

# Estudo do Fluxo de Múons em Física de UHECRs

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## Resumo

Neste trabalho propomos investigar a física pertinente à determinação do fluxo de múons gerados em eventos de raios cósmicos de altíssima energia (UHECRs). Aqui focamos na interação destes com prótons e também sua geração em processos de reação eletrofracos de neutrinos. Fornecemos curvas teóricas baseadas no modelo desenvolvido por E. Berger *et al.* [1], para a função de estrutura do próton, que respeita teoremas de unitarização das seções de choque hadrônicas. Este modelo foi extrapolado para altíssimas energias e pode ser generalizado para colisões lépton-núcleo.

## Introdução

### Espalhamento Inelástico Profundo (DIS)

É o espalhamento inelástico em altas-energias entre um lépton-nucleon, caracterizado pelos quadrimomento do lépton incidente, do lépton espalhado e do nucleon. A mediação é feita pela troca de um bóson, o qual transfere para o nucleon um quadrimomento igual à diferença entre os quadrimomento dos léptons. Esta é a técnica usada para sondar a estrutura interna de uma partícula.

### Funções de Estrutura

Uma função de estrutura busca parametrizar nosso desconhecimento sobre a estrutura interna do nucleon (próton ou nêutron), dada a virtualidade  $Q^2$  do bóson virtual que funcionará como sonda. A função de estrutura considerada aqui, proposta por E. L. Berger et al. é expressa como:

$$F_2^p(x, Q^2) = \frac{F_p}{x_p^p(Q^2)(1-x_p)^3} x^p(Q^2)(1-x)^3, \quad x \geq x_p$$

$$F_2^p(x, Q^2) = (1-x) \left( \frac{F_p}{1-x_p} + A(Q^2) \ln \left( \frac{x_p}{x} \frac{(1-x)}{(1-x_p)} \right) + B(Q^2) \ln^2 \left( \frac{x_p}{x} \frac{(1-x)}{(1-x_p)} \right) \right), \quad x \leq x_p$$

## Método

- 1) Realizou-se uma revisão bibliográfica na física de raios cósmicos, com ênfase nos processos de interação lépton-próton.
- 2) Foi construído um programa num CAS (sistema algébrico computacional), e reproduzidas as seções de choque presentes na literatura (Refs. [1] e [2]).
- 3) O programa foi adaptado para calcular a seção de choque para interações lépton-próton.
- 4) O modelo para função de estrutura, apresentado em [2], foi utilizado para obter a seção de choque total para interação múon-próton em altíssimas energias.

## Resultados

### Seção de choque diferencial

Para a seção de choque diferencial lépton-nucleon (interação de lépton com a matéria), consideramos a expressão geral para a troca de fóton virtual em termos das funções de estrutura:

$$\frac{d^2 \sigma^{lA}}{dx dy} = \frac{4 \pi}{m_{pr} E y} \left( \frac{\alpha}{x} \right)^2 \frac{F_2^A}{y} \left[ 1 - y - \frac{m_{pr} xy}{2 E} + \left( 1 - \frac{m_l^2}{m_{pr} E xy} \right) \left( \frac{y^2 + 2 m_{pr} xy / E}{2(1+R^A)} \right) \right]$$

No nosso modelo, nos restringimos ao caso  $A=1$ , então esta equação pode ser escrita como

$$\frac{d^2 \sigma^{lp}}{dx dy} = \frac{4 \pi}{m_{pr} E y} \left( \frac{\alpha}{x} \right)^2 \frac{F_2^p}{y} \left[ 1 - y - \frac{m_{pr} xy}{2 E} + \left( 1 - \frac{m_l^2}{m_{pr} E xy} \right) \left( \frac{y^2 + 2 m_{pr} xy / E}{2} \right) \right]$$

Para calcular a seção de choque total e fazermos a extrapolação proposta, foi criado um programa no software Mathematica (Fig.1), de forma a permitir uma fácil generalização para outros casos de interesse, como no cálculo da seção de choque de neutrinos, reproduzindo com sucesso resultados presentes nos artigos referenciados ao final do trabalho (Figs. 2 e 4), e apresentando novas curvas teóricas (Fig.3).

### Ultrahigh Energy Muon Scattering

Clear[{"a", "b", "c", "d", "e", "f", "g", "h", "i", "j", "k", "l", "m", "n", "o", "p", "q", "r", "s", "t", "u", "v", "w", "x", "y", "z"}];

Parâmetros (onde usamos Q=Q^2, C=1 e h=1)

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