SciBooNE

and other neutrino cross section measurements

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Rencontres de Moriond EW 2010
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Outline

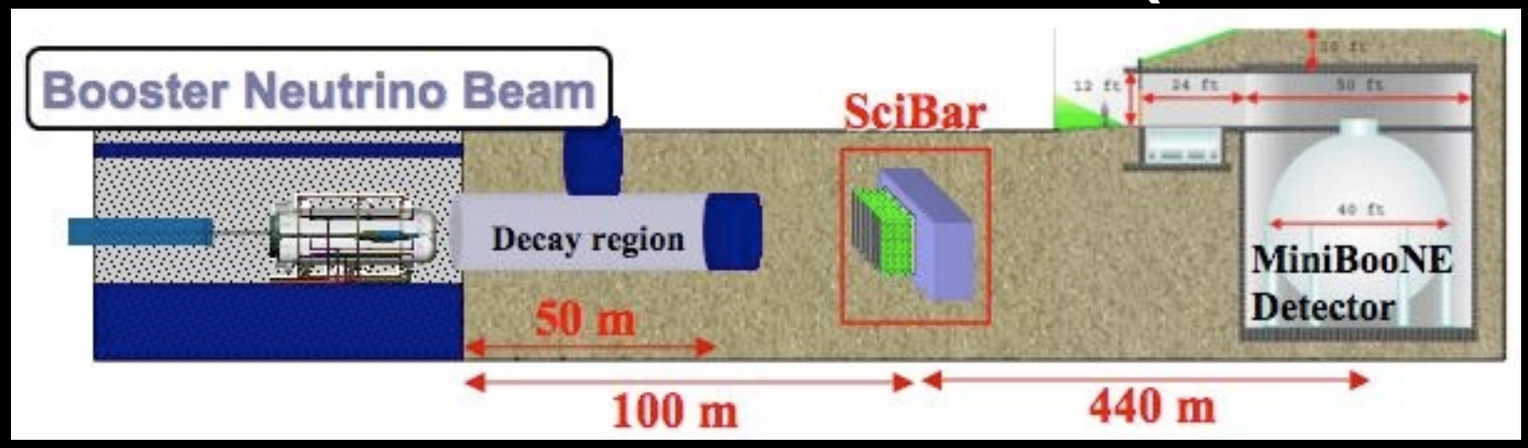
- SciBooNE experiment (FNAL-E954)
  - Introduction
  - Neutral current π^0 production
  - Coherent π production
  - Future experiments

Note:

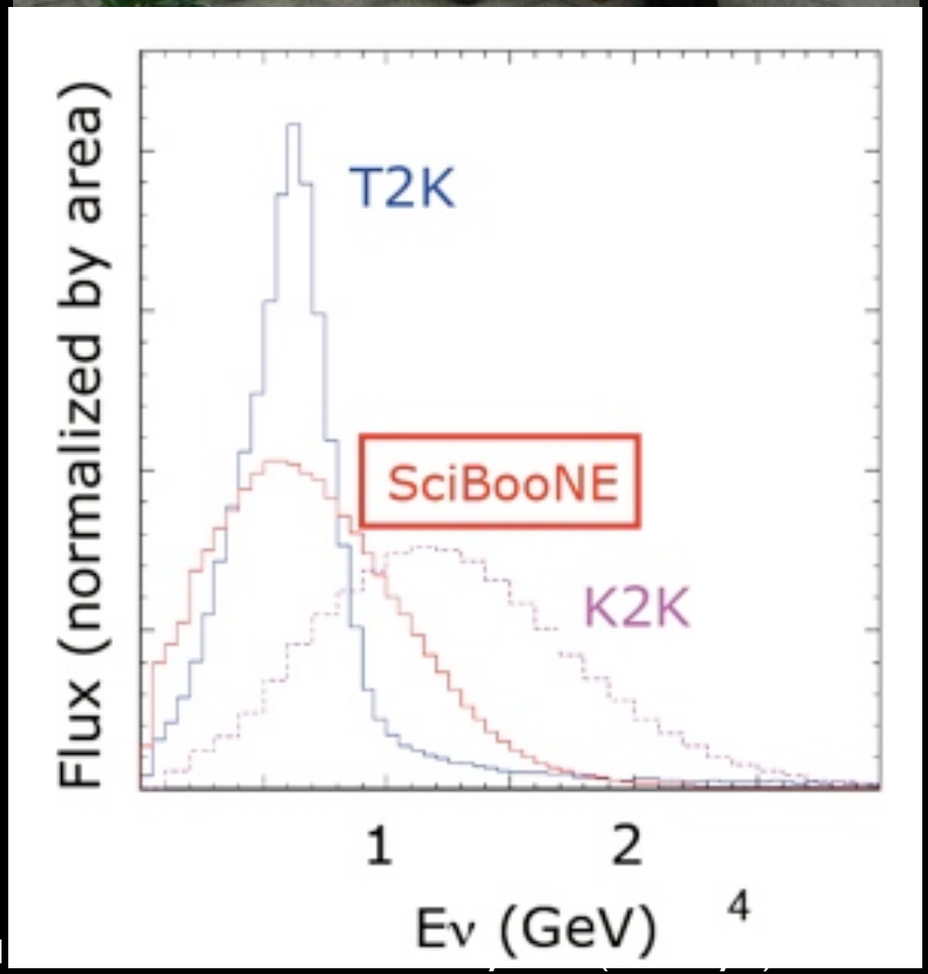
* Results from MiniBooNE already presented and not repeated

* $\sigma \sim 10^{-38} cm^2$ or 10 fb for ~1GeV ν on N

SciBooNE (FNAL E-954)



- Measurement of neutrino and anti-neutrino cross-sections
  - Essential input for neutrino oscillation experiments
  - Energy matched with T2K
- Short baseline oscillation search together with MiniBooNE



Proposed in 2005,

Data taking 2007-2008

SciBooNE and other neutrino cross section measu

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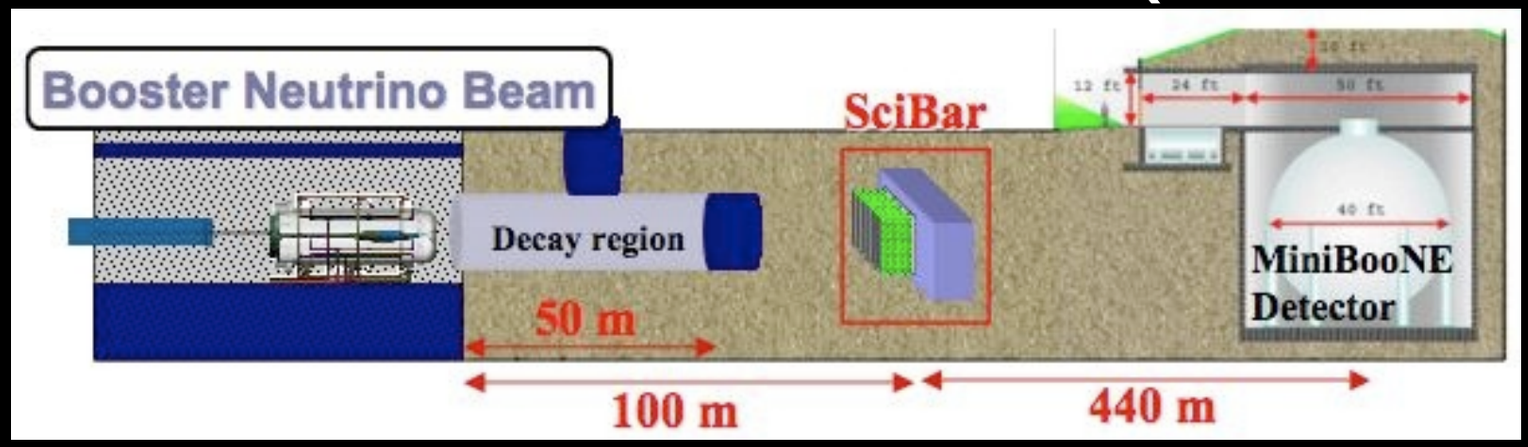

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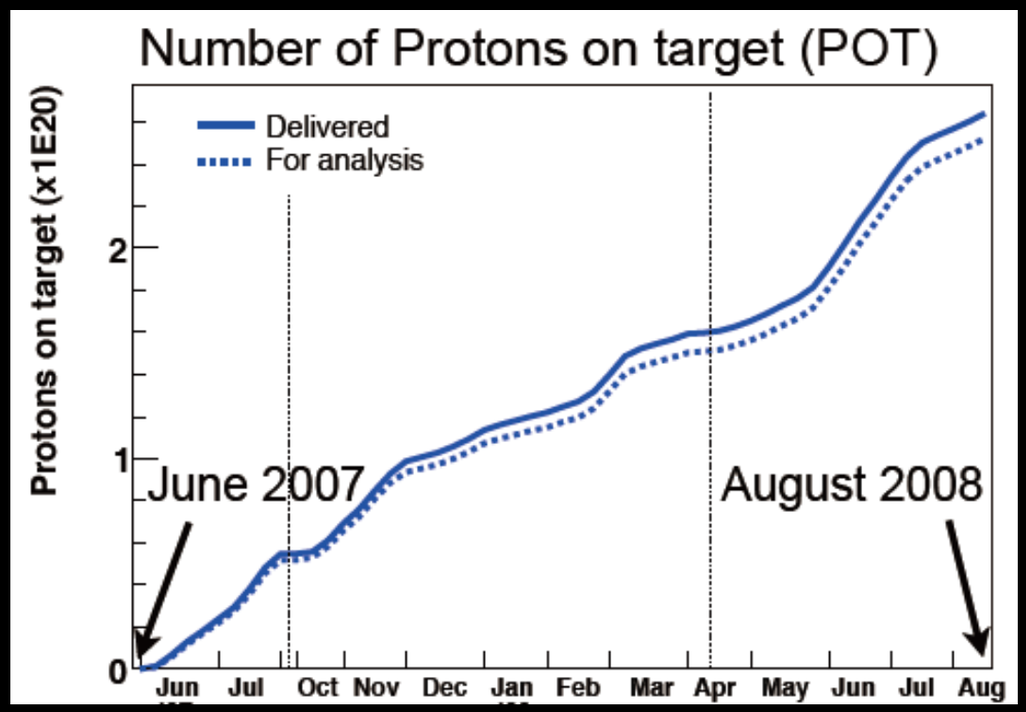
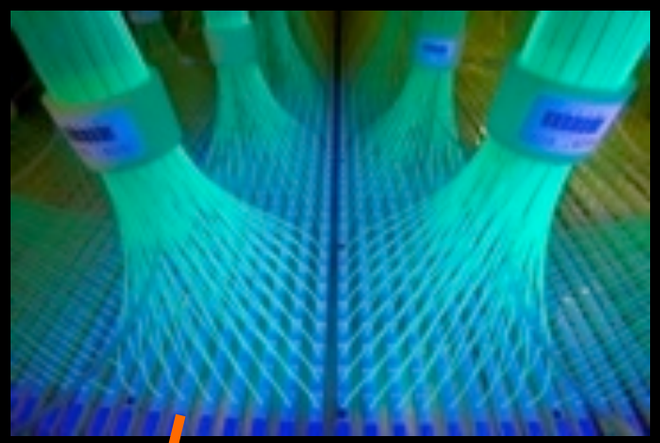
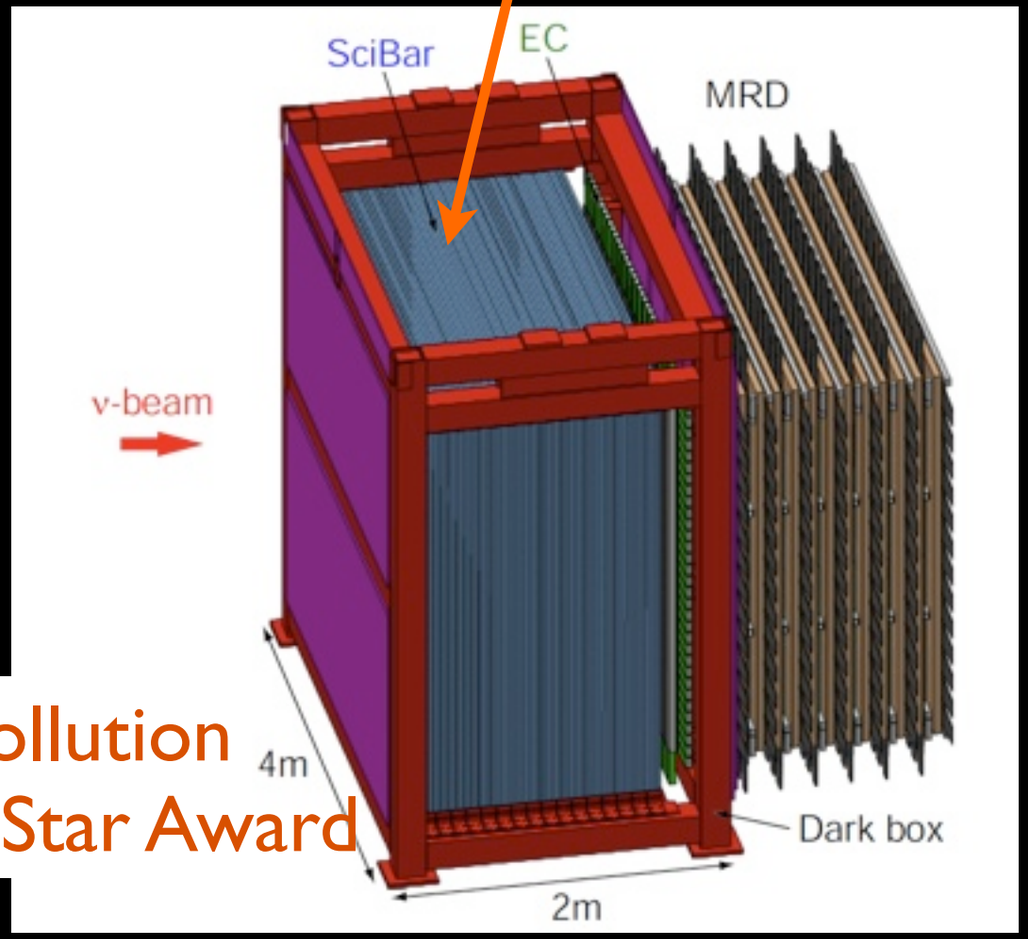
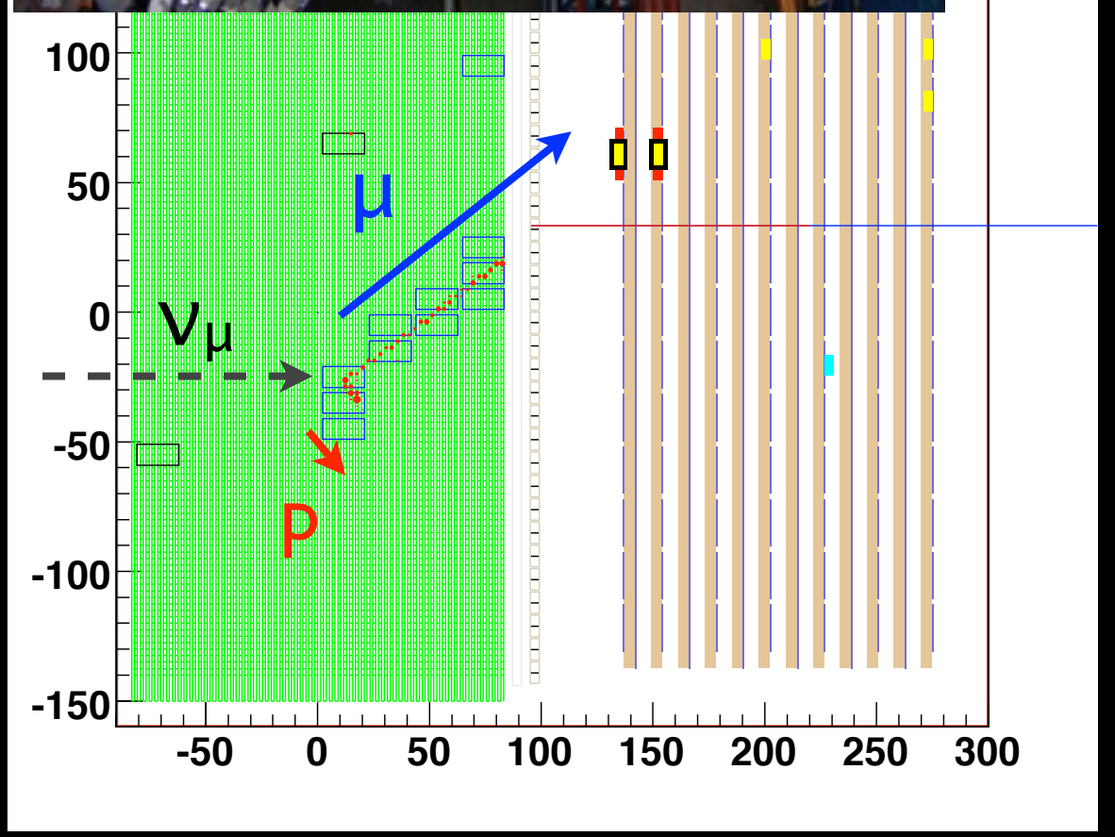


SciBooNE detectors

Main detector
"SciBar" :14,336
plastic scinti. bar,
1.3x2.5x300cm^3
Also acts as target (CH)







DOE Pollution Prevention Star Award

SciBooNE

Physics from SciBooNE

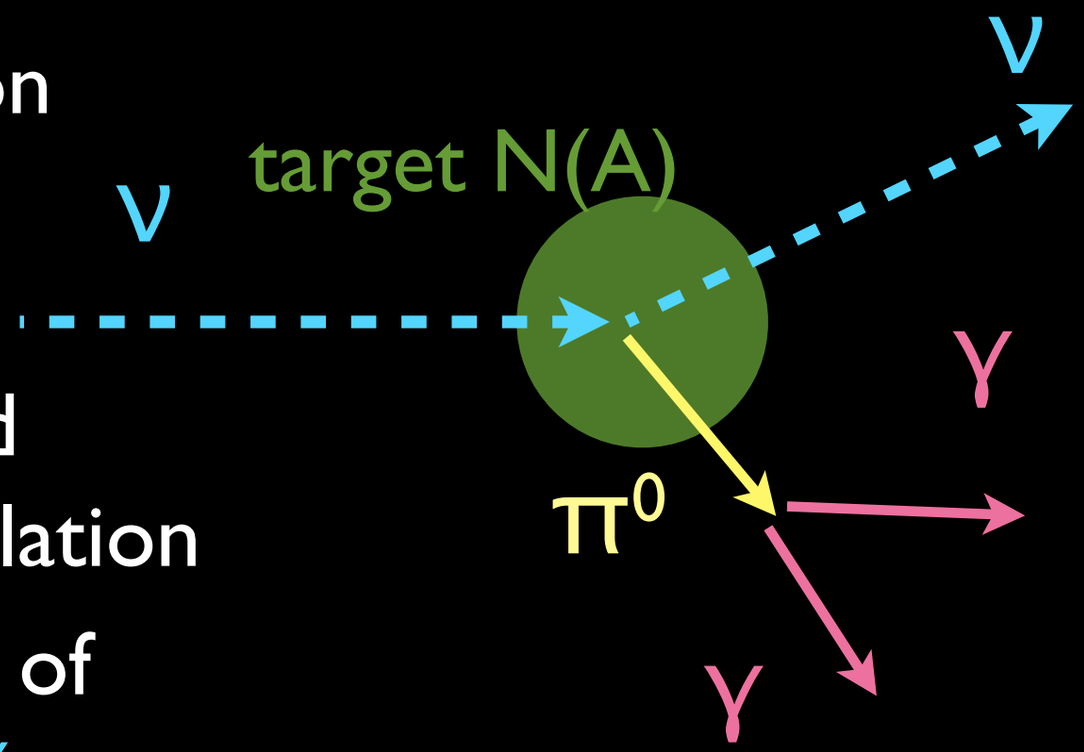
CC: charged current
NC: neutral current

- CC quasielastic scattering
- CC coherent π^+ production
  [Moriond last year, PRD 78, 112004 (2008)]
- CC π^0 production
- NC elastic production
- NC π^0 production
  [This year's highlight, PRD 81, 033004 (2010) + update]
- Neutrino flux measurement (for oscillation study)
- Anti neutrino cross section measurements

Others coming soon (future Moriond?)

NC π^0 production

- Can mimic ν_e CC interaction if one of γ's is missed (very low E, overlap)
  - One of major background in search for $\nu_\mu \rightarrow \nu_e$ oscillation
    - T2K needs uncertainty of $\sigma(NC\pi^0)/\sigma(CC) < 10\%$
  - Kinematics of π^0 also important
- Two production mechanisms known:
  - Through nucleon resonance
  - Coherent scattering with whole nucleus
    - σ(CC-cohπ) very small in ~1GeV [K2K, SciBooNE]
    - NC evidence [MiniBooNE]



[Josh's talk in YSF today]

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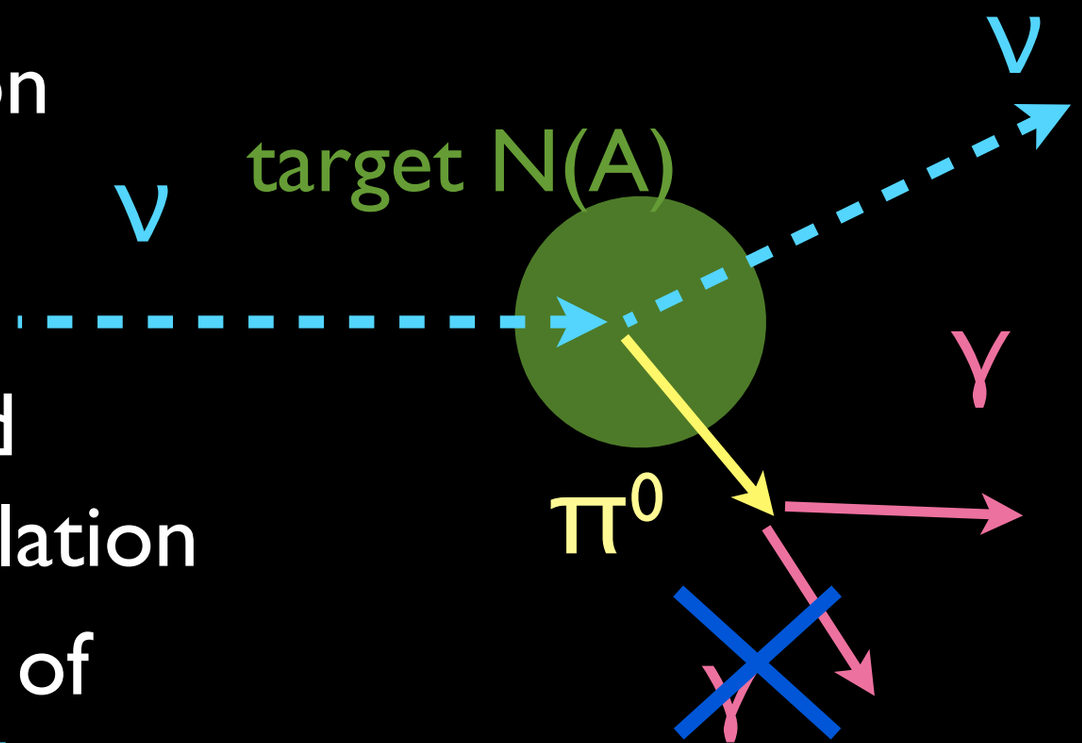
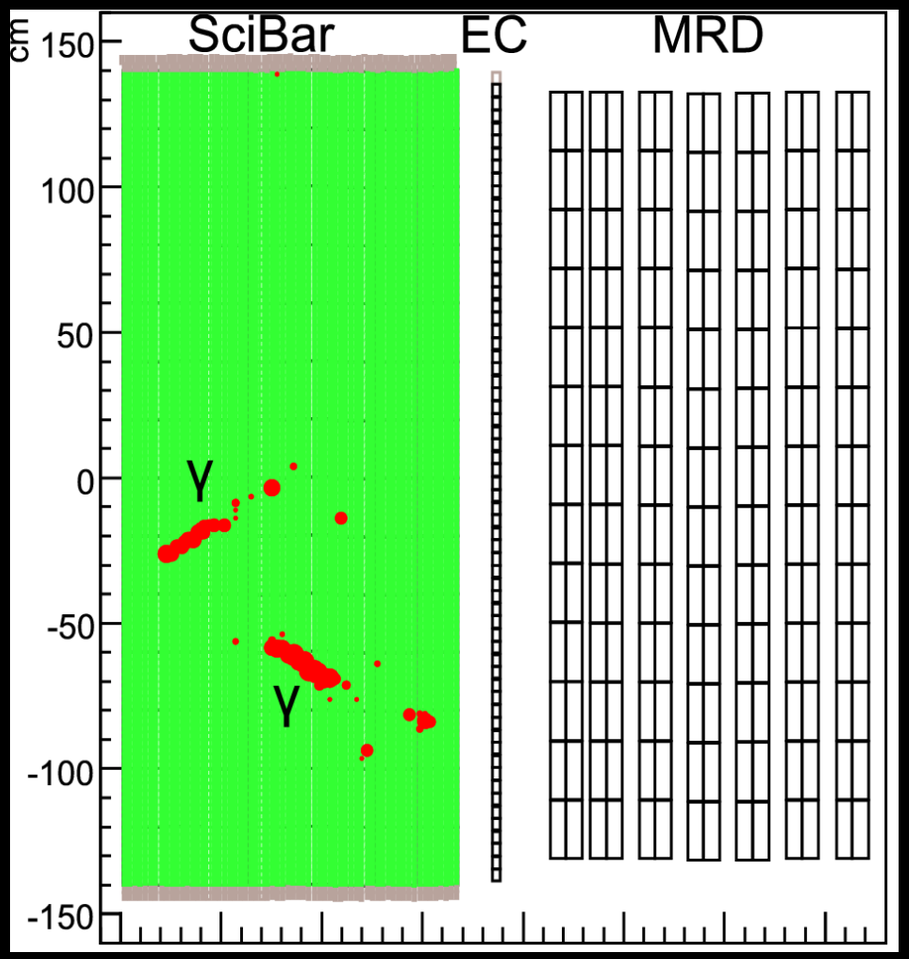


[Josh's talk in YSF today]

NC π^0 singal

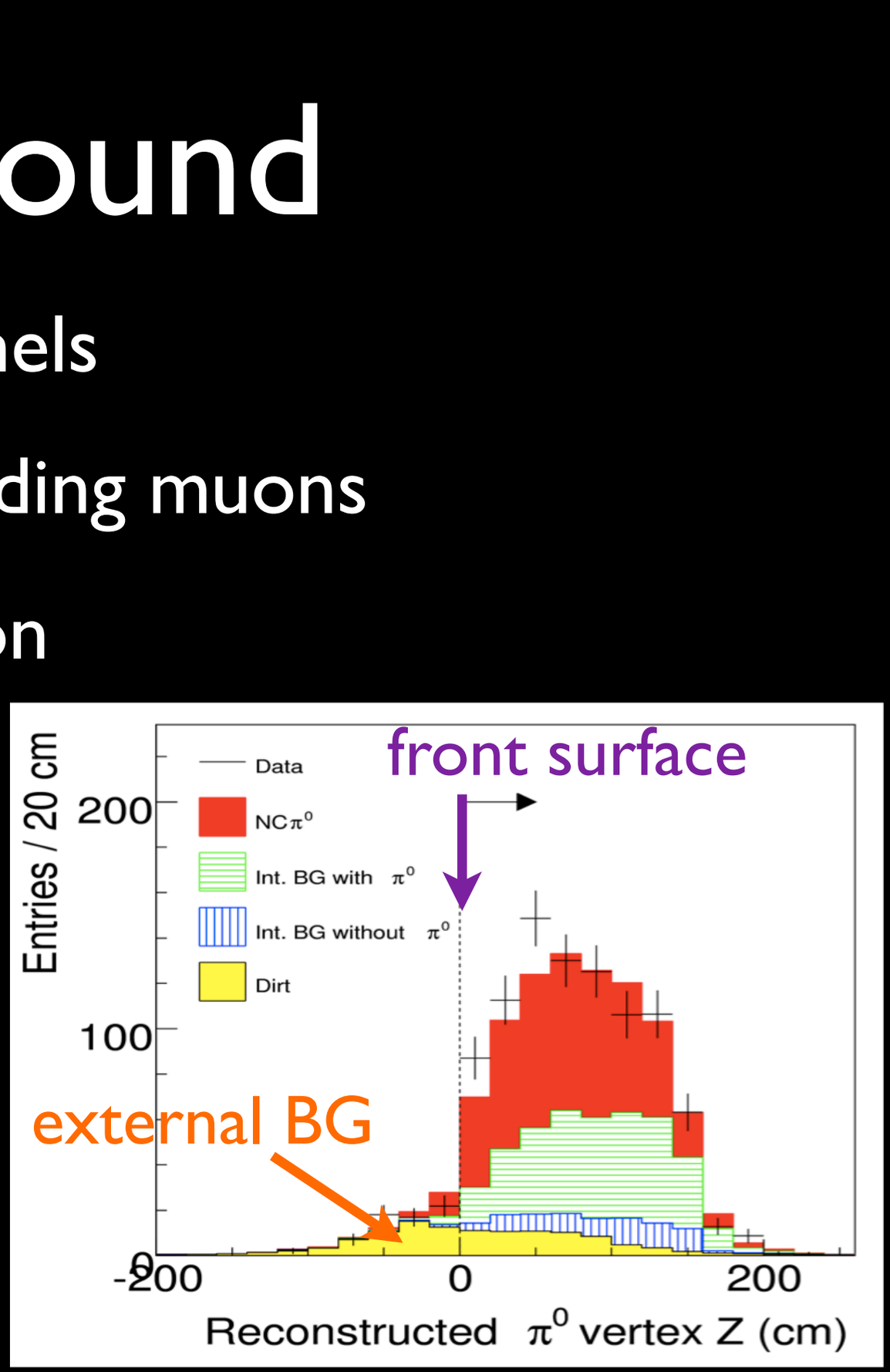
- "Inclusive" NC π^0 production, $\nu_\mu + C \rightarrow \nu_\mu + \pi^0 + X$
  - At least one π^0 out of target nucleus (i.e. after nuclear interaction)
- Both γ converted inside SciBar
  - SciBar ~$4X_0$: 30% of π^0
  - Require two separated tracks

Candidate (real data)

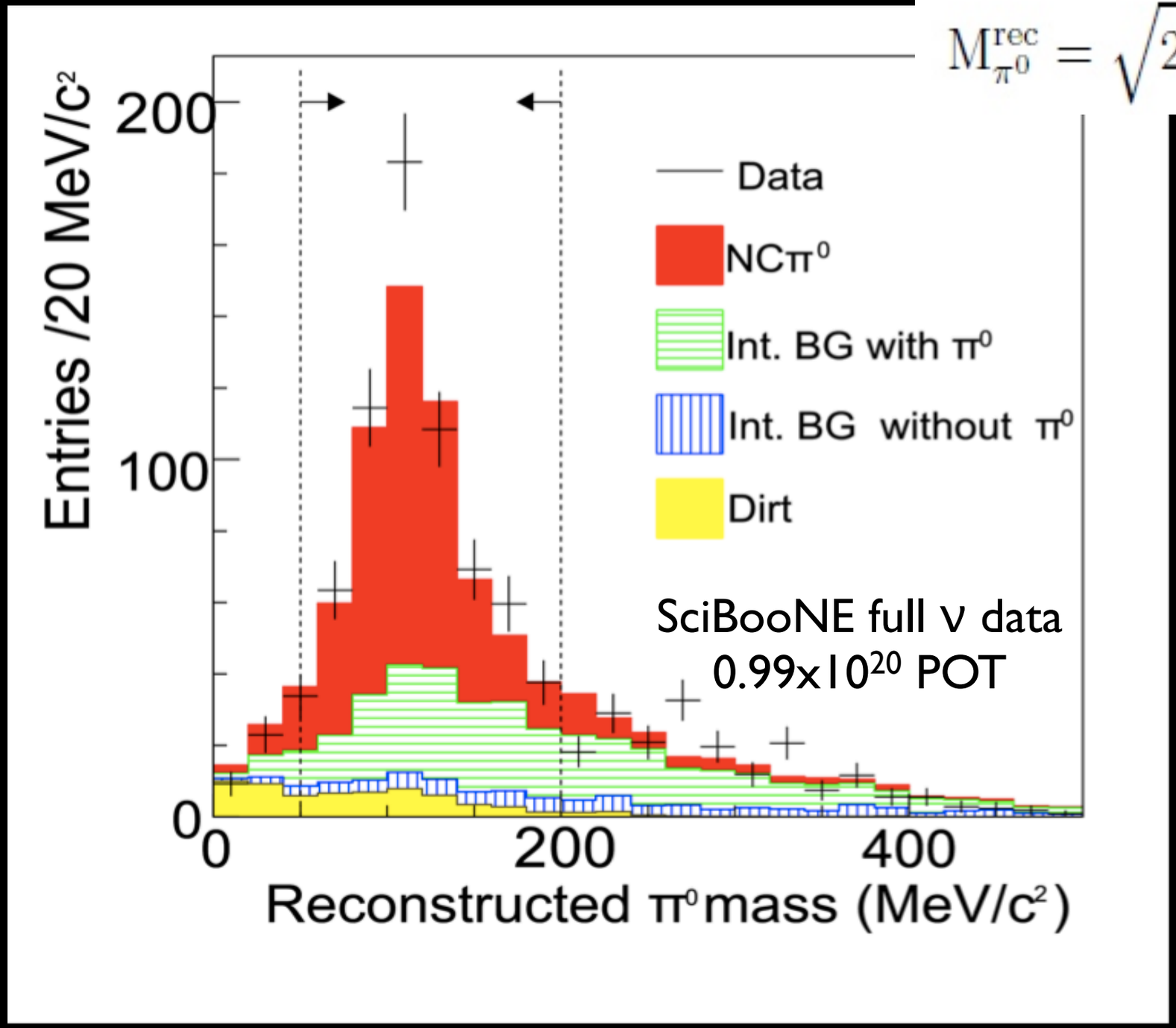


Background

- Other ν interaction channels
  - Mostly CC: reject by finding muons
- Particles from ν interaction in surrounding material
  - Veto by outer layers
  - Reconstruct π^0 vertex



$$M_{\pi^0}^{rec} = \sqrt{2E_{\gamma 1}^{rec} E_{\gamma 2}^{rec} (1 - \cos\theta^{rec})}$$



* Hits around tracks included for energy calculation

Clear π^0 peak seen in $\gamma\gamma$ invariant mass distribution!

Signal region: $50 < M_{\pi 0}^{rec} < 200$ MeV/c^2

Event selection summary

full ν mode data (0.99×10^{20} POT)

	Data	MC			Signal eff. (%)
		Signal	Internal BG	External BG	
>=2 tracks	11,926	1,893	9,808	895	27.3
No decay-e nor side escaping	5,609	1,377	3,785	606	19.8
Isolated track pair	3,614	1,314	1,706	595	18.9
No MIP in EC	2,791	1,202	1,088	579	17.3
>=2 recon'd γ	973	443	389	121	6.5
π0 vertex	905	428	382	65	6.2
Invariant mass	657	368	202	38	5.3

Rejection of ν interaction inside

Rejection of particles from outside

*MC normalized by CC candidates

NCπ^0 cross-section

- Cross-section ratio to total CC
  - Cancel absolute ν flux uncertainty
  - CC candidates selected using MRD muon tag
    - 21,702 events w/ 19% efficiency

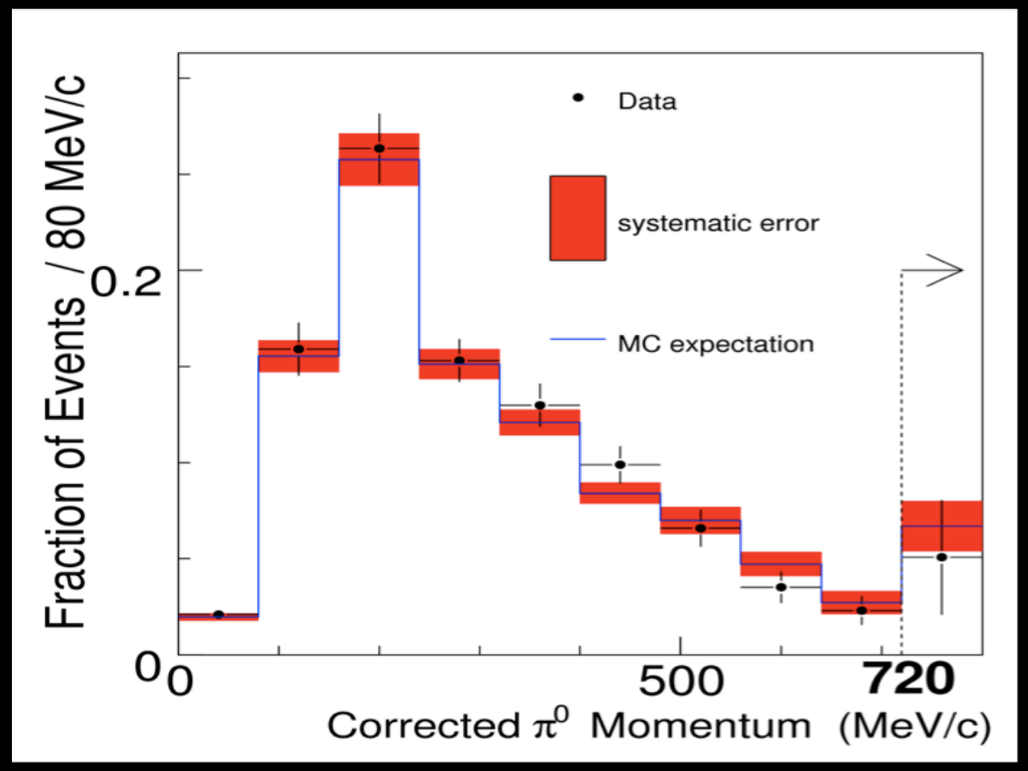
$\sigma(NC\pi^0)/\sigma(CC)= 7.7\pm0.5(stat)\pm0.5(syst)\times10^{-2}$

for $<E\nu>=1.1$GeV

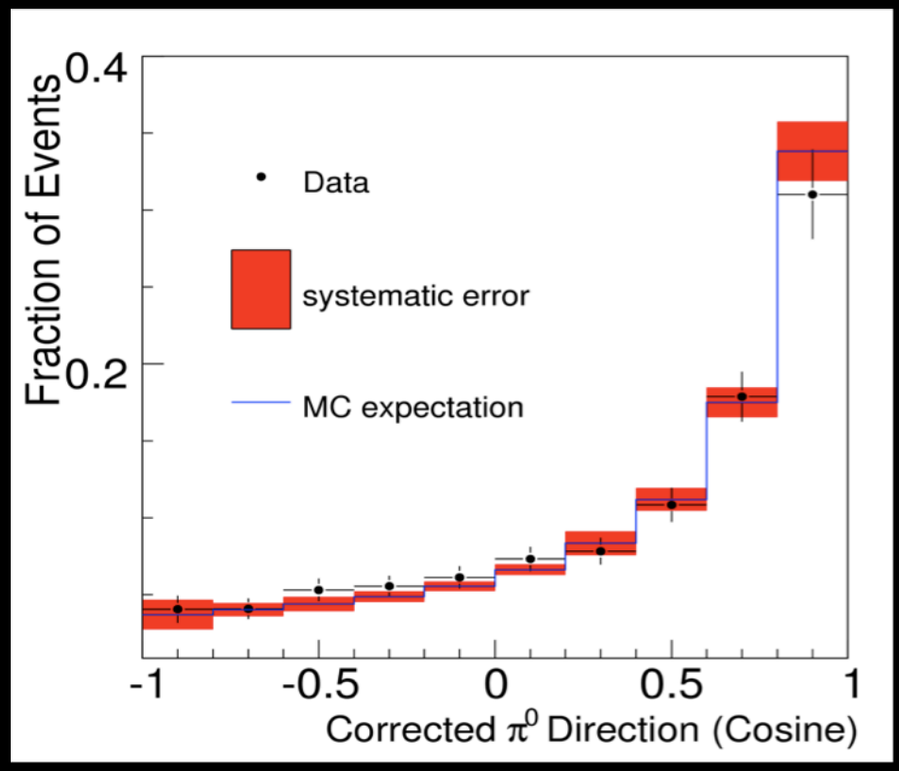
  - Largest syst error: detector response (~0.4×10^{-2})
- MC expectation 6.8×10^{-2} consistent with data
  MC: 'NEUT' interaction simulation package used in Super-K, K2K, T2K

PRD 81, 033004(2010)

π^0 kinematics



$p\pi$



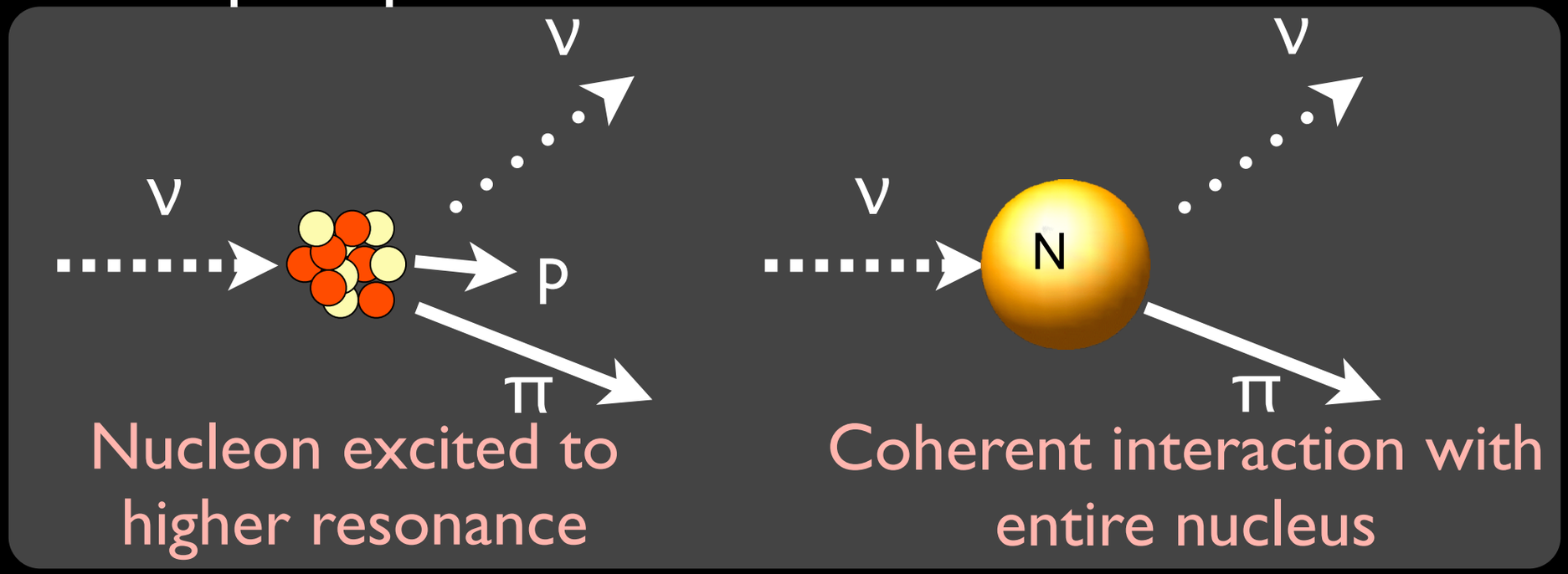
$\cos\theta_\pi$

- BG subtracted, unfolded & efficiency corrected by MC
- Normalized to unit area (shape only)
- Good agreement of MC model to data

Update after PRD publication

Coherent π^0 production

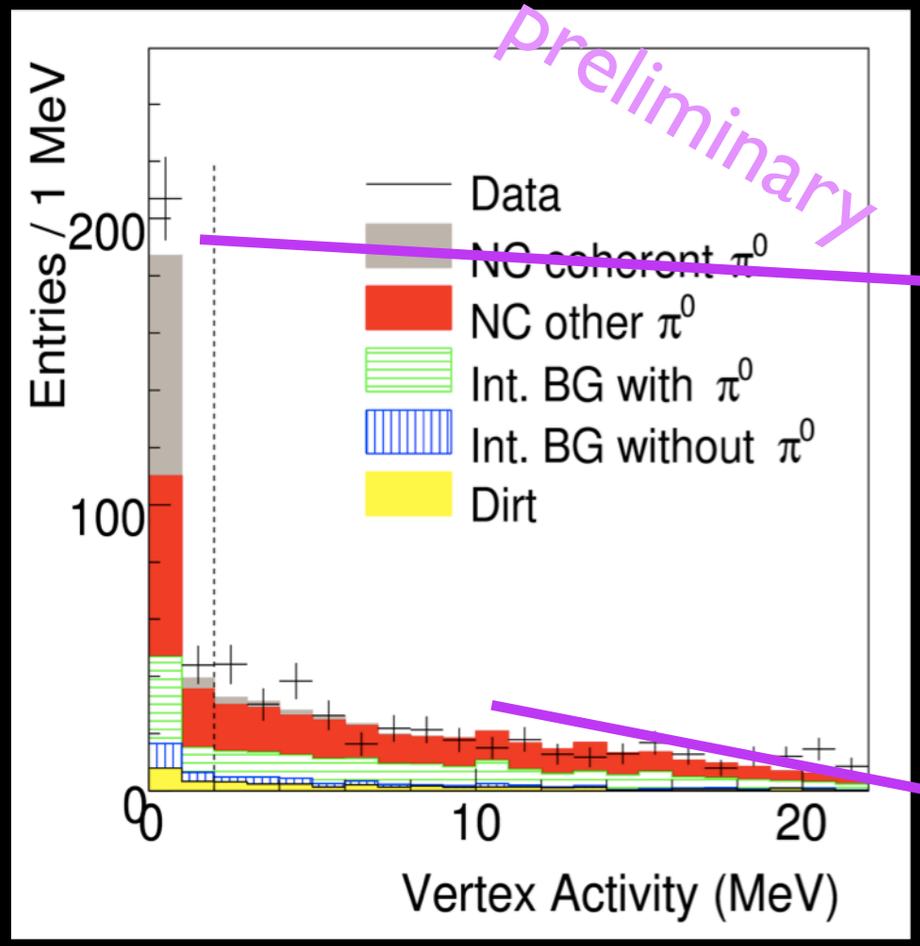
- Two pion production mechanisms



- Previous SciBooNE and MiniBooNE analyses:
  - Using only π^0 kinematics
    - Coherent π^0 more forward because of small Q^2
- SciBar is a fully active detector!
  - Can look for recoil nucleon
    - Less model dependent analysis

Coherent π^0 production

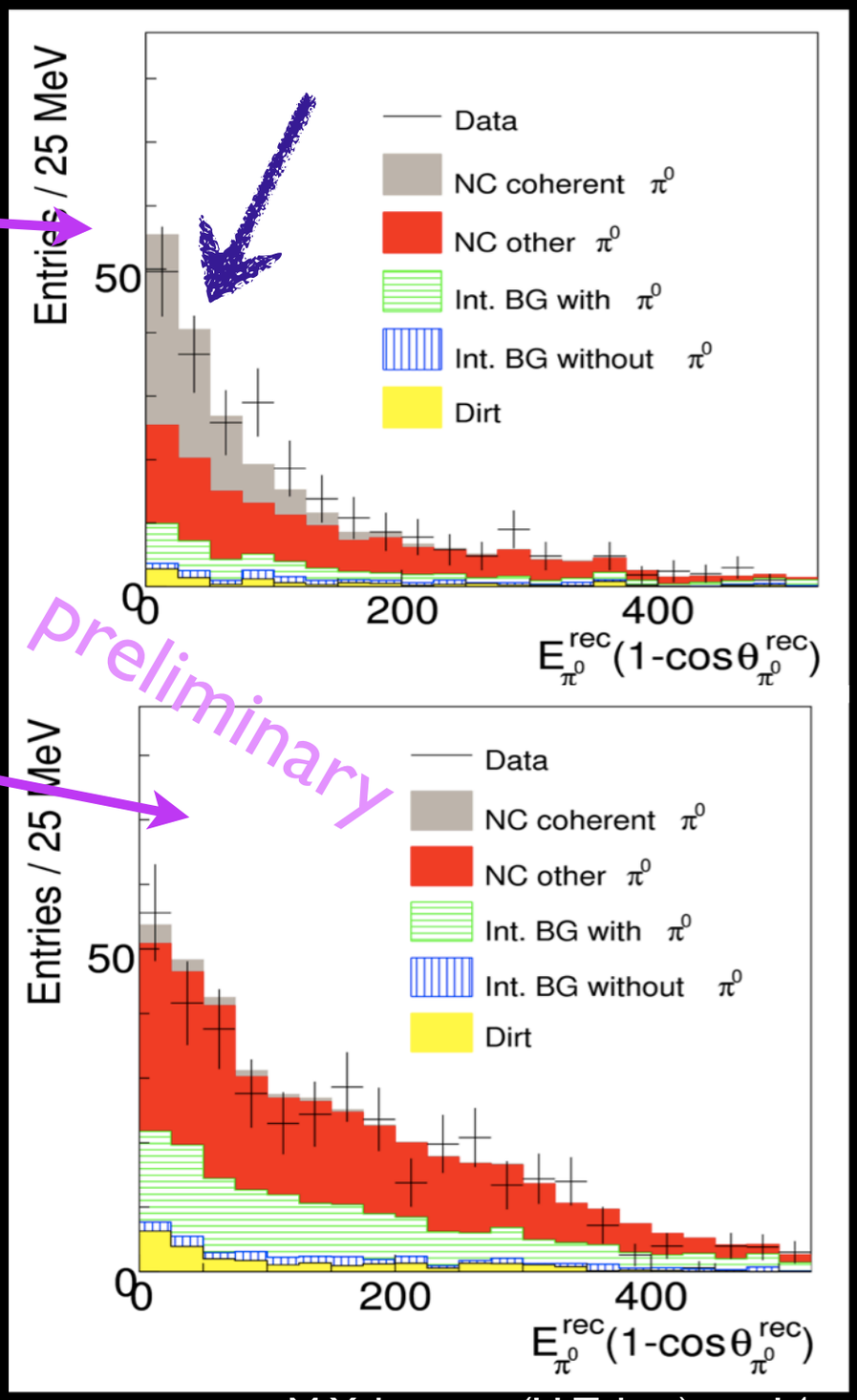
(after fitting with MC templates)



Energy deposit around π^0 vertex

<2MeV

>2MeV

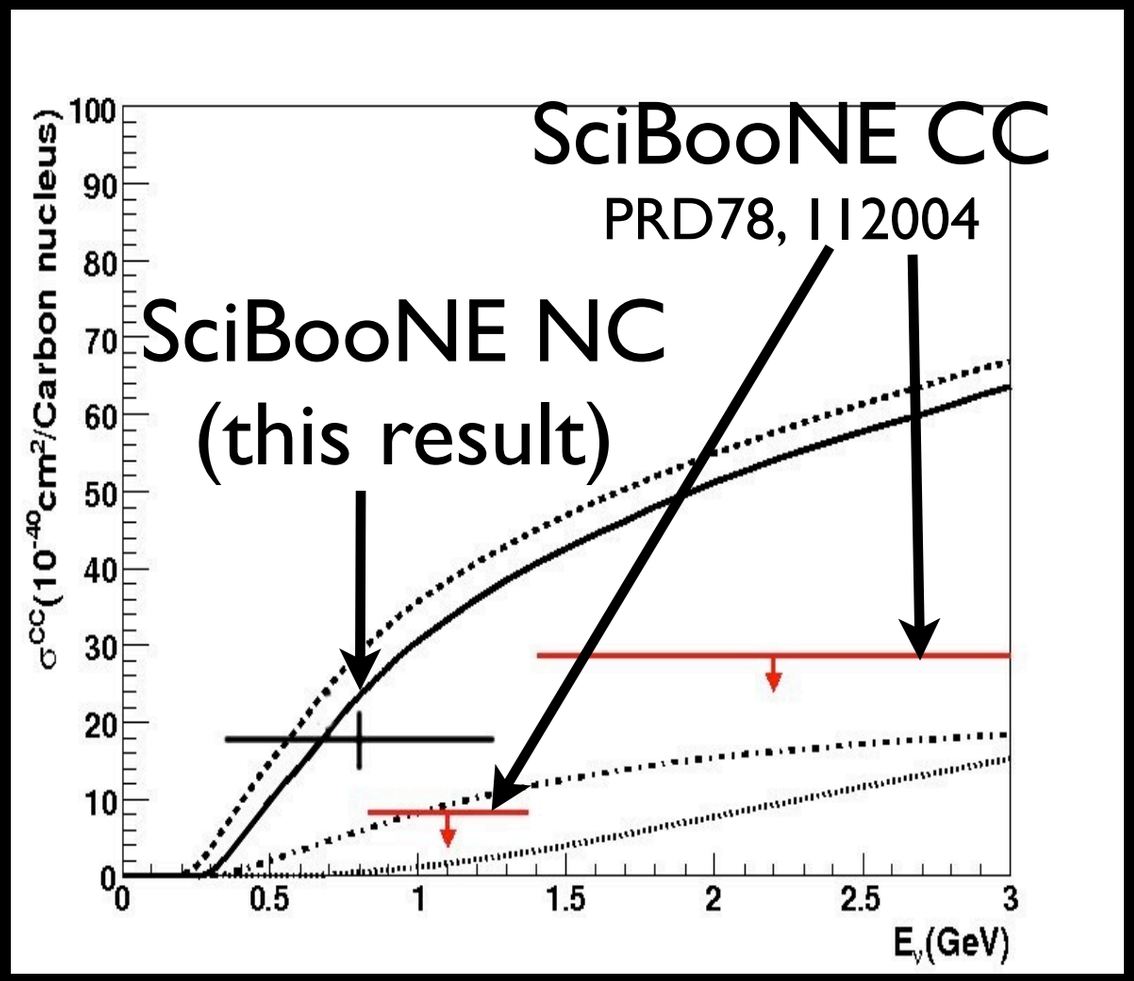


Clear evidence of coherent production!

SciBooNE

Coherent π^0 production

$\sigma(\text{NC-coh}\pi^0)/\sigma(\text{CC})=(1.17\pm0.23)\times10^{-2}$ preliminary

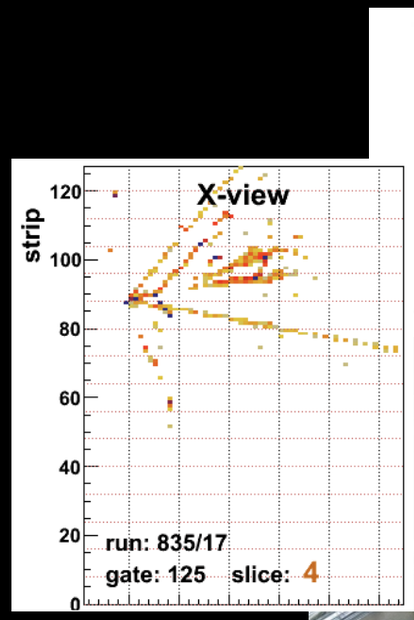


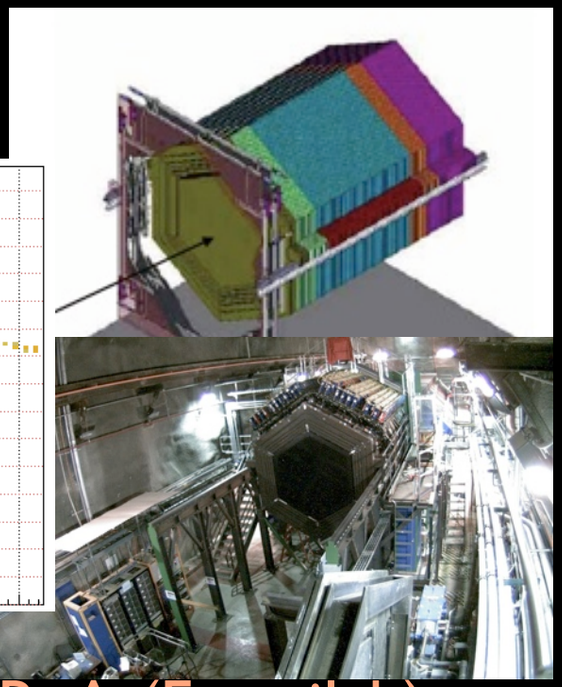
Assuming
$\sigma(CC) = 7.6 \times 10^{-39}$ cm^2 at 0.8 GeV by NEUT
$\sigma(CCcoh)=2\sigma(NCcoh)$

- $\sigma(\text{NC-coh}\pi^0)/\sigma(\text{NC}\pi^0)$ =17.9±3.9%
  - Good agreement with MiniBooNE (PLB664, 41) 19.5±1.1±2.5%
- Most of models predict $\sigma(\text{CC-coh}\pi)/\sigma(\text{NC-coh}\pi)\sim2$
  - SciBooNE results: 0.14±0.30
  - Homework for theorists!

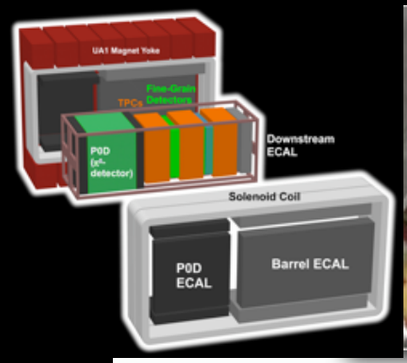
Future prospects

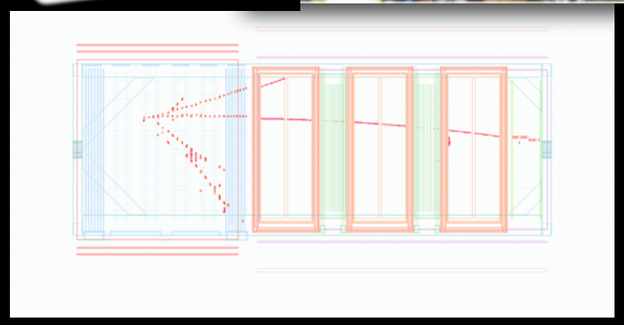
- SciBooNE/MiniBooNE actively analyzing data
- More players coming into the field!



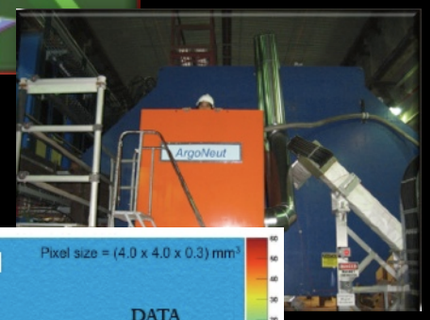


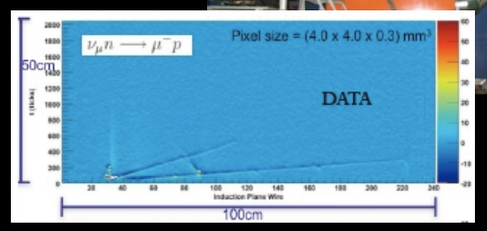
MINERvA (Fermilab)
Dedicated experiment





T2K ND280
LBL near detector





ArgoNEUT (Fermilab)
New technology

Continue to be exciting area in future!

Summary

- Neutrino cross section is important for precise neutrino oscillation measurements
- Reported new results from SciBooNE
  - Neutral current π^0 production
    - BG mode for $\nu_\mu \rightarrow \nu_e$ search
      $\sigma(NC\pi^0)/\sigma(CC) = 7.7 \pm 0.5(stat) \pm 0.5(syst) \times 10^{-2}$
    - π^0 kinematics well reproduced by MC
  - Coherent NC π^0 production
    - Found evidence consistent with MiniBooNE
    - CC/NC ratio needs better theory
- More results will come soon! Stay tuned!

Backup

Systematic errors on $\sigma(NC\pi^0)/\sigma(CC)$

	Error ($\times 10^{-2}$)	
Detector response	-0.39	+0.38
ν interaction, nuclear model	-0.25	+0.30
External background	-0.10	+0.10
ν beam	-0.11	+0.22
Total	-0.48	+0.54

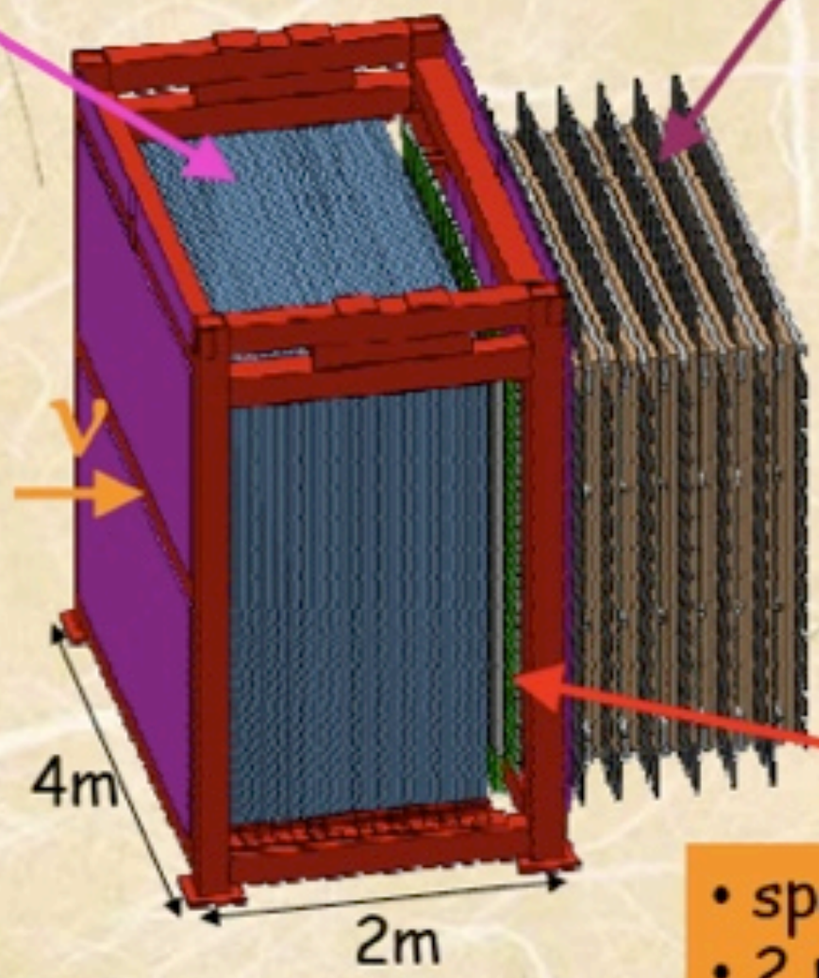
Detector response: PMT cross-talk, hit threshold
ν interaction: CC resonant π cross section

SciBooNE detector

SciBar

- scintillator tracking detector
- 14,336 scintillator bars (15 tons)
- Neutrino target
- detect all charged particles
- p/π separation using dE/dx

Used in K2K experiment



Muon Range Detector (MRD)

- 12 2"-thick steel + scintillator planes
- measure muon momentum with range up to 1.2 GeV/c

Parts recycled from Past experiment

Electron Catcher (EC)

- spaghetti calorimeter
- 2 planes (11 X_0)
- identify π^0 and ν_e

Used in CHORUS, HARP and K2K

DOE-wide Pollution Prevention Star (P2 Star) Award

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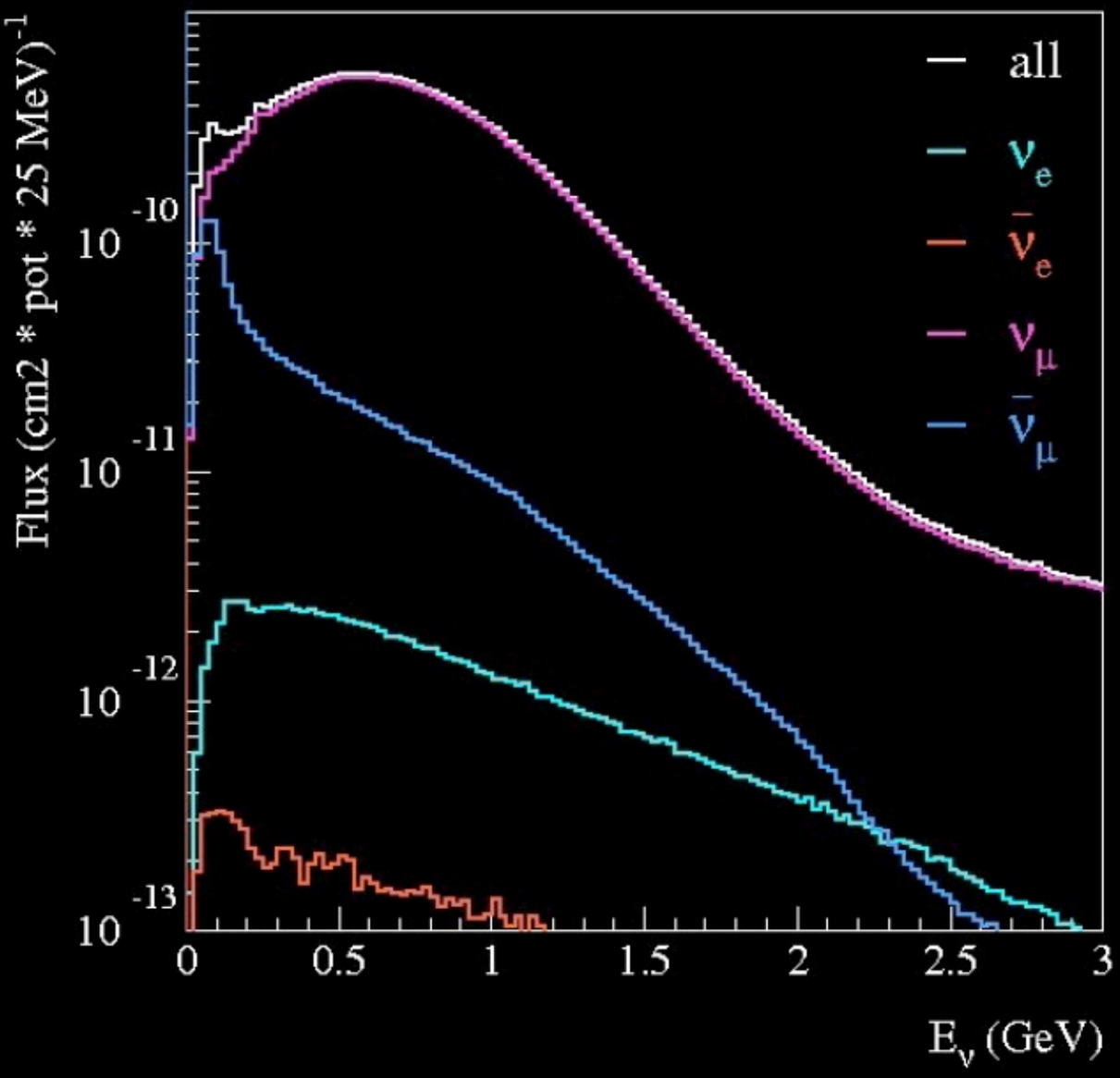
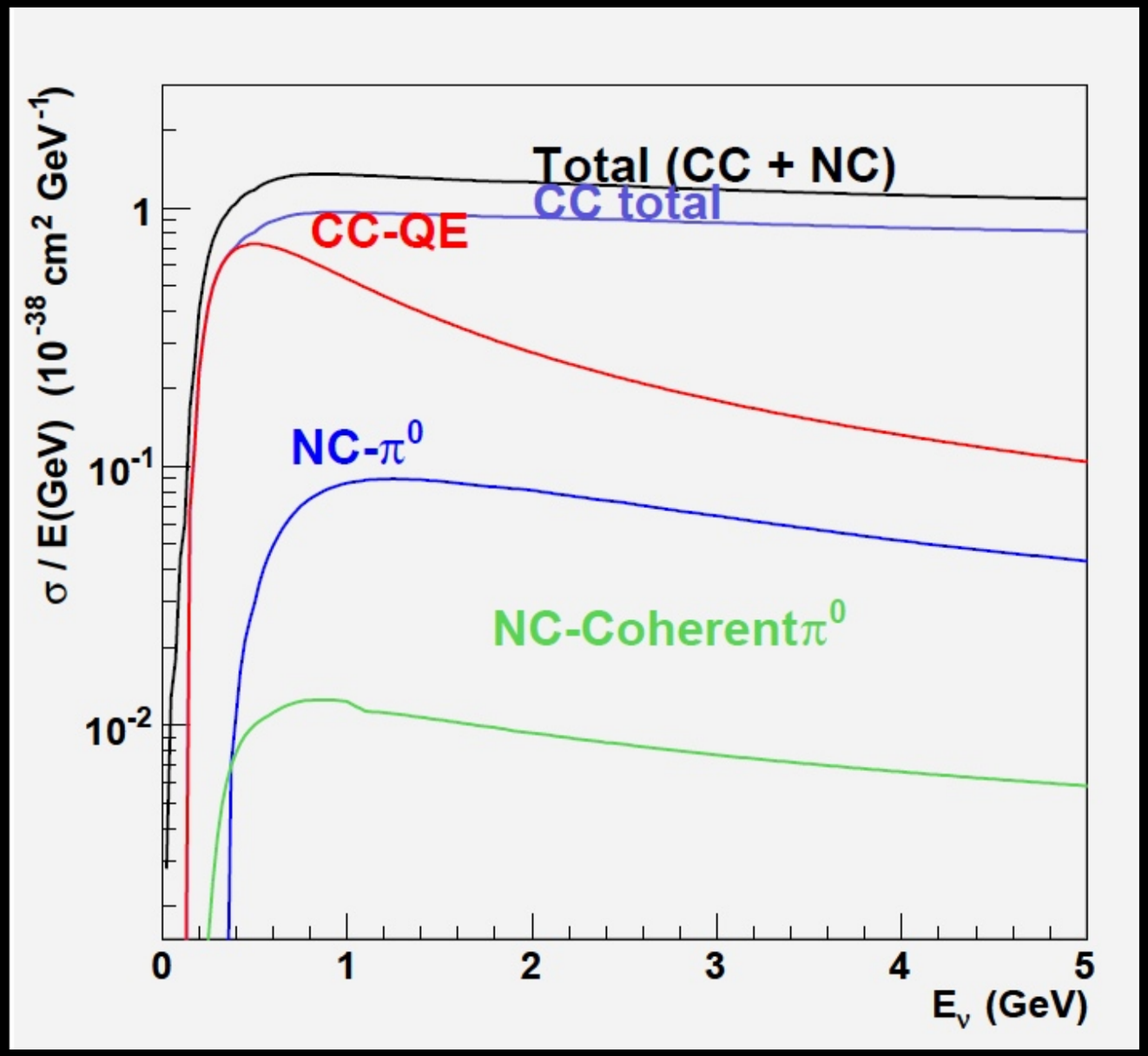
Neutrino energy spectrum



ν interaction simulation

‘NEUT’ library

Used for Super-K, K2K, SciBooNE, T2K



Quasi Elastic (QE) $\nu_\mu n \rightarrow \mu p$

Llewellyn-Smith formalism

resonant π production

Rein-Sehgal (2007)

Coherent π production

Rein-Sehgal (2006)

DIS

GRV98 PDF
Bodek-Yang correction

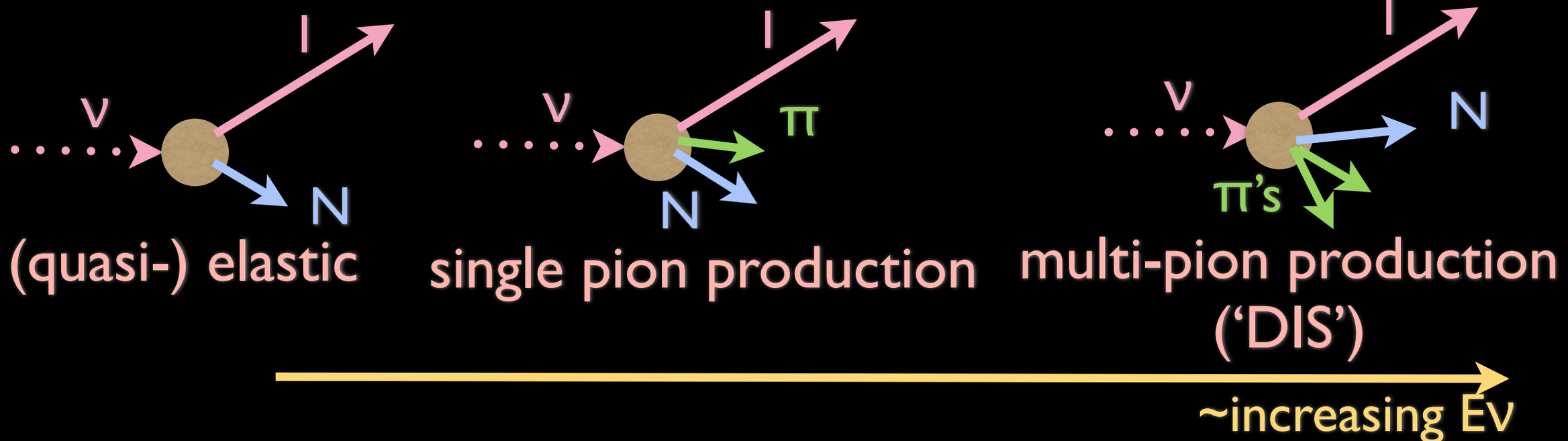
For recoil nucleon in nucleus, the relativistic Fermi gas model of Smith and Moniz is used

ν interaction in ~GeV

(region of interest for many oscillation exp.)

- ν-nucleus (nucleon) scattering dominates.
  - Charged current: $l^{\pm}$ in the final state
  - Neutral current: ν the final state

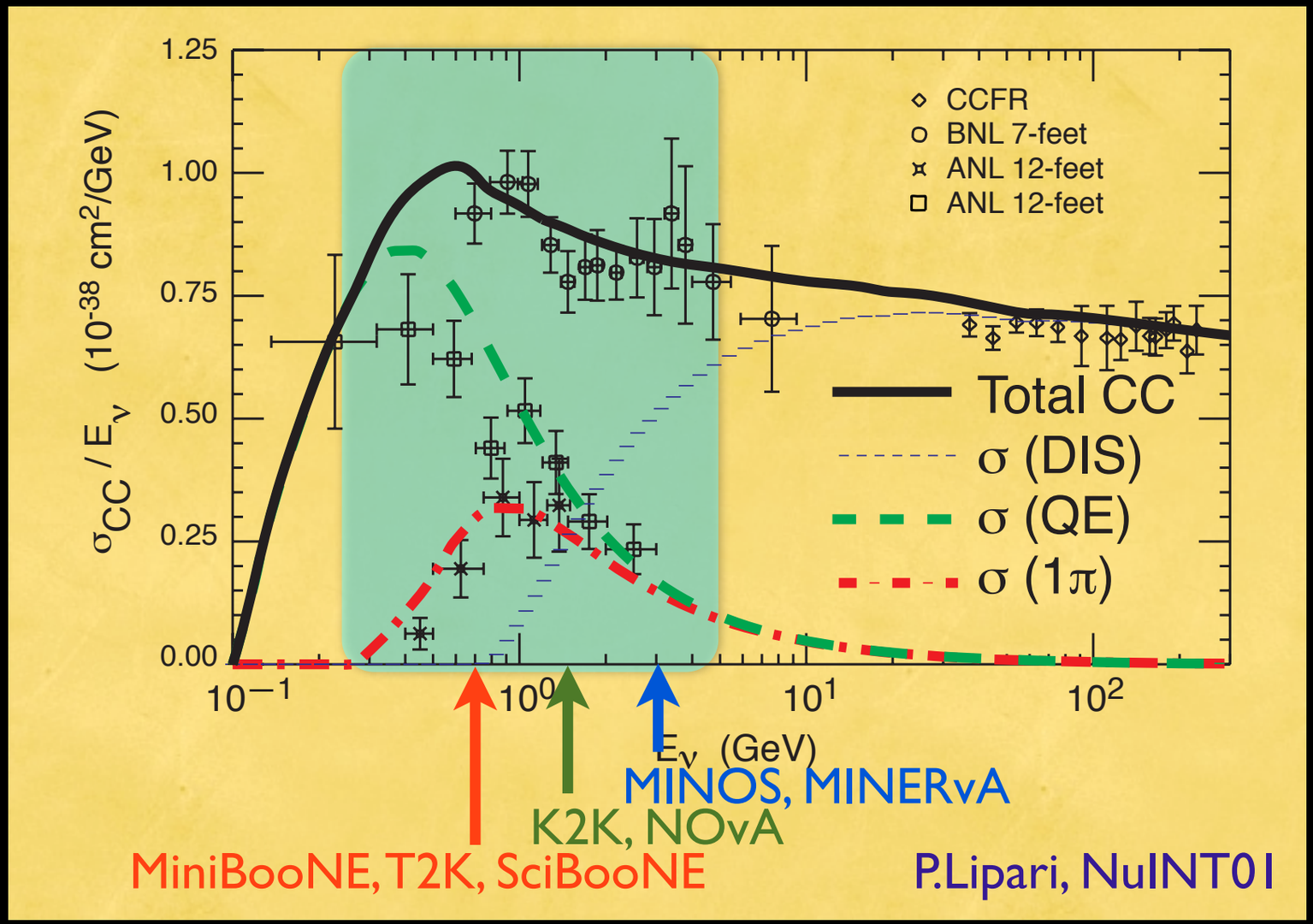
l: lepton (ν or charged)



- All channels contribute at ~1GeV!
- Nuclear interaction inside the target nucleus changes final state particle type, charge, number and kinematics.

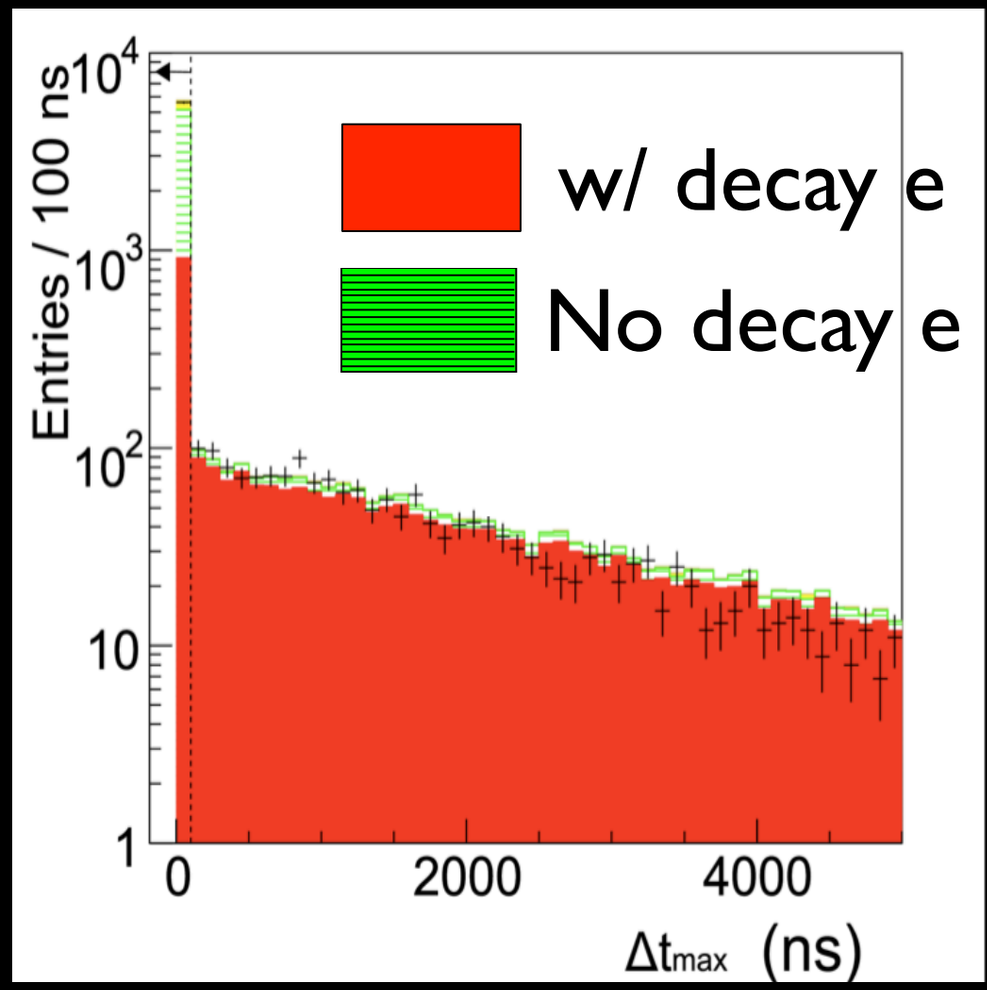
Knowledge of ν interaction

- Based on bubble chamber experiments in 80's-90's
- Uncertainty 20-40%, even much worse for anti-neutrino
- Recent oscillation exp'ts have renewed interest and needs
- Growing efforts over past decade!



Background (1)

- "Internal" background:
  Neutrino interaction inside SciBar
- Mostly CC events (σ_{CC} >x10 $\sigma_{NC\pi^0}$)
  - Reject muons by requiring
    - No track escaping from side
    - No decay electron, identified with delayed timing signal (fig.), if track stops inside SciBar
    - Response of EC not consistent with muon if track exits from downstream



*MC normalized by CC candidates

Background (2)

- "External" background:
  - ν interaction in surrounding material (wall, soil)
    - Veto charged particles using outer layers
    - Reconstructed π^0 vertex to be inside the detector
- Cosmic rays
  - Small fraction (1.8%) after π^0 selection
  - Can be accurately estimated using off-time sample