1 Theory

Useful formula:

$$p = 0.3 \cdot B \cdot V \cdot r \tag{1}$$

2 Results

2.1 Neutrino momentum

The pion had an initial radius of 27.0 ± 0.9 cm, this gives a momentum of 120.1 ± 3.8 MeV/c. The track length was measured to be 79.3 ± 0.9 cm. The graph provided gave a corresponding 128.5 ± 5.9 MeV/c. Comparing the two values, we infer that the pion has indeed decayed while at rest in the laboratory frame.
Next, we measured the length of the μ track, and found it to be 0.597 ± 0.085 cm. From the graph again, a momentum of 27.64 ± 1.26 MeV/c was read, in fairly good agreement with the theoretical 29.8 MeV/c value.

2.2 V0

We found two V_0-canditate events. It is important to note that the angle between the two produced particles in each case was close to 0°, so the possibility of these being pair productions is considerable.
On image 2898 (???) we detected a primary vertex with 2 visible outgoing particles and one distant vertex of two particles with opposite charges (meaning it was a decay process) which is suspected to have come from the primary vertex. The distance of the two vertices was measured to be 137 cm.

2.2.1 The secondary vertex

The neutral particle decayed into two particles with an angle of $(0 \pm 0.1)°$ between them, this made the association to the primary vertex an easy task. We measured the two radii to be (56 ± 2) cm for the negative, 750 ± 50 for the positive particle. From Eqn. 1, in a coordinate system with the x-axis along the supposed V_0 path, we get

$$\begin{aligned} p_- &= ((249.2 \pm 8.9)\,\mathrm{MeV/c}, \quad (0.22 \pm 0.22)\,\mathrm{MeV/c}) \\ p_+ &= ((3337.1 \pm 222.7)\,\mathrm{MeV/c}, \, (-2.92 \pm 2.92)\,\mathrm{MeV/c}) \end{aligned}$$

The total V_0 momentum is then

$$|p_0| = (3586.21 \pm 222.89)\,\mathrm{MeV/c} \tag{2}$$

2.2.2 A first look at the primary vertex

The primary vertex consists of the incoming proton, and two positively charged particles: particle 1 has a path with radius (2000 ± 200) cm and angle $(2 \pm 0.3)°$, particle 2 (1700 ± 100) cm and $(4.5 \pm 0.3)°$. Using the incoming beam as the direction of the x-axis and the

Name	Mass (MeV)	Distance (m)	Decays into	Fraction
Λ	1115.7	0.079	$\mathrm{p}\,\pi^-$	63.9%
K^0_S	497.6	0.027	$\pi^+\,\pi^-$	69%
K^0_L	497.6	15.3	$\pi^\pm\, e^\mp \nu_e$ $\pi^\pm \mu^\mp \nu_\mu$	40.6% 27.0%
Σ^0	1192.6	$2.22 \cdot 10^{-11}$	$\Lambda\,\gamma$	100%
Ξ^0	1314.9	0.087	$\Lambda\,\pi^0$	99.5%

Table 1: Possible neutral particles[4]

Figure 1: First primary vertex examined.

positive quarter plane being the top right one, we can write down the momenta:

$$\begin{aligned} p_1 &= ((8893.4 \pm 889.8)\,\mathrm{MeV/c}, \quad (310.6 \pm 56.0)\,\mathrm{MeV/c}) \\ p_2 &= ((7540.7 \pm 444.2)\,\mathrm{MeV/c}, \quad (-593.5 \pm 52.7)\,\mathrm{MeV/c}) \\ p_0 &= ((3585.7 \pm 62.6)\,\mathrm{MeV/c}, \quad (222.9 \pm 19.2)\,\mathrm{MeV/c}) \end{aligned}$$

$$\Sigma p = ((20019.7 \pm 1019.1)\,\mathrm{MeV/c}, \, (-220.3 \pm 79.3)\,\mathrm{MeV/c})$$

The momenta of the three particles do not add up to the momentum of the incoming proton (23877 MeV/c in the x-direction), this offers two probable explanations to check first:

- Another neutral particle was created which was not detected, or
- One neutral particle was created that decayed into neutral particles very close to the primary vertex, and one of these decayed, showing up as a secondary vertex.

Of course other options are also possible, but we are hoping to find the event to be one of these two types.

2.2.3 Determining V_0

Unfortunately, we cannot conclude much from the secondary vertex, situated (138 ± 1) cm away from the primary vertex, showing the path of two particles which leave the chamber. We assume that the V_0 particle decayed into two charged particles and nothing else, as the overall momentum already matches what we expect, thus a possible neutral particle would have a pro- or retrograde motion, and we regard this as unlikely. Looking at Table 1, we see 3 possible scenarios:

- V_0 is a Λ particle, another neutral particle left the primary vertex undetected; the secondary vertex contains a proton and a pion,

- instead of a Λ, a K^0_S was created, which decayed into a pair of pions,
- A Σ^0 was created at the proton-proton collision, which then decayed within a few picometers, resulting in a Λ baryon which decayed into a proton and a pion, and a photon.

We can calculate the mass of the V_0 for these scenarios:

$$m_{\mathrm{V}_0}(\mathrm{p},\, \pi^-) = (1103.2 \pm 1028.3)\,\mathrm{MeV}$$
$$m_{\mathrm{V}_0}(\pi^+,\, \pi^-) = (532.8 \pm 2132.2)\,\mathrm{MeV}$$

The uncertainty is tremendous in both cases. We decided for the proton-pion case after comparing the relative errors. This means the V_0 was a Λ baryon.

2.2.4 Primary vertex revisited

The incident proton

References

[1] Unspecified author, *Advanced Laboratory Course (physics601): Description of Experiments* (University of Bonn, 2018).

[2] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments* (Springer-Verlag, 1987), p. 305.

[3] G. Seul, *Properties of elementary particles* (University of Bonn, 2009).

[4] Particle Data Group.