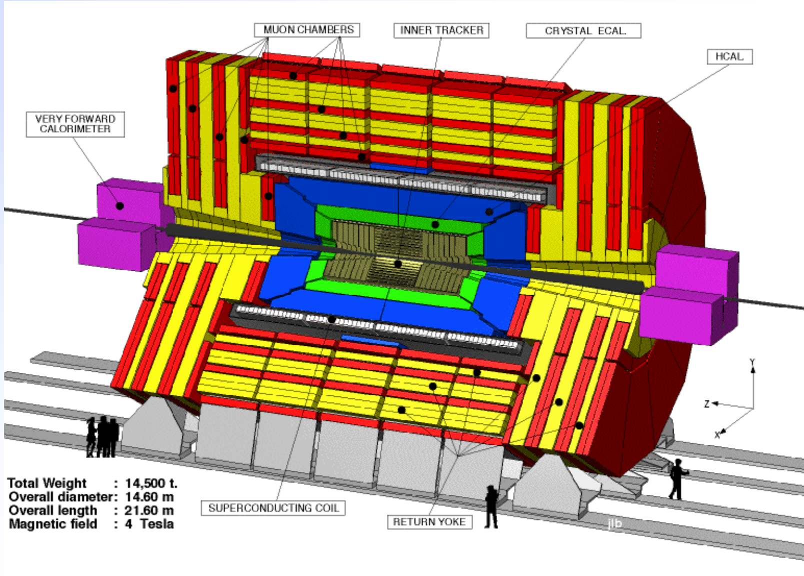
Croatian Teacher Programme

14-18 April 2019

CERN

Ubrzivači i detektori u fizici elementarnih čestica

Mirko Planinić
PMF



I zašto je Hrvatska postala članica CERN-a?

Fabiola Ginotti

28.veljače 2019. Tehnički muzej

Blaženka Divjak

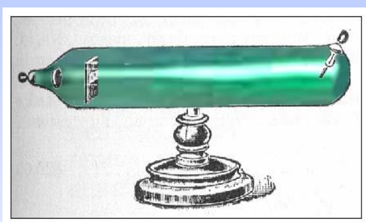
Da ne bi bilo ...

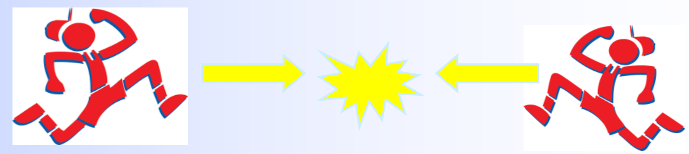
Nego ...

Sadržaj

- Od ubrzivača do suprasudarivača

- Linearni i kružni ubrzivači
  - Pokus





- Leptonski, hadronski sudarivači

- Interakcija čestica s materijom

- Sažetak

Mirko Planinić

Danas na rasporedu

Monday, 15 April

08:30 → 12:00 **Lectures** — 40-S2-D01 - Salle Dirac

- **08:30** **Introduction to CERN** ¶ — 1h
  Speaker: Jeff Wiener (CERN)
  CERN - a short and ... | HRTP19_Basics.pdf | HRTP19_Objectives...

- **09:45** **Particle Physics 1** — 1h
  Speaker: Vuko Brigljevic (Rudjer Boskovic Institute (HR))

- **11:00** **Particle Detectors 1** — 1h
  Speaker: Mirko Planinic (University of Zagreb (HR))

12:00 → 13:30 **Lunch break** — 1h 30m

Danas na rasporedu

13:30 → 17:45 **Workshops & Visits**

13:30 **Cloud Chamber Workshop & Microcosm+GLOBE** 3h

The whole group meets in front of S'Cool LAB at 13:30!

Group 1

13:30-15:00 Microcosm & GLOBE exhibitions
15:00-16:30 Cloud Chamber Workshop

Group 2

13:30-15:00 Cloud Chamber Workshop
15:00-16:30 Microcosm & GLOBE exhibitions

16:30 **Synchrocyclotron - Group 1** 30m

This group meets at the CERN Main Reception in Building 33 at 16:30!

17:00 **Synchrocyclotron - Group 2** ¶ 30m

This group meets at the CERN Main Reception in Building 33 at 17:00!

18:30 → 19:30 **Welcome to CERN!** 500-1-201 - Mezzanine

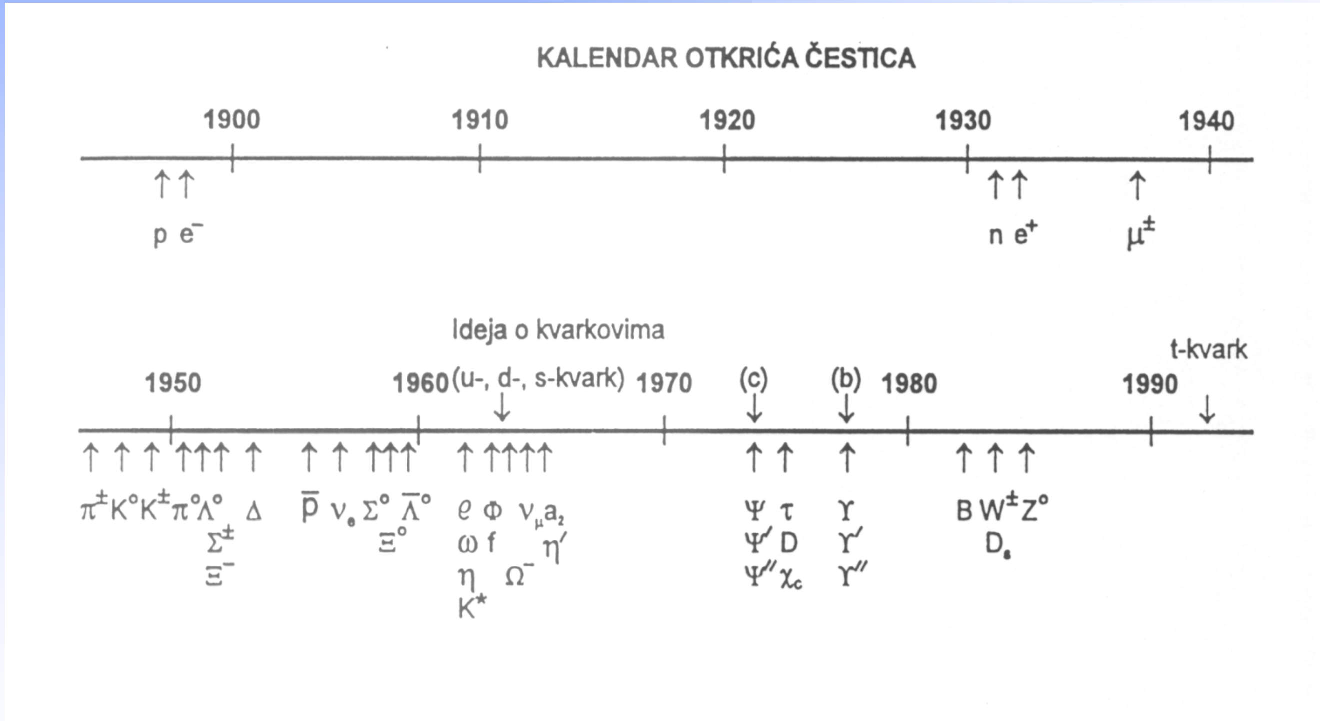
18:30 **Welcome Reception** 1h

Speakers: Anja Kranjc Horvat (University of Potsdam (DE)), Jeff Wiener (CERN)

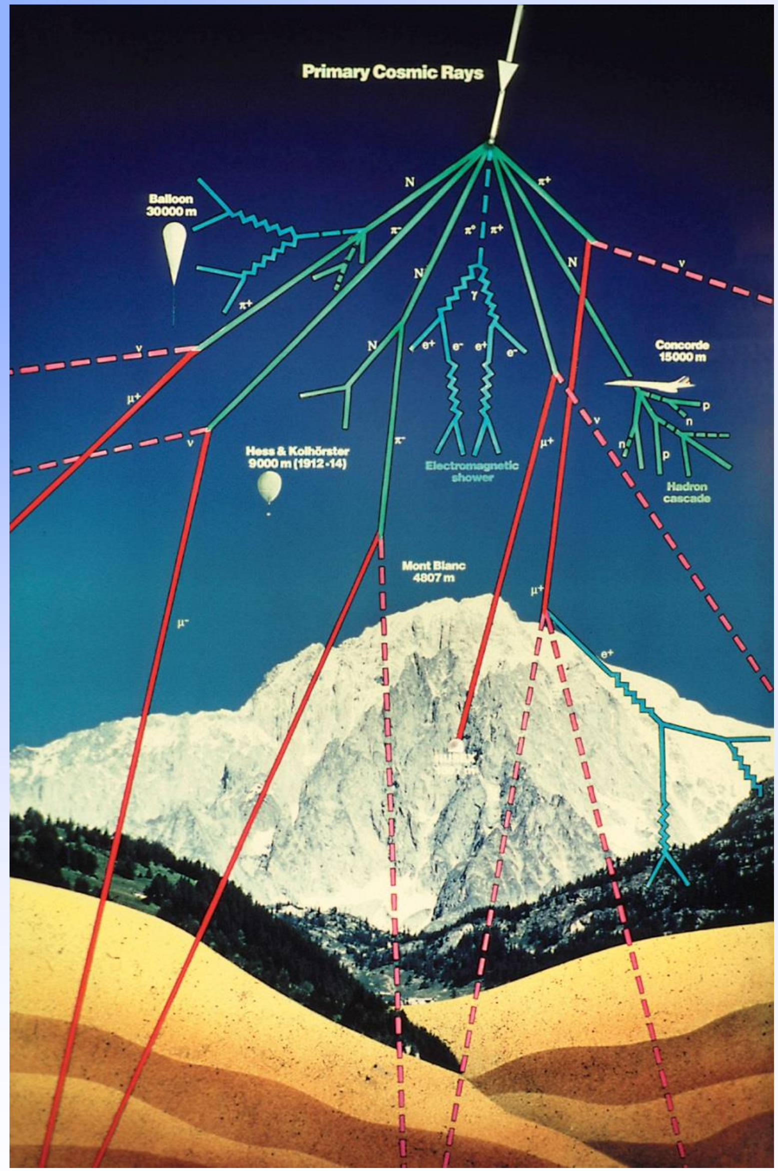
Kako smo od ubrzivača u Pisi došli do LHC-a ?

Ubrzivači i otkrića novih čestica

- Najvažnija otkrića novih čestica nakon primjene ubrzivača



Možemo li koristiti kozmičke zrake ?



Mirko Planinić

Kozmičko zračenje

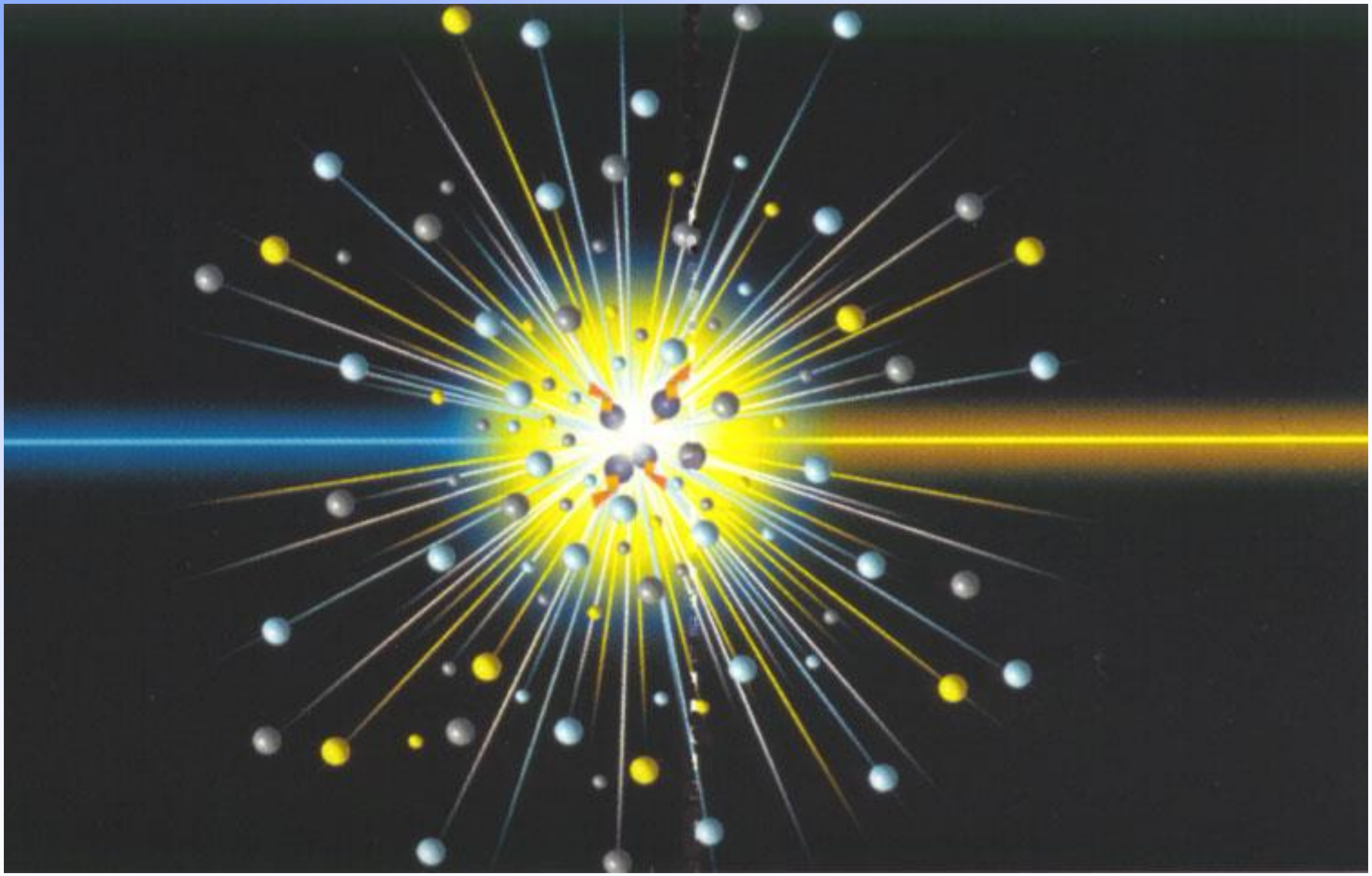
Kozmičke zrake konstantno bombardiraju Zemlju

Njihove energije mogu biti puno redova veličine iznad LHC-a

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

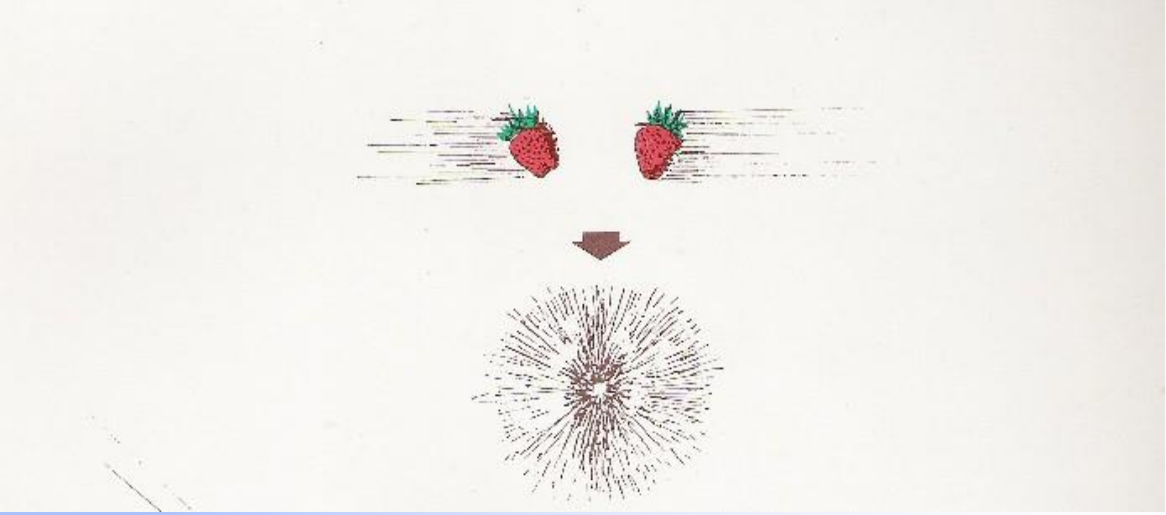
Za vidjeti najmanje čestice: potrebne su najveće energije!

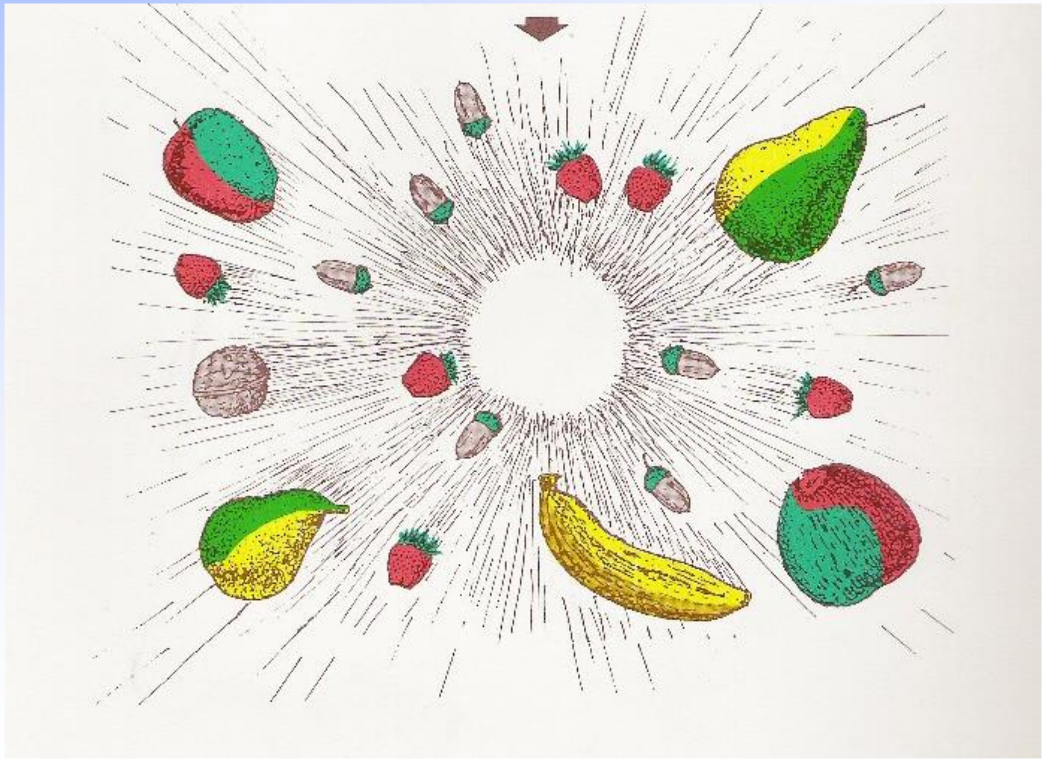
$E = mc^2$



Mirko Planinić

$E = mc^2$

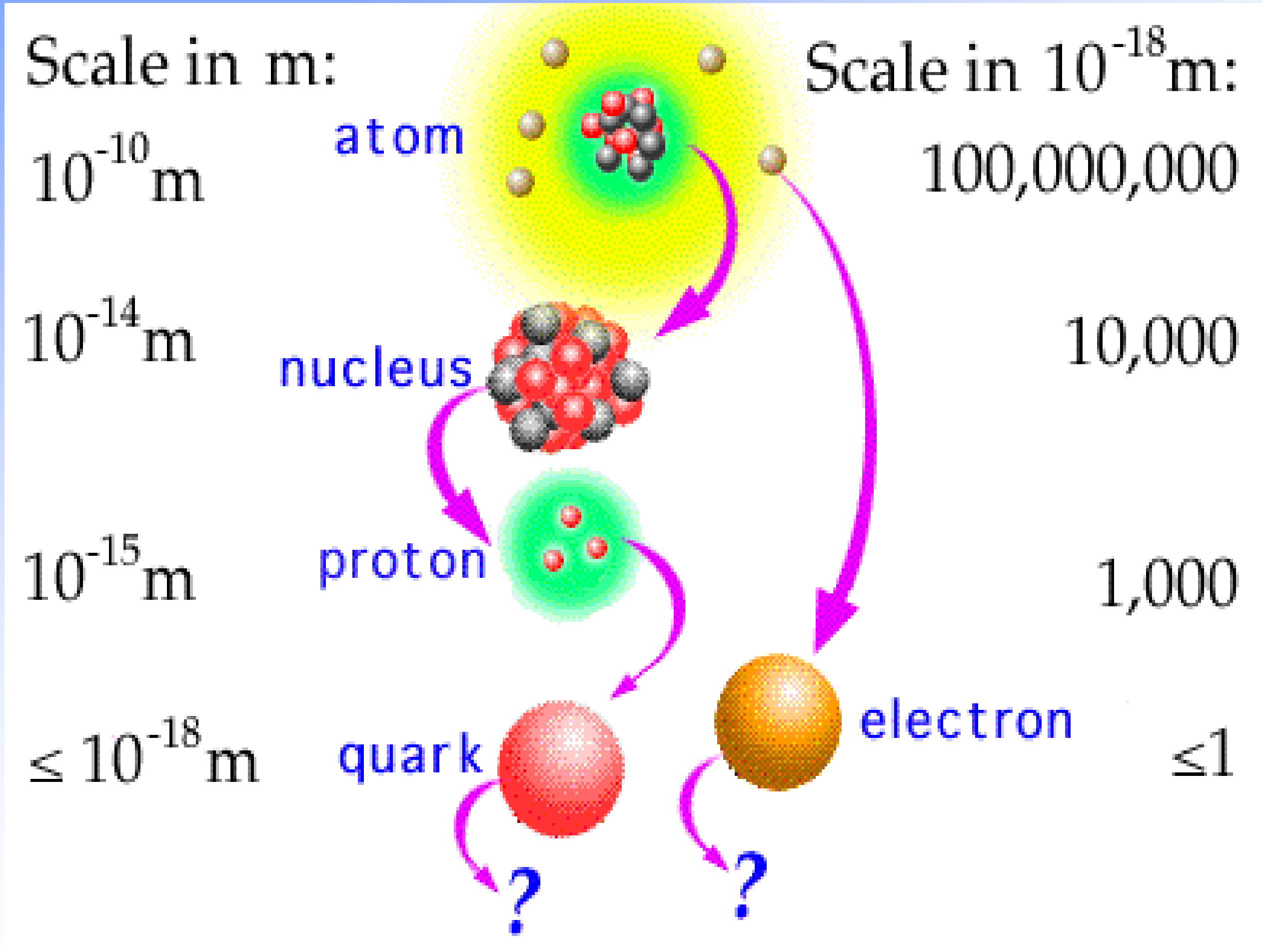




Mirko Planinić

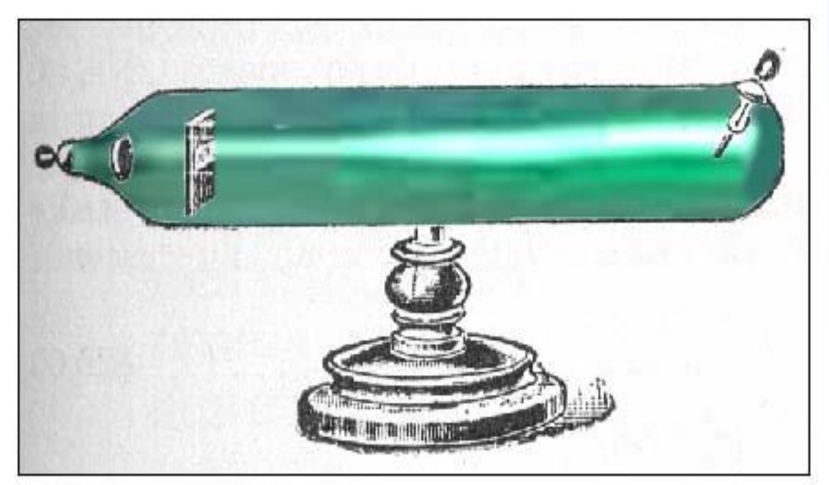
Uranjanje u subatomski svijet

- Da bismo "elektronskim mikroskopom" postigli rezoluciju $\Delta x \cong 10^{-15} m = 1 fm$ treba elektrone ubrzati na energi $E \cong \frac{\hbar c}{\Delta x} \cong 1 GeV$

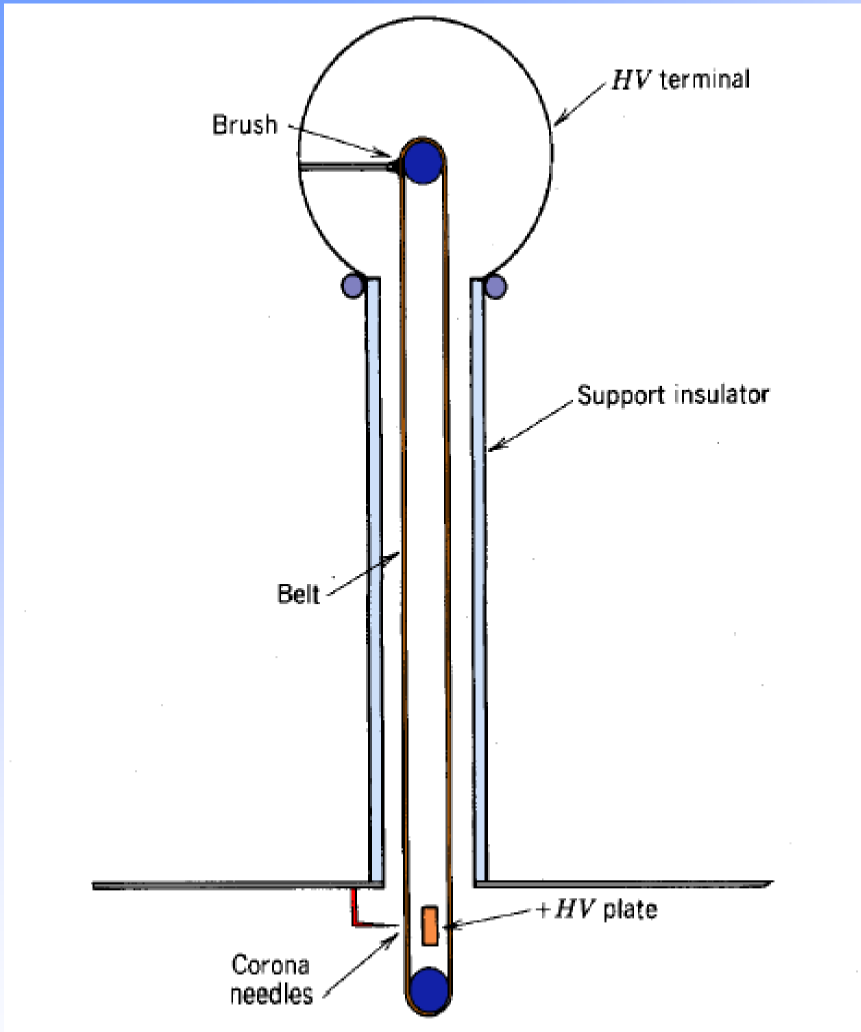


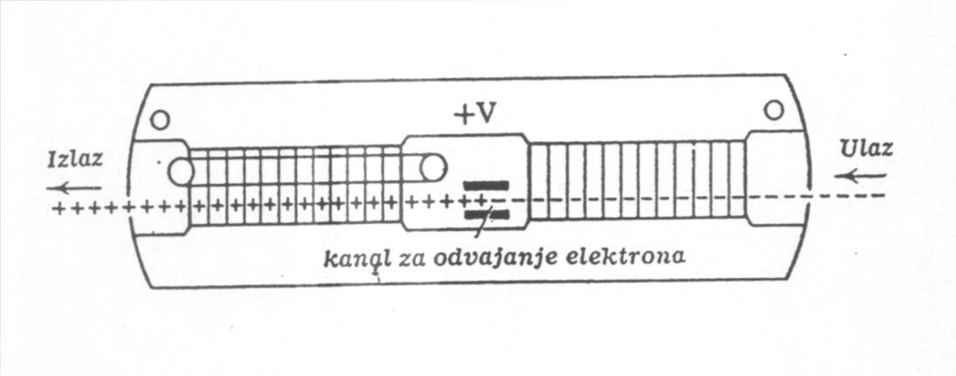
Kako ubrzati nabijenu česticu ?

POKUS !!!!



Van de Grafov ubrzivač

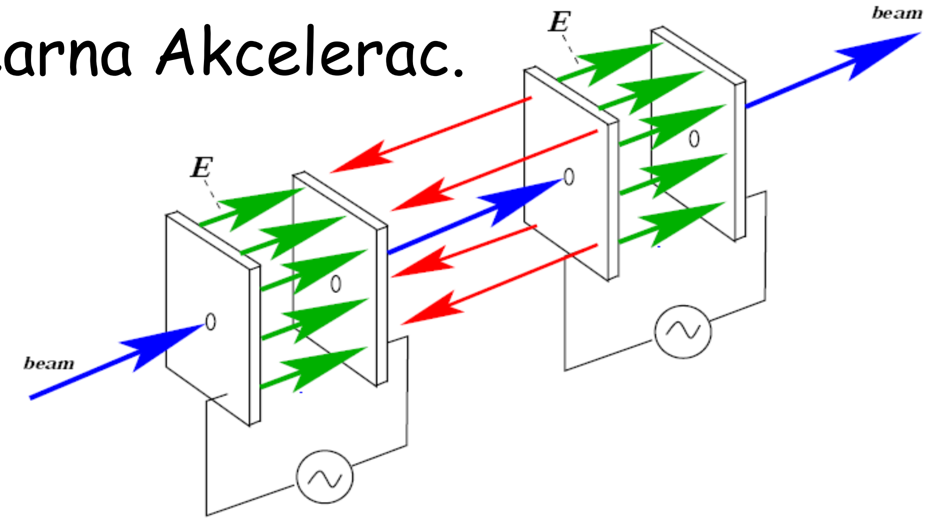




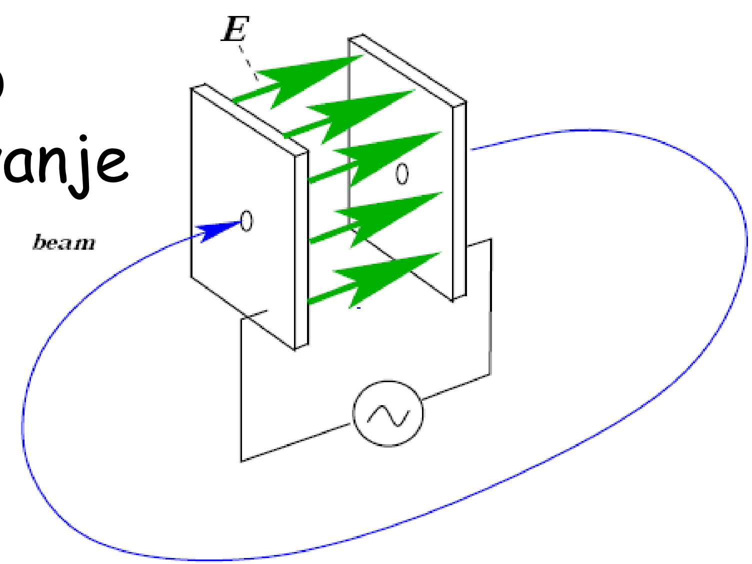
Što je ograničavajući faktor?

Vremenski promjenljiva električna polja

Linearna Akcelerac.



Kružno
ubrzavanje

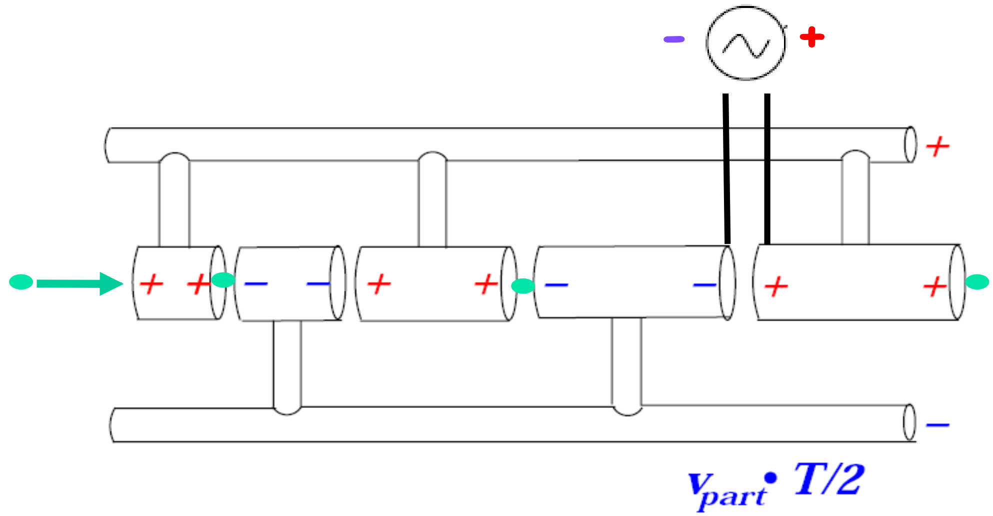


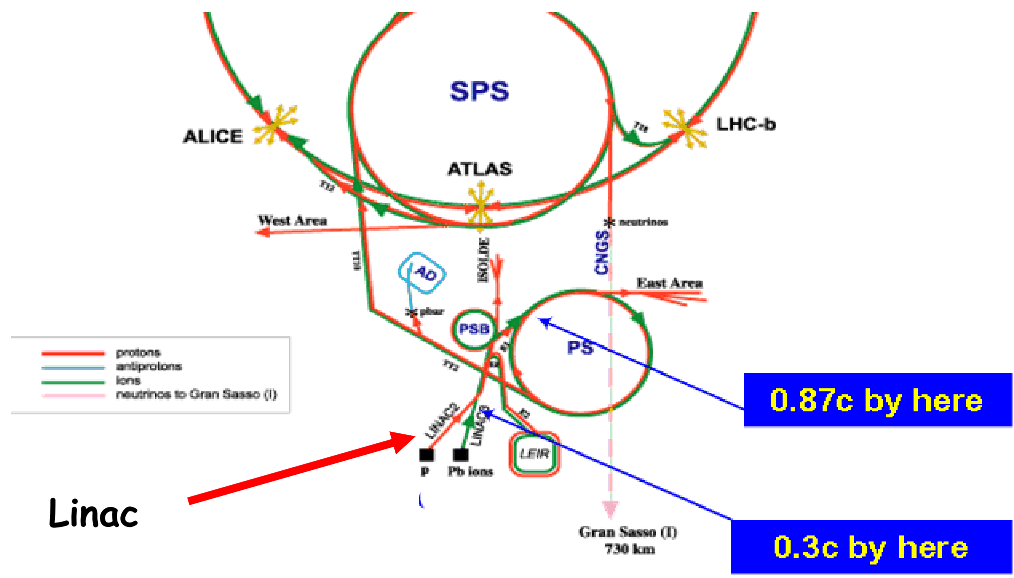
Linearni akceleratori

Linac

Wideroe

1928.





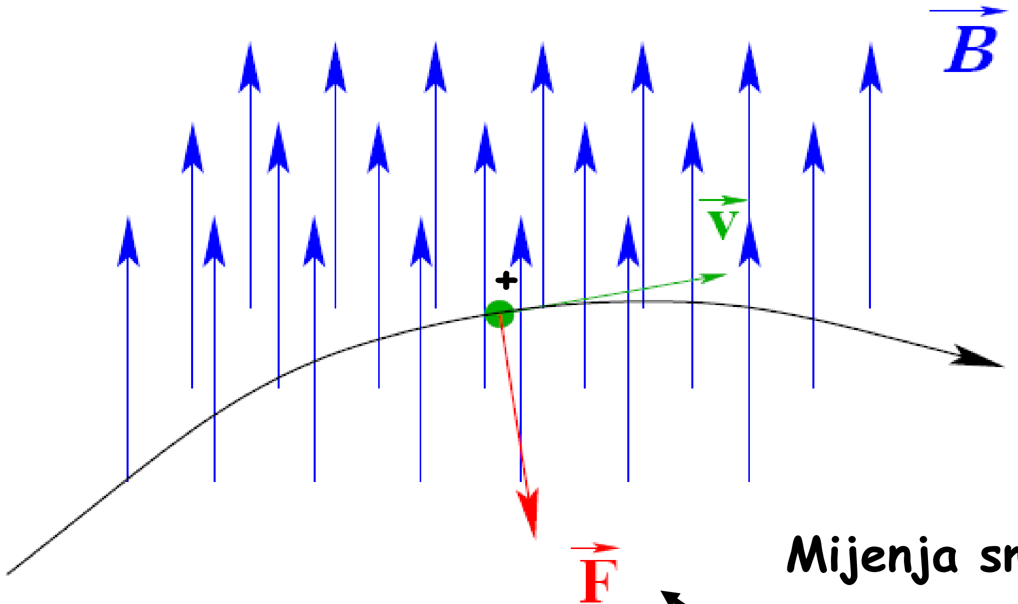
Linac

Konceptualno pitanje

Snop čestica u sudarivaču je:

a) kontinuiran
b) čestice dolaze u nakupinama

Sile na čestice



Mijenja smjer

Lorentz:

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

Ubrzava nabijene čestice

Ciklotron

Centripetalna sila=Lorentzova sila

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

Reorganizacija:

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

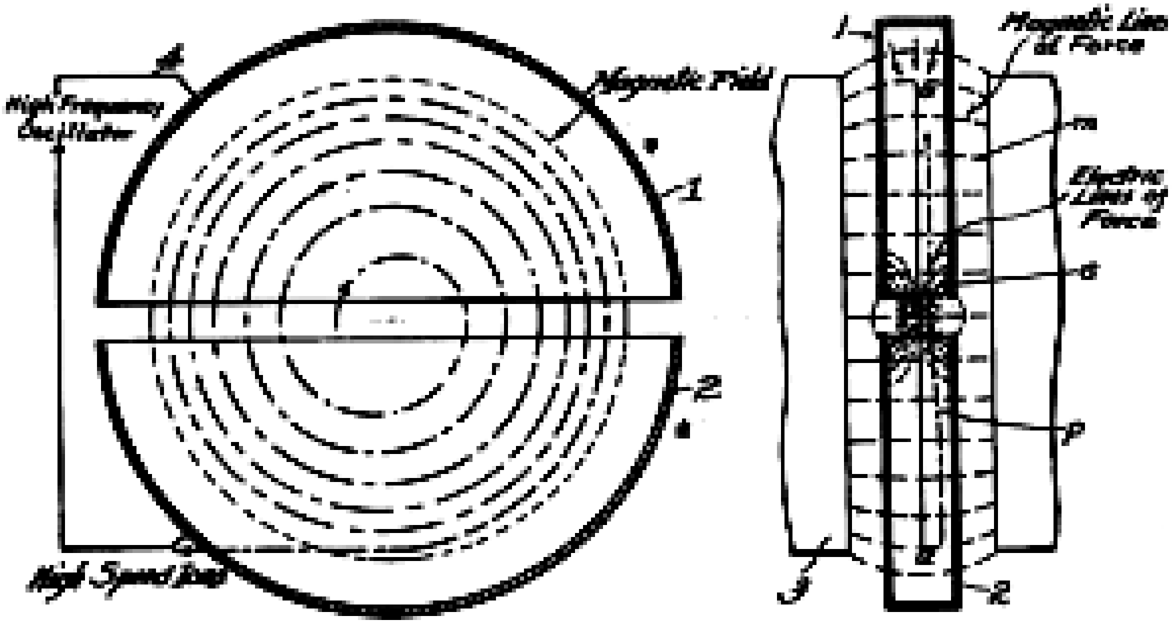
$$\downarrow$$

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

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

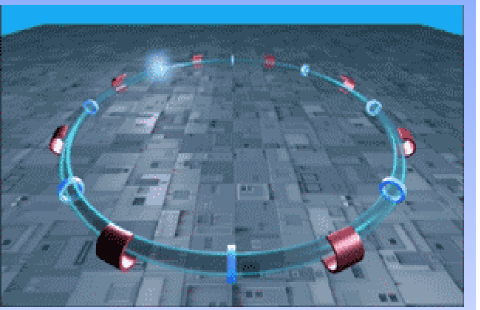
$$f = \frac{Bq}{2m\pi}$$

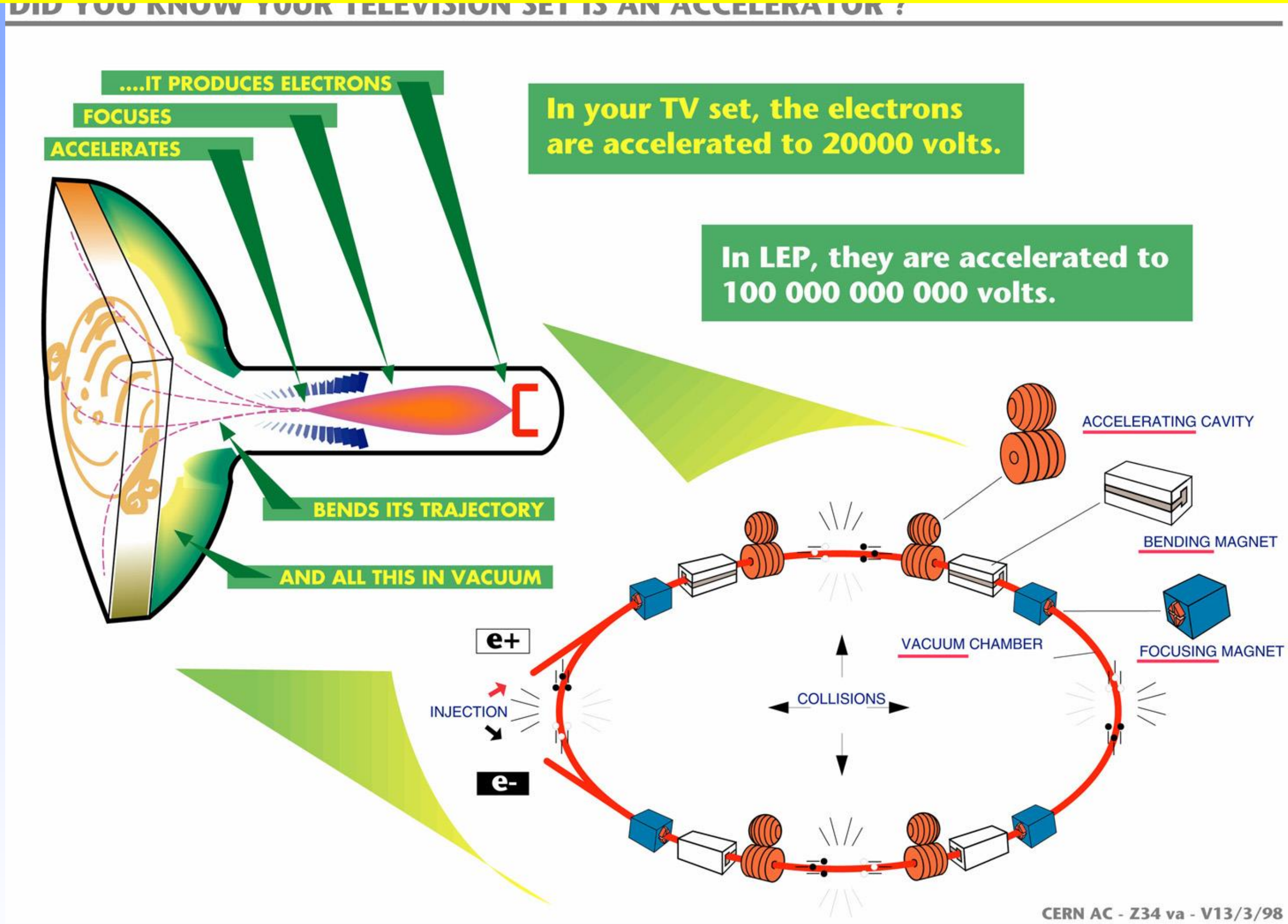
Kontinuiran snop čestica



Ubrzavanje čestica

stara televizija je ubrzivač čestica u malom!

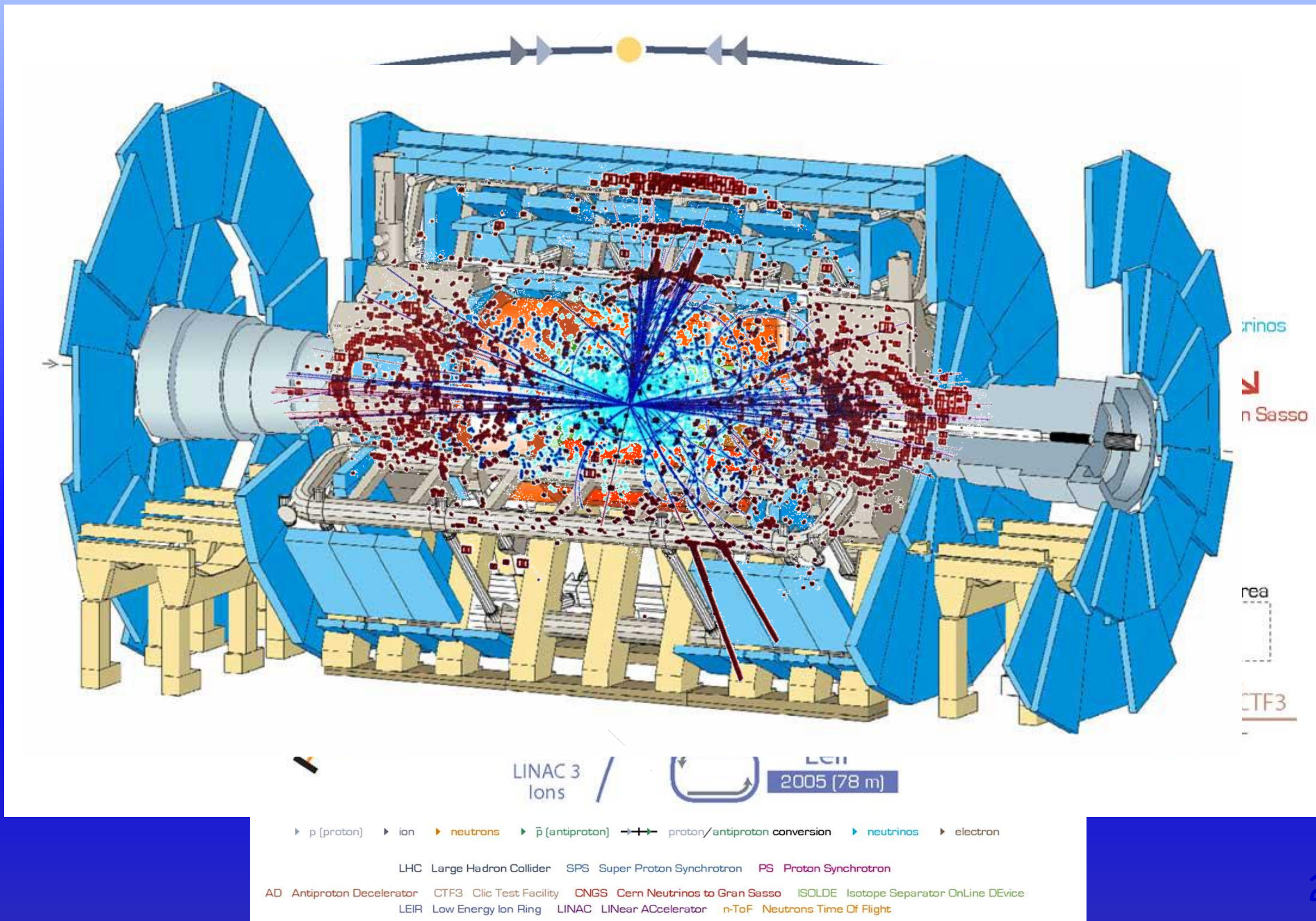




FILM

Mirko Planinić

LHC UBRZAVAČKI LANAC



Akceleratorski lanac

Nosač aviona -12 čvorova

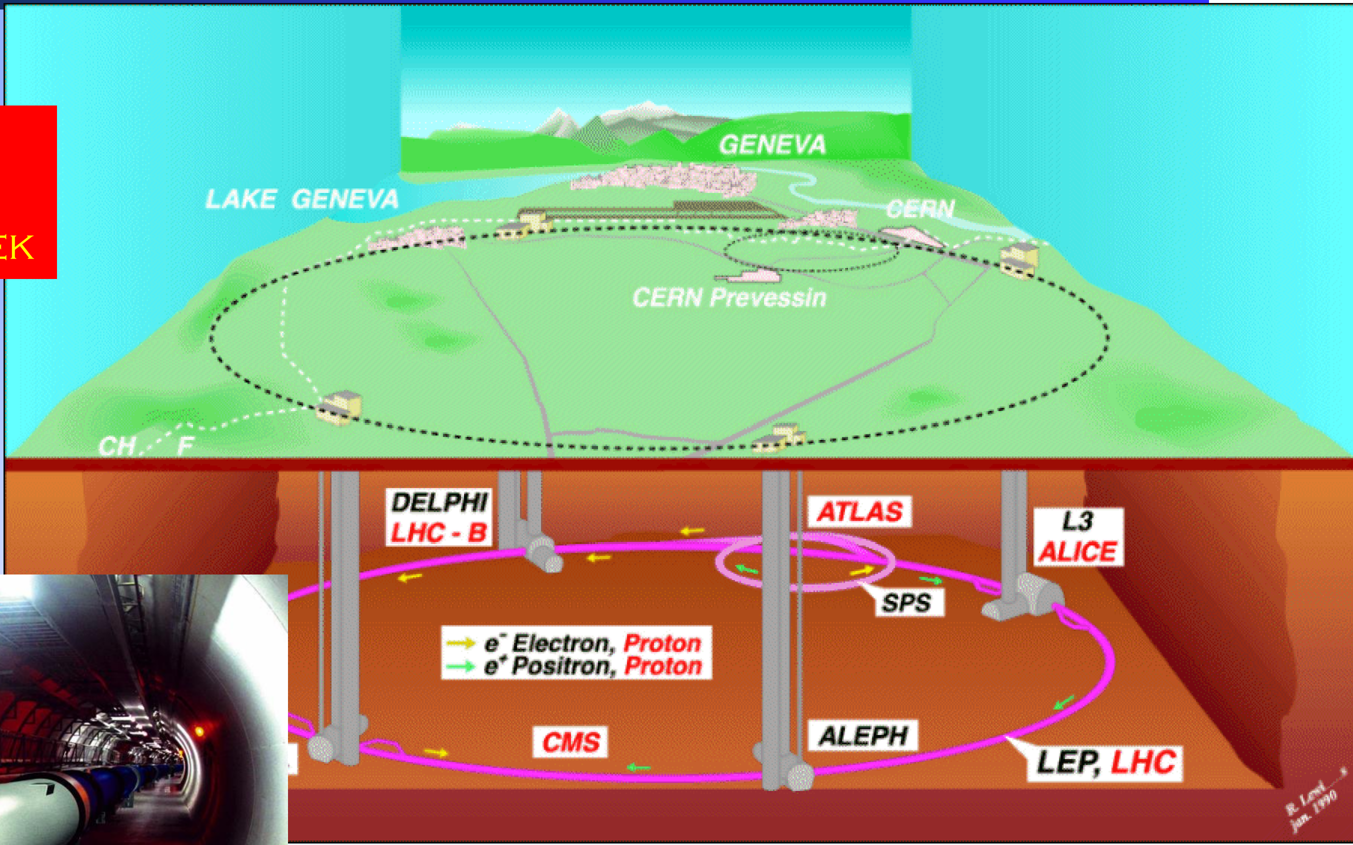
ENERGIJA SNOPA

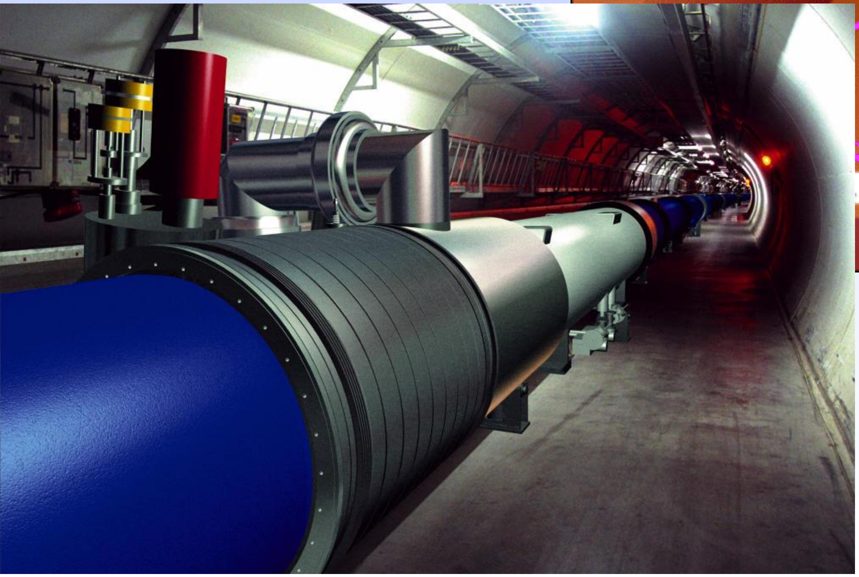
2808 nakupina, 1.15 x 10^{11} protona po nakupini

Snop putuje kroz vrlo hladnu, vrlo mračnu, vrlo tanku cijev...

LHC – Zašto mu se divimo?

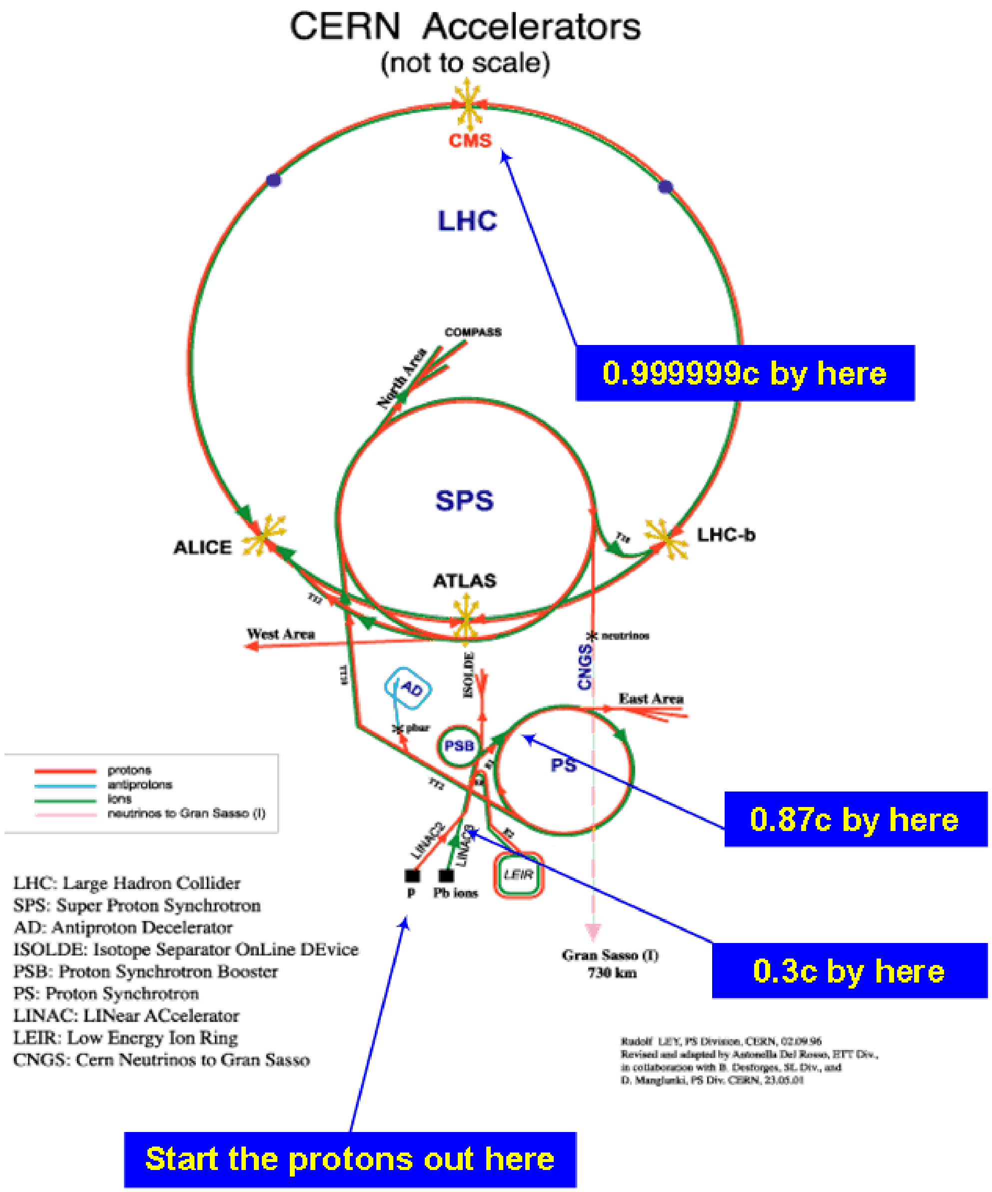
Proton-proton sudari
E = 7000 + 7000 GeV
800 million sudara/sek





Supravodljivi magneti

Akceleratori i LHC eksperimenti na CERN-u



Energije:

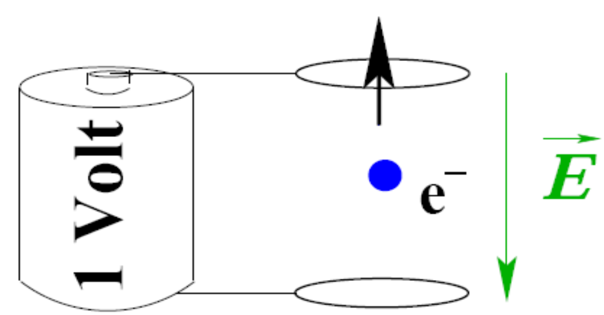
Linac 50 MeV

PSB 1.4 GeV

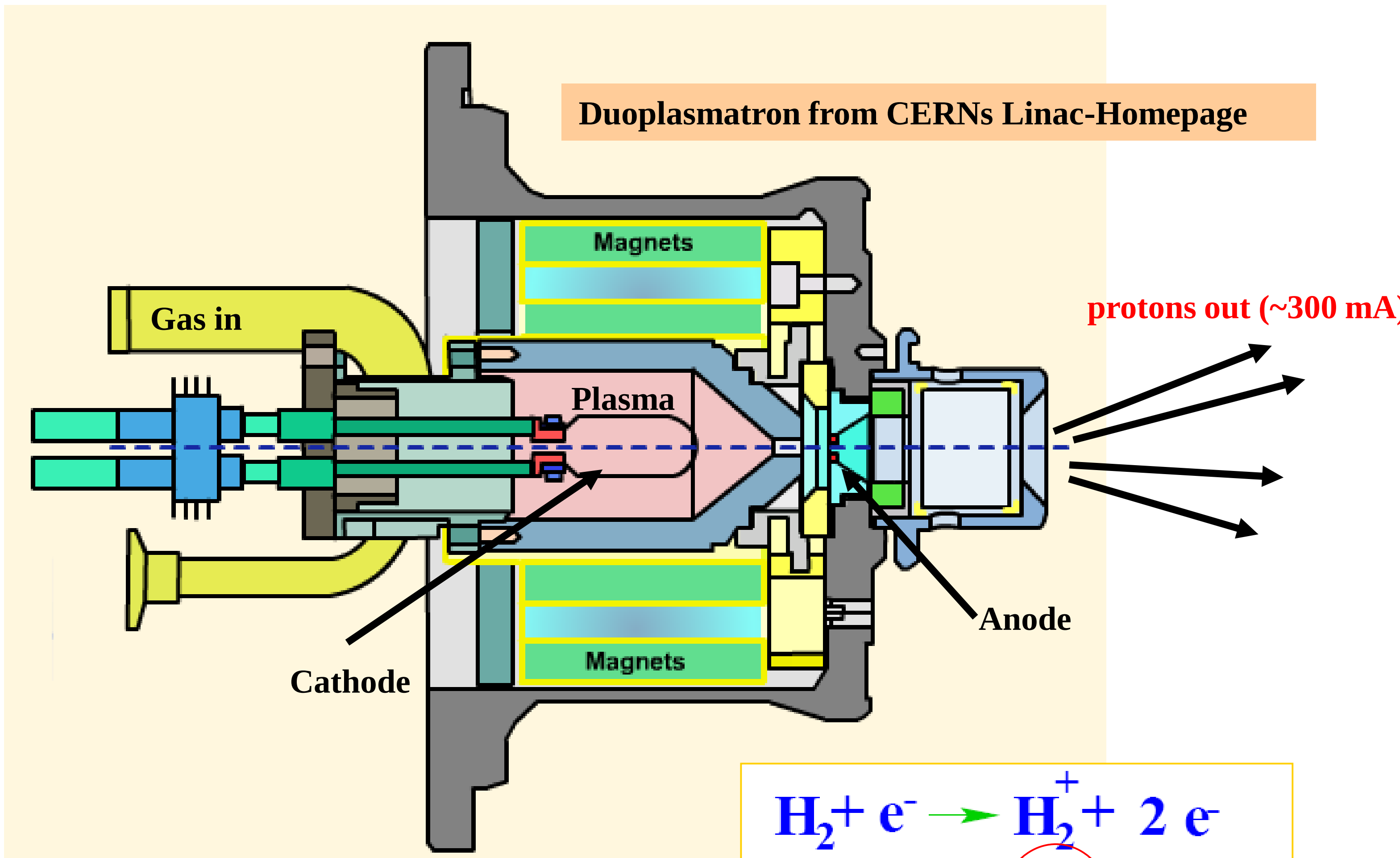
PS 28 GeV

SPS 450 GeV

LHC 7 TeV

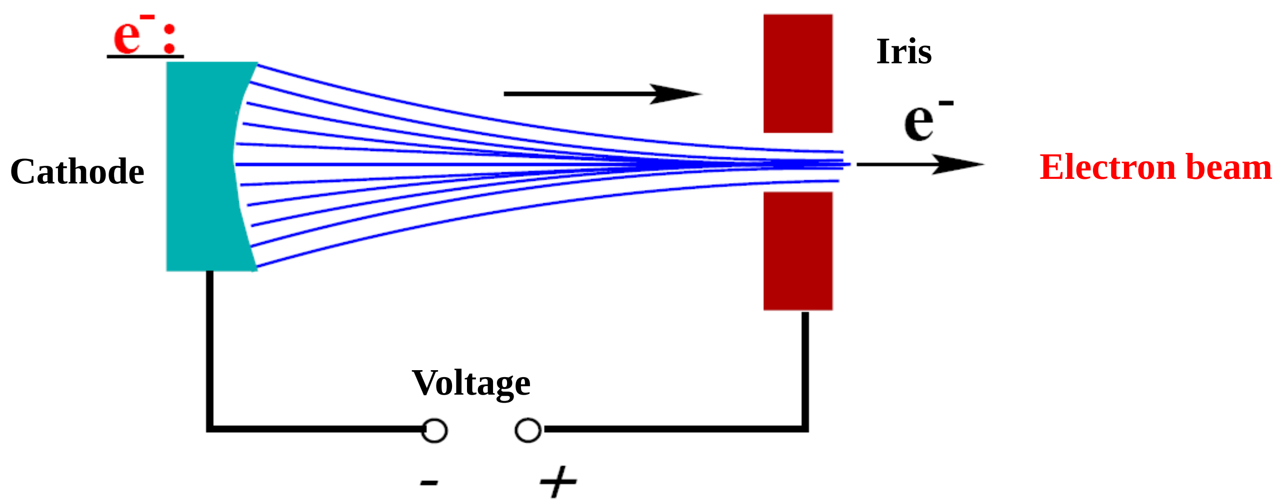


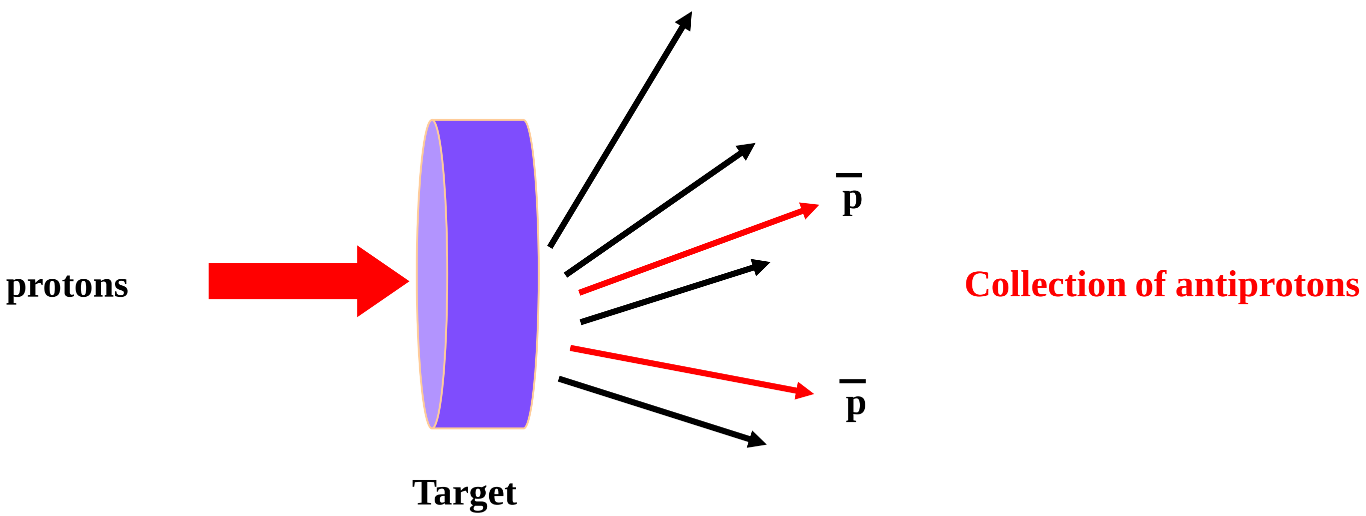
Kako dobiti protone ?



$$H_2 + e^- \rightarrow H_2^+ + 2\,e^-$$
$$H_2^+ + e^- \rightarrow H^+ + H + e^-$$
$$H + e^- \rightarrow H^+ + 2\,e^-$$

Kako dobiti elektrone ili antiprotone ?





Pitanja koja se postavljaju ...

Koje čestice ćemo ubrzavati ?

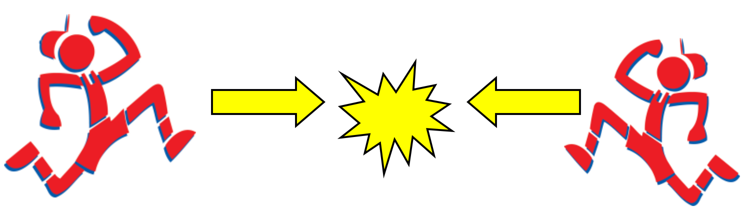
Kružno ili linearno ?

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)

Ograničavajući faktori kružnih ubrzivača

1) Gubitak energije zračenjem:

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

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

2) Istraživanja na malim dimenzijama → mali udarni presjek

Luminoznost: L=broj čestica u jed. vrem./jedinica površine

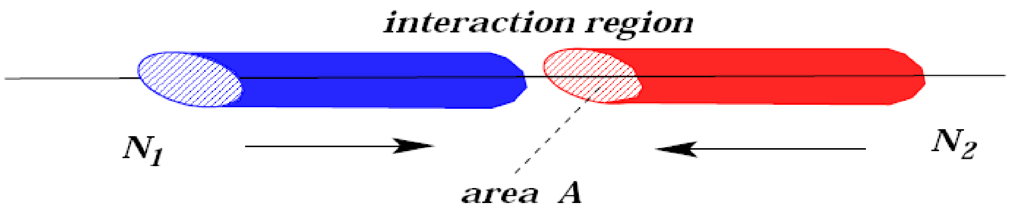
Vjerojatnost događaja=udarni presjek * luminoznost

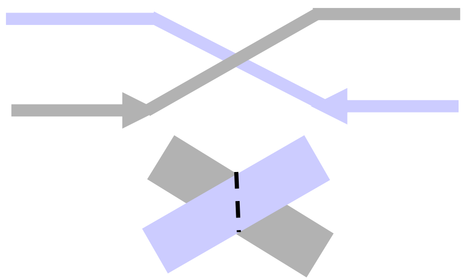
3) Raspoloživa energija: $s = (p_a + p_b)^2 \sim$

- $E_a m_b$ Za fiksiranu metu
- $4E^2$ Za sudarivač $E_a = E_b = E$

Mirko Planinić

Luminoznost





$$A = \pi \varepsilon \beta *$$

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

Broj čestica po nakupini (dva snopa)

Broj nakupina po snopu

Okretna frekvencija

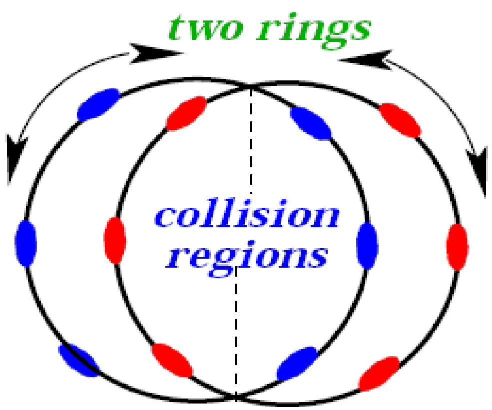
$$L = \frac{N_b^2 n_b f_{rev}}{4\pi \varepsilon \beta *} F$$

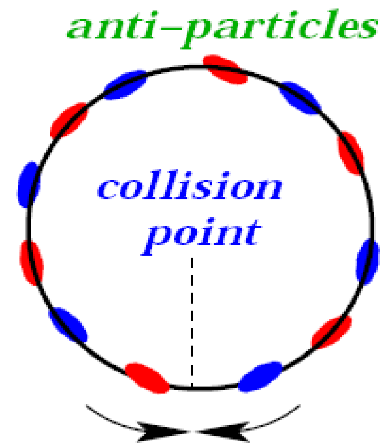
Formfaktor iz poprečnog kuta

Emitancija

Optička beta function

Sudarivači





❑**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)

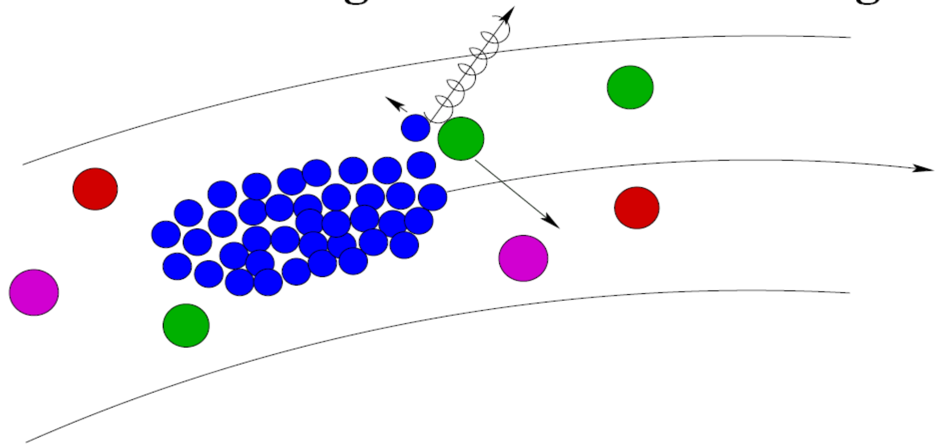
❑Snopovi utječu **jedan na drugoga: snopovi se moraju razdvojiti kad se ne sudaraju**

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

Bremsstrahlung + Coulomb Scattering



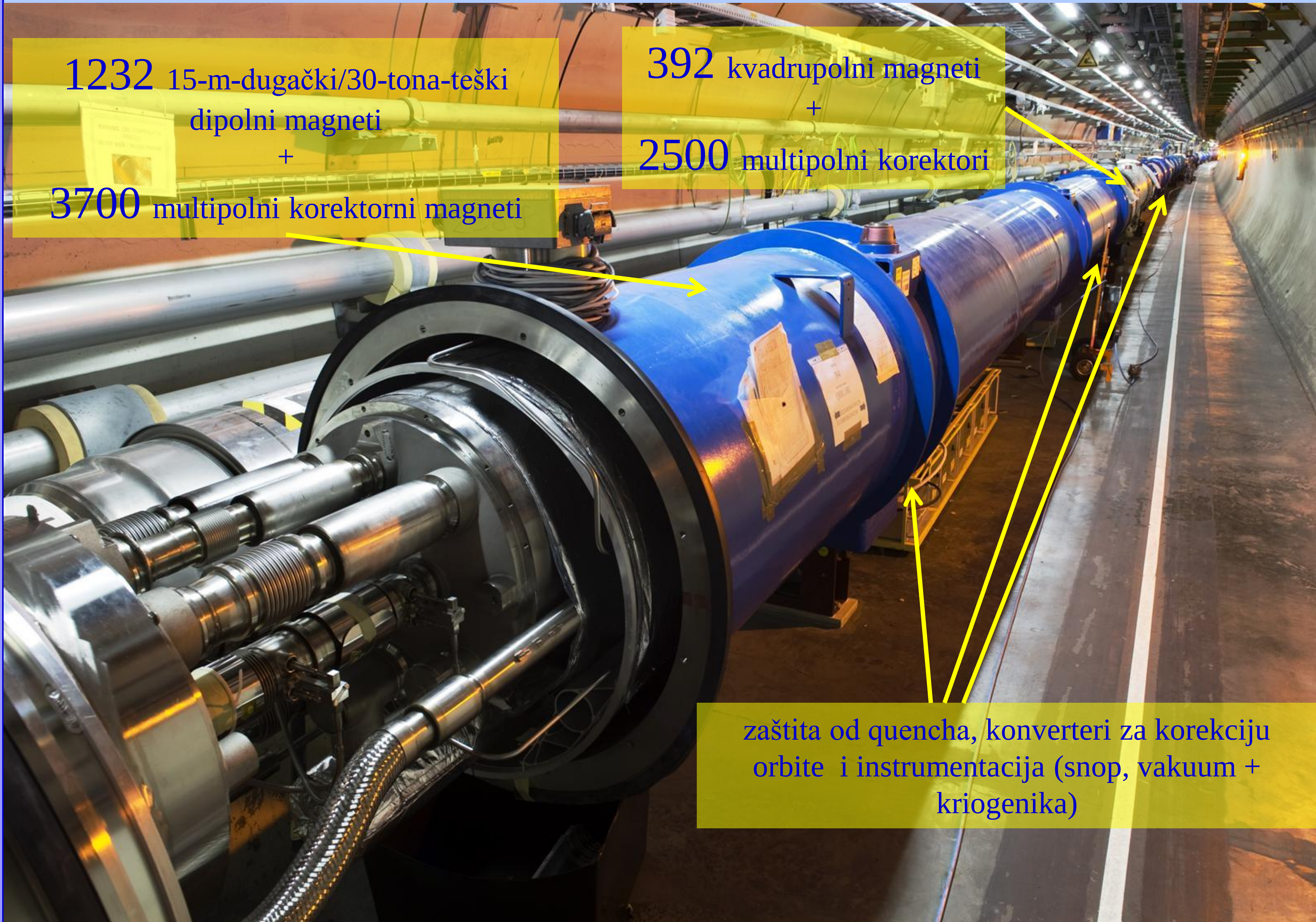
- “Rasipanje “ snopa
- Gubitak čestica
- Neželjeni sudari
- Ograničava Luminoznost

LHC: from design…

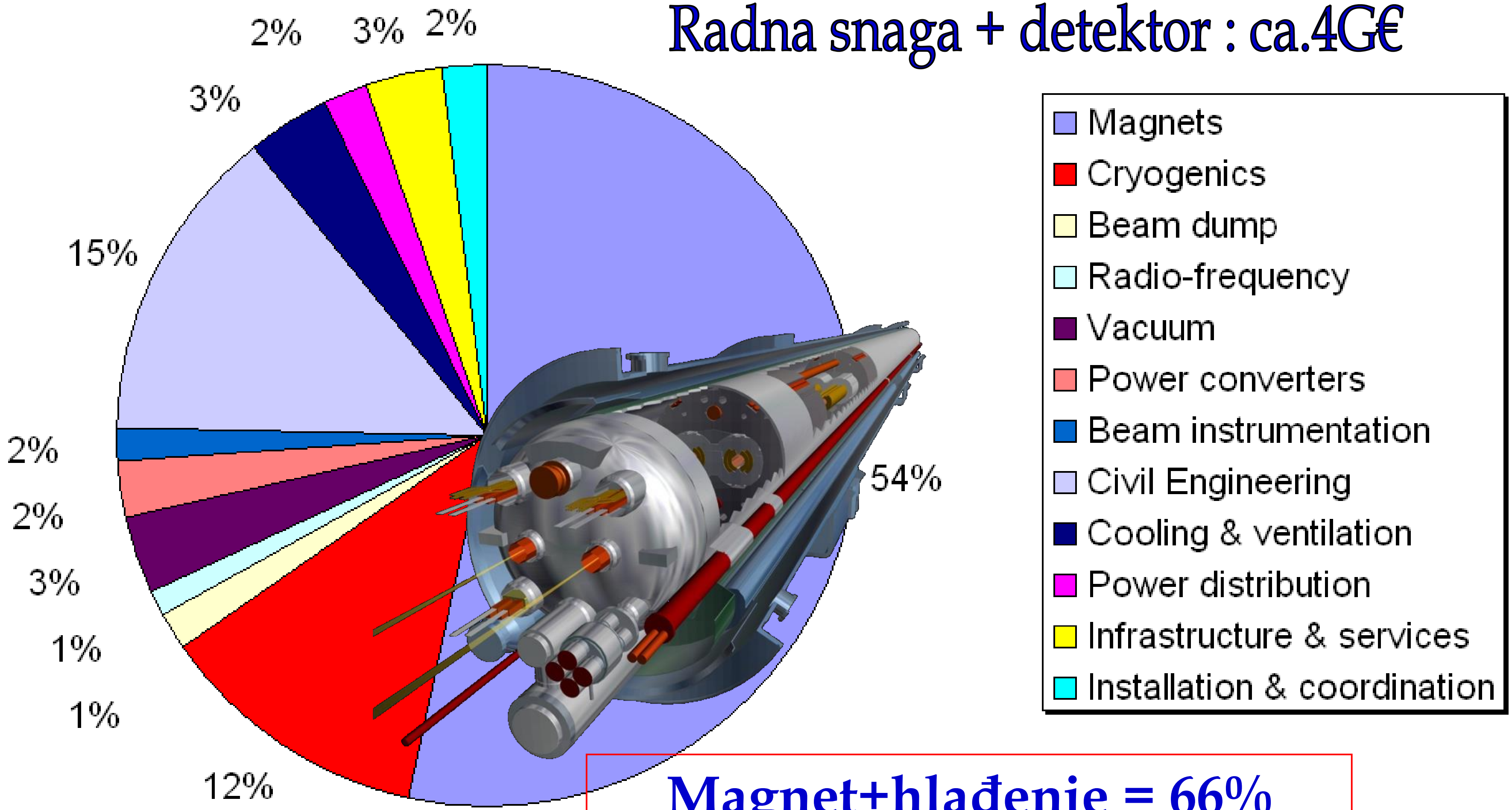
Prva ideja LHC 1985. Konstrukcija odobrena 1995.

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
Največa luminoznost IP1 :	10^{34} cm^2s^{-1}

KAKO TO IZGLEDA U REALNOSTI



LHC Mašina: 2.2 G€ (material+vanjski rad)
Radna snaga + detektor : ca.4G€



Magnet+hlađenje = 66%

Konceptualno pitanje

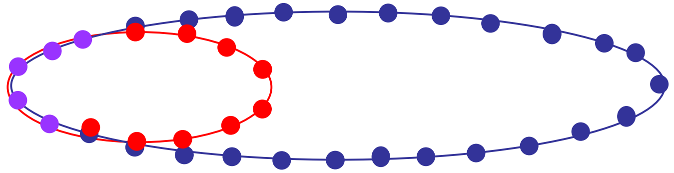
Supravodljive magnete koristimo jer:

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

Supravodljiva Tehnologija

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)

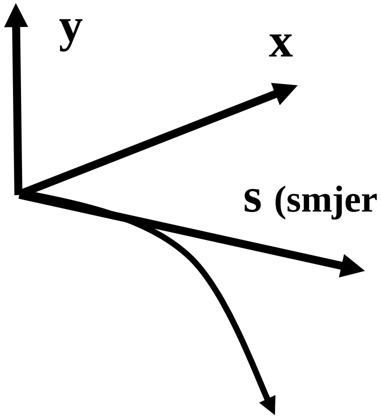
$$F_x = -e v_s B_y$$

$$F_r = m v_s^2 / \rho$$

$$p = m v_s$$

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

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

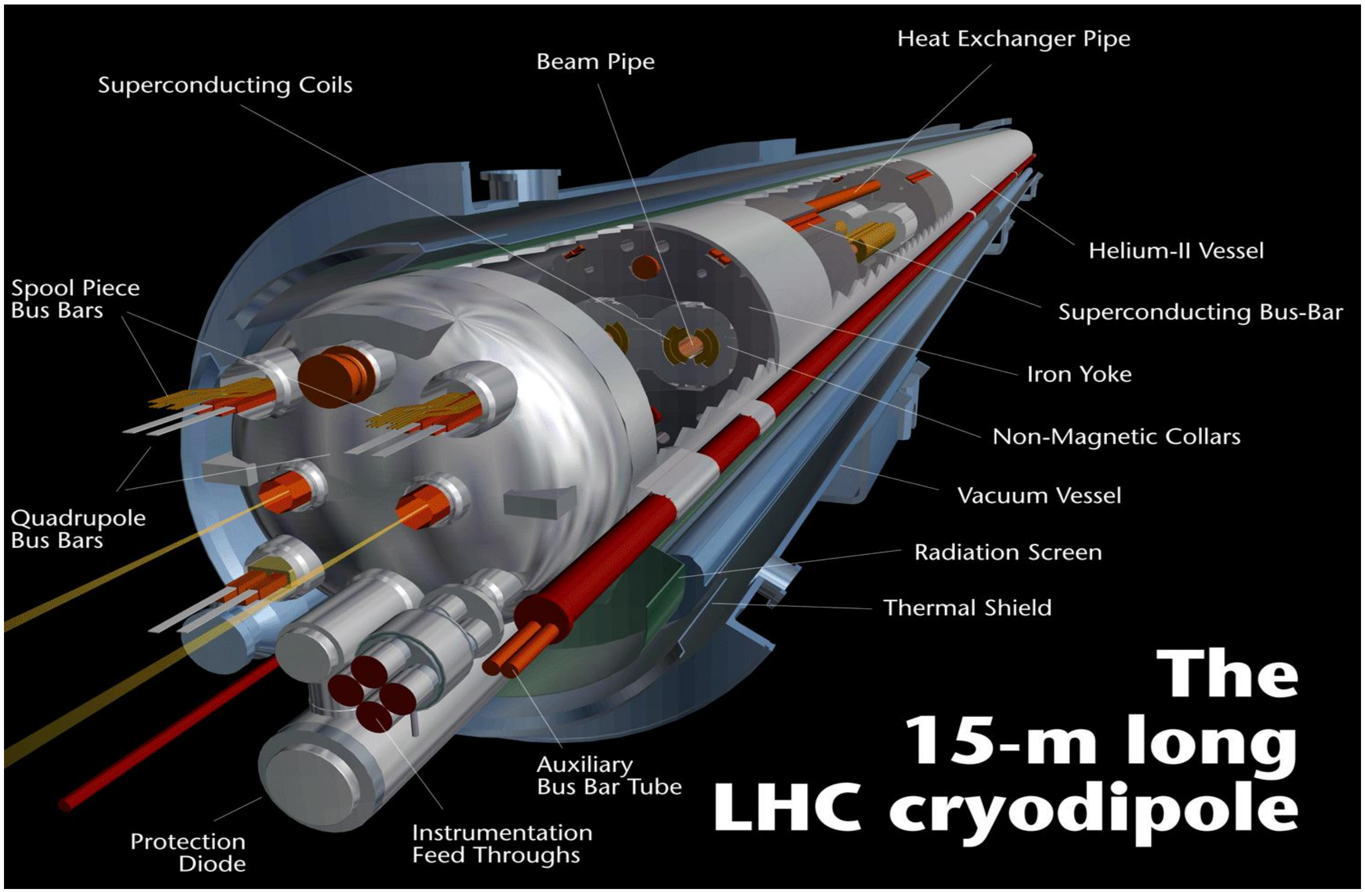


”Magnetic rigidity”

Supravodljivi Dipol za LHC

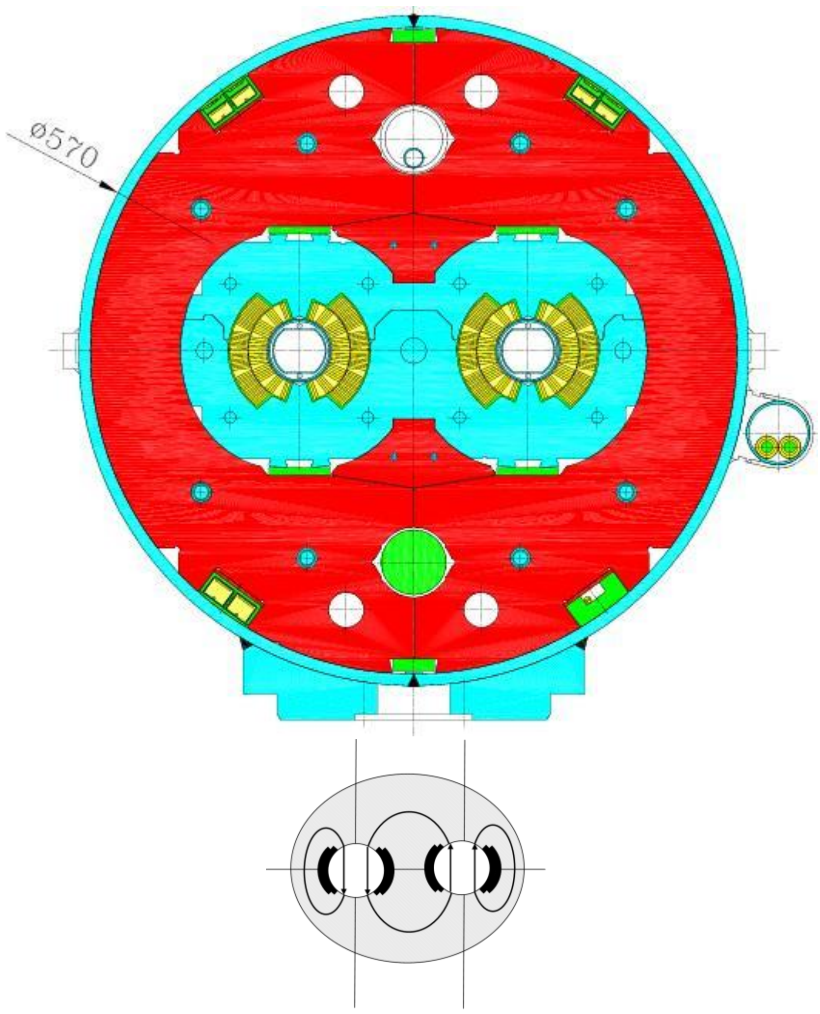
TEHNOLOGIJA

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



LHC Dipole

TEHNOLOGIJA



"Two in one"
konstrukcija

Radna temperatura
1.9 K !

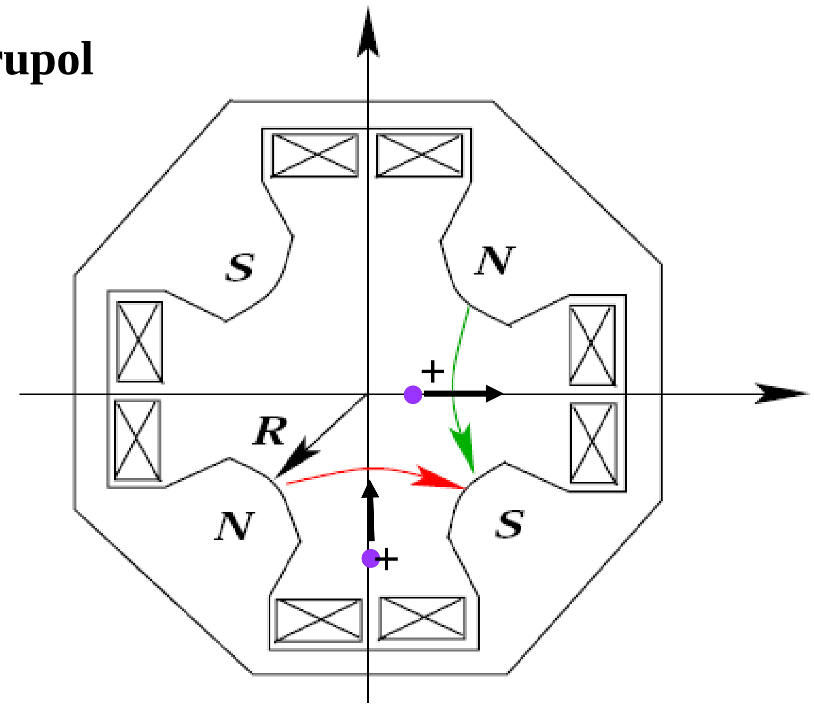
Najhladnije mjesto u svemiru ... !!!

Fokusiranje: Kvadrupol

FOKUSIRANJE

Čestice se moraju fokusirati da bi ostale u akceleratoru

Kvadrupol



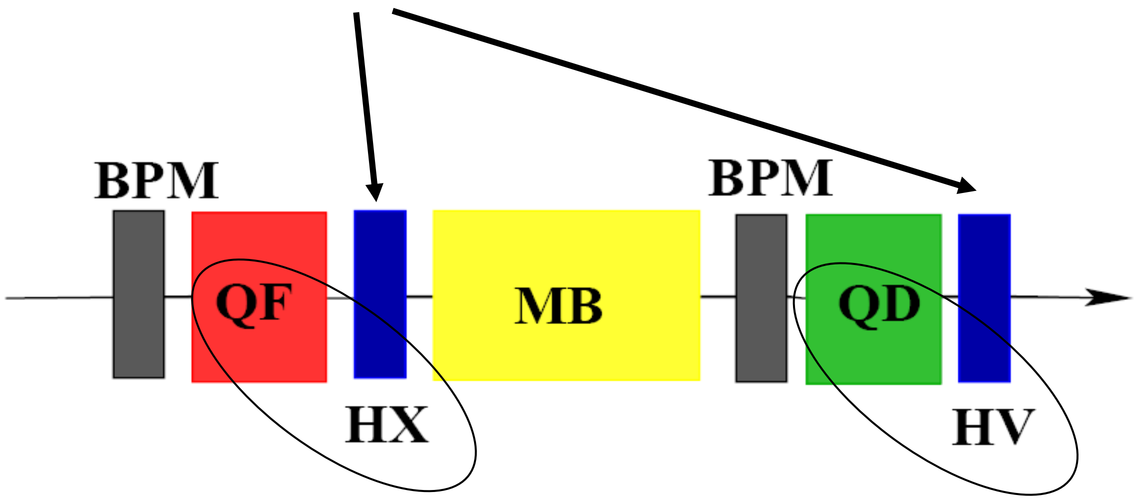
Pozitivne čestice se gibaju prema nama: Defokusiranje u horizontalnoj ravnini, a fokusiranje u vertikalnoj ravnini.

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

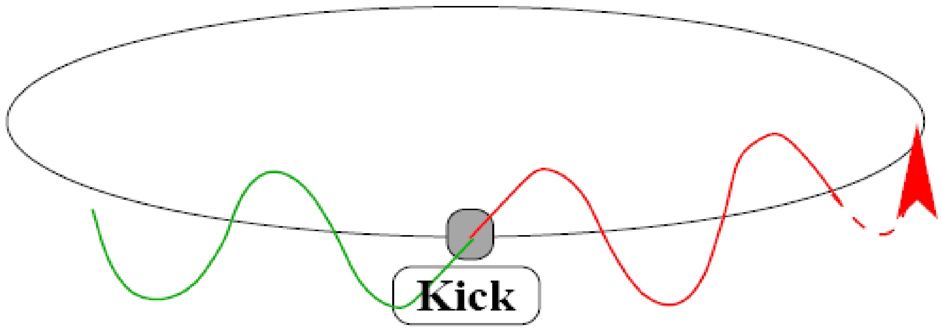
Korektori

FOKUSIRANJE

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 pozitivni cijeli broj, snop vidi uvijek istu magnetsku grešku što daje efekt rezonancije. Zbog toga Q nije cijeli broj...

Moguće greške

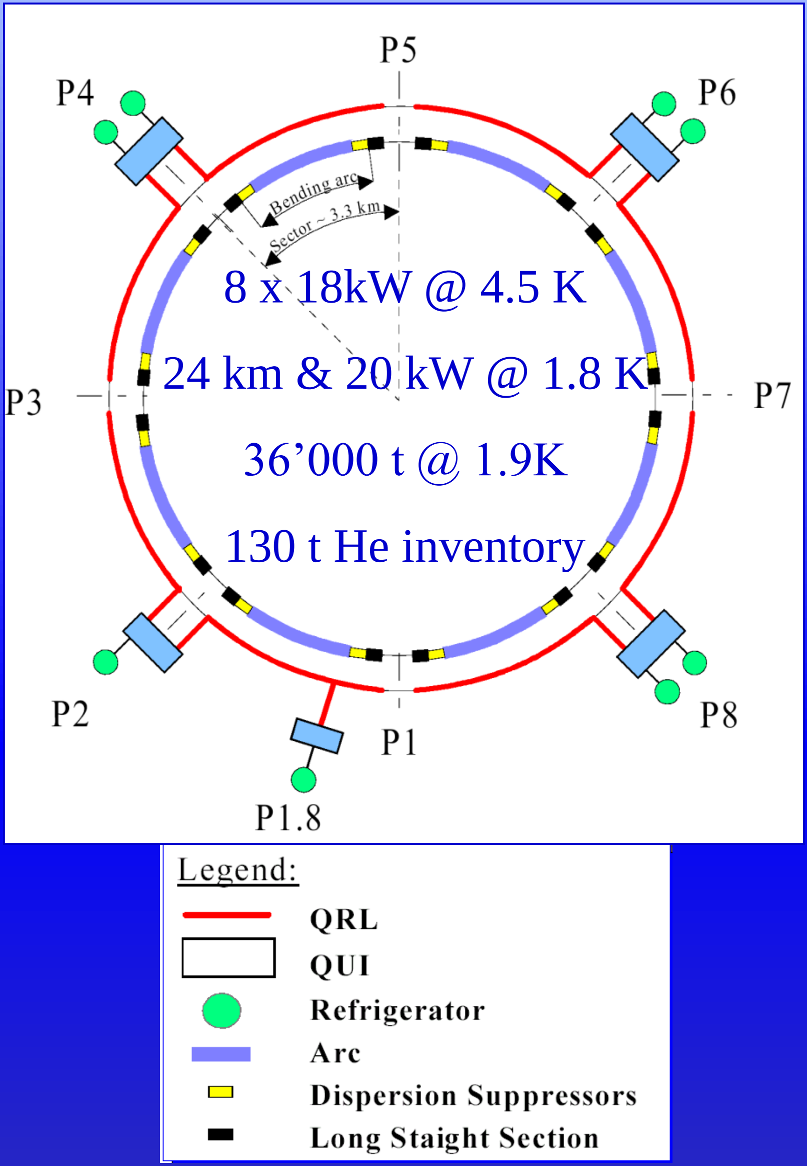
FOKUSIRANJE

Što treba uzeti u obzir ?:

Micanje površine Zemlje
Vlakovi
Mjesec
Godišnja doba
Građevinski radovi
...

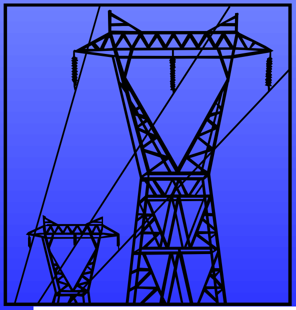
Kalibracija magneta je važna

Hlađenje



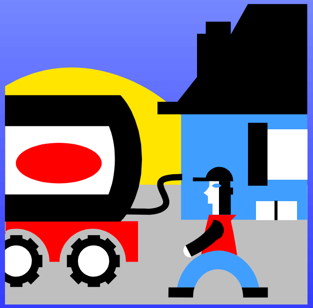
Snaga struje

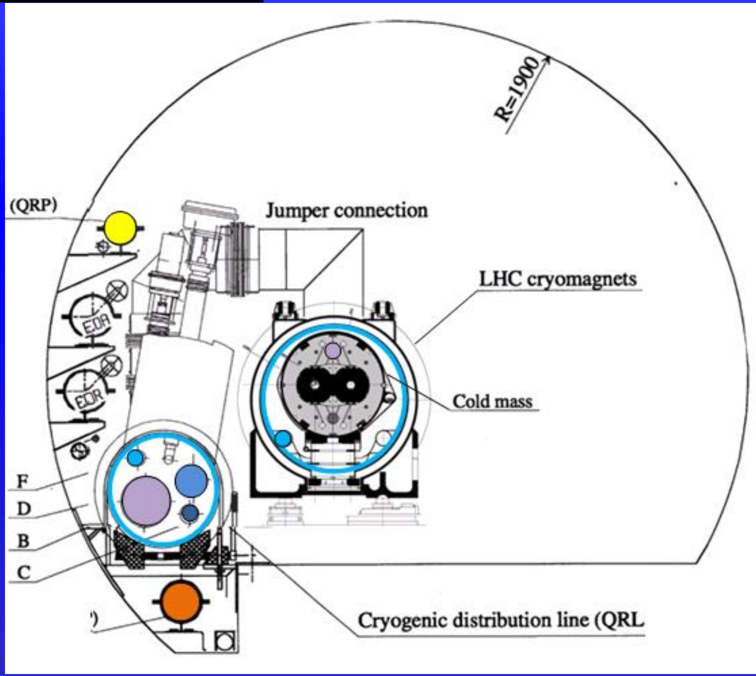
32 MW;
24 GWh/mjesečno
1.2 MCHF/mjesečno



Helij i dušik

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





Budući akceleratori

LINEARNI SUDARIVAČI –

Cijena proporcionalna energiji snopa

KRUŽNI SUDARIVAČI

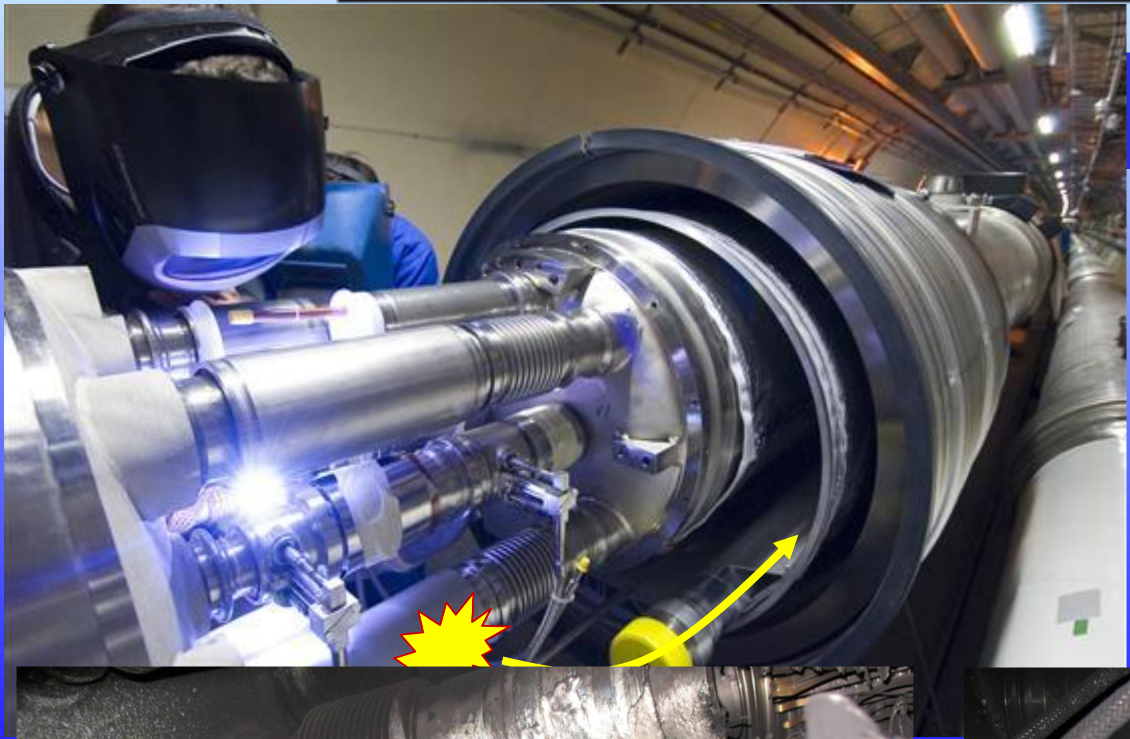
Cijena proporcionalna kvadratu energije snopa

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

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

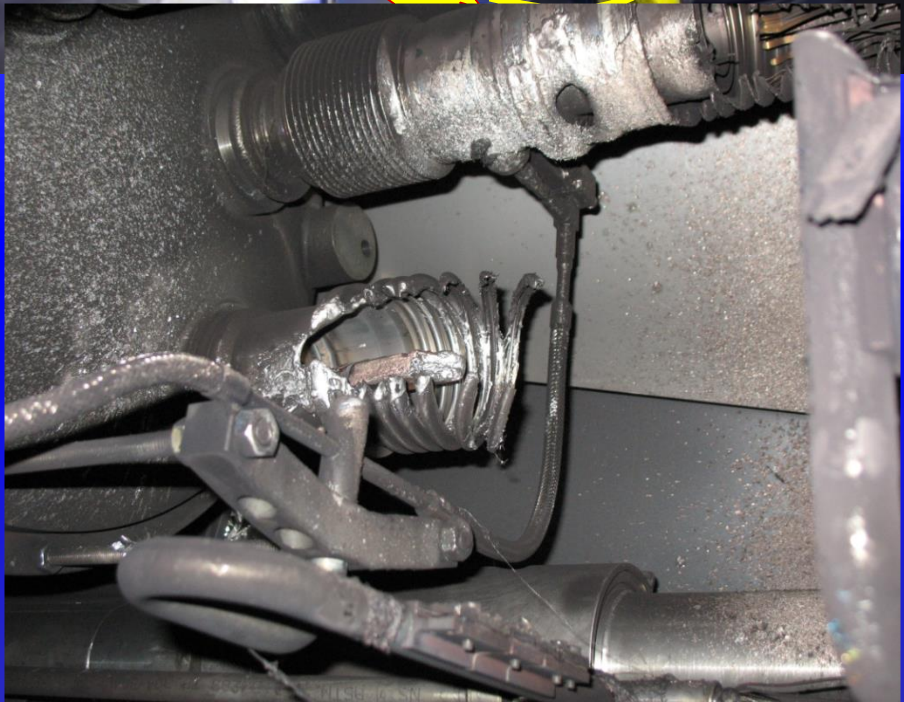
Beam Commissioning in 2008: September 10

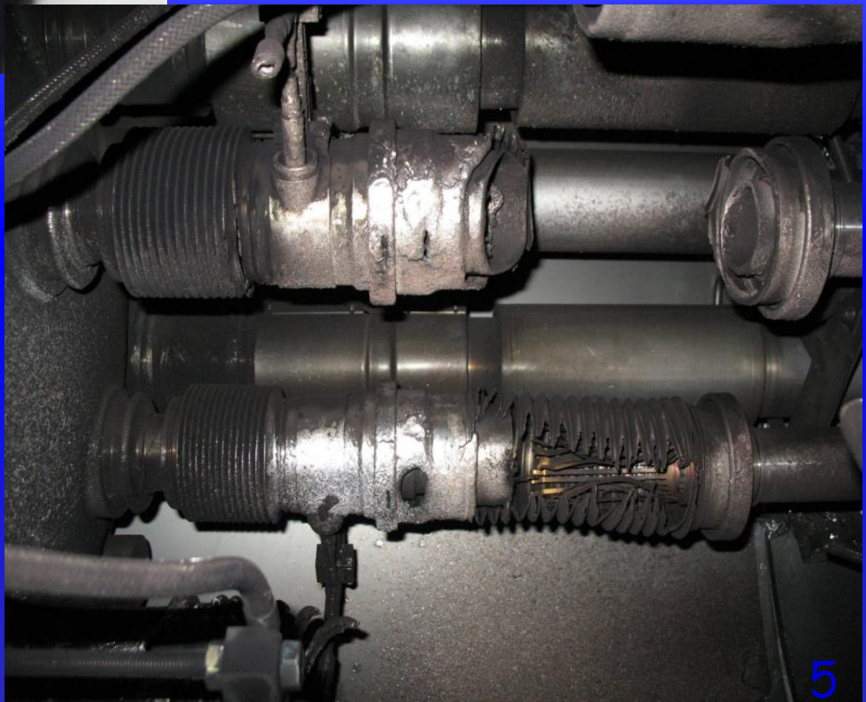
19 RUJAN 2008: NEZGODA U SEKTORU 3-4



Iskra je probušila dio gdje je zatvoren helij za hlađenje

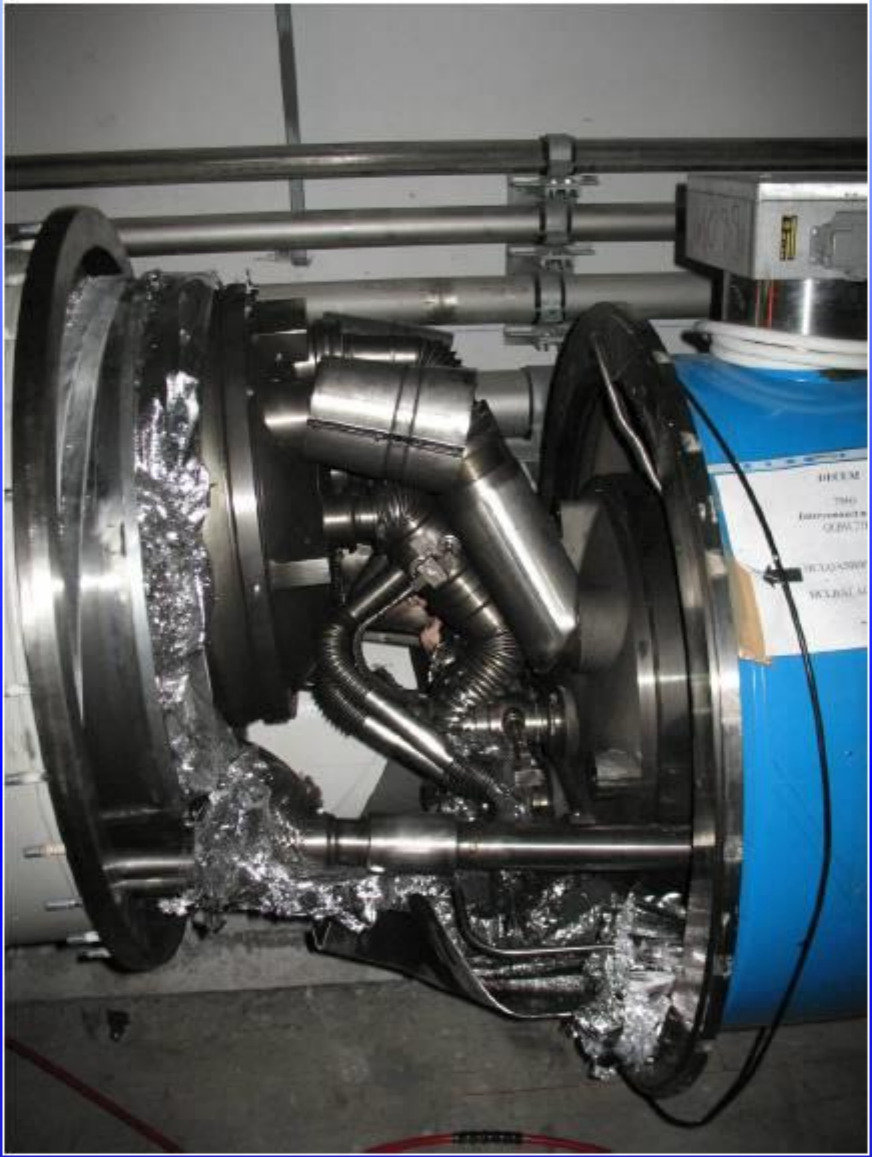
Veliki val plina pod visokim tlakom putovao je u oba smjera.



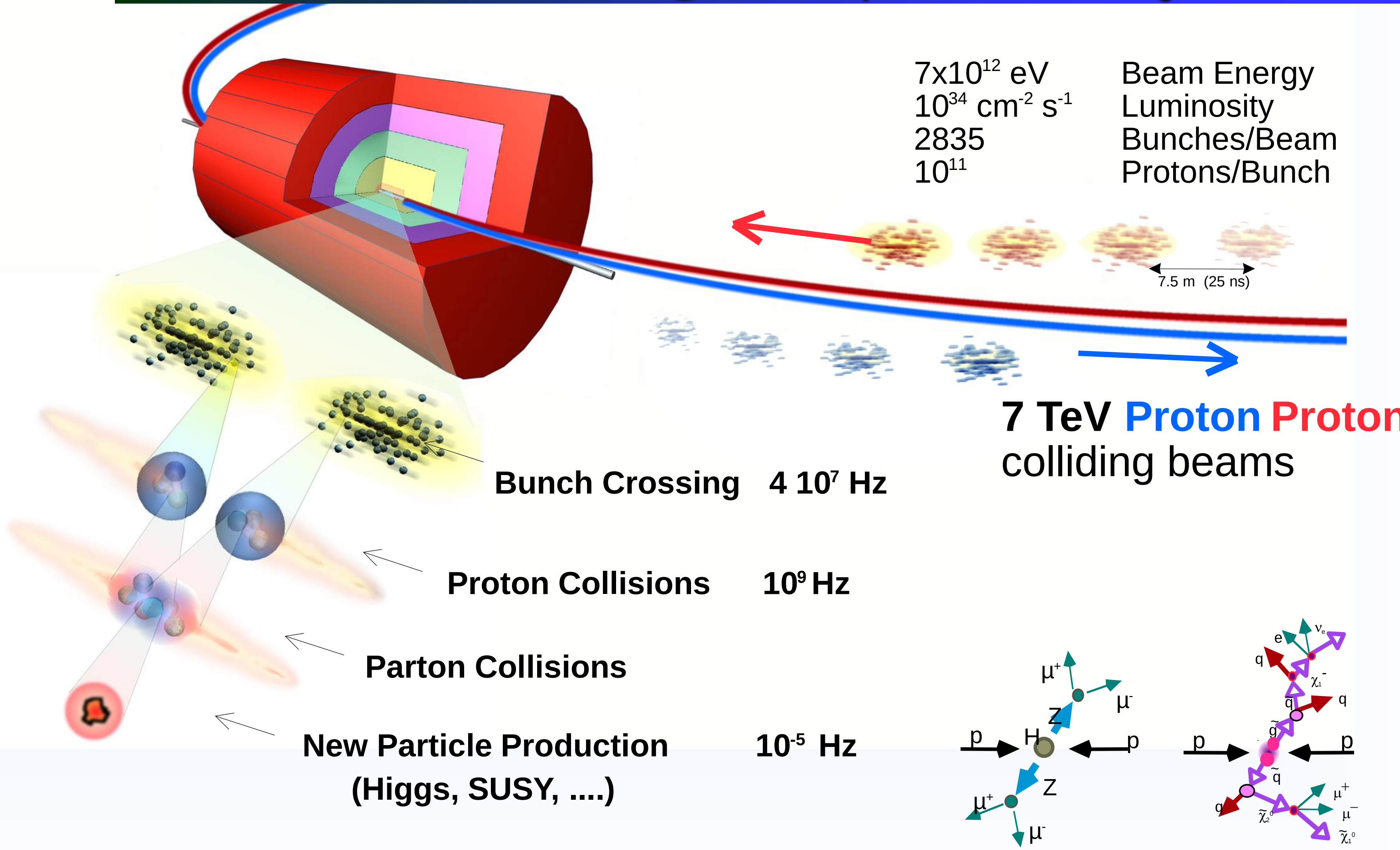


Collateral damage: magnet displacements

Collateral damage: magnet displacements



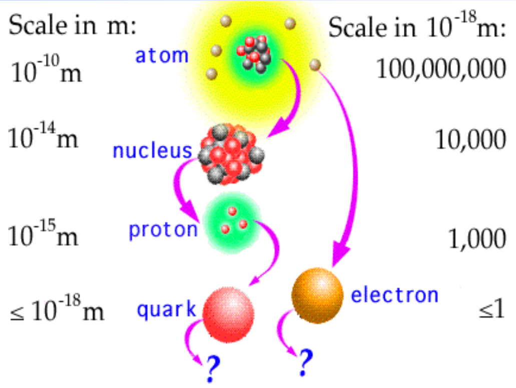
LHC sudari: igla u plastu sijena!



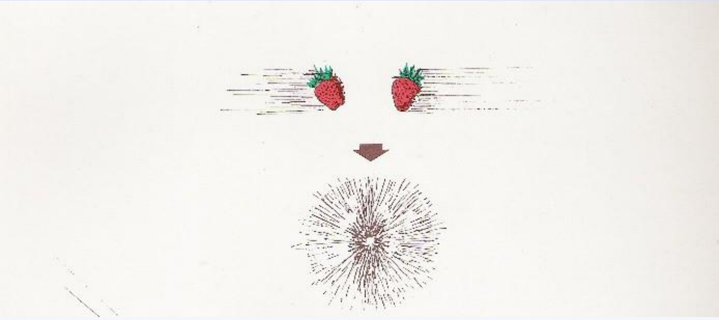
Tražimo 1 događaj od 10,000,000,000,000

Podsjetnik na temeljne koncepte

1) gledanje malih dimenzija traži velike energije



2) masa je isto što i energija

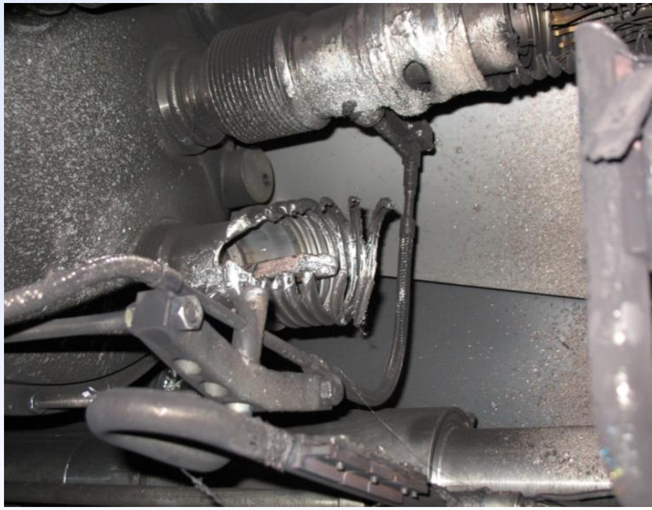


Podsjetnik na temeljne koncepte

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!