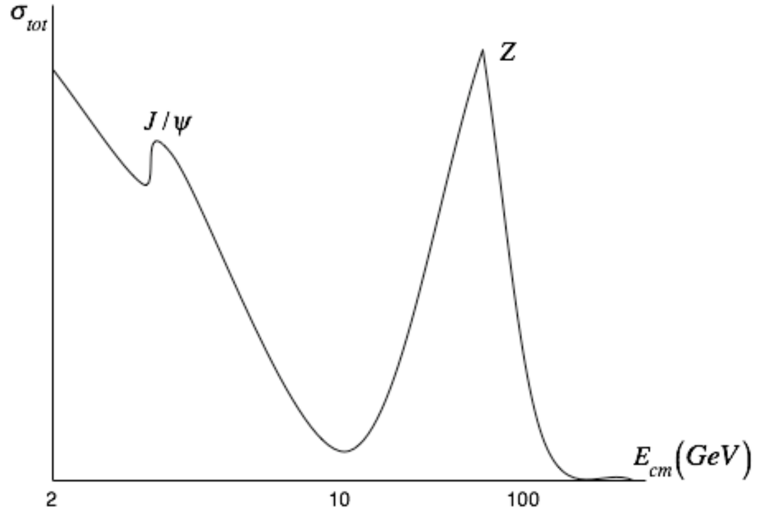
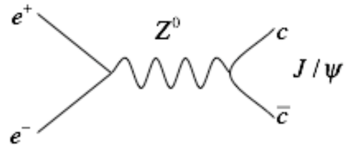
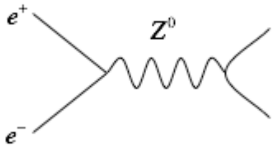
LEP (1989 – 2000)
e^+e^- at CERN.
Circumference 26, 256, 883mm
(1mm change → 10MeV change in energy of electrons)
Detects TGV (French express train) electric train – affects magnets.
Detects water level in lake Geneva – gravitational pull of the water on land.
Detects moon – gravity.

LEP phase 1 (1989 – 1995)
e^+e^- each with ~50GeV, giving $E_{cm} \le 100GeV$.
$\sigma_{tot}\left(e^-e^+ \to anything\right)$







$M_Z = 91.2GeV$
$E_{e^+} = E_{e^-} = 45.6GeV$
→ Real Z^0 production

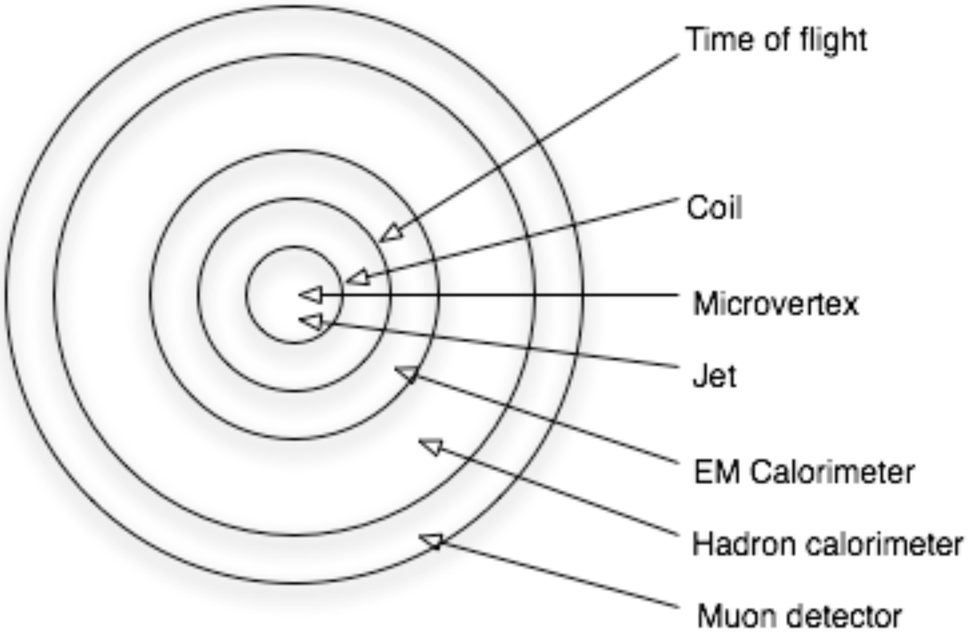
LEP Phase 2 (1996 – December 2000)
e^+e^- each with ~100GeV.
Why?

a. At $E_{cm} \ge 160GeV$, can produce pairs of real $W^\pm$ ($M_{W^\pm} \sim 80.4GeV$
b. Want to get highest possible energy to see what happens.
    - Higgs
    - Supersymmetry
    - Unexpected (outside Standard Model)

Experiments
Experiments are normally multipurpose.
4π detectors – try to detect everything and then interpret.

LEP had 4 interaction points → competing, but each had their own speciality.
E.g. lepton detection – cannot be optimistic for detecting everything.

OPAL
Omni Purpose Apparatus LEP



Microvertex: Si solid state charged particles $\leq 5\mu m$ precision.
Jet: gas detector. Charged particles – electrons drift to anode – timing drift time → position – track of charged particles.

Coil: magnetic field. Bends charged particles → sign of charge → momentum.

Time of flight – scintillator counters – charged particles → velocity 4 momentum from coil → mass.

Electromagnetic calorimeter

- Detects $e^+e^-\gamma$
- Electromagnetic shower from Bremsstrahlung
- Energy measured by Cerenkov radiation.
- Uses Lead Glass – helps Bremsstrahlung
- Can't detect μ as Bremsstrahlung $\propto mass^{-4}$.
- Energy ½ of initial energy in I X_0.
- Lead glass is 24 X_0 wide.

Hadron Calorimeter

- Hadrons: π, K, P, J/ψ
- Particle comes in, strikes iron layer and turns into a hadronic shower through the strong interaction. Detector finds particles. Iron → detector → iron …

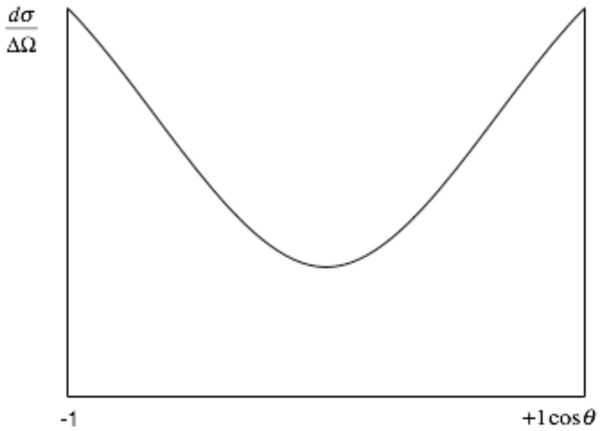
Only μ and τ are left.
Muon Detector:

- Drift chamber
- For charged particles, gets the position and track → muons.

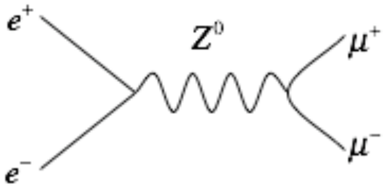
τ are not detected as they decay too quickly – have to reconstruct.

Z^0, $W^{\pm}$ - Mediators of Weak Interaction

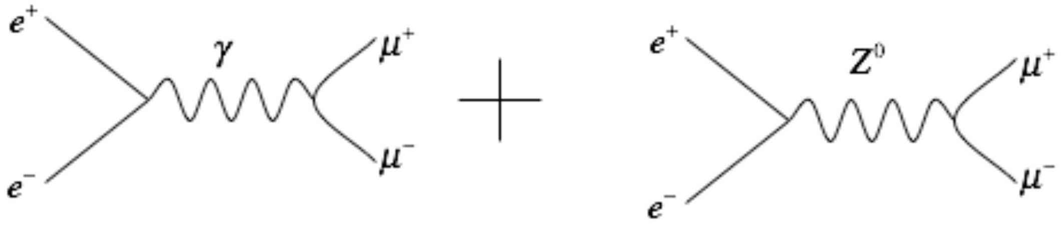
Z^0 neutral – couples to quarks and leptons.
Also, γ neutral – couples to quarks and leptons.
Electroweak unification: $Z^0 \equiv \gamma$ at energies $\geq 100 GeV$ (distances $\leq 10^{-18} m$, the range of weak)
Consider e^+e^- annihilation.
At energies $<< 100 GeV$ $\left(M_{Z^0}\right)$, γ is the dominant process.



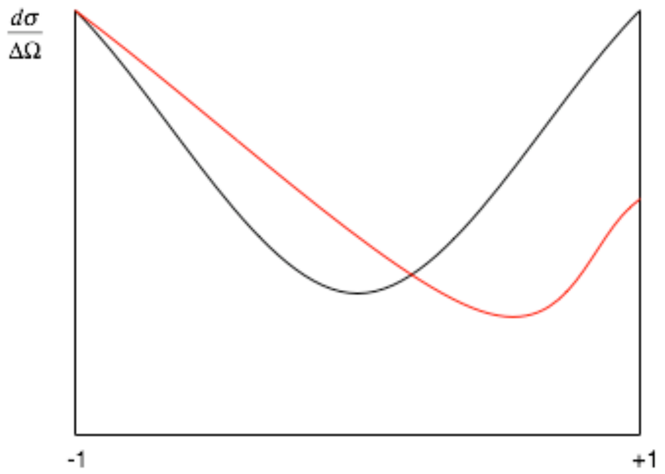
At $E = M_{Z^0}$ (100GeV), Z^0 resonance is produced.



At $E > M_{Z^0}$, get:



Interference Effect

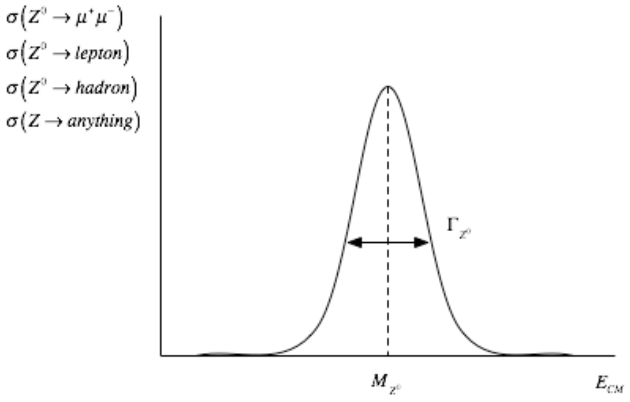


Higher probability of backward production.

Asymmetry = $\frac{N_F - N_B}{N_F + N_B}$

$\mu^+\mu^-$ - asymmetry at energies $\leq 43.7GeV$ → evidence for virtual Z^0 and prediction of Z^0 mass of 93GeV (known now to be $\sim 91.6GeV$)

Don't use e^-e^+ detection as can't distinguish from elastic scattering.



$M_{Z^0} = (91.1876 \pm 0.0021)GeV$

$\Gamma_{Z^0} = (2.4952 \pm 0.0023)GeV$

$\Delta E \Delta t \sim \hbar :\ \Delta E \equiv \Gamma_{Z^0},\ \Delta t = \tau_{Z^0}$

-> $\tau_{Z^0} = 10^{-25}s$

Z^0 cannot have any momentum due to the experimental setup → stationary → at rest energy → can only have one energy for Z^0.