Today schedule:

1. Questions & Answers regarding Computational Lecture #1 (10 minutes)
2. RF acceleration short lecture.(20 minutes)
3. 10 minutes break.
4. Group A will go to ATF control (~50 min)
5. Group B will simulate RF acceleration (~50 min)
6. Short break for switch between computer and control rooms

PHY542-4. Beam Acceleration

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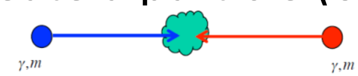
March. 23, 2015

PHY 542 – 01. Fundamentals of Accelerator Physics and Technology with Simulations and Measurements Lab

Acceleration is needed!!

- In colliders: The minimum energy required to create a particle (or group of particle) with total mass M is: $E_{\min} = Mc^2$



  - High energy colliding particles=>high energy center mass=> massive particles production (cross section σ)
  - luminosity:

$$L = f_c \frac{N_1 N_2}{A} \cong f_c \frac{N_1 N_2}{2\pi\sqrt{\beta_{x1}\varepsilon_{x1} + \beta_{x2}\varepsilon_{x2}}\sqrt{\beta_{y1}\varepsilon_{y1} + \beta_{y2}\varepsilon_{y2}}}$$

Numbers of events

$$N_{A\to B} = \sigma_{A\to B} \cdot L$$

$$\varepsilon_{n,s} = \beta\gamma\sqrt{\langle s^2\rangle\langle s'^2\rangle - \langle ss'\rangle^2}$$

- Normalized emittance ~preserved during acceleration, geometrical emittance reduced ~$1/\gamma$.

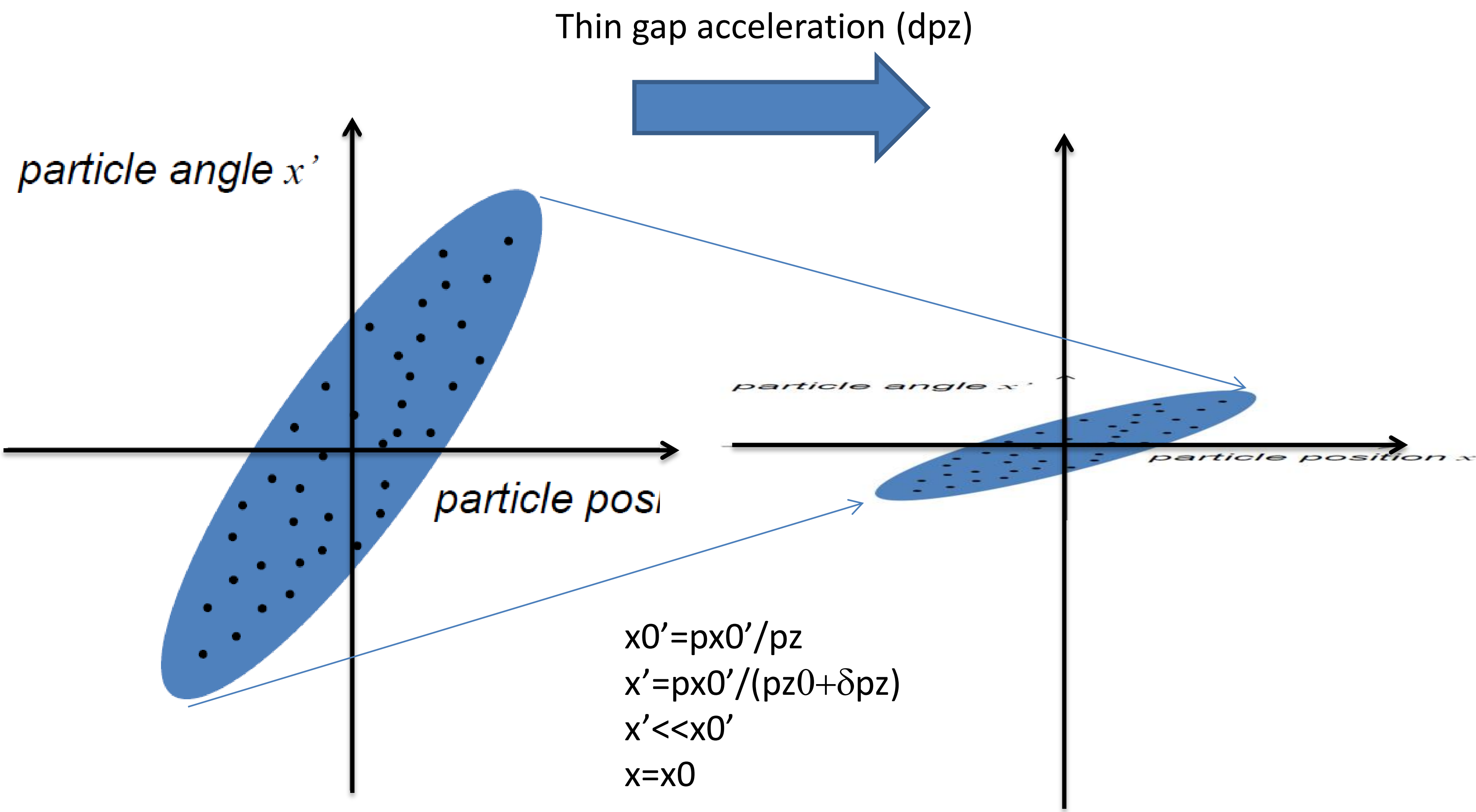
where s is either x or y.

The peak normalized rms brightness is given by

$$B_n = \frac{2I}{\varepsilon_{n,x}\varepsilon_{n,y}}$$

- In light source: Brightness B ~$1/\gamma^2$.

Geometrical emittance transformation



$x0' = px0'/pz$

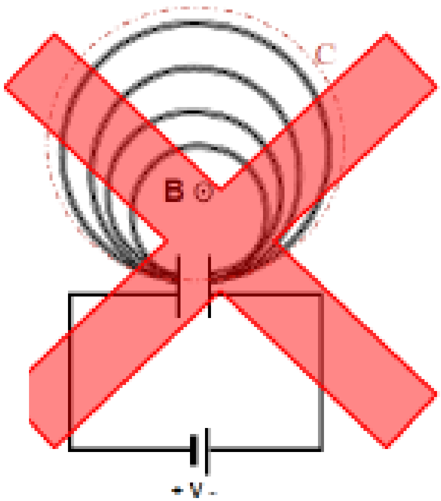
$x' = px0'/(pz0 + \delta pz)$

$x' << x0'$

$x = x0$

Acceleration

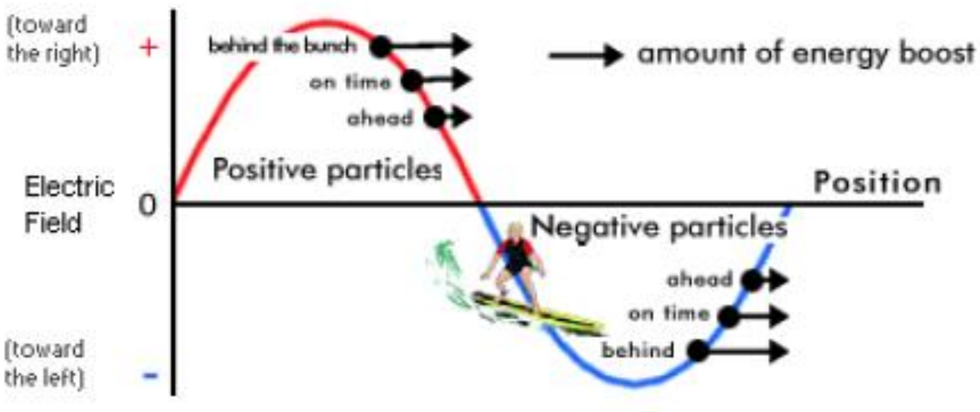
$$\frac{d\vec{p}}{dt} = q\left(\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right); \quad \frac{dE}{dt} = q\left(\vec{E} \cdot \vec{v}\right);$$



- Single pass acceleration
- Limited by maximum voltage per until discharge. ~1.5 MV in air

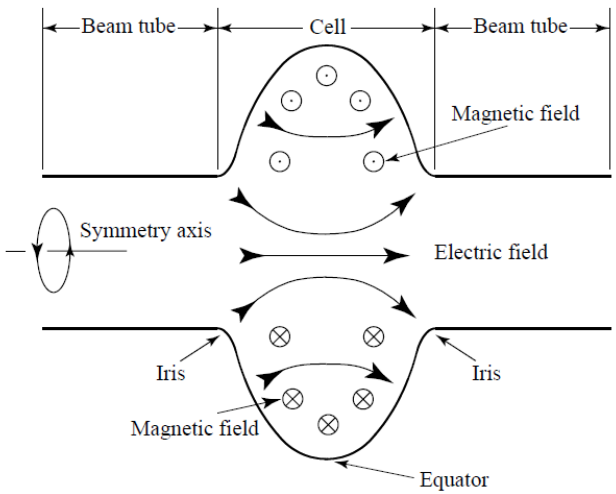
$$\Delta E = e\oint \vec{E} \cdot d\vec{l} = -\frac{e}{c}\frac{\partial}{\partial t}\left(\int \vec{H} \cdot d\vec{s}\right)$$

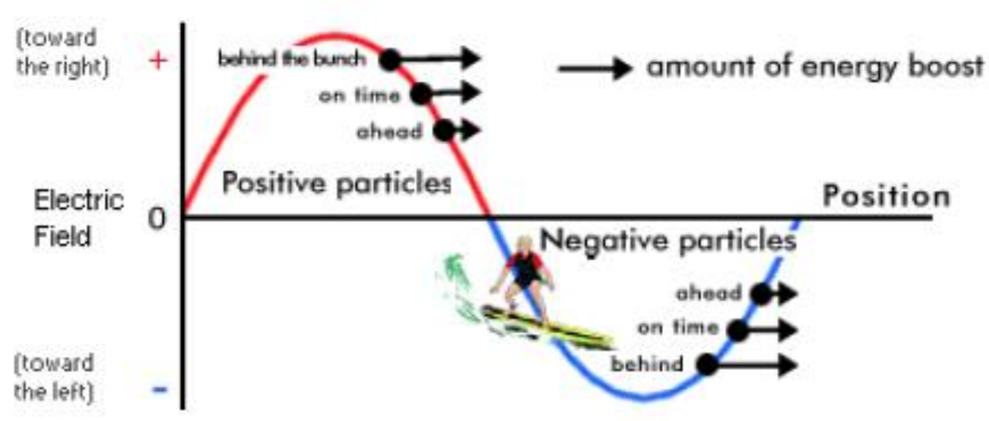
Maxwell equation prohibits multiple acceleration is DC electric field:



- In RF cavities energy gain depends on the phase.
- The main purpose of using RF cavities in accelerators is to add (remove) energy to charged-particle beams at a fast acceleration rate

RF Field acceleration:





The RF field must be synchronous (correct phase relation) with the beam for a sustained energy transfer.

$$E_z(z,t) = E(z)\cos\left(\omega t - \int_0^z k(z)\,dz + \phi\right),$$

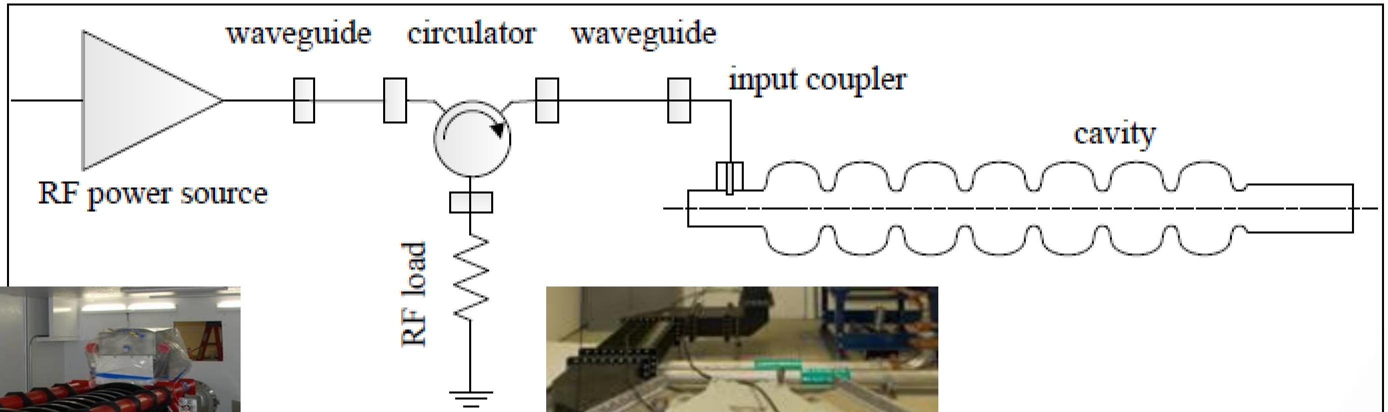
For efficient particle acceleration, the phase velocity of the wave must closely match the beam velocity. If we consider a particle of charge *q* moving along *+z* direction with a velocity at each instant of time equal the phase velocity of the traveling wave, then the electric force on the particle is given by

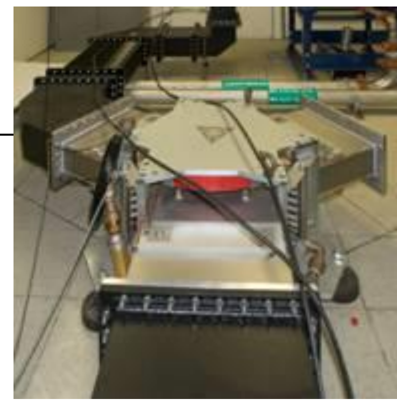
$$F_z = q\,E(z)\,\cos\phi$$

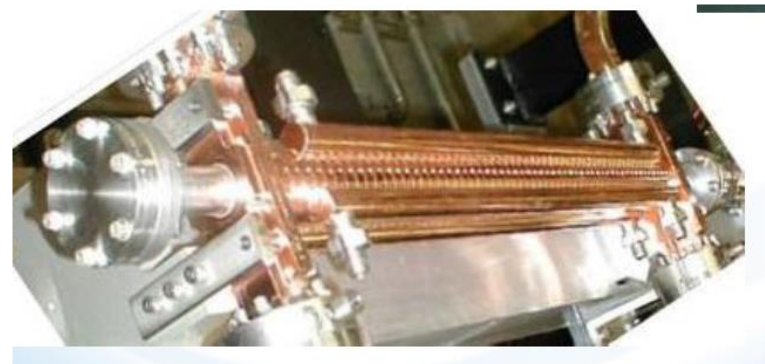
Energy gain

$$\Delta\mathcal{E} = q\int_{-L/2}^{L/2} E(0,z)\cos\left[\omega t(z) + \phi\right]\,dz$$

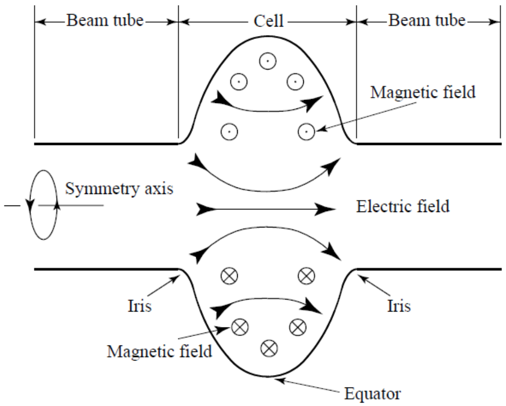
RF Cavity connected to RF power source



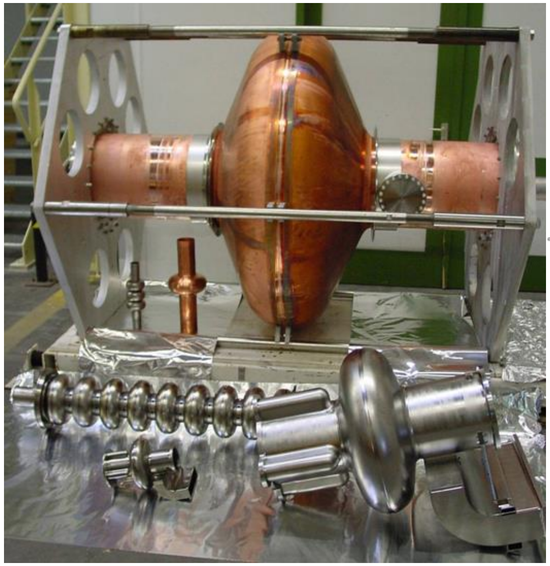


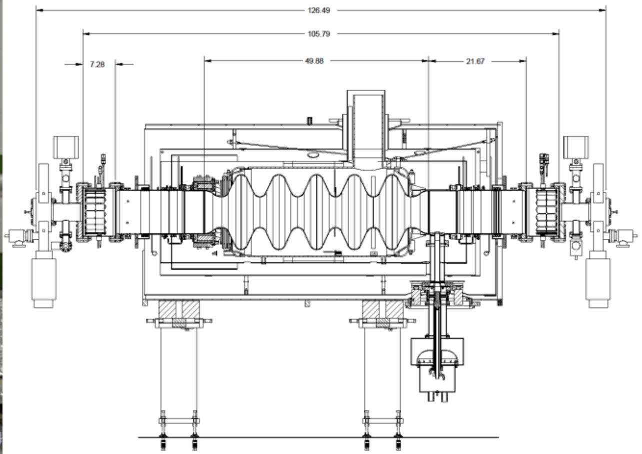


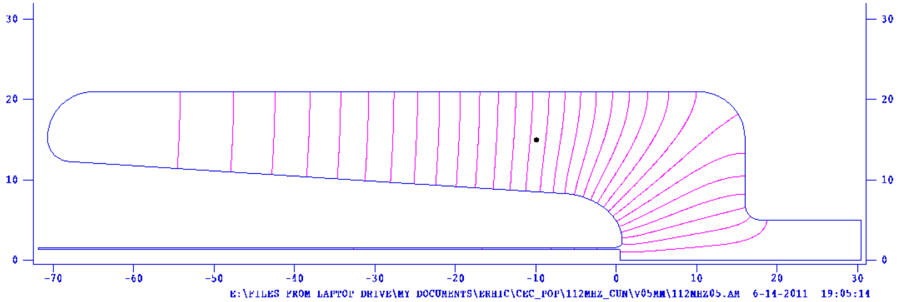
RF cavities



Typical Single cell

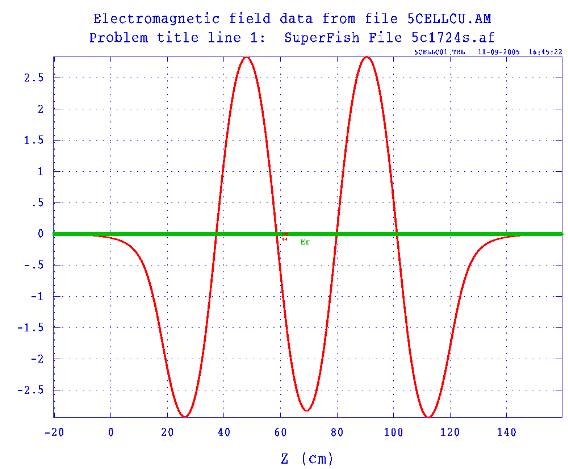




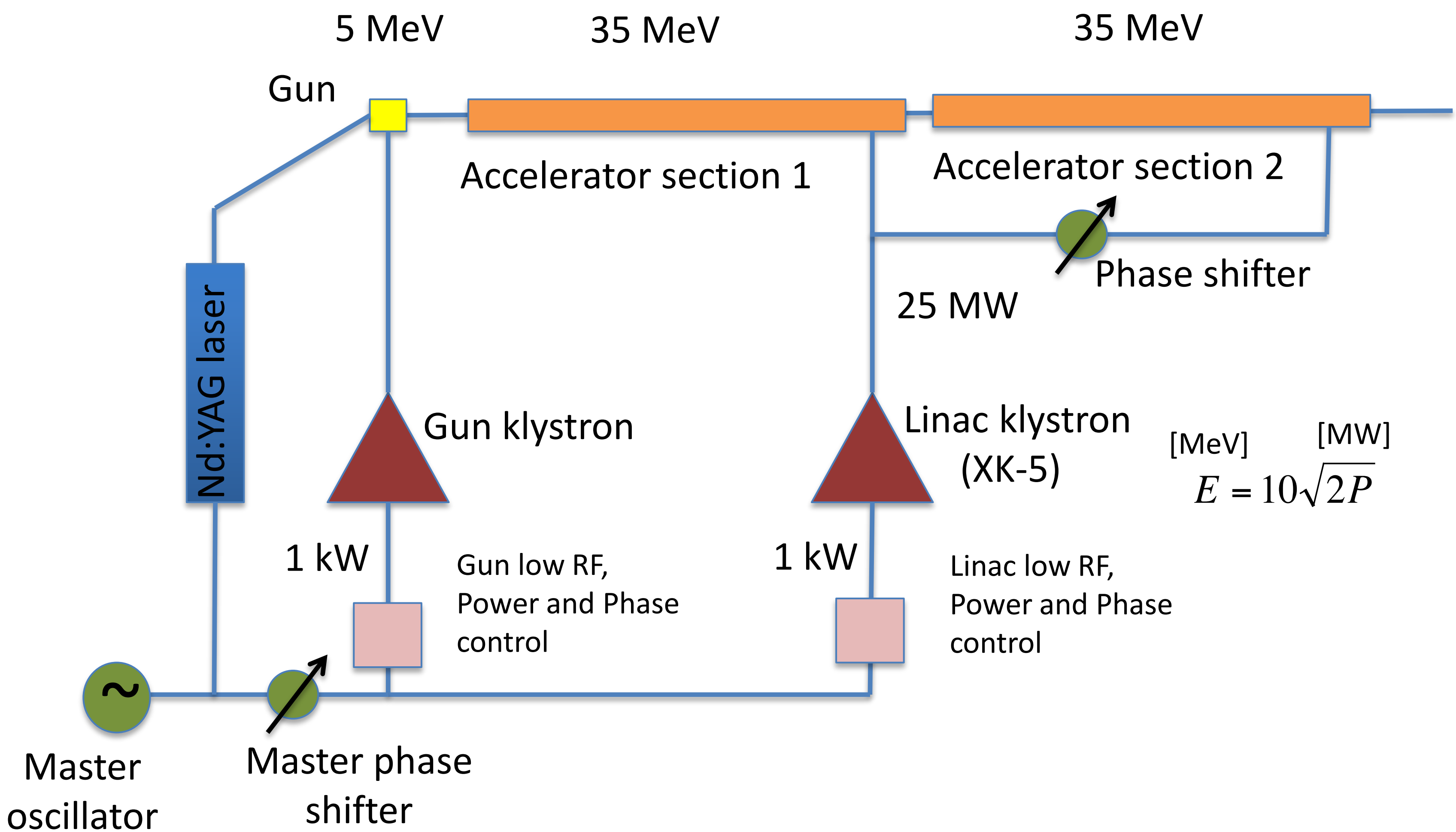


Quarter-wave 112MHz resonator

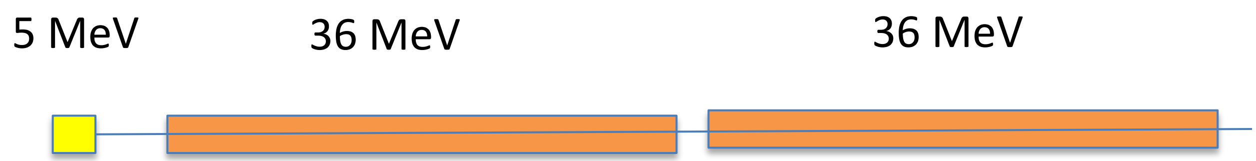
ERL: 5Cell cavity 704MHz



ATF accelerator system



Multi linacs acceleration



$E=E_{inj}+Elinac1+Elinac2$

$Elinac1=eU1\cos(phi1)$
$Elinac2=eU2\cos(phi2)$

If there is enough voltage provided by one linac.
The final energy can be reached by combination different phases.

For ATF:
U1=U2=36MV, Einj=5MeV
Efinal=35MeV

phi1	phi2
65.4	65.4
65.4	-65.4
0.0	99.6
0.0	-99.6
90.0	33.6
-90.0	-33.6
33.6	90.0
-33.6	-90.0