Ubrzivači čestica

Povijest

- Početak razvoja datira s kraja dvadesetih godina prošlog stoljeća.
- Primjena velike razlike potencijala nad vakuumskim cijevima (Breit, Tuve, Lauritsen, Van de Graff)
- Prva nuklearna reakcija primjenom ubrzanih protona dogodila se 1930. Cockcroft and Walton na Cavendish Laboratory. Protoni ubrzani do 300keV u reakciji $Li^7(p,2\alpha)$
- Problemi visokonaponskih akceleratora: na višim energijama dolazi do izbijanju aparature
- Rješenje u kaskadnim akceleratorima

Kaskadni akceleratori

- Wideroe (1928); Lawrence and Sloan (1930) prvi uređaji koji kaskadno ubrzavaju čestice (protona i lakih jezgri) primjenom elektromagnetske indukcije
- Bez značajnije primjene
- Svi su bazirani na primjeni električnog polja za ubrzavanje čestica

Ciklotron

- 1929 (Lawrence) Princip kaskadnog ubrzavanja čestica održavanih u spiralnoj putanji magnetskim poljem
- Ideja je nezavisno rođena kod nekolicine fizičara Thibaud, Lawrence, Szilard ali ju je ostvario E.O.Lawrence na Berkeleyu

Ograničenja

- Dostizanje relativističkih brzina zahtijevaju neke modifikacije
- Vaksler (1945) McMillan (1946) fazna stabilnost – omogućava ubrzavanje protona do 7GeV
- Christophilos (1950); Courant, Livingston i Snyder (1952) metoda jakog fokusiranja omogućava energije od 30GeV

Ubrzavanje elektrona

- Betatron: Kerst (1940) ubrzava elektrone do nekoliko MeV
- Kombinacijom tehnika ubrzavanja, fokusiranje i sinkroniziranja dobivano sinkrotron

Klasifikacija akceleratora

Tip akceleratora	**Čestice koje ubrzavamo**	**E-električno polje**	**H-magnetsko polje**	**Putanja**	*Karakteristična energija (MeV)*
elektrostatički, Van de Graff	e, p, d, α	konstantno	Nema	pravocrtna	12
kaskadni, Cockcroft-Walton	e, p, d, α	Konstantno	Nema	pravocrtna	4
betatron	e	nema	promjenjivo	kružna	300
ciklotron	p, d, α	stalna ω	Konstantno	spiralna	25
sinkrociklotron	p	promjenjiva ω	Konstantno	spiralna	700
sinkrotron	e	stalna ω	promjenjivo	kružna	10^3
proton sinkrotron	p	promjenjivu ω	promjenjivo	kružna	10^4
jako fokusiranje	p	promjenjivu ω	promjenjivo	kružna	$3x10^4$
linearni akcelerator, rf	p, d	ω ~ 200 Mcps	nema	pravocrtna	30
linearni akcelerator	e	ω ~ 3000 Mcps	nema	pravocrtna	10^3
teški ioni, Linac	C^{12}, O^{16} Au	ω ~ 70 Mcps	nema	pravocrtna	10 x A od iona

S h e m e

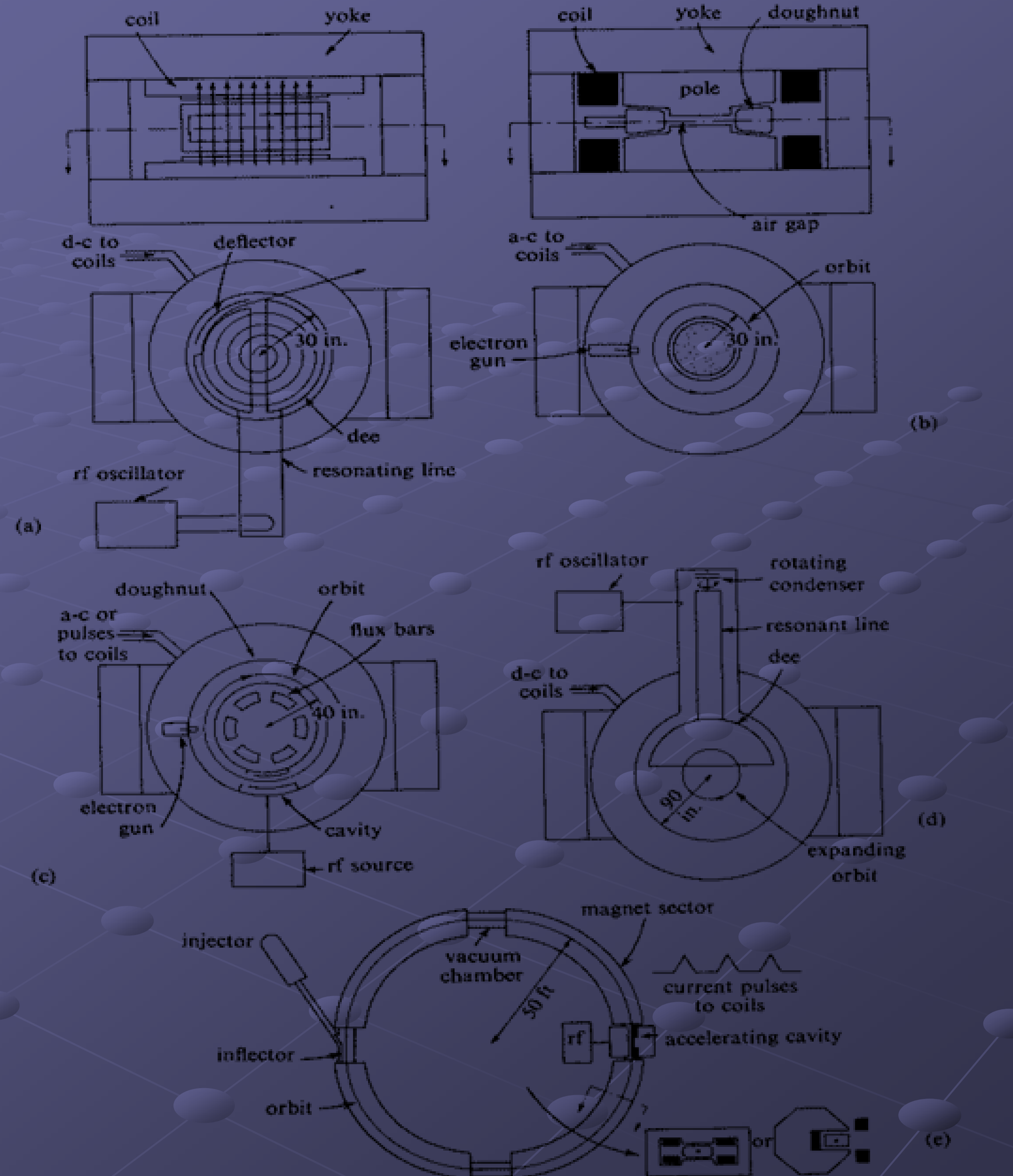


Figure 4-2 Diagrams of some of the most important circular (magnetic) accelerators, with typical dimensions: (a) cyclotron, (b) betatron, (c) electron synchrotron, (d) synchrocyclotron, (e) proton synchrotron (or electron race track). [*Nuclear Engineering Handbook*, McGraw-Hill, New York, 1958.]

Izvori čestica (projektila)

- svi akceleratori zahtijevaju izvor iona (elektrona) za početno ubrzavanje
- egzotične vrste čestica (π, κ) dobivaju se na produkcijskim metama pogodnim reakcijama
- vođenje snopa i lančano umrežavanje akceleratora

Proizvodnja pozitivnih čestica (injektor)

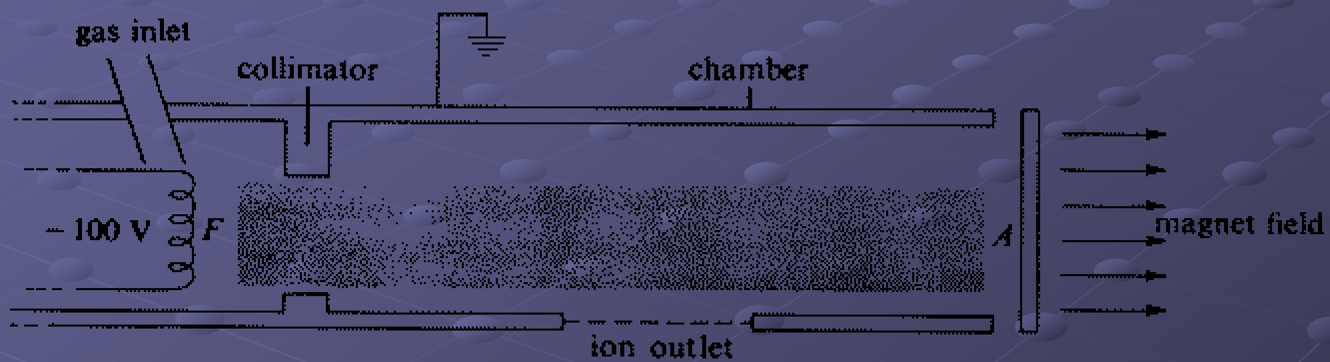


Figure 4-1 A typical positive-ion source. Electrons emitted by the filament *F* at – 100 V oscillate between it and the anode *A*, while they curl around the lines of force of the containing magnetic field. The electrons form positive ions by impact in the gas present in the chamber. The mixture of positive ions and electrons, called plasma, fills the shaded region. Positive ions are extracted from the plasma through the aperture. [R. S. Livingston and R. J. Jones.]

Van de Graff

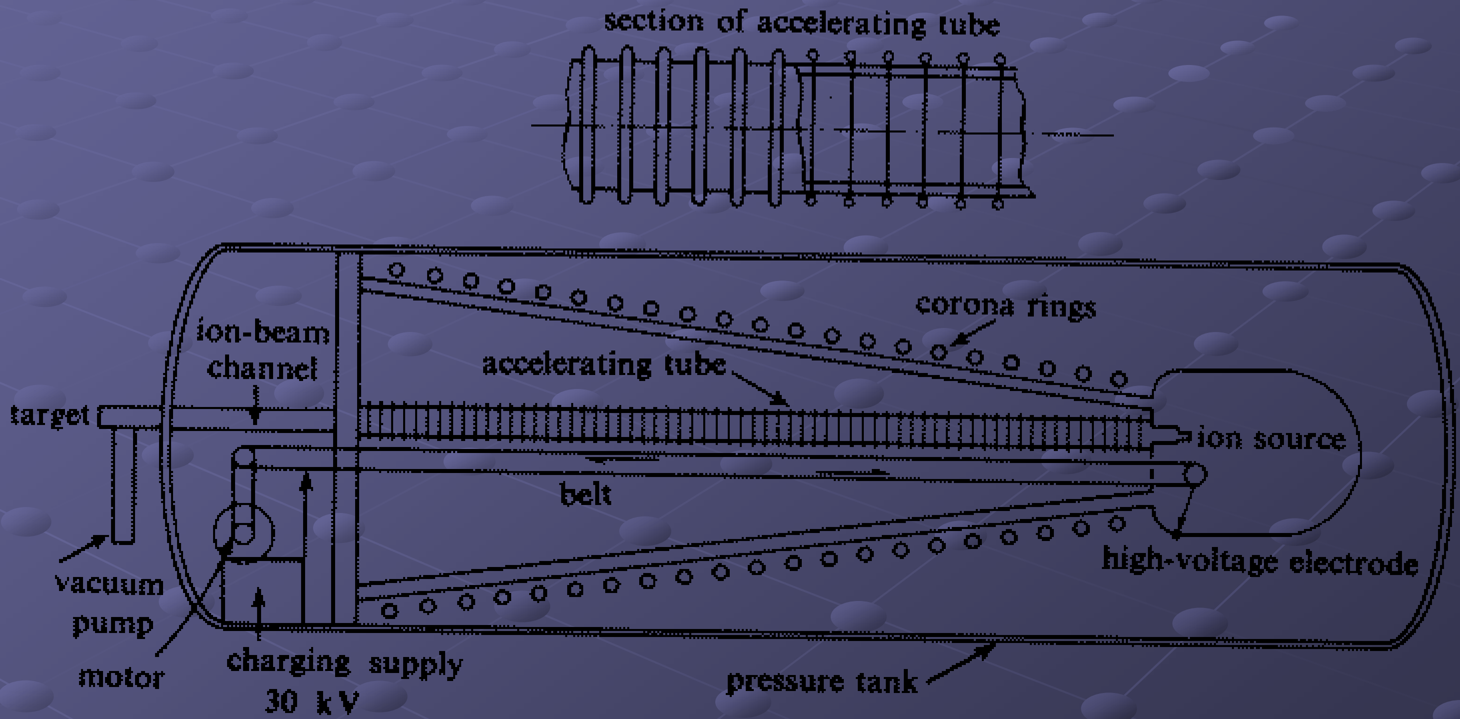


Figure 4-3 A Van de Graaff accelerator.

Tandem

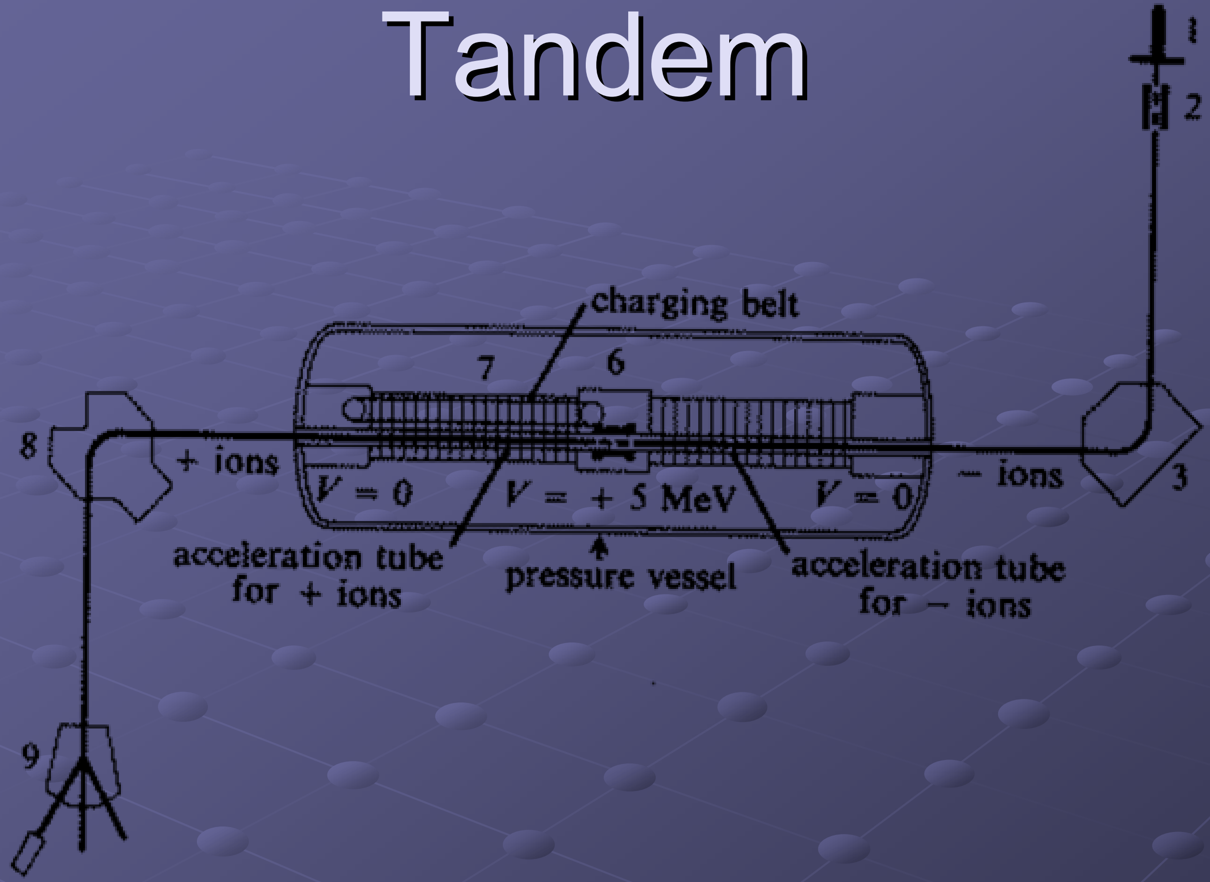
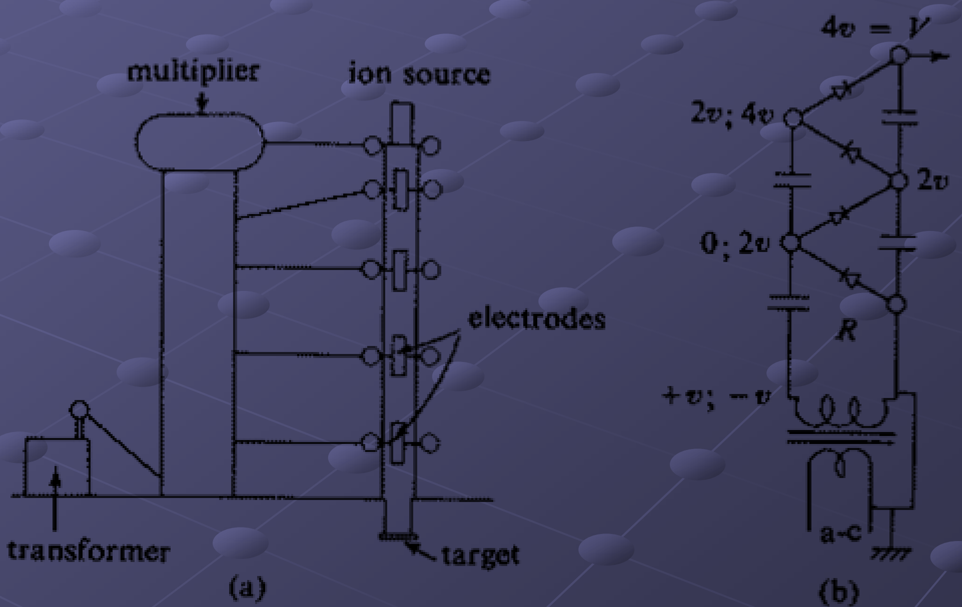


Figure 4-5 Two-stage tandem accelerator. 1, source of positive ions. 2, electron-adding canal. The ions are passed through gas at low pressure where they capture electrons and become negatively charged. 3, the negative ions are preaccelerated to 80 keV and injected into the Van de Graaff accelerator, where they acquire an energy of 5 MeV. 6, the ions are stripped of electrons and charged positively by passing through gas at low pressure. 7, the positive ions are accelerated to 10 MeV. 8, deflecting and analyzing magnet. 9, switching magnet. [Courtesy High Voltage Engineering Corp., Burlington, Mass.]

Cockcroft-Waltonov akcelerator

Figure 4-4 A Cockcroft–Walton accelerator. The general layout is shown in (a). The multiplication principle is indicated in (b). Alternating current travels up the line of capacitors to the left and is distributed to all the rectifiers R returning to ground through the capacitors to the right. The d-c flows through the rectifiers in series. When no current is drawn at V the potentials on the capacitors to the right are constant and have the values indicated on the figure. The potentials on the capacitors on the left oscillate between the limits indicated on the figure. The voltage V is four times as large as the peak input voltage v.



Betatron

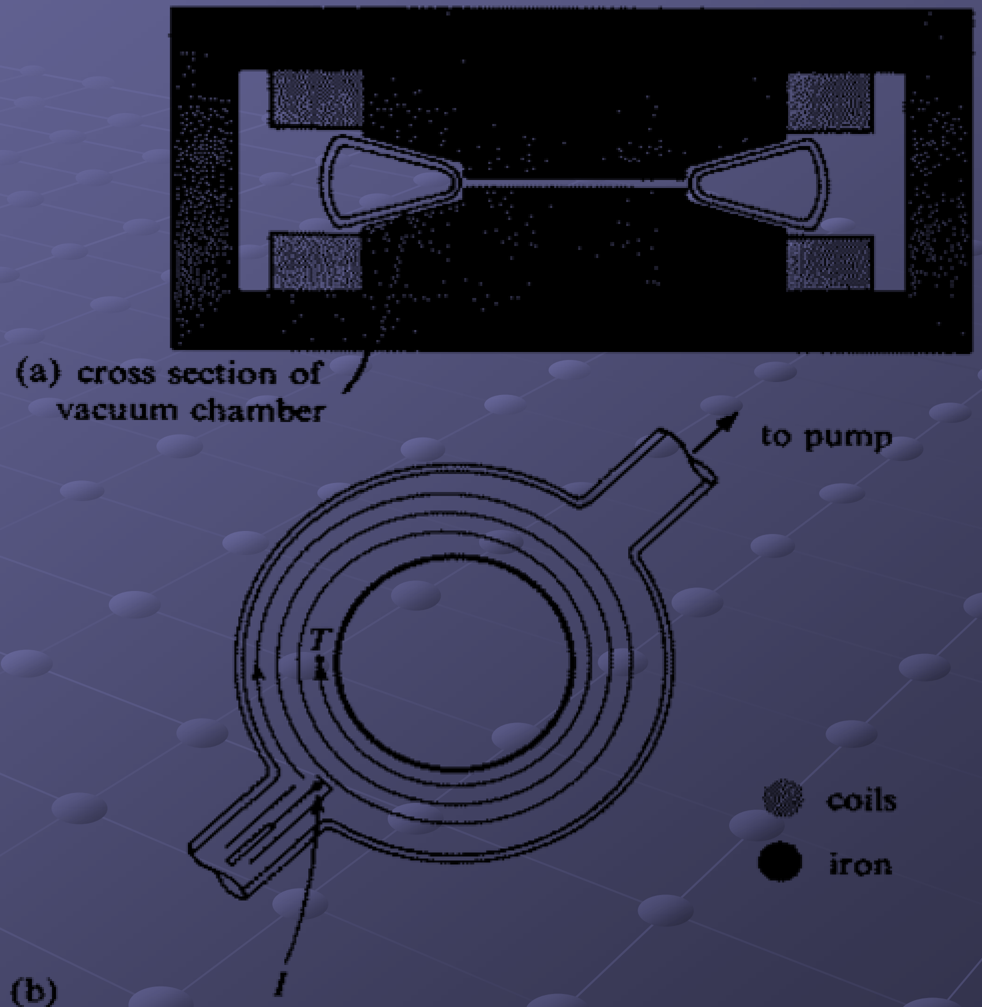


Figure 4-6 A betatron: (a) cross section; (b) plan view. The accelerating flux passes chiefly through the central gap. *I*, injector; *T*, target.

Betatronska frekvencija

$$\frac{e}{c} B_o R = p$$

$$\int E\,ds = -\frac{1}{c}\frac{d\phi}{dt}$$

$$\frac{dp}{dt} = eE = -\frac{1}{c}\frac{e}{2\pi R}\frac{d\phi}{dt}$$

$$\phi = \pi R^2 < B >$$

$$\frac{d\phi}{dt} = \pi R^2 \frac{d < B >}{dt}$$

$$\frac{dp}{dt} = -\frac{e}{c}\frac{R}{2}\frac{d < B >}{dt}$$

$$-R\frac{e}{c}\frac{dB_0}{dt} = \frac{dp}{dt}$$

$$2\frac{dB_0}{dt} = \frac{d < B >}{dt}$$

Betatrons ke oscilacije

$$\vec{F} = -e(\vec{E} + \frac{1}{c}\vec{v} \otimes \vec{B})$$

$$\frac{dp_r}{dt} - mr\dot{\theta}^2 = -e\frac{r}{c}\dot{\theta}B_z$$

$$\frac{dp_z}{dt} = \frac{e}{c}r\dot{\theta}B_r$$

$$p_\theta = mr^2\dot{\theta} - \frac{r}{c}rA = konst.$$

$$B_z = B_o(\frac{r}{R})^{-n}$$

$$\frac{eB_o}{mc} = \omega_0$$

$$\omega_{radial} = (1-n)^{1/2}\omega_0$$

$$\omega_z = n^{1/2}\omega_0$$

Ciklotron

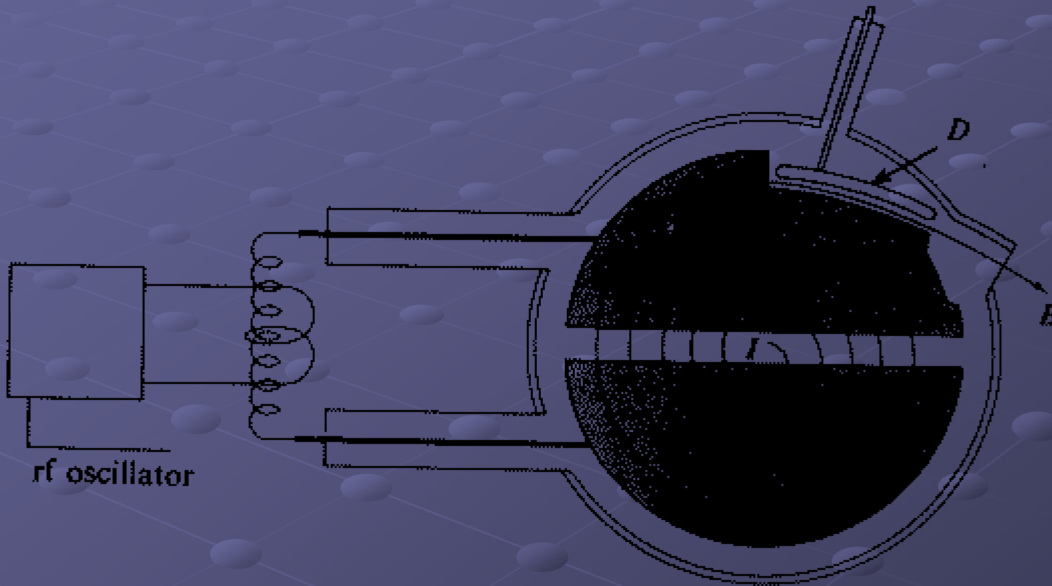


Figure 4-7 Essential parts of a cyclotron (not including the magnet), showing dees (hollow semicircular accelerating electrodes), dee stem insulators, resonant circuit with an rf power source, and deflector plate *D*. The path of the ions from the source at the center *I* to the point of emergence at *B* is shown schematically.

Ciklotronska frekvencija

$$T = \frac{2\pi}{\omega}$$

$$\frac{\pi r}{v} = t = \frac{\pi}{\omega}$$

$$\frac{eB}{mc} = \omega$$

Fazne oscilacije i stabilnost

$$\omega = \frac{eB}{mc} = \frac{eBc}{E}$$

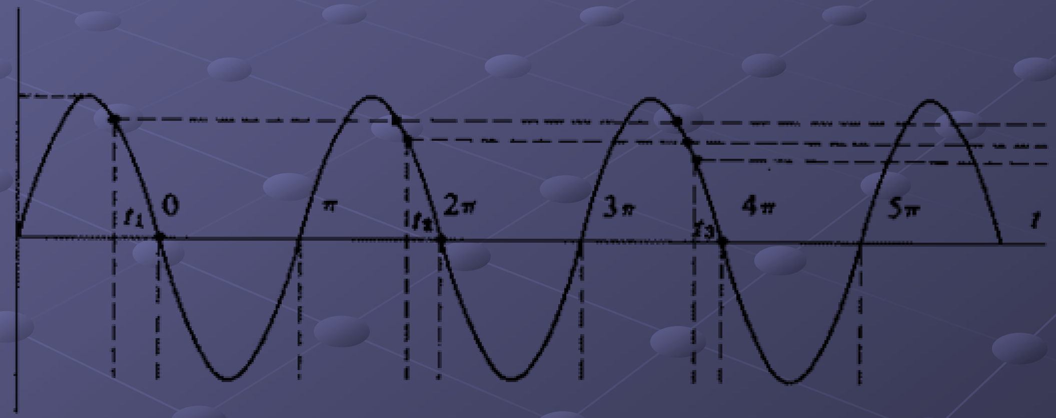
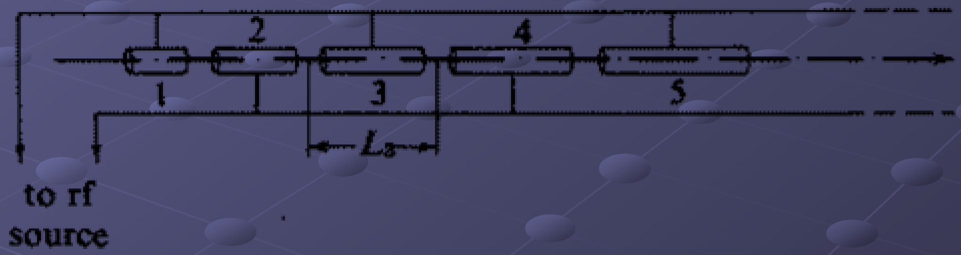


Figure 4-9 Variation of accelerating potential with time, showing origin of phase oscillations.

Linearni akceleratori (Linac)

Figure 4-15 Linear accelerator, Lawrence–Sloan type. Drift tube 3 has a length $L_3 = [3(2e/m)V_0]^{1/2}(T/2)$.



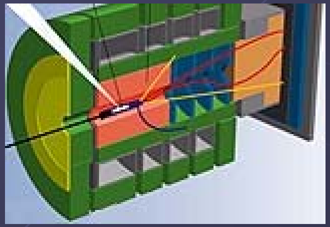
Moderni akceleratori

- Kompozitni akceleratorski sustavi
- Tvornice egzotičnih čestica
- Sinhrotronsko zračenje
- Sudarivači
- Luminoznost

explore RHIC Relativistic Heavy Ion Collider

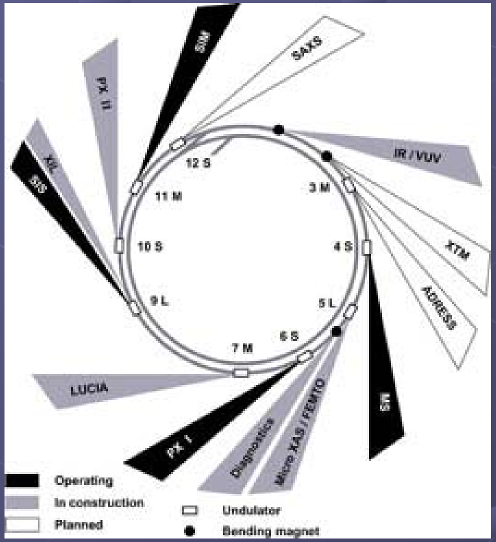
Jefferson Lab

PAUL SCHERRER INSTITUT PSI



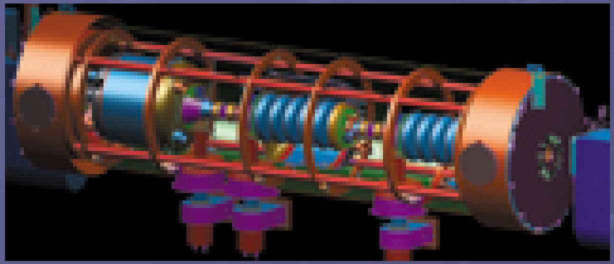
Fermi National Accelerator Laboratory

SLS na PSI


SIM
SAXS
PX II
XIL
SIS
IR / VUV
12 S
11 M
3 M
10 S
4 S
XTM
9 L
5 L
ADRESS
7 M
6 S
LUCIA
MS
PX I
Diagnostics
Micro XAS / FEMTO
Operating
In construction
Planned
Undulator
Bending magnet

Jlab -- CEBAF

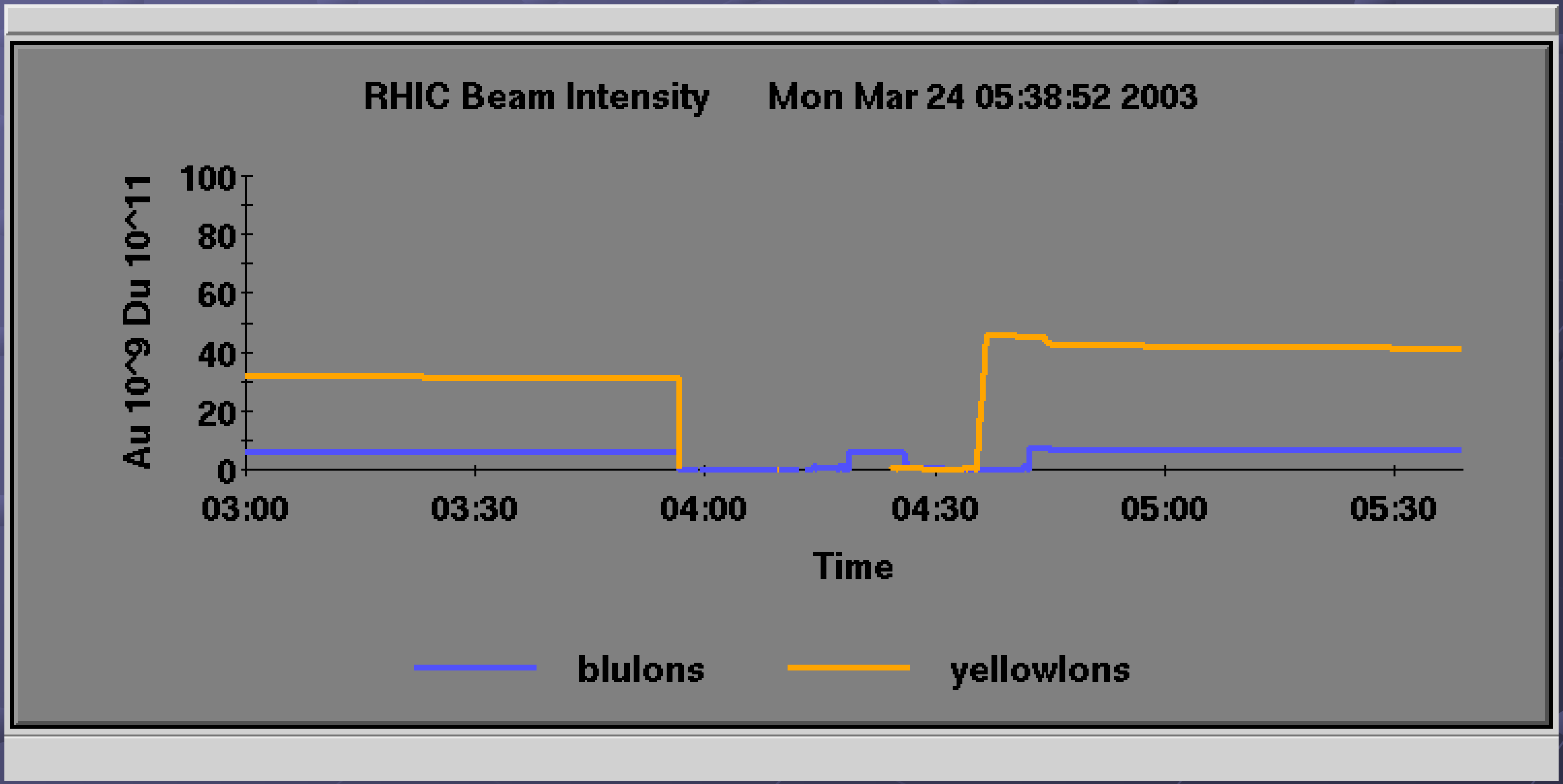
- http://casa.jlab.org/



Brookhaven RHIC status

RHIC - AGS machine status

RHIC is currently in routine deuteron-gold physics operation, using 56 bunches/ring (since Wed Feb 26) deuteron bunch merging (since Fri Feb 28), and rebucketing in both rings (since Fri Mar 7). Peak luminosities for STAR, PHENIX, and BRAHMS are 4.6-5.1x1028 cm2s-1, 110-130% of the dAu program goal, and typical average luminosities are 1.5-2.5x1028 cm2 s-1, 100-150% of the dAu program goal. Since start of physics we have had 102 reasonable production stores delivering peak ZDC rates up to 25kHz; these stores have delivered an integrated luminosity of 12-20 nb-1; RHIC integrated luminosity is averaging about 2.5-3 nb-1/week at beta*=2m locations (PHENIX and STAR). Both ramps have had consistent ramp efficiencies of over 95% with 56 bunches and routine rebucketing. Current typical starting bunch intensities at store are 6-7e8 Au ions/bunch and 9-11e10 d/bunch. Good (not typical) injector intensities are now 8-9x108 Au/bunch and 9-11x1010 d/bunch at RHIC injection.



CDF FermiLab

The Collider Detector at Fermilab

The Collider Detector at Fermilab (CDF) experimental collaboration is committed to studying high energy particle collisions at the world's highest energy particle accelerator. The goal is to discover the identity and properties of the particles that make up the universe and to understand the forces and interactions between those particles.