Outlook on Heavy Flavour Physics at HERA II

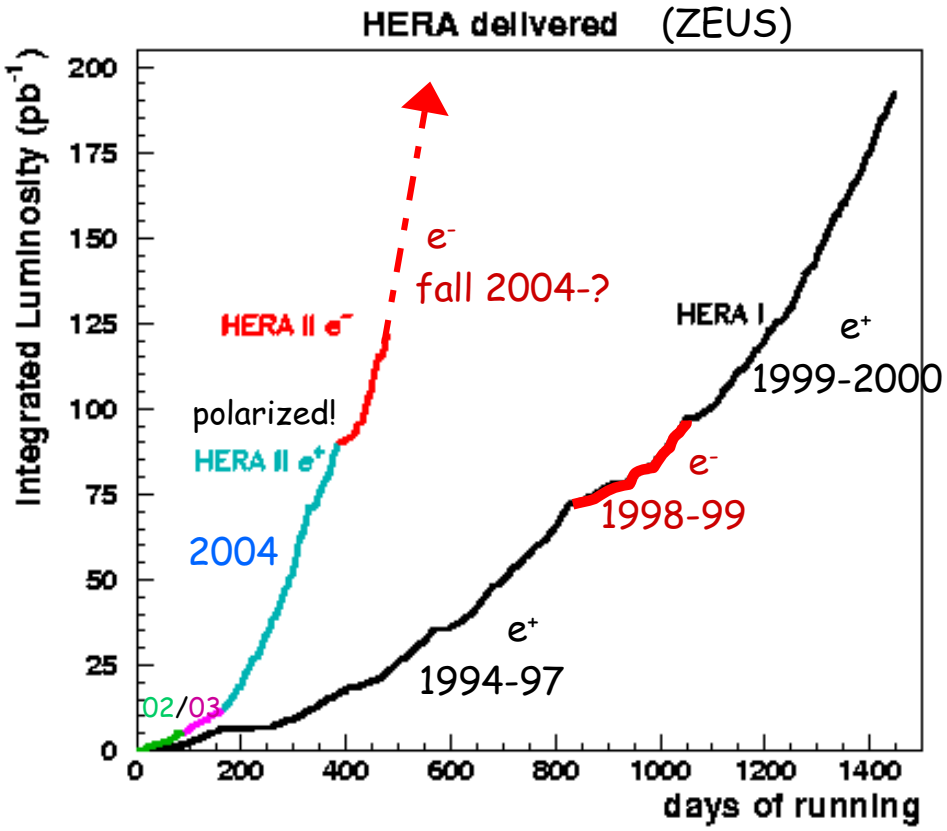
Achim Geiser, DESY Hamburg

HERA-LHC workshop, DESY, Hamburg, 22. March 05

- HERA II performance
- Detector upgrades and status (somewhat ZEUS-centric)
- Implications for Heavy Flavour Physics
- Conclusions

HERA I and HERA II

HERA I + II luminosity:



HERA I:

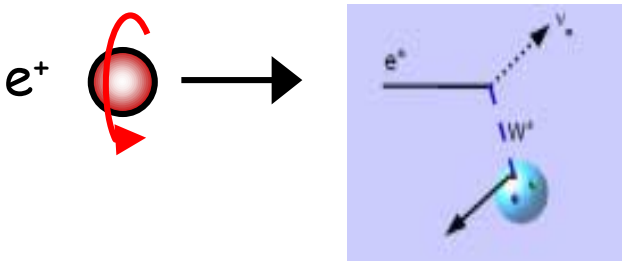
- E_e = 27.5 GeV, electron or positron
- E_p = 820 GeV 1992-97
  920 GeV 1998-2000

HERA II:

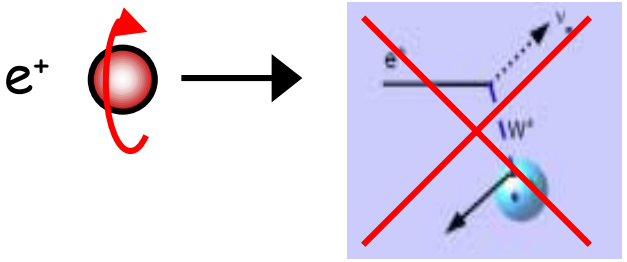
- detector and luminosity upgrade
- 2002: large, unexpected backgrounds, identified and overcome in 2003
- efficient data taking since fall 2003
- long running period scheduled till 2007, goal: ~700 pb^{-1}
- 2003/4: polarized positrons
- 2004-6: polarized electrons, already more than 1998/99
- 2006/7: polarized positrons

Weak interactions are "left-handed"!

- righthanded positrons interact (*CC*)



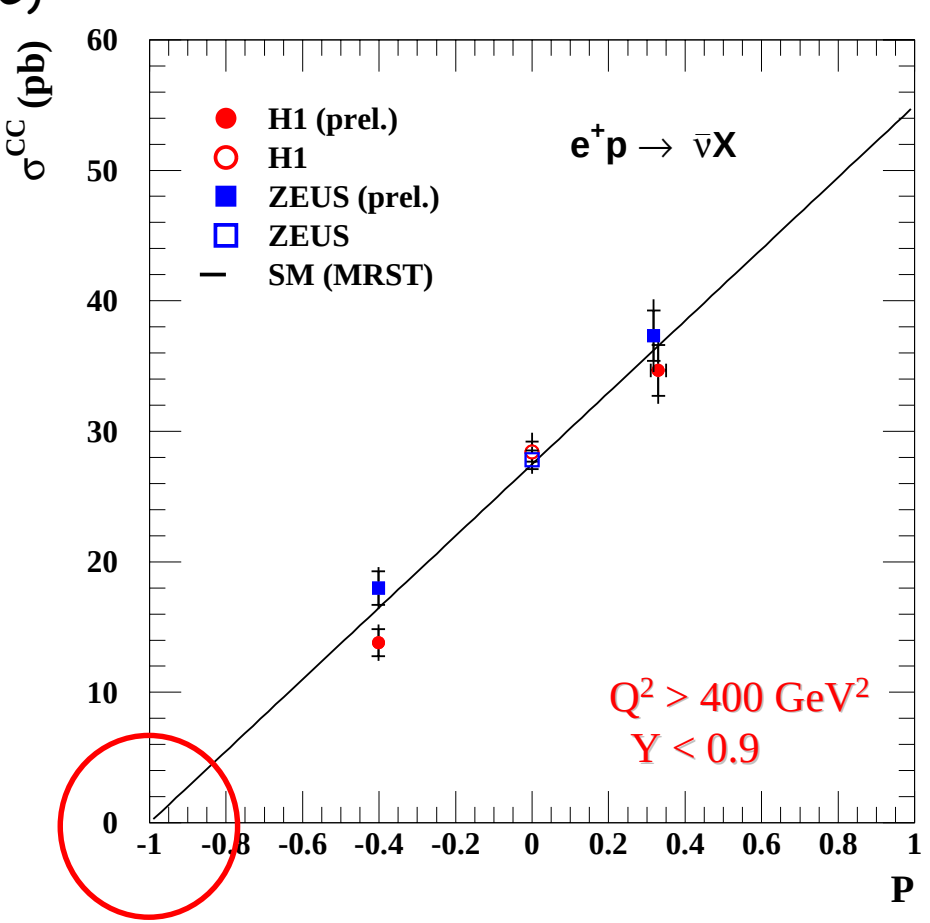
- lefthanded positrons do not!



- cross section linearly proportional to polarization

$$\rightarrow \sigma_{CC}(P) = (1+P)\ \sigma_{CC}(P=0)$$

- consistent with SM expectation



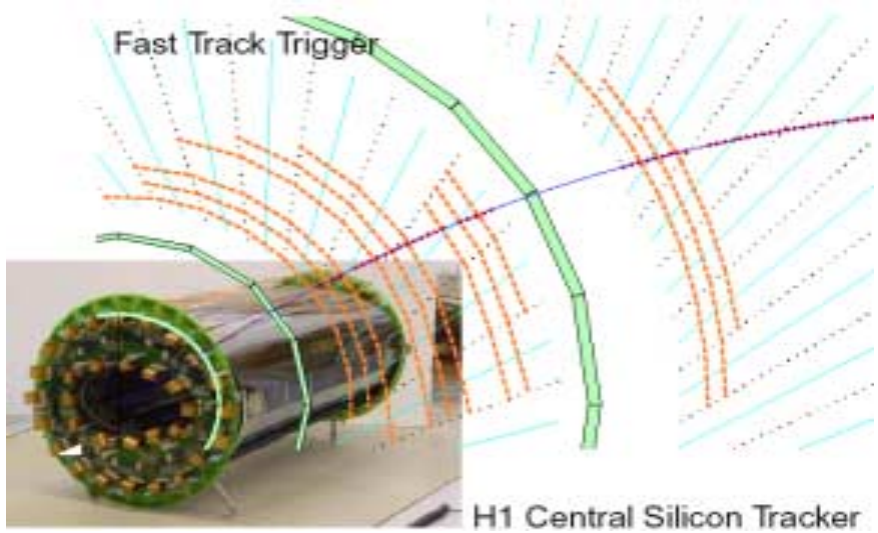
$\sigma_{CC}(P=-1) = -3.7 \pm 2.4 \pm 2.7$ pb H1

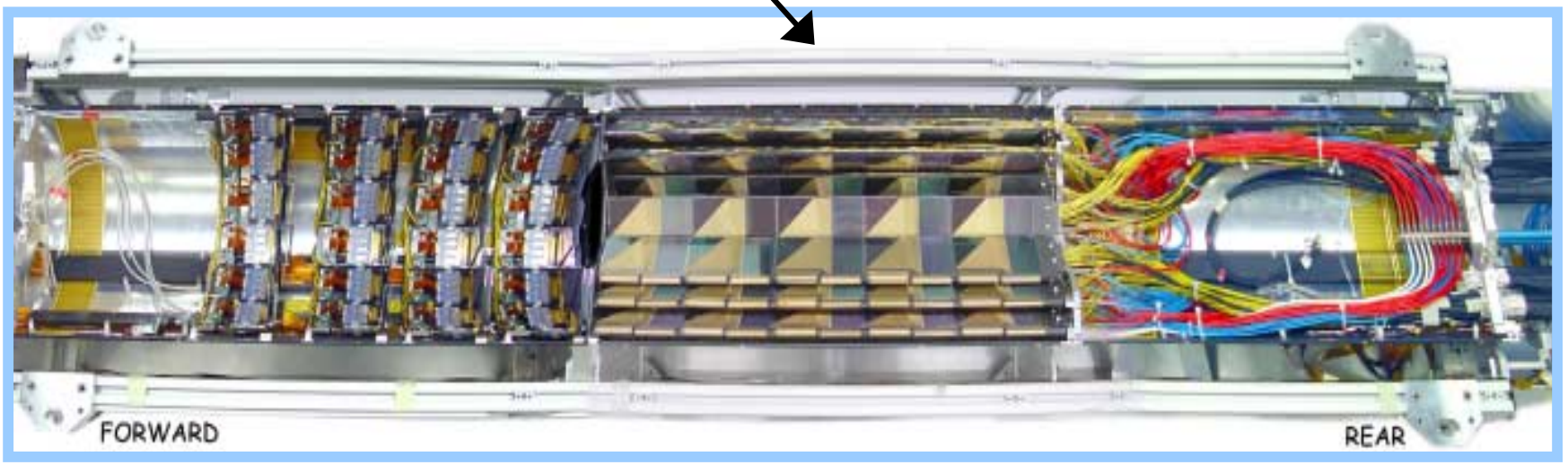
Detector upgrades for HERA II

upgrades most relevant for
heavy flavour production:

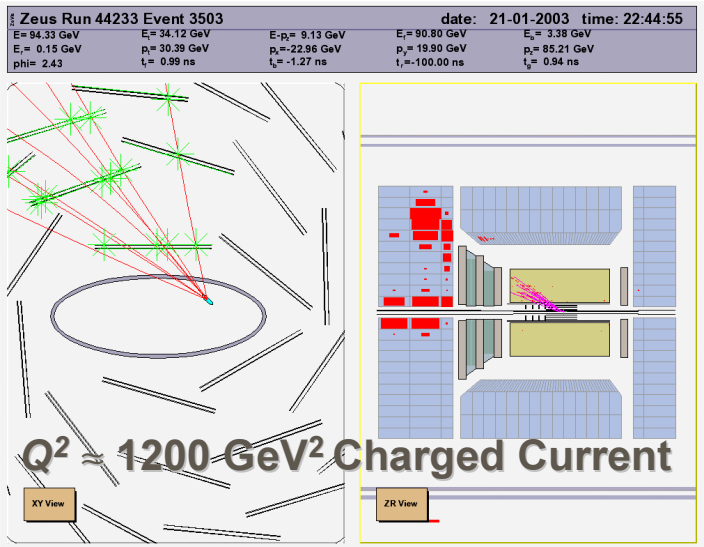
- H1 Fast Track Trigger
  + ZEUS Global Tracking Trigger

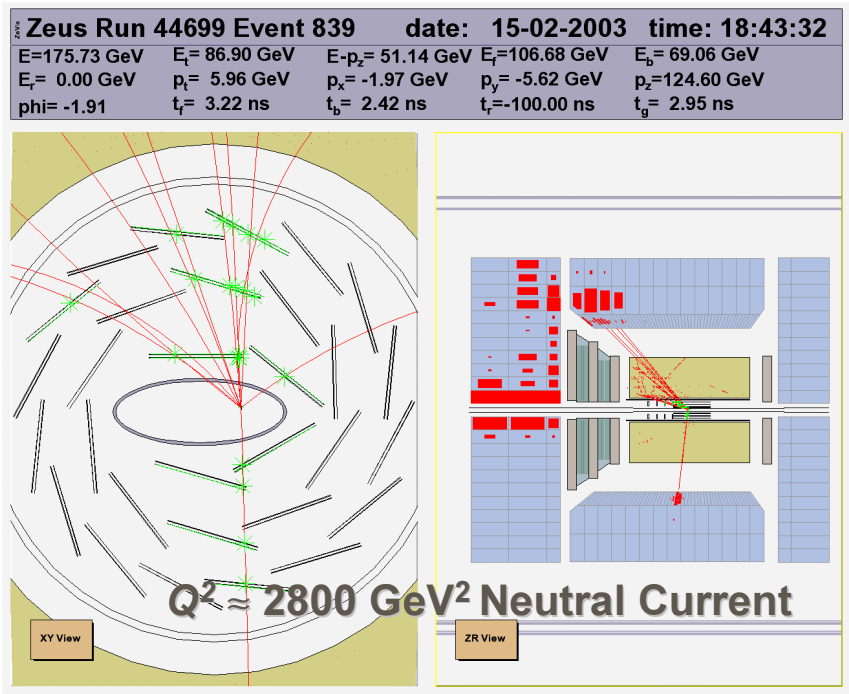
- ZEUS Micro-Vertex Detector (MVD)
  + H1 vertex detector upgrade

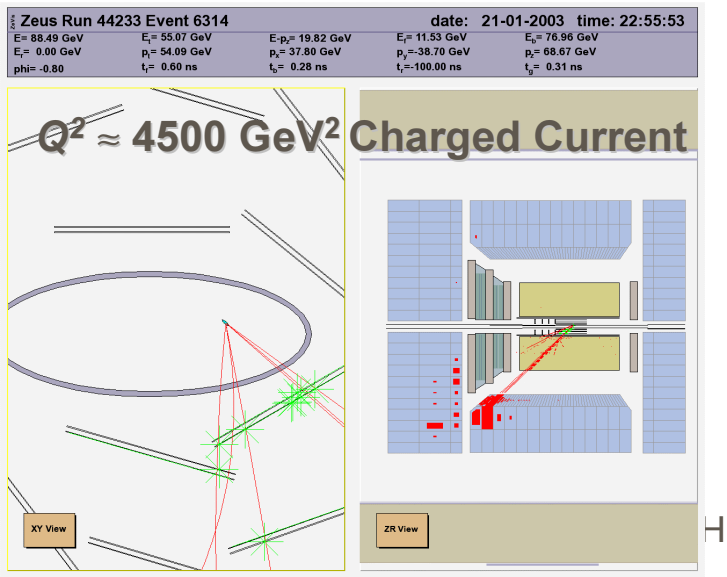




Some of the first HERA II *ep* collisions:



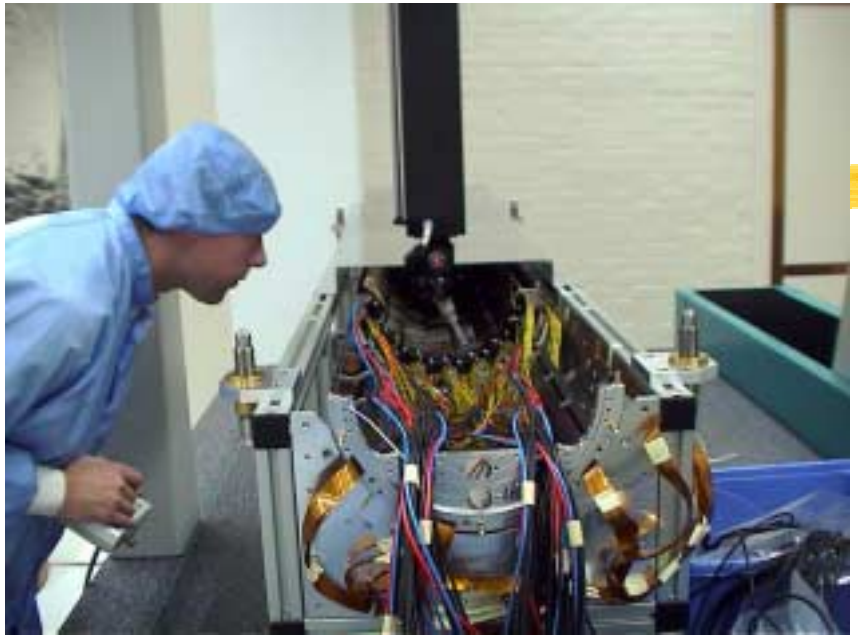


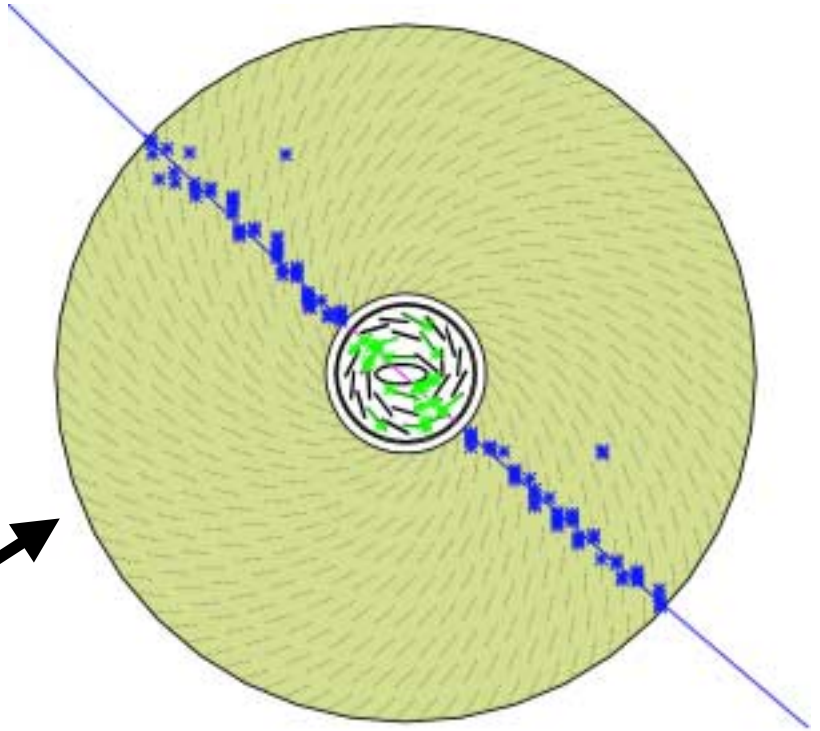


achieved so far: ~ 130 pb^{-1}
(~ 60-70 pb^{-1}physics)

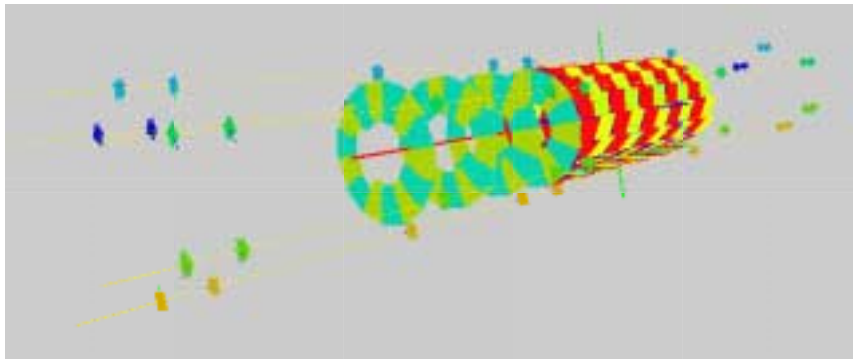
HERA II goal: ~700 pb^{-1} till 2007

MVD Alignment

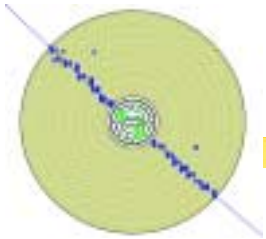


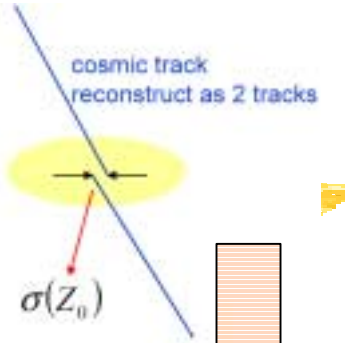


- 3 Step process:
  - ⇒ Survey of ladder positions before installation in the lab,
  - ⇒ Further alignment using cosmic data,
  - ⇒ Monitoring of stability using an in situ laser system with semi-transparent position sensors.



Alignment Status





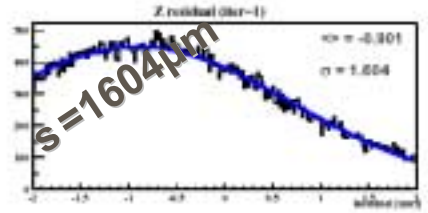
Track Residuals

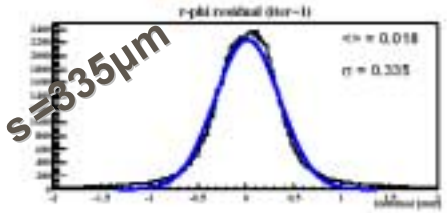
r-z sensor

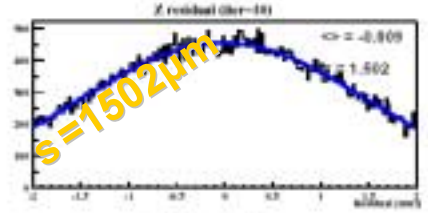
r-phi sensor

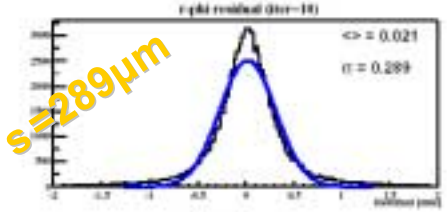
Global alignment

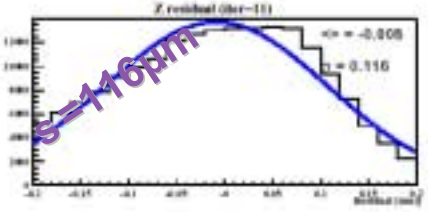
Internal alignment

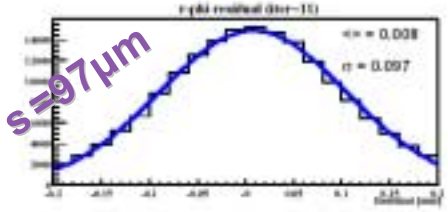


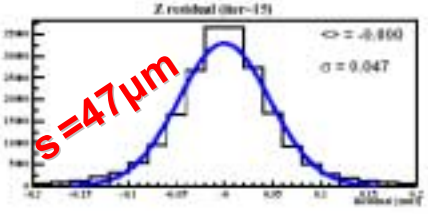


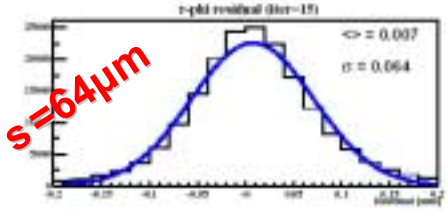








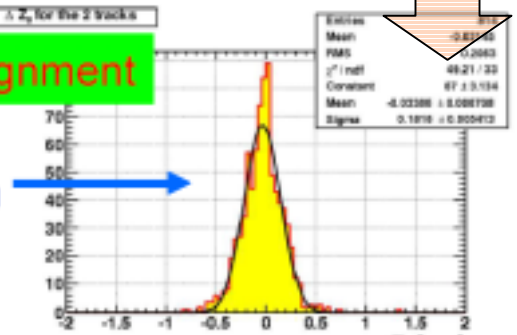




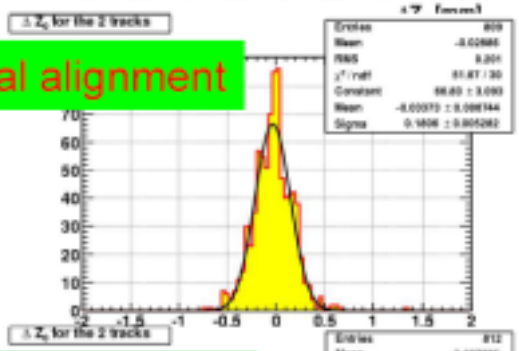
Impact Parameter

No alignment

σ = 180 μm

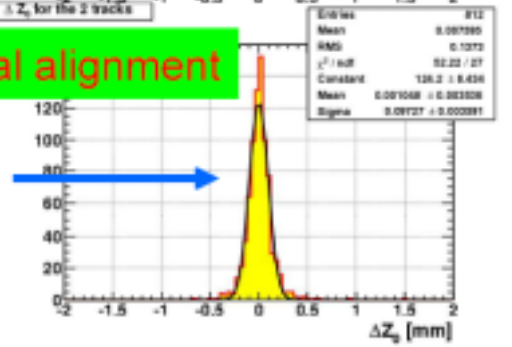


MVD global alignment

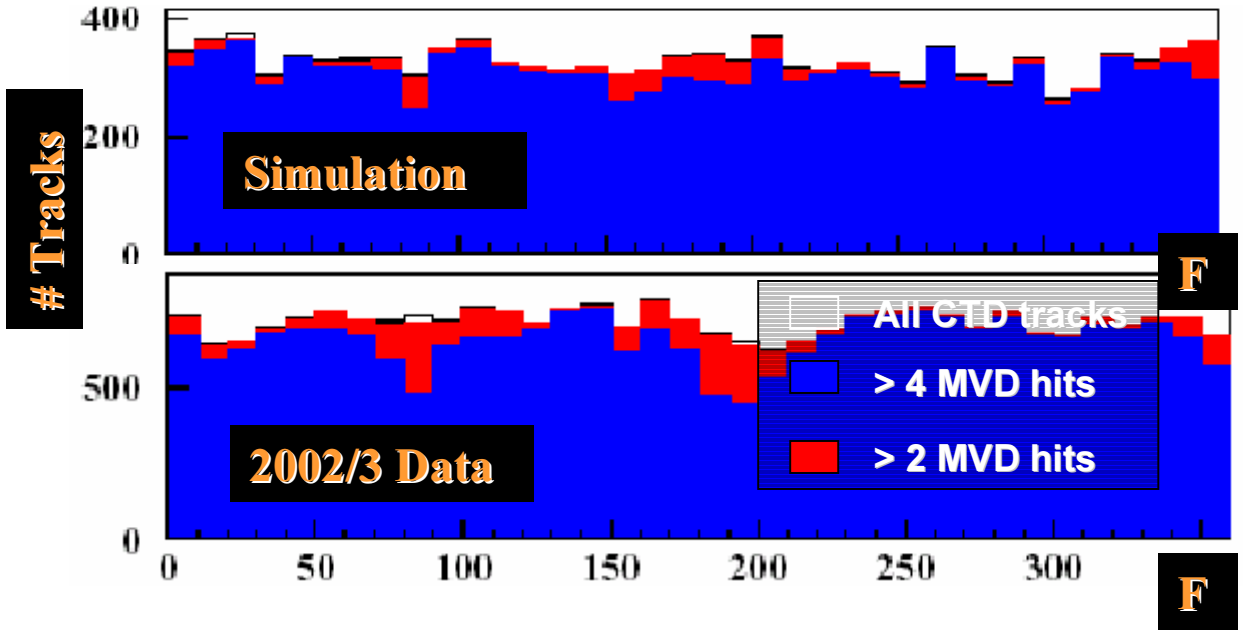


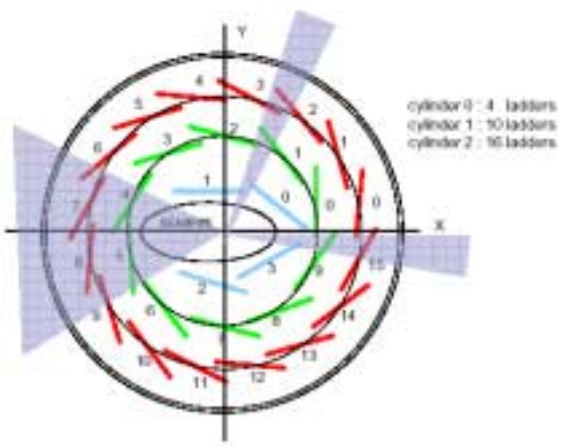
MVD internal alignment

σ = 100 μm



MVD Tracking Efficiencies





Note: Acceptance holes

Efficiency estimates from NC DIS: (Tracks in CTD and MVD fiducial)

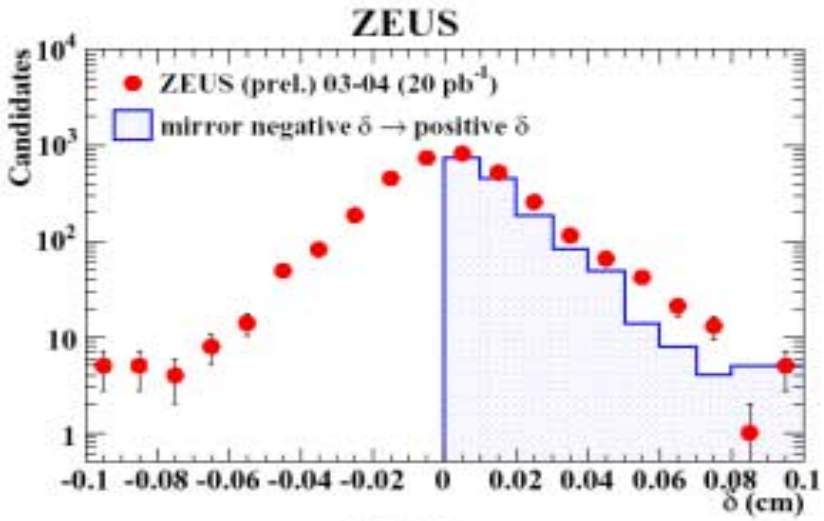
	> 4 MVD hits	> 2 MVD hits
Data	91.4%	99.3%
MC	93.8%	99.3%

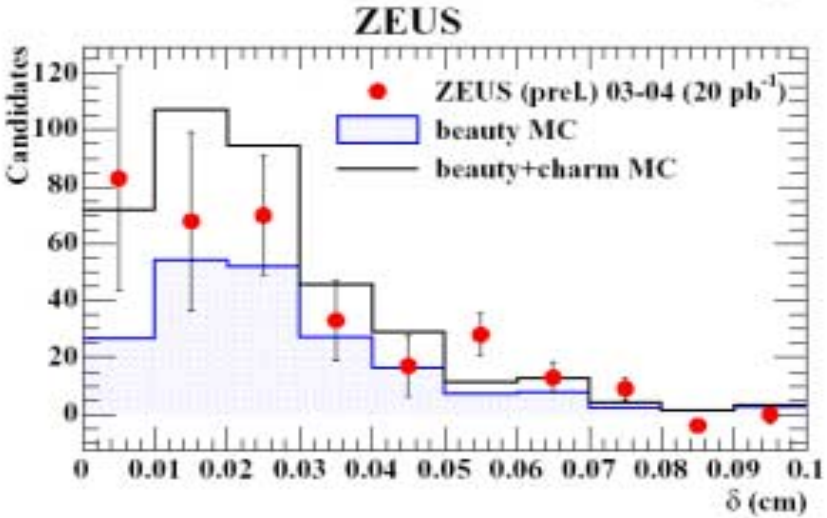
Beauty in HERA II data

- First preliminary results using new ZEUS MVD:
  - muon impact parameter distribution (muon+dijet events):
  - excess at positive impact parameter, consistent with p_T^{rel}
- Outlook:

  improve previous measurements by ~ order of magnitude

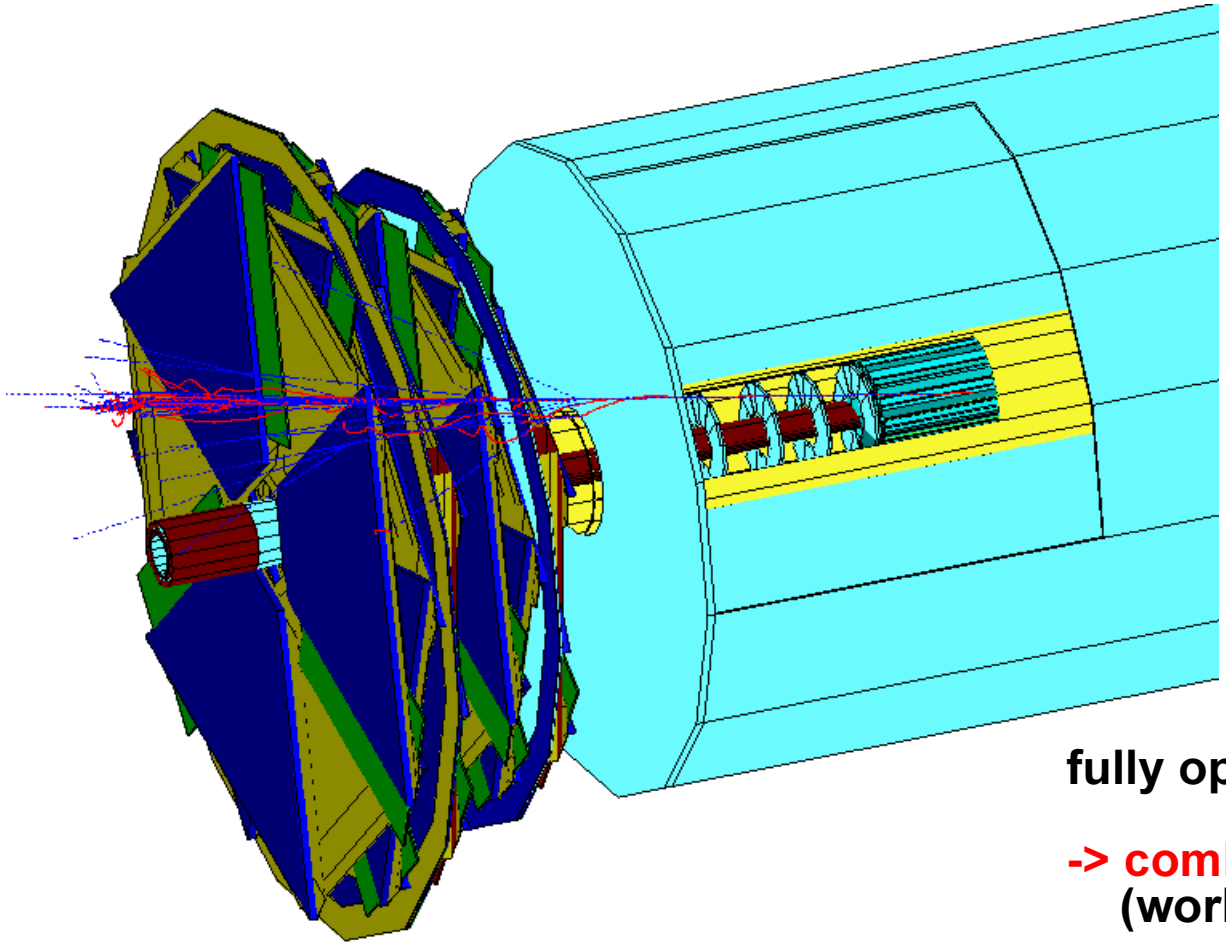
  + new double differential measurements

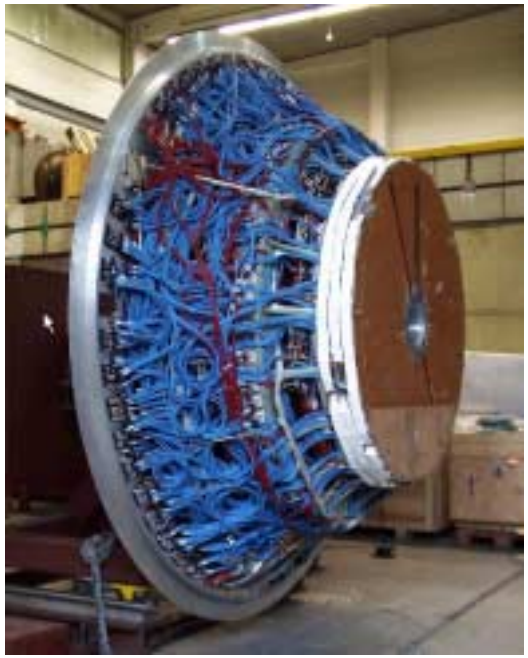




ZEUS Straw Tube Tracker

Goal: extend tracking acceptance into forward region





fully operational during 2003/4 run

-> combined forward tracking
(work in progress)

(ZEUS) Hardware Upgrade Summary

- ZEUS MVD has completed the commissioning phase,

  i. e. design goals have been reached:
  - Reliable and well monitored detector operation (data quality, radiation, alignment),
  - High tracking efficiency (>99%),
  - Precision is approaching the goal (Impact parameter resolution $\approx 100\ \mu m$)
  - final alignment + tracking error studies ongoing

- STT comissioning ongoing, successful data taking 2003/4

- other improvements (H1 FTT, ZEUS GTT, BAC trigger, ...) well under way

- Ready for new data with full secondary vertexing capability, improved forward tracking efficiency, improved efficiency for semileptonic leptons

=> great opportunities for heavy flavour physics!

Main HFL Upgrade Physics Goals

- Tests of perturbative QCD
  - Heavy quark mass sets additional perturbative QCD scale
  - Measure single + double differential cross sections with single or double heavy flavour tag + compare with predictions
- Gluon and heavy quark structure of photon and proton
  - study charm and beauty content of DIS and high E_T dijet events with single or double heavy flavour tag
- High mass vector meson production)
  - study e.g. color octet contribution)
- Strange quark sea of proton) not
  - study charm production in CC events) discussed
- Charm structure of pion) here
  - study charm production in ZEUS FNC events)
- Diffractive heavy flavour production)
  - study charm production in diffractive events)
- Exotics)

Assumptions for HERA II HFL Physics

- Luminosity increase by ~ factor 5 -> factor 5 in statistics
  - from HERA II collider performance
- Maintain high trigger efficiency for beauty (~ factor 1)

  Moderate trigger efficiency change for charm (~ factor $^1/_2$ ZEUS, > 1 H1?)
  - from trigger upgrades (GTT/FTT) -> compensate loss from increased luminosity
- ZEUS: add MVD -> gain ~factor 2-10 acceptance (w.r.t. D* or μ)
  - from secondary vertices in inclusive sample
- ZEUS: improved muon reconstruction + lower pt cuts (μ, jet)

  recover signal/background ratio using MVD impact parameter

  -> net gain for beauty: ~ factor 5
  - from muon + jet sample, also other channels!
- Extend phase space further into forward region
  - from improved forward tracking (ZEUS+H1)
- Overall expected gain: ~1-2 orders of magnitude in statistics

  (2007) larger η coverage, lower pt thresholds

Single Charm tag

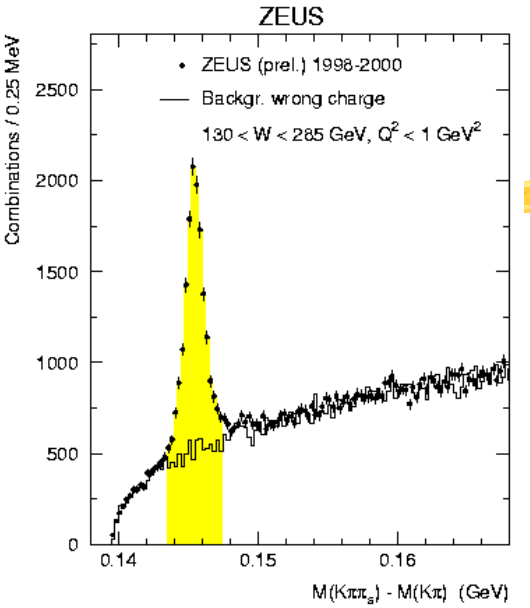
- **Main channel so far: D*-> K π π**

  ~30000 events (1995-00) for fragmentation studies and spectroscopy

  ~20000 events for cross section calculations

- smaller samples from other D meson decays

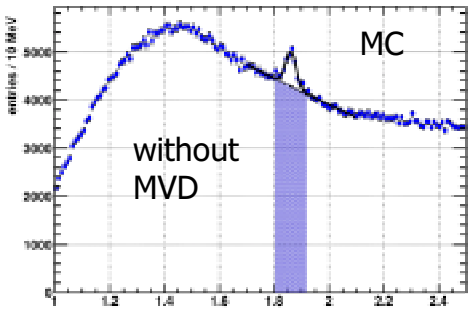
D*



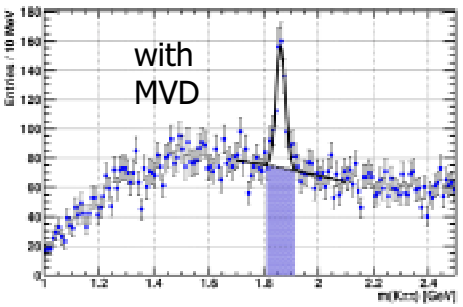
- **upgrade (ZEUS):**
- D*: more multiple scattering (slow π) and tighter trigger => somewhat less efficiency

D+

- D+: long lifetime + MVD => much better bg reduction



- semileptonic charm decays can also be complemented by MVD information

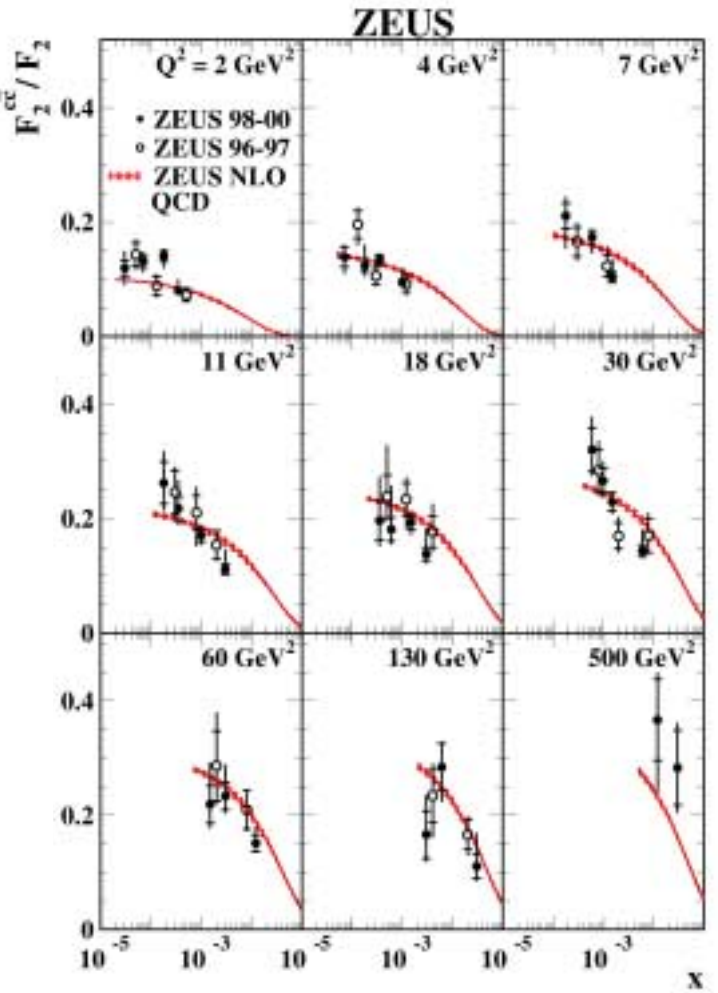


=> should become fully competitive with D* channel for cross section measurements and charm contribution to F_2 (DIS).

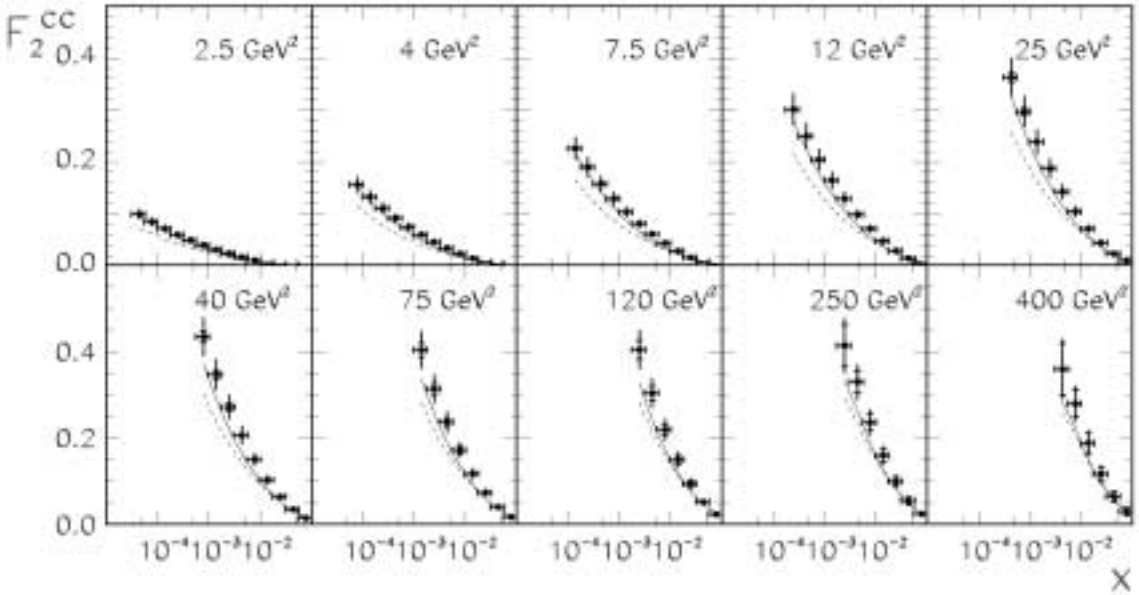
E.g. charm contribution to F_2

DIS

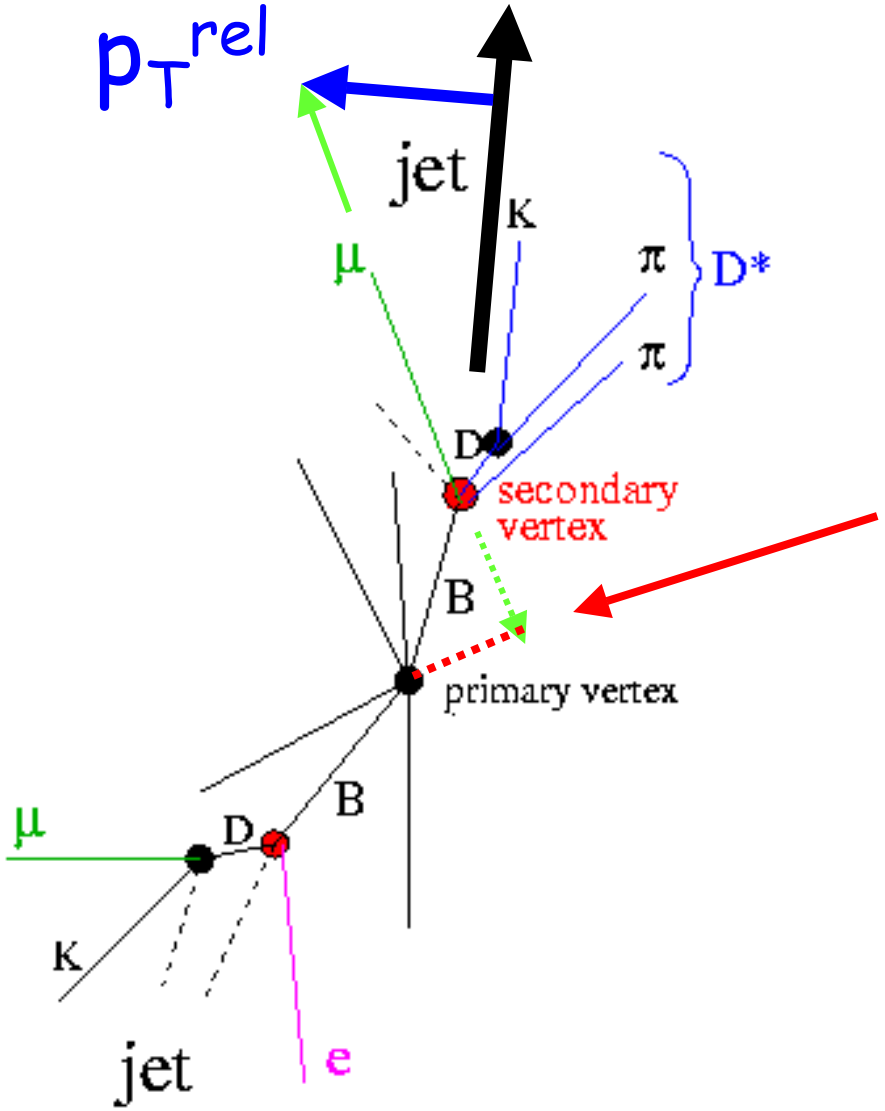
today



2007 ? 500 pb^{-1}



Tagging semileptonic beauty decays



1) p_T^{rel} :

p_T of μ with respect to jet axis

2) impact parameter

(H1: HERA I+II, ZEUS: HERA II)

of μ with respect to primary vertex or secondary vertex

3) D* μ correlations

4) μ μ/e correlations

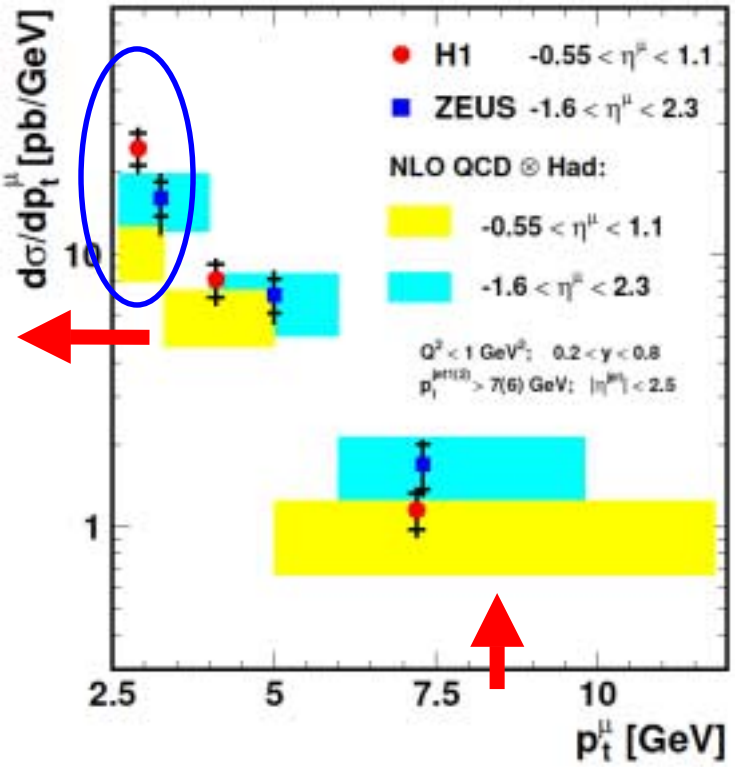
Single Beauty tag: Test of QCD

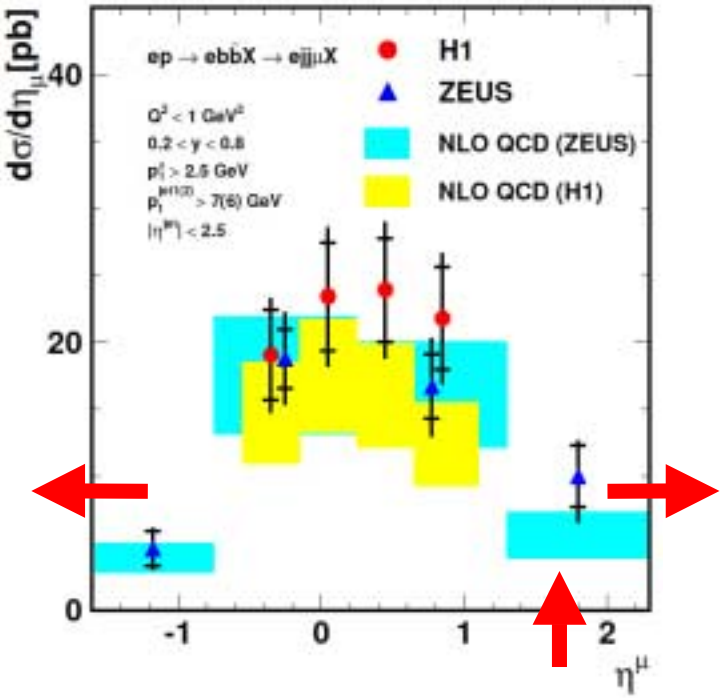
Example: beauty in photoproduction

- **Current analysis**

  2 jets E_T > 6,7 GeV, $|\eta|$ < 2.5

  muon pt > 2.5 GeV, -1.6 < η < 2.3





- **HERA II analysis** (expected)
  - more statistics -> finer binning, double differential?
  - improved muon η coverage: -2 -> +3
  - muon p_T coverage down to 1.5 GeV
  - better systematics (MVD, MC@NLO)

-> more detailed QCD tests

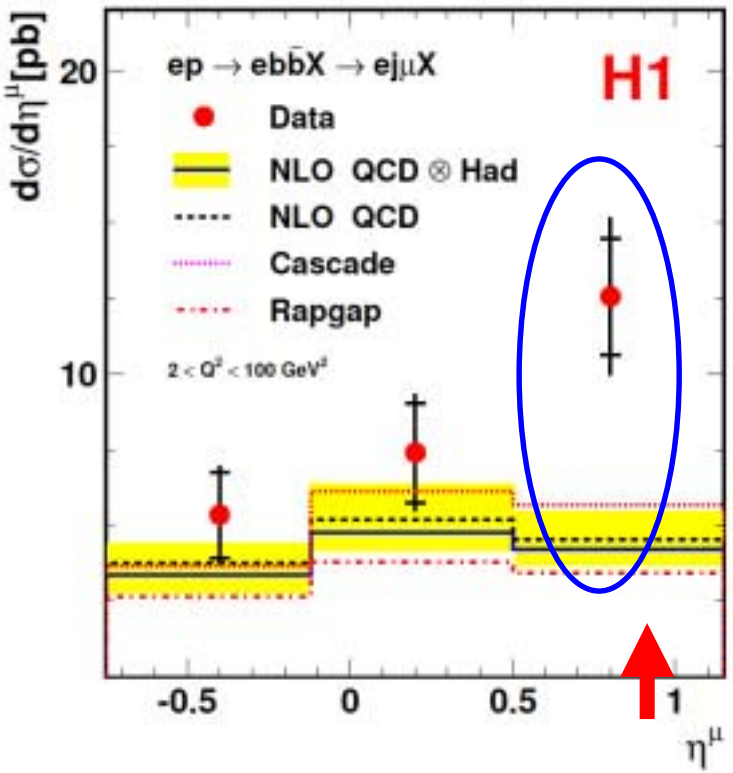
Single Beauty tag: Test of QCD

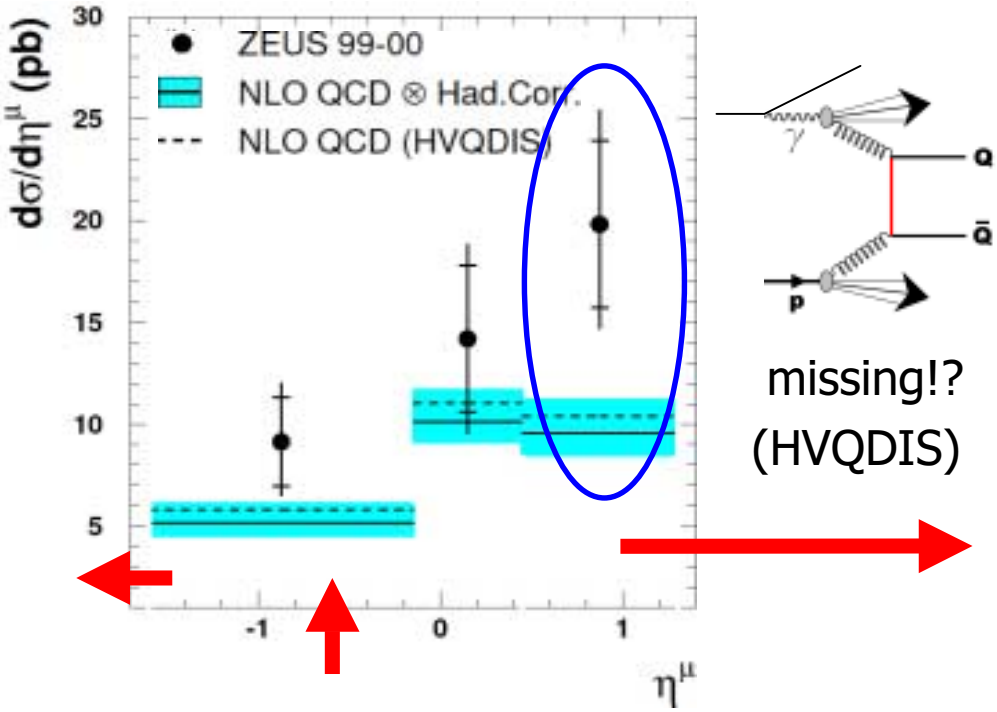
Example: beauty in DIS

- **Current analysis**

  1 jet in Breit frame

  muon pt > 2/2.5 GeV, $-1.6 < \eta < 1.2$





- **HERA II analysis** (expected)
  - more statistics -> finer binning, double differential?
  - improved muon η coverage: -2 -> +3
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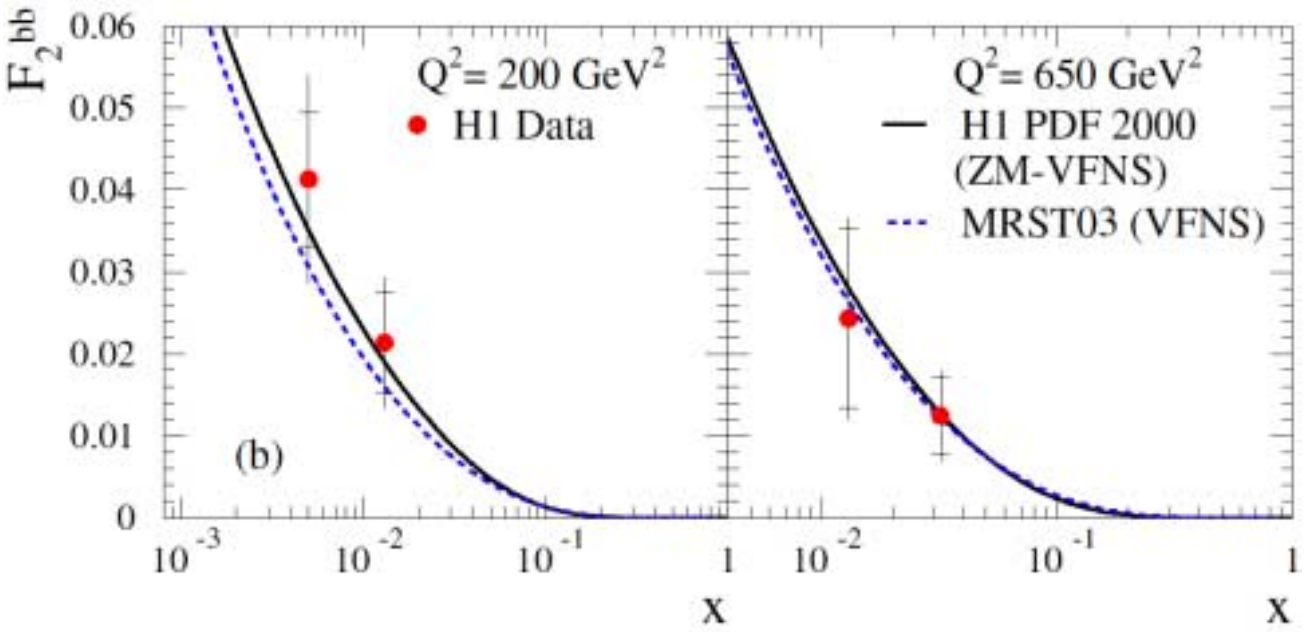
  - better systematics

-> more detailed QCD tests

Beauty contribution to F_2

- **Current analysis**

  2 impact parameter tags in H1 (see talk P. Thompson yesterday)



- **HERA II analysis** (expected)
  - more statistics, similar analysis by ZEUS MVD

-> test „b contribution to proton structure function" (at high Q^2)

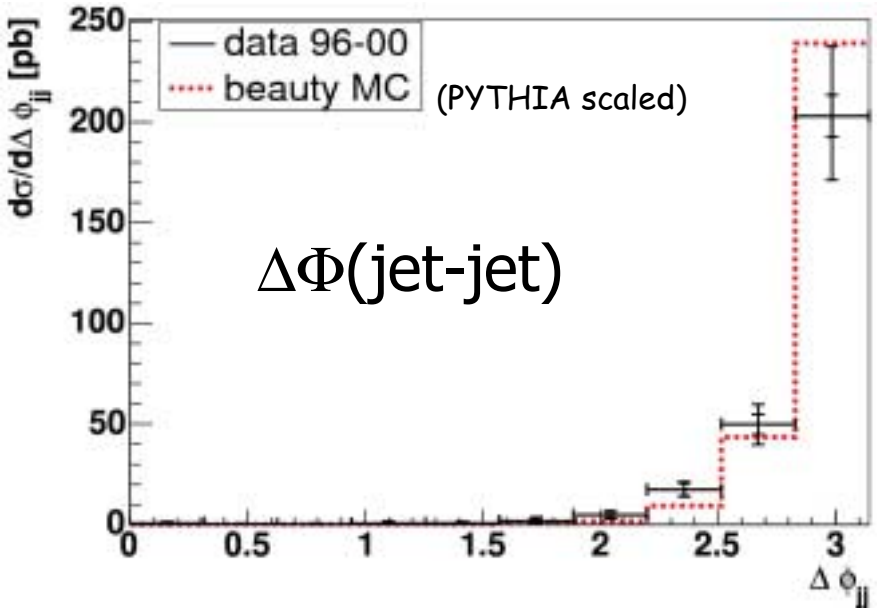
Measure Jet-Jet correlations

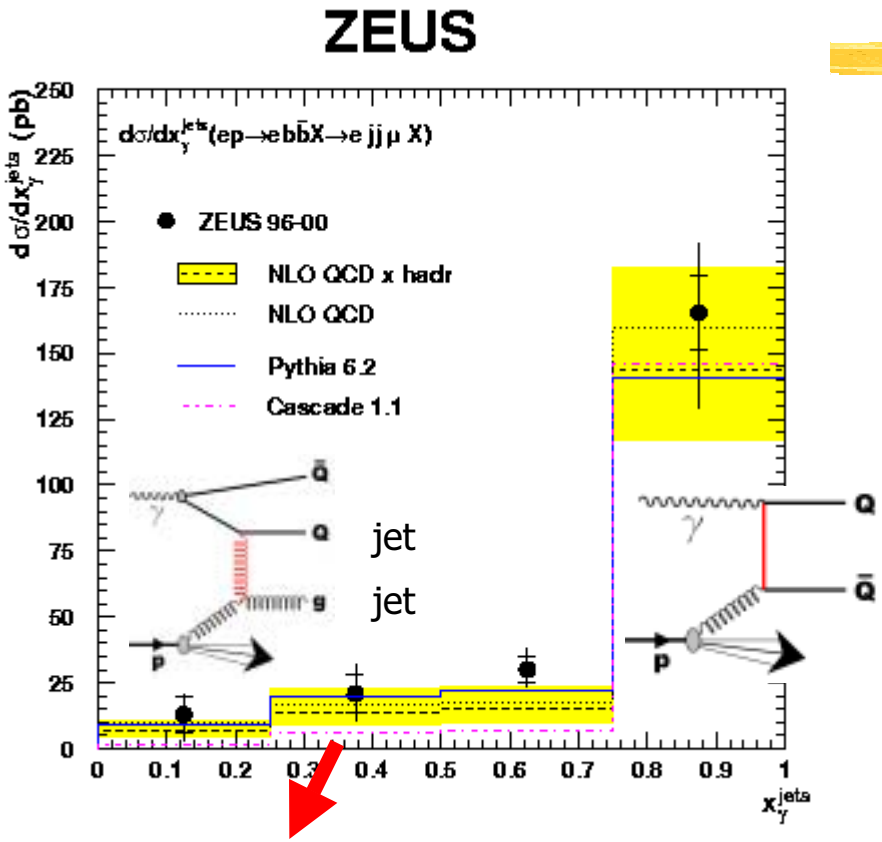
Example: beauty in μ + dijet

(similar for charm)

thesis O. Gutsche:

(not yet officially released by ZEUS)



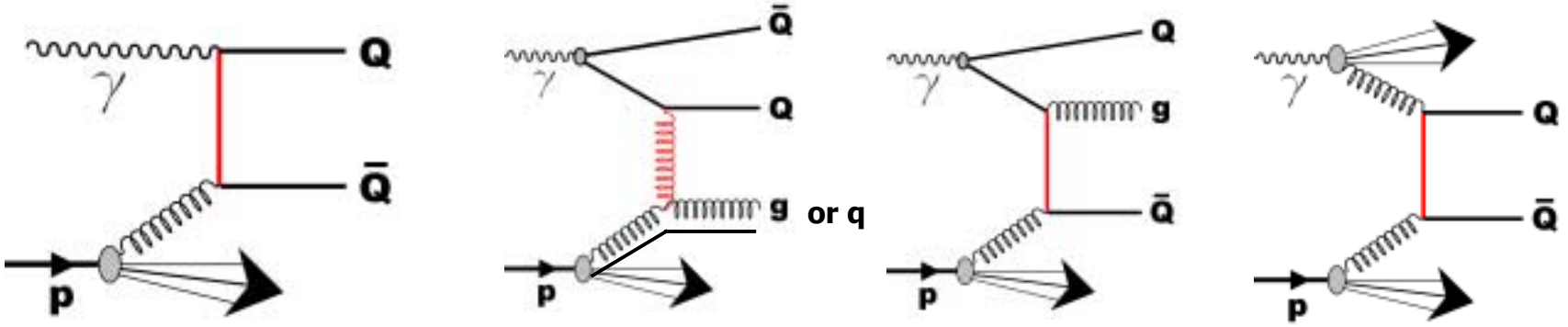


- Δφ for low X_γ region can not be described by fixed order calculation,
  since no additional gluon radiation allowed
  (not shown, public soon for charm)

-> need MC@NLO!

Why measure $Q\bar{Q}$ correlations?

- some NLO diagrams (massive scheme), **Q**=b,c



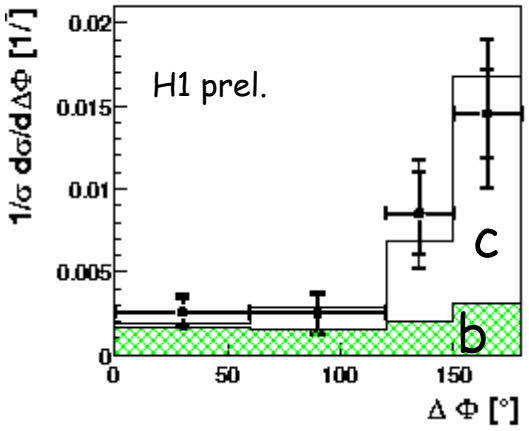
- 3rd jet not always detected (forward or low E_T)
- single tag measurement does not distinguish **Q** and g/q for 2nd jet
- double tag measurement does. combine!

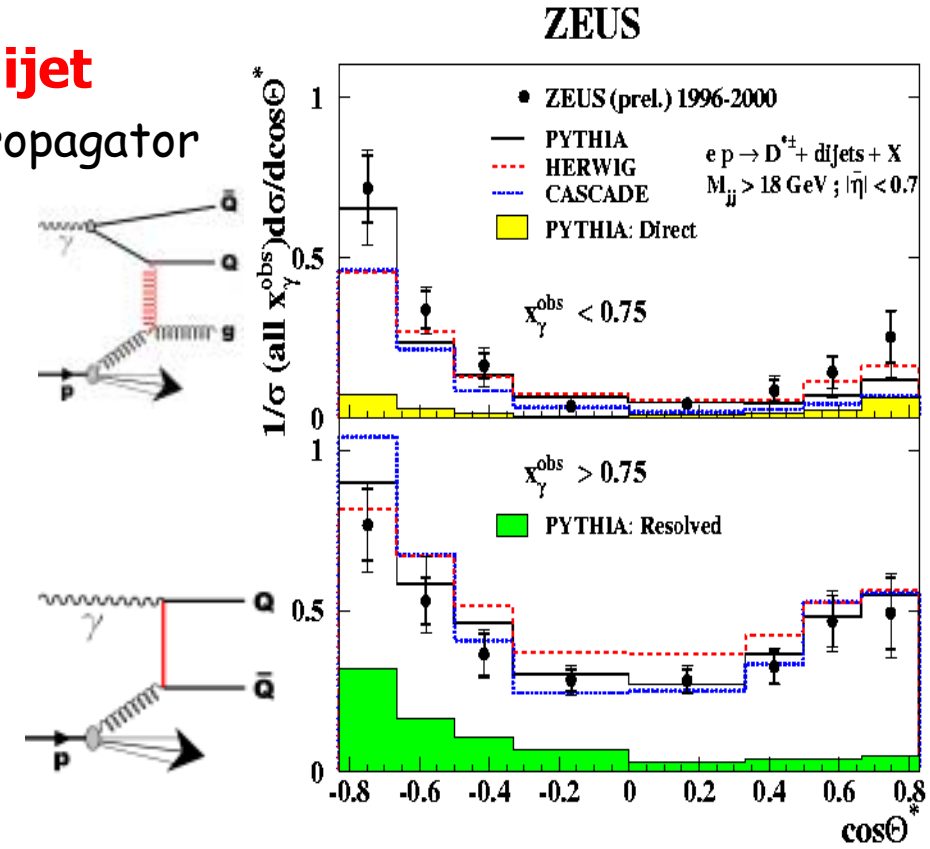
=> test and understand NLO QCD
use result to directly test NLO gluon distribution in proton

Double Charm tag

- **so far mainly indirectly: D* + dijet**
  angular distributions vs. x_γ => q or g propagator
  => 2nd jet is likely to be c or g

- **verify directly using D* + μ**
  low statistics

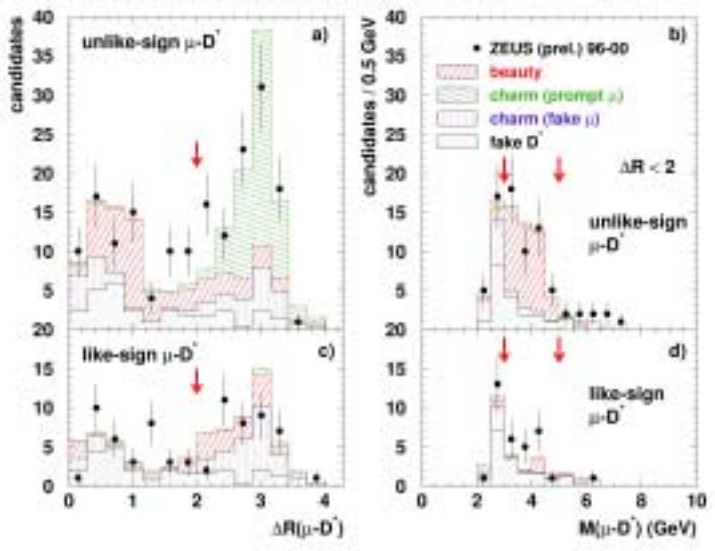




- **HERA II:**
  larger statistics, -> better direct double tag measurements

Double beauty tag

Examples: D*+μ, μ+μ



- **Current D*+ μ analysis**

  pt(mu) > 1.4 GeV, pt(D*) > 1.5 GeV

  ~ 34 events D*+μ from same b

  ~ 15 events D*+μ from different b's

  ~ 60 events D*+μ from different c´s

  muon efficiency + luminosity will increase,

  but will stay statistics limited

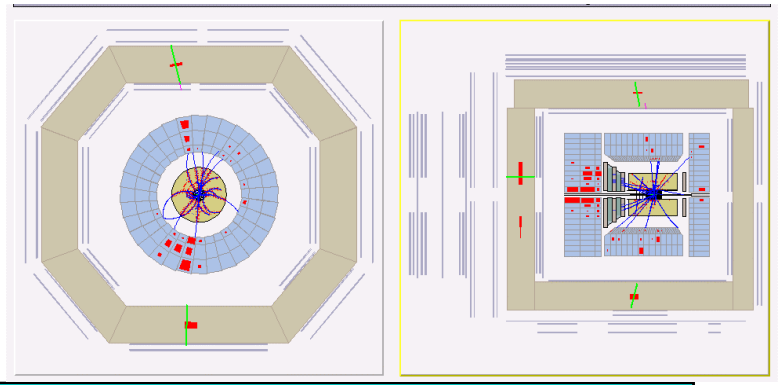
- **HERA I+II dimuon analysis**

  prospects:

  2 low pt muons (no explicit jet requirement)

  => O(10^3) beauty signal events / 100 pb^{-1}

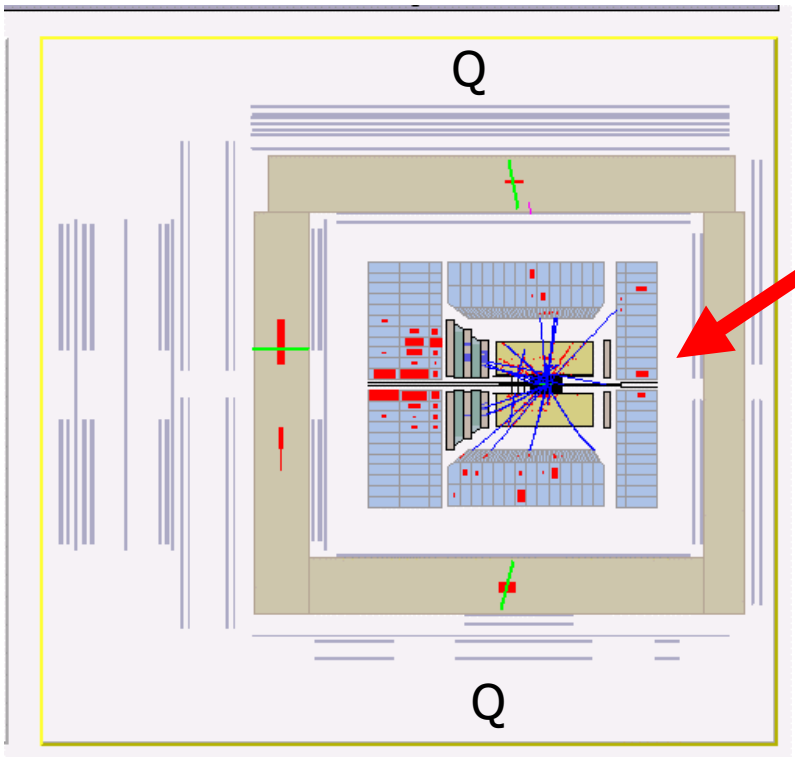
  separate b, c and light flavours through charge + momentum correlations, ptrel, MVD



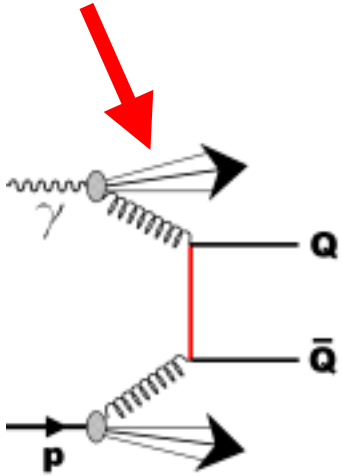
=> high statistics high purity samples, measure double differential distributions

Double beauty tag

separate pointlike/hadronlike photon coupling?



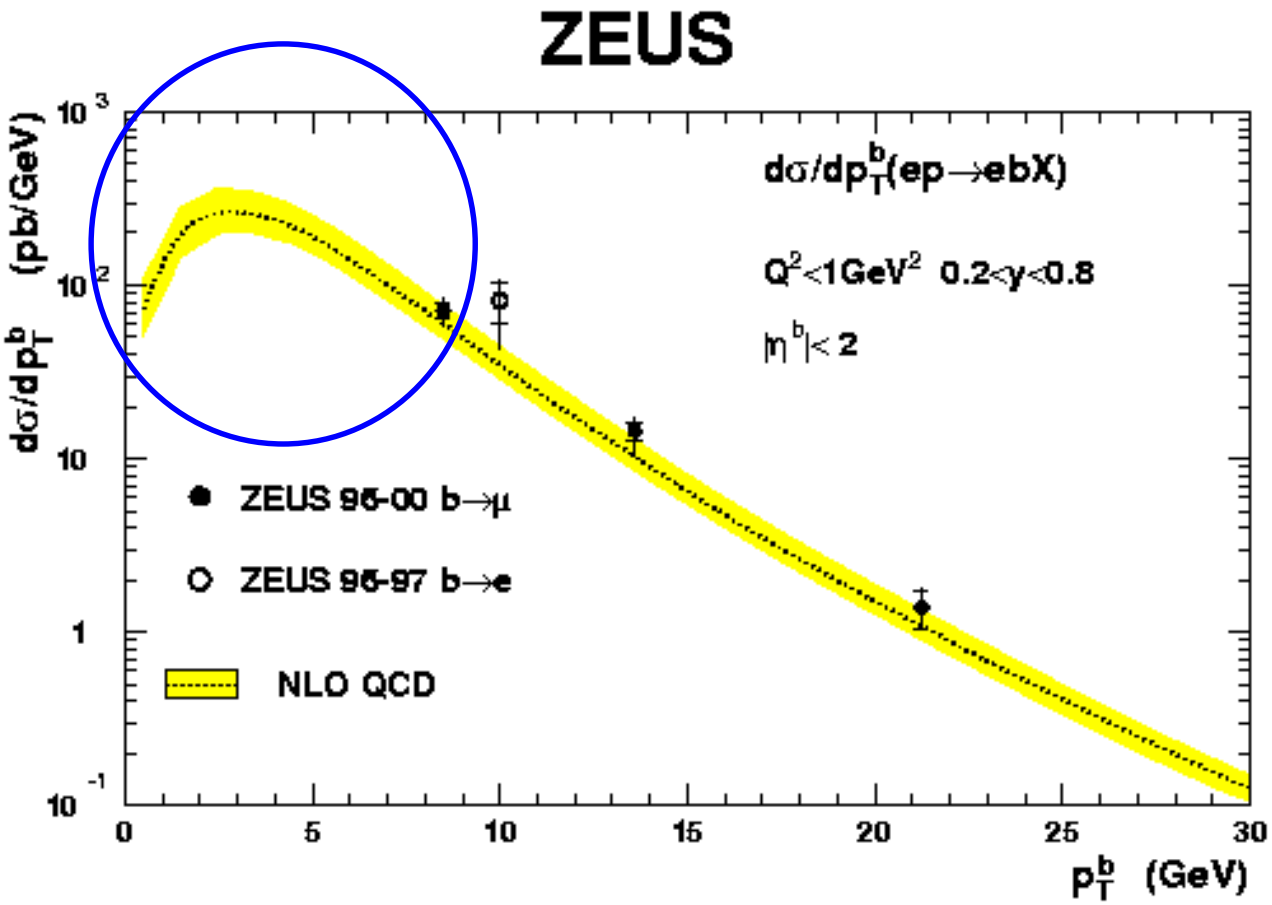
photon remnant?



Double beauty tag

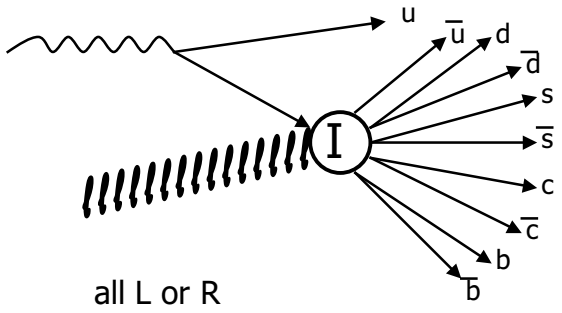
sensitive to very low p_T, almost full rapidity range

-> measure total beauty cross section (soon!)



An experimental and theoretical challenge: Search for QCD instantons through multi-flavour tag ??

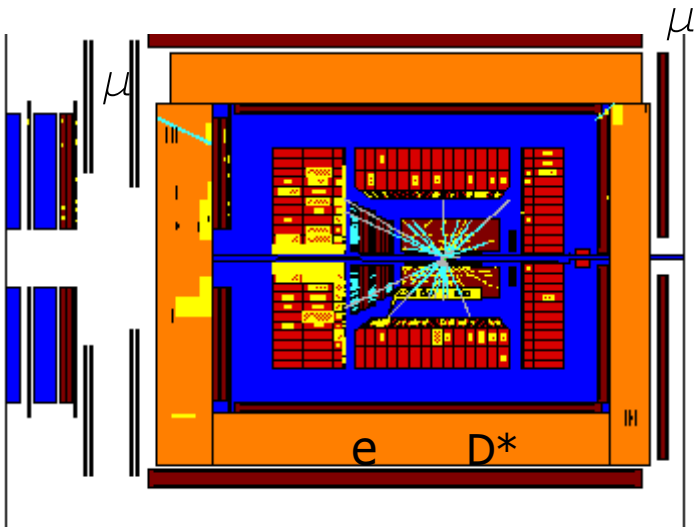
- Flavour democracy => instanton „couples" to all kinematically allowed flavours



- $b\bar{b}$ $c\bar{c}$ $s\bar{s}$ $u\bar{u}$ $d\bar{d}$ (+ gluons) , b -> c -> s, c -> s

=> 6 chances to get lepton (μ or e)
4 chances to get $D^{(*)}$ meson
6 chances to get V^0 (K^0,Λ) directly from s quark
>=10 chances to get V^0 from fragmentation/decay

=> look for „isotropic" events with several (at least 3) flavour tags, e.g.



but: cross section currently not calculable
(could it be „large"?)
QCD background (e.g. $b\bar{b}$ $c\bar{c}$ final state) needs NNLO calculation
=> not for tomorrow ...

Conclusions

- HERA II era has begun!
- detector upgrades ready and performing well
- First competitive results from beauty production with ZEUS MVD expected soon
  - hope for preliminary results by summer conferences
- Very good prospects also for charm, but more difficult to make quantitative estimates
- extensive studies of multi-differential distributions in single and double tagged charm and beauty events are becoming possible => QCD tests, gluon distribution
- Many other interesting physics topics!