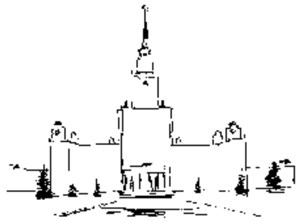


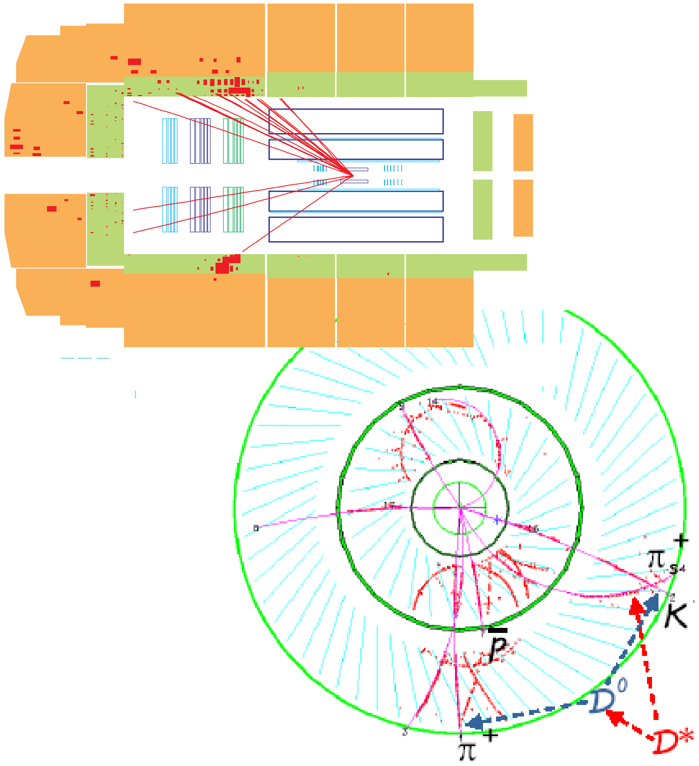
XVIIIth International Workshop

on High Energy Physics and Quantum Field Theory

June 17-23, 2004   Peterhof, Russia

Recent Results from H1 at HERA

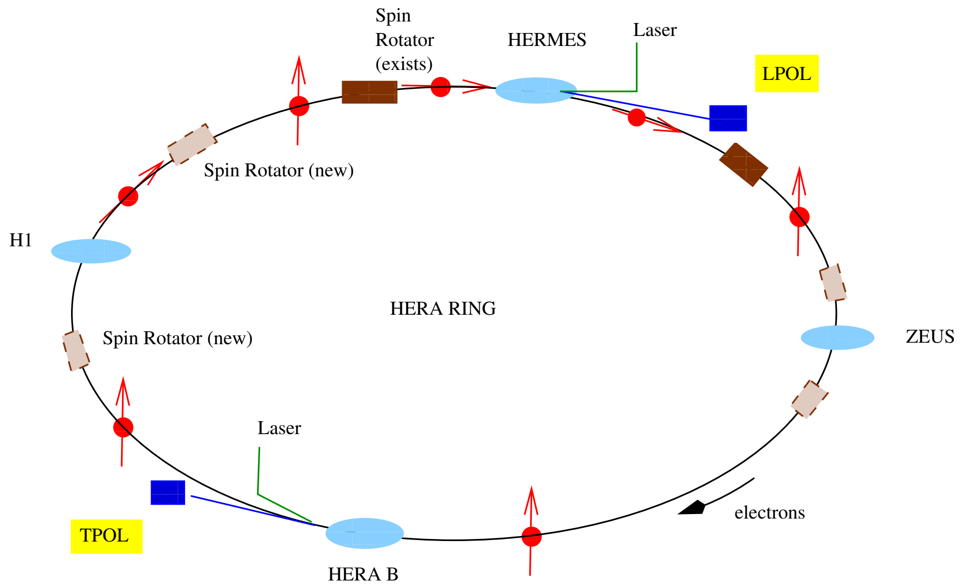
S. Levonian, DESY

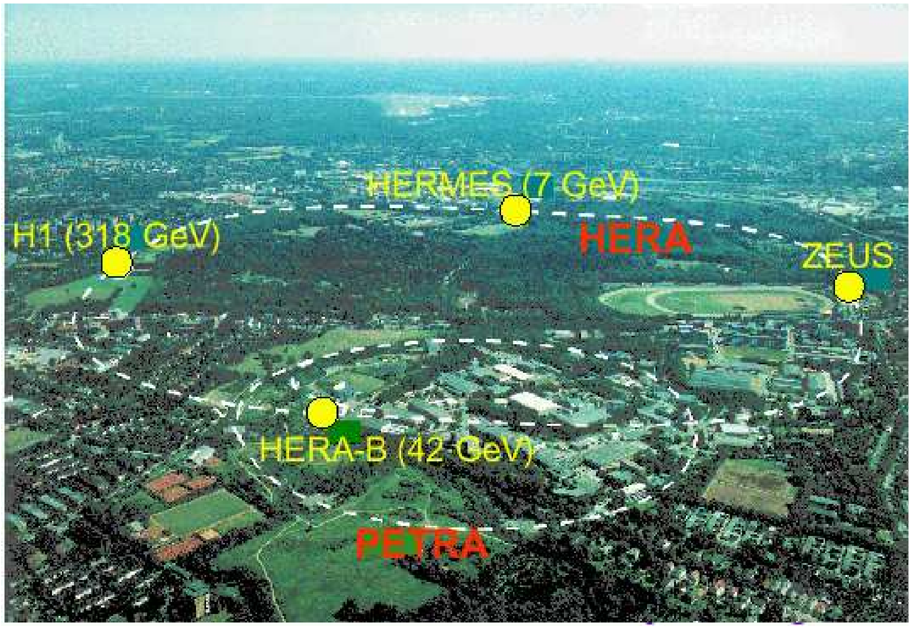


- HERA status
- Proton Structure
- Diffraction
- Heavy Flavours
- Spectroscopy
- Searches
- Summary

HERA facility

p(920) × e(27.6)





H1, ZEUS: ep **(318 GeV)**
[DIS at high Q^2 and at low x]

HERMES: $\vec{e}\vec{N}$ **(7.2 GeV)**
[Spin physics]

Data taking scheduled until 2007 (± 0.5)

HERA-B: pA **(42 GeV)**
[Charm and beauty]

Data taking finished in 2003

History Overview

★ **1993-2000: H1 @ HERA-1**

105 pb^{-1} of e^+p and **15** pb^{-1} of e^-p → final results

■ **2001-2003: Upgrade and startup**

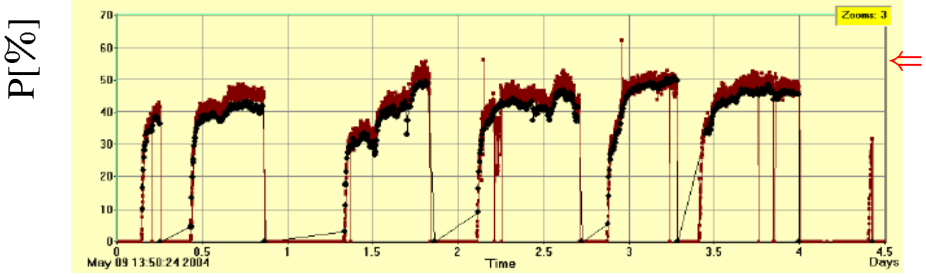
- final focusing magnets inside the detectors → $\mathcal{L} \times 3$
- spin rotators installed around H1 and ZEUS IP → $e^{+/-}_{L/R}$
- difficult startup – (high background)

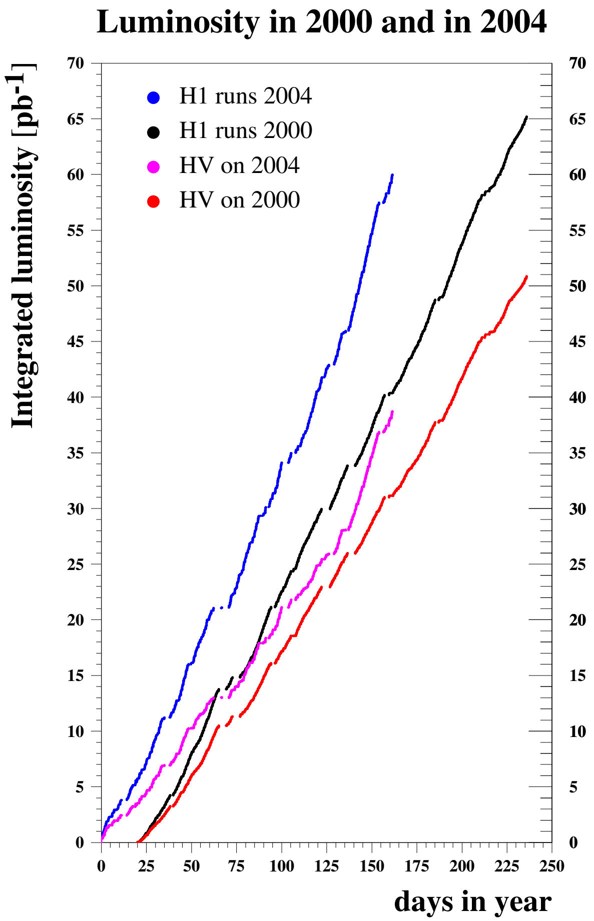
■ **2004: Real start of the data taking**

- $I_p = 100$ mA, $I_e = 50$ mA → approaching the design
- $L_{sp} \simeq 1.3 \cdot 10^{30}/\mathrm{cm^2 s mA^2}$ → $\sim 70\%$ of the design
- HERA duty cycle – main priority now ($40\% \rightarrow 55\%$)

■ **Prospects:**

- run until Aug'04 → ~ 60 pb^{-1} of $\vec{e}^{\,+}p$ data
- 2 months shutdown → switch to e^-
- data taking until 2007 → ~ 0.6fb^{-1} (e^+/e^-, L/R)



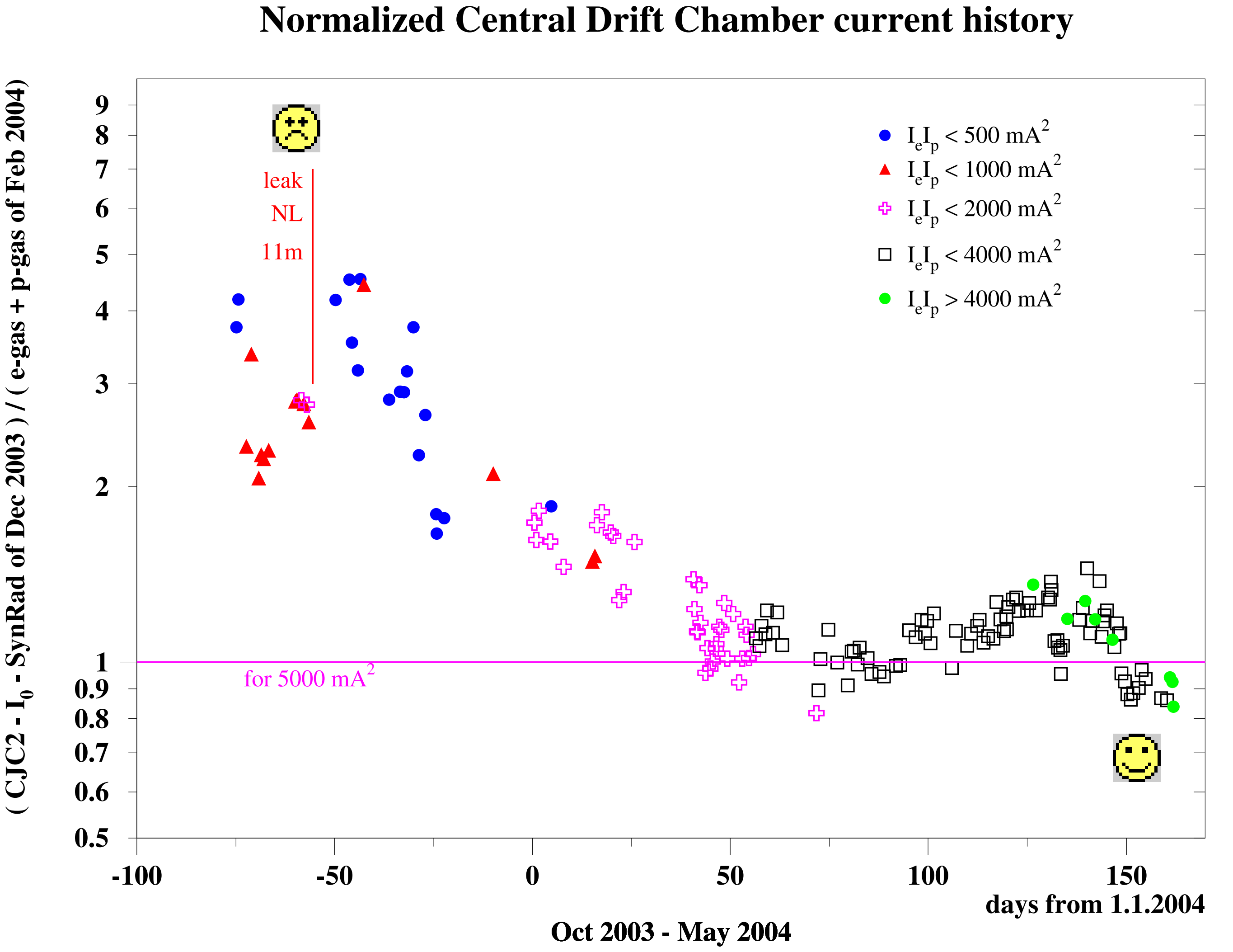


★ **H1 @ HERA-2**

20 pb^{-1} $\vec{e}_R p$ $(\langle P \rangle = 33\%)$

22 pb^{-1} $\vec{e}_L p$ $(\langle P \rangle = 40\%)$

HERA-2 Data Taking: Backgrounds



- Components:

  Synchr. Radiation
  e-gas
  p-gas

- Mechanism:

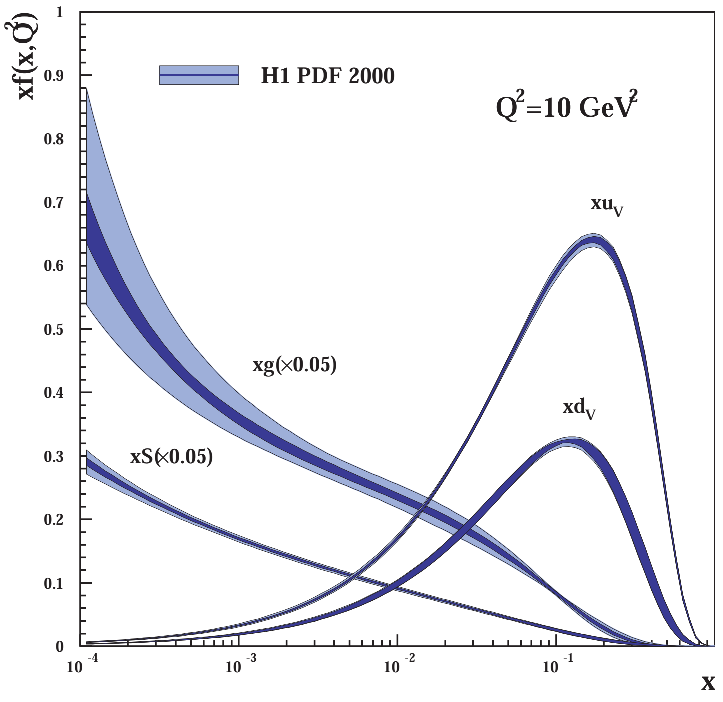
  e-beam (SR,HOM) $\rightarrow$ beampipe outgassing
  p-beam $\times$ bad vacuum $\rightarrow$ huge bgr rate

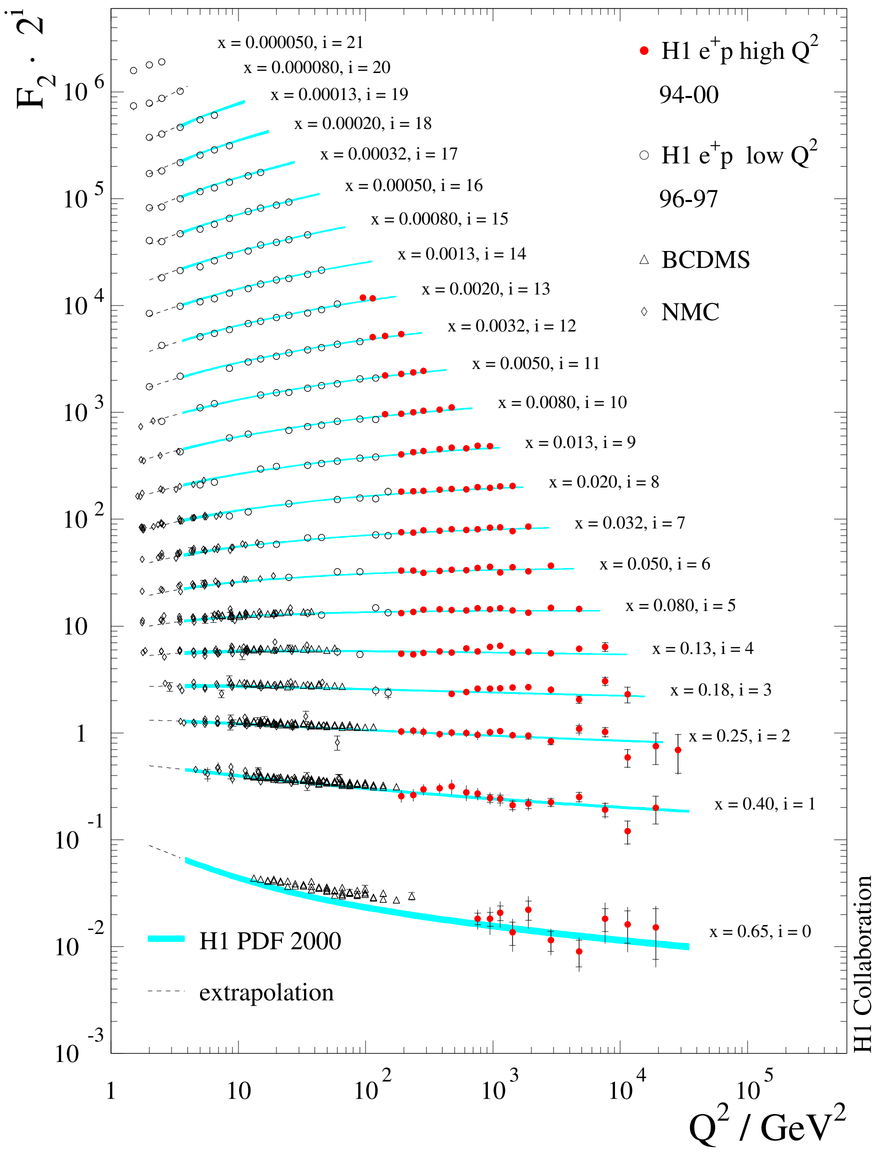
- Measures:

  better SR masks
  improved pumping
  beam conditioning

Proton Structure

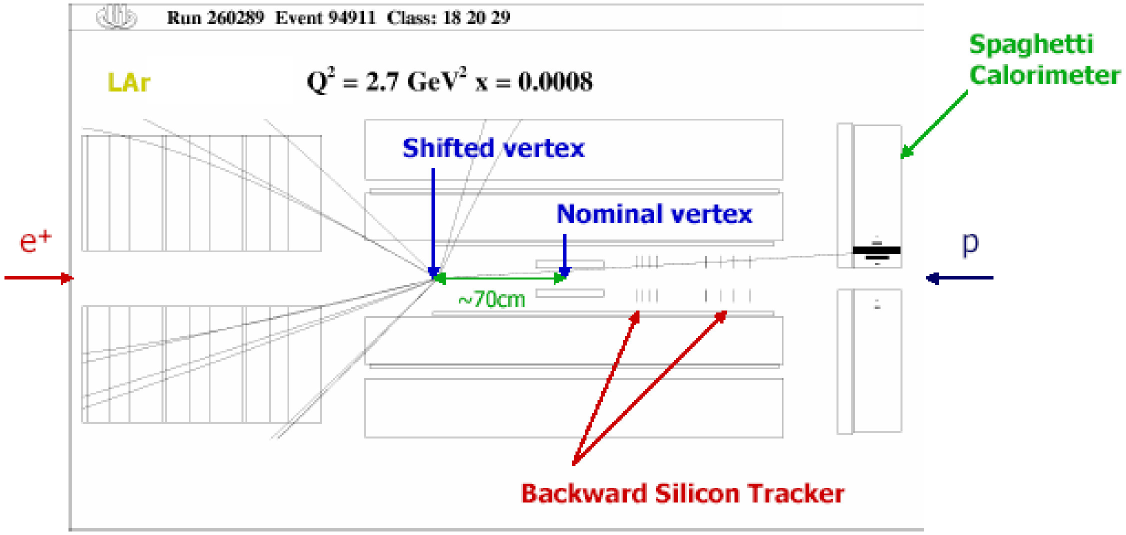
- 2-3% precision in bulk of phase space
- Nicely described by QCD →
- NLO PDFs extracted with error bands

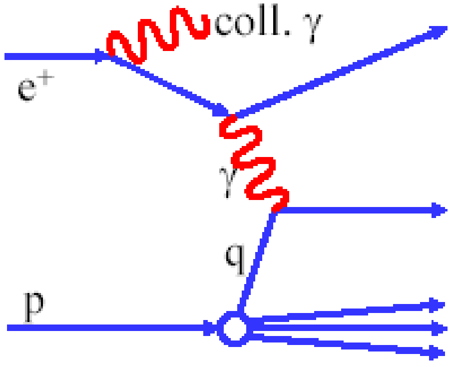




Large x, large Q^2 are statistically limited $\Rightarrow$ HERA-2

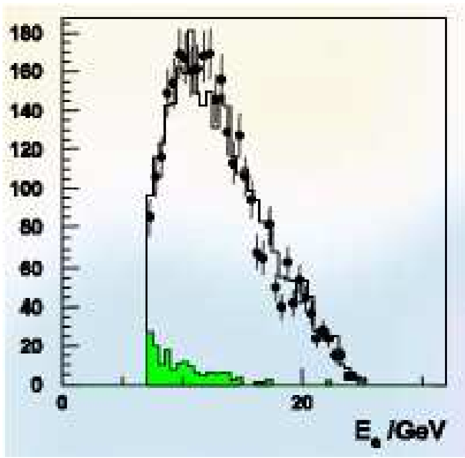
New measurement of F_2 at low Q^2 using ISR events



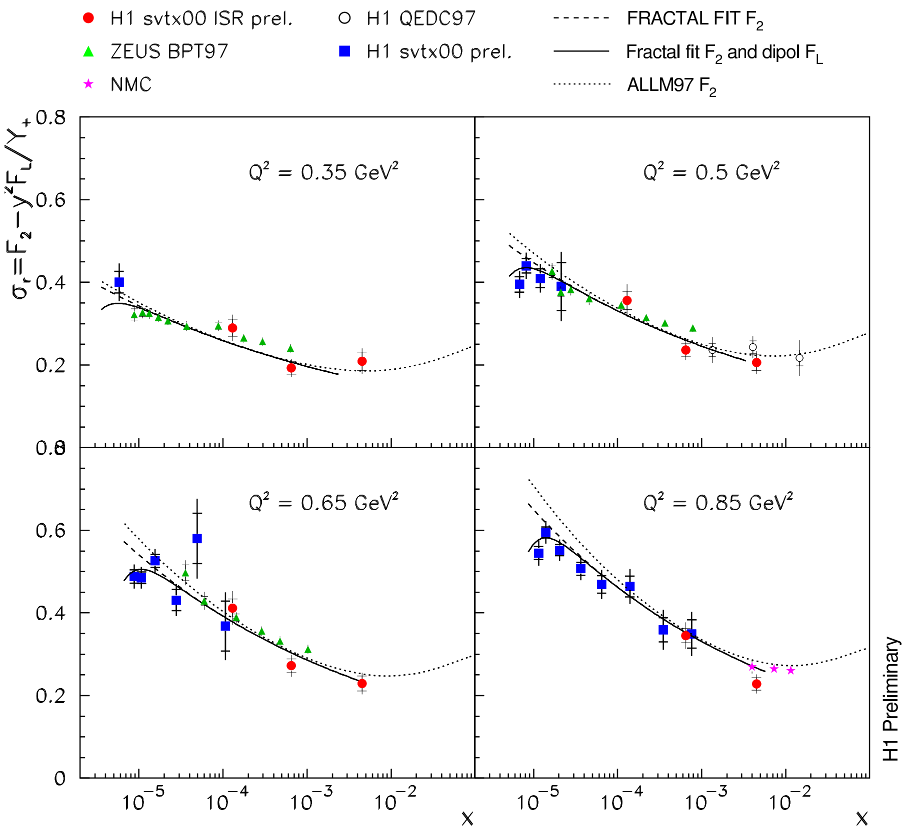


$\langle E_{\rm eff}\rangle \sim 15$ GeV
(c.f. nominal $E_e = 27.6$ GeV)

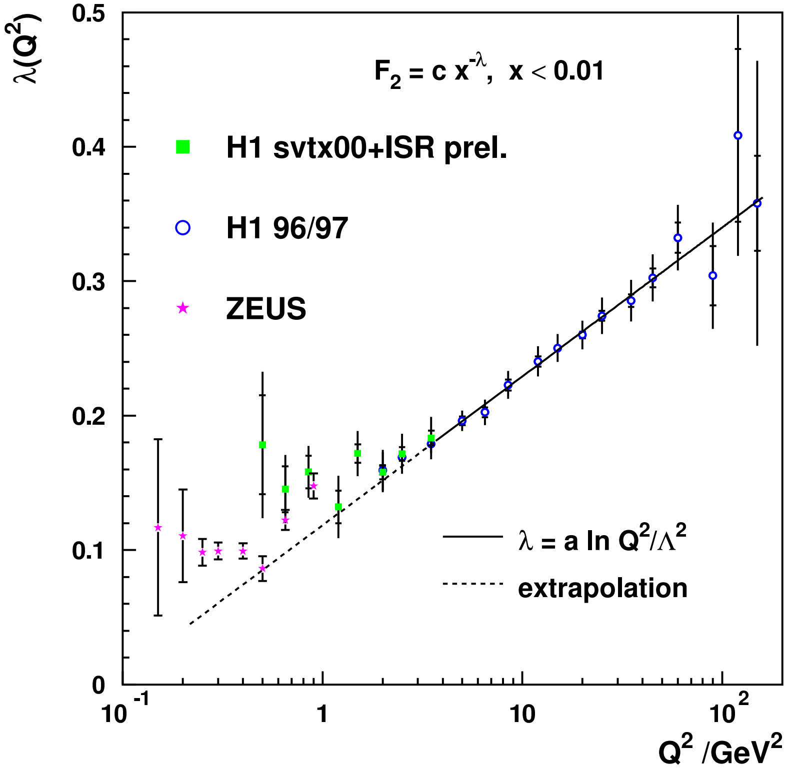
- Use shifted vertex data to access low Q^2
- Use ISR to access larger $x = Q^2/(ys)$ at given Q^2
- Identify ISR events without tagging γ via $\Sigma = \sum_{e+h}(E - p_z) = 2E_e$ (New method!)



F_2 at low Q^2



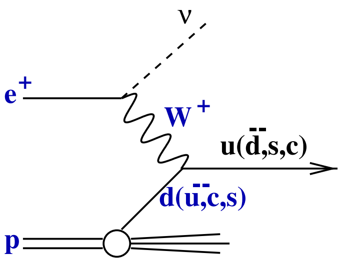
Extract slope $\lambda(Q^2)$ $(= \alpha_{I\!P}(0) - 1)$

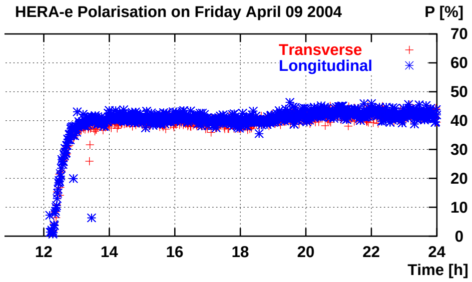


Typical presision is 10%. Result is consistent with previous measurements.

Cover intriguing ”trasition region” $Q^2 \sim 1$ GeV^2 at the limit of pQCD

HERA-2: Polarized CC cross section

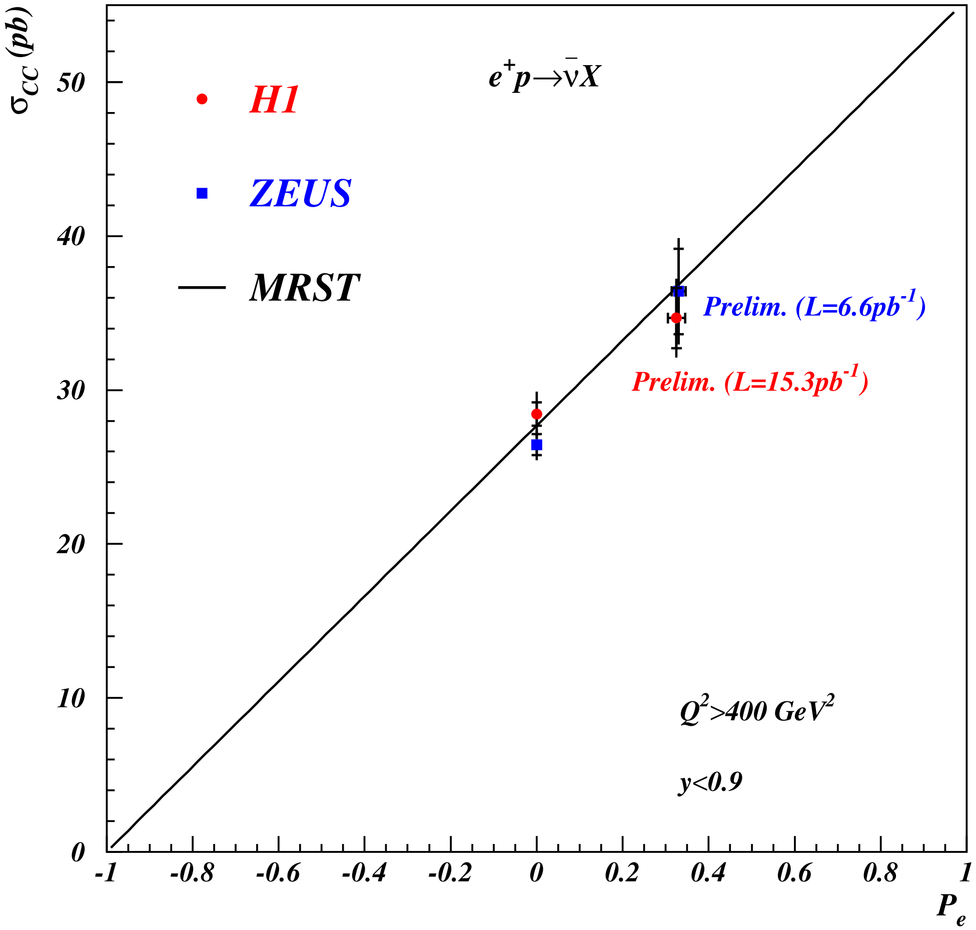




$$(\tilde{\sigma}_{CC}^{e^+p})_{LO} = [1+P]x[(\bar{u}+\bar{c})+(1-y^2)(d+s+b)]$$

$$(\tilde{\sigma}_{CC}^{e^-p})_{LO} = [1-P]x[(u+c)+(1-y^2)(\bar{d}+\bar{s}+\bar{b})]$$

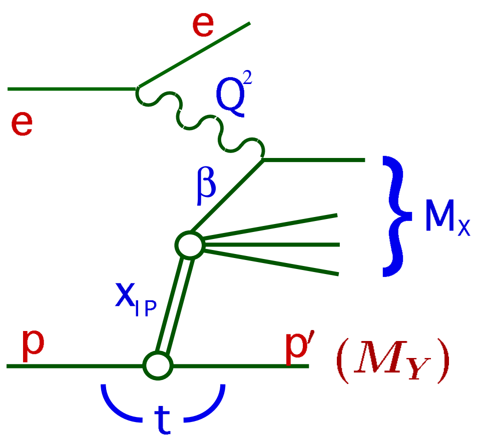
- First measurement with longitudinally polarized right-handed positrons
- Expected polarization dependence confirmed with limited precision
- Polarization flipped in April; 22 pb^{-1} of e_L^+p data collected so far. Go back to e_R^+p in July.



$$P = \frac{N_R - N_L}{N_R + N_L}$$

Diffraction at HERA

- Fundamental aim: understand high energy limit of QCD (gluodynamics; CGC ?)
- Novelty: for the first time probe partonic structure of diffractive exchange
- Practical motivations: study factorization properties of diffraction; try to transport to hh scattering (e.g. predict diffractive Higgs production at LHC)



$x_{I\!P} = \frac{Q^2+M_X^2}{Q^2+W^2}$

(momentum fraction of colour singlet exchange)

$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$

(fraction of exchange momentum, coupling to γ^*)

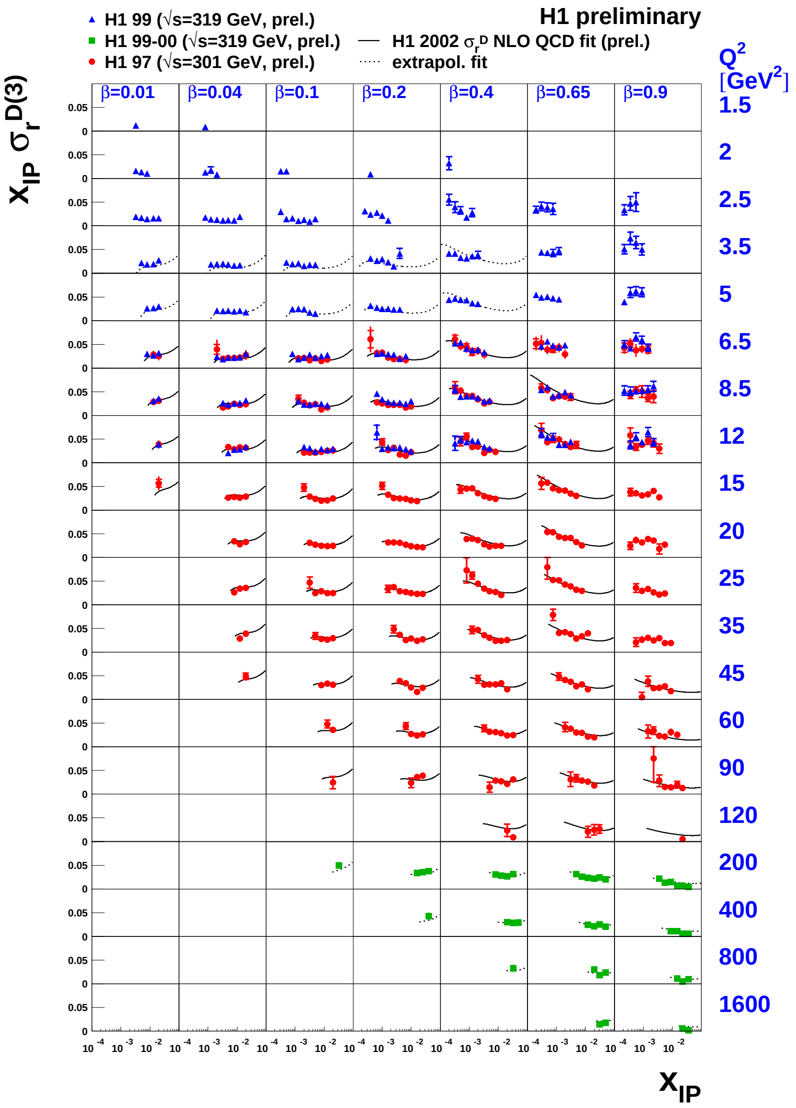
$t = (p - p')^2$

(4-momentum transfer squared)

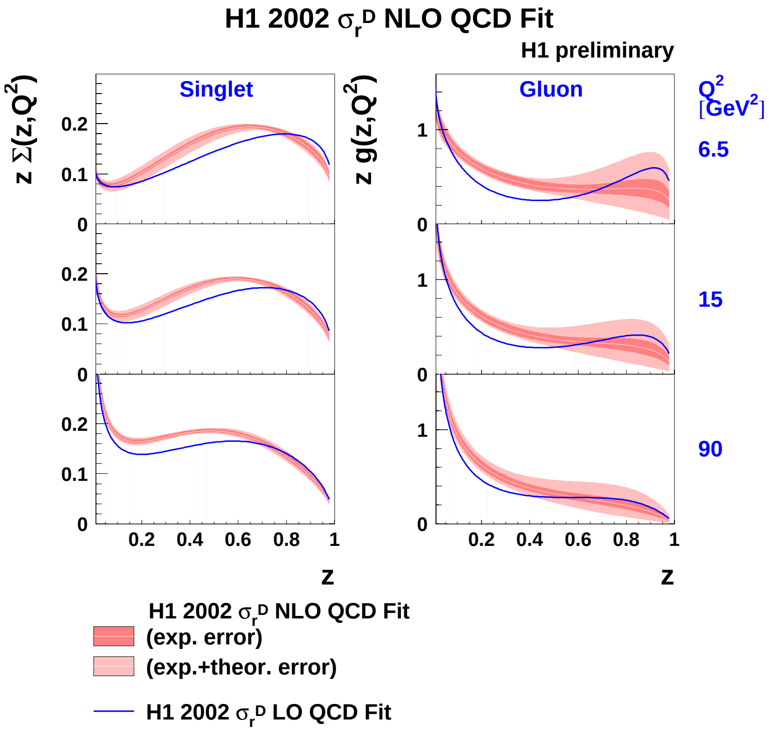
QCD factorization in DDIS (Collins et al.):

$$\sigma_r^{D(4)} \propto \sum_i \hat{\sigma}^{\gamma^* i}(x, Q^2) \otimes f_i^D(x, Q^2; x_{I\!P}, t)$$

Inclusive Diffraction and Diffractive PDF's

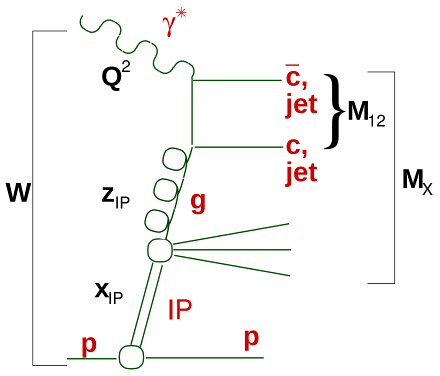


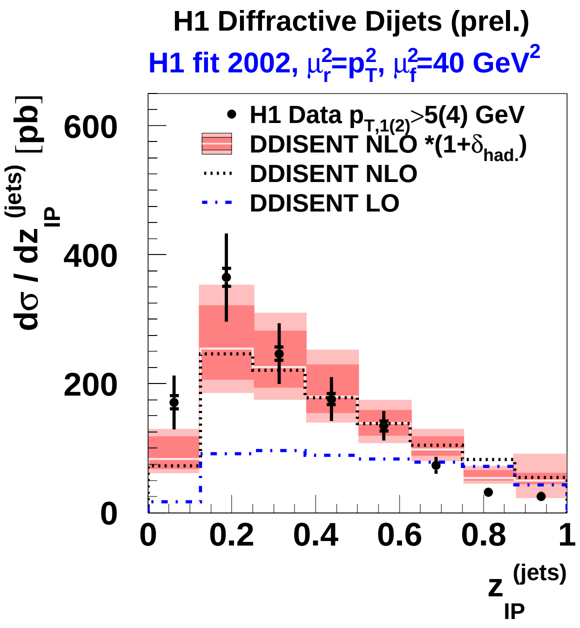
- Precise data, well described by NLO QCD
- Resulting diffractive PDF's are gluon dominated
- Singlet part is well constraind, but substantial (theor.) uncertainty for gluon at highest fractional momenta z

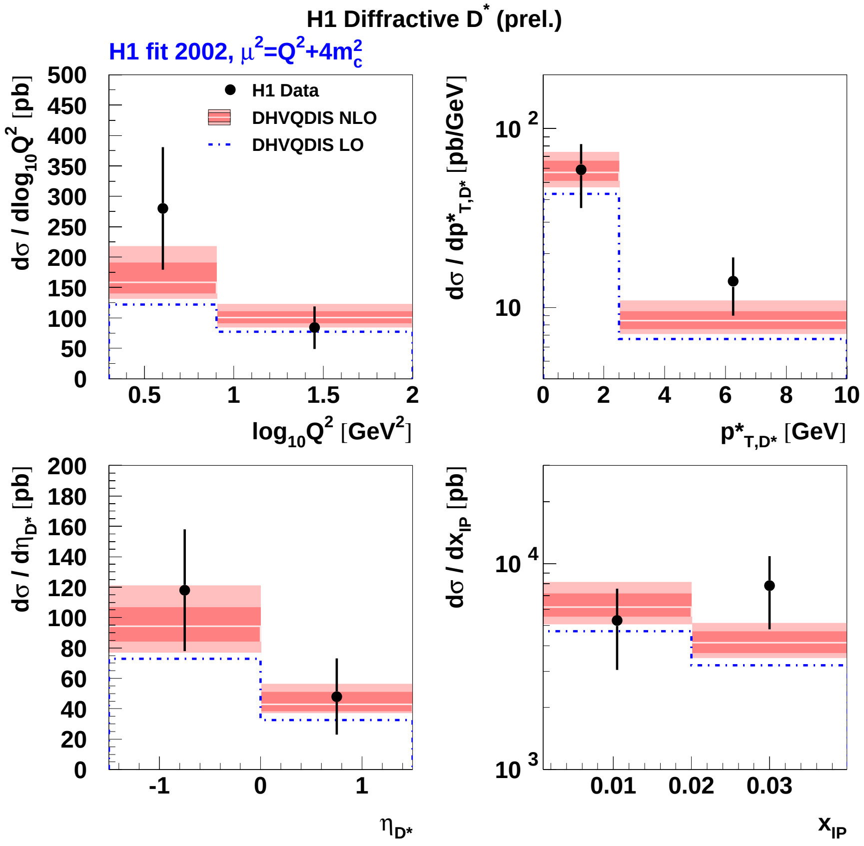


⇒ test them on diffractive final states

Test QCD factorization in DIS



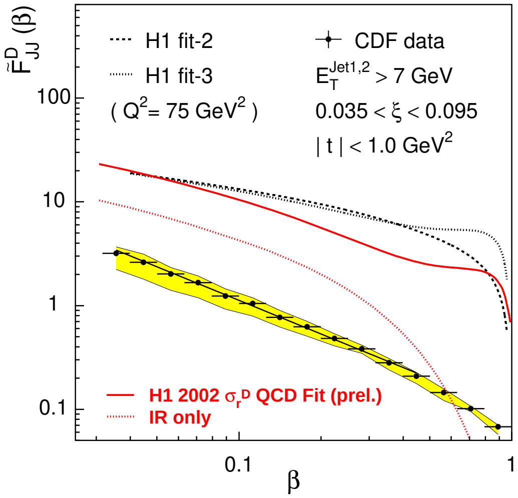




Consistent picture of diffractive DIS to NLO QCD!

Factorization tests: from DIS via γp to Tevatron

Tevatron vs HERA

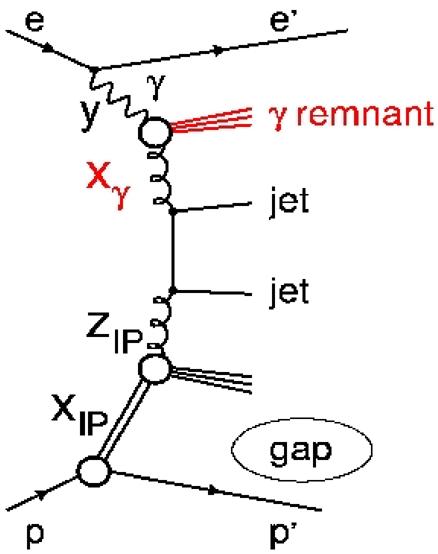


Factorization breakdown by factor of $\sim$ 10 !

(Gap survival probability; soft physics, hence hard to calculate precisely)

$Q^2 \approx 0$:

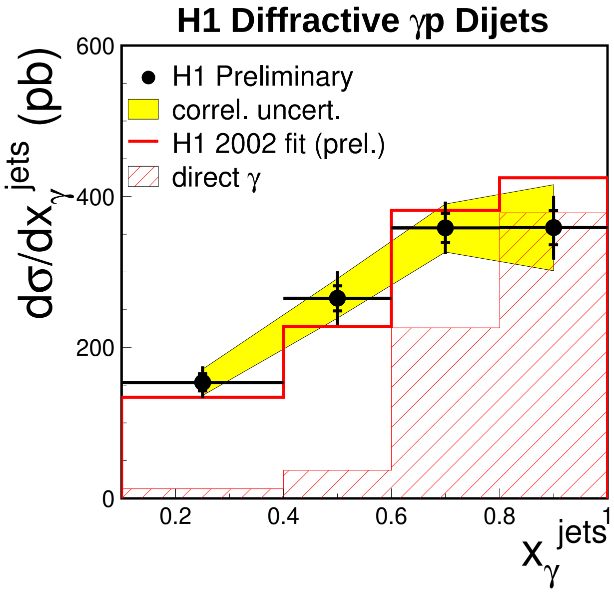
can secondary interactions fill the gap?



$x_\gamma = 1$ – direct photon coupling, DIS-like

$x_\gamma < 1$ – resolved photon, hadron-like

(N.B: LO+PS comparisons need NLO... in progress...)

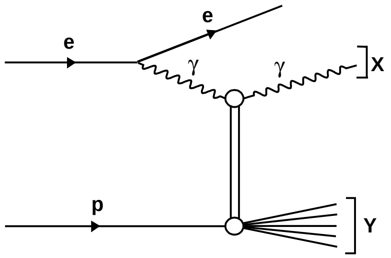


No sign of suppression γp wrt DIS (and resolved wrt direct processes)

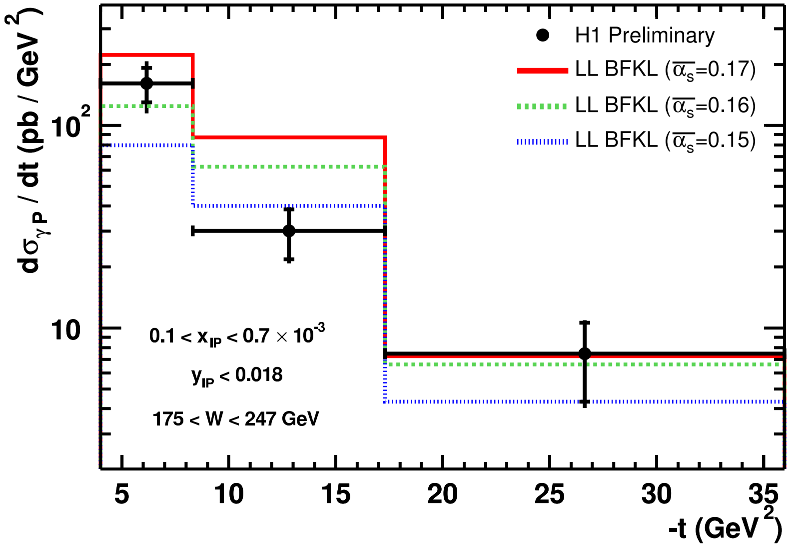
BFKL at work: Exclusive high-$|t|$ J/ψ and photons

$\mathbf{Q^2 \approx 0}$

Truly elastic photon scattering at $|t| < 35$ GeV^2



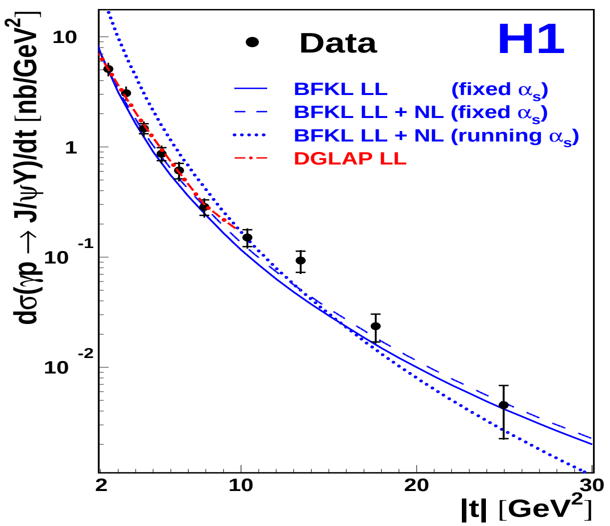
First ever measurement of this clean process!

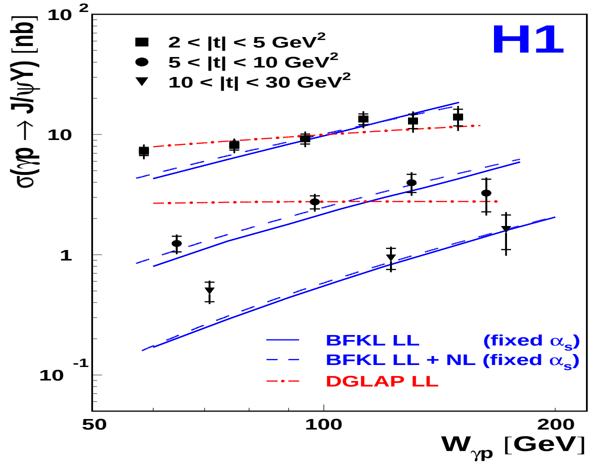


BFKL does a fair job

(J/ψ: LL+NL, γ: only LL is available)

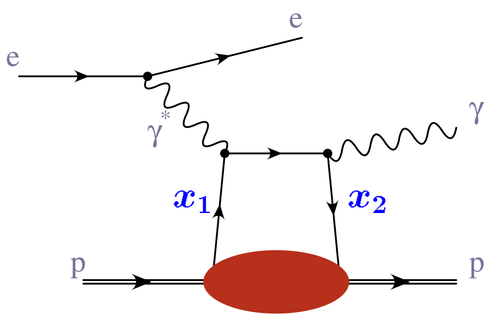
High-$|t|$ J/ψ photoproduction





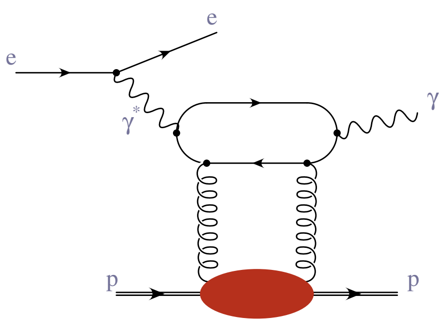
DVCS (Deeply Virtual Compton Scattering)

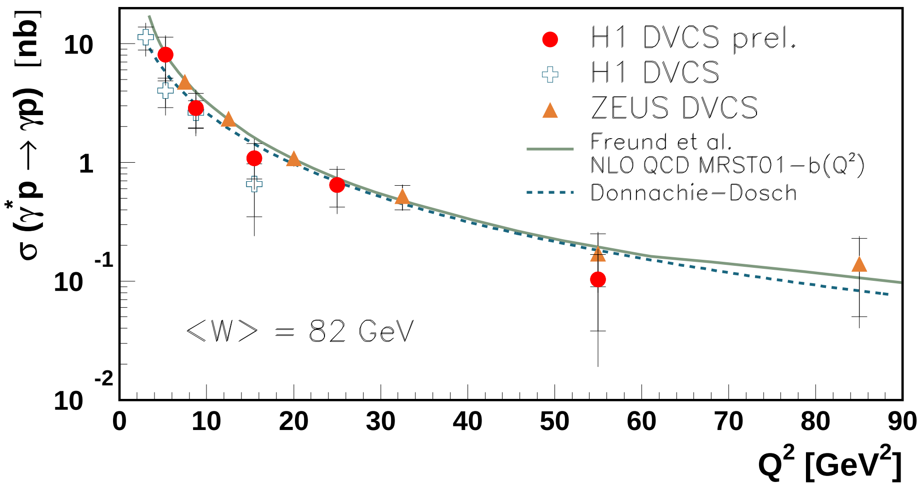
LO

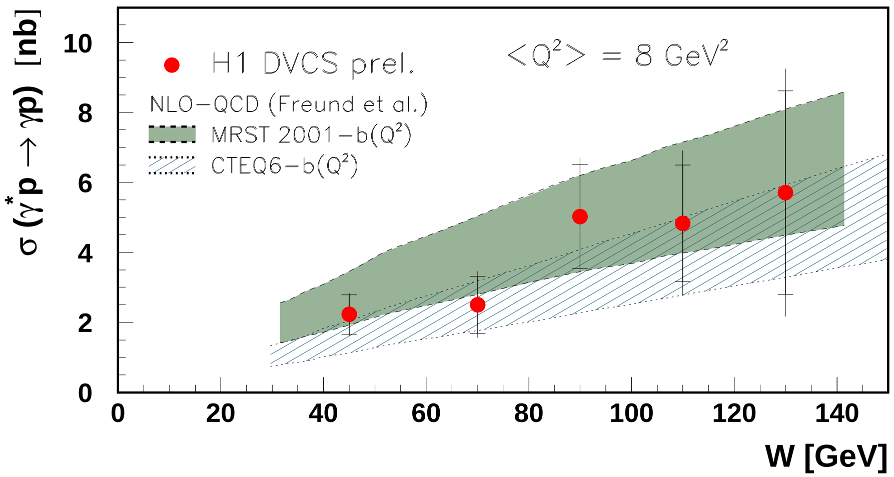


$G(x_1, x_2, Q^2)$

NLO







– Non-forward nature → access to GPD's

– Clean process (no VM WF involved)

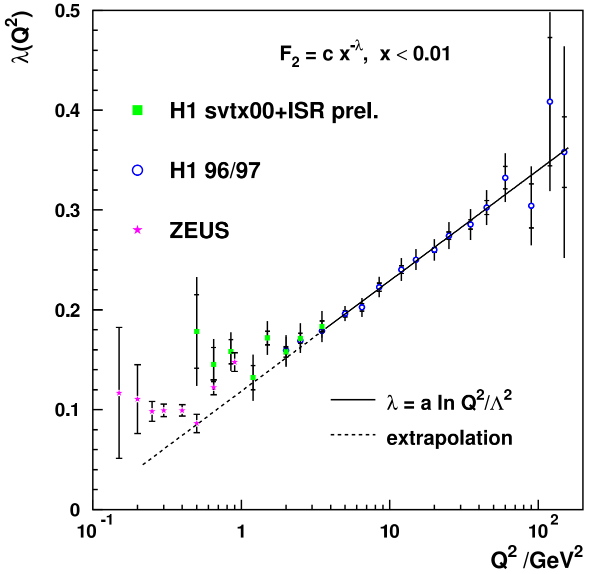
– Fully calculable in QCD (*FS, Freund, DD, ...*)

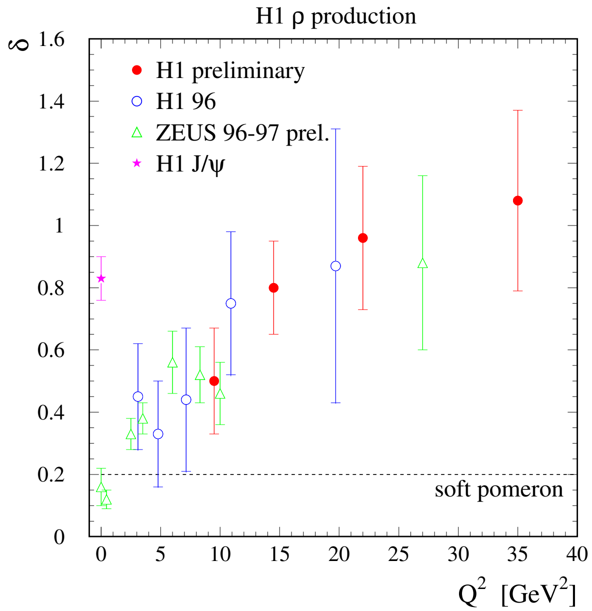
- Data are well described by calculations
- Main theor. uncertainty: t-slope
- Need to measure t-dep. (H1 VFPS)

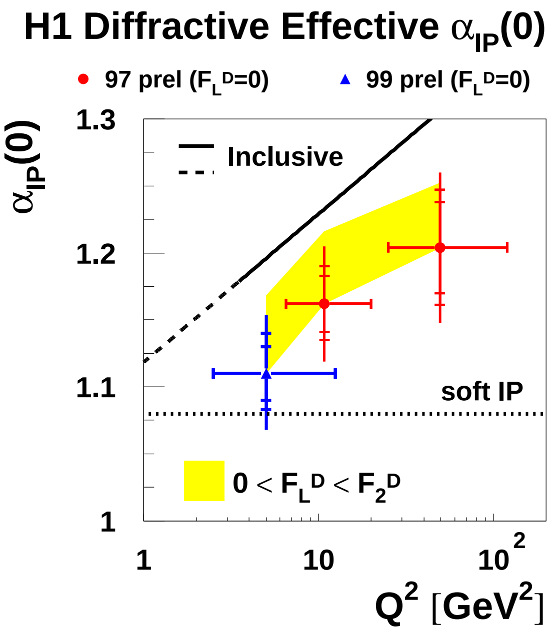
⇒ One of the major topics for HERA-2

Pomeron intercept in inclusive, elastic and diffractive DIS

Optical theorem







$\lambda = (\alpha_{I\!P}(0) - 1)$

$\delta = 4(\overline{\alpha_{I\!P}(0)} - 1)$

Unitarity corrections?

Understanding of colour singlet exchange remains a major challenge in QCD:

It is a complicated interplay between soft and hard phenomena

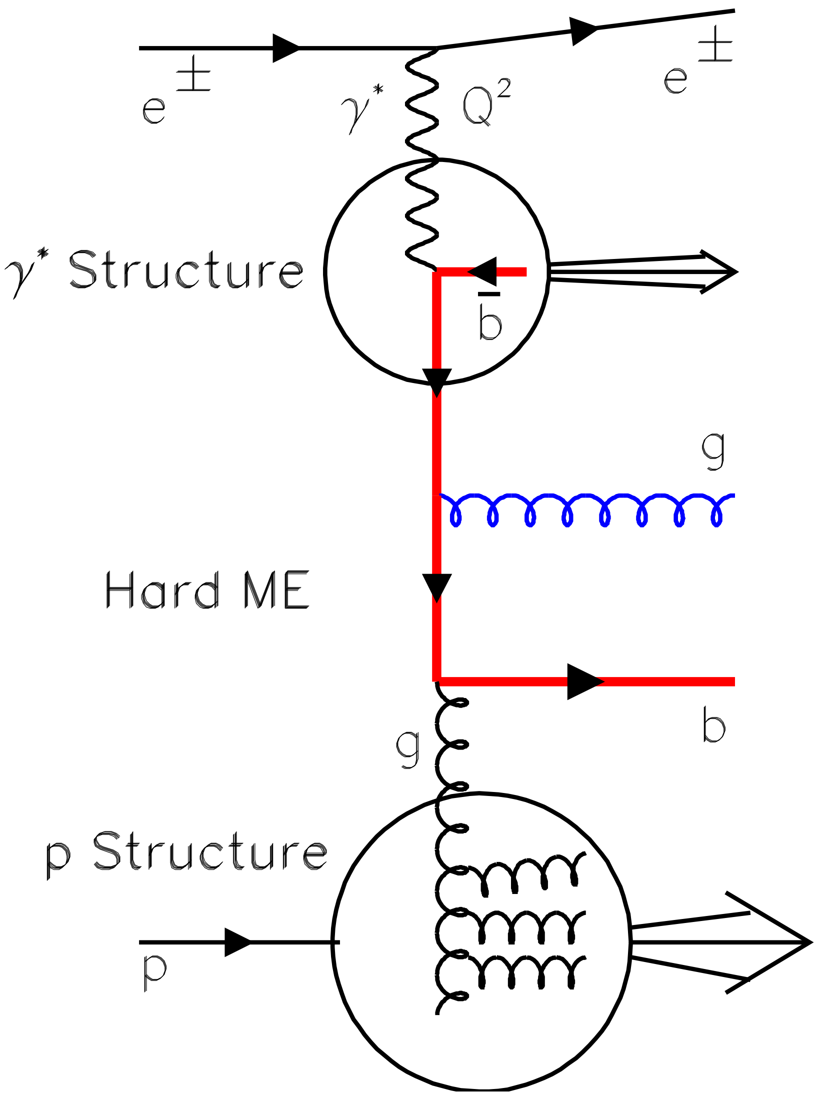
Beauty at HERA

- Factorization:
  - ⊗ Photon Structure
  - ⊗ Matrix Element
  - ⊗ Proton Structure
  - ⊗ Fragmentation

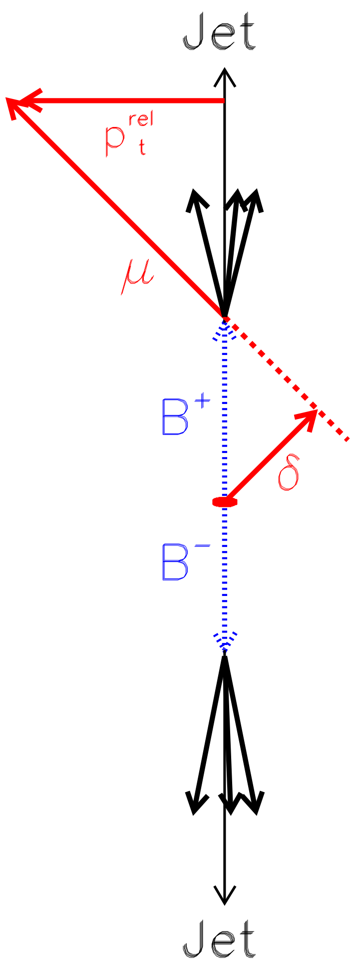
- Relevant scales:

  $m_b \sim 5$ GeV
  $Q^2 < 1$ GeV² (γp) or > 2 GeV² (DIS)
  p_t^b ($p_t^{jet} > 6$ or 7 GeV)

- QCD interpretation:
  - ▷ NLO $\mathcal{O}(\alpha_s^2)$ calculations
    γp: FMNR (*Frixione et al.*)
    DIS: HVQDIS (*Harris, Smith*)
  - ▷ (LO $\mathcal{O}(\alpha_s)$ + PS) Monte Carlo
    Pythia / Rapgap (DGLAP)
    Cascade (CCFM)

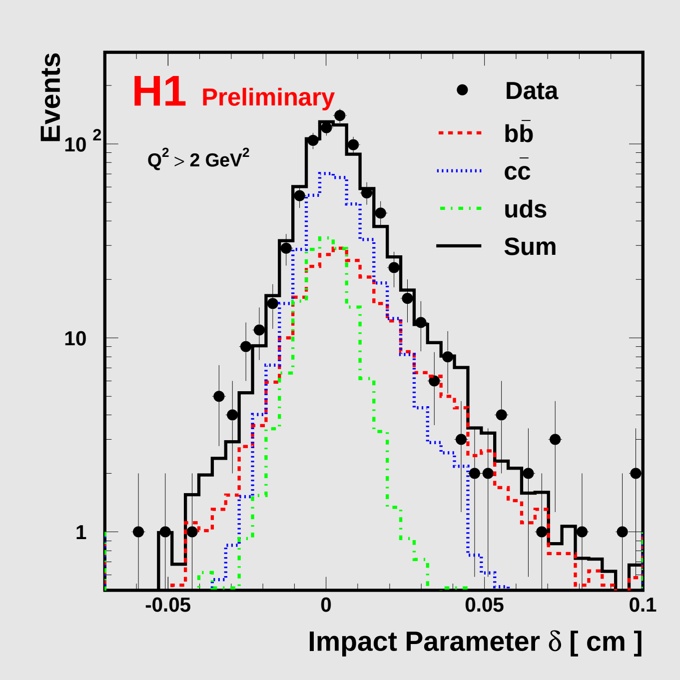


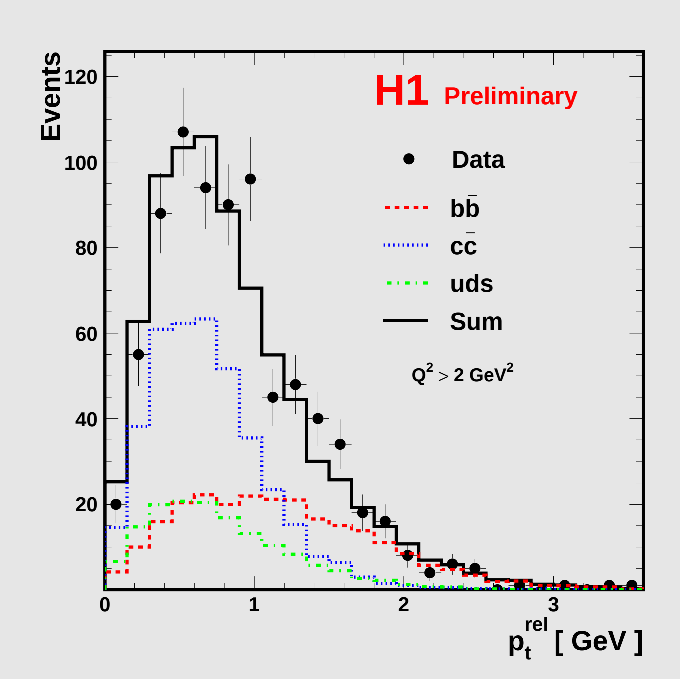
Experimental Observables



- Large B-mass:
  p_t^{rel} – p_t of μ relative to jet axis

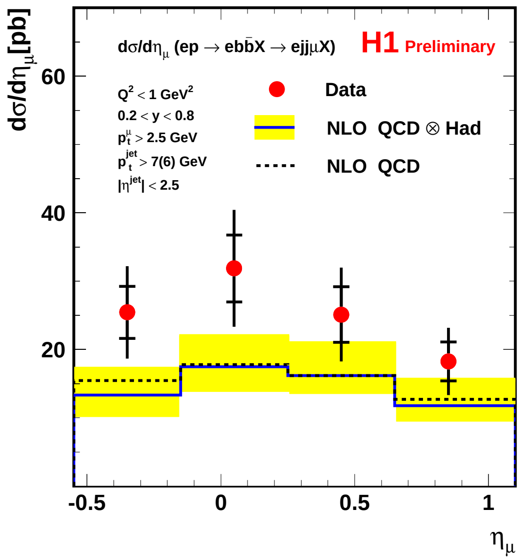
- Large B-lifetime:
  δ – impact parameter of μ wrt event vertex

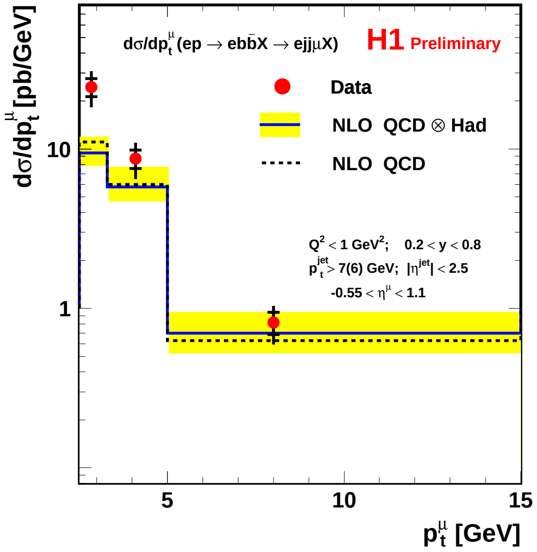


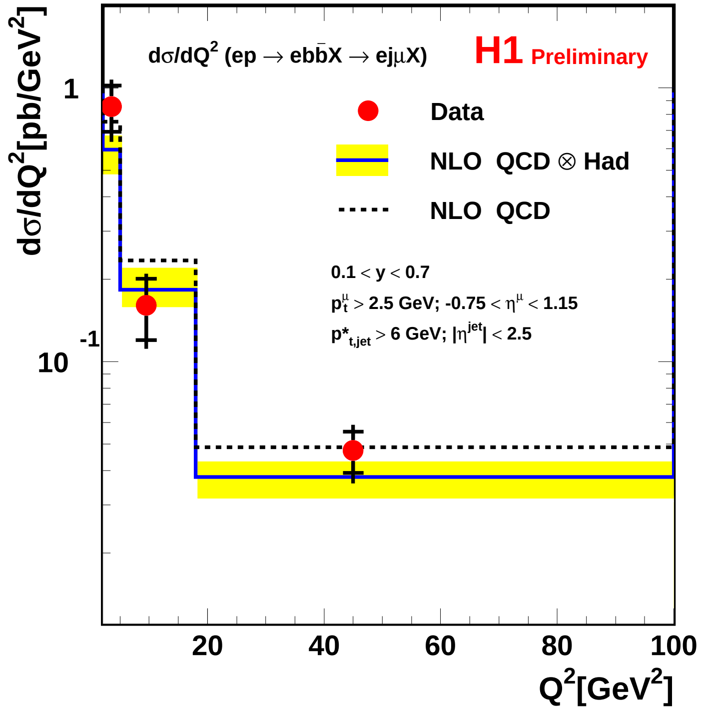


- DIS sample: ~ 800 events,
  γp sample: ~ 1600 events
- 3 parameter fit of b, c and uds fractions (taken from MC) simultaneousely to p_t^{rel} and δ
  $\Rightarrow$ b-fraction (typically 30%)

Beauty in DIS and photoproduction





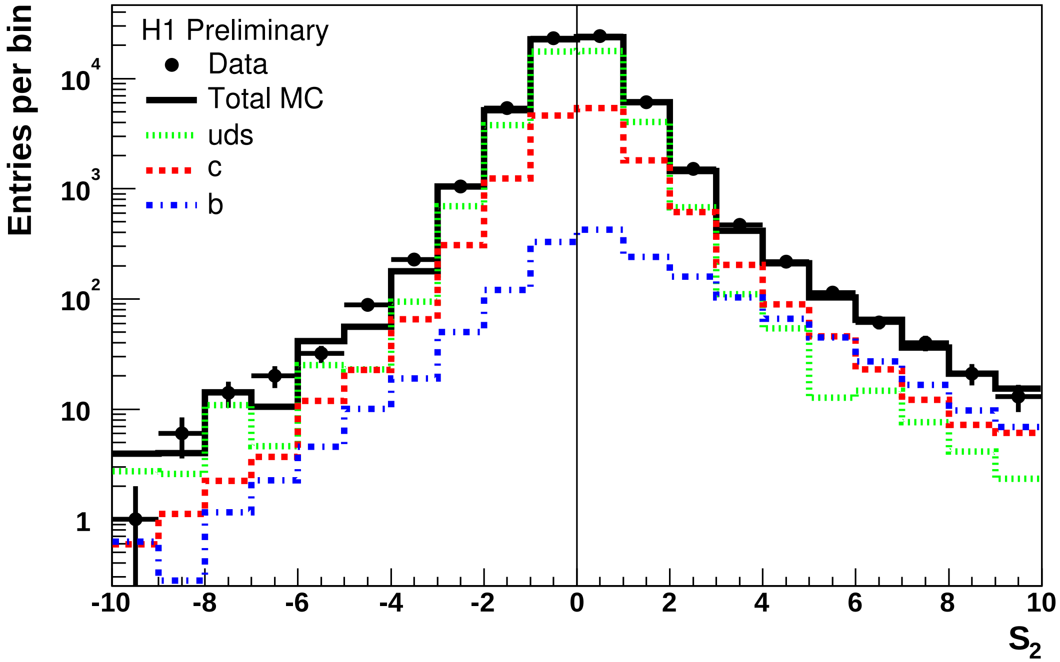


DIS cross section well described by NLO QCD

γp: NLO QCD (FMNR) is too low at small p_t^μ and agree with photoproduction data at high p_t^μ

$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at high Q^2: Method

- New results on beauty and charm production, using H1 central silicon tracker (CST)
- Flavour identification on the basis of 1 or 2 tracks with largest significance $S = \delta/\sigma(\delta)$:



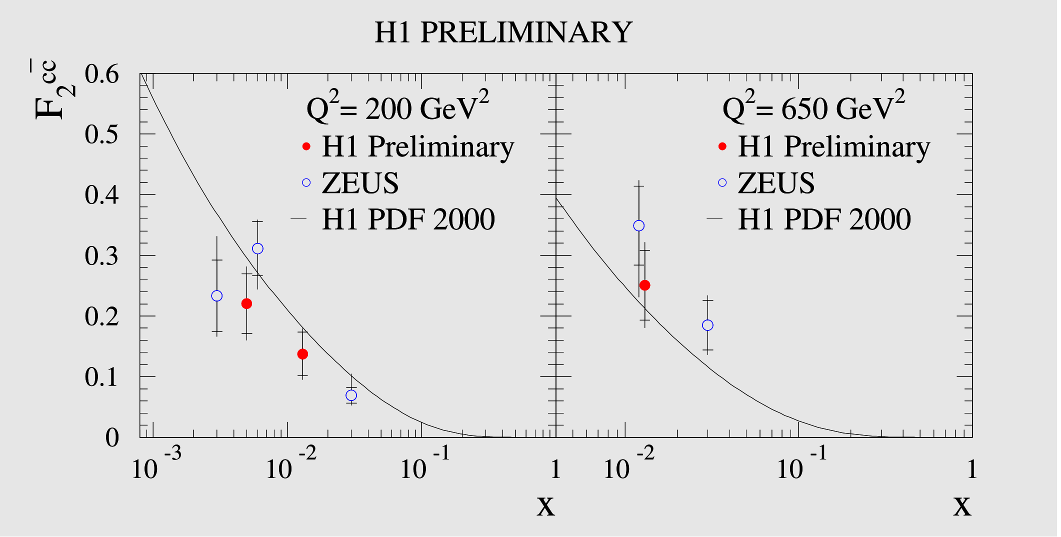
- Determine ratios $f^{c\bar{c}} = \frac{F_2^{c\bar{c}}}{F_2}$ and $f^{b\bar{b}} = \frac{F_2^{b\bar{b}}}{F_2}$
- $f^{c\bar{c}} \sim 25\%$, $f^{b\bar{b}} \sim 2\%$ in measured region of $Q^2 > 150$ GeV^2 and $0.1 < y < 0.7$
- Acceptance is large, hence extrapolation to F_2 is small

$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at high Q^2: Result

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

Good agreement with

ZEUS measurements

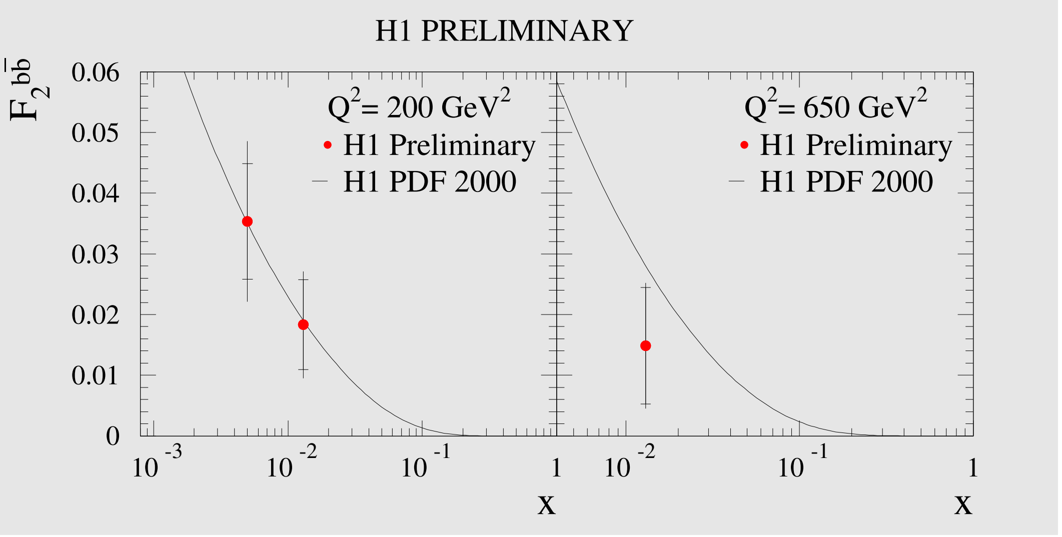


First $F_2^{b\bar{b}}$ measurement

Good agreement with

expectations from NLO

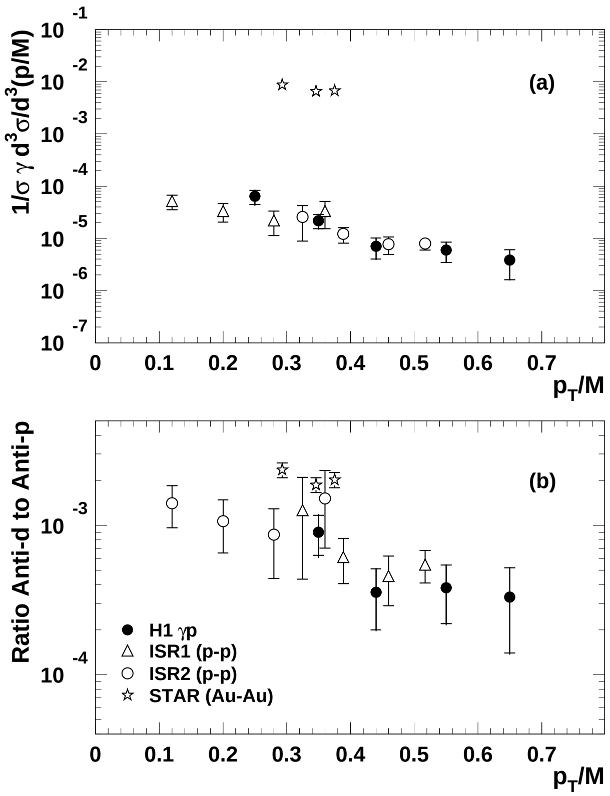
calculations using H1 pdf's

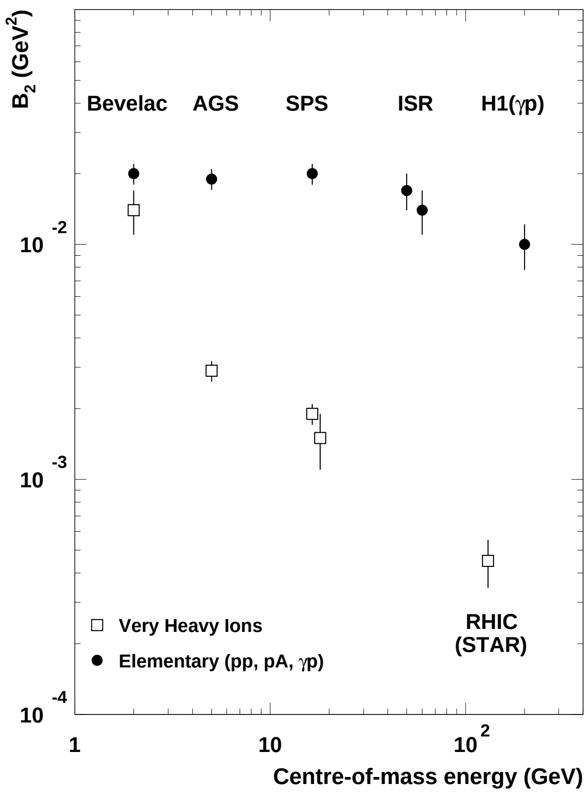


Photoproduction of anti-deuterons

- Anti-deuterons are identified using $\mathbf{dE/dx}$
- Invariant x-section way below that in heavy ion collisions
- Ratio $\bar{\mathrm{d}}/\bar{\mathrm{p}}$ only sligtly smaller for "elementary" collisions

Coalescence model parameter B_2 inversly proportional to size of interaction region (IR) at "freeze-out"





Nothing heavier than $\bar{d}$ found

Size of IR larger in AA and grows with E

PQ story: Introduction

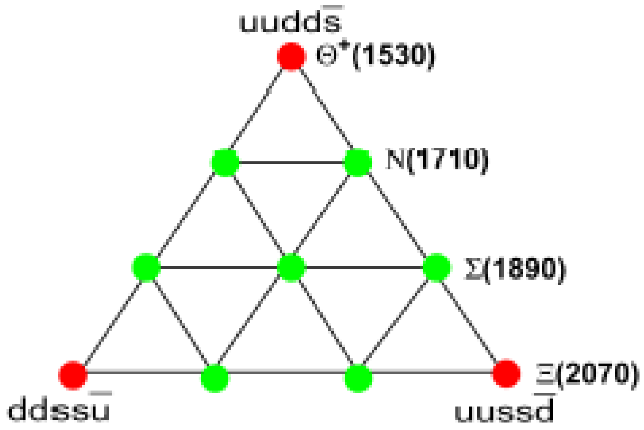
Very successful hadron classification scheme, but who said this is all? Definitely not QCD. In QCD larger configurations are not forbidden.

15 years of exotic baryons searches ended in controversy and general prejudice against those. In 1988 PDG dropped the discussion on that topic making fantastically precise prediction:
"...it will be another 15 years before the issue is decided."

So the time bomb was loaded and the clock started...
...and the field has exploaded exactly in predicted time

Meanwhile, in 1997 DPP using Soliton model predicted $M(\Theta^+) \approx 1530$ MeV with narrow width $\Gamma \approx 15$ MeV

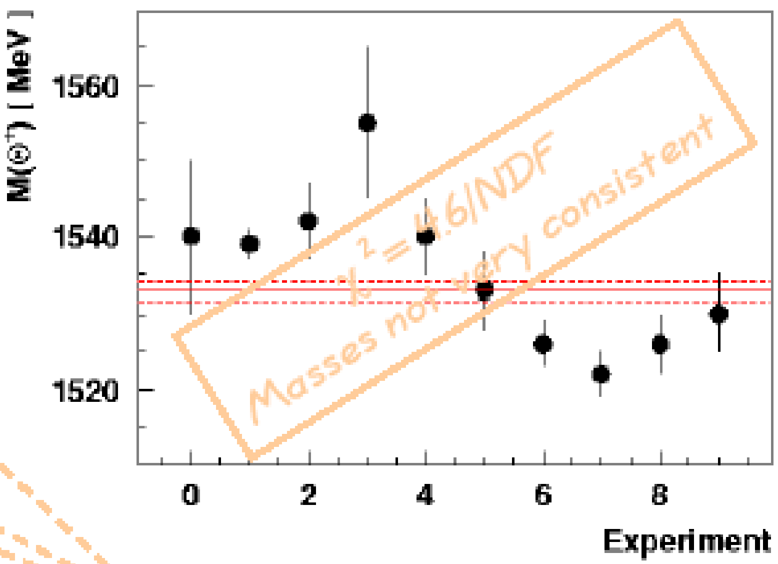
And now: ...



PQ story: Status of Θ^+

by courtesy of K.Daum (H1)

No.	Experiment	Channel	Mass (MeV)
0	LEPS	K^+n	1540 ± 10
1	DIANA	K^0p	1539 ± 2
2	CLAS	K^+n	1542 ± 5
3	CLAS	K^+n	1555 ± 10
4	SAPHIR	K^+n	1540 ± 5
5	ITEP	K^0p	1533 ± 5
6	HERMES	K^0p	1526 ± 3
7	ZEUS	K^0p	1522 ± 3
8	SVD	K^0p	1526 ± 4
9	COSY-TOF	K^0p	1530 ± 5



Sign of S not determined

$\mathcal{B}=1$ & $S=1$

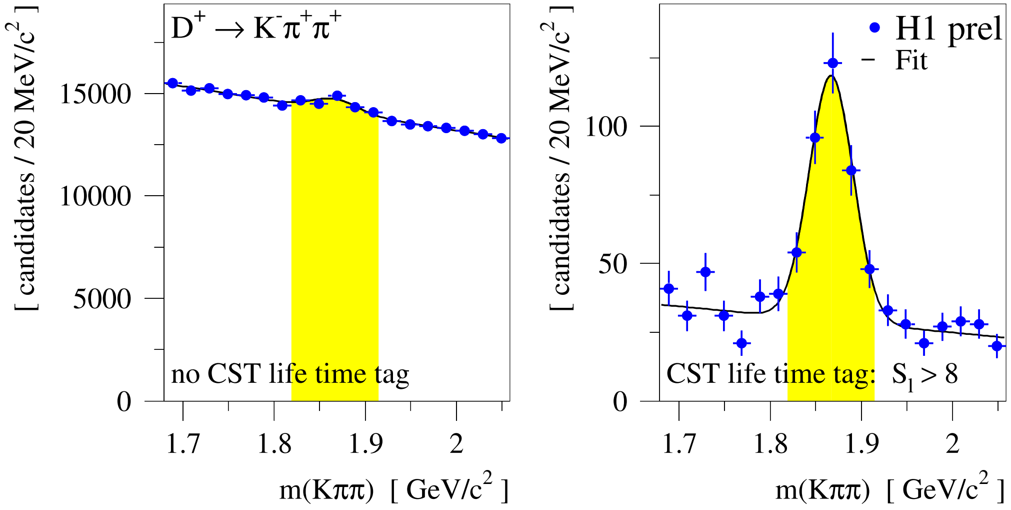
$\Downarrow$

Minimal quark content: $uudd\bar{s}$

- $M(\Theta^+) - M(K) - M(n) = 100$ MeV
- *Small natural width*

Θ^+ is produced by fragmentation from vacuum. QCD vacuum is flavour blind, hence...

PQ story: What about charmed analogue of Θ^+ ?



$\Theta_c \to \bar{D}p$ – where to look?

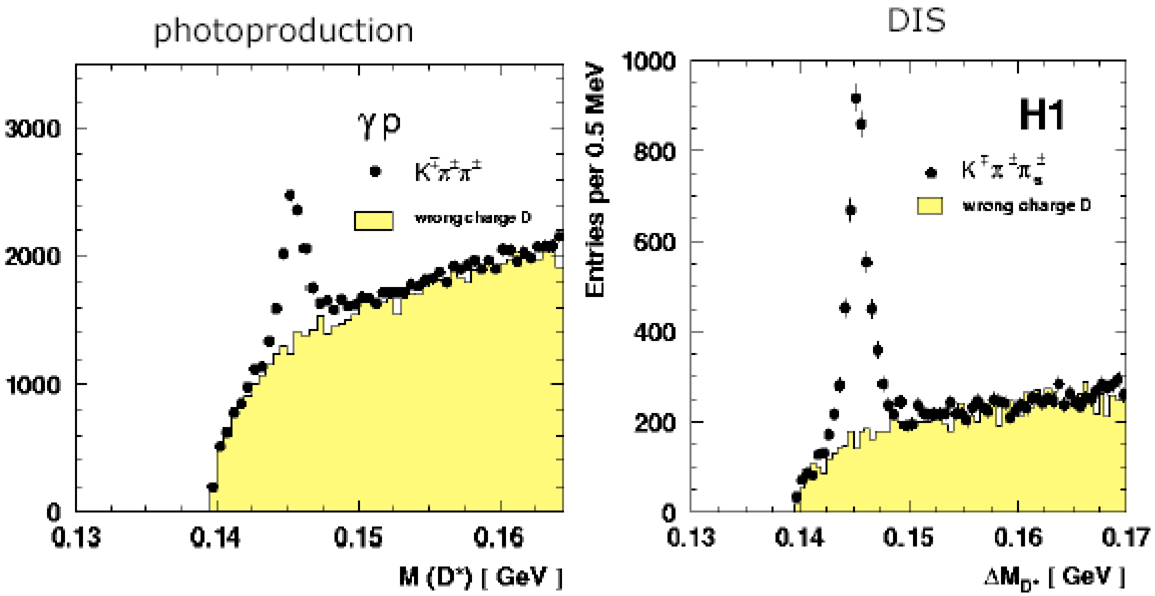
D^+ pseudoscalar meson:

either huge background, or low yield

D^* vector meson experimentally is much easier (small Q-value in D^* decay $\to$ ΔM technique)

DIS is cleaner than γp, hence:

- base analysis on DIS and
- use γp, as a cross check



PQ story: D^* and proton selection

★ D^* selection

- 1996-2000 data, $\mathcal{L} = 75$ pb^{-1}
- $1 < Q^2 < 100$ GeV^2, $0.05 < y_e < 0.7$
- $p_t(D^*) > 1.5$ GeV; $-1.5 < \eta(D^*) < 1$
- $p_t(K) + p_t(\pi) > 2$ GeV
- Inelasticity $z(D^*) > 0.2$

3400 D^* in DIS

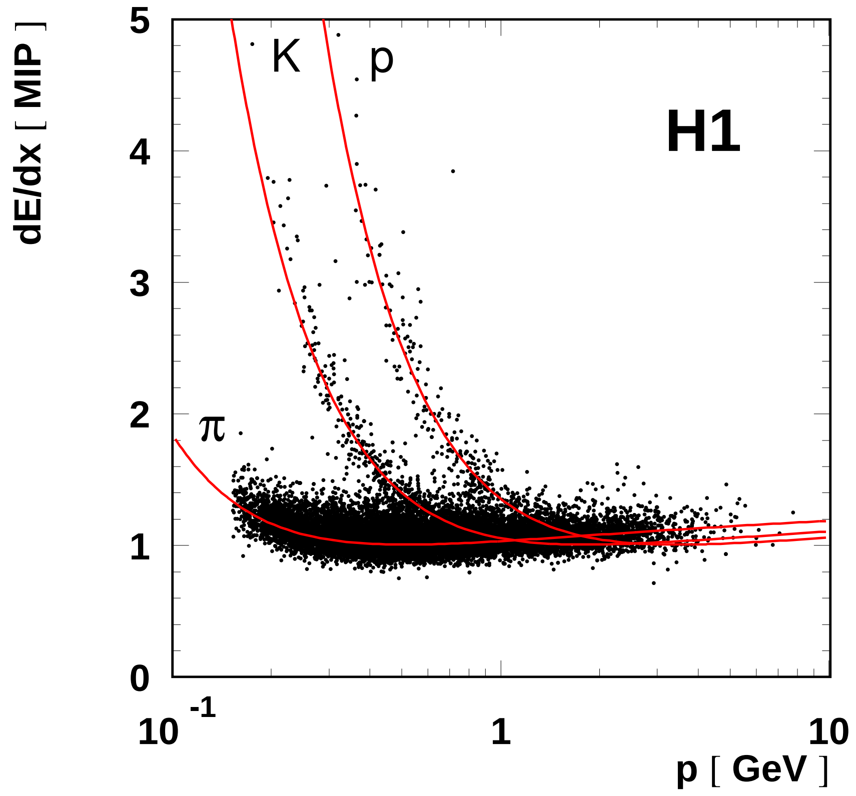
★ Proton selection

- $L(p) > 0.3$ for $p(p) < 2$ GeV
  $L(p) > 0.1$ for $p(p) > 2$ GeV

★ Search strategy

- Use $\Delta m(D^*)$ technique to improve 4-particle mass resolution ($35 \rightarrow 12$ MeV)
- Cut on $L(p)$ to suppress pion background

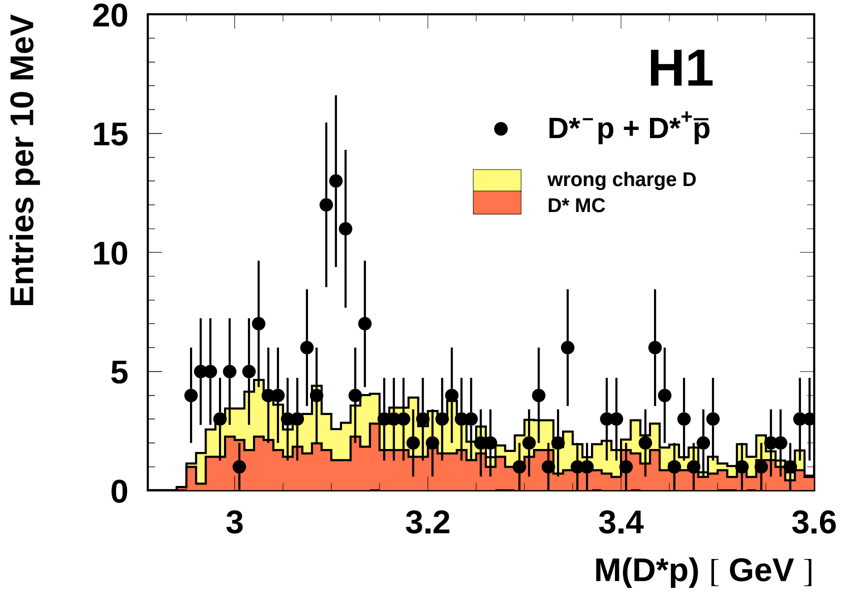
Use dE/dx for background suppression:



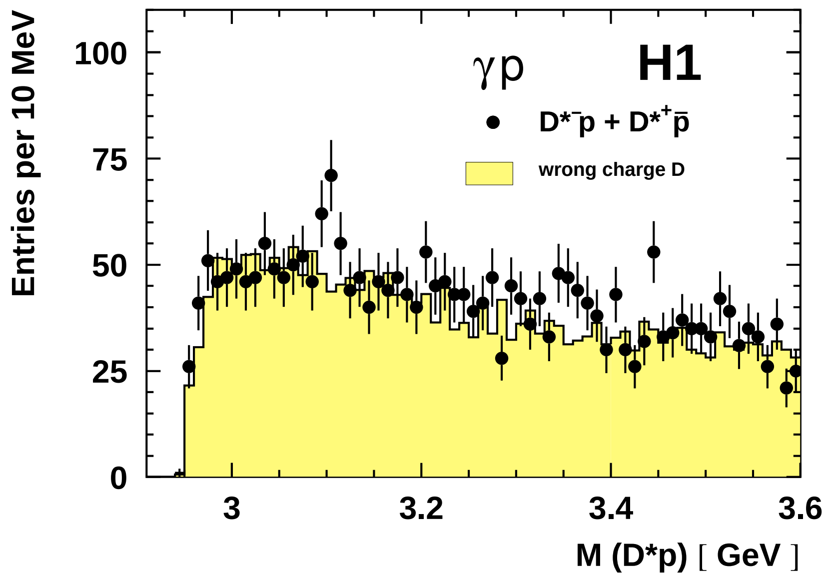
- 8% average resolution in dE/dx
- Norm. likelihood: $L(\pi)+L(K)+L(p)=1$

PQ story: Signal

DIS



Photoproduction



Mass = 3099 ± 3 MeV

Gauss width = 12 ± 3 MeV

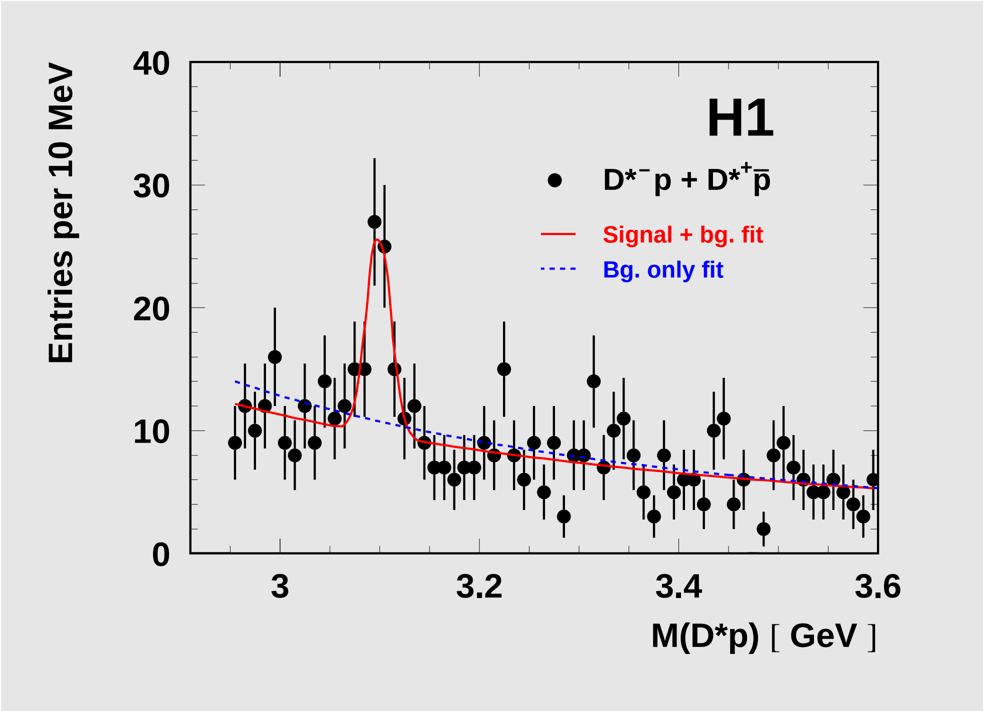
$N_{\rm signal} = 50.6 \pm 11.2$

Mass = 3103 ± 4 MeV

Gauss width = 7 ± 3 MeV

$N_{\rm signal} = 43 \pm 14$

PQ story: Significance estimate



- BG only hypothesis: $N_b = 51.7 \pm 2.7$ events within 2σ of peak position $\Rightarrow$ bgr fluctuation (Poisson) probability = 4×10^{-8} which corresponds to 5.4σ (gaussian)
- Difference in likelihoods for fit with $(N_s + N_b = 95)$ and without signal gives 6.2σ significance

Passed tests (incomplete list)

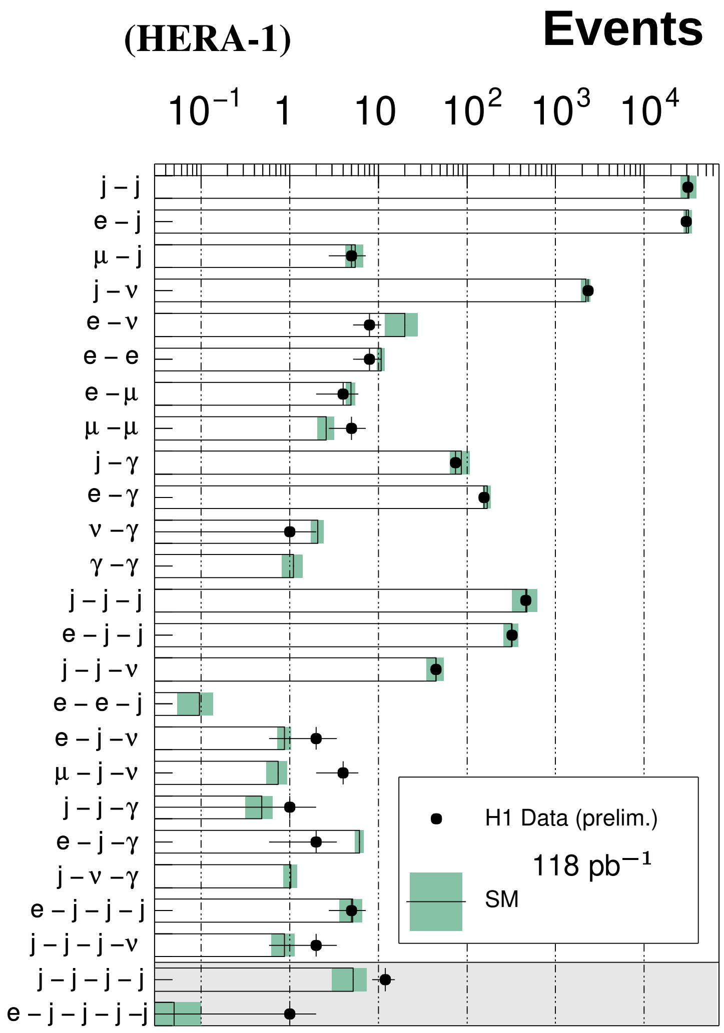
- All possible reflections and mass combinations from particles forming D^* and D^*p
- $D_1/D_2 \to D^*\pi$
- $D_{s1}/D_{s2} \to D^0 K$
- $D^{*0} \to D^0\gamma$ with γ-conversion
- Eventual technical problems (all signal events are scanned)
- Different versions of combinatorial backround modelling
- Acceptance effects
- Four independent analyses
- Signal found in all running periods
- ⋆ (preliminary) signal is also seen in HERA-2 data

$C = -1$ and $B = 1$ state is observed in H1. Its minimal quark content is $uudd\bar{c}$

BSM searches: Strategy

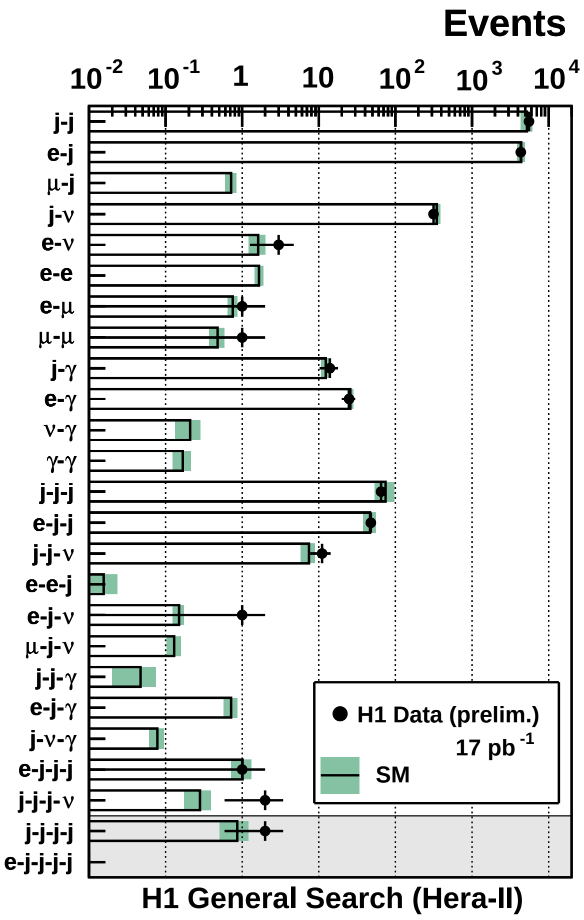
- Search strategies:
  - ▷ Dedicated search: maximize S(BSM)/B(SM)
  - ▷ Generic search: minimize B(SM)
- Objects and phase space definition:
  - ▷ objects: $e,\ \mu,\ \gamma,\ j,\ \nu$
  - ▷ $p_t(\mathrm{object}) > 20$ GeV
  - ▷ $10^o < \theta(\mathrm{object}) < 140^o$
  - ▷ isolation requirement: $R_{\eta\phi}(\mathrm{object}) > 1.0$
- Analysis
  - ▷ analyse all topologies with $N_{\mathrm{obj}} \geq 2$
  - ▷ compare with SM MC coctail

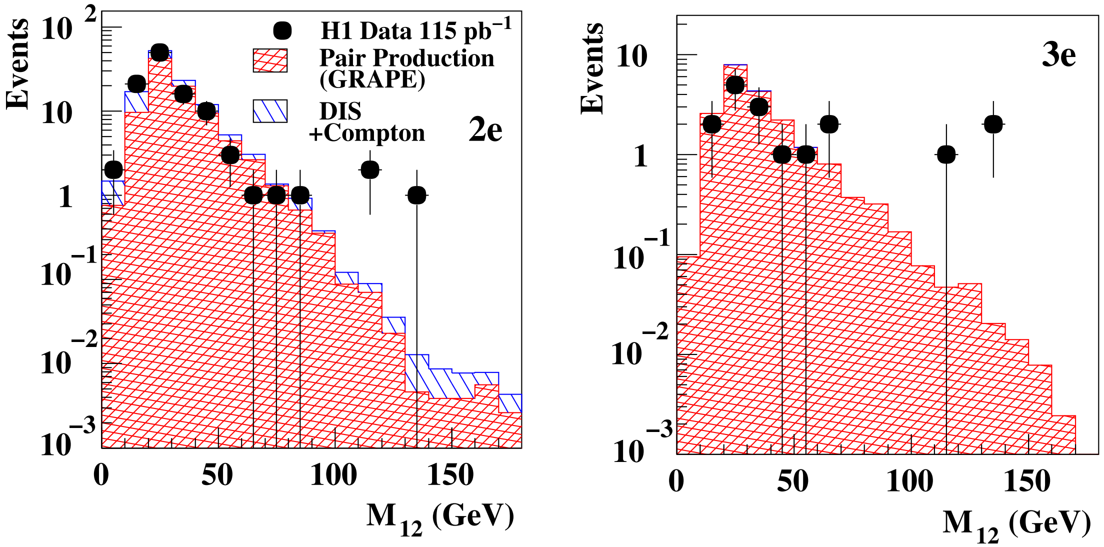
Good overall agreement with SM
Deviations: multi-e with $M > 100$ GeV,
events with isolated leptons and missing p_T

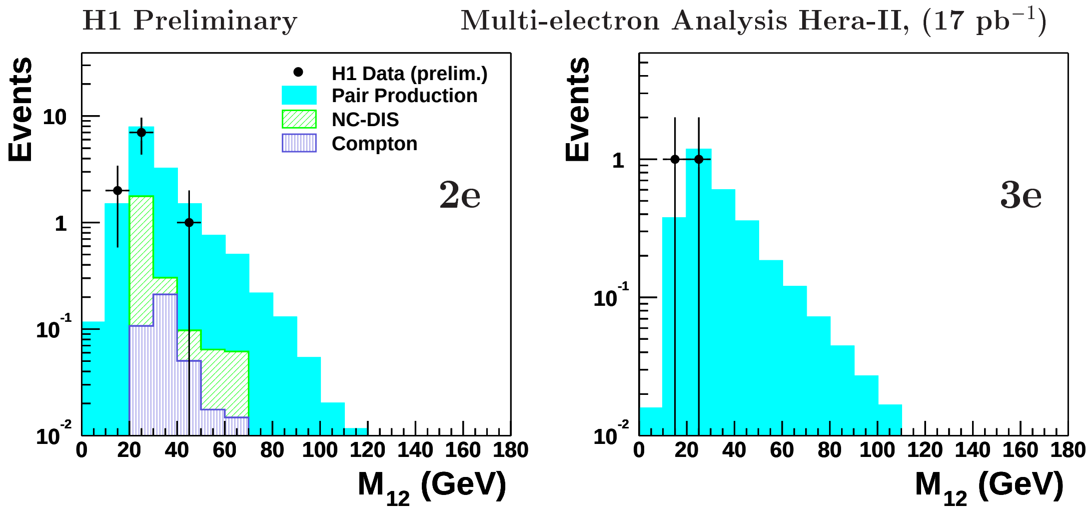


H1 General Search

HERA-2 vs HERA-1: Multilepton events



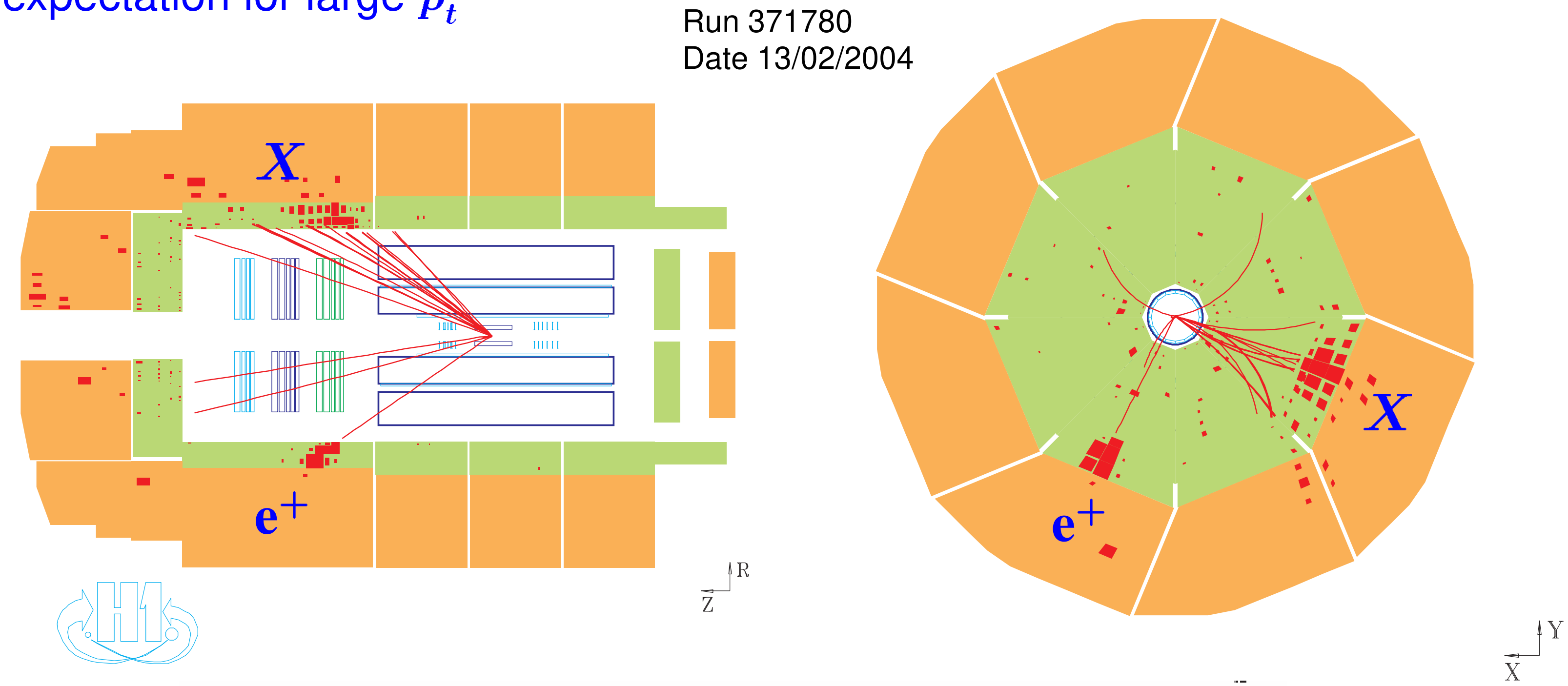




No new events at high masses yet

Isolated lepton events

- New data contain isolated lepton events
- Rate for isolated e^+ events above SM expectation for large p_t^X
- HERA-1 analysis extended to include τ channel



(Prel.) data/ SM	HERA I e (118 pb^{-1})	HERA I μ (118 pb^{-1})	HERA I τ (108 pb^{-1})	HERA II e (17 pb^{-1})	HERA II μ (17 pb^{-1})
Full sample	11/11.54	8/2.94	5/5.81	3/1.61	0/0.44
$p_T^X > 25$ GeV	5/1.76	6/1.68	0/0.53	2/0.34	0/0.29

List of other search results in H1

- Most recent H1 publications
  - ▷ Search for Squark Production in R-Parity Violating Supersymmetry at HERA (hep-ex/0403027)
  - ▷ Search for bosonic stop decays in R-parity violating supersymmetry in e^+p collisions at HERA (hep-ex/0405070)
  - ▷ Search for Single Top Quark Production in ep Collisions at HERA (Eur. Phys. J. C33 (2004) 9, 10/03 and hep-ex/0310032)

- Preliminary results
  - ▷ Search for doubly charged Higgs production at HERA (EPS03, July 2003)
  - ▷ A Direct Search for Magnetic Monopoles at HERA (EPS03, July 2003)
  - ▷ Search for Superlight Gravitinos at HERA (EPS03, July 2003)

Outlook: task(wish)list for future HERA running

★ High p_t anomalies (and BSM searches)

- isolated lepton events (e, μ, τ)
  - H1 (135 pb^{-1}): 13/4.6
  - ZEUS (130 pb^{-1}): 9/5.9
- multi-e at high mass (H1 only)

High $\mathcal{L}$

★ Pentaquarks

H1:	Θ_s^+(?)	Θ_c^+(3099)
ZEUS:	Θ_s^+(1522)	Θ_c^+(–)

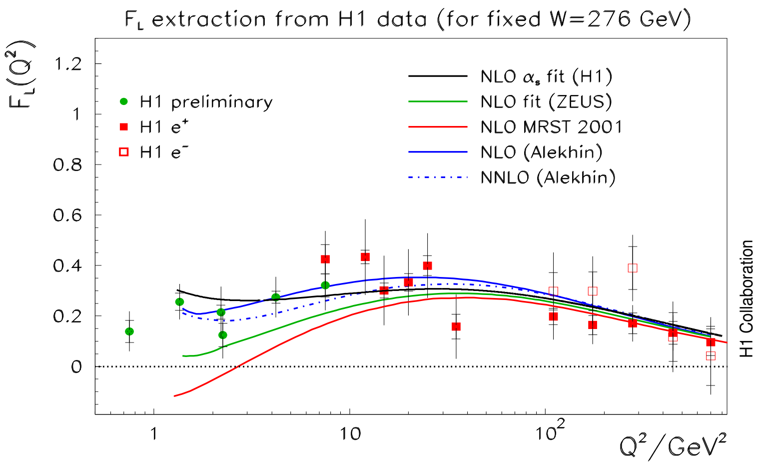
High $\mathcal{L}$

★ xF_3, CC $\rightarrow u_v, d_v$; $F_2^{c,b}$, ...

Too large statistical errors

High $\mathcal{L}$

★ F_L (also high x PDF's)



Low E_p run

★ Precision low-x physics
u/d, $\bar{u} - \bar{d}$, α_s precision
Saturation, BBL, ...

limited by detector acceptance
Requires eD scattering
Requires eA scattering

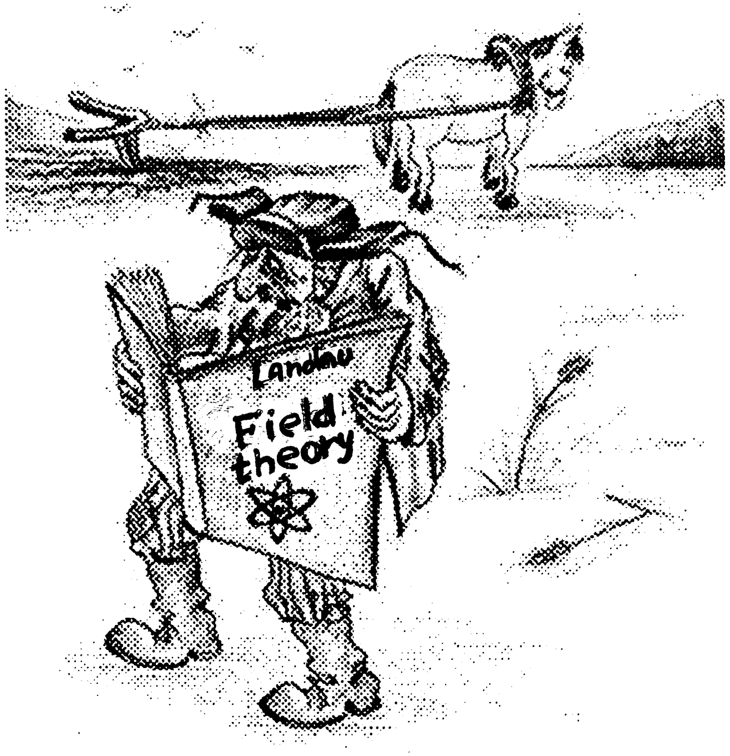
HERA-3

Summary

- Still many new measurements and new techniques using HERA-1 data
- After difficult startup HERA-2 is now putting on full speed. H1 detector is in a good shape and taking high quality data
- Top priority is highest possible luminosty, with preference of e^+ running:
  - to clarify observed high p_t anomalies
  - to make electro-weak measurements
  - to reach new level of precision in broad range of physics topics
- Some measurements will not be possible at HERA-2. To complete physics programme requires HERA operation beyond 2007. There is a strong interest in H1 (and beyond) in HERA-3 physics.

Final remark

Best progress is achieved by combining theoretical and experimental efforts:



Thanks to the organisers for fruitful atmosphere and excellent environment!