$\boxed{1}$ [redacted]

$e^+e^- \rightarrow Z'$

$M_{Z'}$ ($\sim$ TeV)

$\boxed{\text{FASCIO + BERSAGLIO}}$

$$\xrightarrow{e^+} \; \overset{e^-}{\bullet}$$

E_{e^+} di soglia ? $\quad E_{soglia} = E_{soglia}(M_{Z'})$

$\boxed{\text{COLLIDER}}$

$$\xrightarrow{e^+} \; \xleftarrow{e^-} \qquad E(e^+) = E(e^-)$$

per ottenere s.f serve $\sqrt{s}\Big|_{s.f.} = M_{Z'}$

con $\boxed{\text{FASCIO + BERSAGLIO}}$

$$\sqrt{s}\Big|_{s.i.} = \sqrt{(E_{e^+} + m_e)^2 - p_{e^+}^2} =$$

$$= \sqrt{\underbrace{E_{e^+}^2} + m_e^2 + 2E_{e^+}m_e - \underbrace{p_{e^+}^2}}$$

$$= \sqrt{2m_e^2 + 2E_{e^+}m_e}$$

per produrre Z' deve essere

$$\sqrt{s}\Big|_{s.i.} = \sqrt{s}\Big|_{s.f.}$$

$$\Leftrightarrow \sqrt{2m_e^2 + 2E_{e^+}m_e} = M_{Z'}$$

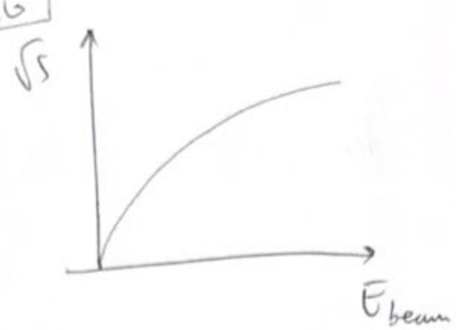
se $M_Z \sim$ TeV $\Rightarrow$ trascuro m_e^2

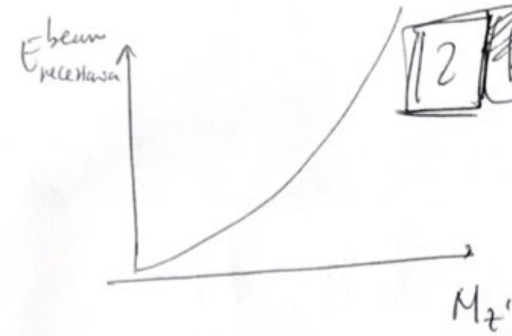
$$\Rightarrow \sqrt{s} \simeq \sqrt{2m_e E_{e^+}} = M_{Z'}$$

$$\Leftrightarrow E_{e^+} = \frac{M_{Z'}^2}{2m_e}$$

12

FASCIO + BERSAGLIO





COLLIDER

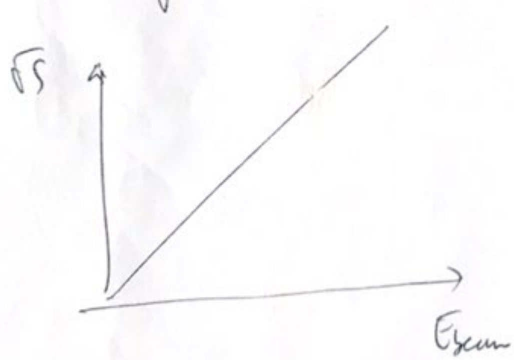
s.i. $\xrightarrow{E_{e^-}} \quad \xleftarrow{E_{e^+}}$

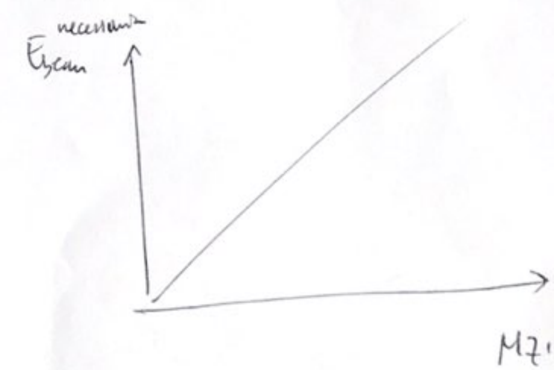
$E_{e^-} = E_{e^+} = E_{beam}$

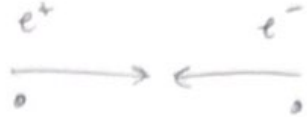
$p_{e^-} = -p_{e^+}$

$$\begin{pmatrix} E_{e^-} \\ \vec{p}_{e^-} \end{pmatrix} + \begin{pmatrix} E_{e^+} \\ \vec{p}_{e^+} \end{pmatrix} = \begin{pmatrix} 2E_{beam} \\ \vec{0} \end{pmatrix}$$

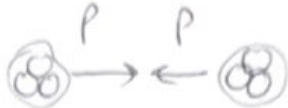
$$\Rightarrow \sqrt{s} = \sqrt{(2E_{beam})^2 - 0^2} = 2E_{beam} = M_{Z'}$$





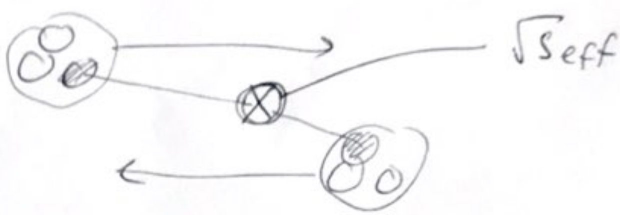


$\sqrt{s}$ <u>fissato</u> $\to$ in ogni collisione uguale



le interazioni sono fra quark

ogni quark ~~...~~ trasporta una frazione variabile di impulso del protone



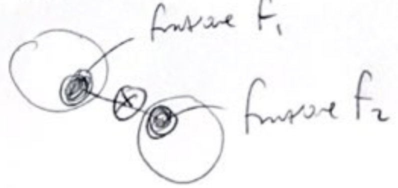
$\boxed{ES}$ LHC $p+p$

$$\xrightarrow{p}\ \xleftarrow{p} \qquad p(p) = 6.5\ \text{TeV} \sim E_p$$

$$\Rightarrow \begin{pmatrix} E_p \\ \vec{p}_p \end{pmatrix} + \begin{pmatrix} E_p \\ -\vec{p}_p \end{pmatrix} \qquad \underline{LAB} = \underline{CdM}$$

$$\Rightarrow \sqrt{s} = \sqrt{(2E_p)^2} = 2E_p = 13\ \text{TeV}$$

<u>MA</u> interazione elementare è fra quark



$$\begin{pmatrix} f_1 E_p \\ f_1 \vec{p}_p \end{pmatrix} + \begin{pmatrix} f_2 E_p \\ -f_2 \vec{p}_p \end{pmatrix}$$

$$\Rightarrow \sqrt{s} = \sqrt{\left(E_p\,(f_1+f_2)\right)^2 - \left(p_1\,(f_1-f_2)\right)^2}$$

$f \sim 0.3$ caso semplice $f_1 = f_2 = 0.3$

$$\Rightarrow \sqrt{s}_{eff} = E_p \cdot (f_1+f_2) = \underset{\substack{\uparrow \\ 3.9\ \text{TeV}}}{0.6\,E_p} < \underset{\substack{\uparrow \\ 13\ \text{TeV}}}{2\,E_p}$$

① invece di nominale

② <u>variabile</u> evento per evento

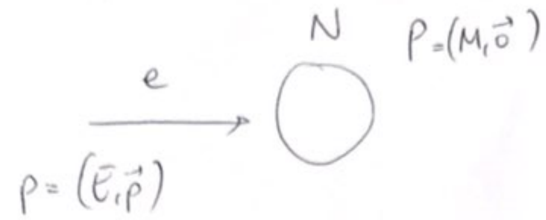
$\Rightarrow$ collisioni adroniche sono collisioni di <u>spettro</u>

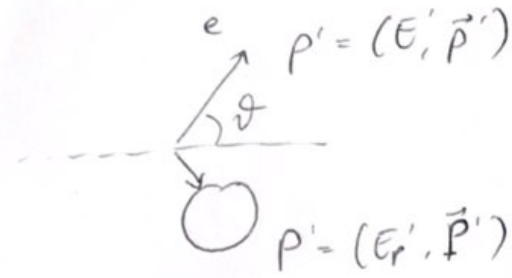
$\longrightarrow$ <u>STORIA DELLA J/ψ</u>

<u>MASSA INVARIANTE $\neq \sqrt{s}$</u>

SCATTERING ELASTICO

elettrone su nucleo





$$m_e^2 = p^2 = E^2 - \vec{p}^{\,2} = p'^2 = E'^2 - \vec{p}\,'^2$$

$$M^2 = P^2 = P'^2 = E_P'^2 - \vec{P}\,'^2$$

conservazione del 4-impulso

$$p + P = p' + P'$$

$$\Leftrightarrow (p+P)^2 = (p'+P')^2$$

$$\Leftrightarrow p^2 + P^2 + 2p\cdot P = p'^2 + P'^2 + 2p'\cdot P'$$

$$\Leftrightarrow \cancel{m_e^2} + \cancel{M^2} + 2p\cdot P = \cancel{m_e^2} + \cancel{M^2} + 2p'\cdot P'$$

$$\Leftrightarrow p\cdot P = p'\cdot P'$$

Sperimentalmente* e' difficile misurare momento nel nucleo P' $\Rightarrow$ ricavo:

$$\Rightarrow P' = p + P - p'$$

$\Rightarrow \quad p \cdot P = p' \cdot P' = p' \cdot (p + P - p')$

$\Leftrightarrow \quad p \cdot P = p' \cdot p + p' \cdot P - \underbrace{p'^2} = p' \cdot p + p' \cdot P - m_e^2$

e svolgo i prodotti

$$p = \begin{pmatrix} E \\ \vec{p} \end{pmatrix} \quad P = \begin{pmatrix} M \\ \vec{0} \end{pmatrix} \quad p' = \begin{pmatrix} E' \\ \vec{p}' \end{pmatrix}$$

$\Rightarrow \quad p \cdot P = EM$

$p' \cdot P = E'M$

$p' \cdot p = EE' - \vec{p}' \cdot \vec{p}^*$

$\Leftrightarrow \quad EM = E'E - \vec{p}' \cdot \vec{p}^* + E'M - m_e^2$

$= E'E - \underbrace{p'p\cos\vartheta} + E'M - m_e^2$

angolo fra direzione entrante e uscente di e!

FINO A ORA ESATTO

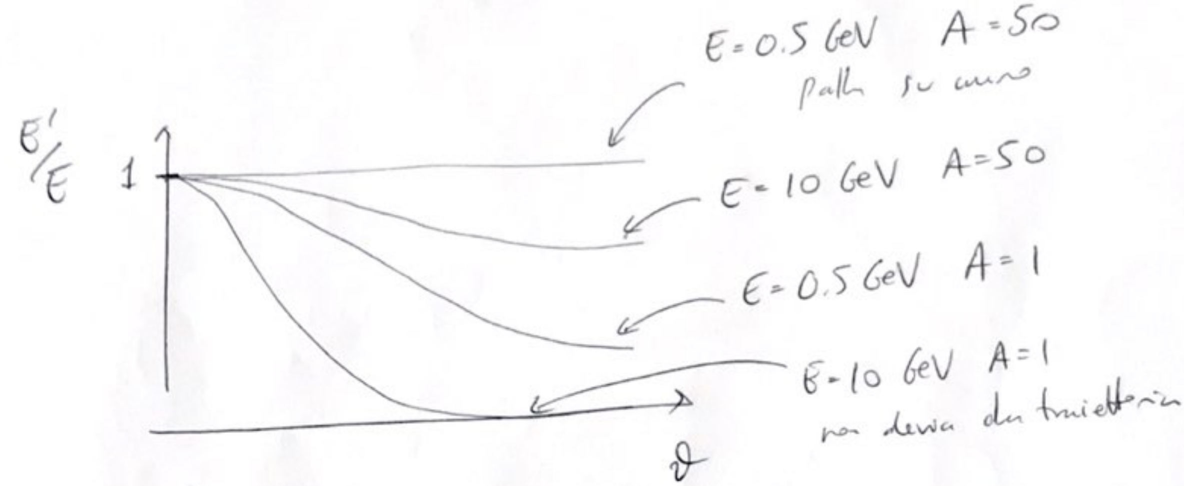
mettiamoci in approssimazione $E_e \gg m_e \Leftrightarrow m_e \sim 0$
$\Rightarrow p' = E'$
$p = E$

$\Rightarrow \quad EM = E'E - E'E\cos\vartheta + E'M - \cancel{m_e^2}$

$\Leftrightarrow \quad EM = E'(E(1-\cos\vartheta) + M)$

$$\Rightarrow \quad E' = \frac{E}{1 + \frac{E}{M}(1-\cos\vartheta)}$$

$$\Leftrightarrow \quad \frac{E'}{E} = \frac{1}{1 + \frac{E}{M}(1-\cos\vartheta)}$$



Questo era caso di elettrone su nucleo trascurando m_e

ELETTRONE + NUCLEO $\xrightarrow{e^-}$ M

FOTONE + ELETTRONE $\gamma \rightsquigarrow e^-$

$m_\gamma = 0$
NON è approx
è esatto

SCATTERING COMPTON

se $E_e \gg m_e$

$$\frac{E'}{E} = \frac{1}{1 + \frac{E}{M}(1-\cos\vartheta)}$$

$M = M_{nucleo}$ in $e+N$
$= m_e$ in $\gamma + e$

SCATTERING COMPTON

e^- elastico