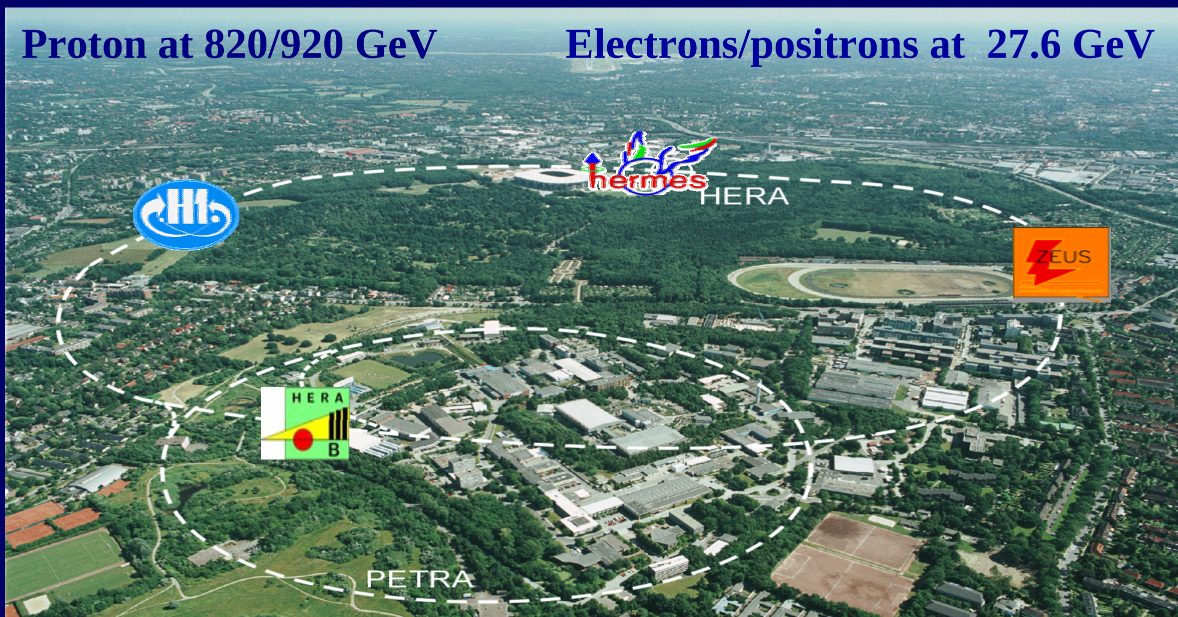
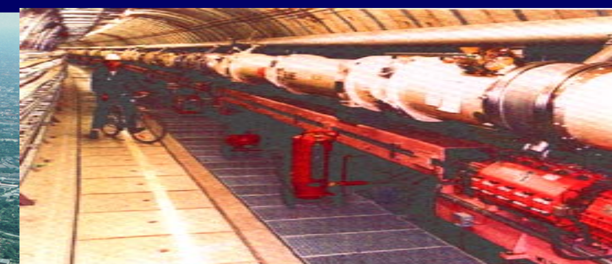
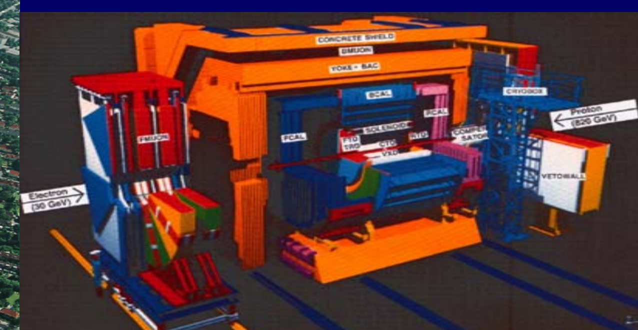
ZEUS physics

S.Chekanov

University of Chicago Review (Sep. 1, 2004)

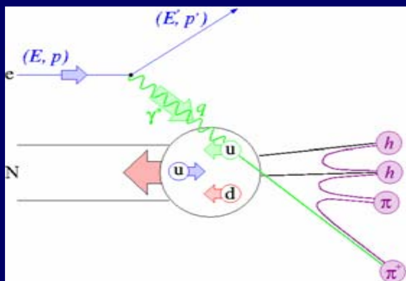




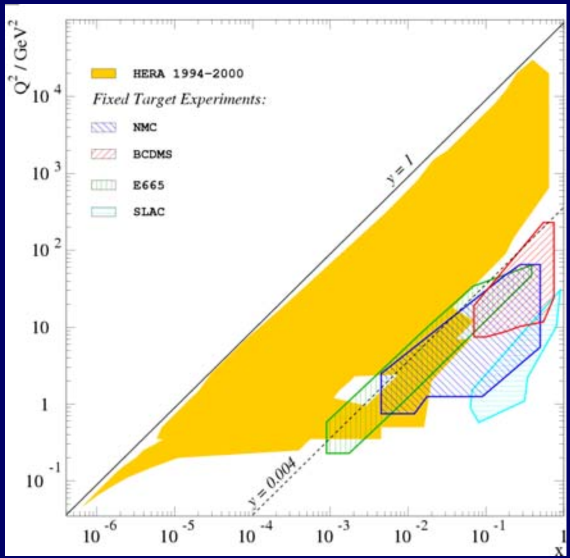


- HERA physics
- ZEUS group
- Hardware responsibilities
- HERA status
- Most recent results (emphasis on ANL analyses)

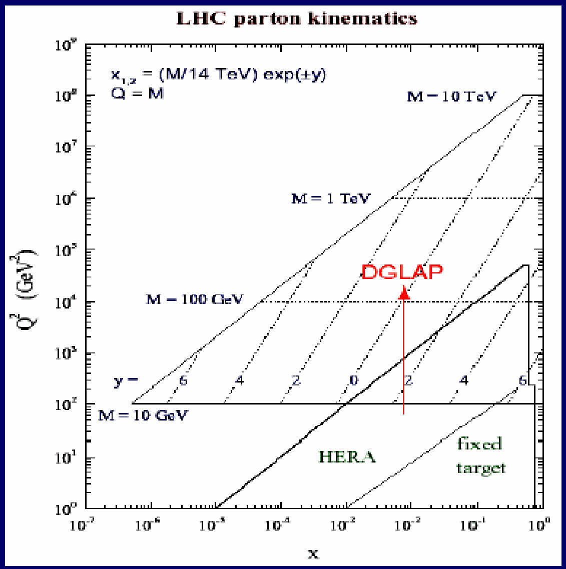
Importance of HERA physics



- ***$Q^2 = -q^2$***: 4-momentum transfer squared
- ***x***: fraction of proton momentum carried by quark



- **ep collisions at HERAI (1992-2000)- clean environment for:**
  - PDF determination, photon structure, jets, diffraction, other QCD aspects
- **HERAII (2000-2007):**
  - LHC has limitations to discover new physics due to large PDF uncertainties (especially at high x)
  - HERAII data on PDF very valuable (at high Q^2 and x).
  - More data needed on high E_T jets (significant impact on PDF at x>0.01)
  - HERAI results on F_3 statistically very limited
  - HERAII provides runs with polarized leptons - first results on polarization in DIS!
  - New heavy-flavor physics program with dedicated detectors (MVD and STT + new tracking trigger)



see HERA-LHC workshop for details

Physics done by ANL group (HERAI)

- PDF determination and F_2
- Jet physics (multi-jets, dijets, forward jets)
- Charm production and F_2^{cc}
- Beauty cross sections
- Exotics
- Diffraction
- Strange-sea studies via φ(1020) mesons
- Prompt photons
- Studies of hadronisation:
  - correlations, multiplicities, Bose-Einstein effect
- Pentaquarks:
  - Θ^+ (1530), $\Xi^{--}_{3/2}$ and $\Xi^0_{3/2}$

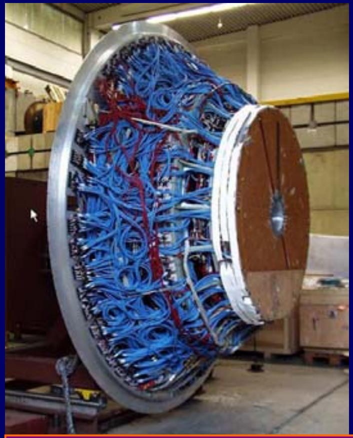
ANL group contributed to every aspect of ZEUS physics program

only small fraction of these results will be discussed

Hardware Responsibilities of the Group

Barrel calorimeter
Argonne leader in construction
Currently no involvement in maintenance

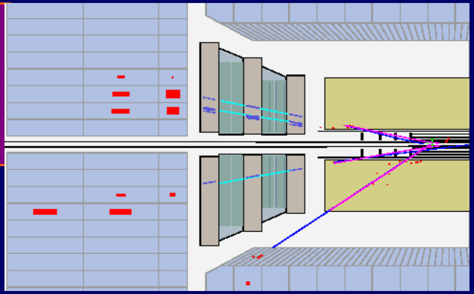
Barrel Presampler
Built under leadership of Argonne
Being maintained by Argonne



Calorimeter First Level Trigger Processor (CFLTP)
Built and maintained by Argonne

Small Angle Rear Tracking Detector Trigger (SRTD)
Built and maintained by Argonne

Straw Tube tracker
Front-end readout built by Argonne
First forward tracker to work in a collider experiment



→ first HERAII events

Present Activity

Name	Position	Activity
J Loizides	Student	CFLTp/SRTD FLT maintenance Analysis: Jets+D^*: Charm in HERA II data Trigger coordinator for Heavy Flavor Group; Shift leader
S Miglioranzi	Student	CFLTp/SRTD FLT maintenance Forward tracking, beauty cross-sections with MVD
S.Chekanov	Assistant physicist	QCD physics coordinator BPRE on-site person, CFLTp maintenance: Pentaquarks, prompt photons, charm, BE effect, Shift leader
S.Magill	Physicist	BPRE coordination, calibration Forward jets, prompt photons; AMZEUS finances, Shift leader
J Repond	Physicist	ZEUS group coordination, Member of ZEP STT electronic readout; Shift leader
R Yoshida	Physicist	
M.Derrick	Emeritus	Physics chairman in 2002; Member of ZEP
B.Musgrave	Emeritus	Prompt photons in DIS

+1-2 DESY summer students

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R Yoshida	Physicist	ZEUS spokesperson
M.Derrick	Emeritus	Physics chairman in 2002; Member of ZEP
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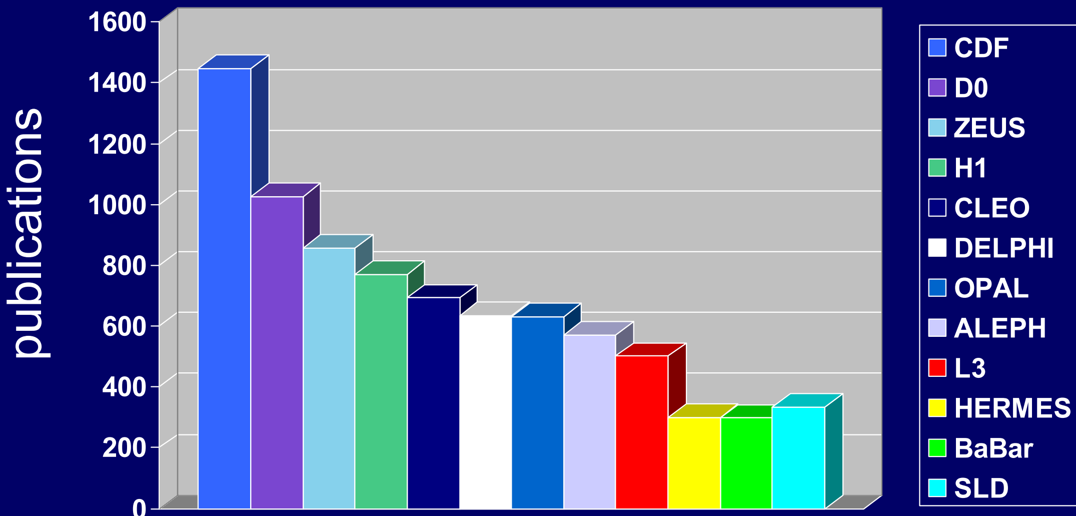
Physics Output



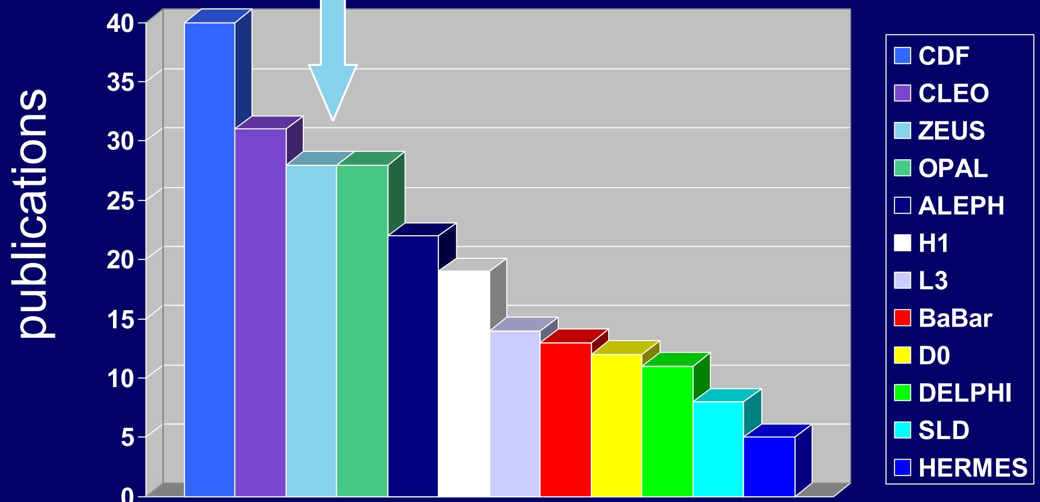
ZEUS papers are some of the most cited in literature.

ZEUS

ZEUS

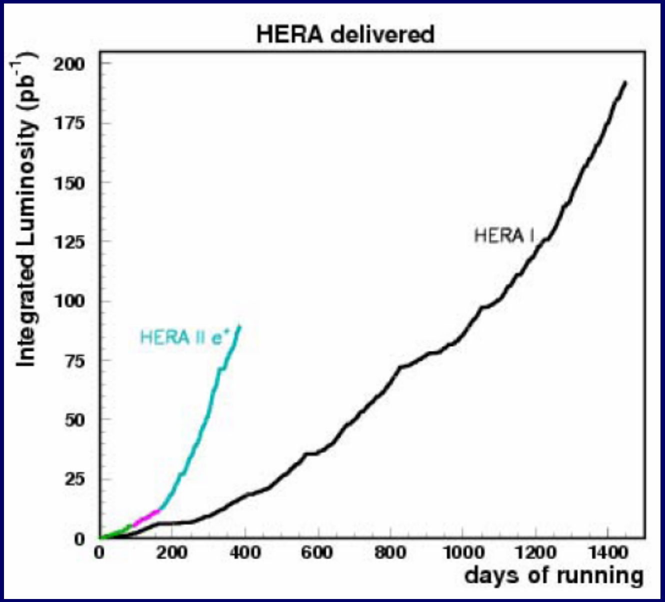
45 papers prepared for ICHEP04

27 papers – new results



Cited > 100 times

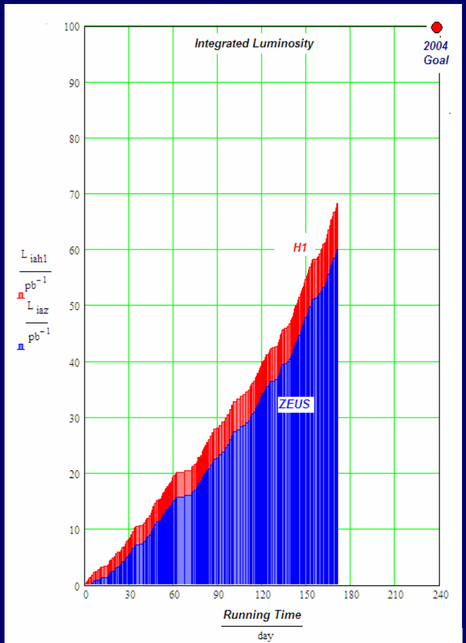
HERA status



Peak Luminosity:

- doubled since January 2004
- twice as large as in Y2000

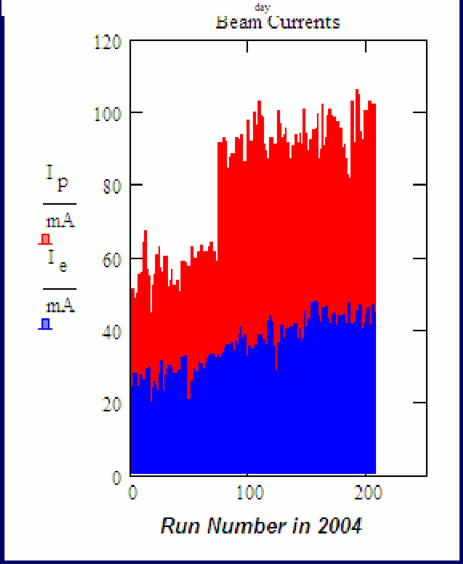
Record Value : **3.7 10^{31}cm^{-2}s^{-1}**



Beam Currents increased steadily:

- some limitations from cavity vacuum

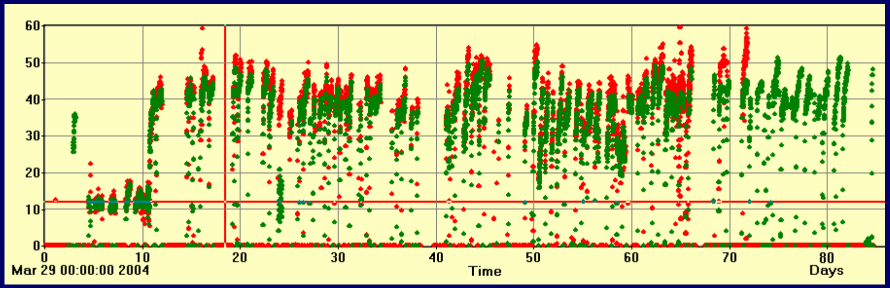
- vacuum needs to be improved

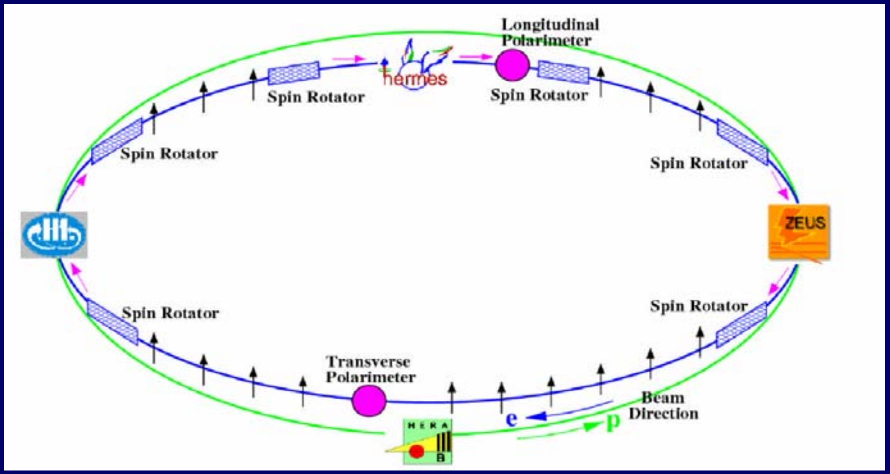


HERA has proven that it can deliver the promised luminosity (~1 pb^{-1}/day)

ZEUS has taken data with good (but not yet good enough!) efficiency

HERA status





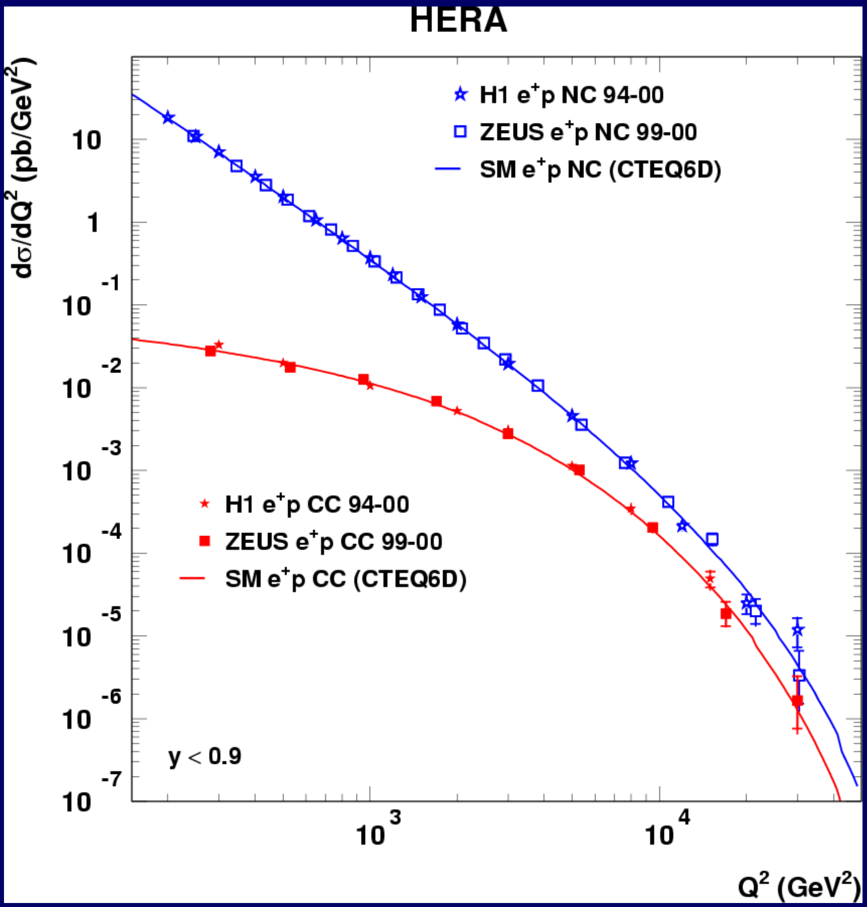
Polarization in collisions: 30-40%
Polarization without collisions up to 50%

HERA will run with e- in the fall 2004 and spring/summer 2005:

- So far only 16 pb^{-1} with e^- collected at HERA-I
- Beam lifetime expected to be somewhat shorter
- Particle backgrounds due to tails in transverse e- distribution expected to increase
- Expecting more frequent background “spikes”

The end of HERA II is “very firmly” set to mid 2007

Charged and Neutral Current DIS



- Excellent agreement with the SM
- EM and EW cross sections are similar ("electroweak unification" at high Q^2)
- Use this data in QCD fits

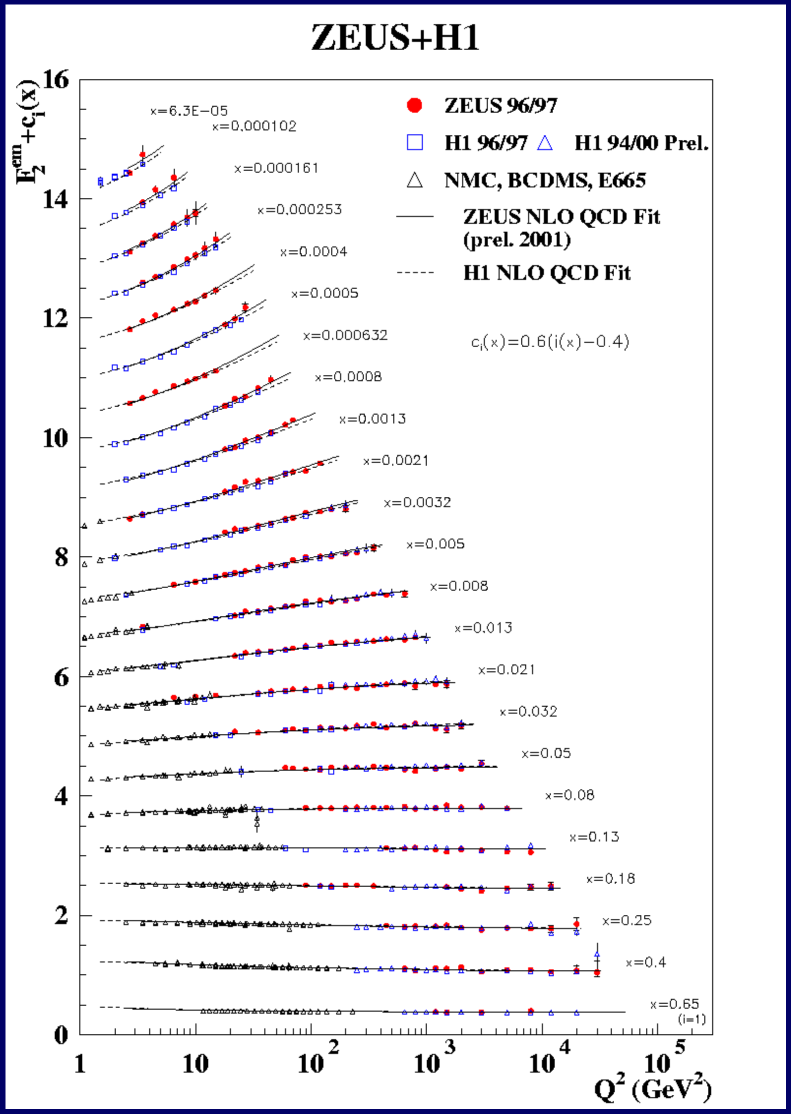
CC DIS cross sections suppressed due to large W mass:

$$\frac{d\sigma^{CC}_{e^\pm p}}{dxdQ^2} = \frac{G_F^2 Y_+}{4\pi x} \frac{M_W^4}{\left(Q^2 + M_W^2\right)^2} \left[F_2^{CC}\left(x,Q^2\right) - \frac{y^2}{Y_+} F_L^{CC}\left(x,Q^2\right) \pm \frac{Y_-}{Y_+} x F_3^{CC}\left(x,Q^2\right) \right]$$

$$\frac{d\sigma^{NC}_{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{x} \frac{1}{Q^4} \left[F_2^{NC}\left(x,Q^2\right) - \frac{y^2}{Y_+} F_L^{NC}\left(x,Q^2\right) \pm \frac{Y_-}{Y_+} x F_3^{NC}\left(x,Q^2\right) \right]$$

$F_2 \sim \sum x(q_i + \overline{q_i})$
- Dominates cross section
- Direct information on quarks

F_2 measurements



Scaling observed at high x: probing the "partons" (quarks) in the proton

Scaling violations, increasing as x decreases: QCD dynamics and high gluon density

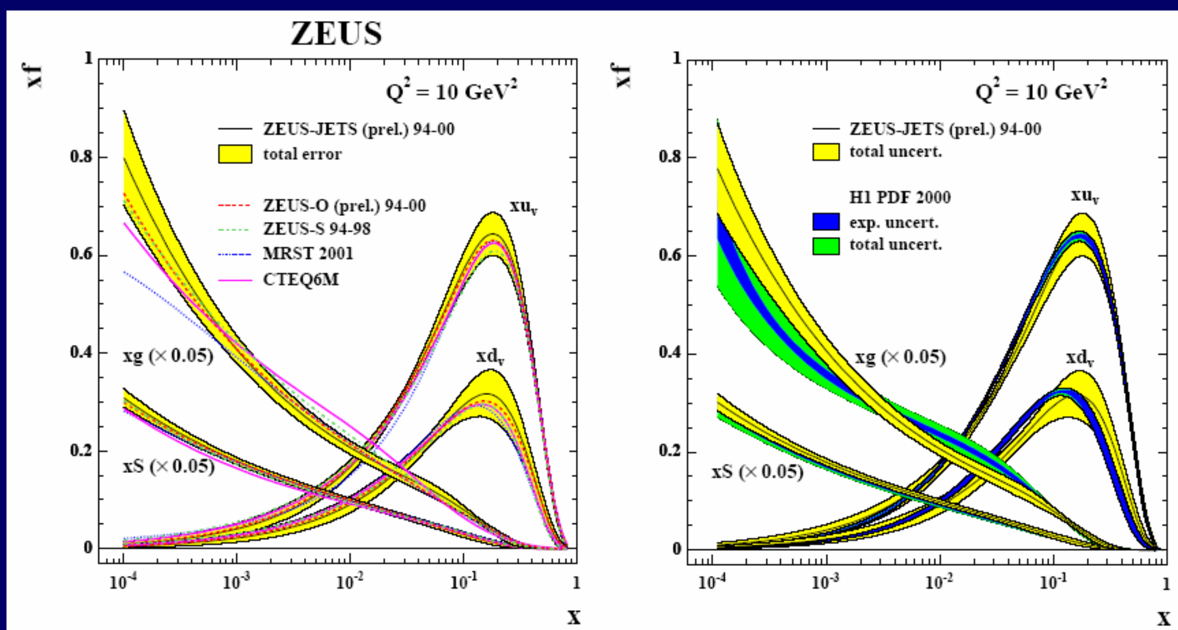
NLO QCD (DGLAP) gives a consistent description of the data over many decades in x and Q2

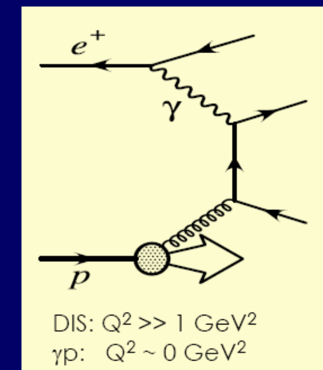
- *Very precise (2% precision)*
- *Data in wide range of Q^2 and x*
- *Good agreement with DGLAP evolution*

.. now let's extract parton densities (PDF)

ZEUS Jets QCD Analysis

- ❑ HERA data at high x are still less precise than fixed-target experiments
- ❑ Include jet observables:
  - ✓ sensitive to gluon at x~0.01-0.1 through BGF process
  - ✓ only inclusive jets and dijet measurements included so far

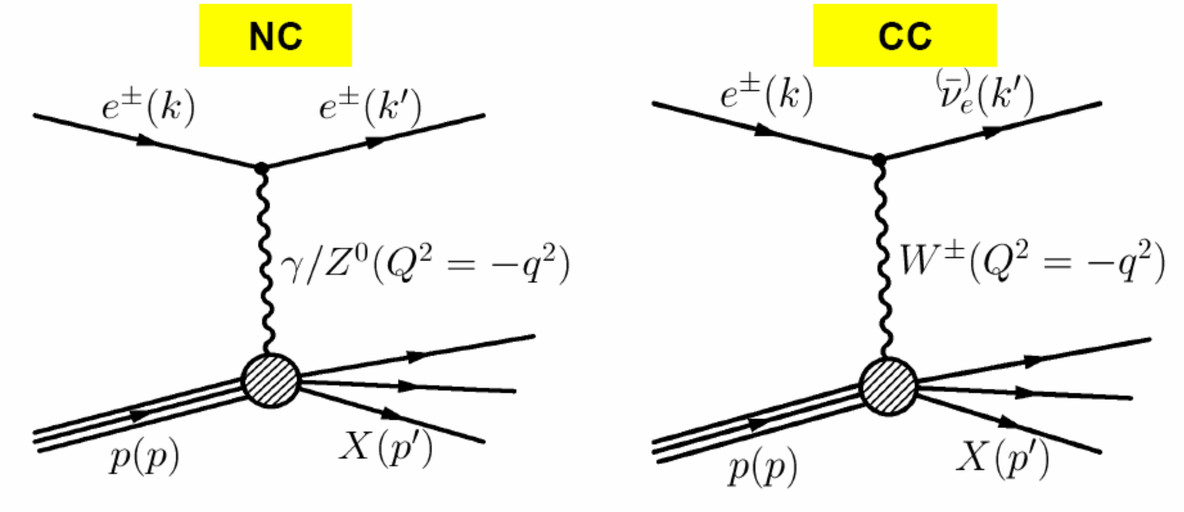




BGF process

Improvement in determination of gluon densities at mid-to-high x

DIS at HERAII: collisions with polarized leptons



NC DIS:

Z^0 couples differently to the left and right handed lepton

Contribution at high Q^2

(dependence of electroweak terms in the cross section)

CC DIS: Pure EW dependence

Linear dependence on polarization

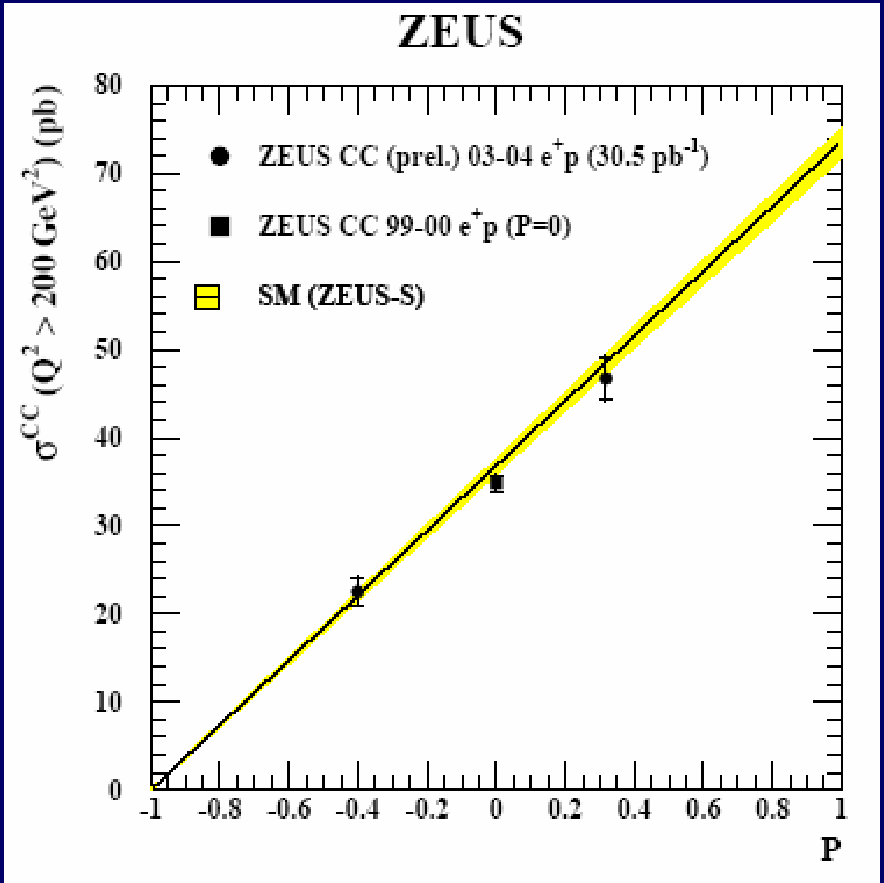
Contribution to all Q^2

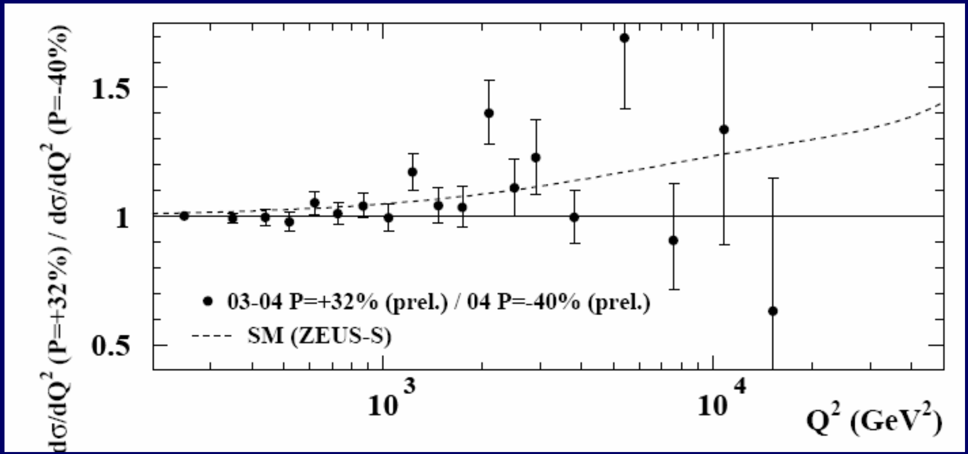
$$\sigma_{CC}^{\pm}(P) = (1 \pm P)\sigma_{CC}^{\pm}(0)$$

HERA II data: 16.4 pb^{-1} with P= -40.2%

14.1 pb^{-1} with P=+31.8%

First Results on Polarization

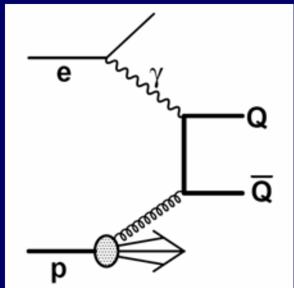




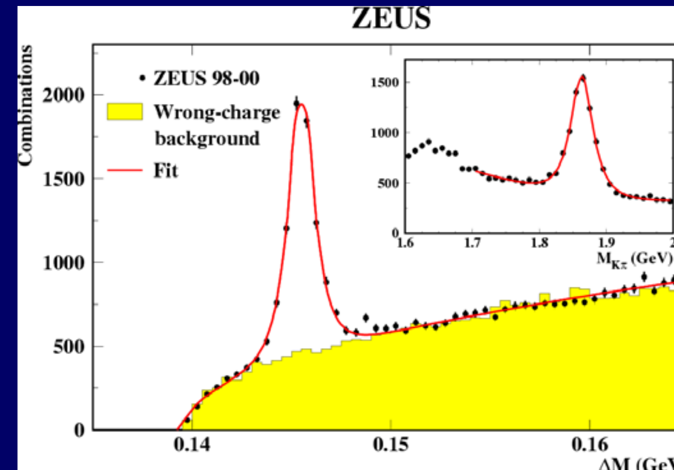
Polarization effect established in CC DIS

More data are needed for NC DIS

Agreement with the SM for both CC & NC DIS

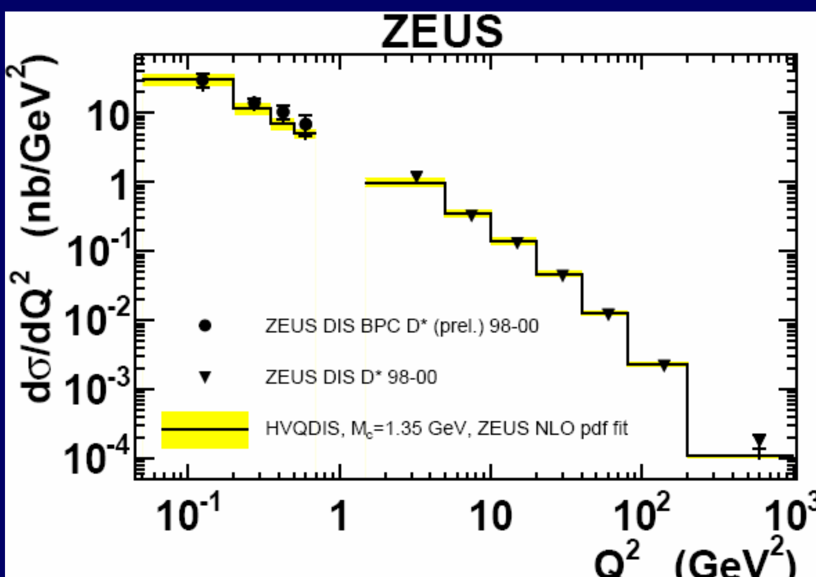


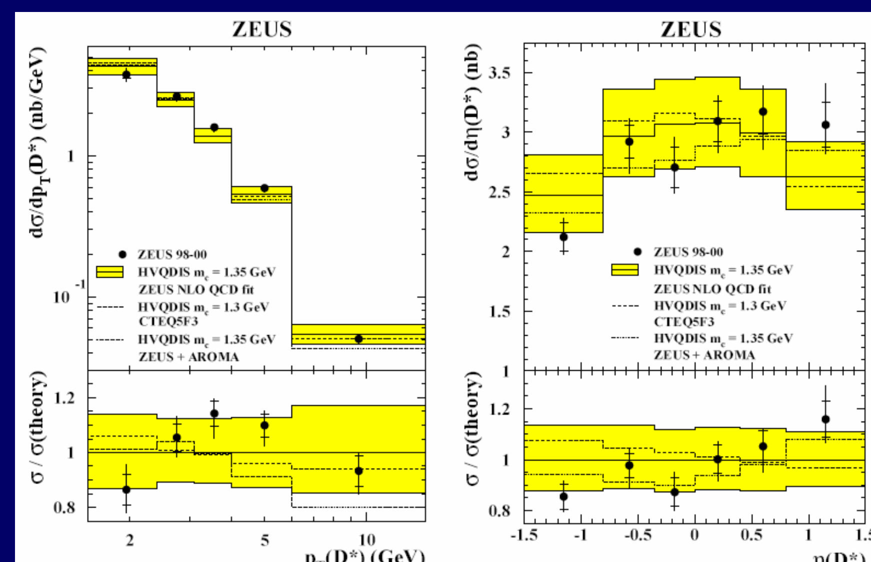
Charm Studies



Charm production directly sensitive to gluon density in proton

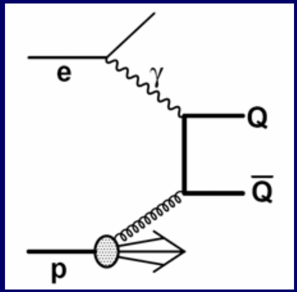
Look at "golden" decay channel: $D^{*} \rightarrow D^{0}\pi \rightarrow K\pi\pi$



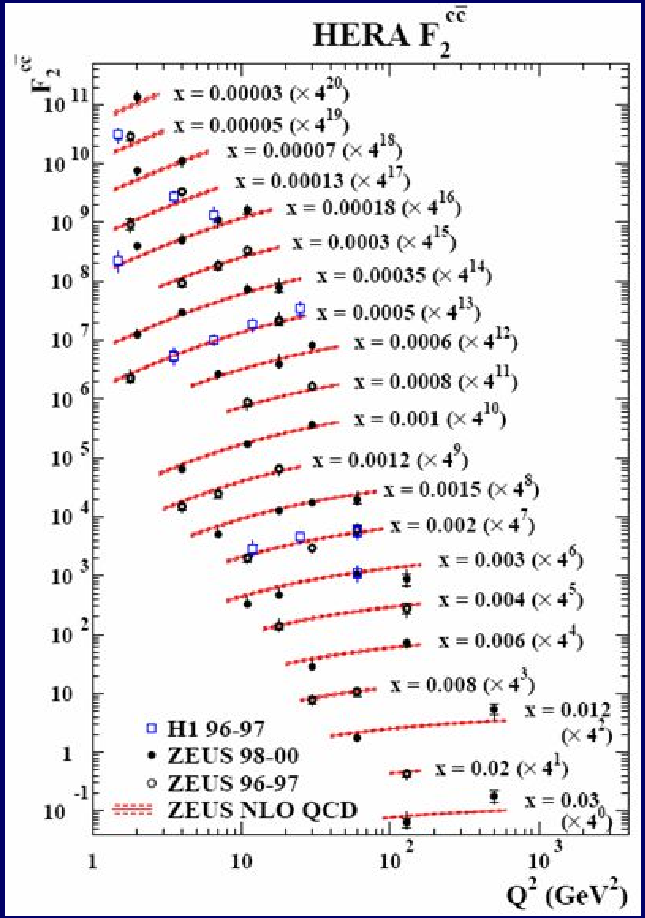


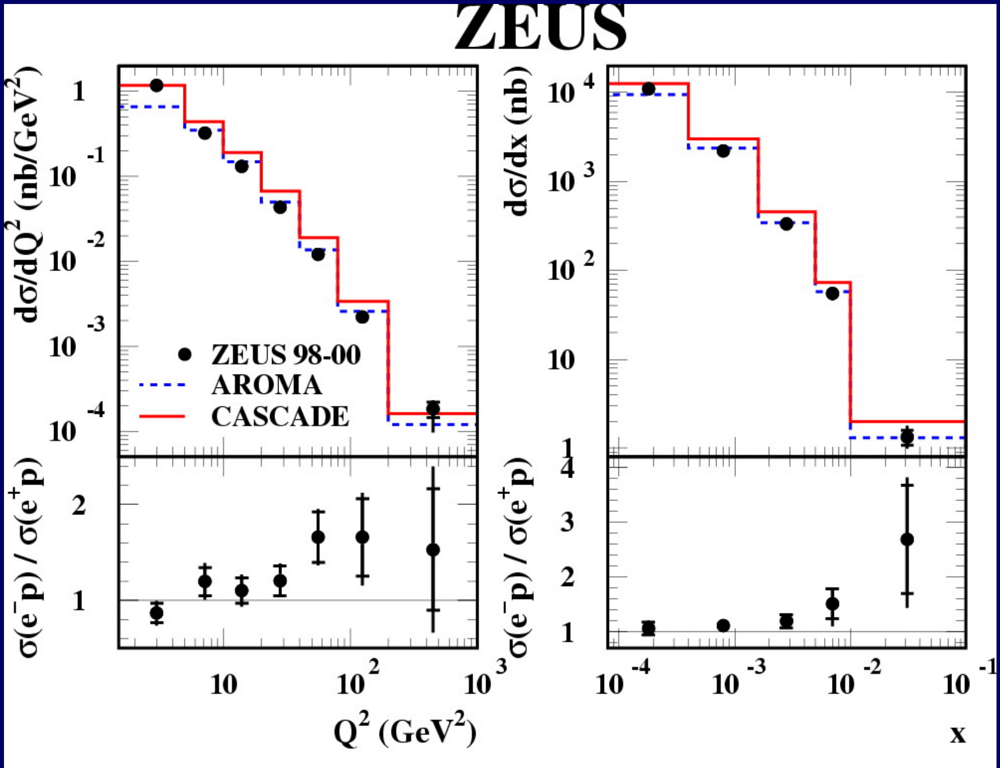
Measurements of F_2^{cc}

(charm contribution to F_2)



(done at ANL)





Good agreement with ZEUS NLO fit for F_2^{CC} over large Q^2 and x range

- Difference between e^+p and e^-p
- Contradicts the SM
- Need e^-p data from HERAII to check

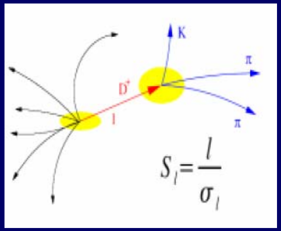
Charm Studies Using HERA II Data

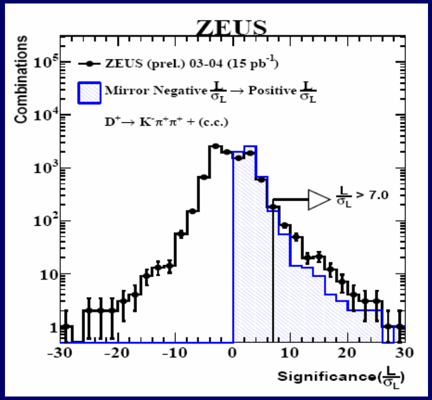
(from presentation of Argonne student J.Loizides at ICHEP04)

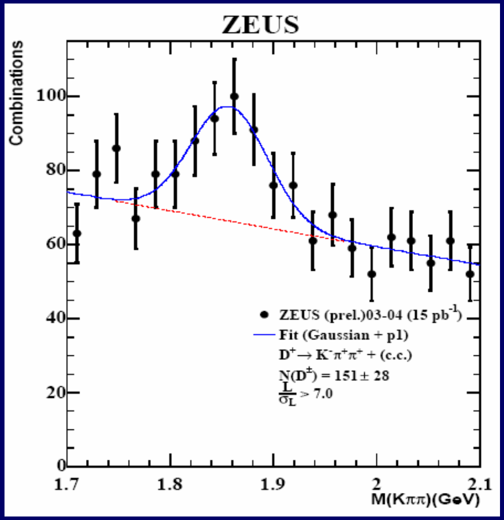
Charm tagging using decay length

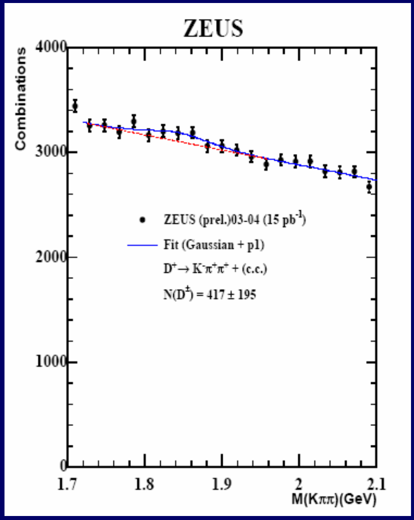
Use new MVD detector

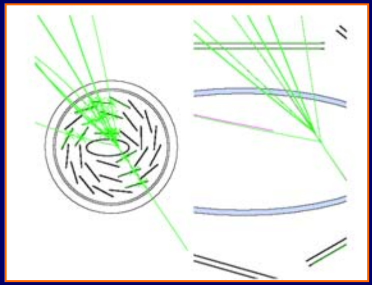
Decay length significance $S_l = l/\sigma_l$





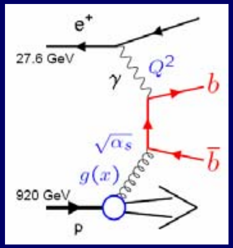






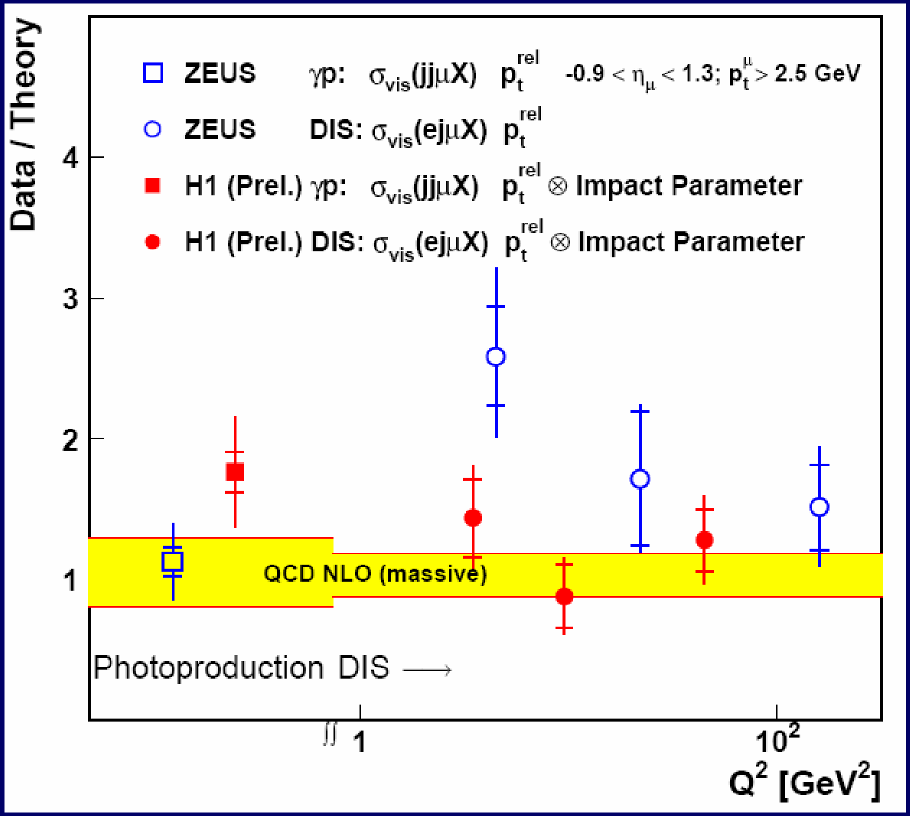
First look at HERA II data shows that lifetime tagging with MVD works as expected

Large potential for the future



Beauty Production

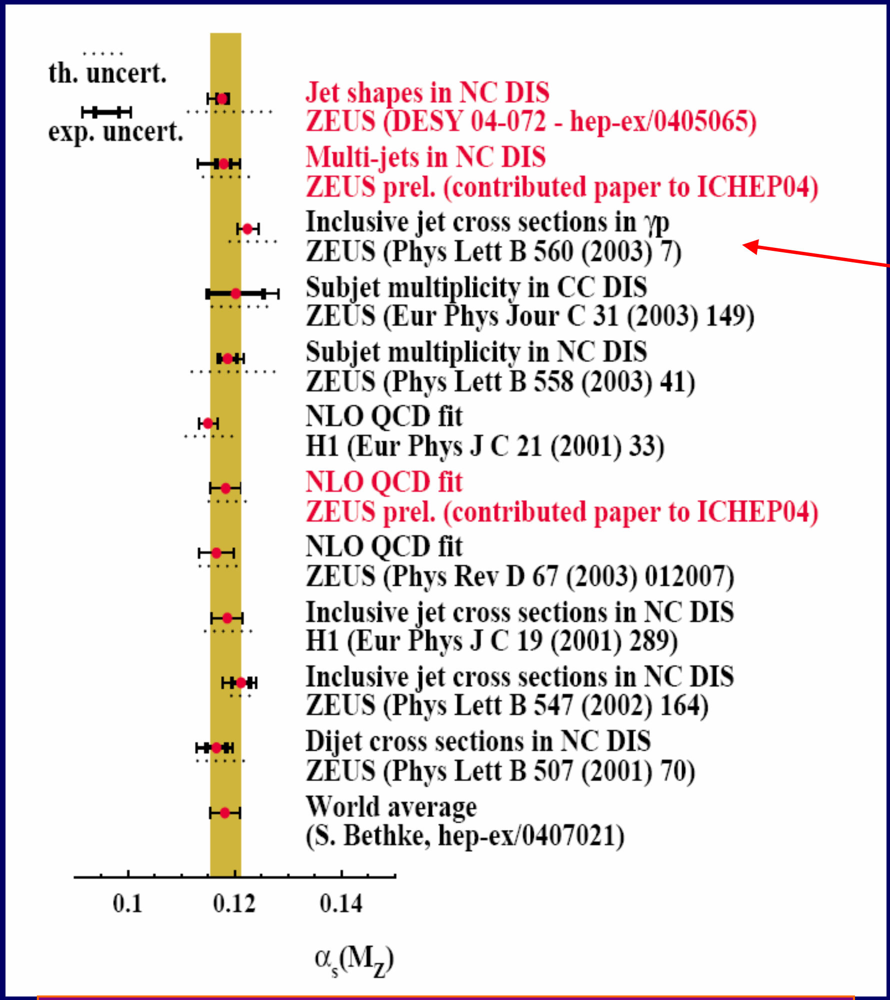
- Driven by gluons
- QCD calculations:
  - γp: FMNR (Frixione et al.)
  - DIS: HVQDIS (Harris, Smith)
- Multi-scale problem
  - m_b ~ 5 GeV
    hard scale ensure reliable QCD calculations
  - Q^2 (< 1 GeV^2 – γp, >2 GeV^2 –DIS)
  - p_T^b



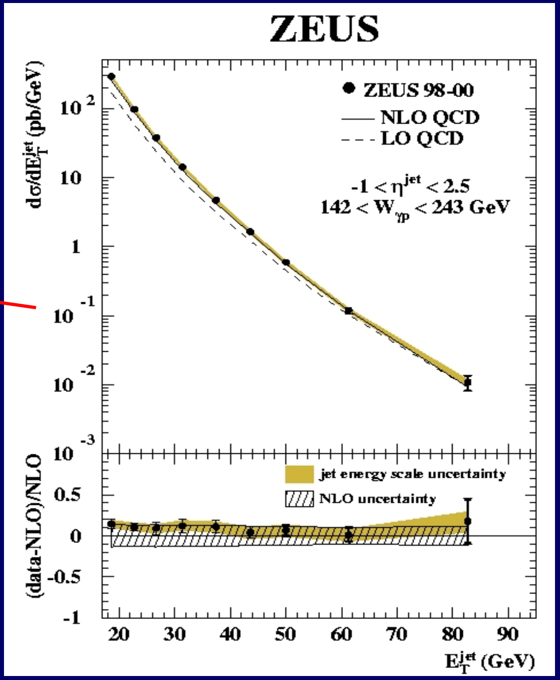
Data somewhat above massive NLO QCD

HERAII data very valuable

QCD studies: $\alpha_s(M_Z)$



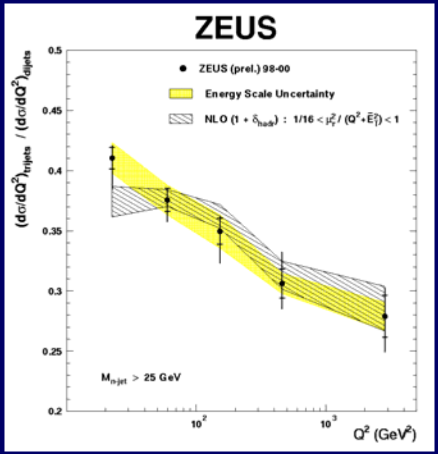
Competitive results
Theoretical uncertainties dominate
Significant impact on world average



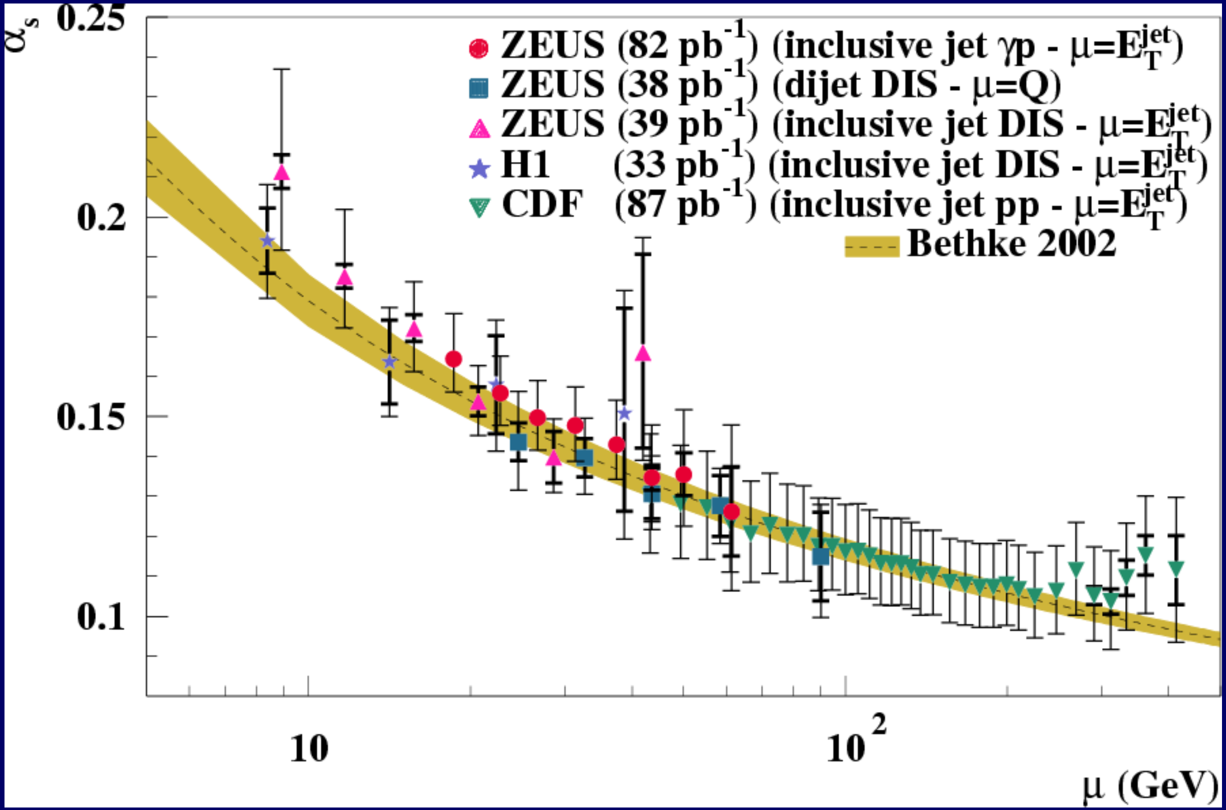
Most precise jet measurement (1% energy-scale uncertainty!)

Latest measurement:

(3/2)-jet ratio



Running α_s

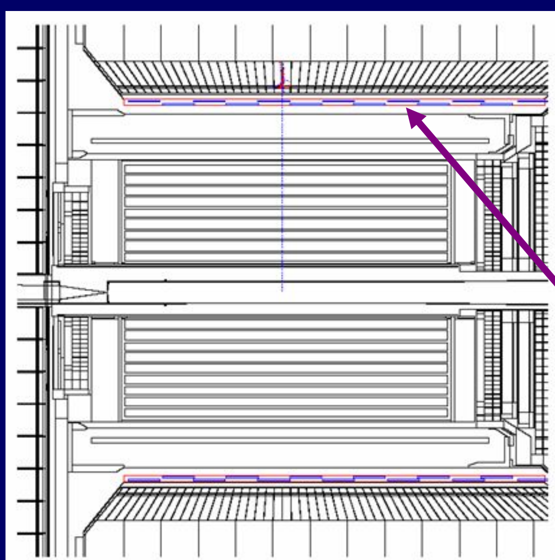


- Covers significant range in energy scale
- Running of α_s in single experiment
- Theoretical uncertainties dominate - NNLO QCD is needed

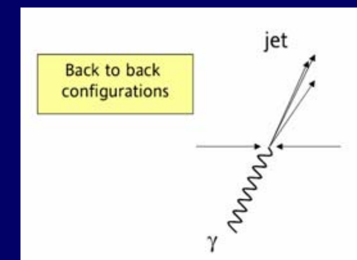
Barrel Preshower Detector (BPRE)

Argonne constructed BPRE detector:

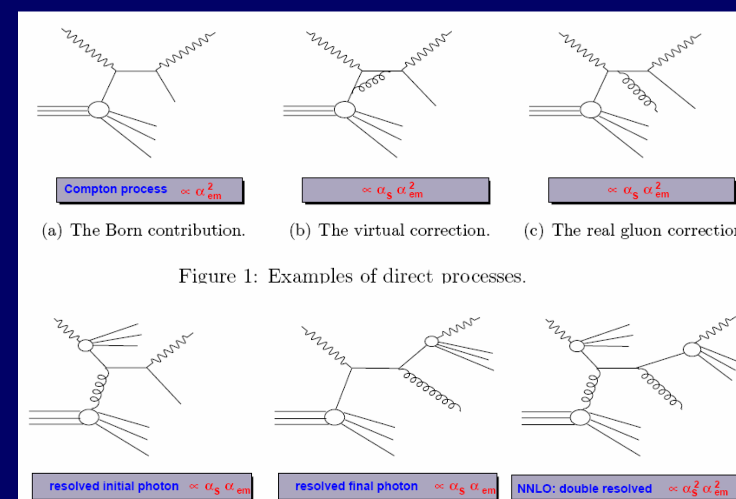
- Presently used for correction of scattered lepton
- Prompt photon reconstruction
- Dead material maps
- Correct electromagnetic components of jets



Reconstruct **γ+jet** final state:



NLO+NNLO calculations available to test QCD in great details:



(a) The Born contribution. (b) The virtual correction. (c) The real gluon correction.

Figure 1: Examples of direct processes.

(a) Resolved initial photon. (b) Resolved final-state photon. (c) Double resolved process.

Figure 2: Examples of the resolved processes.

Prompt photons using BPRE

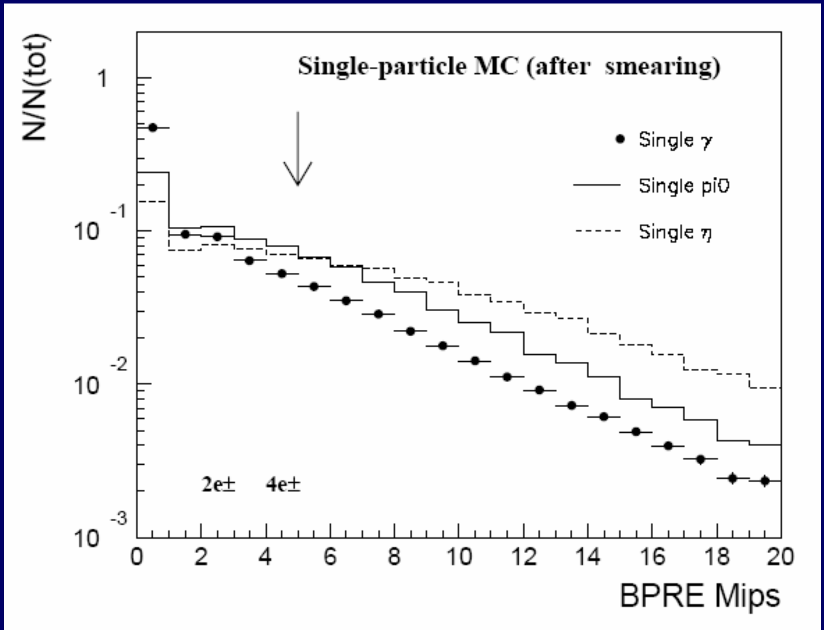
Two methods to reduce pion background:

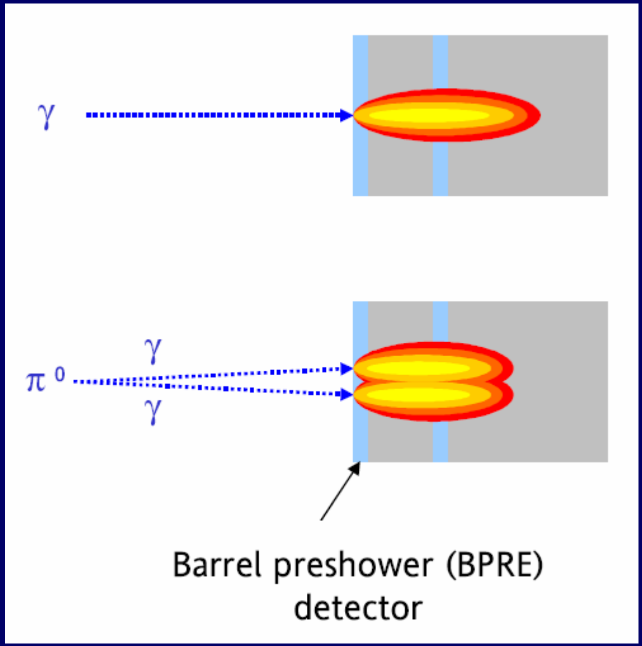
1) Shower-profile method (used so far)

- works well al low E_T fails at high E_T

1) conversion-probability method (ANL)

- best works at high E_T

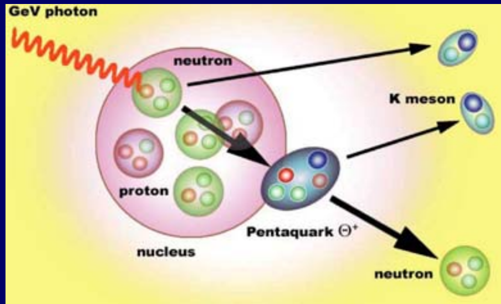




- BPRE has different response to γ and π^0 / η
- BPRE can be used to reduce background

Pentaquarks

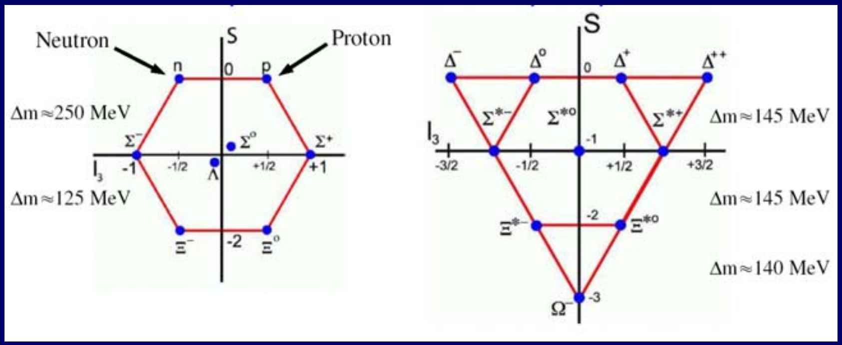
renaissance of hadron spectroscopy?



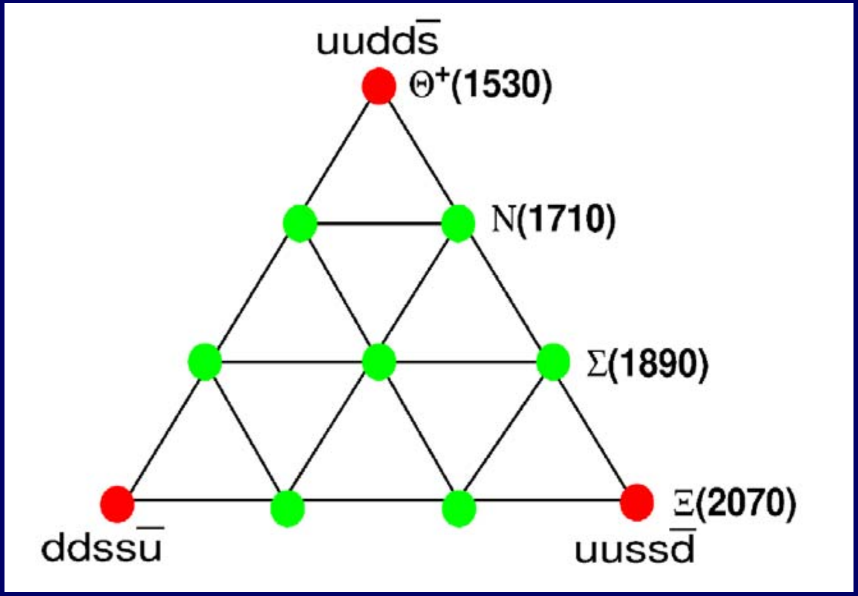
Constituent Quark model:

mesons $q\bar{q}$ baryons qqq

Does not predict more complicated states (but can accommodate them)

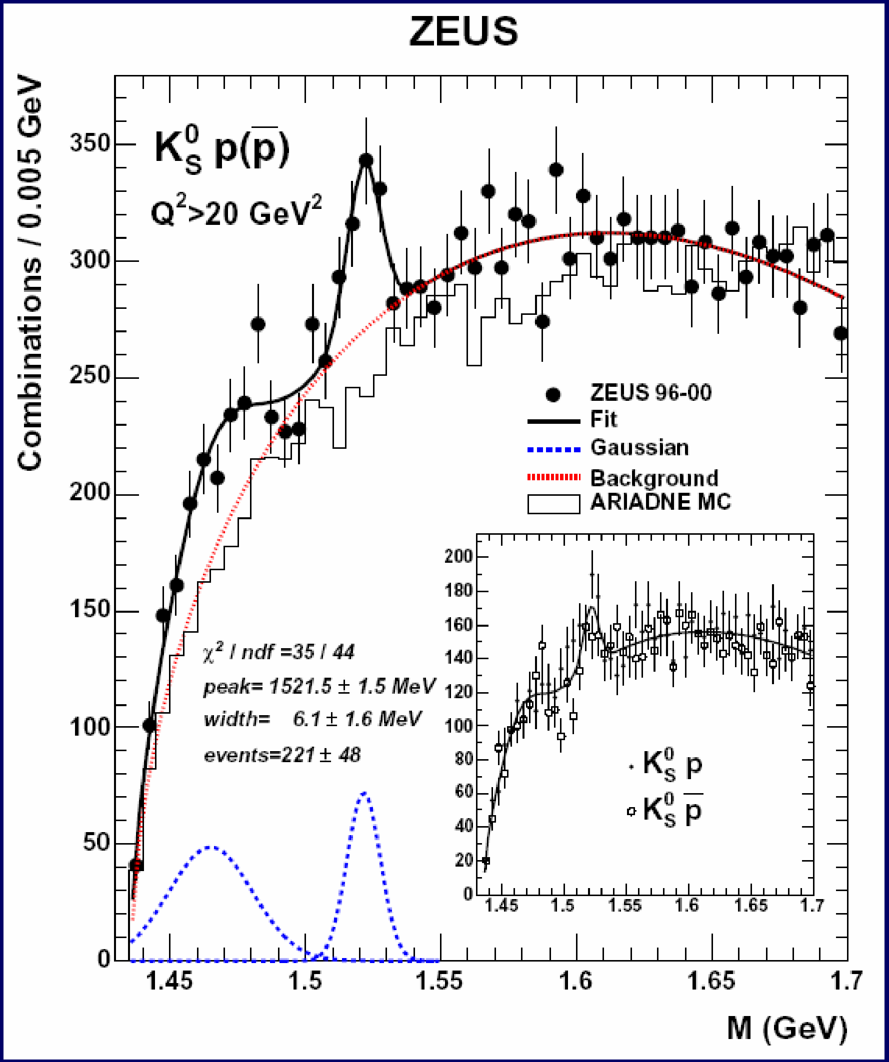


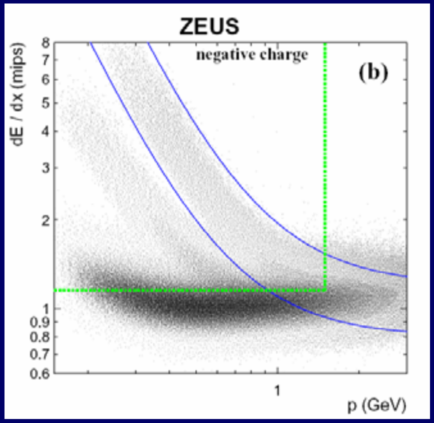
A number of fixed-target experiments observed a narrow baryonic state at 1530 MeV consistent with pentaquark predictions (Diakonov, Petrov, Polyakov)

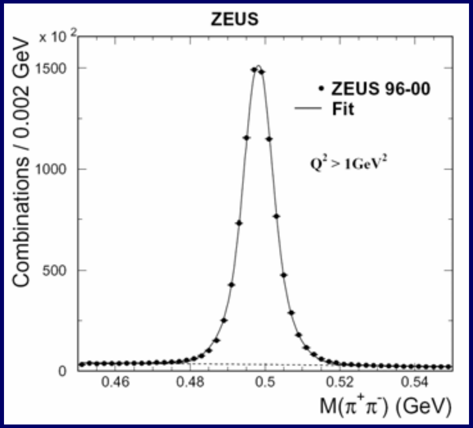


Experimental studies at ZEUS initiated by ANL group

ZEUS observation







(anti)protons are combined with $K^0{}_S$

Signal 4.6 σ at ~ 1522 MeV

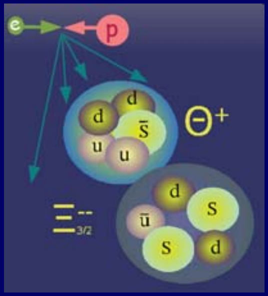
Breit-Wigner width Γ=8 ±4 MeV

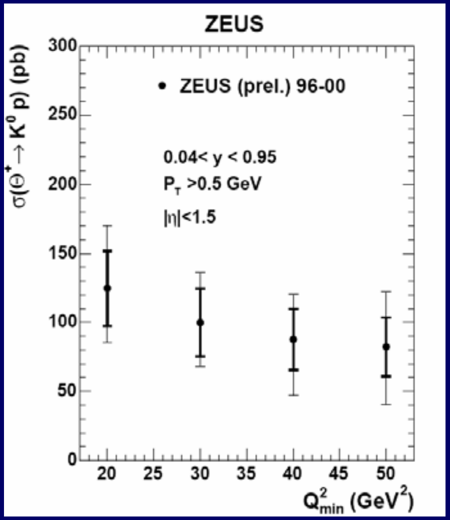
First evidence:

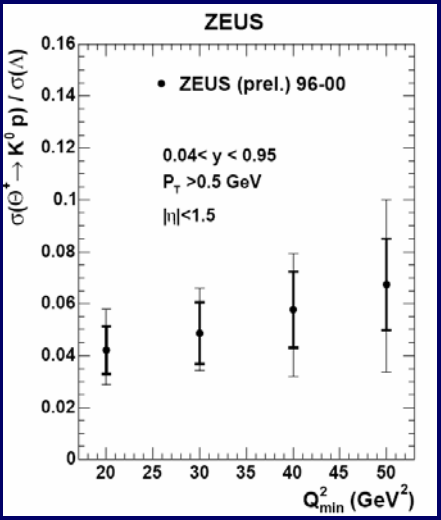
- in HEP colliding experiment
- for antipentaquark

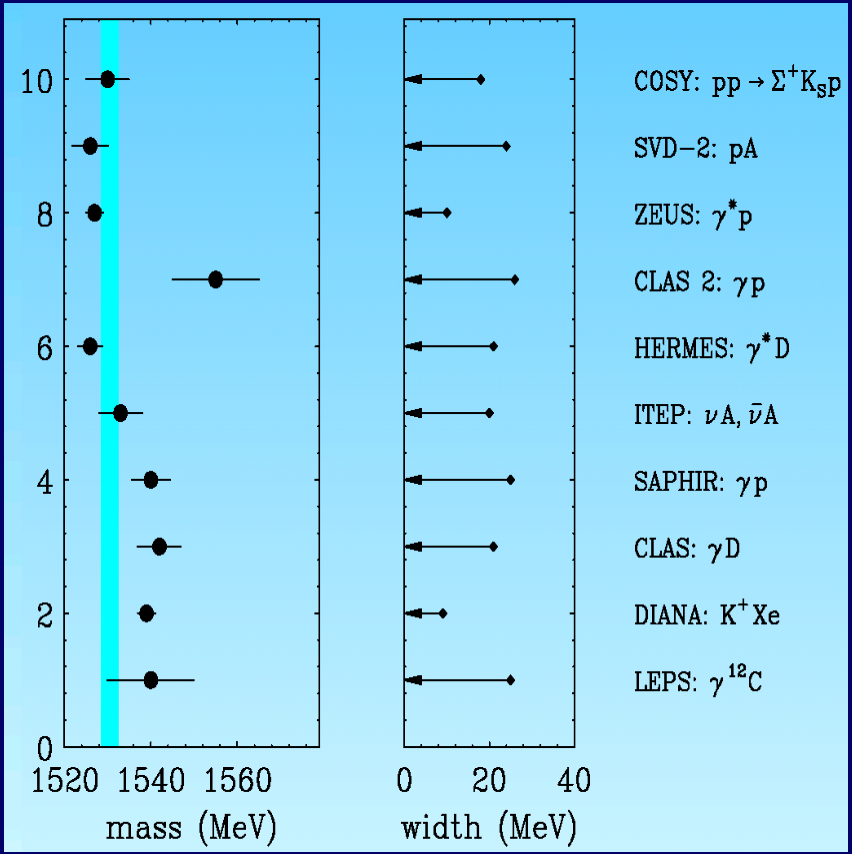
(done at ANL)

ZEUS observation





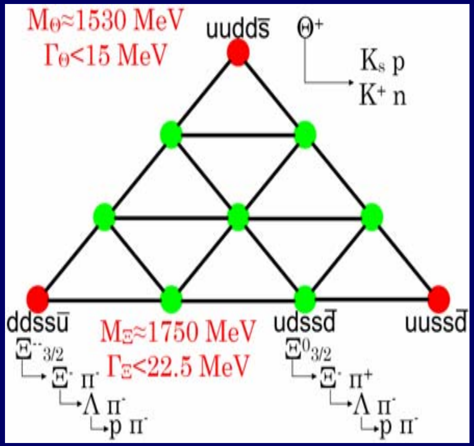




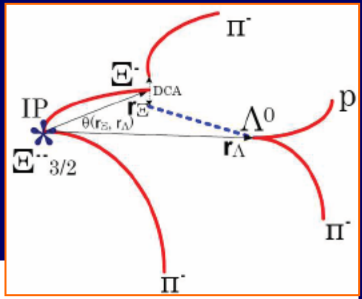
$$\frac{\sigma(ep \to e\theta^+ X \to eK^0 pX)}{\sigma(ep \to e\Lambda X)} = 4.2 \pm 0.9(stat)^{+1.2}_{-0.9}(syst)\%$$

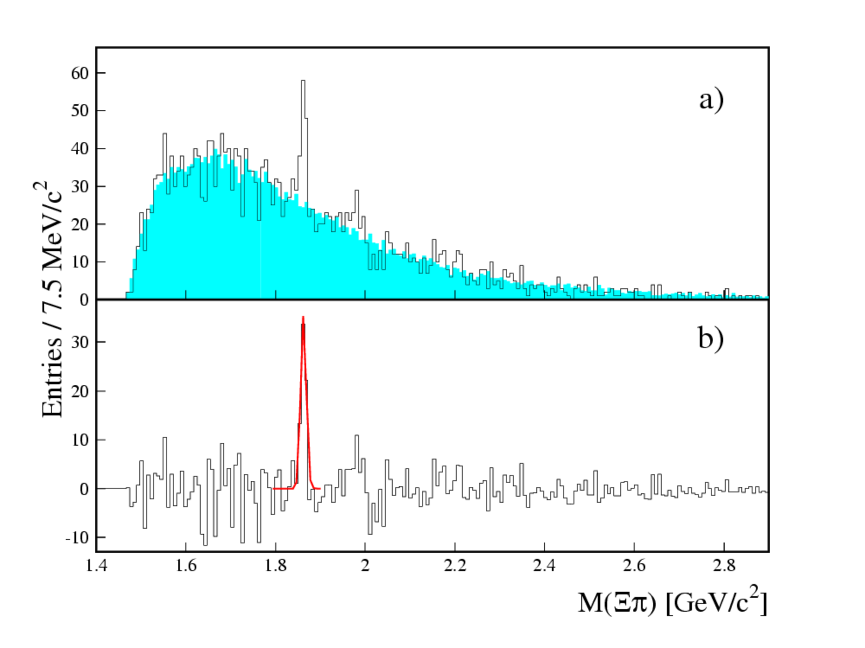
- ZEUS has the largest number of reconstructed events
  → one of the most precise measurements
- Significant impact on the word average m=1530 ±2 MeV
- Cross sections in DIS

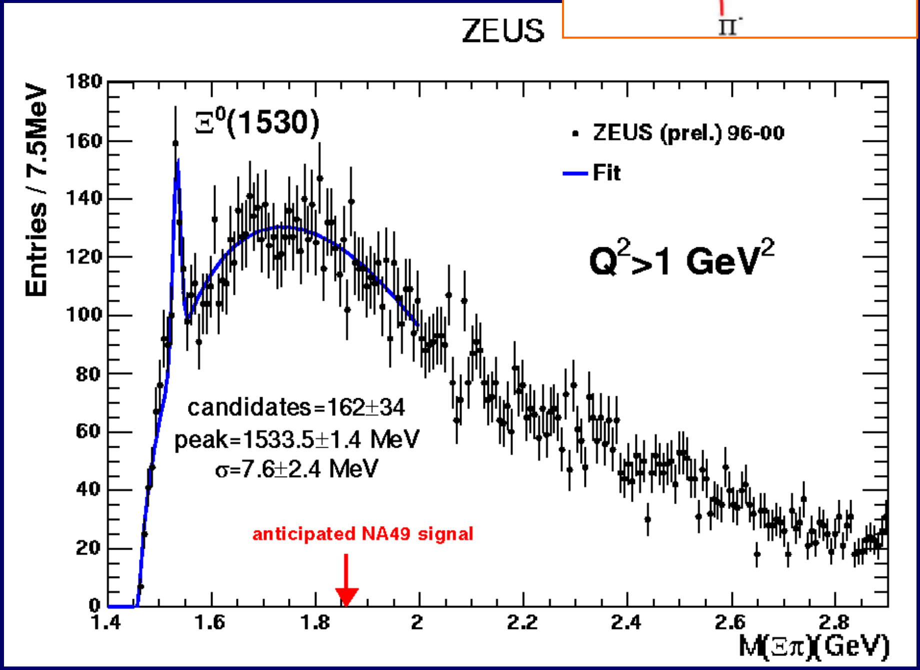
Other ZEUS strange pentaquarks



Pentaquark explanation of θ^+ was strengthened by NA49 observation of $\Xi^{--}_{3/2}$ and $\Xi^0_{3/2}$ pentaquark states with mass 1862 MeV







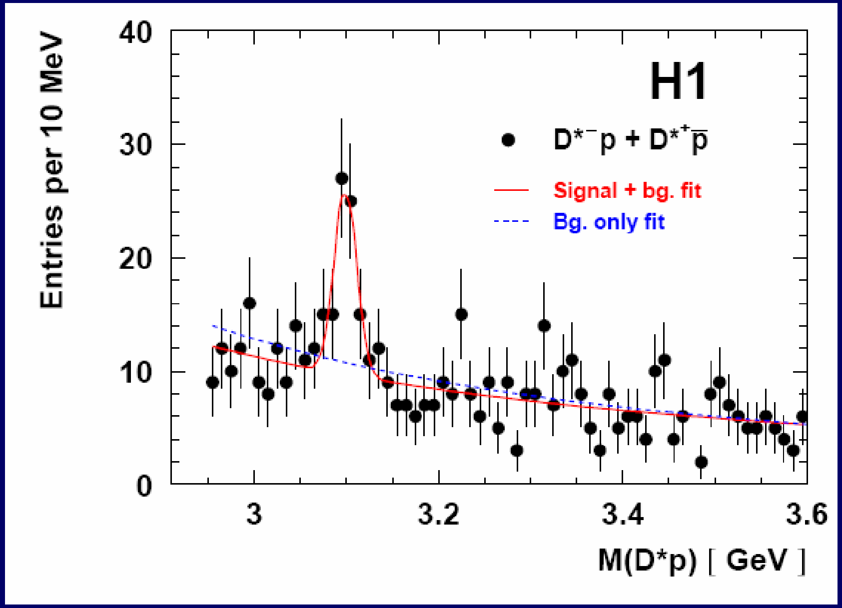
Very clean PDG Ξ^0(1530) signal

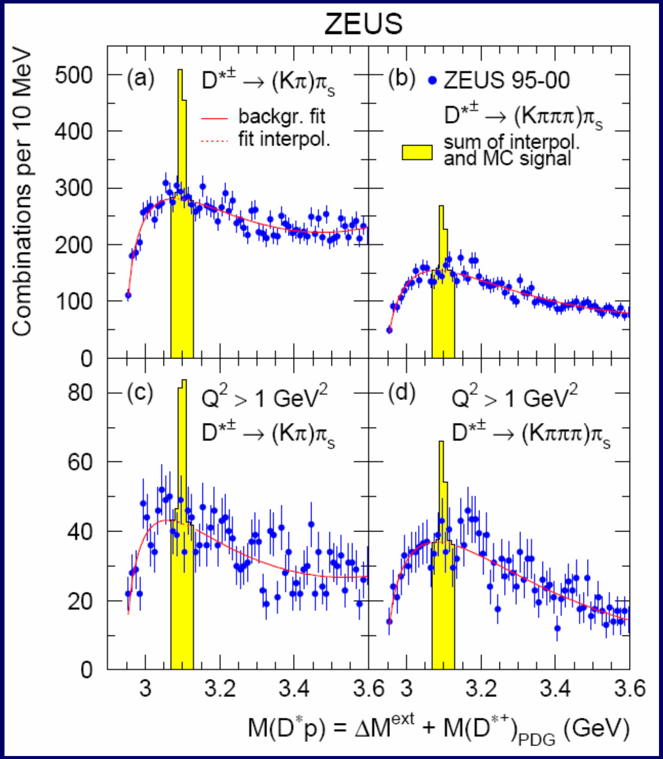
ZEUS does not observe NA49 signal

Charm pentaquarks

If $\theta^{+} = uudd\bar{s}$ exists, then $\theta^{0}{}_{c} = uudd\bar{c}$ should also exist

H1 observation: narrow signal at 3099 MeV
(Phys. Lett. B588 (2004) 17)





ZEUS has larger event sample

ZEUS data are not compatible with H1 observation

Assuming Gaussian statistics,

$$R = N(\theta_c \rightarrow D^* p / D^*) \approx 1$$

excluded at 9 σ level

Summary

- HERAII achieves now stable operation
- ZEUS data provides many precise tests of QCD
  - Analysis of pre-upgrade data producing a wealth of important results
- NLO calculations show good agreement with measurements over a huge kinematic range
- Precise PDF determinations:
  - Jet observables included
  - Important impact on physics of future hadron collider (LHC)
- Precise α_S measurements
  - Significant impact on world average
- Polarisation effect in CC DIS measured
  - Consistent with the SM predictions
- Many new results on pentaquark states
  - First colliding experiment which observes possible 5-quark state
  - Cross sections in DIS
  - No signals are seen for heavier pentaquarks
- Argonne group makes significant contributions to the experiment
  - Management (spokesperson, physics chairman)
  - Data analysis (physics group coordination, jets, charm, pentaquarks..)
  - Hardware (BPRE, STT, CFLTp, SRTD-FLT)