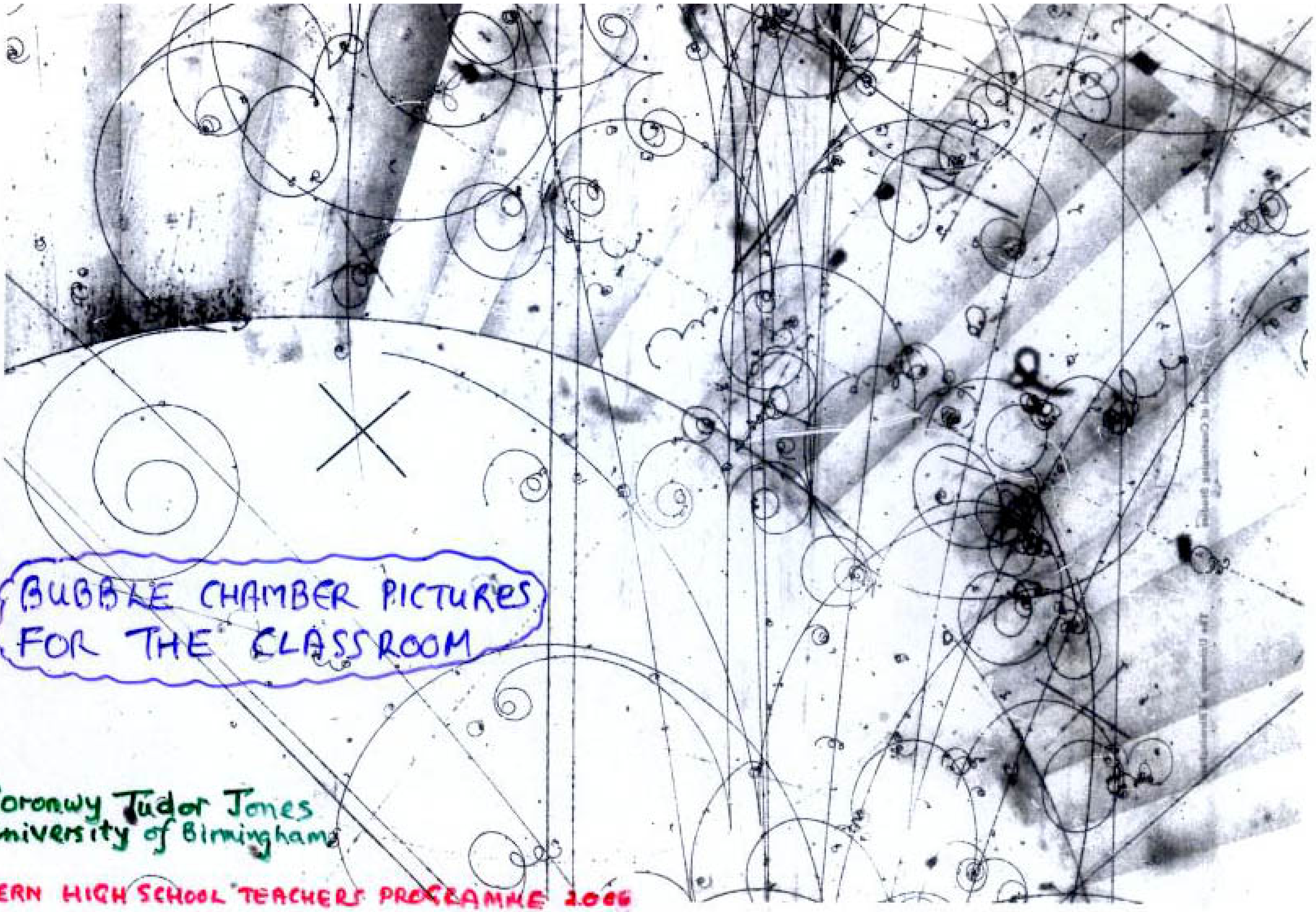

BUBBLE CHAMBER PICTURES FOR THE CLASSROOM
Goronwy Tudor Jones
University of Birmingham
CERN HIGH SCHOOL TEACHERS PROGRAMME 2006

Introductory Remarks

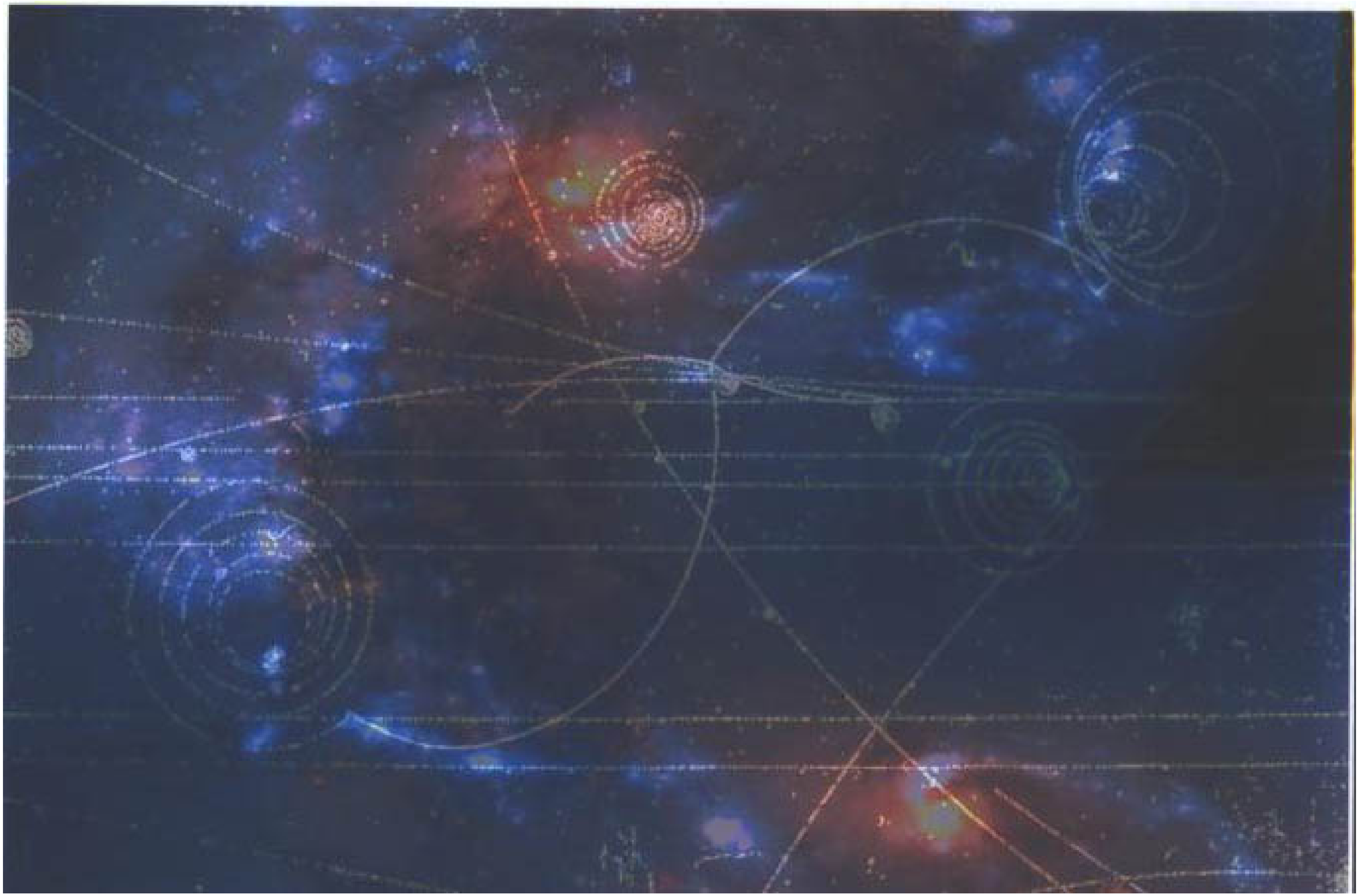
Bubble chamber pictures popular

- beautiful (∴ 'cool' ?)
- illustrate VISUALLY and QUALITATIVELY many phenomena/principles

  eg
  - $E = mc^2$
  - Momentum conservation
  - Statistical nature of quantum phenomena
  - Collisions
  - Decays
  - Accelerated charges radiate (mobile!)

Purpose of these lectures

- 'Comfort layer of knowledge' for teacher
- To invite you to think of contributing to the bubble chamber activity



PLAN

Lecture 1 Background information

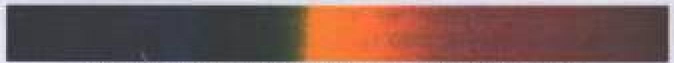
- How do we establish the existence of substructure?
  - discrete spectra
  - Rutherford type experiments
- The Spectrum of HADRONS
  → strongly interacting particles (or particles that feel the strong nuclear force)
  - dominated by the BUBBLE CHAMBER
- The Bubble Chamber
- Conservation laws

Lecture 2 The Bubble Chamber Web Site

- Teachers explore BC web site for ~1 hour
- Session for
  - questions
  - reactions
  - suggestions for improvements, activities ...

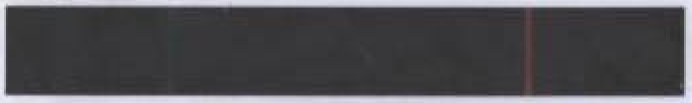
Visible and H atom Spectrum

Visible Spectrum



The visible spectrum is continuous and ranges from blue to red light.

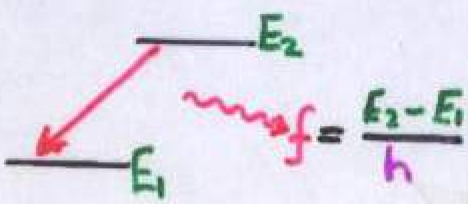
Hydrogen Line Spectrum



The visible hydrogen spectrum is composed of discrete lines. Shown are the colors of the photons in the visible region that are emitted by excited hydrogen atoms.

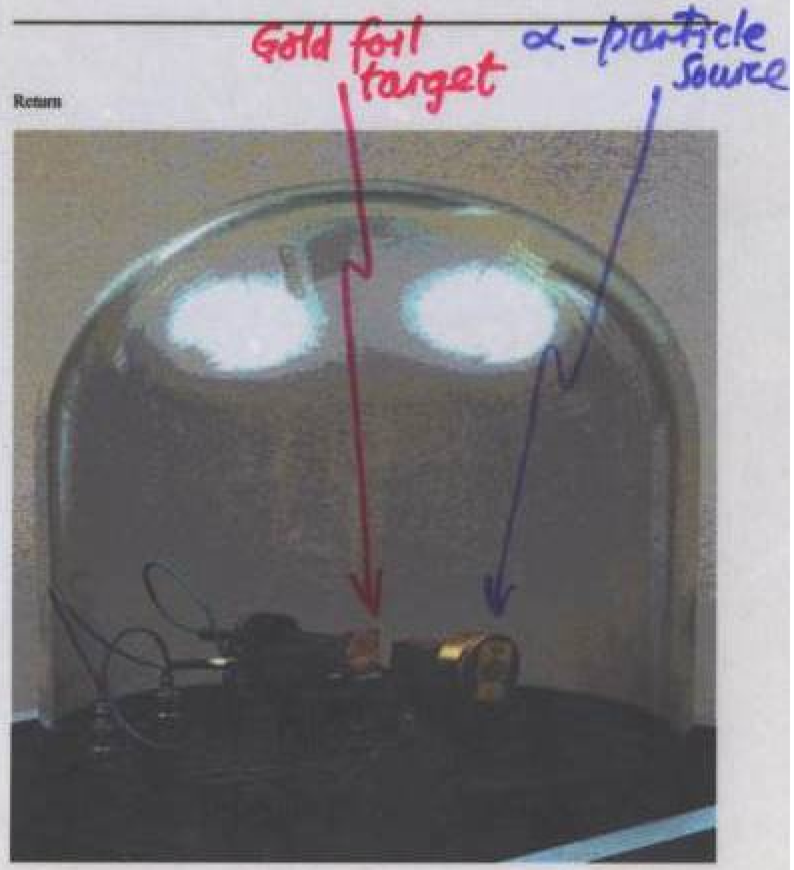
Both pictures are from Zumdahl, Introductory Chemistry: A Foundation

ATOMS ARE
CONFINED ELECTRON WAVES



Rutherford Scattering Apparatus

Return

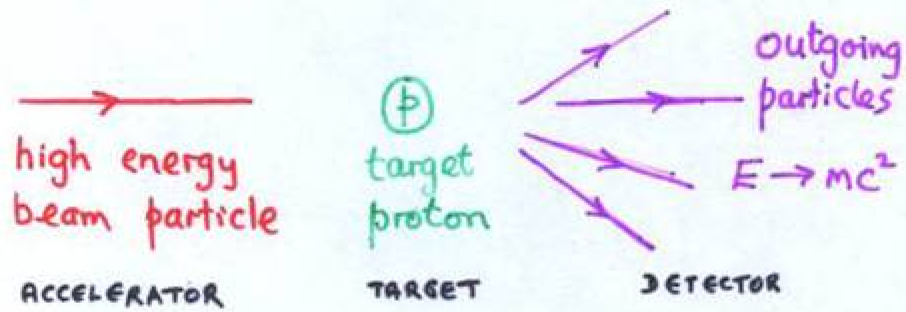


EVIDENCE FOR SUB-STRUCTURE OF PROTON AND OTHER SO-CALLED ELEMENTARY PARTICLES

- Discrete spectrum of "hadrons" (strongly interacting particles) ⇦
- Deep inelastic scattering

Here:
<u>not</u> analysis of spectrum to get at quark properties
<u>but</u> to introduce bubble chamber and its part in discovering the spectrum

Typical FIXED TARGET particle physics experiment

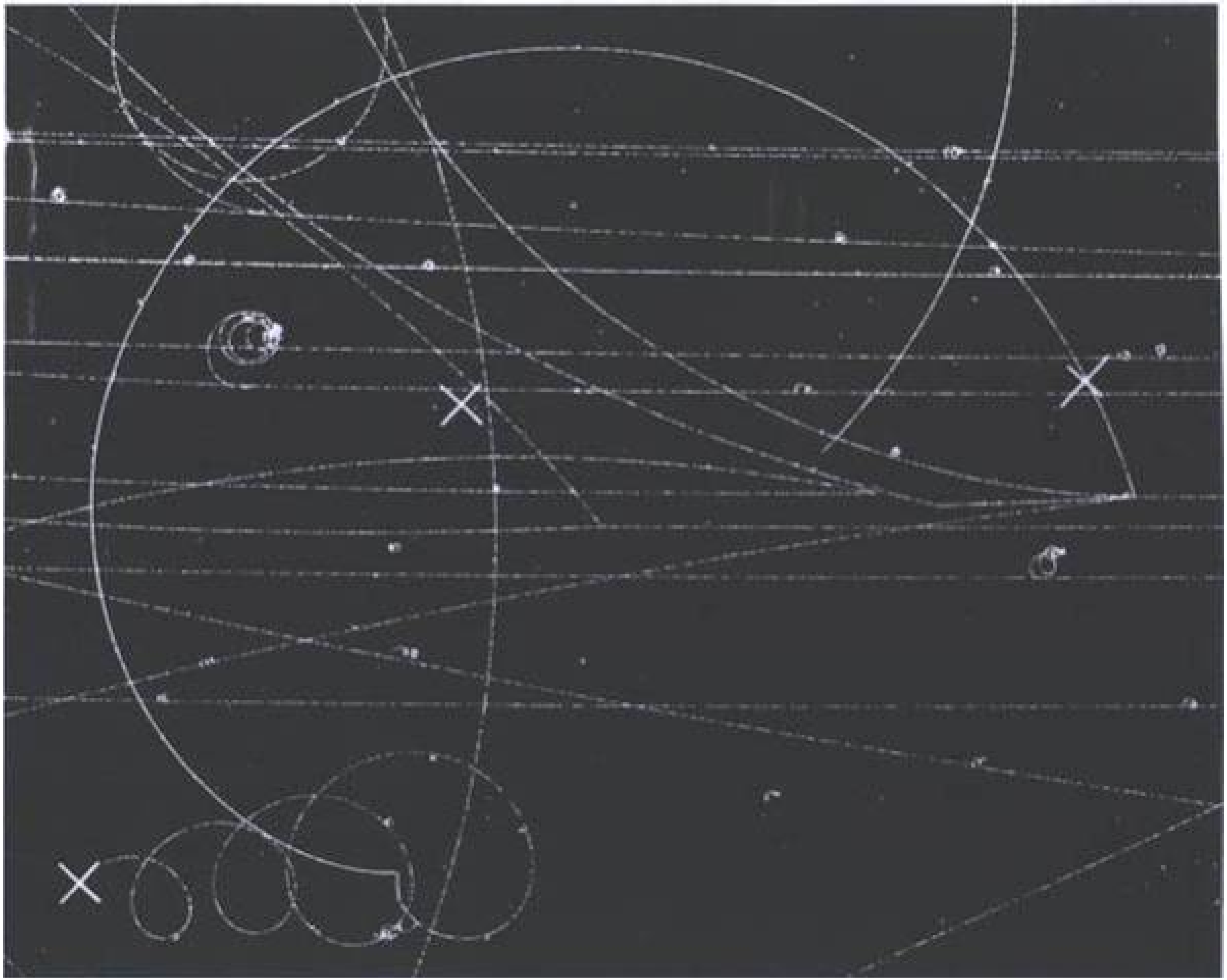


FOUND: discrete mass spectrum

i.e. not all masses are created in nature (even if the energy is available)

QM + Relativity → CONSTITUENTS

The story of the discovery of the discrete mass spectrum was dominated by the BUBBLE CHAMBER



HISTORICAL INTRODUCTION

~1950

ATOM - electrons held near nucleus by 'exchange of virtual photons'

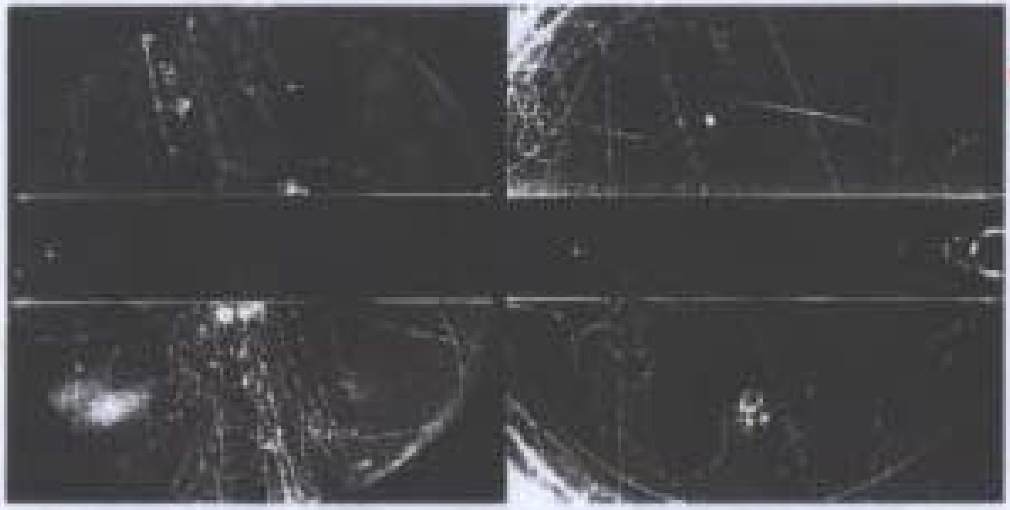
NUCLEUS - neutrons and protons held together by 'exchange of virtual pions'

BUT: μ and 'strange particles' did not fit into this neat picture

For the next 15 years or so, with the bubble chamber as a major tool, many more particles* were found.

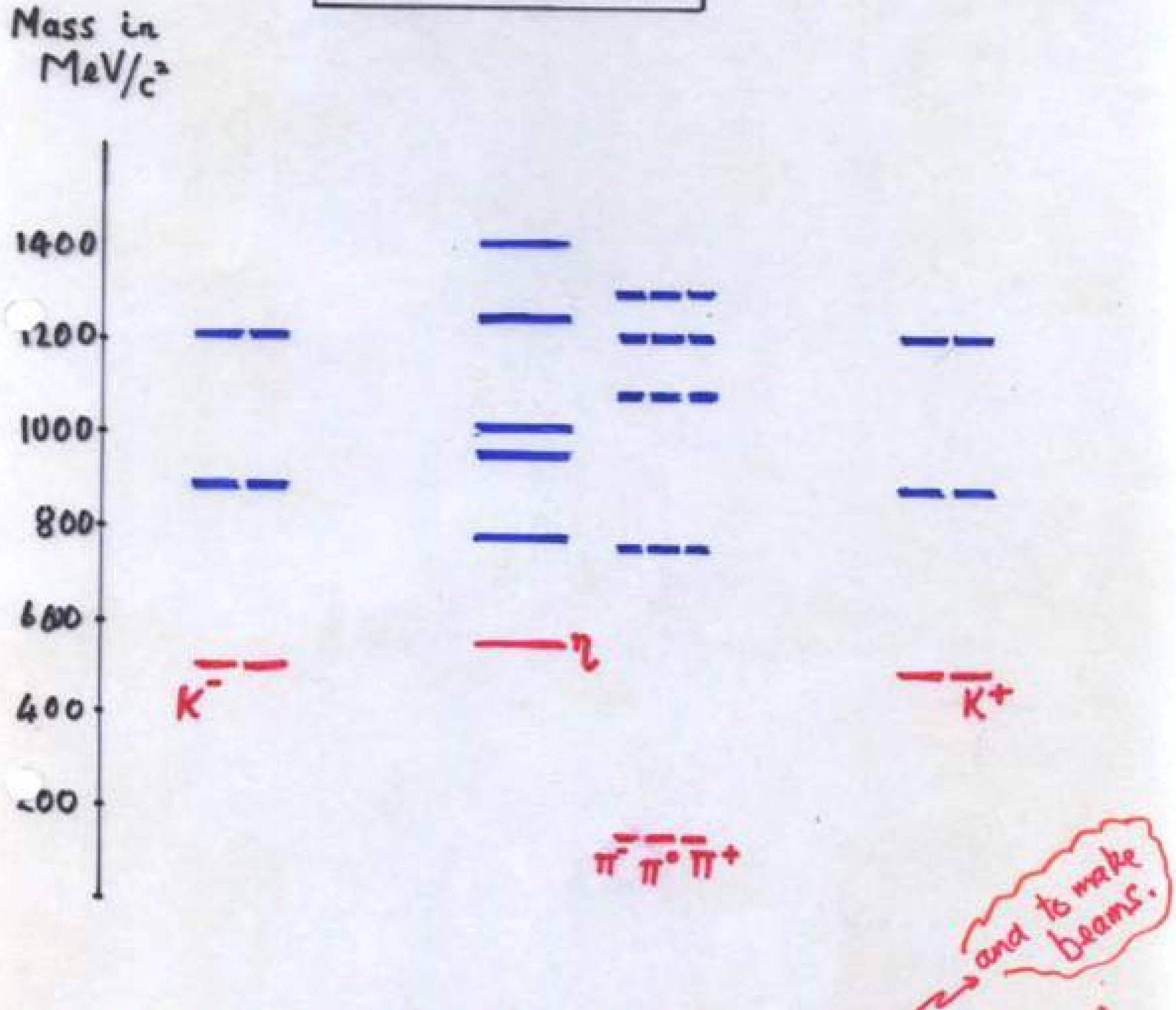
Examination of the properties of these particles led to the prediction of the existence of quarks.

* The 'stable' particles: $\pi, K, n, p, \Lambda, \Sigma^0, \Omega^-$ etc.
Unstable particles (lifetimes $\sim 10^{-23}$ second) which are excited states of the stable particles



DISCOVERY OF KAON

MESON SPECTRUM



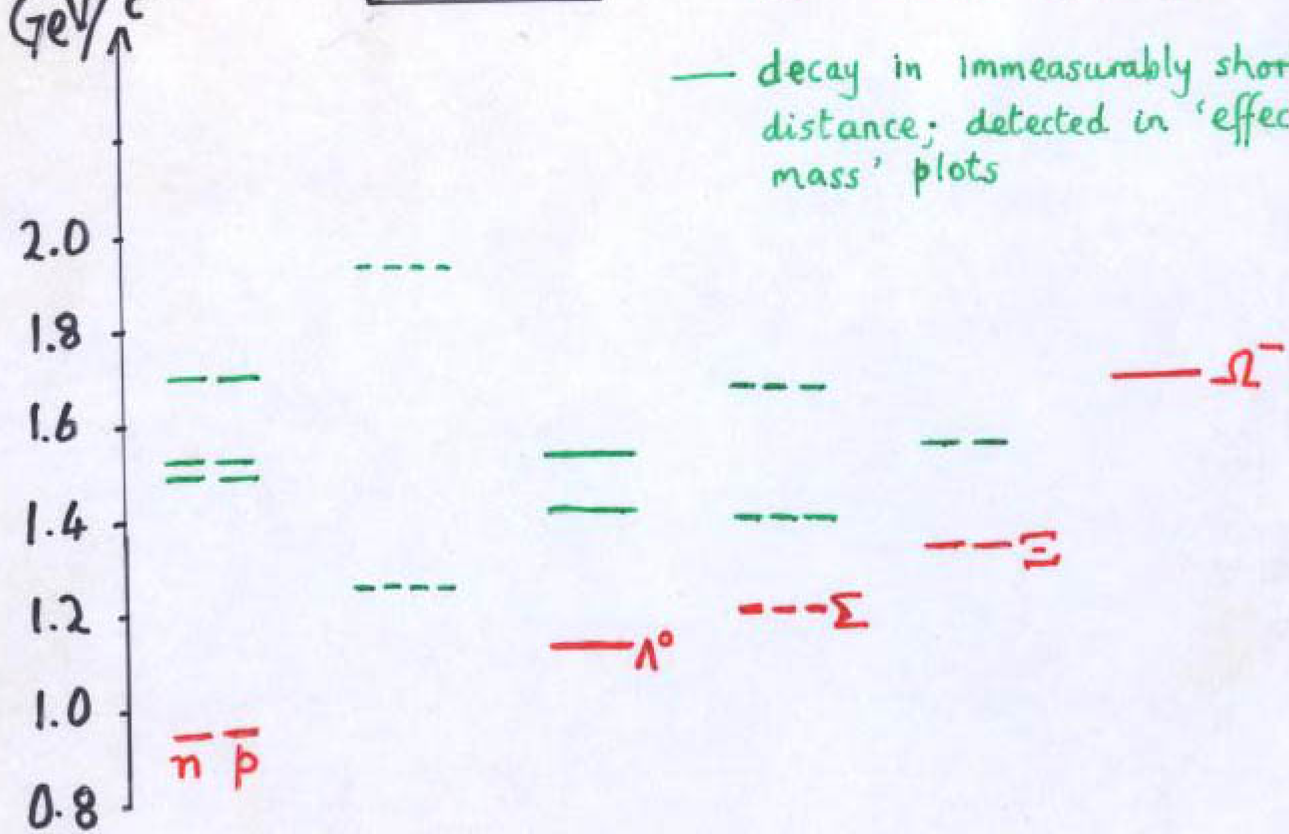
— TRAVEL FAR ENOUGH FOR DECAYS TO BE SEEN (most!)

— DECAY WITHIN IMMEASURABLY SHORT DISTANCE; DETECTED IN 'EFFECTIVE MASS' PLOTS AS BUMPS.

BARYON SPECTRUM

— travel far enough for decays to be seen (most!)

— decay in immeasurably short distance; detected in 'effective mass' plots



So what? Only some masses ⇒ only some energies

⇒ QM + constituents → SPECTROSCOPIC EVIDENCE FOR QUARKS

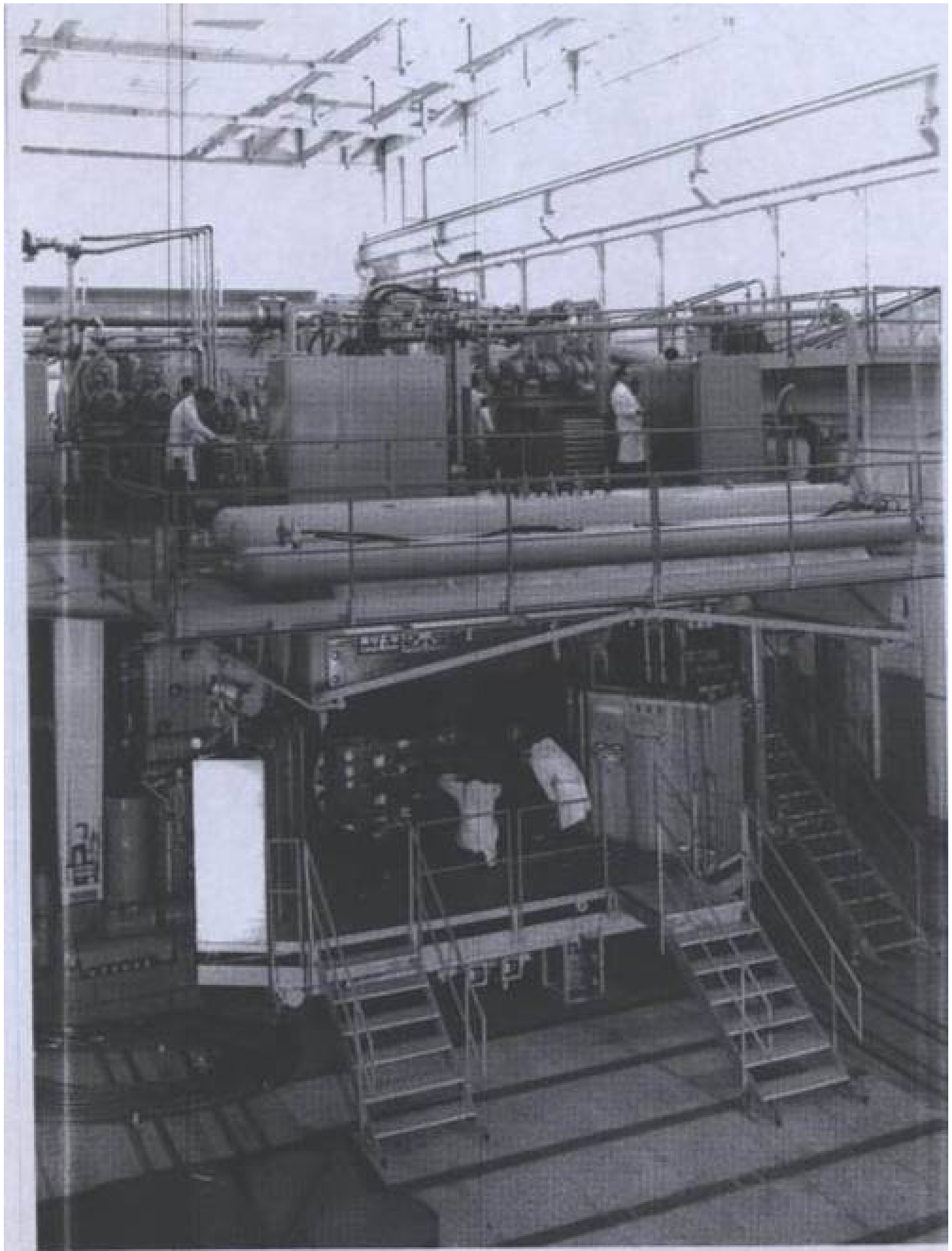
When the nucleon revealed its presently known spectrum, we may have hoped to have before us the essential ingredients for the understanding of its structure, just as the Balmer formula of the hydrogen spectrum gave Bohr the clue for its dynamics.

Quantum Theory + Elementary Particles
Victor F Weisskopf
CERN 65-26, 1965

THE BUBBLE CHAMBER

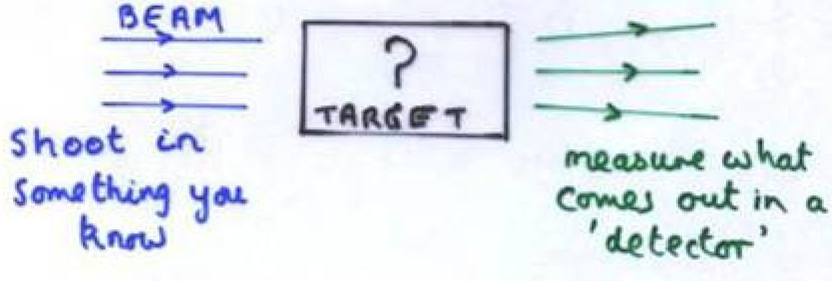
When charged particles force their way through a specially prepared liquid (such as superheated hydrogen), they leave trails of bubbles which can be photographed to give a permanent record of the particles' trajectories.

- The Physical Principles of Particle Detectors
- A Simple Estimate of the Mass of the Positron
- A Lot can Happen in a few Millionths of a Second



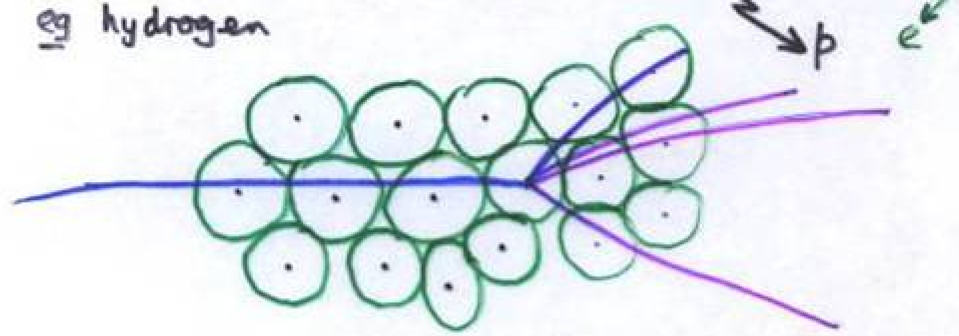
THE CERN 2m BUBBLE CHAMBER

Typical particle physics experiment



Bubble chamber is both TARGET and DETECTOR

eg hydrogen



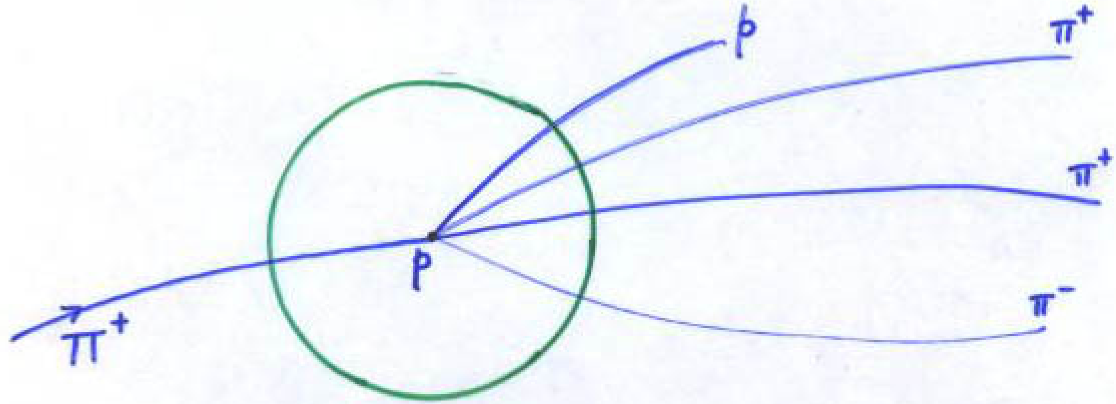
Typical beam energy ~ GeV

To ionize atom ~ 10 eV

[Highly relativistic particle loses ~ 0.25 MeV/cm in H_2]

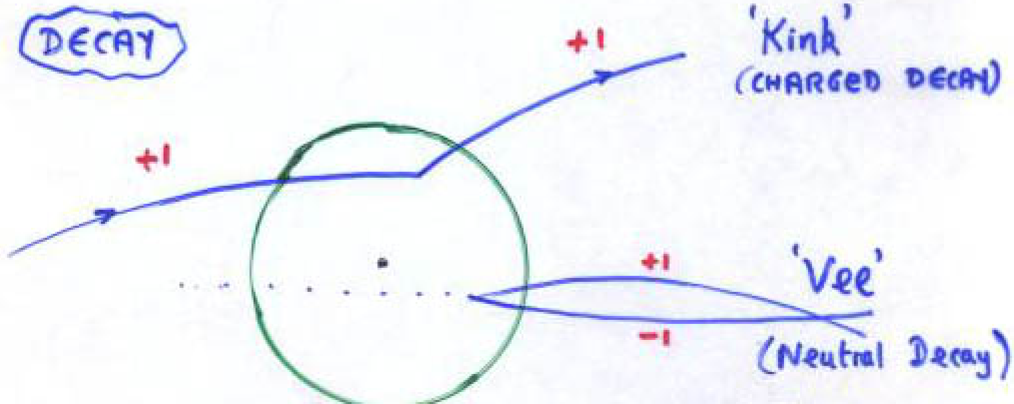
COLLISIONS and DECAYS

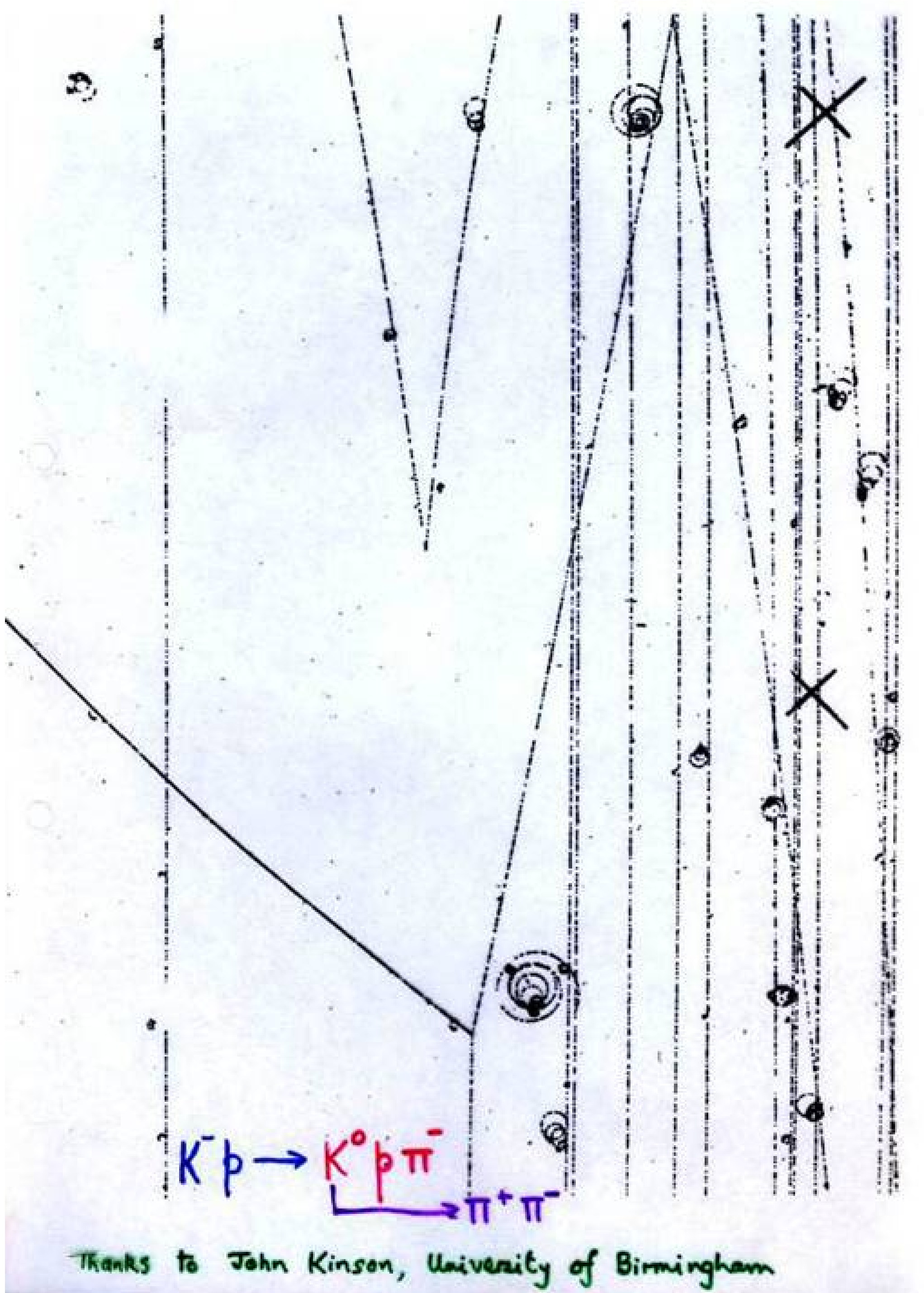
eg. COLLISION



Q: 1 + 1 ⟶ 1 + 1 + 1 − 1 ✓

DECAY





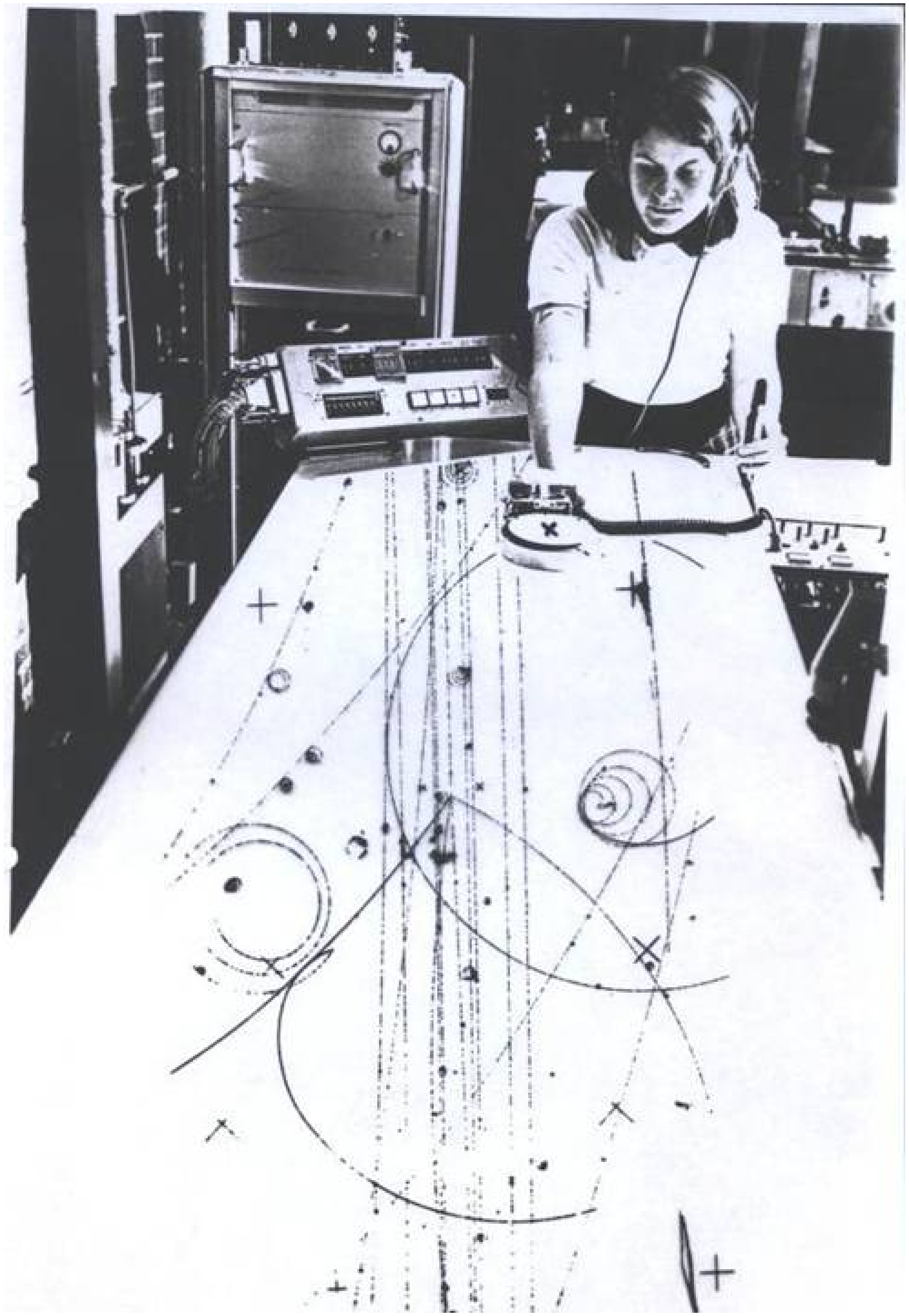
$K^- p \rightarrow K^0 p \pi^-$
$\rightarrow \pi^+ \pi^-$
Thanks to John Kinson, University of Birmingham

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

	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

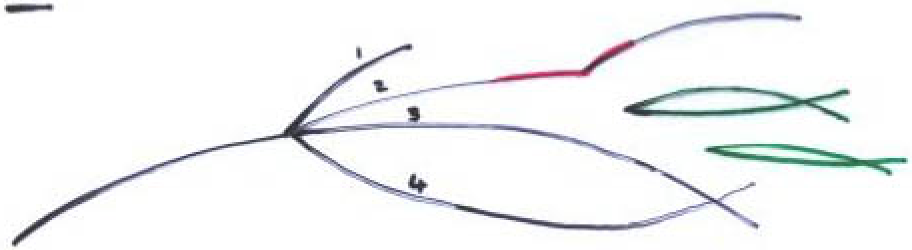


DATA PROCESSING

① SCANNING

Find all 'events' and classify them

eg



N(prongs) = 4

N(kinks) = 1

N(vees) = 2

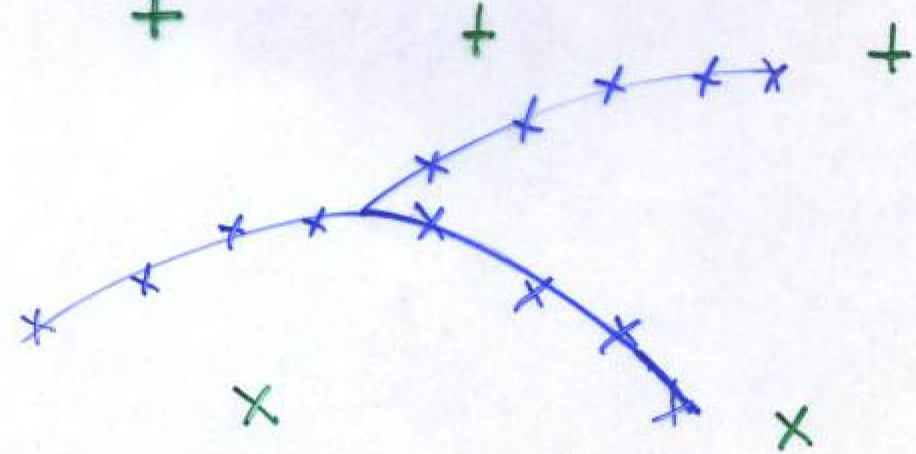
Classified as a 412 event

CERN HST 2001

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 its way through the liquid.

Speed $= v$

Momentum $p = mv$

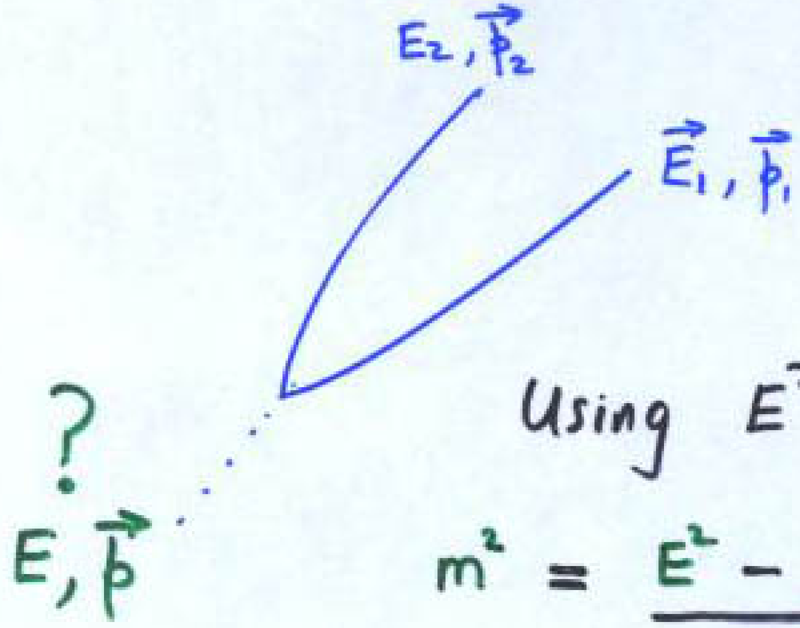
Kinetic energy $E = \frac{1}{2}mv^2$

also $E = p^2/2m$

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

How can we 'weigh' a particle?

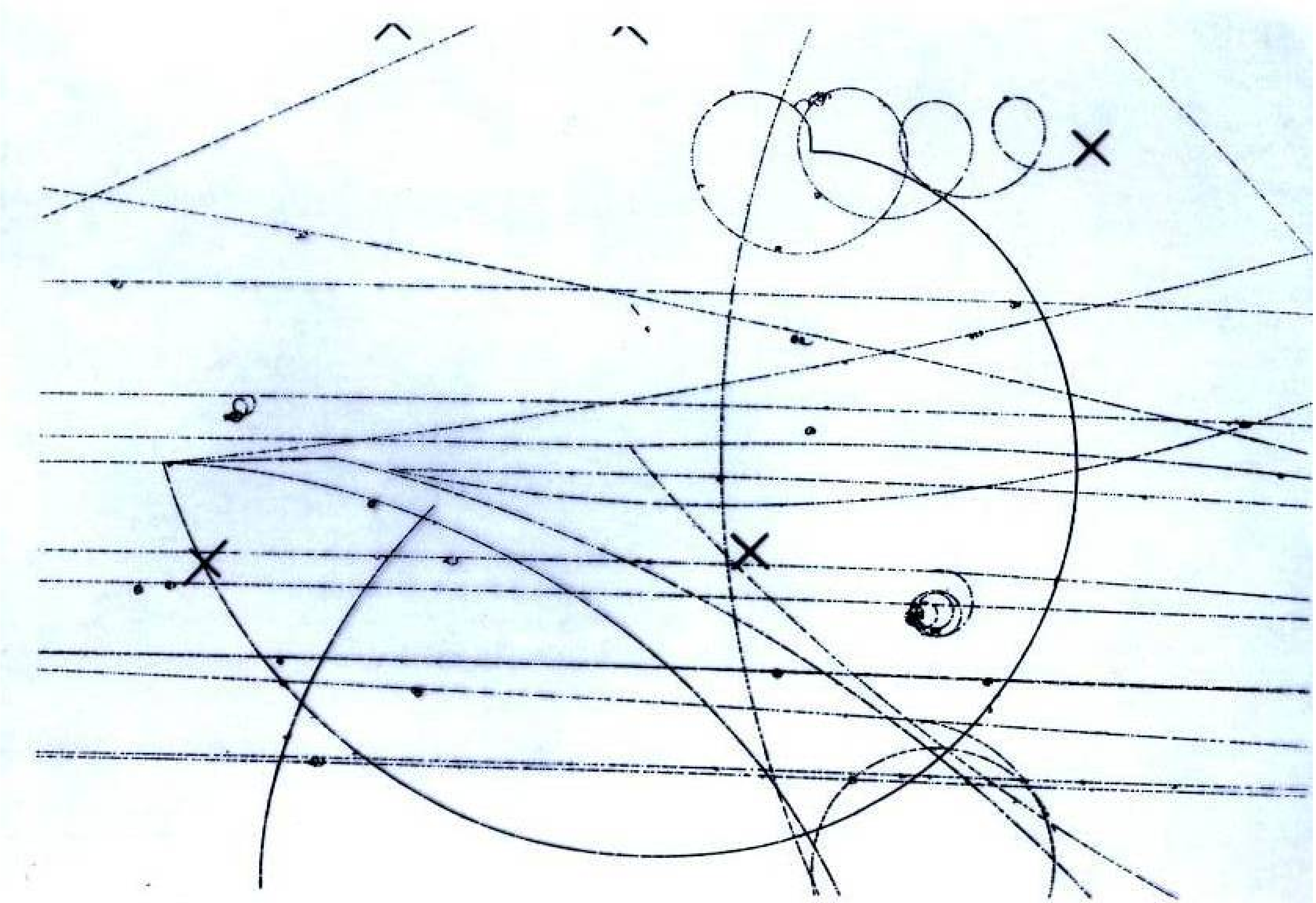
→ determine its mass



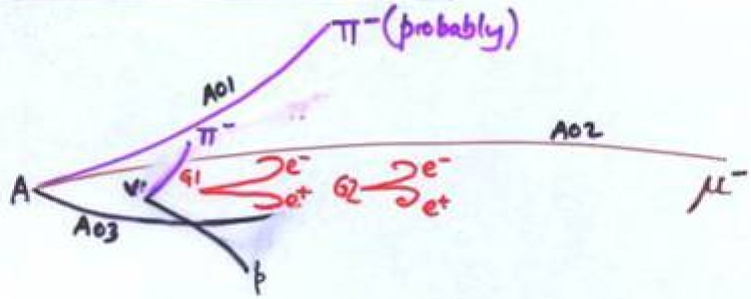
Using $E^2 = p^2c^2 + m^2c^4$

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

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



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⁻
				$m_\Lambda =$

GAMMA G1 (raw measurement)

81	76	-18	20	e^+
257	247	-54	42	e^-
				$m_{\gamma_1} =$

GAMMA G2 (raw measurement)

38	22	-21	22	e^+
113	63	-63	69	e^-
				$m_{\gamma_2} =$

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
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)

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

$\dagger$ Kinematics programme gets 'improved' fitted values by constraining the γs to pass through the primary vertex A.