



Croatian Teacher Programme

9-13 April 2017

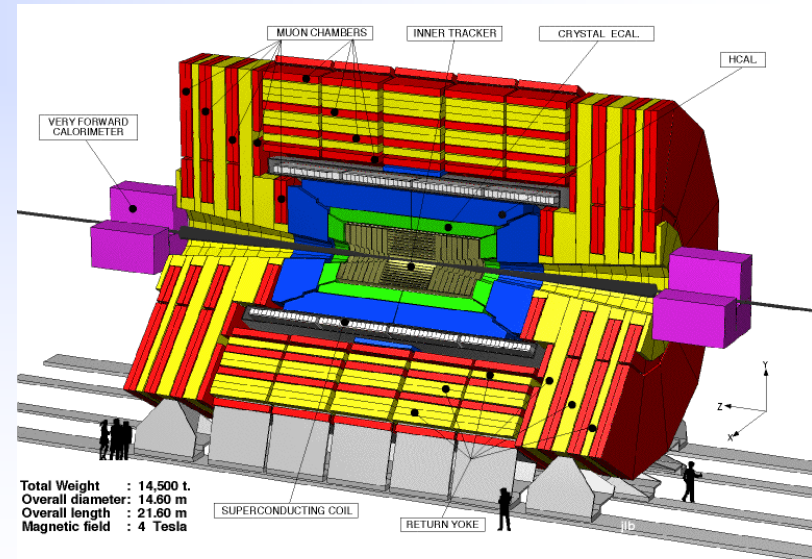
CERN

Europe/Zurich timezone

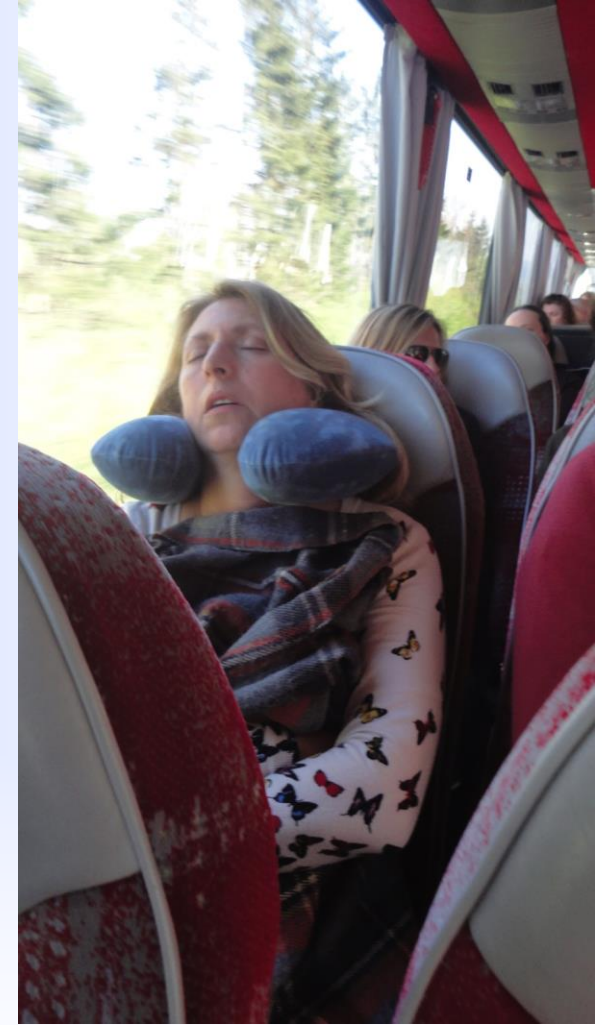


Ubrzivači i detektori u fizici elementarnih čestica

Mirko Planinić
PMF



Da ne bi bilo ...



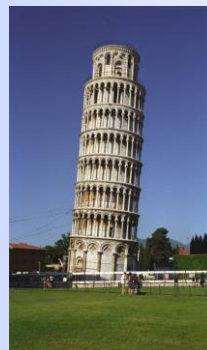
Nego ...



Podijelili smo vam klikere jer mi volimo interaktivno ...

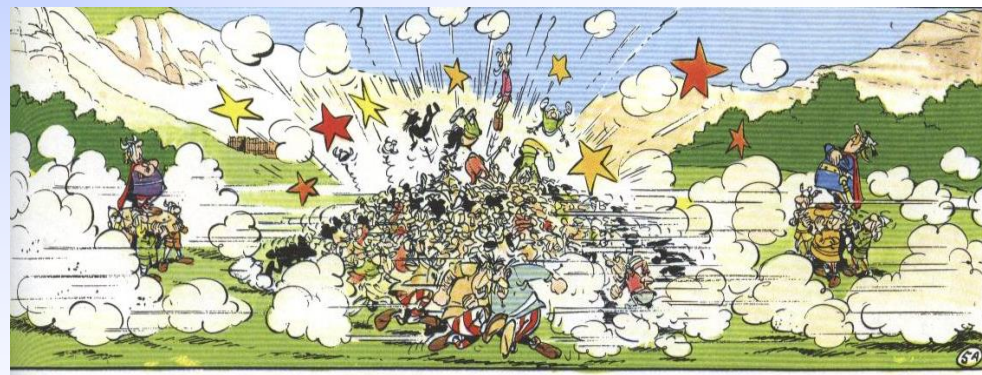
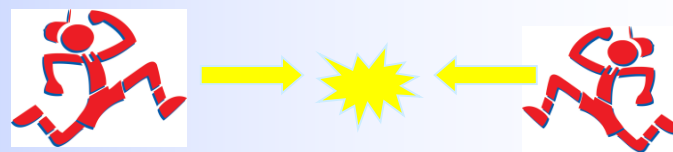
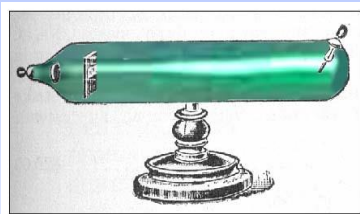
Sadržaj

- Od ubrzivača do suprasudarivača



- Linearni i kružni ubrzivači

- Pokus



- Leptoni, hadronski sudarivači
- Interakcija čestica s materijom
- Sažetak

Danas na rasporedu

09:00 → 12:30 Lectures 

 3-R-002 - Teacher Training Roo...

09:00

Introduction to CERN

 1h

Speaker: Jeff Wiener (CERN)



CERN - a short and s...



H RTP17_Basics.pdf



H RTP17_Objectives....

10:00

Particle Physics 1

 1h

Speaker: Vuko Brigljevic (Rudjer Boskovic Institute (HR))

11:00

Coffee break

11:30

Detectors 1

 1h

Speaker: Mirko Planinic (University of Zagreb (HR))

12:30 → 14:00

Lunch break



Danas na rasporedu

14:00 → 17:00 Workshop & Exhibitions

14:00 Cloud Chamber Workshop & Microcosm

🕒 3h 📍 143-R-003 - S'Cool LAB

Group 1

14:00-15:30 Cloud Chamber Workshop

15:30-17:00 Microcosm & GLOBE

Group 2

14:00-15:30 Microcosm & GLOBE

15:30-17:00 Cloud Chamber Workshop

17:00 → 17:45 Visits

17:00 Synchrocyclotron SC

🕒 45m

Meet at the CERN Reception (Bat33) at 17:10!

18:30 → 19:30 Social Events

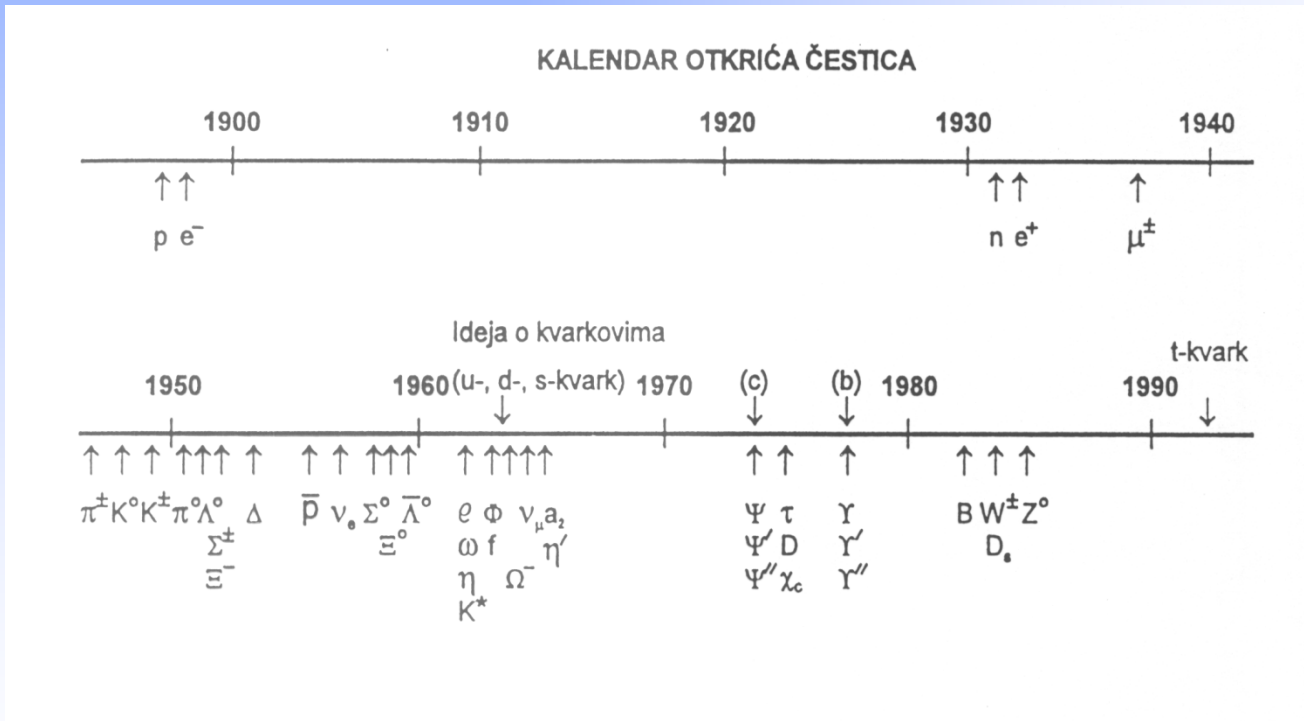
📍 61-1-201 - Pas perdis - Not a ...

Kako smo od ubrzivača u Pisi došli do LHC-a?

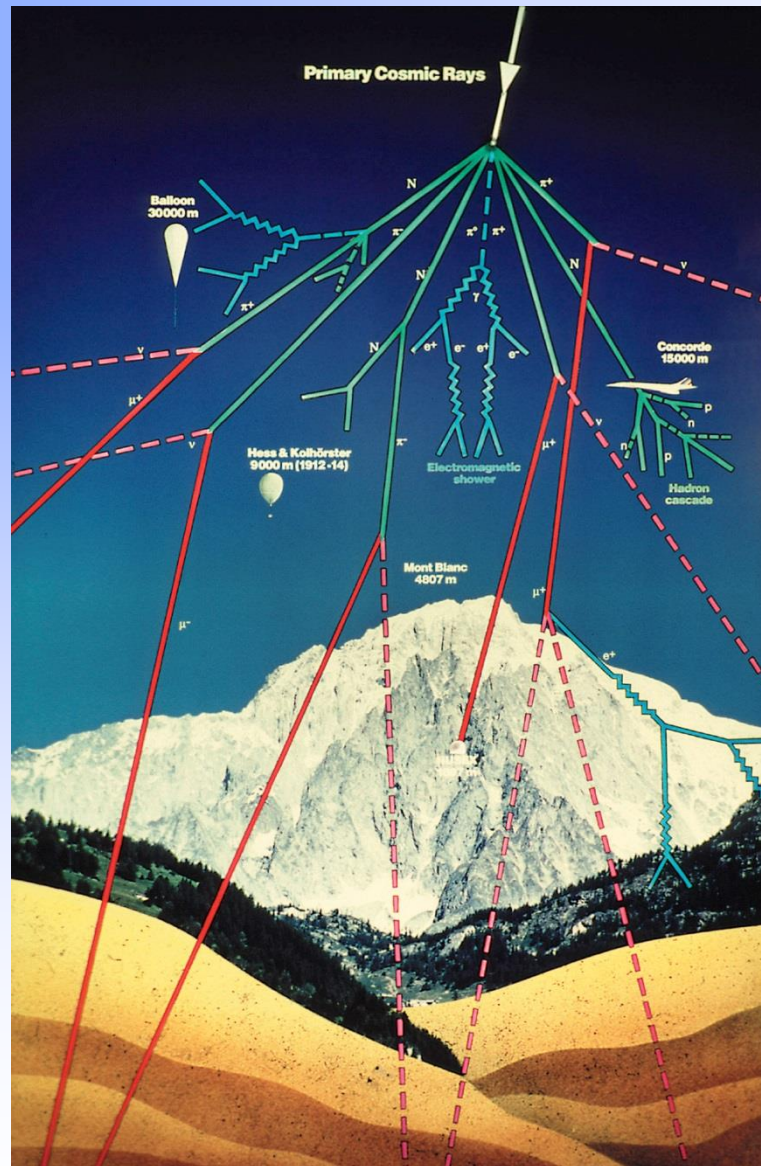


Ubrzivači i otkrića novih čestica

- Najvažnija otkrića novih čestica nakon primjene ubrzivača



Možemo li koristiti kozmičke zrake ?



Kozmičko zračenje

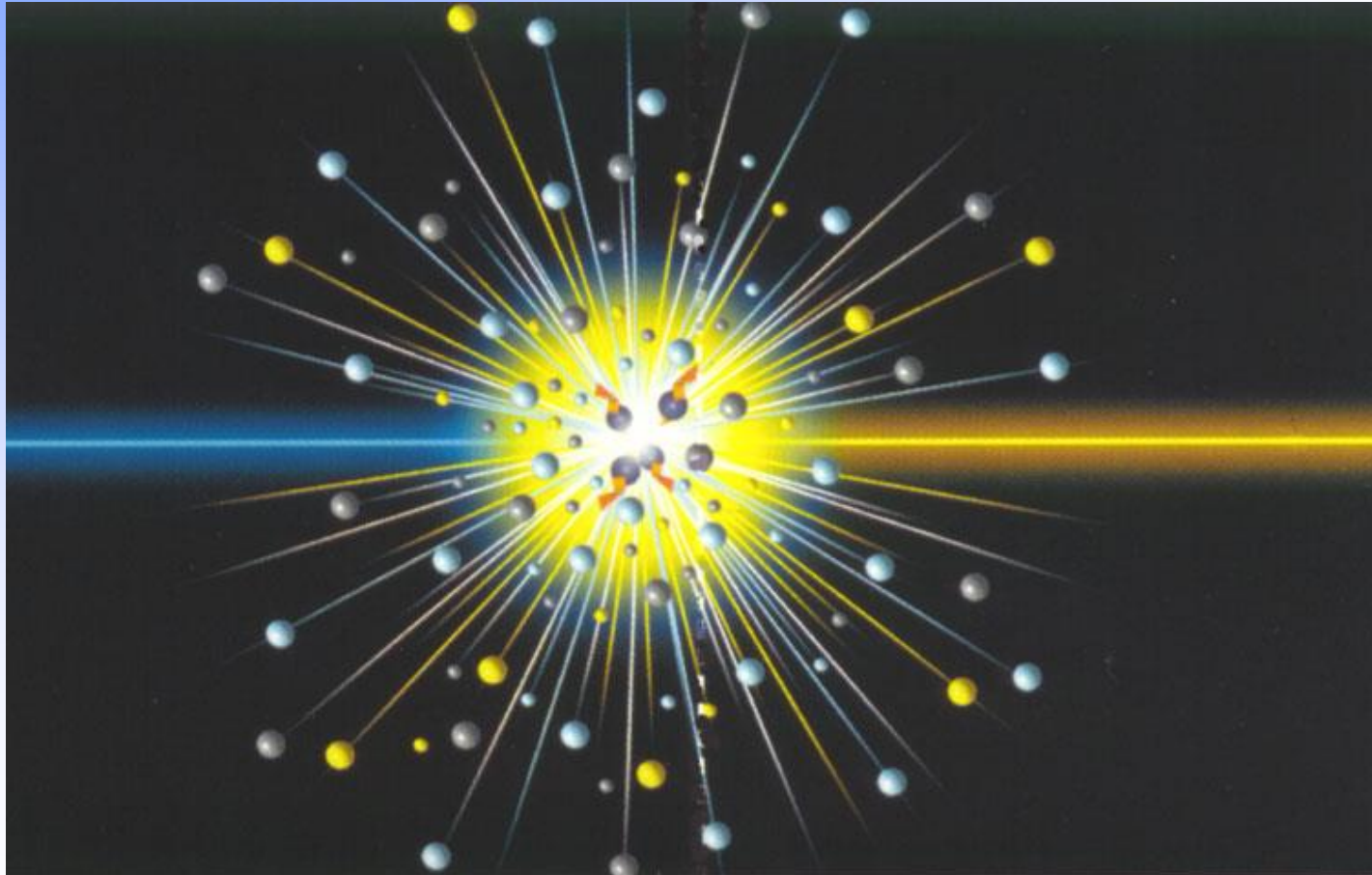
Kozmičke zrake konstantno bombardiraju Zemlju

Njihove energije mogu biti puno redova veličine iznad LHC-a

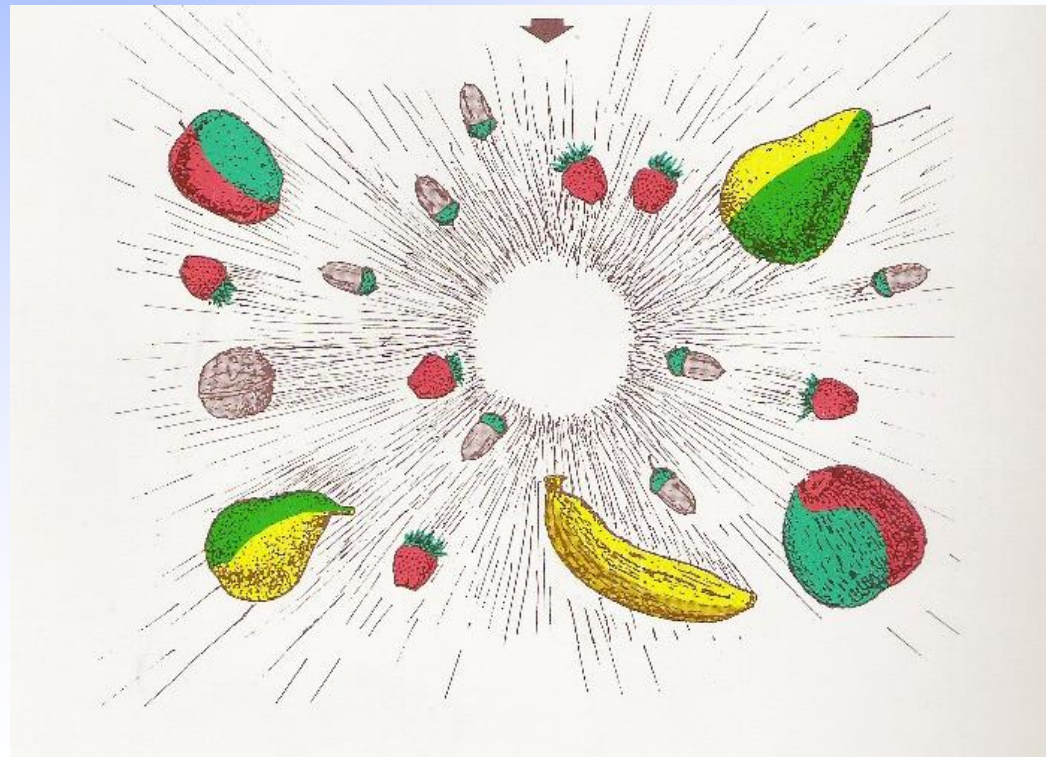
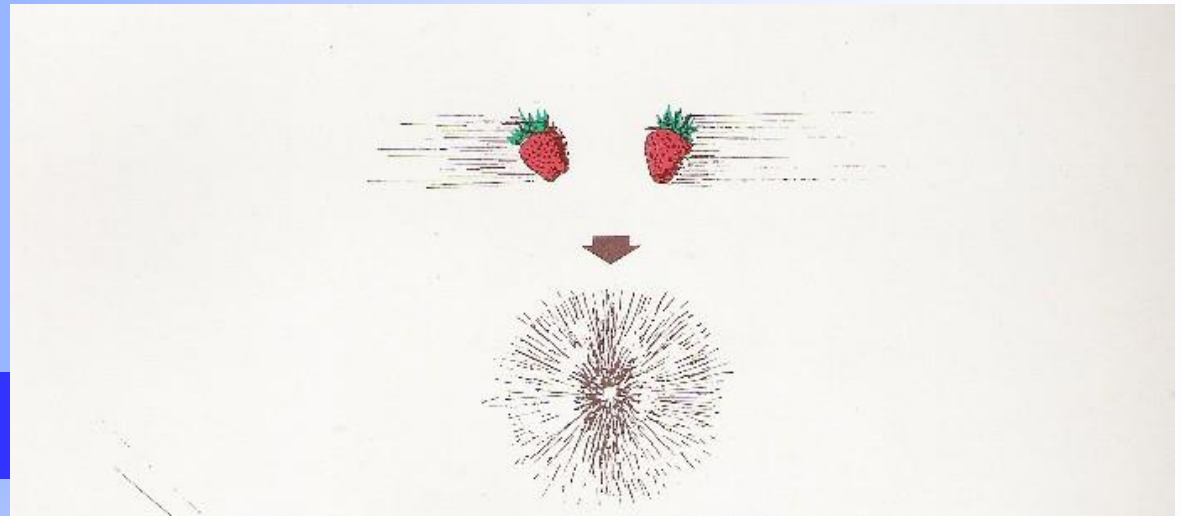
- Ukupni tok: 350 Hz
100 m ispod zemlje (~
1% toka na površini)

Za vidjeti najmanje čestice:
potrebne su najveće energije!

$$E = mc^2$$



$$E = mc^2$$

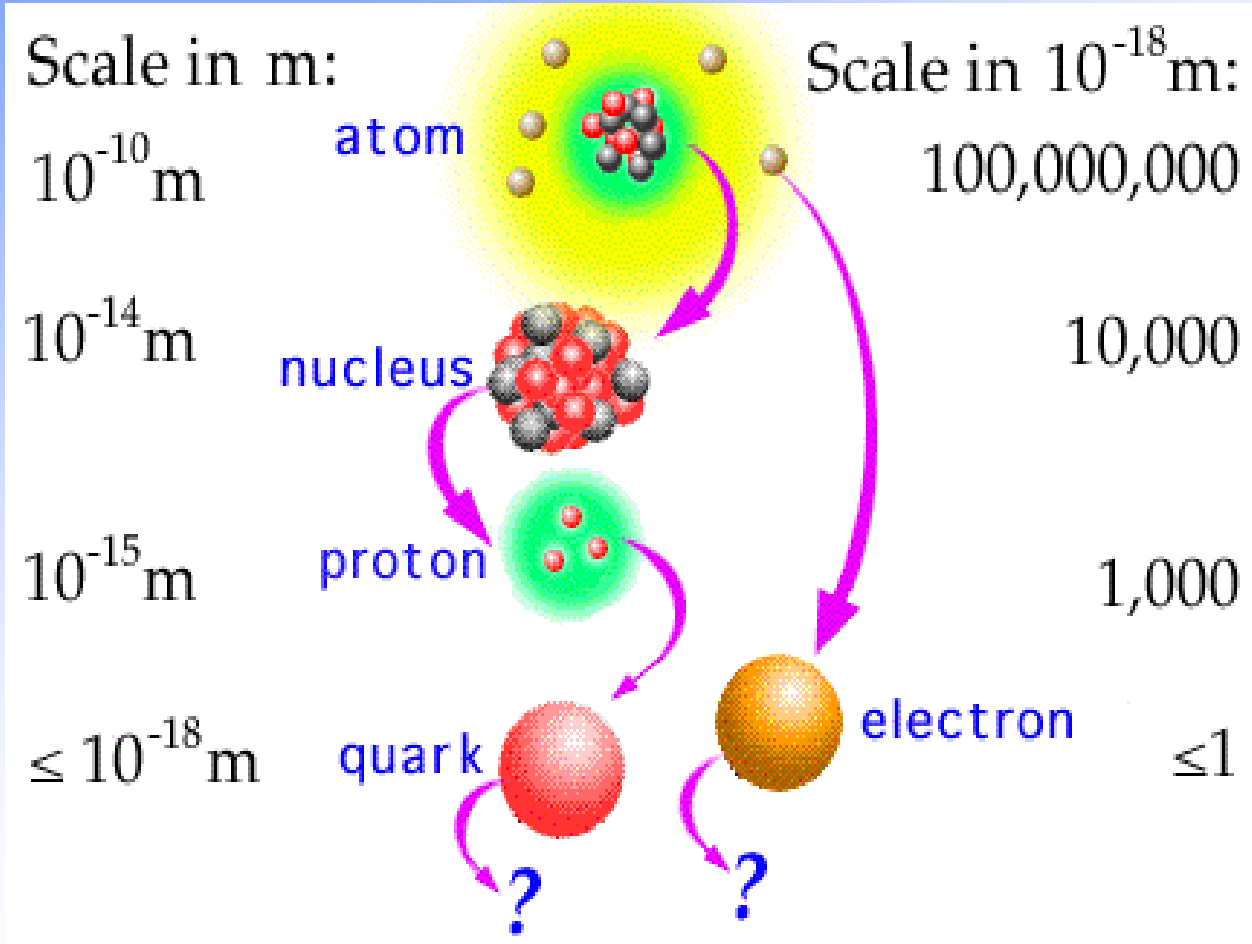


Uranjanje u subatomske svijet

- Da bismo "elektronskim mikroskopom" postigli rezoluciju

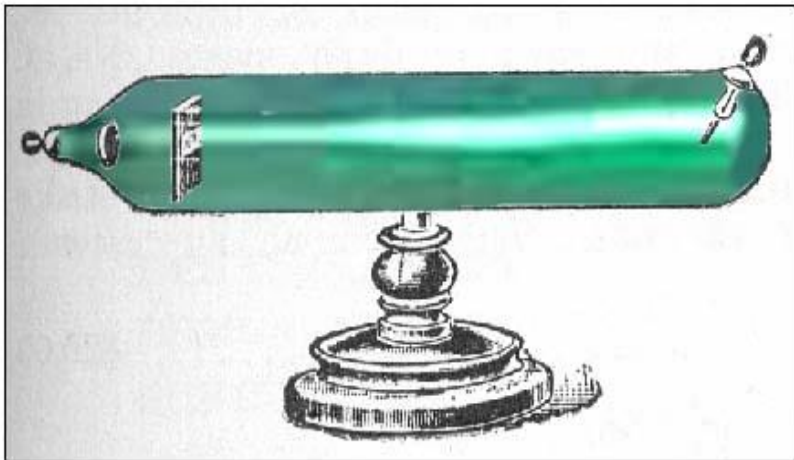
$$\Delta x \cong 10^{-15} \text{ m} = 1 \text{ fm}$$

treba elektrone ubrzati na energiji $E \cong \frac{\hbar c}{\Delta x} \cong 1 \text{ GeV}$

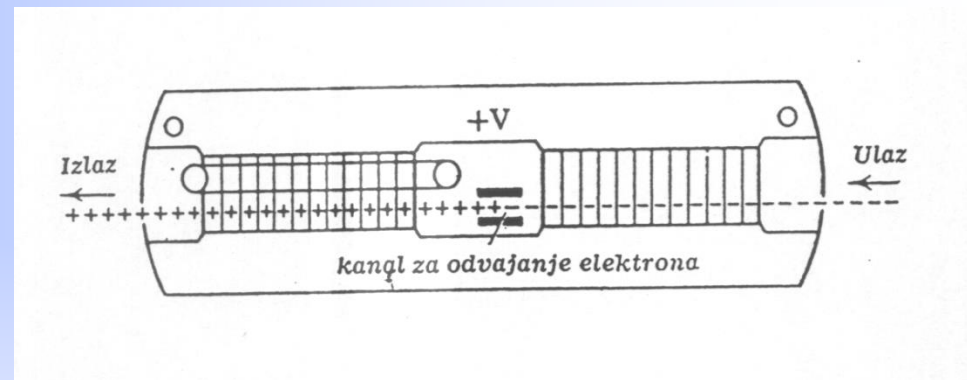
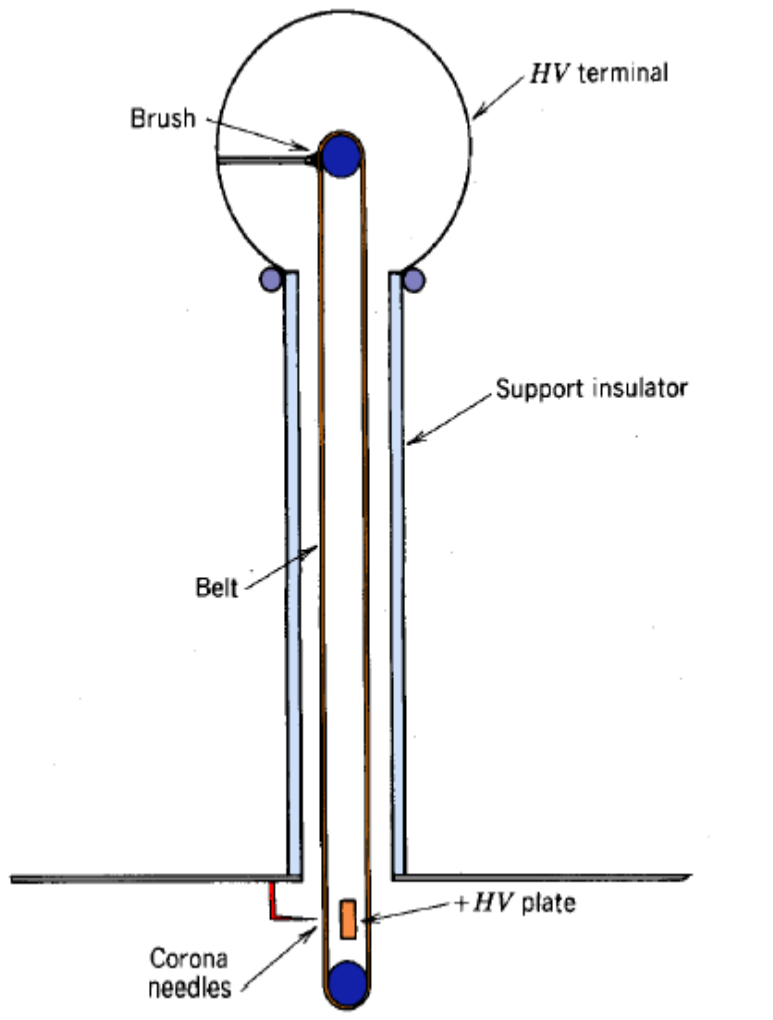


Kako ubrzati nabijenu česticu ?

POKUS !!!!



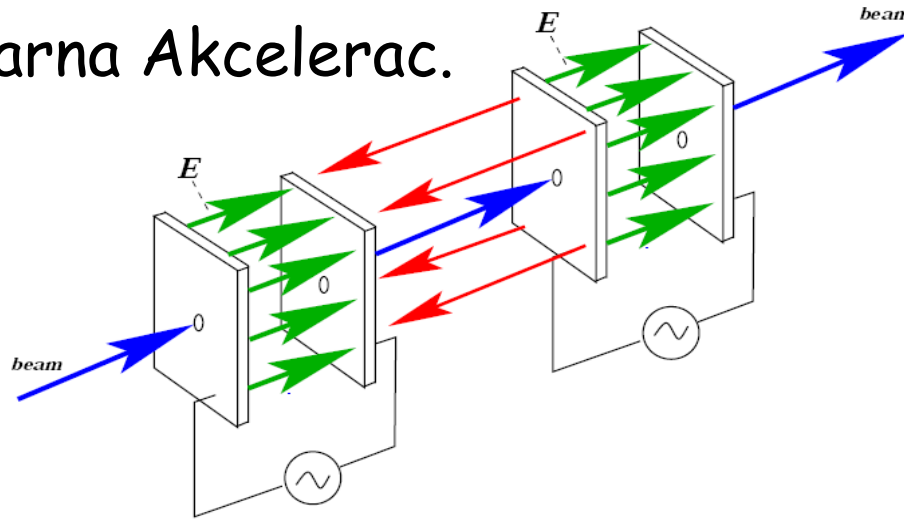
Van de Graafov ubrzivač



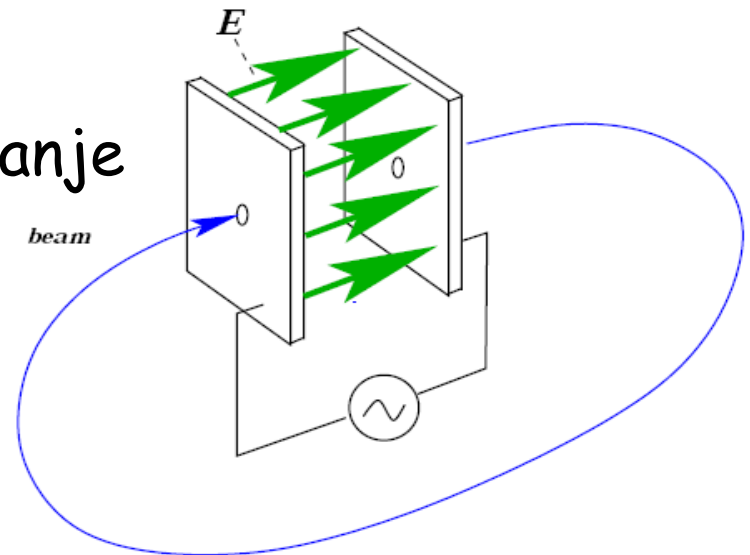
Što je ograničavajući faktor?

Vremenski promjenljiva električna polja

Linearna Akceleraac.

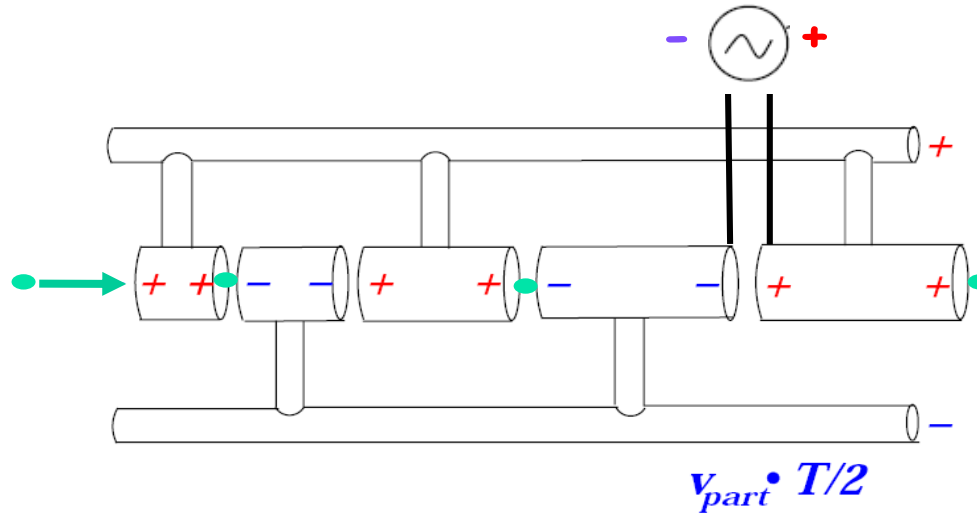


Kružno
ubrzavanje

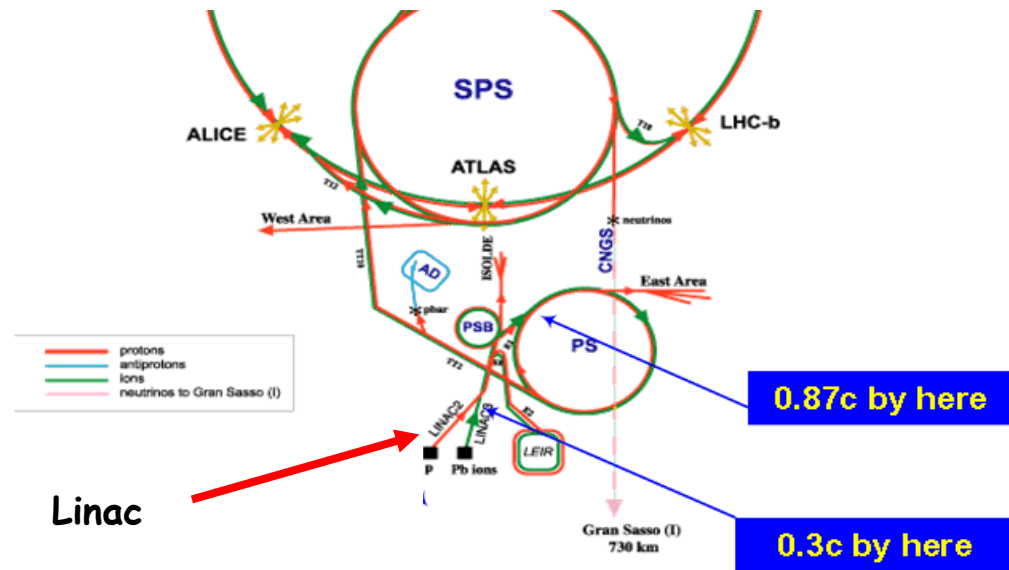


Linearni akceleratori

Linac



Wideroe
1928.



Linac

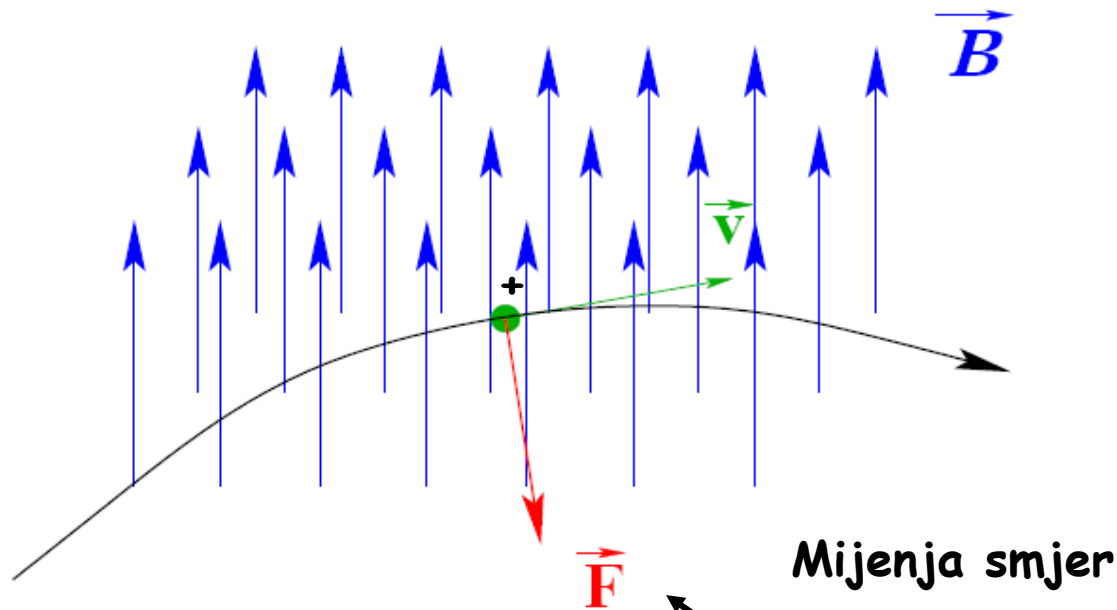
Konceptualno pitanje

Snop čestica u sudarivaču je:

- a) kontinuiran
- b) čestice dolaze u nakupinama



Sile na čestice



Lorentz:

$$\frac{d\vec{p}}{dt} = Q * (\vec{E} + \vec{v} \times \vec{B})$$

Ubrzava nabijene čestice

Ciklotron

Centripetalna sila = - Centrifugalna sila:

$$\frac{mv^2}{r} = Bqv$$

Reorganizacija:

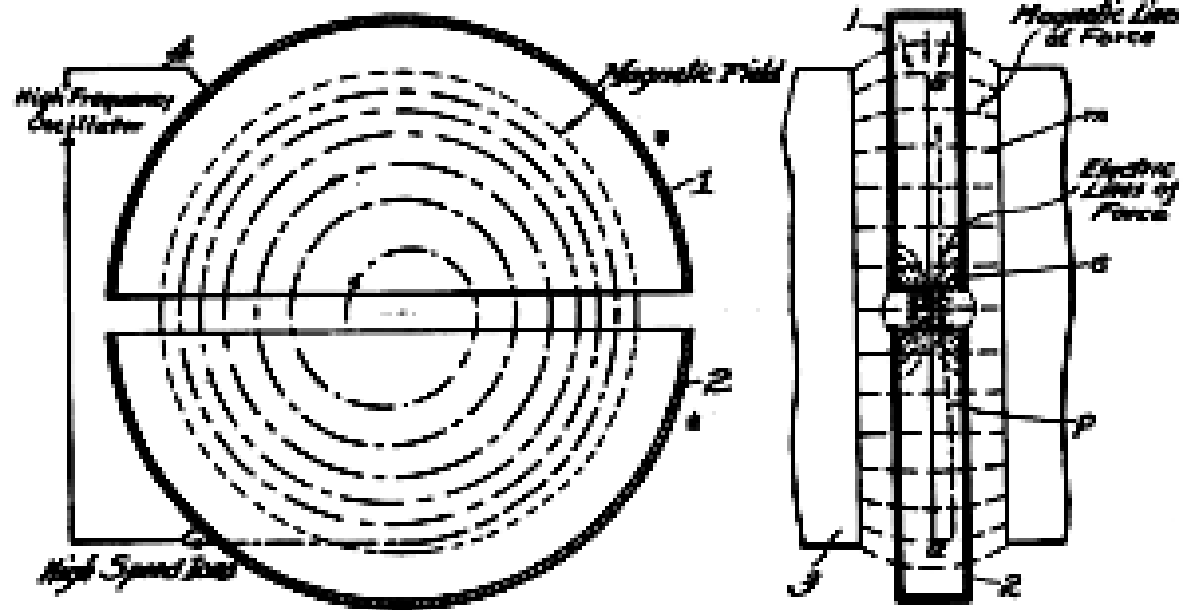
$$\frac{v}{r} = \frac{Bq}{m}$$

$$\downarrow$$
$$\omega = \frac{Bq}{m}$$

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

$$f = \frac{Bq}{2m\pi}$$

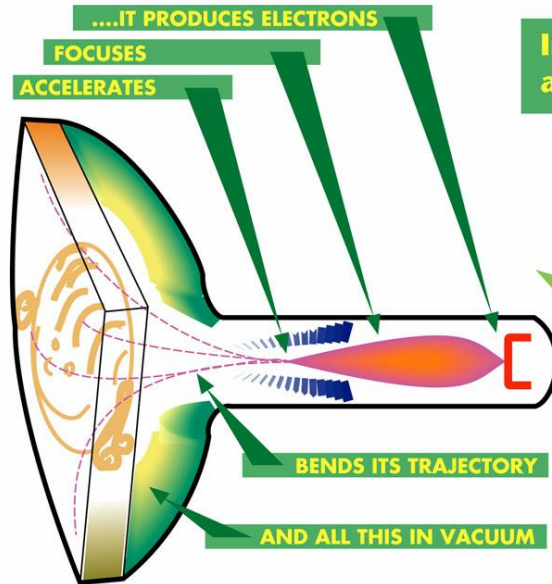
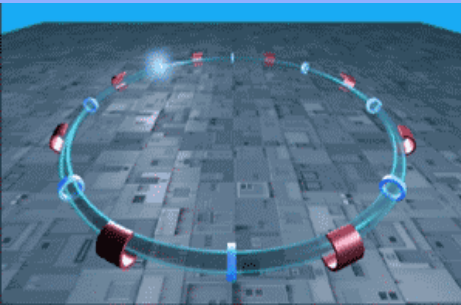
Kontinuiran snop čestica



Ubrzavanje čestica

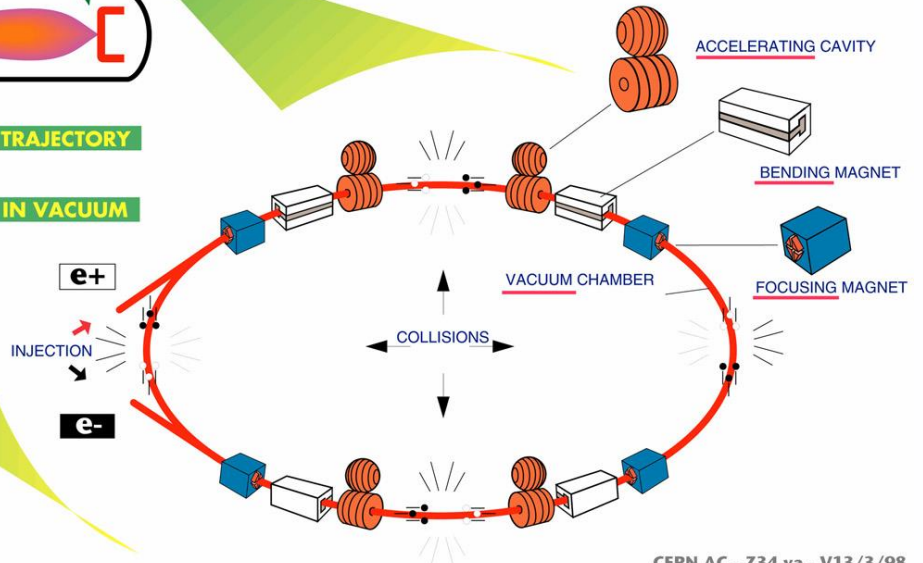
stara televizija je ubrzivač čestica u malom!

DID YOU KNOW YOUR TELEVISION SET IS AN ACCELERATOR ?



In your TV set, the electrons are accelerated to 20000 volts.

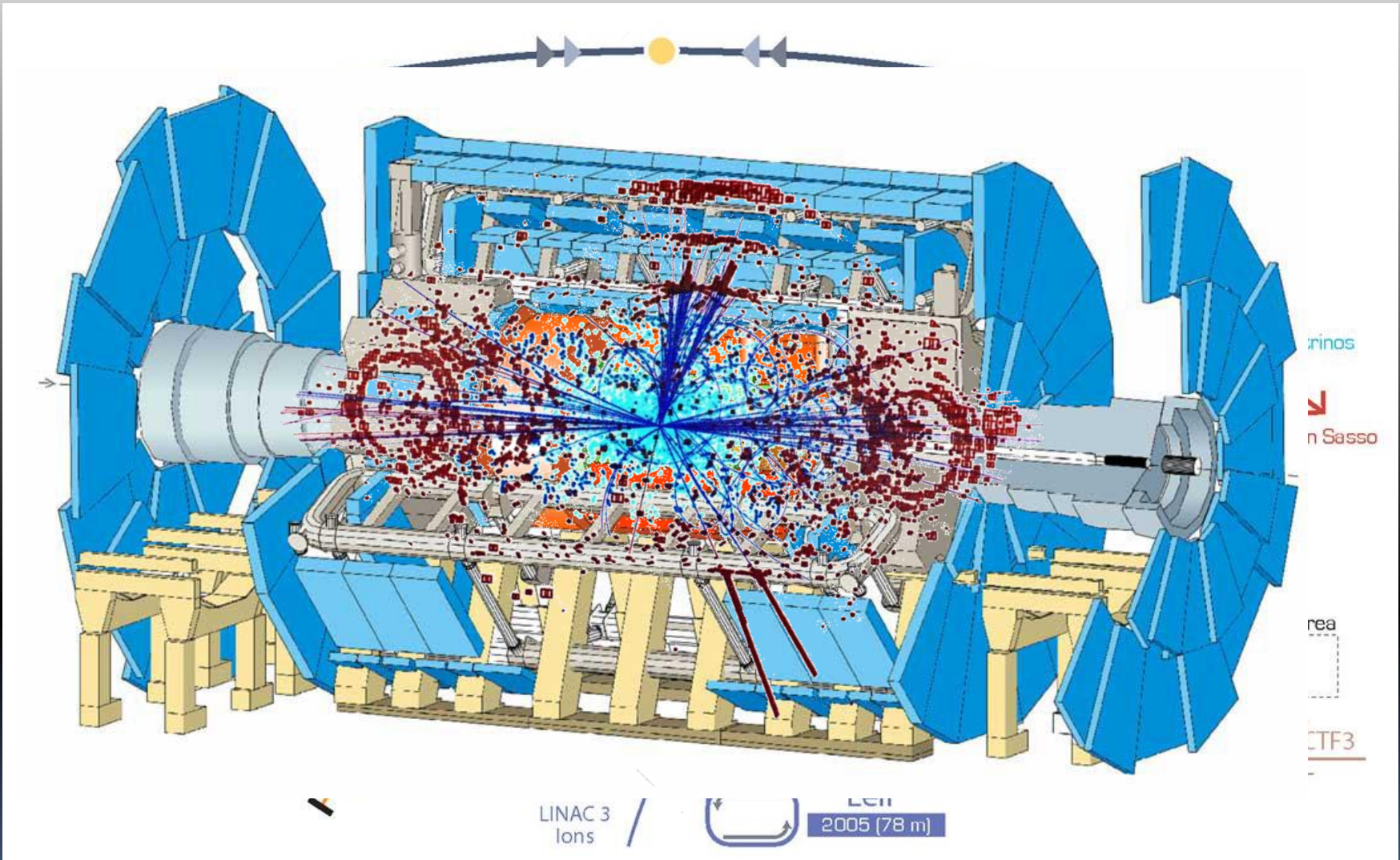
In LEP, they are accelerated to 100 000 000 000 volts.



FILM

CERN AC - Z34 va - V13/3/98

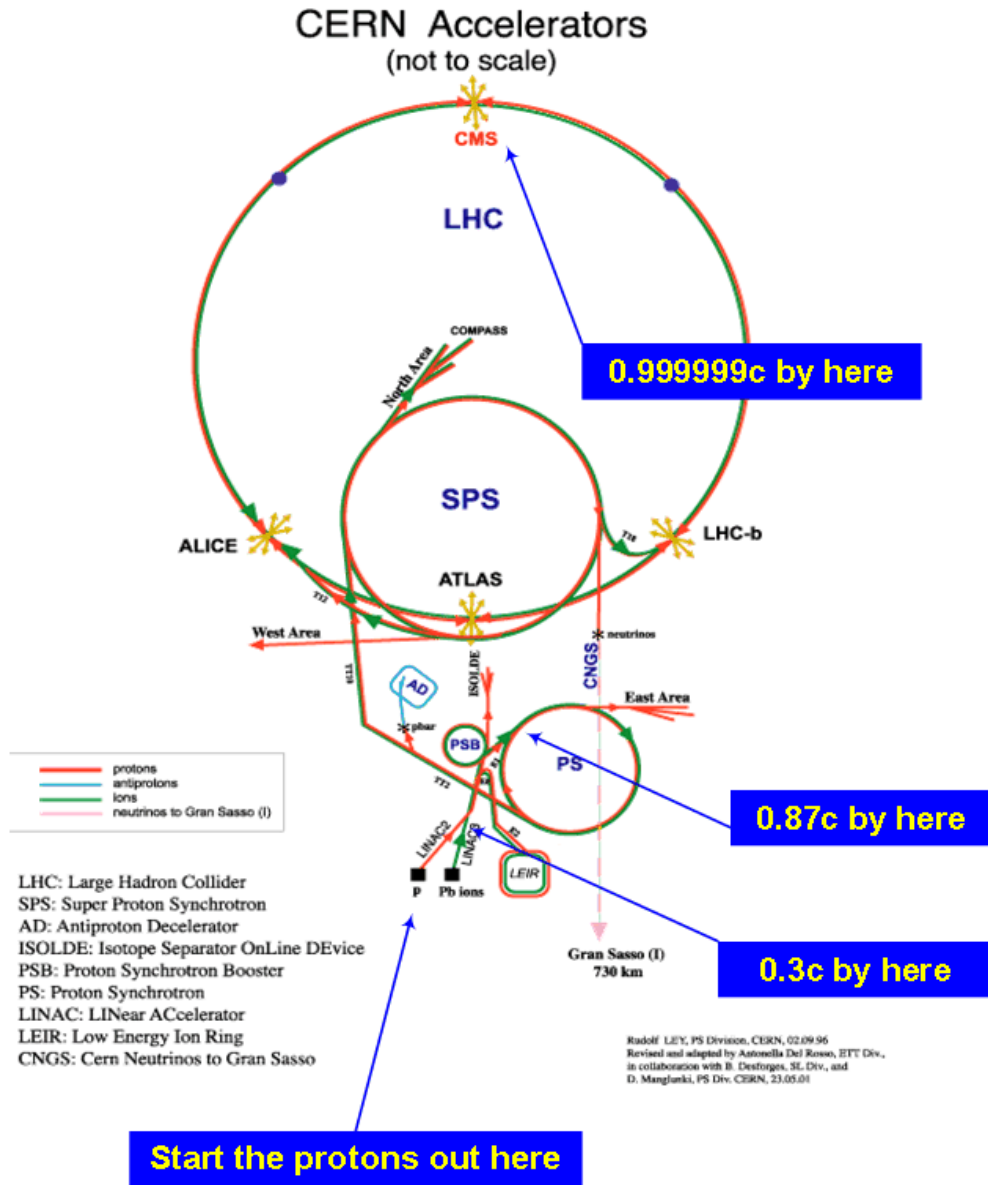
CERN's particle accelerator chain



▶ p (proton)
 ▶ \bar{p} (antiproton)
 ▶ neutrons
 ▶ neutrinos
 ▶ electron
 ↔ proton/antiproton conversion

LHC Large Hadron Collider
 SPS Super Proton Synchrotron
 PS Proton Synchrotron
 AD Antiproton Decelerator
 CTF3 Clic Test Facility
 CNGS Cern Neutrinos to Gran Sasso
 ISOLDE Isotope Separator OnLine DEvice
 LEIR Low Energy Ion Ring
 LINAC LINear ACcelerator
 n-ToF Neutrons Time Of Flight

Akceleratori i LHC eksperimenti na CERN-u



Energije:

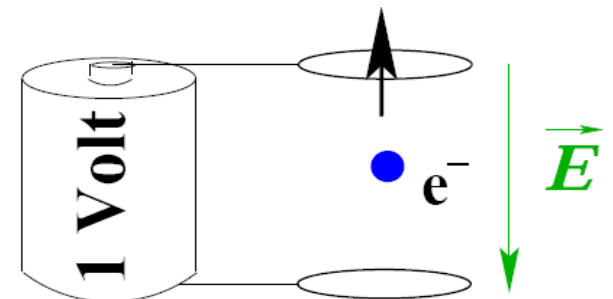
Linac 50 MeV

PSB 1.4 GeV

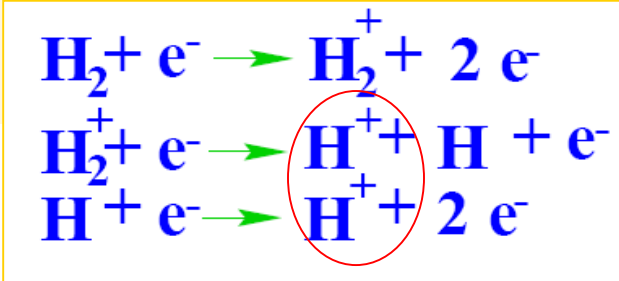
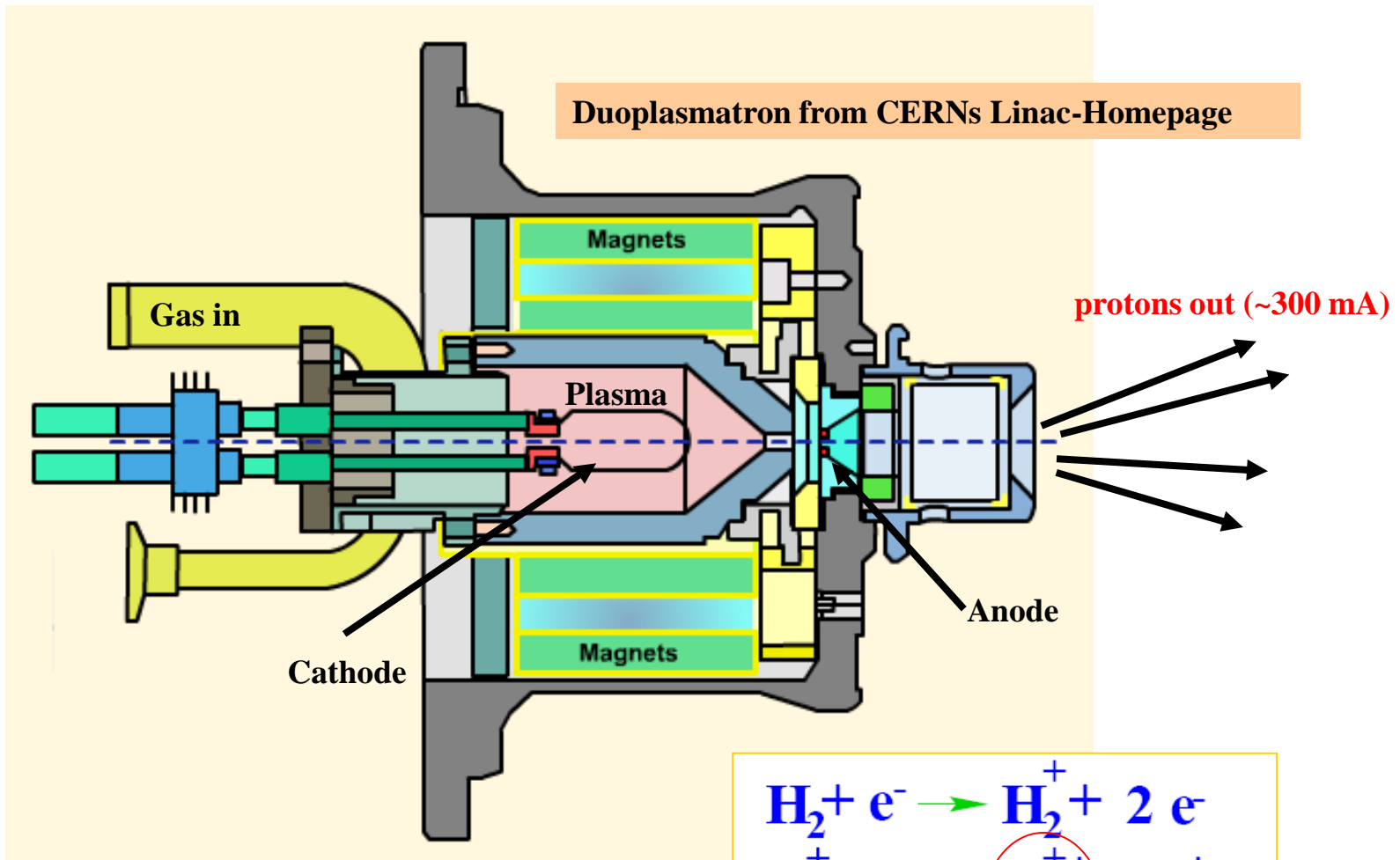
PS 28 GeV

SPS 450 GeV

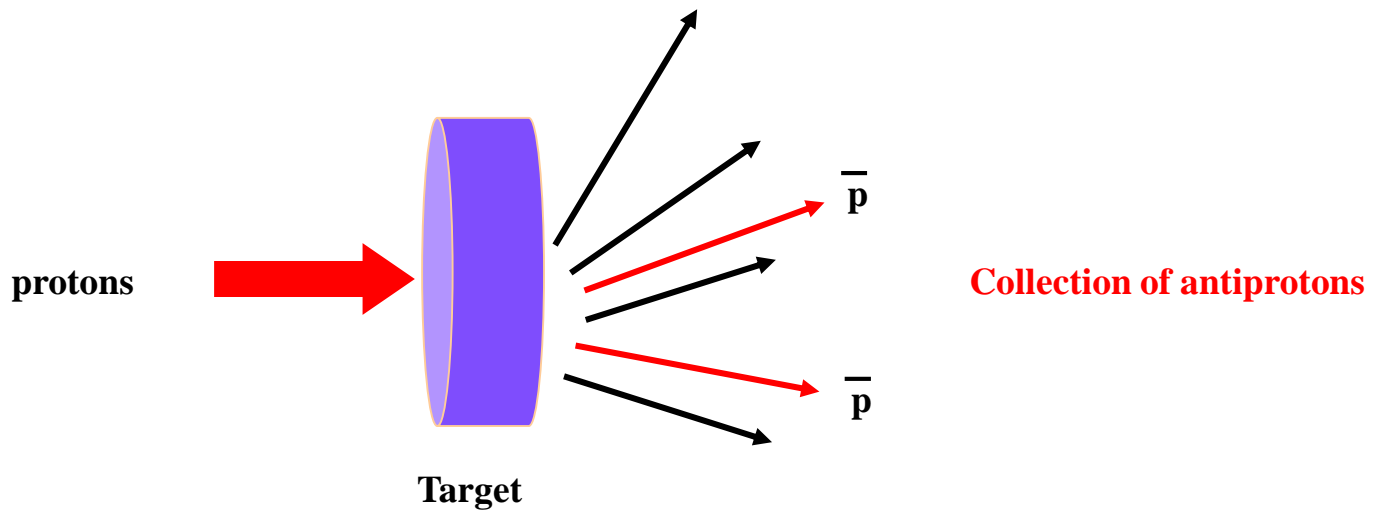
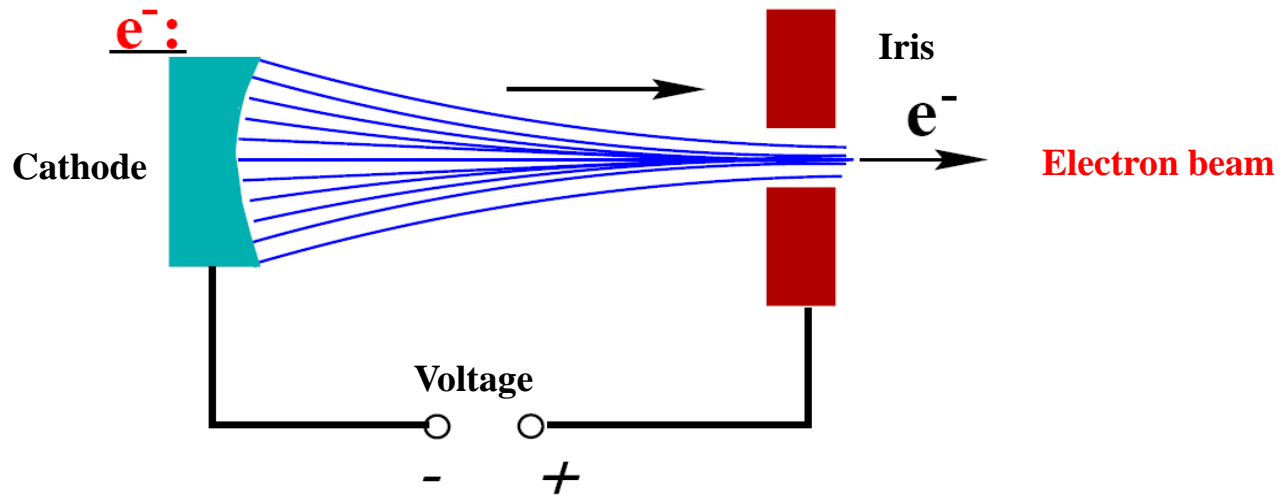
LHC 7 TeV



Kako dobiti protone ?



Kako dobiti elektrone ili antiprotone ?



Pitanja koja se postavljaju ...

Koje čestice ćemo ubrzavati ?

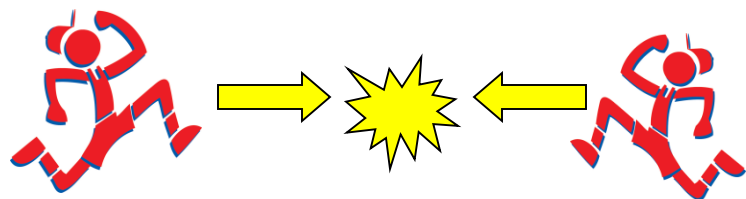
Kružno ili linearno ?

Da li ćemo sudarati snop i čvrstu metu
ili snop na snop ?

Zašto hadronski sudarivač?

- Mane:
 - Hadroni su kompleksni
 - Prisutan veliki broj čestica
 - Energija i vrsta sudarajućeg partona (kvark, gluon) nisu poznati
 - Kinematika događaja nije potpuno određena
- Prednosti:
 - Dostupnost većih energija

Leptonski sudarivač
(sudar dvije točkaste čestice)

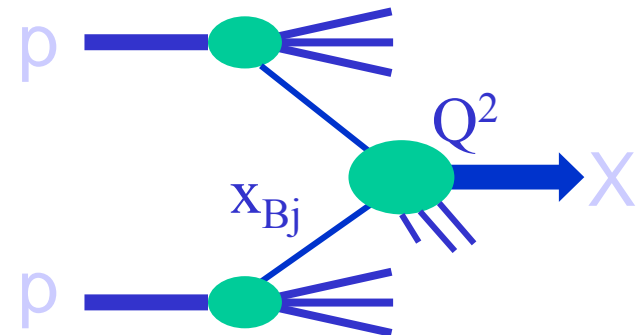
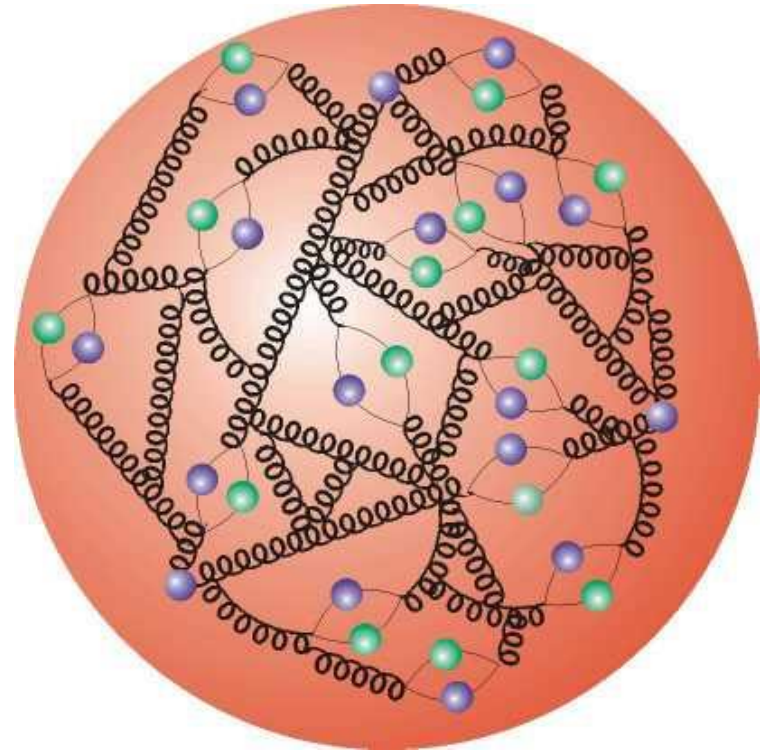


Hadronski sudarivač
(sudar ~50 točkastih čestica)



Proton: kompleksan objekt

- Kompliciran:
 - Valentni kvarkovi, gluoni, kvarkovi mora
- Točan sastav ovisan o:
 - $Q^2: \sim(M^2+p_T^2)$

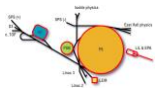


Konceptualno pitanje

Sudarivač čestica koristimo rađe nego sudare na čvrstoj meti jer:

- a) je tako sudar čestica vjerojatniji
- b) je manje zračenje u okolici sudara
- c) tako bolje iskoristimo energiju





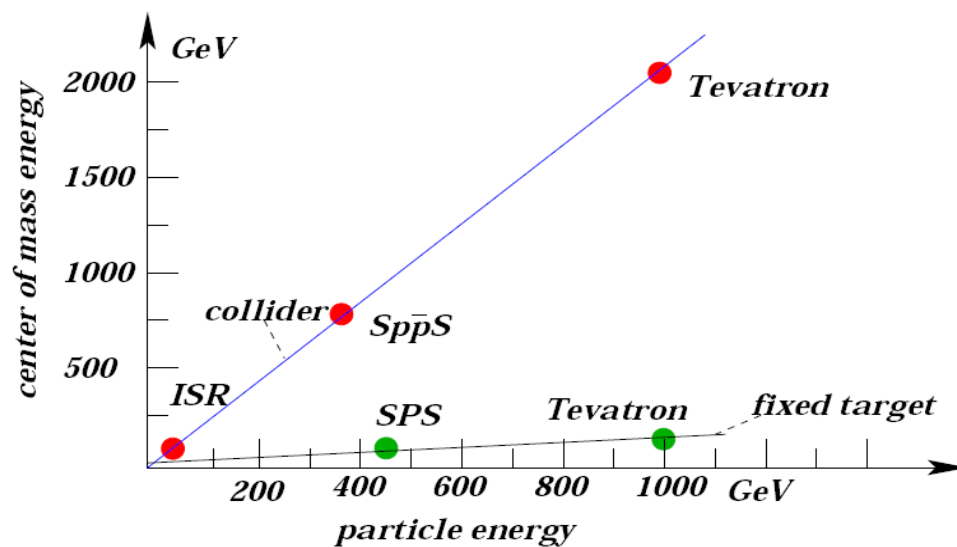
Eksperiment

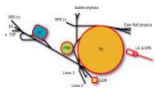
**Sudarivač čestica je
interesaniji od sudara
na čvrste mete...**

**1960: electron/positron
sudarivač**

**1970: proton antiproton
sudarivač**

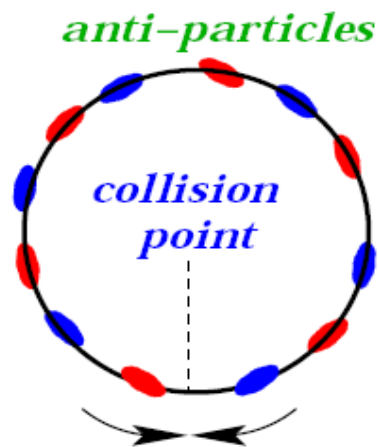
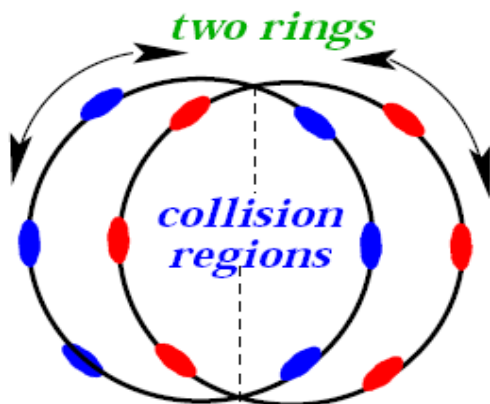
2000: ioni, zlato



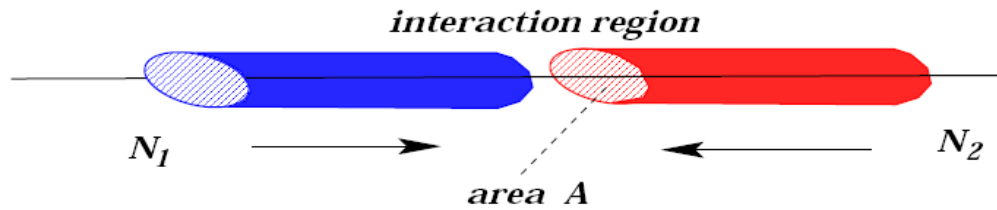


Sudarivači

EXPERIMENT

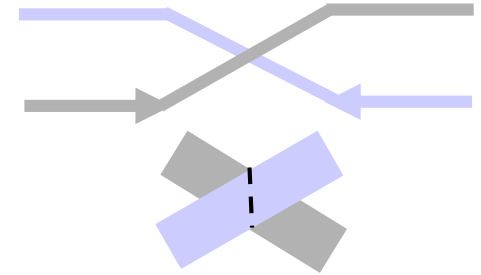


- Sve čestice se ne sudaraju u isto vrijeme -> potrebno je dugo vrijeme
- Potrebna su dva snopa
- Antičestice se teško (skupo) proizvode (1 antiproton na 10^6 protona)
- Snopovi utječu jedan na drugoga: snopovi se moraju razdvojiti kad se ne sudaraju



$$A = \pi \epsilon \beta *$$

$$N_{ev} / \text{sec} = \sigma \cdot L$$



EKSPERIMENT

Broj čestica po nakupini (dva snopa) →

Broj nakupina po snopu →

Okretna frekvencija →

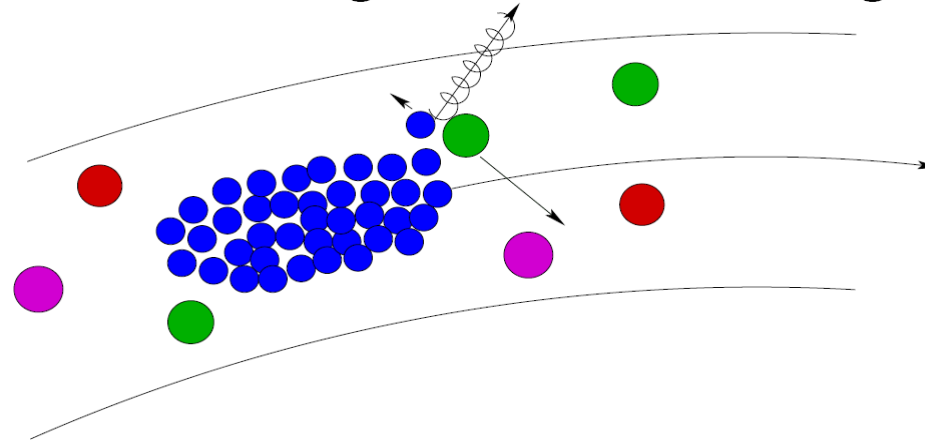
Formfaktor iz poprečnog kuta →

$$L = \frac{N_b^2 n_b f_{rev}}{4\pi\epsilon\beta * } F$$

Emitancija →

Optička beta function →

Bremsstrahlung + Coulomb Scattering



- “Rasipanje “ snopa
- Gubitak čestica
- Neželjeni sudari
- Ograničava Luminoznost

Ograničavajući faktori kružnih ubrzivača

1) Gubitak energije zračenjem:

$$\frac{\Delta E}{2\pi R} = \frac{4\pi e^2 \beta^2 \gamma^4}{3R}$$

$$\gamma = \frac{E}{m} \quad \beta = \frac{v}{c} \cong 1$$

2) Istraživanja na malim dimenzijama  mali udarni presjek

Luminoznost: $L = \text{broj čestica u jed. vrem./jedinica površine}$

Vjerojatnost događaja = udarni presjek * luminoznost

3) Raspoloživa energija:

$$s = (p_a + p_b)^2 \sim$$

$$E_a m_b$$

Za fiksiranu metu

$$4E^2$$

Za sudarivač $E_a = E_b = E$

Prva ideja LHC 1985. Konstrukcija odobrena 1995.

Energija sudara:	7+7 TeV
Broj nakupina čestica:	2808
Broj čestica po nakupini:	1.15×10^{11}
Struja snopa:	0.582 A
Spremljena energija po snopu:	362 MJ
Najveća luminoznost IP1 :	$10^{34} \text{ cm}^2\text{s}^{-1}$

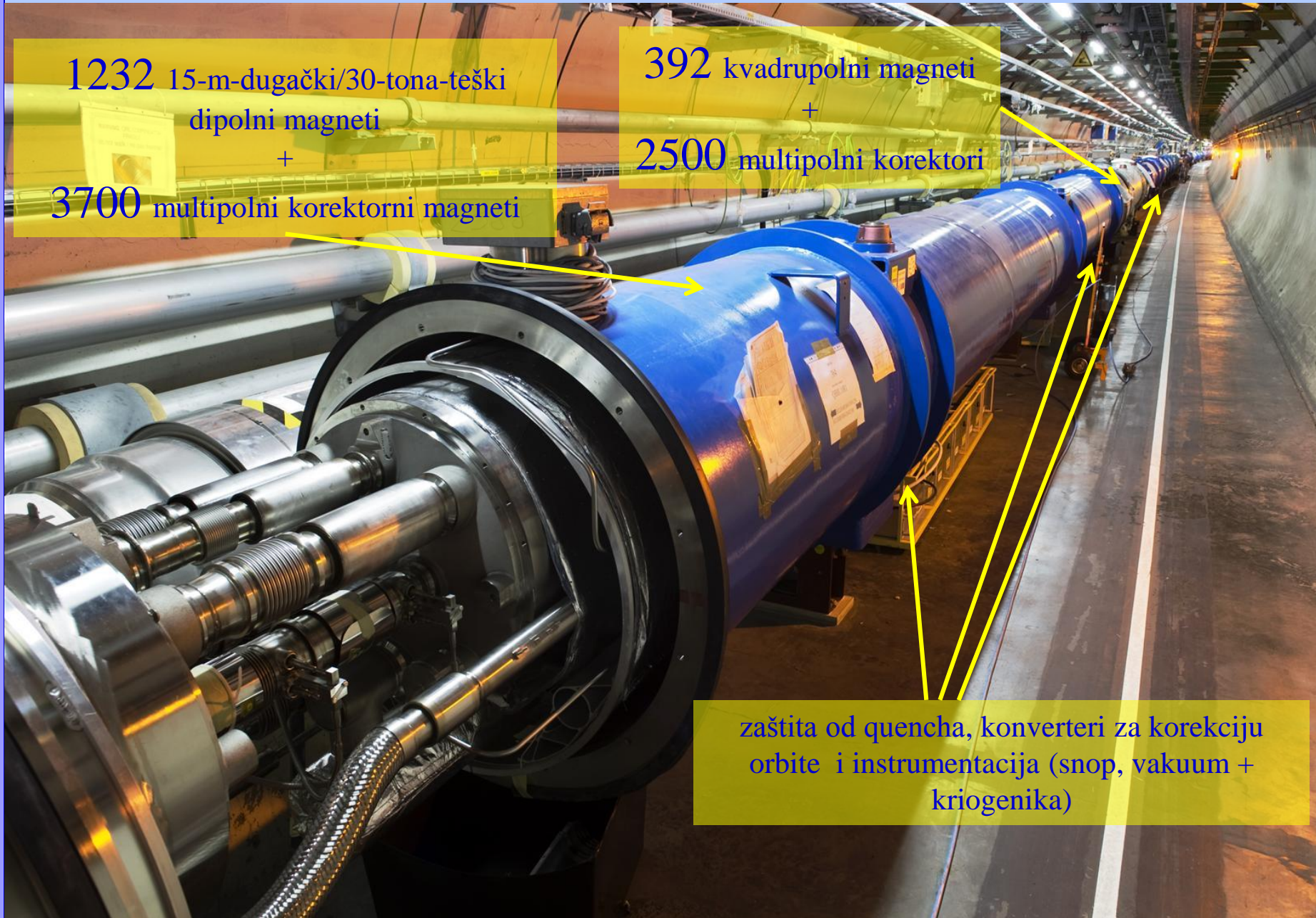
KAKO TO IZGLEDA U REALNOSTI



26/02/2010

CERN and The Large Hadron Collider

M.Pojer



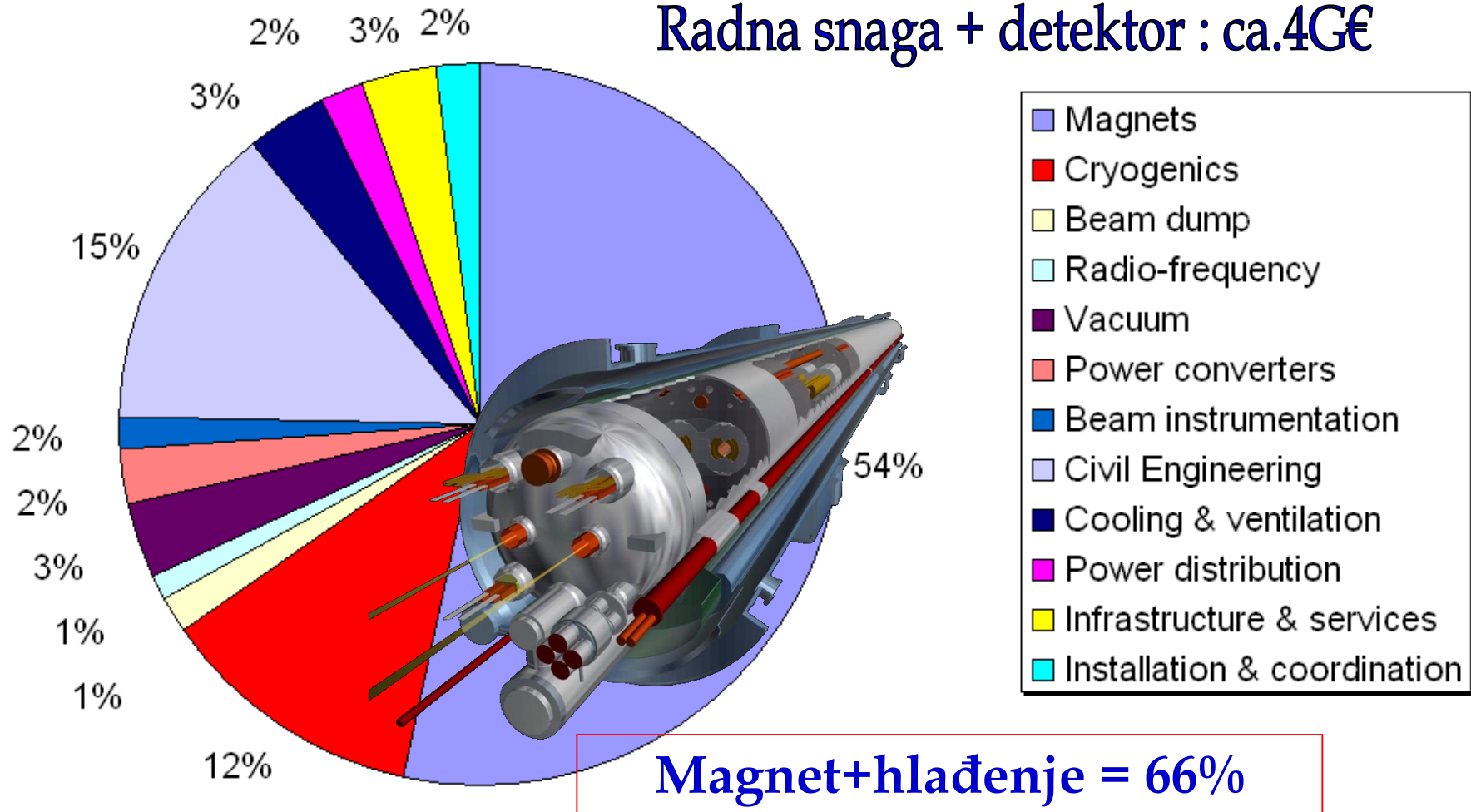
1232 15-m-dugački/30-tona-teški
dipolni magneti
+
3700 multipolni korekturni magneti

392 kvadrupolni magneti
+
2500 multipolni korektori

zaštita od quenča, konverteri za korekciju
orbite i instrumentacija (snop, vakuum +
kriogenika)

LHC Mašina: 2.2 G€ (material+vanjski rad)

Radna snaga + detektor : ca.4G€



Konceptualno pitanje

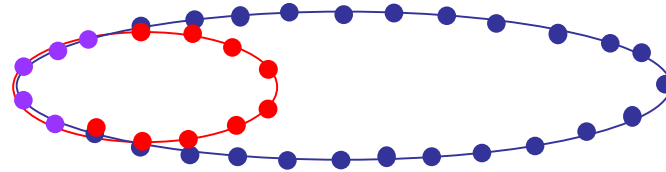
Supravodljive magnetne koristimo jer:

- a) tako možemo ubrzavati više čestica
- b) tako možemo imati veći sudarivač
- c) su troškovi kad akcelerator radi manji
- d) jer ih je lakše napraviti



ZAŠTO SUPRAVODLJIVI MAGNETI?

Manji radijus, manji broj čestica u akceleratoru, manji akcelerator



Štedi energiju ALI komplicirana konstrukcija

Dipolni magnet

Dipolni magnet, savija putanju u horizontalnoj ravnini (vertikalno polje)

$$F_x = -ev_s B_y$$

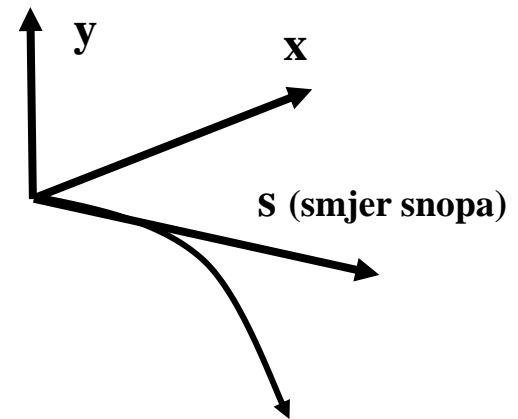
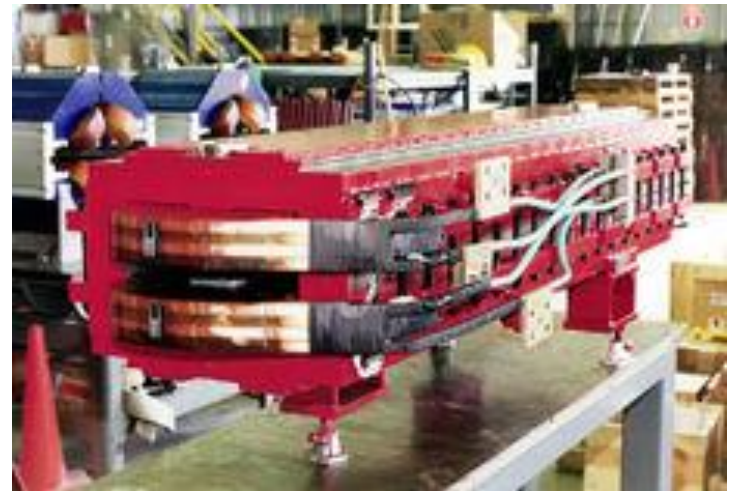
$$F_r = mv_s^2 / \rho$$

$$p = mv_s$$

$$\frac{1}{\rho(x, y, s)} = \frac{e}{p} B_y(x, y, s)$$

$$B\rho = \frac{p}{e}$$

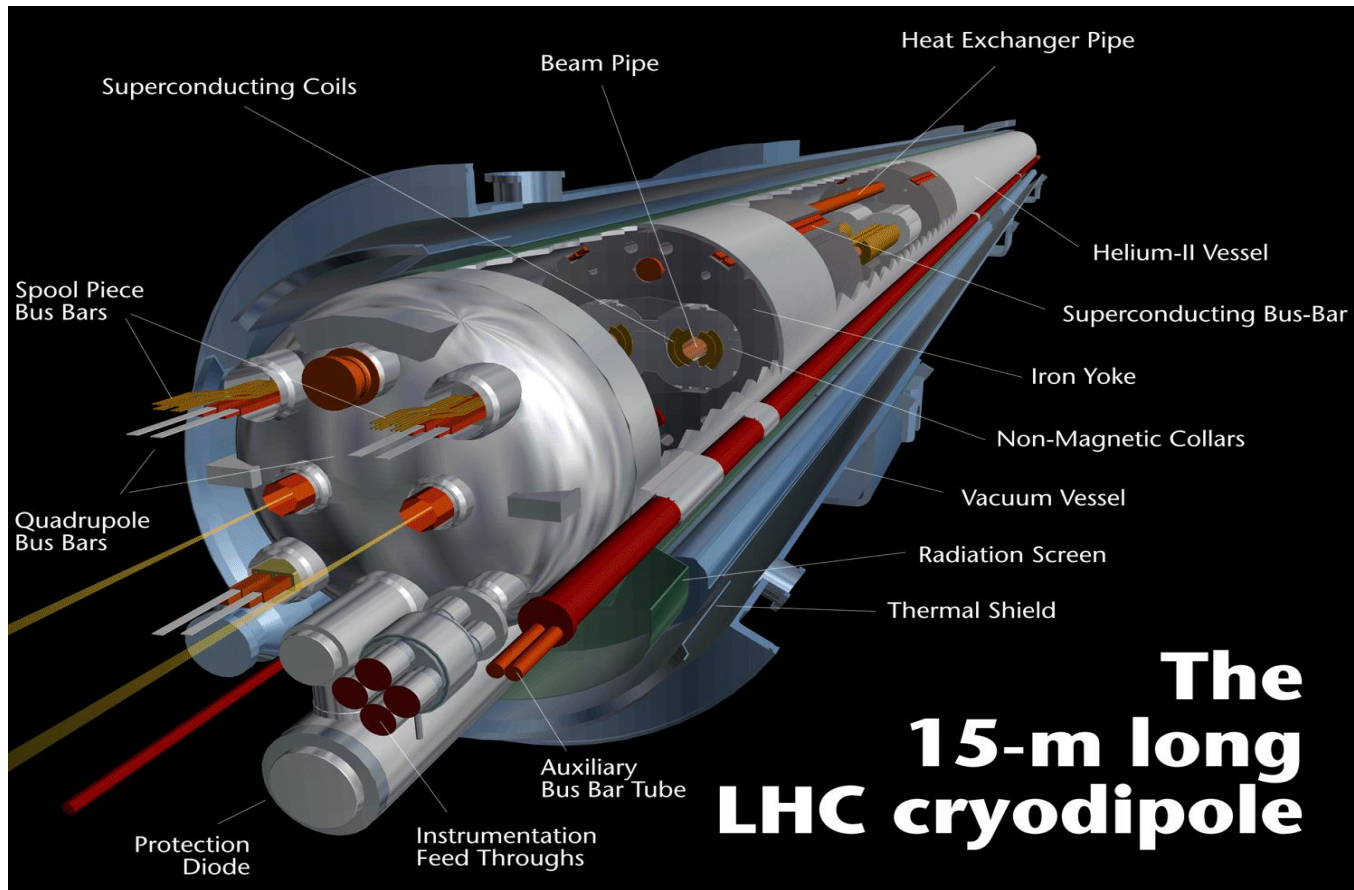
”Magnetic rigidity”



Supravodljivi Dipol za LHC

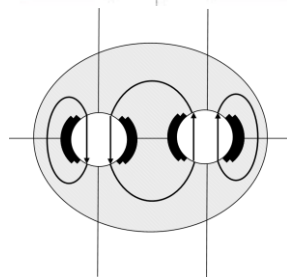
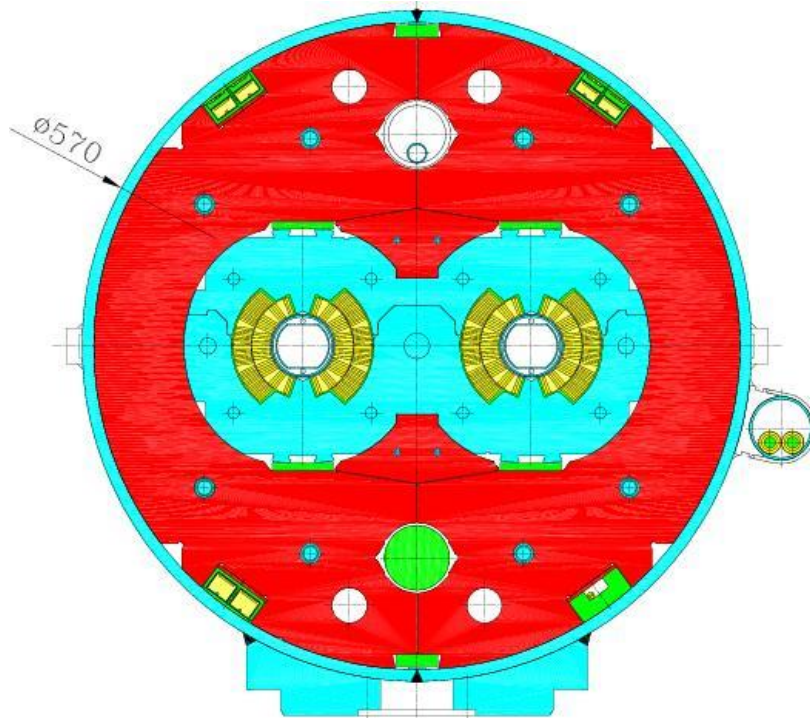
LHC dipole (1232 + rezerve) 3 firme (Njemačka, Francuska i Italija, high tech projekt)

TEHNOLOGIJA



LHC Dipole

TEHNOLOGIJA



“Two in one”
konstrukcija

Radna temperatura
1.9 K !

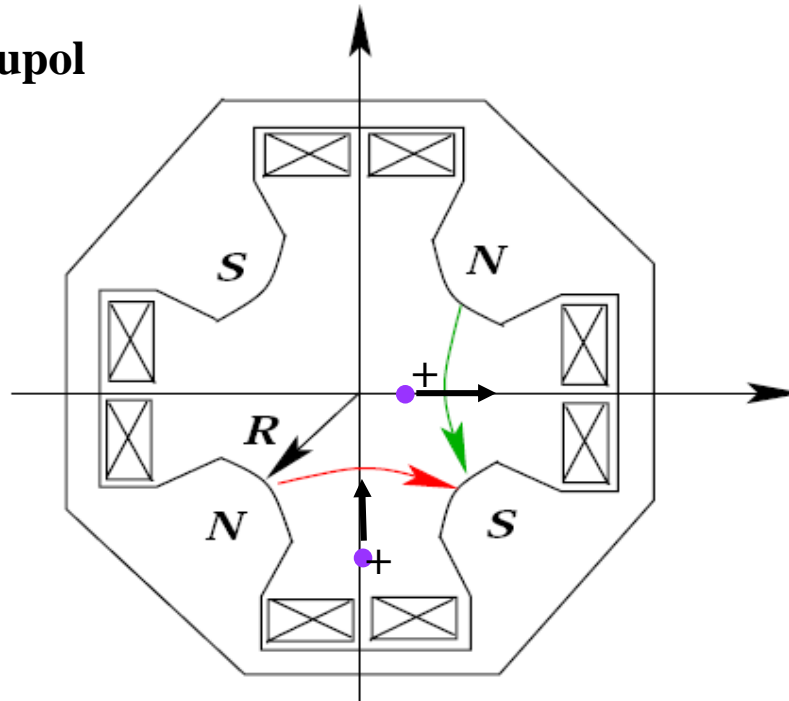
Najhladnije mjesto
u svemiru ... !!!



Fokusiranje: Kvadrupol

Čestice se moraju fokusirati da bi ostale u akceleratoru

Kvadrupol



Pozitivne čestice se gibaju prema nama: Defokusiranje u horizontalnoj ravnini, a fokusiranje u vertikalnoj ravnini.

$$\frac{d\vec{p}}{dt} = Q * (\vec{E} + \vec{v} \times \vec{B})$$

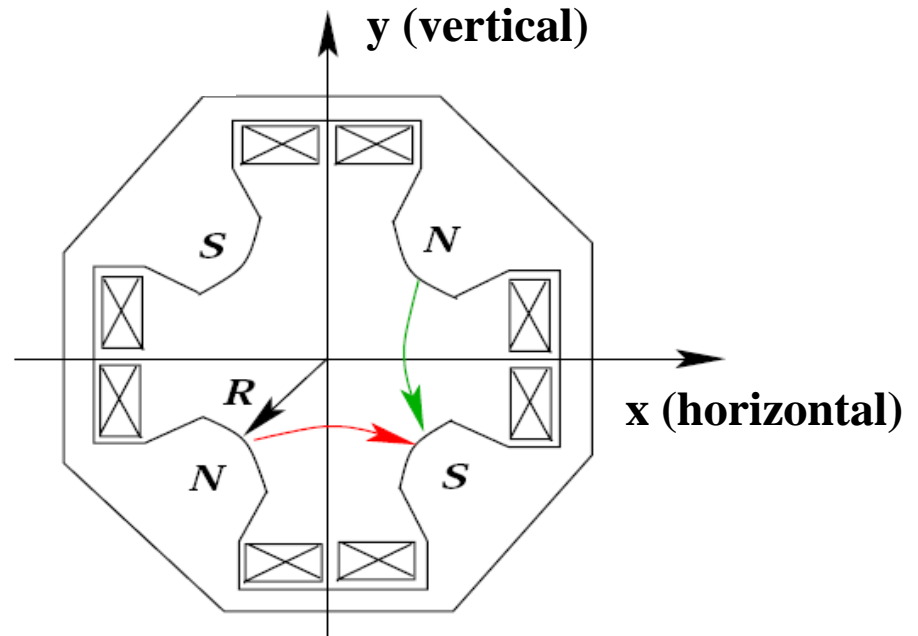
Kvadrupol 2

$$B_x = -g \cdot y$$

$$B_y = -g \cdot x$$

$$F_x = g \cdot x$$

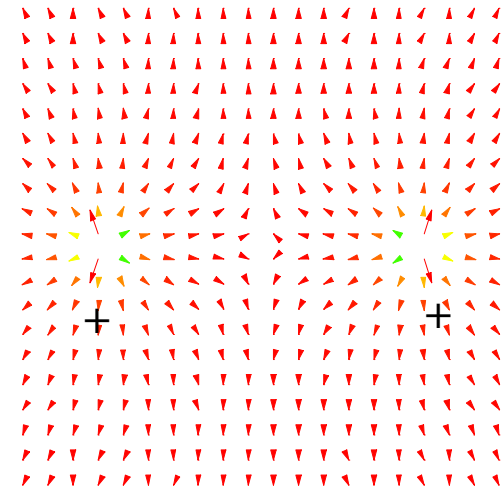
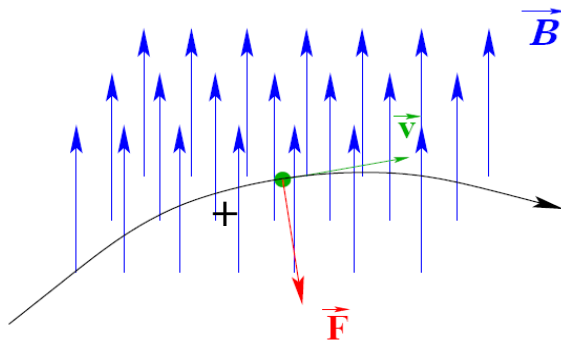
$$F_y = -g \cdot y$$



Sila je proporcionalna x i y . Više se svijaju dalje čestice.

Efekti zbog drugih čestica

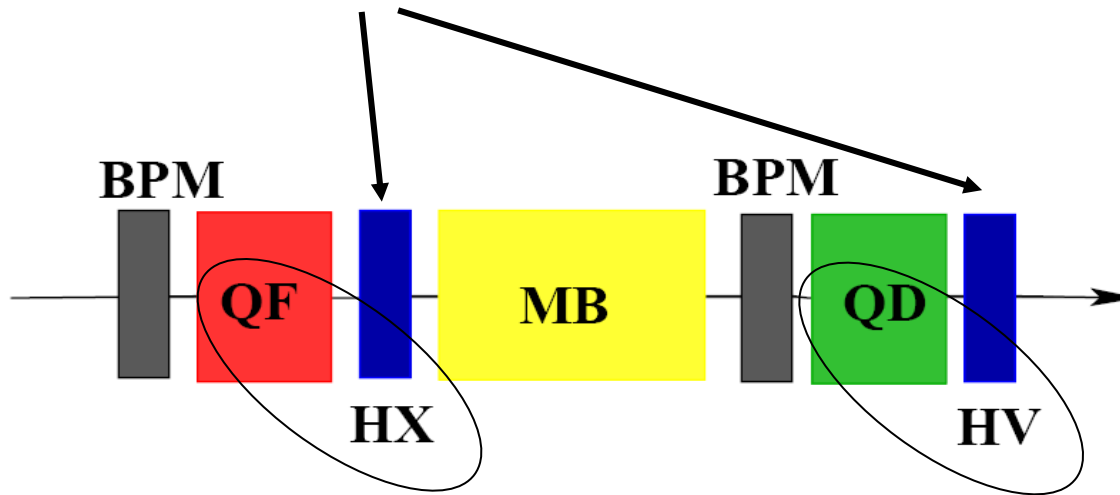
FOKUSIRANJE



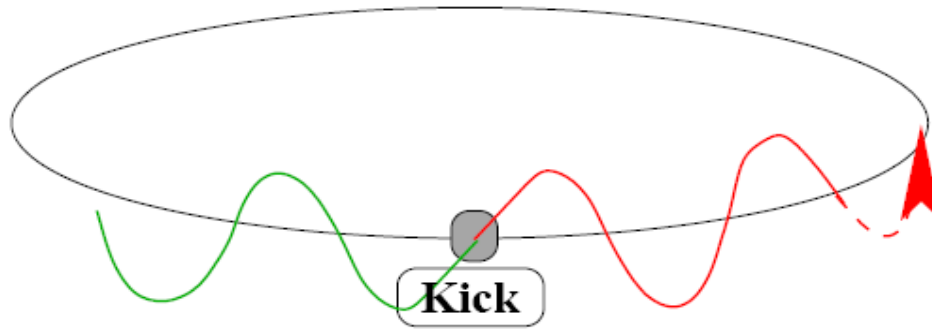
$$\frac{d\vec{p}}{dt} = Q * \left(\vec{E} + \vec{v} \times \vec{B} \right)$$

Potrebna je korekcija polja kvadrupola ...

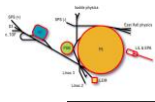
Beam Position Monitors se upotrebljavaju da se mjeri centar snopa pored kvadrupola, snop mora biti u središtu. Mali dipolni magneti se koriste da bi korigirali greške u poziciji...



Moguće greške



Q-broj daje broj oscilacija koje čestica napravi u jednom krugu. Ako je taj broj pozitivan cijeli broj, snop vidi uvijek istu magnetsku grešku što daje efekt rezonancije. Zbog toga Q nije cijeli broj...



Moguće greške

FOKUSIRANJE

Što treba uzeti u obzir ?:

Micanje površine Zemlje

Vlakovi

Mjesec

Godišnja doba

Građevinski radovi

...

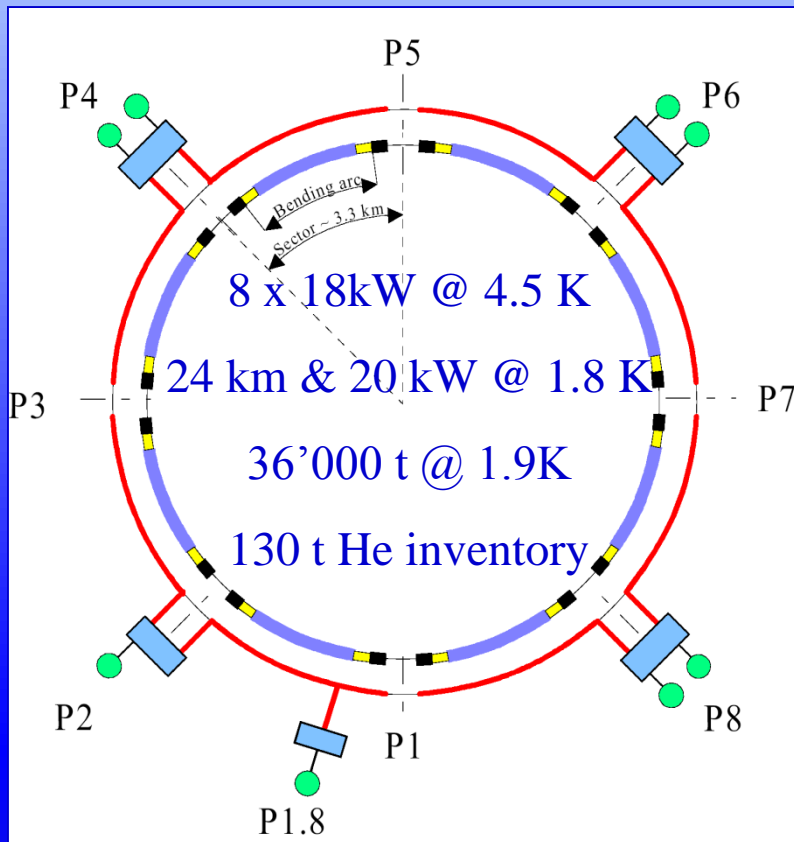
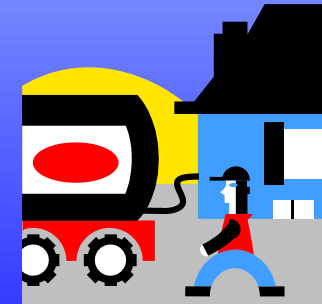
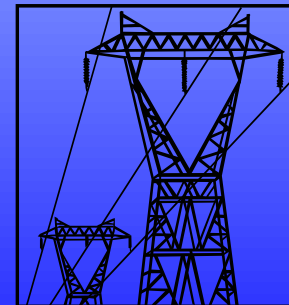
Kalibracija magneta je važna

Snaga struje

32 MW;
24 GWh/mjesečno
1.2 MCHF/mjesečno

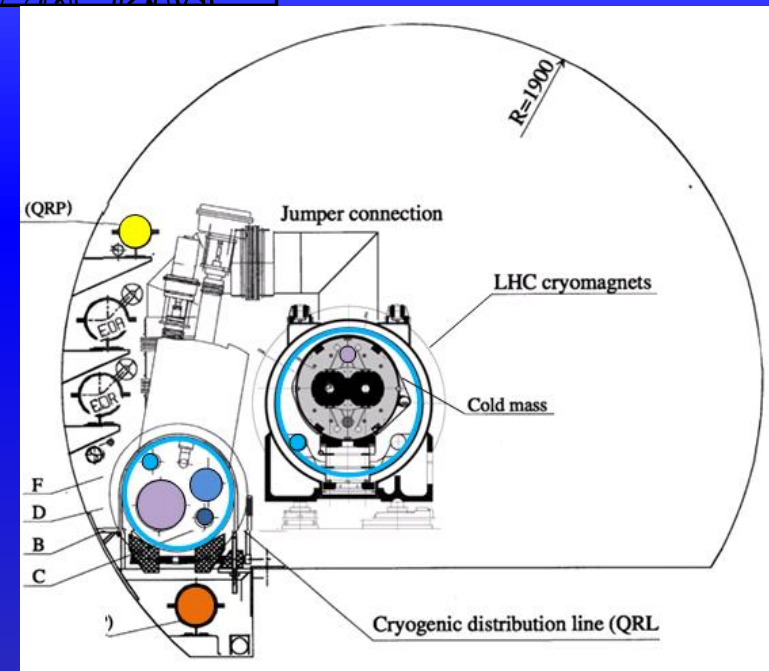
Helij i dušik

130 t of He – 4 MCHF
10'000 t of LN2 – 1.6 MCHF



Legend:

- QRL
- QUI
- Refrigerator
- Arc
- Dispersion Suppressors
- Long Straight Section



Example: LHC 1

EXAMPLE: LHC

Table 2.1: LHC beam parameters relevant for the peak luminosity

		Injection	Collision
Beam Data			
Proton energy	[GeV]	450	7000
Relativistic gamma		479.6	7461
Number of particles per bunch		1.15×10^{11}	
Number of bunches		2808	
Longitudinal emittance (4σ)	[eVs]	1.0	2.5 ^a
Transverse normalized emittance	[$\mu\text{m rad}$]	3.5 ^b	3.75
Circulating beam current	[A]	0.582	
Stored energy per beam	[MJ]	23.3	362
Peak Luminosity Related Data			
RMS bunch length ^c	cm	11.24	7.55
RMS beam size at the IP1 and IP5 ^d	μm	375.2	16.7
RMS beam size at the IP2 and IP8 ^e	μm	279.6	70.9
Geometric luminosity reduction factor F^f		-	0.836
Peak luminosity in IP1 and IP5	[$\text{cm}^{-2}\text{sec}^{-1}$]	-	1.0×10^{34}
Peak luminosity per bunch crossing in IP1 and IP5	[$\text{cm}^{-2}\text{sec}^{-1}$]	-	3.56×10^{30}

LINEARNI SUDARIVAČI -

Cijena proporcionalna energiji snopa

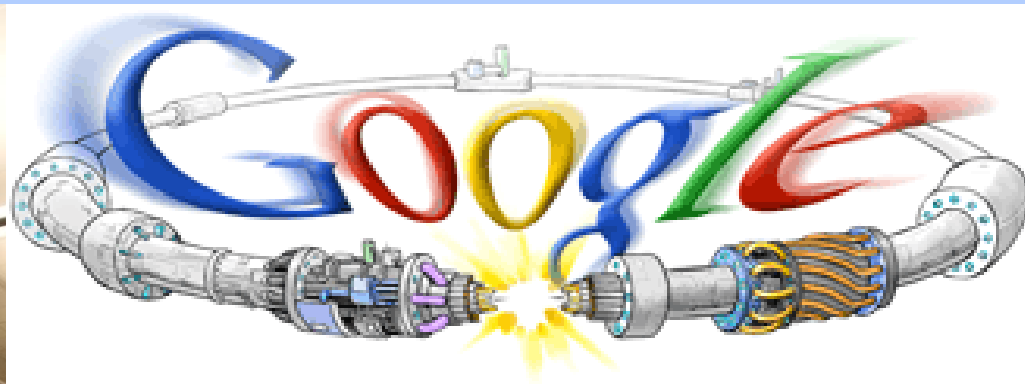
KRUŽNI SUDARIVAČI

Cijena proporcionalna kvadratu energije snopa

International Linear Collider (ILC), 35 km, 500 GeV, electron-positron

Compact Linear Collider (CLIC), 38 km, 3 TeV, electron-positron

Beam Commissioning in 2008: September 10



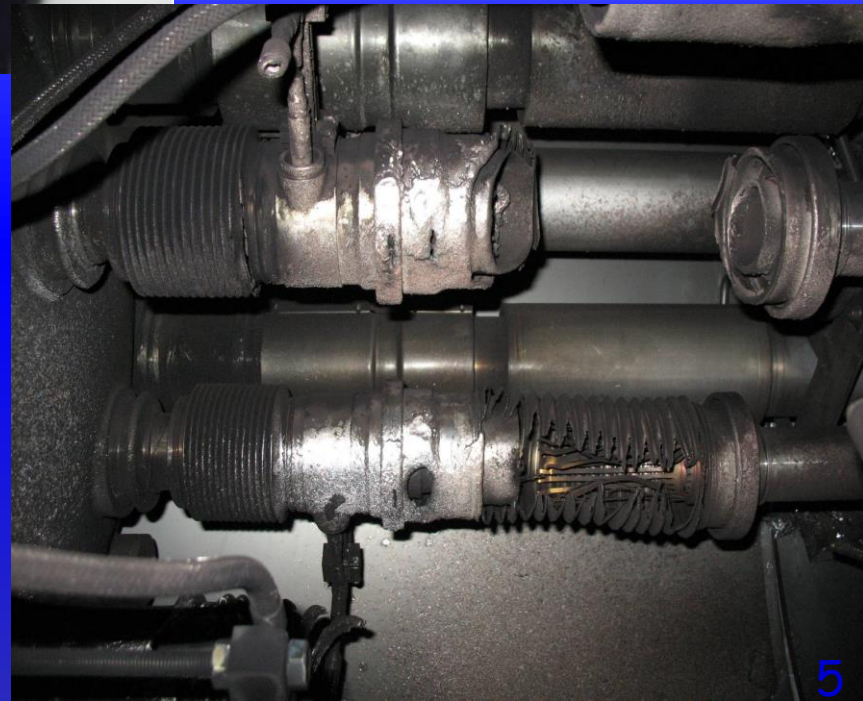
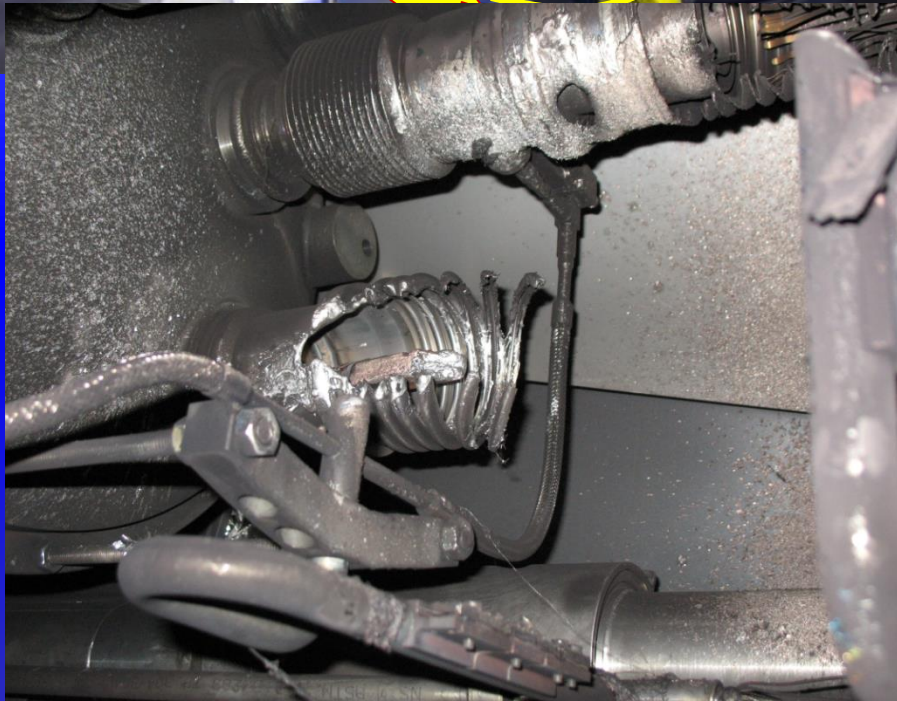
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3-4

Iskra je probušila dio gdje je zatvoren helij za hlađenje

Veliki val plina pod visokim tlakom putovao je u oba smjera



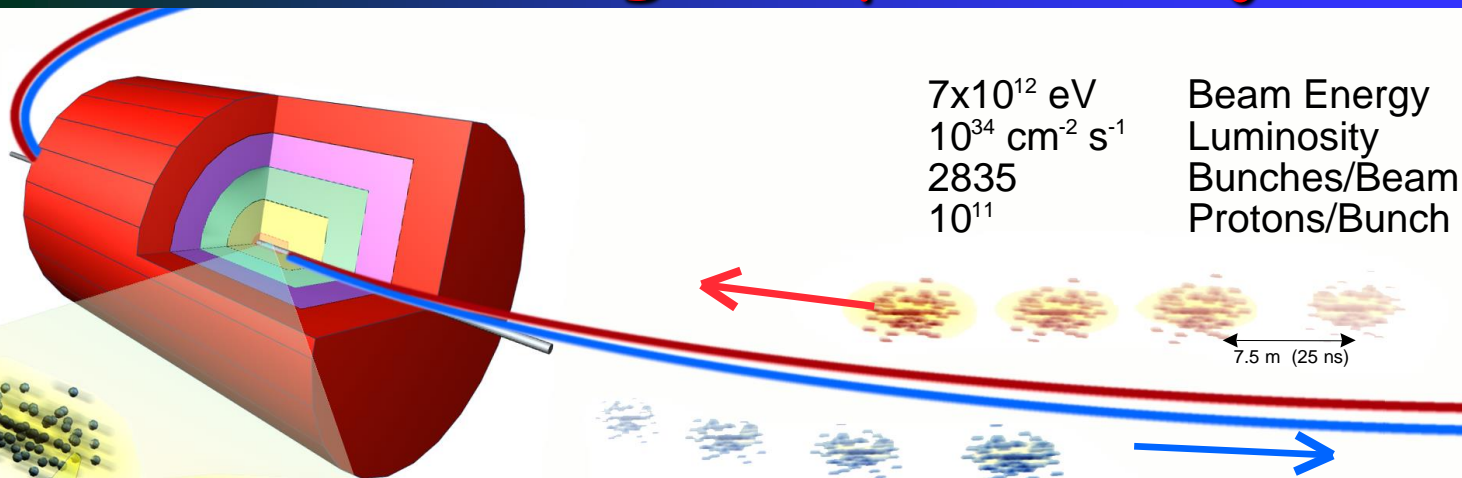
Collateral damage: magnet displacements



Collateral damage: magnet displacements



LHC sudari: igla u plastu sijena!



7×10^{12} eV
 10^{34} cm⁻² s⁻¹
 2835
 10^{11}

Beam Energy
 Luminosity
 Bunches/Beam
 Protons/Bunch

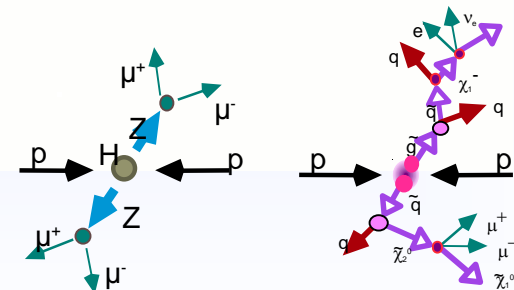
7 TeV **Proton Proton** colliding beams

Bunch Crossing $4 \cdot 10^7$ Hz

Proton Collisions 10^9 Hz

Parton Collisions

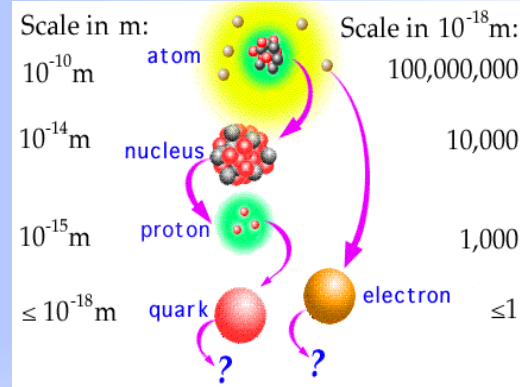
New Particle Production (Higgs, SUSY,) 10^{-5} Hz



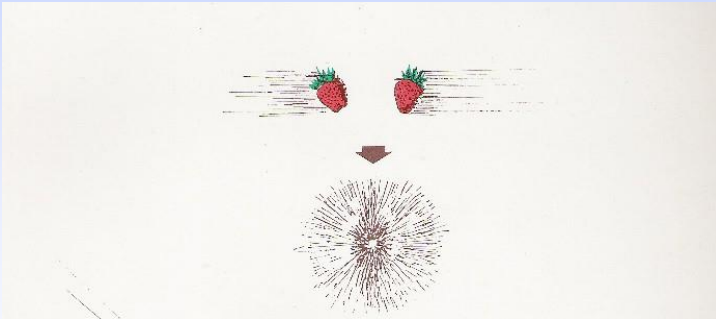
Tražimo 1 događaj od 10,000,000,000,000

Podsjetnik na temeljne koncepte

1) gledanje malih dimenzija traži velike energije



2) masa je isto što i energija

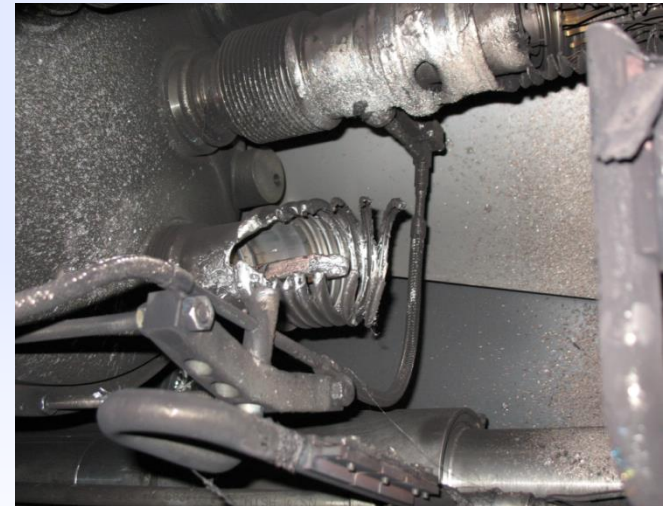


Podsjetnik na temeljne koncepte

3) Snop čestica koji kruži gubi energiju zračenjem

$$\Delta E \sim \frac{1}{R} \left(\frac{E_{SNOP}}{m} \right)^4$$

4) Ne treba odustati ako se pojave problemi



Hvala na pažnji!

