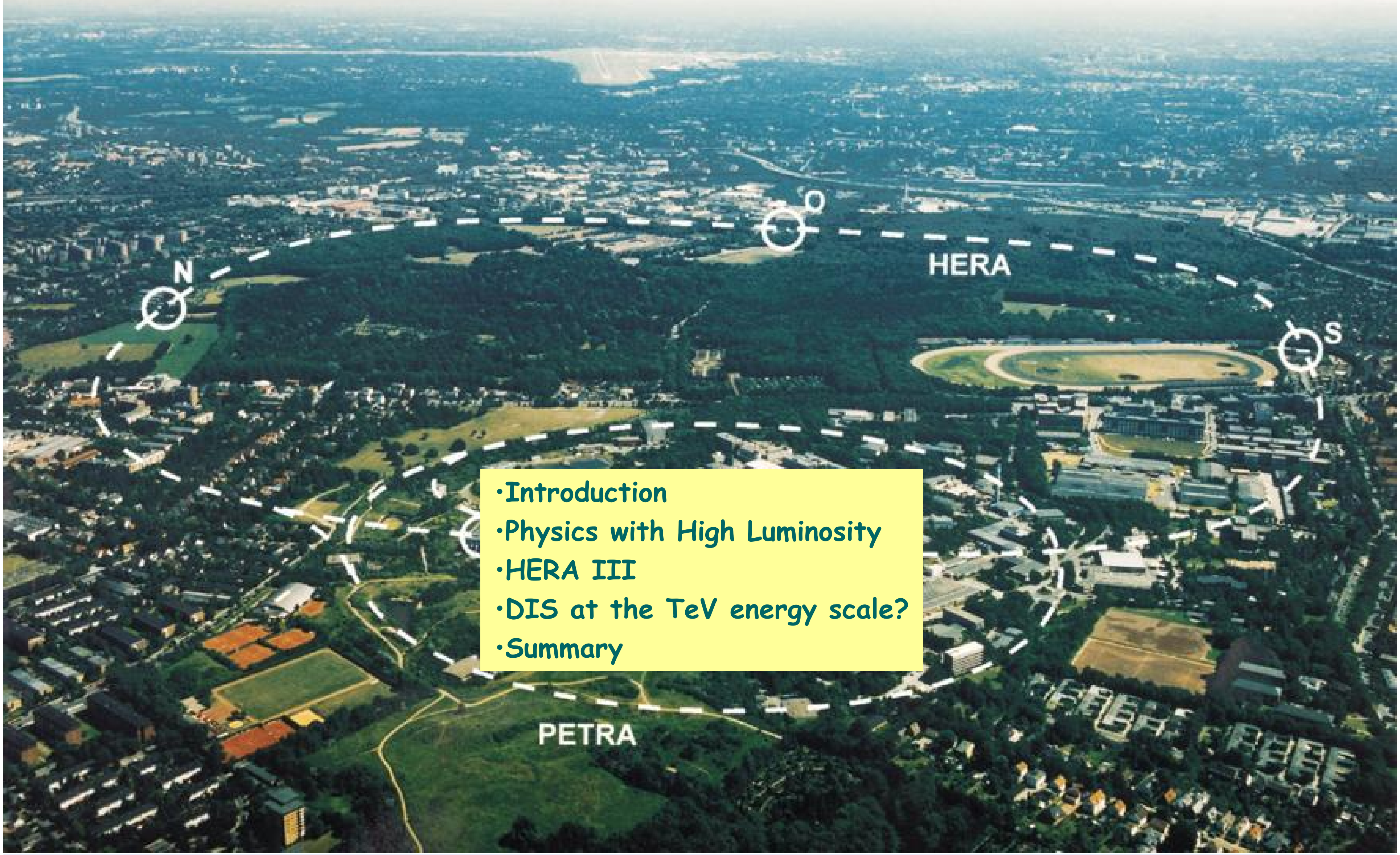
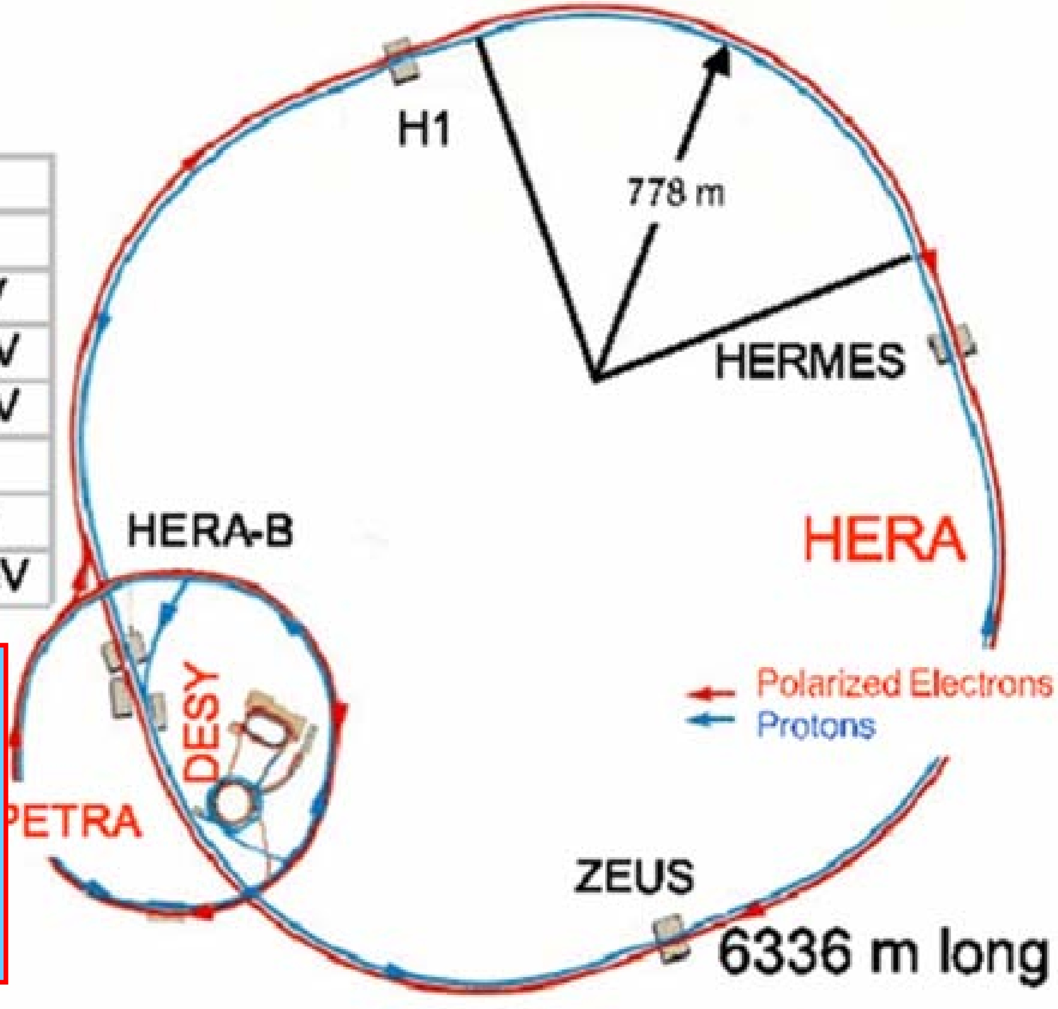
The Future of HERA and Beyond?



- Introduction
- Physics with High Luminosity
- HERA III
- DIS at the TeV energy scale?
- Summary

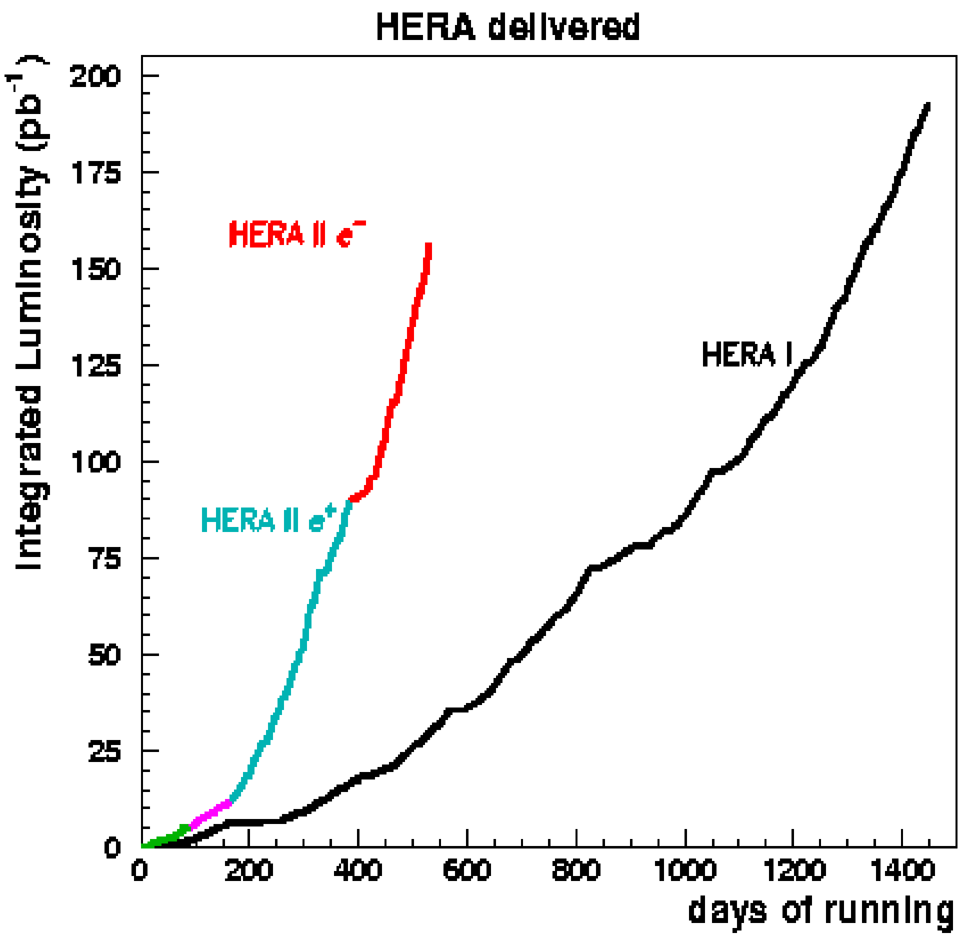
HERA and its Pre-Accelerator Chain

	Protons	Electrons	
20 keV	Source	Source	150 keV
750 keV	RFQ	Linac II	450 MeV
50 MeV	Linac III	Pia	450 MeV
8 GeV	DESY III	DESY II	7 GeV
40 GeV	PETRA	PETRA	12 GeV
920 GeV	HERA-p	HERA-e	27.5 GeV



In 2001 the DESY directorate decided to use PETRA as a 3rd generation synchrotron light source considering the HERA programme to be exploited by 2006 and TESLA to be the next accelerator project of the laboratory.

HERA II has started



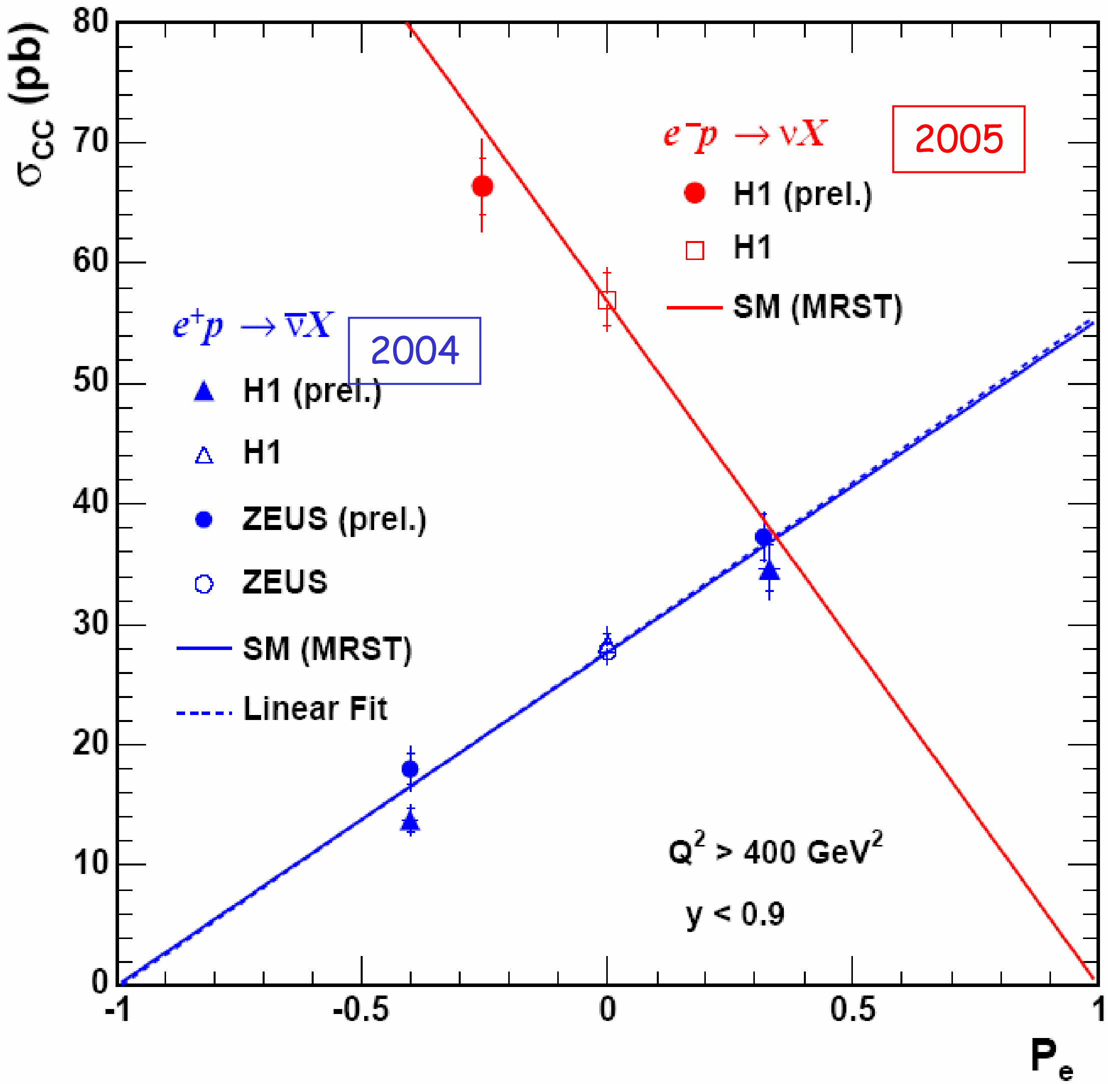
Status 29.4.05 – yesterday: the first HERA day with 1pb^{-1} HV on for ZEUS

- HERAI: H1 and ZEUS took about 130pb^{-1} with HV on
- 2002/03 background problems
- 2004: positrons (50 pb^{-1})
- 2005: so far 30 (H1) 50 (ZEUS)
- Specific Luminosity tripled (I → II)
- Luminosity sum of polarised data is so far 10 times below the final goal.

for HERAII programme see also:

- F. Eisele, R. Yoshida talks at HERA-LHC Workshop March 05
- Ringberg Workshop (2003) Proceedings ed by G.Grindhammer, B.Kniehl, G.Kramer

First Measurements of the helicity dependence of the CC cross section



$$\sigma_{e^+ p \to \bar{\nu} X}(P_{e^+} = -1) = 0.2 \pm 1.8(sta) \pm 1.6(sys)\, pb$$

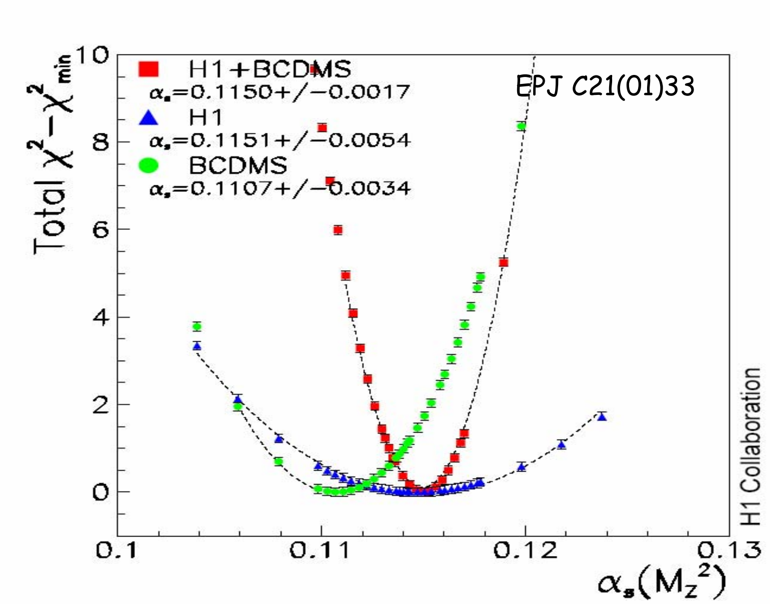
F.Willeke HERA LHC workshop 3/05

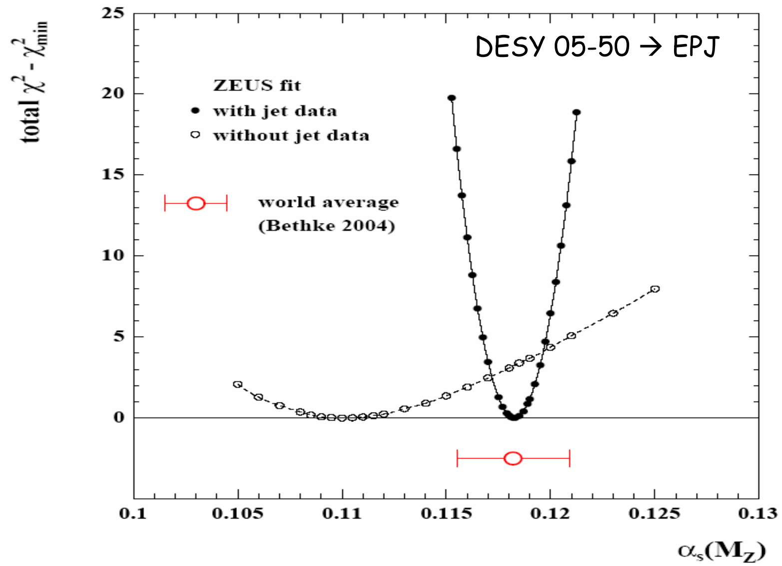
HERA Improvement Program:

rich program with 70 items defined in 2003, program well underway, the most important ones being:

BU Magnet Refurbishing	→ next/last shutdown moved to 11/05		1.0 M€
Proton RF Systems	Improved low-level controls Suppression of long. Instability	2/2/.5 PJ	0.55 M€
Diagnostics Systems	improved monitors (BPM, SR)	1./0.3/0.1 PJ	0.15 M€
Vacuum System	better pumping in RF sections	0/0.5/1.0PJ	0.5 M€
Power Supply Systems	add'l Ps for spin matching	0 /0.3/0.2 PJ	0.2 M€
e-RF Systems	RF Modulator upgrade	0/0.5/.95 PJ	0.13 M€
Cryogenic Systems	compressor and controls upgr.	0 /0.5/1.5 PJ	0.45 M€
Summe:	**14.6 PJ @ 0.605 M€** (add'l only)		**1.13 M€**

HERA has the potential to determine the world average of α_s

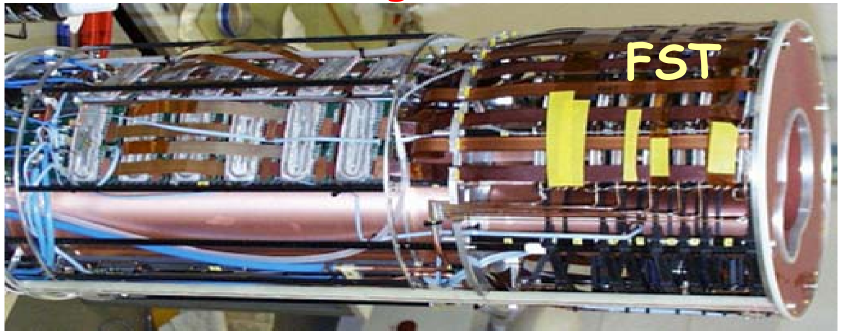


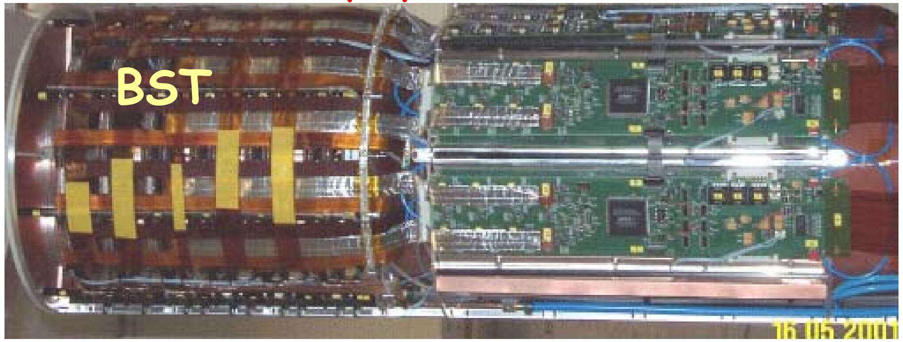


<HERA> 0.1186 ± 0.0011 (exp) ± 0.0050 (thy)

- More and more accurate data (luminosity, instrumentation, analyses of data and of all uncertainties (HQ, low x, ..)
- Determines PDF's better
- Cross calibration of ZEUS - H1
- Inclusive and Jets – an issue??
- use/need NNLO – what is δμ?
- Deuterons would disentangle nonsinglet – singlet evolution and halve alpha_s error

New tracking detectors of H1 and ZEUS for HF physics in HERA II



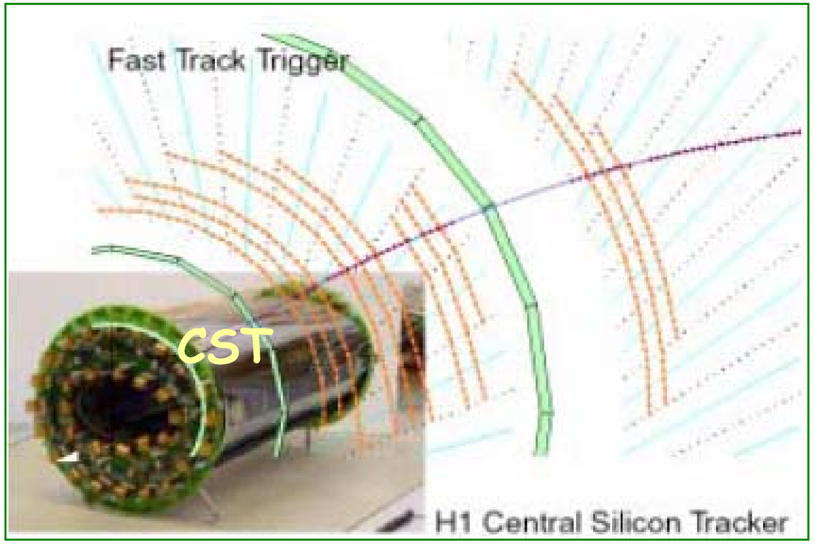


charm and beauty

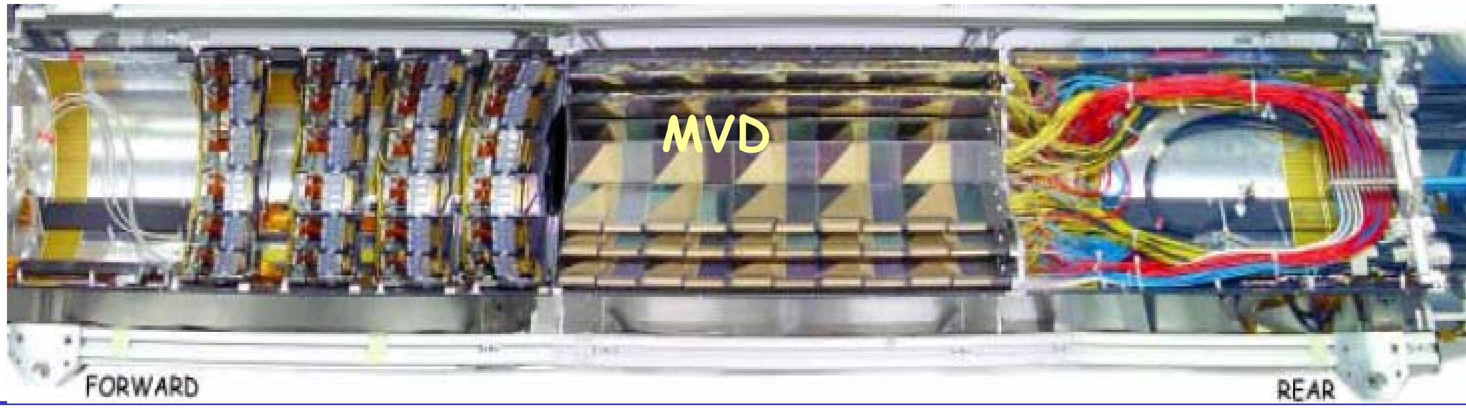
evt vtx (lo and hi y)

eID (DVCS, J/Ψ, searches)

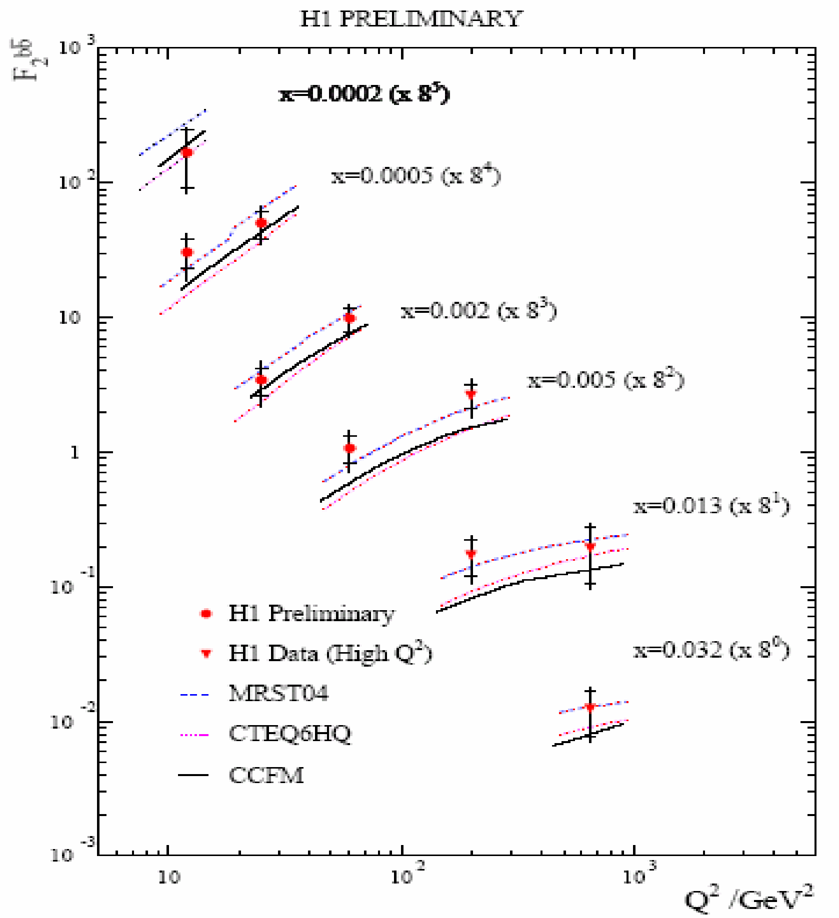
F_L



Huge investments for high lumi phase by H1 and ZEUS – also STT, FTD



Measurements of heavy quark distributions and HQ physics



Beauty and charm physics at HERA requires high luminosity (400 pb^{-1})

c(x,Q2), b(x,Q2)

QCD near and beyond threshold

c and b jets

fragmentation

J/Ψ and the gluon distribution

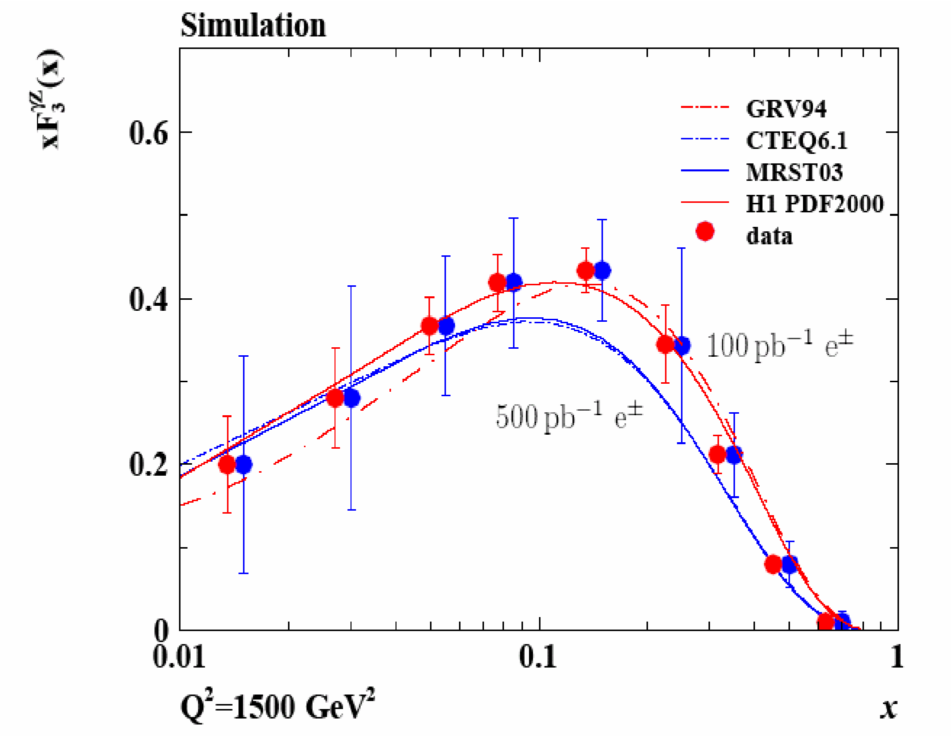
…

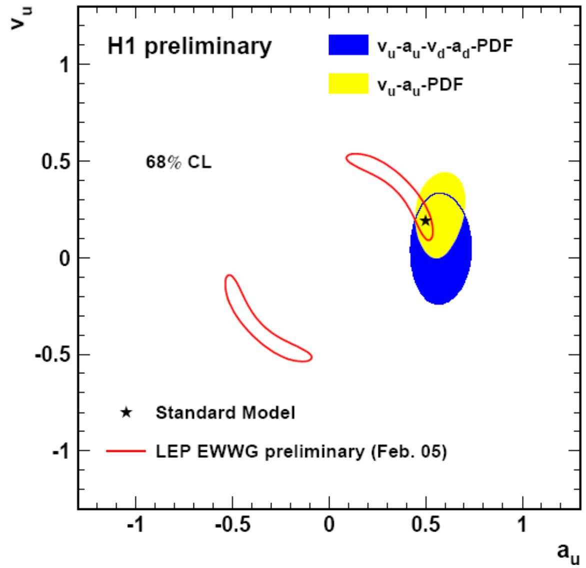
→ Lifetime based, small extrapolations for c and b, high luminosity, extend to fwd/bwd regions

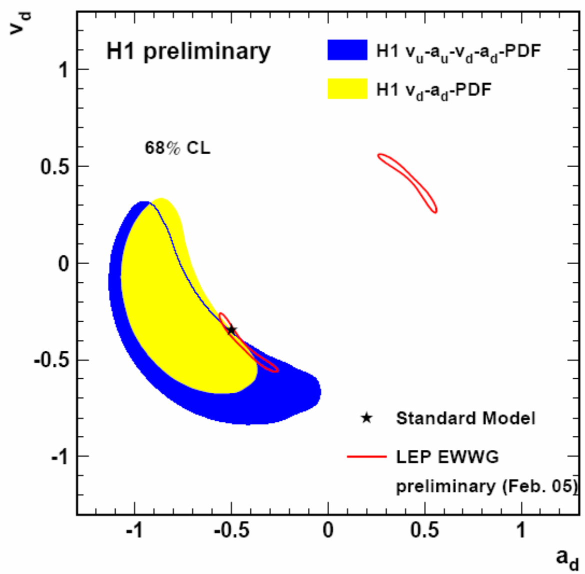
Electroweak Physics at HERA

light quark weak neutral current couplings

using Z exchange to access 2uv+dv and
possible sea quark asymmetry at lower x





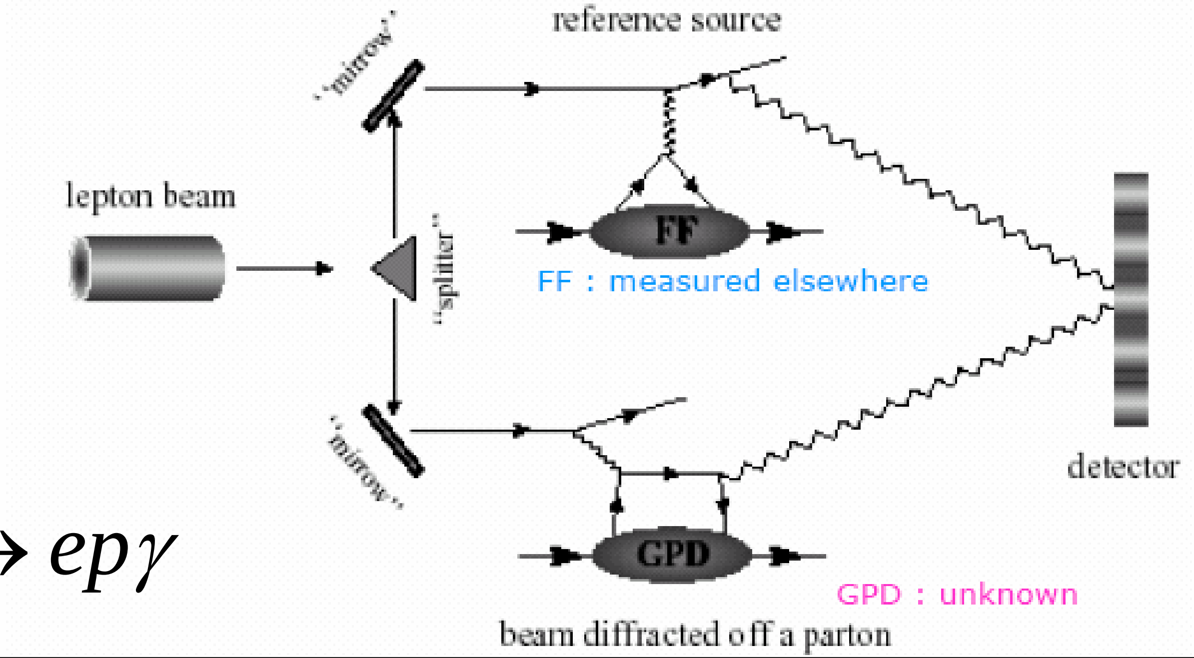


Deeply Virtual Compton Scattering

[V.Belitsky, D.Müller,hep-ph/0206306]

nucleon hologram with leptoproduction: interference of Bethe-Heitler (reference) and DVCS (sample) amplitudes

map transverse proton size: access parton amplitudes (GPD)

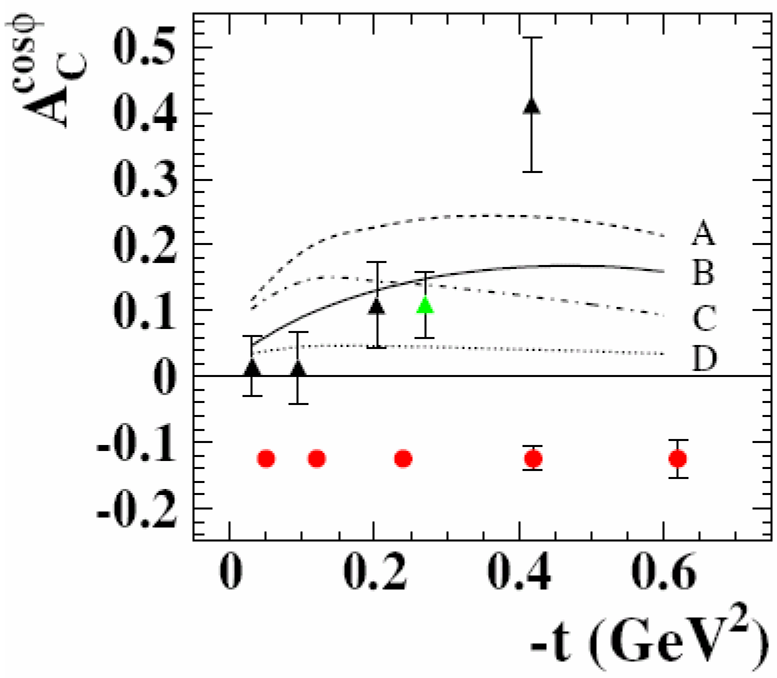


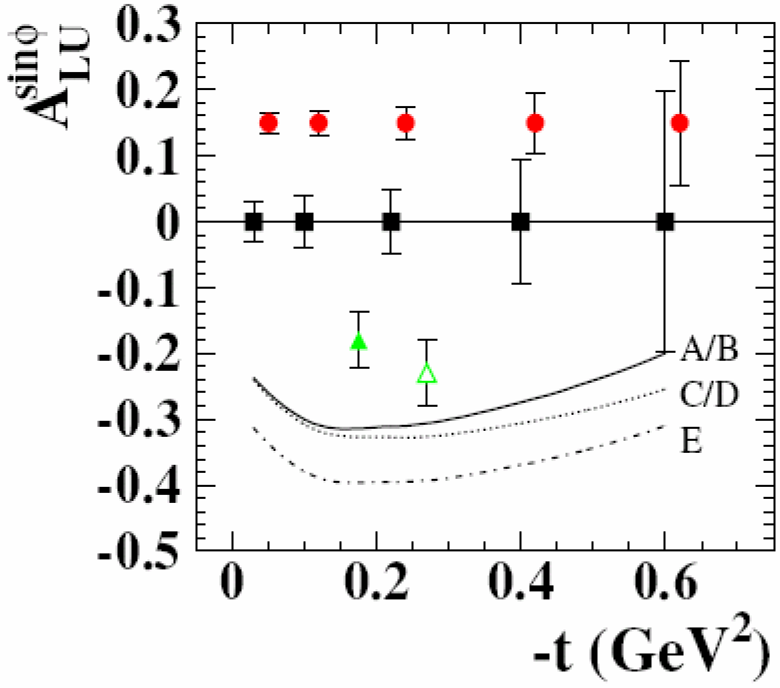
$$ep \rightarrow ep\gamma$$

HERMES detector to tag recoiling proton in DVCS

Silicon - scintillating fibre detector, currently under test at DESY

HERMES for 06-07: t, x, Q^2 dependence of charge and spin asymmetries





Multidimensional measurements
x 0.04-0.4, Q^2 1-8 GeV^2
2 years of running $e^\pm$ polarised
mainly off protons

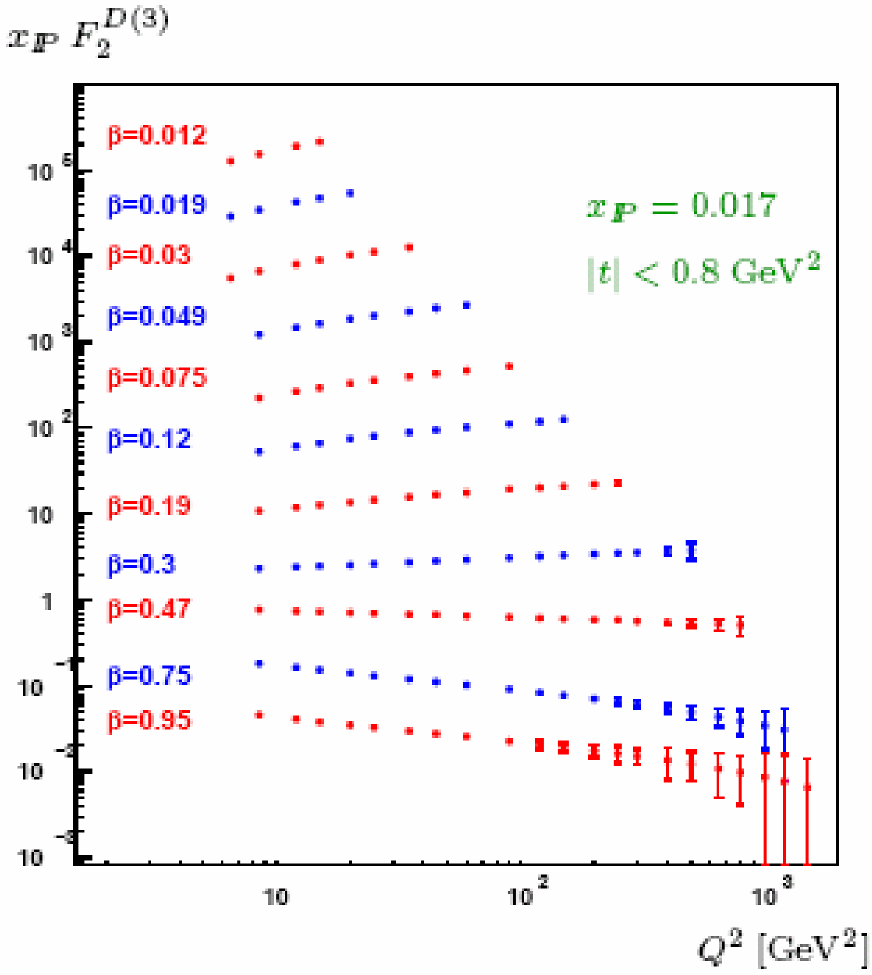
→ **constrain GPD's**

(A,B,C,D: Vanderhaegen et al)

DVCS with H1 and ZEUS
improved cross section, t
and new asymmetry
measurements at low x (high
luminosity required)

Inclusive diffraction – p tagged (FPS/VFPS) and untagged

Predicted $F_2^{D(3)}$ for 350 pb^{-1} (50% VFPS operation efficiency over 3 years)



10^6 Events for $Q^2 > 5$ GeV^2

$\longrightarrow$ Study t dependence

$\longrightarrow F_2^{D(4)}(Q^2, \beta, x_{I\!P}, t)$

Uncorrelated systematic errors can reach 2-3 % (similar to F_2 precision)

$\longrightarrow$ Extract diffractive pdf's at fixed $x_{I\!P}$ and t and predict final states at same $x_{I\!P}$ and t to test factorization theorem

HERA-LHC Workshop, 21th April 2005

Xavier Janssen

- Parton dynamics at high densities

- Event shapes

- Diffractive factorisation ?

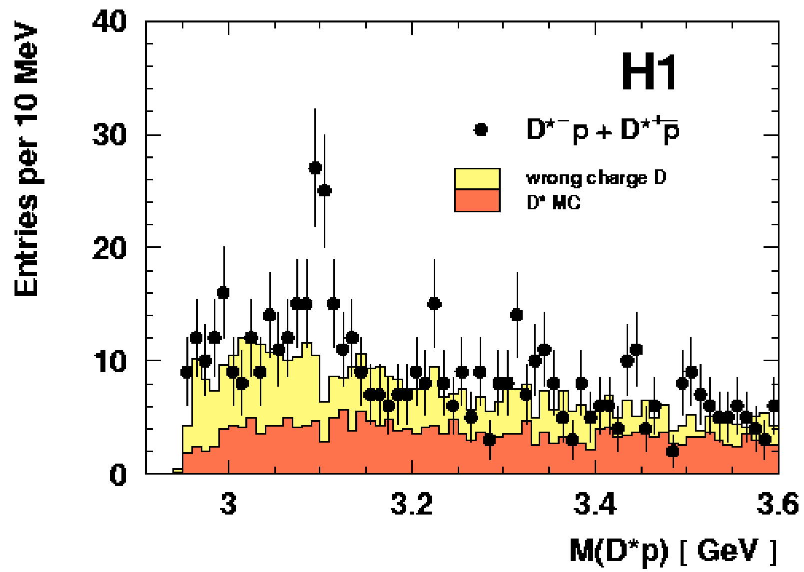
- Forward jets and azimuthal decorrelations ?

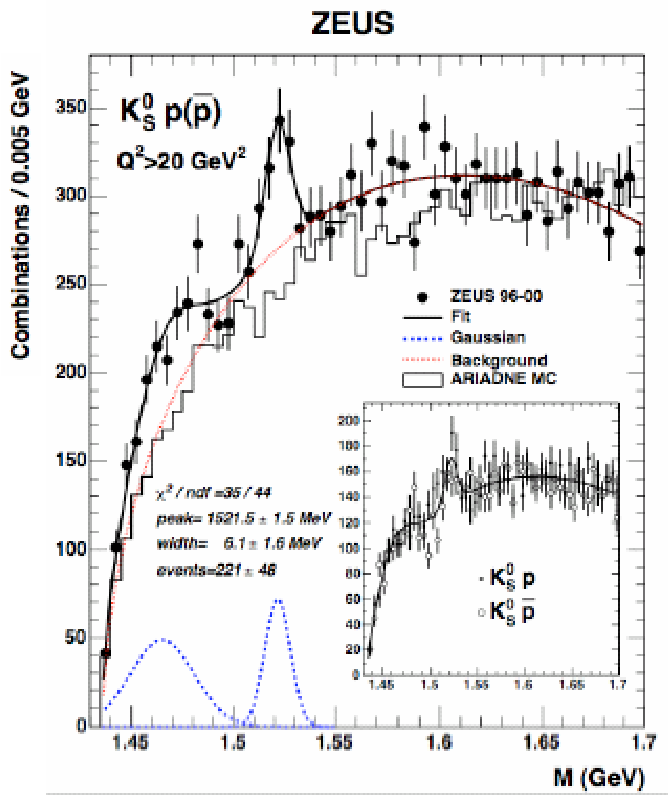
- Unintegrated parton distributions

→ important for QCD and the understanding of the LHC data . DGLAP at low x??

- Searches for exotics beyond the SM

Clarification of exotic puzzles

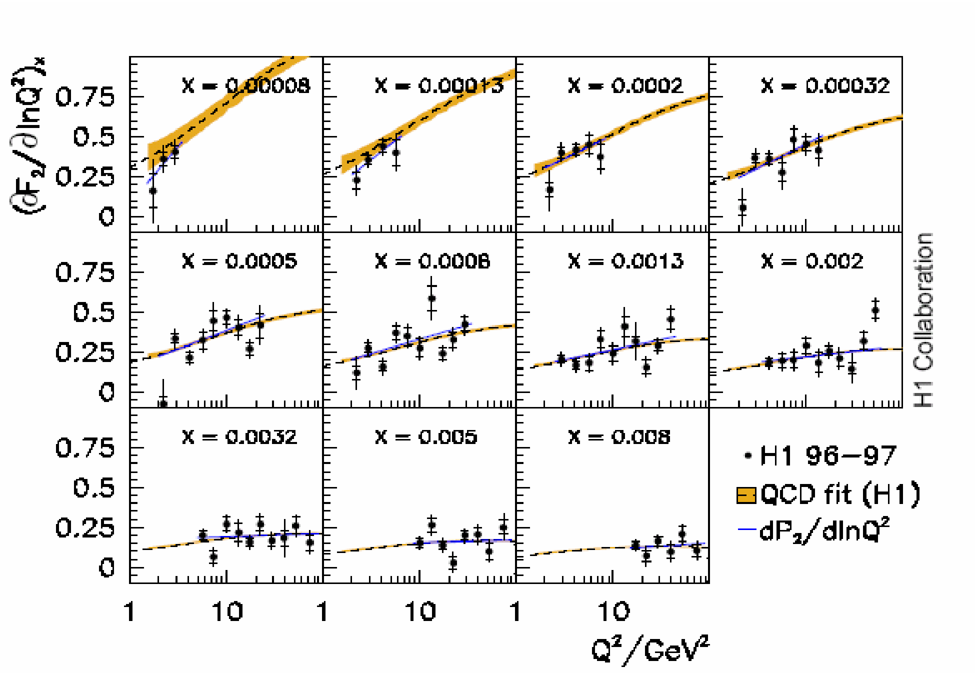




H1 Preliminary 1994-2005 $e^{\pm}p$ 192 pb^{-1}	Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
Full Sample	25 / 18.3 ± 2.5 (70%)	9 / 4.8 ± 0.8 (85%)	34 / 23.1 ± 3.2 (73%)
P_T^X > 25 GeV	11 / 3.0 ± 0.6 (81%)	6 / 3.0 ± 0.6 (86%)	17 / 6.0 ± 1.1 (84%)

ZEUS: 7 / 5.7 (HERA I)

Running at lower energy?



$$\sigma_r = F_2 - y^2 F_L$$

$$y \approx 1 - \frac{E_e'}{E_e}$$

reduce E_p
to keep y high

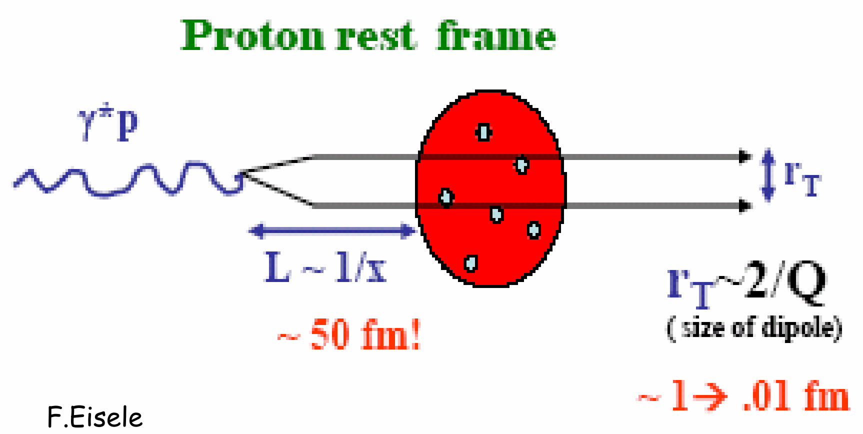
•F2 (derivative) to be measured more accurately and to be confronted with FL data

•Genuine test of QCD at low x to higher order (dF2~P x g and FL~P x g – is g the same? C. Gwenlan)

•Possibilities of low Ep running will be evaluated [FL needs 30-50pb-1 luminosity equivalent]

•Low energy run interesting for more than FL: energy dependence of cross sections, high x

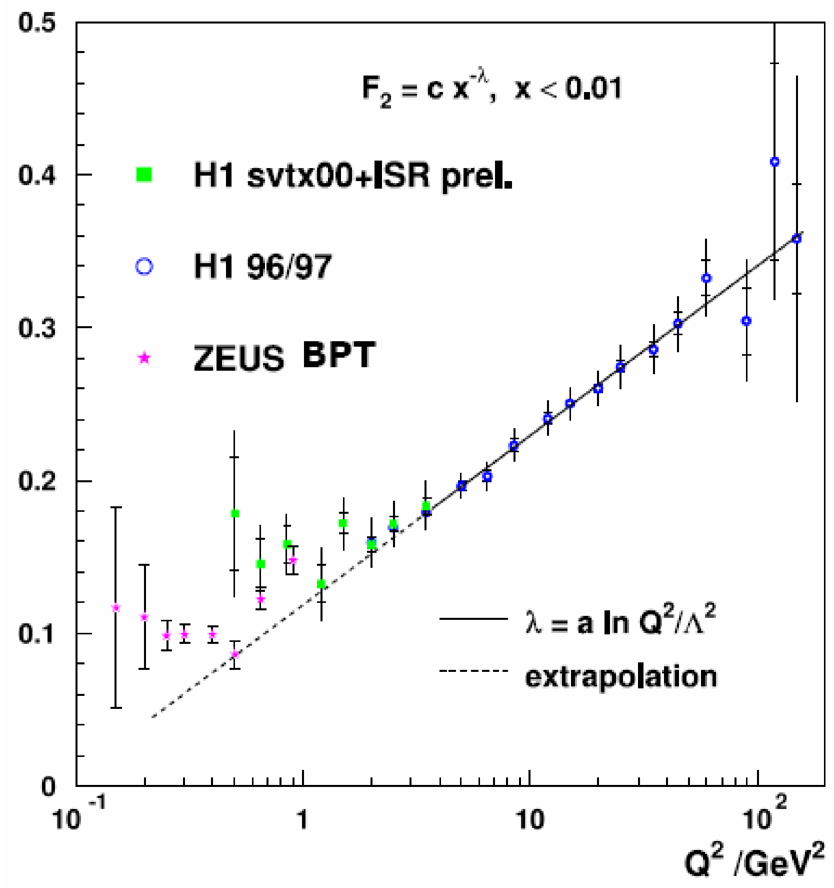
Low x Precision Measurement at HERA III



At low x<0.01 a color dipole of variable size 2/Q interacts with the proton at high CM energy $s^{\gamma p} = W^2 \approx Q^2/x \approx 1000 \div 90000\ GeV^2$

Low x = high energy scattering!

Q^2 steers the transition from hard collisions (perturbative QCD) to soft hadron physics.

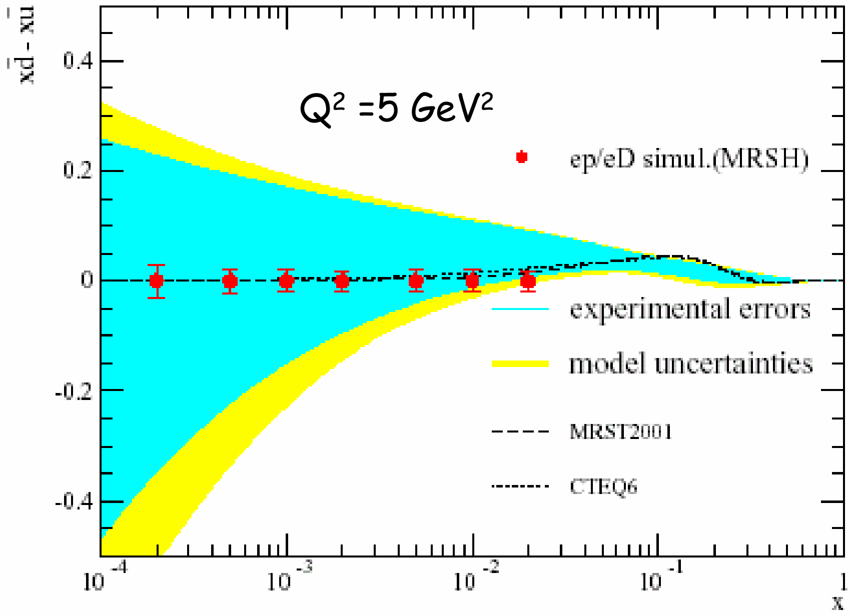


Precision measurements of F_L, VM Diffraction, Saturation.?

For $Q^2 < 5$ will not be able to get much better result. Yet, at 0.3 fm partons become 'observable' – a so far lost opportunity

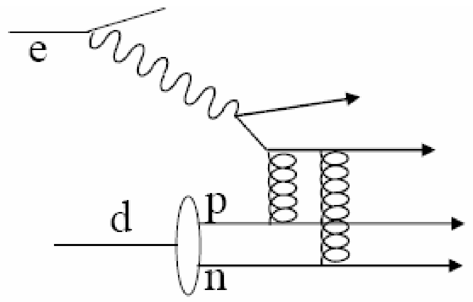
Electron-Deuteron Scattering at HERA III

simulated accuracy ($20pb^{-1}$ eD, 40 ep)

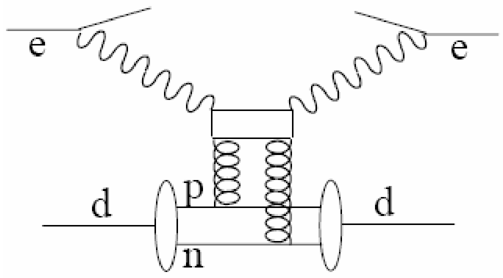


Sea asymmetry: important for astrophysics, LHC, to know.

Glauber-Gribov shadowing is related

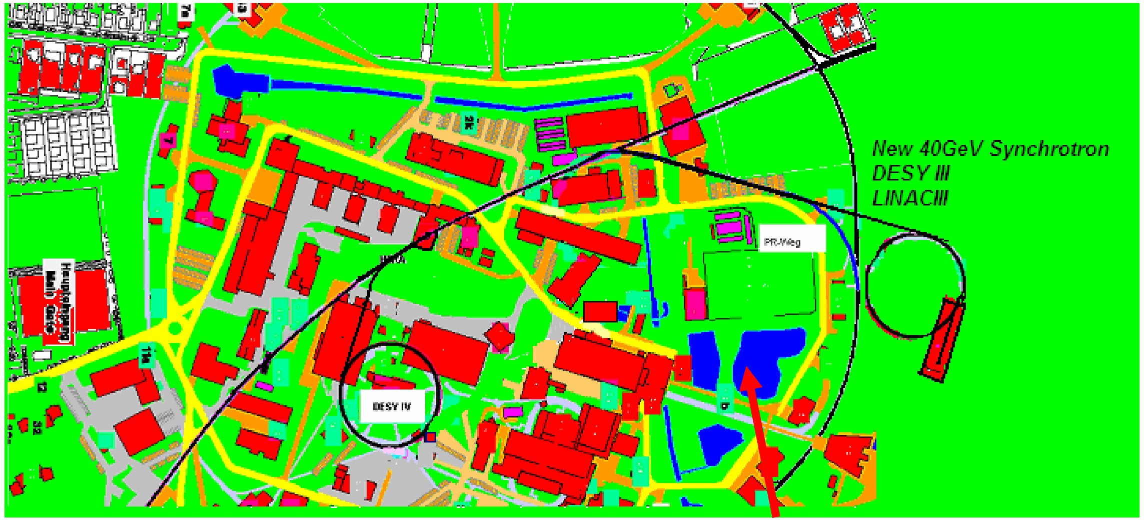


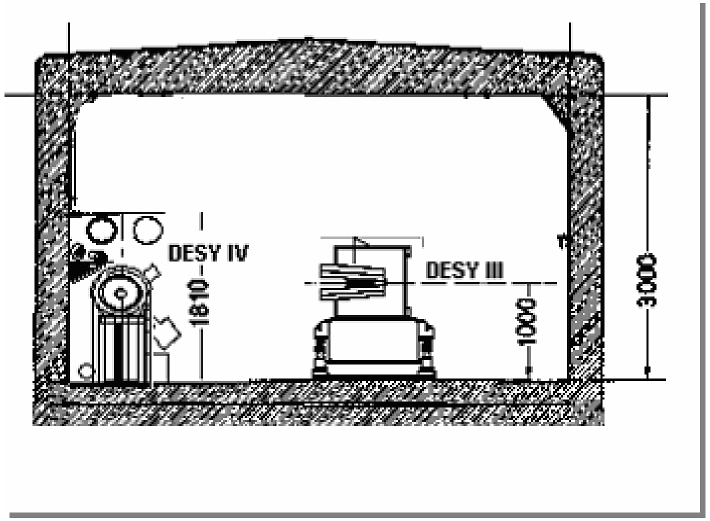
to diffraction



Could tag proton accurately and reconstruct en cross section 'free' of nuclear corrections

HERA beyond 2007 would require new injectors





Possible site for a new HERA p-injector

F. Willeke at DIS04

Preliminary ideas:

- Direct injection from DESY II into HERA-e (alternatively via a damping ring in the DESY tunnel)
- New tunnel for DESY III and a new superconducting 40GeV Proton Booster

HERA will be untouched, but HERA III misses human and financial resources

• Madison 1980 Leon Lederman in the future HEP panel

“two problems: shortage of money and overconfidence of theorists” and one question: what is the origin of the black force (Star Wars I - Mad1980)

Leon's one question may be resolved on May 19th

But the problems remain

We seem to need more money
Theorists believe firmly (?) in something else

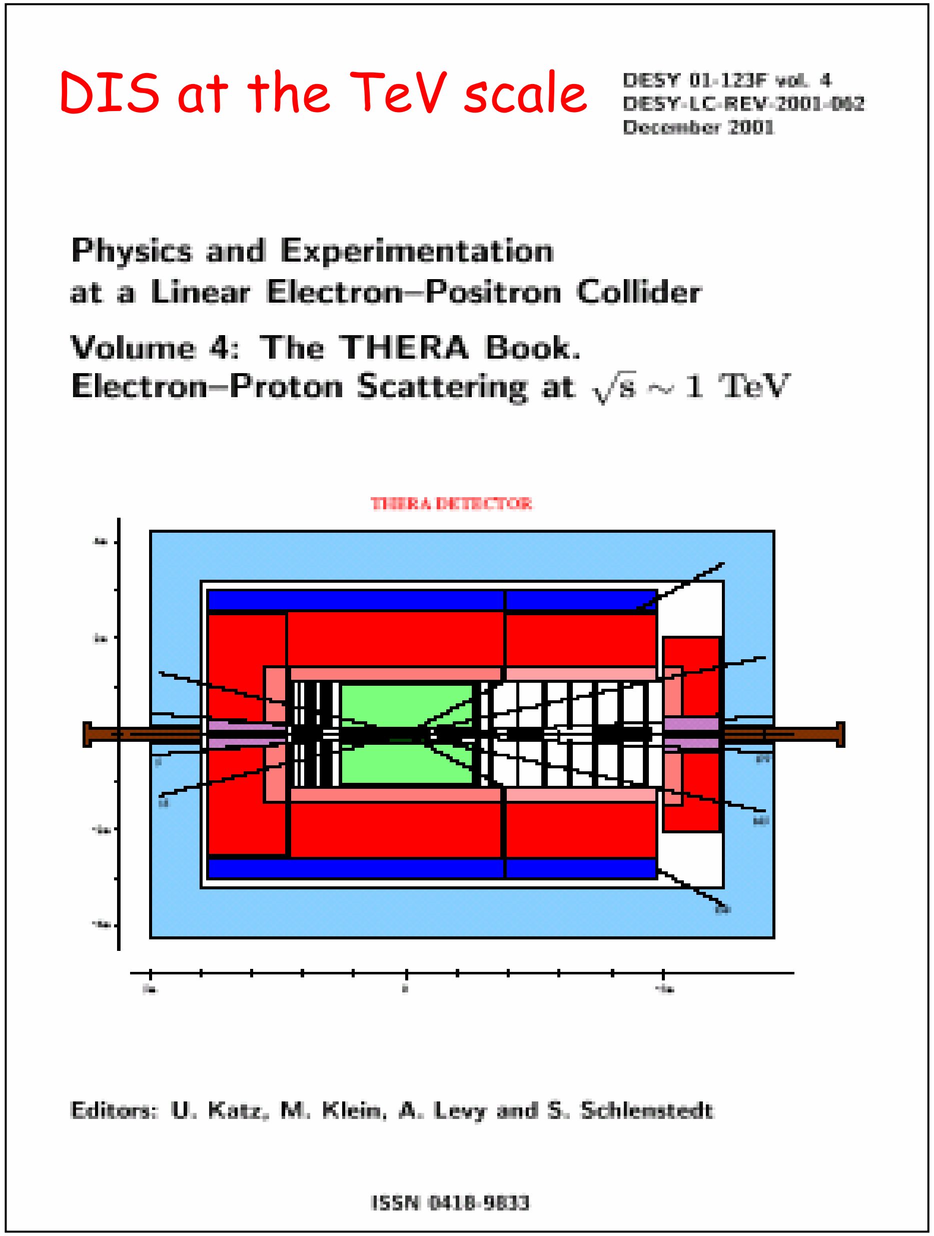
and the whole HEP field is in a state of change
which implies danger and chance at the same time

Parton interaction discoveries at the energy frontier*)

1970	→	2000	→	2015
DIS: Bjorken scaling – QPM, PV neutral currents scaling violations – QCD		high parton densities diffraction		?
e+e-: J/Ψ gluons – 3jet events		three neutrinos electroweak theory		… ILC
hh: open charm, W,Z,bottom quark		top quark		LHC …

the standard model emerged as a result of decades of joint research in e+e-, ep, hh accelerator experiments including quark and neutrino mixing

*) incomplete


DIS at the TeV scale

DESY 01-123F vol. 4
DESY-LC-REV-2001-062
December 2001

Physics and Experimentation
at a Linear Electron–Positron Collider

Volume 4: The THERA Book.
Electron–Proton Scattering at $\sqrt{s} \sim 1$ TeV

Editors: U. Katz, M. Klein, A. Levy and S. Schlenstedt

ISSN 0418-9833

LEP-LHC

A. Verdier LHC Workshop Aachen 90, p.820
E. Keil LHC Project Report 93 (1997)

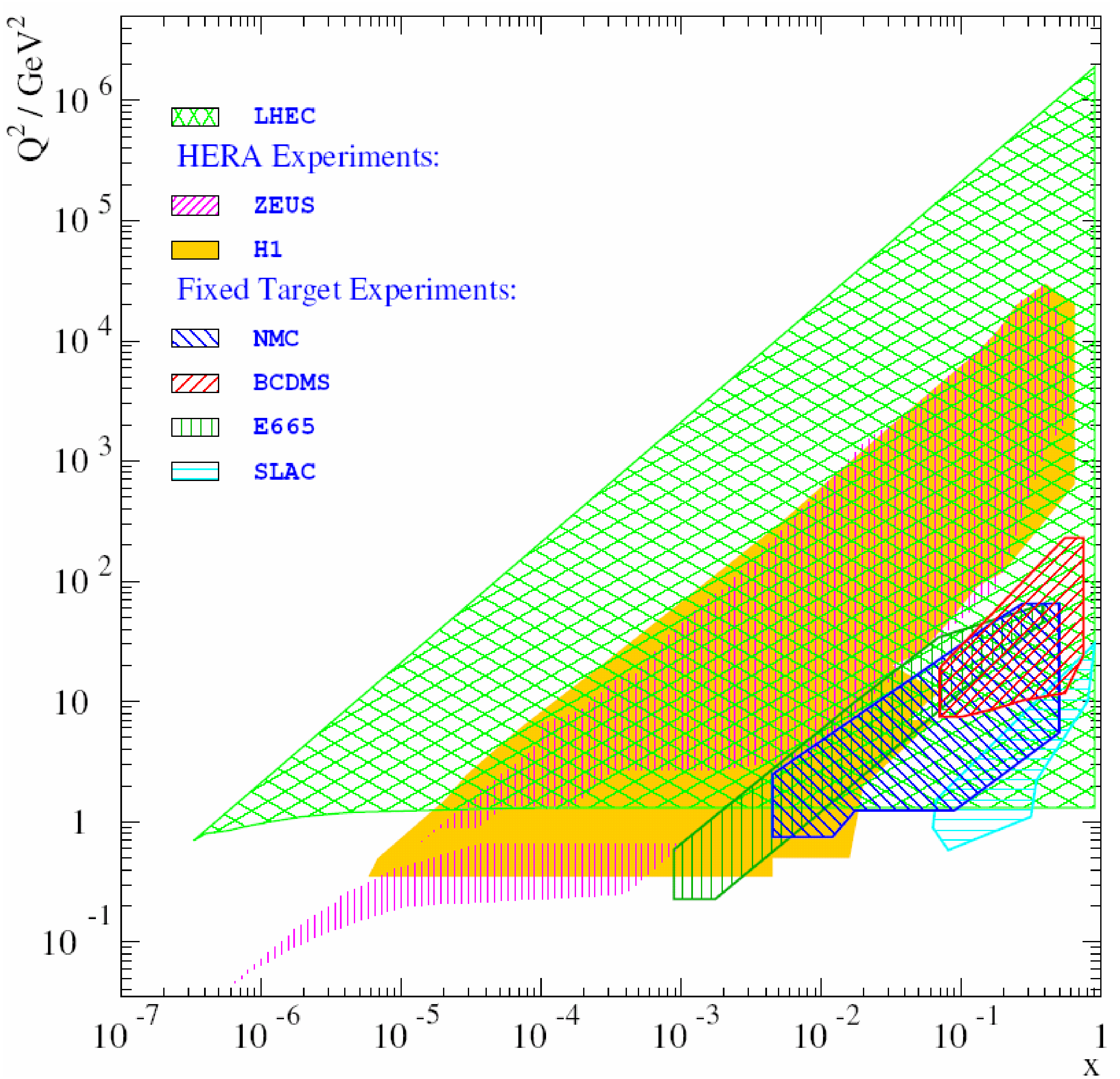
R. Brinkmann, F. Willeke THERA book
and Proceedings Snowmass 2001

QCD explorer (CLIC-LHC')

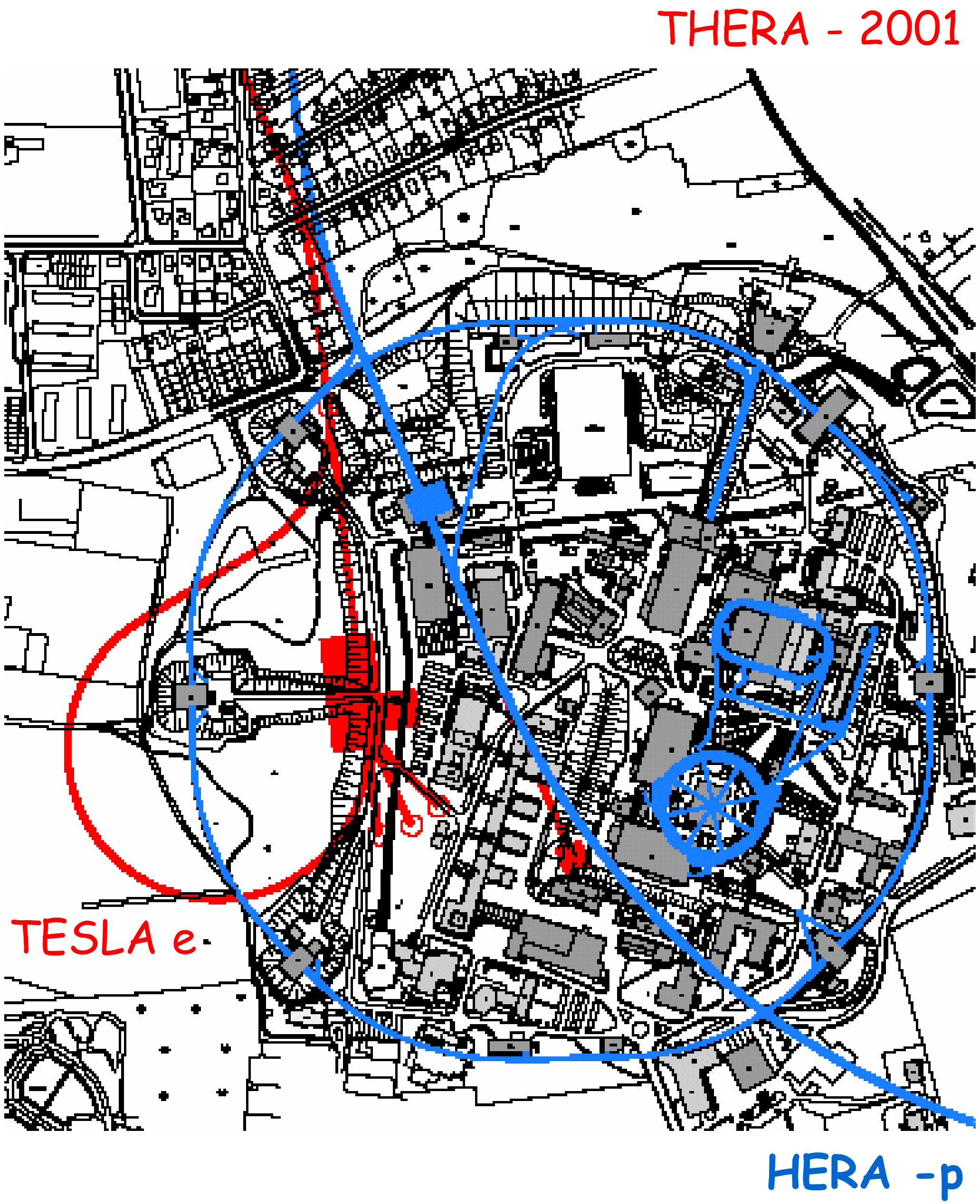
D. Schulte, F. Zimmermann CLIC 608

LHEC F. Willeke (a study)

All these ep options are 'cost effective'



Q^2 / GeV^2
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
LHEC
HERA Experiments:
ZEUS
H1
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
1
x



√s up to 2TeV
x down to 10^{-6} in DIS region

e can be highly polarised
→ LQ spectroscopy

Peak luminosity up to 4 10^{31}
depending on Ee=Ep
and IR layout (dynamic focus)
note: I(e) is constant with time
[40 .. 200 pb-1 per year, 50%]

Cavities will be cold:
-standing wave type: acc. in
both directions to double E(e)
-time structure of few 100ns fits
to HERA and Tevatron bc time

→THERA or ILC-Tevatron
remain possible

CERN-AB-2004-079
CLIC Note 608

QCD EXPLORER BASED ON LHC AND CLIC-1

D. Schulte, F. Zimmermann
CERN, Geneva, Switzerland

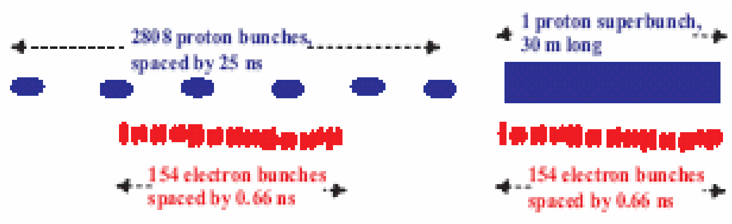
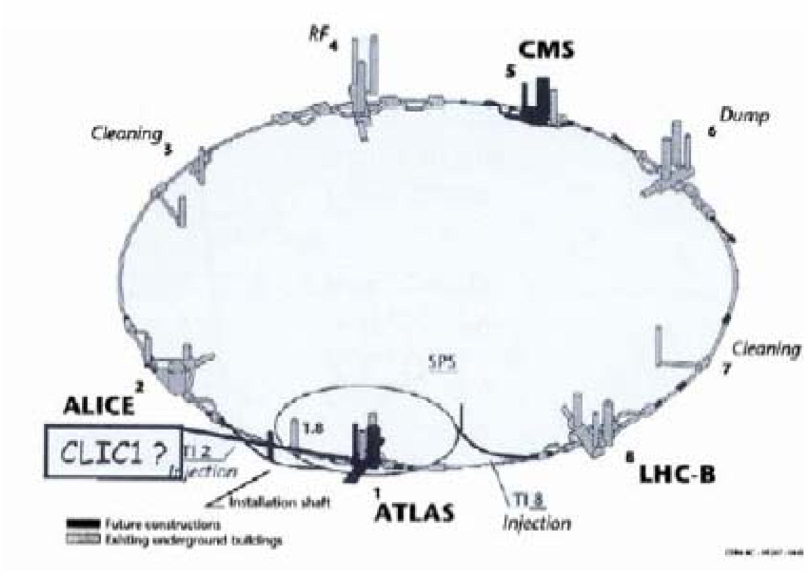


Figure 1: Bunch filling patterns in LHC and CLIC for the nominal LHC (left) and with an LHC superbunch (right).

Upgraded LHC and CLIC



$1.1\ 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

Table 1: Beam Parameters

parameter	symbol	electrons	protons
beam energy	E_b	75 GeV	7 TeV
bunch population	N_b	4×10^9	6.5×10^{13}
rms bunch length	σ_z	35 μm (Gaussian)	12.4 m (uniform)
bunch spacing	L_{sep}	0.66 ns	N/A
number of bunches	n_b	154	1
effective line density	λ	2.0×10^{10} m^{-1}	2.1×10^{12} m^{-1}
IP beta function	$\beta^*_{x,y}$	0.25 m	0.25 m
spot size at IP	$\sigma_{x,y}$	11 μm	11 μm
full interaction length	l_{IR}	2 m	
norm. rms emittances	$\gamma\epsilon_{x,y}$	73 μm	3.75 μm
collision frequency	f_{coll}	100 Hz	
luminosity	L	1.1×10^{31} cm^{-2}s^{-1}	
beam-beam tune shift	$\xi_{x,y}$	N/A	0.004

L perhaps higher with TESLA cavities
(L. Gladilin et al., hep-ph/0504008)

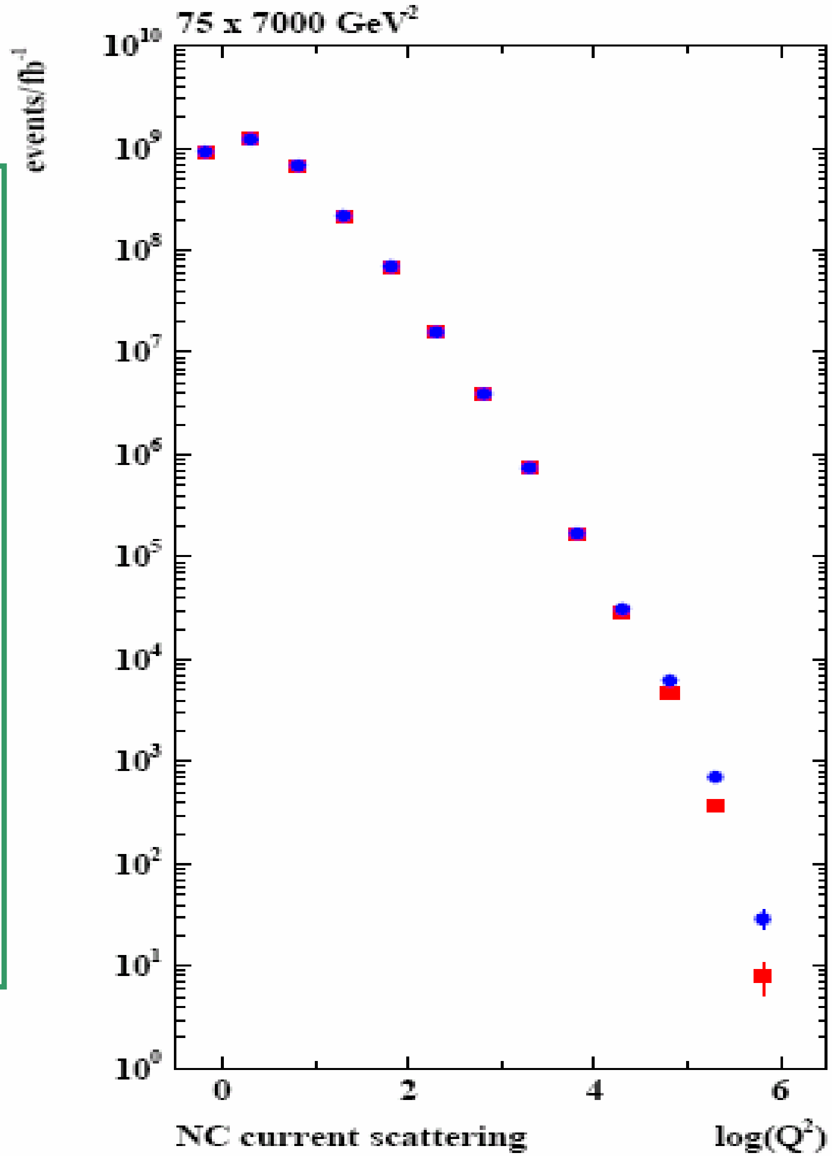
The challenge for ep (HEP) to conquer the TeV scale is the luminosity

•Low and medium x:

needs energy and acceptance but easy for luminosity

NOTE: can do eA at THERA and LHEC (RHIC, ALICE)

- bb limit
- nuclear pdf's
- CGC



High x and Q^2 can only be accessed with a collider with peak luminosities of $\sim 10^{32}$ cm^{-2} s^{-1}

A tentative lattice study – a new electron ring on top of the LHC

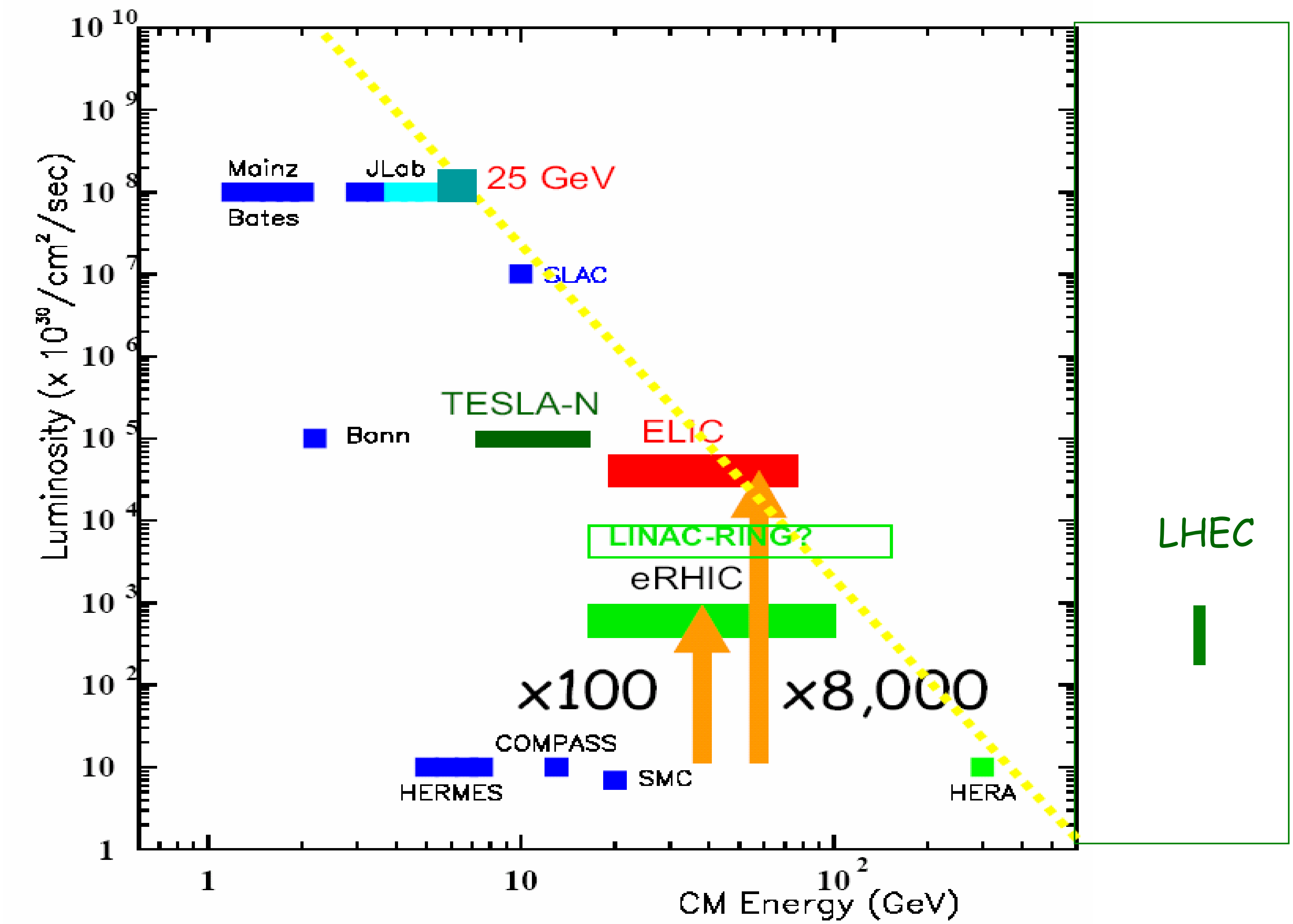
Design to be studied further and discussed with CERN

Beam Energies	$E_p = 7\times 10^3\,\mathrm{GeV}$	$E_e = 75\,\mathrm{GeV}$
Beam Currents	$I_p = 566.6\ \mathrm{mA}$	$I_e = 49.77\ \mathrm{mA}$
Emittance	$\varepsilon_{Np} = 4\,\mu\mathrm{m}$	$\varepsilon_{xe} = 18\,\mathrm{nm}$
β^*	$\beta_{xp} = 1.8\,\mathrm{m}$	$\beta_{xe} = 0.055\,\mathrm{m}$
	$\beta_{yp} = 0.5\,\mathrm{m}$	$\beta_{ye} = 0.055\,\mathrm{m}$
p Bunch Length	$\sigma_s = 7\,\mathrm{cm}$	
Synchrotron Radiation Power		$P_{erf} = 60\,\mathrm{MW}$
beam-Beam Tuneshift	$\Delta\nu_{xp} = 1.69\times 10^{-3}$	$\Delta\nu_{xe} = 0.019$
	$\Delta\nu_{yp} = 3.21\times 10^{-3}$	$\Delta\nu_{ye} = 0.037$
Crossing Angle	$\theta_c = -2.5\,\mathrm{mr}$	
Hourglass factor	$R(\sigma_s) = 0.925$	
Center of Mass Energy	$E_s = 1.449\,\mathrm{TeV}$	
Peak Luminosity	$L_{peak} = 2.40\times 10^{32}\,\mathrm{sec}^{-1}\cdot\mathrm{cm}^{-2}$	

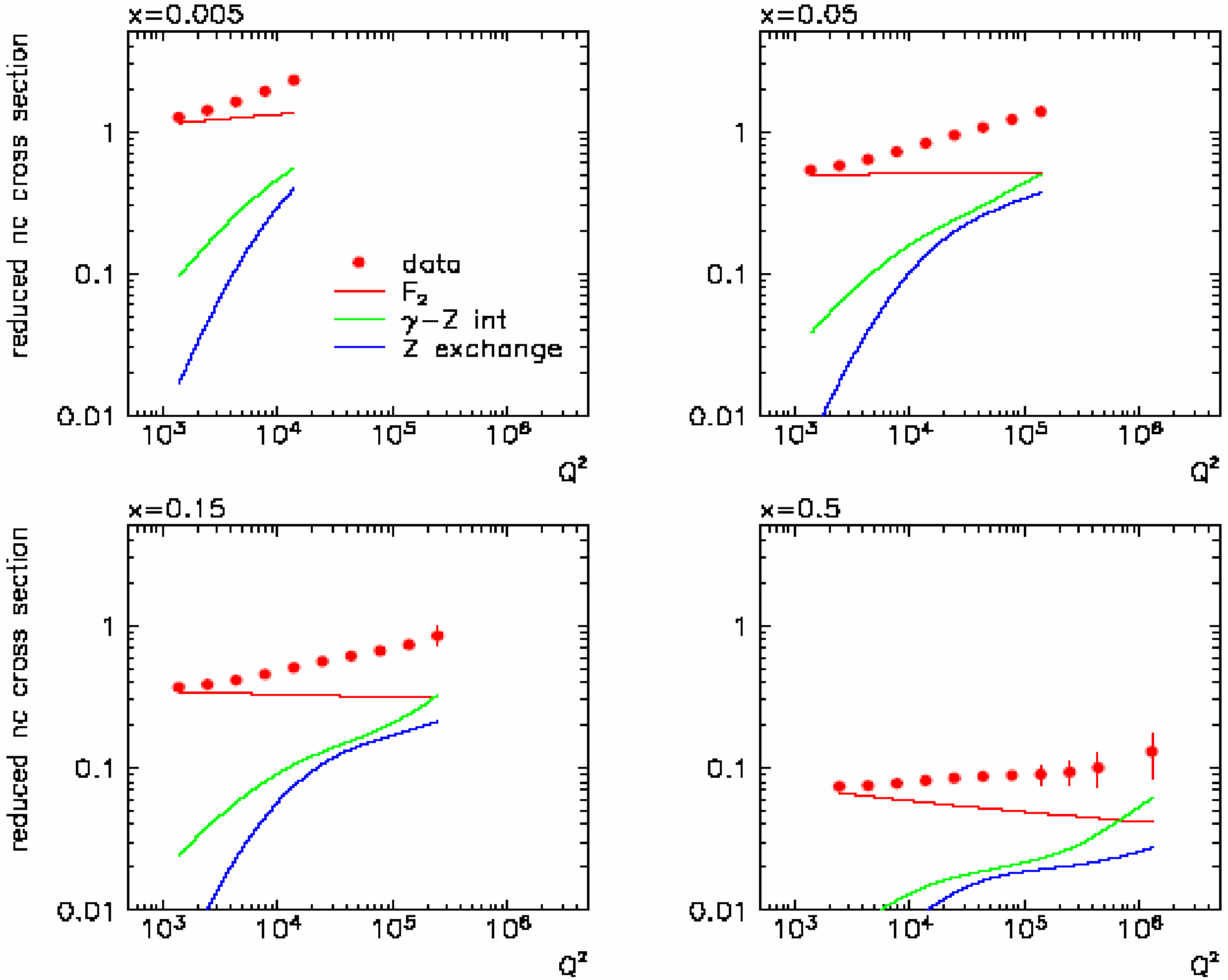
F. Willeke 23.4.05

Possible gain factor 2-4 by reducing E_e to 60 GeV and reducing bunch distance.
Parasitic operation. Lower Ee possible. Focusing magnets (10° clearance). …

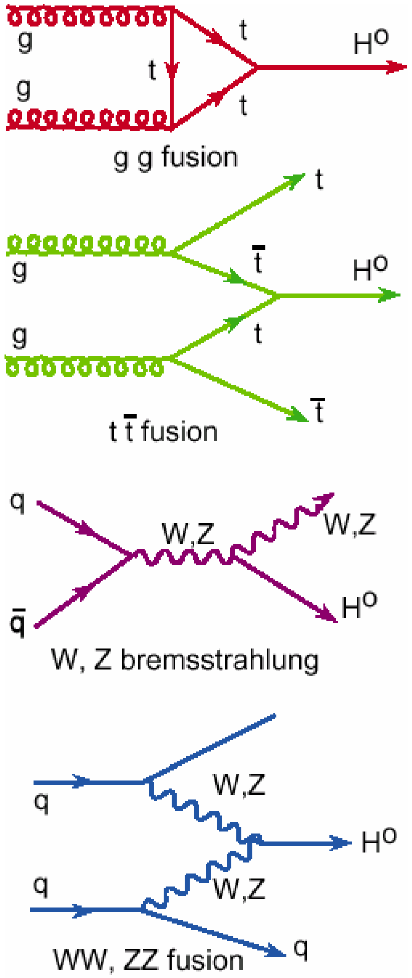
Lepton nucleon scattering - machines and visions

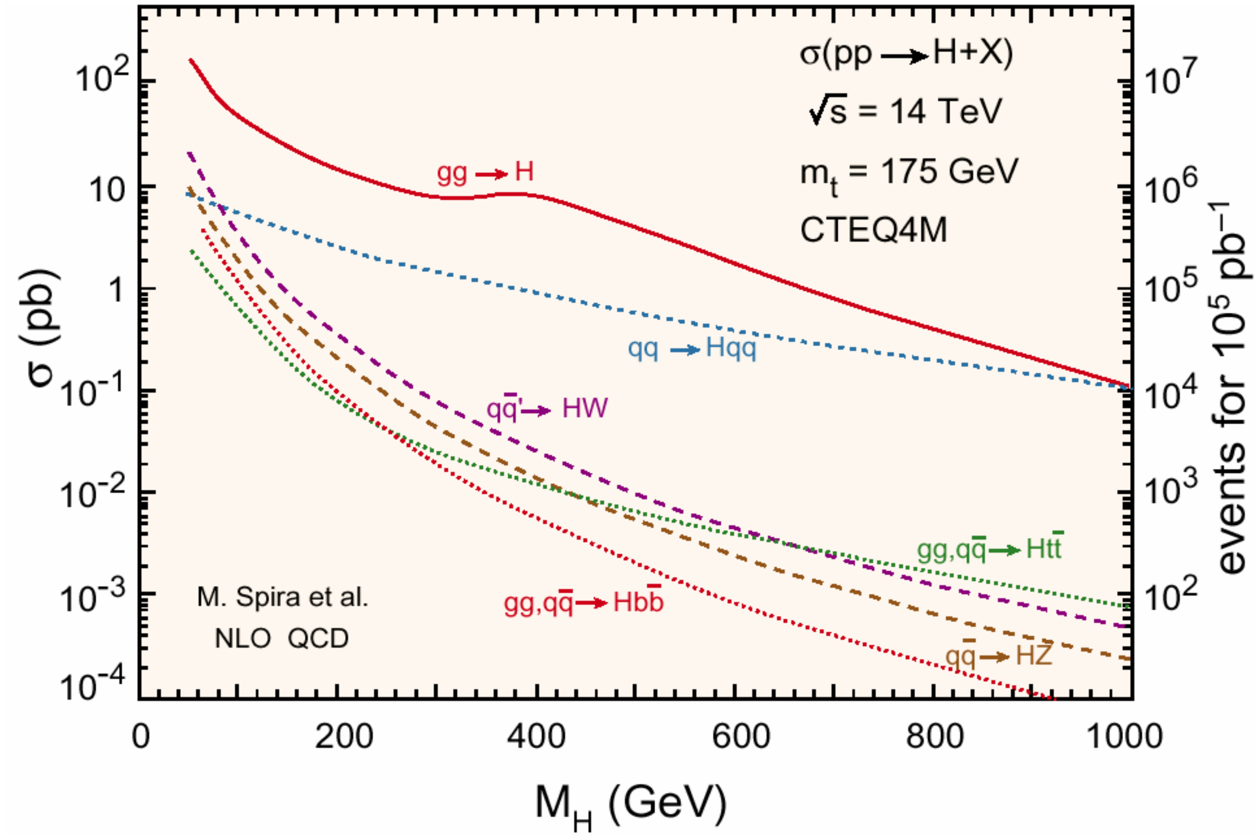


Reduced NC cross section at THERA/LHEC energies for 200pb-1



SM Higgs at the LHC





LHC needs an ep machine operating in the TeV energy range
How reliable would be HERA's extrapolations at low/high x?

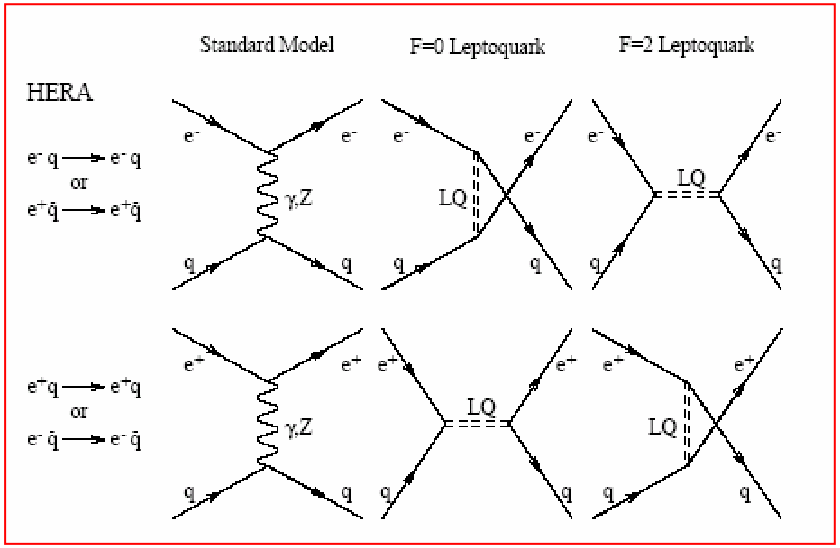
Leptoquarks

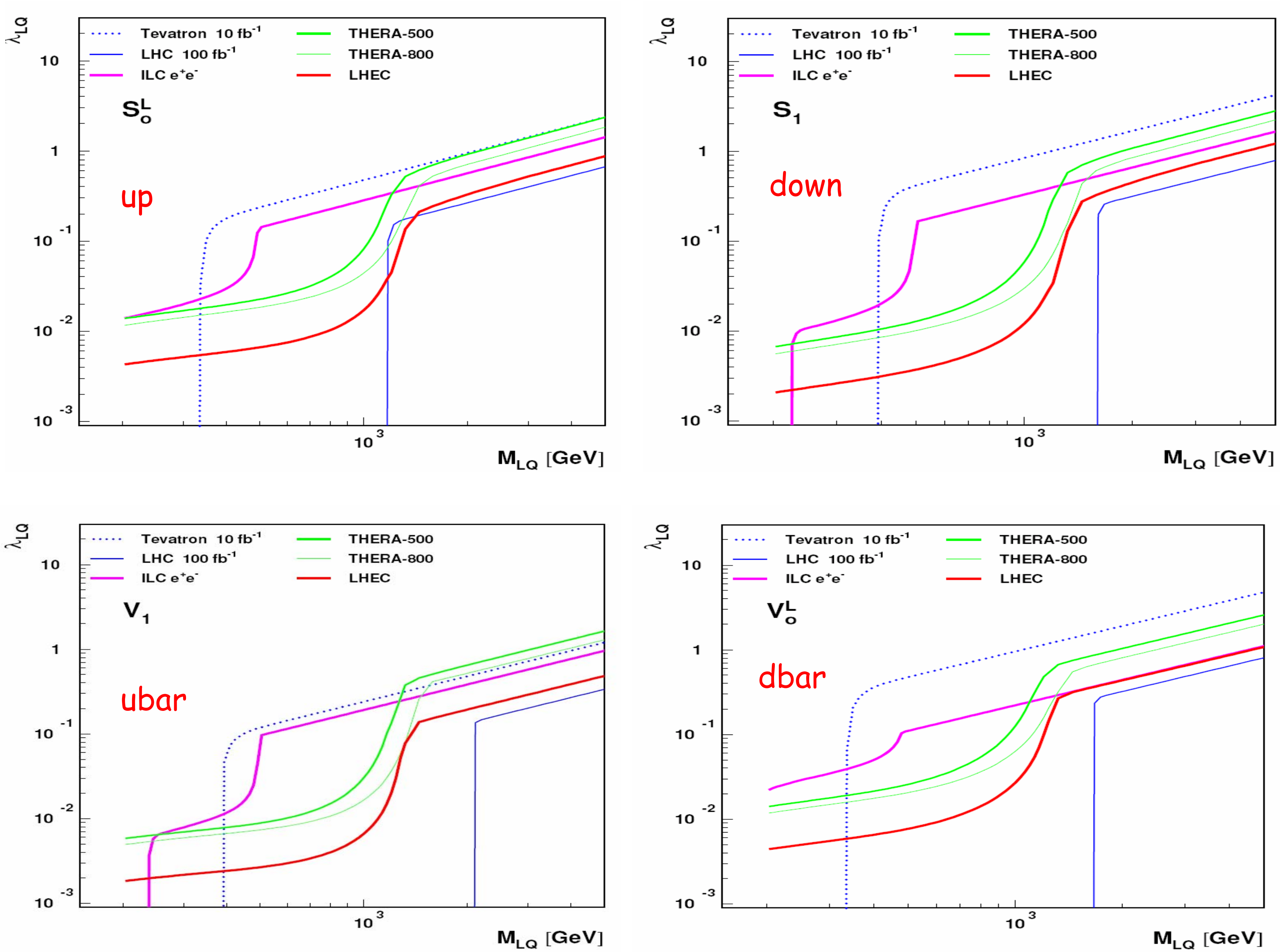
Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
$S_\circ^L$	2	$-1/3$	$1/2$	$e_L u$	νd	$\tilde{d}_R$
$S_\circ^R$	2	$-1/3$	1	$e_R u$		
$\tilde{S}_\circ$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\bar{\tilde{u}}_L$
		$+1/3$	0		$\nu \bar{d}$	$\tilde{d}_L$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	$1/2$	$e_L u$	νd	
		$+2/3$	0		νu	
$V_\circ^L$	0	$-2/3$	$1/2$	$e_L \bar{d}$	$\nu \bar{u}$	
$V_\circ^R$	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_\circ$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	$1/2$	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	

$e^{\pm}$ p ideal for LQ spectroscopy

LQ physics related to

- substructure
- extra dimensions
- SUSY





F. Zarnecki (prel)

With HERA becoming a success the route is open to dig deeper