MINERνA with Cryogenic Targets

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Nuclear Physics Group Meeting

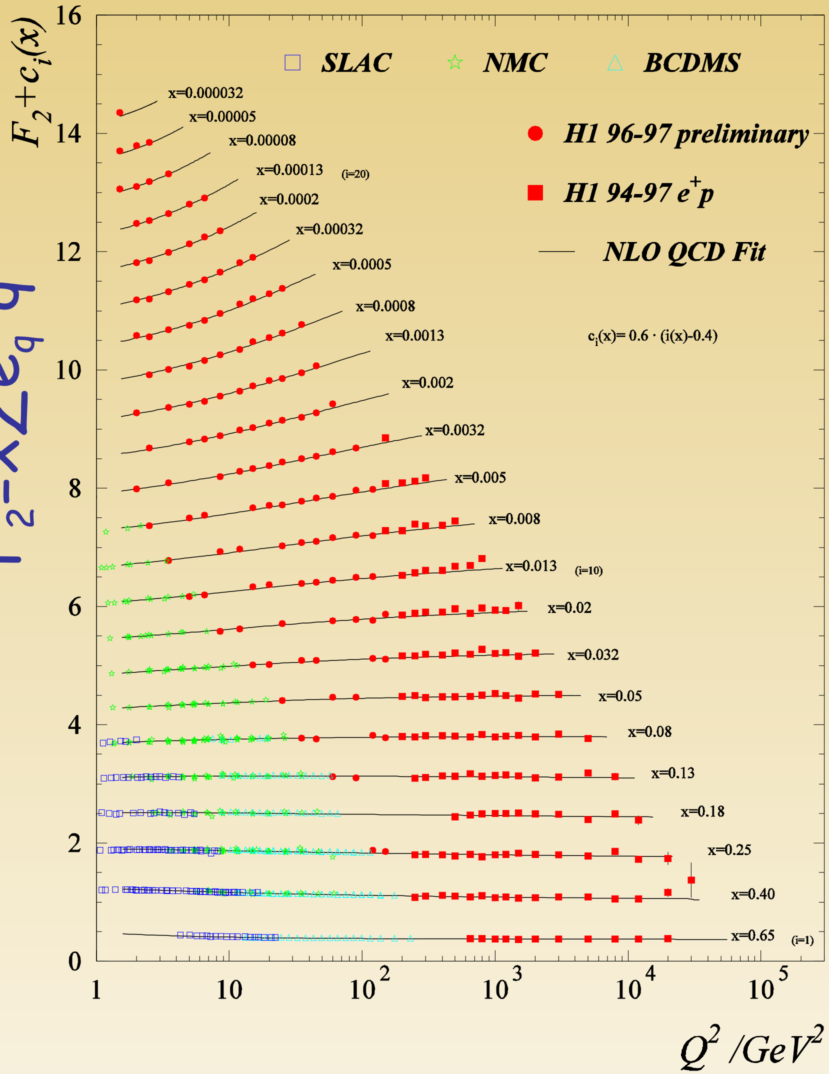
Sep 22, 2009

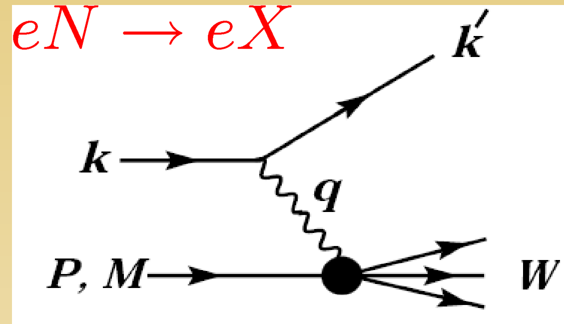
Outline

1. Physics with hydrogen Target: d/u
2. Resolution with helium target

PDFs from lepton DIS

$F_2 = x \sum e_q^2 q$





$$Q^2 = 4E_e E'_e \sin^2(\theta_e/2); \; x_{\text{Bjorken}} = \frac{Q^2}{2M(E_e - E'_e)}$$

Charge symmetry:

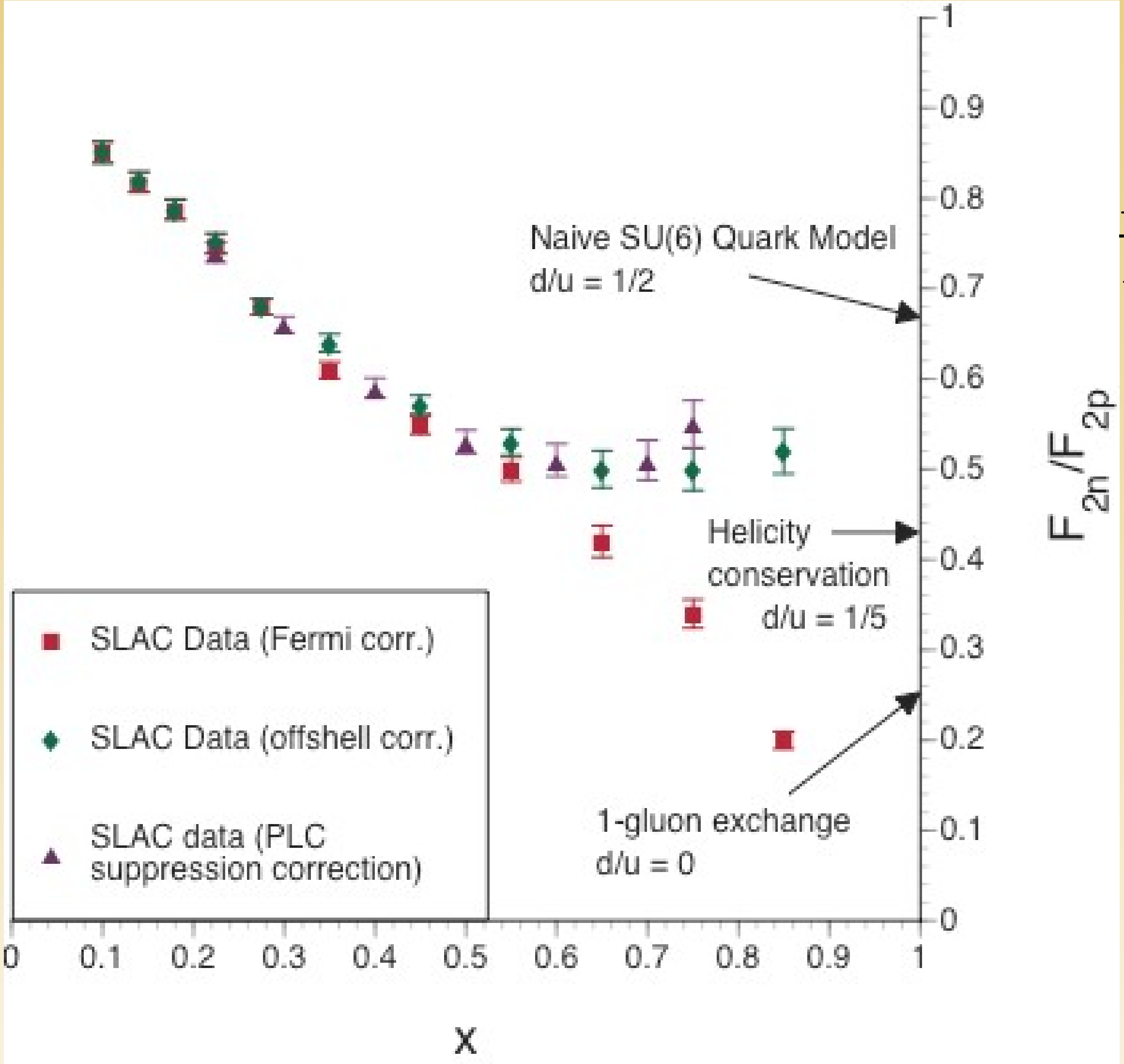
u in proton = *d* in neutron

$$F_{2p}/x = 4(u + \bar{u}) + (d + \bar{d}) + (s + \bar{s}) + 4(c + \bar{c})$$

$$F_{2n}/x = 4(d + \bar{d}) + (u + \bar{u}) + (s + \bar{s}) + 4(c + \bar{c})$$

$\sigma_{(e,e')} \rightarrow F_2 \rightarrow q(x)$

d/u subject to big nuclear correction



$$\frac{F_{2n}}{F_{2p}} = \frac{4d+u}{4u+d} = \frac{4d/u+1}{4+d/u}$$

$$\frac{d}{u} = 0 \rightarrow \frac{F_{2n}}{F_{2p}} = \frac{1}{4}$$

$$\frac{d}{u} = \frac{1}{5} \rightarrow \frac{F_{2n}}{F_{2p}} = \frac{3}{7}$$

$$\frac{d}{u} = \frac{1}{2} \rightarrow \frac{F_{2n}}{F_{2p}} = \frac{2}{-}$$

From BONUS proposal

d/u at x=1 limit

$$p\uparrow = \frac{1}{\sqrt{2}}u\uparrow(ud)_{S=0} + \frac{1}{\sqrt{18}}u\uparrow(ud)_{S=1} - \frac{1}{3}u\downarrow(ud)_{S=1} - \frac{1}{3}d\uparrow(uu)_{S=1} - \frac{\sqrt{2}}{3}d\downarrow(uu)_{S=1}$$

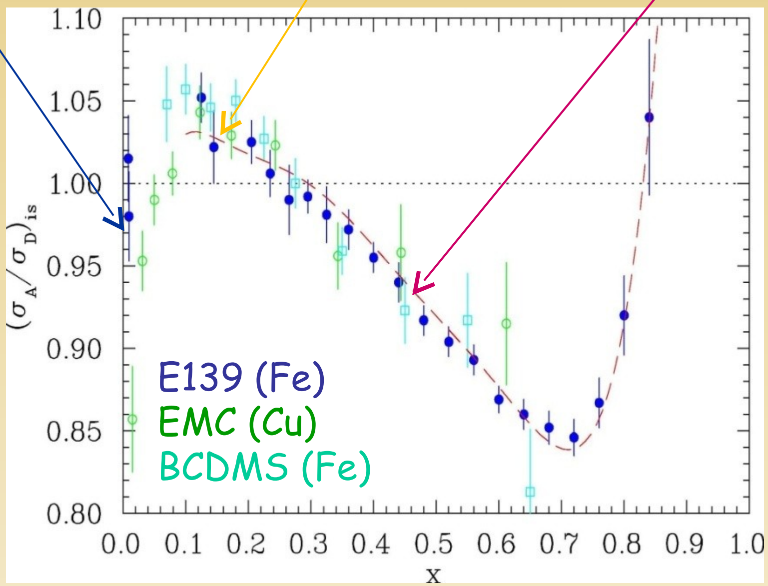
- **SU(6) spin-flavor symmetry:**
  - d/u=(1/9+2/9)/(1/2+1/18+1/9)=1/2
  - The mass difference between N and Δ implies symmetry breaking
- ***S=0* diquark dominance**
  - d/u=(0)/(1/2)=0
  - Hyperfine-perturbed quark model with one-gluon-exchange (Isgur *et al.*); MIT bag model with gluon exchange (Close & Thomas); Phenomilogical quark-diquark(Close) and Regge (Carlitz) arguments
- **S_z=0 diquark dominance**
  - d/u=(1/9)/(1/2+1/18)=1/5
  - pQCD with helicity conservation (Farrar and Jackson); quark counting rule (Brodsky *et al.)*
- Others:
  - Diquark model (Close & Roberts)

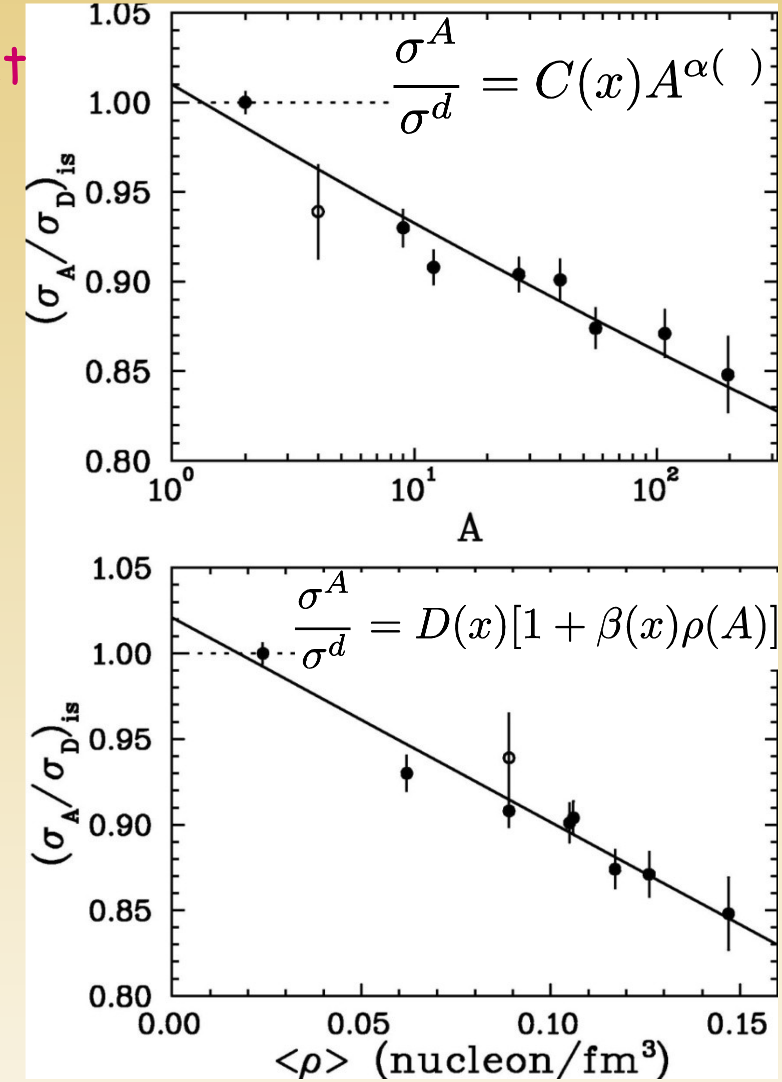
Nuclear effects in A/D ratios

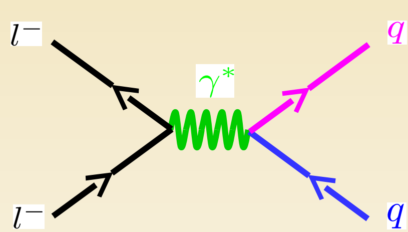
Gomez et al., PRD49(1994)4348

SLAC E139 at x=0.6

Shadowing….Anti-shadowing…EMC effect

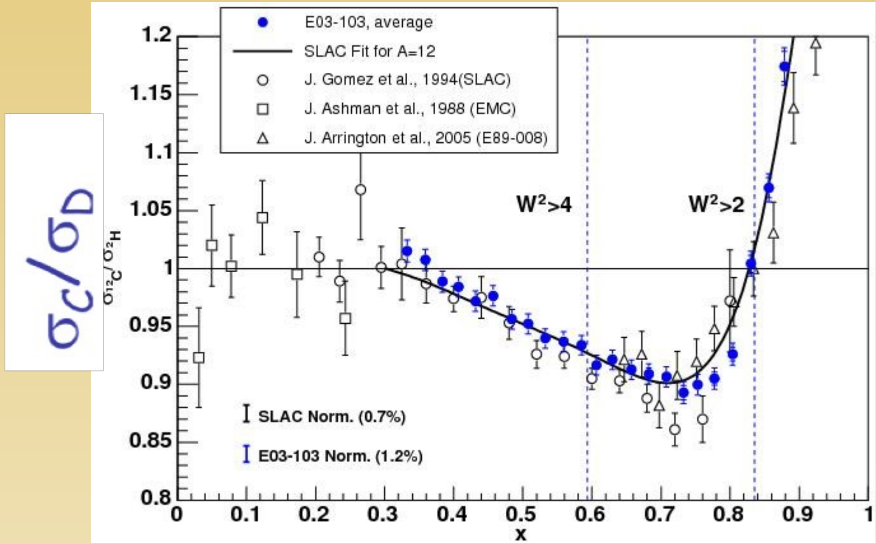


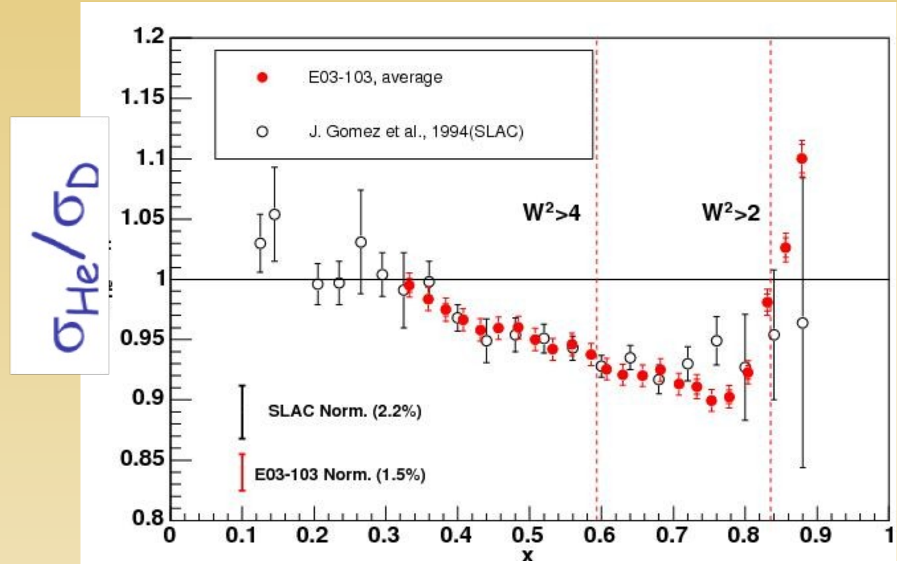


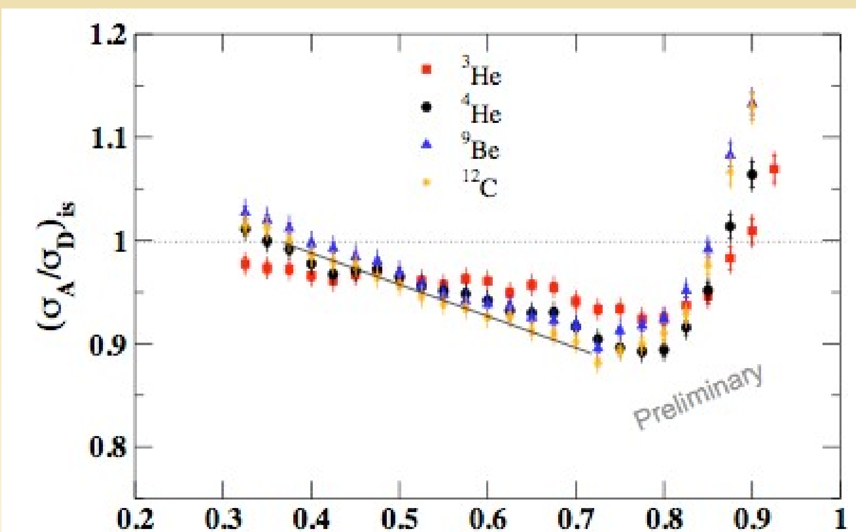


EMC: A-dependence or density-dependent?

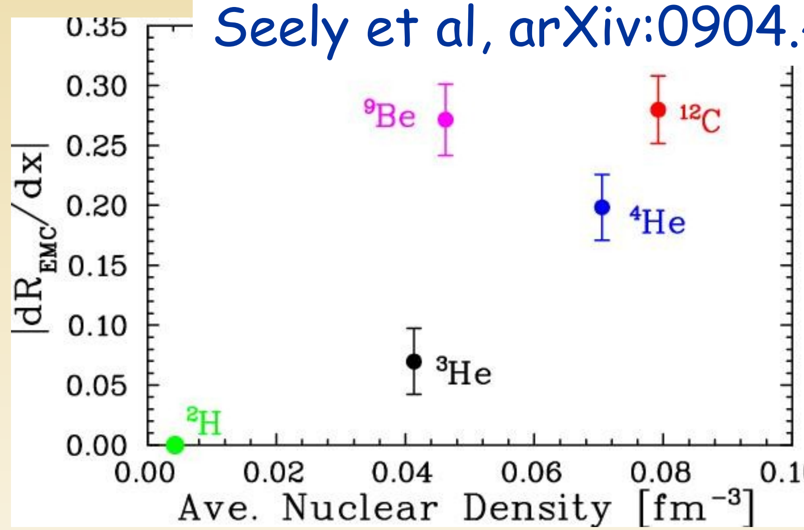
Jlab results on EMC effects of light nuclei







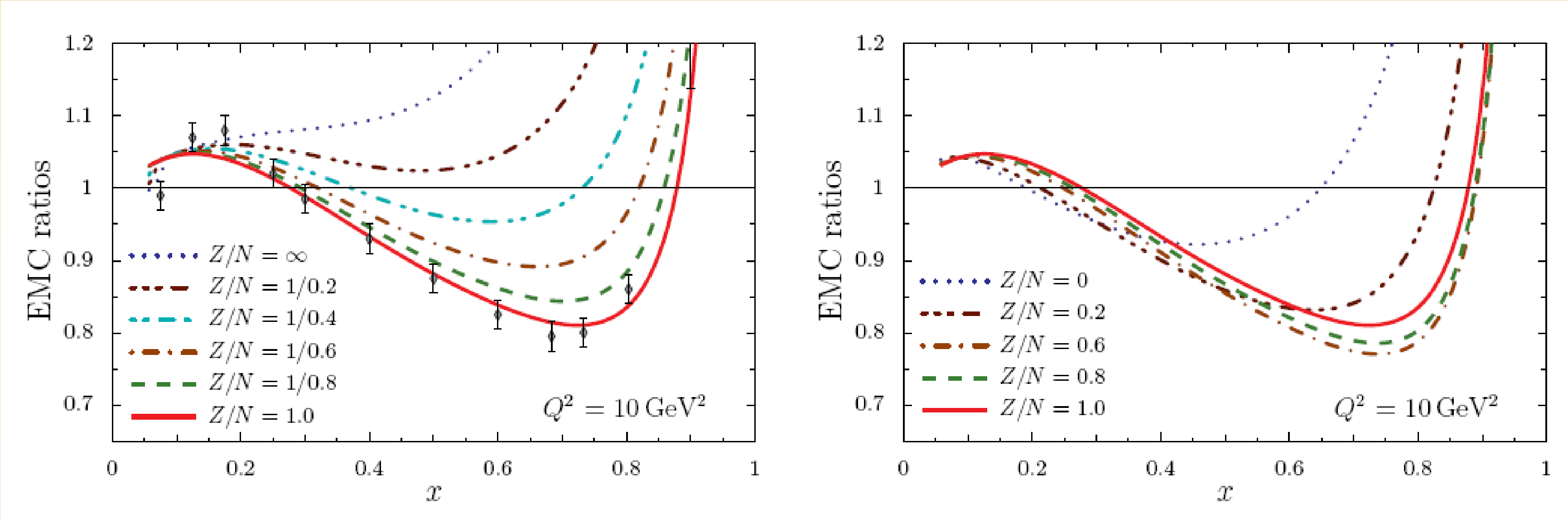
Seely et al, arXiv:0904.4448



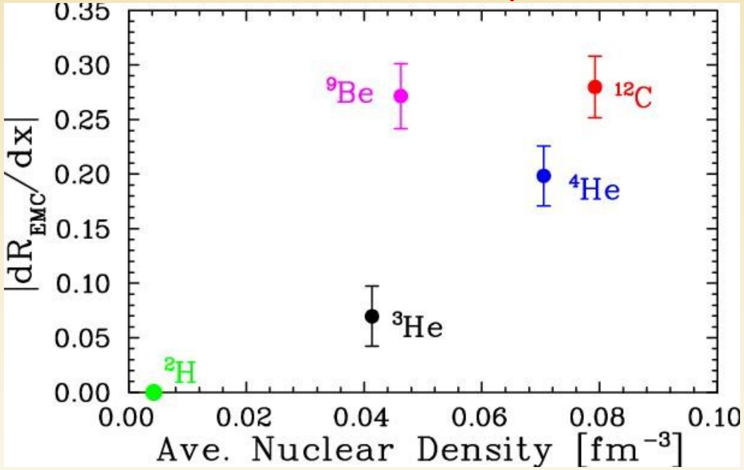
EMC: not A-dependence nor density-dependent.

EMC effect for Z ≠ N nuclei

Cloet, Bentz, and Thomas, PRL102(2009)252301 [arXiv:0901.3559]



Isovector mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs in nucleons

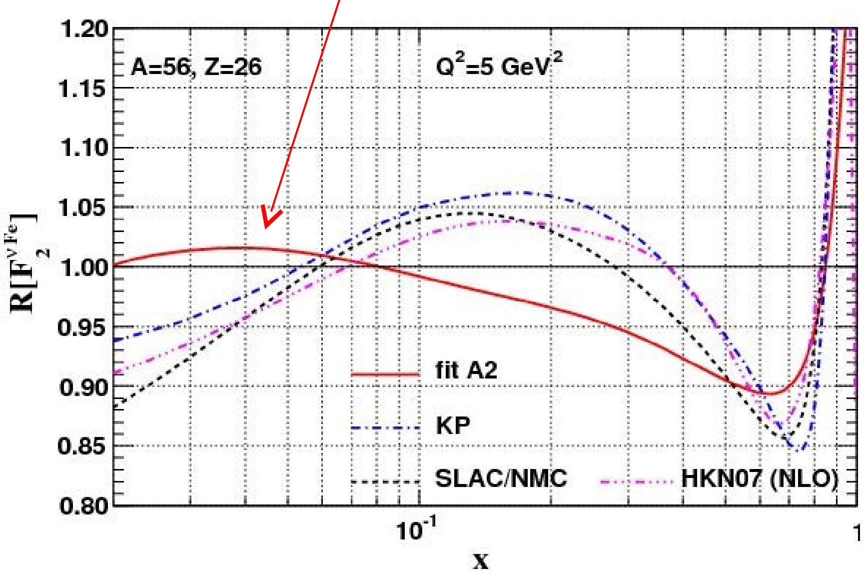


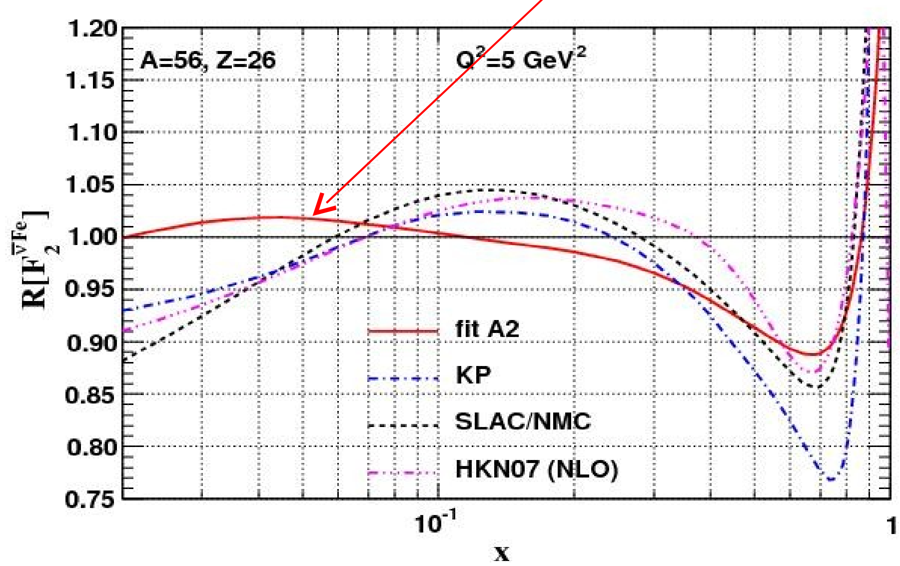
EMC for neutrino experiment

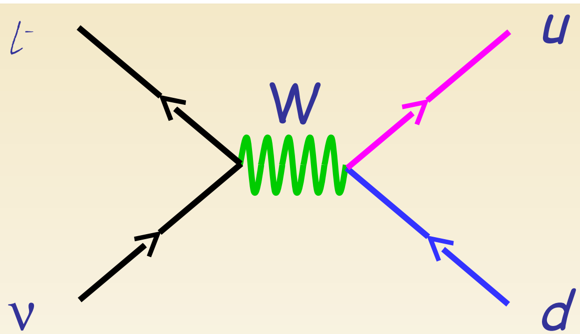
Schienbein *et al.*, PRD77(2008)054013

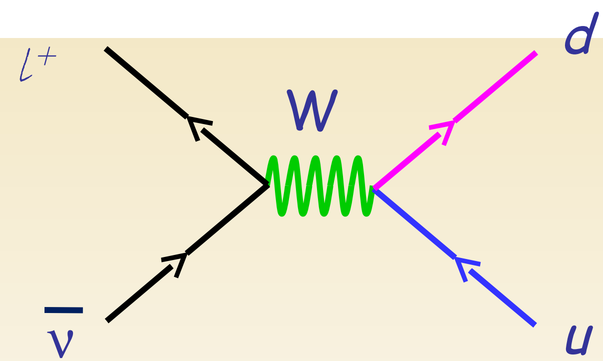
neutrino+iron

anti-neutrino+iron



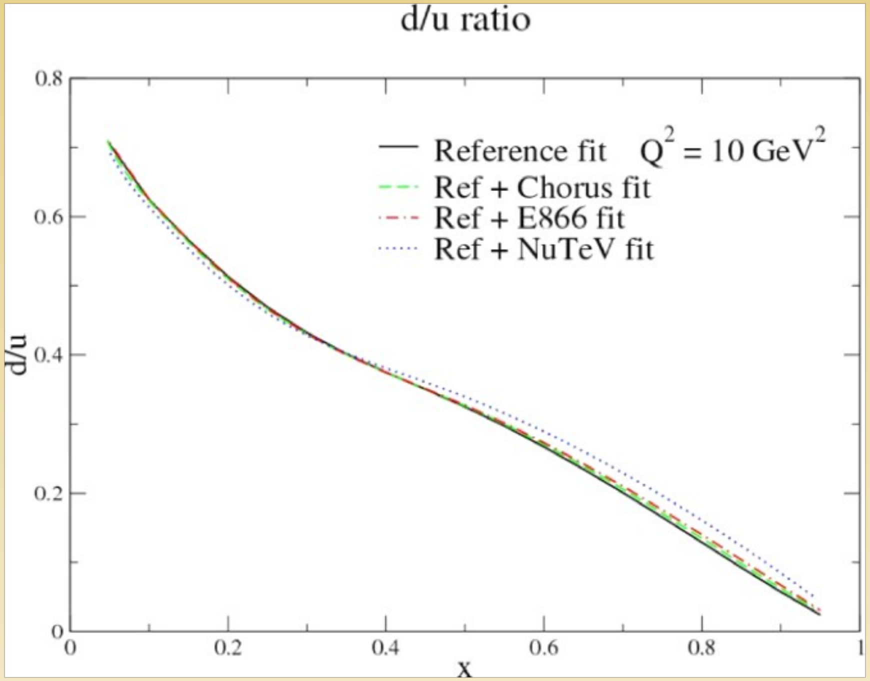


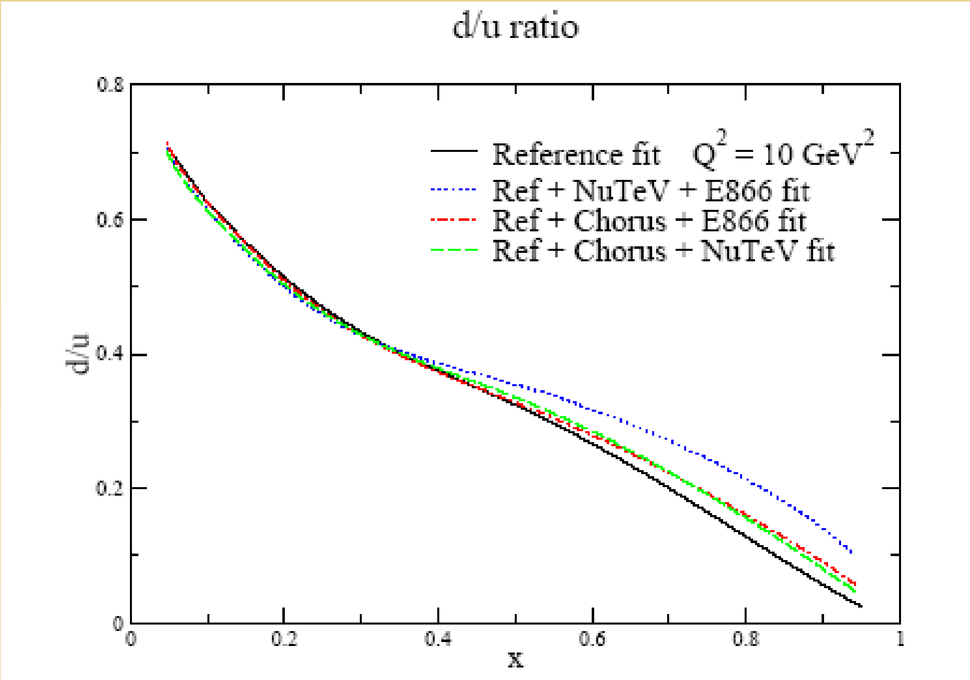




Neutrino NuTeV vs. Drell-Yan E866

Owens et al., PRD75(2007)054030





Neutrino NuTeV has different Pull at large *x* from Drell-Yan E866.

d/u from W asymmetry in ppbar reaction

Melnitchouk & Peng, Phys. Lett. B400(1997)220

$$\frac{d\sigma}{dx_F}(W^+) = K\frac{2\pi G_F}{3\sqrt{2}}\left(\frac{x_1x_2}{x_1+x_2}\right)\left\{\cos^2\theta_c\ \left(u_p(x_1)\ \bar{d}_h(x_2)\ +\ \bar{d}_p(x_1)\ u_h(x_2)\right)\right.$$
$$\left. +\ \sin^2\theta_c\ \left(u_p(x_1)\ \bar{s}_h(x_2)\ +\ \bar{s}_p(x_1)\ u_h(x_2)\right)\right\}$$

$$\frac{d\sigma}{dx_F}(W^-) = K\frac{2\pi G_F}{3\sqrt{2}}\left(\frac{x_1x_2}{x_1+x_2}\right)\left\{\cos^2\theta_c\ \left(d_p(x_1)\ \bar{u}_h(x_2)\ +\ \bar{u}_p(x_1)\ d_h(x_2)\right)\right.$$
$$\left. +\ \sin^2\theta_c\ \left(s_p(x_1)\ \bar{u}_h(x_2)\ +\ \bar{u}_p(x_1)\ s_h(x_2)\right)\right\}$$

$$R_{ph}(x_F) \equiv \frac{d\sigma/dx_F\ (W^+)}{d\sigma/dx_F\ (W^-)}$$

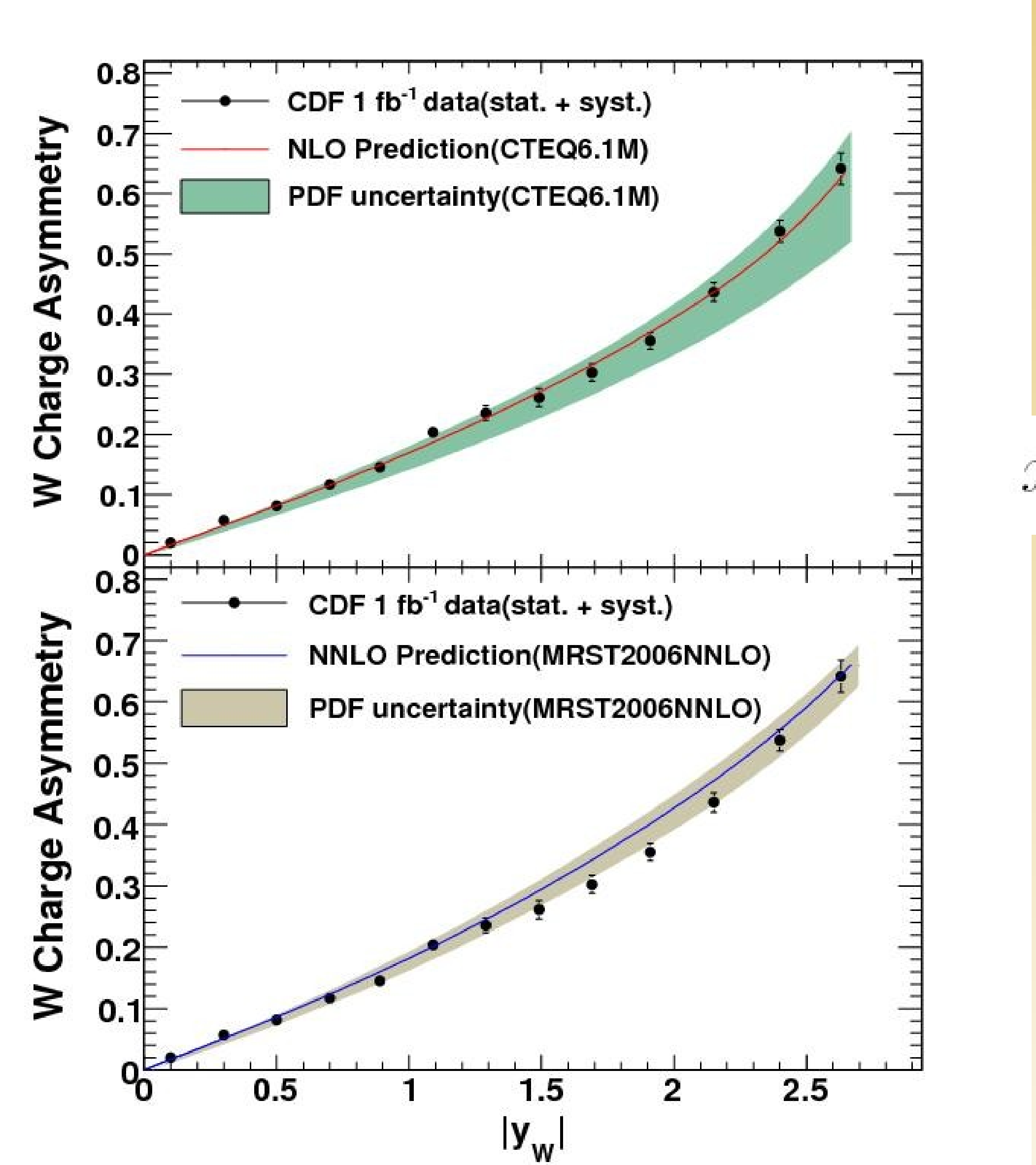
$$R_{p\bar{p}}(x_F) \approx \frac{u(x_1)}{d(x_1)}\cdot\frac{d(x_2)}{u(x_2)}$$

$$A(y_l) = \frac{d\sigma/dy_l(l^+)\ -\ d\sigma/dy_l(l^-)}{d\sigma/dy_l(l^+)\ +\ d\sigma/dy_l(l^-)}$$

$$y_l\ =\ 1/2\ln\left[(E_l+p_l)/(E_l-p_l)\right]$$

$$x_F = (M_W/\sqrt{s})(e^y - e^{-y}))$$

W asymmetry at CDF



$$R_{p\bar{p}}(x_F) \approx \frac{u(x_1)}{d(x_1)} \cdot \frac{d(x_2)}{u(x_2)}$$

$$x_F = (M_W/\sqrt{s})(e^y - e^{-y}))$$

Phys. Rev. Lett 102(2009)181801

(anti-)neutrino cross section on hydrogen

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dx\,dy} = \frac{G_F^2 M_p E_\nu}{\pi}\left[xy^2 F_1^{\nu(\bar{\nu})}(x,Q^2) + (1 - y - \frac{M_p x y}{2E_\nu})F_2^{\nu(\bar{\nu})}(x,Q^2) \pm y(1-\frac{y}{2})xF_3^{\nu(\bar{\nu})}(x,Q^2)\right]$$

$$\begin{aligned}
F_1^{\nu} &= d(x) + s(x) + \bar{u}(x) + \bar{c}(x) \sim \frac{F_2^{\nu}}{2x} \\
F_1^{\bar{\nu}} &= u(x) + c(x) + \bar{d}(x) + \bar{s}(x) \sim \frac{F_2^{\bar{\nu}}}{2x} \\
F_3^{\nu} &= 2\left[d(x) + s(x) - \bar{u}(x) - \bar{c}(x)\right] \\
F_3^{\bar{\nu}} &= 2\left[u(x) + c(x) - \bar{d}(x) - \bar{s}(x)\right]
\end{aligned}$$

$$\begin{aligned}
\frac{d^2\sigma^{\nu}}{dx\,dy} &\sim \frac{G_F^2 M_p E_\nu}{\pi}\left[2x(1-y+y^2/2)(d+s+\bar{u}+\bar{c}) + 2x(y-y^2/2)(d+s-\bar{u}-\bar{c})\right] \\
&= \frac{G_F^2 M_p E_\nu}{\pi}\cdot 2x\left[(d+s) + (1-y)^2(\bar{u}+\bar{c})\right] \\
\frac{d^2\sigma^{\bar{\nu}}}{dx\,dy} &\sim \frac{G_F^2 M_p E_\nu}{\pi}\left[2x(1-y+y^2/2)(u+c+\bar{d}+\bar{s}) - 2x(y-y^2/2)(u+c-\bar{d}-\bar{s})\right] \\
&= \frac{G_F^2 M_p E_\nu}{\pi}\cdot 2x\left[(1-y)^2(u+c) + (\bar{d}+\bar{s})\right]
\end{aligned}$$

$$\frac{d^2\sigma^{\nu}}{d^2\sigma^{\bar{\nu}}}(x,y) \sim \frac{d(x)}{u(x)}\cdot\frac{1}{(1-y)^2}$$

$$\frac{d_v}{u_v} = \frac{d-\bar{d}}{u-\bar{u}} \sim \frac{[F_2^{\nu}/x + F_3^{\nu}] - [F_2^{\bar{\nu}}/x - F_3^{\bar{\nu}}]}{[F_2^{\bar{\nu}}/x + F_3^{\bar{\nu}}] - [F_2^{\nu}/x - F_3^{\nu}]} = \frac{(d+s)-(\bar{d}+\bar{s})}{(u+c)-(\bar{u}+\bar{c})}$$

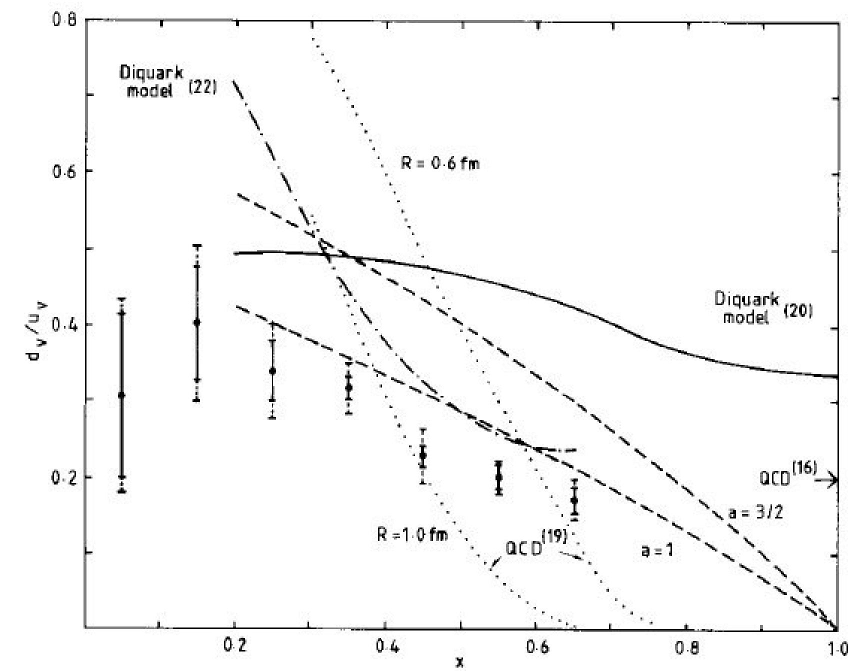
Four independent constraints from hydrogen data.

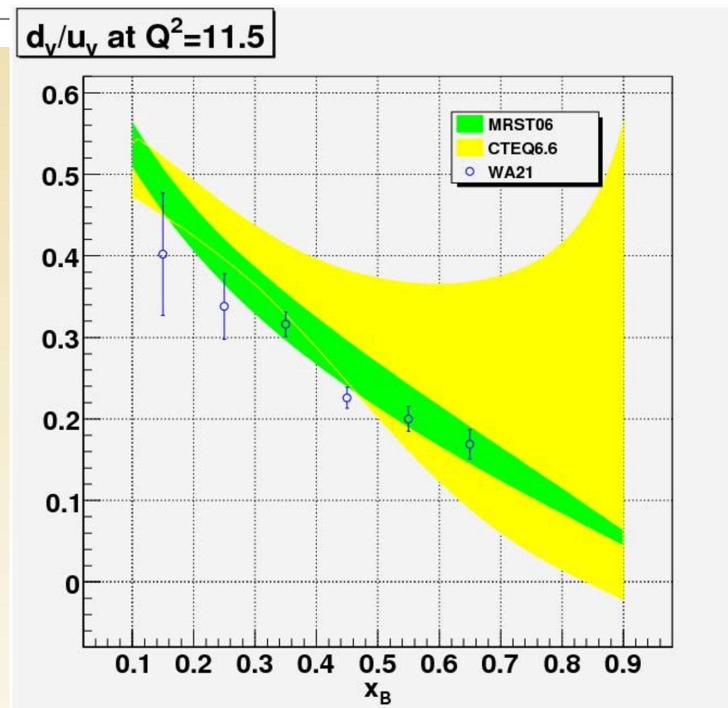
WA21: (anti-)neutrino on hydrogen

Jones et al, Z. Phys. C44(1989)379

Table 5. Structure functions $x\,d_v$, $x\,u_v$, and the ratio d_v/u_v

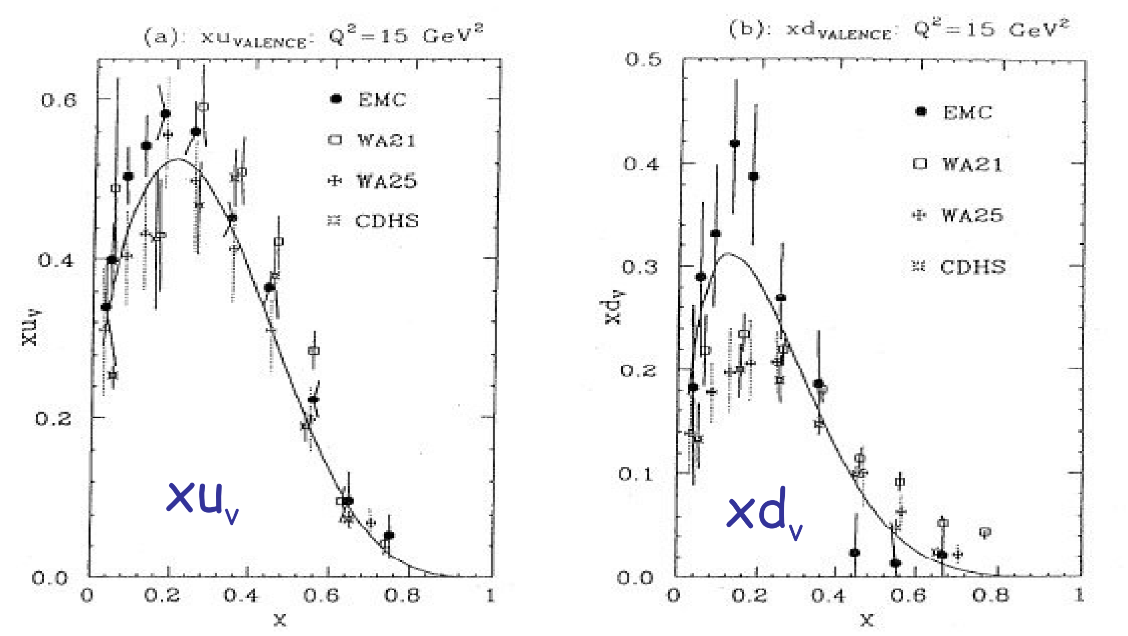
x interval	$x\,d_v$	$x\,u_v$	d_v/u_v
0.0–0.1	$0.189 \pm 0.033 \pm 0.023$	$0.617 \pm 0.116 \pm 0.073$	$0.306 \pm 0.107 \pm 0.052$
0.1–0.2	$0.211 \pm 0.019 \pm 0.019$	$0.524 \pm 0.062 \pm 0.058$	$0.402 \pm 0.075 \pm 0.057$
0.2–0.3	$0.222 \pm 0.015 \pm 0.018$	$0.656 \pm 0.047 \pm 0.067$	$0.338 \pm 0.040 \pm 0.044$
0.3–0.4	$0.209 \pm 0.006 \pm 0.010$	$0.660 \pm 0.025 \pm 0.037$	$0.316 \pm 0.015 \pm 0.023$
0.4–0.5	$0.117 \pm 0.004 \pm 0.012$	$0.517 \pm 0.023 \pm 0.054$	$0.226 \pm 0.013 \pm 0.033$
0.5–0.6	$0.065 \pm 0.003 \pm 0.006$	$0.324 \pm 0.018 \pm 0.009$	$0.200 \pm 0.015 \pm 0.019$
0.6–0.7	$0.024 \pm 0.002 \pm 0.002$	$0.141 \pm 0.011 \pm 0.015$	$0.169 \pm 0.018 \pm 0.023$

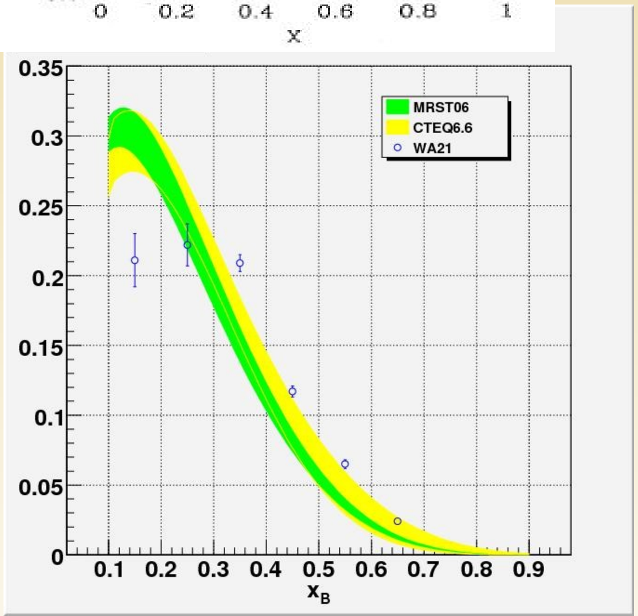




Valence quark from WA21

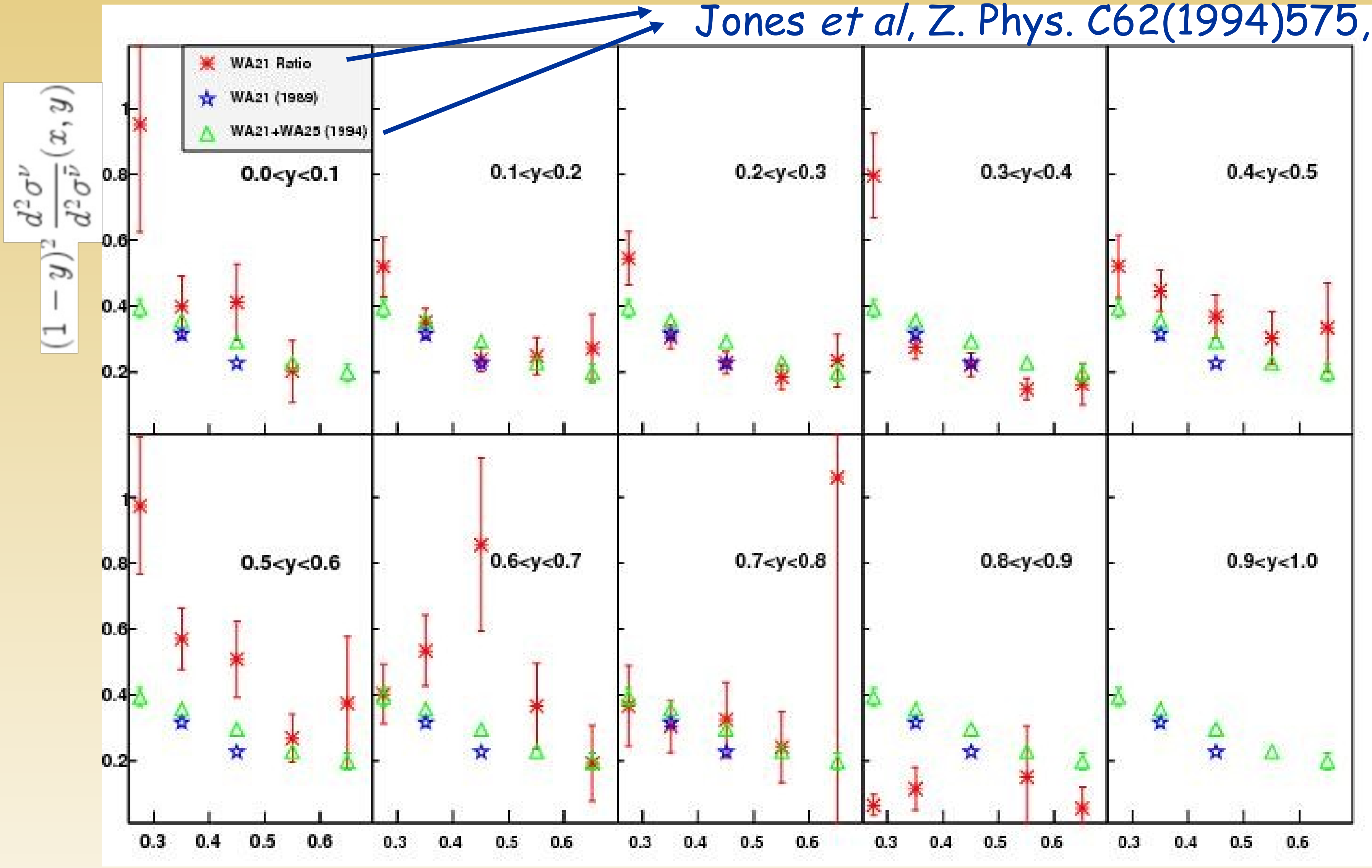
Sterman *et al*, Rev. Mod. Phys. 67(1995)157



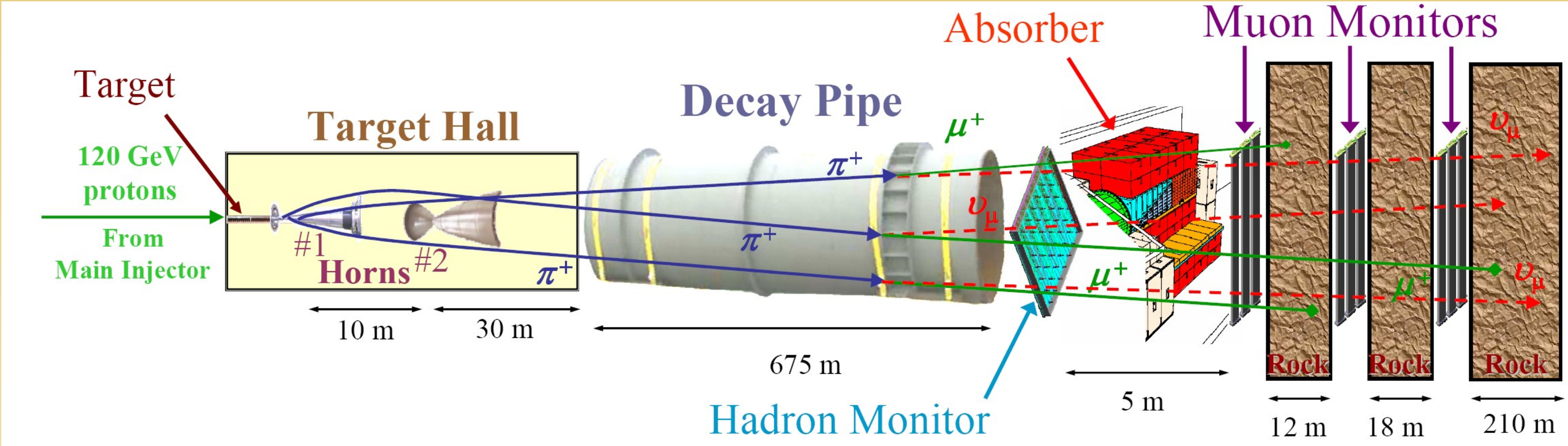


Neutrino to anti-neutrino ratio from WA21

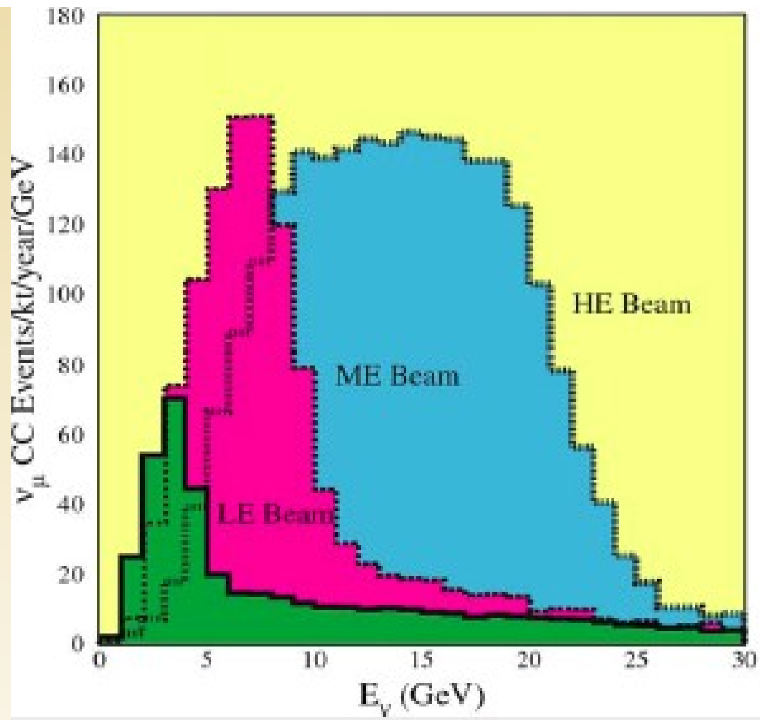
Jones *et al*, Z. Phys. C62(1994)575,601



NUMI beam line

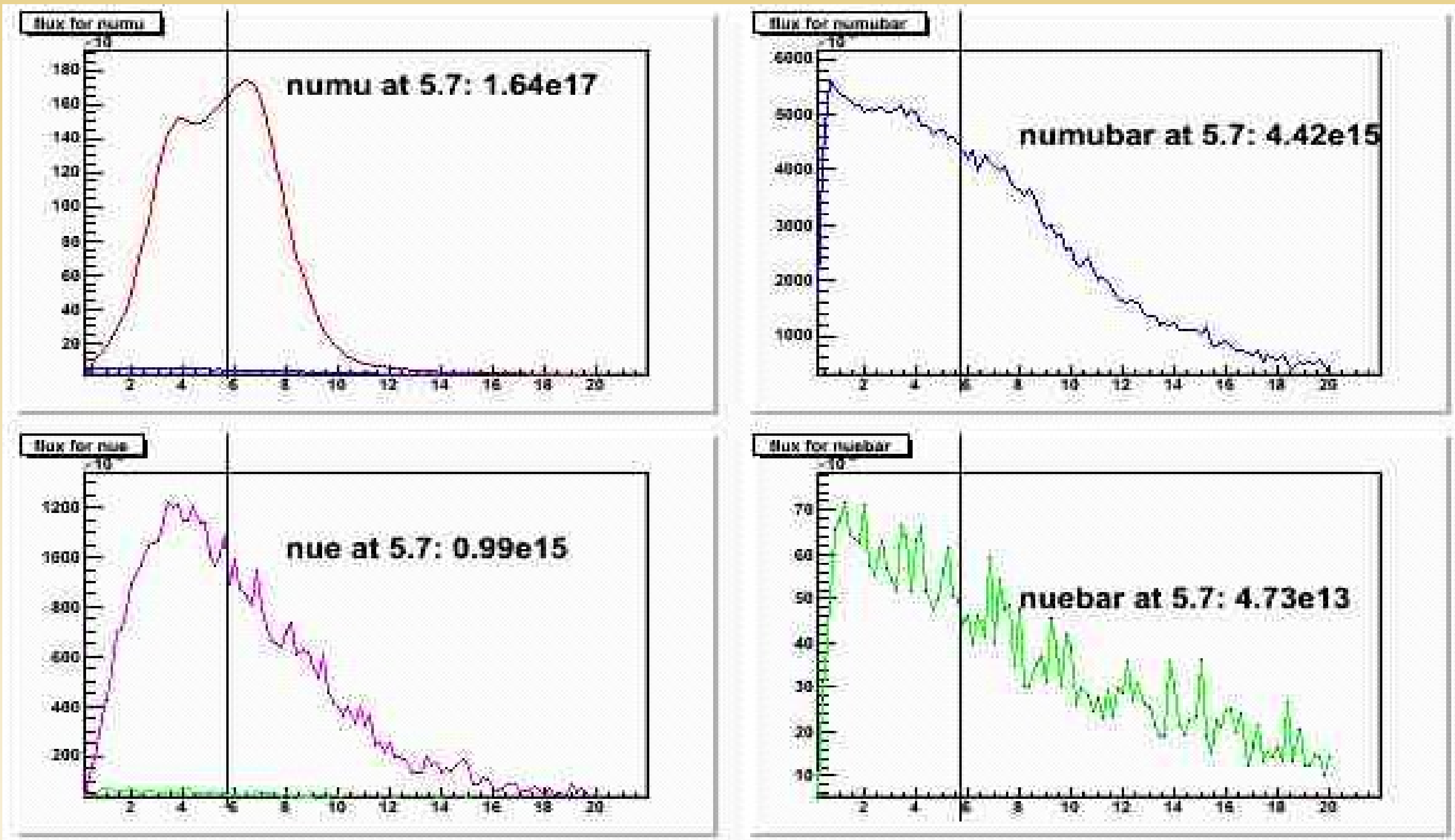


- Most powerful ν beamline so far in the world.
  - $4X10^{20}$ protons/year
- Configurable beam
  - Wide range of ν energies
  - Neutrino and anti-neutrino



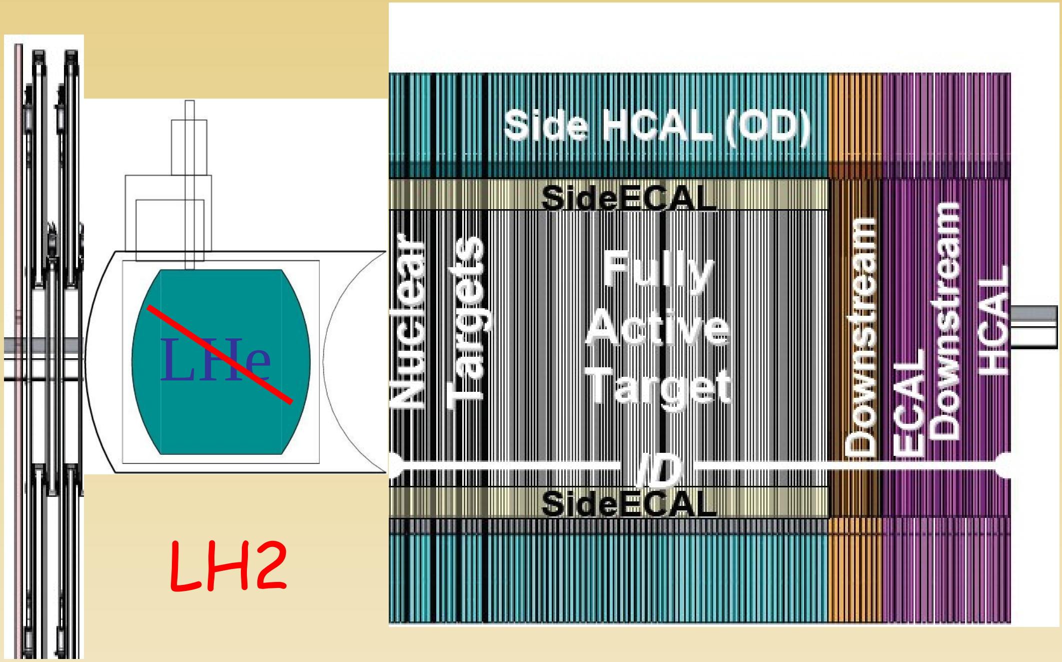
Nominal Beam for MINERVA

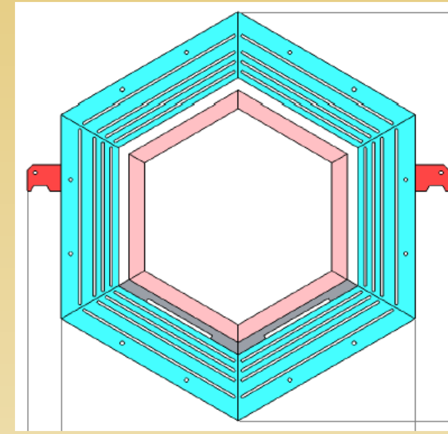
Combo beam: 1 year LE+3 year ME; 4.0 x 10^{20} POT per year

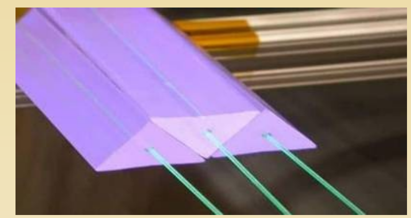


$$\text{At } E = 5.7 \text{ GeV: } \nu_\mu : \bar{\nu}_\mu : \nu_e : \bar{\nu}_e = 3467 : 93 : 21 : 1$$

MINERνA

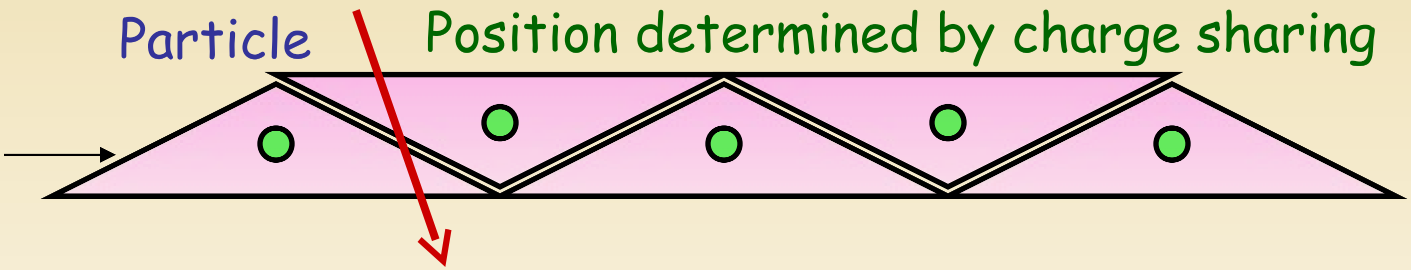






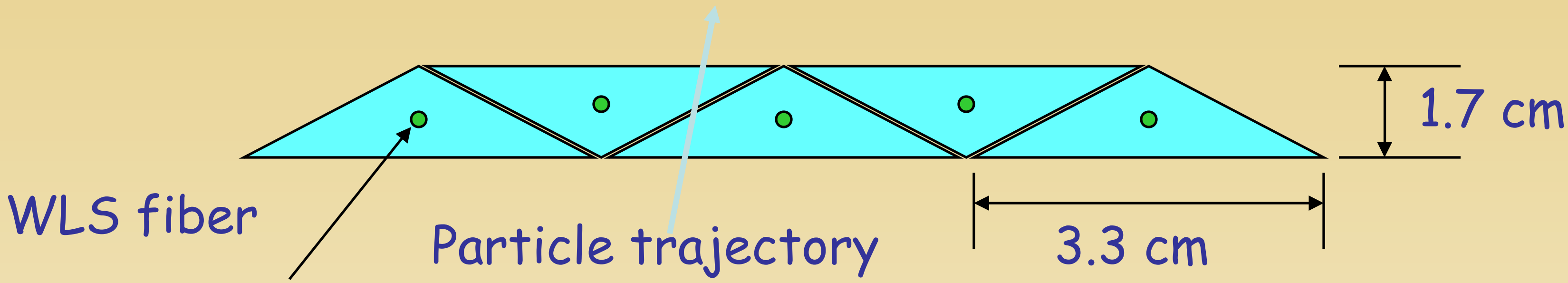
Particle

Position determined by charge sharing

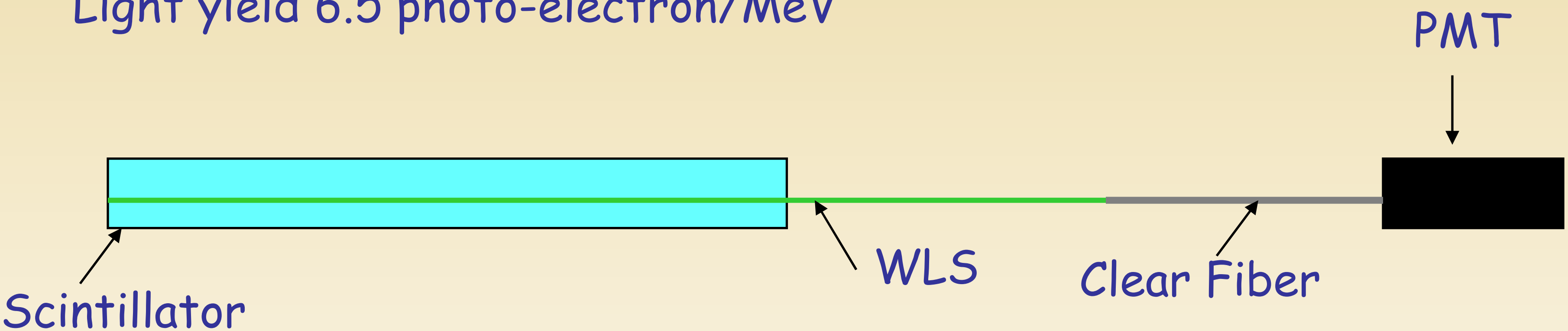


Active Scintillator Target

Triangular scintillators are arranged into planes – Wave length shifting fiber is read out by Multi-Anode PMT

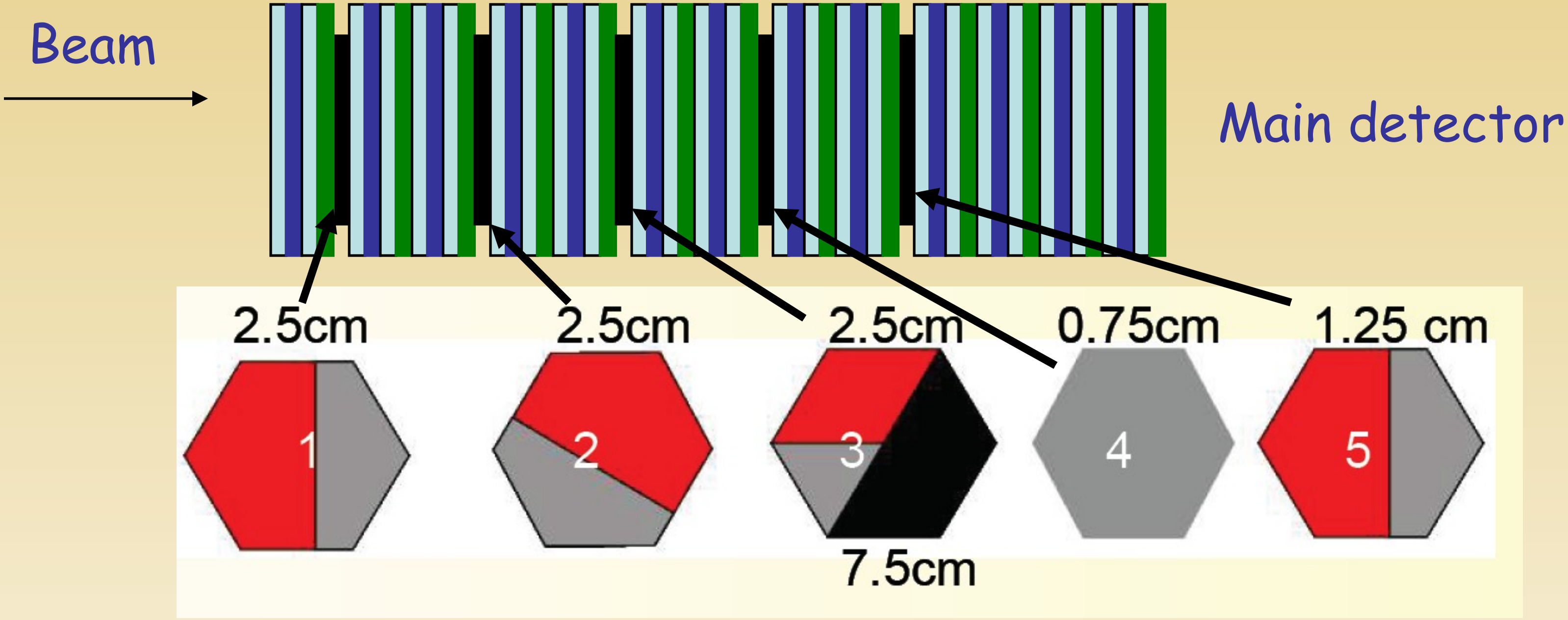


2.5 mm resolution with charge sharing
Light yield 6.5 photo-electron/MeV



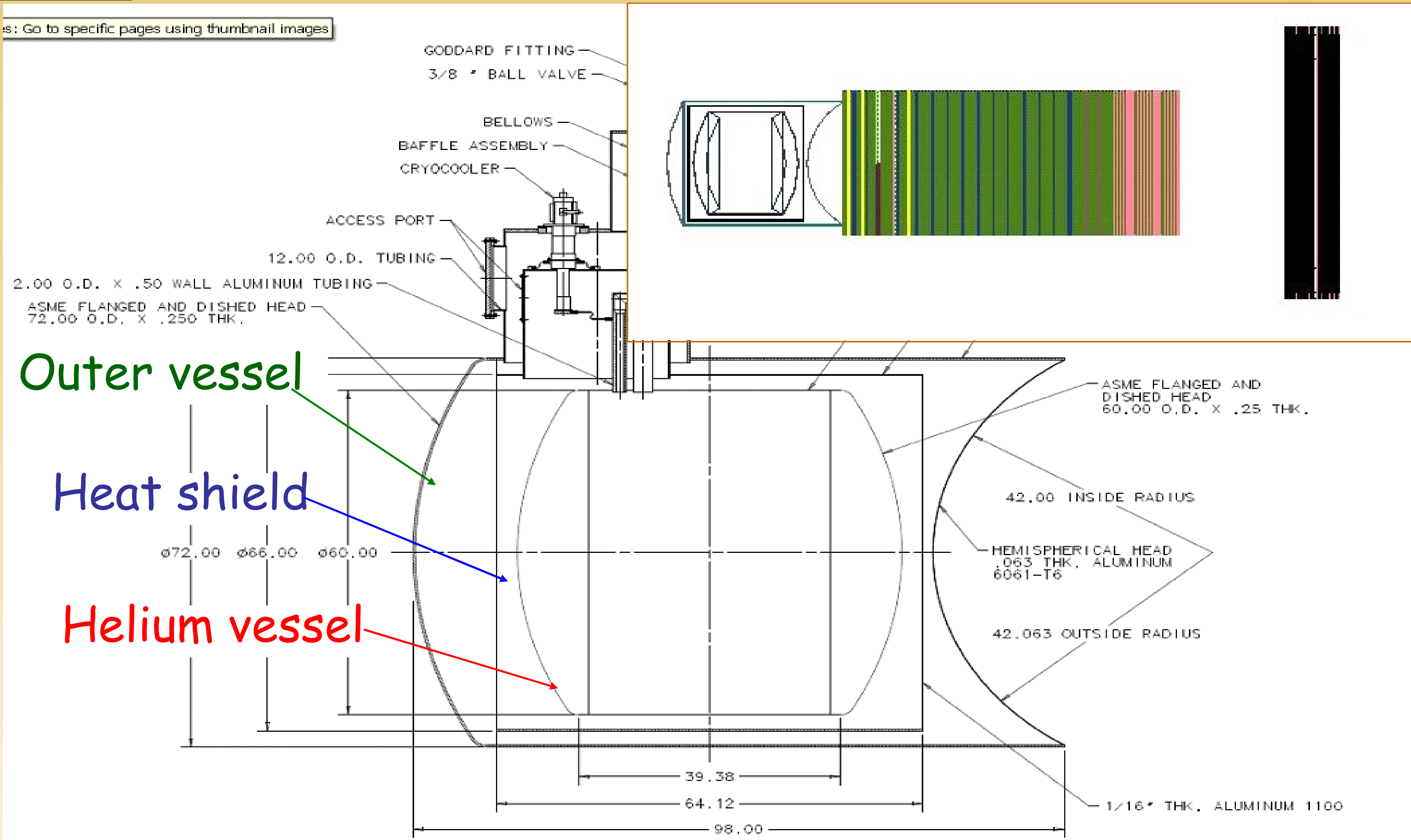
MINERνA Nuclear Targets

XUXVXUXV (4 tracking modules) between

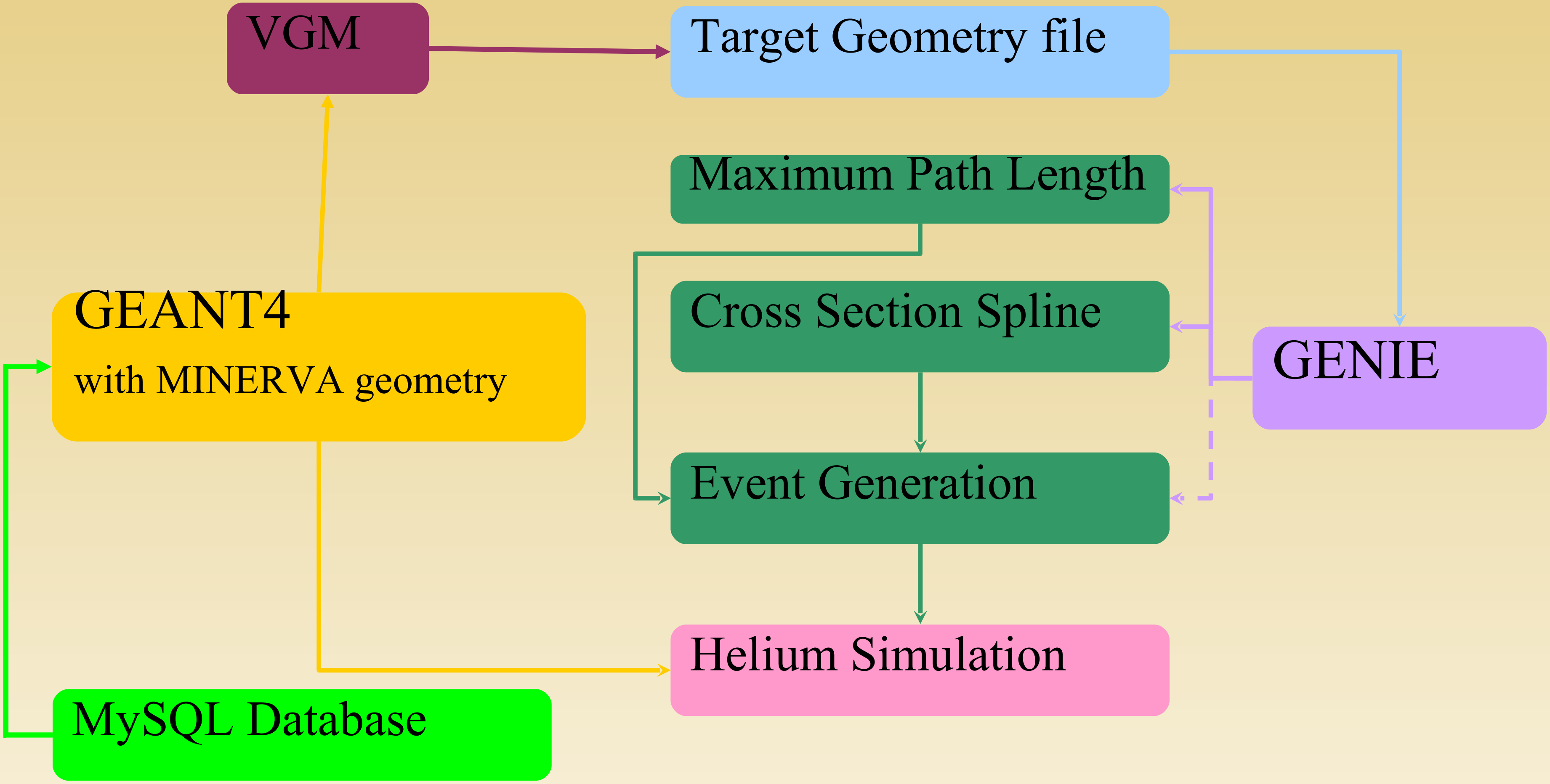


Carbon, Iron, Lead – mixed elements in layers to give same systematics

Design for the Cryogenic Target

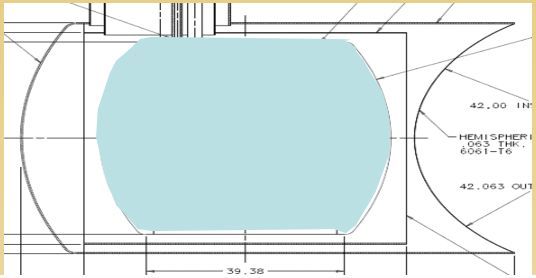


Flow chart for Helium Simulation

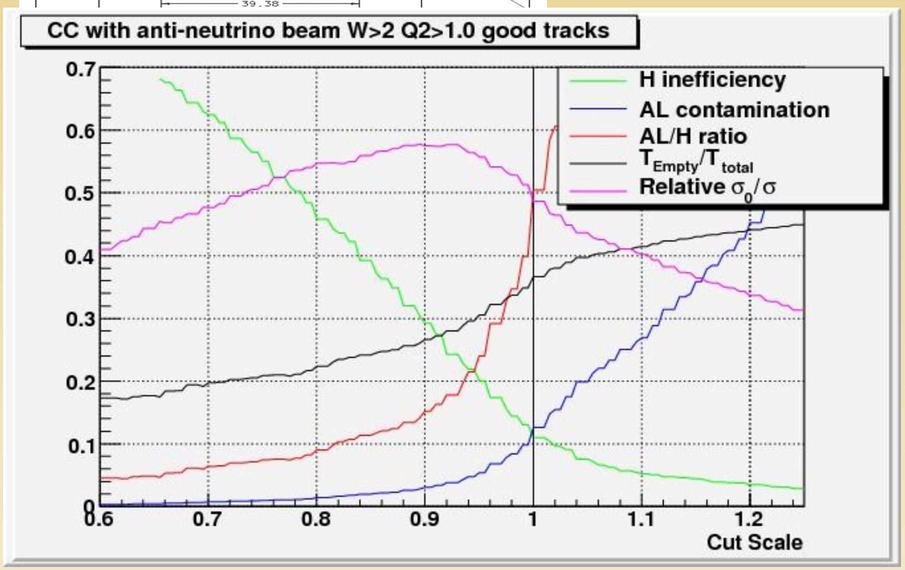


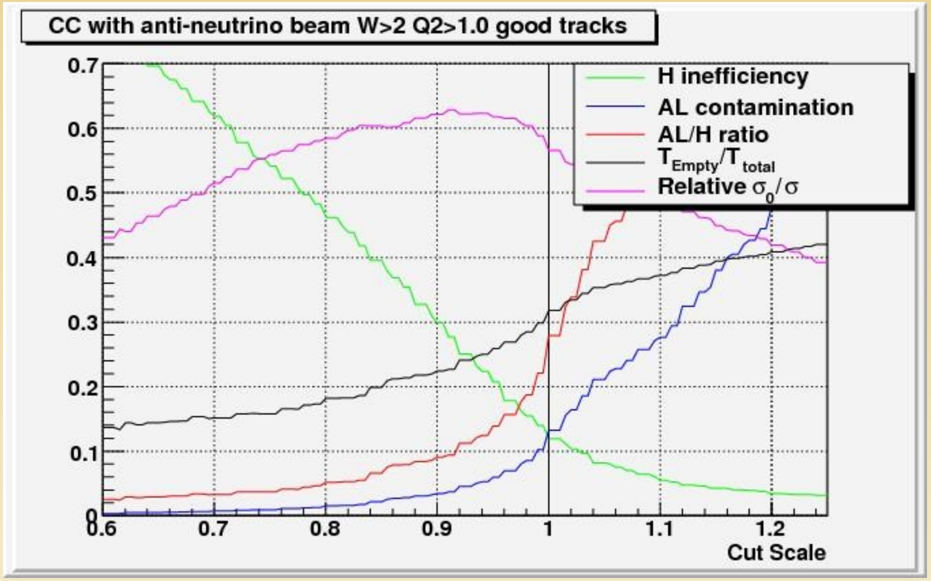
GENIE and GEANT4 simulation are independent steps.

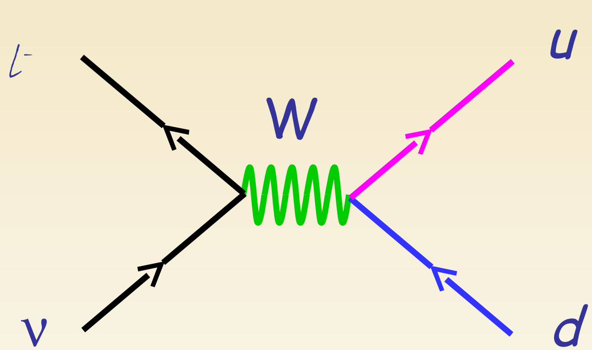
Empty Target Background

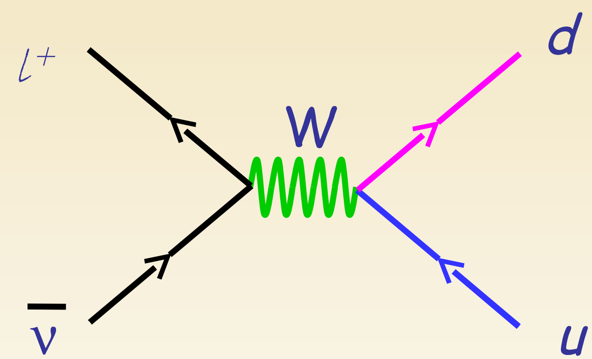


- neutrino beam: Al/H=6.7
- anti-neutrino beam: Al/H=3.5



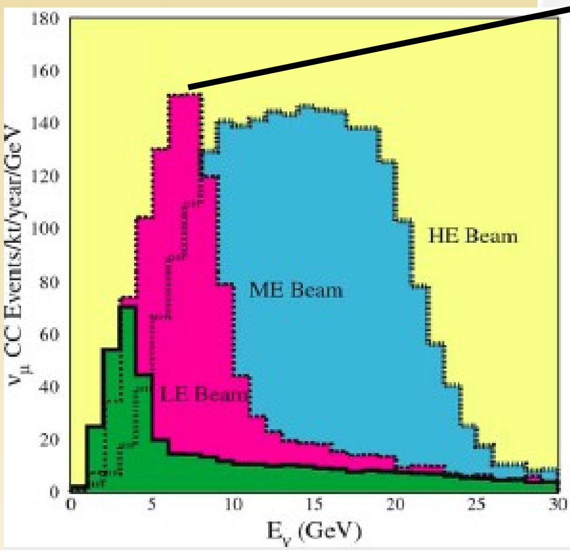


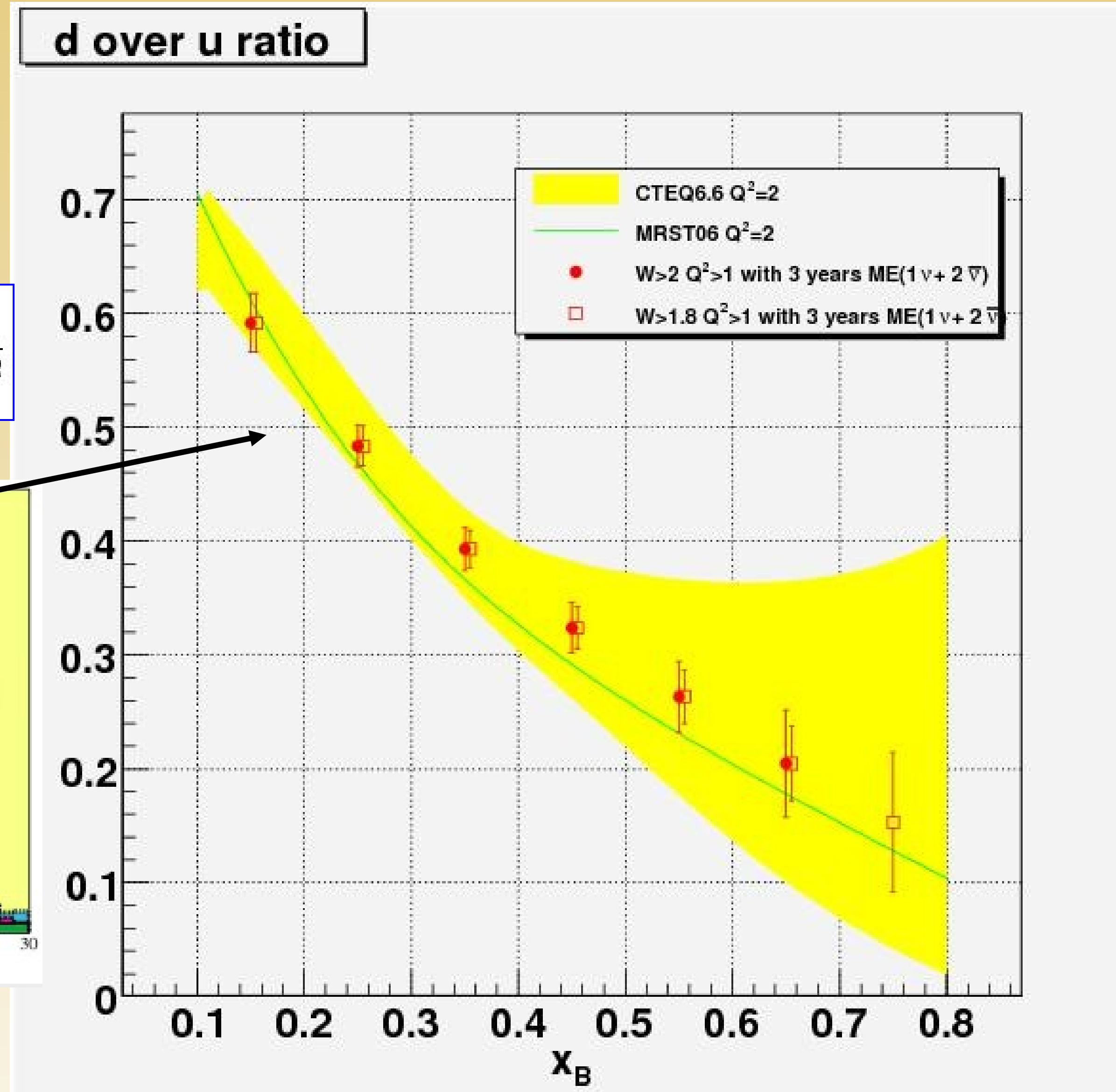




Projection with NUMI ME (anti-)neutrino beam

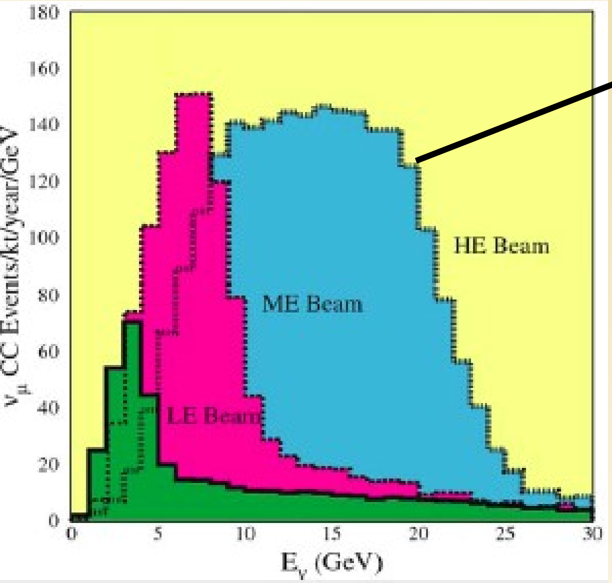
$$\frac{d^2\sigma^{\nu}}{d^2\sigma^{\bar{\nu}}}(x,y) \sim \frac{d(x)}{u(x)} \cdot \frac{1}{(1-y)^2}$$

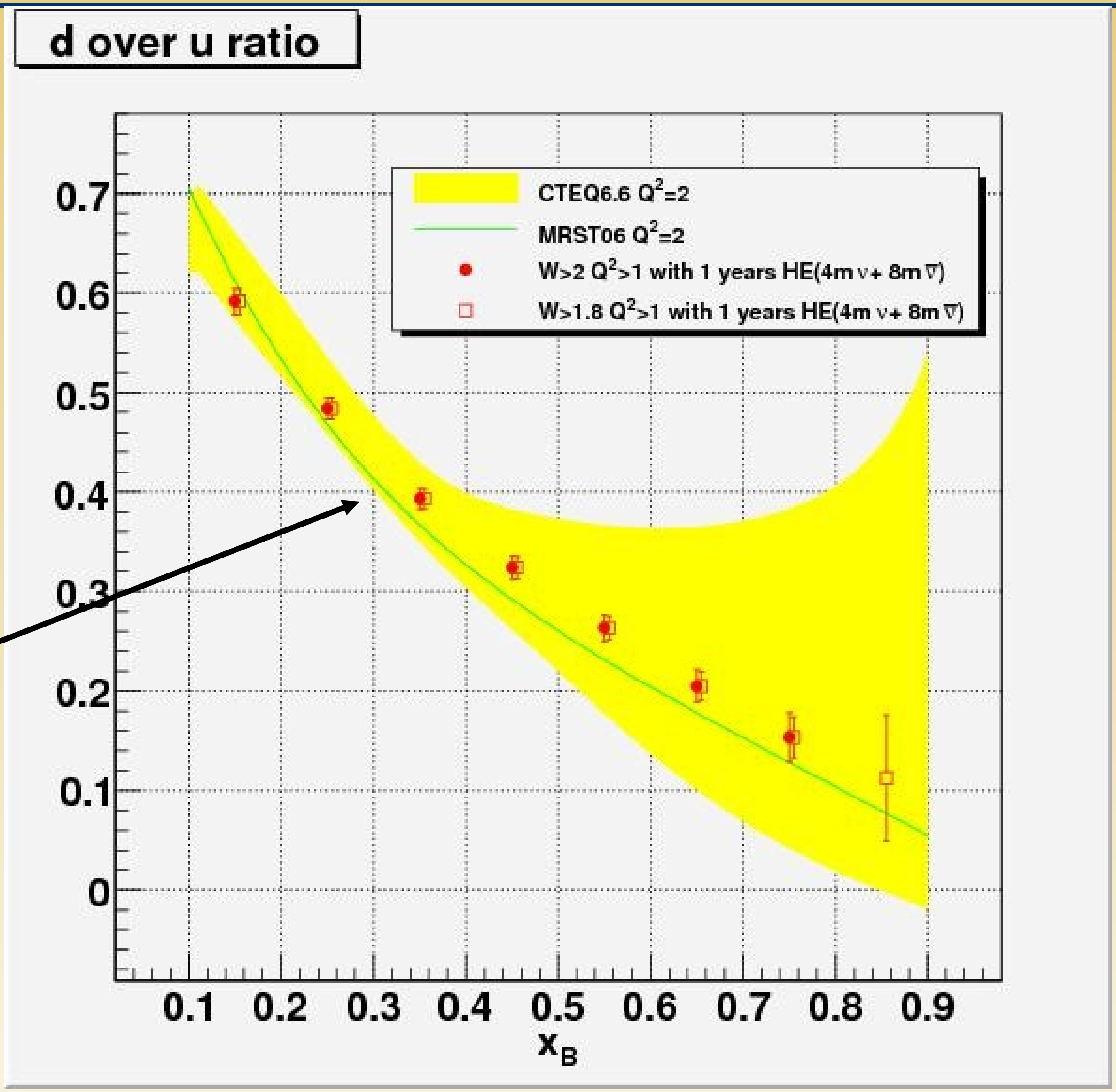




Projection with NUMI HE (anti-)neutrino beam

$$\frac{d^2\sigma^{\nu}}{d^2\sigma^{\bar{\nu}}}(x,y) \sim \frac{d(x)}{u(x)} \cdot \frac{1}{(1-y)^2}$$

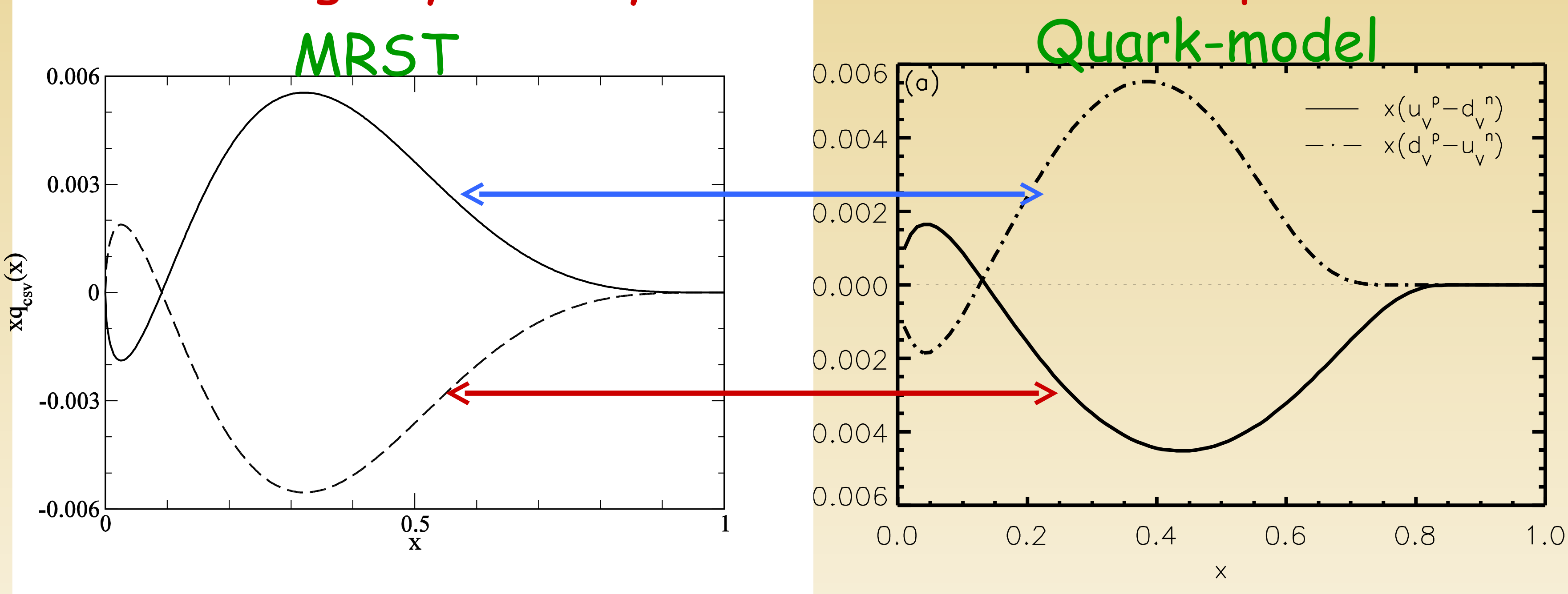




Charge Symmetry Violation

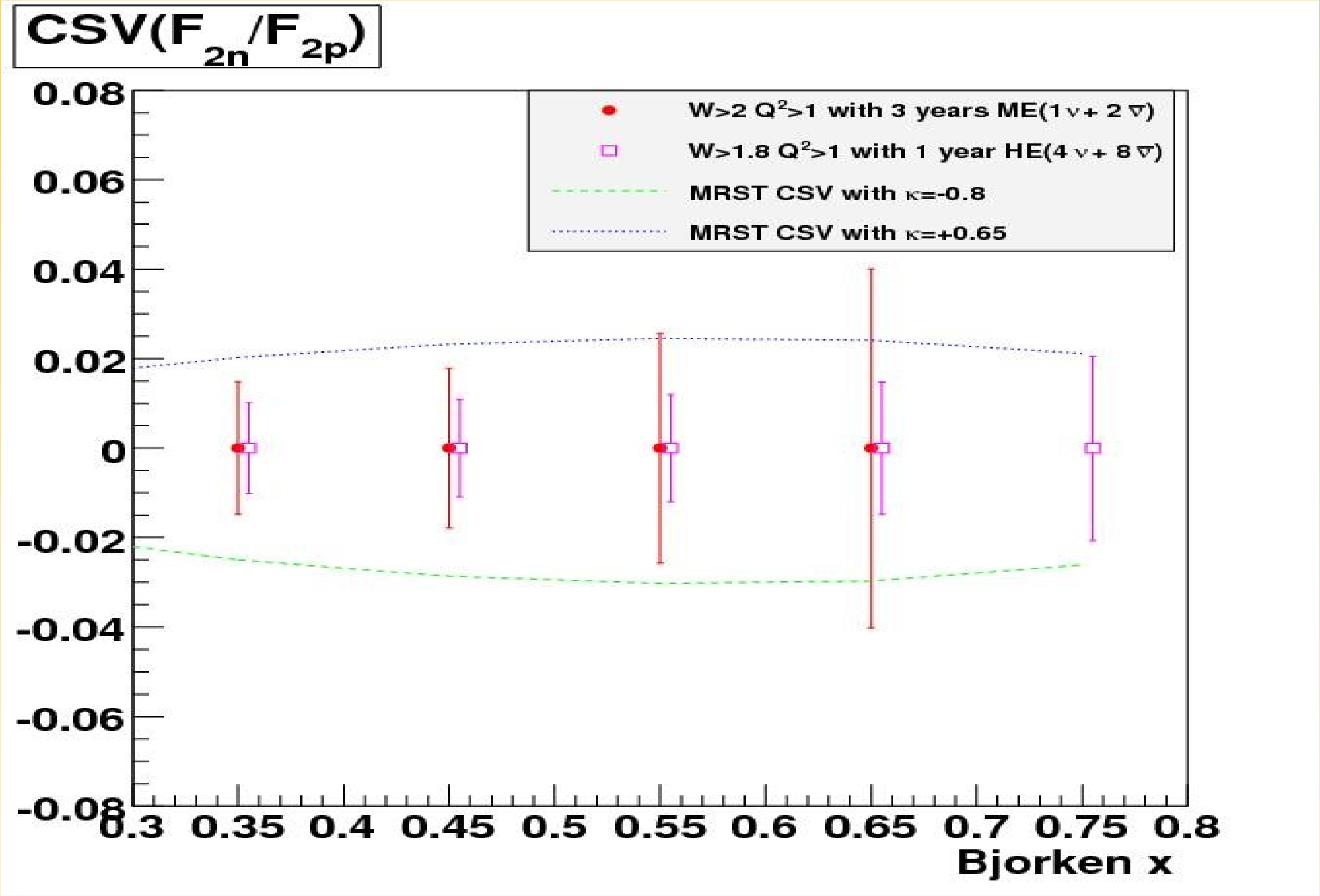
- **Charge symmetry (*u*** in proton = ***d*** in neutron) in PDFs not precisely tested. The violation could be up to 5~10% level, which could partially explain the NuTeV anomally in Weinberg angle and the dbar/ubar asymmetry.

Charge symmetry violation for valence quarks

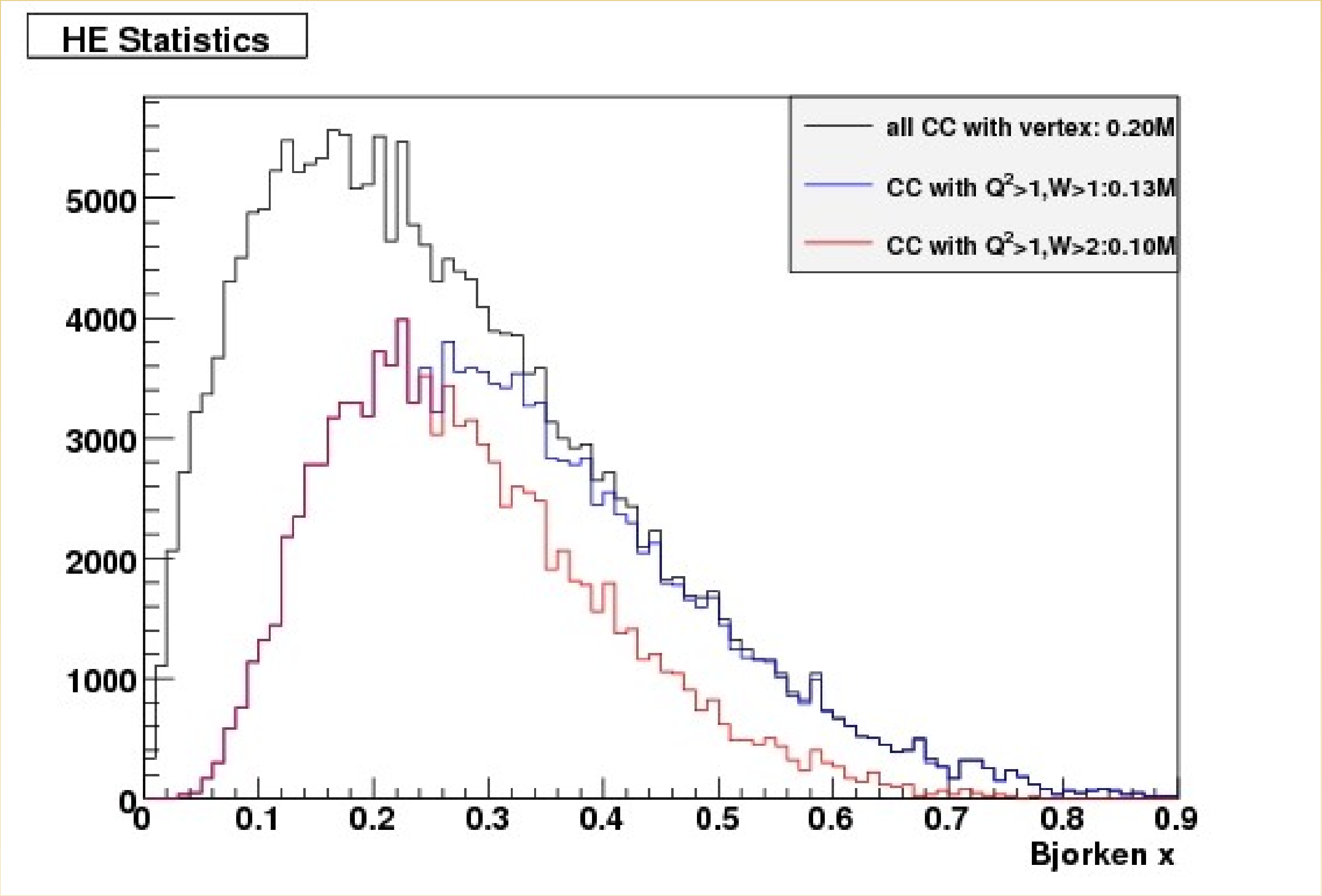


Recent review, Londergan, Peng & Thomas, arXiv:0907.2352.

Projection on Charge Asymmetry

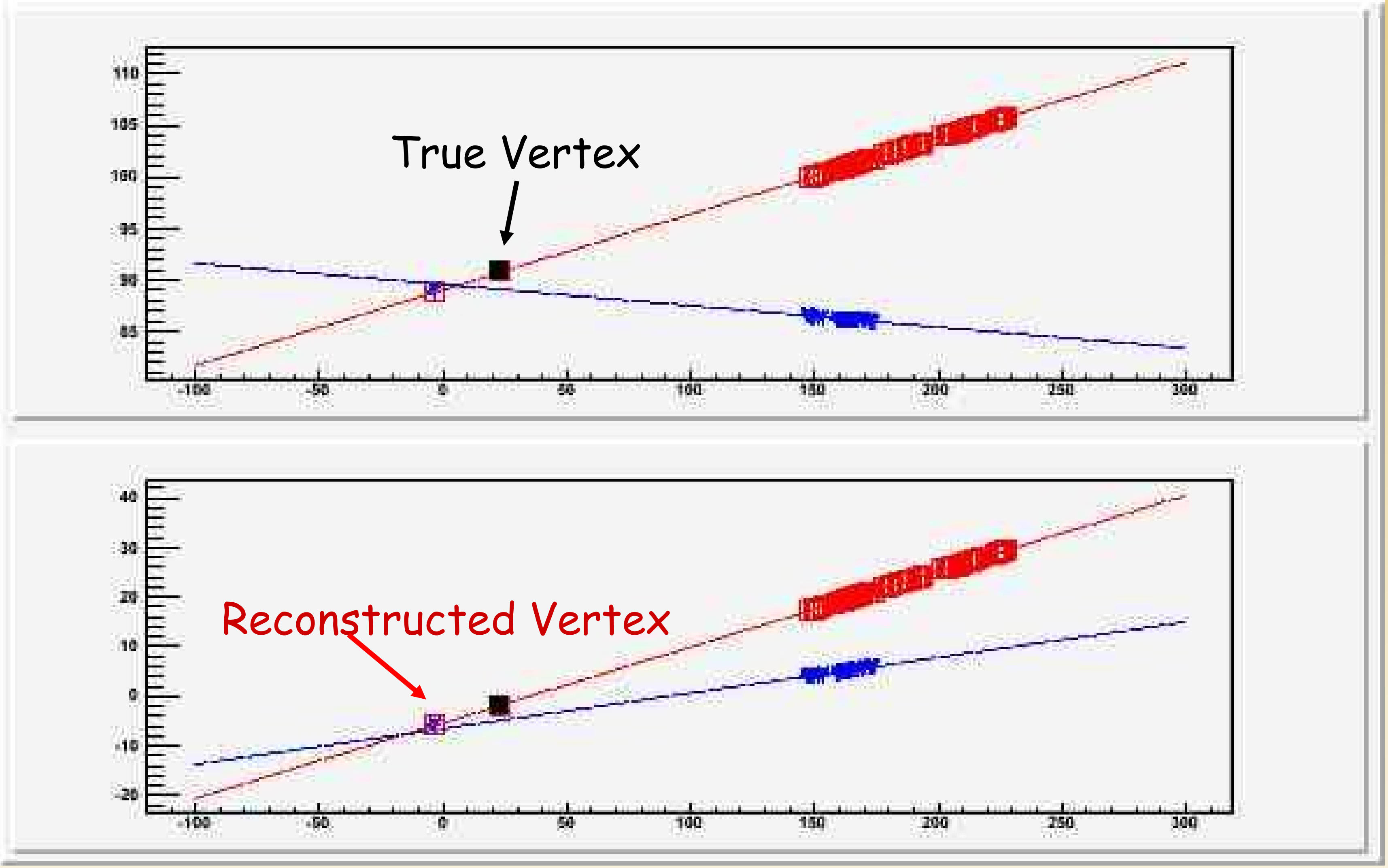


CC events with 4-year combo neutrino flux on He

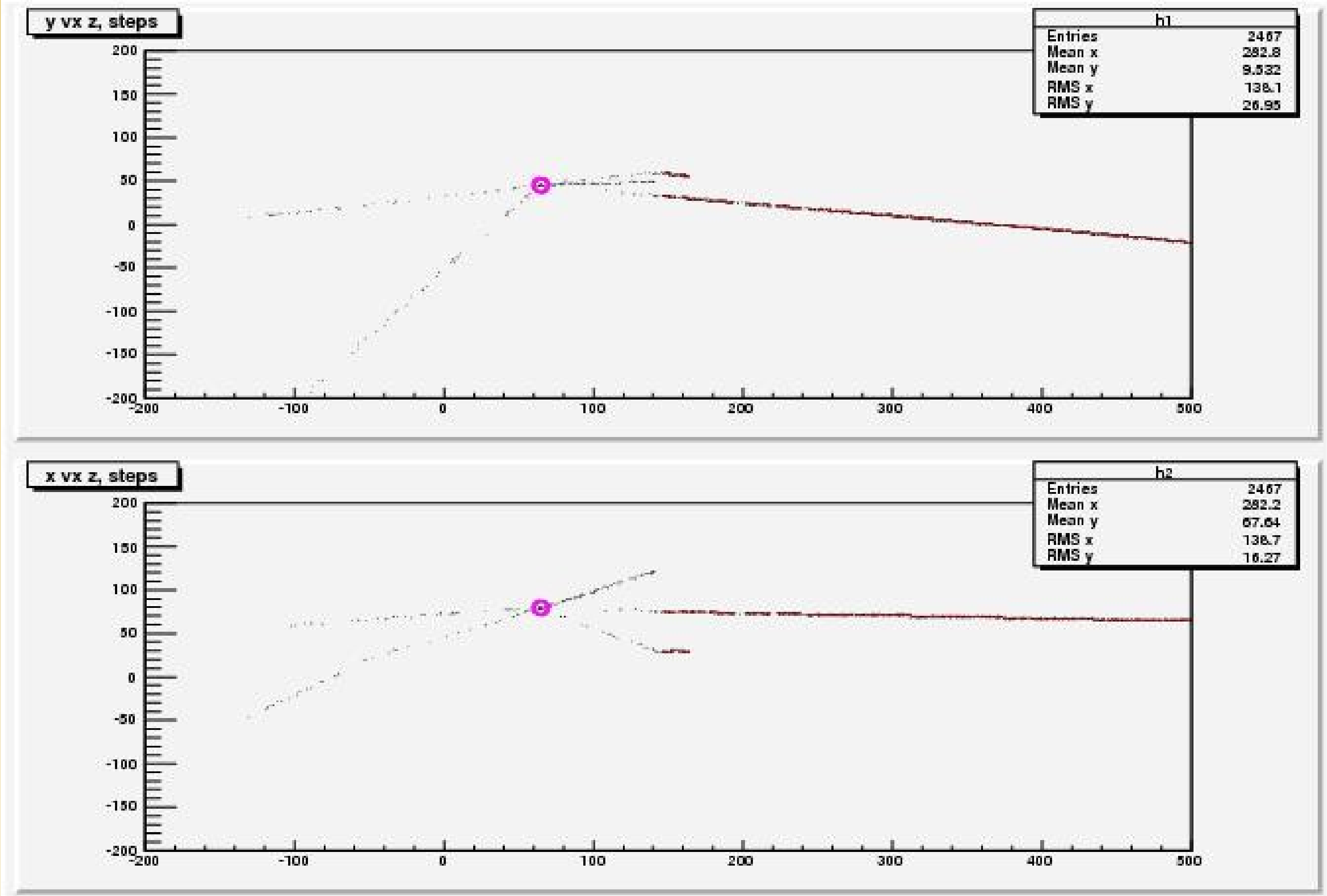


About 0.6M DIS and 0.4M CC produced from Helium.

A Example Vertex Reconstruction



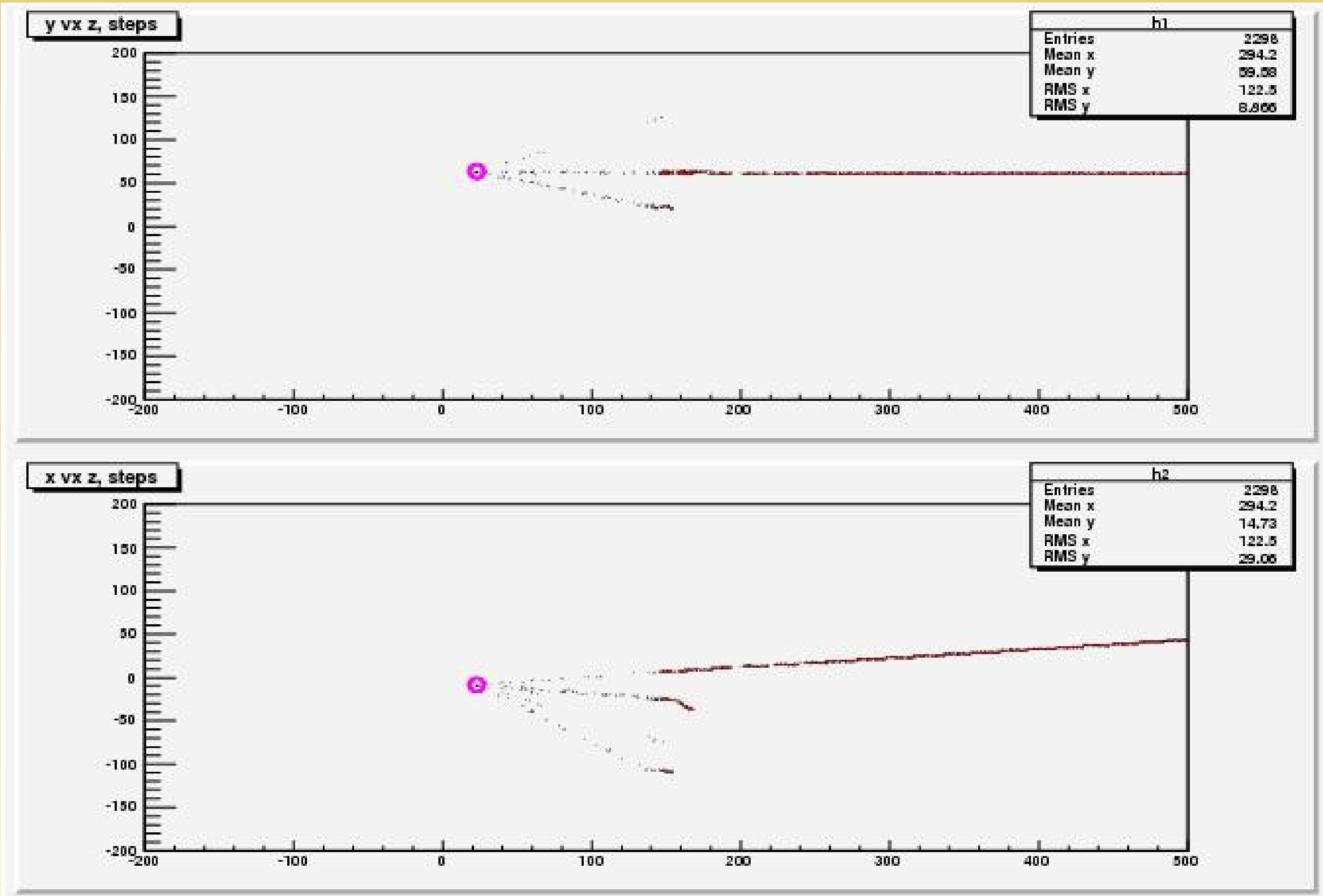
Secondary Reaction before the Detector



(Reconstructed Vertex_z from muon and pion: 1160.4)

Area Mass: HE ~50*0.114=5.7 g/cm^2; AL ~1.43*2.7=3.9 g/cm^2

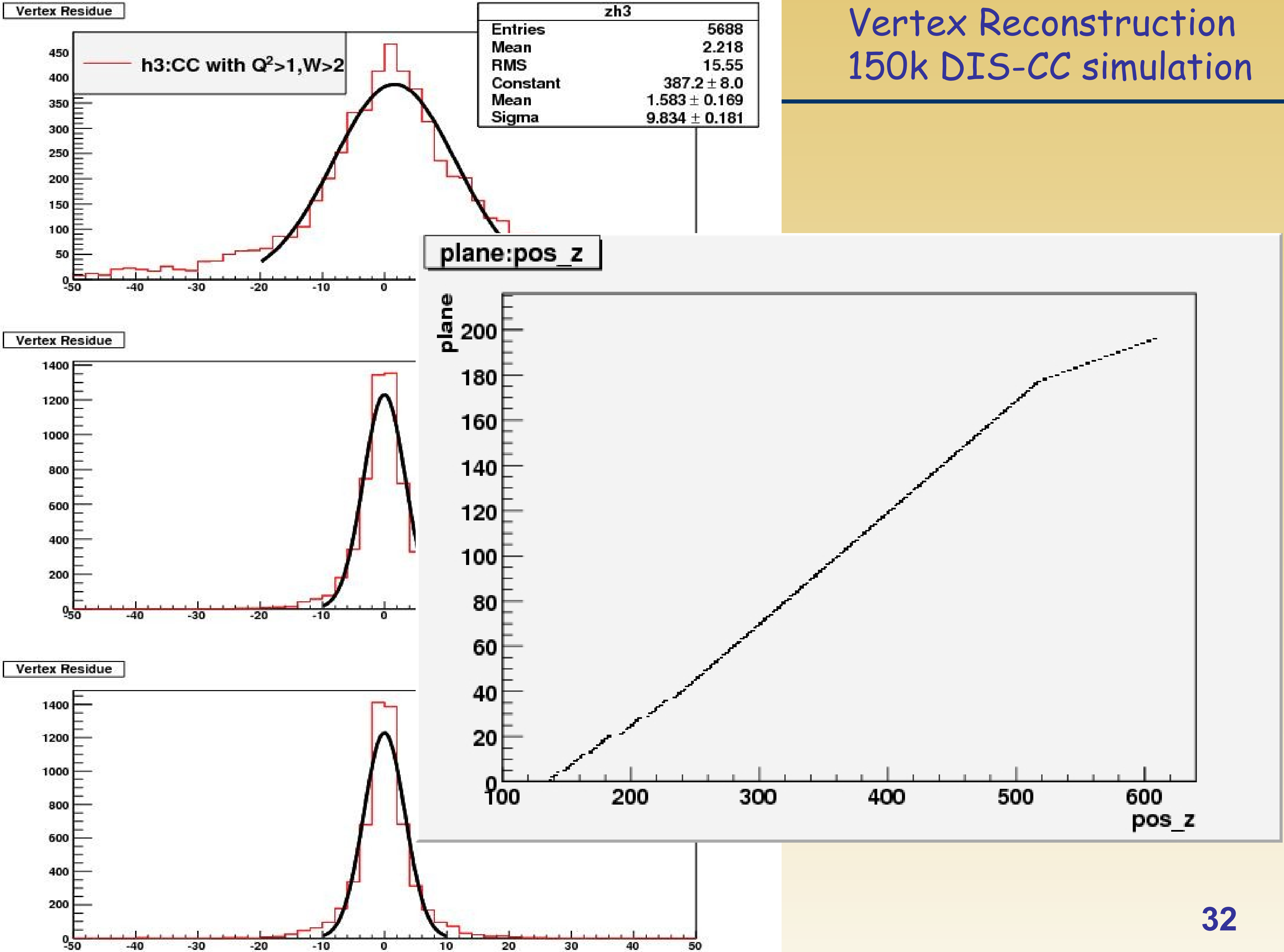
Secondary Reaction in the Detector



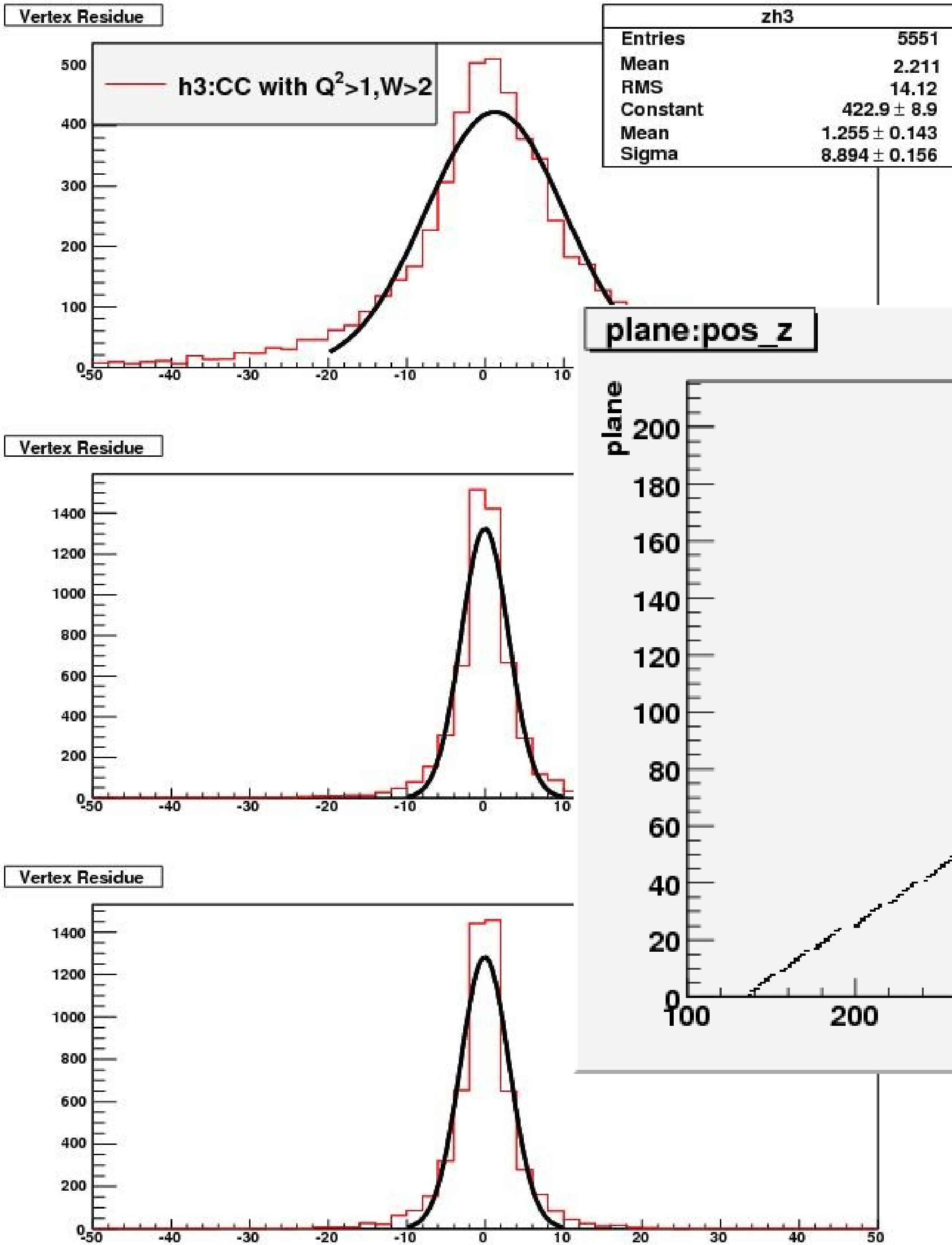
(Reconstructed Vertex_z from muon and pion: -70 cm)

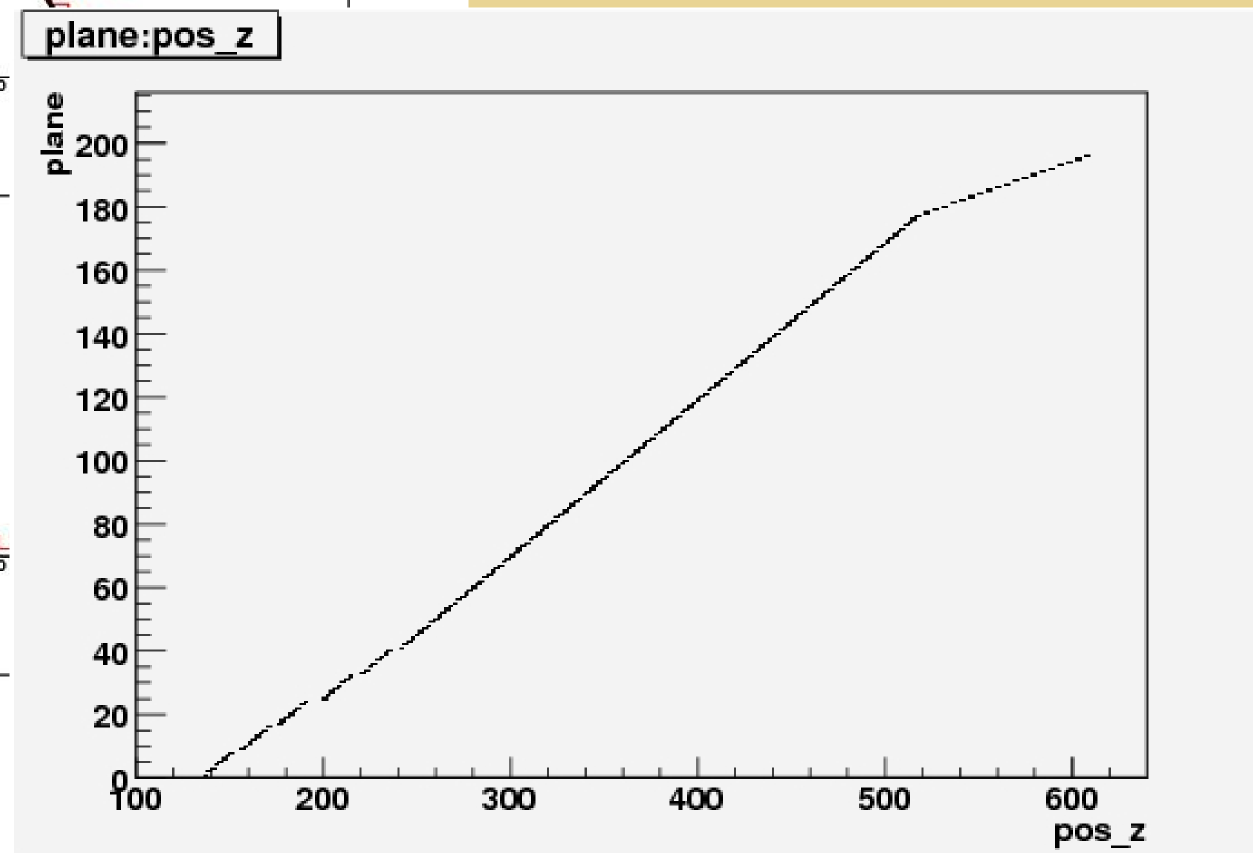
Area Mass of one plane: ~4.32*1.032=4.5 g/cm^2

Vertex Reconstruction
150k DIS-CC simulation



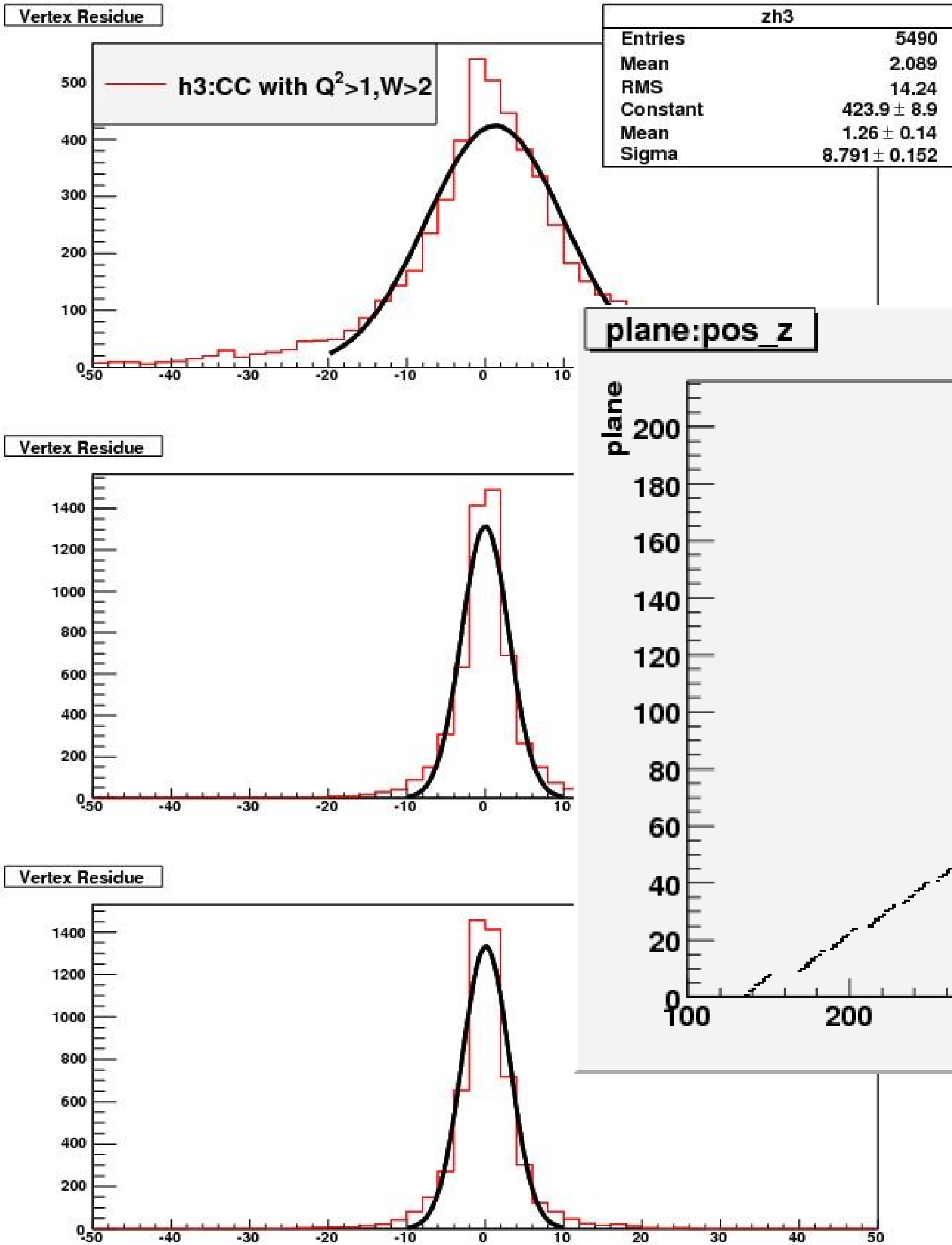
Vertex with module switch
145k DIS-CC simulation

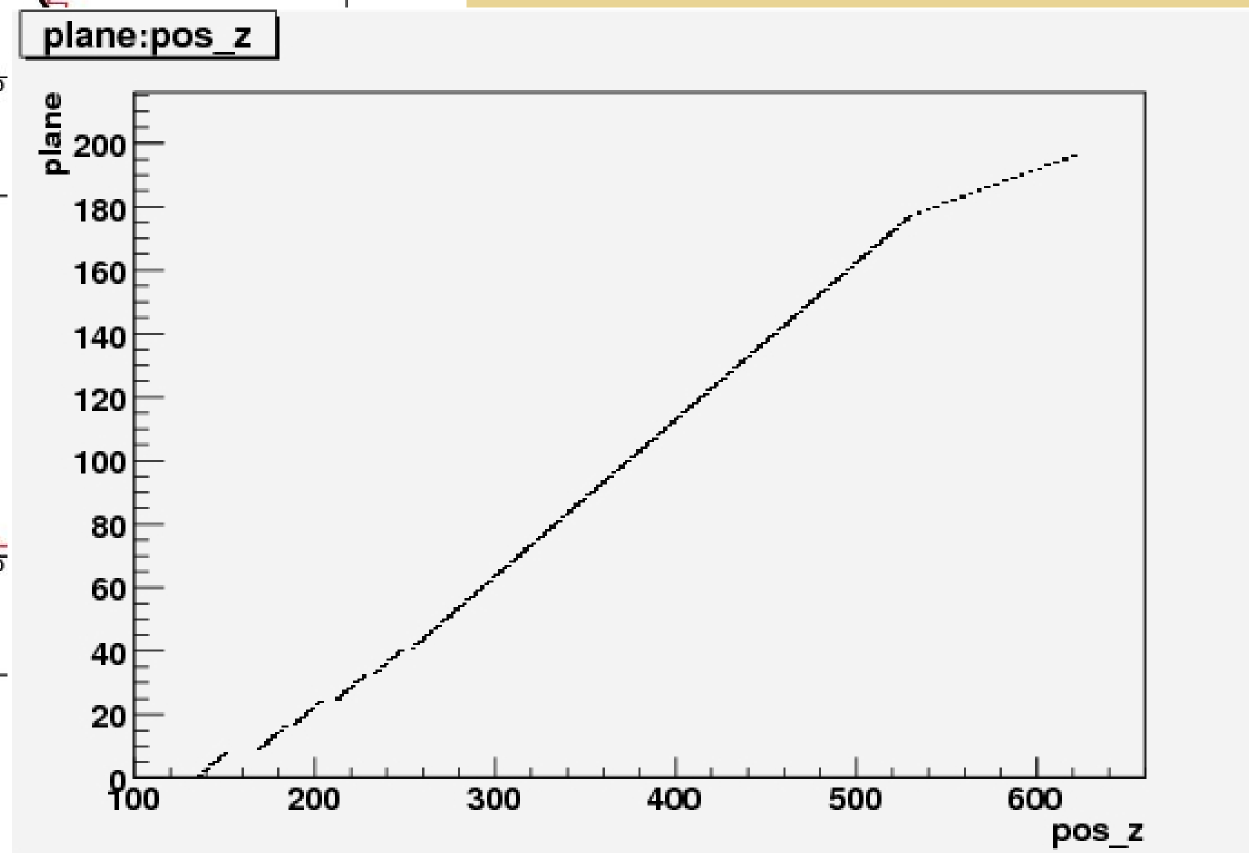




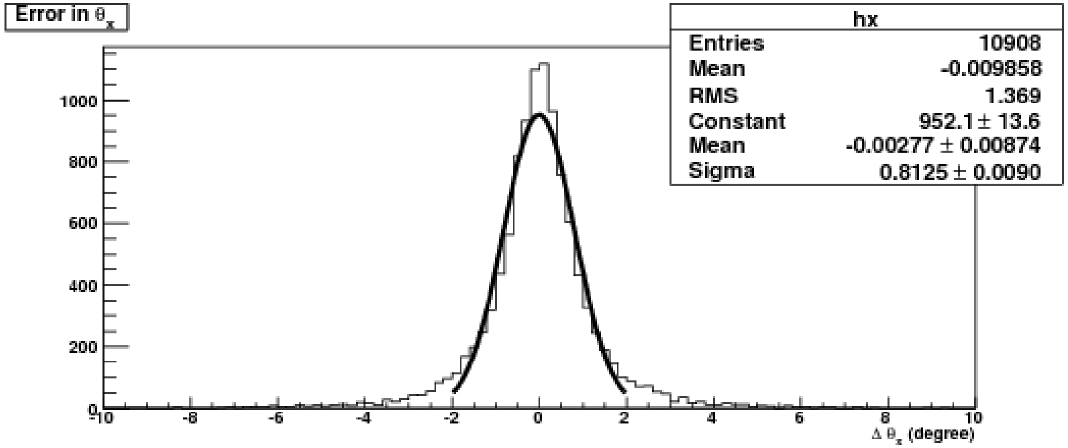
Statistics gain of ~10%

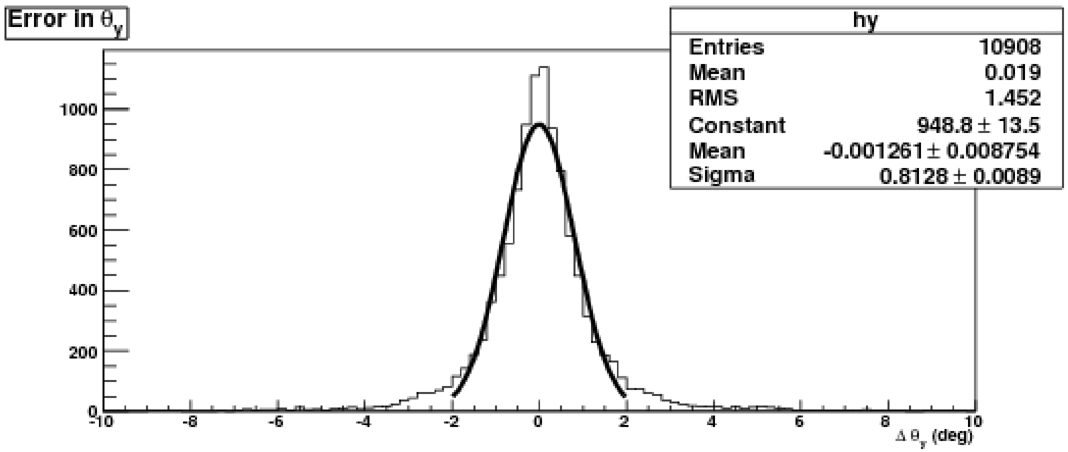
Vertex with switch & gap
145k DIS-CC simulation

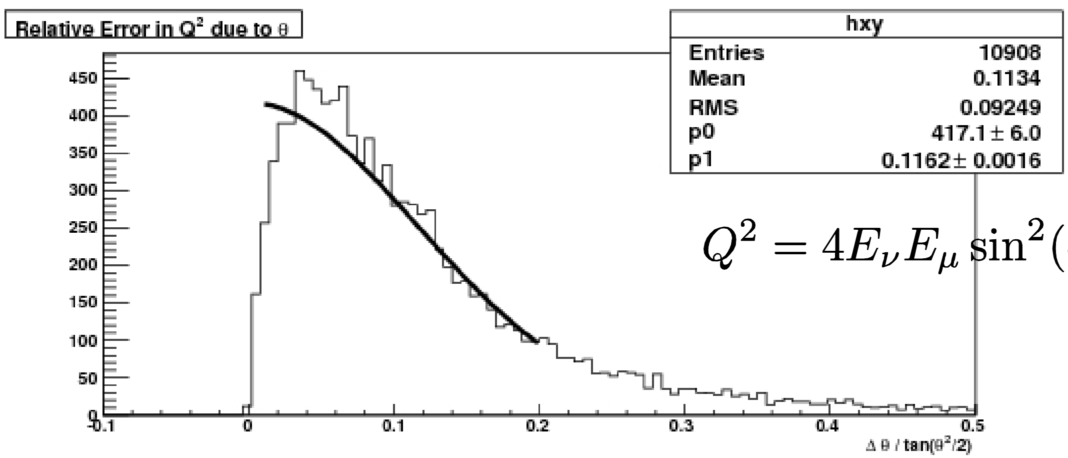




Angle Resolution





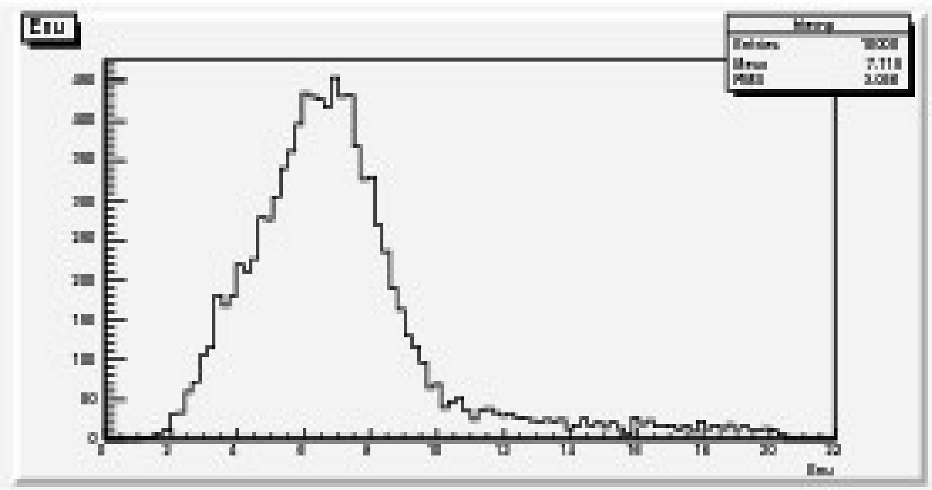


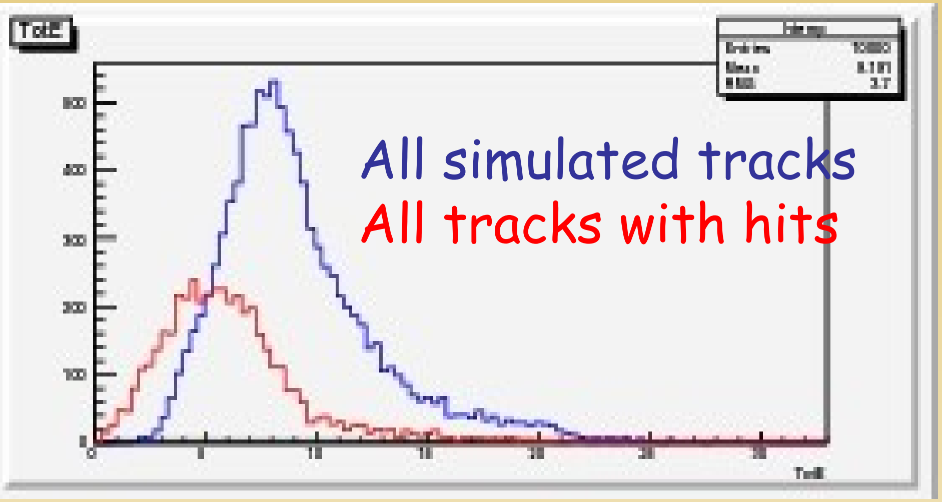
0.8 degrees error in angles

~12% relative error in Q^2

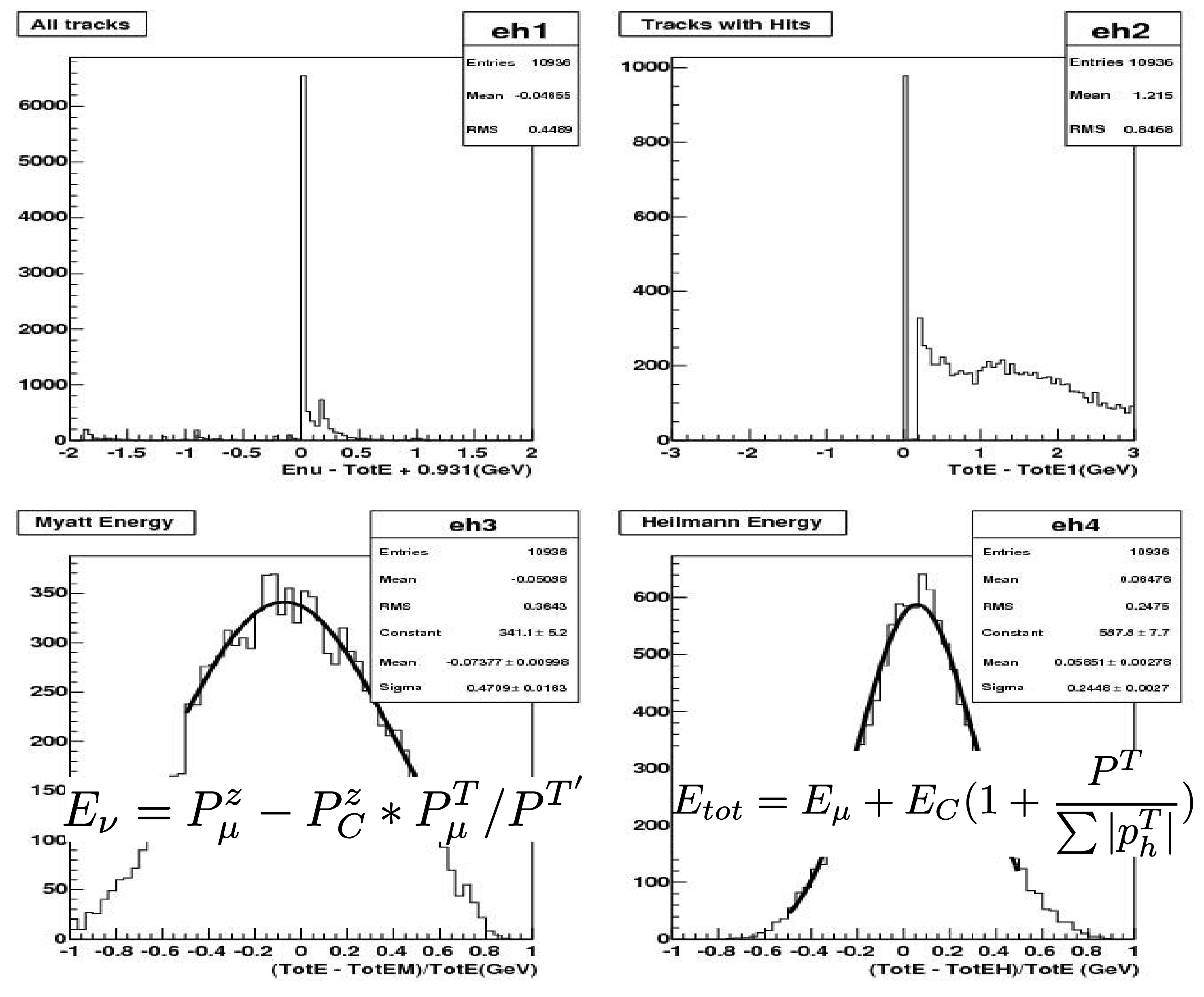
$$Q^2 = 4E_\nu E_\mu \sin^2(\theta_\mu/2); x_{\rm Bjorken} = \frac{Q^2}{2M(E_\nu - E_\mu)}$$

Energy Reconstruction for Detected Events





Energy Reconstruction for Detected Events



$$E_\nu = P^z_\mu - P^z_C * P^T_\mu / P^{T'}$$

$$E_{tot} = E_\mu + E_C\left(1 + \frac{P^T}{\sum |p^T_h|}\right)$$