

1 Theory

Useful formula:

$$p = 0.3 \cdot B \cdot V \cdot r \quad (1)$$

2 Results

2.1 Multiplicity

Of the 64 inelastic scattering events, 11 had two, 35 four, 13 six, and 5 eight outgoing charged particles, giving a total of 280 charged tracks from 64 events, giving an average charged multiplicity of $m_{\text{chg}} = 4.375$. This matches our expectations for $s \approx 47 \text{ GeV}^2$.⁵ From this, the π^0 multiplicity is

$$m_0 = \frac{m_{\text{chg}}}{4} = 1.094$$

As at high energies, positive, negative and neutral pions are created in equal numbers,^{5,6} we expected the multiplicity to be around 1.3 ± 0.3 .

The other way we calculated the neutral pion multiplicity is to count the detected pair productions. We found 4 such events. The formula then reads

$$m_{\pi^0} = \frac{n_{\text{pp}} \cdot l}{2 \cdot n_{\text{inel}} \cdot ((x_0 \cdot e^{-l/x_0} - 1) + l)} = 0.5026 \pm 0.0003, \quad (2)$$

where the error comes from the uncertainty of the measured length of (148.739 ± 0.085) we examined. This result is in disagreement with the first, and the reason is the low pair production count we recorded (quantifying this uncertainty would also give a much larger deviation for the multiplicity)

2.2 Neutrino momentum

The pion had an initial radius of $27.0 \pm 0.9 \text{ cm}$, this gives a momentum of $120.1 \pm 3.8 \text{ MeV/c}$. The track length was measured to be $79.3 \pm 0.9 \text{ cm}$. The graph provided gave a corresponding $128.5 \pm 5.9 \text{ MeV/c}$. 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 $0.597 \pm 0.085 \text{ cm}$. From the graph again, a momentum of $27.64 \pm 1.26 \text{ MeV/c}$ was read, in fairly good agreement with the theoretical 29.8 MeV/c value.⁵

2.3 V0

We found two V_0 -candidate 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 .

2.3.1 The secondary vertex

The neutral particle decayed into two particles with an angle of $(0 \pm 0.1)^\circ$ between them, this made the association to the primary vertex an easy task. We measured the two radii to be $(56 \pm 2) \text{ cm}$ 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

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

The total V_0 momentum is then

$$|p_0| = (3586.21 \pm 222.89) \text{ MeV/c} \quad (3)$$

2.3.2 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 $(2000 \pm 200) \text{ cm}$ and angle $(2 \pm 0.3)^\circ$, particle 2 $(1700 \pm 100) \text{ cm}$ and $(4.5 \pm 0.3)^\circ$. Using the incoming beam as the direction of the x-axis and the positive quarter plane being the top right one, we can write down the momenta:

$$\begin{aligned} p_1 &= ((8893.4 \pm 889.8) \text{ MeV/c}, \quad (310.6 \pm 56.0) \text{ MeV/c}) \\ p_2 &= ((7540.7 \pm 444.2) \text{ MeV/c}, \quad (-593.5 \pm 52.7) \text{ MeV/c}) \\ p_0 &= ((3585.7 \pm 62.6) \text{ MeV/c}, \quad (222.9 \pm 19.2) \text{ MeV/c}) \\ \Sigma p &= ((20019.7 \pm 1019.1) \text{ MeV/c}, \quad (-220.3 \pm 79.3) \text{ MeV/c}) \end{aligned}$$

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.

2.3.3 Determining V_0

Unfortunately, we cannot conclude much from the secondary vertex, situated $(138 \pm 1) \text{ cm}$ away from the

Name	Mass (MeV)	Distance (m)	Decays into	Fraction
Λ	1115.7	0.079	$p \pi^-$	63.9%
K_S^0	497.6	0.027	$\pi^+ \pi^-$	69%
K_L^0	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%

Table 1: Possible neutral particles⁴



Figure 1: First primary vertex examined.

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_S^0 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:

$$m_{V_0}(p, \pi^-) = (1103.2 \pm 1028.3) \text{ MeV}$$

$$m_{V_0}(\pi^+, \pi^-) = (532.8 \pm 2132.2) \text{ MeV}$$

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.

2.3.4 Primary vertex revisited

The overall missing momentum of the system (the incoming proton has a momentum of 23895 MeV/c, hitting a stationary proton) is

$$p_{\text{missing}} = ((7743.0 \pm 994.5) \text{ MeV/c}, (282.9 \pm 76.9) \text{ MeV/c})$$

It turns out that the simplest proposition for the missing momentum, the Σ^0 particle, would explain this missing momentum. To see this, check the conservation laws:

- Baryon number: the Σ^0 (uds) gives 1, this means one of the created charged particles must be a baryon, the other one a meson.
- Strangeness: Σ^0 has $S = -1$, the baryon or the meson should have a \bar{s} quark.

- Flavours: the baryon and the meson should have 3 u, 1 d, 1 \bar{s} quarks.

Overall, one of the created particles is a proton, the other a positively charged Kaon (K^+ , $u\bar{s}$). To check our proposition, we look at the energy conservation:

- The initial energy is $23895 + 938 = 24833$ MeV.
- $E(p_1, p^+) = (8948.1 \pm 884.3)$ MeV if we assume p_1 belongs to a proton,
- $E(p_2, K^+) = (7580.1 \pm 441.9)$ MeV,
- $E(p_{\text{missing}}, \Sigma^0) = (7543.2 \pm 981.3)$ MeV,

giving an overall energy of (24071.4 ± 1392.9) MeV, which matches the initial energy. Switching the proton and kaon tracks yields (24077.6 ± 1394.4) MeV, also a valid result, thus we cannot uniquely assign the two final particles to tracks.

To sum up our results, we explain the event as a $pp \rightarrow p K^+ \Sigma^0$, $\Sigma^0 \rightarrow \gamma \Lambda$ collision, where we detected $\Lambda \rightarrow p \pi^-$.

References

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- ⁵ R. C. Fernow, *Introduction to Experimental Particle Physics* (Cambridge University Press, 1986).
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