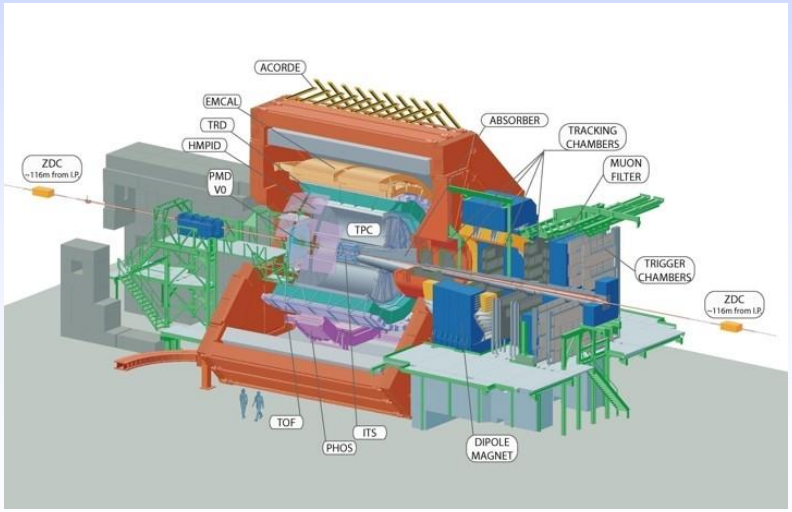
Croatian Teacher Programme

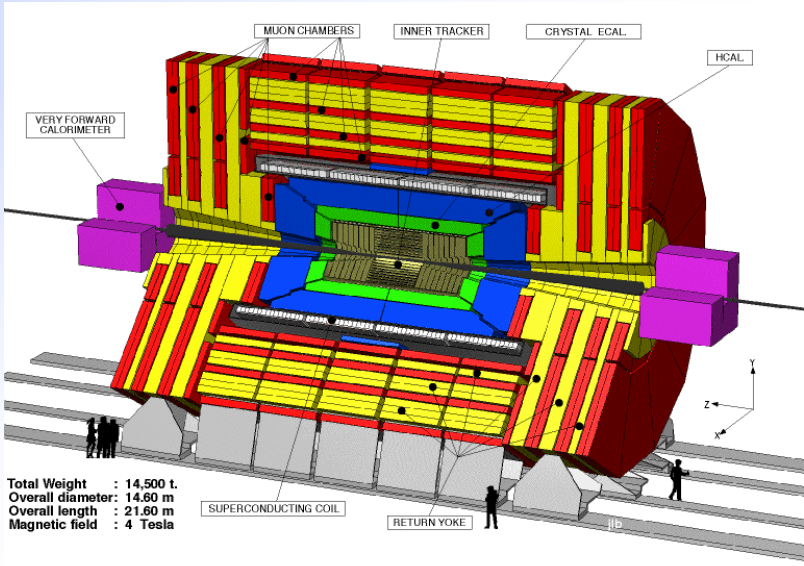
9-13 April 2017
CERN
Europe/Zurich timezone

CERN

Detektori u fizici elementarnih čestica

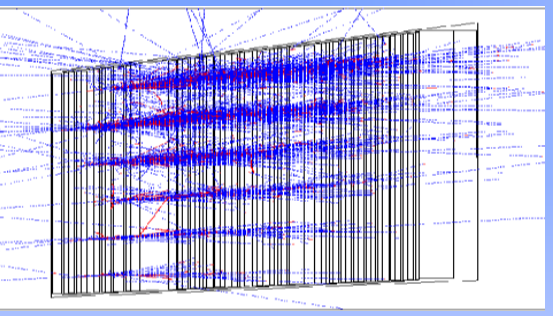
Mirko Planinić
PMF



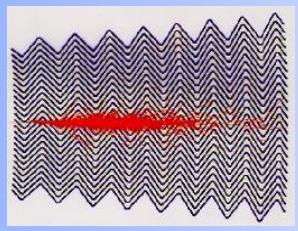


Sad kad smo upoznali ubrzivače...

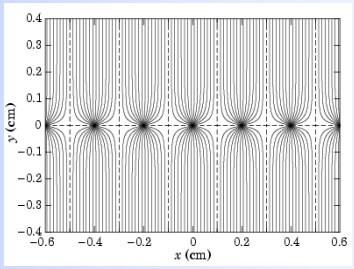
Ajmo nešto reći o detektorima ...



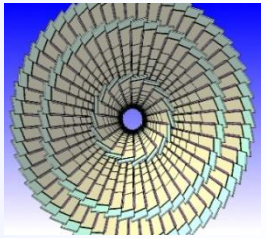
- Elektromagnetski kalorimetar

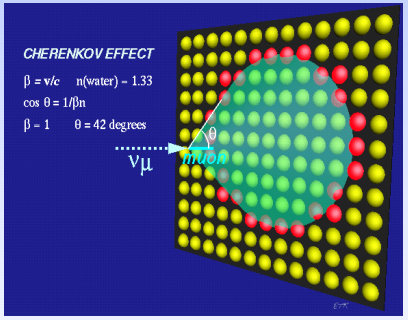


- Hadronski kalorimetar



- Mnogožičane komore
- Poluvodički detektori



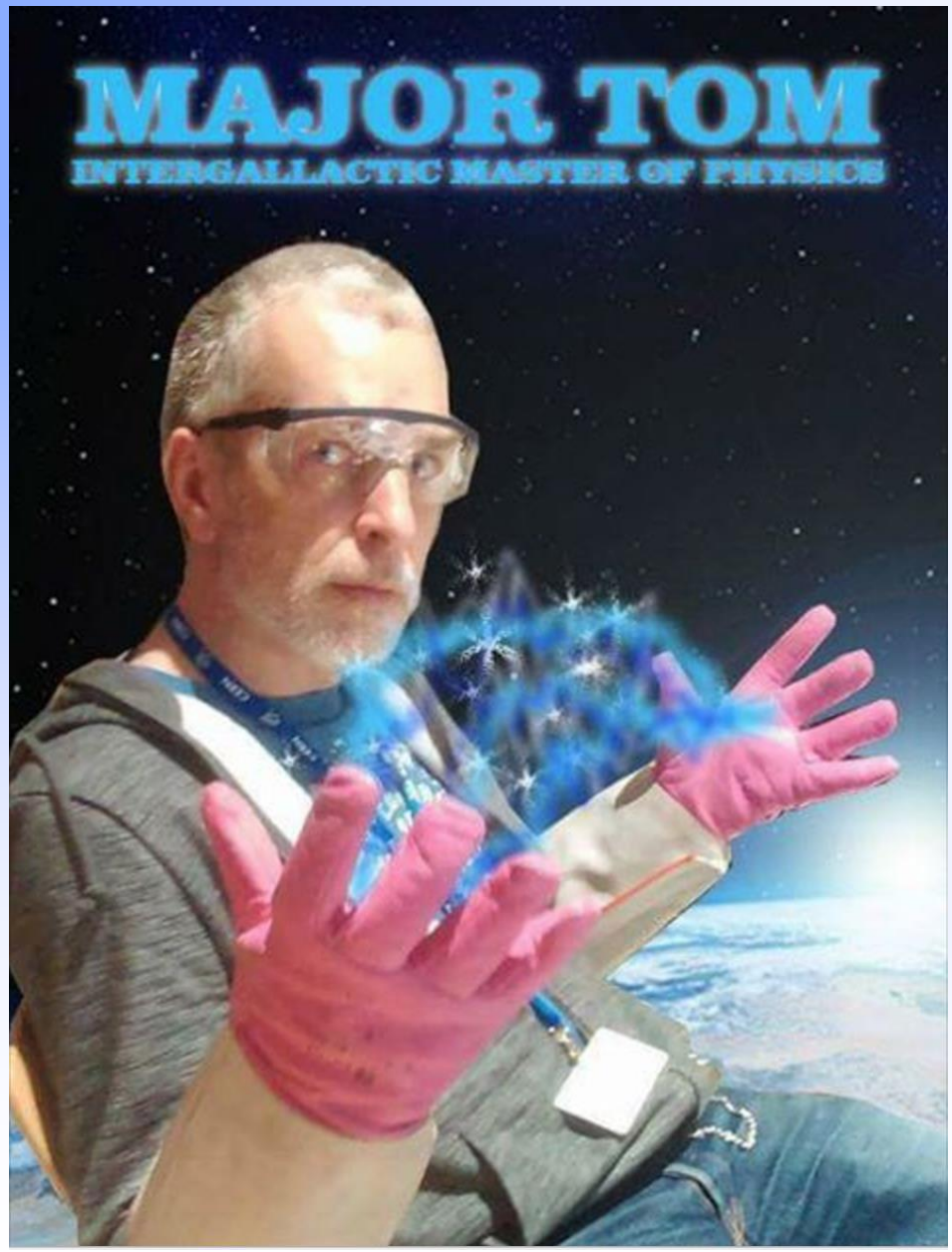


- Čerenkovljevi detektori

- Hibridni detektori (ALICE, CMS)
- Spin-off
- Kvarkovsko – Gluonska Plazma
- Sažetak
- Interakcija čestica s materijom

S'Cool TOM

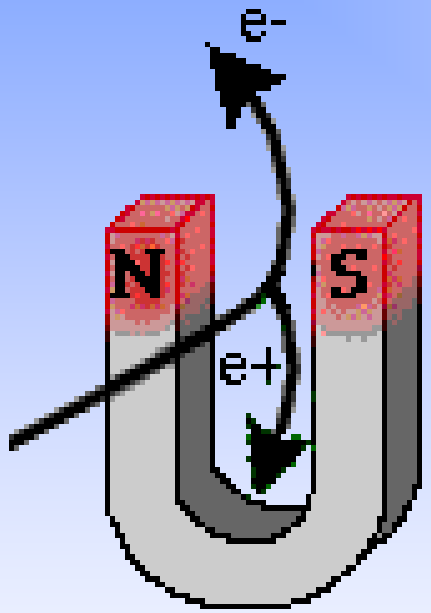
Idemo na posao …

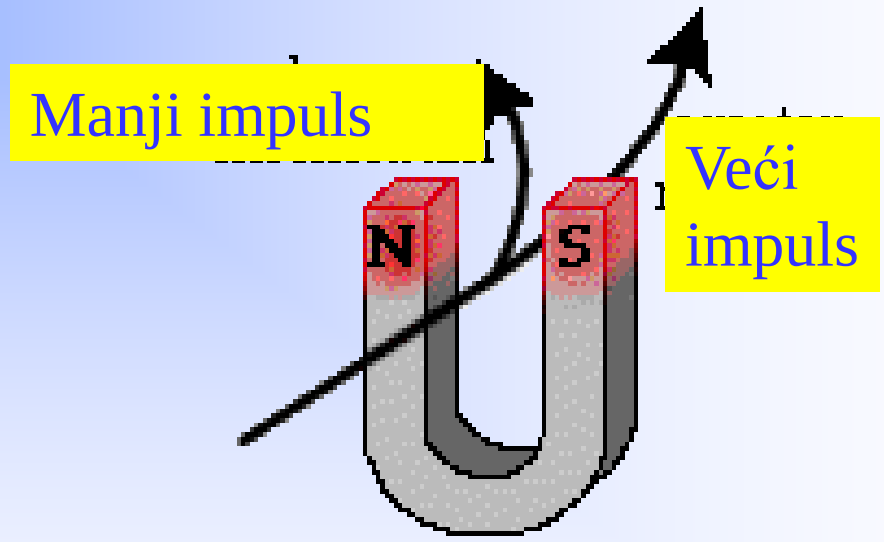


Što je cilj detekcije čestica?

- Detekcija čestica

Cilj detekcije je izmjeriti $p_\mu = (E, \vec{p})$ *čestica u konačnom stanju u sudarima visokih energija.*





Uvod u detekciju čestica

- Mjerenja čestica u konačnom stanju
  - Stabilne čestice:
    - Fotoni: γ
    - Leptoni: $e^-, \mu^-, \nu_e, \nu_\mu, \nu_\tau$
    - Hadroni: p, n, π^+, K^+, K^0_L
  - Nestabilne čestice :
    - Direktna rekonstrukcija: Primjer: $\pi^0 \to \gamma + \gamma$

$$m_a^2 = (p_b + p_c)^2$$

$$p_a = p_b + p_c$$

    - Identifikacija i djelomična rekonstrucija: Primjer:

$$e^- e^+ \to \tau^+ \tau^- \to \nu_\tau \bar{\nu}_\tau \mu^+ \nu_\mu e^- \bar{\nu}_e$$

Najvažniji zadaci detektora

- Najvažniji zadaci detektora
  - Mjerenje položaja: Odrediti točke prolaza nabijenih čestica ("hits")
  - Tragovi: rekonstrukcija putanje čestica uz upotrebu nekoliko mjerenih položaja točaka uzduž putanje
  - Mjerenje impulsa: Mjerenje impulsa nabijenih čestica unutar magnetskog polja iz rekonstrukcije zakrivljenosti putanje
  - Mjerenje energije: Deponiranje energije čestice u dijelu detektora
  - Identifikacija čestica: Masa i vrijeme proleta
  - Određivanje naboja čestice: Zakrivljenost nabijenih čestica u magnetskom polju
  - Okidanje (trigger): Okidanje detektora na "zanimljivim" događajima
  - Data acquisition: Isčitavanje "događaja" i spremanje nakon okidanja

Konceptualno pitanje

Koji od sljedećih procesa ne uzrokuju nabijene čestice:

a) Ionizacija
b) Zakočno zračenje
c) Čerenkovljevo zračenje
d) Comptonovo raspršenje

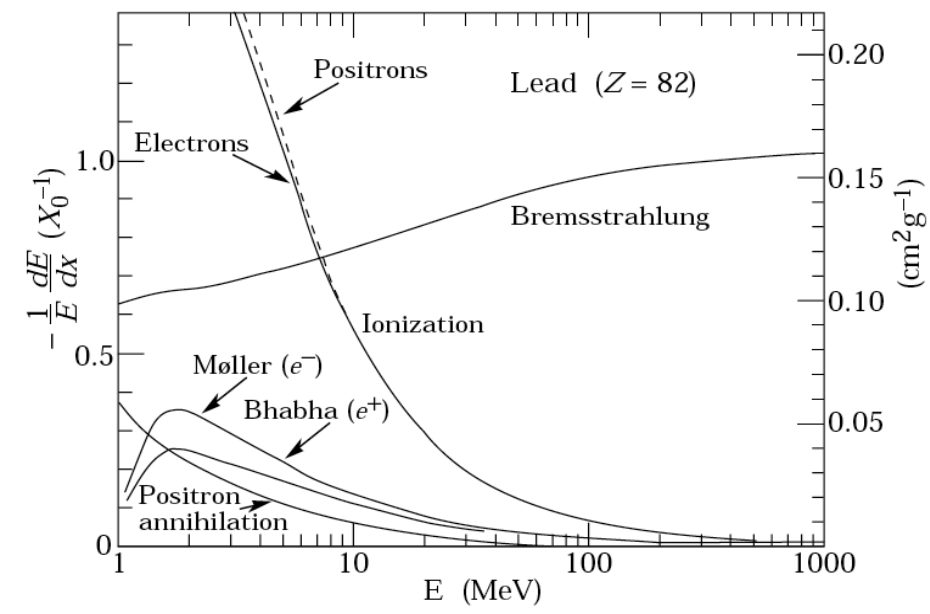
Interakcija čestica pri prolasku kroz materiju

- Pregled interakcija

  - Čestice stvorene u visokoenergijskim sudarima međudjeluju elektromagnetski i /ili nuklearno pri prolasku kroz materijal detektora

- Glavni procesi za nabijene čestice su:

  - Ionizacija
  - Čerenkovljevo zračenje
  - Zakočno zračenje

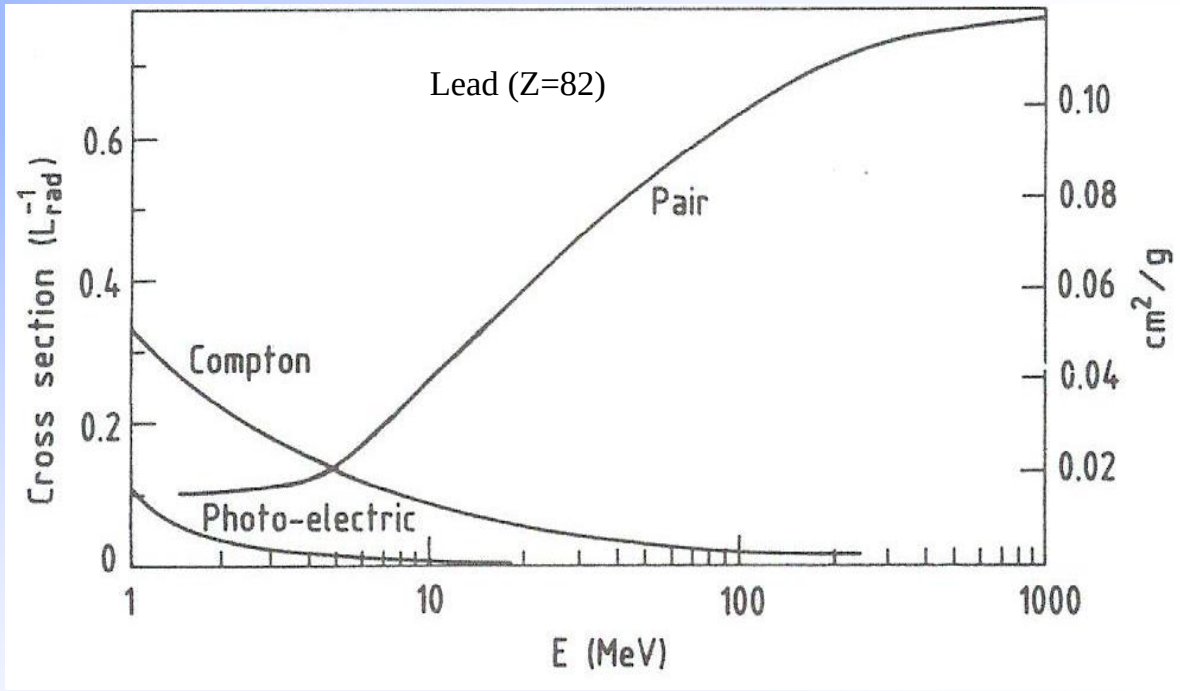


C. Fabjan, 1987

Interakcija čestica pri prolasku kroz materiju

- Glavni procesi za fotone:γ

- Fotoelektrični efekt
- Comptonovo raspršenje
- Produkcija parova



C. Fabjan,
1987

Konceptualno pitanje

Dublje u materiju prodiru:

a) fotoni
b) nabijene čestice
c) ovisi o vrsti nabijenih čestica

Zakočno zračenje

Gubitak energije elektrona zračenjem:

$$\frac{dE}{dx} = -\frac{E}{X_0}$$

Radijacijska duljina X_0 je debljina medija koja reducira srednju energiju snopa elektrona za faktor e.

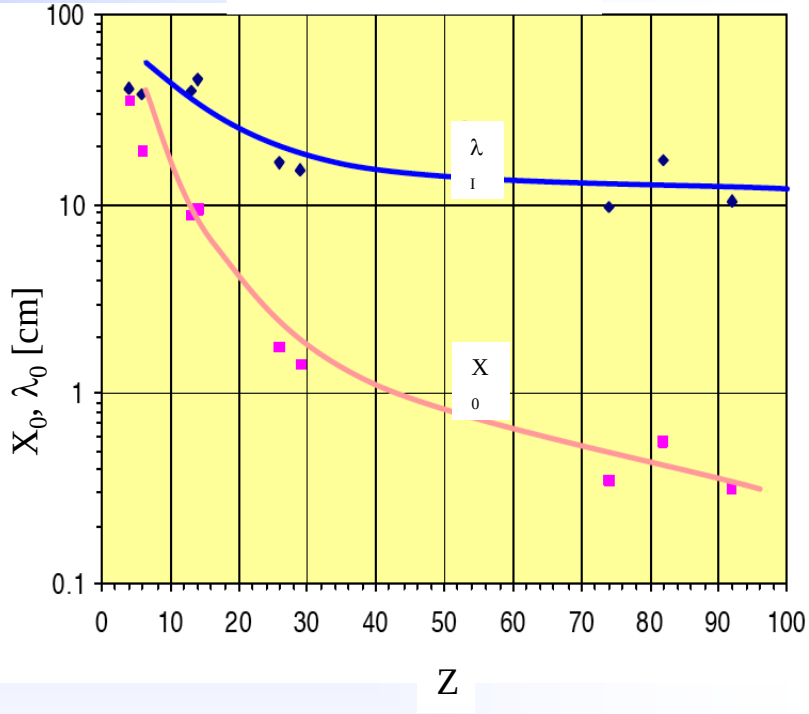
Kritična energija E_c je energija kod koje je gubitak energije na zračenje jednak gubitku energije na ionizaciju.

$$E_c \cong \frac{600}{Z} MeV$$

Interakcija s materijom

- Usporedba nuklearne interakcijske duljine (u cm) s radijacijskom duljinom (u cm)

Materijal	Z	A	Z/A	X_0 (cm)	λ_I (cm)	Gustoća (g/cm^3)
H_2 (tek.)	1	1.008	0.992	866	718	0.0708
He	2	4.002	0.500	756	520	0.125
C	6	12.01	0.500	18.8	38.1	2.27
Al	13	26.98	0.482	8.9	39.4	2.70
Cu	29	63.55	0.456	1.43	15.1	8.96
Pb	82	207.2	0.396	0.56	17.1	11.4
W	74	183.8	0.403	0.35	9.58	19.3
U	92	238.0	0.387	0.32	10.5	19.0
Scint.			0.538	42.4	81.5	1.03
BGO			0.421	1.12	22.1	7.10
CsI			0.416	1.85	36.9	4.53
NaI			0.427	2.59	41.1	3.67



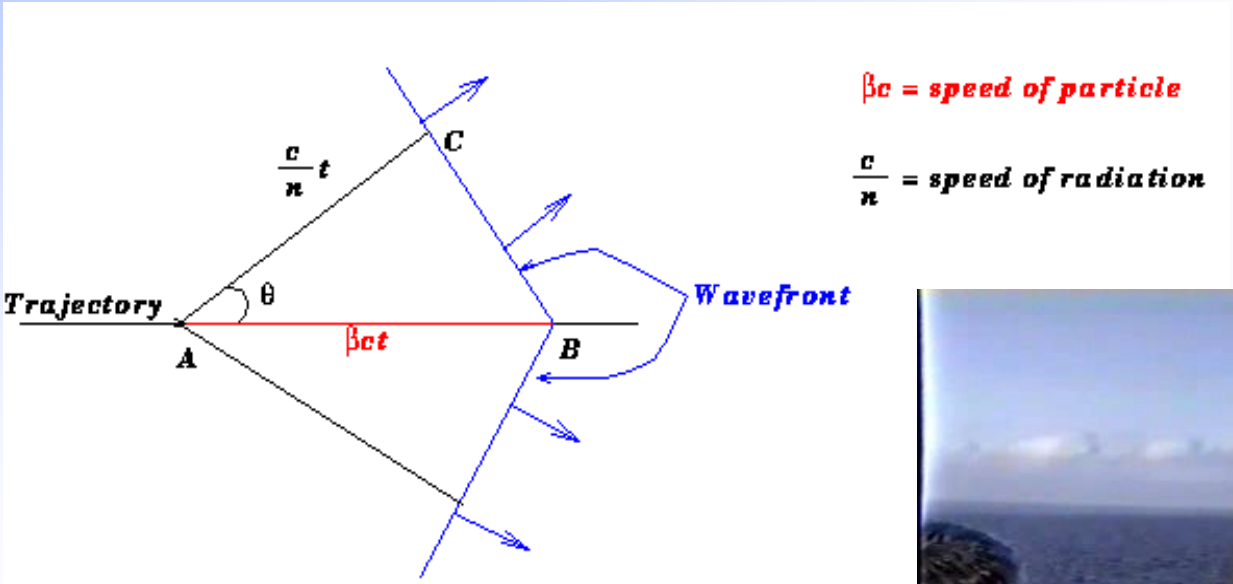
Čerenkovljevo zračenje

Čerenkovljev efekt nastaje kad se nabijena čestica kreće brzinom većom od *c/n* (brzinom svjetlosti u tom mediju) gdje je

- *c* brzina svjetlosti u vakuumu
- *n* index loma u tom sredstvu

➔ Emitira se "udarni val" fotona

Simul.



Čerenkovljevi detektori

Svojstva čerenkovljevih detektora

- Mjerenjem kuta mjerimo brzinu
- Dominira plava svjetlost

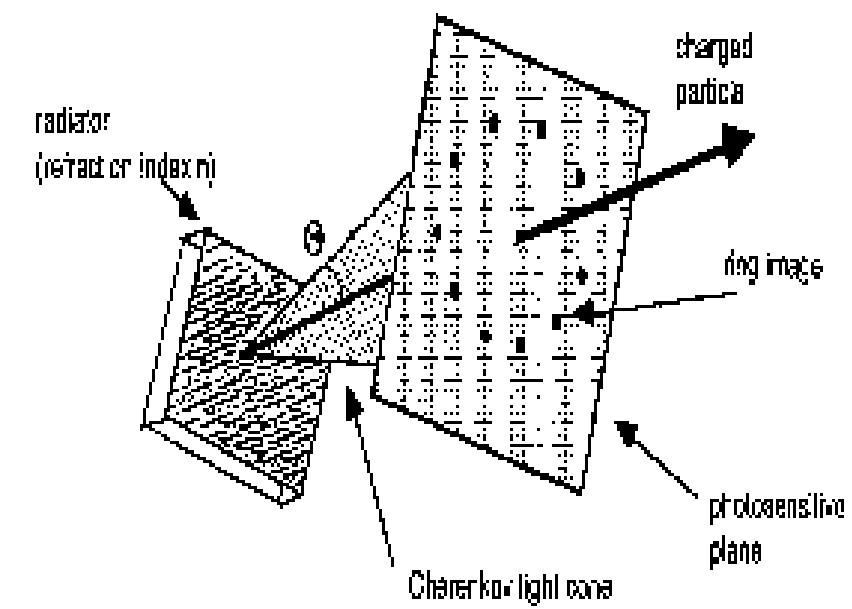
$$\cos\theta = \frac{ct/n}{\beta ct} = \frac{1}{\beta n}$$

Broj fotona ~ $\frac{1}{\lambda^2}$

λ-valna duljina

Primjena čerenkovljevih detektora

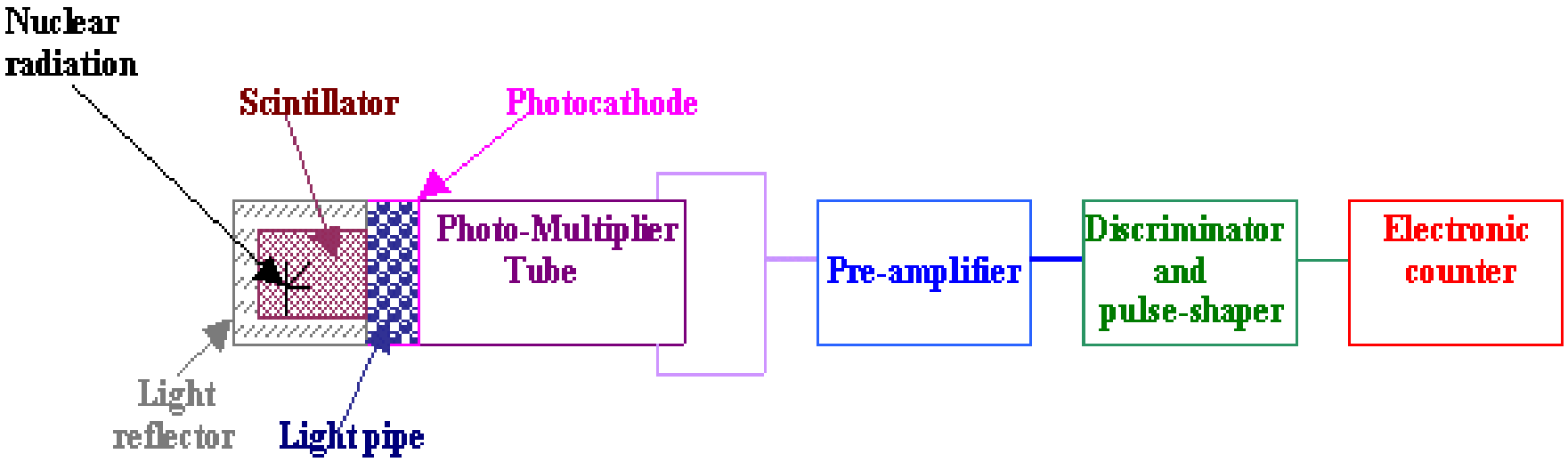
- Detektori praga (razdvajanje čestica istog impulsa a različitih masa)
- Identifikacija čestica (RICH➔STAR)



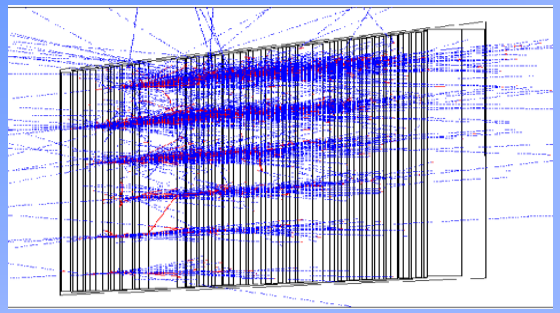
Uvod u detekciju čestica

- Detekcija čestica

Scintilatorima



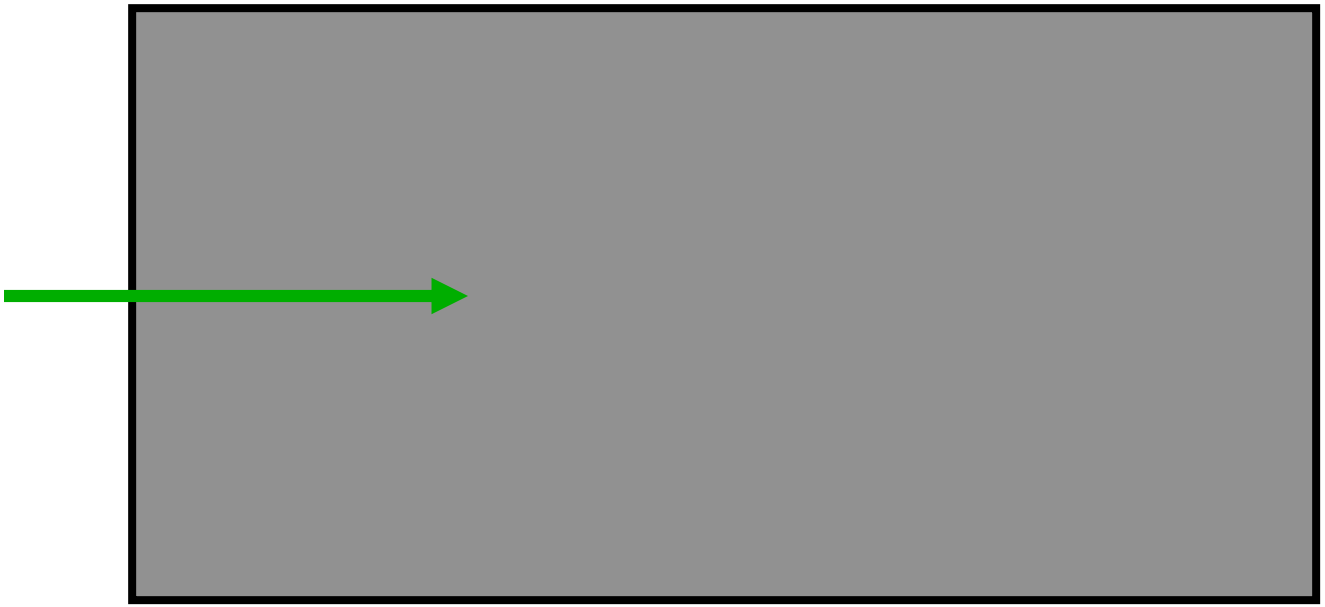
Kalorimetri



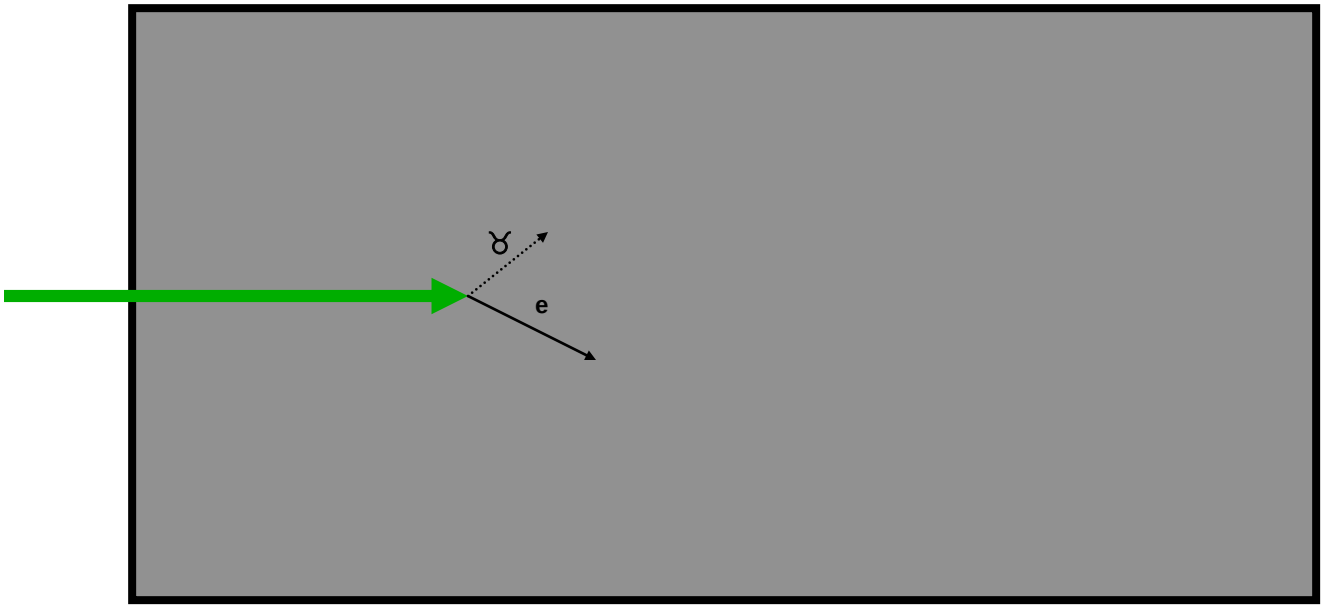
Energija i pozicija čestica se može mjeriti metodama totalne apsorpcije :

- Ulazna čestica interagira u detektoru velike mase, stvarajući sekundarne čestice ...➔*pljusak*.
- Gotovo sva početna energija čestice se pojavljuje ili kao ionizacija ili kao pobuđenje medija ➔"*kalorimetar*"
- Nužni su za određivanje energije neutralnih hadrona.
- Energijska rezolucija ~ $E^{-\frac{1}{2}}$ ➔dobra na vis. Energ.
- Kalorimetri daju brzu (100 ns) inf. o ukupnoj energiji

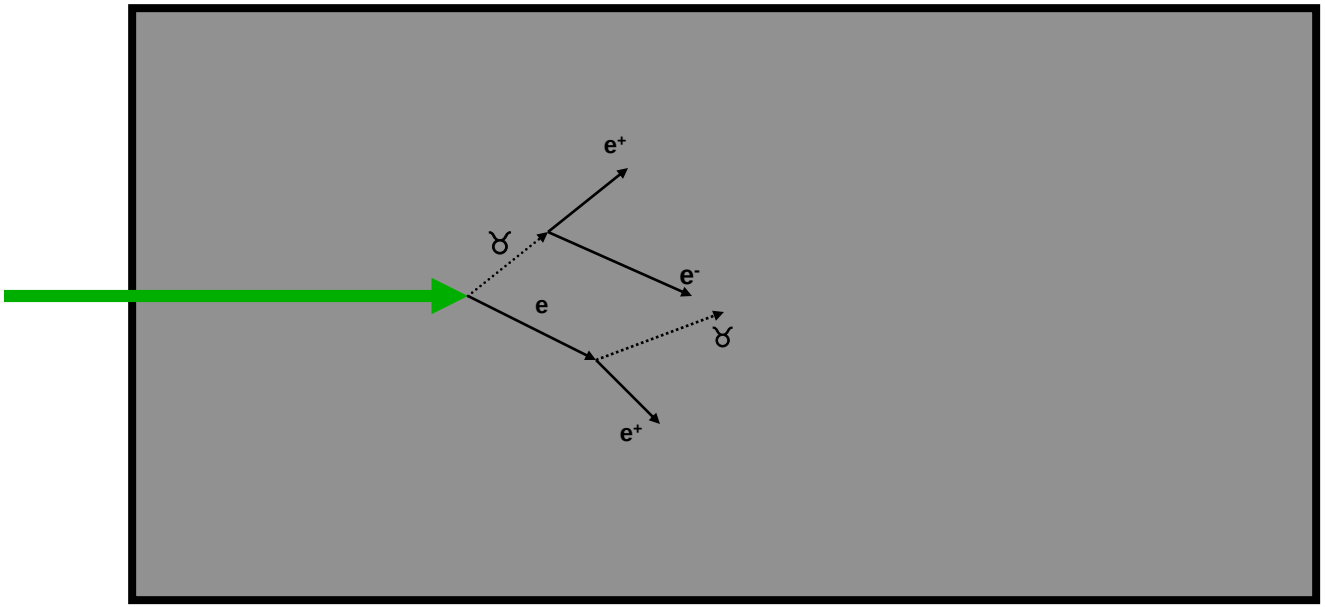
Elektromagnestki pljusak



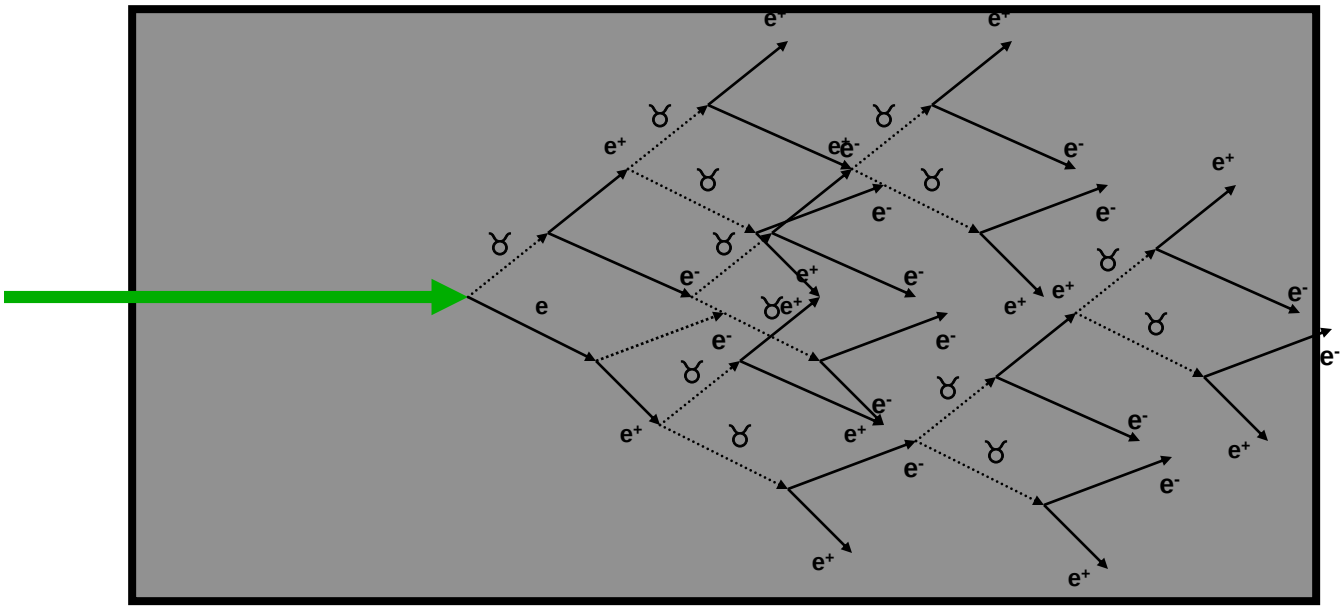
Elektromagnetski pljusak



Elektromagnetski pljusak

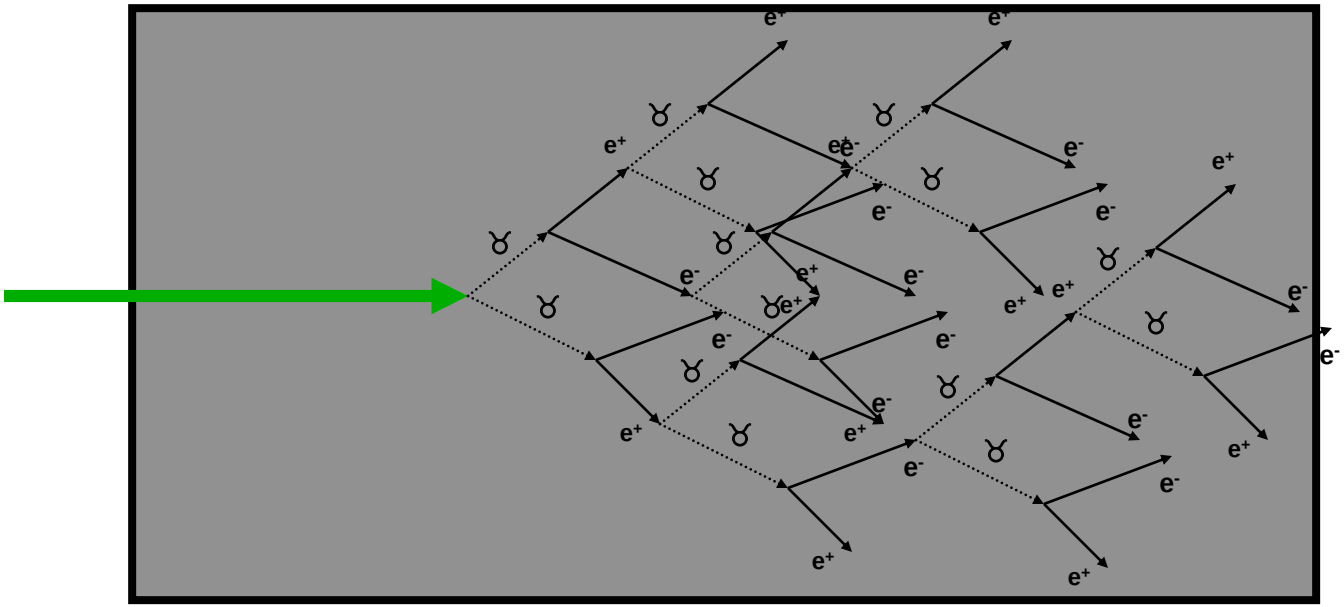


Elektromagnetski pljusak



• this process repeats itself in a “cascading” fashion until there is not enough energy in the particles to continue

Elektromagnetski pljusak



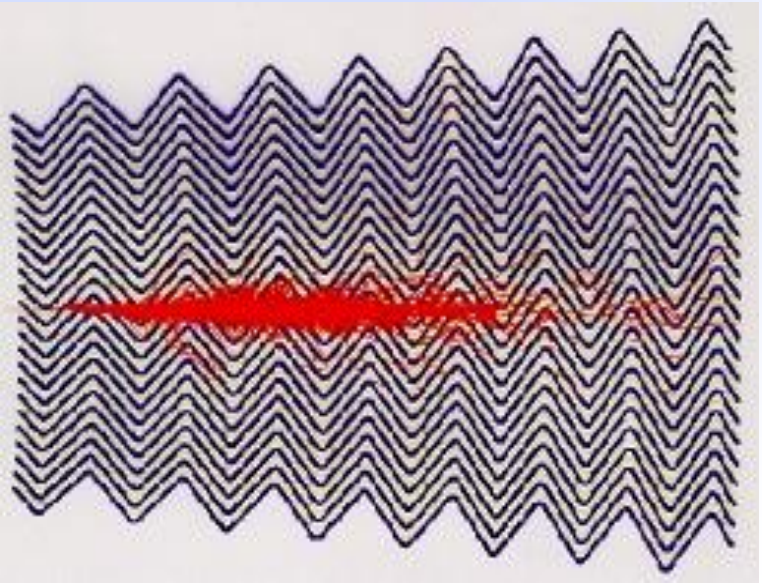
*Uočite: Stvaraju se samo fotoni, elektroni i pozitroni

Hadronski kalorimetar

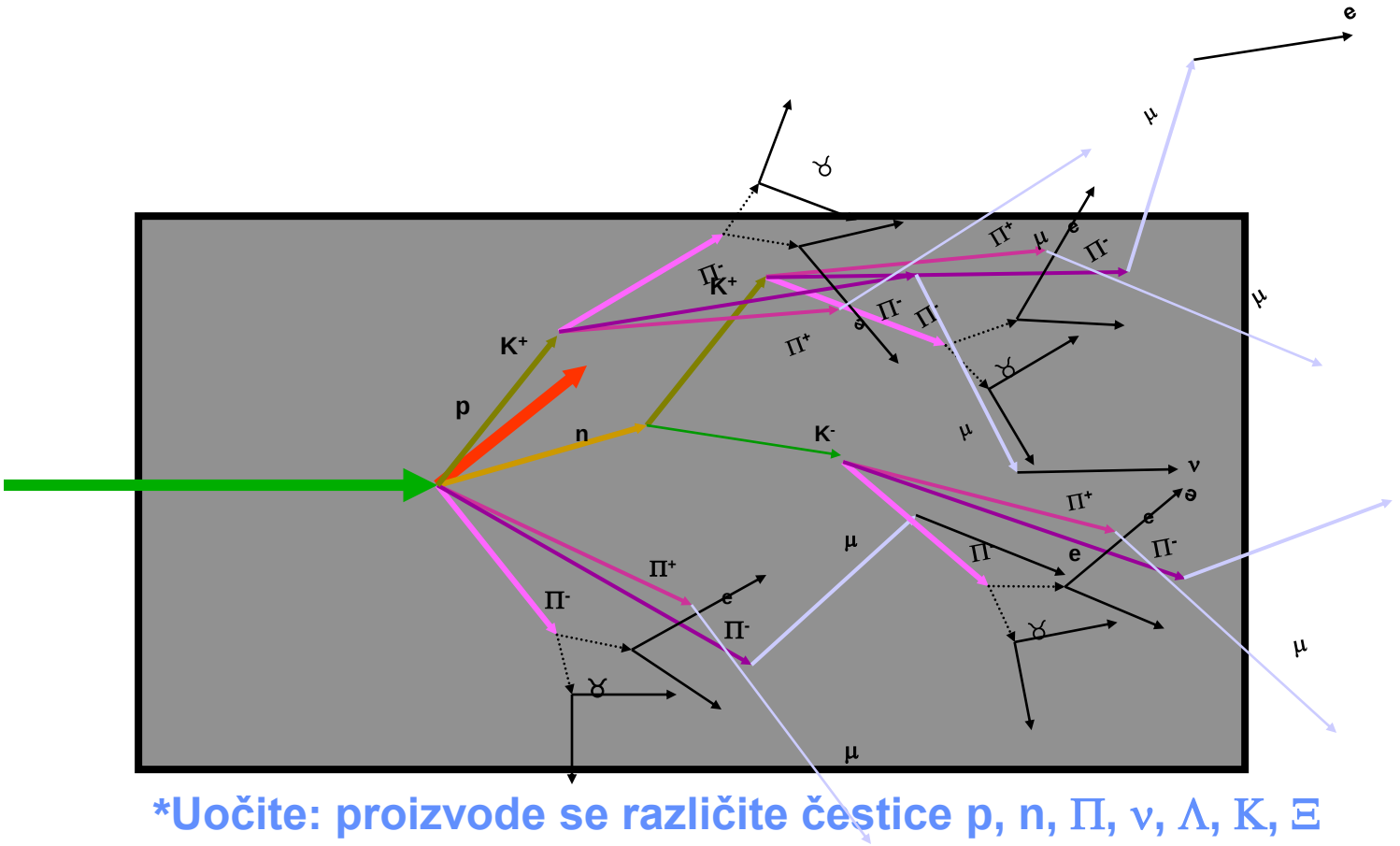
Hadronski pljusak : ulazni hadron ➔ neelastični sudar ➔proizvodnja sekundarnog hadrona …

- λ je velik u odnosu na X_0 ➔Hacal su veliki u odnosu na Ecal

- U hadronskoj kaskadi 30 % energije se gubi (razbijanje jezgre,nuklearna pobudjenja, evaporacija neutrona)

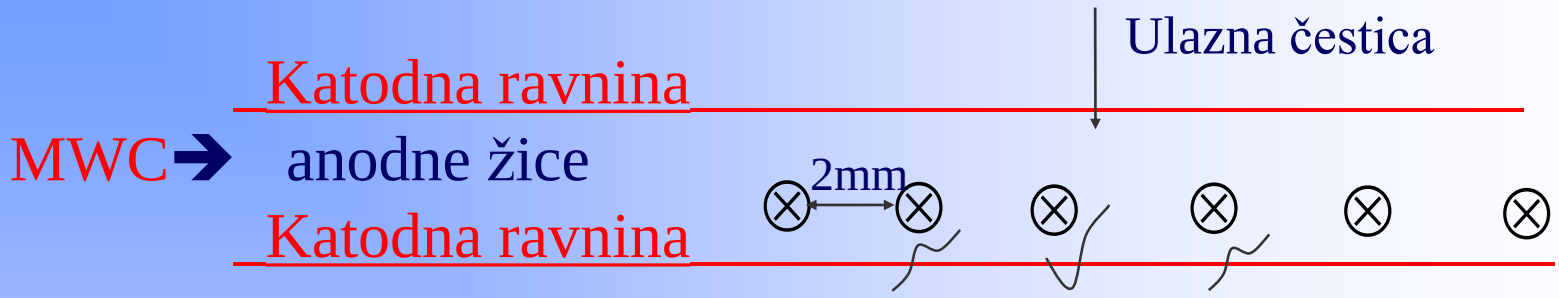


Hadronska kaskada

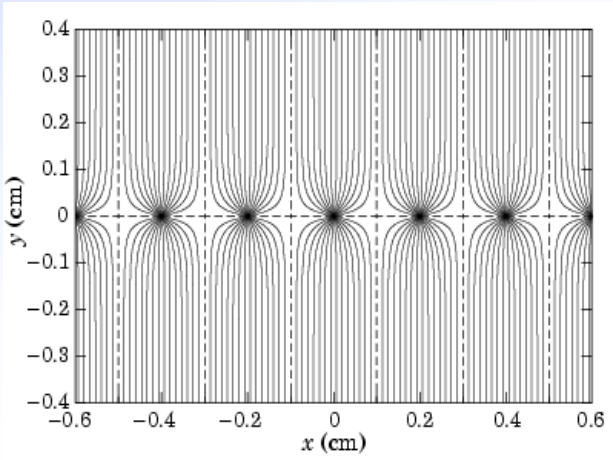


*Uočite: proizvode se različite čestice p, n, Π, ν, Λ, K, Ξ

Mnogožičane komore



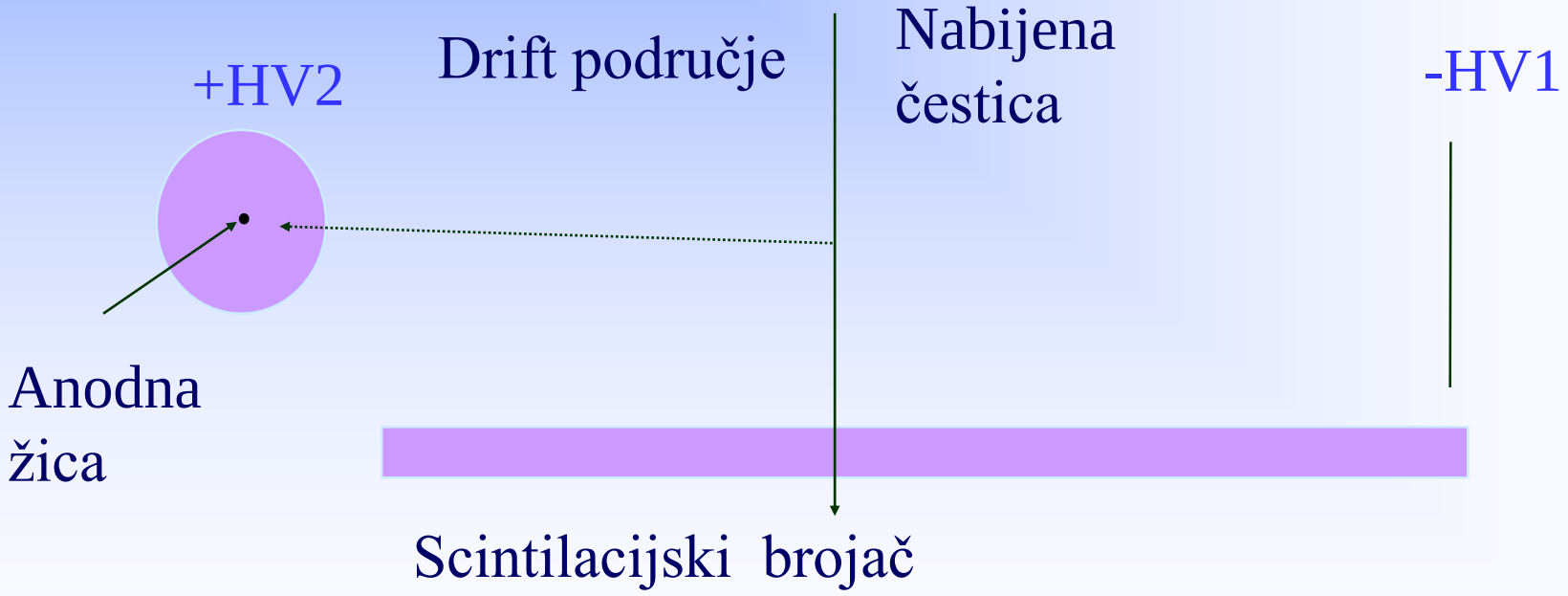
- Svaka žica djeluje kao nezavisni proporcionalni brojač
- Katode su na neg. pot. (2kV) dok su anode uzemljene
- Signal na žici koja okida je negativan i velik
- Signal na susjednim žicama je mali i pozitivan
- Prostorna rezolucija ~ 1 mm
- Razlučivanje više hitaca



Ostale ionizacijske komore

Driftne (vlačne) komore

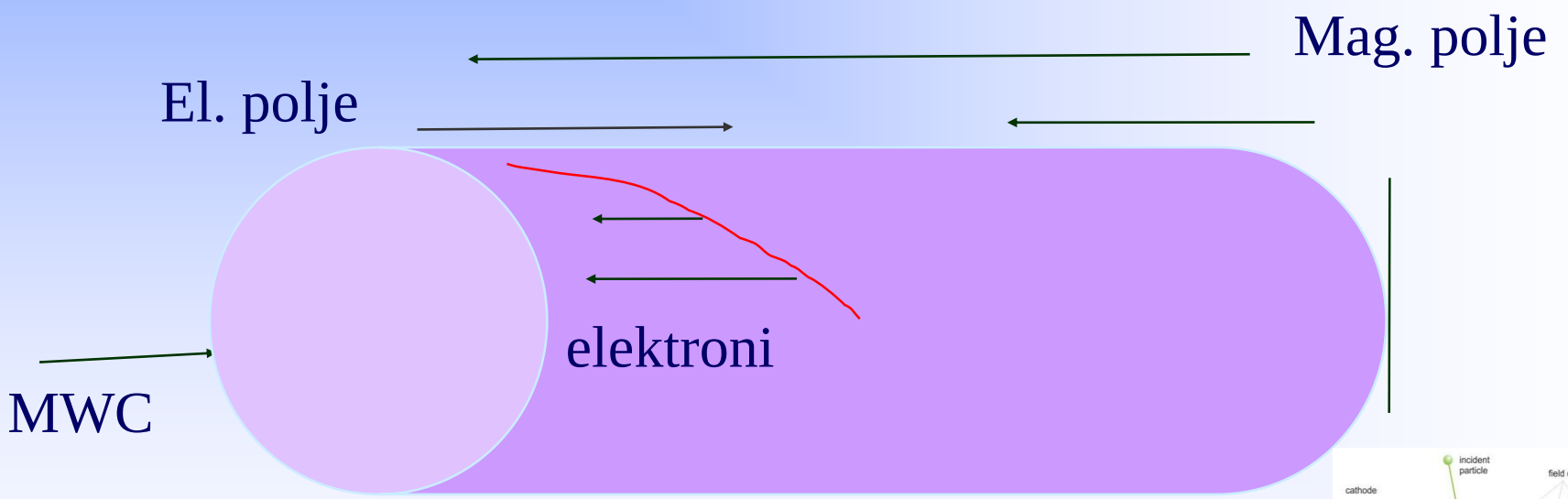
➢Prostorna informacija ➔iz mjerenja vremena pomaka (drifta) elektrona u ionizacijskom dogadjaju

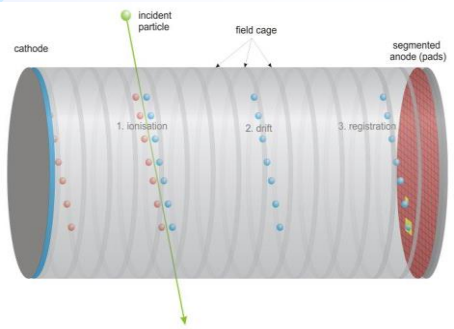


Ostale ionizacijske komore

Komore vremenske projekcije (time projection chamber)

- 3D tračni detektor
- Kombinacija vlačne i mnogožičane komore

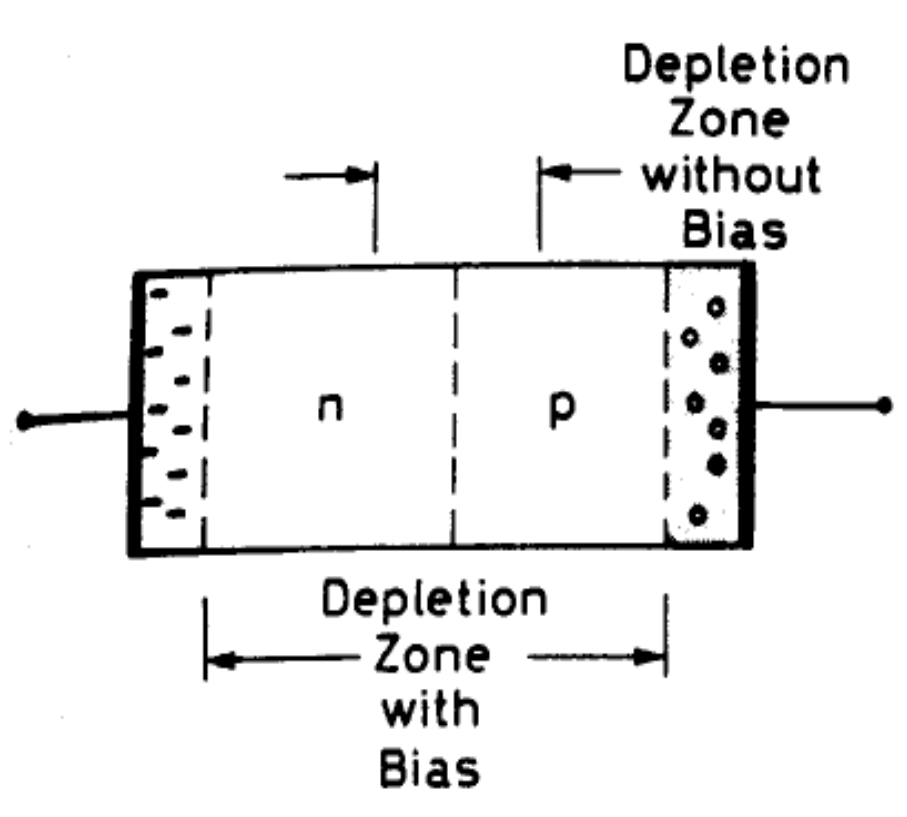




Poluvodički detektori

Analogni plinskim ionizacijskim detektorima:

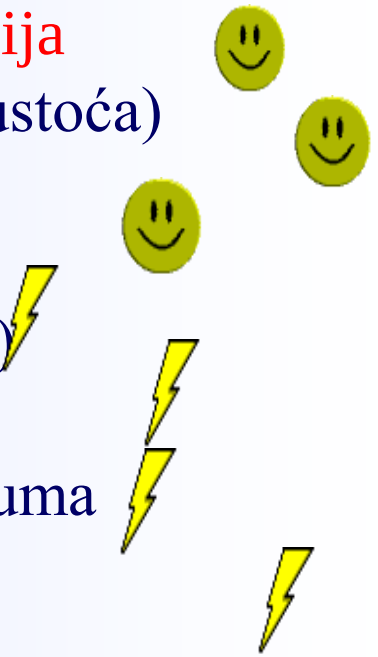
- Čestica u prolazu stvara parove elektron-šupljina (elektron-ion)
- Umjesto plina medij je poluvodički (čvrsti) materijal



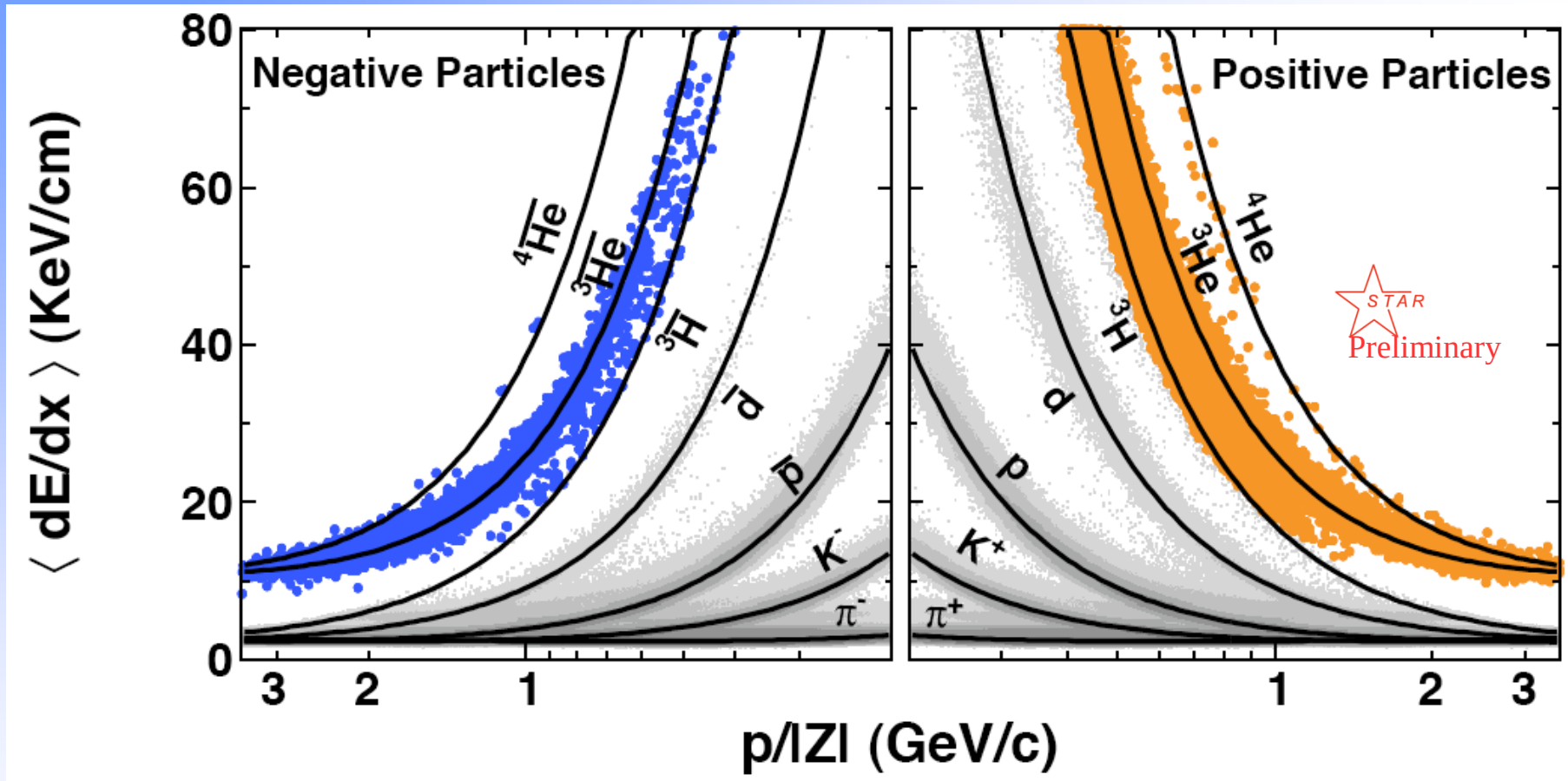
- Negativan napon na p-stranu, pozitivan napon na n-stranu
- Veći napon = više aktivnog medija + bolje skupljanje naboja
- Previsok napon ➔ poluvodič postaje vodič

Poluvodički detektori (usporedba s ionizacijskim detektorima)

- $E_{\text{elektron – šupljina}} < E_{\text{elektron-ion}}$ ➔ Bolja energijska rezolucija
- Bolja moć zaustavljanja od plinskih detektora (veća gustoća)
- Male dimenzije (<50 μm) ➔ dobra poz. Rezolucija
- Veća osjetljivost na zračenje (kraći vijek trajanja)
- Detektori male površine (cm^2) (svaka traka ➔ pojačalo)
- Više materijala ➔ interakcija čestica koje detektiramo
- Detektori trebaju ponekad hlađenje radi smanjivanja šuma



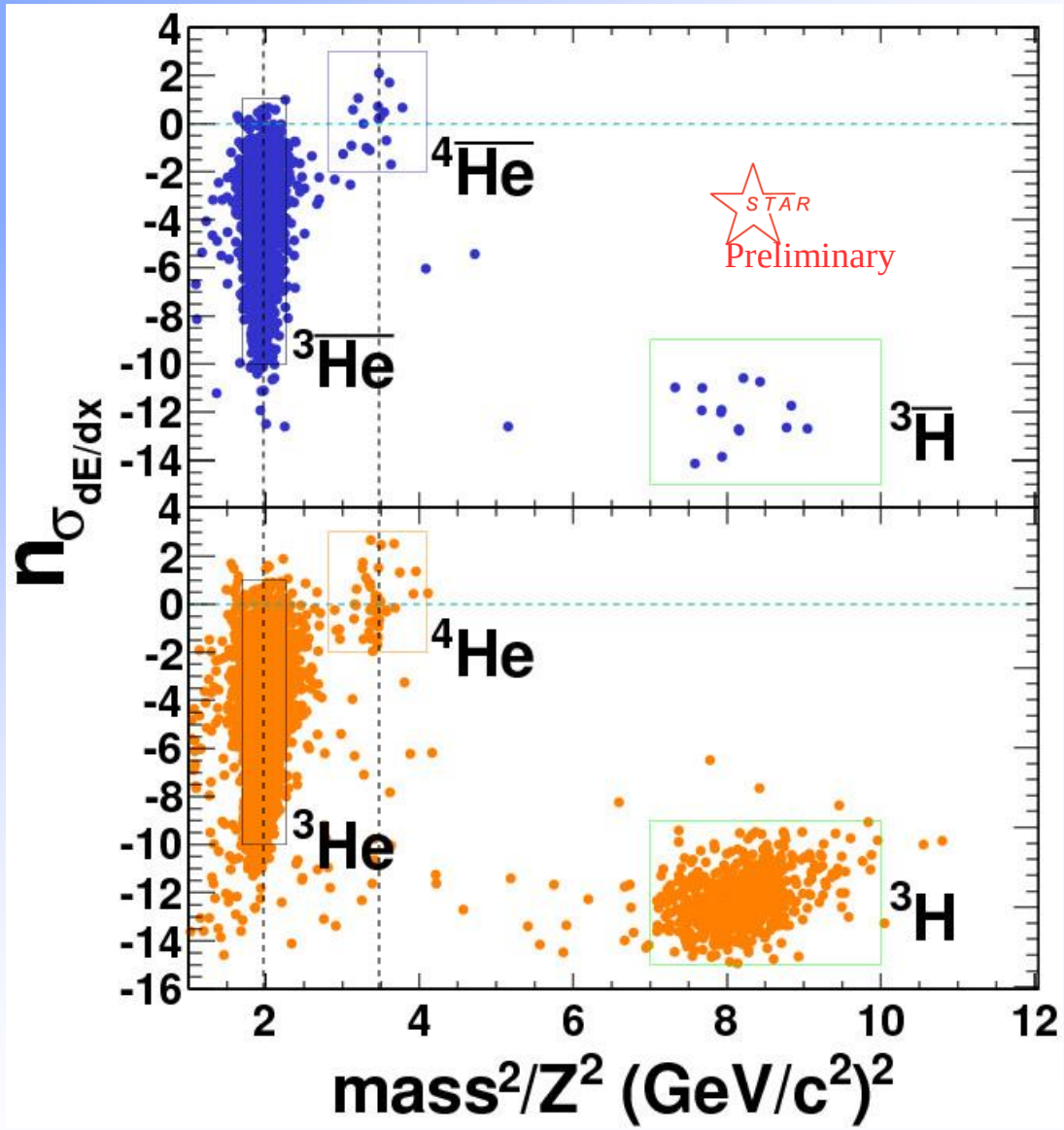
Kako još identificirati čestice ...



dE/dx vs Rigidity

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}\right]$$

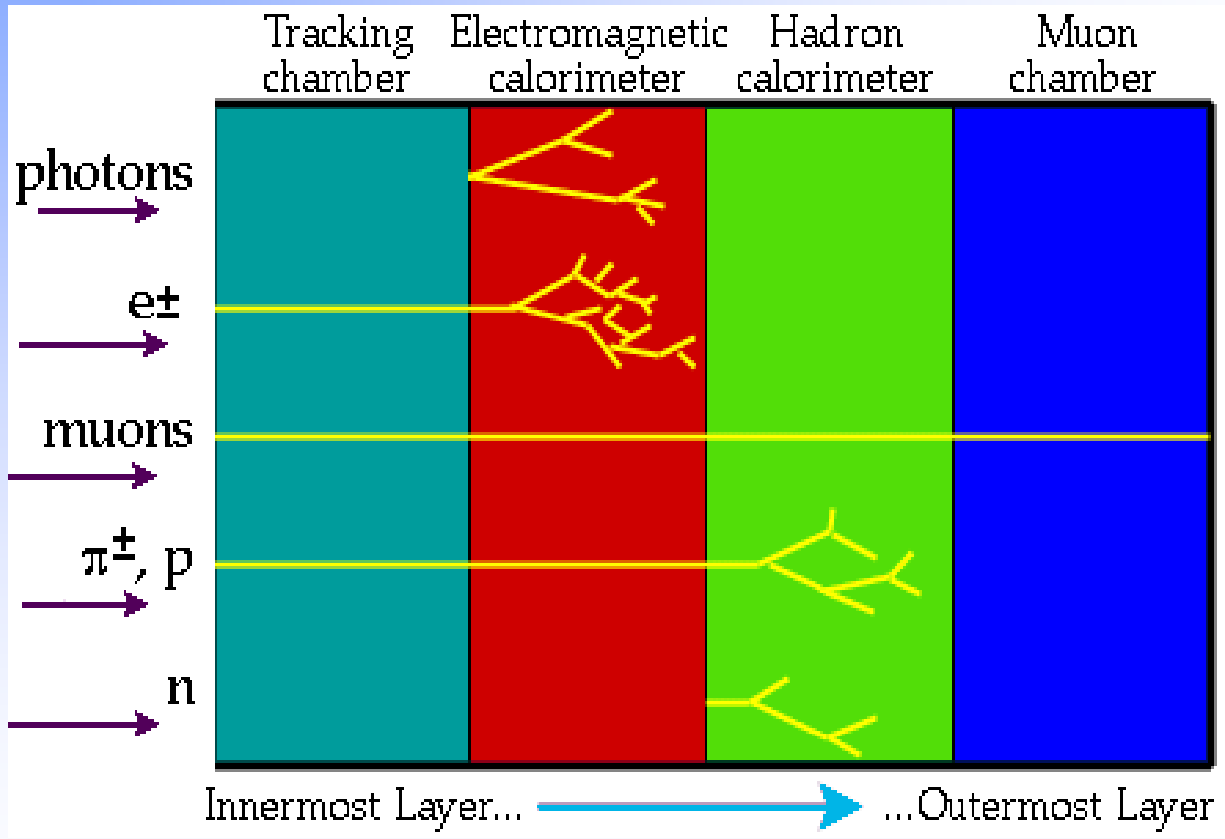
Kombinirano prepoznavanje čestica (TPC+TOF)



Hibridni detektori

Eksperimenti u FEČ ➔Istovremena detekcija više čestica

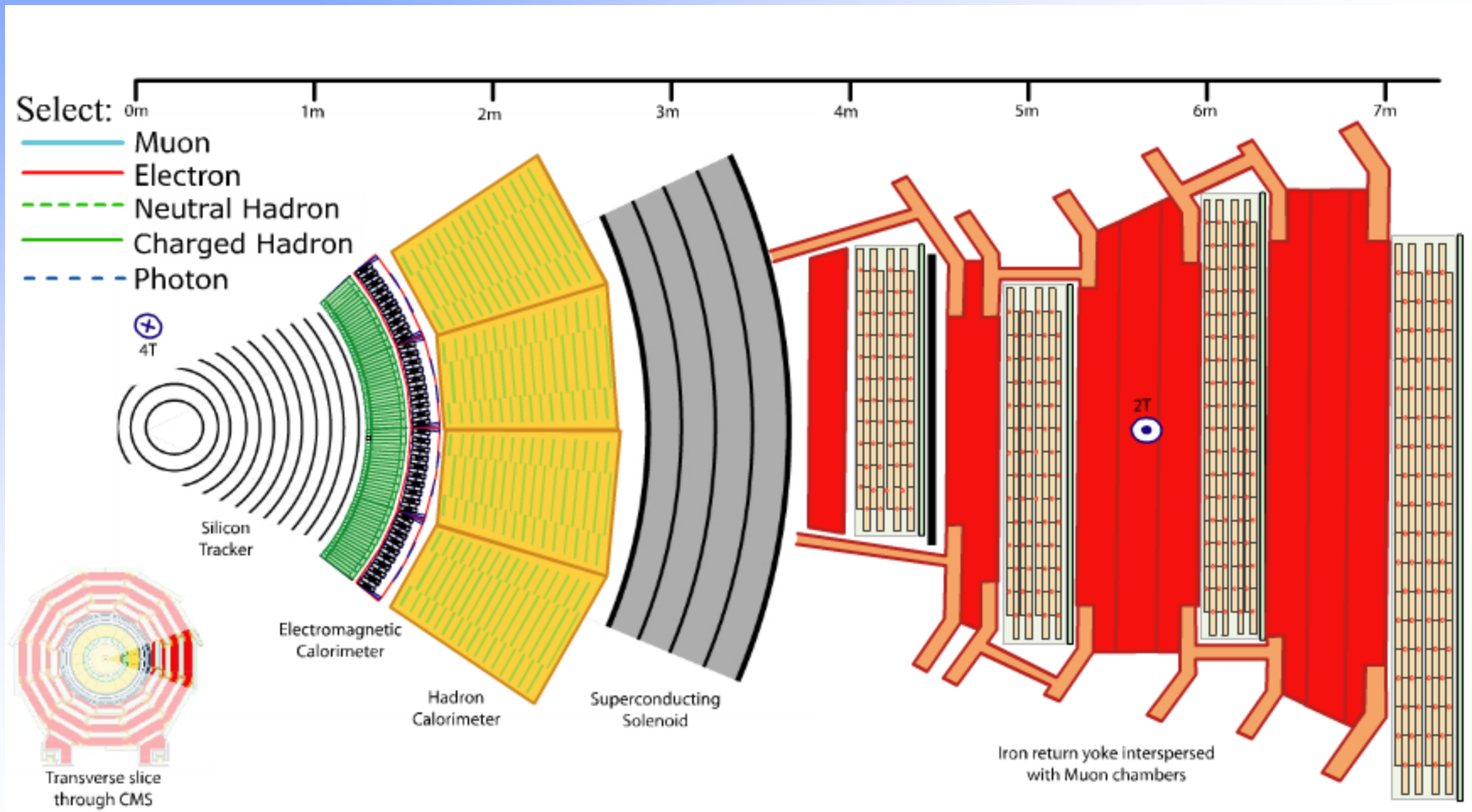
Redoslijed detekcije čestica ilustriran je na slici:



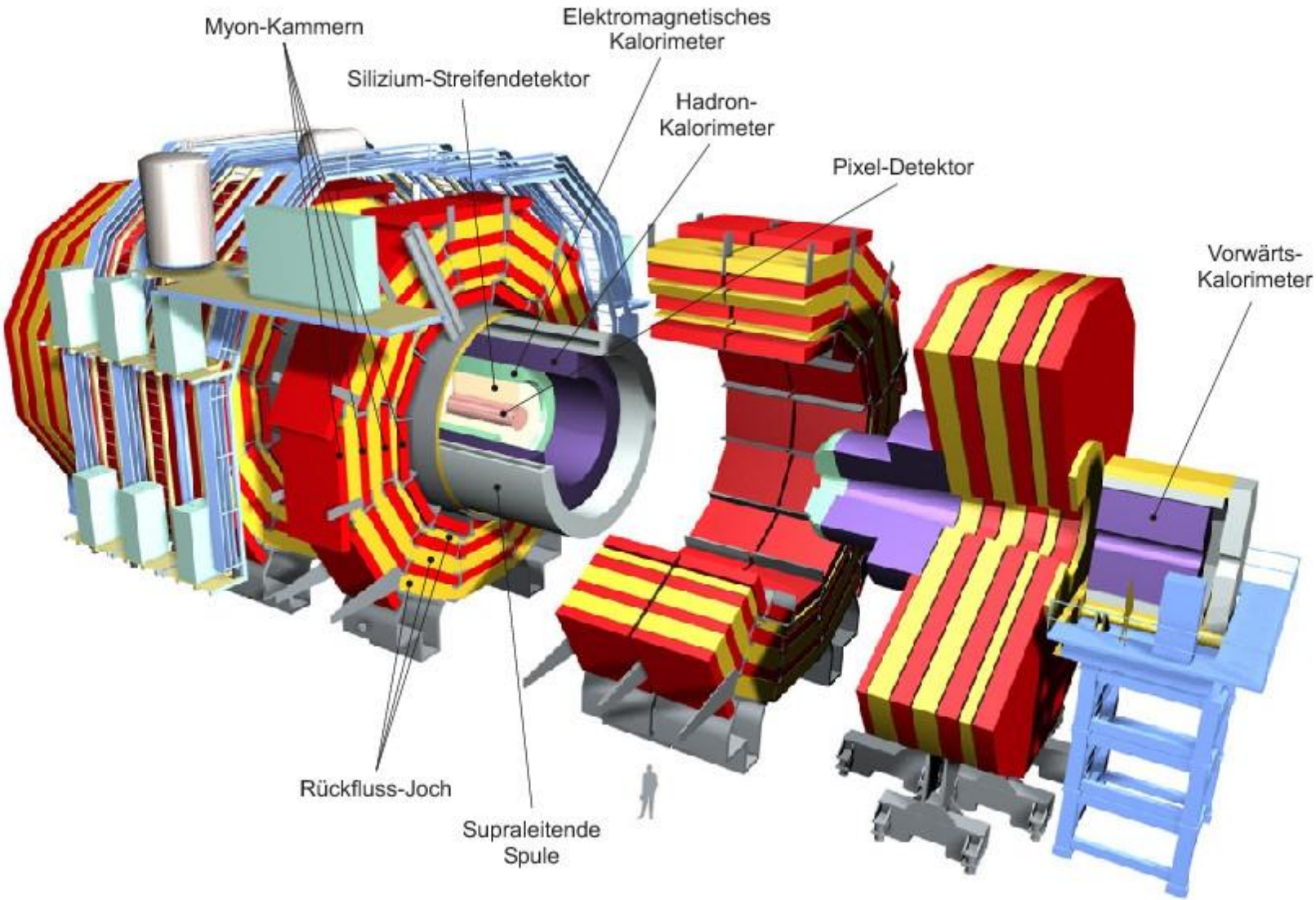
Transverse slice through CMS detector

Click on a particle type to visualise that particle in CMS

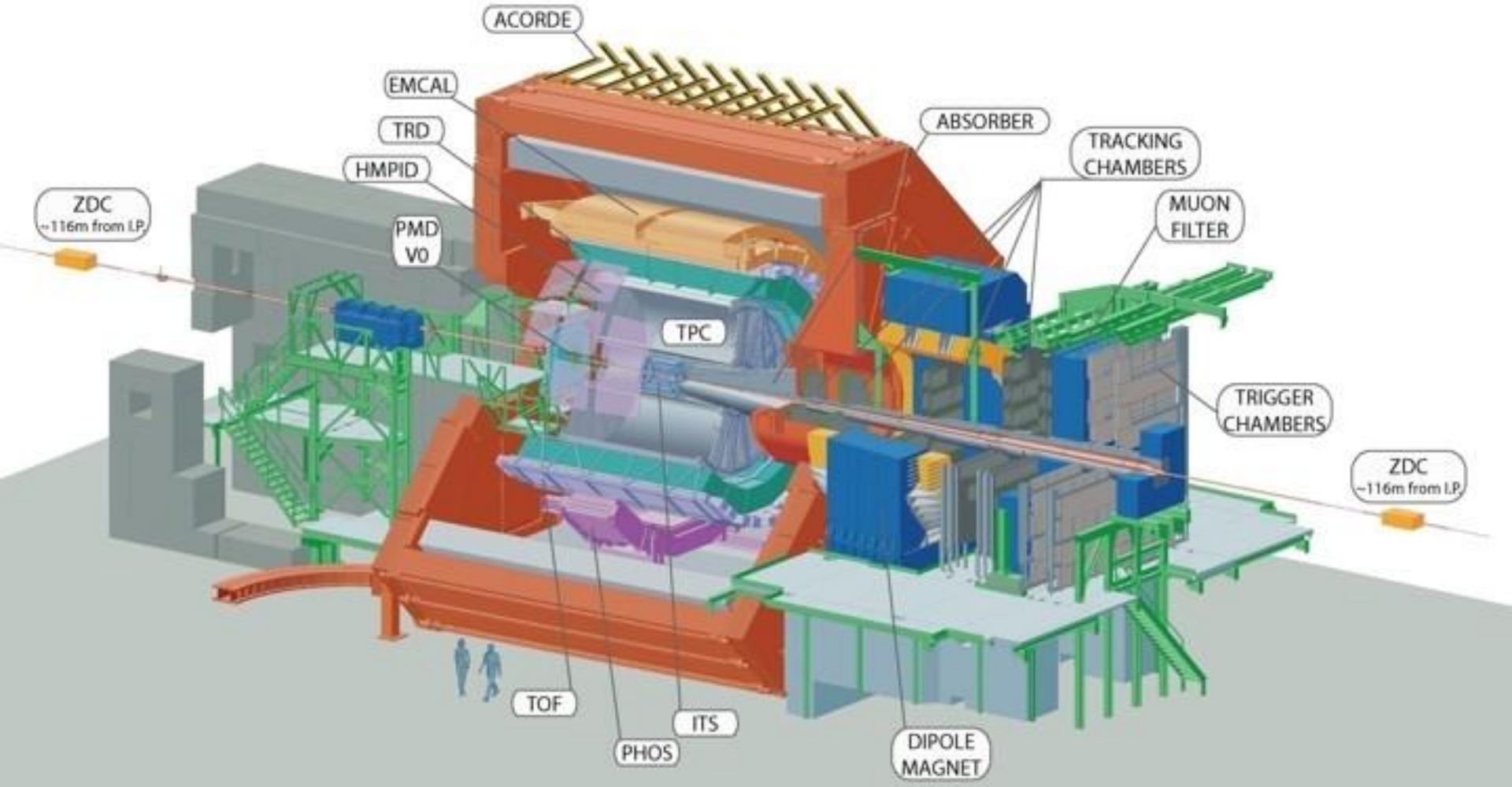
Press “escape” to exit



CMS detektor



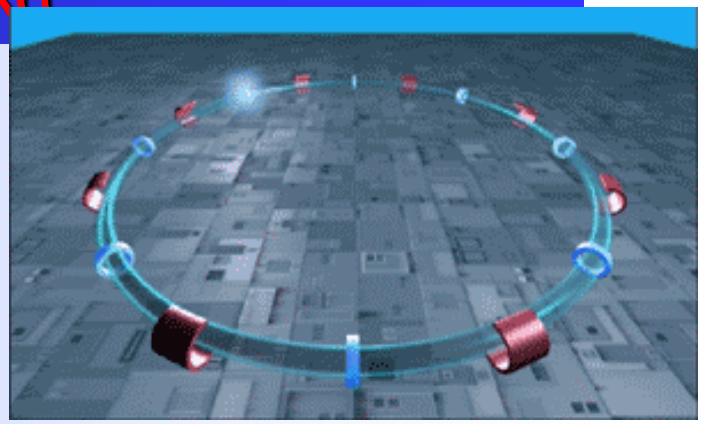
ALICE eksperiment



IZAZOV UČESTALOSTI SUDARA

FILM ATLAS EVENT FREQ

Izazov podataka

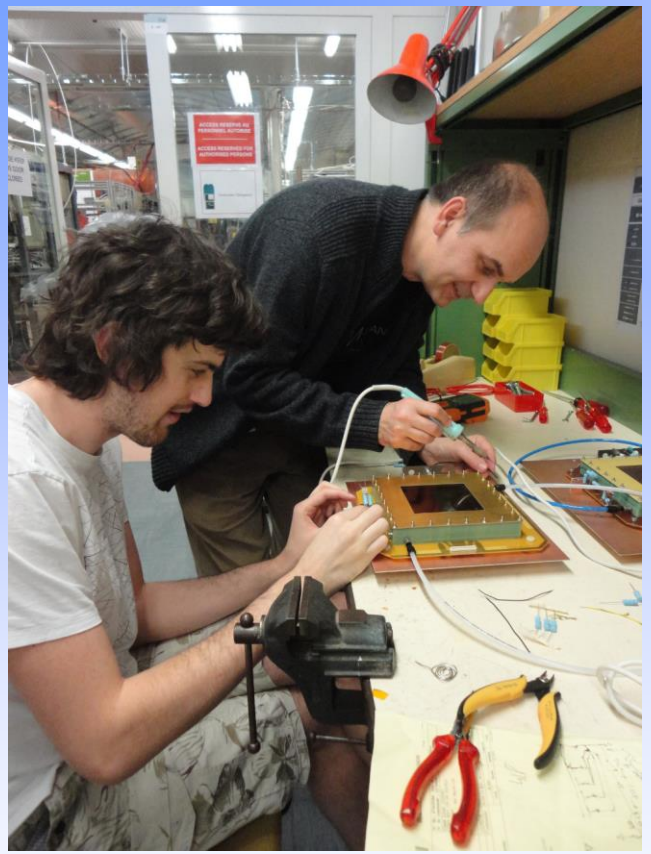


- **Oko** 10 Petabyte **podataka** svake godine
  - **Što je ekvivalentno 20 km visokom tornju naslaganih CD-ova**
- **Za analizu podataka: više od** 100 000 **danas najboljih** PC-ova
- **Ovi zahtjevi su veći od mogućnosti bilo kojeg** pojedinačnog **računalnog centra na svijetu**

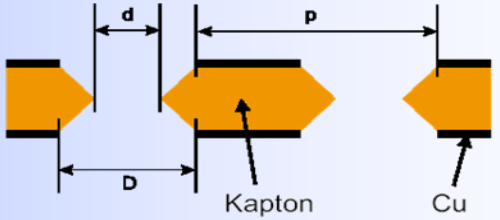
IZAZOV PODATAKA

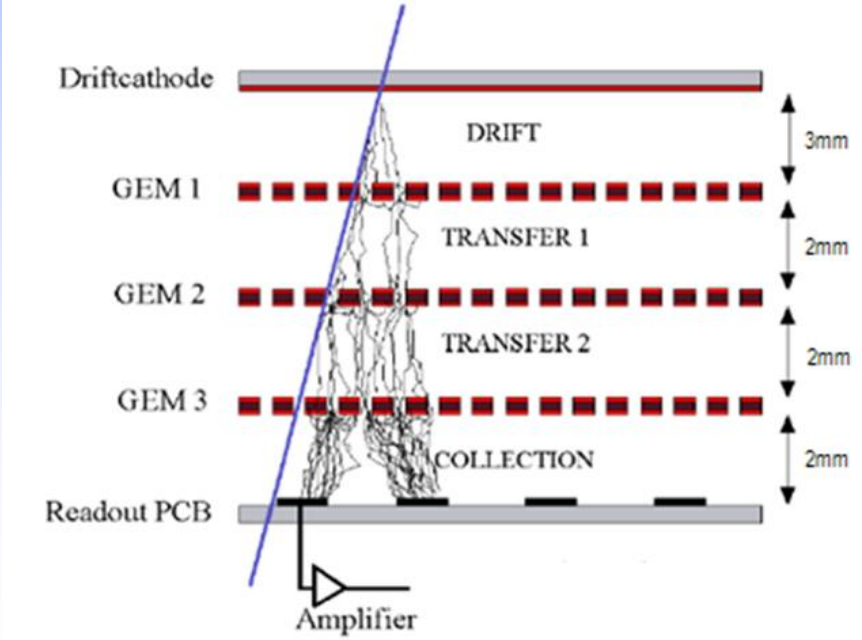
FILM ATLAS EVENT FREQ

GEM (Gas Electron Multiplier) detektori



$$D = 70\,\mu\text{m}$$
$$d = 60\,\mu\text{m}$$
$$p = 140\,\mu\text{m}$$





Hardverski doprinos – GEM detektori za TPC upgrade

Spin off company - PicoLogic

www.picologic.hr

PicoLogic

Floating multi-channel picoammeters

Izvoz u: Njemačku, SAD, Finsku, Indiju, Mađarsku, Rumunjsku, Izrael, Španjolsku, CERN

Hvala na pažnji!