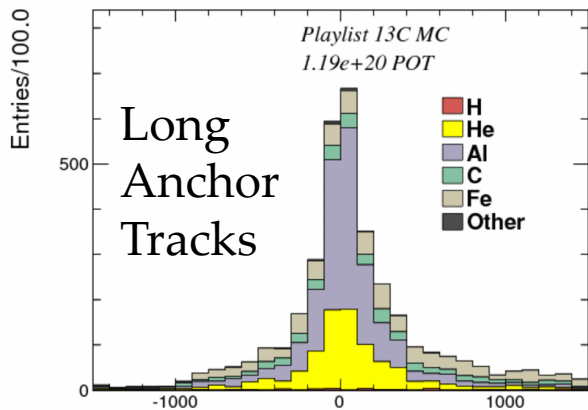


reco-true vtx x (mm): ShortAnchorTracks, vtx-fit success





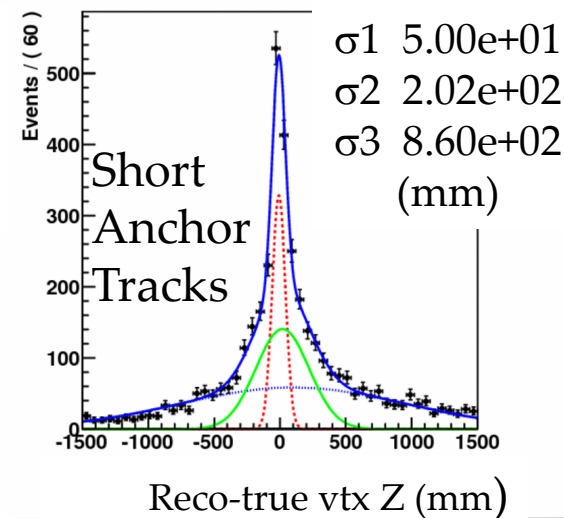
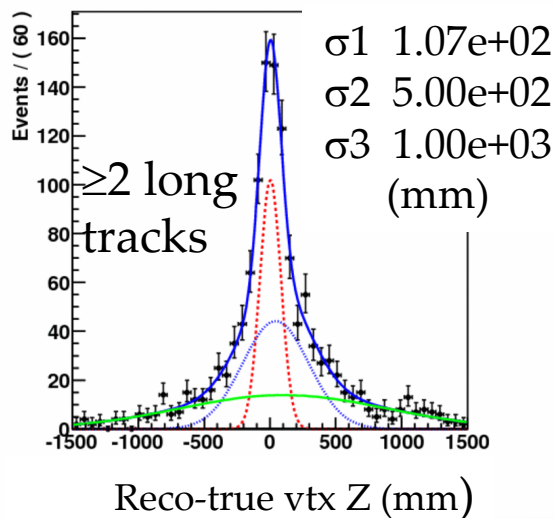
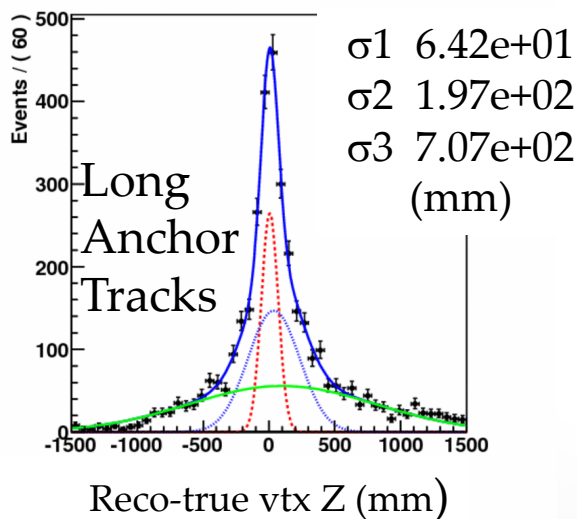
# Z-Vertex Resolution



reco-true vtx z (mm): LongAnchorTracks, vtx-fit success

reco-true vtx z (mm) : 2 long tracks, vtx-fit successful

reco-true vtx z (mm): ShortAnchorTracks, vtx-fit success

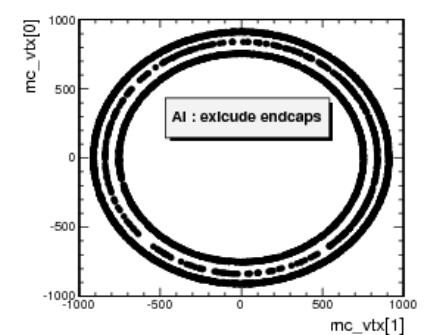
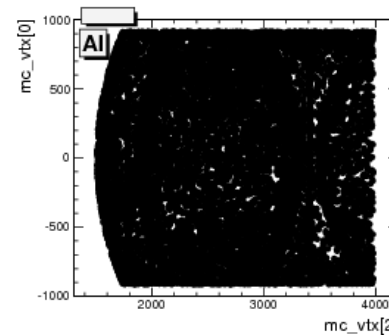
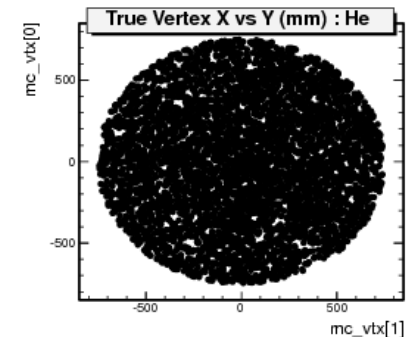
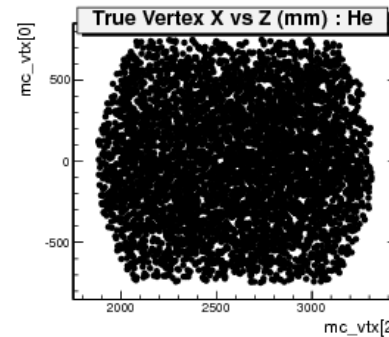


# Data : He-filled VS Empty Target ...

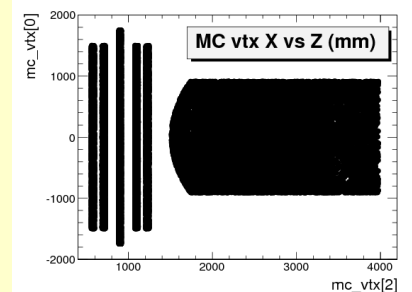
# Imaging Cryogenic Target Region from Data Events



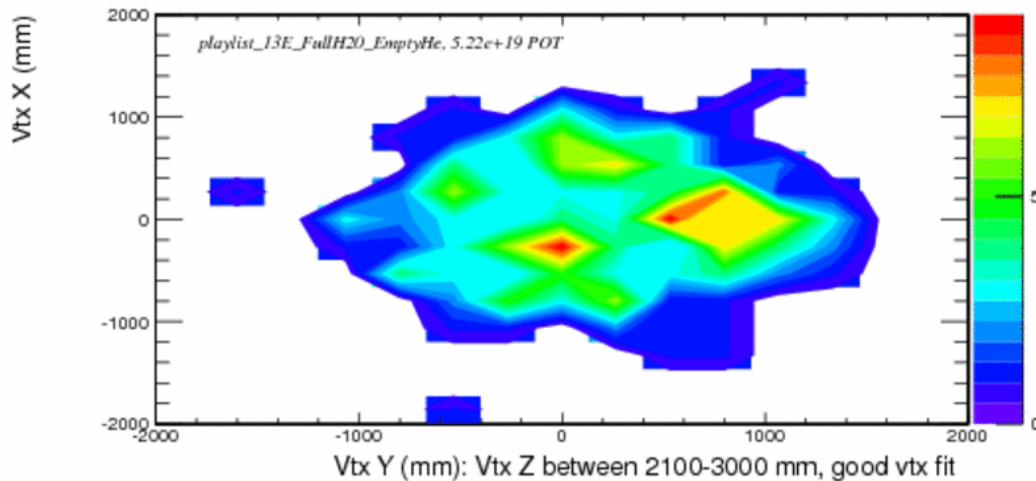
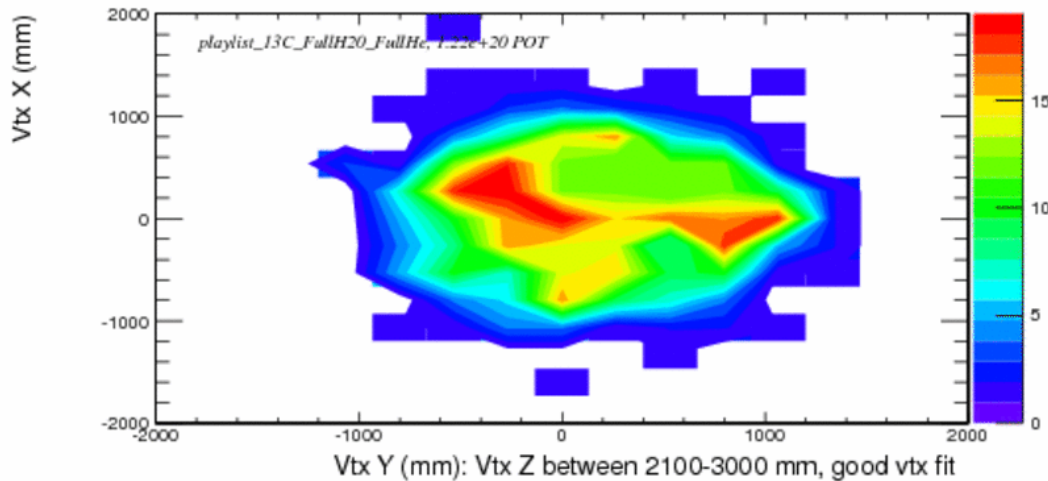
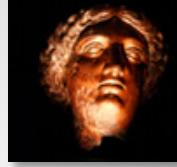
- Use events from playlist 13C (full He) and playlist 13E (empty He)
- Check if we can we image the Aluminum vessel, using events
  - X vs Z vertex
  - Y vs Z vertex
  - X vs Y vertex, requiring Z vertex between 2100-3000 mm
- For reference shown are the position and dimension of cryogenic and veto detector used if the reconstruction software
  - Cryogenic target inner and outer radius ~710 mm and ~750 mm



Position and dimension for cryo and veto detectors in geometry file in Minerva analysis software

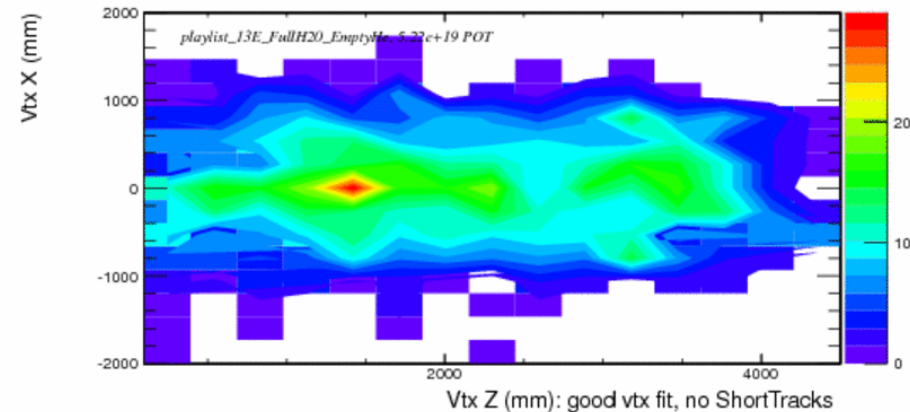
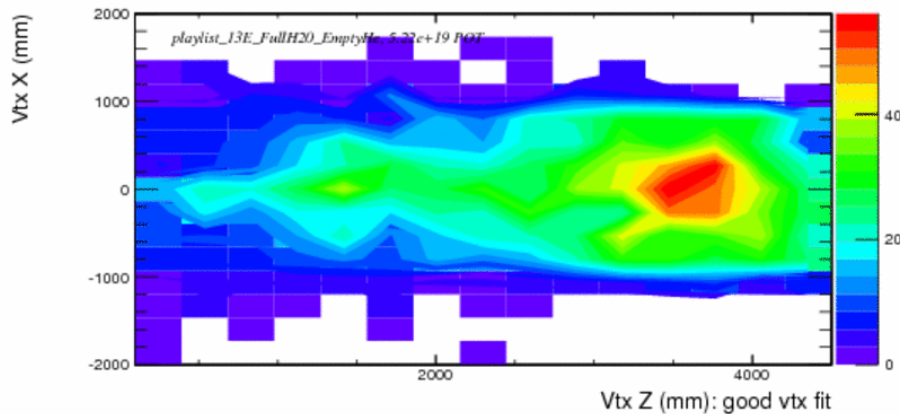
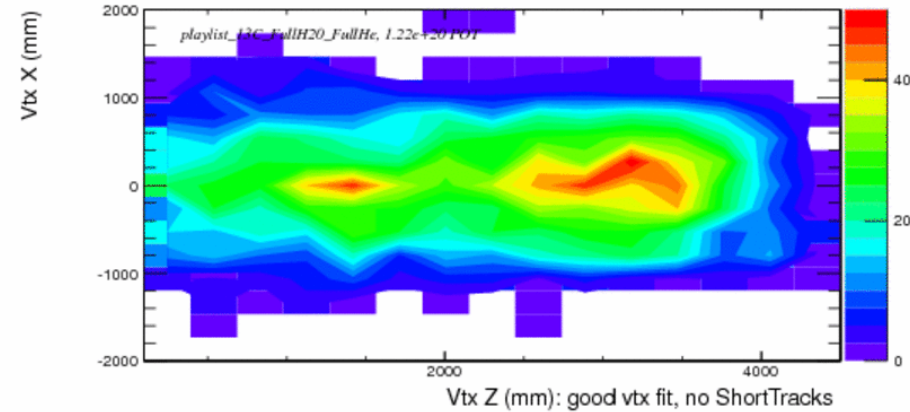
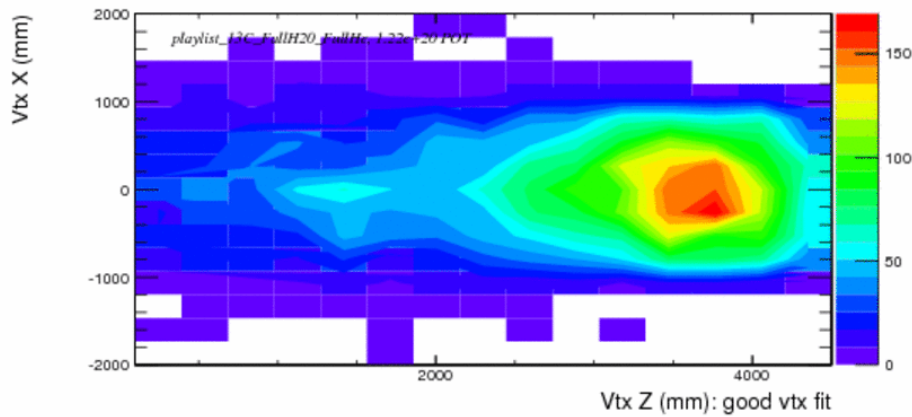


# Vertex X vs Y (mm) : Events with Z vertex between 2100-3000 mm



- Upper plots : playlist 13C (full He)
- Lower plots: playlist 13E (empty He)
- Can see the image for Cryogenic target inner and outer radius  $\sim 710$  mm and  $\sim 750$  mm

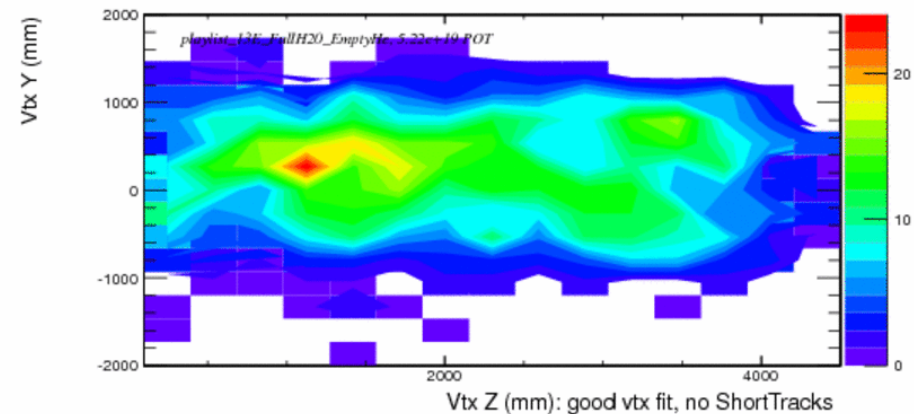
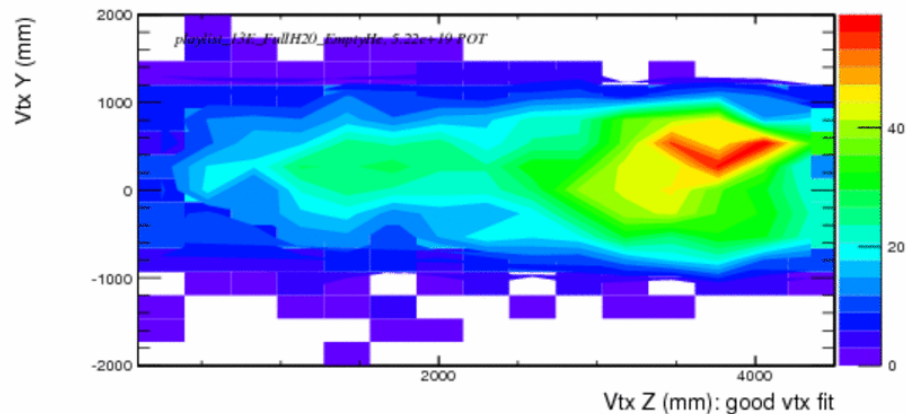
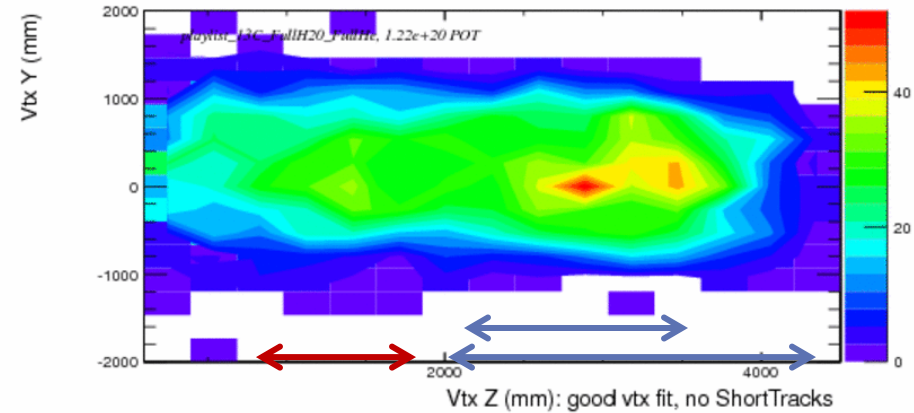
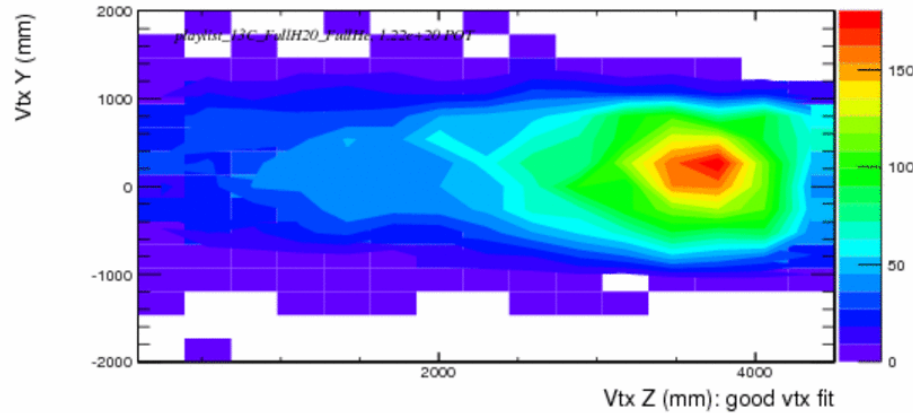
# Vertex X vs Z (mm)



- Upper plots : playlist 13C (full He), lower plots: playlist 13E (empty He)
- Right plots : exclude events selected by “AnchorShortTrack”-ing



# Vertex Y vs Z (mm)



- Upper plots : playlist 13C (full He), lower plots: playlist 13E (empty He)
- Right plots : exclude events selected by “AnchorShortTrack”-ing

# Data Yields



	Playlist 13C:Full He, Full water 1.22e+20 POT*	Playlist 13E :Empty He, Full water 5.22e+19 POT*
Require good vertex fit		
>=2 long trks	916	386
LongAnchorTrack	1479	617
ShortAnchorTrack	3732	1492
Total	6127	2495

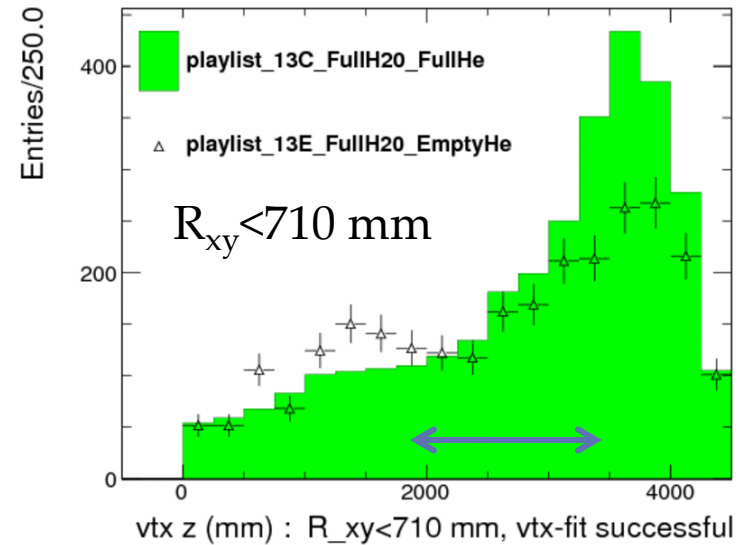
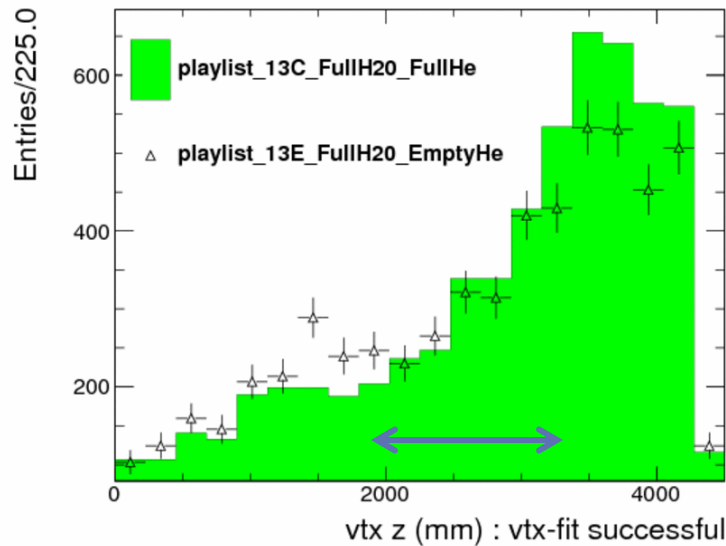
- \*Still need to recover missing data at the analysis stage
- Current vertex quality requirement is most likely not optimal in this case
  - Can be optimized to improve selection efficiency

	Playlist 13C	Playlist 13E
Require good vertex fit, Z vtx 2100-3000 mm		
>=2 long trks	201	87
LongAnchorTrack	394	127
ShortAnchorTrack	0	0
Total	595	214

- ShortAnchorTrack-ing picks up events at the downstream end of the target only

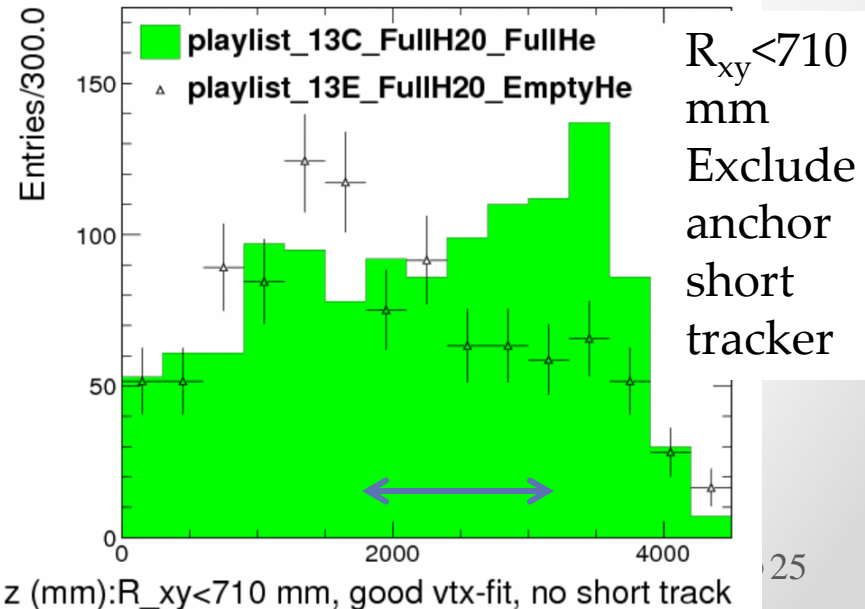


# Comparison : 13C, 13E Data

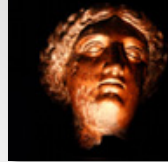


## 13E data normalized to POT for 13C

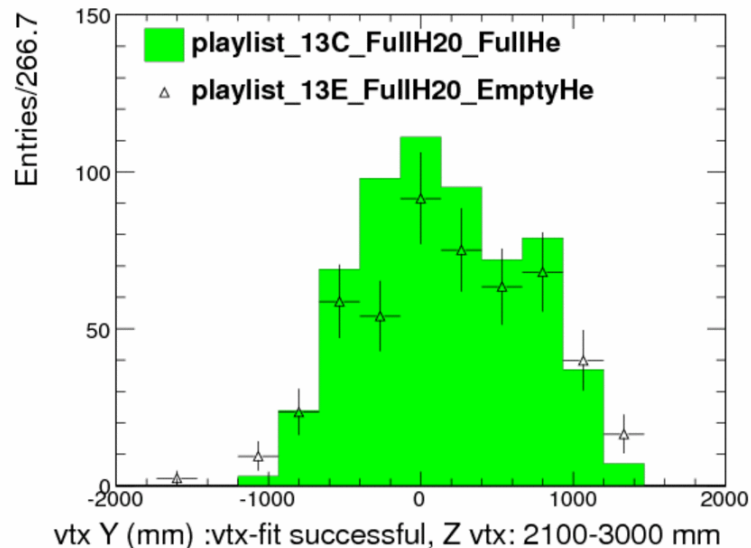
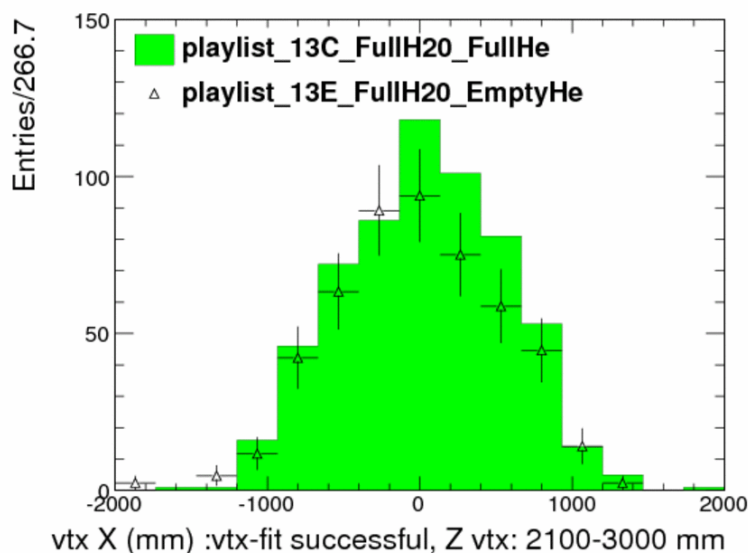
- Z vertex
  - Right plots require vertex X and Y within 710 mm radius
  - Lower right plot : exclude events from ShortAnchorTrack-ing
- \*Still need to recover missing data at the analysis stage for proper POT normalization



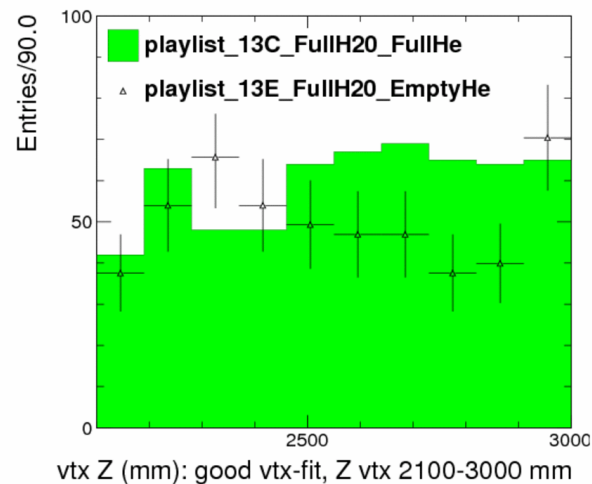
# Comparison : 13C, 13E Data



## 13E data normalized to POT for 13C



- X and Y vertex : Require Z vertex to be within 2100-3000 mm
- \*Still need to recover missing data at the analysis stage for proper POT normalization





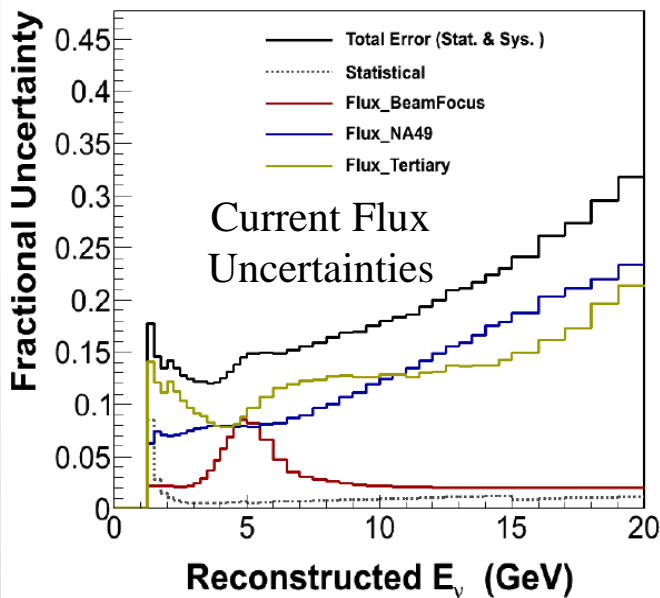
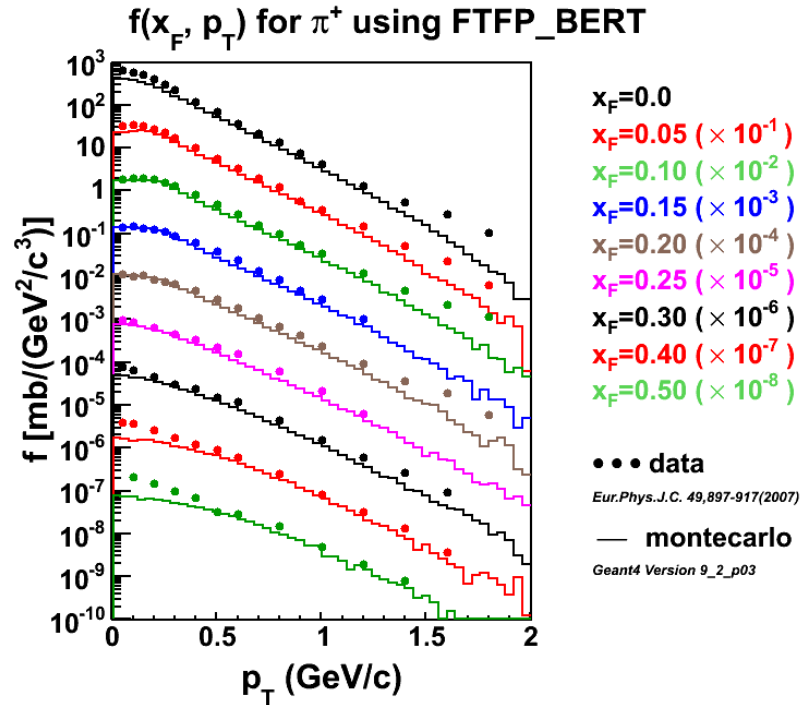
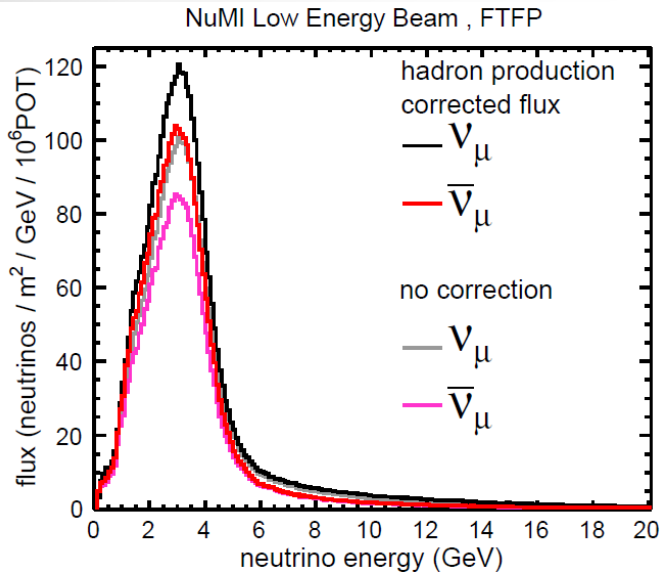
# Status and Plan

- Developing code for He-target event reconstruction studies
  - Two-track-vertex reconstruction in the cryo-target region
    - Current version of vertex reconstruction code is ready for that purpose
      - There is room for optimization and improvement
- Investigating the data Monte Carlo difference
- The data distributions look promising
- To do:
  - Include missing data events and increase MC statistics
  - Working on implementing the code for muon selection and muon energy reconstruction
  - Also working on including information related to extra-energy, truth-matching
  - Also looking at obtaining the recoil energy for these events
  - ..

# BACKUP



# Neutrino Flux



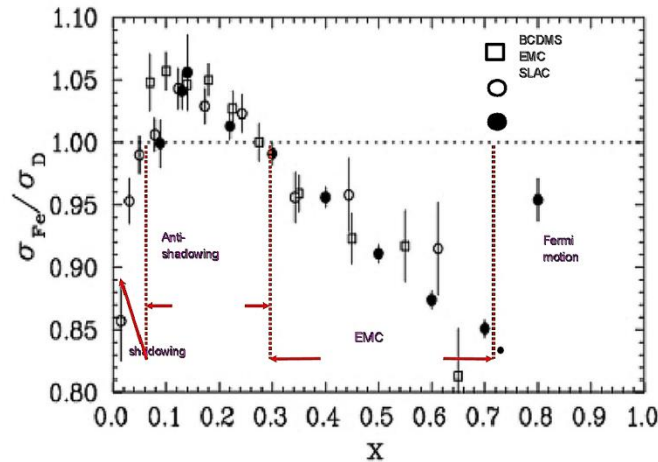
- Hadron production simulated with Geant4 to predict flux.
- Flux is reweighted based on hadron production data compared to Geant4
- Flux uncertainties will improve in future with more work



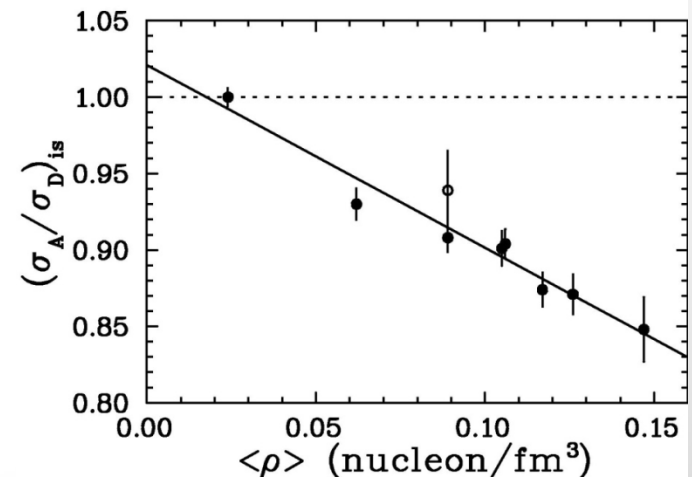
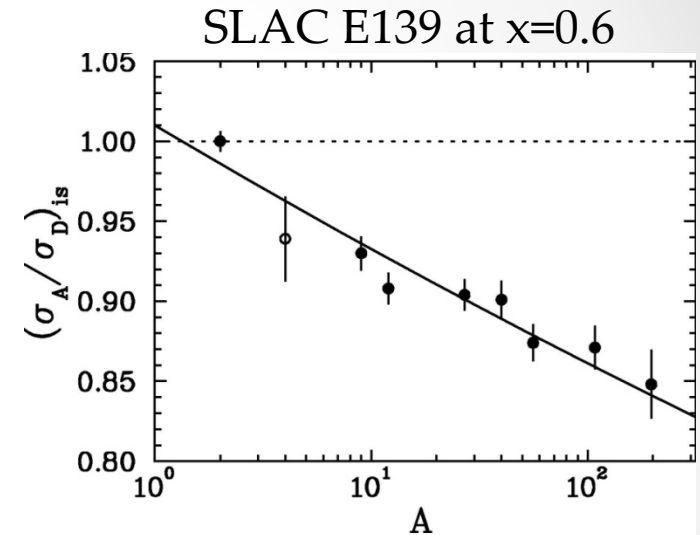
# Physics Case

- $\nu N$  scattering is a very useful input for understanding partons in the nucleon
  - Flavor-sensitive probe means separation of  $u, d, s$  quark content of the nucleon
  - Neutrino and Anti-neutrino beams means a separation of valence and sea quarks
  - PDF determination important for hadron colliders
- Neutrino data today would play a key role in global PDF fits, except...
  - Very little data on nuclear effects in neutrinos
  - Theory of nuclear effects not well enough understood for a reliable *a priori* prediction

# Nuclear Effects in A/D Ratios

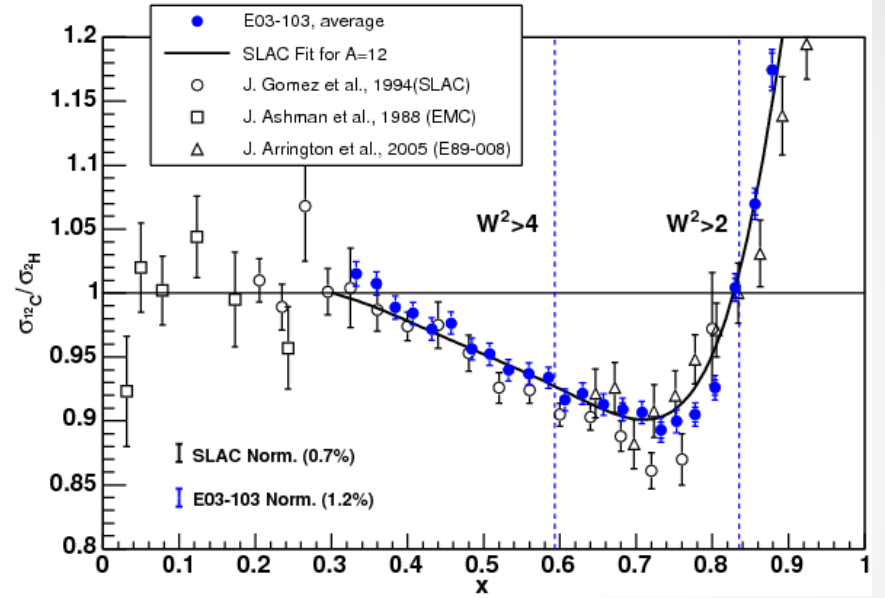
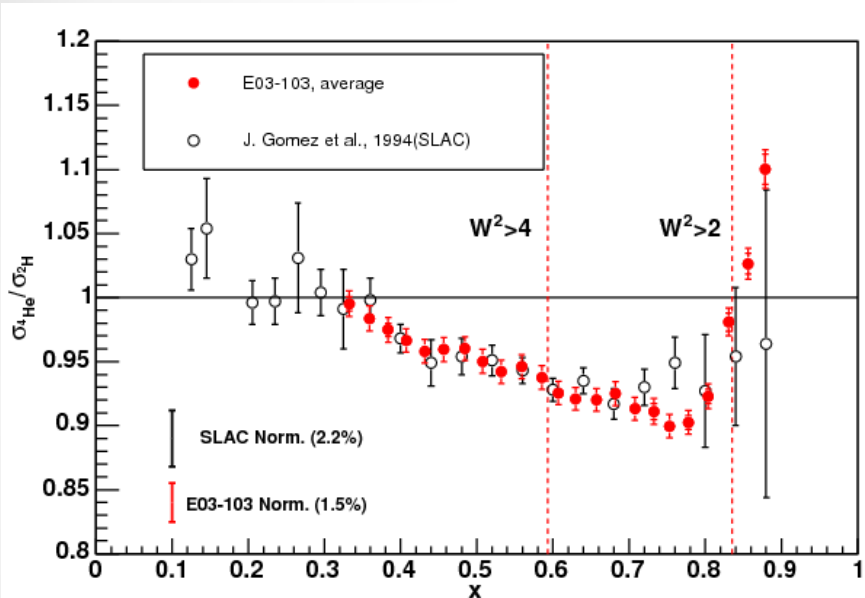


- The structure functions of a nucleon within a nucleus are different from the structure functions of a free nucleon.
- Fe/D cross sections show 13% nuclear effect.
- Precision neutrino data requires better understandings of nuclear effects.





# EMC Effect for Helium & Carbon

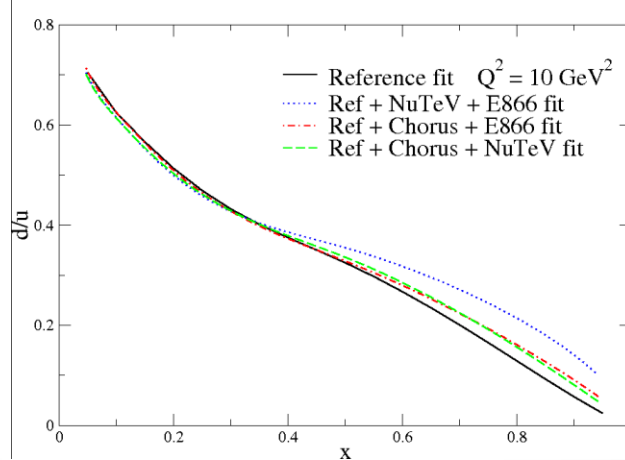
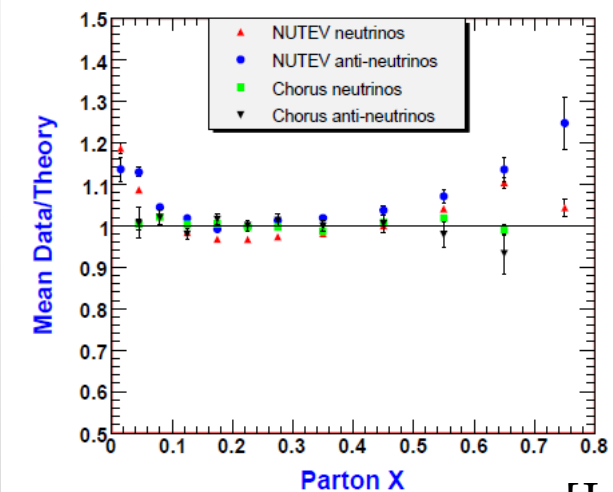
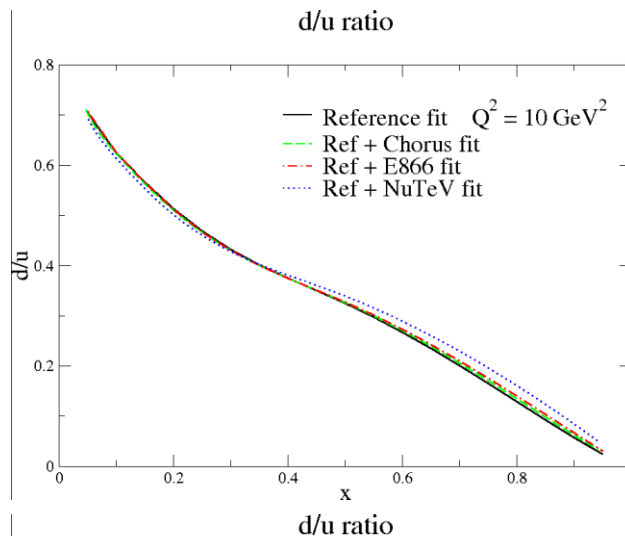
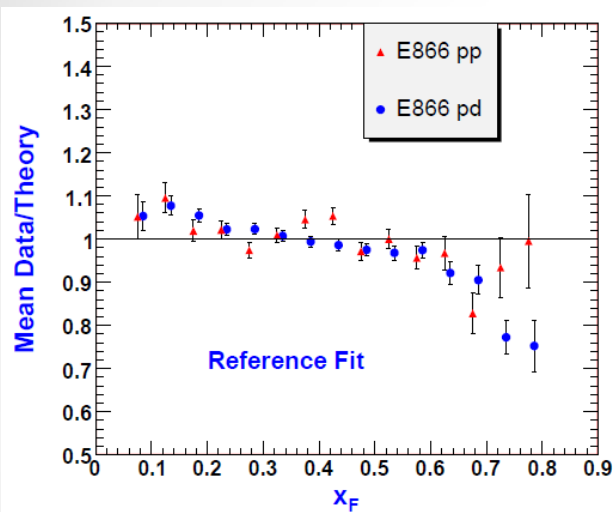


- Jefferson Lab E03-013 data [Ref: J. Arrington, nucl-ex/0701017]
- $^4\text{He}$  show similar nuclear EMC effect as  $^{12}\text{C}$





# Neutrino Data for PDFs

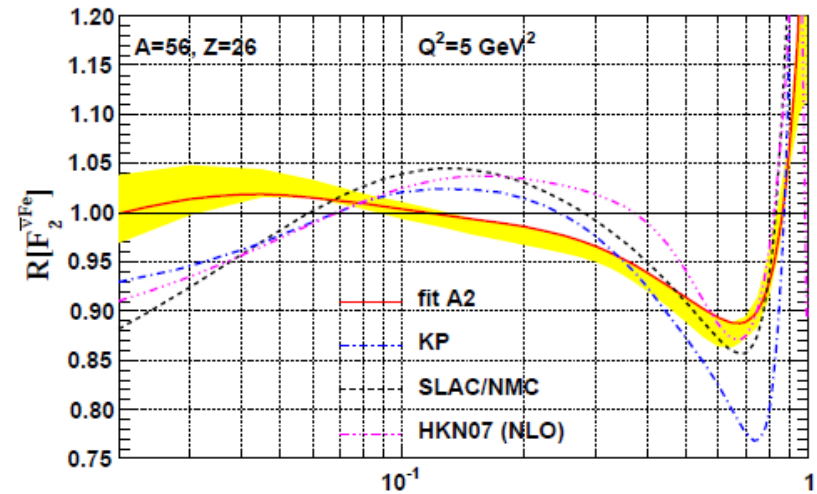
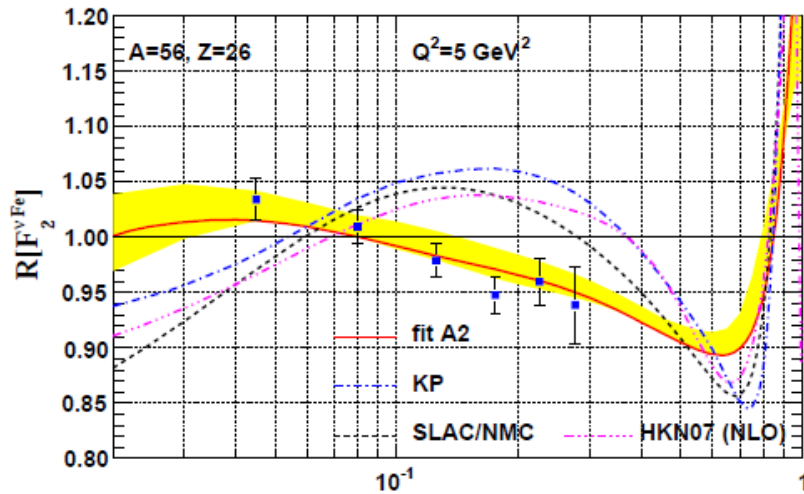


- At large  $x$ , the neutrino data on iron target from NuTeV experiment seem to pull the PDF fits in a different way from the E866 Drell-Yan data. Reducing the nuclear corrections for NuTeV can reduce the tension.

[J. F. Owens *et al.*, Phys.Rev.D75(2007)054030]



# Nuclear Effects for Neutrino Data

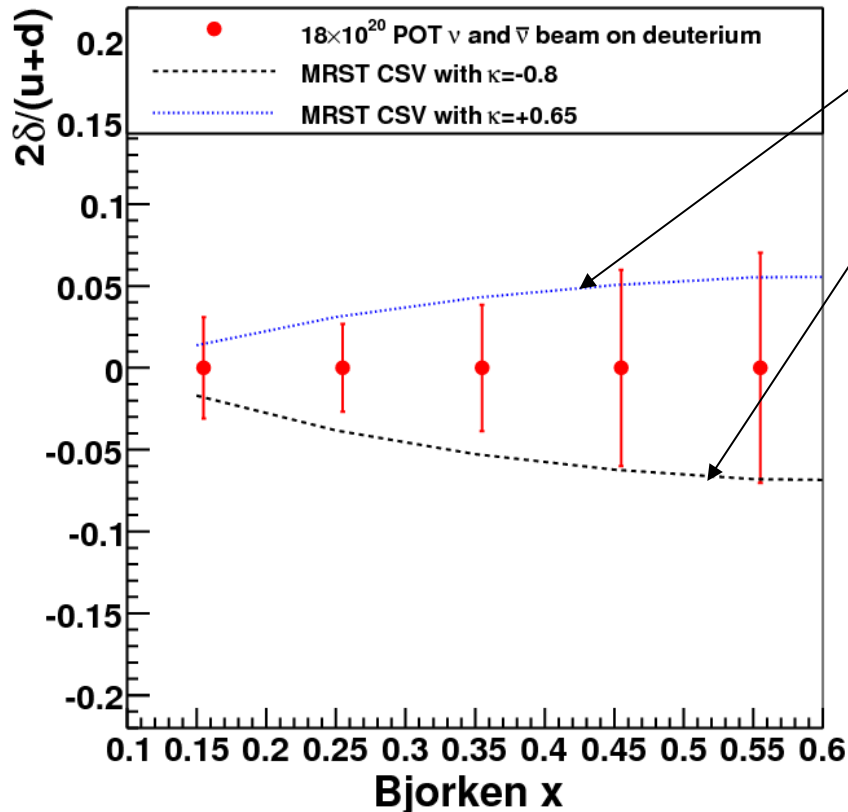


Ingo Schienbein *et al.*, Phys.Rev.D80(2009)094004;PRD77(2008)054013

- The Fe/D ratios extracted from NuTeV data and the free-nucleon PDFs differ in both shape and magnitude from those by using the models and charged lepton DIS data.

# Another Possible Goal: CSV Measurement with D<sub>2</sub>

The neutrino to anti-neutrino cross section ratio on deuterium is a direct measurement of Charge Symmetry Violation (CSV).



The 90% confidence region based on the MRST fit with assumed x dependence for CSV effects

$$u_p - d_n = -(d_p - u_n) \equiv \delta(x)$$

$$f(x) = (1-x)^4 x^{-0.5} (x - 0.0909)$$

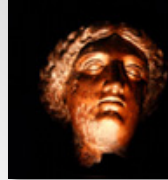
Ignoring sea (large x):

$$\frac{d^2 \sigma^{\nu D}}{d^2 \sigma^{\bar{\nu} D}} \sim \frac{d_p(x) + d_n(x)}{u_p(x) + u_n(x)} \cdot \frac{1}{(1-y)^2}$$

$$2\delta(x)/[u(x) + d(x)] \sim 1 - (1-y)^2 \frac{d^2 \sigma^{\nu D}}{d^2 \sigma^{\bar{\nu} D}}$$

*But... requires precise flux ratio!*

# MINERvA's DIS Event



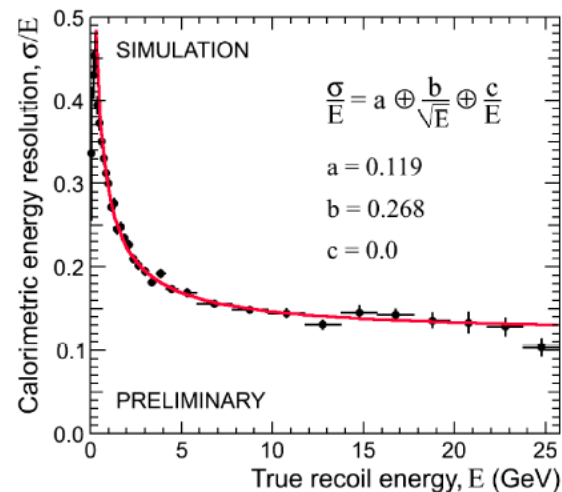
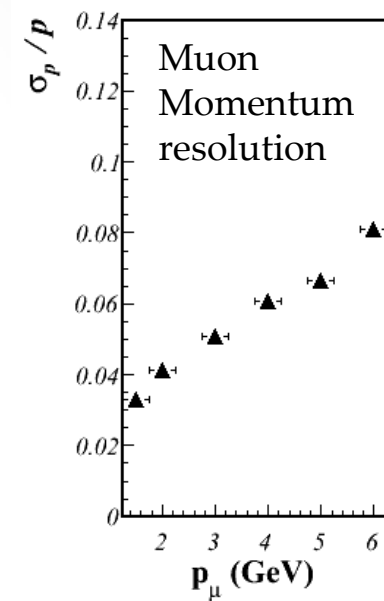
## Reconstruction

- Crucial Ingredients to determine  $x, y, Q^2$ :
  - Muon Energy and angle ( $E_\mu, \theta_\mu$ )
    - Tracking well understood, tie to MINOS reconstruction
  - Hadronic (recoil) Energy Measurement ( $E_{had}$ )
    - Studies underway, will tie to 2010 test beam data
  - Charge (for  $\nu$ /anti- $\nu$  discrimination)
    - Use MINOS Near Detector for muon charge

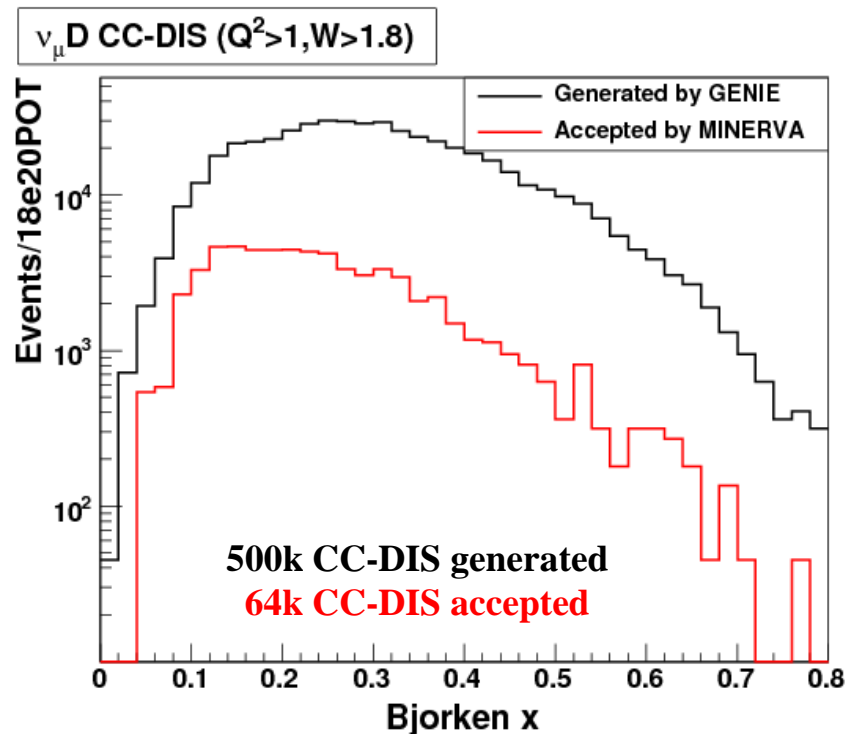
$$E_\nu = E_{had} + E_\mu \quad y = \frac{E_{had}}{E_\nu}$$

$$Q^2 = 4E_\mu E_\nu \sin^2\left(\frac{\theta_\mu}{2}\right) \quad x = \frac{Q^2}{2M_p \nu}$$

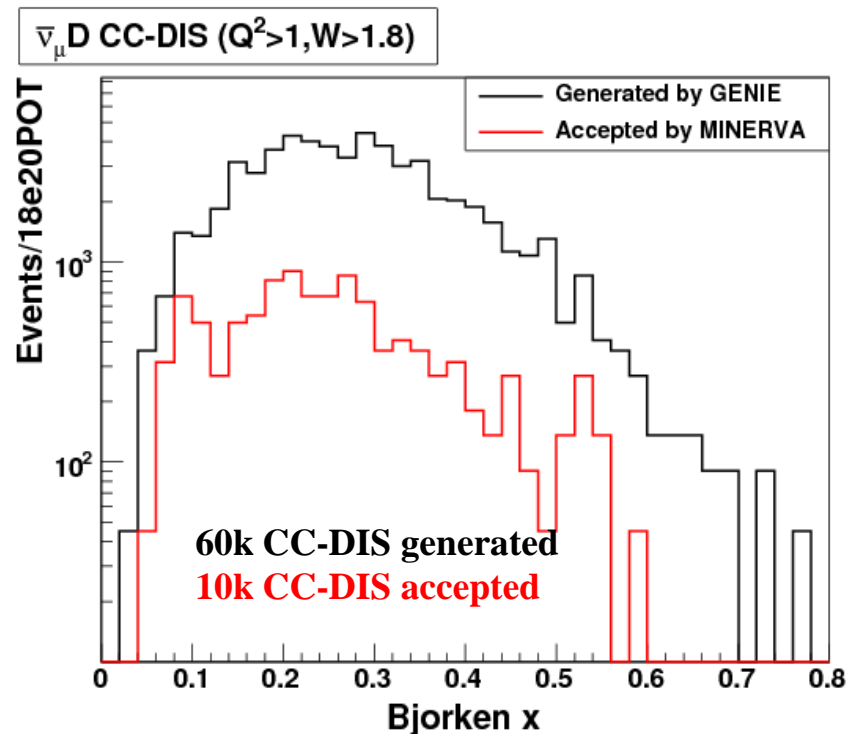
- For Cryogenic Target events, vertex resolution is also important (to remove cryostat events)
  - Studies already show 25/94mm position resolution in transverse/longitudinal direction for  $D_2$  events



# CC-DIS Events from D<sub>2</sub>



$\bar{\nu}_{\mu}$



- **Accepted by MINERvA** means two+ tracks passing 4+ planes including a momentum analyzable muon.
- The mass of the deuterium to fill the existing cryogenic target is 0.372 ton
- For both neutrino and anti-neutrino cases, the beam is **18\*10<sup>20</sup> POT** ME flux, which is the nominal beam for NOvA and will be used by MINERvA.

# MINERvA

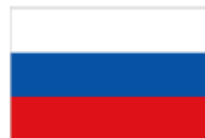
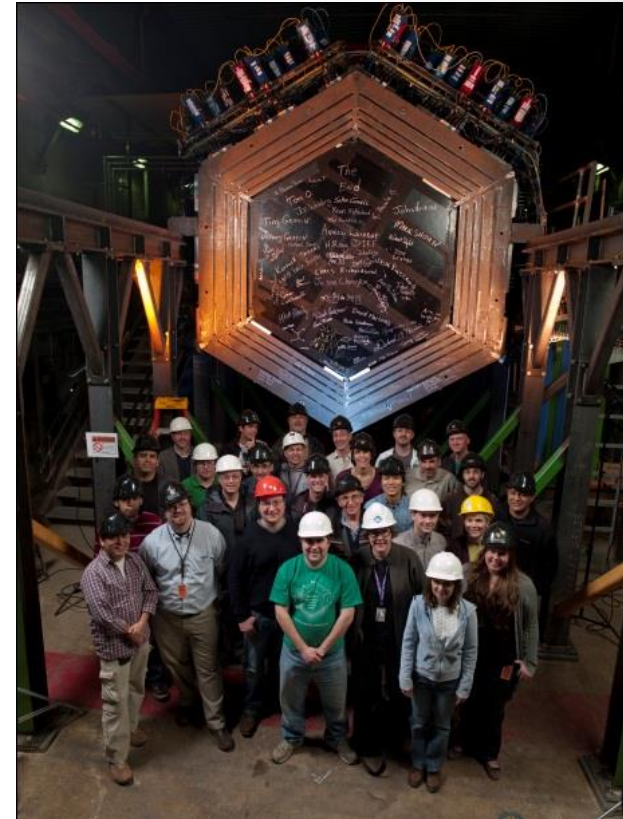
## Main INjector ExpeRiment v-A



- MINERvA is a neutrino scattering experiment at Fermilab in Batavia, IL, USA.
- Collaboration of 80 nuclear and particle physicists.

University of Athens  
University of Texas at Austin  
Centro Brasileiro de Pesquisas Físicas  
Fermilab  
University of Florida  
Université de Genève  
Universidad de Guanajuato  
Hampton University  
Inst. Nucl. Reas. Moscow  
Mass. Col. Lib. Arts  
Northwestern University

Otterbein University  
Pontificia Universidad Catolica del Peru  
University of Pittsburgh  
University of Rochester  
Rutgers University  
Tufts University  
University of California at Irvine  
University of Minnesota at Duluth  
Universidad Nacional de Ingeniería  
Universidad Técnica Federico Santa María  
William and Mary



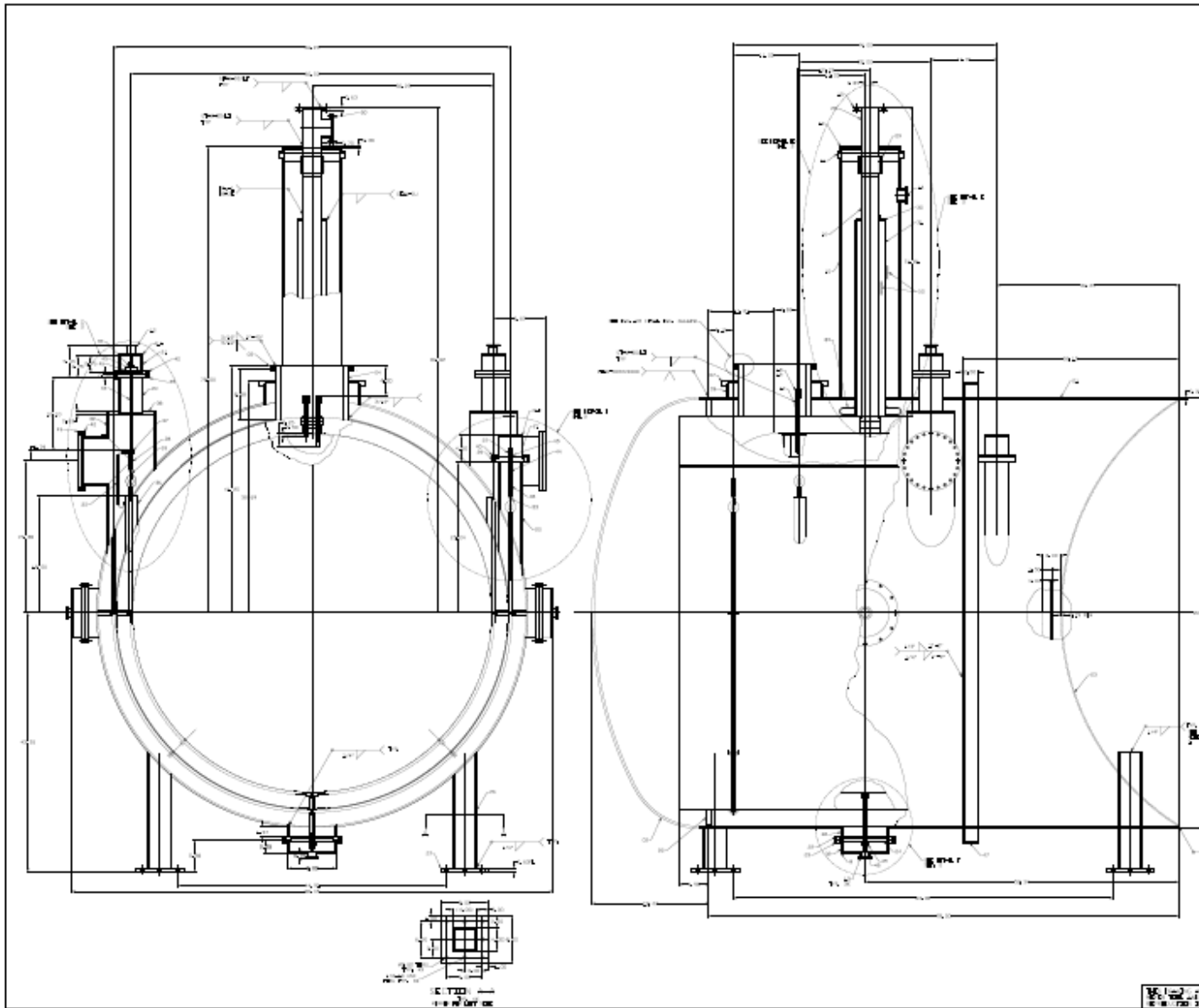


# Total POTs

From 3/22/2010	nu	nub	total
nu -LE	3.98E+20		
nu-0 current	7.38E+18		
nu-ME	1.47E+19		
nu-HE	8.15E+18		
nub-LE		1.70E+20	
nub-ME		1.92E+19	
Total Special	3.02E+19	1.92E+19	4.94E+19
total	4.29E+20	1.89E+20	6.18E+20
He Filled	1.90E+20		
He Empty	5.50E+19		
Water Target	1.96E+20		

From Howard Budd's AEM report on April 30, 2012

- For MINERvA
  - 97.1% Live 3/22/10 to now
  - 97.7% live on NT07
- Do not include Aug 23-26 when MINOS was down at the start of NT-04 run.



ITEM	QTY	DESCRIPTION	UNIT
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2	1	FLANGE	CLM 300.0
3	1	HEAT TREATING	CLM 300.0
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NOTES:  
 1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.  
 2. ALL SURFACES ARE TO BE FINISHED TO A 32 RMS SURFACE FINISH UNLESS OTHERWISE SPECIFIED.  
 3. ALL DIMENSIONS ARE TO BE TAKEN FROM THE EXTERNAL SURFACE UNLESS OTHERWISE SPECIFIED.  
 4. ALL DIMENSIONS ARE TO BE TAKEN FROM THE CENTERLINE UNLESS OTHERWISE SPECIFIED.  
 5. ALL DIMENSIONS ARE TO BE TAKEN FROM THE FACE UNLESS OTHERWISE SPECIFIED.  
 6. ALL DIMENSIONS ARE TO BE TAKEN FROM THE BACK UNLESS OTHERWISE SPECIFIED.  
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 17. ALL DIMENSIONS ARE TO BE TAKEN FROM THE MIDDLE UNLESS OTHERWISE SPECIFIED.  
 18. ALL DIMENSIONS ARE TO BE TAKEN FROM THE EDGE UNLESS OTHERWISE SPECIFIED.  
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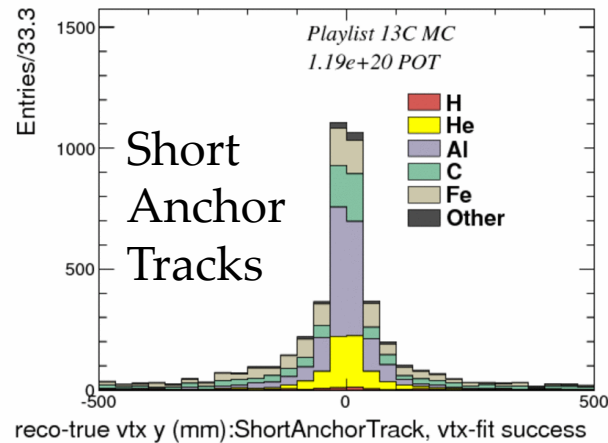
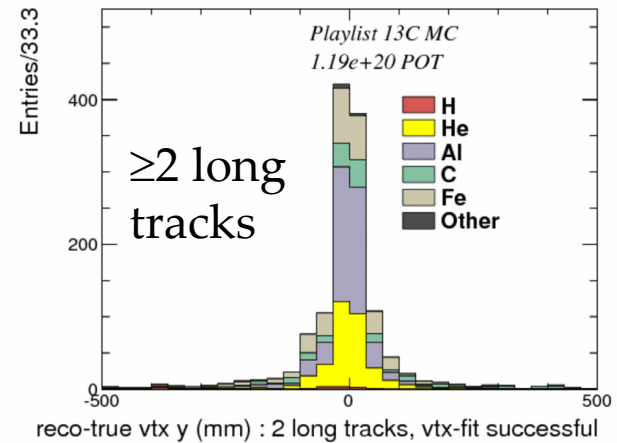
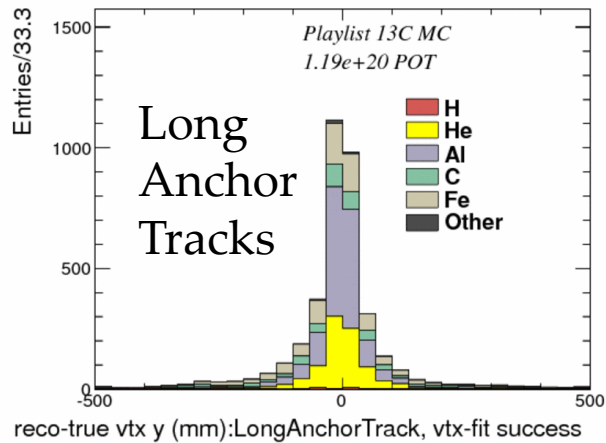
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 REVISED - UPD. I. NO. 01/1/10

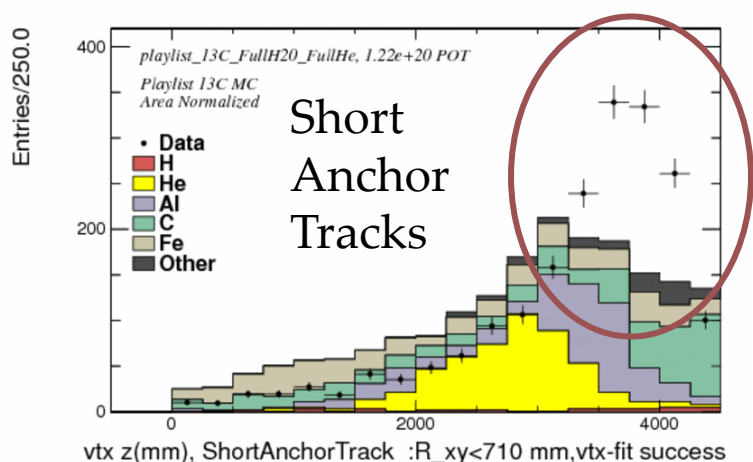
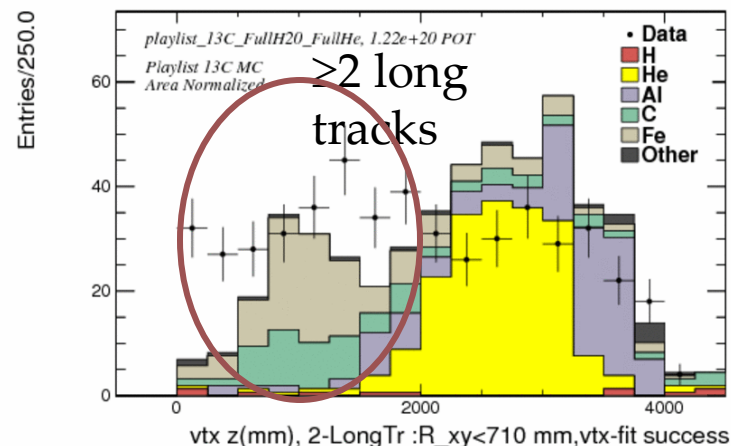
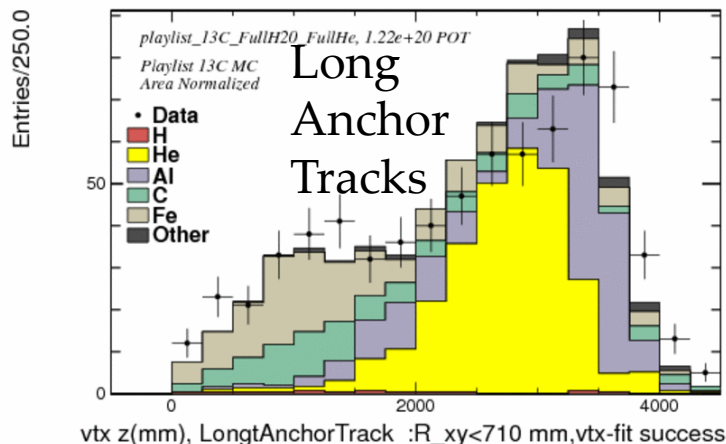
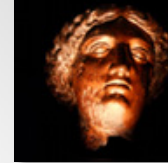




# Vertex-Y Resolution



# Reconstructed Z-vertex : With Radial Selection



- Agreement is better for “LongAnchorTrack” events
- Work in progress to understand the data-MC difference