Physics at HERA III - experimental view

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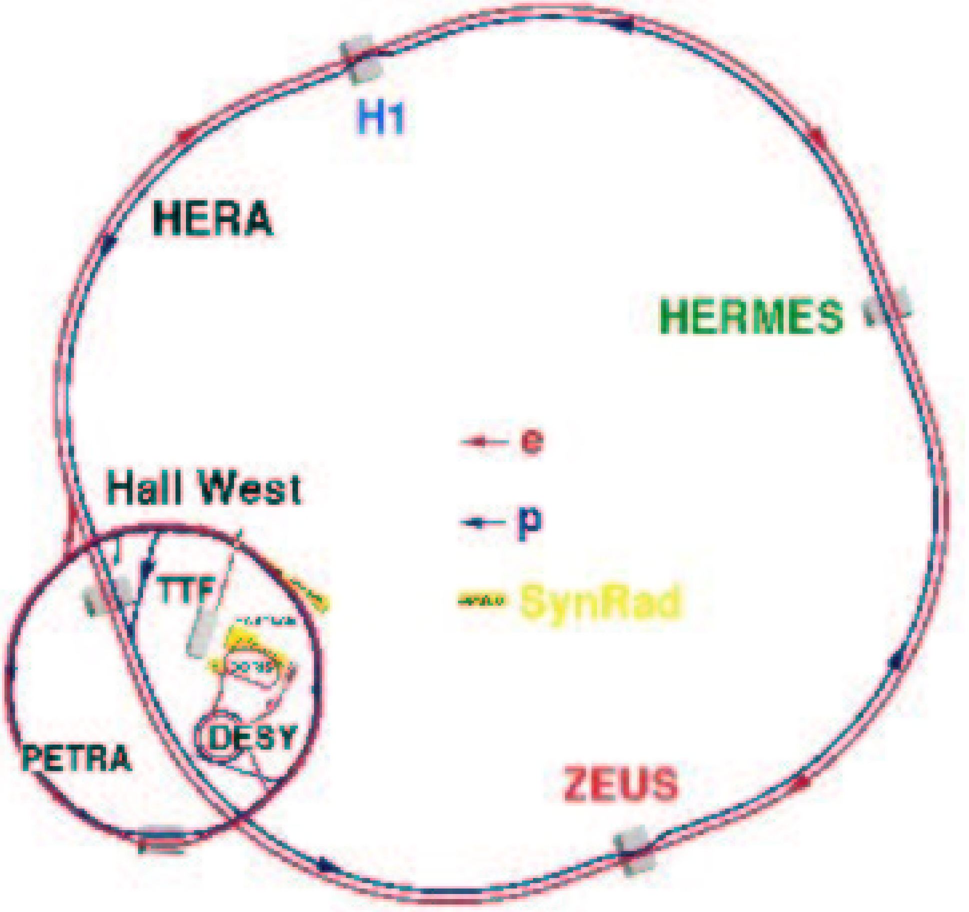
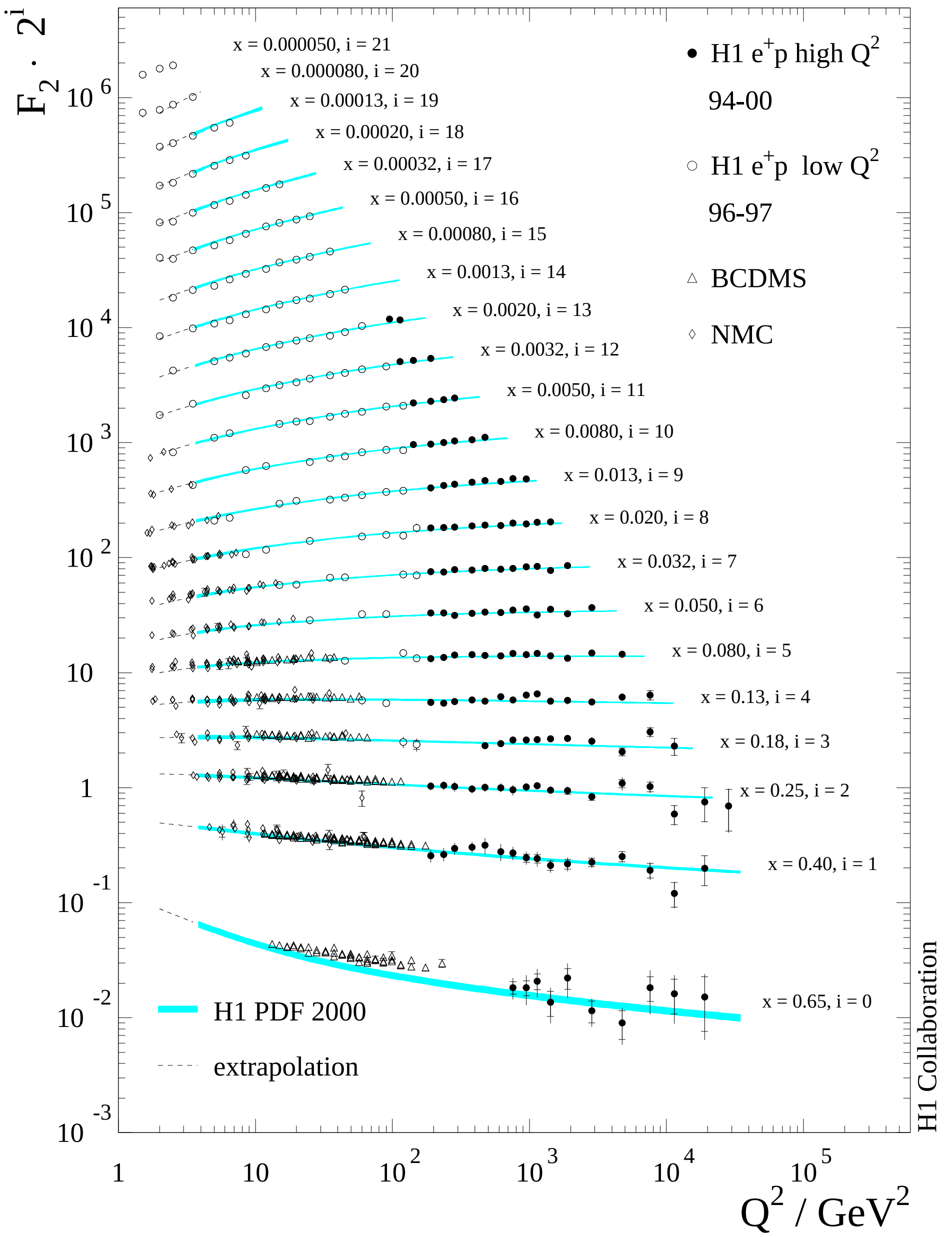
CIPANP 2003

- $\overline{\mathrm{d}} - \overline{\mathrm{u}}$
- Diffraction in eD
- Spectator tagging
- Low x and $\mathrm{F_L}$
- A new collider experiment
- QCD radiation patterns
- eA
- Spin



F_2 and α_S from HERA I

- Deep inelastic scattering in collider mode.
- $E_p = 920$ GeV (since 1998), $E_e = 27.6$ GeV.
- HERA I e^+p luminosity: 105 pb^{-1}.
- Scaling violations well described by NLO DGLAP QCD analysis over 4 decades in x and Q^2.
- $\alpha_S(M_Z^2) = 0.1150 \pm 0.0017\,(\text{exp.})\,^{+0.0009}_{-0.0005}\,(\text{model}) \pm 0.005\,(\text{scale})$
- NNLO calculation underway.



Parton density extraction

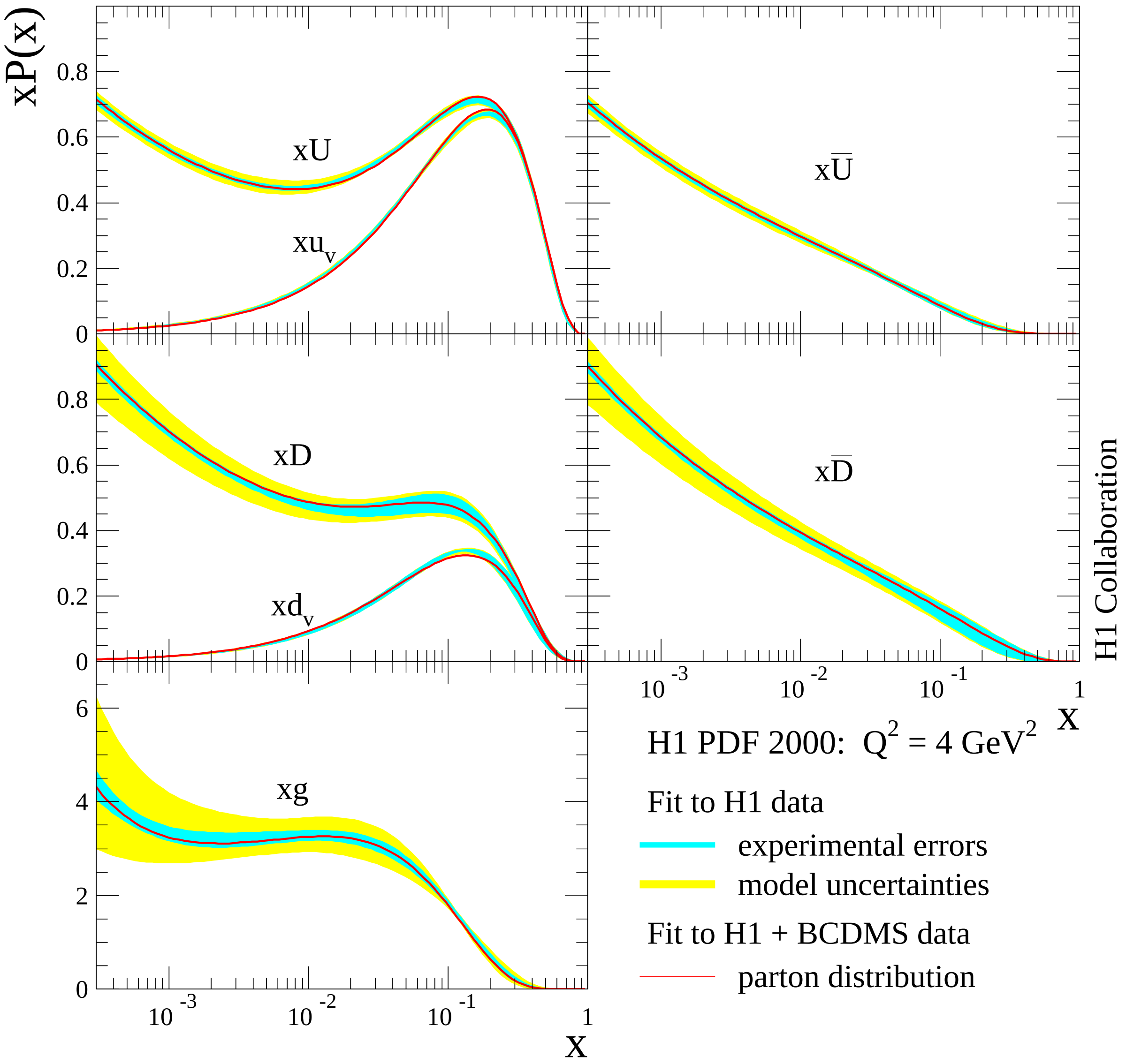
- Parameterization of parton densities at a starting scale $Q_0^2 = 4\,\mathrm{GeV}^2$.
- 10 parameters determined from fit to F_2 in NLO:

$$F_2^{\mathrm{e.m.}} = \frac{4}{9}x(U+\overline{U})+\frac{1}{9}x(D+\overline{D})$$

$U = u + c$, etc

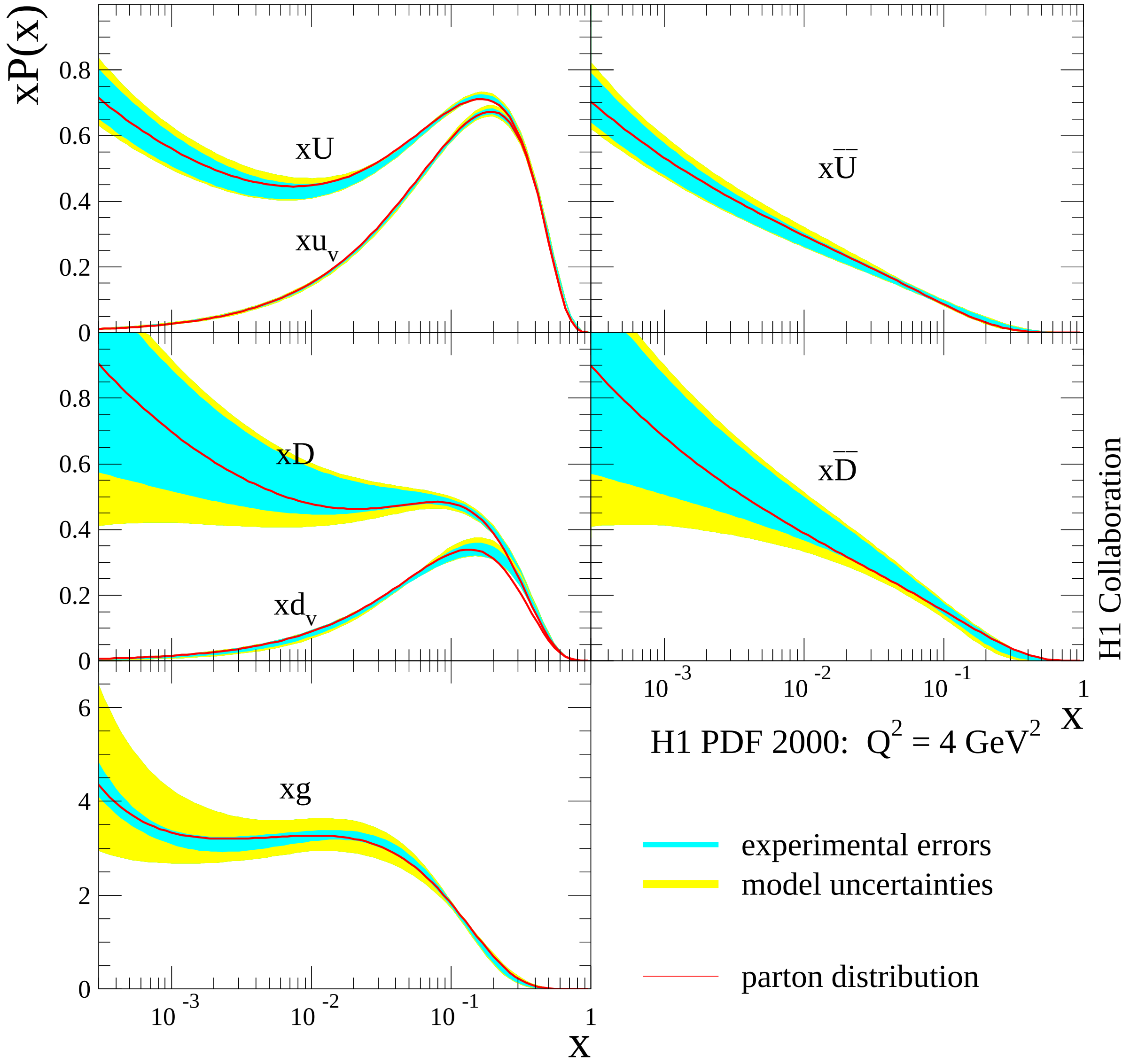
- Assuming $\overline{u} = \overline{d}$ at low x we reach at $x = 0.01$:
- 1% experimental accuracy for xU.

  2% for xD.



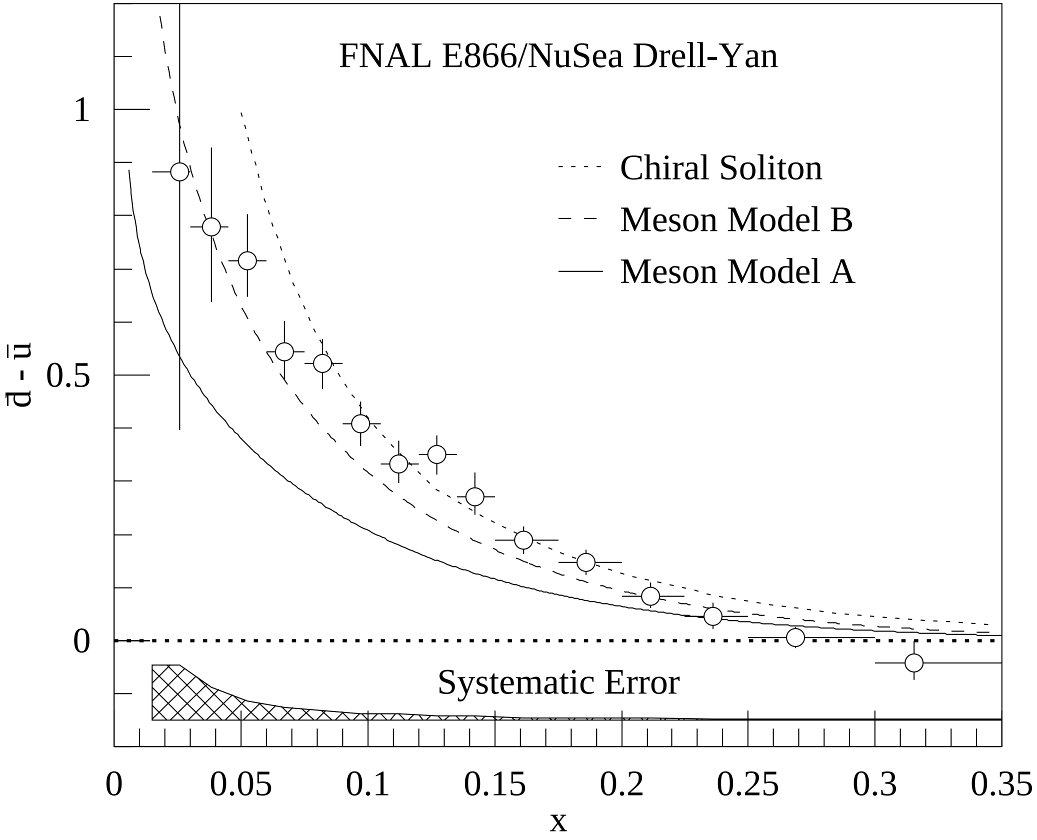
Unconstrained PDF extraction

- Extraction of parton densities without the constraint $x\bar{d} - x\bar{u} = 0$ at low x reduces the experimental accuracy to
- 6% for xU
  20% for xD
  at $x = 0.01$.



$\bar{\mathrm{d}} - \bar{\mathrm{u}}$ from fixed target experiments

- Violation of the Gottfried sum rule known since NMC 1991.
- Positive $\bar{\mathrm{d}} - \bar{\mathrm{u}}$ from Drell-Yan in E866 (NuSea) measured for $x > 0.03$.
- Explanations include:
  - Chiral soliton model.
  - Meson cloud model $p \to \pi^+ n \; > \; p \to \pi^- \Delta^{++}$
  - Pauli blocking for the Dirac sea.

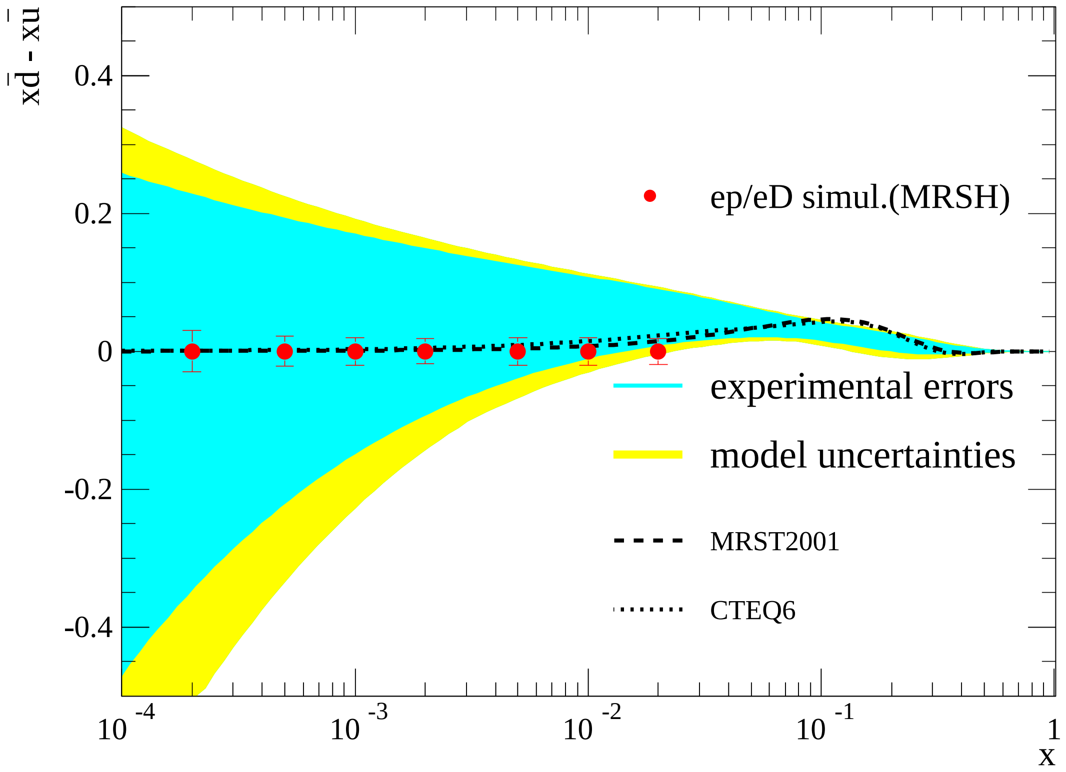


- What happens at low x?

Measure $\overline{\mathrm{d}} - \overline{\mathrm{u}}$ in eD scattering

- Run HERA with 920 GeV deuterons.
- $F_2^d \approx F_2^p + F_2^n$
  within shadowing corrections.
- $F_2^p = x\left(\frac{4}{9}u_v + \frac{1}{9}d_v + \frac{8}{9}\overline{u} + \frac{2}{9}\overline{d}\right)$
  with $u_v = u - u_{\rm sea}$ and $u_{\rm sea} = \overline{u}$.
  and similar for F_2^n.
- Using local isospin invariance
  $d^n = u^p$ etc. we can form
- $\frac{1}{2}(F_2^p + F_2^n) - F_2^p$
  $= x\left(\frac{1}{6}(d_v - u_v) + \frac{1}{3}(\overline{d} - \overline{u})\right)$
  $\approx \frac{1}{3}x\left(\overline{d} - \overline{u}\right)$ at low x.

Simulation with 40 pb^{-1} of ep and 20 pb^{-1} of eD:

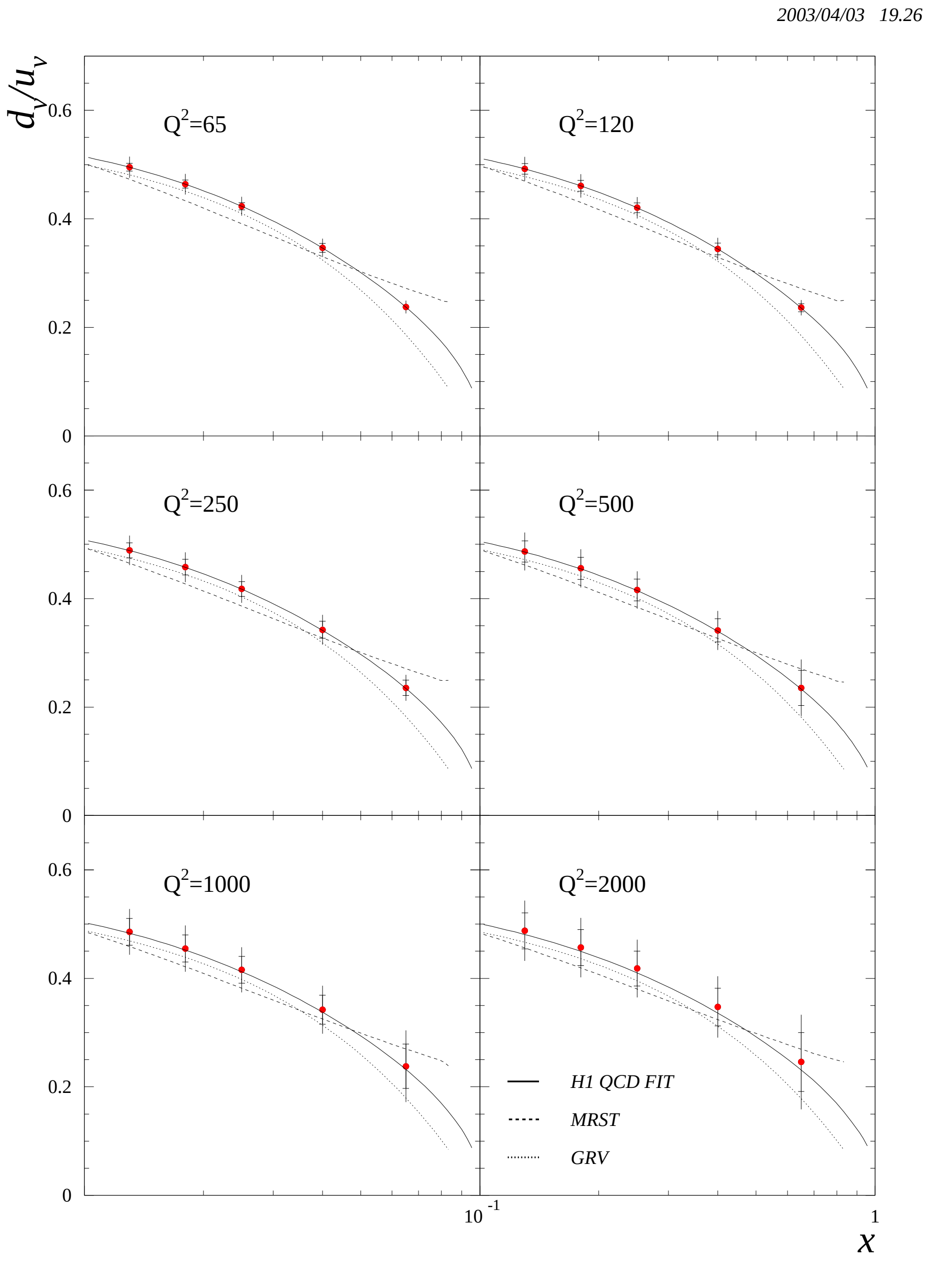


$Q^2 = 5\,\mathrm{GeV}^2$.

Shaded: HERA I error band.

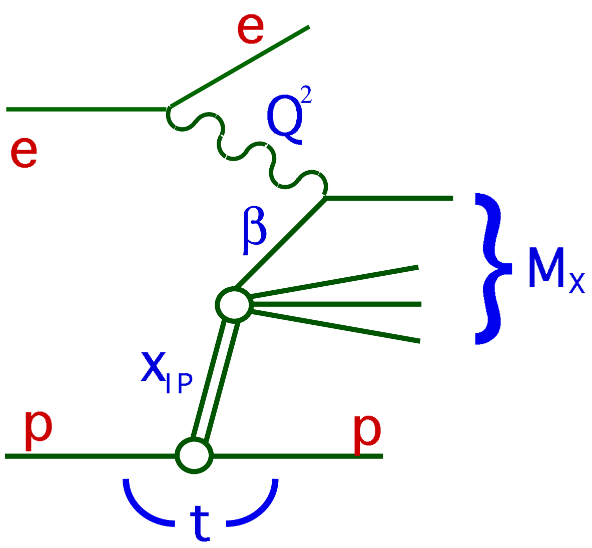
Valence quarks at large x from eD and ep

- Extract F_2^n from eD scattering by tagging the spectator proton.
- Reduce Fermi motion correction for en (6.5% spread in E_n) by measuring E_p with 1% resolution.
- Simulation for 50 pb^{-1} eD and 50 pb^{-1} ep at $E_p = 460$ GeV.
- at high x:
  $\frac{F_2^n}{F_2^p} \longrightarrow \frac{1+4d_v/u_v}{4+d_v/u_v}$



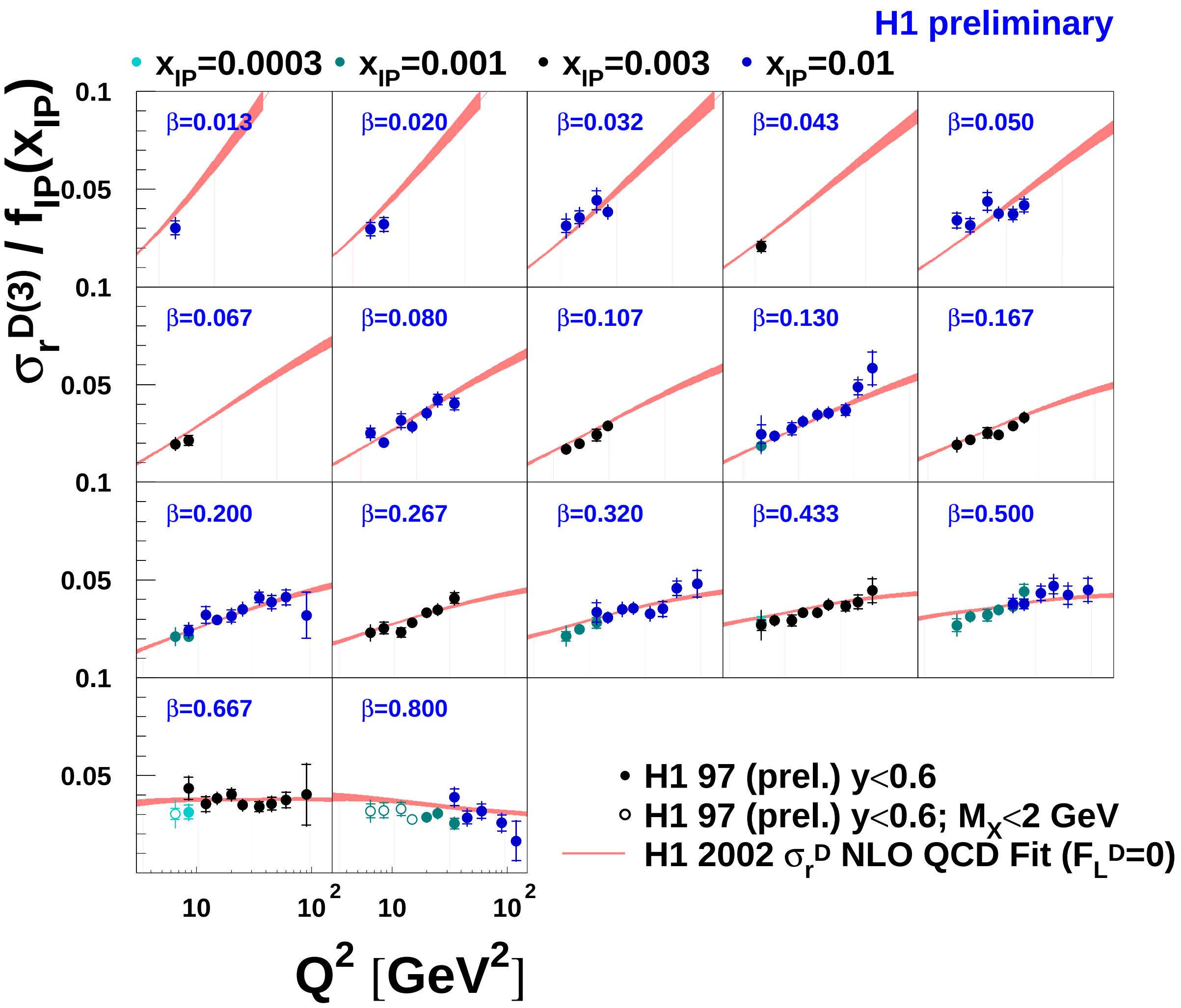
Diffraction

- Deep inelastic diffraction:



- Determine the partonic structure of the diffractive exchange.

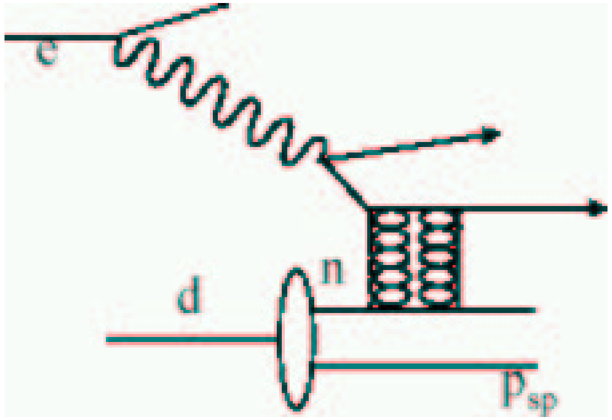
HERA I measurements and QCD analysis:



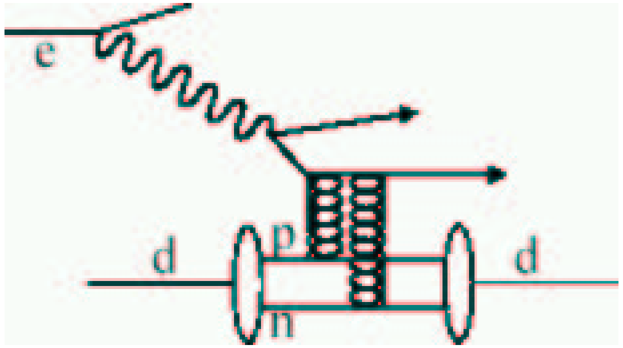
Positive scaling violations up to large β.

Diffraction in eD

- n-diffraction, tag p:



- D-diffraction, tag D:



- Is the structure of neutron diffraction the same as that of proton diffraction?
- Is coherent diffraction off the deuteron the same as proton diffraction?
- Need p, n, and D tagging detectors.

Tagging at H1

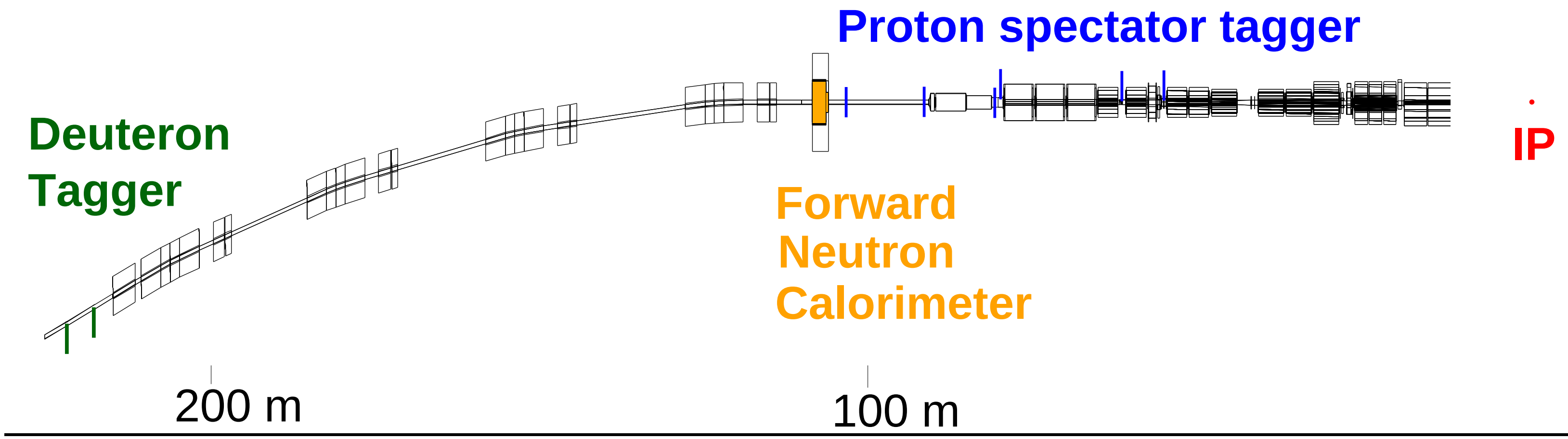
- Diffractive deuteron measurement in Roman Pots at 220 m (VFPS). Existing.

- High acceptance around $x_{I\!P}$ of 0.02.

- Neutron tagging in a lead-scintillator sampling calorimeter with $\sigma_E/E = 64\%/\sqrt{E}$. Existing.

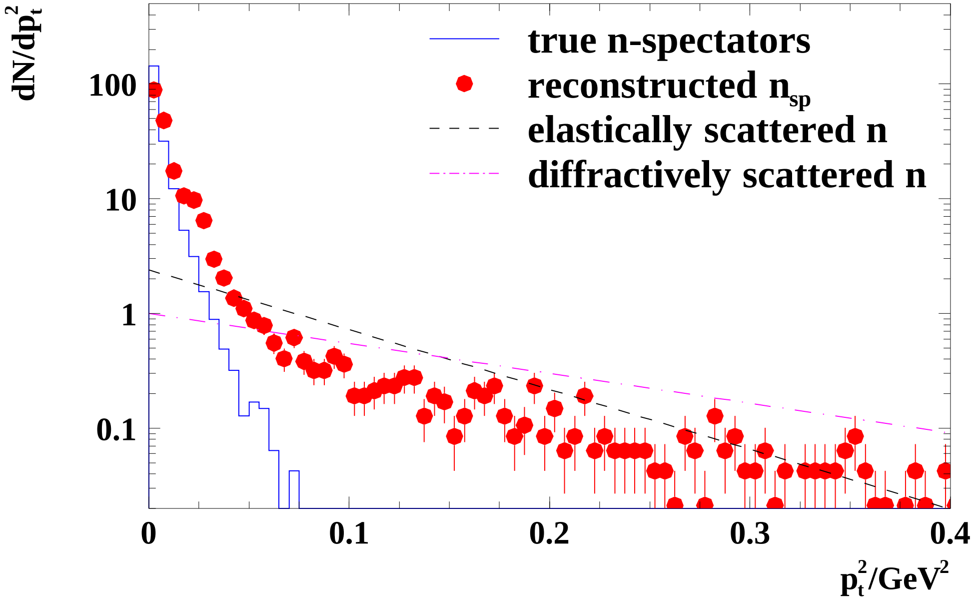
- Proton spectator tagging at $z = 0.5$ in several Roman Pot stations between 60 and 100 m with fiber detectors.

- Needs upgrade.



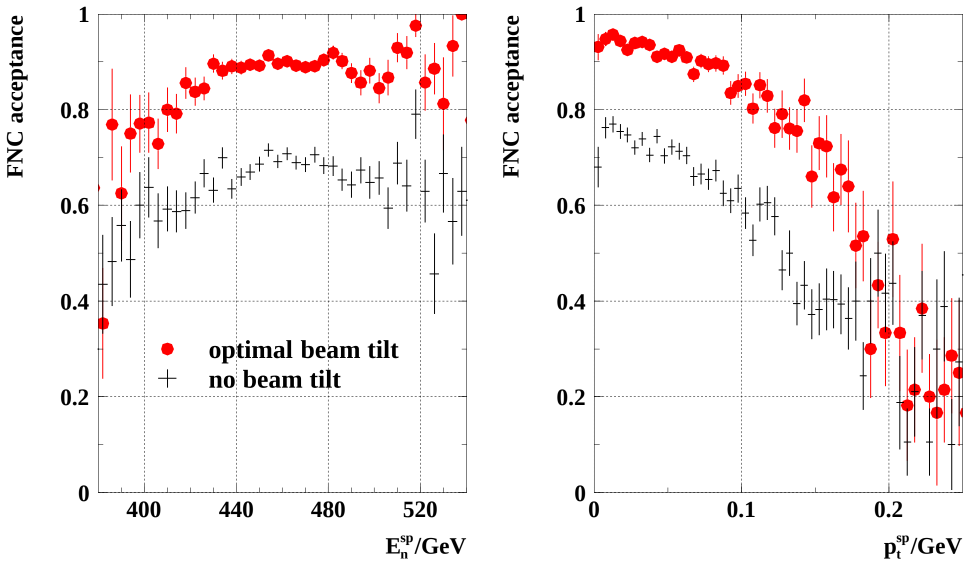
Neutron tagging

eD simulation: separate spectator and diffractive neutrons using p_t^n:



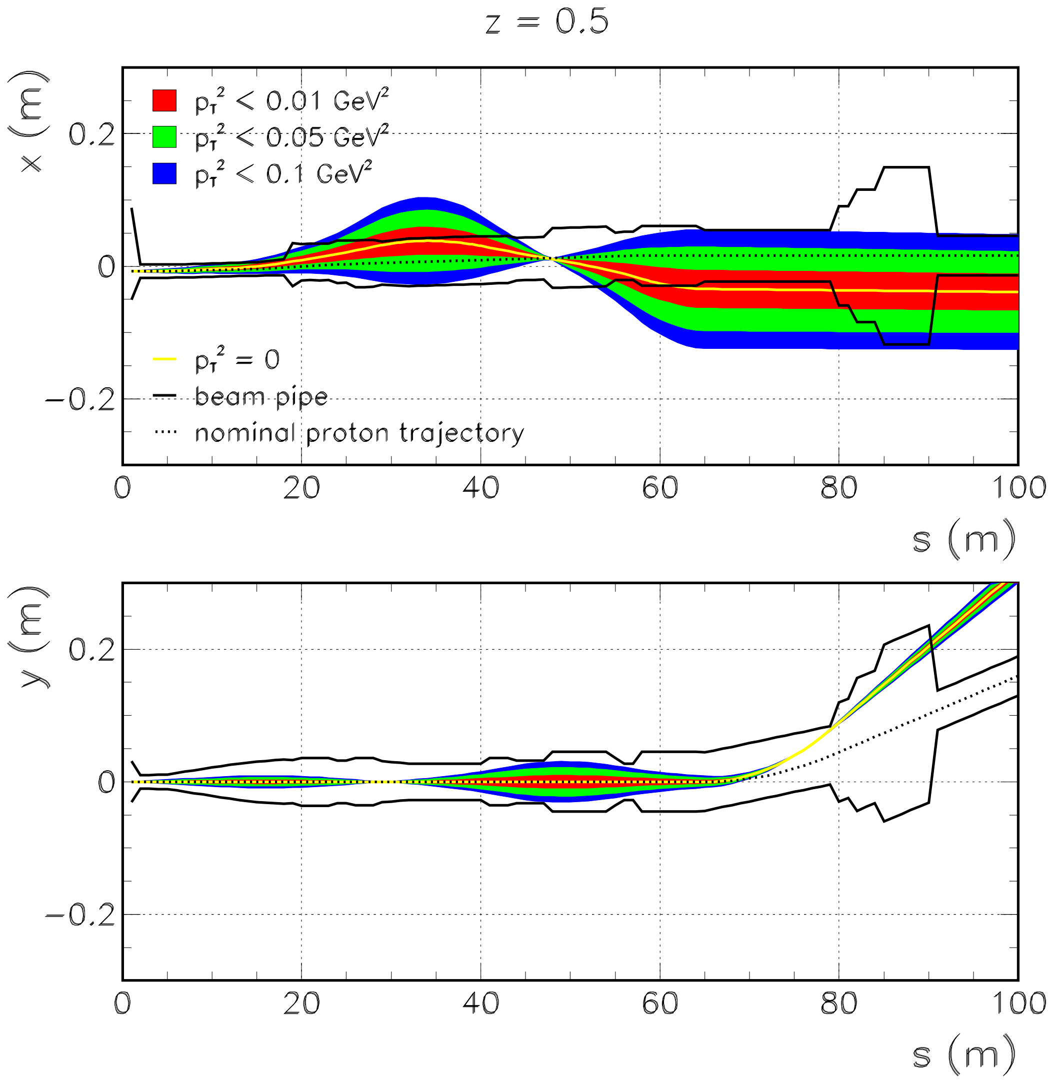
FNC p_t^n resolution is 12 MeV in a fine granularity preshower calorimeter.
Beam spread at the IP adds 20 and 75 MeV in x and y in the HERA II optics.
May be reduced at the cost of luminosity.

FNC acceptance is up to 90% with 0.2 mrad beam tilt at the IP:



Spectator proton tagging

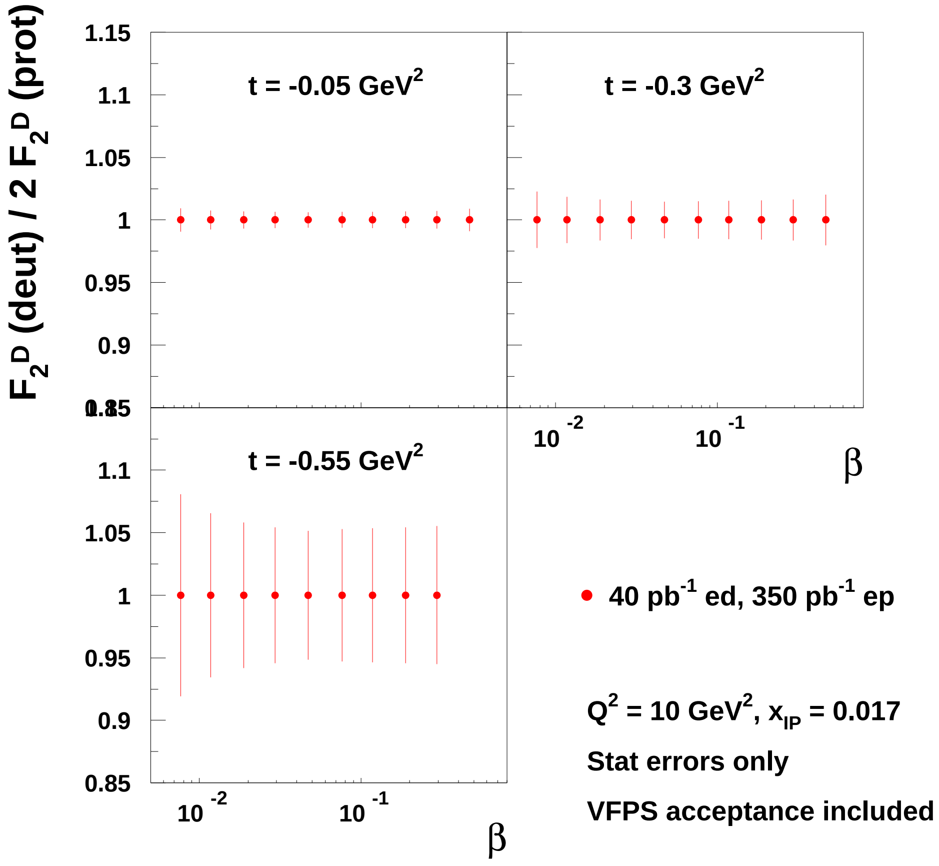
- Want highest acceptance out to spectator proton p_T^2 of 0.1 GeV^2.
- Need wider beam pipe around 30 m and IP beam tilt to get up to 95%.
- Horizontal stations between 60 and 80 m.
- Vertical stations between 90 and 100 m.
- Exploit dispersion in beam optics for p_L measurement.
  Get 1% resolution with fiber detectors.



Deuteron diffraction

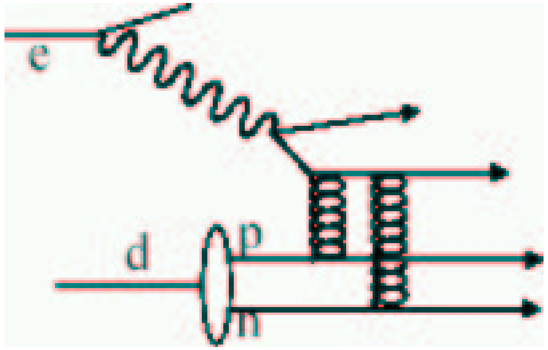
- Measure coherent diffraction in eD.
- Compare to diffraction in ep, measured in the same detector (H1 VFPS) at HERA II.
- Expect a statistical accuracy of 1% at low $|t|$.

Simulation:

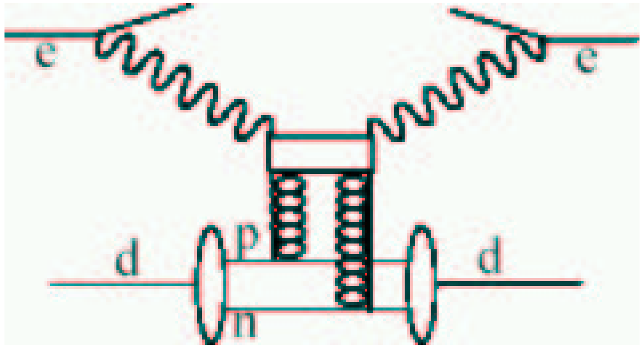


Shadowing

- Following Gribov, shadowing in eD...



- ...is related to diffraction:



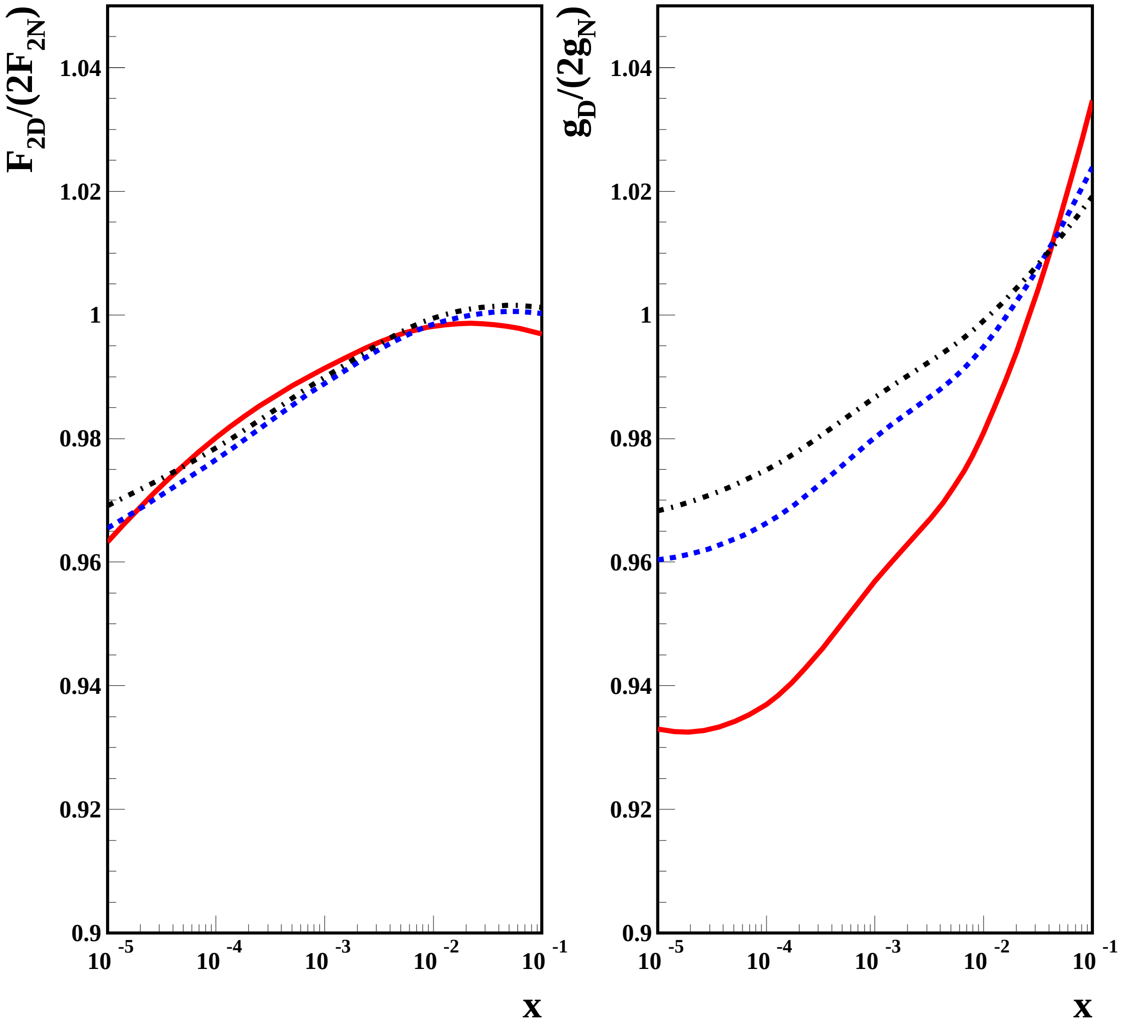
- The Gribov theory can be tested in $eD \to eXp$ DIS by studying the predicted spectator p_t^p and E_p dependence of F_2^n/F_2^p.

- Using the QCD factorization theorem and a parameterization of the partonic structure for diffraction the shadowing corrections can be calculated with high precision.

Nuclear shadowing corrections

- Shadowing corrections for F_2^d and the gluon density of the deuteron compared to the nucleon average.
- The correction amount to a few percent in deuterium.
- Effects up to 20% are predicted for eO and up to 50% for ePb at low x.

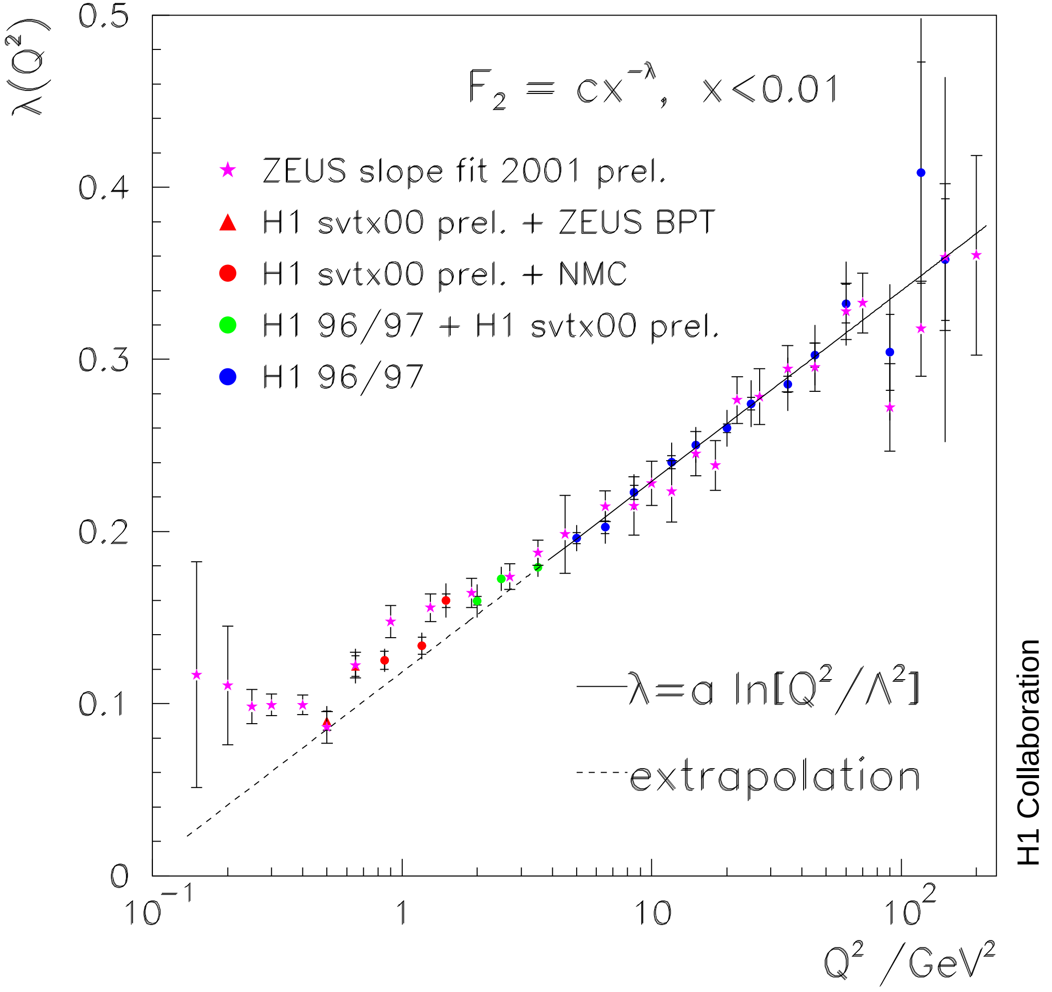
$Q = 2$, 5, 10 GeV.



Rising F_2 at low x

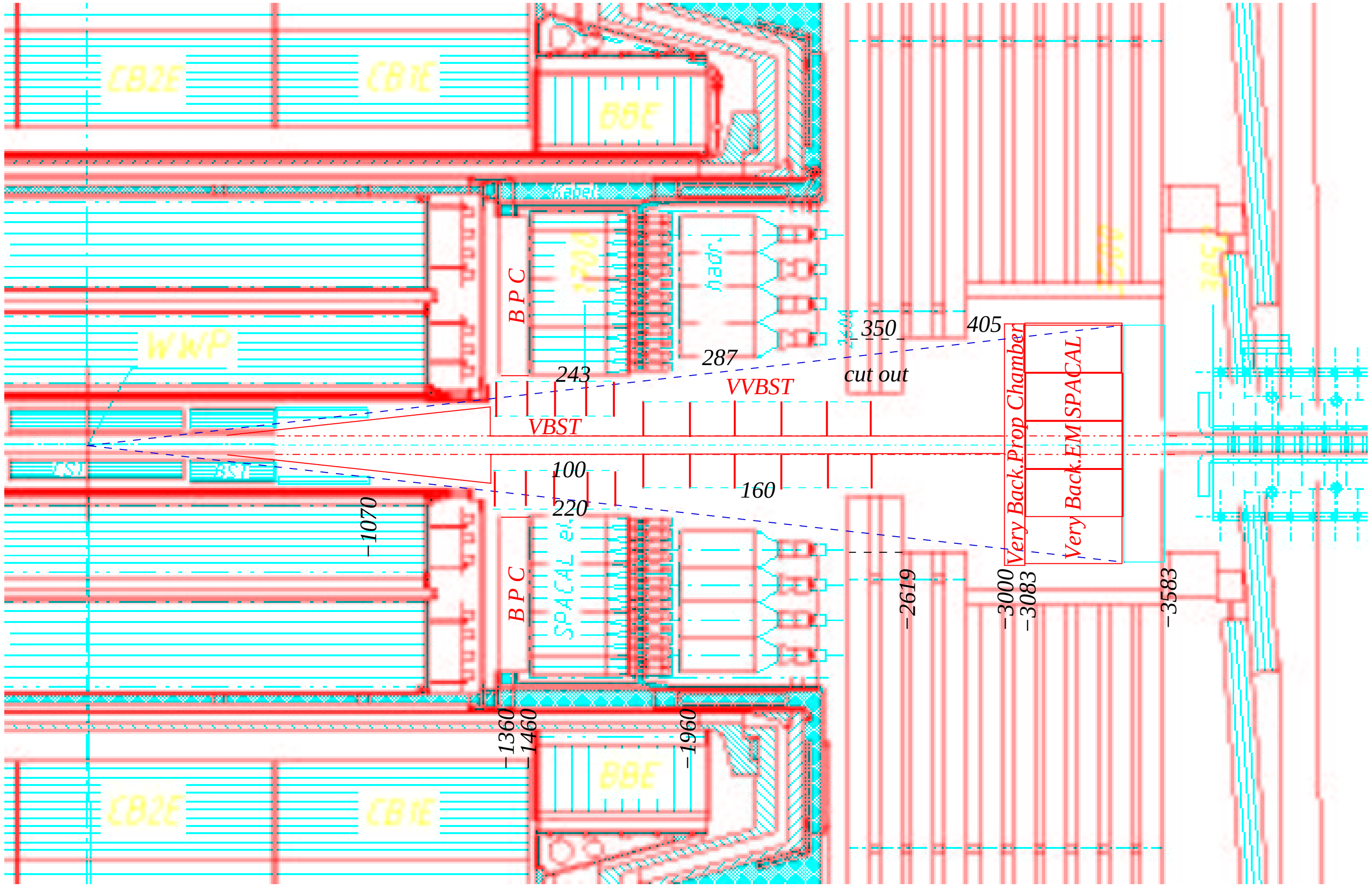
- F_2 rises at low x like $x^{-\lambda}$
- Hadronic cms:
  $W^2 = Q^2/x$ at low x, so
  $F_2 \sim W^{2\lambda}$ at fixed Q^2.
- λ is observed to rise with $\ln Q^2$.
- Around $Q^2 = 0.5\,\mathrm{GeV}^2$ λ levels out around 0.1, similar to the energy dependence of hadron-hadron interaxtions.
- What physics governs this transition?
- Difficult acceptance region for H1 and ZEUS.

HERA I results:



H1 backward upgrade

- Remove lumi upgrade magnets.
- Install very backward
  - Silicon strip detectors
  - MWPC
  - Pb-fibre spaghetti calorimeter.



- Acceptance: $0.1 < Q^2 < 10\,\mathrm{GeV}^2$.

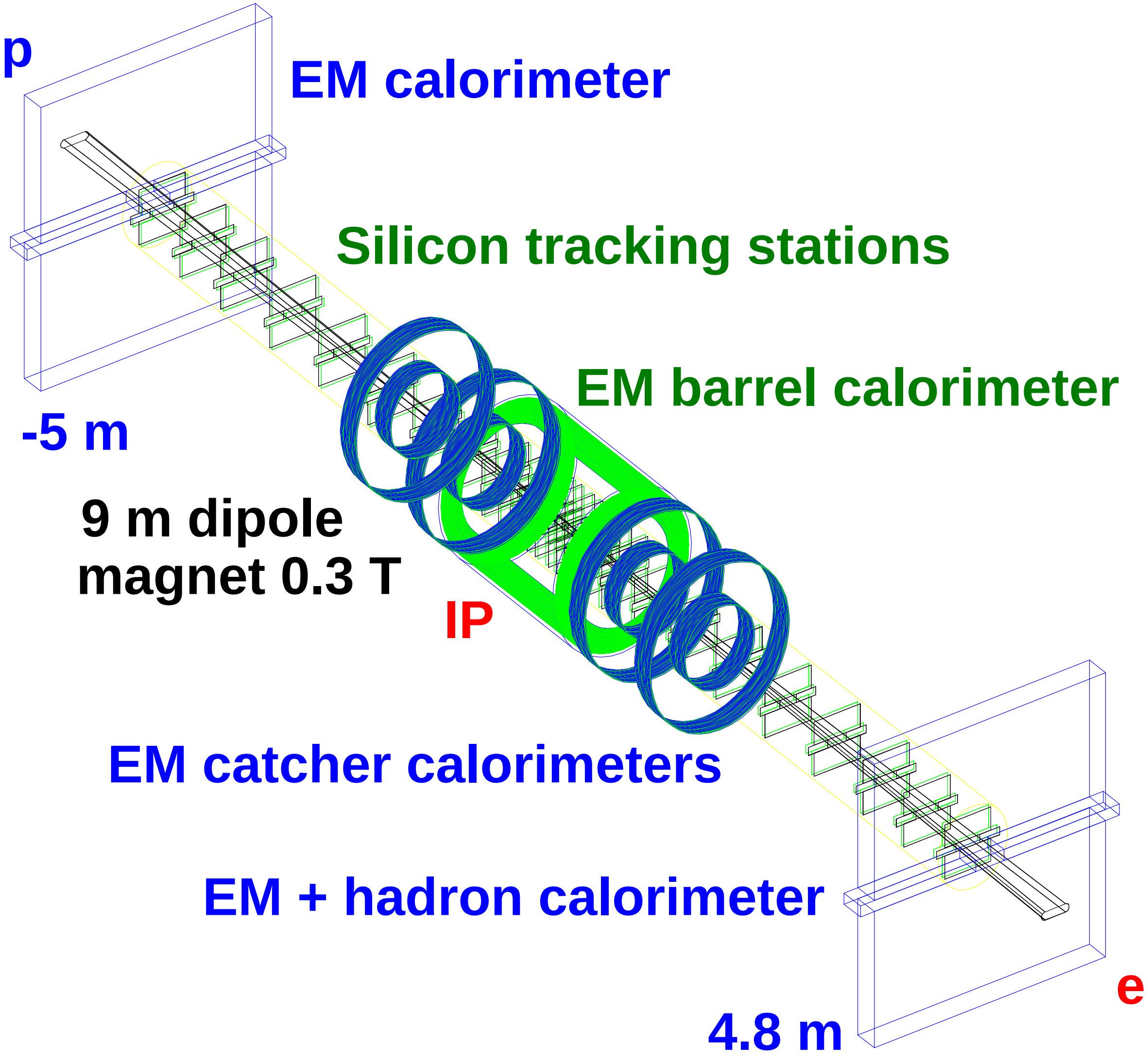
A new collider detector for HERA

- A compact large acceptance detector, see the talk by I. Abt.
- Q^2 range down to 0.1 GeV^2 covered.
- Geometric tracking coverage out to $\eta = 5.5$
- In addition:

  Forward hadron detector for diffraction.

  n and p spectator taggers for eD.

  Luminosity detector.

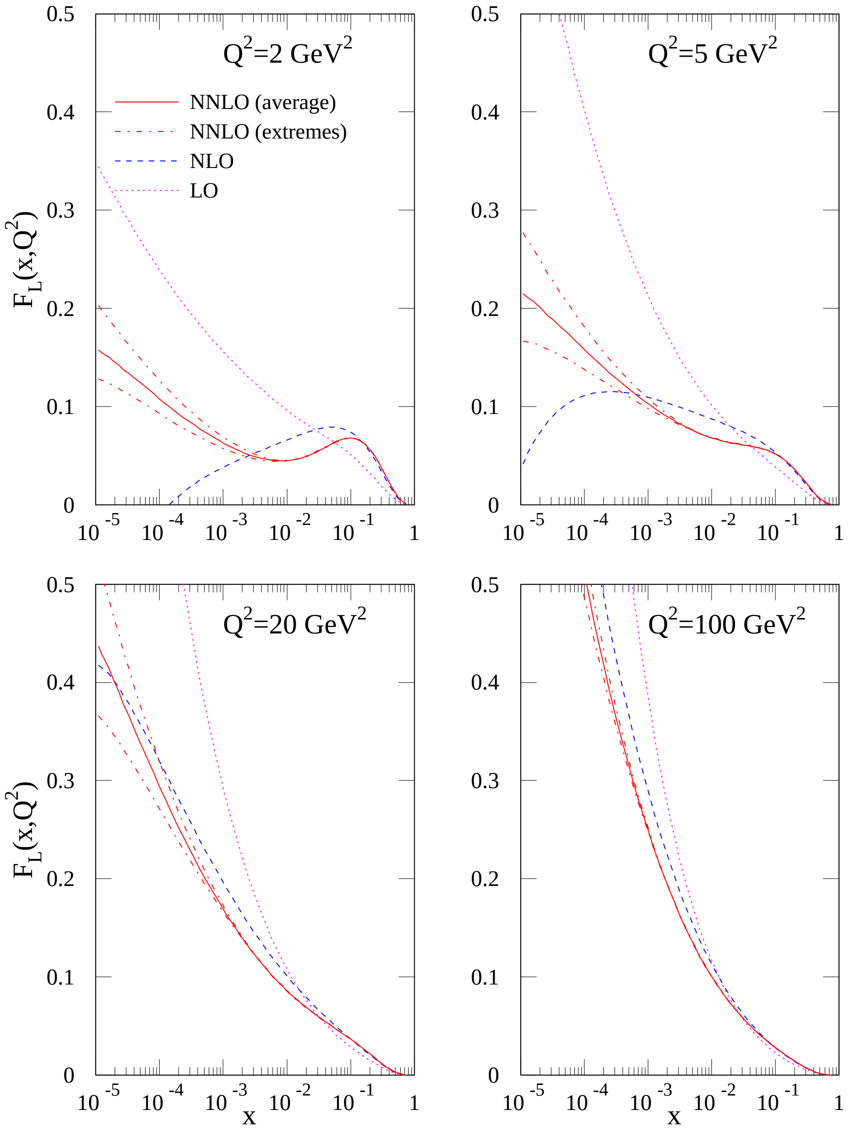


Longitudinal structure function

- Neutral current DIS cross section:

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[(1+(1-y)^2\,F_2 - y^2 F_\mathrm{L}\right]$$

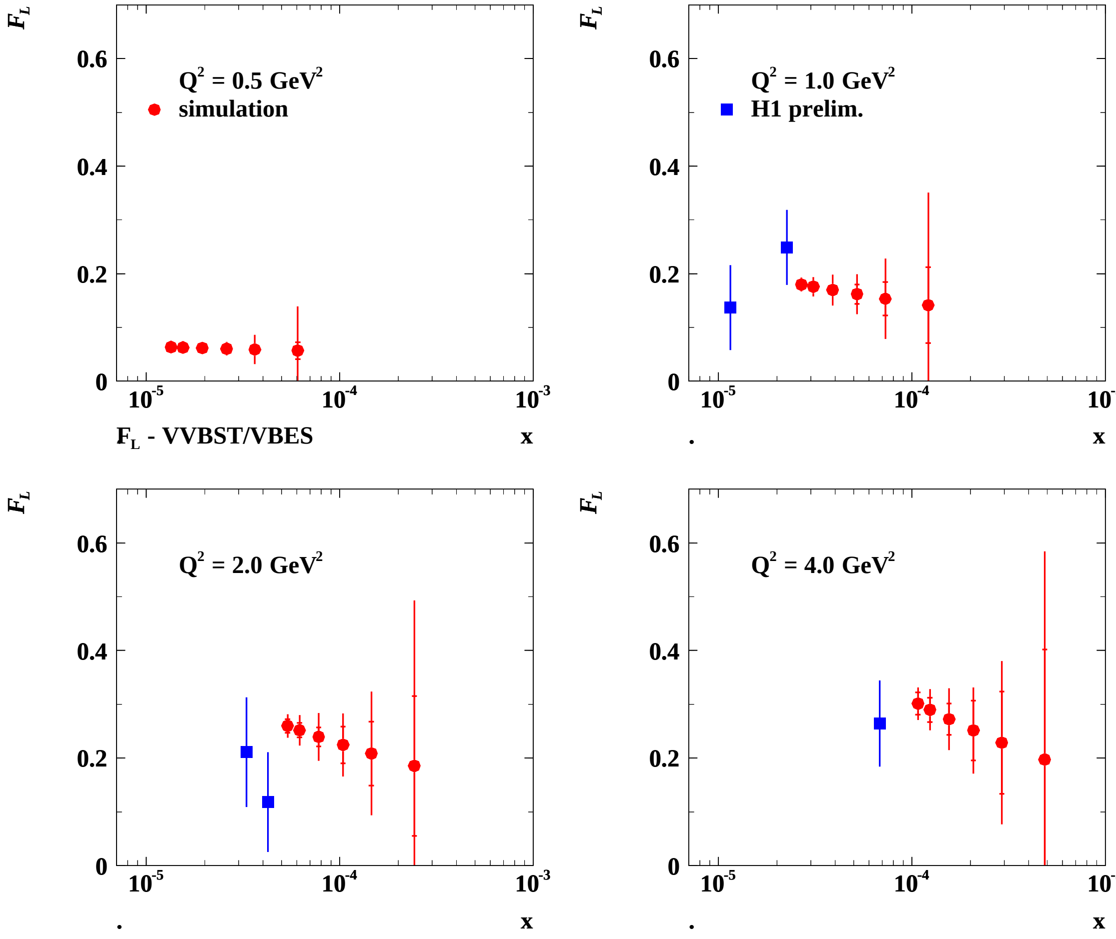
- $F_\mathrm{L} > 0$ due to gluon radiation.
- Large NNLO corrections to F_L at low x and Q^2.
- F_L is an independent observable to test the extraction of the gluon density from the F_2 analysis.



Measure F_L at low Q^2

- Separate F_L and F_2 at fixed x, Q^2 by varying the beam energy.
- F_L contributes most at high y, which means low energies for the scattered positron. Need good e/π separation against the photoproduction background.
- Expect several high precision F_L points at low Q^2.
- At higher Q^2 this measurement is part of the HERA II program.

Simulation for the H1 backward upgrade assuming 5 pb^{-1} each at $E_p = 920$, 500,and 400 GeV:



QCD radiation patterns

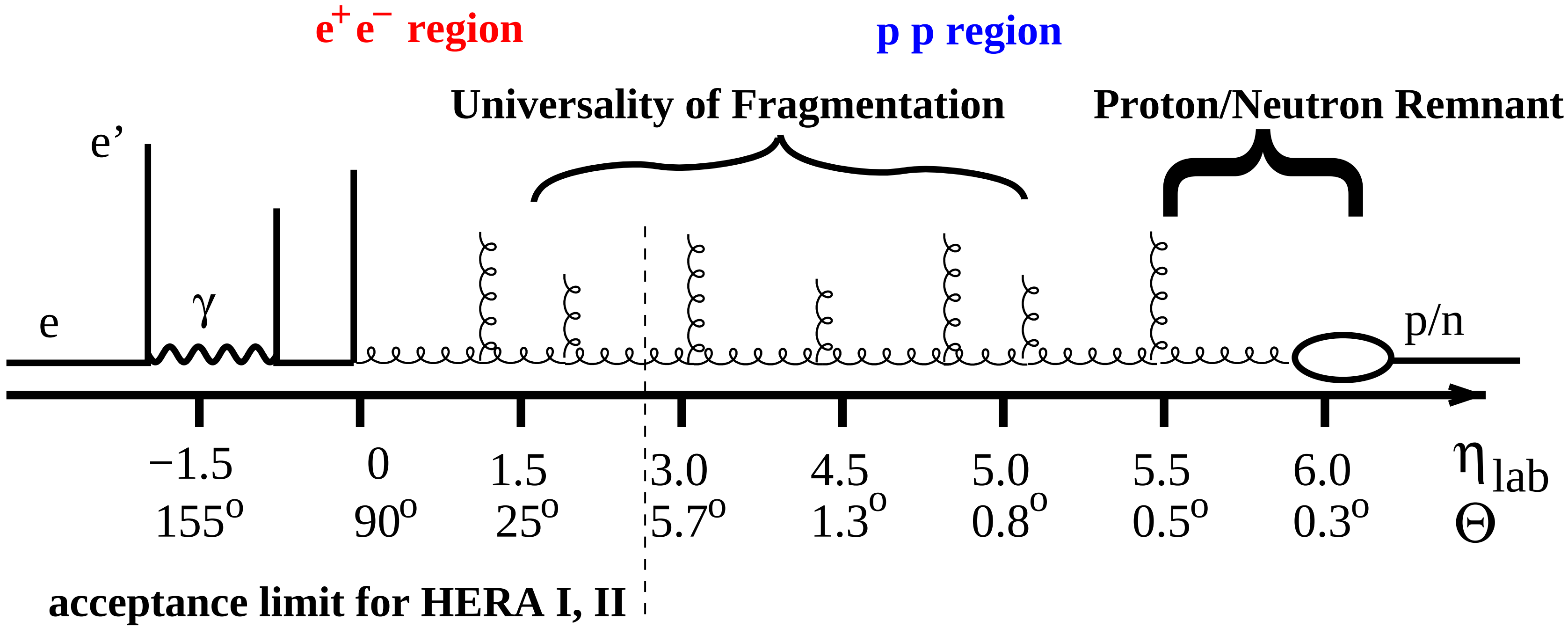
- At HERA:

  Hard scattering products in the backward and central region with fragmentation like in e^+e^-.

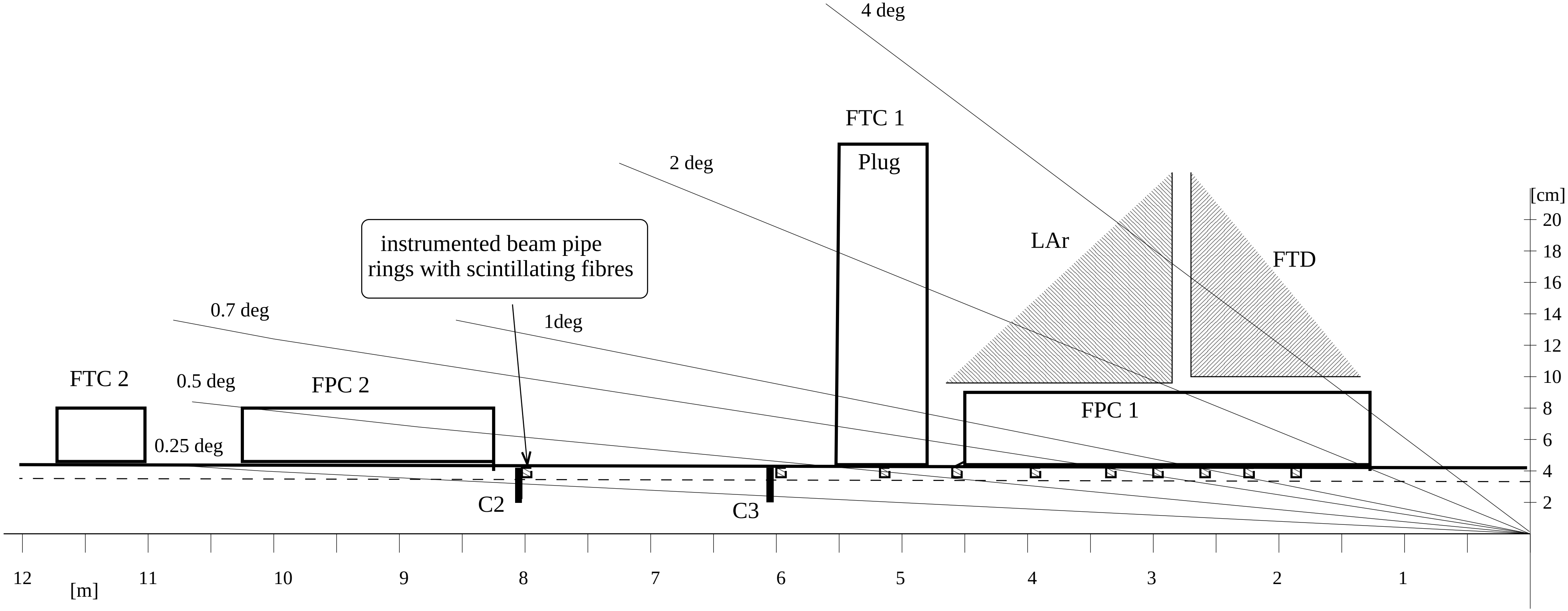
  Proton remnant fragmentation in the forward region like in pp.

- Universality of fragmentation can be tested.

- The region beyond $\eta = 2.7$ is not explored.

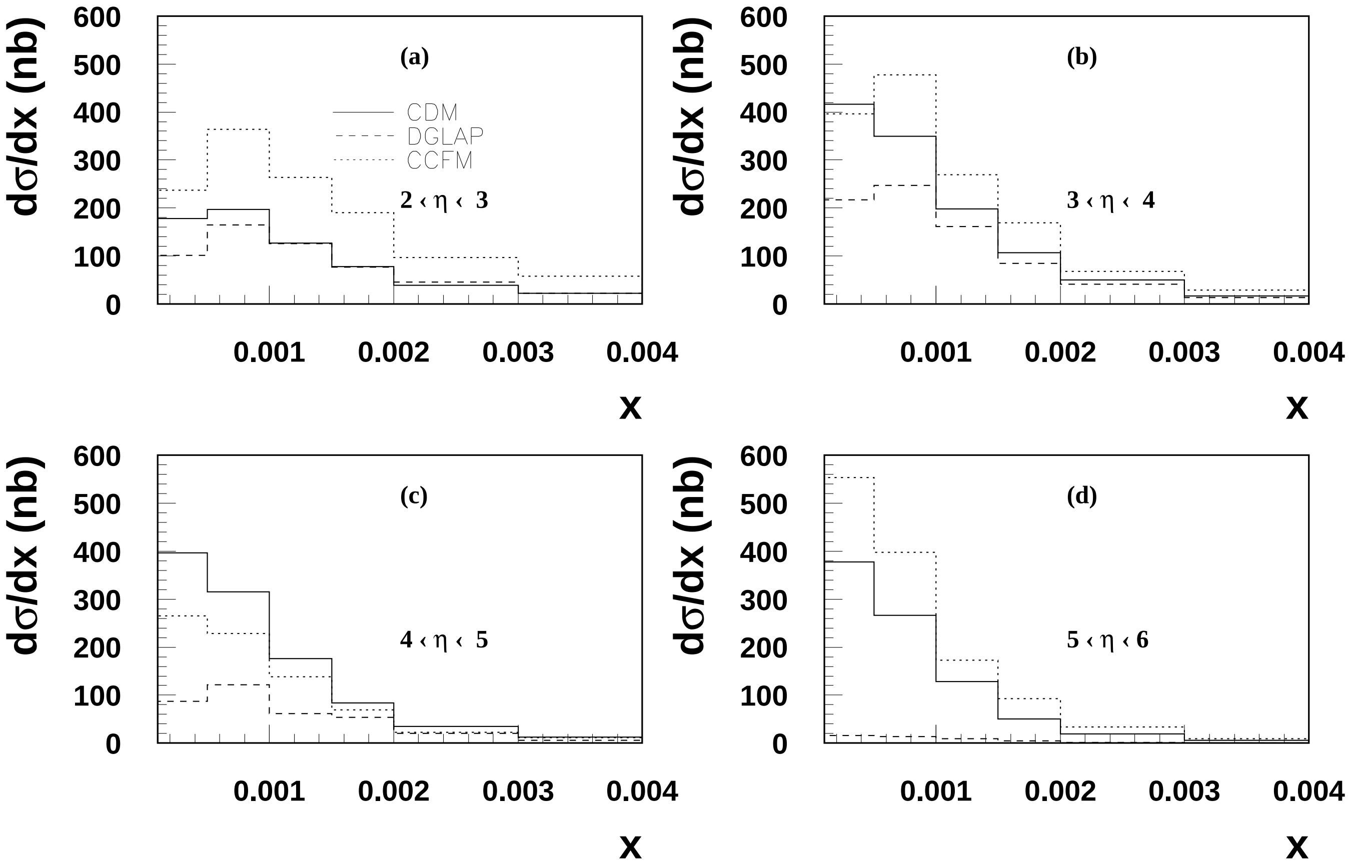


H1 forward upgrade ideas



Forward jets

Simulation:



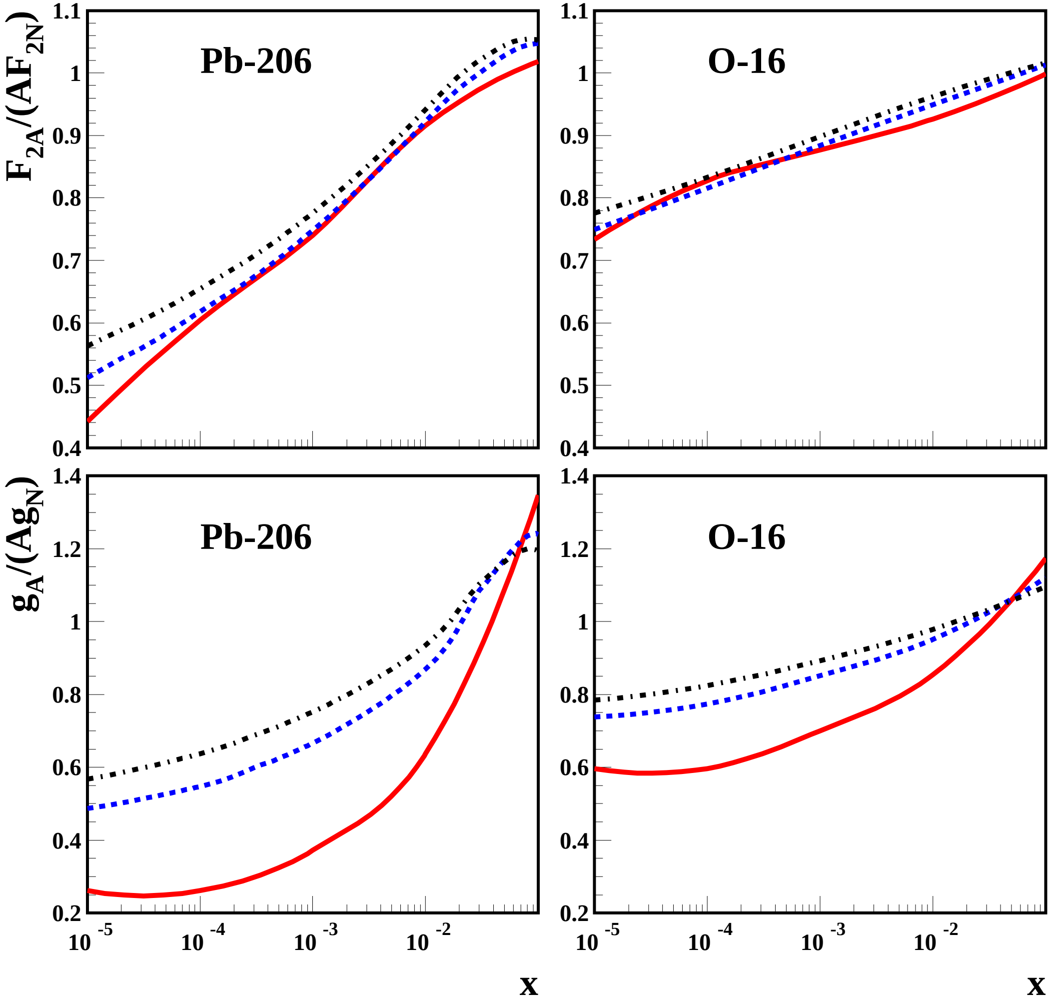
Approaches to parton radiation:

- DGLAP evolution with strict k_T ordering predicts small forward jet rates.
- CCFM and Color Dipole Model with features of BFKL evolution predict higher rates at large η.
- Multi-parton exchange is not fully included in any approach.

eA

- The number of partons encountered by a projectile in a nucleus grows like $\mathrm{A}^{1/3}$ (6 for Pb).
- At high parton densities non-linear recombination effects are expected to limit the rise of F_2.
- Leading twist nuclear shadowing theory predicts suppressions up to 50% in the x and Q^2 range accessible with eA at HERA.
- Does diffraction contribute 50% to the toal cross section?
- Requires beam cooling.

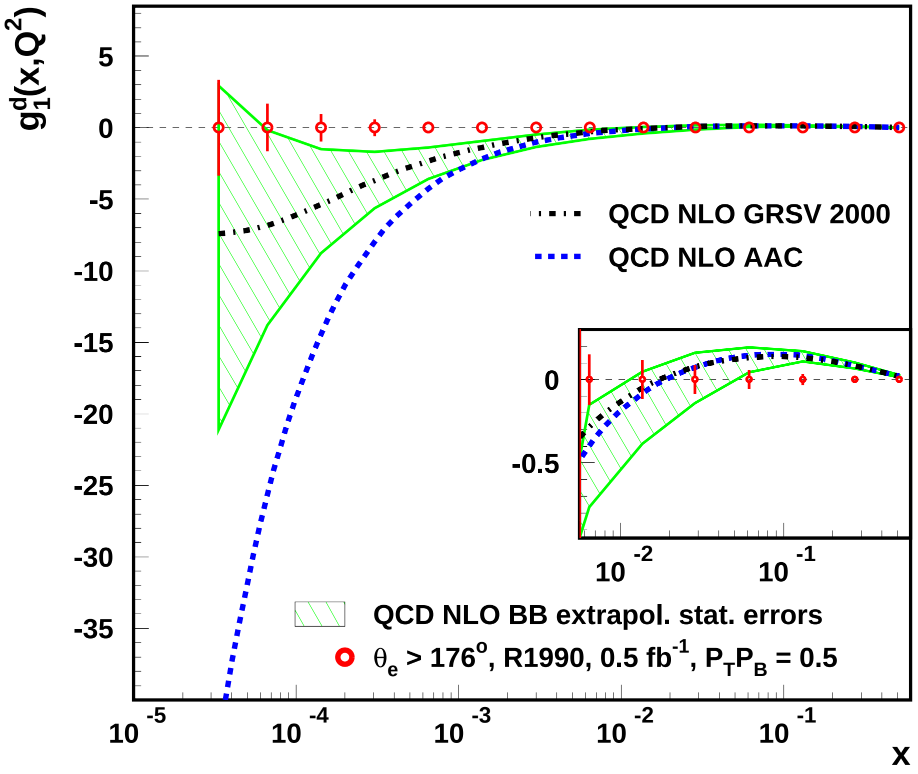
$Q = 2$, 5, 10 GeV:

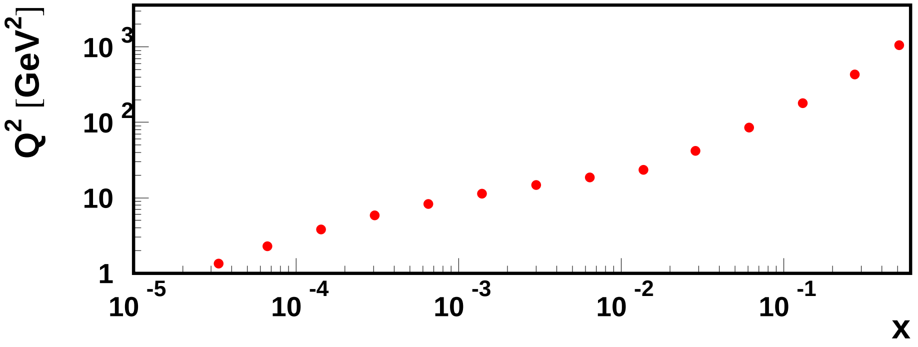


Spin

- Nucleon spin carried by quarks (only 15 to 20%), gluons, and angular momentum.
- Study with longitudinally polarized beams.

  D has 25 times less and weaker depolarizing resonances than p.
- Measure asymmetry for opposite and parallel helicities. Expect about 1% at $x = 0.001$. Need large $\mathcal{L}$ and $\mathcal{P}$.
- Extract quark spin contribution in g_1.
- Gluon contribution accessible in di-jet or charm production.





Summary: HERA III physics program

1. eD operation:
    - Measure $\overline{d} - \overline{u}$ with 2% accuracy at low x.
    - Measure d_v/u_v at high x.
    - Study n, p, and coherent D diffraction.

2. Return to ep with increased acceptance at low Q^2 and extended forward rapidity coverage:
    - Study the transition region from DIS to photoproduction around 0.5 GeV^2.
    - Measure F_L at low Q^2.
    - Study QCD radiation patterns in the forward direction.

3. eD and eA operation:
    - Study nuclear shadowing.
    - Search for QCD saturation effects at high parton densities.
    - Study diffraction in eA. Approach black-body limit?

4. Polarized eD:
    - Study the nucleon spin structure at low x and high Q^2.
    - Study polarized photoproduction and diffraction.

Status

- A Letter of Intent for a new collider experiment at HERA focussing on low x, diffraction, and extended forward rapidity coverage was submitted to the May 2003 DESY PRC.
- A second Letter of Intent to measure eD scattering with H1 at HERA was submitted as well. It is supported by 156 physicists from 39 instituts.
- The physics case for these LoIs was received favourably by the PRC.
- New collaborators are welcome to both LoIs.
- A new 40 GeV p pre-accelerator and an e damping ring are required if PETRA is converted to a dedicated 3rd generation synchrotron light source.
- With a strong community and some external resources it may be possible to realize the HERA III program. Strong support by theorists has been expressed in a letter by Altarelli, Bjorken et al.
- Until then, the HERA II physics program aims for 1 fb^{-1} by 2007.