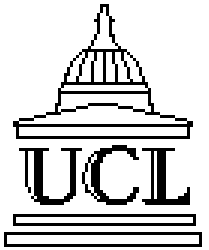
Results from HERA and some Implications for LHC

RHUL

28/03/2005



Jon Butterworth

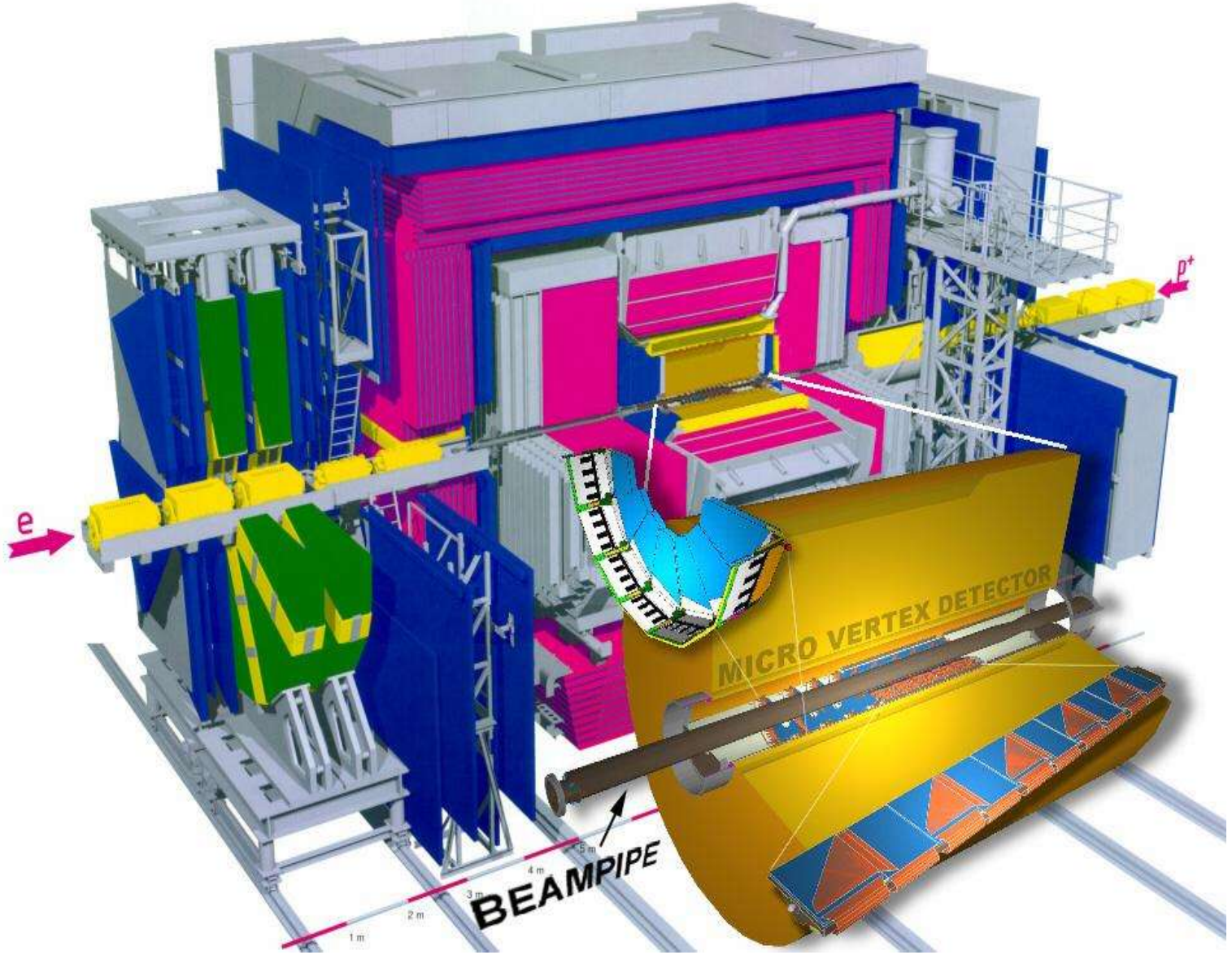
- HERA status and plans
- Recent highlights
- Impact of HERA data at the LHC

HERA

The world's only lepton-hadron collider

ZEUS

One of the two colliding beam experiments

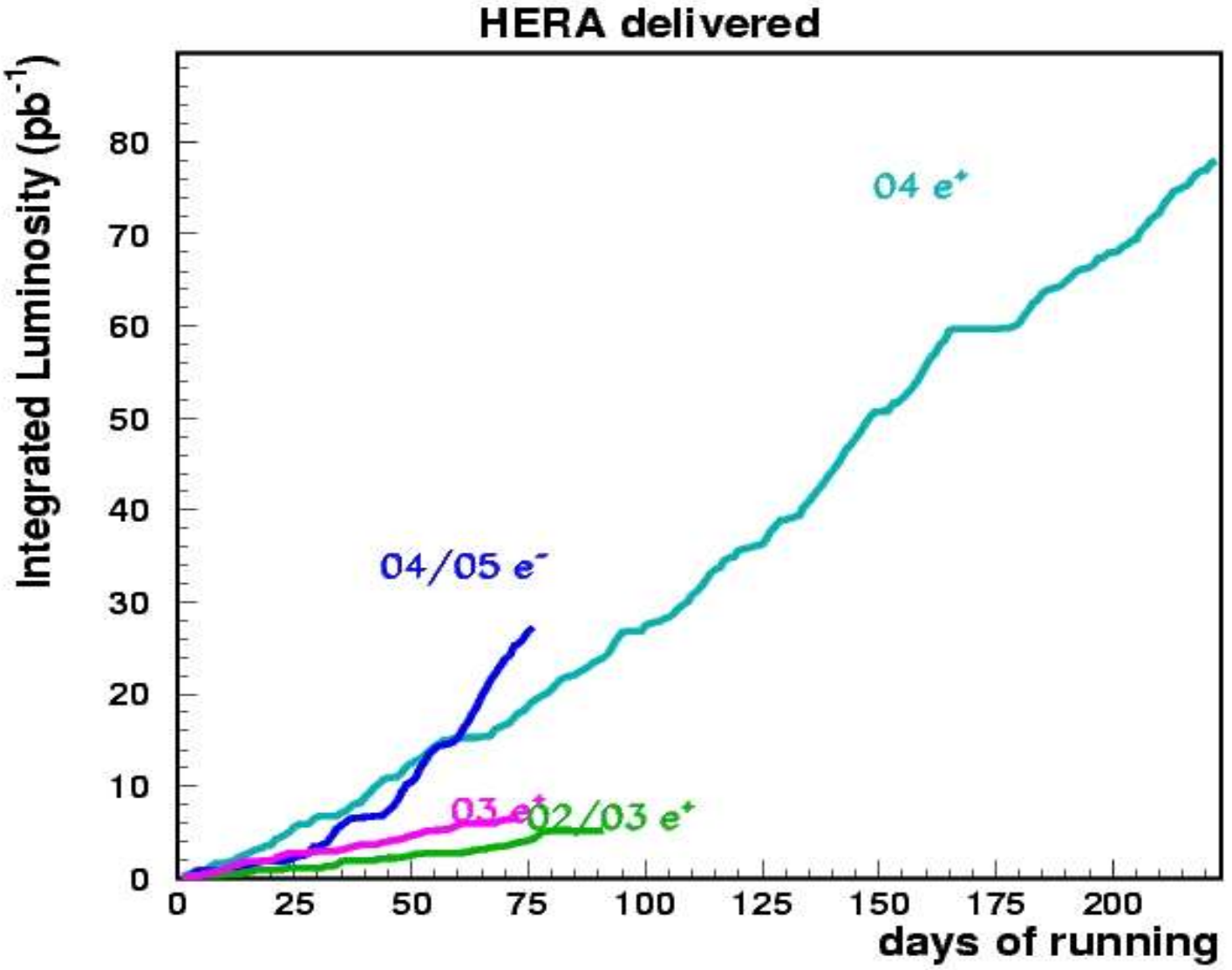


Also H1 (colliding beam), HERMES (polarized e-target) and ex-HERA-B (p-target)

The HERA story so far
ZEUS & H1

- HERA I (1992-2000)
  - 27 GeV e^+ on 820 GeV p 70 pb^{-1} per experiment
  - 27 GeV e^- on 920 GeV p 25 pb^{-1} per experiment
  - 27 GeV e^+ on 920 GeV p 95 pb^{-1} per experiment

HERA II



Polarization around 40%

The future of HERA

- HERA II (2003-2007)
  - Polarized electron (factor 10 in statistics)
  - Precision heavy flavour and high x physics.
  - Scheduled to finish 2007, about 600 pb^{-1} total/expt
  - Petra injector ring given over to synchrotron radiation from then on.

The future of HERA

- HERA III (2007-?)
  - Proposed to measure F_L ,low x, saturation region, deuteron & possible ions.
  - Beats a potential eRHIC proposal in most ways (and by ~ten years).
  - Statement of Interest; continuation of H1, new small, purpose-built replacement for ZEUS.
  - Not in current DESY planning (see Petra).

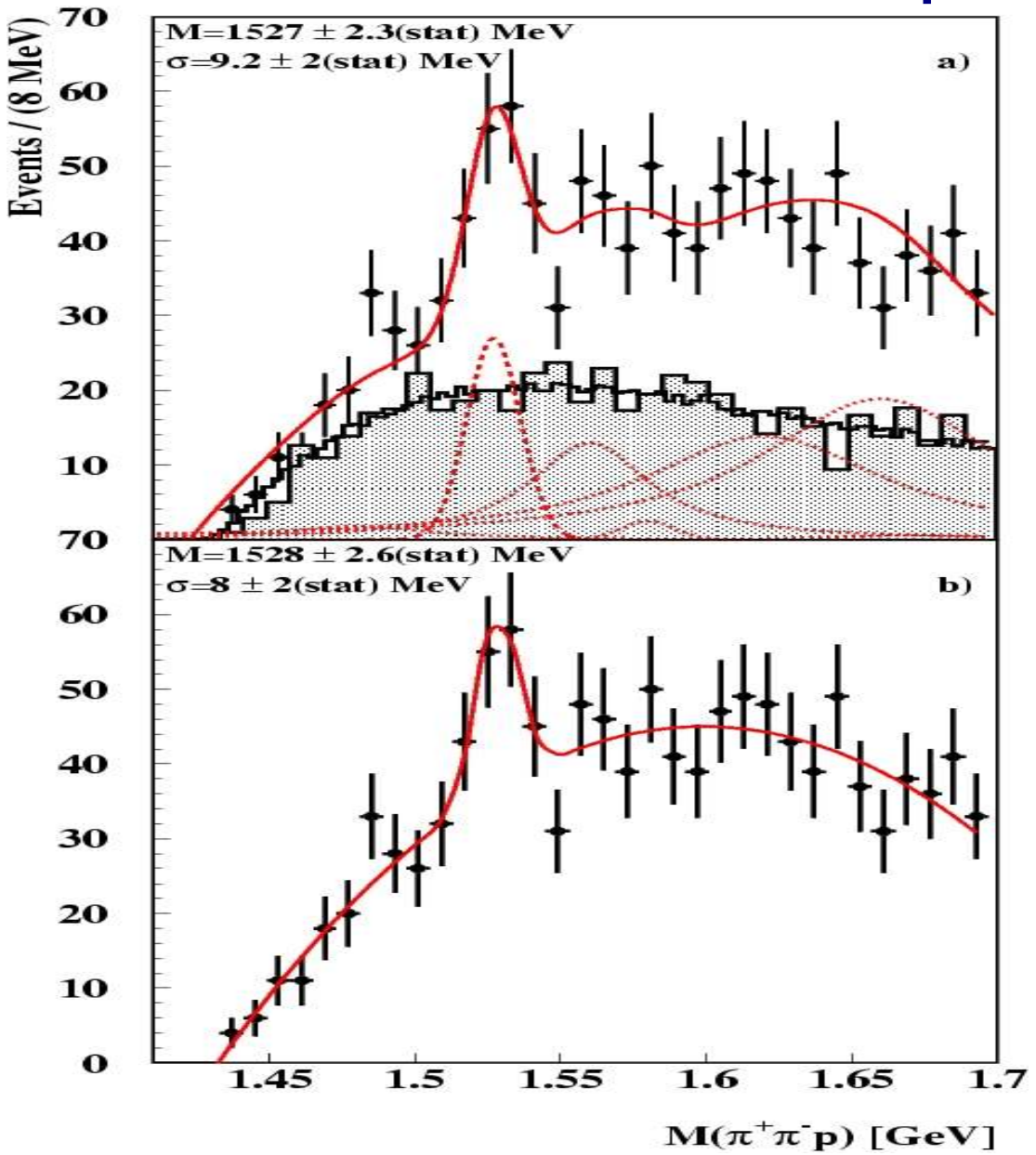
Some recent highlights

- Pentaquarkery
- Polarization
- Heavy Flavours
- Jet physics and parton distributions - next section.

Pentaquarks (?)

- θ^+ Recently observed in nK^+
  - Manifestly exotic (baryon with an anti-strange quark) *[LEPS, Saphir, CLAS – fixed target, low energy photoproduction]*
  - Narrow peak, around 1535 MeV (predicted by soliton model, Diakonov et al)
  - If it is a pentaquark it should also decay to pK^0
- Observed by HERMES and ZEUS at HERA
  - ZEUS is first observation in fragmentation. Also see antipentaquark.

Pentaquarks (?)

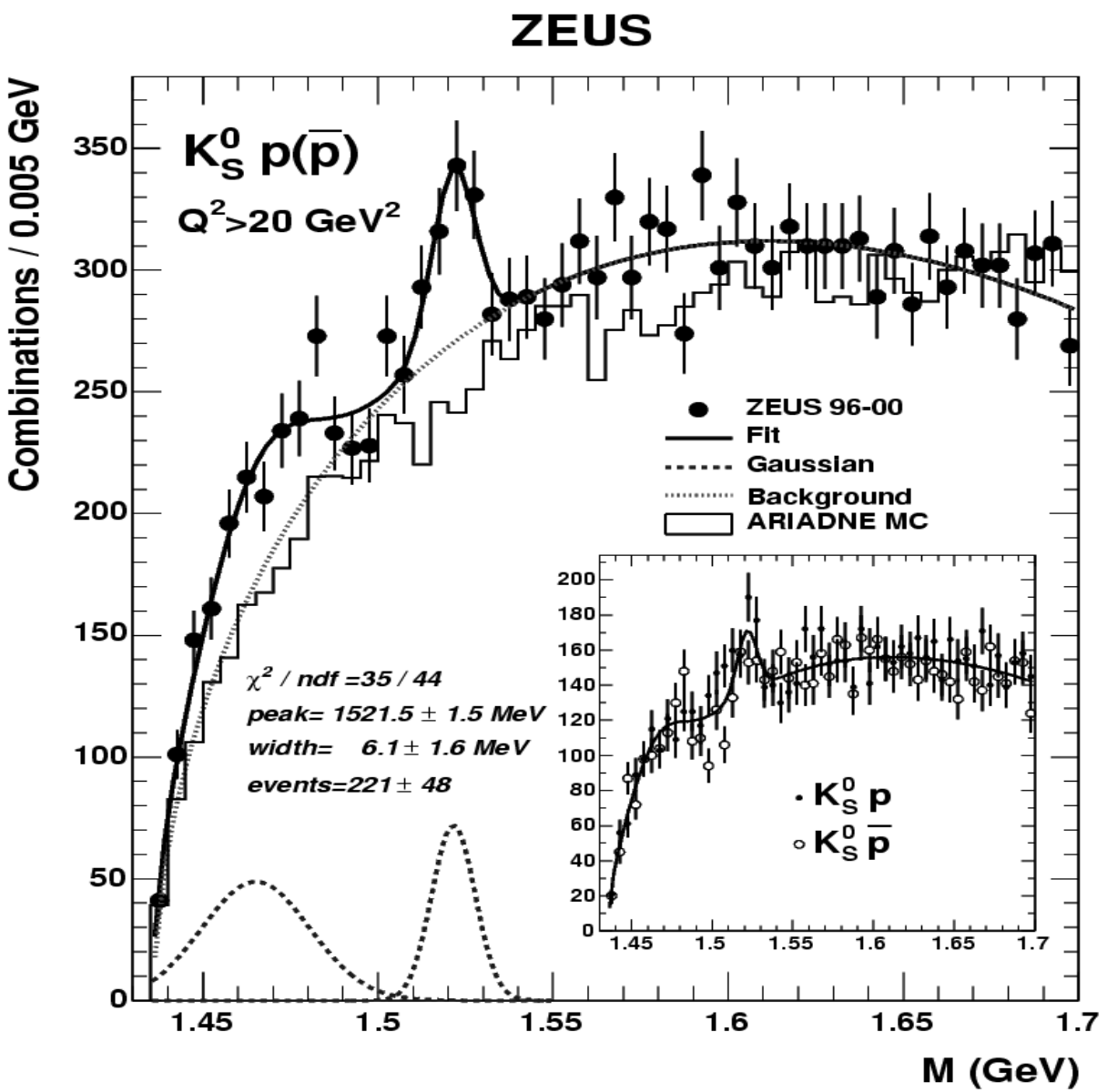


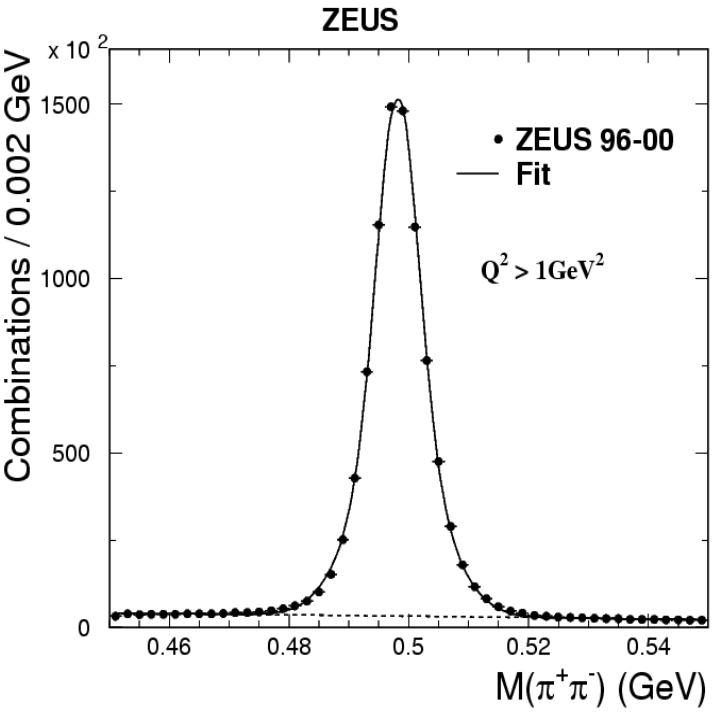
Negative results from LEP & Tevatron. Positive results from ITEP, DIANA, Spring-* (as well as CLAS, LEPS, SAPHIR, ZEUS & H1...)

No statement from H1

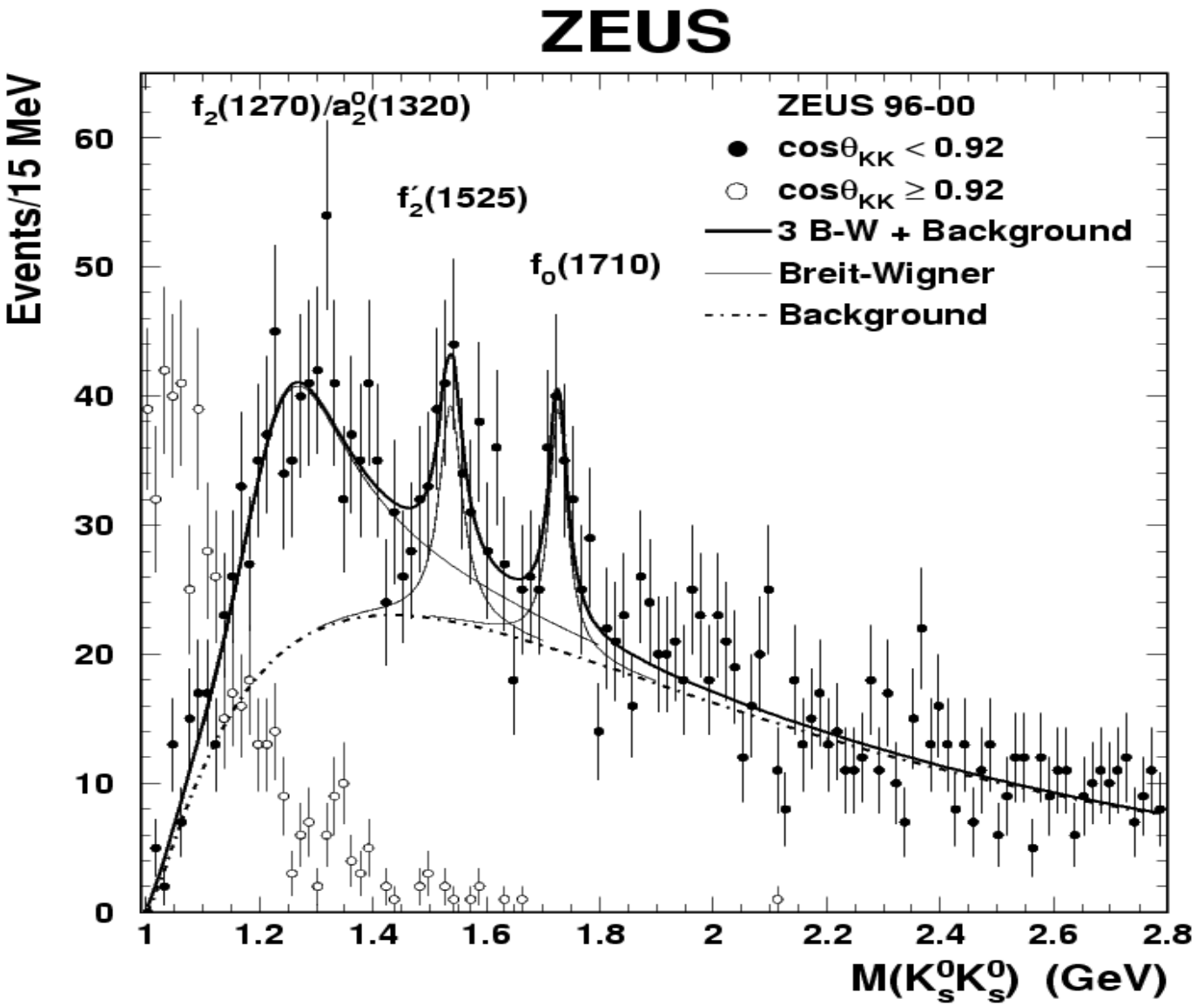
HERA II and H1 data essential to settle the issue.

Pentaquarks (?)





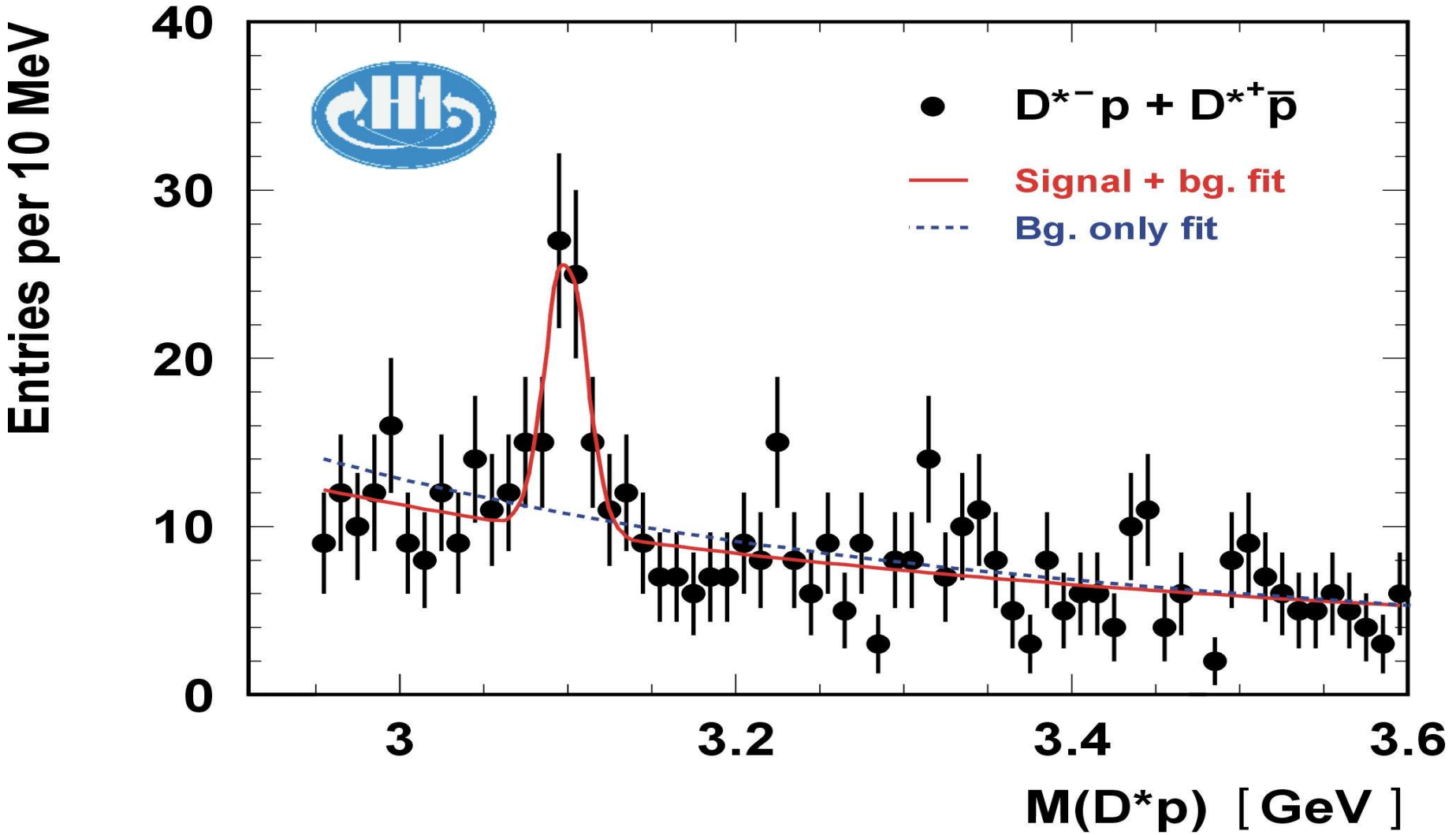
An aside - glueballs (?)



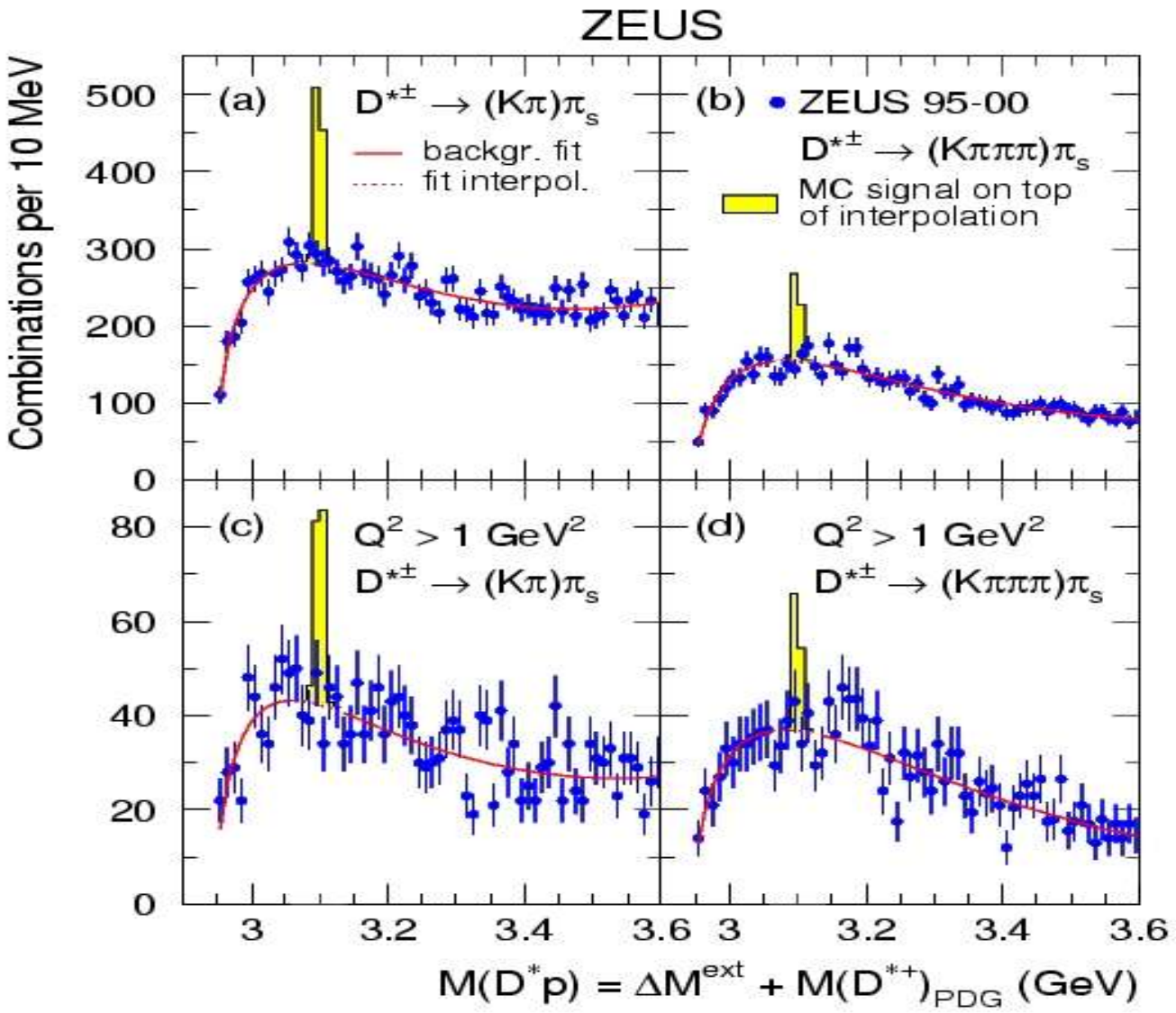
Strange Pentaquark Summary

- Seen by some, not by others.
  - Look in H1, and new ZEUS data.
  - Problems/excuses....
  - Not obvious the Kp state is the same as the Kn
  - Await new CLAS data.

Charm Pentaquarks (?)

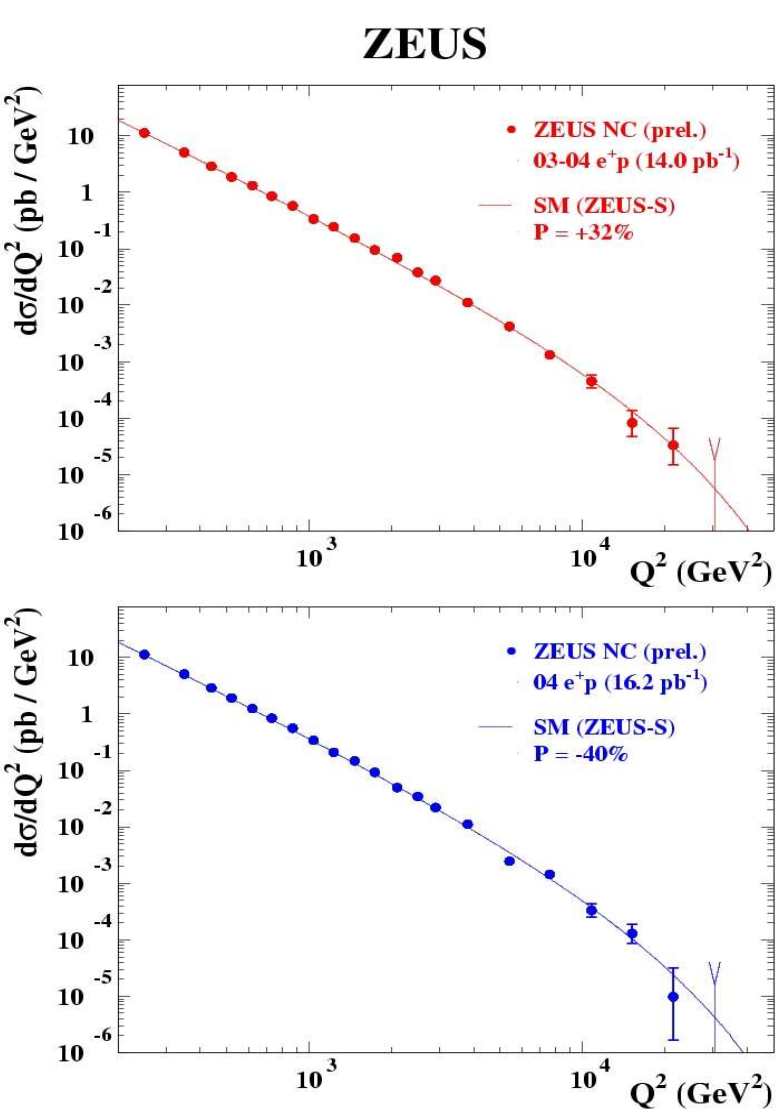


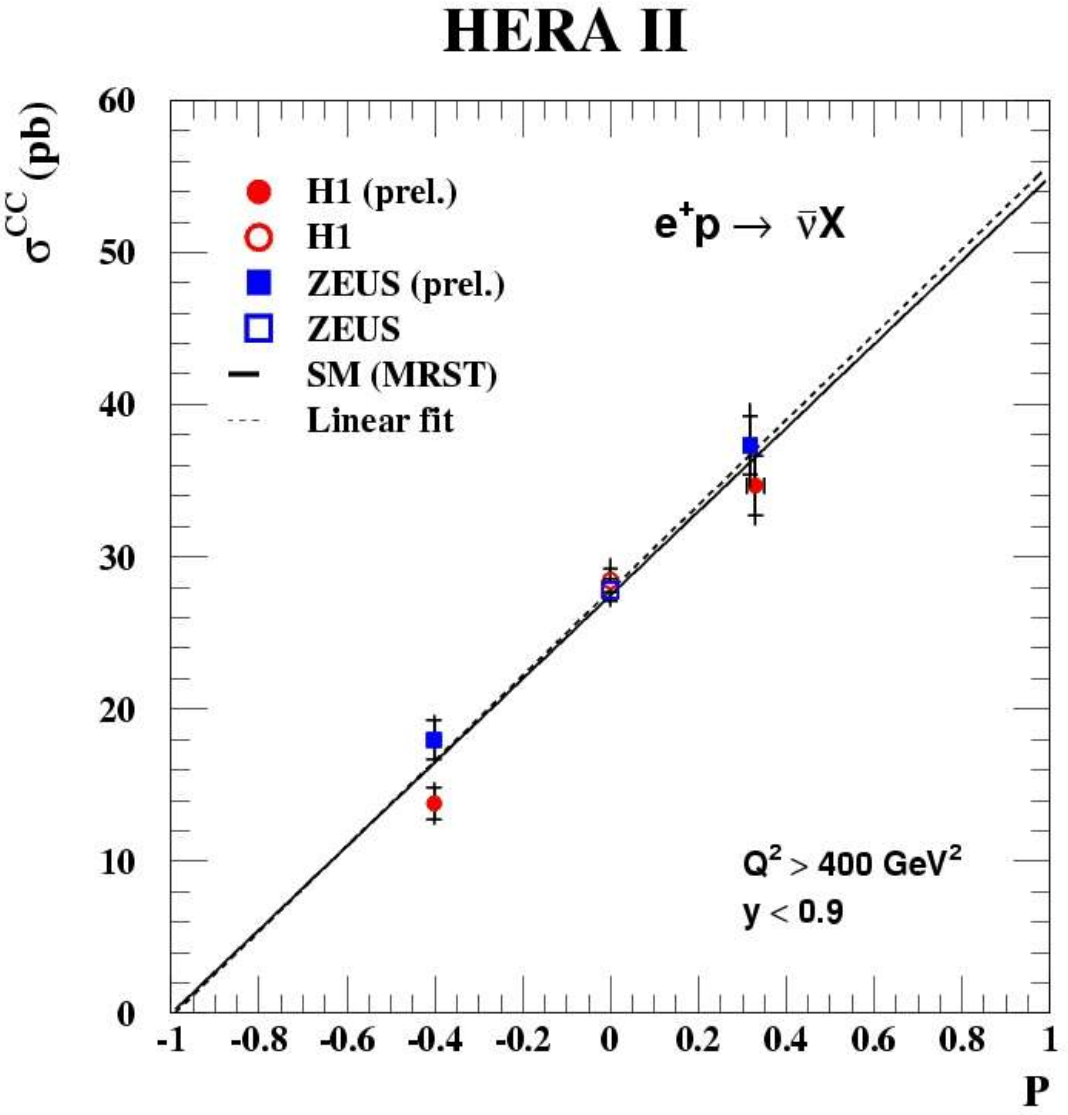
Charm Pentaquarks (?)



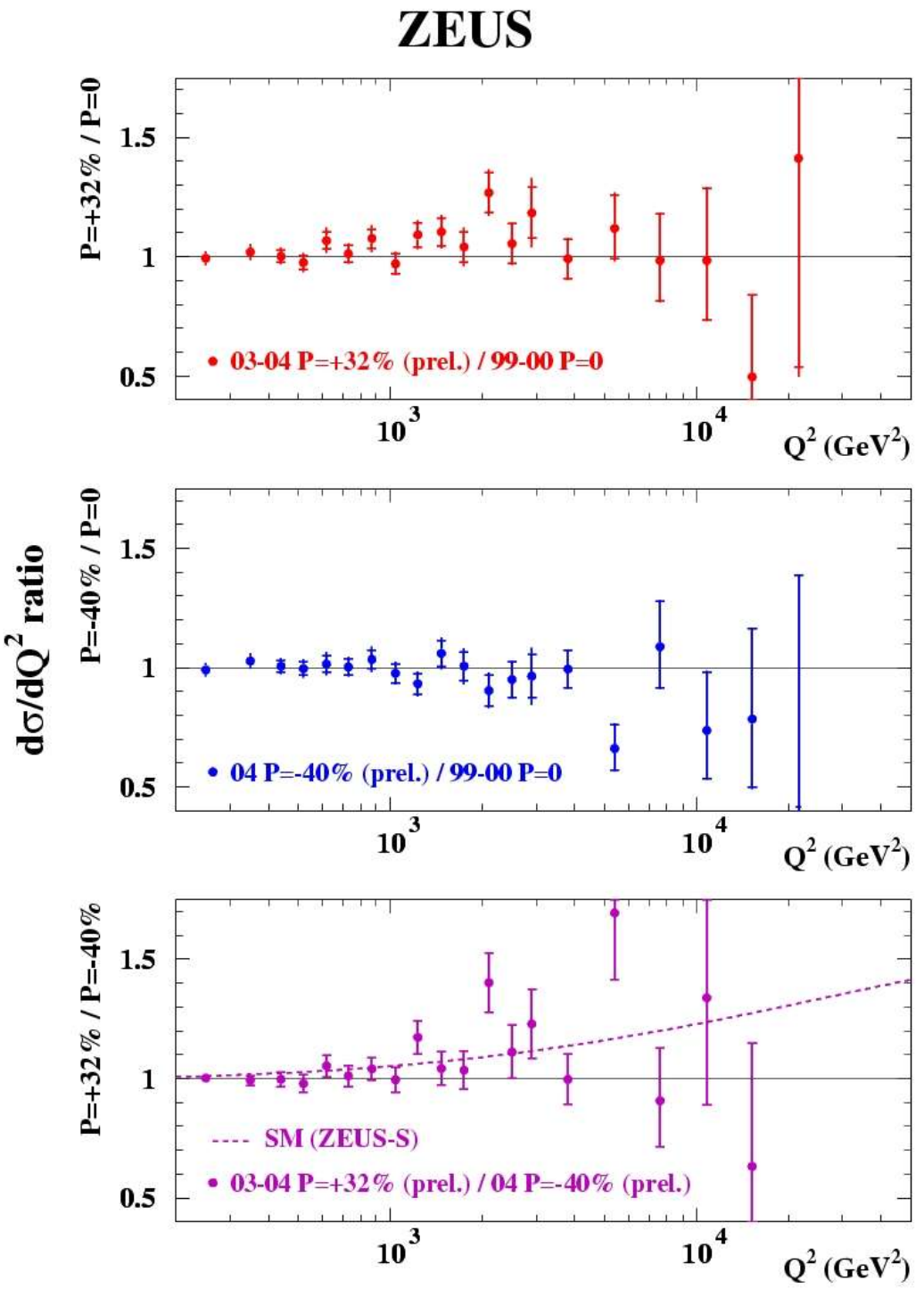
Also negative results from LEP and Tevatron...

Polarized Charged Current Cross Section





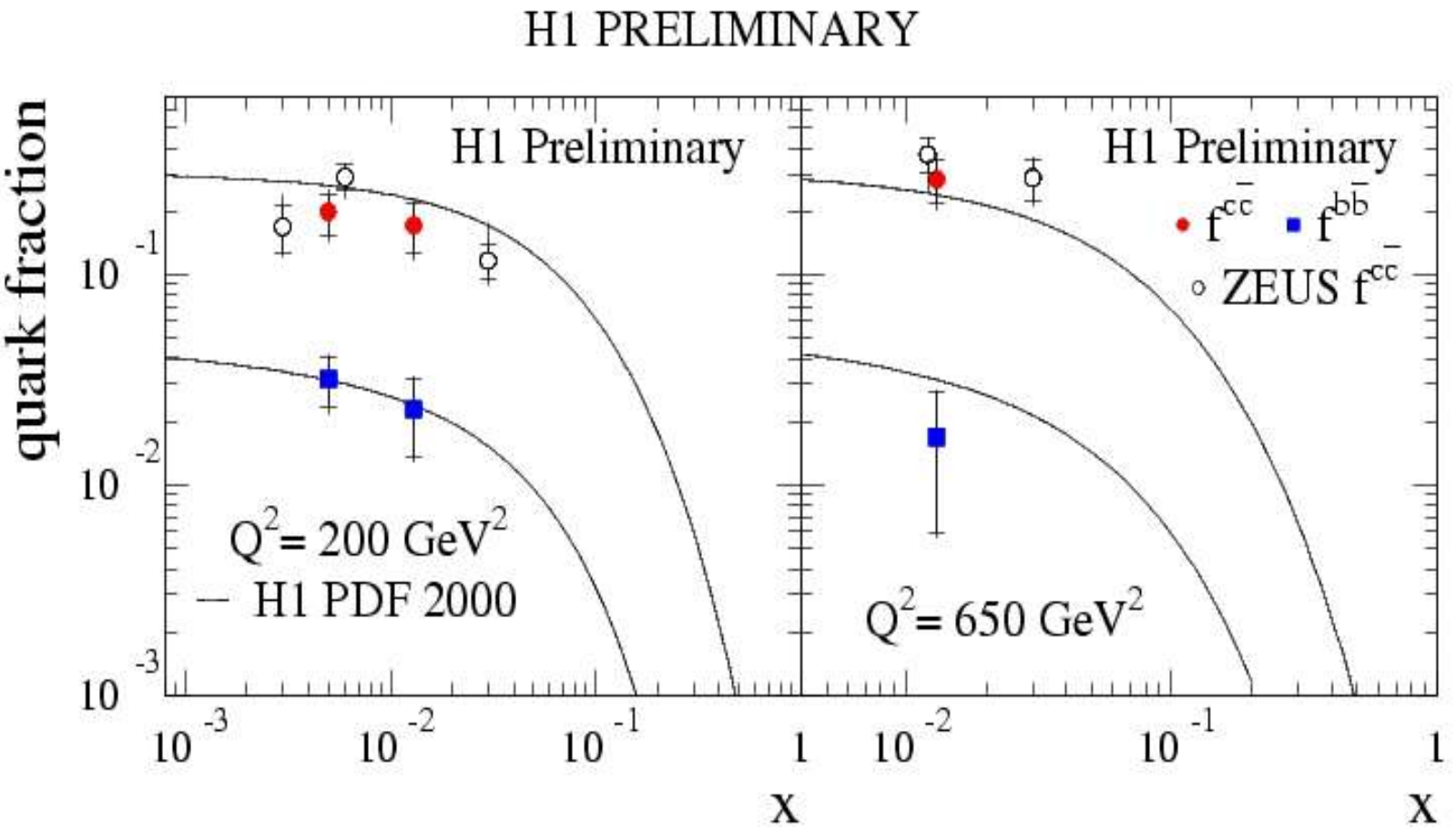
Polarized Neutral Current Cross Section



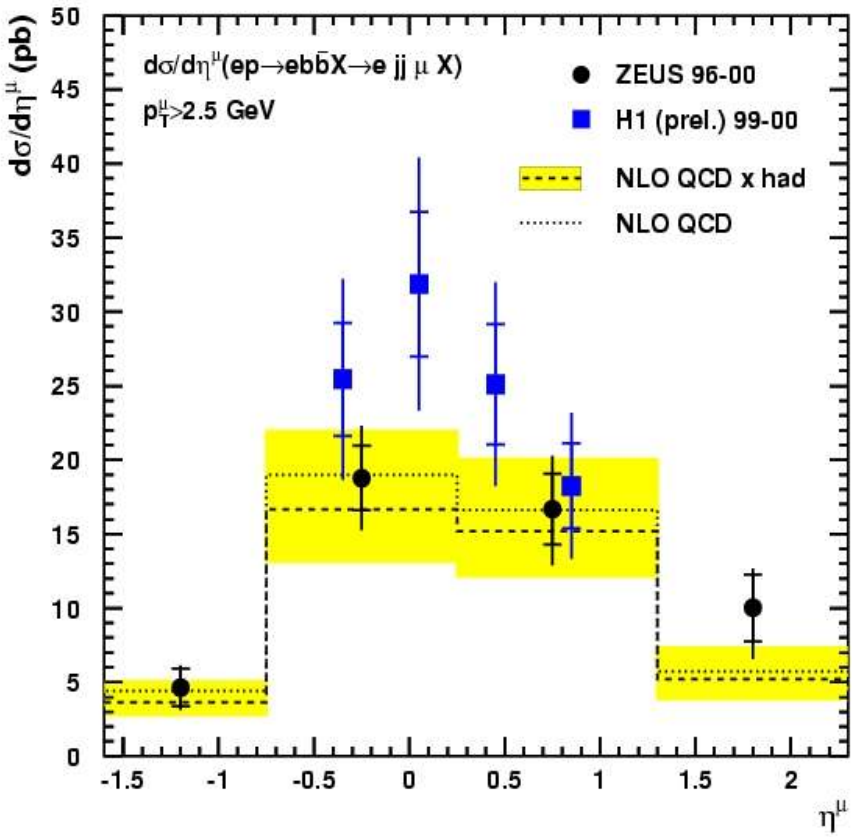
Charm and Beauty Production

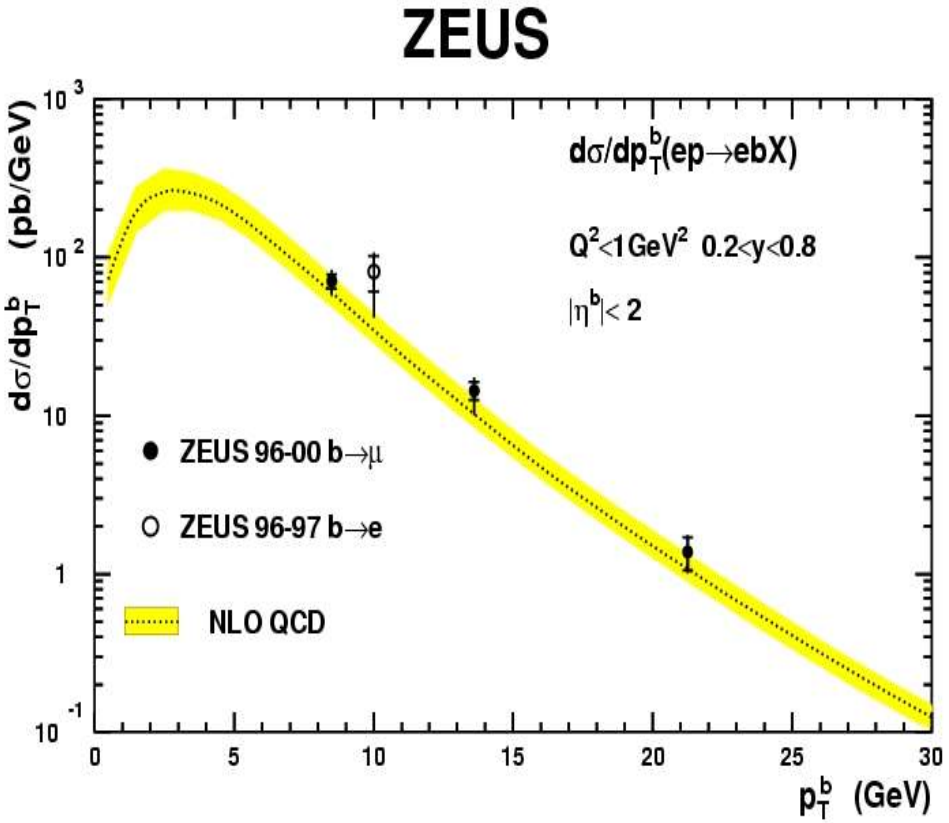
- How are heavy flavours produced in hadronic collisions?
  - Challenging multiscale problem in QCD (Transverse energy, Quark mass, Photon Virtuality).
  - Obviously important to understand these processes for LHC (b-tagging for searches)...

Charm & Beauty Production (DIS)



Beauty Photoproduction





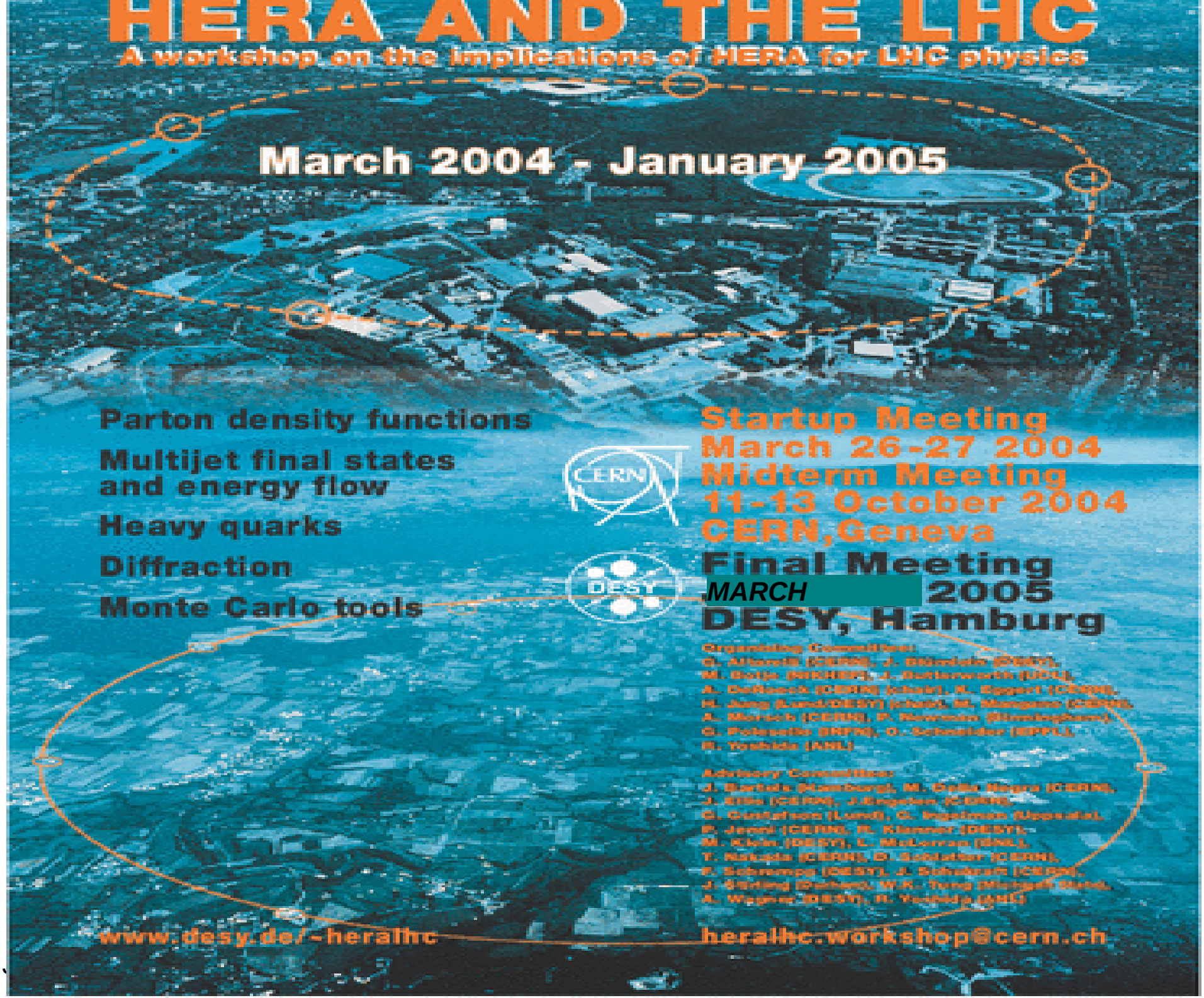
Impact of HERA at the LHC

Studying QCD is interesting now and vital for the future of high energy physics, particularly the LHC.

HERA is a precision QCD machine, as well as a QCD "discovery" machine. Data from HERA are needed to fully exploit the LHC.

HERA AND THE LHC

A workshop on the implications of HERA for LHC physics



March 2004 - January 2005

Parton density functions

Multijet final states and energy flow

Heavy quarks

Diffraction

Monte Carlo tools

Startup Meeting
March 26-27 2004
Midterm Meeting
11-13 October 2004
CERN, Geneva
Final Meeting
MARCH **2005**
DESY, Hamburg

Organising Committee:
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M. Botje [NIKHEF], J. Butterworth [UCL],
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Areas of Impact

- Precision measurement of QCD inputs
  - α_s : from jet rates, jet substructure, event shapes, PDF fits, fragmentation fits...
  - Parton distributions from structure functions, jets and charm.
  - Fragmentation parameters: strange, charm, beauty, leading particles.

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  - Parton distributions from structure functions, jets and charm.
  - Fragmentation parameters: strange, charm, beauty, leading particles.
- Testing ground for non- or semi-perturbative models
  - Underlying events; minijets, multiparton interactions, saturation
  - Soft underlying events, rescattering, forward neutrons & protons.
  - Diffractive structure functions, gaps between jets, survival probability.

Areas of Impact

- Testing ground for calculational techniques
  - Very forward jets, low x.
  - Multijets, matrix element/parton showers.
  - Evaluation of theoretical uncertainties.
  - Beauty & charm production cross sections and dynamics.
  - DIS/photoproduction transition; multiscale QCD
  - “Intrinsic” transverse momentum, k_T factorization

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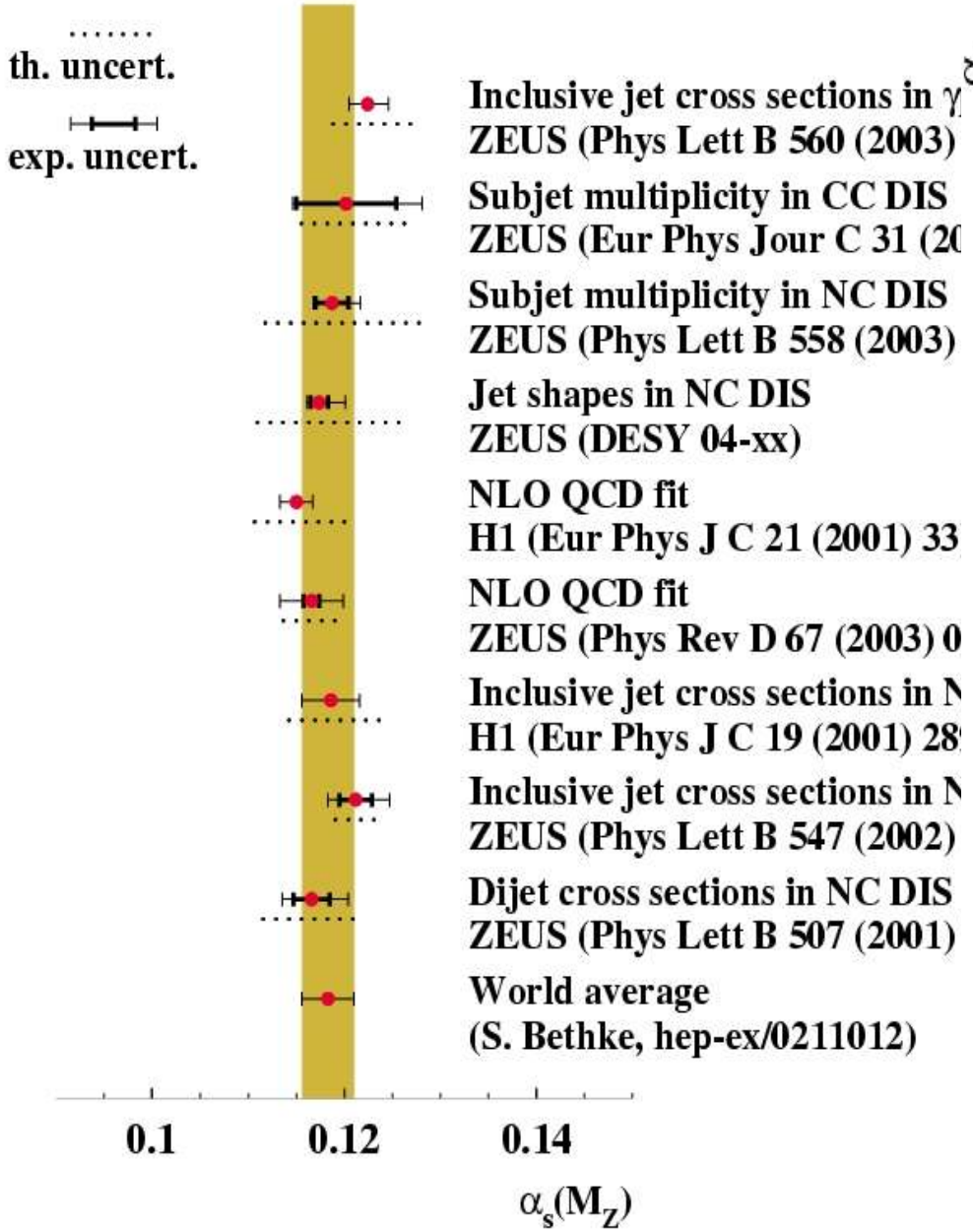
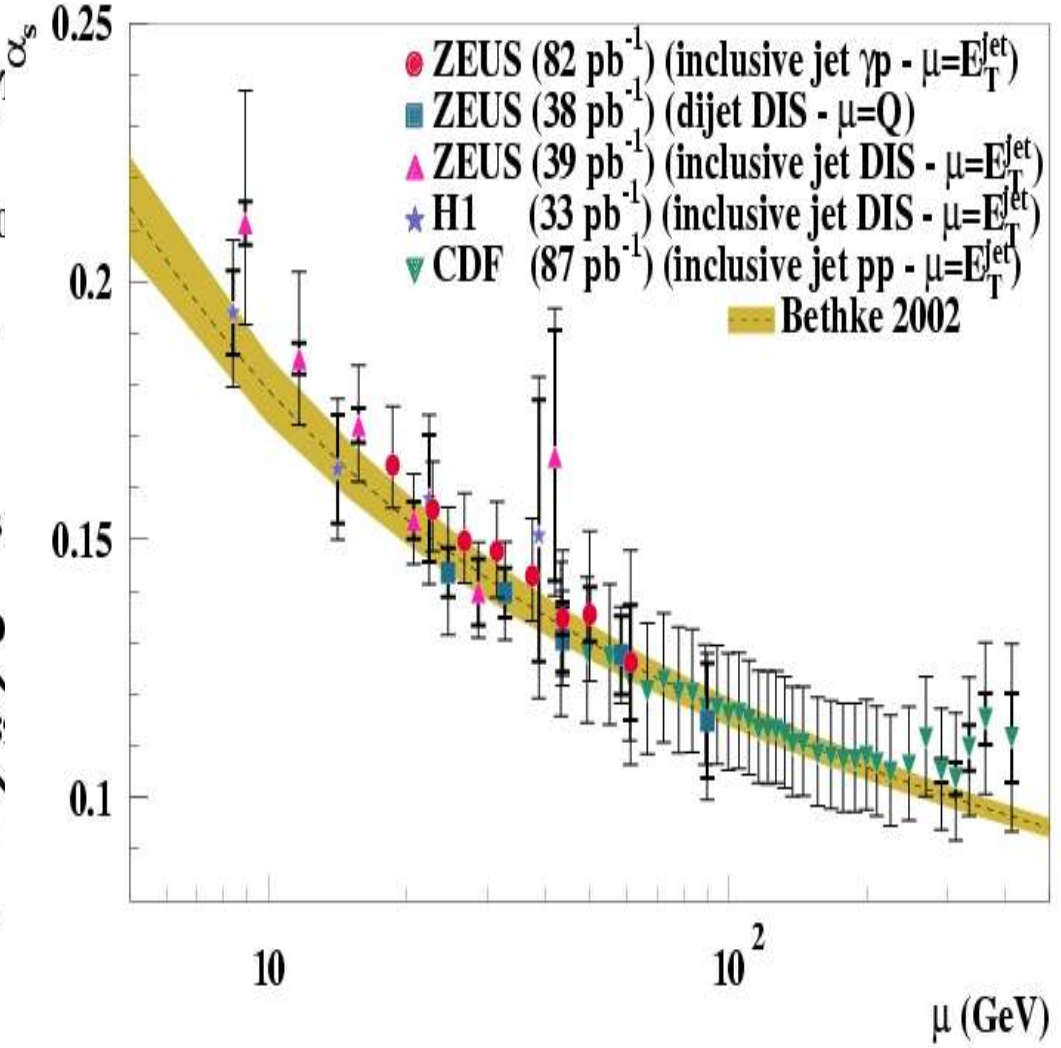
Gain a *quantitative* understanding of hadronic production mechanisms at high energies.

... a few examples.

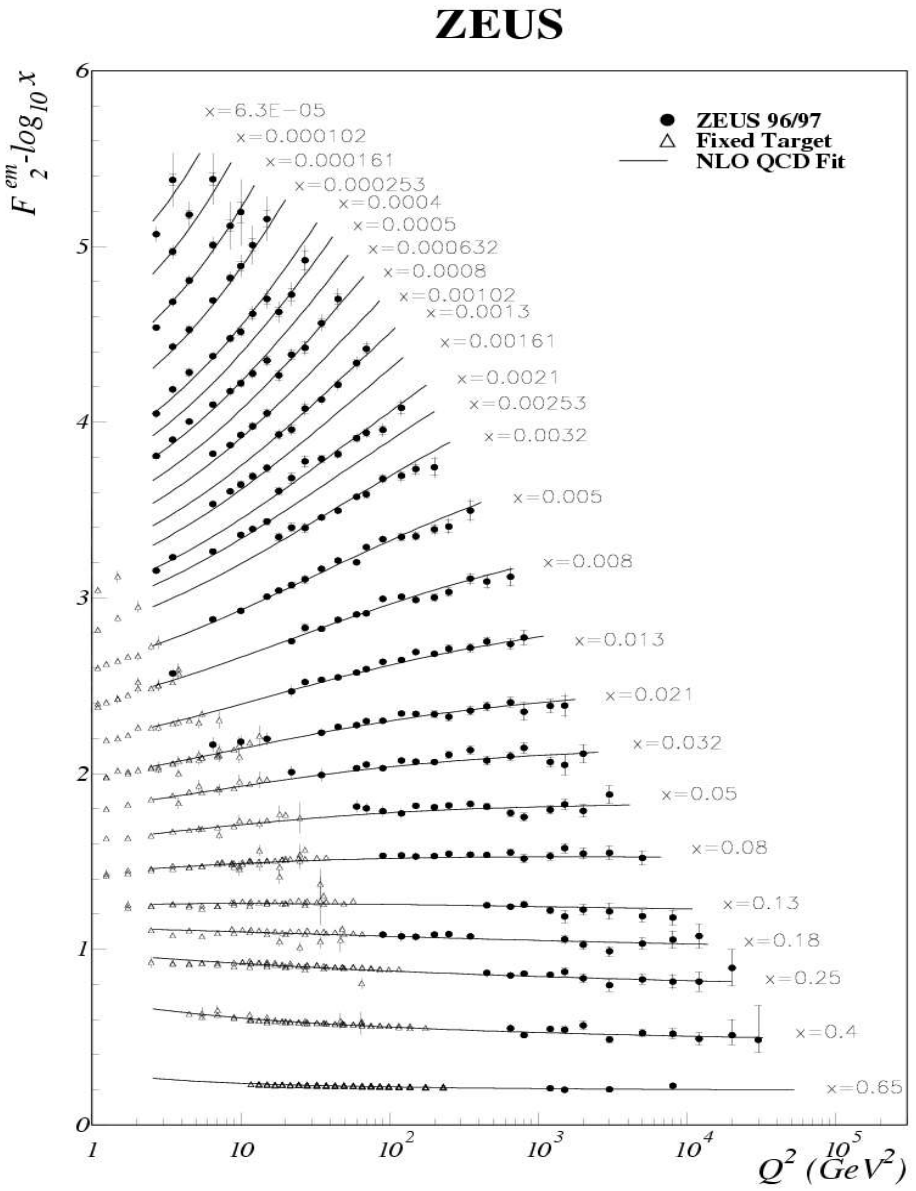




Precision jet physics in a hadronic environment

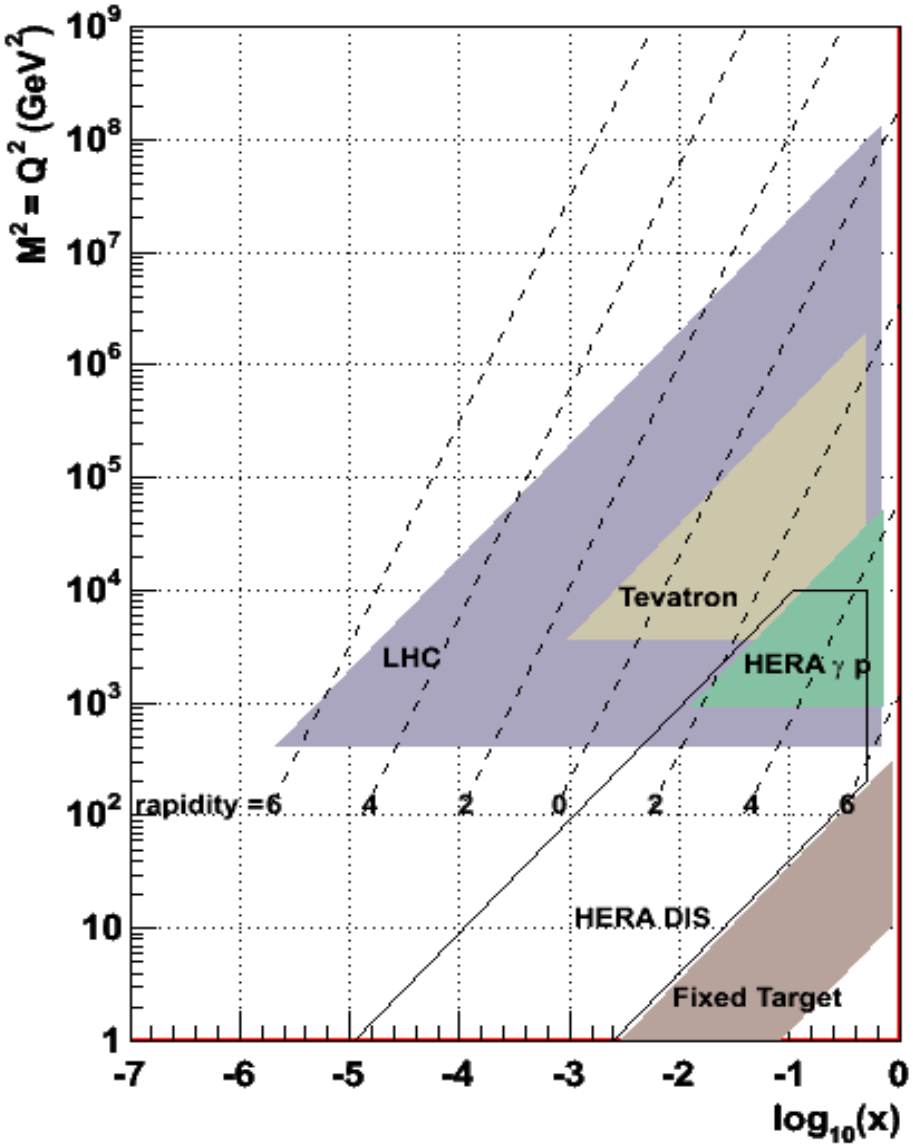
Parton Distributions in Proton

- HERA data drives the global fits.



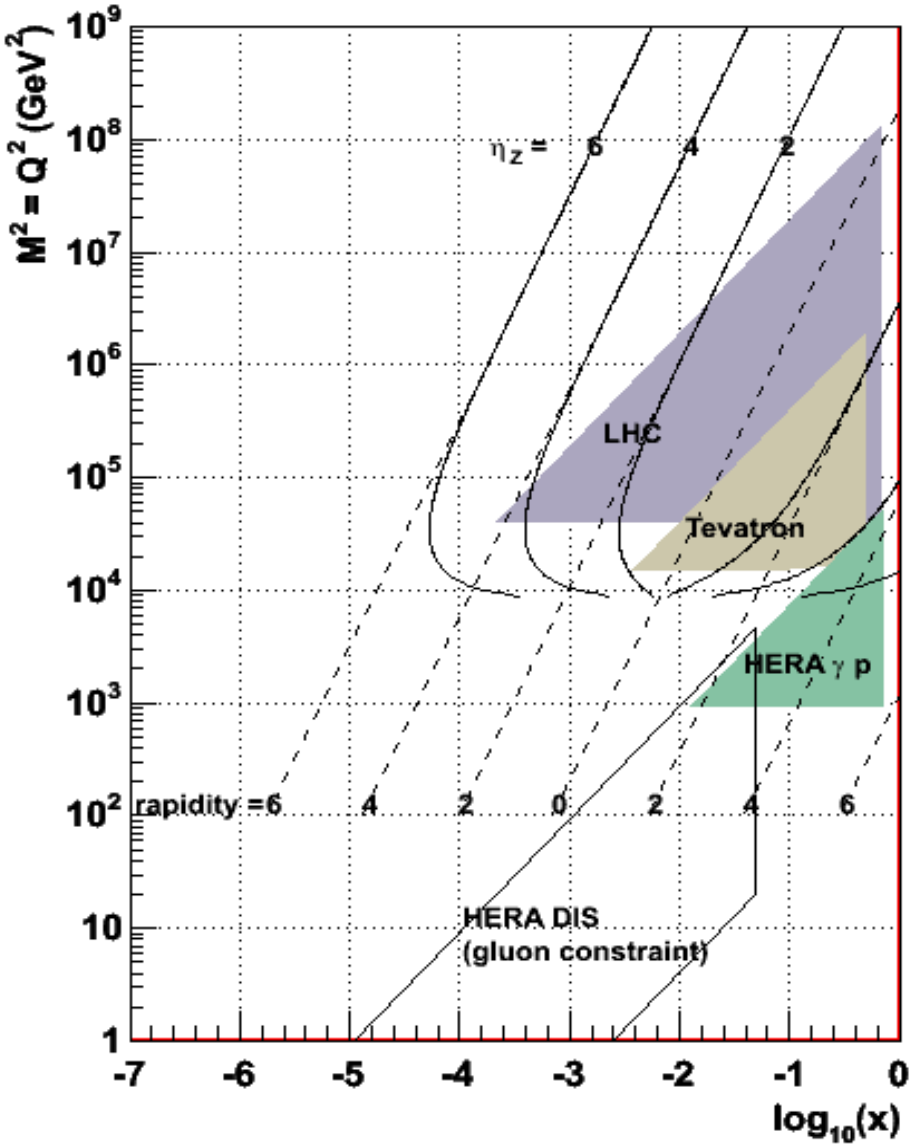
Parton Distributions in Proton

- Small overlap with LHC region
- Use DGLAP to evolve up in Q^2



Parton Distributions in Proton

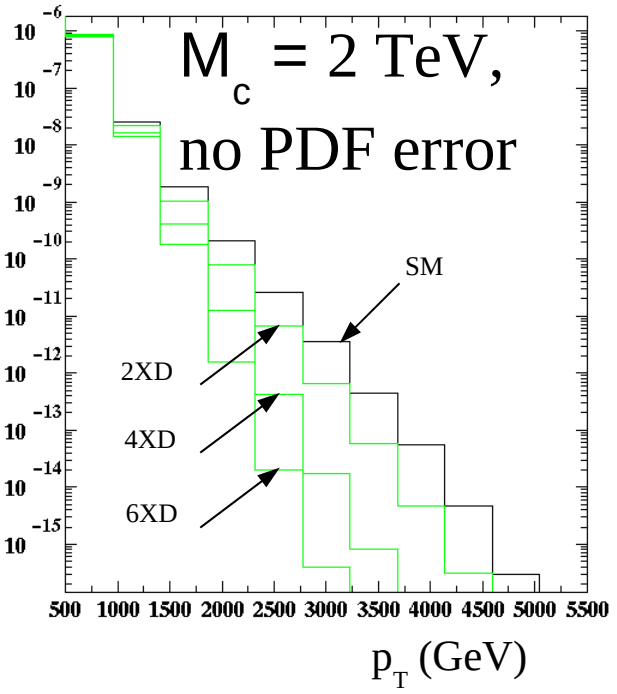
- Small overlap with LHC region
- Use DGLAP to evolve up in Q^2
- LHC will be able to measure parton luminosities using W, Z production
- Cannot do high x at intermediate Q^2.
- Badly need high x information from elsewhere.

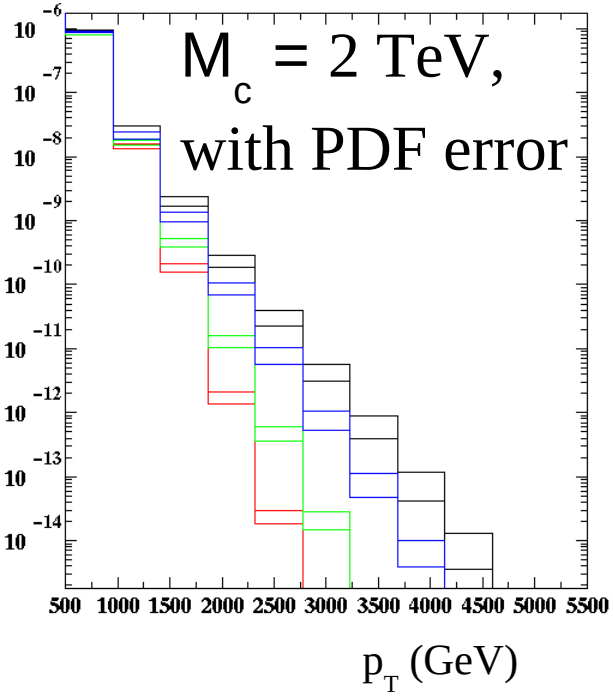


PDFs versus new physics...

- Example: Absolute level and shape of cross sections approaching kinematic limit (new physics or just PDFs?)

Ferrag et al: Dijet cross section potential sensitivity to compactification scale of extra dimensions (M_c) reduced from ~5 TeV to 2 TeV.





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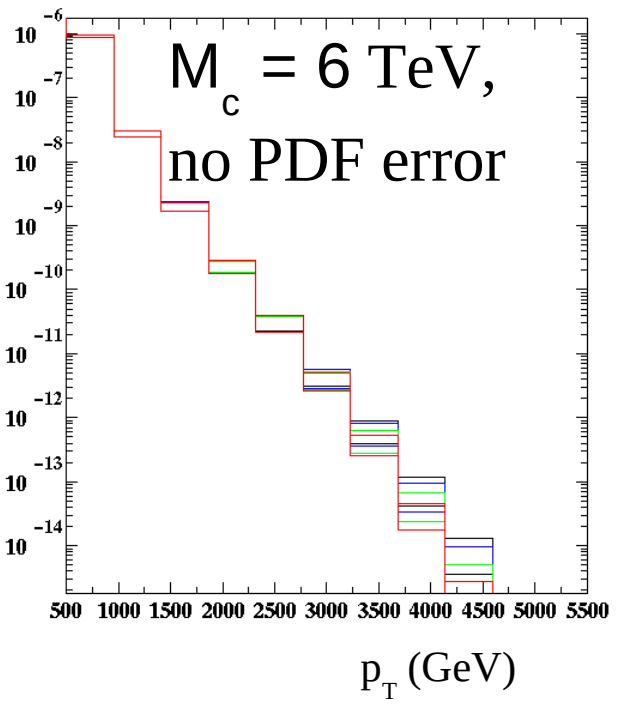

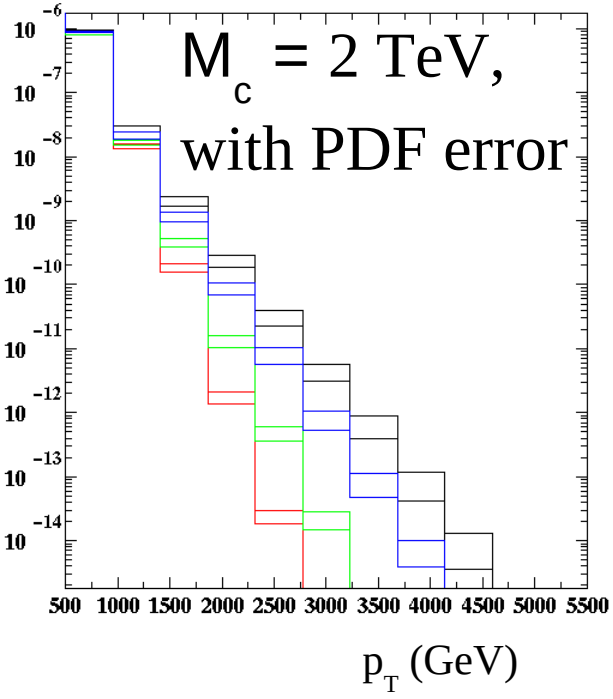

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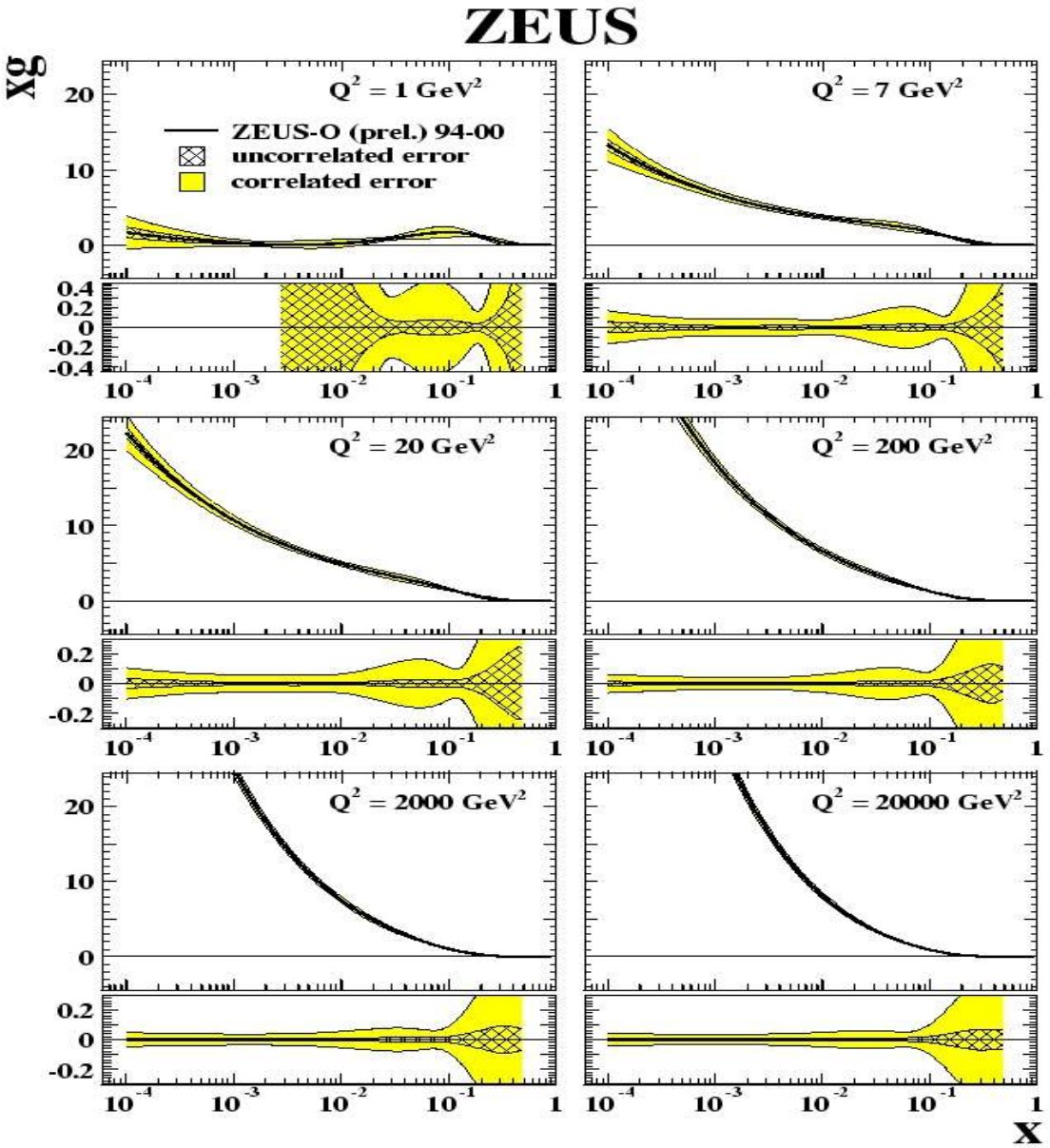
- Dominant uncertainty in production rates for many processes at LHC.



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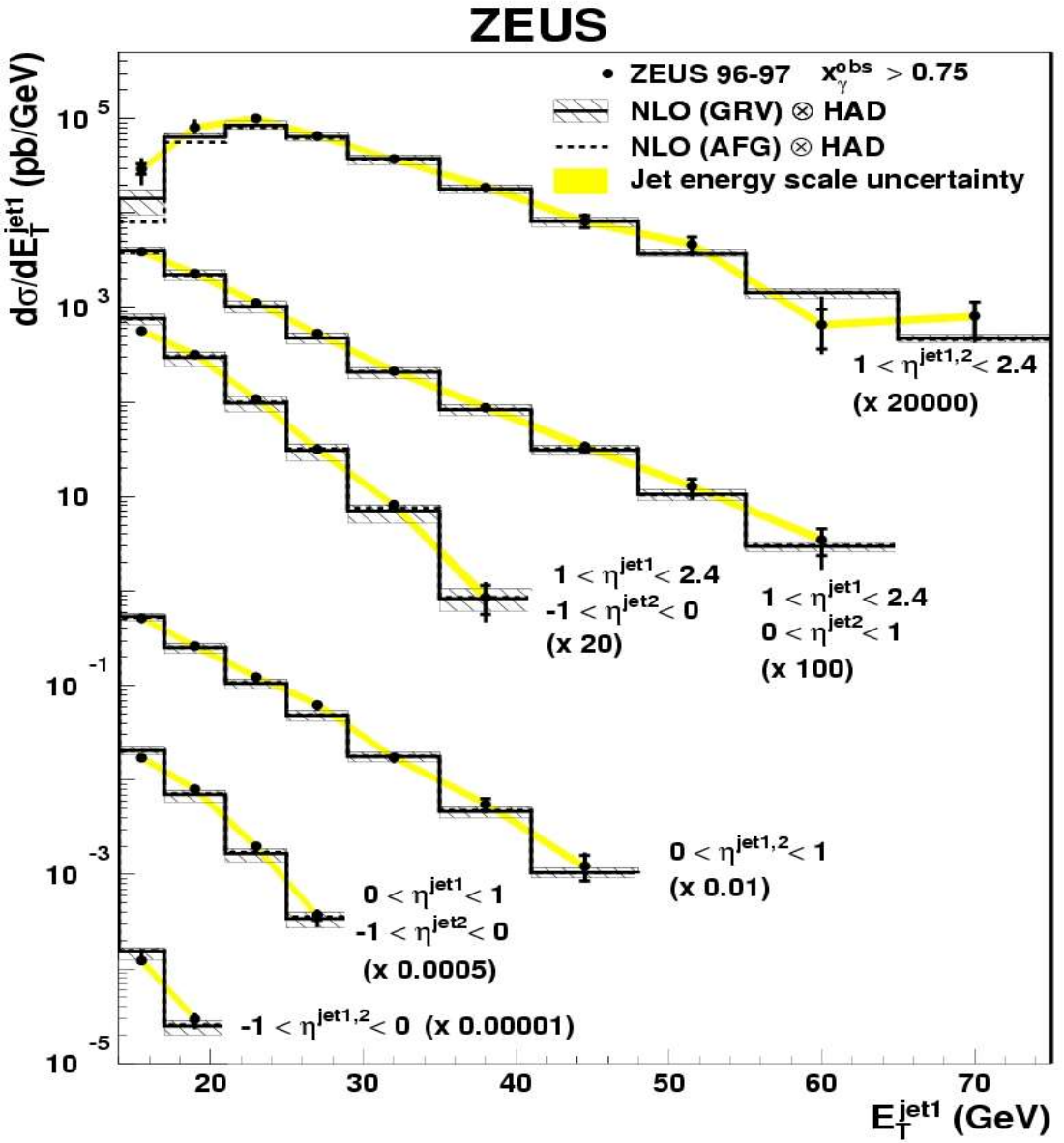

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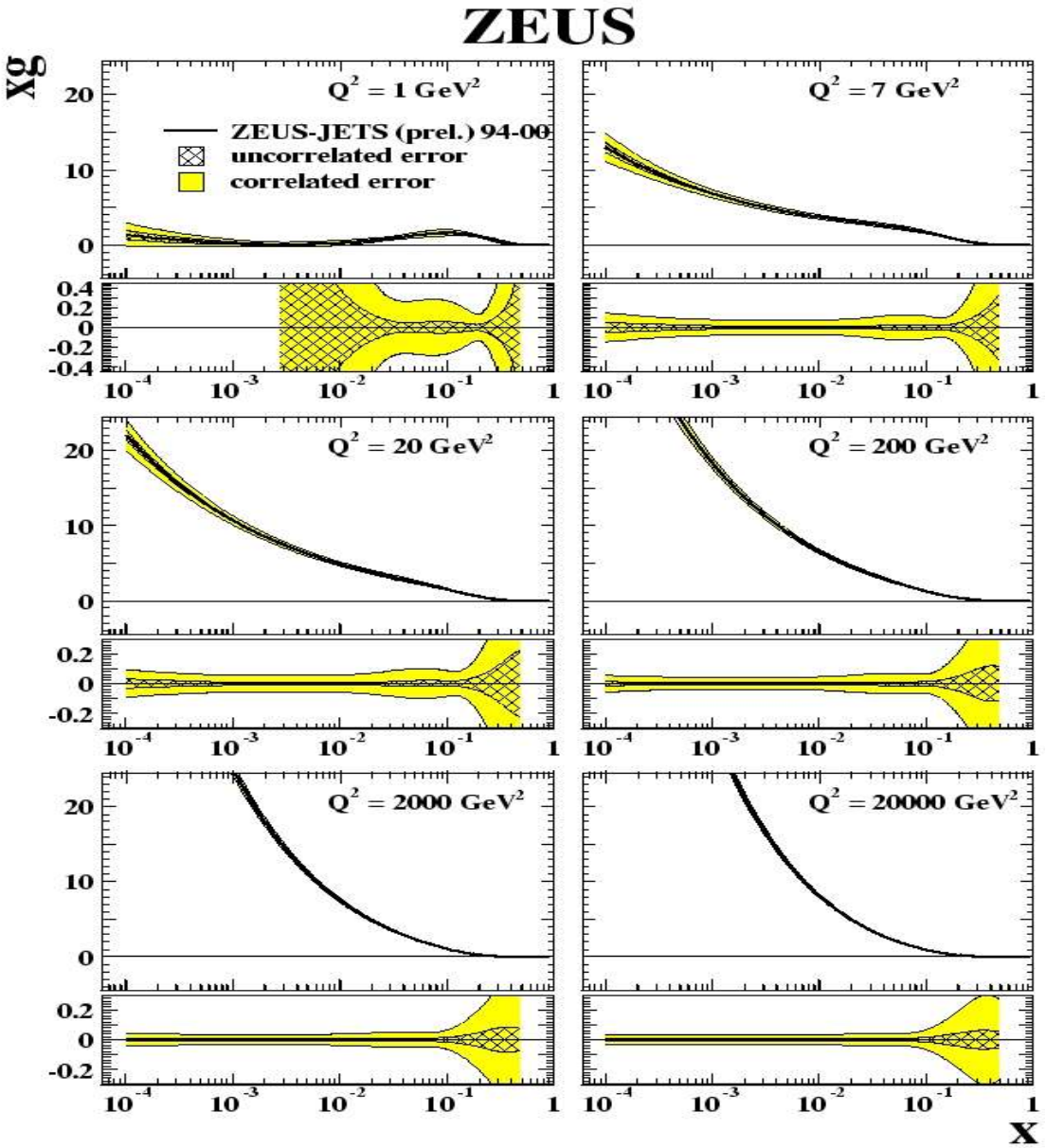

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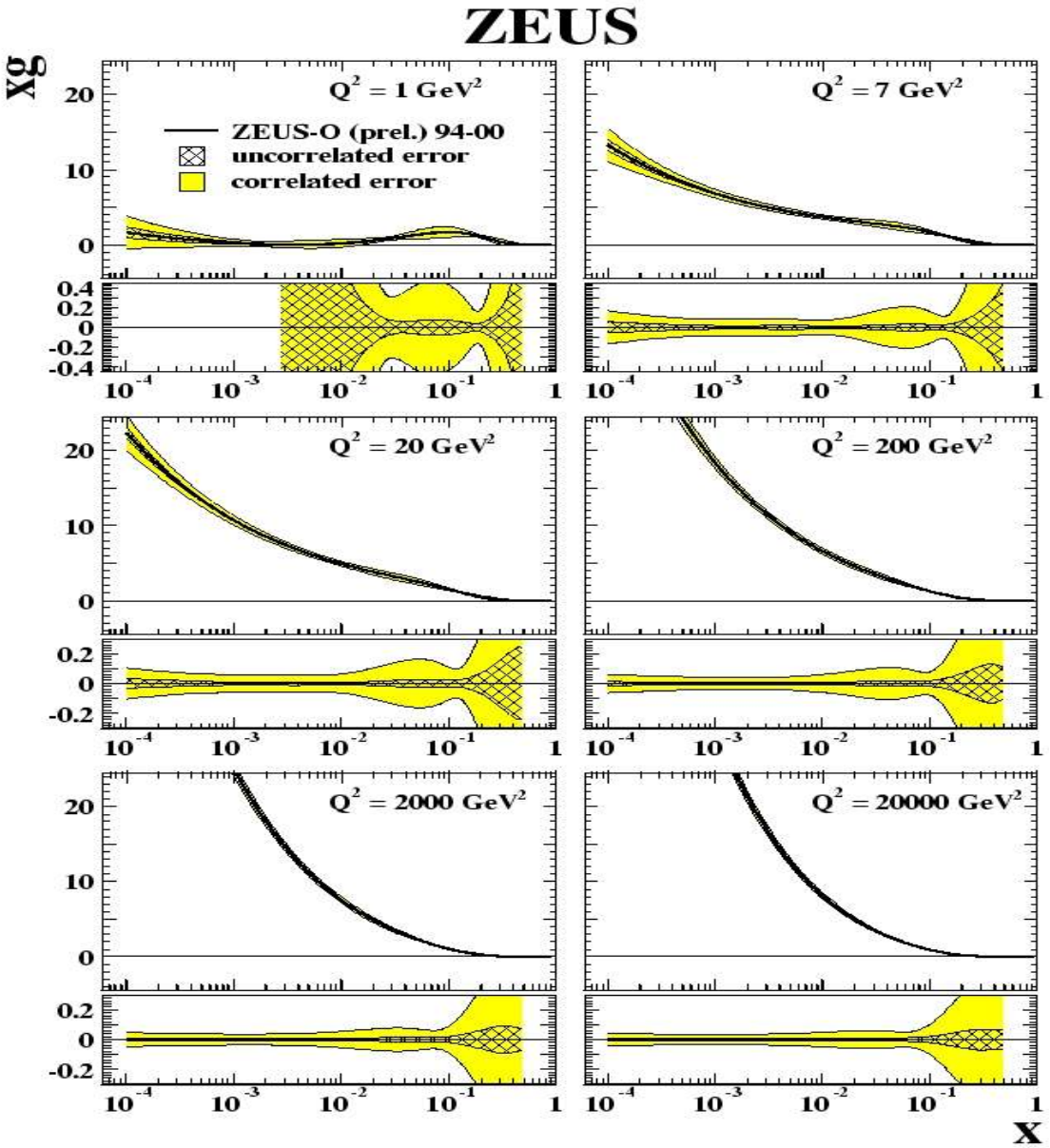

Parton Distributions in Proton

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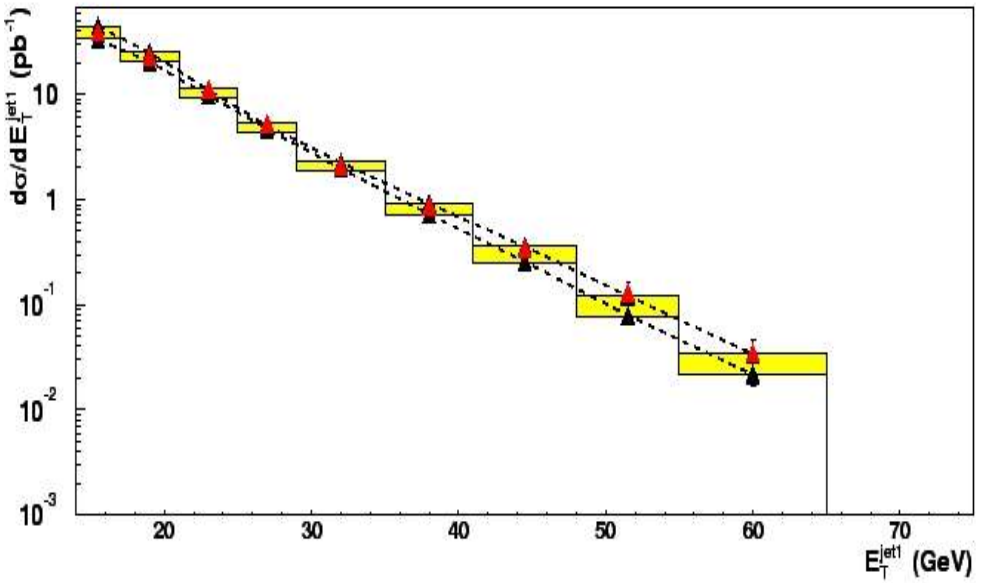
- Statistically limited at high E_T = high x
- Cross sections not optimised for sensitivity to high x gluon.
- Can do much better with the rest of HERA I + HERA II

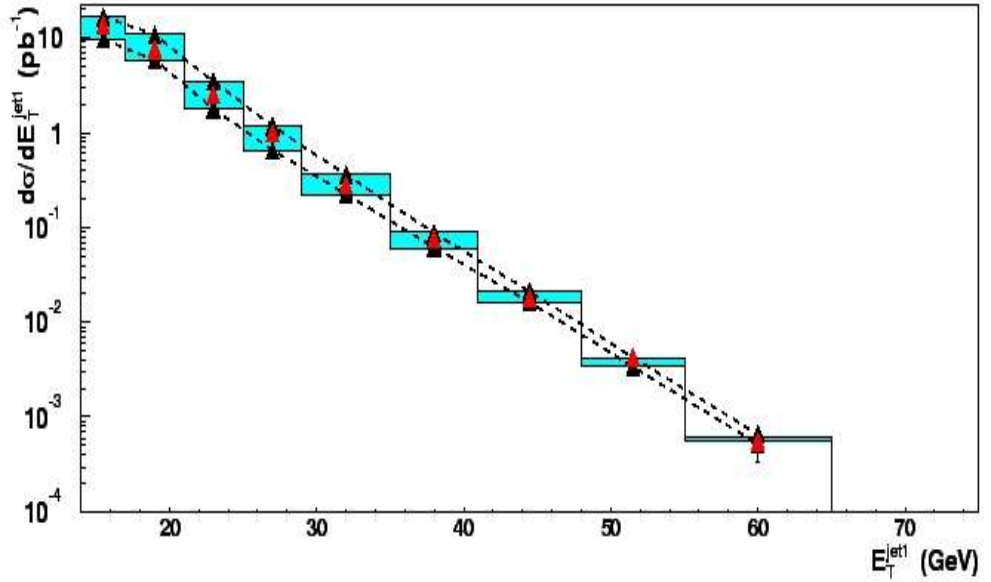


$E_T^{jet1}>14$GeV , $E_T^{jet2}>11$GeV

$x_\gamma>0.75$, $1<\eta^{jet1}<2.4$, $0<\eta^{jet2}<1$

Published

All flavors up/down error
ZEUS gluon up/down error
Data+stat+syst errors
Data+energy scale uncertainity



$E_T^{jet1}>15$GeV , $E_T^{jet2}>10$GeV

$x_\gamma<0.75$, $2<\eta^{jet1}<3$, $2<\eta^{jet2}<3$

Optimised

All flavors up/down error
ZEUS gluon up/down error
Data+stat+syst errors (est)
Data+energy scale uncertainity (est)

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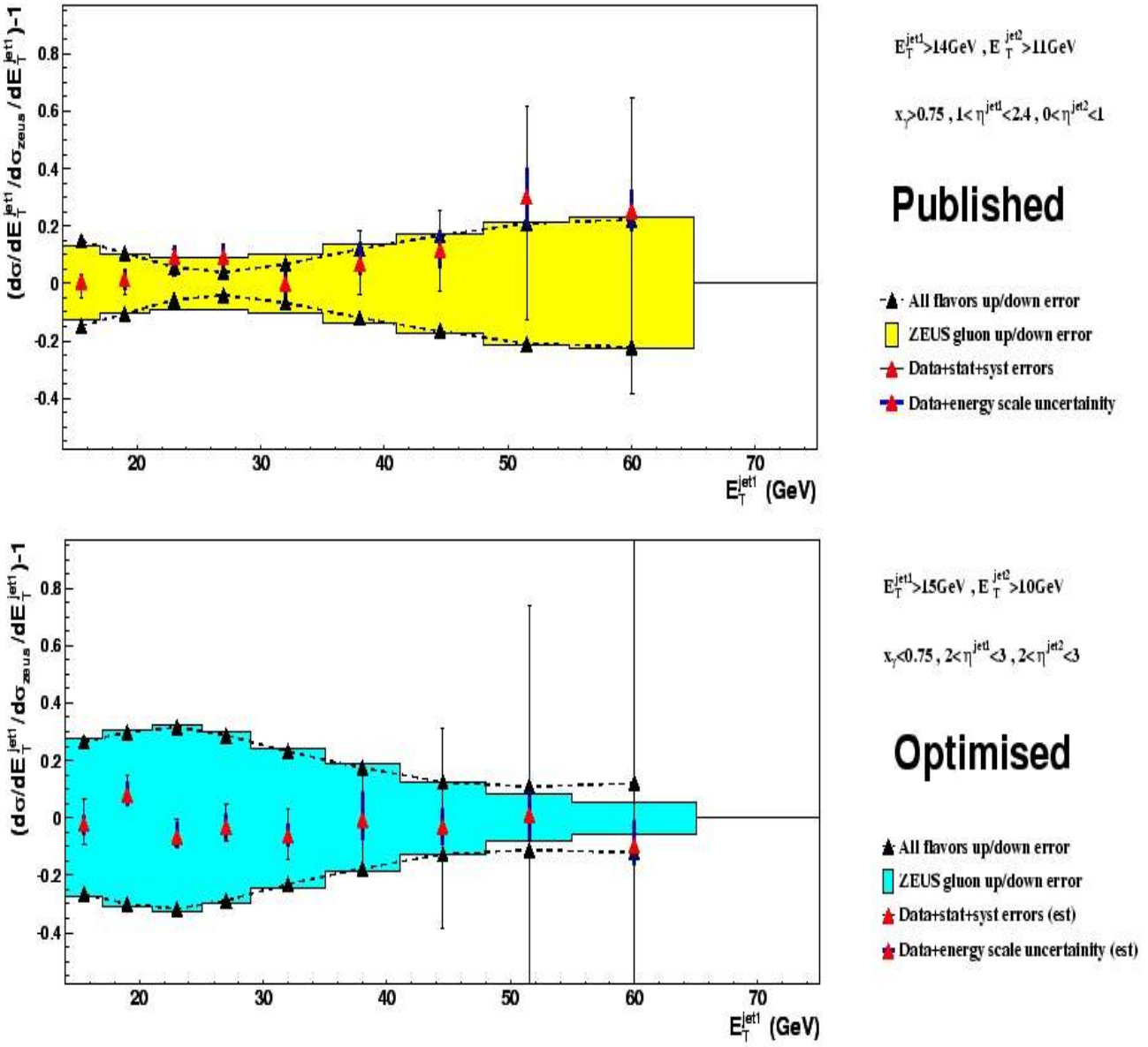
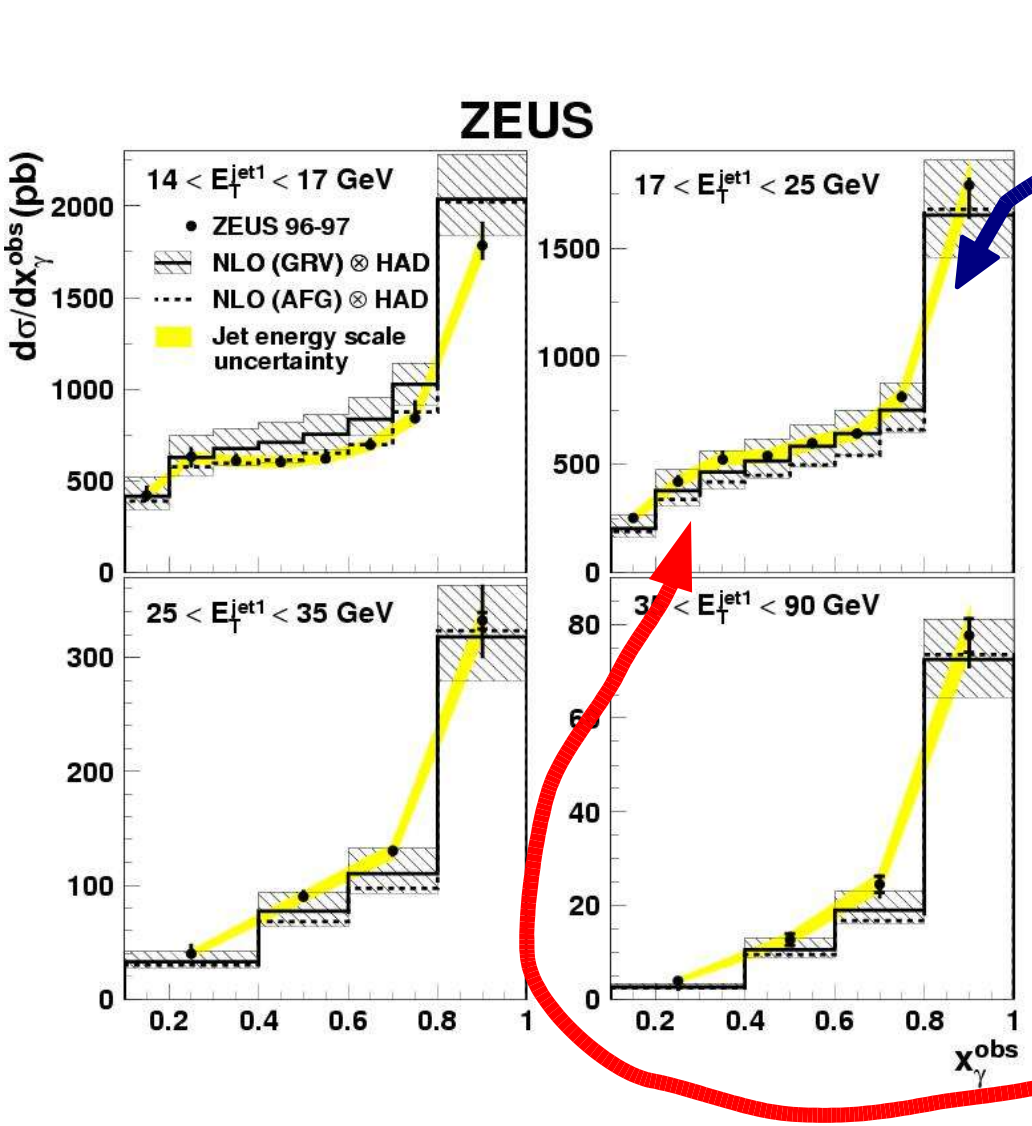


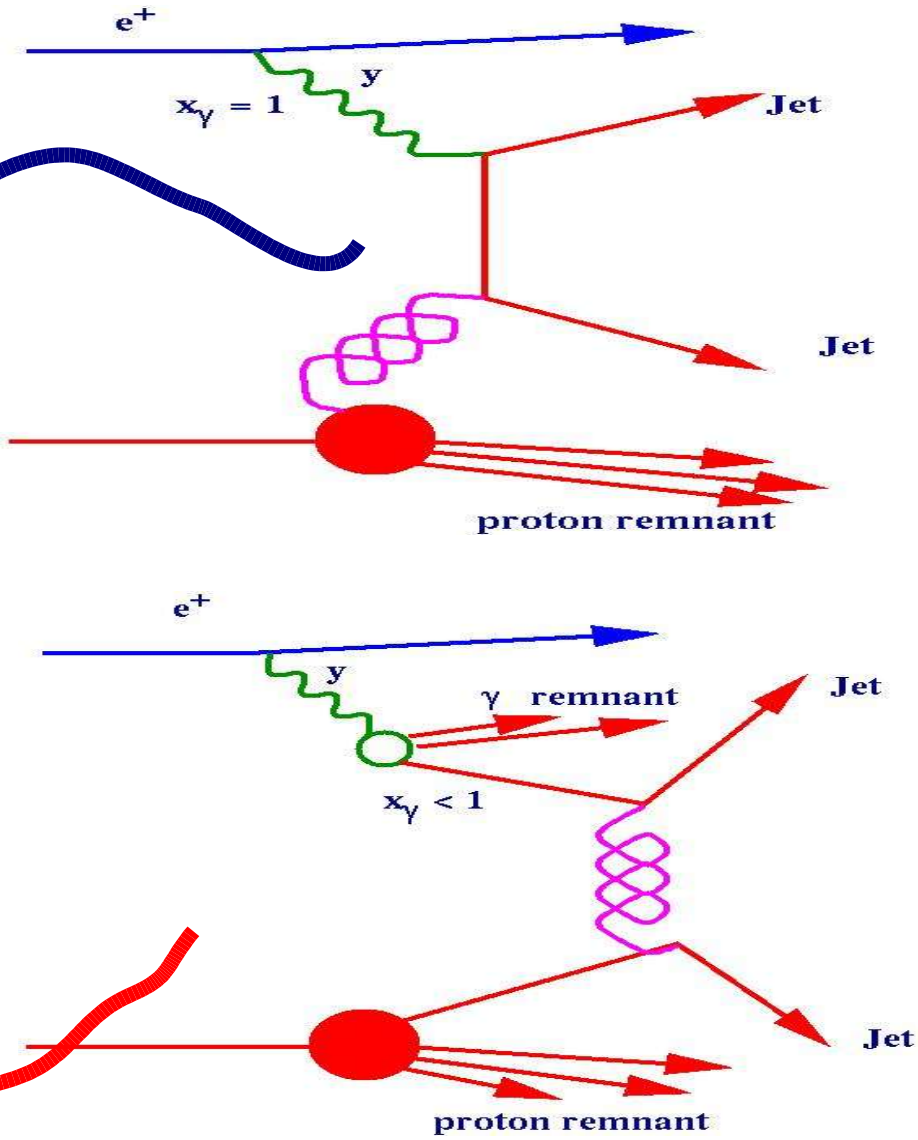
500 pb^{-1}. C. Targett-Adams

Testing Models and Calculational Techniques

- HERA as a 'hadron-hadron' collider
  - Almost on-shell photons come along with the electron beam & collide with protons.
  - These photons can fluctuate to acquire a hadron-like structure.
- HERA can look like a hadron-hadron machine (hadronic photon vs proton)
  - can also do "simpler" measurements with a pointlike photon (in Deep Inelastic Scattering or direct photoproduction).

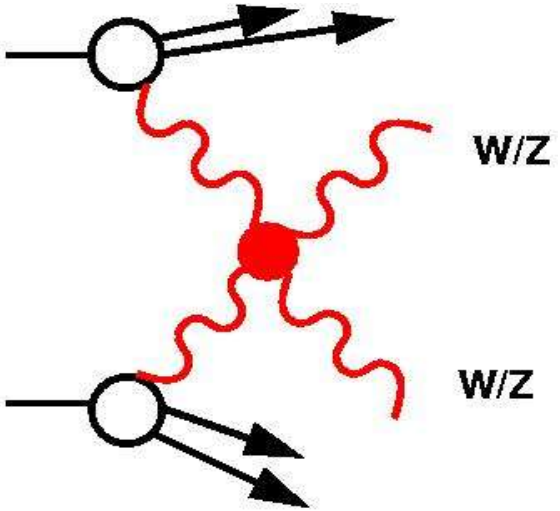
HERA as a 'hadron-hadron' collider

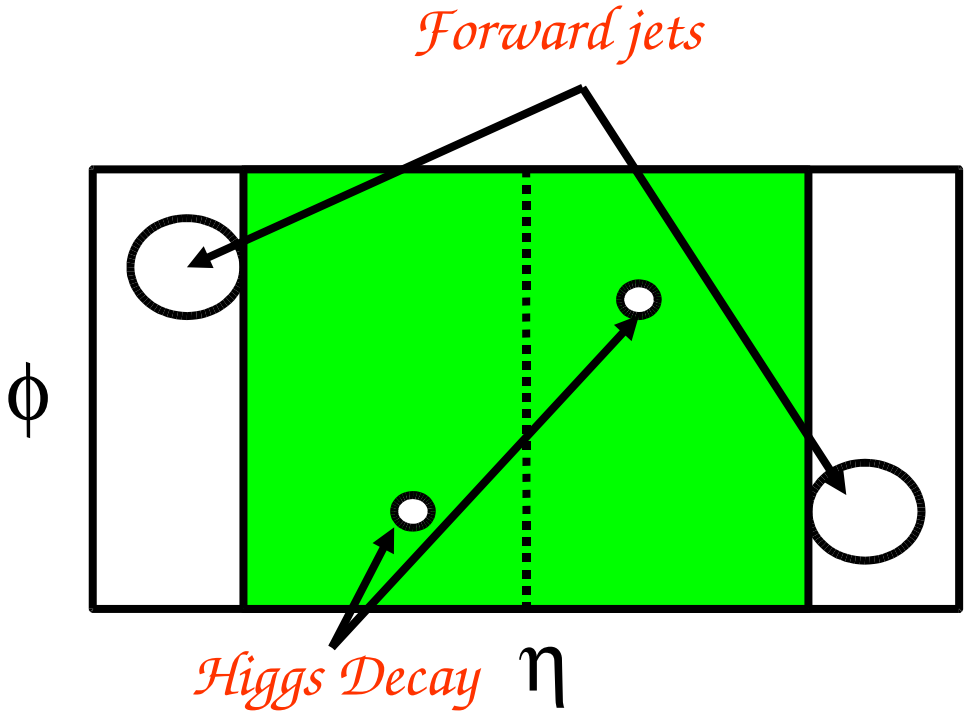




Forward Jets and Low x

Back to vector boson fusion





Background rates and efficiencies critical.

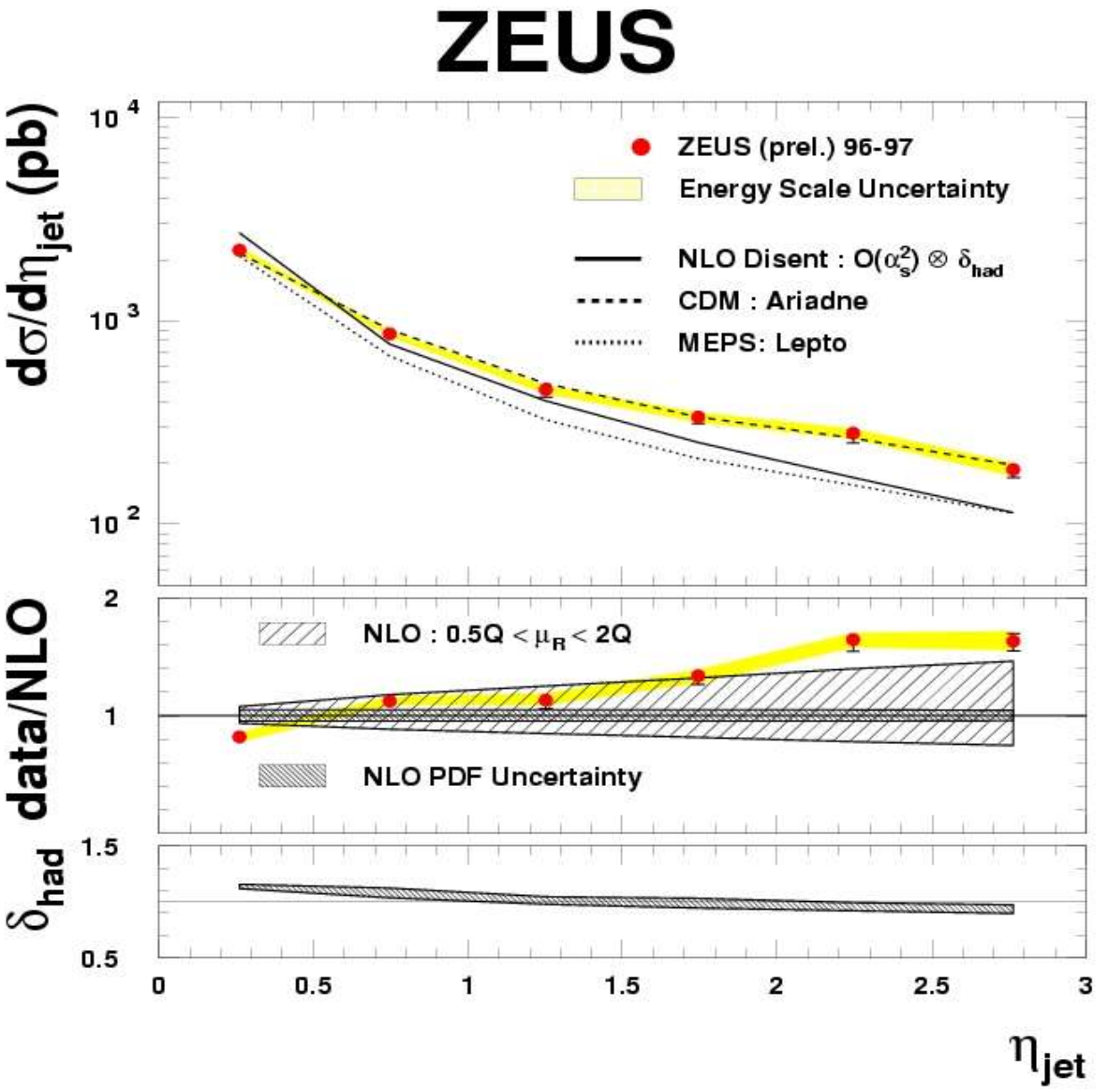
Also possible to use as a trigger at LHCb?

(*E.Rodrigues, HERA-LHC wkshp)*

Forward Jets and Low x

How well is the rate predicted?

Uncertainties blowing up at high rapidities.



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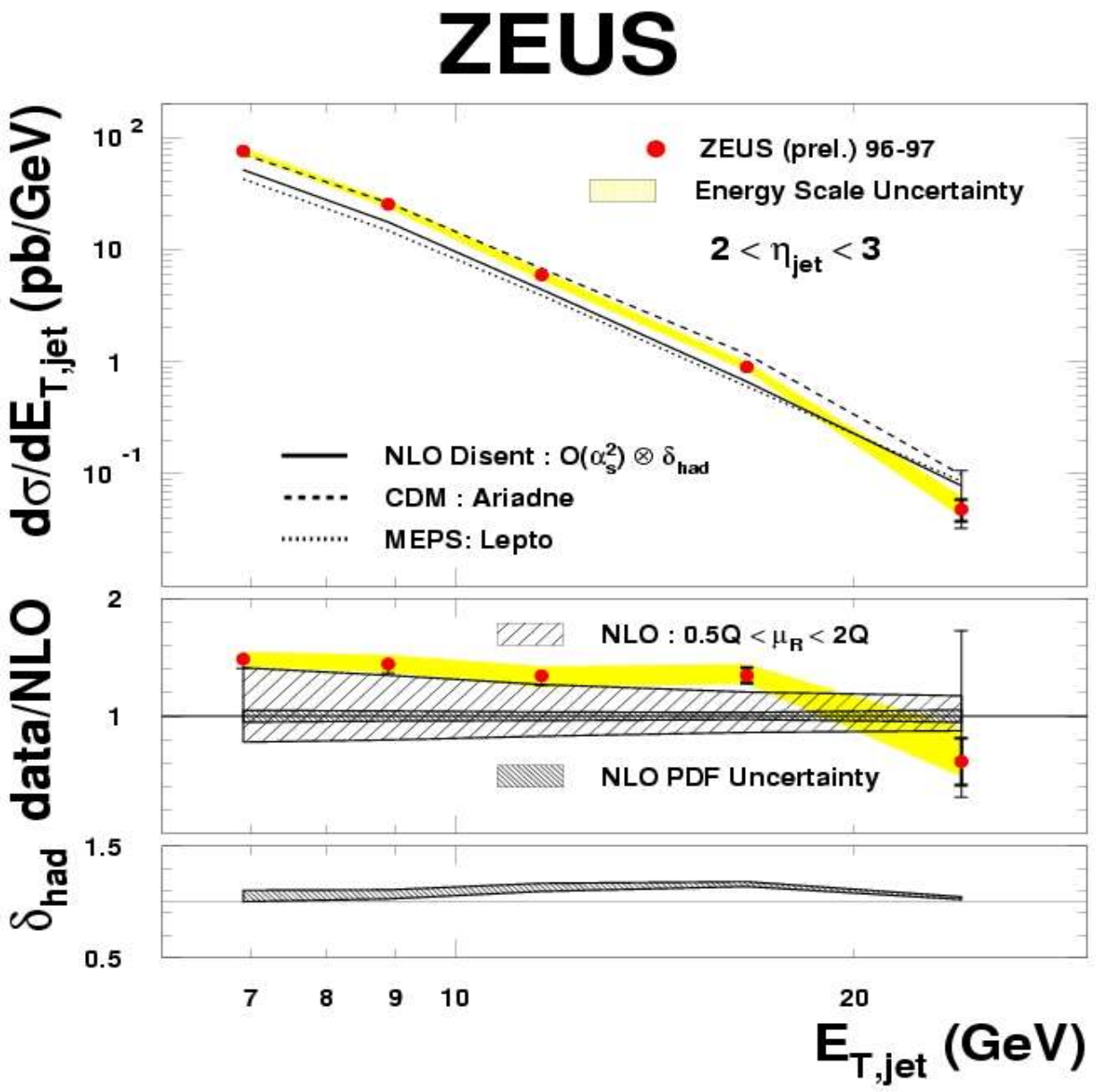
Not particularly a low E_T effect.



Summary

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  - http://www.desy.de/~heralhc/
- Working out what we need to know from current colliders should be a priority for LHC physicists *now,* while new measurements can still be proposed.

HERA II

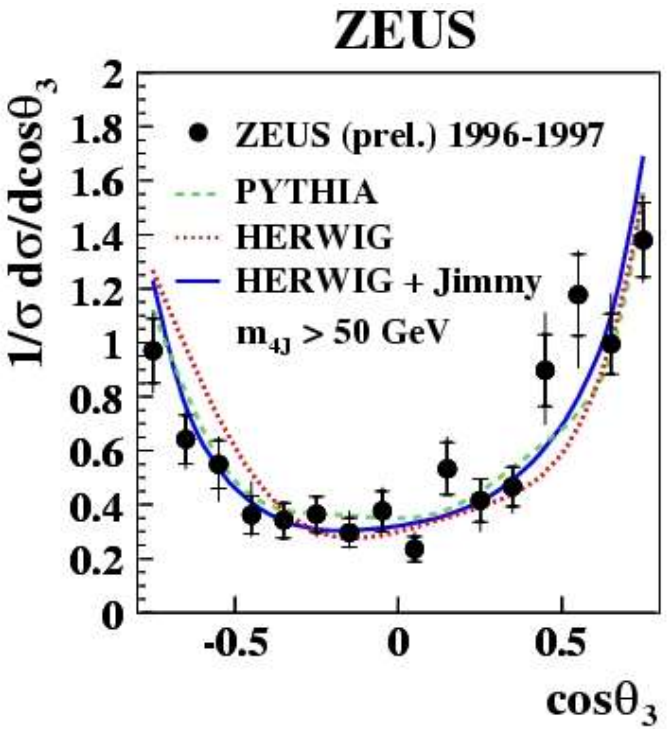
- Will add precision high x and high Q2 data (charged current, neutral current and jets)
- Will add precision charm & beauty DIS and photoproduction.
- Diffraction and searches not covered here. Both have significant results from HERA I and will be added to in HERA II.

Personal Opinion

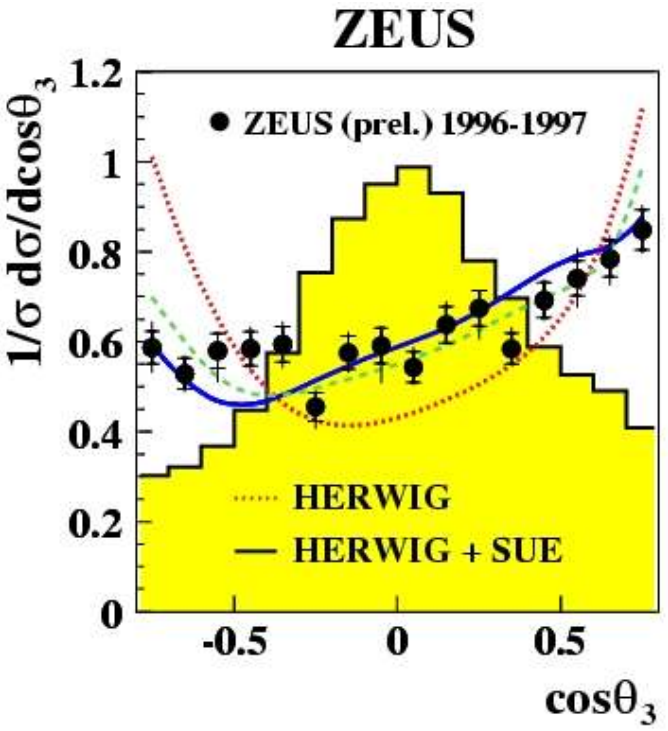
- To abandon HERA after the HERA II program is bordering on scientific vandalism
- The additional investment required to (at least) measure F_L should be found if at all possible.
- HERA III could
  - Make important fundamental measurements which also have implications at LHC
  - Provide data in europe for a significant non-LHC community (LC is 10 years away).
  - Provide valuable experience in running a real accelerator for our new accelerator centres in the UK

Four-jet cross sections

Photoproduction, jet transverse energy > 6 (5) GeV. No mass cut.



Four jet Mass > 50 GeV.
QCD (LO+PS) doing well.



No mass cut. Need something else. Multiparton interaction models are favoured.

Why care about underlying events

- Inevitable property of hadronic collisions. Impact on jet energies and profiles, energy flow, isolation of photons...

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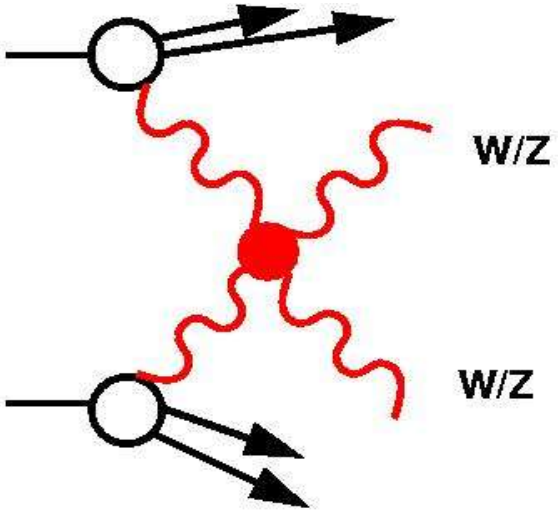
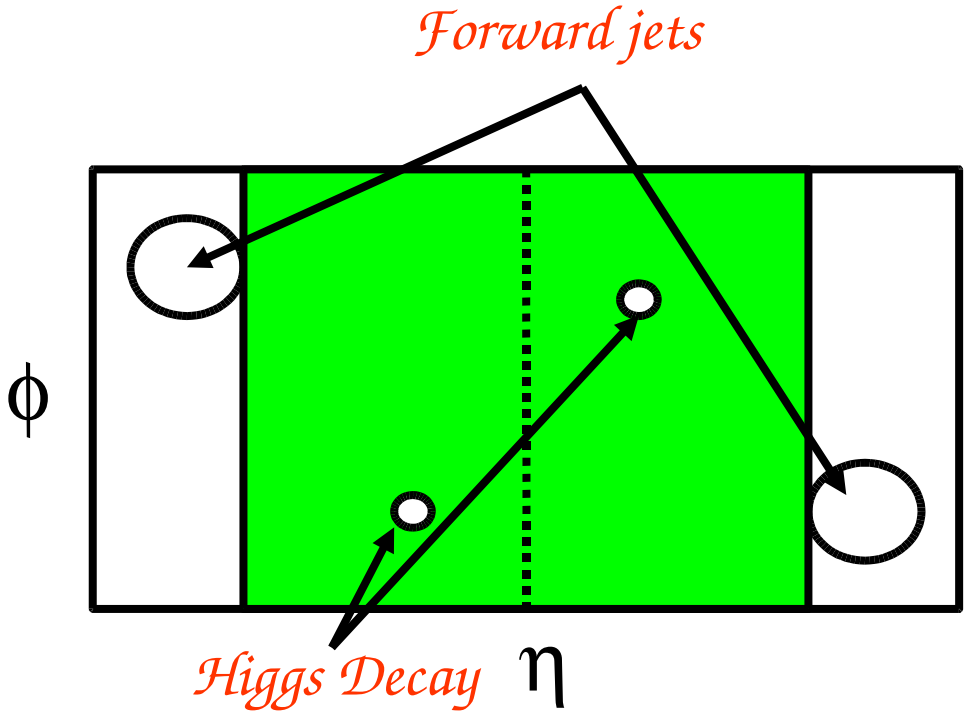
- Natural consequence of eikonalisation of the parton model in high density PDF region. Related to saturation and total cross sections.
- Responsible for diffractive factorisation breaking/gap survival probability
- Related to absorption/rescattering corrections to forward proton and neutron production.

Vector Boson Fusion at LHC

Commonly used minijet veto in WW events.





Les Houche Higgs Working group:
Minijet veto at 20-30GeV
(hep-ph/0203056).

Great sensivity to choice of underlying event model.

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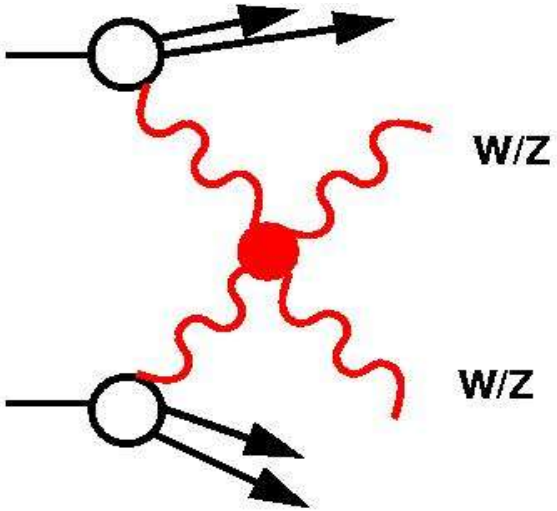

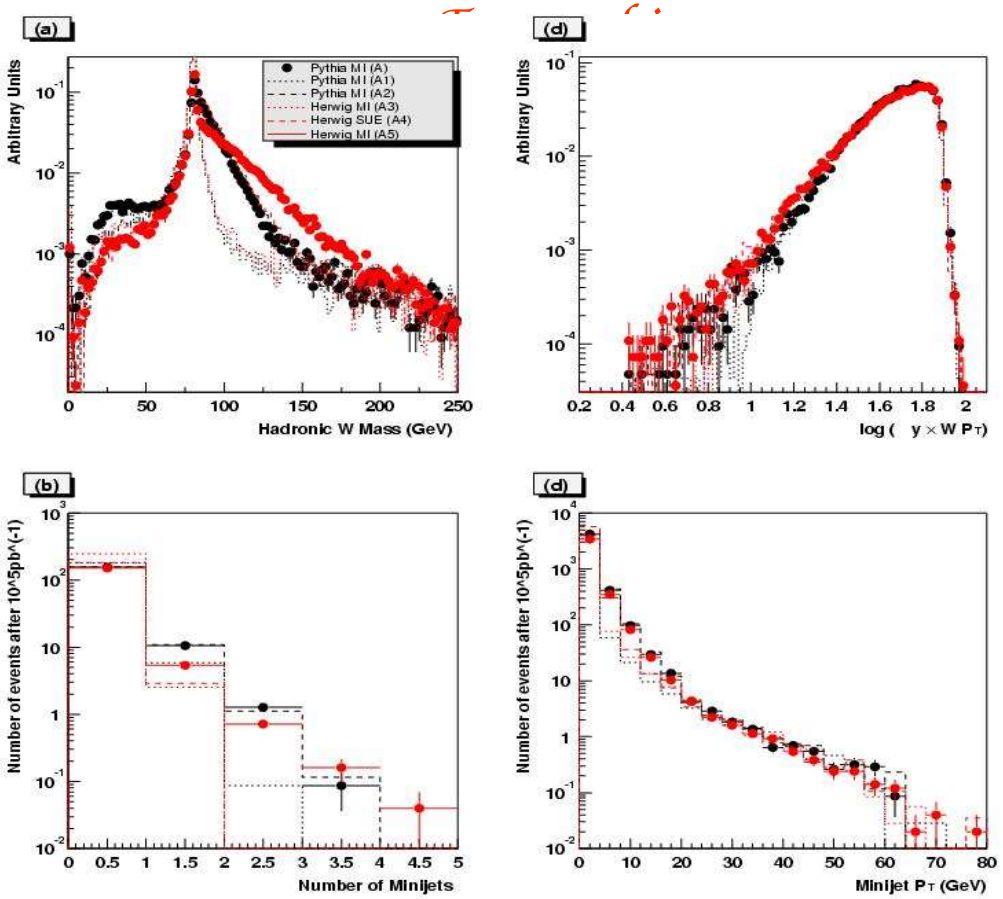

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Great sensivity to choice of underlying event model.

Also determines 'survival probability' in diffractive events.

Double Pomeron Scattering as a Search Channel at LHC

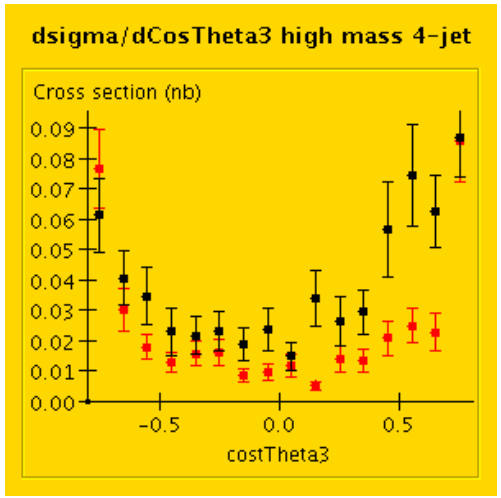
- An area of increasing interest. Much phenomenological progress in the past year. Several talks in the diffractive sessions this week.
- Possibly the cleanest way see a low-mass Higgs at LHC. Other search channels also possible.
- Requires leading proton tagging, triggered with central detector
- Would also do some excellent diffractive QCD physics
- Predictions require a good understanding of diffractive processes, particularly diffractive PDFs and factorization breaking/ survival probabilities/ rescattering

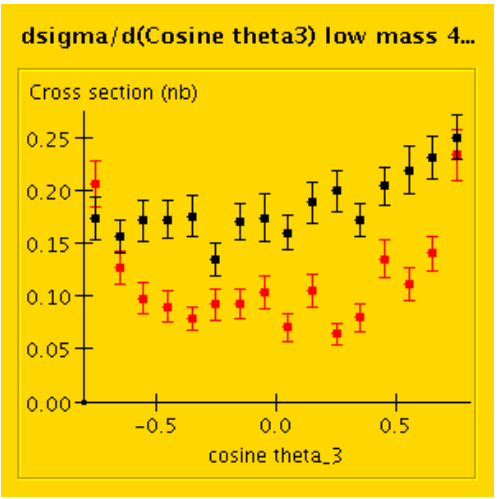
What might we learn from HERA about underlying events

- Learn about energy dependence and target dependence of models by comparing γp, pp(bar) and γγ.
- Learn about proton PDFs at low x -> input to multiparton interaction models.
- Look at behaviour of jet finding for the same kinematics but with & without an underlying event.
- Test models which predict both minimum bias & underlying event by studying tagged photoproduction.
- Look at forward neutron and proton rates in photoproduction vs DIS.

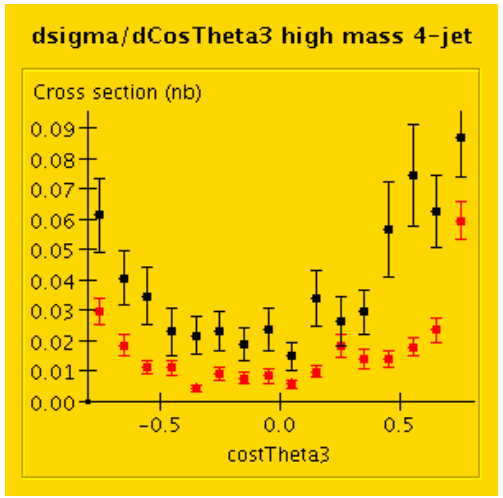
Four-jet cross sections

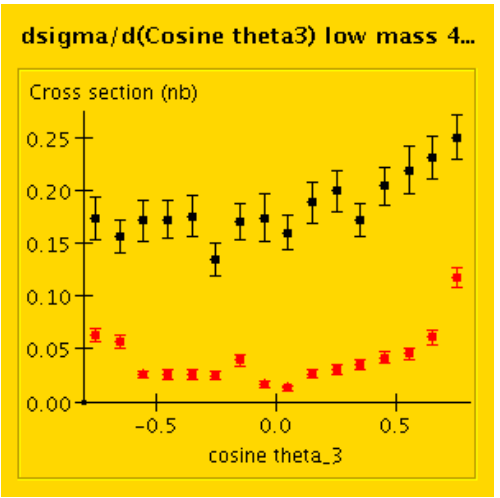
Same data: compare absolute cross sections.





HERWIG+JIMMY, as tuned to Tevatron data minimum bias data.





HERWIG default.

NB: Both these options give a decent fit to the high ET data.