In Search of Meaning

(Particle Physics, Bubble Chambers and Art)

February 6, 2007

What does it all mean?

That's a difficult question!

Simpler questions:

- What is the physical world made of?
- What are its laws?

In ancient mythology, gods were the cause of natural phenomena

600 BC The concept that one could understand the physical world by observation and reasoning seems to have developed about this time

500 BC - Some good ideas - atoms and the void
(Leucippus and Democrituus)

But progress stalled for 2000 years

-Experiments not much in vogue

-Reason alone good enough

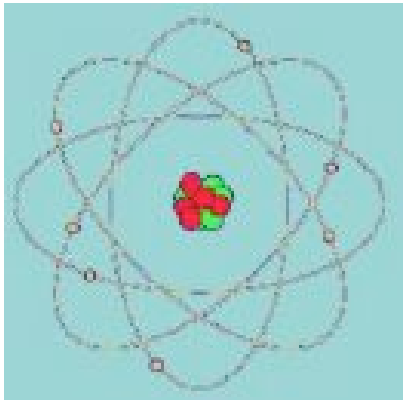
By the 1600's Science was doing well -
gradually got back to elements and atoms

Experiment and theory worked together:

The scientific method

Experimenter: Look at what I measured !
Theorist: I can explain that, and I also predict ...
Experimenter: I checked, you're wrong ! Try again.

Much progress next 300 years
Rutherford atom 1911
- tiny nucleus
-electrons orbiting about nucleus



Rutherford found the nucleus by scattering alpha particles off atoms in thin gold foils

gentle scatter
(marshmallow)

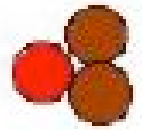
hard scatter
(marble inside marshmallow)

Alpha's are from radioactive decay - low energy, but good enough for Rutherford

Invent accelerators get higher energy - deeper probing of nucleus

Found nucleus had substructure !

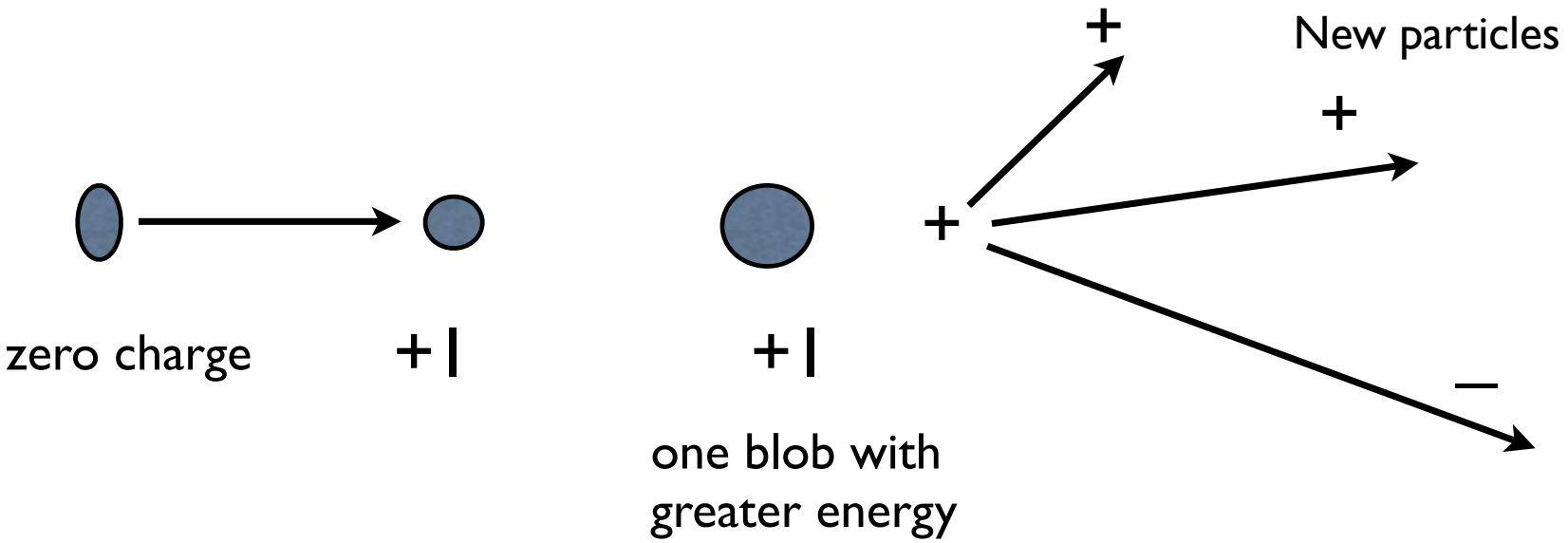
- protons and neutrons



Natural to ask if there was deeper structure yet
Increase energy of incident particle - probe deeply

Now what's really going on when we collide particles

Particles are blobs of energy ..... $E = mc^2$



Give nature energy, she will make anything that's allowed
The new particles are produced from the energy - they are not constituents within the other two particles

Problem is, we cannot see these tiny particles

Invent the Bubble Chamber

(Nobel prize for this-Don Glaser)

A device that generates a trail of bubbles in a liquid when a charged particle moves through the liquid

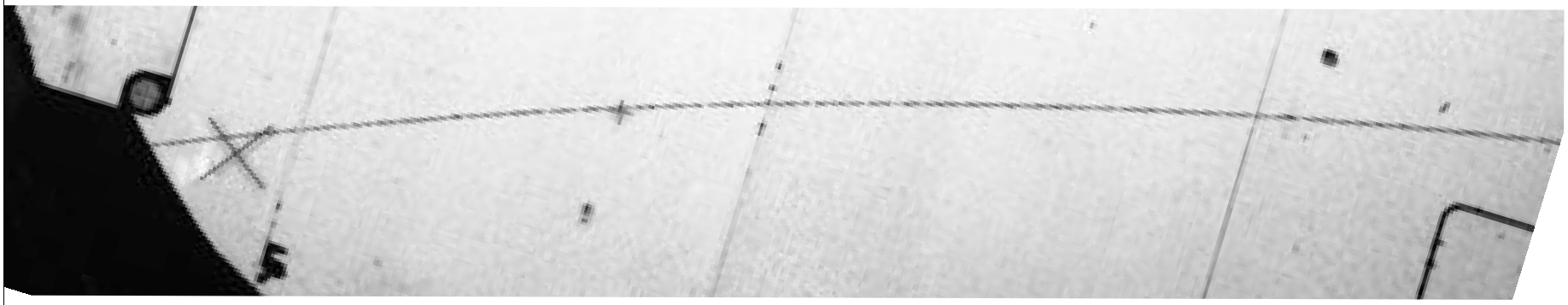
Like a jet's condensation trail

Plane may not be visible, but you know where it went

Particles are not visible - we want to follow their paths

A bubble chamber allows us to do that

A single track passing through the liquid



Why just bubbles along the track?
Why doesn't the liquid bubble everywhere?

Good question - answer requires some discussion

Water boils at 212 degrees F at sea level

200 degrees F at Lake Tahoe

Water can be greater than 212 F in a pressure cooker and not boil ... why?

Boiling depends on the pressure, but...
Also requires micro bubbles

Micro bubbles

- difficult to form in a very clean system

Can be formed by collisions of the molecules, but ...
Unlikely to get large enough micro bubble this way
Too small to grow larger - collapse back quickly

EXAMPLE - clean water, clean glass, microwave oven
Heat beyond 212F, still may not boil ... superheated

Drop coffee in ... boils explosively

What does all that have to do with bubble chambers?

The point is - a bubble chamber is like a pressure cooker
It is a closed system with pressure on the liquid

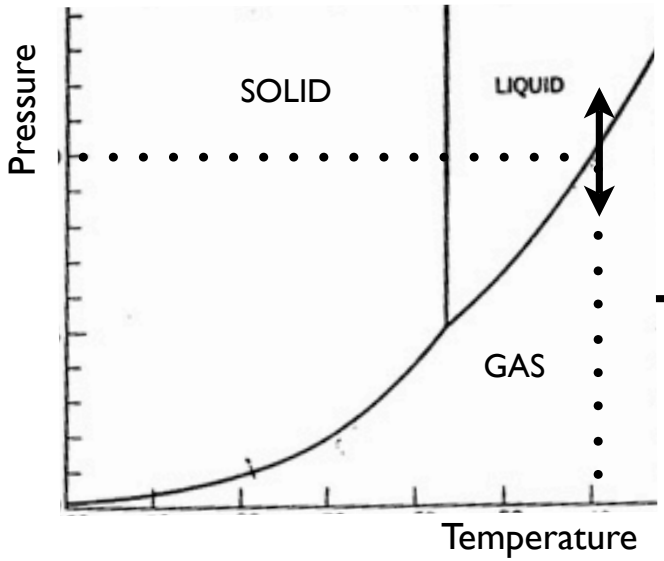
With pressure on, temperature is not high enough to cause boiling, but ...

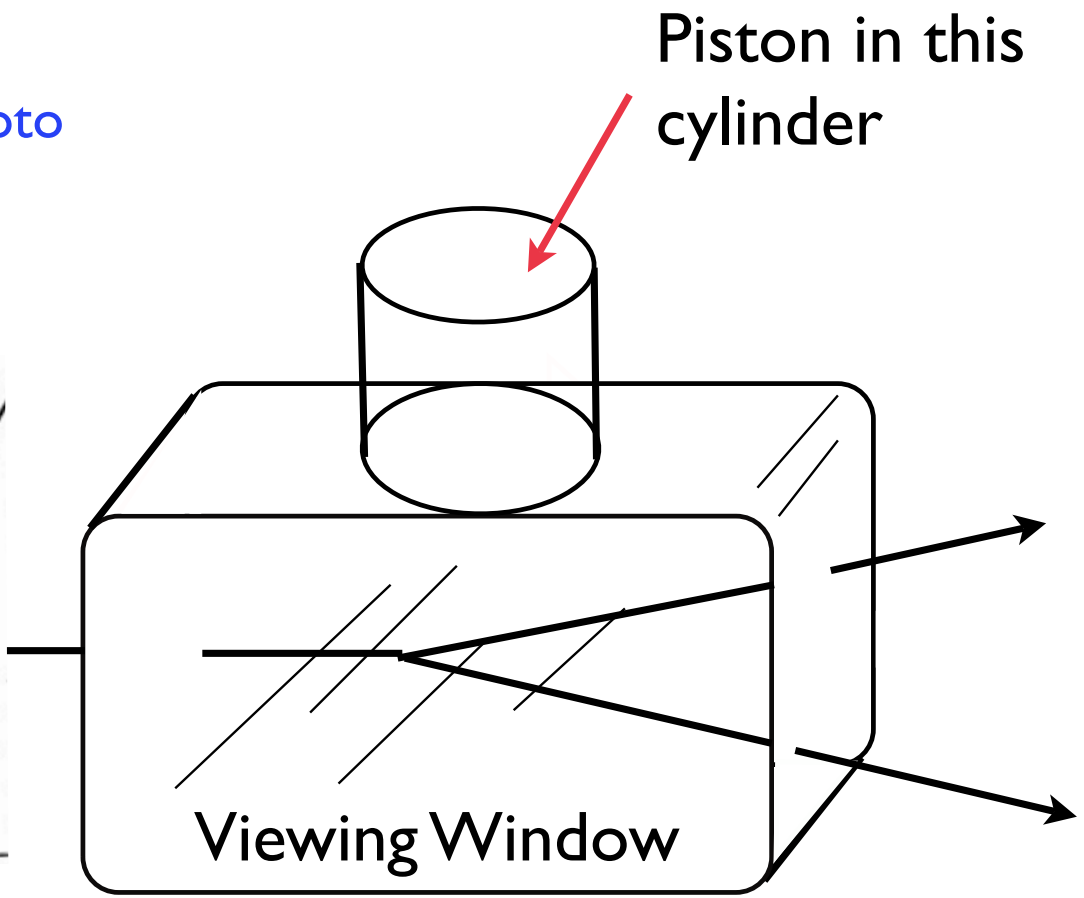
If pressure is reduced - liquid is then superheated
All it needs is some large starter micro bubbles

A charged particle provides those micro bubbles

Compress
Constant temperature
Expand → superheated

Particle goes through
Bubbles form - take photo
Compress

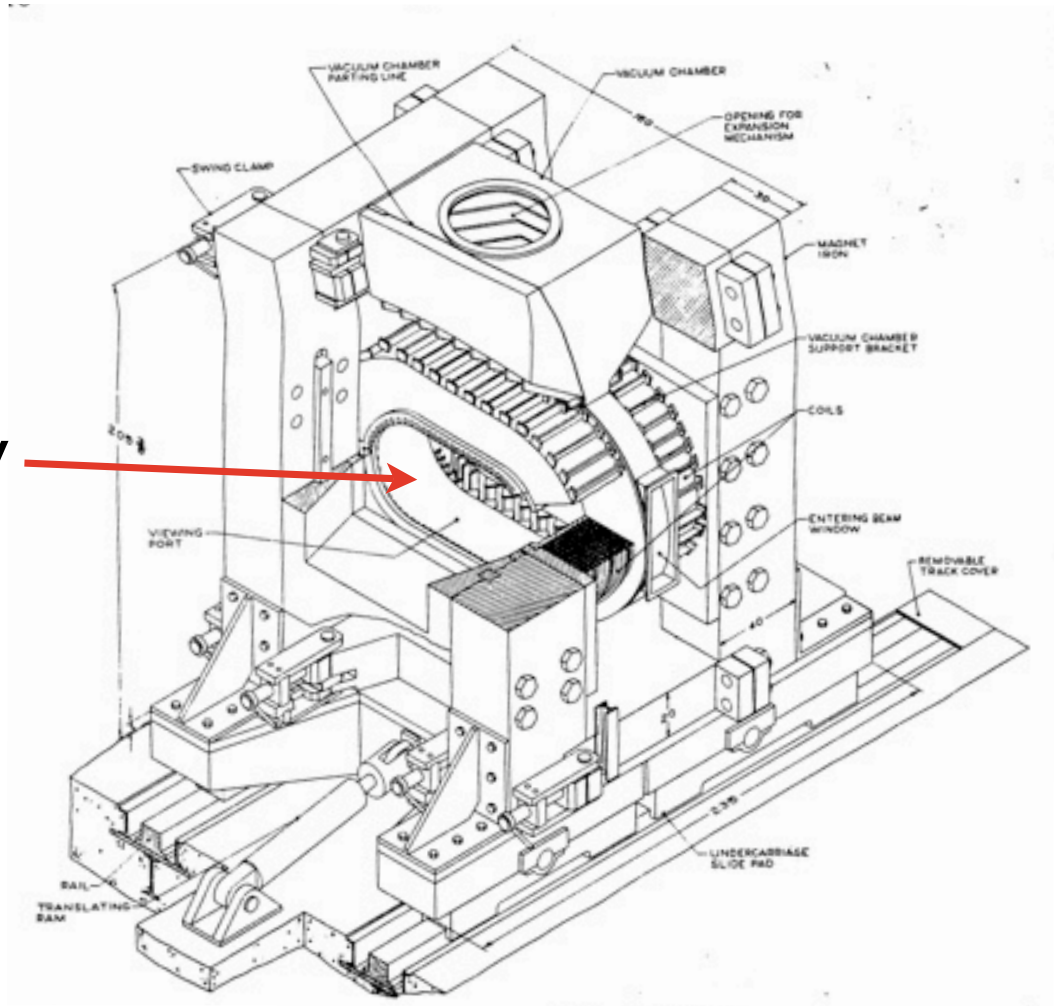


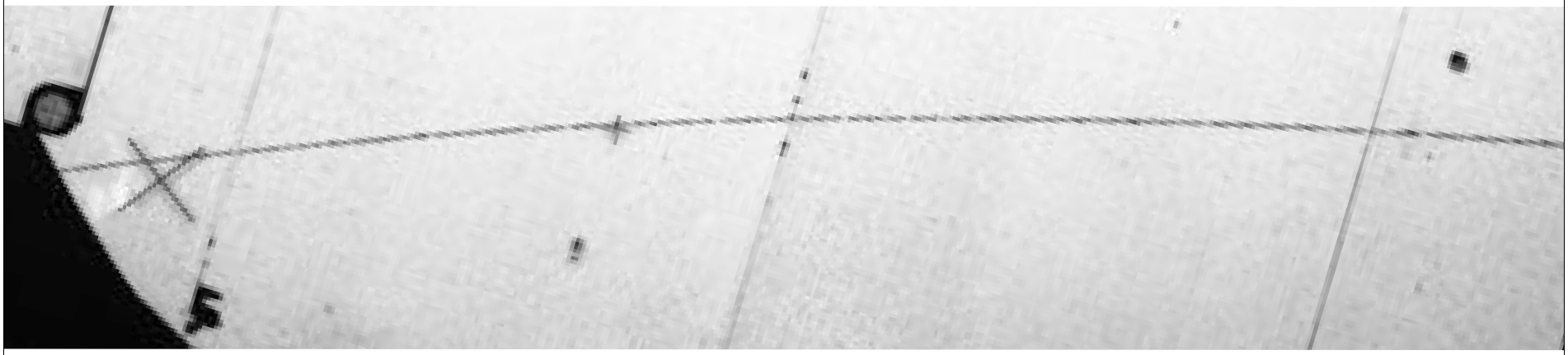


The real thing is a little more complicated

Window

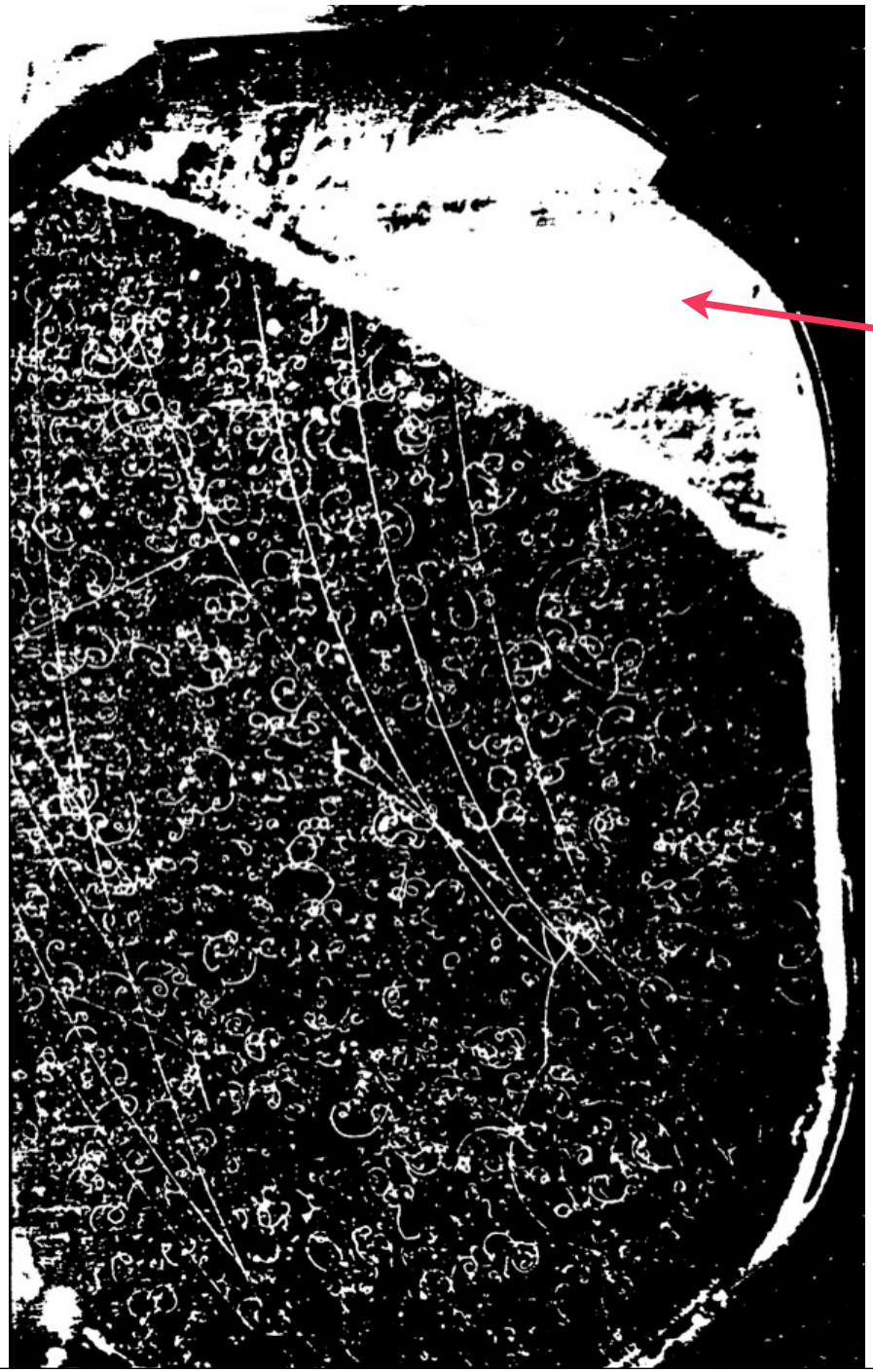
(Cameras not shown)





Can almost see individual bubbles along track
Note no bubbles in the bulk of the liquid
Some bubbling starting at cracks on the bottom

Now we have to compress to squeeze out bubbles



If you don't compress properly ...

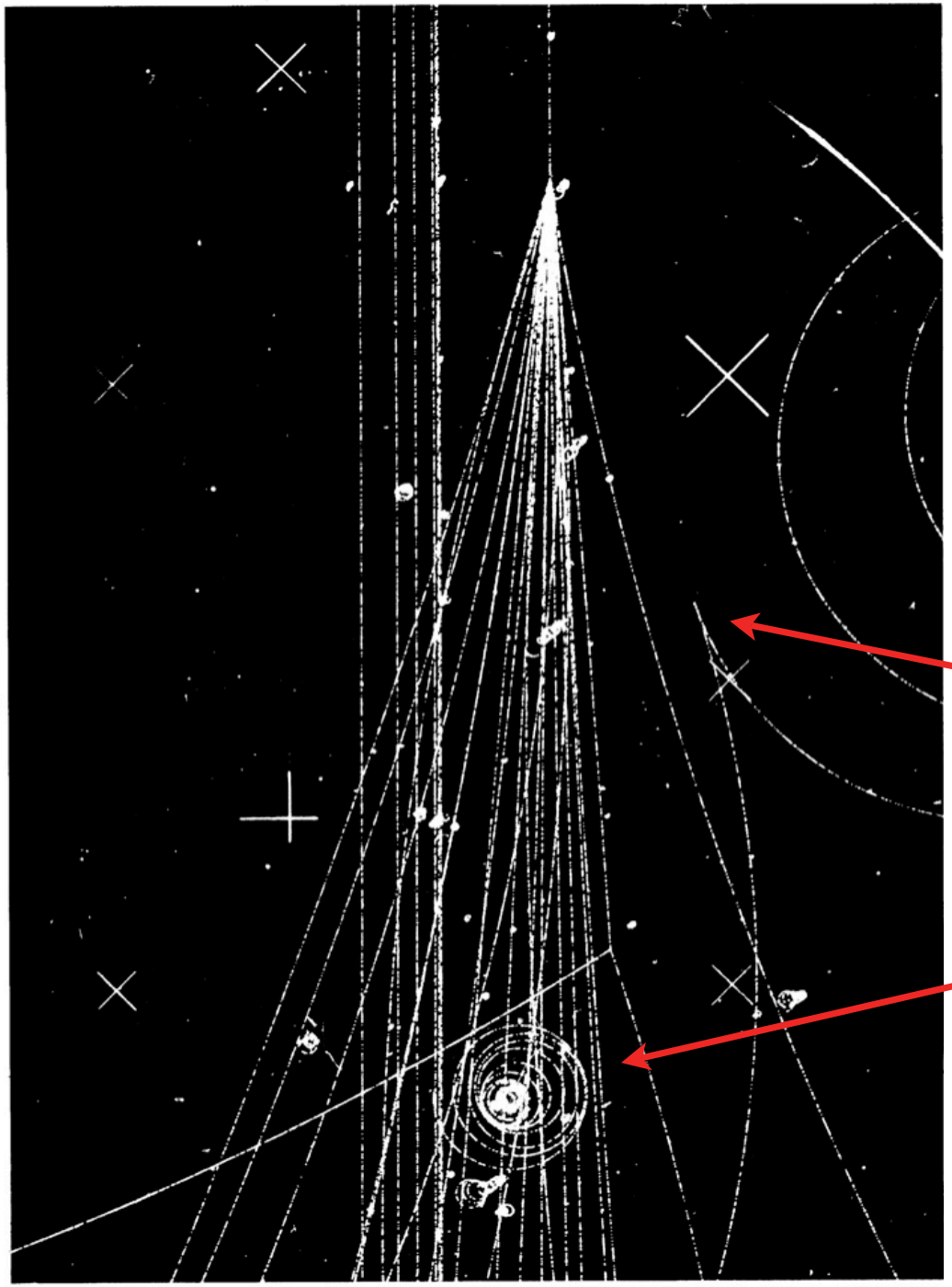
FOAM!

Bubbles not squeezed out each cycle - foam builds up

Can cycle chambers about once per second-this one every 6 seconds

Too many tracks and you get this

Next, a few examples of the production of particles and their decay products



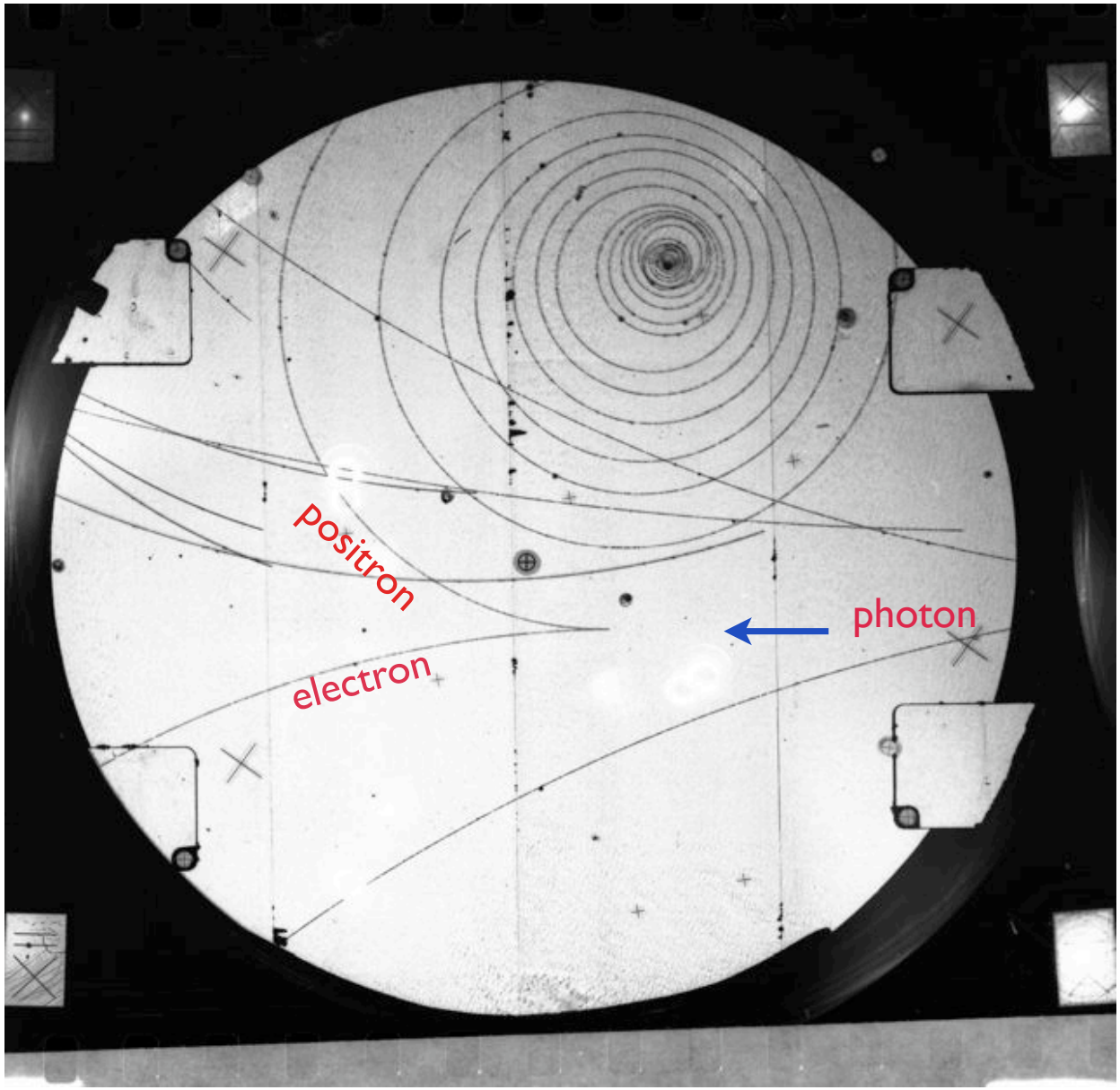
Protons into liquid hydrogen BC
This is what you want
Nice clean tracks

Incoming proton produces pions and a high energy photon (gamma ray)

Photon is quantum of light - radio, X-ray, light - just different frequencies

Photon (invisible) converts to e+ and e-

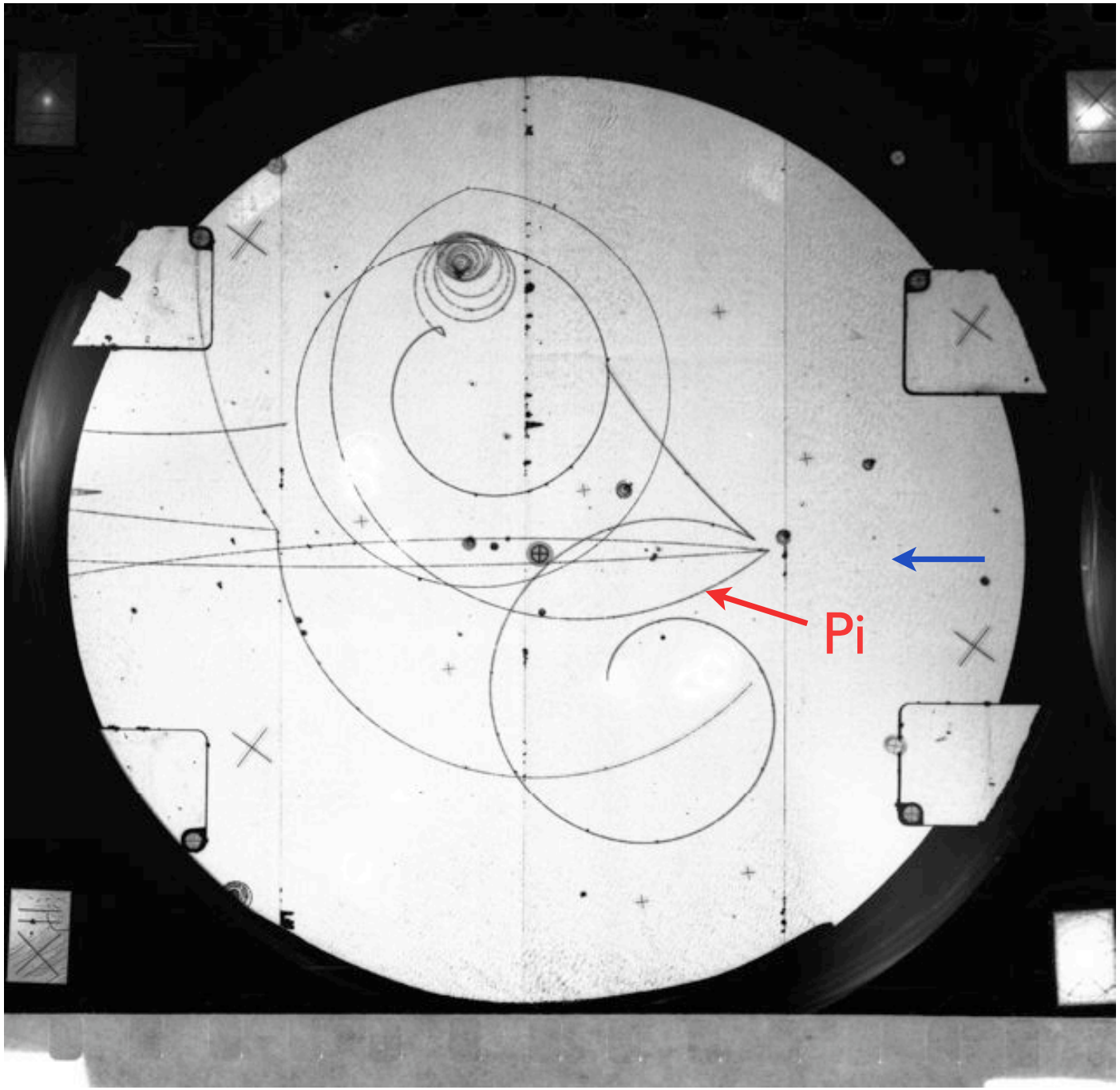
Proton knocks e- out of atom
e- curls up in magnetic field



Photon incoming ←
converts to electron (-)
and anti electron (+)
(called a positron)

Photon is uncharged
leaves no track

Positive electron curls up
in magnetic field as it
loses energy making
micro bubbles

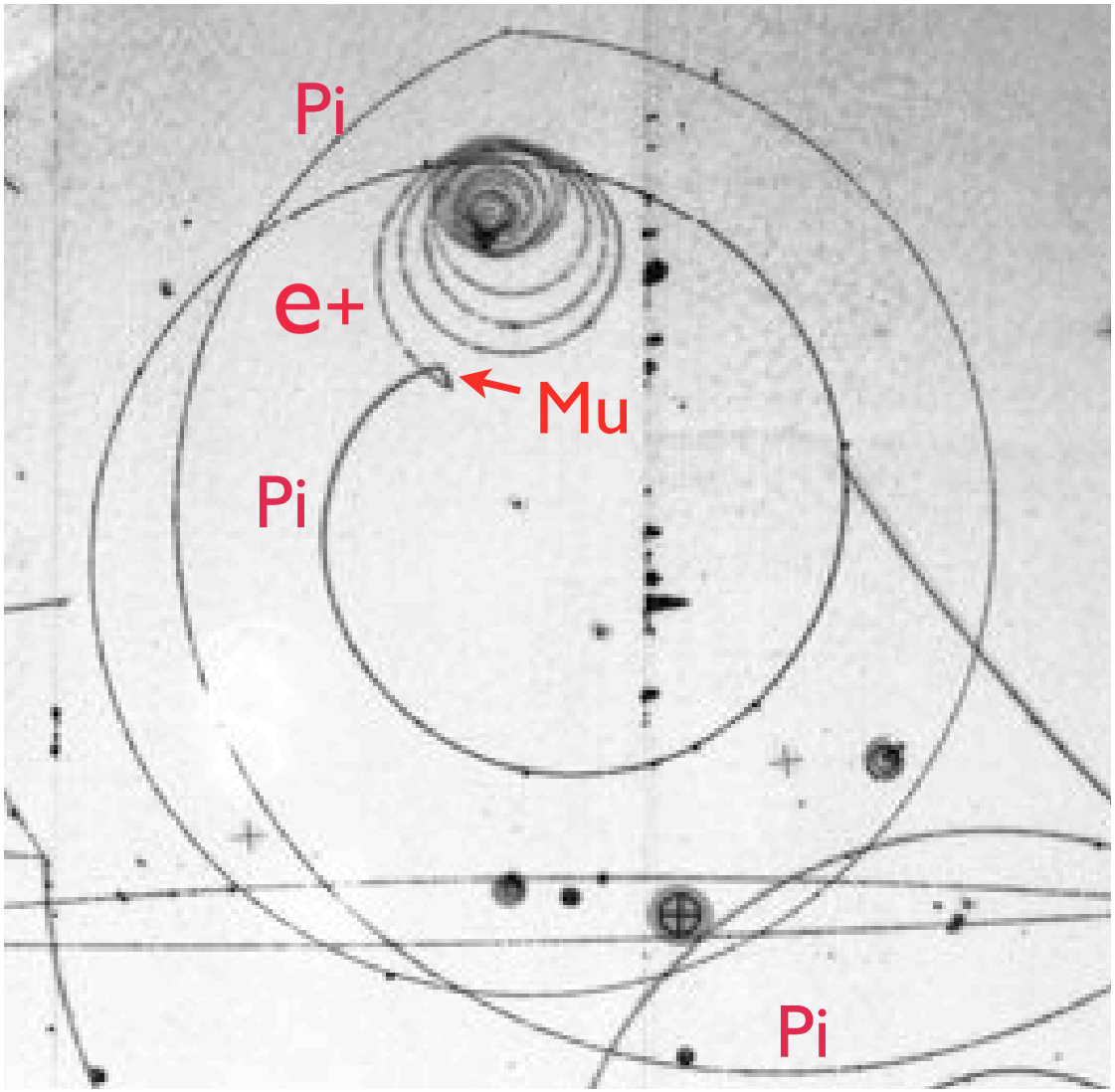


Neutral particle coming in

Interaction produces a Pi meson among other things

Pion-1/7th as heavy as proton decays to muon plus neutrino

Let's take a closer look



Pi meson scatters off hydrogen nucleus

Pi stops and decays to Mu meson (short track) and one (invisible) neutrino

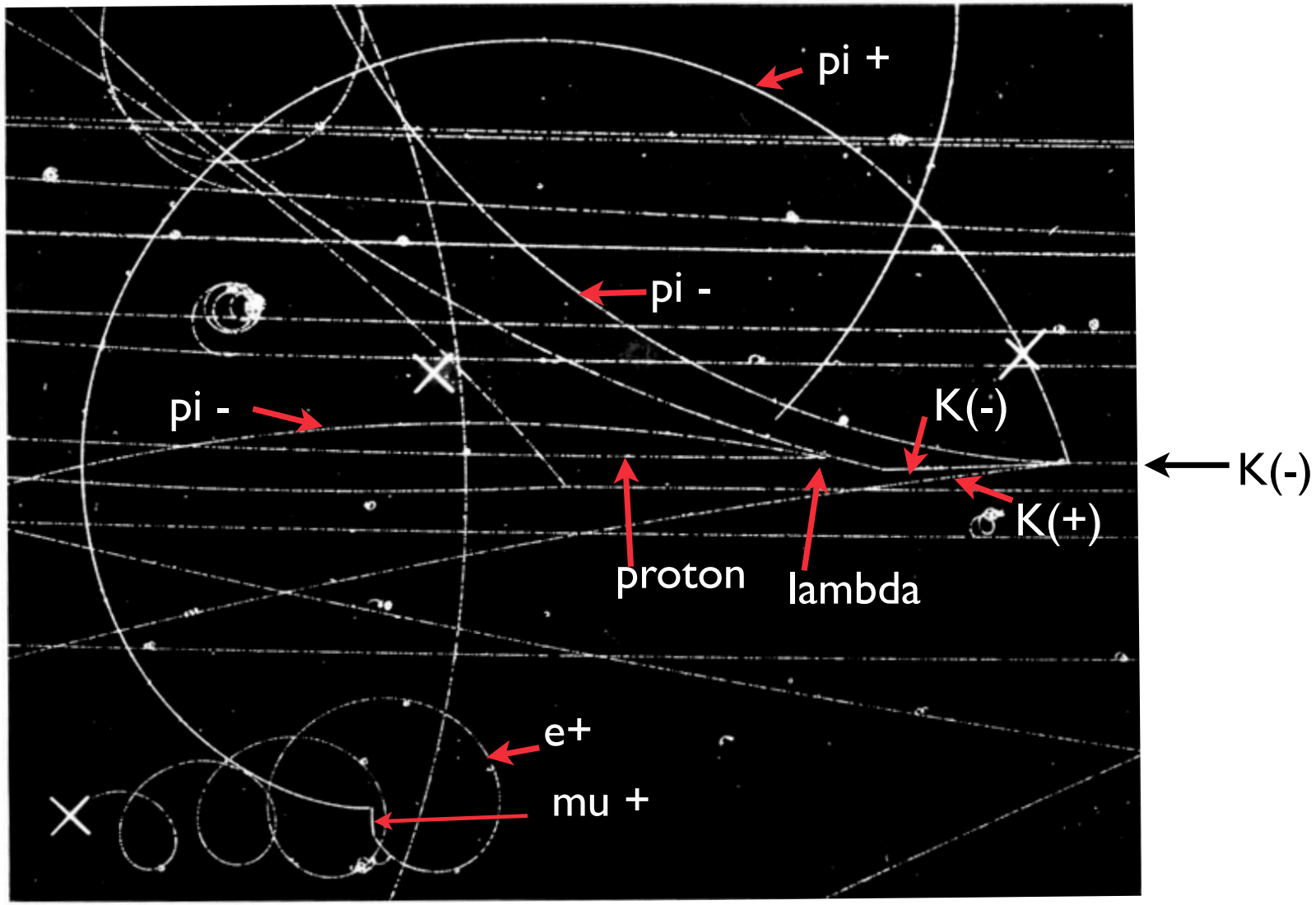
Mu stops and decays to positron and two neutrinos

This is the life history of the Pi

Many new particles produced

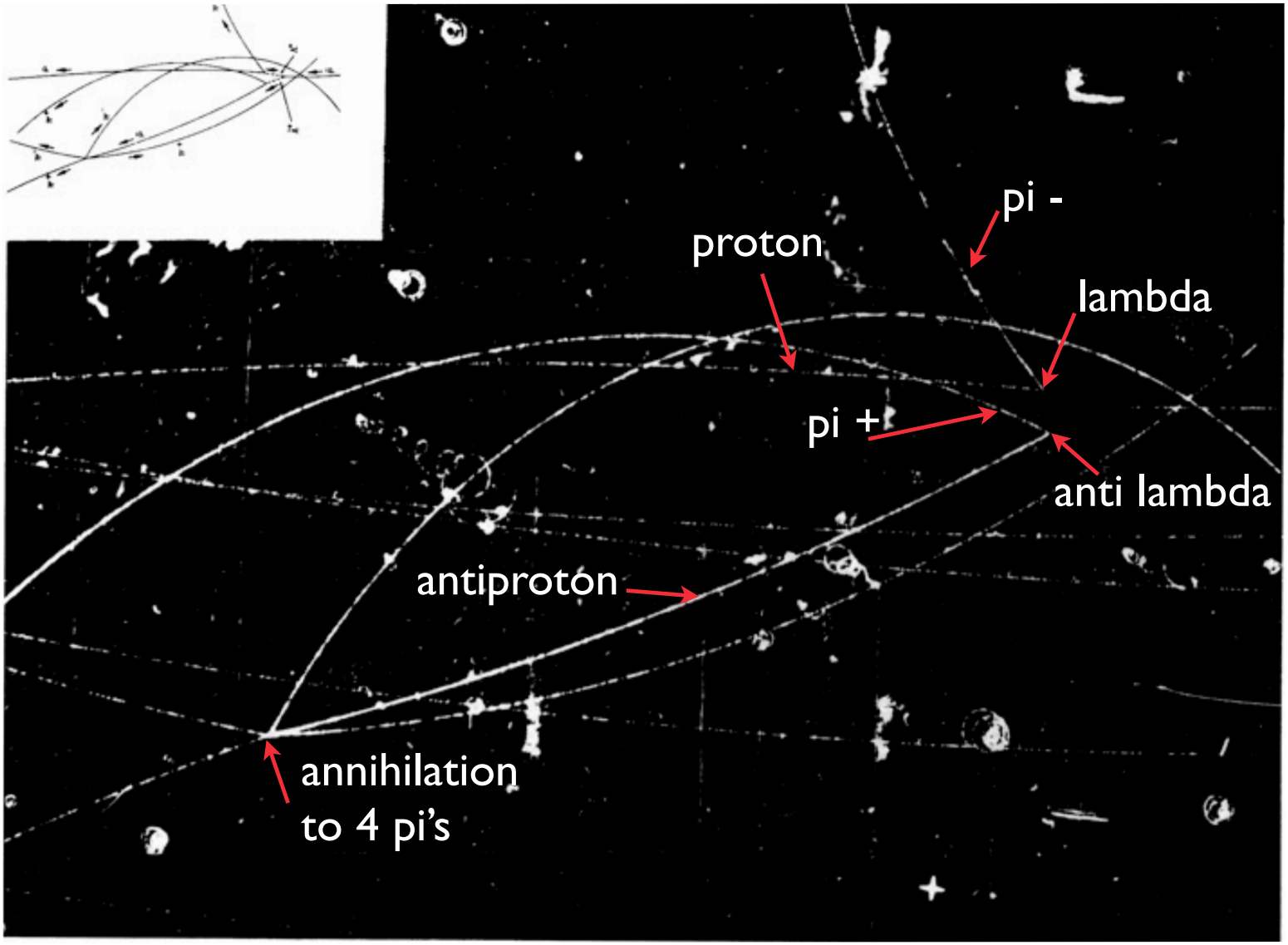
K(-) + proton → lambda + K(+) + K(-) + pi(+) + pi(-)

pi(+) → mu(+) → e(+)



anti proton hits proton → lambda and anti lambda

lambda → proton and pion (-)



← antiproton

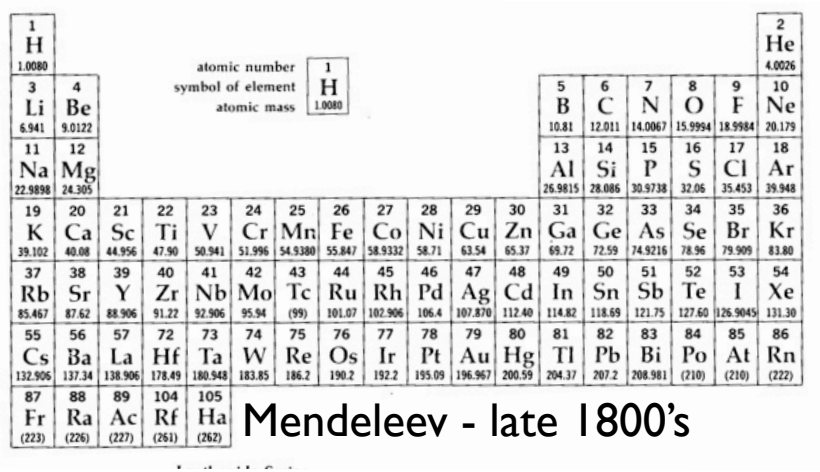
Too much to go through - just an example of the complexity

Many new particles were discovered - too many!

(Nobel prize for this-Luis Alvarez)

Surely there must be connections among them

Chemical elements are arranged in a periodic table that results from elements having different numbers of protons in their nuclei



1 H 1.0080																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.179
11 Na 22.9898	12 Mg 24.305											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.941	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.467	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	57 La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.981	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Ha (262)													

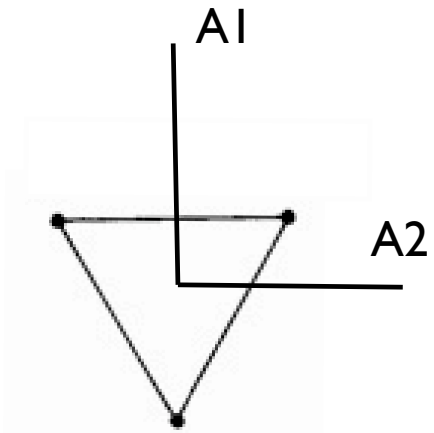
Mendeleev - late 1800's

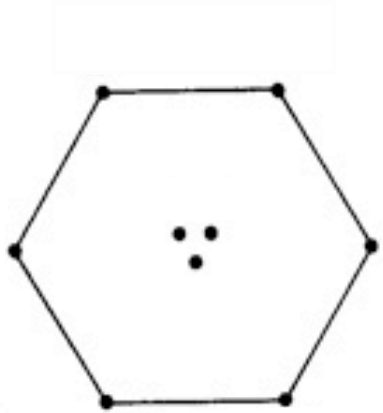
Any pattern to the new particles?

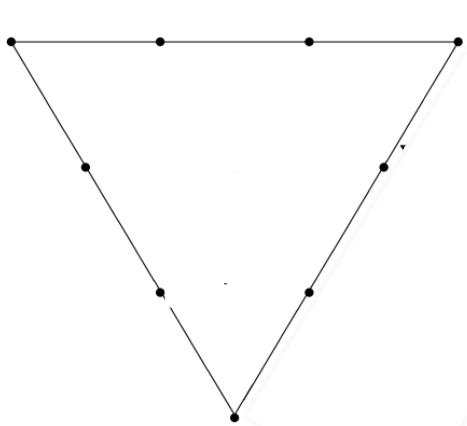
Searching for patterns, relation ships ...

Murray Gell-Mann (in 1961) looked at Group Theory - pure math.
It generates patterns using 2 parameters that we can call A1 and A2.
Their values determine each point's position in the plots below

*The large plots are made by combining several of the small triangles





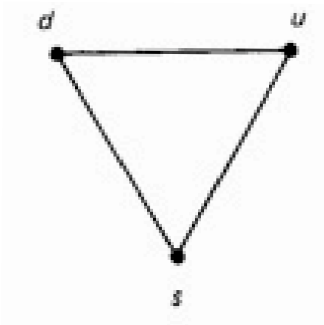


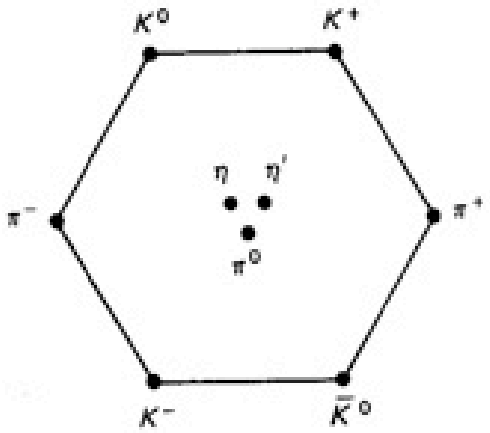
Gell-Mann chose A1 and A2 to correspond to physical properties of particles, such as charge, to see if each point could represent a particle.

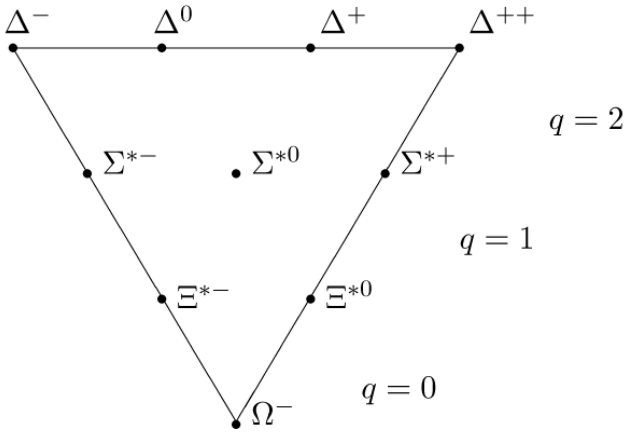
He found this ...

(Nobel prize for this-M. Gell-Mann)

The known particles fell onto points on the plots!







There was a little problem - no particles for the small triangle plot

If the large plots are made from the small plot, does that mean that the known particles are made from 3 unknown particles???

The basic mathematical pattern, from which all the other patterns were generated, called for exotic new particles.

electric charge 1/3 and 2/3 that of the proton or electron
and other new characteristics

After long searches, they were found (not in BC's) ..... QUARKS.

These are today the fundamental particles for our understanding of high energy particle physics. For example, the proton = 3 quarks. The pion is a quark and an anti quark.

Bubble chambers provided the data that led to these patterns that generated the search for the quarks - the bubble chamber legacy.

Enough bubble chamber physics

On to Art