Produção Difrativa de Mésons Vetoriais

Rodrigo Ribamar Silva do Nascimento
Universidade do Estado de Santa Catarina

UDESC UNIVERSIDADE DO ESTADO DE SANTA CATARINA

Seções

Introdução

A Estrutura dos Hádrons
- DIS
- DIS no modelo de Pártons
- As Equações de Evolução – DGLAP
- Parametrizações

Produção Difrativa de Mésons Vetoriais
- Mésons
- *Hadronic Diffraction*
- Seção de Choque p/ o Processo $\gamma^* p \to pV$

Resultados

Seções

Introdução

A Estrutura dos Hádrons
- DIS
- DIS no modelo de Pártons
- As Equações de Evolução – DGLAP
- Parametrizações

Produção Difrativa de Mésons Vetoriais
- Mésons
- *Hadronic Diffraction*
- Seção de Choque p/ o Processo $\gamma^* p \to pV$

Resultados

Seções

Introdução

A Estrutura dos Hádrons

- DIS
- DIS no modelo de Pártons
- As Equações de Evolução – DGLAP
- Parametrizações

Produção Difrativa de Mésons Vetoriais

- Mésons
- *Hadronic Diffraction*
- Seção de Choque p/ o Processo $\gamma^* p \to pV$

Resultados

Seções

Introdução

A Estrutura dos Hádrons
- DIS
- DIS no modelo de Pártons
- As Equações de Evolução – DGLAP
- Parametrizações

Produção Difrativa de Mésons Vetoriais
- Mésons
- *Hadronic Diffraction*
- Seção de Choque p/ o Processo $\gamma^* p \to pV$

Resultados

Introdução

O Modelo Padrão

Introdução

O Modelo Padrão para a Física de Partículas

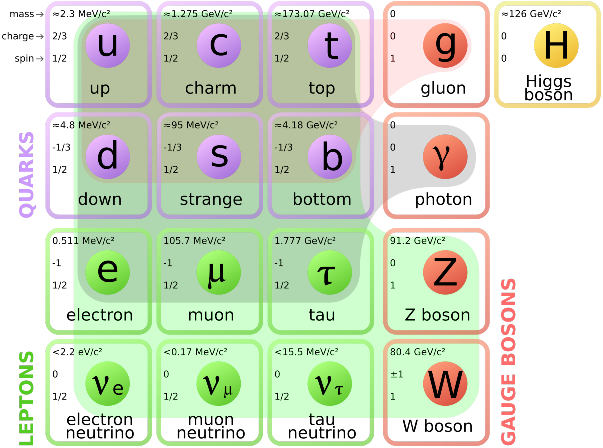


Figura 1: Fonte: (WORKMAN et al., 2022)

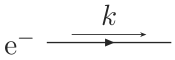
UDESC

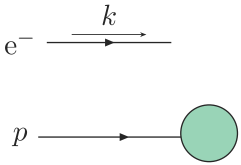
DIS

Deep Inelastic Scattering

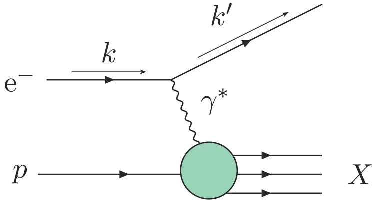
A Estrutura dos Hádrons

Deep Inelastic Scattering



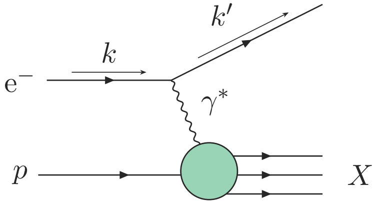


k
e^-
p


k'
k
e^-
γ^*
p
X

A Estrutura dos Hádrons

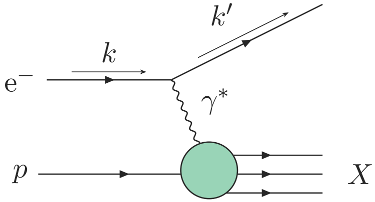
Deep Inelastic Scattering



$$\left.\frac{d\sigma}{d\Omega dE'}\right|_{ep\to eX} = \left(\frac{\alpha^2}{4E^2\sin^4\theta/2}\right)\frac{1}{4EE'}L^{\mu\nu}_{(L)}W^{(H)}_{\mu\nu}$$

A Estrutura dos Hádrons

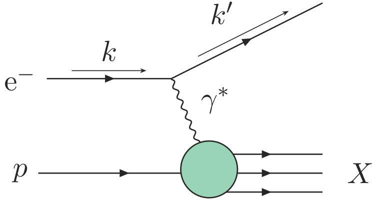
Deep Inelastic Scattering



$$\left.\frac{d\sigma}{d\Omega dE'}\right|_{ep\to eX} = \left(\frac{4\alpha^4 E'^2}{q^4}\right)\left[2\sin^2\frac{\theta}{2}W_1(\nu, Q^2) + \right.$$
$$\left. + \cos^2\frac{\theta}{2}W_2(\nu, Q^2)\right]$$

A Estrutura dos Hádrons

Deep Inelastic Scattering

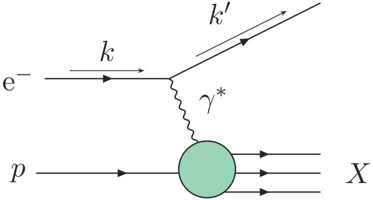


$$\left.\frac{d\sigma}{d\Omega dE'}\right|_{ep\to eX} = \left(\frac{4\alpha^4 E'^2}{q^4}\right)\left[2\sin^2\frac{\theta}{2}W_1(\nu,Q^2) + \right.$$
$$\left. + \cos^2\frac{\theta}{2}W_2(\nu,Q^2)\right]$$

$$\left.\begin{aligned} s &\equiv (p+k)^2 = E_{cm}^2, \\ t &\equiv (k-k') = -Q^2, \\ u &\equiv (k-p_x)^2 \end{aligned}\right\}$$

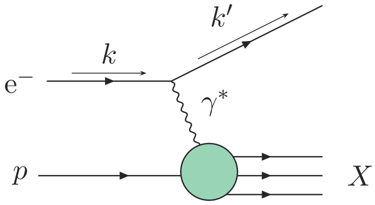
A Estrutura dos Hádrons

Deep Inelastic Scattering



$$\left.\frac{d\sigma}{d\Omega dE'}\right|_{ep\to eX} = \left(\frac{4\alpha^4 E'^2}{q^4}\right)\left[2\sin^2\frac{\theta}{2}W_1(\nu,Q^2) + \right.$$
$$\left. + \cos^2\frac{\theta}{2}W_2(\nu,Q^2)\right]$$

$$\left.\begin{aligned} s &\equiv (p+k)^2 = E_{cm}^2, \\ t &\equiv (k-k') = -Q^2, \\ u &\equiv (k-p_x)^2 \end{aligned}\right\} \qquad s+t+u = M^2 + W^2$$



$$\frac{d\sigma}{d\Omega dE'} = \frac{1}{s+u}\left(\frac{4\pi\alpha^2}{s^2t^2}\right)\times$$
$$\times\left[-(s+u)tMW_1(\nu,Q^2)+\right.$$
$$\left.-us\nu W_2(\nu,Q^2)\right]$$

$$\left.\begin{aligned} s &\equiv (p+k)^2 = E_{cm}^2, \\ t &\equiv (k-k') = -Q^2, \\ u &\equiv (k-p_x)^2 \end{aligned}\right\} \qquad s+t+u = M^2+W^2$$

Stanford Linear Accelerator - SLAC (1960)

$$\lim_{Q^2,\nu\to\infty} MW_1(\nu, Q^2) \approx F_1(x)$$

$$\lim_{Q^2,\nu\to\infty} \nu MW_2(\nu, Q^2) \approx F_2(x)$$

Stanford Linear Accelerator - SLAC (1960)

$$\lim_{Q^2,\nu\to\infty} MW_1(\nu, Q^2) \approx F_1(x)$$

$$\lim_{Q^2,\nu\to\infty} \nu MW_2(\nu, Q^2) \approx F_2(x) \implies x \equiv \frac{Q^2}{2M\nu}$$

Stanford Linear Accelerator - SLAC (1960)

$$\lim_{Q^2,\nu\to\infty} MW_1(\nu, Q^2) \approx F_1(x)$$

$$\lim_{Q^2,\nu\to\infty} \nu MW_2(\nu, Q^2) \approx F_2(x) \implies x \equiv \frac{Q^2}{2M\nu}$$

$$\sigma_L^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2}\left[F_2(x,Q^2) - 2xF_1(x,Q^2)\right]$$

$$\sigma_T^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2}\left[2xF_1(x,Q^2)\right]$$

UDESC

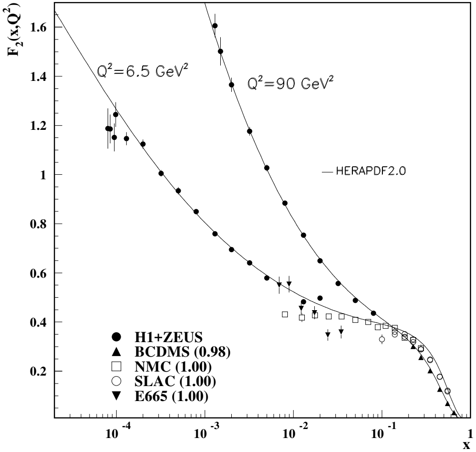
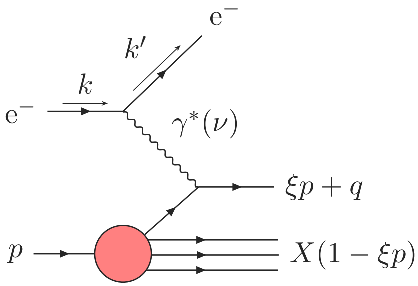


Figura 2: Fonte: (WORKMAN et al., 2022)

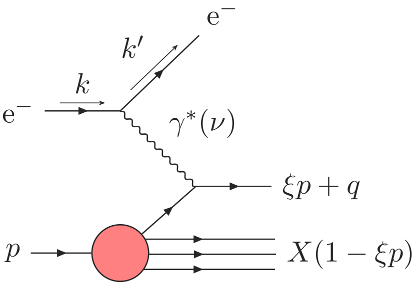


Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

A Estrutura dos Hádrons

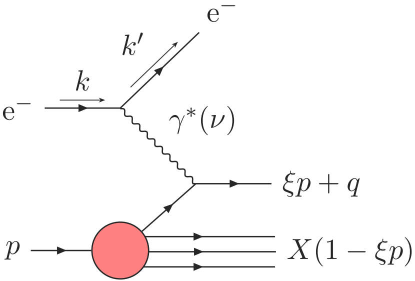
DIS no Modelo de Partons



Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

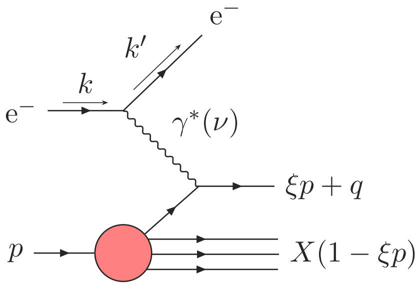
$$m_q^2 = (\xi p + q)^2 = 0$$



Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

$$m_q^2 = (\xi p + q)^2 = 0 \implies \boxed{\xi = x}$$

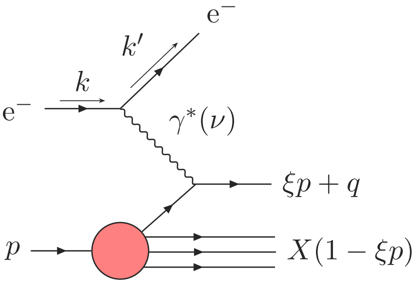


Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

$$m_q^2 = (\xi p + q)^2 = 0 \implies \boxed{\xi = x}$$

$$\sigma^{\gamma^* p} = \sum_q \int_0^1 d\xi\, f_q(\xi) \hat{\sigma}^{\gamma^* p}_{L,T}$$



Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

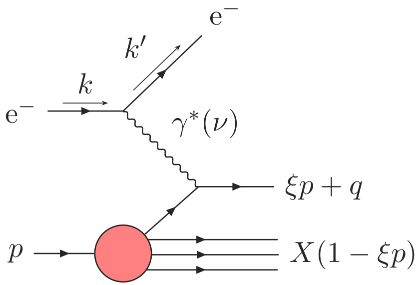
$$m_q^2 = (\xi p + q)^2 = 0 \implies \boxed{\xi = x}$$

$$\sigma_L^{\gamma^* p}(x, Q^2) = 0$$

$$\sigma_T^{\gamma^* p}(x, Q^2) = \frac{4\pi^2\alpha}{Q^2} 2xF_1(x, Q^2)$$

A Estrutura dos Hádrons

DIS no Modelo de Partons



Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

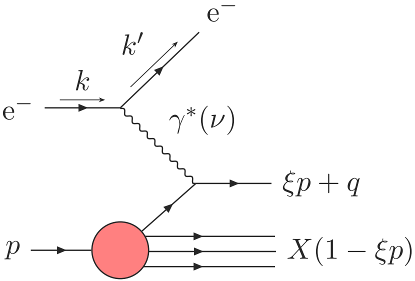
$$m_q^2 = (\xi p + q)^2 = 0 \implies \boxed{\xi = x}$$

$$\sigma_L^{\gamma^* p}(x, Q^2) = 0 \implies$$

$$F_2(x, Q^2) = 2x F_1(x, Q^2)$$

$$\sigma_T^{\gamma^* p}(x, Q^2) = \frac{4\pi^2\alpha}{Q^2} 2x F_1(x, Q^2)$$

UDESC



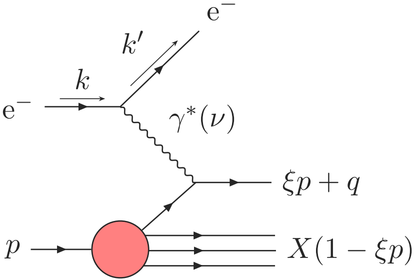
Função Densidade Partônica (PDF):

$$\sum_q \xi_q p = p$$

$$m_q^2 = (\xi p + q)^2 = 0 \implies \boxed{\xi = x}$$

$$\sigma^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2} \sum_q \int_0^1 d\xi f_q(\xi) e_q^2 \delta\left(1 - \frac{x}{\xi}\right)$$

$$\sigma^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2} \sum_q e_q^2 x f_q(x)$$



Resultados Experimentais (KONRATH, 2016; MARTINS, 2014)

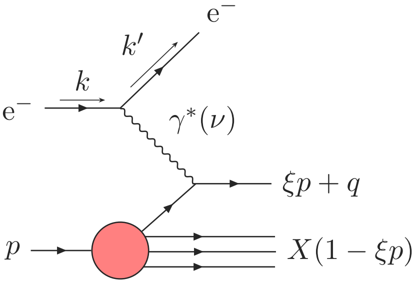
$$f_u = \int_0^1 x u(x)\, dx = 0.36$$

$$f_d = \int_0^1 x d(x)\, dx = 0.18$$

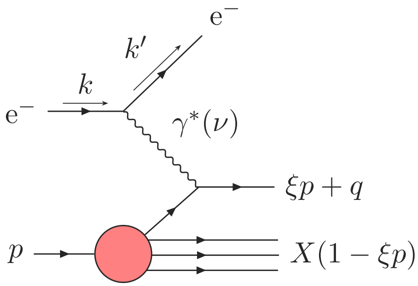
$\boxed{\approx 54\%}$ $\rightarrow$ quarks u e d

A Estrutura dos Hádrons

DIS no Modelo de Partons



E AGORA??



E AGORA??

$\downarrow$ via QCD

$$\boxed{F_i(x) \to F_i(x, Q^2)}$$

A constante de acoplamento α_s

- Determina a intensidade da força de interação forte;
- Depende da distância ou da escala de momento entre as partículas;
- É obtida por meio da equação do grupo de renormalização;

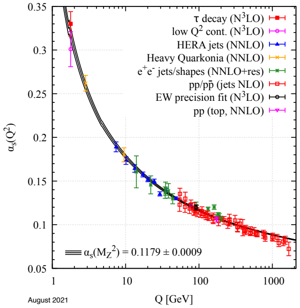


Figura 2: Evolução da constante de acoplamento forte em função de Q. Fonte: (WORKMAN et al., 2022)

A Estrutura dos Hádrons

QED

A constante de acoplamento α_s

$$\frac{d\alpha_s(Q^2)}{dt} = \beta(\alpha_s(Q^2))$$

$$t = \log\left(\frac{Q^2}{\mu^2}\right)$$

$$\beta(\alpha_s) = \mu^2 \frac{d\alpha_s}{d\mu^2}$$

A função β expressa a dependência de α_s na escala de energia de algum processo, e é dada pela expansão pertubativa $\beta(\alpha_s) = -\alpha_s^2[b_0 + b_1\alpha_s + \mathcal{O}(\alpha_s^2)]$

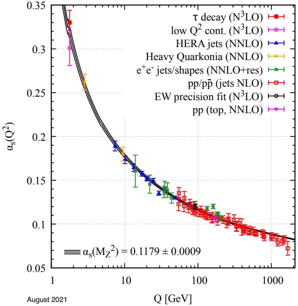


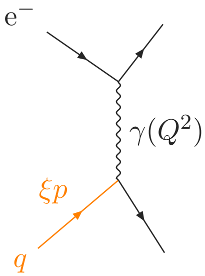
Figura 2: Evolução da constante de acoplamento forte em função de Q. Fonte: (WORKMAN et al., 2022)

DGLAP

As Equações de Evolução

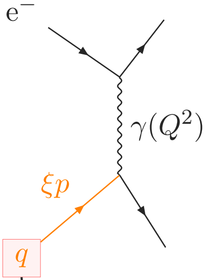
DGLAP

Remodelando as Funções de Estrutura



DGLAP

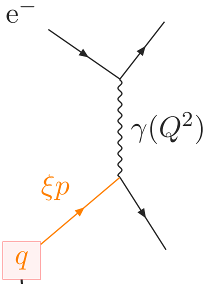
Remodelando as Funções de Estrutura



$$\boxed{q(x) \implies q(x,Q^2) = q(x) + \Delta q(x,Q^2)}$$

DGLAP

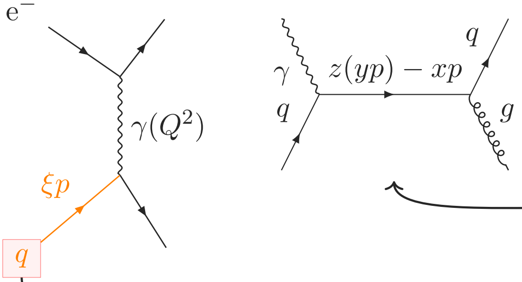
Remodelando as Funções de Estrutura



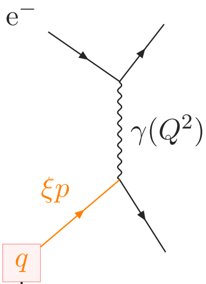
$$q(x) \implies q(x, Q^2) = q(x) + \Delta q(x, Q^2)$$

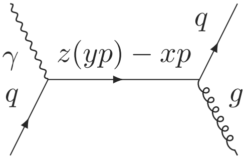
DGLAP

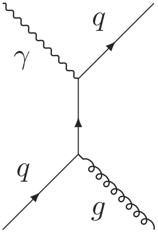
Remodelando as Funções de Estrutura



$$q(x) \implies q(x, Q^2) = q(x) + \Delta q(x, Q^2)$$



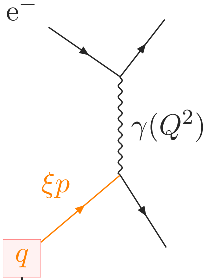




$$q(x) \implies q(x, Q^2) = q(x) + \Delta q(x, Q^2)$$

DGLAP

Remodelando as Funções de Estrutura

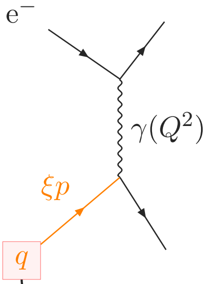


$$\frac{\alpha_s t}{2\pi} \int_x^1 \frac{dy}{y} q(y) P_{qq}\left(\frac{x}{y}\right)$$

$$q(x) \implies q(x, Q^2) = q(x) + \Delta q(x, Q^2)$$

DGLAP

Remodelando as Funções de Estrutura



$$\frac{\alpha_s t}{2\pi}\int_x^1 \frac{dy}{y}\, q(y) P_{qq}\left(\frac{x}{y}\right)$$

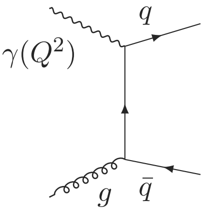
$$t = \ln\left(\frac{Q^2}{\mu^2}\right)$$

$$q(x) \implies q(x,Q^2) = q(x) + \Delta q(x,Q^2)$$

UDESC

DGLAP

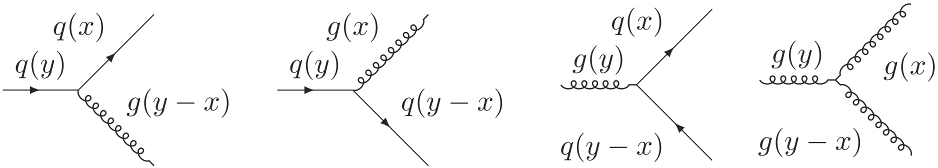
Processo $\gamma g \to q\bar{q}$



$$\boxed{\ldots g(y) P_{qg}\left(\frac{x}{y}\right)}$$

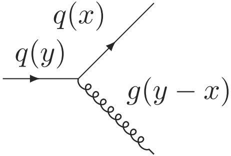
DGLAP

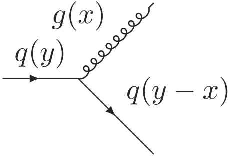
Funções de splitting

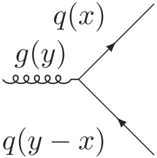


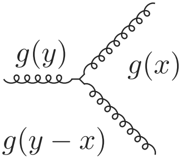
DGLAP

Funções de splitting





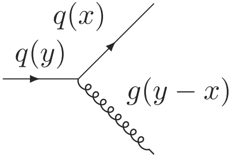


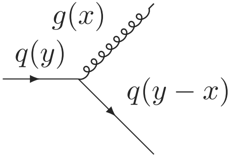


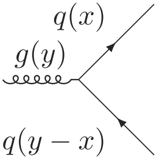
$$\boxed{P_{qq}\left(\frac{x}{y}\right)} \quad \boxed{P_{gq}\left(\frac{x}{y}\right)} \quad \boxed{P_{qg}\left(\frac{x}{y}\right)} \quad \boxed{P_{gg}\left(\frac{x}{y}\right)}$$

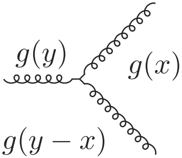
DGLAP

Funções de splitting







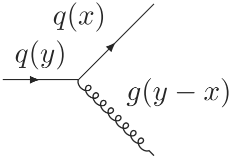


$\boxed{P_{qq}\left(\frac{x}{y}\right)}$ $\boxed{P_{gq}\left(\frac{x}{y}\right)}$ $\boxed{P_{qg}\left(\frac{x}{y}\right)}$ $\boxed{P_{gg}\left(\frac{x}{y}\right)}$

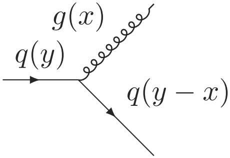
$$\frac{dq(x,t)}{dt} = \frac{\alpha_s}{2\pi}\int_x^1 \left[q(x,t)P_{qq}\left(\frac{x}{y}\right) + g(x,t)P_{qg}\left(\frac{x}{y}\right)\right]\frac{dy}{y}$$

DGLAP

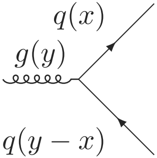
Funções de splitting



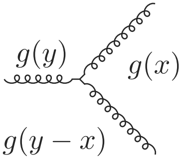
$$\boxed{P_{qq}\left(\frac{x}{y}\right)}$$



$$\boxed{P_{gq}\left(\frac{x}{y}\right)}$$



$$\boxed{P_{qg}\left(\frac{x}{y}\right)}$$



$$\boxed{P_{gg}\left(\frac{x}{y}\right)}$$

$$\frac{dg(x,t)}{dt} = \frac{\alpha_s}{2\pi}\int_x^1 \left[\sum_j q_j(x,t)P_{qg}\left(\frac{x}{y}\right) + g(x,t)P_{gg}\left(\frac{x}{y}\right)\right]\frac{dy}{y}$$

Parametrizações

Distribuições partônicas

Parametrizações partônicas

Grupos

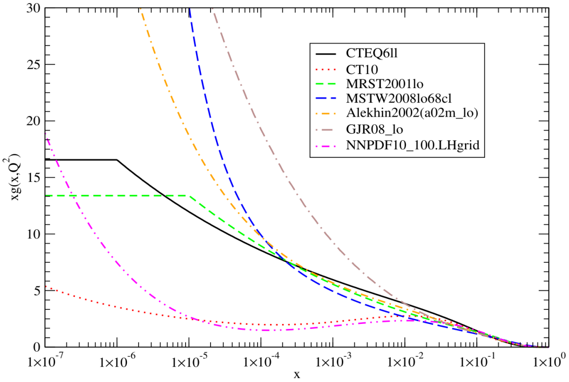


Figura 3: Distribuições gluônicas em função da fração de momentum para a escala $Q^2 = 2,4\mathrm{GeV}^2$. Fonte: (MARTINS, 2014)

Mésons Vetoriais

Produção difrativa

Mésons Vetoriais

Propriedades

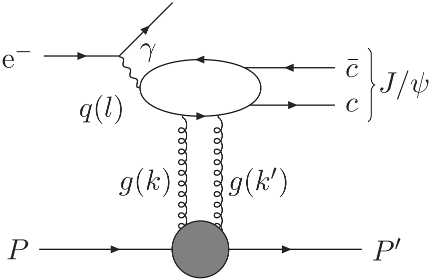
Méson	Conteúdo de Quarks	Carga	Massa	Tempo de Vida	Principais Decaimentos
ρ	$u\bar{d}, (u\bar{u} - d\bar{d})\sqrt{2}, d\bar{u}$	1,0,-1	775,5	4×10^{-24}	$\pi\pi$
K^*	$u\bar{s}, d\bar{s}, s\bar{d}, s\bar{u}$	1,-1	894	1×10^{-23}	$K\pi$
ω	$(u\bar{u} + d\bar{d})\sqrt{2}$	0	782,6	8×10^{-23}	$\pi\pi\pi, \pi\gamma$
ψ	$c\bar{c}$	0	3097	7×10^{-21}	$e^+e^-, \mu^+\mu^-\pi, 5\pi, 7\pi$
D^*	$c\bar{d}, c\bar{u}, u\bar{c}, d\bar{c}$	1,0,-1	2008	3×10^{-21}	$D\pi, D\gamma$
Υ	$b\bar{b}$	0	9460	1×10^{-20}	$e^+e^-, \mu^+\mu^-\pi, \tau^+\tau^-$

Tabela 1: Algumas propriedades físicas dos mésons vetoriais. Fonte: (MARTINS, 2014)

[. . .]Good and Walker who in 1960, wrote: *"...A phenomenal is predicted in which a high energy particle beam undergoing diffraction scattering from a nucleous will acquire components corresponding to various products of the virtual dissocitions of the incidente particle... These diffraction-produced system would have a characteristic extremelt narrow distribution in transverse momentum and would have the same quantum numbers of the initial particle..."*
For the sake of definiteness, we will say that *"every reaction in which no quantum numbers are exchange between high energy colliding particles is domined asympthotically by diffraction."* (PREDAZZI, 1998)

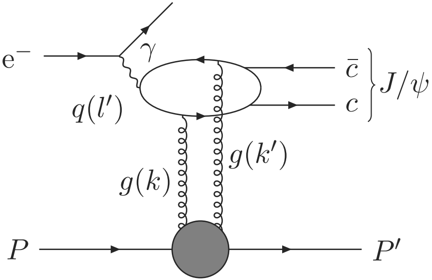
Mésons Vetoriais

Fotoprodução do Méson J/ψ



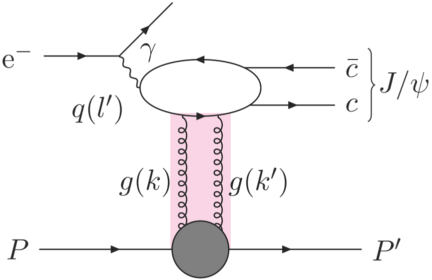
Mésons Vetoriais

Fotoprodução do Méson J/ψ

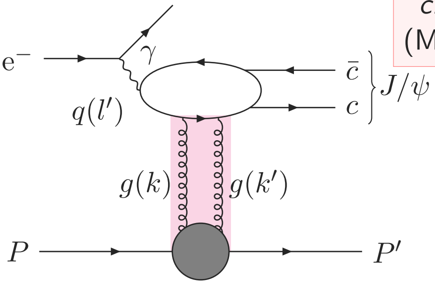


Mésons Vetoriais

Fotoprodução do Méson J/ψ



Fotoprodução do Méson J/ψ



c. sec. - HERA: (MARTINS, 2014) $\rightarrow$

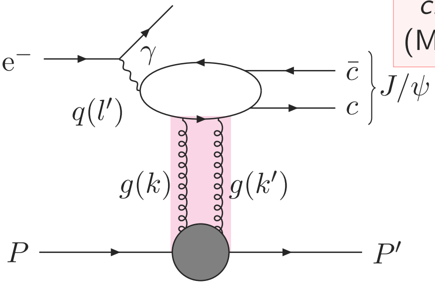
$\sigma^{\gamma p \rightarrow Vp}(W^2) \sim W^{0,2}$

$V \rightarrow \rho, \omega,$ e ϕ

(Aumenta)

Mésons Vetoriais

Fotoprodução do Méson J/ψ



c. sec. - HERA: (MARTINS, 2014)

$\sigma^{\gamma p \to Vp}(W^2) \sim W^{0,2}$

$V \to \rho, \omega,$ e ϕ

(Aumenta)

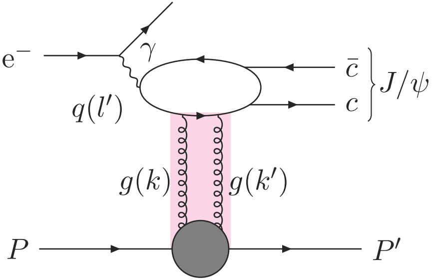
Este aumento é ainda mais significatico para o processo J/ψ

(pQCD)

$$\left.\frac{d\sigma^{\gamma g \to c\bar{c}}}{dt}\right|_{t=0} \propto \left[\bar{x} g(\bar{x}, \bar{Q}^2)\right]^2$$

UDESC

Fotoprodução do Méson J/ψ

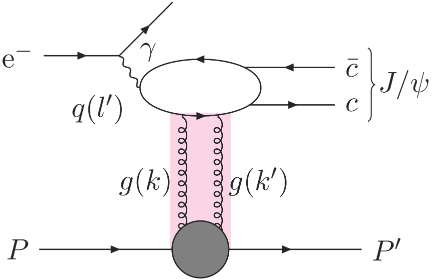


$$\left.\frac{d\sigma^{\gamma g \to c\bar{c}}}{dt}\right|_{t=0} \propto \left[\alpha_s x_P g(x_P, \bar{Q}^2)\right]^2$$

1. x_P – fração de momentum portada pelo do próton
2. $g(x_P, \bar{Q}^2)$ – distrib. de glúons a Q^2 efetivo
3. α_s – constante de acoplamento *strong*

Mésons Vetoriais

Fotoprodução do Méson J/ψ



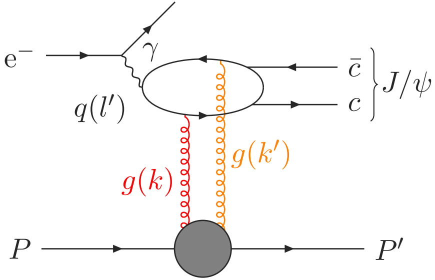
$$\bar{Q}^2 = \frac{Q^2 + M_V}{4}$$

$$\left.\frac{d\sigma^{\gamma g \to c\bar{c}}}{dt}\right|_{t=0} \propto \left[\alpha_s x_P g(x_P, \bar{Q}^2)\right]^2$$

1. x_P – fração de momentum portada pelo do próton
2. $g(x_P, \bar{Q}^2)$ – distrib. de glúons a Q^2 efetivo
3. α_s – constante de acoplamento *strong*

Mésons Vetoriais

Amplitude de Espalhamento

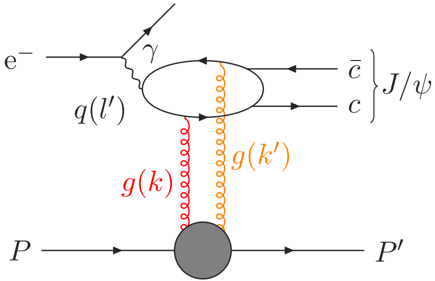


$$A_T = -4\pi^2 i\alpha_s W^2 \int \frac{dk^2}{k^4}\left(\frac{1}{l^2 - m_c^2} + \right.$$
$$\left. - \frac{1}{l'^2 - m_c^2}\right) f(x_P, k^2) e_c g_\psi M_\psi$$

UDESC

Mésons Vetoriais

Amplitude de Espalhamento

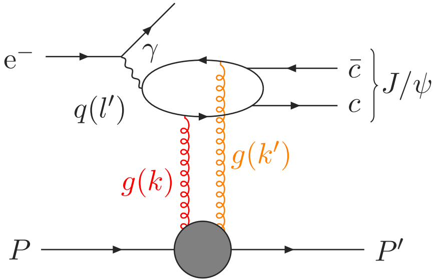


$$A_T = -4\pi^2 i\alpha_s W^2 \int \frac{dk^2}{k^4}\left(\frac{1}{l^2 - m_c^2} + -\frac{1}{l'^2 - m_c^2}\right) f(x_P, k^2) e_c g_\psi M_\psi$$

$$\frac{d\sigma_T^{\gamma^{(*)}p\to\psi p}}{dt} = \frac{1}{16\pi W^4}|A_T|^2$$

Mésons Vetoriais

Amplitude de Espalhamento



$$A_T = -4\pi^2 i\alpha_s W^2 \int \frac{dk^2}{k^4}\left(\frac{1}{l^2 - m_c^2} + -\frac{1}{l'^2 - m_c^2}\right) f(x_P, k^2) e_c g_\psi M_\psi$$

$$\left.\frac{d\sigma_T^{\gamma^{(*)}p\to\psi p}}{dt}\right|_{t=0} = \frac{16\Gamma^{\psi}_{e^+e^-} M_\psi^3 \pi^3}{3\alpha_{em}\left(Q^2 + M_\psi^2\right)^4}\left[\alpha_s(\bar{Q}^2) x_P g(x_P, \bar{Q}^2)\right]^2 \left(1 + \frac{Q^2}{M_\psi}\right)$$

Resultados

Análise Numérica

Resultados

Análise Numérica

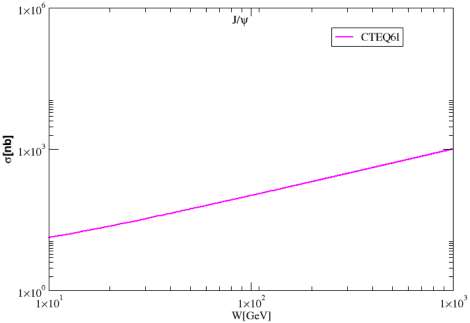


Figura 4: Seção de choque total para J/ψ em função da energia do centro de massa tomando por referência os parâmetros estudados em (MARTINS, 2014).

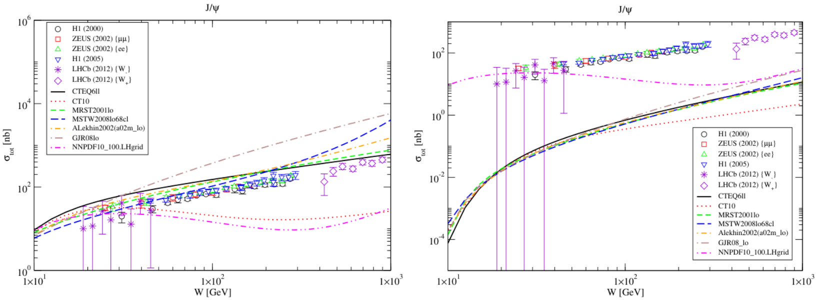


Figura 4: Seção de choque total para J/ψ em função da energia do centro de massa com $b_V = 4,5\ \mathrm{GeV}^2$ e $\alpha_s - 0,20$ fixos para $\mu^2 = 2,4\ \mathrm{GeV}^2$ e $\mu^2 = 9,0\ \mathrm{GeV}^2$ respectivamente.

Referencias

KONRATH, R. **Colisões Hadrônicas e Interações Multiplas**. 85 p. Dissertação (Mestrado em Física) — UFSC–PPGF, Universidade Federal de Santa Catarina, 2016.

MARTINS, L. A. S. **Determinação da Distribuição de Glúons do Próton na Fotoprodução de Mésons Vetoriais no Grande Colisor de Hádrons**. 71 p. Dissertação (Mestrado em Física) — UFPEL–IFM(PPGF), Universidade Federal de Pelotas, 2014.

PREDAZZI, E. Diffraction : past, present and future. 1998.

WORKMAN, R. L. et al. Review of particle physics. **PTEP**, v. 2022, p. 083C01, 2022.

Contato:
Rodrigo Ribamar Silva do Nascimento
rodrigo.nascimento@edu.udesc.br
github.com/physikices

UDESC
UNIVERSIDADE DO ESTADO DE SANTA CATARINA