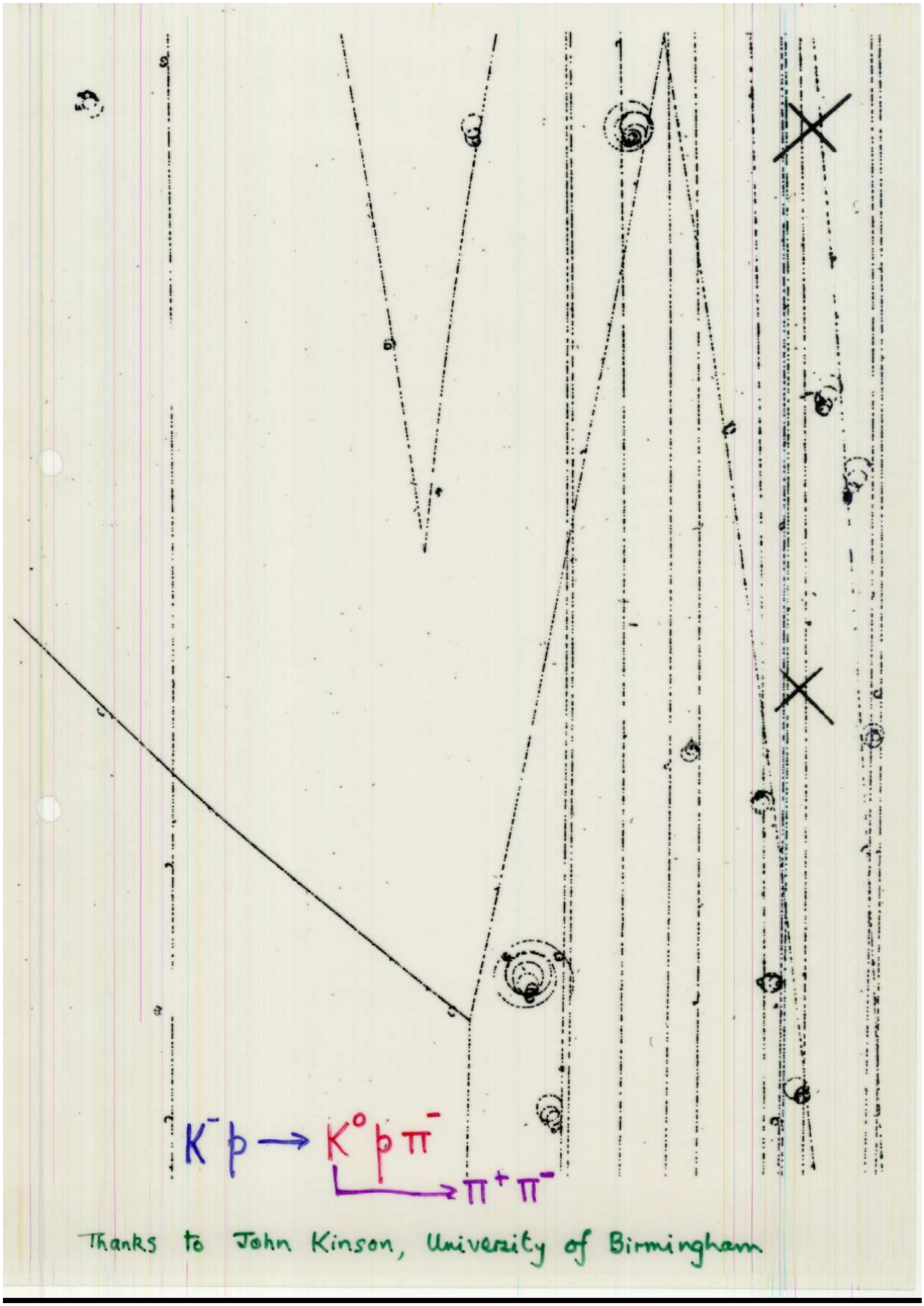


Thanks to John Kinson, University of Birmingham

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

	p_x (GeV/c)	p_y	p_z	E(GeV)
K^-	8.26131	-0.15642	0.01320	8.27753
p	0.	0.	0.	0.93828
π^-	4.49326	0.73621	-0.51122	4.58391
p	0.32496	-0.45360	0.04282	1.09250
K^0	3.44322	-0.43912	0.48159	3.53952

DATA PROCESSING

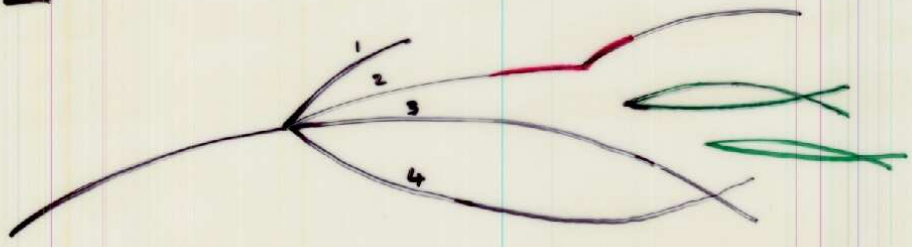
Aim: to get as close as possible to measuring energy E and momentum p of all particles taking part in the interactions

DATA PROCESSING

① SCANNING

Find all 'events' and classify them

eg



N(prongs) = 4

N(kinks) = 1

N(vees) = 2

Classified as a 412 event

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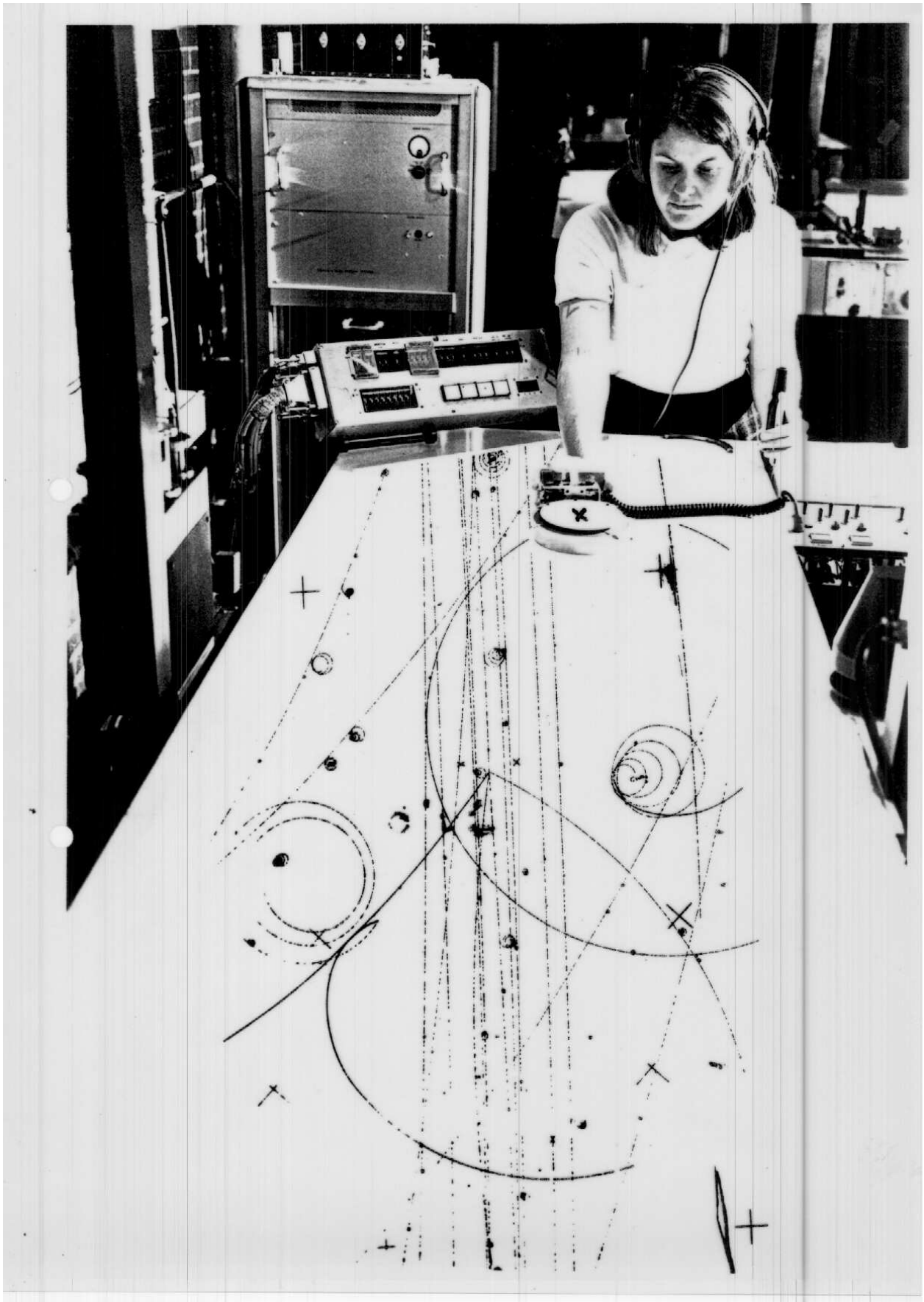
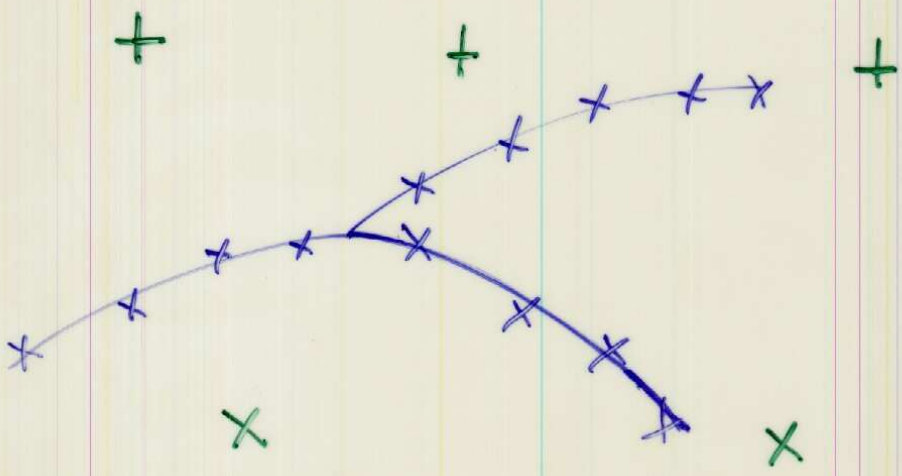


(2) MEASURING

* Measurer feeds into computer, for each track, the co-ordinates of several views (so that the event can be reconstructed in 3 dimensions)

* Co-ordinates of 'fiducial' crosses on the bubble chamber walls are also measured (their positions are accurately known reference points)



* Computer calculates the best curve fitting the measurements (with errors)

* Then the momentum from the radius of curvature

$$\frac{mv^2}{r} = Bqv \Rightarrow p = (Bq)r$$

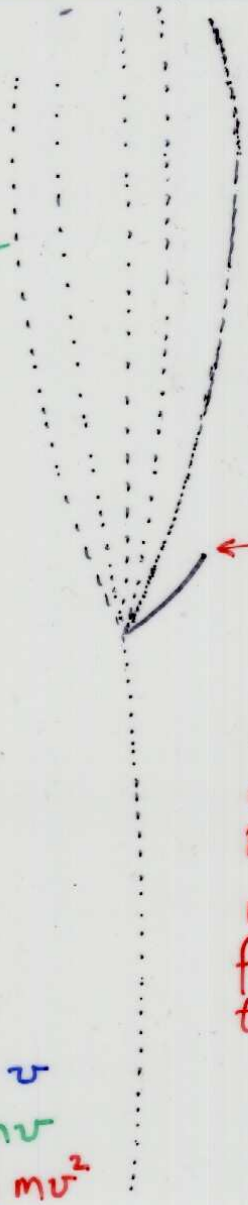
(Corrections are made to allow for the slowing down of the particle as it deposits energy)

(Electrons are hardest to measure because they spiral unpredictably.)

Synchrotron radiation

bremsstrahlung (braking radiation)

RELATING WHAT WE CAN MEASURE ON BUBBLE CHAMBER PICTURES TO QUANTITIES THAT TELL US HOW PARTICLES ARE MOVING.



NUMBER OF BUBBLES PER CENTIMETRE (some tracks look more 'solid' than others) → gives SPEED of particle

CURVATURE (some tracks straighter than others) → gives momentum of particle

RANGE (distance particle travels before stopping)

Particle stops when all its energy has been used up, making bubbles as it forces it way through the liquid.

Speed $= v$

Momentum $p = mv$

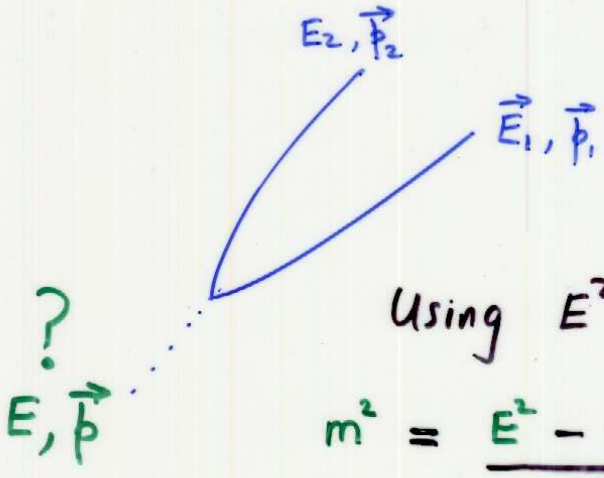
Kinetic energy $E = \frac{1}{2}mv^2$

also $E = \frac{p^2}{2m}$

Knowing any two of v, p and E – can calculate m → WEIGH THE PARTICLE!

How can we 'weigh' a particle?

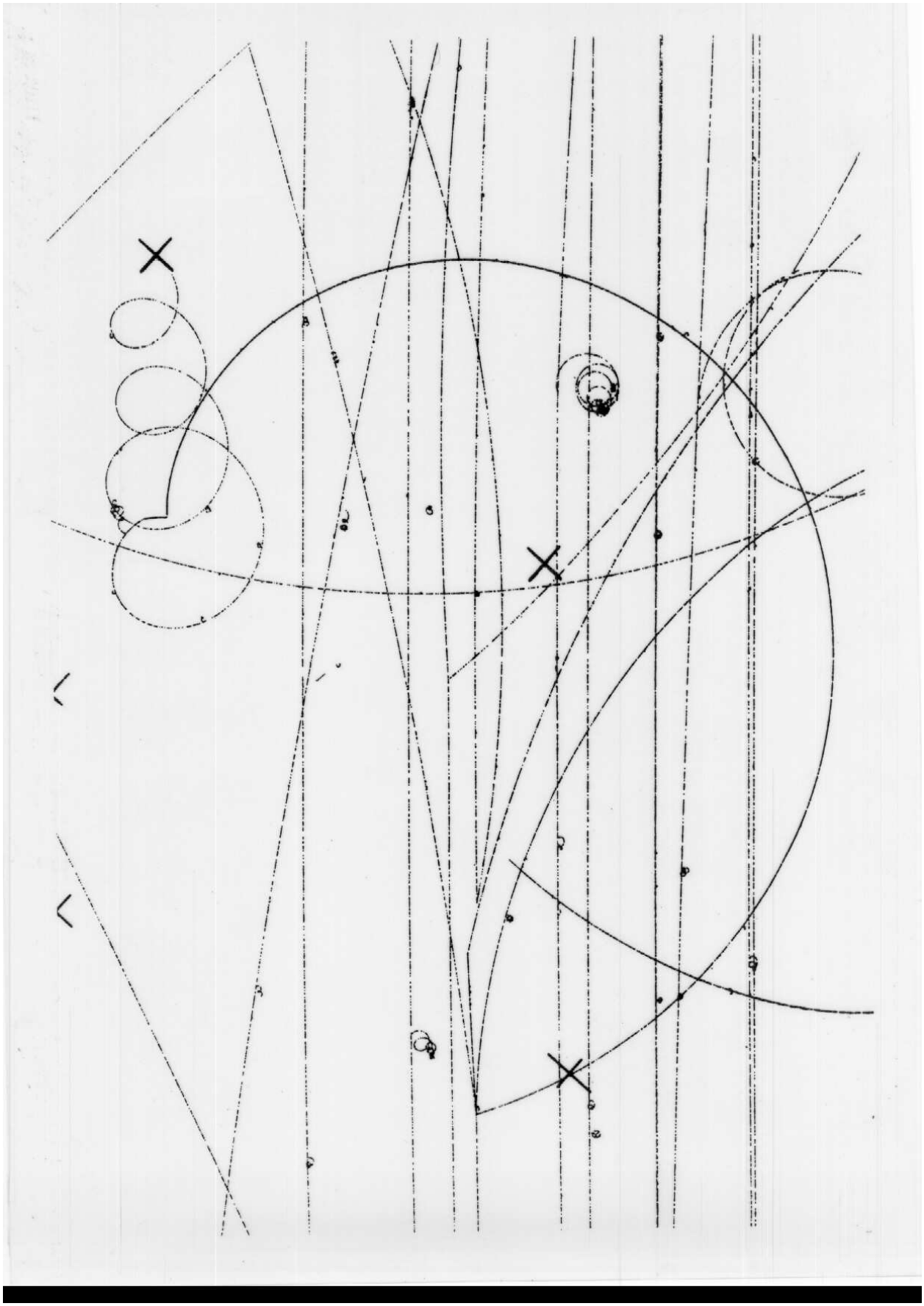
→ determine its mass



Using $E^2 = p^2c^2 + m^2c^4$

$$m^2 = \frac{E^2 - p^2c^2}{c^4}$$

$$= \frac{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 c^2}{c^4}$$



Summary of 'stable' (lifetime $\gg 10^{-23}$ sec) particle properties

(Tailored to analysis of bubble chamber pictures.)

	Particle name	Mass in MeV/c^2	Main decays	%	Mean life in seconds	$c\tau$ (cm)	Comment
γ	gamma	0	e^+e^-		stable		Strictly not a decay, but a 'materialisation' in the field of a nucleus.
ν	neutrino	0			stable		Neutrinos show up in final states as unseen partners in decays: eg. of μ and π.
e^-	electron	0.511	stable				Curls up characteristically in bubble chamber.
e^+	positron	0.511					• Annihilates with electron. • Also curls up characteristically in bubble chamber
μ^-	mu minus	105.7	$e^-\bar{\nu}_e\nu_\mu$	100	2.2×10^{-6}	$\sim 10^5$	Usually escapes; sometimes kinks.
μ^+	mu plus	105.7	$e^+\nu_e\bar{\nu}_\mu$	100	2.2×10^{-6}	$\sim 10^5$	Usually escapes; sometimes kinks.
π^-	pi minus	139.6	$\mu^-\bar{\nu}_\mu$	100	2.6×10^{-8}	780	May kink or 'pimue'
π^+	pi plus	139.6	$\mu^+\nu_\mu$	100	2.6×10^{-8}	780	May kink or 'pimue'
π^0	pi zero	135.0	$\gamma\gamma$	98.80	8.4×10^{-17}		May give e^+e^- pair(s)
			γe^+e^-	1.20			When e^+e^- come directly from interaction, it is called a Dalitz pair.
$K^\pm$	kaon	493.7	$\mu\nu$	63.51	1.2×10^{-8}	371	May kink.
			$\pi\pi^0$	21.16			May kink.
			$\pi^\pm\pi^+\pi^-$	5.59			May give 'trident'.
K^0	kay zero	497.7	$\pi^+\pi^-$	68.61	0.9×10^{-10}	2.68	This is K^0_S; may give 'vee'.
p	proton	938.3	stable				Low energy p often stops in bubble chamber - characteristic dark track.
n	neutron	939.6	$pe^-\bar{\nu}$	100	887		Sometimes identified via a proton it collides with.
Λ	lambda	1116	$p\pi^-$	63.9	2.6×10^{-10}	7.89	May give 'vee'.
Σ^+	sigma plus	1189	$p\pi^0$	52	0.8×10^{-10}	2.4	May kink.
			$n\pi^+$	48			May kink
Σ^0	sigma zero	1193	$\Lambda\gamma$	100	7.4×10^{-20}		May give Λ and γ.
Σ^-	sigma minus	1197	$n\pi^-$	99.85	1.5×10^{-10}	4.4	May kink
Ξ^0	xi zero	1315	$\Lambda\pi^0$	99.5	2.9×10^{-10}	8.7	$\Lambda + \gamma$s to downstream point
Ξ^-	xi minus	1321	$\Lambda\pi^-$	100	1.6×10^{-10}	4.9	Λ from kink possible.
Ω^-	omega minus	1672	ΛK^-	67.8	0.8×10^{-10}	2.5	Λ from kink possible
			$\Xi^0\pi^-$	23.6			$\Lambda + \gamma$s to downstream point
			$\Xi^-\pi^0$	8.6			Λ to 2^{nd} kink possible.

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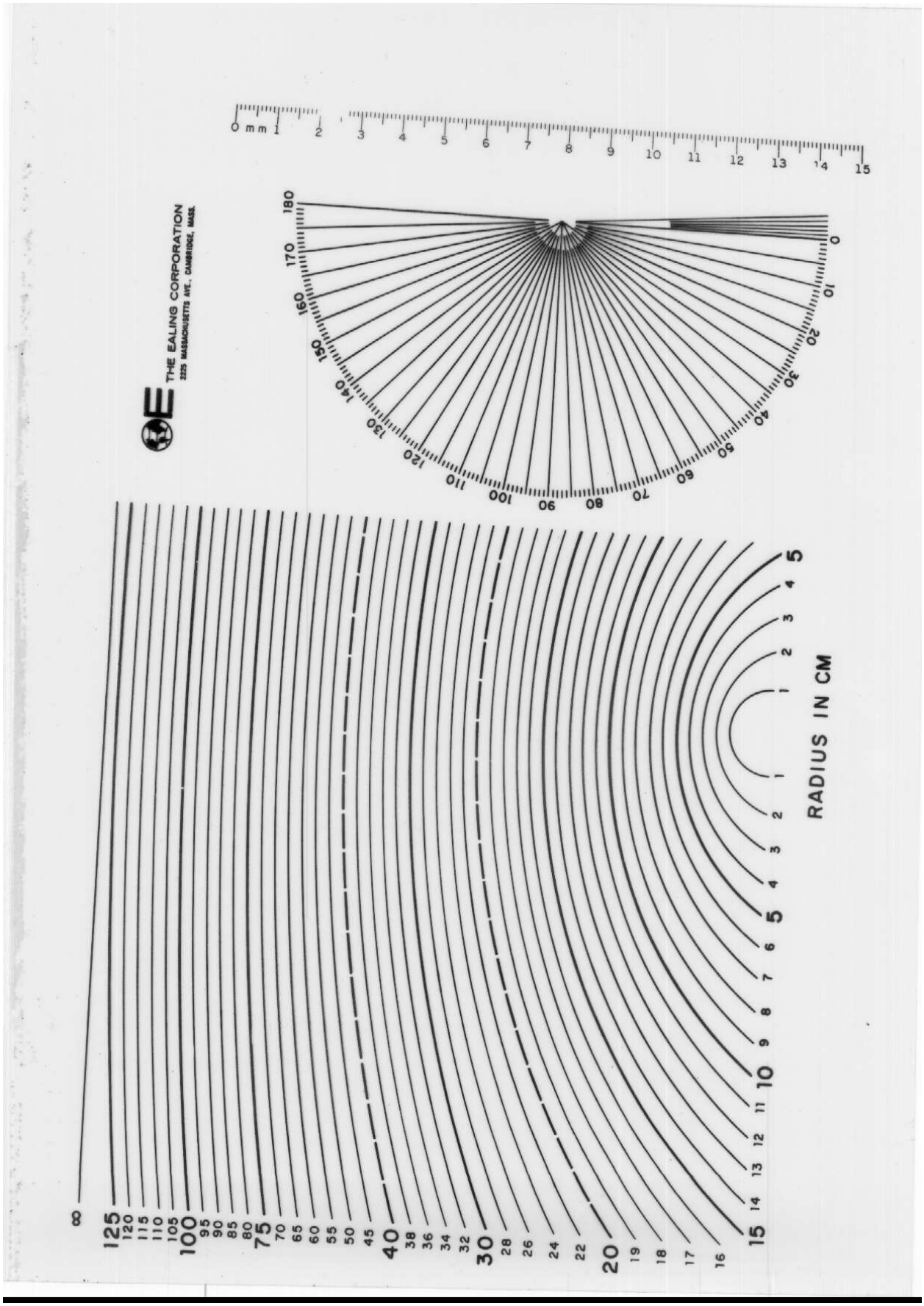
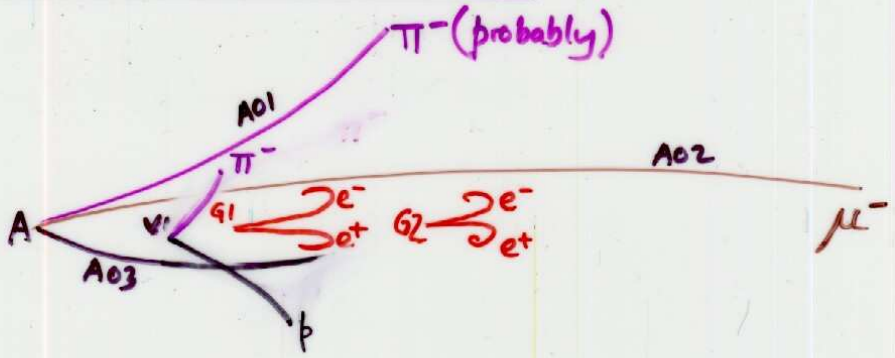

THE EALING CORPORATION
2225 MASSACHUSETTS AVE., CAMBRIDGE, MASS.
RADIUS IN CM

Come and weigh a photon!



Vertex V1 (raw measurement)

E (MeV)	p_x (MeV/c)	p_y (MeV/c)	p_z (MeV/c)	Comment
1159	541	340	235	p by ID
195	80	-13	109	Unique π^-
				m_Λ =

GAMMA G1 (raw measurement)

81	76	-18	20	e^+
257	247	-54	42	e^-
				m_{γ_1} =

GAMMA G2 (raw measurement)

38	22	-21	22	e^+
113	63	-63	69	e^-
				m_{γ_2} =

PRIMARY VERTEX TRACKS

Track Label	E	p_x	p_y	p_z	Comment
A01	1146	1022	404	-295	π^+ probably
A02	24696	24375	-2353	-3196	μ^- in EMI
A03	1003	217	178	-217	Stopping p
G1	318	307	-61	58	Fitted γ_1 [4]
G2	141	84	-76	84	Fitted γ_2
V1	1371	633	319	364	$\Lambda^0 \to p\pi^-$

Problem Evaluate the effective mass of the two photons γ_1 and γ_2.

Sketch Solution $M(G1 \oplus G2) =$

$$\left\{(318+141)^2 - (307+84)^2 - (-61-76)^2 - (58+84)^2\right\}^{1/2} = 137$$

MeV

This is the mass of the π^0 (approx.)

$$\pi^0 \to \gamma\gamma$$

[4] Kinematics programme gets 'improved' fitted values by constraining the γs to pass through the primary vertex A.