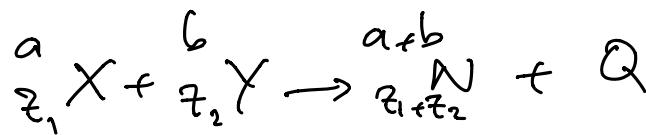


Fusione Nucleare

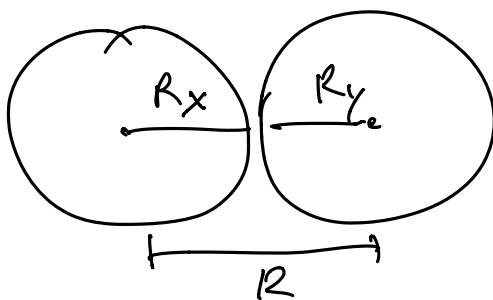
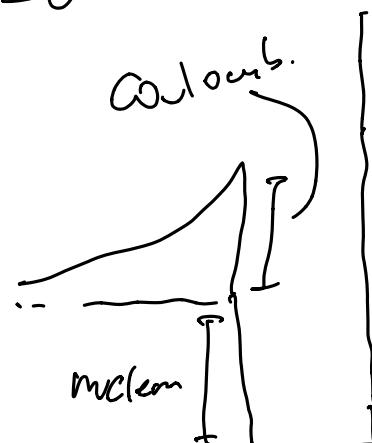
nuclei più leggeri



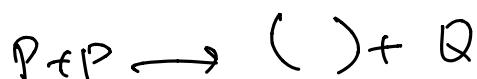
$$\frac{\partial B}{\partial A} > 0 \quad Q > 0 \quad \text{per } A < 60$$

ciascun nucleo ha Z_1, Z_2

BARRIERE DI CATTURA



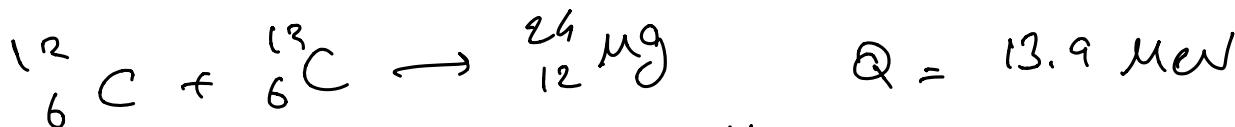
$$U(R) = \frac{Z_x Z_y e^2}{4\pi} \frac{1}{R} = \alpha Z_1 Z_2 \frac{1}{(R_x + R_y)}$$



$$U(R) = \frac{e^2}{4\pi} \frac{1}{2R_0} = \frac{1}{2} \alpha R_0^{-1} = 550 \text{ keV}$$

energia cinetica minima per p : $K_p = 550 \text{ keV}$

BARRIERA CINETICA PER INNESSARE LA FUSIONE



$$Q = 2M_C - M_{Mg}$$



$$U(R) = \alpha Z^2 \frac{1}{2R_0 A^{1/3}}$$

$$R = 2R_C = 2R_0 A^{1/3}$$

$$U(R) = 0.115 \frac{1}{Z R_0} \quad r=6, A=12$$

$$= \underline{\underline{9 \text{ MeV}}} \quad ^1$$

Invezzare 9 MeV per produrre 13.9 MeV

$$I = \frac{Q}{eMc} \approx \frac{13 \text{ MeV}}{8 \times 1.1 \cdot 10^9 \text{ GeV}} \approx 6 \times 10^{-4}$$

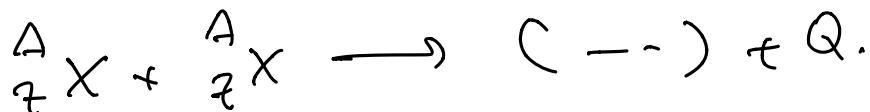
$$v_p = v_n \approx 938 \text{ MeV}$$

$$q' = \frac{13.9 - 6}{2Mc} \sim 0(10^{-4})$$

diammetre r_X, r_Y (nuclei in protoni r_c)

si aumenta diametro del Q non dim.
troppo

Fusione soprattutto per nuclei leggeri $Z \approx \frac{A}{2}$



$$U(R) = \frac{e^2}{c \alpha} Z^2 \frac{1}{2 R_0 A^{1/3}}$$

$$= \frac{\alpha}{8} \frac{1}{R_0} A^{5/3} \quad U \propto A^{5/3}$$

$$= (0.145 \text{ MeV}) A^{5/3} = (145 \text{ keV}) A^{5/3}$$

NB: non vale per $\boxed{|A| \leq 1}$

$$\text{Helio} \quad A=4 \quad Z=2 \quad A^{5/3} \approx 10 \quad U(R) = 1.45 \text{ MeV}$$

Se nuclei sono confinati \Rightarrow temperatura
energia cinetica media

For Z_a continent: granite

un gas di nuclei $M(A, Z)$

$$kT = (0.145 \text{ MeV})$$

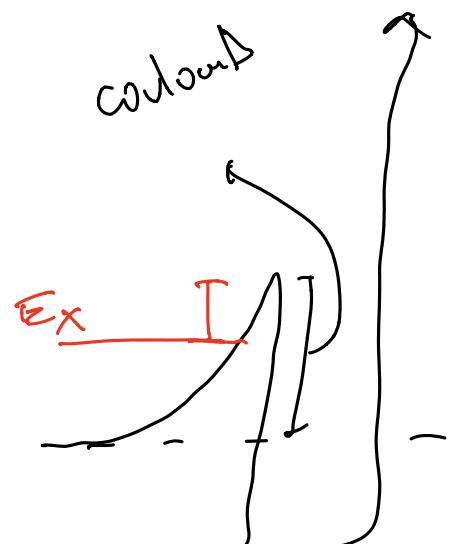
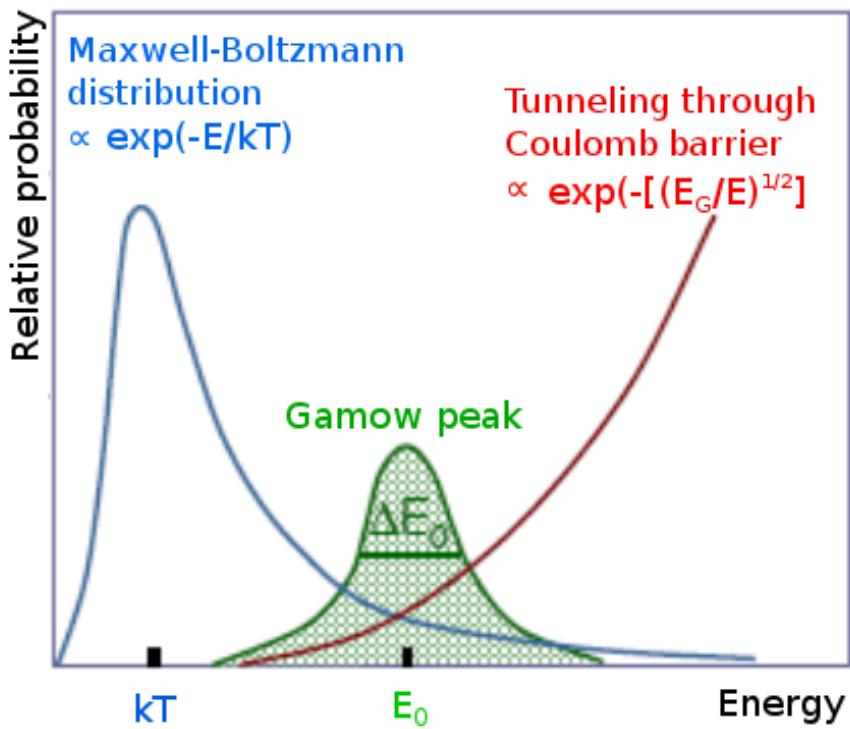
$$K = 8.6 \times 10^{-5} \text{ eV K}^{-1}$$

$$\Rightarrow 0.145 \text{ MeV} \Rightarrow T = 1.6 \times 10^9 \text{ K}$$

distribuzione di Maxwell-Boltzmann

$$\frac{dn}{dv} \propto \frac{v^2}{(8kT/m)^{3/2}} e^{-\frac{1}{2} \frac{mv^2}{kT}}$$

Velocità
particelle



Fusione Stellare

produzione di energia nel Sole

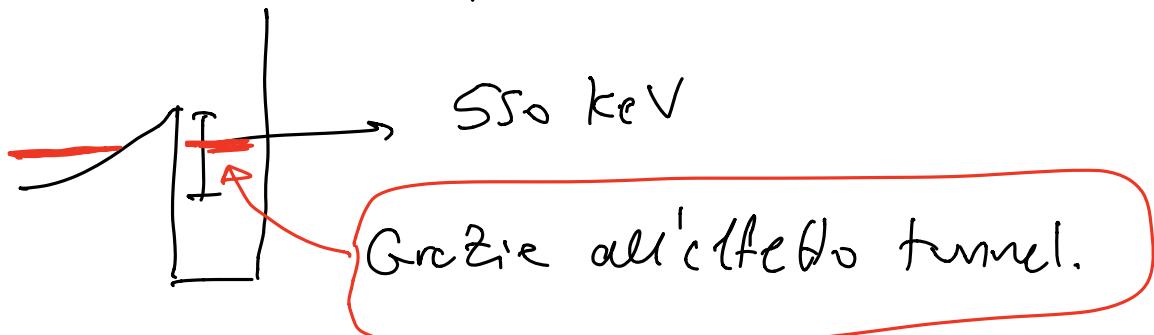


$$\gamma = \frac{26 \text{ MeV}}{4 \times \text{mc}^2} \approx 7 \times 10^{-3}$$

Temperature interne del Sole: $T = 1.5 \times 10^7 \text{ K}$

$$k_F = \frac{3}{2} kT \approx 190 \text{ keV}$$

$\leftarrow 550 \text{ keV}$ che servono per fission
 $p+p \rightarrow (\sim) + Q$



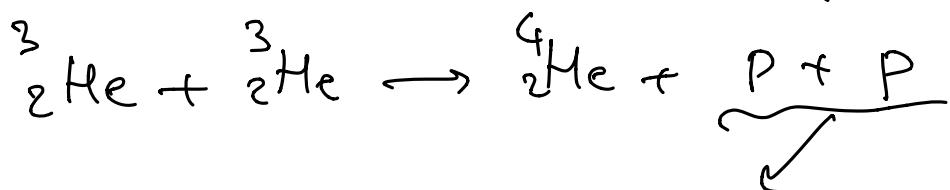
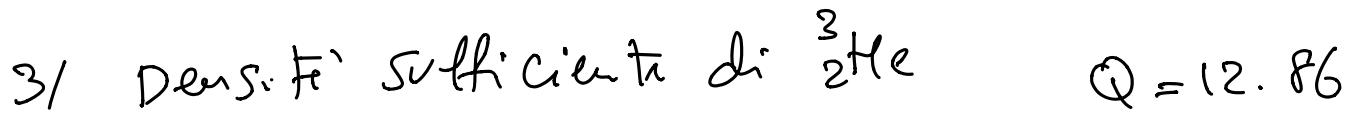
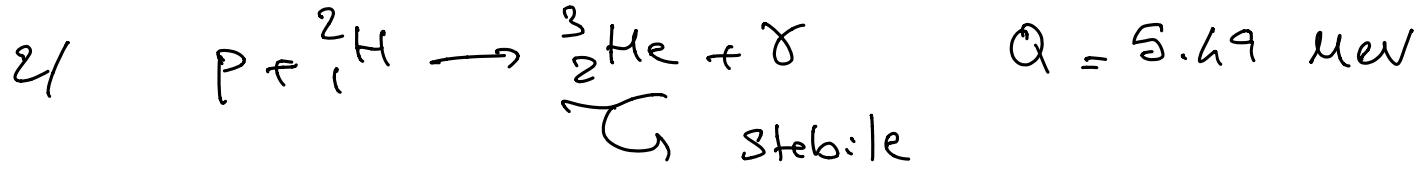
Interazione debole non nucleare!

$$\sigma \approx 10^{-SS} \text{ cm}^2 \quad 1b = 10^{-26} \text{ cm}^2$$

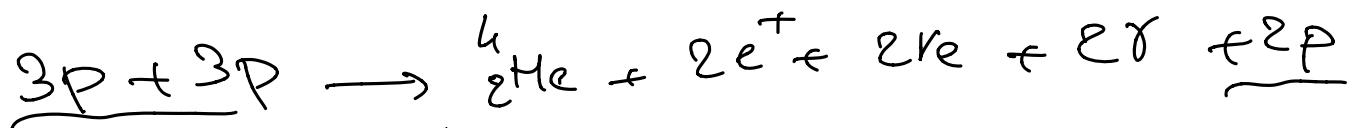
processo raro po' cui dopo $5 \times 10^9 \text{ yrs.}$

Sole a metà vita

processo lento Sole ancora bruciante



Processo totale



$$Q = 4m_p - m_\alpha - 2m_e = 26.7 \text{ MeV}$$

$$\langle E_\nu \rangle \approx 0.3 \text{ MeV}$$

Interazioni poco/debole

\Rightarrow sfruttate venendo osservate sulle tem.

$$Q' = 26.7 - 2 \times 0.3$$

$$\approx 24 \text{ MeV}$$

e^+ anti-particelle di e^-

Sole ricco di atomi e quindi di e^-

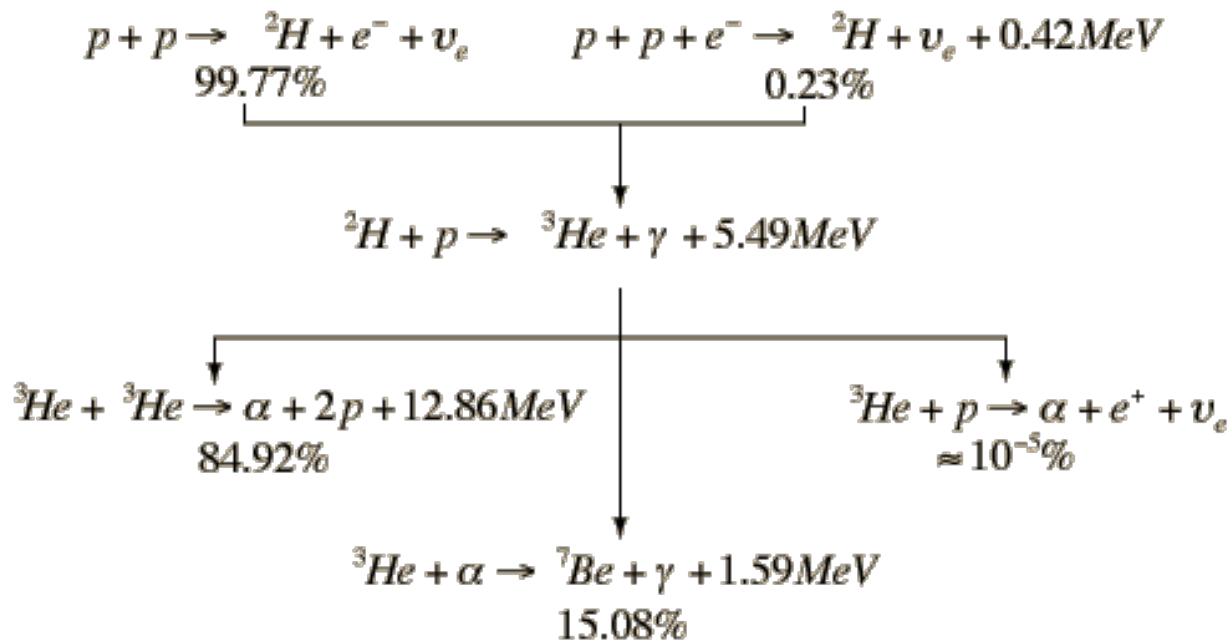


$$Q_{\text{tot}} = 24 \text{ MeV} + 2 \times 1 \text{ MeV} \approx 26 \text{ MeV}$$

Nel sole produzione di 26 MeV per $4p \rightarrow C^{--} + Q$

$$\eta = \frac{26 \text{ MeV}}{4 \text{ MeV}} = 0.007$$

Ciclo P-P principio nel Sole



Nucleosintesi: Stellare

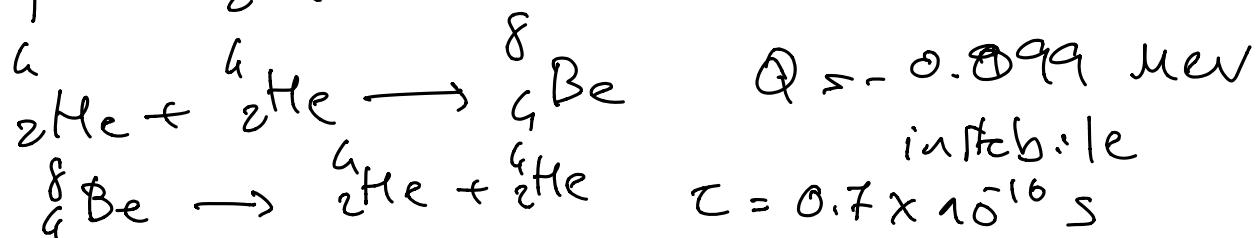
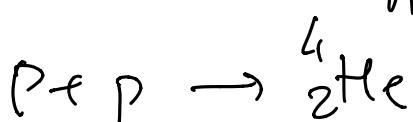
si produce ^4He finché si esauriscono Prof. esaurito H: si brucia tutto l'idrogeno.

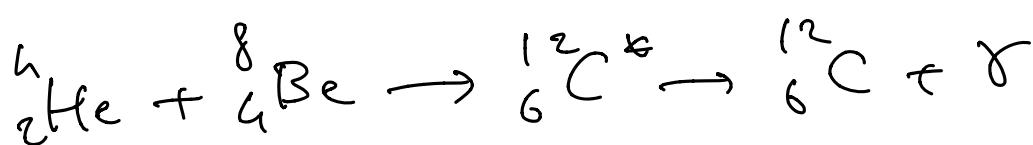
=> Contrazione gravitazionale

aumento nuovo utile.

=> aumenta $\bar{K} \Rightarrow$ aumento T

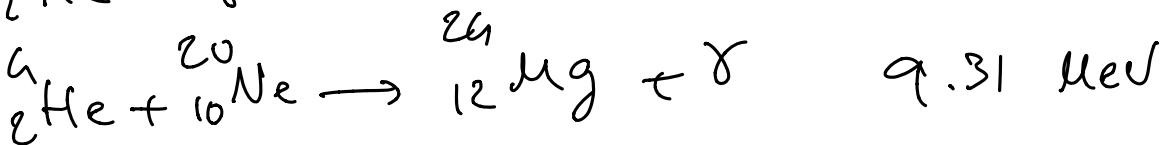
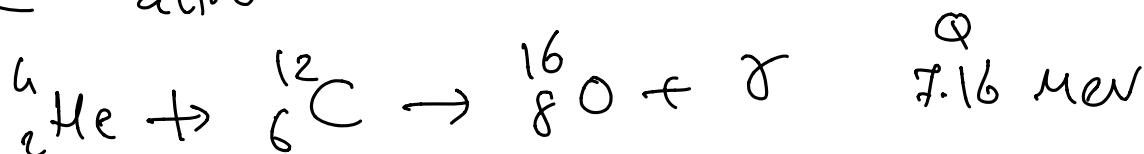
=> nuove reazioni nucleari con nuclei più pesanti.



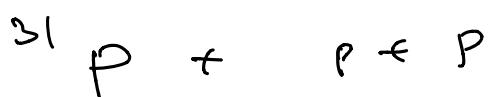
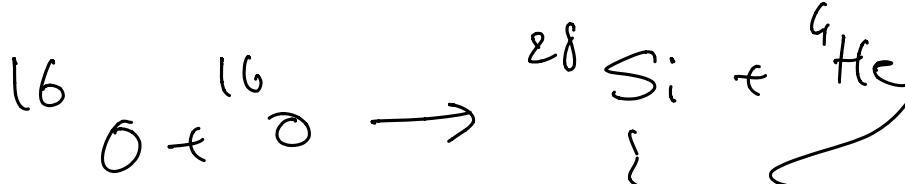
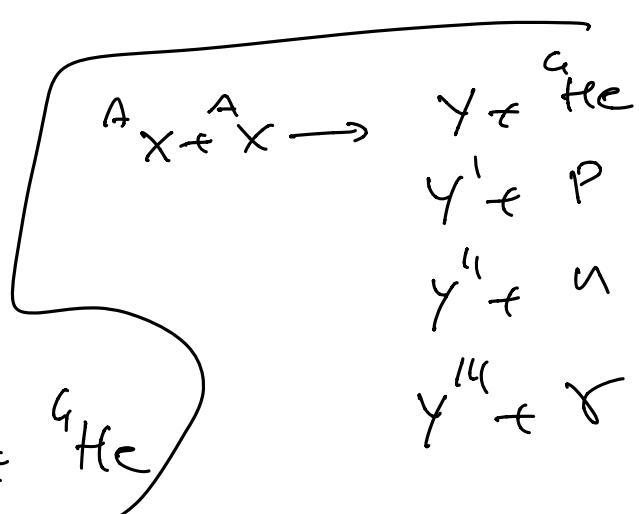
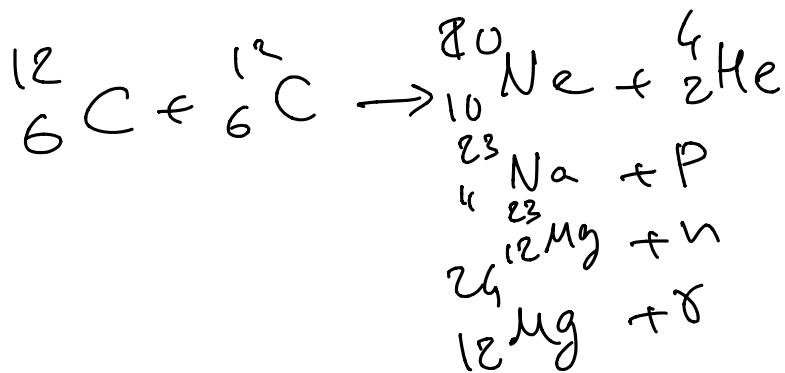


multiplic. ($A \approx 6$, $Z \approx 2$) $\propto \alpha = {}^4_2 \text{He}$

${}^{12}_6 \text{C}$ altro nucleide molto (esato).



Escrivendo ${}^4_2 \text{He} \Rightarrow$ Contrazione $\Rightarrow T \nearrow$
 \Rightarrow aumenta $\overline{\text{IC}}$ ${}^{12}_6 \text{C}$, ${}^{16}_8 \text{O}$, ${}^{20}_{10} \text{Ne}$, ${}^{24}_{12} \text{Mg}$



S

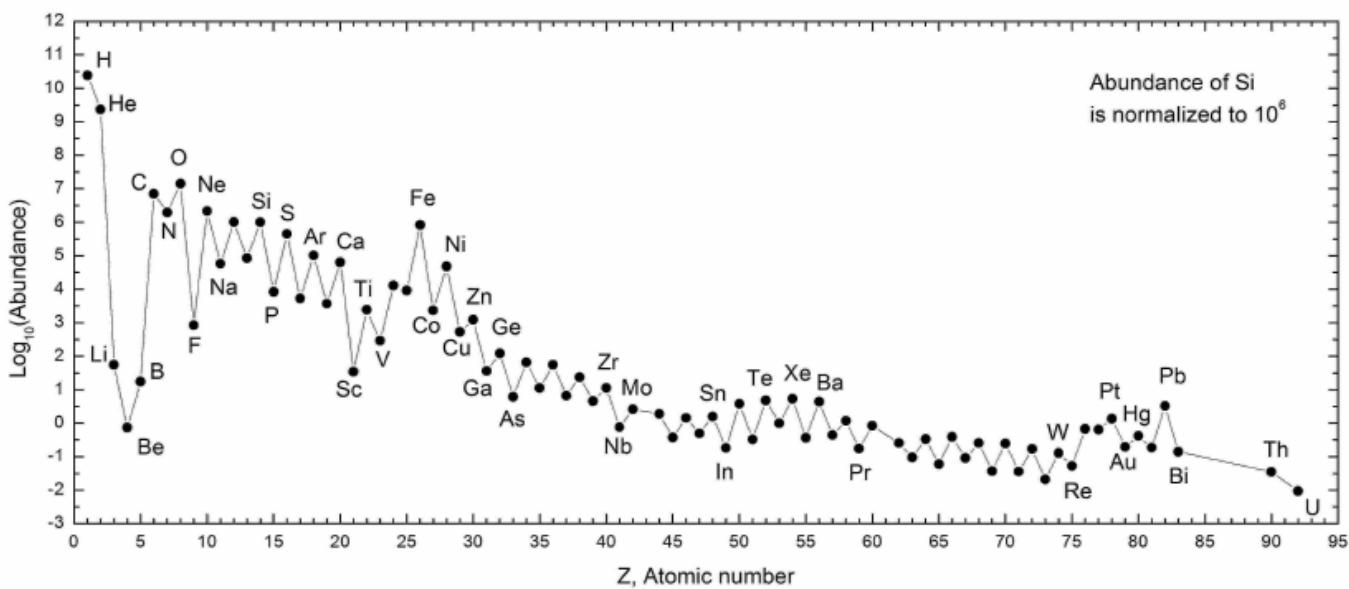
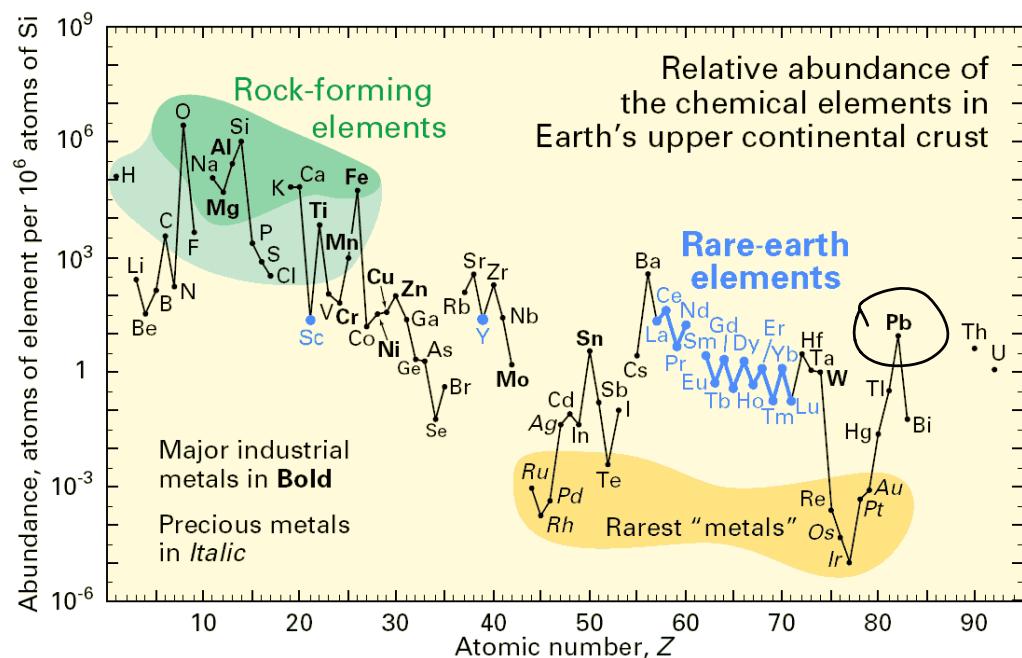
Si: bruciando ${}^{12}_6 \text{C}$, ${}^{16}_8 \text{O} \Rightarrow$ produce ${}^{28}_{14} \text{Si}$, ${}^{31}_1 \text{P}$, S

Si: continue faccio $\frac{\partial B}{\partial A} \approx 0$ al Feudo
 $A \approx 60$

Non si producono elementi più pesanti di $A=60$

Elementi + pesanti:

- catene di neutroni
 - collesso gravitazionale delle stelle
 $M > 1.5 M_{\odot}$
- ad esempio nelle supernovae

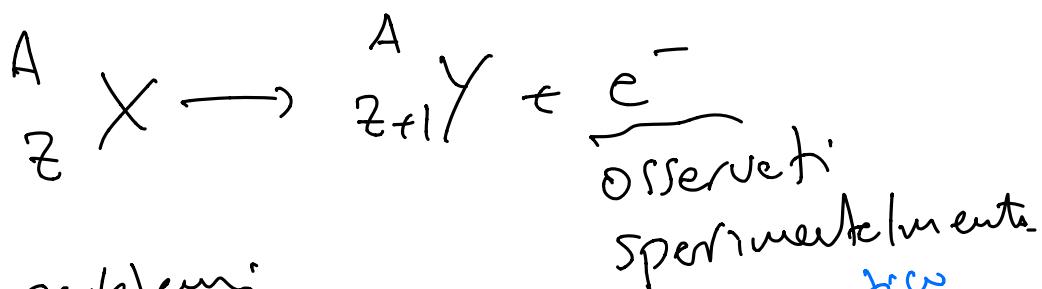


Decadenimento β

Raggi: $\beta: e^-, e^+$

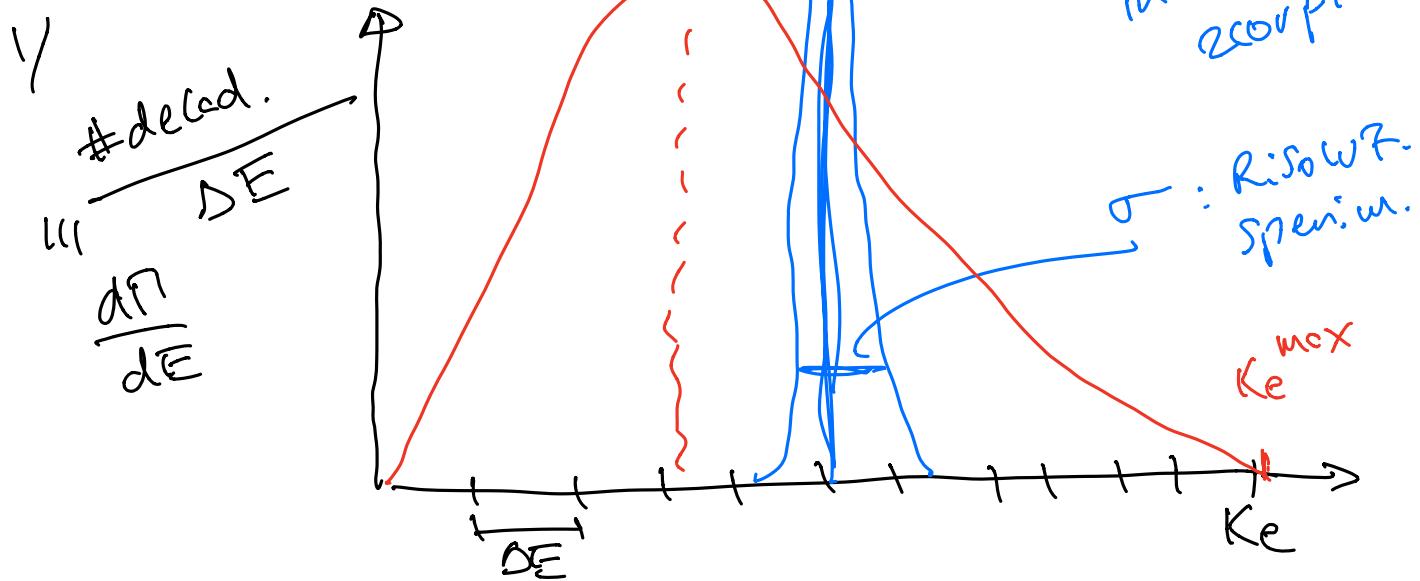
per similitudine con decad. α .

Si perdeva che fosse:



Ci sono diversi problemi

Sperimentali:



Forme osservate non compatibile con

- decadimento due corpi
- Risotto zone sperimentale

$$m_X = m_Y + K_e + E_e = E_Y + E_e \quad \text{nd c.d.m. di } X$$

$$\overrightarrow{P_Y} + \overrightarrow{P_e} = \overrightarrow{P} \quad P_Y = P_e = P$$

$$m_X = \sqrt{m_Y^2 + P^2} + \sqrt{m_e^2 + P^2}$$

$$P^2 = \frac{(m_x^2 + m_y^2 - m_e^2)^2}{4m_x^2} - m_y^2$$

$m_x \approx m_y \approx A m_p \gg m_e$

$$P^2 \approx \frac{4m_x^4}{4m_x^2} - m_y^2 \approx 0$$

$$P \text{ piccol.} \Rightarrow E_y = m_y + K_y = m_y + \frac{P^2}{2m_y}$$

$$K_y \ll m_y$$

$$m_x = E_y + E_e = m_y + \underbrace{K_y}_{\ll m_y} + E_e$$

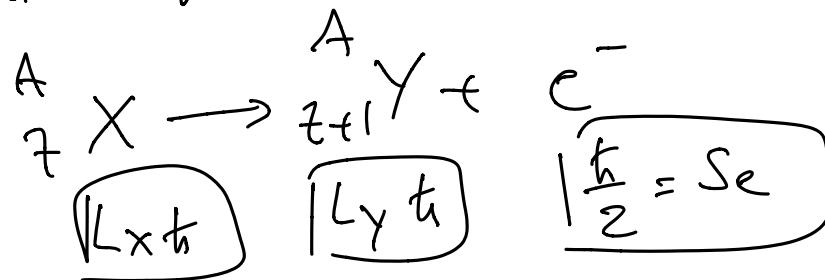
$$\Rightarrow \boxed{E_e \approx m_x - m_y}$$

Mi aspetto E_e monografico anche in LAB
calcolate boost di Lorentz?

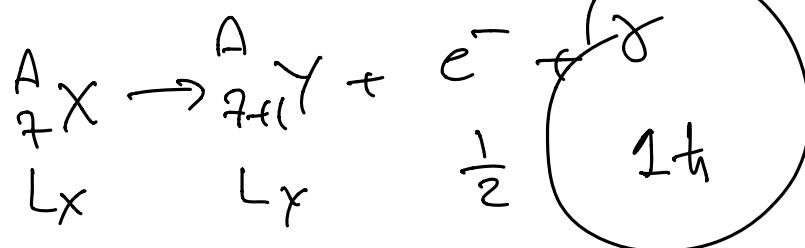
del c.d.m \rightarrow LAB

Non si conserva perfino con $\beta \ll 1$

e/ momenti angolari



A: bosoni A pari



non va bene.

Pauli nel 1930:

Ipotesi: esiste nuove particelle

- fermione $S = \frac{1}{2}$

- massa piccola.

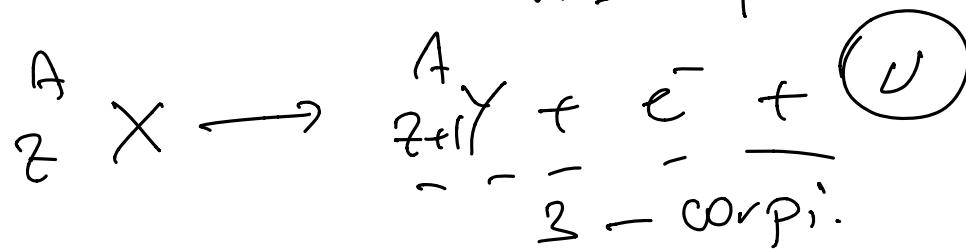
misura di K_e confronto con $K_e^{\text{mex.}}$

K_e ha poche energie
poche masse.

- neutrino: conservazione ener.

Fermi: neutrino $m_\nu \ll m_p$

$$m_\nu \approx m_p$$



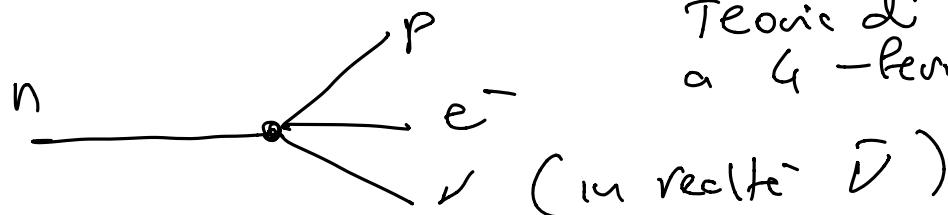
e^- non-mono-cromatico.

ipotesi: misce $m_\nu \Rightarrow$ predire lo spettro.

Interazione
debole

stimare massa \Leftarrow delle misure

Teorie di Fermi
a 4-fermioni.



Spiega anche le collisioni elettroniche.

