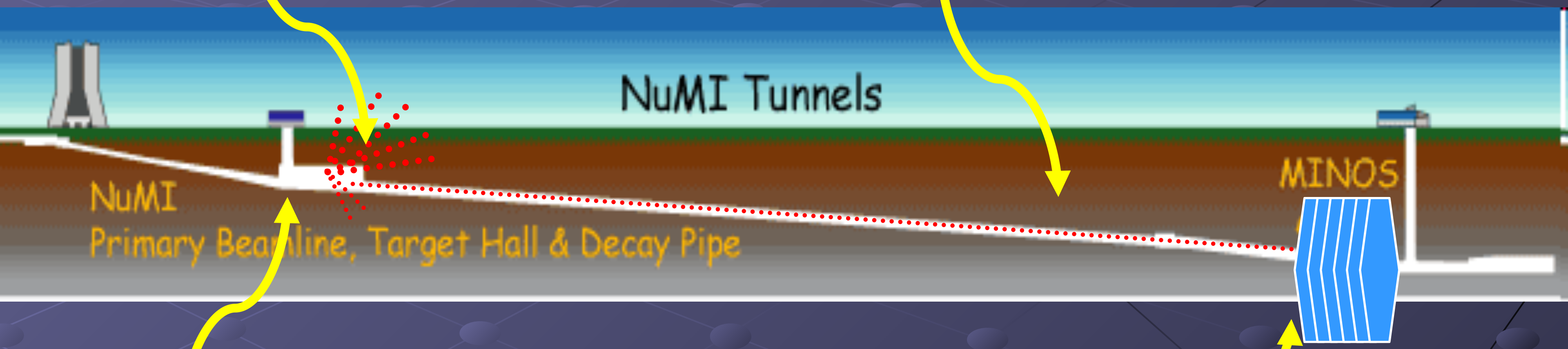
Neutrino Pathway: Creation to Target

Multi-directional neutrino spray

Only the neutrinos that happen to travel down the beam line are detected.

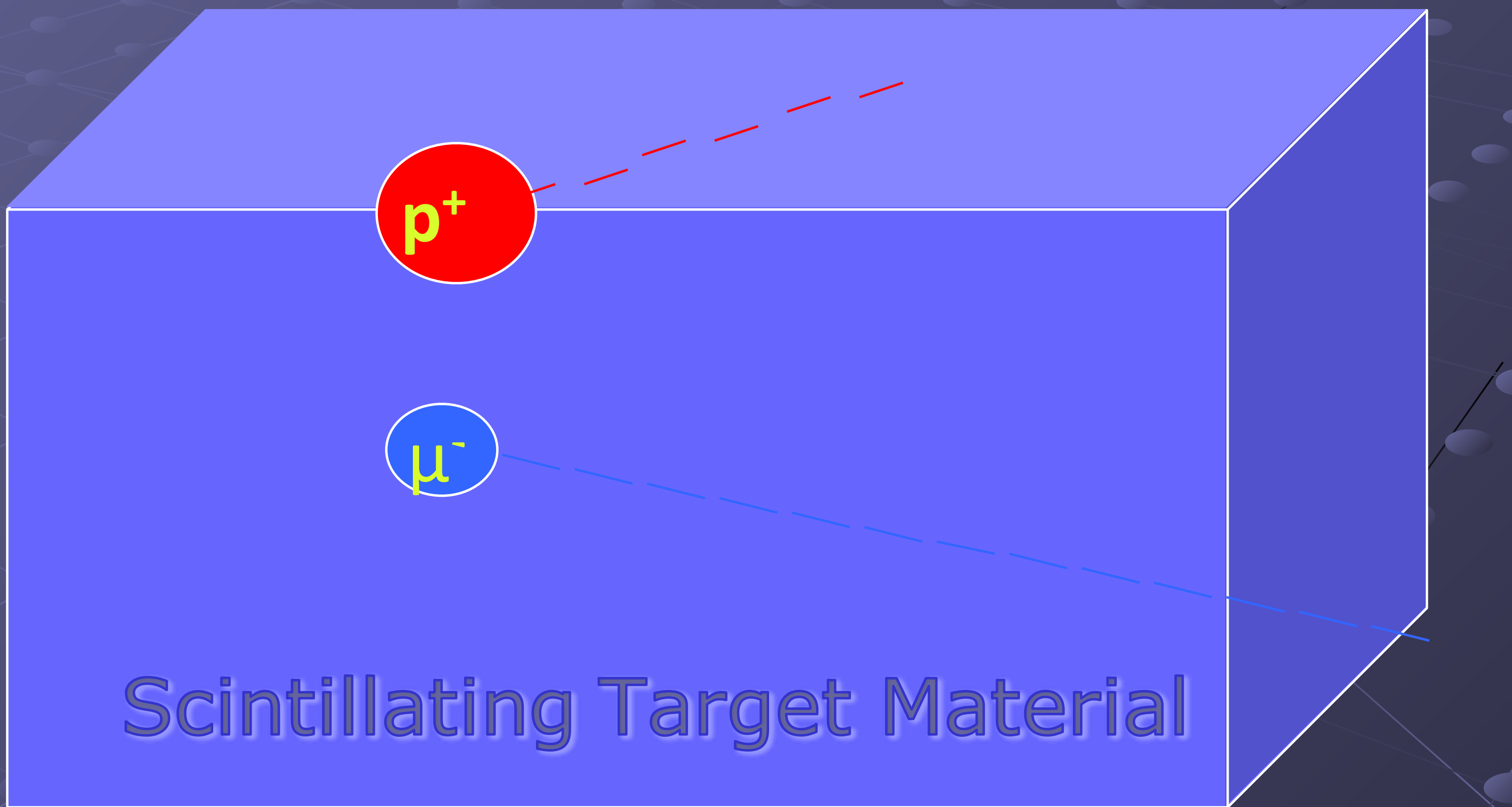


Site of pion & neutrino creation (from original high energy proton).

MINERnA &
“near MINOS” Detectors

MINERvA's Principal Interaction Of Interest (What we see)

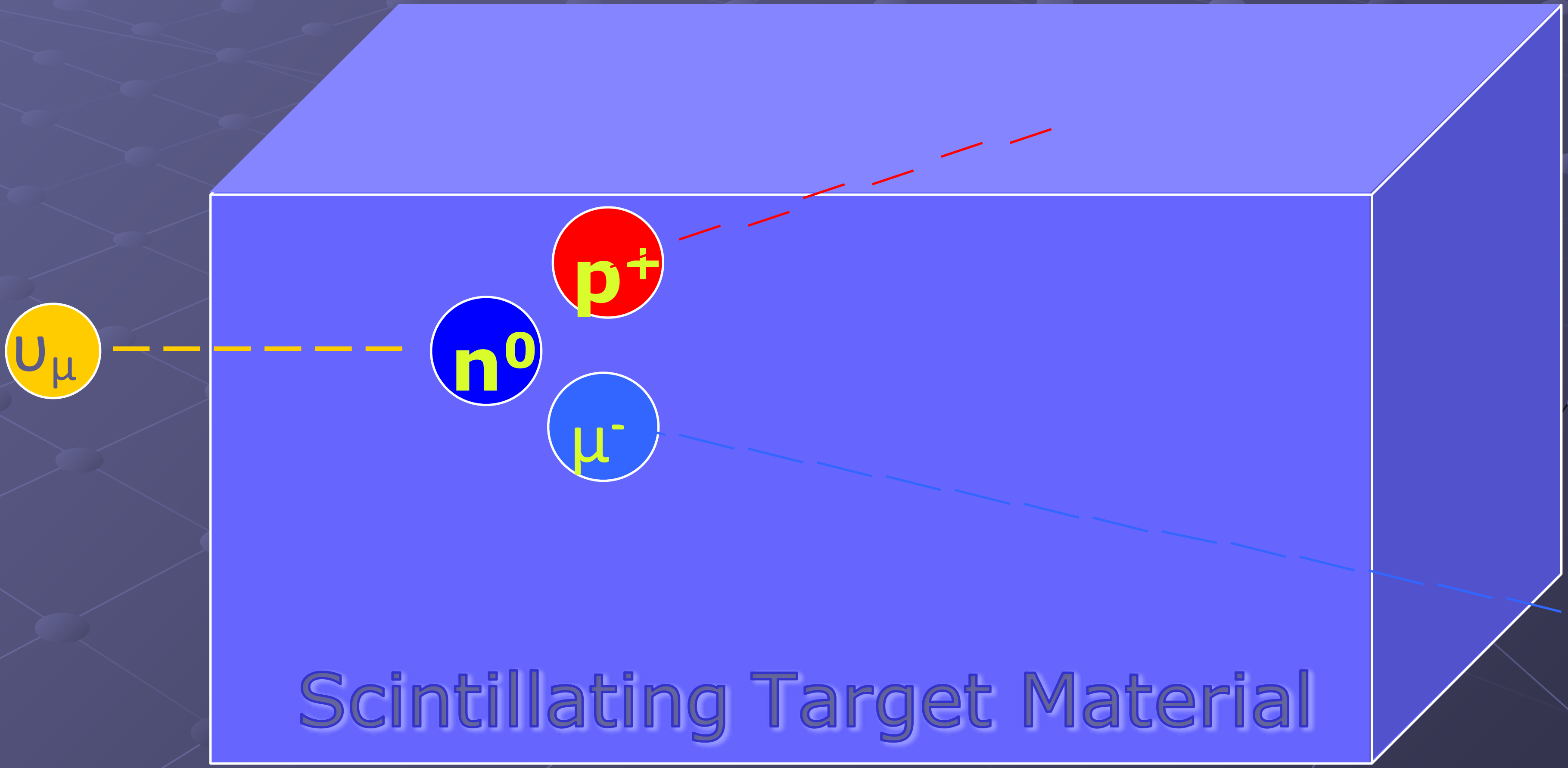
A proton and muon "appear" out of nowhere in the scintillating target



MINERvA's Principal Interaction Of Interest (Revealed)

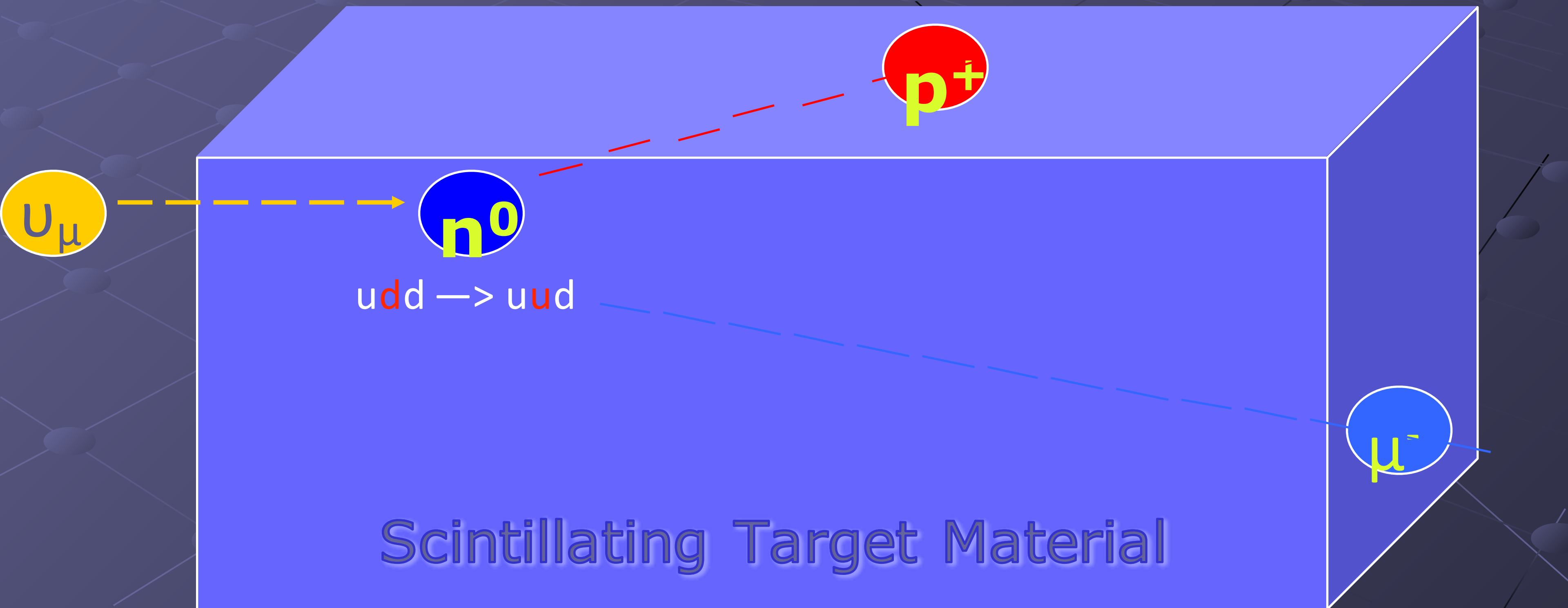
neutrino + neutron → proton + muon

$\nu_{\mu-}$ + n^0 → p^+ + μ^-

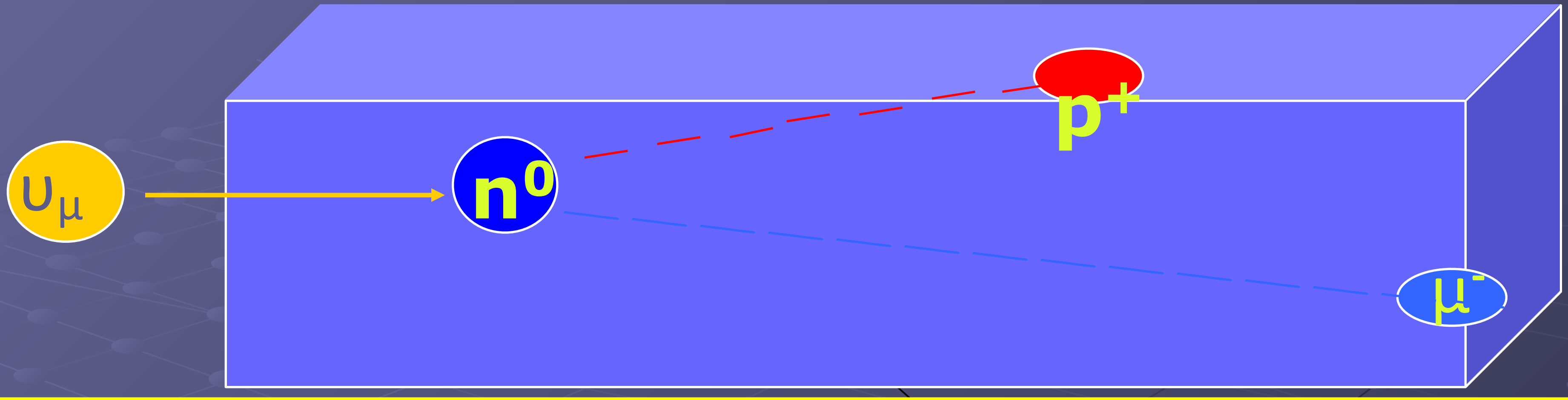


What's Going On?

- A neutrino with kinetic energy strikes a neutron at 'rest' in the nucleus of an atom…
- Which causes one of the neutron's down quarks to flip "up" (udd to uud) … transforming it to a proton!
- Simultaneously, a muon is generated as the neutrino annihilates



What's Going On?

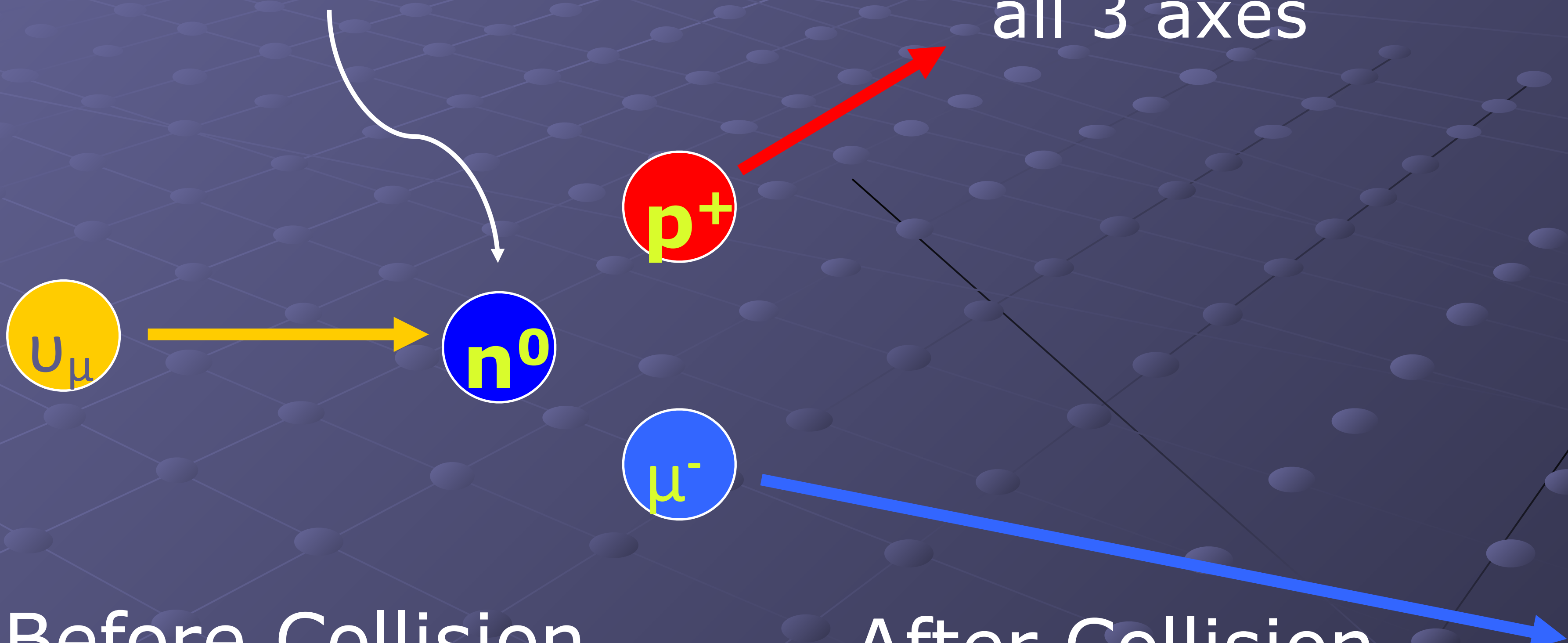


- Also, there is a net gain of mass & a loss of energy during the interaction ($E = \Delta mc^2$)…
- Some of the neutrino's pre-collision kinetic energy changes into new mass (the muon) and some is transferred to the kinetic energies of the muon and proton.

Important Momentum Ideas

At the position and time of the interaction **only!**

Momentum is conserved in all 3 axes



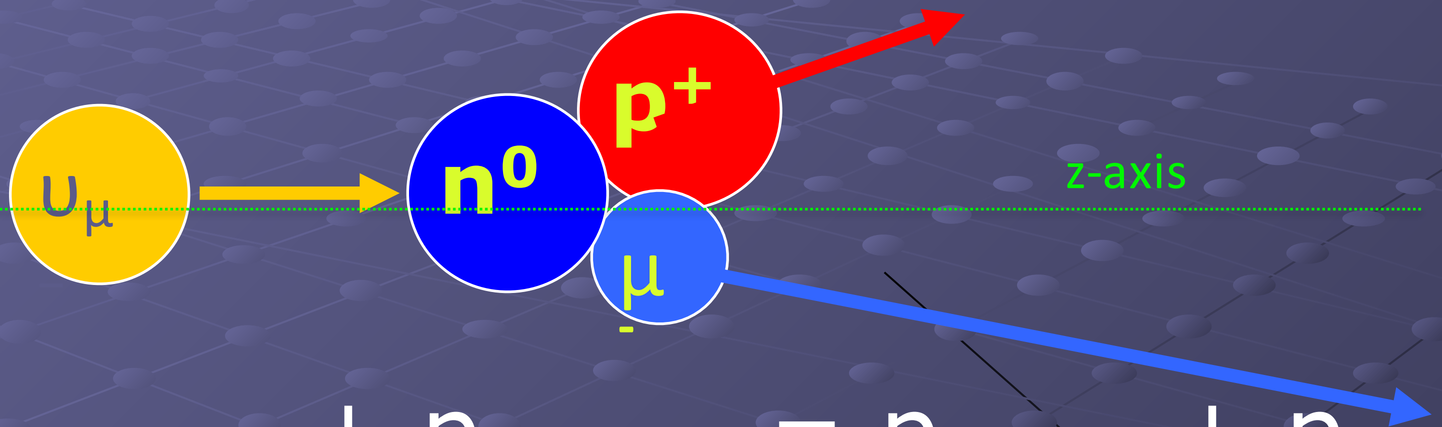
Before Collision

After Collision

$$p_{neutrino} + p_{neutron} = p_{proton} + p_{muon}$$

Important Momentum Ideas continued

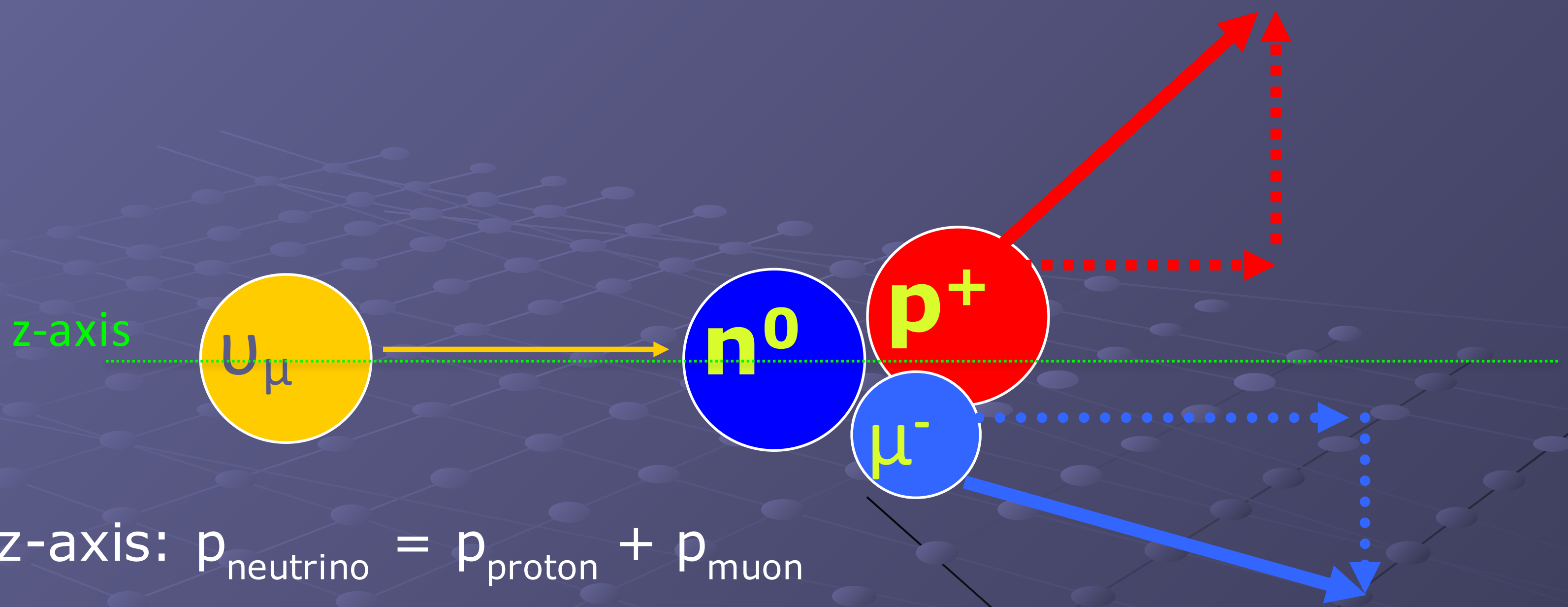
The beam is aimed so that neutrinos only have momentum in the z-axis!



$p_{neutrino} + p_{neutron} = p_{proton} + p_{muon}$

In the z-axis: $p_{neutrino} = p_{proton} + p_{muon}$

Important Momentum Ideas continued



z-axis: $p_{neutrino} = p_{proton} + p_{muon}$

If the target neutron is totally at rest…

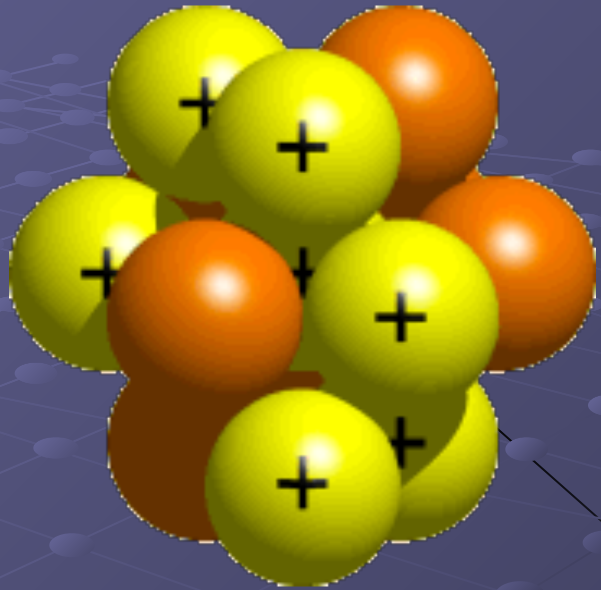
… then in the x-axis & y-axis

$$p_{proton} + p_{muon} = 0$$

SUMMARY

- A neutrino with all the initial z-axis momentum collides with a presumably stationary neutron
- the neutron transforms into a proton, while the neutrino annihilates into a muon
- the total momentum of the proton & muon in the z-direction equals that of the neutrino
- the total momentum of the proton & muon in the x & y direction should equal zero

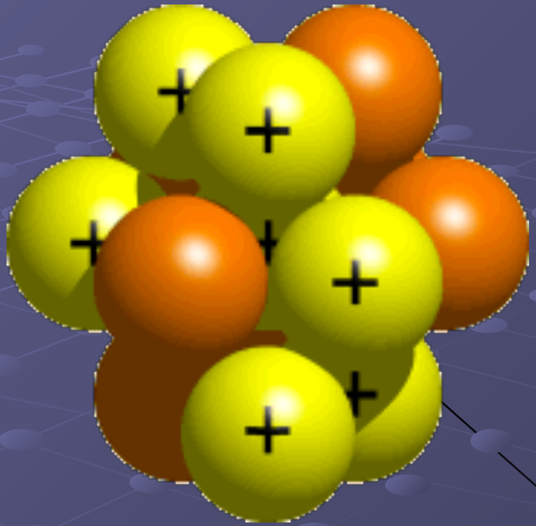
A Closer Look at Nucleons in Carbon



Basic assumption is that nucleons are more or less stationary

- That is, they have zero momentum when confined in nucleus

A Closer Look at Nucleons in Carbon



But if confined in nucleus, then must consider ...

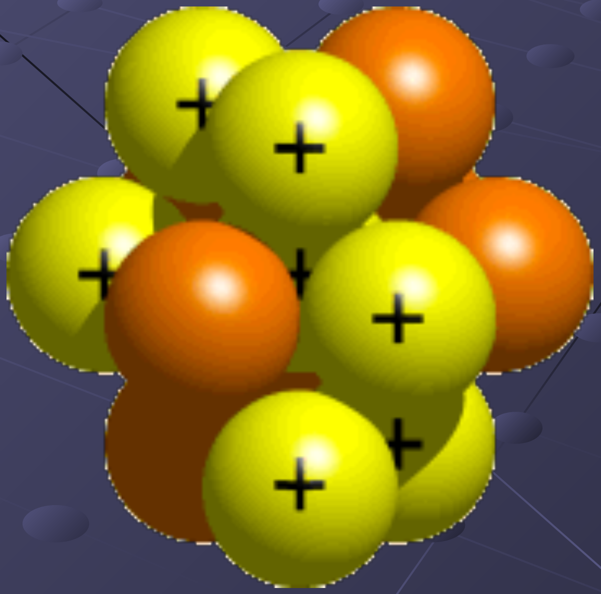
HEISENBURG

Uncertainty Principle

At quantum level …

Product of uncertainty in position & momentum of a particle > minimum value

↳ $\Delta x \cdot \Delta p > h/4\pi$



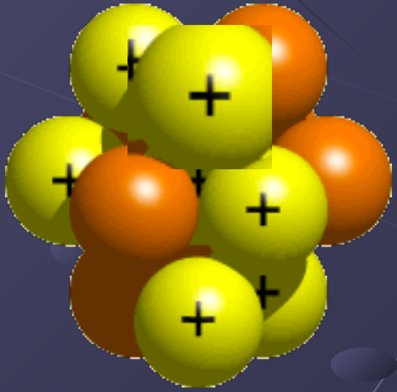
Uncertainty Principle continued

If nucleons are bound in a nucleus then
Δx ~ extent of nucleus ~ 1 fermi

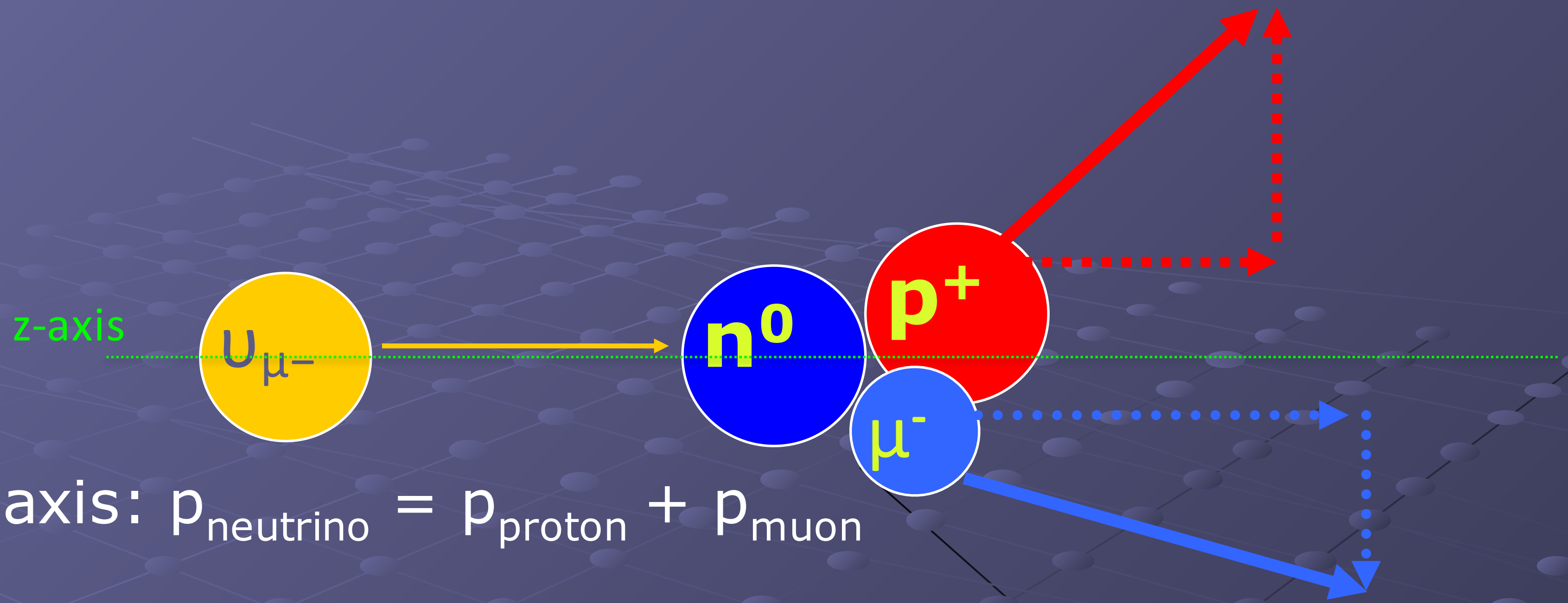
And a non-zero Δx requires a non-zero Δp

That is, nucleons must have non-zero momentum when confined in nucleus

$$\Delta p > \frac{h}{4\pi} \cdot \frac{1}{\Delta x}$$



Going Back to MINERvA interactions



z-axis: $p_{neutrino} = p_{proton} + p_{muon}$

If the target neutron has motion…

… then in the x-axis & y-axis

$$p_{proton} + p_{muon} \neq 0$$

Reversal in Approach

Data from MINERvA gives momentum (& energy) of muon/proton pairs in all 3 directions

For each pair can use x & y momenta to get x & y momenta of target neutrons

By plotting distribution of x & y momenta of neutrons can get uncertainty in their momenta Δp

Applying Δp to Uncertainty Principle allows derivatio n of uncertainty in position of neutrons Δx

Which in turn gives an approximation of the extent of the carbon nucleus

EQUATION

$$\Delta x > \frac{h}{4\pi} \cdot \frac{1}{\Delta p}$$

Δp is in units of MeV/c

h is in units of MeV·s