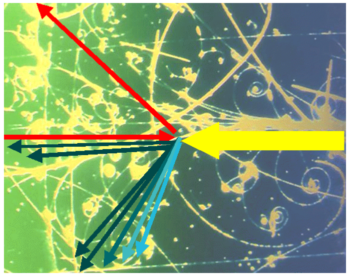
Zakład XII
Struktury hadronów

Instytutu Fizyki Jądrowej im. Henryka Niewodniczańskiego w Krakowie



Nasz cel: badanie fundamentalnych oddziaływań podstawowych składników materii – kwarków i gluonów.

http://www.ifj.edu.pl/dept/no1/nz12/index.html

Kierownik: prof. dr hab. Jan Figiel

6 fizyków
1 student

Uczestniczymy w następujących eksperymentach i projektach:

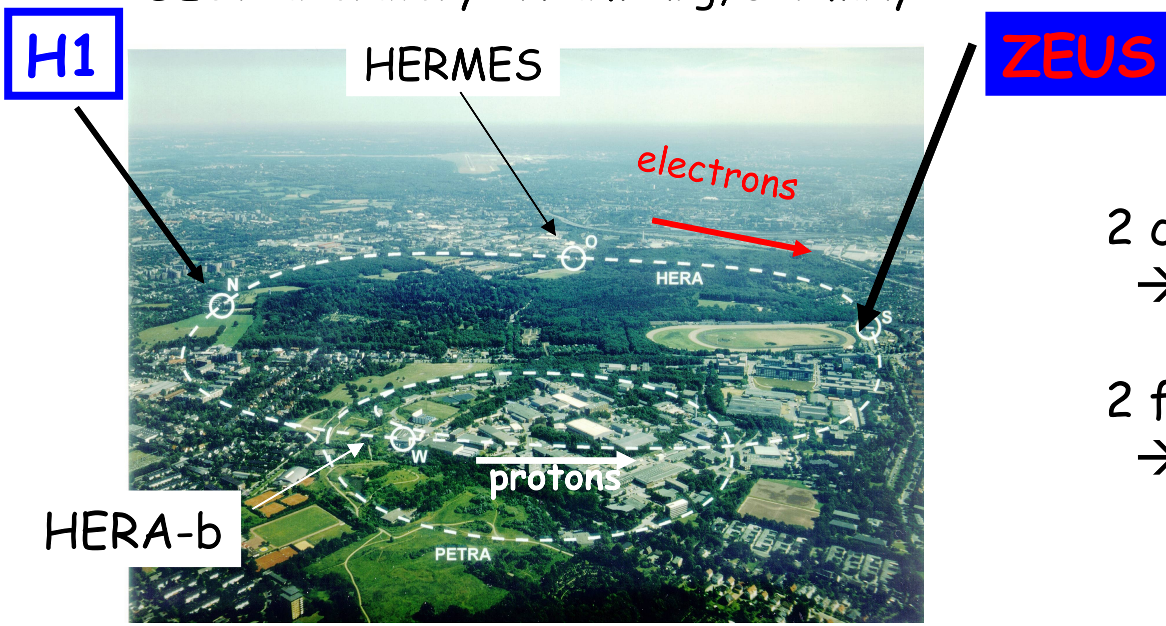
- Eksperyment ZEUS w laboratorium DESY w Hamburgu:
  badanie oddziaływań elektron (pozyton) – proton przy najwyższych energiach.

European Organization for Nuclear Research

- Eksperyment ALICE w CERN-ie:
  badanie oddziaływań jądro-jądro na LHC własności plazmy kwarkowo-gluonowej

HERA electron-proton collider

DESY laboratory in Hamburg, Germany



2 collider experiments
→ ZEUS and H1

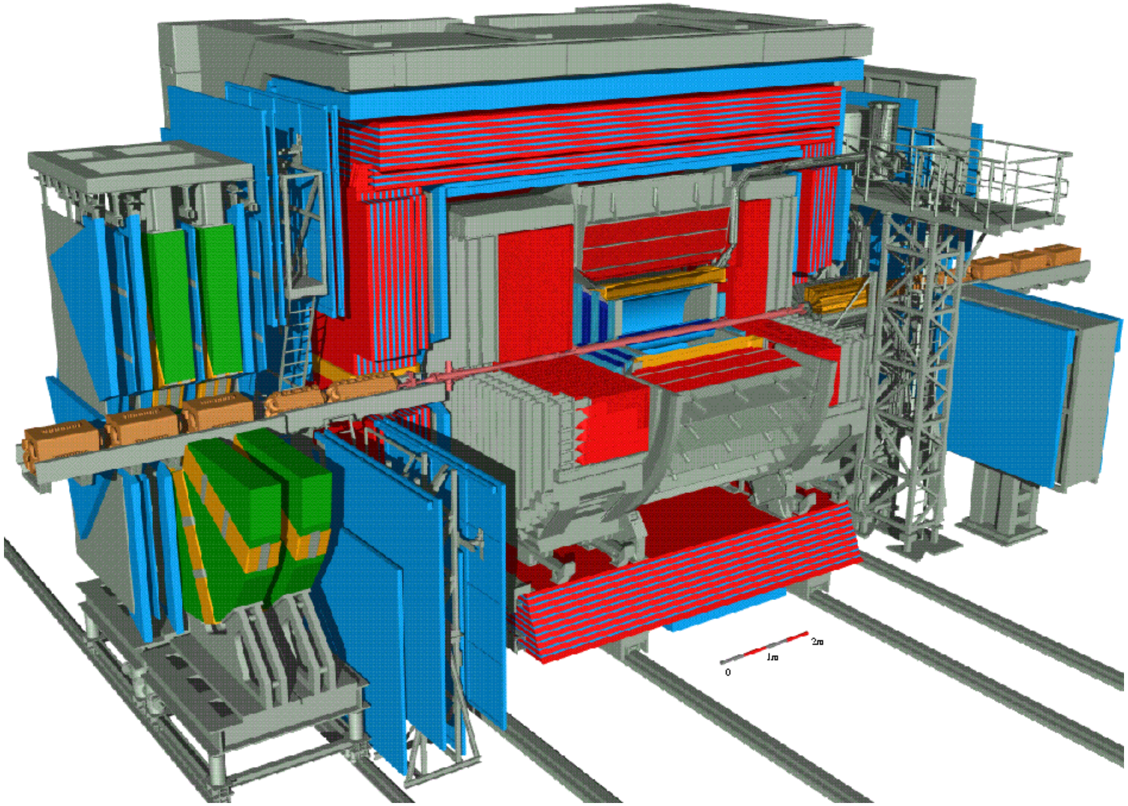
2 fixed target experiments
→ HERMES and HERA-b

- 920 GeV protons (820 before1998)
- 27.5 GeV $e^{\pm}$
- 300/318 GeV c.o.m. energy
- 220 bunches, 96ns. crossing time
- 90 mA protons,40 mA positrons
- Instantaneous luminosity: $1.8 \times 10^{31} cm^2 s^{-1}$

HERA construction approved 1984

$5.12 \times 10^{31} cm^2 s^{-1}$ after upgrade

Zeus Detector



Complete 4π detector

Tracking:
- central tracking detector
- Silicon μ-Vtx

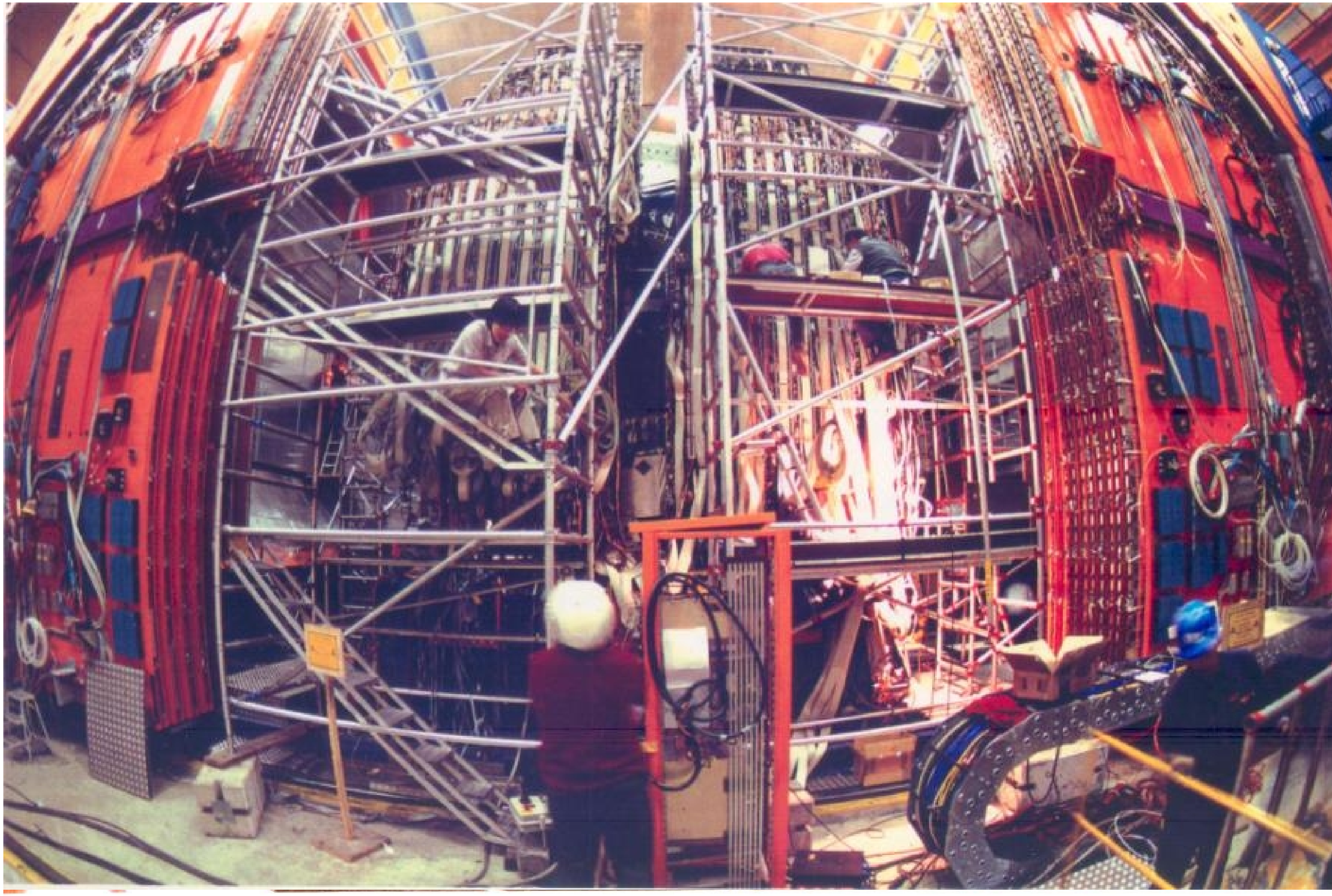
(operate in a B field of 1.43 T)

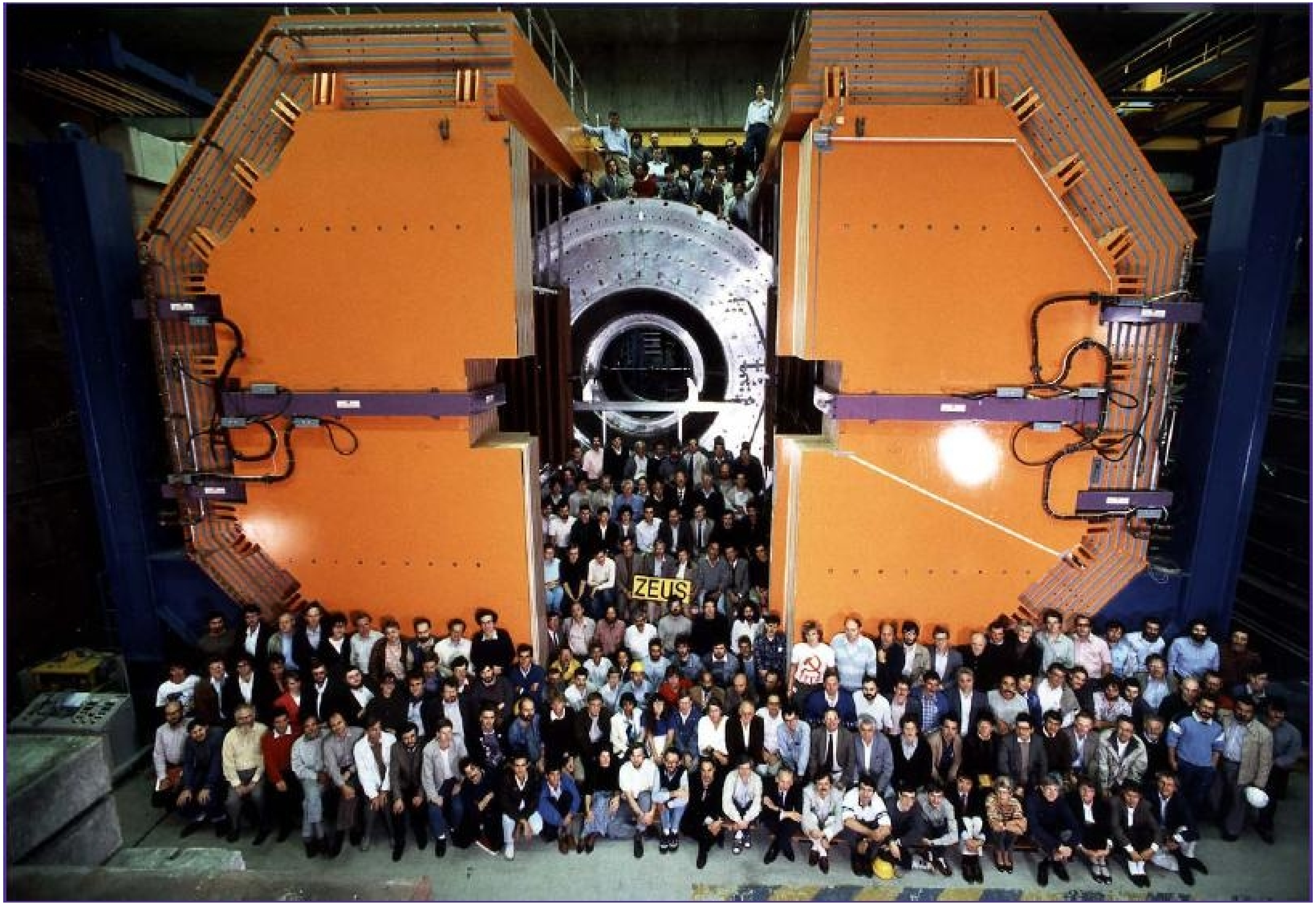
Calorimeters:
- uranium-scintillator (CAL)
  - $\sigma(E)/E = 0.18/\sqrt{E}$ [emc]
  - $\sigma(E)/E = 0.35/\sqrt{E}$ [had]
- instrumented-iron (BAC)

Muon chambers

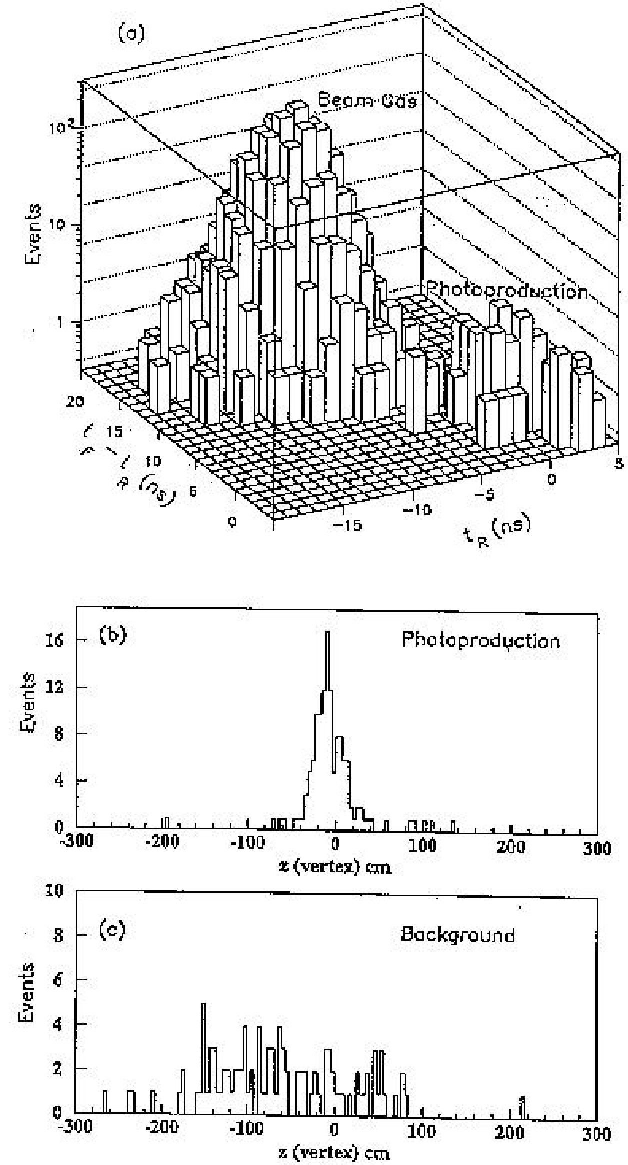
Experiment approved 1986

18 countries, ~400 members

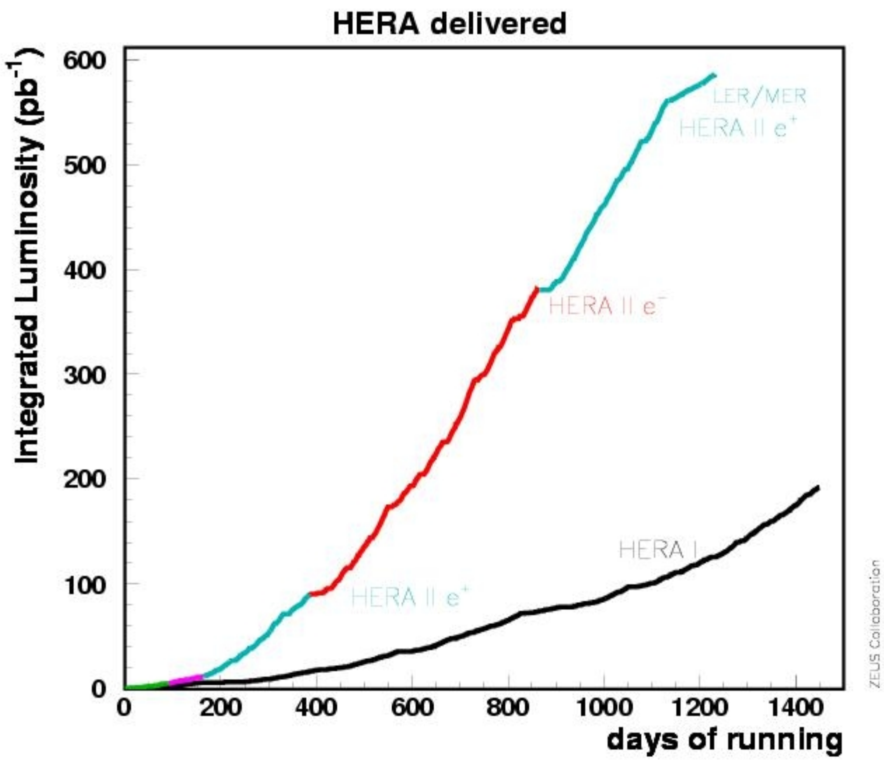



ZEUS

First luminosity on May 31, 1992
-first paper that September



Control room in the mid-90's



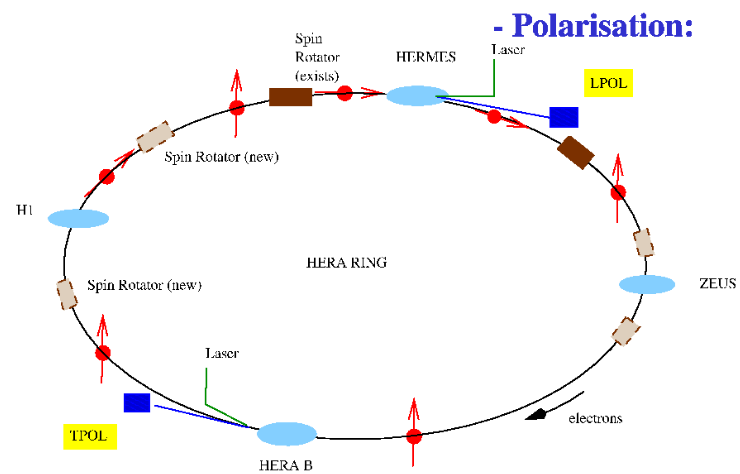
HERA I: 1992-2000
~180 pb-1/experiment delivered. (mostly e^+)

Upgrade: 2001-2002

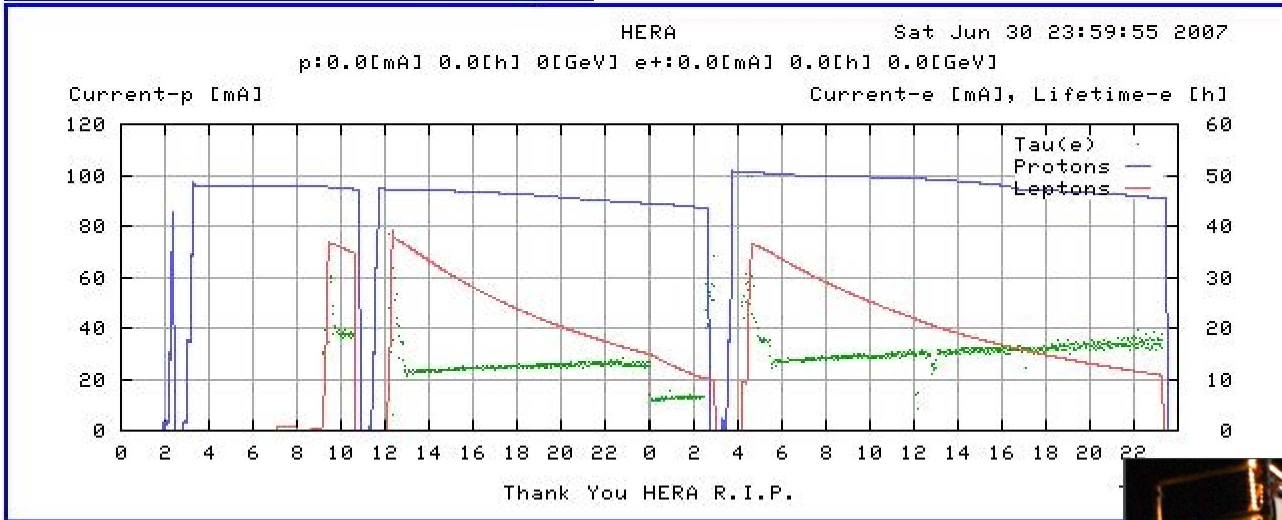
HERA II: 2002-2007
~580 pb-1/experiment delivered. (e^+ and e^-)

For HERA II:

- Luminosity ~x3 (low-β insertion)
- Long. polarized leptons
- Some running at lower proton energy: 460 and 575 GeV

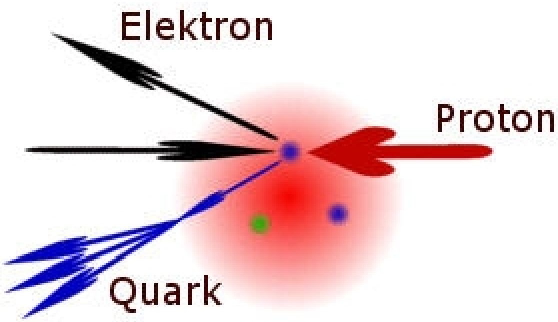


HERA last fill on 30/6/07 at 11:30 pm

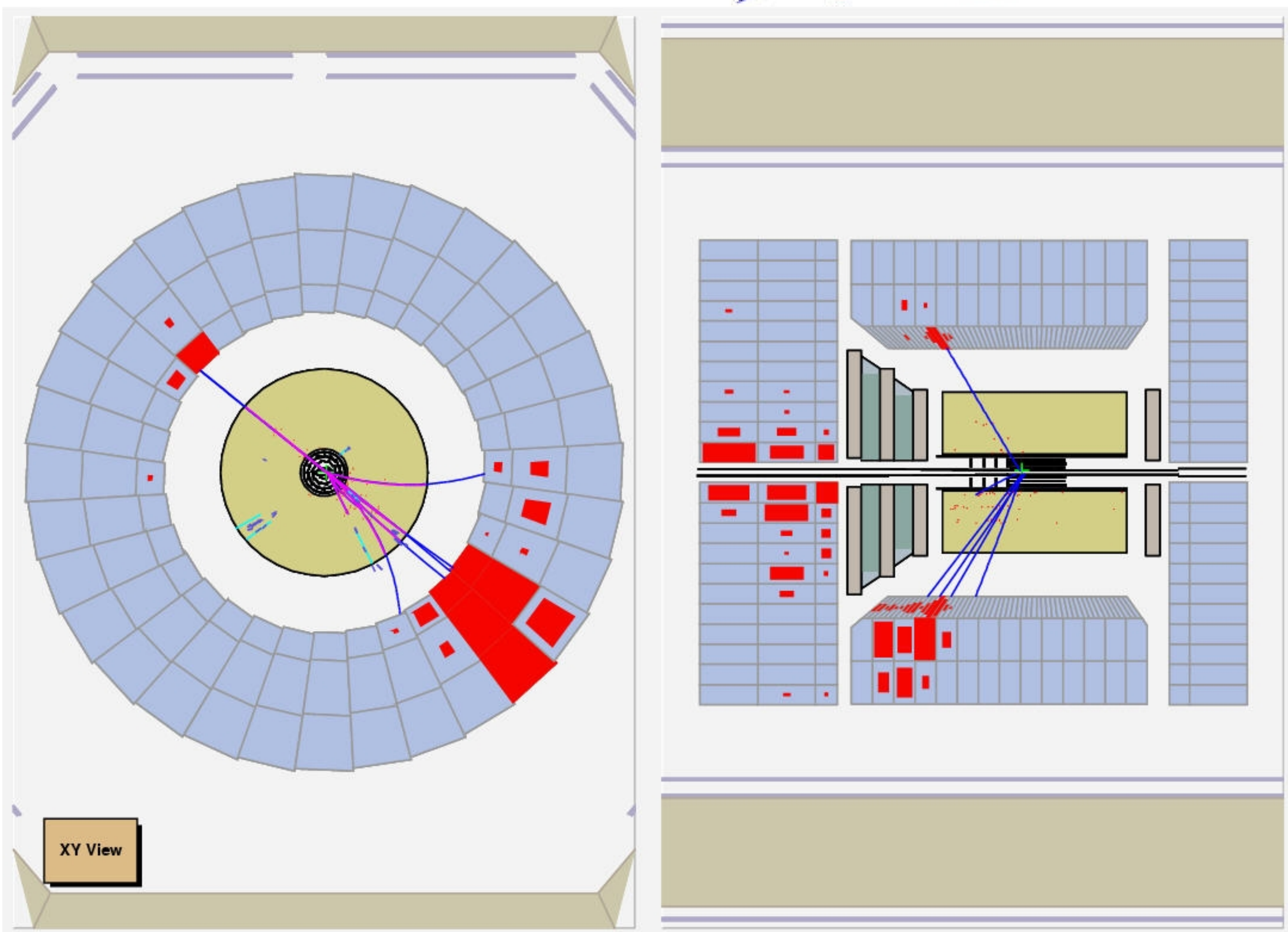


Physics at HERA

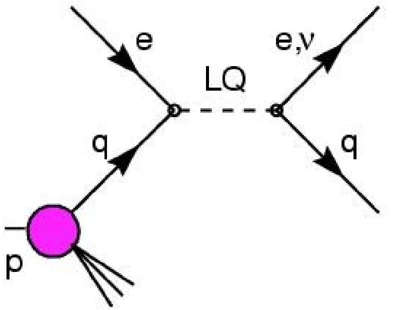
27.5 GeV

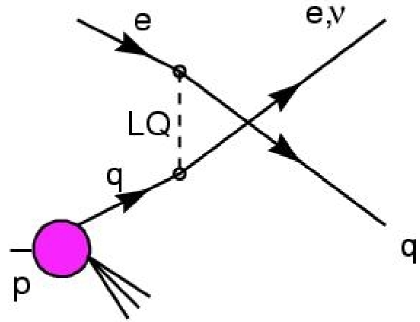


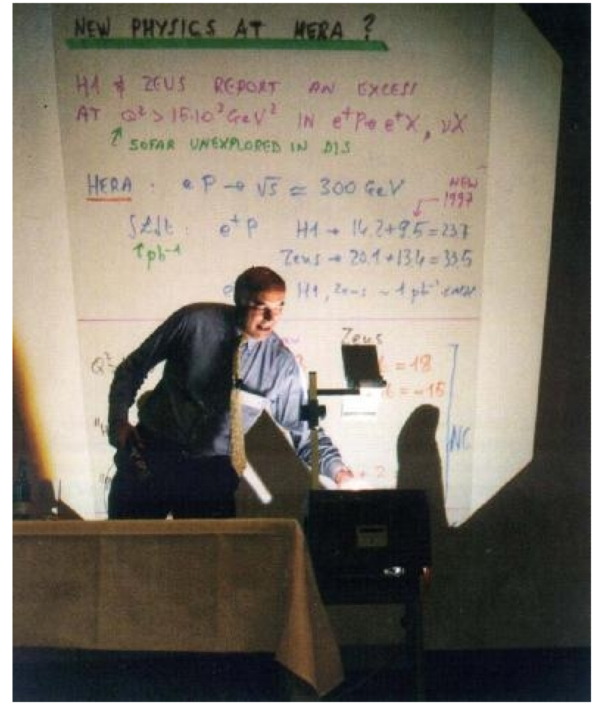
920 GeV



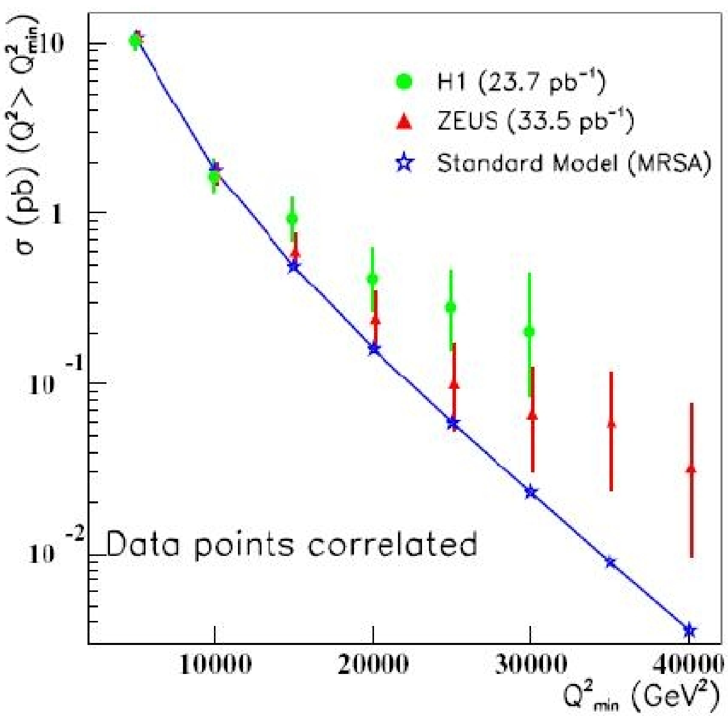
1997



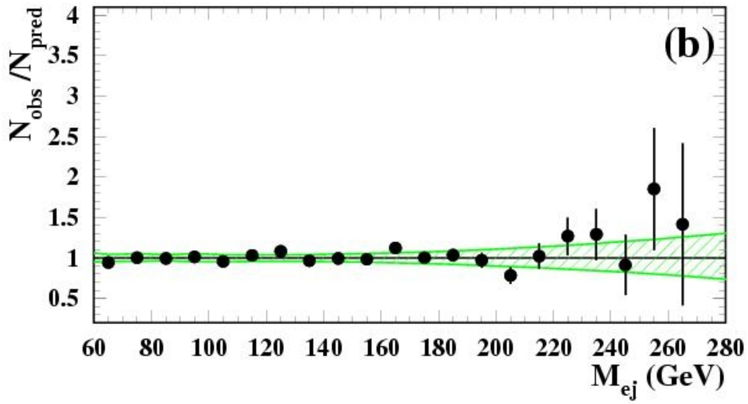




1994-97 Preliminary NC Cross Sections

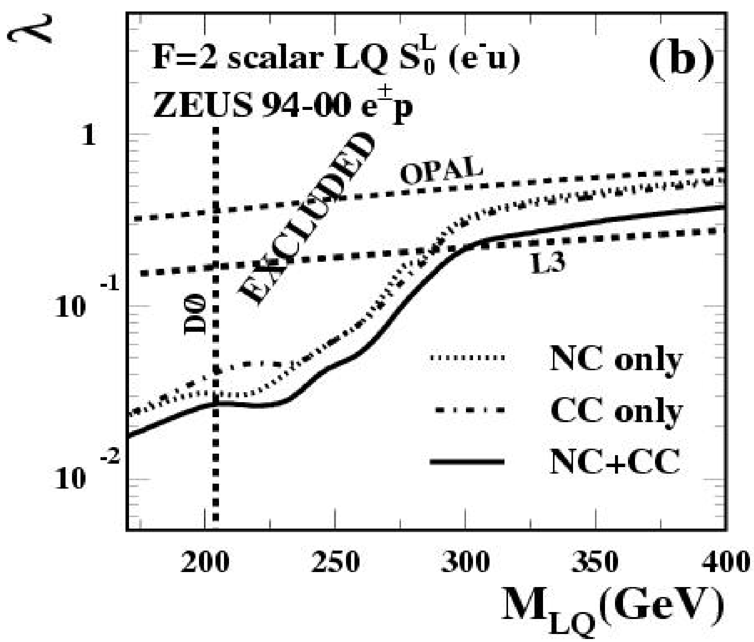


2003

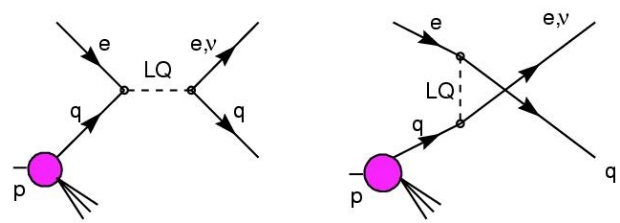


After ~100 pb^{-1} of data
--no excess.

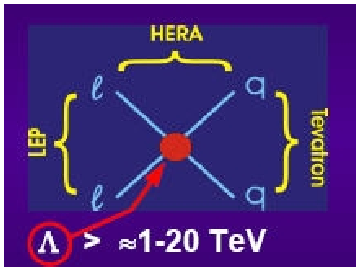
(similar results for H1)



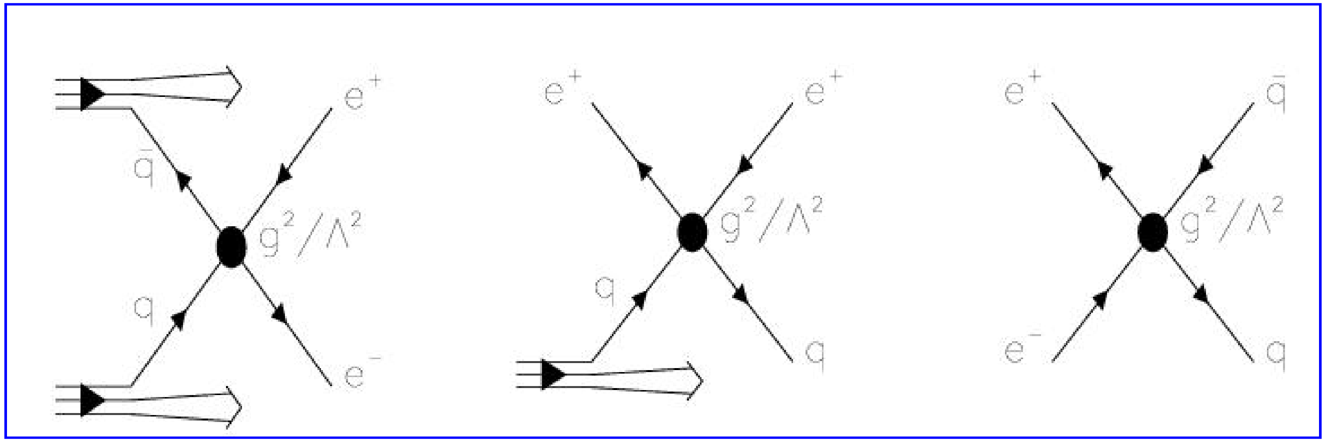
Limits were set:



contact interactions



Contact Interaction Limits



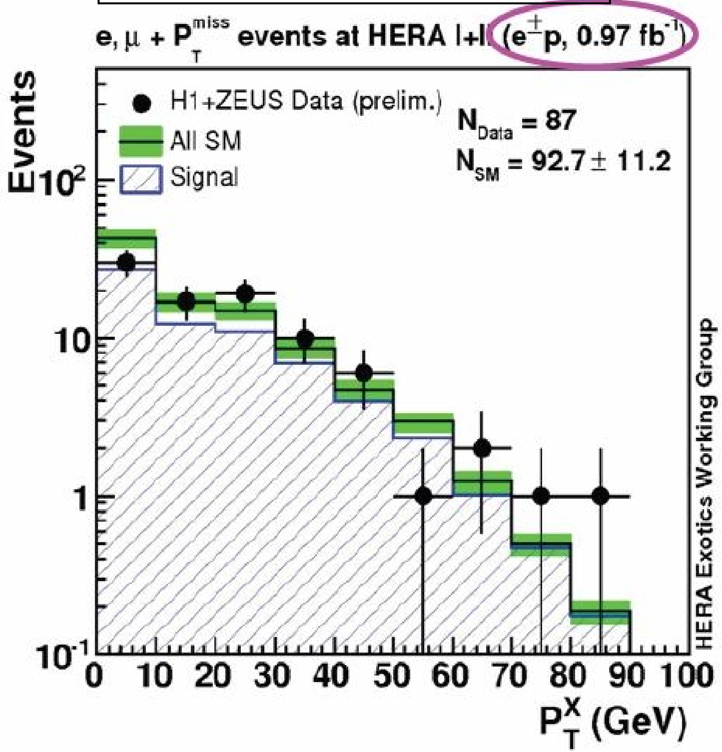
Summary from ~2004

95% CL limit [TeV]		ZEUS		H1		DØ		CDF		ALEPH		L3		OPAL	
Model	Coupling structure $[\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}]$	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
LL	[+1, 0, 0, 0]			2.3	2.8	4.2	3.3	3.7	2.5	6.2	5.4	2.8	4.2	3.1	5.5
LR	[0, +1, 0, 0]			1.8	3.2	3.6	3.4	3.3	2.8	3.3	3.0	3.5	3.3	4.4	3.8
RL	[0, 0, +1, 0]			1.9	3.2	3.7	3.3	3.2	2.9	4.0	2.4	4.6	2.5	6.4	2.7
RR	[0, 0, 0, +1]			2.3	2.8	4.0	3.3	3.6	2.6	4.4	3.9	3.8	3.1	4.9	3.5
VV	[+1, +1, +1, +1]	7.0	6.5	5.4	5.1	6.1	4.9	5.2	3.5	7.1	6.4	5.5	4.2	7.2	4.7
AA	[+1, −1, −1, +1]	5.3	4.6	3.9	2.5	5.5	4.7	4.8	3.8	7.9	7.2	3.8	6.1	4.2	8.1
VA	[+1, −1, +1, −1]	3.4	3.3	2.9	2.9										
LL−LR	[+1, −1, 0, 0]	4.0	2.7			4.5	3.9								
LL+RL	[+1, 0, +1, 0]	4.7	4.7												
LL+RR	[+1, 0, 0, +1]	4.3	4.2	3.7	3.8	5.1	4.2			7.4	6.7	3.7	4.4	4.4	5.4
LR+RL	[0, +1, +1, 0]	5.6	5.6	4.1	4.3	4.4	3.9			4.5	2.9	5.2	3.1	7.1	3.4
LR+RR	[0, +1, 0, +1]	4.8	4.8												
RL−RR	[0, 0, +1, −1]	2.6	3.9			4.3	4.0								

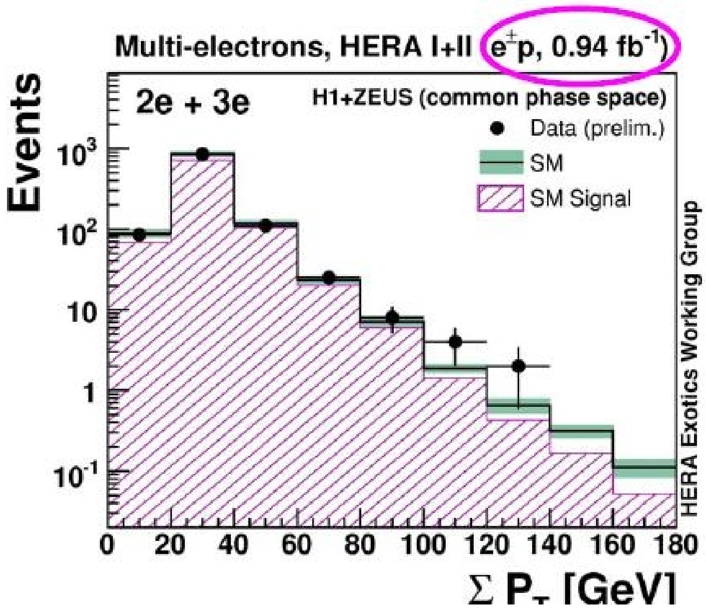
2-7 TeV range limits from all three colliders

Channels where excesses at HERA were reported previously:

lepton + missing P_T

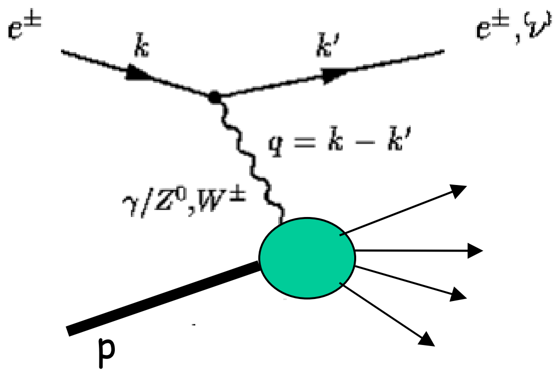


multi-leptons



No compelling indications of BSM in the total data set

Introduction: Deep Inelastic Scattering



Described by 2 kinematic variables

$$Q^2 = -q^2$$

x = $Q^2/2p.q$

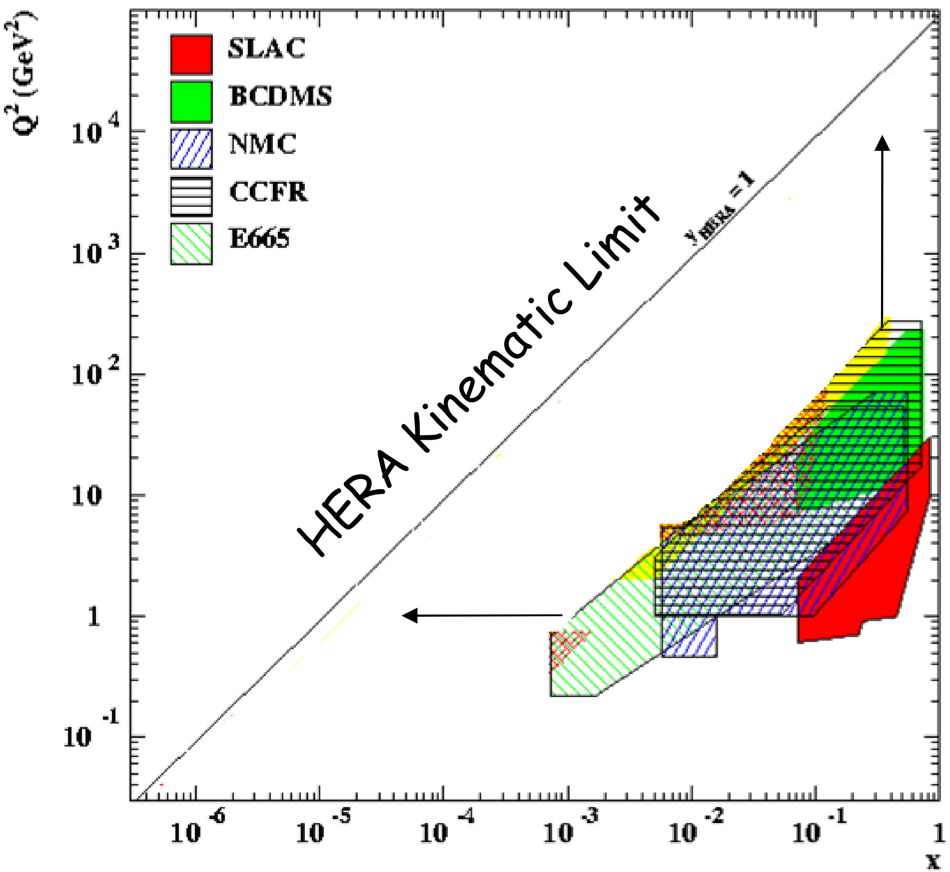
$$\frac{d\sigma^2_{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+ F_2 - y^2 F_L \mp Y_- xF_3)$$

Mostly about F_2

$y = Q^2/xs$, the inelasticity parameter, $Y_\pm = (1 \pm (1-y)^2)$

F_2, F_L, and xF_3 are structure functions of the proton.

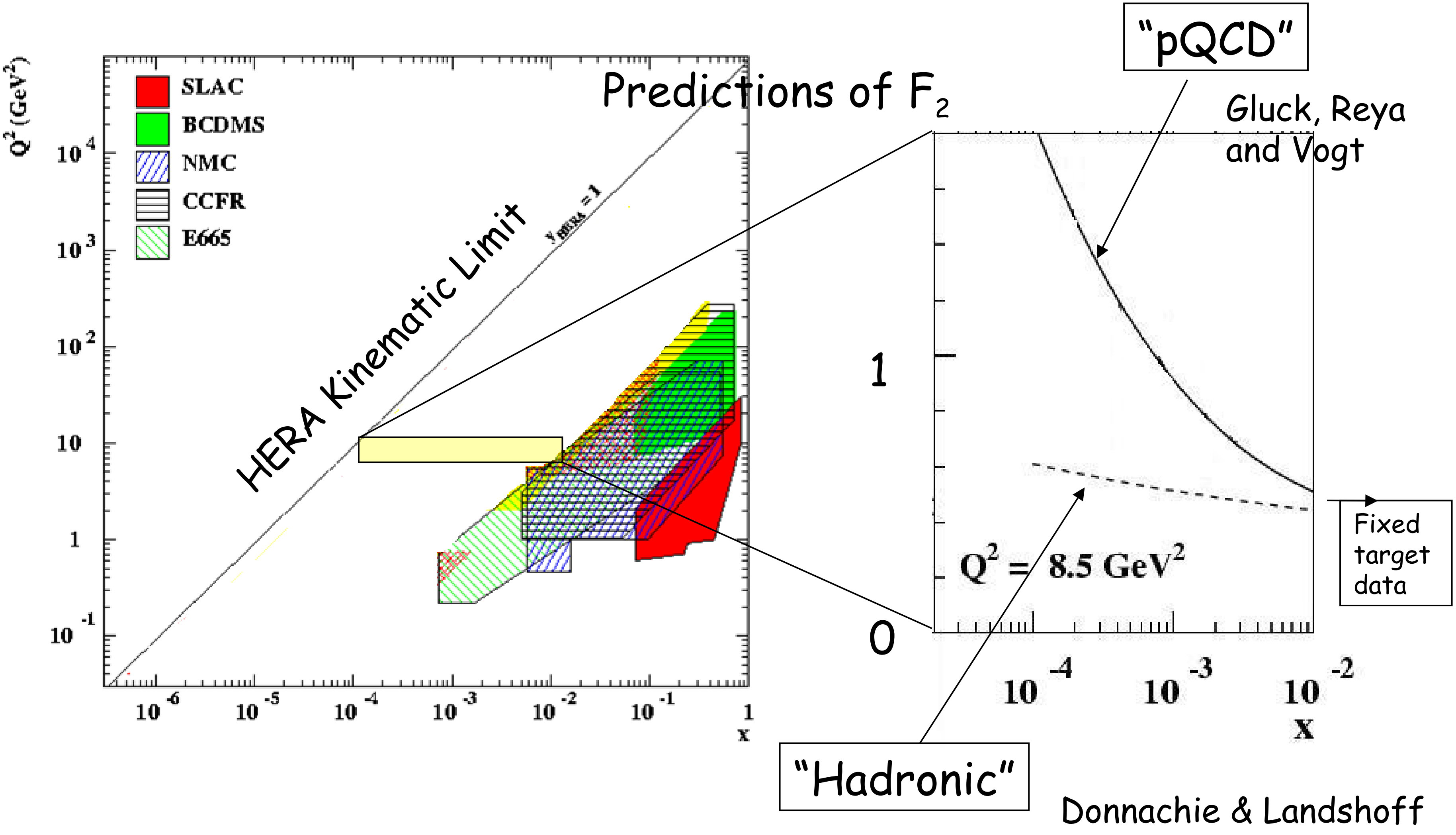
- F_L: longitudinal component, damped by y^2.
- xF_3: Small at $Q^2 \ll M_Z^2$,



In the early 90's, HERA was about to push the proton structure function measurements by 2 orders of magnitude in x and Q^2.

Clearly, the first measurements would be in relatively low Q^2 and would extend to low x.

What were the expectations?
What would be the proton structure at low x?

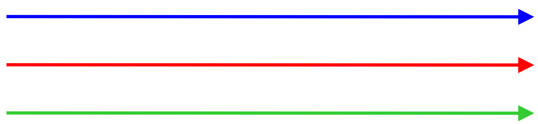


Why such different predictions?

Two ways to think about the problem

pQCD

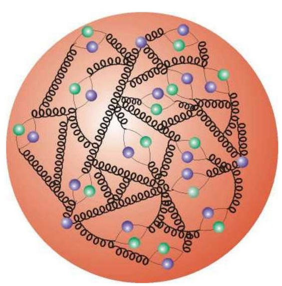
Quarks are asymptotically free!



Proton is a beam of partons whose behavior can be understood using perturbative QCD!

OR

Hadronic

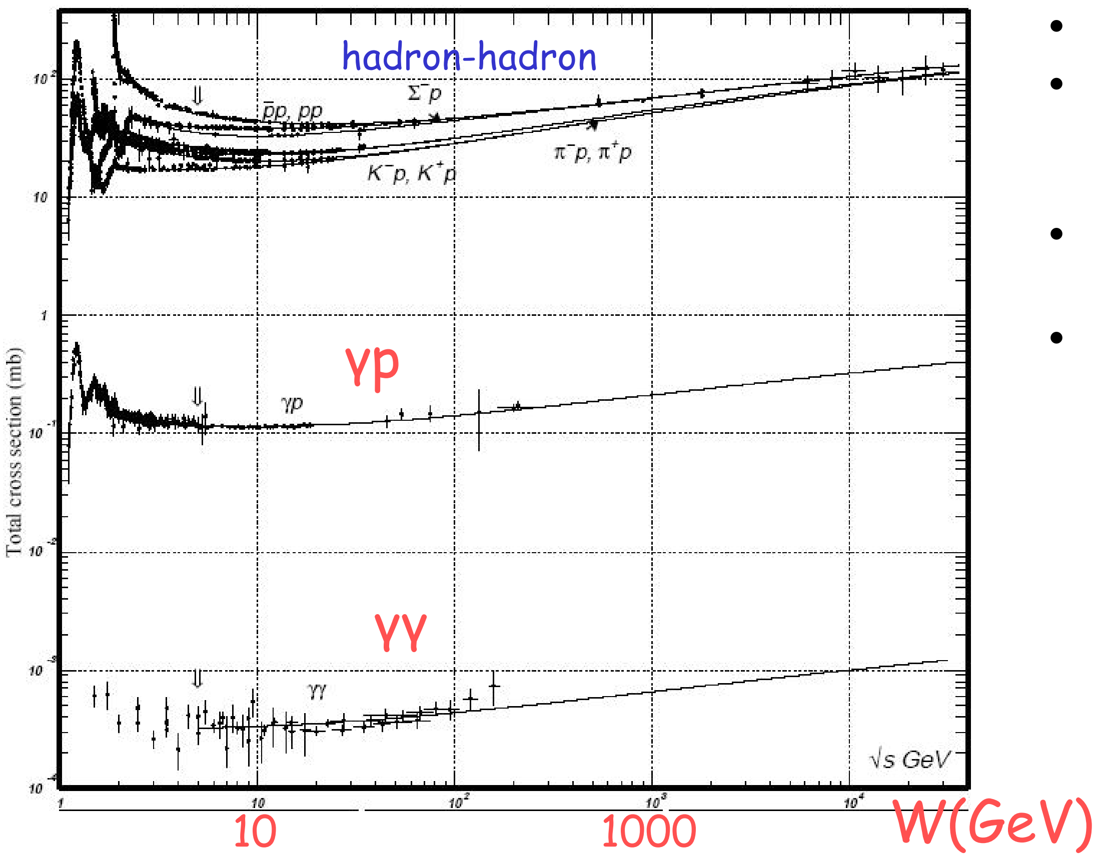


Protons are hadrons—whose constituents are confined. The behavior of hadrons is not understood from the first principles of QCD: however we have relatively good phenomenology to describe them.

Before HERA: hadronic view of the proton and F_2

$$\sigma_{tot}(\gamma^* p) \approx \frac{4\pi^2\alpha}{Q^2} F_2(W, Q^2)$$

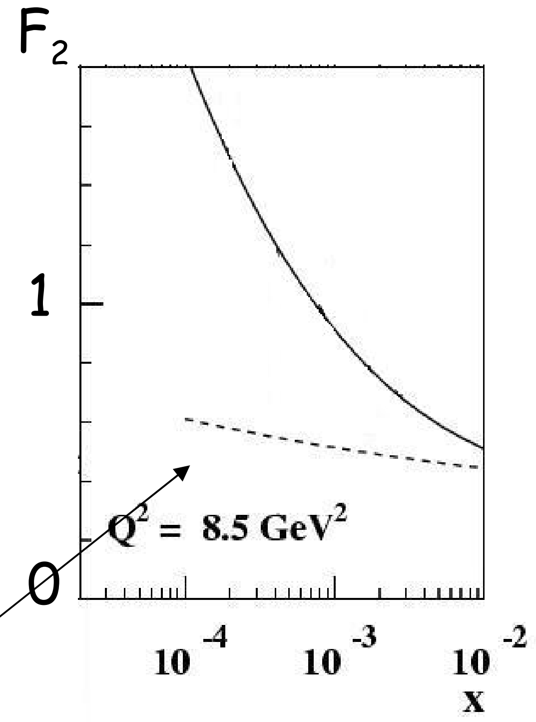
W: γ^*P cms energy



- F_2 at low x is simply related to the total γ^*P cross-section.
- $x \approx Q^2/W^2$ so as x falls W rises
- small x limit of DIS is a large energy limit of the γ^*p cross-section.
- at HERA W goes up to ~300 GeV.
- Large energy limit of total cross-sections is where the Pomeron trajectory dominates in Regge phenomenology: slow rise of the cross-section.

Hadronic view of F_2

- We do not understand how hadrons are formed and behave from first principles.
- We do, however, have a phenomenology that describes most of the properties of hadron-hadron collisions. (Regge) This is somehow the result of QCD in the strong coupling limit.
- Virtual-photon proton cross section (or F_2 at low x) is yet another total cross-section which should be dominated by the properties of the proton as a hadron → governed by the same Pomeron trajectory as other hadronic cross-sections: slow power rise with W (or 1/x) .

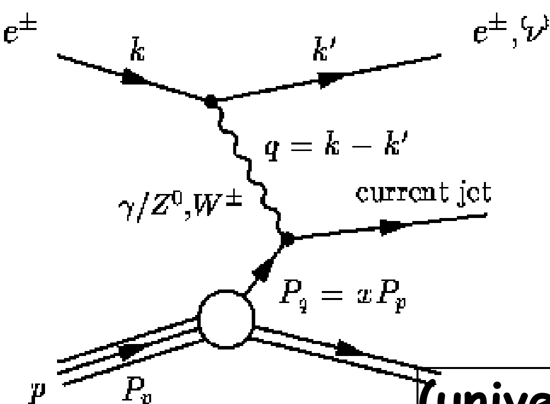


Donnachie and Landshoff (1993)

against x. If the HERA experiments find results for νW_2 significantly larger at small x than our extrapolations, we claim that this will be a clear signal that they have discovered new physics. Of course, the hope is that they will discover the Lipatov pomeron. In relation

pQCD view of F_2

- Asymptotic freedom!   A proton at a high energy collider is a beam of partons.
- A proton knows itself as a proton only to the extent that the non-perturbative "initial distributions of partons" are somehow determined by the hadronic properties of the proton.
- The parton distributions at any Q^2 can be calculated via perturbative QCD given enough data to determine it at some Q^2.



x→ momentum frac. of parton
Q^2→resolving power of probe

Factorization:

$$\sigma_{DIS} \sim f_p(x) \otimes \hat{\sigma}$$

(universal) parton densities

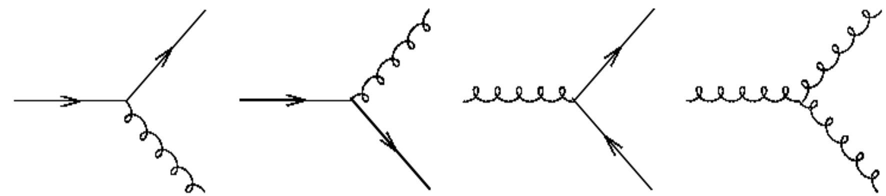
PQCD cross-sec.

pQCD view of F_2

DGLAP evolution equations:

$$\frac{\partial f_p}{\partial \ln Q^2} \sim f_p \otimes P$$

***P*'s are splitting functions:**

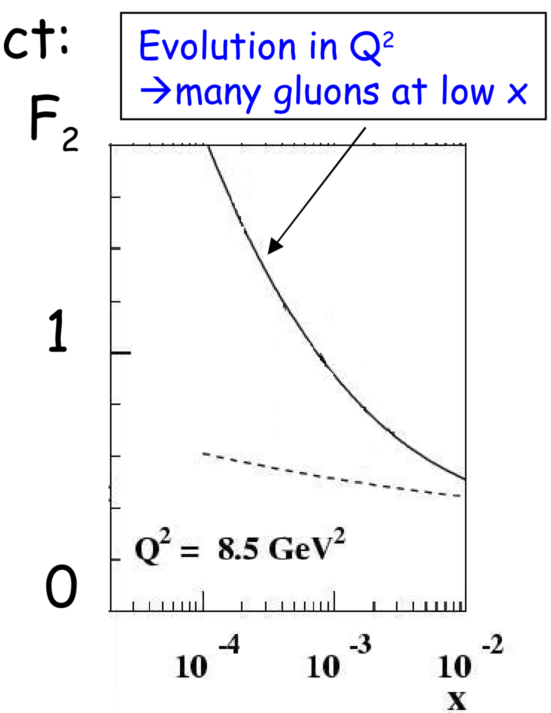


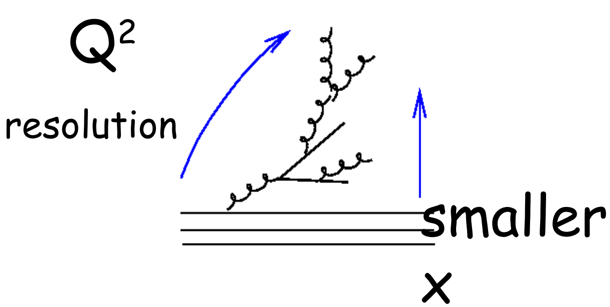
And (LO (or in DIS scheme..))

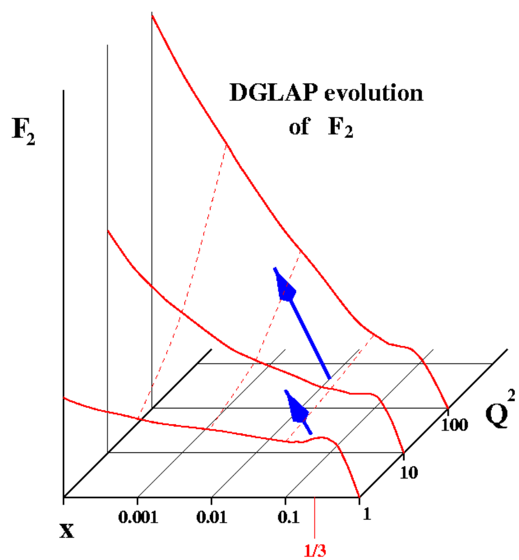
$$F_2(x,Q^2) = x\sum_q e_q^2(q(x,Q^2) + \bar{q}(x,Q^2))$$

where q, $\bar{q}$ are quark, antiquark densities in the proton.

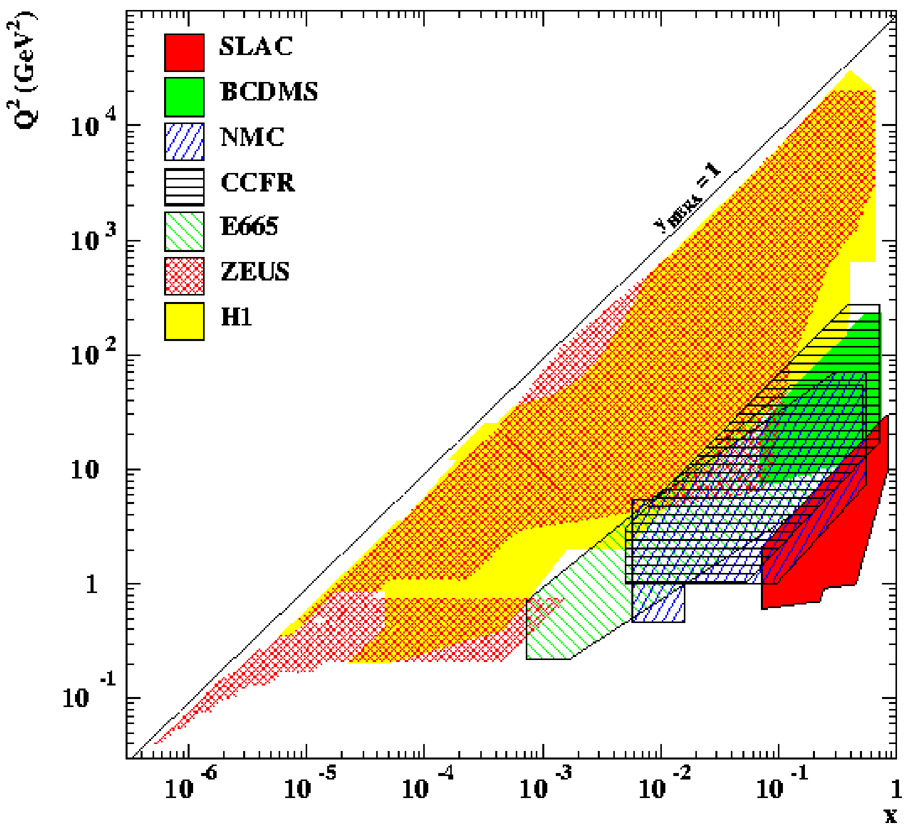
Predict:

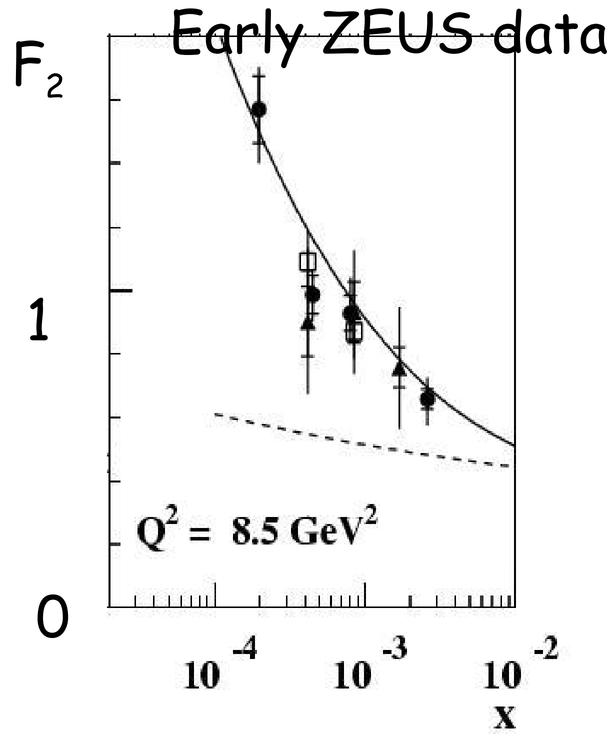




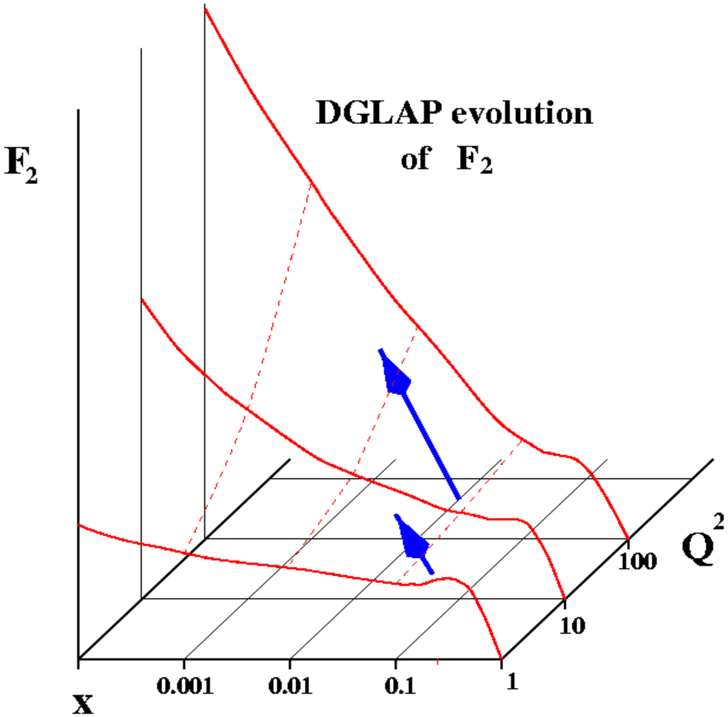


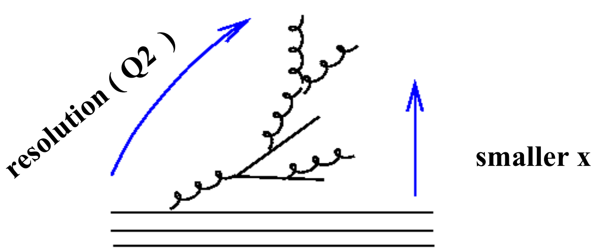
Measurements at HERA

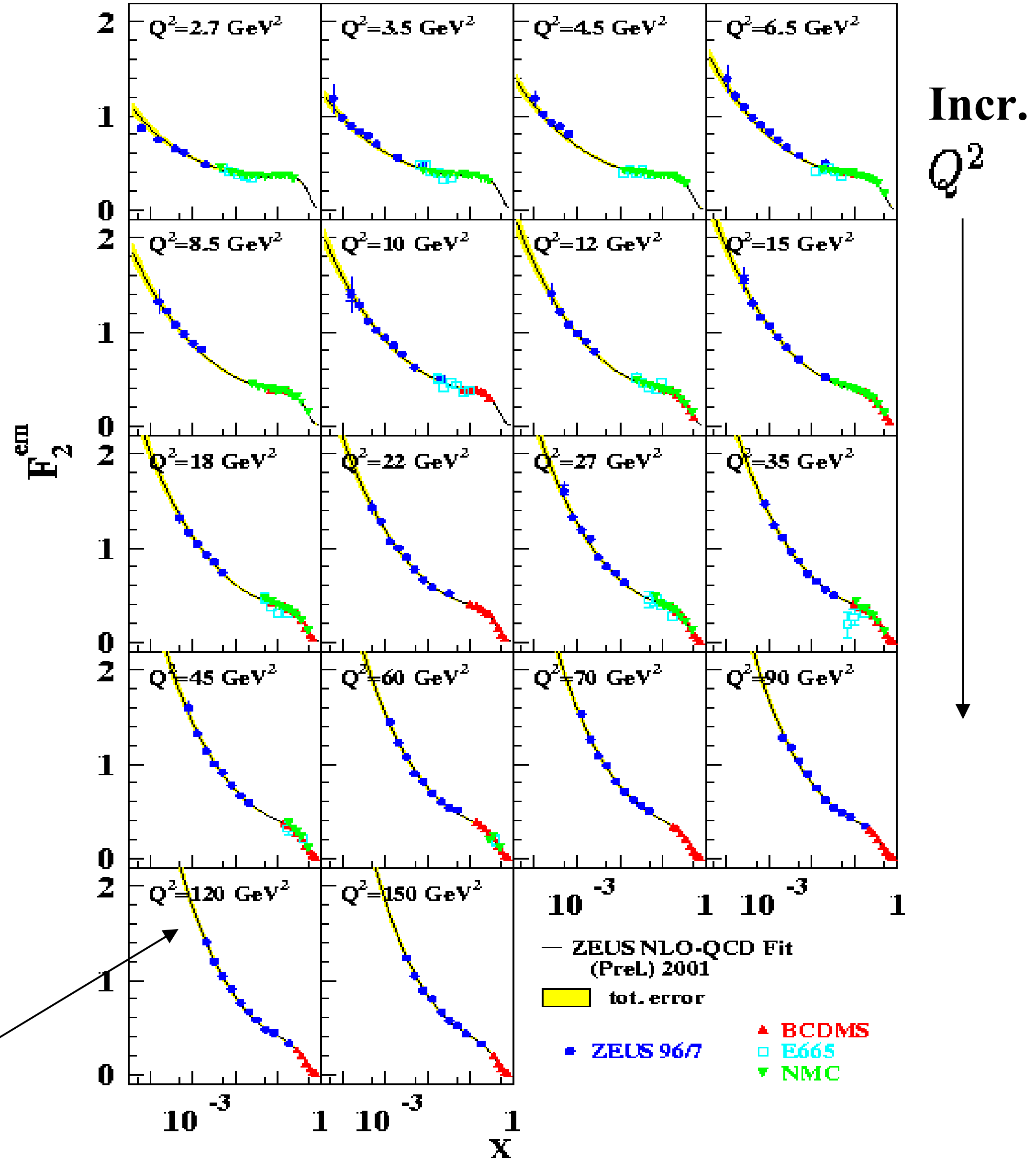




HERA measurements and pQCD

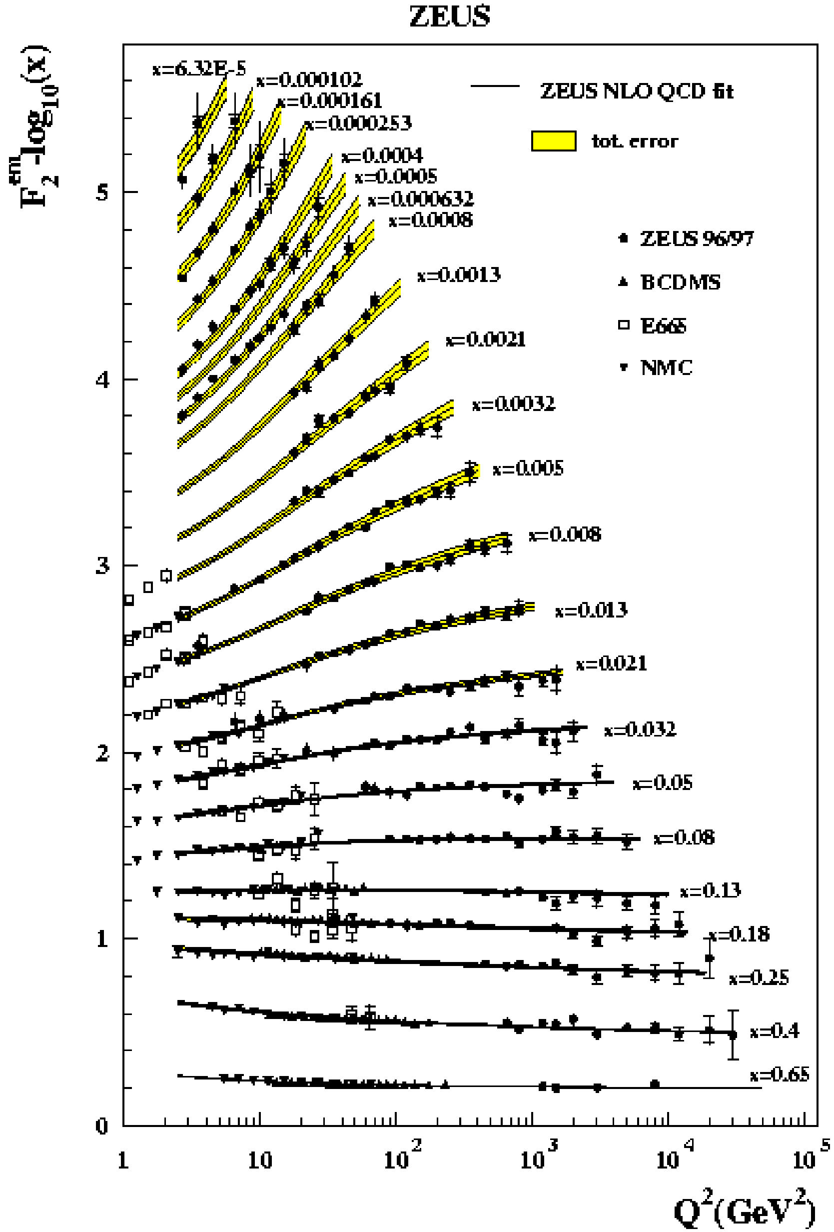


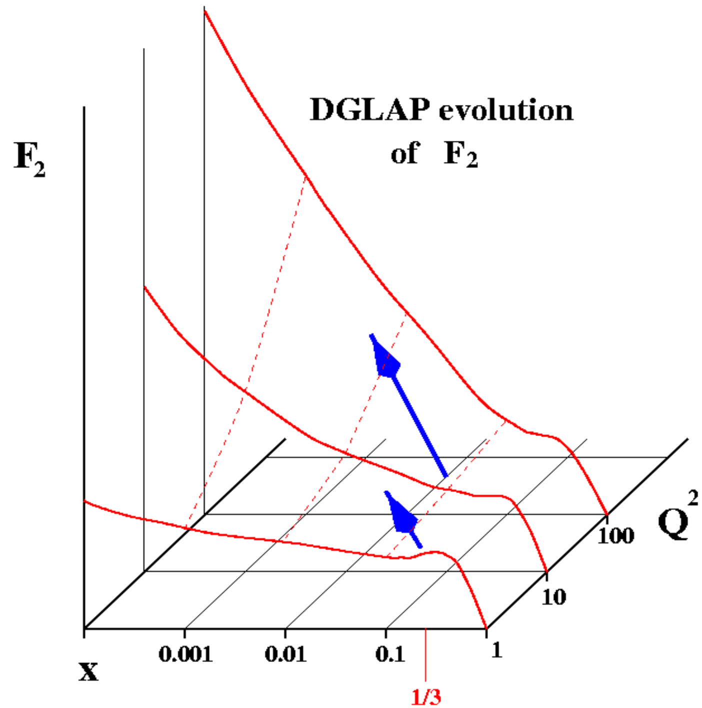




Lines are pQCD fits to parton distributions.

Scaling violation of F_2

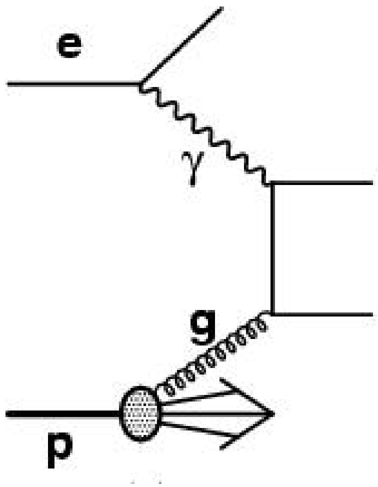




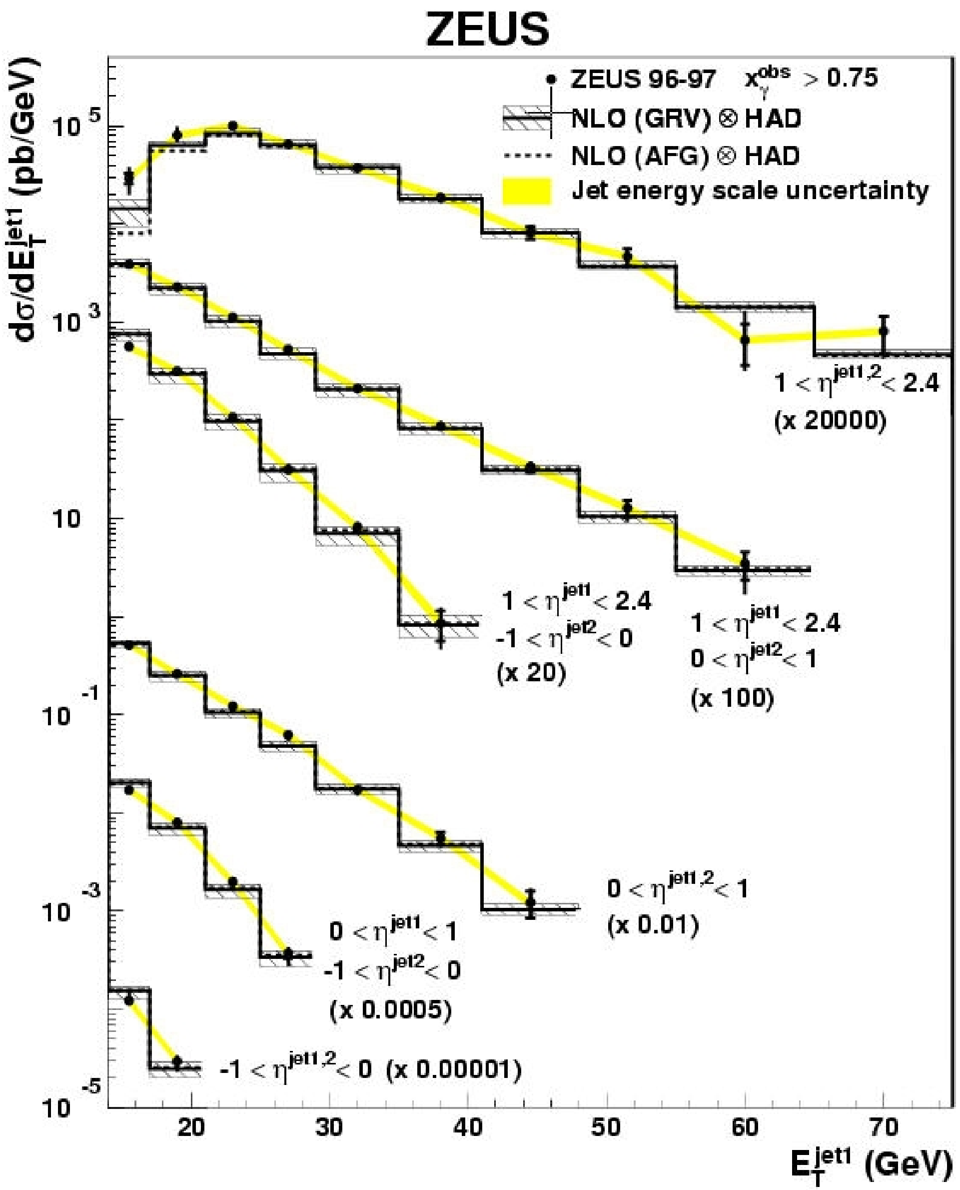
To LO:

$$\frac{\partial F_2}{\partial \ln Q^2} \sim \alpha_s x g$$

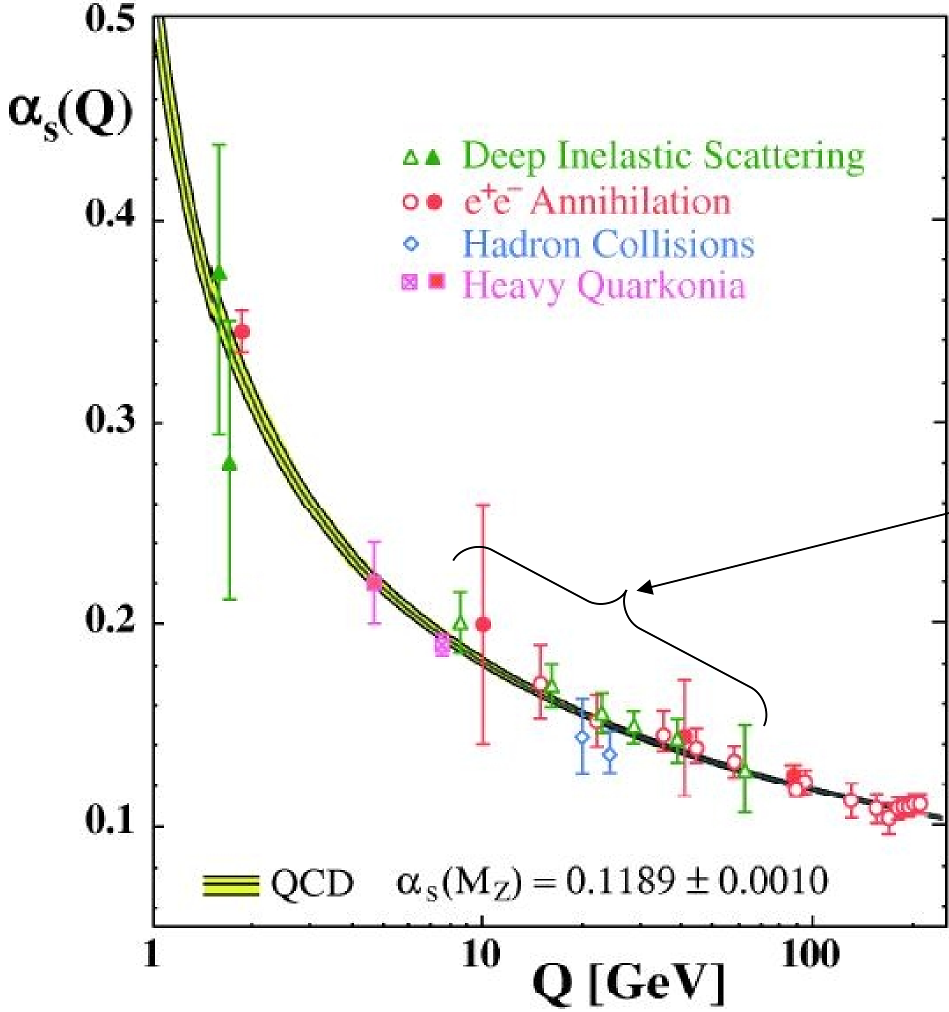
Additional information: jets at HERA



Jets can probe the gluon



- Jet measurements are consistent with NLO QCD fits from F_2
- Can be used to further constrain the gluon and/or α_s



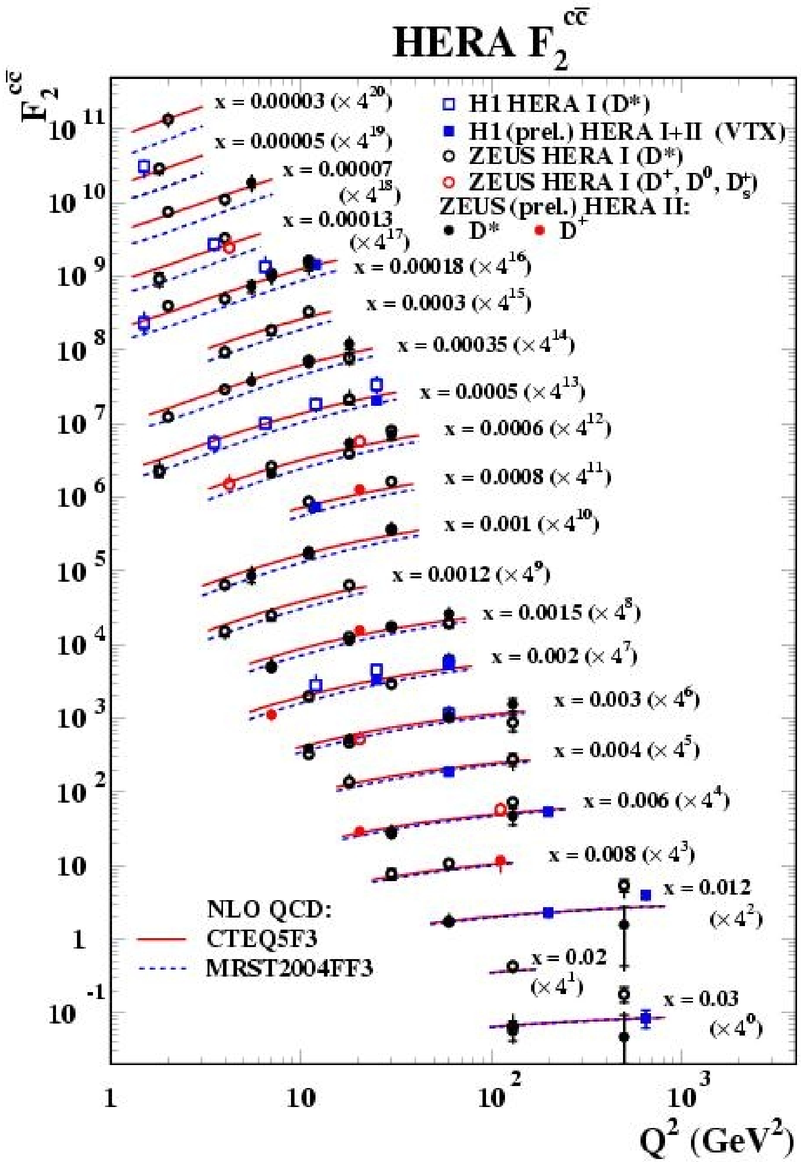
S. Bethke
hep-ex/0606035

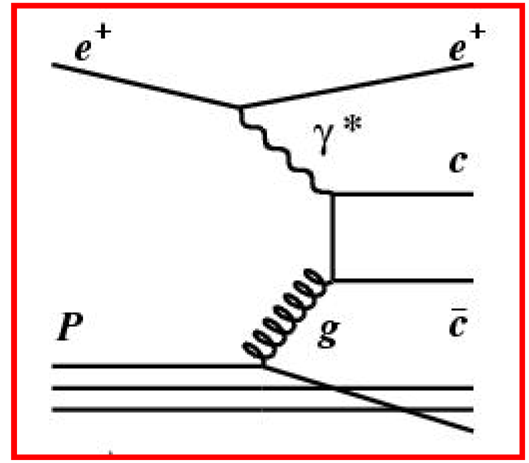
HERA measurement
(green triangles)

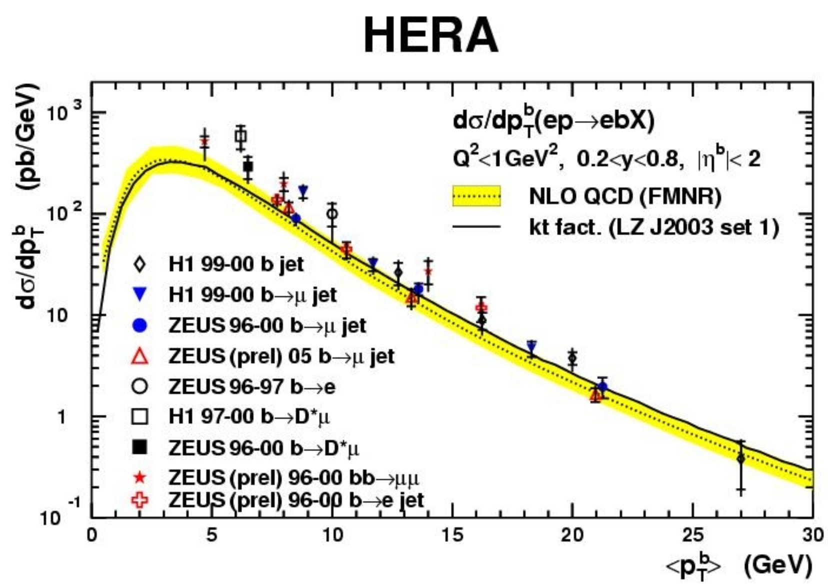
α_s measurement at HERA are as precise as those from LEP

Charm and beauty

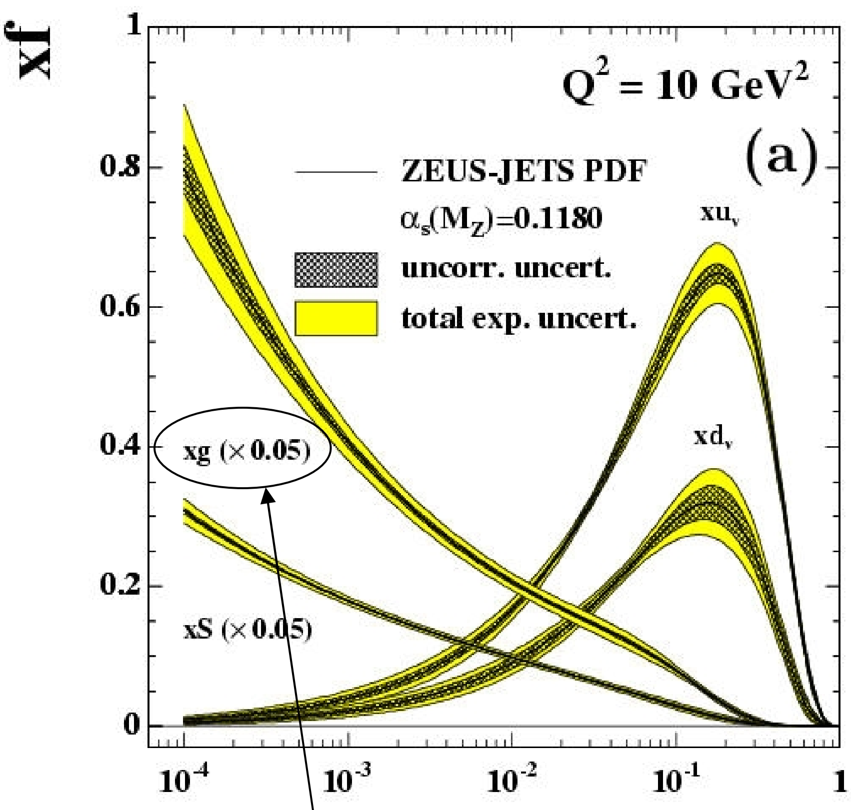
$$\frac{d\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\{[1+(1-y)^2]F_2^{c\bar{c}}(x,Q^2) - y^2 F_L^{c\bar{c}}(x,Q^2)\}$$







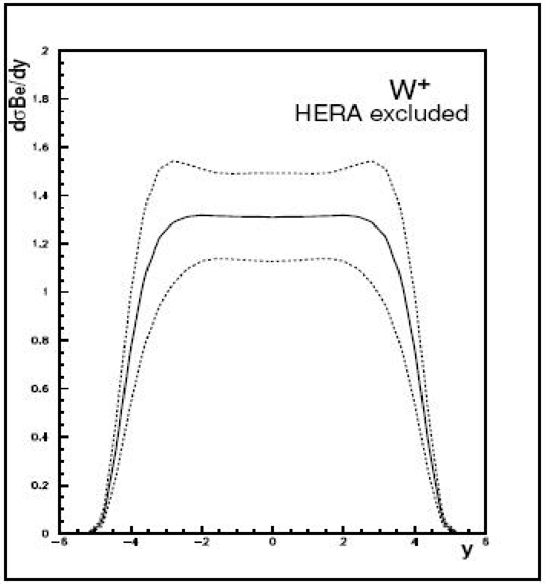
Parton densities from ZEUS data

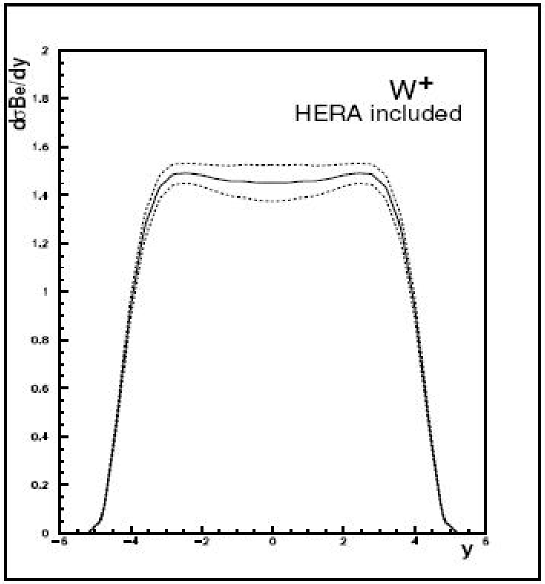


Proton is mostly gluons at low x

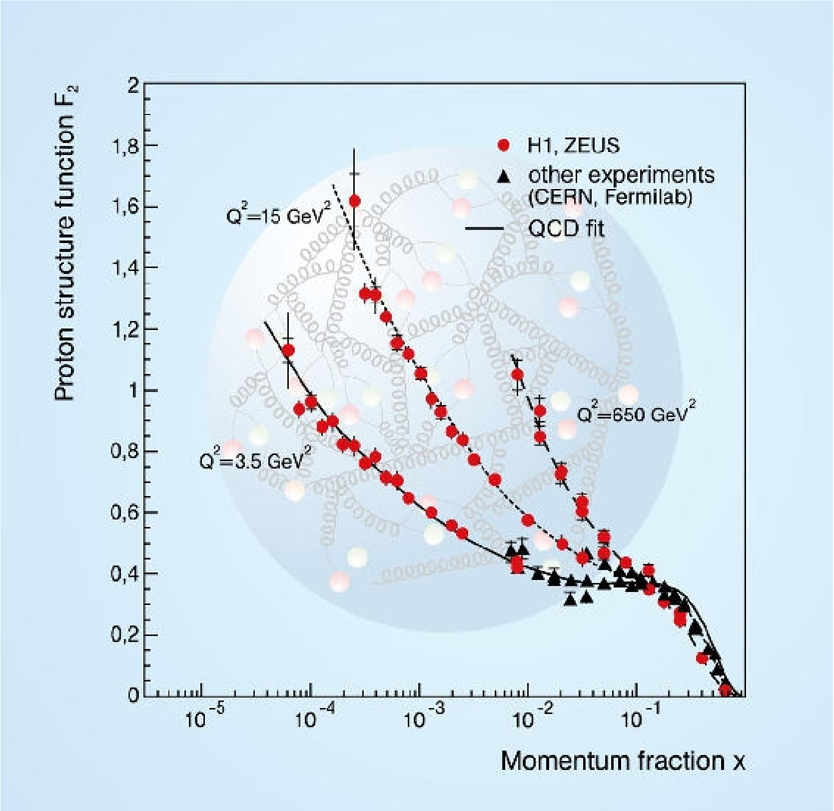
Predicts e.g.

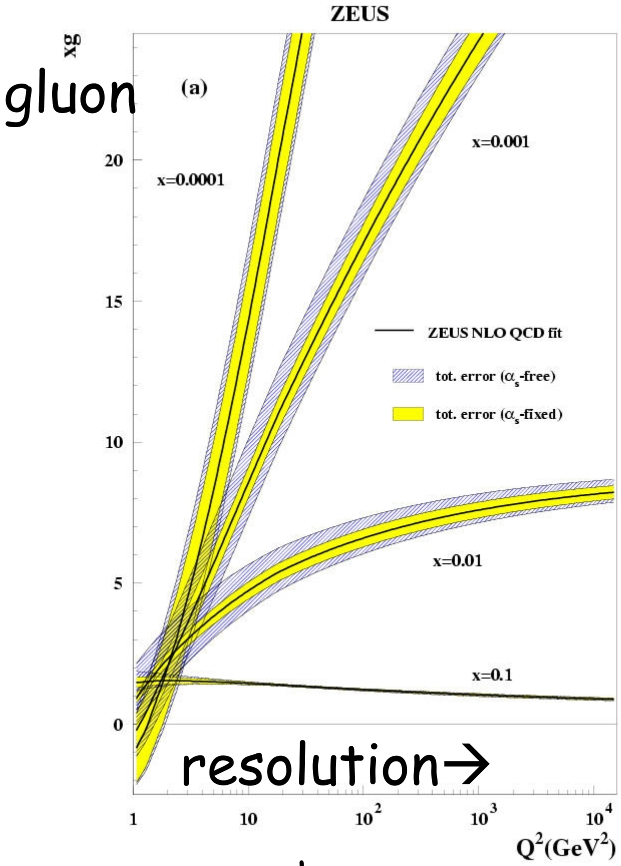
W$^+$ production at LHC





Triumph of perturbative QCD



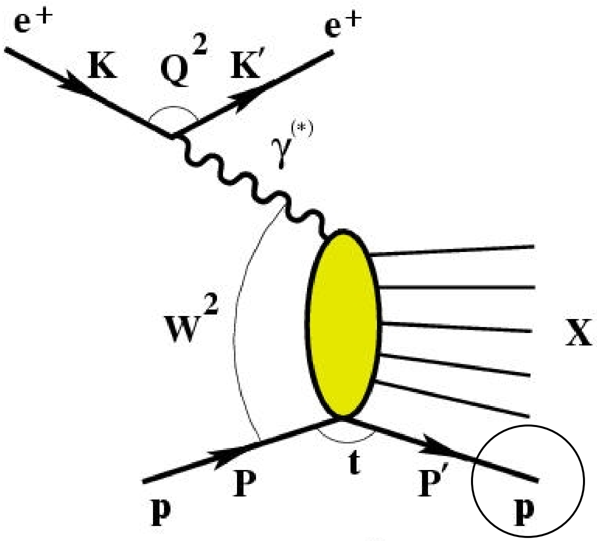


A part of Wilczek's comments upon the Nobel Prize announcement

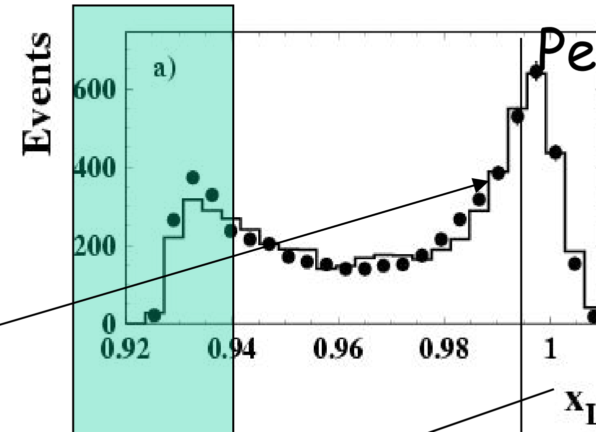
proposed specific experimental tests of our ideas. In the fourth paper some technical objections to the theory were cleared up, and in the fifth and sixth papers further experimental consequences, regarding the pointwise evolution of structure functions, were derived. The most dramatic of these, that protons viewed at ever higher resolution would appear more and more as field energy (soft glue), was only clearly verified at HERA twenty years later.

On the other hand…

Has the hadronic proton completely vanished (only manifestation in the parton densities) ?



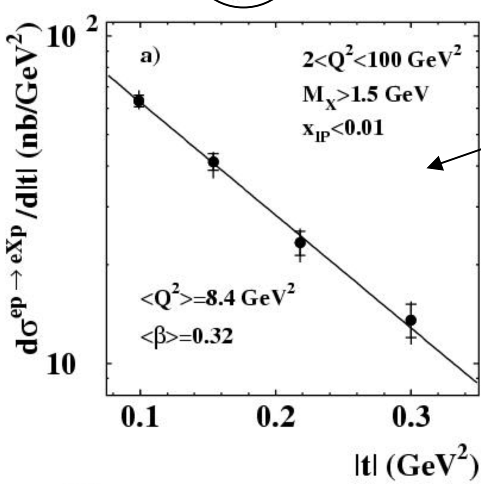
Look for leading protons in the final state



Peak!

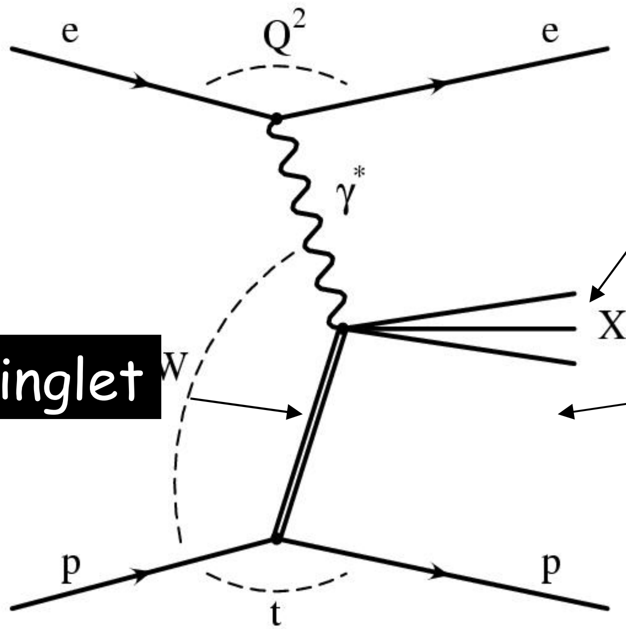
carries most of the beam momentum

t is small



If proton carries most of the beam momentum and t is small →

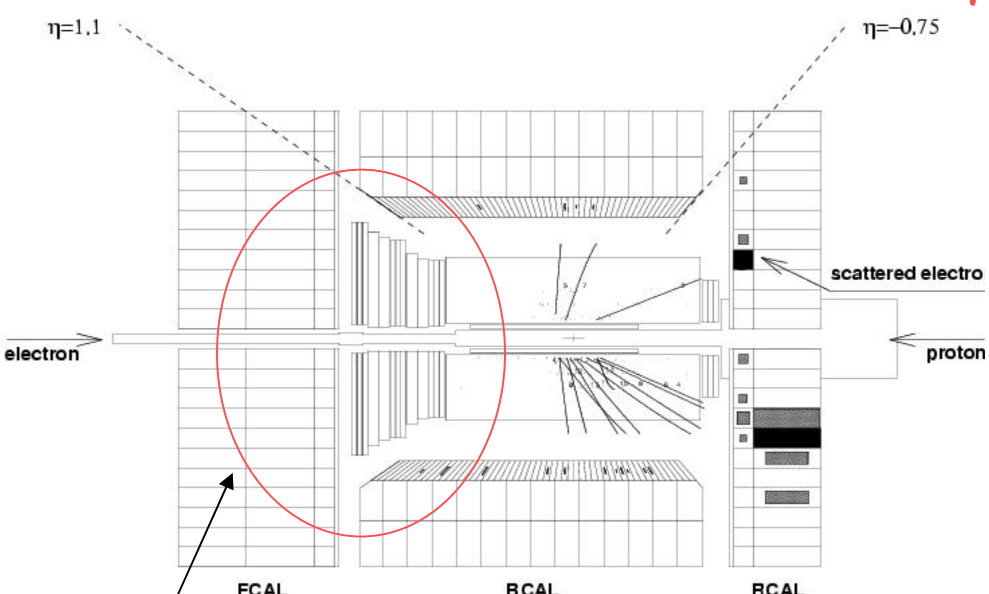
…then



color singlet

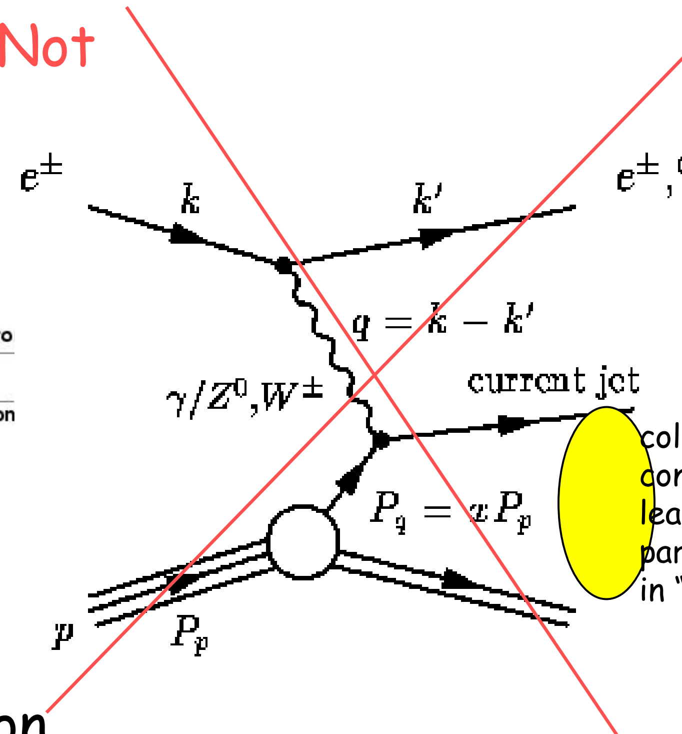
Mass of X, Mx, must be small with respect to W

X is far away in rapidity from the proton→ a rapidity gap



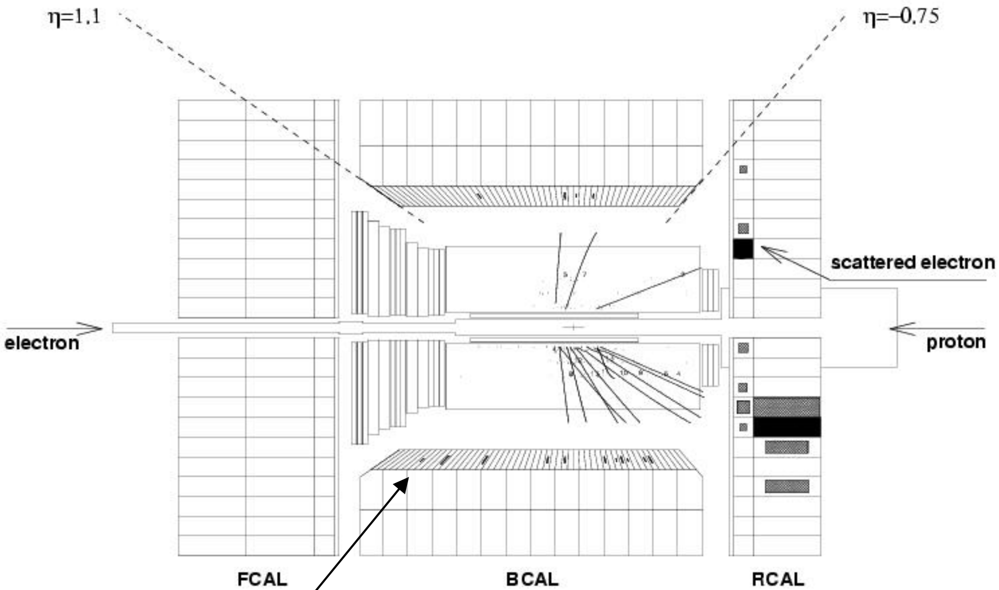
No particles in the proton direction

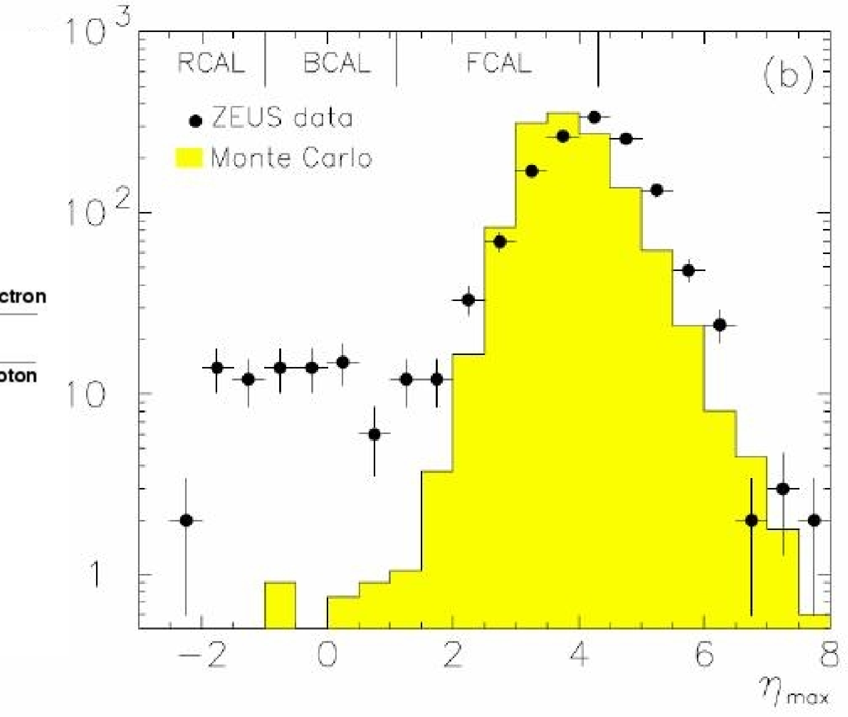
Not



color connection leads to particles in "gap".

1993

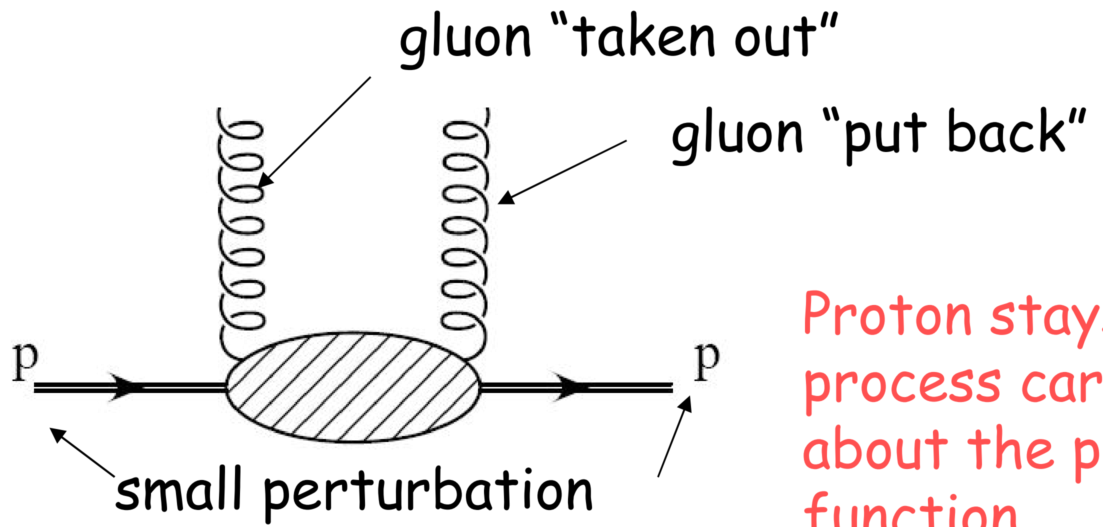




η_{max}, the most forward energy deposit

~10% of DIS events are "rapidity gap" events

In the simplest interpretation 2 gluons in a color singlet state are exchanged:



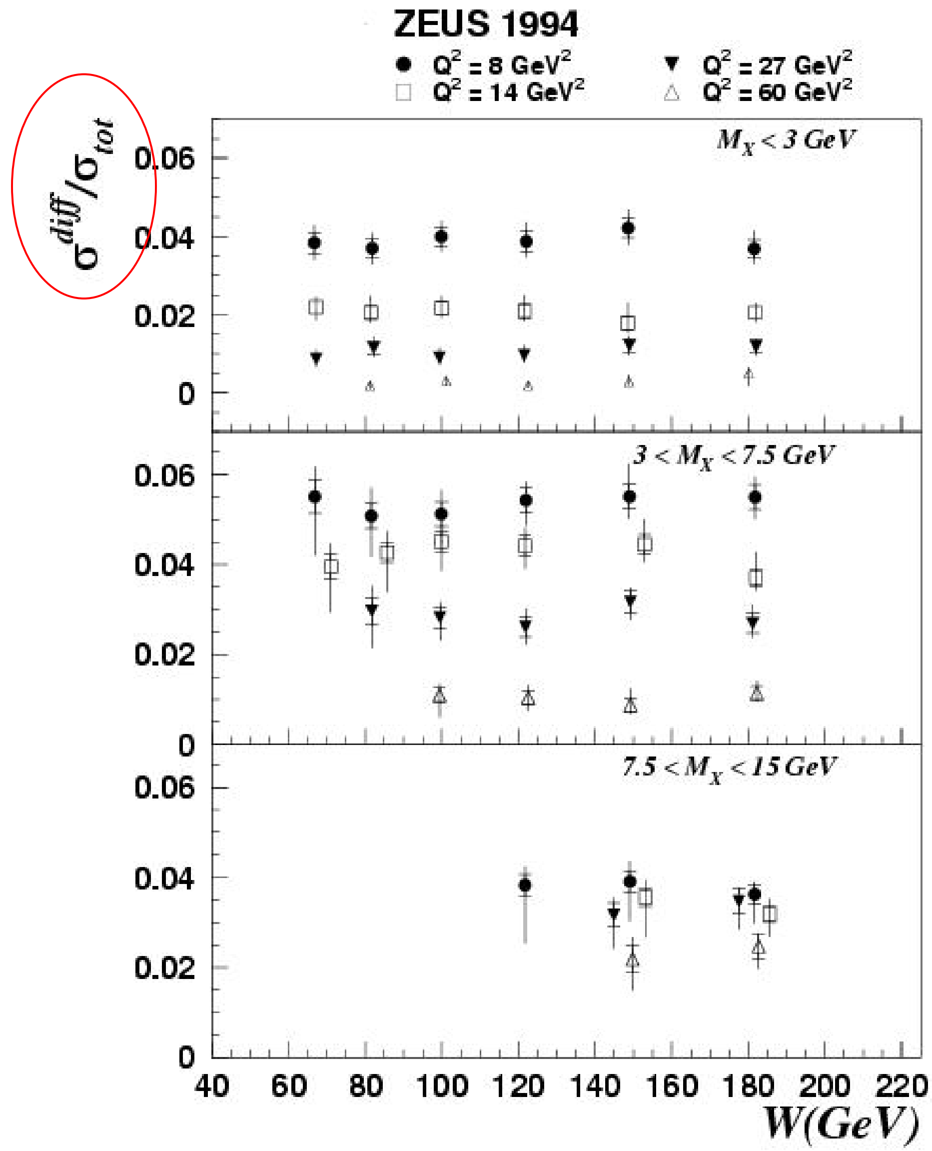
Proton stays intact: this process carries information about the proton wave function.

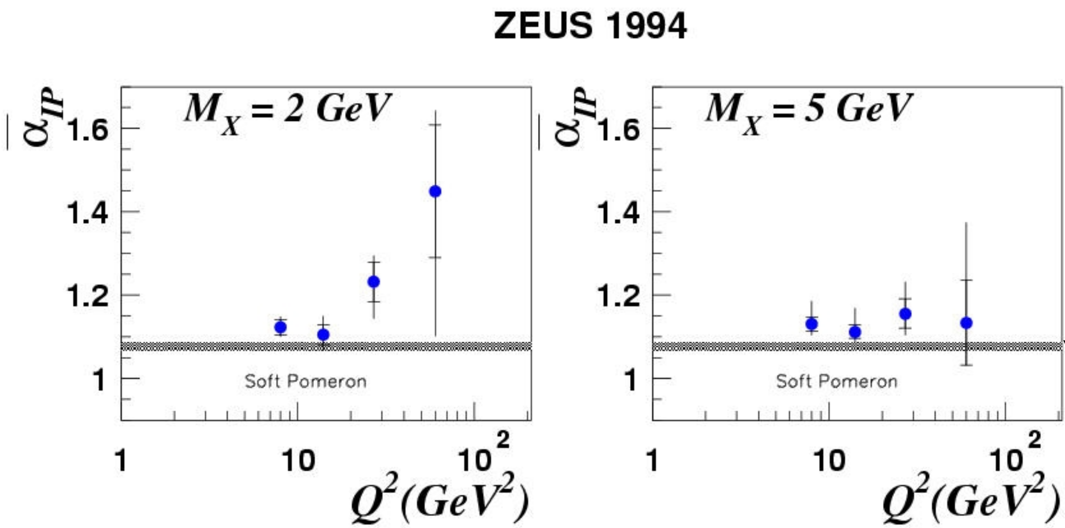
Here, proton is behaving as a hadron!

This is "diffraction" familiar from hadronic physics: however, with some peculiarities

- Sizable part of F_2 even at high Q^2 (~10% at 30 GeV^2). → High Q^2 means interpretable in terms of pQCD(?)
- Ratio to total cross section is flat with W (or x). How is this possible? If
  - σ_{tot} ~ gluon density
  - σ_{diff}~(gluon density)^2

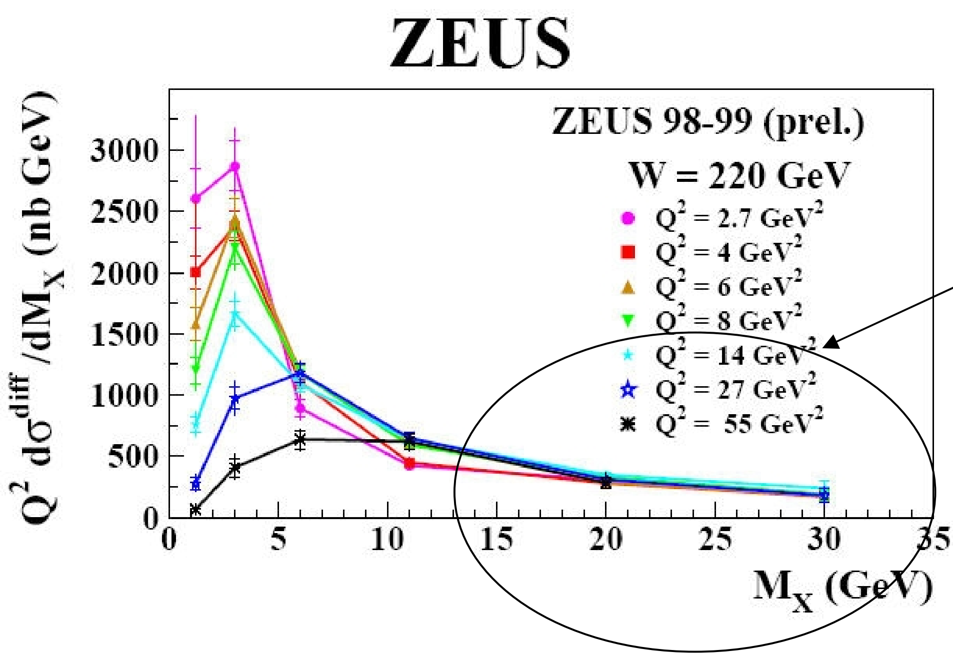
(Naively…)





Energy dependence of diffractive DIS is not like the usual hadronic diffraction.

Expectation from hadron-hadron data.



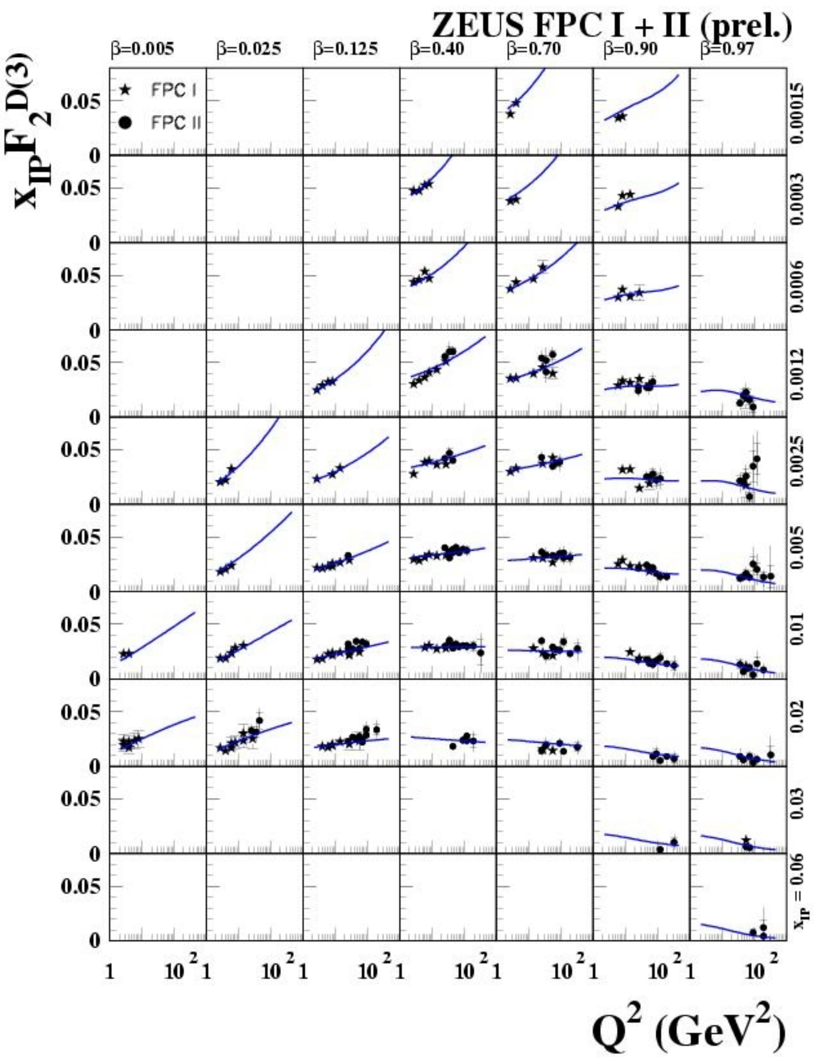
At high Mx, diffractive DIS is not vanishing at high Q^2.—"leading twist" in pQCD language.

Proton as a hadron

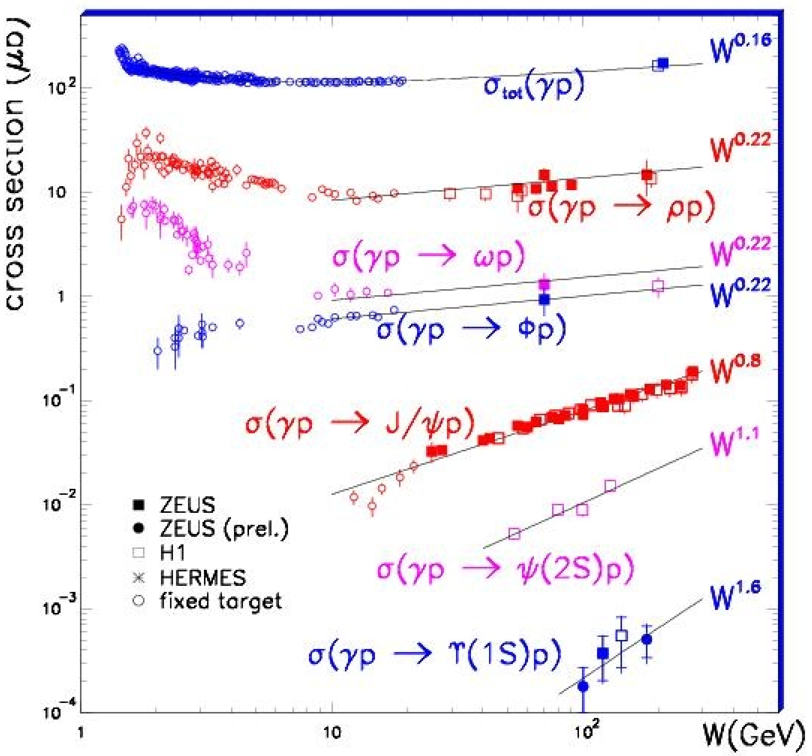
- In DIS diffraction we have:
  - A phenomenon that is clearly related to the hadronic nature of the proton—i.e. that of confined color.
  - that exists at 10% level at high Q2—where perturbative QCD should be usable.
  - that does not conform to the expectation from the hadronic phenomenology.
  - that does not conform to the naïve expectation of 2 gluon exchange.
- Plenty of mysteries:
  - We observe protons as hadrons clearly in the kinematic region where asymptotic freedom+partons appears to give a good description of data.
  - Do we, then, truly understand the evolution of partons in the proton—especially at low x?
  - Is diffractive DIS the opportunity to finally begin to unravel confinement from a perturbative point of view?

A lot of high precision data from HERA exists→

Diffractive DIS cross-section



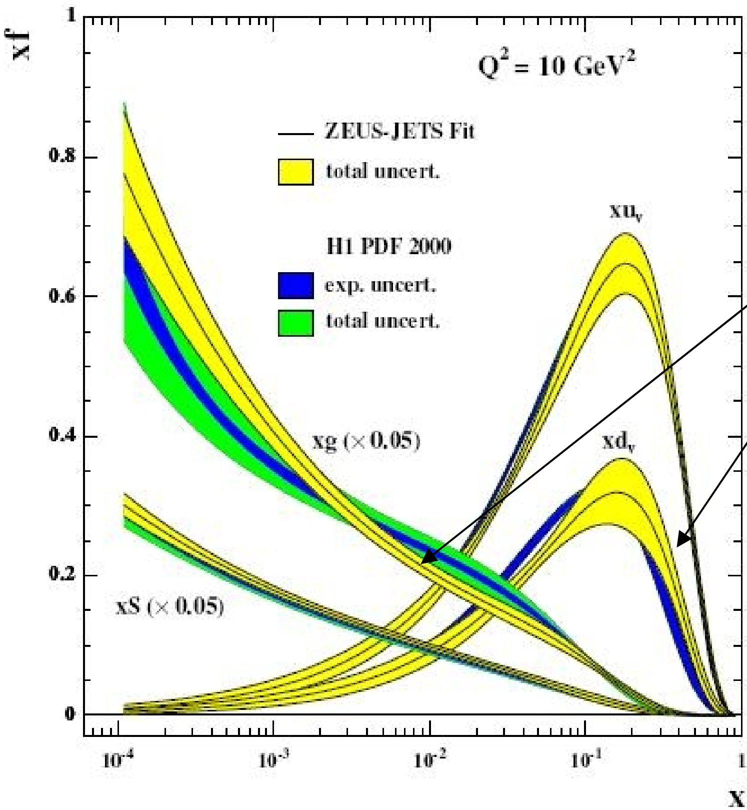
Elastic VM production



So far, no true understanding of this phenomenon

Combining H1 and ZEUS F_2 results

H1-ZEUS Working Group: A. Cooper-Sarkar, K. Nagano, J. Ferrando
Y. Ri, A. Glazov, M. Klein, V. Shekelian, Z. Zhang, E. Rivzi, U. Martyn



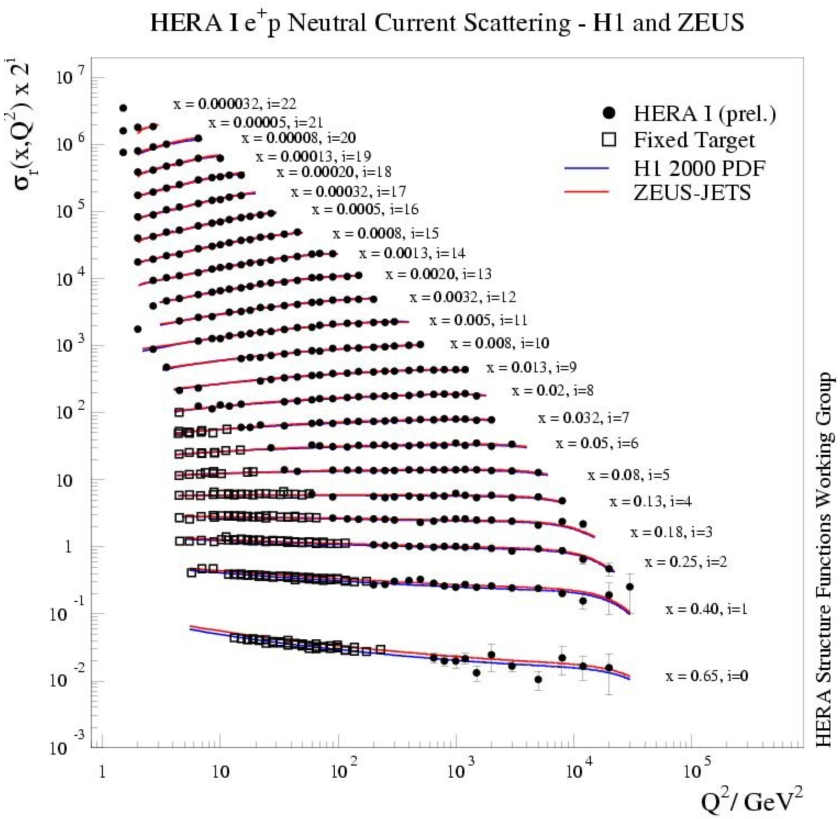
Some understood differences between H1 and ZEUS PDF's

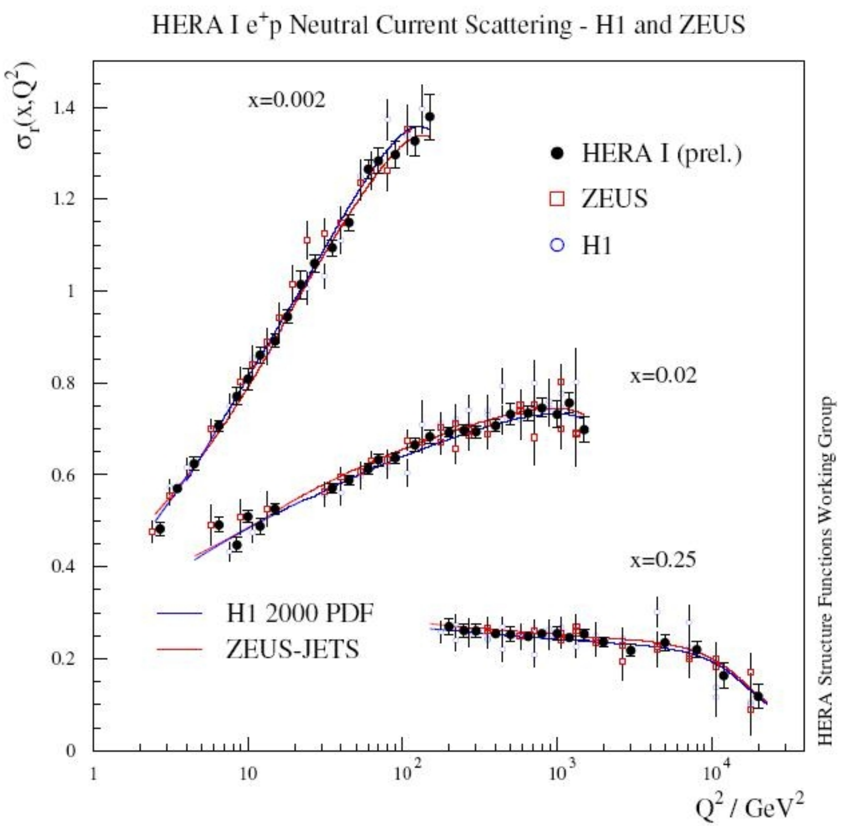
ZEUS uses jet-data to constrain mid-x gluon→ smaller uncertainty

H1 uses BCDMS data to pin down the high-x behavior→ smaller uncertainty

Still, there appears to be some systematic differences.

H1-prelim-07-007,ZEUS-prel-07-026

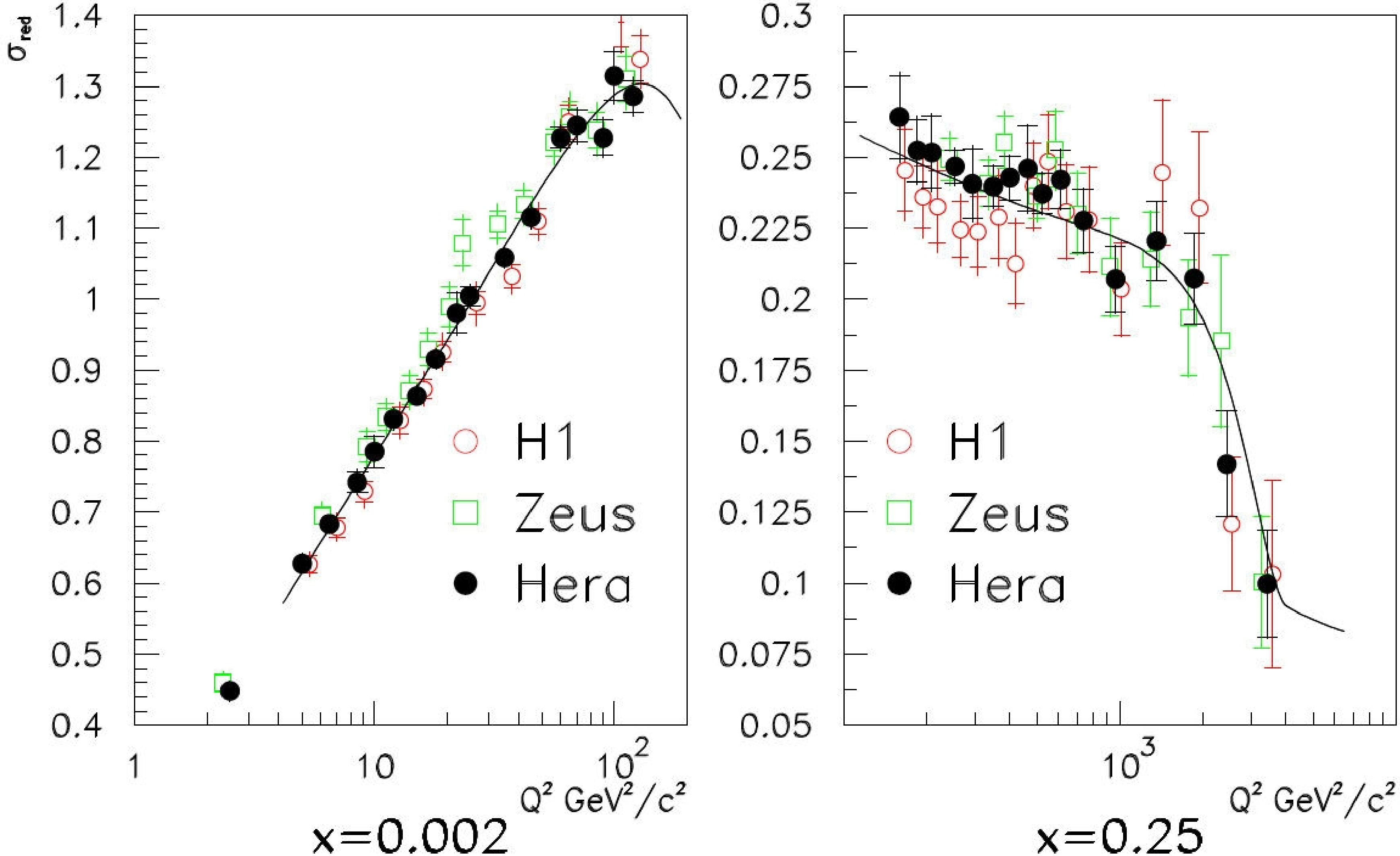




χ_2/dof = 510/599

H1 and ZEUS measurements are consistent.

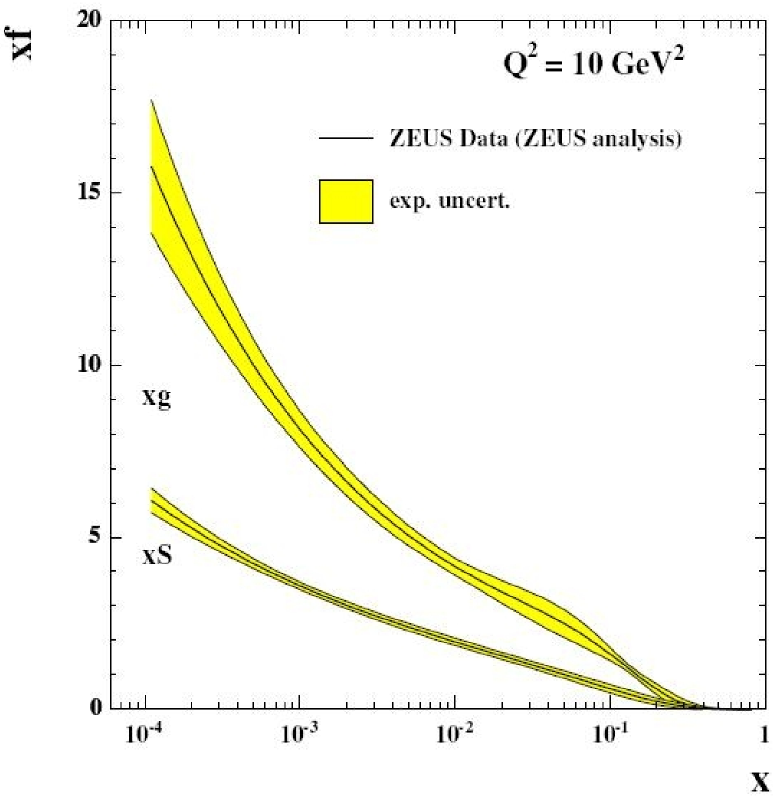
Of course, this procedure also produces a combined F_2



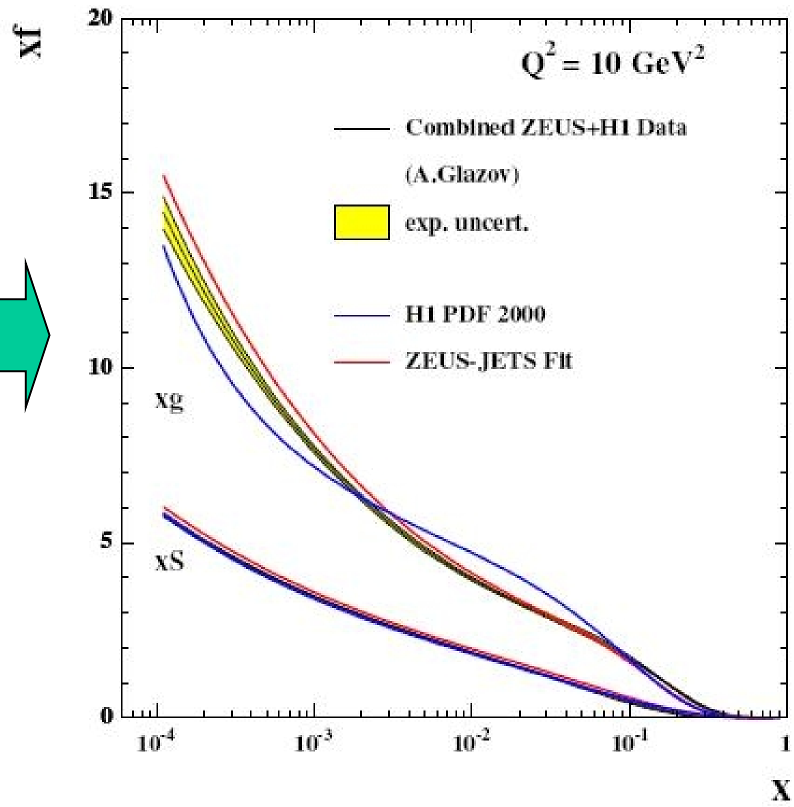
The improvement is (much) better than √2 !!!

Leads to (very) significant improvements in parton densities

ZEUS data only



H1+ZEUS data



Note: These plots are taken from the proceedings of HERA-LHC workshop hep-ph/0601012 and uses an earlier version of the combined data.

Only HERA I data have been combined so far

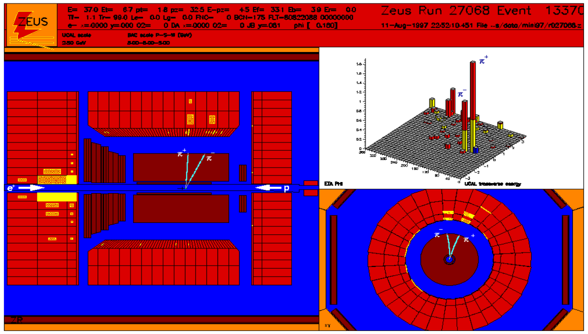
Concluding remarks and outlook

- HERA ep collider has ceased operations as of July 2007.
- The experiments H1 and ZEUS have together recorded about 1 fb^{-1} of data.
- The rise of F_2 at low x and diffractive DIS are two of the most important discoveries at HERA. The quantitative understanding of the latter phenomena is still missing.results from ZEUS.
- Although data taking is over, there is a lot more to come →

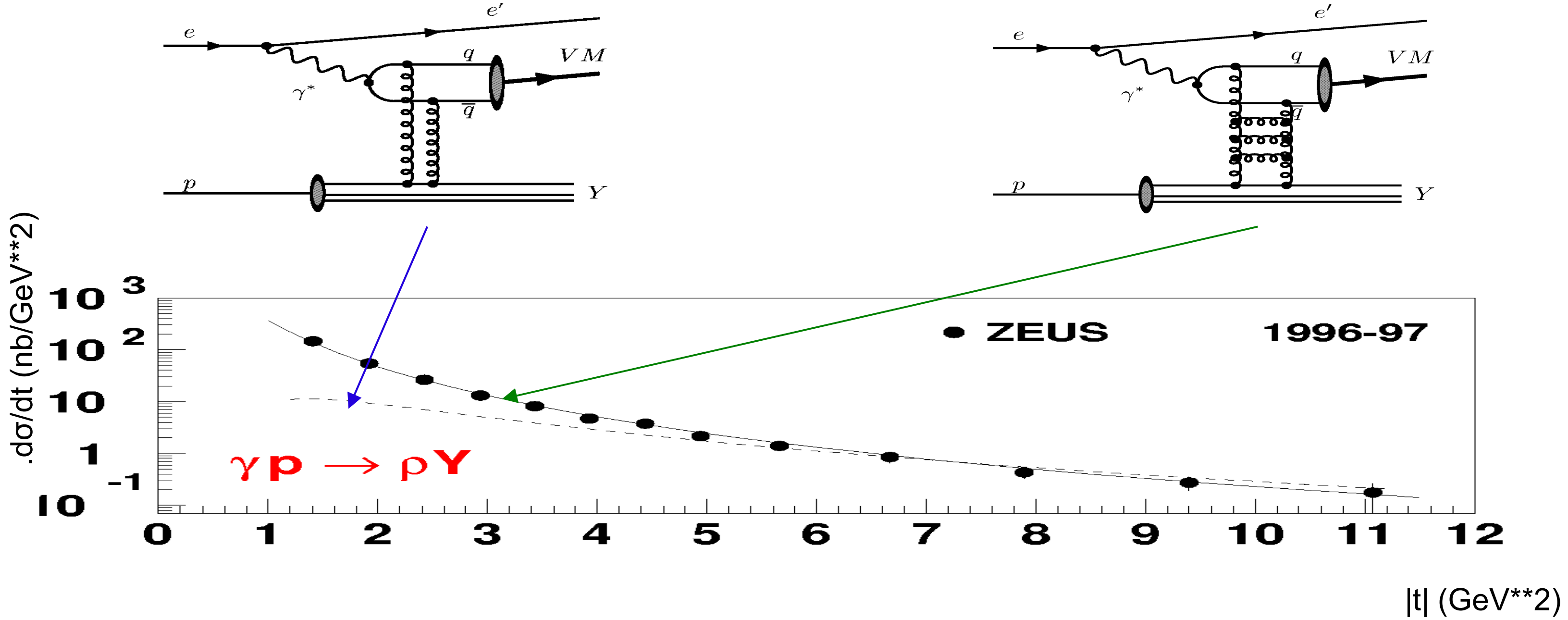
Outlook

- Full analysis of HERA II data—will probably take 2-3 years more.
- ~30-50% improvement in statistically limited measurements (high Q^2, E_T), <1% experimental precision in alpha_s.
- Factor x(2?) improvement in systematics in F_2 (improved understanding and H1+ZEUS combination)
- Charm and beauty cross-section to 5 and 20% respectively—micro-vertex detectors.
- Electroweak measurements.
- F_L measurement for the first time at HERA.

Przykład prostego oddziaływania: $ep \rightarrow e\,\rho^0\,N' \rightarrow e\,\pi^+\,\pi^-\,N'$



A to mozliwe diagramy chromodynamiki kwantowej (QCD) dla tej reakcji:

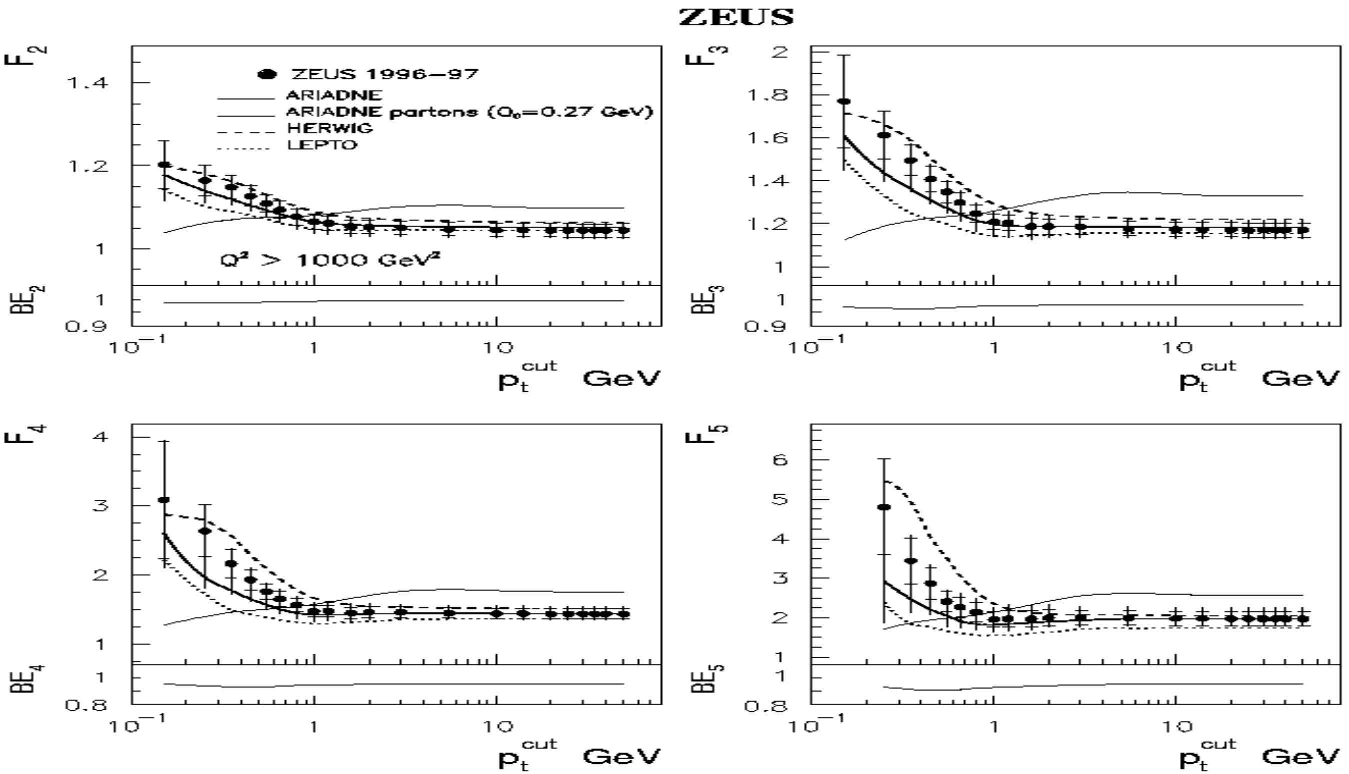


Pomeron QCD: 2 gluony czy drabina gluonowa?

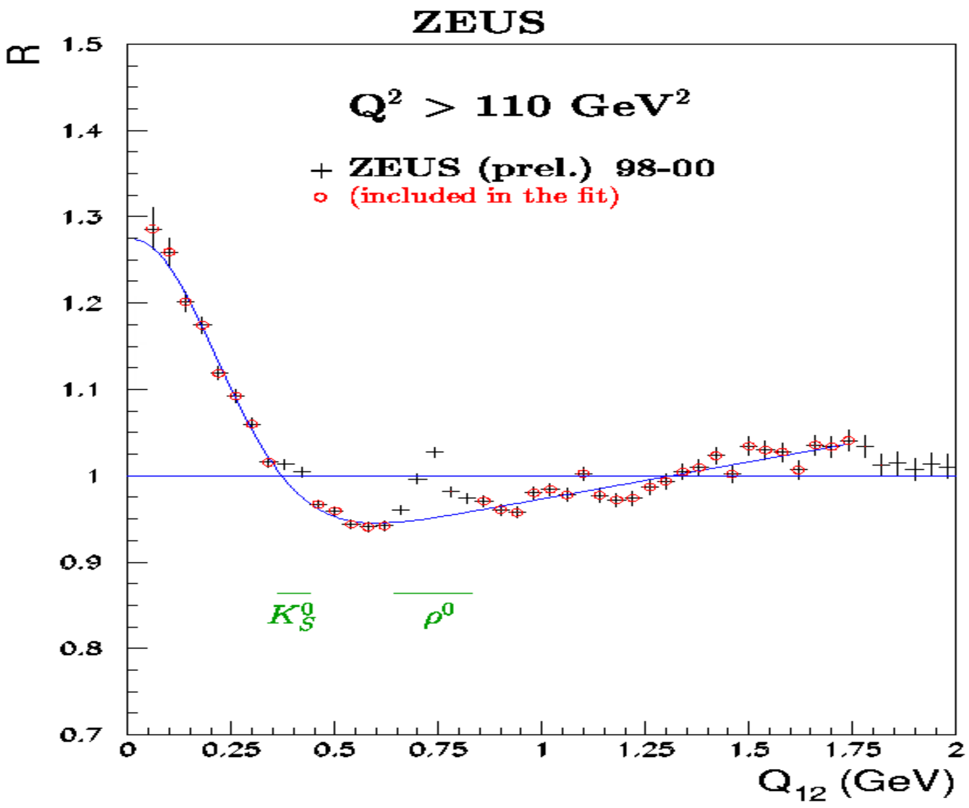
Na to pytanie usiłujemy odpowiedzieć w Krakowie...

Wybrane tematy badań w Krakowie:

- Dyfrakcyjna kwazi-fotoprodukcja mezonów wektorowych ρ, φ and J/Ψ
- Szczegółowe własności wielo-hadronowych stanów końcowych produkowanych w głęboko-nieelastycznych oddziaływaniach e-p :
  - korelacje między hadronami,
  - fluktuacje krotności hadronów, momenty krotności,
  - interpretacja w ramach perturbacyjnej QCD



• Korelacje Bosego-Einsteina: rozmiar obszaru emisji hadronów



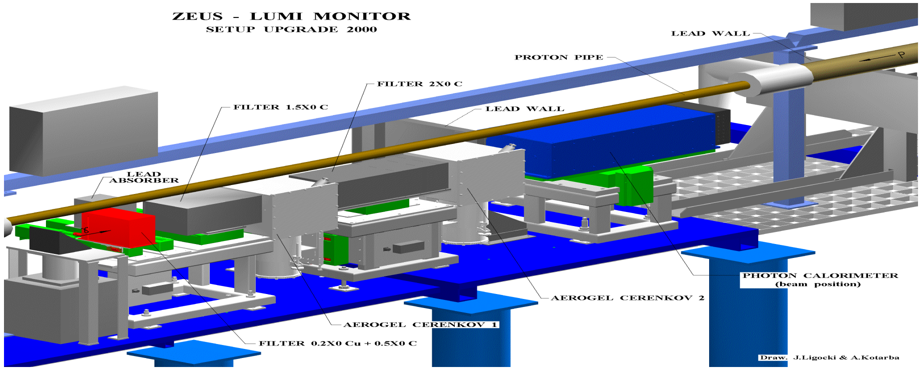
• badanie produkcji cząstek dziwnych
• efekty saturacji.

Monitor świetlności

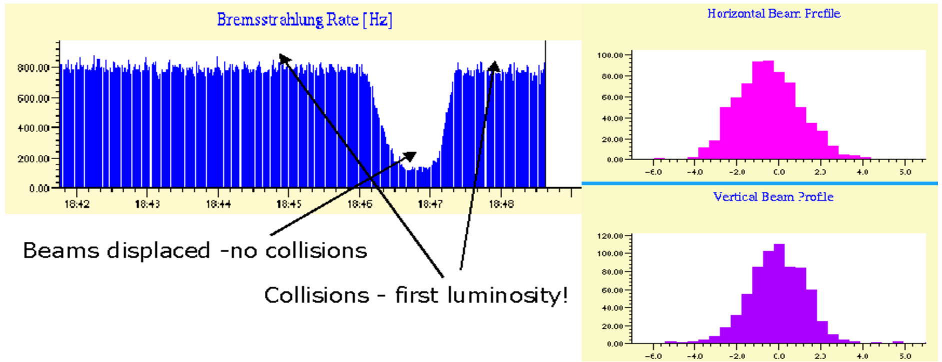
świetlność = liczba obserw. przypadków/(przekrój czynny · czas)

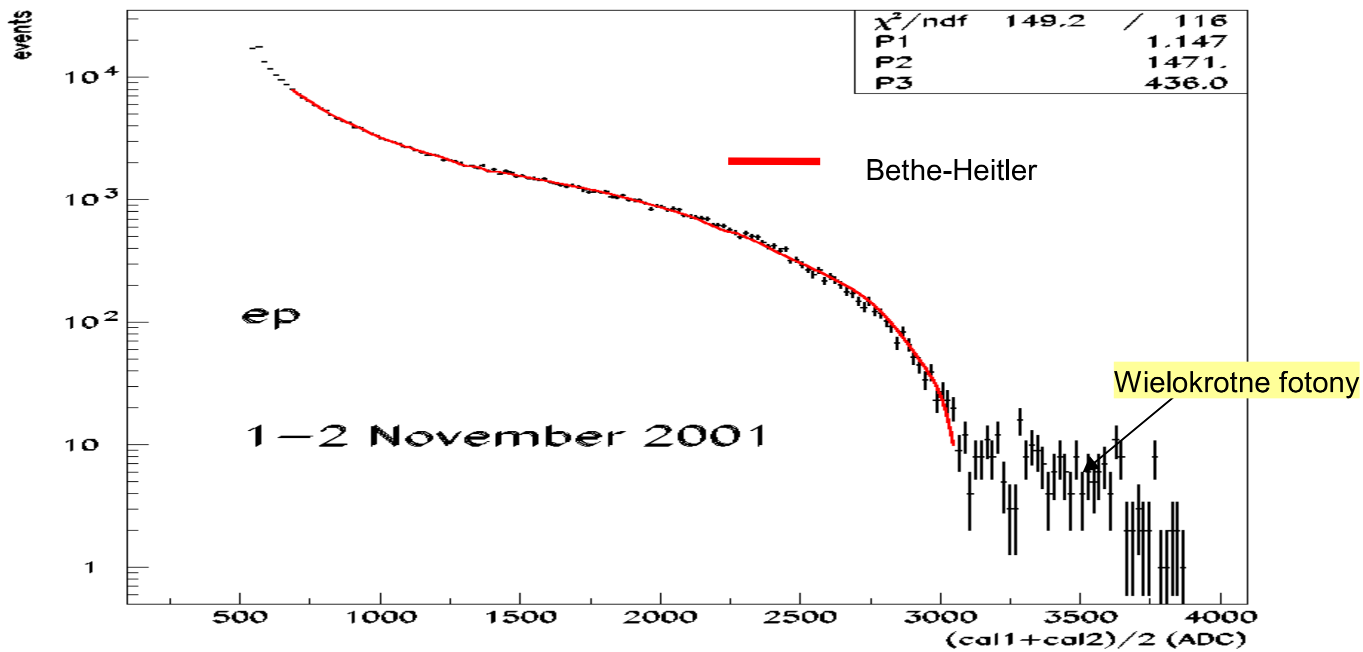
Zaprojektowaliśmy i zbudowali nowy monitor świetlności dla eksperymentu ZEUS, spełniający wymagania przebudowanego akceleratora HERA, i mierzymy świetlność na bieżąco.

Zasada pomiaru świetlności: zliczanie fotonów hamowania $ep \rightarrow ep\, \gamma$



Pierwszy pomiar świetlności 21.10.2001:





Nasz cel: pomiar świetlności z dokładnością lepszą niż 2%

Proponowane tematy prac magisterskich w Zakładzie Struktury Hadronów (NZ12):

Pomiar ekskluzywnego przekroju czynnego na produkcję mezonu J/PSI lub/i PHI w eksperymencie ZEUS przy akceleratorze HERA w DESY w Hamburgu

opiekun: dr Dorota Szuba, dorota.szuba@desy.de

Analiza materiału doświadczalnego zebranego w eksperymencie ZEUS w 2007 roku
Przy energii protonu 460 GeV oraz 575 GeV, kontynuacja prac grupy krakowskiej.
Wymagana przyzwoita znajomość angielskiego, możliwa praktyka w DESY.

Korelacje w końcowych stanach hadronowych w eksperymencie ZEUS przy akceleratorze HERA w DESY w Hamburgu

opiekun: dr Piotr Stopa piotr.stopa@ifj.edu.pl

Analiza materiału doświadczalnego zebranego w eksperymencie ZEUS w okresie HERA II 2002-2007.