Discovery of neutral currents in ν interactions in Gargamelle

Giulia De Rosi & Laura Dieringer

HASCO Summer School 2013, Göttingen

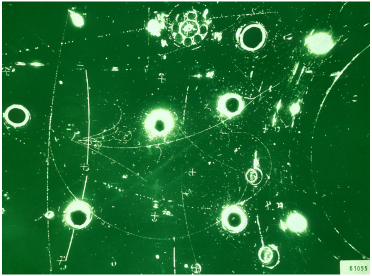
Wednesday, 17 July 2013

How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.

An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.

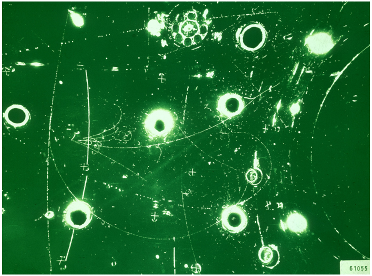


How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.

An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.

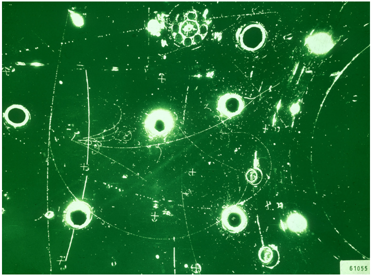


How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.

An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.

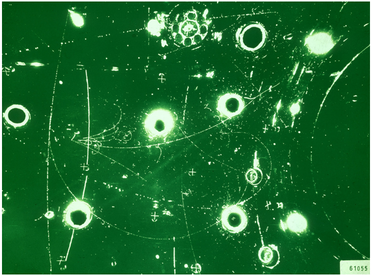


How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids → local bubbles along the particle track.

An uniform magnetic field in the chamber → particle bent → from its curvature radius → its momentum.

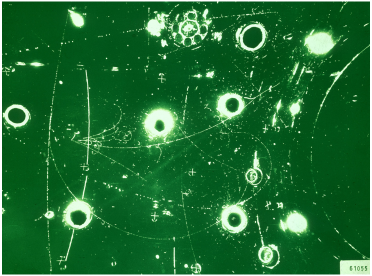


How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.

An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.

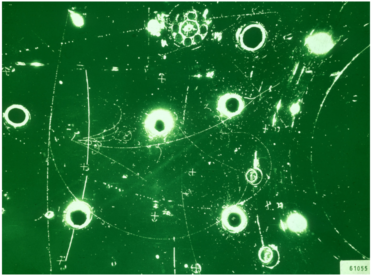


How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.

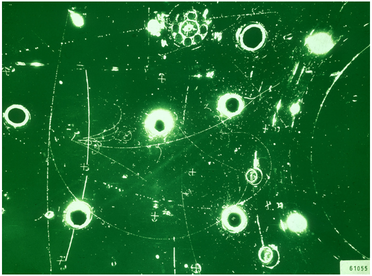
If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.

An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.



How a bubble chamber works?

A bubble chamber is a metal cylinder filled with a heated, near to boiling liquid in a metastable state.
If a charged particle crosses the bubble chamber, it ionizes locally the atoms of the liquids $\rightarrow$ local bubbles along the particle track.
An uniform magnetic field in the chamber $\rightarrow$ particle bent $\rightarrow$ from its curvature radius $\rightarrow$ its momentum.



Introduction

- Experimental observation of neutral weak current whose mediator is the neutral massive boson Z, through neutrino interactions without muon or electron in the final state → a confirmation of unified EW theory;

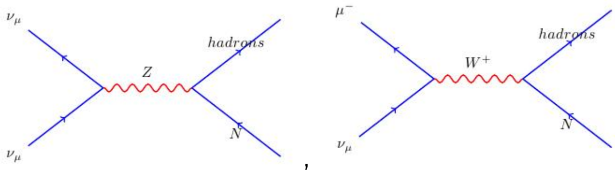
Introduction

- Experimental observation of neutral weak current whose mediator is the neutral massive boson Z, through neutrino interactions without muon or electron in the final state → a confirmation of unified EW theory;

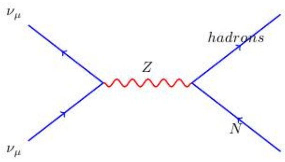
Introduction

- Experimental observation of neutral weak current whose mediator is the neutral massive boson Z, through neutrino interactions without muon or electron in the final state → a confirmation of unified EW theory;

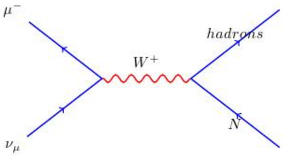
- events induced by neutral particles and produce hadrons:
  NC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \nu_\mu/\bar{\nu}_\mu + hadrons$
  CC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \mu^-/\mu^+ + hadrons$
- absence (NC) or presence (CC) of one muon μ;
  where ν_μ and $\bar{\nu}_\mu$ come from: $\pi^+ \rightarrow \mu^+ + \nu_\mu$ & $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
  (π comes from the primary proton interaction);



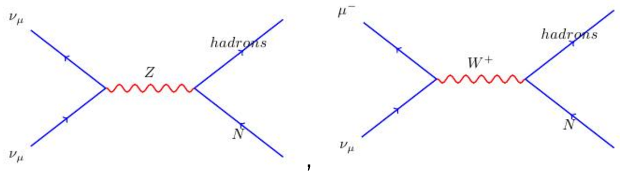
- events induced by neutral particles and produce hadrons:
  NC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \nu_\mu/\bar{\nu}_\mu + hadrons$
  CC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \mu^-/\mu^+ + hadrons$
- absence (NC) or presence (CC) of one muon μ;
  where ν_μ and $\bar{\nu}_\mu$ come from: $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ & $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  (π comes from the primary proton interaction);



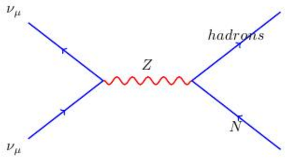
,



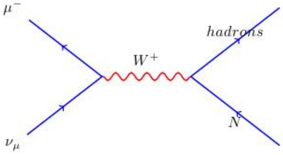
- events induced by neutral particles and produce hadrons:
  NC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \nu_\mu/\bar{\nu}_\mu + hadrons$
  CC: $\nu_\mu/\bar{\nu}_\mu + N \rightarrow \mu^-/\mu^+ + hadrons$
- absence (NC) or presence (CC) of one muon μ;
  where ν_μ and $\bar{\nu}_\mu$ come from: $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ & $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  (π comes from the primary proton interaction);



- events induced by neutral particles and produce hadrons:
  NC: $\nu_\mu/\bar{\nu}_\mu + N \to \nu_\mu/\bar{\nu}_\mu + hadrons$
  CC: $\nu_\mu/\bar{\nu}_\mu + N \to \mu^-/\mu^+ + hadrons$
- absence (NC) or presence (CC) of one muon μ;
  where ν_μ and $\bar{\nu}_\mu$ come from: $\pi^- \to \mu^- + \bar{\nu}_\mu$ & $\pi^+ \to \mu^+ + \nu_\mu$
  (π comes from the primary proton interaction);



,



- 1973, Gargamelle: giant bubble chamber filled with Freon (CF_3Br) at $\rho = 1.5 \times 10^3 Kg/m^3$ to detect particles at CERN;
- 83000 ν pictures and 207000 $\bar{\nu}$ pictures;
- dimension of the chamber are such that hadrons are identified by interaction or by range-momentum and ionisation.

- 1973, Gargamelle: giant bubble chamber filled with Freon (CF_3Br) at $\rho = 1.5 \times 10^3 Kg/m^3$ to detect particles at CERN;
- 83000 ν pictures and 207000 $\bar{\nu}$ pictures;
- dimension of the chamber are such that hadrons are identified by interaction or by range-momentum and ionisation.

- 1973, Gargamelle: giant bubble chamber filled with Freon (CF_3Br) at $\rho = 1.5 \times 10^3 Kg/m^3$ to detect particles at CERN;
- 83000 ν pictures and 207000 $\bar{\nu}$ pictures;
- dimension of the chamber are such that hadrons are identified by interaction or by range-momentum and ionisation.

Analysis of the signal and background

- Background comes from neutral hadrons of CC events which behave in a similar way to the NC events in which we are interested;
- neutral hadrons of CC events come from ν interactions in the shielding and they yield to a "neutron star" in the bubble chamber (i.e. AS = associated events)
- the incoming neutral particle direction is obtained from the direction of the observed total momentum with a cut in total energy of > 1 GeV applied to any observed events.

Analysis of the signal and background

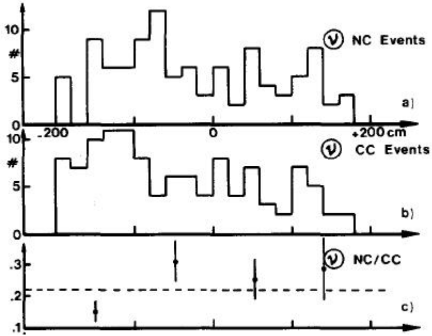
- Background comes from neutral hadrons of CC events which behave in a similar way to the NC events in which we are interested;
- neutral hadrons of CC events come from ν interactions in the shielding and they yield to a "neutron star" in the bubble chamber (i.e. AS = associated events)
- the incoming neutral particle direction is obtained from the direction of the observed total momentum with a cut in total energy of > 1 GeV applied to any observed events.

Analysis of the signal and background

- Background comes from neutral hadrons of CC events which behave in a similar way to the NC events in which we are interested;
- neutral hadrons of CC events come from ν interactions in the shielding and they yield to a "neutron star" in the bubble chamber (i.e. AS = associated events)
- the incoming neutral particle direction is obtained from the direction of the observed total momentum with a cut in total energy of > 1 GeV applied to any observed events.

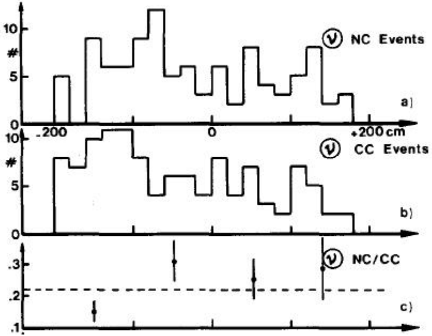
"Infinite" mean free path of ν for both NC and CC events $\rightarrow$ similar spatial distributions (almost flat) along ν-beam axis of NC and CC events:

- NC events;
- CC events;
- ratio NC/CC normalized.



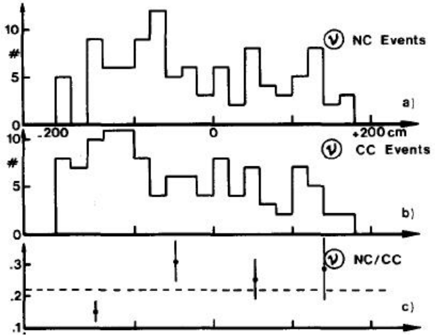
"Infinite" mean free path of ν for both NC and CC events $\rightarrow$ similar spatial distributions (almost flat) along ν-beam axis of NC and CC events:

- NC events;
- CC events;
- ratio NC/CC normalized



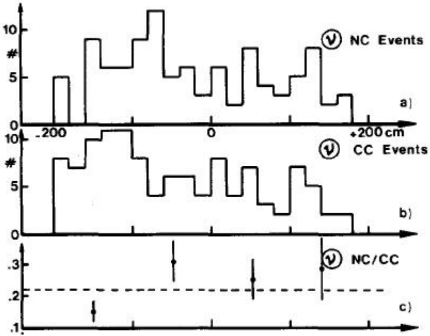
"Infinite" mean free path of ν for both NC and CC events $\rightarrow$ similar spatial distributions (almost flat) along ν-beam axis of NC and CC events:

- NC events;
- CC events;
- ratio NC/CC normalized.



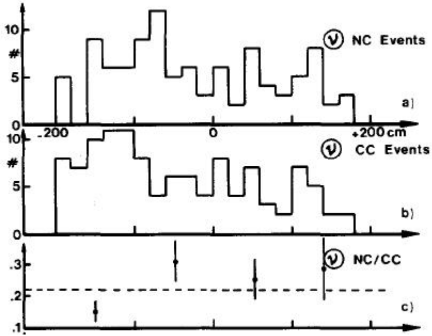
"Infinite" mean free path of ν for both NC and CC events $\rightarrow$ similar spatial distributions (almost flat) along ν-beam axis of NC and CC events:

- NC events;
- CC events;
- ratio NC/CC normalized.



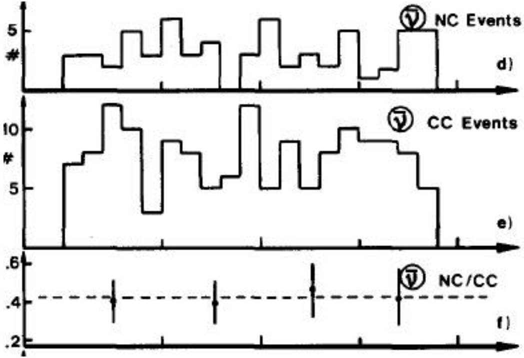
"Infinite" mean free path of ν for both NC and CC events $\rightarrow$ similar spatial distributions (almost flat) along ν-beam axis of NC and CC events:

- NC events;
- CC events;
- ratio NC/CC normalized.



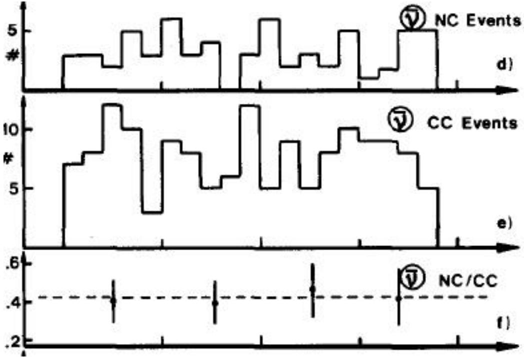
For $\bar{\nu}$-beam axis:

- NC events;
- CC events;
- ratio NC/CC.



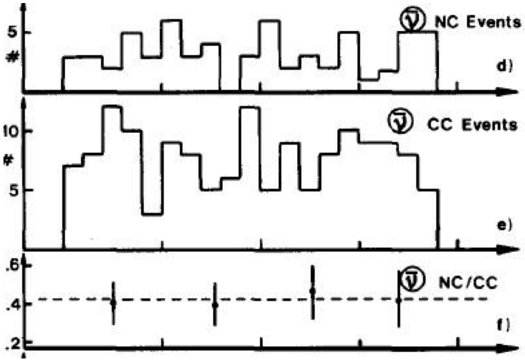
For $\bar{\nu}$-beam axis:

- NC events;
- CC events;
- ratio NC/CC.

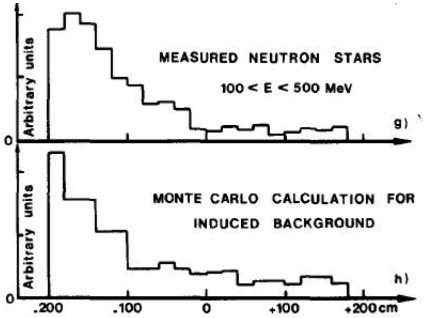


For $\bar{\nu}$-beam axis:

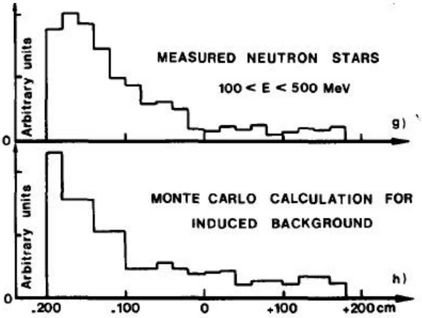
- NC events;
- CC events;
- ratio NC/CC.



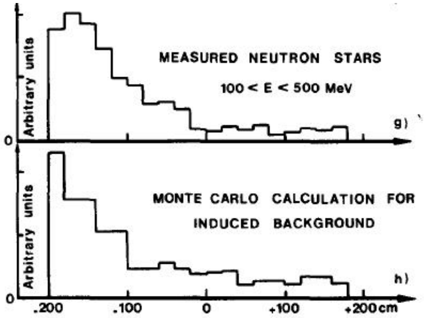
- Bigger cross section due to the strong interaction → exponential attenuation of the distribution of neutron stars (different from the flat distribution);
- distribution of neutron star events, computed with Monte-Carlo method, is compatible with the previous exponential distribution;



- Bigger cross section due to the strong interaction → exponential attenuation of the distribution of neutron stars (different from the flat distribution);
- distribution of neutron star events, computed with Monte-Carlo method, is compatible with the previous exponential distribution;



- Bigger cross section due to the strong interaction $\rightarrow$ exponential attenuation of the distribution of neutron stars (different from the flat distribution);
- distribution of neutron star events, computed with Monte-Carlo method, is compatible with the previous exponential distribution;



Some numbers...

In a volume of 3 m^3:

for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS;

Some numbers...

In a volume of 3 m^3:
for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS;

Some numbers...

In a volume of 3 m^3:
for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS;

Some numbers...

In a volume of 3 m^3:
for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS;

Some numbers...

In a volume of 3 m^3:

for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS;

Some numbers...

In a volume of 3 m^3:

for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS.

Some numbers...

In a volume of 3 m^3:
for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS.

Some numbers...

In a volume of 3 m^3:
for ν:

- 102 NC;
- 428 CC;
- 15 AS;

for $\bar{\nu}$:

- 64 NC;
- 148 CC;
- 12 AS.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- If neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Evaluation of the background

- Others background contributions come from cosmic rays or low energy captured $\mu \rightarrow$ negligible;
- if neutral hadrons are produced by primary protons $\rightarrow$ equal rate in ν and $\bar{\nu}$ runs.
  Instead we observe rate 4 times larger in ν run than in $\bar{\nu}$ run;
- Most important source of background: ν interacts in the shielding and produce a neutron star in the bubble chamber.

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(NC/CC)_\nu = 0.21 \pm 0.03$$
$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

with only statistical errors;

$$\Downarrow$$

compatible with the Weinberg parameter $\sin^2\theta_W$ in the range [0.3-0.4]

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(NC/CC)_{\nu} = 0.21 \pm 0.03$$
$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

with only statistical errors;

$$\Downarrow$$

compatible with the Weinberg parameter $\sin^2\theta_W$ in the range [0.3-0.4]

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(NC/CC)_{\nu} = 0.21 \pm 0.03$$
$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

with only statistical errors;

$\Downarrow$

compatible with the Weinberg parameter $\sin^2\theta_W$ in the range [0.3-0.4]

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(\mathrm{NC/CC})_{\nu} = 0.21 \pm 0.03$$
$$(\mathrm{NC/CC})_{\bar{\nu}} = 0.45 \pm 0.09$$

with only statistical errors;

$\downarrow$

compatible with the Weinberg parameter $sin^2\theta_W$ in the range [0.3-0.4].

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(\mathrm{NC}/\mathrm{CC})_{\nu} = 0.21 \pm 0.03$$
$$(\mathrm{NC}/\mathrm{CC})_{\bar{\nu}} = 0.45 \pm 0.09$$

with only statistical errors;

$$\downarrow$$

compatible with the Weinberg parameter $sin^2\theta_W$ in the range [0.3-0.4].

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(NC/CC)_{\nu} = 0.21 \pm 0.03$$
$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

  with only statistical errors;

  $\downarrow$

  compatible with the Weinberg parameter $sin^2\theta_W$ in the range [0.3-0.4].

Conclusions

- We observe 102 NC in ν run and 64 NC in $\bar{\nu}$ run;
- the spatial distribution is very similar to CC ν-like interactions;
- events not compatible both in number and spatial distribution with a background due to neutral particle interactions in the bubble chamber;
- best estimates

$$(NC/CC)_{\nu} = 0.21 \pm 0.03$$
$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

  with only statistical errors;

$$\downarrow$$

  compatible with the Weinberg parameter $sin^2\theta_W$ in the range [0.3-0.4].