(A few highlights of) Heavy flavor measurements at HERA

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on behalf of the H1 and Zeus Collaborations

The HERA $e^{\pm}p$ collider (1992-2007)

Center of mass energy:

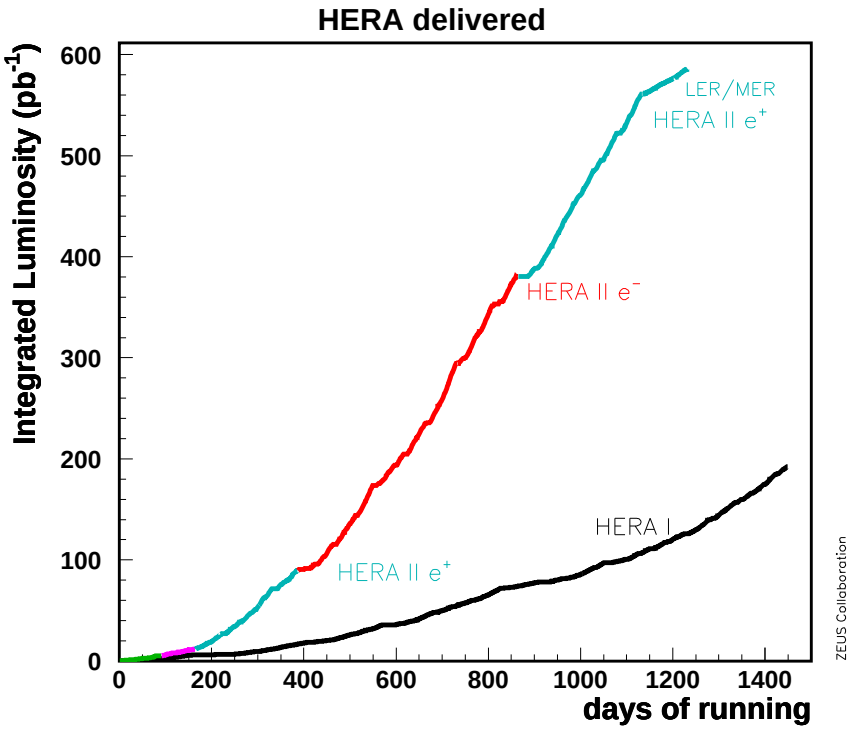
year	energy [GeV]
1992-1997	300
1998-2007	320

Luminosity:

Available for physics
(approximate, depends on the analysis)

Data Set	e^+p (pb^{-1})	e^-p(pb^{-1})
HERA I	120	20
HERA II	240	250

Some 0.5 fm $^{-1}$ of HERA II data per experiment

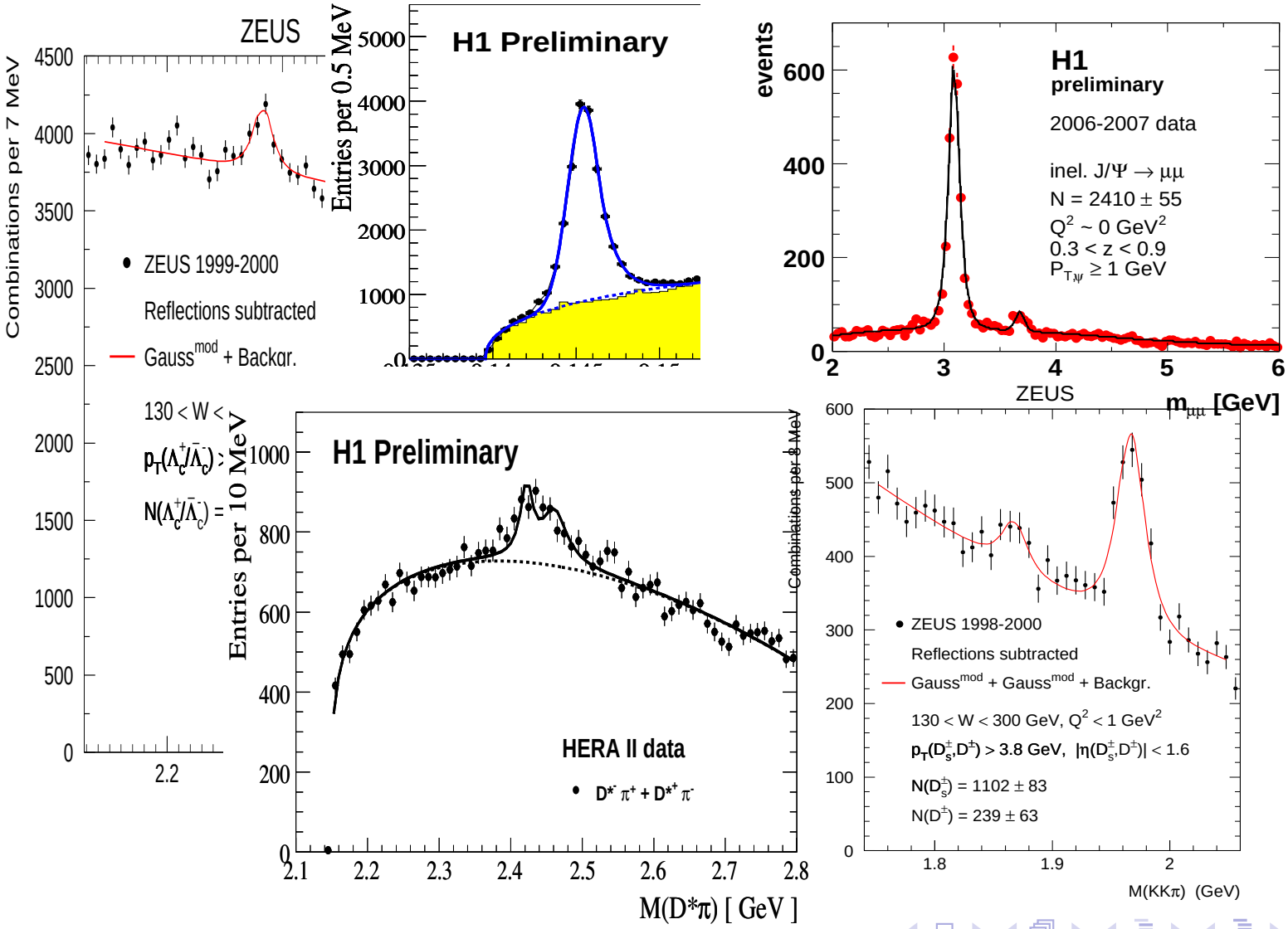


The present and the future

- Analysis of HERA II data ongoing
- Expect many new results in the years to come

HERA: Heavy Quark Land

DIS, Diffraction, γp, big phase space, lumi, ...



Lots of physics ... not enough time ...

More than 50 papers on heavy flavors published with HERA I data ...

Zeus Collaboration:

JHEP 07(2007)074 • EPJ C51 (2007) 301-315
PLB 649 (2007) 111-121 • EPJ C50 (2007) 299-314
EPJ C44 (2005) 351-366 • NPB 729 (2005) 492-525
EPJ C44 (2005) 13-25 • EPJ C38 (2004) 29-41
PLB 599 (2004) 173-189 • NPB 695 (2004) 3-37
PLB 590 (2004) 143-160 • PRD 70 (2004) 012008
PRD 69 (2004) 012004 • NPB 672 (2003) 3-35
EPJ C27 (2003) 173-188 • PLB 545 (2002) 244-260
EPJ C18 (2001) 625-637 • PLB 481 (2000) 213-227
EPJ C12 (2000) 35-52 • EPJ C6 (1999) 603-627
PLB 437 (1998) 432-444 • EPJ C6 (1999) 67-83
ZPC76 (1997) 599-612 • PLB 407 (1997) 402-418
ZPC75 (1997) 215-228 • PLB 401 (1997) 192-206
PLB 349 (1995) 225-237

H1 Collaboration:

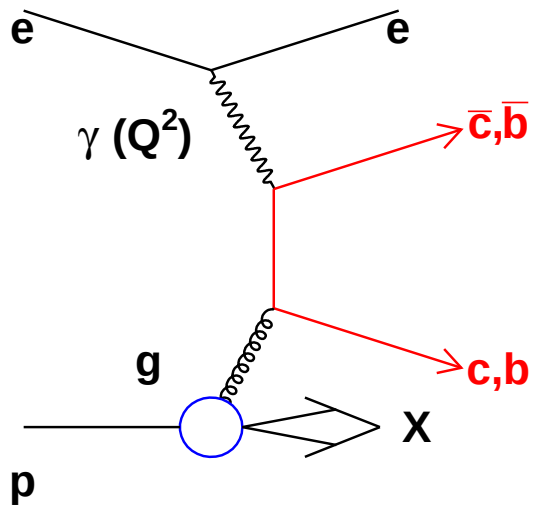
EPJ C51:271-287,2007 • EPJ C50:1-20,2007
EPJ C50:251-267,2007 • EPJ C47 (2006) 597-610
EPJ C46 (2006) 585-603 • EPJ C45 (2006) 23-33
PLB 621 (2005) 56-71 • EPJ C41 (2005) 453-467
EPJ C40 (2005) 349-359 • EPJ C38 (2005) 447-459
PLB 588 (2004) 17-28 • PLB 568 (2003) 205-218
PLB 541 (2002) 251 • EPJ C25 (2002) 1, 41-53
EPJ C25 (2002) 1, 25-39 • PLB 520 (2001) 191
PLB 528 (2002) 199 • PLB 483 (2000) 23-35
PLB 467 (1999) 156-164 • EPJ C10 (1999) 373-393
NPB 545 (1999) 21-44 • PLB 421 (1998) 385
ZPC 72 (1996) 593 • NPB 472 (1996) 32
NPB 472 (1996) 3 • NPB 468 (1996) 3
PLB 338 (1994) 507

... many HERA II perliminaries out, many more yet to come ...

Heavy flavors in DIS

Dominant process in HERA is

Boson Gluon Fusion (BGF):



Multiple hard scales available for pQCD

- Quark masses $\sim$ 1.4 (4.7) GeV
- Q^2 from $\sim 10^0$ to 10^3 GeV
- Quark transverse momentum of few GeVs

Sensitivity to

- Heavy quark production
- Heavy quark fragmentation
- The gluon structure of the proton

Theoretical approaches

- HVQDIS: Full NLO (FFNS)
- RapGap: LO+PS (DGLAP)
- Cascade: LO+PS (CCFM)

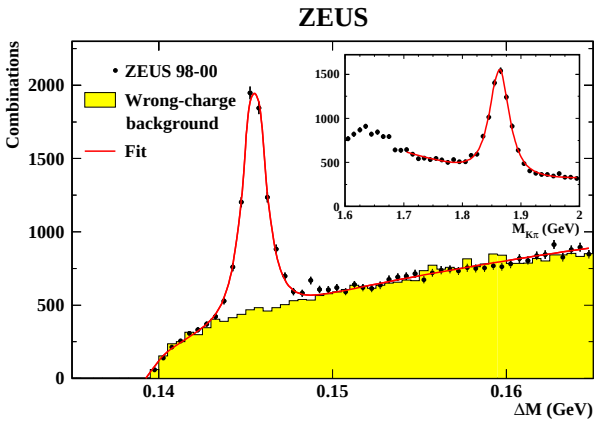
Theoretical uncertainties

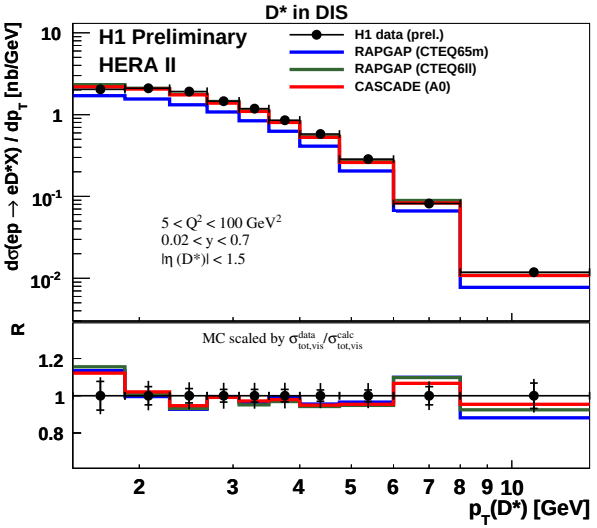
- Factorization and renormalization scales
- PDFs
- Charm mass

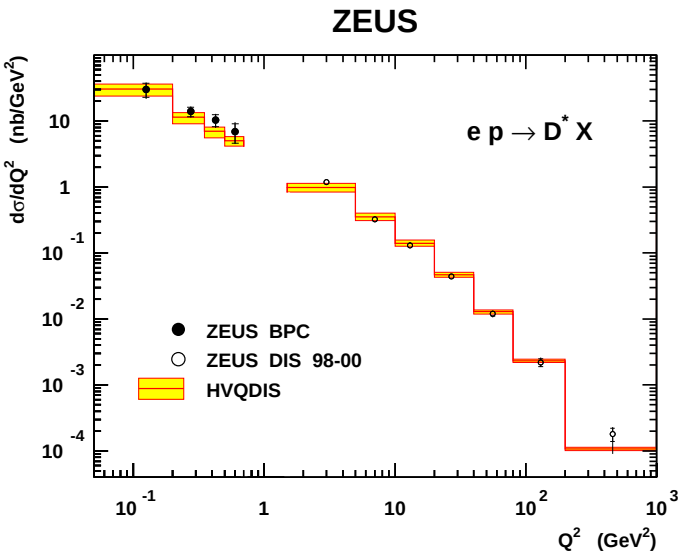
Charm tagging: $D^{*+} \to D^0 \pi_s^+ \to (K^- \pi^+)\pi_s^+$

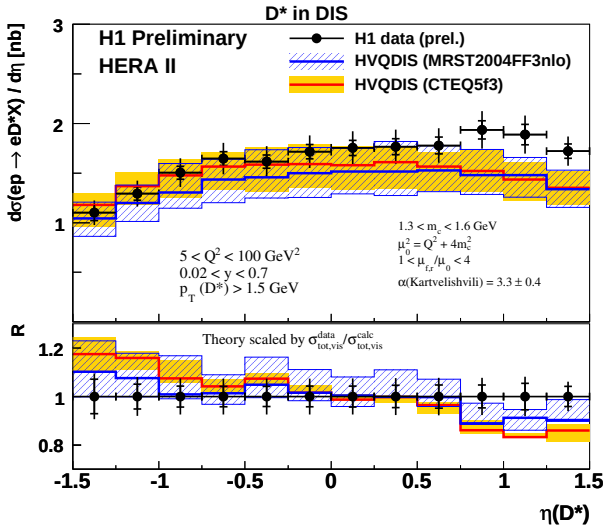
Small phase space: $\Delta m = m_{D^{*+}} - m_{D^0} = 146$ MeV

$\Delta m(exp) = m(K^- \pi^+ \pi_s^+) - m(K^- \pi^+)$



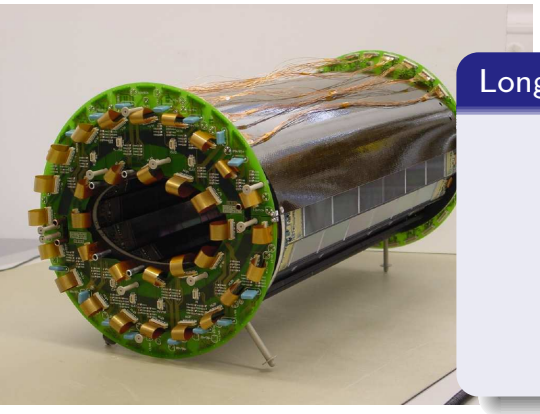






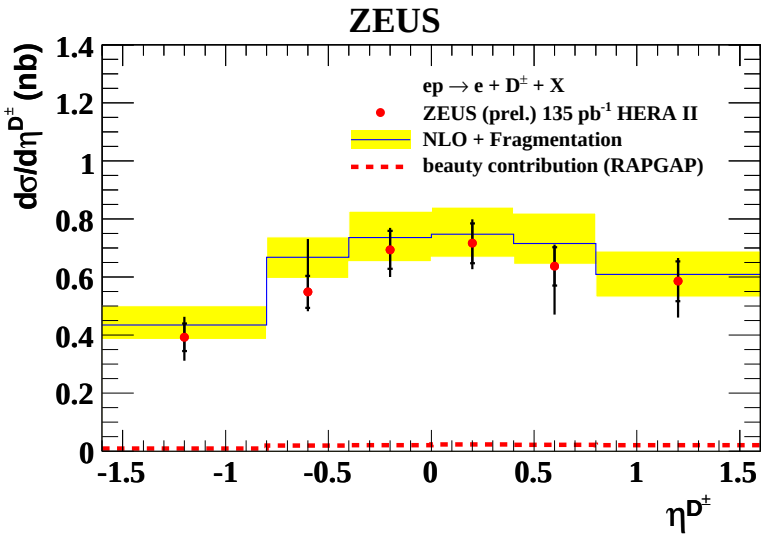
Good descriptions, sizable scale uncertainties

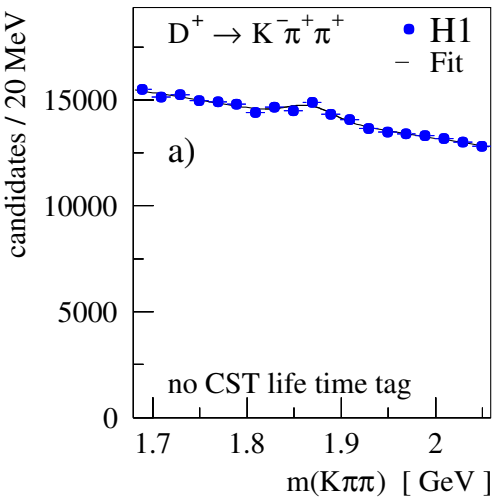
Charm tagging: secondary vertices

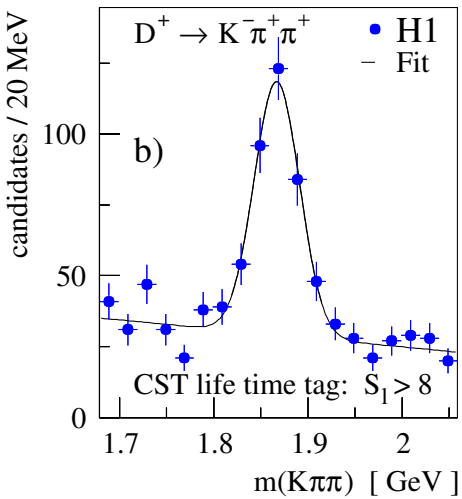


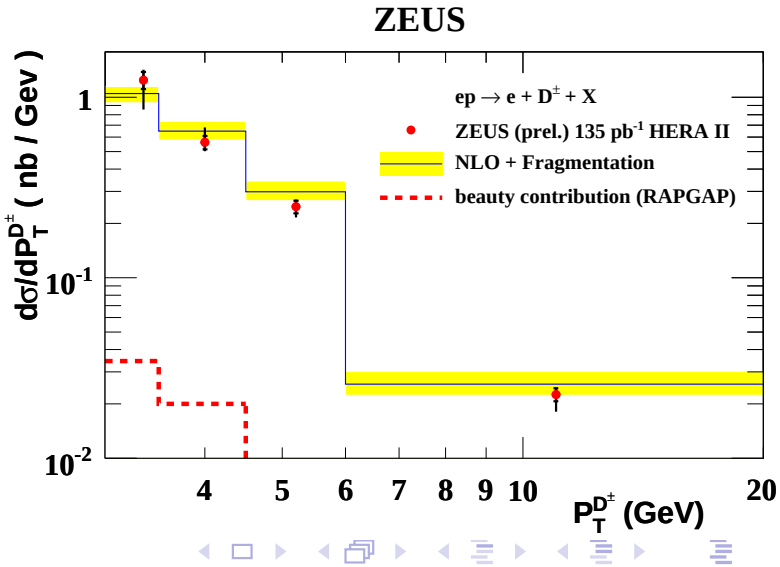
Long lived particles

- produce secondary vertices
- use silicon detectors
  challenging measurement!
- use decay length significance
- get imporved S/N



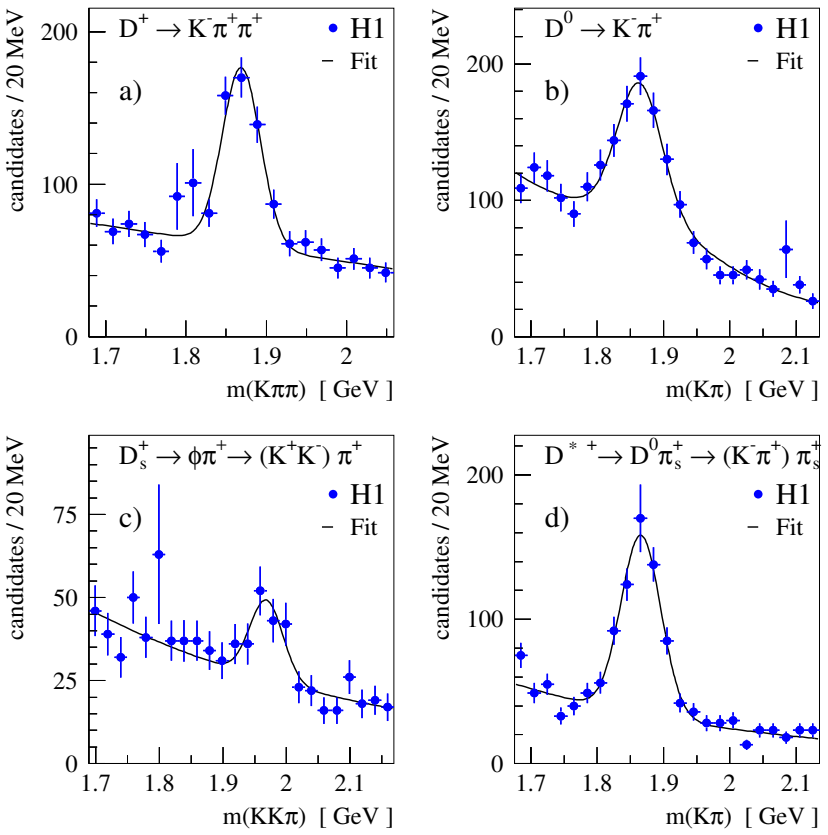


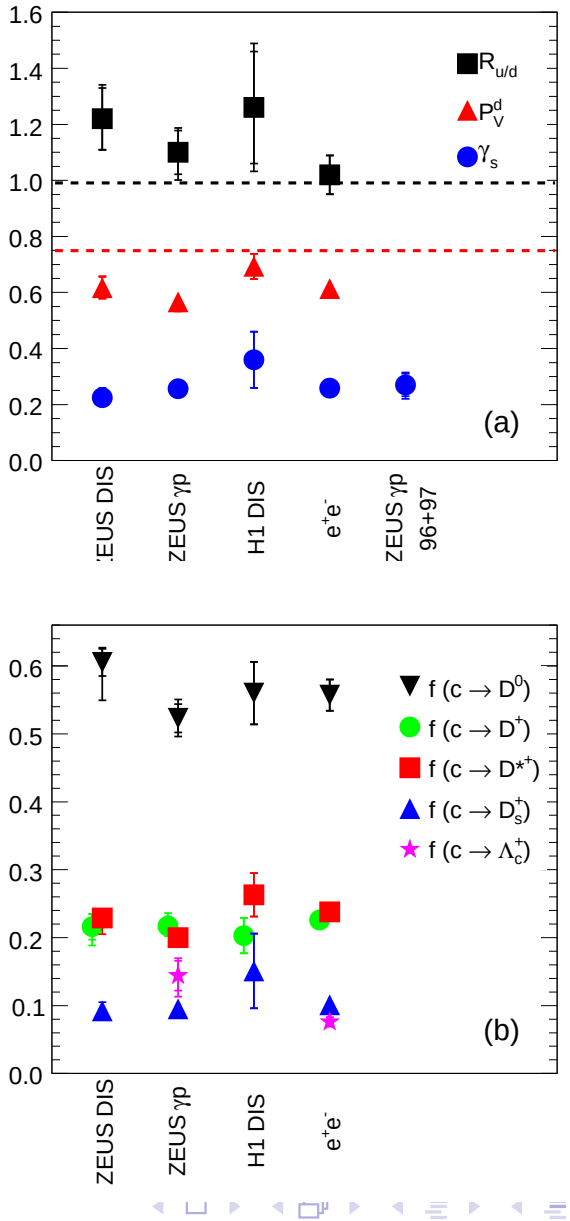




Charm fragmentation fractions and ratios

Measure as many charmed particles as possible





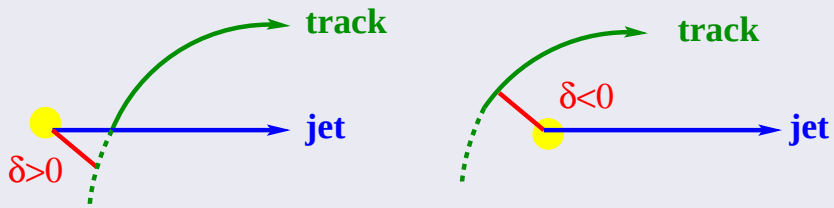
Form cross section ratios to check

- isospin invariance ($R_{u/d} = \frac{neut}{ch}$)
- naive spin counting ($P_V^d = \frac{V}{V+PS}$)
- strangeness suppresion ($\gamma_s = \frac{2s}{no-s}$)
- universality of fragmentation ($c \longrightarrow h$)

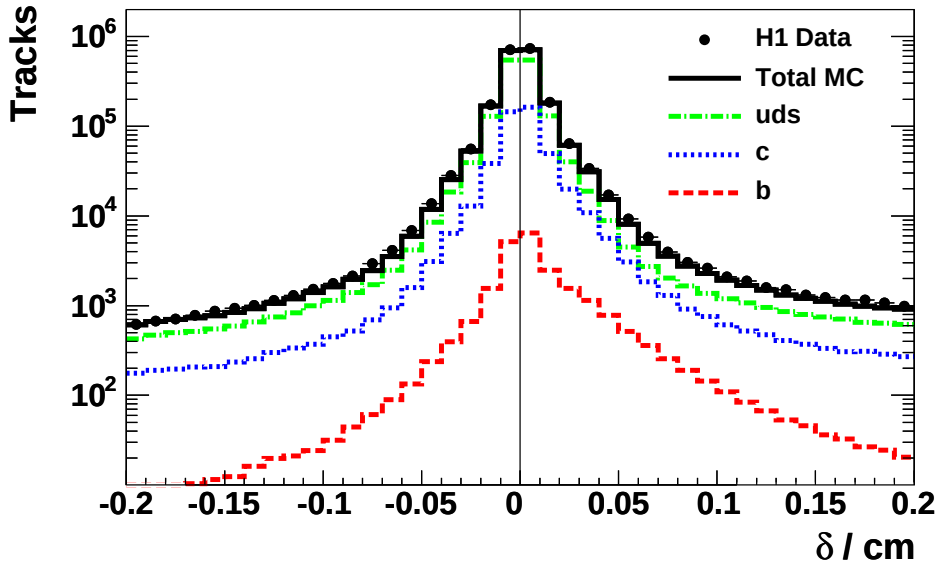
Inclusive heavy flavor tagging

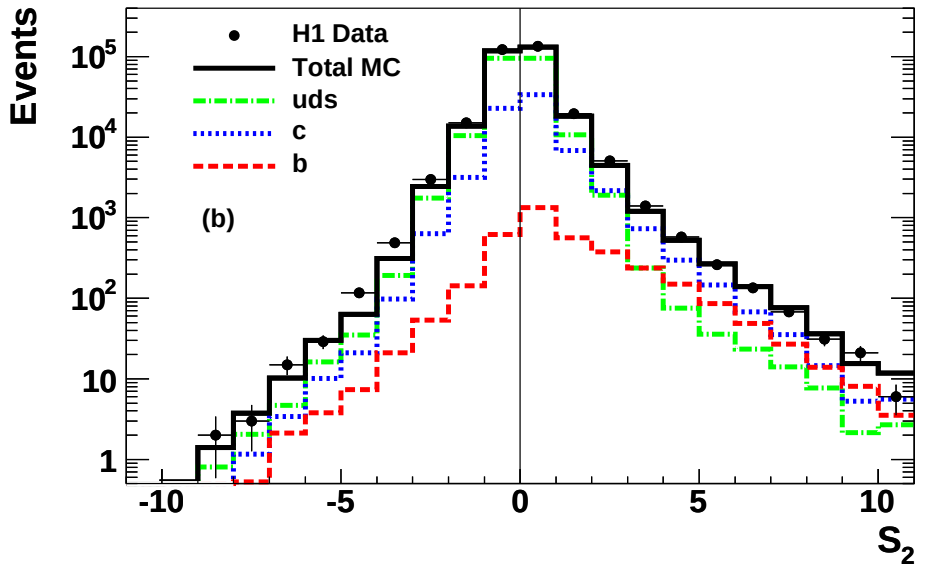
Displaced Track Method

- use all tracks linked to a vertex
- particles linked to secondary vertex are called displaced tracks
- measure signed impact parameter δ w.r.t primary vertex

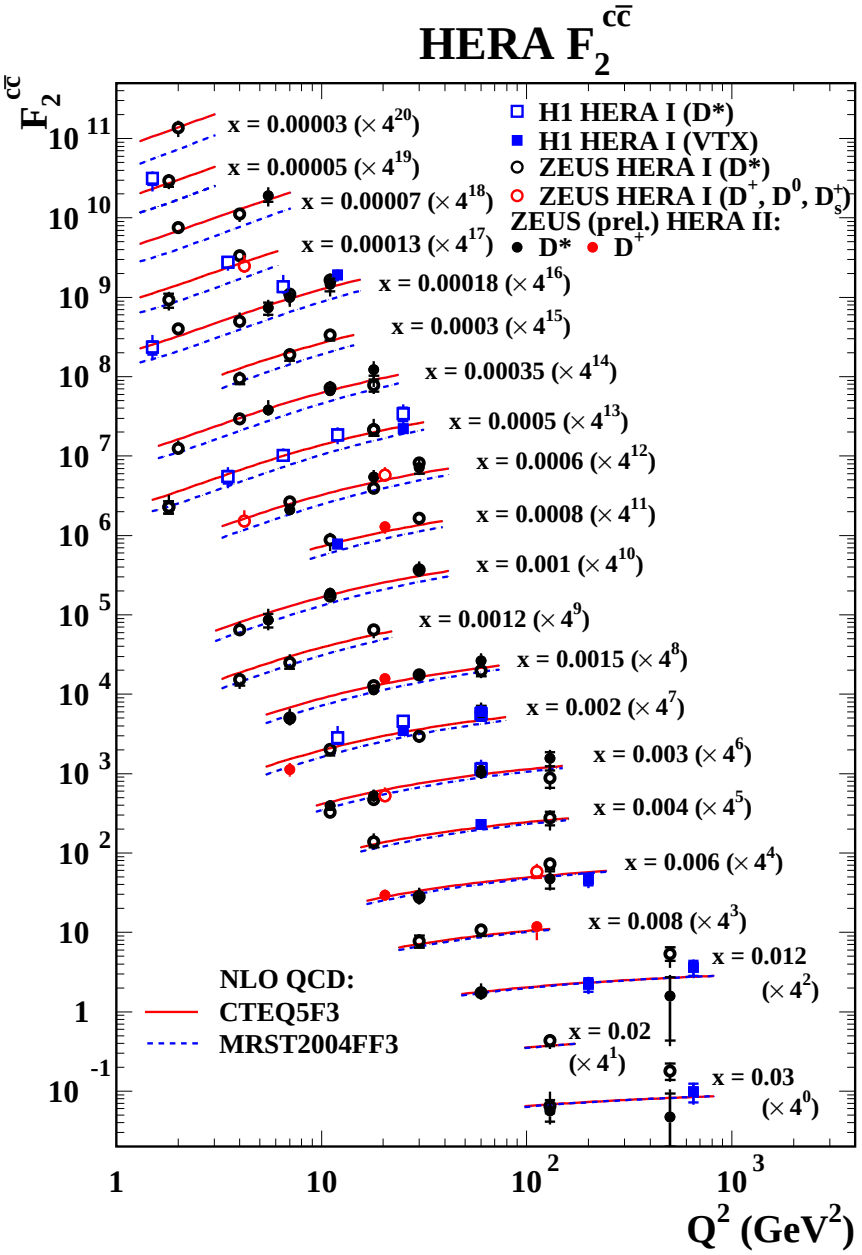


- use its significance to tag heavy flavors:
  - Charm and beauty asymmetric due to their long lifetime
  - light flavors mostly symmetric
- negative side: resolution; positive side: resolution and signal.
- take first and second (S_2) most significant track
- substract negative from positive side
- get clean sample dominated by heavy flavors





The charm in the proton

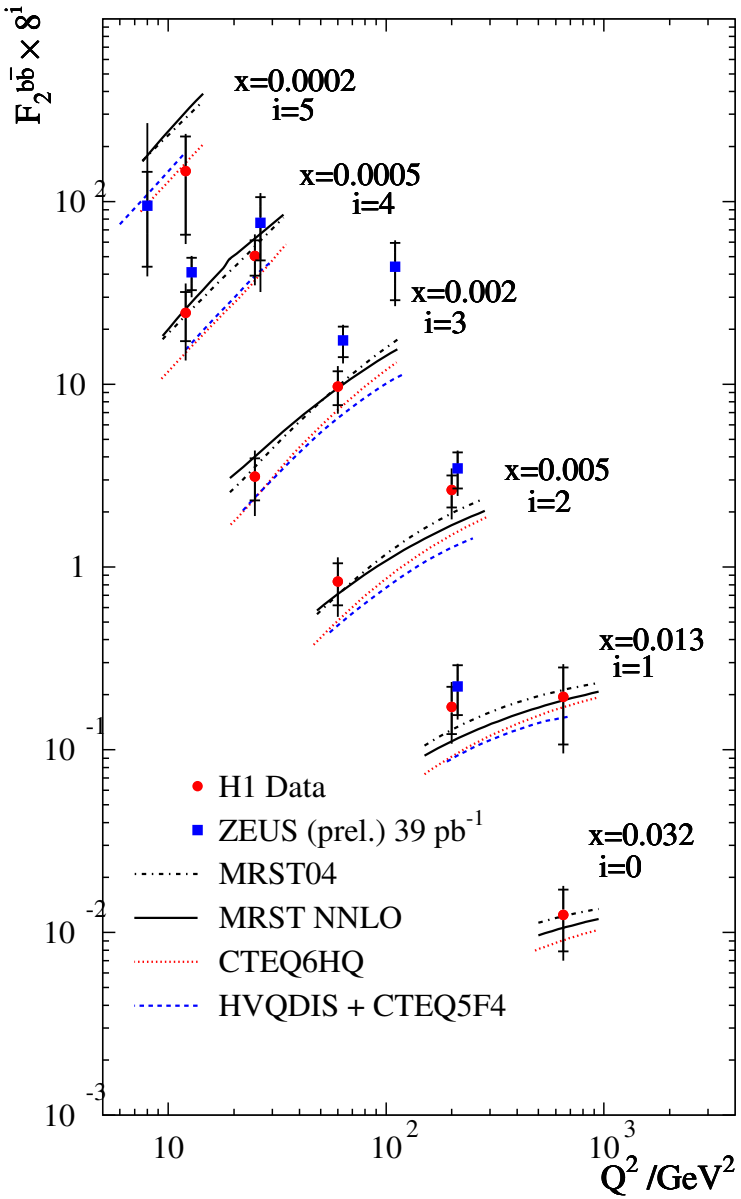


$F_2^{c\bar{c}}$

$$\frac{d^2\sigma^{ep\to c\bar{c}X}}{dx\ dQ^2} \approx \frac{2\pi\alpha^2}{Q^4 x}(1+(1-y)^2)F_2^{c\bar{c}}(x,Q^2)$$

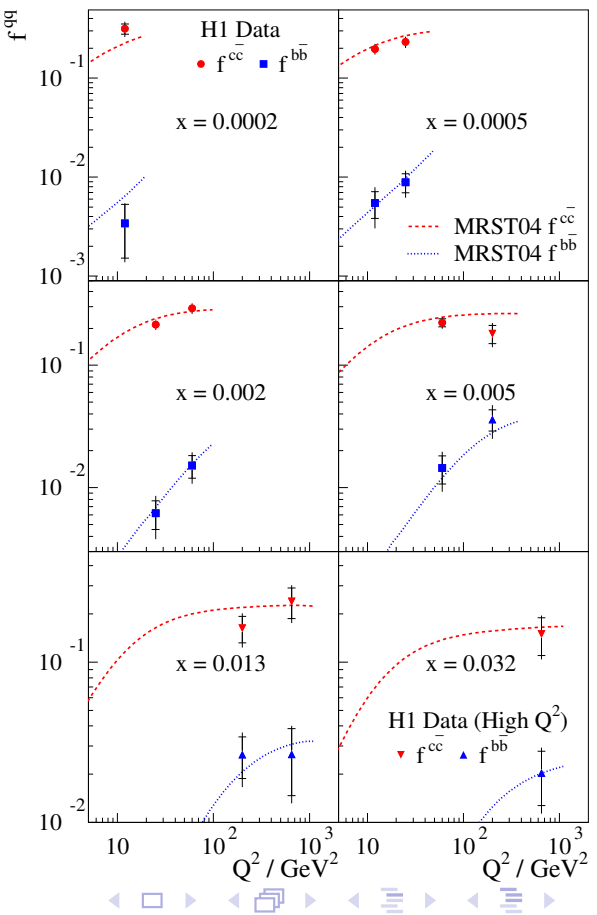
- Huge phase space covered
- Small errors.
- Good agreement among
  - different techniques
  - different data sets
  - different experiments
  - data and theory
- Clear scaling violations
- Close to constraint the gluon.

The beauty in the proton



- First measurement of F_2^{bb} ($\sigma^{c\bar{c}} \ll \sigma^{b\bar{b}}$)
- Differences among theory predictions
- Charm, more than 20% of the proton
- Beauty up to 1.5 %

$$f^{q\bar{q}} = \frac{F_2^{q\bar{q}}}{F_2}$$



Summary

HERA

- About 0.5 fb^{-1} of HERA II data per experiment available
- The H1 and Zeus Collaborations are very active analyzing them

Charm and beauty

- High statistics in charm analysis with different and complementary techniques $\longrightarrow$ precision physics
- pQCD describes data in general but sizable uncertainties from scales and PDFs
- Big contributions from $F_2^{q\bar{q}}$ to F_2
- Many beautiful and charming analysis not shown and many more to come

STAY TUNED!