Summer Student Lecturs 2020
Q&A - Partical Accelerators

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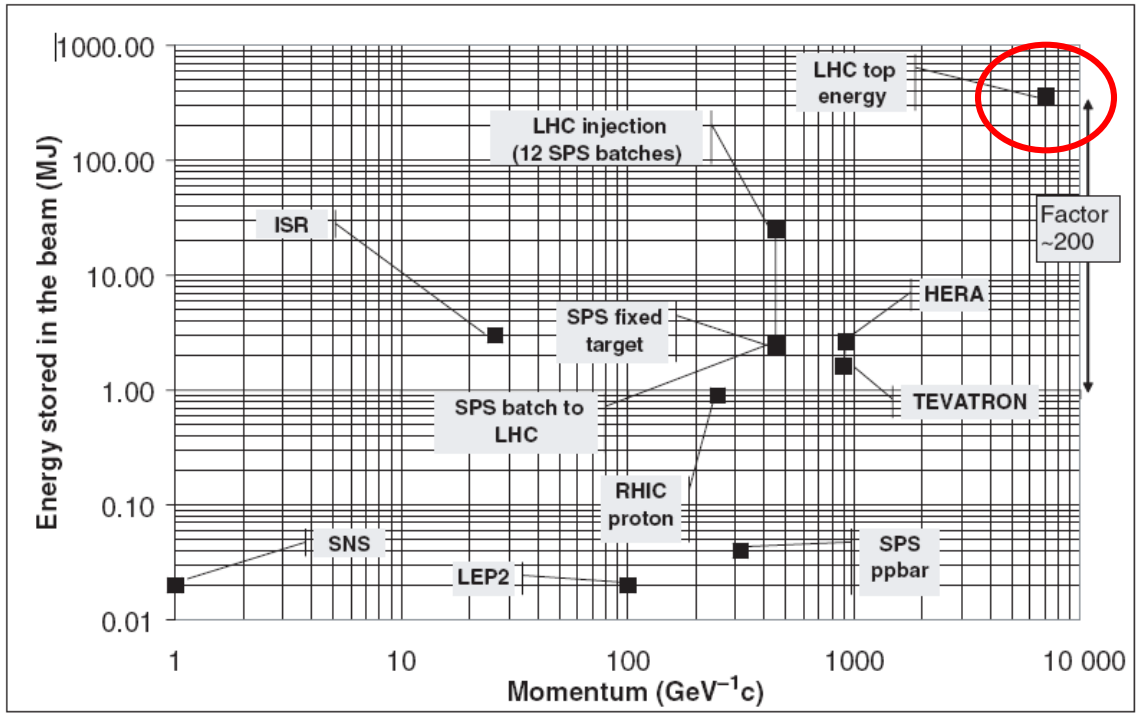
Q1: Can energy be harnessed using the collisions of particles?

(Asked by: Dhruv)

- Different from fission or fusion processes, where the nucleons before and after the reactions are the same.
- The purpose of particle collisions in high energy physics is to put as much energy in the beam particles as possible, create new particles in the collision and study their properties.
- In order to measure the properties of the newly created particles, they fly through different stages of particle detectors. In the caloriemeters the particles are stopped to measure their energy. So the released collision energy in absorbed on purpose.

Large amount of energy stored in beam and magnets.

Energy stored in the beam of different Storage Rings



Energy stored in magnet system	10	GJ
Energy stored in one main dipole circuit	1.1	GJ
Energy stored in one beam	362	MJ

Enough to melt 500 kg of copper

Economic measures for energy recovery and reducing power consumption of accelerators

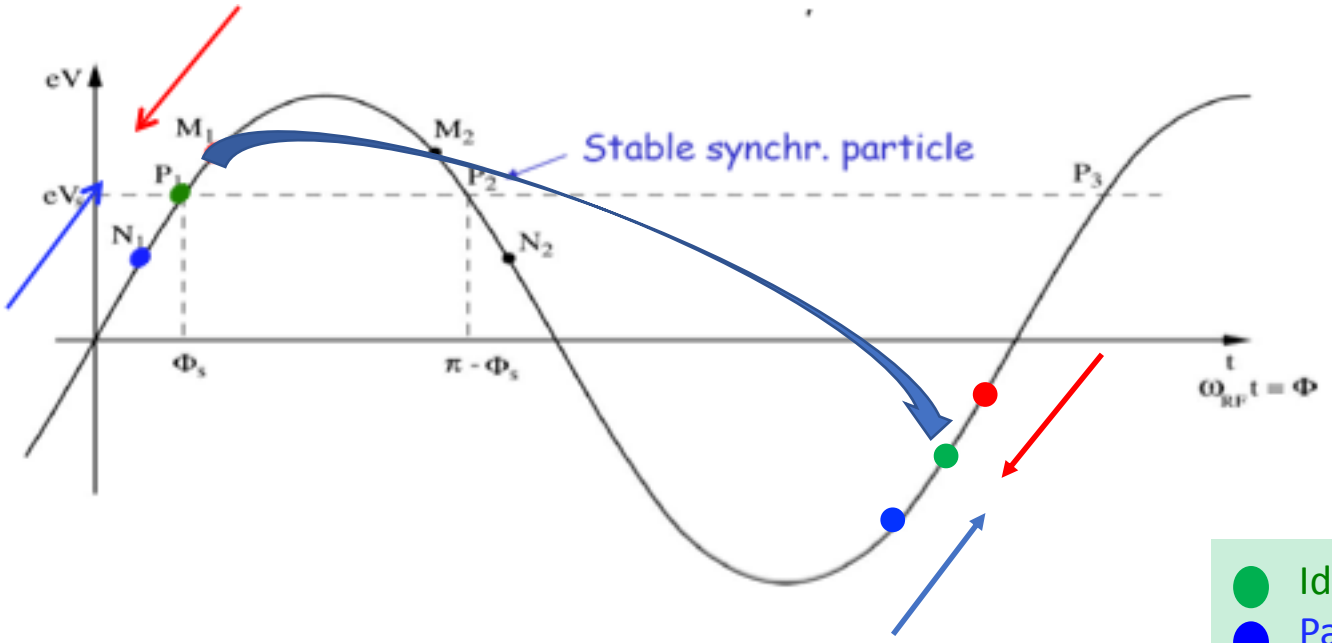
- Energy-recovery linacs,
- Usage of wast-heat from cooling and cryo plats,
- Short-term storage of magnet energy from one cycle to the next
- …

Beam Energy Recovery: put beam in deceleration phase

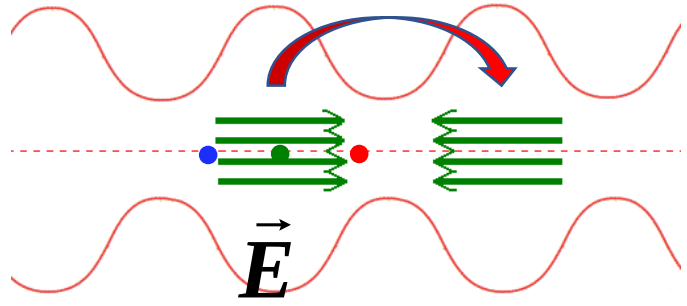
(Principle of an Energy Recovery Linac)

The Acceleration & "Phase Focusing"

Δp/p≠0 below transition



field in a cavity



Focussing effect in the longitudinal direction keeping the particles close together ... forming a "bunch"

For de-acceleration we go for the negative half wave.

- Ideal particle
- Particle with Δt < 0 (early) → lower energy gain → gets slower
- Particle with Δt > 0 (late) → higher energy gain → gets faster

→ ***M_1 & N_1 will move towards P_1 → stable***

Short-term storage of magnet energy from one cycle to the next.

Energy recovery ... The old style,

PS Generator / Dynamo Machine

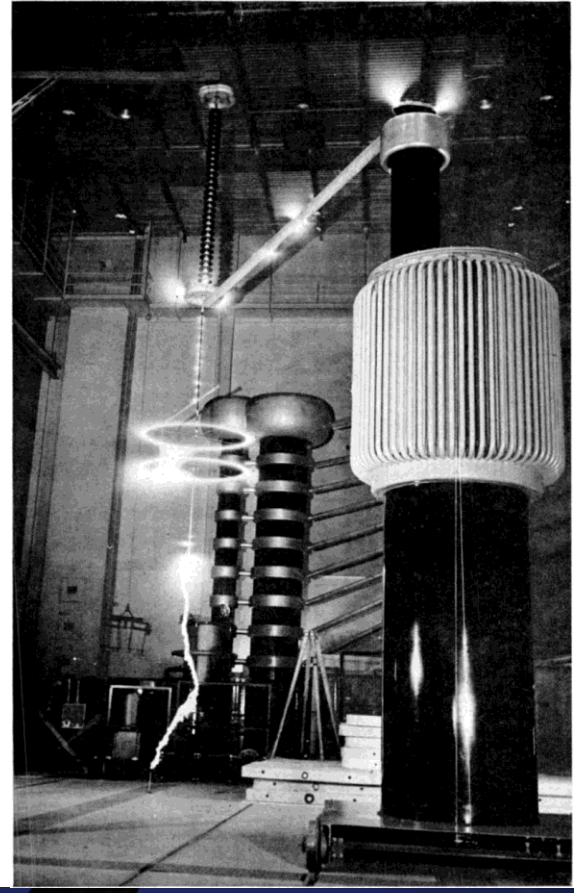
PS cycle time = 4 seconds

Today done with capacitors.

Q2: What is Corona Formation?

(Asked by: Jonathan)

- Electrostatic Accelerators
- A corona will occur when the strength of the electric field (potential gradient) around a conductor is high enough to form a conductive region, but not high enough to cause electrical breakdown or arcing to nearby objects.



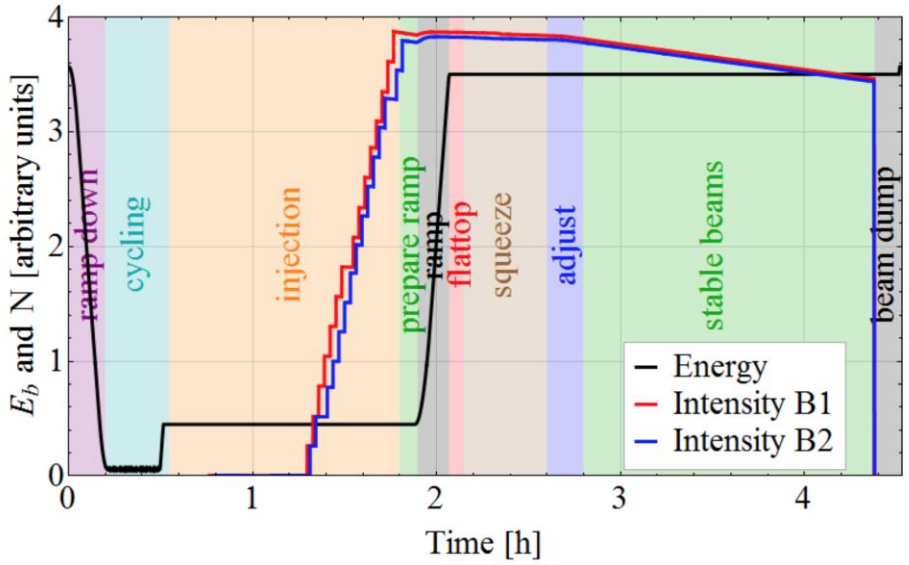
Large corona discharges *(white)* around conductors energized by a 1.05MV transformer in a U.S. NIST laboratory in 1941

Long exposure photograph of corona discharge on an insulator string of a 500 kV overhead power line. Corona discharges represent a significant power loss for electric utilities.

Q3: Was the LHC ever used to accelerate a particle in a circular path indefinitely until the strength of the magnetic field permits? (Instead of colliding particles) If so, what is the max strength achieved and the max velocity achieved?

(Asked by: Jonathan)

In LHC particles are accelerated to maximum achievable energy before putting beams into collisions.



Max. energy defined by max magnetic field.

B_{max} = 8.33 T

$p_{proton} \approx E_{proton}$ = 7 TeV → γ = 7461 → v/c = 0.99999998

$$\frac{p}{q} = B\,\rho$$

Beam rigidity

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

Relativistic gamma

Q4: Is bunching a phenomenon which takes place when accelerating particles or is it done on purpose because it is useful when conducting experiments?

(Asked by: Jonathan)

- This depends on the way how you accelerator the particles.
- In electrostatic accelerators particles travel through a direct voltage and independent on their timing and initial energy they gain a constant energy ΔE.
- When using RF fields for acceleration, the energy gain depends on the RF phase the particle sees when it enters the accelerating structure.
  - Therefore, particles can gain more or less energy or can even be decelerated when passing at a wrong phase. This leads to a bunching effect.
    → Phase focusing (lecture 3, from slide 17)
  - However, a bunched beam is necessary for efficient and low-loss RF acceleration.
  - Special accelerators, so-called RFQs are places first after the particle source to generate a bunched beam before injection into a Linac.

Q5: Are there any ‘edge effects’ in LINACS from being non-periodic?

(Asked by: Joshua)

- **Optics is not defined**, so more difficult to optimize the beam size at IP
- **Much less efficient** in the sense that all particles that do not collide are lost.
- A storage ring collider brings the particles back turn by turn to the IP. So they get another chance to do physics.

Typical number of “events” per bunch crossing:

LHC: 20 – 40 (out of 10^14)

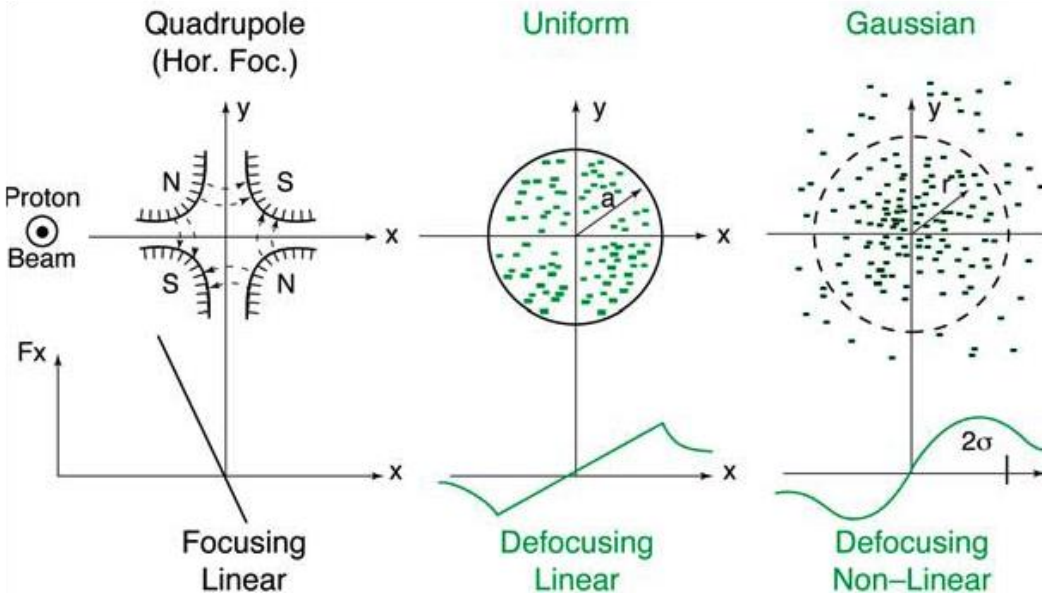
LEP 1 – 2

- Advantage: Linac beams do not radiate. So for Leptons we can reach higher energies.

Q6: Are there any cases when particle interactions in the beam become an issue? Like affecting bunching?

(Asked by: Joshua)

Particles see the electromagnetic field inside the bunch and from one beam to the other during collisions.



Space charge within a bunch:
A strong effect that is specially important at low energies and it is always de-focusing.

Most simple case leads to linear space charge tune shift

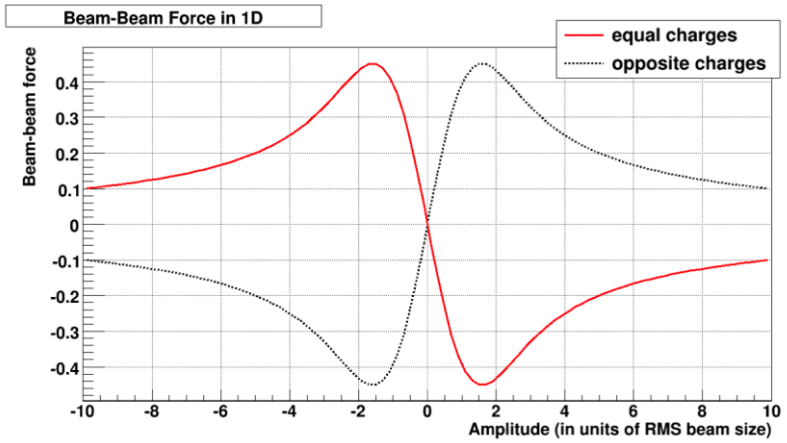
$$\Delta Q_{x,y} = -\frac{r_0 N}{2\pi E_{x,y} \beta^2 \gamma^3}$$

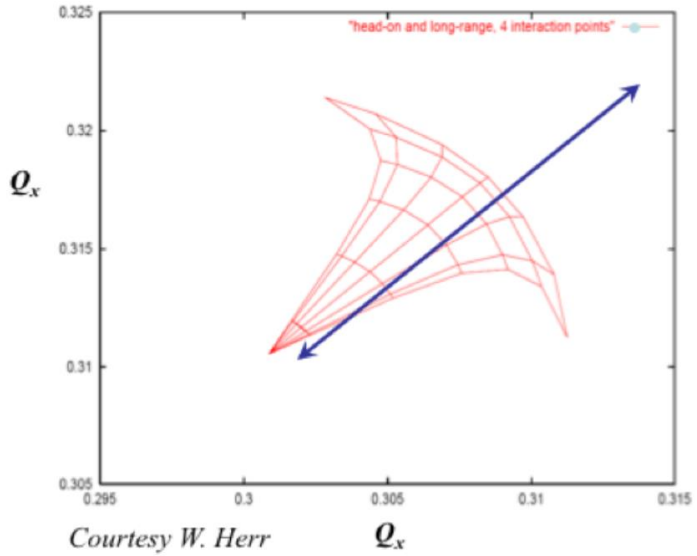
→ puts a limit to N_p

Eigenfrequency of the particles is changed due to the intra beam interaction.
→ Particles are pushed onto resonances and are lost.

Particle interactions between two beams, so-called beam-beam effects

Strong (de-) focusing effect that changes the tune of each single particle





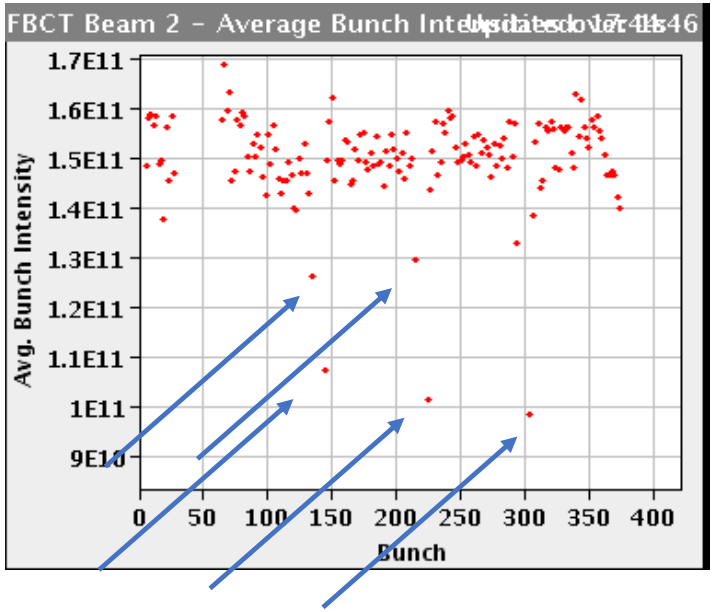


Fig. 33: Calculated tune shift due to the beam-beam interaction in LHC.

observed particle losses when beams are brought into collision