Physics 564 – Particle Physics

Matthew Jones - Phys 378

- Office hours: after class or by appointment
- Web page:

  http://www.physics.purdue.edu/~mjones/phys564

  Should contain:
  - Course outline, nominal schedule
  - Lecture notes
  - Assignments
  - Supplementary material (long derivations)
  - Computing instructions and examples

Other information

- Particle Data Group: http://pdg.lbl.gov
  - order your free copy today.
- Text: Halzen & Martin
  - Provides most of the theoretical background
  - Not out of date, but by now it is incomplete
- Other texts:
  - Perkins, Griffiths, Aitchison & Hey, Leader & Predazzi, Bjorken & Drell, de Wit & Smith, …
- Historical development:
  - *The Rise of the Standard Model,* Hoddeson, *et al. (ed.)*
  - *Constructing Quarks,* Pickering

Other information

- Grading: 70% assignments, 30% final project
- Assignments:
  - Plan for about 6 assignments
  - Some computing component to assignments
  - Free to use any platform/software you want
  - Examples using ROOT will be provided on web the page
  - Everyone should have an account with PCN
  - First exercise will be to make sure that this really works as advertised

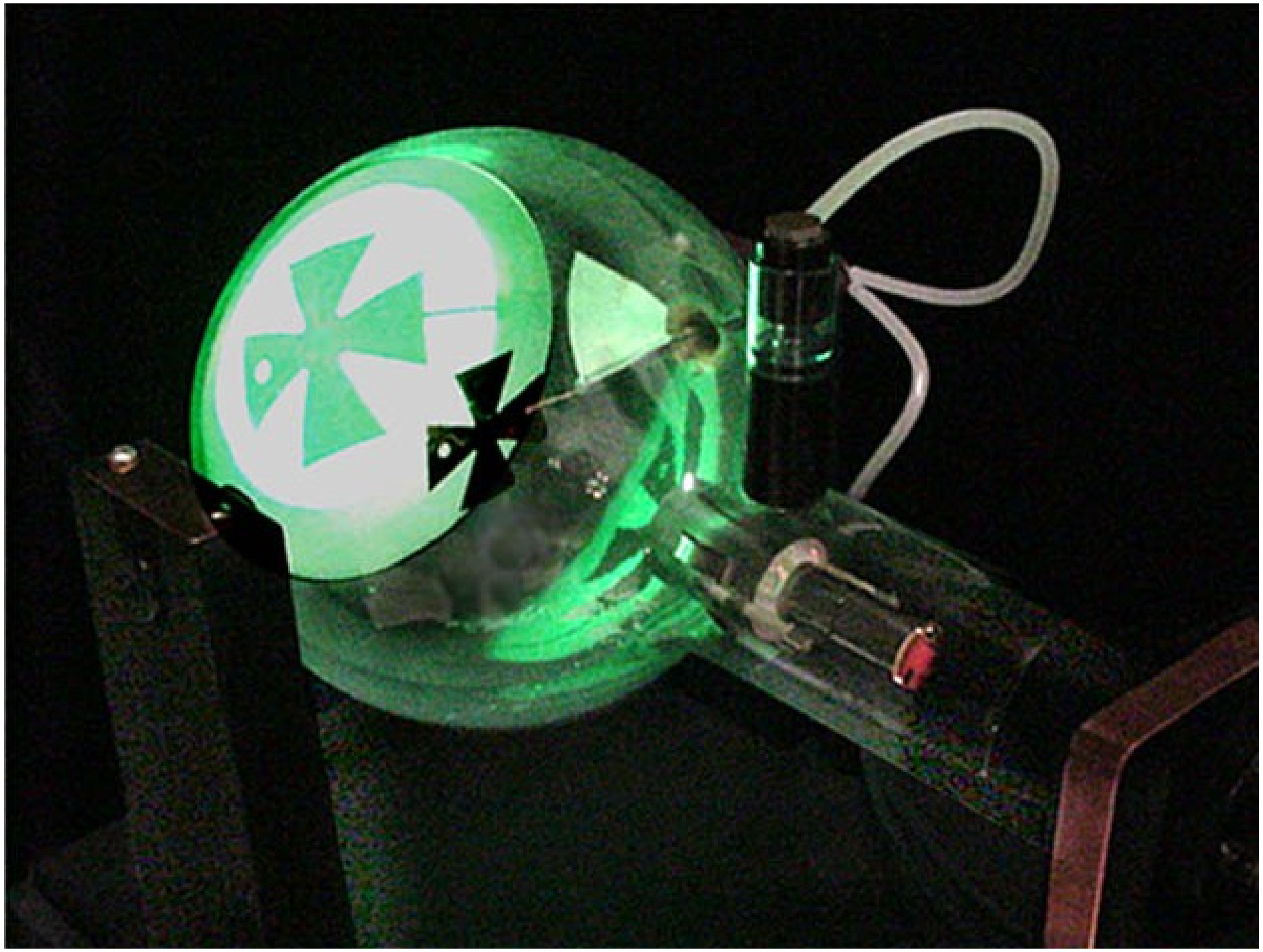
Relation to other subjects

- Quantum Field Theory, String Theory
  - *eg*. *Quantum Field Theory,* Ryder, Itzekson & Zuber
- Detector Instrumentation
  - *eg. Introduction to Experimental Particle Physics,* Fernow
- Accelerator Physics
  - *eg. An Introduction to Particle Accelerators*, Wilson
- Nuclear Physics
  - *eg. Introductory Nuclear Physics*, Krane
- Astrophysics, Cosmology
- Course dedicated to Standard Model and its extensions, *eg.* Phys 565.

Pre-Modern Particle Physics

- Particle concept is not new:
  - Central forces, action at a distance (Newton)
  - Kinetic theory of gases (Bernoulli, 1738)
  - Boscovich: gasses composed of massive, point like particles with central forces
  - No quantum mechanics but otherwise similar to the way we think of particle physics
  - Forces turn out to be a consequence of the exchange of “virtual quanta”

“Modern” Physics



The first particle accelerator?

“Modern” Physics

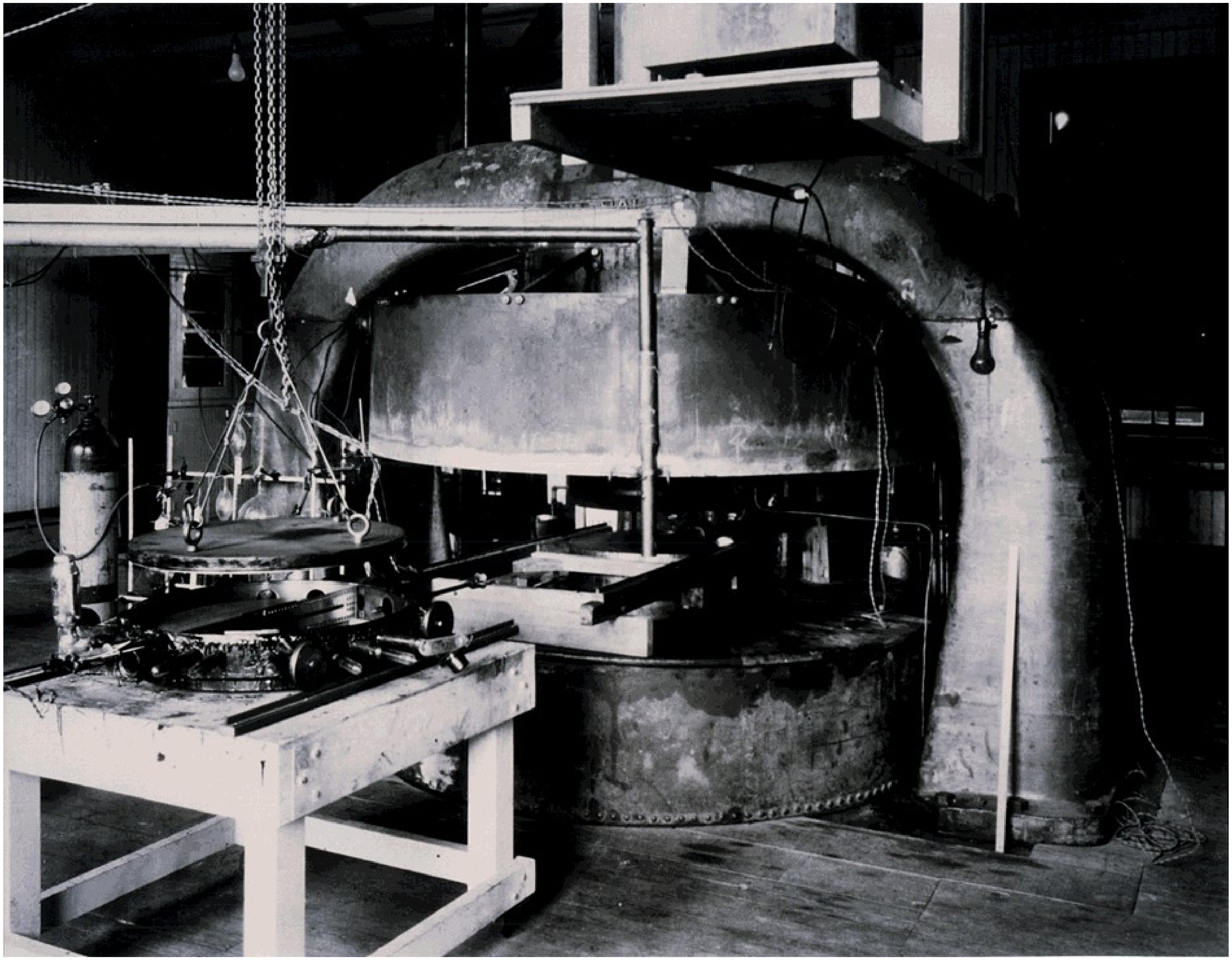
- X-rays (Roentgen, 1895)
- Electron (Thompson, 1897) – measured Q/m
- Radioactivity (Becquerel, 1900)
- Atomic model (Rutherford, 1911)
- Cosmic Rays (Hess, 1912)
- Proton (1919)
- Neutron (1931)

$\Rightarrow$ Nuclear Physics

Quantum Mechanics

- Particle nature of x-rays (Compton, 1924)
- Wave nature of matter (de Brogle, 1925)
- Wave mechanics (Schrodenger, 1926)
- Relativistic Quantum Mechanics (Dirac, 1928)
- Particle accelerators:
  - Particles emitted in nuclear decays
  - Cosmic rays (Hess, 1912)
  - Ray transformer (Wideroe, 1928)
  - Electrostatic (Cockcroft Walton, 1932-34)
  - Cyclotron (Lawrence, 1930)
  - Betatrons, synchrotrons (1940's)

Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays

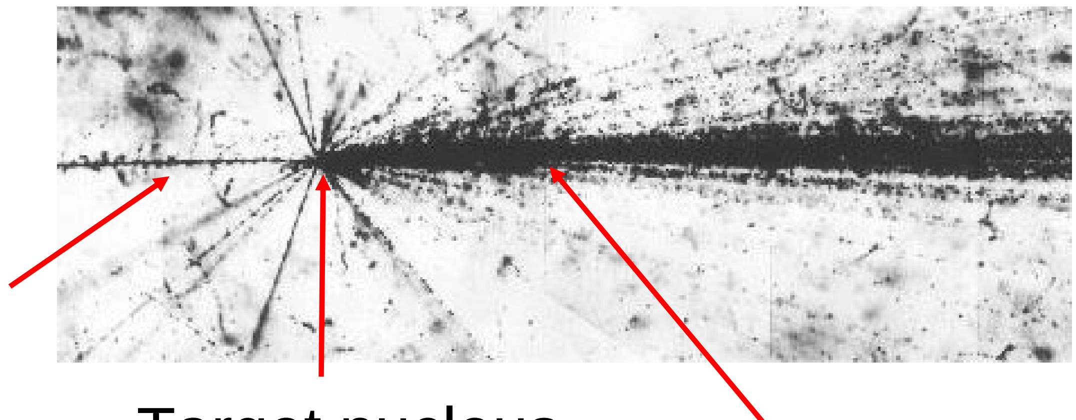


Particle Detectors

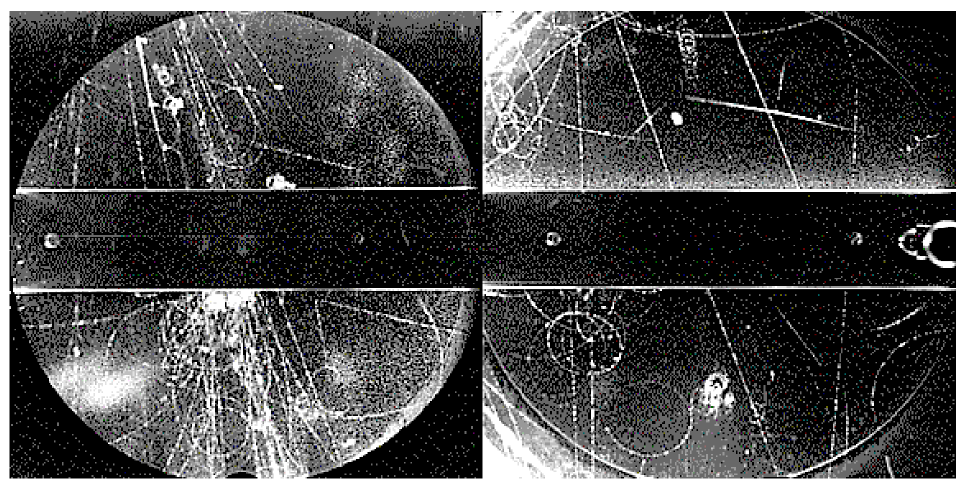
- Charged particles will ionize the material through which they move.
- The ions produce chemical or physical changes in the material.
  - Photographic emulsion
  - Cloud chamber
  - Bubble chamber
  - Spark chamber
  - Modern electronic tracking detectors

Particle Detectors

- Emulsion:



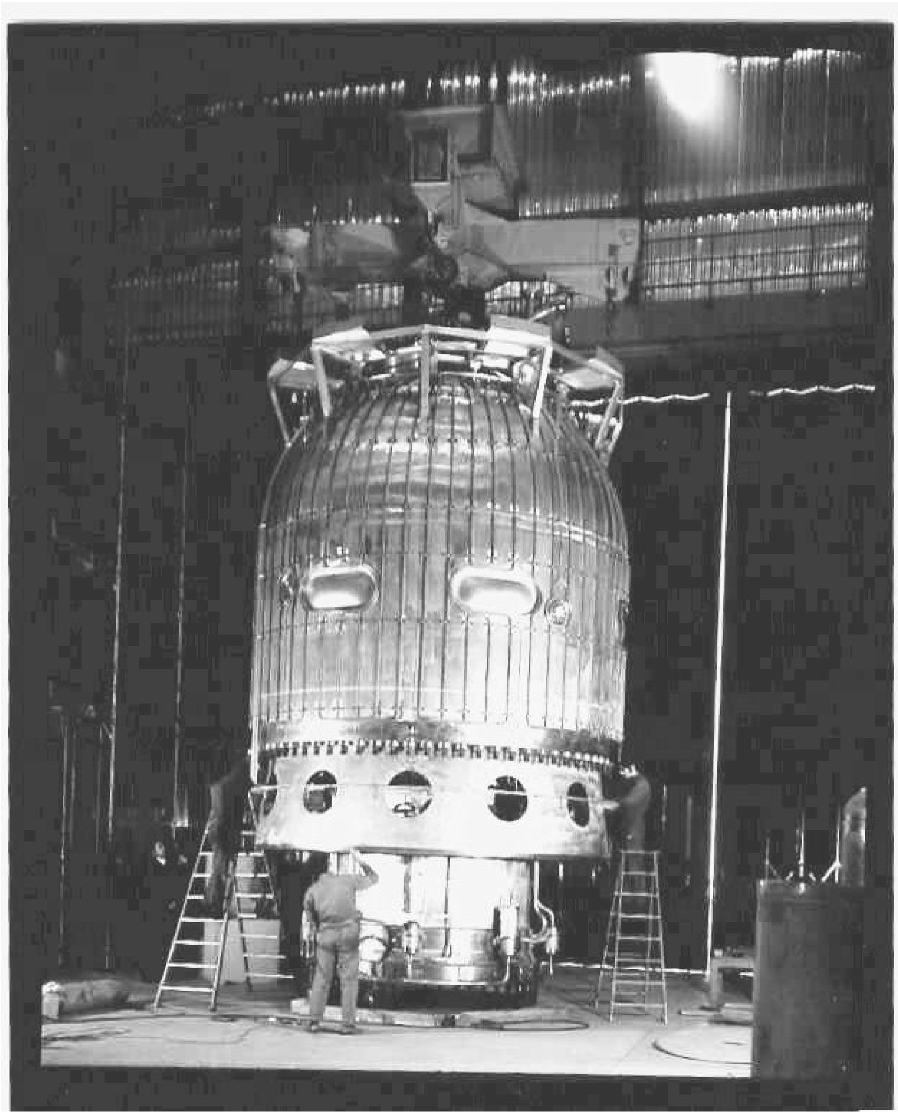
- Cloud Chamber:



Particle Detectors

- Bubble Chambers
  - Used in *fixed target* experiments at particle accelerators
  - The detector material *is* the target
  - Filled with liquid H_2, D_2, freon, *etc…*
  - Pressure keeps it in a liquid state
  - Charged particles ionize it
  - Sudden reduction in pressure produces bubbles along the ionized paths

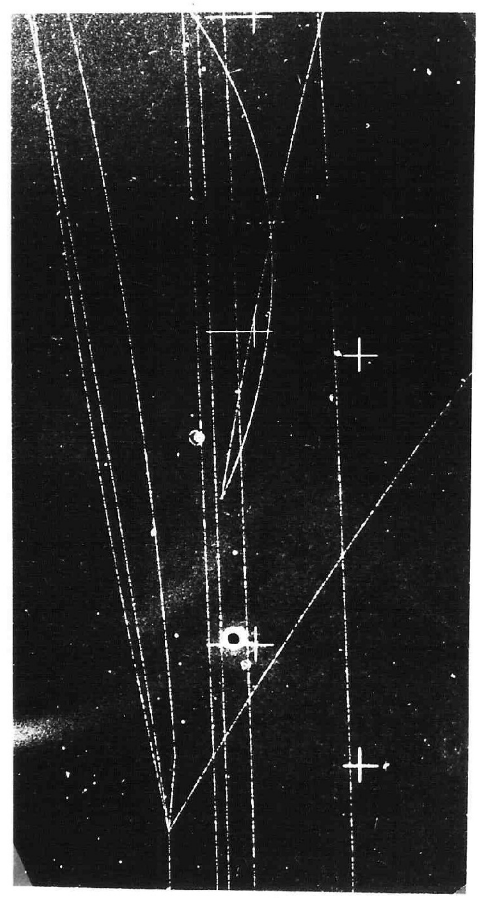
Bubble Chambers

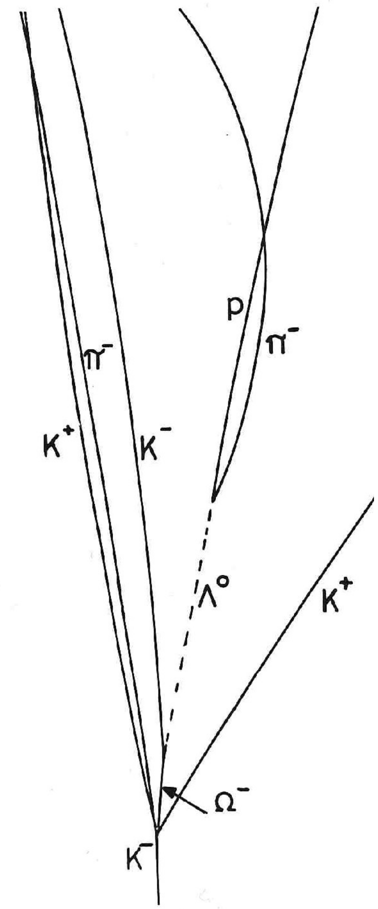


$K^- p \rightarrow \Omega^- K^+ K^+ \pi^-$ AT 10 GeV/c

$\quad \hookrightarrow \Lambda^0 K^-$

$\qquad \hookrightarrow p\,\pi^-$



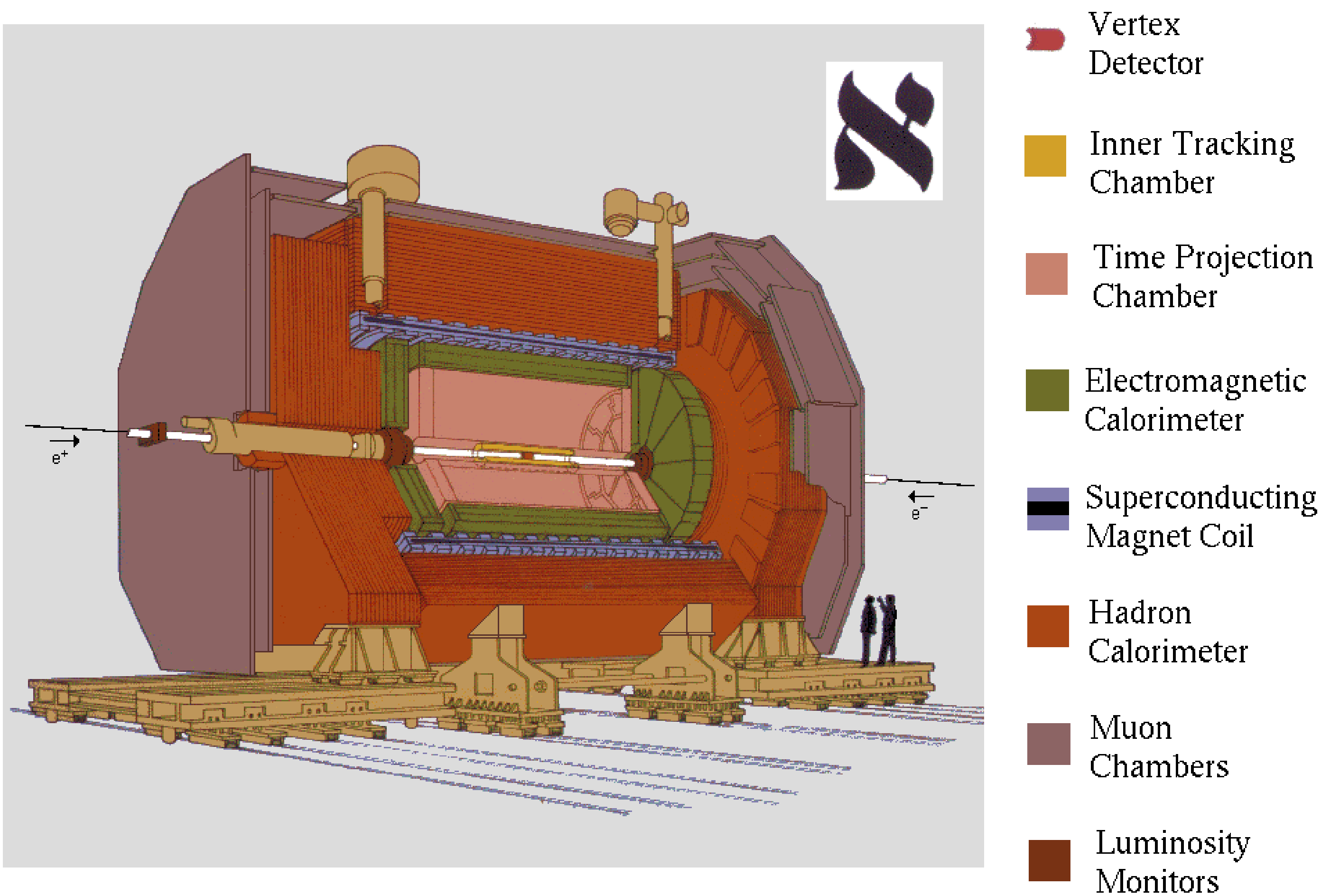


Modern Particle Detectors

- Still only detect charged particles
- Indirectly sensitive to neutral particles:
  - eg. $\gamma \rightarrow e^+e^-$, $np \rightarrow pp\pi^-$
- Can be triggered:
  - Electronic signals recorded only when something "interesting" happens
- Data written to mass storage medium
- Analyzed "offline"

Modern Particle Detectors

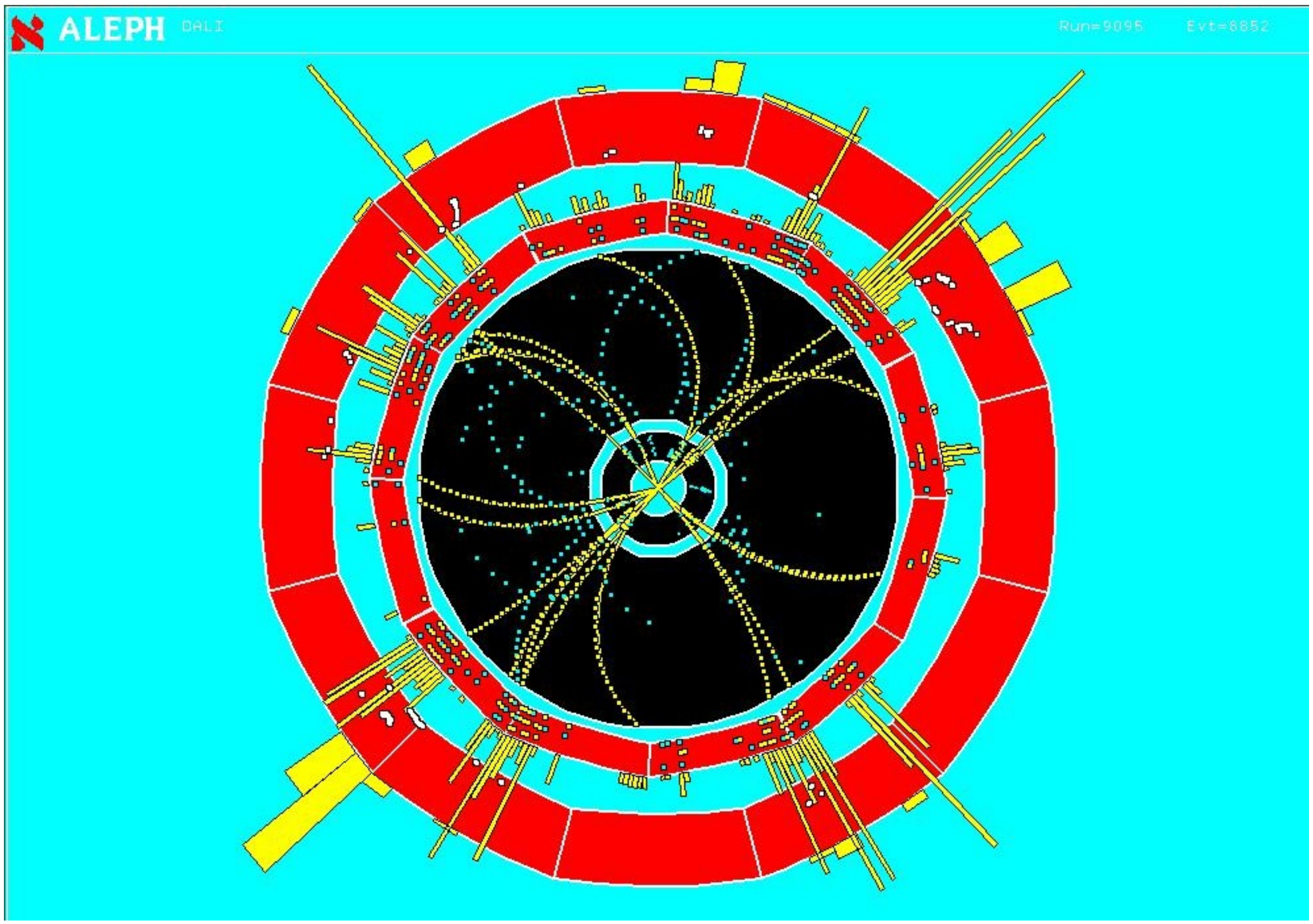
- ALEPH detector:



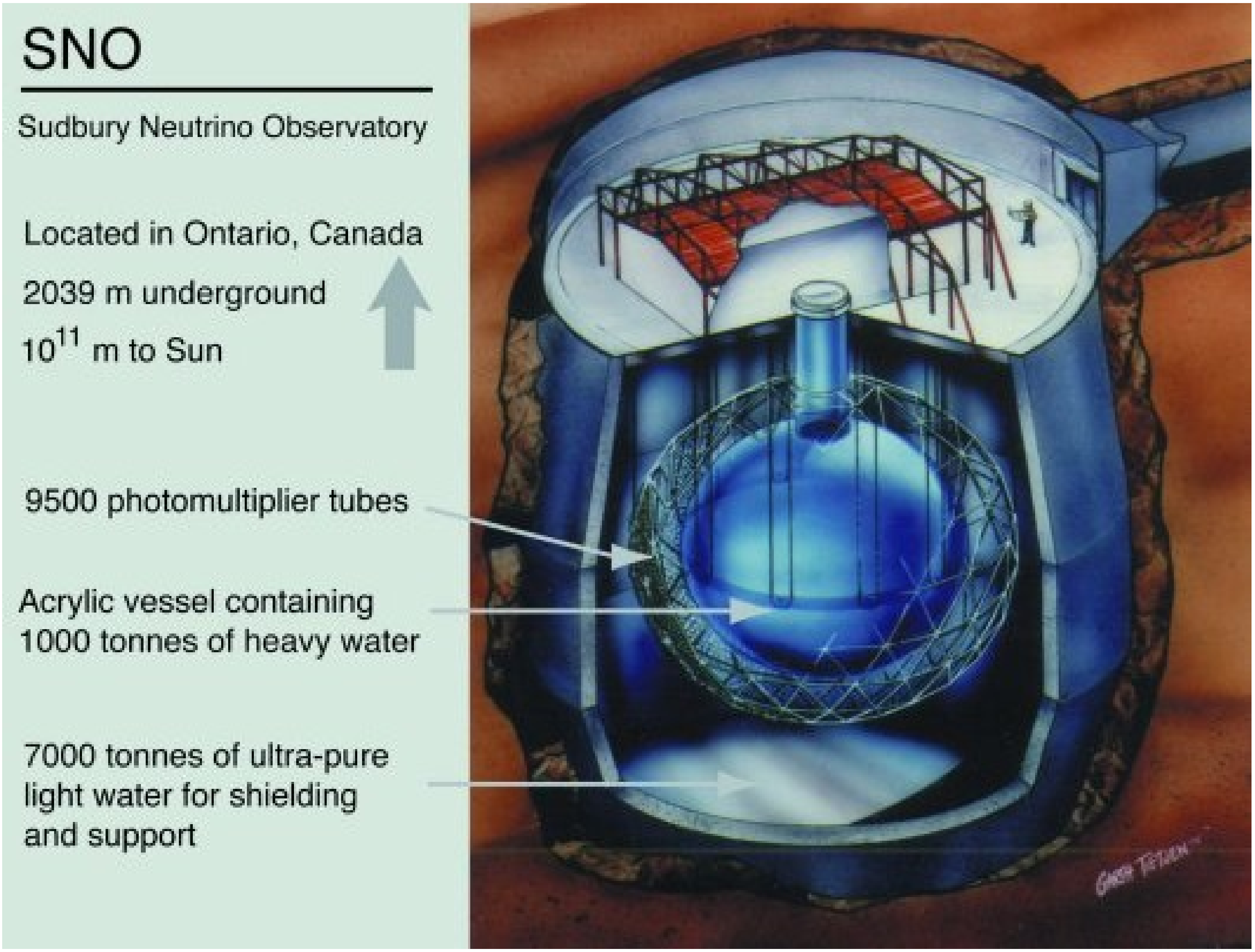
The ALEPH Detector

Modern Particle Detectors

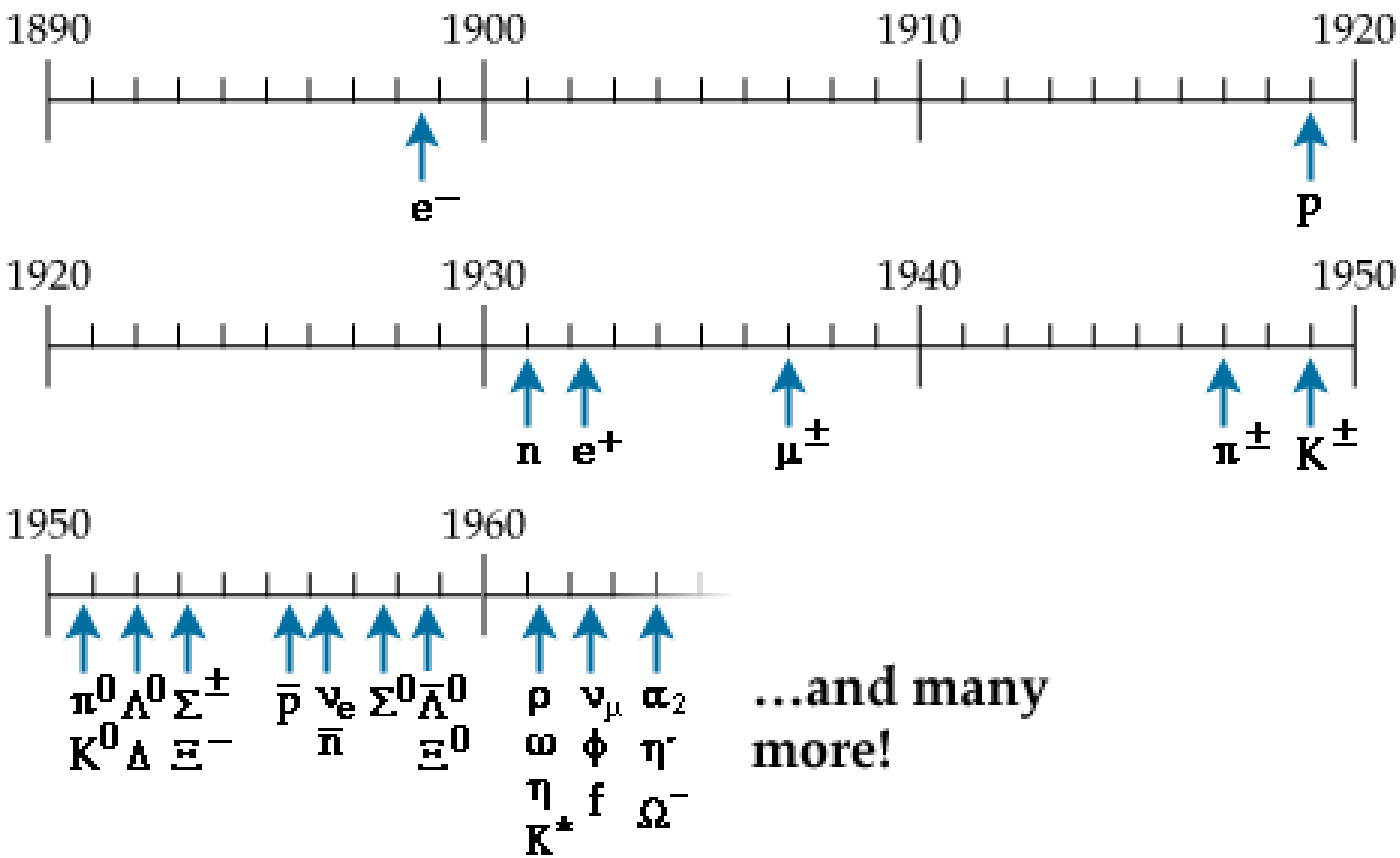
- ALEPH detector:



Other Particle Detectors



Particles


1890
1900
1910
1920
e⁻
p
1920
1930
1940
1950
n
e⁺
μ±
π±
K±
1950
1960
π⁰ Λ⁰ Σ±
K⁰ Δ Ξ⁻
p̄ νe Σ⁰ Λ̄⁰
n̄ Ξ⁰
ρ νμ α₂
ω φ η'
η f Ω⁻
K*
…and many more!

Particle Physics

- What are their properties?
  - Mass and charge
  - Spin and magnetic moment
  - Internal quantum numbers: C, P, “Isospin”
  - Lifetime
  - Branching fractions
- The Particle Data Group compiles the Review of Particle Properties…

Example:

BOTTOM, CHARMED MESONS
$(B = C = \pm 1)$

$B_c^+ = c\overline{b}$, $B_c^- = \overline{c}b$, similarly for B_c^*'s

$B_c^\pm$

$I(J^P) = 0(0^-)$
I, J, P need confirmation.

Quantum numbers shown are quark-model predicitions.

Mass $m = 6.4 \pm 0.4$ GeV
Mean life $\tau = (0.46^{+0.18}_{-0.16}) \times 10^{-12}$ s

B_c^- modes are charge conjugates of the modes below.

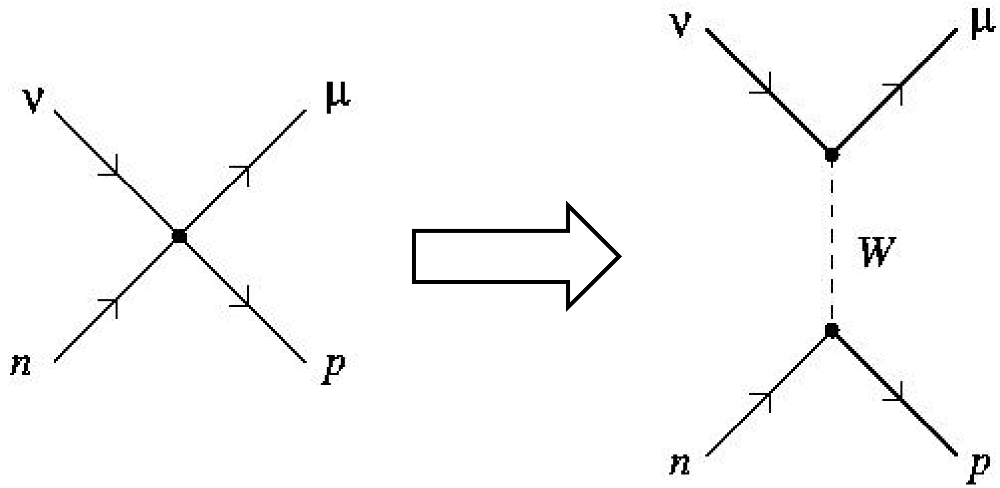
B_c^+ DECAY MODES × B($\overline{b} \to B_c$)	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\overline{b} \to B_c$).			
$J/\psi(1S)\ell^+\nu_\ell$ anything	$(5.2^{+2.4}_{-2.1}) \times 10^{-5}$		–
$J/\psi(1S)\pi^+$	$< 8.2 \times 10^{-5}$	90%	2448
$J/\psi(1S)\pi^+\pi^+\pi^-$	$< 5.7 \times 10^{-4}$	90%	2429
$J/\psi(1S)a_1(1260)$	$< 1.2 \times 10^{-3}$	90%	2255
$D^*(2010)^+\overline{D}^0$	$< 6.2 \times 10^{-3}$	90%	2546

Phenomenology

- Which particles are truly elementary?
- Do we understand why particles have their observed properties?
- What can we calculate?
- Are the calculations reliable?
- Can we compare them with experiment?
- Is there an underlying theory that explains everything?

Phenomenology

- Particles that don't interact are described by quantum mechanics and special relativity
- Interactions are described by
  – Empirical parameterizations
  – Dynamical models



Particle Interactions (Forces)

- Particles interact by the exchange of virtual quanta
- Only know of four forces:
  - Electromagnetism
  - Weak nuclear force
  - Strong nuclear force
  - Gravity

"Electroweak"

- Each is associated with a class of particles
  - *eg*. Electromagnetism → photon

Particle Interactions

- If we know how a particle couples to a particular force carrier then we can calculate probabilities:

$$\mathcal{P}(\nu n \rightarrow \mu p) \sim |\langle \mu p | H | \nu n \rangle|^2$$

- What is harder is doing the reverse…
  - Measure probabilities
  - Deduce the form of the Hamiltonian, *H*
- That is essentially what Particle Physics is about.

Unanswered Questions

- What are the *most fundamental* types of matter?
- Are there only four forces?
- Is the model that describes them self-consistent?
- Why does nature look this way?
- Are there cosmological implications?
- We think we might get some answers in the next decade…