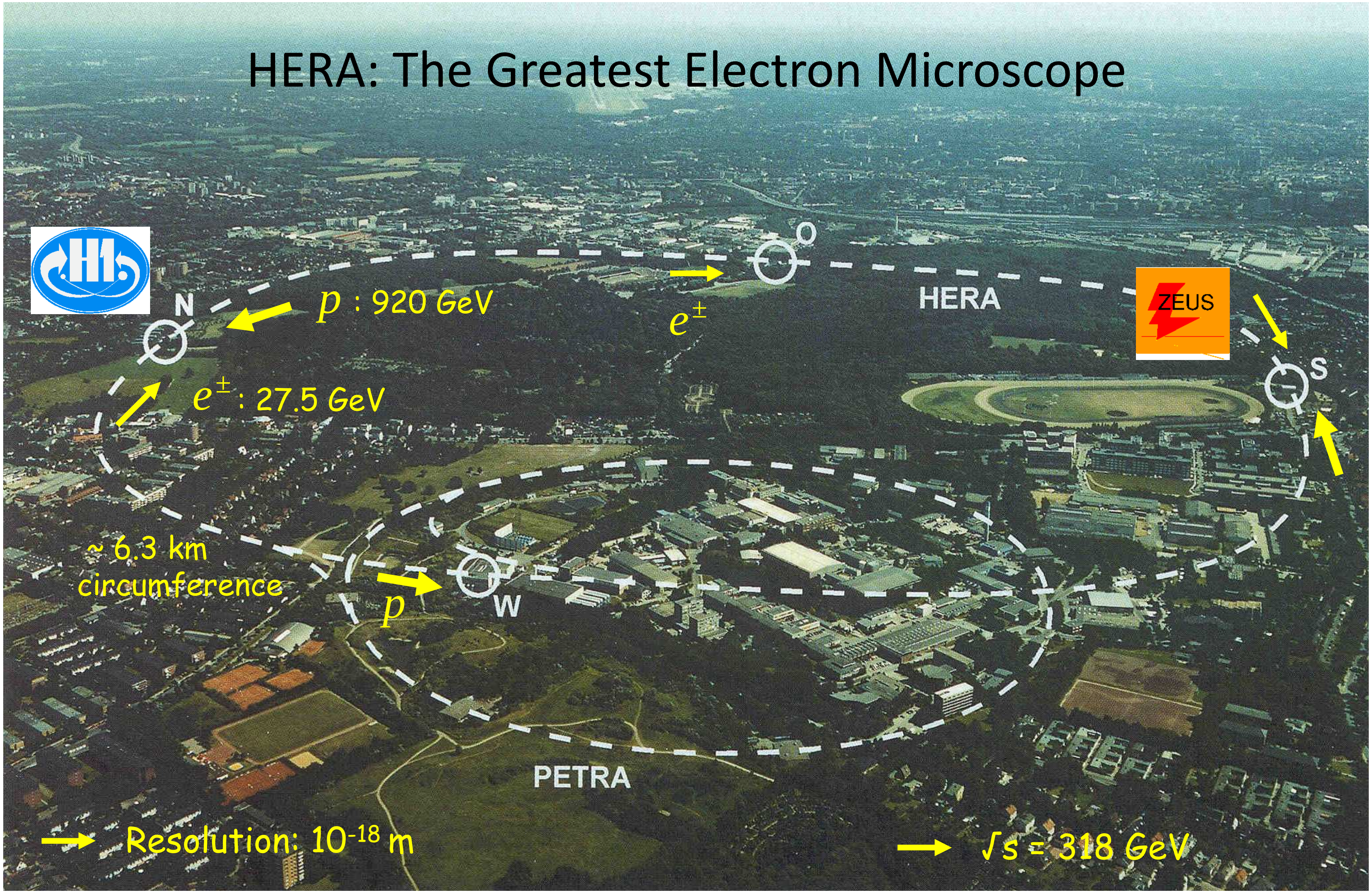
First Physics Results at HERA

HERA SYMPOSIUM 2012 :

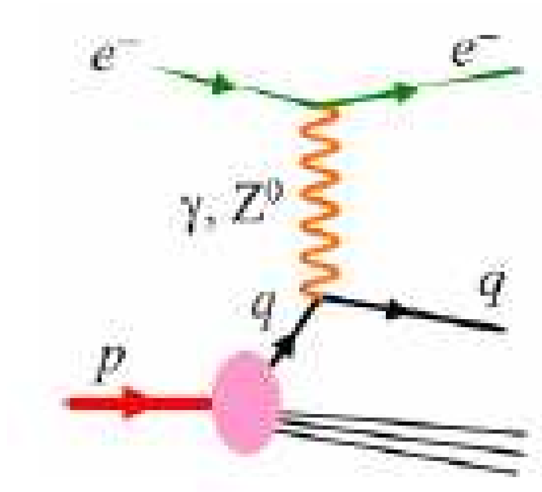
20 Years of DIS at HERA

HERA: The Greatest Electron Microscope

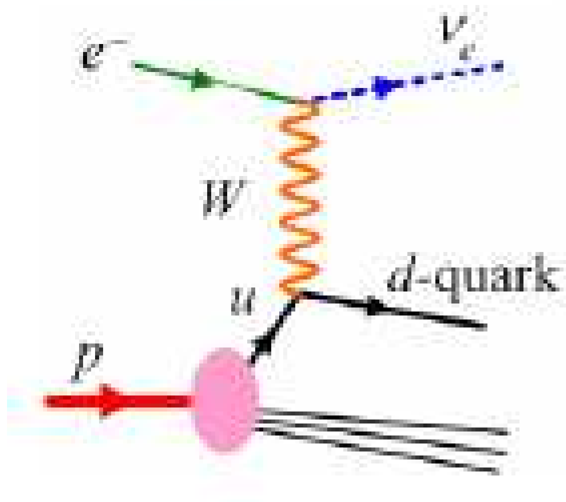


At HERA Neutral and Charged Currents

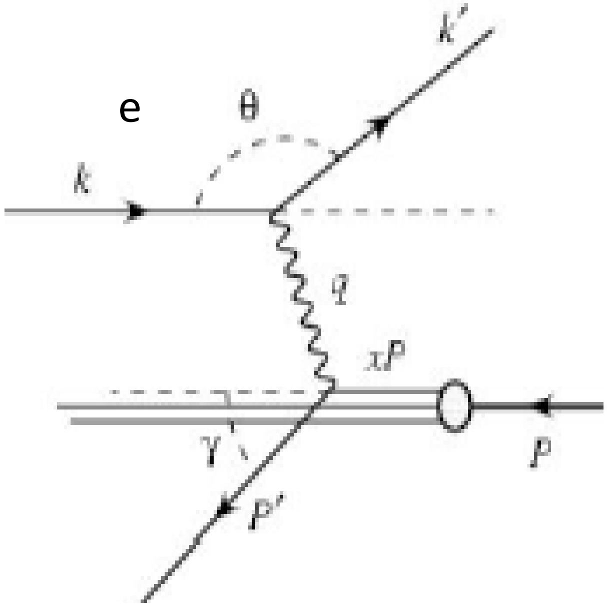
Neutral Currents (NC)



Charged Currents (CC)



Kinematics of Deep Inelastic Scattering (DIS)



$Q^2 = - q^2 = - (k - k')^2$: a measure of the probing power.
High Q^2 ↔ small distance scale

$x = Q^2 / 2pq$: fraction of proton's momentum carried by the struck quark.
High x ↔ valence quark
Low x ↔ sea quarks

ZEUS
A DETECTOR FOR HERA

LETTER OF INTENT

Carleton, Manitoba, McGill, Toronto, York
Canada

Bonn, DESY, Freiburg, Hamburg, Siegen
Germany

Weizmann Institute
Israel

Bologna, Ferrara, Florence, Frascati, L'Aquila, Lecce,
Milan, Padua, Palermo, Rome, Turin
Italy

Amsterdam, Nijmegen
The Netherlands

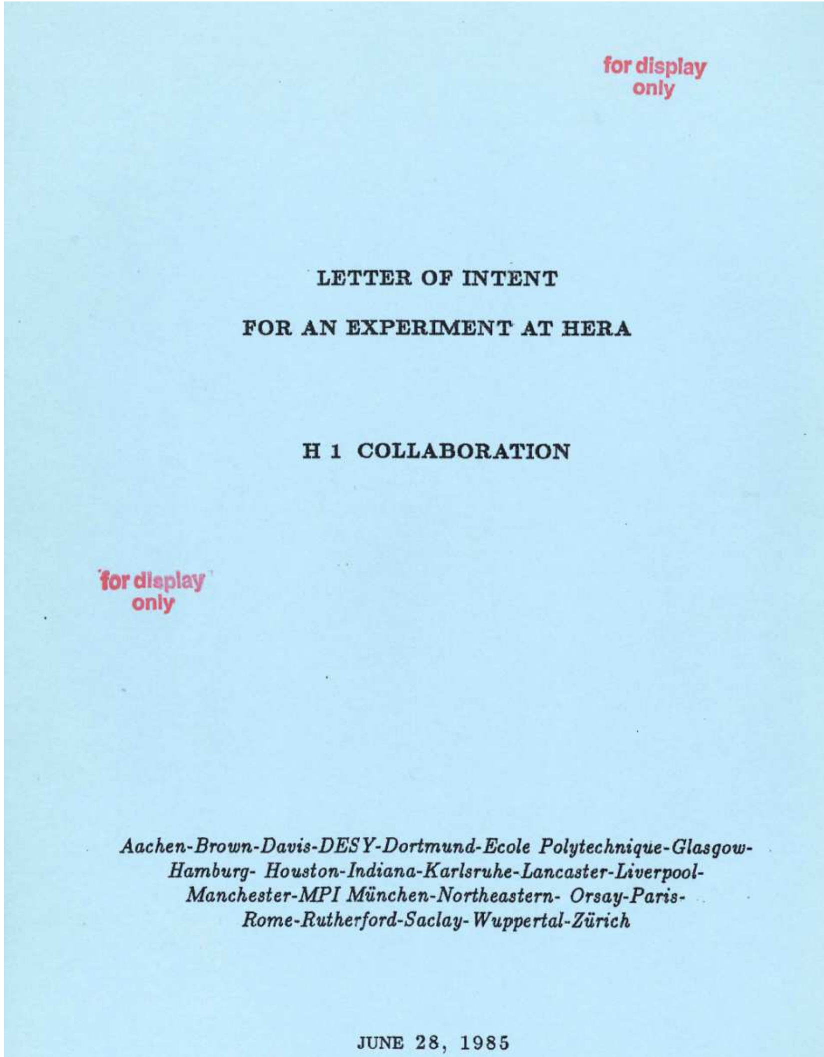
Cracow, Warsaw
Poland

Madrid
Spain

Bristol, London(IC), London(UC), Oxford, Rutherford
United Kingdom

Argonne, Columbia, Illinois, Michigan, Ohio, Pennsylvania,
Princeton, Virginia, Wisconsin
USA

JUNE 1985



LETTER OF INTENT

FOR AN EXPERIMENT AT HERA

H 1 COLLABORATION

Aachen-Brown-Davis-DESY-Dortmund-Ecole Polytechnique-Glasgow-Hamburg- Houston-Indiana-Karlsruhe-Lancaster-Liverpool-Manchester-MPI München-Northeastern- Orsay-Paris-Rome-Rutherford-Saclay-Wuppertal-Zürich

JUNE 28, 1985

Design goals of detectors

The H1 and ZEUS detectors were optimised for :

- Neutral and Charged Currents at high Q^2
- Exotics : leptons (electrons and muons) , Missing E_t (hermiticity), Multi-jet signatures
- Tagging of photoproduction events

(no forward proton detectors in the first years)

Some nuances (in a nutshell) between the H1 and ZEUS detectors

- H1 : Main optimisation for scattered electron measurement : 0.1/√Ee resolution for electron energy at large Q^2 (> 100 GeV^2), small granularity .

  0.5 / √Eh resolution for hadron energy.

  Calorimeter (Ar + lead) inside the solenoid coil

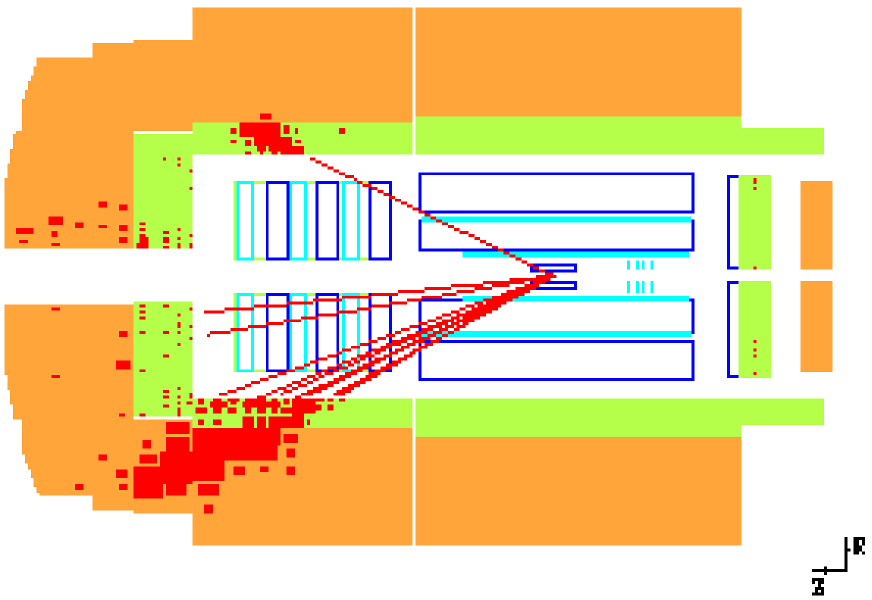
- ZEUS : Main optimistion for CC at high Q^2

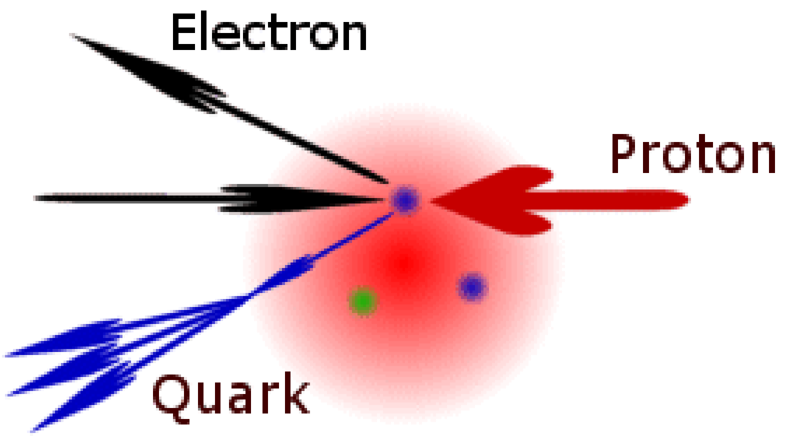
  0.35 / √Eh excellent resolution for hadron energy :

  0.18 /√Ee resolution for electron energy

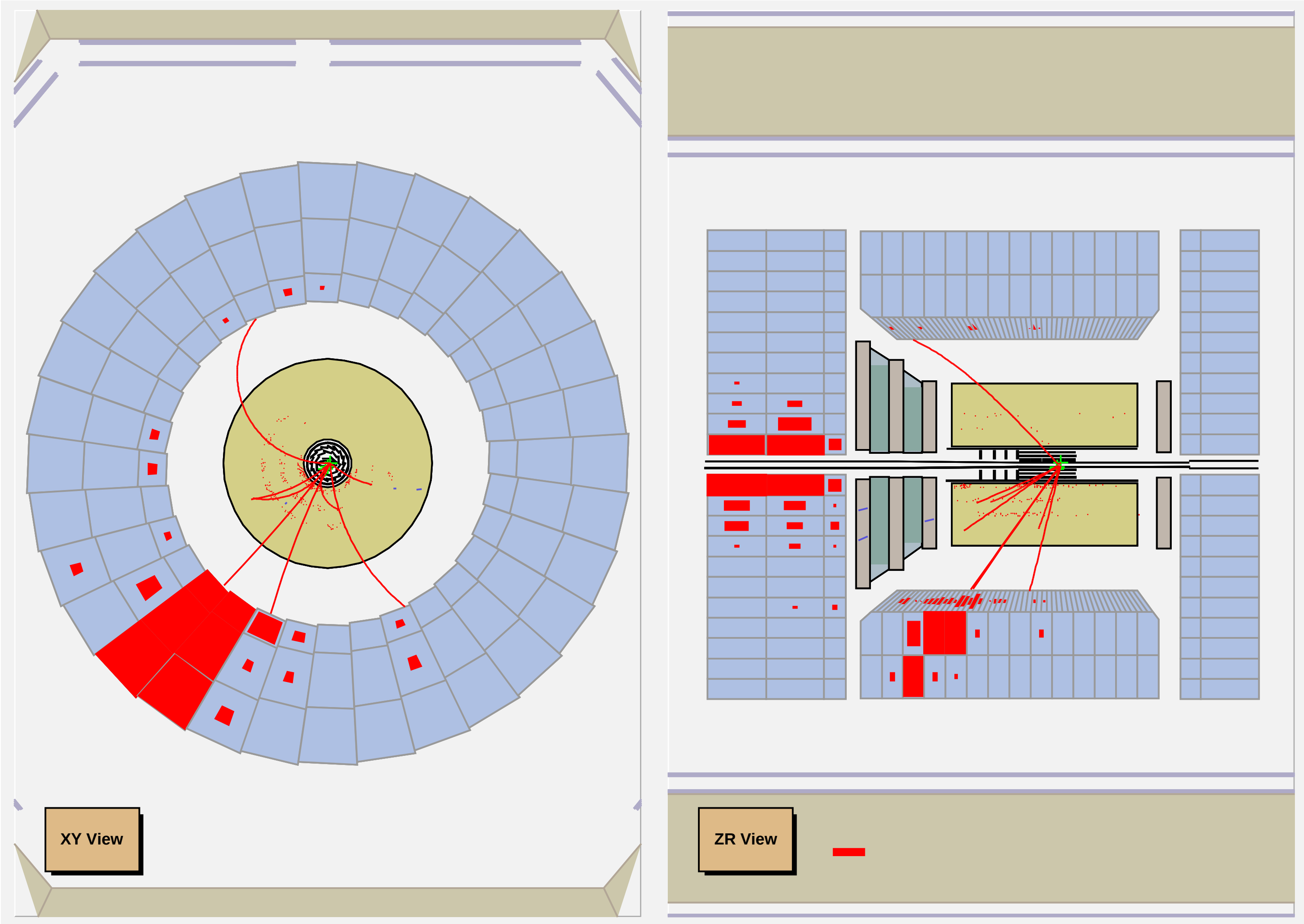
  Uranium calorimeter outside the solenoid coil

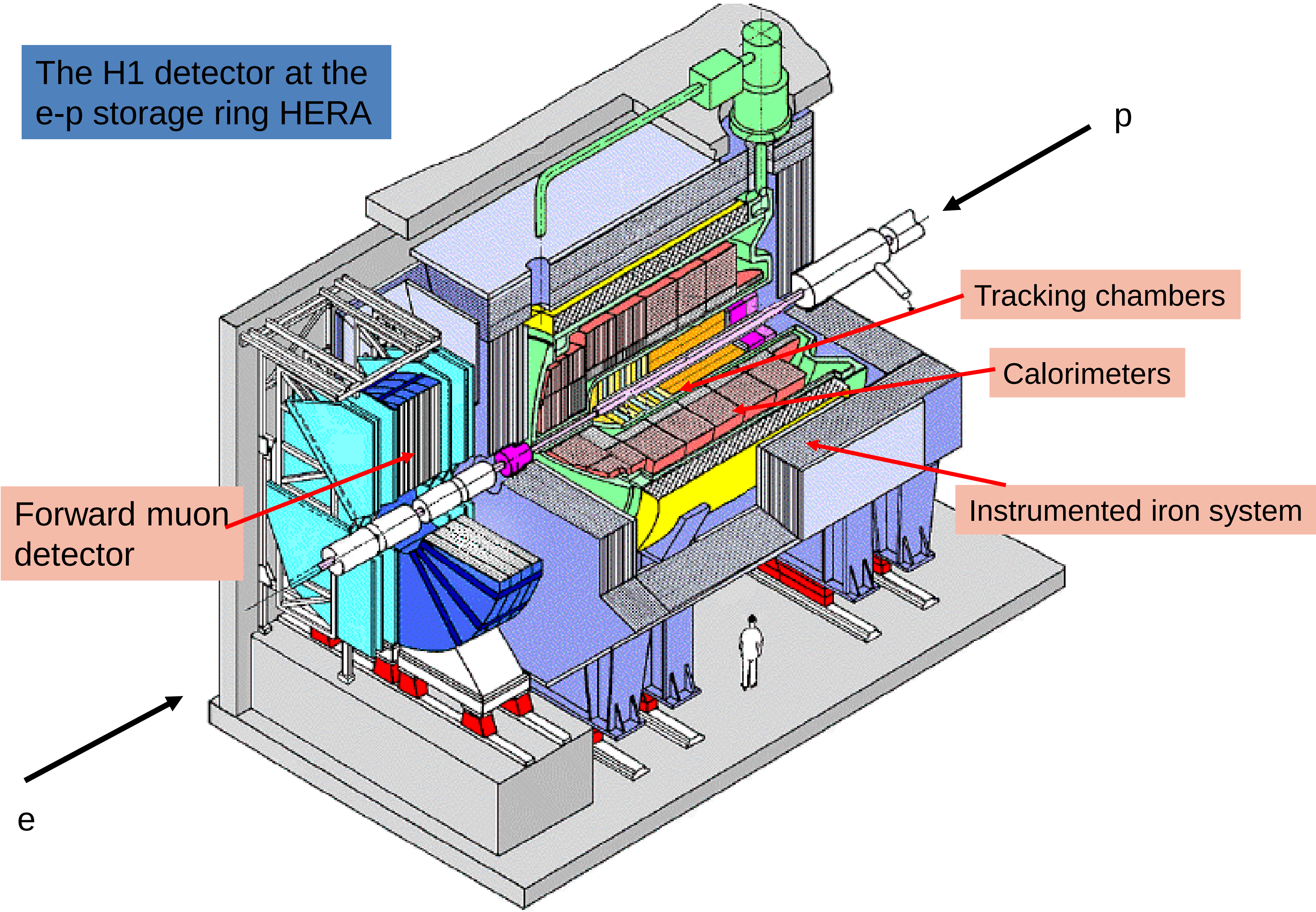
HERA e-p scattering events observed in the H1Detector



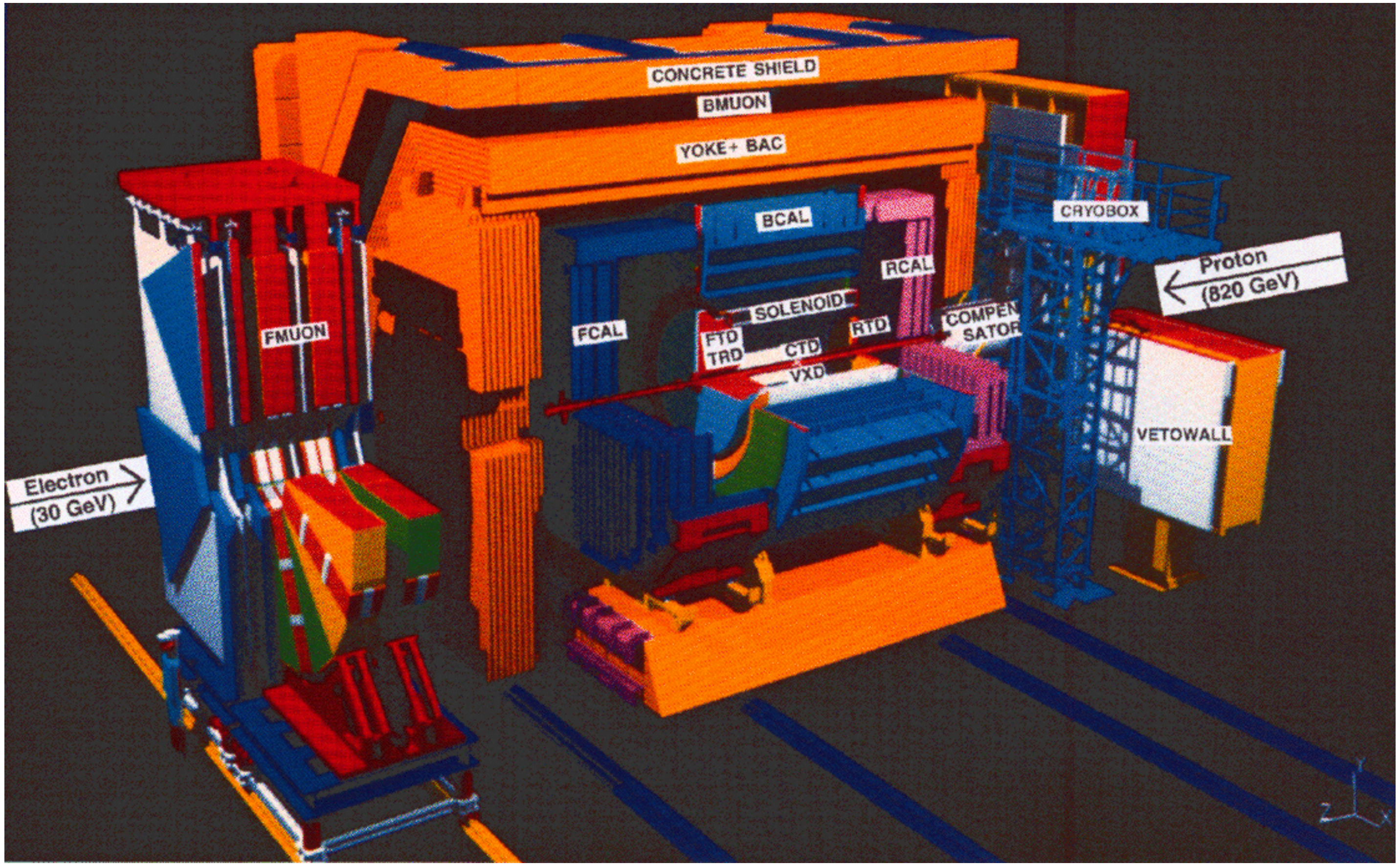


HERA Charged Current event observed in the ZEUS Detector

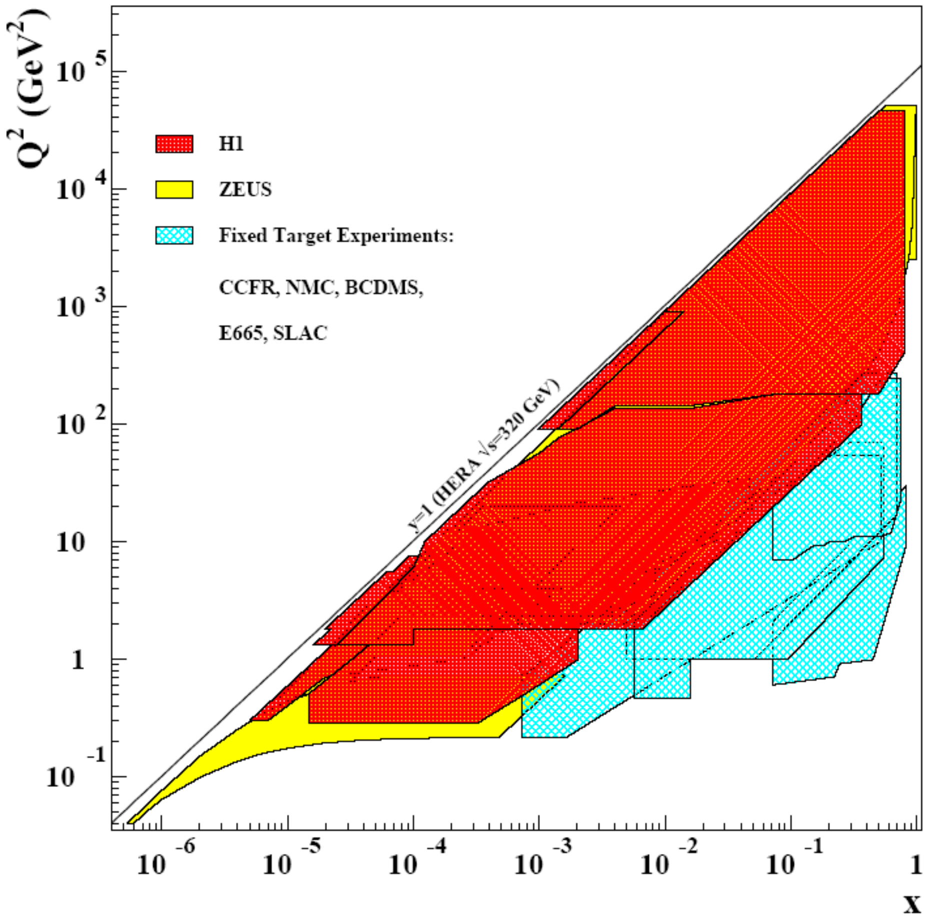




The H1 detector at the
e-p storage ring HERA
p
Tracking chambers
Calorimeters
Instrumented iron system
Forward muon
detector
e


CONCRETE SHIELD
BMUON
YOKE+ BAC
BCAL
RCAL
CRYOBOX
Proton
(820 GeV)
FMUON
FCAL
SOLENOID
FTD
TRD
CTD
VXD
RTD
COMPEN
SATOR
VETOWALL
Electron
(30 GeV)

In 1992 HERA has opened up a new kinematic domain



The physics interest in the early proposals of HERA was focused on large Q^2.

The discoveries were at small x !!

Spätschicht 19.10. 03

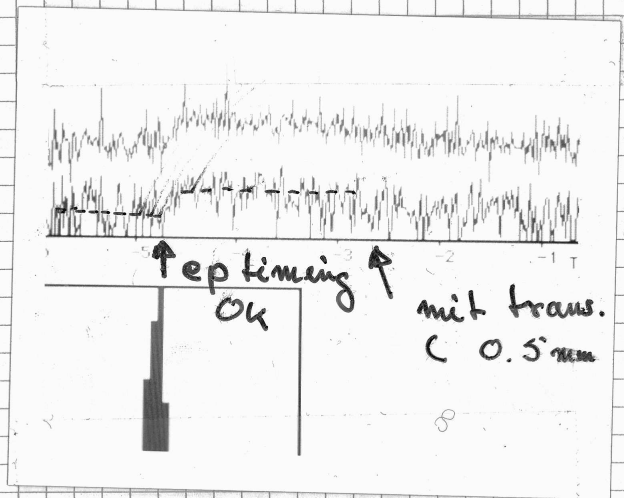
Protonenstrahl ~ 72 μA ≃ 10^{10}

Elektronenstrahl ~ $2 \cdot 10^{9}$

Elektronen und Protonen ~~vertikal~~ transversal mit den ± 7 mm Positionsmonitore auf die richtige Lage gebracht. Timing abgeglichen so dass die beiden Bunche sich im WWD-Nord treffen. ⇒ Zunahme der e γ Koinzidenz Rate um ein Faktor 2!

⇒ erste e-p Kollisionen in HERA

19. 10. 91 um 18^{50}



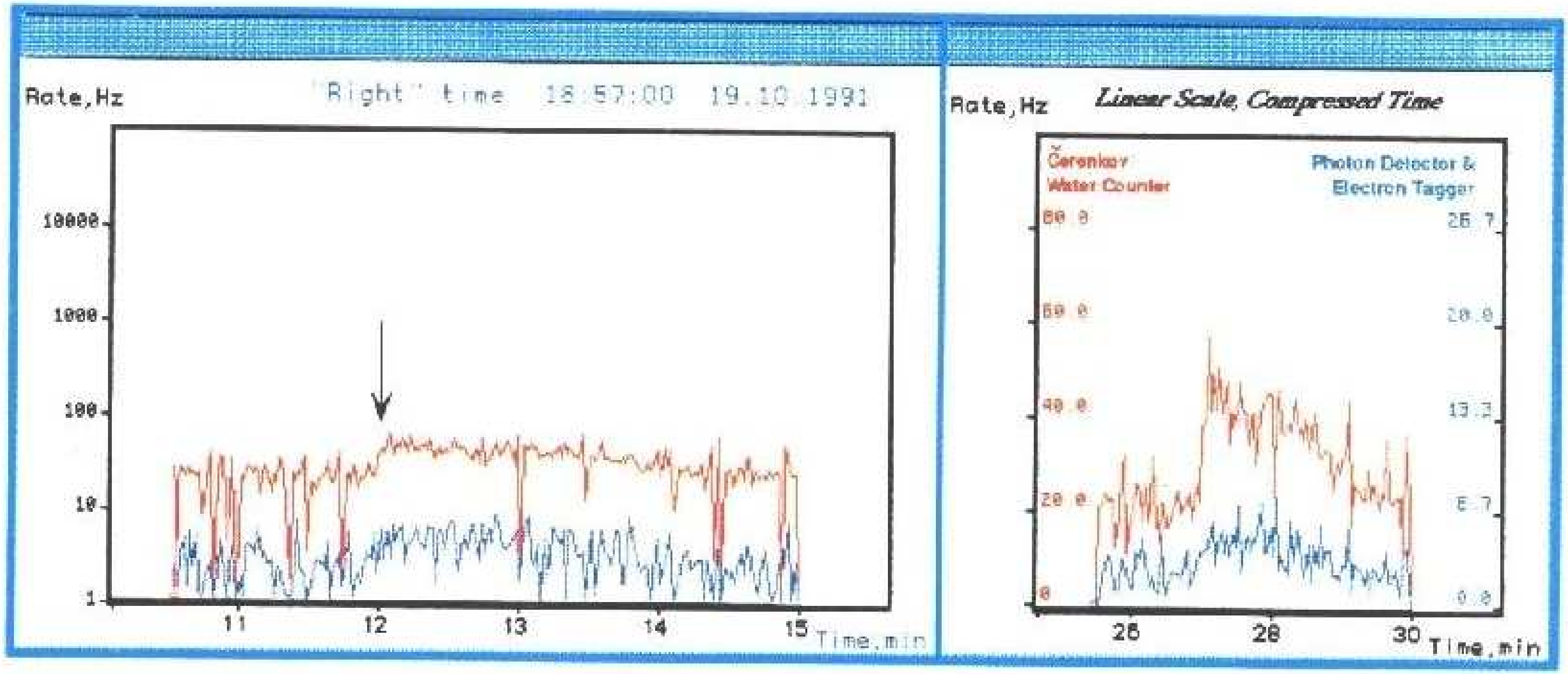
mit trans. Beule getrennt
(0.5 mm vertikal getrennt)

e- File: HE-12000-1910

FIRST HERA e-p COLLISIONS

AS OBSERVED BY THE H1 LUMINOSITY-DETECTOR

SATURDAY 19 OCTOBER 1991, 18:54



12 GeV electrons on 480 GeV Protons

HERA Status Mai 31, 1992 10⁰⁰h

There was luminosity tonight ($L \sim 2 \cdot 10^{27}$) for a few hours (Mr. Willeke on shift); however for H1 it did not succeed.

The proton beam is rather unstable and delicate to handle. There are longitudinal instabilities; also, if at e-injection the two beams touch, the p-beam may get lost.

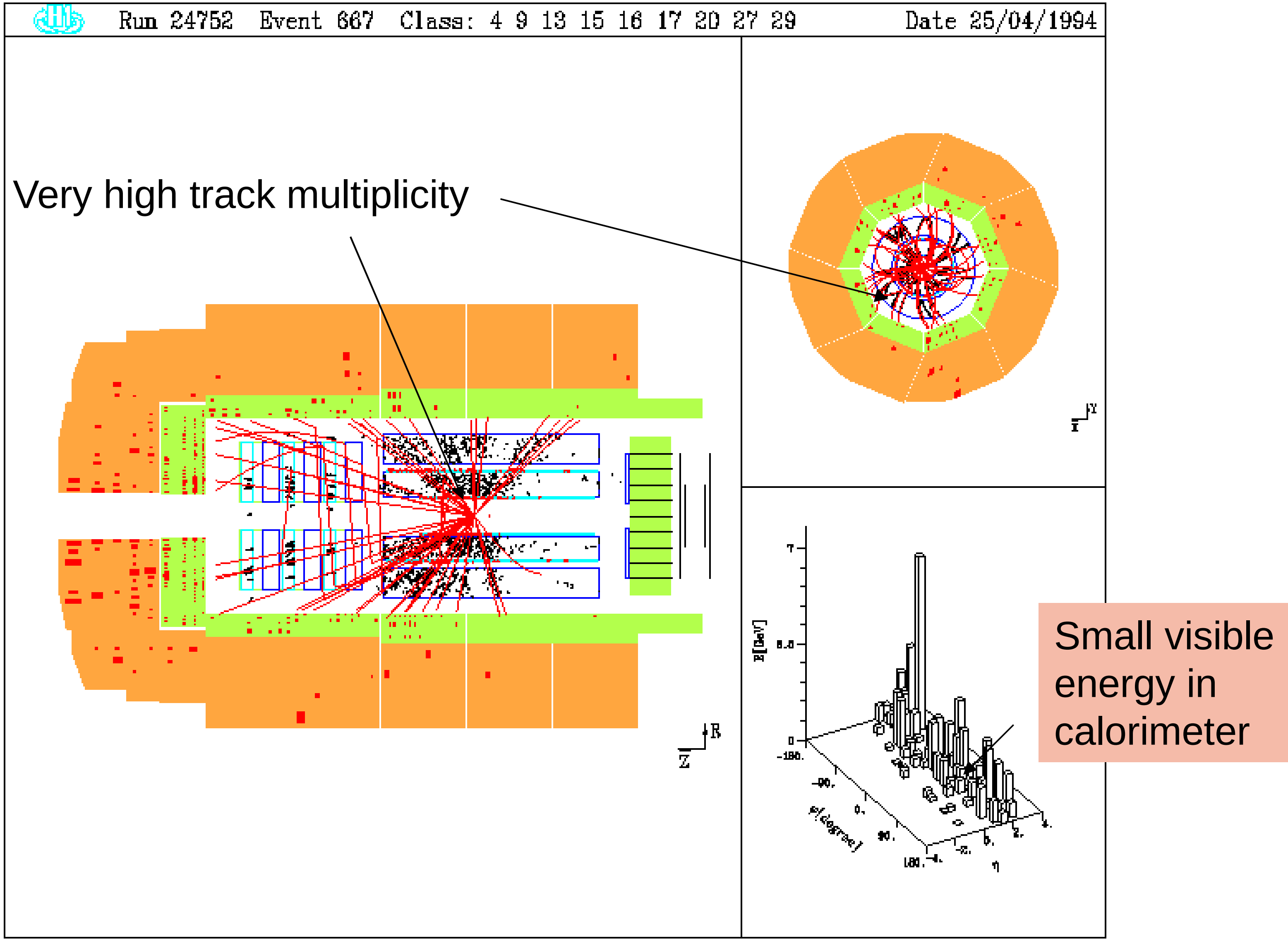
The HERA people will continue trying to get luminosity.

E.L.

31 May 1992, 20h 42, F.Brasse presses the Button

											9031	"	"	"	820/50	27/340	All changers; Thresholds changed;
											20958	"	"	"	820/36	27/365	All sensitive det
											14593	"	"	"			Sensitive detector
"	"	"	"	"	"		"				9507	"	"	"	820/36	27/330	All detectors.
21143	"	18.09	18.12	"		on	"		"		1985	"	"	"	820/36	27/330	"
21144	"	18.13	18.26	"	"	"			"		7068	"	"	"	820/36	27/320	"
21145	"	18.26	19.01	"	"	"	"		"		18678	"	"	"	820/36	27/310	Run stopped :- HERA
21148	"	19.32	20.00	"	"				"		8739	"	"	"	820/35	27/290	All trackers of
21152	"	20.07	20.14	"	"				"		4318	"	"	"	"	"	
21153	"	20.15	20.17	"	"				"		891	"	"	"	"	"	
21158	"	20.24	20.32	"	"				"		4533	"	"	"	820/34	27/270	Hera announce
21159	"	20.32	20.36	"	"				"		1119	"	"	"	"	"	
21160	"	20.36	20.41	"	"	on	"	"	1/m		2917	"	"	"	"	"	
21161	"	20.42	21.21	1st LUMINOSITY RUN WITH ALL DETECTORS – FB presses the							21795	BUTTON		"	"	"	All detectors o
21162	"	21.21	21.37	"	"	"	"	"	"		21795	"	–	–	820/32	27/250	Run stopped to allo
21167	"	21.42	21.53	"	"	"	"	"	"		6836	"	"	"	820/30	27/240	Global option z
21169	"	21.54	22.14	"	"	–	"	"	"		10018	"	"	–			same conditions
21173	"	22.19	22.40	"	"	"	"	"			11519	"	"	"			
21178	"	22.55	23.09	"	"	"	"	"	"		6535	"	"	"	820/25	27/220	After ... trigger
21180	"	23.10	23.27	"	"	–	–	–	"		8493	"	"	"	"	–	
21185	1.6.92	00.36	00.53	"	"	ON	–	–	PERM IBM	7949	7949	"	"	"	820/25μA	27/220μA	Run 21183: WARN
21187	"	00.53		"	F. Nitbogal	ON	–	–	PERM IBM		9711	"	"	"	820GeV/25μA	27GeV/220μA	DC ...
21188	"	1:15	1:15		"						0						
21189	1.6.	1:15	2:10	"	"	"	–	–	"		25241	"	"	"	820GeV/25μA	27GeV/225μA	trigger rate 7
21190	1.6.92	2:10	3:08	"	"	"	–	–	"		19646	"	"	"	820GeV/25μA	27GeV/220μA	Restart run bec
21191	"	3:12	3:26	"	"	"	–	–	"		2060	"	"	"		0	Central tracker de
21192	"	3:26	3:26		"												

Many events looked like: :



One of the very first H1 DIS events

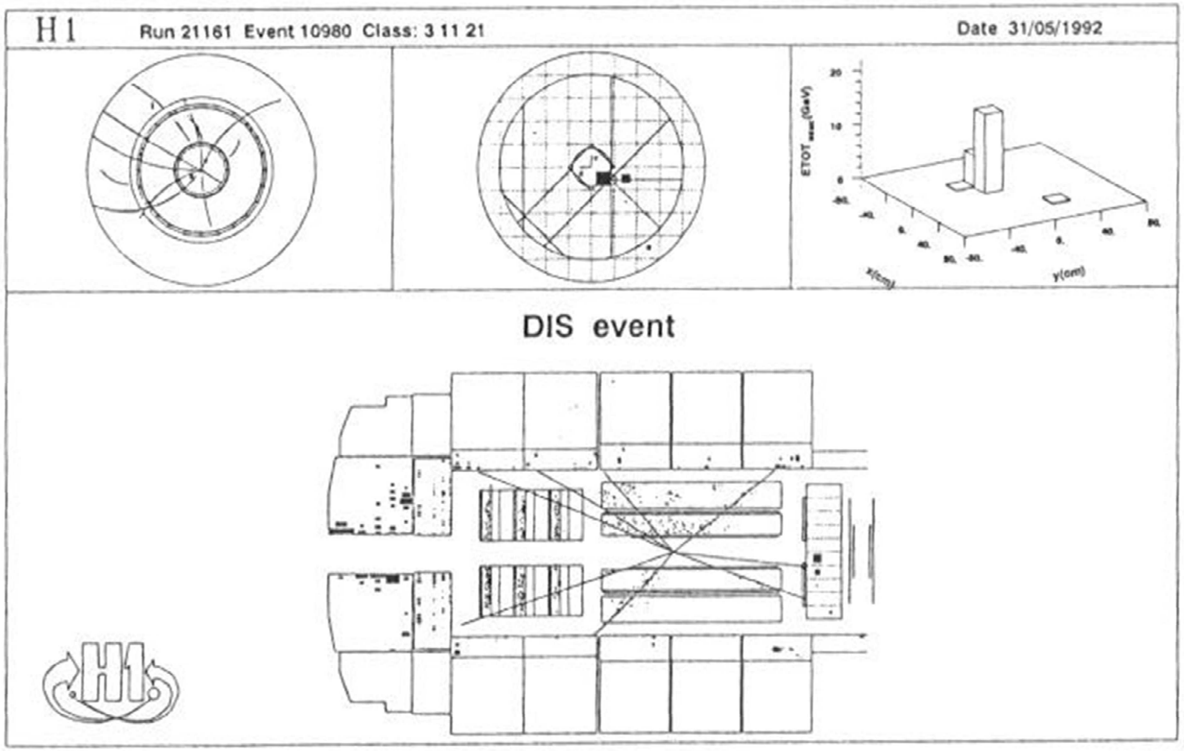
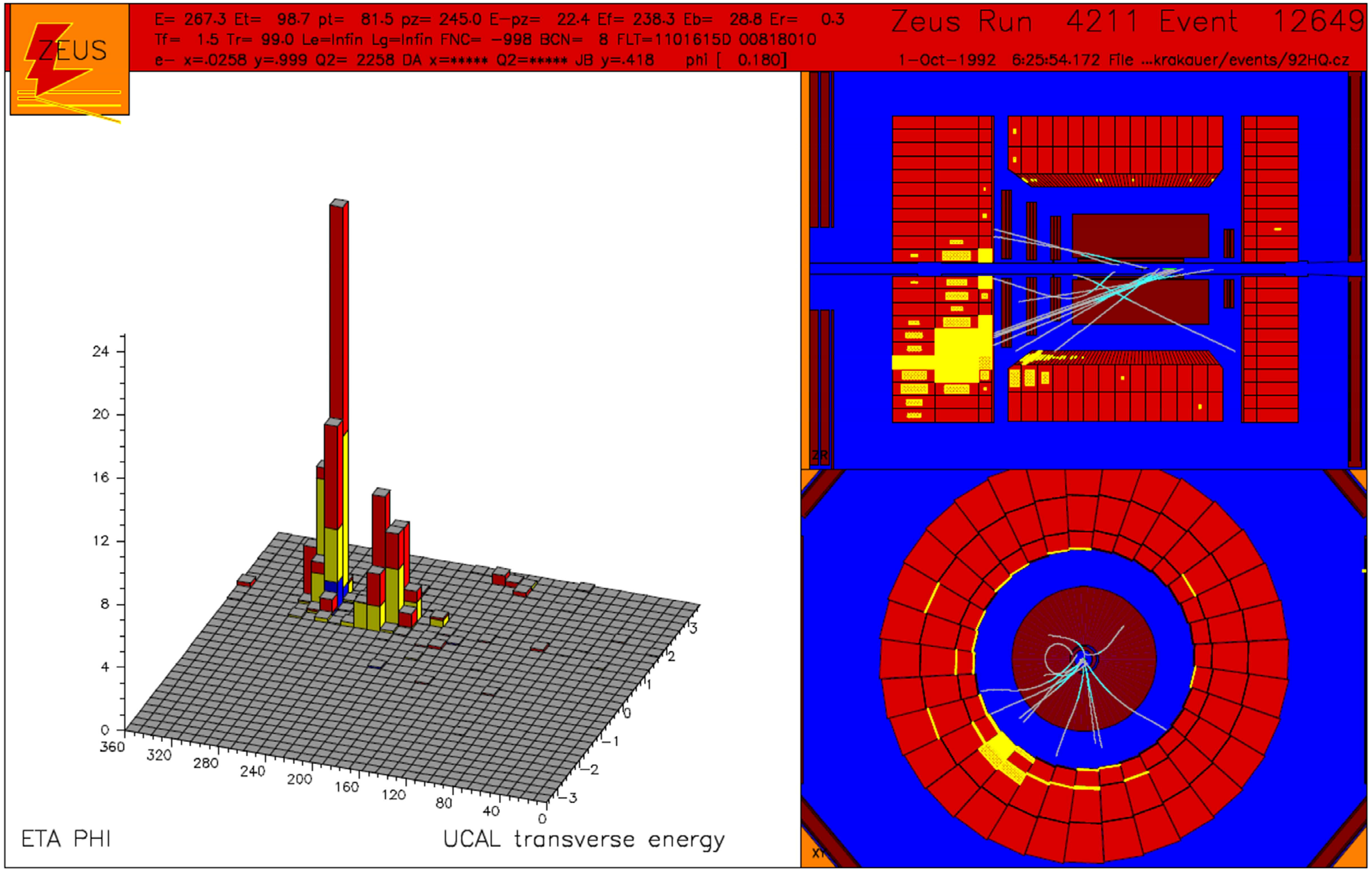
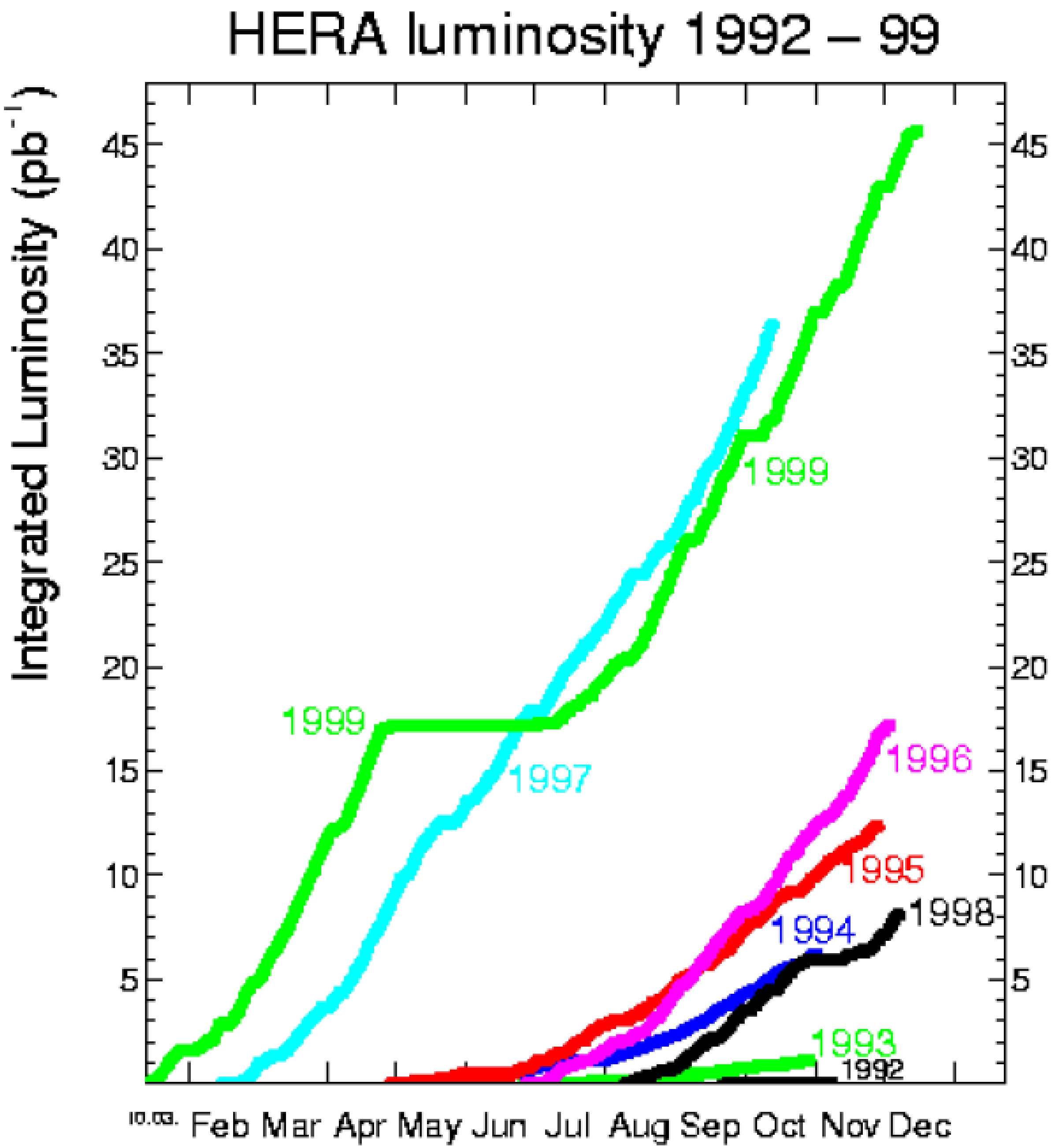


Figure 3. Low Q^2 deep inelastic event as seen in the H1 detector

One of the very first ZEUS CC events





First Physics runs

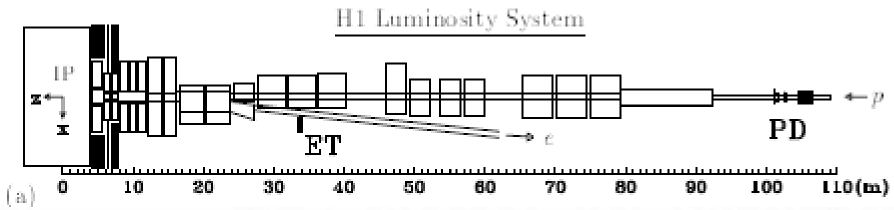
1.5 nb^{-1} (June-July 1992)

24 nb^{-1} (Sept-Nov 1992)

580 nb^{-1} (1993)

First publication by H1 or ZEUS	Physics topics
1992	Total Cross Section
1992	Photoproduction, Structure of the Photon
1992	Inclusive DIS, Low x Physics, Gluon Density
1993	HFS in DIS, Jets, Gluon Density, α_s
1994	Large Rapidity Gap, Diffractive SF
1994	Vector Meson Production
1994	Electroweak Physics
1993	Searches

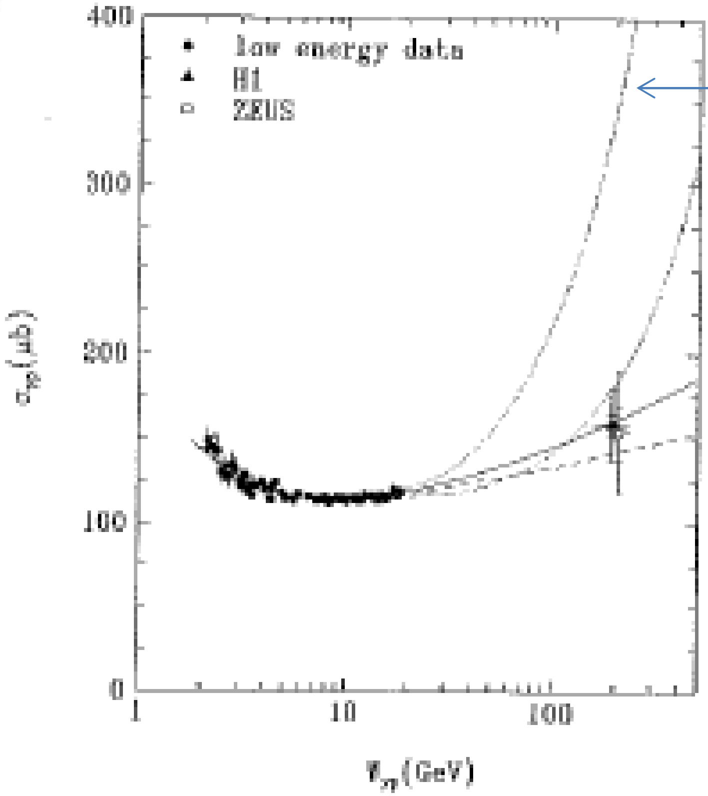
Total Photoproduction Cross Section



$$\frac{d\sigma_{ep}}{dy} = \sigma_{tot}(W_{\gamma p})Flux(y) = \sigma_{tot}(W_{\gamma p})\frac{\alpha}{2\pi}\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{max}(y)}{Q^2_{min}(y)}$$

Lumi = 1.5 nb^{-1}

First publication of HERA results : September 1992! (ZEUS)

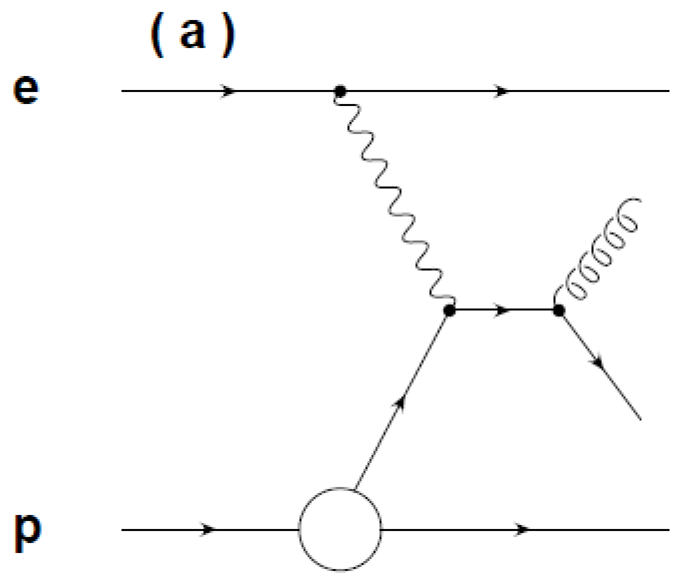


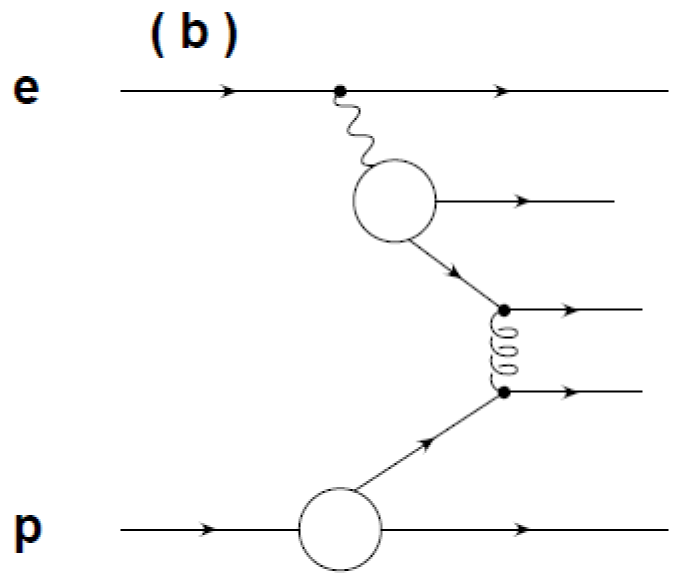
Minijets (DG)

Regge fits of low energy data : DL and ALLM

Photoproduction at HERA

At LO : two types of interaction

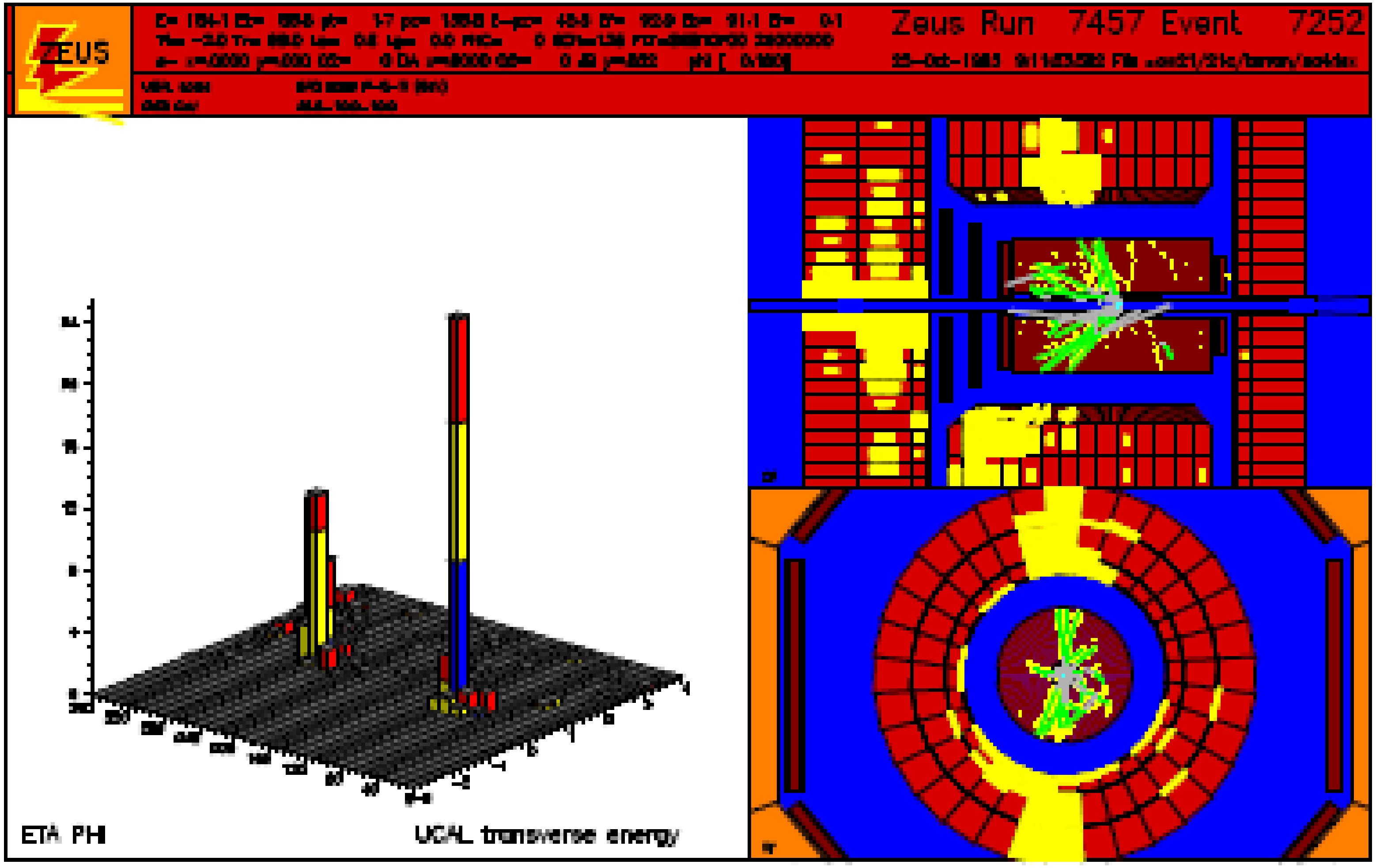




The photon couples directly to a parton of the proton: the ***direct process***

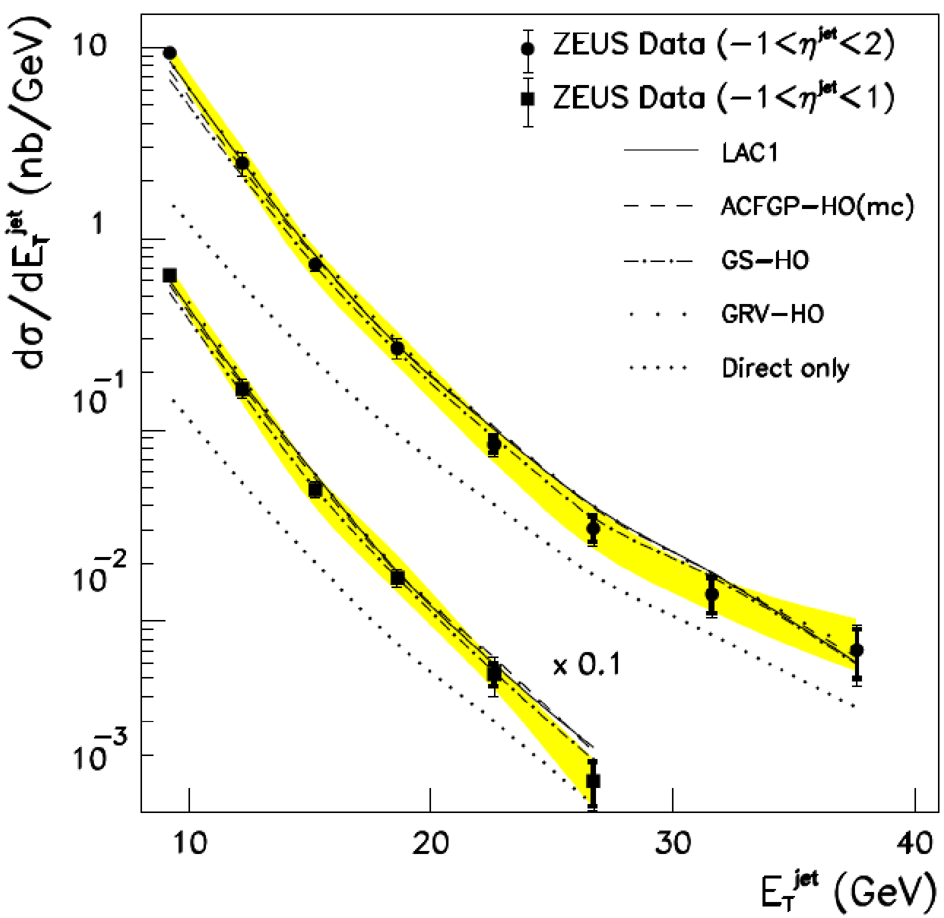
The photon couples indirectly to the proton via the own parton content of the photon : the ***resolved process***

A nice *direct* event



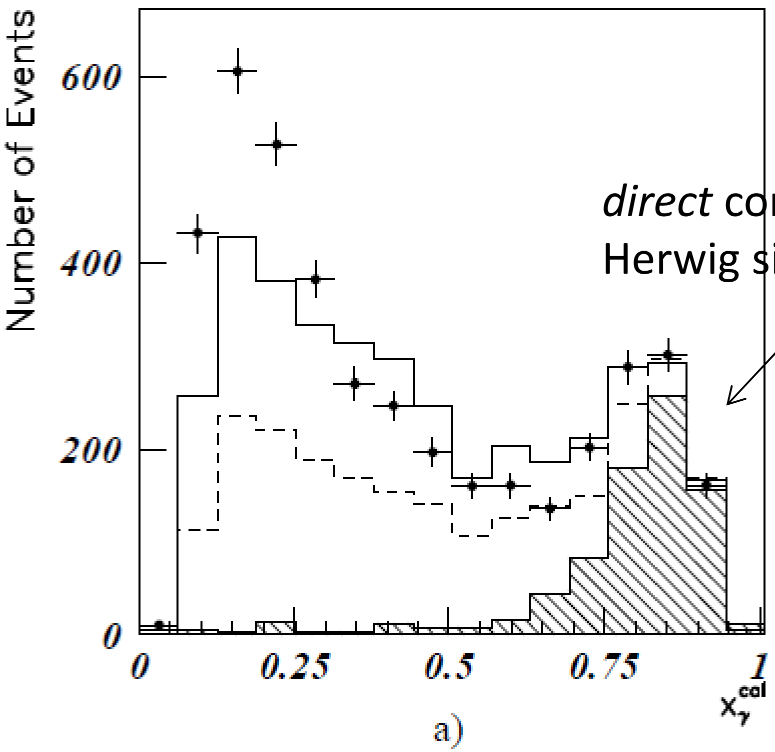
Photoproduction at HERA : Inclusive jet production

ZEUS 1993



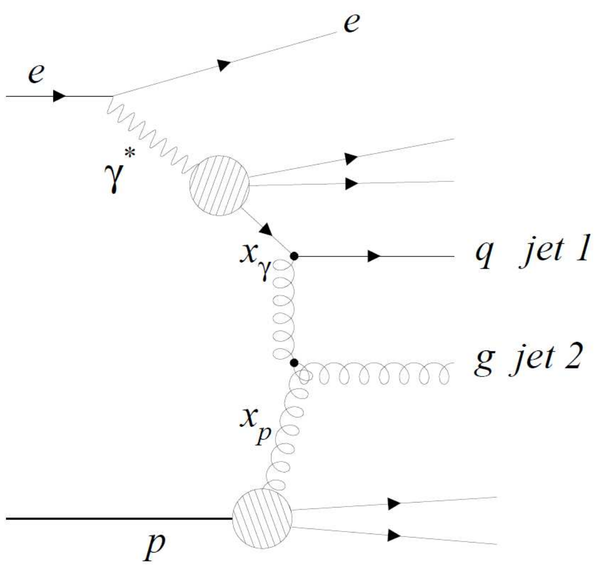
The *direct* contribution is a small fraction of the cross section

Photoproduction at HERA : Two jets production



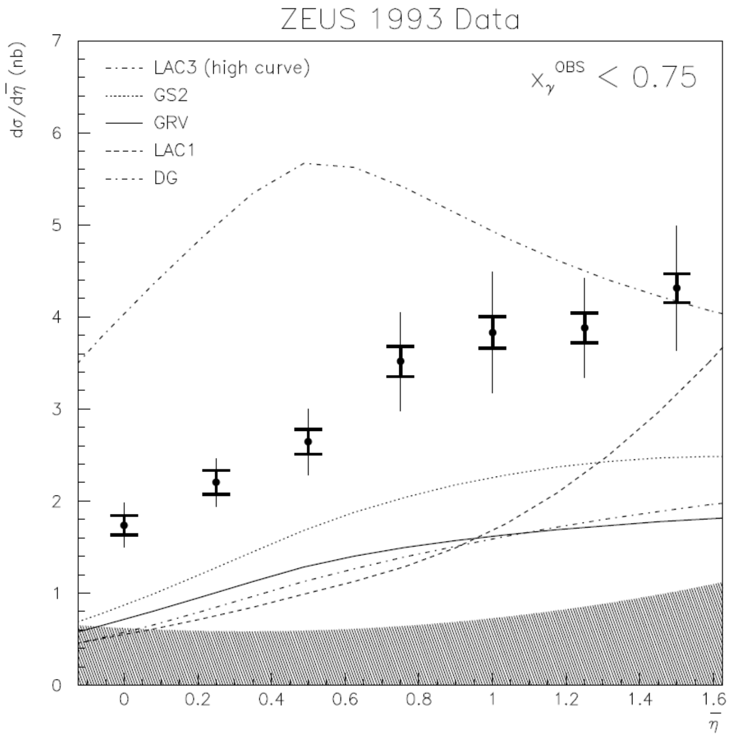
direct contribution to Herwig simulation

A clear signal of *resolved* photons



X_γ^{cal} is the fraction of the photon's momentum participating in the production of the two jets

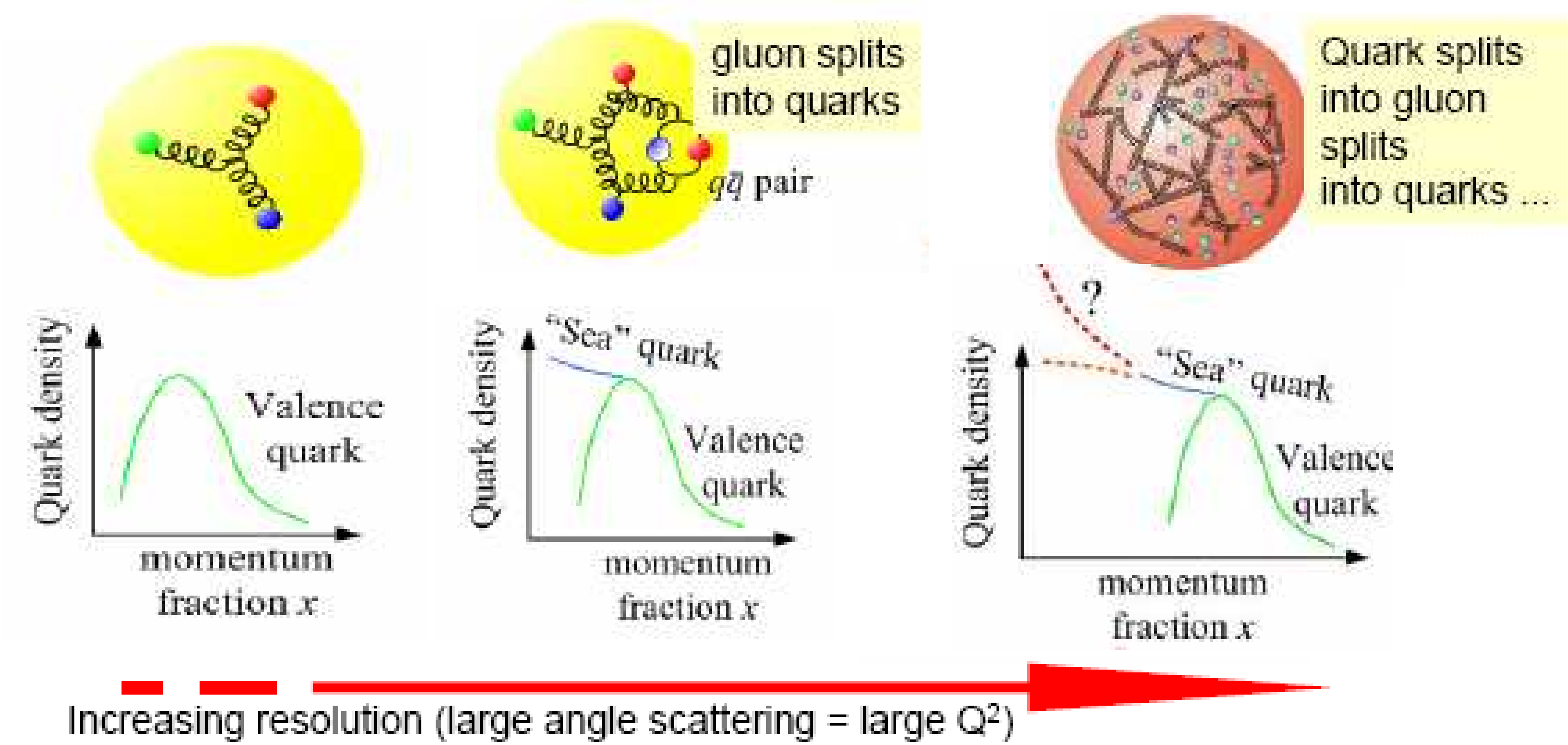
Photoproduction at HERA : Two jets production



LO parameterisations of the photon SF failed to describe the observed *resolved* photon contribution.

X_γ^{obs} is the fraction of the photon's momentum participating in the production of the two jets

Structure of the proton – simple view before HERA (Yamazaki)



Early HERA DIS discovery. Lumi = 22.5 nb^{-1}. Rise of F_2 as $x \to 0$

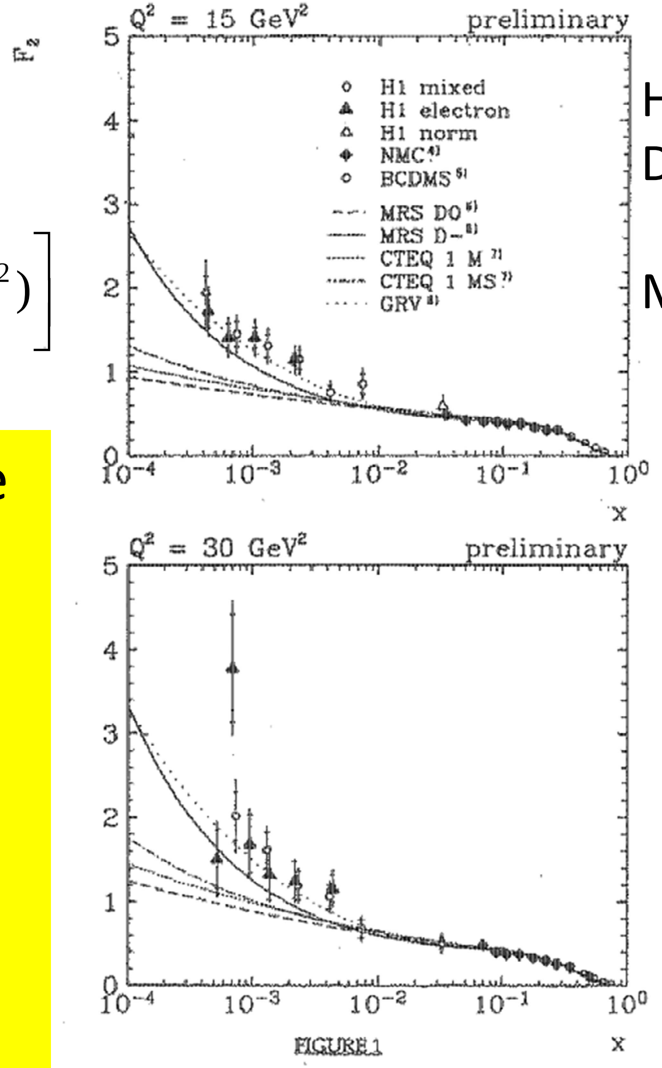
$$\frac{d\sigma}{dxdQ^2} \propto F_2(x,Q^2)$$

$$F_2(x,Q^2) = \sum_{quarks} e^2 x\left[q(x,Q^2)+\bar{q}(x,Q^2)\right]$$

Impressive and unexpected rise of F_2 as $x \to 0$

Rise of the sea quark and gluon densities.

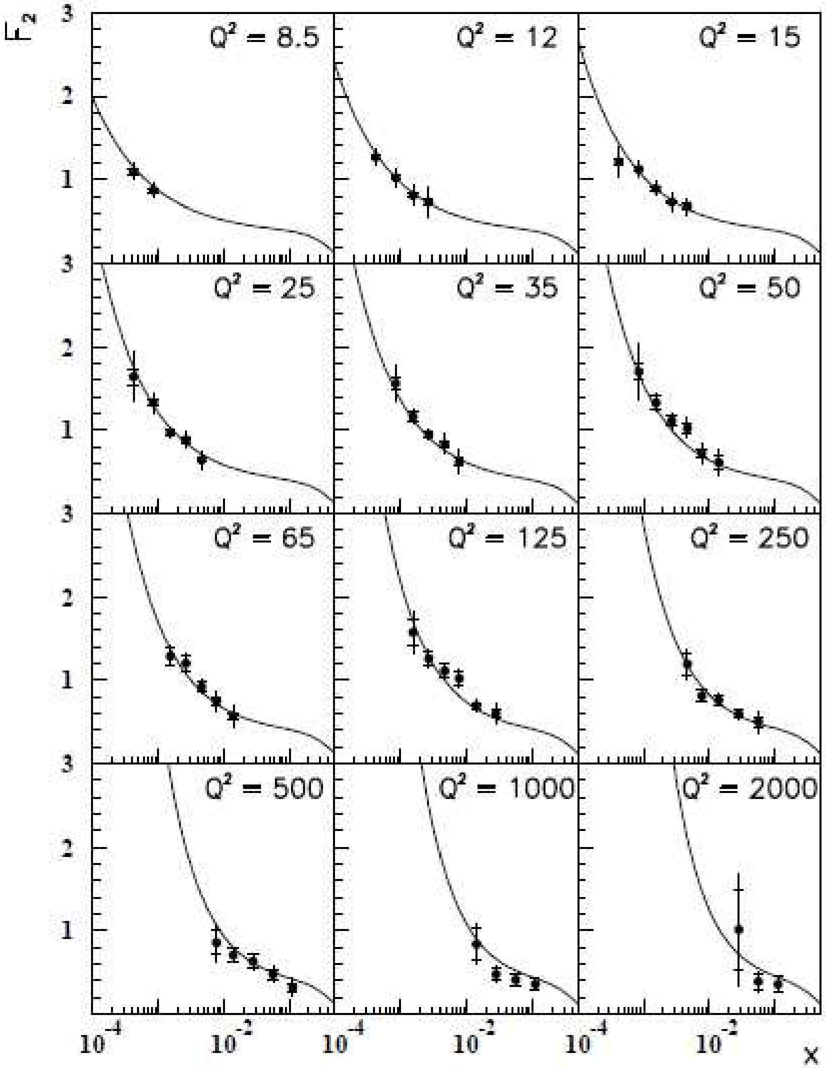
The rise increases with Q^2



H1 preliminary F_2 compared to previous experimental results [4,5] and various parton parametrisations [6,7,8]

H1, March 1993, Durham workshop and Moriond Conf.

ZEUS 1993 F_2


F_2
Q^2 = 8.5
Q^2 = 12
Q^2 = 15
Q^2 = 25
Q^2 = 35
Q^2 = 50
Q^2 = 65
Q^2 = 125
Q^2 = 250
Q^2 = 500
Q^2 = 1000
Q^2 = 2000
10^{-4}
10^{-2}
x

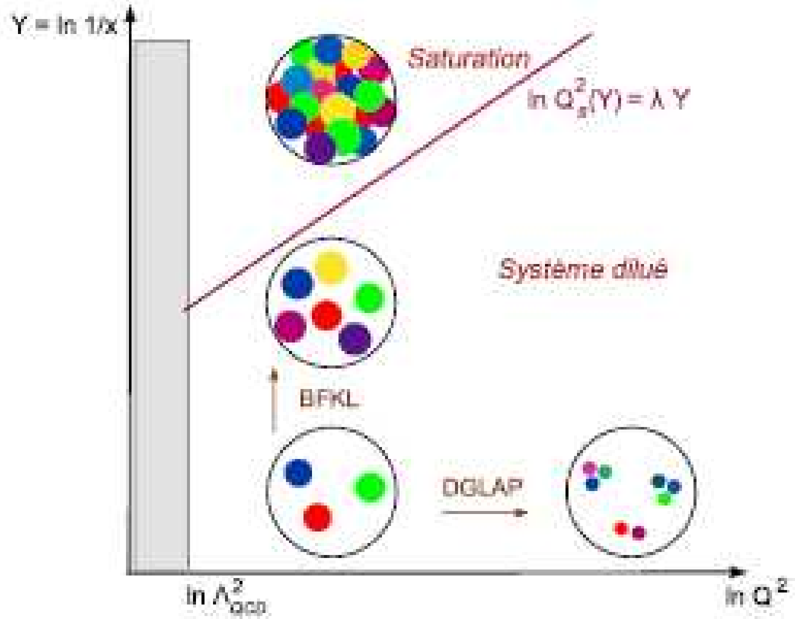
Early HERA DIS discoveries , Rise of F2 as $x \to 0$

Why was it a sur prise ?
Large spread in the theoretical predictions.
Extrapolations from pre-HERA data indicated a « flattish » F_2 , that's also what came out from Regge-like arguments :
$F_2 \approx x^{-\varepsilon}$ as $x \to 0$ where $\varepsilon \approx 0.08$

Was however predicted by the fathers of QCD (1974) but forgotten since. The gluon should rise at low x for Q^2 high enough and the rise should increase with Q^2.

> The most dramatic of the QCD foundational papers 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.
> Frank Wilczek (QCD, Foundational papers)

The argument over the interpretation began immediately after the presentation of the data : two possible mechanisms of evolution



Fixed x, Q^2 increasing.
DGLAP approximation of evolution equations :

- Well known scaling violation proportional to α_s and to gluon density in the proton.
- Neglect $\alpha_s \ln(1/x)$ terms but do contain $[\alpha_s \ln(Q^2) \ln(1/x)]^n$ terms !

DGLAP = Dokshitzer/Gribov/Lipatov/Altarelli/Parisi

Fixed Q2 , x decreasing.
BFKL approximation :

Inclusion of $[\alpha_s \ln(1/x)]^n$ term leads to a strongly rising parton density.

BFKL= Balitsky/Fadin/Kuraev/Lipatov

Questions raised in 1993

How valid are the DGLAP and BFKL approximations in the low x domain of HERA ?

Q^2 evolution of F_2 is perfectly described by DGLAP evolution equations down to $Q^2 \approx 2$ GeV^2 and $x \approx 10^{-4}$.

(Hints of departure fom DGLAP in forward jet production at low x → next slide)

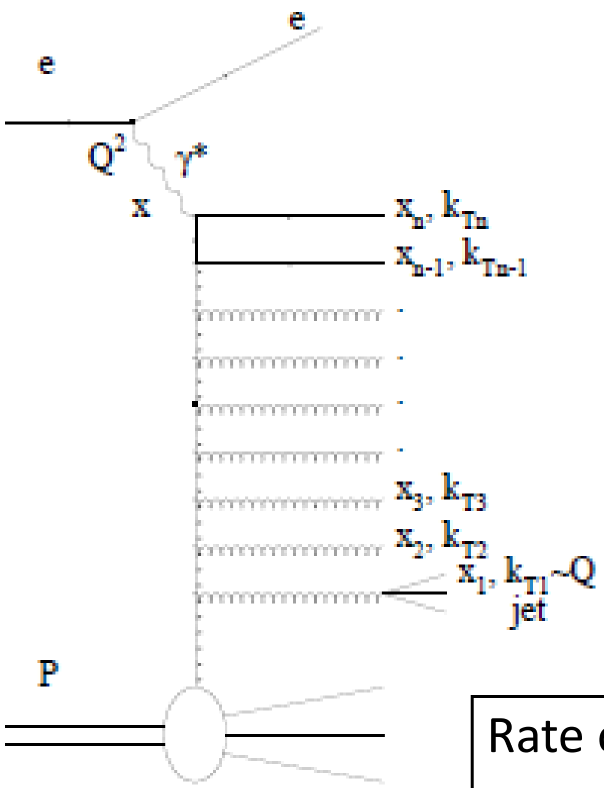
Saturation effects?

No saturation observed on inclusive cross section.

Which mechanism to extrapolate to the LHC domain ?

DGLAP evolution equations.

Forward jet production in the low x regime



Due to different ordering in k_T and x_i of the cascade, BFKL predicts an higher rate of forward jet at very small x

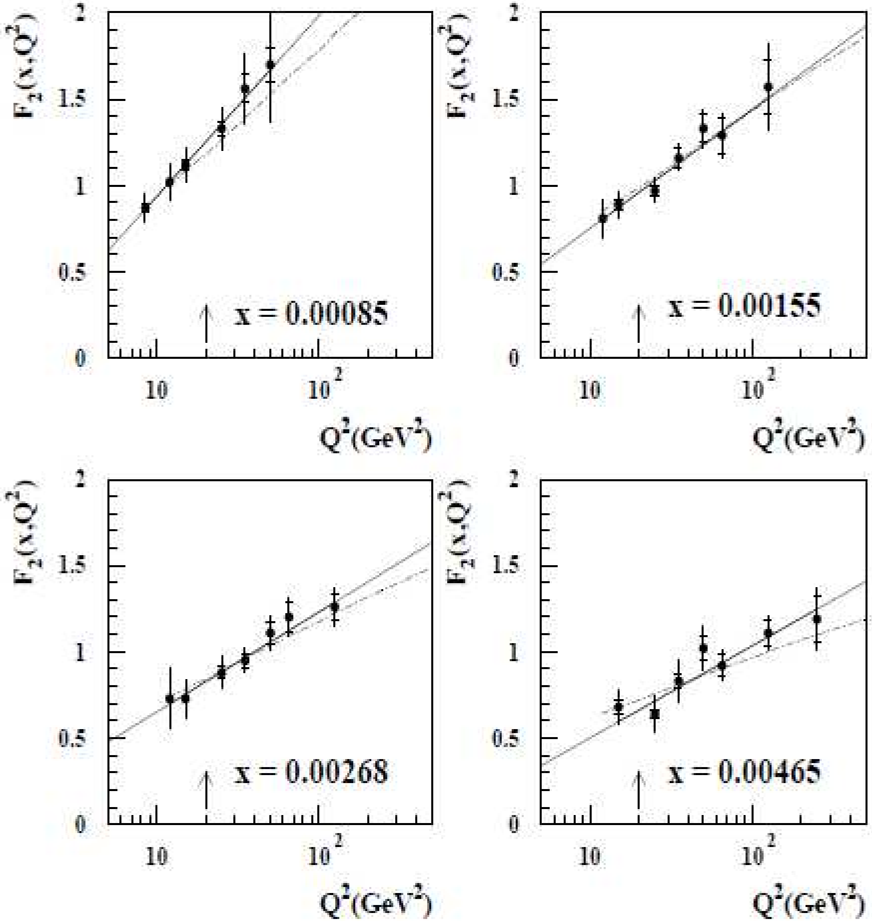
forward jet

Hints for BFKL.
No firm conclusion

Rate of forward jets (H1, 1993 data)		DGLAP inspired	BFKL inspired
x range	Data events	MEPS events	CDM events
$2.\ 10^{-4}$ - $1.\ 10^{-3}$	279	141	282
$1.\ 10^{-3}$ - $2.\ 10^{-3}$	158	101	108

Clear pattern of scaling violation at lox x

ZEUS 1993 (Lumi = 0.54 pb^{-1})



Approximation at LO

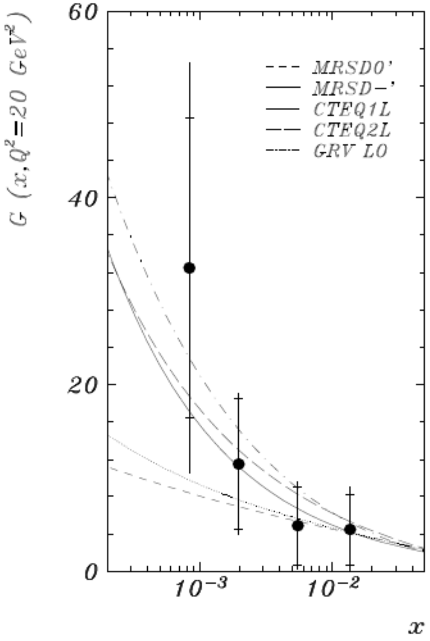
$$\frac{dF_2(x,Q^2)}{d\ln Q^2} \approx \frac{10\,\alpha_s(Q^2)}{27\pi} g(2x,Q^2)$$

Gluon density from scaling violations

Approximation at LO
$$\frac{dF_2(x,Q^2)}{d\ln Q^2} \approx \frac{10\,\alpha_s(Q^2)}{27\pi} g(2x,Q^2)$$

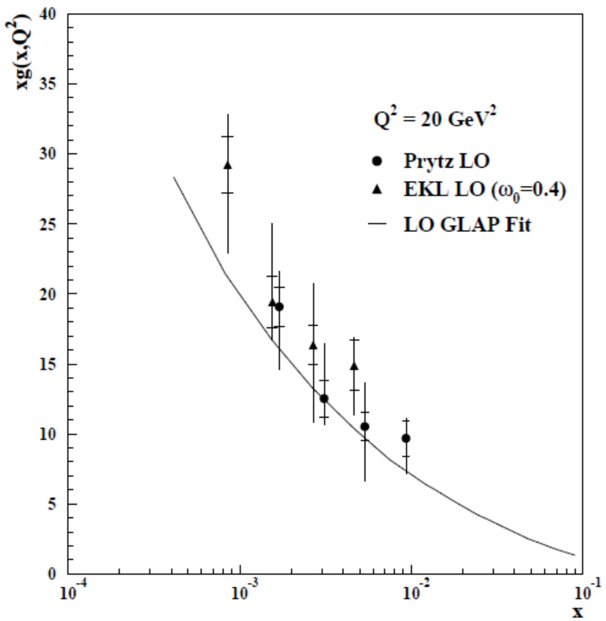
Need to assume α_s from world average to extract the gluon density

H1 1992

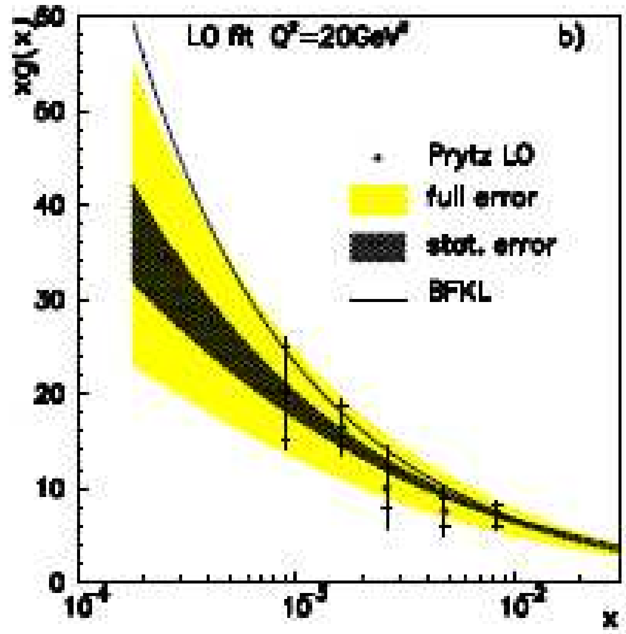


Lumi = 0.022 pb^{-1}

ZEUS 1993

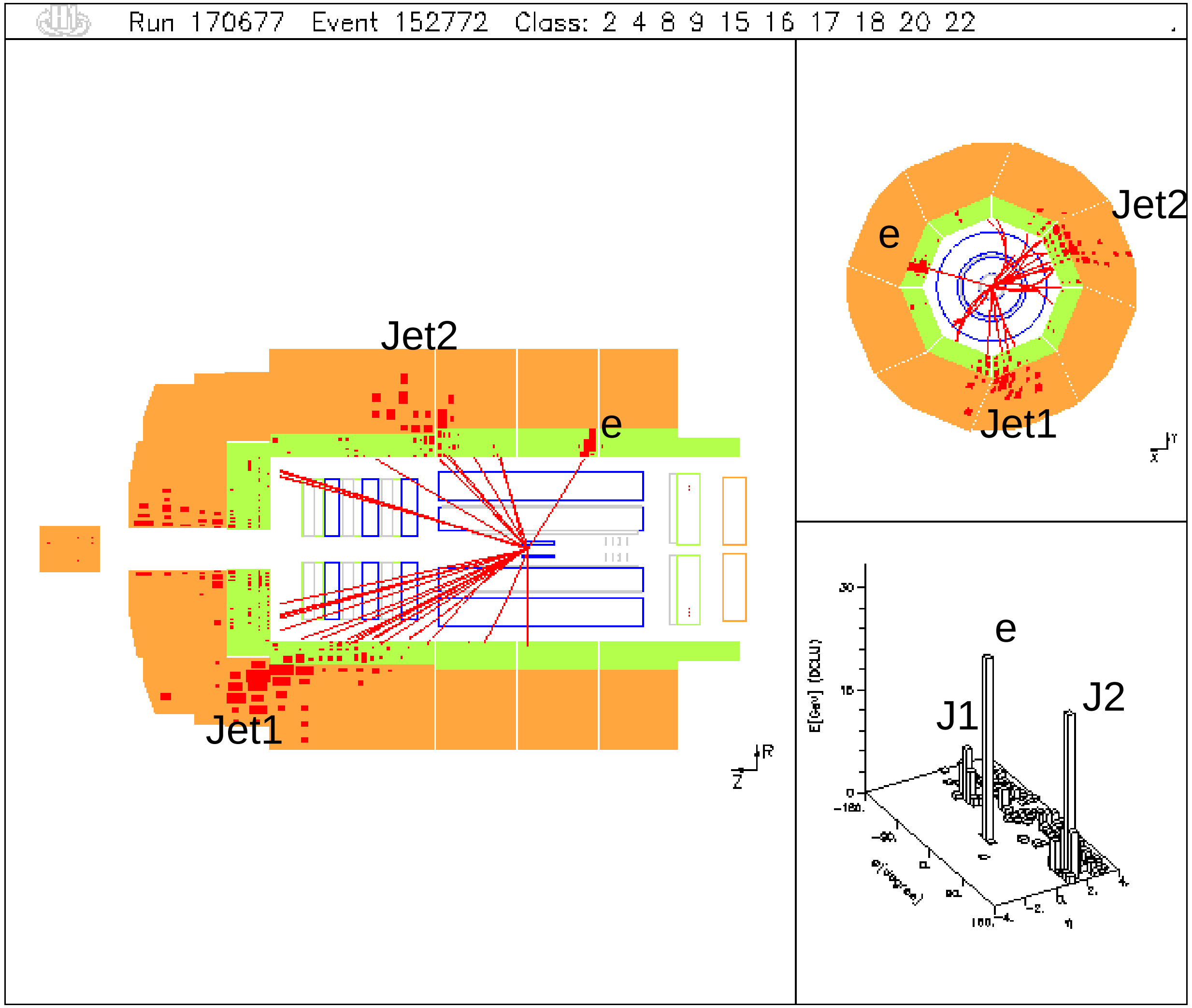


H1 1993

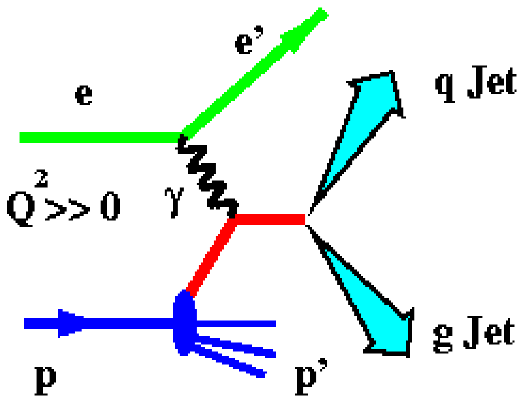


Lumi = 0.54 pb^{-1}

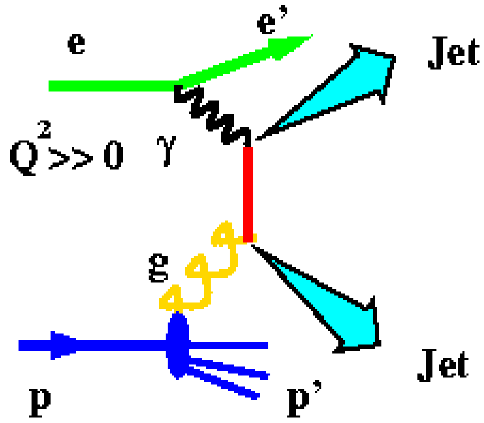
A NC-DIS event with two jets $ep \rightarrow e' Jet_1 Jet_2$



Jet production processes at HERA



QCD-COMPTON



BGF

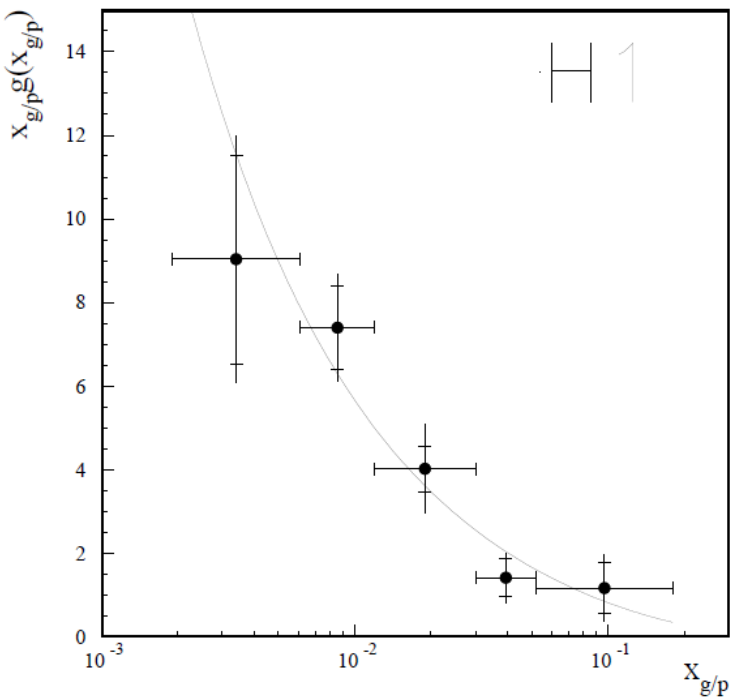
In Boson-Gluon-Fusion jets are directly sensitive to the gluon density in the proton and to α_s

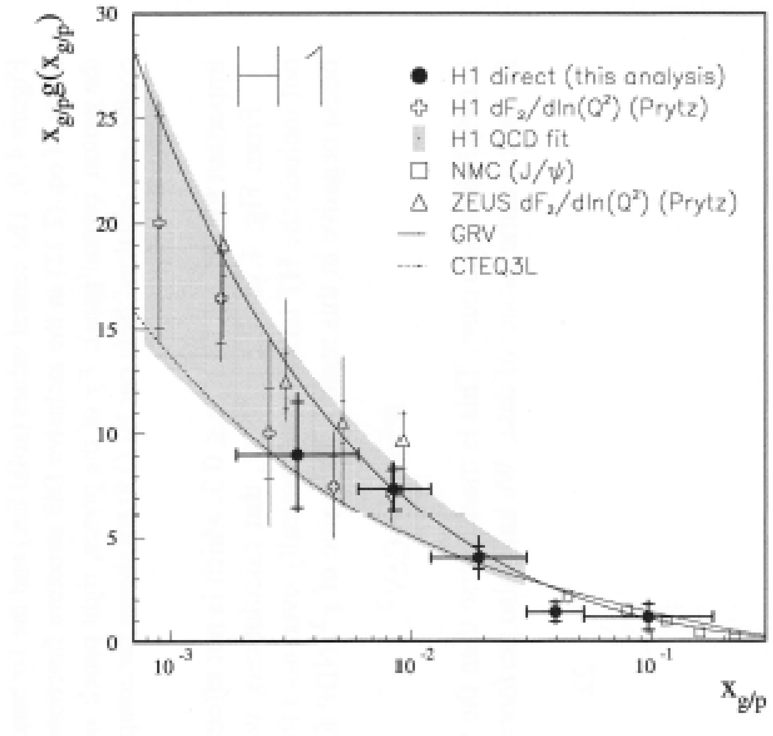
Direct determination of gluon density from multi-jet events

- DIS (2+1) jet cross section : $\sigma_{2+1} \approx \alpha_s$ (A. g + B. q)
- In first analyses α_s and quark densities were supposed to be known to extract the gluon density.
- It has taken many years to fully disentangle quark densities, gluon density and α_s . → next talks

Direct determination of gluon density from multi-jet events

1993 data





Agreement between direct and indirect measurement of the gluon density has constitued an important test of perturbative QCD

Determination of the strong coupling constant from multi-jet events

From the ratio $$R_{2+1}(Q^2) = \frac{\sigma_{2+1}(Q^2)}{\sigma_{tot}(Q^2)}$$

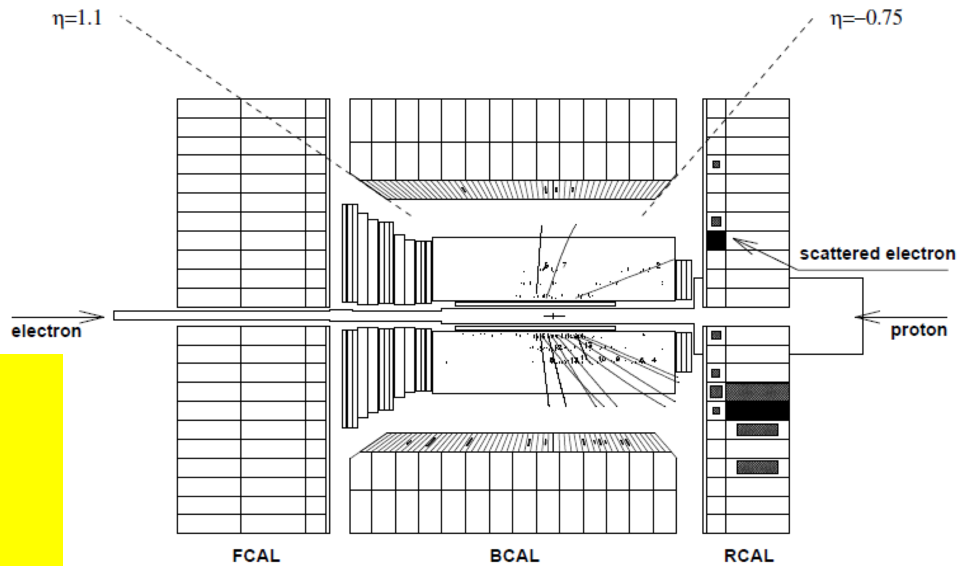
Small sensitivity to quark and gluon densities

At NLO :
$$\sigma_{1+1} = A_{1,0} + A_{1,0}\,\alpha_s$$
$$\sigma_{2+1} = A_{2,1}\,\alpha_s + A_{2,2}\,\alpha_s^2$$

First determination with a modest luminosity of 0.3 pb^{-1} :

$\alpha_s(M^2_Z)$ = 0.123 ± 0.018 (very promising !) (H1, 1993)

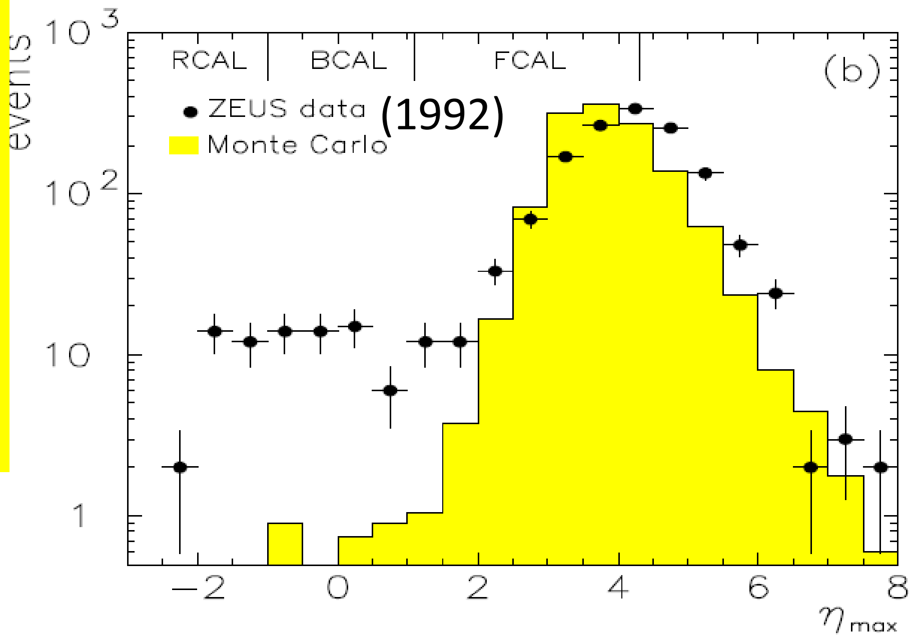
Early HERA discovery : hard diffraction in DIS



10% of NC DIS events have gap between forward proton and central activity.

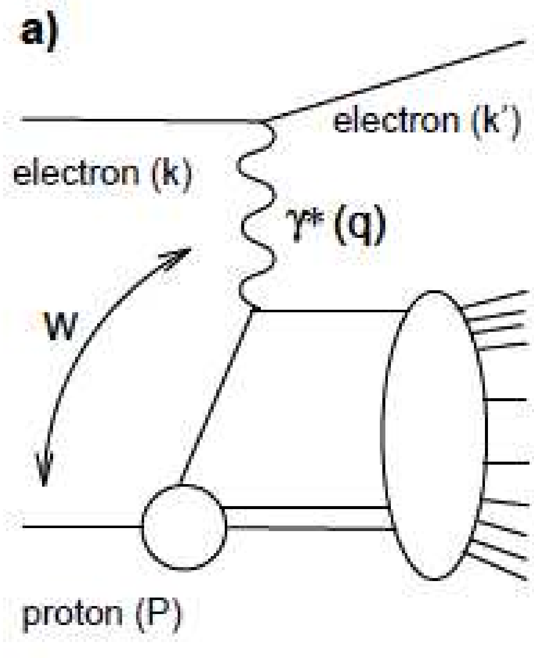
Not described by the (at that time) simulation programmes.

Considerable renewed interest in theoretical approaches to diffraction

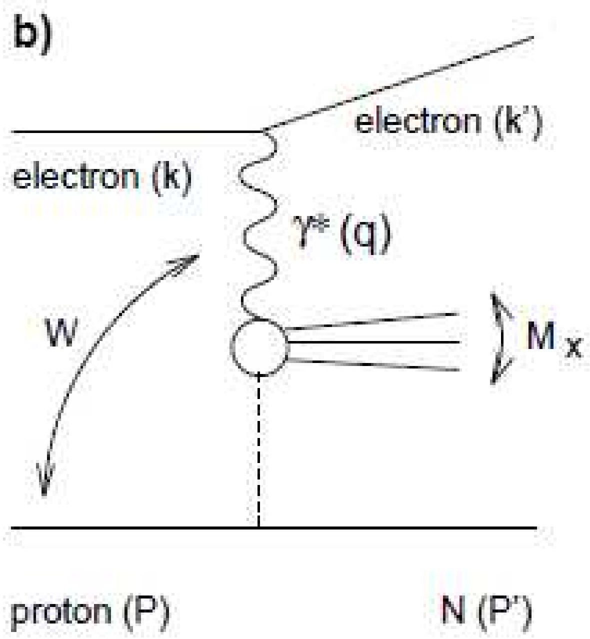


Hard Diffraction at HERA

Std DIS



Diffractive DIS



No colour flow between
the scattered quark and
the proton remnant

Theoretical approaches to Diffraction

Since the very early data two types of interpretations have been (and are still) considered :

1) VMD like, fluctuation of the virtual photon in VM. In modern langages : dipole models

2) electron- Pomeron scattering

Without any assumption on the diffraction mechanism it is possible to define useful variables :

$$x_{\mathbb{P}} = \frac{Q^2 + M_X^2}{Q^2 + W^2} \qquad \beta = \frac{Q^2}{Q^2 + M_X^2}$$

First Measurement of the Deep-Inelastic Structure Function of Proton Diffraction

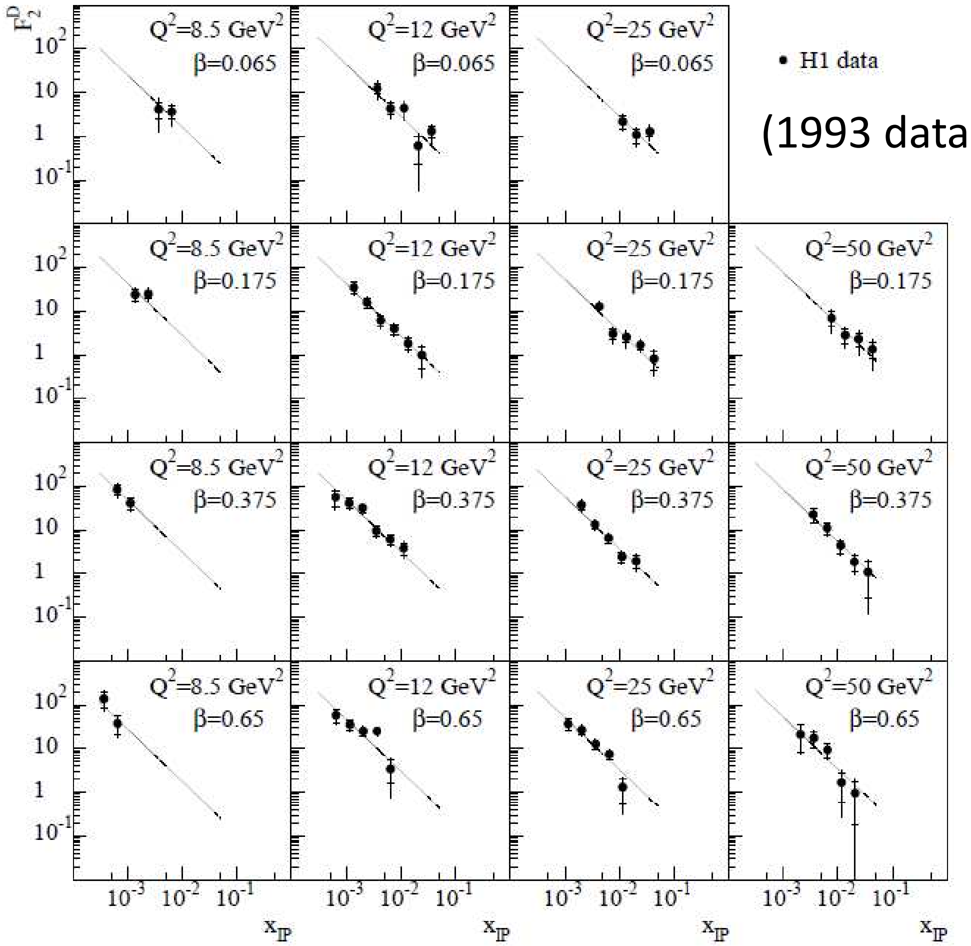
$$\frac{d^3\sigma_{diff}}{d\beta dQ^2 dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4}\left(1+(1-y)^2\right) F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

Pomeron interpretation :

$x_{I\!P}$ = the momentum fraction of the Pomeron in the proton

β = the momentum fraction of the struck quark within the Pomeron

$$x = \beta\, x_{I\!P}$$

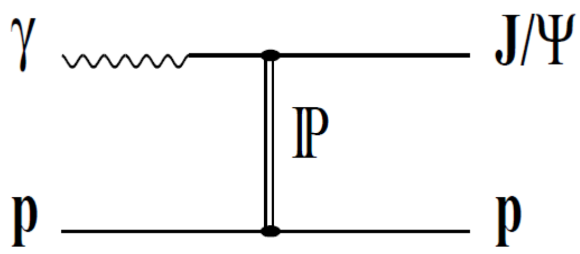


(1993 data)

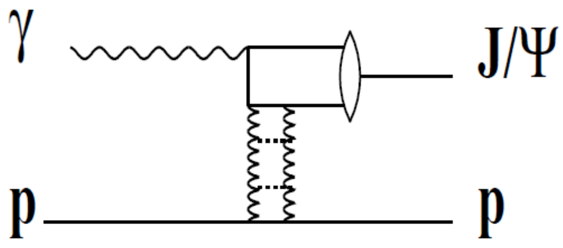
Elastic production of ψ VM

Two possible mechanisms of production:

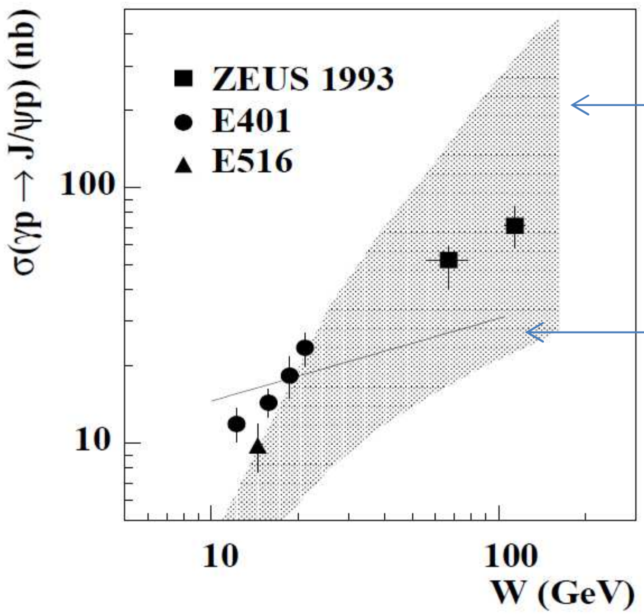
Pomeron exchange



Perturbative QCD



$Q^2 < 4\ GeV^2$

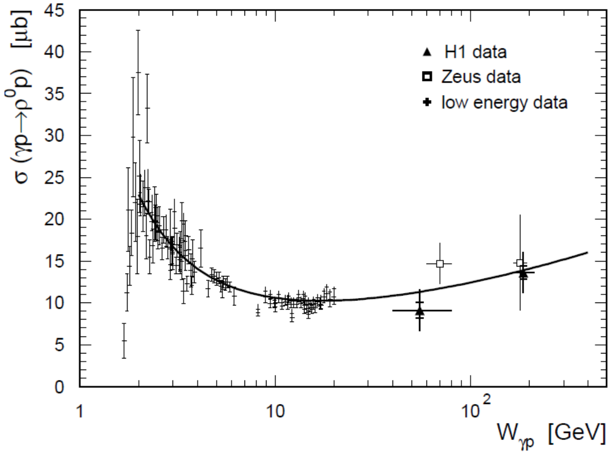


Shaded region :
perturbative QCD

Solid line :
soft pomeron exchange

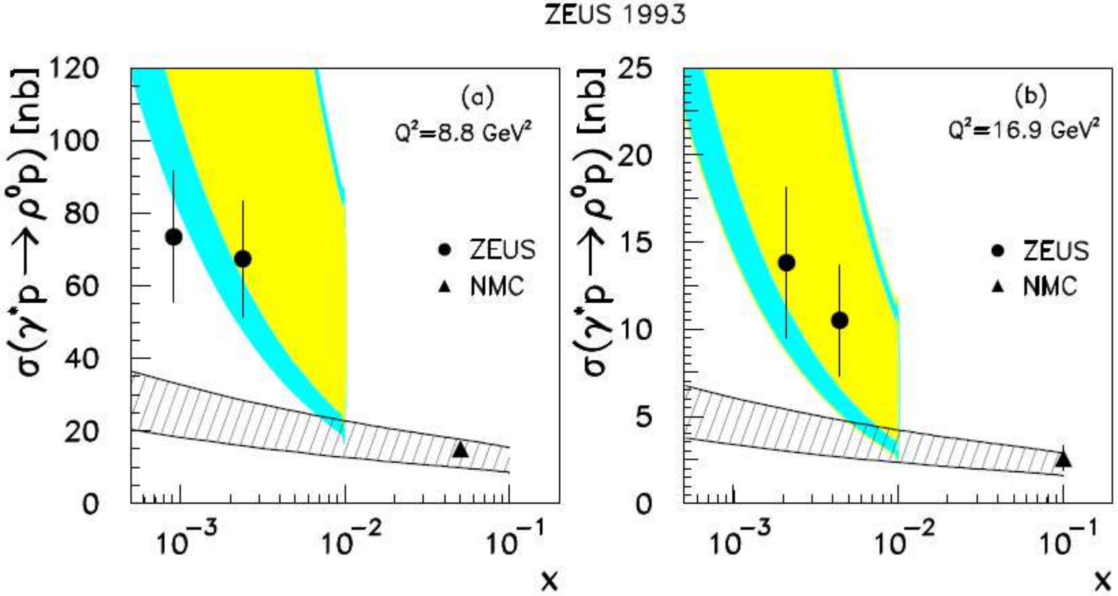
Elastic production of ρ VM

Photoproduction



Solid line : soft pomeron

Production in DIS

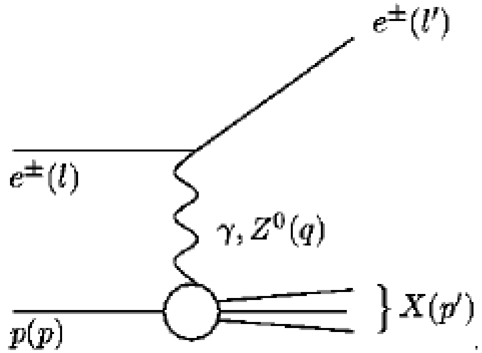


Hatched area : soft pomeron model
Shaded area : perturbative QCD

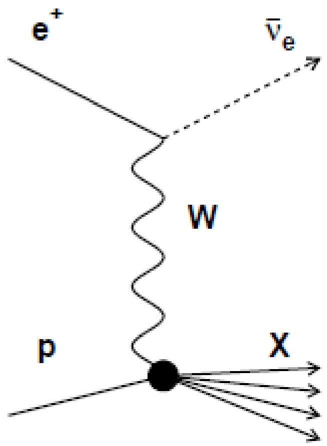
EW unification

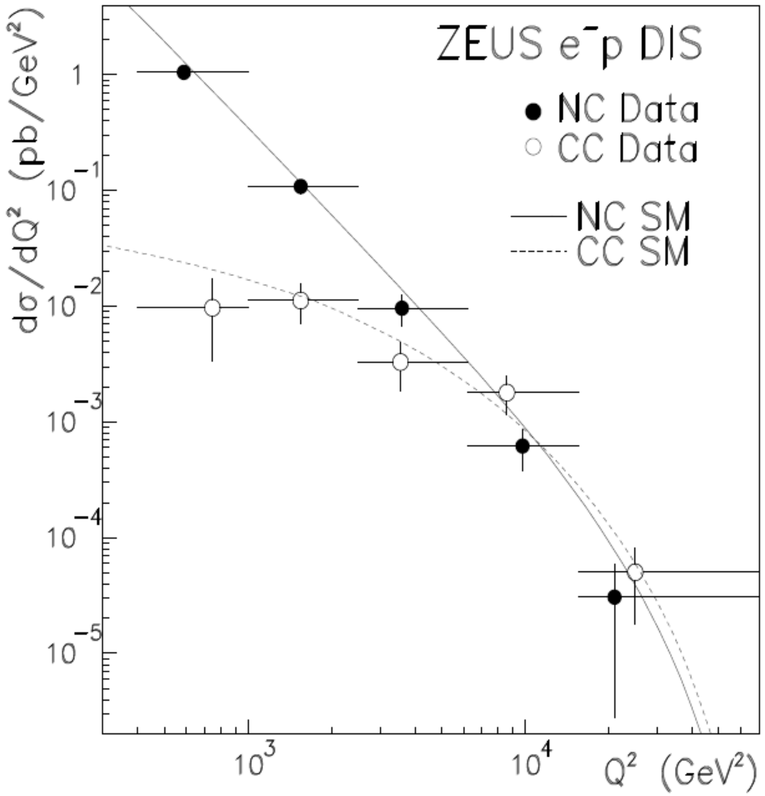
Beautiful demonstration of EW unification

NC



CC



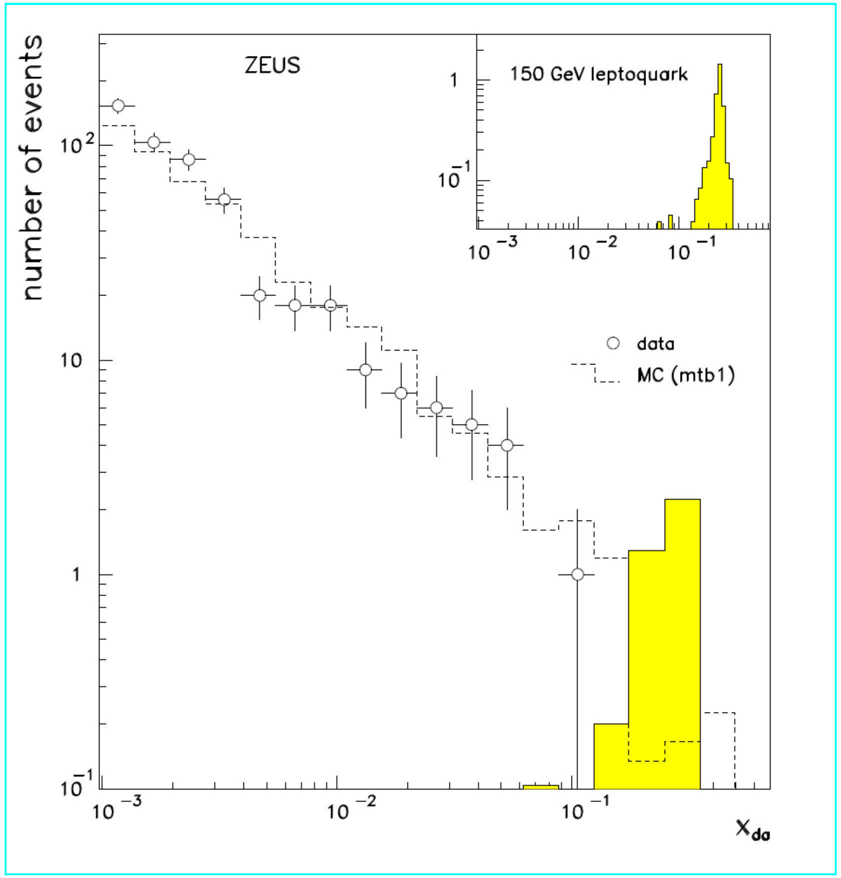


(1993)

Desesperately seeking Leptoquark since the early runs in 1992

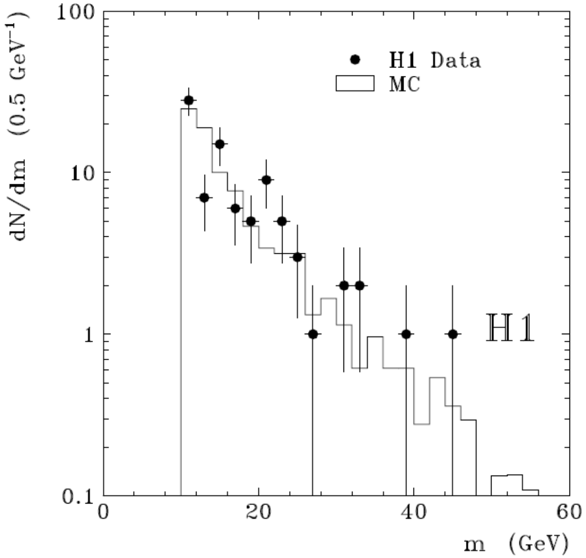
Looking for a peak in the s-channel at

$$x_0 = \frac{M^2{}_{LQ}}{s}$$

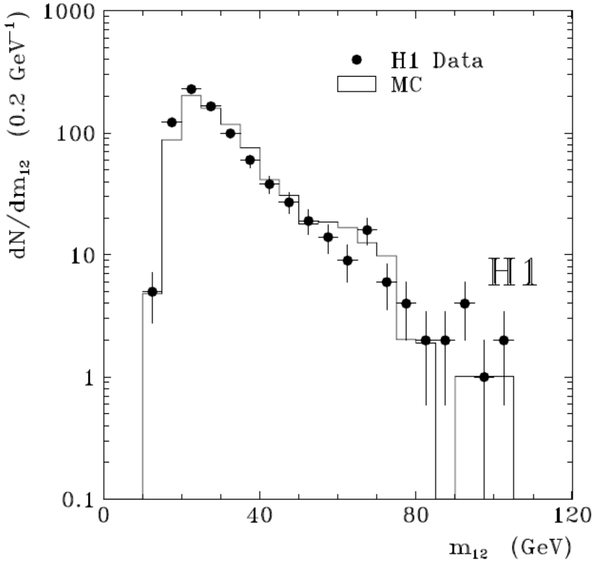


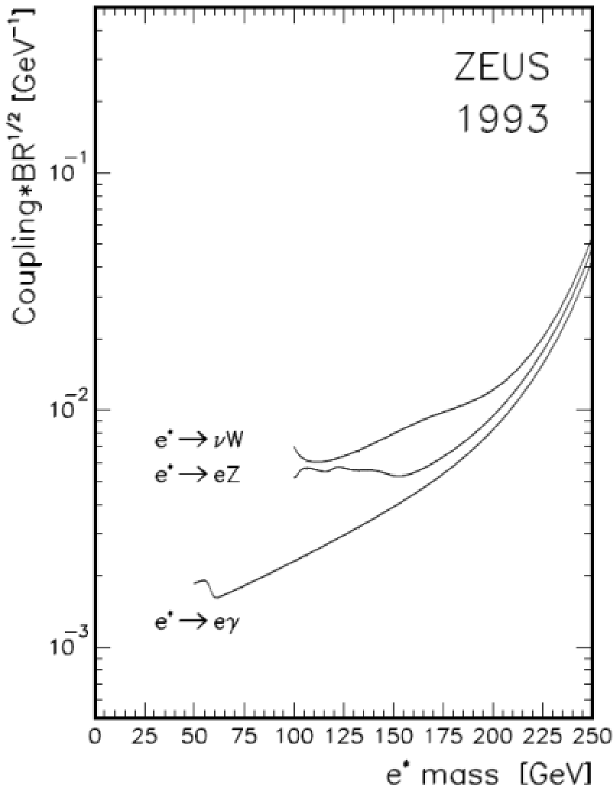
Limits on excited electrons in a new mass range

e-gamma pairs



jet-jet pairs





Summary

First physics results at HERA include discoveries which will stay in the legacy of HERA.

They have brought new insight mainly into:

the structure of the proton at small x.

+ the diffraction and the structure of the « Pomeron »

+ the structure of the photon

Many of the HERA data were well ahead of theory !

They have given us appetite for much more data.

→ next talks.

EXTRA

How one problem has cured a second problem

1) **Pollution** of LAr by desorption of freon from G10 read out boards

2) Outer vessel of Lar calorimeter : crimp junction alu-steel **not tight**

Cut an alu cylinder of the warm vessel to redo the crimping outside the hall.

Meanwhile : fill the LAr inner vessel with pure gas : N2, Ar, He and then pump it to obtain a rough vacuum, again and again for several months.

No more leaks , and stability of the LAr signal at the 10^{-3} level per year

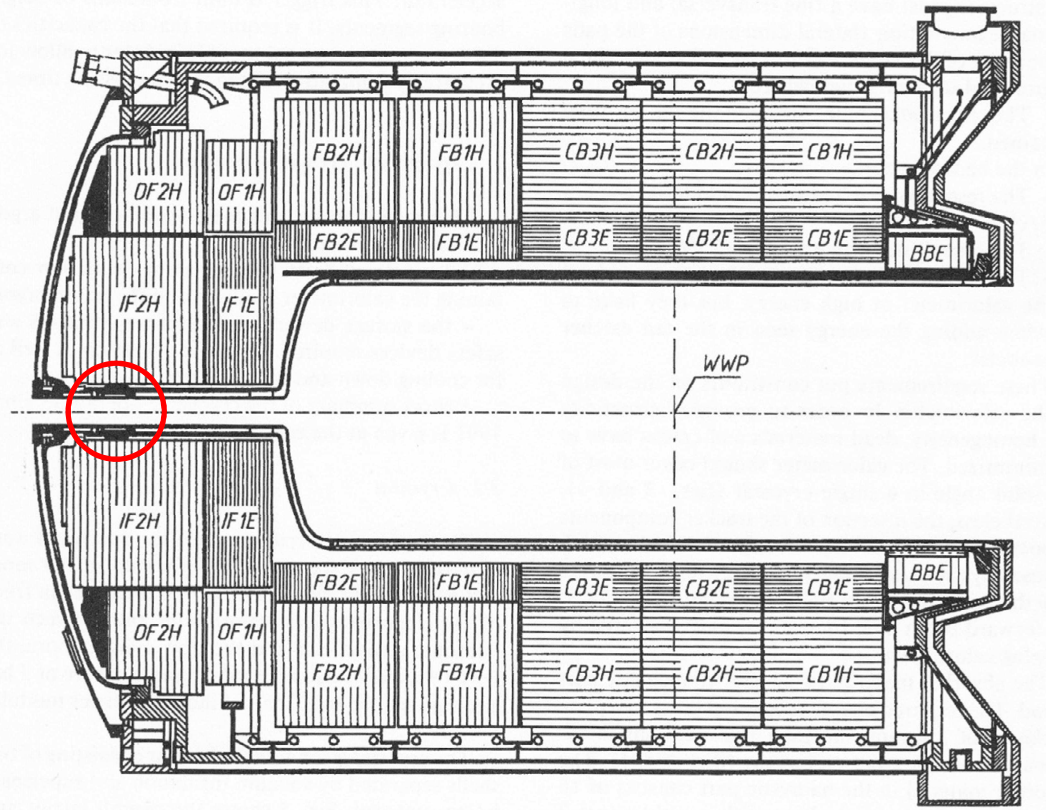


Fig. 3. Longitudinal cross section of the H1 liquid argon calorimeter. The orientation of absorber plates is indicated b horizontal and vertical lines respectively.

Jefferson Lab
Thomas Jefferson National Accelerator Facility
Exploring the Nature of Matter

Hugh E. Montgomery
Laboratory Director and Jefferson Science Associates President

June 18, 2012
Phone: (757) 269-7552
e-mail: mont@jlab.org

John Dainton,
Joerg Gayler,
Volker Korbel

Dear Friends,

I am writing in reaction to the sad news that Friedhelm Brasse has died.

I knew Friedhelm from our time on the European Muon Collaboration experiment which I joined in early 1973 and left in 1983. At the time I joined Friedhelm was already a member and he stayed a member until moving on to the H1 experiment.

Since I started my post-graduate career in electroproduction with the Mancaster experiment on NINA at Daresbury, I was aware of the competing groups at DESY, especially F21 with, if I am not mistaken, Brasse, Flaugher, Gayler, Korbel and May. One version of the story of the observation of the high cross-section and scaling in the deep inelastic regime in the sixties that I have heard is that the F21 measurements predated those from SLAC, but that Brasse did not have access to the same visionaries as did the SLAC-MIT team at SLAC.

In the formation phase of EMC, there were several key players. Gabathuler was obviously one, and he emerged as the first spokesman. But there were others, and extremely important was Friedhelm Brasse. Friedhelm was, in my opinion, the strongest of the senior people at the technical level. As we moved into mounting of the experiment, Friedhelm naturally became the person who worried about the stuff on the floor, especially the pieces that belonged to no particular sub-detector, such as alignment. During this time I developed a very great respect for the dedication and thoroughness with which Friedhelm approached his work.

At first reading Friedhelm projected a rather taciturn demeanor. However, with increasing familiarity, one detected a fairly dry but definite humor. This contributed to his enjoying a very successful term as the EMC spokesman. I like to think that I developed a friendship with Friedhelm and I recall his making considerable efforts to persuade me to seek a position at DESY. In 1983, I left CERN to go to Fermilab rather than DESY and so was unable to enjoy further working with Friedhelm

In summary, Friedhelm Brasse was a talented experimental physicist, who made seminal contributions to the field of deep inelastic scattering for a large fraction of the time that subject existed as a sub-field of particle physics. The support he gave his colleagues in his work was unstinting.

To all his close friends and family, please allow me to extend my condolences.

2 Hugh E. Montgomery
Laboratory Director