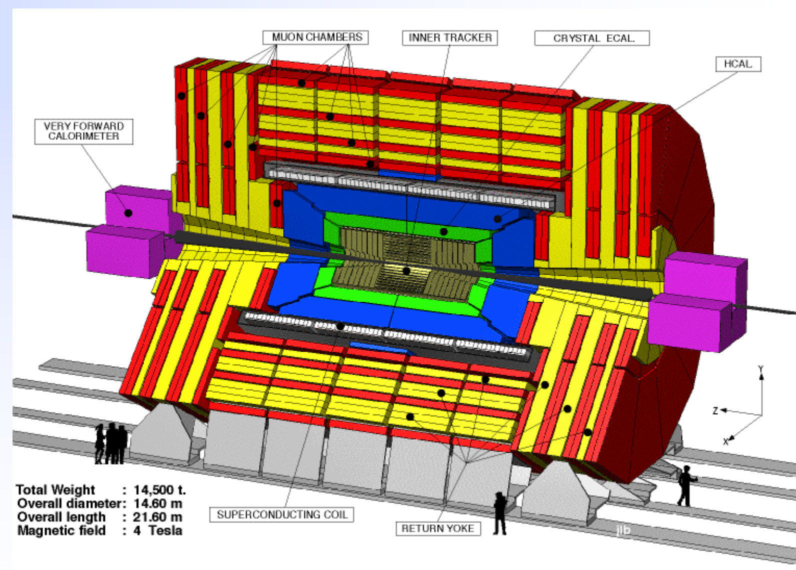
# Croatian Teacher Programme

24–28 Mar 2024
CERN
Europe/Zurich timezone

# 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

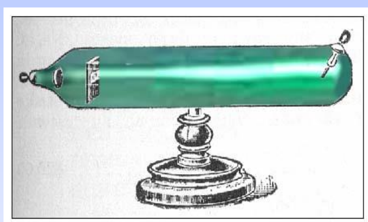
# Da ne bi bilo ...

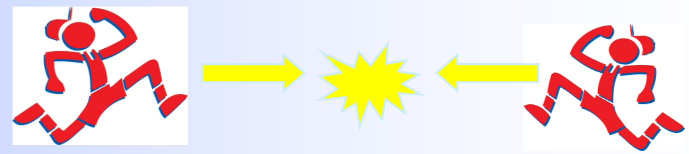
# Nego ...

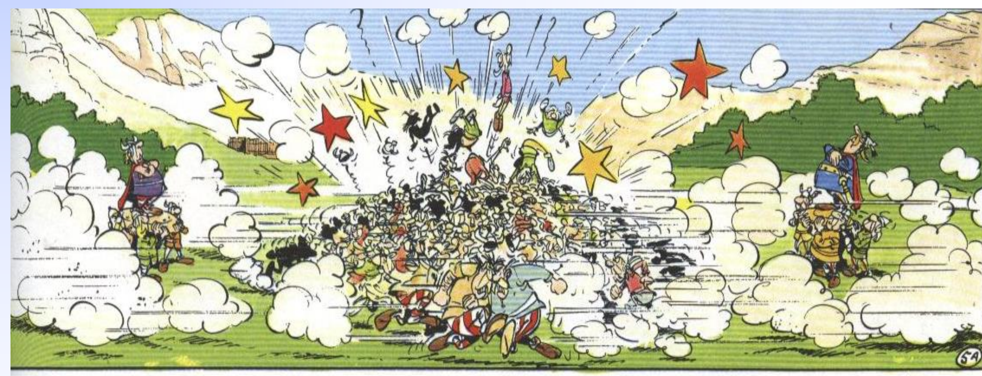
# Sadržaj

- Od ubrzivača do suprasudarivača


- Linearni i kružni ubrzivači
  - Pokus







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

Mirko Planinić

# Danas na rasporedu

| | |
|---|---|
| 08:30 | **Welcome to CERN!**<br>**Speaker**: Jeff Wiener (CERN) |
| 09:30 | **Particle Physics 1**<br>**Speaker**: Vuko Brigljevic (Rudjer Boskovic Institute (HR)) |
| 10:25 | **Coffee Break** |
| 10:50 | **Accelerators and Detectors 1**<br>**Speaker**: Mirko Planinic (University of Zagreb (HR)) |
| 11:50 | **Astro Particle Physics and Cosmology 1**<br>**Speaker**: Nikola Godinovic (Technical University of Split FESB) |

13:45

## Cloud Chamber Workshop, Synchrocyclotron & ATLAS Control Room

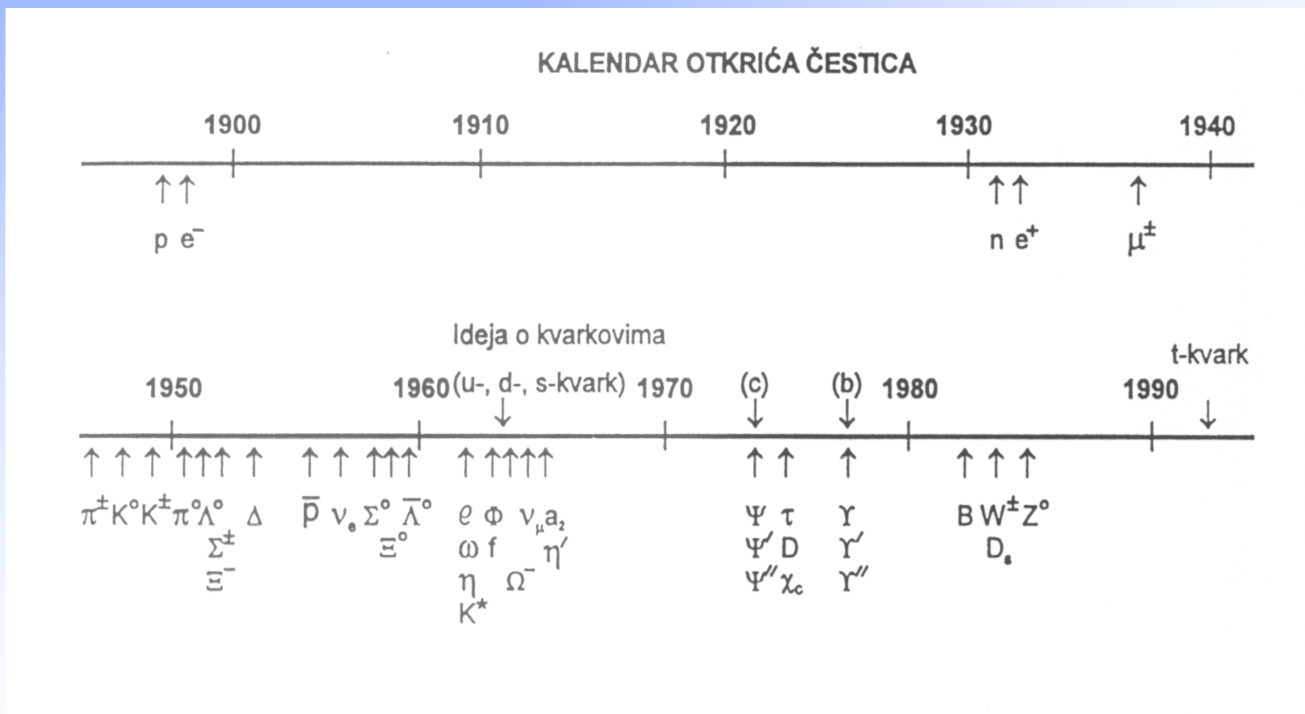
The whole group meets in the Main Building at 13:45!

**Group 1**
13:45-14:00 Walk to Science Gateway
14:00-15:30 Cloud Chamber Workshop
15:30-15:45 Walk to the SC
15:45-16:15 Synchrocyclotron
16:15-16:30 Walk to ATLAS
16:30-17:15 ATLAS Control Room
17:15-17:30 Walk to the Main Building

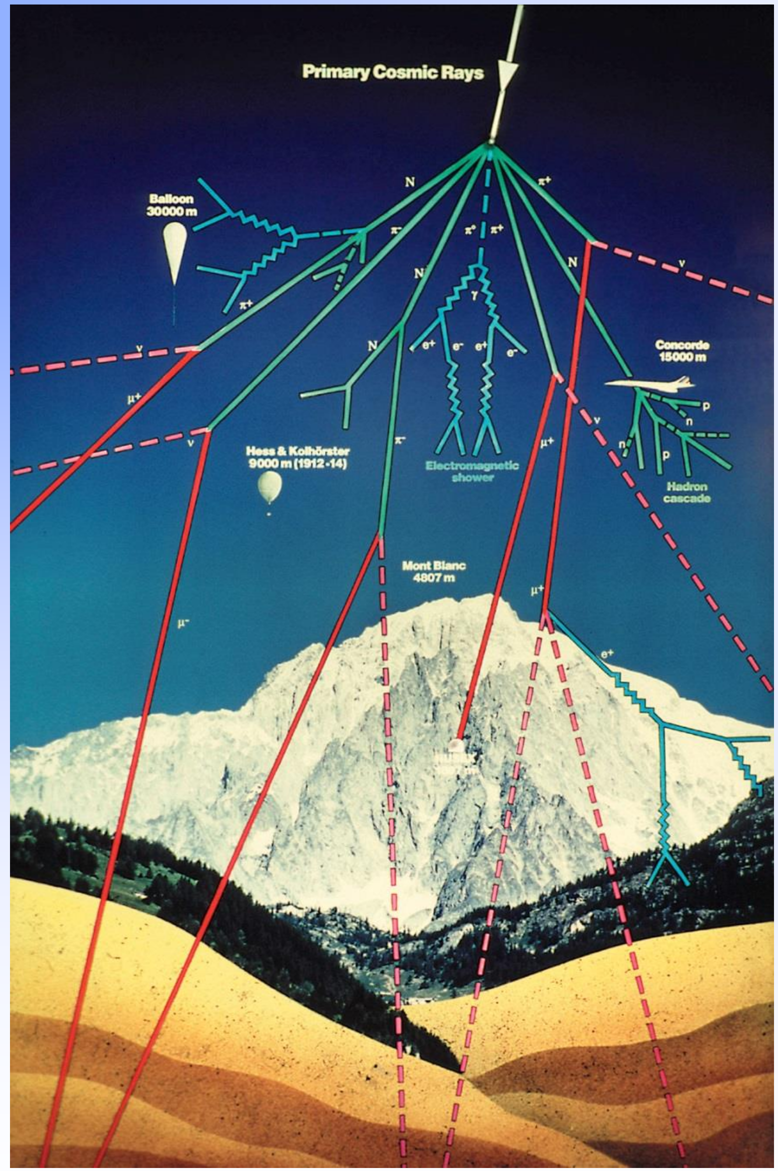
# Kako smo od ubrzivača u Pisi došli do LHC-a ?

# Ubrzivači i otkrića novih čestica

- Najvažnija otkrića novih čestica nakon primjene ubrzivača



# Možemo li koristiti kozmičke zrake ?

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# Kozmičko zračenje

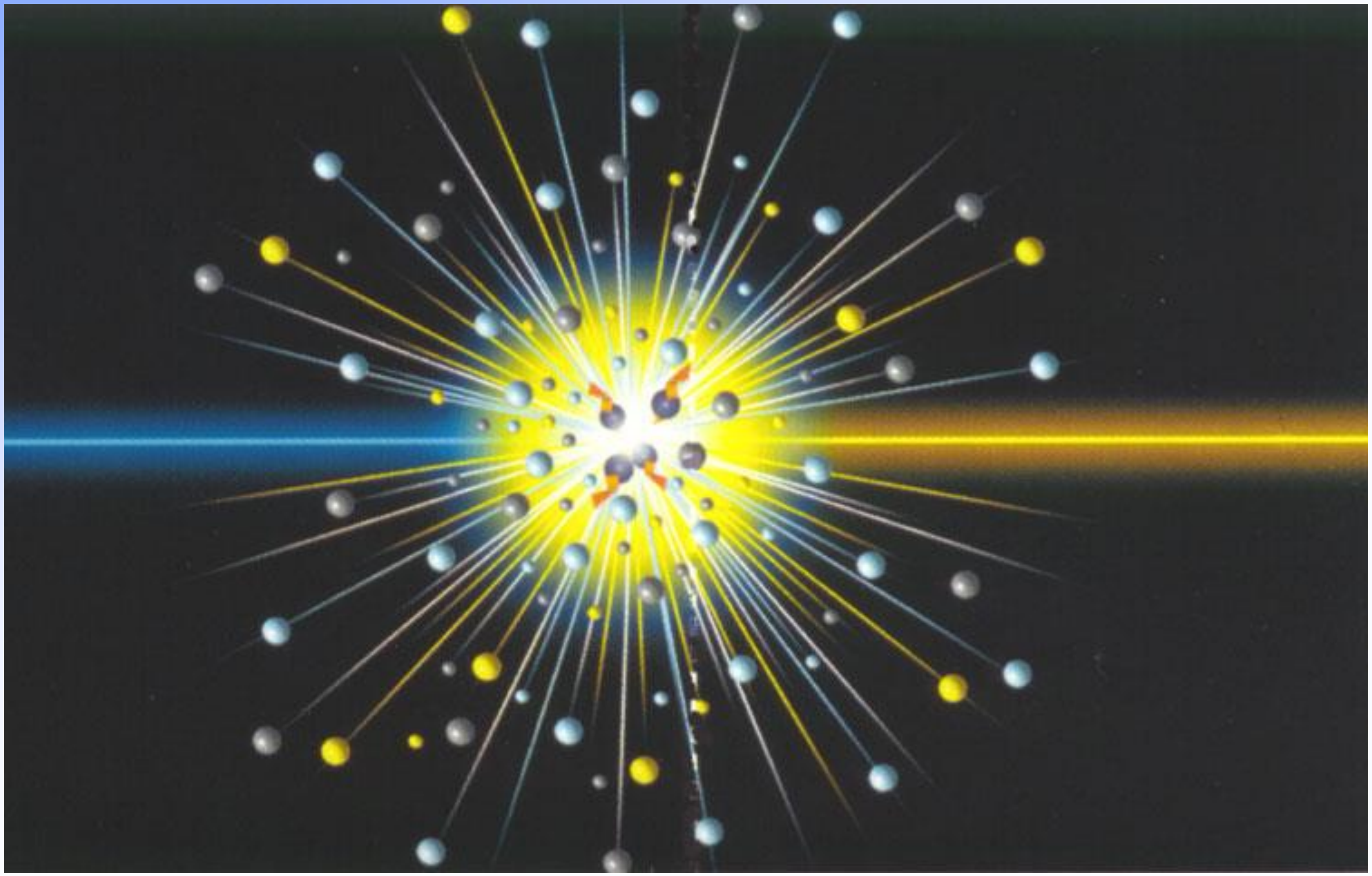
## Kozmičke zrake konstantno bombardiraju Zemlju

Njihove energije mogu biti puno redova veličine iznad LHC-a

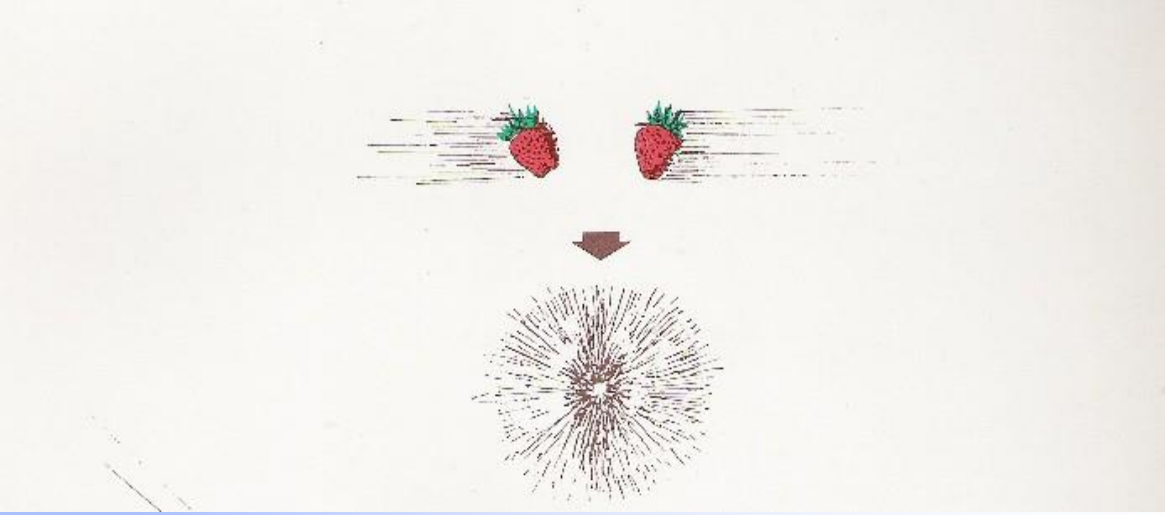
- Ukupni tok: 350 Hz 100 m ispod zemlje (~ 1% toka na površini)

# Za vidjeti najmanje čestice: potrebne su najveće energije!

$E = mc^2$

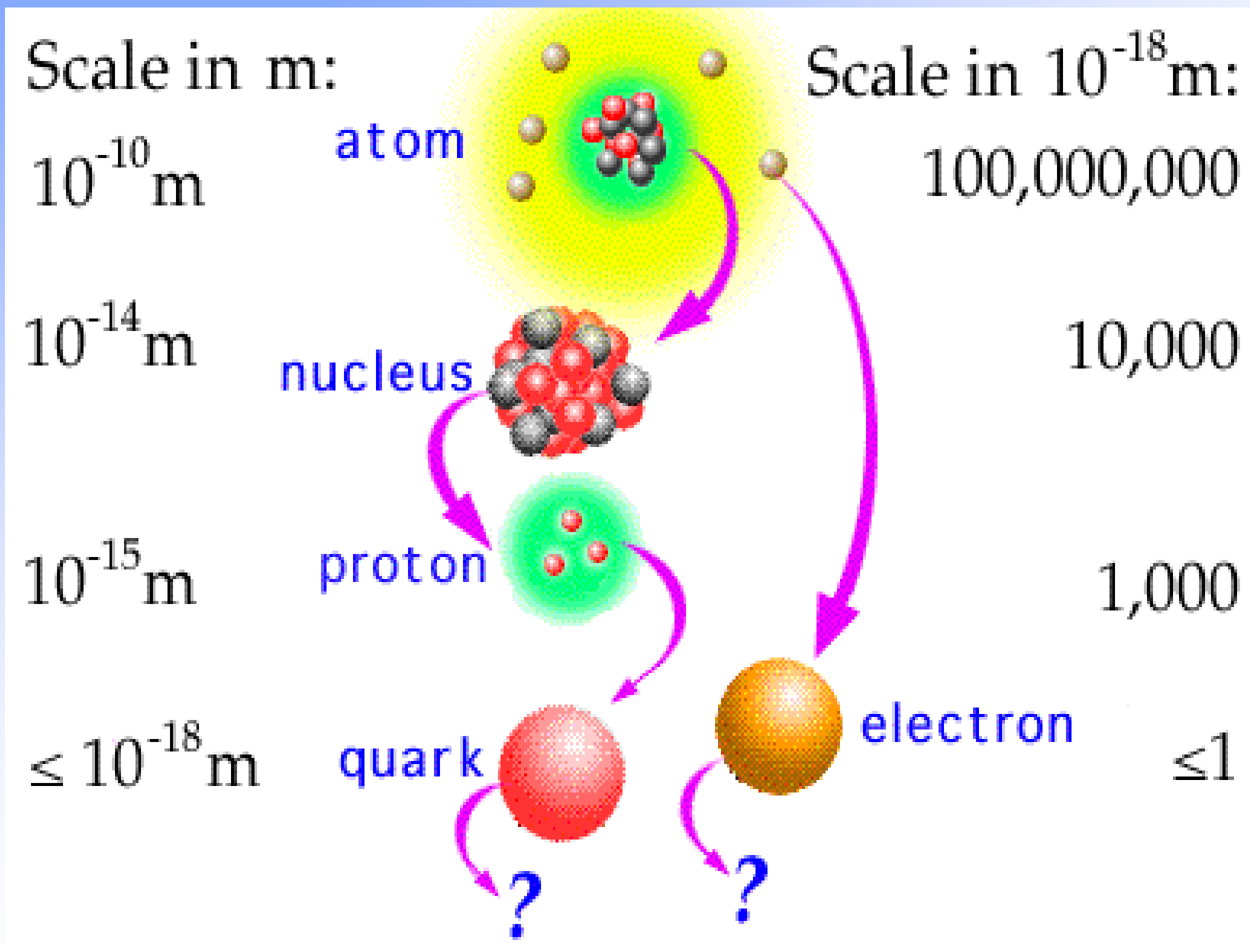


# $E = mc^2$



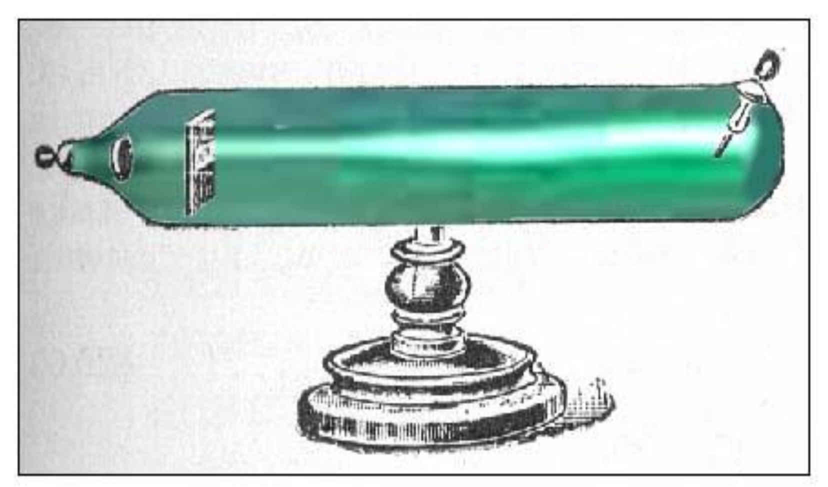
# Uranjanje u subatomski svijet

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

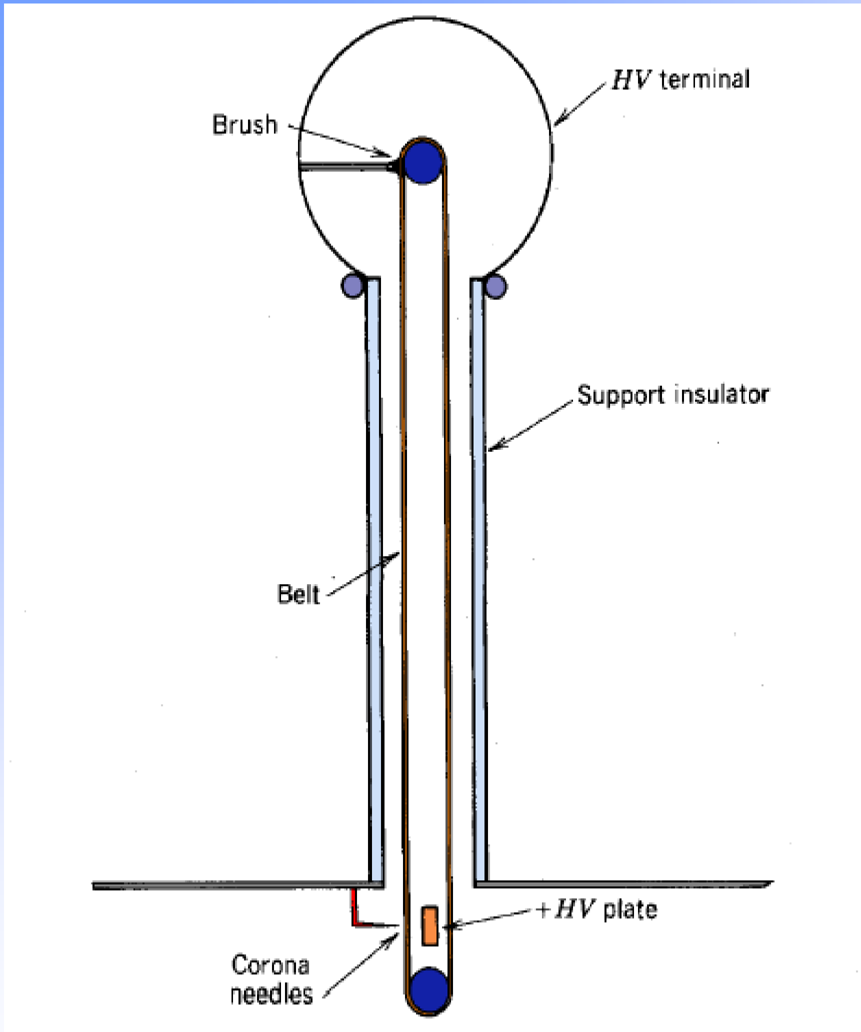


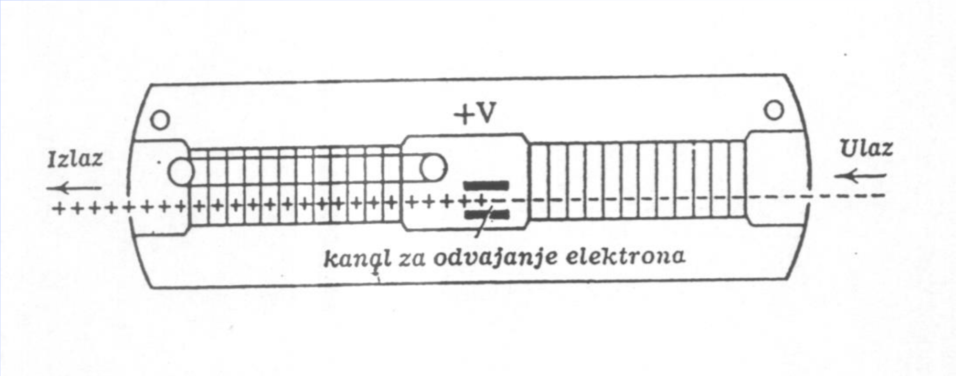
# Kako ubrzati nabijenu česticu ?

POKUS !!!!



# Van de Grafov ubrzivač

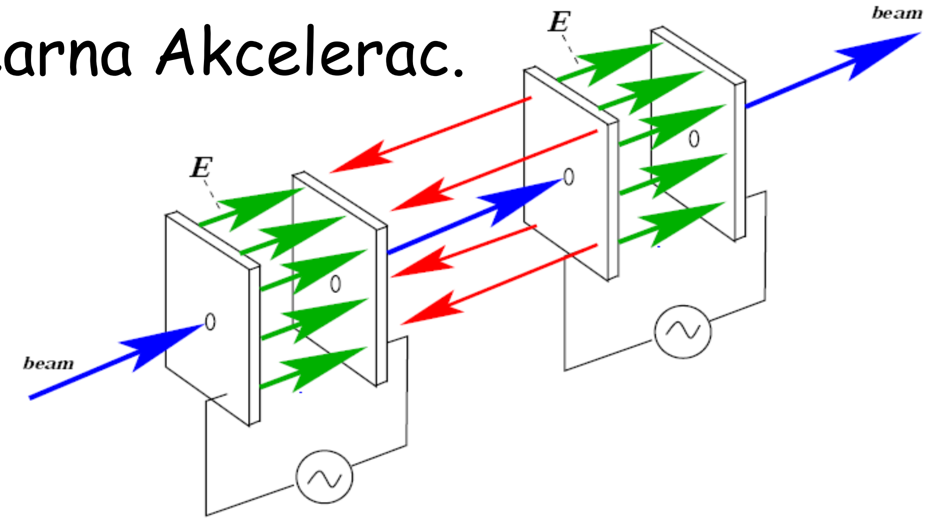


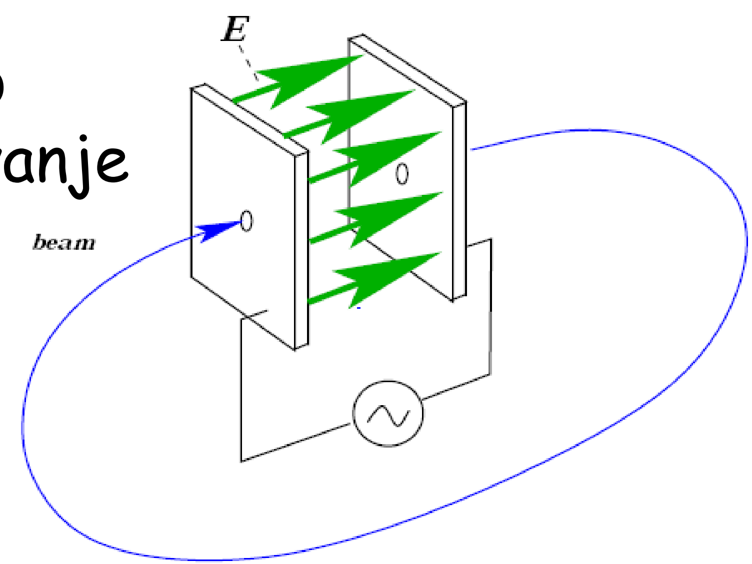

Što je ograničavajući faktor?

# Vremenski promjenljiva električna polja

Linearna Akcelerac.

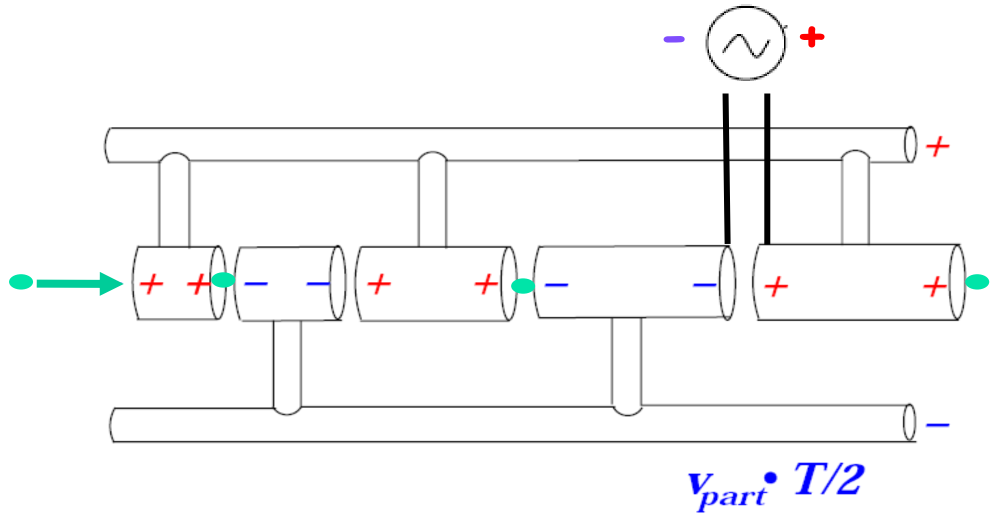



Kružno
ubrzavanje



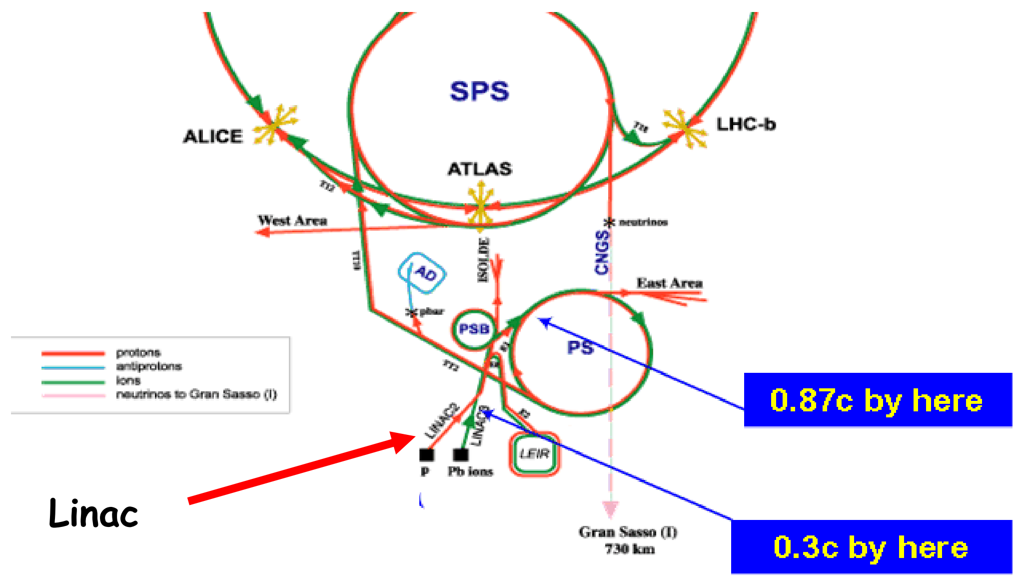
# Linearni akceleratori

**Linac**

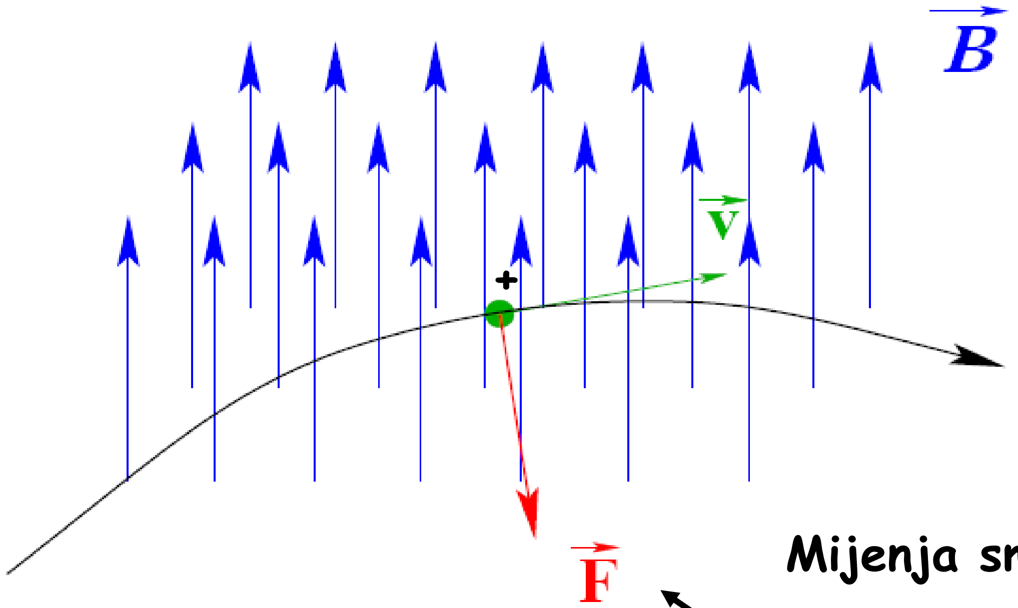



*Wideroe*

*1928.*



# 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**

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

**Kontinuiran snop čestica**

**Reorganizacija:**

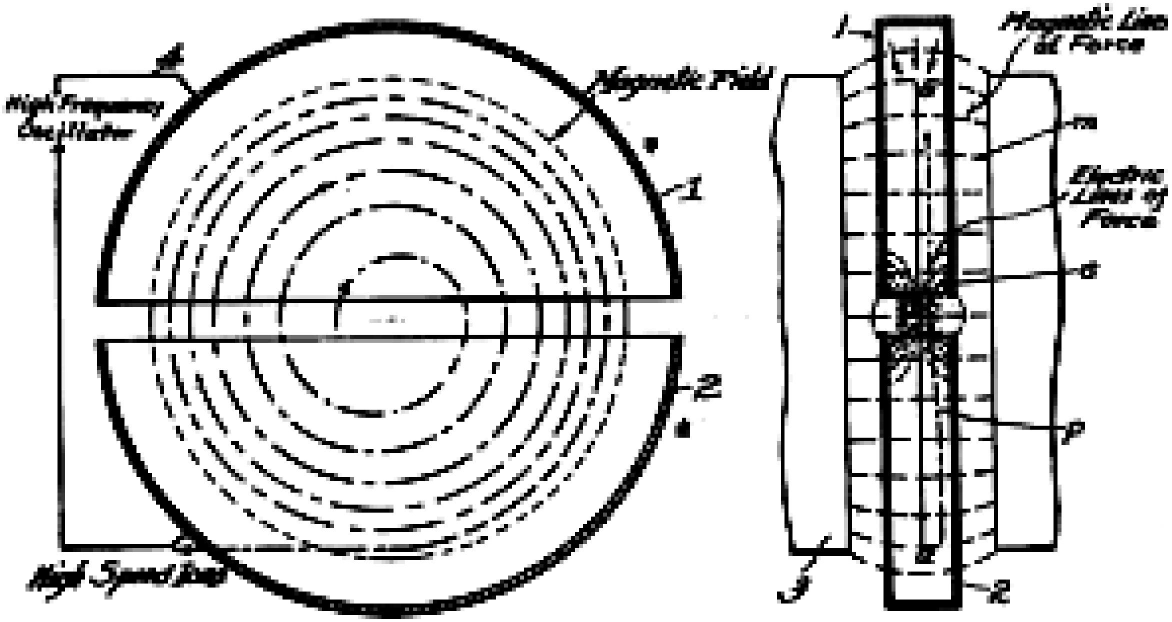
$$\frac{v}{r} = \frac{Bq}{m}$$

$$\downarrow$$

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

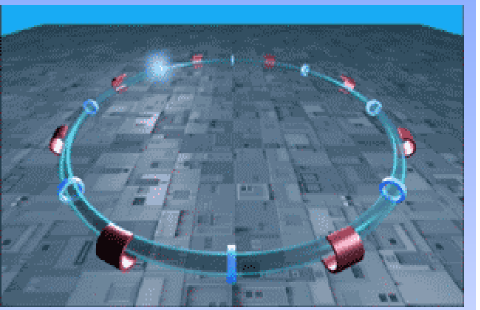
$$f = \frac{\omega}{2\pi}$$

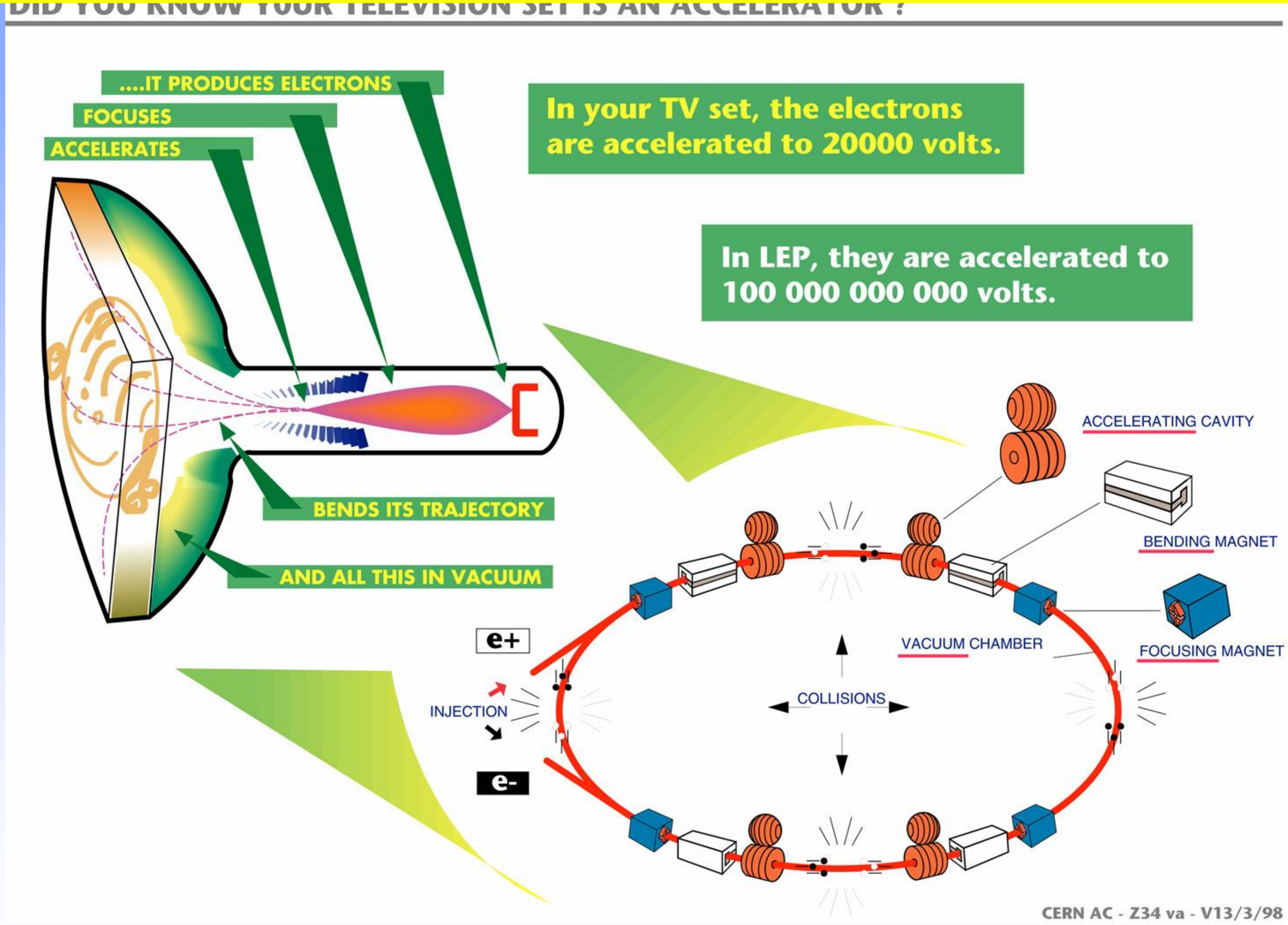
$$f = \frac{Bq}{2m\pi}$$




# Ubrzavanje čestica

## stara televizija je ubrzivač čestica u malom!

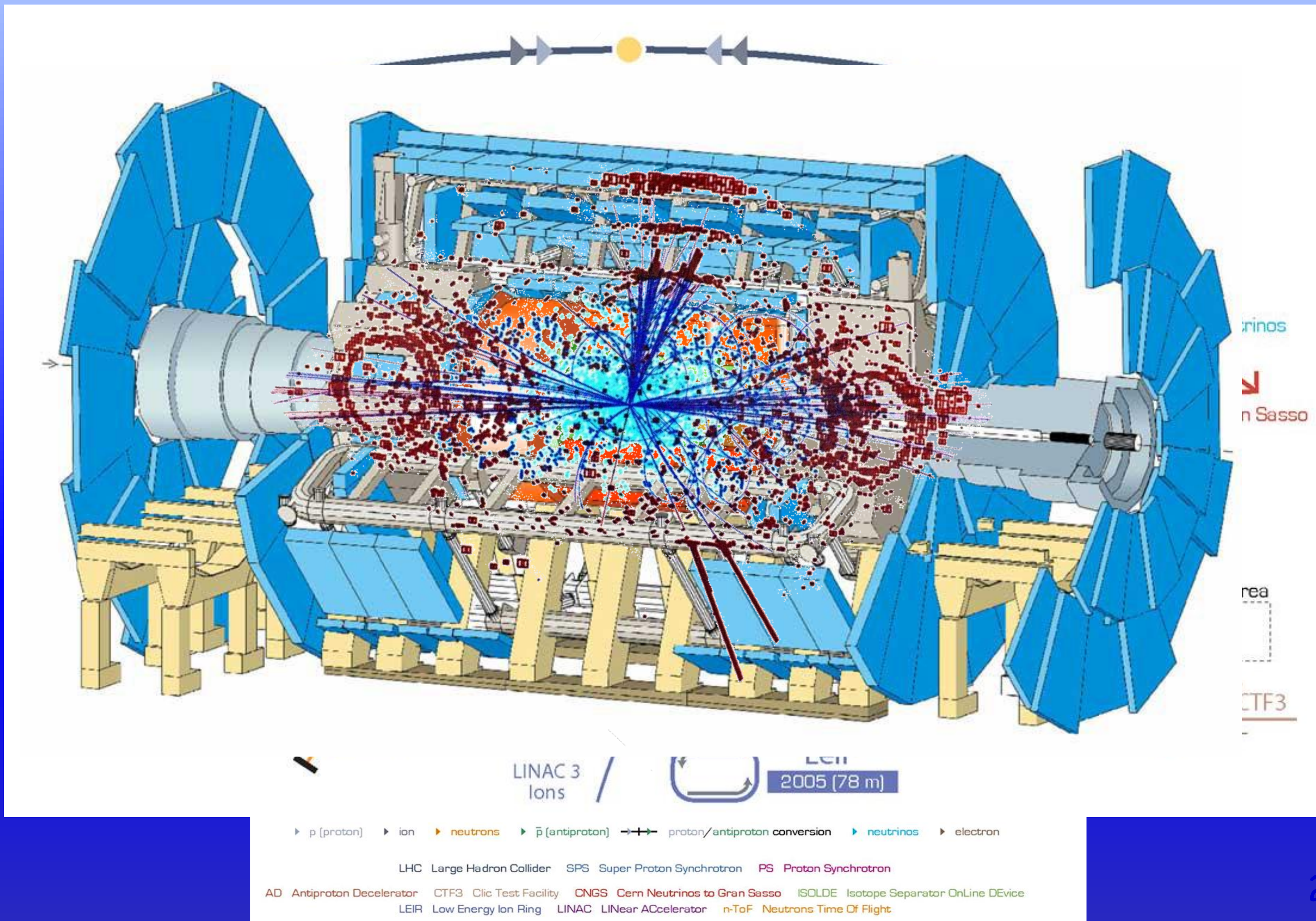





FILM

Mirko Planinić

# LHC UBRZAVAČKI LANAC



# Akceleratorski lanac

# Nosač aviona -12 čvorova

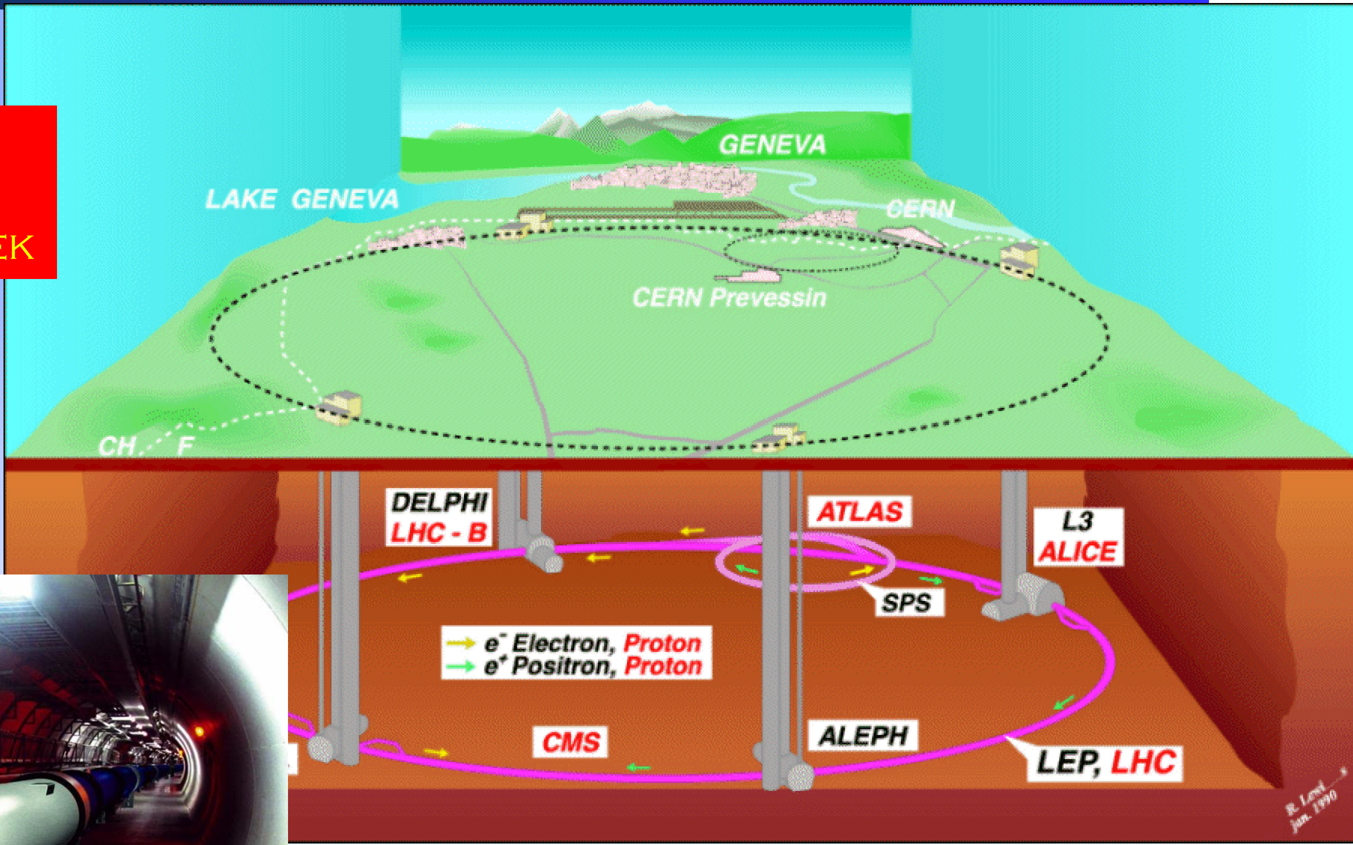
ENERGIJA SNOPA

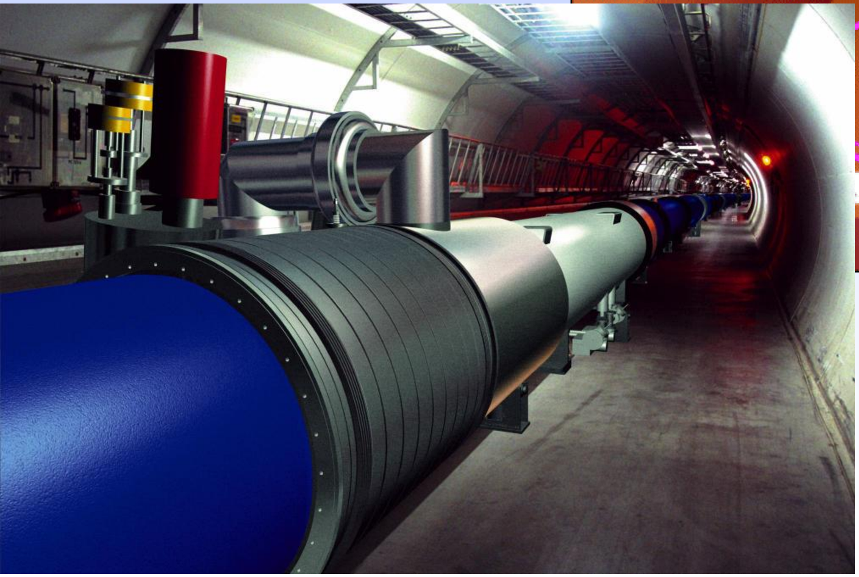
2808 nakupina, 1.15 x $10^{11}$ protona po nakupini


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

# LHC – Zašto mu se divimo?

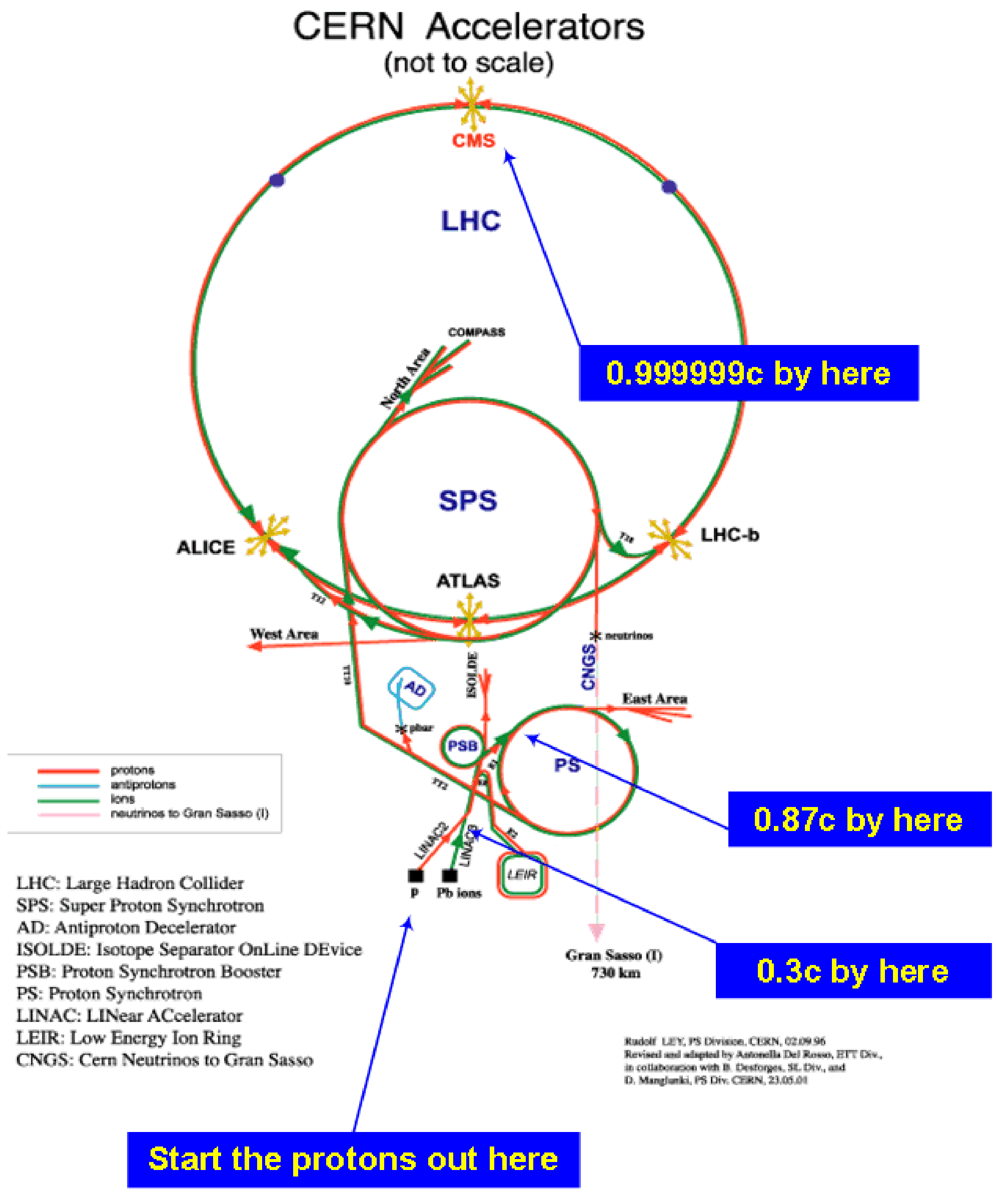
Proton-proton sudari
E = 7000 + 7000 GeV
800 million sudara/sek



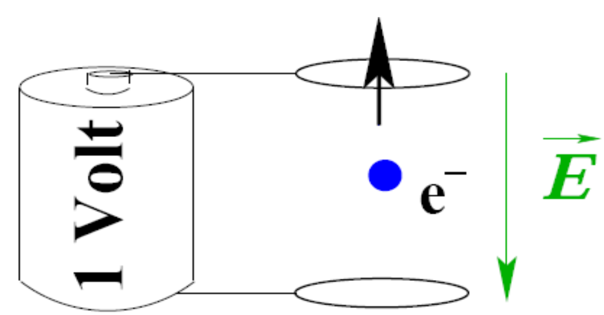
Supravodljivi magneti

# Akceleratori i LHC eksperimenti na CERN-u

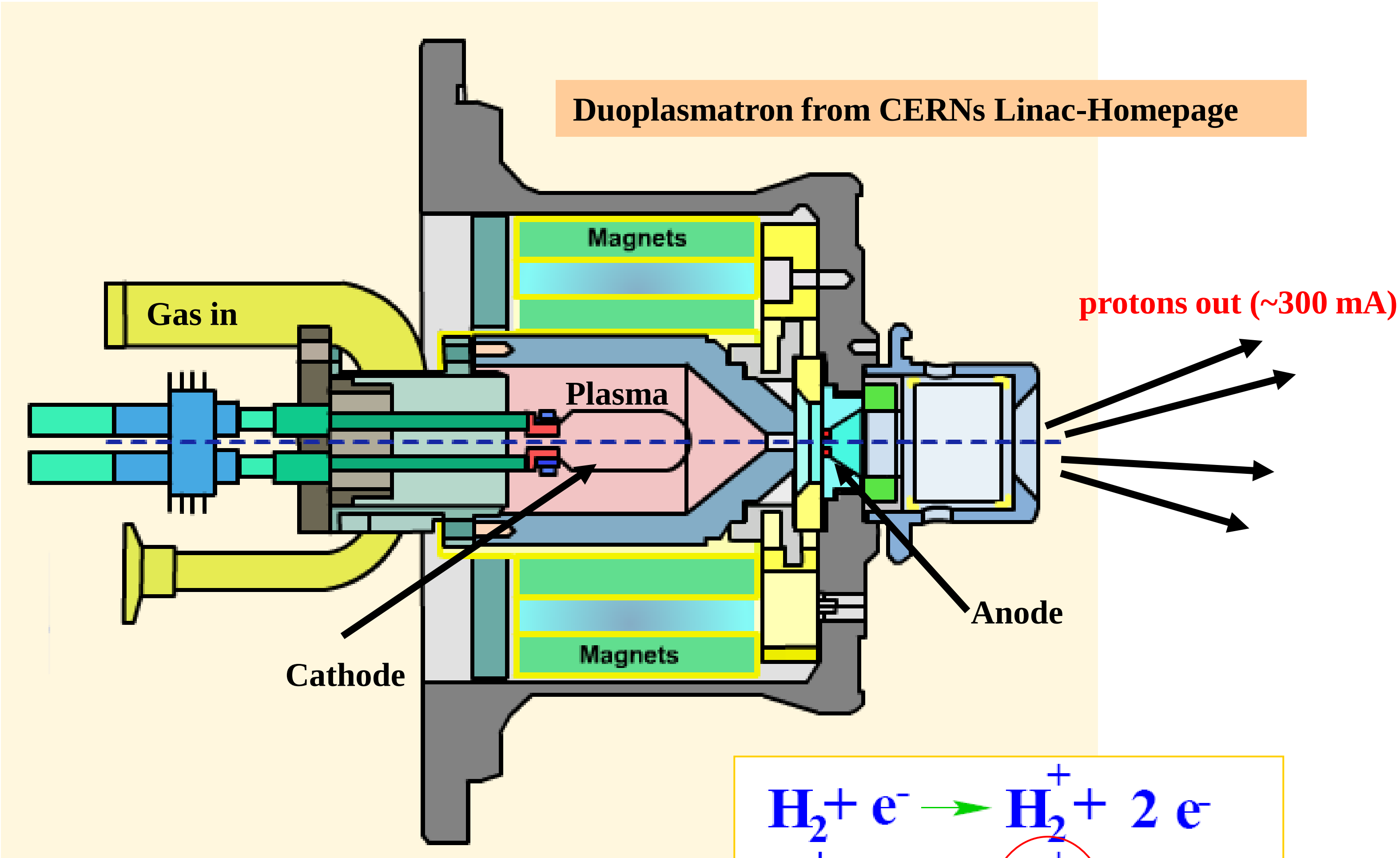



## Energije:

| | |
|---|---|
| Linac | 50 MeV |
| PSB | 1.4 GeV |
| PS | 28 GeV |
| SPS | 450 GeV |
| LHC | 7 TeV |



# Kako dobiti protone ?

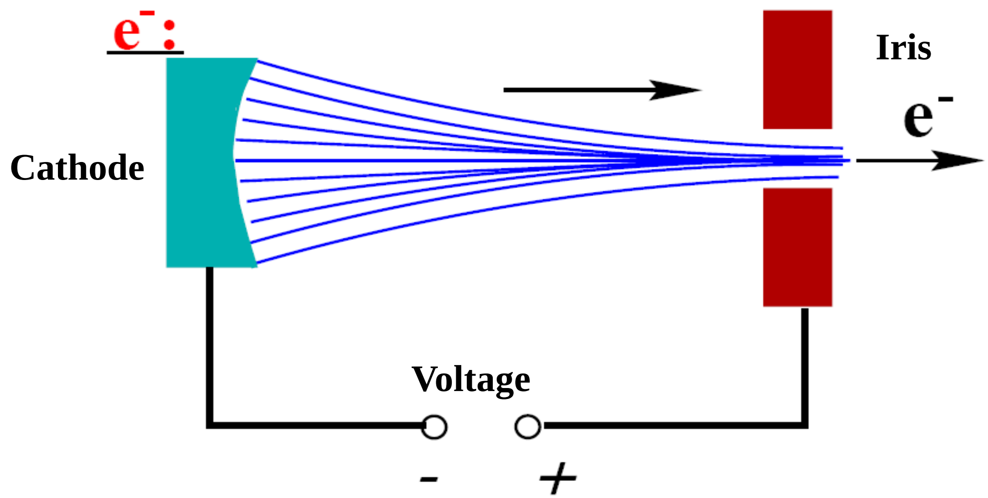



$$H_2 + e^- \rightarrow H_2^+ + 2e^-$$

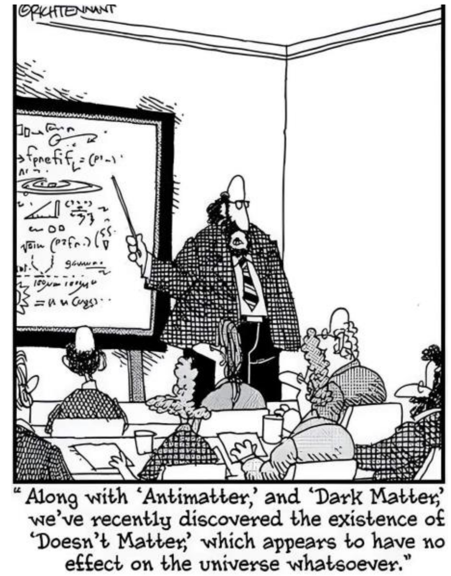
$$H_2^+ + e^- \rightarrow H^+ + H + e^-$$

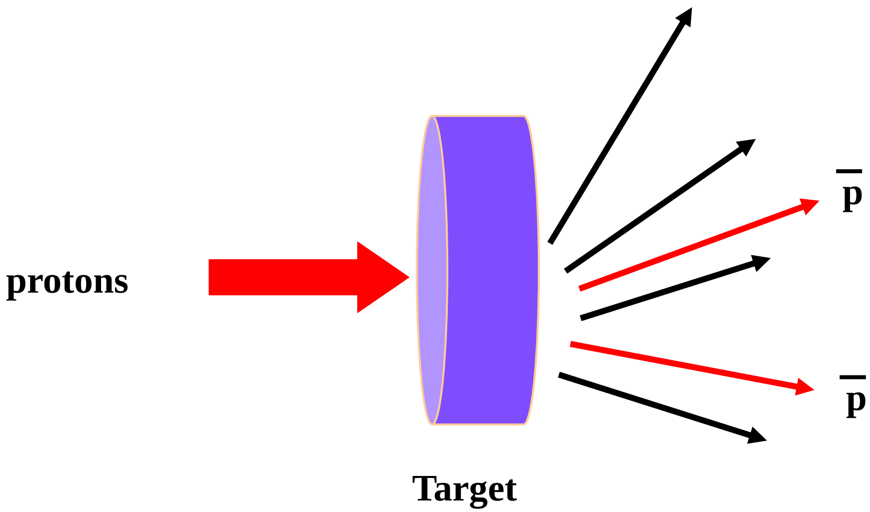
$$H + e^- \rightarrow H^+ + 2e^-$$

# Kako dobiti elektrone ili antiprotone ?




Electron beam




Collection of antiprotons

# Pitanja koja se postavljaju ...

Koje čestice ćemo ubrzavati ?

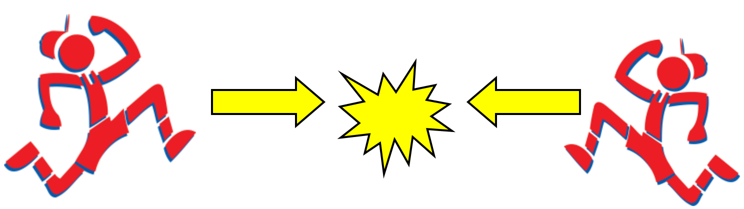
Kružno ili linearno ?

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

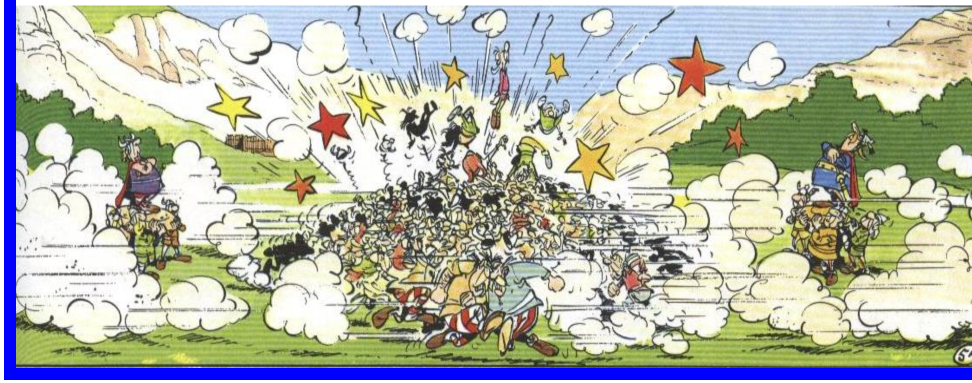
# Zašto hadronski sudarivač?

- Mane:
  - Hadroni su kompleksni
    - Prisutan veliki broj čestica
    - Energija i vrsta sudarajučeg 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

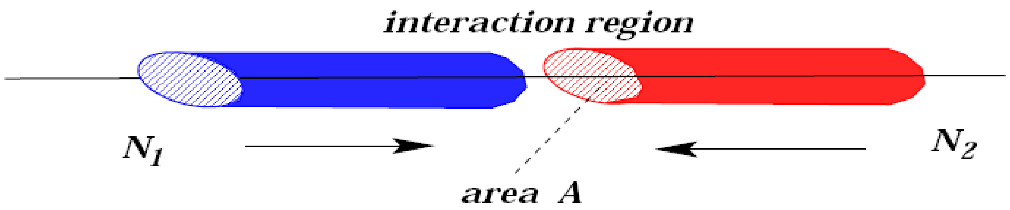
Vjerojatnost događaja=udarni presjek * luminoznost

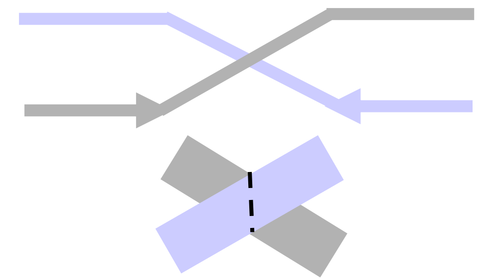
3) Raspoloživa energija: $s = (p_a + p_b)^2 \sim$

$E_a m_b$ Za fiksiranu metu

$4E^2$ Za sudarivač $E_a = E_b = E$

# Luminoznost



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

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



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

Broj čestica po nakupini (dva snopa)

Broj nakupina po snopu

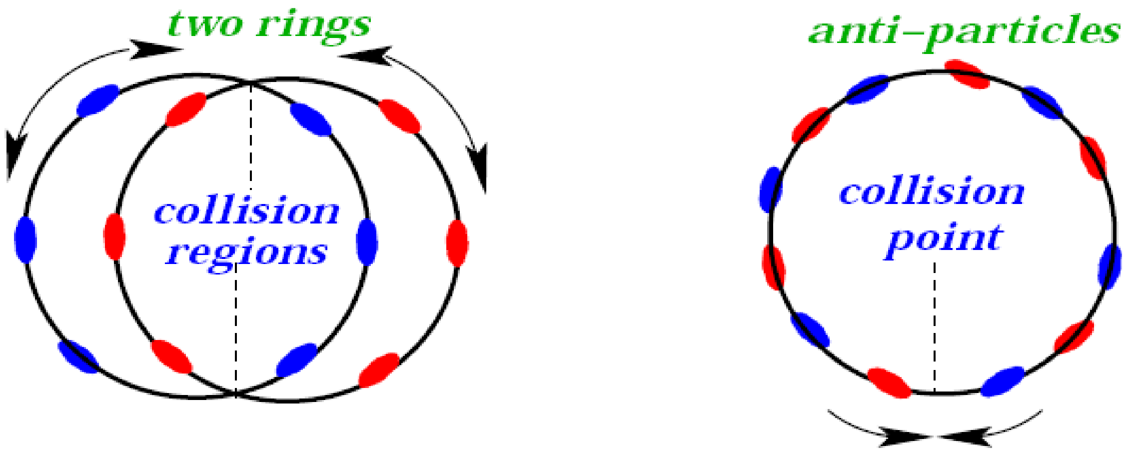
Okretna frekvencija

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

www.kahoot.it

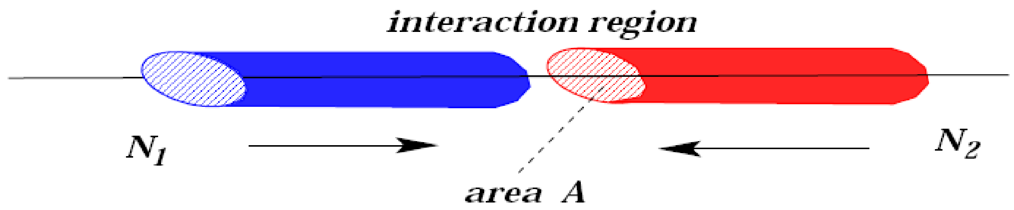
Sudarivač čestica koristimo rađe nego sudare na čvrstoj meti jer:

a) je tako sudar čestica vjerojatniji
b) je manje zračenje u okolici sudara
c) tako bolje iskoristimo energiju
d) tako zaobiđemo zakon očuvanja energije

# Luminoznost: veličina snopa

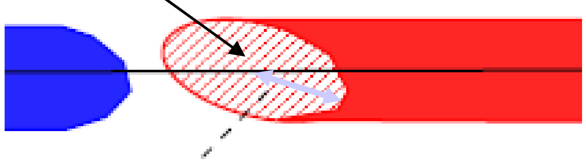
EKSPERIMENT

**Trebamo uski snop na mjestu sudara:**

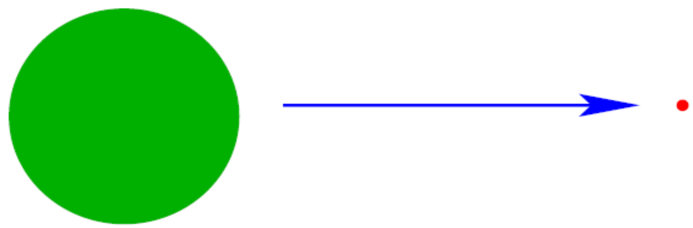



$$L = \frac{N_b^2 n_b f_{rev}}{4\pi\varepsilon\beta *} F$$

$$\sigma = \sqrt{\varepsilon\beta *}$$



*LHC:*



$\langle\beta\rangle_{arc}$ = *80 meter*  $\beta_{IP}$ = *0.5 meter*

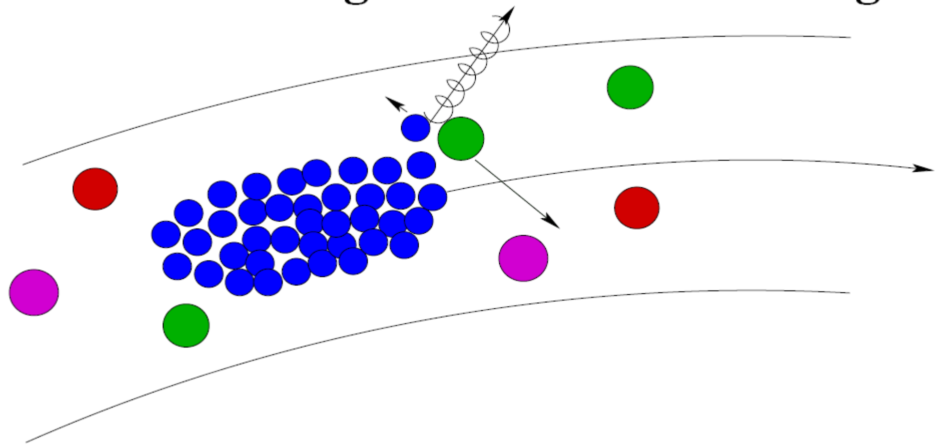
**Ograničenje:** **Dostupno magnetsko polje**

**Magnetski otvor**

# Vakuum



**Bremsstrahlung + Coulomb Scattering**



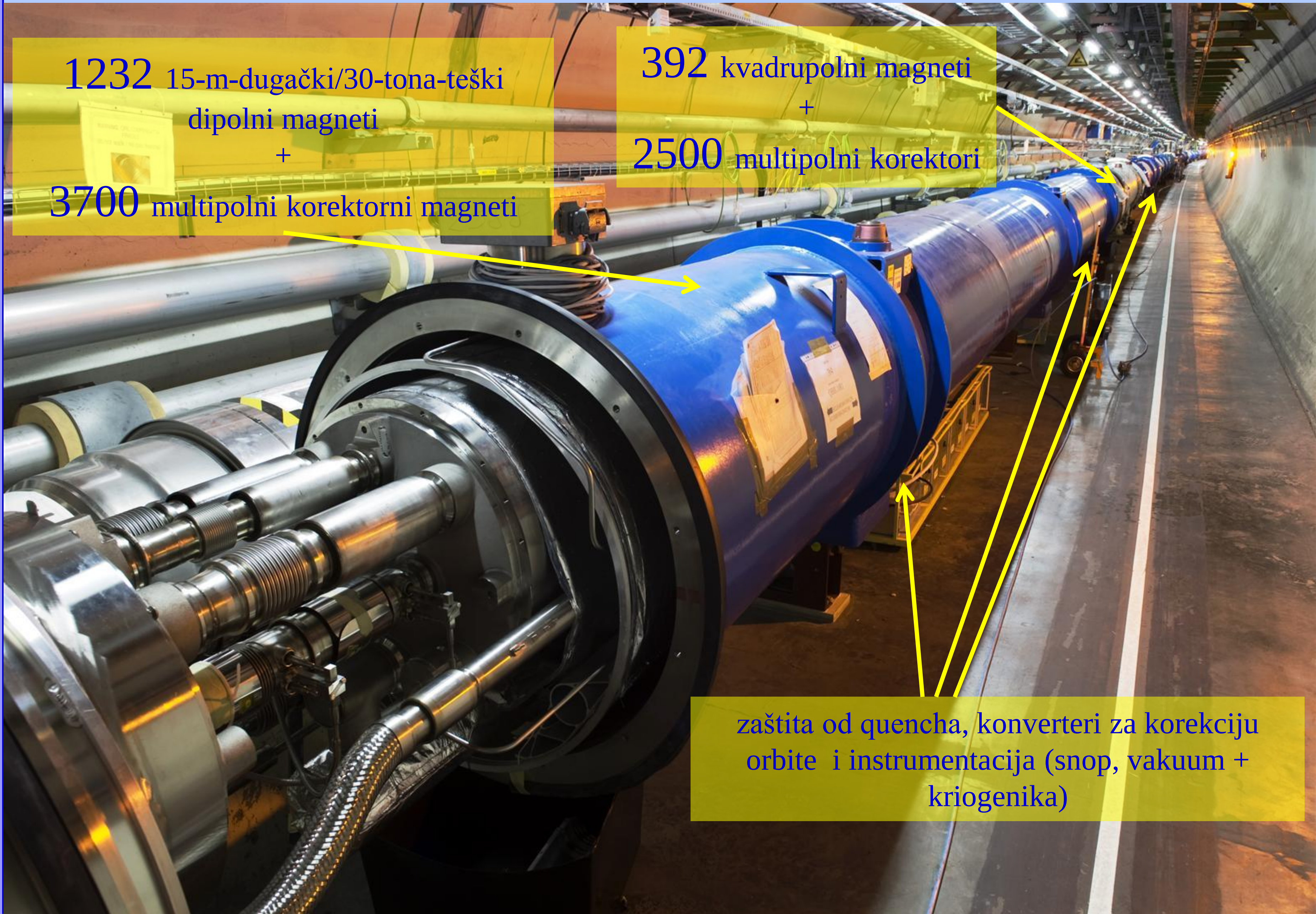
- ❑ “Rasipanje “ snopa
- ❑ Gubitak čestica
- ❑ Neželjeni sudari
- ❑ Ograničava Luminoznost

# LHC: from design…

Prva ideja LHC 1985. Konstrukcija odobrena 1995.

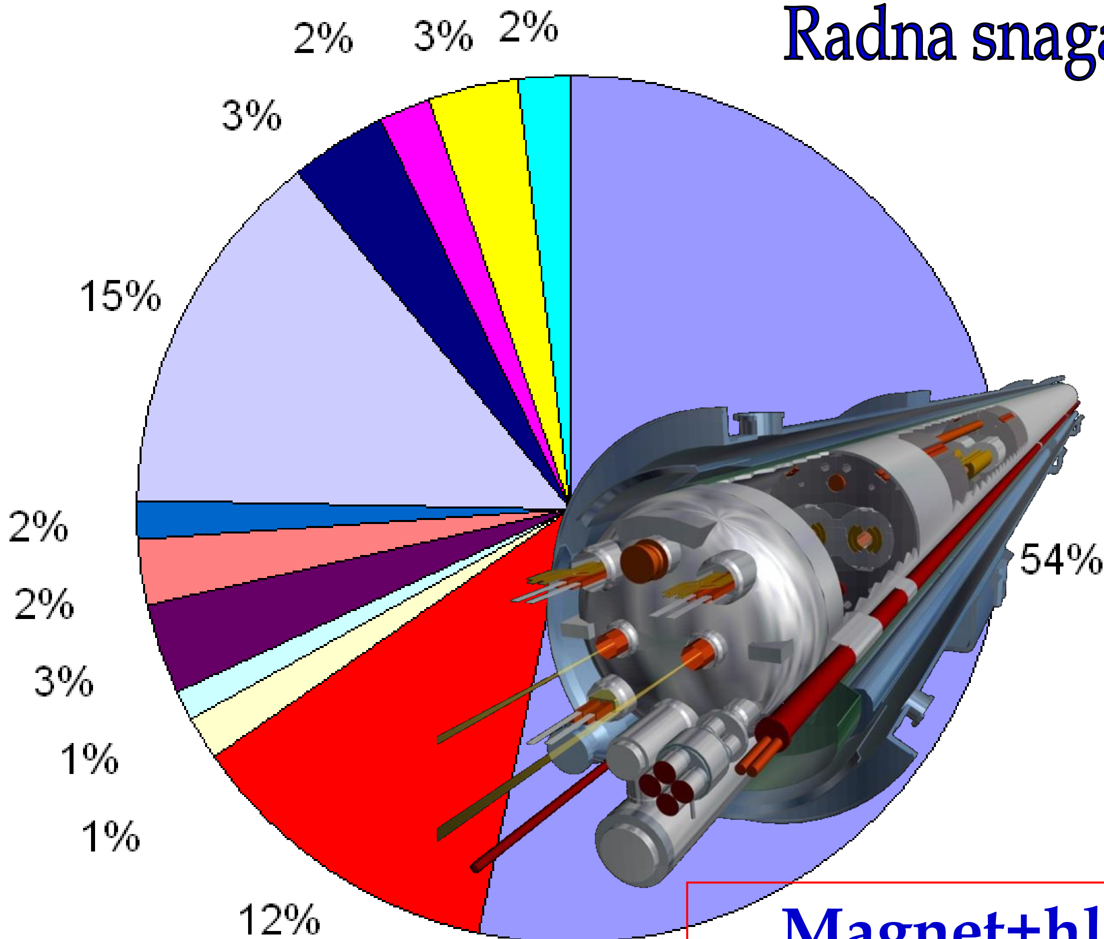
| | |
|---|---|
| Energija sudara: | 7+7 TeV |
| Broj nakupina čestica: | 2808 |
| Broj čestica po nakupini: | $1.15 \times 10^{11}$ |
| Struja snopa: | 0.582 A |
| Spremljena energija po snopu: | 362 MJ |
| Najveća luminoznost IP1 : | $10^{34}$ $cm^2s^{-1}$ |

# Kako to izgleda u realnosti



# Troškovi LHC-a

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




**Magnet+hlađenje = 66%**

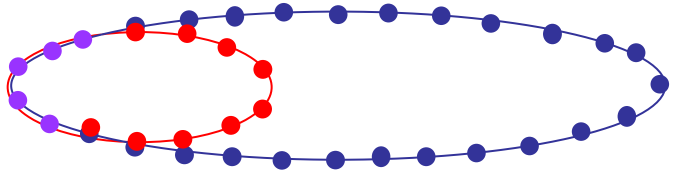
# Konceptualno pitanje

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

## ZAŠTO SUPRAVODLJIVI MAGNETI?

**Manji radijus, manji broj čestica u akceleratoru, manji akcelerator**

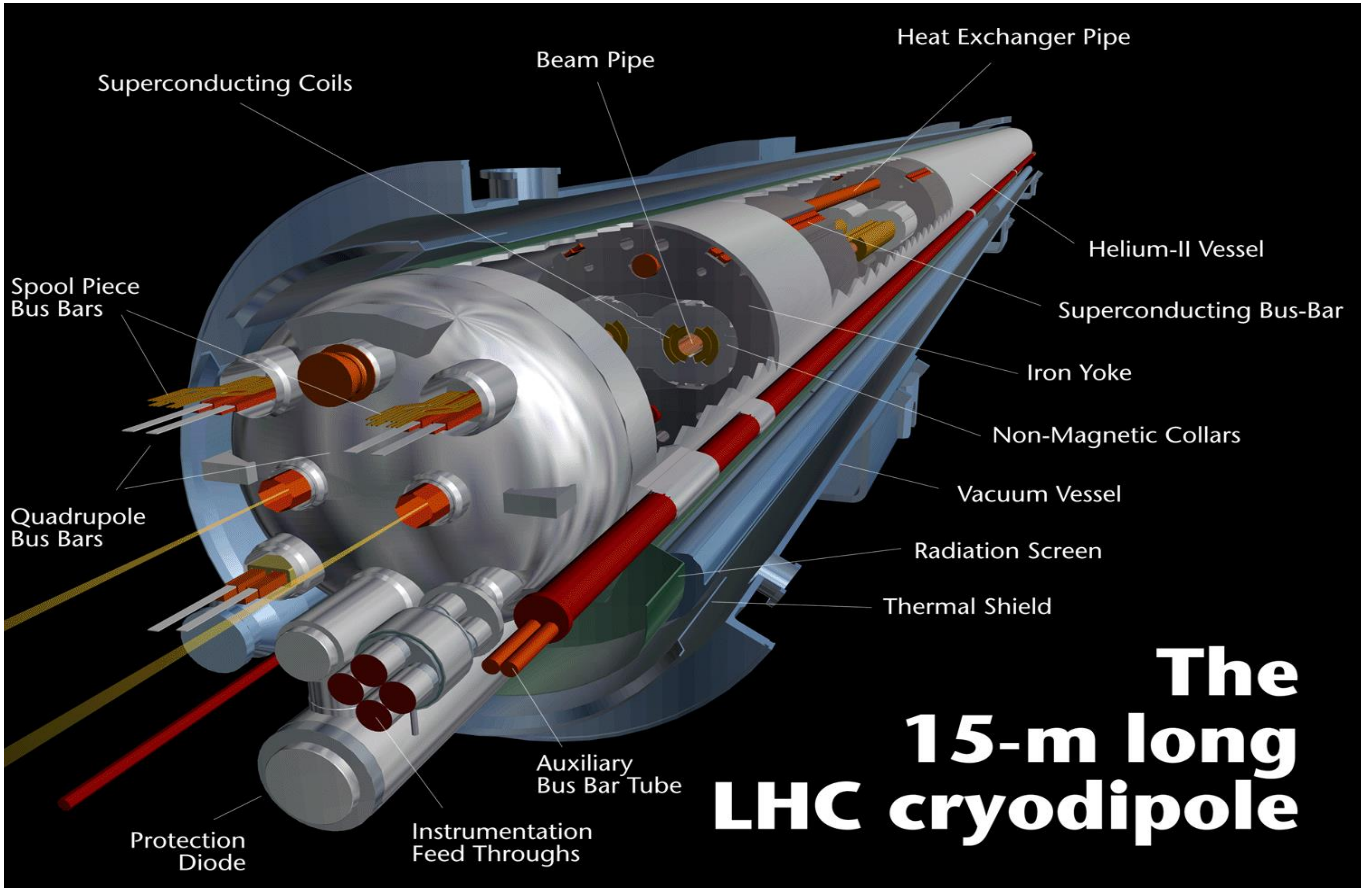


## Štedi energiju ALI komplicirana konstrukcija

# Supravodljivi Dipol za LHC

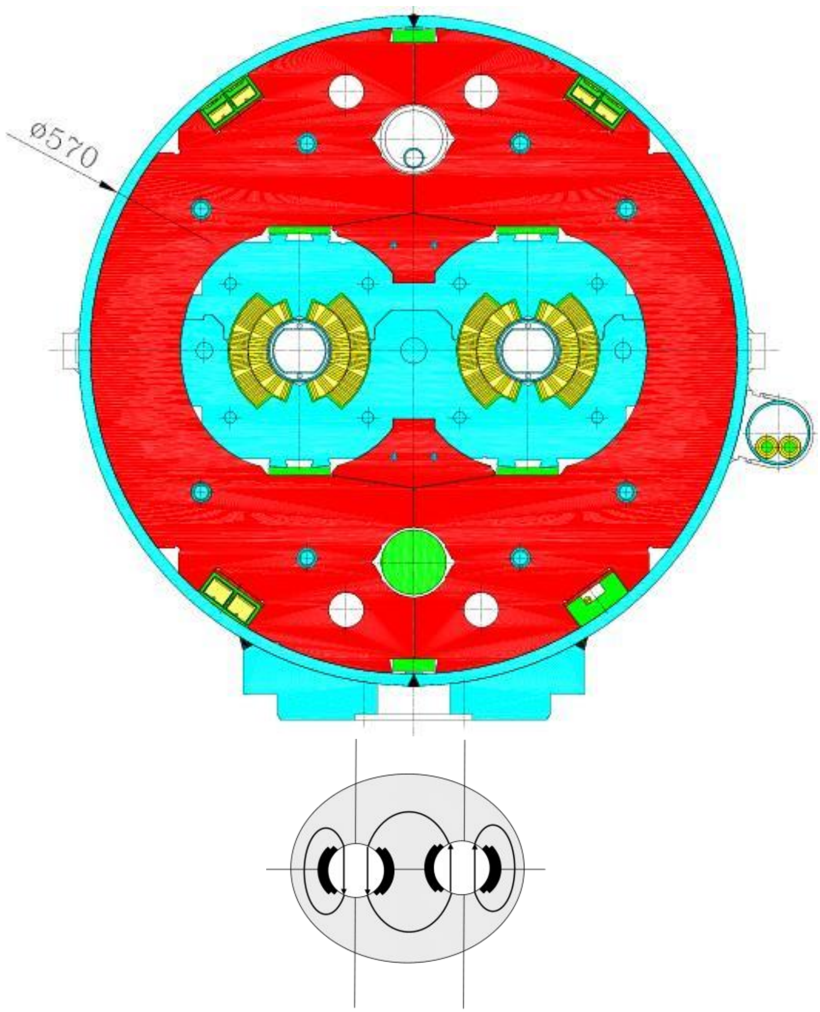
TEHNOLOGIJA

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 !**

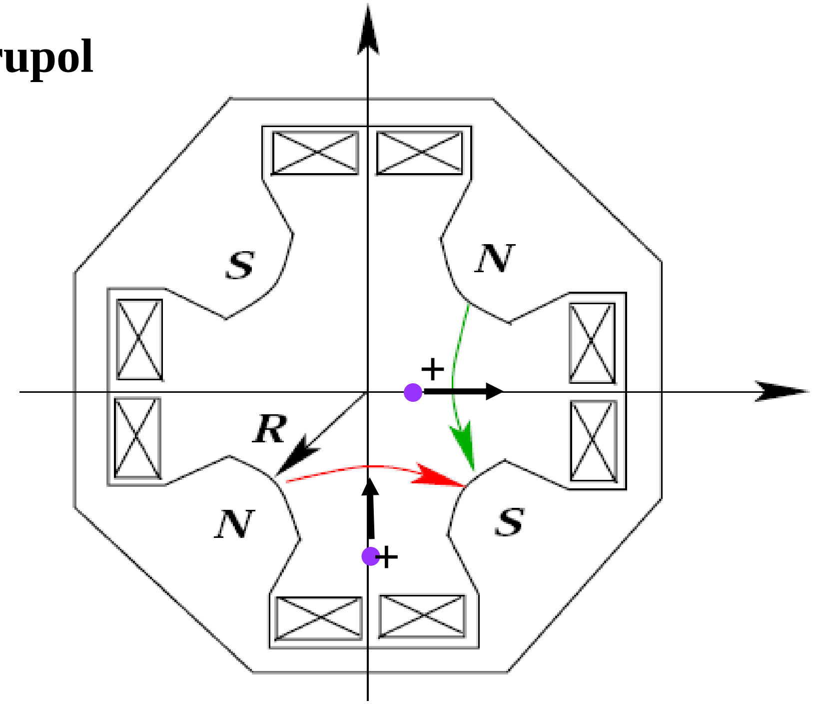
**Najhladnije mjesto u svemiru ... !!!**

# Fokusiranje: Kvadrupol



**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.**

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

# Moguće greške

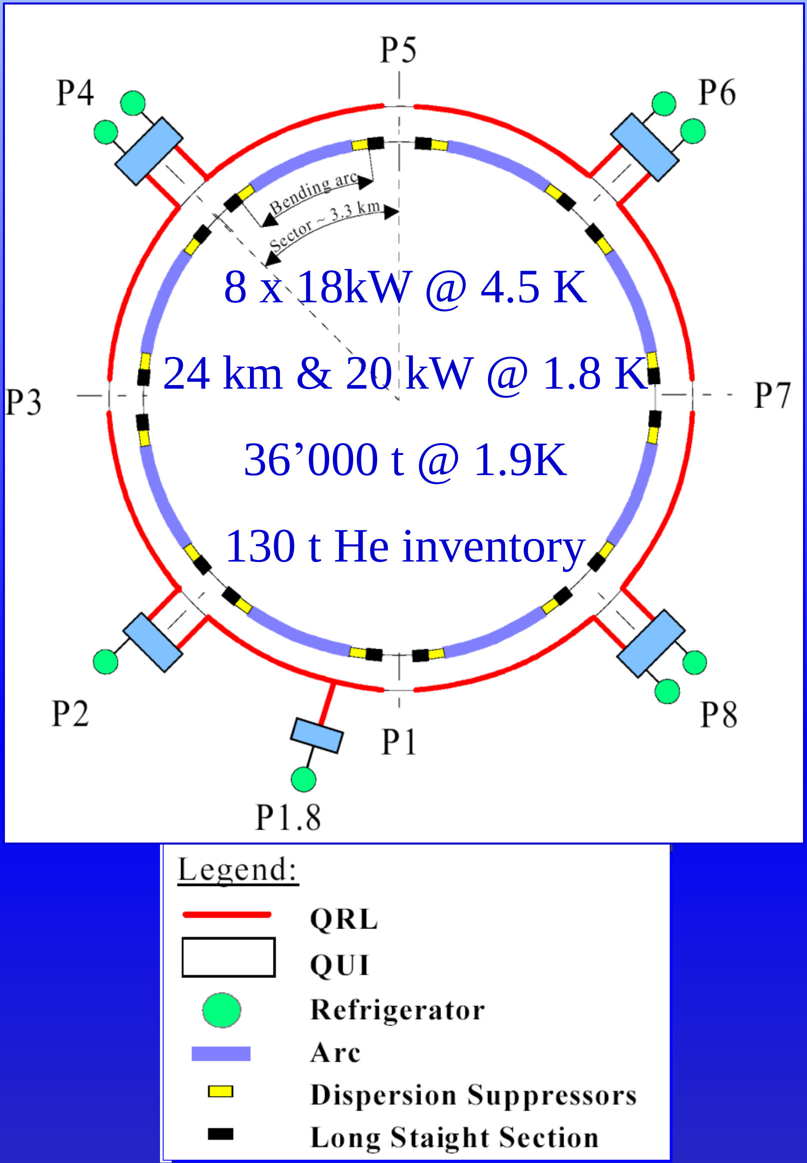


**Što treba uzeti u obzir ?:**

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

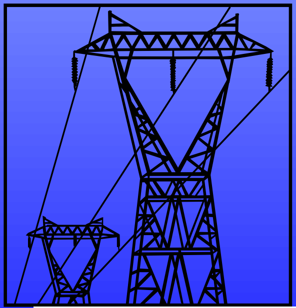
**Kalibracija magneta je važna**

# Hlađenje



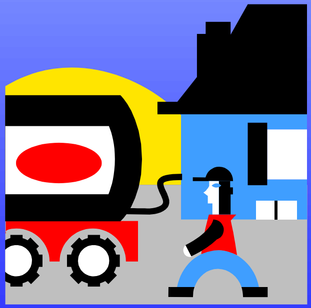

## Snaga struje

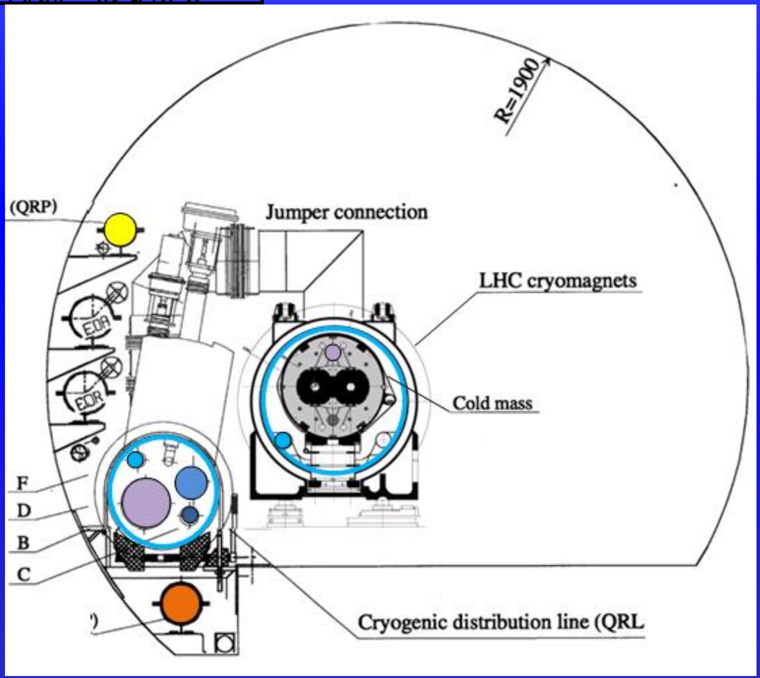
32 MW;
24 GWh/mjesečno
1.2 MCHF/mjesečno



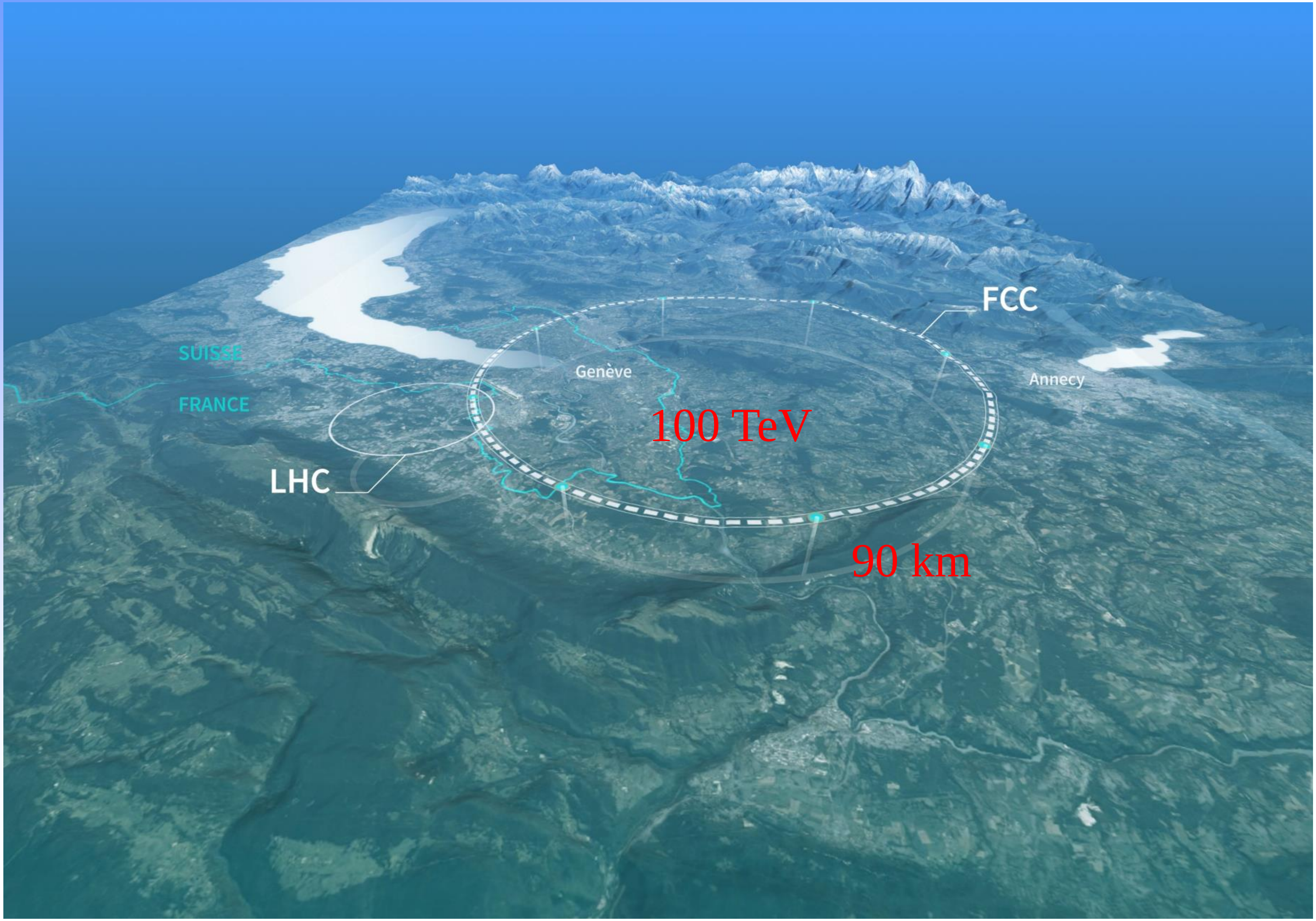
## Helij i dušik

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





# FCC-FUTURE CIRCULAR COLLIDER

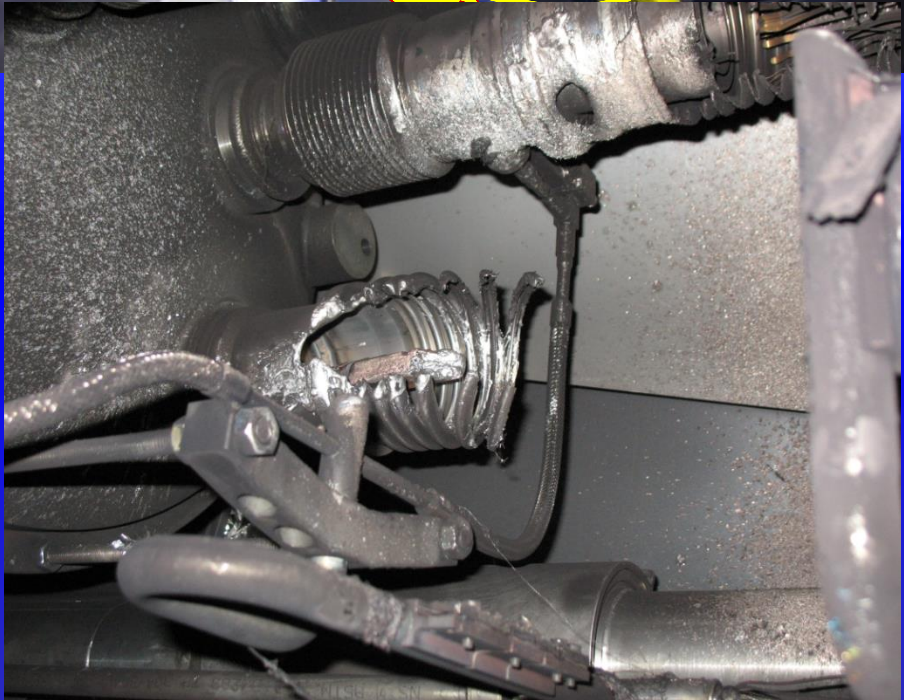


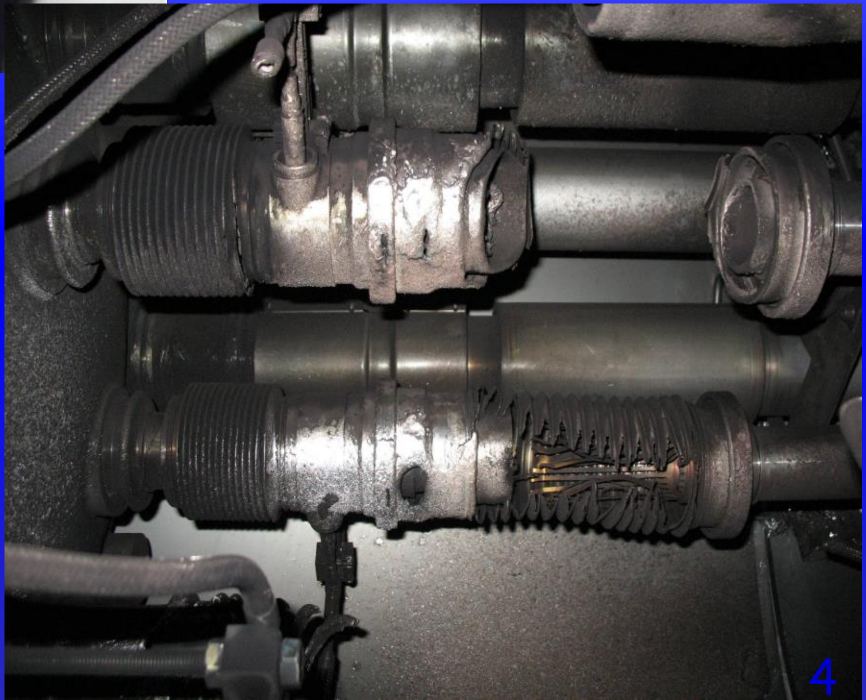
# Beam Commissioning in 2008: September 10

# 19 RUJAN 2008: NEZGODA U SEKTORU 3-4

Iskra je probušila dio gdje je zatvoren helij za hlađenje

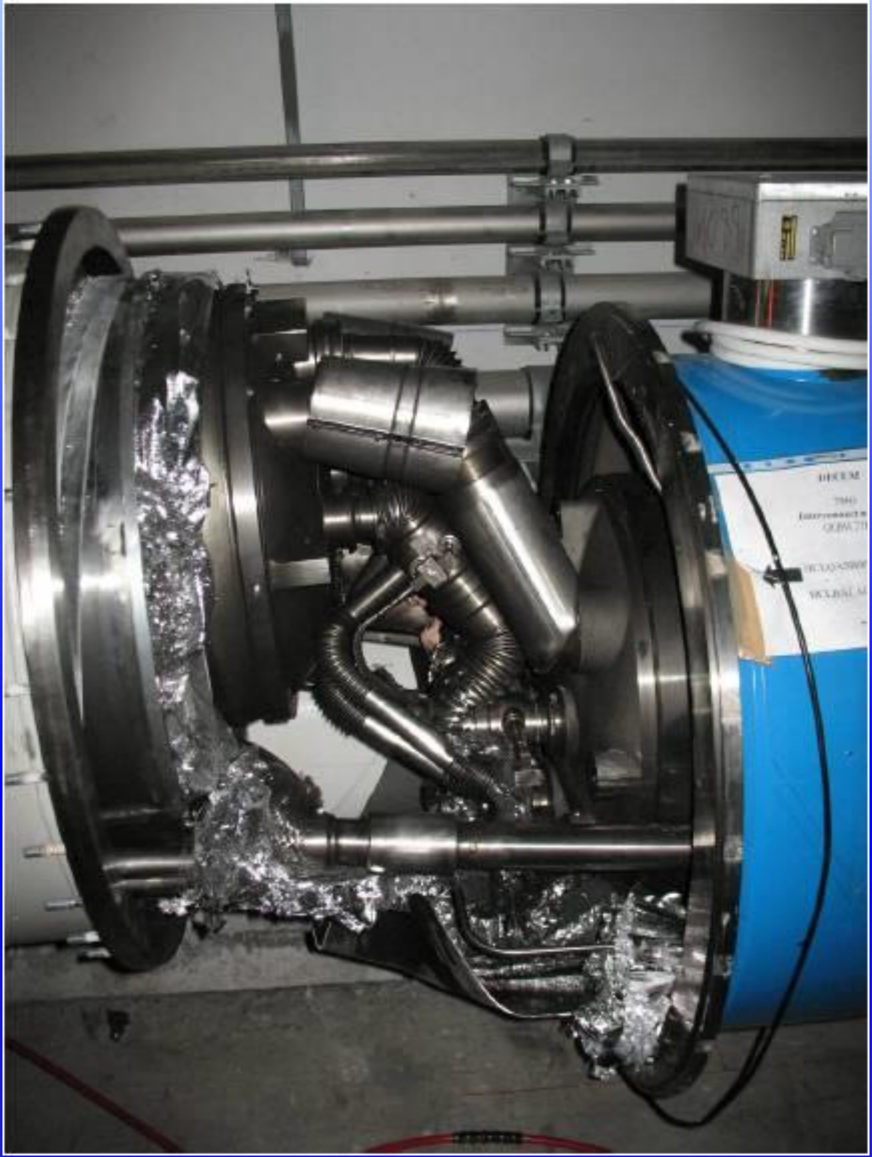
Veliki val plina pod visokim tlakom putovao je u oba smjera.



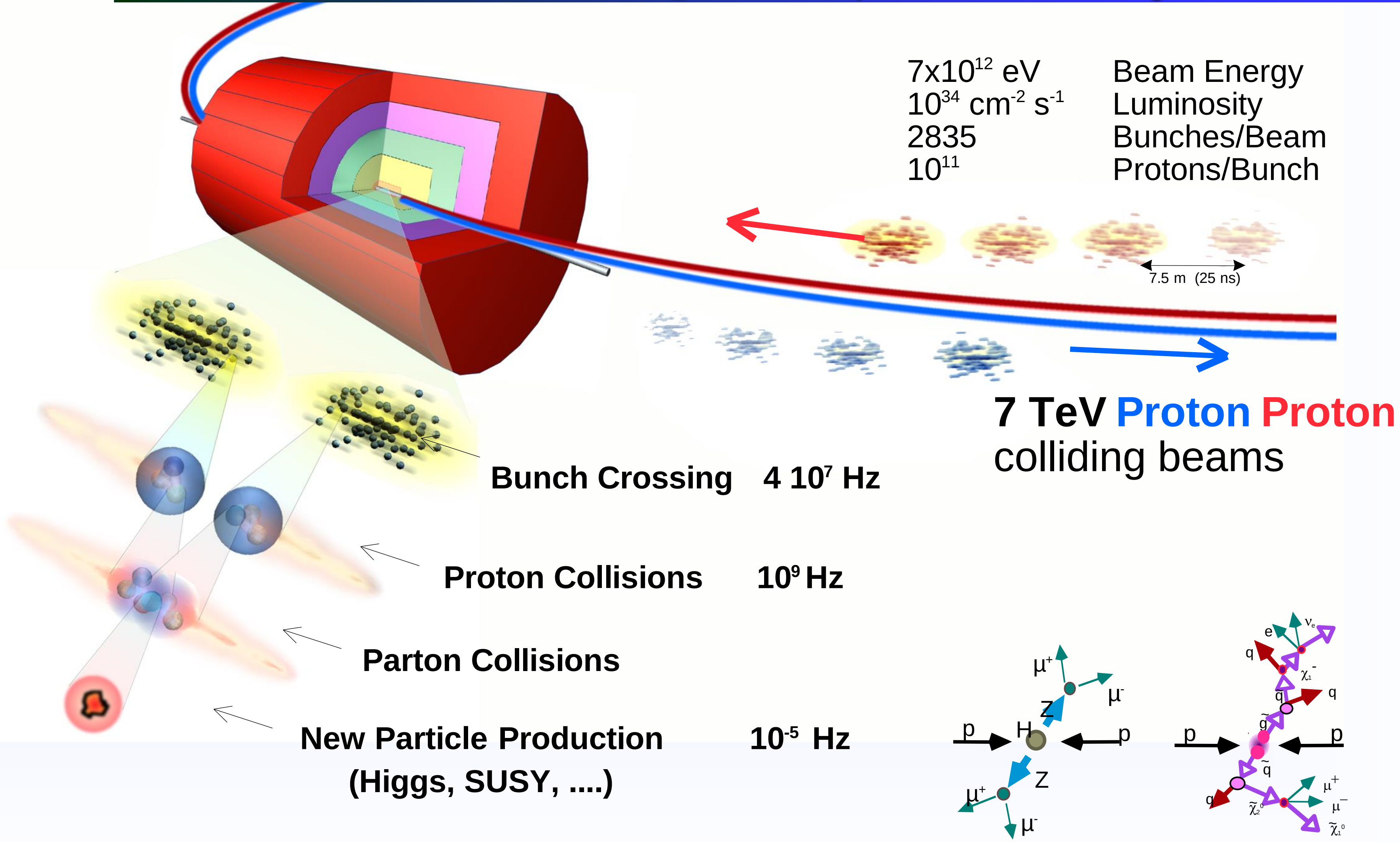


# Collateral damage: magnet displacements

# Collateral damage: magnet displacements



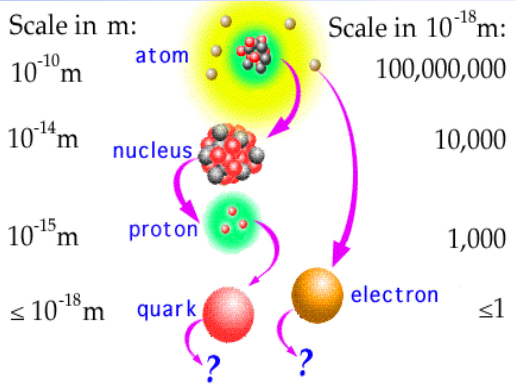
# LHC sudari: igla u plastu sijena!



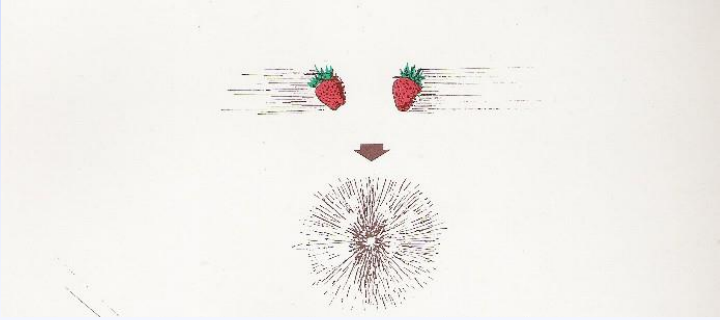

**Tražimo 1 događaj od 10,000,000,000,000**

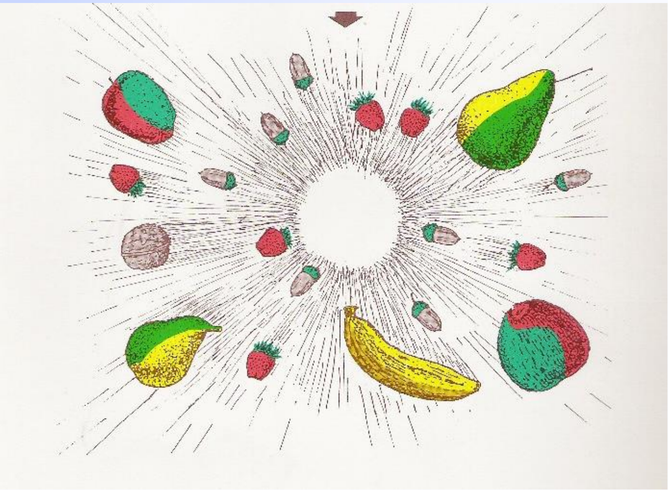
# Podsjetnik na temeljne koncepte

1) gledanje malih dimenzija traži velike energije




2) masa je isto što i energija



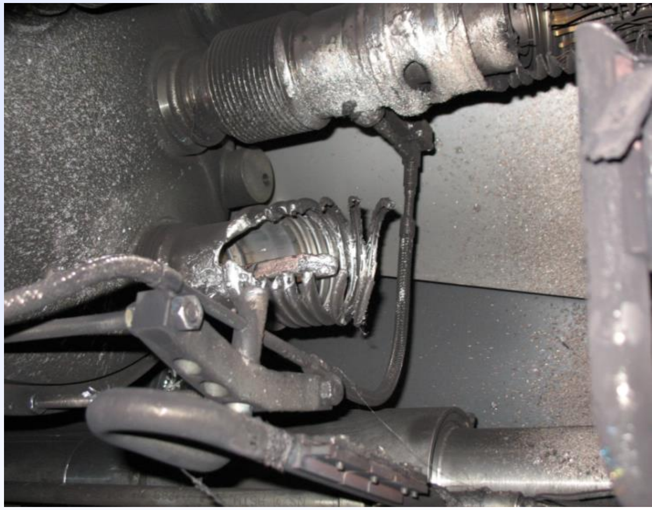


# Podsjetnik na temeljne koncepte

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!