BUBBLE CHAMBER LAB

Abstract

This experiment examines the branching ratio for the $K^- \rightarrow \pi^-\pi^-\pi^+$ decay, the K^- meson decay rate and the interaction cross section for $K^- p^+$ interactions. The results, after corrections for systematic error, were as follows:

BR = 9.87 +- 3.7 %, σ = 38.8 +- 5.7 mbarn and $\tau = 1.41*10^{-8}$ +- $2.1*10^{-9}$ sec.

The accepted values are: BR = 5.59%, σ = 35 mbarn and $\tau = 1.2*10^{-8}$ sec.

Introduction

The purpose of bubble chamber experiments is to study elementary particles. A bubble chamber allows the experimenter to determine the charge momentum and location of a charged particle as it moves through the chamber. Armed with this information, and the conservation laws, physicists examine particles interactions. They can discover new particles by finding peaks in reaction cross sections or by observing particles that result from decay and scatters but which do not behave like any currently know particle. They can determine decay rates, branching ratios and interaction cross sections by examining the frequency of certain interactions. Furthermore, new conservation laws may be discovered as well as old ones discarded based on the types of interactions that are observed. All this information in turn can shed light on the "fundamental building blocks of nature" (if they are ever found), and helps us understand the mechanisms by which the fundamental forces are propagated.

In our experiment we examined the interactions and decays for a 1.5 Gev/c beam of K^- mesons by counting the number interactions as well as the number of beams that were recorded on the bubble chamber film. The film was recorded in the 25" bubble chamber at LBL, and the magnetic field in the bubble chamber was 1.667 T. We separated our counts based on the number of charged particles that existed after the interactions. This way we were able to distinguish between decays and $p^+ K^-$ interactions.

Theory

The theoretical areas of physics involved in high energy nuclear physics include quantum mechanics, quantum field theory, quantum chromodynamics, conservation laws and relativistic collisions. In order to understand this lab only a basic understanding of conservation laws, statistics and relativity is required. Since the necessary elements of these theories will be discussed during the analysis and problem sections of this report, I will use the theory section in order to provide a basic introduction to high energy physics. I will focus on the strong and the weak nuclear interactions, since these are the two types of interactions that are observed in this lab.

The world of elementary particles is divide into two categories: hadron and leptons. The hadrons are then divided into two subcategories, namely baryons and mesons. Baryons are fermions and generally are the most massive of the particles. Included among them are the proton, the neutron and numerous other heavy particles. The mesons are bozons, and they include the, pions, the eta particle, and the kaons which are the focus of this experiment. Finally, the leptons are fermions, and are the least massive of the particles. Included among them are the electron, the muon and the neutrino.

The interactions between hadrons take place via the strong nuclear force. The mesons are in fact mediators for hadronic reactions. Their existence was predicted by H. Yukawa in 1935 by making an analogy to quantum electro dynamics. For strong interactions, the idea is that the interactions take place via an exchange of particles. If we assume that the exchanged particle has a mass m and a momentum p, then the change in energy of our system when the particle is created is: $\Delta E = \sqrt{p^2c^2 + m^2c^4}$. In order for our system not to violate conservation of energy, we use Heisenberg's uncertainty principle to determine that the lifetime of the particle can be at most: $T < 2\pi h/\Delta E$, so that the range of the particle, and hence the range of the interaction is Tp/c. Assuming that p = c and neglecting the kinetic energy of the exchanged particle, we can in fact determine the maximum range of the strong nuclear force to be $2\pi h/mc$.

During strong interactions, there are a number of quantities that are conserved. Specifically, these quantities are energy, momentum, charge, lepton number, baryon number, isospin, strangeness, charm and parity.

The conservation of lepton and baryon numbers simply refers to the conservation of leptons and baryons. Hence, a baryon is assigned a baryon number of 1 while an antiparticle of a baryon is assigned a baryon number of -1. The assignment of lepton number works in an analogous fashion.

Strangeness was a property that arose out of the fact that some hadrionic particles decayed much slower than would be expected. Their decay times were on the order of 10^{-13} seconds rather than the expected 10^{-23} seconds. It was suggested that these particles could only be created in pairs, a property which was then described with the concept of strangeness.

Isospin is used to describe the fact that elementary particles of a similar mass, for example the proton and the neutron, are in fact elements in a charge mutiplet which is separated by an electromagnetic field. For example, the neutron and the proton both have an isospin $I = 1/2$, but the proton is in the state $I_z = +1/2$ while the neutron is in the $I_z = -1/2$ state.

Parity, which describes spatial symmetry, must also be conserved in strong nuclear reactions. The conservation of parity essentially states that interactions looks identical in the x,y,z coordinate frame and in the -x,-y,-z coordinate frame.

Finally the traditional quantities like energy, angular as well as linear momentum and charge are naturally also conserved in strong interactions.

The other type of interaction that is of importance in this experiment is the weak interaction which describes the kaon decays: $k^- \rightarrow \mu \bar{\nu}$. The weak interactions were discover in nuclear beta decays and are currently thought to be propagated by to intermediate bozons. Specifically, these bozons are the W^{+-} and the Z^0 particles. The particle W^{+-} is responsible weak interactions where charge transfers take place, and the Z^0 particle mediates weak interacts which have no charge exchange. The range of the weak interaction can be calculated by the same principles that we used for the strong nuclear force, thus the range is $2\pi\hbar/mc$ where m is the mass of the intermediate bozons. The intrinsic coupling of the weak interaction is thought to be the same as it is for the electromagnetic force, hence the weak and the electromagnetic force are considered to be unified.

The conservation laws of weak interactions are different from those for the strong interactions. Specifically, the conservation of isospin (ΔI = 1,1/2), strangeness (ΔS = 1,0), charm (ΔC = 1,0) and parity do not hold.

Finally, I would like to address the concept of resonances in nuclear reactions. Resonances are peaks in in the cross sections of certain interactions at certain energies. If such a peak occurs, it can be inferred that a particles is being created at that particular energy level of the interacting system. These resonances are used to detect the existence of elementary particles that have extremely short mean lives. For example, a particles with a mean life of 10^{-23} seconds moving near the speed of light will only travel $3 * 10^{-15}$ m until it decays. Tracks of that size clearly are not detectable in a bubble chamber.

Bubble chamber

The bubble chamber is a device that is used to detect charged particles. The particle beam that enters the bubble chamber is prepared by an elaborate set of filters and accelerators that are used to create a beam of the required particles at the required energy.

For the bubble chamber data used in this experiment, the particle beam originates in a hydrogen gas chamber. The gas is passed through an arch chamber which strips the electrons off the hydrogen atom. The resulting proton beam is then accelerated through a Cockcroft-Walton accelerator and a linear accelerator to approximately 10 Mev. This beam enters the the Bevatron, a circular accelerator, which accelerates the beam particles to any where from 10 Mev to 6.2 Bev. Once the particles have reached the desired energy, the beam is concentrated within a narrow beam width, and then the beam is allowed to spiral inward toward the beam target. When the beam strikes the target a plethora of particles is created which are immediately separated based on momentum with a magnetic field and a collimator. The beam resulting from those particles which have the desired momentum is directed through a bending magnet which further narrows the momentum spectrum of the beam and a spectrometer which separates the beam particles based on their masses. Once the desired beam purity is reached, the beam is injected into the bubble chamber.

The bubble chamber is a closed vessel that contains liquid hydrogen at a temperature above its normal boiling point, under sufficient pressure so as to keep the hydrogen in it liquid form. Just before the particle beam reaches the chamber, the hydrogen is allowed to expand, so that for a fraction of a second the hydrogen enters a superheated state. During this brief interval, the beam enters the chamber and small bubbles form around the charged particles. A picture of the chamber is then taken which records the location of the bubble tracks created by the charged particles. After the picture is taken, the hydrogen is compressed so as to eliminate all the bubbles, and the entire cycle is repeated.

Procedure

The procedure in this lab simply required us to examine 500 frames of bubble chamber film, recorded in the 25" bubble chamber at LBL, searching for any reactions that took place in the bubble chamber as a result the incoming beams of particles. Specifically we were looking for kaon decays and interactions between the incoming kaon beam and the protons in the bubble chamber. These reactions, along with with a count of the total number of beams that entered the chamber were recorded and used as the data for the subsequent analysis. One of the major difficulties in scanning bubble chamber film is the fact that certain camera angles tend to make it appear that certain particles reacted when in fact their paths were simply on a line perpendicular to the photograph surface. This problem was alleviated by taking pictures at different angles so as to preserve three dimensional information about the particle tracks. In order to take advantage of this fact, the film viewing equipment allows the user to look at all three picture angles, and also allows the user to superimpose the pictures. Finally it was also necessary to select a fiducial region, a region in which we would accept good events. Choosing such a region increases the accuracy of our observations because it helps you filter out events that may have been triggered by particles other than the kaon.

Data and Analysis

To begin with let us understand how the data collected in this experiment can be adjusted in order to account for our scanning inefficiencies.

Say that:	the number of events counted by Ted is:	T
	the number of events counted by Rainer is:	R
	Ted's efficiency is:	E_T
	Rainer's efficiency is	E_R
	total number of events that occurred	N
	the total number of events counted by Ted and Rainer:	X

Then:

$$T = E_T * N$$

$$R = E_R * N$$

$$X = E_R * E_T * N + (1 - E_T) * E_R * N + (1 - E_R) * E_T * N$$

$$= E_T * N + E_R * N - E_R * E_T * N$$

Both missed ↓ $(1 - E_R)(1 - E_T) N = N - X$ OK,

To solving this for E_T, E_R and N we get:

$$E_R = \frac{-X + R + T}{T}$$

$$E_T = \frac{-X + R + T}{R}$$

$$N = \frac{R * T}{-X + T + R}$$

Note that in this analysis T and R are the number of correct events that we observed. So, if T (R) observed an event which turned out not to be an actual event, it was not counted when analyzing our efficiency. Furthermore, this analysis assumes that all the events detected by both of us, X, are actual events which are also classified correctly. (ie. 1 prong events aren't mistaken to be 3 pronged events. etc.)

Now breaking down our data by type of event:

0 prong events: $X = 39$; $R = 29$; $T = 37$; $E_R = 73\%$; $E_T = 98.1\%$; $N = 40$

1 prong events: $X = 98$; $R = 91$; $T = 93$; $E_R = 92.5\%$; $E_T = 94.5\%$; $N = 98$

2 prong events: X = 155; R = 141; T = 151; E_R = 91.4%; E_T = 97.9%; N = 155

3 prong events: X = 11; R = 9; T = 11; E_R = 81.8%; E_T = 100%; N = 11

4 prong events: X = 10; R = 9; T = 10; E_R = 90%; E_T = 100%; N = 10

Total number of events:

X = 313; R = 282; T = 305; E_R = 90.1%; E_T = 97.4%; N = 314

Finally, we counted 492 +- 22.2 tracks/51 Frames

which gives: 4823 +- 217 total tracks.

In our subsequent calculations, we always use N the corrected number of events that occurred.

3) The Branching Ratio

The number of three pronged events that occurred are essentially equal to the number of $K^- \to \Pi^+\Pi^+\Pi^-$ events. We detected 11 such events, and since we detected 109 1 prong events, the branching ratio is:

$$BR = 11/109 = 10.1\% \pm 3.7\%$$

We should note that decays and interactions can be recognized by the number of charged by-products. By charge conservation, a decay must have an odd number of charged by products, while an interaction has an even number of charged by-products.

In the calculation above, we only included statistical error, the calculation of which will be discused in the error section and the error due to the measurement of the length of fiducial region. We note that the currently accepted value for the branching ratio is 5.59 +- .03% which means that we are off by one and a half standard deviations. As we shall see later, even if we incorporate the systematic errors we will not be able to account for this discrepancy. The only explanation than which we found for our result was that the film which we used may be one of those 1:20 cases which lies on the two σ boundary of the gausian distribution.

4)The beam attenuation due to scattering:

The number of protons per unit volume is: $\dfrac{N_A * \rho}{A}$

So the scattering cross section per unit area is: $\dfrac{N_A * \rho * \sigma}{A}$

So:

$$dN = -N\left(\frac{N_A * \rho * \sigma * dx}{A}\right) \Rightarrow \ln N = -\frac{N_A * \rho * \sigma * x}{A} \Rightarrow N = N_0 * \exp\left(\frac{N_A * \rho * \sigma * dx}{A}\right)$$

For the attenuation due to the decay, we note that:

$$dN = -N * \frac{dt_{part}}{\tau} = -N * \frac{dt_{lab}}{\gamma * \tau} \quad \text{now} \quad dt_{lab} = \frac{dx}{v} = \frac{dx}{\beta * c} \quad \text{so:}$$

$$dN = -N * \left(\frac{dx}{\beta * c * \gamma * \tau}\right) \Rightarrow N = N_0 * \exp * \left(-\frac{dx}{\beta * c * \gamma * \tau}\right)$$

If we now assume that the two processes are independent, we have:

$$N = N_0 * \exp\left(\frac{-x * N_A * \rho * \sigma}{A} - \frac{x}{\gamma * c * \beta * \tau}\right)$$

5) The scattering cress section and the decay rate:

The average number of K^- present while the beam traverses the fiducial region is:

$$\langle N \rangle = \frac{1}{L} * \int_0^L N * dN = \frac{N_0}{L} * \int_0^{L} \exp(-x(k_e + k_\sigma)) * dx \quad \text{where} \quad k_e = \frac{1}{\gamma * \beta * c * \tau} \quad \text{and} \quad k_\sigma = \frac{N_A * \rho * \sigma}{A}$$

so that:

$$\langle N \rangle = \frac{N_0}{L} * \left[\frac{1}{k_e + k_\sigma}\right] * \left[1 - 1 + L * (k_e + k_\sigma) - \frac{L^2}{2} * (k_e + k_\sigma)^2 \ldots\right] \approx N_0 - \frac{L * N_0}{2} * (k_e + k_\sigma)$$

now if we assume a constant decay rate over the short fiducial region we have:

$\langle N \rangle = \approx N_0 - (\Delta N_\tau + \Delta N_\sigma)/2$ where ΔN_τ is the number decays and ΔN_σ is the number of interactions.

now: $N_0 - \frac{L*N_0}{2}*(k_\tau + k_\sigma) = N_0 - (\Delta N_\tau + \Delta N_\sigma)/2 \Rightarrow (k_\tau + k_\sigma)*L*N_0 = \Delta N_\tau + \Delta N_\sigma$

so that: $\frac{N_A*\rho*\sigma*L*N_0}{A} = \Delta N_\sigma$; $\frac{L*N_0}{\gamma*\beta*c*\tau} = \Delta N_\tau$ or $\sigma = \frac{\Delta N_\sigma*A}{N_A*\rho*L*N_0}$; $\tau = \frac{L*N_0}{\gamma*\beta*c*\Delta N_\tau}$

plugging in the numbers we have:

$\sigma = 39.5 \pm 5.7$ mbarn

$\tau = 1.47*10^{-8} \pm 2.1*10^{-9}$ sec

where we used:

$p = \gamma m v$ to obtain γ and β since we need $\gamma\beta$ we note that:

$\gamma\beta = pc/mc^2 = 3.038$

$N_0 = 4823$; $\Delta N_\tau = 109$; $\Delta N_\sigma = 205$; $L = 30$cm; $\rho = .069$gr/cm.

The errors given with the values only include the statistical error and the error due to the measurement of the fiducial region.

The accepted values are:

$\sigma = 35$ mbarn (1)

$\tau = 1.2*10^{-8}$ sec (1)

We note that the statistical error already manages to account for most of our deviation from the expected value in the case of the reaction cross section. The high value for τ may be a refection of the same skewing of data seen for the branching ratio. Both measurements point to the fact that there were fewer $k^- \rightarrow \mu\bar{\nu}$ decays than would be expected.

Error Analysis

Statistical error:

We already included the statistical error in our data section, so that this section will only briefly show how the error is calculated.

Given some value F which depends on a data vector $\overline{X}$ then the standard deviation of F is: $\sigma_F = \sqrt{\sum_i \left(\left(\frac{\delta F}{\delta x_i} \right)^2 * \sigma_{x_i}^2 \right)}$

now since we have counting statistics in this experiment: $\sigma_{x_i} = \sqrt{x_i}$

Systematic error:

1) Small angle scattering:

If the scattering angle between a K^- and p^+ is small then it may be missed.

a) We will assume a worst case situation. Let us assume that we can detect no reactions where the momentum transfer is such that the p^+ leaves a track of 1 cm, but can detect all reactions with a greater momentum transfer. So:

1 cm in the bubble chamber => 140 Mev/c (2)

b) Now it seems safe to assume that we can detect all reactions that have a scattering angle which is > 2º, so if we were to miss all the interactions that have a scatter angle of < 2º then the resulting change to the cross section would be:

$$\left(.0012*.14\frac{Gev}{c}\right)^2 * \left(70\frac{mbarn}{\left(Gev/c\right)^2}\right) = 1.6*10^{-3}\,mbarn \quad \text{where we used} \quad \frac{d\sigma}{dt} = \frac{70\ mbarn}{\left(Gev/c\right)^2} \quad \text{and} \quad t = (p\theta)^2$$

This is clearly an insignificant correction since it is by 4 orders of magnitude smaller than the statistical error.

2)Small angle decays:

Some decays, in which the change in momentum of the resulting muon, when compared to the kaon, is small, may not be detected. In order to have a condition in which the change in momentum is at a minimum, we assume that the neutrino from the $K^- \to \mu^- \bar{\nu}$ decay is emitted in the direction opposite of the kaon. Then:

$P_K = P_\mu - P_\nu$ and $E_K = E_\mu + E_\nu$

this gives: $(E_K - P_\nu)^2 = M_\mu^2 * c^4 + P_\mu^2 * c^2 = M_\mu^2 * c^4 + (P_K + P_\nu)^2 * c^2$

so that: $$P_\nu = \frac{c^3}{2} * \frac{(M_K^2 - M_\mu^2)}{(E_K + c * P_K^2)}$$

Substituting in the correct numbers gives:

P_ν = .0759 GeV/c so that P_μ = 1.42 GeV/c. In order to see if we could detect such a small change in momentum, we note that if a 1.5 GeV/c charged particle travels 10 cm, its displacement off the horizontal in the 1.667 T magnetic field of the bubble chamber is .35cm while the corresponding displacement for a 1.42 GeV/c charged particle is .36 cm. Thus, the difference is .2 mm, which clearly is not detectable. Error of Roundoff Δ = .01 cm

To estimate the error resulting from our inability to detect certain decays, we note that we fail to detect only those decays which have a decay angle of under 2°. (see systematic error #1) Since Kaons are spinless, their decay is isotropic. Now a 2° angle in the lab frame corresponds to a 4° center of mass angle so that 4/180 = 2.2% of the decays are missed. This changes our τ to $1.44 * 10^{-8}$ sec and the branching ratio BR = 9.87%

3) There are naturally some errors due to the fact that neither my partner nor I has perfect scanning efficiency, even for those interactions which we believe to be easy to detect. The effects of this inaccuracy are compensated for in the data used in the analysis (see Data and Analysis section). It should be noted however that error resulting from our scanning inefficiency are quite small.

4) Another systematic error could arise from the fact that, when a kaon decays, it is no longer available to interact with the protons and, similarly, if a kaon interacts, it can no longer decay. If we are to avoid this systematic error, our analysis most take this fact into account. Our analysis in section 4)

fails to do so, therefore we will estimate the resulting errors to our calculated values for τ and σ.

Say that P_σ is the probability that a Kaon would scatter with a proton, while the kaon crosses the fiducial region, if no decays were to occur. Similarly, we will call P_τ the probability that a kaon would decay, while crossing the fiducial region, if no scatters were to occur. In that case, the probability of a scatter being observed if both scatters and and decays are occurring is: $P_\sigma' = (1 - aP_\tau)*P_\sigma$ and similarly, the probability of a decay if both effects are being observed is: $P_\tau' = (1 - bP_\sigma)*P_\tau$ where $a + b = 1$ and $a/b = P_\sigma'/P_\tau'$. (a and b are used to recognize the fact that a particle must either decay or scatter, but that it can't do both.) Applying this analysis we find that we must adjust our reaction counts in the following way (note we use the τ from part 2): $\Delta N_\tau = 112.6$, $\Delta N_\sigma = 206.6$. This leads to $\sigma = 39.8$ mbarn and $\tau = 1.38*10^{-8}$ sec. Thus $\Delta\sigma = .3$ mbarn and $\Delta\tau = -.06*10^{-8}$ sec.

5) Another systematic error consists of inconsistencies in our judgements on which particles and which reactions should should be recorded. At it was not always obvious if a beam did in fact belong to the correct momentum range and particle type, or if the beam crossed a large enough part of the fiducial region. An estimate of this error is based on the fact that Ted an I disagreed about whether a kaon particle was to be counted toward our total beam count about once every second frame, so for about 5% of the count. The reason this error is not self correcting is that we felt that we were much stricter about whether or not to count a beam when it did not react. Hence, we estimate that we undercounted the total number of beams by 2.5%. The corrected beam count is then: 4944. So using the adjusted values from part 4) we get: $\sigma = 38.8$ mbarn and $\tau = 1.41*10^{-8}$. The effect here is to have a $\Delta\sigma = -.1$ mbarn and $\Delta\tau = .03*10^{-8}$ sec.

Questions

1)

a) The reason that it is not feasible to measure the lifetime of a K^- particle at rest is that the K^- meson would immediately be drawn into the nearest atom nucleus. In contrast, the K^+ meson would clearly not be drawn into the nucleus because of its charge and it would not react with the electrons since the $K^+ e^-$ interaction cross section is extremely small.

b) The special theory of relativity essentially makes it possible to study particles with small life times since the lifetime of the particle in the Lab frame is increased by a factor of γ from what it is in the particle's frame. In our experiment $\gamma = 3$.

c) We note that K^+ is the antiparticle of K^-. Comparing the quantum numbers of these two particles we see that charge, strangeness and I_3 (the direction of the isospin) change sign. In general, the lepton number and the baryon number also switch sign.

2)

a) Since $\sigma = 39.5$ mbarn and classically $\sigma = \pi r^2 \Rightarrow r = 1.12 * 10^{-13}$ cm

b) From energy and momentum conservation we have:

$$m^2c^4 = \left(E_K + m_p c^2\right)^2 - p_K^2 c^2 \Rightarrow m = 2.02 \frac{\text{Gev}}{c^2}$$

c) If we were to observe a resonance particle, that particle would have to "absorb" all the conserved quantities. Therefore:

	K^- meson	proton	resonance part.
Charge:	-	+	0
Lepton number:	0	0	0
baryon number:	0	1	1

strangeness:	-1	0	-1
spin:	0	1/2	1/2
Isospin:	1/2	1/2	1 - 0
parity:	-	+	-

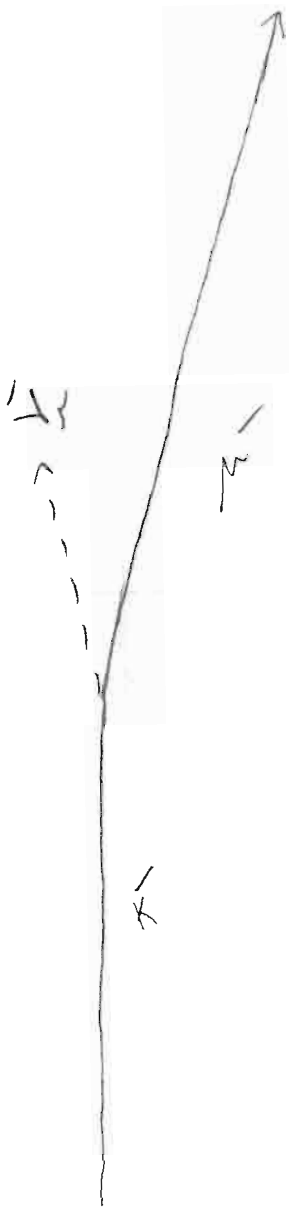
Conclusion

After correcting for systematic errors our our results for the branching ratio, the scattering cross section and the decay rate are as follows:

BR = 9.87 +- 3.7 %, σ = 38.8 +- 5.7 mbarn and $\tau = 1.41*10^{-8}$ +- $2.1*10^{-9}$ sec.

Since the accepted value for the cross section is 35 mbarn, we find that our value fo the cross section is well within the range of the accepted value. For the branching ratio and the decay rate, however our values differ from the accepted BR = 5.59% and $\tau = 1.2*10^{-8}$ sec by more than would be expected. In fact, BR is off by slightly more than one standard deviation, while τ is off by exactly one standard deviation. One possible explanation is that there were to few $k^- \to \mu \bar{\nu}$ decays in our set of bubble chamber films. Such a conclusion is consistent with the fact that both the decay rate and the branching ratio are too high. We note that such an explanation seems plausible since our values differ from the expected values by about one standard deviation which means than data skewed in the manner that ours is, is to be expected 17% of the time.

EVENT 1

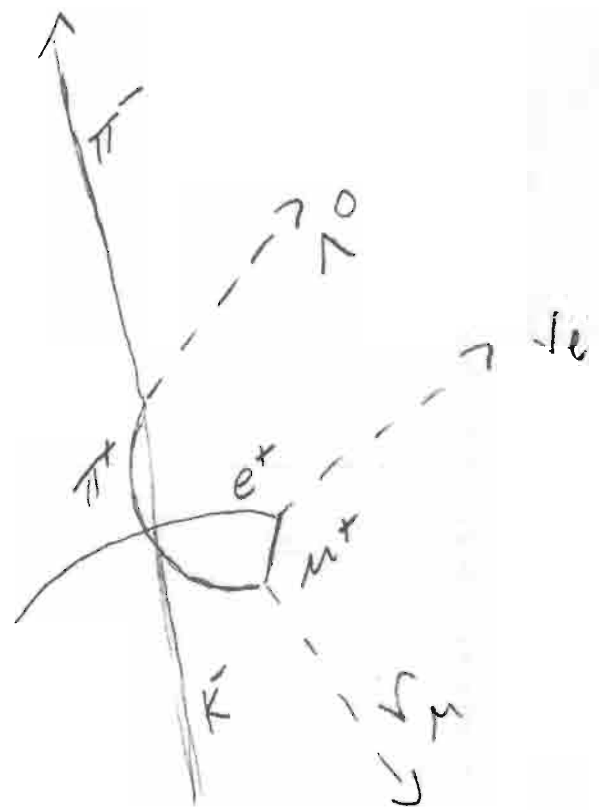


$K^- \rightarrow \mu^- + \bar{\nu}_\mu$

Frame 586

View I

Event 2



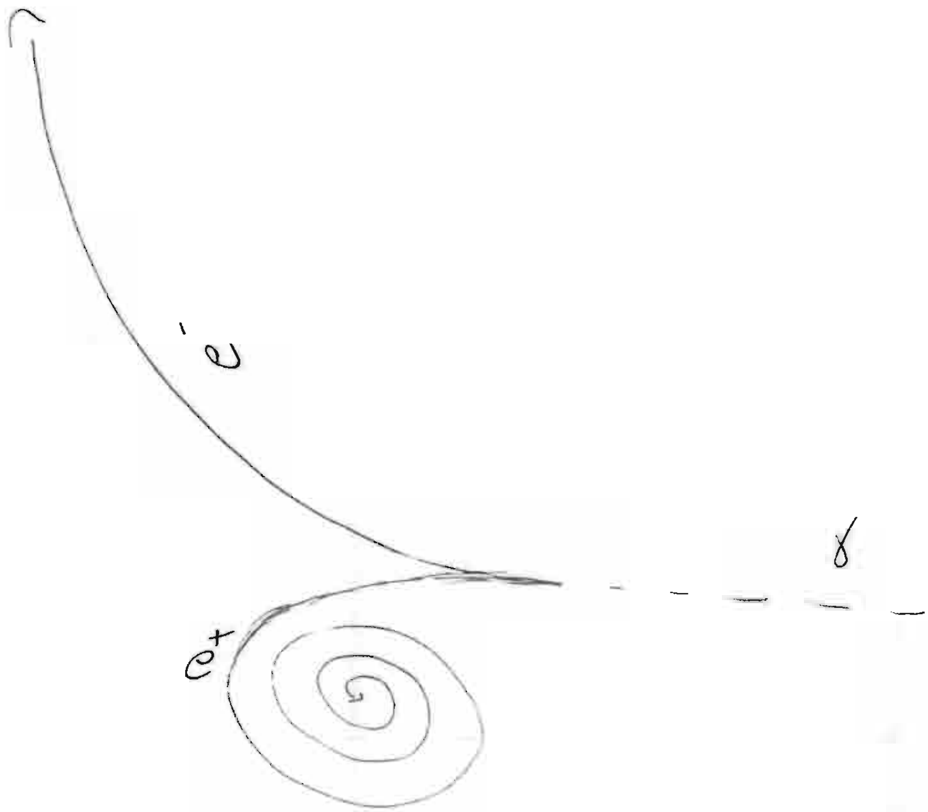
Frame:
287
View II

$K^- p^+ \to \pi^+ \pi^- \Lambda^0$

↳ $\pi^+ \to \mu^+ \nu_\mu$

↳ $\mu^+ \to e^+ + \nu_e$

EVENT 3



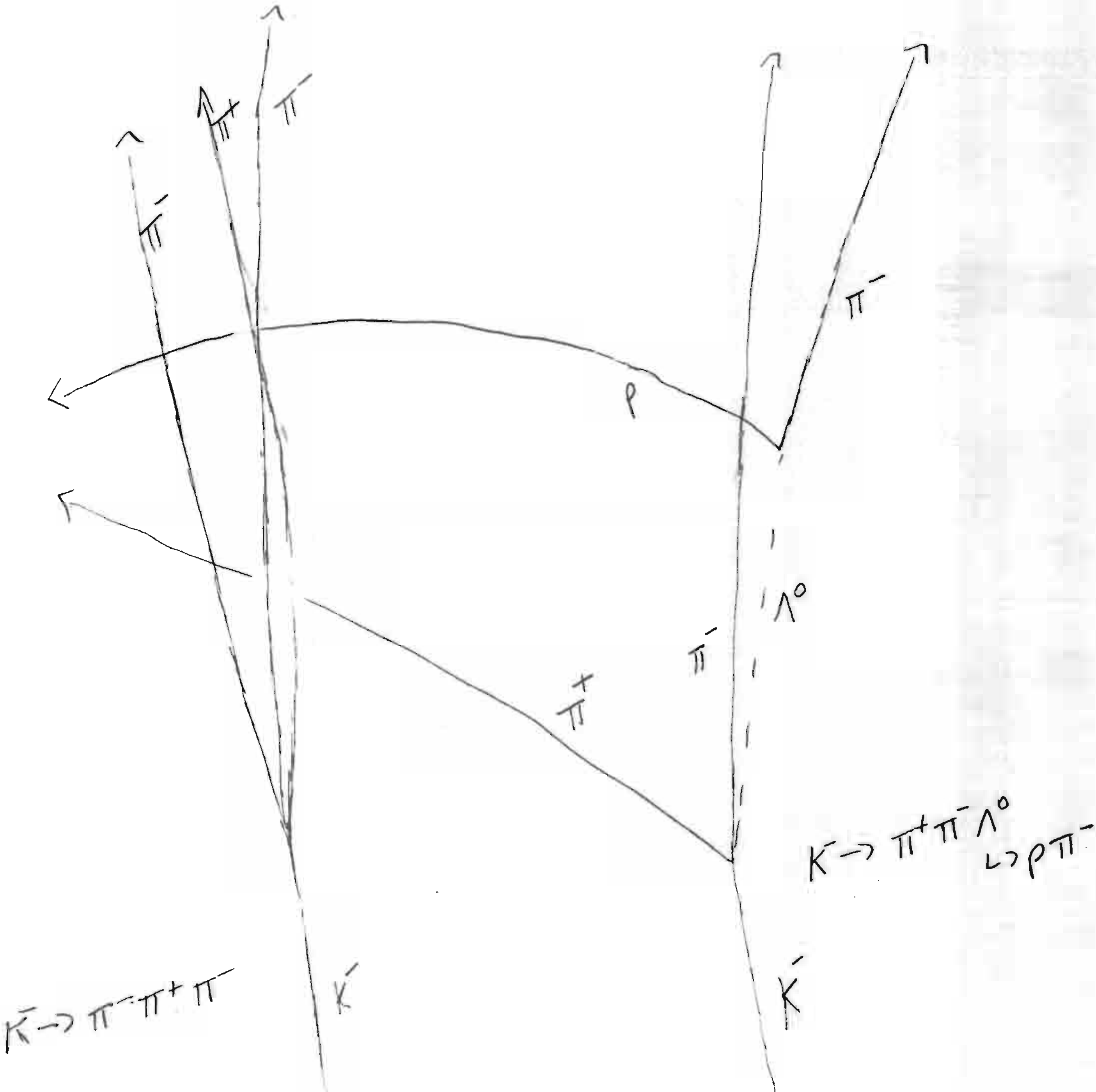
$\gamma \to e^+e^-$

FRAME 202

VIEW I

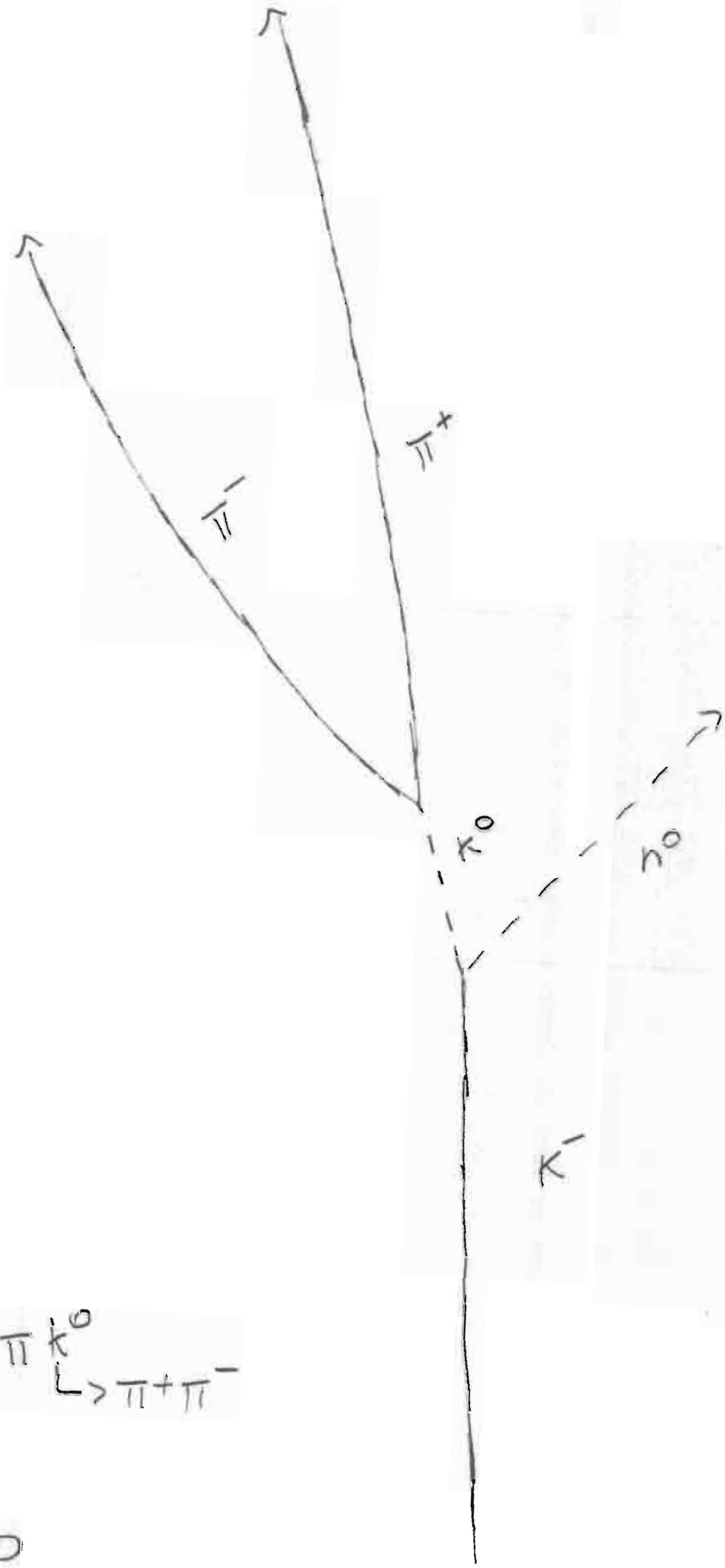
EVENT 5

EVENT 4



VIEW I FRAME 257

EVENT 6



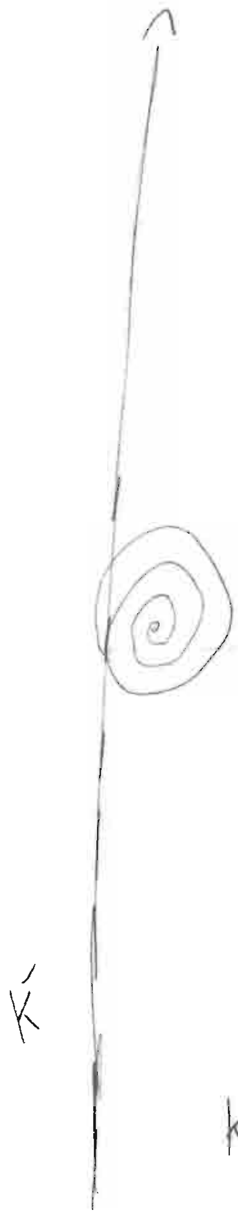
$K^- p \to \pi K^0$

$\quad \hookrightarrow \pi^+ \pi^-$

FRAME 350

VIEW I

EVENT 7

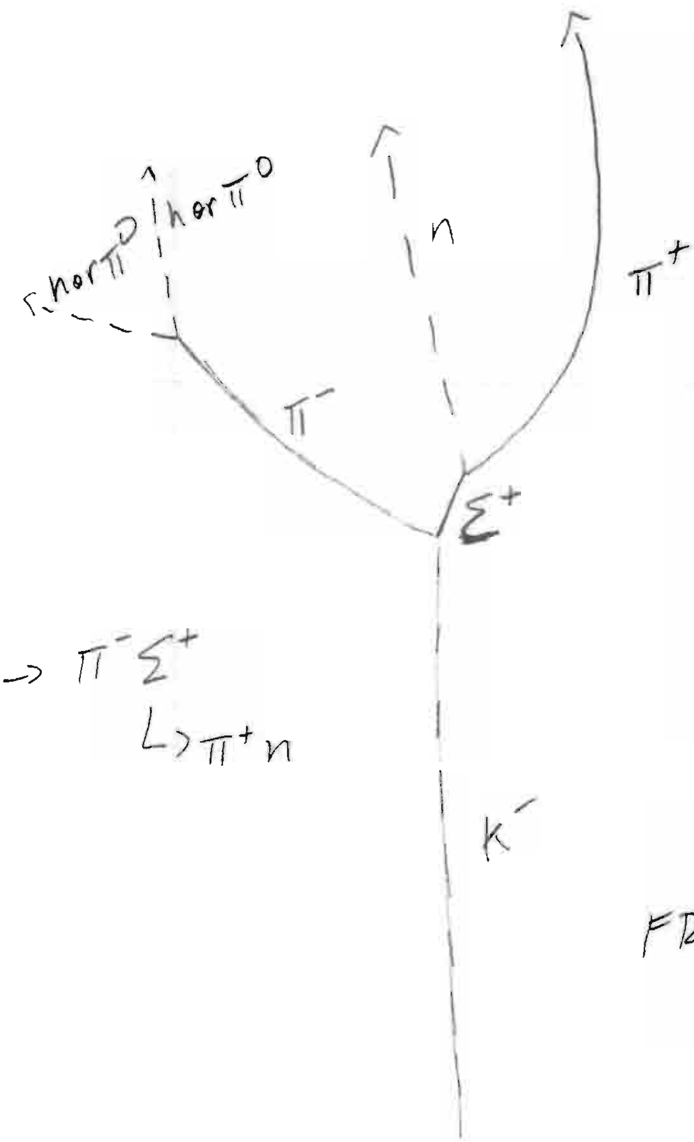


$K^- e^- \rightarrow K^- e^-$

FRAME 522

VIEW I

EVENT 8

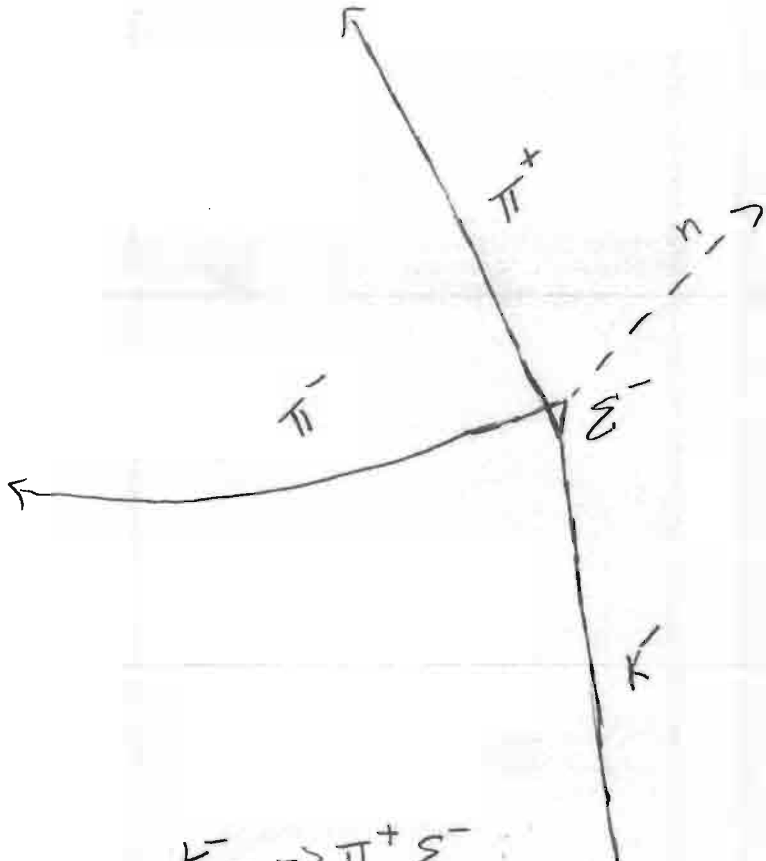


$K^- p \rightarrow \pi^- \Sigma^+$
$\quad \hookrightarrow \pi^+ n$

FRAME 457

VIEW I

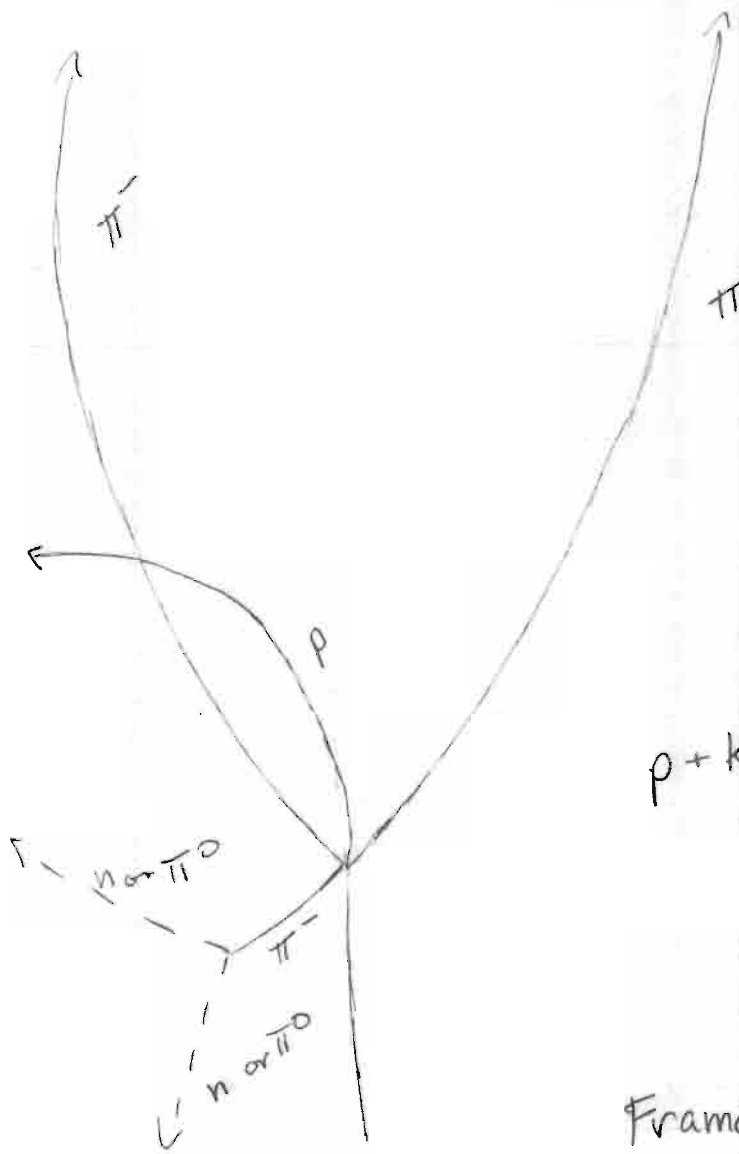
EVENT 9



$K^- p \rightarrow \pi^+ \Sigma^-$
$\hookrightarrow \pi^- n$

FRAME 543
VIEW I

EVENT 10



$p + K^- \rightarrow p + \pi^+ \pi^- \pi^-$
$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \llcorner \pi p$
$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \rightarrow \pi\, r$

Frame 201

View I

[redacted]

~~200~~
200 {13}
201 4p
204 1p, 1p
205 1p
208 1p, 2p
210 {12}
216 1p
220 {13}
222 3p
223 2p
224 0p—V
228 invalid
229 2p-1p
230 {13} 1p
231 1p
234 2p
~~233~~6 1p
238 2p, 1p ← Error
239 0p
240 {13}
242 2p, 2p ←E
243 2p, 2p
246 1p-N ←E
248 1p, 0p ←E
250 {5}, 1p-V
251 1p
→ 252 2p-4p-lob
254 2p
258 0p-3p ←E
257 2p-V, 3p
260 {12}
263 2p
→ 264 2p-V
265 2p-V, 2p
266 1p1
26[illegible] 2

270 {14} 1p
272 1p
273 2p ←E
275 2p
278 0p
279 2p
280 {11} 1p, 1p, 2p-1p
282 1p
→ 283 1p, 2p-V
285 0p
286 2p
→ 287 2p
289 2p
290 {5} 0p
291 2p, 0p ←E
293 2p
294 2
300 {5} 0p-V ←E
301 1p, 2p 2p
304 2p
305 2p
307 1p
309 2p-V
310 {3} 2p
311 0p
313 1p
314 2p-V
316 2p-1p
318 1p, 1p
320 {13}
322 1p, 1p
323 ~~3~~, 3p
327 0p-V
328 2p
330 {11}
335 2p
33[illegible] 1p

340 {13} 2p, -2p 1p
342 2p
343 2p-V, 2p
344 1p
345 1p, 2p, 2p ←E
346 2p
350 {9} 0p-V
351 2p
353 2p
355 2p-1p-2p
4p-1p-2p
357 0p
358 1p, 2p
360 {9} 2p-1p
361 1p
368 0p
370 {14} 1p, 2p-V, 0p
375 3p
376 2p-V ←E
377 2p
378 2p
379 1p
380 {5}
381 1p
383 2p
385 4p
390 {7} 2p
391 2p ← 392 1p
393 1p, 0p
394 1p
395 1p
396 4p
399 2p, 0p-V
400 {8}
401 1p ← 402 2p
404 1p
405 1p-V

406 [illegible]
407 1p
408 1p, 1/ < 409 0p
410 [illegible] 3p
411 4p
415 2p
418 1p
419 0p, 1p
420 {6}
423 1p
424 1p
425 1p, 2p
427 0p - V, 2p
429 2p 0p
430 [illegible] 4p
431 0p - [illegible]
432 2p
433 1p 2p 1p
434 0p, 1p 2p
436 2p, 2p, 1p
438 2p, 1p, 2p
439 2p
440 {4}
442 1p
443 1p, 4p
444 2p - wierd shit
445 2p - V
446 2p
447 0p
448 0p
450 {5}, 2p
451 1p
452 2p - V
454 1p
455 2p, 1p, 1p
457 2p
458 [illegible]

460 {14} 1p
461 1p
462 2p
470 {7}, 1p < 473 0p
478 2p
480 {5} 2p - 1p
481 1p
482 1p < 483 2p
490 {8} [illegible] 3p
494 1p, 0p < 497 2p
500 {9}
503 2p - 1p
506 2p
507 1p 2p - V,
508 4p - V etc
510 2p - 3p {10}
511 2p 2p
512 2p
516 1p
517 2p - V
2p
520 {11}
521 1p, 3p
522 2p
524 0p 526 2p
525 4p
1p 527 1p
528 2p
530 {4} 2p - V, 1p
531 1p
532 2p - V 1p 0p
534 2p 533 0p
536 1p
537 1p
538 2p - V
540 {4}
541 1p, 1p
542 [illegible]

544 1p
545 1p
550 {10} 2p 2p
552 0p
557 1p, 2p
559 1p - V, 2p
560 [illegible]
562 2p
569 0p
570 [illegible] 1p
571 2p
572 2p
573 2p - V
575 2p - V
576 0p - V
577 1p 2p, 1p
578 1p
579 2p ← not errors
580 {9} 1p 2p
581 2p 0p
582 2p
586 1p, 1p, 1p
590 {14}
591 2p
592 2p
594 1p
596 2p - V
597 0p - V
598 2p
599 0p, 2p
600 {9} 2p, 2p

601 1p
606 0p-V, 2p
607 2p-1p
610 §13§ 2p
612 ~~2p~~
613 2p, 1p
616 1p, 2p
617 2p ~~2p-V~~
620 §11§ ~~1p~~
621 ~~2p~~
622 1p
625 ~~1p~~ 623 2p
627 2p
630 §1§ 2p
631 2p
634 2p 637 4p
640 §8§
642 2p
646 7p
648 2p
649 2p, 1p
650 §10§
659 6p
660 §12§ ~~3p~~ 1p
664 1p
665 1p
666 1p, 2p
668 1p
669 1p, 1p
670 §12§ 2p
671 ~~2~~ Error
673 3p, 2p
674 6p, 1p
676 0p, 2p - stuff 8p
677 ~~1p~~
678 2p, 1p, 2p
680 §12§
681 2p, 2p

683 3p-V
687 2p
687 1p
688 2p, 2p
689 2p - 1p
690 2p §11§
691 2p, 1p, 1p 0p and two V's
694 2p-V, 2p-stuff
695 2p
697 2p, 1p
700 §12§
701

We Missed.

	0-P	1-P	2-P
out of region ←	~~299~~	204	220
		220	~~220~~ Chident.
out.		~~252~~	~~289~~
Kink on 4P. ←		~~294~~	~~294~~
		~~307~~	323
		~~358~~	353
		~~439~~	
		448	
out		~~566~~	
		missed 6	

They Missed.

0-P	1-P	2-P	3+4-P
226	270	242	~~289(3)~~
285	340	~~307~~	~~294(4)~~
291	379	345	
~~358~~	392	346	
419	393	376	
497	433	433	
532	436	~~439~~	
659	455	519	
	532	616	
	669	616	
		617	
		289	

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Bad Calc data – Scratch.

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