Precision Measurements in Neutrino Interactions

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OUTLINE

I Detectors

II Pentaquark

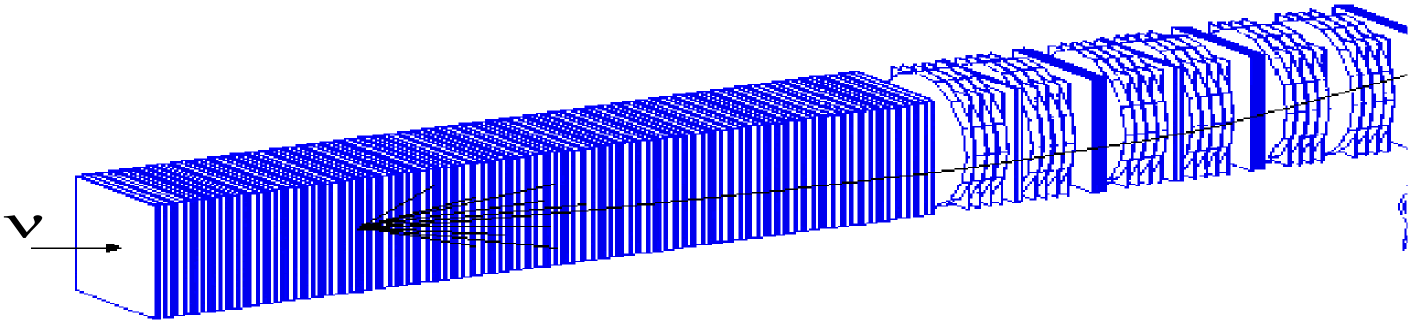
III Dimuons: Charm and the Strange Sea

IV The Weak Mixing Angle

ACKOWLEDGEMENTS

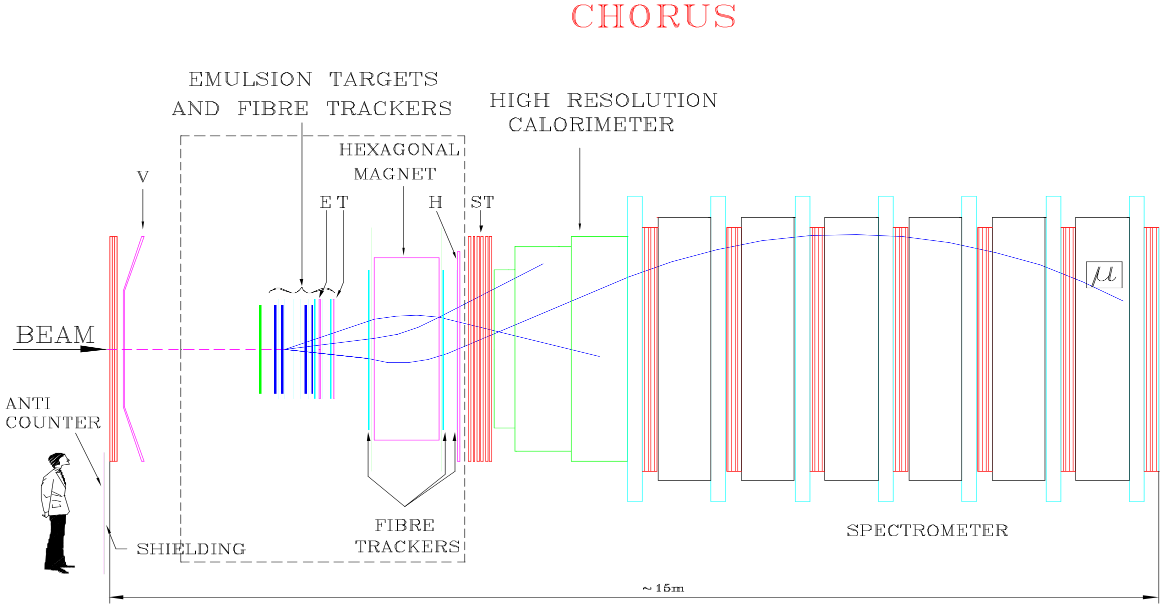
- NuTeV, CHORUS and NOMAD collaborations.
- Roberto Petti.

THE NuTeV DETECTOR.



- Calorimeter Target
  - Material: Iron, liquid scintillator.
  - Mass: 690 tons.
  - Number of Interactions: 1.3×10^6 ν_μ CC,
    0.46×10^6 $\bar{\nu}_\mu$ CC
  - Physics: Dimuons, Structure Functions, $\sin^2\theta_W$.

THE CHORUS DETECTOR. $< E_\nu >$ = *27 GeV*



$\Uparrow$ Emulsion Target

$\Uparrow$ Calorimeter Target

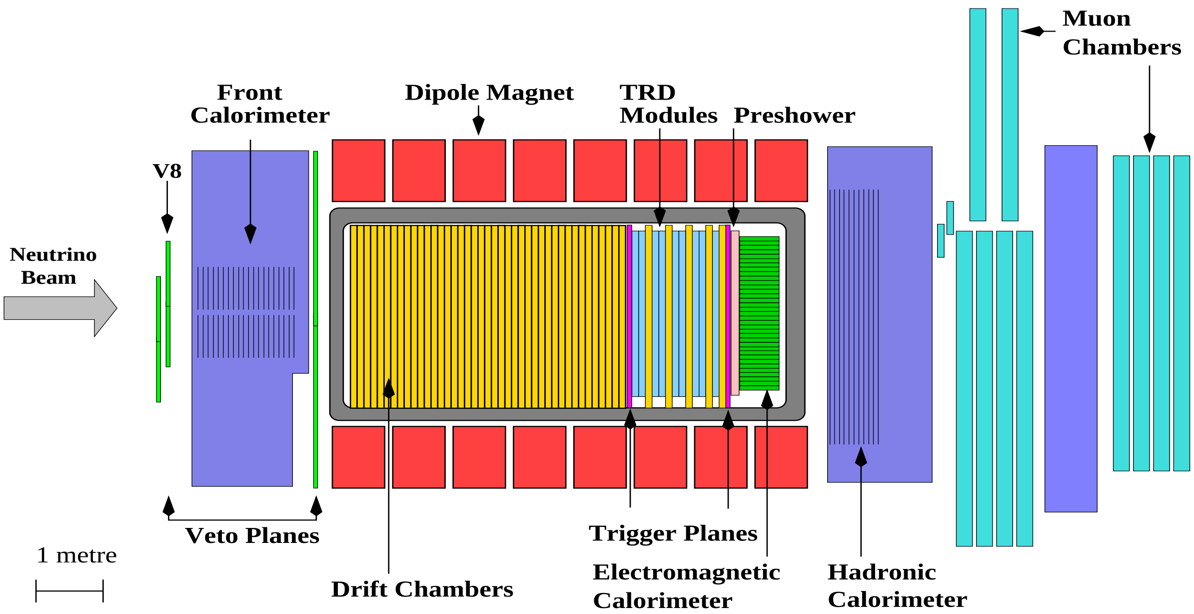
❖ Emulsion Target

- Material: Nuclear emulsion.
- Mass: 770 kg
- Number of Interactions: 2.0×10^6 ν_μ CC
- Physics: Oscillations, Charm.

❖ Calorimeter Target

- Material: Lead, scintillator.
- Mass: 112 tons.
- Number of Interactions: 1.5×10^7 ν_μ CC
- Physics: Dimuons, trimuons, J/ψ, Structure Functions.

THE NOMAD DETECTOR. $< E_\nu > =$ 24.3 GeV



⇑ FCAL Target ⇑ Coil Target ⇑ Drift Chambers Target

❖ FCAL (Front Calorimeter) Target

- Material: Iron, scintillator.
- Mass: 17.7 tons
- Number of Interactions: 1.2×10^7 ν_μ CC
- Physics: Dimuons, cross sections and SF.

❖ Front Coil Target

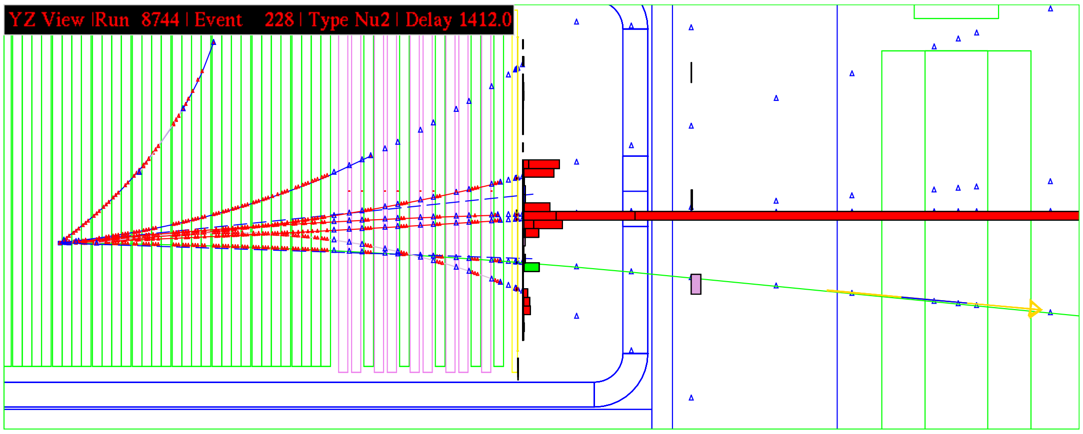
- Material: Aluminium.
- Mass: $\sim$ 3.0 tons
- Number of Interactions: 1.5×10^6 ν_μ CC
- Physics: $\sin^2\theta_{\mathrm{W}}$, Particle production, CS, SF.

❖ Drift Chambers Target

- Material: Carbon. Low density: 0.1 gm.cm^{-3}.
- Mass: 2.6 tons.
- Number of Interactions: 1.3×10^6 ν_μ CC
- Physics: Oscill., $\sin^2\theta_{\mathrm{W}}$, Particle production,CS and SF.

NOMAD TYPICAL EVENTS

ν_μ CC candidate



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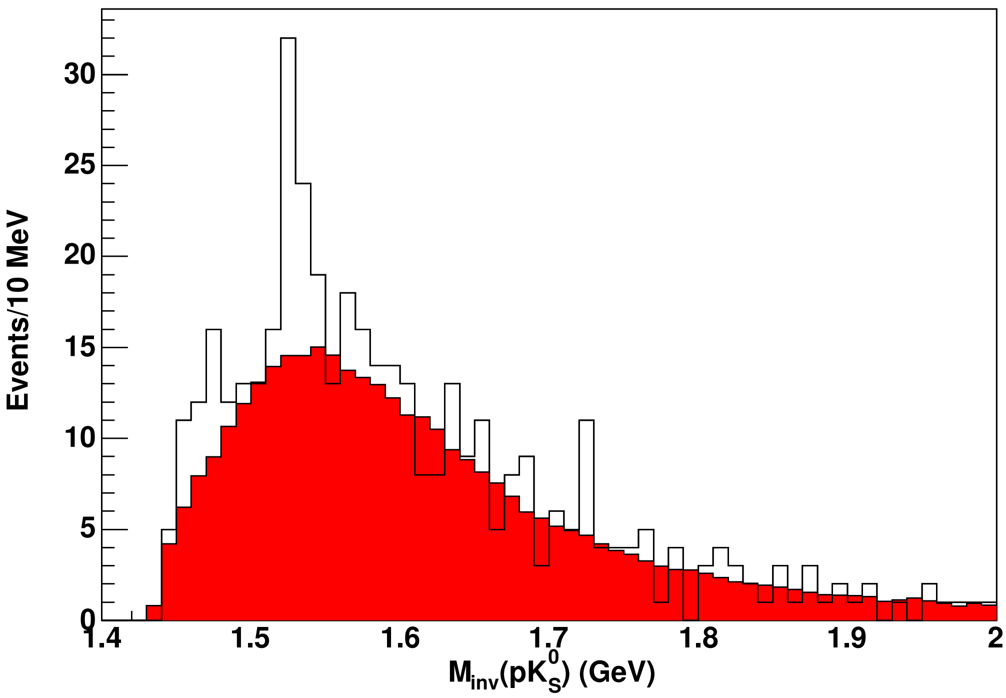
NOMAD: PENTAQUARK.

A positive strangeness baryon, the Θ^+, mass $\sim$ 1530 MeV/c^2
has been observed in several experiments,
including in bubble chamber neutrino data.
Observed in its K^+n and $K^0_s p$ decays.

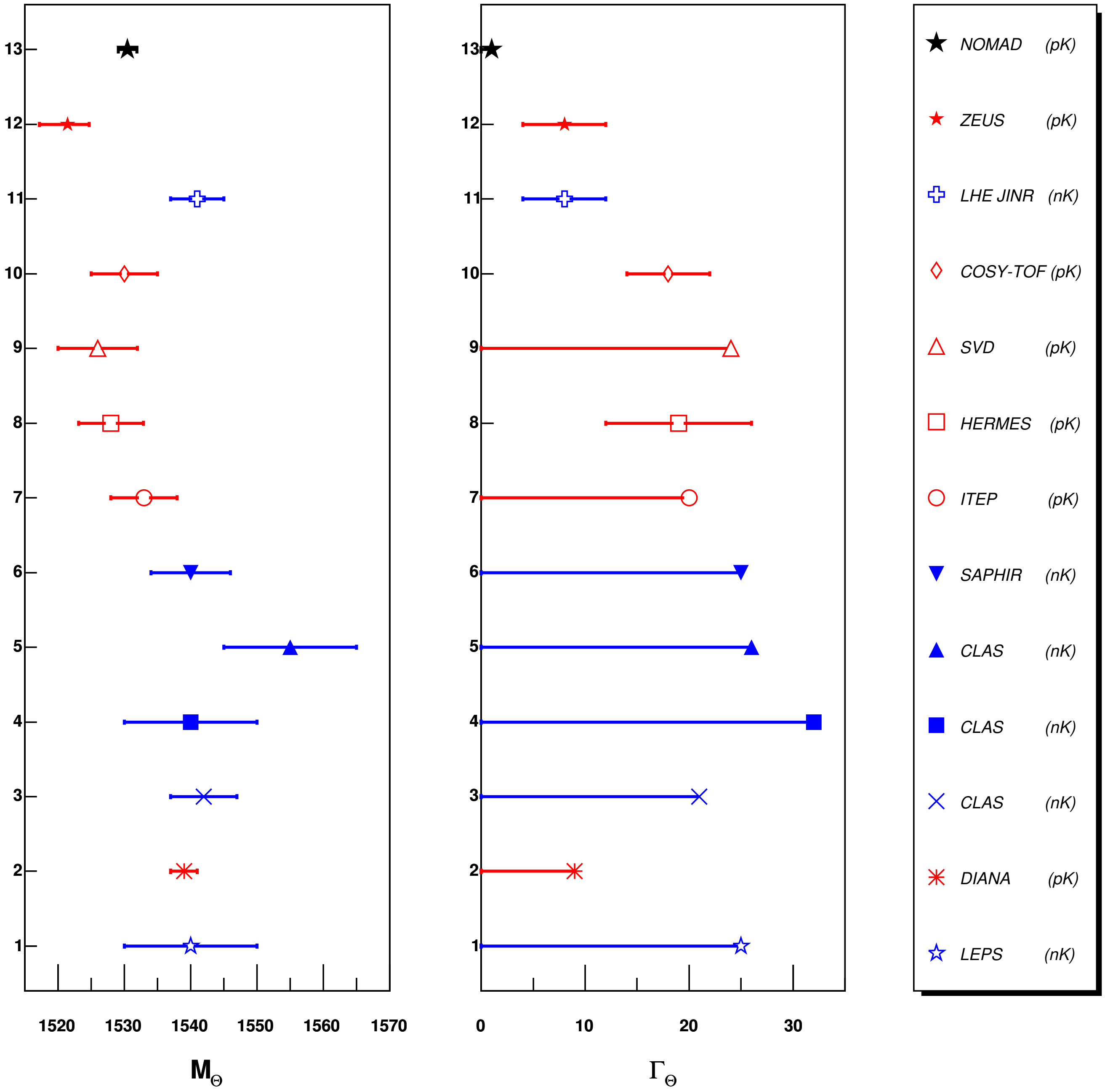
Believed to be a PENTAQUARK $uudd\bar{s}$

NOMAD searched for the Θ^+ in $K^0_s p$ in CC and NC.
NOMAD can reconstruct individual particles
and, in particular, 25000 K^0_s's.
(Nucl. Phys. B621 (2002) 3)
High purity K^0_s sample and 60% purity proton sample.

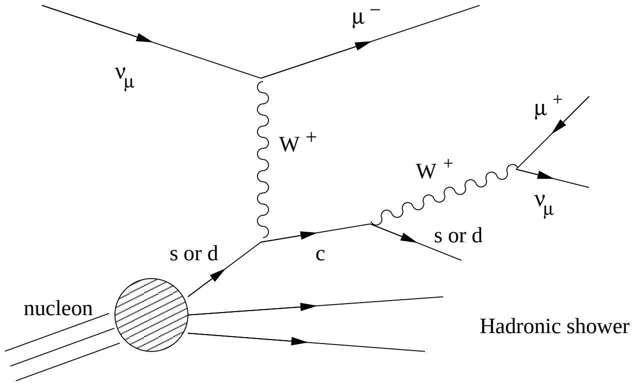


Signal of 33 events $\rightarrow$ 4.3 σ.
Mass resolution: 9 MeV/c^2
Mass of 1528.7 $\pm$ 2.5 MeV/c^2
Width $<$ a few MeV/c^2

NOMAD: PENTAQUARK.



OPPOSITE SIGN DIMUONS → CHARM PRODUCTION.



For an ISOSCALAR target:

$$\frac{\mathrm{d}^3\sigma^{\mathrm{LO}}_{\mu\mu}(\nu_\mu \mathrm{N} \rightarrow \mu^-\mu^+\mathrm{X})}{\mathrm{dxdydz}} = \frac{d^2\sigma_c^{LO}(\nu_\mu N \rightarrow \mu^- cX)}{d\xi dy} D(z)B_c$$

$$\frac{\mathrm{d}^2\sigma^{\mathrm{LO}}_{\mathrm{c}}(\nu_\mu \mathrm{N} \rightarrow \mu^-\mathrm{cX})}{\mathrm{d}\xi\mathrm{dy}}\mathrm{D(z)B_c} = \frac{2\mathrm{G_F^2 M E_\nu}}{\pi(1+\mathrm{Q2/M_W^2})^2}\left(1-\frac{\mathrm{m_c^2}}{2\mathrm{ME_\nu}\xi}\right)$$

$$\times[|\mathrm{V_{cs}}|^2\mathrm{s}(\xi,\mathrm{Q}^2) + |\mathrm{V_{cd}}|^2(\mathrm{u}(\xi,\mathrm{Q}^2)+\mathrm{d}(\xi,\mathrm{Q}^2))/2]\mathrm{D(z)B_c}$$

Production of CHARM is off s or d quarks.

Smallness of s content is compensated by large V_{cs}
50% of charm is from interaction off an s quark in NEUTRINO, and 90 % in ANTINEUTRINO interactions.

- Energy dependence of dimuon production yields m_c.
- x- dependence yields $s(\xi, Q^2)$, in the form of κ:

$$\kappa = \frac{s + \bar{s}}{\bar{u} + \bar{d}}, \quad \text{with} \quad s = \int_0^1 xs(x)dx$$

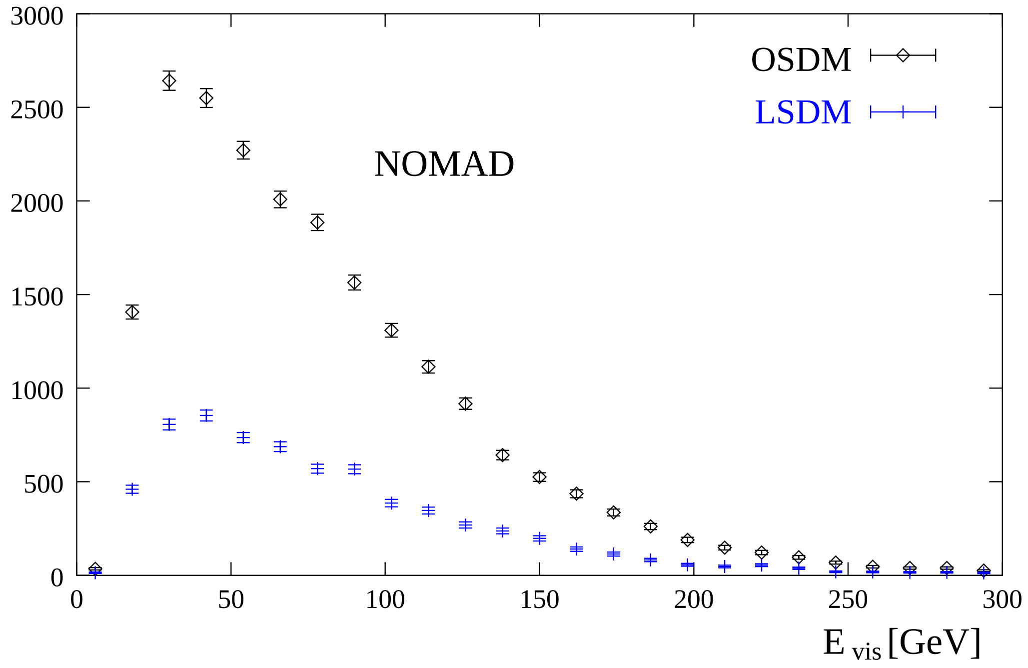
- Energy fraction of recoil jet carried by the μ^+ yields D(z), the charm fragmentation function.
- Overall rate yields B_c, the effective semi-leptonic branching ratio.

DIMUON RESULTS

NUMBERS OF EVENTS

EXPERIMENT	NEUTRINO	ANTINEUTRINO
CHARM II	3100	700
CDHS	9922	2123
CCFR	5030	1060
NuTeV	5102	1458
CHORUS	10718 ± 288	420 ± 63
NOMAD (partial sample)	5330 ± 209	173 ± 47
NOMAD (complete sample)	13659 ± 169	

The background is evaluated using LIKE SIGN dimuons.



DIMUONS: RESULTS OF FITS

LO calculations

EXP.	m_c GeV/c^2	k	B_μ
CHARM II	$1.8 \pm 0.3 \pm 0.3$	$0.39 \pm 0.07 \pm 0.07$	$0.091 \pm 0.007 \pm 0.007$
CDHS		$0.47 \pm 0.08 \pm 0.05$	0.084 ± 0.014
CCFR	$1.31^{+0.20}_{-0.22}\,^{+0.12}_{-0.11}$	$0.373^{+0.048}_{-0.041} \pm 0.018$	$0.105 \pm 0.007 \pm 0.005$
NuTeV	$1.33 \pm 0.19 \pm 0.10$	$0.32 \pm 0.06 \pm 0.04$	$0.1140 \pm 0.0108 \pm 0.0115$
CHORUS	$1.46 \pm 0.15 \pm 0.10$	$0.56 \pm 0.050 \pm 0.045$	$0.098 \pm 0.005 \pm 0.014$
NOMAD	$1.25^{+0.11+0.04}_{-0.10-0.06}$	$0.411^{+0.195+0.055}_{-0.123-0.010}$	$0.095 \pm 0.007 \pm 0.013$

NLO calculations

CCFR	$1.69 \pm 0.16\,^{+0.12}_{-0.10}$	$0.468^{+0.061}_{-0.046}\,^{+0.024}_{-0.025}$	$0.1047 \pm 0.0076^{+0.0065}_{-0.0052}$
NOMAD	$1.58^{+0.09+0.04}_{-0.09-0.08}$	$0.458^{+0.187+0.057}_{-0.131-0.012}$	$0.095 \pm 0.007 \pm 0.013$

m$_c$ depends on what order the calculation is performed at

HIGHER order $\rightarrow$ LARGER charm quark mass

From the CHARM production threshold in e$^+$ e$^-$ collisions

In $\overline{MS}$ scheme. hep-ph/0109084 v3

$$m_c(m_c) = 1.304 \pm 0.027$$

c

NuTeV LO Results

Model	m_c	k
BGPAR	$1.33 \pm 0.19 \pm 0.10$	$0.32 \pm 0.06 \pm 0.04$
GRV	$1.65 \pm 0.18 \pm 0.09$	$0.37 \pm 0.05 \pm 0.03$
CTEQ	$1.63 \pm 0.17 \pm 0.09$	$0.44 \pm 0.06 \pm 0.04$

EACH set of PARAMETERS
is intimately tied to the PARTON DISTRIBUTIONS
used to derive it

DIMUONS:THE STRANGE SEA

NuTeV Analysis: Distinguish between s and $\bar{s}$

- NLO calculation
- Fix $B_\mu = 0.093 \pm 0.008$
- Fix Collins-Spiller Fragmentation variable $\epsilon = 0.75 \pm 0.25$
- CTEQ type parametrization:

$$
\begin{aligned}
s^+(x,Q_0) &= \kappa^+(1-x)^{\alpha^+}x^{\gamma^+}[\bar{u}(x,Q_0)+\bar{d}(x,Q_0)] \\
s^-(x,Q_0) &= s^+(x)tanh[\kappa^-(1-x)^{\alpha^-}x^{\gamma^-}(1-\frac{x}{x_0})]
\end{aligned}
$$

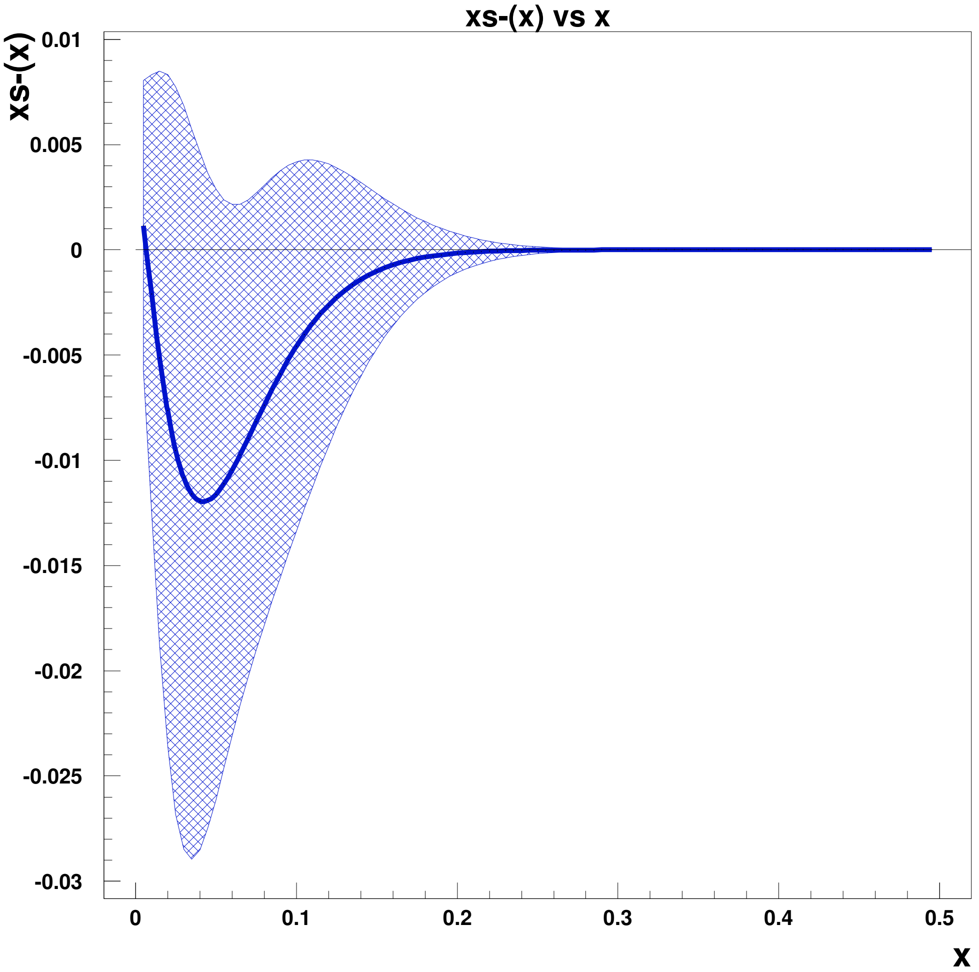
with

$$
s = \frac{s^+ + s^-}{2}, \quad \text{and} \quad \bar{s} = \frac{s^+ - s^-}{2}
$$

- x_0 constrained by:

$$
\int s^-(x,Q_0)dx = 0
$$

DIMUONS: THE STRANGE SEA



RESULT

$$\int xs^{-}(x)dx = -0.0009 \pm 0.0014$$

To explain the NuTeV $\sin^2\theta_W$ anomaly would require $+0.006$

c

NuTeV $\sin^2\theta_W$ *STRATEGY*

NEUTRAL CURRENT structure functions depend on $\sin^2\theta_W$:

$$F^{NC}{}_2 = x(q+\bar{q})(\frac{1}{2} - \sin^2\theta_W + \frac{10}{9}\sin^2\theta_W^4)$$

and

$$xF^{NC}{}_3 = x(q-\bar{q})(\frac{1}{2} - \sin^2\theta_W)$$

CHARGED CURRENT structure functions do NOT.
This allows the computation of $\sin^2\theta_W$ through the ratio:

$$R^\nu = \frac{\sigma(\nu N \to \nu X)}{\sigma(\nu N \to \mu^- X)} \quad \text{and/or} \quad R^{\bar{\nu}} = \frac{\sigma(\bar{\nu} N \to \bar{\nu} X)}{\sigma(\bar{\nu} N \to \mu^+ X)}$$

$$R^\nu = (\frac{1}{2} - \sin^2\theta_W + \frac{5}{9}(1 + r)\sin^2\theta_W^4) \text{ with } r = \frac{\sigma(\nu N \to \mu^- X)}{\sigma(\bar{\nu} N \to \mu^+ X)} \sim \frac{1}{2}$$

Prone to UNCERTAINTIES from modelling
such as charm mass and strange sea.

ALTERNATIVE: Measure CC AND NC
in BOTH ν AND $\bar{\nu}$ interactions.
The Paschos-Wolfenstein method.

$$R^- = \frac{\sigma(\nu N \to \nu X) - \sigma(\bar{\nu} N \to \bar{\nu} X)}{\sigma(\nu N \to \mu^- X) - \sigma(\bar{\nu} N \to \mu^+ X)}$$

$$R^- = \frac{R^\nu - rR^{\bar{\nu}}}{1-r}$$

Large CANCELLATION of uncertainties

BUT must be done in SEPARATE ν and $\bar{\nu}$ beams since NC are indistinguishable when produced in ν and $\bar{\nu}$ interactions.

NuTeV $\sin^2\theta_W$ *ANALYSIS*

SELECTION OF ν's and $\bar{\nu}$'s.

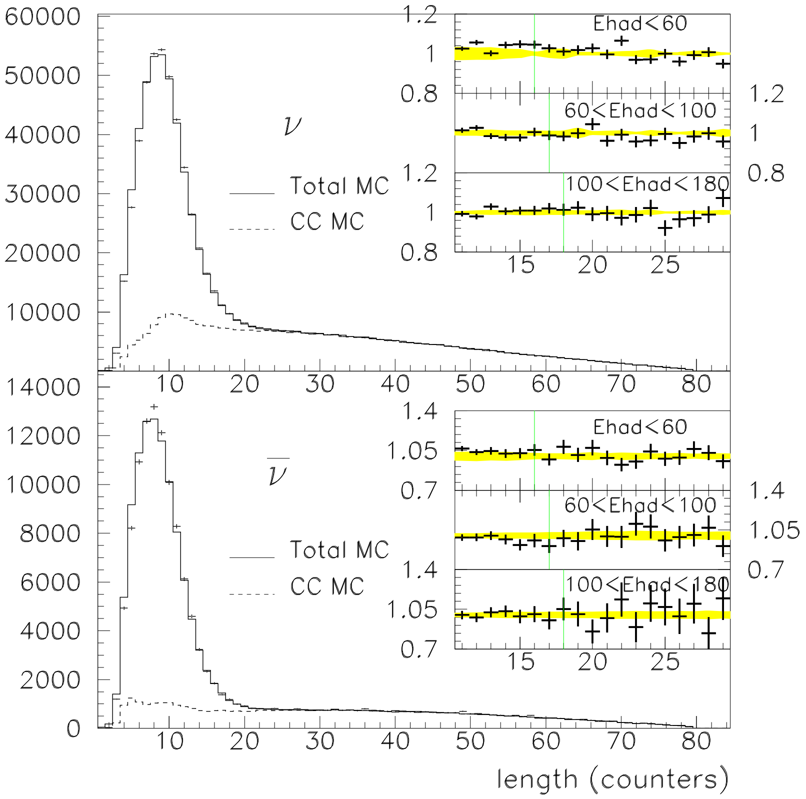
The Sign Selected Quadrupole Train beamline at Fermilab
Dipole magnets following proton target selected
the sign of the parent pions

$\Downarrow$

ν or $\bar{\nu}$ beams of high purity.
In ν beam only 0.03% of the events were due to $\bar{\nu}$'s.
In $\bar{\nu}$ beam only 0.04% of the events were due to ν's.

SELECTION OF CC AND NC

Selected on the basis of the penetrating power
of the μ in CC events $\Rightarrow$ EVENT LENGTH



Cut at 16-18 counters (Energy dependent cut).

$\Downarrow$

$R^{\nu}{}_{exp} = 0.3916 \pm 0.0013$ and $R^{\bar{\nu}}{}_{exp} = 0.4050 \pm 0.0027$
(Note: ν_eCC and $\bar{\nu}_e$CC appear as NC.)

WEAK MIXING ANGLE:THE CALCULATION

- MODEL:
  LO + higher twist and longitudinal scattering.
- PARTON DISTRIBUTIONS:
  Obtained from CC events using same target (Fe) and model (CCFR).
  Assumption on the strange sea: $s(x) = \bar{s}(x)$
- STRANGE SEA:
  Obtained from CCFR and NuTeV (same detector) dimuon data.
- CHARM MASS:
  CC charm production suppression modelled using
  slow rescaling formalism with parameters
  also determined from CCFR and NuTeV dimuon data.
- NUCLEAR EFFECTS:
  Included in PDF's,assumed to be the same in NC as in CC.
- QED and EW RADIATIVE CORRECTIONS
  D.Bardin and V.A. Dokuchaeva JINR-E2-86-260(1986).

Source of Uncertainty	$\delta\sin^2\theta_W$	δR^ν	$\delta R^{\bar\nu}$
TOTAL STATISTICS	0.00135	0.00069	0.00159
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
ν_e, $\bar\nu_e$ Flux	0.00039	0.00025	0.00044
TOTAL MODEL	0.00064	0.00101	0.00212
Charm prod., strange sea	0.00047	0.00089	0.00184
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

WEAK MIXING ANGLE: $\sin^2\theta_W$

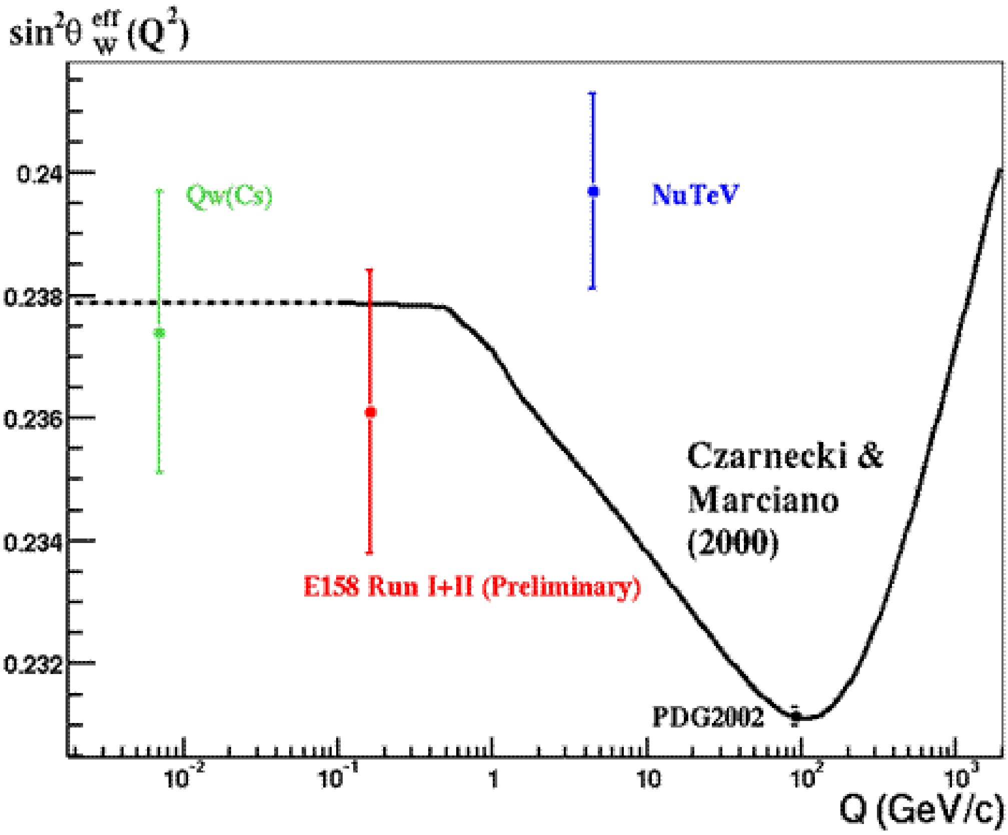
Simultaneous fit to R^{ν} and $R^{\bar{\nu}}$
to reduce systematics

$$\sin^2\theta_W^{(\text{on-shell})} = 0.22773 \pm 0.00135(stat) \pm 0.00093(syst)$$

Expectations from Standard Model:

$$\sin^2\theta_W^{(\text{on-shell})} = 0.2227 \pm 0.0004$$

$$\text{Difference} \quad = \quad 0.0050 \pm 0.0016 \quad \rightarrow \quad 3\sigma$$



WHERE does the difference come from?

$R^{\nu} = 0.3916 \pm 0.0013$ SM : 0.3950

$R^{\bar{\nu}} = 0.4050 \pm 0.0027$ SM: 0.4066

A difference of $3\,\sigma$ in the NEUTRINO data

POSSIBLE SOURCES OF DISCREPANCY I

ELECTROWEAK CORRECTIONS

New calculation: K.Diener et al
hep-ph/0310364 and hep-ph/0311122.
Improved treatment of initial state mass singularities.
Could REDUCE discrepancy by about 1 σ.

NLO

NuTeV estimates this to be a SMALL effect
But NuTeV FULL NLO calculation in progress.

NUCLEAR EFFECTS

PDF's that are used are extracted from iron CC data
Already include the RIGHT nuclear effects, in principle

But could nuclear effects be DIFFERENT in NC and CC ???
Miller and Thomas hep-ex/0204007
Shadowing due to VMD could be different in NC and CC.
VMD is a Low-x phenomenon $\longrightarrow$ affects mostly sea quarks.
Effect CANCELS to some extent in R^{-}.

POSSIBLE SOURCES OF DISCREPANCY II

THE STRANGE SEA

The computation assumes that the strange sea is SYMMETRIC.
What if it is NOT?
Non-perturbative effects:
Brodsky and Ma, Phys. Letters B392 (1997) 452.

NuTeV analysis of dimuon data DOES NOT support this:
$\int xs^-(x)dx = -0.0009 \pm 0.0014$

To explain the NuTeV $\sin^2\theta_W$ anomaly would require +0.006

But CTEQ analysis, INCLUDING the NuTeV dimuon data
Could explain away part of the effect:
$-0.001 < \int xs^-(x)dx < +0.004$

ISOSPIN VIOLATION

Could $u^p(x) \neq d^n(x)$?
Martin et al, hep-ph/0308087 :Examined constraints from data.
For valence quarks:

$$R^- = \frac{1}{2} + \sin^2\theta_W + (1 - \frac{7}{3}\sin^2\theta_W)\frac{[\delta U_v] - [\delta D_v]}{2V^-}$$

$$[\delta U_v] - [\delta D_v] = \int_0^1 x(u_v^p(x) - d_v^n(x)) - \int_0^1 x(d_v^p(x) - u_v^n(x))$$

Best fit gives $[\delta U_v] = -[\delta D_v] = 0.002$

$\downarrow$

$\Delta\sin^2\theta_W \sim -0.0018$ or -0.0015 including sea quarks.

$\downarrow$

Can account for about 1 σ of the effect.

NOMAD $\sin^2\theta_W$ *STRATEGY I*

NOMAD did not collect much $\bar{\nu}$ data.
The method used by NuTeV to extract $\sin^2\theta_W$
is therefore NOT applicable.

INSTEAD used

$$\mathrm{R}^{\nu} = \frac{\sigma^{\mathrm{NC}}}{\sigma^{\mathrm{CC}}} = \frac{1}{2} - \sin^2\theta_{\mathrm{W}} + \frac{5}{9}(1+\mathrm{r})\sin^4\theta_{\mathrm{W}}$$

Can NOMAD match the accuracy of NuTeV
WITHOUT $\bar{\nu}$ data ?

Look at NuTeV itself.

Source of Uncertainty	$\delta\sin^2\theta_W$	δR^{ν}	$\delta R^{\bar{\nu}}$
TOTAL STATISTICS	0.00135	0.00069	0.00159
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
TOTAL MODEL	0.00064	0.00101	0.00212
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

$\bar{\nu}$'s REDUCE model systematics, but COSTLY in statistics.

Compute error on $\sin^2\theta_W$ just from ν's. $\longrightarrow R^{\nu}$

LOSE in systematics but GAIN in statistics.

Error on R^{ν} = 0.00130

Error on $\sin^2\theta_W \longrightarrow$ 1.6 $\times$ Error on R^{ν} = 0.0021

SIMILAR to error on $\sin^2\theta_W$ using R^{-} = 0.00162

NOMAD $\sin^2\theta_W$ *STRATEGY II*

Still, IMPORTANT to have internal checks
to replace the $\bar{\nu}$ data:

- NOMAD reduces and evaluates systematics by examining the CC differential cross section:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{dxdQ}^2}$$

  Addresses:
  Higher Twist in xF_3 and Uncertainties on PDF's.

- Evaluates m_c using its own dimuon data (More sensitive than NuTeV because of the lower energy of NOMAD)

- Evaluates strange sea content also using its higher statistics dimuon sample 13600 events.

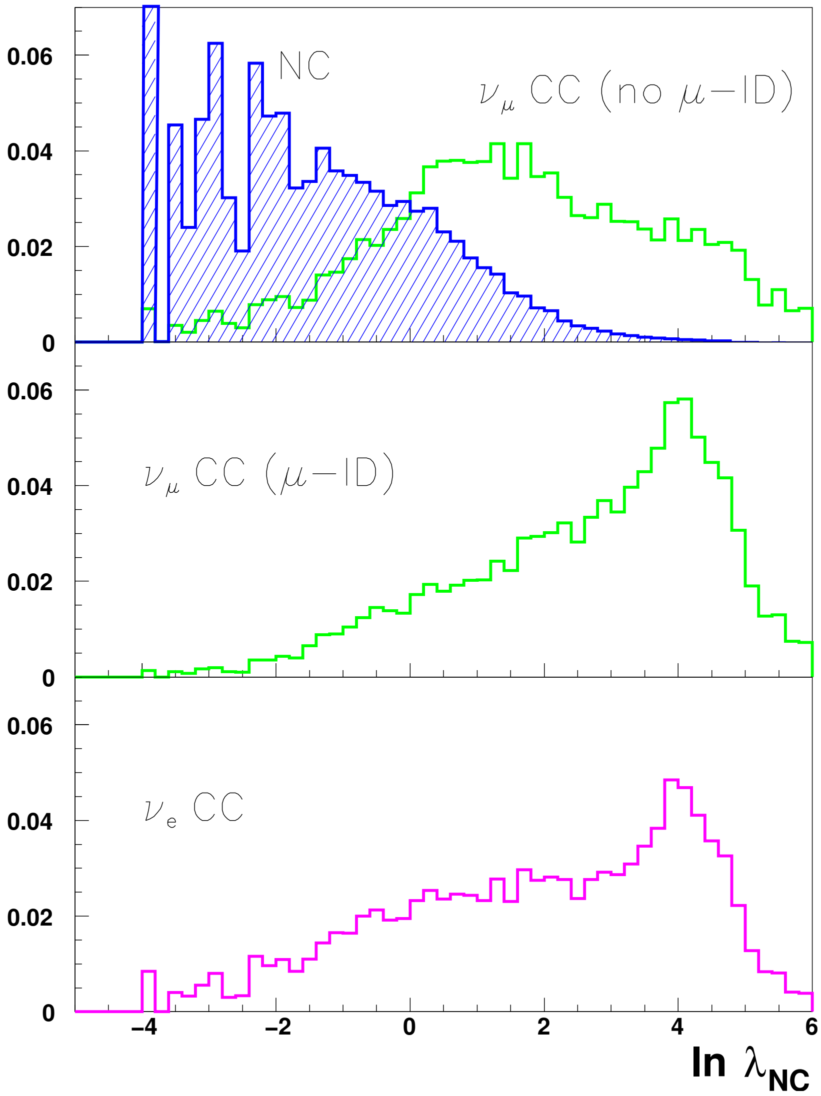
NOMAD $\sin^2\theta_W$ ANALYSIS: NC/CC SEPARATION

Identification of ν_μ^{CC}

- μ ID in muon chambers $\longrightarrow$ 90% of ν_μ^{CC}
- If NO μ then
- Select NEGATIVE track most likely to be an unidentified CC μ using a Likelihood built on:
  - Angle and P$_T$ of track relative to ν beam.
  - Change in "Collimation" of visible energy when excluding the track
    (If the CC μ is left as part of the jet, the jet will be wider).

- Taking this track as being the μ and using the Monte Carlo, build TWO likelihoods
  $\mathcal{L}^{NC}$ for neutral current events, and
  $\mathcal{L}^{CC}$, for charged current events,that failed to be identified as such
  based on kinematical variables:
  - Angles of μ and hadron jet relative to beam.
  - Angle in transverse plane between μ and hadron jet.
  - Transverse momentum component of μ relative to visible momentum vector.
  - Missing P_T.
- For each event compute $ln\ \lambda_{NC} = ln\frac{\mathcal{L}^{CC}}{\mathcal{L}^{NC}}$

NOMAD $\sin^2\theta_W$ *ANALYSIS: NC/CC SEPARATION*



NEUTRAL CURRENT DEFINITION: $ln\ (\lambda_{NC}) < 0$

- Retains 2.0 % of ν_μ^{CC} as ν_μ^{NC}.
- Efficiency of ν_μ^{NC} selection: 60%.
- Recovers inefficiencies of muon chambers.
- Rejects ν_e^{CC} as well.

NOMAD $\sin^2\theta_W$ ANALYSIS:DATA SIMULATOR

Efficiencies calculated using simulators based on REAL DATA

IDENTIFIED DATA ν_μ^{CC} events: $P_\mu > 4$ GeV/c $\longrightarrow$ BIASED

$\Downarrow$

KEEP HADRON JET, RESCALE P_μ

$\Downarrow$

ROTATE and BALANCE P_T

$\Downarrow$

UNBIASED ν_μ^{CC} SAMPLE $\rightarrow$ ν_μ^{CC} DATA SIMULATOR $\longrightarrow \epsilon_{DS}^{CC}$

$\Downarrow$

REMOVE MUON

$\Downarrow$

REMOVE 1 POSITIVE TRACK

$\Downarrow$

ROTATE and BALANCE P_T

$\Downarrow$

UNBIASED ν_μ^{NC} SAMPLE $\rightarrow$ ν_μ^{NC} DATA SIMULATOR $\longrightarrow \epsilon_{DS}^{NC}$

Repeat procedure for Monte Carlo events $\longrightarrow \epsilon_{MS}^{CC}$ and ϵ_{MS}^{NC}.
Then

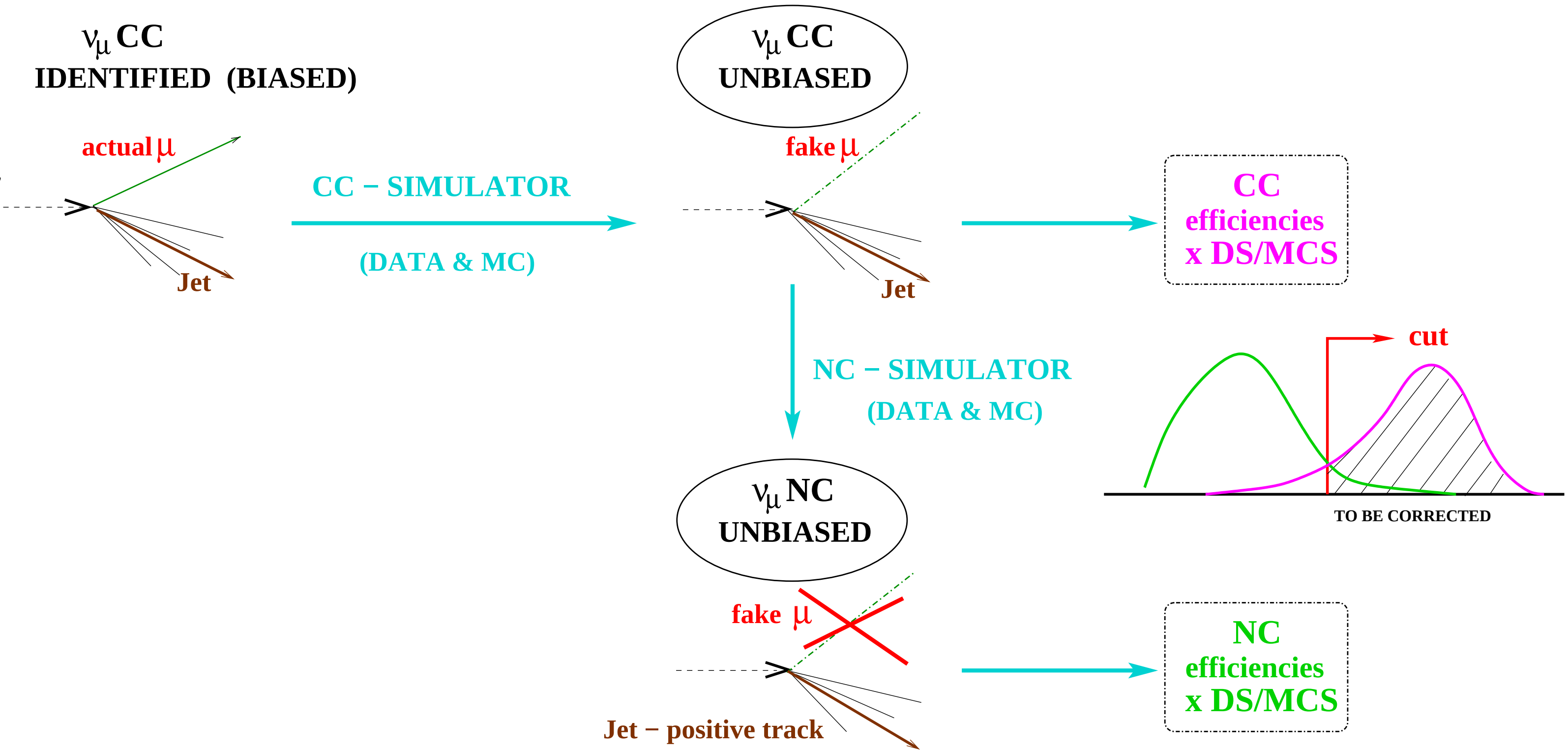
$$\epsilon^{CC} = \frac{\epsilon_{MC}^{CC} \times \epsilon_{DS}^{CC}}{\epsilon^{CC}{}_{MS}} \text{ and } \epsilon^{NC} = \frac{\epsilon_{MC}^{NC} \times \epsilon_{DS}^{NC}}{\epsilon^{NC}{}_{MS}}$$

NOMAD $\sin^2\theta_W$ *ANALYSIS:DATA SIMULATOR*

Efficiencies calculated using simulators based on REAL DATA

Start with

IDENTIFIED DATA ν_μ^{CC} *events:* $P_\mu > 4$ *GeV/c* $\rightarrow$ *BIASED*



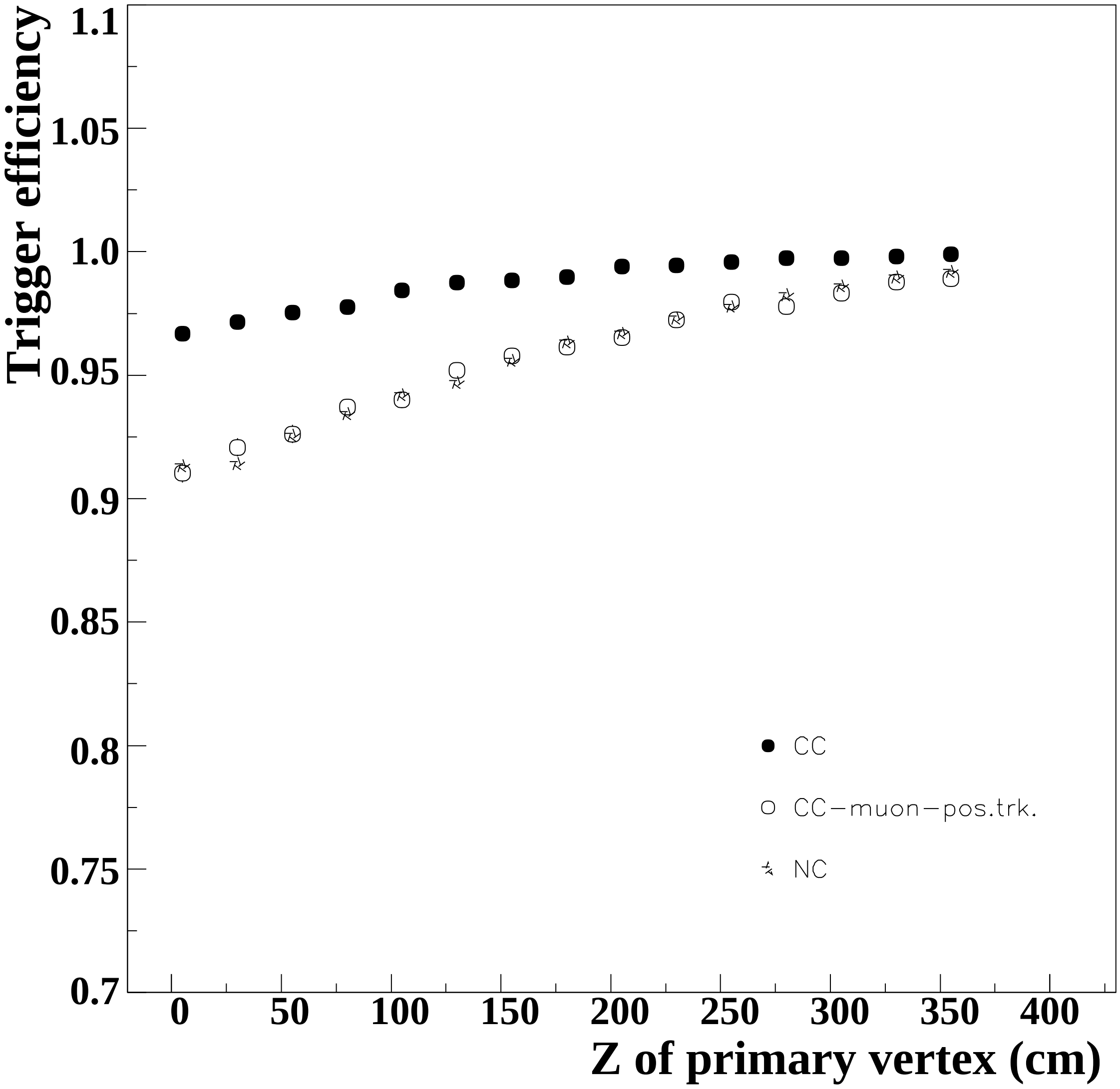
$\boxed{\textit{UNBIASED } \nu_\mu^{CC} \textit{ SAMPLE} \rightarrow \nu_\mu^{CC} \textit{ DATA SIMULATOR} \rightarrow \epsilon_{DS}^{CC}}$

$\boxed{\textit{UNBIASED } \nu_\mu^{NC} \textit{ SAMPLE} \rightarrow \nu_\mu^{NC} \textit{ DATA SIMULATOR} \rightarrow \epsilon_{DS}^{NC}}$

Repeat procedure for Monte Carlo events $\longrightarrow$ ϵ_{MS}^{CC} and ϵ_{MS}^{NC}.

$$\epsilon^{CC} = \frac{\epsilon_{MC}^{CC} \times \epsilon_{DS}^{CC}}{\epsilon^{CC}{}_{MS}} \text{ and } \epsilon^{NC} = \frac{\epsilon_{MC}^{NC} \times \epsilon_{DS}^{NC}}{\epsilon^{NC}{}_{MS}}$$

NOMAD $\sin^2\theta_W$ *ANALYSIS:DATA SIMULATOR*



MC NEUTRAL CURRENT SIMULATOR reproduces MC NEUTRAL CURRENT BEHAVIOUR

$\downarrow$

Indicates that DATA NEUTRAL CURRENT SIMULATOR will reproduce DATA NEUTRAL CURRENT BEHAVIOUR

DATA SIMULATORS allow the determination of the TRIGGER EFFICIENCIES from the DATA themselves. CHARGED PARTICLE TRIGGER can be used.

PRELIMINARY ESTIMATES OF EXPERIMENTAL SYSTEMATICS

Relative uncertainties: $\delta R^{\nu}/R^{\nu}$

General selection

Trigger Efficiency	0.0010
Charged Multiplicity Correction (2.4±0.05)%	0.0003

Event Classification

Energy scale (3.0±1.5)%	0.0005
Muon ID (Detector)	0.0002
μ-chambers acceptance (CC)	0.0008
Hadron decays (NC)	0.0007
Kinematic selection (0.940±0.006)	0.0010

Beam contamination

Integral ν_e Flux (± 1.5)%	0.0002
Integral $\bar{\nu}_\mu$ Flux (± 5.0%	0.0004
Integral $\bar{\nu}_e$ Flux (± 8.0%	0.0002

Total experimental systematics

Total above systematics	0.0019
Statistical uncertainty	0.0018

MODELLING I

In parallel: effort to produce
a model as general as possible
and including as much available
information as possible

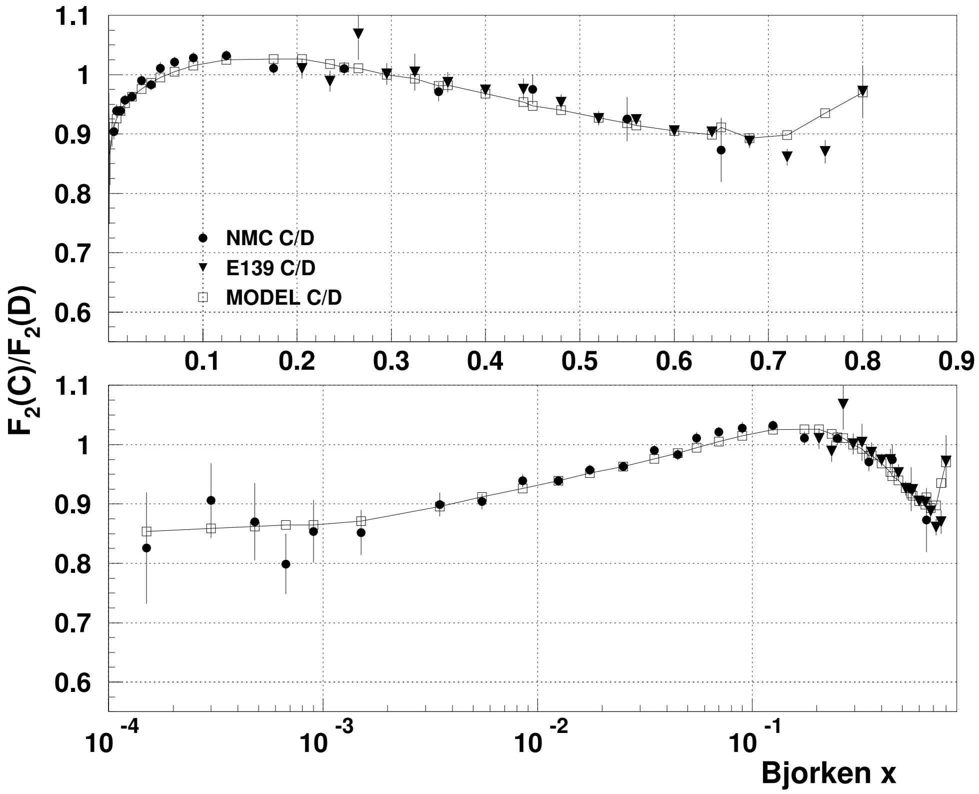
- Order: NNLO. Done in conjuction with Sergey Alekhin.
- Include Higher Twist and Target Mass corrections

$$F_i(x, Q^2) = F_i^{LT,TMC}(x, Q^2) + \frac{H_i^{(4)}(x)}{Q^2}$$

- Use all available charged lepton scattering data:
BCDMS, SLAC, NMC, HERA, E665, JLAB
Electron and muon on proton and deuterium.
- Uncertainties on parton distributions extracted.
Allows realistic estimates of systematics.
- Low Q^2: Stop evolution at 1 GeV^2
and extrapolate to $Q^2 = 0$ to give photo production limit (F_2=0.).

MODELLING II

- Nuclear effects. Done in conjunction with Sergey Kulagin.
  (S. Kulagin, R.Petti Paper in preparation)
  Shadowing, Off-shell binding energy, Fermi Motion, non-iso-scalarity.
  Assume two universal parameters for ALL nuclei
  One for LOW x and one for HIGH x.
  Use available charged lepton scattering data.
  Extract F_2^A/F_2^D.



- Electroweak corrections. Done in conjunction with Arbuzov and Bardin

NOMAD PRELIMINARY TOTAL SYSTEMATICS

Source of Uncertainty	$\delta R^{\nu}/R^{\nu}$
TOTAL STATISTICS	0.0019
TOTAL EXPERIMENTAL	0.0018
TOTAL MODEL(**)	0.0009
OVERALL UNCERTAINTY	0.0028

To be compared to the relative error on R^{ν} from NuTeV

$0.00130/0.3916 = 0.0033$

Note that these numbers are evaluated assuming just the main target events.

The coil events would double the statistics and also improve the systematics (statistics limited).

(**) Preliminary evaluation at just one kinematic point:

$E_{\nu} = 45.7$ GeV, x=0.24, y=0.5

NuTeV - NOMAD COMPARISON

	NuTeV	NOMAD
NC Statistics	360k	300k (x 2)
Detector	Calorimeter	High. Res. Ind.particles
Target Material	Iron	Carbon (Alum.)
Analysis	Straightforward	Complex
CC backg. in NC	20%	6%
Eff. estimates	Monte Carlo	Data Simulator
ν_e^{CC}	1.7 % of ν_μ^{CC} Look like ν_μ^{NC}	1.5 % of ν_μ^{CC} Fully identified
$\mathrm{R}^{\bar{\nu}}$	Yes	No
$< \mathrm{Q}^2 >$	20 GeV^2	15 GeV^2
QCD Calculation	LO	NNLO
m$_c$, Strange sea	$\Delta m_c = 140$ MeV	Combined Fits $\Delta m_c = 50$ MeV
Nuclear Effects	Same in CC/NC	In Model
EW Corrections	Bardin, Dokuchaeva	New Calculation

THE FUTURE.

$\bar{\nu}_e$ e elastic scattering at Reactors hep-ex/0403048 v2

$$\frac{d\sigma}{dT} = \frac{G^2 m}{2\pi}[(C_V+C_A)^2+(C_V-C_A)^2(1-\frac{T}{E})^2+(C_A^2-{C_V}^2)m\frac{T}{E^2}]$$

with T=KE (e), E (ν), C_A= 1/2, C_V=1/2+ $2\sin^2\theta_W$.

- Background
  - Radioactivity
  - Cosmic muons $\longrightarrow$ 300 mwe overburden
  - Electrons from muon decay.
  - Inverse Beta Decay(IBD) $\bar{\nu}_e p \longrightarrow e^+ n$
    Must detect neutron: Gadolinium.
- Normalization on IBD.
- 3 $<$ E_{vis} $<$ 5 MeV
- 2 reactors, 3.6 GW, 900 live days $\longrightarrow$ 13000 events.

$$\delta \sin^2\theta_W = 0.0020$$

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