Coherent-π production ~Experiments~

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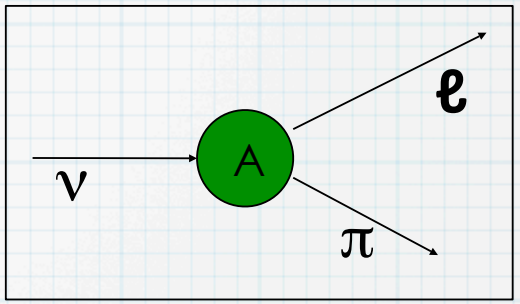
Outline

- Introduction
- Previous results
- Recent results at low energy
  - K2K, MiniBooNE, SciBooNE
- Future prospect
- Summary

Coherent pion production

- Neutrino interacts with nucleons *coherently*, producing a pion
- No nuclear breakup occurs



Charged Current (CC): $\nu_\mu + A \rightarrow \mu + A + \pi^+$

Neutral Current (NC): $\nu_\mu + A \rightarrow \nu_\mu + A + \pi^0$

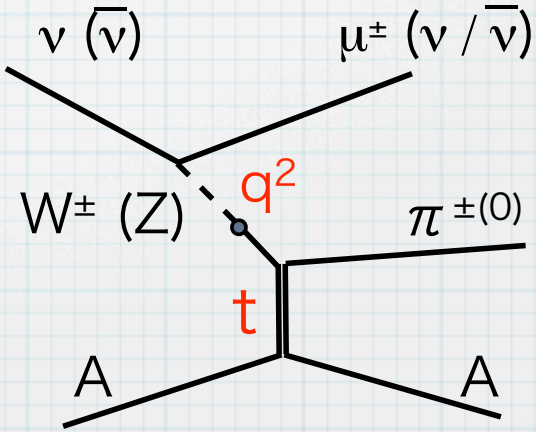
Coherence requires:

$$t = (q - p_\pi)^2 < 1/R^2$$

where R is the size of the nucleus.

From the Rein-Sehgal model:

1) $\sigma(CC) = 2\,\sigma(NC)$
2) $\sigma(A) \sim A^{1/3}$



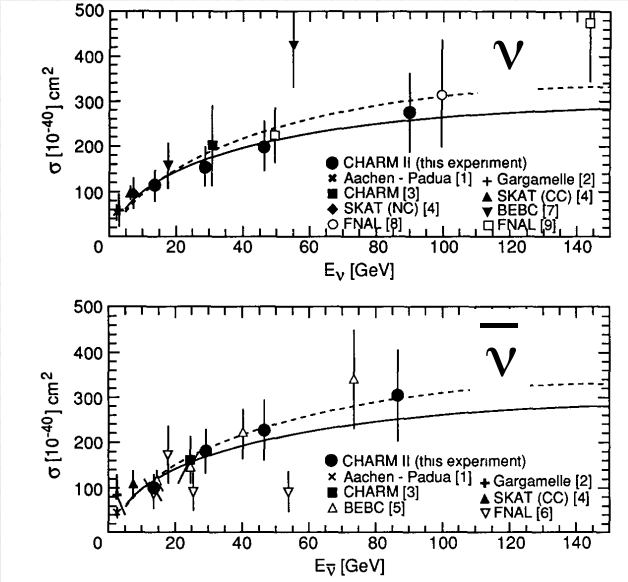
Characterized by a small momentum transfer to the nucleus, forward going π.

Measurements in past

- Measurements for ν, $\bar{\nu}$ CC and NC modes
- High energy region: >7GeV (CC), >2GeV (NC)
- R&S model agrees with the high energy results (for various nuclear targets)

Assume:

- $A^{1/3}$ dependence
- σ(CC coherent)=2*σ(NC coherent)



Plots from Phys.Lett. B313, 267-275 (1993)

Experiments	CC/NC	$\nu / \bar{\nu}$	E	Target <A>
Aachen-Padova	NC	$\nu, \bar{\nu}$	2	Al <27>
Gargamelle	NC	$\nu, \bar{\nu}$	2	Freon <30>
CHARM	NC	$\nu, \bar{\nu}$	20-30	Glass <20.7>
CHARM II	CC	$\nu, \bar{\nu}$	20-30	Glass <20.7>
BEBC	CC	$\bar{\nu}$	5-100	Ne/H_2 <20>
SKAT	CC, NC	$\nu, \bar{\nu}$	3-20	Freon <30>
FNAL 15-ft	NC	ν	2-100	Ne/H_2 <20>
FNAL 15-ft E632	CC	$\nu, \bar{\nu}$	10-100	Ne/H_2 <20>

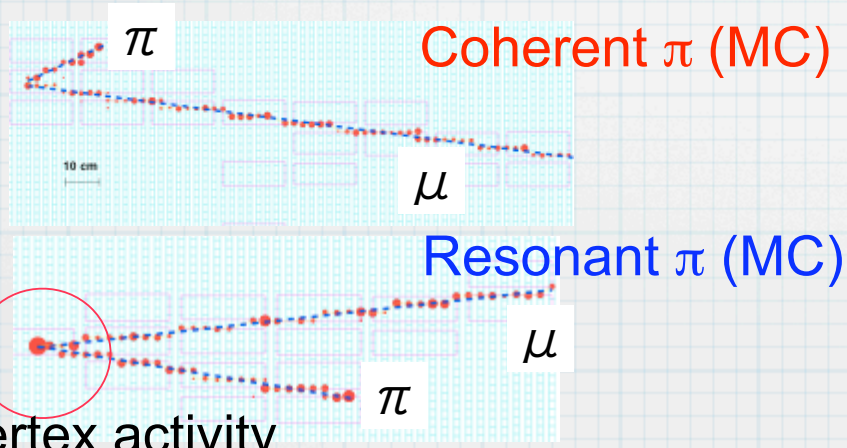
Recent results
at low energy (~1GeV)

ν CC coherent π^+

K2K-SciBar

Phys.Rev.Lett. 95,252301 (2005)

- <Ev>=1.3 GeV
- Target: Scintillator (CH)
- Tracking detector
- Experimental signature:
  - Two MIP-like (μ+π) tracks
  - By looking at recoil proton (vertex activity) isolate coh-π

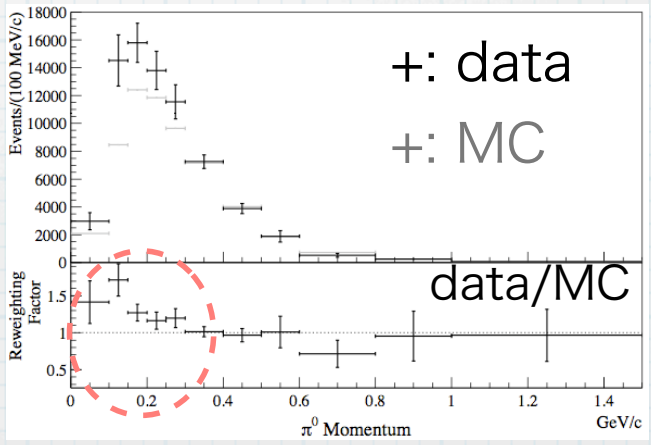


ν NC coherent π^0

MiniBooNE,

Phys.Lett. B664,41 (2008)

- <Ev>=1.1GeV
- Target: Mineral oil (CH_2)
- Cherenkov detector
- Experimental signature:
  - Two e-like ring ($\pi \rightarrow \gamma\gamma$) events
- Higher production rate than prediction at low π^0 momentum
  ➜ weighting factor for MC



Recent results
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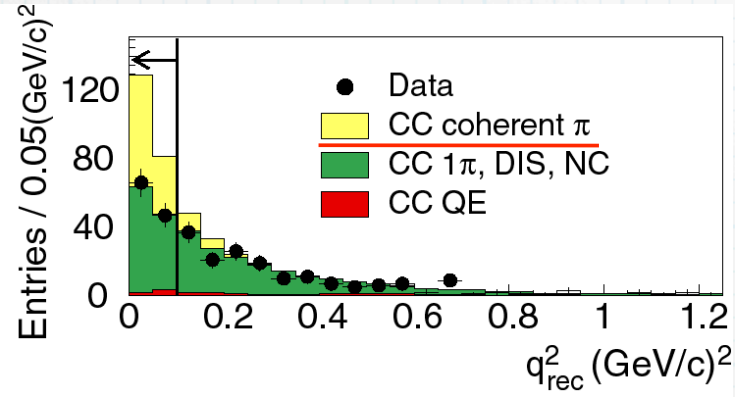


Cross section ratio:

σ(CC coh-π) / σ (CC)

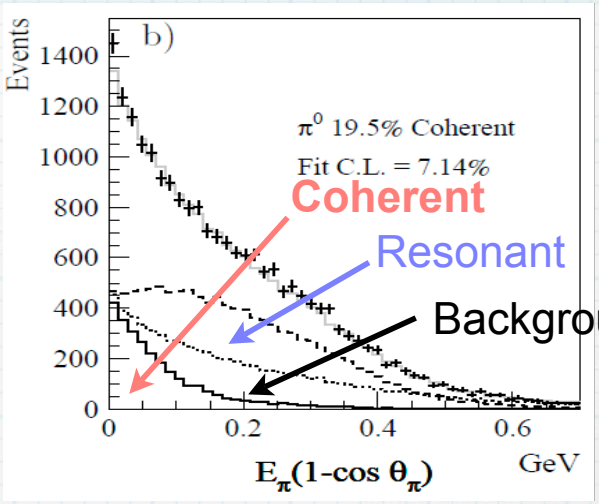
$= (0.04 \pm 0.29\ (\text{stat.})\ ^{+0.32}_{-0.35}\ (\text{sys.})) \times 10^{-2}$

No evidence of CC coherent π prod.

ν NC coherent π^0

MiniBooNE,

Phys.Lett. B664,41 (2008)



Coherent fraction in NC-1π^0:

$N_{coh}/(N_{coh} + N_{res}) = (19.5 \pm 1.1 \pm 2.5)\%$

➜ 65% of R&S model prediction

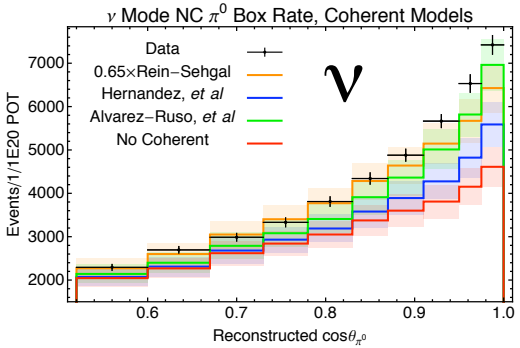
Clear evidence of NC coherent π prod.

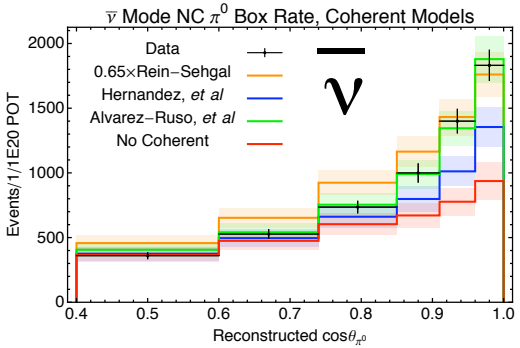
More NC-π^0 from MiniBooNE

C.E. Anderson at NuInt09

Coherent Production Models

- Models for NC coherent π^0 production demonstrate wide variabilities in their predictions
- Forward angular distribution (particularly for antineutrino mode) is very sensitive to predictions
- MiniBooNE uses the Rein–Sehgal[a] prediction scaled by 0.65 by default in MC; also incorporated predictions from Hernandez, *et al*[b], and Alvarez-Ruso, *et al*[c]





[a] Nud. Phys. B223, 29, (1983)
[b] arXiv:0903.5285v1; thanks to Juan Nieves for predictions
[c] Phys. Rev. C **76**, 068501 (2007); thanks to Luis Alvarez-Ruso for predictions

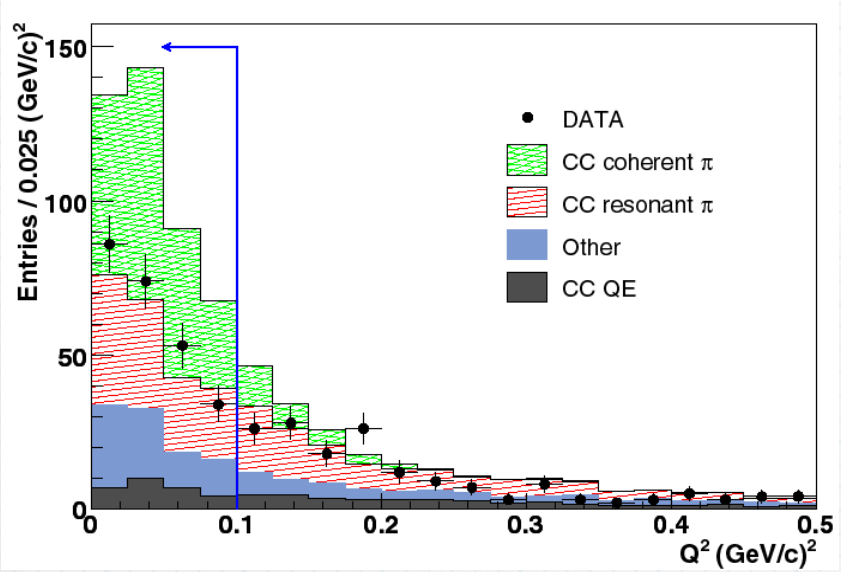
NOTE: MC distributions are absolutely normalized

- New NC-π^0 results for both ν and $\bar{\nu}$ beam modes.
- Demonstrated comparison between data and models
- ν and $\bar{\nu}$ data suggest:
  - Clear evidence of non-zero NC coh-π
  - Forward angular distribution is sensitive to model predictions

CC coh-π results from SciBooNE

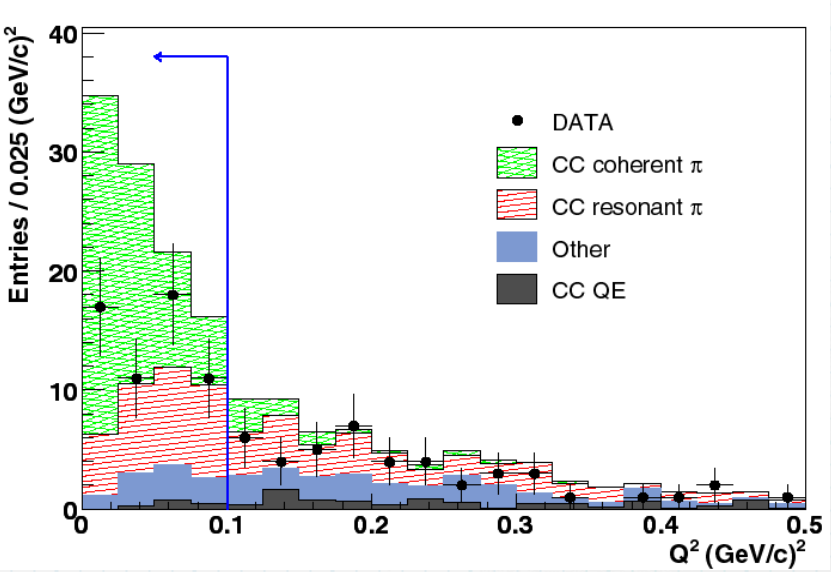
Phys . Rev. D78 112004, 2008

MRD stopped sample
<Eν>= 1.1 GeV



$$\sigma(\text{CC coherent}\,\pi)/\sigma(\text{CC})$$
$$= (0.16 \pm 0.17(stat)^{+0.30}_{-0.27}(sys)) \times 10^{-2}$$

MRD penetrated sample
<Eν>= 2.2 GeV

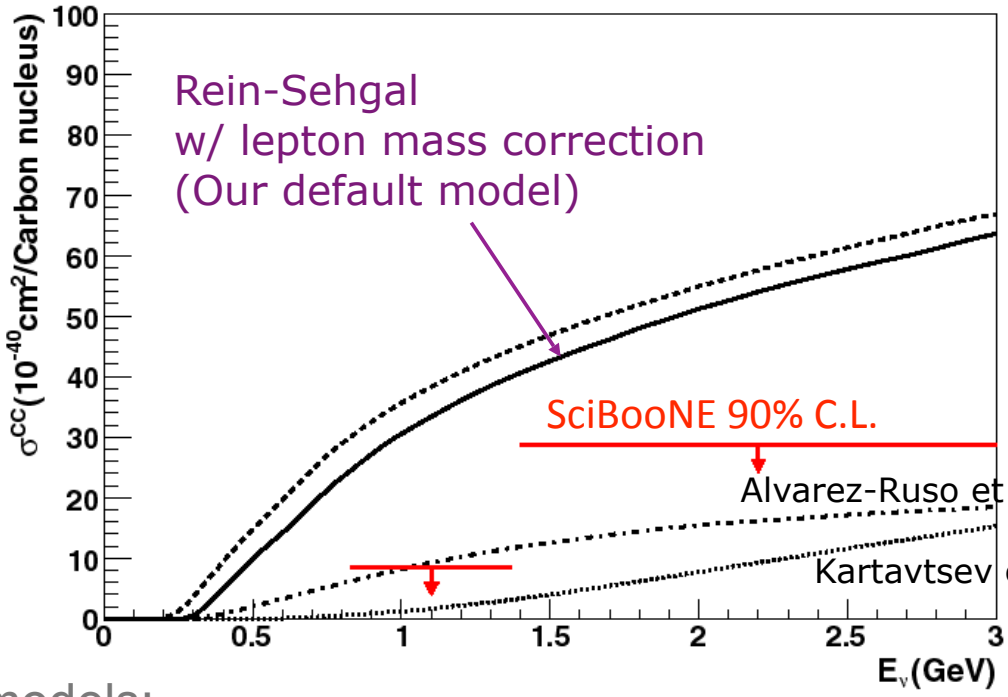


$$\sigma(\text{CC coherent}\,\pi)/\sigma(\text{CC})$$
$$= (0.68 \pm 0.32(stat)^{+0.39}_{-0.25}(sys)) \times 10^{-2}$$

No evidence of CC coherent pion production was found.

➜ Confirmed K2K results

Upper limit on cross section



Measured upper limits on σ(CC coherent π)/σ(CC) ratios are converted to upper limits on absolute cross sections by using σ(CC) predicted by MC simulation.

New theoretical models:

[1] Phys.Rev.D79:013002,2009.
[2] arXiv:0812.2653 [hep-ph]
[3] arXiv:0901.2837 [nucl-th]
[4] arXiv:0901.2366 [nucl-th]
[5] ...

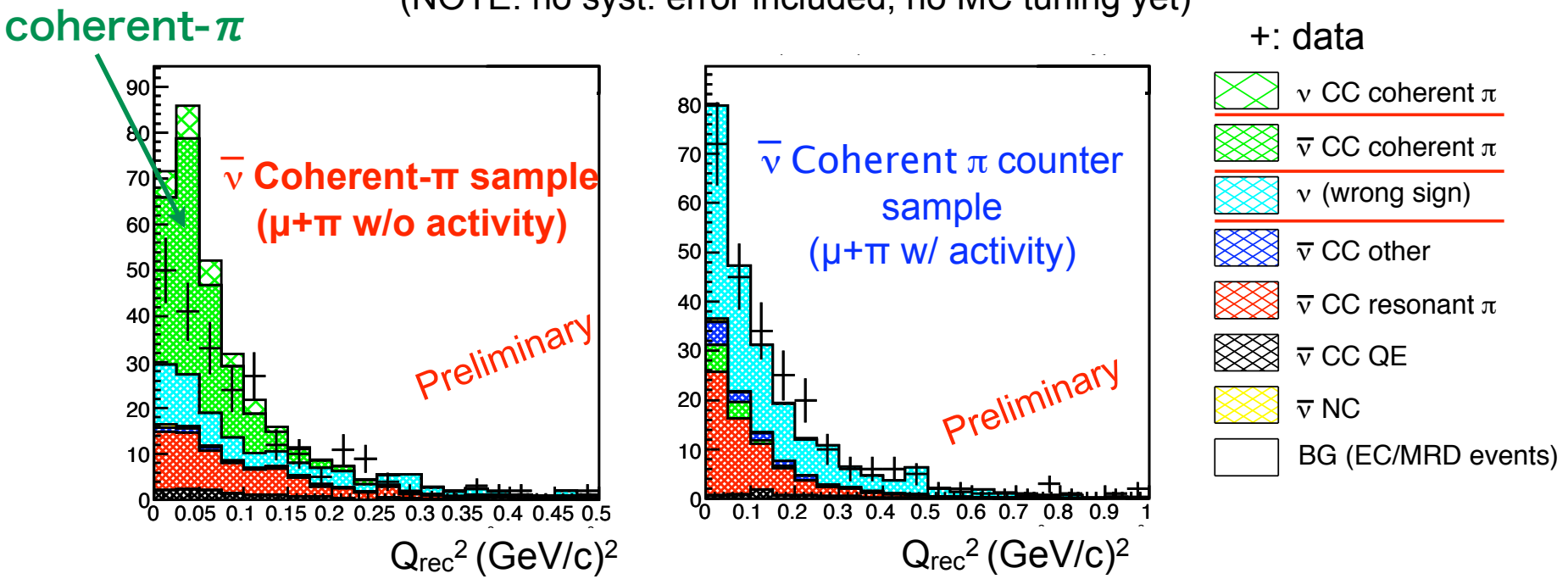
Recently proposed CC coherent π models predict production of CC coherent π events just below our upper limit.

➜ Search for $\bar{\nu}$ CC coherent pion production, since $\bar{\nu}$ data is expected to be more sensitive to look at CC coherent π production than ν data.

Search for $\bar{\nu}$ CC coherent π at SciBooNE

Used the same selection criteria as ν coherent π

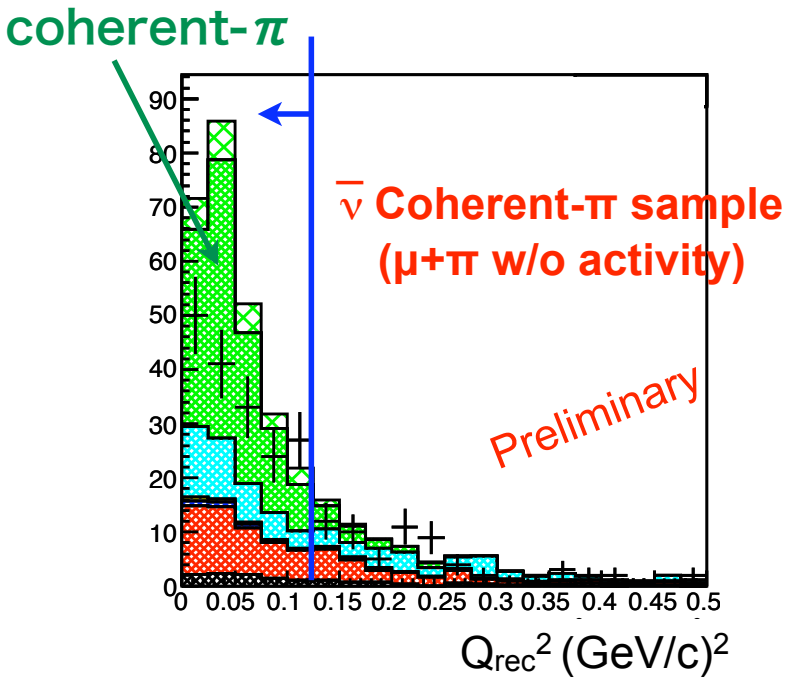
(NOTE: no syst. error included, no MC tuning yet)



$\bar{\nu}$ coherent π sample also show data deficit at low Q^2 region.

But data suggest non-zero CC coherent π component.

Search for $\bar{\nu}$ CC coherent π at SciBooNE



Preliminary & stat. error only

Define signal region: $Q^2<0.1$

- 139 events observed
- 80 non-coh π evts (BG)

➜ Data - BG: 59±14 (stat)

R&S prediction: 151 ($\bar{\nu}$:130 ν:21)

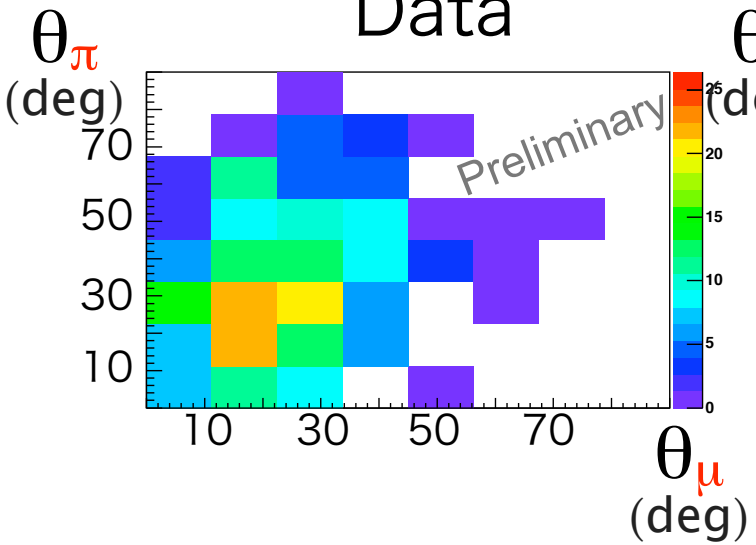
➜ 33% of R&S: 50 ($\nu+\bar{\nu}$)

4σ level "data excess".

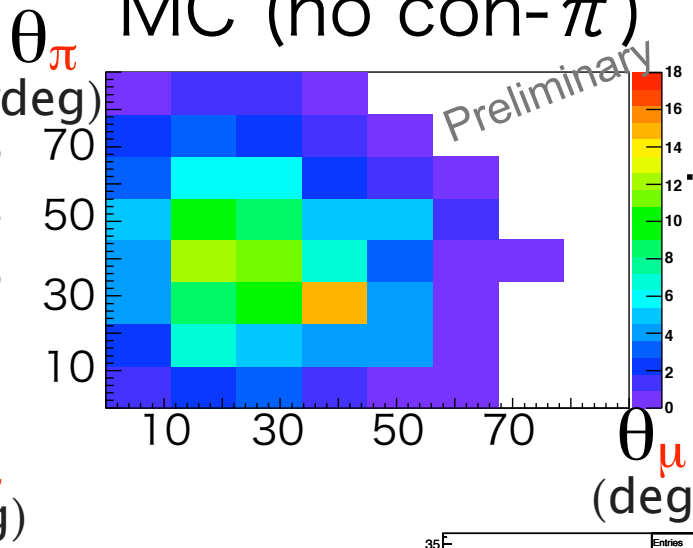
But consistent with ν CC coh-π upper limit (33% of R&S) within stat error.

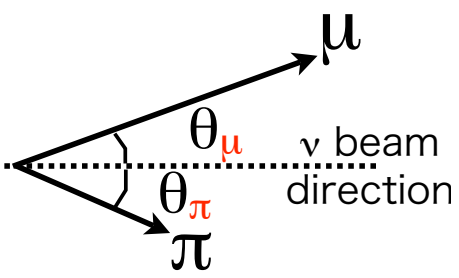
$\bar{\nu}$ CC coherent π sample in θ_π vs θ_μ

Data

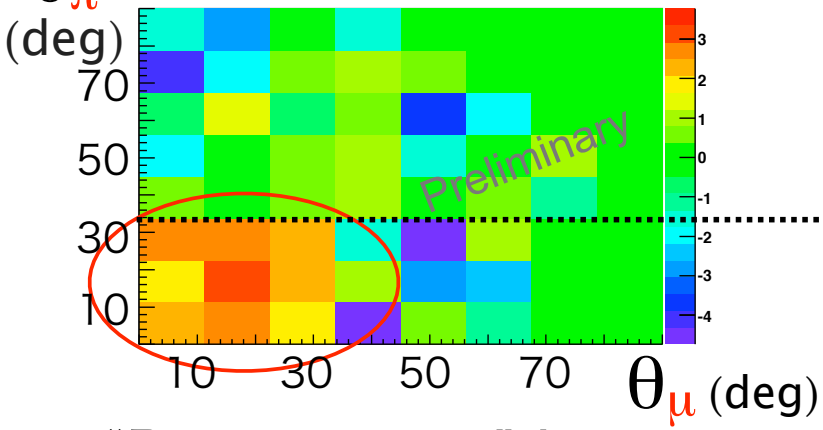


MC (no coh-π)



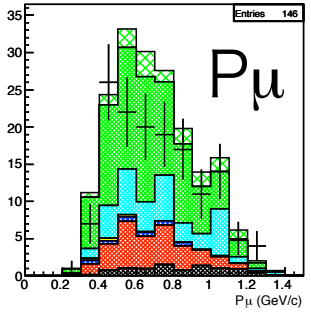


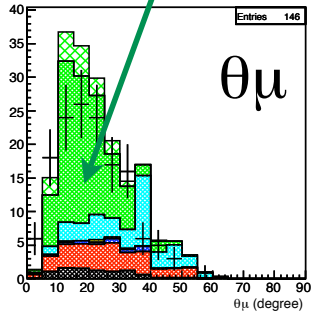
θ_π [Data-MC(no coh)] / stat. err



"Data excess" in
small θπ && small θμ

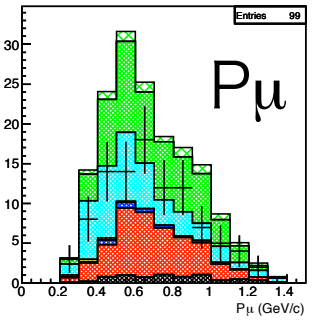
θπ <35°

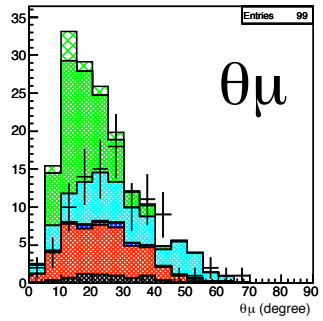




coherent-π

θπ >35°

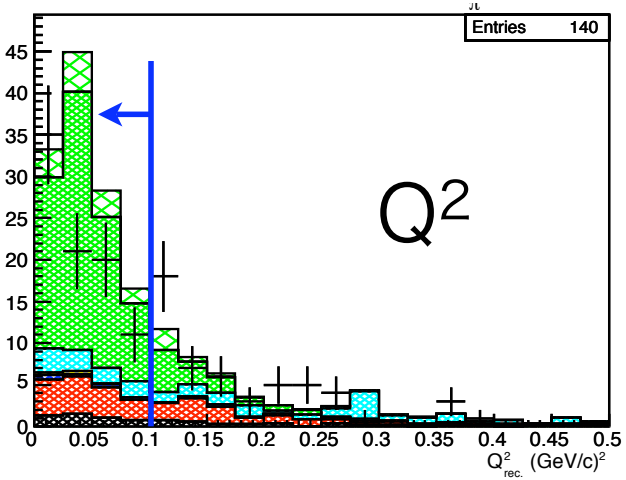




Significance

Preliminary & stat. error only

$\bar{\nu}$ coh-π, $\theta\pi < 35$



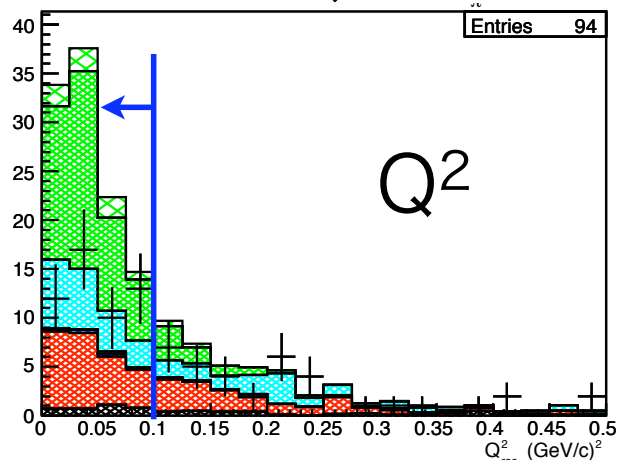
Signal region: $Q^2<0.1$

- 87 events observed
- 31 non-coh π evts (BG)

➜ Data - BG: 56±11 (stat)

R&S prediction: 92 ($\nu+\bar{\nu}$)

$\bar{\nu}$ coh-π, $\theta\pi > 35$



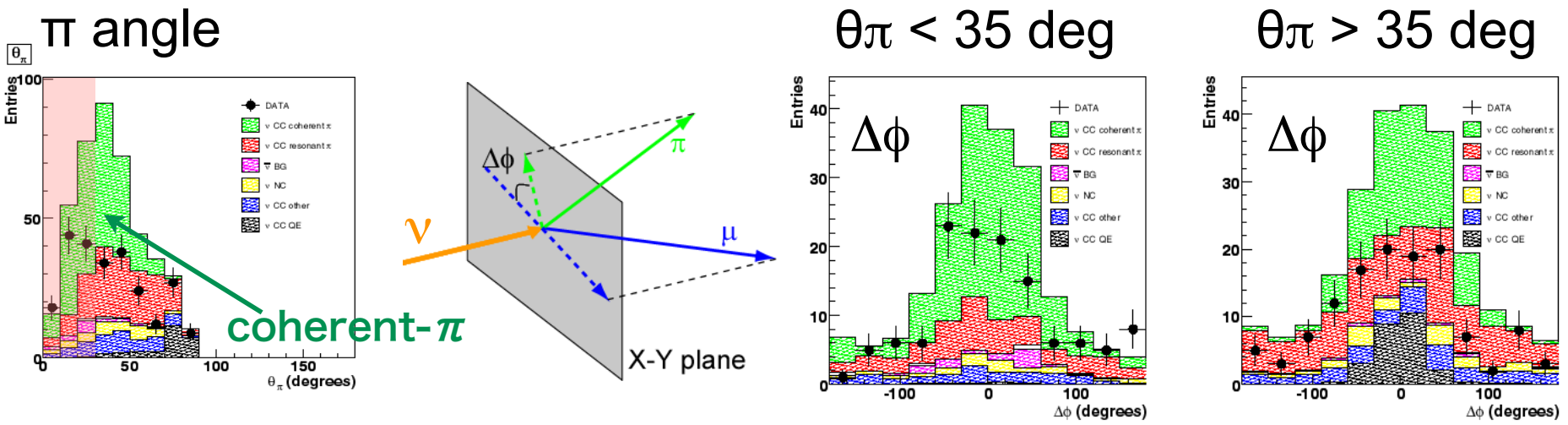
Signal region: $Q^2<0.1$

- 52 events observed
- 49 non-coh π evts (BG)

➜ Data - BG: 2.6±8.5 (stat)

R&S prediction: 59 ($\nu+\bar{\nu}$)

ν CC coherent π



K. Hiraide at NuInt09

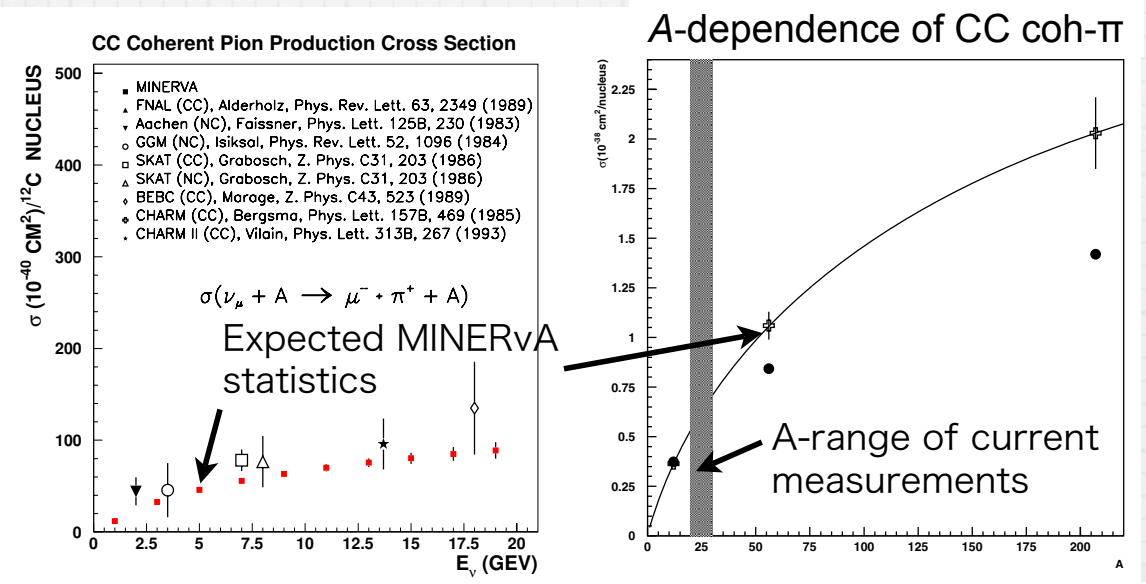
- Similar enhancement in ν data

  ➜ Pions from CC coh-π production tend to be produced more forward than prediction.

- Pion kinematics can be a responsible to improve coherent pion model.

Future prospect

- MINERvA has excellent capability for CC and NC coherent π productions
  - Wide energy range: Ev ~2-20 GeV
  - Several nuclear targets: H, He, C, Fe, Pb
  - Data taking starts soon.
    - Have been running with the full Tracking Prototype in the v beam since mid April 2009!



Summary

- Several measurements on coherent pion production.
- Recent results on CC/NC coherent π at low energy, ~1GeV.
  - Although good agreement between high energy results and R&S model, the results at low energy do not.
- Data suggest: pions from coherent π (CC and NC) tend to be produced more forward than R&S model prediction.
- A variety of models has been proposed.
- New experimental results will be published shortly.
- Experimental & theoretical studies are in progress.