# Deep Inelastic Scattering
# DIS

Particle Physics

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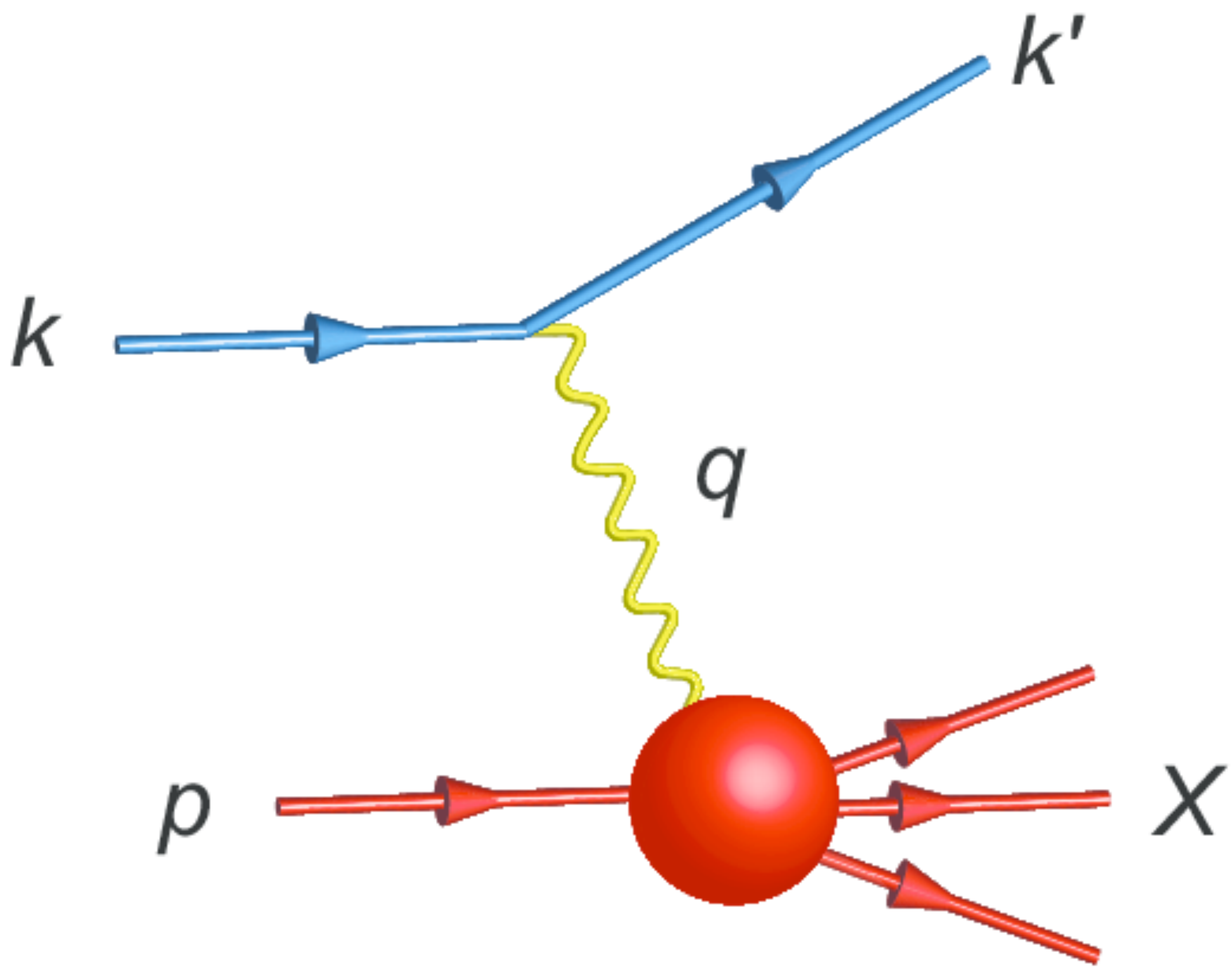
**NPAC 2022**

# Overview

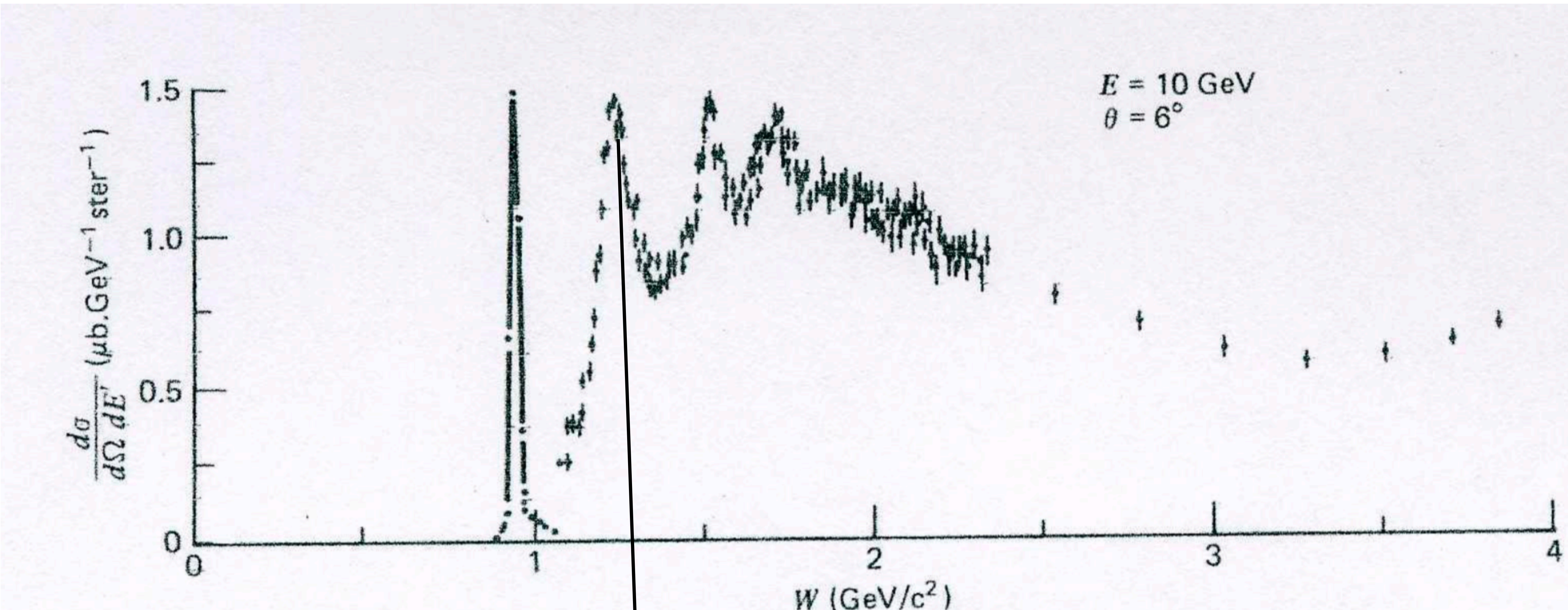
- Introduction to Deep Inelastic Scattering
  - ✓ Kinematics
  - ✓ Electron-proton scattering formalism
    - ✦ The Hadronic tensor
  - ✓ Elastic scattering
    - ✦ Point like particle
    - ✦ e p → e p
- Parton model and Bjorken Scaling invariance
  - ✓ Structure functions (brief reminder)
  - ✓ Spin of quarks
  - ✓ Sea quarks
  - ✓ Evolution of the different models
- Scaling violation and DGLAP equations
  - ✓ Invitation
  - ✓ From low to high $Q^2$, why ?
  - ✓ DGLAP
  - ✓ Recap

# Scattering kinematics



# e-p inelastic scattering

- SLAC experiments 1967-



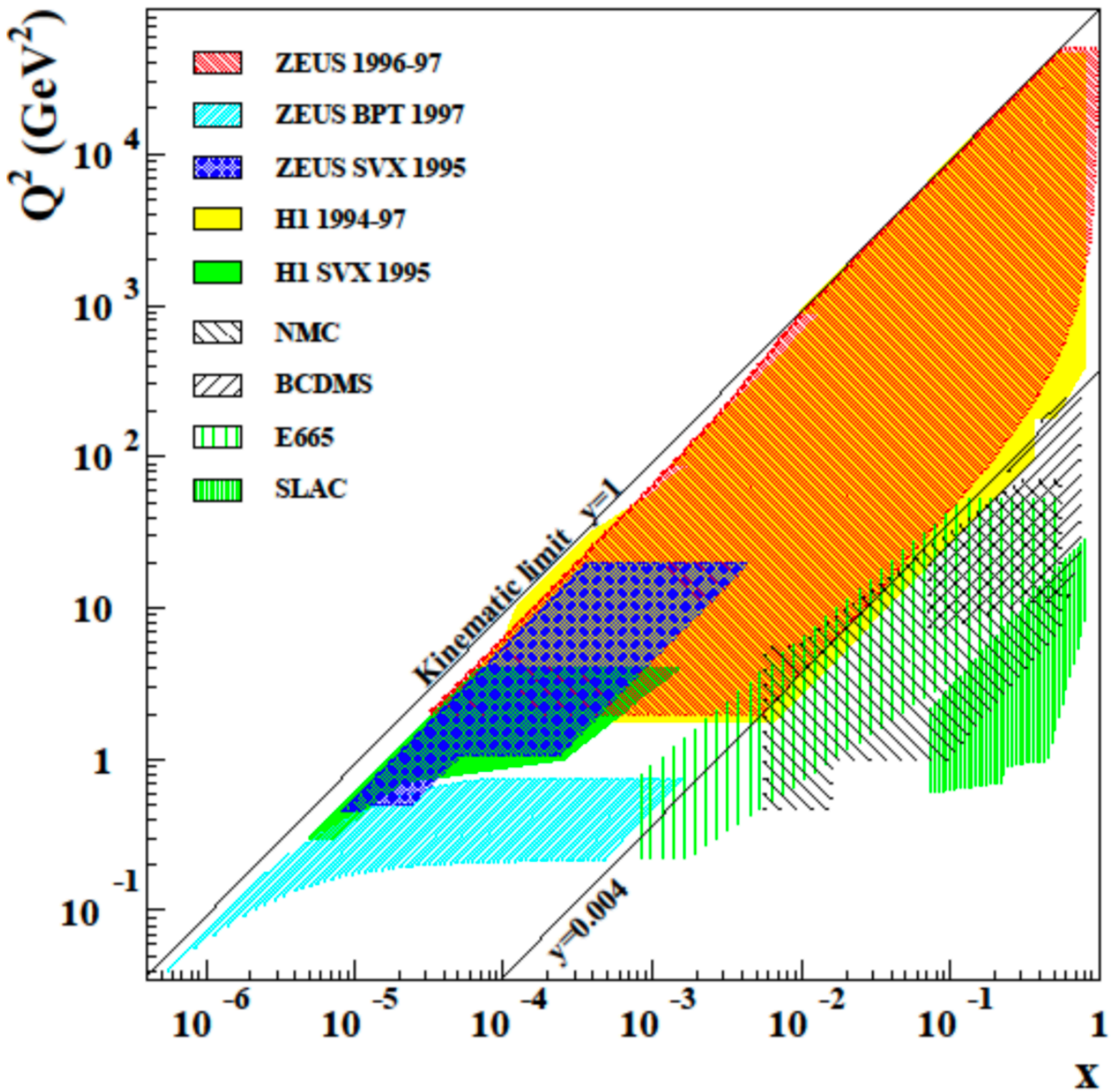

**Elastic peak**

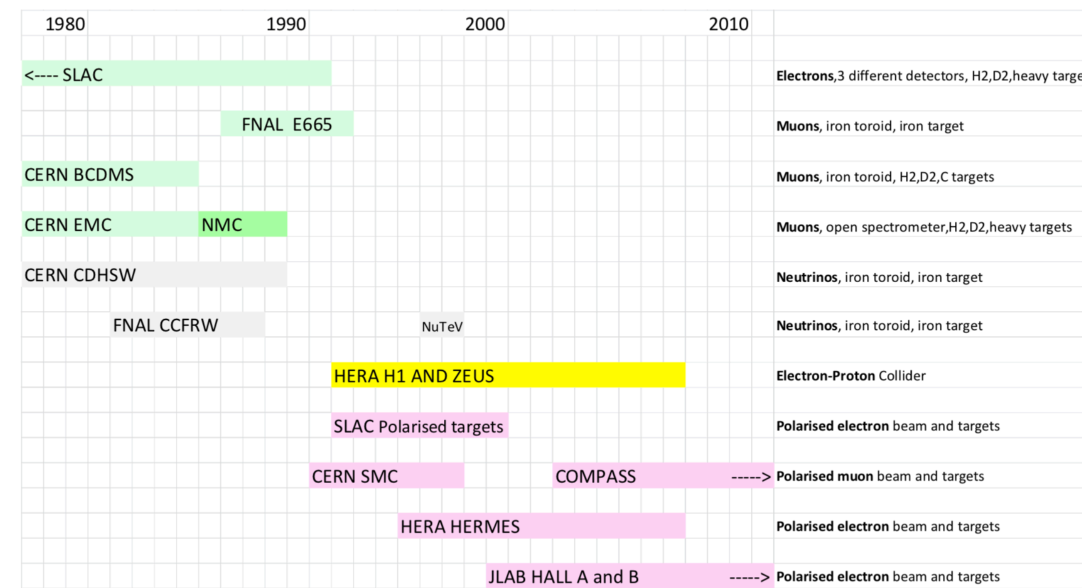
**DIS continuum**

**Resonances**
**ep → eΔ**

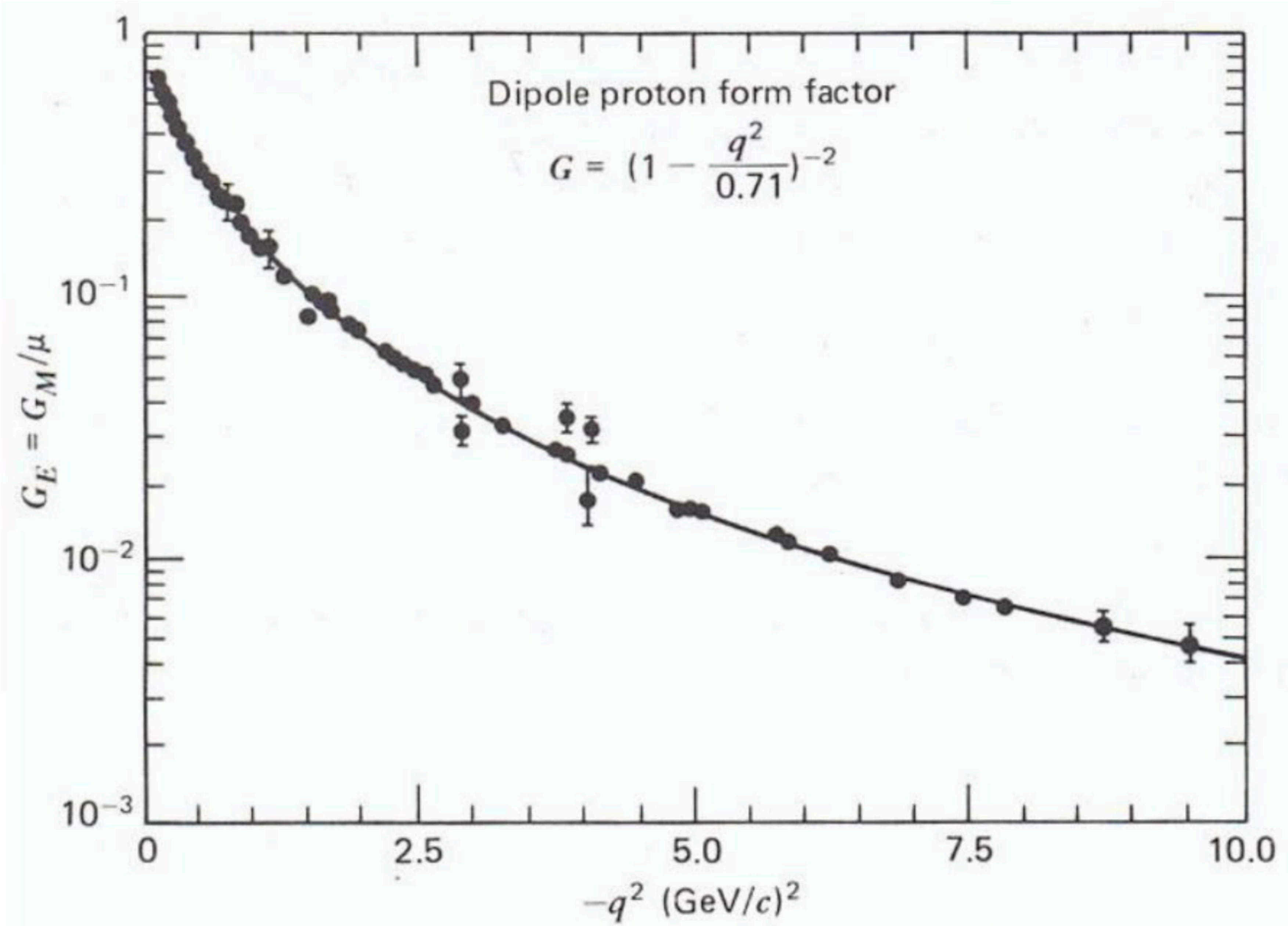
NPAC Noyaux Particules Astroparticules Cosmologie

# Kinematic 2D space



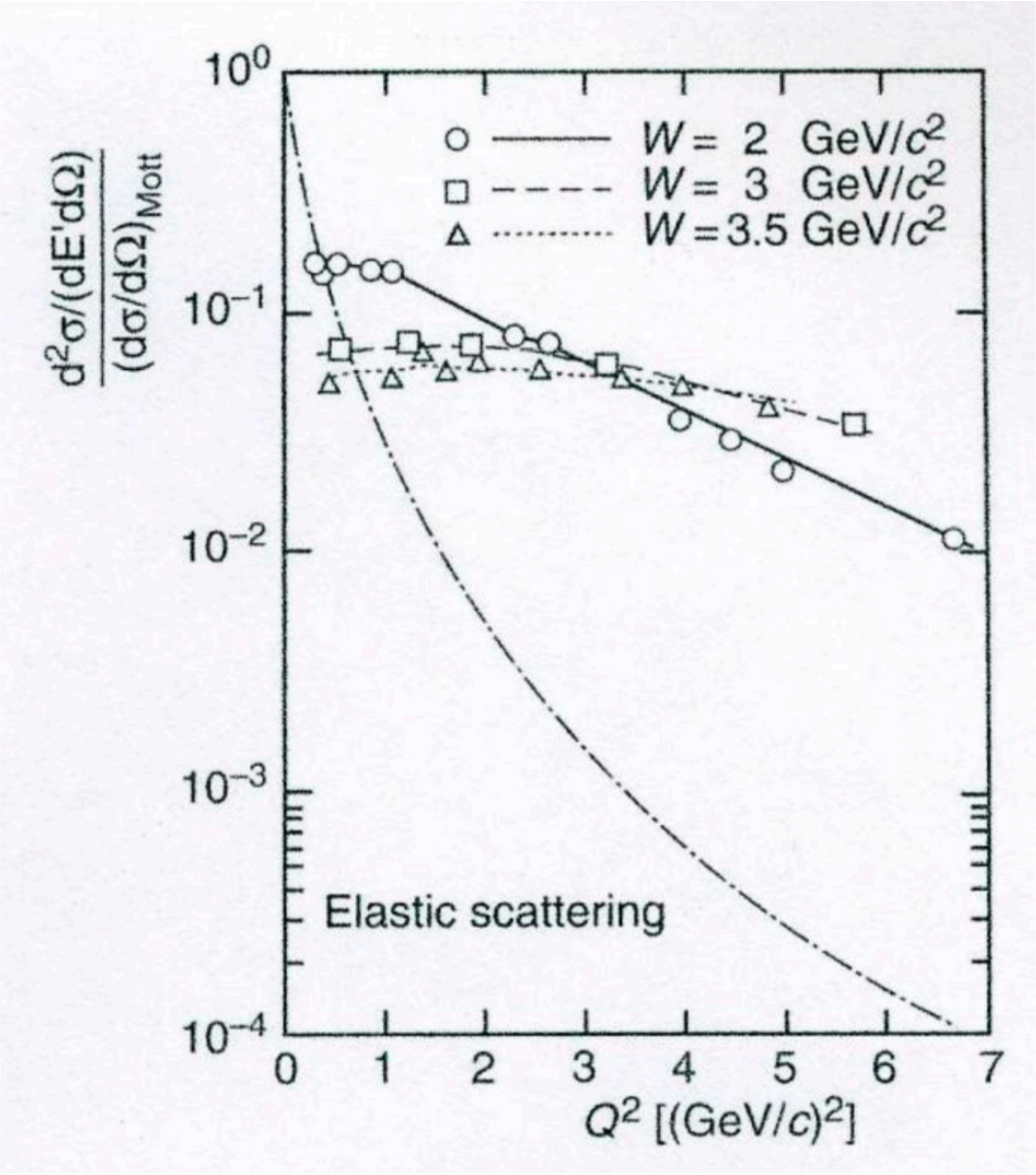
# e-p Elastic scattering




**$W = M_p$**

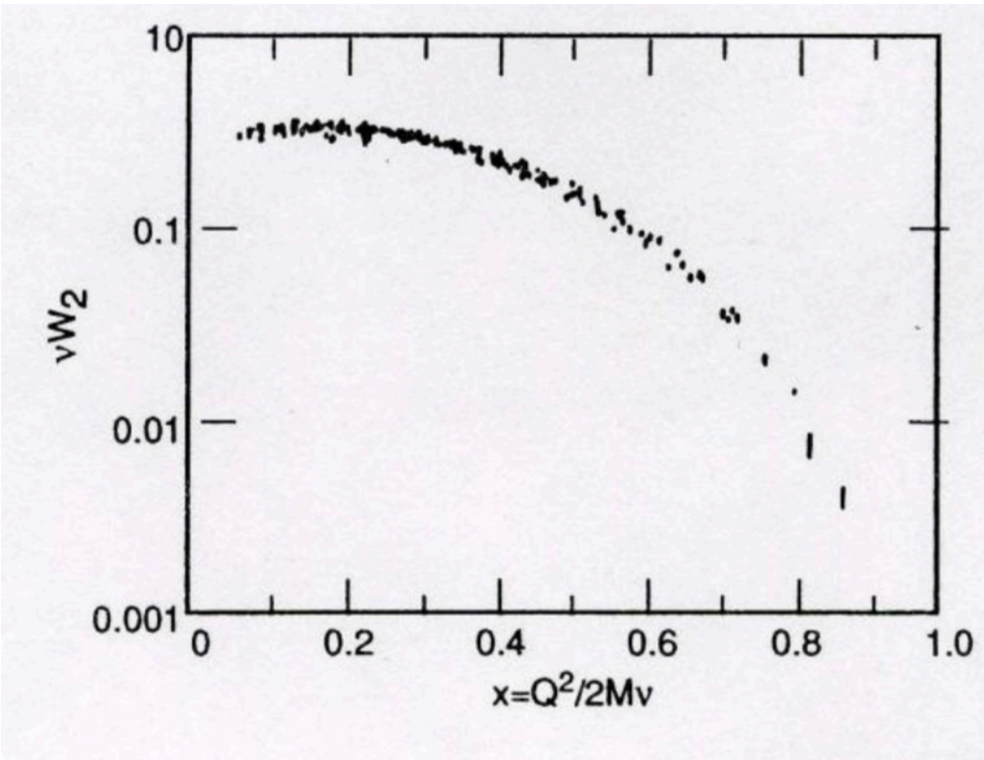
# e-p inelastic scattering

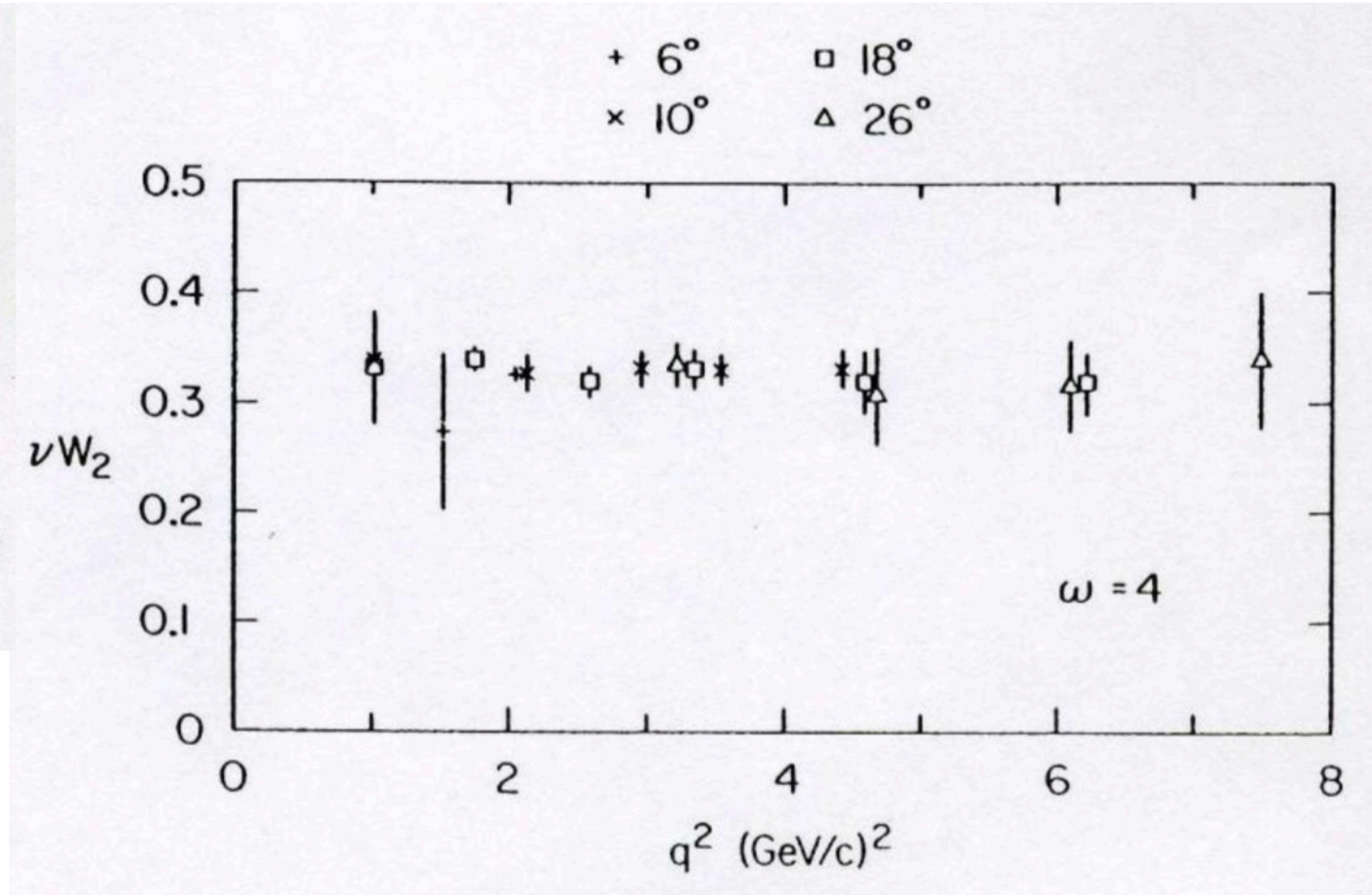
- Reminder: point-like particle in the parton! (valence quarks)




**Bjorken scaling**
**Invariance vs $Q^2$**

# Bjorken scaling

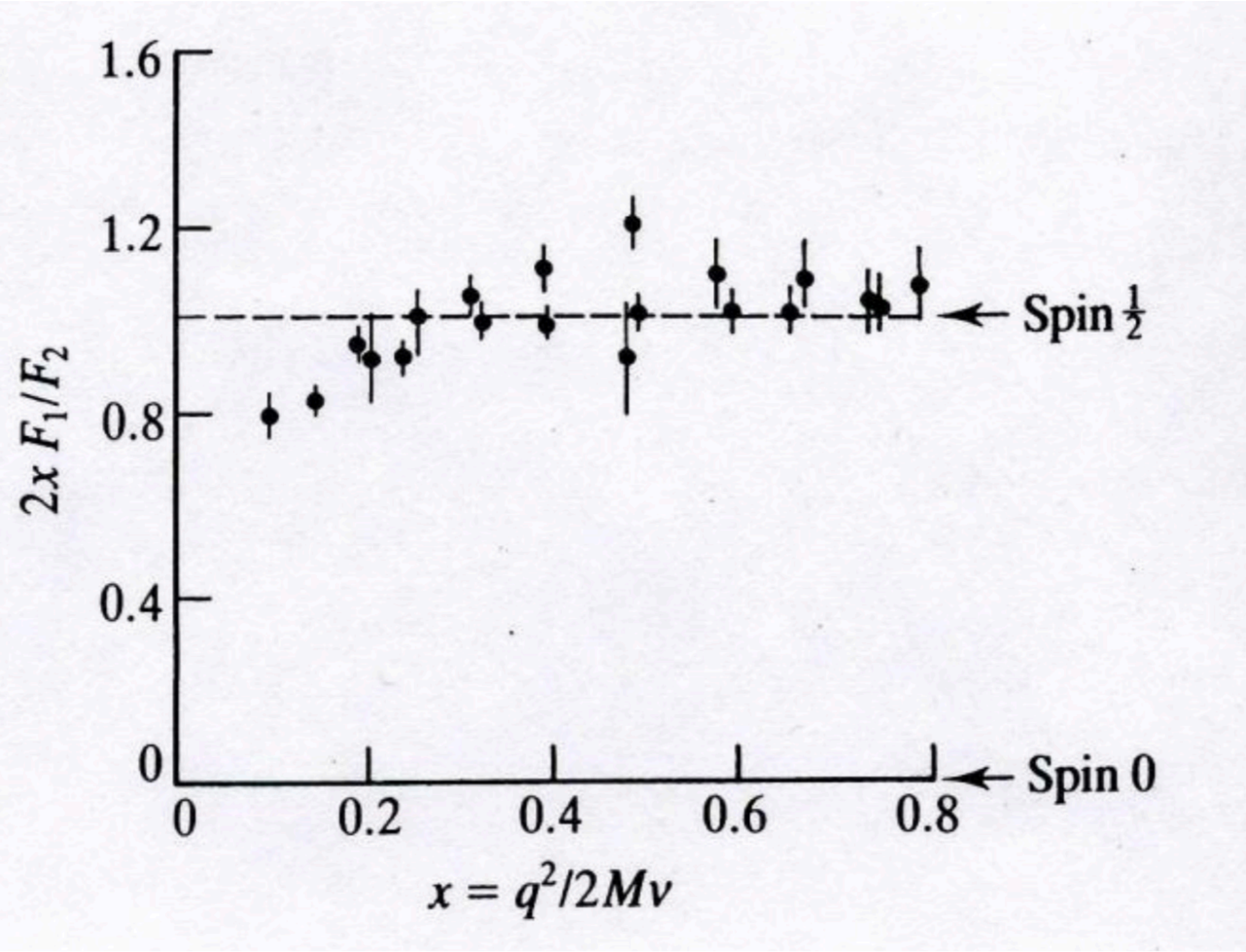



$\nu W_2$ depends on x

$\nu W_2$ does no depends on $Q^2$

# Quarks: a spin 1/2 particles



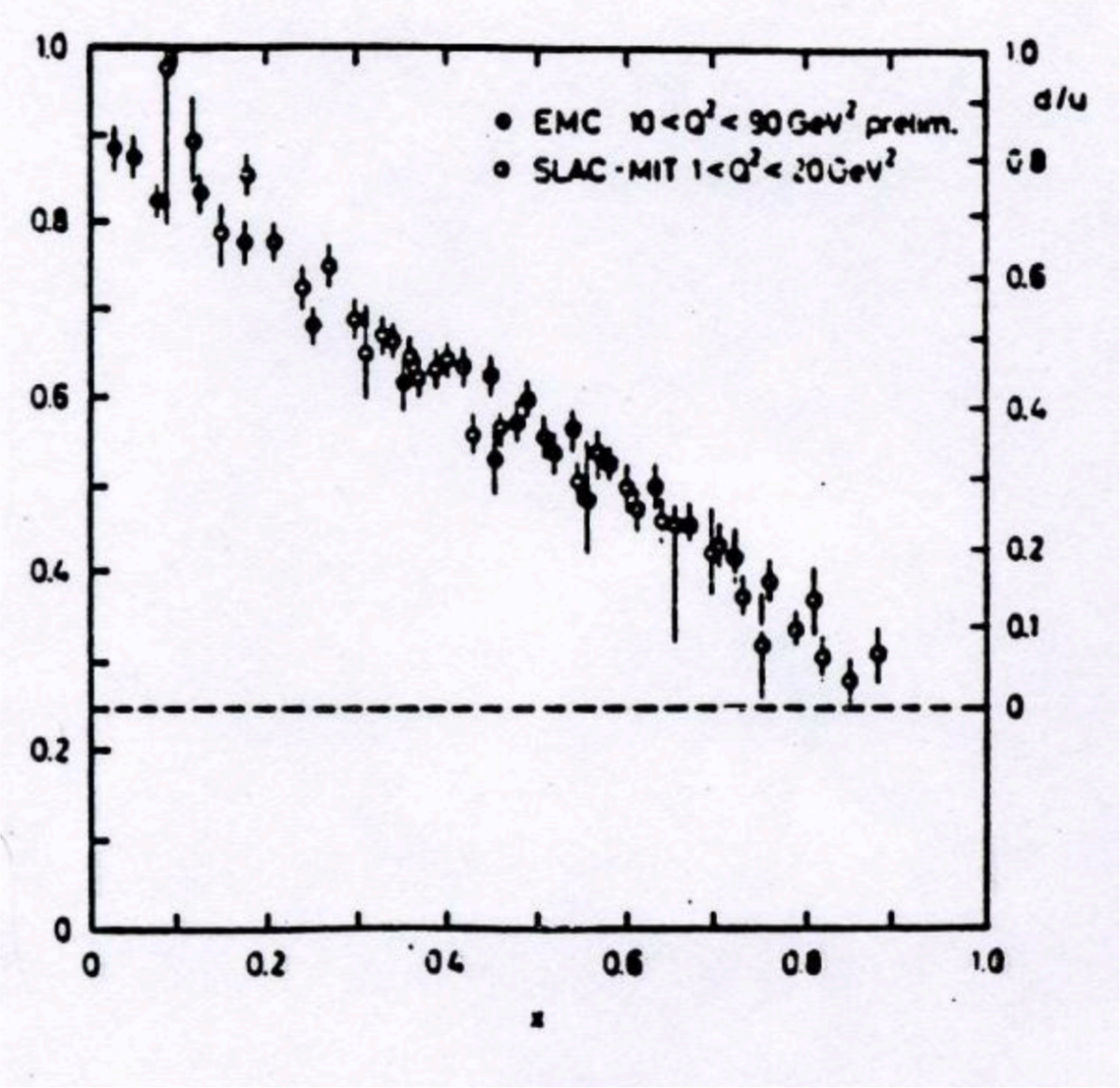
# Valence and sea quarks

$R_2 = F_2^{en} / F_2^{ep}$

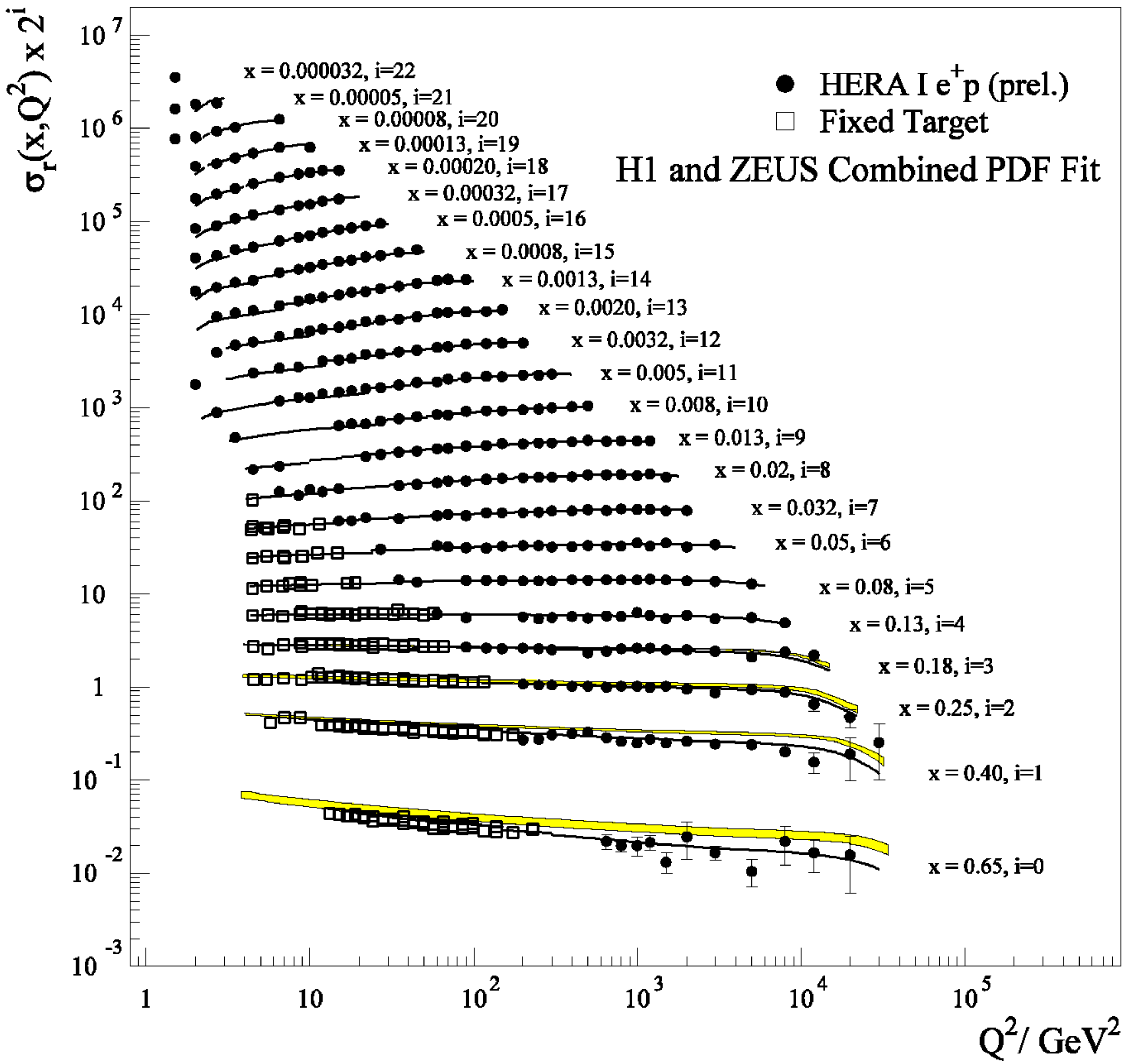
- low x: sea dominates $R_2 = 1$
- High x: $R_2 = 0.25$

demonstrates:

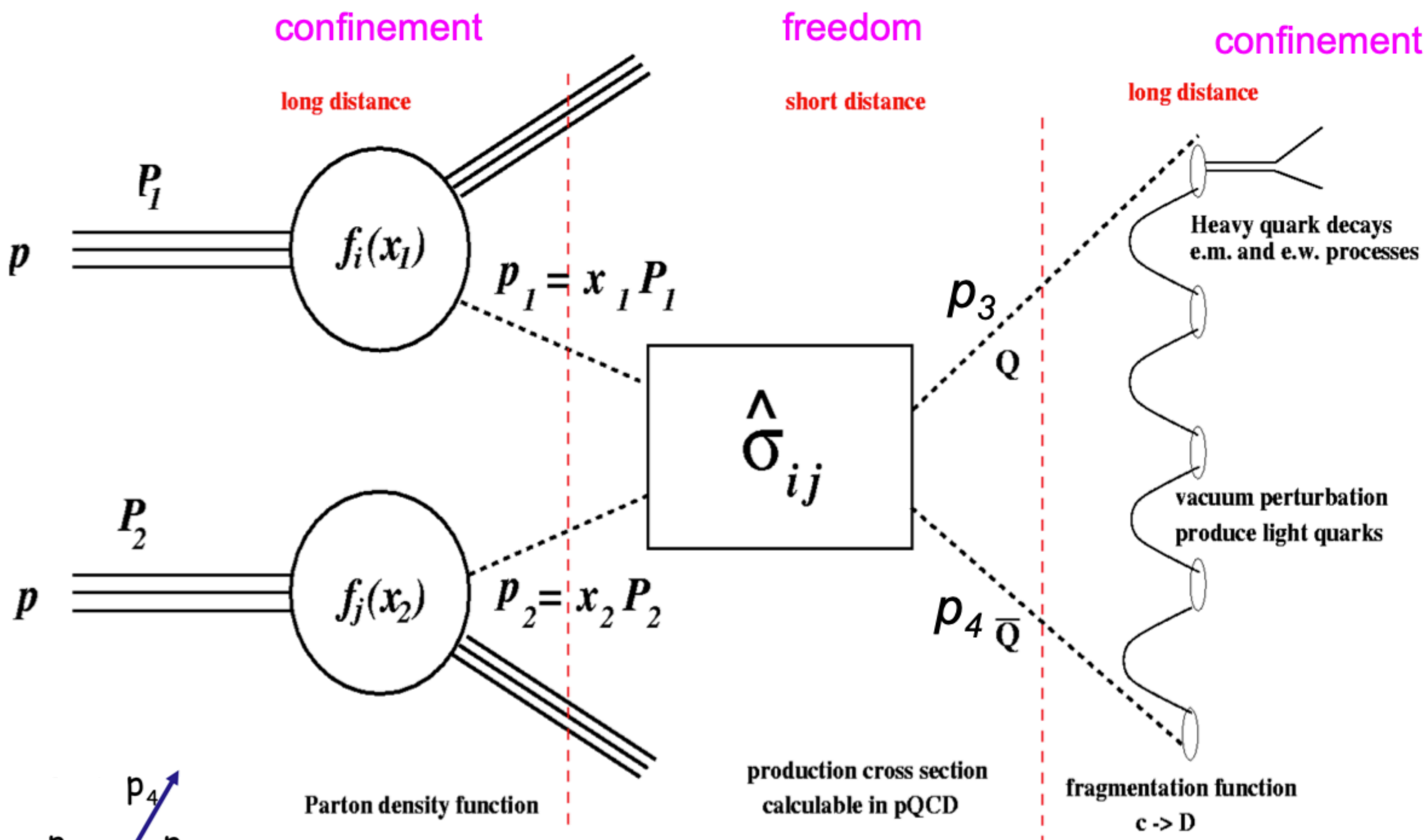
$d_v(x) / u_v(x) \sim 1\text{-}x$

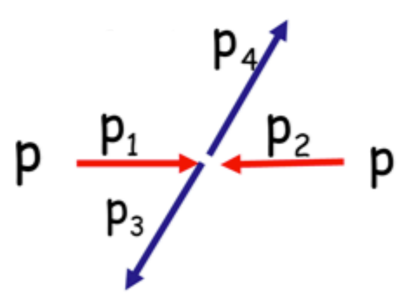


# Bjorken scaling violation



# QCD Factorisation theorem




a factorization scale $\mu_F$

a renormalization scale $\mu_R$

$$\sigma_{2\to n} = \sum_{a,b} \int_0^1 dx_a dx_b\, f_{a/h_1}(x_a, \mu_F)\, f_{b/h_2}(x_b, \mu_F)\, \hat{\sigma}_{ab\to n}(\mu_F, \mu_R)$$

# QCD Factorisation theorem

- According to QCD factorisation theorem
  - ✓ It exists a “factorisation scale” for which we can separate
    - ✦ long distance effects are included in pdfs
    - ✦ hard scatter process ( parton a + parton b —> n )
      - Cross section $d\hat{\sigma}$ computable at a renormalisation scale $\mu_R$) $d\sigma$
  - ✓ The “factorisation scale” is named $\mu_F$ is not well defined
    - ✦ Taken as the energy scale of the hard process
    - ✦ Varied in the computation of the systematic uncertainties in the cross section prediction

a factorization scale $\mu_F$

a renormalization scale $\mu_R$

$$\sigma_{2\to n} = \sum_{a,b} \int_0^1 dx_a dx_b \, f_{a/h_1}(x_a, \mu_F) \, f_{b/h_2}(x_b, \mu_F) \, \hat{\sigma}_{ab\to n}(\mu_F, \mu_R)$$

$f_{a/h1}$ : pdf of parton a in hadron h1

$f_{b/h2}$ : pdf of parton b in hadron h2

# From HERA to LHC pdfs ?

LO, $p_T[M] = 0$

$\Longrightarrow E = (x_1+x_2)\sqrt{s}/2\,,\;\; p_z = (x_1-x_2)\sqrt{s}/2$

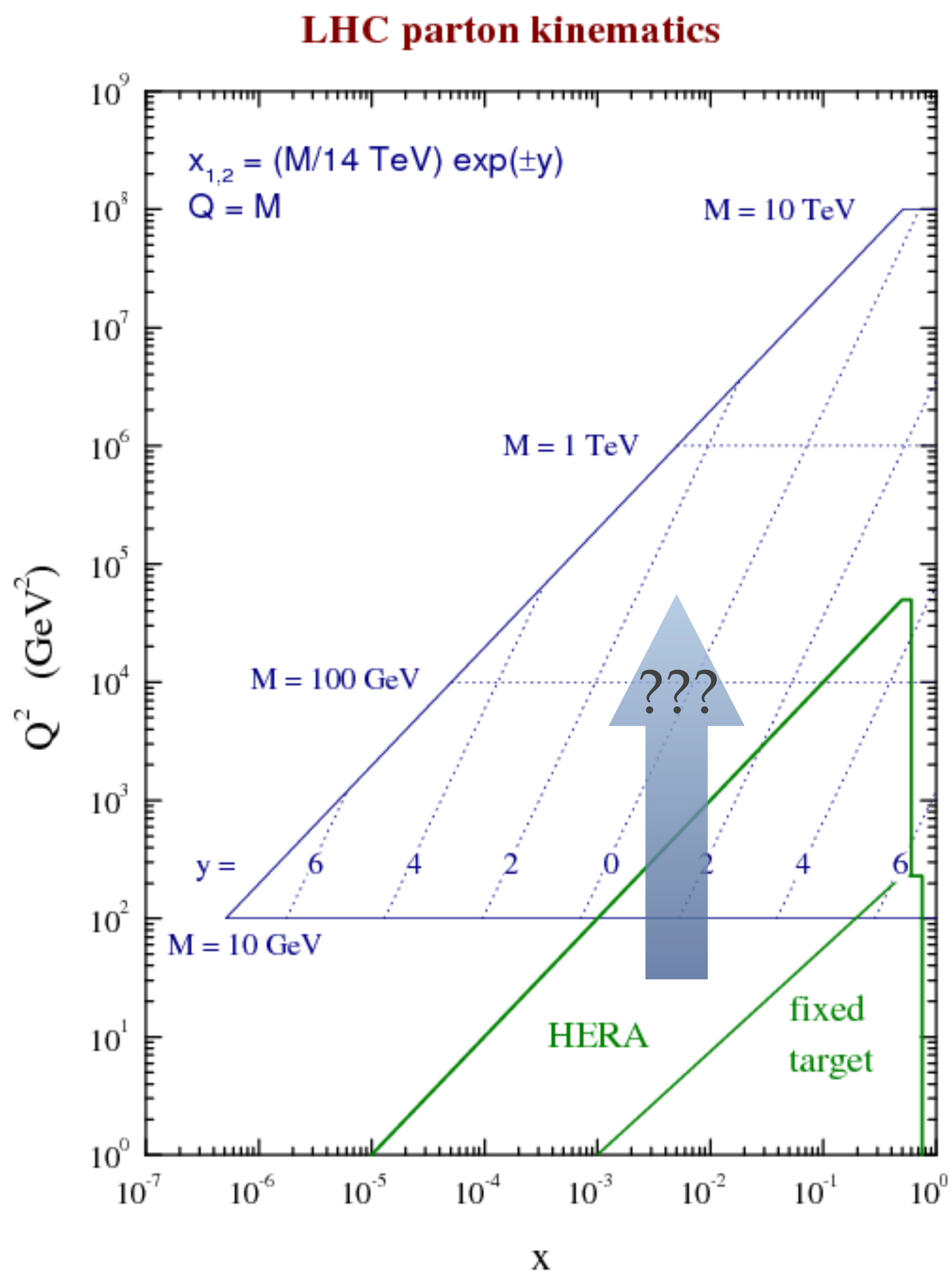
$M^2 = E^2 - p_z^2 = x_1\, x_2\, s$

$y = 0.5 \times \ln[\,(E+p_z)/(E-p_z)\,]$

$y = 0.5 \times \ln[\,(E+p_z)^2/M^2]$

$y = 0.5 \times \ln[\,x_1^2\, s/M^2]$

$$M^2 = x_1\, x_2\, s$$
$$x_1 = M/\sqrt{s}\, e^{y}$$
$$x_2 = M/\sqrt{s}\, e^{-y}$$

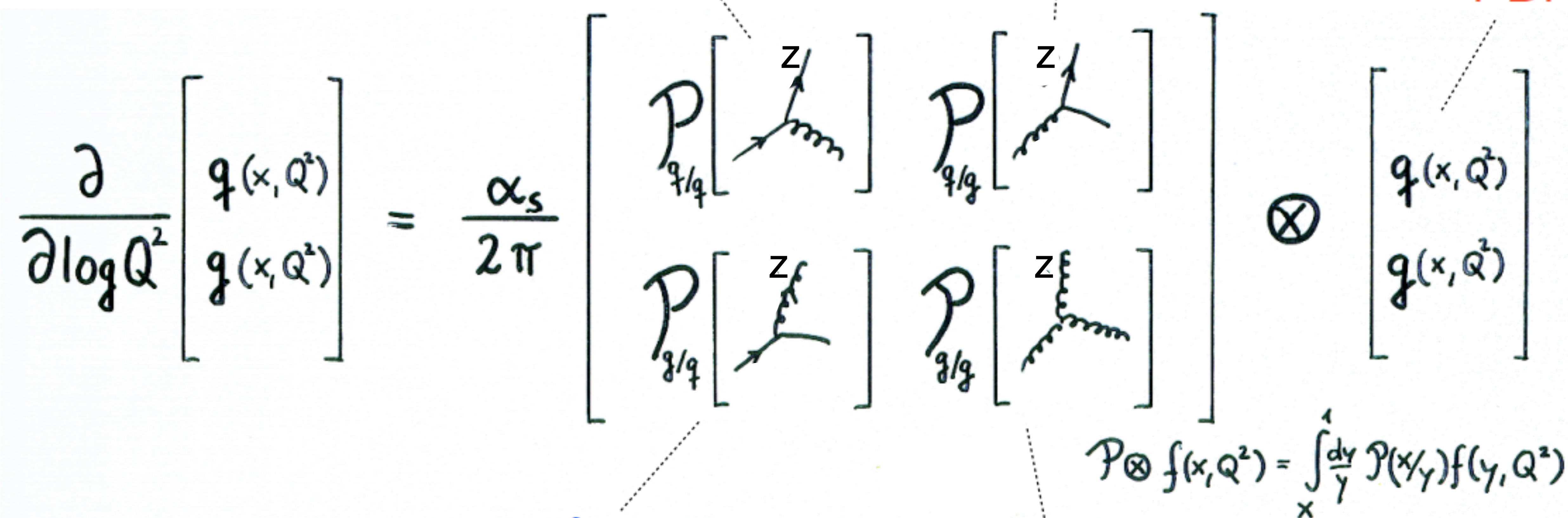


Dokshitzer, Gribov, Lipatov, Altarelli, Parisi

$$\frac{4}{3}\left[\frac{1+z^2}{1-z}\right]$$

$$\frac{1}{2}\left[z^2+(1-z^2)\right]$$

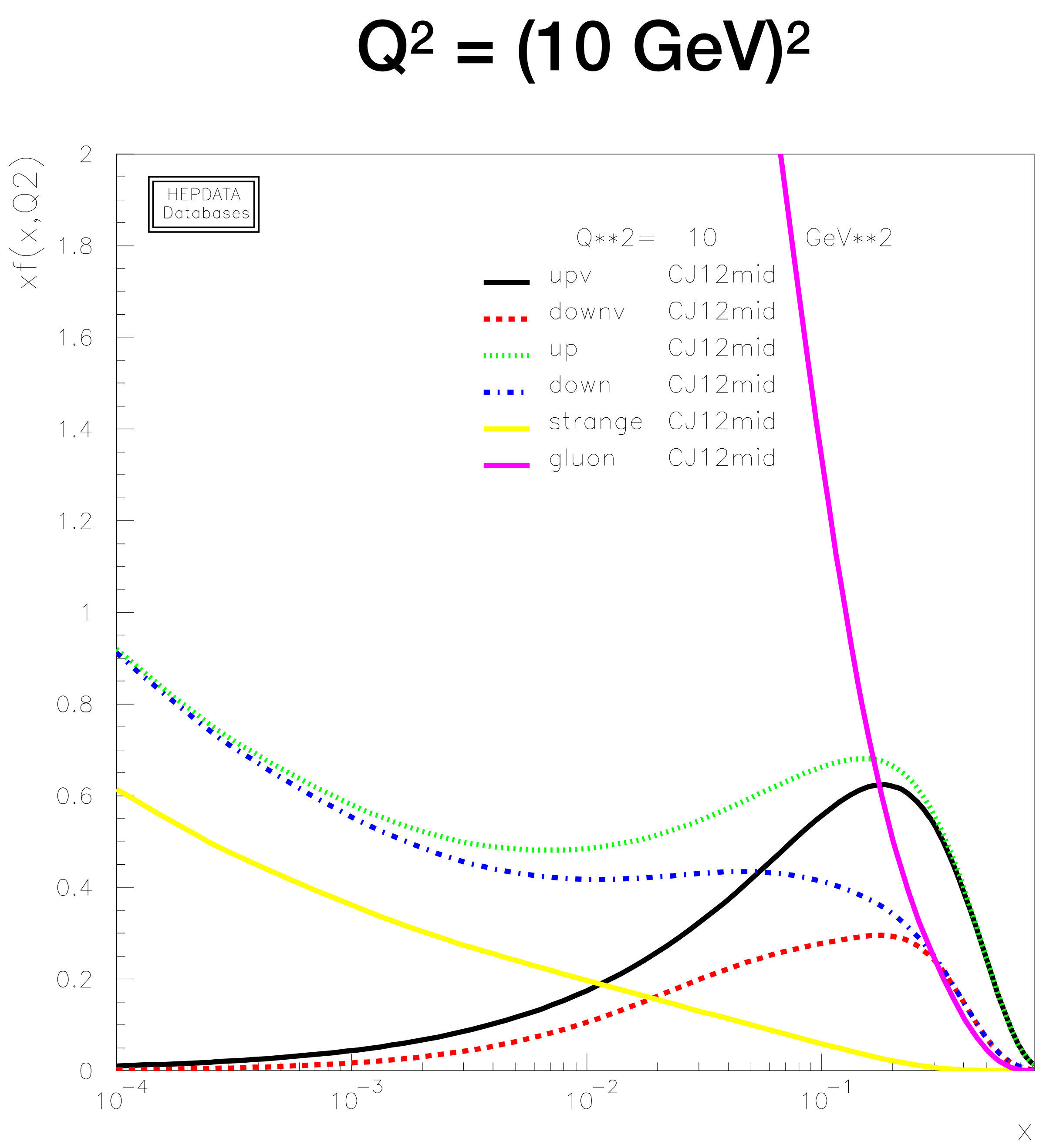
PDFs

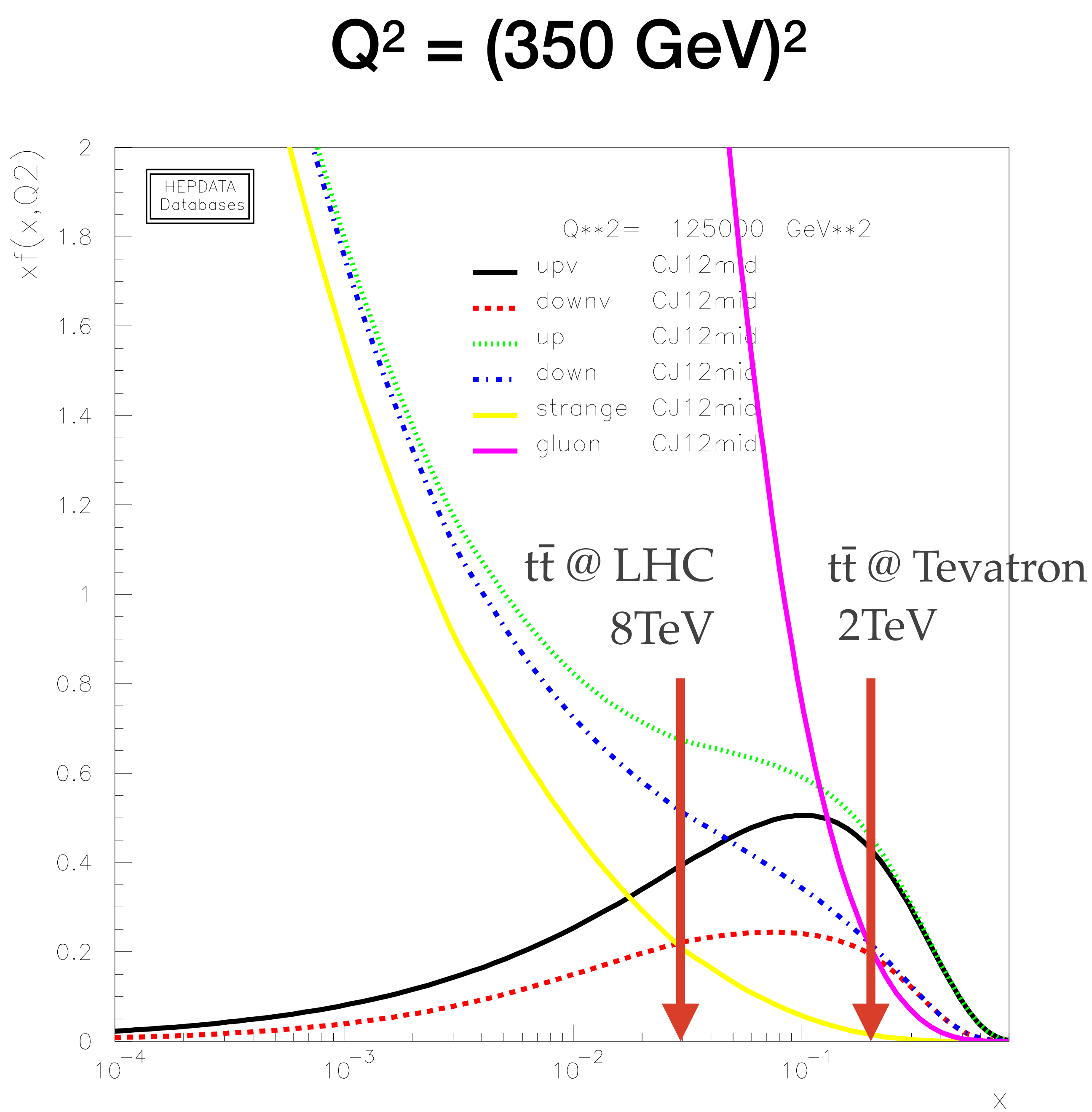



$$\frac{4}{3}\left[\frac{1+(1-z)^2}{z}\right]$$

$$6\left[\frac{z}{1-z}+\frac{1-z}{z}+z(1-z)\right]$$

# Parton density function recap




tt production threshold