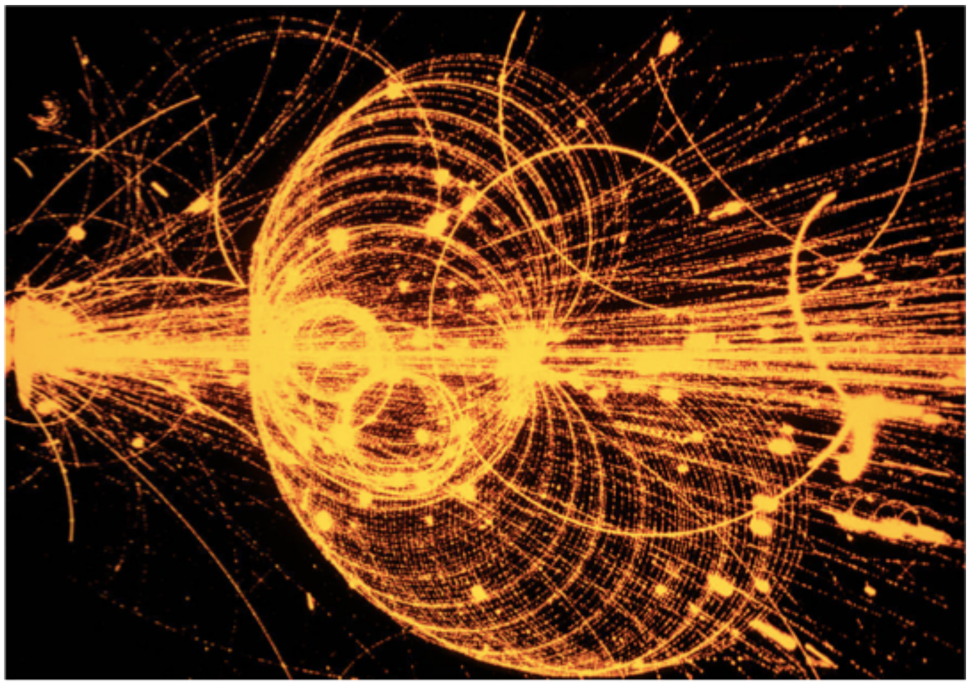
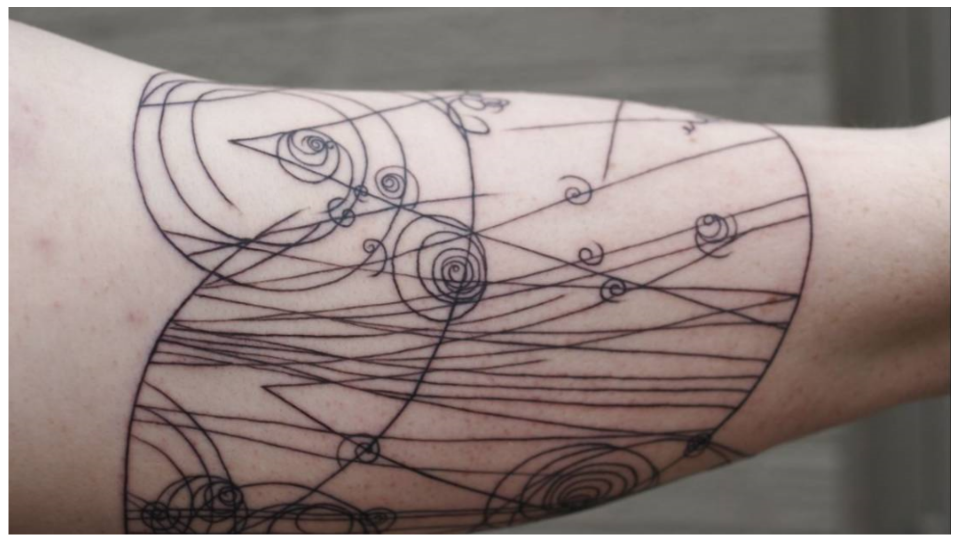
The Past and Future of
ν / $\bar{\nu}$ – Hydrogen/Deuterium Experiments





Jorge G. Morfín
Fermilab

Why Do we Need ν-Nucleon Scattering Results?

NuSTEC White Paper: Status and Challenges of Neutrino–nucleus Scattering:
Progress in Particle and Nuclear Physics 100 (2018) 1–68

- General challenges facing the community:
  - Future high-precision neutrino interaction experiments are needed to extend the current program of GeV-scale neutrino interactions and should include a feasibility study of a **high statistics hydrogen or deuterium scattering experiment to supplement the currently poorly known (anti)neutrino–nucleon cross sections**.
- Quasi-elastic Scattering:
  - improvement of our knowledge of the axial part of the nucleon–nucleon transition matrix elements via **a new high statistics hydrogen and/or deuterium cross section experiment.**
  - **Using targets of hydrogen and deuterium will help to factorize nucleon cross-sections and nuclear uncertainties such as Fermi momentum or final state interactions.**

Why do we Need ν-Nucleon Scattering Results?

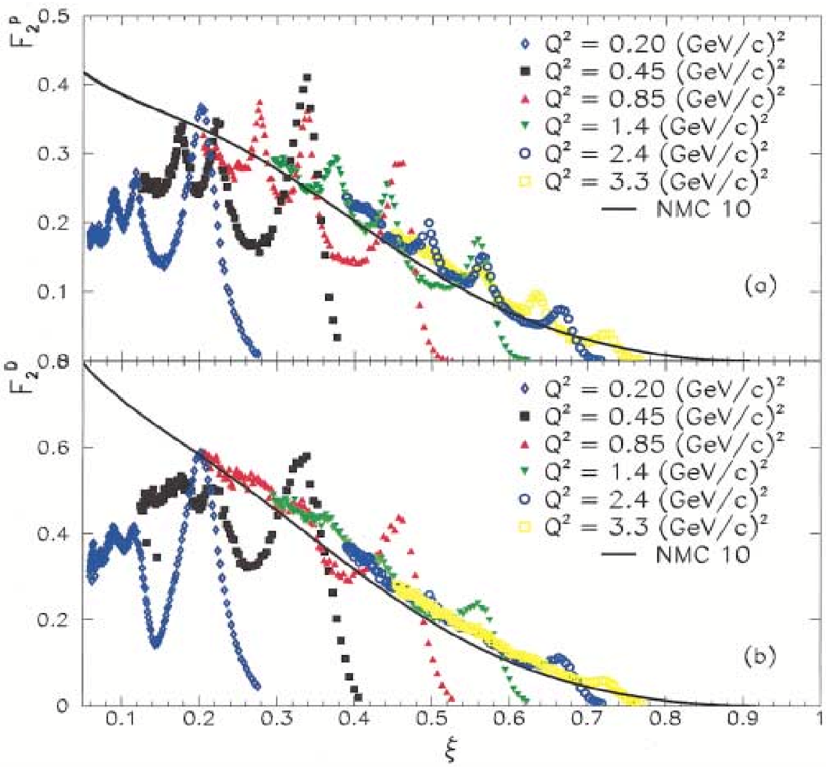
- Resonance Production
  - The most important challenges are **improving knowledge of the axial part of nucleon-Δ transition matrix elements, either via a new hydrogen and/or deuterium experiment** or via lattice-QCD calculations;
  - We need the axial-vector form factors for the higher-W resonances.
  - Event generators performance cannot exceed the data precision. In the resonance region it is rather difficult to take decisions how to improve their performance. Typically, the generators reproduce either MiniBooNE or MINERνA carbon target pion production data quite well.
  - **Old bubble chamber ANL and BNL deuterium pion production data are not very difficult to reproduce with reasonable precision. Thus generators need more precise experimental data to justify more ambitious upgrades.**

Why do we Need ν-Nucleon Scattering Results?

- SIS and DIS Scattering (W > 1.4 GeV, **(≈50-55)%** of DUNE events!)
  - **NOvA informal-We've been led to an empirical adjustment of multi-pi production based on our own data. As far as priorities go, getting the multi pion production single nucleon cross sections in shape would probably have the biggest impact.**
  - **There is initial theoretical consideration that quark-hadron duality for neutrinos is different than charged lepton duality that is used in GENIE in this kinematic region. An experimental check of this for nucleons and consequent update of GENIE would be helpful.**
  - **Multiplicities - a statistically significant measurement of multiplicities off of H/D target would certainly improve ν-nucleon hadronization models (fragmentation functions) and enable more accurate assessments of models of final state interactions.**
  - **Clarification of the interplay of "duality" with higher-twist (non-perturbative QCD effects) with nucleons would help in clarifying nuclear higher-twist effects.**
  - **Partonic nuclear effects – To compare the many $\overset{(-)}{\nu}$–Fe structure function results directly with a statistically significant $\overset{(-)}{\nu}$–D result would help better understand recent ν nPDF results that yield rather different nPDFs compared to charged lepton scattering.**

Quark-hadron duality for neutrinos is different than charged lepton duality that is used in GENIE in this kinematic region. **An experimental check of this for nucleons and consequent update of GENIE would be helpful**

- If you take F_2 determined from a QCD fit to DIS data and extrapolate down in ξ, the extrapolation approximately runs right through the middle of the resonances



JLAB: recent experimental data on F_2 of the reactions $ep \to eX$, $eD \to DX$ in the resonance region

solid curve — global fit to the world's DIS data by NMC collaboration

The data at various values of Q^2 and W average to a smooth curve if expressed in terms of ξ.

$$\xi = \frac{2x}{(1 + \sqrt{1 + 4m_N^2 x^2/Q^2})}$$

What about ν-n and ν-p scattering?

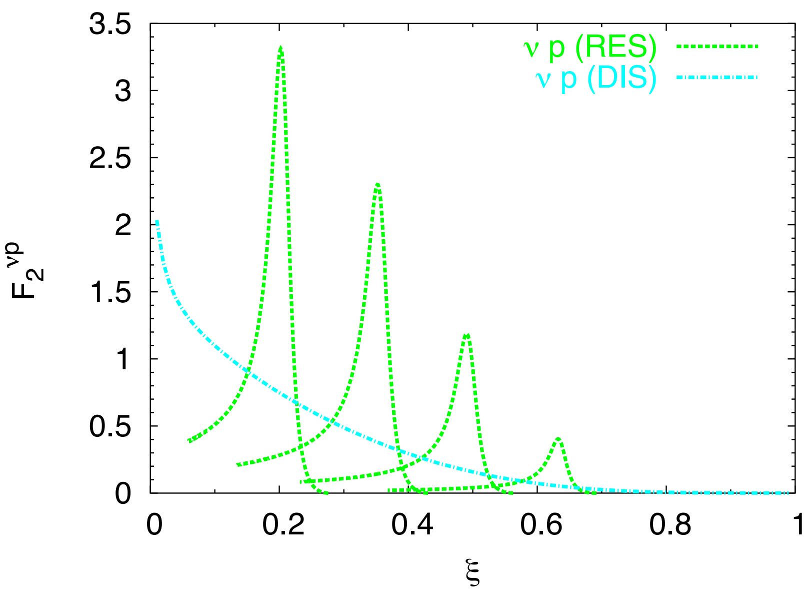
Resonance estimates from Lalakulich, Melnitchouk and Paschos

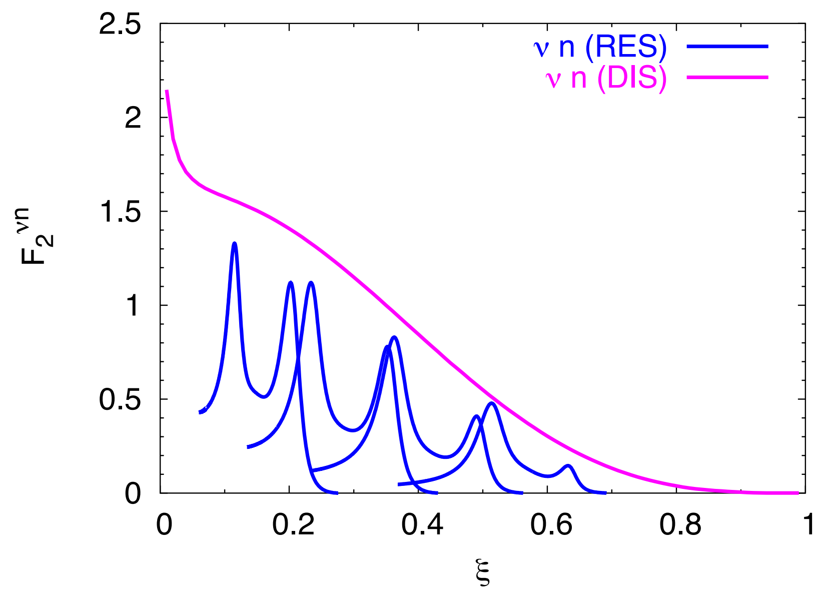
Oops!

Low-lying resonances: $F_2^{\nu n(res)} < F_2^{\nu p(res)}$, DIS: $F_2^{\nu n(DIS)} > F_2^{\nu p(DIS)}$

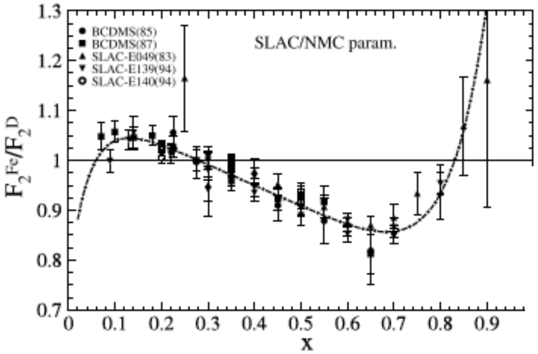
$F_2^{\nu p(res-3/2)} = 3F_2^{\nu n(res-3/2)}$
$F_2^{\nu p(res-1/2)} \equiv 0$

$F_2^{\nu n(res)}$: finite contributions from isispin-3/2 and -1/2 resonances



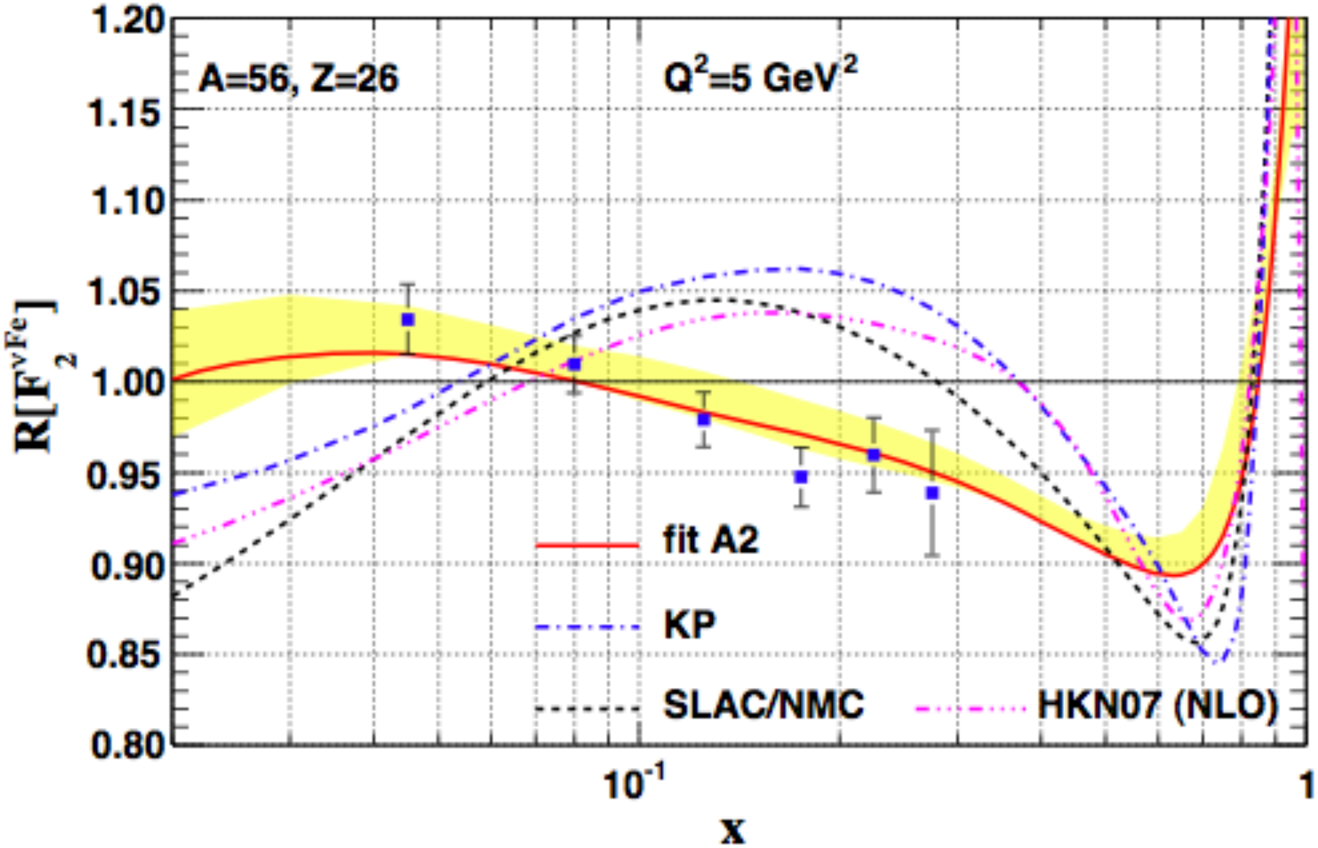


Partonic nuclear effects – To compare the many ν–Fe structure function results directly with a statistically significant ν–D result would help better understand recent ν nPDF results that yield rather different nPDFs compared to charged lepton scattering.

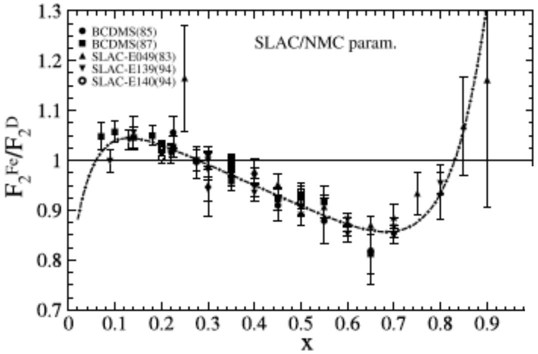


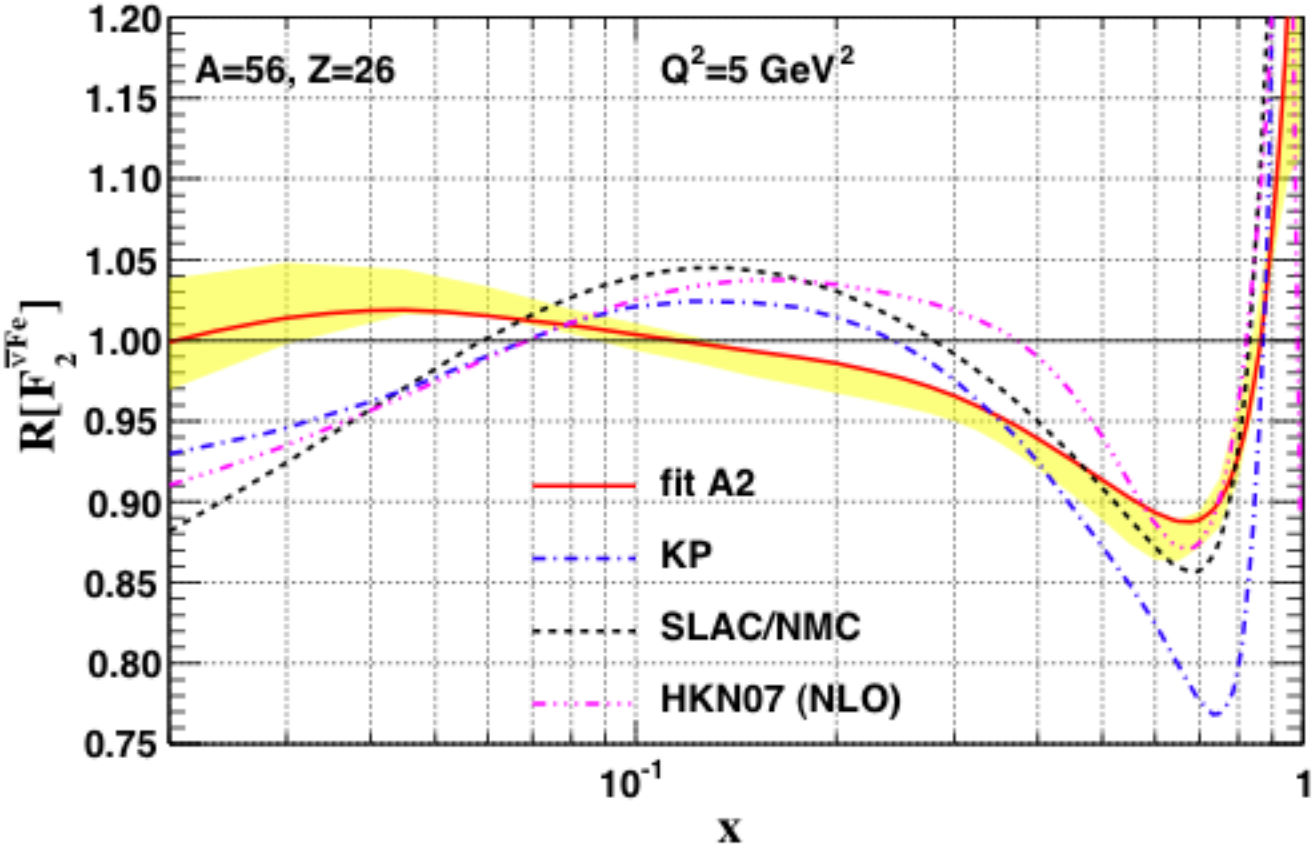
F_2 Structure Function Ratios: ν-Iron

nCTEQ had to "fabricate" the nucleon denominator in the ratio of Fe/N from CTEQ parton distributions.



F_2 Structure Function Ratios: $\overline{\nu}$-Iron





NuSTEC Workshop on Shallow-and Deep-Inelastic Scattering

11-13 October – GSSI, L'Aquila, Italy

Right before and in same location as the NuInt18 Workshop

http://nustec.fnal.gov/nuSDIS18/ https://indico.cern.ch/event/727283/

1) General introduction and considerations from non-neutrino communities.
   A) Introduction to SIS/DIS Theory and Models
   B) e-A community studies of the SIS/DIS region

2) Generator / Transport treatments of the SIS and DIS region.
   A) Improved Rein-Sehgal Model above the Delta
   B) Status of the Bodek-Yang Model
   C) Generator/Transport Treatments:
      GiBUU, GENIE, NEUT, NuWRO
   D) Generator Comparison of SIS/DIS treatment- Overview

3) Sensitivity of oscillation parameters to the SIS and DIS region.
   A) NOvA
   B) Atmospheric Neutrino Studies, SK and HK

4) Resonant and non-resonant contributions with W > Delta
   A) Isobar models of resonance production
   B) Dynamical coupled-channel models
   C) pi-nucleon scattering community studies
   D) Experimental nu-A higher-W pion production studies

5) The transition from SIS to DIS
   A) Duality in e-nucleon / nucleus scattering
   B) Duality in neutrino nucleus scattering
   C) Higher Twist and Duality in the SIS/DIS transition
   D) Chiral Field and Regge theory in the transition region

6) Nuclear modifications of structure functions and nuclear PDFs
   A) Nuclear Medium Effects on Structure Functions I
   B) Nuclear Medium Effects on Structure Functions II
   C) nPDFs from e/mu-A and nu-A scattering I
   D) nPDFs from e/mu-A and nu-A scattering II
   E) MINERvA results of Inclusive and DIS on nuclear targets

7) Hadronization in the nuclear environment
   A) Hadronization studies from the e/mu-A community
   B) The AGKY hadronization model
   C) Hadronization in FLUKA and DPMJET
   D) NOMAD Hadronization Studies

There is a growing voice within the community for new high-statistics measurements of (anti)neutrino interactions off H and D. What do we have now?

The Bubble Chamber Era served as an essential introduction to HEP experimentation!

BEBC

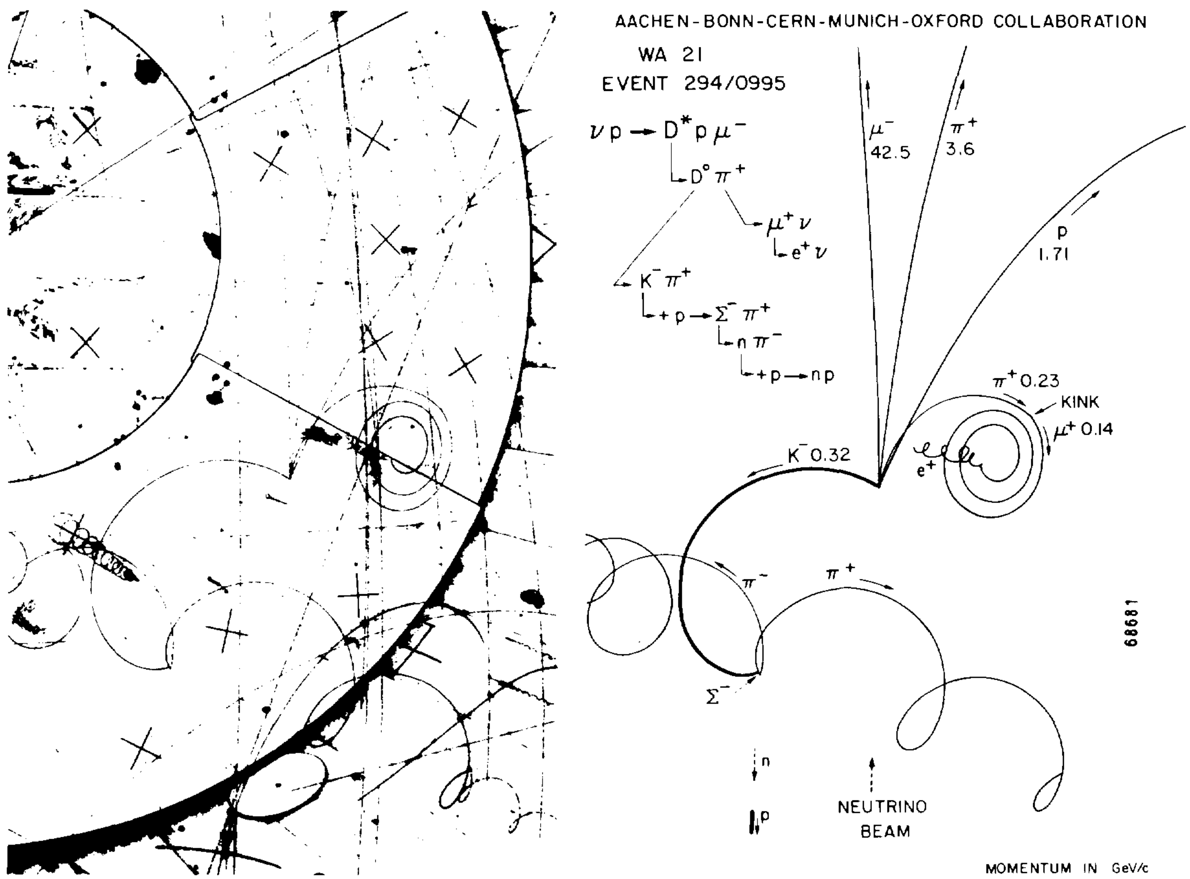


Fig. 1 Production and decay of a charmed meson state in the Big European Bubble Chamber (BEBC)

Concentrate on the big European bubble chambers with which I was personally involved

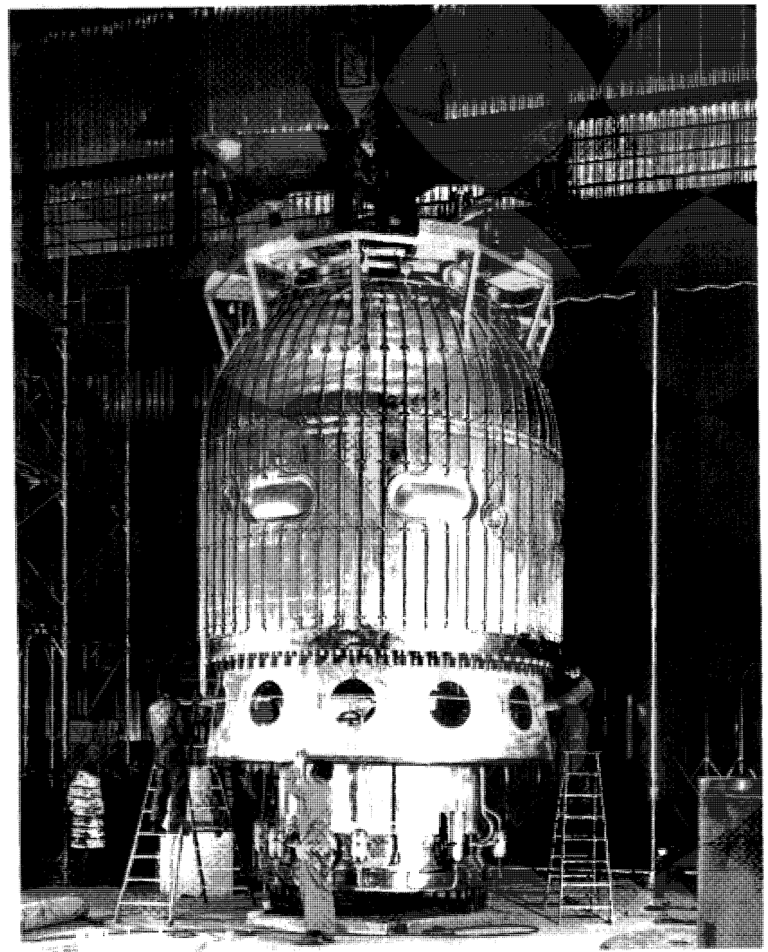


Fig. 3 BEBC chamber vessel

- On the left, Gargamelle mainly using heavy liquids like CF_3Br
- BEBC, on right, followed for ν + H, ν + D and ν + Ne/H scattering.

LIST OF BEBC EXPERIMENTS

NUMBER OF PICTURES/EXPERIMENT

Experiment	Liquid	Particles	Energy	Number of
T225/231	H_2	π^-	21 GeV/c	106 500
T243	H_2	$\bar{p}$	12 GeV/c	293 000
WA17	H_2	Neutrino	350 GeV/c	271 696
WA19	Ne	Antineutrino Hadrons Neutrino	400 GeV/c 70 GeV/c 400 GeV/c	181 458 5 500 162 701
WA20	Ne	Dump	400 GeV/c	70 100
WA21	H_2	Neutrino Antineutrino	350/400 GeV/c 400 GeV/c	462 706 389 164
WA22	Ne	Neutrino Hadron	400 GeV/c 20 GeV/c	165 395 2 500
WA24	TST	Antineutrino Neutrino	330 GeV/c 350 GeV/c	272 060 315 890
WA25	D_2	Antineutrino Neutrino	400 GeV/c 400 GeV/c	395 085 135 461
WA26	H_2	K^-	70 GeV/c	53 200
WA27	H_2 D_2	K^+ K^+	70 GeV/c 70 GeV/c	299 574 32 736
WA28	H_2	K^-	110 GeV/c	273 100
WA30	TST	π^-	70 GeV/c	243 553
WA31	TST	Antiproton	70 GeV/c	190 044
WA32	Ne	Proton	70 GeV/c	11 000
WA47	Ne	Neutrino Antineutrino Hadron	400 GeV/c 400 GeV/c various	385 556 395 112 28 204
WA51	Ne	$\pi^{\pm}$	25/60 GeV/c	32 267
WA52	Ne	Dump	400 GeV/c	136 200
WA59	Ne	Antineutrino Neutrino Positron	400 GeV/c 400 GeV/c 15/20/40 GeV/c	61 041 36 315 8 002
WA66	Ne	Dump	400 GeV/c	292 450
WA73	H_2	Proton	5 GeV/c	22 200
PS180	Ne	Oscillation Calibration	19 GeV/c	786 904 214 618

Total number of pictures 6.296.903

NUMBER OF PICTURES IN VARIOUS BEAMS

Neutrino	1 501 331
Antineutrino	1 693 920
Hadrons SPS	1 201 880
Hadrons PS	399 500
Beam dump	498 750
Oscillation + calibration	1 001 522
Total	6.296.903

NUMBER OF PICTURES IN VARIOUS LIQUIDS

Hydrogen	1 899 444
Neon	2 812 622
Hydrogen TST in Neon	1 021 547
Deuterium	563 290
Total	6.296.903

Reminder: Basis of Operation

- The medium is a superheated liquid in which a charged particle leaves a trail of bubbles in its wake.
- The liquid is brought to the sensitive state by reducing its pressure synchronously with the passage of the particle.
- The bubbles grow in diameter for a desired growth time.
- When they have reached a suitable size, a flash system is triggered to enable the chamber volume to be photographed from several viewpoints.
- The set of views is used for subsequent stereoscopic reconstruction of the tracks.
- **Millions** of pictures have to be examined by teams of “scanners” and all found events analyzed by physicists.

Gargamelle: Interior optical ports, scan table and physicist/scan team

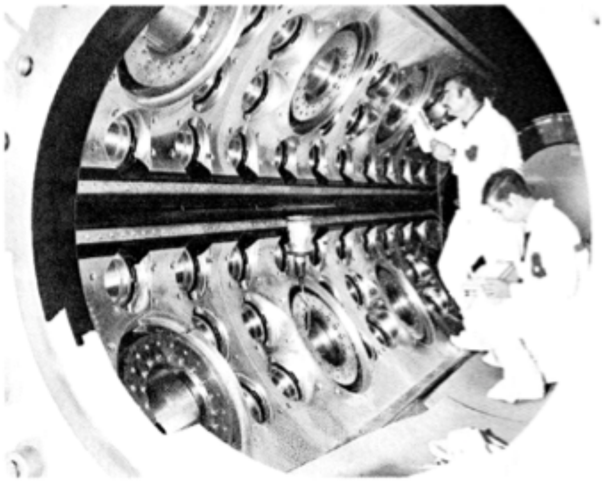


FIGURE 4.8. Interior of Gargamelle. Technicians are seen making final adjustments inside the bubble chamber during the summer of 1970, before the installation of the membranes. The larger holes are for the optical systems leading to the cameras, the smaller holes are for the in- and outflow of gas for compression and decompression. Source: CERN PIO/102-8-70.

FIGURE 4.9. Measuring events from Gargamelle, April 1971. Projectors enlarge the images of the 70 mm bubble-chamber film onto a scanning table where an operator takes measurements. The computer console behind her asks for information specifying, for example, when additional measurements are required for certain tracks. Source: CERN 151-04-71.

The main advantages of the bubble chamber:

- High detection efficiency for charged tracks over a 4π solid angle. Essentially free from bias due to detector geometry.
- High precision reconstruction, within a strong magnetic field, allowed excellent spatial resolution and accurate track parameter determination.
- Direct and generally unambiguous observation of events. We did not need a complex pattern recognition process to associate signals from discrete detector components in order to recognize the event.
- A large amount of information was recorded for each event, which can provide decisive evidence for new particles or interaction processes. In this respect the bubble chamber was an effective explorative instrument (previous D* production and decay picture).

The disadvantages of the bubble chamber

- **Low data rate**. Even under rapid-cycling conditions, event rates are far below those achievable by counter methods (by at least a factor of 10^3).
- Required tedious and long term off-line analysis. Results were certainly not immediately available.
- No inherent selectivity. Separation of low cross-section processes was slow and inefficient.
- The detection system had rather poor:
  - time resolution.
  - precision at high energies.
- **A big problem – inefficient detection of neutral particles compromising determination of incoming neutrino energy.**

Evolution of the Bubble Chamber – trying to remain a relevant detector technique.

- With the progressive increase in accelerator energies and emphasis on ν physics, there was a corresponding growth in bubble chamber size up to **BEBC and 15' chambers containing some 30 m^3 of liquid**.
- Then an interesting reversal of this trend with the development of minuscule chambers devoted to the study of short-lived particles.
- Main types of bubble chambers
  - **Large Cryogenic Chambers – subject of the rest of the talk**
  - Rapid cycling chambers (**10-50 Hz**)- represented an attempt to improve the data rate and to offer the possibility of selecting specific types of events with the aid of external triggering.
  - High-resolution chambers - With the discovery of "charmed" states a tracking detector required sufficient spatial resolution to observe track lengths of less than 1 mm. Required a vertex resolution (setting error) of 10 μm .

The Large Cryogenic Chambers: BEBC and the 15'

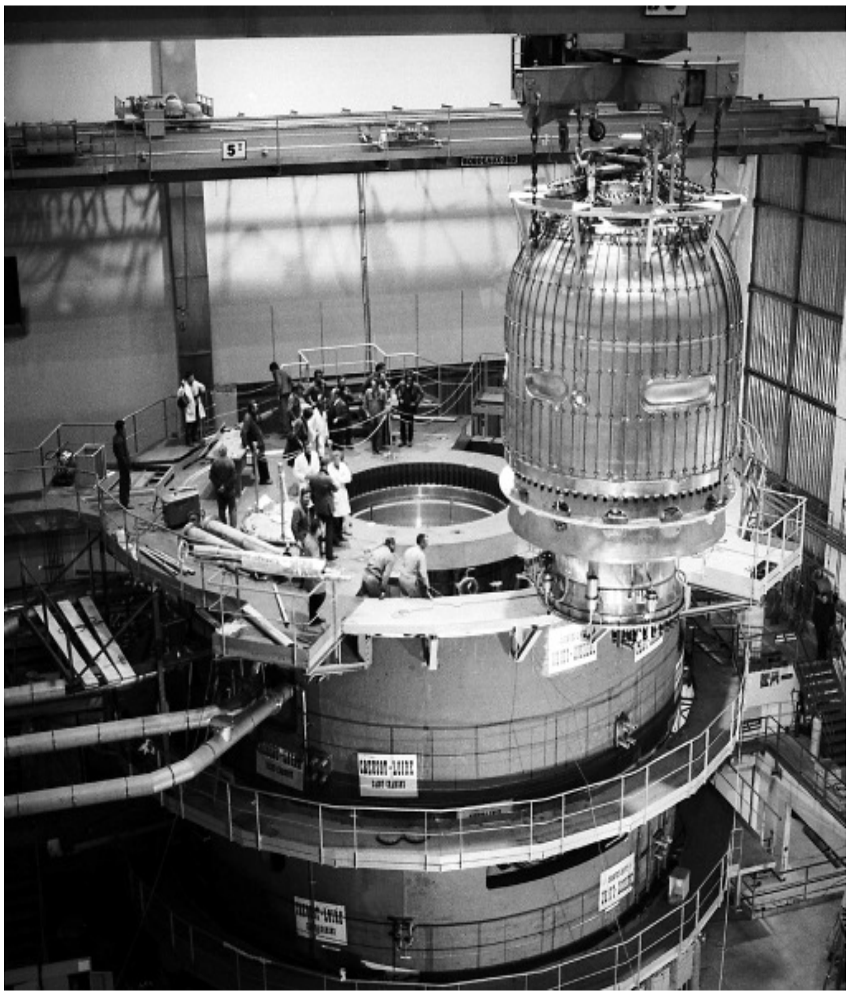
- Main characteristics of this type of chamber:
  - Large capacity ≈ 30 m^3 of liquid
  - Use of wide-angle (fish-eye) optics.
  - A superconducting magnet provided a field of 3-4 T.
- The penalty one pays for the large volume is increased distortion due to turbulence.
- The problem is aggravated owing to the relatively long delay needed to obtain resolvable bubbles under bright field illumination conditions.
- These effects, in combination with optical resolution limits, restrict the achievable setting error to around 300 μm in space.
- In spite of this, high accuracy was possible by virtue of the combination of high magnetic field and long track length yielding a ≈ 4% error on 100 GeV/c track in BEBC.
- Eventually had a choice of new high-resolution cameras reducing the setting error to 100 μm BUT reducing the field of view to 20% of the chamber volume

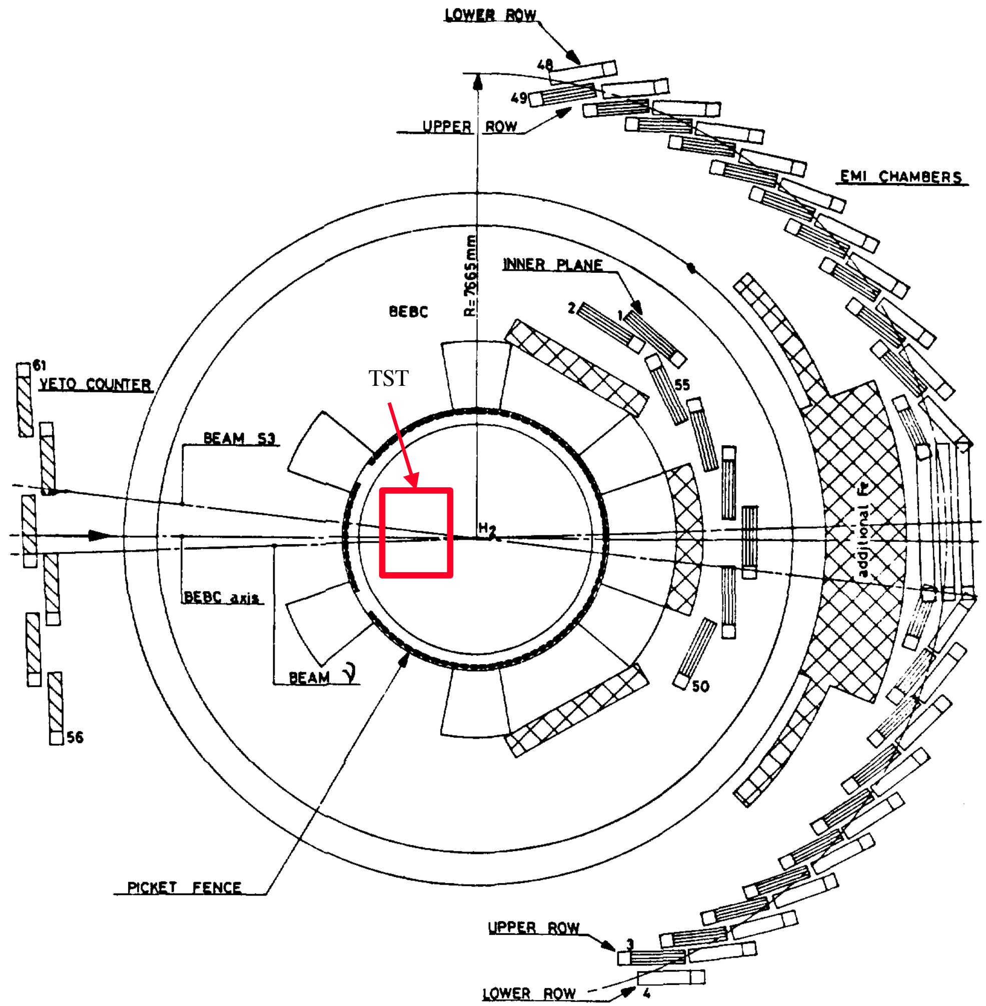
Hybrid Bubble Chamber Systems

- Internal hybrid - use a composite filling to separate the target from the detector functions of the chamber.
  - introduction of metal plates in the chamber to improve gamma conversion and muon identification
  - Interactions occur in a track-sensitive target (TST) of hydrogen or deuterium within a chamber filled with a neon-hydrogen mixture.
  - Object is obviously to maintain high resolution in the vertex region, while improving the detection of neutral pions and neutrons by virtue of the shorter gamma conversion and interaction length of the surrounding mixture.

- External – Application essential to successful study of Neutrino Interactions was the External Muon Identifier (EMI)

Full Hybrid BEBC Facility





You will hear about BC ν-nucleon QE and π production tomorrow. Here is a BEBC total cross section measurement

TOTAL CROSS SECTIONS FOR CHARGED-CURRENT NEUTRINO AND ANTINEUTRINO INTERACTIONS IN BEBC IN THE ENERGY RANGE 20–200 GeV

Aachen–Bonn–CERN–London–Oxford–Saclay Collaboration

P.C. BOSETTI, H. DEDEN, M. DEUTSCHMANN, P. FRITZE, H. GRÄSSLER, F.J. HASERT, J. MORFIN, H. SEYFERT, P. SCHMITZ, R. SCHULTE, K. SCHULTZE and H. WEERTS
III. Physikalisches Institut der Technischen Hochschule, Aachen, Germany

K. BOCKMANN, H. EMANS, C. GEICH-GIMBEL, R. HARTMANN, A. KELLER, T.P. KOKOTT, W. MEINCKE, B. NELLEN and R. PECH
Physikalisches Institut der Universitat, Bonn, Germany

D.C. CUNDY, J. FIGIEL, A. GRANT, D. HAIDT, P.O. HULTH, D.J. KOCHER, D.R.O. MORRISON, E. PAGIOLA, L. PAPE, V. PETERSON‡, CH. PEYROU, P. PORTH, P. SCHMID, H. WACHSMUTH and K.L. WERNHARD
CERN, European Organization for Nuclear Research, Geneva, Switzerland

S. BANERJEE, K.W.J. BARNHAM, R. BEUSELINCK, I. BUTTERWORTH, E. CLAYTON, D.B. MILLER, K.J. POWELL and E.J.W. WEST
Imperial College of Science and Technology, London, UK

W.M. ALLISON, C.L. DAVIS, P. GROSSMANN, R. McGOW, J.H. MULVEY, G. MYATT, D.H. PERKINS, R. PONS, D. RADOJICIC, P. RENTON and B. SAITTA
Department of Nuclear Physics, Oxford, UK

M. BLOCH, M. DEBEER, W. HART, J. SACQUIN, B. TALLINI and D. VIGNAUD
Centre d'Etudes Nucléaires, Saclay, France

Received 9 August 1977

The charged-current cross sections for neutrinos and antineutrinos on nucleons in the energy range 20–200 GeV are given. Taken in conjunction with the previous Gargamelle results, they show that σ/E is almost constant with energy for antineutrinos, and falls with energy for neutrinos. The value of $\langle q^2\rangle/E$ decreases with energy for both neutrinos and antineutrinos, and these deviations from exact Bjorken scaling are consistent with those observed in electron and muon inelastic scattering. We find no evidence for new heavy quark states with right-handed coupling.

Used the CERN narrow-band beam

- ν and $\bar{\nu}$ on nucleons in the energy range 20-200 GeV.
- Used the CERN narrow-band (dichromatic) neutrino beam.
- BEBC (diameter 3.7 m) filled with 74% molar Ne/H_2 mixture (ρ = 0.71 g/cm3).
- Fiducial volume of 17 m^3(mass 12 t), chosen so that the minimum downstream path-length of secondaries from an interaction vertex was 0.5 m.
- The chamber field was 35 kG, giving a momentum resolution of $\Delta p/p = 4\%$ for a 100 GeV/c charged particle over 2 m track length.
- The chamber was equipped with a single plane External Muon Identifier (EMI) consisting of 49 modules of multi-wire proportional chambers:
  - approximately 6 m from the center of BEBC
  - separated from the chamber liquid by 0.5-1.5 m Fe absorber
  - covered an angular range of $\pm 80°$ horizontal and $\pm 60°$ vertical.
  - efficiency of the EMI for detection of muons was 98% for $P_\mu > 5$ GeV/c
- All film was double scanned with $e \approx 99\%$ for finding an event
- **Total analyzed sample ($E_\nu > 20$ GeV) : 250 $\bar{\nu}$ and 517 ν CC events!**
  - **No BIG concern for details of systematic errors!**

The CERN Narrow Band Beam

- The CERN Narrow Band Beam used 400 GeV protons:
  - 125 m long dipole plus quadrupole channel
  - selected $\pi^{\pm}$, $K^{\pm}$ secondaries p = 200 GeV/c ($\pm 5\%$).
  - followed by a decay tunnel 305 m long,
  - muon absorber consisting of 184 m steel shielding followed by 170 m of rock.

- solid state detectors, both fixed and movable, placed in gaps in the steel shielding at depths of 30, 50, 70 and 94 m to monitor beam stability and measure the integrated muon flux.

- Moving counters obtained the relative calibration of fixed counters, and absolute calibration used exposures of nuclear emulsion.

Results 1

- Due to measurement errors and loss of some neutral hadron energy, the observed energy distributions were broader than those expected for perfect resolution. **The magnitude of the mean hadron energy loss was 20%, determined from transverse momentum balance and from measurement of 70 GeV/c π^- interactions obtained in special runs**.
- Taking these effects into account, made a separation of events due to neutrinos from π-decay(ν_π) and K-decay (ν_K), with uncertainties smaller than the statistical errors in the sample.
- For ν_π events, $E_{\nu\pi} = E_{vis} + E_{loss}$
- For ν_K events, took $< E_{\nu K} >$ computed from the beam parameters and the radial position of the event in the chamber.

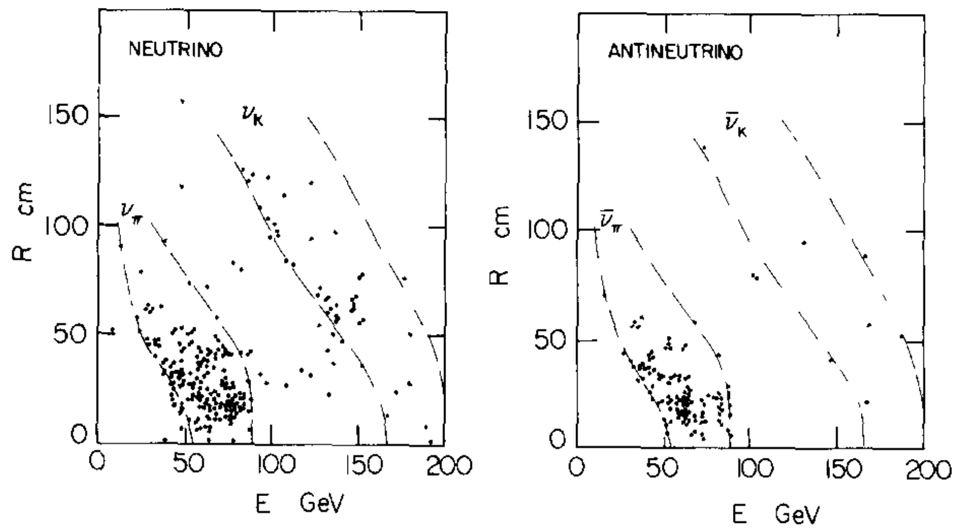


Fig. 1. Scatter plots of visible energy of events versus radius from the beam axis for neutrino and antineutrino interactions. The lines indicate the regions inside which 90% of the ν_π or ν_K events should lie, assuming perfect energy resolution and cross sections rising linearly with energy. They are based on the parameters of the beam, parent momentum 200 GeV/c $\pm$5%, r.m.s. beam divergence 0.20 mrad.

Results 2

Table 1
Neutrino and antineutrino cross sections

	Gargamelle [4]	BEBC (this experiment)			
Energy range (GeV)	2–10	20–60	60–100	100–150	150–200
		ν_π	ν_π	ν_K	ν_K
σ^ν/E	0.72 ± 0.05	0.67 ± 0.06	0.56 ± 0.05	0.61 ± 0.05	0.51 ± 0.05
N(events)	–	136	123	161	97
$\sigma^{\bar\nu}/E$	0 29 ± 0.02	0.26 ± 0.03	0.25 ± 0.03	0.32 ± 0.04	
N(events)	–	90	87	73	
$R = \sigma^{\bar\nu}/\sigma^\nu$	0.40 ± 0.02	0.39 ± 0.05	0.45 ± 0.06	0 56 ± 0.07	
$\int F_2(x)\,dx$	0.48 ± 0.04	0.45 ± 0.04	0.39 ± 0.04	0.43 ± 0.04	
$\int xF_3(x)\,dx$	0.41 ± 0.06	0.39 ± 0.08	0.30 ± 0.08	0.24 ± 0.08	
$B = \int xF_3/\int F_2$	0.86 ± 0.04	0.86 ± 0.10	0.77 ± 0.11	0.56 ± 0.12	

Cross sections (in units of 10^{-38} cm^2 nucleon^{-1} GeV^{-1}) are corrected to those for an isoscalar target. Errors quoted for the BEBC experiment are statistical. Systematic errors on all cross sections are estimated to be ⩽ 7%. Systematic errors drop out in the ratio R, except for the ν_K point, where an uncertainty of ±10% in the K^+/K^- ratio should be included.

- The BEBC data incorporated other small correction factors:
  - +2% to all points to allow for EMI inefficiency
  - -3% for wide-band background
  - -2% for events due to neutrinos from $K_{\mu 3}$ decay
  - A correction for the P_μ > 5 GeV/ cut

The BEBC energy corrections

Beam in the "x" direction: mu in the x-y plane

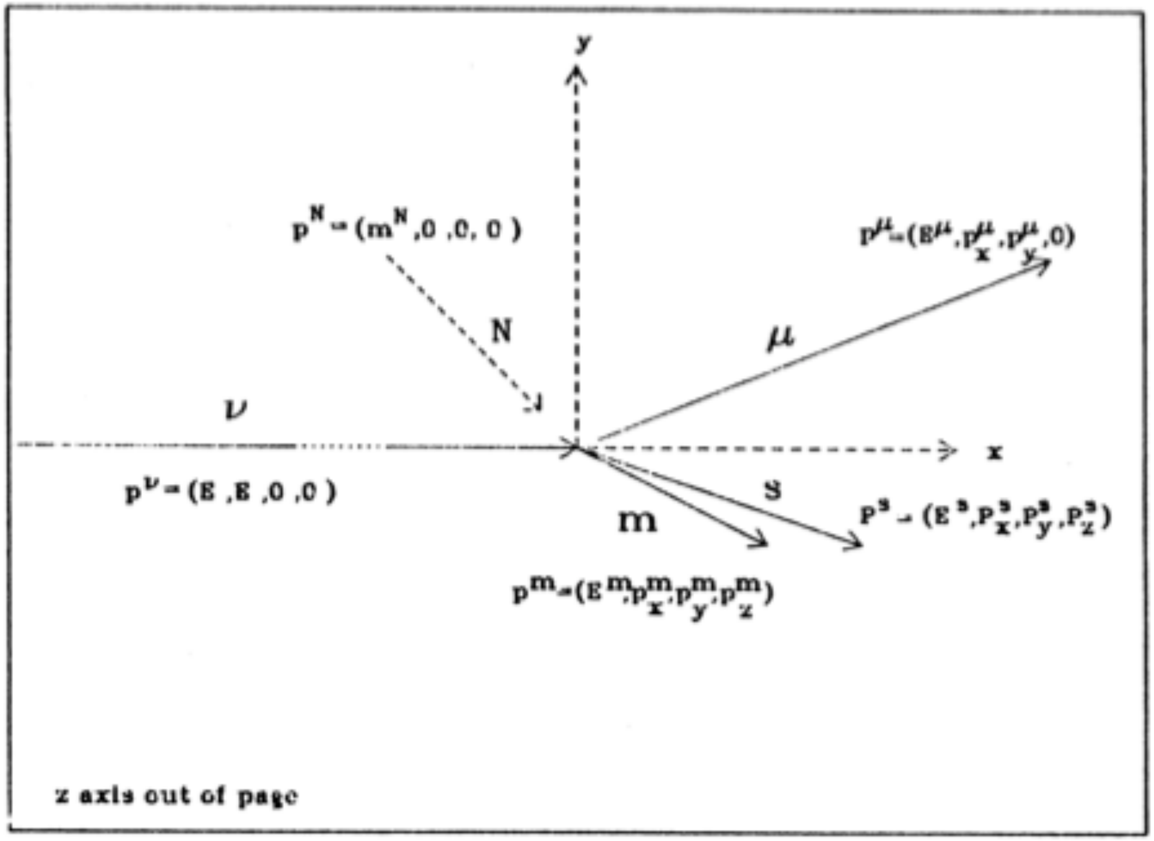


FIG 3.1 DEFINITION OF 4-MOMENTA

$$E + m_N = E^\mu + E^s + E^m$$

$$E = p_x^\mu + p_x^s + p_x^m$$

$$0 = p_y^\mu + p_y^s + p_y^m$$

$$0 = p_z^s + p_z^m$$

The Myatt (event-by-event) Method

- Employ momentum balance transverse to the beam direction
- Assume the seen and missing hadronic systems have the similar properties and the same direction in space – implies:

$$p_x^s / p_y^s = p_x^m / p_y^m$$

- which leads to neutrino energy:

$$E = p_x^\mu + p_x^s * p_y^\mu / p_y^s$$

- Giving an estimate of neutrino energy from measured quantities.
- Obviously breaks down if the muon and hadron system lie on the same side with respect to the neutrino direction.
- Obviously also this method is not strictly applicable for nucleons within a nucleus with initial Fermi momentum.

The BEBC "Constant" Correction Method

- Rather than trying for an event-by-event correction that has the problems mentioned above. Use a global method:
- $E = E_\mu + \nu$ with $\nu = E^s - m_N$
- ν is then scaled by a constant $C = \langle p_y^\mu \rangle / \langle p_y^s \rangle$ obtained by averaging over all events.
- Typical values for C from higher-statistics BEBC experiments was 1.19 for ν and 1.24 for $\overline{\nu}$.
- Also employed the minimum pion threshold condition

$$W^2 \geq (m_N + m_\pi)^2$$

- Which gave a constraint on ν_{min}

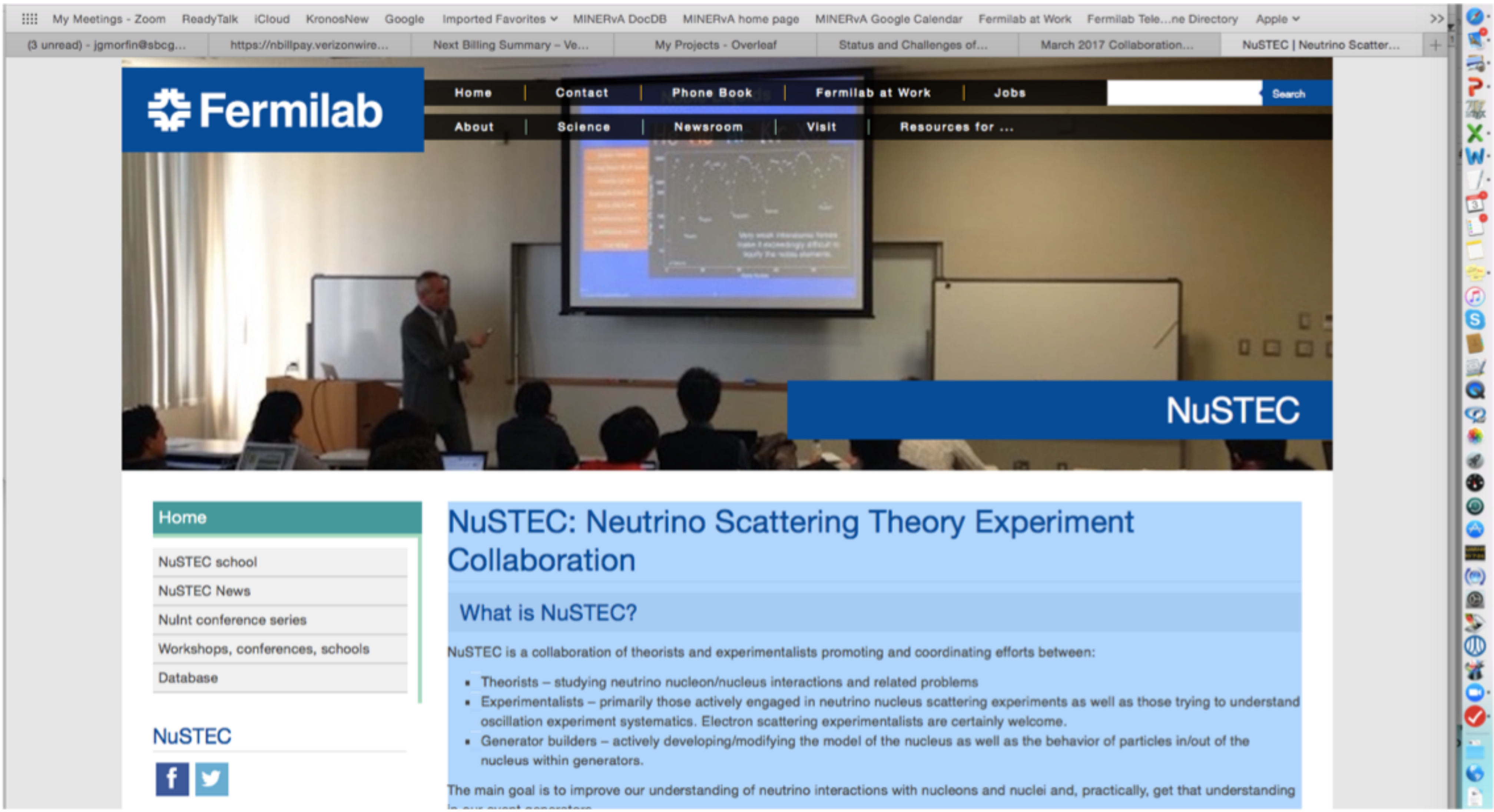
$$\nu \geq \nu_{min} = \frac{2E^\mu(E^\mu - p_z^\mu) + 2m_N m_\pi + m_\pi{}^2 - m_\mu{}^2}{2(m_N - (E^\mu - p_z^\mu))}$$

The Future of ν-nucleon Experimentation

- Around 13 years ago I asked Fermilab cryogenic engineers and those (still around) familiar with the Fermilab 15' chamber how difficult it would be to make a "rapid-cycling" cryogenic H/D bubble chamber of sufficient mass to get significant results in the NuMI beam.
- They were very skeptical of associating the term "rapid-cycling" with any chamber filled with ≈ 30 m^3 of liquid! And were also concerned with the OSHA safety requirements that were not yet fixed for the situation being considered.
- There were too many unknowns for even an informal considered conclusion - although numbers like (60 – 80) M$ were tossed around if it could be done at all..
- More recently there have been some very interesting considerations of a modern neutrino nucleon experiment.
- **Tomorrow afternoon, Alan Bross will present an idea that could lead to a nu-nucleon experiment using contemporary experimental techniques.**
- **Is there sufficient need to improve the neutrino-nucleon model to justify a new, high statistics nu/nubar-H/D experiment?**

Neutrino Scattering Theory Experiment Collaboration (NuSTEC)

http://nustec.fnal.gov



NuSTEC: Membership

- THEORISTS
- Luis Alvarez Ruso (co-spokesperson)
- Sajjad Athar
- Maria Barbaro
- Omar Benhar
- Richard Hill
- Patrick Huber
- Natalie Jachowicz
- Andreas Kronfeld
- Marco Martini
- Toru Sato
- Rocco Schiavilla
- Jan Sobczyk (nuWRO)

- EXPERIMENTALISTS
- Sara Bolognesi
- (Steve Brice)
- Raquel Castillo
- Dan Cherdack
- Steve Dytman (GENIE)
- Andy Furmanski
- Yoshinari Hayato (NEUT)
- Teppei Katori
- Kendall Mahn
- Camillo Mariani
- Jorge G. Morfín (co-spokesperson)
- (Ornella Palamara)
- Jon Paley
- Roberto Petti
- Gabe Perdue (GENIE)
- Federico Sanchez
- (Sam Zeller)

( ) indicates advisor

NuSTEC Projects

NuSTEC White Paper: Status and Challenges of Neutrino-Nucleus Scattering

L. Alvarez-Ruso,[1] M. Sajjad Athar,[2] M.B. Barbaro,[3] D. Cherdack,[4] M.E.Christy,[5] P. Coloma,[6] T.W. Donnelly,[7] S. Dytman,[8] R. J. Hill,[9,10,6] P. Huber,[11] N. Jachowicz,[12] T. Katori,[13] A. S. Kronfeld,[6] K. Mahn,[14] M. Martini,[15] J. G. Morfín,[6] J. Nieves,[16] G. Perdue,[6] R. Petti,[17] D. G. Richards,[18] F. Sánchez,[19] T. Sato,[20] J. T. Sobczyk,[21] and G. P. Zeller[6]

- Two expanded (9 day) and three shorter (5 day) schools on neutrino nucleus scattering physics.
- Input to the present workshop via Richard Hill a co-organizer
- The NuSTEC Workshop on Shallow-and-Deep Inelastic Scattering.
- Multiple collaborative projects between the NuSTEC members reflecting both theory and experimental needs.

The Present Analysis of Old BC Data

- We were left with a disagreement between results of the ANL and BNL neutrino nucleon experiments. BEBC results did not seem to enter the considerations.

- The disagreement between ANL and BNL results was resolved using the method from the work of Wilkinson and colleagues that, most likely, will be discussed in detail in tomorrow's presentations on QE and π production.