MINERvA Neutrino Masterclass

Masterclass Hands on Particle Physics

Comentario de resultados

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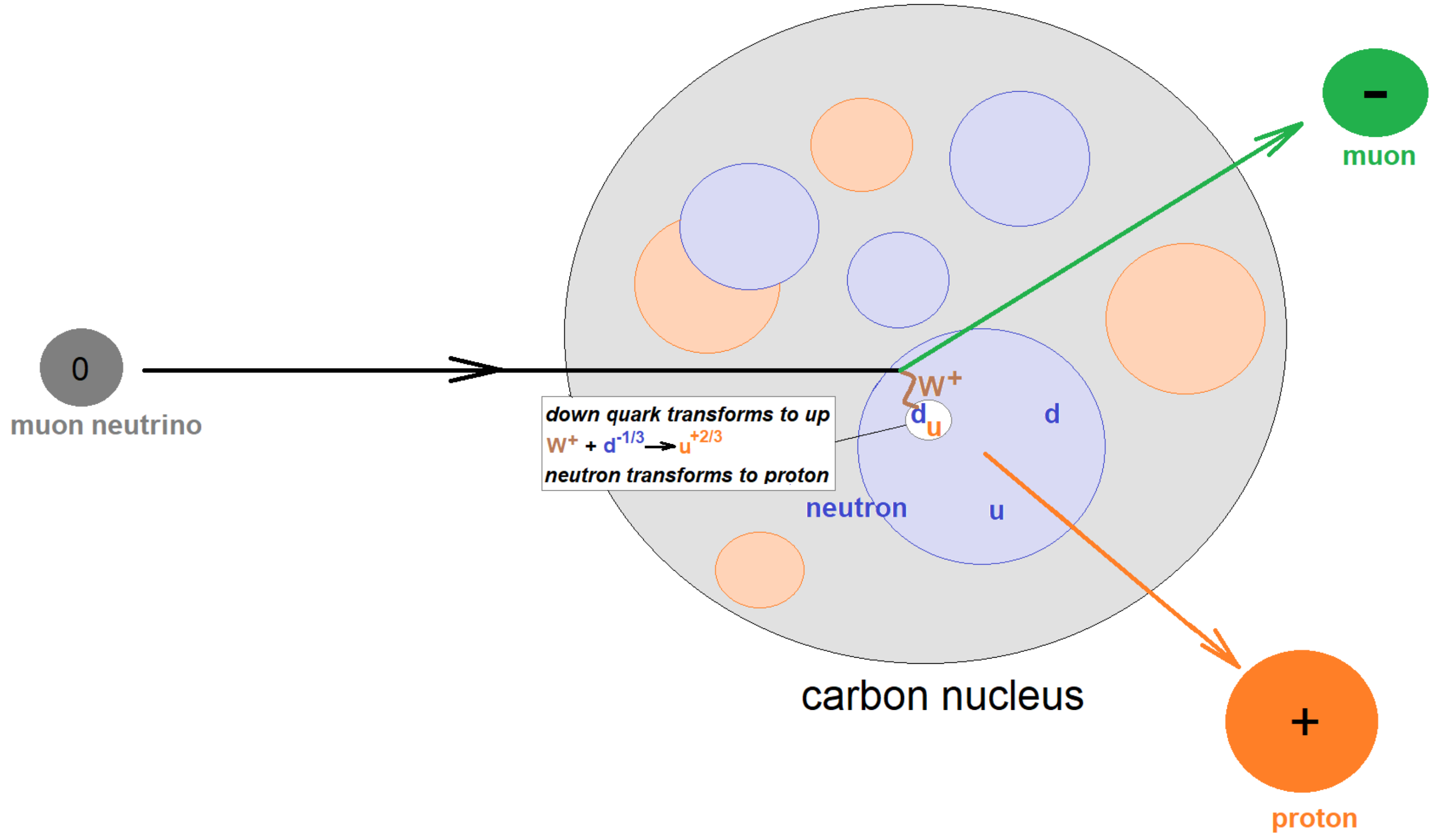
Signal and background events

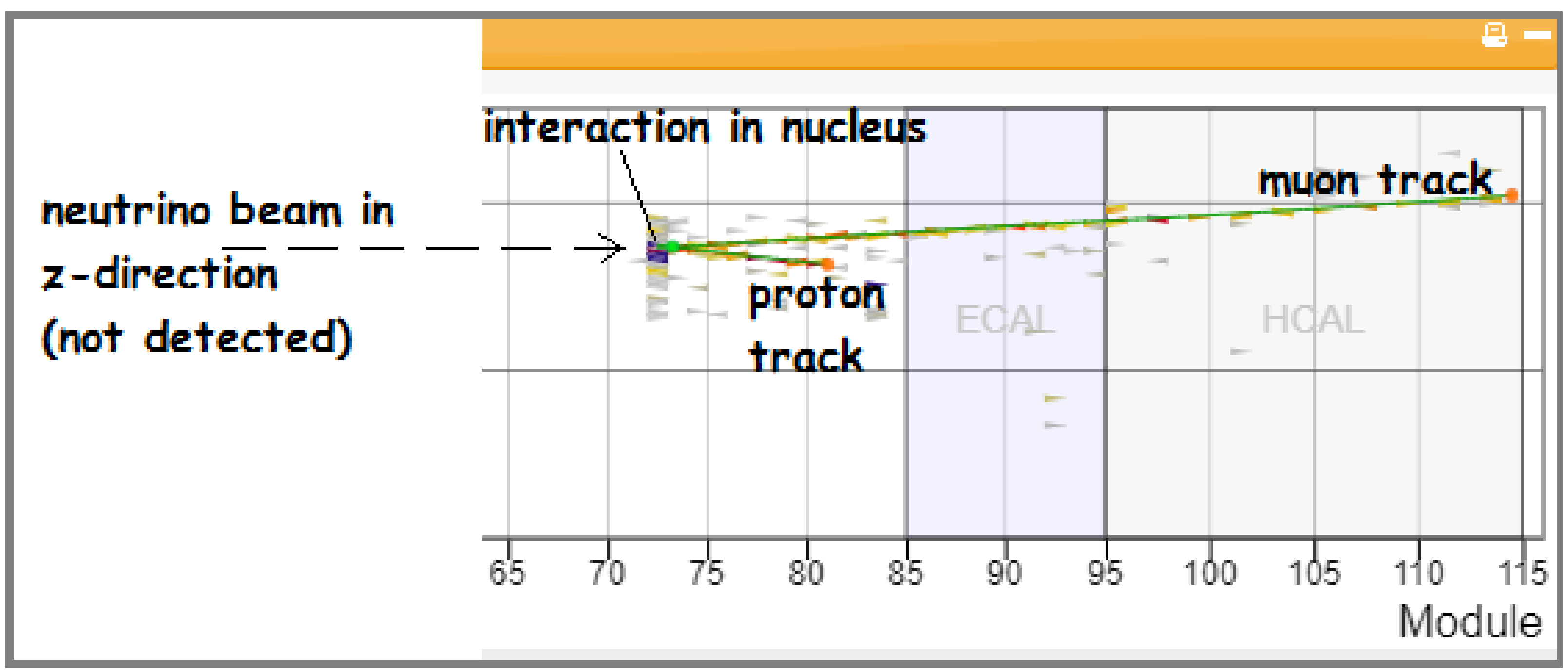
- There are both **background** and **signal** events
- In each **signal** event, a neutrino penetrates a nucleus in carbon target and undergoes a weak interaction with a neutron in that nucleus
  - → The neutrino interacts with the neutron to become a muon, causing the neutron to become a proton!



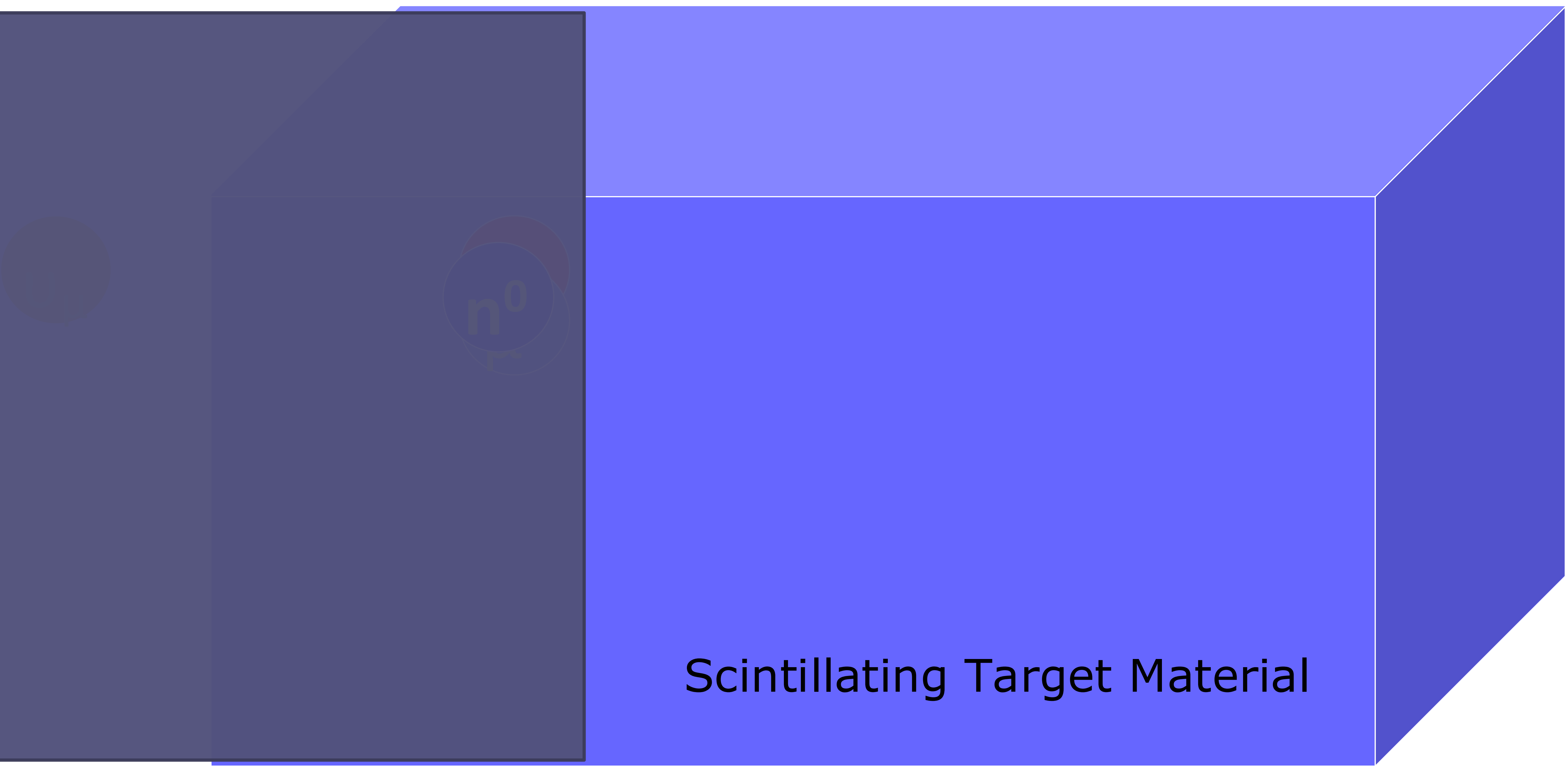
- **Background** event: any other event type

Interaction kinematics

- While **MINERvA** cannot directly detect the neutrino, it detects and measures the kinematics of both the muon and the proton that emerge from the interaction
- You can find this kinematic information with **Arachne**, the MINERvA event display that you will use to visualize the events.
- You will then put this information into a spreadsheet which applies conservation of momentum to give the momentum of the system prior to the interaction in three dimensions.

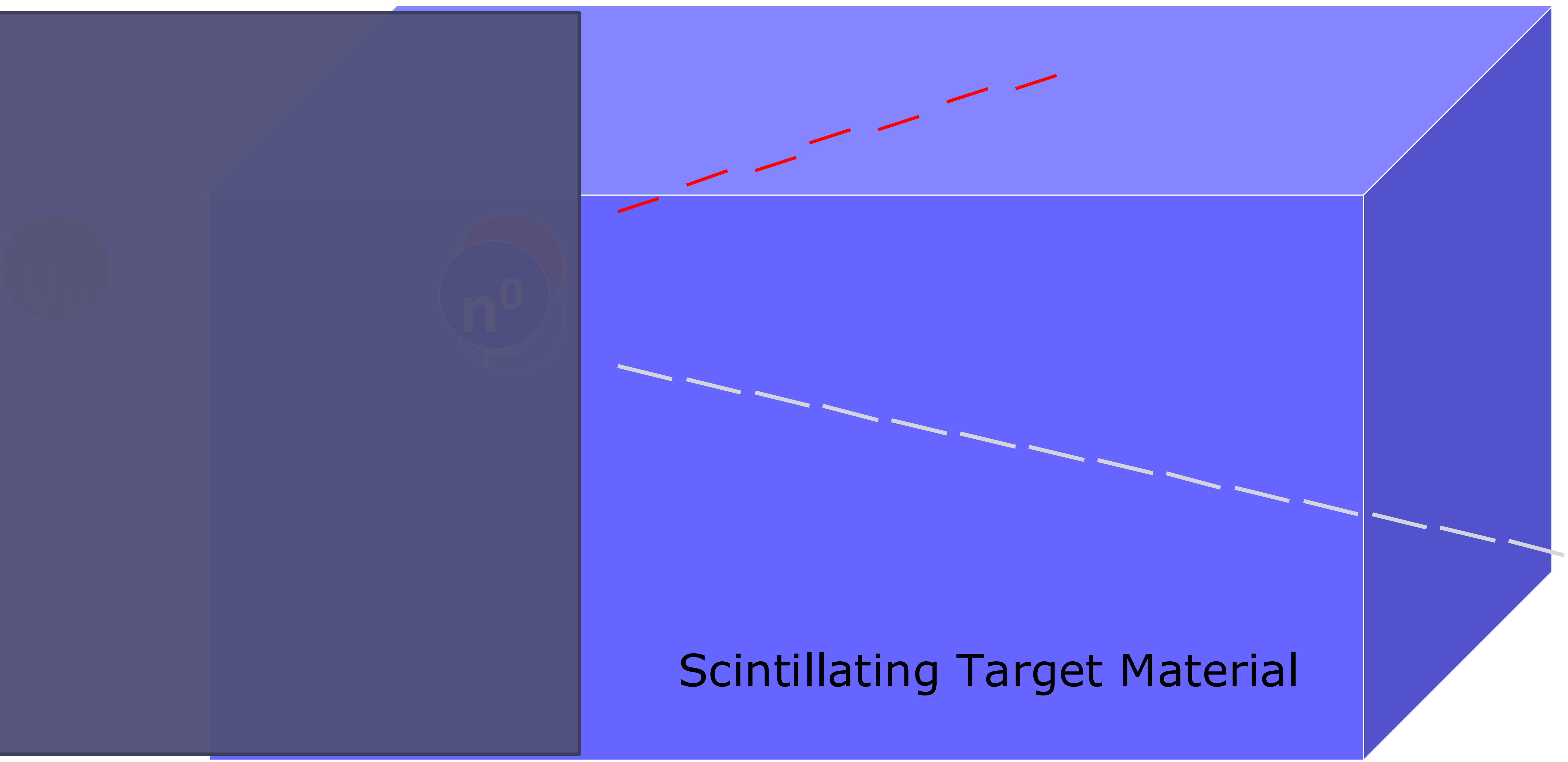


MINERvA's Principal Interaction Of Interest (What we see)



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

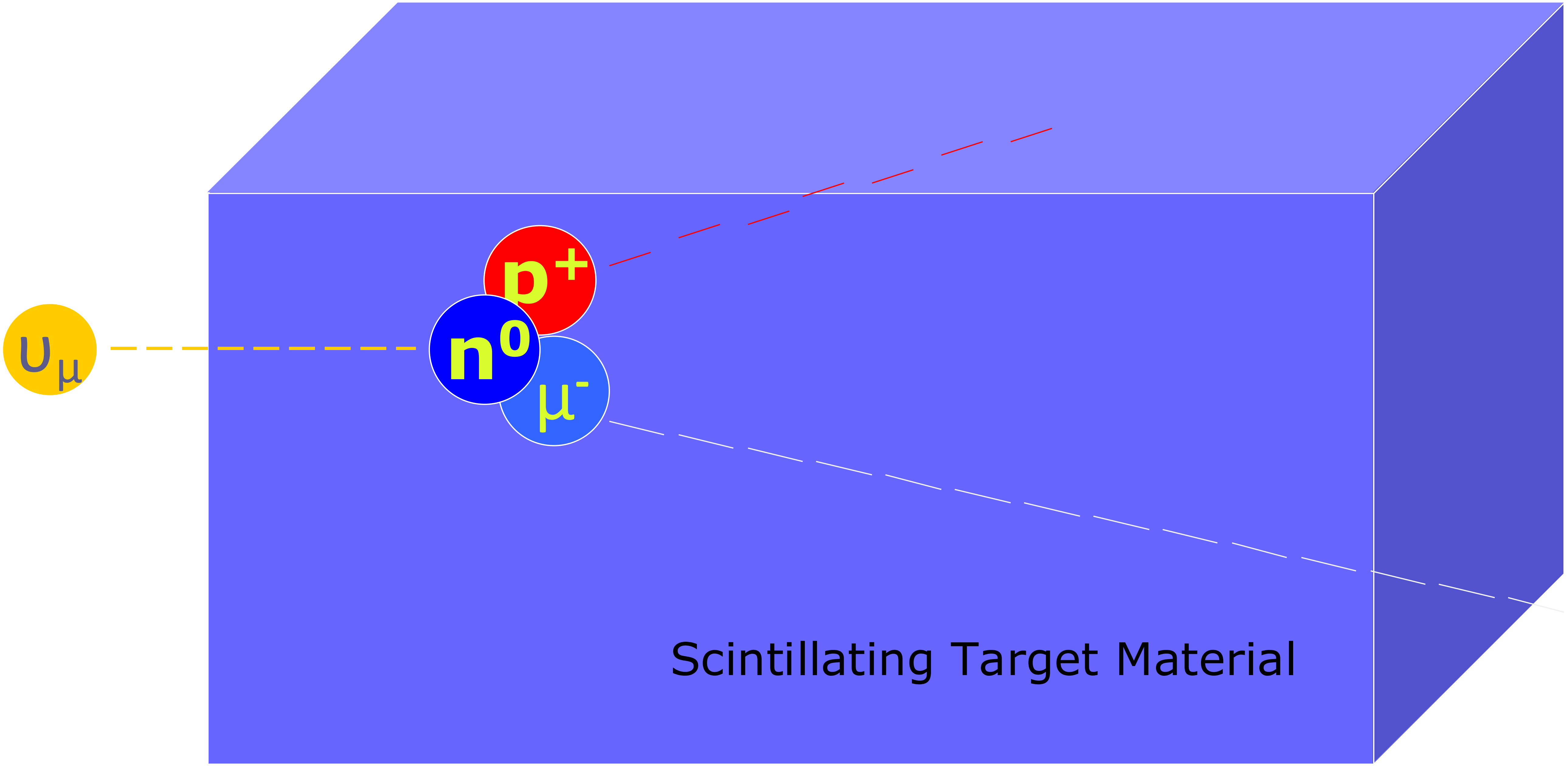
A proton and muon "appear" out of nowhere in the scintillating target



MINERvA's Principal Interaction Of Interest (Revealed)

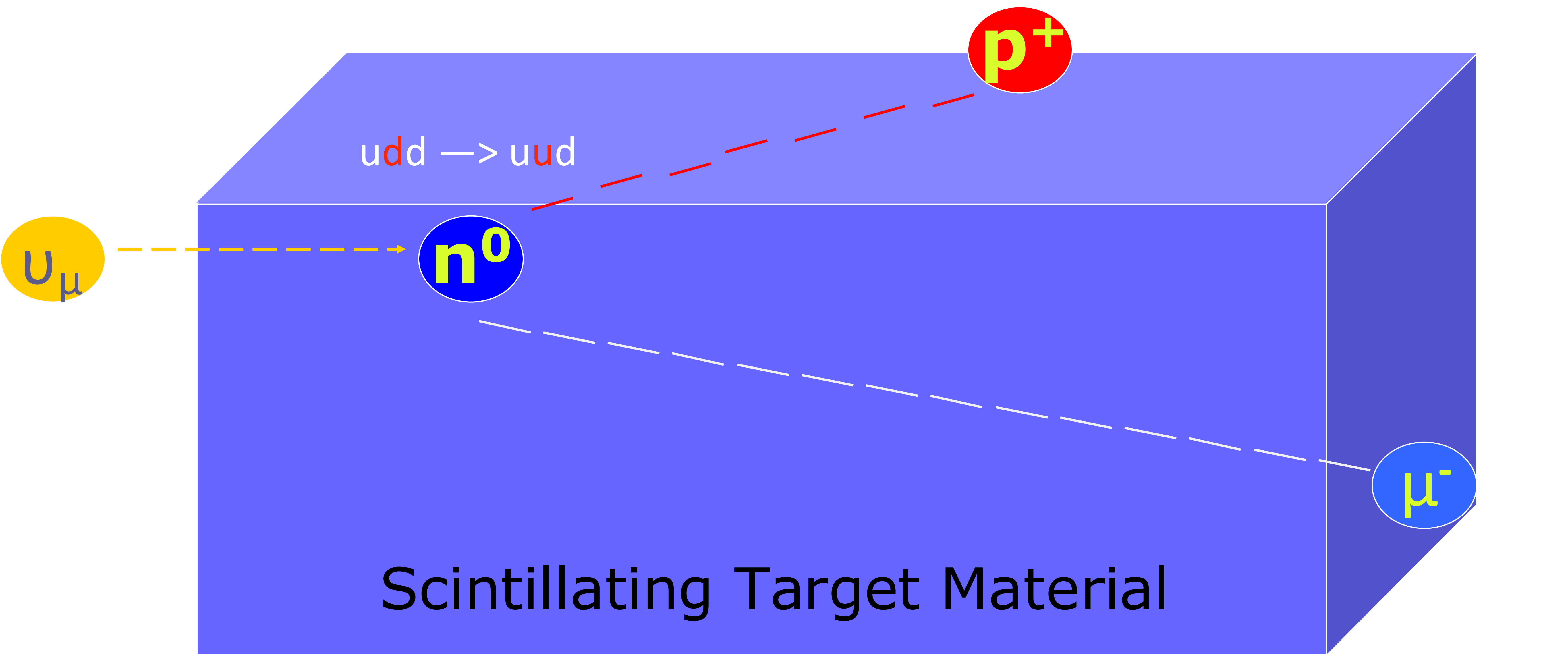
neutrino + neutron → proton + muon

$$\nu_{\mu^-} + n^0 \rightarrow p^+ + \mu^-$$



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



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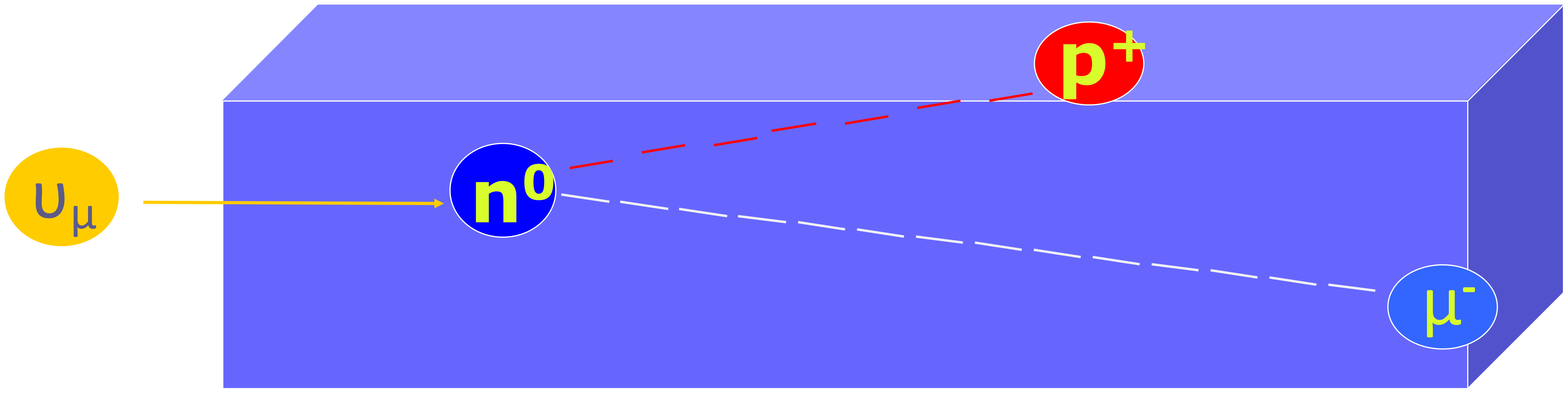


- Also, there is a net gain of mass & a loss of energy during the interaction ($E = \Delta mc^2$)

- 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.

Masterclass objectives

- Determine which events are **signal** events *(from which effective measurements may be made)* and which events are **background** (that cannot be used for measurements).

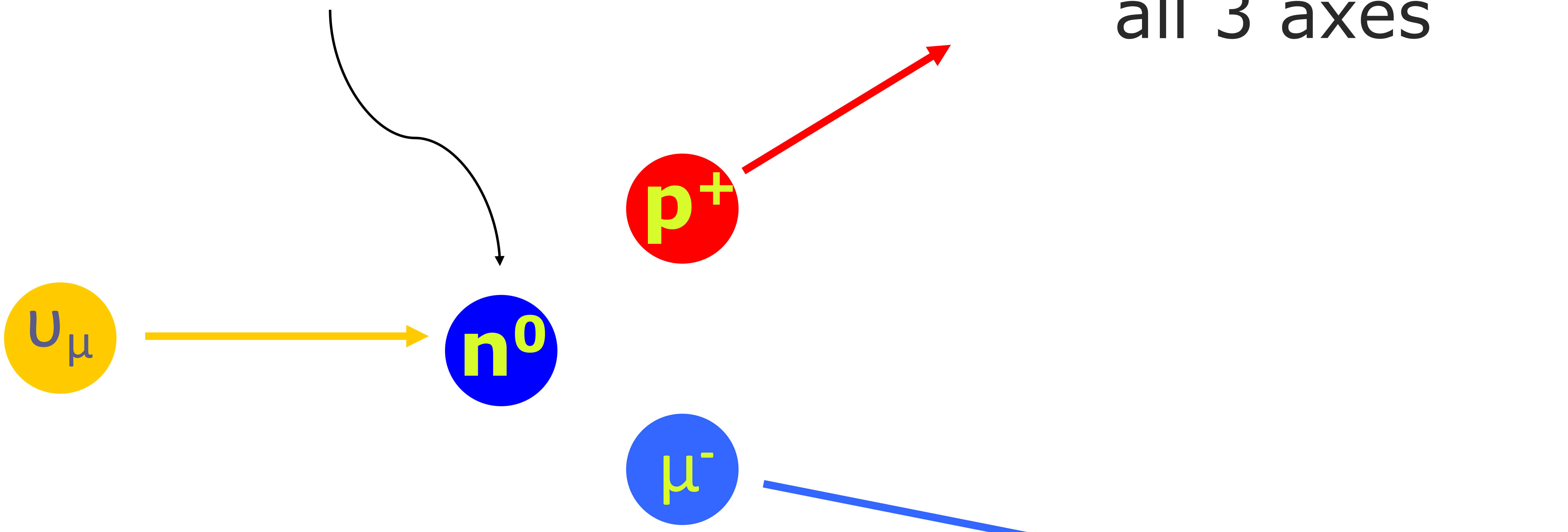
- Apply conservation of momentum and energy to measure the approximate **energy of a neutrino beam** from the Fermilab accelerator complex.

- Apply conservation of momentum and energy to measure the **properties of neutrons** in nuclei of atoms in the target of a neutrino beam.

Momentum Conservation

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

Momentum is conserved in all 3 axes



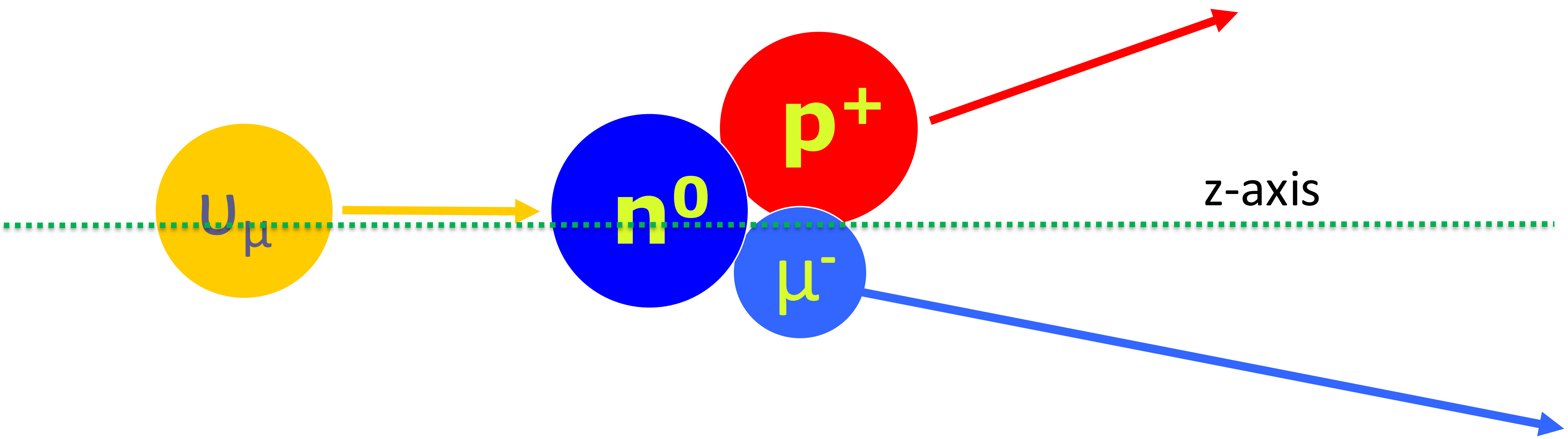
Before Collision

After Collision

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

Momentum Conservation

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

Momentum Conservation

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

FNAL-MINERvA-2024-03-25

D24 | fx 3

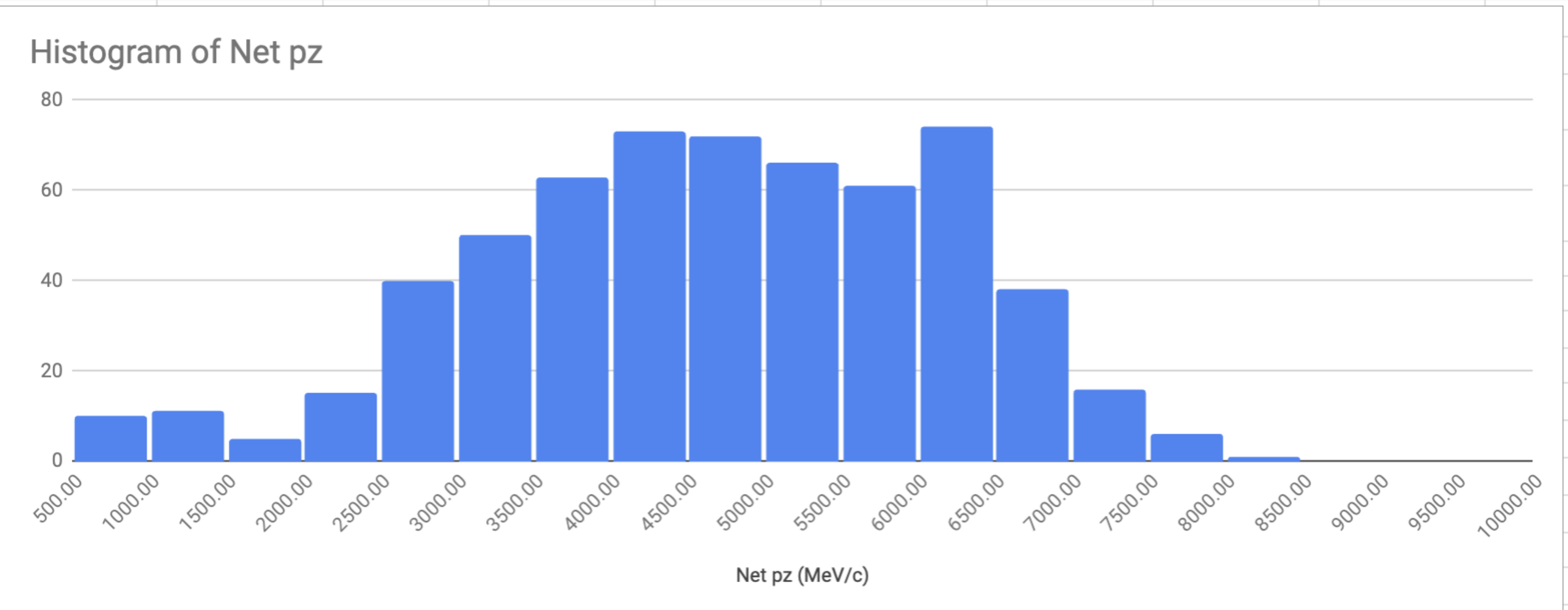
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2			ers initially seen in Rows 6-9, Columns C-N are placeholders only. Please overwrite them as you enter actual data.												*Cells below (Columns O, P, and Q) contain form*		
3																	
4	**merged**		**ground**	**Signal Event**	**Muon**					**Proton**					**Net**	**Net**	**nu-beam**
5	**Tuple**	**Entry**	**a 1)**	**Slice No.**	**KE (MeV)**	**v/c**	**px (MeV/c)**	**py (MeV/c)**	**pz (MeV/c)**	**KE (MeV)**	**v/c**	**px (MeV/c)**	**py (MeV/c)**	**pz (MeV/c)**	**px (MeV/c)**	**py (MeV/c)**	**pz (MeV/c)**
6	1	0		8.00	3,900.91	1.00	216.88	-618.13	3,950.59	149.67	0.51	-404.93	168.17	333.0	-188.05	-449.96	4,283.
7	1	1		6	3657.228461	0.9996104682	481.1571926	-404.2494757	3,707.88	229.23	0.60	-377.94	366.27	453.4	103.21	-37.98	4,161.
8	1	2		13	5433.205762	0.999820258	305.8229353	450.1413187	5510.403178	222.54	0.59	-276.19	-252.49	571.8	29.63	197.65	6,082.
9	1	3		4	2789.784268	0.9993419497	-387.6257508	-83.01515678	2865.589942	317.1095393	0.6644360457	589.2264459	259.7579881	529.899932	201.60	176.74	3,395.
10	1	4		16	3,256.78	0.99951	296.85	-621.23	3,288.84	331.88	0.67	-691.93	226.69	450.0	-395.08	-394.54	3,738.
11	1	5		1	4,303.67	0.99972	-103.46	-484.88	4,379.44	151.40	0.51	-25.26	388.02	394.65	-128.72	-96.86	4,774.
12	1	6	1														
13	1	7		16	4,685.40	0.9997597532	477.5293491	252.9459501	4,758.66	129.9290636	0.4780447288	377.5155437	231.3060912	254.1810209	855.04	484.25	5,012.
14	1	8		12	3,737.62	0.9996266001	-600.6682665	-27.70212263	3,793.83	100.6545082	0.4294483008	-311.3805579	56.40446148	314.3562823	-912.05	28.70	4,108.
15	1	9		3	4,848.45	0.999775311	-295.4307845	257.0810679	4,936.83	138.8654079	0.4912003088	66.94732257	408.0054534	329.9162209	-228.48	665.09	5,266.
16	1	10		10	5,703.09	0.9998365752	-474.3692348	-89.88577369	5,787.03	132.451618	0.4818282709	429.8556261	129.3239493	254.01	-44.51	39.44	6,041.
17	1	11		1	4,423.82	0.9997311957	-268.6516708	-310.446515	4,508.95	138.2201278	0.4902730271	315.7212772	358.8118567	223.561826	315.72	358.81	223.
18	1	12		2	1,495.91	0.9978468197	471.9893509	79.2221565	1,524.09	253.9384696	0.6170124695	-7.308542741	41.89963611	734.2099979	464.68	121.12	2,258.
19	1	13	1														
20	1	14		3	5968.814264	0.999850563	411.6492861	-458.6319542	6041.555785	201.5686747	0.5678697201	-318.4285188	417.114398	378.6708619	93.22	-41.52	6,420.
21	1	15		4	5,935.67	0.9998489186	-334.7303114	-222.6615757	6,026.36	340.2139228	0.6793261568	296.6579432	266.1358802	771.4613344	-38.07	43.47	6,797.
22	1	16		6	3095.915258	0.9994618329	505.3873747	-148.0682539	3155.549537	361.0675456	0.6918342247	-109.0857395	-201.3911907	869.0652321	396.30	-349.46	4,024.
23	1	17		5	5,102.75	0.9997967206	-123.3501849	-467.8972533	5,184.15	428.9783452	0.7274270972	402.8763775	-421.8996347	805.2807702	279.53	-889.80	5,989.
24	1	18		3	4,418.65	0.9997305799	614.2480472	-116.6250692	4,479.00	241.6544384	0.6064152697	-569.261259	205.8403261	381.1980759	44.99	89.22	4,860.
25	1	19	1														
26	1	20		2	2,430.83	0.9991423822	474.4661225	206.4491596	2,480.26	216.2790297	0.5827820969	133.9362614	357.8620846	553.6351549	608.40	564.31	3,033.
27	1	21		15	5609.308424	0.9998311668	396.7338001	283.2996877	5692.507298	330.1919794	0.6730075067	-556.1958358	-385.950933	519.7643371	-159.46	-102.65	6,212.
28	1	22		12	4309.795476	0.9997171287	173.1898586	-695.6785874	4354.931765	402.31	0.7142993076	-179.4135308	713.3972245	612.74	-6.22	17.72	4,967.
29	1	23	1														
30	1	24	1														
31	1	25		9	3,573.89	0.9995926165	-15.82238301	615.0232122	3,625.56	237.7528978	0.6029398099	192.5382952	-424.0572708	534.4673167	176.72	190.97	4,160.
32	1	26		13	5588.667733	0.9998299403	-206.0610921	-555.2936103	5661.803166	241.85	0.6065851845	228.4296524	523.0015086	431.84	22.37	-32.29	6,093.

Valencia - DG A | Valencia - DG B | Valencia - DG F | Valencia - DG G | videocon plots

http:/go.uv.es/mamtor/minerva_hoja

Momentum Conservation

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



Avg pz = 4,683.14 MeV/c
Med pz = 4,733.85 MeV/c
StdDev= 1507.746 MeV/c

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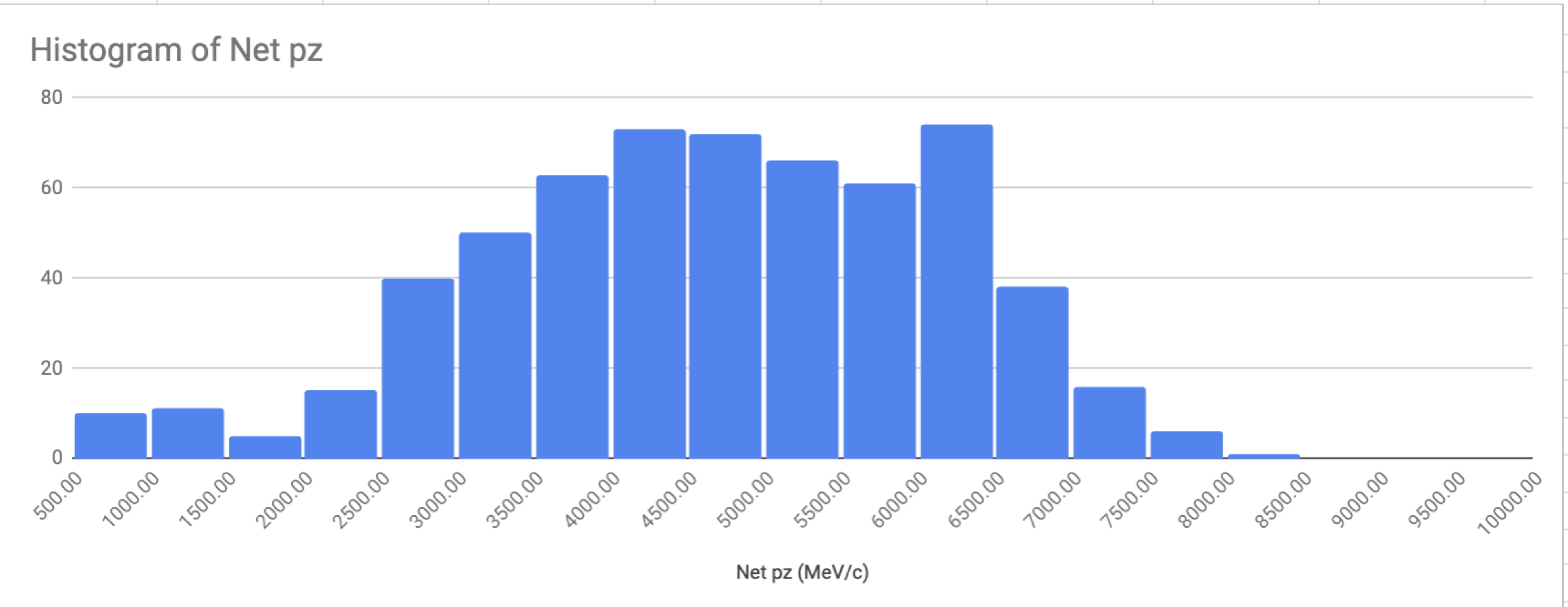


Avg pz = 4,683.14 MeV/c
Med pz = 4,733.85 MeV/c
StdDev= 1507.746 MeV/c

Avg pz = $\sum_{i=1}^{N} \frac{pz^i}{N}$

Average or mean value

Med pz = median

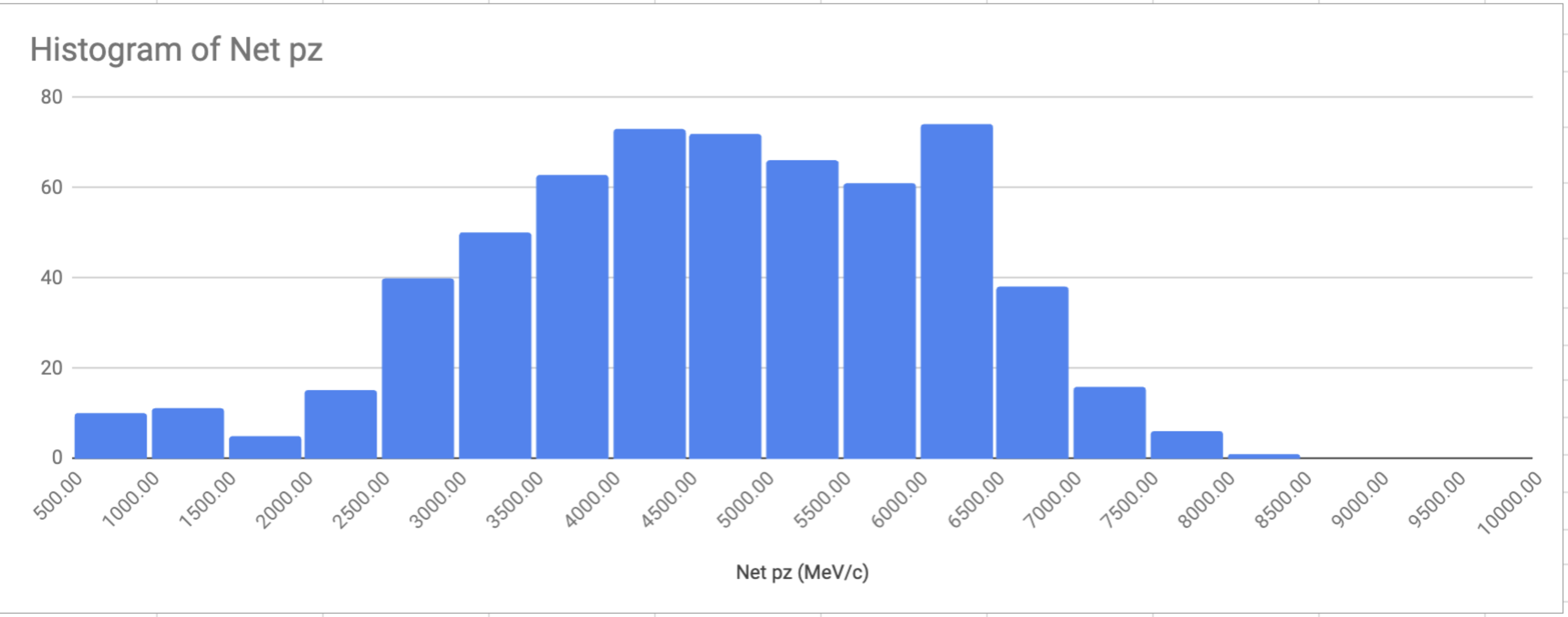
central value in a distribution

StdDev = standard deviation

dispersion of the data

Momentum Conservation

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



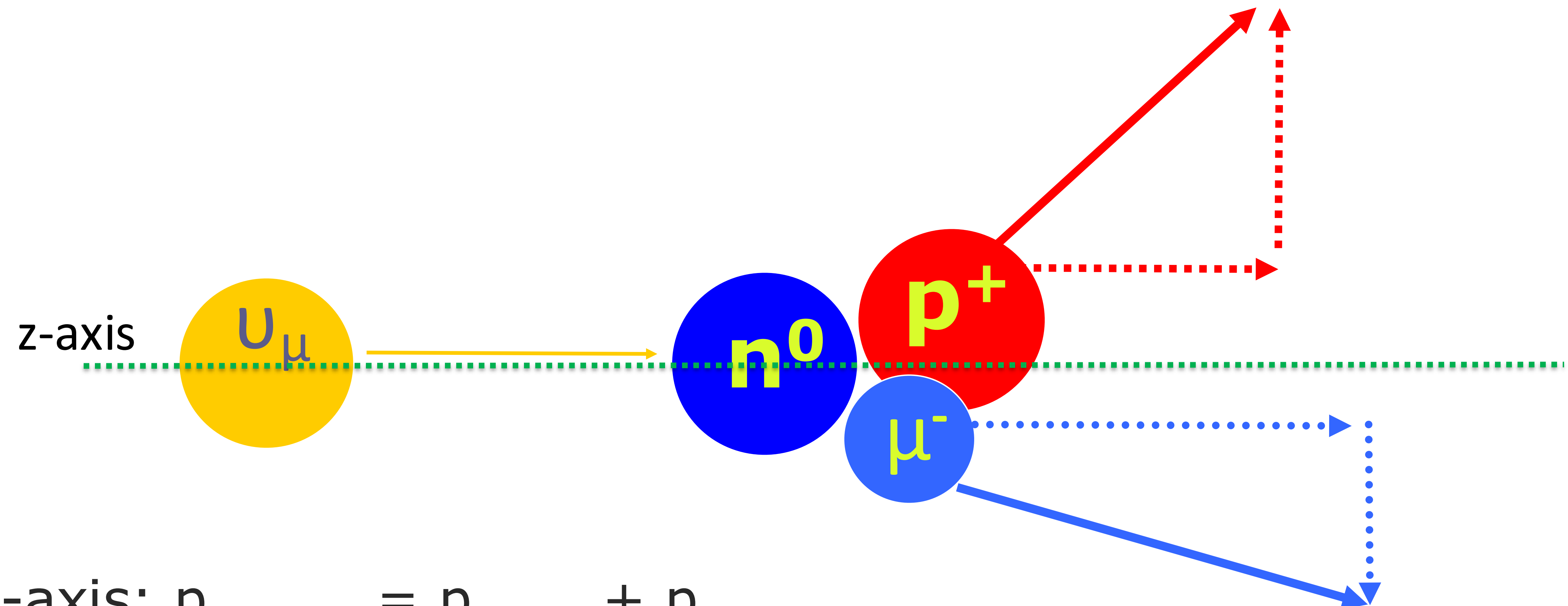
Avg pz = 4,683.14 MeV/c
Med pz = 4,733.85 MeV/c
StdDev= 1507.746 MeV/c

⇒ We can reconstruct the initial **neutrino momentum**

$E^2 = p^2c^2 + m^2c^4$ For neutrinos: $pc >> mc^2$

⇒ $E_{beam} = p_{neutrino}\, c$ ⇒ **initial neutrino energy**

Momentum Conservation



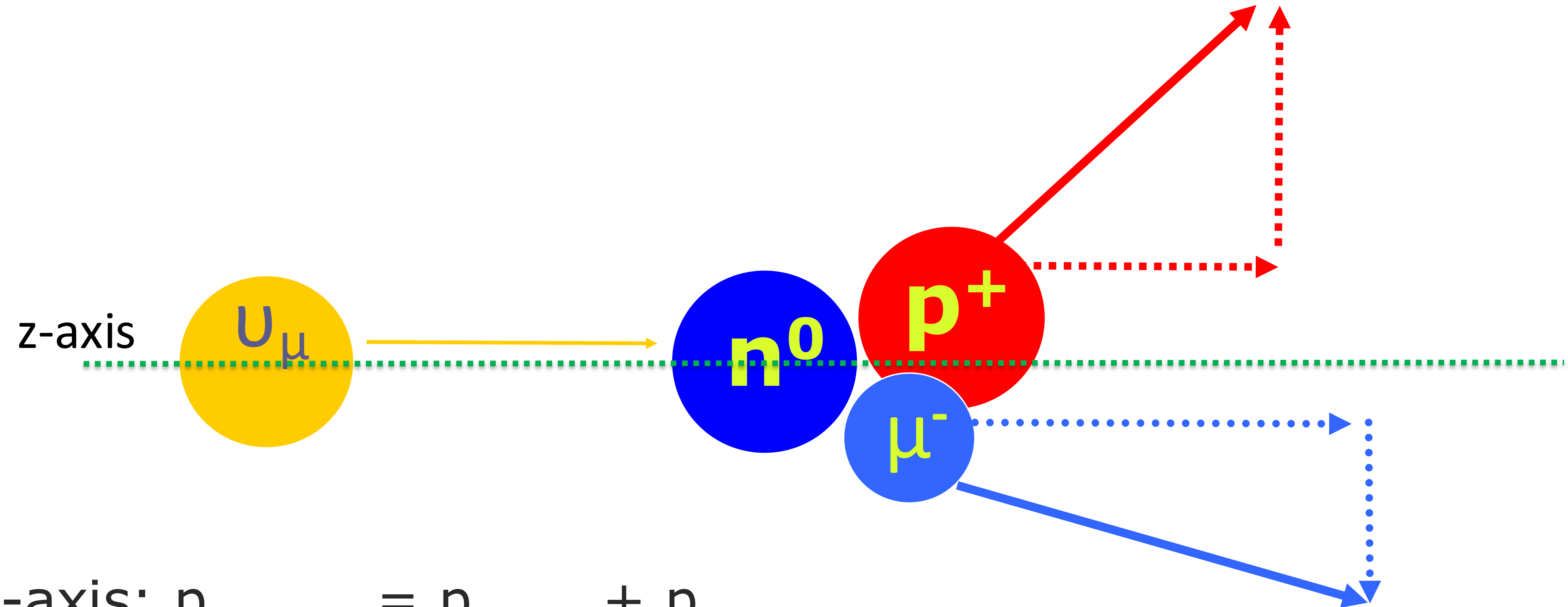
z-axis: $p_{neutrino} = p_{proton} + p_{muon}$

If the target neutron is totally at rest…

… then in the x-axis & y-axis

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

Momentum Conservation



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

If the target neutron has motion…

… then in the x-axis & y-axis

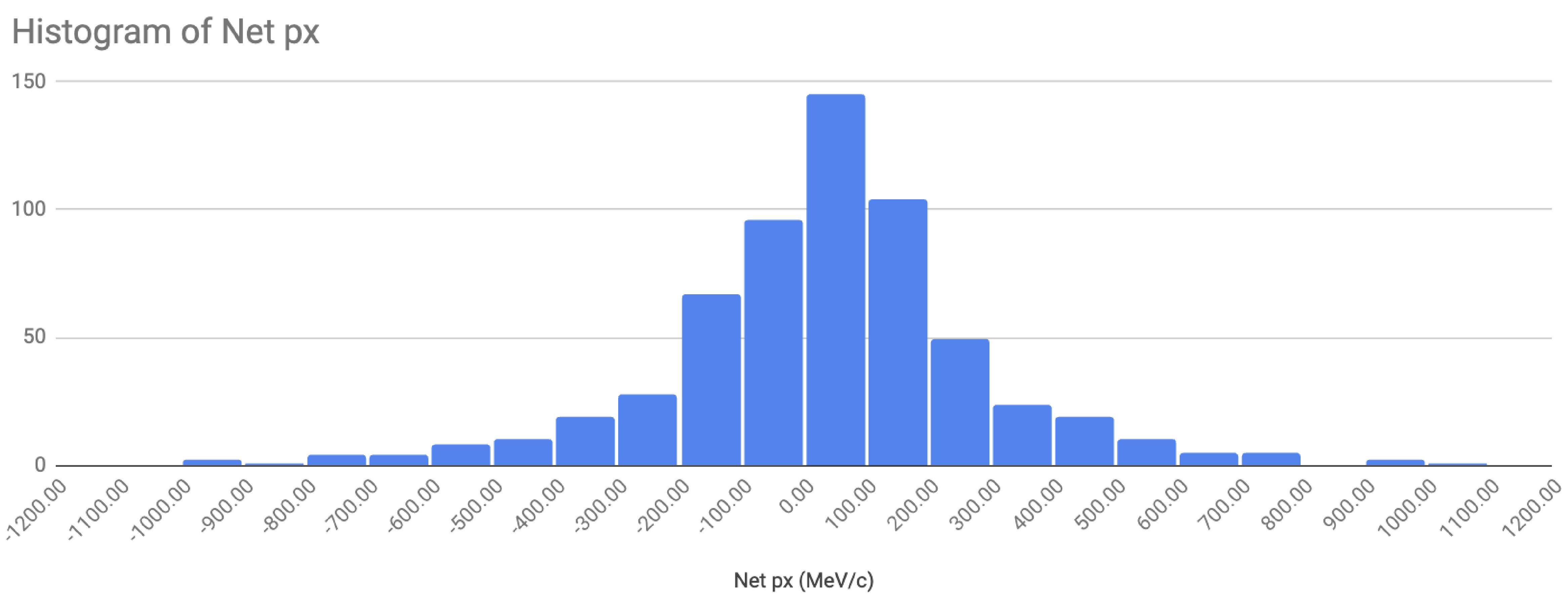
$p_{proton} + p_{muon} \neq 0$

Momentum in x-y directions

x-y axis: $p_{neutron} = p_{proton} + p_{muon}$

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

Histograms net p_x



⇒ distribution centered in 0

$\Delta p_x = 255.0$ MeV/c

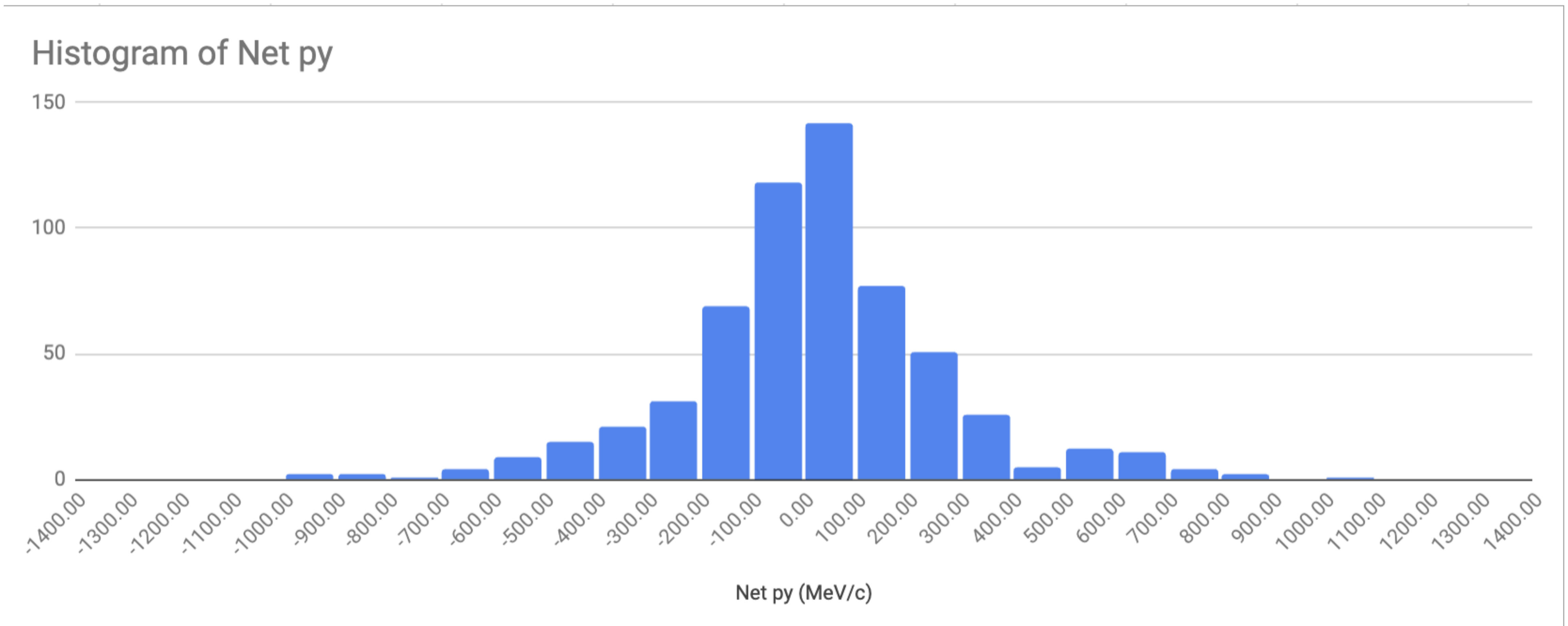
⇒ width of the distribution of p_x : Δp_x

Momentum in x-y directions

x-y axis: $p_{neutron} = p_{proton} + p_{muon}$

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

Histograms net p_y



⇒ distribution centered in 0

⇒ width of the distribution of p_y : Δp_y

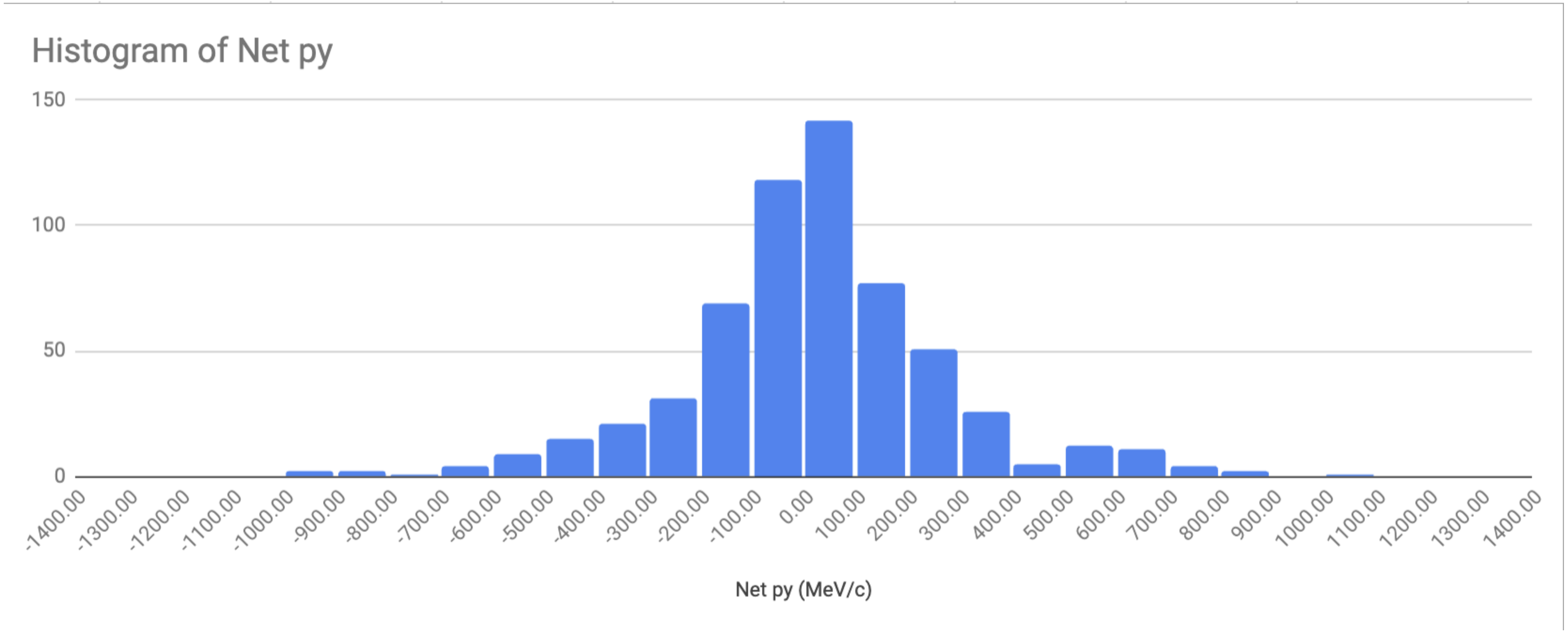
Δp_y = 256.21 MeV/c

Momentum in x-y directions

x-y axis: $p_{neutron} = p_{proton} + p_{muon}$

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

Histograms net p_y



⇒ distribution centered in 0

⇒ width of the distribution of p_y : Δp_y

But: neutron at rest!!

Origin of neutron momentum ?

Origin of neutron momentum ?

1) Classical thermal equilibrium of neutrons with atoms in the scintillator

$$T = 300K \rightarrow \langle KE_{\mathrm{n}} \rangle = \frac{3}{2} k_B T = 3.9 \times 10^{-8}\,\mathrm{MeV}$$

Too small!!

$$\langle p_{\mathrm{n}} \rangle = \sqrt{2 m_{\mathrm{n}} \langle KE_{\mathrm{n}} \rangle} = 8.5 \times 10^{-3}\,\mathrm{MeV/c}$$

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Too small!!

2) **Heisenberg uncertainty principle** and neutron confinement in the nucleus

$\Delta p_x\ \Delta x \geq h/4\pi \rightarrow \Delta p_x = (100\ \mathrm{Mev*fm/c})/\ \Delta x$

$\Delta x = 2*R = (1.25\ \mathrm{fm})\ A^{1/3} = 5.7\ \mathrm{fm}$ $\rightarrow \Delta p_x \geq 18\ \mathrm{MeV/c}$

Better, but still small

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Better, but still small

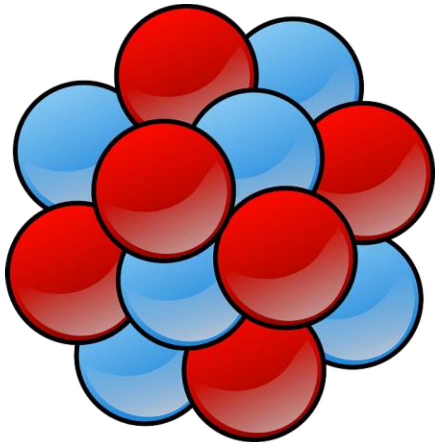
3) **Fermi gas**: exclusion principle applied to neutrons confined in the nucleus

$$\rightarrow p_{\rm Fermi} = \left(\frac{3\pi^2 N}{V} \right)^{1/3} = 241\,{\rm MeV/c}$$

Typical value of transverse moment in MINERvA

Estimation of the radius of the nucleus

The results on transverse momentum of the neutron can be used to estimate the size of the **carbon nuclear radius.**



⇒ We can compare our results with the average radius of a nucleus with A nucleons:

$$R = R_0\, A^{1/3} = (1.25\ \text{fm})\, A^{1/3} \rightarrow R(C, A{=}12) = 2.9\ \text{fm}$$

Estimation of the radius of the nucleus

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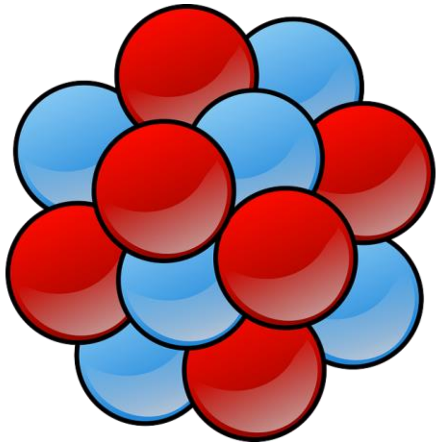

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$$\Delta p_x\, \Delta x \geq h/4\pi \rightarrow \Delta x = (100\ \mathrm{Mev{*}fm/c})/\ \Delta p_x$$

Estimation of R

Estimation of the radius of the nucleus

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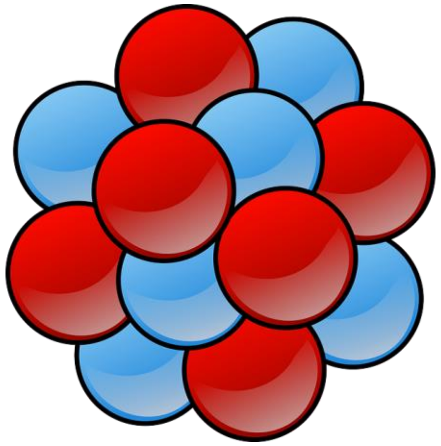

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1) **Heisenberg** uncertainty principle:

$$\Delta p_x\, \Delta x \geq h/4\pi \rightarrow R \approx \Delta x = (100\ \text{Mev*fm/c})/\ \Delta p_x$$

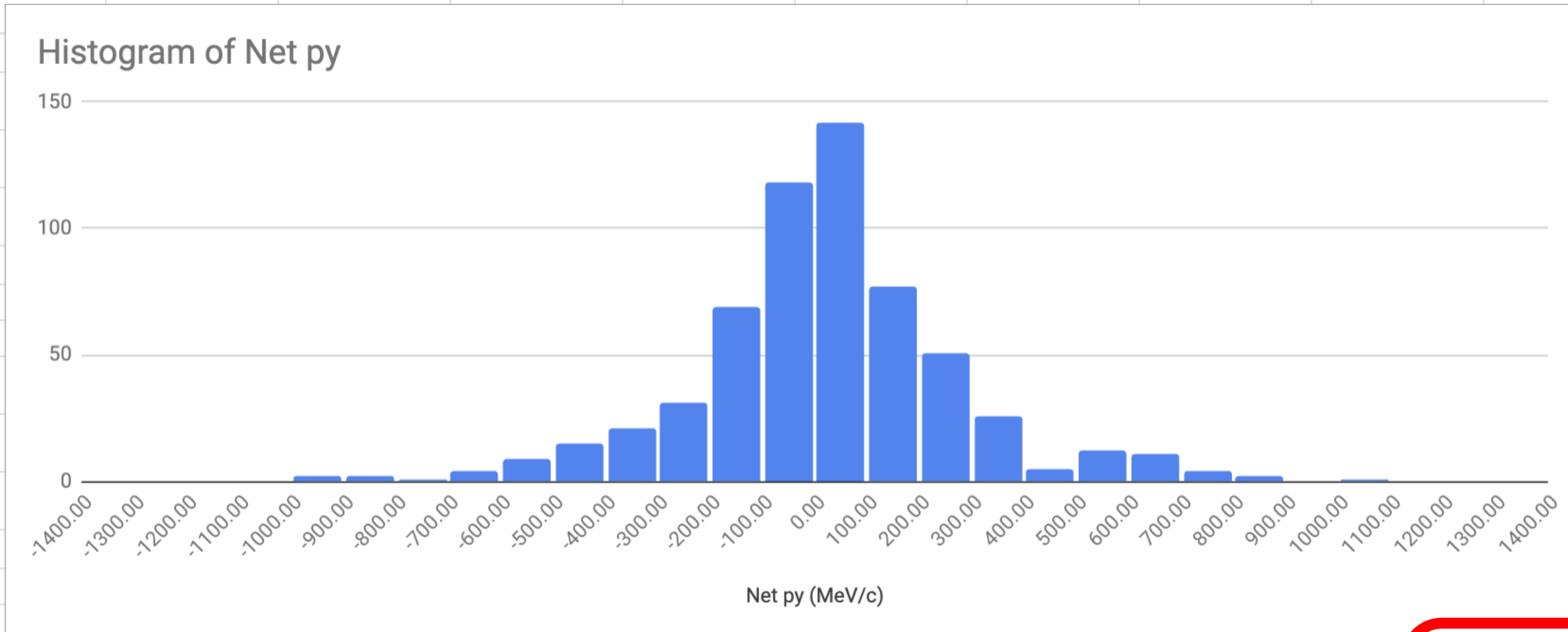
Estimation of R

2) **Fermi gas** approximation: neutrons must obey the exclusion principle

$$p_{\text{Fermi}} = \left(\frac{3\pi^2 N}{V}\right)^{1/3} \rightarrow p_{\text{Fermi}}(^{12}C) \simeq \frac{300\text{MeV}/c}{R_0}$$

Estimation of R_0

Momentum Conservation in x-y



Calculated:		
Std Dev =	256.21	MeV/c
delta-y =	0.39	fm (Heisenberg)
delta-y =	1.17	fm (Fermi Gas)
Visual:	(FWHM/2) =	
Std Dev =	300.00	
delta-x =	0.33	fm (Heisenberg)
delta-x =	1.00	fm (Fermi Gas)

Estimation of C nuclear radius R and R_0

$$\Delta p_x, \Delta p_y \Rightarrow \Delta x, \Delta y$$

$$R = R_0\, A^{1/3} = (1.25 \text{ fm})\, A^{1/3} \rightarrow R(C, A{=}12) = 2.9 \text{ fm}$$

$$R_0 = 1.25 \text{ fm}$$

http:/go.uv.es/mamtor/minerva_hoja

MINERvA Neutrino Masterclass

Masterclass Hands on Particle Physics

Videoconferencia

zoom

https://go.uv.es/mamtor/videoconf