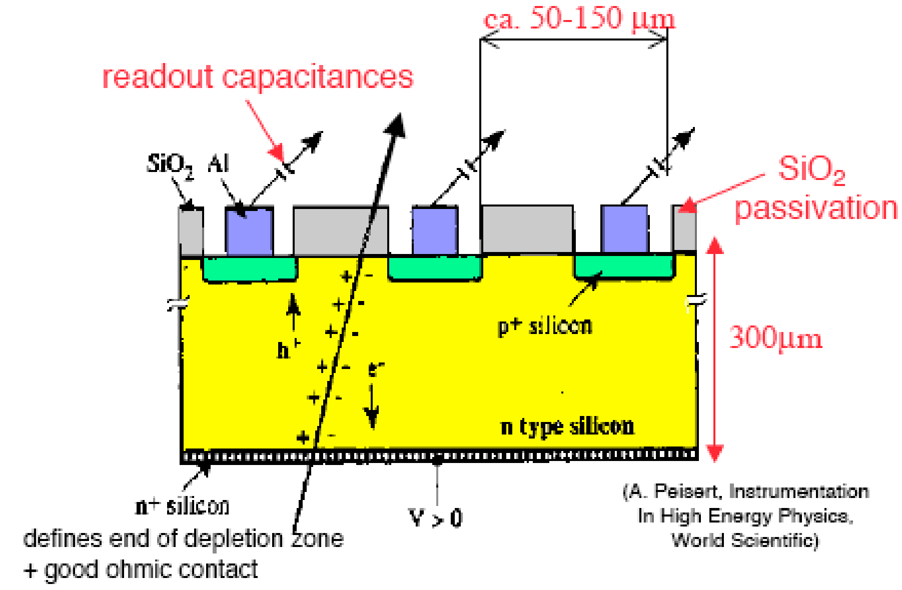
PHY492: Nuclear & Particle Physics

Lecture 26

Particle detectors
Particle identification
Accelerators I

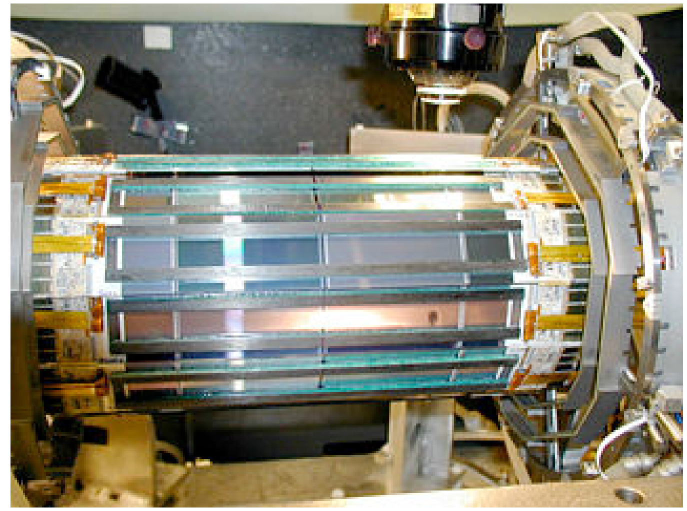
Silicon detectors, silicon strip detectors

Single sided w/capacitive readout

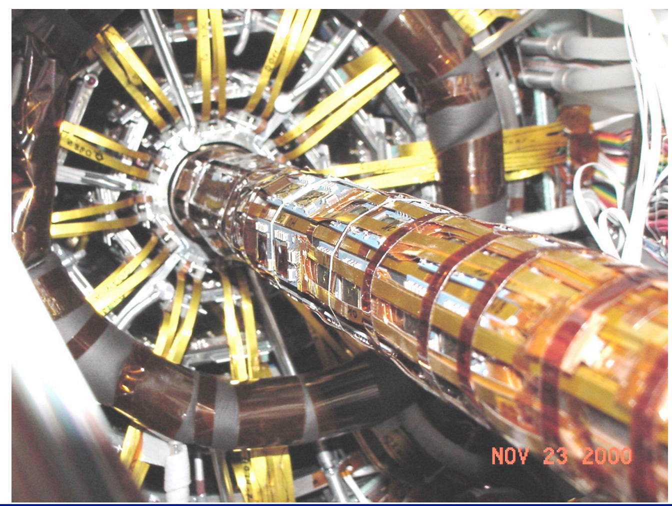


- Inaccessible for years ! "Robust"
- Other detector concepts
  - Double sided or drift laterally
  - Pixels w/bump bonding to readout
- Radiation damage a major concern
- Replace silicon crystal with diamond

CDF Silicon VerteX

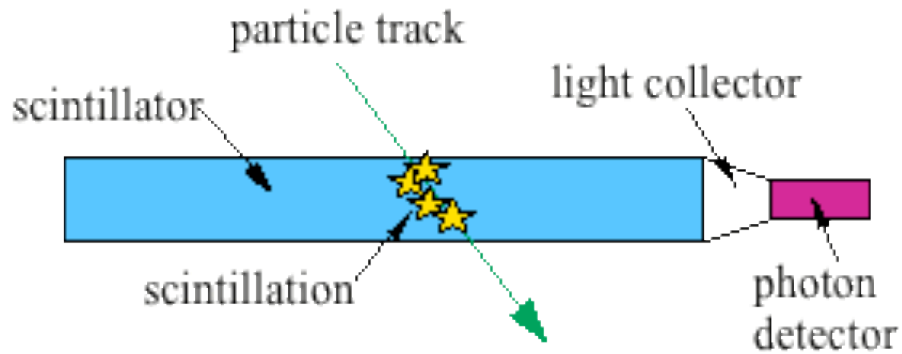


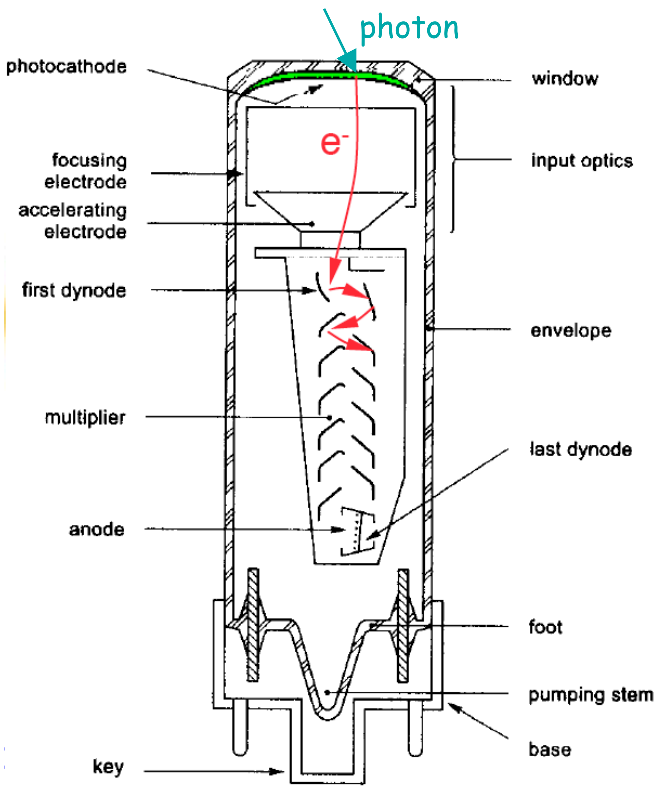
L00 insertion



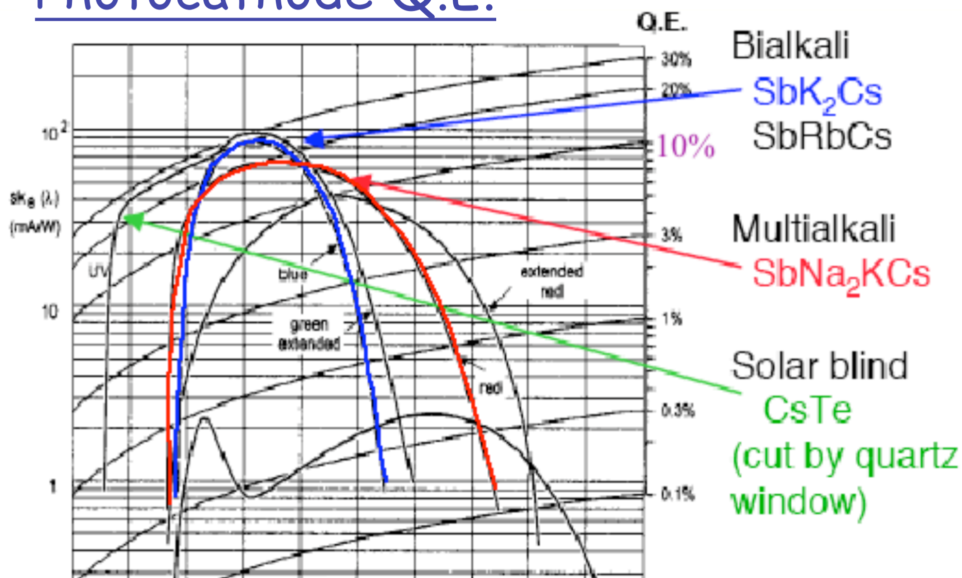
Scintillator basics

- Rutherford used scintillation
  - ZnS screen - flashes
  - Eyes were photo detectors
- Photo-multiplier tube (PMT)





Photocathode Q.E.

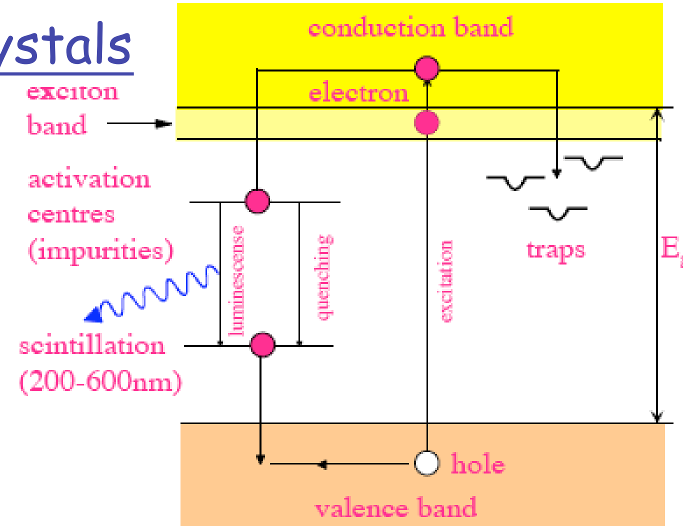


$$Q.E.(\%) \approx 124 \cdot \frac{sk_e(mA/W)}{\lambda(nm)}$$

Scintillators

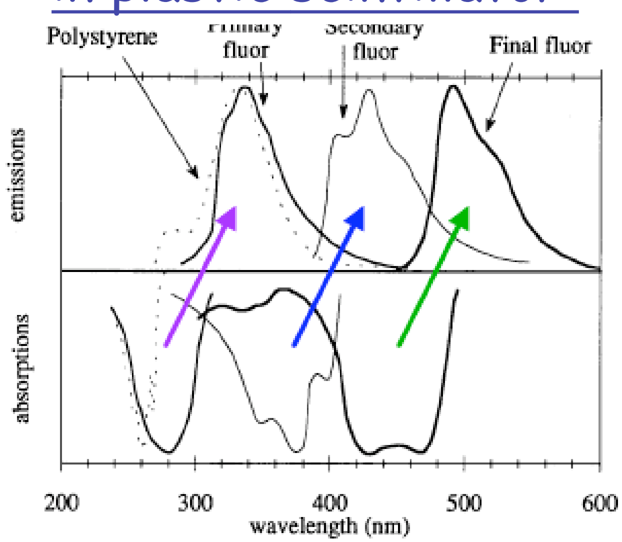
- Inorganic (high output, slow)
  - Crystals NaI, CsI, BaF_2
  - Glasses $PbWO_4$, $Ba_4Ge_3O_{12}$
  - Cryogenic liquids LAr (UV)
  - all are temperature dependent!

Crystals



Wave-shifting

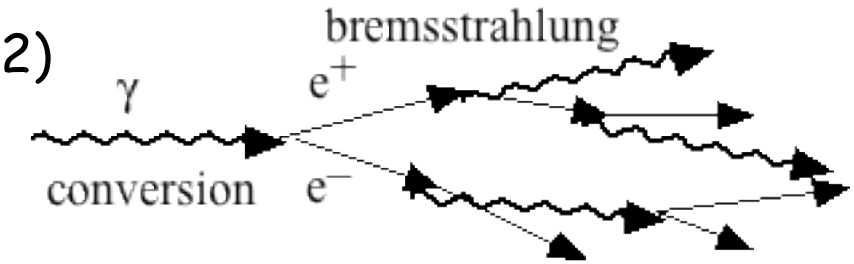
in plastic scintillator



- Organic (low output, fast fluorescence)
  - monocrystals naphthalene, anthracene
  - solvents (mineral oil) + waveshifters
  - plastic + waveshifters + polymerization
  - fluorescence in UV, must be waveshifted

Calorimeters

- Electro-magnetic shower (Lecture 12)
  - Pair production / Bremsstrahlung
  - Energy deposited as ionization

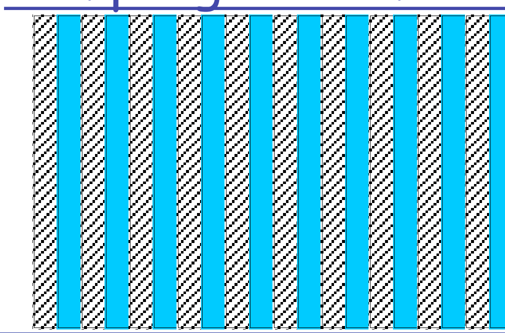


- Total absorption calorimeter
  - Crystals for photons & electrons
  - Liquid Argon ionization & tracking for electromagnetic and hadronic

CMS $PbWO_4$ Crystal

- Sample fixed % of ionization
- EM sampling calorimeters (15%)
  - Pb plates ($0.5X_0$ = 3 mm)
  - Scintillator/LAr filler (4-6mm)
- Hadronic sampling calorimeters (5%)
  - Fe plates (6-10 mm, length = 2m)
  - Scintillator/LAr filler (6mm)

Sampling calorimeter

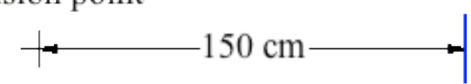


Particle ID techniques

Time of flight

Fermilab's CDF parameters: $t_c = 5 \text{ ns}; \quad \delta t = 0.1 \text{ ns}; \quad \dfrac{\delta t}{t} \sim 0.05$

$$\frac{\delta m}{m} = \gamma^2 \frac{\delta t}{t};$$

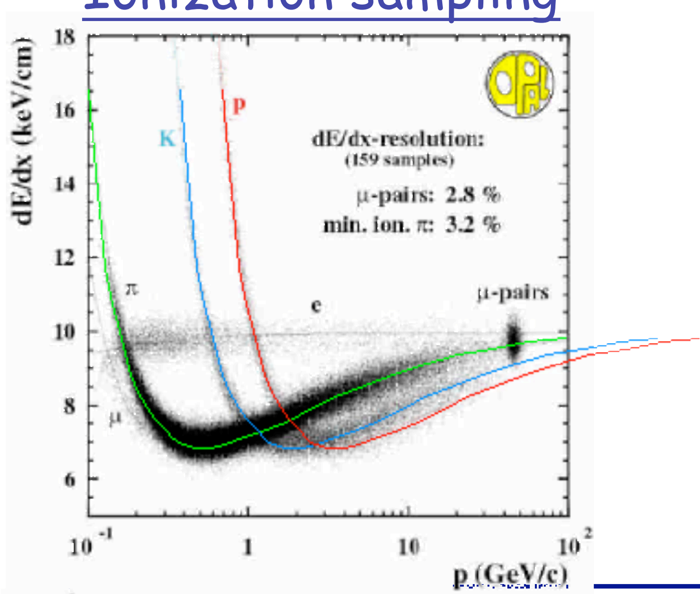


$$\gamma = \frac{E}{m} \sim 3: \quad \frac{\delta m}{m} = 9\left(0.05\right) = 45\%$$

$E_\pi \leq 0.5 \text{ GeV}; \quad E_K \leq 1.5 \text{ GeV}; \quad E_p \leq 3 \text{ GeV}$

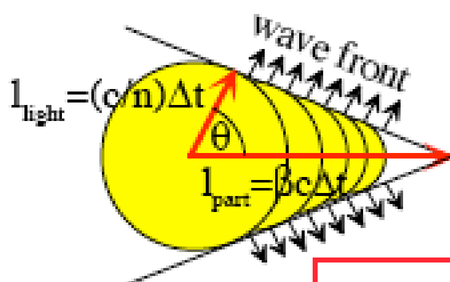
separate: e/π/K/p   eπ/K/p   eπK/p

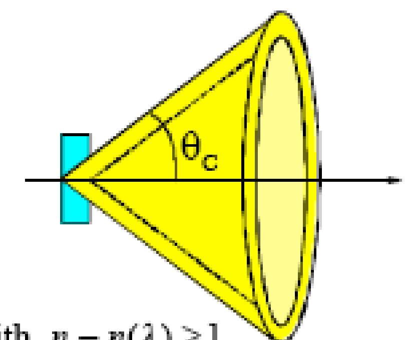
Ionization sampling



Cerenkov radiation

$\beta \geq \beta_{thr} = \dfrac{1}{n}$ n : refractive index



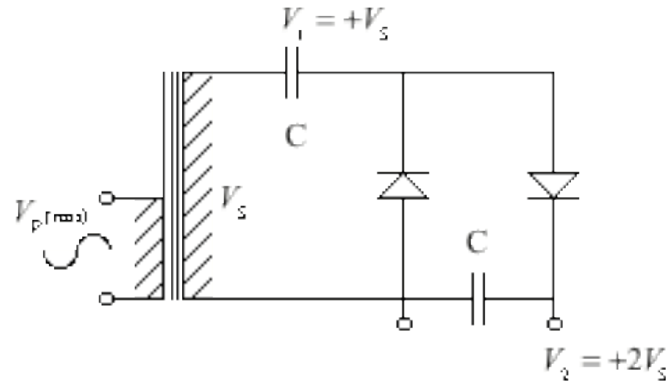


$\boxed{\cos\theta_C = \dfrac{1}{n\beta}}$ with $n = n(\lambda) \geq 1$

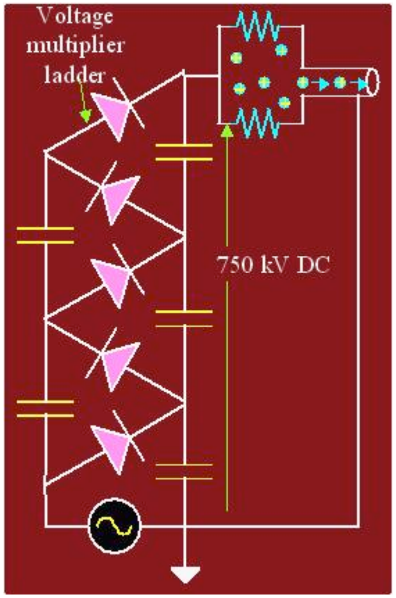
Accelerators- particle sources

- Ion sources
  - Positive ions (e.g., H^{+1}, Au^{+79})
  - Negative ions (H^{-}) for injection into positive beams
- DC e-guns: 50-500 kV acceleration
  - thermionic emission (grid pulsed)
  - laser pulse on photocathode
- RF e-guns
  - cathode one wall of an RF cavity
  - >10 MeV, low "emittance" beams
- Positron sources
  - photon conversions (γ --> e+e-)
  - 20 GeV to >100 GeV electrons
- Antiproton sources
  - 120 GeV proton collisions, Li lens.

- Cockcroft-Walton (1 MeV)



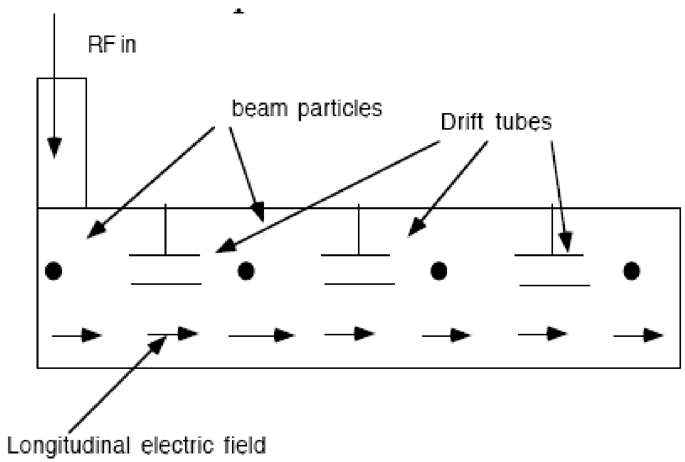
Cockcroft-Walton Ion source



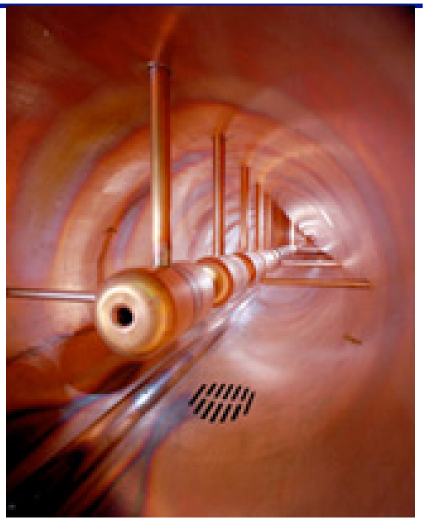
Fermilab

Accelerators - Linear accelerator (Linac)

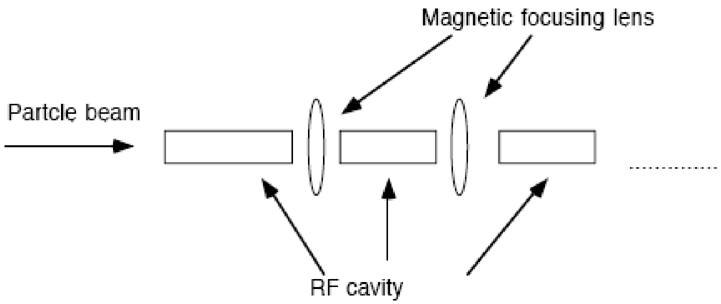
- Drift tube (Alvarez) linac



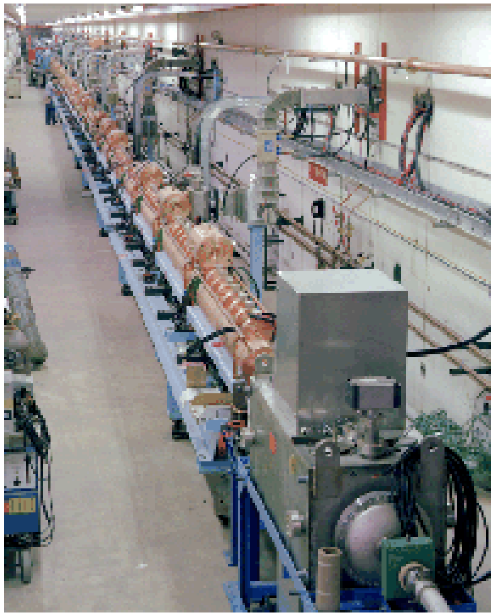
Fermilab's
201 MHz
116 MeV Linac



- RF cavity linac



Fermilab's
805 MHz
400 MeV Linac



Cyclotrons

- Continuous beam cyclotron

  Constant frequency

$$p = mv = 0.3qBR$$

$$\omega = \frac{v}{R} = \frac{0.3qB}{m} \quad (m \text{ in GeV/c}^2)$$

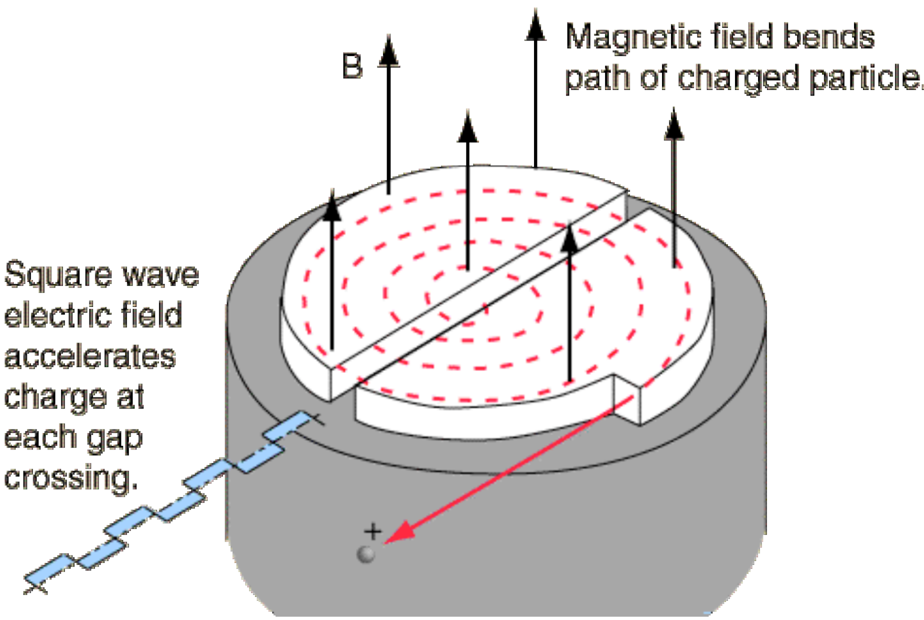
- Relativistic cyclotron

  ω depends on *v* and *R*

  --> pulse or B(r)

$$p = \gamma mv = 0.3qBR$$

$$\omega = \frac{v}{R} = \frac{0.3qB}{\gamma m} \quad (m \text{ in GeV/c}^2)$$



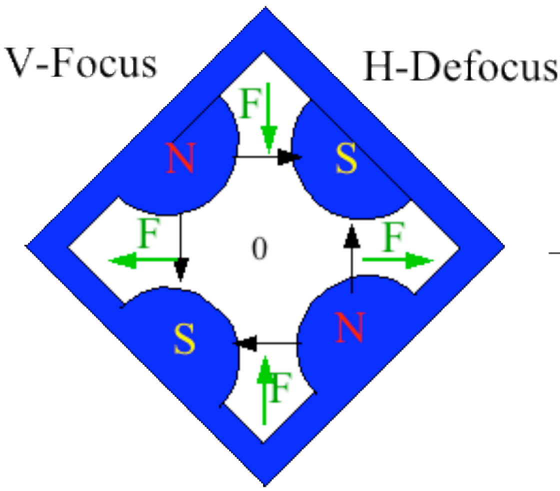
q = 1, p = 2 GeV/c, R = 1m

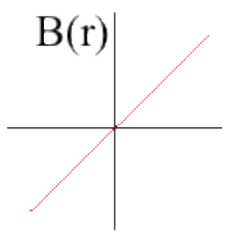
$$B = \frac{p}{0.3R} = \frac{2}{0.3(1)} = 6.7\,\mathrm{T} = 67 \text{ kgauss}$$

Needs superconducting magnet!

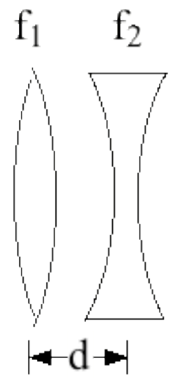
Quadrupoles

For positive particles moving into the page, Quadrupole magnet below will focus in the vertical plane and defocus in the horizontal plane





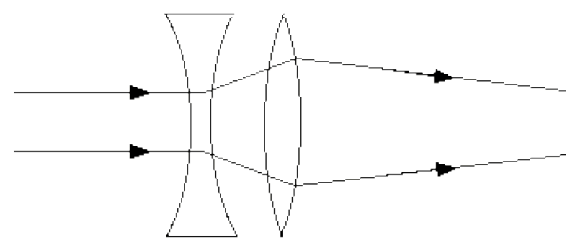
Quadrupole doublets, second rotated 90° wrt the first



Strong focusing with quadrupole magnets

$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$ is positive for a large range of focal lengths and d=> net focusing both radially and vertically

horizontal



vertical