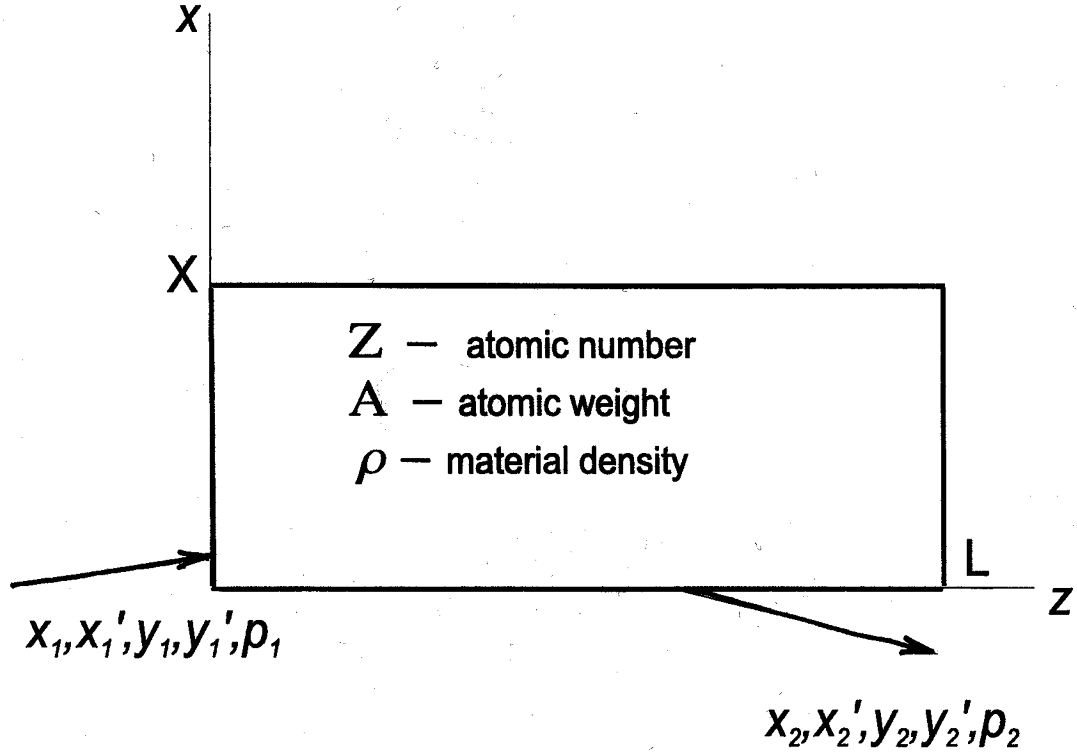
Proton Scattering in LHC Collimators



Proton interaction with atoms:

electromagnetic - ionization and Coulomb scattering,

mean free path **~μm**

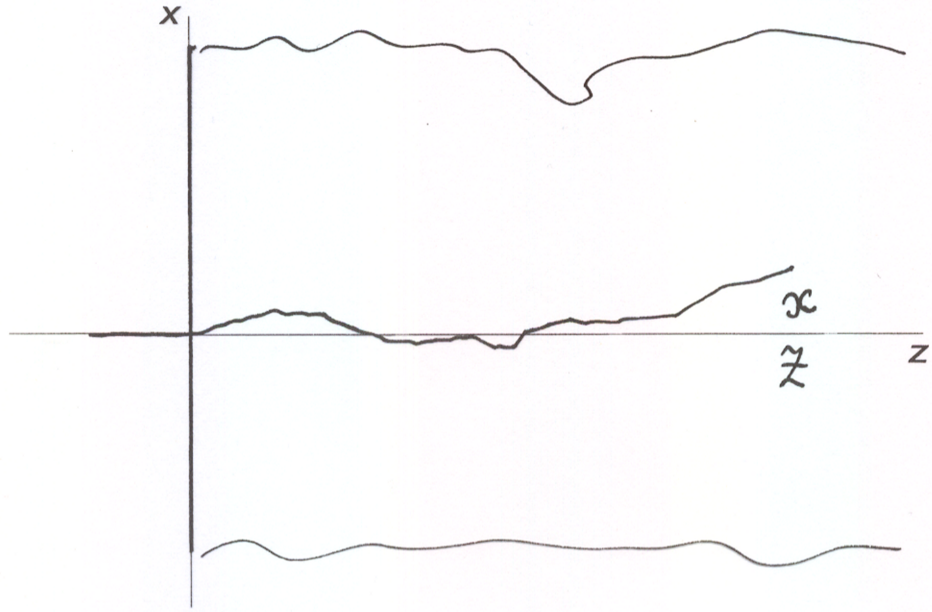
bremsstrahlung and lepton pair production

mean free path **~cm**

nuclear - elastic and inelastic

mean free path **~cm**

Multiple Coulomb Scattering



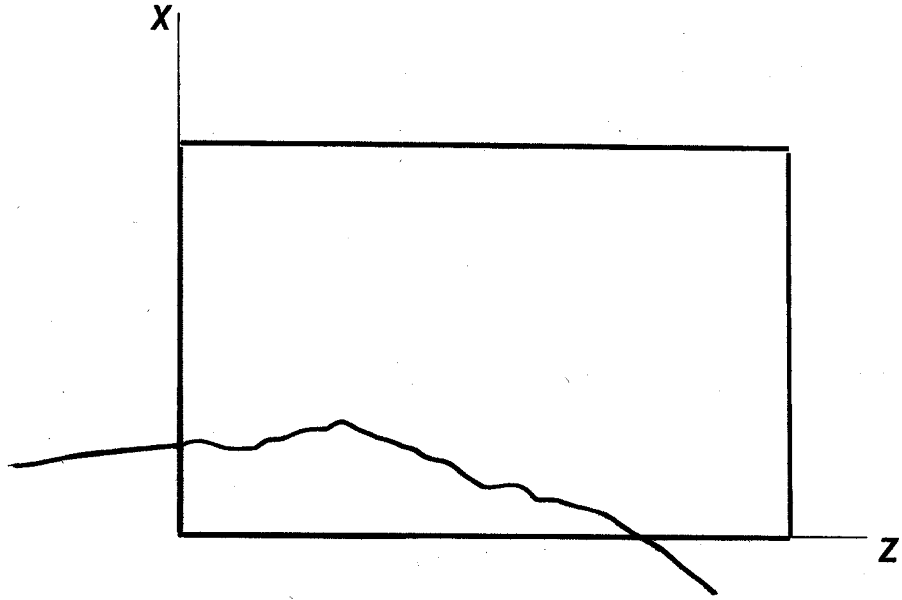
Fermi distribution : $\Phi(x, x' | z) =$

$$\frac{2\sqrt{3}}{\pi \theta_s^2} \exp\left[-\frac{4}{\theta_s^2 z}\left(x'^2 - \frac{3}{z} x x' + \frac{3}{z^2} x^2\right)\right]$$

$$\theta_s^2 = \left(\frac{21\,\mathrm{MeV}}{p}\right)^2 \frac{1}{X_R}, \quad X_R \text{ - rad. length}$$

$$\langle x^2 \rangle \sim \theta_s^2 z^3$$

Edge Scattering Problem



Fermi (Moliere etc.) distributions are valid for an <u>infinite media</u>.

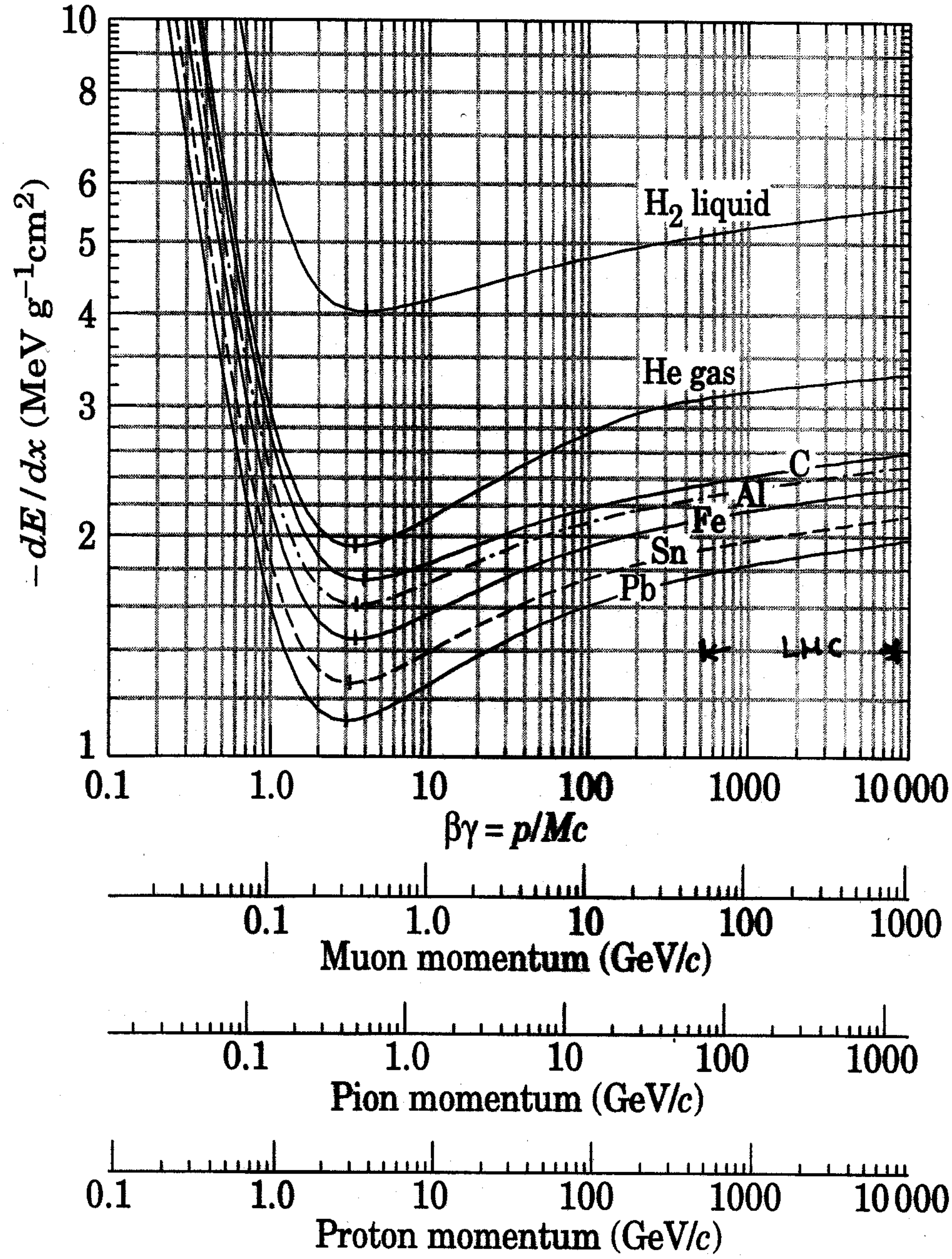
To simulate a correct trajectory near the edge as a series of steps Δz_i one must keep

~~[illegible]~~ $\Delta x_i << x_i$

and calculate

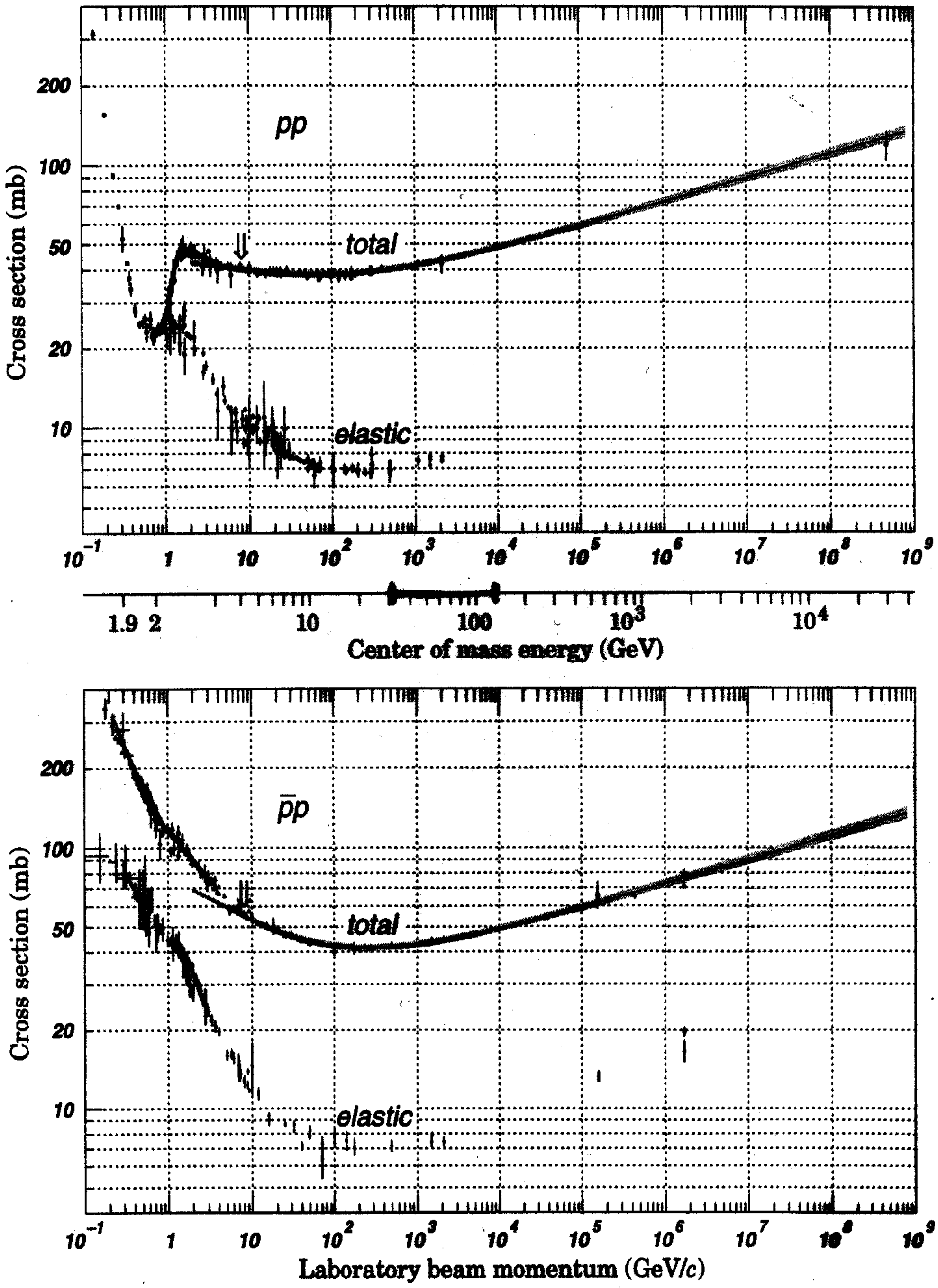
$$\Delta z_{i+1} = f(x_i, x_i')$$

Ionization Energy Losses



D.E.Groom et al., The European Physical Journal C15(2000)1 ;
http://pdg.lbl.gov

Proton-Proton Cross Sections



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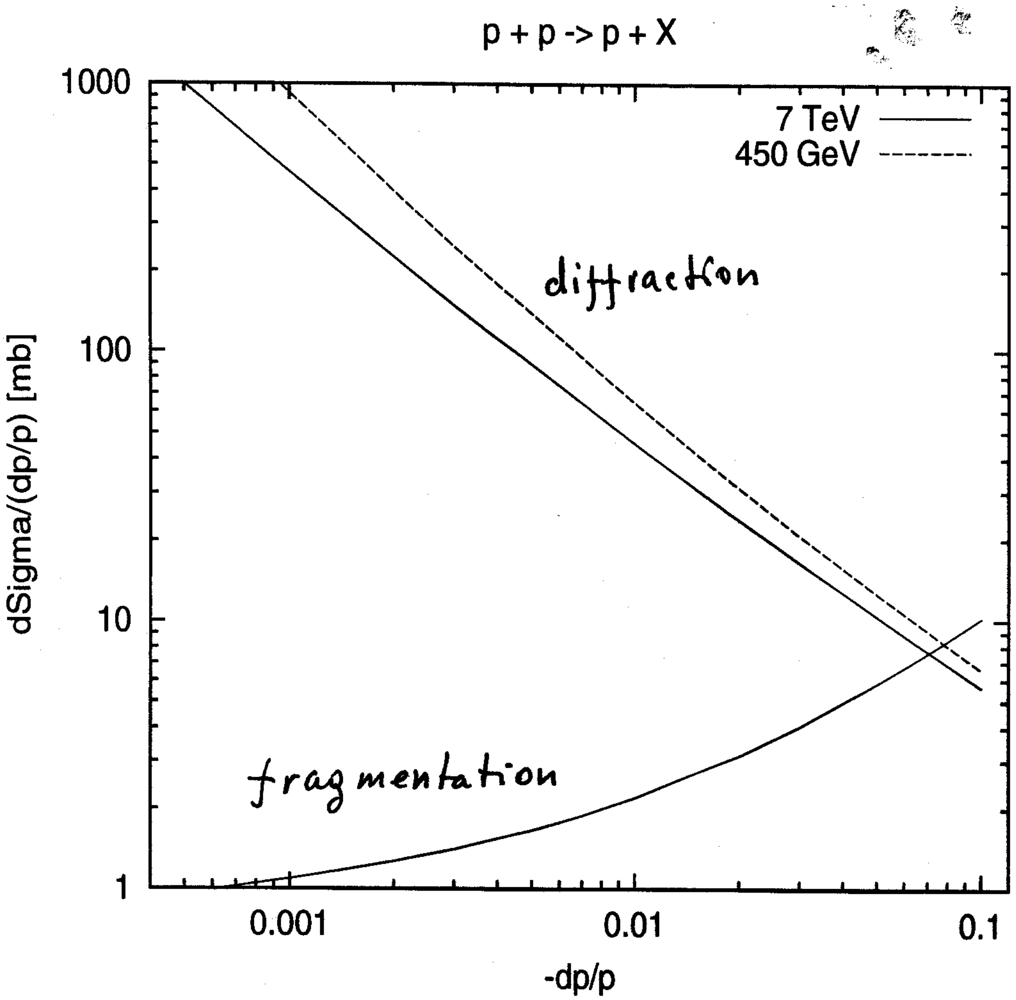
Proton-Proton Elastic Scattering

$$\frac{d\sigma_{pp}^{el}}{dt} \approx \sigma_{pp}^{el} B_p e^{B_p t} \quad , \quad t = -p^2\theta^2$$

$$B_p \approx \begin{cases} 10.7 \ (\mathrm{GeV}/c)^{-2} & @ \ 450 \ \mathrm{GeV} \\ 11.7 \ (\mathrm{GeV}/c)^{-2} & @ \ 7000 \ \mathrm{GeV} \end{cases}$$

$$\sqrt{\langle\theta^2\rangle} \approx \begin{cases} 7.3 \ \mathrm{mrad} & @ \ 450 \ \mathrm{GeV} \\ 0.5 \ \mathrm{mrad} & @ \ 7000 \ \mathrm{GeV} \end{cases}$$

Inelastic Diffraction and Projectile Fragmentation



Phenomenological differential cross-sections in the form of Regge-expansion :

diffraction - Field&Fox 1974

fragmentation - Barashenkov&Slavin 1981

(integrated over the entire range of scattering angles)

From proton-proton to proton-nucleus interaction

Theory of multiple scattering of particles inside nuclei - Glauber/Sitenko

incoherent elastic scattering -

$$\left(\frac{d\sigma}{dt}\right)_{pA} = \left(\frac{d\sigma}{dt}\right)_{pp} \cdot \frac{\sigma_{pA}^{incoh}}{\sigma_{pp}^{el}}$$

single diffraction -

$$\left(E\frac{d^3\sigma}{dp^3}\right)_{pA} = \left(E\frac{d^3\sigma}{dp^3}\right)_{pp} \frac{\sigma_{pA}^{dif}}{\sigma_{pp}^{dif}}$$

fragmentation -

$$\left(E\frac{d^3\sigma}{dp^3}\right)_{pA} = \left(E\frac{d^3\sigma}{dp^3}\right)_{pp} \cdot \frac{\sigma_{pA}^{in}}{\sigma_{pp}^{in}} \cdot V_1(A)$$

V_1 - probability to interact for 1 of 3 constituent quarks

Coherent Elastic Scattering

Elastic scattering on the entire nucleus = coherent scattering

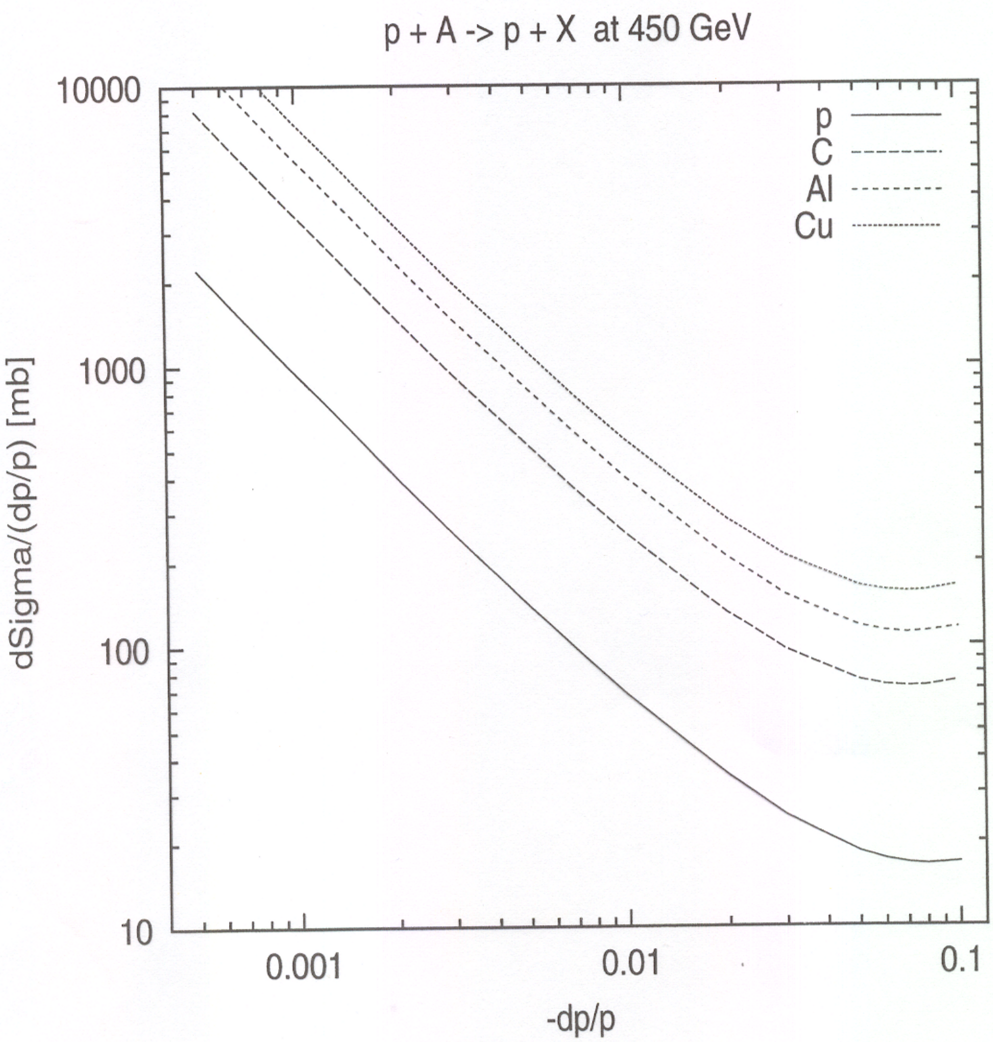
$$\frac{d\sigma_{pA}^{coh}}{dt} \approx \sigma_{pA}^{coh} \cdot B_c e^{B_c t}$$

$$\sigma_{coh}^{pA} \sim Z$$

$$B_c \sim A^{1/3}$$

$$B_c >> B_p$$

Single Diffraction and Fragmentation on Nuclei

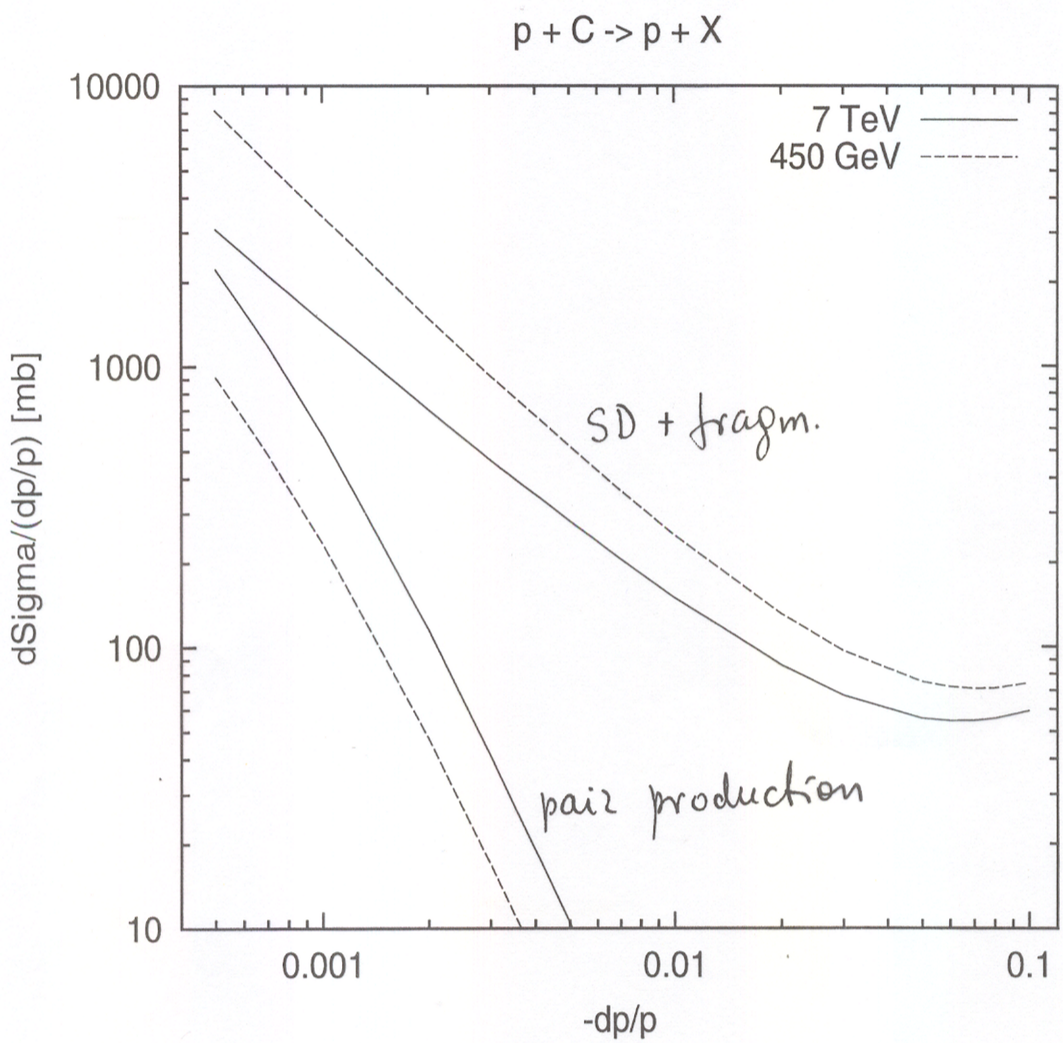


Roughly :

Single Diffraction ~ $A^{1/3}$

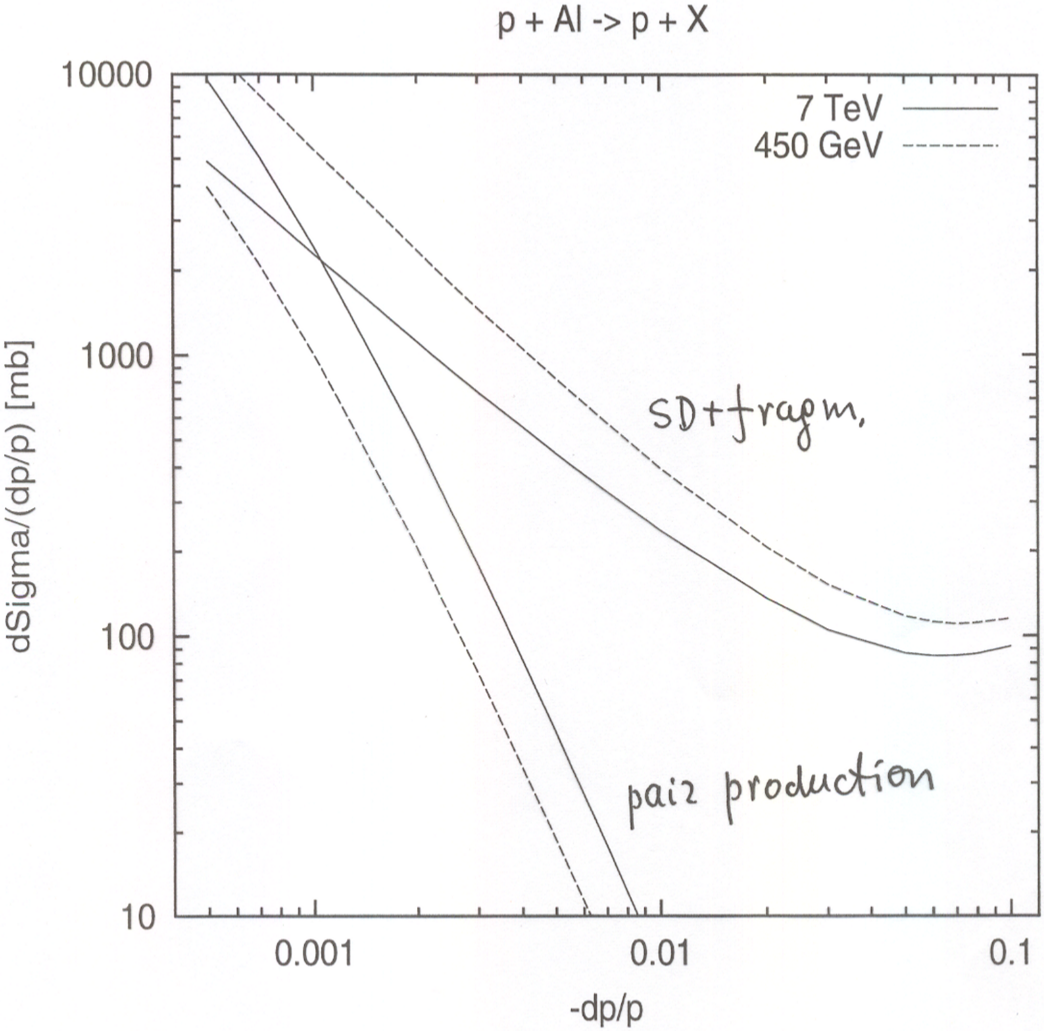
Fragmentation ~ $A^{2/3}$

Inelastic Interactions with Nuclei (Carbon)



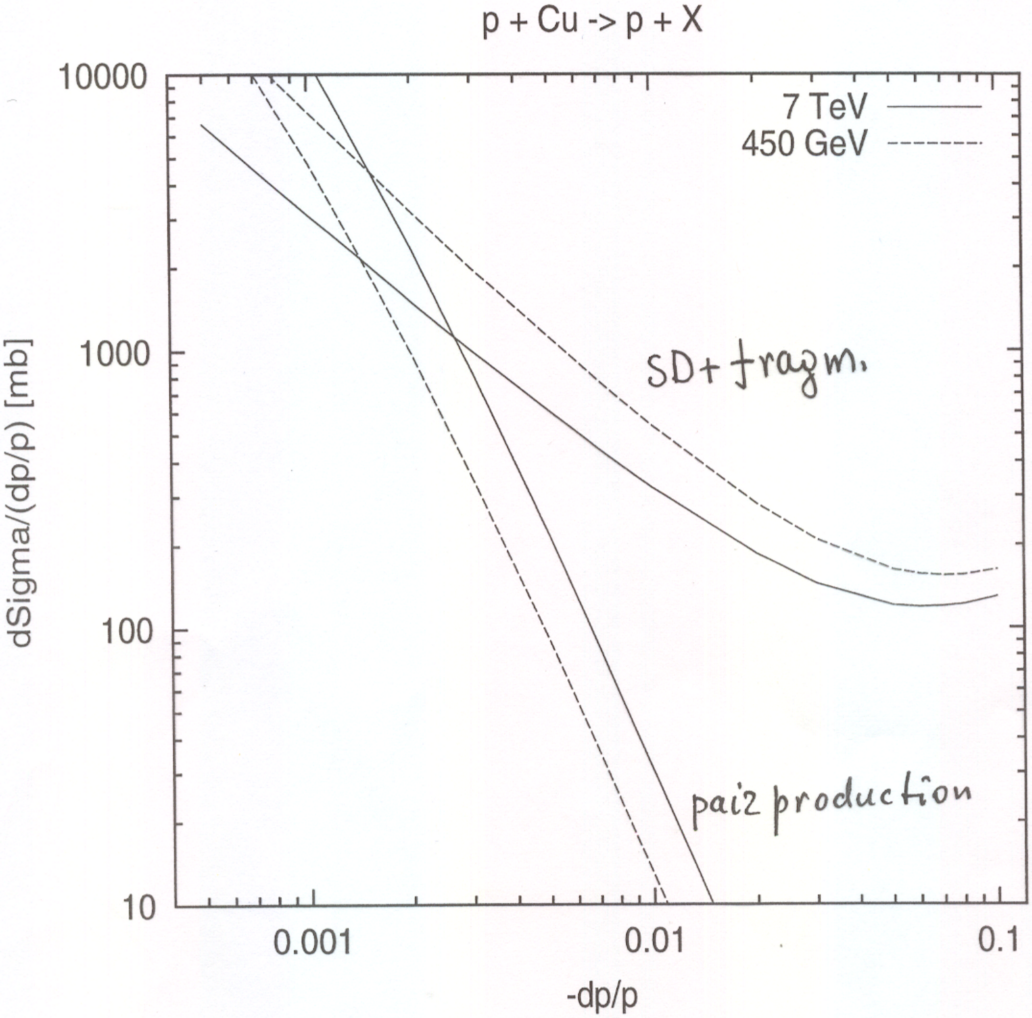
(integrated over the entire range of scattering angles)

Inelastic Interactions with Nuclei (Aluminum)



(integrated over the entire range of scattering angles)

Inelastic Interactions with Nuclei (Copper)



(integrated over the entire range of scattering angles)

STRUCT Code

SSCL-MAN-0034, Dallas, 1994
(a reference manual)

the code was developed in late 80's

routines for particle tracking in synchrotrons - A. Drozhdin

routines for proton scattering in targets, collimators and septa - I. Baishev

The code is used mainly for simulation of proton loss distributions

Proton Losses in IR3 of LHC