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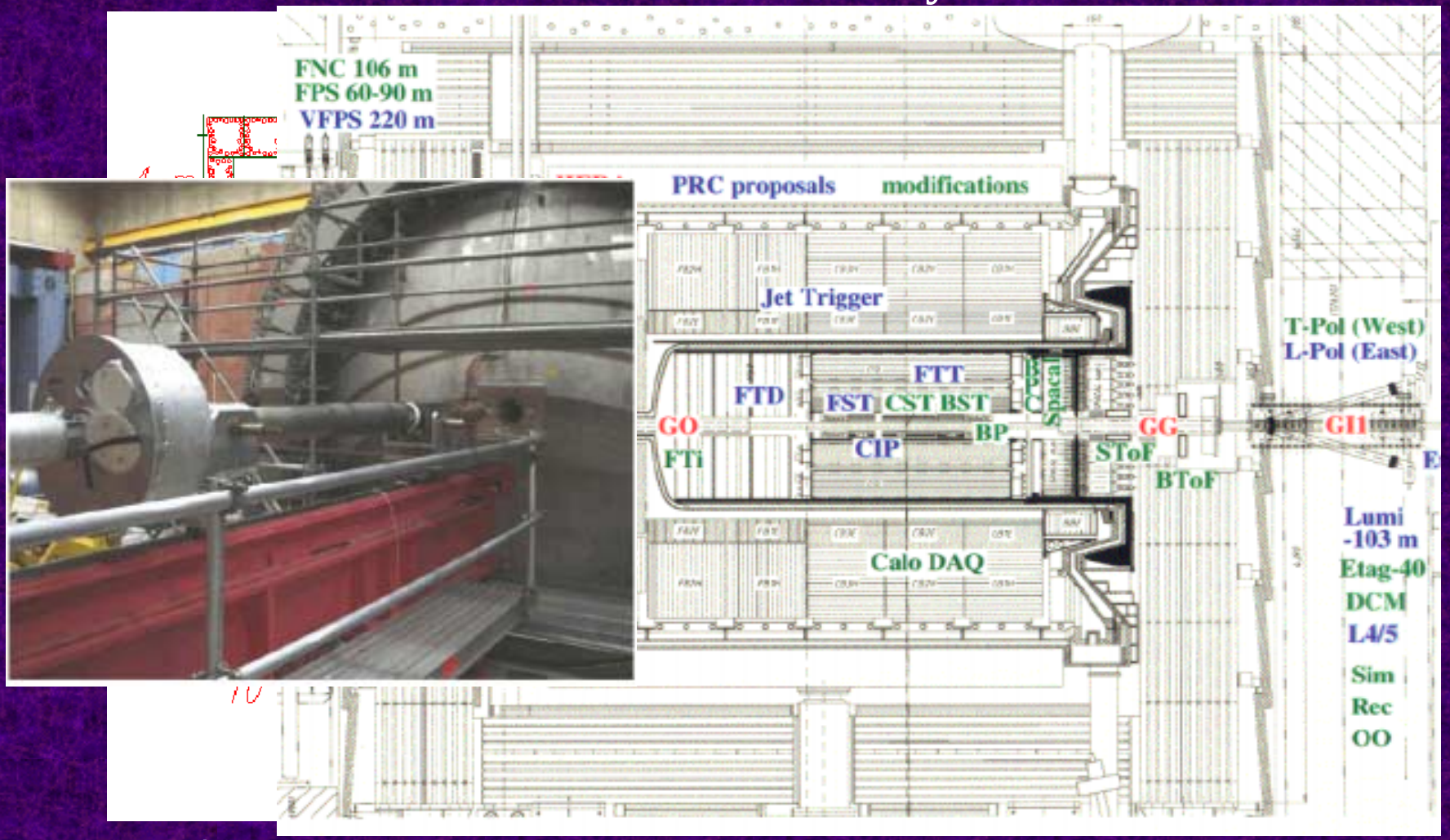
Heavy Quark Physics @ HERA II

DESY
11.11.03

- What's new for HERA II and what does it mean for HQ physics – a reminder..
- HQs in DIS, diffraction, photoproduction
- Spectroscopy – is there a role for HERA II?
- Production mechanisms
- Single t production?
- Summary

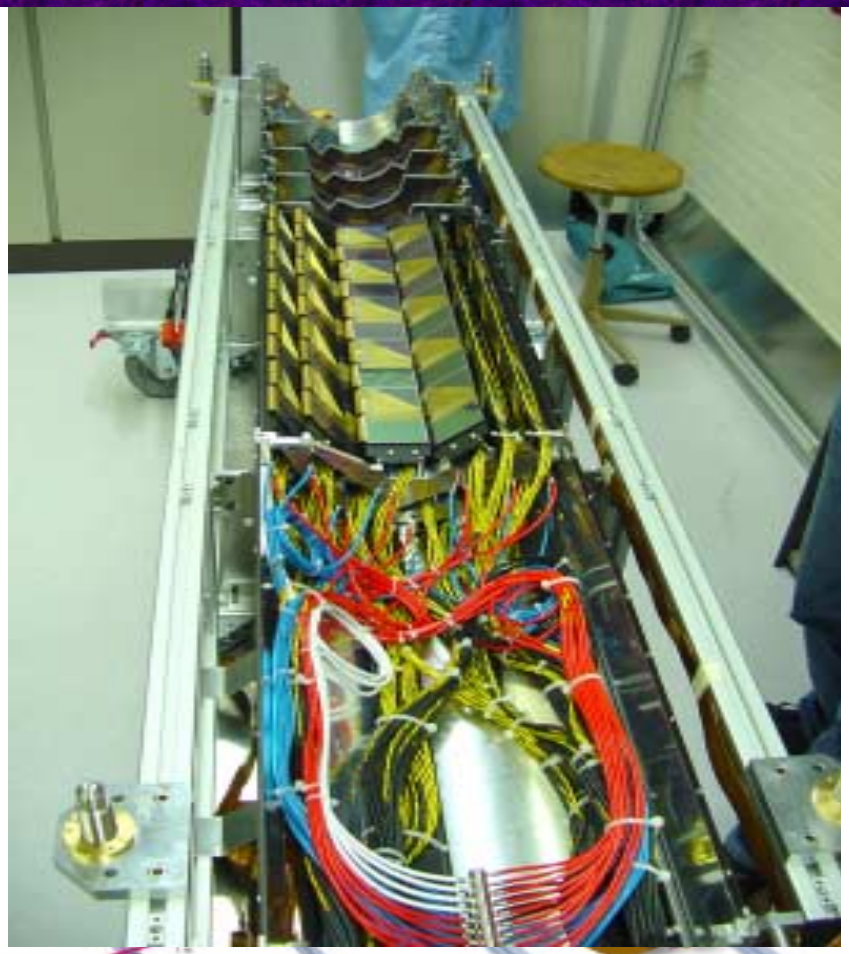
HERA II Physics

- **Both ZEUS & H1 have made major upgrades in order to utilise the increase in HERA luminosity to the full.**



Vertex Region

- **The ZEUS MVD mostly 3 layers in barrel and 4 forward wheels; > 200K readout channels.**



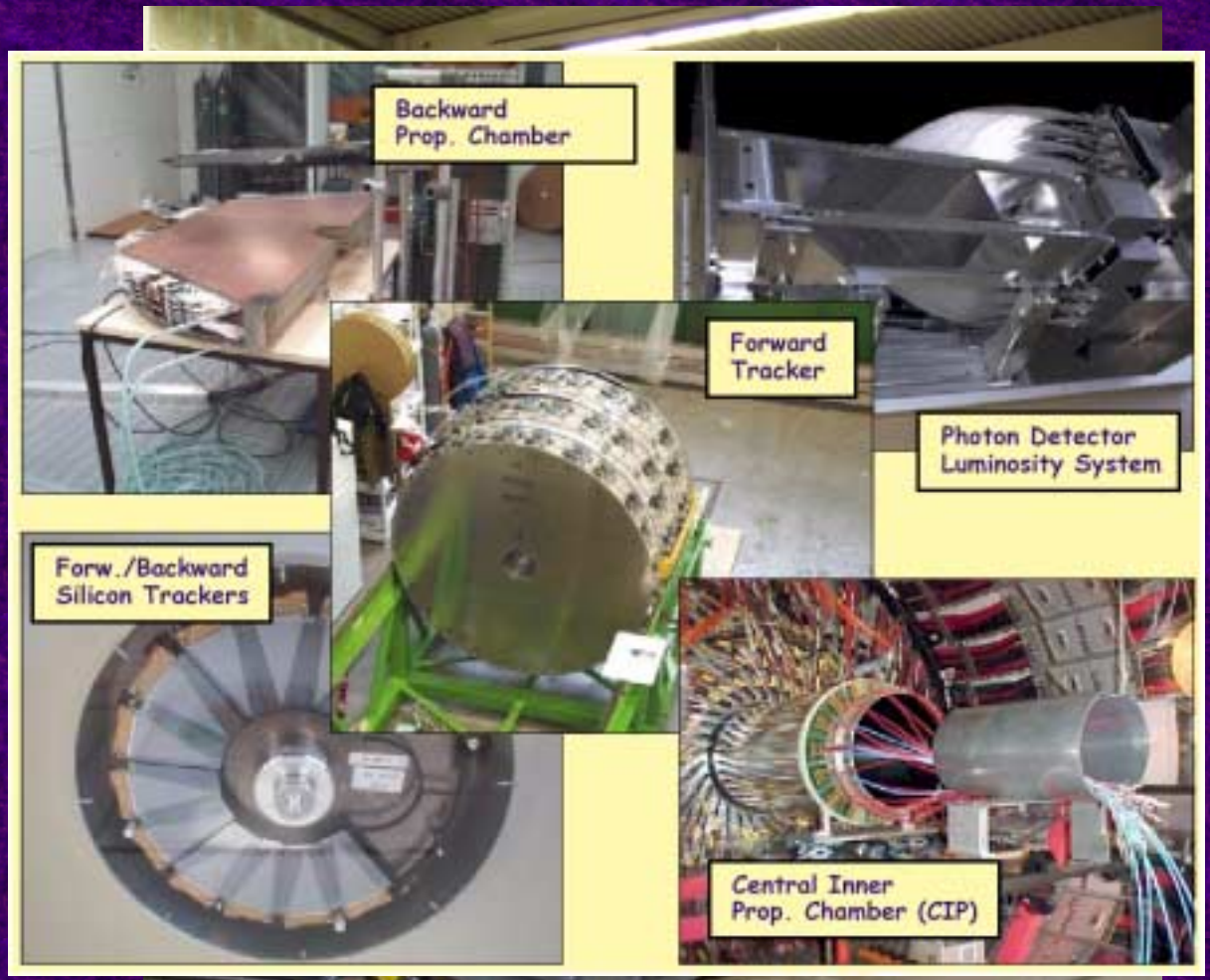
Vertex Region

- **H1 Si – 2 very thin CST layers; 5 disks covering $8 < \theta < 17^{o}$**

Forward Physics

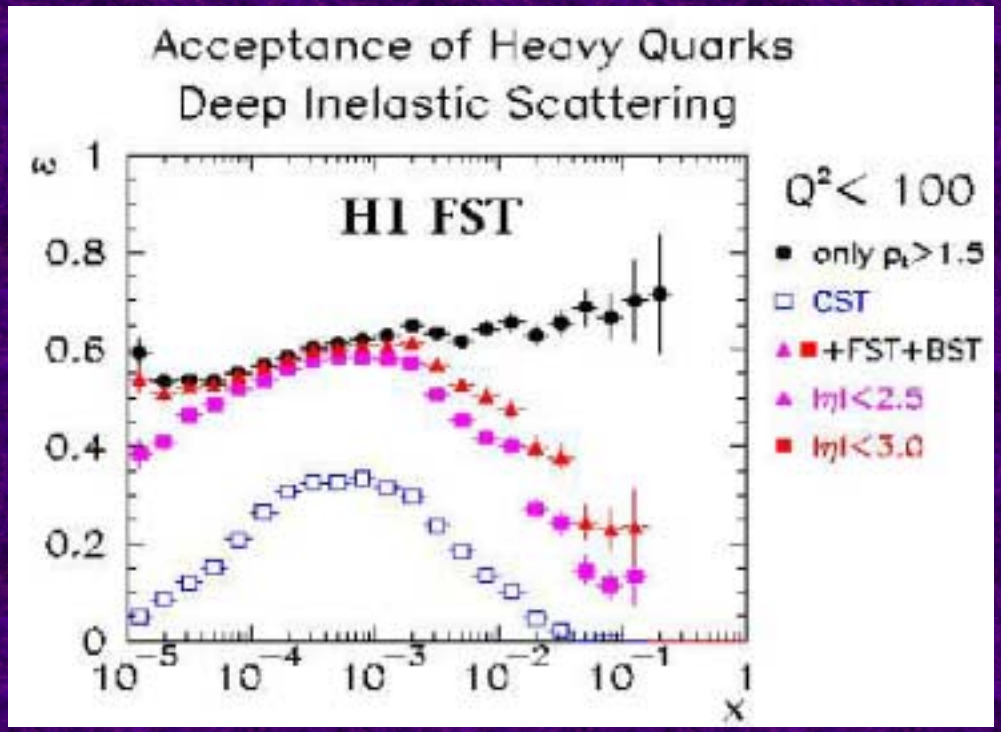
- ZEUS major upgrade in forward direction replacement of TRD's with two stations of straw-tube chambers, each with 3 stereo layers.

- H1 have made improvements to various parts of their tracking systems.

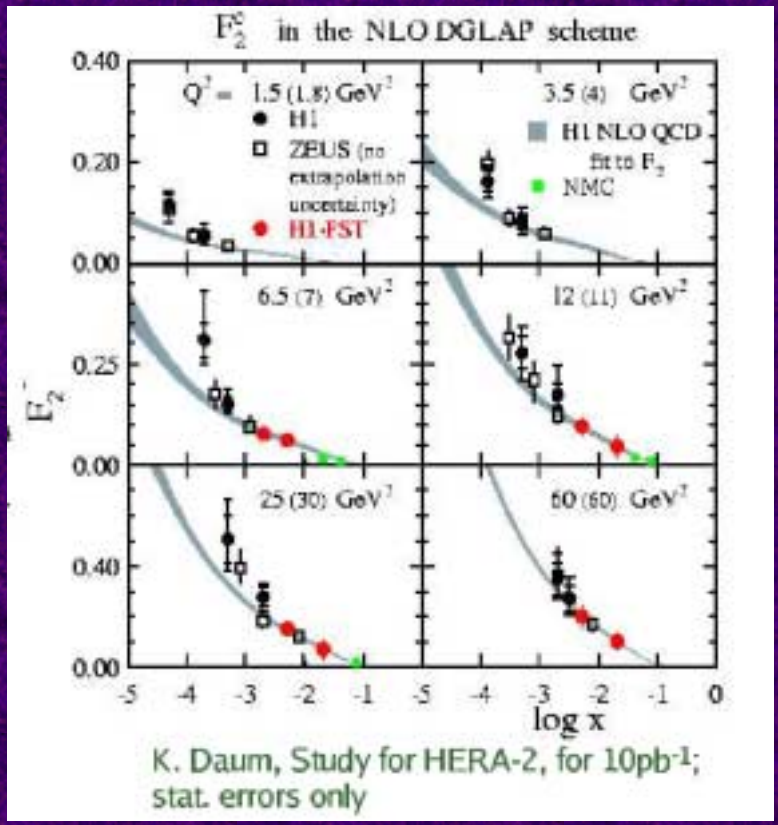


Forward Physics

- **H1 forward disks**

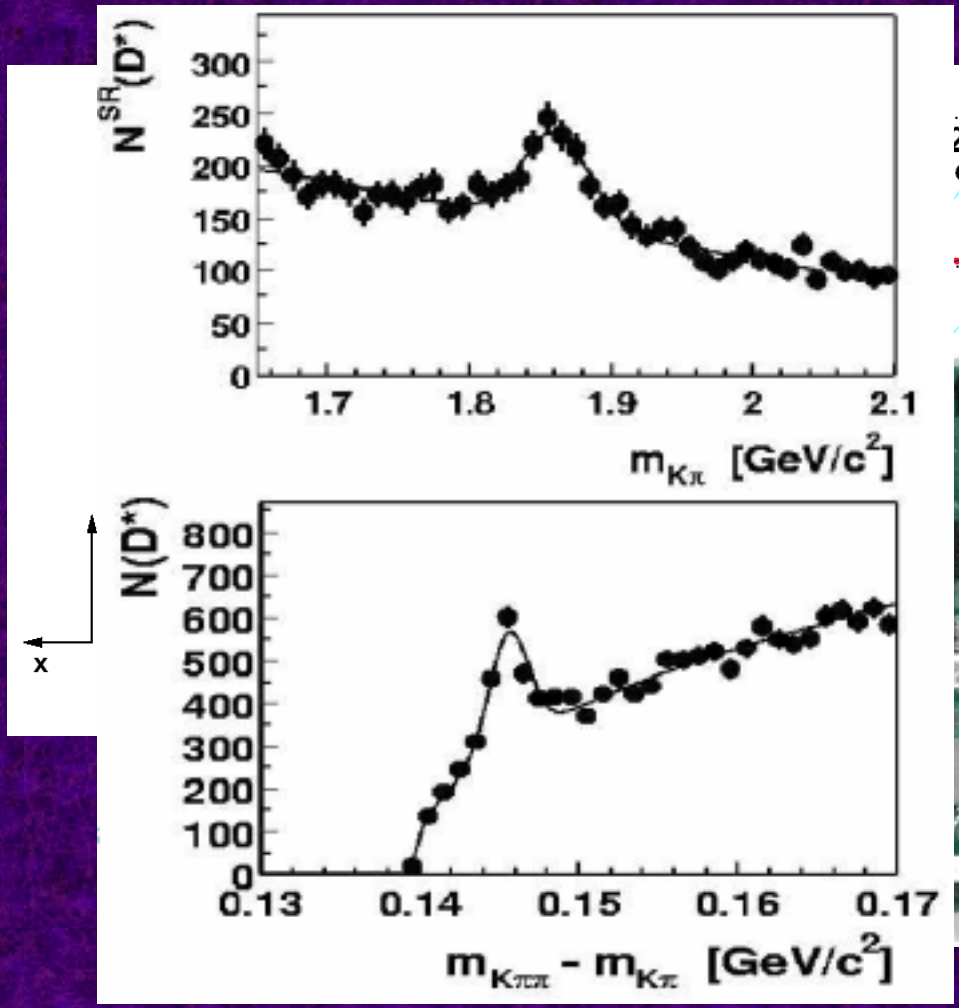


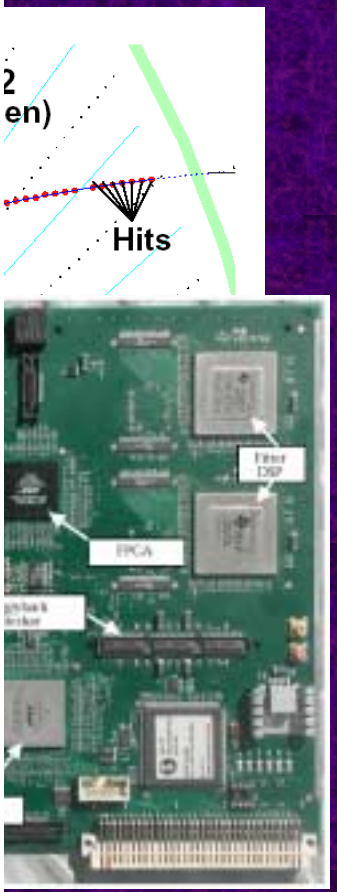
- **Extends charm coverage to higher *x* – similar improvement for ZEUS Si disks and STT.**



Vertex Physics

- **H1 fast track trigger – now installed and being commissioned – can produce mass peaks within 100 μs.**



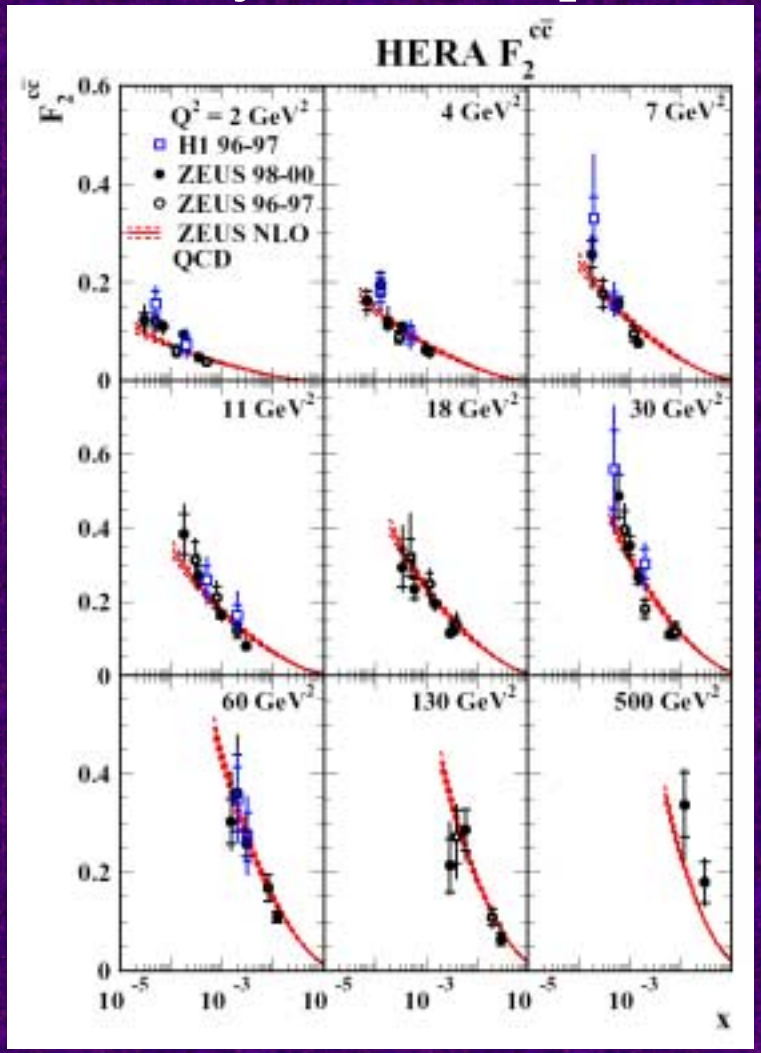


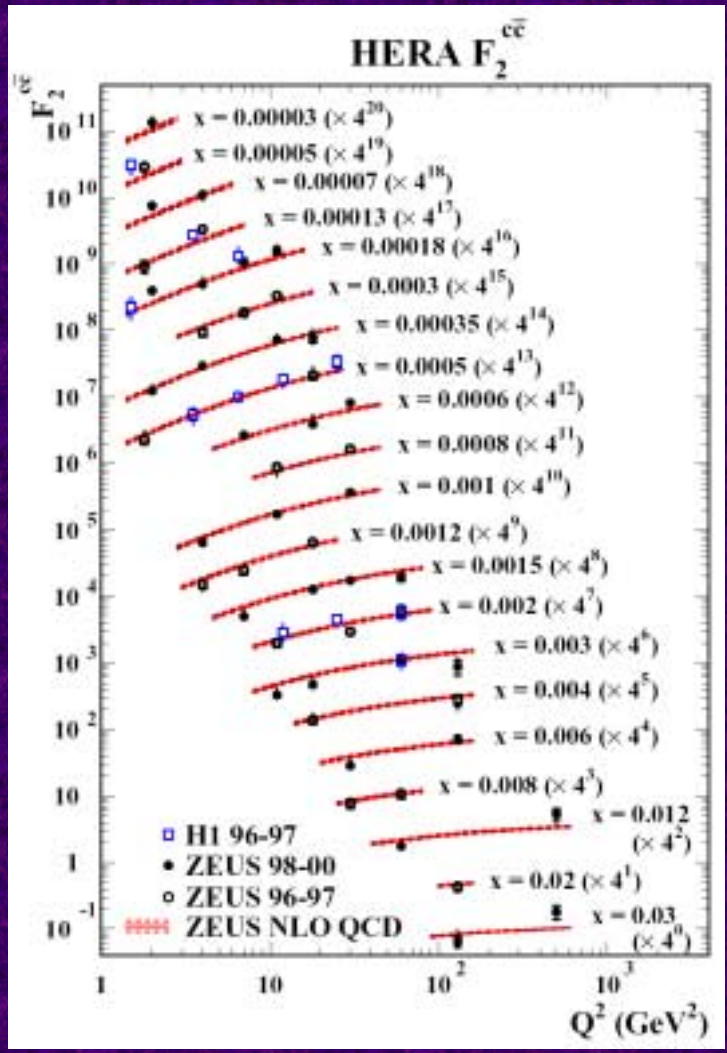
HERA II prospects

- So optimistically HERA II promises factor 5 increase in luminosity, with lepton polarisation, greatly improved tracking, DAQ and triggering.
- This implies generally order of magnitude improvement in statistics and increased kinematic range and coverage.
- What does this mean for the physics reach of HERA II?

HQ in DIS

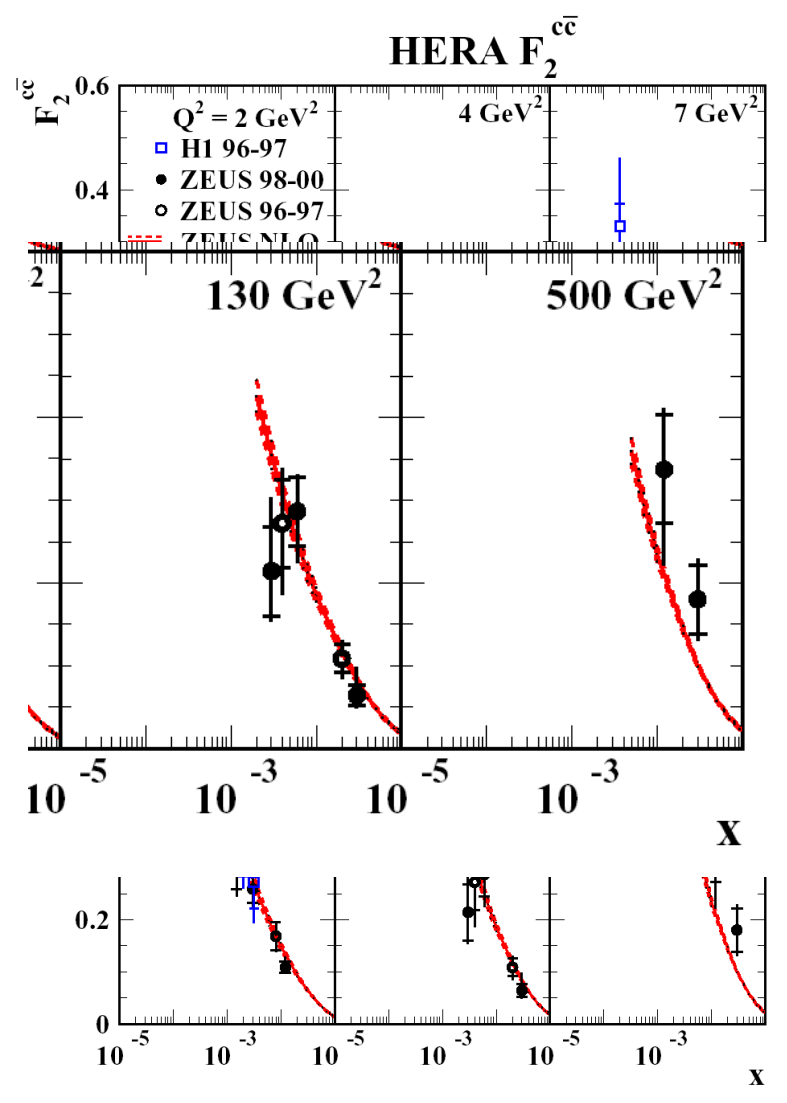
- **HERA I has already told us a lot about the charm quark density inside the proton.**

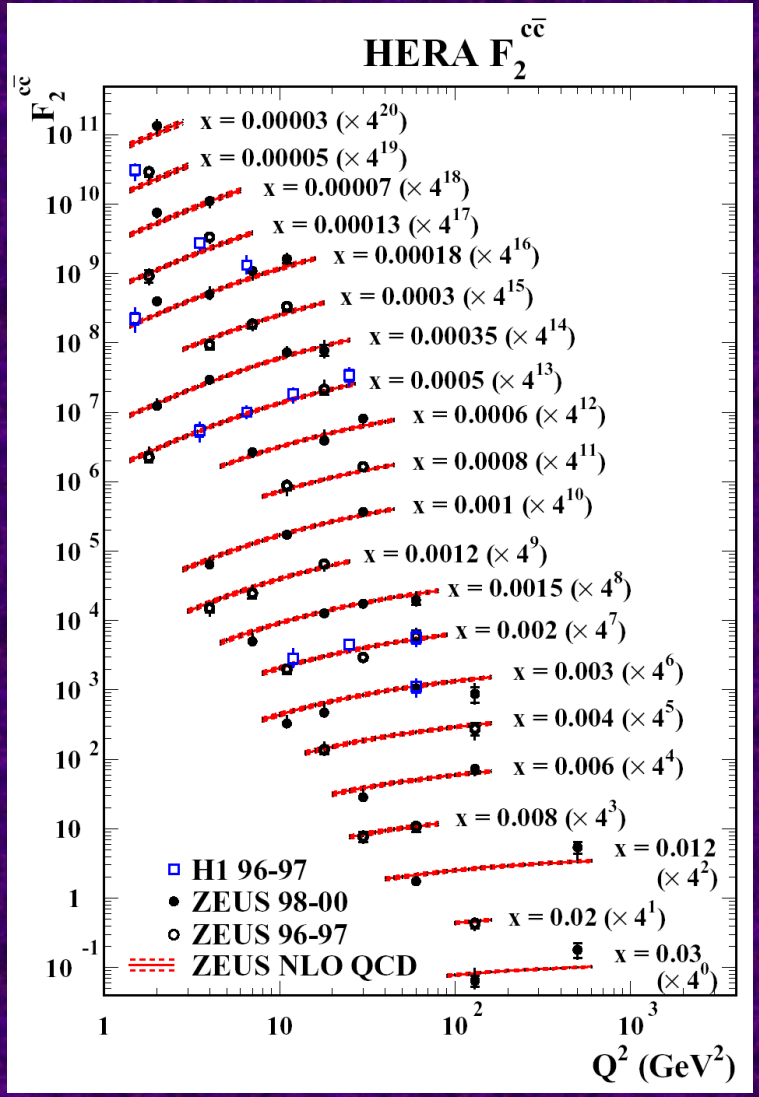




HQ in DIS

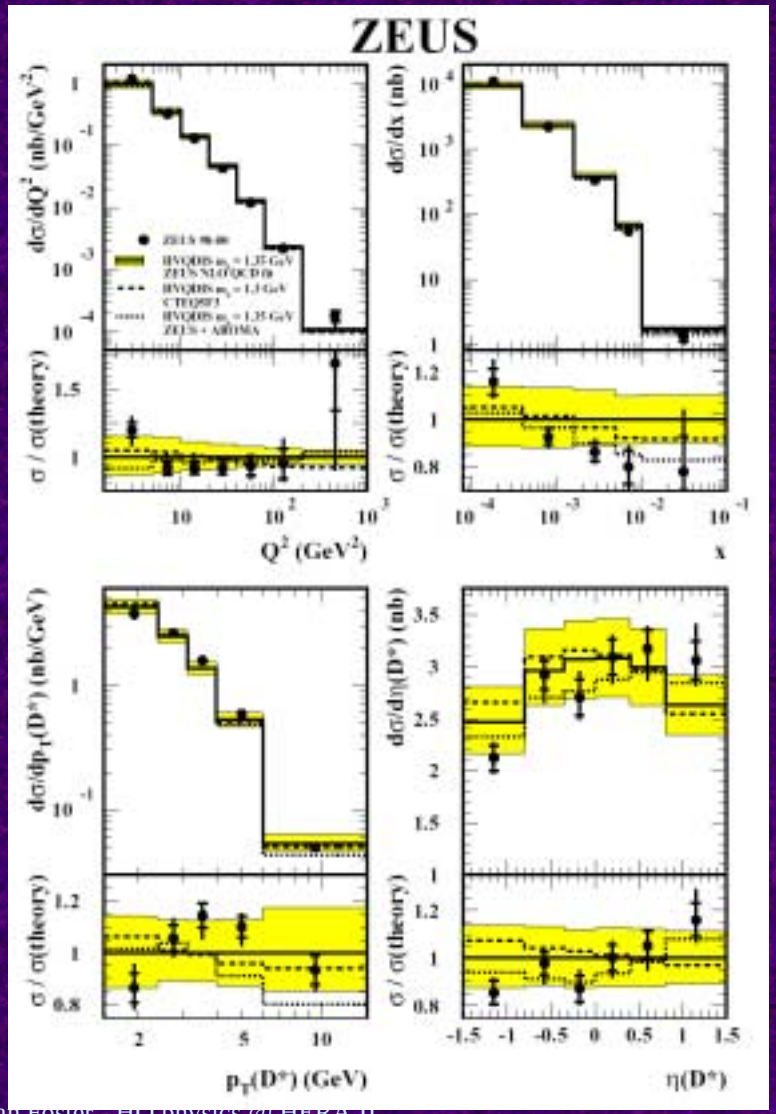
- Some of the open questions are obvious.

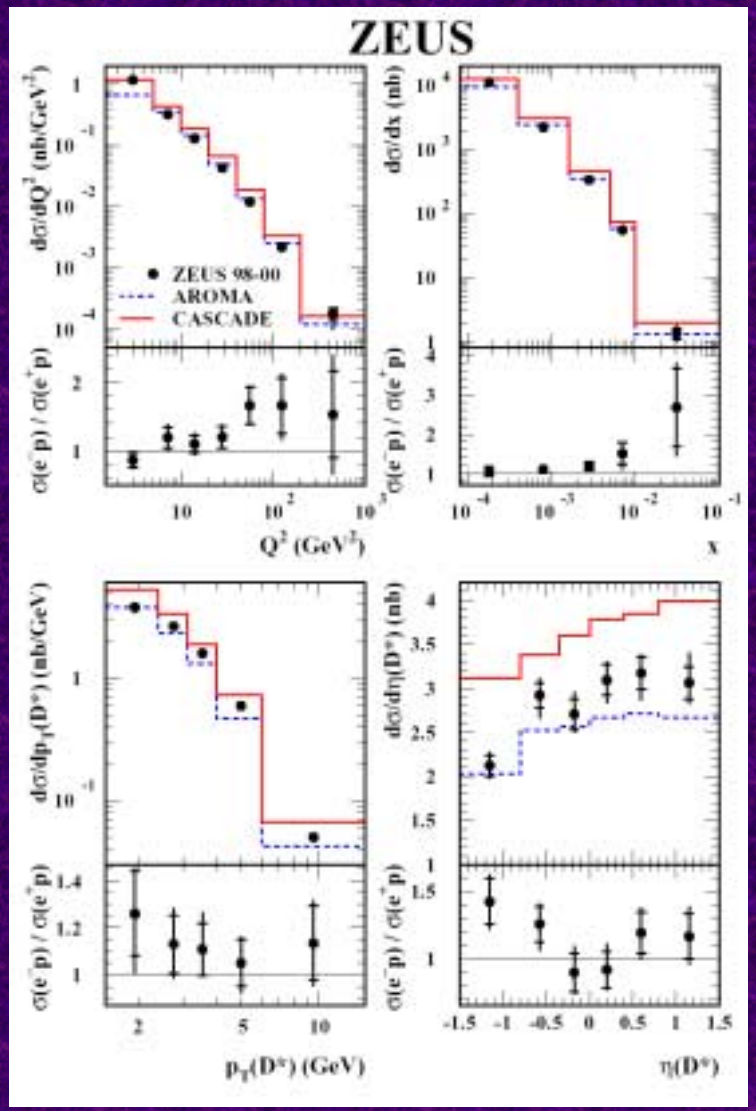




HQ in DIS

- **Some are (much) more obscure.**

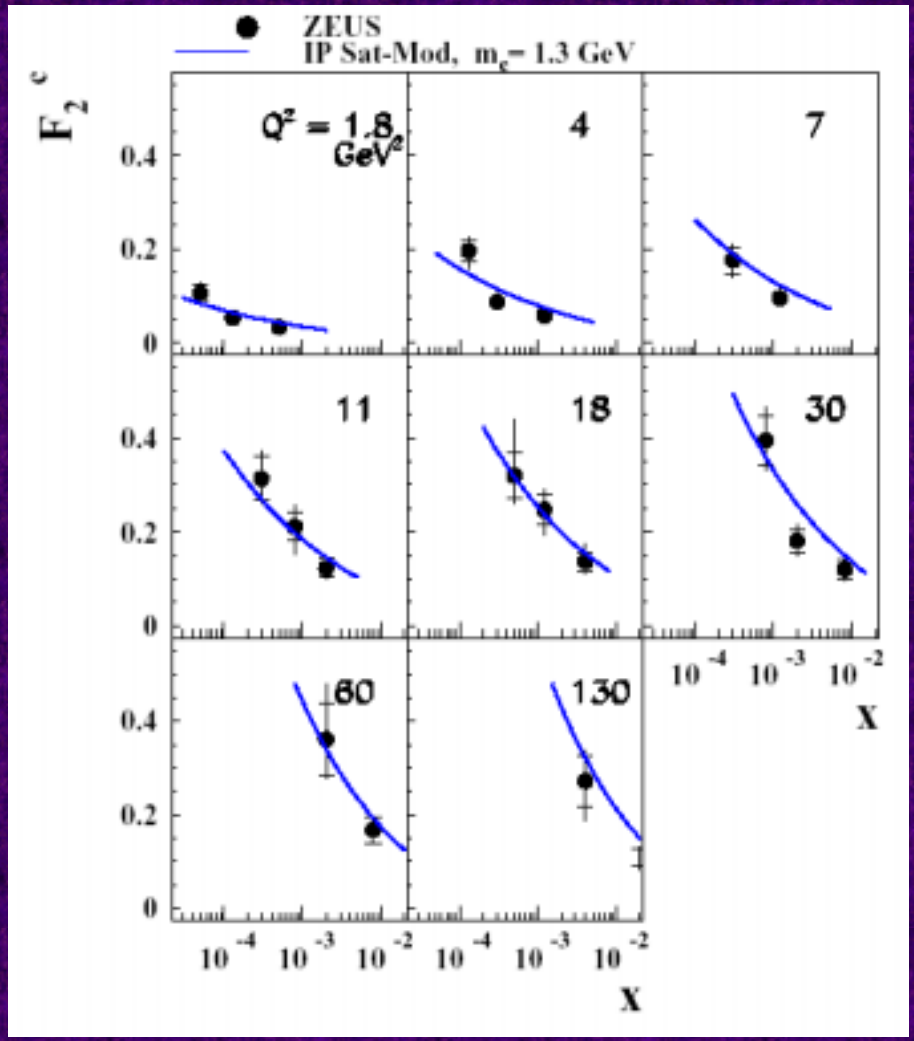




HQ in DIS

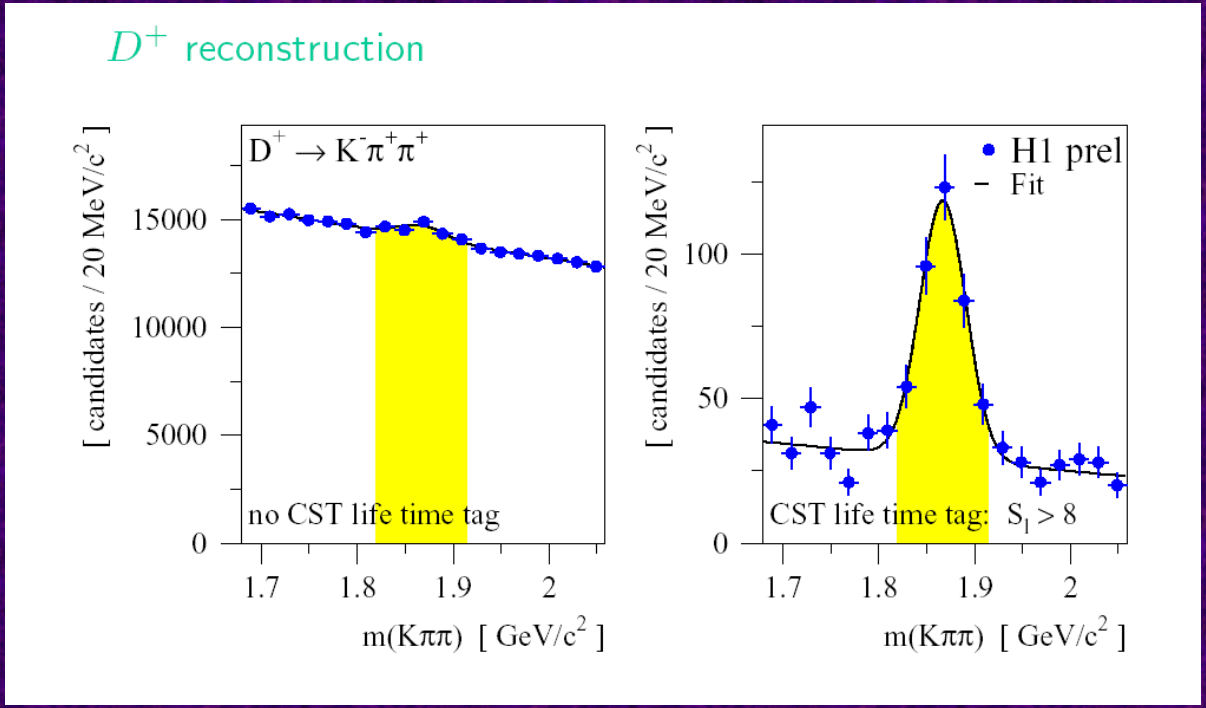
- **The promise of HERA II is great, since charm production in DIS is sensitive probe to all sorts of dynamical models.**

- **Saturation model of Kowalski & Teaney.**



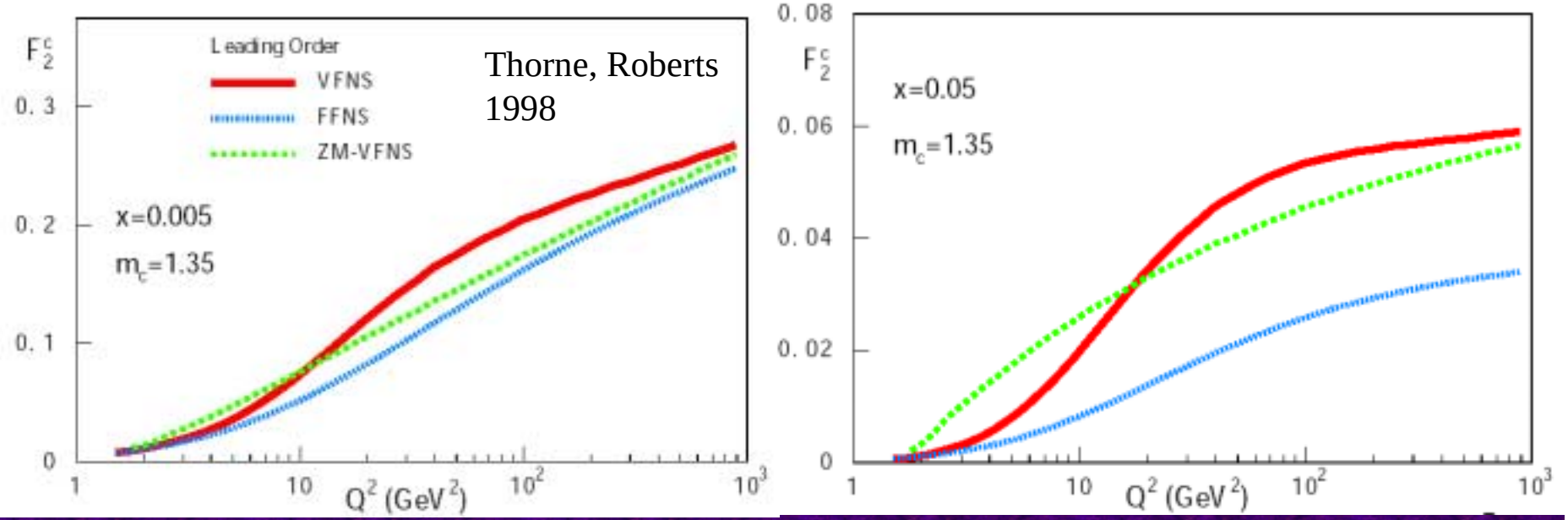
HQ in DIS

- The D* tagging method in D* ? $K\pi\pi_s$ will not be as effective (@ ZEUS) because of increased multiple scattering from the MVD.
- However this will be more than offset by ability to use separated vertex or large impact parameter tag, as already demonstrated at HERA I by H1.



HQ in DIS

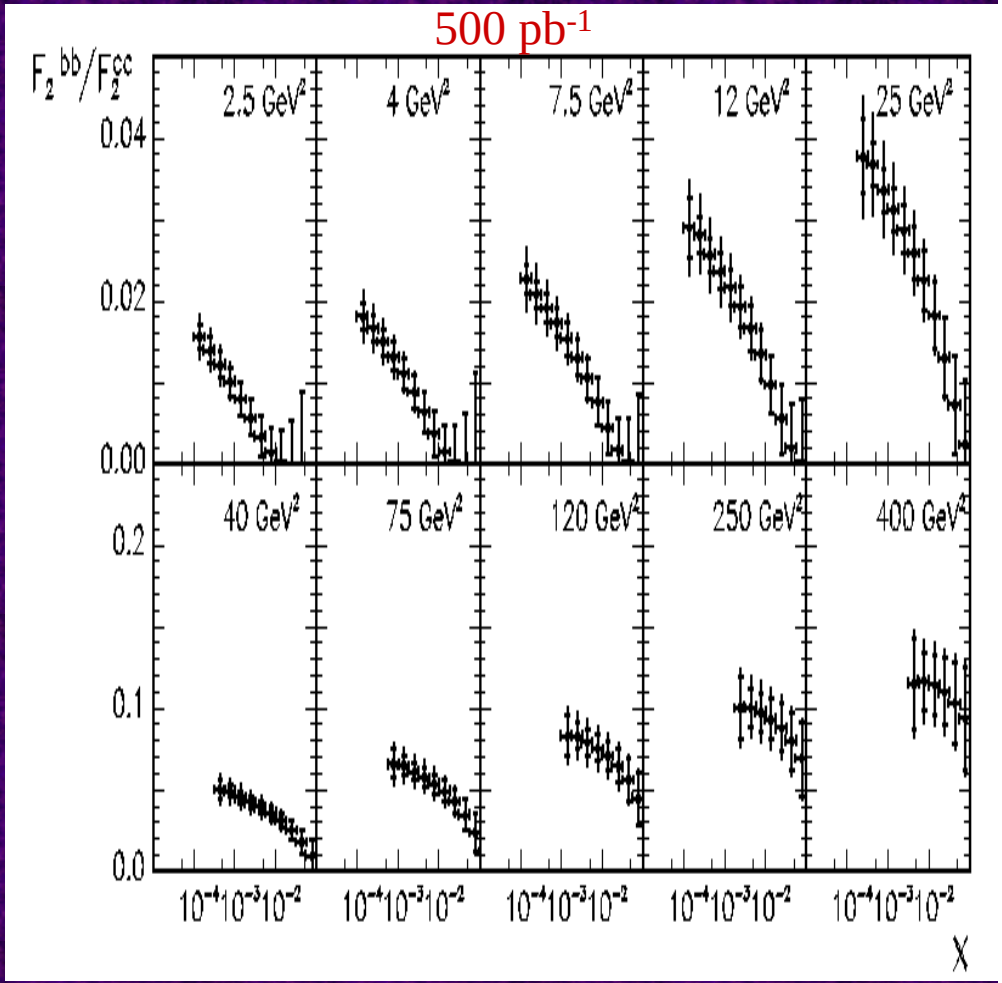
- We will need substantial part of the HERA II statistics to resolve many of the interesting issues in charm in DIS, even with substantial improvement in tagging efficiency.



- The mechanism to take charm mass into account can give substantial mods. to theoretical expectation as function of Q^2 at higher x. Intrinsic charm can also modify these predictions but unlikely we can get useful info. on this at HERA II.

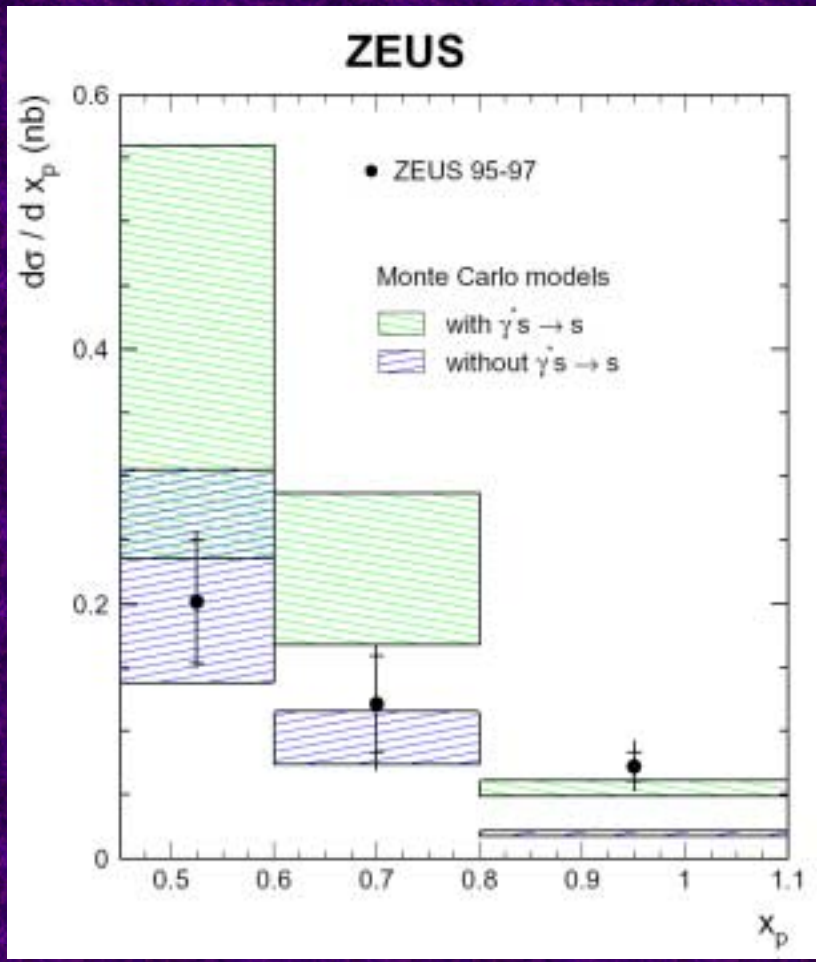
HQ in DIS

- Very precise measurements of F_2^c will be possible for HERA II; also gives accurate gluon determination and cross-check with the more global QCD fits.
- Accurate b contribution to F_2 will become possible – cross-check of VFNS and clean test of photon-gluon fusion process.



HQ in DIS

- HERA II should allow both collaborations to make a full flavour decomposition of the inclusive F_2 structure function.
- For example, charm signal in charged currents (expect ~ 50K events) in principle measures the s-quark density (+ leading particles in NC etc.; but also competing non-s diagrams from gluon splitting in CC).
- Constrain fit with s from leading ϕ?
- At HERA II, both singlet & non-singlet pdfs - *u,d,s* (CC DIS) *& c,b,g* (NC DIS) - can be determined with good accuracy.

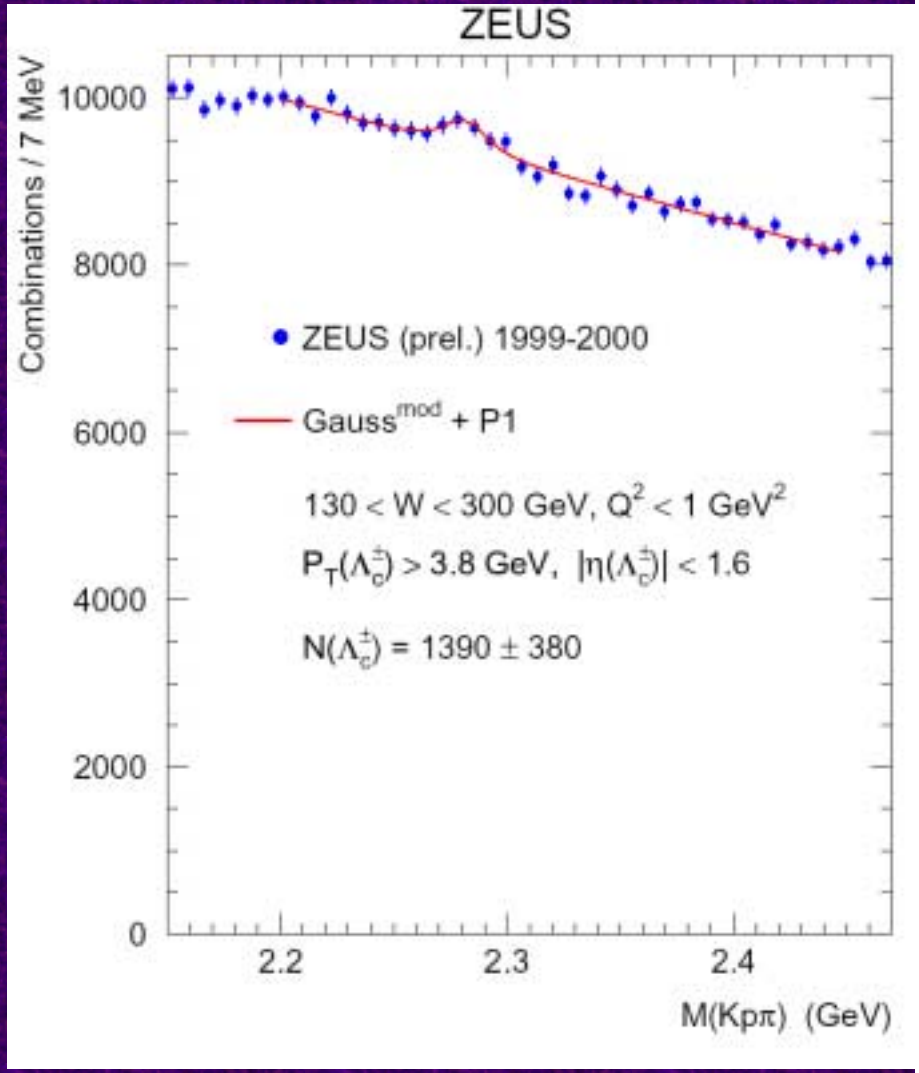


HQ & Polarisation

- Polarisation in DIS will be a unique tool @ HERA II for exploring EW couplings.
- In principle the spin orientation of the struck quark can carry through a memory into the final-state hadron.
- In c and b production, one can be sure that the struck quark is in one of the c or b hadrons and there is a correlation between the detected heavy-quark hadron and the struck quark.
- Using weak decay of Λ_c, can analyse for spin orientation of struck quark and hence disentangle spin-dependent σs.

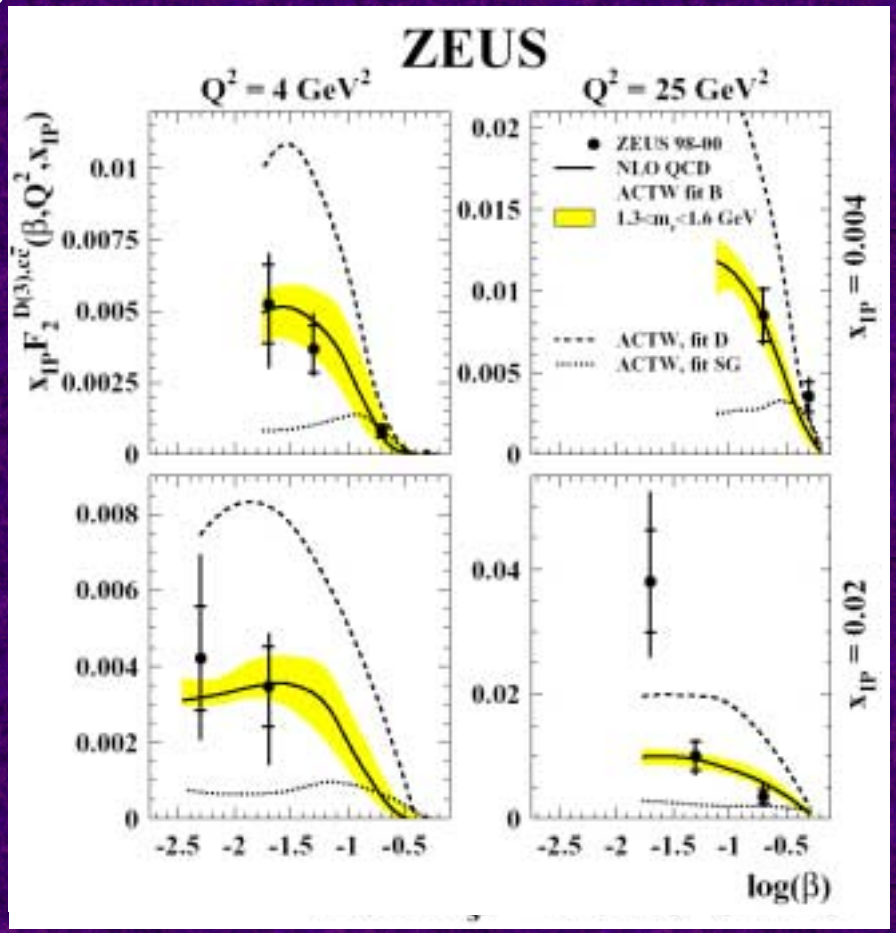
HQ & Polarisation

- But first signal reported for inclusive Λ_c production reported at this year's conferences, so difficult to believe that statistically significant results can be obtained via this technique.



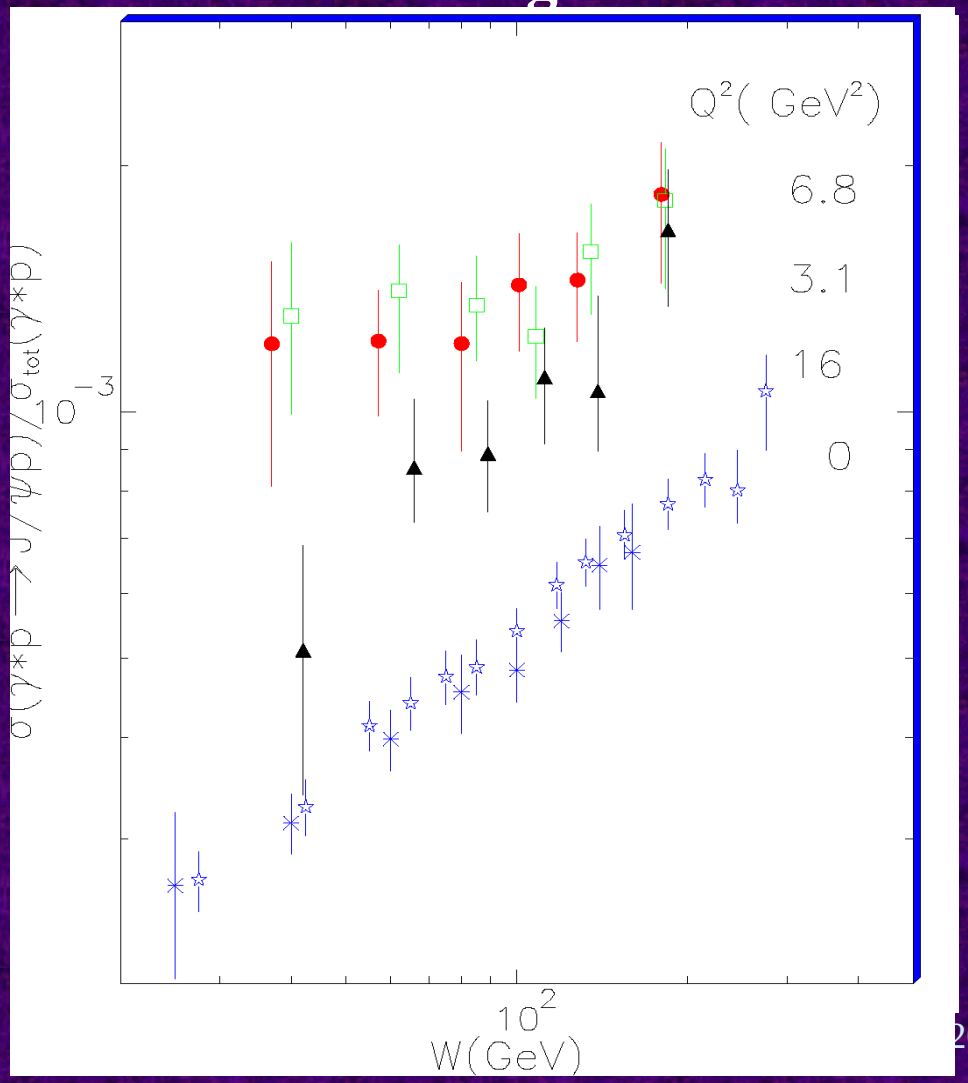
HQ in Diffraction

- The structure of diffraction and its mechanism and explanation in the framework of pQCD is one of the most fruitful areas of HERA I physics.
- In the charm sector, very strongly limited by statistics.
- However, also very good discrimination amongst models – one of the areas where we will most benefit from the statistics of HERA II.



HQ in Diffraction

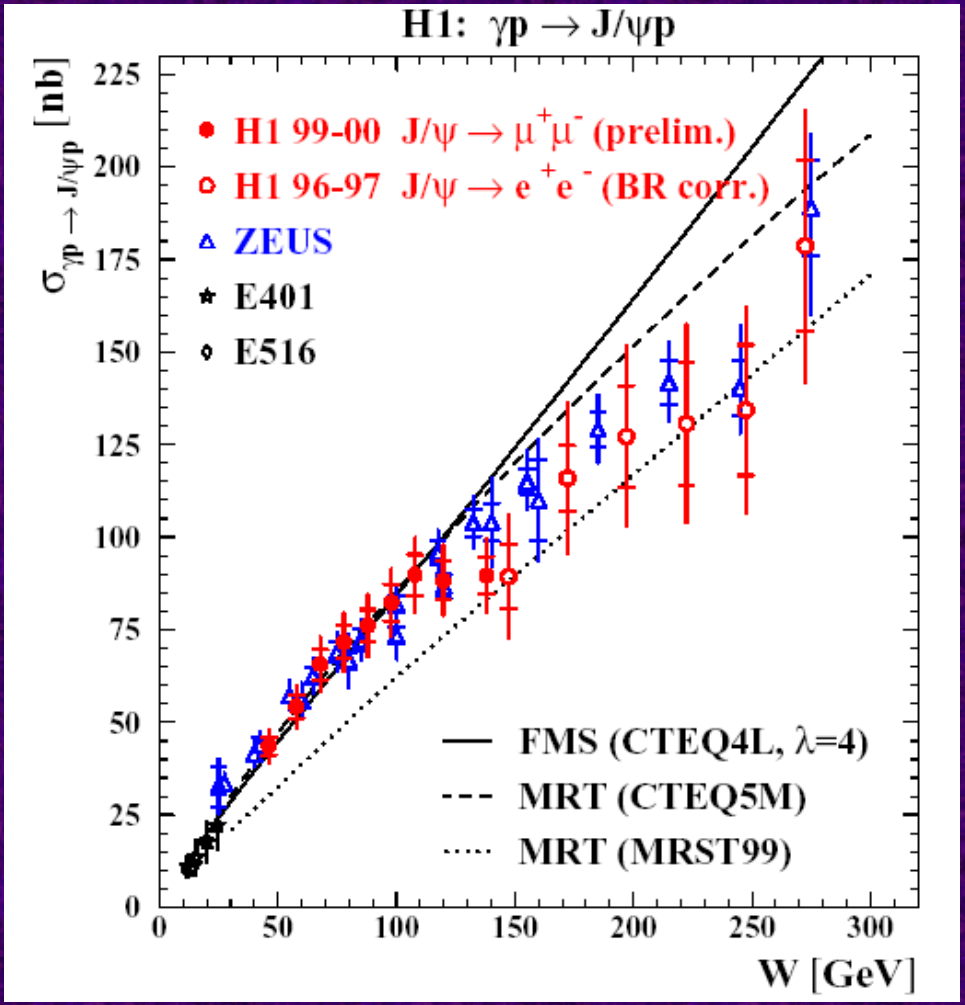
- Charm production cf inclusive F_2 will also be additional constraint on gluon pdf of diffractive exchange.
- In exclusive processes, the heavy c quark gives clearly different behaviour to light quarks – opening the relationship of QCD models of diffraction.
- One of the areas where one clearly sees the effect of m_c as a hard scale. Again, in all of these studies, the statistics of HERA II will be decisive.



HQ in Diffraction

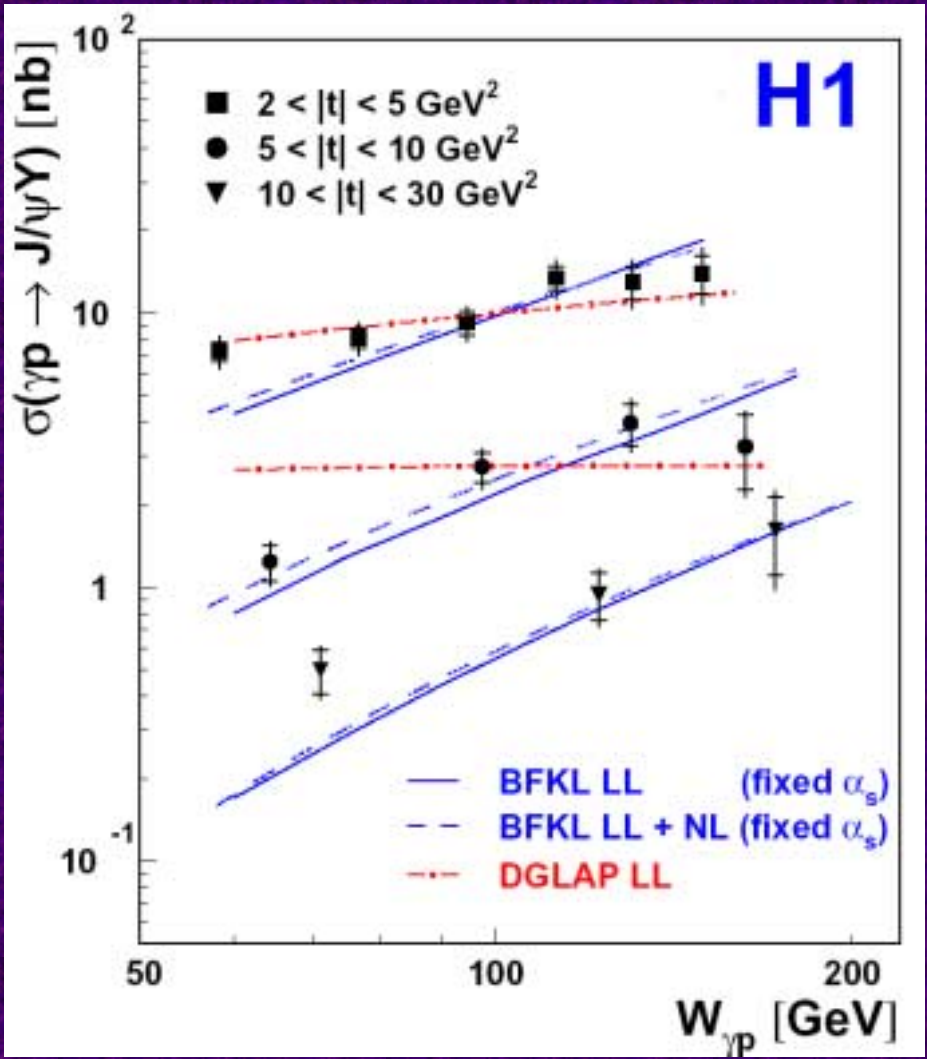
- Diffractive VM production in photoproduction now in much better agreement between H1 and ZEUS.

- Some statistics gain still to be expected at the highest W, and some extra kinematic reach from the extended tracking in the detectors, but generally HERA II data will not add so much to the current picture.



HQ in Diffraction

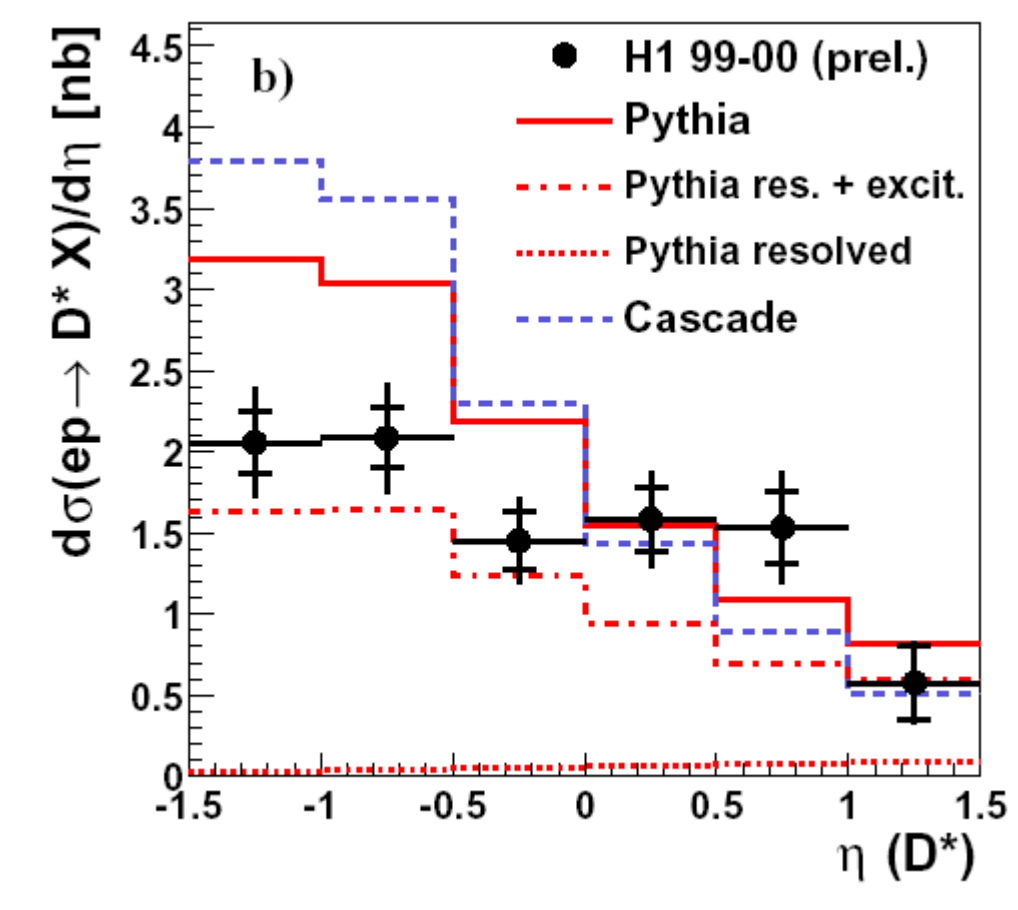
- Diffractive J/ψ production in photoproduction at high t sensitive tool to QCD evolution in diffraction.
- Again, obviously statistics limited and these type of studies will greatly benefit from HERA II data; the very distinctive final state and kinematic regime should allow efficient triggers at HERA II.
- Saturation models can also describe many features of J/ψ data.



HQ in Photoproduction

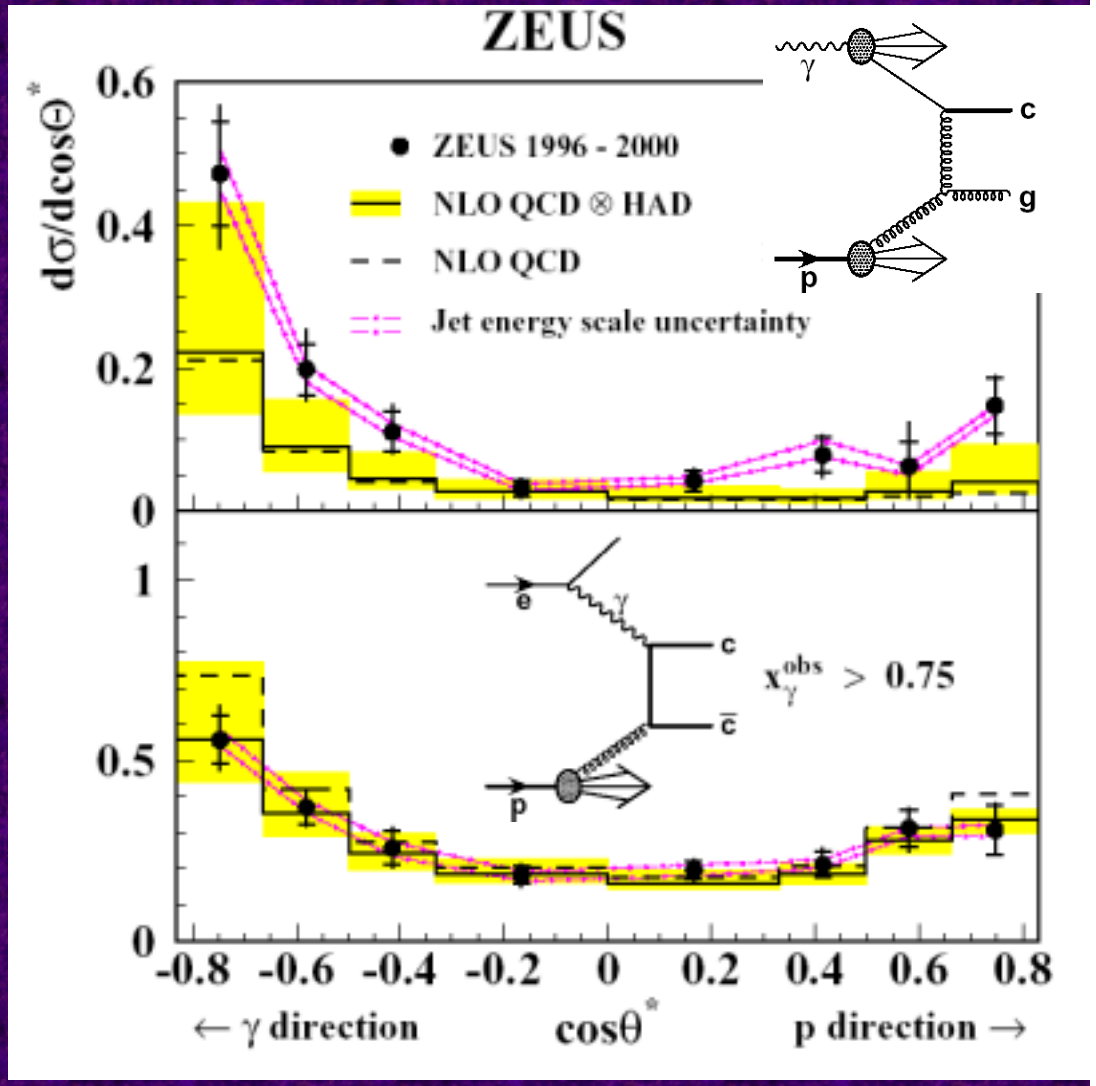
- In general statistics not a problem with photoproduction results, except where extra requirements on tagging – e.g. double jet tags.

- However, we still have considerable work to do to understand the details even of relatively simple quantities such as inclusive differential cross sections.



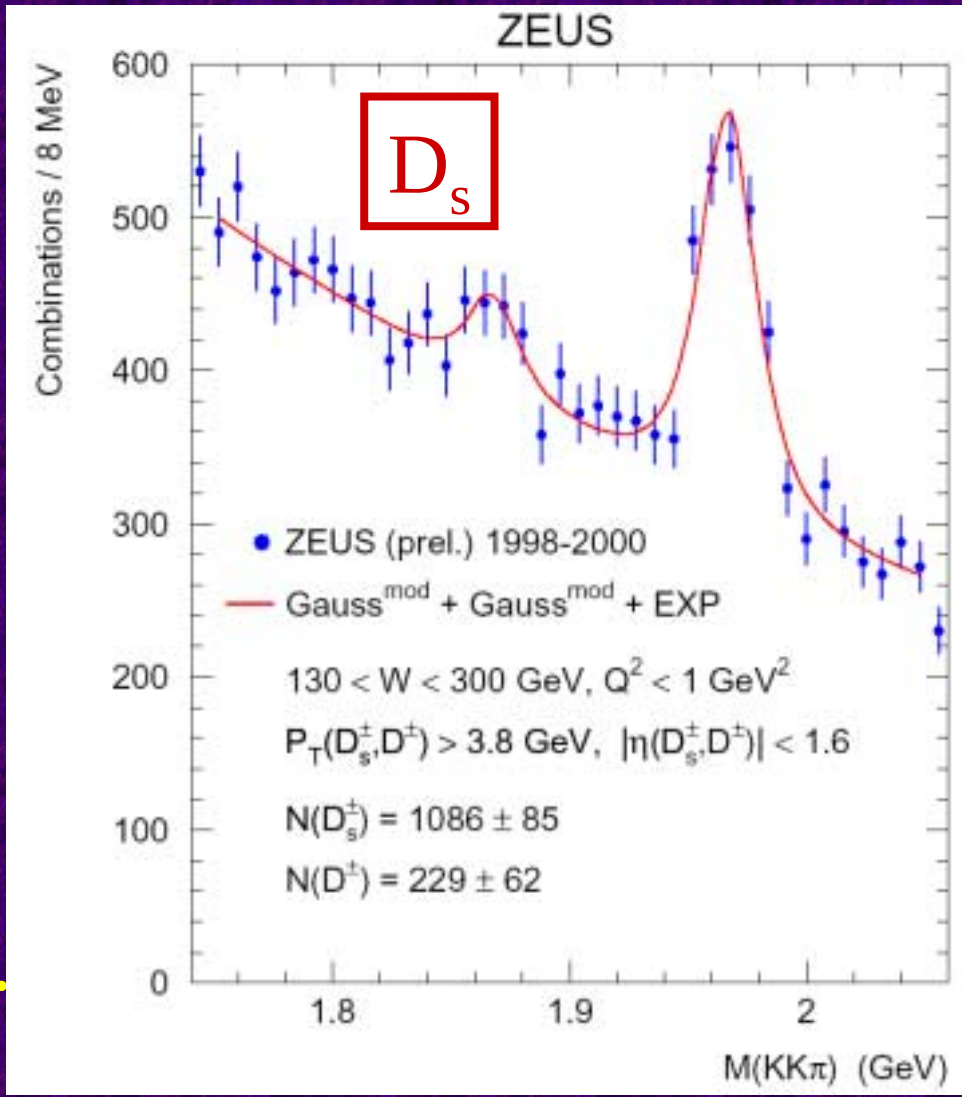
HQ in Photoproduction

- Study of angular distributions in dijet events where one of the jets contains a D* can disentangle the dynamics of the c-production process.
- In principle, this method, with greatly increased statistics at HERA II, can lead to determination of c (and g) density in γ.



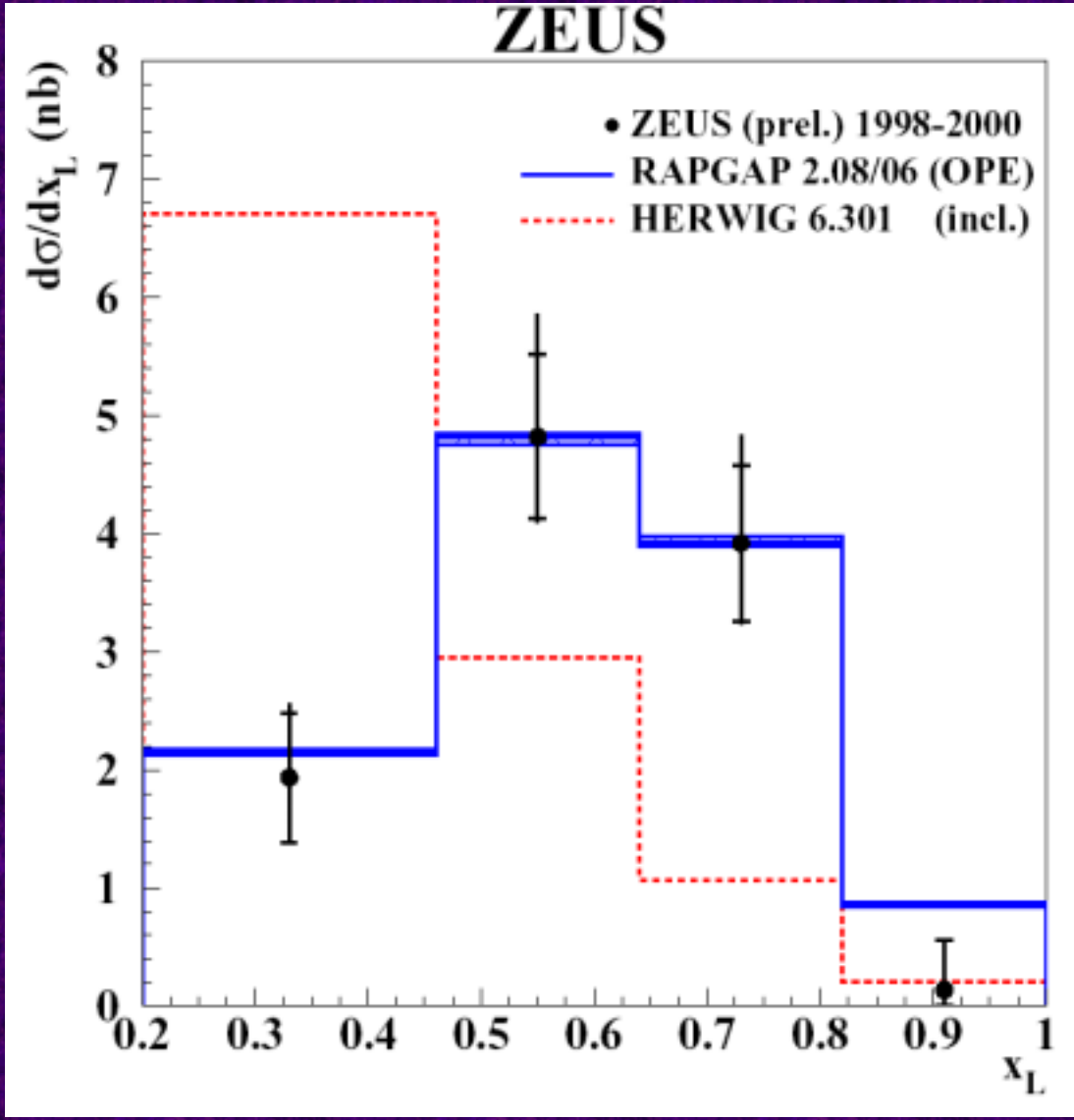
HQ in Photoproduction

- Since charm tagging works over a wide range of momenta, has rather high efficiency and high purity, charm is a useful method to look at fragmentation.
- The study of all these charm particles has allowed the determination of fragmentation probs. to u,d, ratios of P/V, strangeness suppression etc. to ~5 – 10%. This can certainly be improved at HERA II.



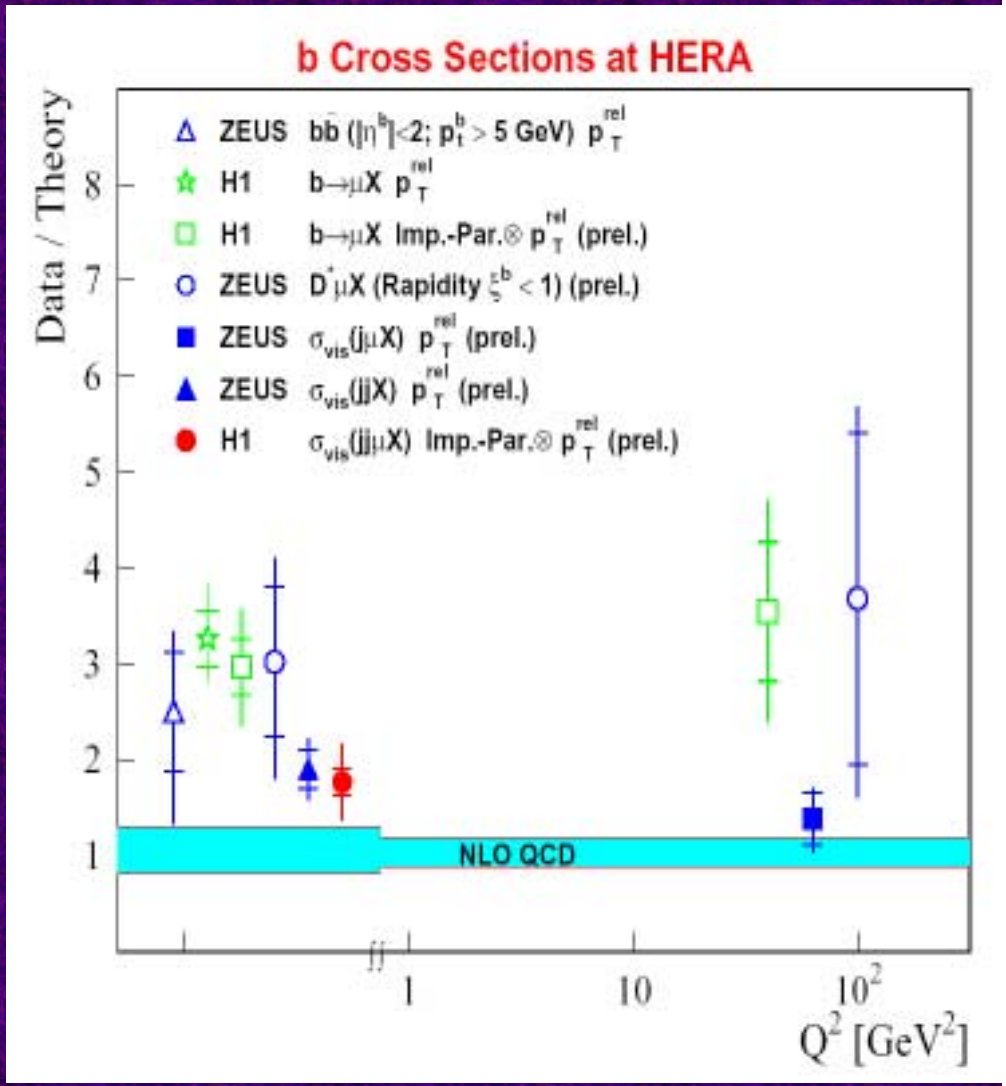
HQ in Photoproduction

- By looking at events containing leading neutrons and a charm tag, we can get a handle on the c (& g) density in the π.
- This is a classic "double-tag" experiment which needs the increased statistics of HERA II (and more!).



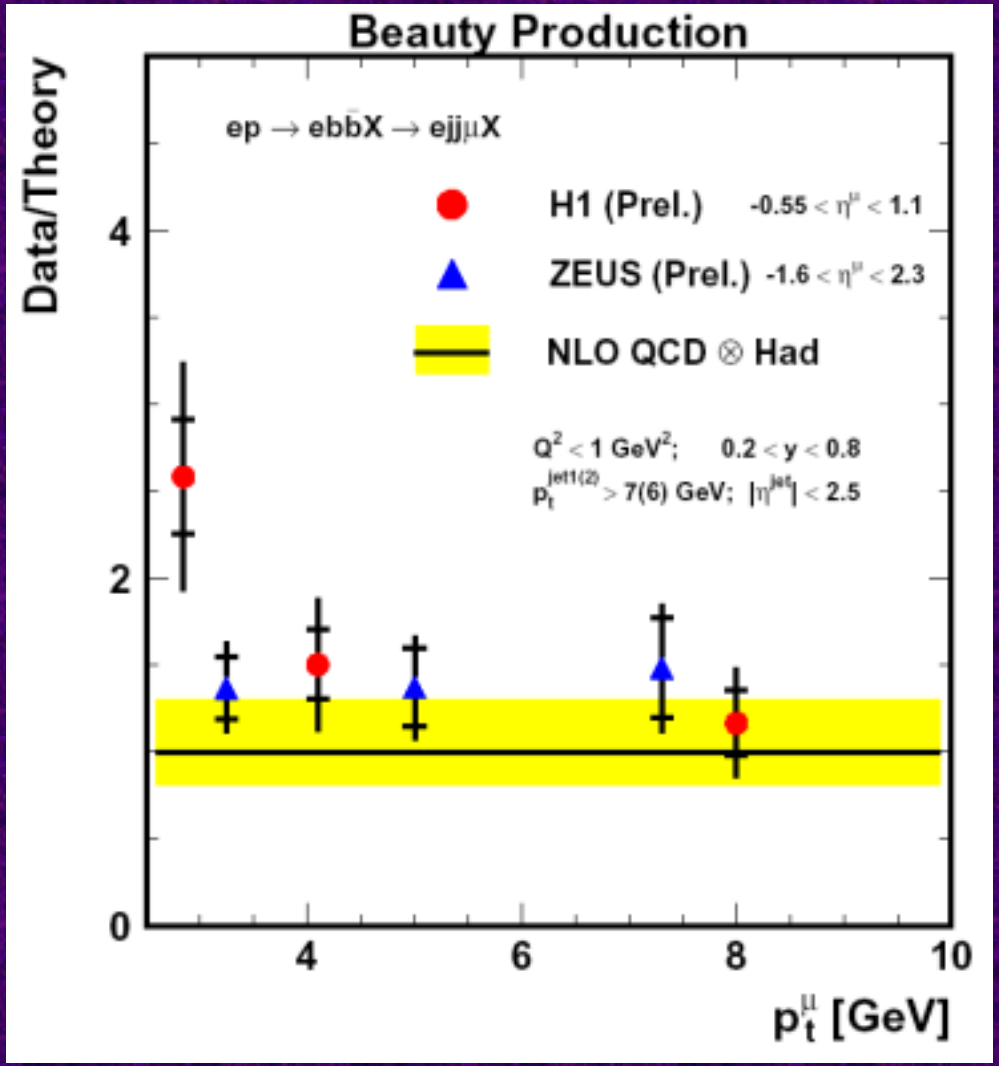
B production

- B production both in photoproduction and DIS is really in its infancy at HERA I and will be a major study at HERA II.
- The most recent results from H1 & ZEUS for photoproduction imply a much smaller discrepancy between data and NLO QCD
- Related to differences in extrapolation from meas. σ for fully inclusive and dijet final states.



B production

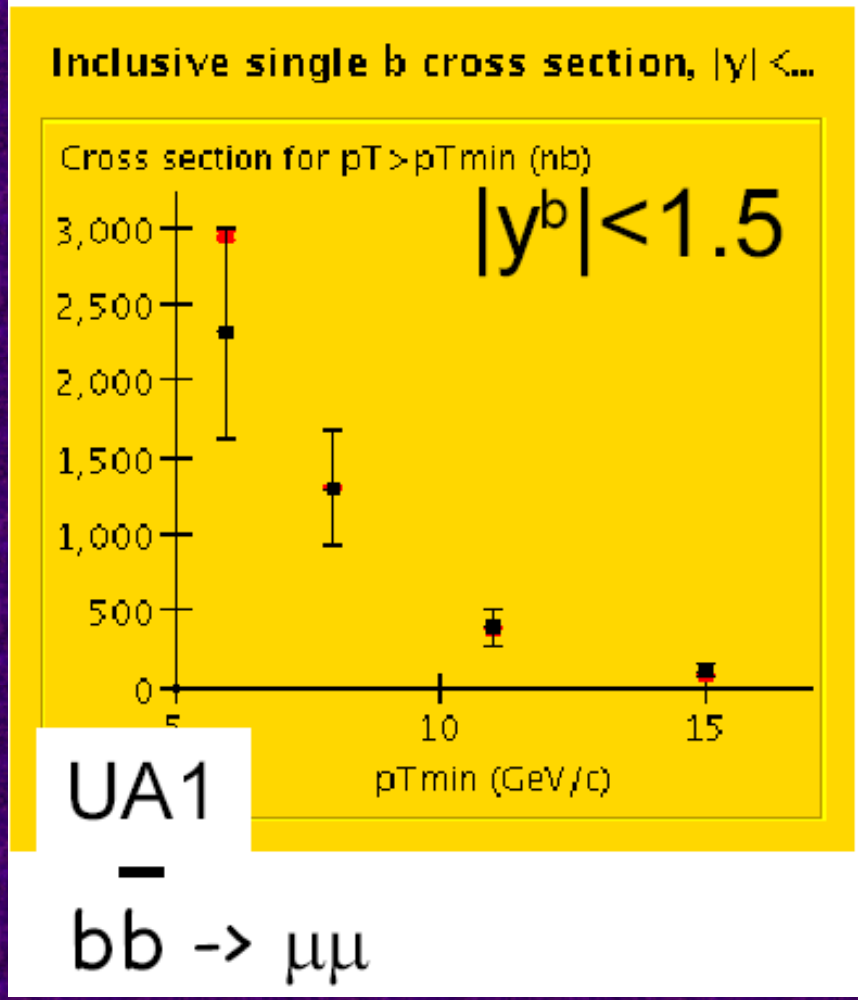
- Good agreement between H1 & ZEUS, and with NLO QCD.



- However…

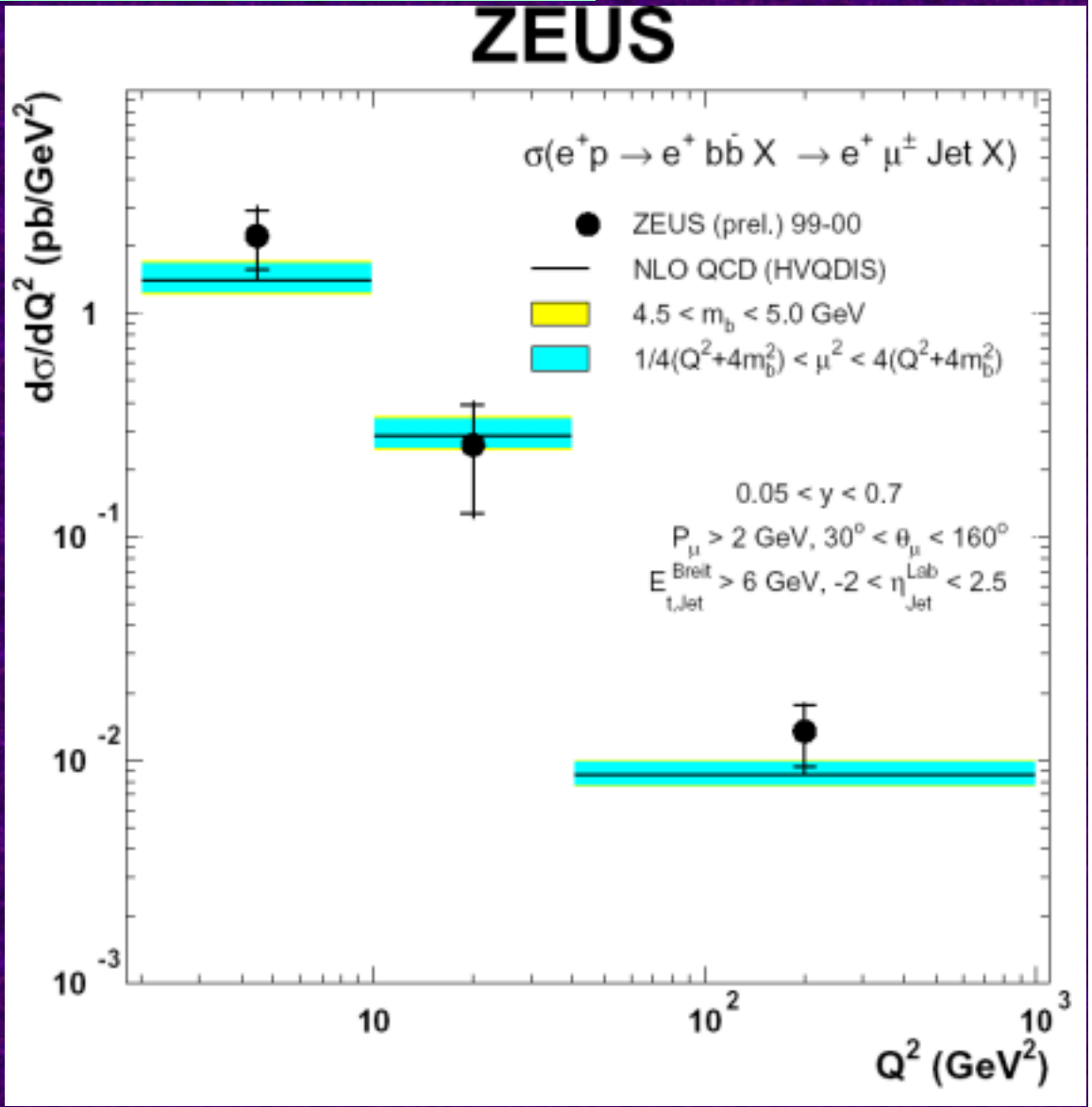
B production

- **Jetweb –** http://jetweb.hep.ucl.ac.uk **allows comparison between different experiments with implementation of experimental cuts. Comparison with PYTHIA LO +PS scaled to HERA jet σ predicts HERA & Tevatron etc. σ(b).**
- **There may still be a problem with the QCD prediction of σ(b) being too low – but it is surely less than we thought and this will have to wait for HERA II.**



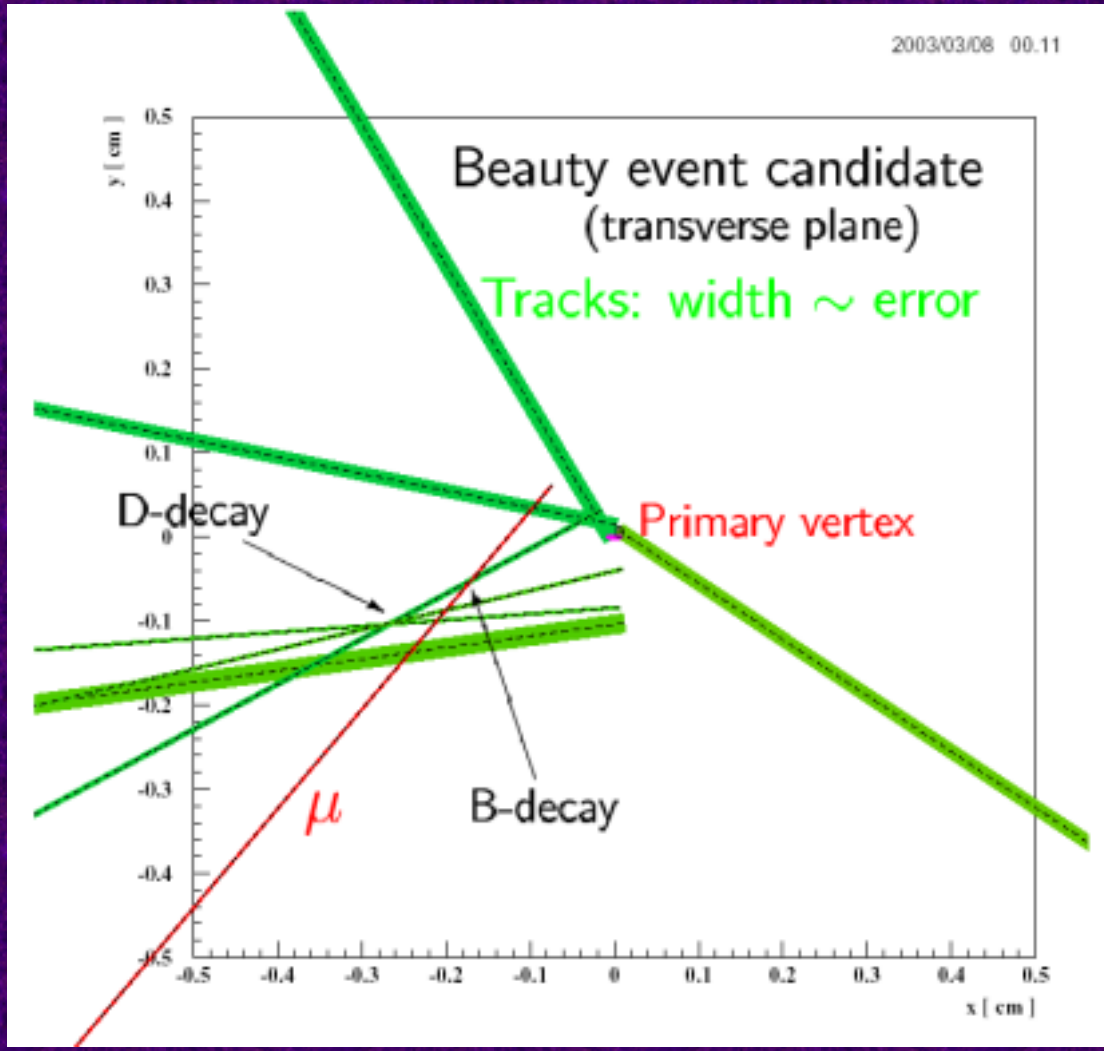
B production

- However, at least in DIS, we seem to have a reasonable understanding of the differential cross sections also.
- But we need many more than 3 bins! => HERA II.



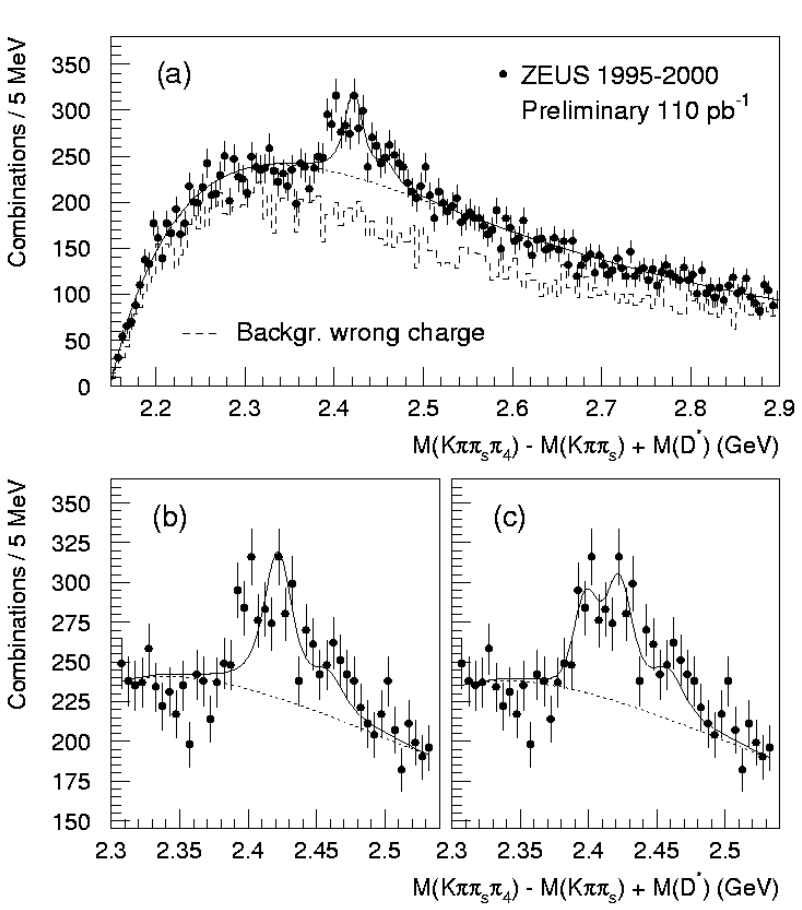
B production

- One of the things we have seen start at HERA I has been the use of the vertex detectors to do vertex tagging.
- This will be the name of the game at HERA II.

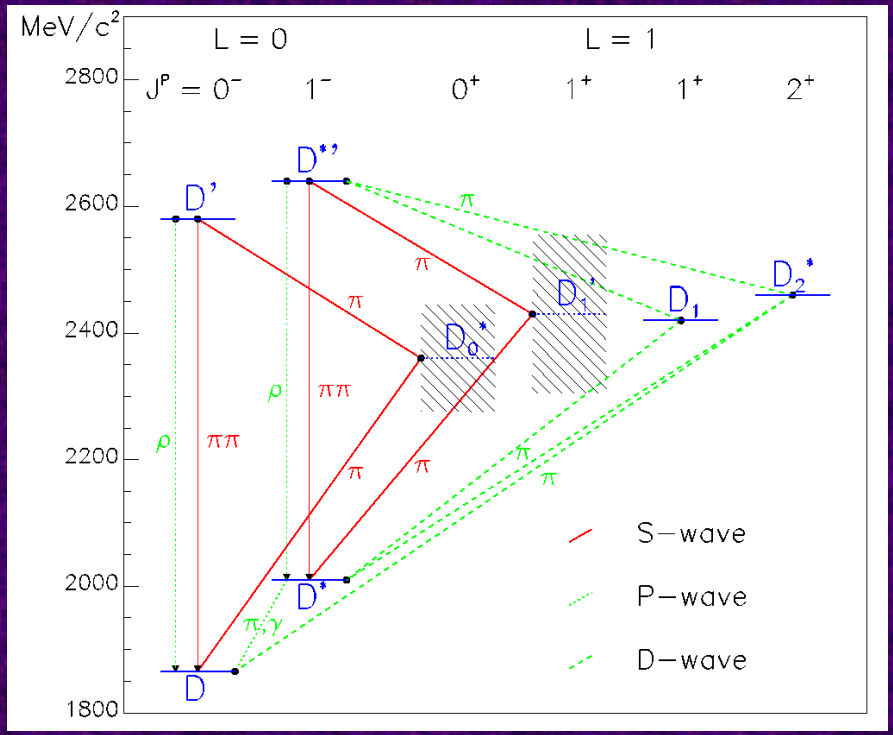


Charm spectroscopy in γp

- **The large HERA I data sample gave the opportunity to make useful contributions to charm spectroscopy.**

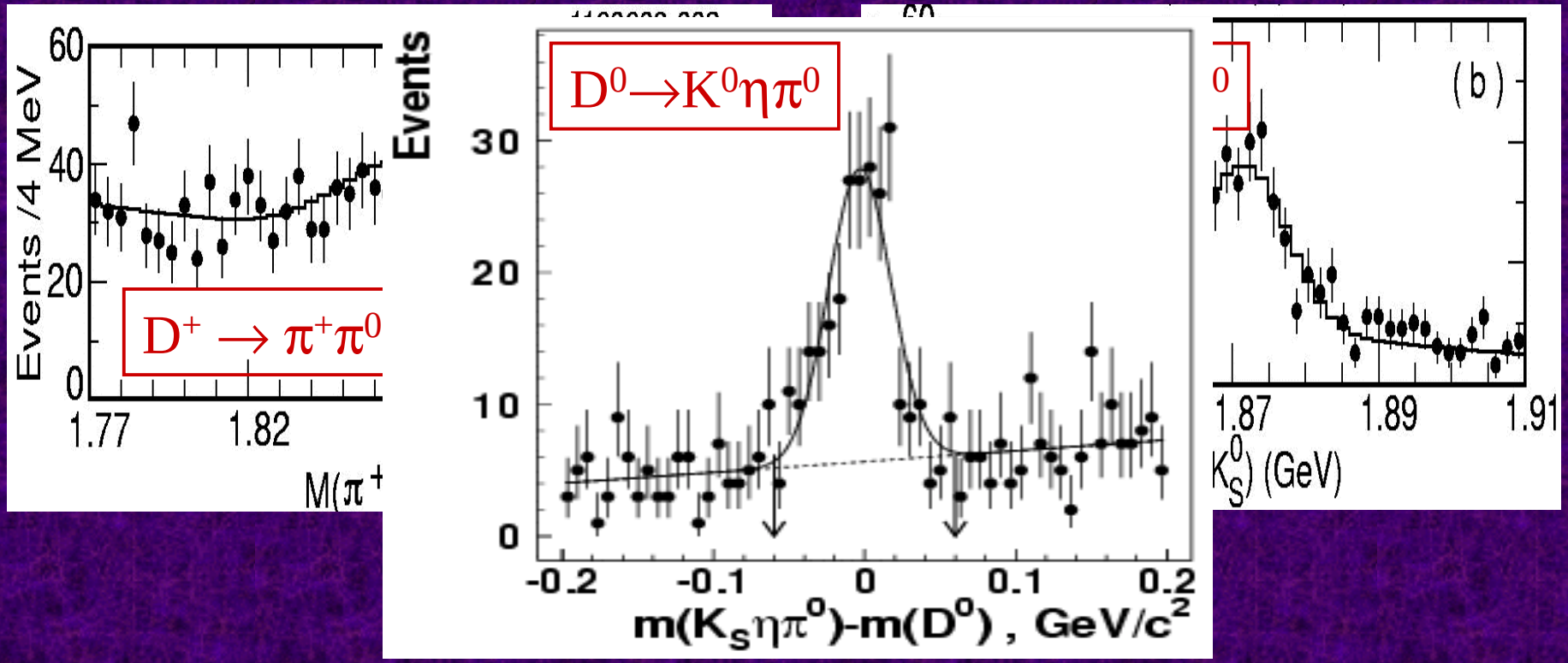


- Rich spectrum - D_1 ,D_2* established; D*' seen by DELPHI, not OPAL/CLEO



Charm spectroscopy in γp

- However, the B and c/τ factories are now going full steam ahead and will make even the HERA II data samples insignificant e.g. in 2004, CLEO-c plans 6M tagged D decays.

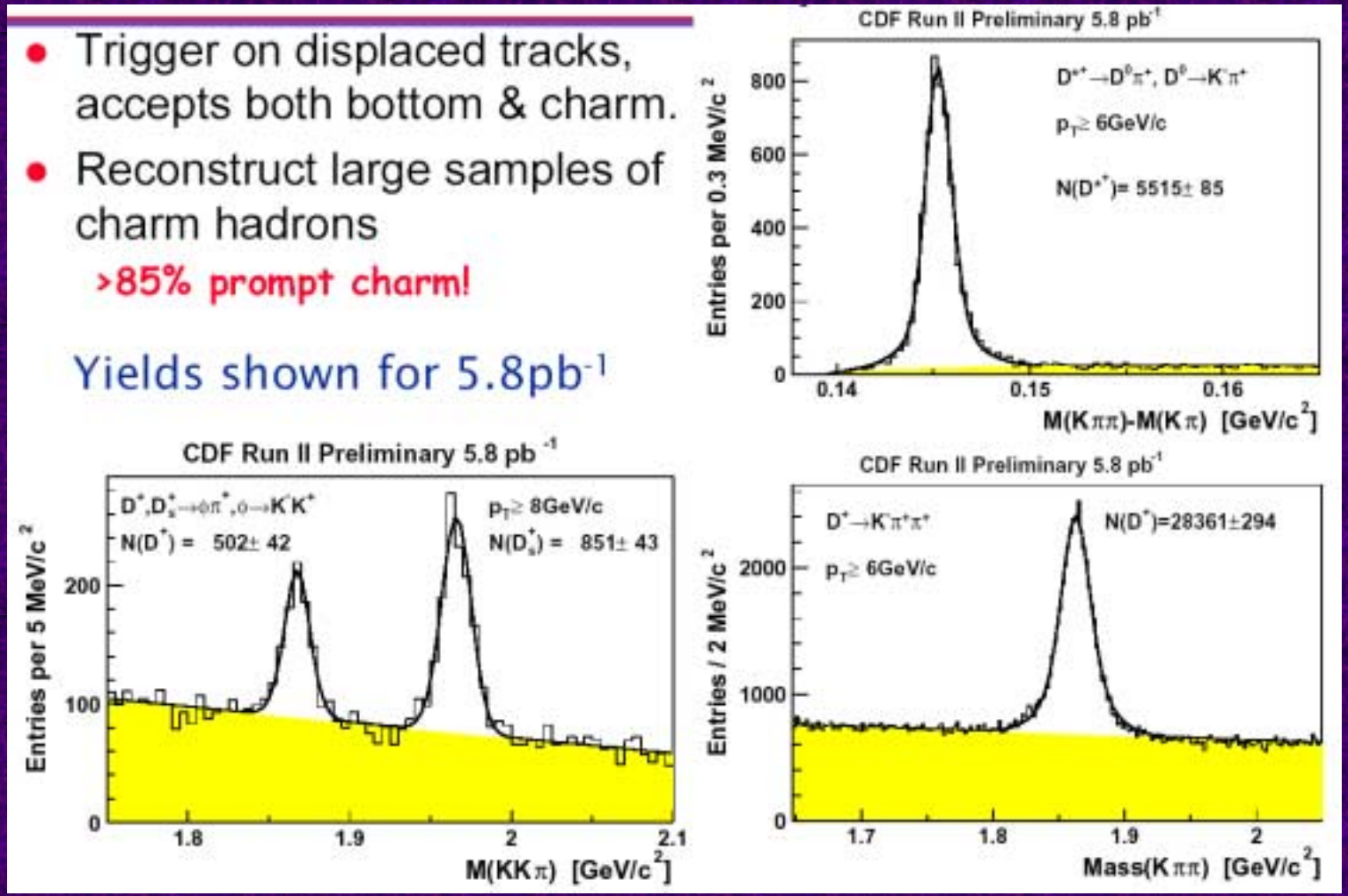


Charm spectroscopy in CDF

- **And that is even before thinking about CDF….**

- Trigger on displaced tracks, accepts both bottom & charm.
- Reconstruct large samples of charm hadrons
  - >85% prompt charm!

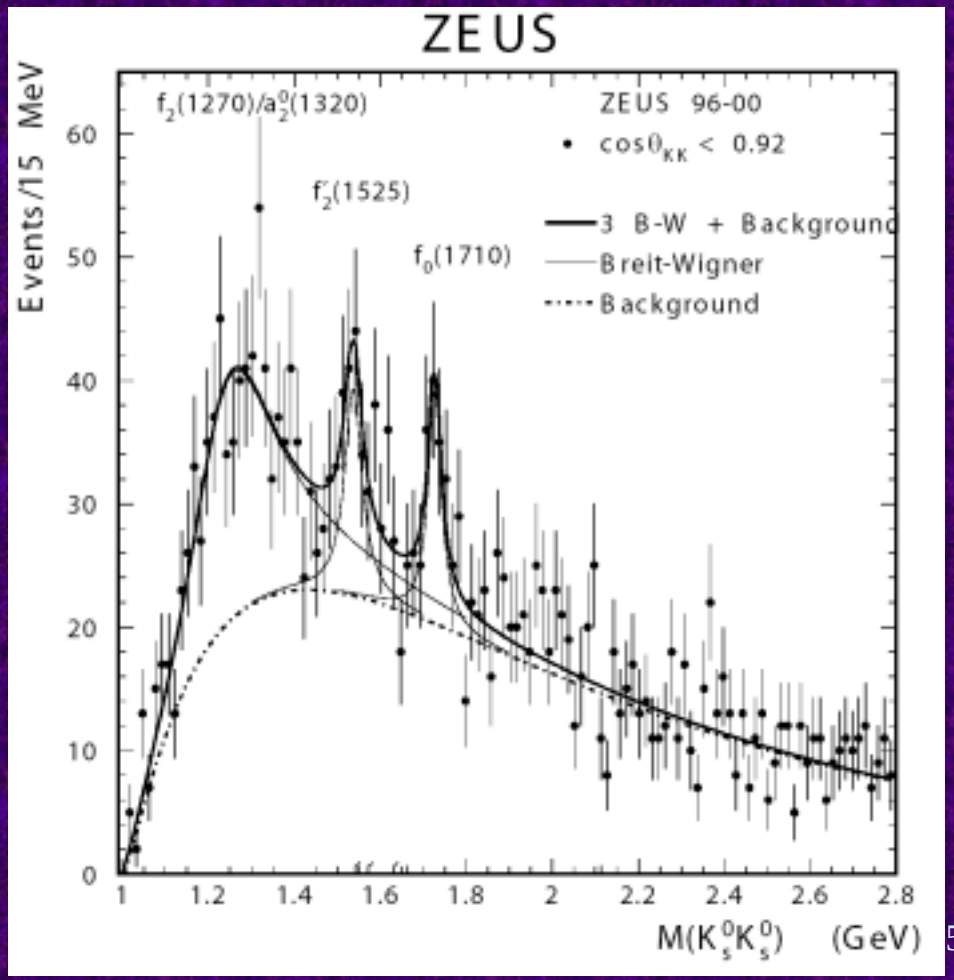
Yields shown for 5.8pb^{-1}



- **For "standard" spectroscopy, HERA II not competitive.**

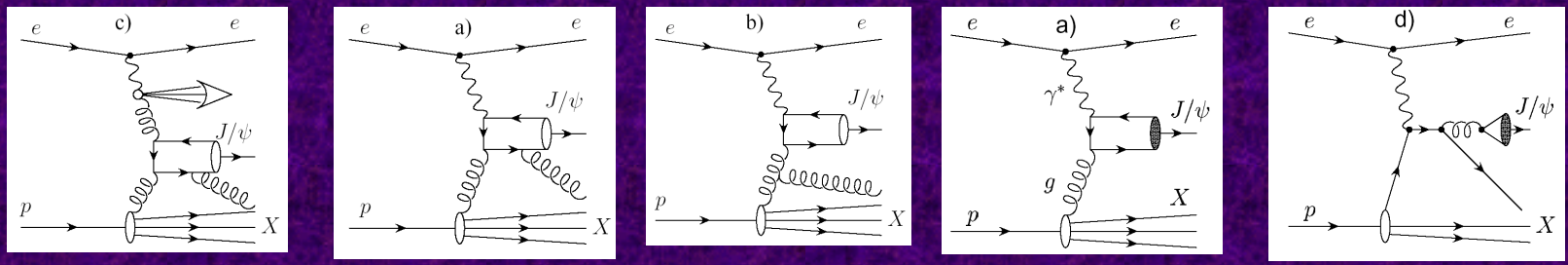
Charm spectroscopy

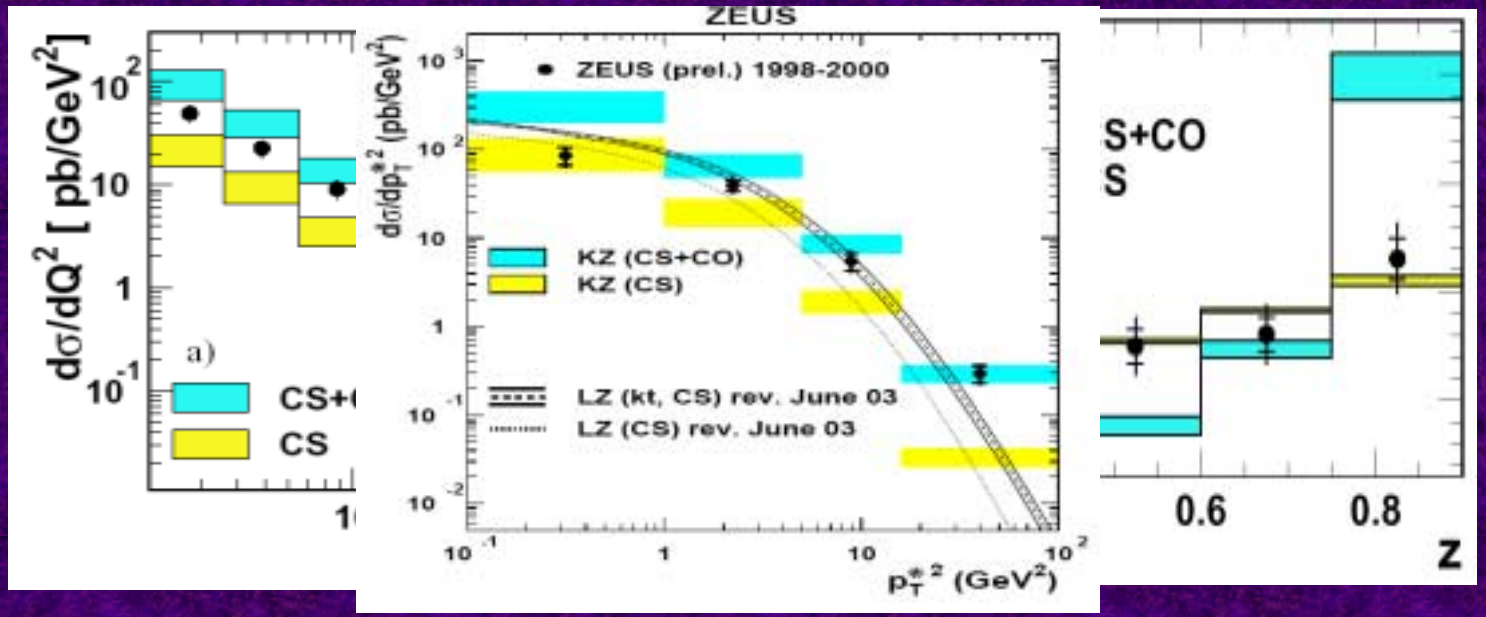
- However HERA II can reach states that other machines cannot reach – e.g. states coupling strongly to gluons can be copiously produced at HERA.
- Not obvious why such states should want to decay to charm; but then we didn't expect to see them in light-quark decays either.
- Pentaheavyquarks?
- HERA II can do charm spectroscopy – we should look in those places where we are competitive.



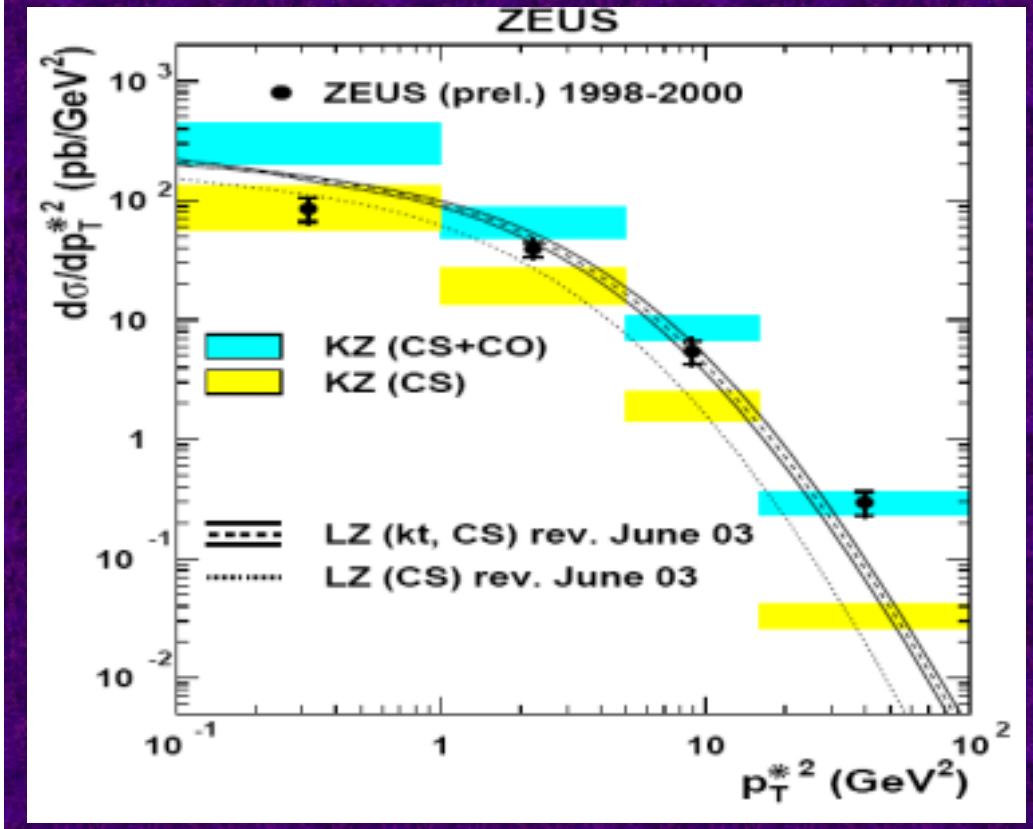
Production mechanisms

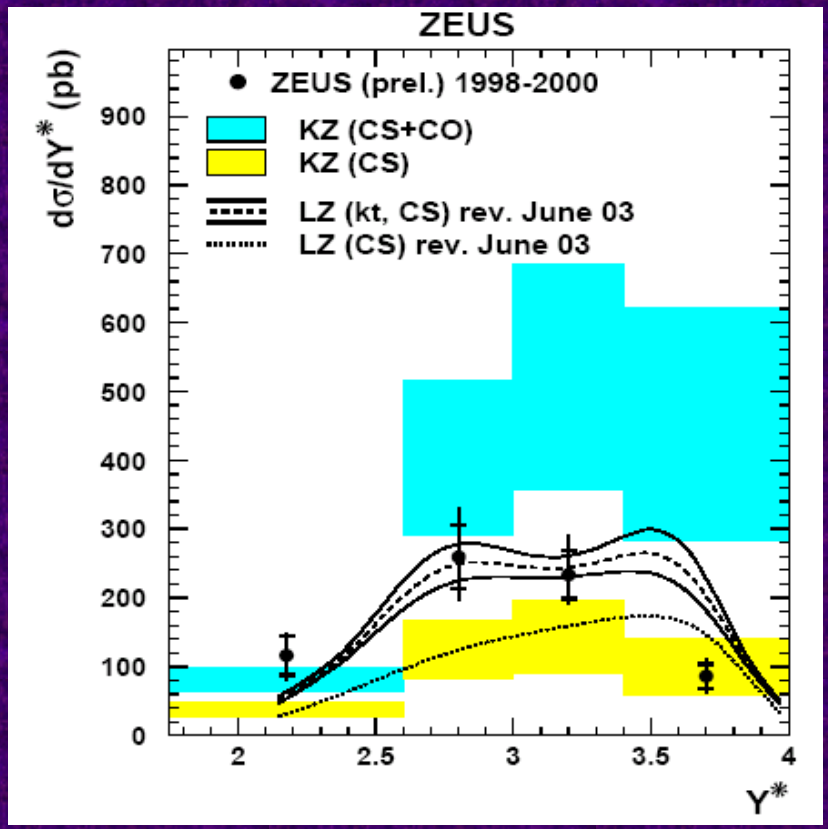
- As an electron-proton collider, HERA II has access to unique production mechanisms that can provide strong tests of QCD.





Production mechanisms

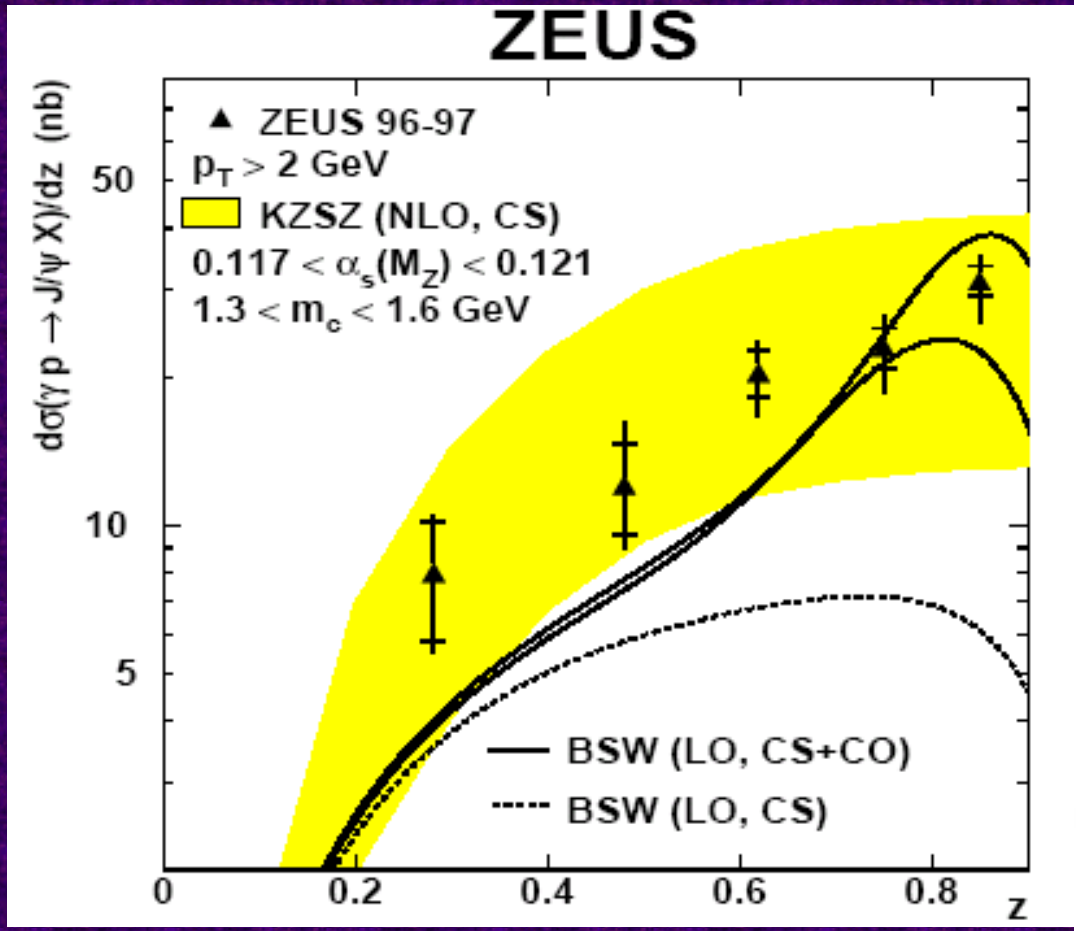




- **Rather good general agreement between Lipatov-Zotov and the data.**

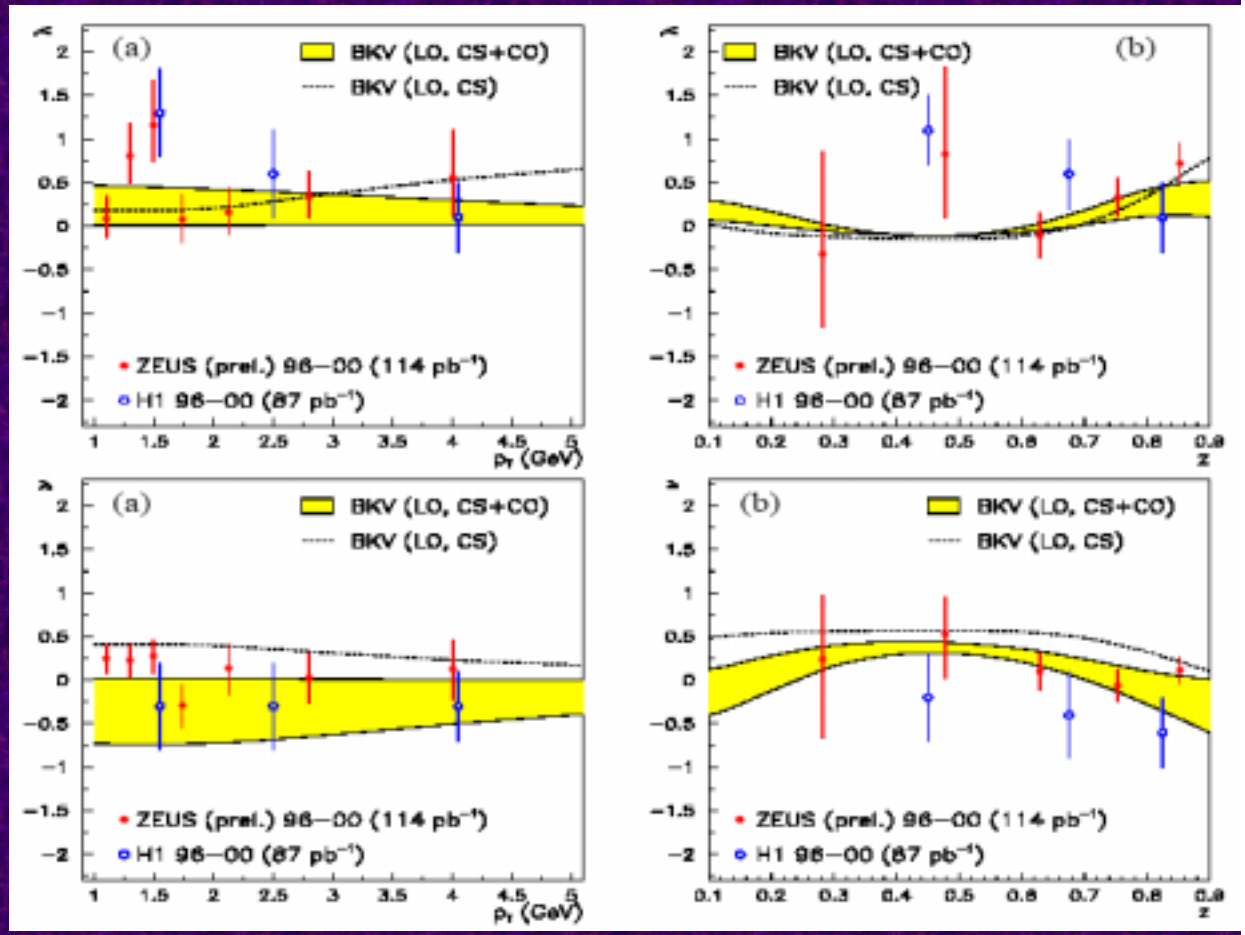
Production mechanisms

- Interplay with Tevatron can give extra constraints on relative importance of CO & CS; large uncertainties in MEs mean not so obvious that HERA II statistics very helpful without significantly more theoretical work.



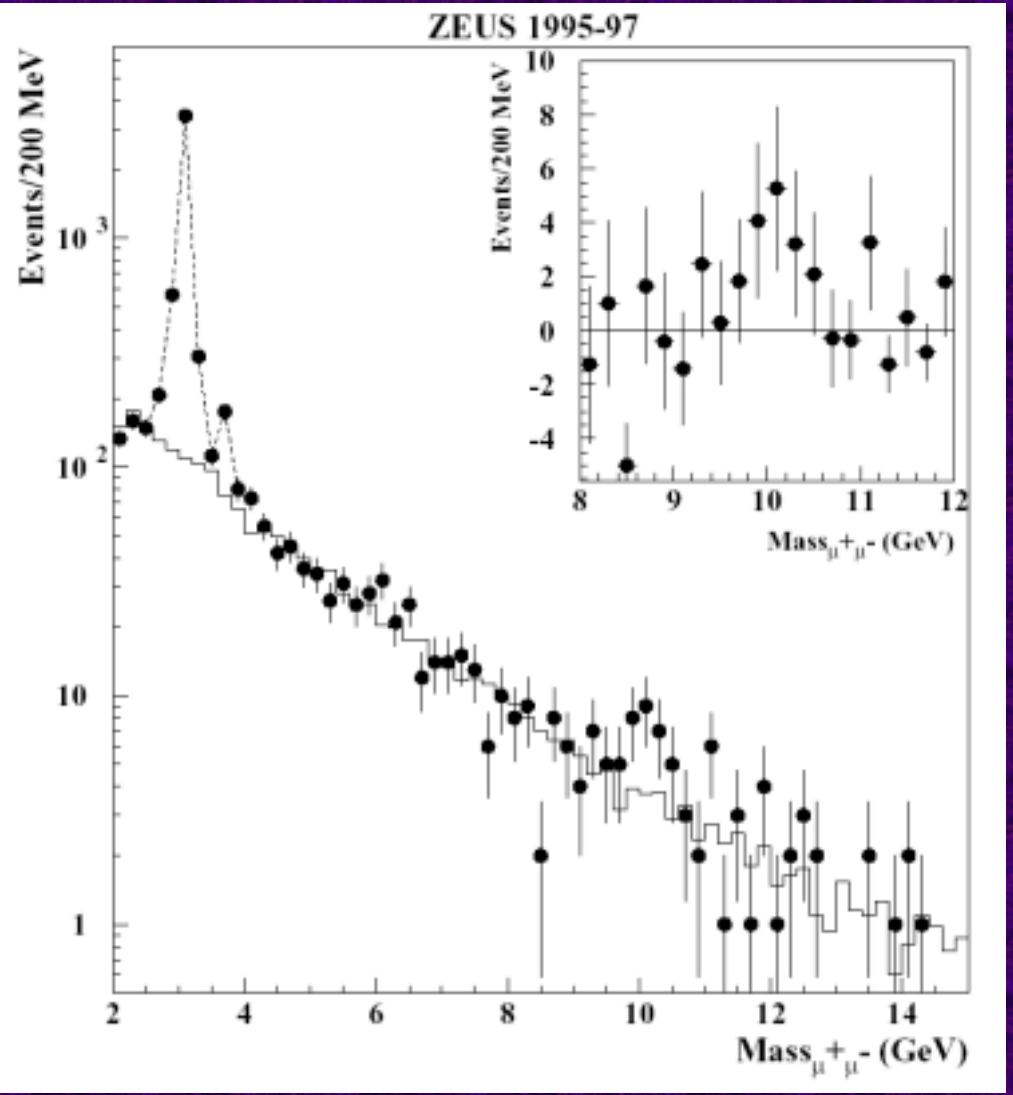
Production mechanisms

- Study of the J/ψ polarisation gives normalisation-independent information to discriminate between models.
- Clearly much more accurate data at HERA II required – and preferably less uncertainty in theory.



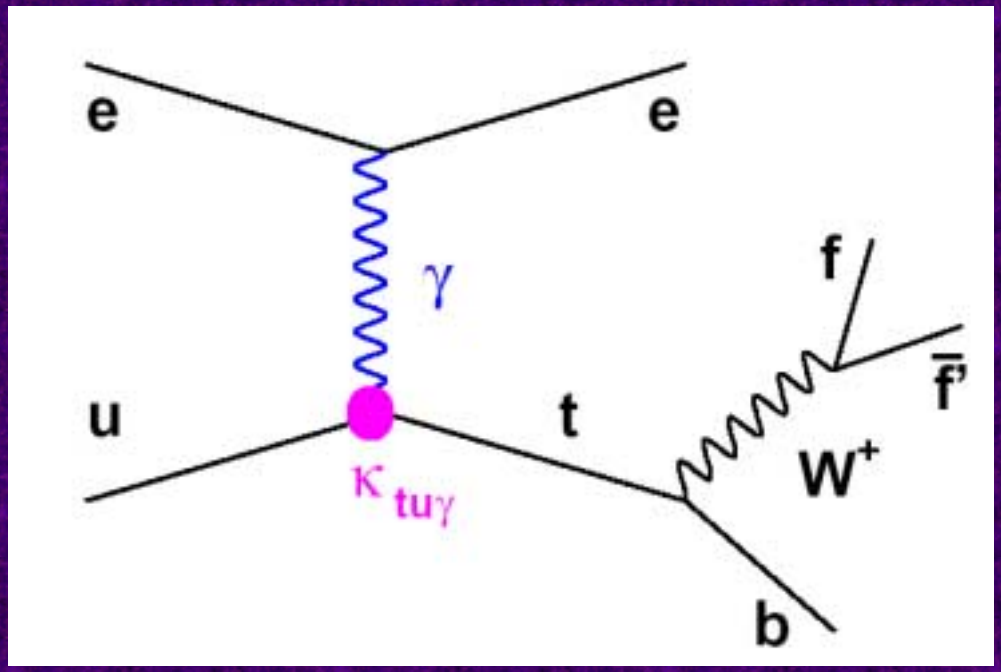
Production mechanisms

- One process at least where we know HERA II will be vital, and which may well be a help in unraveling the J/ψ problems, is ? production – at HERA I we barely (?) saw elastic production, let alone inelastic. However, we probably can expect only < 100 events even at HERA II - probably not enough.



Single top production

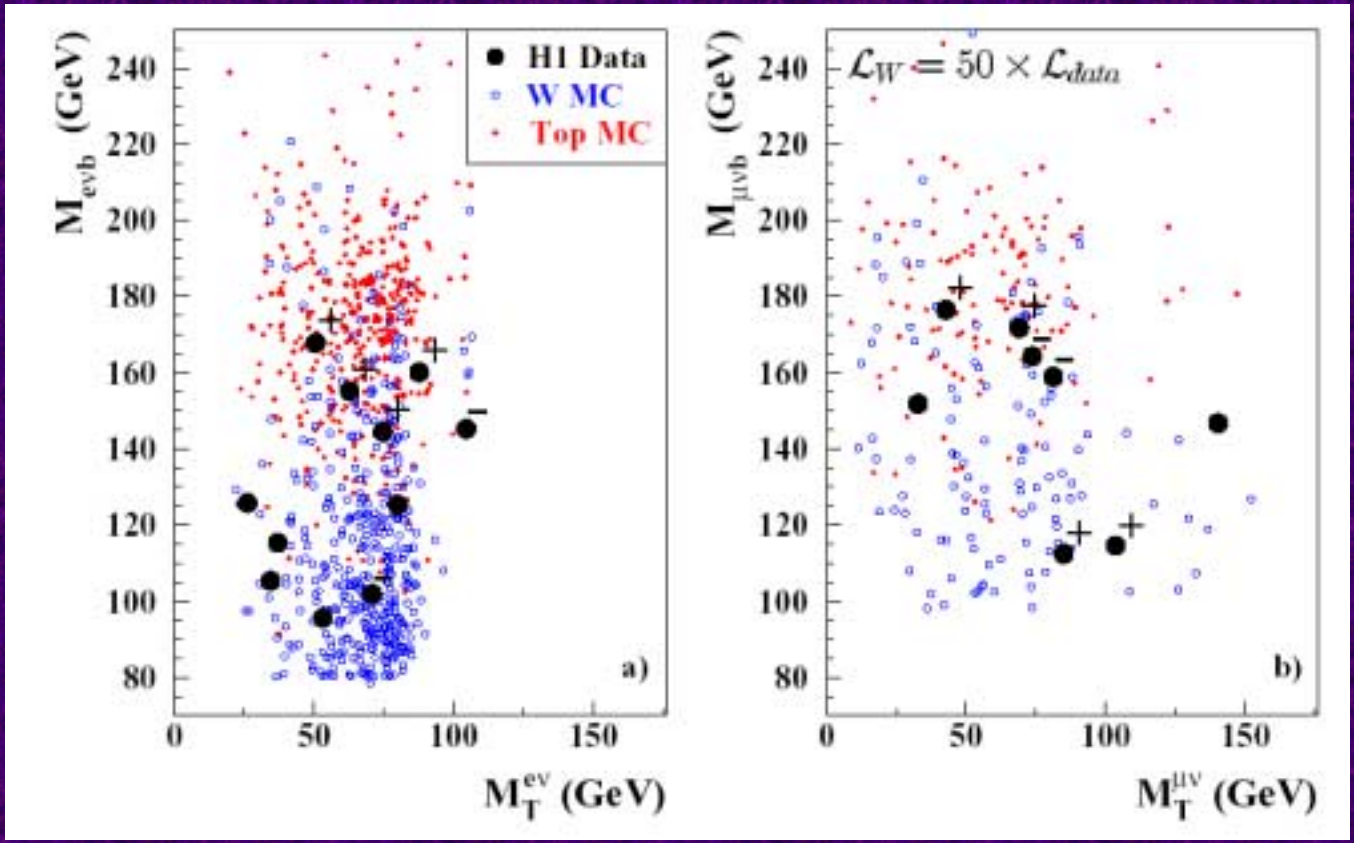
- HERA cannot produce $t\bar{t}$ pairs and single production is highly suppressed in the SM – FCNC process.



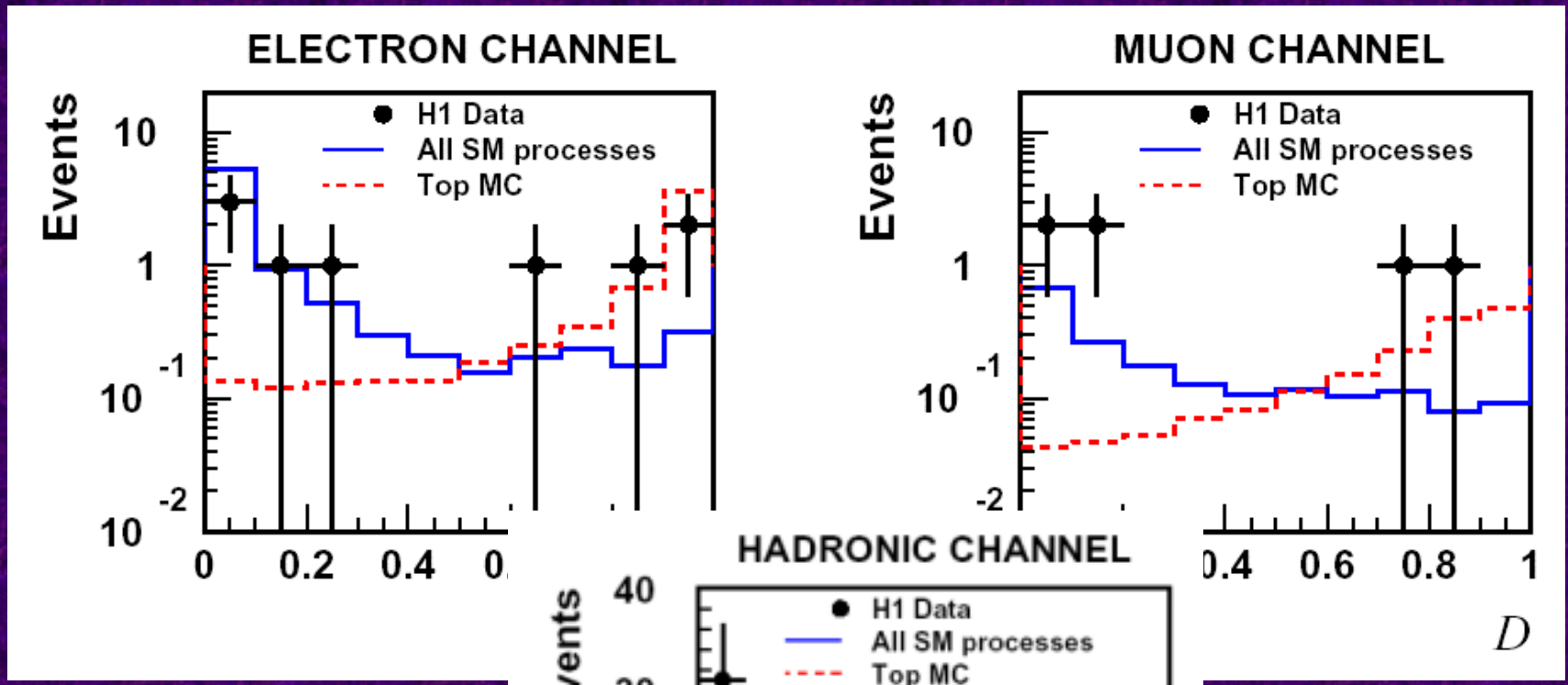
- Observation of events with high p_t lepton, jet and high missing p_t sensitive to this process – and lots of other things.

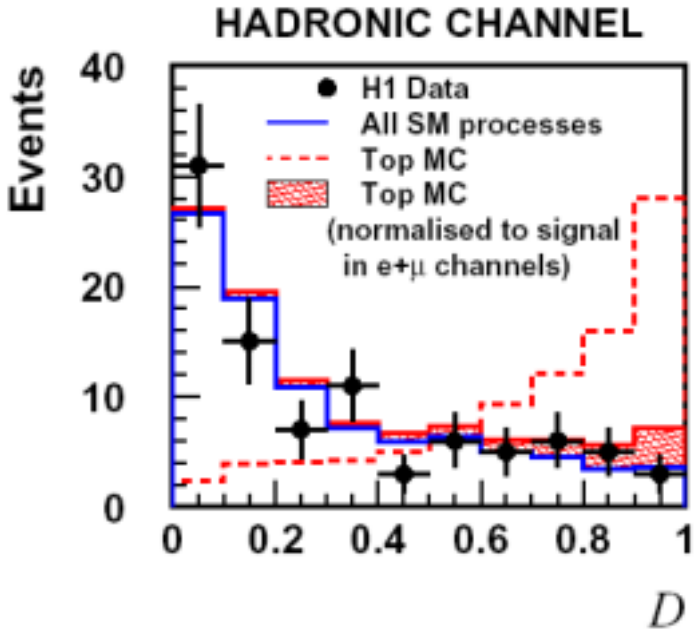
Single top production

- As is well known, there is an excess of such events in H1, although not in ZEUS and not in either experiment in the hadron channel.



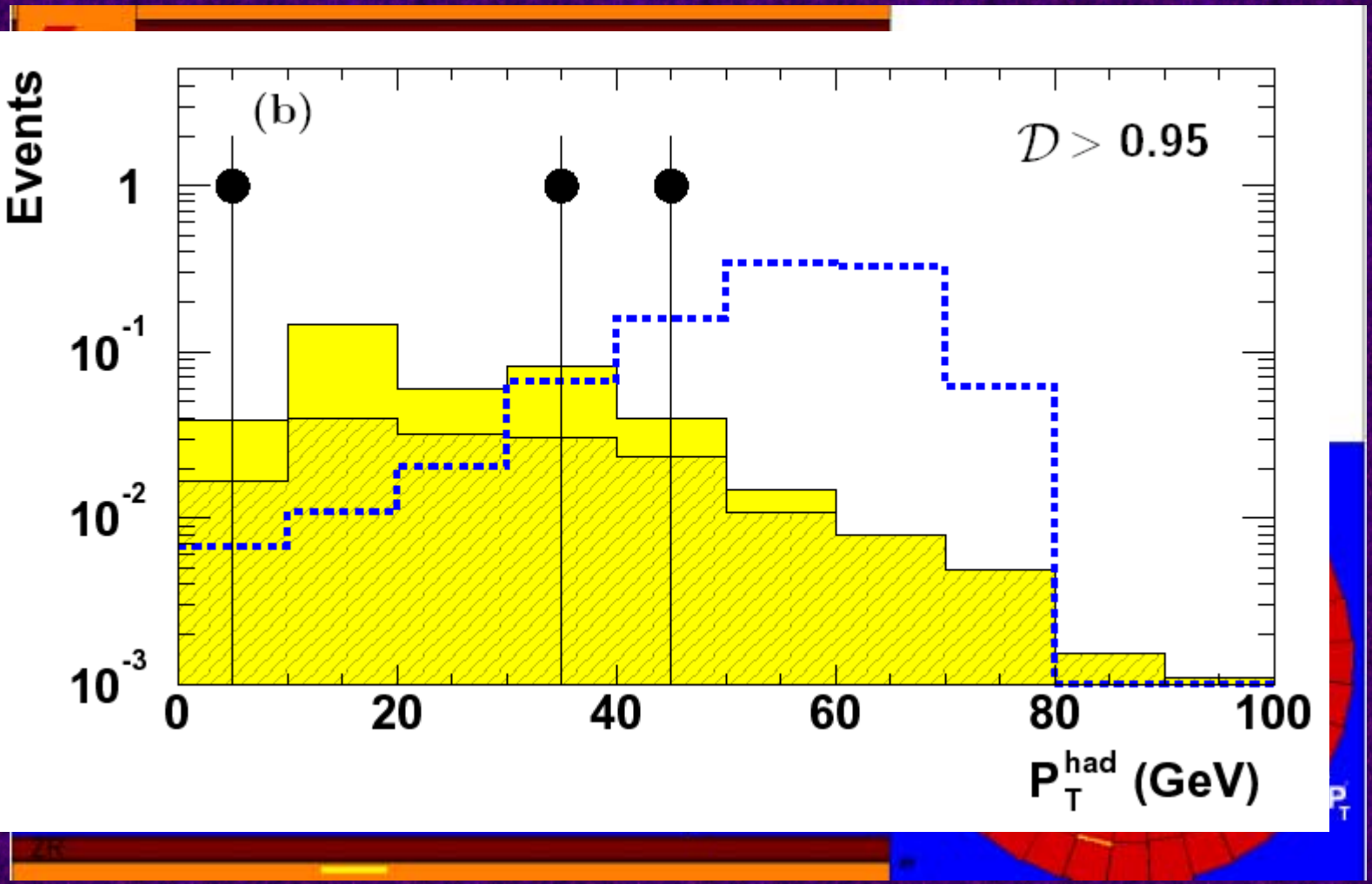
Single top production





Single top production

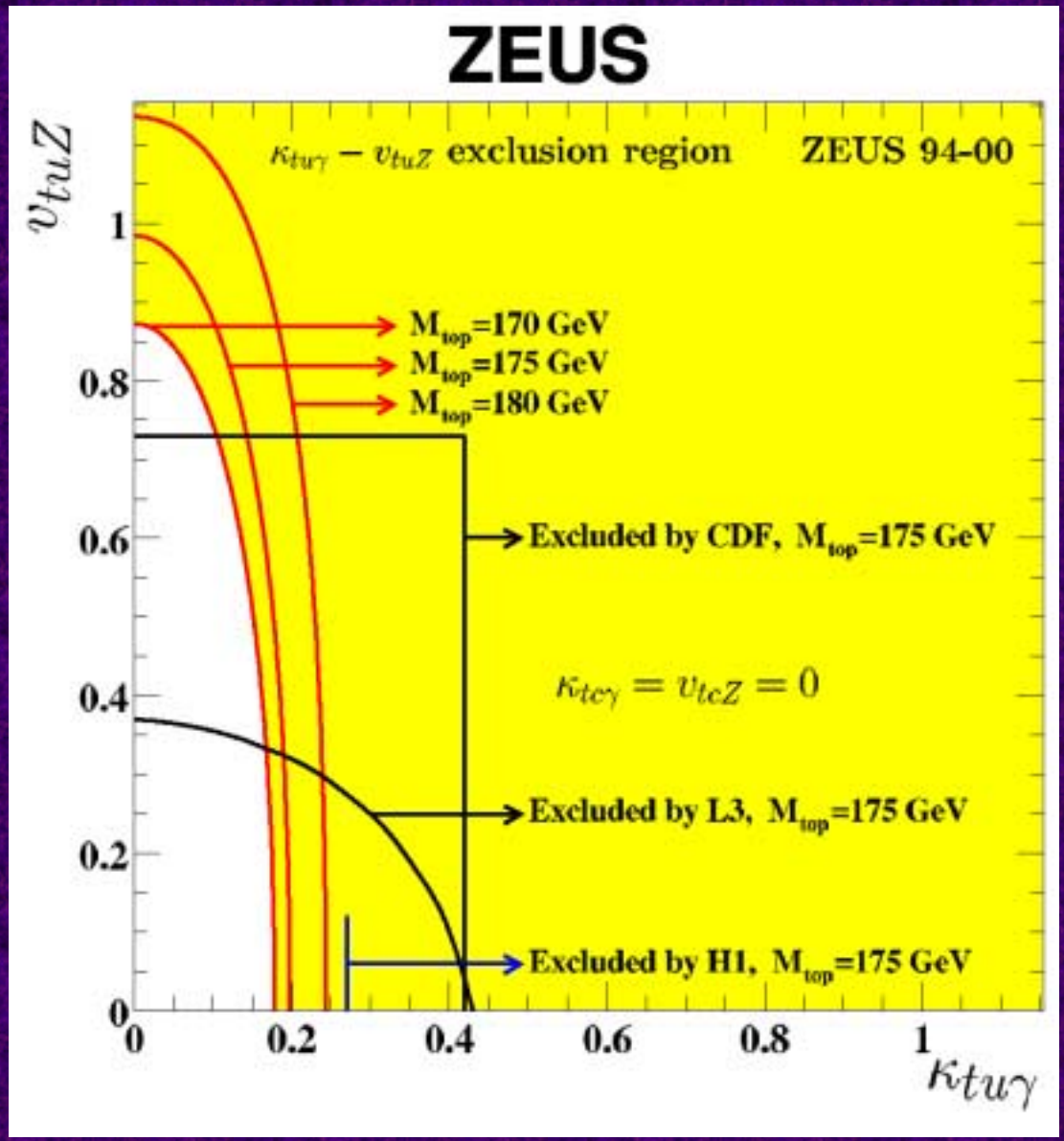
- Finally ZEUS sees an anomaly wrt Standard Model (?)



- See 2 events with $p_T^X > 25$ GeV^2 c.f. 0.12±0.02 from S.M.

Single top production

- This is perhaps the clearest and most important area where just the statistics gain (and the better b tagging) at HERA II will really pay dividends.

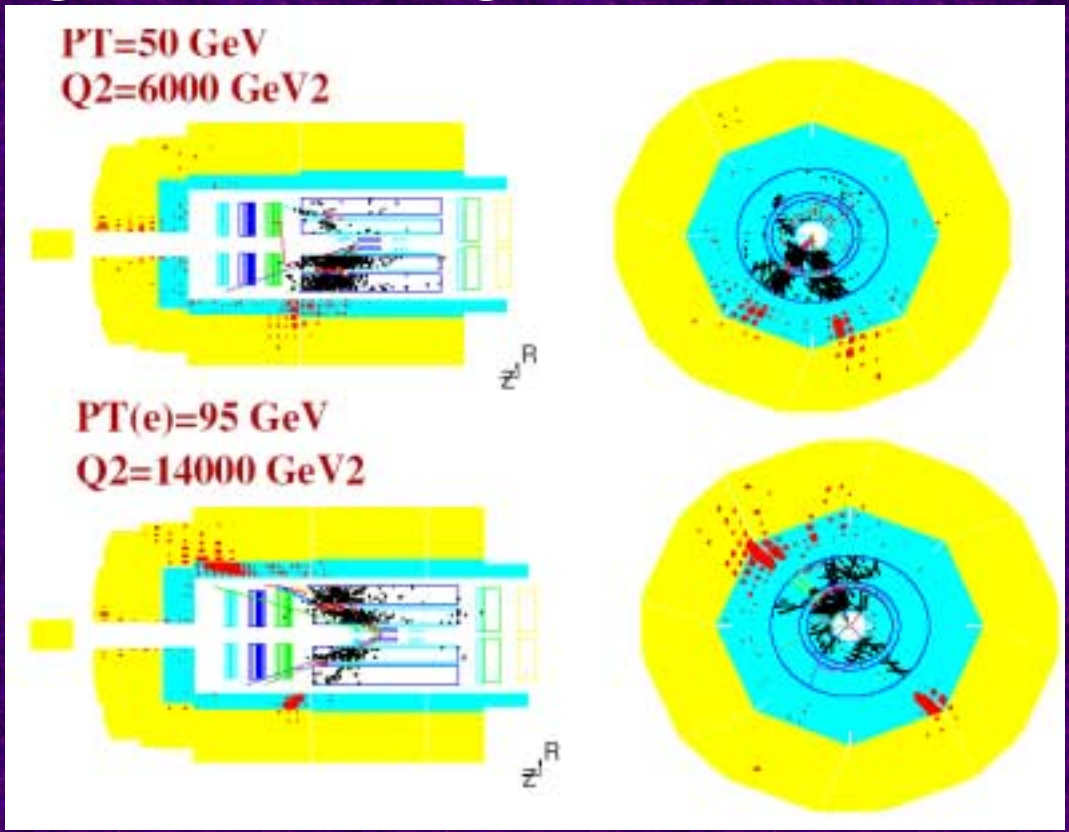


Summary

- Heavy quark physics at HERA I has been exceptionally rich. Not only have we measured production cross sections over wide range of Q^2, we have made contributions to QCD understanding of heavy quarks, to spectroscopy and to diffraction.
- HERA II promises much. There will be factors of ~5 in integrated luminosity; the tagging efficiency and kinematic reach for heavy quark measurements will increase because of the improvements to the detectors in general and the vertex detectors in particular.
- Many areas will benefit – particularly DIS and heavy quark structure functions, and everything to do with B production. This is a very exciting prospect indeed.

Summary

- **HERA II is starting up in earnest – first data are starting to come through.**



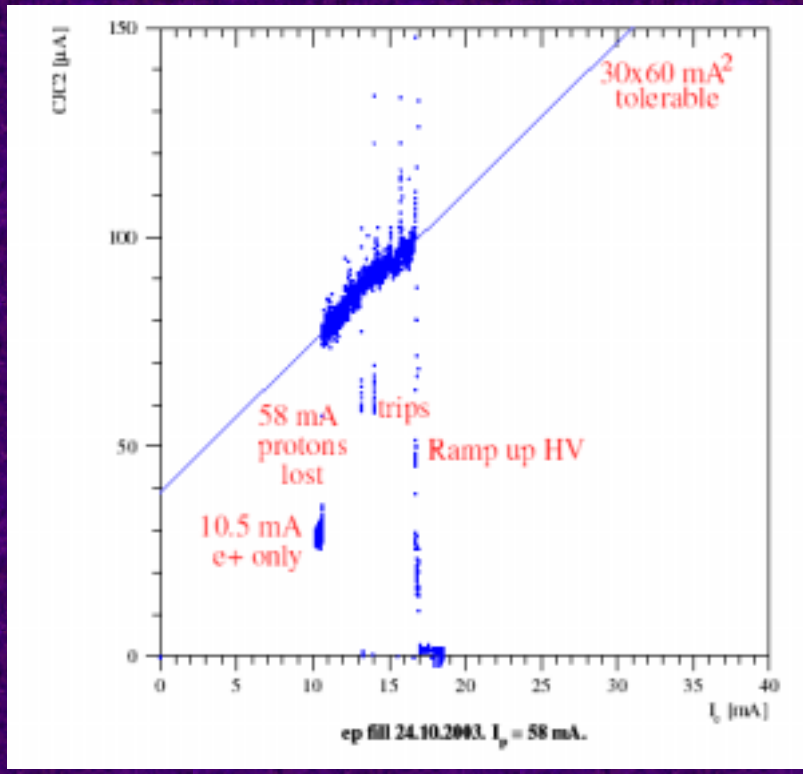
- **The Si detectors, although being baked nicely, are not yet cooked and still there and working…**

Summary

- Background conditions under study.

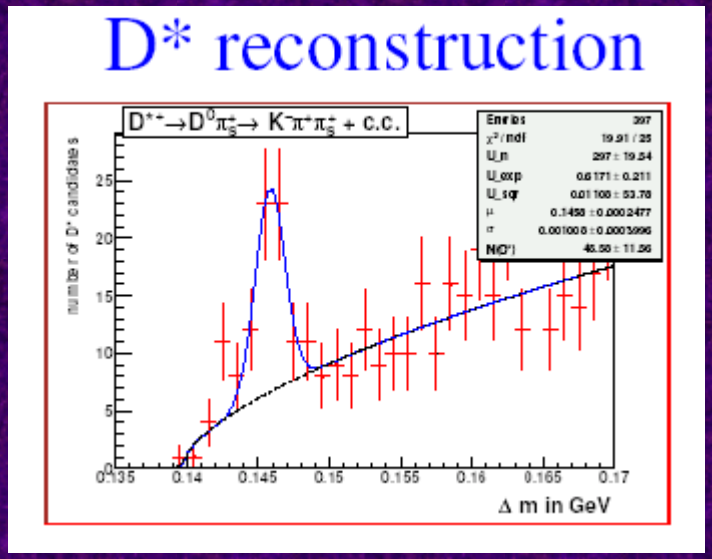
- ZEUS - reflected synchrotron rad. greatly reduced. Particle backgrounds also look good if machine carefully tuned. Proton-related backgrounds still under study – but promising.

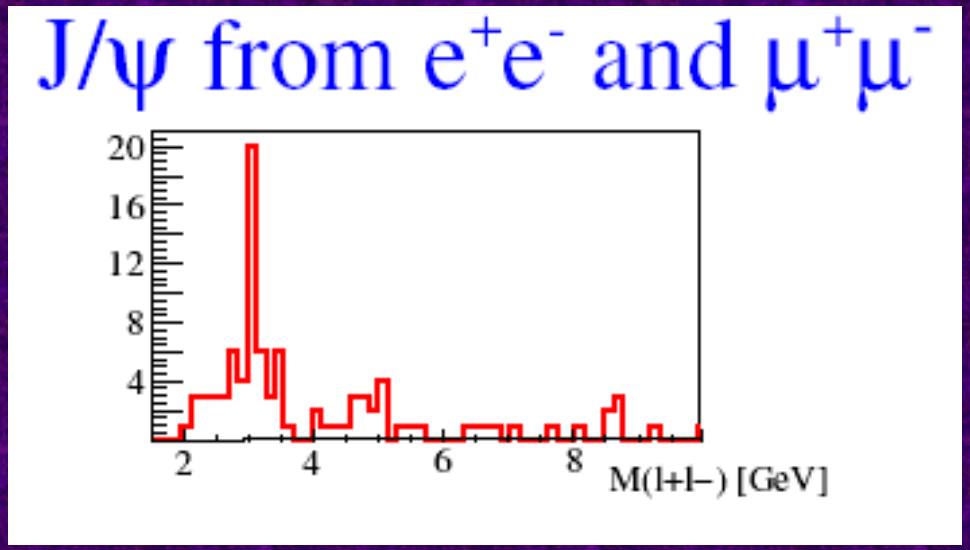
- H1 – vacuum conditioning worked. Need factor 3 better vacuum to run with HERA II design currents.



Summary

- First HQ signals starting to emerge from HERA II data.





- These signals from H1 – the opening of the HERA II floodgates?

The WeizmannWorkshop

Summary

- **Fingers crossed, touch wood, etc. etc. –**

  The next five or so years promise to be some of the most exciting at HERA yet.