KAHOOT:

$$A \to B + C$$

quanti gradi di libertà nella scelta dell'impulso?

$$\vec{p}_A = \vec{p}_B + \vec{p}_C$$

$$\hookrightarrow \vec{p}_B = (7, 3, -94)$$

$$\vec{p}_C = (p_A^x - 7,\ p_A^y - 3,\ p_A^z + 94)$$

$$A \to B + C + \underbrace{D + E}$$

FISICA DELLE PARTICELLE

PARTICELLE

INTERAZIONI

TEORIA

ESPERIMENTO

teoria

- sezione d'urto σ
- rate di transizione Γ
- calcolo quantità ($dE/dx \ldots$)

esperimento

- produrre particelle
- le rivela
- misura quantità

1) DOVE MI PROCURO PARTICELLE?

es) raggi cosmici

1912

elettrometro di Wulf

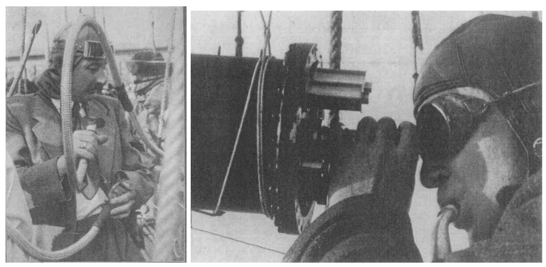
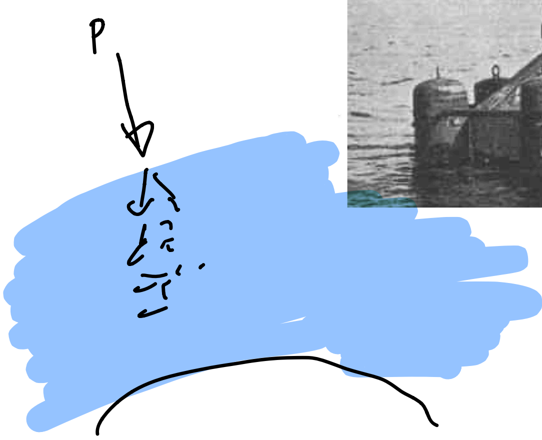


FIGURE 2. Dr. M. Schrenk (*left*) with a breathing apparatus in the balloon gondola and V. Masuch, reading an electrometer (*right*), preparing for their balloon launch on May 13th, 1934 [10].



$p \to \ldots$

$(\tau \simeq 26\,ns)$

$\pi \to \mu + \nu$

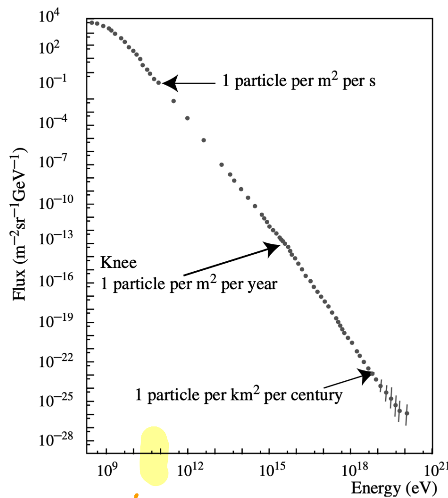
$\quad \hookrightarrow e + \nu$

$(\tau \simeq 2\,\mu s)$

$\pi \to \gamma + \gamma$

flusso ↑ di particelle

$\lesssim 10$ GeV → ANNI 1920 (lezione di oggi)



all'entrata dell'atmosfera

85% p
12% α
1% nuclei
2% elettroni

LHC
($\sqrt{s}$
p → ← p)

→ energia dei raggi cosmici

② COME LE RIVELO!

- messa
- $\underline{P} = (E, \vec{p})$
- q (carica elettrica)
- spin
- momento magnetico
- altri # quantici
  ↪ corrispondono a SIMMETRIE (cf. Teorema di Noether)

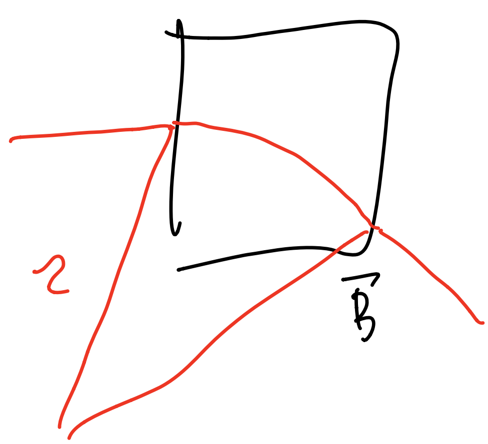
lascia segnali

- $dE/dX|_{\text{IONIZZ.}}$
- $dE/dX|_{\text{RADIAZIONE (BREMSSTRAHLUNG)}}$
- Cherenkov
- fotoelettrico / produz. di coppie
  compton

Cosa misuro e COME

- $\vec{p}$?

  se $q \neq 0$: uso $\vec{B}$



$$\vec{F} = q\vec{v} \times \vec{B}$$

se $\vec{B} \perp \vec{v}$:

$$F = qvB = m\frac{v^2}{r}$$

$$= \frac{pv}{r}$$

$$P = qBr$$

↳ $q/|q|$ dal verso in cui curva

DATO B & r, DEVO ASSUMERE z PER SAPERE P!

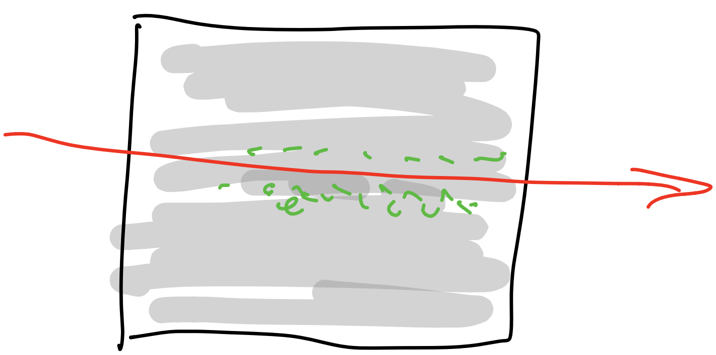
$$\frac{P}{1\,\mathrm{GeV}/c} = \underbrace{0.3}_{\frac{3\cdot 10^{8}}{10^{9}}} \cdot \frac{B}{1\,T} \cdot \frac{r}{m}\, \underbrace{z}_{\text{carica}/e}$$

Come misuro r?

(A) TECNICHE VISUALIZZANTI

Camera di Wilson

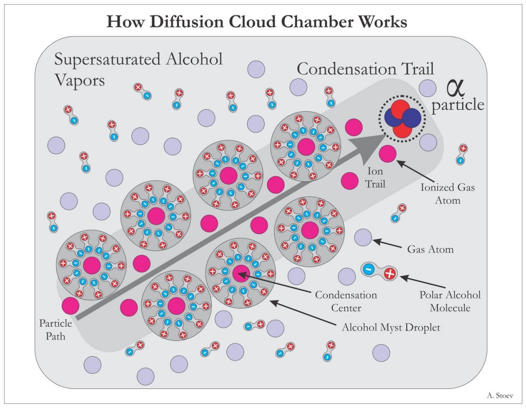
CAMERA A NEBBIA

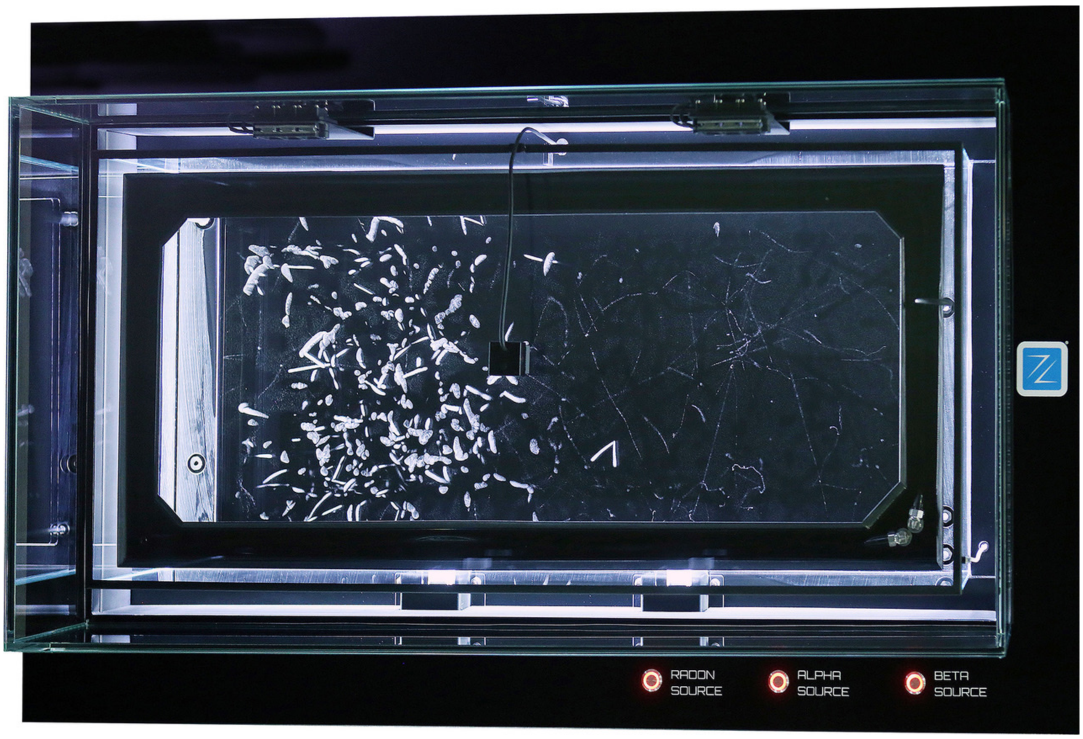


particella

queste coppie elettrone-ione!

RAFFREDDO → $\Delta E / W$ → potenziale di ionizzazione

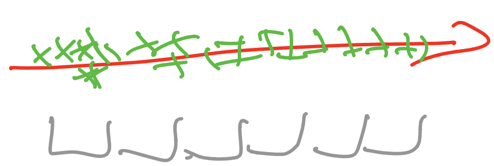




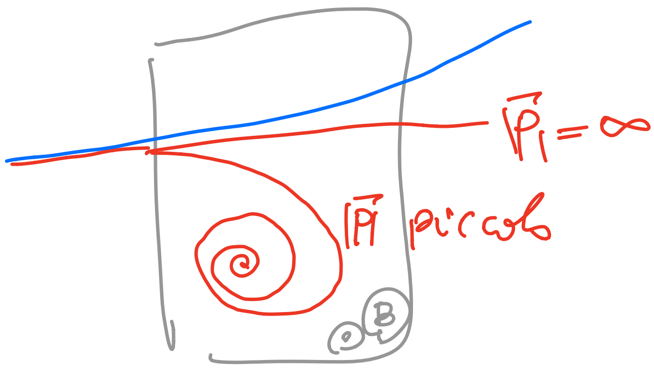
se mando $z=1$ e poi $z=2$

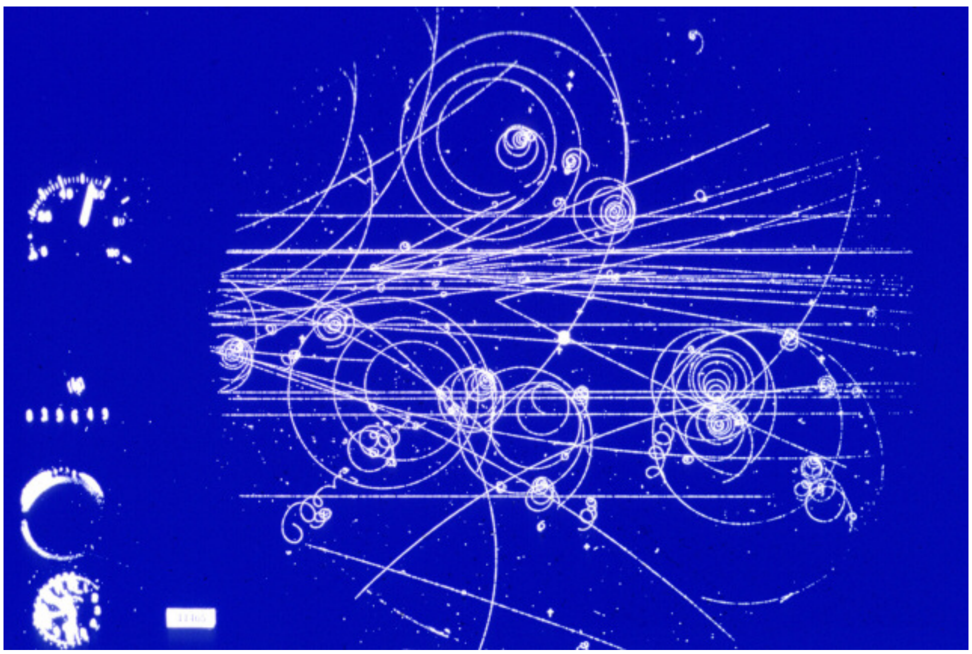
$$\left.\frac{dE}{dx}\right|_{\text{IONIZZ.}} \propto z^2$$

LO "SPESSORE" DELLA TRACCIA DIPENDE CIOE' DA z^2 DELLA PARTICELLA

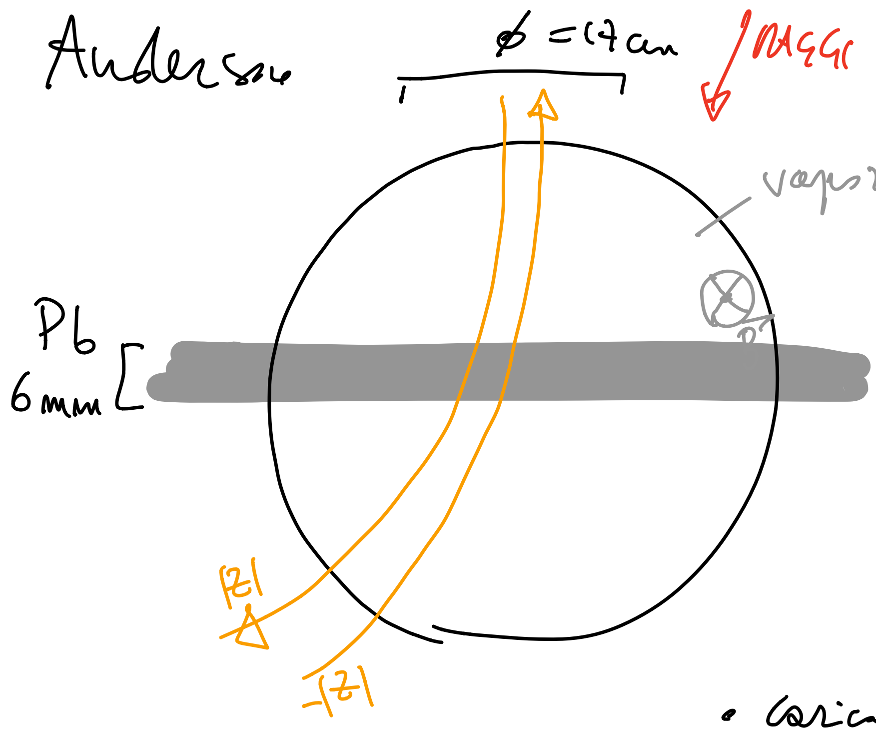


6 cm


$|\vec{P}_1| = \infty$
$|\vec{P}|$ piccolo
B



Anderson



$B = 1.7$ T

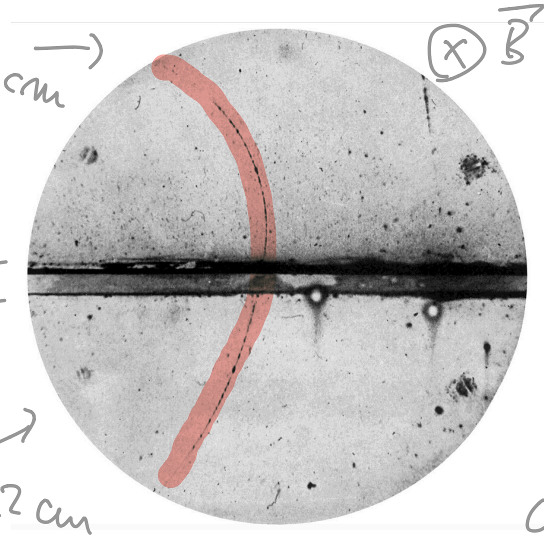
$\Delta t = 25$ ms

1600 foto

- carica: $\frac{dE}{dx}$
- |carica|: curvatura
- direzione: blocco di Pb

$r = 4.5$ cm

$\otimes \vec{B}$



6 mm $= X_0(\text{Pb})$

$r = 12$ cm

PER CASA:
- calcolare p dalle 2 misure di r
- calcolare l'energia depositata nel Pb da un elettrone
- come sopra ma assumendo sia un protone

Carica: $+1$

$m \simeq 511$ keV $= m_e$

POSITRONE!

MQ $i\hbar \frac{\partial \psi}{\partial t} = H\psi$

$\hbar = c = 1$

$$i \frac{\partial \psi}{\partial t} = H\psi$$

particelle libere

$H = \frac{p^2}{2m}$ $\qquad p = -i\nabla$

$$i \frac{\partial \psi}{\partial t} = -\frac{\nabla^2}{2m}\psi$$

$$H = \sqrt{p^2 + m^2}$$

$$= \sqrt{-\nabla^2 + m^2} \qquad \left(\simeq m + \frac{p^2}{2m} \ldots\right)$$

$$i \frac{\partial \psi}{\partial t} = \sqrt{-\nabla^2 + m^2}\,\psi$$

ALLEVIO

$$\left(i \frac{\partial}{\partial t}\right)^2 \psi = (H)^2 \psi$$

$$-\frac{\partial^2}{\partial t^2}\psi = (-\nabla^2 + m^2)\psi$$

$$\frac{\partial^2}{\partial t^2} - \nabla^2 = \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2}$$

$$= \partial_\mu \partial^\mu$$

$$\partial_t \equiv \frac{\partial}{\partial t}$$

$$\partial_x = \frac{\partial}{\partial x}$$

$$\boxed{(\Box + m^2)\psi = 0}$$

EQ. DI KLEIN GORDON

MA

- non rispetta $i\frac{\partial}{\partial t}\psi = H\psi$
- 2° ordine $\rightarrow$

$$\rho = |\psi|^2$$

PER SCHROEDINGER

$$\frac{\partial}{\partial t}\rho = \vec{\nabla}\vec{J}$$

cerco soluzioni di K-G

$$\psi(x,t) \equiv A \cdot e^{i\vec{p}\cdot\vec{x}} e^{-iEt}$$

$$\left(\frac{\partial^2}{\partial t^2} - \nabla^2 + m^2\right)\psi = 0$$

$$(-iE)(-iE)\psi - (i\vec{p})(i\vec{p})\cdot\psi + m^2\psi = 0$$

$$= (-E^2 + p^2 + m^2)\psi = 0$$

$$E = \pm\sqrt{p^2 + m^2} \equiv \pm E_p$$

NON POSSO BUTTARE VIA LA SOLUZ. CON E<0, PERCHE' SIGNIFICA BUTTARE VIA PARTE DELLE ψ, CHE QUINDI NON FORMEREBBERO PIU' UNA BASE COMPLETA!!!

$E_p \geq 0$

STESSA TECNICA CHE SI USA CON LA EQ. DI SCHROEDINGER (PROVATE!)

$$\begin{cases} \times\psi^* & \dfrac{\partial^2}{\partial t^2}\psi - \nabla^2\psi + m^2\psi = 0 \\ \times\psi & \dfrac{\partial^2}{\partial t^2}\psi^* - \nabla^2\psi^* + m^2\psi^* = 0 \end{cases}$$

$$\begin{cases} A & \psi^*\dfrac{\partial^2}{\partial t^2}\psi - \psi^*\nabla^2\psi + m^2\psi^*\psi = 0 \\ B & \psi\dfrac{\partial^2}{\partial t^2}\psi^* - \psi\nabla^2\psi^* + m^2\psi\psi^* = 0 \end{cases}$$

$$A - B \qquad \psi^*\frac{\partial^2}{\partial t^2}\psi - \psi\frac{\partial^2}{\partial t^2}\psi^*$$

$$-\psi^* \nabla^2 \psi + \psi \nabla^2 \psi^* = 0$$

$$\left[\frac{\partial}{\partial t}\left(\psi^* \frac{\partial}{\partial t}\psi\right) - \frac{\partial \psi^*}{\partial t}\frac{\partial \psi}{\partial t}\right]$$

$$-\left[\frac{\partial}{\partial t}\left(\psi \frac{\partial}{\partial t}\psi^*\right) - \frac{\partial \psi}{\partial t}\frac{\partial \psi^*}{\partial t}\right]$$

$$-\nabla\left(\psi^* \nabla \psi - \psi \nabla \psi^*\right) = 0$$

$$\frac{\partial}{\partial t}\left(\psi^* \frac{\partial}{\partial t}\psi - \psi \frac{\partial}{\partial t}\psi^*\right)$$

$$= \nabla\left(\psi^* \nabla \psi - \psi \nabla \psi^*\right)$$

$$\rho \equiv i\left(\psi^* \frac{\partial}{\partial t}\psi - \psi \frac{\partial}{\partial t}\psi^*\right)$$

$$\vec{J} \equiv -i\left(\psi^* \nabla \psi - \psi \nabla \psi^*\right)$$

$$\partial/\partial t\, \rho = -\vec{\nabla}\cdot\vec{J}$$] EQUAZIONE DI CONTINUITÀ

SE PRENDO UN'ONDA PIANA

$$\psi \equiv A e^{i\vec{p}\vec{x}} e^{-iEt}$$

$$\rho = i\left[A^* e^{-i\vec{p}\vec{x}} e^{iEt} \cdot A e^{i\vec{p}\vec{x}}(-iE)e^{-iEt} - A e^{i\vec{p}\vec{x}} e^{-iEt} A^* e^{-i\vec{p}\vec{x}}(iE)e^{iEt}\right]$$

$$= i(-iE - iE)|A|^2$$

$$= 2E|A|^2 = \pm 2E_p |A|^2$$

devo passare all'eq. di Dirac!

	EQUAZIONE
spin 0	K-G
spin 1/2	Dirac
spin 1	PROCA

Dirac: $H^2 = p^2 + m^2$

$$i \frac{\partial \psi}{\partial t} = H\psi$$

$$i \frac{\partial \psi_a}{\partial t} = H_{ab}\psi_b$$

$$|\psi\rangle = |\psi, t\rangle$$

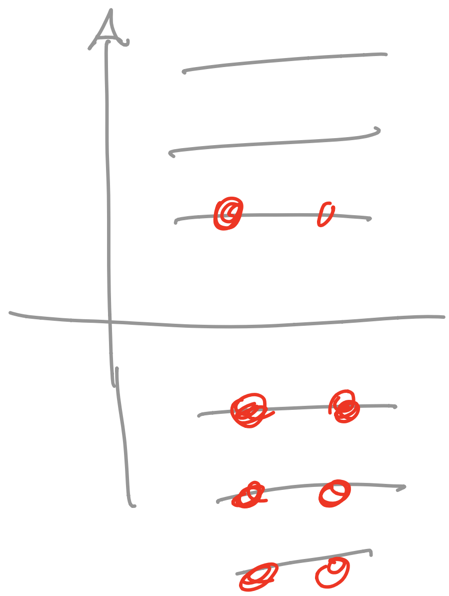
$$\rightarrow |\psi\rangle = |\psi, t, a\rangle$$

↳ VEDI "APPROFONDIMENTI"

Dirac impone $H^2 = p^2 + m^2$

- Dirac RISOLVE $\frac{\partial^2}{\partial t^2} \to \frac{\partial}{\partial t}$
- RISOLVE $\rho < 0$
- rimangono soluzioni ad $E < 0$

DIRAC SEA | FEYNMAN



$$\gamma \rightarrow e^- + e^+$$