Cryogenic Target Event Reconstruction in MINERνA

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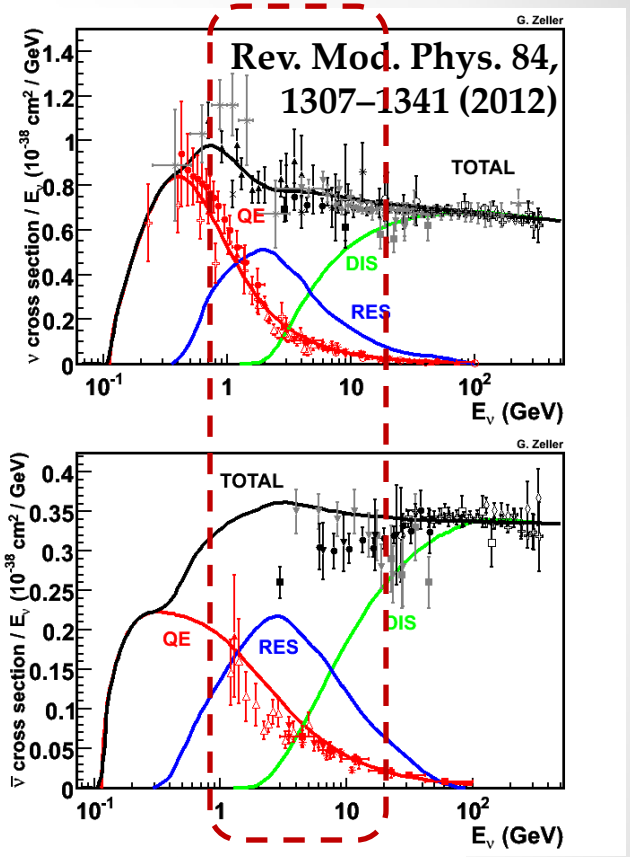
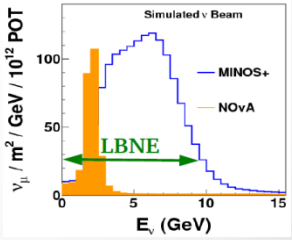
Outline

- Physics Motivation
- Neutrino beam and flux
- The MINERνA 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

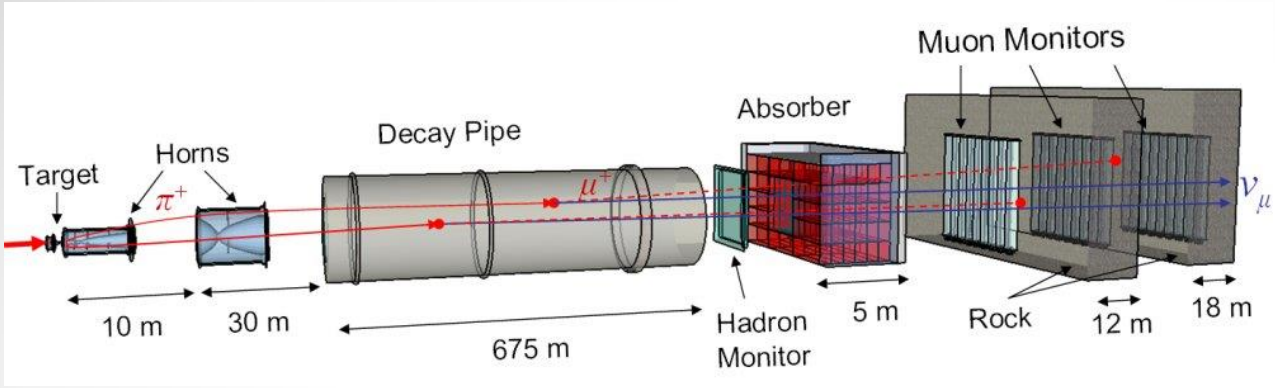
Physics Goals for MINERνA

- 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 ν and anti-ν interactions in nuclear matter in 1-10 GeV energy range is crucial for current and upcoming neutrino oscillation experiments
- Medium Energy (ME) Beam in NOνA era
  - Structure Functions on various nuclei





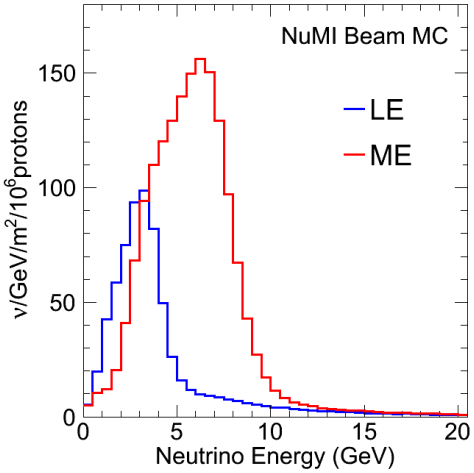
Neutrinos at the Main Injector



MINERvA

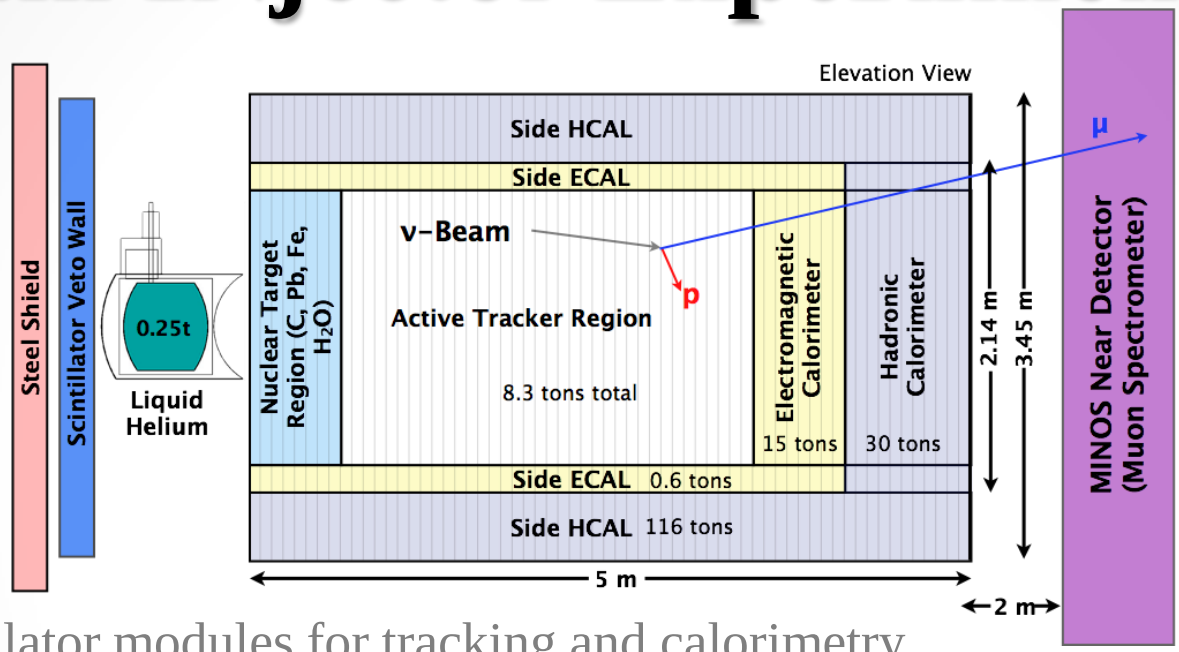
MINOS Near Detector

- Magnetic horns focus pions and kaons, which decay into muons and neutrinos
- ν 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 μs 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: 3.98×10^{20} protons on target (POT)
LE anti-neutrino mode 1.7×10^{20} POT

MINERvA
Main INjector ExpeRiment ν-A

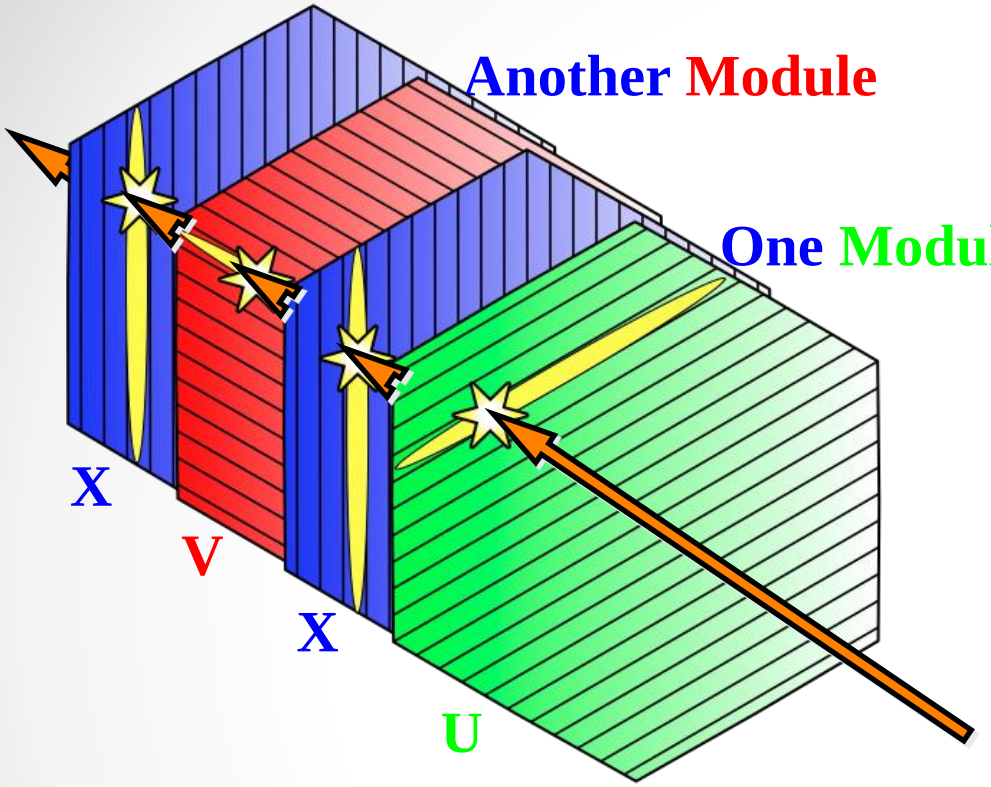


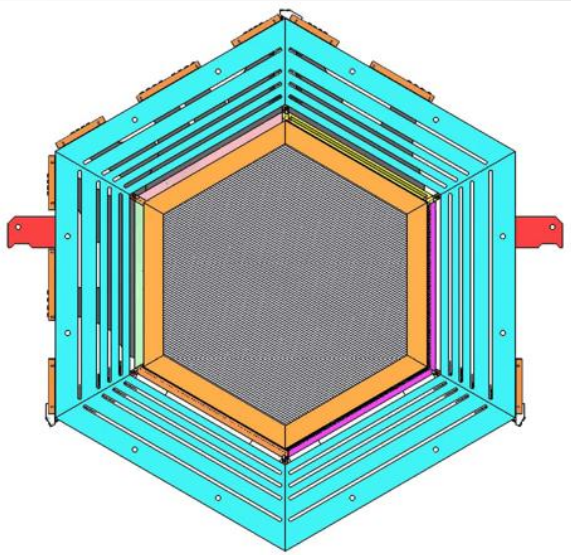
- 120 scintillator modules for tracking and calorimetry (~32k readout channels).
- MINOS Near Detector serves as muon spectrometer
- Construction completed Spring 2010.
- Helium and Water added in 2011
  - About half of the POT in neutrino mode taken with Helium and water targets

- M. Datta, Hampton U.

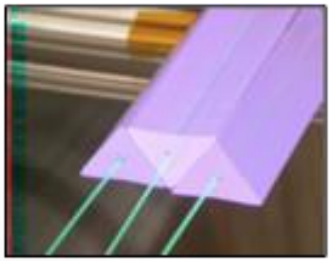
Target	Fiducial Mass (tons)	ν_μ CC Events in 1.0e20 POT
Plastic	6.43	313k
Helium	0.25	14k
Carbon	0.17	9.0k
Water	0.39	20k
Iron	0.97	54k
Lead	0.98	57k

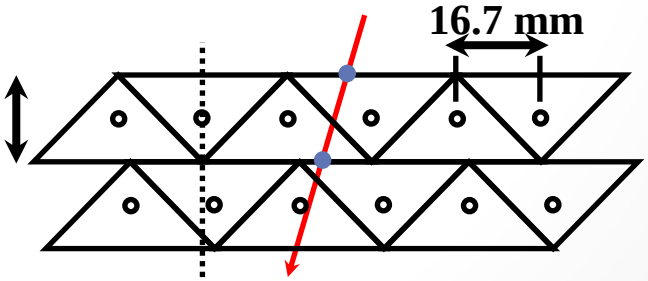
MINERvA





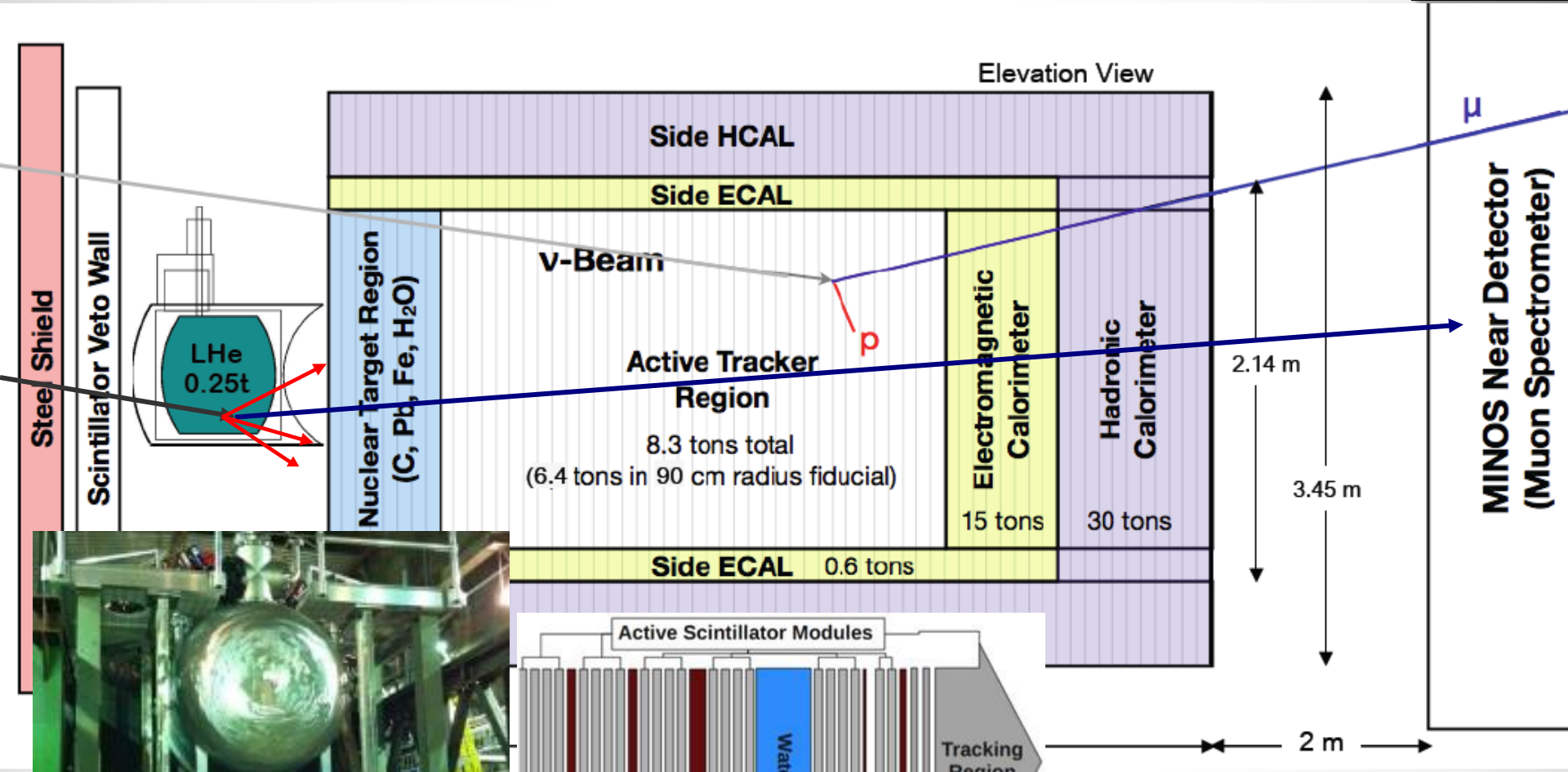
Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry

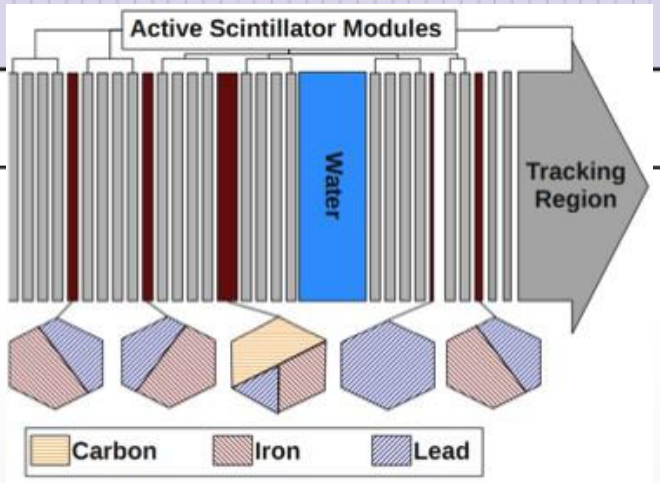




Charge sharing for improved position resolution (<3 mm) and alignment

Target Region



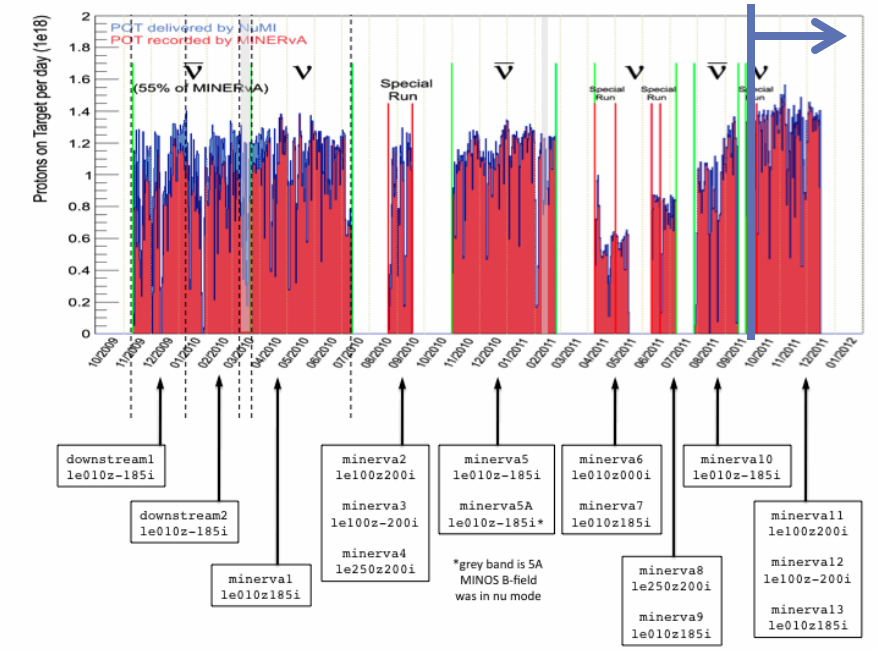


Targets: C, Pb, Fe, water
Cryogenic target : liquid He.
Proposal for liquid deuterium and hydrogen targets

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



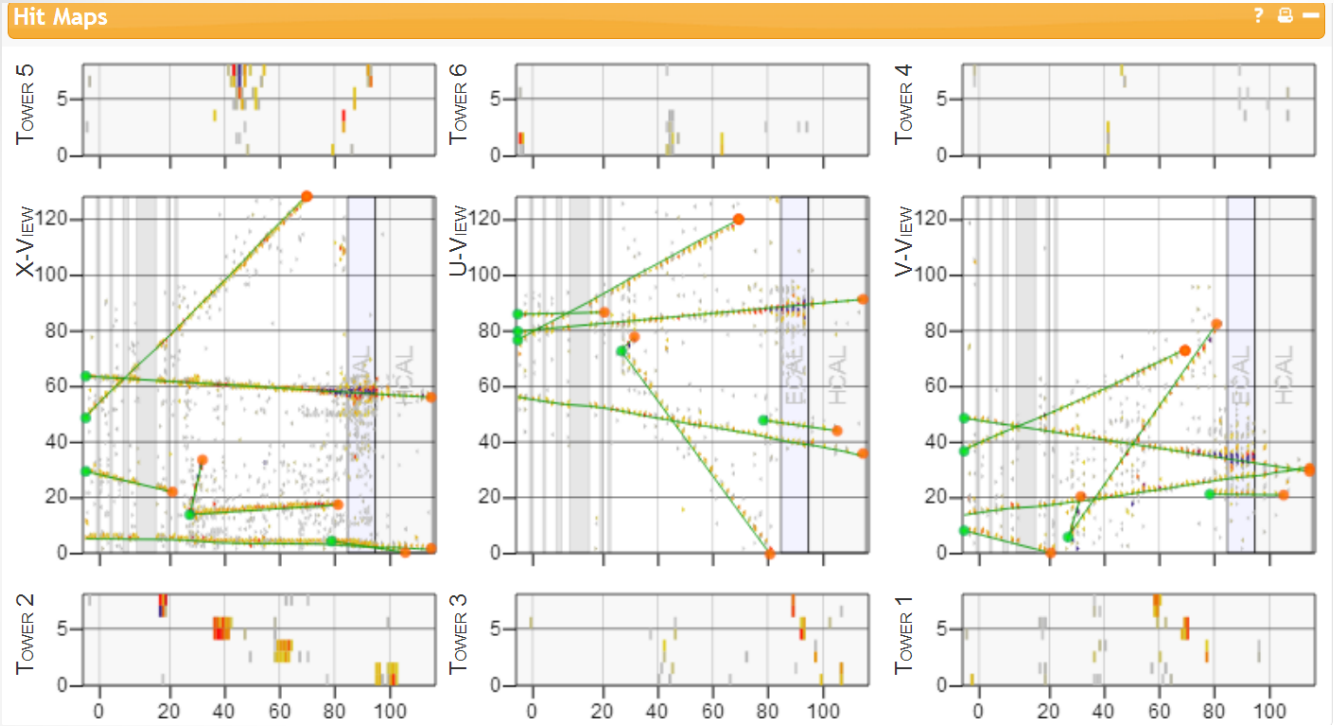
- Target installed in July 2011
- Filled with He in late September 2011
- Neutrino beam exposure beginning in October 2011
  - **Playlist 13 (LE ν): ~1.9e20 POT, 18-10-2011 to 30-04-2012**
  - Playlist 11 (pseudo ME ν) : 24-09-2011 to 30-09-2011

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

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 < 4293.04mm (first plane location), then those tracks together with the anchor track is passed to the vertex fitting algorithm

Two Reconstructed Long Tracks

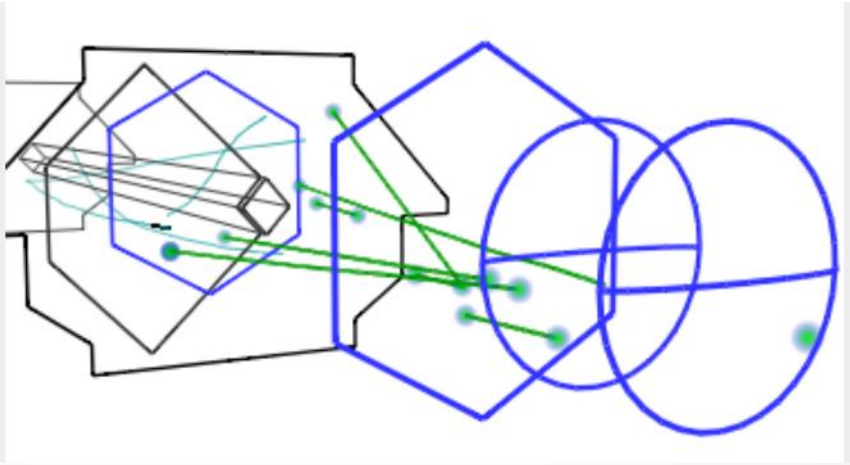


Slice Info

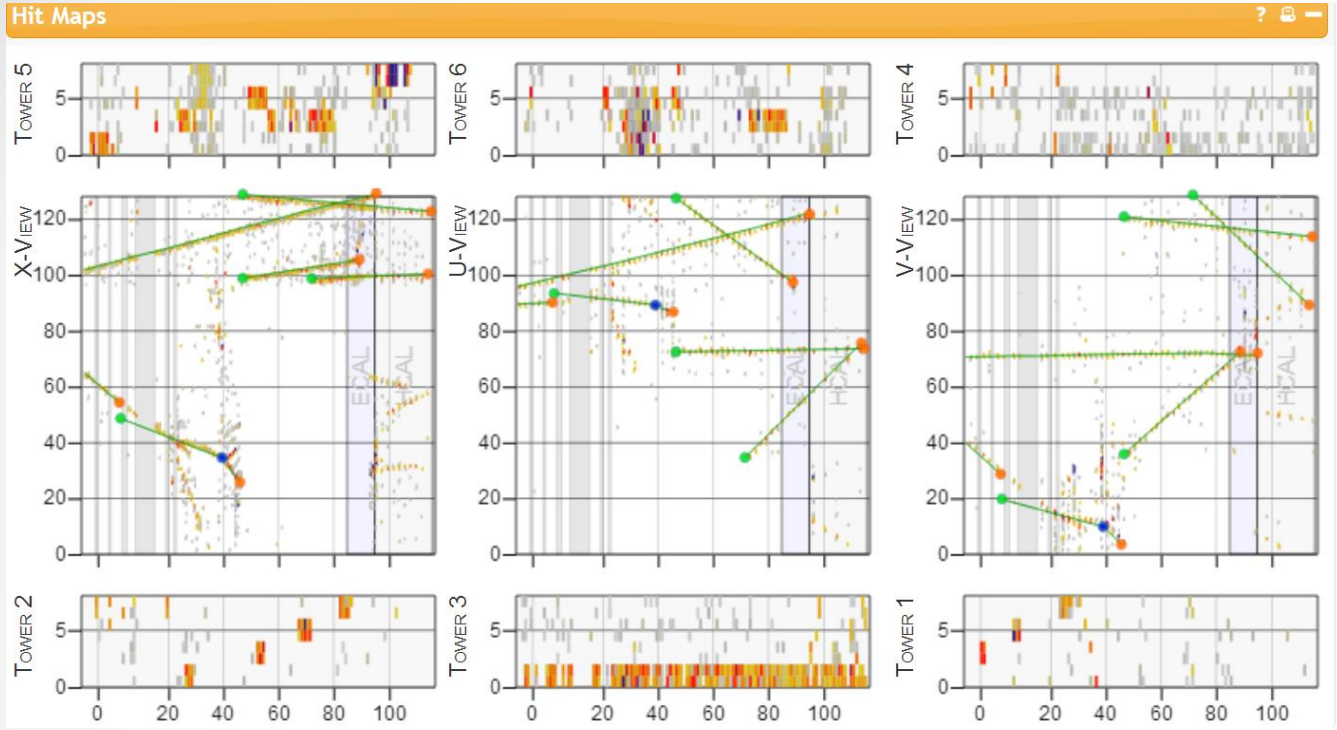
Event ID	MV|3601|57|12|All Slices
SW Ver	v10r5p1
Time	23:15:39 11/22/2011 CST (1.2 years ago)
Hits	3200 ID, 223 OD, 27 Veto
Reco	2462 clusters, 7 tracks, 15 vertices, 10 blobs
Slice	All Slices of 9
Hits	3200 ID, 223 OD, 27 Veto
Reco	2462 clusters, 7 tracks, 15 vertices, 10 blobs
Mean time	3357 ns
Total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

▸ Other Information

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



Long Anchor Track

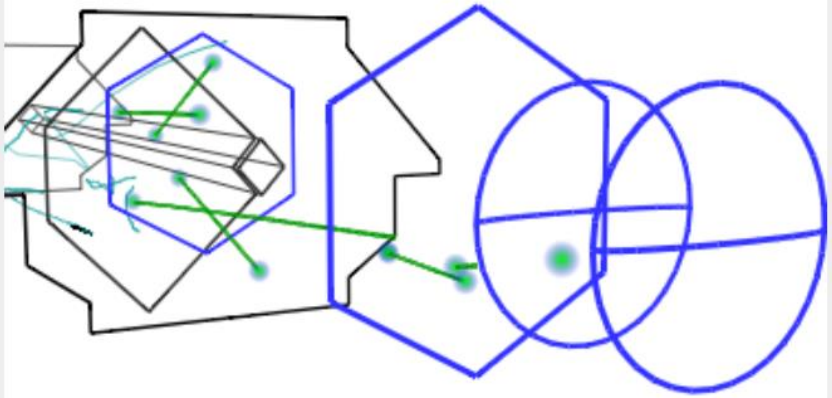


Slice Info

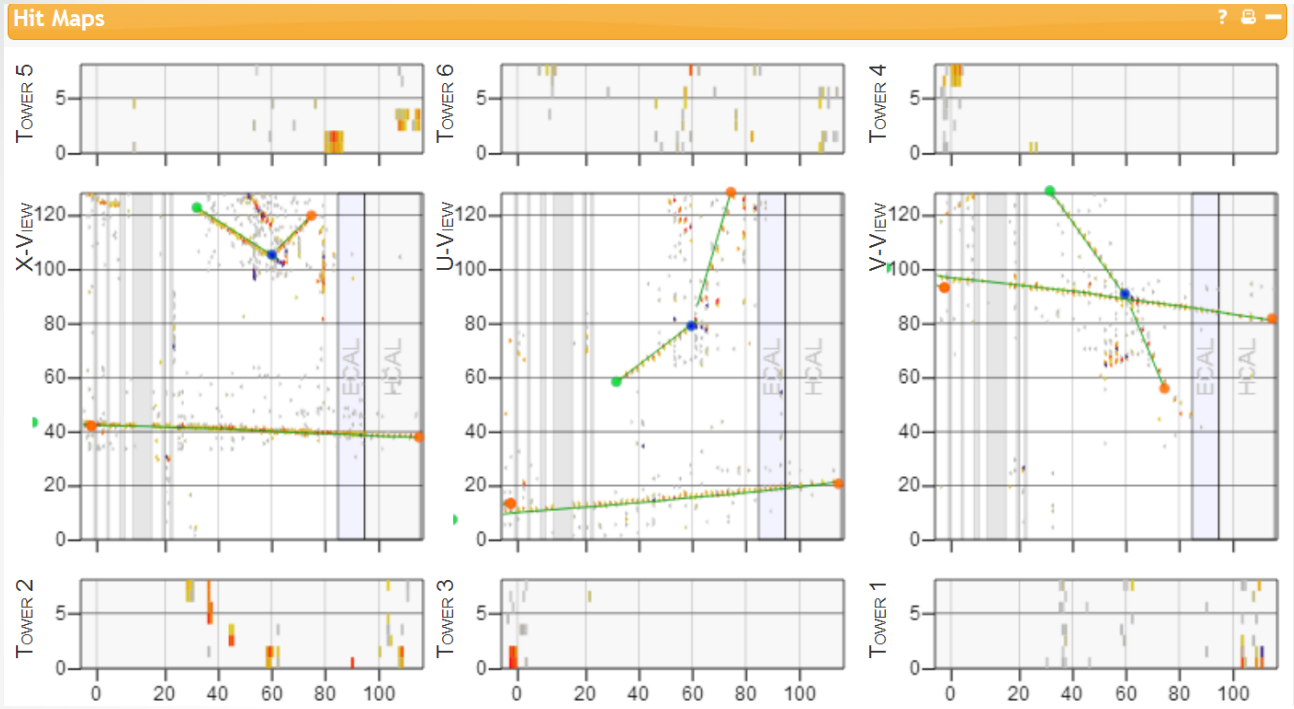
Event ID	MV|3601|31|22|All Slices
SW Ver	v10r5p1
Time	15:29:20 11/22/2011 CST (1.2 years ago)
Hits	2644 ID, 1339 OD, 23 Veto
Reco	2052 clusters, 7 tracks, 12 vertices, 3 blobs
Slice	All Slices of 15
Hits	2644 ID, 1339 OD, 23 Veto
Reco	2052 clusters, 7 tracks, 12 vertices, 3 blobs
Mean time	2443 ns
Total PE	26278 pe
Vis Energy	6257.6 MeV
Filters	(none)

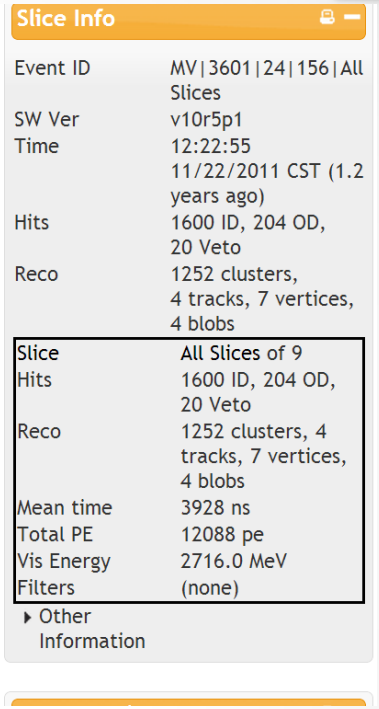
▸ Other Information

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

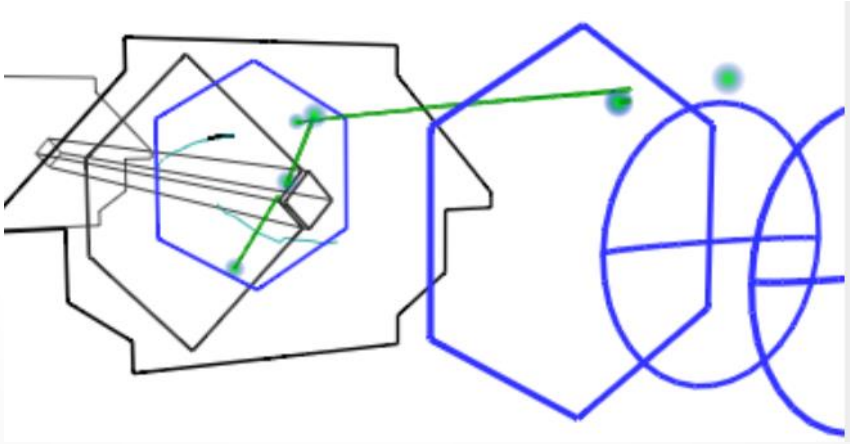


Short Anchor Track



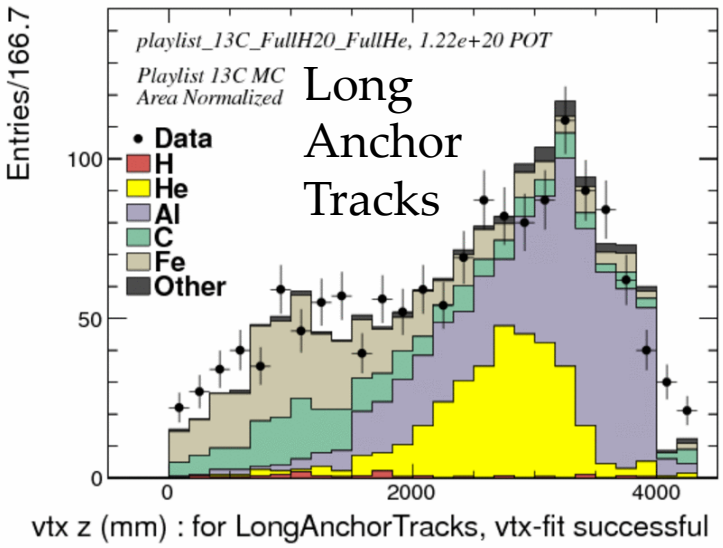


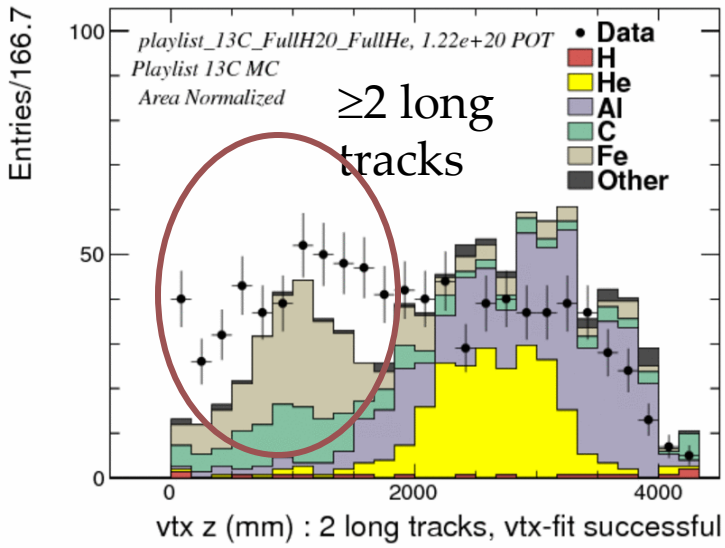
Run-Subrun-Gate
3601-24-56
Playlist :
Minerva 13C

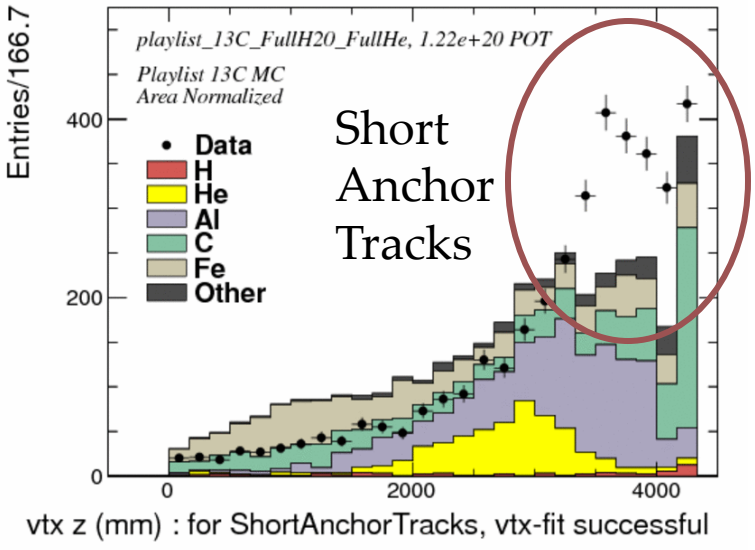


Data-MC Comparison …

Reconstructed Z-vertex

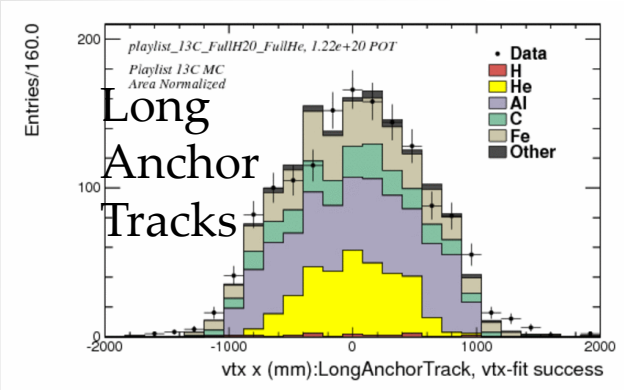


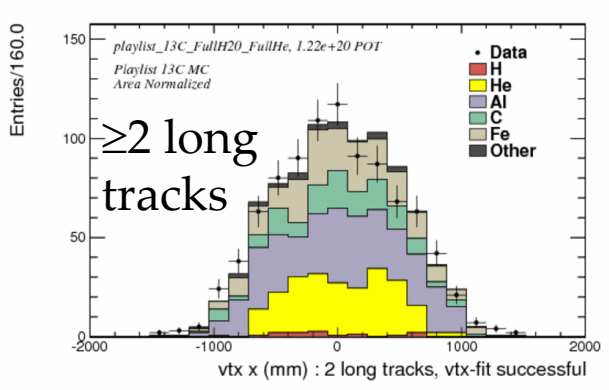


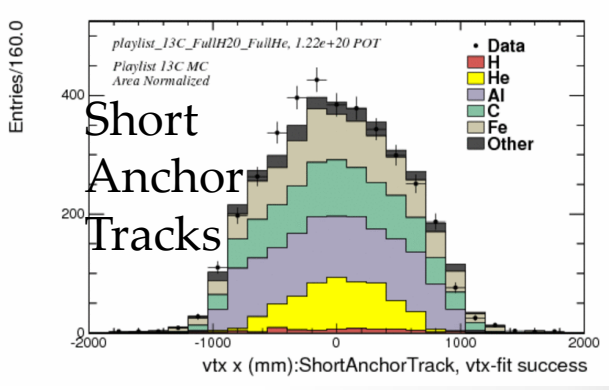


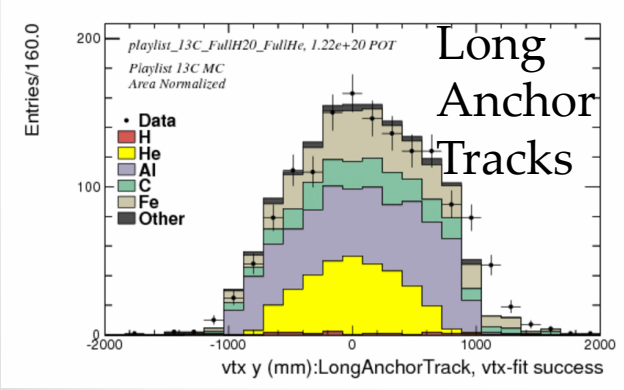
- Agreement is better for "LongAnchorTrack" events
- Work in progress to understand the data-MC difference

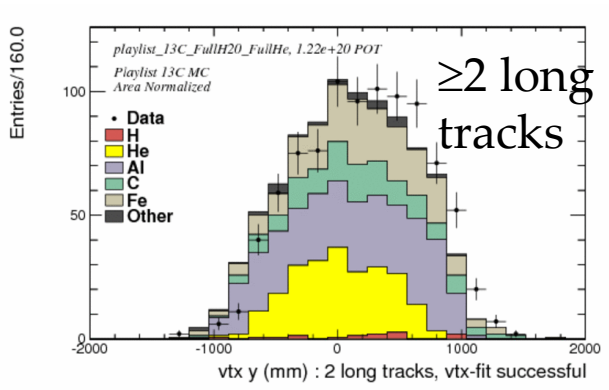
Reconstructed vertex-X and vertex-Y

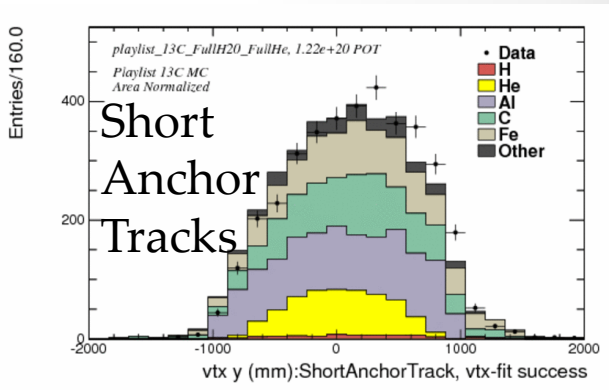




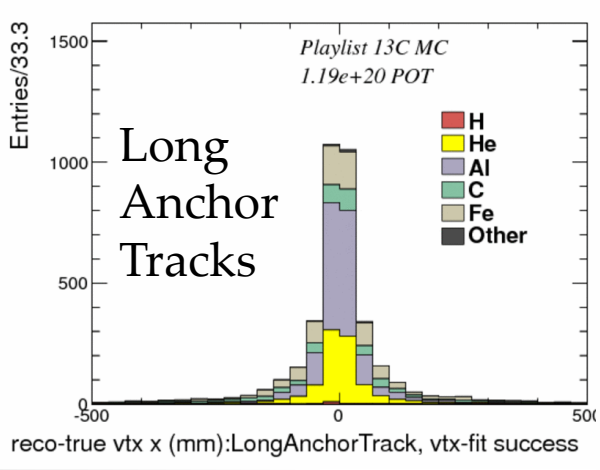


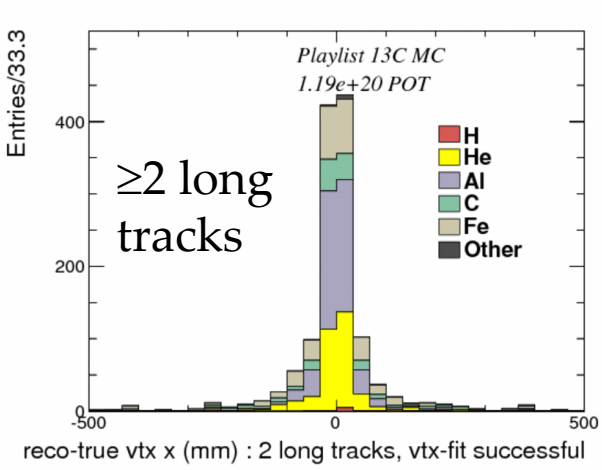


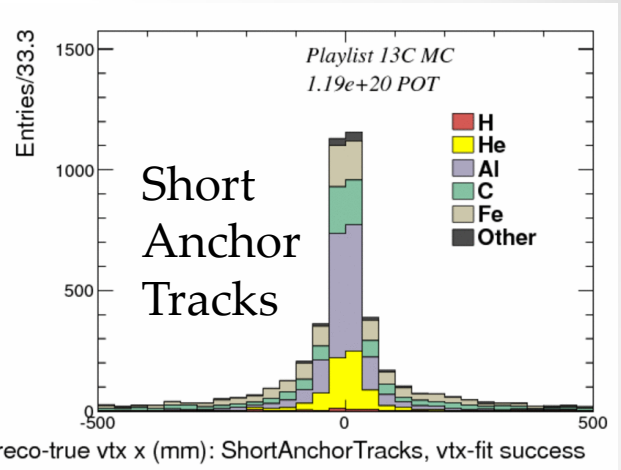


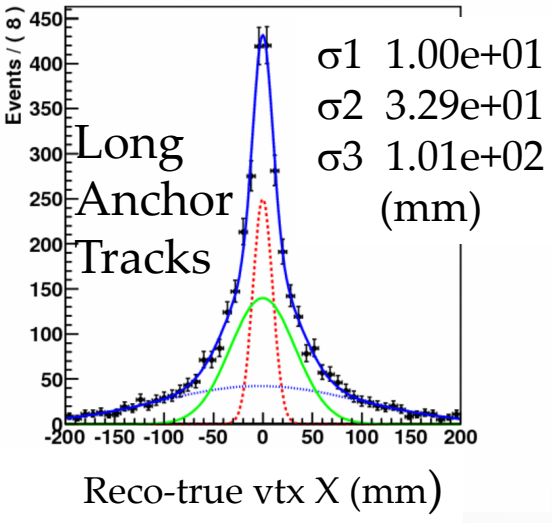


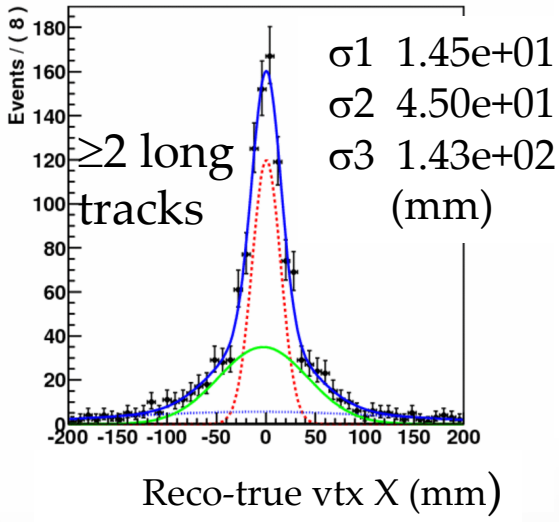
Vertex-X Resolution

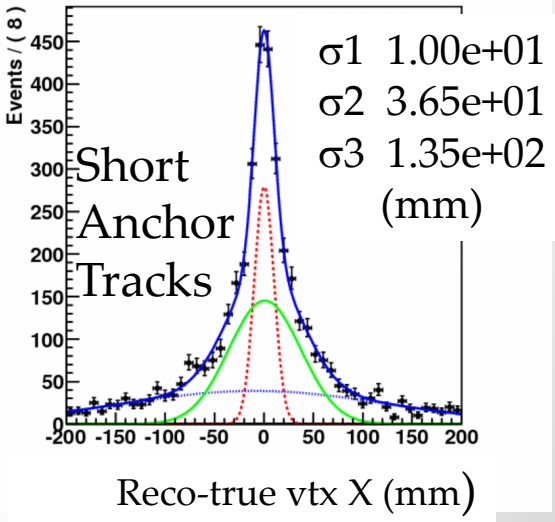




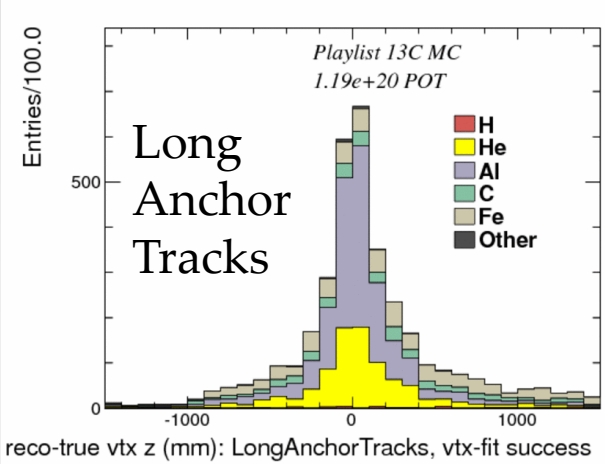


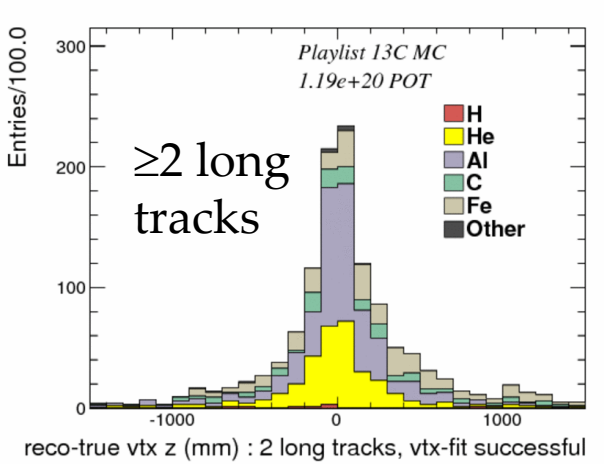


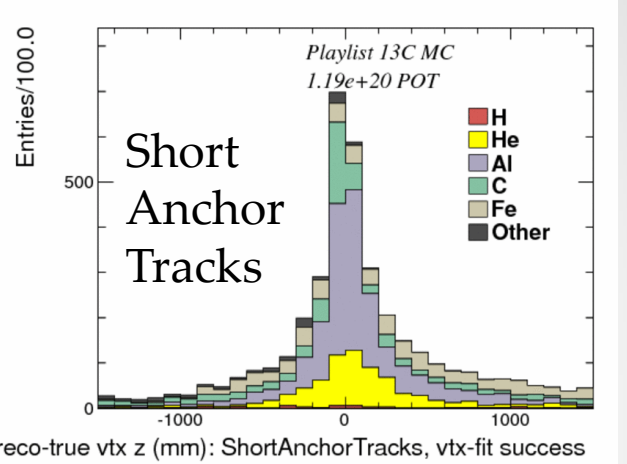


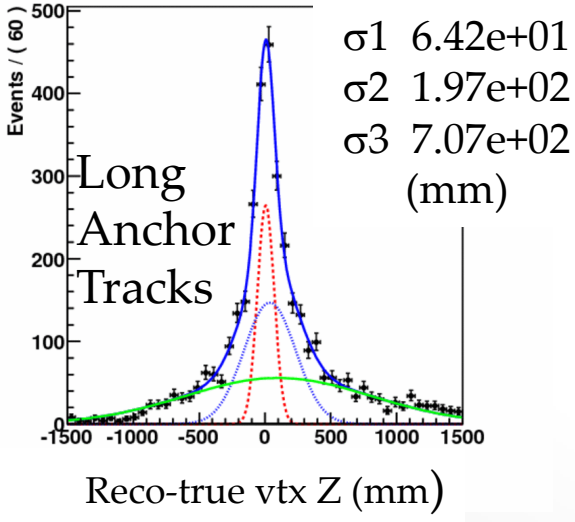


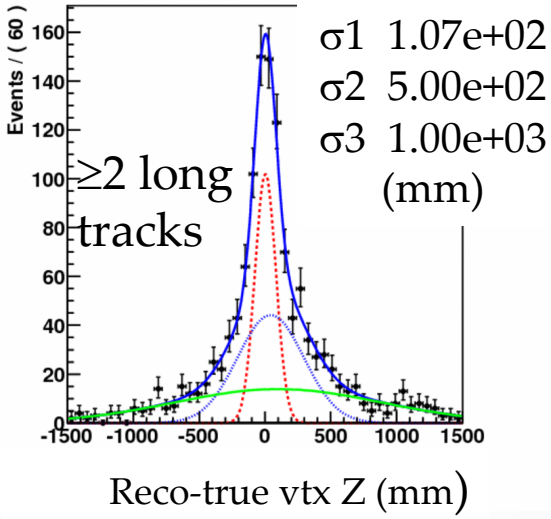
Z-Vertex Resolution

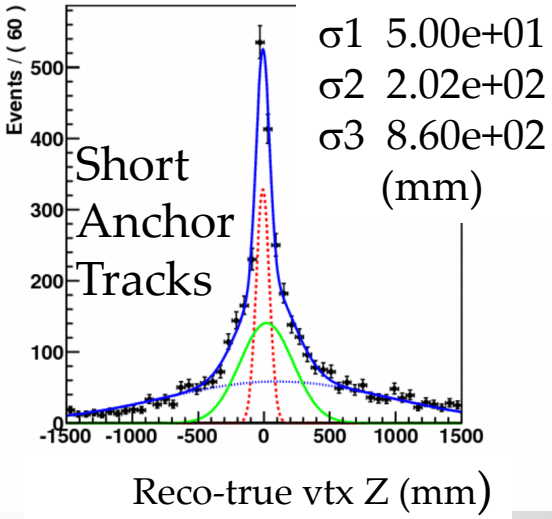








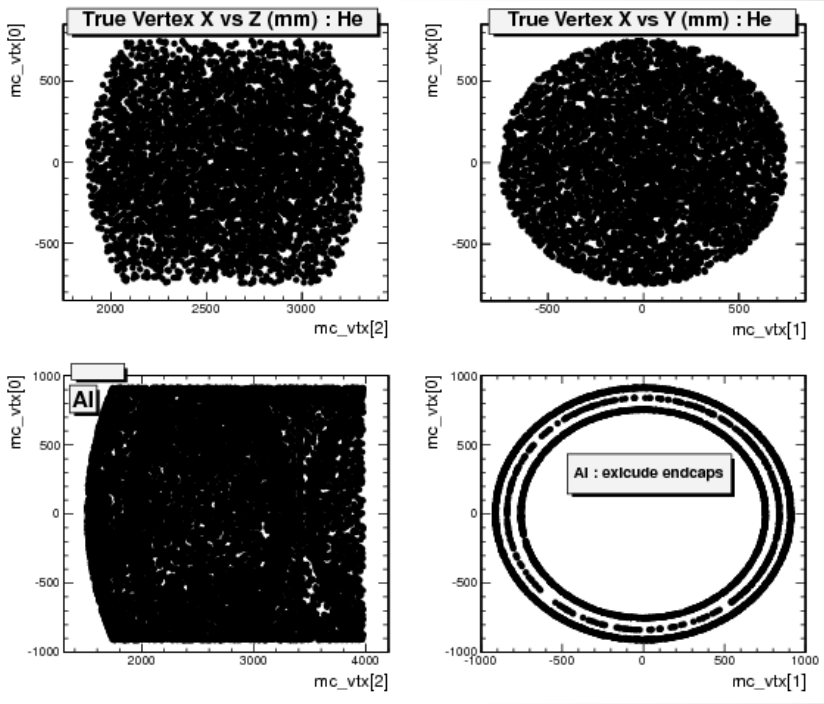




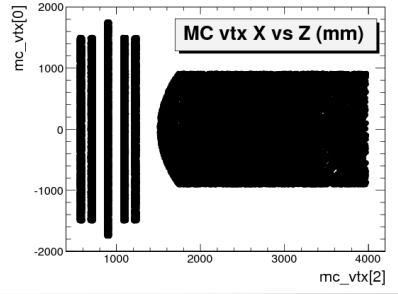
Data : He-filled VS Empty Target

Imaging Cryogenic Target Region from Data Events

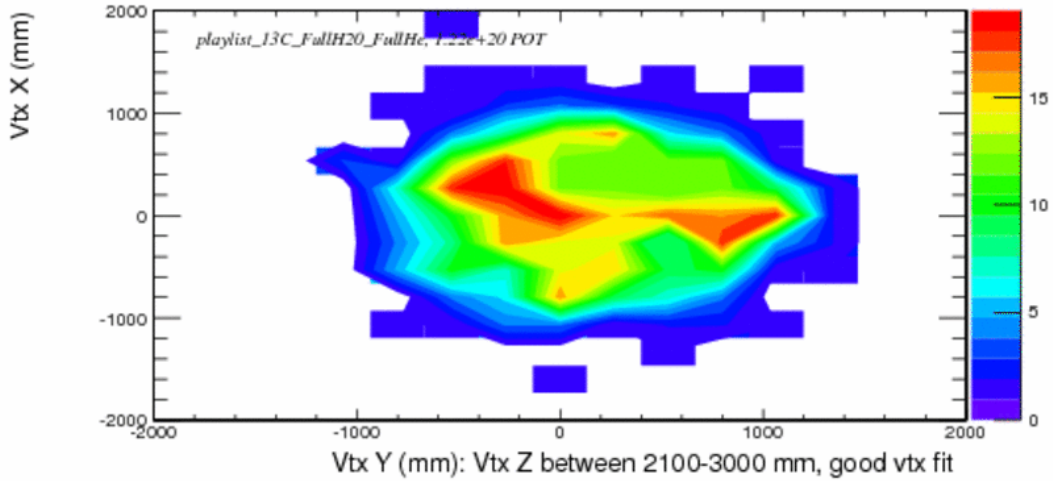
- Use events from playlist 13C (full He) and playlist 13E (empty He)
- Check if we can we image the Aluminum vessel, using events
  - X vs Z vertex
  - Y vs Z vetex
  - X vs Y vertex, requiring Z vertex between 2100-3000 mm
- For reference shown are the position and dimension of cryogenic and veto detector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

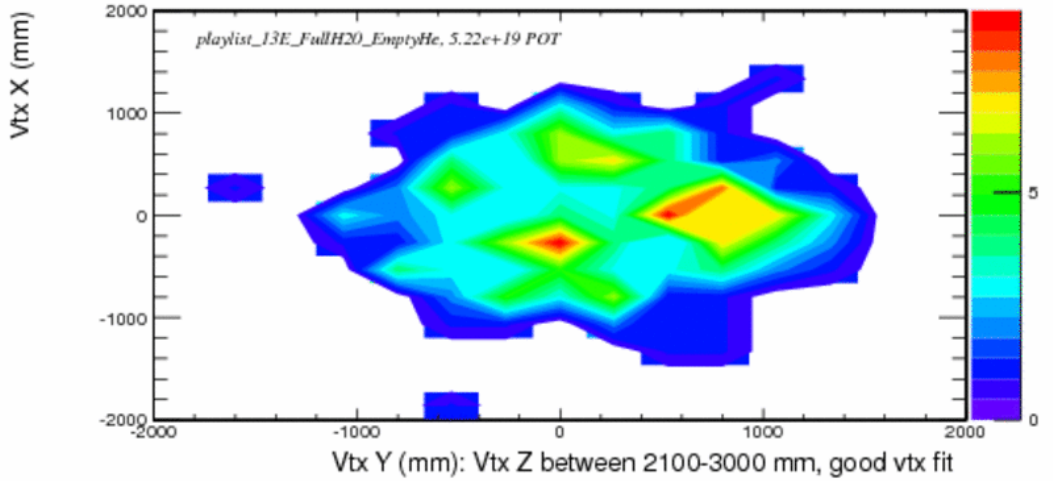


Position and dimension for cryo and veto detectors in geometry file in Minerva analysis software



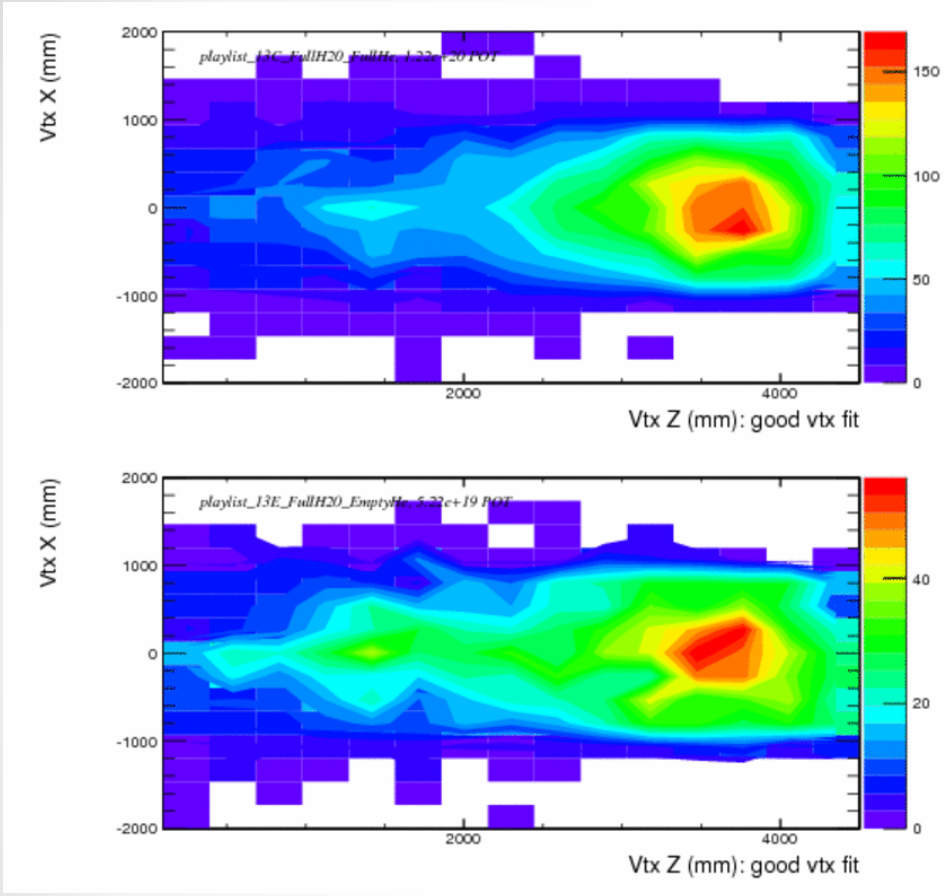
Vertex X vs Y (mm) : Events with Z vertex between 2100-3000 mm

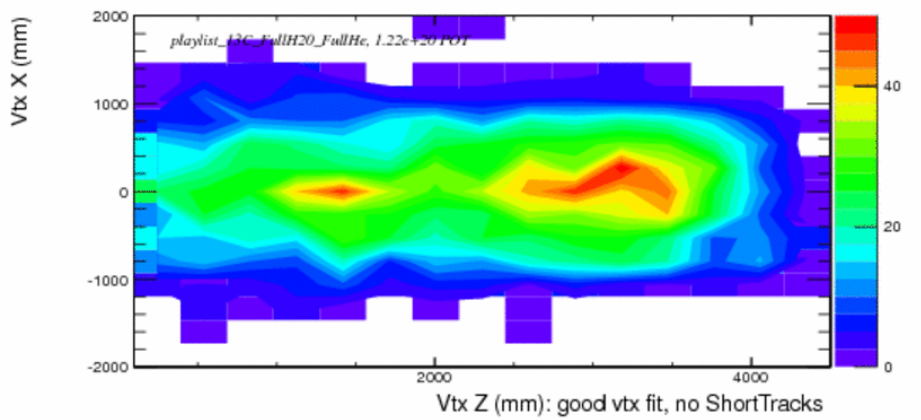


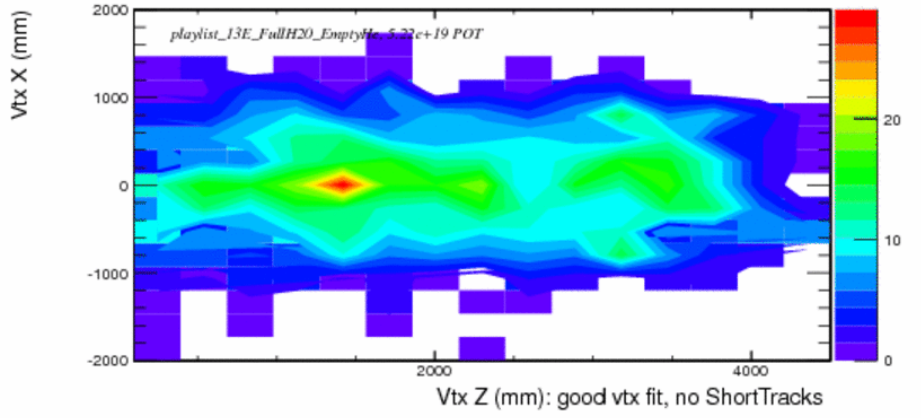


- Upper plots : playlist 13C (full He)
- Lower plots: playlist 13E (empty He)
- Can see the image for Cryogenic target inner and outer radius ~710 mm and ~750 mm

Vertex X vs Z (mm)

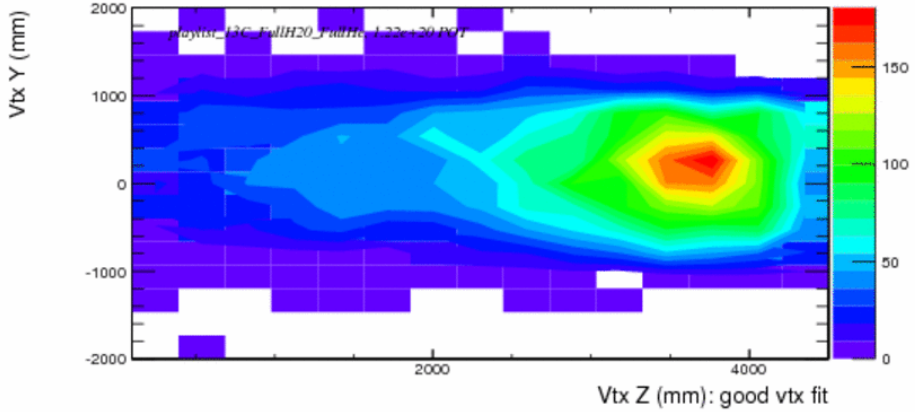


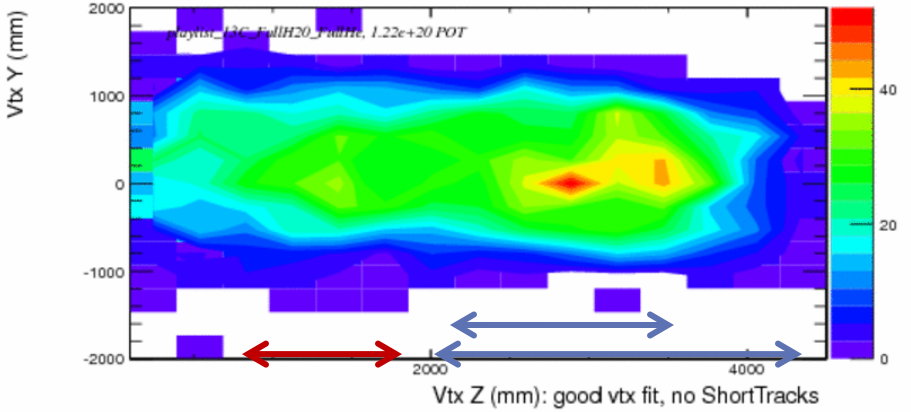


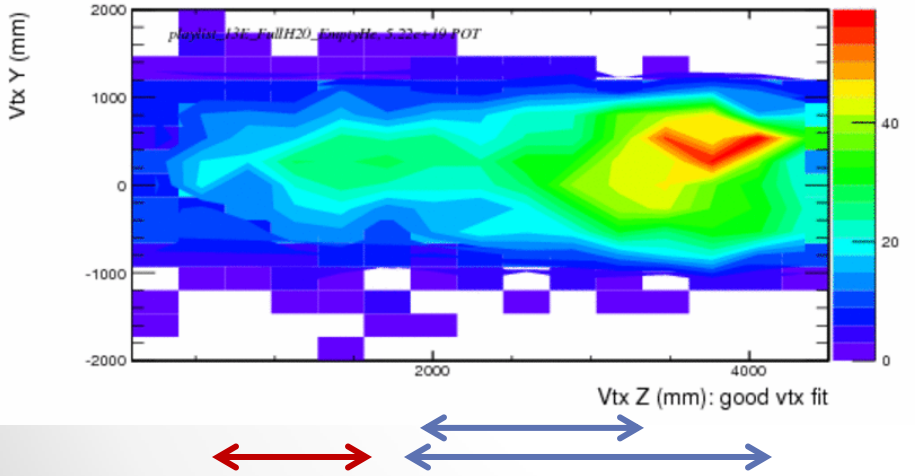


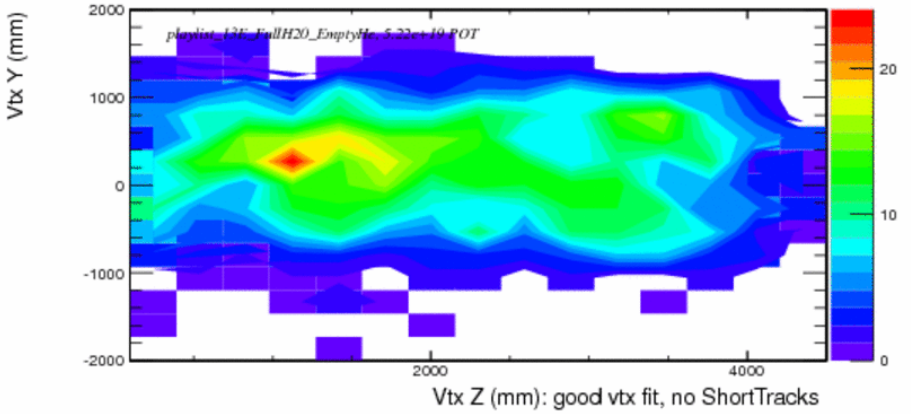
- Upper plots : playlist 13C (full He), lower plots: playlist 13E (empty He)
- Right plots : exclude events selected by “AnchorShortTrack”-ing

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

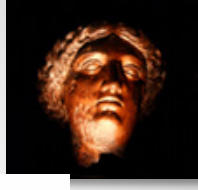
	Playlist 13C:Full He, Full water 1.22e+20 POT*	Playlist 13E :Empty He, Full water 5.22e+19 POT*
Require good vertex fit		
>=2 long trks	916	386
LongAnchorTrack	1479	617
ShortAnchorTrack	3732	1492
Total	6127	2495

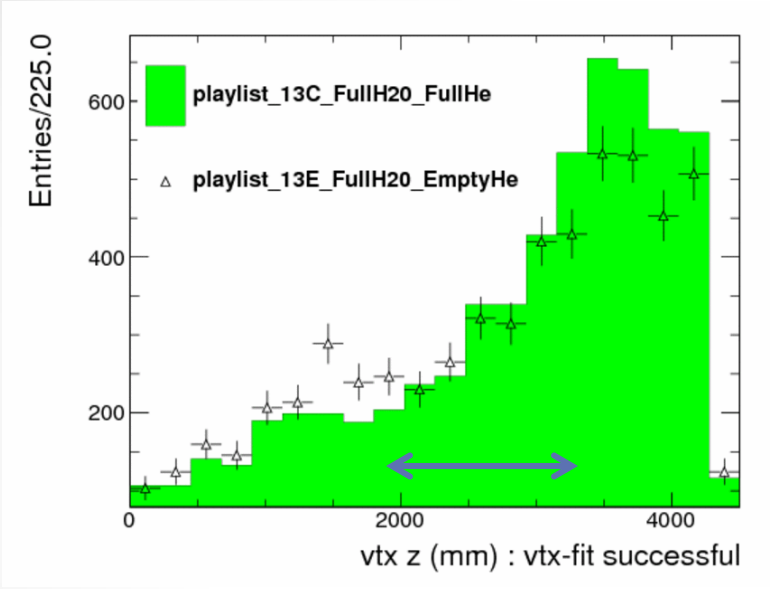
- *Still need to recover missing data at the analysis stage
- Current vertex quality requirement is most likely not optimal in this case
  - Can be optimized to improve selection efficiency

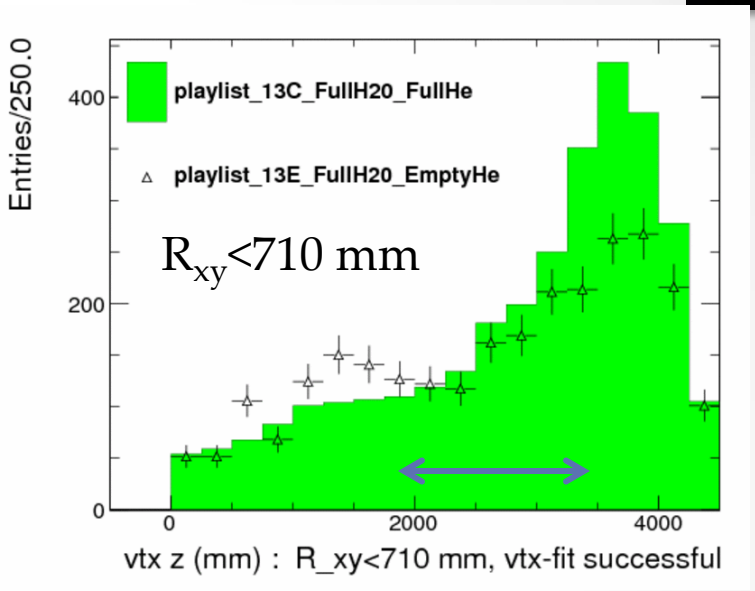
	Playlist 13C	Playlist 13E
Require good vertex fit, Z vtx 2100-3000 mm		
>=2 long trks	201	87
LongAnchorTrack	394	127
ShortAnchorTrack	0	0
Total	595	214

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

Comparison : 13C, 13E Data

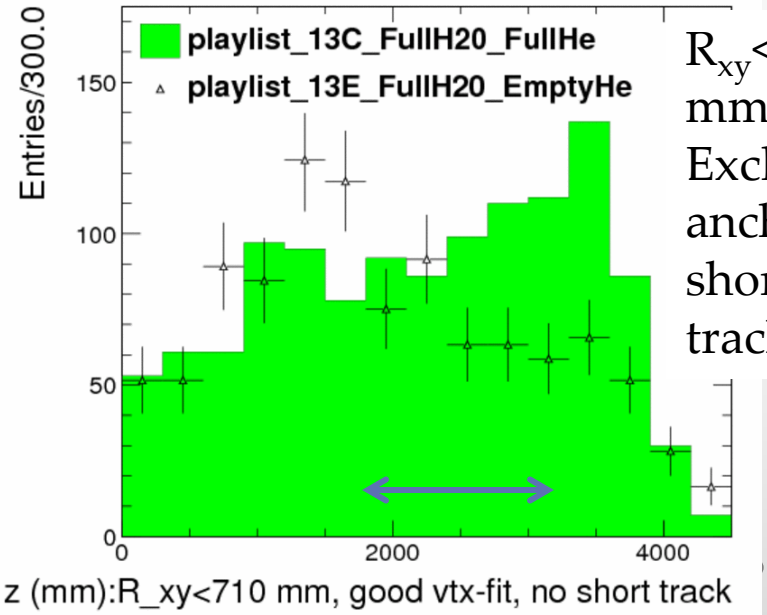






13E data normalized to POT for 13C

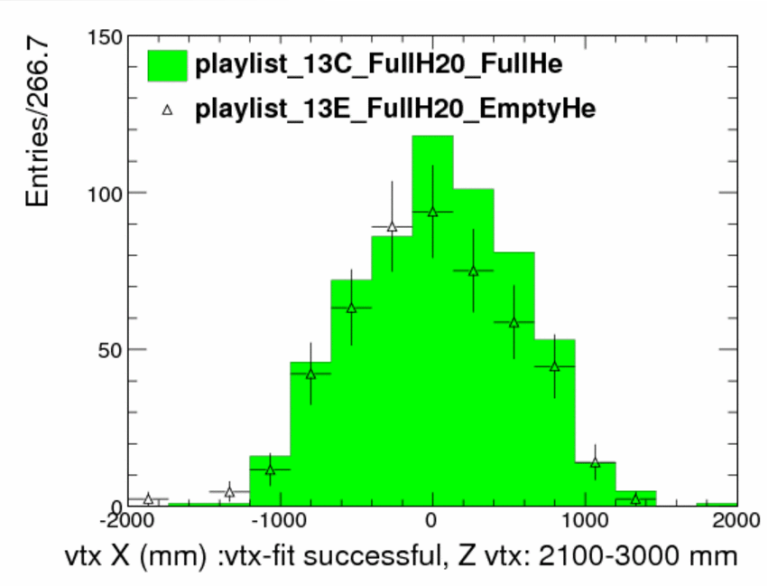
- Z vertex
  - Right plots require vertex X and Y within 710 mm radius
  - Lower right plot : exclude events from ShortAnchorTrack-ing
- *Still need to recover missing data at the analysis stage for proper POT normalization

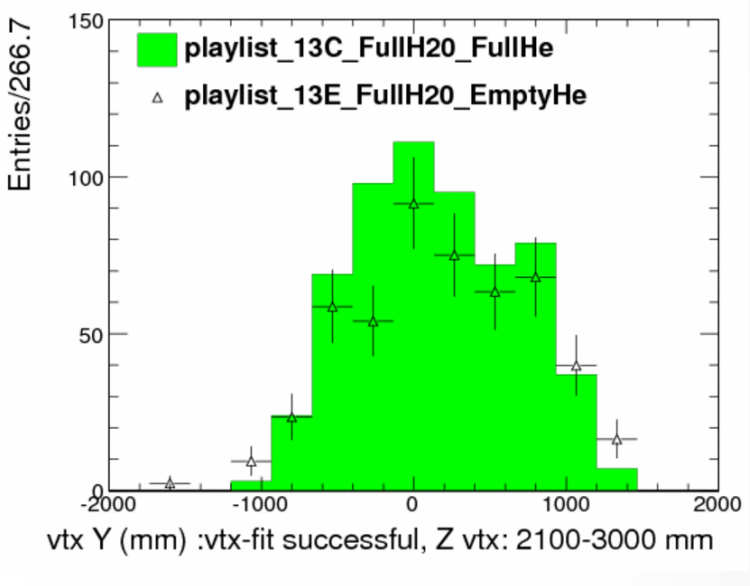


R_{xy}<710 mm Exclude anchor short tracker

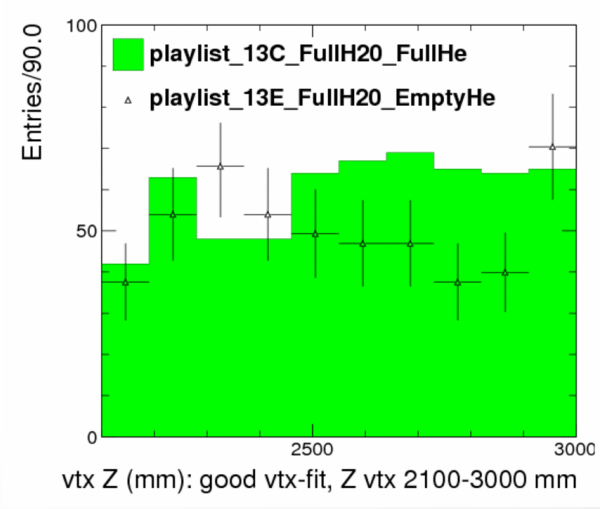
Comparison : 13C, 13E Data

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

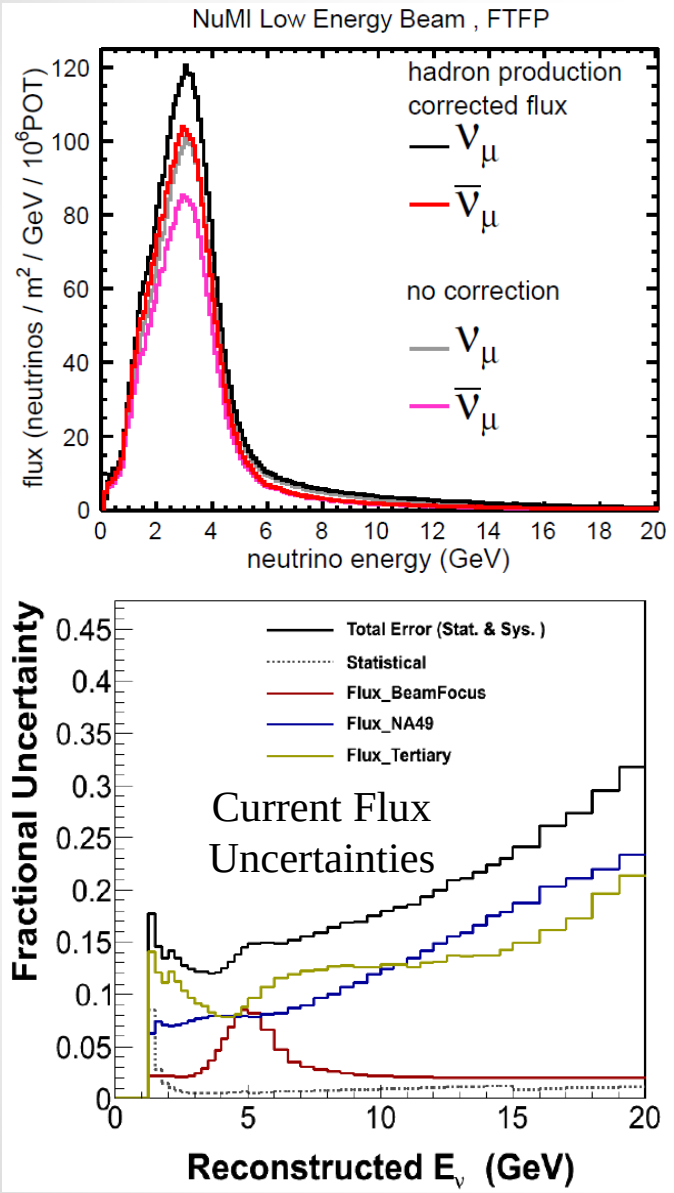


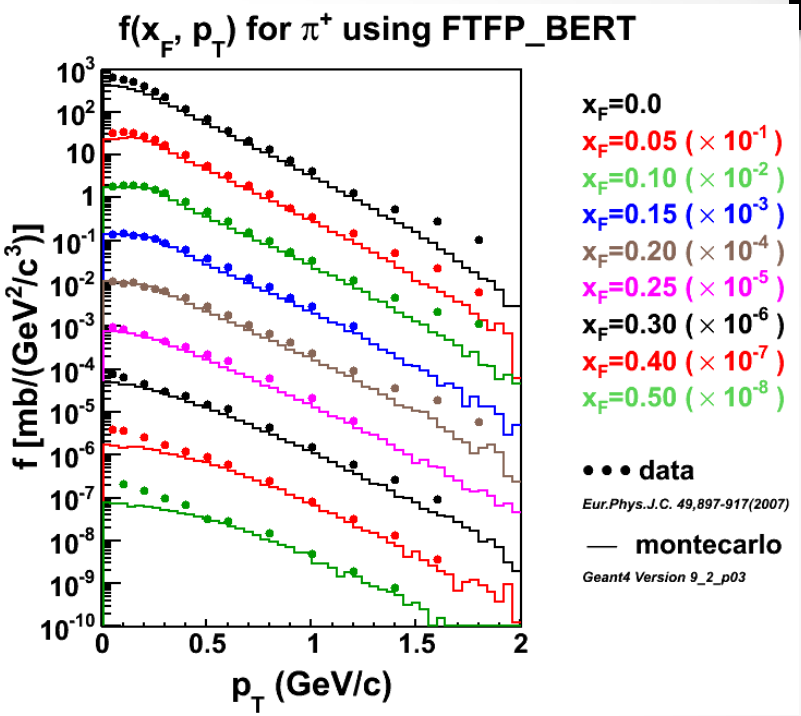
Status and Plan

- 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



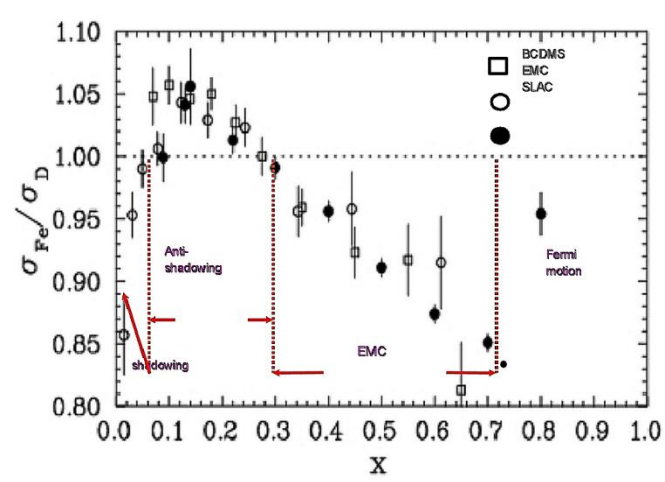


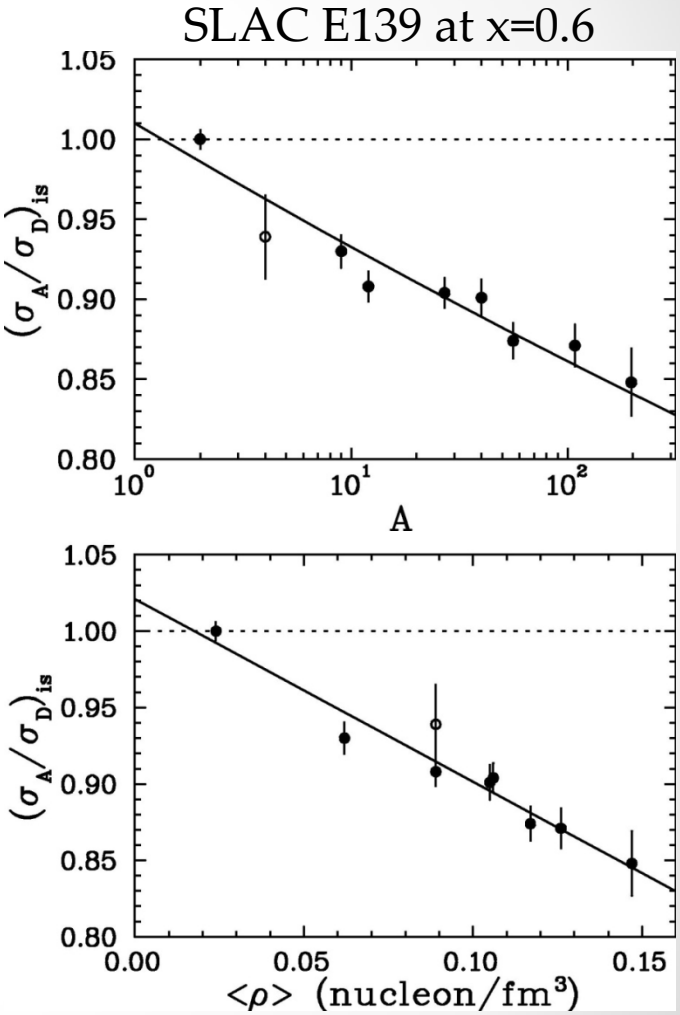
- Hadron production simulated with Geant4 to predict flux.
- Flux is reweighted based on hadron production data compared to Geant4
- Flux uncertainties will improve in future with more work

Physics Case

- νN 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

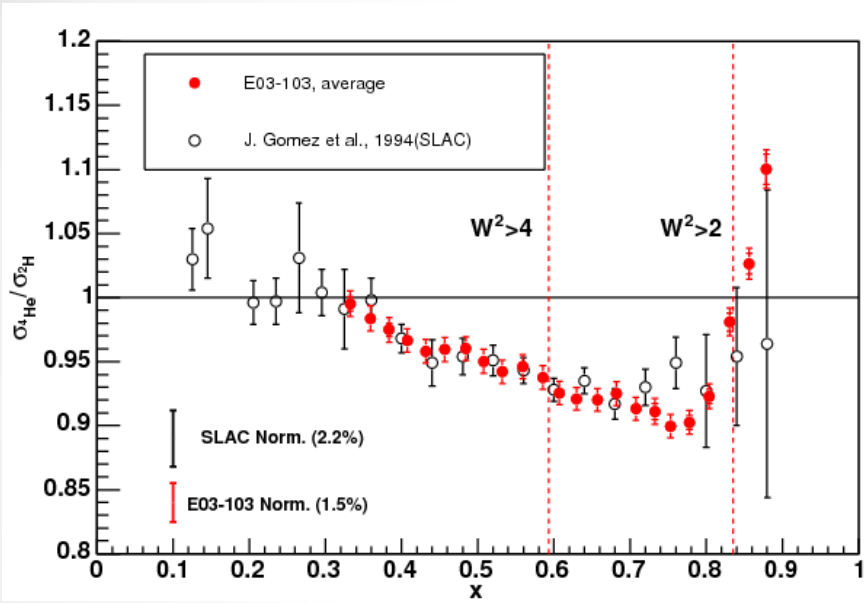
Nuclear Effects in A/D Ratios

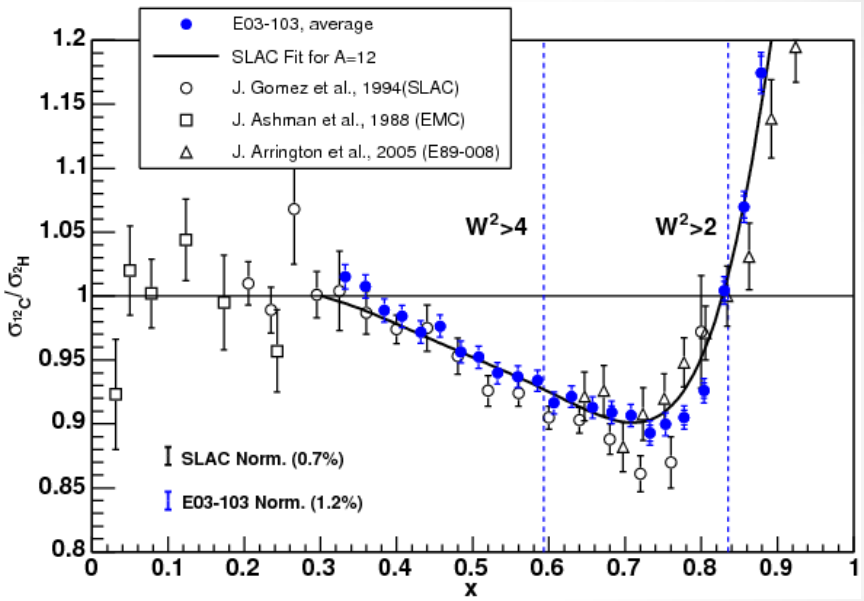




- The structure functions of a nucleon within a nucleus are different from the structure functions of a free nucleon.
- Fe/D cross sections show 13% nuclear effect.
- Precision neutrino data requires better understandings of nuclear effects.

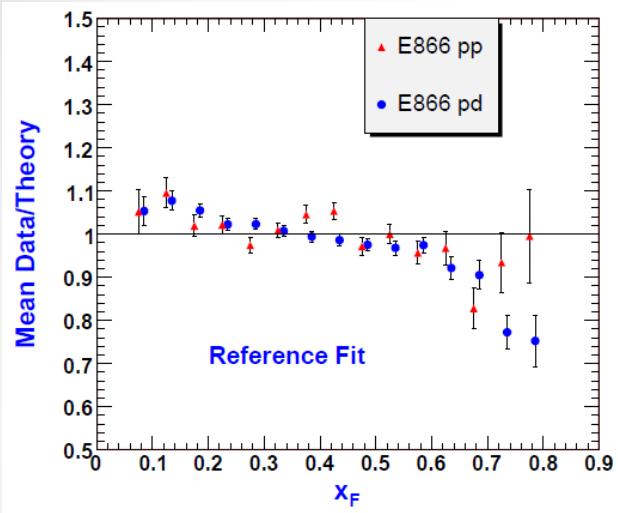
EMC Effect for Helium & Carbon

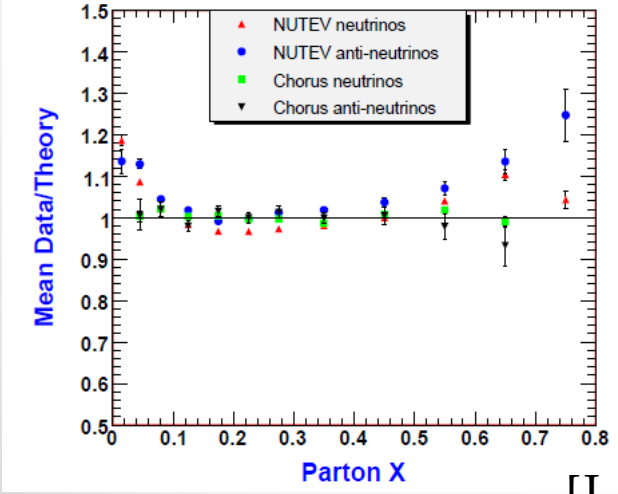


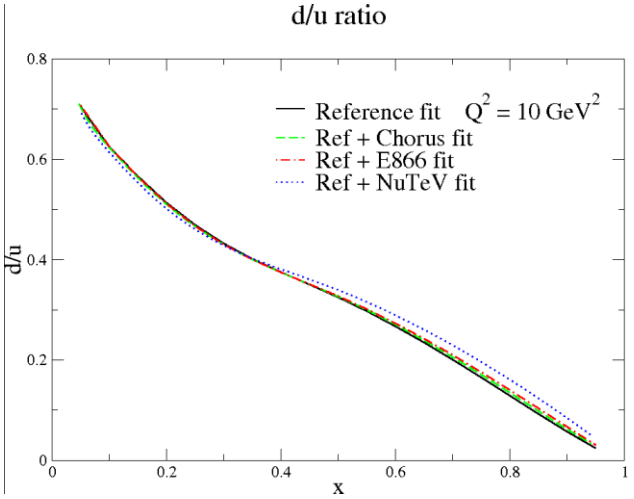


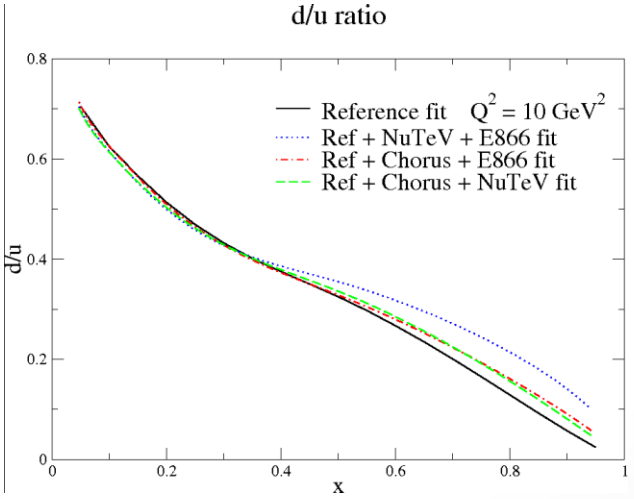
- Jefferson Lab E03-013 data [Ref: J. Arrington, nucl-ex/0701017]
- ^{4}He show similar nuclear EMC effect as ^{12}C

Neutrino Data for PDFs



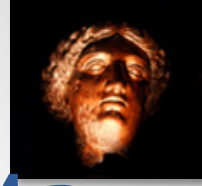




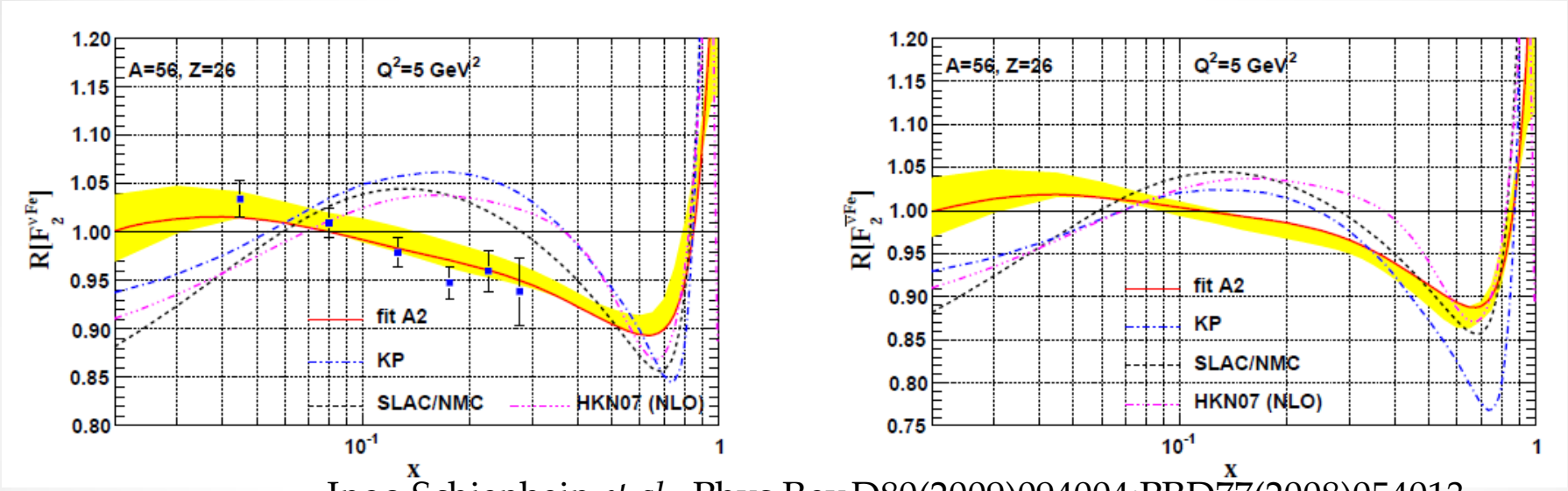


- At large *x*, the neutrino data on iron target from NuTeV experiment seem to pull the PDF fits in a different way from the E866 Drell-Yan data. Reducing the nuclear corrections for NuTeV can reduce the tension.

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



Nuclear Effects for Neutrino Data

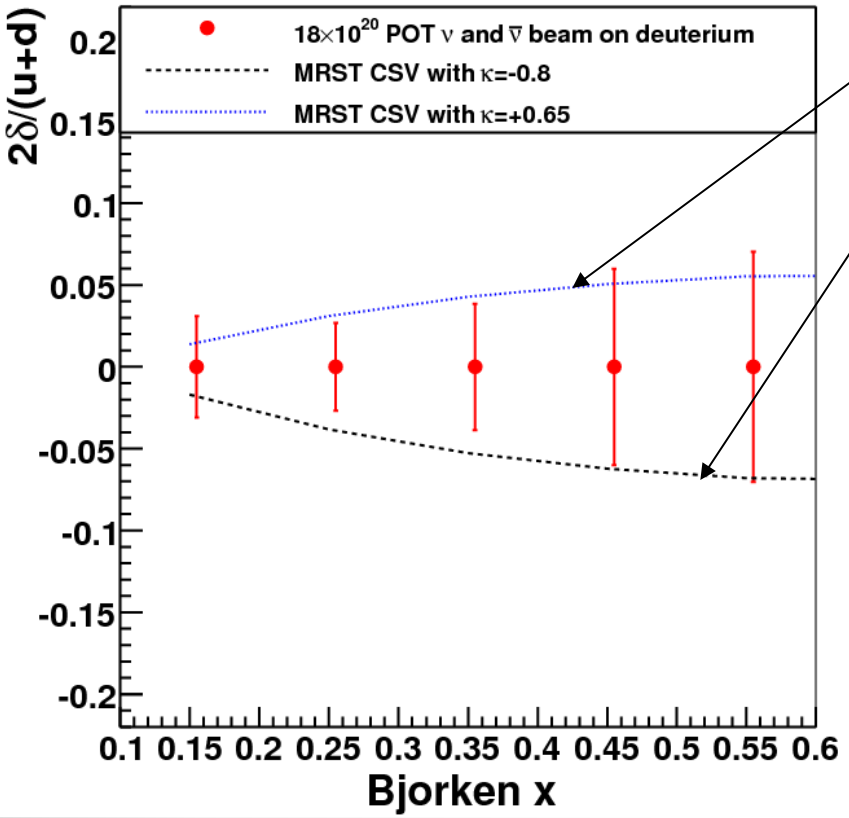


Ingo Schienbein *et al.,* Phys.Rev.D80(2009)094004;PRD77(2008)054013

- 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_2

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!

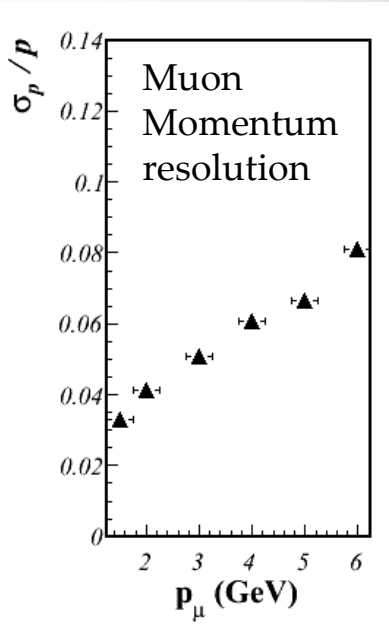
MINERvA's DIS Event Reconstruction

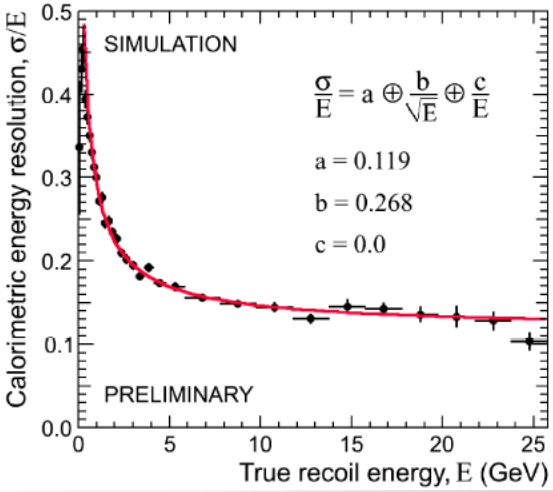
- Crucial Ingredients to determine x,y,Q^2:
  - Muon Energy and angle (E_μ, θ_μ)
    - Tracking well understood, tie to MINOS reconstruction
  - Hadronic (recoil) Energy Measurement (E_{had})
    - Studies underway, will tie to 2010 test beam data
  - Charge (for ν/anti-ν discrimination)
    - Use MINOS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

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

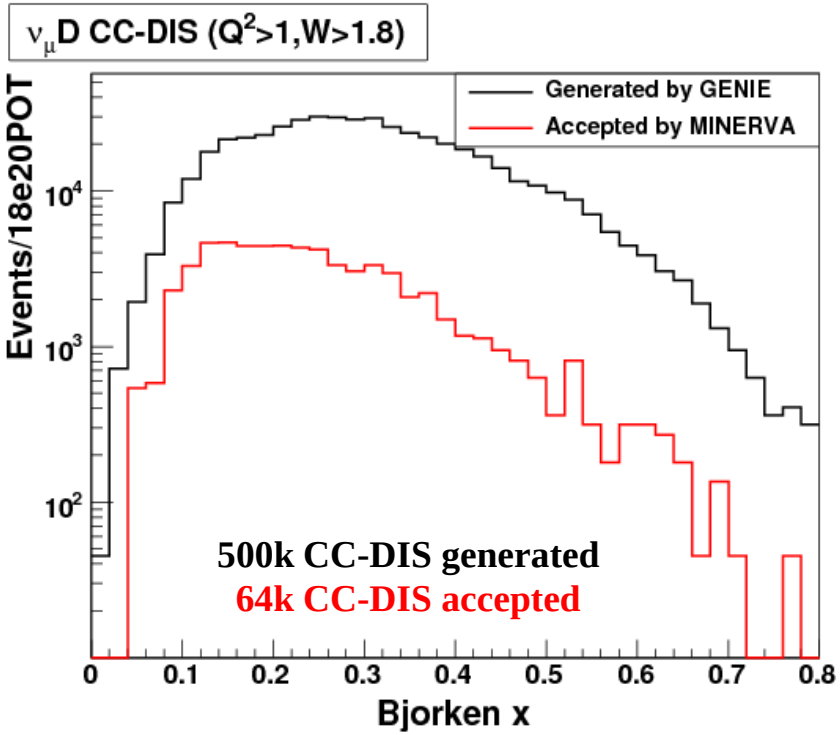
$$Q^2 = 4E_\mu E_\nu \sin^2\left(\frac{\theta_\mu}{2}\right) \qquad x = \frac{Q^2}{2M_p\nu}$$

- 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

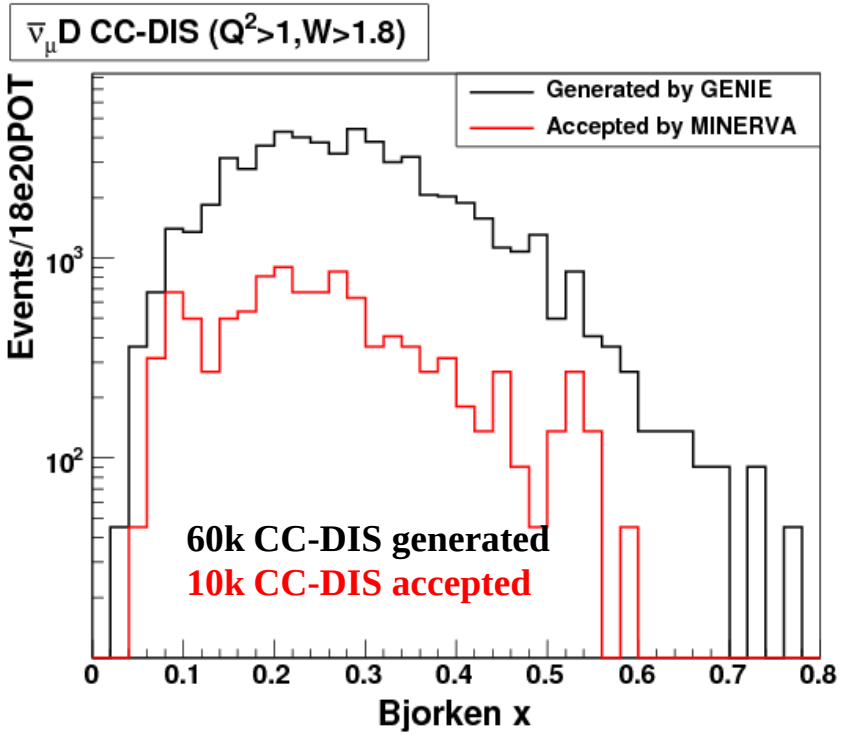




CC-DIS Events from D_2



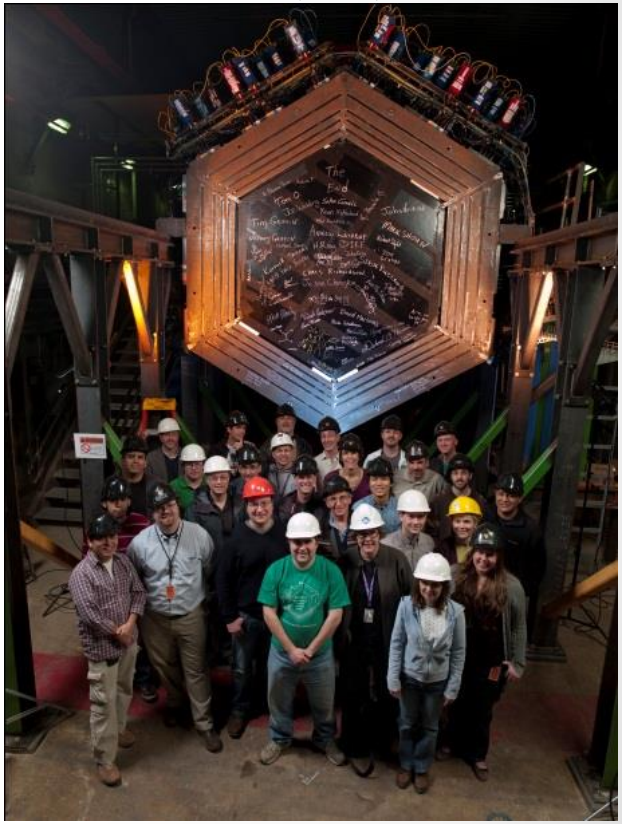
ν



- Accepted by MINERνA 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 $18*10^{20}$ POT ME flux, which is the nominal beam for NOνA and will be used by MINERνA.

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.



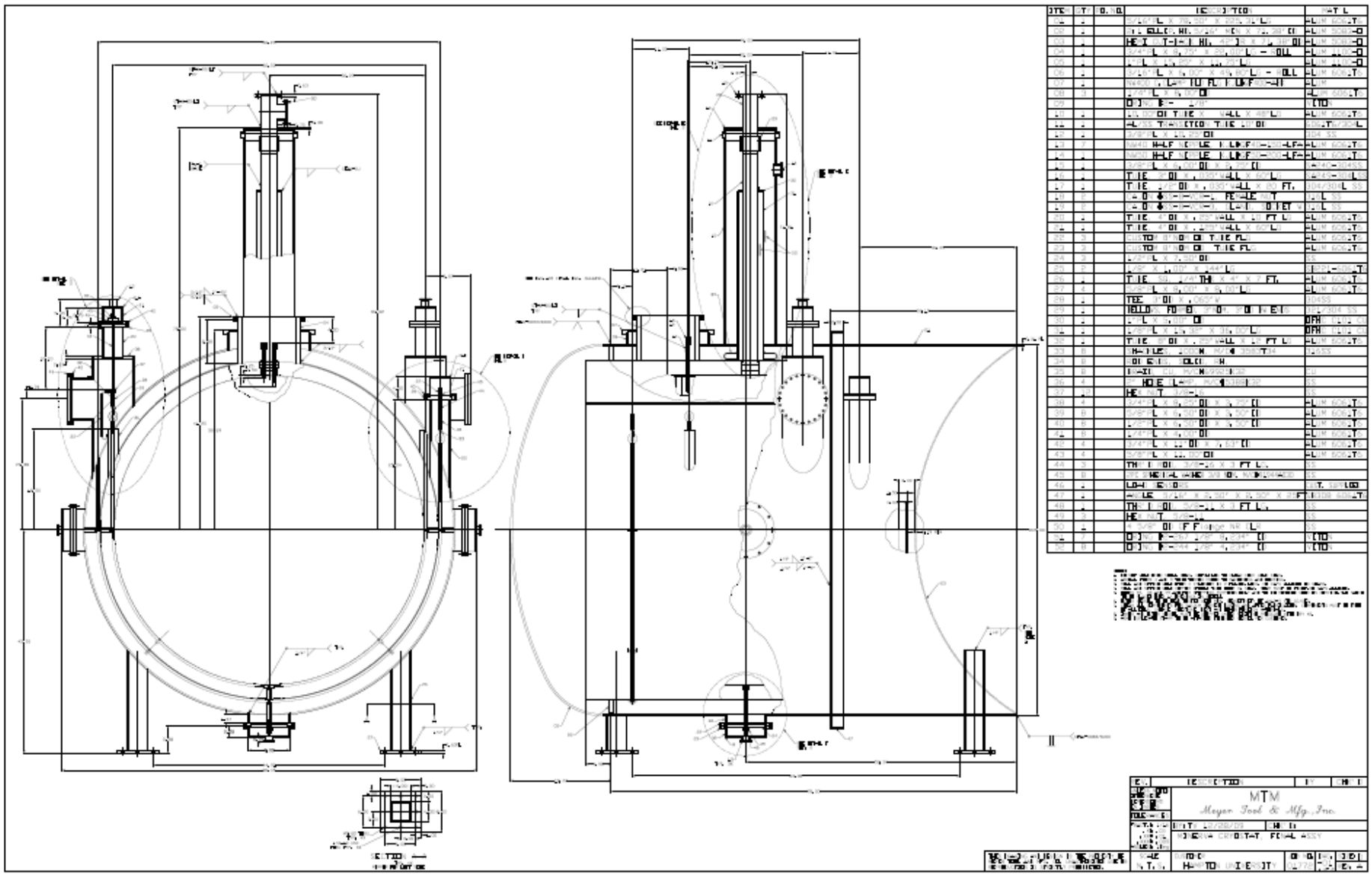
University of Athens
University of Texas at Austin
Centro Brasileiro de Pesquisas Físicas
Fermilab
University of Florida
Université de Genève
Universidad de Guanajuato
Hampton University
Inst. Nucl. Reas. Moscow
Mass. Col. Lib. Arts
Northwestern University
Otterbein University
Pontificia Universidad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

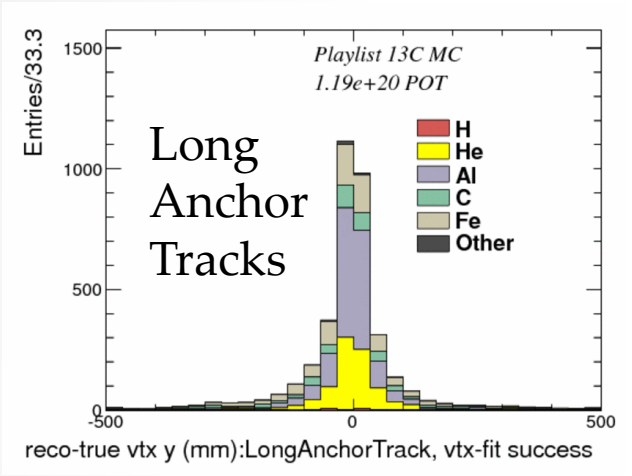
From 3/22/2010	nu	nub	total
nu -LE	3.98E+20		
nu-0 current	7.38E+18		
nu-ME	1.47E+19		
nu-HE	8.15E+18		
nub-LE		1.70E+20	
nub-ME		1.92E+19	
Total Special	3.02E+19	1.92E+19	4.94E+19
total	4.29E+20	1.89E+20	6.18E+20
He Filled	1.90E+20		
He Empty	5.50E+19		
Water Target	1.96E+20		

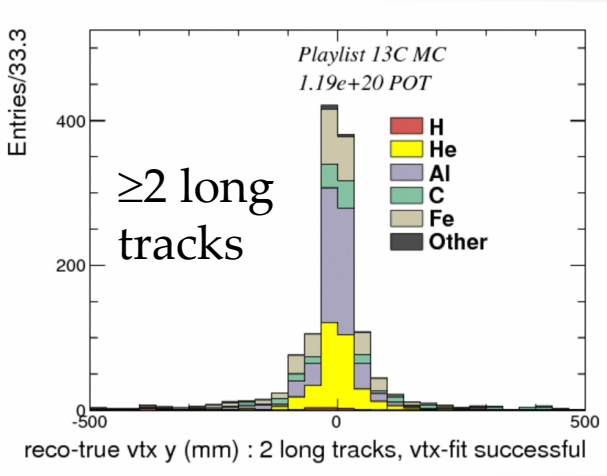
From Howard Budd's AEM report on April 30, 2012

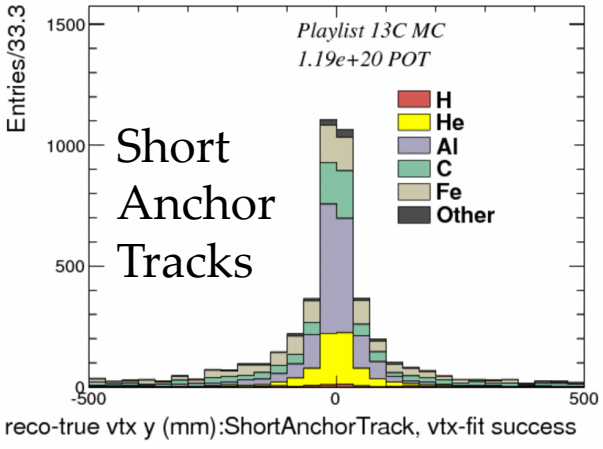
- For MINERvA
  - 97.1% Live 3/22/10 to now
  - 97.7% live on NT07
- Do not include Aug 23-26 when MINOS was down at the start of NT-04 run.



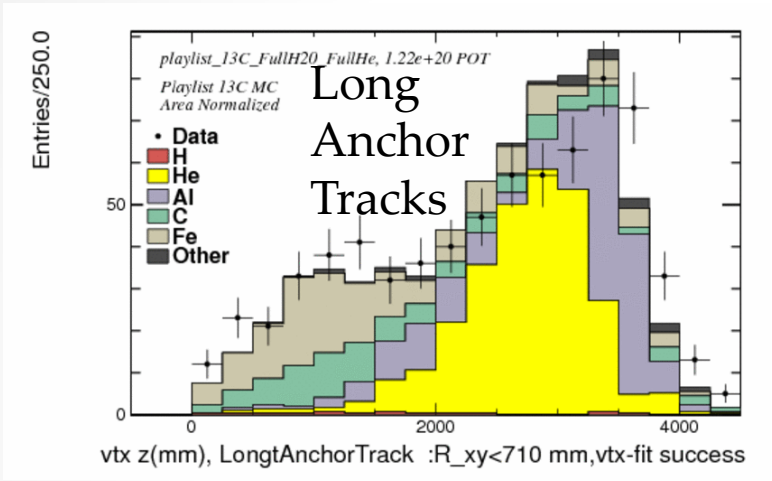
Vertex-Y Resolution

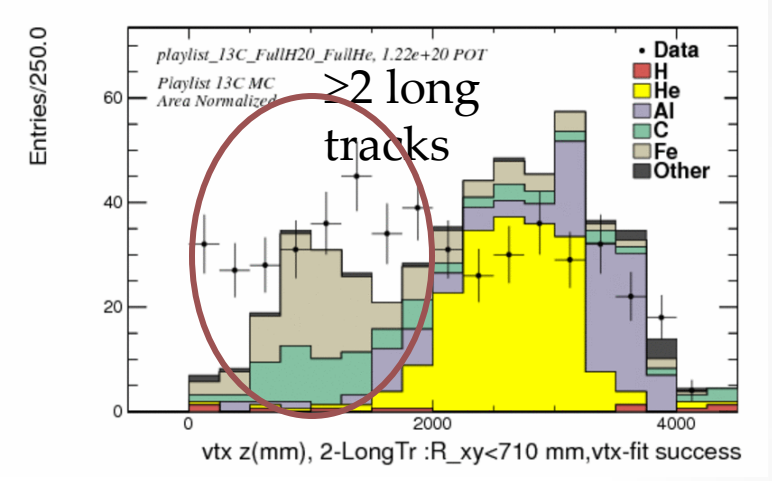


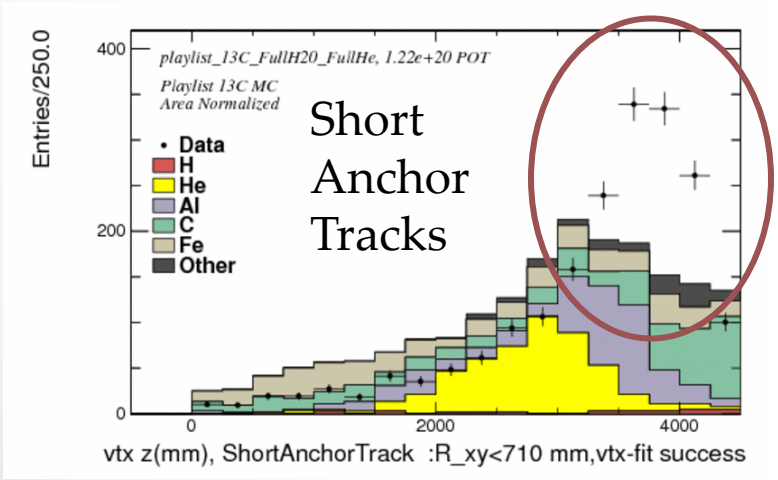




Reconstructed Z-vertex : With Radial Selection







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