Accelerators

Lecture V

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V) LEP, LHC + more

- LEP

- LHC

- Other HEP Projects

- Future Projects

- What else?

LEP

Precision Experiment:

LEP1:

$E = 45.6$ GeV Z_0 $\frac{0}{0}$ 0.003%

($m_Z = 91$ GeV)

LEP2:

$E = 80.5$ GeV $W^{+/-}$ $\frac{0}{0}$ 0.1%

($m_W = 80.5$ GeV)

$E = 100$ GeV → ?

Limits:

$2 \cdot \pi \cdot R = 27$ km

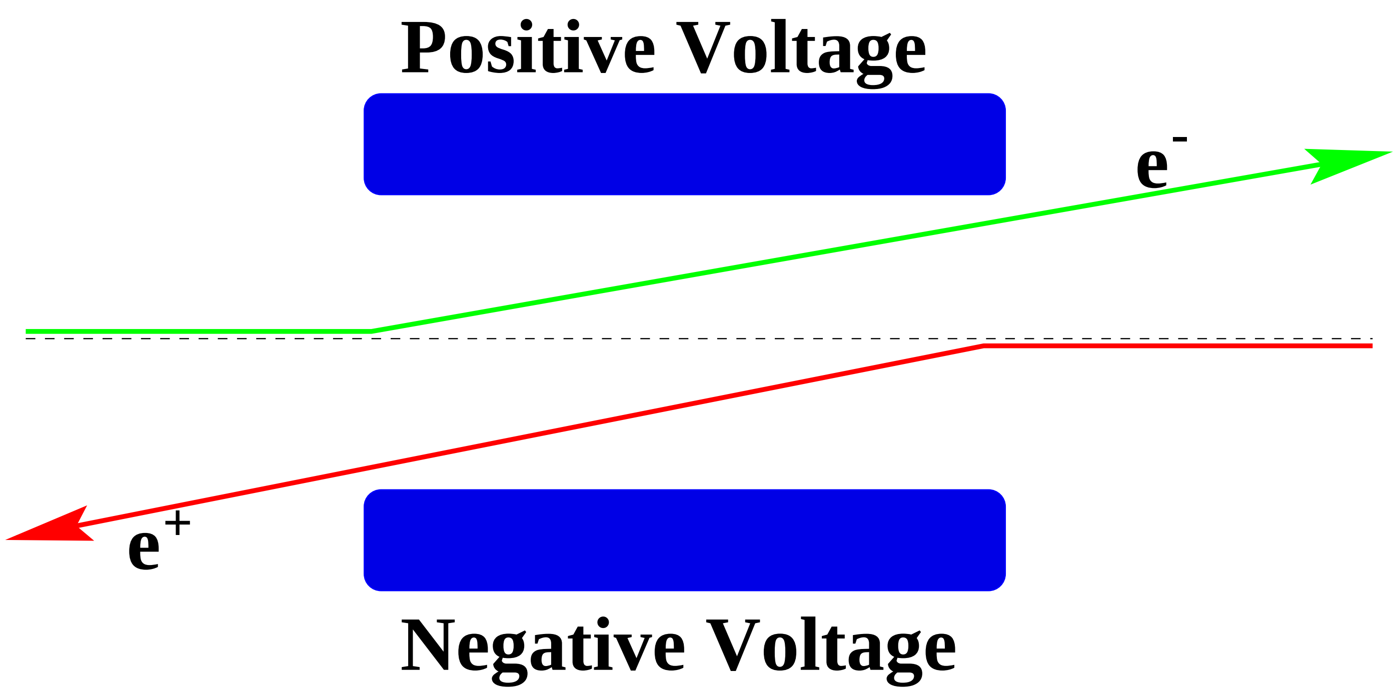
- $P > 20$ MW
- $U > 2.8$ GeV
- $P > 40$ kW (10 MW)
- $\sigma \propto \gamma$

Beam Separation for e^-/e^+

- ***Lorentz Equation:***

$$\vec{F} = e * \vec{E} + e * \vec{v} \times \vec{B}$$

→ **Electrostatic Separation**



Sparking: +/- 150 kVolt

Luminosity

$$L \propto \frac{N_p^2 \cdot n_b}{\sigma_x \cdot \sigma_y}$$

- $N_{b,\,max}$:
  - *LEP1:* *TMCI, beam-beam*
  - *LEP2:* *heat loss*

$$I_b = e \cdot N_b \cdot f_{rev} = 0.3 \div 1.0 \ \mathrm{mA}$$

- I_{tot} : *RF power* $(P = U \cdot I)$

8 mA → $n_b = 8 \div 12$ *bunches / beam*

- σ: *synchrotron radiation*
  closed orbit
  - $\sigma_x \propto \gamma$
  - σ_y
    - *quantum excitations*
    - *coupling*
    - *vertical dispersion*

LEP Orbit

Horizontal Orbit:

- ***beam offset in quadrupoles:***
  - → *Lake Geneva*
  - → *moon*

→ ***energy error***

Vertical Orbit:

- ***beam offset in quadrupoles***
- ***beam separation***

→ ***orbit deflection depends on particle energy***

→ ***vertical dispersion [D(s)]***

$$\sigma_y = \sqrt{\varepsilon \cdot \beta_y + \delta_y^2 \cdot D^2}$$

→ ***small vertical beam size relies on good orbit***

- ***1994: 13000 vertical orbit corrections in physics***

Average Luminosity

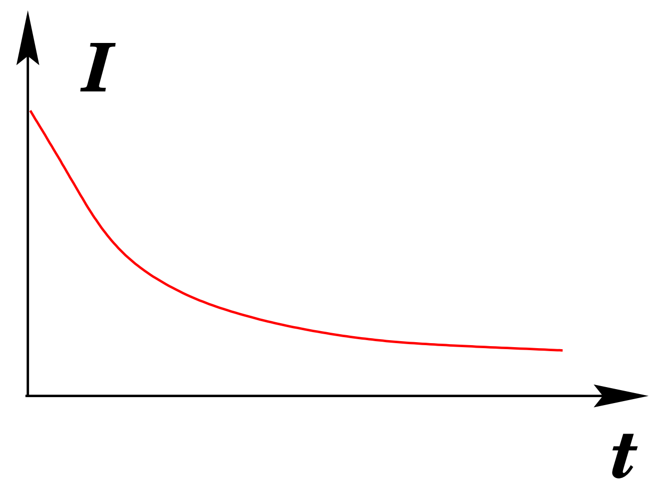
$$L \propto n_b \cdot \frac{I_{e^+} \cdot I_{e^-}}{\sigma_x \cdot \sigma_y}$$

- ***beam size is determined by synchrotron radiation and optics***

→ ***constant***

- ***Beam Lifetime:***

$$I(t) = I_0 \cdot e^{-t/\tau}$$



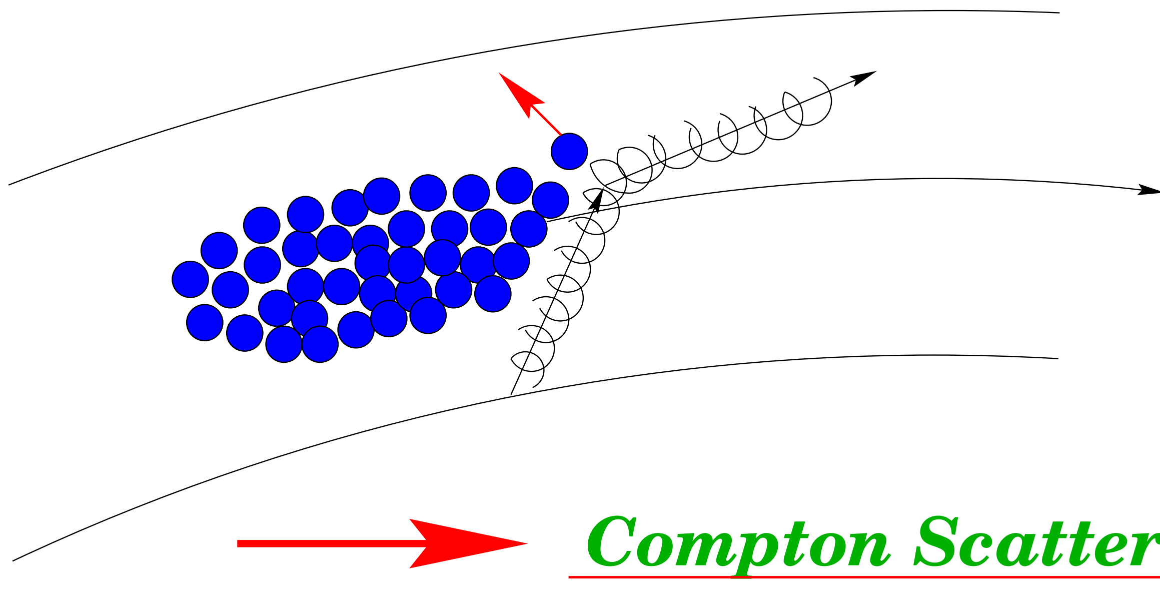
- ***Residual gas pressure***

$P < 10^{-8}$ *Torr*

[atmosphere: P = 750 Torr]

- ***Compton scattering***

Thermal and Synchroton Radiation Photons:



Compton Scattering

Beam Gas 10^{-10} Torr	τ_g = 200 hours
Beam thermal photons	τ_{tp} = 80 hours
Beam synchrotron photons	τ_{sp} = 134 hours
Total	τ_{tot} = 40 hours

LHC - Hardware

- **7 TeV p-p Collider:**

  → discovery potential (Higgs)

- **LEP Tunnel:** $(2 \pi R = 27$ km)

  → B = 8.4 T

- **Superconducting Magnets:**
  - f(T, B, I) I = 11700 A T = 1.9 K

    → magnet quench!
  - double bore; L = 15 m
  - field quality

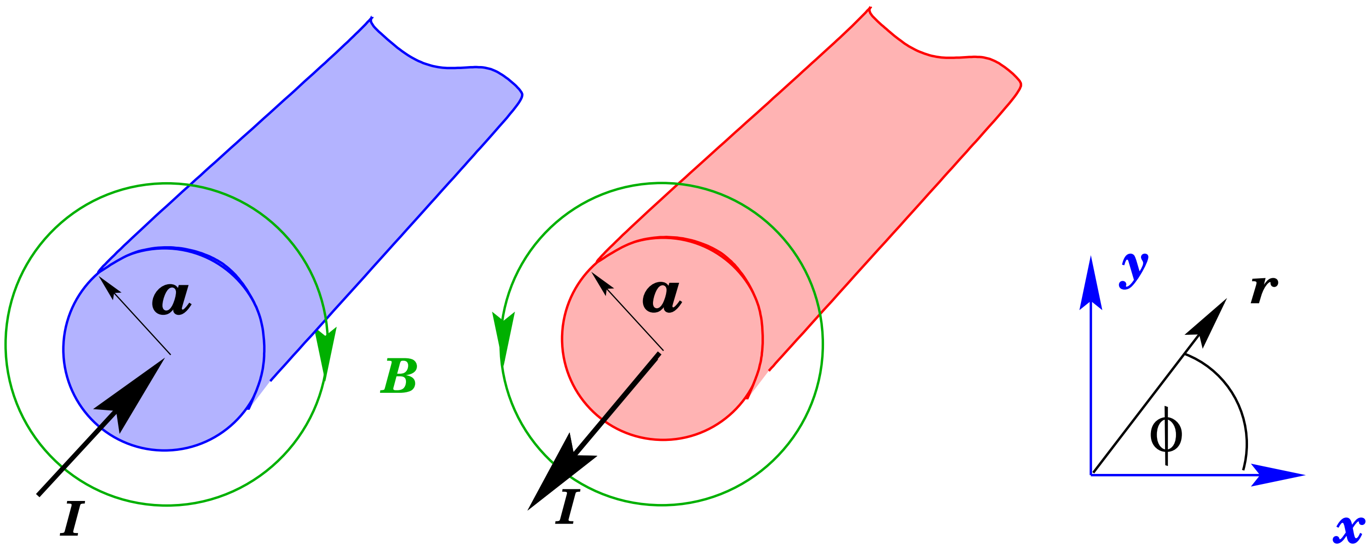
- **Cooling:** superfluid He

  30 kTons coldmass; 90 Tons He

- **p-p and Ion Beams:** (Pb; Ca)

- **4 Experiments** (2 + 2)

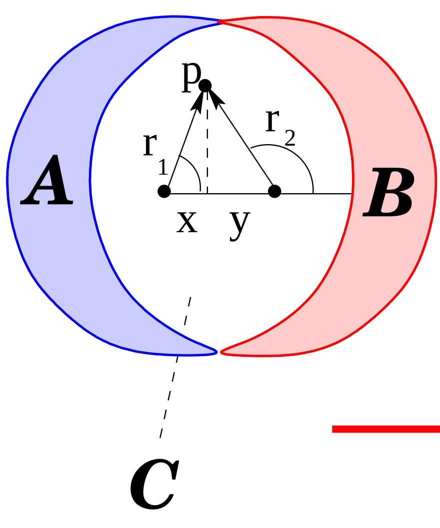
Superconducting Magnets



- $r > a$: $\vec{B} = \dfrac{\mu_0 \cdot I}{2\pi r} \cdot [-\sin(\phi), \cos(\phi), 0]$

- $r < a$: $\vec{B} = \dfrac{\mu_0 \cdot j \cdot r}{2} \cdot [-\sin(\phi), \cos(\phi), 0]$

- Overlap the two cylinders:



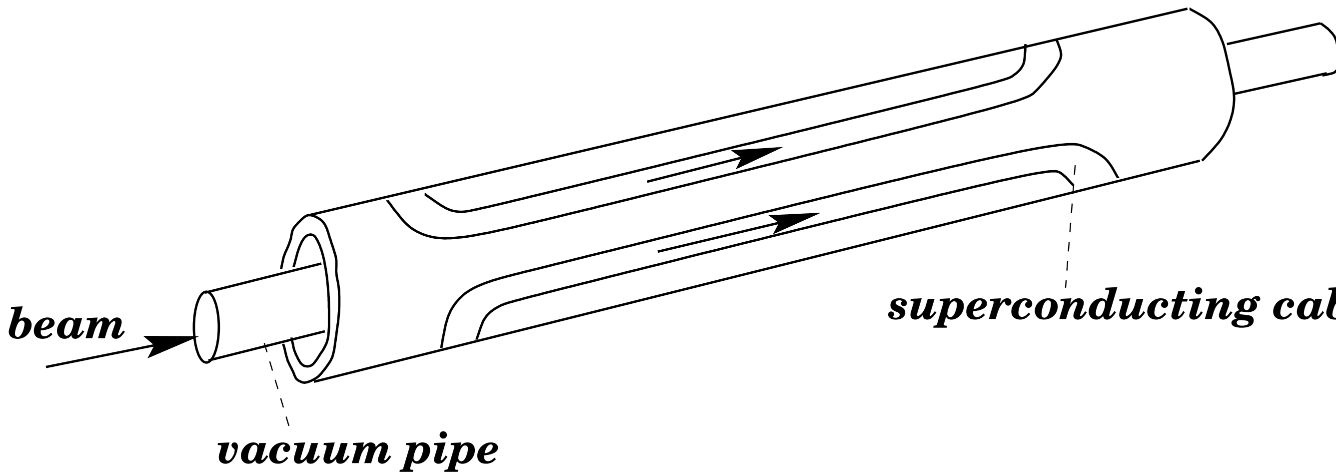
$$r_1 \cdot \cos(\phi_1) - r_2 \cdot \cos(\phi_2) = d$$

$$r_1 \cdot \sin(\phi_1) - r_2 \cdot \sin(\phi_2) = 0$$

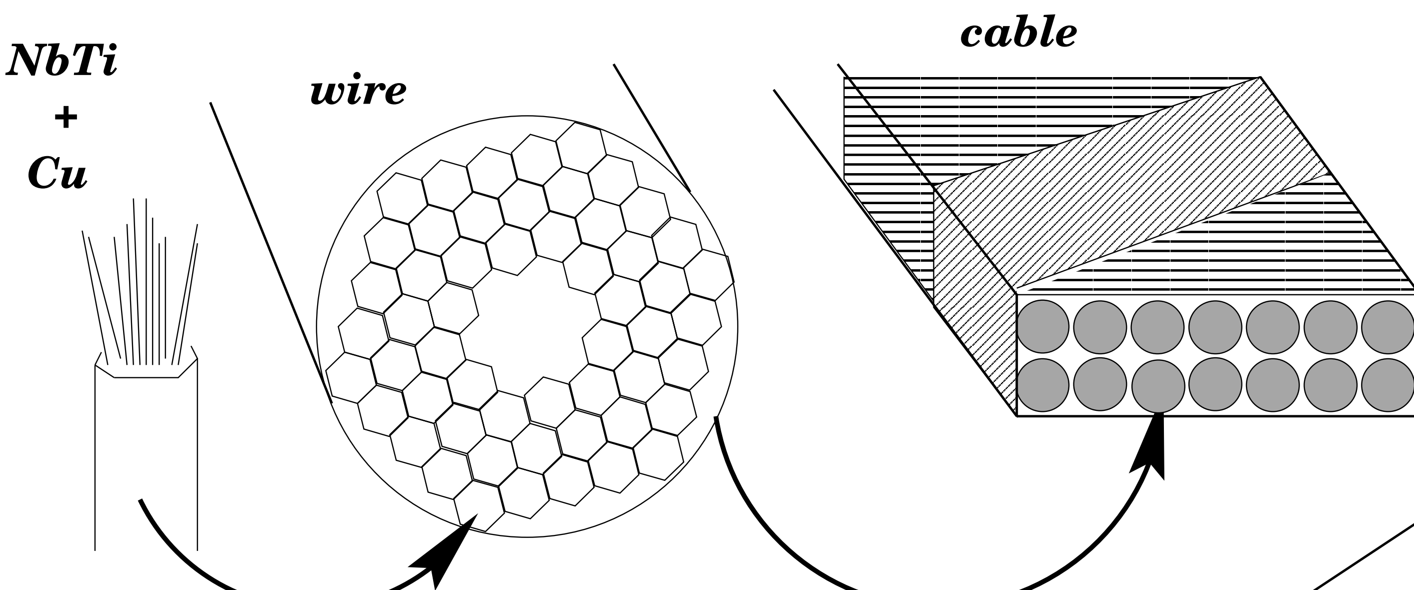
$\rightarrow$

$$\left.\begin{aligned} B_y &= const. \\ B_x &= 0 \\ j &= 0 \end{aligned}\right\} \text{ in } C$$

Coil Winding:

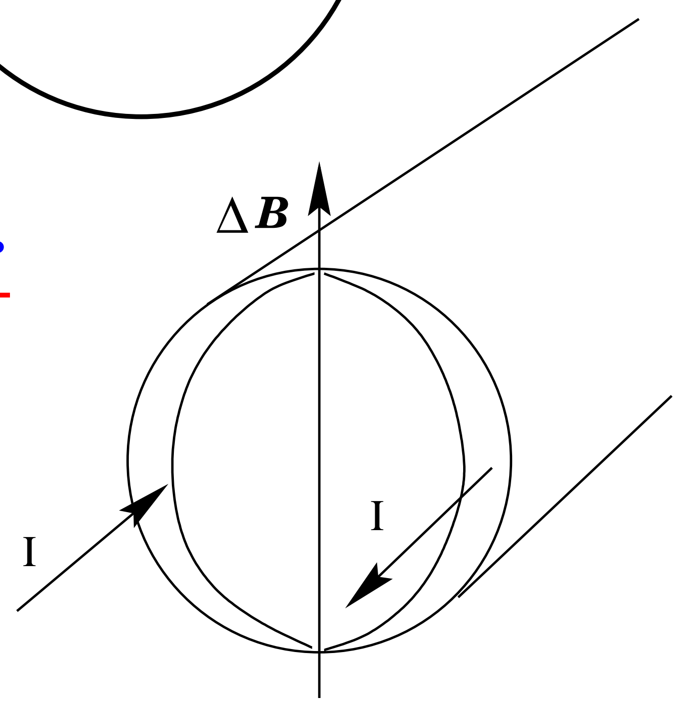


Superconducting Cable:



Persistent Currents:

$$\frac{\partial B}{\partial t} = -c \cdot rot\,\vec{E}$$



$$L = \frac{N_p^2 \cdot n_b}{\varepsilon \cdot \beta} \cdot \frac{f_{rev}}{2 \cdot \pi}$$

- **Beam-Beam Interaction:**

$$\Delta Q \propto \frac{N_b}{\varepsilon} < 5 \cdot 10^{-3}$$

→ $N_p = 10^{11}$

- **Beam Size:**

magnet quality + *aperture* → ε

- β: *quadrupole strength* + *aperture*

→ β = 0.5 meter

→ $n_b = 2835$

→ $I_{beam} = 0.5$ A

Beam Power

$E = 300$ MJ

$\triangleq$ 120 kg TnT

Synchrotron Radiation

$P = 0.5$ W/m

Summary LHC

- **Magnet Technology:**

  $B = 8.4\ T$; field errors

  quench performance

- **Beam Energy:**

  $E = 7\ TeV$; beam losses

- **Bunch Current:**

  $N_p = 10^{11}$; beam-beam limit

- **Beam Current:**

  $I = 0.5\ A$; synchrotron radiation

  collective effects

Other Projects

- **Tevatron:** $p / \bar{p}$ $E = 1$ TeV 1985

  Chicago, USA

  6.3 km; 1 ring; $B = 4.5$ T; $T = 4.2$ K

  $n_b = 6 \leftrightarrow 36$; $I_{beam} = 2$ mA; range: 6

- **HERA:** e / p $E = 0.9$ TeV 1991

  Hamburg, Germany

  6.3 km; 2 rings; $B = 5.5$ T; $T = 4.4$ K

  $n_b = 180$; $I_{beam} = 0.5$ mA; range: 20

- **RHIC:** Au/Au; p / p

  New York, USA

  $E = 0.25$ TeV 1999

  3.8 km; 2 rings; $B = 3.5$ T; $T = 4$ K

  $n_b = 57 \leftrightarrow 114$; $I_{beam} = 13\ \mu$A; range: 7

- **LHC:**

  $B = 8.4$ T; $T = 1.9$ K; range = 16; $I_{beam} = 0.5$ A

Future

- **VLHC:** magnet technology

  95 km; 2 ring; B = 12 T; n = 20800

  520 km; 2 ring; B = 2 T; n = 130000

- **Muon Collider:** muon source

  muon lifetime ($\tau = 2.2\ \mu s$)

  lepton collider without synchrotron radiation

- **Linear Collider:** 500 GeV / 3 TeV

  - USA / Japan — NC
  - Germany — SC
  - CERN — NC; 2 beams

Linear Collider

- ***No Bending Field:***

  → *reduced synchrotron radiation*

- ***Beam Size:*** $\sigma \propto 1 / \gamma$

- ***High Frequency:***

  $$\vec{E} = -\frac{\partial \vec{A}}{\partial t}$$ → *high frequency*

  $$\lambda = \frac{c}{f}$$ → *small structure*

  - ***Tesla:*** *1.3 GHz*
  - ***NLC:*** *11.4 GHz*
  - ***CLIC:*** *30 GHz*

→ *alignment and wakefields*

What Else?

- ***High Energy Physics***
- ***Nuclear + Atomic Physics:***
  - *LEAR:* *anti-hydrogen*
- ***Synchrotron Radiation Sources:***
  - *solid state physics*
  - *chemestry*
  - *biology*
- ***Hospitals:*** *cancer treatment*
- ***Industry:***
  - *surface treatment*
  - *sterilisation*
  - *nuclear waste disposal*