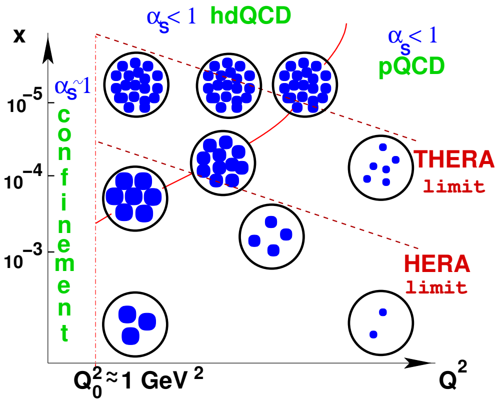
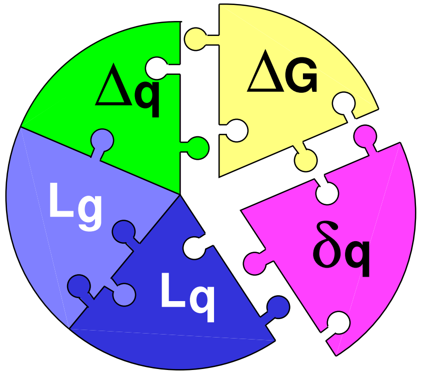
European Workshop On The QCD Structure Of The Nucleon
April 3-6, 2002 Ferrara, Italy

# HERA-III

S. Levonian, DESY

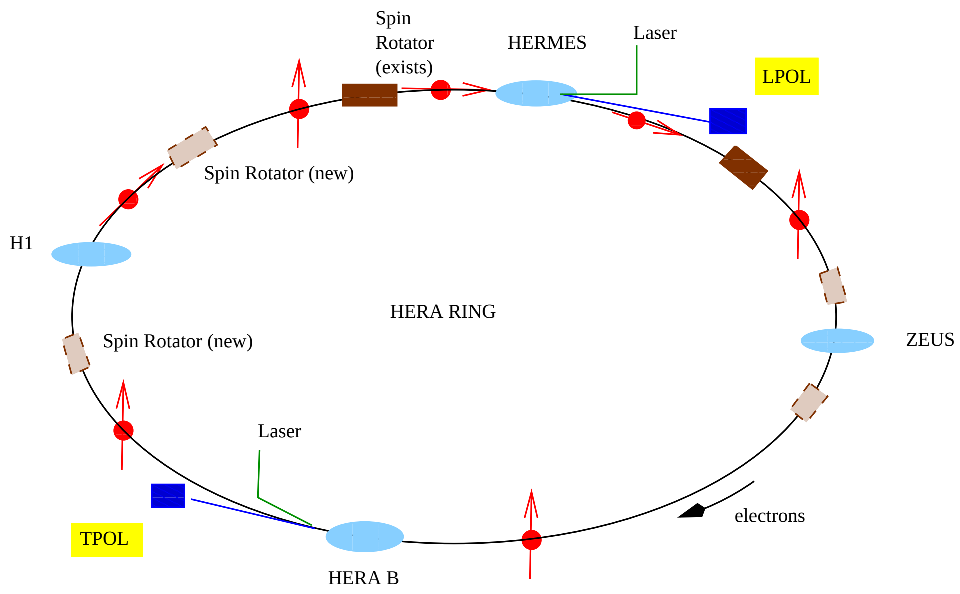


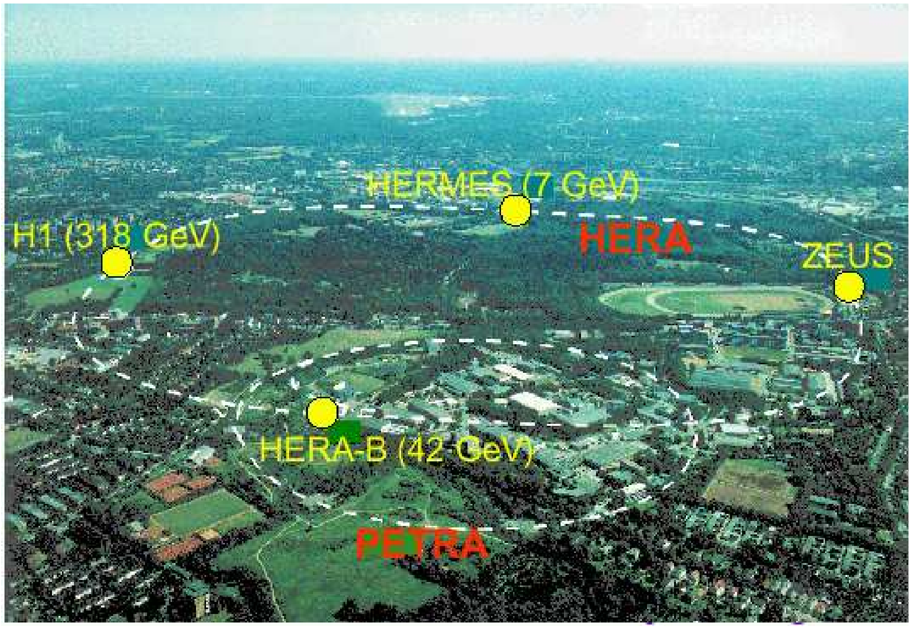




- Physics potential
- Machine aspects
- Detector requirements

# HERA facility

p(920) $\times$ e(27.5)




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

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

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

# HERA-1 vs HERA-2

**1993 – 2000**

$\mathcal{L} = 120$ pb$^{-1}$

per $ep$ experiment

detector acceptance
for $Q^2 > 0$ GeV²

$e-$beam polarization

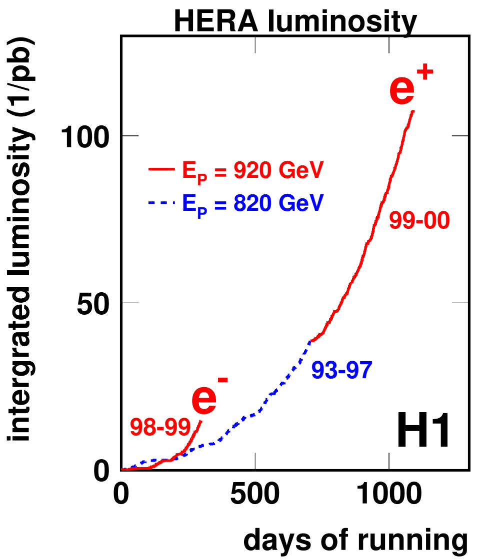
$\langle P_b \rangle \approx 55\%$

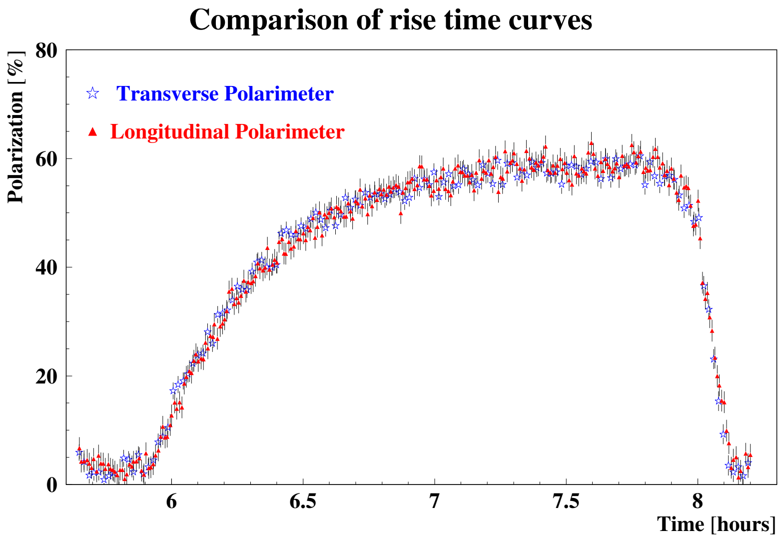
**2002 – 2006 (?)**

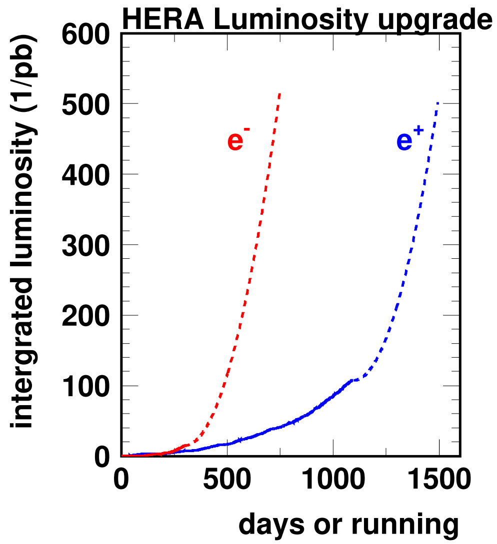
$\mathcal{L} = 1000$ pb$^{-1}$

stronger focusing

$\rightarrow$ acceptance
for $Q^2 > 5$ GeV²



# HEP at DESY

Main road: **HERA-I** $\rightarrow$ **HERA-II** $\rightarrow$ (2007-2012) $\rightarrow$ **TESLA (THERA)**

Q1: Where QCD at HERA will be in 2006 ?

- nucleon structure
- parton dynamics
- spin physics

Q2: What next ?

- $eA$ ? (HERA workshops 96,99)
- $\vec{e}\vec{p}$ ? (HERA workshops 97,99)

(recent review in Durham WS, Dec. 6-7,2001)

- HERA-I highlights

  $F_2^p$, $g(x)$, low-$x$ and diffraction

  spin: first determination of $\Delta G/G$

- HERA-II prospects

  precision: $F_2^{D(4)}$, $\alpha_s$, $F_L$, VM, DVCS ($\vec{e}p$)

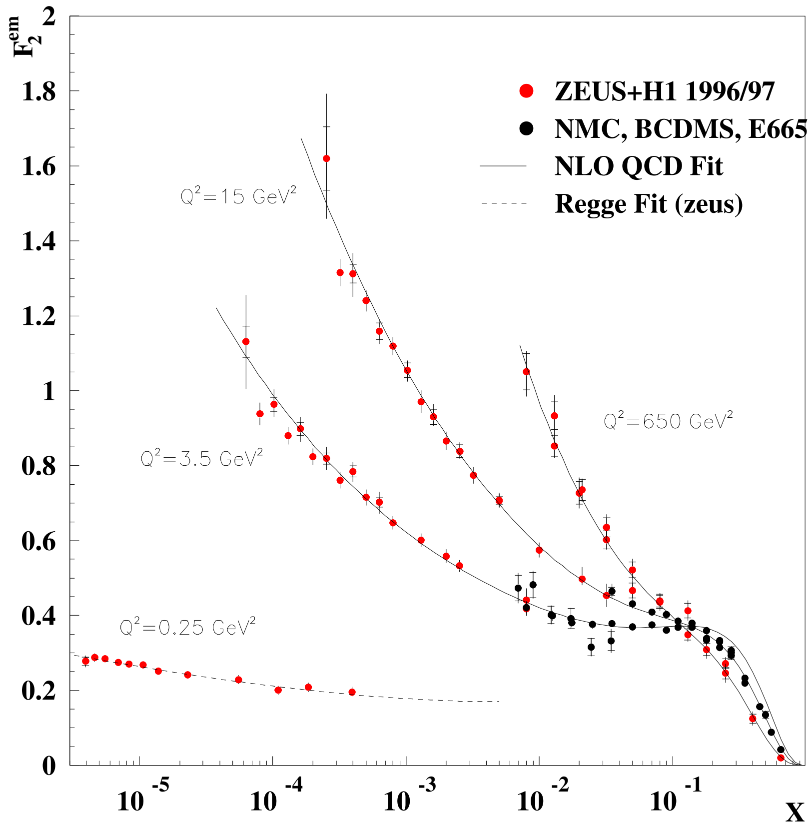
  high $Q^2$: $xF_3^p$, CC $\rightarrow q_v(x)$

  spin: good $\Delta G(x)$ $(x > 0.01)$, first $h_1(x)$

$\Rightarrow$ Options for HERA-III

(physics driven, time/resources constraints)

# HERA-I: Structure of the Proton




★ High precision:
$1\%$(stat) $\oplus$ 2-3$\%$(syst)

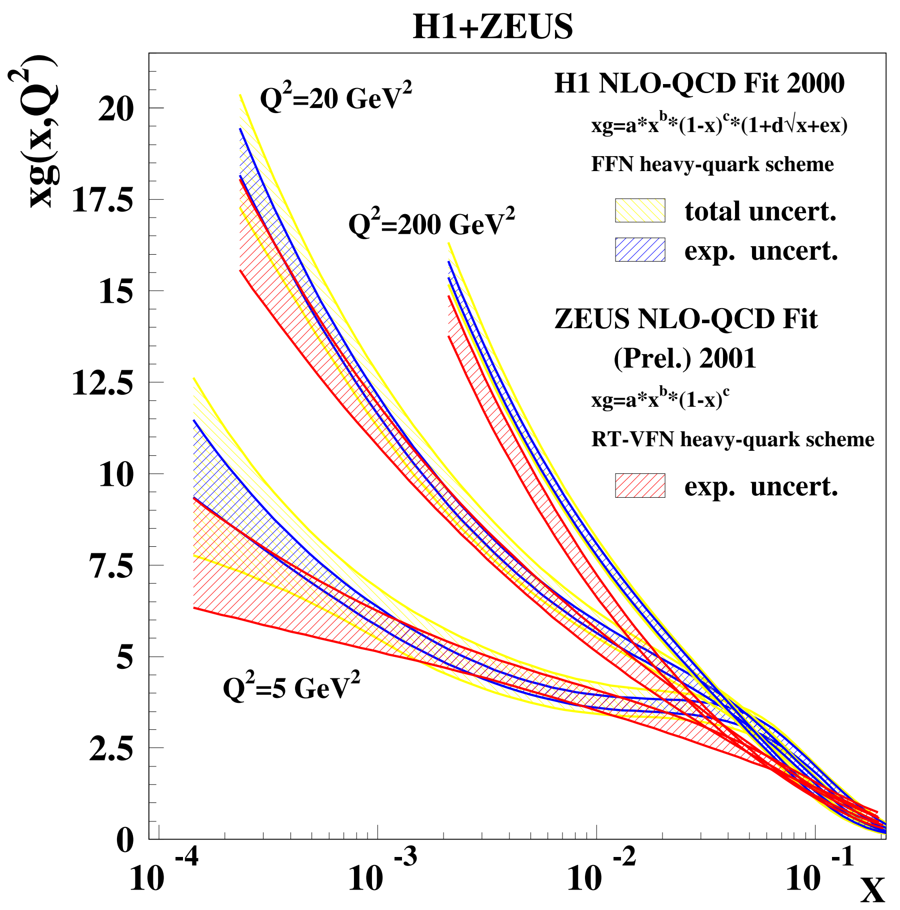
★ Strong rise at low $x$: $F_2 \sim x^{-\lambda}$
(i.e. $\sigma_{\gamma^* p} \sim W^{2\lambda}$ )

★ NLO QCD (linear DGLAP) perfectly describes data at $Q^2 > 2$ GeV$^2$

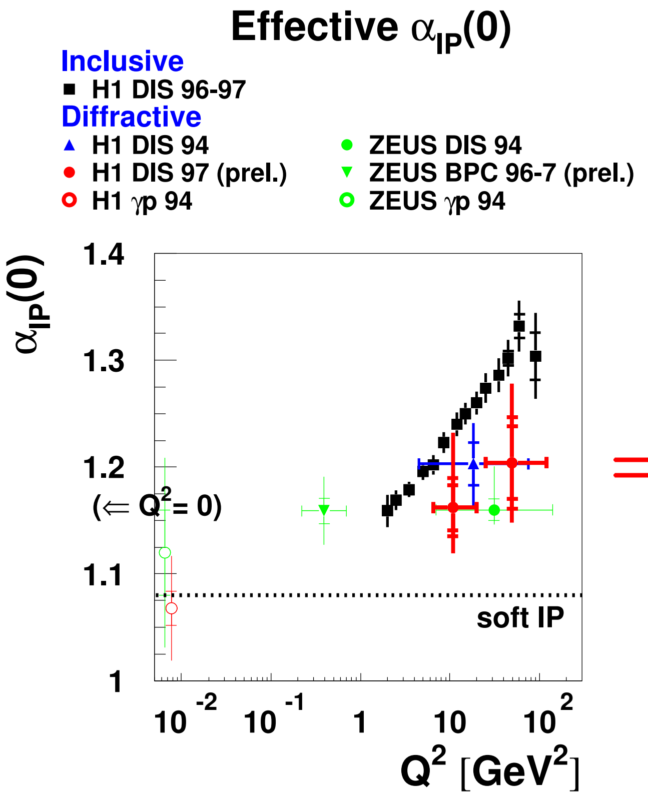
$\Rightarrow$ no sign of saturation?

# Low-$x$ and Diffraction

$xg(x, Q^2)$ from scaling violation of $F_2$




$\sigma_{\text{diff}} \propto |xg(x)|^2$




$\Rightarrow ?$

better precision for $F_2^D$ needed

(HERA-II)

# Hunting for gluon saturation

There is a controversy about parton saturation at HERA, both between theorists and experimentalists. ($Q^2_{sat} = \alpha_s N_c \frac{dN_g}{dy} / \pi R^2$ is too small in HERA-ep)

One needs conditions, when linear DGLAP evolution equations break down unambiguously, and yet at high enough $Q^2$ ($Q^2_{sat} \gg \Lambda^2_{QCD}$, $\alpha_s(Q^2_{sat}) \ll 1$)

$\Rightarrow$ magnify gluon density

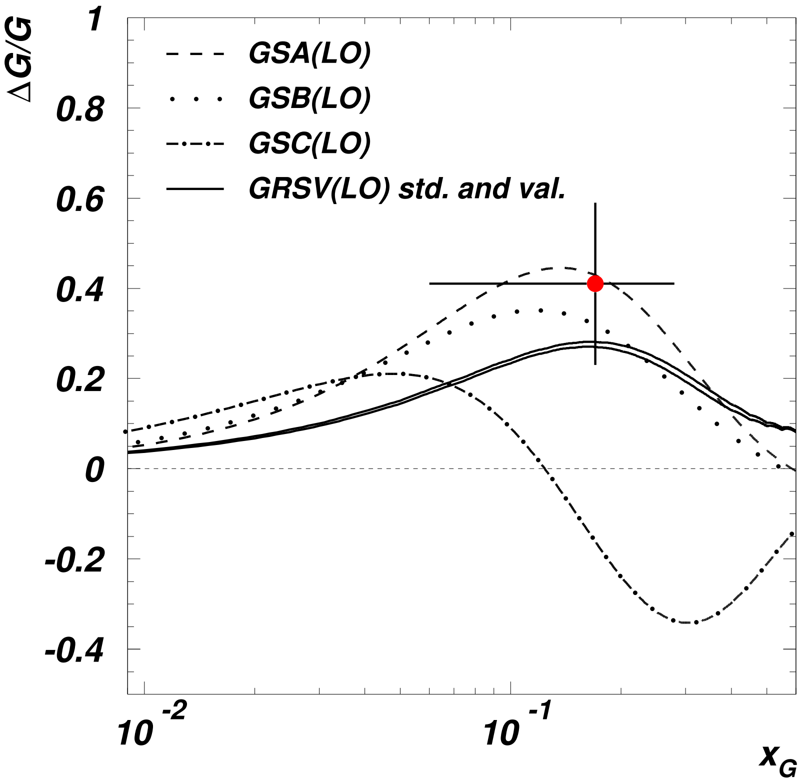
***ep*** **:** $x = Q^2/ys$; $xg(x, Q^2) \sim s^{\lambda(Q^2)}$ $\rightarrow$ increase energy (THERA)
***eA*** **:** $xg_A(x) \sim A^{1/3} xg_p(x)$ $\rightarrow$ fill nuclei instead of protons (HERA-III)

$\boxed{eCa^{40} \text{ (HERA)} \approx 1.8\,\text{TeV (e)} \times 0.9\ \text{TeV (p)}}$

# Gluon polarization

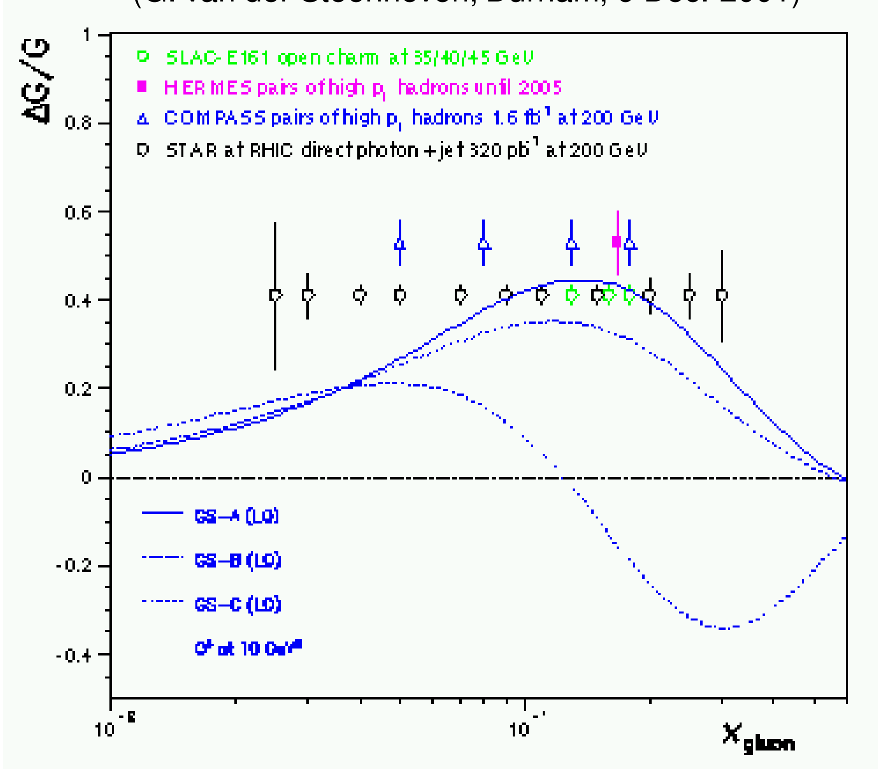
2000

2006




Significant model dependence

(G. van der Steenhoven, Durham, 6 Dec. 2001)




All data only at $x > 0.02$

# Spin at high energies

There are two problems with $\Delta G(x)$ measurement at fixed target:

- All gluons are below $x = 0.01$
- Strong model dependence; one needs higher scales for reliable extraction

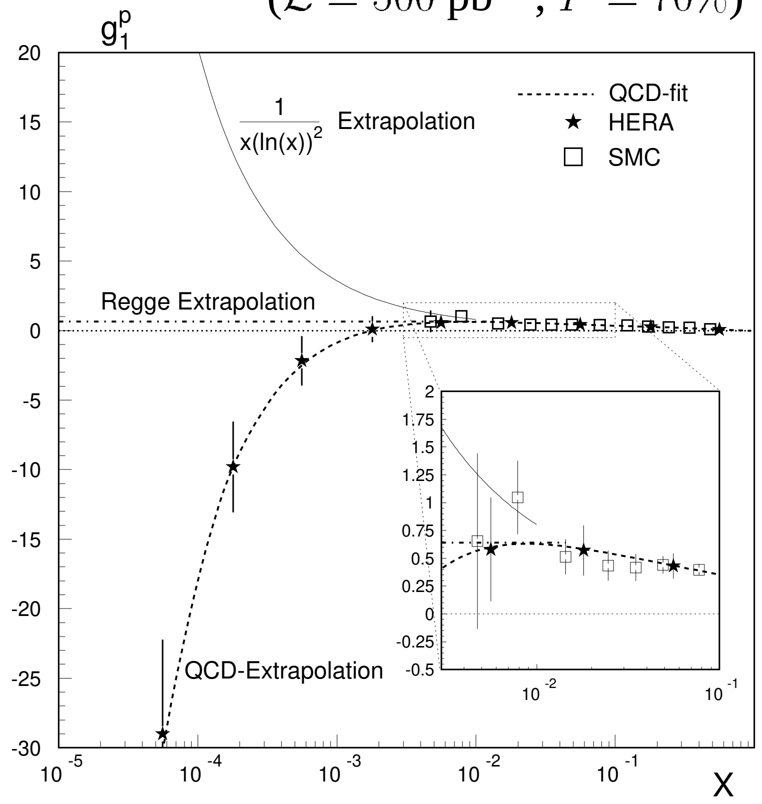
Additional advantage of high energies – several methods can be used to measure $\Delta G$:

- from scaling violation of $g_1(x, Q^2)$
- from dijet events
- possibly from heavy quarks ($\gamma g \to c\bar{c}$)

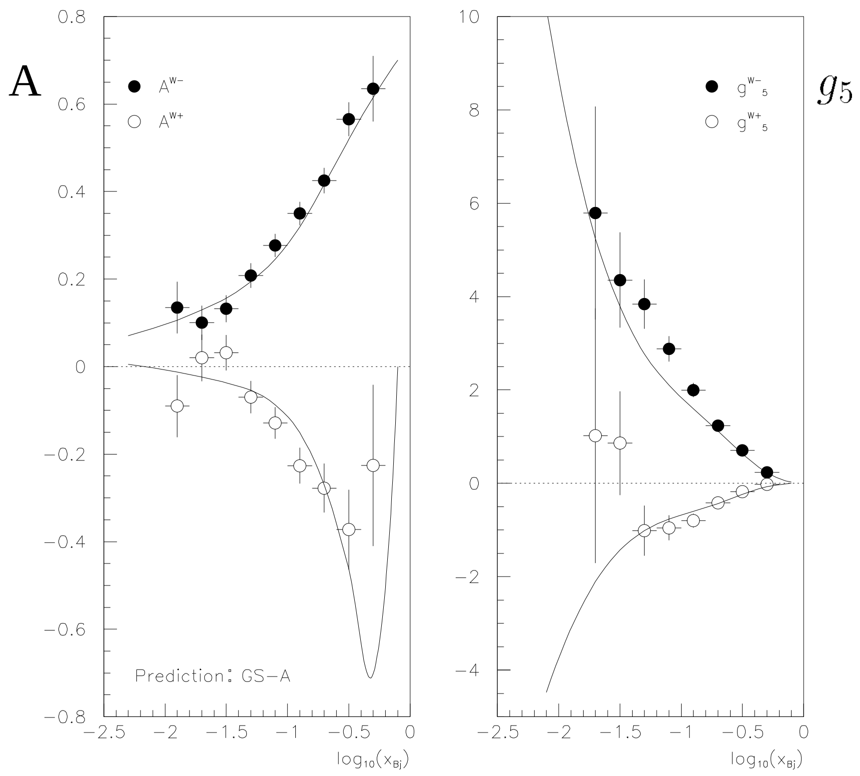
$\Rightarrow$ Go to the collider mode

# $\vec{e}\vec{N}$ at HERA-III

$(\mathcal{L} = 500\ \text{pb}^{-1},\ P = 70\%)$




Contreras et al. DESY-proc 98-01 (500 $\text{pb}^{-1}$)




$g_1$ at low $x$ is unknown

(Note: exp. asymmetries are small → precision!)

$g_5$ needs high $Q^2$ (CC asymmetries)

# Physics Objectives for HERA-III

Three problems will remain open even after HERA-II

- the partonic structure of the neutron
- the nucleon spin composition (at low $x$)
- gluon saturation and confinement

CGC – new form of matter in high energy limit of QCD ?

$\vec{e}\vec{p}$ option: spin physics in a new high energy domain

– helicity structure of DIS at low x, in pQCD regime

– make use of the advantages of collider geometry

$eA$ option: amplification of the gluon density

– non-linear QCD effects, gluon saturation, deconfinement

– parton propagation through the nuclear matter, BBL

Deuterons (polarized and unpolarized):

– spin physics program similar to $\vec{e}\vec{p}$ option, plus $\vec{e}\vec{n}$

– SF measurements: $F_2^d,\ F_2^n,\ u/d, \bar{u}$-$\bar{d}$, $\alpha_s$ precision

# Polarized Deuterons

"spin tune" $\nu_0 \equiv G\gamma$ $\quad (G = (g-2)/2, \quad \gamma = E/m)$

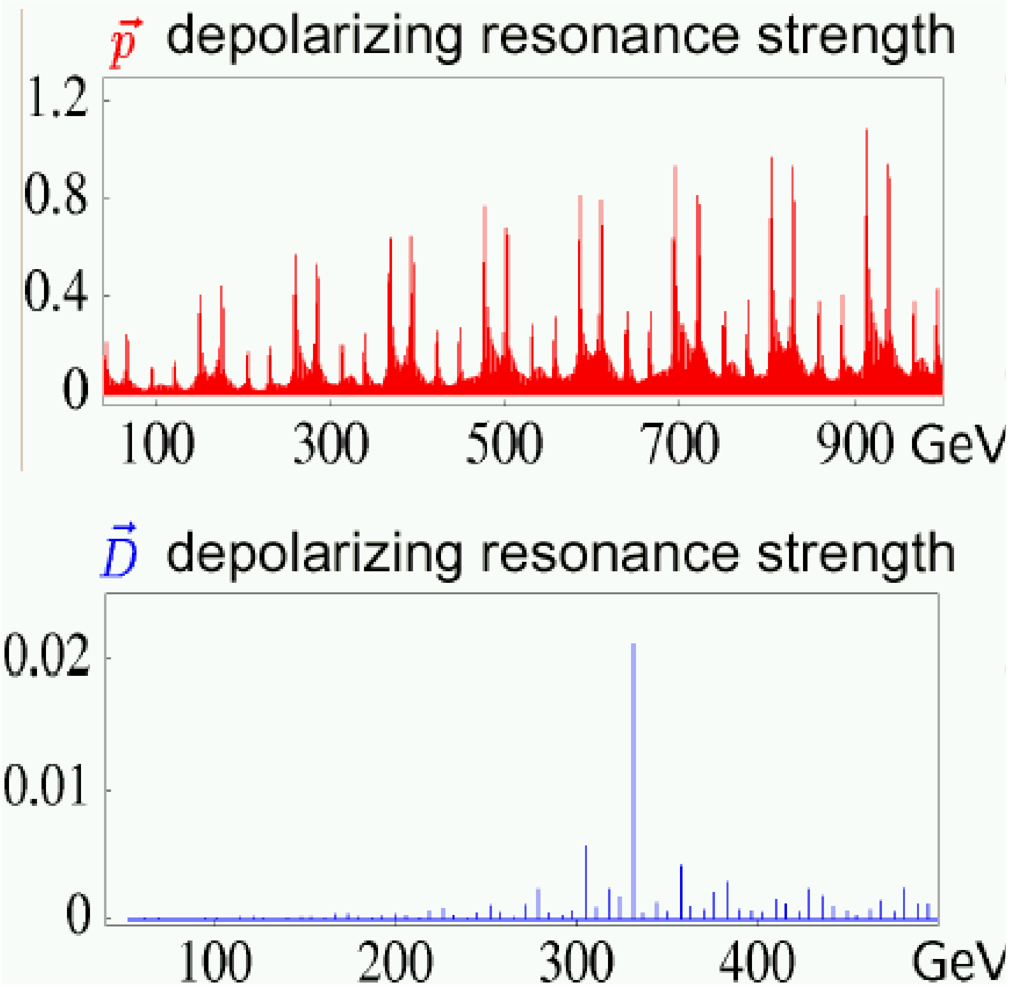
E.g. for 920 GeV protons ($G_p = 1.79$):
1 mrad orbit kick $\Rightarrow$ $100^o$ of spin precession
$\nu_0 = 1756$ $\Rightarrow$ thousands of resonances to cross!

$\Rightarrow$ requires at least 4 Siberian Snakes

For deuterons $G_d = -0.143$ and $\gamma_d = \gamma_p/2$
$\Rightarrow$ resonances are 25 times weaker and 25 times rarer for $D$ than for $p$

Ya.Derbenev, V.Anferov, phys./0003104:
No snakes! Use transverse RF dipoles to rotate and stabilize longitudinal $\vec{P}$

needs simulation for real HERA machine



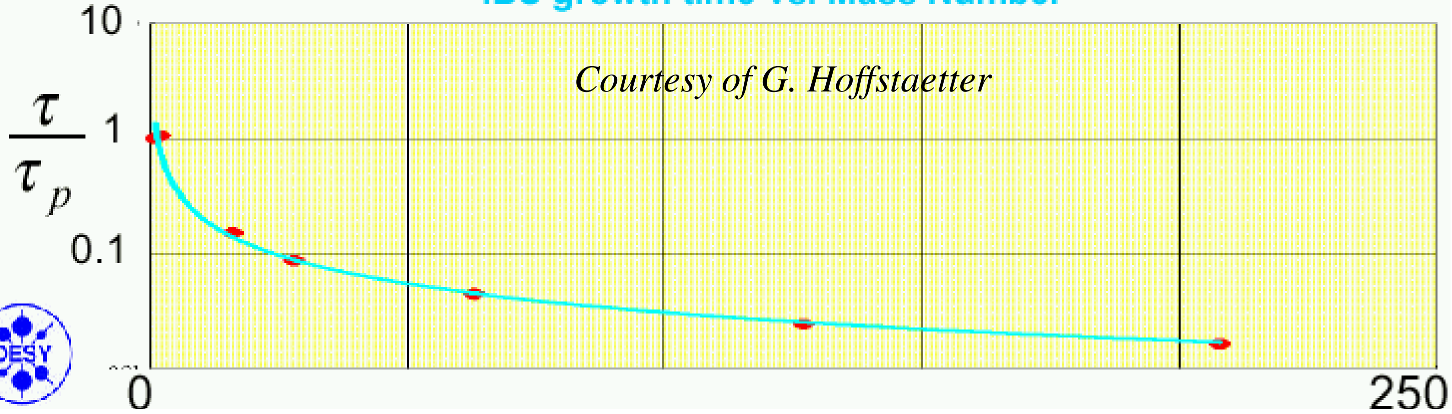
# Ions in HERA

Problem: Intra Beam Scattering, reducing beam lifetime

$$\frac{1}{\tau_{IBS}} \propto I_{bunch} \cdot (\frac{Z}{A})^2 \cdot \frac{1}{\gamma^3} \cdot Z$$

| | Deuteron | $^{16}O^{8+}$ | $^{208}Pb^{82+}$ |
|---|---|---|---|
| $\epsilon_N$ | 2.5$\mu$m | 2.5$\mu$m | 2.0$\mu$m |
| $N_{ppb}$ | $5.0 \cdot 10^{10}$ | $6.0 \cdot 10^9$ | $4.8 \cdot 10^8$ |
| $\mathcal{L}$ | $3.5 \cdot 10^{31}$ | $4.4 \cdot 10^{30}$ | $3.4 \cdot 10^{29}$ |
| $\sum_{xyz} \tau_{IBS}$ | 140min | 20min | 2.5min |

IBS growth time vs. Mass Number




$\Rightarrow$ needs $e$-cooling for heavy ions to obtain $L_A \approx L_p/A$

# Machine summary for HERA-III

- Polarized protons:
  - Polarimeters
  - Spin rotators
  - Flattening Snakes
  - At least 4 Siberian Snakes
- Polarized deutrons (very attractive!):
  - $\vec{D}$ source
  - Simulation for real machine

- Nuclei acceleration:
  - Deuterons are straight forward $\Rightarrow$ natural starting point
  - Electron cooling required for $A > 4$
  - Different $A$ bunches $(D, O^{16}, Ca^{40})$ circulating simultaneously?

# Typical measurements

## $eA$

- Inclusive SF: violate DGLAP, change $x$-dep: $F_2 \sim Q^2 \ln(x_0/x)$
- $\sigma_{diff}/\sigma_{tot}$ $(\rightarrow 1/2?$ – BB limit)
- $\sigma_{VM}(x, A)$ $(\sim A^{4/3} \rightarrow \sim A^{0.4}$ as $x$ diminishes – colour transparency/opacity)

$\Rightarrow$ large effects, hence moderate luminosity is sufficient:

$\boxed{\mathcal{L} \cdot A \approx 10 \text{ pb}^{-1}\text{/ion}}$

## $\vec{e}\vec{p}$

- $\Delta G(x)$ requires to measure small asymmetries at low $x$
- $g_5(x)$ $\rightarrow$ high $Q^2$ $\rightarrow$ low $\sigma_{CC}$
- DVCS $\rightarrow$ GPD's, $J_q$ – proceeds via complicated extraction

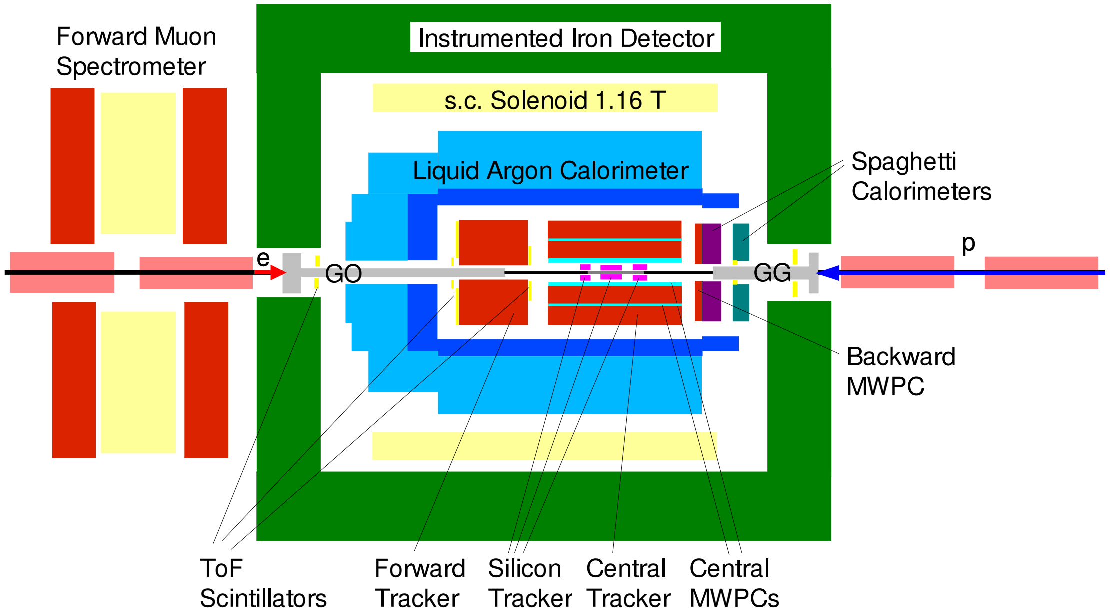
$\Rightarrow$ large luminosity and beam polarization, control over systematics ($\mathcal{L} \approx 500$ pb$^{-1}$)

# Experiments at HERA-III

## 1. Same setup as presently (H1, ZEUS, HERMES)

detectors will be 15-18 years old $\rightarrow$
modifications in tracking, electronics
may be necessary

H1 at HERA-II




## 2. Only one collider detector

– simpler for machine tuning/stability
– saving resources / concentrating efforts

## 3. Two collider detectors, optimized for different physics

– low-$x$, $n/p$-tagging, high acceptance, small beam divergence
– high $\mathcal{L}$, polarization, large statistics (stronger focusing, no beamline detectors)

# Detectors: nucleon tagging

## $z \approx 1$: (Existing Roman Pots at 220m)

coherent diffraction: $eA \to eAX$

## $z \approx 0.5$: (p-tagger at 90m, to be built)

select $en + p_s$ events

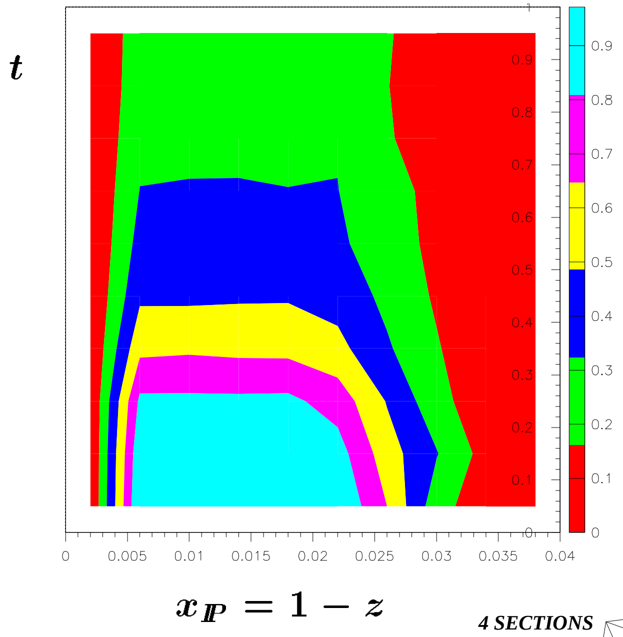
(good $t-$resolution is essential)

## $n$ at $\theta \approx 0$: (Existing FNC, at 107m)

distinguish central $eA$ from

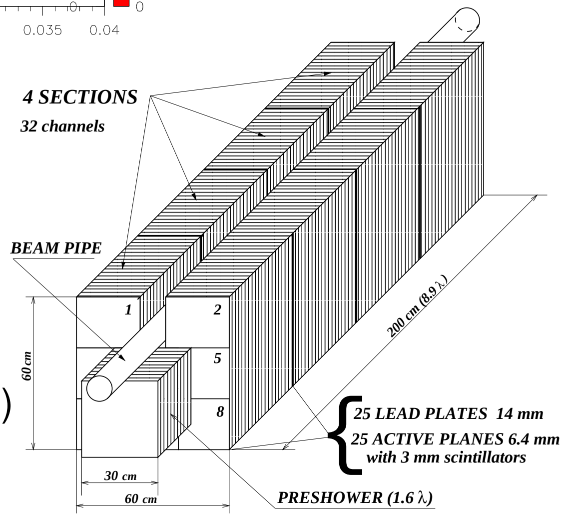
peripheral $eA$ collisions

H1 VFPS acceptance

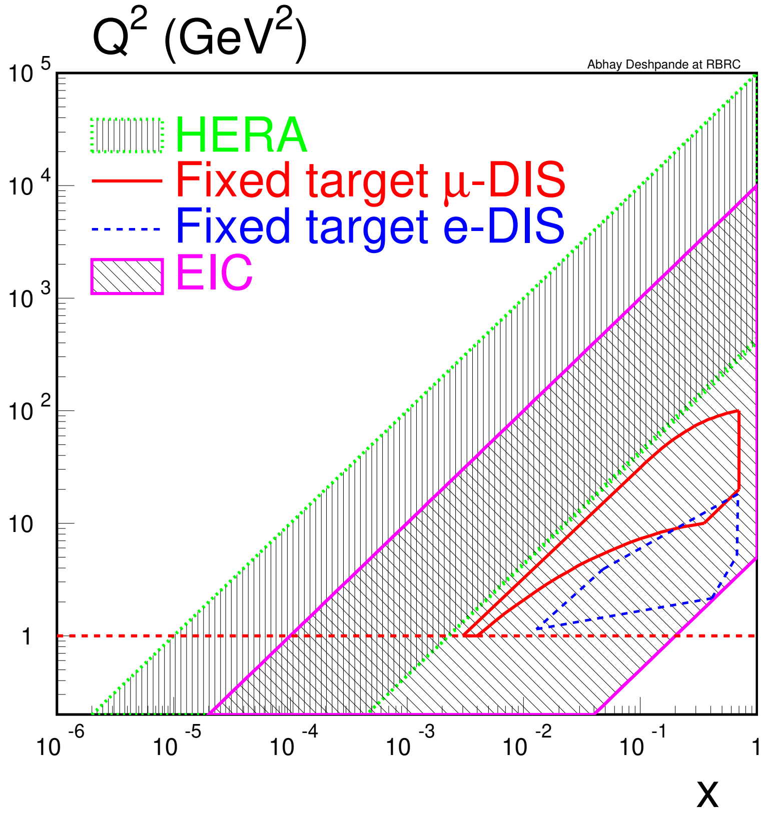


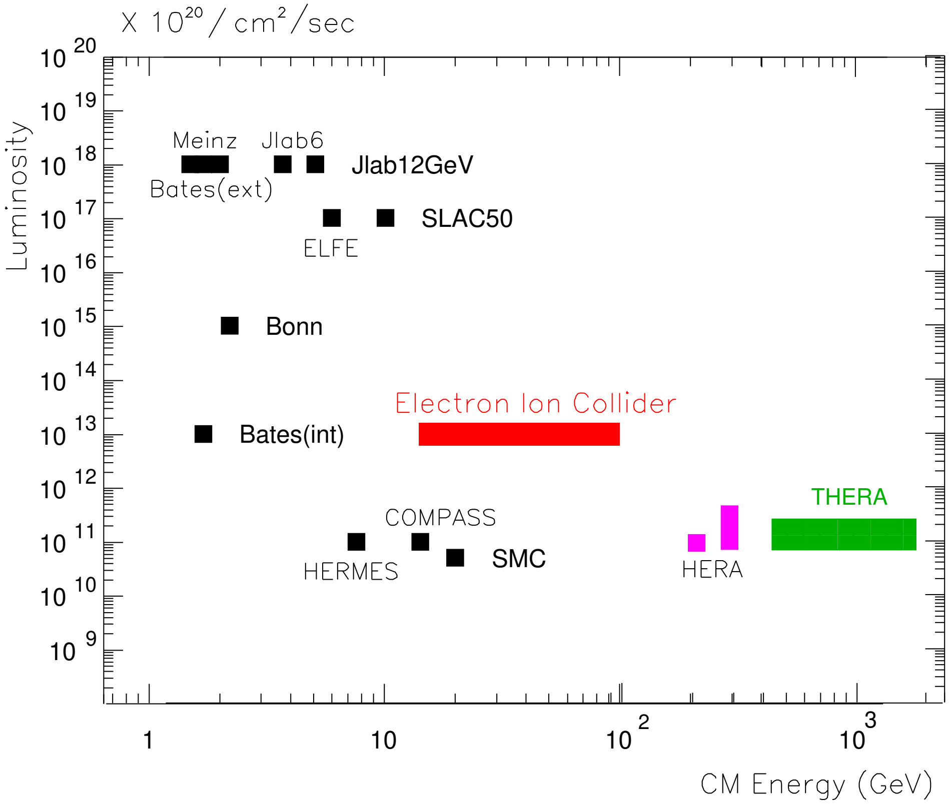

H1 FNC detector

(acceptance $\theta < 0.6$ mrad)



# eA and polarized e-p/d Experiments



# Summary

- HERA is a unique $lN$ collider, and its potential must be fully exploited

- HERA-III:
  Neutron structure and high $x$ flavor decomposition
  Spin structure of the nucleon at low $x$ and large $Q^2, x$
  QCD in a regime of weak coupling and high parton density

$$\Rightarrow \quad eD, \quad \vec{e}\vec{D}, \quad eA \; (A = O^{16}, Ca^{40})$$

- Most of the infrastructure and the apparatus are in place.
  Additional investments are moderate. LOI by the end of 2003