DIS2001: Theory part

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for details look at
http://dis2001.bo.infn.it

DESY
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Where we are

HERA I   1992 - 2000   YOUTH

- main processes measured and analysed
- precise QCD calculations done
- new ideas/models formulated

HERA II   2001 -   MATURITY

- enormous increase in data taking
- more precise calculations
- real test for models
- discoveries

Parton distributions from global analysis

MRST parton distribution update (R. Thorne)

- fit with NLO DGLAP evolution from $Q_0^2 = 1\ GeV^2$

- 14 data sets, 1540 points, errors added in quadrature

- fit to new D0 jet data gives higher gluon at large x

$$xg(x, Q_0^2) \sim (1-x)^{5.6}$$

- negative gluon at Q_0^2 and low x, enforced by HERA data and momentum sum rule

- F_L dangerously small at smallest x, Q^2

- $\alpha_S(M_Z^2) = 0.117$ from jet data, $\alpha_S(M_Z^2) = 0.1205$ from sf data. Compromise in fit $\alpha_S(M_Z^2) = 0.119$

- new data much more restrictive

$$\Delta\sigma_W(LHC/\mathrm{Tev}) \approx \pm\ 2\%$$

Theoretical uncertainties

- full NNLO corrections (A. Vogt)

$$F_2(x,Q^2) = C \otimes f \qquad\qquad \partial f/\partial \log Q^2 = P \otimes f$$

$$\begin{aligned} C &= \quad C^{(0)} + \alpha_s\, C^{(1)} + \alpha_s^2\, C^{(2)} + \cdots \\ P &= \alpha_s P^{(0)} + \alpha_s^2\, P^{(1)} + \alpha_s^3\, P^{(2)} + \cdots \end{aligned}$$

$C_i^{(2)}$ computed, $P_{ij}^{(2)}$ promised by end of year.

- small x resummation $(\alpha_s^n \ln^{n-1}(1/x))$
- large x resummation $(\alpha_s^n \ln^{2n-1}(1-x))$
- low Q^2, higher twist:

$$F_2 = F_2^{LT}(x, \ln Q^2) + F_2^{HT}(x, \ln Q^2)\, M^2/Q^2 + \cdots$$

- nonlinear evolution equations: shadowing/saturation
- assumptions on the form of initial pds

How good is global fit (J. Collins)

- find global χ^2_{min} and corresponding χ^2_i for each data subset
- in the region of parameters $\chi^2 - \chi^2_{min} \approx \sqrt{2N}$ find $\chi^2_{i\,(min)}$ for each subset seperately
- if $\chi^2_{i\,(min)} < \chi^2_i$ considerable (by a few units) then the experiment i disagrees with global fit

This may be because important physics is neglected in global fit.

Pdf uncertaintes (D. Stump)

1. Traditional error analysis (Hessian matrix)

2. Constrained fitting (Lagrange multiplier)

Focus on uncertainty on physical quantity, e.g. σ_W, due to initial pdf.
Consider fits required to raise/lower σ_W by given amount.

Parton distributions from the lattice

(R. Petronzio)

Mean value on the lattice

$$< \mathcal{A} >= \int d\phi \; e^{S[\phi]} \; \mathcal{A}(\phi) = \sum_{\{\phi_i\}} \mathcal{A}(\{\phi_i\})$$

Lattice configurations $\{\phi_i\}$ well sampled.
For parton distribution

$$< h \,|\, \bar{\psi}(0) \; \Gamma \; \psi(\lambda \hat{n})) \,|\, h >$$

Lattice spacing corresponding to Λ_{QCD} sampled. Nonperturbative evolution $\Lambda_{QCD} \to \mu_0$.

2 years of computing, 100 computers, 12-15 Gflops. 3-4 days on future computers

Computed first moment of valence quark distribution in pion

$$\int_0^1 dx \, x \, q_V(x, 2.4 \text{ GeV}) = 0.28$$

15% higher than in experiment. Aim: 5% precision.

Polarized parton distributions

Found from polarized lepton-nucleon scattering

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

$$\Delta G(x,Q^2) = G_+(x,Q^2) - G_-(x,Q^2)$$

$\pm$ parton helicity along/opposite of nucleon helicity. Important for nucleon spin decomposition

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

L_z orbital angular momentum.

NLO global analysis of

$$g_1(x,Q^2) = C_q \otimes (\Delta q + \Delta\bar{q}) + C_G \otimes \Delta G$$

Difficulties: no flavour separation due to lack of charged current neutrino data. Semi-inclusive polarized DIS $lp \to lhX$ could help but large uncertainties for fragmentation function $D_q^h(z,Q^2)$.

Results: (D. Stamenov)

- $\Delta\Sigma$ quite well constrained in contrast to ΔG. Direct measurement of ΔG necessary.

- spin sum rule:

$$\frac{1}{2}\Delta\Sigma + \Delta G = 0.52 \pm 0.22$$

  Only more accurate determination of ΔG tells if $L_z \neq 0$.

- small x scattering with polarized protons would be important for understanding of spin propertites of nucleon

ΔG determination: need polarized gluons

$$\vec{l}\,\vec{N}: \qquad \gamma^* g \to q\bar{q} \qquad \gamma^* g \to c\bar{c}$$

$$\vec{p}\,\vec{N}: \qquad gq \to \gamma q \qquad gg \to q\bar{q}$$

(HERMES,RHIC,COMPASS) + new experiments.

Other issues discussed:

- $g_2(x, Q^2)$ sf, higher twist, no parton interpretation
(M. Anselmino)

- transversity $h_1(x)$: transverse polarized quark distribution, in transverse polarized nucleon.
Chiral-odd quantity needs chiral-odd partner
(D. Boer, A. Bacchetta)

- Collins fragmentation function, azimuthal asymmetry in $lN^{\uparrow} \to l\pi X$
(P. Mulders)

- Λ polarization in DIS, $lN^{\uparrow} \to l\Lambda^{\uparrow}X$, transverse spin transfer
(F. Murgia)

Generalized (skewed) parton distributions

Up to now diagonal parton distributions

$$f^q(x) \sim \int d\lambda\, e^{i\lambda x} \; < p \,|\, \bar{\psi}(0)\, \gamma^+ \, \psi(\lambda \hat{n})) \,|\, p >$$

Polarized parton distributions: $\gamma^+ \to \gamma^+ \gamma^5$.
Now

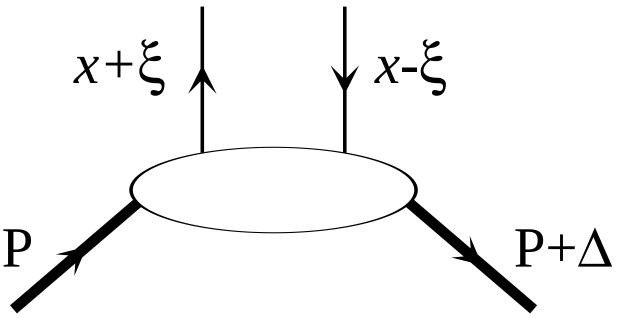
$$\int d\lambda\, e^{i\lambda x} \; < p' \,|\, \bar{\psi}(0)\, \gamma^+ \, \psi(\lambda \hat{n})) \,|\, p > =$$

$$= H^q(x,\xi,t)\, \bar{u}'\gamma^+ u + E^q(x,\xi,t)\, \bar{u}' \frac{i\sigma^{+\alpha}\Delta_\alpha}{2M} u$$

ξ is related to $\Delta = p' - p$, and $t = -\Delta^2$.

With off-diagonal elements full leading twist structure of the proton is studied.

(Overview by M. Diehl)



Forward limit: $H^q(x,0,0) = q(x)$

Elastic form factors: $\int dx\, H^q(x,\xi,t) = F_1(t)$

$$\int dx\, E^q(x,\xi,t) = F_2(t)$$

Proton spin: $1/2 = J_q + J_g$

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \frac{1}{2}\int dx\, x\{H^q(x,\xi,0) + E^q(x,\xi,0)\}$$

Similarly for gluons.

Evolution equations:

- $|x| > \xi$ DGLAP - like

- $|x| < \xi$ Brodski-Lepage - like

- NLO evolution is know

Processes sensitive to GPD:

- DVCS: $\gamma^* p \to \gamma p$

- timelike DVCS: $\gamma^* p \to \gamma_* p \to \mu^+ \mu^- p$ (Diehl/Berger)

- vector meson production: $\gamma^* p \to V p$

- inclusive diffractive sf at $M^2 \ll Q^2$ (T. Teubner)

Theoretical issues:

- NLO analysis (A. Freund)

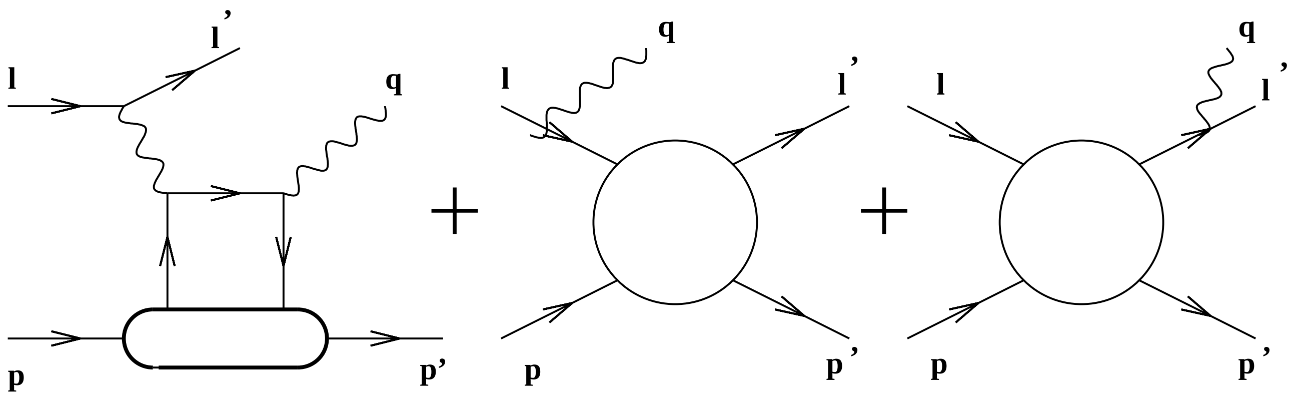
- GPD at large momentum transfer (P. Kroll)

- twist-3 from polarized lepton DVCS (D. Mueller)

- quark orbital angular momentum (J. Ralston)

(Constant $Q^2 F_2/F_1$ vs $Q F_2/F_1$ as seen by JLAB)

DVCS



T_{DVCS} $\qquad$ T_{BH}

Cross section

$$\int \frac{d\sigma}{d\phi} d\phi \sim \int |T_{DVCS} + T_{BH}|^2 = \int |T_{DVCS}|^2 + \int |T_{BH}|^2$$

where

$$T_{DVCS} \sim \int dx \left(\frac{1}{x - \xi + i\epsilon} + \frac{1}{x + \xi - i\epsilon} \right) H^q(x, \xi)$$

$$= \underbrace{i\pi H^{q+\bar{q}}(\xi, \xi)}_{Im} + \underbrace{I\!P \int \frac{dx}{x - \xi} H^{q+\bar{q}}(x, \xi)}_{Re}$$

Hard interactions

Issues addressed:

- Resummation of large logarithms

$$\sigma = \alpha_s L + \alpha_s^2 L^2 + \cdots + \alpha_s^n L^n + \cdots$$

  - heavy quarks: $\ln(p_T^2/m_Q^2)$ (S. Frixone)
  - X-sections at small x: $\ln(1/x)$ (N. Zotov)
  - thrust X-section: $\ln(1-T)$ (M. Dasgupta)

- NNLO calculations
  - for Higgs production (M. Grazzini)
  - general method (T. Gehrmann)

- MC issues:
  - small-x MC (L. Lönnblad)
  - merging NLO and PS (T. Schoerner, B. Poetter)

Problems

- b production in $p\bar{p}$, γp, $\gamma\gamma$,$\gamma^*\gamma^*$ scattering.
  NLO calculations give too small contribution.
  Different calculation schemes: k_T factorization ?

- small-x MCs based on CCFM branching for gluon radiation and k_T factorization

$$P_{gg}(z) = \frac{1}{z} + \frac{1}{1-z} + z(1-z) - 2$$

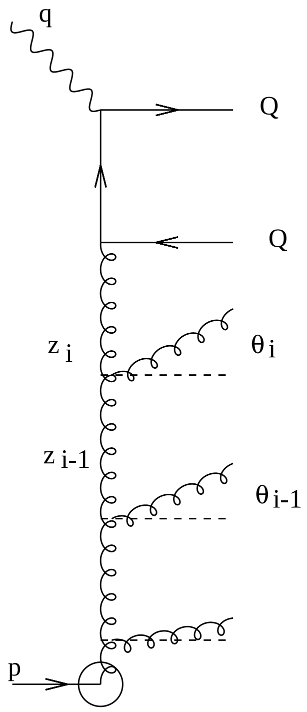
  Without finite term "everything" agrees (including bottom production). With finite terms forward jet production strongly suppressed.

- Local Parton Hadron Duality in multiparticle production (L. Zawiejski)

  - successful in inclusive single and two particle observables

  - fails in multiplicity fluctuations

CCFM branching



Angular ordering: $\theta_i > \theta_{i-1}$

Splitting function: $z = z_i / z_{i-1}$

$$P_{gg}(z) = \frac{\Delta_{NS}(z)}{z} + \frac{1}{1-z}$$

Off-shell $\gamma^* g \to q\bar{q}$ cross section. $(k_g^2 = -k_T^2 \neq 0)$

Small x and diffraction

Discussed problems:

- Collinear versus k_T factorization (J. Collins)

$$F_2 = C \otimes pdf \qquad\qquad F_2 = \int dk_T\, \phi(k_T)\, f(k_T)$$

f unintegrated gluon distribution, ϕ impact factor

- NLO in $\ln(1/x)$ computation of impact factor ϕ (S. Gieseke)

- k_T factorization formula and dipole picture

$$F_2 \sim \int dzdr\, \psi^*(r,z)\, \sigma_{qq}(r,x)\, \psi(r,z)$$

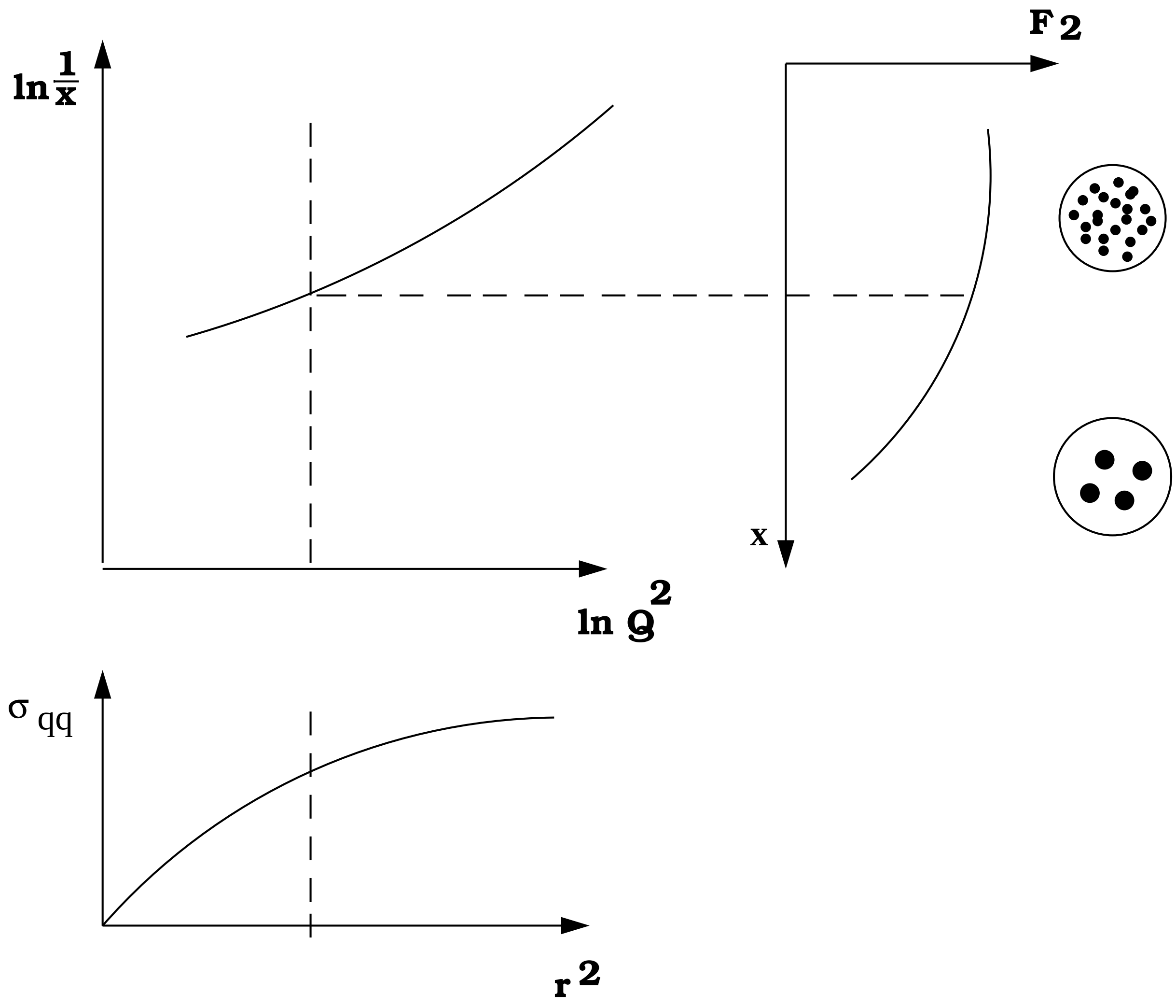
for small r:

$$\sigma_{qq}(r,x) \sim r^2\, xg(x, c/r^2)$$

for large r modelling, e.g. saturation model:

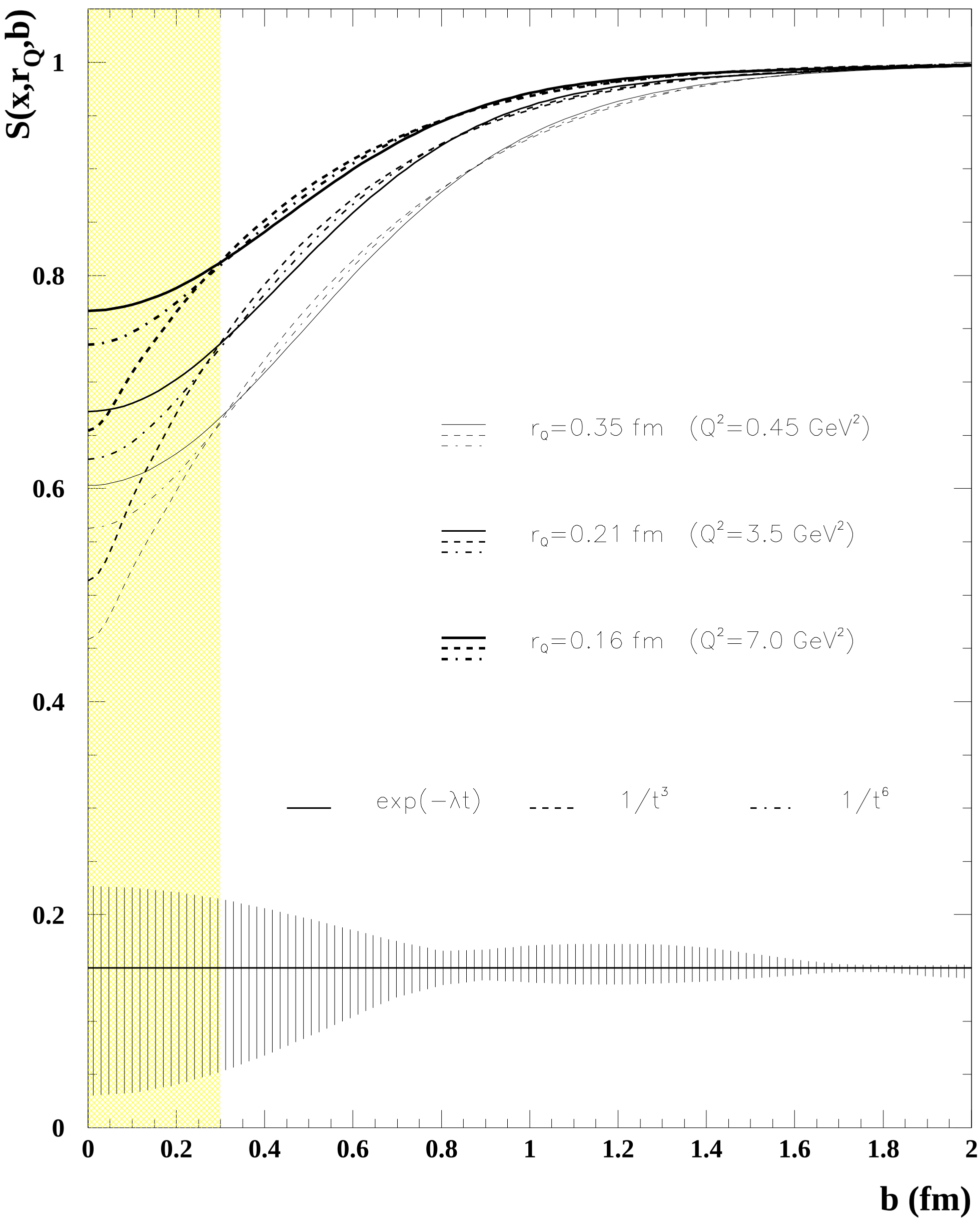
$$\sigma_{qq}(r,x) \to \sigma_0$$

- saturation, what does it mean ? (Golec-Biernat, Schildknecht, Lublinsky)



- new look at saturation/unitarity limit (A. Staśto)

Extract S matrix describing $q\bar{q}-p$ scattering from t-dependence of diffractive vector meson production. If $S(x,r,b) \approx 0$ unitarity limit is reached.



- black body/unitarity limit in DIS at small x at large nucleus (V. Guzey)

- diffractive parton distributions extracted from saturation model (K. Golec-Biernat)

- skewed parton distributions in F_L^D at $\beta \to 1$ (T. Teubner)

- odderon (G.P. Vacca, I. Ivanov, T. Golling)

Odderon

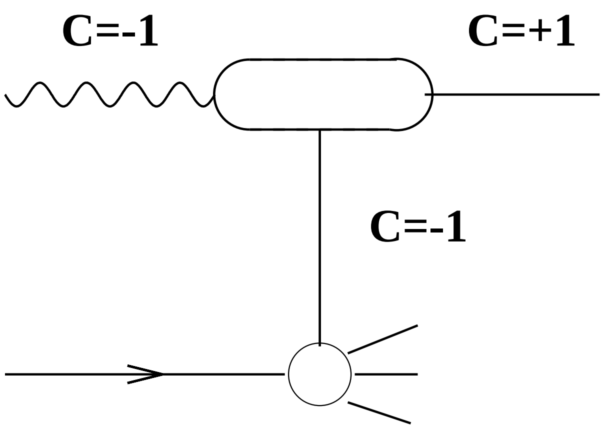
Pomeron:

describes in high energy limit exchange with vacuum quantum numbers: $C = +1 \quad P = +1$

Odderon:

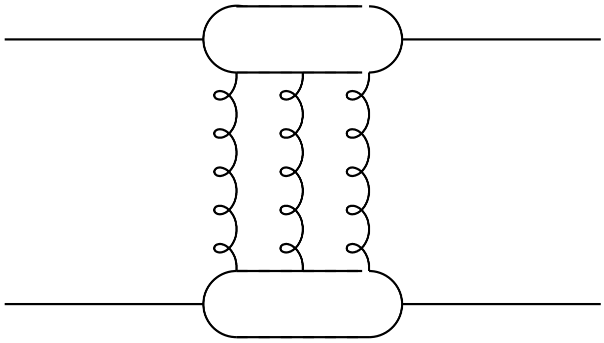
charge conjugated partner of Pomeron: $C = -1$
$P = -1$ (photon quantum numbers)

Can be seen in: $\sigma_{pp} - \sigma_{p\bar{p}}$ diffraction



$$\gamma\, p \to \{\pi^0\ ,\ \eta\ ,\ \eta_c\ ,\ f_2\} + X$$

Odderon in QCD



Bound state of three gluons exists with $\alpha_{odd}(0) = 1$.
(Bartels, Lipatov, Vacca)
Also nonperturbative odderon from Heidelberg QCD vacuum model.

η_c production

Kwiecinski et al.: 3 noninteracting gluons, $\sigma = 1$ pb

Vacca et al.: bound state of 3 gluons, $\sigma = 11$ pb

π_0 production

Golling: H1 experiment $\sigma_{\pi_0} < 39$ nb,
with Heidelberg odderon $\sigma = 400$ nb

Summary

It was exciting meeting showing strong interest of our community in future developments.

Awaiting new HERA II data we have to rethink our ideas, also in terms of better presentation.

Appologies

for incomplete coverage of topics and contributions