Low-x and diffraction: an experimental review

R. Yoshida Argonne National Laboratory
DIS 2002, Krakow: 30 April

Not meant to be at all exhaustive !
(or even balanced !)

- Inclusive diffraction: a parable
- Low-x structure function: nature of soft-hard transition
- Leading baryon production: factorization properties
- Diffraction in hadron-hadron interactions
- Impact parameter and DIS
- Summary
- "Conclusions"

Inclusive diffraction

(a parable)

$$\frac{d^3\sigma^{diff}}{dx\,dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{xQ^4}(1 - y + y^2/2) \quad F_2^{D(4)}(x, Q^2, x_{IP}, t)$$

Hard diffractive factorization: $F_2^{D(4)} = \sum_i C_i \otimes f_i^D(x, Q^2, x_{IP}, t)$

Diffractive parton densities:

Parton densities conditional on proton variables x_{IP}

and t

The dpdf's obey the usual DGLAP equations...

But, unlike the usual pdf's, dpdf's "know" something about the whole proton

The actual experimental measurement: apparent Regge factorization →

Inclusive diffraction

The experimental data were shown to be amenable to the interpretation:

$$F_2^{D(3)} = f_{IP/p}(x_P) F_2^{IP}(\beta, Q^2)$$

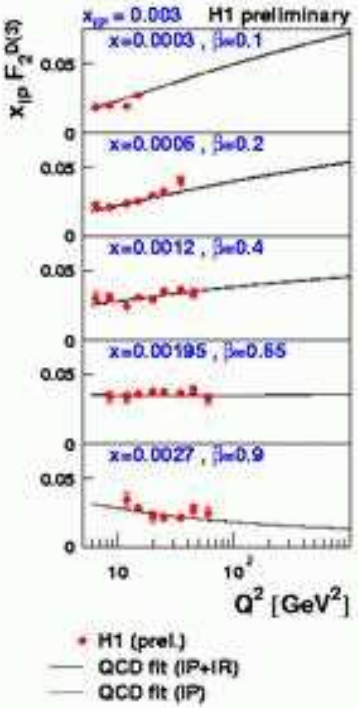
Pomeron structure function

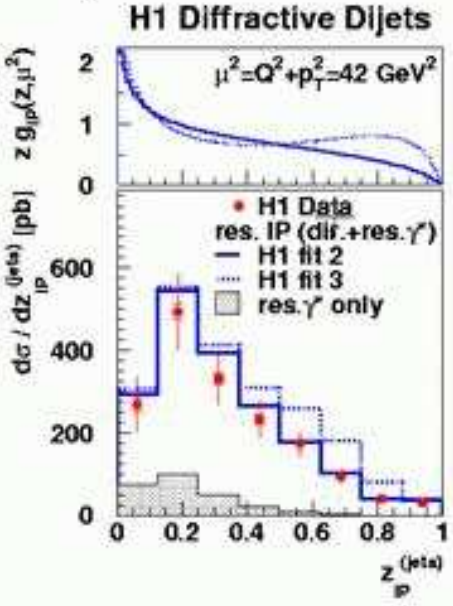
Pomeron flux factor

$$f_{IP/p} \approx \frac{1}{x_{IP}^{1+\delta}}$$

Triple Regge expectation

DGLAP analysis → pdf for Pomerons





What does this interpretation say in words?

Inclusive diffraction

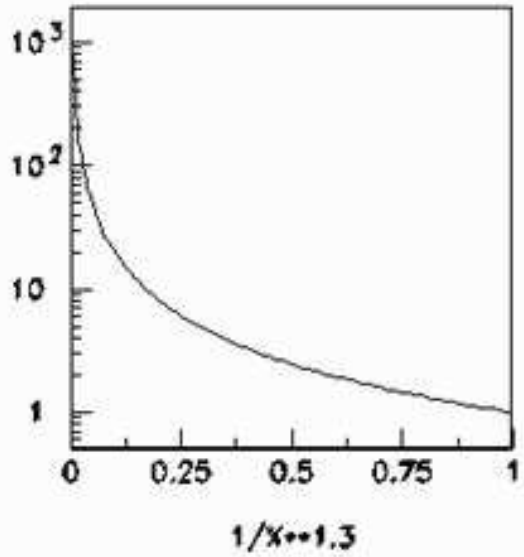
What does the diff. pdf know about the proton?

The partons inside the proton organize themselves into a color singlet object (the Pomeron) with probability $1/x_{IP}^{1+\delta}$

This is a statement about correlations of partons in the proton!
(Result of some complicated non-pert. dynamics?)

The flux comes from triple Regge theory but...

Looks like some kind of Bremsstrahlung spectrum



Is something "simple" going on?

Inclusive diffraction

In the dipole picture:

Photon wave function

$$\frac{d\sigma^D}{dt}\Big|_{t=0} = \frac{1}{16\pi}\int d^2\rho \int_0^1 dz \; |\Psi(z,\rho,Q^2)|^2 \sigma^2(x,\rho)$$

Size of dipole

Dipole cross-section

In the Golec-Biernat-Wuesthoff (GB&W) model:

$R_0^2(x) = 1/Q_0^2 \cdot (x/x_0)^\lambda$ ← Separation of gluons 1/(gluon density)

$$\sigma(x,\rho) = \sigma^0[1 - exp(-\frac{\rho^2}{4R_0^2(x)})]$$

Cross-section controlled by ratio of dipole size to gluon separation

Inclusive diffraction

It turns out that:

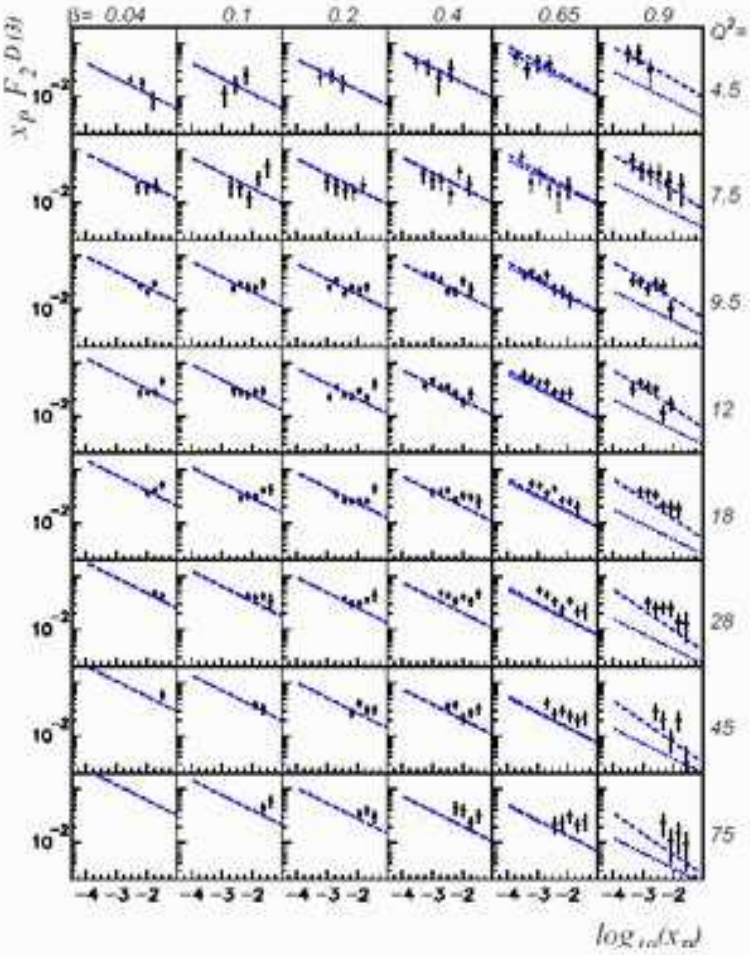
GBW dipole cross-section corresponds to a "Regge factorization"

$$f_{IP/p} \approx \frac{1}{x_{IP}^{1+\delta}}$$

$$\delta = \lambda = 0.29$$

A consequence of "geometrical scaling"

H1 data



Inclusive diffraction

In the GB&W model, the mysterious Pomeron flux, and the Pomeron itself turns out to be patterns that naturally arise from the simple geometrical relationship between the density of partons and the effective size of the virtual photon.

Moral of the parable...

Diffractive parton densities

A simple behavior of an apparently complex object in one language

Bremsstralung-like

Pomeron flux (parton correlations)

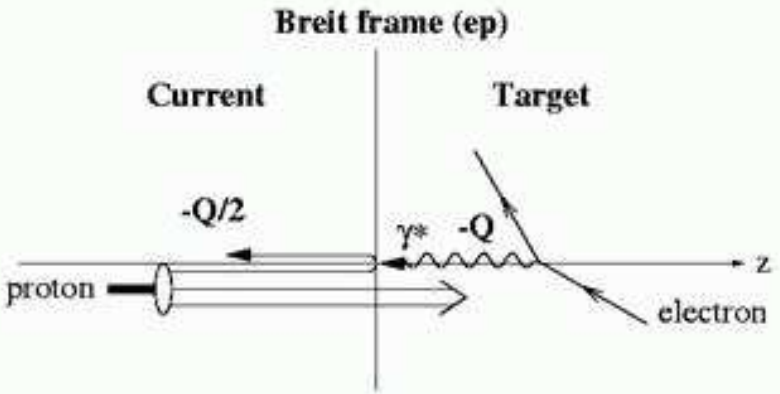
corresponds to a rather simple picture in another language

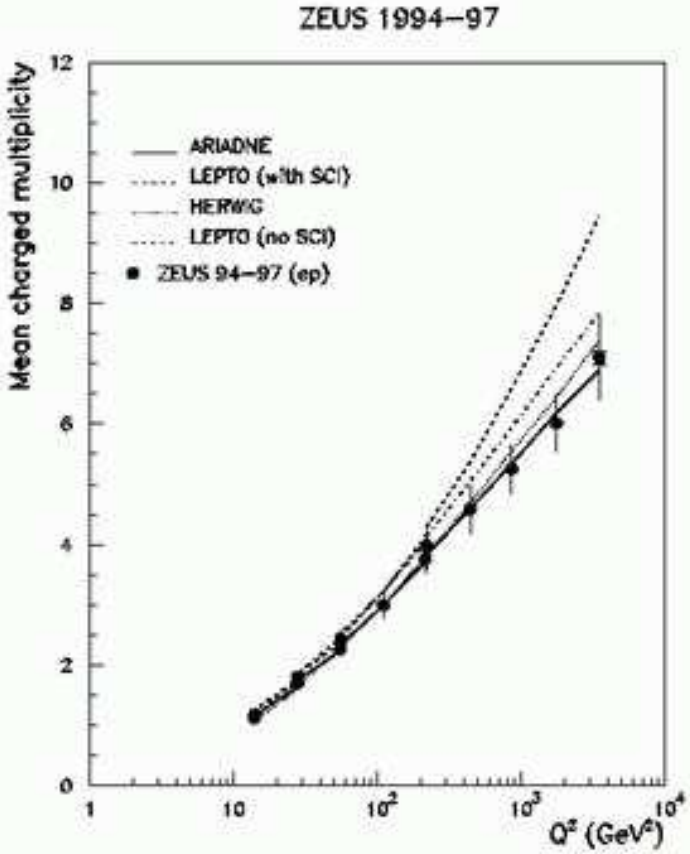
Dipole cross-section

What about other kinds of data?

Low-x structure function

Actually, let's start with hadron multiplicities...





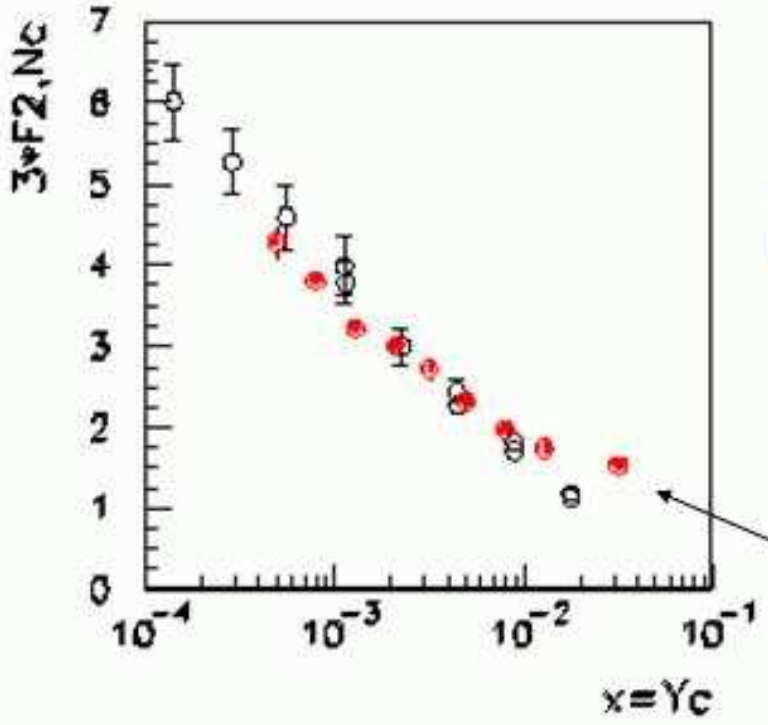
Q is the available energy to produce Hadrons.

Energy **2 ~ 1/x

Evolution in 1/x!

Low-x structure function

How do you choose the x scale? There are many choices, but...



Resolution scale

$$Y_c = (Q_c/Q)^2$$

LPHD infrared cutoff = ~500 MeV

Lupia and Ochs (hep/ph/9711255)

And...

x = Yc : compare with F2

ZEUS 96-97 F2 (Q2=22 GeV2)

Low-x structure function

"the picture"

$$F_2 \propto \sigma_{tot} \propto f < n >$$

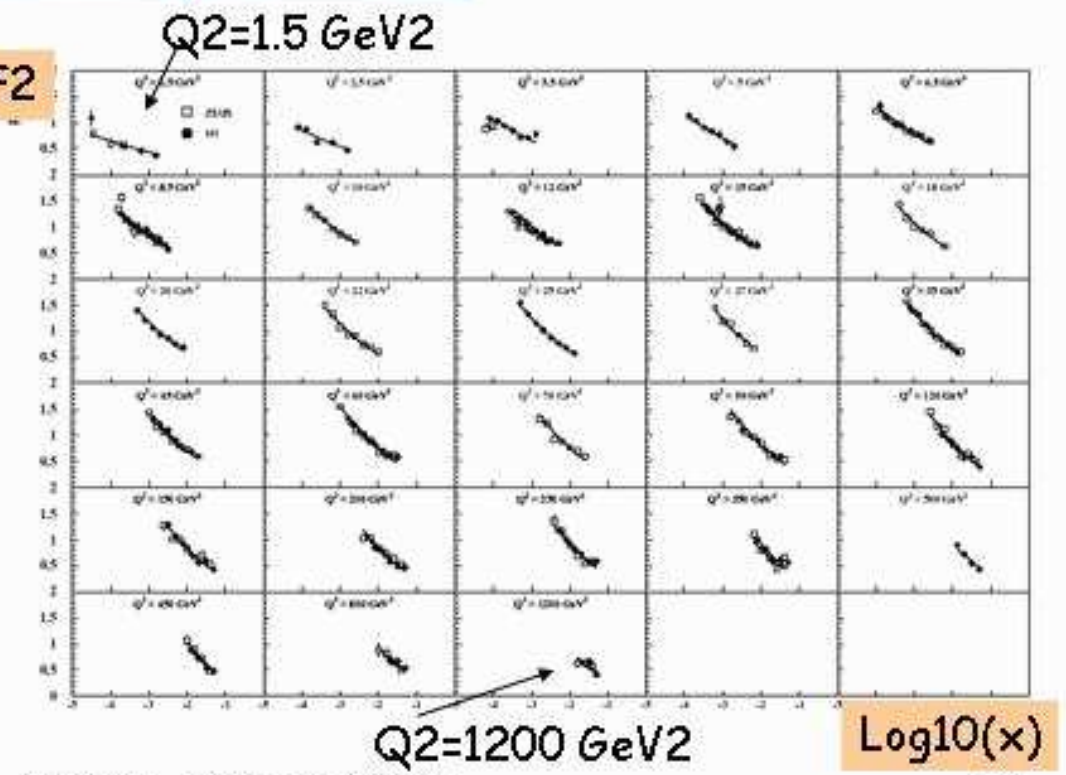
Number of "partons"

Probability to interact

De Roeck and De Wolf
hep-ph\9609203

MLLA fit to F2

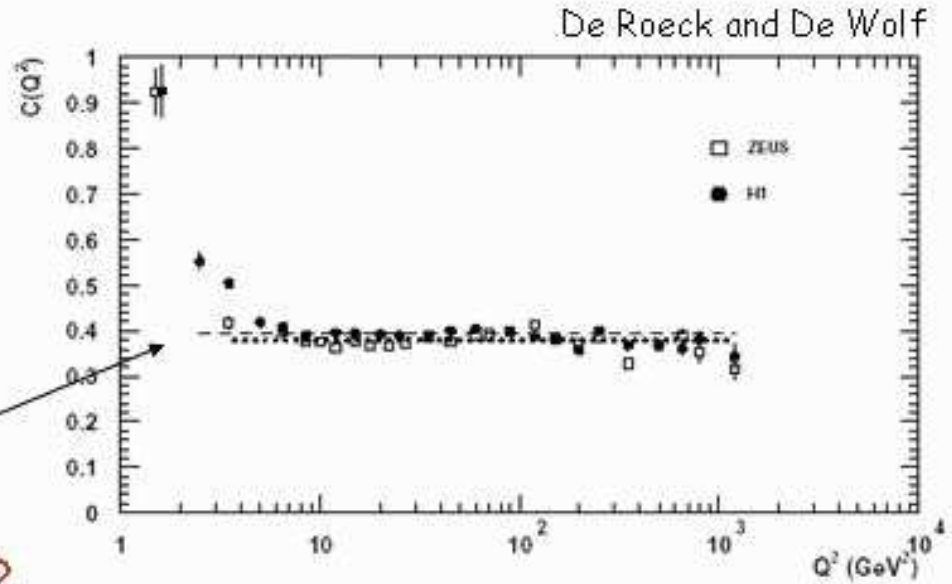
Normalization factor
for each Q2:



Low-x structure function

Normalization:

Begins to deviate from around 5 GeV2



Did we learn something?

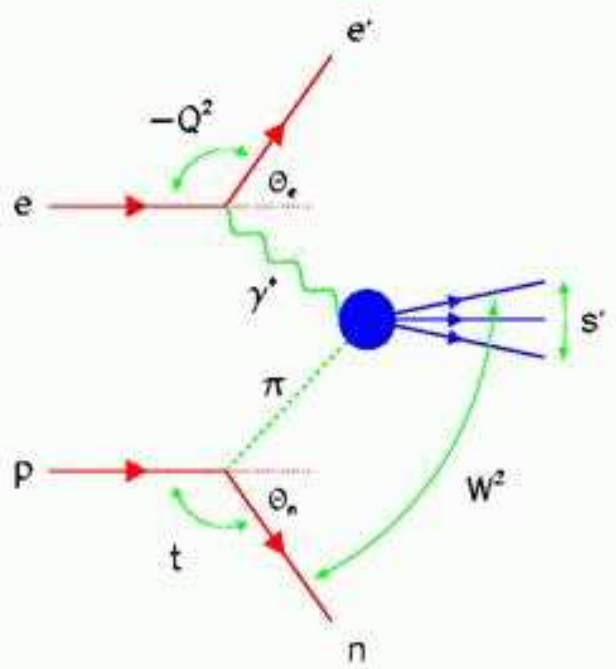
1. One rising curve looks much like another(?) ... or

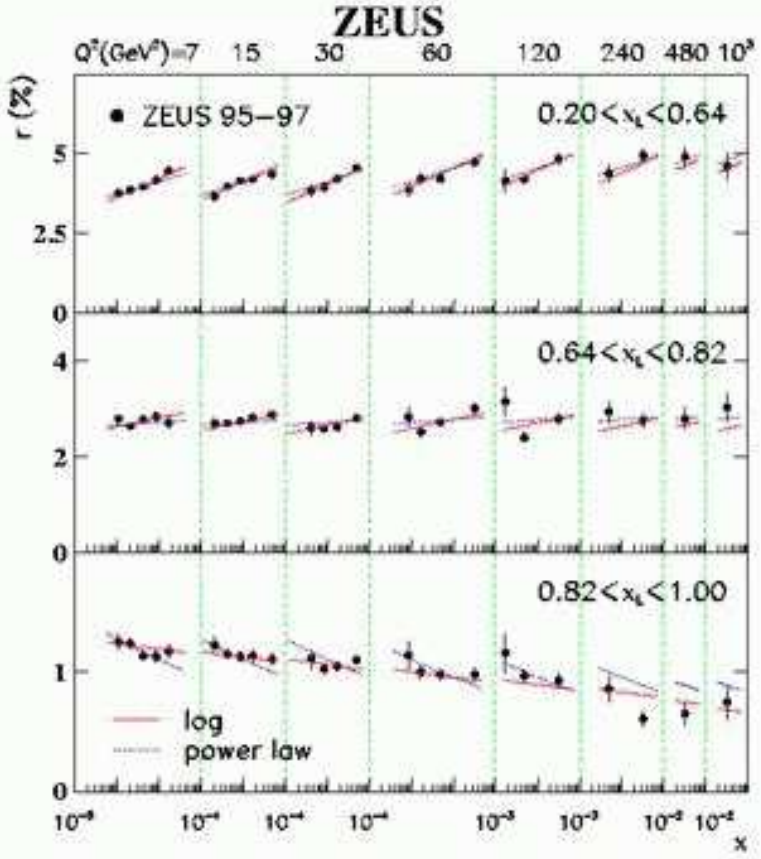
2. Transitions (from one dynamic to another) maybe very smooth.

Leading baryon production

Leading neutrons:

Ratio to total DIS





Leading baryon production

Leading neutrons:

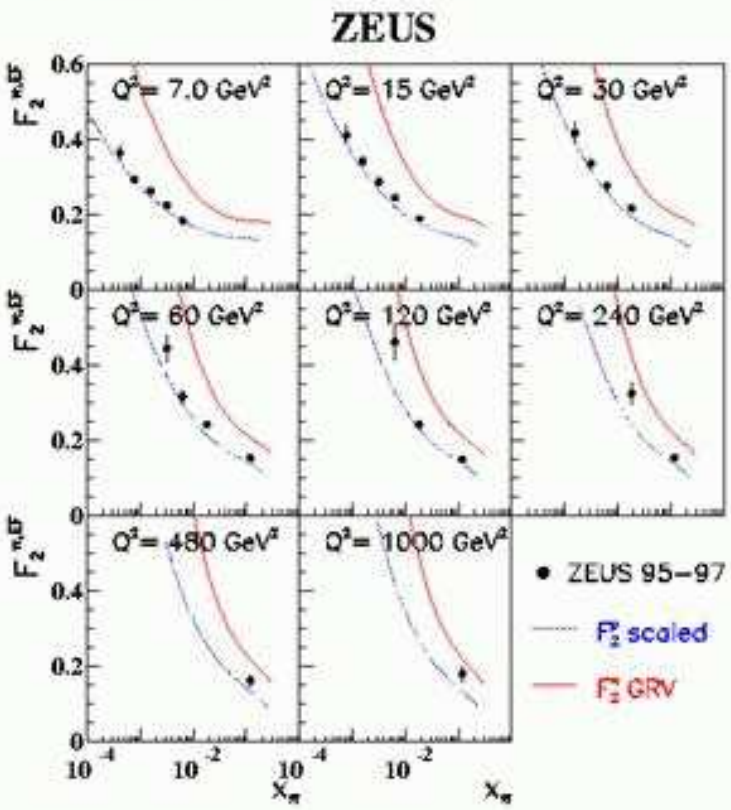
Norm. ambiguous

If analyzed in terms of One Pion Exchange:

Leads to a pion structure which is like the proton structure.

Fits in with $\sigma_{tot} \propto f < n >$ idea just discussed!

But this is exactly like the Pomeron structure analysis !



Leading baryon production

What are we saying here?

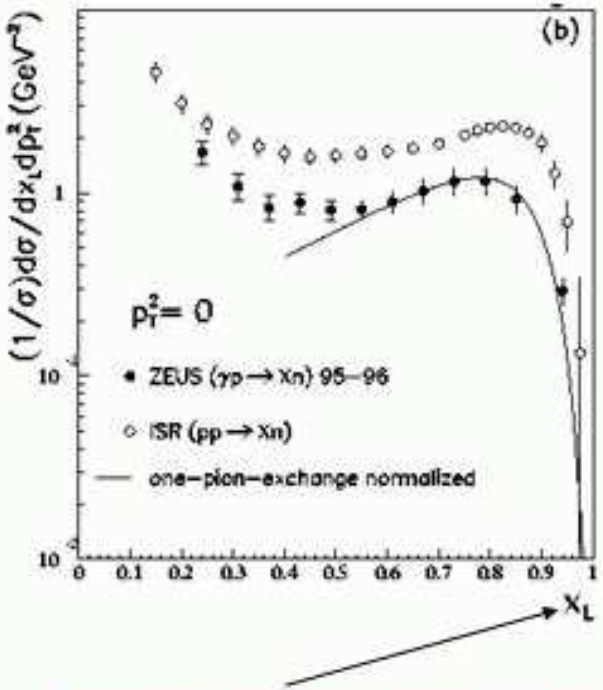
Leading neutrons:

"Protons are organized into a neutron and a pion with a flattish momentum sharing."

AND

This structure persists smoothly into the Deep Inelastic Region.

i.e. as hadron-hadron become (virtual) photon-parton collisions!



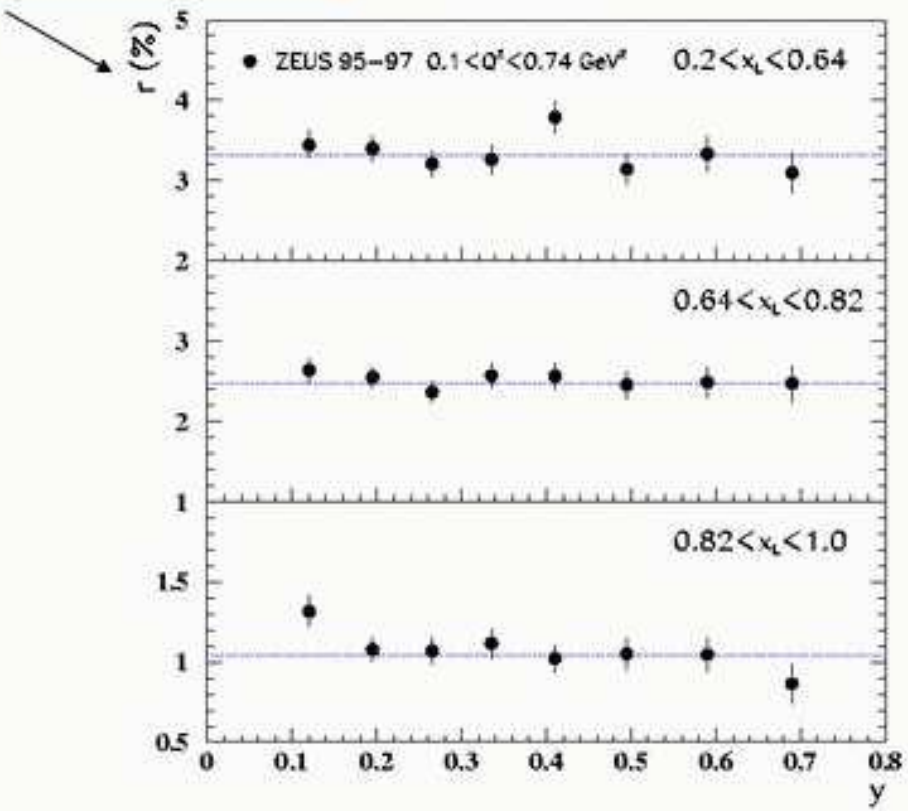
1-XL is the "pion" mom. frac.

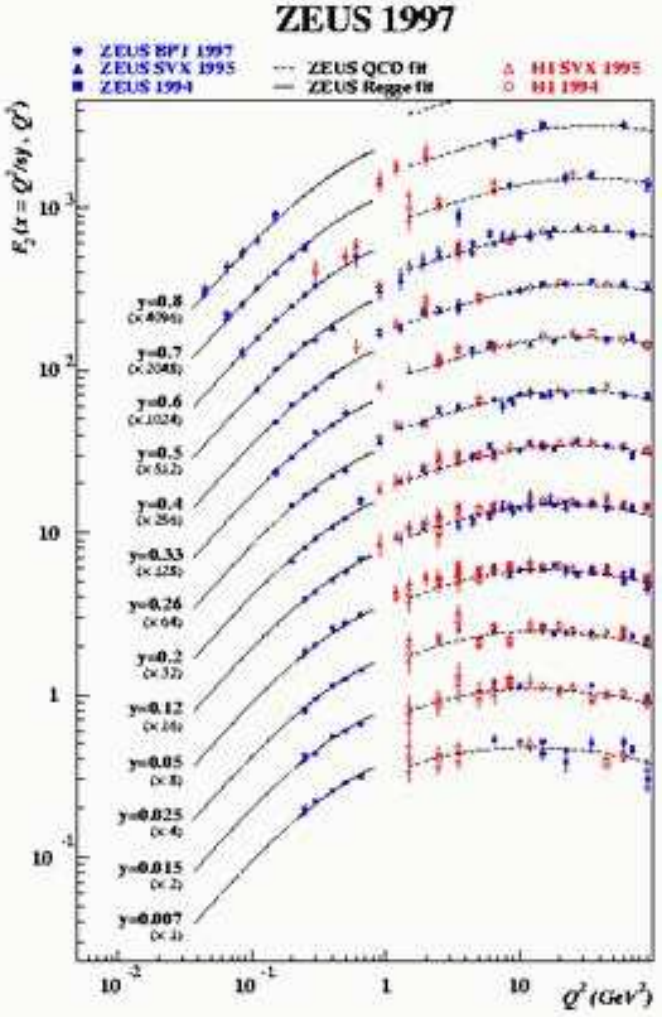
Leading baryon production

Amazingly smooth

Leading neutrons:

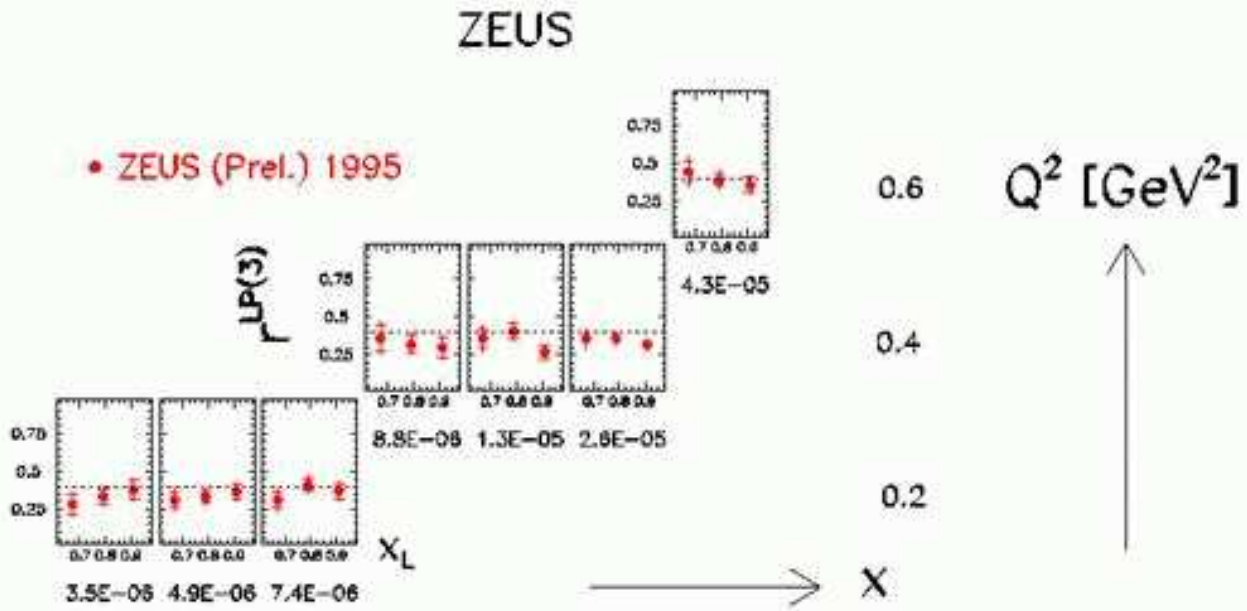
Neutron fraction





Leading baryon production

Leading protons: (below the diffractive peak)



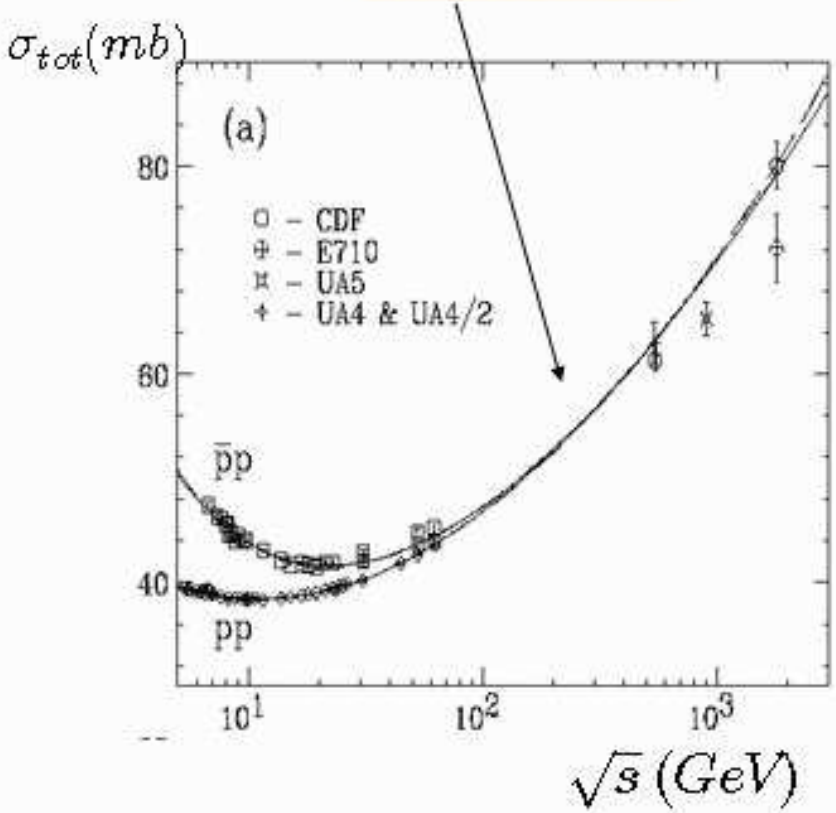
The story seems to be similar for leading protons.

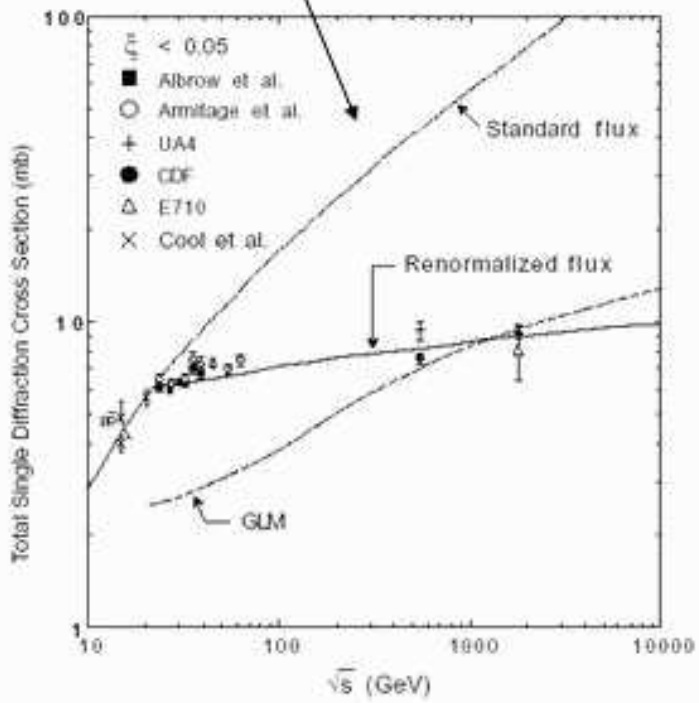
What is this data trying to tell us??

Diffraction in hadron-hadron interactions

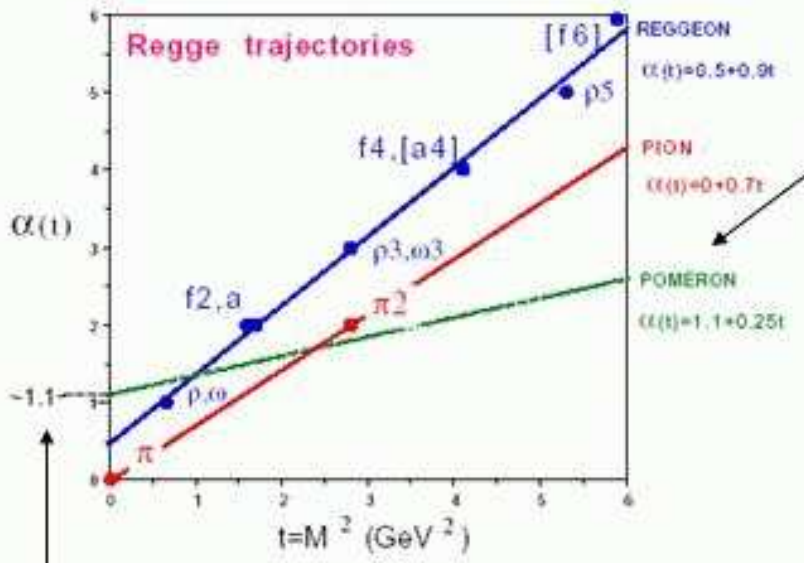
What is wrong with the following picture?

This Pomeron predicts this SD cross-section





Diffraction in hadron-hadron interactions



Does this make sense?

Ok "because far away from unitarity bounds" ?

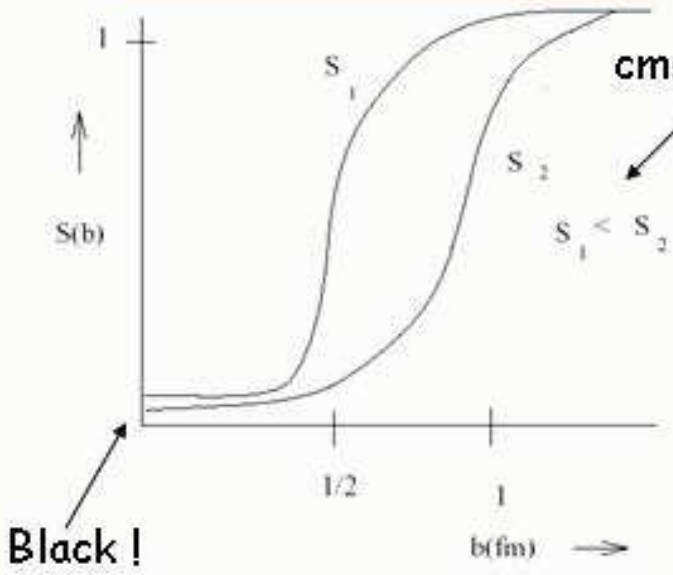
Impact parameter analysis says otherwise..

Diffraction in hadron-hadron interactions

Amaldi and Schubert: NPB 166(1980)301.

Impact parameter analysis of ISR data: use t dist. (Fourier trans. of impact parameter)

The S-matrix looks like:



1. Unitarity limit is already there at small impact parameter.

2. The rise of the (total) cross-section with energy comes from increasing size.

3. Diffractive dissociation grows slowly. (it vanishes for complete absorption)

Impact parameter and DIS

Some remarks and questions:

- The blackness argument is the same as multi-Pomeron exchange. (I'm told)

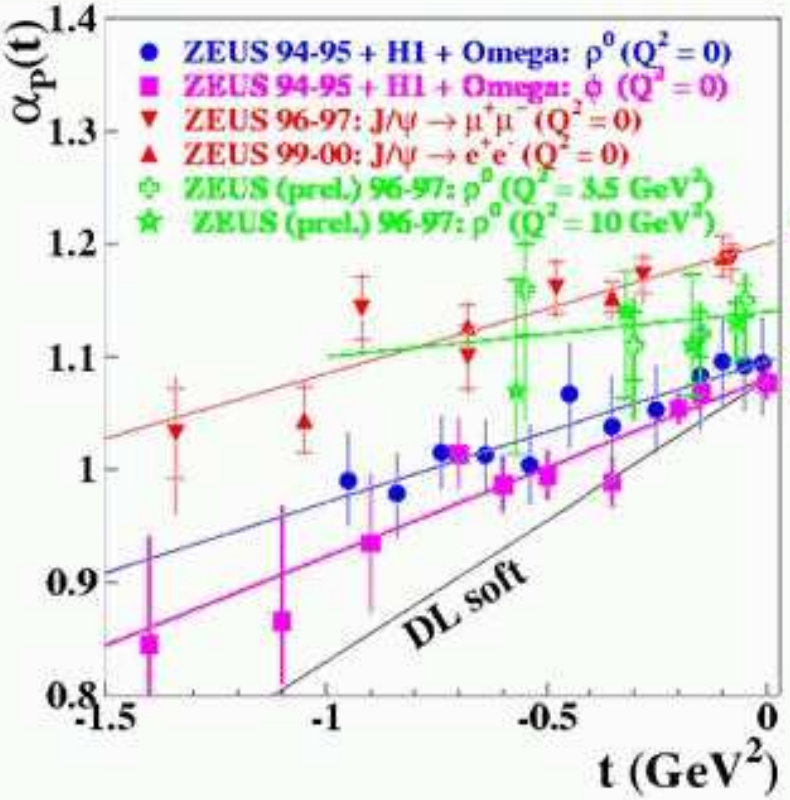
- In the GB&W model, the t dependence of the dipole cross-section is ignored.

- Is it possible that saturation effects in DIS are stronger at small impact parameters?

- Are there ways to look at impact parameter dependence in DIS?

Impact parameter and DIS

Can VM production shrinkage tell us something?



J/ψ: (1.198±0.012) + (0.114±0.025) ·t

DIS ρ^0 prelim.:
(1.14±0.03) + ($0.04^{+0.15}_{-0.08}$)·t

ρ^0: (1.096±0.021) + (0.125±0.038) ·t

ϕ: (1.081±0.010) + (0.158±0.028) ·t

These kinds of numbers predicted by Nikolaev, Zakharov and Zoller (ZfP A351 (1995) 435)

BFKL diffusion in impact parameter Space!

Impact parameter and DIS

First attempt at impact parameter analysis of HERA data:

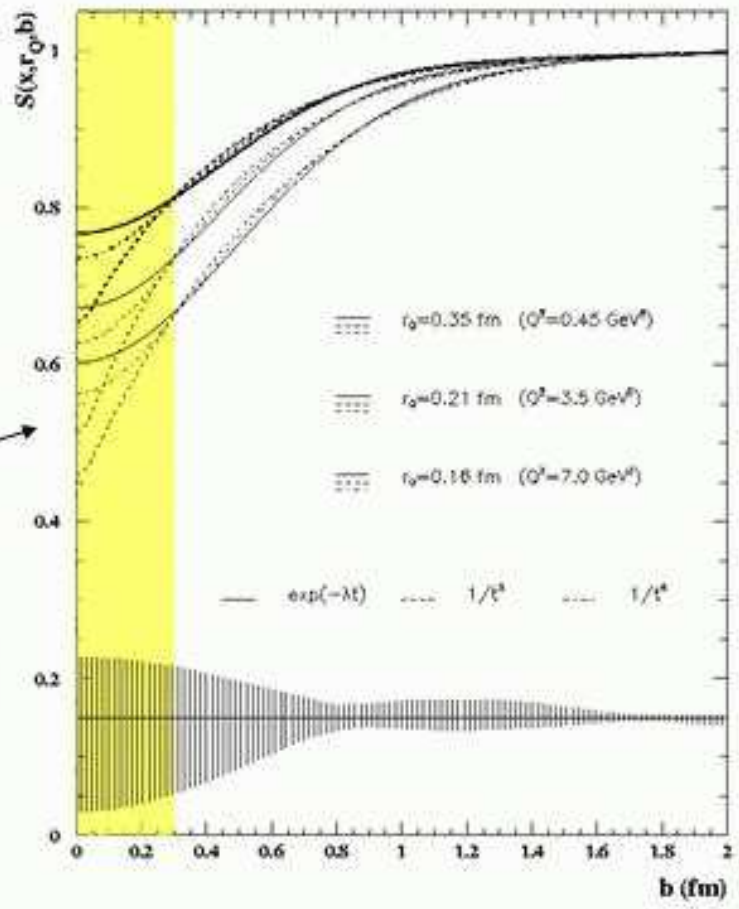
Munier, Stasto and Mueller (NPB 603(2001) 427)

Using DIS rho production data:

Grey-ish proton

Quark saturation for b = 0.3 fm at Q2= 1-1.5 GeV2-ish ?

(Model dependent)



Summary

- DIS diffraction

  An example of where a change of language brought a new understanding. ⟶ Are there other such opportunities?

- Low-x F2

  Is there something simple behind the resemblance to multiplicity of hadrons as function of energy?

  Suggests transition of "different dynamics" is very smooth

- Leading baryons

  Is the pion at low-x same as proton at low-x?

  Can we understand leading baryon production in a more transparent way—given the apparently simple factorization?

- Impact parameter

  Is the impact parameter interpretation of pp data correct?

  Can we apply it at HERA?

"Conclusions"

There's an abundance of data on diffraction(-ish) phenomena !

Many phenomena exhibit a surprisingly "simple looking" patterns:

Many of the phenomena are "contrary to expectations" in some intriguing way.

Examples of those I did not mention are:

Normalization of leading neutron data—or where are the missing forward baryons ?

Why does the longitudinal and transverse rho production have the same W dependence ?

Important to look for connections, patterns using as many different "languages" as possible and in as many different kinds of data !