

## NDD:

- Uvod
- Interakcije delcev s snovjo
- Detekcijski sistemi:
  - v fiz. osnovnih delcev,
  - hozmologi;
  - in medicinski fizika, ...
- Analiza podatkov

## Interakcije delcev s snovjo

- Nabiti delci:
  - Bethe-Bloch en. (debeli absorberji)
  - Landau (tenki absorberji)
  - Svetloba Čerenkova
- Nebaj o neutrinoih in temni snovi

### 1.1.1 Izgube energije nabitih Kaonov v detektorju (Bethe-Bloch)

$$\left[ -\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \dots \right] \text{Bethe-Bloch}$$

↓ dann, nadaljuje po 2 min pos  
naprej z enačbo...

Definirano Bethe-Bloch:

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \frac{Z}{A} \frac{\beta^2}{\gamma^2} \left[ \ln \frac{2m_e c^2 (\beta\gamma)^2}{I^2} \frac{W_{\max}}{W_{\min}} - 2\beta^2 - 2 \right]$$

↓ lastnosti snovi

↓ lastnosti delca

$$\beta = \frac{N}{c}$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

$$2\pi N_a r_e^2 m_e c^2 \approx 0,1535 \frac{\text{cm}^2}{\text{mol}} \text{ NeV}$$

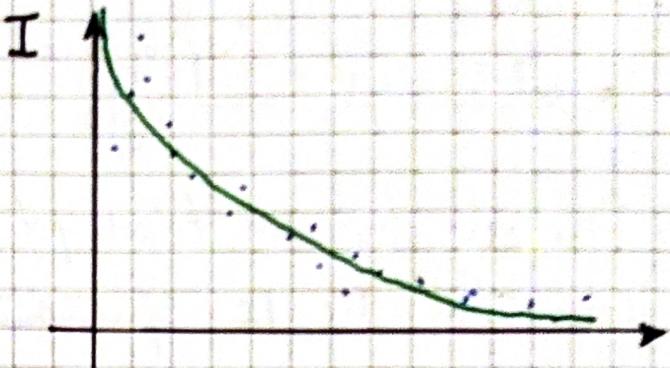
$$W_{\max} = \frac{2m_e c^2 (\beta\gamma)^2}{1 + 2\gamma \frac{m_e}{M} + \left(\frac{m_e}{M}\right)^2} \approx 2m_e c^2 (\beta\gamma)^2$$

↑ Malo, izguba en. pri  
oni interakciji

↑ Za μ, ki ima več  
maso

$$I \approx \begin{cases} Z(12 + \frac{7}{Z}) \text{ eV} ; Z < 13 \\ Z(9.76 + 58.52^{-1.19}) \text{ eV} ; Z \geq 13 \end{cases} \rightarrow \text{Best fit essentially}$$

↑  
Specifčna ionizacijska  
energija



$$\text{N}^{\text{Zračunajmo}} = 2\pi N_a r_e^2 M_e c^2 10^{23}$$

$$\frac{2\pi \cdot 6,022 \cdot (2.817 \cdot 10^{-15} \text{ cm})^2}{\text{Mol}} 0,511 \text{ MeV} = 0,1535 \frac{\text{eV}^2 \text{ MeV}}{\text{mol}}$$

$$K_{\text{mass}}^{+,-} = 0,493 \text{ MeV} \quad (\text{Cu: } g = 8.92 \text{ g/cm}^3)$$

$$p = 2.5 \text{ GeV/c}$$

$$Z = 29$$

$$A = 63.5 \text{ g/mol}$$

$$I = 29(9.76 + 58.5 \cdot 29^{-1.19}) \text{ eV} = 313.9 \text{ eV}$$

$$\beta = \frac{pc}{E} = \frac{pc}{\sqrt{(pc)^2 + (Mc^2)^2}}$$

$$\beta = \frac{2.5 \text{ GeV/c} \cdot c}{\sqrt{(2.5 \frac{\text{GeV}}{\text{c} \cdot \text{c}})^2 + (0.493 \text{ GeV})^2}}$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}} = 5.159$$

$$\beta\gamma = 5.061 \quad \text{korz } \delta, c$$

$$T_{\text{ioniz}}: -\frac{dE}{dx} = \dots = 13.47 \frac{\text{MeV}}{\text{cm}}$$

$Z = 1$  vodno pri  
nos, ker imamo za 1  
charged delec

$$W_{\text{Au}} = \dots = 26.7 \text{ MeV}$$

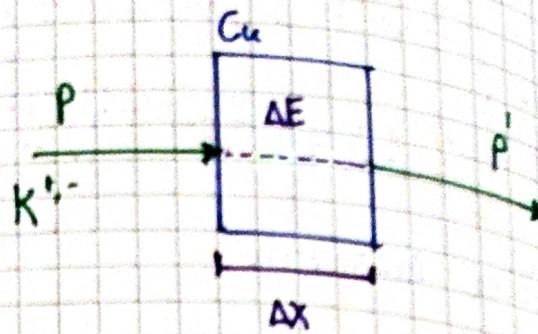
$\hookrightarrow$  Tu maj velike decimalne  
zraci: In  $\leq$

2.2.

b) Energija ločljivosti  $\Delta x = 5 \text{ cm}$

$$\Delta E = \left( -\frac{dE}{dx} \right) \cdot \Delta x = \overline{\Delta} \\ = 67.35 \text{ MeV}$$

poravnane  
izgube



↪ Približel, ker se telom poti  $\beta$  spreminja. Če  $p \sim \text{GeV}$  poten  
izgube  $\text{MeV}$  res ne spremenimo dosti:

Meritve  $E$  so odvisne od ločljivosti  $R$ :

$$R = \frac{\overline{\Delta}}{\Delta}$$

Ponavadi Gauss:

$$p(\Delta) = \frac{1}{\sqrt{2\pi\beta}} \exp\left(\frac{(\Delta - \overline{\Delta})^2}{2\beta^2} \cdot (-1)\right)$$

Sigma se dobri empirično.

Nen-rel.:

$$\beta_0^2 = 4\pi N_a r_c^2 (m_e c^2)^2 \frac{Z}{A} \Delta x$$

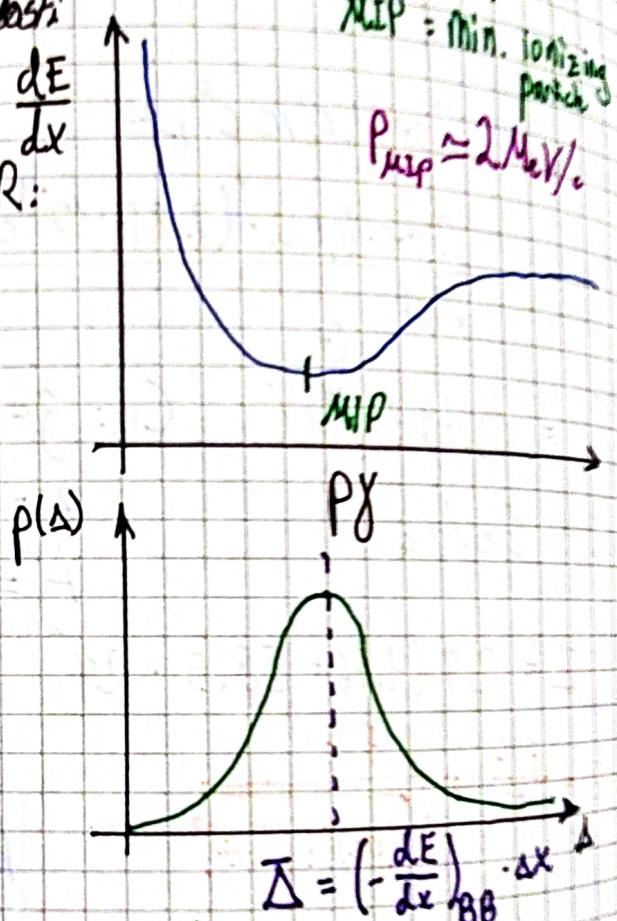
Rel.:

$$\beta^2 = \beta_0^2 \frac{1 - \frac{1}{2}\beta^2}{1 - \beta^2} \approx \frac{\beta_0^2}{2}$$

↑ Varianca B.B. en.  
prof. blinder

Pri nas:  $\beta_0^2 = 0,1569 \frac{\text{MeV}^2 \text{cm}^2}{\text{mol}} 8,92 \frac{\text{g}}{\text{cm}^3} \frac{2,9 \text{ mol}}{63,5 \text{ g}} 5 \text{ cm} = 3,146 \text{ MeV}^2$

$$3,146 \cdot 1,441 = 44.12 \text{ MeV} \quad \rightarrow \quad \beta = 6.64 \text{ MeV}$$



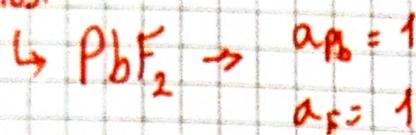
1.1.3  $\text{PbF}_2$  Kaj če imamo molekulo?

po vseh komponentah

$$\left( \frac{\partial f}{\partial x} \right)_{\text{zmes/molekula}} = W_1 \left( \frac{1}{g_1} \frac{df}{dx} \right)_1 + \dots$$

$$W_i = \frac{a_i A_i}{\sum a_i A_i}$$

$a_i$  ... Zastopanost



$$a_{\text{F}} = 1$$

1.2 Landau

Kaj so tanki in debeli absorberjev?

- debeli  $\rightarrow \beta - \beta$  en.  $\beta > 10$
- tanka  $\sim$  simulacije
- zelo tanki  $\rightarrow$  Landau en.  $\beta < 0.01$

St. interakcij  
pač pač  $\dots \Rightarrow \beta = \frac{\bar{\Delta}}{W_{\text{KX}}} \leftarrow$  poup. ali najverjetnejše izgube

## Plinski detektorji (Ionizacijska celica, ...)

↳ Merimo leje je detec letel v plinu, da ga žim manj zmotimo.

$e^-$  ioni in pozitroni nabijeni ionizirani glednili plinu npr. Ar

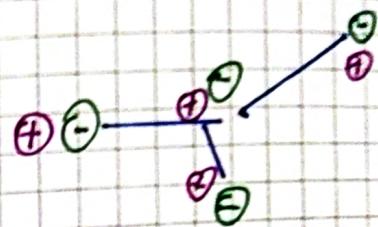
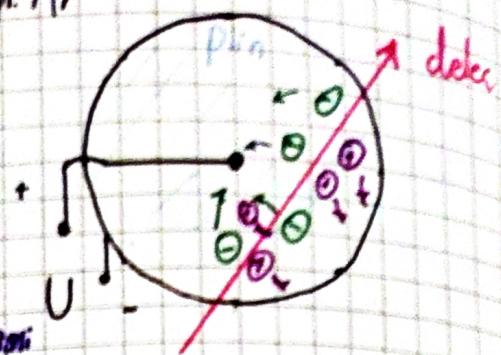
$$W \sim 10 \text{ eV} \quad (\text{Ar}: W = 26 \text{ eV})$$

$$N = \frac{\Delta E}{W} \quad Z_N = \sqrt{F \cdot N}; \quad Ar: F = 0,2$$

Substancialni delni nivo  
čisto statistično neodvisno

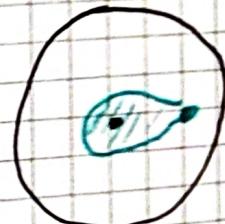
$$R = \sqrt{\frac{F \cdot W}{\Delta E}} \quad \text{čestvirost plinskega detektorja}$$

Ker je parov malo (mali signal) uporabimo pomnoževanje v plinu. Tačno nujno, da izbiti  $e^-$  z sponjem. Ustranijo nate pere.



Elastrem tega pomnoževanja je G-M cel, ki lahko že samo en detec zaznava. Tu clamo nižjo napetost, da ostane signal sorazmern z energijo detca.

dejansko obliku  
kisotnih  $e^-$



Zbrani naboju: • brez pomnoževanja:  $Q = N \cdot e_0$

• z pomnoževanjem:  $Q = M \cdot N e_0$

multiplication

Na koncu res zazipa  $\beta_Q$  ampak ta ima še  $\beta_M$  in  $\beta_N$ .

multiplication  
ima svoje fikacije

Skupaj:

$$R^2 = \left(\frac{\beta_N}{N}\right)^2 + \left(\frac{\beta_M}{M}\right)^2 = \left(\frac{\sqrt{FN}}{N}\right)^2 + \left(\frac{b}{N}\right)^2$$

$$= \frac{F}{N} + \frac{b}{N}$$

$$\Rightarrow R = \sqrt{\frac{W(F+b)}{\Delta E}}$$

Ločljivost detektorja v primeru pomnoževanja  
(podobna se)

### Nabava 3.1.1 [Ločljivost ionizacijske celice]

$$d = 10\text{ cm}$$

$$\text{MIP detekcija} \rightarrow -\frac{dE}{dx} = 2 \frac{\text{MeV cm}^{-2}}{\text{g}}$$

"Magic plin": 75% Ar + 25% izobutana C<sub>4</sub>H<sub>10</sub> + ...

$$W_{Ar} = 26\text{ eV}$$

Volumenski  
deleži

$$g_{Ar} = 1.66 \text{ g/L}$$

$$W_{i20} = 23\text{ eV}$$

$$g_{i20} = 2.5 \text{ g/L}$$

$$F_{Ar} = 0.2$$

$$F_{i20} = 0.2$$

a) Ločljivost brez pomnoževanja. Preko izračunamo deponirano energijo. Ločeno po komponentah.

$$\Delta E_{Ar} = Q_1 \left(-\frac{dE}{dx}\right) \cdot d \cdot g_{Ar}$$

$$\Delta E_{i20} = Q_2 \left(-\frac{dE}{dx}\right) \cdot d \cdot g_{i20}$$

$$\Delta E_{Ar} = 0.75 \cdot \frac{2 \text{ MeV cm}^{-2} \cdot 10\text{ cm} \cdot 1.66 \text{ g}}{1000 \text{ cm}^3} = 24.9 \text{ keV}$$

$\Leftrightarrow : 1000$  ?

S: tlakom plina

tu ne boemo kuppljivali

$$\Delta E_{i20} = \dots = 12.5 \text{ keV}$$

Uporabili delcer pravčno mrežico pri izmeritvah:

$$N_{Ar} \cdot \frac{\Delta E_{Ar}}{W_{Ar}} \cdot 958 \rightarrow \beta_{Ar} = \sqrt{F_i N_i} = 13.8$$

$$N_{i20} \cdot \frac{\Delta E_{i20}}{W_{i20}} \cdot 534 \rightarrow \beta_{i20} = \dots = 10.3$$

Tril je zato to, kako se sestojmo komponenti:

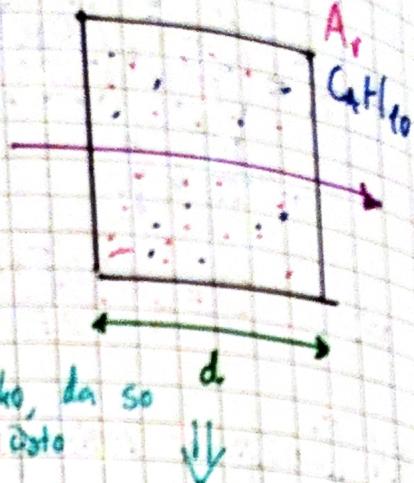
$$N = N_1 + N_2$$

$$\beta^2 = \beta_1^2 + \beta_2^2$$

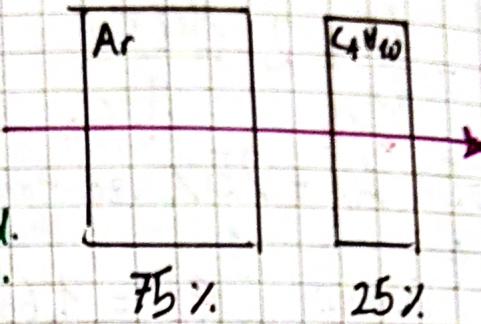
$$R = \frac{\beta_N}{N} = \frac{\sqrt{\beta_1^2 + \beta_2^2}}{N_1 + N_2} =$$

$$= \frac{17.3}{1492} = 1.1\%$$

pod pretpostavko, da so  
tisti rezultanti (ter nista  
res, hence  $F$ ).



proporcionalni  
↑ Števki "plm d."  
↓ "plm." 2 pomoč.



### Naloga 3.2.1 [S pomoči žerajom]

$M = 900$  b) Zatojuju pu poglavju halo se poslabša ločljivost zaradi pomoči.

Pri del, kočju pom. prispeva:

$$\frac{b}{R} = ? \quad R_M^2 = \frac{b}{N} \Rightarrow R_M = \sqrt{\frac{b}{N}} = \sqrt{\frac{0.5}{1492}} = 1.8\%$$

primarno št. dolcer, ne št. zadnjih  
(torej ne pomnoženo z  $\lambda$ )

12.01.08 02.11.11  
v FS

Skupaj pu prispev:

$$R = \sqrt{R_N^2 + R_M^2} = \sqrt{(1.1\%)^2 + (1.8\%)^2} = 2.9\%$$

### Naloga 3.2.2 [Zalogj cilindrična geometrije]

$$a = 0.008 \text{ cm}$$

$$b = 1 \text{ cm}$$

$$U = 2000 \text{ V}$$

$$\frac{E(r=a)}{a} = ?$$

$$V_s \quad d = 1 \text{ cm}$$

kontaktni

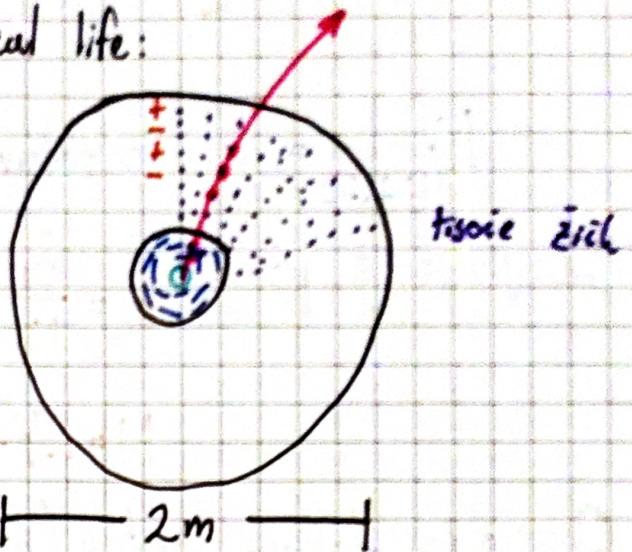
$$E(r) = \frac{U}{r \ln(\frac{b}{a})}$$



Kako bi  $U$  bio isto polje v konel.

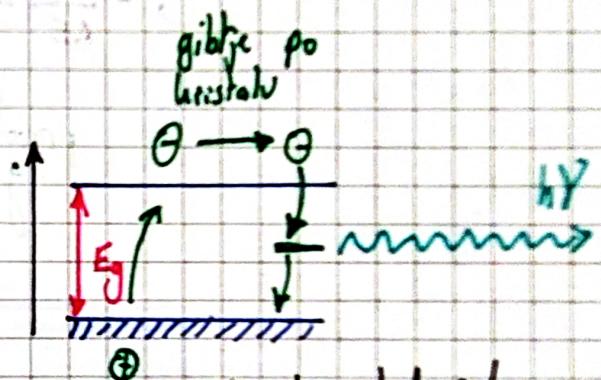
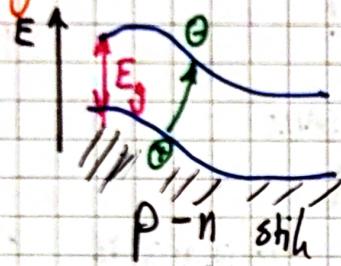
$$E = \frac{U}{d} \Rightarrow U = 52 \text{ kV}$$

Real life:



### Scintilacijski detektori:

Polprevodnik:



Scintilatori: - anorganski (kristali)

raznjava svetloba, ki nastane.

- Organski (plastična + benzen, ...)

Sevalni prehod preko  
vnešnega stanja  
(če pada cel gap bo foton izbit/ioniziran)  
drugič in nikoli ne bo prisel ven.

Energija potrebna za nastanek 1 γ:

antracen (?)  $W = 60 \text{ eV/foton}$  } Organski  
plastični scint.  $W = 25 \text{ eV/foton}$

NaI(Tl)  $W = 100 \text{ eV/foton}$  } anorganski  
BGO  $W = 300 \text{ eV/foton}$

$$g(\text{NaI(Tl)}) = 3.79 \text{ g/cm}^3$$

$$g(\text{BGO}) = 7.1 \text{ g/cm}^3$$

Boljši pogosto prideleči fotonov / light yield:

$$LY = \frac{N \text{ fotonov scint. svetlobe}}{\Delta E \text{ detek.}}$$

$$LY_{NaI(Tl)} = 40\,000 \text{ fotonov/MeV}$$

Lokativnost je potem:  $R = \frac{Z_N}{N} = \frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}}$

$$N = LY \cdot \Delta E$$

Običajno se izkuštevajo kristala / scintilatorja:

$$\mathcal{E} = \frac{E_Y}{AE} = \frac{N \cdot hY}{AE}$$

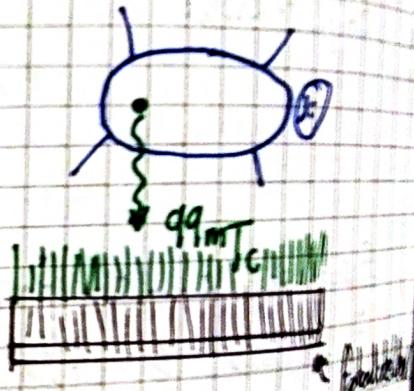
Vidimo samo  
pravokotne  $\gamma$

kolimator iz  
svinčenih ploščic

NaI(Tl)

MedFiz:

SPECT kamra

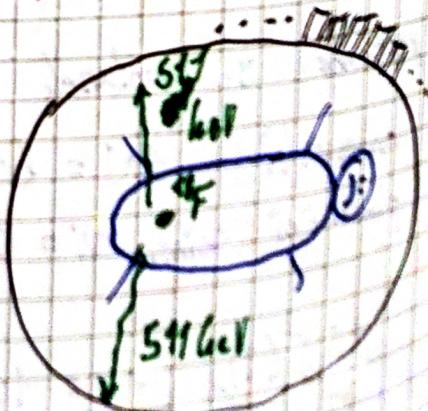


PET scanner  
(position em. tomography)

iz anihilacije

$e^+ e^-$

$^{18}F \rightarrow \beta^- \text{ razpad}$



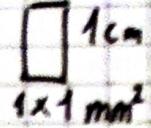
Zgodovinsko pomembni BGO ( $\text{Bi}_4\text{Ge}_3\text{O}_{12}$ )  
 ↓ danes v PET scannerjih

LSO ( $\text{Lu}_2\text{SiO}_5(\text{Ce})$ )

Naloge 4.2.1 [Locljivost SPECT kamere]

$$\frac{N_{\gamma}}{E_{\gamma}} = \frac{140.5 \text{ keV}}{E_{\gamma}} \rightarrow \text{en } \gamma \\ E_{\gamma} = 40000 \text{ MeV}$$

$$R_E \propto R_N = \frac{1}{\sqrt{N}}$$



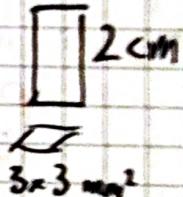
$$N = \Delta E \cdot L \cdot Y$$

Predpostavimo, da je  $L \cdot Y$   
 Se žarki popolno ustvari.

$$N = \Delta E \cdot L \cdot Y = \frac{140 \text{ keV} \cdot 40000}{\text{MeV}} = 5620$$

$$R_N = \frac{1}{\sqrt{5620}} = 1.33\%$$

Naloge 4.2.2 [Pet locljivost brez podanega LV]  $\rightarrow E_{\gamma} = 511 \text{ keV}$



BGO  $W = 300 \text{ eV}$

$$N = \frac{\Delta E}{W} = \frac{511 \text{ keV}}{300 \text{ eV}} = 1700$$

$$R = \frac{1}{\sqrt{N}} = 2.42\%$$

Naloge 4.1 [CsI(Tl) + BELLE-2]

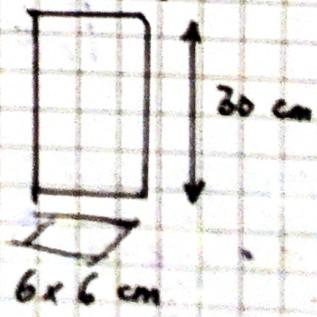
$$\Delta E = 4 \text{ GeV}$$

$$CsI(Tl) := L \cdot Y = 60000 \text{ MeV}$$

$$N = \Delta E \cdot L \cdot Y = 240 \cdot 10^6$$

$R = 0,0065\%$   $\rightarrow$  žal je preveč vidljivo večja

8736 kristalov CsI(Tl)



$$N_{\text{uznem}} = N \cdot E_{\text{cat}} \cdot QE$$



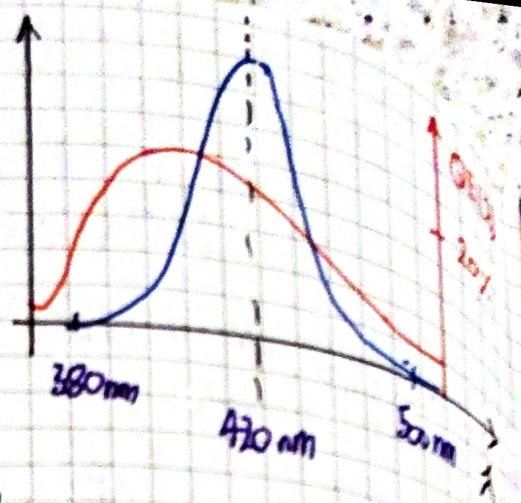
reflektor (Ecollection)

fotoelement  $\rightarrow$  svoj Quantum eff.

$E_{\text{coll}} \approx 70\%$

$\text{QE} \approx 20\times$

Na izpitu vzam  
nalo zredko medres  
Vzemo da ponis koko in  
boji.



### Particle identification detectors

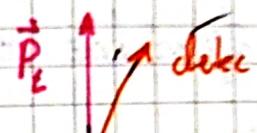
↪ Trdi, da ločimo načine detec med sabo.

Detec lahko prepoznamo po:

- Masa
- Lahko interagira

V eksperimentih imamo (slavof vedno) močno magnetno polje. To je zato, da  
izozijo, da lahko iz radija temic dobimo gibanje kvelicino.

$$P_E = qBR \rightarrow q \dots naboj delca$$



iz tega izmerimo gibanje kvelicino

Mas dobitimo potem lahko, da izmerimo še hitrost:

$$P = \gamma m v \quad \frac{Vs}{m^2}$$

Tipične veličnosti:

$$P_E = qBR = 1.6 \cdot 10^{-19} \text{ As} \cdot 1 \text{ T} \cdot 1 \text{ m} \cdot 3 \cdot 10^8 \frac{\text{m}}{\text{s}} = 300 \text{ MeV}$$

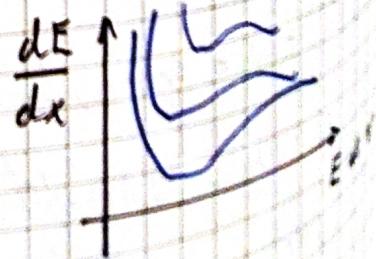
Zatem nato pa: Lahko izmerimo hitrost?

↪ Time-of-flight (mnenje česa preleta)

↪  $\frac{dE}{dx}$  izmerimo v plinskim detektorju

↪ Svetloba Čerenkova

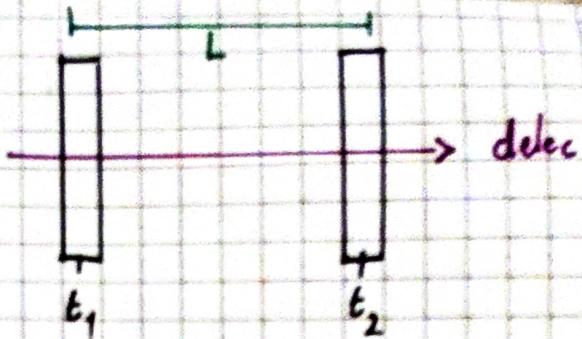
↪ Transition radiation (prehodno sevanje) → Potovanje med sosednjimi fotiki



Time of flight detektori

$$TOF = t_2 - t_1 = \frac{L}{V} = \frac{L}{\beta c}$$

$$\beta = \frac{pc}{E} = \frac{pc}{\sqrt{p^2 + m^2c^2}}$$



Tori:

$$TOF_1 = \frac{L}{c}, \quad TOF_2 = \frac{L}{c} \left[ 1 + \left( \frac{mc^2}{pc} \right)^2 \right]$$

Kaj se imamo dve vroči detektori in jih hocimo ločiti? Kališno bo rezulta ravan praktika?

$$\Delta t = TOF_1 - TOF_2 = \frac{L}{\beta_1 c} - \frac{L}{\beta_2 c}$$

$$\Delta t = \frac{L}{c} \left[ \sqrt{1 + \left( \frac{mc^2}{p_1 c} \right)^2} - \sqrt{1 + \left( \frac{mc^2}{p_2 c} \right)^2} \right]$$

Običajno  $p_1 = p_2 = p$

### Nalogia 5.1 [Ločevanje $\pi^+$ in $K^+$ ]

$$m_\pi = 140 \text{ MeV} \quad \text{a) } \vec{p} = 2 \text{ GeV}/c$$

$$m_K = 493 \text{ MeV}$$

$$L = 2 \text{ m}$$

$$\Delta t = \frac{2 \text{ m}}{3 \cdot 10^8 \text{ m}} \left[ \left( 1 + \left( \frac{0.146 \text{ GeV}}{2 \text{ GeV}} \right)^2 \right)^{\frac{1}{2}} - \left( 1 + \left( \frac{0.493 \text{ GeV}}{2 \text{ GeV}} \right)^2 \right)^{\frac{1}{2}} \right]$$

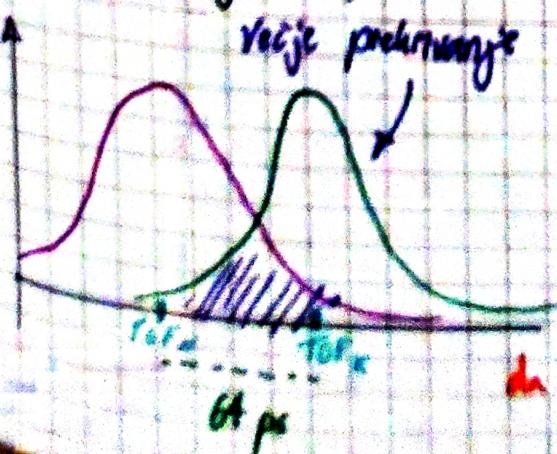
$$= 1.83 \cdot 10^{-10} \text{ s} = 183 \text{ ps}$$

$$\text{b) } \vec{p} = 4 \text{ GeV}/c$$

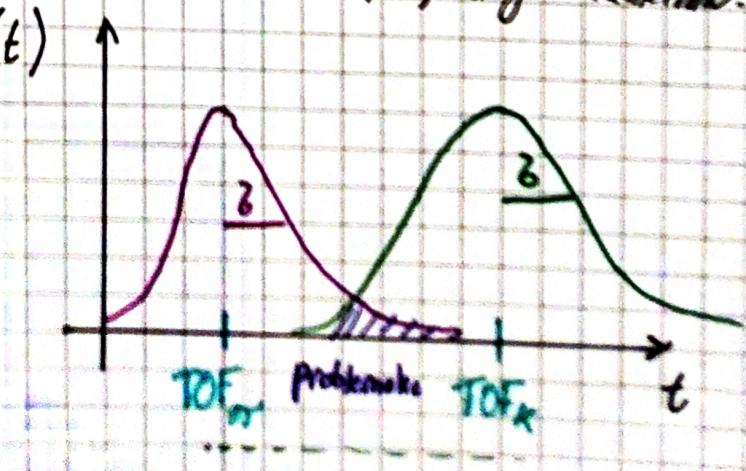
$$\Delta t \rightarrow \Delta t = 46 \text{ ps}$$

Hitrinosti luči  
kajo detektorom  
ne ustvarjajo izkorist.

Detektor ima svojo lastnost  $R$  oz.  $\beta$



Vzorec je da zgradišmo detektor s tako lastnostjo, da lahko ločimo daleč, za kar je dovoljne razlike v dosegih.



*(Máme nějaký dešer)*

Podporujeme Gaussovo rozdělení:  $Gauss(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$

$x_0$	$g(x)[\%]$	$f(x)[\%]$
8	68.3	84.1
22	95.5	97.7
38	99.73	99.865
42	99.994	99.997
58	99.9994	99.9997
82.3	80	90
445.3	10	95
1322.3	98	99
2588.3	99	-

$$g(x_0) = \int_{-\infty}^{x_0} Gauss(x) dx$$

$$f(x_0) = \int_{-\infty}^{x_0} Gauss(x) dx$$

• Če hočemo mít 99% izložitelsk.

$$\Rightarrow X_{PRAG} = X_1 + 2,327 \cdot \sigma$$

*↑*  
je to 99%

• Če hočemo najít 5% lažních dogodností:

$$\Rightarrow X_{PRAG} = X_2 - 1,645 \cdot \sigma$$

6.1.1 [Kolikána je možnost závraty? Kamb prag je hočemo 95% eff.]

$$\beta = 0.5$$

$$EFF_{\pi} = 95\%$$

$$PRAG = ?$$

$$FAKE_K = ?$$

$$\rightarrow 2 \text{ GeV} \quad \Delta t = 183 \text{ ps}$$

$$D = \frac{|TOF_{\pi} - TOF_K|}{\sigma} = \frac{183 \text{ ps}}{60 \text{ ps}} = 3$$

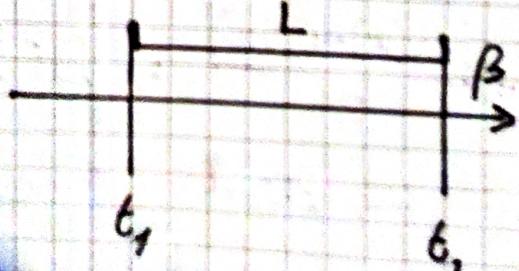
$$\rightarrow 4 \text{ GeV} \quad \Delta t = 46 \text{ ps}$$

$$TOF_{\pi} = \frac{L}{c} \sqrt{1 + \left(\frac{\gamma_{\pi}}{\rho c}\right)^2} = 6.683 \text{ ns}$$

Vzdálenost  $L$

$$TOF_K = \dots = 6.266 \text{ ns}$$

$$\Rightarrow \Delta t = 183 \text{ ps}$$



$$f(x_0) = 95\% \rightarrow x_0 = 1,645 \cdot 3$$

$$\text{TOF}_{\text{PRAG}} = \text{TOF}_\pi + 1,645 \cdot 3$$

$$= 6,782 \text{ ns}$$

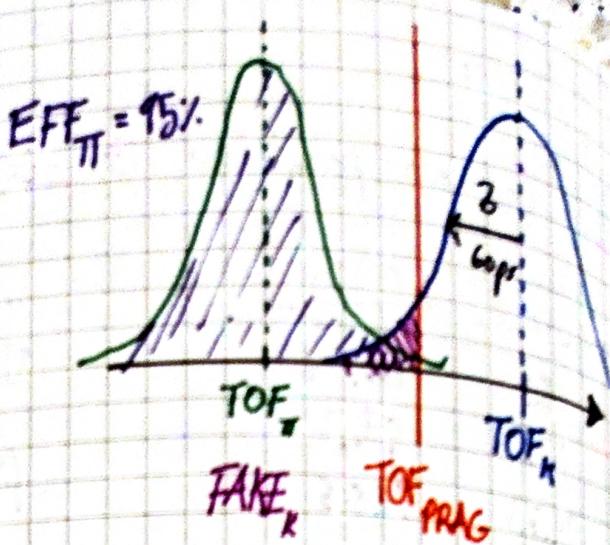
Počítač?  $\text{FAKE}_K = ?$

$$x_0 = \text{TOF}_K - \text{TOF}_{\text{PRAG}} = 84 \text{ ps}$$

↑  
izomice v běžení 3

$$x_0 = \frac{84 \text{ ps}}{60 \text{ ps}} \cdot 3 = 1,43 \rightarrow f(x_0 = 1,43) = 92\%$$

$$\text{FAKE}_K = 1 - f(x_0 = 1,43) = 8\%$$



### 6.1.2 [Locifjrost 5.1.2]

$$N = 10$$

$$\beta_0 = 14 \text{ mrad}$$

$$\beta_0 = \frac{\beta_0}{\sqrt{N}}$$

$$\beta_0 = 4.427 \text{ mrad}$$

$$\theta_c(\pi) = 307,9 \text{ mrad}$$

$$\theta_c(K) = 285,3 \text{ mrad}$$

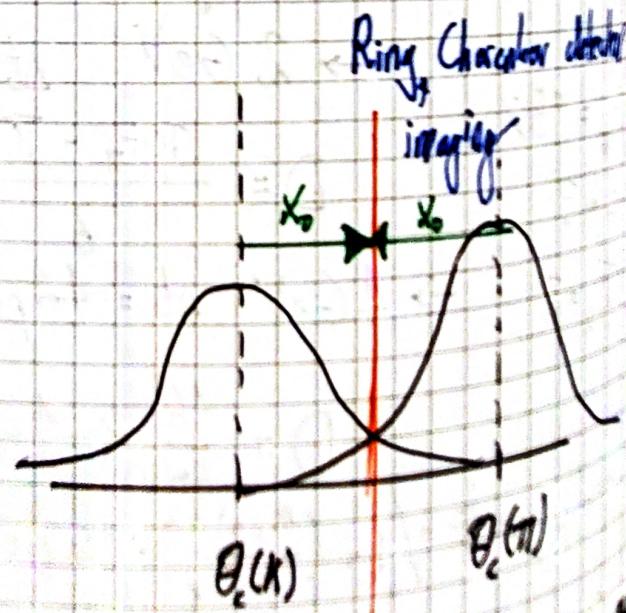
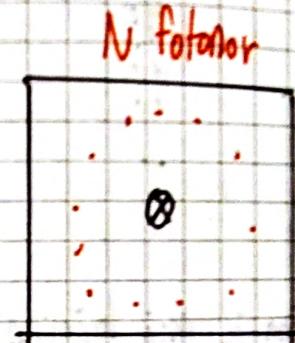
Kolimace mož bězecí?

$$D = \frac{|\theta_c(\pi) - \theta_c(K)|}{\beta} \Rightarrow D = 5.1$$

Kolimace stan EFF\_K a n FAKE\_K = ? Če dám mož bězecí faktor M sestav

$$x_0 = \frac{1}{2} (\theta_c(\pi) - \theta_c(K)) = 11,3 \text{ mrad}$$

$$\theta_{\text{max}} = \theta_c(K) + x_0 = (285,3 + 11,3) \text{ mrad} = 296,6 \text{ mrad}$$



Omn

$$R = \frac{11.3 \text{ rad}}{4.42 \text{ rad}} \Rightarrow R = 2.558$$

$$E_R = f(2.558) \approx 99.4\%$$

Der Punkt ist  $\beta$  km vor der Endstelle  $\mu$  ETW bei  $\pi$  in  $\mu$

$$PKE_{\gamma} = 1 - 99.4\% = 0.6\%$$

Oben:

$$\delta = R = \frac{R_{\text{MAX}}}{2.35}$$

+  
längst

Unter gleicher Ladung

$$\frac{1}{2} = cSR$$

1,3: tödliche Dosis  
max dauer  $t_{D20}$

$$\sin \frac{\theta}{2} = \frac{\theta}{2} = \frac{LcB}{P_t}$$

$$\Rightarrow \theta = \frac{LcB}{P_t} \quad \#$$

$$\cos \frac{\theta}{2} = \frac{R-s}{R}$$

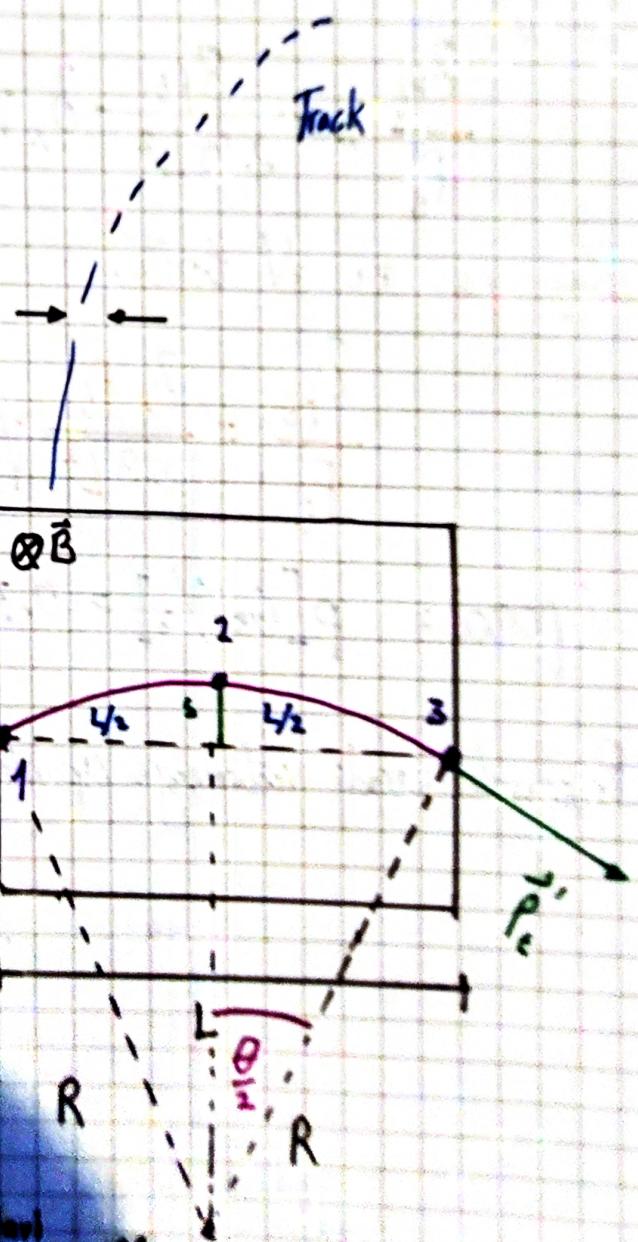
Max

$$1 - \frac{1}{2} \frac{\theta^2}{4} = 1 - \frac{s}{R}$$

$$s = R \frac{\theta}{8}$$

Von da

$$s = \frac{RL^2 c^2 B^2}{8P_t} \quad \xrightarrow{a/h = 0.02} \quad s = \frac{cBL^2}{8P_t}$$



Če merimo 3 točke:

$$S = X_2 - \frac{X_1 + X_3}{2}$$

$$\delta_s^2 = \delta_x^2 + \frac{1}{4}\delta_1^2 + \frac{1}{4}\delta_3^2 ; \text{ Recimo da so vse } \delta_i = \delta_x$$

$$\delta_s^2 = \frac{6}{4} \delta_x^2 \rightarrow \delta_s = \sqrt{\frac{3}{2}} \delta_x \quad \frac{\delta_{P_t}}{P_t} = \frac{\delta_s}{S}$$

Torej:

$$\frac{\delta_{P_t}}{P_t} = \frac{8 P_t}{e B L^2} \delta_x \sqrt{\frac{3}{2}} \quad \text{za 3 točke}$$

Kaj pa za N točk?

$$\frac{\delta_{P_t}}{P_t} = \frac{\delta_x P_t}{e B L^2} \sqrt{\frac{720}{N+4}}$$

Napaka meritve gibalne kolizije  
zavadi traklina / slatkoja.

$$\text{V pomoci: } p[\text{GeV}/c] = 0.3 B[T] R[m]$$

Prispevki zavadi večkratnega sponjenja (v materialu detektorja)

multiple scattering