NuTeV

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Neutrino 2000
Sudbury, Canada
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NuTeV Collaboration

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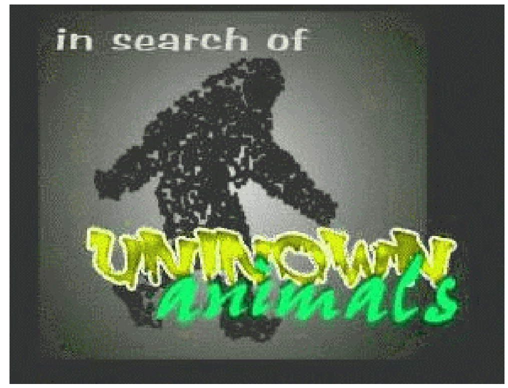

NuTeV

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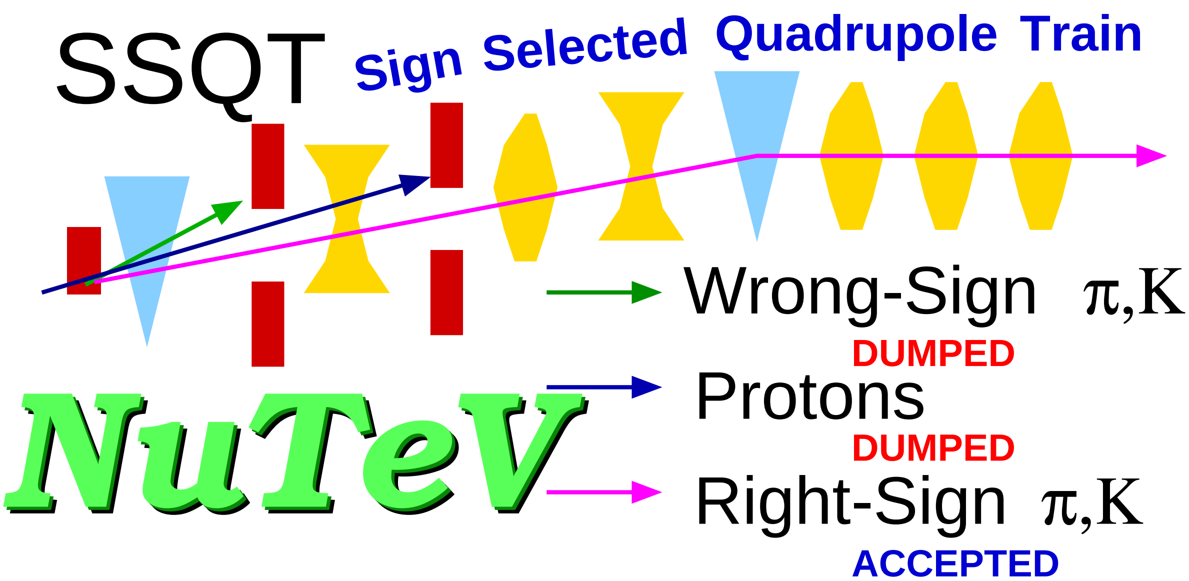
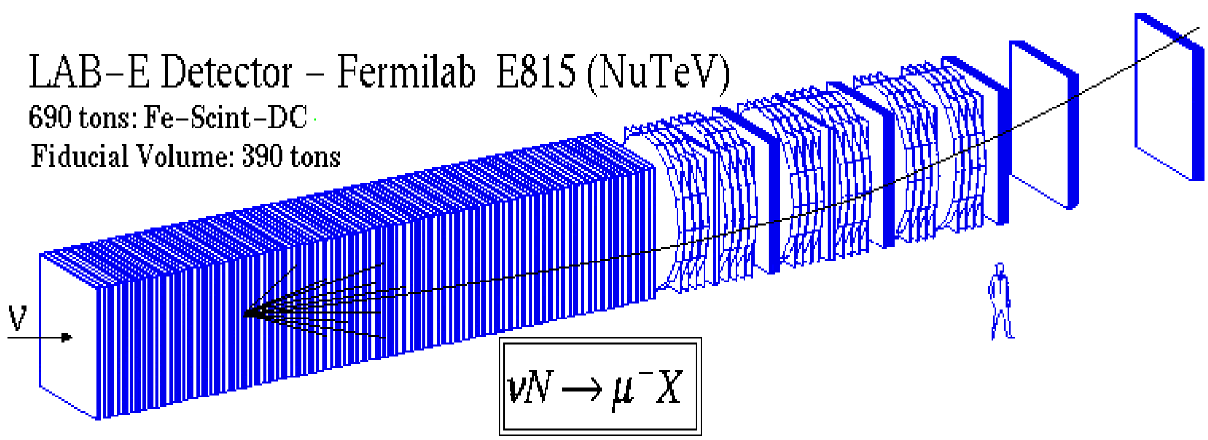
1. Anatomy of one High Energy Neutrino Experiment
2. NuTeV and Future Accelerator ν Experiments
3. Precision Measurements
   - Old Puzzles
   - New Puzzles
4. Searches for "Neu" Physics
5. Conclusions

NuTeV Experiment



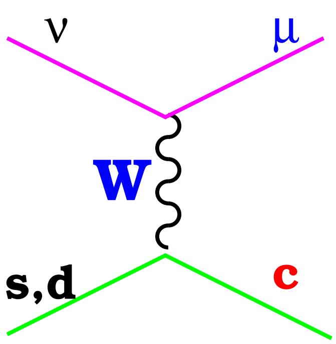


- Separated ν_μ, $\overline{\nu}_\mu$ beams ($\sim 10^{-3}$ purity)
- 10^{-2} $\nu_e/\overline{\nu}_e$, known to few %
- Final state $\mu^\pm$, hadronic energy
- 3.2×10^{18} protons at 800 GeV on target
  - ▷ $\sim 2 \times 10^6$ fiducial events
  - ▷ $\langle E_\nu \rangle \approx 100$ GeV

$$\nu_\mu N \to \mu^- c X$$

How can we serve you?

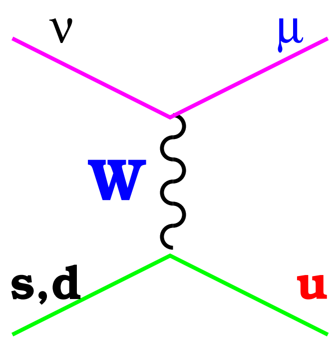
…measure charm suppression in GeV ν cross-sections



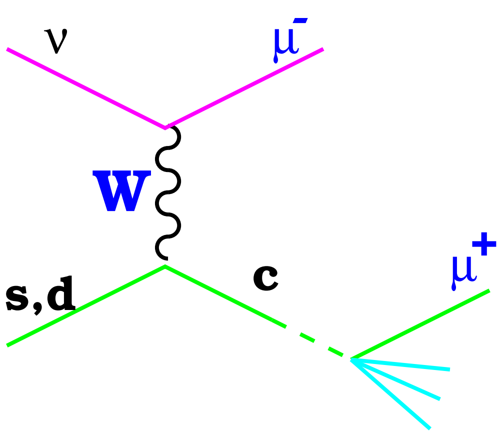
Suppressed by

$$q(x) \to q(\xi \equiv x + \frac{x {m_c}^2}{Q^2})$$

("Slow rescaling")



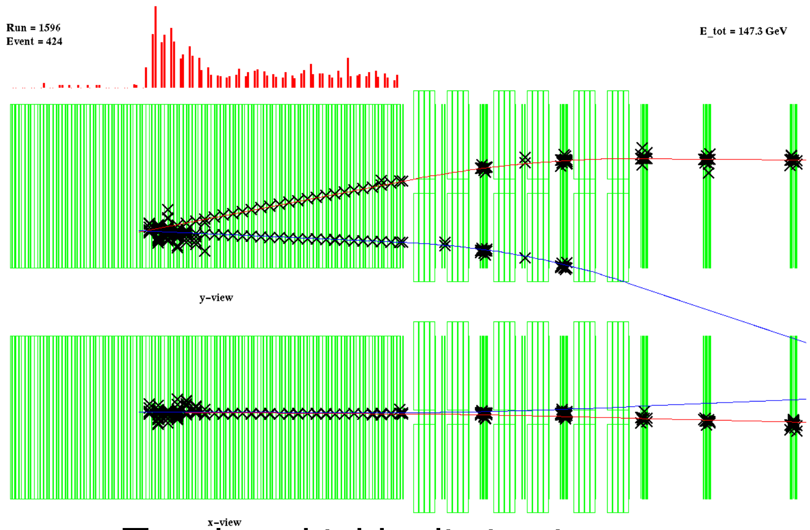
No suppression



- $c \to \mu^+ X$
  $\Rightarrow$ Two muon final state
- $\sim 0.5\%$ of NuTeV events
- Sign-selected beam tags
  leptonic side of event

$$\left\{\frac{d^2\sigma_{\rm charm}}{d\xi\, dy}\right\}_{LO} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left(1-\frac{m_c^2}{2ME_\nu\xi}\right)$$
$$\{\ \xi d(\xi,\mu^2)\ |V_{cd}|^2 +\ \xi s(\xi,\mu^2)\ |V_{cs}|^2\ \}$$

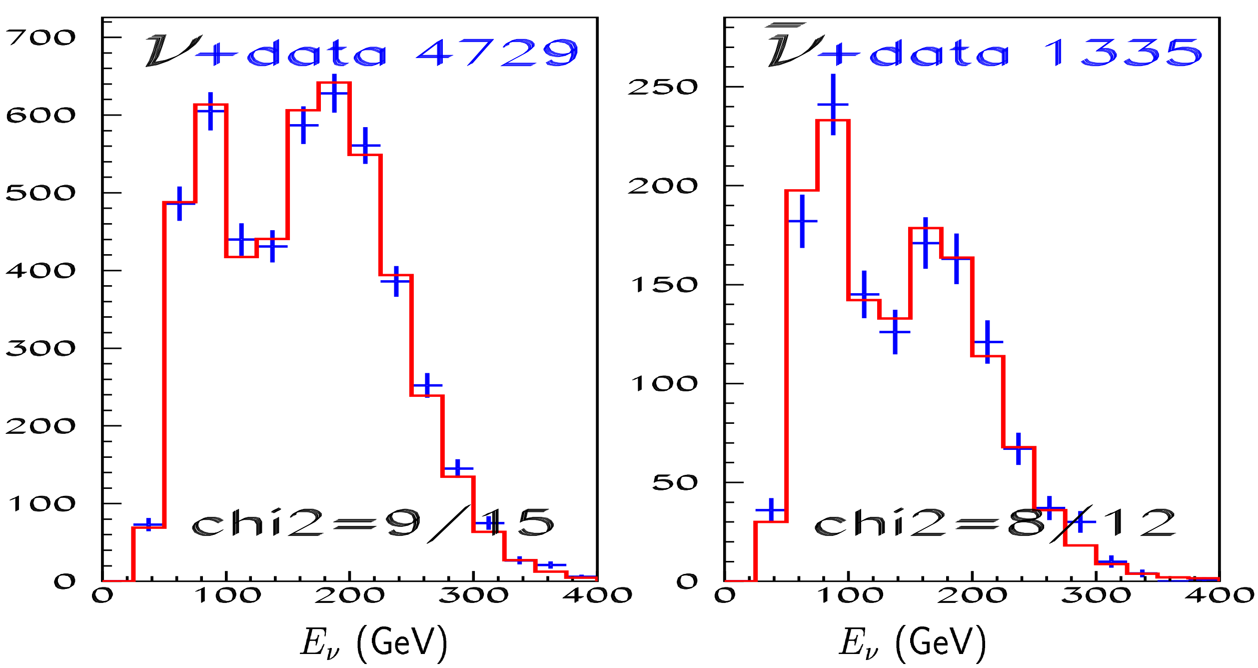
$\nu_\mu N \to \mu^- c X$ (cont'd)



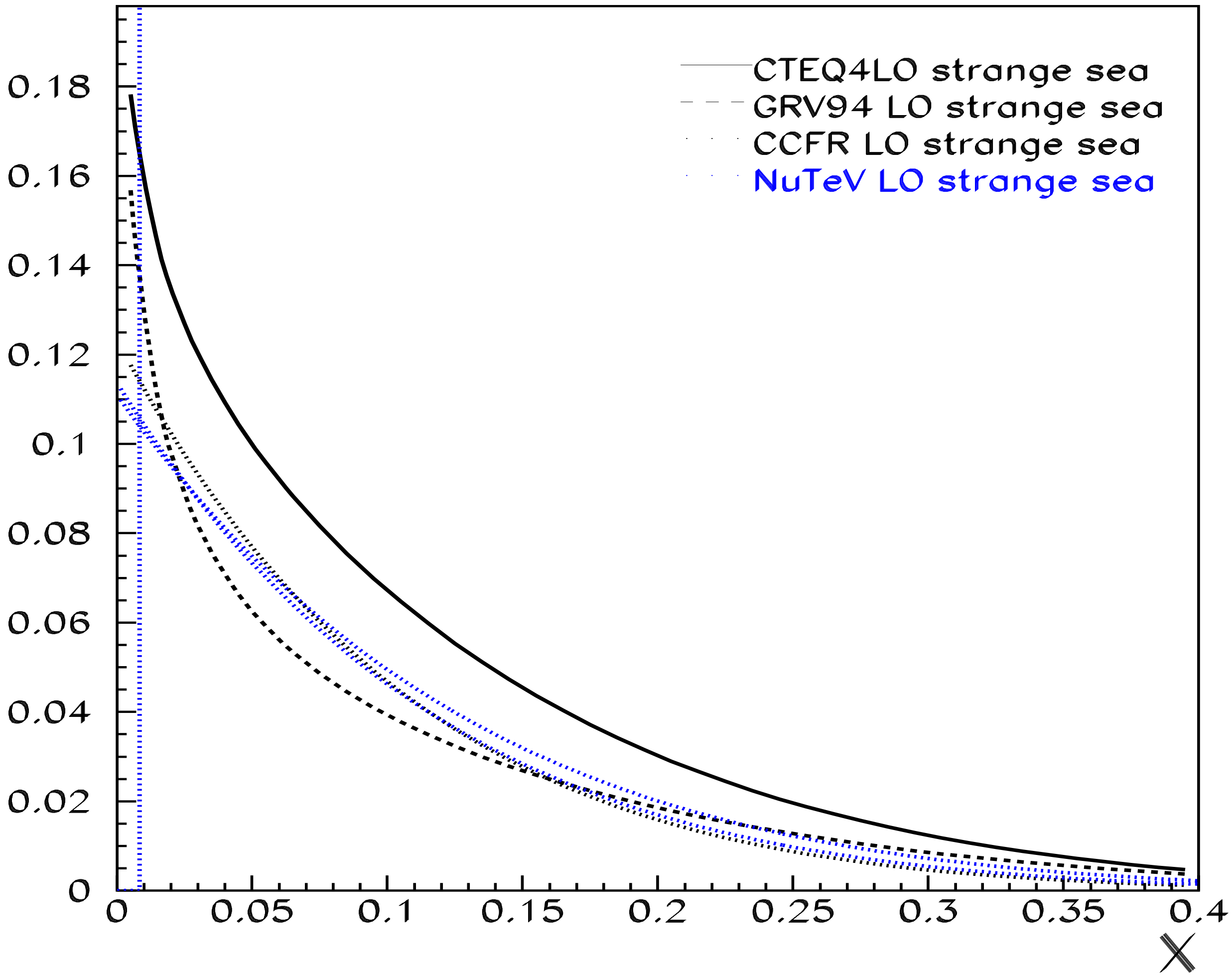
- Topology highly distinctive
- $E_\mu > 3$ GeV with high efficiency

$E_{\rm visible}$ distributions

Low $E_{\rm visible}$ sensitive to charm suppression



$\nu_\mu N \to \mu^- c X$ (cont'd)



Strange sea has been consistently measured to be $\sim 40\%$ of the non-strange sea.

$$\kappa = \frac{2\int x s(x)}{\int (u(x) + d(x))}$$

$$\kappa_\nu = 0.402 \pm 0.092 \pm 0.033 \quad (s(x))$$

$$\kappa_{\bar{\nu}} = 0.439 \pm 0.067 \pm 0.058 \quad (\overline{s}(x))$$

s-$\bar{s}$ asymmetry is small.

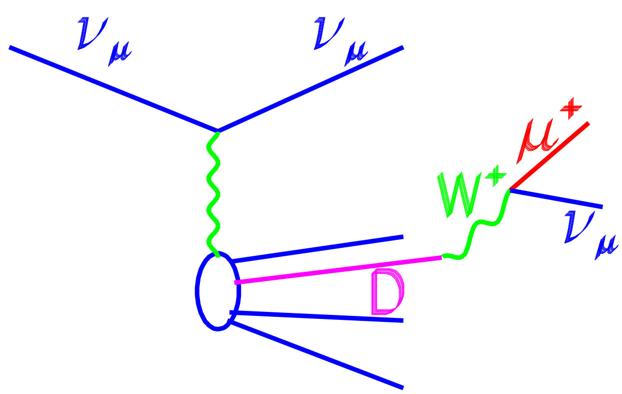
$$\nu N \to \nu c\overline{c} X$$

How can we serve you?

...quantify confusion between $\left\{ \begin{array}{r} \overline{\nu}_\mu N \to \mu^+ X \\ \nu_\mu N \to \nu_\mu \overline{c} c X \\ \hookrightarrow \mu^+ \end{array} \right.$

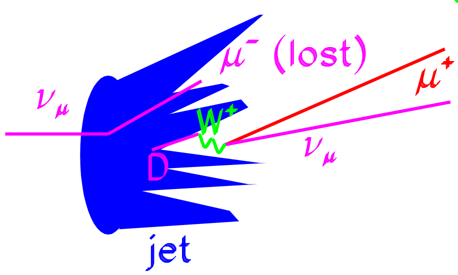
...important for ν FACTORY (H. Schellman)

- $c \to \mu^+ X$
  $\Rightarrow$ Single muon final state
- Sign-selected beam
  $\Rightarrow$ Muon has wrong charge!

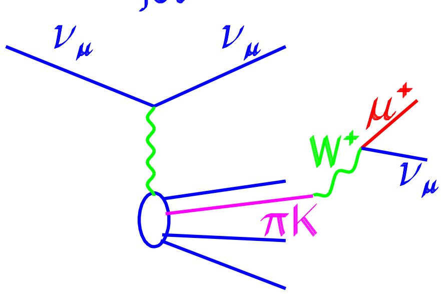


Backgrounds

$\overline{\nu}$ in ν beam ($\sim 10^{-3}$, low E_ν)



Charged-current charm

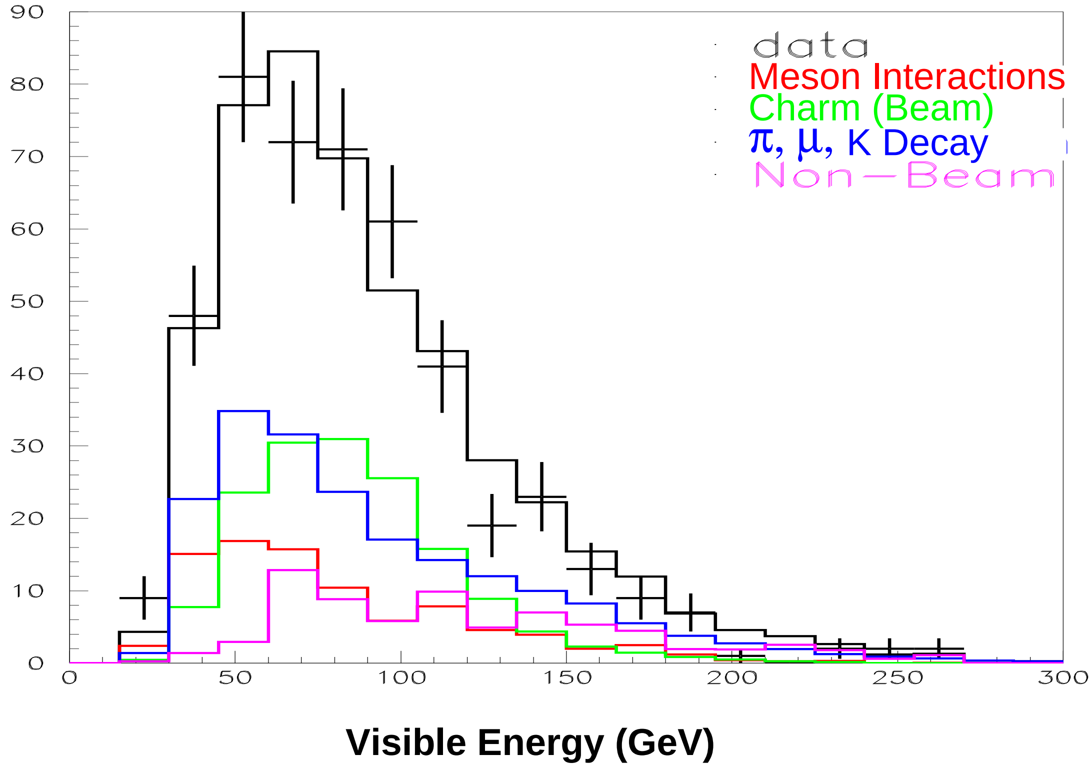


Meson decay (soft E_μ)

$\nu N \to \nu c\bar{c}X$ (cont'd)

Wrong Charge Muons (μ^-) in $\bar{\nu}$ Beam

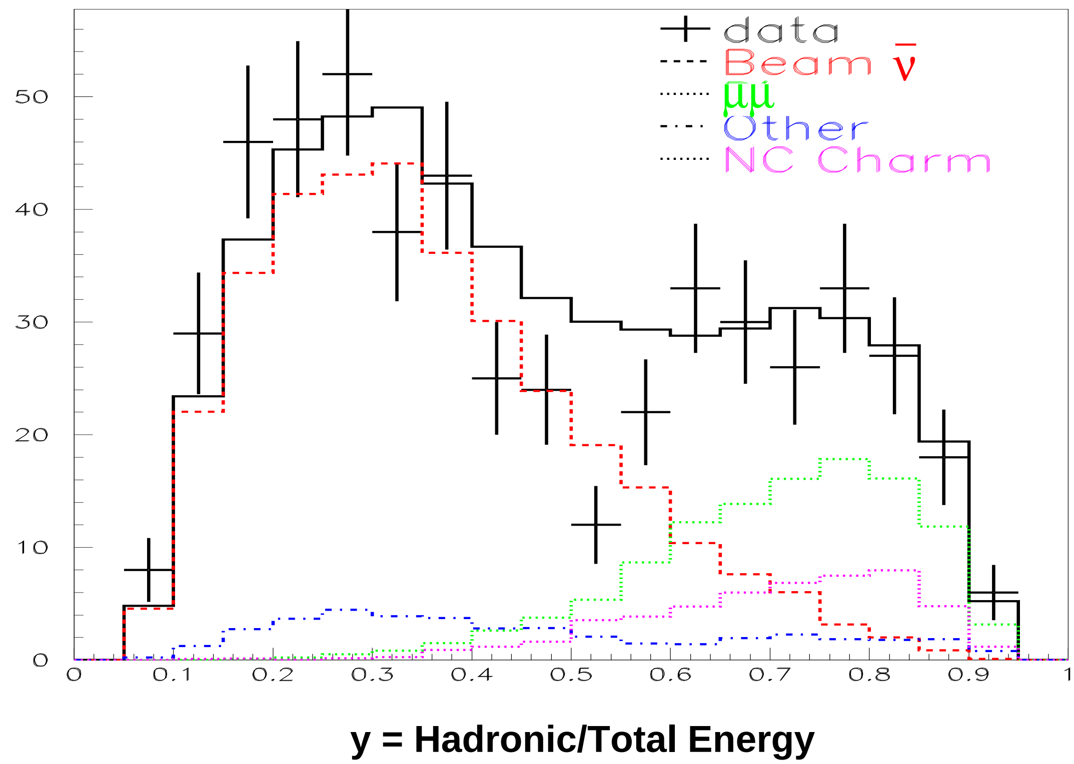
$\bar{\nu} \to \bar{\nu}c\bar{c}X$ highly suppressed



Sample is well-measured, little neutral-current charm

- However, $pp \to c\bar{c}X$, $c \to \nu_\mu \mu^+ X$ in **BEAM** is uncertain
- Measure in this sample!

$\nu N \to \nu c\bar{c}X$ (cont'd)



Backgrounds:

- Beam checked at low y
- Muon loss or misidentification is dominant background
- At $< E_\nu >= 154$ GeV, (BR($c \to \mu$)=9.9%)

$$\frac{\sigma(\nu N \to \nu c\bar{c}X)}{\sigma(\nu N \to \mu^- X)} = (2.1 \pm 1.6) \times 10^{-3}$$

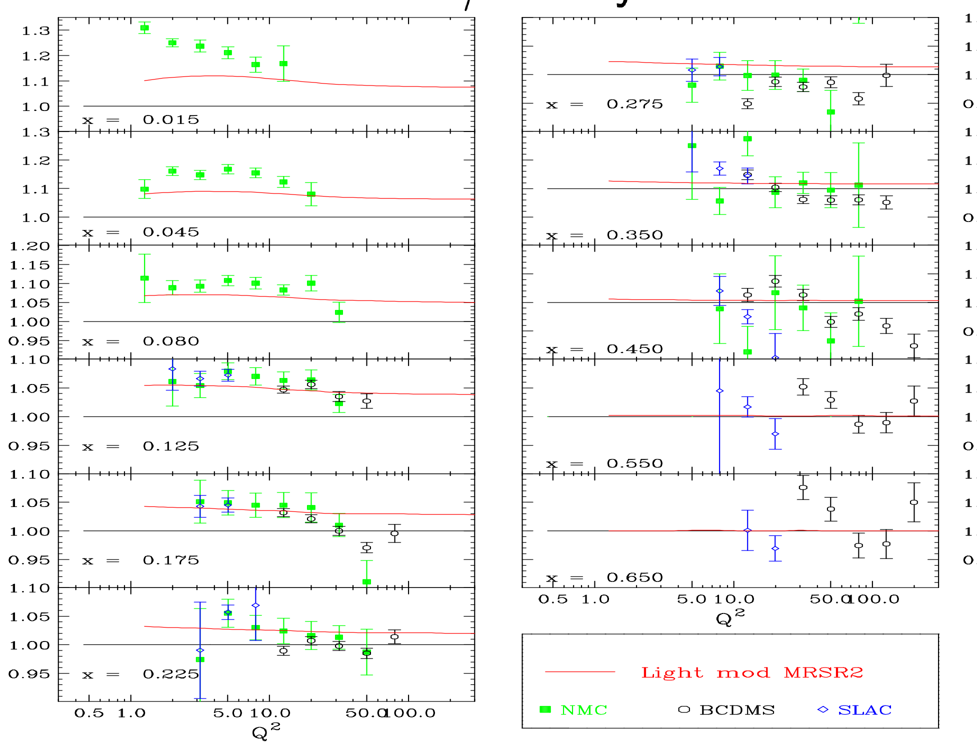
Conclusions:

- Physics backgrounds to $\nu_\mu \leftrightarrow \overline{\nu}_\mu$ at few 10^{-4} level in high energy beam

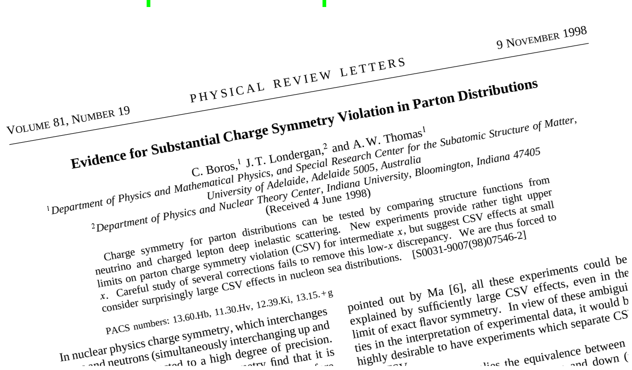
Old Puzzles: CCFR (νN) vs NMC (μN)

Data/Theory

F_2^ν / F_2^μ



- On an isoscalar target, $F_2^\mu = \frac{5}{18} F_2^\nu - \frac{x}{6}(s + \overline{s} - c - \overline{c})$
  - ▷ $\langle q^2_{\mathrm{electric}} \rangle = 5/18$
  - ▷ Strange sea from $\nu N \to \mu^+\mu^- X$ (10% in F_2^μ at $x = 0.01$)
  - ▷ Nuclear corrections $(15 \pm 2)\%$ at $x = 0.01$
- Resolution important since xF_3^ν used for $q/\overline{q}$ (LHC)
- Culprits: Isospin Violation in PDFs? Intrinsic s?


VOLUME 81, NUMBER 19 PHYSICAL REVIEW LETTERS 9 NOVEMBER 1998

Evidence for Substantial Charge Symmetry Violation in Parton Distributions

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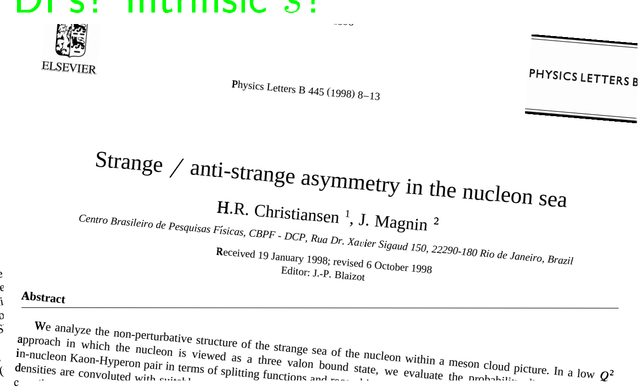
(Received 4 June 1998)

Charge symmetry for parton distributions can be tested by comparing structure functions from neutrino and charged lepton deep inelastic scattering. New experiments provide rather tight upper limits on parton charge symmetry violation (CSV) for intermediate x, but suggest CSV effects at small x. Careful study of several corrections fails to remove this low-x discrepancy. We are thus forced to consider surprisingly large CSV effects in nucleon sea distributions. [S0031-9007(98)07546-2]

PACS numbers: 13.60.Hb, 11.30.Hv, 12.39.Ki, 13.15.+g

In nuclear physics charge symmetry, which interchanges ... and neutrons (simultaneously interchanging up and ... to a high degree of precision. ... find that it is ...

pointed out by Ma [6], all these experiments could be explained by sufficiently large CSV effects, even in the limit of exact flavor symmetry. In view of these ambigui... ties in the interpretation of experimental data, it would b... highly desirable to have experiments which separate CS... the equivalence between ... and down (...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Physics Letters B 445 (1998) 8–13

PHYSICS LETTERS B

Strange / anti-strange asymmetry in the nucleon sea

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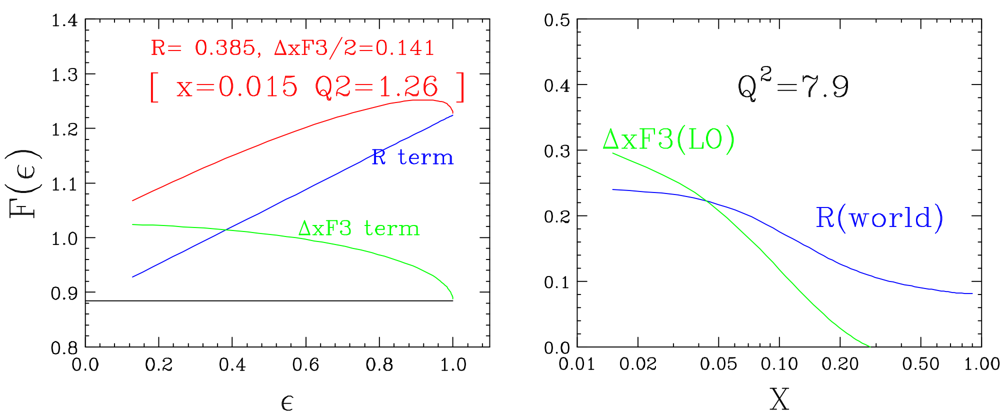
Abstract

We analyze the non-perturbative structure of the strange sea of the nucleon within a meson cloud picture. In a low Q^2 approach in which the nucleon is viewed as a three valon bound state, we evaluate the probability ... in-nucleon Kaon-Hyperon pair in terms of splitting functions and ... densities are convoluted with suitabl...

Old Puzzles (cont'd)

$$\left[\frac{d^2\sigma^\nu}{dxdy} + \frac{d^2\sigma^{\overline{\nu}}}{dxdy}\right]\frac{\pi}{G_F^2 ME} = (1 - y + \frac{y^2}{2(1+R)})F_2$$
$$\pm(y - \frac{y^2}{2})\Delta xF_3$$

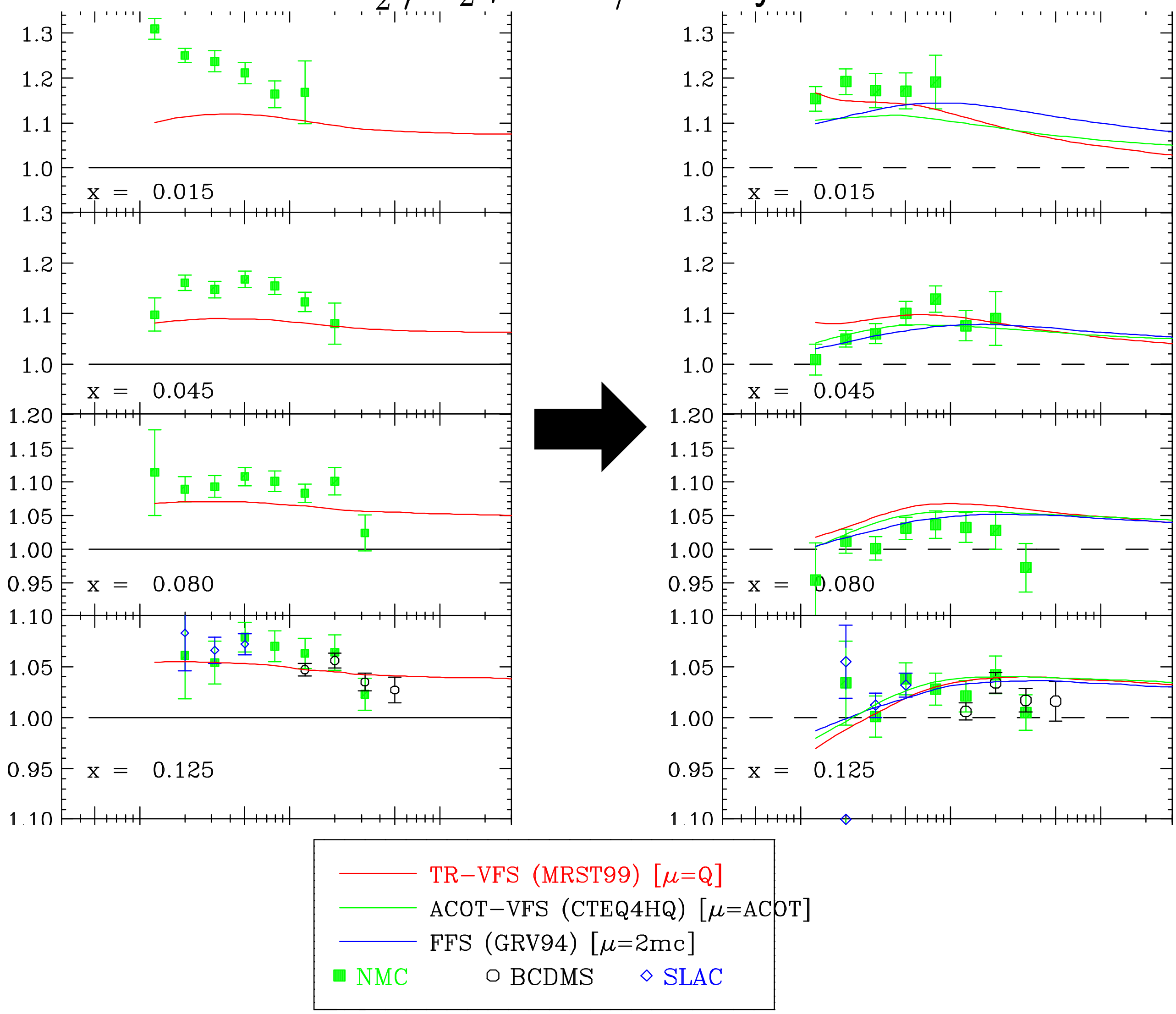
- $\Delta xF_3 = xF_3^\nu - xF_3^{\overline{\nu}} = 2x(s + \overline{s} - c - \overline{c})$
- Previous CCFR analysis:
  Extract $F_2(m_c = 0)$ with ΔxF_3, R constraints
- Model Independent Analysis *of CCFR data*:
  Fit for R, ΔxF_3



  - ▷ Extract $F_2(m_c \neq 0)$
  - ▷ Extract also ΔxF_3 at $x < 0.1$
  - ▷ Take R from external data
  - ▷ NLO calculations to predict F_2^μ / F_2^ν

Old Puzzles (cont'd)

F_2^ν / F_2^μ, Data/Theory



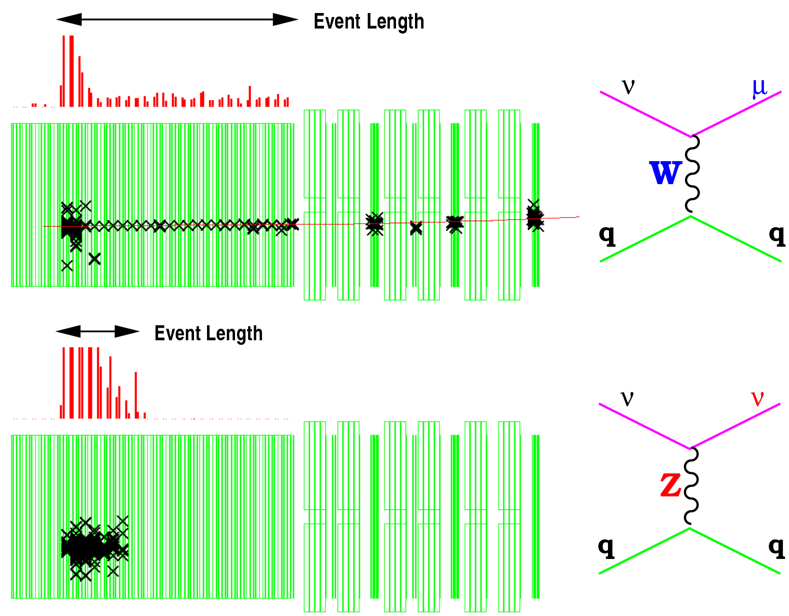
- CCFR/NMC F_2 ratio well described by NLO theory
- CCFR F_2 now extracted without ΔxF_3 prediction, charm mass correction
- Global fits should use revised CCFR F_2 for Tevatron, LHC predictions

New Puzzles: Electroweak Data

Precision Electroweak Data Generally Fits Standard Model Well. . . BUT

- Several discrepant Z^0 measurements $(A_b,\ \sigma^0_{\text{hadrons}},\ A_e)$ can be interpreted as $\sin^2\theta_W^{\text{leptons}} \neq \sin^2\theta_W^{\text{quarks}}$
- Off Z-pole, updated atomic parity violation measurements indicate 2.5σ discrepency (Wieman *et al.*)

$$\frac{\sigma_{NC}}{\sigma_{CC}} \Downarrow \sin^2\theta_W^{\nu N}$$



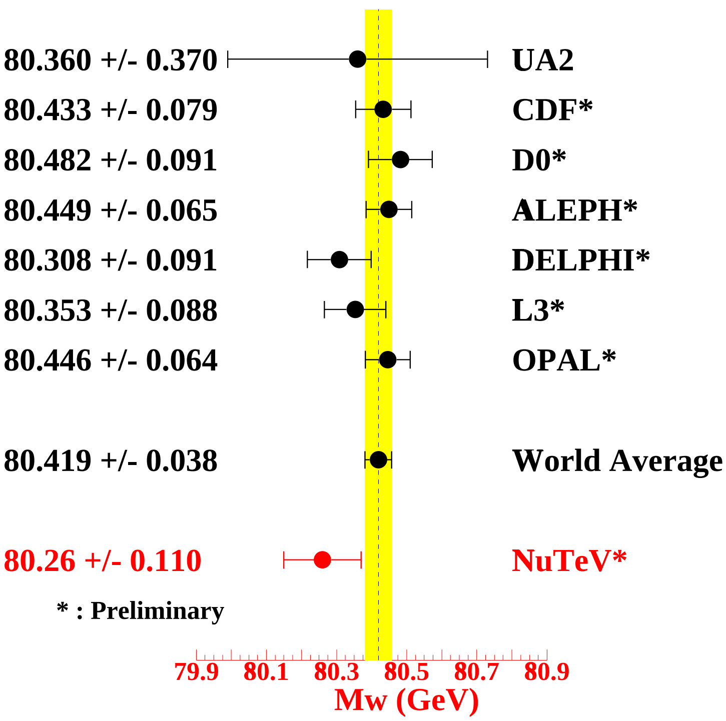
	Short (NC) Events	Long (CC) Events	$R_{20} \equiv \text{Short/Long}$
ν	386K	919K	$0.4198 \pm 0.0008(\text{stat})$
$\overline{\nu}$	88.7K	210K	$0.4215 \pm 0.0017(\text{stat})$

New Puzzles: $\mathit{PRELIMINARY}$ NuTeV $\sin^2\theta_W$

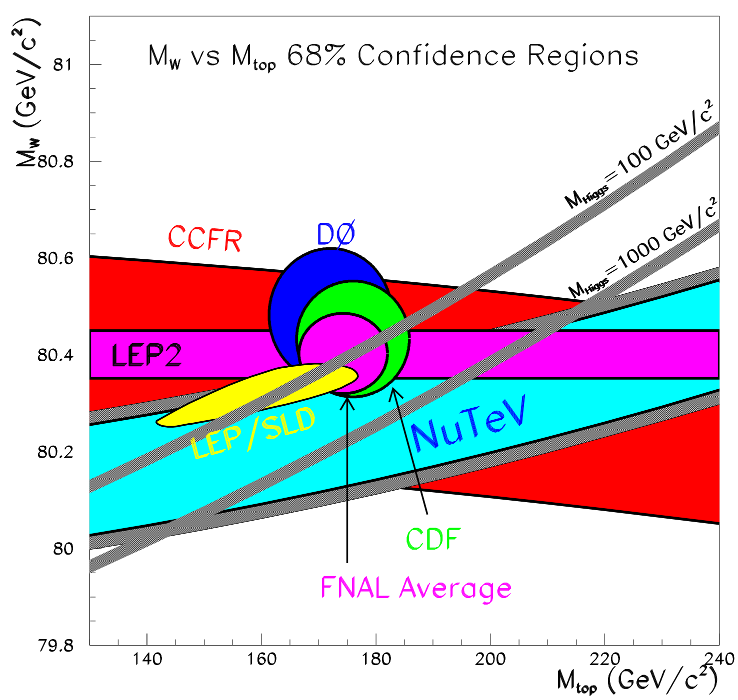
NuTeV measures:

$$\sin^2\theta_W{}^{(\text{on-shell})} = 0.2253 \pm 0.0019(\text{stat}) \pm 0.0010(\text{syst})$$

$$\sin^2\theta_W^{(\text{on-shell})} \equiv 1 - \frac{{M_W}^2}{{M_Z}^2}$$



- The most precise νN measurement of the weak mixing angle
- Precision comparable to collider measurements ...



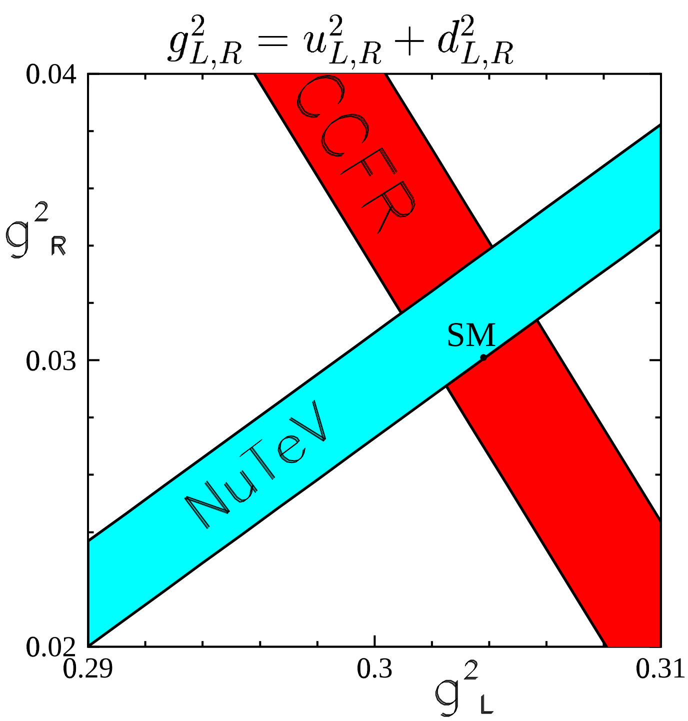
- Global fit indicates preference for light Higgs:
  - ▷ $M_{\text{Higgs}} = 98 \pm^{57}_{38}$ GeV (C.V.)
  - ▷ $M_{\text{Higgs}} \leq 235$ (95% CL)

New Puzzles: NuTeV $\sin^2\theta_W$(cont'd)

$$R^- = \frac{\sigma^{\nu}_{NC} - \sigma^{\overline{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\overline{\nu}}_{CC}} = \left(\frac{1}{2} - \sin^2\theta_W\right) = u_L^2 + d_L^2 - u_R^2 - d_R^2$$

NuTeV measurement → constraint on the Z^0-quark couplings:

$$0.4530 - \sin^2\theta_W = 0.2277 \pm 0.0022 = 0.8587u_L^2 + 0.8828d_L^2 - 1.1657u_R^2 - 1.2288d_R^2$$



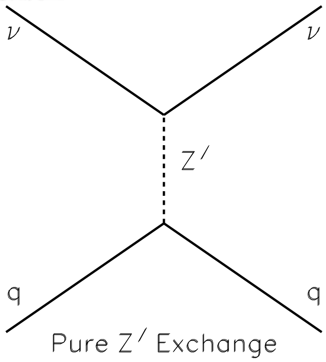
NuTeV R$^-$ constraint:

$$-0.0068 \pm 0.006 = +1.6134\Delta u_L + 0.9972\Delta u_R - 2.0631\Delta d_L - 0.5261\Delta d_R$$

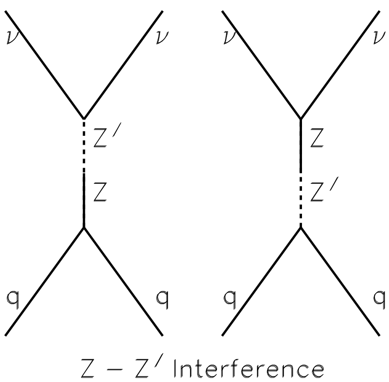
APV constraint:

$$(Q_W^{exp} - Q_W^{SM})/Q_W^{SM} = 0.014 \pm 0.006 = +5.1436(\Delta u_L + \Delta u_R) + 5.7729(\Delta d_L + \Delta d_R) - 2\Delta g_A^e$$

Extra Z Bosons?



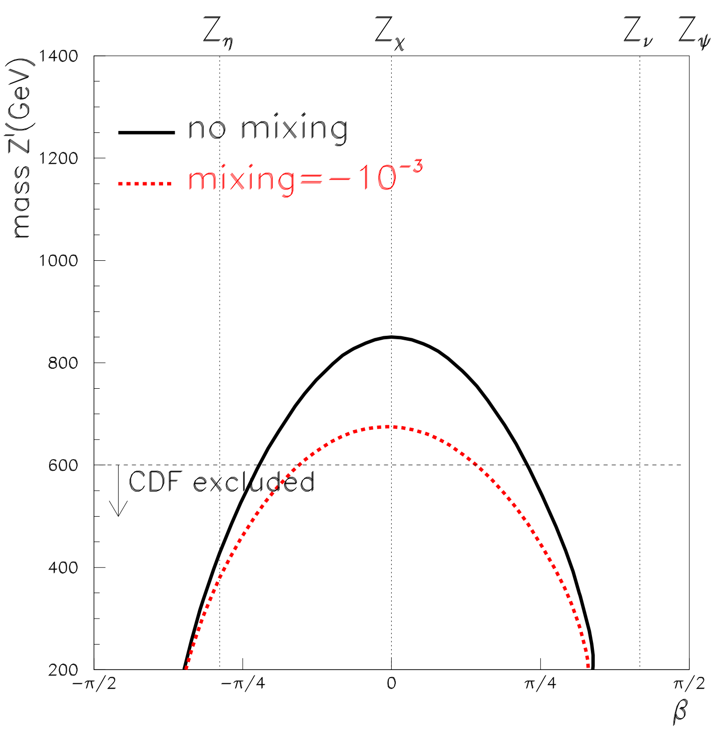
$$\delta q_\beta = \frac{g_E^2 Q_E^{Z'\nu} Q_E^{Z'q}}{2\sqrt{2} G_F M_{Z'}^2}$$ Low E data

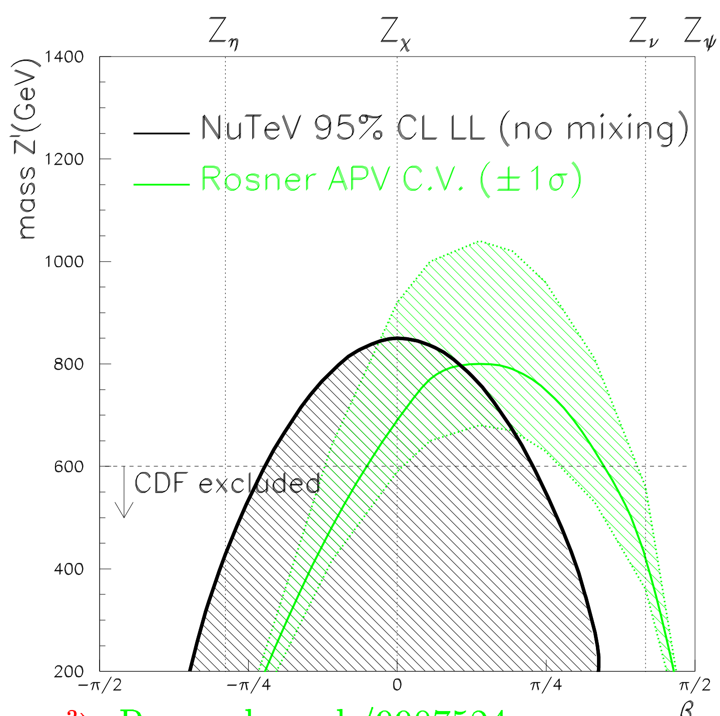


$$\tan^2\theta = \frac{M_0^2 - M_Z^2}{M_{Z'}^2 - M_0^2}$$ Z pole data

<u>95% Confidence Level Lower Mass Limits on Z''s:</u>

$$Z' = Z_\chi cos\beta + Z_\psi sin\beta$$





$mZ_\chi \geq 675$ GeV at 95% CL (mixing=-10^{-3})

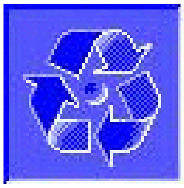
$mZ_\eta \geq 380$ GeV at 95% CL (mixing=-10^{-3})

Rosner hep-ph/9907524

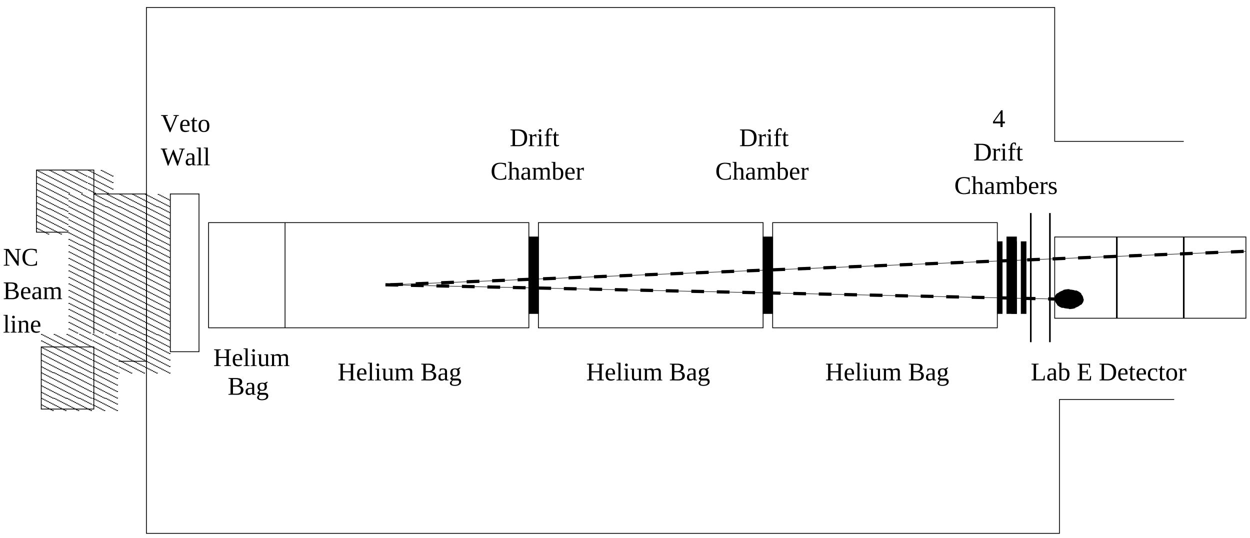
Casalbuoni, et al. hep-ph/0001215

Searching: Decays of New Neutrals

Recycling
an old idea...



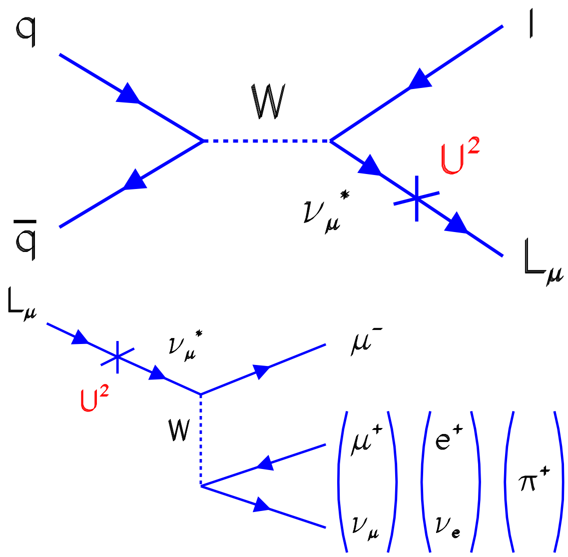
- Massive detector for ν interactions
- Upstream targetless detector for ν (or N^0) decay



Cartoon of $N^0 \to \pi^+\mu^-$ Decay

- **Neutrino detector provides particle ID for μ above ~ 3 GeV, $\pi^\pm$ and $e^\pm$ above ~ 5 GeV**
- **Backgrounds very low**
  - ▷ ν interactions in chambers: ~ 300, 15 two-track
  - ▷ Expected ν in helium: ≈ 10, 0.5 two track
  - ▷ Neutral punch-through into decay volume very low

New Neutrals (cont'd)

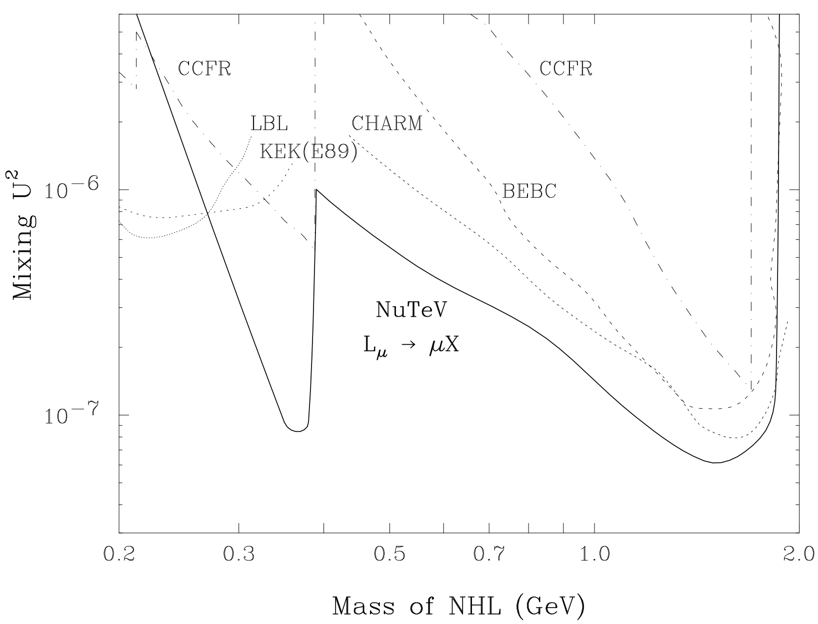


NHL Haiku

*N*eutral *H*eavy *L*.
sterile weak isosinglets
mix with neutrinos.

NuTeV could produce in decays of $\pi^{\pm}$, K, D *up to* 1.9 *GeV*

Sadly, unobserved at NuTeV in $\mu\mu\nu$, $\mu e\nu$, $\mu\pi$, $\mu\rho$



Currently extending search to high mass ($m_T > m_{D_s}$)
(production mechanism unclear)

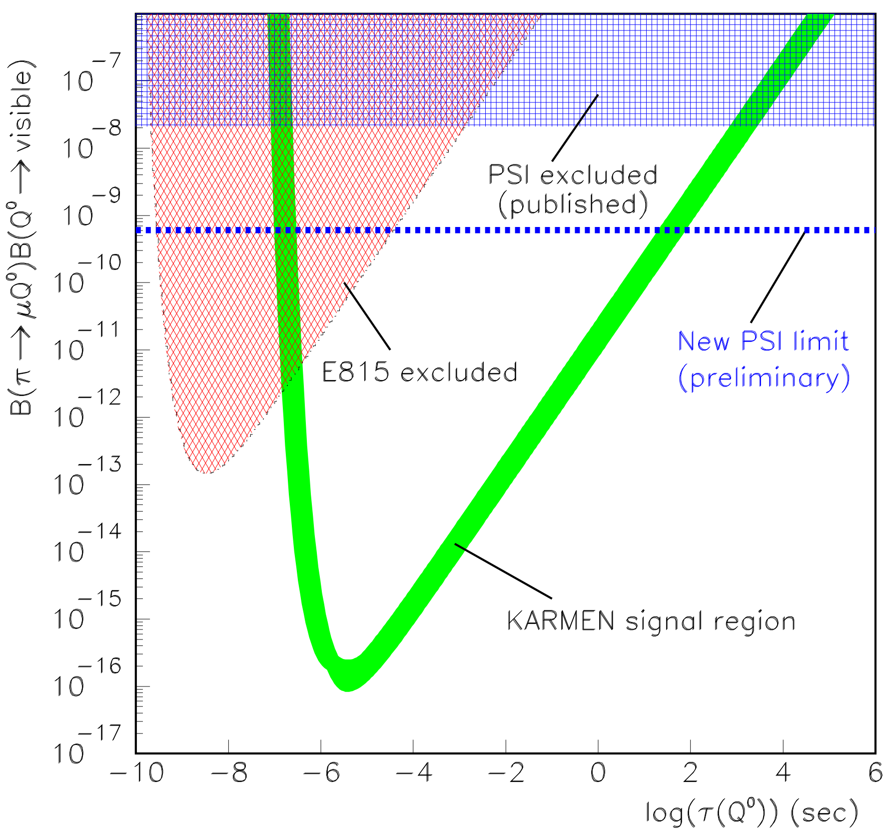
New Neutrals (cont'd)

KARMEN time anomaly

- Hypothesis: due to decay at rest of $\pi^+ \to Q^0\mu^+$, $Q^0 \to e^+e^-\nu$ with $m_{Q^0} \approx m_{\pi^+} - m\mu$

At NuTeV:

- $E_{\pi^\pm} \sim 200$ GeV so Q^0 is relativistic
- Look for forward e^+e^-
- Boost gives us high sensitivity to short τ_{Q^0}, but fewer π^+ than KARMEN



Conclusions

NuTeV is enjoying its data!

- Charm production ($c\bar{s}$, $c\bar{s}$, $c\bar{c}$)

  Future: Model independent results, NLO analysis

- F_2^μ (NMC) vs F_2^ν (CCFR) Resolved!
- $\sin^2\theta_W^{\nu N}$ and Z' limits

  Future: NuTeV Structure functions

  Future: Increased $\sin^2\theta_W$ statistics

- Heavy Neutral searches: mixing model and Q^0 à la KARMEN

  Future: Examine high mass region for NHL signal