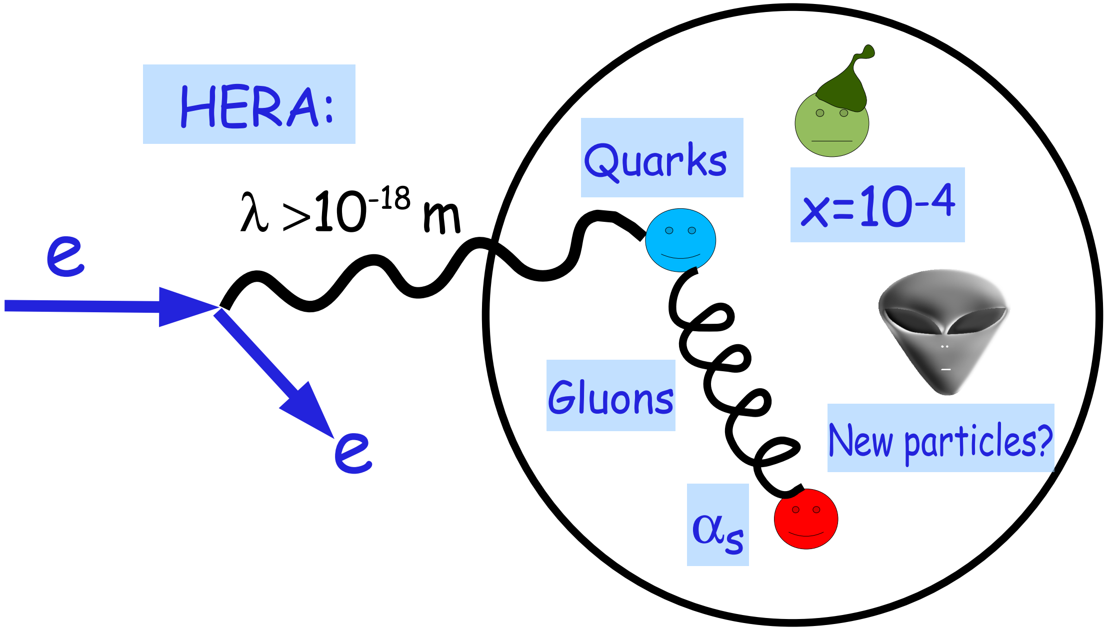
Prospects of HERA measurements

HERA-LHC workshop, March 13, 2007, DESY
Olaf Behnke (Heidelberg)

HERA - LHC



HERA:

$\lambda > 10^{-18}$ m

e

e

Quarks

$x=10-4$

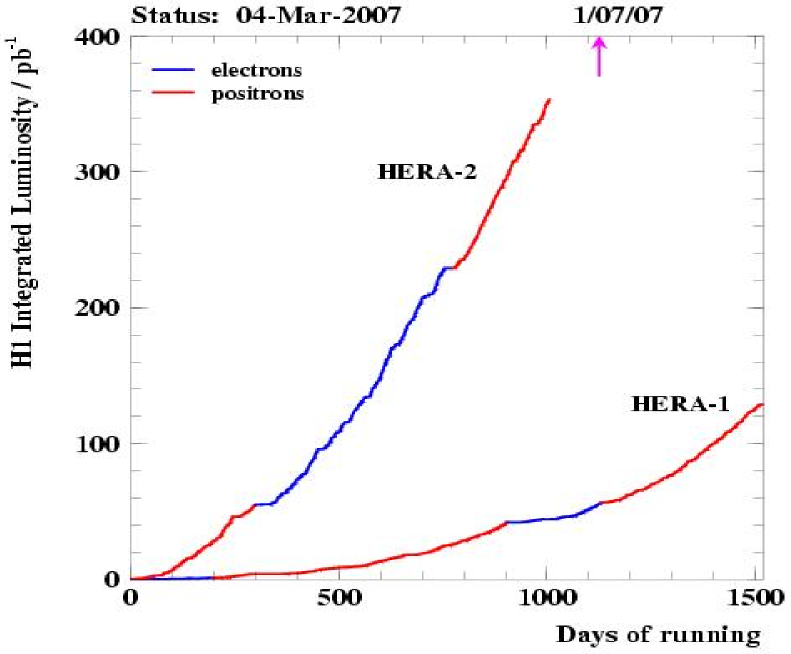
Gluons

New particles?

α_s

LHC

Proton →← Proton



The HERA data are "in the can"

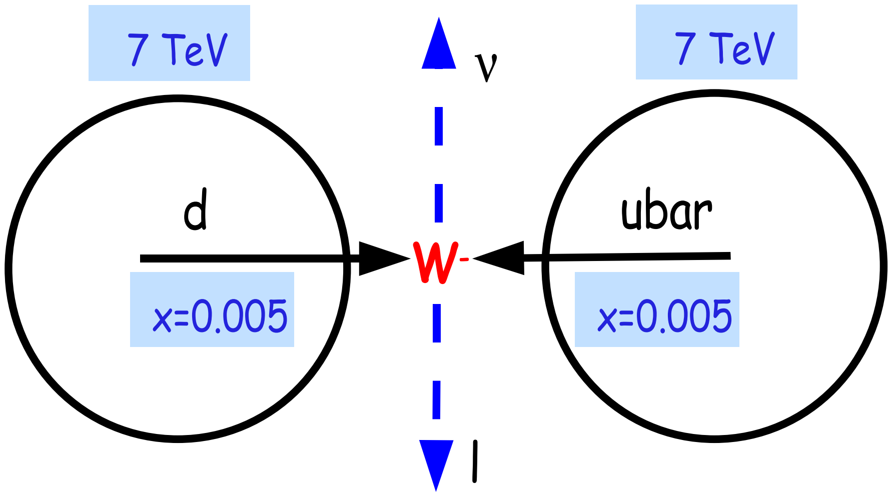
(almost)

	e+p	e-p
HERA I	120 pb-1	16 pb-1
HERA II	~ 190 pb-1	170 pb-1

H1+ZEUS together ~ 1fb-1

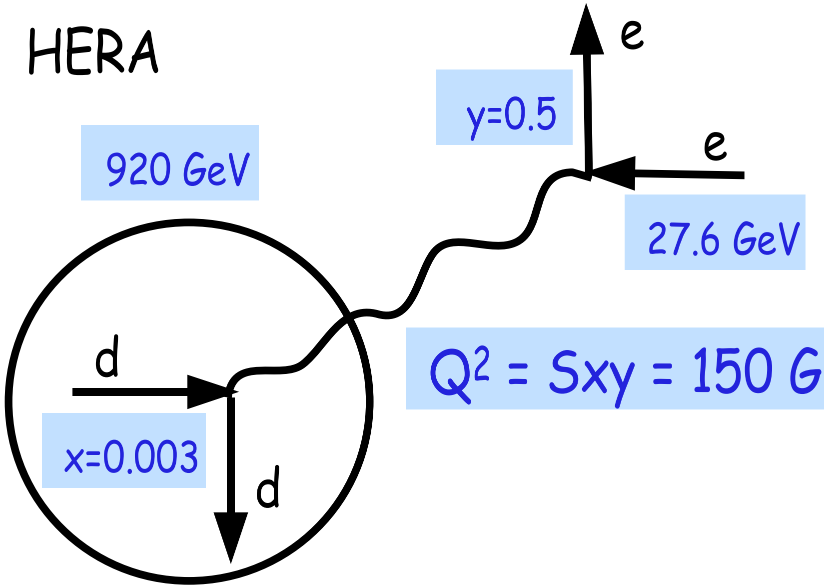
➔ What can we reach in precision?

From HERA to LHC in a nutshell



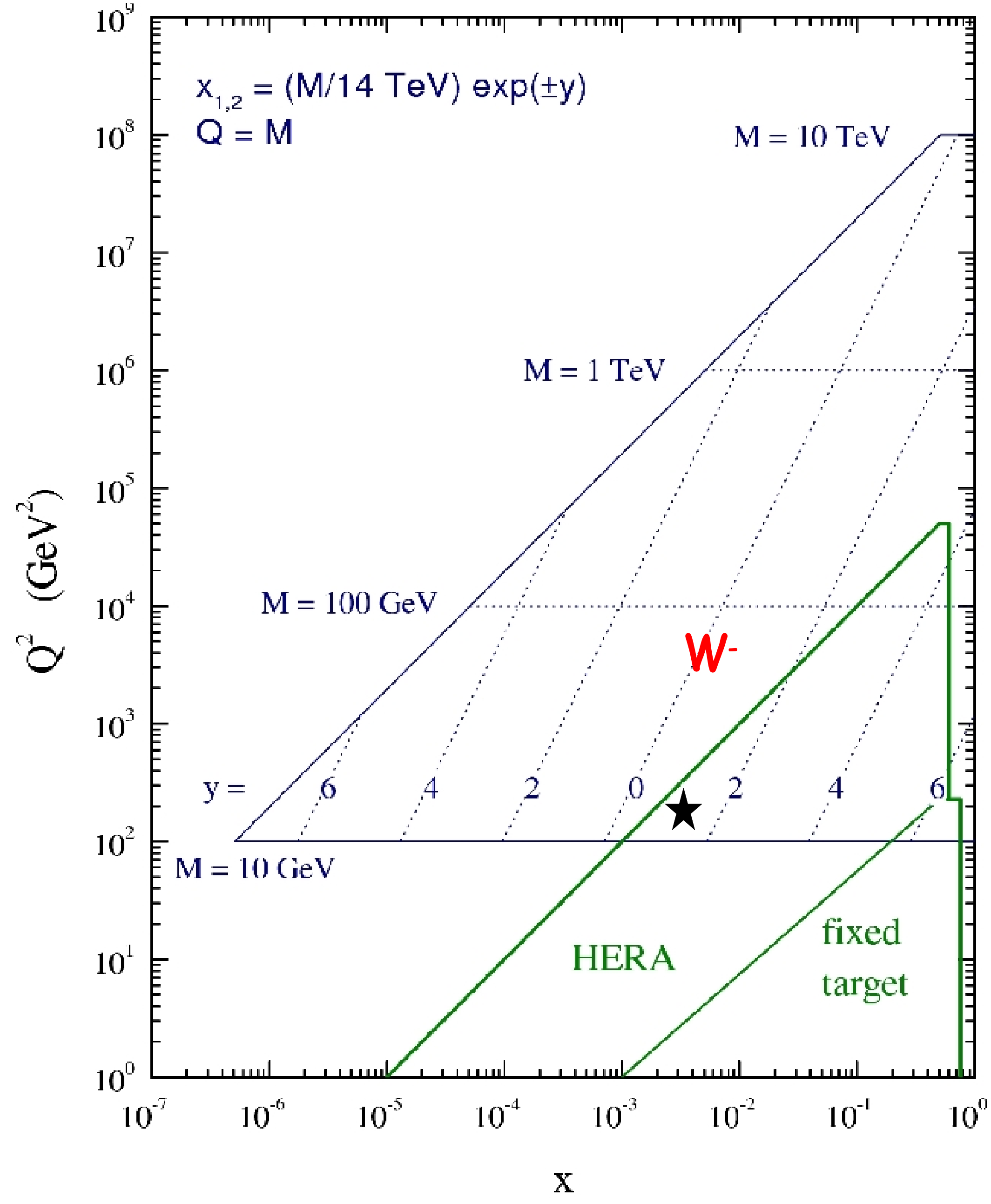
LHC

$Q^2 = (m_W)^2 \sim 6400\ \mathrm{GeV}^2$

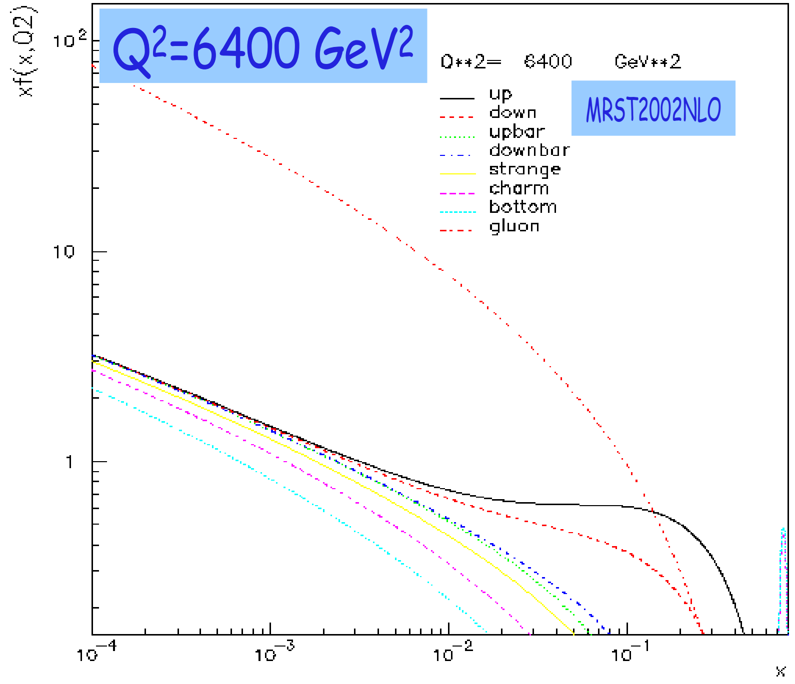


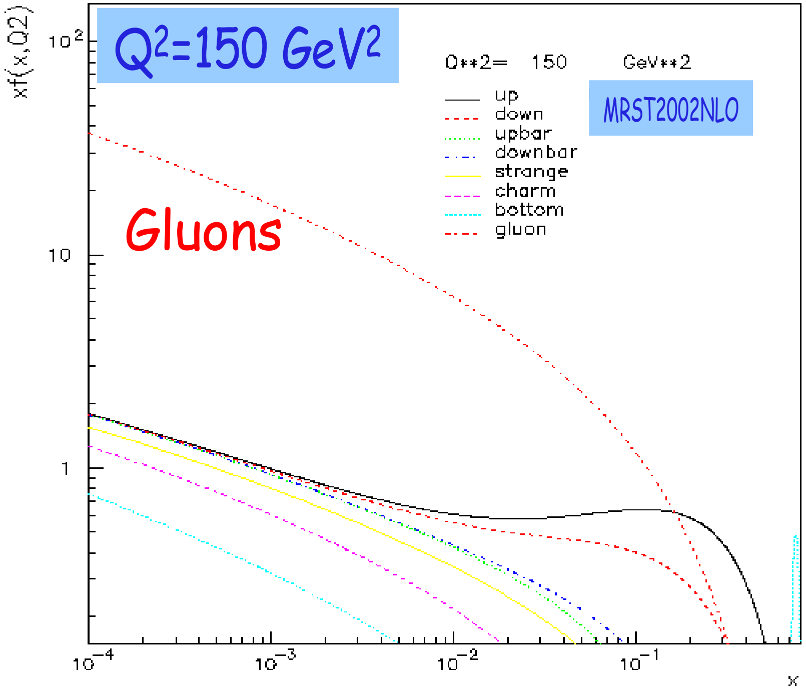
HERA

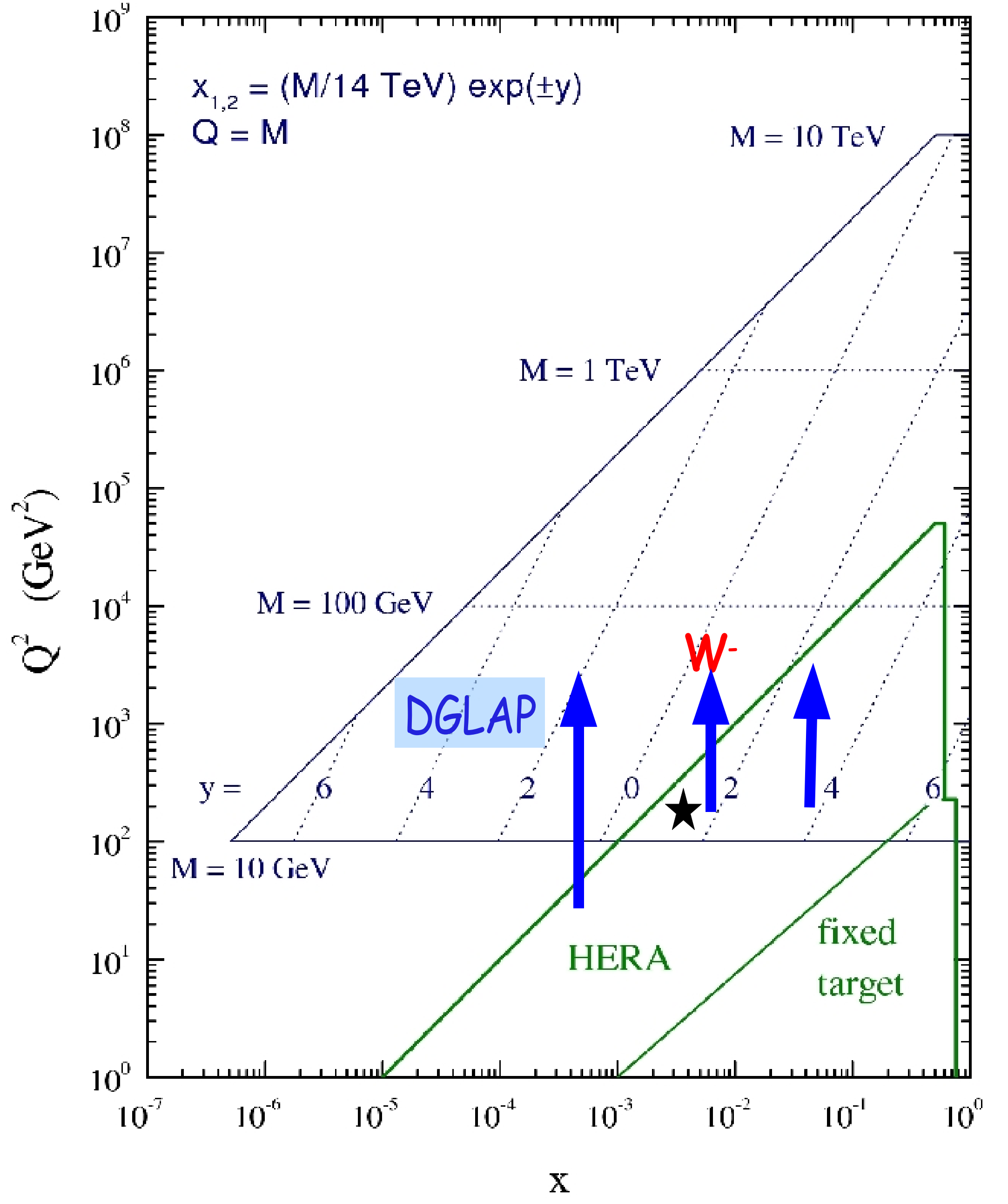
$Q^2 = Sxy = 150\ \mathrm{GeV}^2$



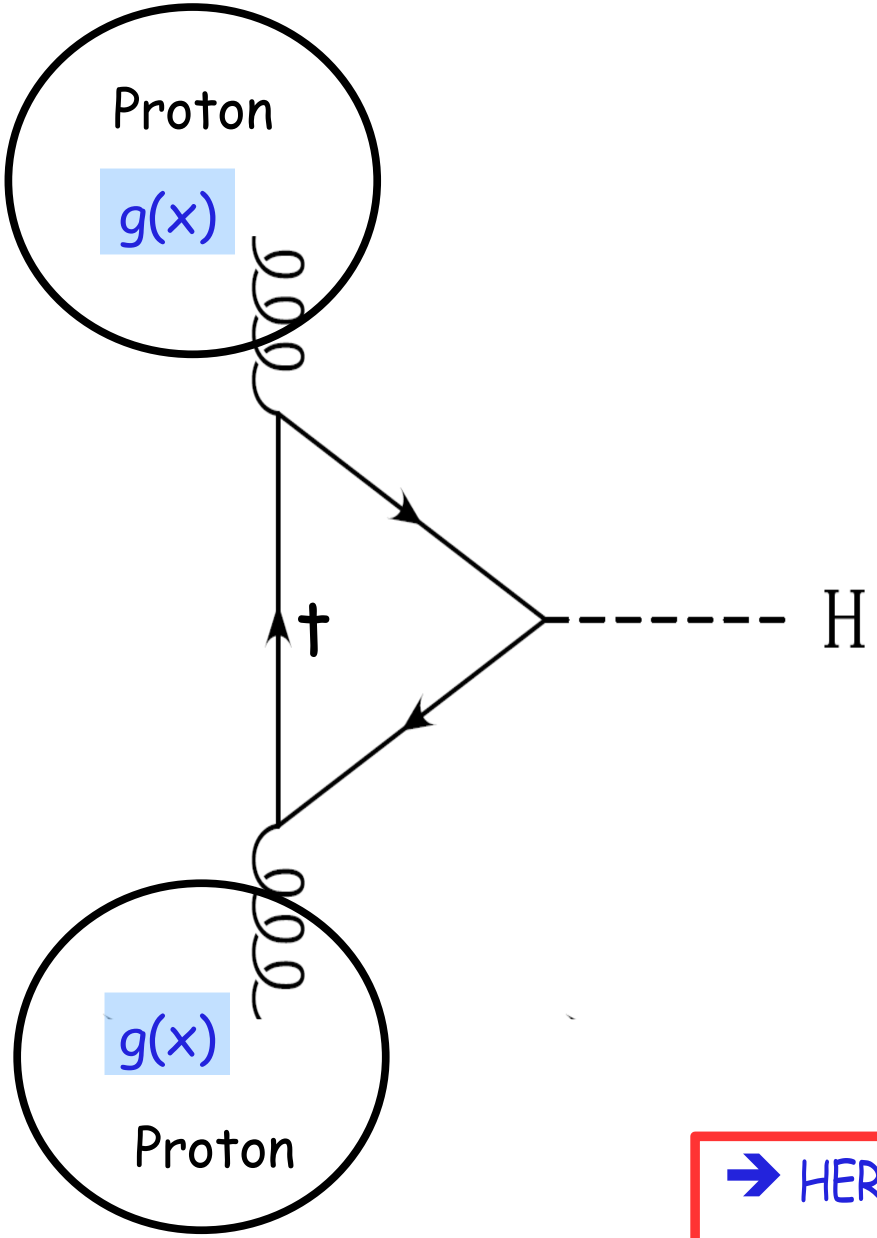
From HERA to LHC in a nutshell



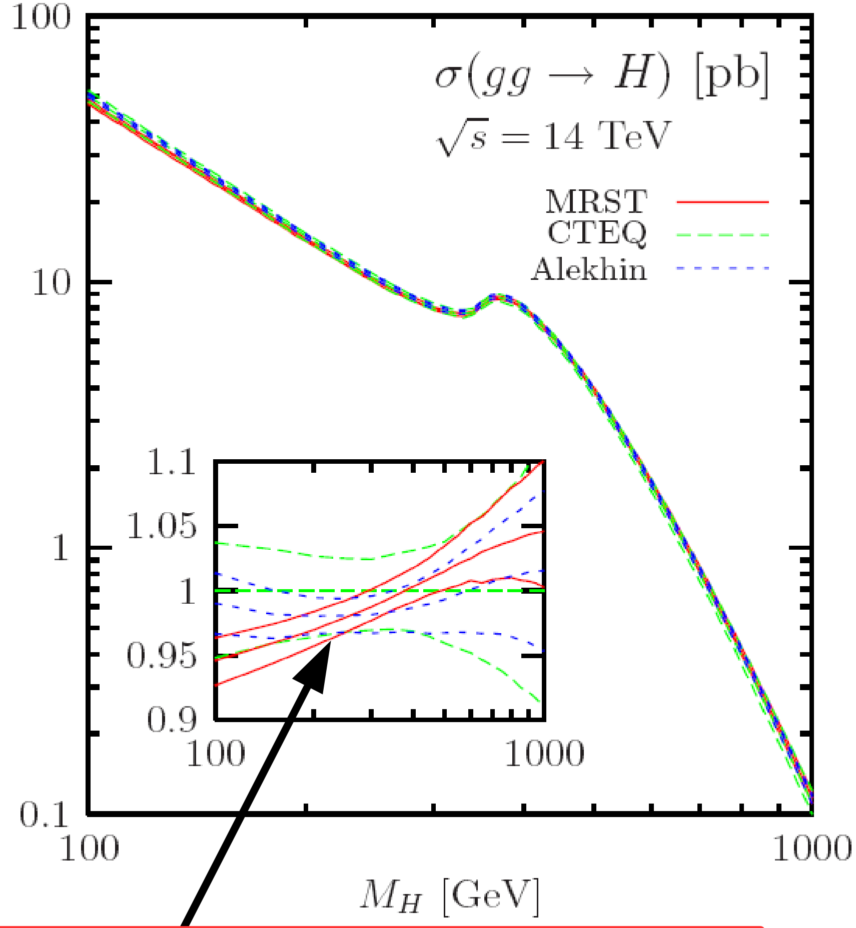




HERA Gluondensity --> LHC

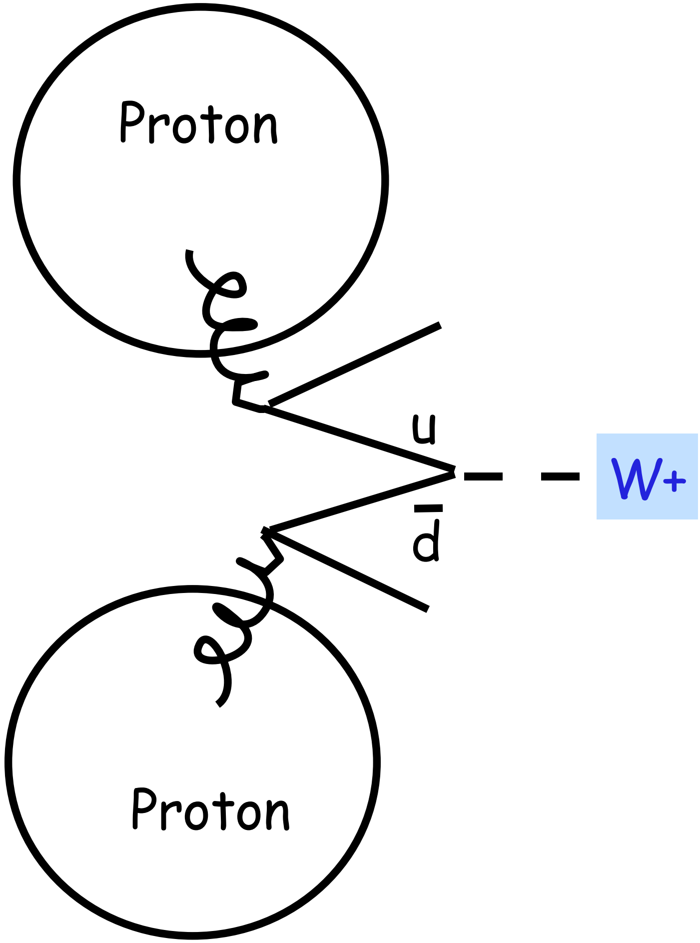


gg-> H
prediction-uncertainty



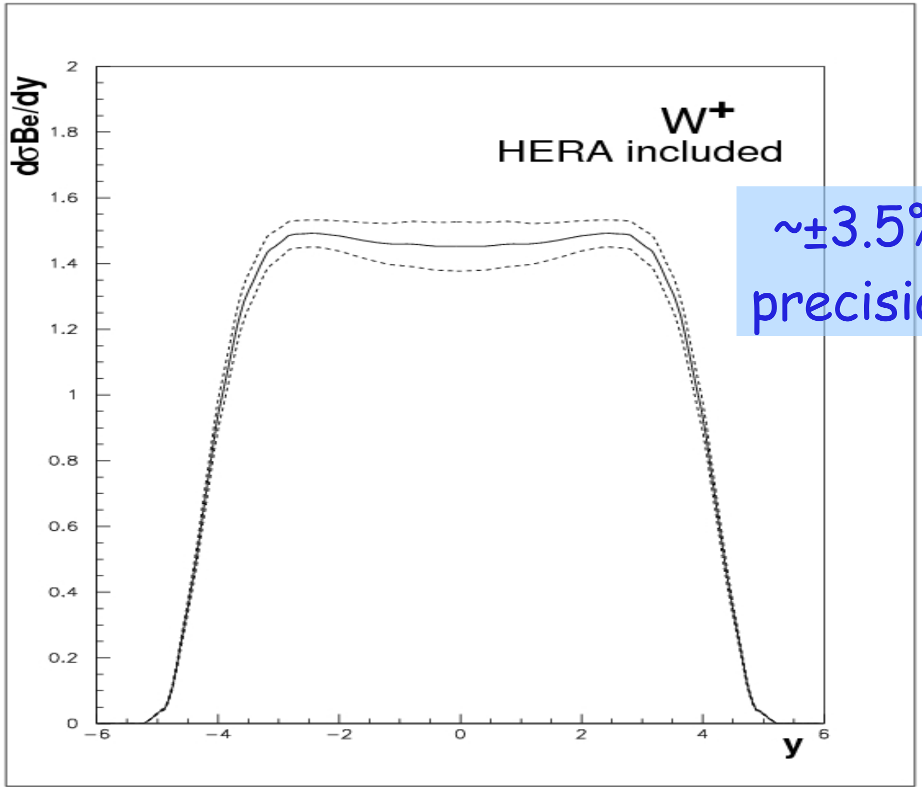
➔ HERA Gluondensity determines precision! How far can we improve this???

HERA proton PDF --> LHC W production



'Lumi' process for LHC

Prediction using ZEUS-S-PDF



~±3.5% precision

➔ HERA u, $\bar{d}$ and gluon determine precision - how far can we improve this?

HERA observables and Proton PDFs

e+p and e-p NC and CC inclusive cross sections:

$$\sigma_{NC}^{\pm} \sim Y_{+}F_2 \mp Y_{-}xF_3$$

U=u+c+b

D=d+s

	F_2	xF_3	σ_{cc}^{+}	σ_{cc}^{-}
U	$4(U+\bar{U})+(D+\bar{D})$	$2(U-\bar{U})+(D-\bar{D})$	$\bar{U}+(1-y)^2D$	$U+(1-y)^2\bar{D}$
D	$4(U+\bar{U})+(D+\bar{D})$	$2(U-\bar{U})+(D-\bar{D})$	$\bar{U}+(1-y)^2D$	$U+(1-y)^2\bar{D}$
$\bar{U}$	$4(U+\bar{U})+(D+\bar{D})$	$2(U-\bar{U})+(D-\bar{D})$	$\bar{U}+(1-y)^2D$	$U+(1-y)^2\bar{D}$
$\bar{D}$	$4(U+\bar{U})+(D+\bar{D})$	$2(U-\bar{U})+(D-\bar{D})$	$\bar{U}+(1-y)^2D$	$U+(1-y)^2\bar{D}$

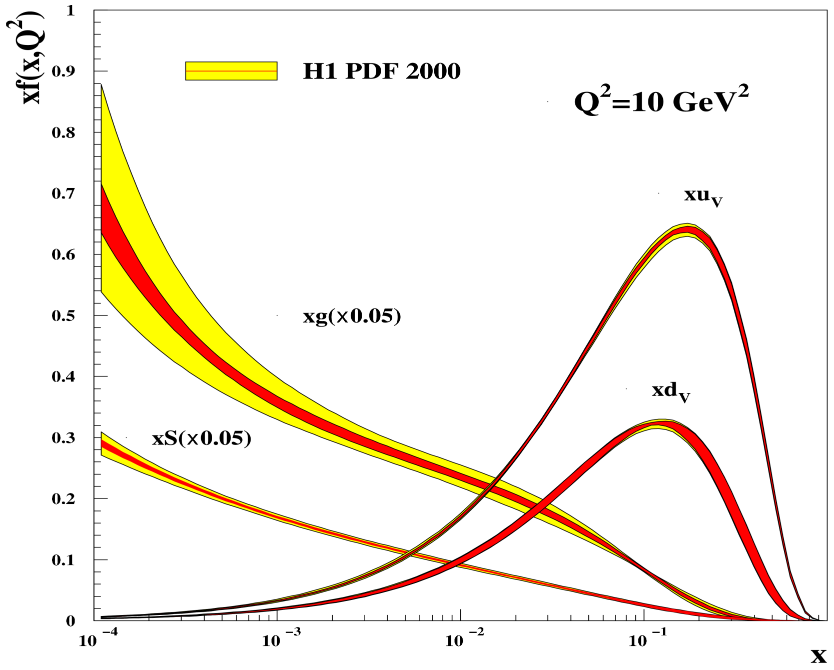
HERA weak points: dbar-ubar asymmetry, s

$Gluon$	$dF_2/dln(Q^2)$ $Jet\ cross\ sections$ $F_2^{c\bar{c}}$ F_L

H1 PDF2000 and H1 PDF-Final

H1 PDF 2000

Datasets	Q^2 [GeV^2]	L [pb^{-1}]
NC e+p 96/97	1.5-150	2-20
NC/CC e+p 94-00	>150	100
NC/CC e-p 94-00	>150	16
BCDMS-p and D	7.5-230	



+

H1 PDF-Final

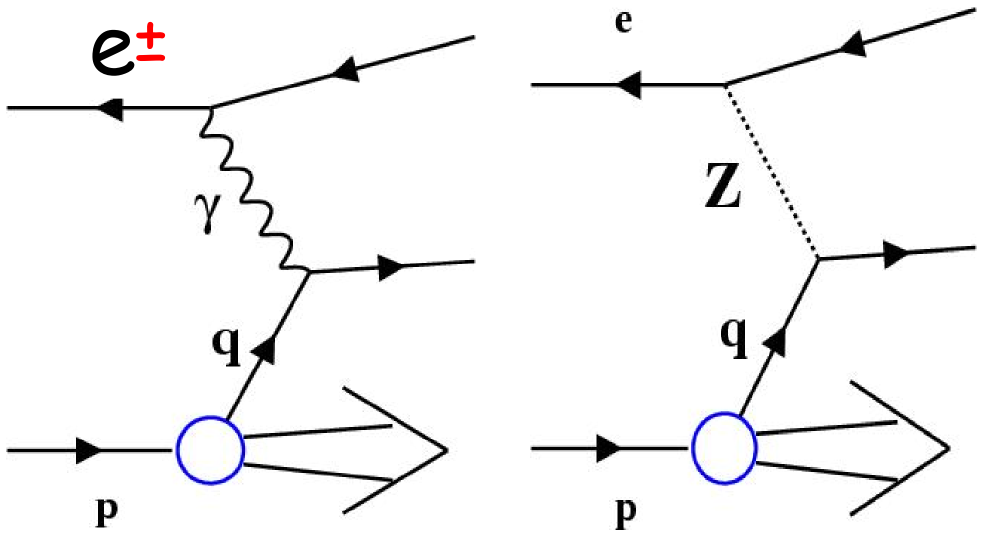
Datasets	Q^2 [GeV^2]	L [pb^{-1}]
NC MB99/SVX00	0.2-8.5	0.5-2
NC e+p 00	10-150	28
NC e+-p 03/07	~20-150	350
NC/CC e+p 03-07	>150	190
NC/CC e-p 03-07	>150	170
DIS jets 94-07	>150	470
γp dijets 94-07	0	470

!!!

Something extremely nice

→ Many systematic challenges, but still also some statistical limitations

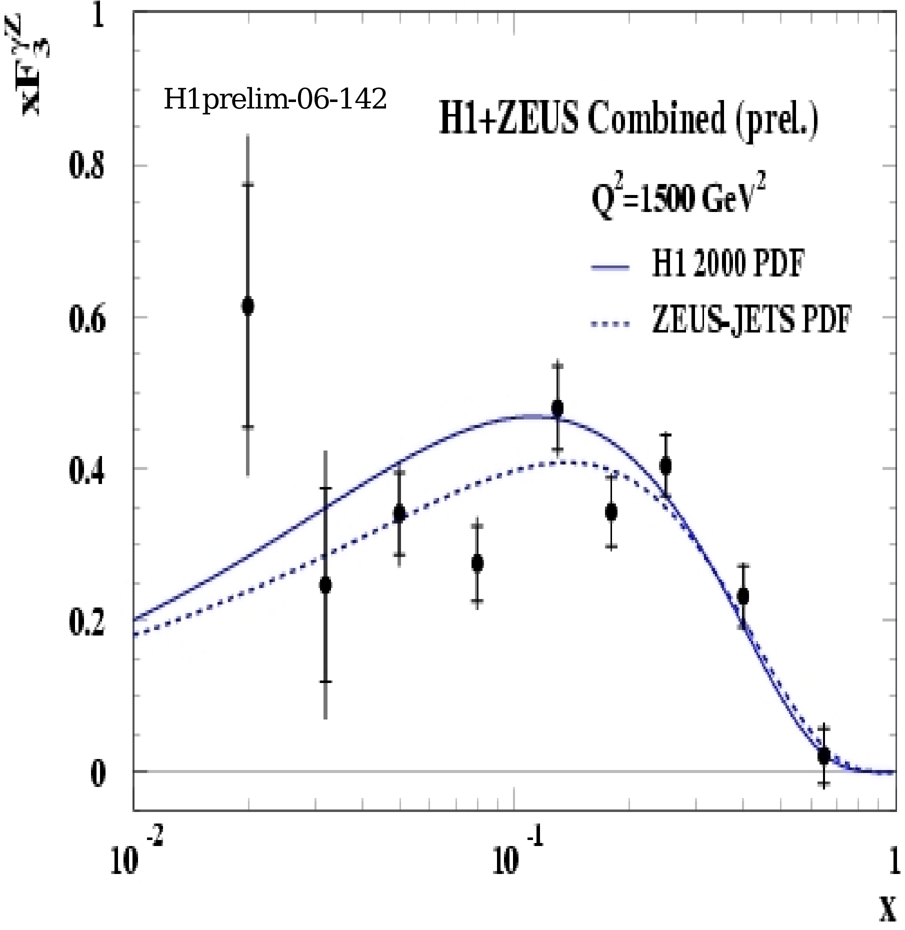
xF_3 and valence quark densities



γZ interference flips sign when e+p -> e-p

$$xF_3 \sim \sigma(e^+p) - \sigma(e^-p) \sim 2u_v + d_v$$

Results shown at ICHEP06 with partial HERA II statistics



➔ ~80% more e+p data and 50% more e-p data still to be added -> expect ~30% stat. improvement

QCD fit prospects

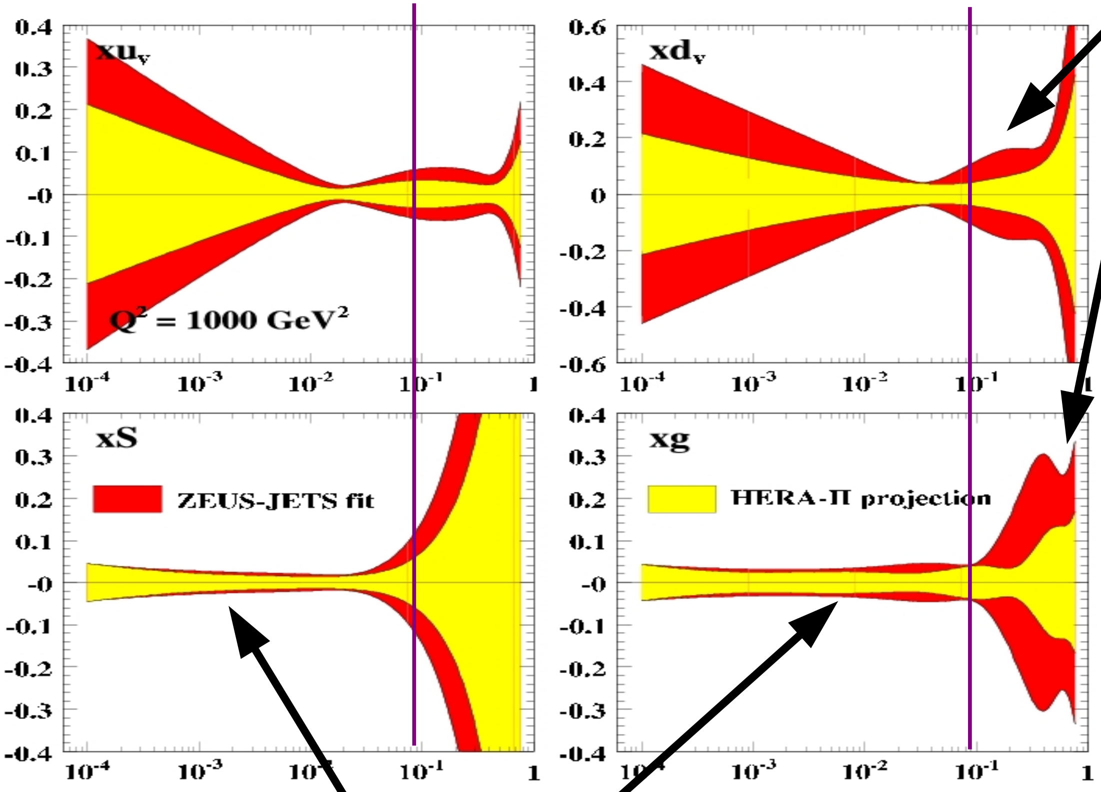
Study by C. Gwenlan, A. Cooper-Sakar,
C. Targett-Adams, HERA-LHC proceedings

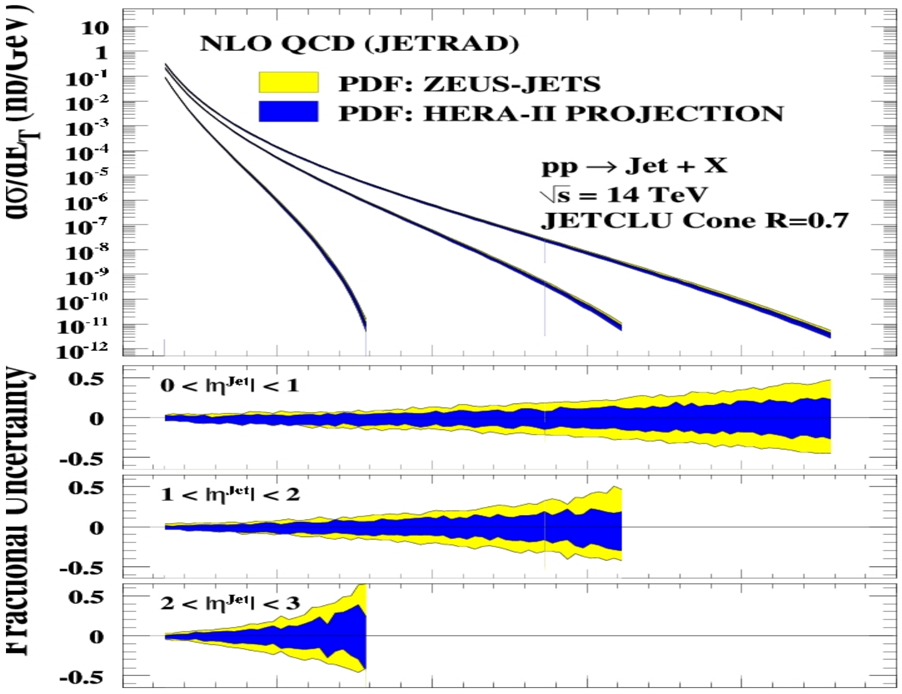
Assumptions:

➔ 700 pb^{-1} Lumi at HERA II ≈ reached by combining H1+ZEUS

➔ Only statistical improvements, no systematical

x≈>0.1 still statistically limited

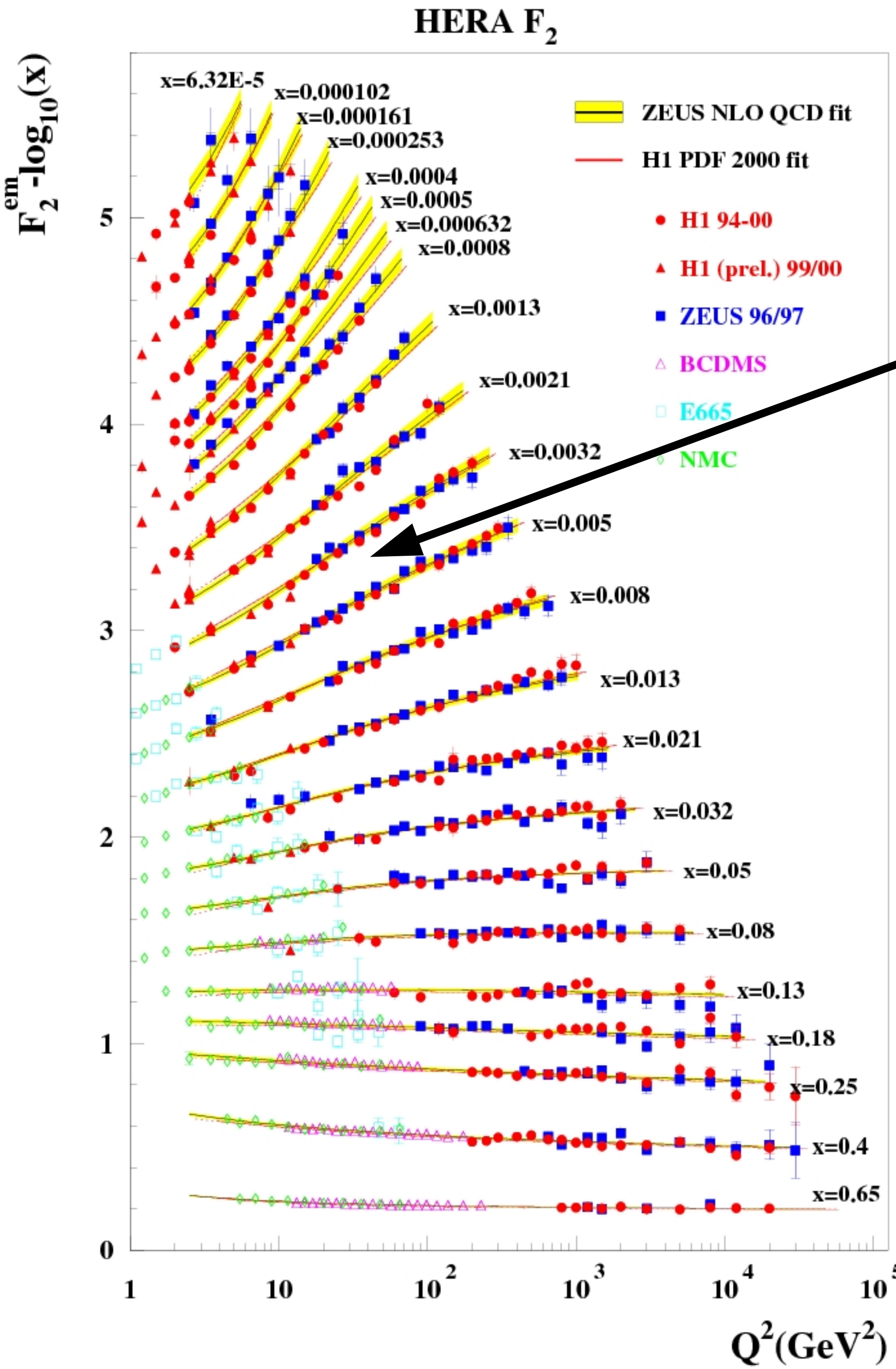




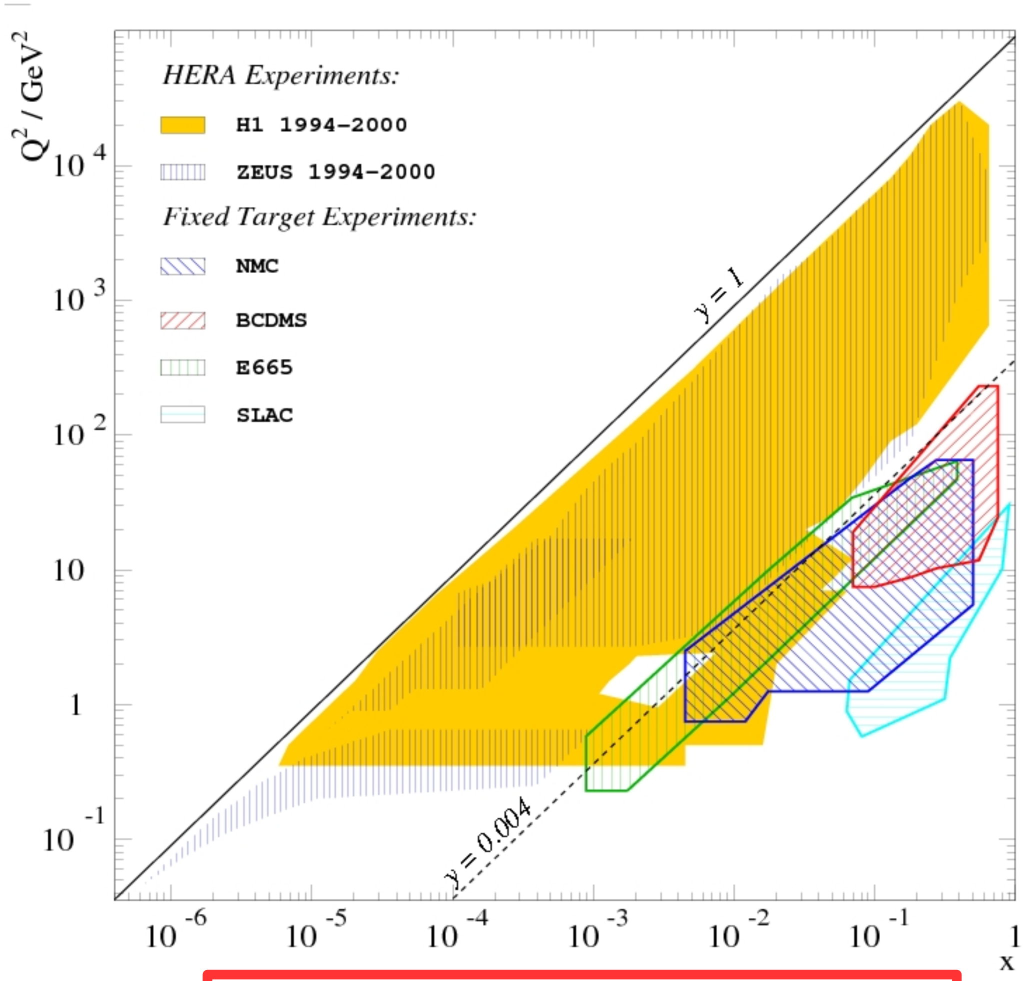
➔ What about sea and gluon improvements at lower x<0.1?

➔ Improvement of PDFs at high x reflected in jets cross sections at LHC

F_2 – HERA reference

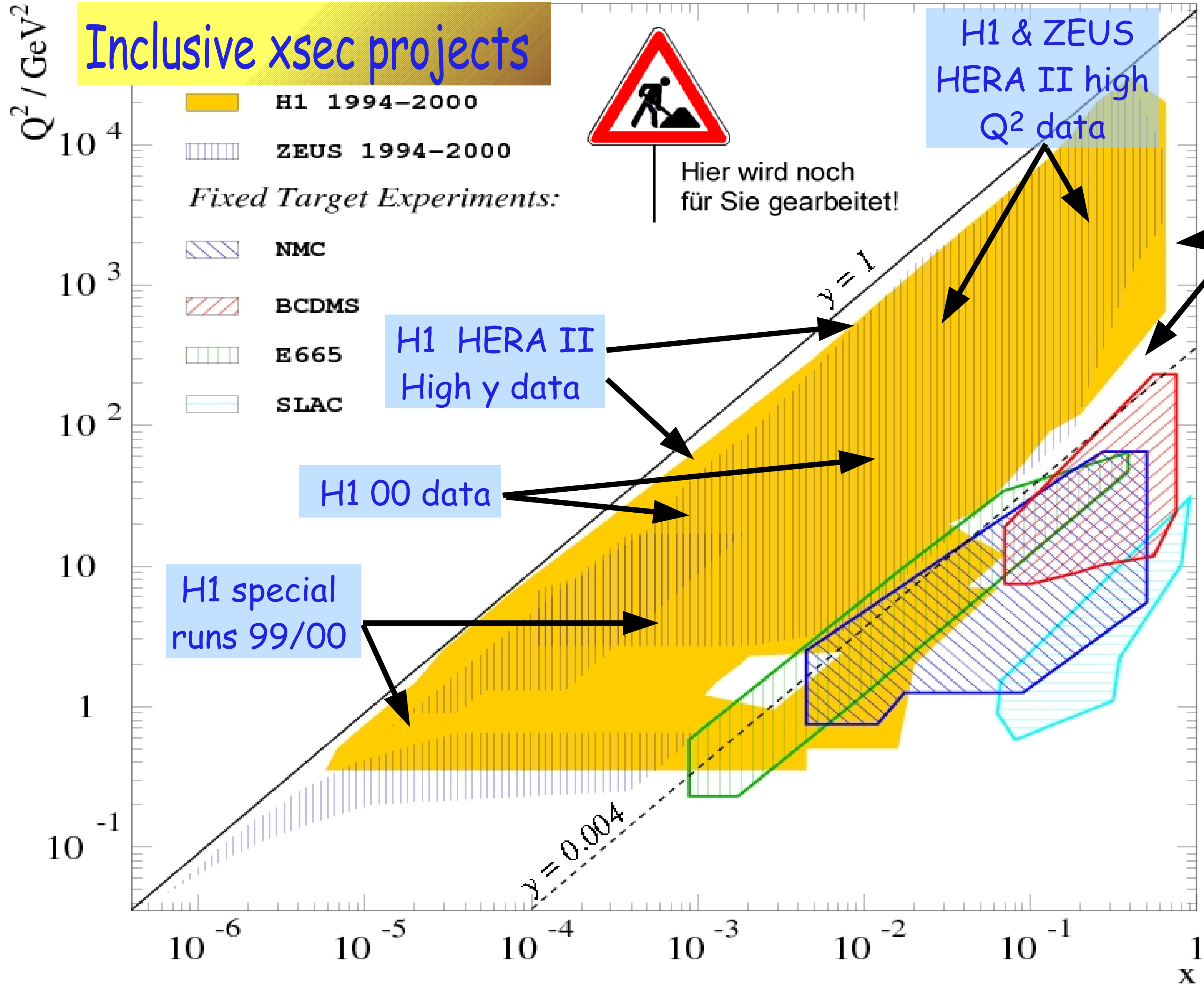


2-3% precision reached with published 96/97 data



➔ Is this the end of the story?

Inclusive xsec projects



H1 & ZEUS
HERA II high
Q^2 data

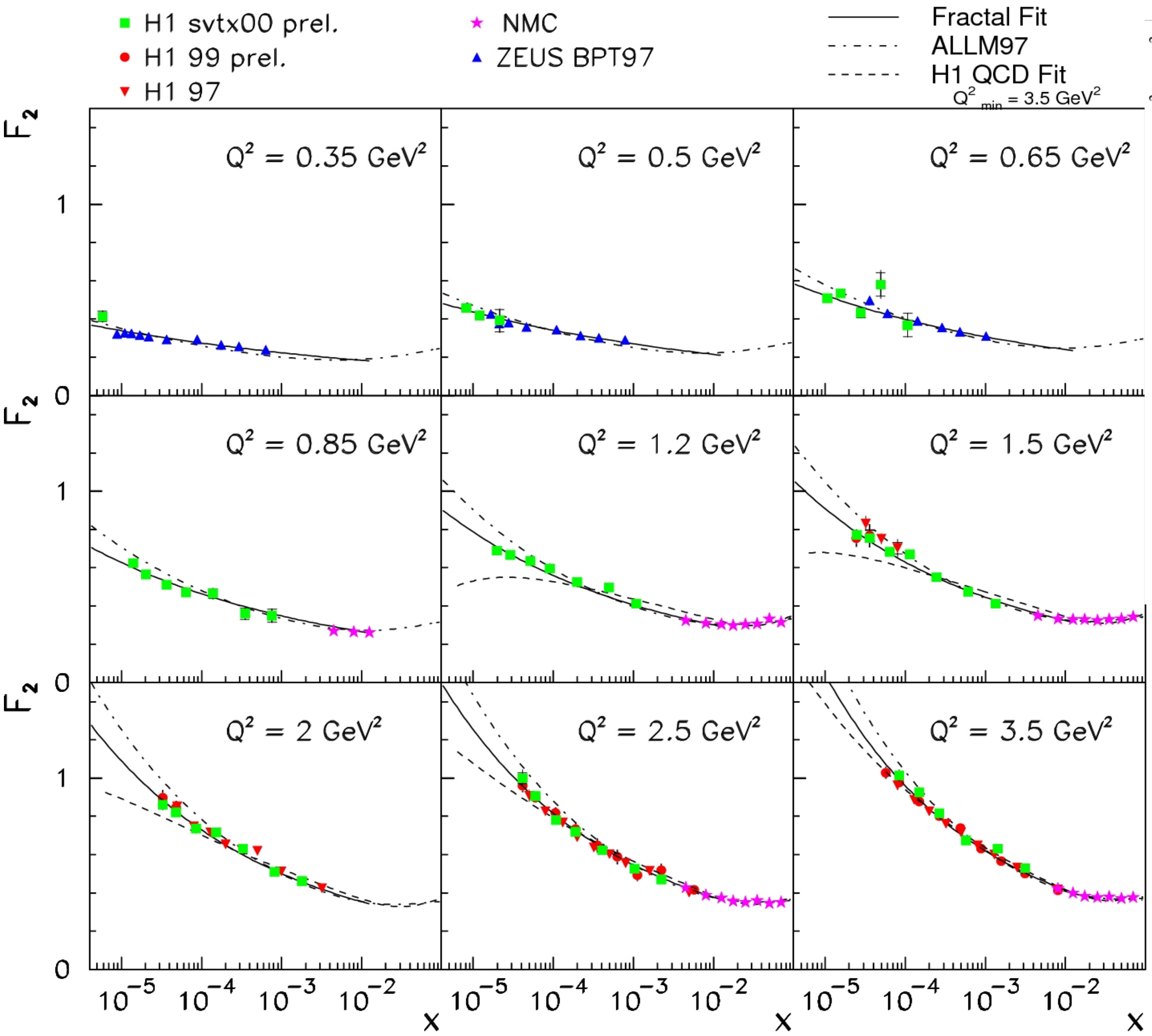
ZEUS
x-> 1

H1 HERA II
High y data

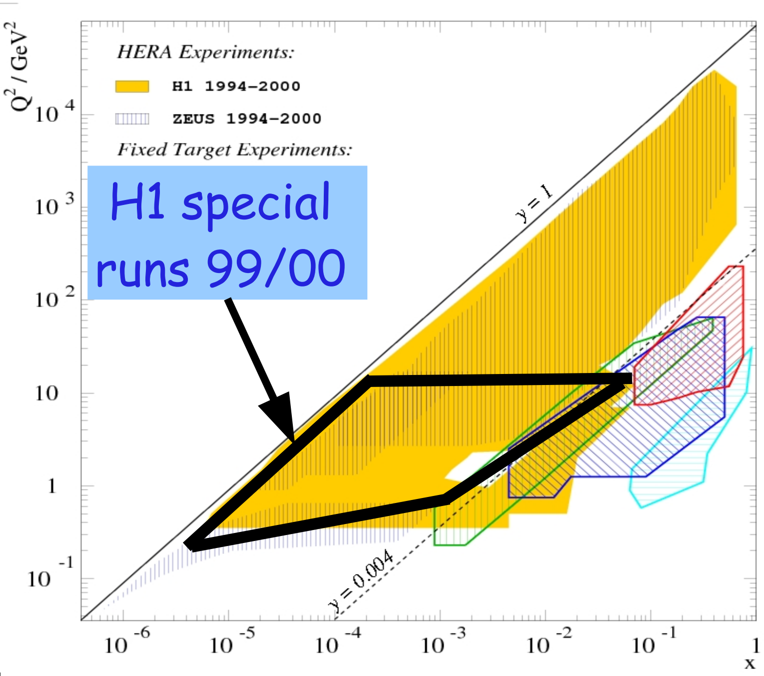
H1 00 data

H1 special
runs 99/00

Transition to non perturbative region $Q^2<1\ \mathrm{GeV}^2$



H1 Collaboration

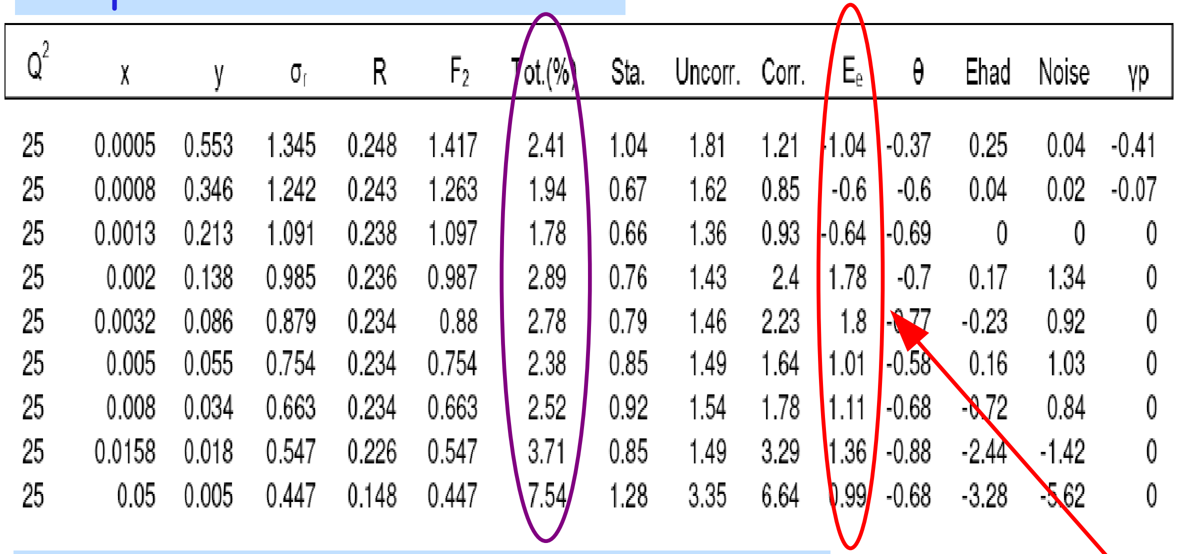


H1 special runs 99/00

➔ up to ~3% precision reached

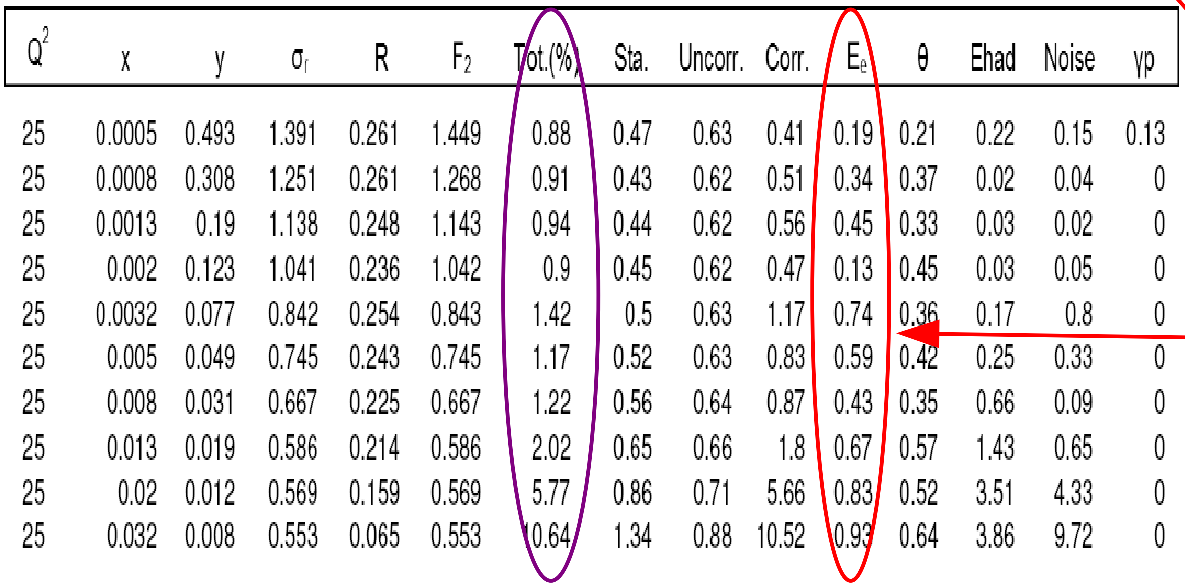
Analysis of H1 2000 Data

H1 published 96/97 data:

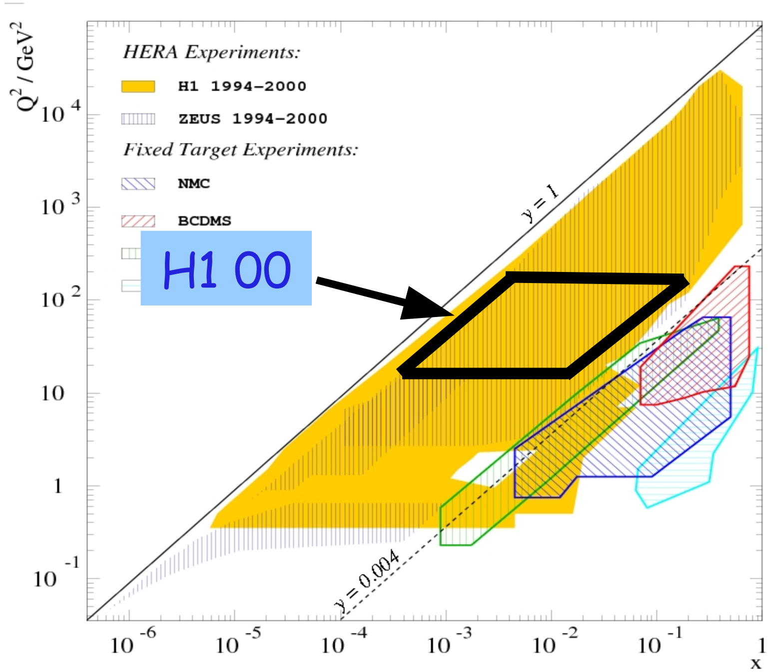


Q^2	x	y	σ_r	R	F_2	Tot.(%)	Sta.	Uncorr.	Corr.	E_e	θ	Ehad	Noise	yp
25	0.0005	0.553	1.345	0.248	1.417	2.41	1.04	1.81	1.21	-1.04	-0.37	0.25	0.04	-0.41
25	0.0008	0.346	1.242	0.243	1.263	1.94	0.67	1.62	0.85	-0.6	-0.6	0.04	0.02	-0.07
25	0.0013	0.213	1.091	0.238	1.097	1.78	0.66	1.36	0.93	-0.64	-0.69	0	0	0
25	0.002	0.138	0.985	0.236	0.987	2.89	0.76	1.43	2.4	1.78	-0.7	0.17	1.34	0
25	0.0032	0.086	0.879	0.234	0.88	2.78	0.79	1.46	2.23	1.8	-0.77	-0.23	0.92	0
25	0.005	0.055	0.754	0.234	0.754	2.38	0.85	1.49	1.64	1.01	-0.58	0.16	1.03	0
25	0.008	0.034	0.663	0.234	0.663	2.52	0.92	1.54	1.78	1.11	-0.68	-0.72	0.84	0
25	0.0158	0.018	0.547	0.226	0.547	3.71	0.85	1.49	3.29	1.36	-0.88	-2.44	-1.42	0
25	0.05	0.005	0.447	0.148	0.447	7.54	1.28	3.35	6.64	0.99	-0.68	-3.28	-5.62	0

Estimated precision for H1 00 data:



Q^2	x	y	σ_r	R	F_2	Tot.(%)	Sta.	Uncorr.	Corr.	E_e	θ	Ehad	Noise	yp
25	0.0005	0.493	1.391	0.261	1.449	0.88	0.47	0.63	0.41	0.19	0.21	0.22	0.15	0.13
25	0.0008	0.308	1.251	0.261	1.268	0.91	0.43	0.62	0.51	0.34	0.37	0.02	0.04	0
25	0.0013	0.19	1.138	0.248	1.143	0.94	0.44	0.62	0.56	0.45	0.33	0.03	0.02	0
25	0.002	0.123	1.041	0.236	1.042	0.9	0.45	0.62	0.47	0.13	0.45	0.03	0.05	0
25	0.0032	0.077	0.842	0.254	0.843	1.42	0.5	0.63	1.17	0.74	0.36	0.17	0.8	0
25	0.005	0.049	0.745	0.243	0.745	1.17	0.52	0.63	0.83	0.59	0.42	0.25	0.33	0
25	0.008	0.031	0.667	0.225	0.667	1.22	0.56	0.64	0.87	0.43	0.35	0.66	0.09	0
25	0.013	0.019	0.586	0.214	0.586	2.02	0.65	0.66	1.8	0.67	0.57	1.43	0.65	0
25	0.02	0.012	0.569	0.159	0.569	5.77	0.86	0.71	5.66	0.83	0.52	3.51	4.33	0
25	0.032	0.008	0.553	0.065	0.553	10.64	1.34	0.88	10.52	0.93	0.64	3.86	9.72	0

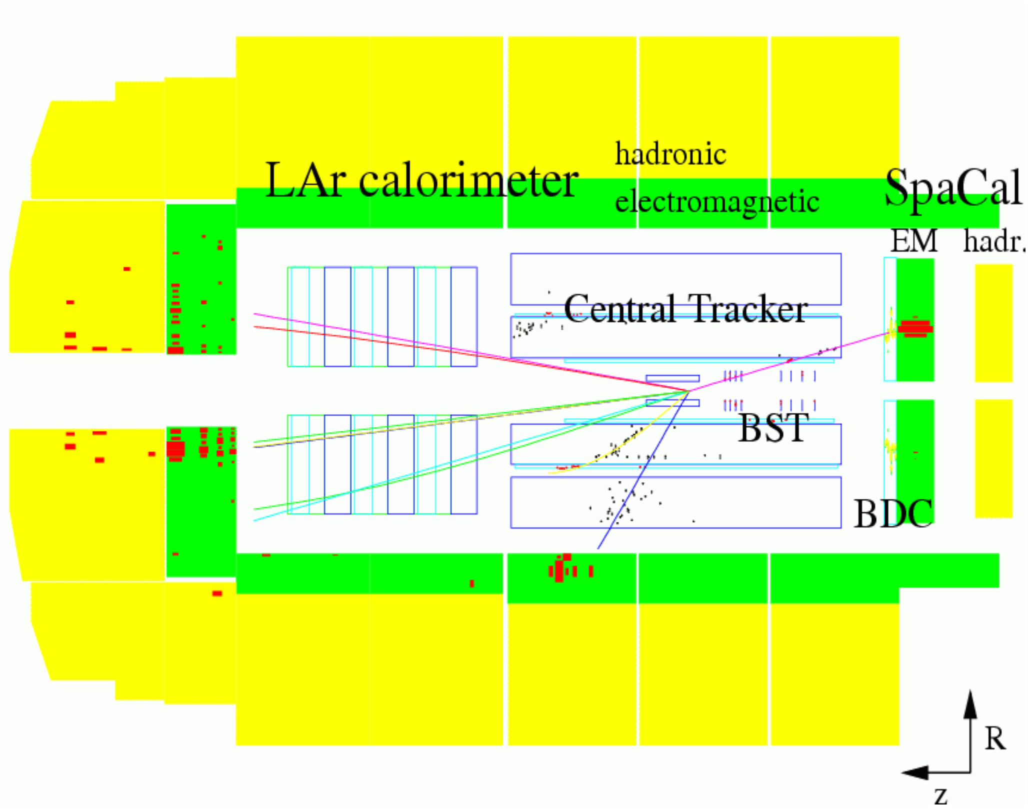


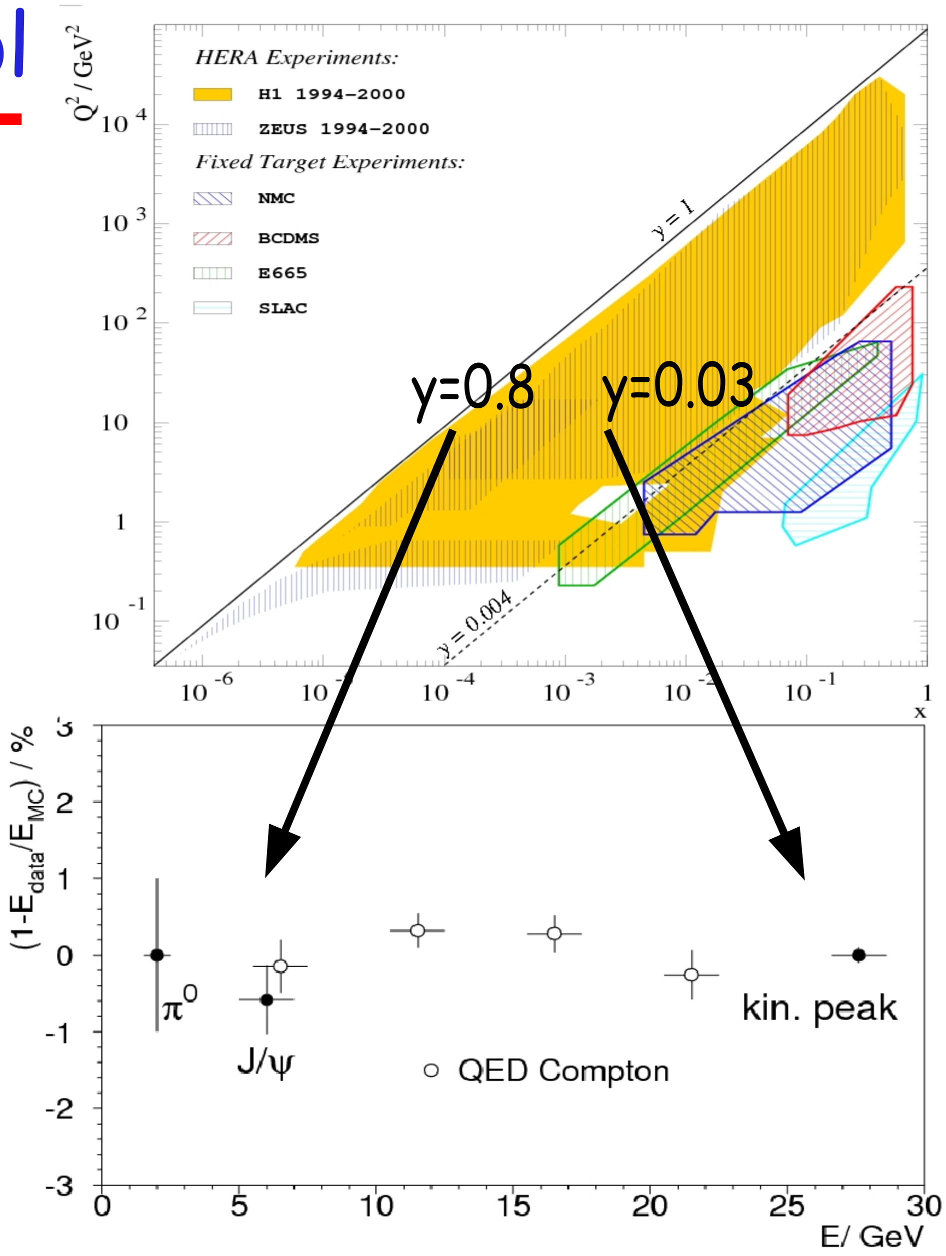
Estimated scattered electron energy scale error:

	3 GeV	27.6 GeV
96/97	2.7%	0.3%
00	1.0%	0.2%

➔ Hard work to reduce systematics!

Electron energy scale control





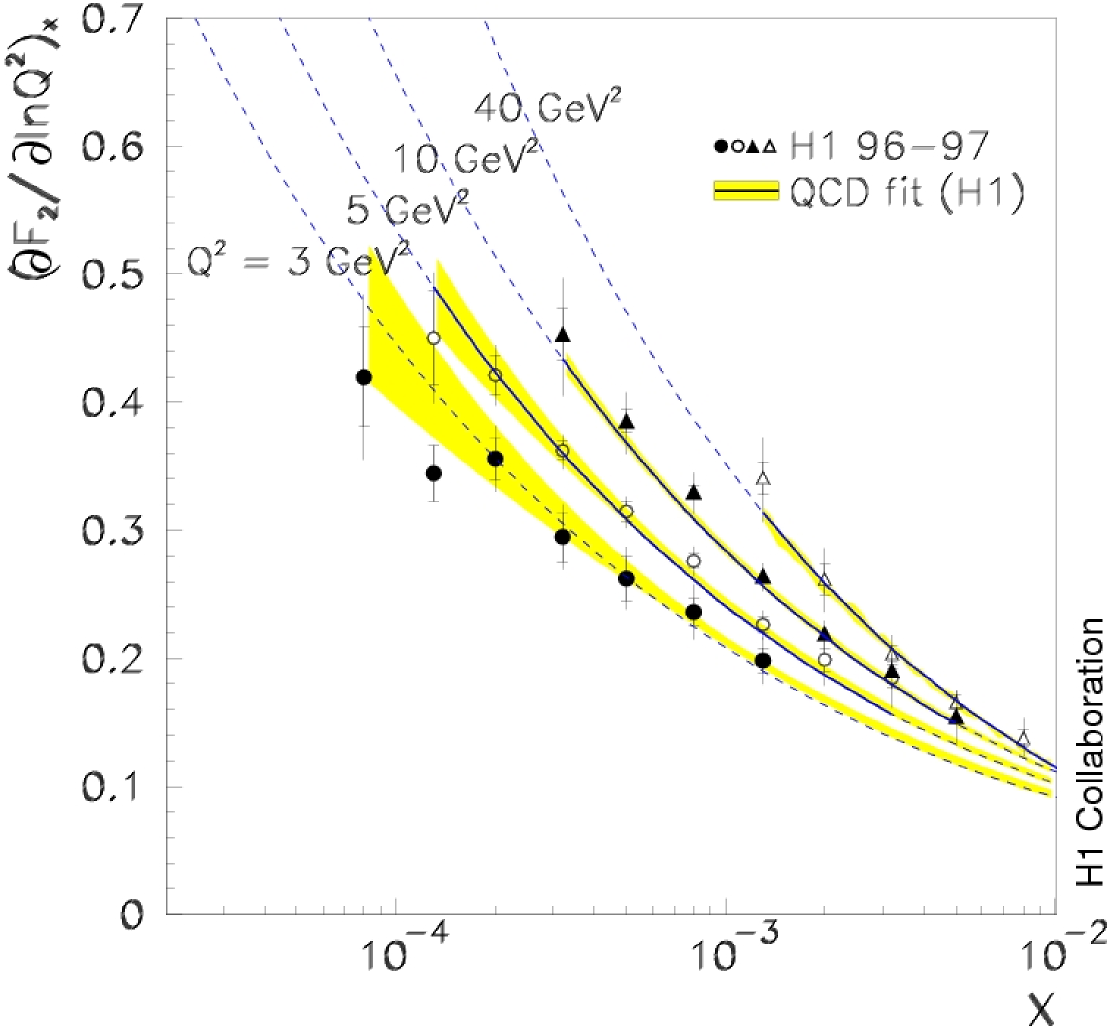
→ Within 1% over full range

Gluon density determination

Gluon	$dF_2/dln(Q^2)$
	Jet cross sections
	$F_2^{c\bar{c}}$
	F_L

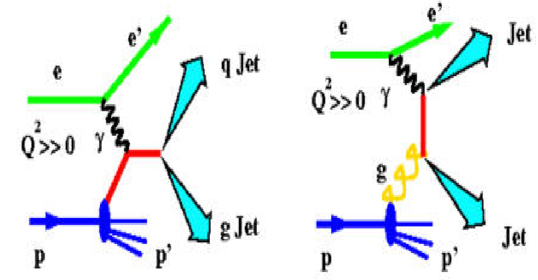
Gluon density from F_2 scaling violations

$$\left.\frac{\partial F_2}{\partial \ln Q^2}\right|_x \propto \alpha_s(Q^2)\,x g(x,Q^2)$$

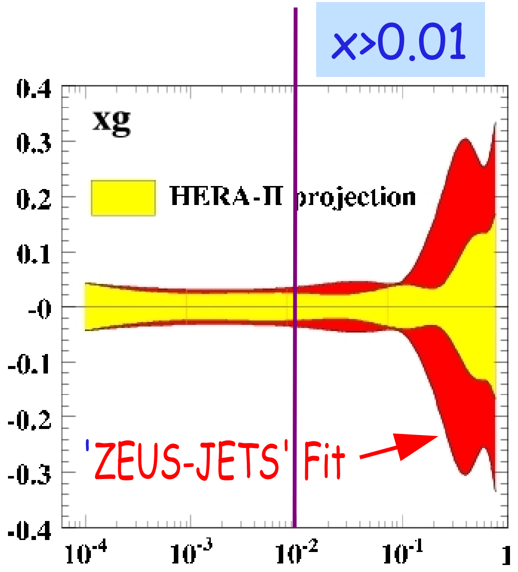


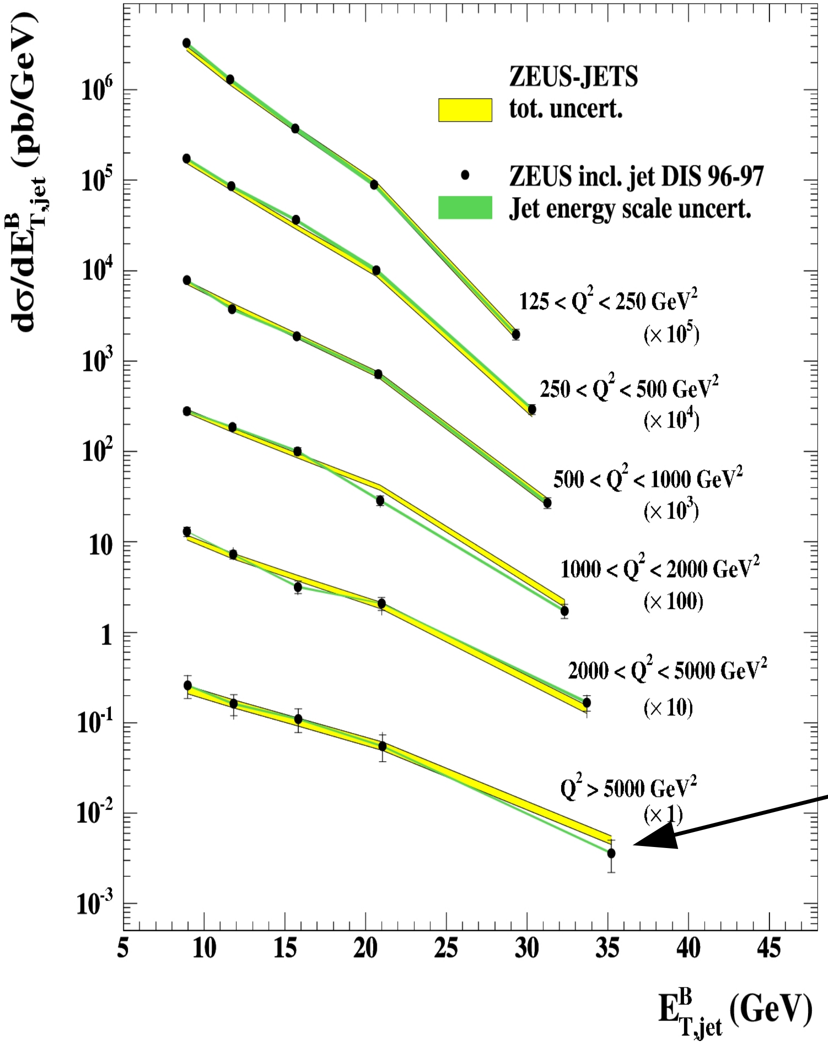
➔ More precision desirable, expect improvements, e.g from analysis of H1 2000 Data

Gluon from jets

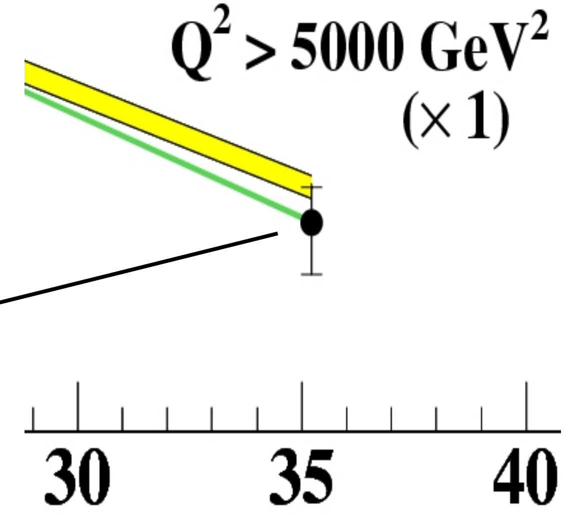


QCD-COMPTON BGF





ZEUS: assuming 1% Jet energy scale error above E_t^{lab} > 10 GeV



➔ At high Q^2 and/or E_t HERA II jet data will remain statistically limited

α_s determination from Jets

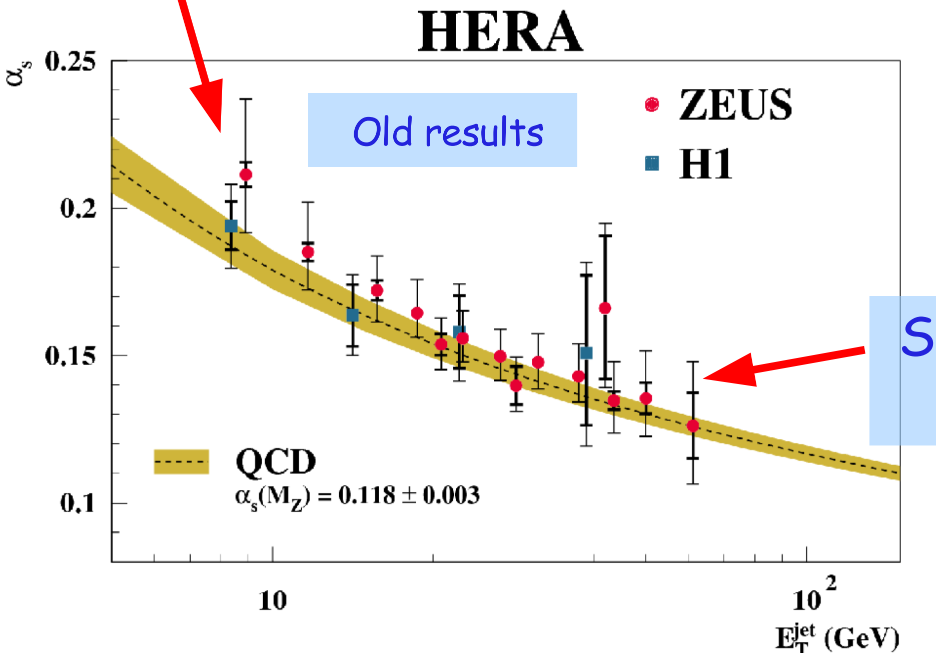
Expect ~70 k inclusive jets
for $Q^2 > 125$ GeV^2 with 350 pb^{-1}

Estimated final H1 exp. precision for $\alpha_s(m_Z)$ from incl. jets:

± 0.0004 (stat.)

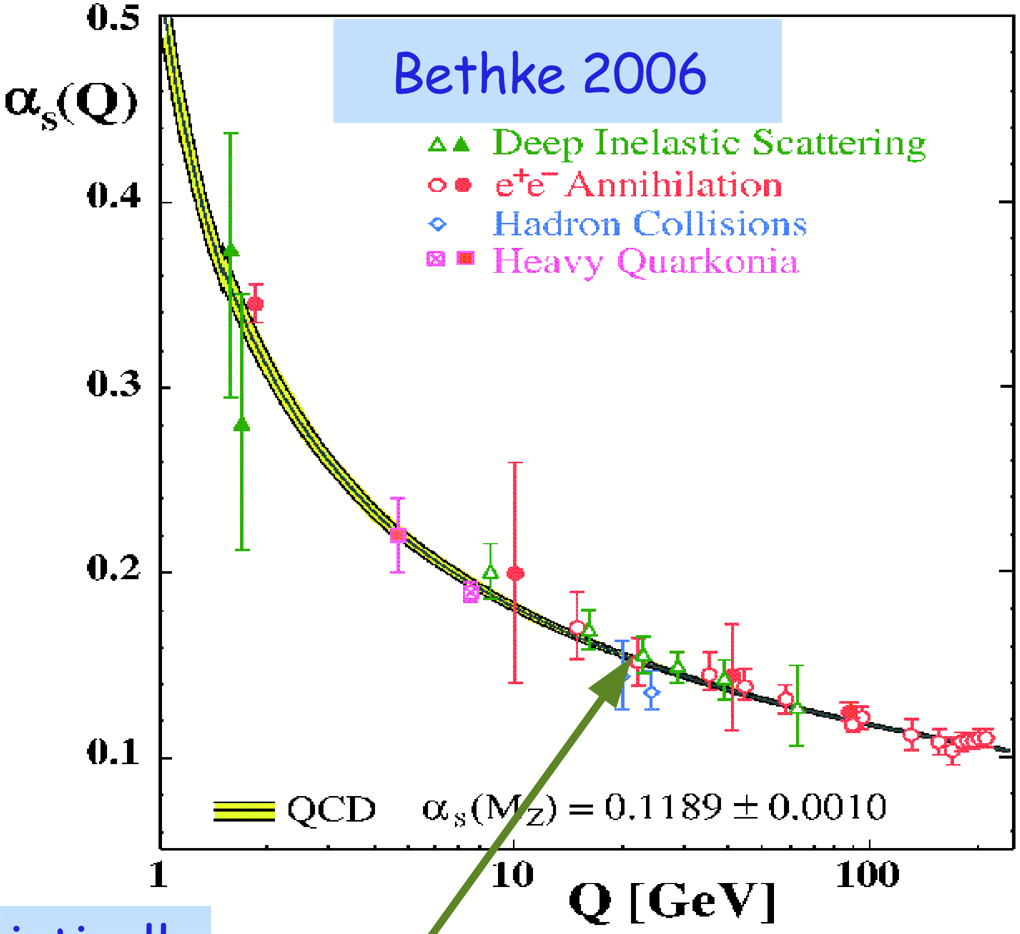
± 0.0030 · σ(had.Escale)/4%

Syst. limited datapoints



Old results

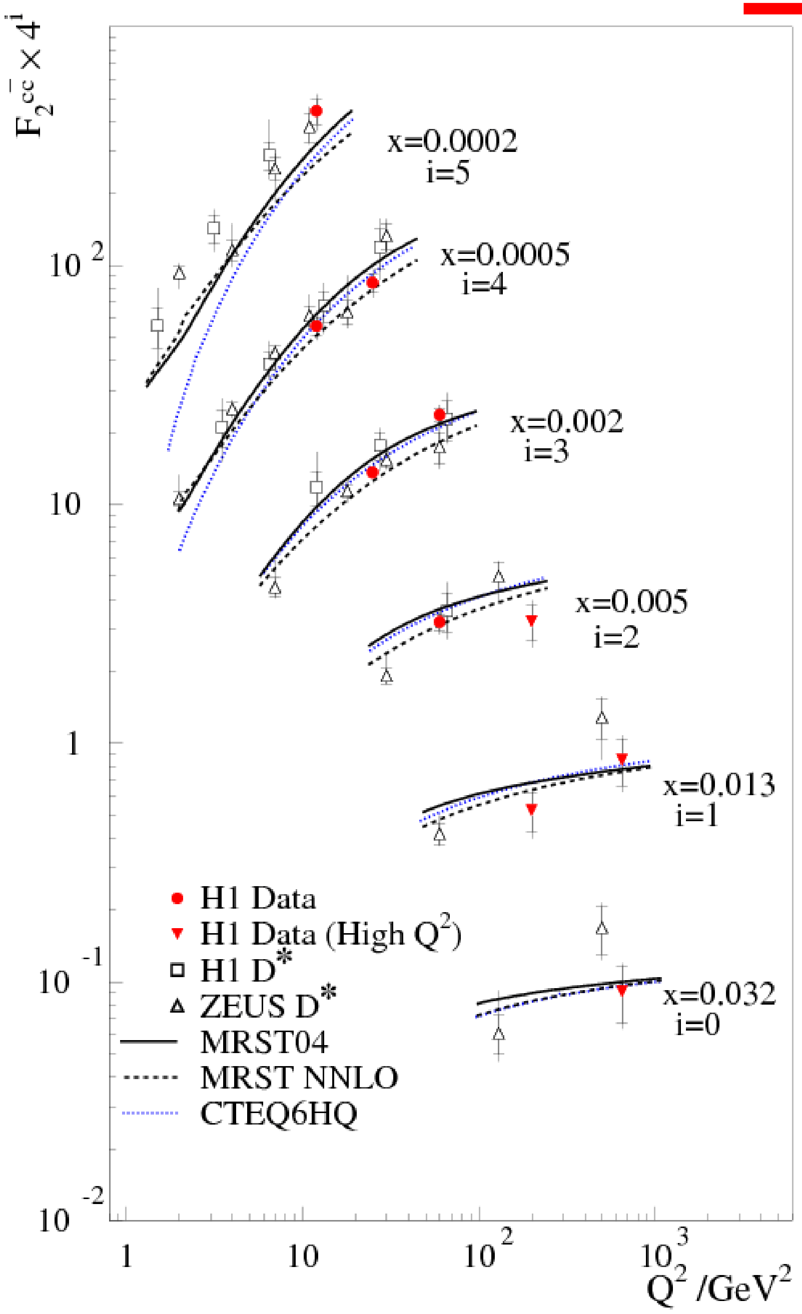
Statistically limited

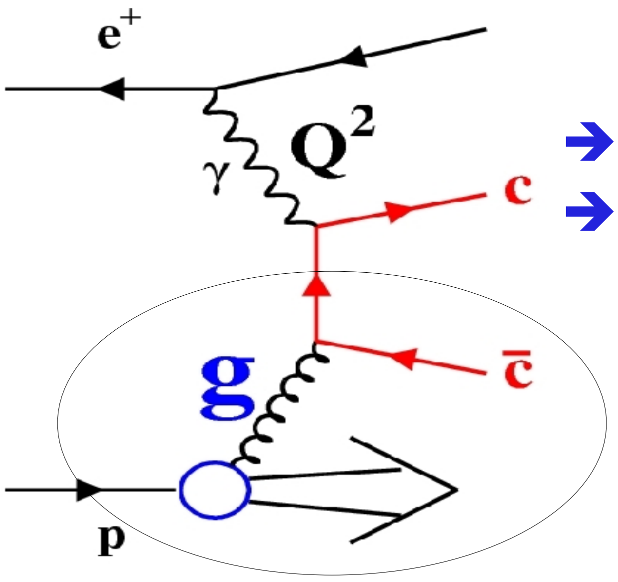


Bethke 2006

Final HERA points will be more precise up to factor of ~2

F_2^{cc}





- ➔ D*, D+, etc.
- ➔ Displaced tracks

HERA I: H1 displaced tracks:

Q^2 [GeV^2]	σ_{stat}	σ_{sys}	σ_{tot}
25	~6%	~8%	~10%
650	~22%	~15%	~27%

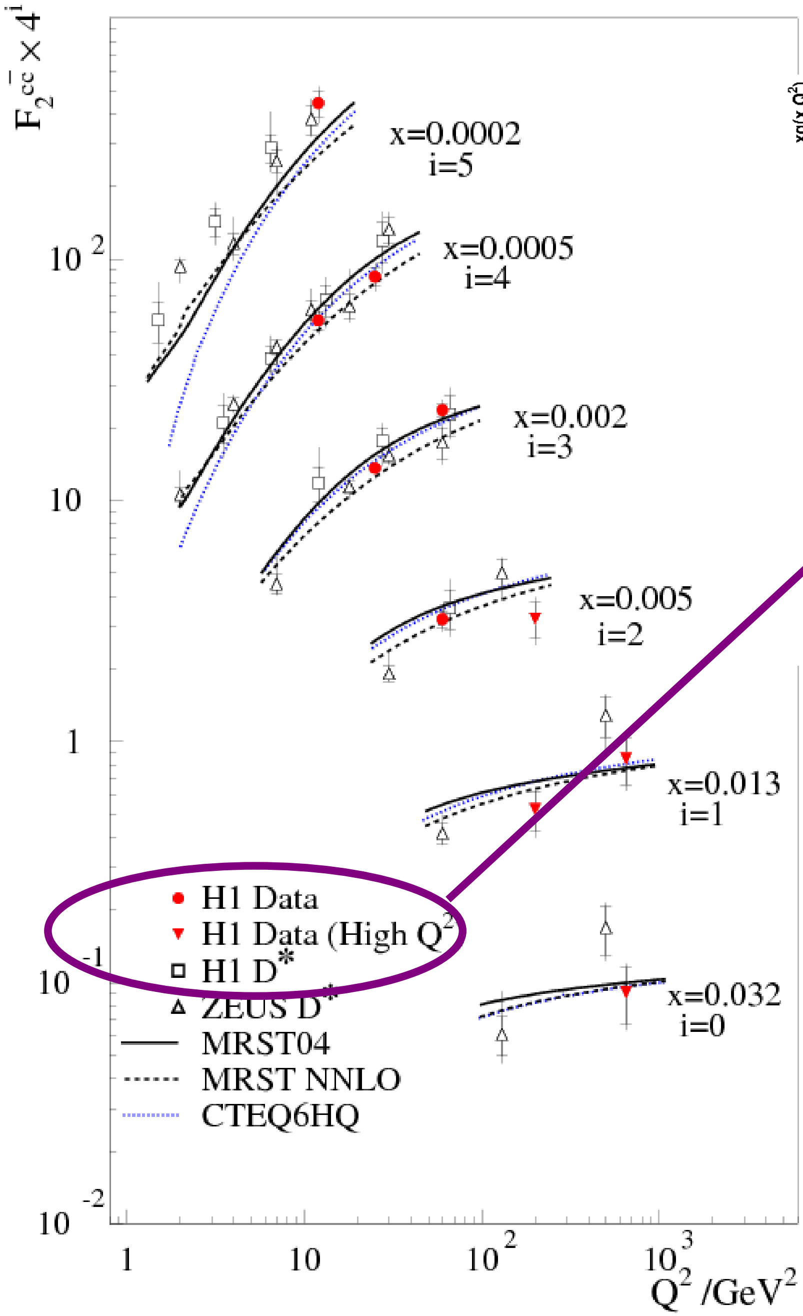
HERA II Projection:

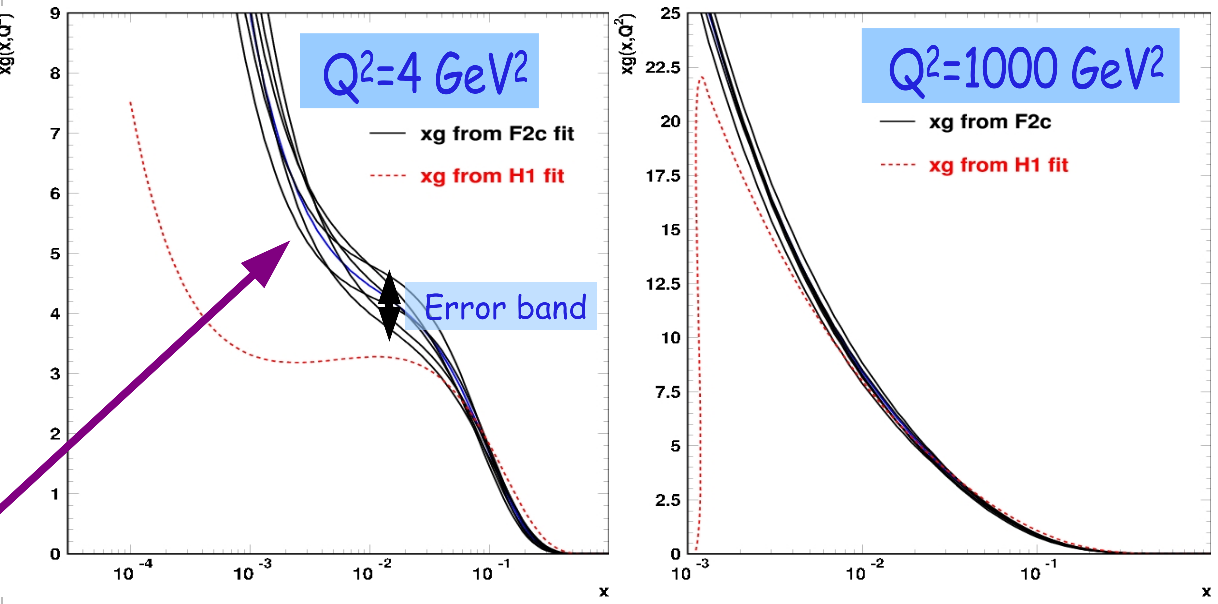
Q^2 [GeV^2]	σ_{stat}	σ_{sys}	σ_{tot}
25	~3%	~4%	~5%
650	~10%	~10%	~14%

+ ZEUS!
+ D* tagging

➔ Enter 'Sub 5% precision era'

Gluon density from F_2^{cc} alone

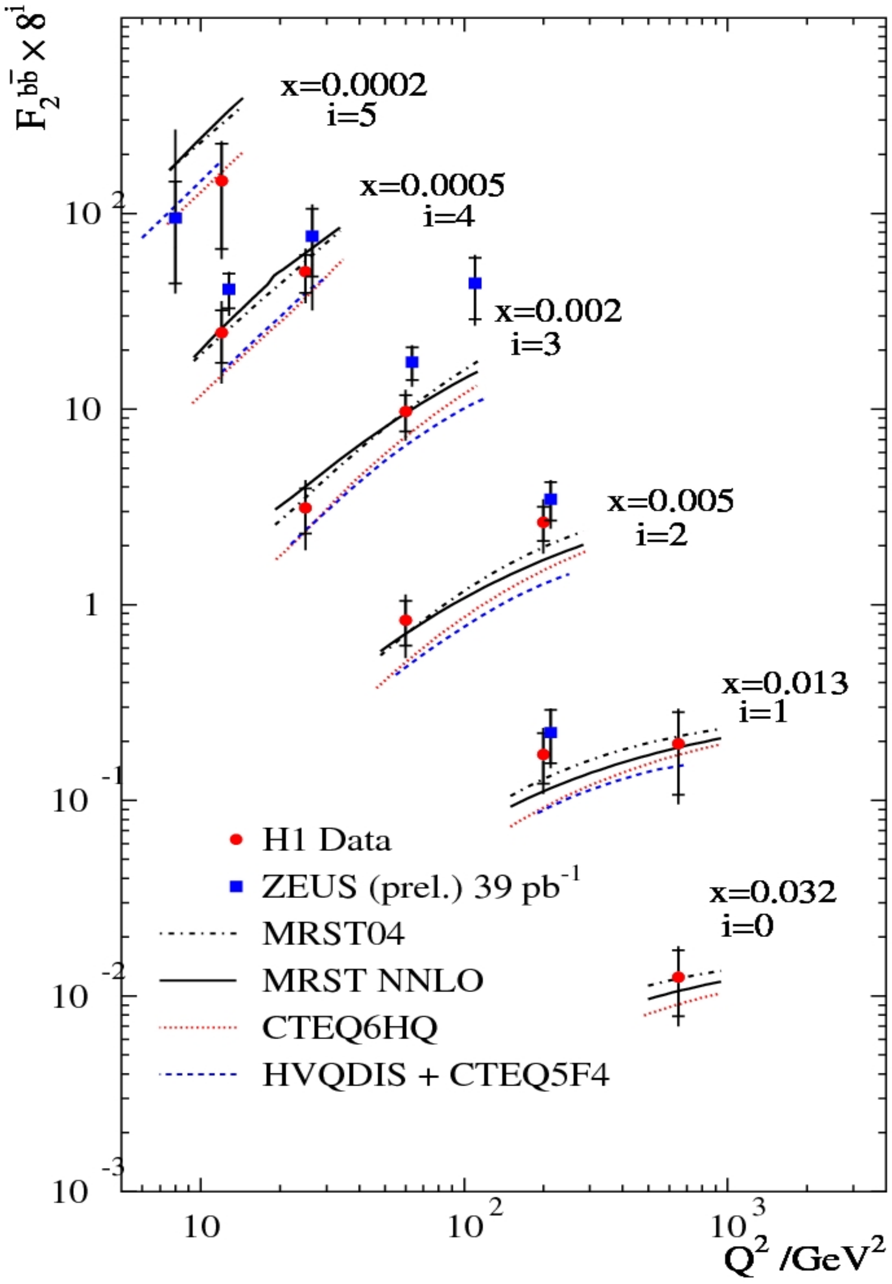


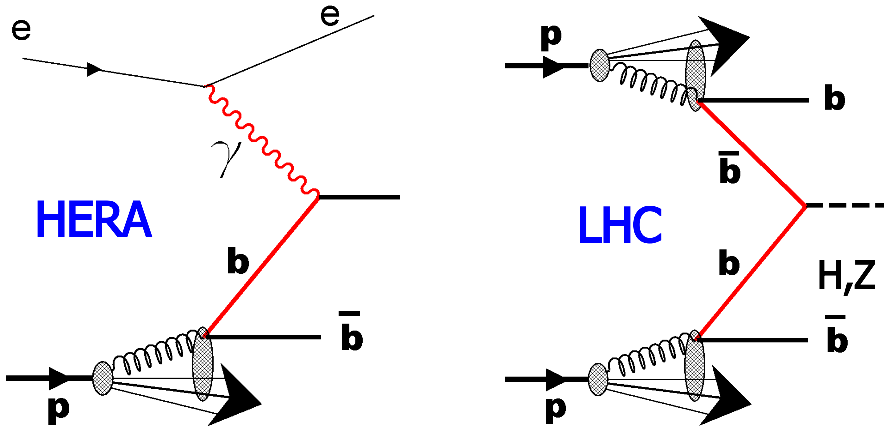


NLO DGLAP fit, experimental errors only, by K. Kutak

➔ With using only H1 HERA I data already relatively precise, providing strong test of consistency with gluon from inclusive DIS scaling violations

F_2bb





LHC luminosity monitor: Z^0 production

➔ gg ¹ bb ¹ Z^0 is 5% of total

➔ Must be known at 20% for 1% accuracy

HERA I: H1 displaced tracks:

Q^2 [GeV^2]	σ_{stat}	σ_{sys}	σ_{tot}
25	~20%	~20%	~30%
650	~40%	~25%	~50%

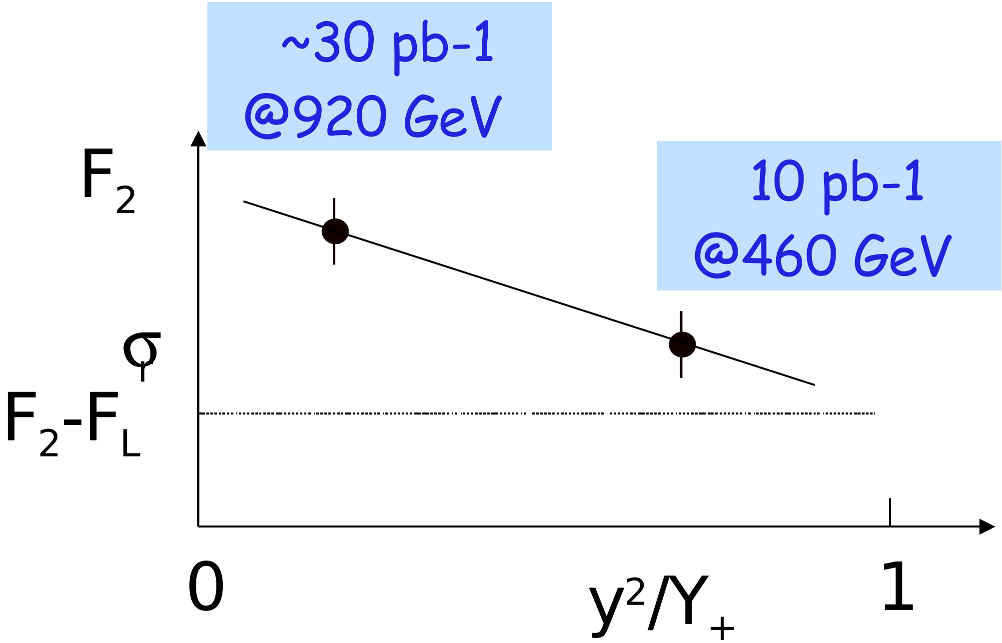
HERA II projection:

Q^2 [GeV^2]	σ_{stat}	σ_{sys}	σ_{tot}
25	~10%	~10%	~15%
650	~20%	~20%	~30%

+ ZEUS!
+ other tagging

➔ 20% goal seems reachable

F_L measurement with 3 months low energy run



~30 pb-1
@920 GeV

10 pb-1
@460 GeV

$$\sigma_r = \left(\frac{2\pi\alpha^2 Y_+}{xQ^4}\right)^{-1} \frac{d^2\sigma}{dx\,dQ^2} = \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)\right]$$

$$F_L(x,Q^2) = \frac{\sigma_r(x,Q^2,y_1) - \sigma_r(x,Q^2,y_2)}{f(y_2) - f(y_1)}$$

$$f(y) = {y^2}/{Y_+}$$

$$F_L = \frac{\alpha_S}{4\pi} x^2 \int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum e_q^2 (1 - {x}/{z}) zg\right]$$

Directly sensititve to gluon density

- Machine Preparation
- Physics prospects

LOW ENERGY MACHINE STUDIES

- **460 GeV tests done on 6.11.06, 6-8.12.06, 16.1.07 and 31.1-2.2.07**
- ***ep* collisions with 5x10 mA^2 in 20x20 bunches observed in H1 and ZEUS on 2.2.07**
- **Specific lumi was 0.35 in standard units, down by a factor 4.5 compared to 920 GeV (factor 4 expected from optics scaling)**
- **H1 could turn on the chambers but observed high beam wall interaction BG due to a horizontal interaction shift by 3mm. BG is expected to be tuned during the low energy run setup phase.**

➔ Succesful HERA machine preparations

The low energy run will start 19.3. and end 2.7.

12/02/07 H1 status report to PRC 15

Low energy run, F_L and gluon density

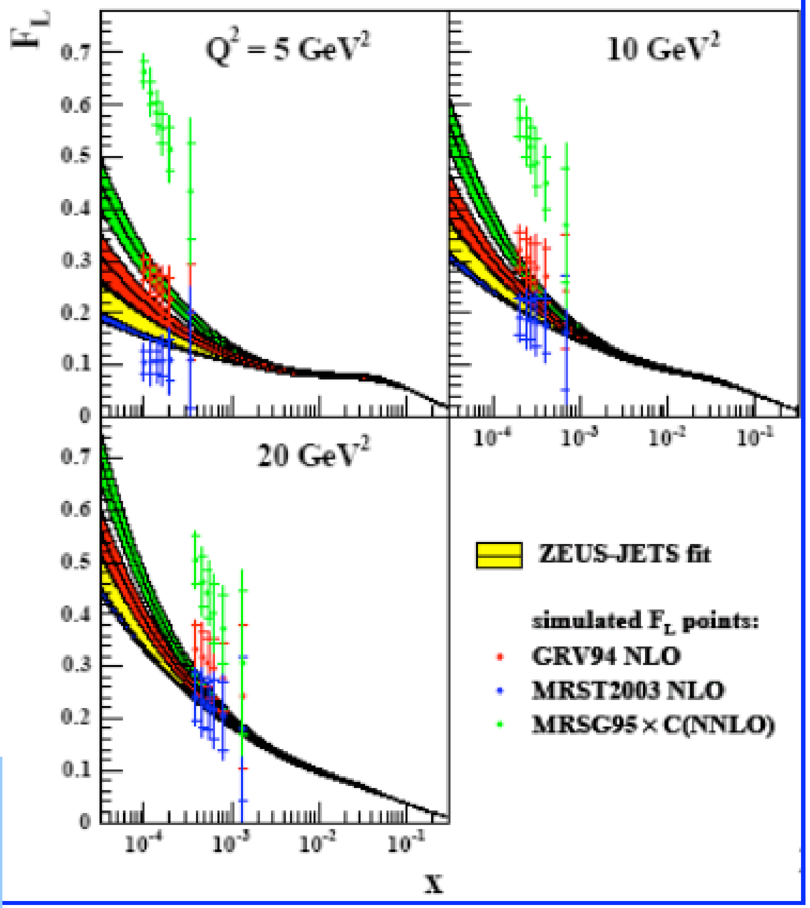
- F_L predictions very sensitive to underlying theory
  → choice of PDF, order of QCD calculation …
- how sensitive is the NLO QCD fit to inclusion of "extreme" sets of simulated F_L data?

Simulated F_L data

extremes provided by Robert Thorne (Cambridge)

	PDF	QCD theory
Max. F_L	MRSG95	NNLO*
Mid. F_L	GRV94	NLO
Min. F_L	MRST2003	NLO

- ZEUS fit relatively stable to inclusion of extreme F_L data-sets
- an F_L measurement of this precision should have power to discriminate between theoretical models



Note: These simulations used somewhat different scenario for proton low energies and luminosities but leading to comparable precision for F_l

C.Gwenlan (HERA-LHC workshop)

Some of the many topics not covered in this talk

- Diffraction:
  - High precision diffractive PDFs –> predictions for LHC
  - Deeply virtual compton scattering ->Test proton transverse degrees of freedom
  - Vector mesons at highest t -> Test of BFKL dynamics

- Hadronic final state:
  - Dijets: How well can we determine 'intrinsic kt' of gluon in p?
  - Multiple interactions/underlying event: Potential of HERA to tune models for LHC?
  - Identified particle spectra

- Beyond standard model: Quark radius limit?

Conclusions:

- ➔ Final HERA II yield: ~360 pb-1 per experiment,
  H1 and ZEUS have collected together
  ~1 fb^{-1} good HERA data

- ➔ Now write the "HERA handbook" of
  Highest precision proton gluon and quark densities
  (improvements at hand often factor ~2, sometimes much more)
  exactly as needed @LHC

- ➔ Complete HERA mission with low energy run starting now for
  direct F_L measurement