

# FISICA DE LAS INTERACCIONES FUNDAMENTALES

1ER CUATRIMESTRE 2026

CLASE 14

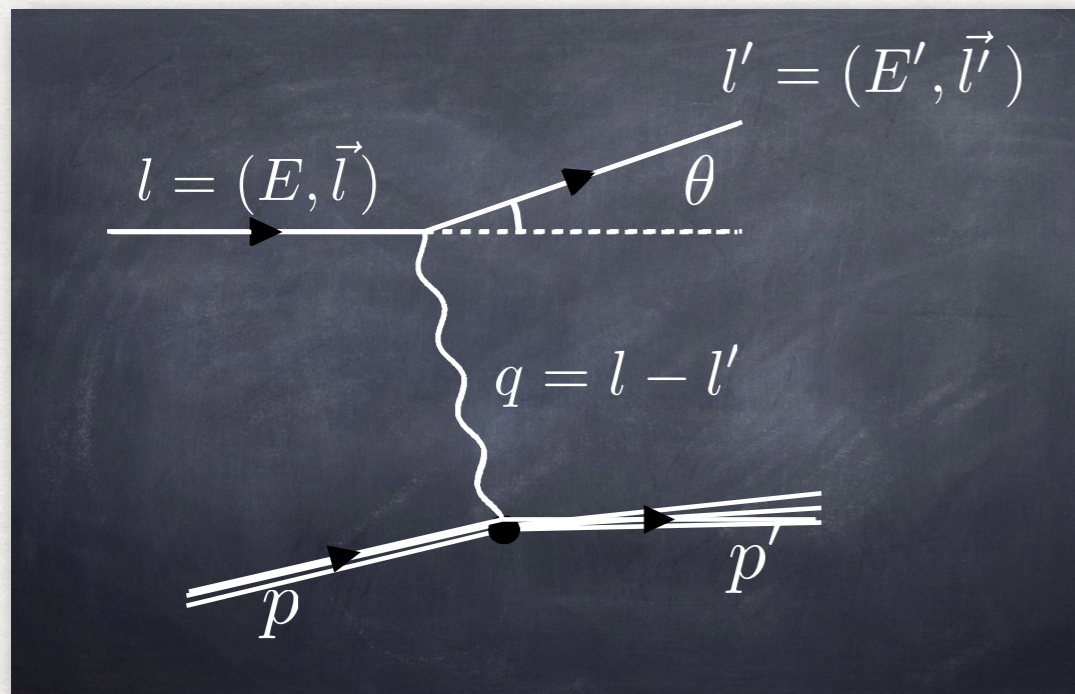
RODOLFO SASSOT

# CLASE 14: QCD y modelo de partones

libertad asintótica (SLAC 1969)

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libertad asintótica (SLAC 1969)



$l^\mu, p^\mu$  fijos

$l'^\mu, p'^\mu$  8 variables

-4 conservación E-p

-1  $l^2 = m_e^2$

~~-1  $p^2 = m_p^2$~~

-1 en c.m.s.  $l - p$ , simetría rotaciones

~~1 variable independiente ( $\theta$  o  $E'$ )~~

2 variables independientes ( $\theta$  y  $E'$ )



R.P. Feynman



J. D. Bjorken

renormalizabilidad de Yang-Mills y QCD ('t Hooft 1971)

libertad asintótica en QCD (Gross, Wilczek, Politzer 1973)

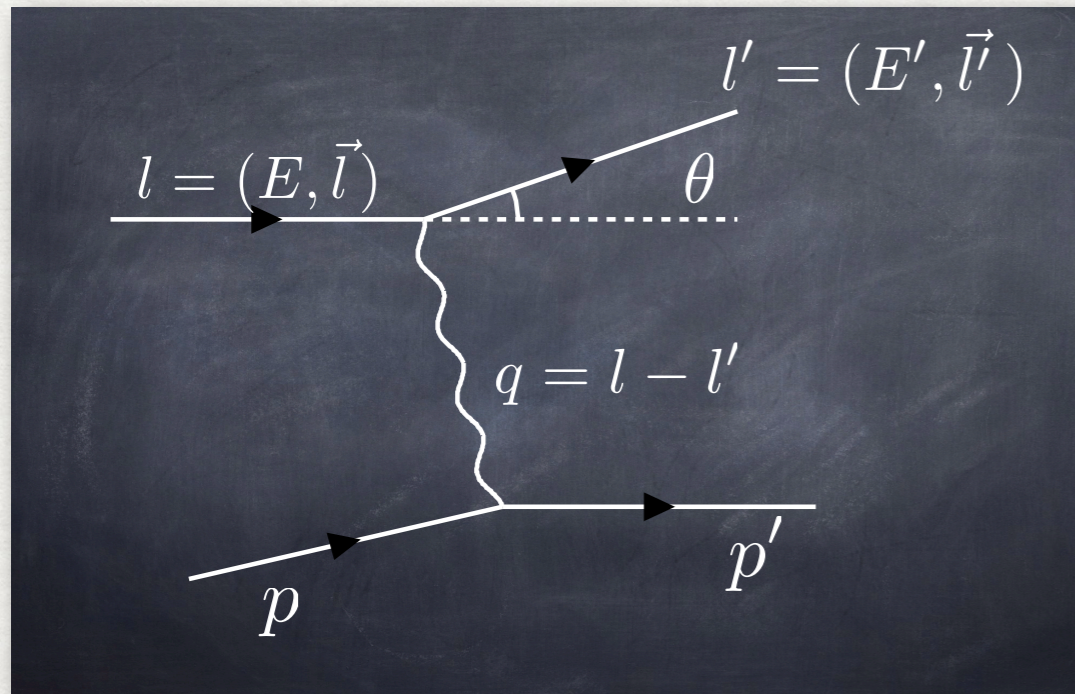
# CLASE 14: QCD y modelo de partones

## Modelo de partones:



R.P. Feynman

J. D. Bjorken



$$q = l - l' \quad (m_l^2 \simeq 0)$$

$$q^2 = (l - l')^2 = l^2 - 2l^\mu l'_\mu + l'^2 \simeq -2EE' + 2|\vec{l}||\vec{l}'|\cos\theta$$

$$(m_l^2 = E^2 - |\vec{l}|^2) \quad \simeq -2(E E' - E E' \cos\theta)$$

$$\simeq -4EE' \sin^2 \frac{\theta}{2}$$

$$Q^2 \equiv -q^2 \simeq 4EE' \sin^2 \frac{\theta}{2}$$

$$q + p = p'$$

$$q = p' - p$$

$$(Q^2 \gg M^2)$$

$$q^2 = (p' - p)^2 = p'^2 - 2p^\mu q_\mu + p^2 \simeq -2p \cdot q$$

$$W_2(x, Q^2) \longrightarrow \delta(x - 1)$$

$$x \equiv \frac{-q^2}{2p \cdot q} = 1 \quad (\text{si } p^2 = M^2)$$

$$< 1 \quad (\text{si } p^2 \neq M^2)$$

$$\frac{d^2\sigma}{dQ^2 dx} = \frac{4\pi\alpha_{em}^2 E'}{Q^4 E} \left\{ W_2(x, Q^2) \cos^2 \frac{\theta}{2} + 2W_1(x, Q^2) \sin^2 \frac{\theta}{2} \right\}$$

variable de Bjorken

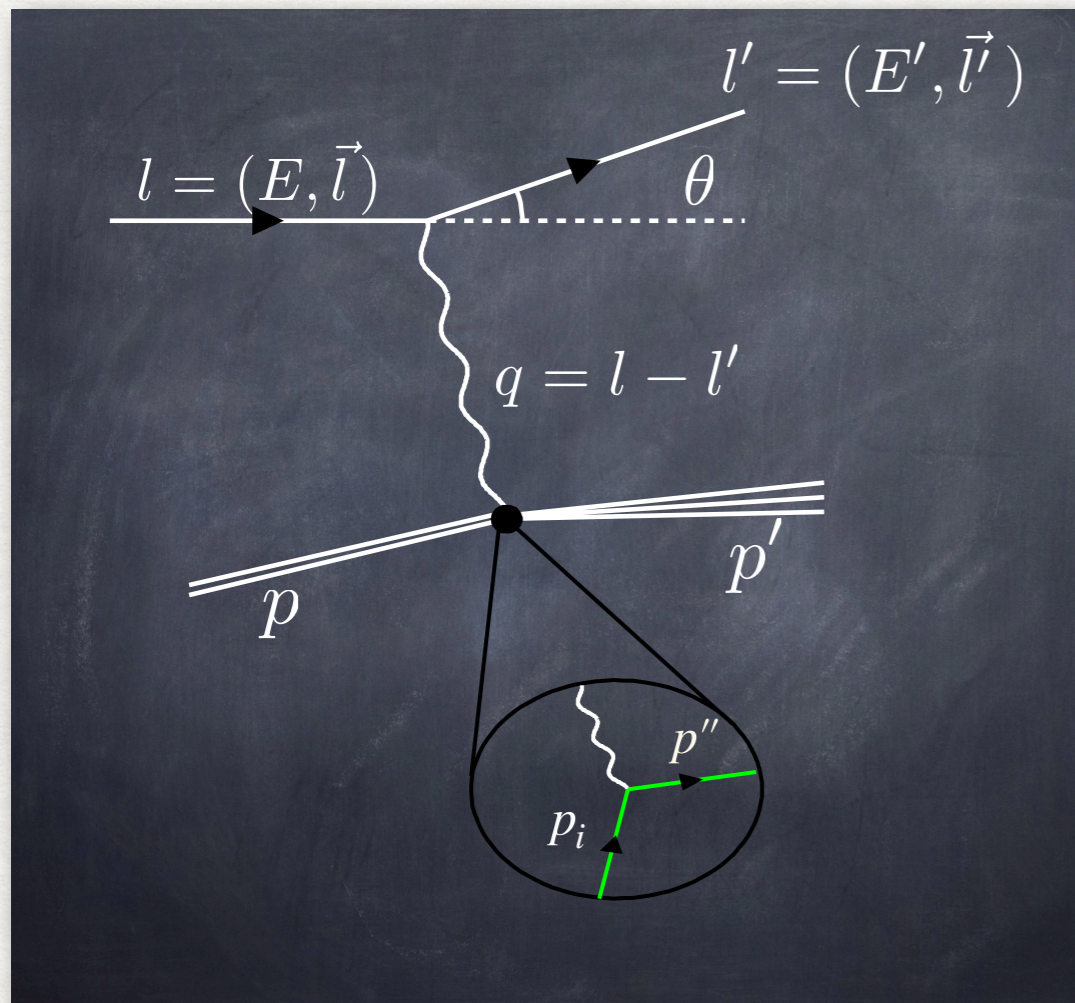
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## Modelo de partones:



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$$\frac{d^2\sigma}{dQ^2 dx} = \frac{4\pi\alpha_{em}^2}{Q^4} \frac{E'}{E} \left\{ W_2(x, Q^2) \cos^2 \frac{\theta}{2} + 2W_1(x, Q^2) \sin^2 \frac{\theta}{2} \right\}$$

$$W_2(x, Q^2) = \sum_i \int_0^1 dy_i e_i^2 f_i(y_i) \delta(y_i - x)$$

$$W_2(x, Q^2) = \sum_i e_i^2 f_i(x)$$

$$f_i(x) \sim \delta(x - 1)$$

$$f_i(x) \sim \delta(x - 1/3)$$

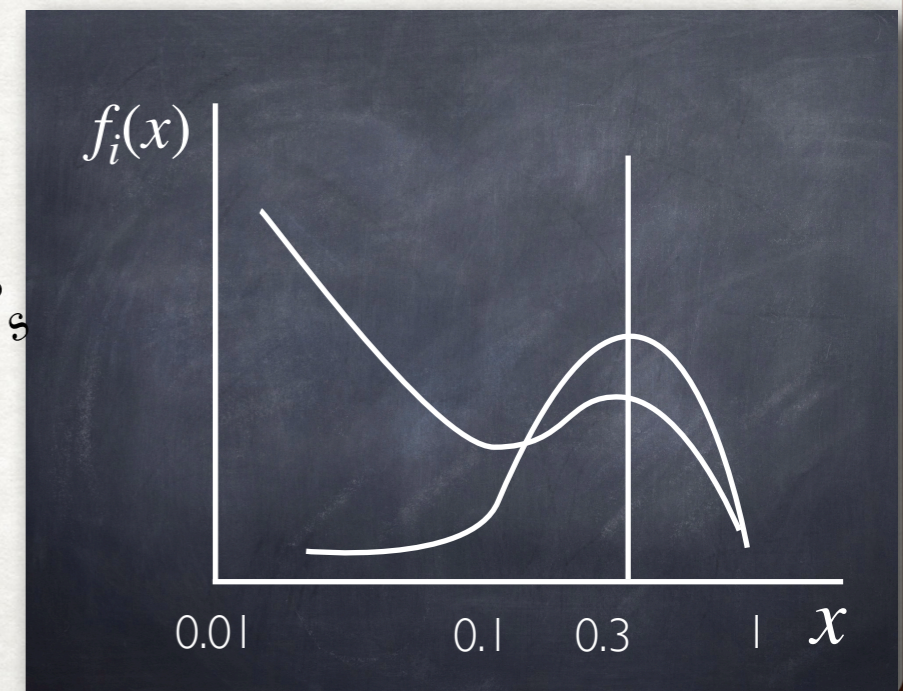
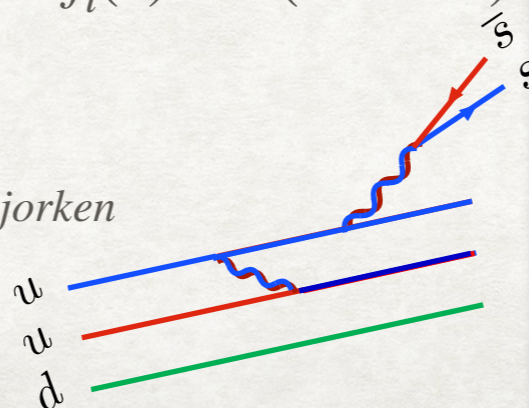
$$p_i = y_i p \quad y_i p + q = p''$$

$$(y_i p + q)^2 = p''^2$$

$$y_i^2 p^2 + 2y_i p \cdot q + q^2 = p''^2$$

$(p^2 = M^2 \simeq 0)$                        $(p''^2 = m_i^2 \simeq 0)$

$$y_i = \frac{Q^2}{2p \cdot q} = x_{Bjorken}$$



# CLASE 14: QCD y modelo de partones

## Modelo de partones:

$$\sigma_{ep} \sim e_u^2 [u(x) + \bar{u}(x)] + e_d^2 [d(x) + \bar{d}(x)] + e_s^2 [s(x) + \bar{s}(x)] + \dots$$



R.P. Feynman



J. D. Bjorken

$$u_{sea}(x) = \bar{u}_{sea}(x)$$

$$u_{val}(x) \equiv u(x) - \bar{u}_{sea}(x)$$

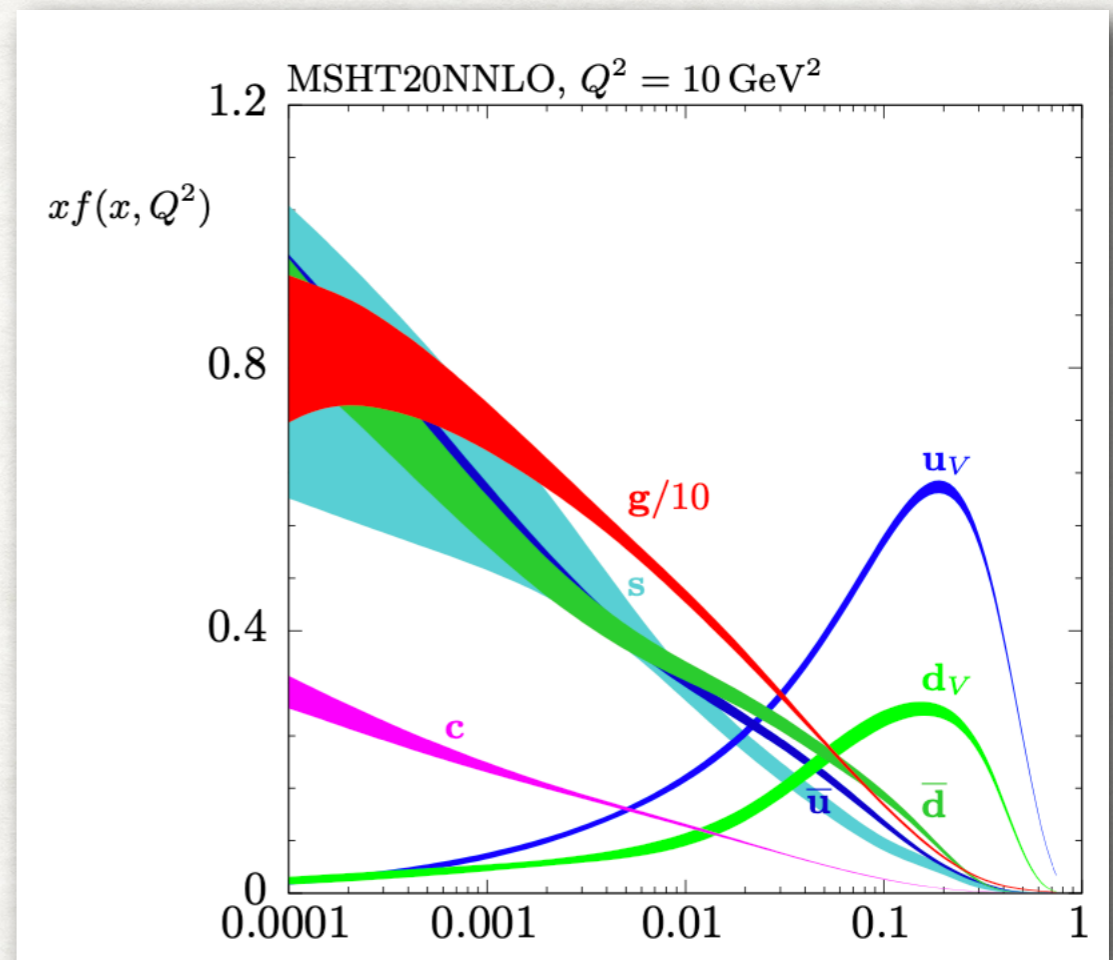
$$\int_0^1 dx u_{val}(x) = 2$$

$$\int_0^1 dx d_{val}(x) = 1$$

$$\int_0^1 dx s_{val}(x) = 0$$

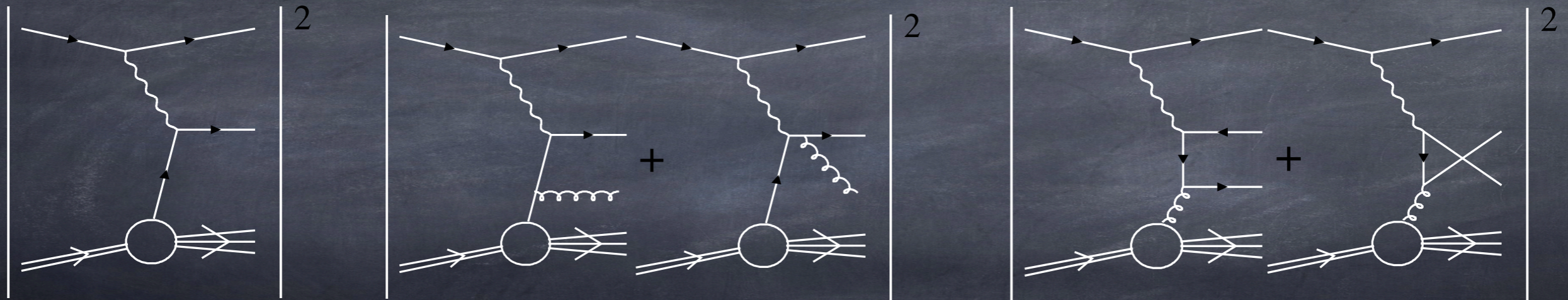
$$\int_0^1 dx x(u + \bar{u} + d + \bar{d} + s + \bar{s} + \dots) = 1 \quad ?$$

$\sim 0.54$



# CLASE 14: QCD y modelo de partones

QCD-improved parton model:



$$\sigma_{ep}(x, Q^2) \sim \sum_i e_i^2 \int_0^1 dy f_i(y) [\delta(x - y) + C_q(x, y, Q^2)] + g(y) C_g(x, y, Q^2)$$

no perturbativa  
(medible)

*universal!*

perturbativa  
(calculable)

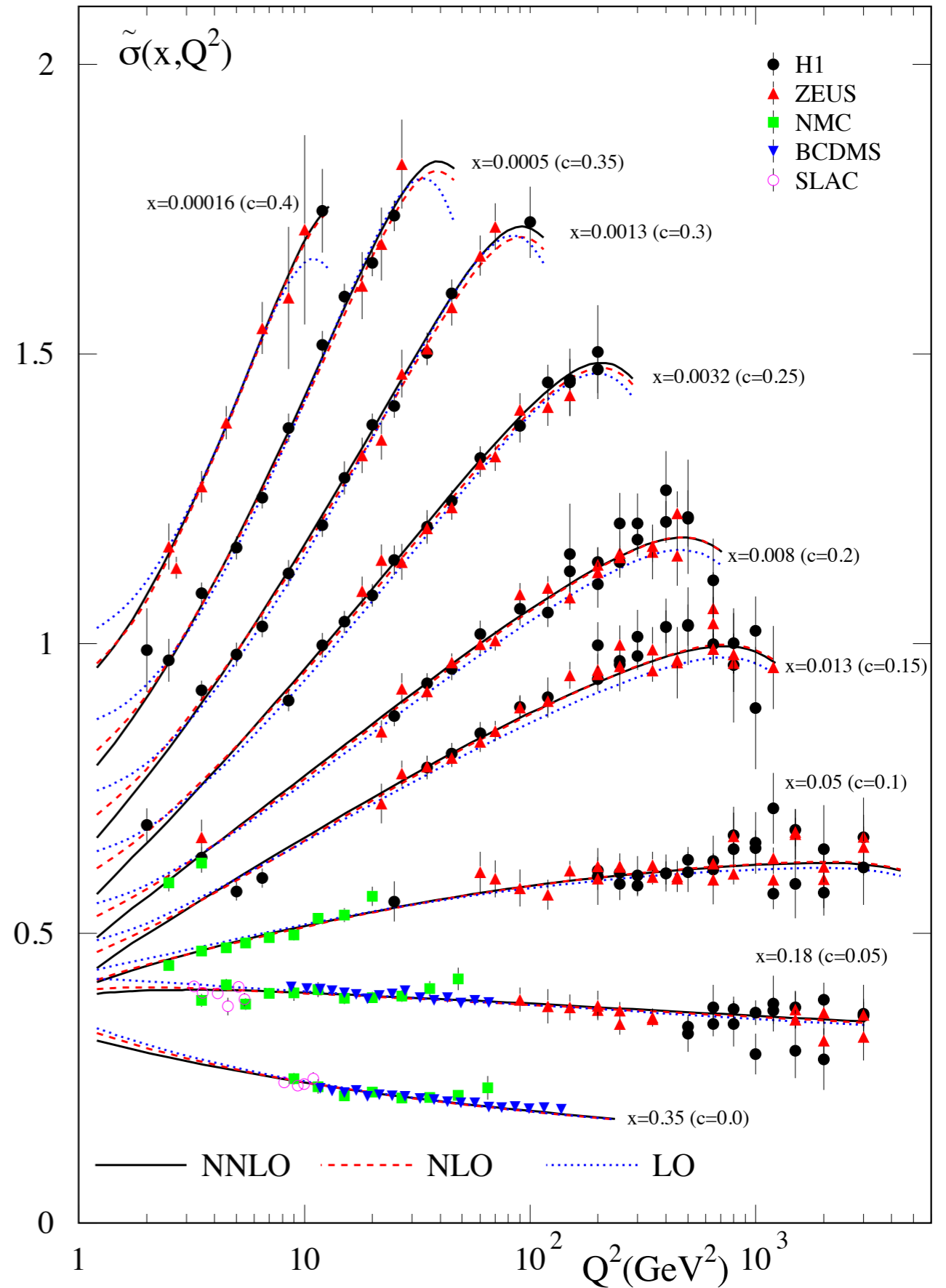
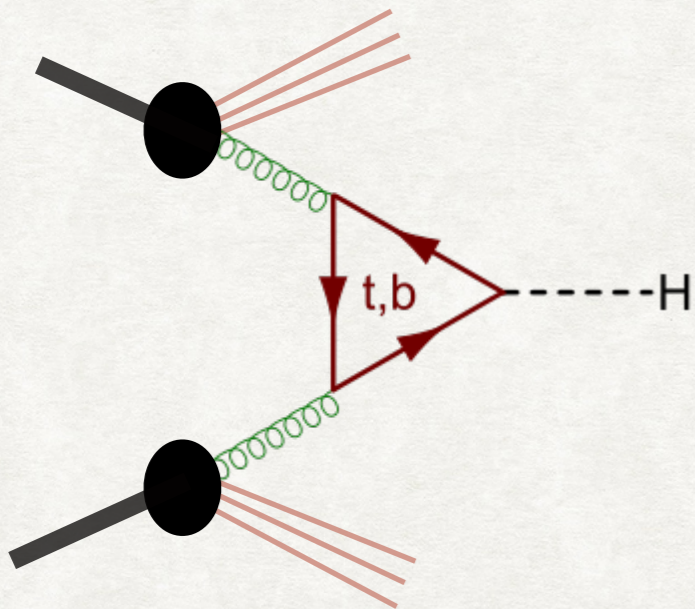
*al orden que te de el cuero*

# CLASE 14: QCD y modelo de partones

QCD-improved parton model:

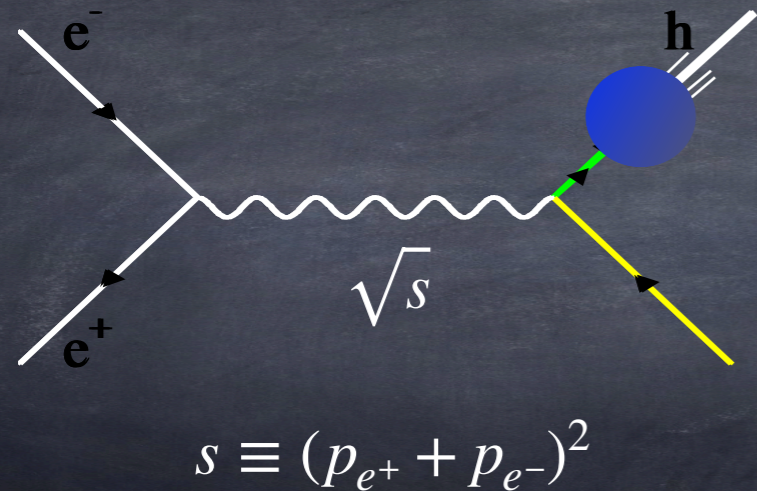
$$\sigma_{ep}(x, Q^2) = \sigma_{eq,g}(x, Q^2) \otimes f_i(x)$$

$$\sigma_{pp}(\eta, M^2) = \sigma_{ij}(\eta, M^2) \otimes f_i(x_1) \otimes f_j(x_2)$$



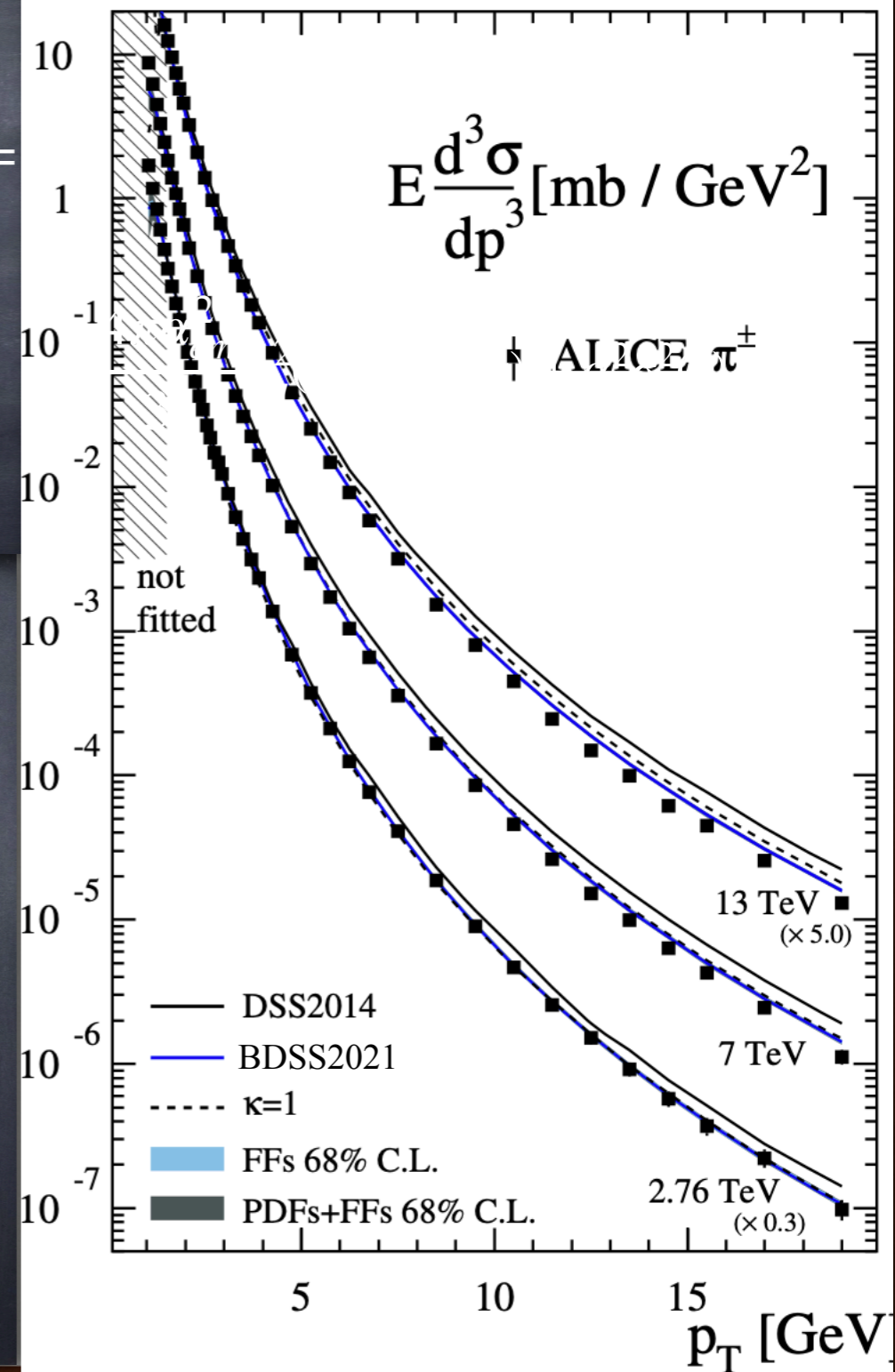
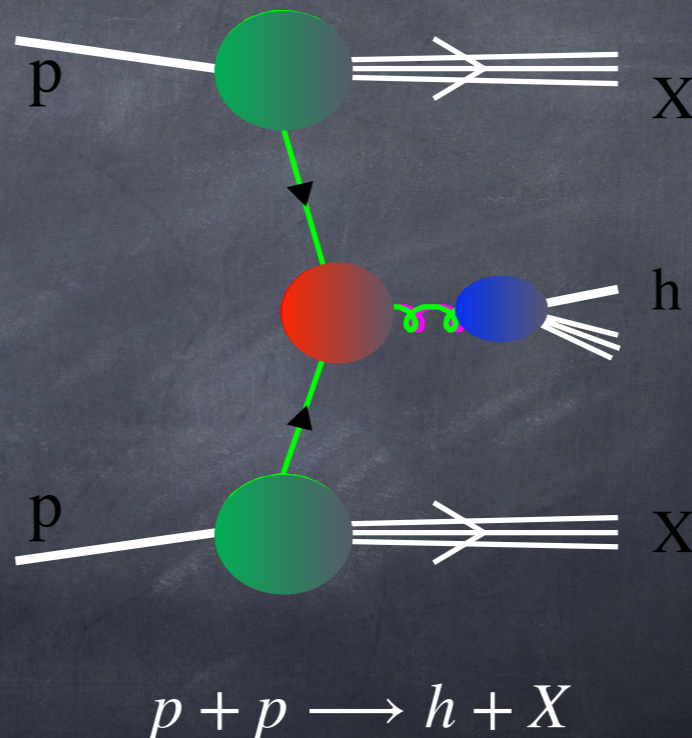
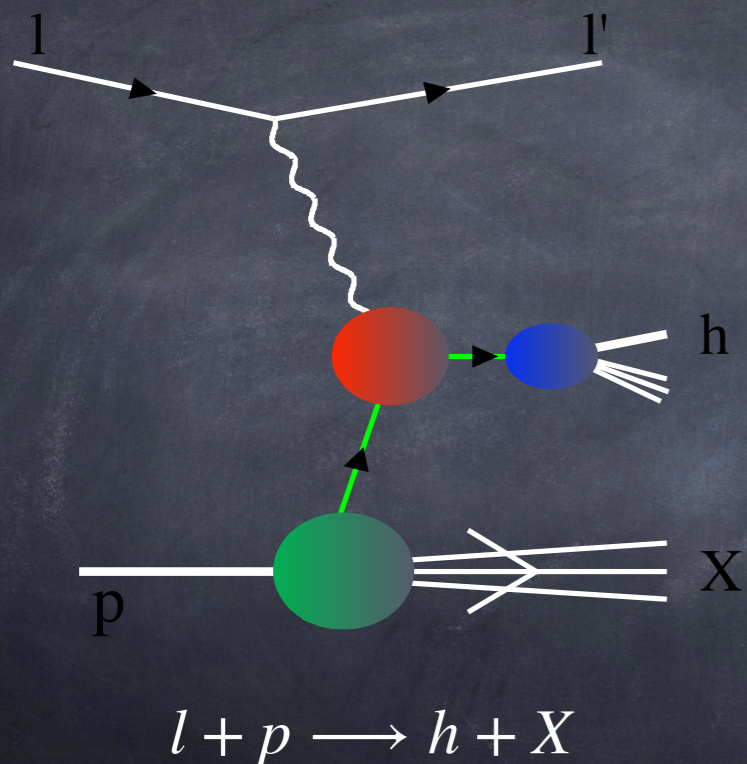
# CLASE 14: QCD y modelo de partones

## Confinamiento y hadronización:



$$\frac{d\sigma}{dz}(e^+e^- \longrightarrow h + X) =$$

$$z \equiv \frac{E_h}{E_q} = \frac{2E_h}{\sqrt{s}}$$



# CLASE 14: QCD y modelo de partones

## Spin del protón:

Modelo de quarks predice la polarización de cada tipo de quark en el proton

$$|p \uparrow\rangle = \frac{1}{\sqrt{18}} [2|u \uparrow d \downarrow u \uparrow\rangle + 2|u \uparrow u \uparrow d \downarrow\rangle + 2|d \downarrow u \uparrow u \uparrow\rangle - |u \uparrow u \downarrow d \uparrow\rangle - |u \uparrow d \uparrow u \downarrow\rangle - |u \downarrow d \uparrow u \uparrow\rangle - |d \uparrow u \downarrow u \uparrow\rangle - |d \uparrow u \uparrow u \downarrow\rangle - |u \downarrow u \uparrow d \uparrow\rangle].$$

$$P(u \uparrow) = 5/9 \quad P(d \uparrow) = 1/9$$

$$P(u \downarrow) = 1/9 \quad P(d \downarrow) = 2/9$$

predicción momentos magnéticos

$$\left. \frac{\mu_p}{\mu_n} \right|_{\psi_S} = -\frac{3}{2}$$

motivación del color y SU(3)



### A crisis in the parton model: where, oh where is the proton's spin?

Zeitschrift für Physik C Particles and Fields

June 1988, Volume 41, Issue 2, pp 239–246

Article

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18 March 1988

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- 39 Citations
- 73 Downloads

$$\Delta q(x) \equiv q^\uparrow(x) - q^\downarrow(x)$$

$$\Delta \Sigma(x) \equiv \Delta u(x) + \Delta d(x) + \Delta s(x)$$

$$\int_0^1 dx \Delta \Sigma(x) = ?$$

$\ll 1$  CERN-EMC 1987

R. Piegai Ph.D Thesis

$$\Delta g? \quad L_q, L_g?$$

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Spin del protón:

Relativistic Heavy Ion Collider (Brookhaven)

