Pion production tuning

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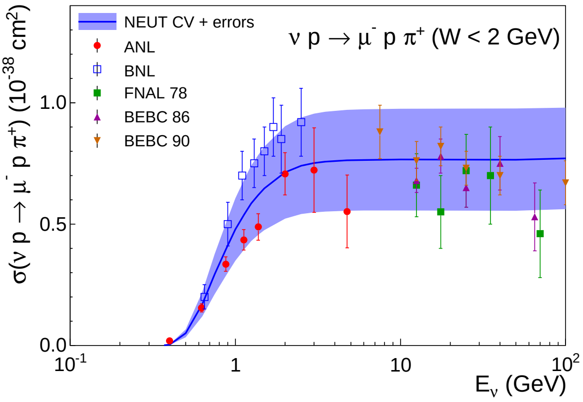
Introduction

1. Reanalyze low-E_ν pion production on deuterium
2. Tune GENIE to reanalyzed data
3. Compare to MINERνA data on CH

D_2 data reanalysis

The two measurements of $\nu_\mu p \to \mu^- p \pi^+$ on D_2 around 1 GeV differ by 30–40%



A. Bercellie and PR

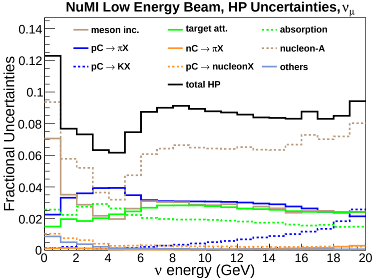
- Bubble chamber measurements on D_2: ∼free nucleons
- Normalization not completely constrained by theory
- Previous work: joint fit to ANL and BNL: K. Graczyk *et al.*, PRD 80, 093001 (2009)

Look for consistency in ratios of event rates to other processes: PRD 90, 112017

- What if the only problem were normalization? (Eg, flux)
  - $\Rightarrow$ consistent $\sigma(\nu_\mu p \rightarrow \mu^- p\pi^+)/\sigma(\text{other})$ between ANL and BNL

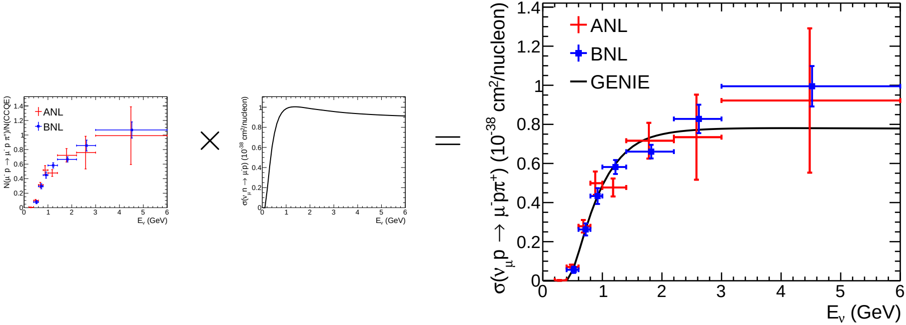
1. Extract event counts from original papers
2. Apply appropriate corrections (efficiency, etc)
3. Make ratios $N(\nu_\mu p \rightarrow \mu^- p\pi^+)/N(\text{CCQE})$ and $N(\nu_\mu p \rightarrow \mu^- p\pi^+)/N(\text{CC inclusive})$

ν flux state of the art, ca 2015



MINERνA latest flux uncertainty: go to the Wine and Cheese! Dec 18, 1pm Central

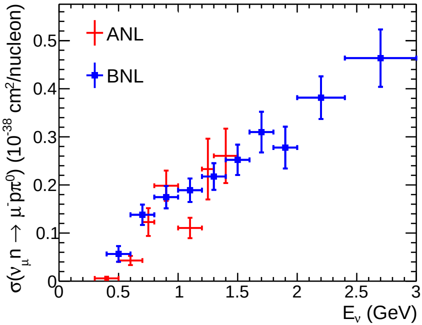
Multiply the ratios by the well-known CCQE cross section to get $\nu_\mu p \rightarrow \mu^- p \pi^+$ cross section



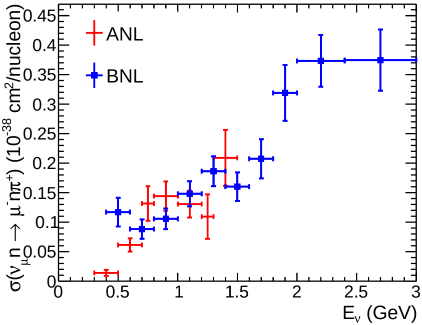
- H_2, D_2 CCQE measurements generally consistent
- Use GENIE 2.8 cross section ($M_A = 0.99$ GeV)
  - Not circular, since M_A from Q^2 shape, not normalization
- Result consistent with GENIE Δ^{++} cross section

Can do essentially the same thing for the other two CC single pion processes

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



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



- Nice consistency here too

Fit to D_2 data

Tuning parameters

- Axial form factor in pion production:

$$F_A(Q^2) = \frac{F_A(0)}{\left(1 + \frac{Q^2}{\left(M_A^{res}\right)^2}\right)^2}$$

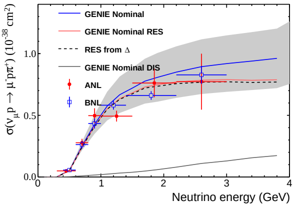
- Nonresonant background scales: `NonRESBGv{n, p}CC1pi` (also NC, not considered). Tie them together in one scale factor
- $F_A(0)$ not a reweightable parameter (needs regeneration), so alternatively, use normalization of all CC resonant events, `NormCCRES`

Fit distributions 1

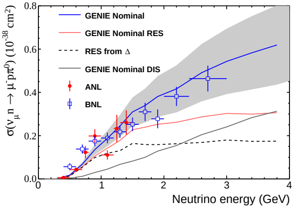
- Use total cross sections for all processes, and $\mathrm{d}\sigma/\mathrm{d}Q^2$ shape-only
- (Double-counts data, but we checked with pseudo-experiments that it doesn't make much difference to the final uncertainties)
- Exclude $Q^2 < 0.1$ GeV, since data less reliable there
- Technicality: Select events by final-state particles, not process, since nonres BG is "DIS".
- (Technicality)^2: GENIE applies FSI in deuterium (seems wrong), so we actually use particles emerging from interaction, not from nucleus

Fit distributions, total cross section

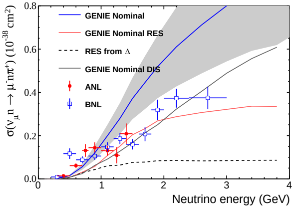
$\nu_\mu p \rightarrow \mu^- p \pi^+$



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

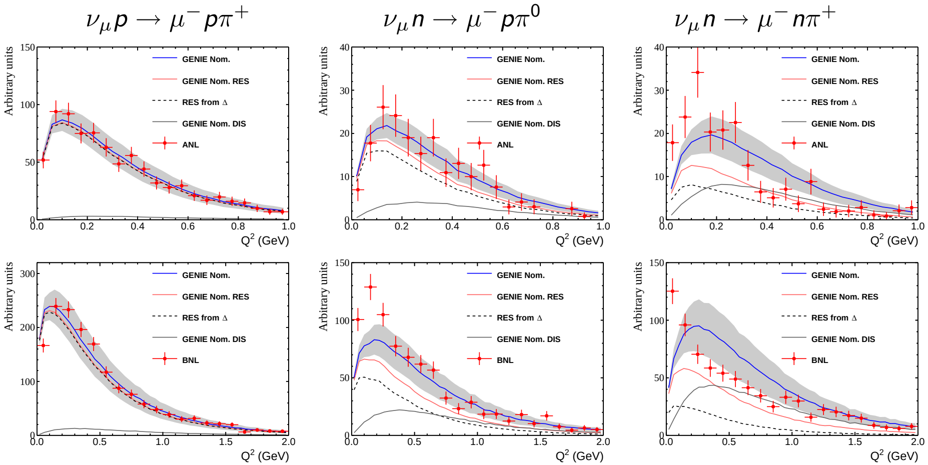


$\nu_\mu n \rightarrow \mu^- n \pi^+$



- Small nonres ("DIS") in $\nu_\mu p \rightarrow \mu^- p \pi^+$: it will drive $M_A^{res} \times F_A(0)$
- Big nonres in $\nu_\mu n \rightarrow \mu^- n \pi^+$: it will drive the nonres scale
- Uncertainties shown are the default GENIE uncertainties

Fit distributions, Q^2



- Top row: ANL. Bottom row: BNL
- Recall $Q^2 < 0.1$ GeV excluded from fit
- $\nu_\mu p \to \mu^- p\pi^+$ will drive M_A^{res}

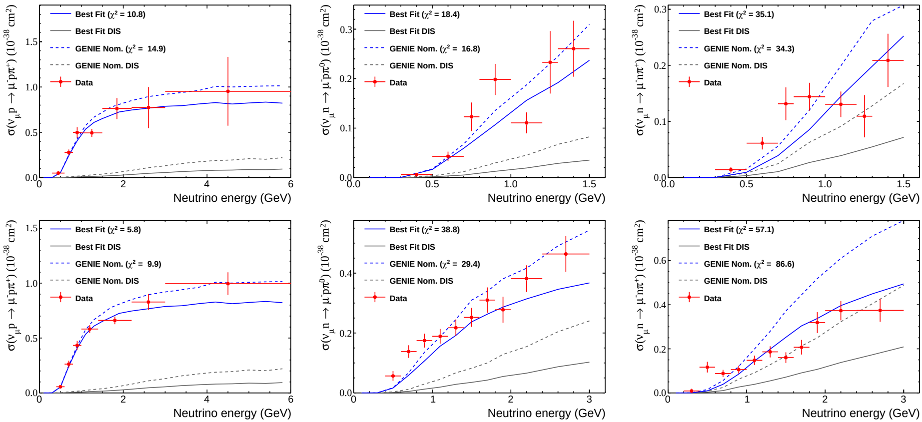
Fit results

Parameter	Nominal	Best fit With Res norm	Best fit With $F_A(0)$
χ^2 for 157 dof	398	324	327
M_A^{res} (GeV)	1.12	0.94 ± 0.05	1.00 ± 0.04
DIS norm. (%)	100	43 ± 4	43 ± 4
RES norm. (%)	100	1.15 ± 7	–
$F_A(0)$ norm. (%)	100	–	107 ± 4

- With GENIE 2.8.2
- Most significant is reduction in nonresonant scale ("DIS norm") by more than half
- M_A^{res} goes down, and RES norm/$F_A(0)$ goes up, but they're anticorrelated
- χ^2 is still pretty terrible: quality of data, not of fit/model

Best-fit distributions, total cross section

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

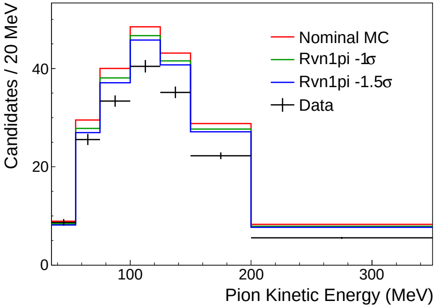


- Top row: ANL. Bottom row: BNL
- Maybe a little tension between $\nu_\mu n \rightarrow \mu^- p\pi^0$ and $\nu_\mu n \rightarrow \mu^- n\pi^+$
- Q^2 distributions in backups

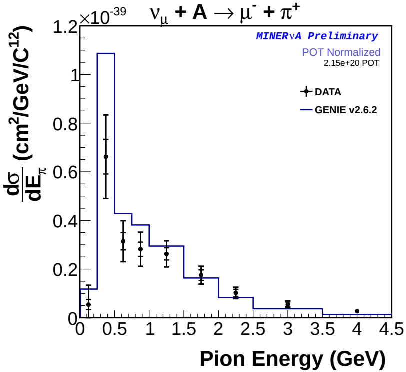
Compare to MINERνA data

Pions in MINERνA data: CH target

CC $N\pi^+$, $W < 1.8$ GeV



CC coherent π^+



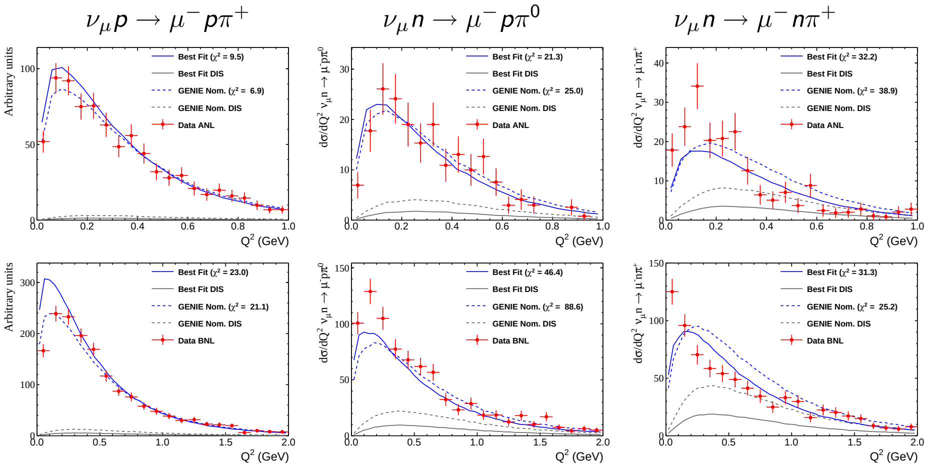
- Incoherent pion production:
  - Reducing nonresonant component reduces MINERνA single pion production by about 5%
  - Still needs around 10% extra reduction, with some shape in pion kinetic energy
- Coherent pion production: reweight $E_\pi < 450$ MeV by 0.5

Conclusion

- We improved the constraint on νN pion production
- Still doesn't describe the νA data, so extrapolation to Ar unclear

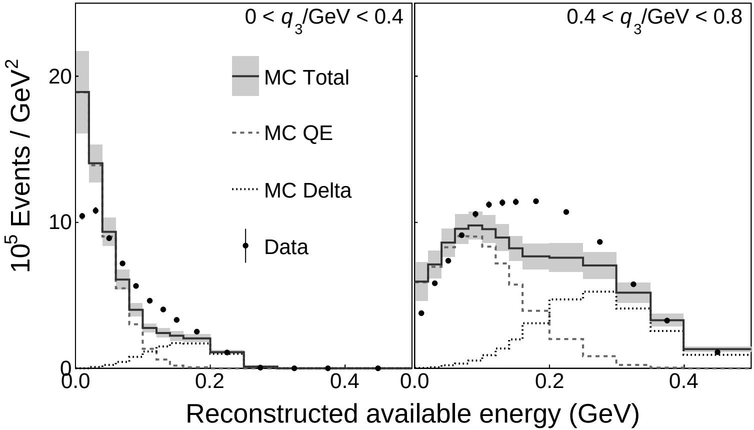
Backup slides

Best-fit distributions, Q^2



- Top row: ANL. Bottom row: BNL
- Maybe a little tension between $\nu_\mu n \rightarrow \mu^- p\pi^0$ and $\nu_\mu n \rightarrow \mu^- n\pi^+$

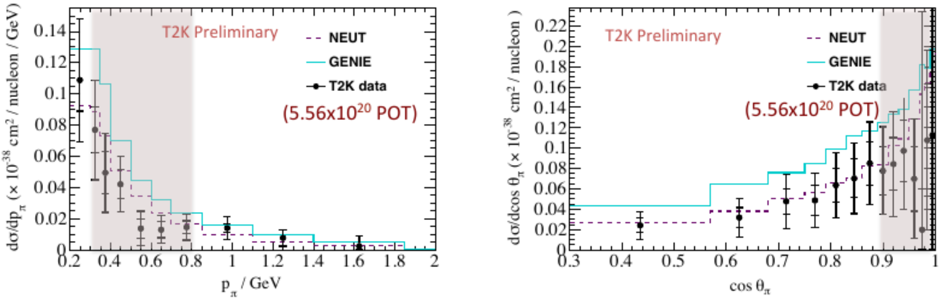
MINERνA CC inclusive in slices of three-momentum transfer



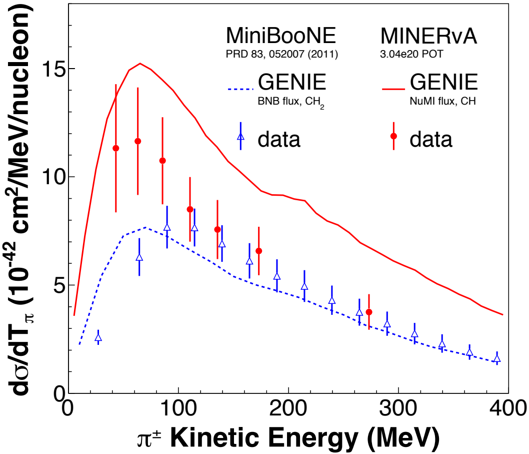
- Excess could be (partially) mismodeling of pion kinematics

T2K data wants GENIE pion reduction too

S. Cao, NuInt 15



MiniBooNE pion production data not so consistent with this picture



- Or really with anyone's picture