

# Sono aperte le schede OPLS

A7CFAS0M	2020	1	Corso di Studi	Modulo	Insegnamento	Anno Corso	Semestre	Crediti	i	Verbalizzante
			FISICA (28204)		FISICA NUCLEARE E SUBNUCLEARE I (1012075)	3	2	6.00		SI
SN17QNSI	2020	0	Corso di Studi	Modulo	Insegnamento	Anno Corso	Semestre	Crediti	i	Verbalizzante
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Codic: per l'accesso diretto al corso

## Effetto Cherenkov

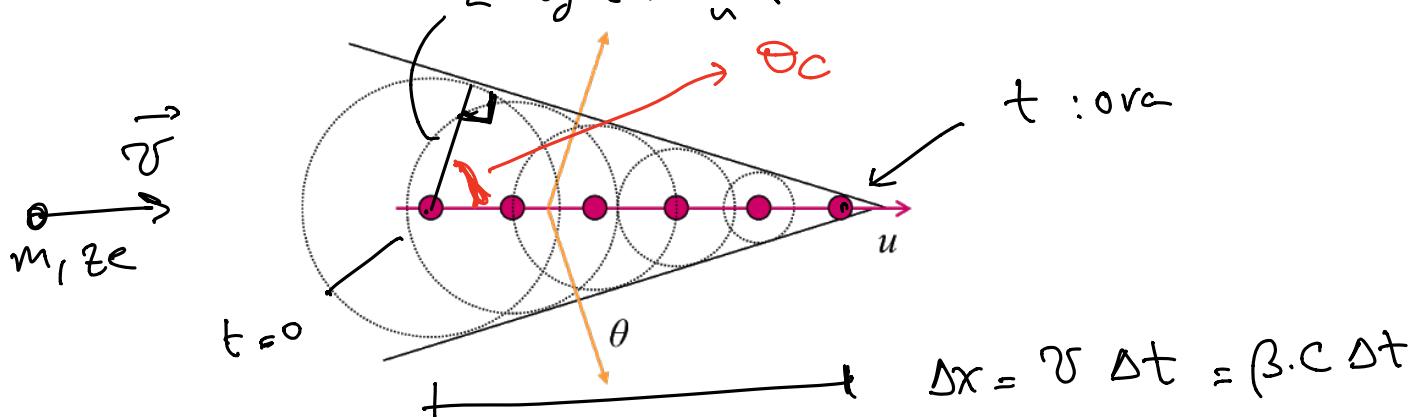
Feynman legato alle polarietà e direzione del urto e al passaggio di particelle con le relazioni.

$$v_{\text{proj,eff.}} > \frac{c}{n} \quad \begin{array}{l} \text{Velocità della luce} \\ \text{nel urto.} \end{array}$$

↳ prop. del urto

Feynman si riferisce a boom supersonico

$$L = v_g \cdot t = \frac{c}{n} t$$



$$L = \Delta x \cos \theta_C \Rightarrow \frac{R}{n} t = \beta c t \cos \theta_C$$

$$\cos \theta_C = \frac{1}{\beta n}$$

n: fattore del urto.  $\beta = \frac{P}{E}$  varia per particelle.

a parità di impulso

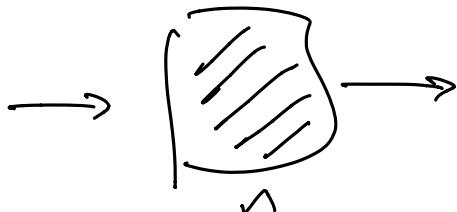
$\beta$  più grande per un più piccole.

Se misurerete impulso con uno strumento.

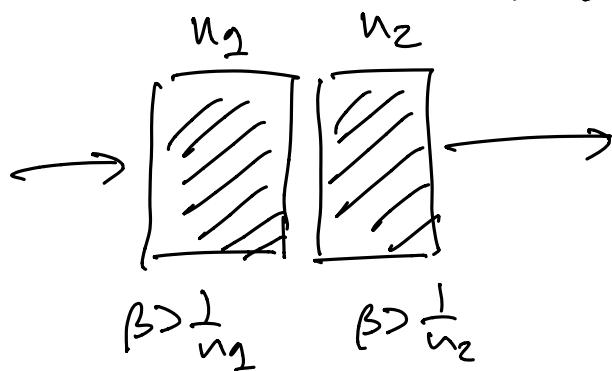
se misurerete corde  $(\Delta c, P) \rightarrow$  stime delle messe.

$$\cos \Delta c < 1 \Rightarrow \frac{1}{\beta n} < 1 \Rightarrow \boxed{\beta > \frac{1}{n}}$$

Cf corde a soglie: succede solo se  $\beta \geq \frac{1}{n}$



Se emissione luce  $\Rightarrow \beta > \frac{1}{n}$ .  
Rivelatore a soglia.



if ① = TRUE & &  
NOT ②

$$\Rightarrow \frac{1}{n_1} < \beta < \frac{1}{n_2}$$

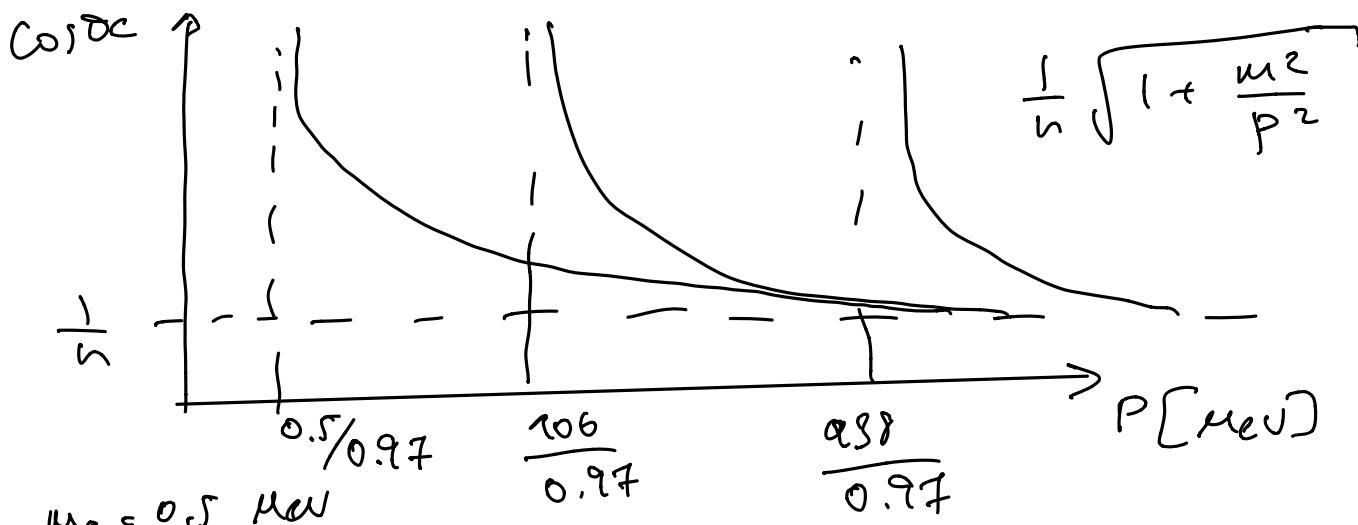
$$\beta \gamma = \frac{P}{m} \quad \beta \gamma = \frac{\beta}{\sqrt{1 - \beta^2}} \Rightarrow \frac{1}{\beta} = \sqrt{1 + \frac{m^2}{P^2}}$$

$$\cos \Delta c = \frac{1}{\beta n} = \frac{1}{n} \sqrt{1 + \frac{m^2}{P^2}} \quad \text{Cherenkov solo per } P > P_{th}$$

$$\beta > \frac{1}{n} \quad \beta_{th} = \frac{1}{n} \quad \frac{1}{n} = \sqrt{1 + \frac{m^2}{P_{th}^2}}$$

$$P_{th} = \frac{m}{\sqrt{n^2 - 1}} \quad n > 1.$$

$$n \approx 1.5 \rightarrow P_{th} \approx \frac{m}{0.97}$$



$$\mu_e = 0.5 \text{ MeV}$$

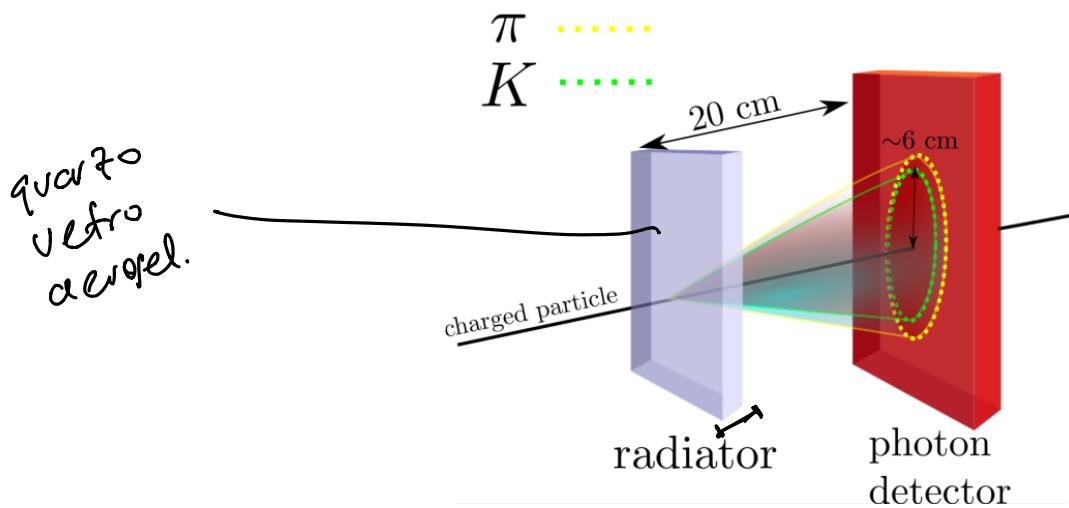
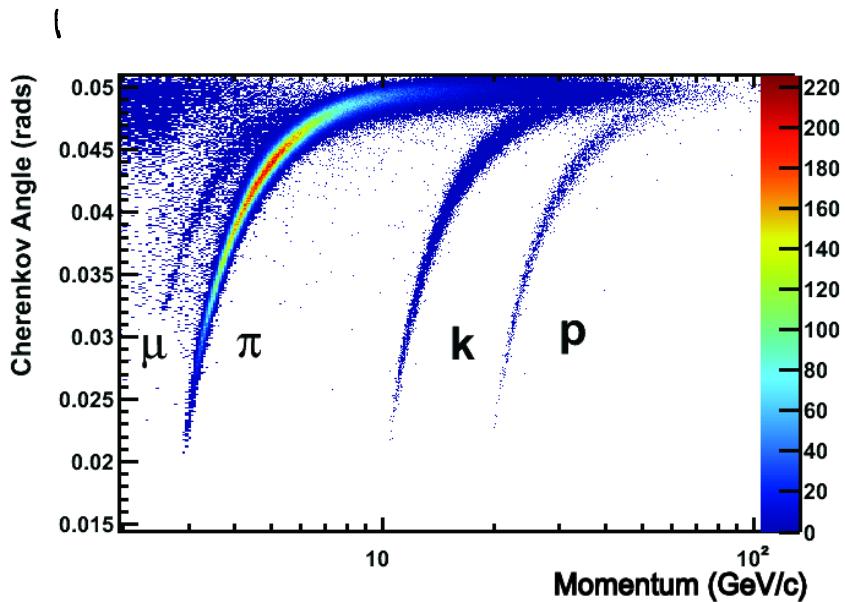
$$\alpha_\mu = 106 \text{ MeV}$$

$$\mu_p = 938 \text{ MeV}$$

$p_T \ll p \gg p_{T\text{th.}} \Rightarrow \cos \theta_{DC}$   
Uscita per tutti.

ad altezze impulso non possibile  
distinguere particelle diverse.

$$\theta_C = \alpha \cos\left(\frac{1}{n} \sqrt{1 + \frac{m^2}{p^2}}\right)$$



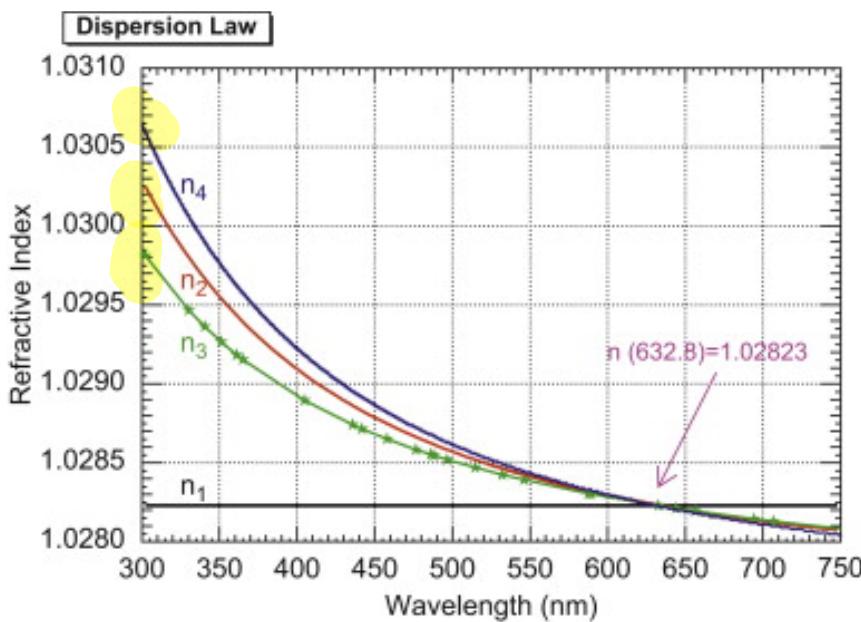
$$\cos \theta_C = \frac{1}{\beta n} < 1 \quad \Rightarrow \frac{1}{n} \quad \beta \rightarrow 1 \quad \text{ultra rel.}$$

avete bisogni di materiali con  $n \approx 1$

aerogel.

materiali al

Si (e C)



# di fotoni Cherenkov emessi e lo spettro

Calcolabile nella elettrodinamica classica

$$\frac{d^2N}{dx dE} = \frac{\alpha \epsilon^2}{4\pi c} \left( 1 - \frac{1}{\beta^2 n(E)^2} \right) = \frac{\alpha \epsilon^2}{4\pi c} \sin^2 \theta_C$$

$dX$ : cammino del moto

$E$ : energia del fotone emesso.

$n = n(\epsilon) = n(\lambda)$  indice di rifrazione del mezzo.  
dipende da  $E$

$$E = h\nu = 2\pi \frac{\epsilon c}{\lambda} \quad \Rightarrow$$

spettro del visibile

$$\frac{dN}{dE} = \frac{dN}{d\lambda} \frac{d\lambda}{dE}$$

$\lambda \in [300, 700] \text{ nm.}$

$$\frac{d\lambda}{dE} = \frac{2\pi \epsilon c}{\lambda^2}$$

$$\frac{d^2N}{dx d\lambda} = \frac{\alpha z^2}{\lambda e} \frac{e^{-\tau_{\text{tot}}}}{\lambda^2} \left( 1 - \frac{1}{\beta^2 n^2(\lambda)} \right)$$

$$= \frac{e^{-\tau_{\text{tot}}}}{\lambda^2} \sin^2 \delta_C(\lambda)$$

nel visible

$$\frac{dN}{dx} = \int_{\text{visible}} \left( \frac{d^2N}{dx d\lambda} \right) d\lambda \quad + \int_{300 \mu\text{m}}^{700 \mu\text{m}} \frac{d\lambda}{\lambda^2}$$

$$= 4.5 \times 10^4 \text{ m}^{-1} \text{ } z^2 \underbrace{\sin^2 \delta_C}_{\text{valore medio nel visible}}$$

$$= 4.5 \times 10^4 \text{ } z^2 \sin^2 \delta_C \text{ fotoni/cm}$$

$$E = \frac{e^{-\tau_{\text{tot}}}}{\lambda} \quad \text{nel visible} \quad \tau_{\text{tot}} \approx 197 \text{ MeV fm.}$$

$$\lambda \in [300, 700] \mu\text{m}$$

$$E_{\text{visibile}} \approx 2 \text{ eV} \quad (1.8 \rightarrow 3.1) \text{ eV visible}$$

$$\text{energia media fotoni Cherenkov} \approx 900 \text{ eV} \cdot \frac{z^2 \sin^2 \delta_C}{\text{cm.}}$$

perdita di energia del proiettile a causa  
di Cherenkov.

$$- \frac{dE}{dx} \Big|_{\text{Cherenkov}} \approx 1 \frac{\text{keV}}{\text{cm.}}$$

nella cassa.

$$- \frac{dE}{dx} \Big|_{\text{ion. min.}} \approx 1.5 \text{ MeV/cm.}$$

H<sub>2</sub>O acqua.  
 $\rho = 1 \text{ g/cm}^3$

$$\left( \frac{\text{perdite Cherenkov}}{\text{perdite ion.}} \right) \approx 10^{-3}$$

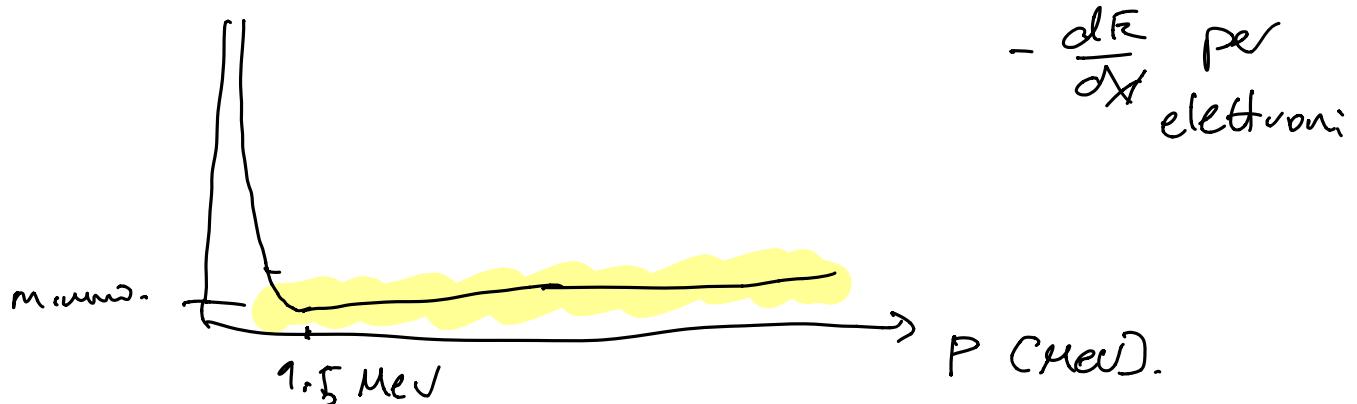
Perdita di energia per  $e^-$ ,  $e^+$

particelle cariche  $\Rightarrow$  Bethe-Bloch.

$$\beta \gamma \approx 3 \text{ m.m.m.} \Rightarrow \frac{P}{m} \approx 3 \Rightarrow P = 1.5 \text{ MeV}$$

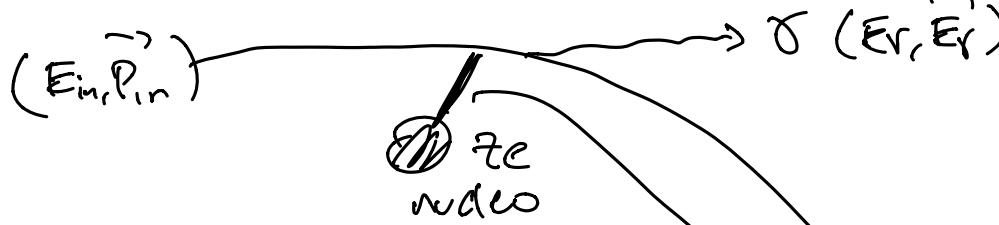
m.m.m.

risalita relativistica non lenta debola per elettroni.



$P > 1.5 \text{ MeV}$  sono al minimo di ionizzazione.

proiettile percuti.: nuclei del metallo  $\Rightarrow$  diffusione Coulombiana multiple



$e^\pm$  leggeri, l'accelerazione forte del nucleo.

$$a = \frac{1}{m} \frac{Ze^2}{4\pi\epsilon_0} \frac{1}{r^2}$$

a dà una a Coulomb  $\propto \frac{1}{m}$

particelle cariche accelerate emette radiazione

potere radiante  $P = \frac{2}{3} \frac{e^2}{m^2 c^3} |\dot{\vec{r}}|^2$  Formula di Larmor classica

porti della non relativistica

Estensione relativistica di Larmor (Lorentz invariante)

$$P = -\frac{2}{3} \frac{e^2}{m^2 c^3} \frac{dP_\mu}{d\tau} \frac{dP^\mu}{d\tau} \quad P_\mu = (E/c, \vec{P})$$

$$\frac{dP_\mu}{d\tau} \frac{dP^\mu}{d\tau} = \frac{1}{c^2} \left| \frac{dE}{d\tau} \right|^2 - \left| \frac{d\vec{P}}{d\tau} \right|^2$$

$$E = \gamma m c^2 \quad \vec{P} = \gamma m \vec{v} = \gamma m c \vec{\beta}$$

$$P = \frac{2}{3} \frac{e^2}{c} \gamma^6 \left[ (\dot{\vec{\beta}})^2 - (\vec{\beta} \times \dot{\vec{\beta}})^2 \right]$$

$\beta, \gamma$  particelle cariche relativistiche

Due casi: limiti

- accelerazione lineare

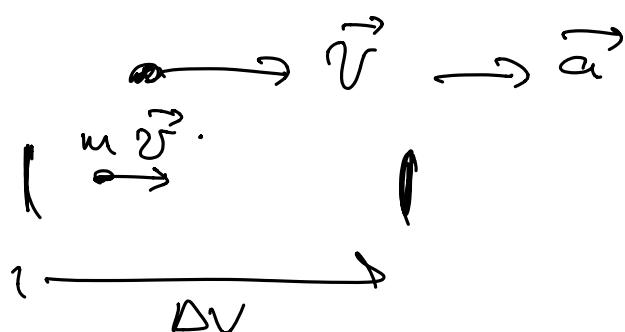
$$\dot{\vec{\beta}} \parallel \vec{\beta}$$

$$\dot{\vec{\beta}} \times \vec{\beta} = 0$$

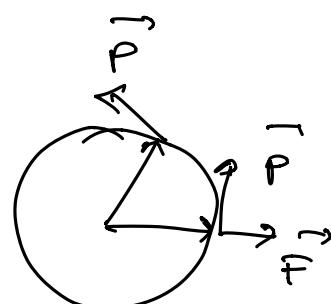
$$P = \frac{2}{3} \frac{e^2}{c} \gamma^6 (\dot{\vec{\beta}})^2$$

accelerazione  $\vec{a} \perp \vec{v}$

moto circolare



$$\vec{\beta} + \vec{\beta}$$



$$P = \frac{2}{3} \frac{e^2}{c} \gamma^6 \left( \dot{\vec{\beta}}^2 - \beta^2 \dot{\vec{\beta}}^2 \right)$$

$$\dot{\vec{\beta}}^2 (1 - \beta^2) = \frac{\dot{\vec{\beta}}^2}{\gamma^2}$$

$$P = \frac{2}{3} \frac{e^2}{c} \gamma^6 \frac{\dot{\vec{\beta}}^2}{\gamma^2} = \frac{2}{3} \frac{e^2}{c} \gamma^4 \dot{\vec{\beta}}^2$$

particelle caricate in moto circolare.

$$P_{\text{irred.}} \propto \gamma^4 = \left( \frac{E}{m} \right)^4 = \frac{E^4}{m^4}$$

proiettili con la stessa energ.

ma nelle diverse  $P_{\text{irred.}}$  cambia molto.

$$E = \text{fissato} \quad \frac{P_e}{P_p} = \frac{m_p^4}{m_e^4} = \left( \frac{1000 \text{ MeV}}{0.5 \text{ MeV}} \right)^4$$

$$\approx 16 \times 10^{12} \leq 10^{13}$$

LHC:  $E = 6.5 \text{ TeV}$  protoni

Radiotracci di particelle cariche accelerate.

Bremsstrahlung      radiazioni frenetiche

effetto dominante per  $e^-$ ,  $e^+$

misurare  $m = 106 \text{ MeV} \approx 200 \times \text{Me.}$

$$\frac{P_e}{P_p} \approx 16 \times (10^2)^4 = 16 \times 10^8$$

$$\approx 10^9 \text{ volte.}$$

$e^-$  Bremsstrahlung  $\propto E_N \text{ MeV}$ ,  $\mu ? \sim \text{TeV}$