Experience from using bubble chamber data

G.M. Radecky
PhD thesis
(ANL 1π)

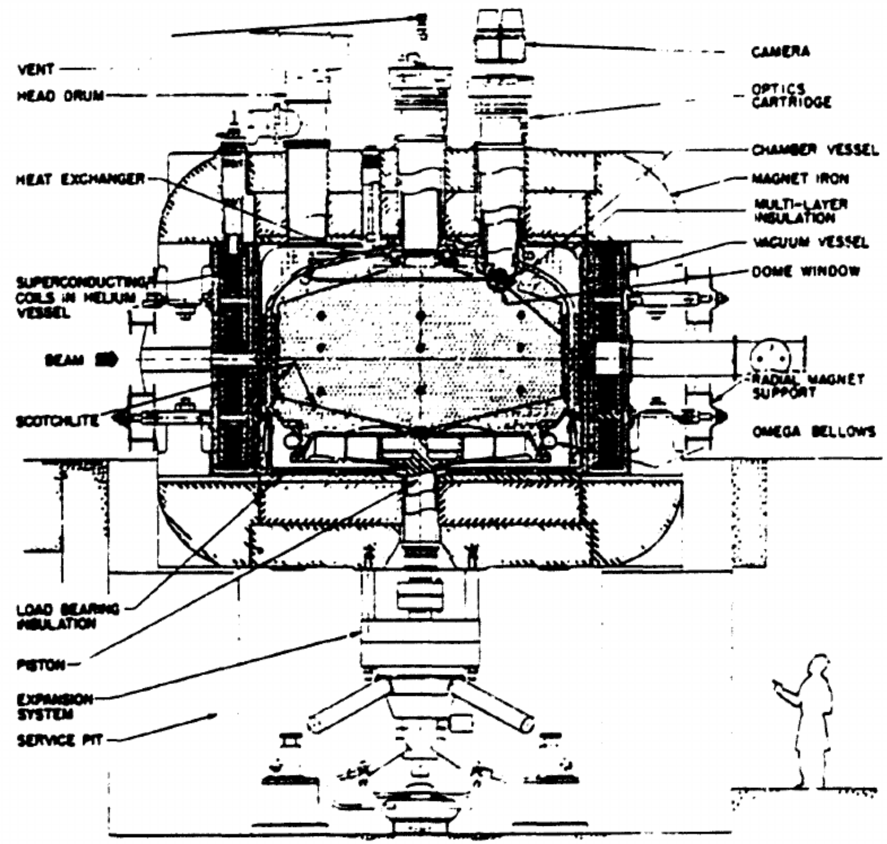


Figure 2.6. Cross section of the 12-foot bubble chamber.

UNIVERSITY of ROCHESTER

Clarence Wret, Callum Wilkinson
H/D detector at FNAL
Monday Sep 13 2021

Disclaimer

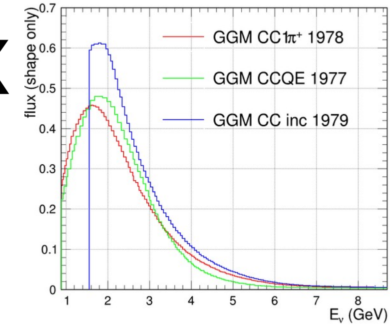
- My parents were kids when some of these bubble chamber measurements were made
- I was born around the last BNL and BEBC publications
- I am **absolutely not** an expert on bubble chambers, nor am I criticising the approach taken at the time
- I've simply read some papers, had some questions on the analysis, and never had them answered
- Some very neat things buried in these papers, e.g. the "single transverse variables" we hear about today at MINERvA and T2K, are discussed in BEBC papers from the 80s...

The energy of the events has been estimated by means of a transverse momentum balancing method [4].

Background

- Worked on tuning CCQE and single pion model to data in NEUT, evaluating nucleon model against nucleon data
- ANL and BNL are of central importance to T2K due to similar neutrino flux
- Have trawled through significant amount of bubble chamber data and implemented them; from theses, conference proceedings, and publications
- NUISANCE has
  - 65 ANL samples
  - 29 BNL samples
  - 11 BEBC samples
  - 5 FNAL samples
  - 2 Gargamelle samples
- Bubble chamber data form one of the back-bones of many neutrino scattering routines (GENIE, NuWro, NEUT, GiBUU)

Issues surrounding the flux



- Flux constraints often come from **CCQE selection**
  - Double counting when using CCQE data?
  - CCQE interaction model dependence baked into the flux?
- Not always clear which flux to use for which measurement
  - If you want my rambling summary from ~5 years ago: https://nuisance.hepforge.org/trac/wiki/ExperimentFlux

e.g. BEBC has two thesis (Wachsmuth, de Wolf) on fluxes, which is only "flux release" for BEBC I found

To obtain the total cross section from the number of events, the neutrino flux has to be measured on an absolute scale. In this analysis, we determine the neutrino flux using 362 quasielastic events identified in our data[10] and the cross section for reaction (2) derived from the $V-A$ theory. As will be discussed in Ref. 10, the quasi-

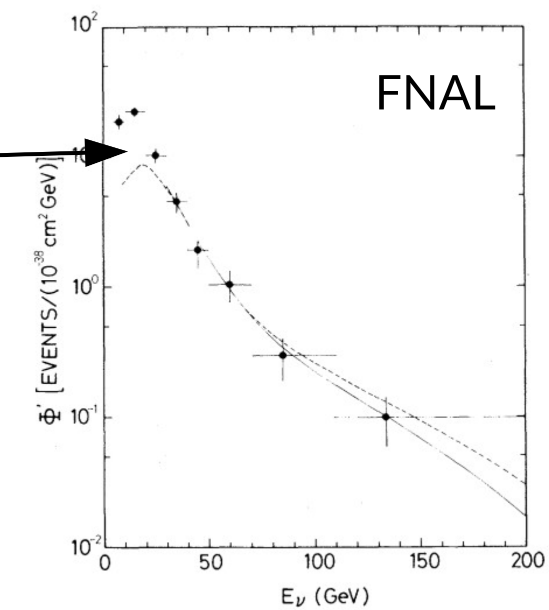
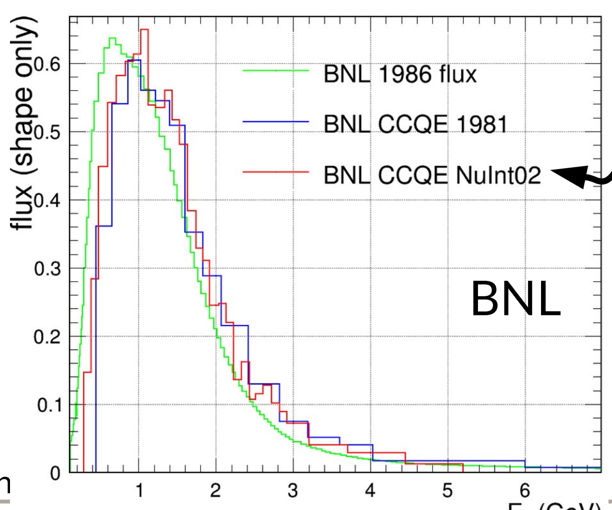


FIG. 2. Neutrino flux distribution obtained from the quasielastic events and the predicted cross section with $M_A = 1.05$ GeV. The solid curve is obtained from the best fit to the flux data for $E_\nu > 30$ GeV. The dashed curve is taken from the Monte Carlo simulation of the flux.



This paper took 2 weeks to find, after finding a colleague at KEK who found it on an internal server

On T2K/HK we briefly flirted with the idea of rerunning flux simulations with modern tools, but there just isn't enough supporting information (or worth it?)

Issues surrounding the systematics

- Systematics treatment

Systematics can be on the 10-20% scale

Scanning efficiencies were often dominant, with largest uncertainties, especially for events with neutrals
Treated uniformly for all events!

Many backgrounds had dedicated side-bands

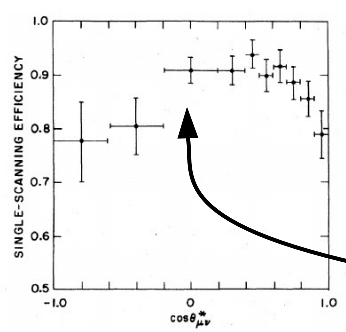
For more on this, see Callum's INT talk

TABLE II. Corrections for the single-pion production reactions.

Correction		Correction factor
(a) $\nu d \to \mu^- p \pi^+ n_s$		
Background	g_1	0.98±0.01
Scanning-measuring efficiency	g_2	1.07±0.05
χ^2 probability cut	g_3	1.01
H_2 contamination in D_2	g_4	0.87±0.02
Loss of fast neutron spectators	g_5	1.22±0.01
Total correction $g_1 \times g_2 \times g_3 \times g_4 \times g_5$		1.12±0.07
(b) $\nu d \to \mu^- p \pi^0 p_s$		
Background from		
$\mu^- p \pi^0 \pi^0$ and $\mu^- n \pi^+ \pi^0$	f_1	−0.202±0.018
$\mu^- p$ and $\mu^- n \pi^+$	f_2	−0.032±0.012
$\nu p \pi^-$	f_3	−0.084±0.014
$nn \to np\pi^-$	f_4	−0.154±0.043
Event assigned to $\mu^- n \pi^+$ and $\mu^- p$	f_5	+0.235±0.071
Scanning-measuring efficiency	g_1	1.13 ±0.06
Correction for three prong	g_2	1.22 ±0.01
Total correction $(1+f_1+f_2+f_3+f_4)g_1 g_2$		1.05 ±0.14
(c) $\nu d \to \mu^- n \pi^+ p_s$		
Background from		
$\mu^- p \pi^0 \pi^0$ and $\mu^- n \pi^+ \pi^0$	f_1	−0.277±0.021
$\mu^- p$ and $\mu^- p \pi^0$	f_2	−0.129±0.063
$\nu p \pi^-$	f_3	−0.021±0.004
$nn \to np\pi^-$	f_4	−0.031±0.016
Event assigned to $\mu^- p \pi^0$ and $\mu^- p$	f_5	+0.024±0.016
Correction for θ_{vis} and P_{vis} cuts	f_6	+0.083±0.049
Scanning-measuring efficiency	g_1	1.13 ±0.06
Correction for three prong	g_2	1.22 ±0.01
Total correction $(1+f_1+ \cdots +f_6)g_1 g_2$		0.890±0.103

7% systematic is better than many current neutrino experiments...

BNL, Kitagaki et al 1986



Clearly not flat efficiency...

Issues surrounding the systematics

- Systematics treatment
  - Bin-by-bin correlations never present
    - Might be fine because low statistics
    - Nonetheless, likely biases any fits
  - What about neutral particles? 3C vs 0C track fits

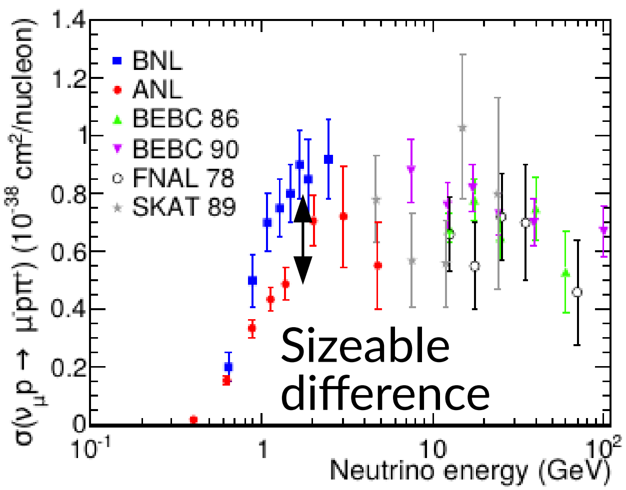
missing transverse momentum and small missing energy and (ii) by a 0C kinematical reconstruction restoring also (when necessary) baryon number conservation (a neutron or a π^0 is added in the final state, with the momentum required by energy-momentum balance).

BEBC CC incl.

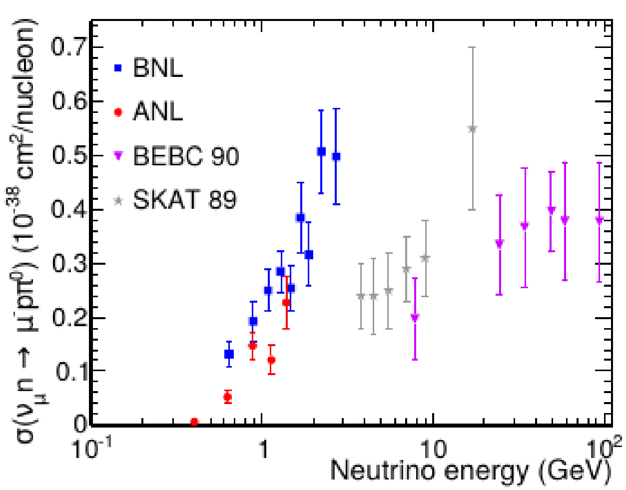
  - Neutrino beam divergence influence on neutrino direction?
    - BNL claim 0.5 degree accuracy of neutrino beam direction
  - Scanning efficiency treatment not clear – often due to human error (single scan/double scan/triple scan)
  - Seemingly, most systematics simply rescaled all events regardless of kinematics, with no correlations between systematics
- Low statistics (e.g. ANL CC1π^0 had 270 events)

Tension in single pion production

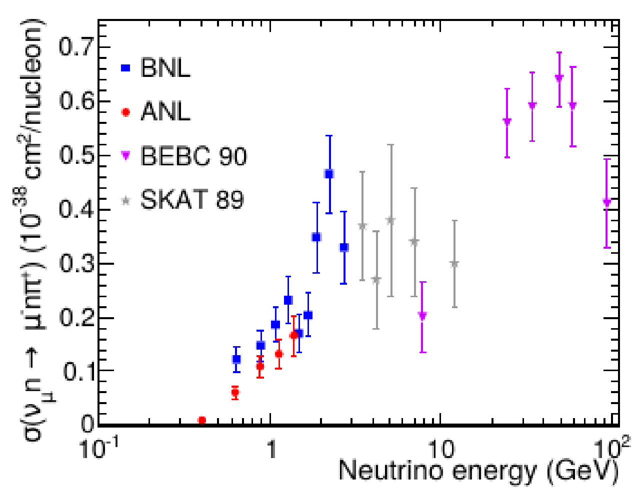
- ANL and BNL 1π measurements in tension
  - So much that GiBUU provide a "ANL vs BNL" tune which is the uncertainty on 1π interactions
  - Difficult to nail down which is wrong/right
  - Some literature on this, some considering it resolved (e.g. Wroclaw group, Rodrigues et al.), although it's unclear what effect it has on e.g. $N(Q^2)$
  - BNL never provided W < 1.4 GeV other than $CC1\pi^{+}1p$



$\nu_\mu p \rightarrow \mu^- p \pi^+$



$\nu_\mu n \rightarrow \mu^- p \pi^0$



$\nu_\mu n \rightarrow \mu^- n \pi^+$

More variables?

- Often just $\sigma(E_\nu)$ and $N(Q^2)$; binning in lepton/pion variables possible but need to dig through thesis
  - Lots of gems in theses, but why not officialised?
- Not always clear if Q^2 suppression in D is applied
  - Oftentimes H and D data is combined: how much data was on H and how much D? Was data on D corrected?
- Are rates always efficiency corrected? We **think** so, but have never had it confirmed

Other notes

- We've tried chasing up some of these issues, but pretty much **never** got a reply
  - e.g. BNL flux, CERN BEBC flux, QE double counting in FNAL and BEBC xsec, general info on scanning efficiencies
  - Mostly in theses from people who have left HEP
  - Some attempts at finding old photographs have failed
  - Attempts at simulating the ANL flux had too little info on beam

Summary

- Bubble chamber data is the **back-bone** for many neutrino generators, alongside *e* scattering
- Relatively many experiments, but from long ago
  - A **cloud of mist** obscures many key analysis decisions
- **Flux** determination, **tension in single pion** production cross-section, impact of **systematics treatment**
- Relatively **low statistics**; simply not enough to constrain nucleon model
- Many **interesting distributions aren't provided**, notably in particle kinematics
  - Almost all papers focus on $\sigma(E_\nu)$, $N(Q^2)$, Adler angles, $M(\pi+N)$, and $M(\pi+\mu)$

Thanks

Backups