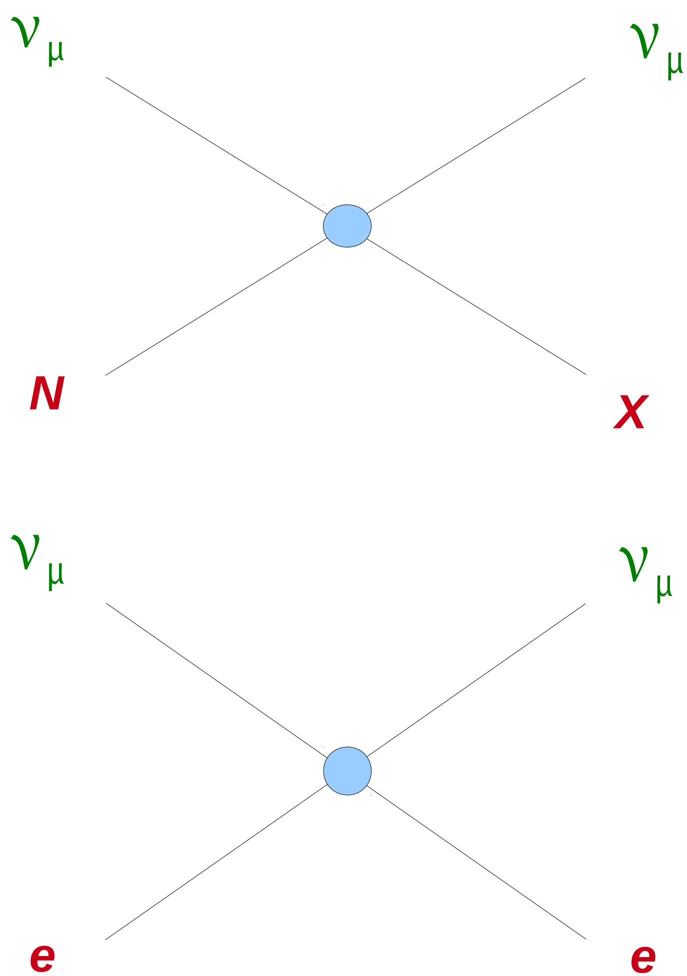
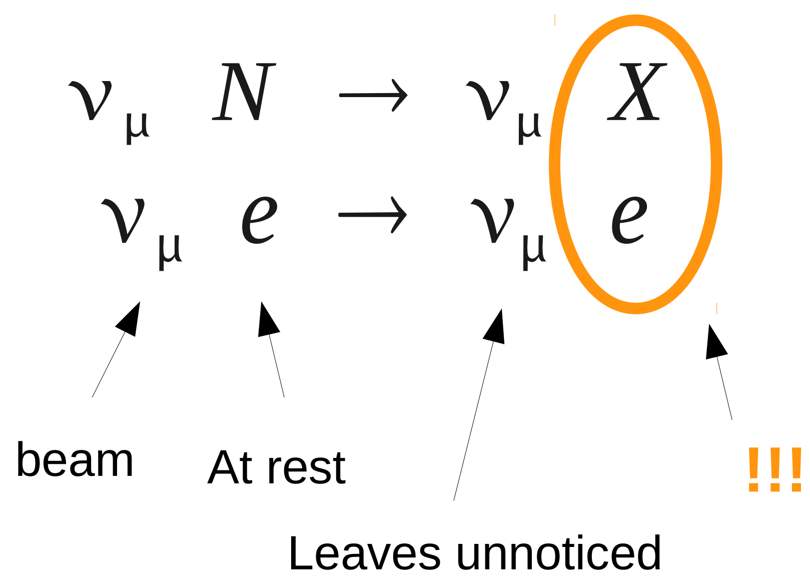
The discovery of neutral currents

- Interlude : basics of statistics
- The process
- Experimental setups; controversy; discovery
- Nobel prize for GSW

Neutral currents : processes of interest

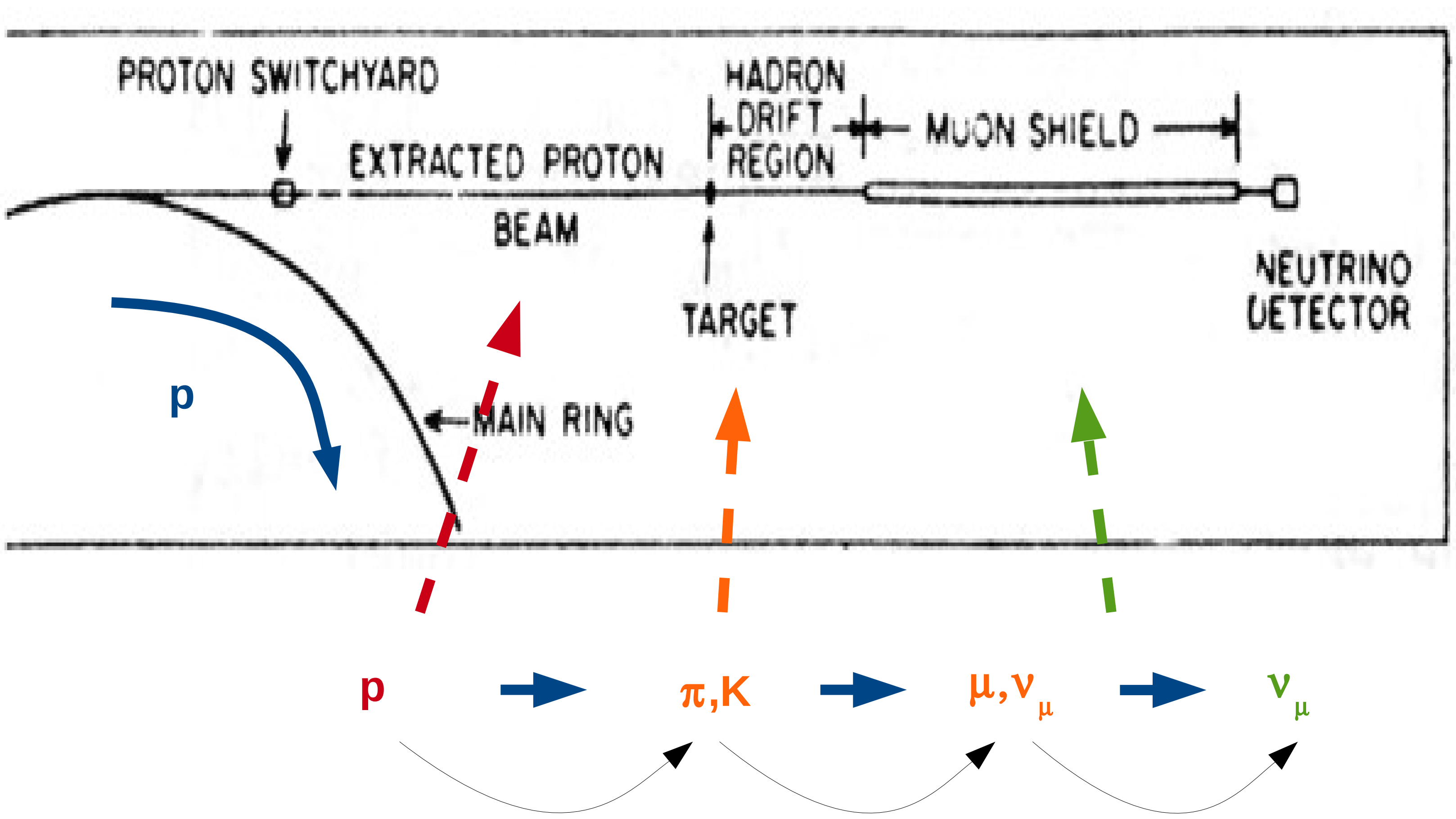
- Unambiguous probe of Z boson exchange:





Experimental set-up 1

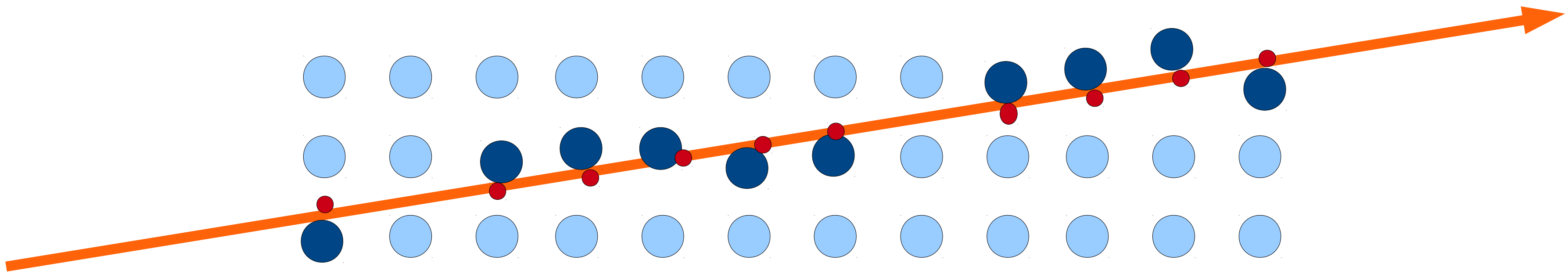
- Beamline : schematic view of Fermilab Neutrino Line (1960's)



Secondary particles   decay   Filter (e.g B field)

Experimental set-up 2

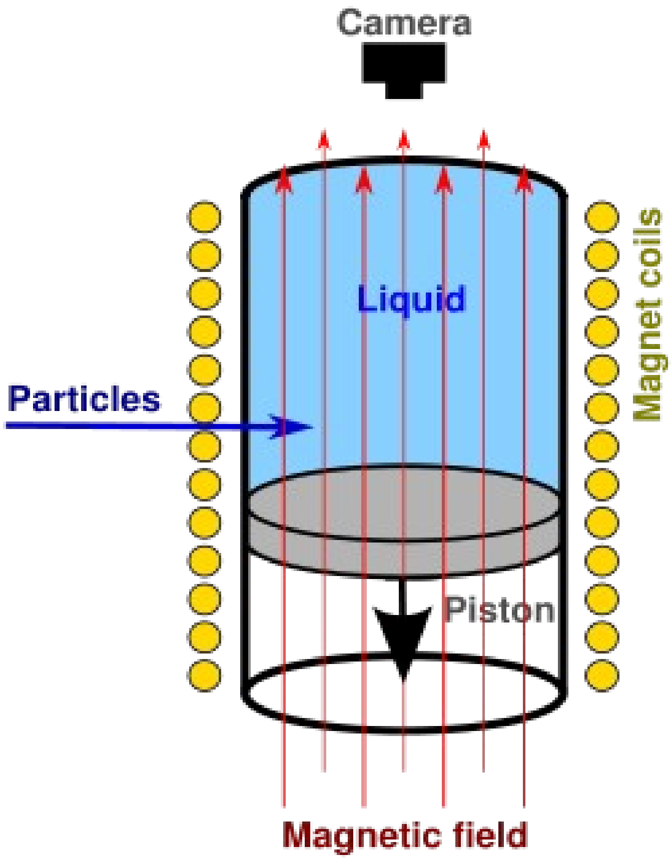
- **Particle detection == ionization**



- **Detector strategies : how to amplify and detect the ionization track?**
  - **Bubble chambers**
  - **Wire chambers**
  - **Calorimeters ......**

Experimental set-up 3

- **Principle of the bubble chamber**



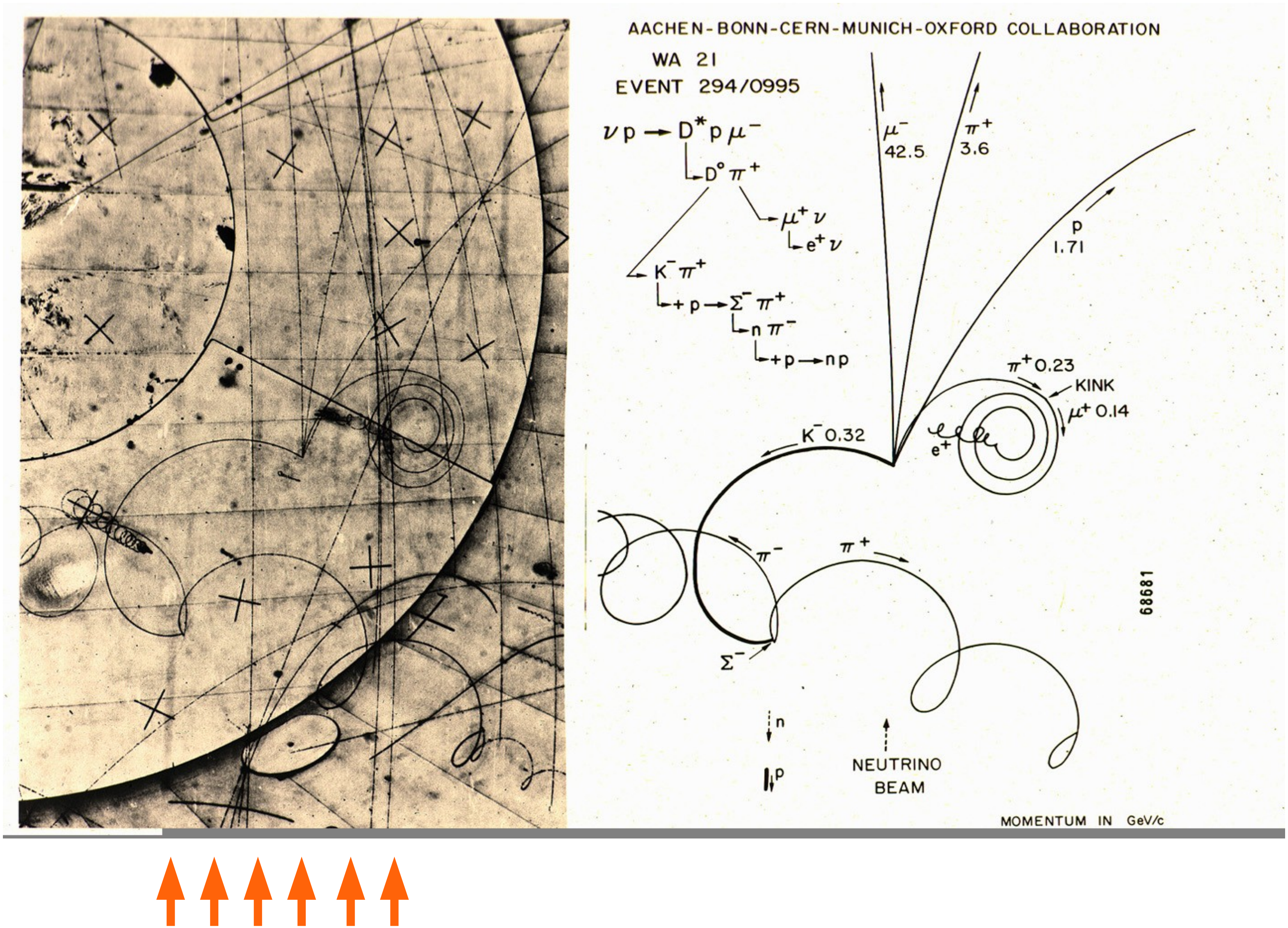
Liquid : “superheated” transparent liquid, often liquid hydrogen

Superheated : liquid above boiling point. Metastable phase, obtained by de-pressurizing the liquid just below its boiling point

The liquid vaporizes around the ionization track, Creating microscopic “bubbles”, which increase in size as the chamber expands

Finally, the camera captures the image. Charged particles are curved by the magnetic field, allowing momentum measurement.

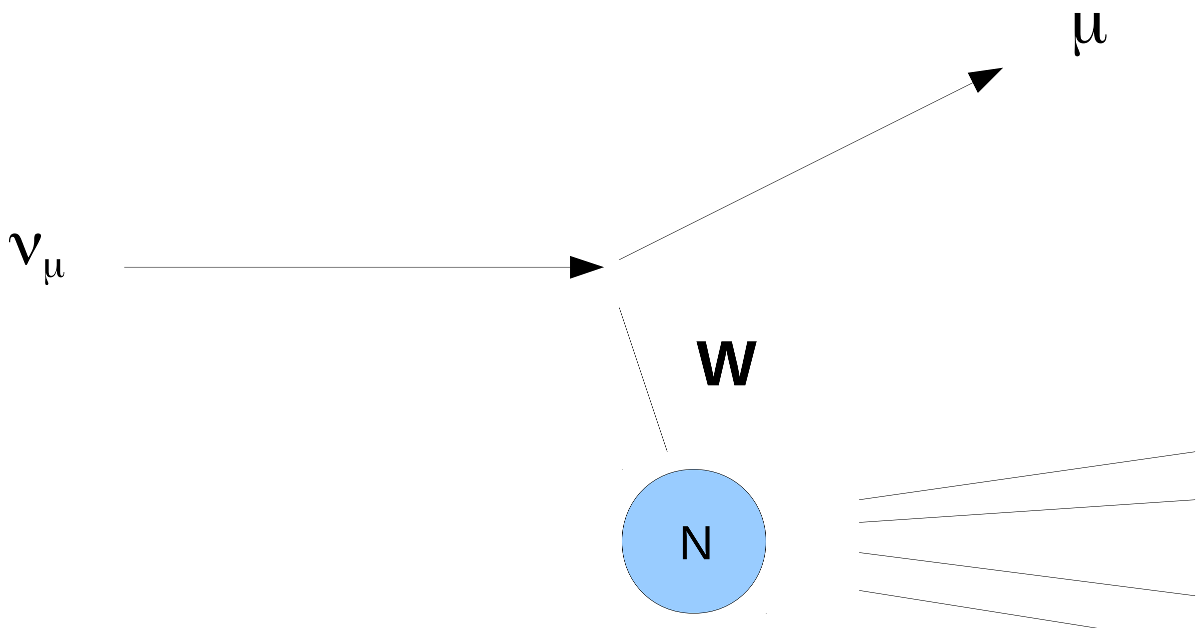
A few events


AACHEN-BONN-CERN-MUNICH-OXFORD COLLABORATION
WA 21
EVENT 294/0995
$\nu p \rightarrow D^* p \mu^-$
$D^\circ \pi^+$
$\mu^+ \nu$
$e^+ \nu$
$K^- \pi^+$
$+ p \rightarrow \Sigma^- \pi^+$
$n \pi^-$
$+ p \rightarrow np$
μ^- 42.5
π^+ 3.6
p 1.71
π^+ 0.23
KINK
μ^+ 0.14
e^+
K^- 0.32
π^-
π^+
Σ^-
n
p
NEUTRINO BEAM
68681
MOMENTUM IN GeV/c

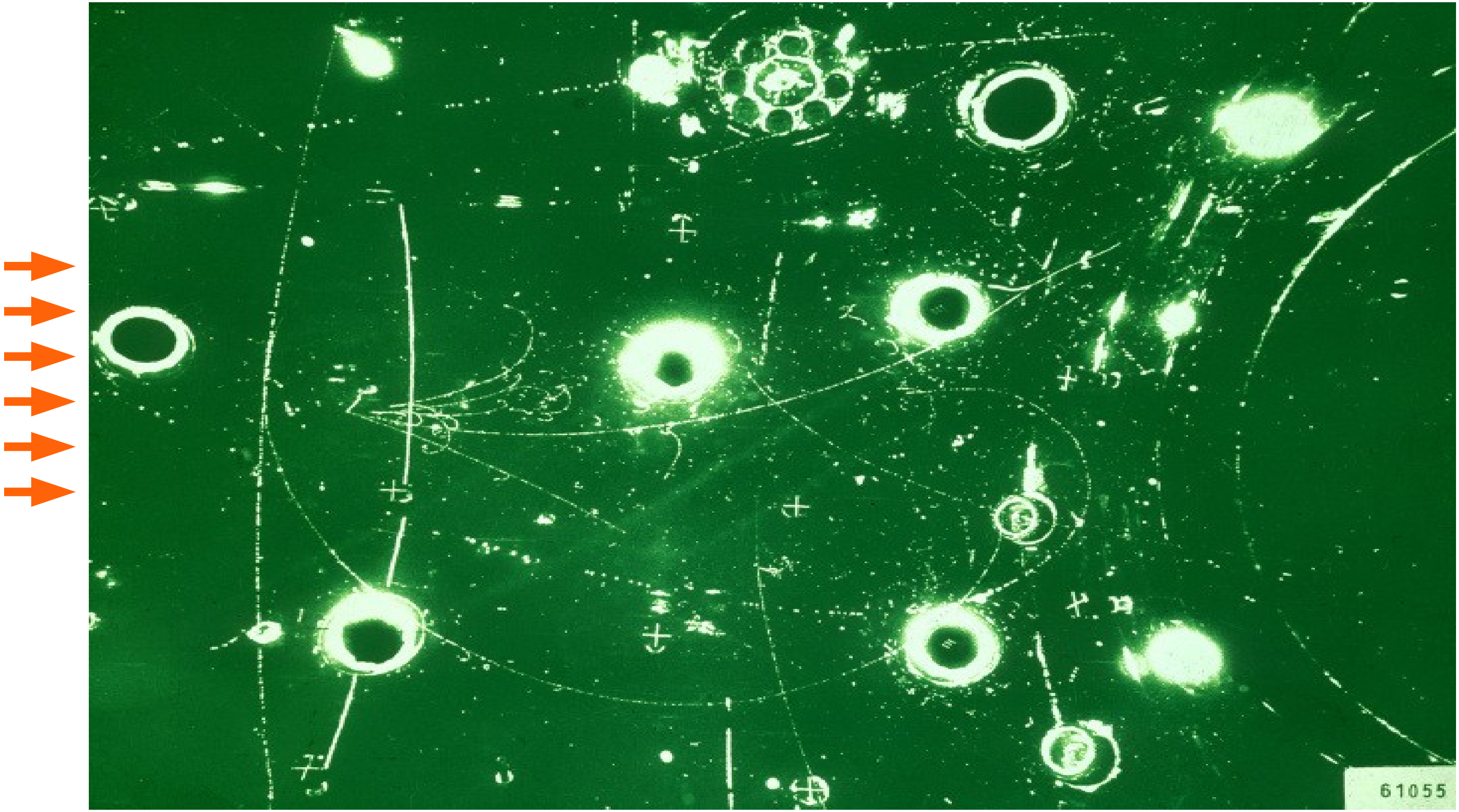
Interpretation

- Observed process: $\nu_\mu + N \rightarrow \mu + X$

- Interpretation :



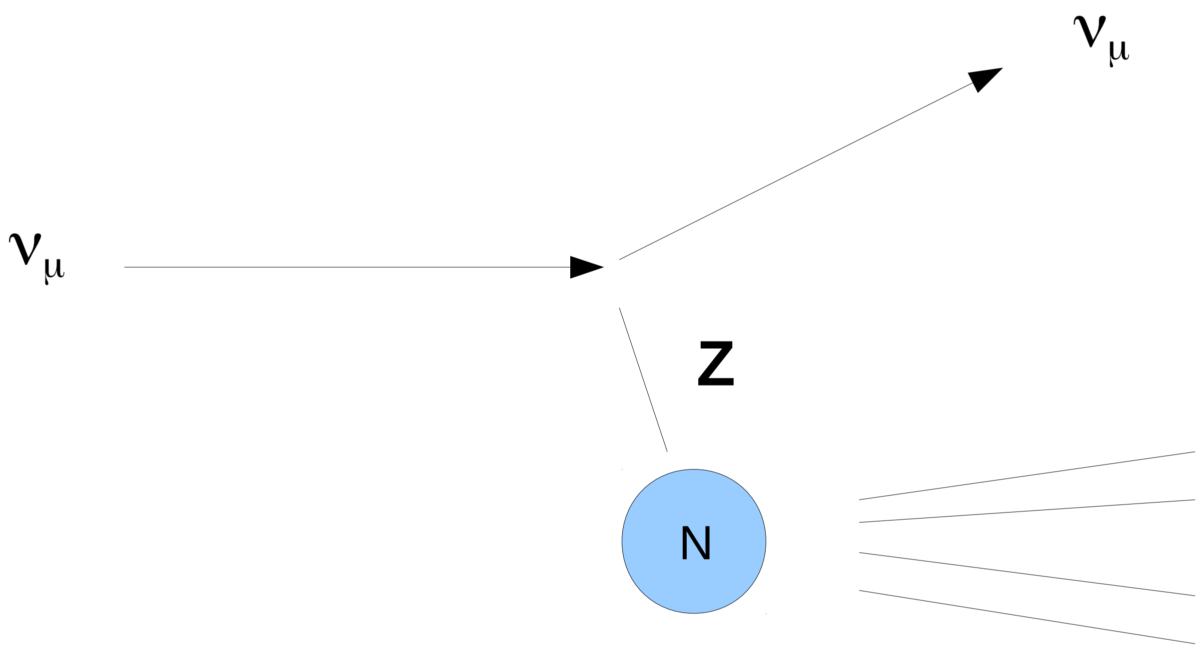
A few events



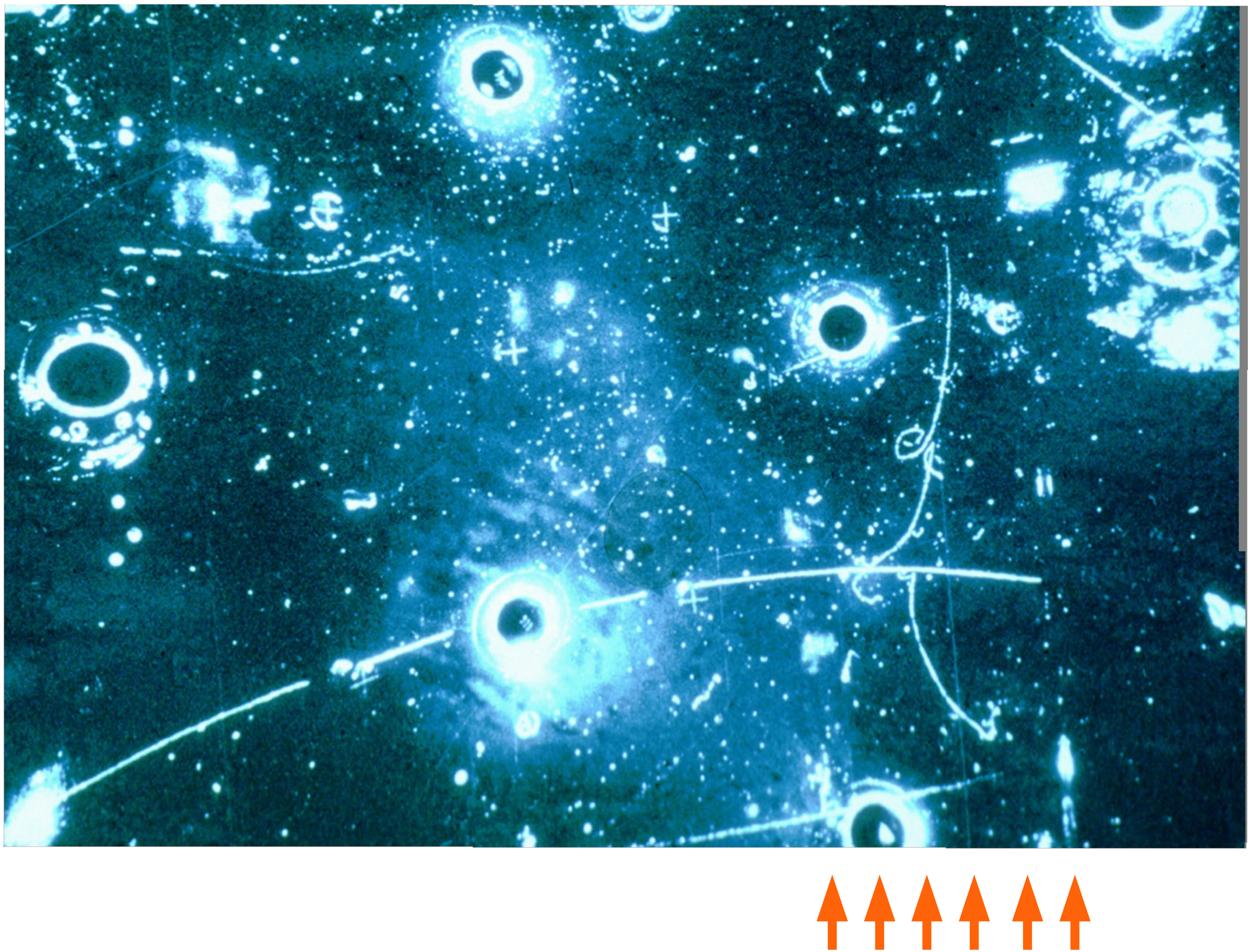
Interpretation

- Observed process: $\nu_\mu + N \rightarrow hadrons + X$

- Interpretation :



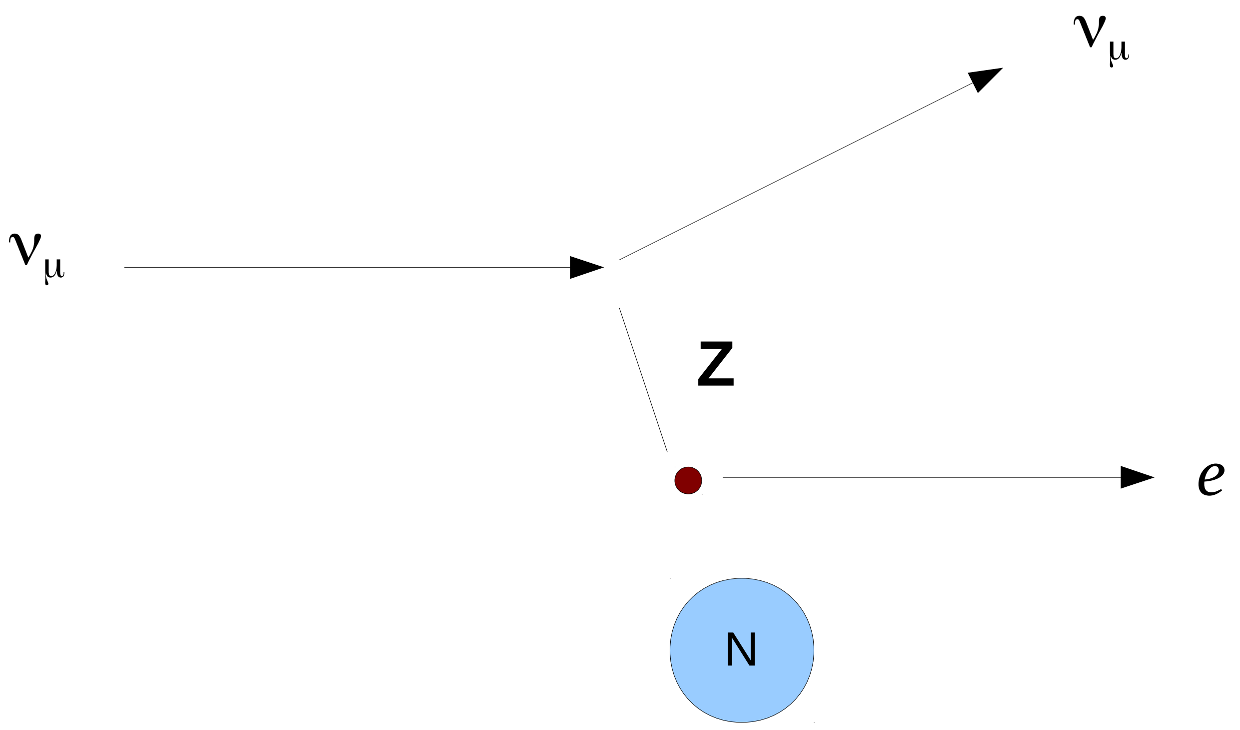
A few events



Interpretation

- Observed process: $\nu_\mu + N \rightarrow e + N$

- Interpretation :



Comments

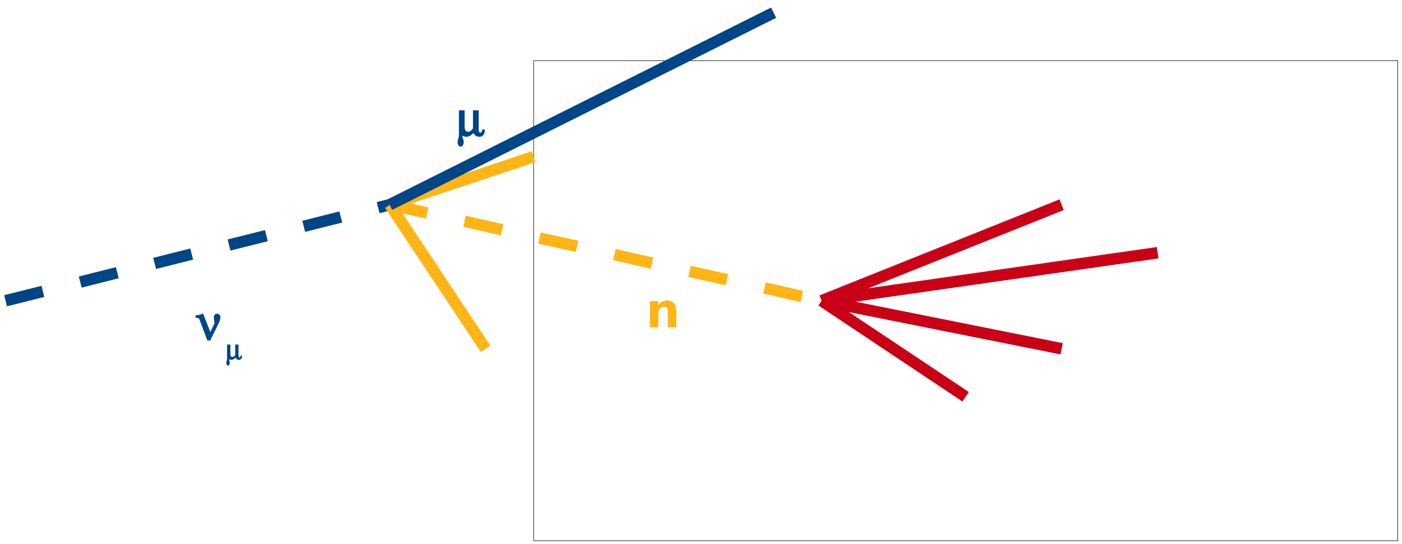
- We observed:
  - A charged current event, signed by the high-momentum muon leaving the interaction (straight track)
  - A hadronic neutral current event, signed by the may soft recoiling hadron tracks (“X”; curved tracks)
  - An electron neutral current event, signed by the soft electron leaving the interaction alone.

- Note the importance of choosing a muon-neutrino beam!! The following would be ambiguous:
  - Electron beam
  - Electron-neutrino beam

  Why?

Results : hadronic neutral currents

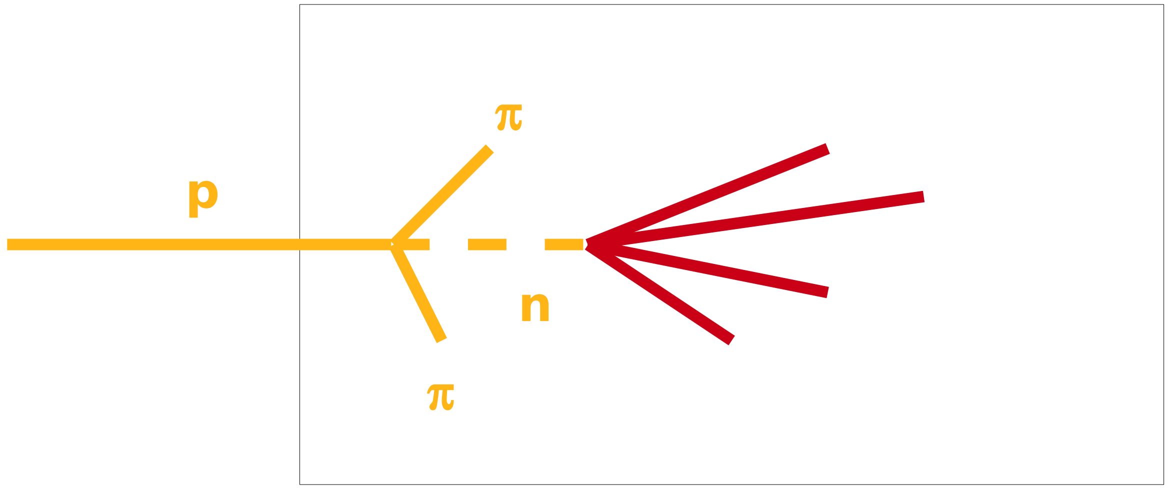
- The observation of hadronic neutral currents was exciting and led to many discussions concerning their interpretation!
- Paper by Gargamelle Collaboration claiming discovery: **“Observation of Neutrino Like Interactions Without Muon Or Electron in the Gargamelle Neutrino Experiment.”** Phys.Lett.B46:138-140,1973
- Controversy : Neutron background?



Controversy and solution

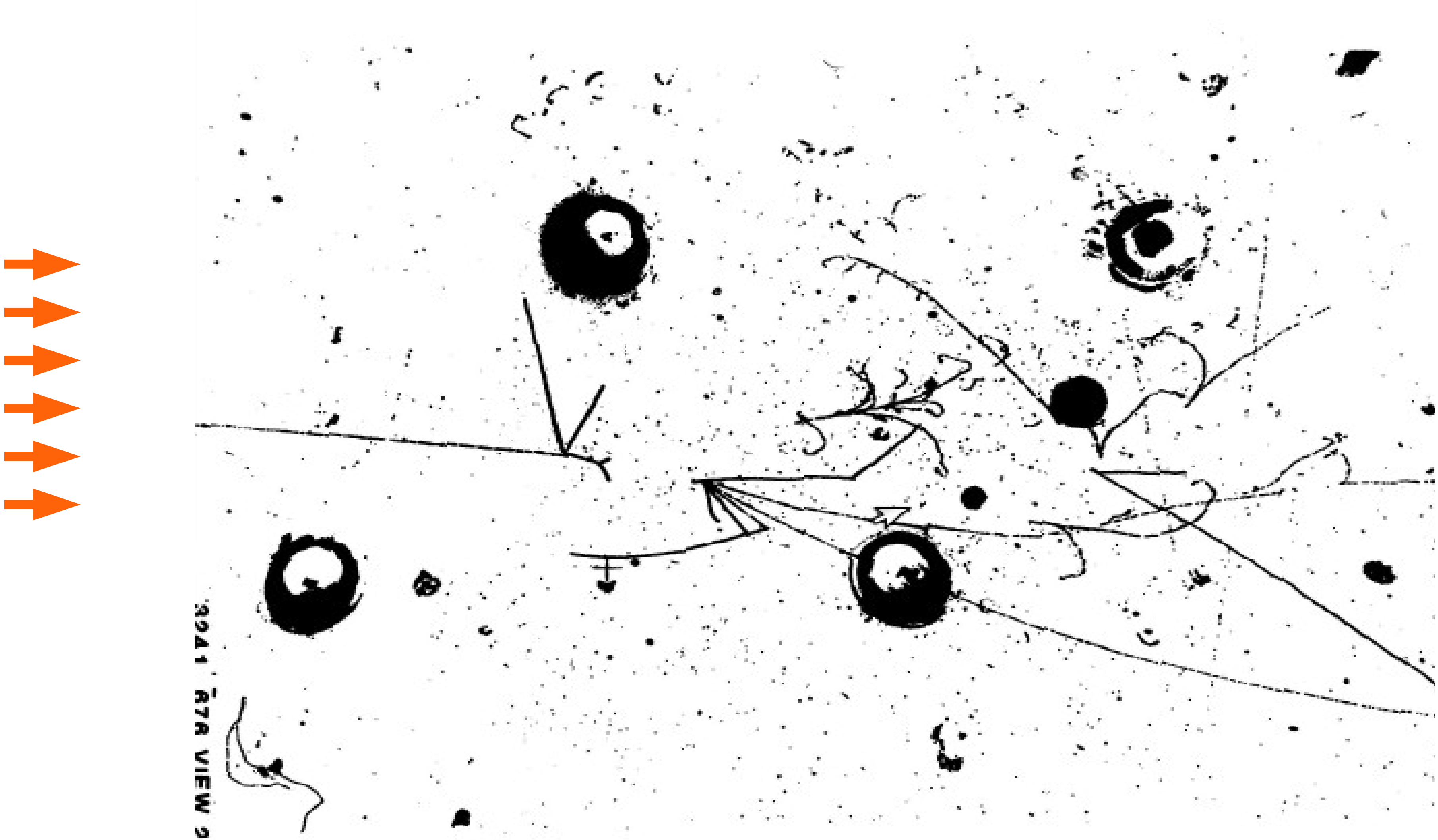
- Issues : neutron propagation and cascades in matter are strong interaction processes that are difficult to predict. So how confident are we that their contribution to the observed event rate is small?

- Cross-check (auxiliary measurement): although we don't know the detail of the neutron interactions with matter, we can induce unambiguous neutron cascade events to **measure** the wanted properties.
  I.e study:



- Remember this! It is an example of a fundamental ingredient of experimental particle physics.

Example proton event



Confirmation

- This "cross-measurement" proved that the neutron background is indeed low.
- This, together with the accumulation of many more candidate events, **confirmed the neutral current interpretation of the observed events**.
- First confirmation of the Electroweak model! Nobel prize for G,S,W.
- What next?
  - Need to establish the existence of the weak bosons themselves (i.e, observe the resonances)
  - Therefore, we need to have an idea of their masses!
  - And therefore, we need to measure $\sin^2\theta_W$.

Interlude

- **Very basic notions of statistics – searches for rare processes**

  - We are always confronting two hypotheses:
    - The "background only" hypothesis
    - The "background+signal" hypothesis
  - Both background and signal are rare processes, thus following a Poisson distribution around their mean expectations:

$$P(n,b)=\frac{b^n e^{-b}}{n!} \qquad P(n,b+s)=\frac{(b+s)^n e^{-(b+s)}}{n!}$$

  - We call a discovery when the **background only hypothesis** can be rejected with confidence, i.e the probability that the background fluctuates **up** to the observed value **n** is very small

    A usual convention is the "5σ" discovery, corresponding to probability smaller than ~3.10^{-7}

Interlude

- **Very basic notions of statistics – searches for rare processes**

  - We call an exclusion when the **background+signal hypothesis** can be rejected with confidence, i.e the probability that the sum of background and signal events fluctuates **down** to the observed value **n** is very small
    A usual convention is the "95% Confidence Level", i.e is **b+s** is true, then only 5% of experiments would see **n** events or less

  - Some applications
    - Assume I know that **b=0**, how many observed events do I need to claim a discovery?
    - Assume I know that **b=0**, and that I observe **n=0**, how many signal events can I exclude at the 95% C.L.?

  - More involved applications
    - Treatment of uncertainties on the background and signal yields
    - Many, many, many more discussions on this subject