Experimental Observation Of Lepton Pairs Of Invariant Mass Around 95 GeV/c^2 At The CERN SPS Collider

不変質量95 GeV/c^2近傍のレプトン対の実験的観測

G. Arnison et al. (UA1 Collaboration).

Phys. Lett. B126, 398-410, 1983.

Contents

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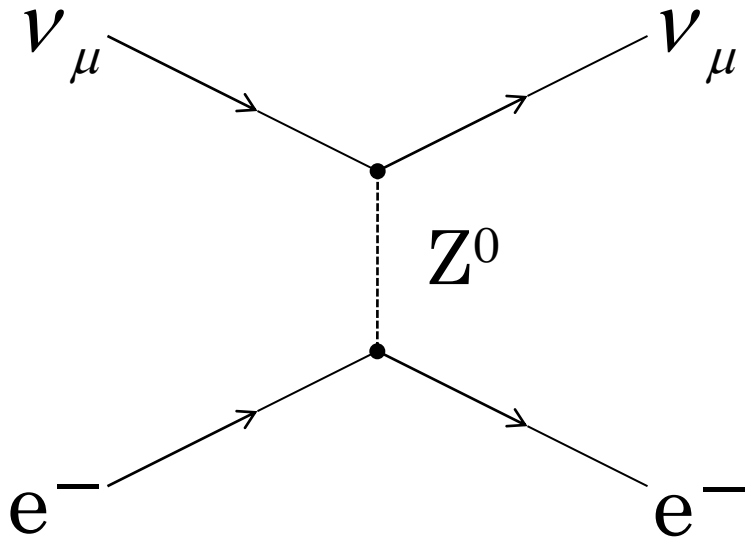
1. Introduction

— Intermediate Vector Boson Z^0 —

- Z^0 is the Intermediate Vector Boson predicted by the electroweak theory as the mediator of weak neutral currents.

- Electroweak theory is a unified theory of electromagnetic and weak interactions.

- There are charged intermediate vector bosons $W^{\pm}$ and a neutral Z^0.



Example of weak neutral current:
ν-e scattering
expressd in Feynman diagram.

2. Experimental Method

— Proton-Antiproton Collider —

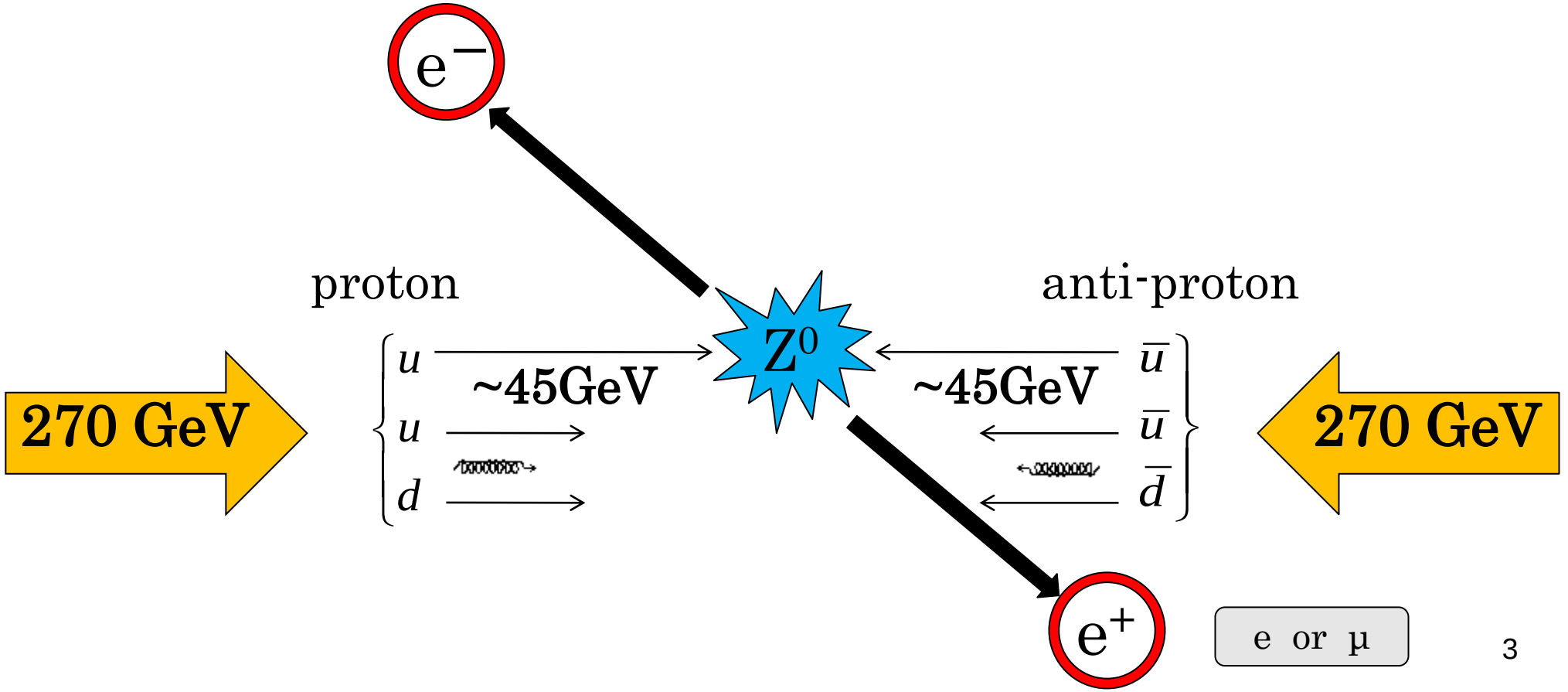
In hadron picture

$$p + \bar{p} \rightarrow Z^0 + X$$

In quark picture

$$u + \bar{u} \rightarrow Z^0$$

$$d + \bar{d} \rightarrow Z^0$$



— Invariant Mass —

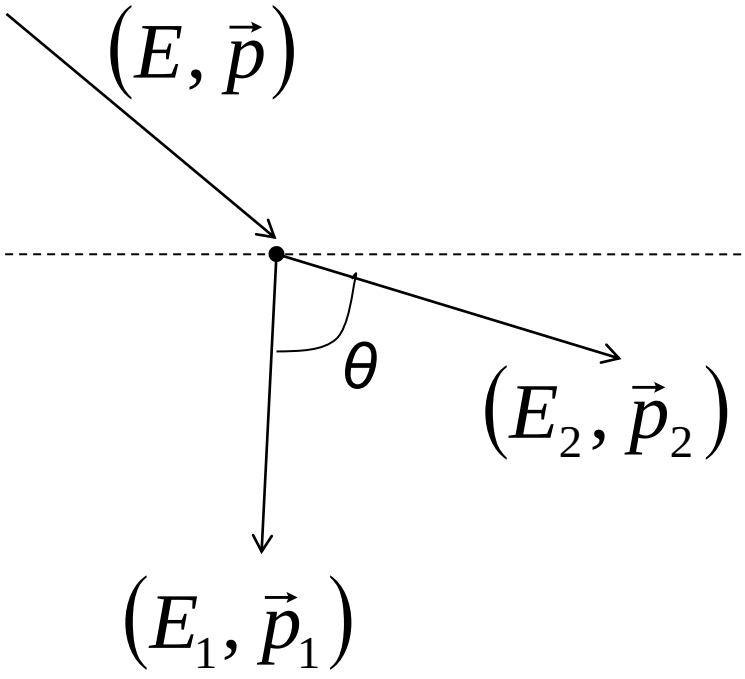
Before decay

$$M_{inv}{}^2 = E^2 - \vec{p}^2$$

After decay

$$M_{inv}{}^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$

$$= (E_1 + E_2)^2 - \left(|\vec{p}_1|^2 + |\vec{p}_2|^2 + 2|\vec{p}_1||\vec{p}_2|\cos\theta\right)$$



— UA1 Experiment at CERN —

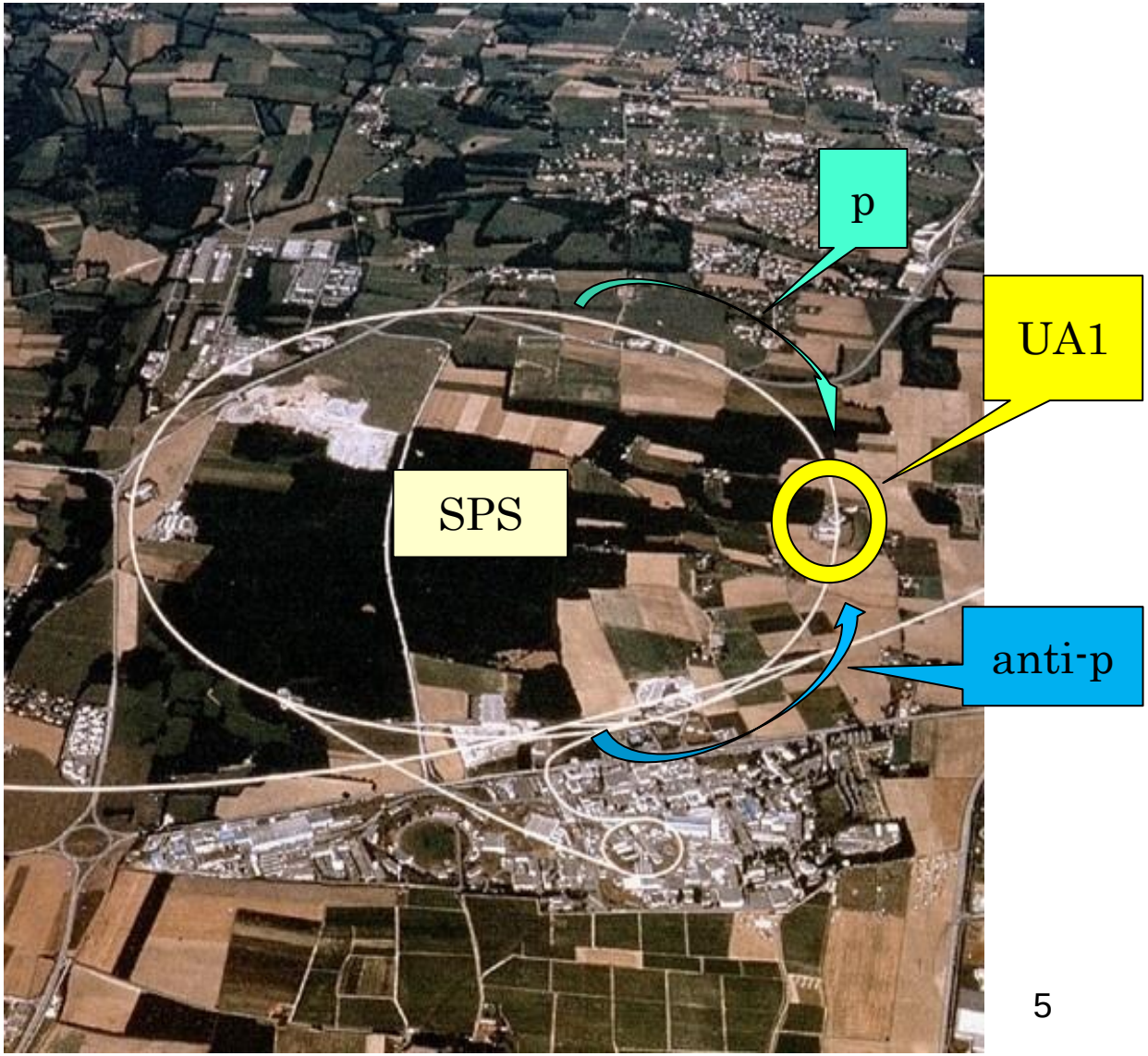
- CERN SPS(Super Proton Synchrotron) collider is located in Geneva, Switzerland.

- In this experiment, a centre-of-mass energy is

$$E_p = E_{\bar{p}} = 270\text{GeV}$$
$$\sqrt{s} = 540\text{GeV}$$

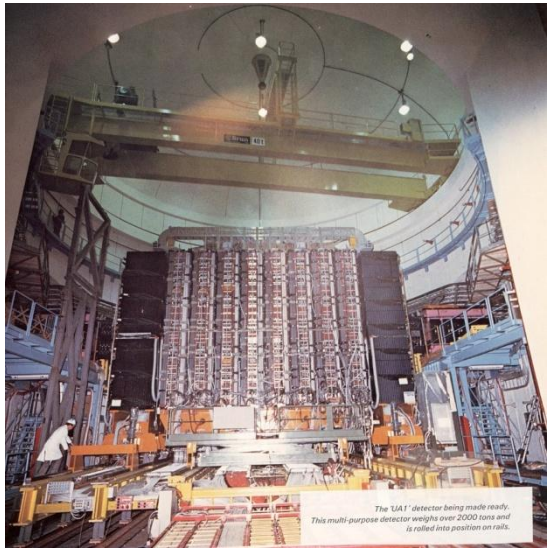
- The integrated luminosity is

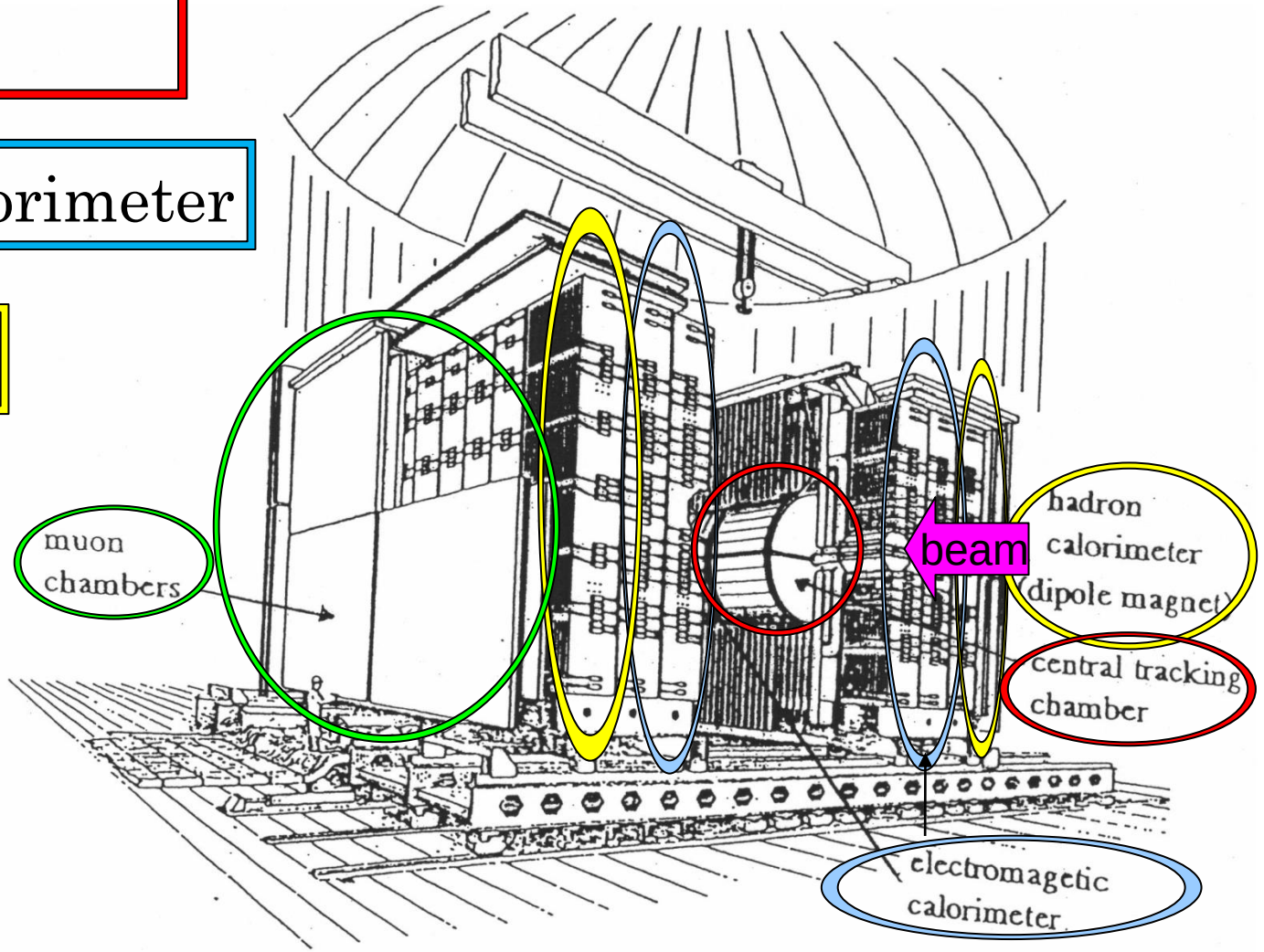
$$\int L dt = 55\ nb^{-1}$$



— Detector —

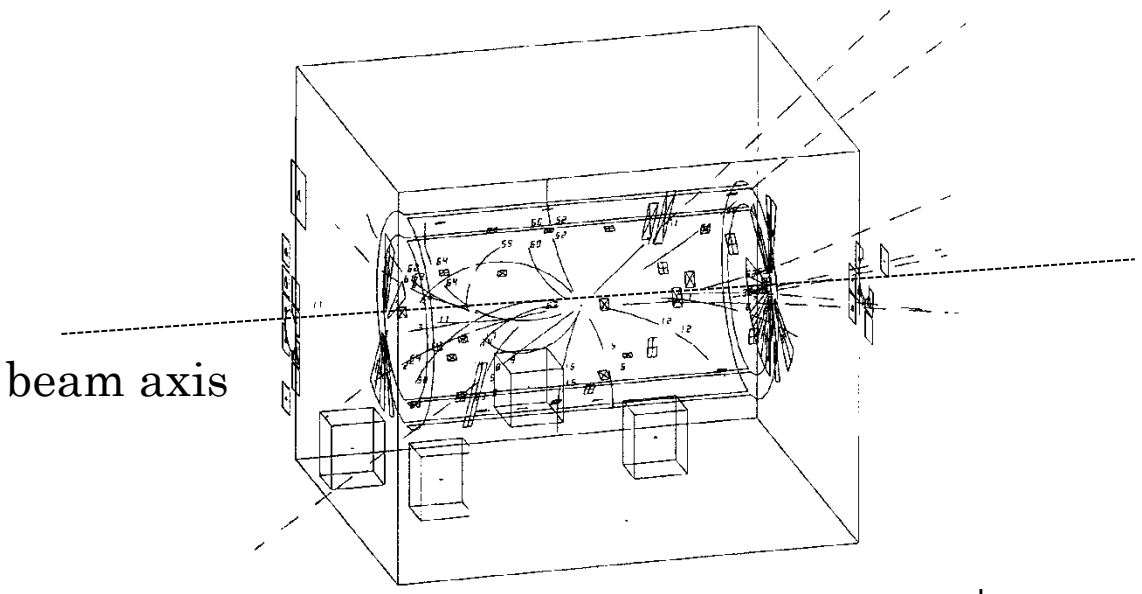
- Central tracking chamber
  B = 0.7 T
- Electromagnetic calorimeter
- Hadron calorimeter
- Muon chamber





— Event Display —

- All tracks from a collision are displayed.
- All calorimeter hits are displayed.



- Thresholds are raised to

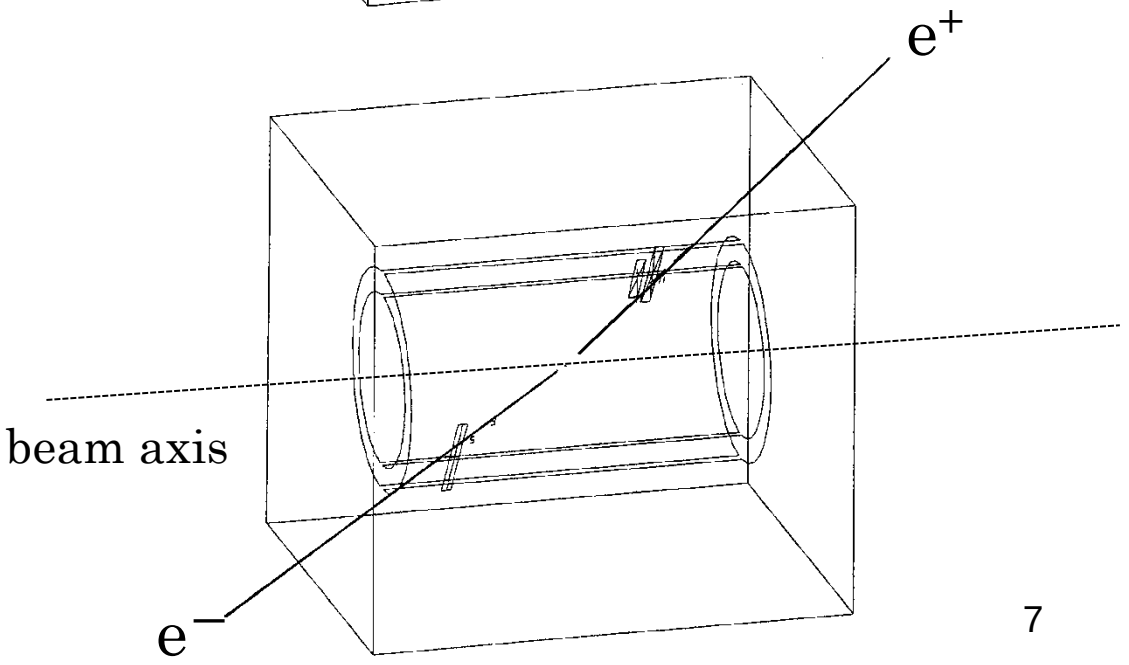
$$P_T > 2\text{GeV/c}$$

for charged tracks and

$$E_T > 2\text{GeV}$$

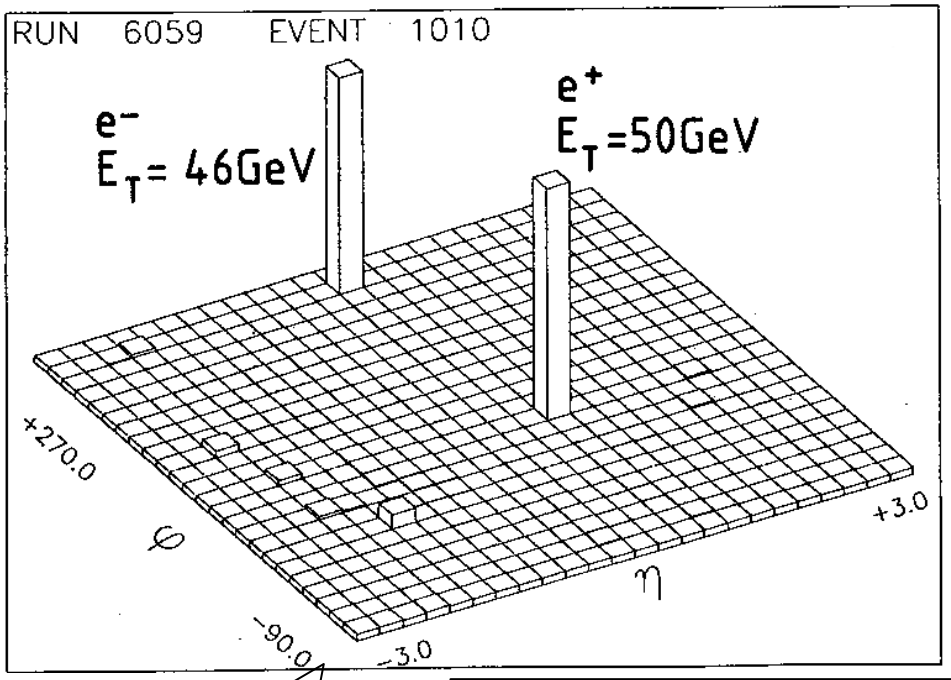
for calorimeter hits.

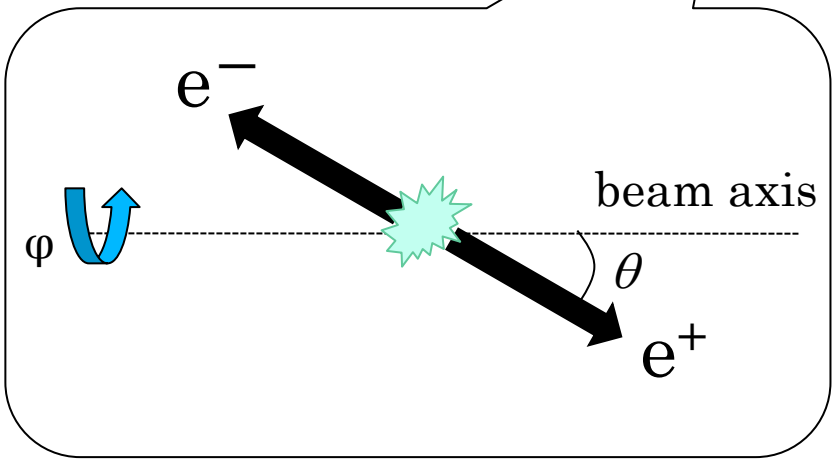
- Then only e^+e^- pair survives these cuts.



3. Data Analysis

- 4 e^+e^- pairs are observed.
- This figure is one of them.
- The other events are similar to this.
- This is electromagnetic energy deposition at angles >5° with respect to the beam direction.





φ: azimuthal angle
η: pseudorapidity

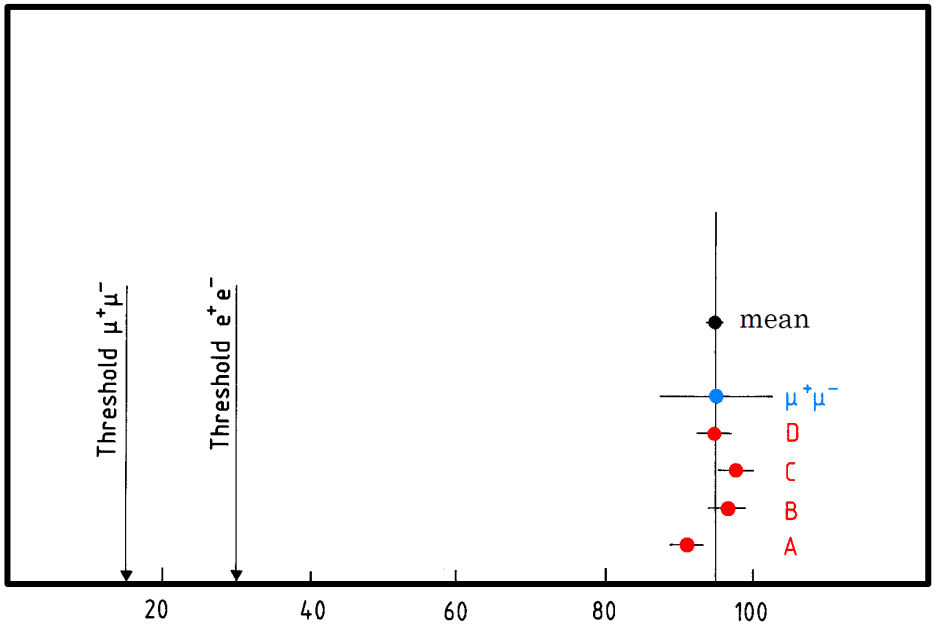
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

4. Result

- This figure shows invariant mass of observed lepton pairs.

- From these observations, we deduce the mass for the Z^0 particle,

$$m_{Z^0} = (95.2 \pm 2.5)\ \text{GeV}/c^2$$



Invariant Mass of Lepton pair [Gev/c^2]

A,B,C,D are e^+e^- pair events.

5. Summary

- Proton-antiproton collider at CERN were used to produce Z^0.
- Quark and antiquark annihilate to Z^0 and decay to a lepton pair.
- UA1 observed this lepton pair.
- These events fit well the hypothesis that they are produced by the process

$$p + \bar{p} \rightarrow Z^0 + X$$
$$Z^0 \rightarrow e^+ + e^-$$
$$Z^0 \rightarrow \mu^+ + \mu^-$$

- This paper reports the observation of four e^+e^- pairs which have the signature of a two-body decay of a particle of mass

$$m_{Z^0} = (95.2 \pm 2.5)\ \text{GeV}/c^2 .$$

- With this discovery, electroweak theory was established.

- $W^{\pm}$ bosons had been observed by UA1 in the same year.

fin

補足 1
— Central Tracking Chamber —

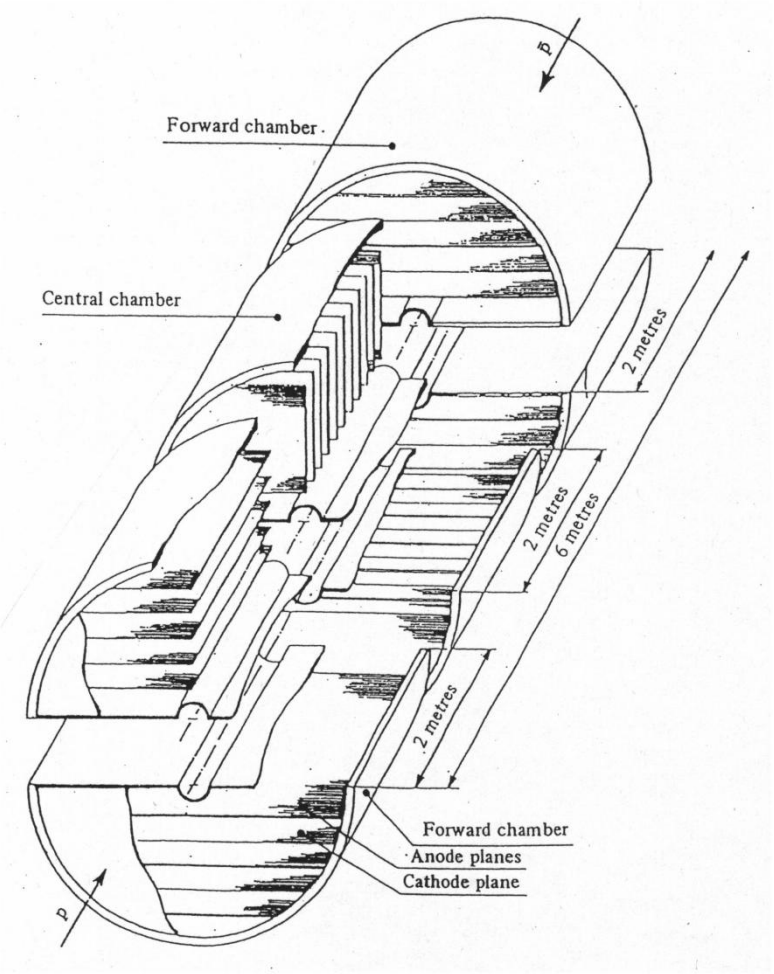
- This gas-filled central detector consist of six main modules over 6000 sense wires for detecting electrical signals.

- The wire are all arranged in planes separated by 20 cm and all wires are parallel to the magnetic field.

- The electrons produced by the ionization and the passage of these particles can be reconstructed from the electrical signals.

- The momentum is

$$p = RqB$$



補足2
— Background —

- Two isolated high E_T electrons
  $E_T > 25$ GeV ($P_T > 7$ GeV/c)
  - $E_{hadron} < 0.8$ GeV

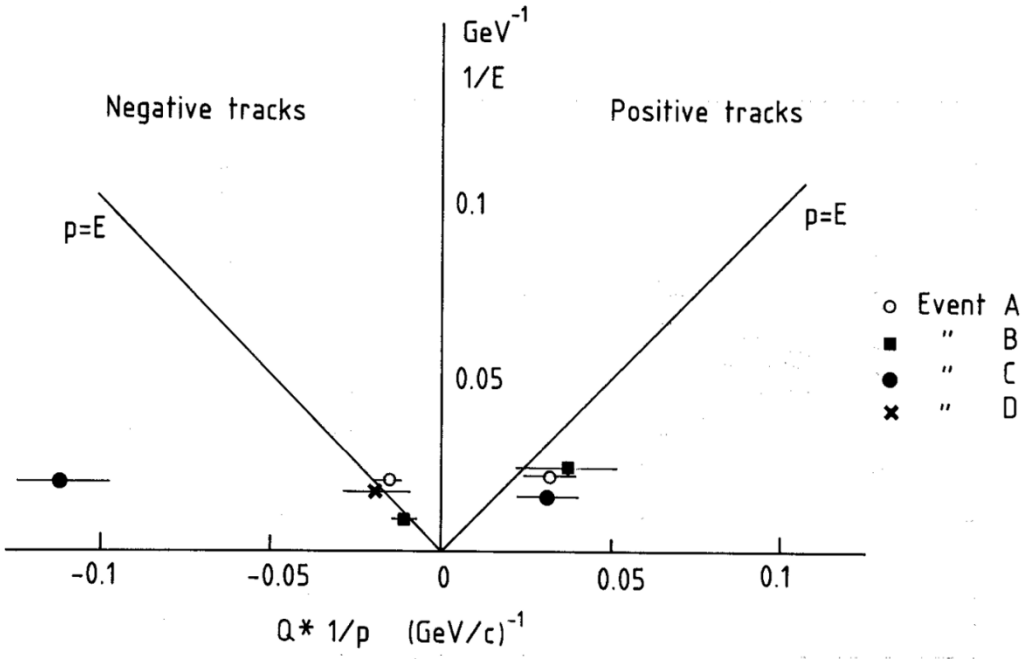
- jets → 1 isolated track ($P_T > 25$ GeV/c)
  1 track observed
  fake muon probability ~ 2×10^{-3}
  fake $e^{\pm}$ probability ~ 6×10^{-3}
  ↓
  negligible

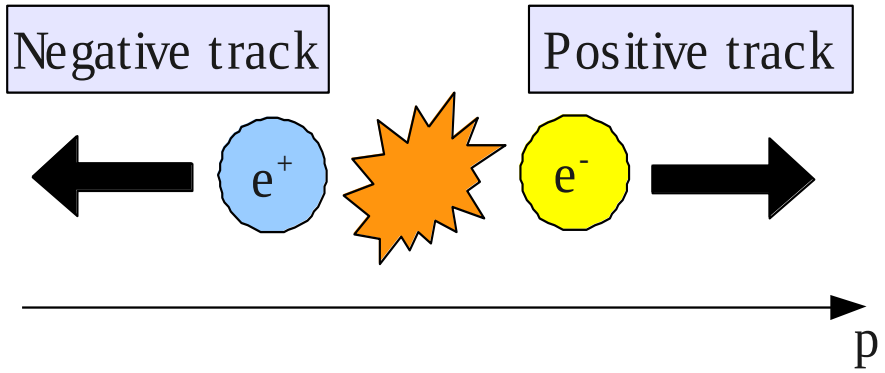
- heavy flavour jets (bb, cc)
  2 events with an isolated μ ($P_T > 15$ GeV/c)
  1 event with an isolated e ($P_T > 25$ GeV/c)
  other jets fake leptons → 10^{-4} events

- Onium decay from a new quark
  $\sigma_{(QQ)}$: negligibly small

- Magnetic deflection in 1/p units compared to the inverse of the energy deposited in the electromagnetic calorimeters.

- Ideally, all electrons should lie on the 1/E = 1/p line.





Weak Boson

- There are W and Z boson in weak boson.
- W decay to one lepton and one neutrino pair.
- Mass of W is

  m_W= 80.398(25) GeV
- Mass of Z is

  m_Z= 91.1876(21) GeV