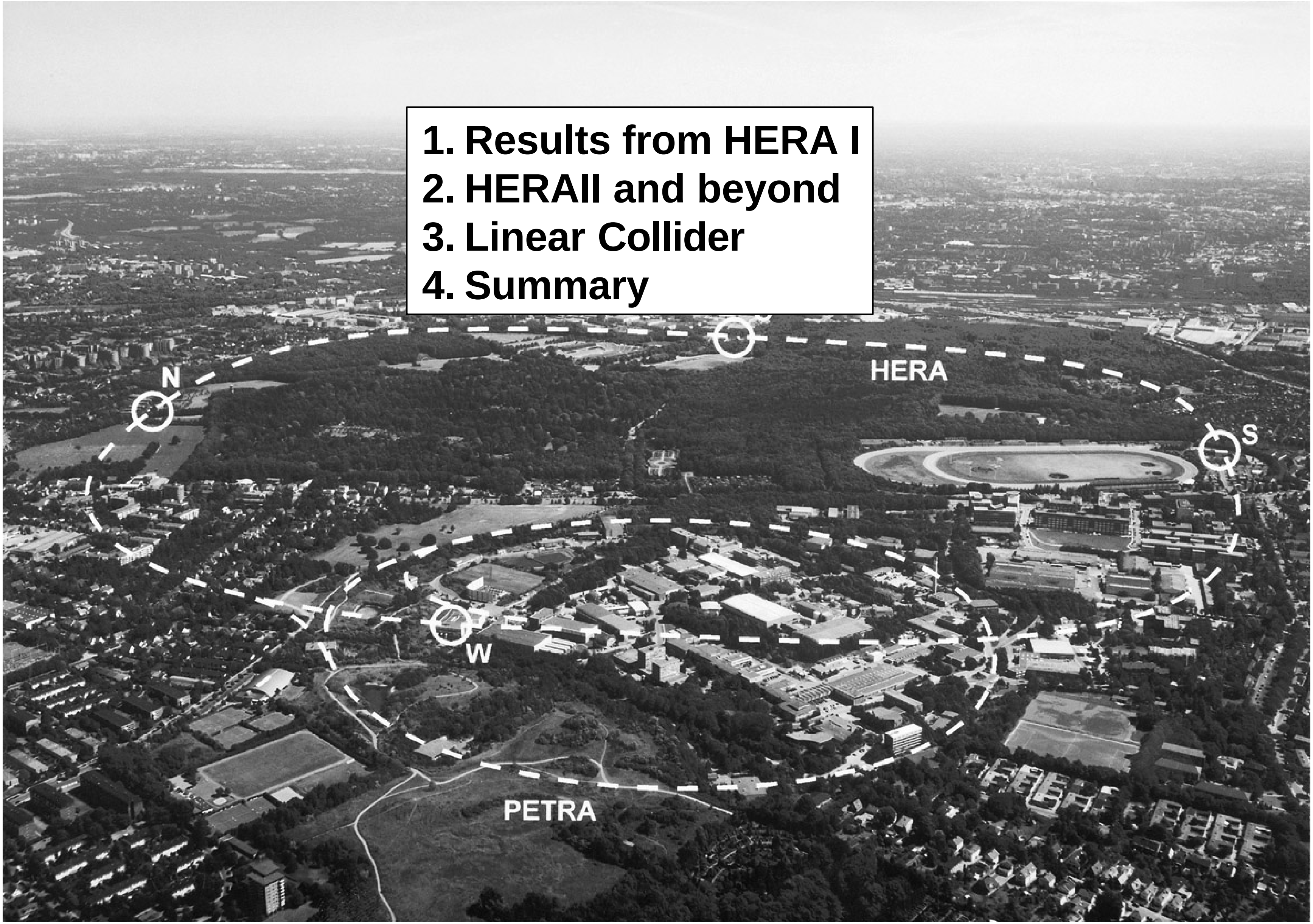
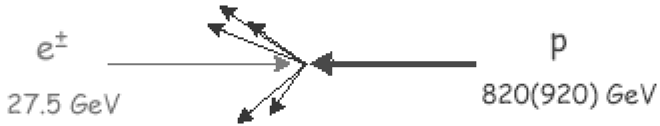
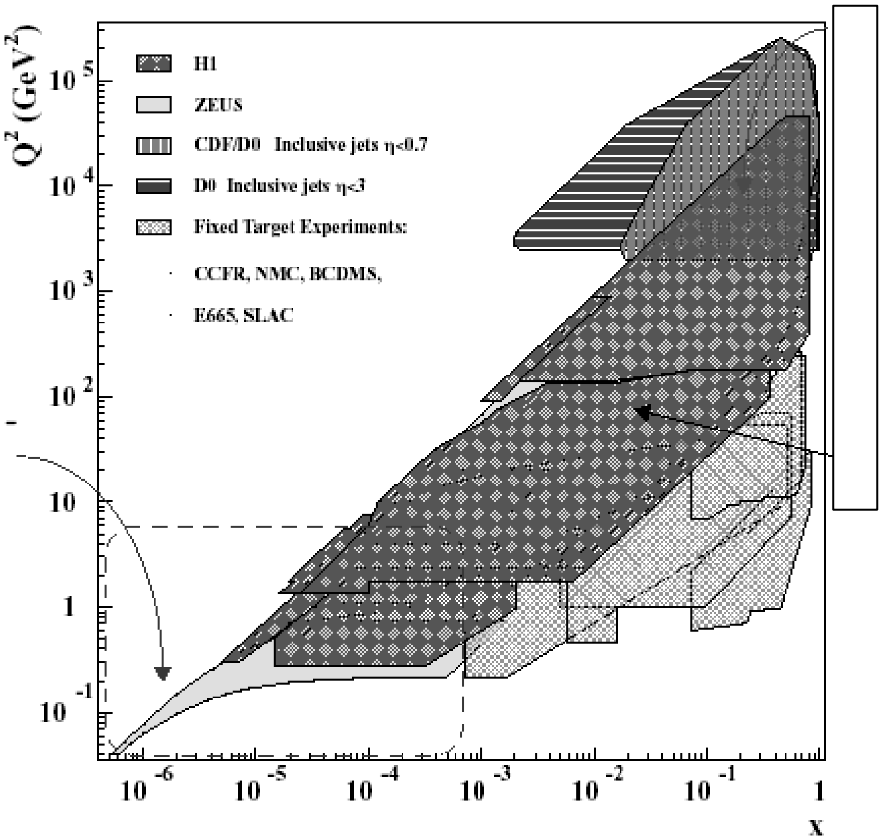


1. **Results from HERA I**
2. **HERAII and beyond**
3. **Linear Collider**
4. **Summary**

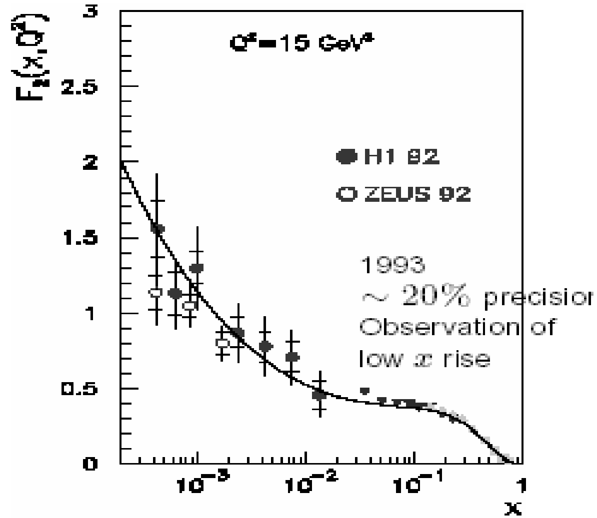
HERA the world's only ep collider



HERA I: 120 pb^{-1} $e^{+}p$, 15 pb^{-1} $e^{-}p$

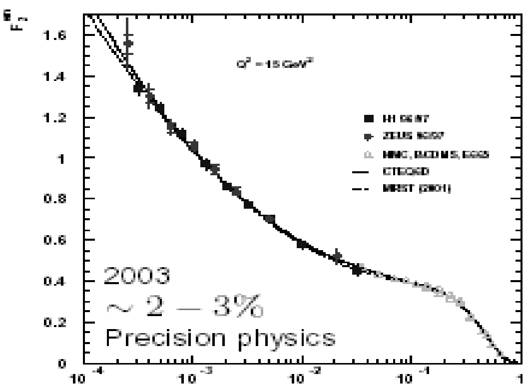


Major task for HERA: precision measurement of proton structure



1992

dF_2: ~20%



2003

dF_2: 2-3%
in big part of
x-Q^2 plane

precision measurement F_2 ✓

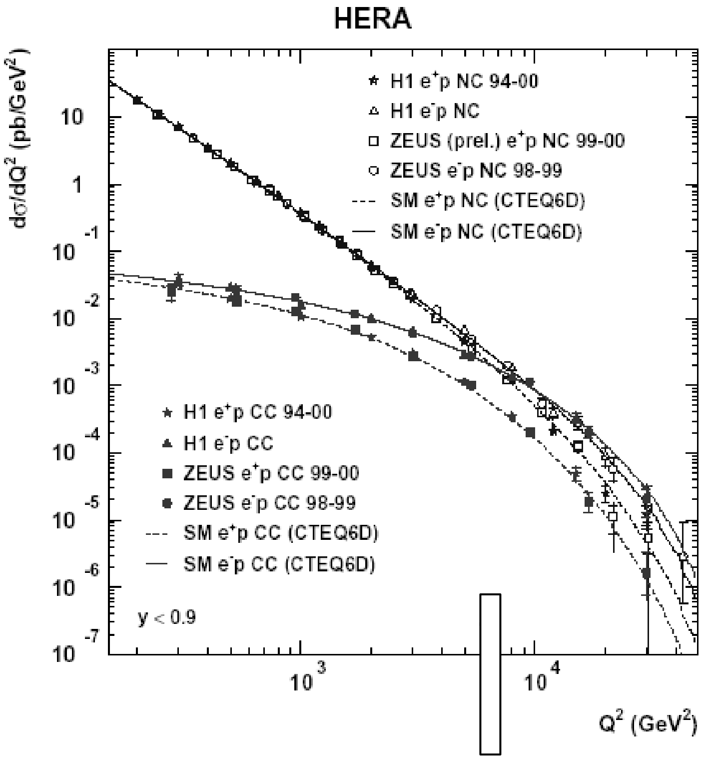
aim: further improvement to 1%

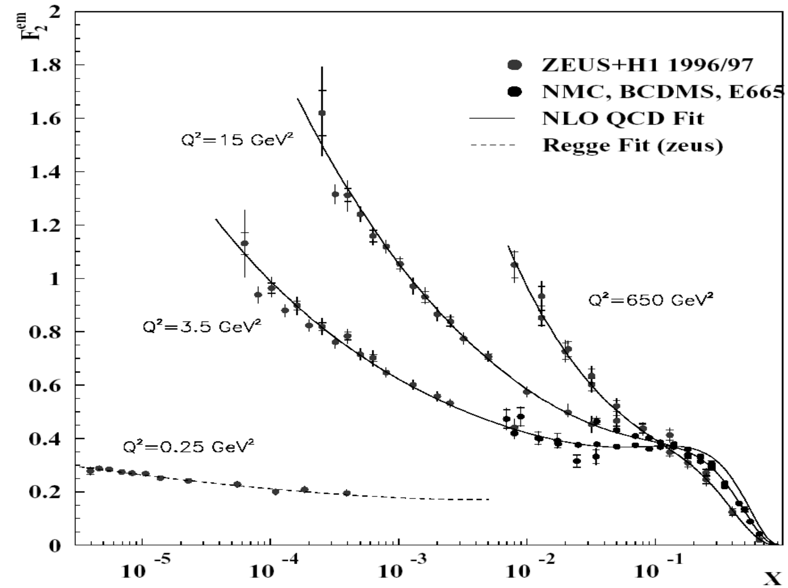
Proton parton densities

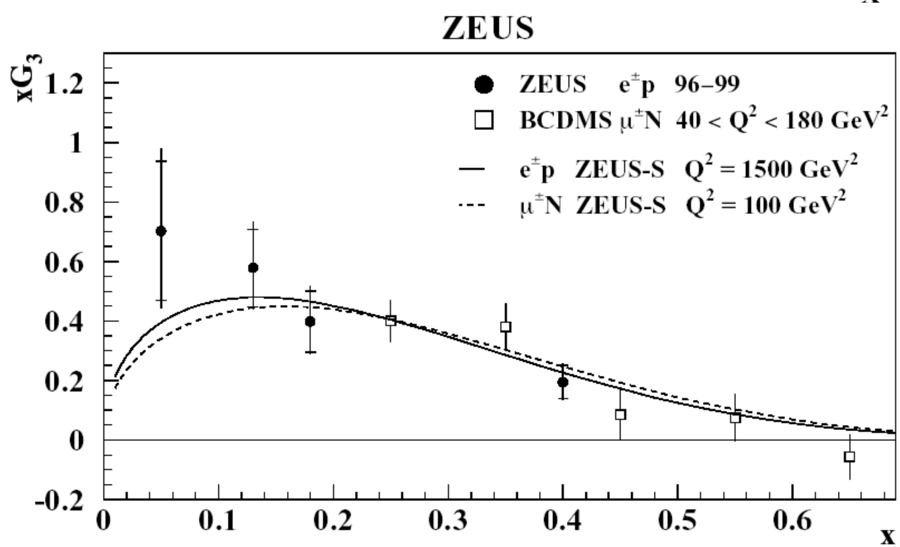
Flavour decomposition

unknowns: $u_v, d_v, u_s, d_s, s, .., g$
processes: DIS,DY,jets,…
e.g. DIS:

- NC-low Q^2: $\sim \bar{q}+q$
- NC-high Q^2: $e^-p - e^+p \sim q - \bar{q}$
- CC: $e^+p \sim \bar{u}+\bar{c} + (1-y^2)(d+s)$

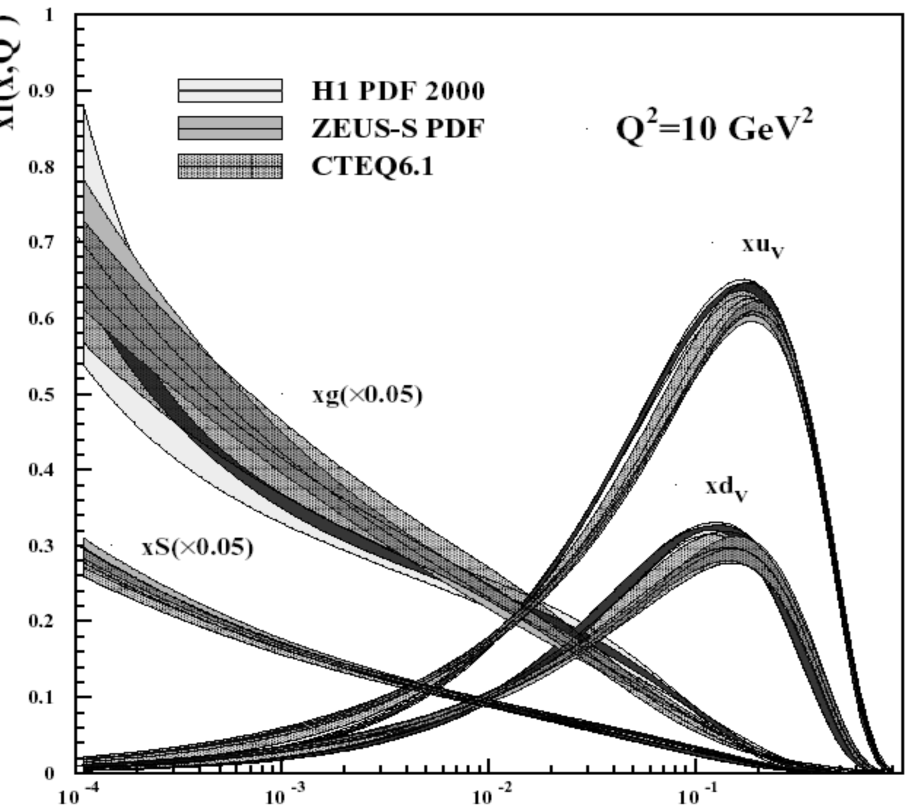






Results of QCD-fits to SF-data:

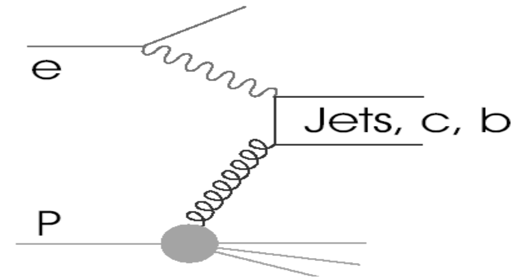
- **only DIS: theor. clean (H1, ZEUS)**
- **global fits: DIS, DY, jets, W/Z → more constraints (CTEQ,MRST,…)**

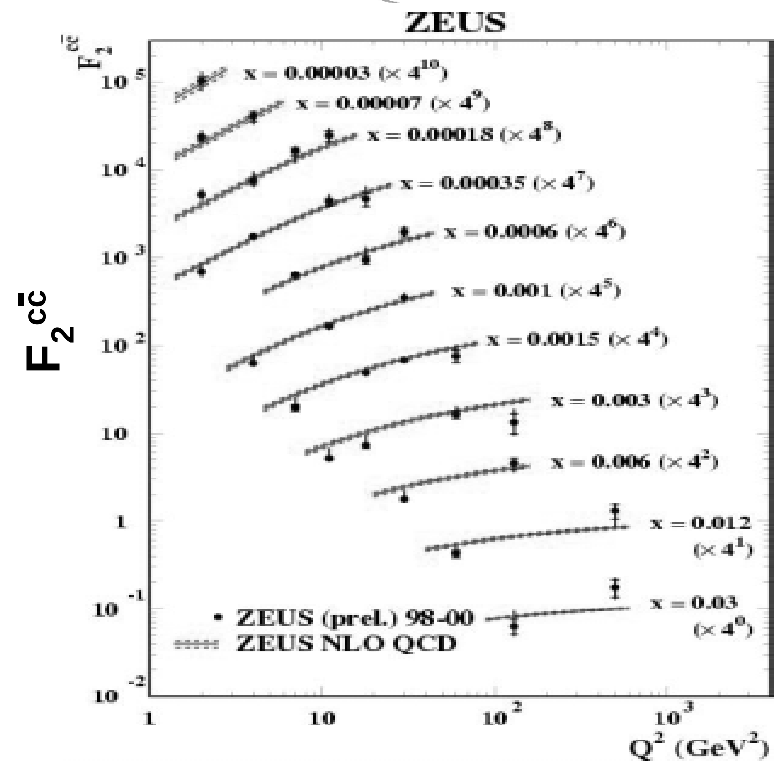


Precision HERA-only ~ global fits
precision at high x needs HERA II

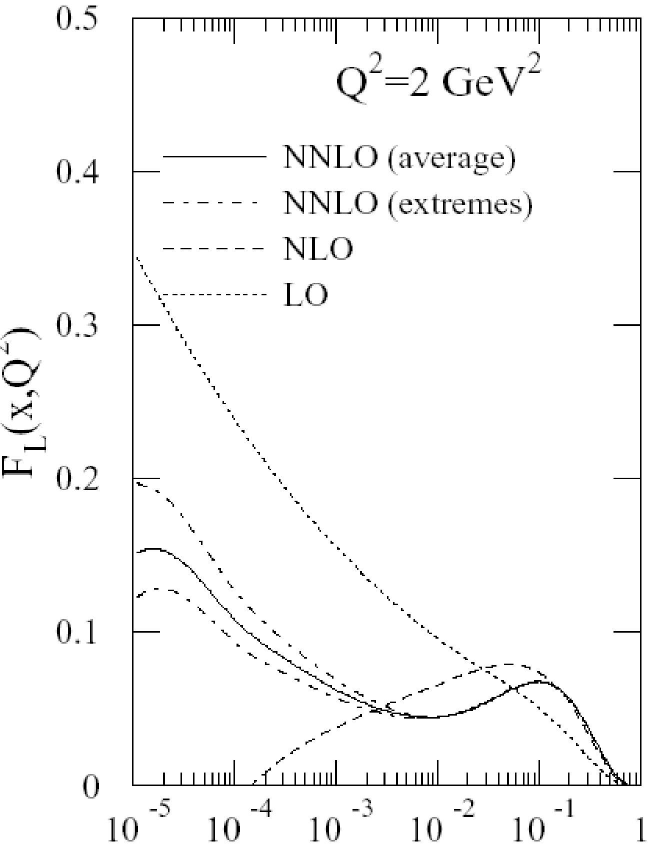
Check consistency of pdfs:

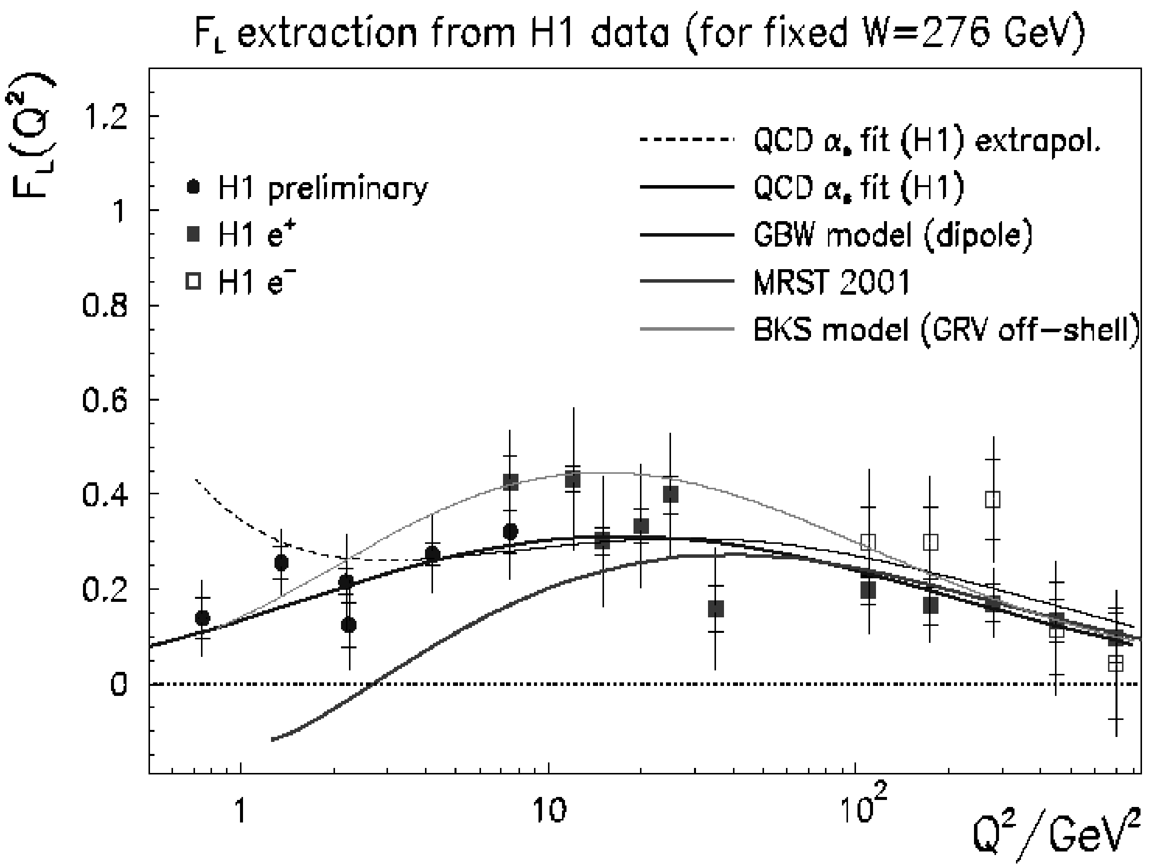
heavy flavour production ~ xg in LO





Check consistency pdfs: F_L longitudinal structure function: xg in NLO (extraction from $s_r = F_2 - (y^2/Y_+)\, F_L$ - measurement needs reduced vs_{ep})



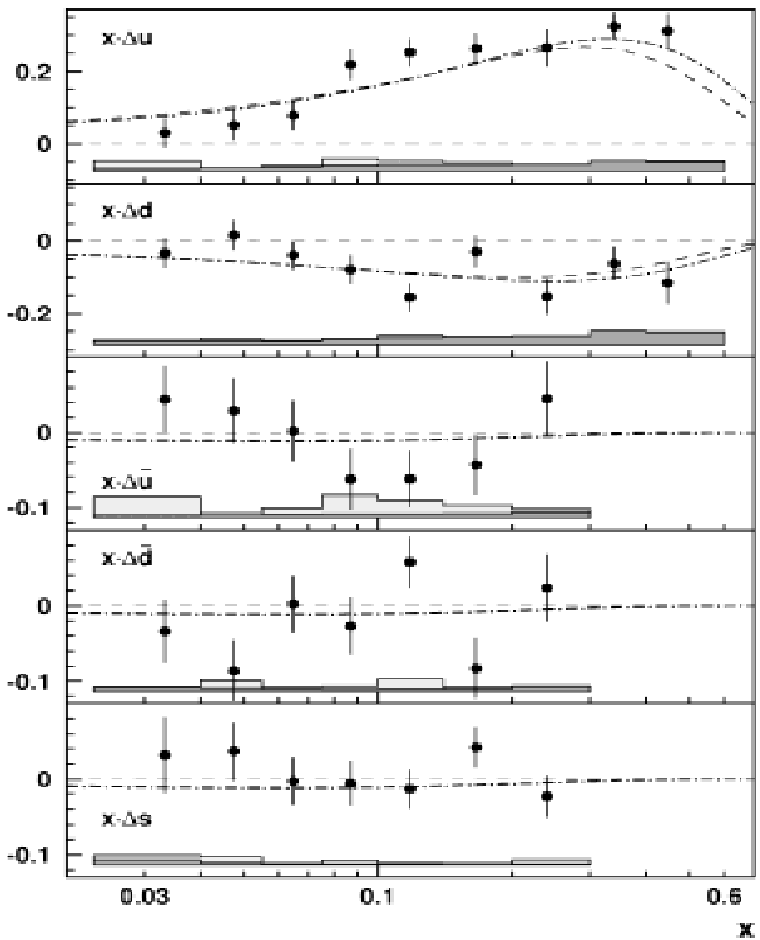


sensitivity – uncertainty to F_L

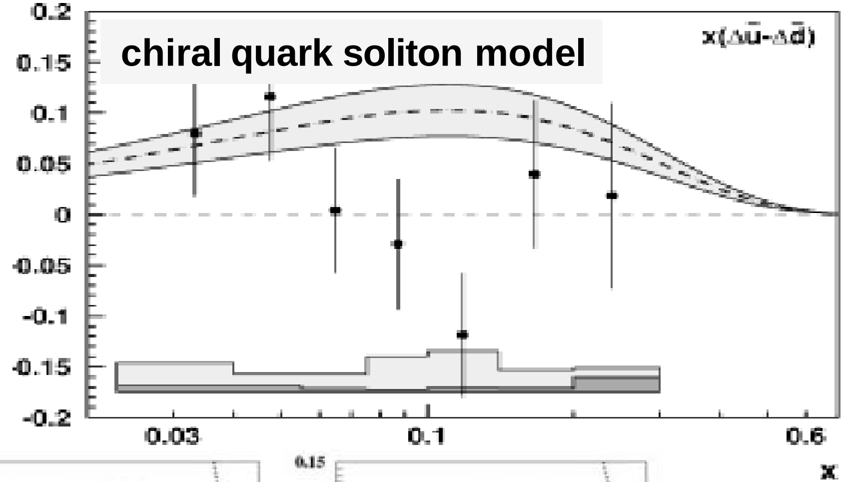
HERA F_L results consistent with (some of) the pdf-determinations

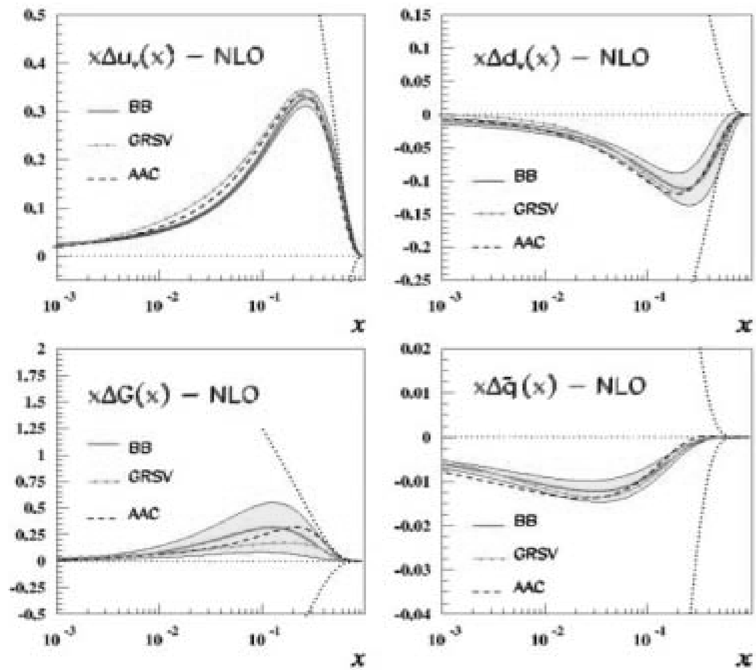
***N*-spin: $\frac{1}{2}=\frac{1}{2}(\Delta u_v+\Delta d_v+\Delta q_{sea})+\Delta q+Lq+Lg$**

flavour decomposition by HERMES by tagging leading particles (p, K)



$D\bar{u}$-$D\bar{d}$: spin asymmetry of sea ?

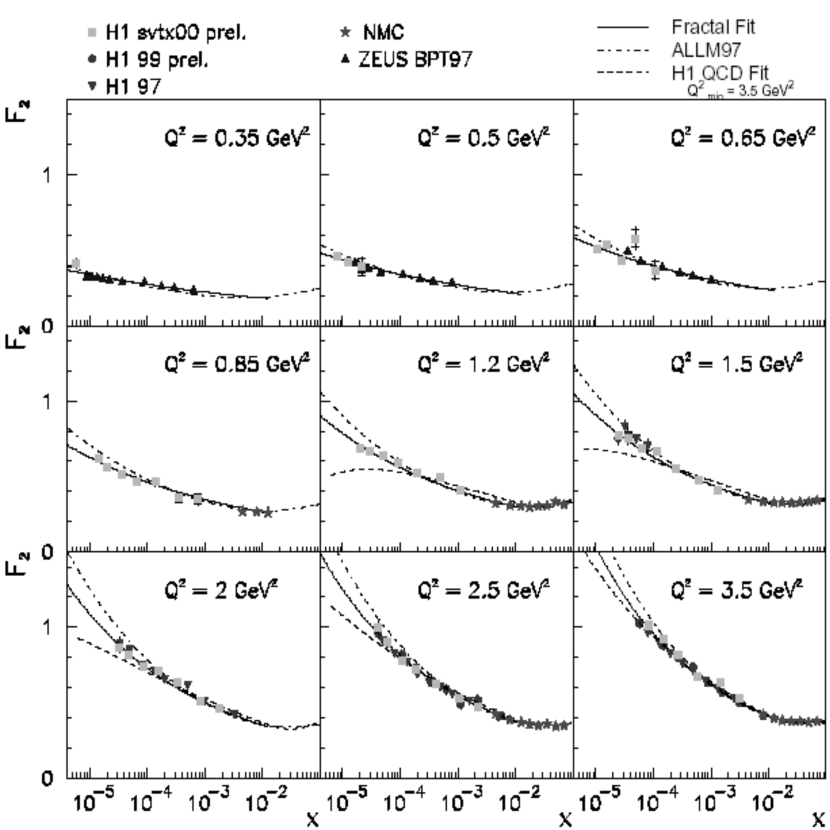




NLO QCD-fits

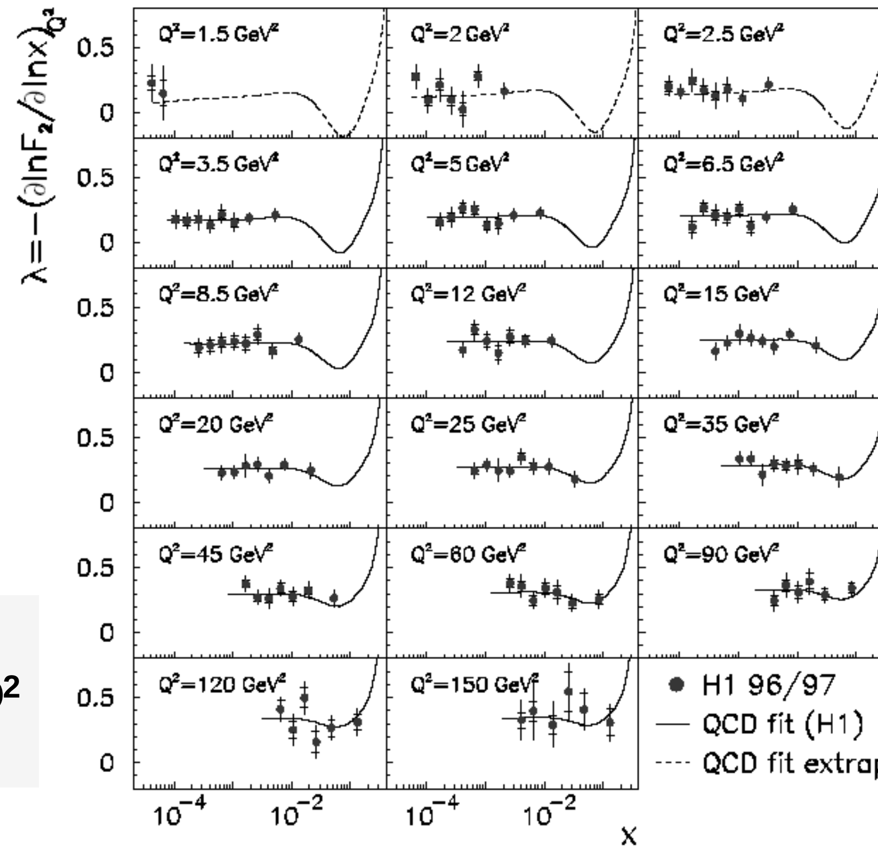
u ✓
d ✓
G hope soon
(Compass)

$F_2 \sim$ s (g*p) at low x (~1/$W_{\gamma^* p}$):



⇨

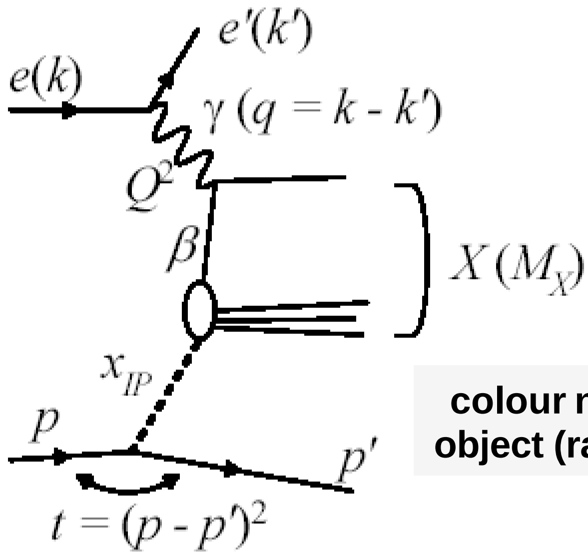
no direct evidence for saturation at HERA
(although models including saturation provide an excellent description of HERA data)



saturation:

- **expect flattening of s vs 1/x at fix. Q^2**
- **extract l = ¶F_2/ ¶lnx at fixed Q^2**

- Why does the proton stay intact in O(10%) of hard (soft) interactions?
- Does QCD describe diffraction?



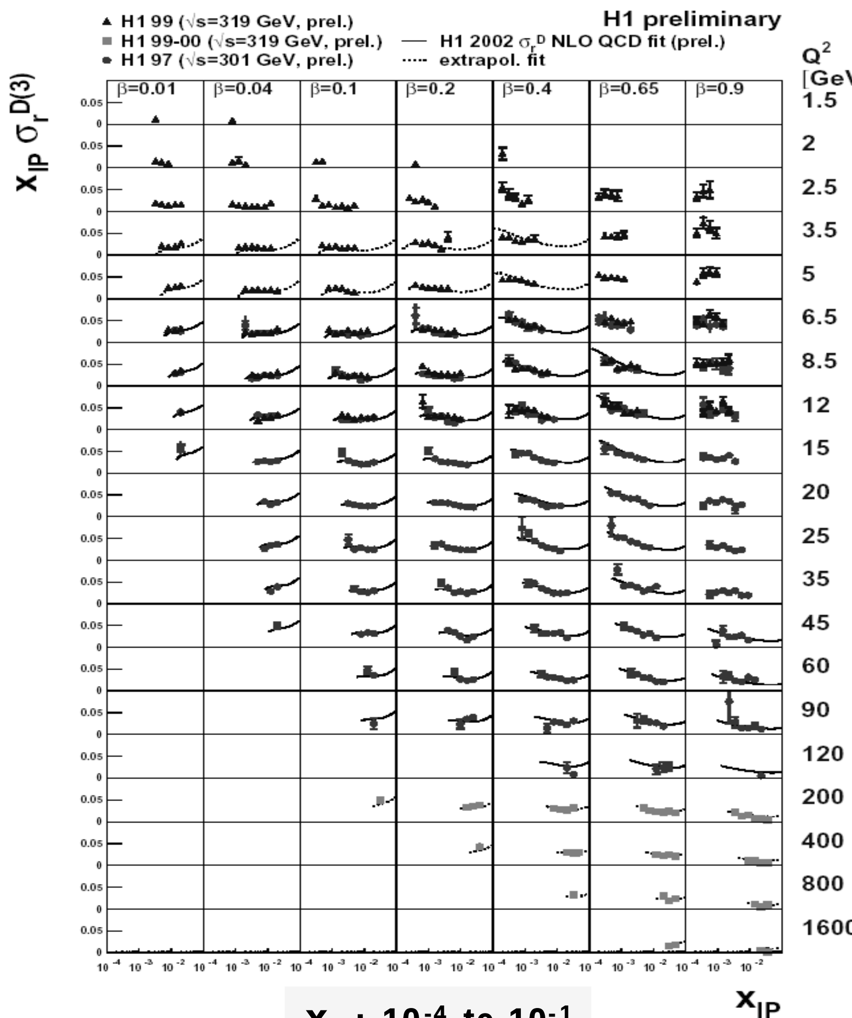
colour neutral object (rap.gap)

$F_2^D(\beta, Q^2, x_{IP})$ … structure function of exchanged system (IP)

β … long. moment fraction of parton in the exchanged system

x_{IP} … long. momentum fraction of the exchanged system in the proton

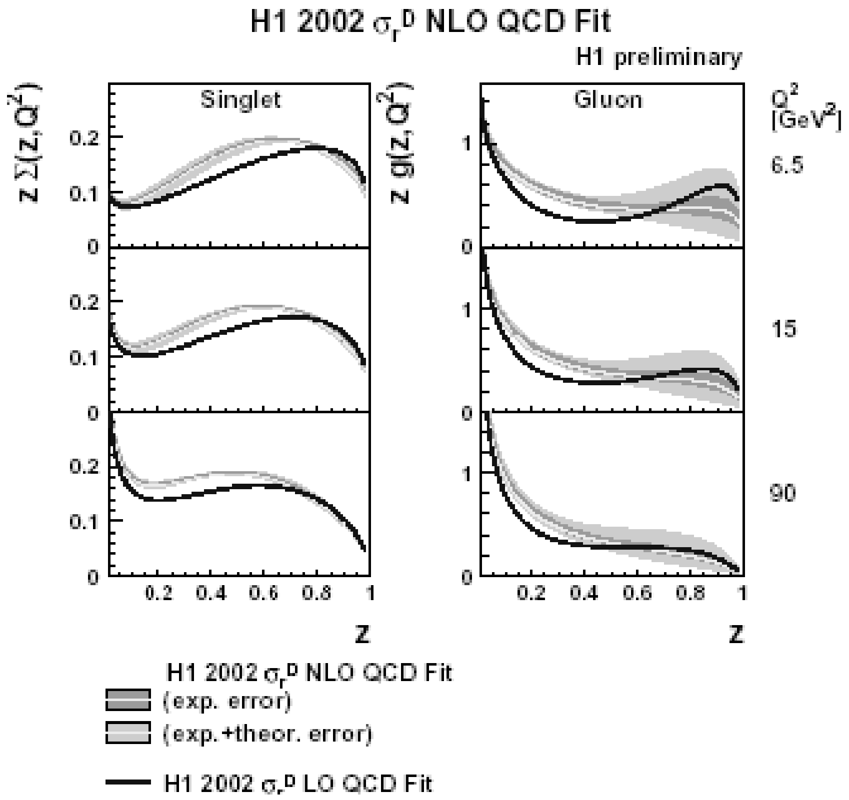
HERA I has produced precision measurements on hard diffraction



x_{IP}: 10^{-4} to 10^{-1}

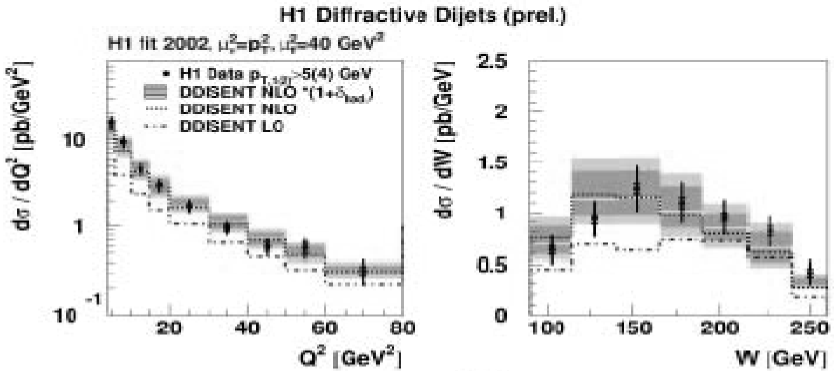
Diffraction at HERA

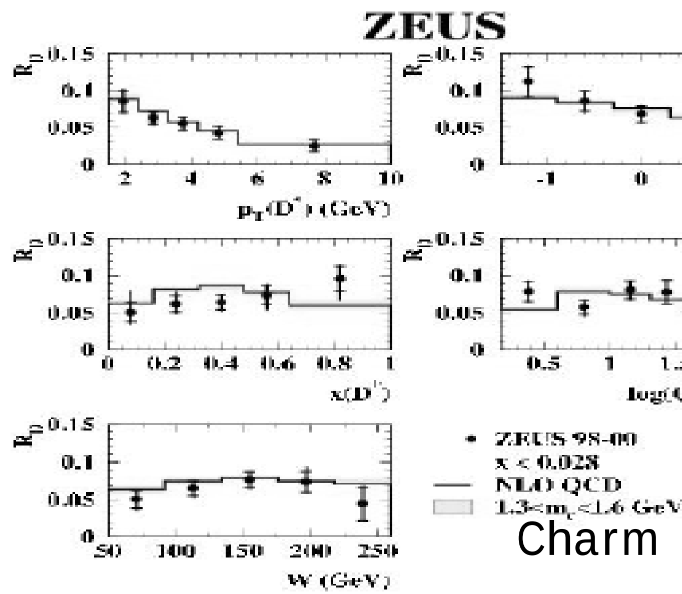
Extract diffractive structure function (using the standard QCD tools)



- **NLO QCD fits describe the data + allow to extract diffractive pdfs,**
- **large gluon contribution,**
- **pdfs can be used to predict s_{jet}, s_{charm},..**

Jets





Charm

Status: all hard diffractive processes at HERA can be described by NLO QCD but fail to describe TeVatron data

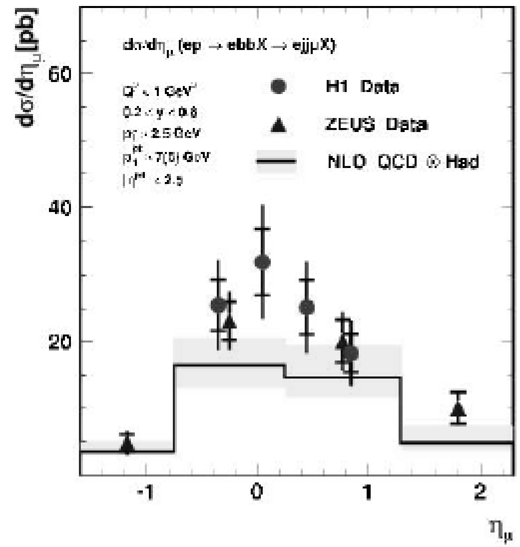
σ_b problem for p-QCD?

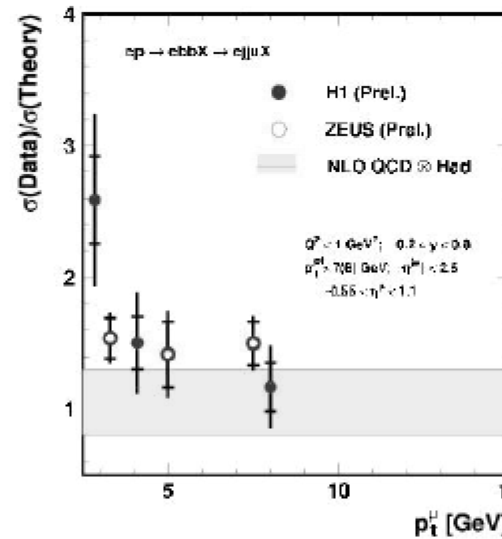
- **TeVatron: data/theory ~ 3**
- **HERA: data/theory ~3**
- **LEP $\gamma\gamma$: data/theory ~3**

several difficulties:

- **2 (3) scales: m_b, p_{Tb}, (Q^2)**
- **HERA/LEP: $m_b \sim p_{Tb}$ small**
- **b in photon?**
- **experimental S/BG ~ 1/1000**

Photoproduction





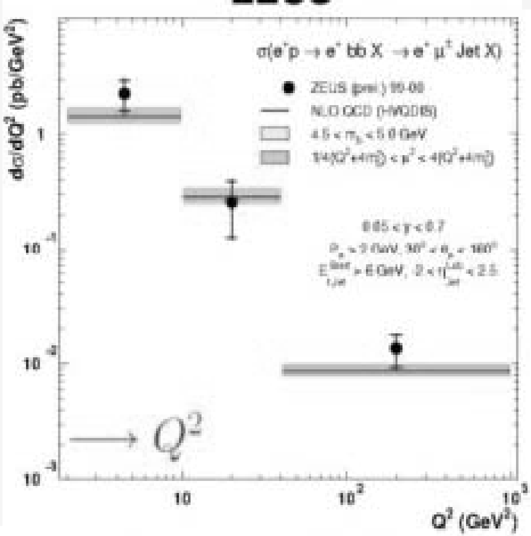
now: new more precise data only slightly above NLO

- **before: extrapolate data to parton level with LO+PS**
- **now: apply hadronisation to NLO in experimental phase space**

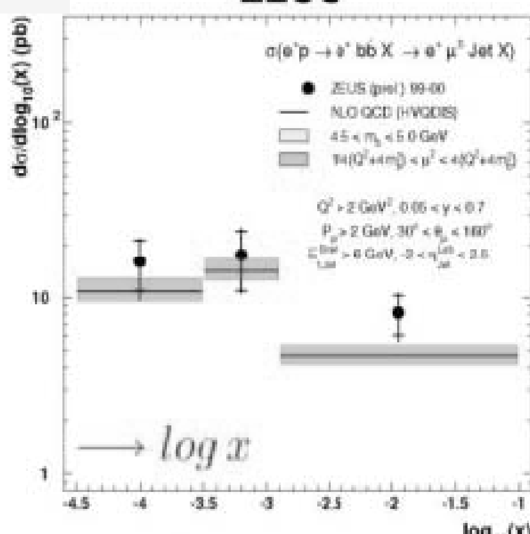
HERAII with higher *L* and improved detectors will resolve issue

DIS

ZEUS



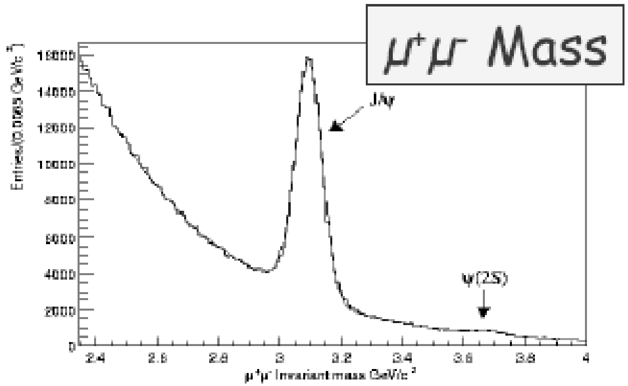
ZEUS

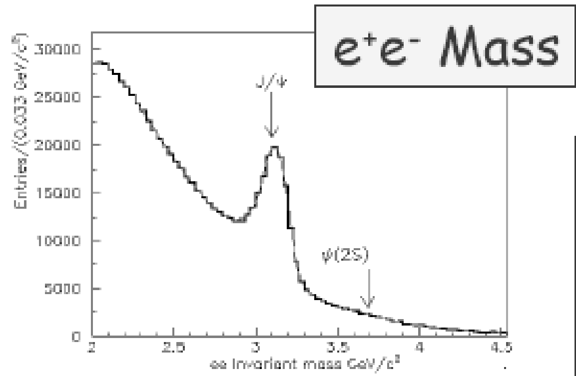


HERA-B: $\sigma(b\bar{b})$

Run 2000: 8,000 J/ψ, 10 b events
$\Rightarrow \sigma(b\bar{b})$ = 32+14-12 (+6-7) nb/nucleon

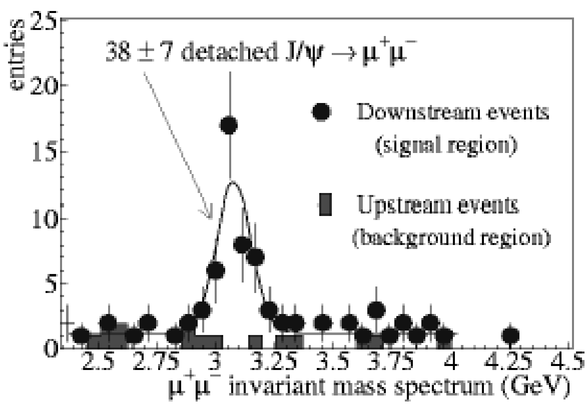
Run 2002/3: 300,000 J/ψ

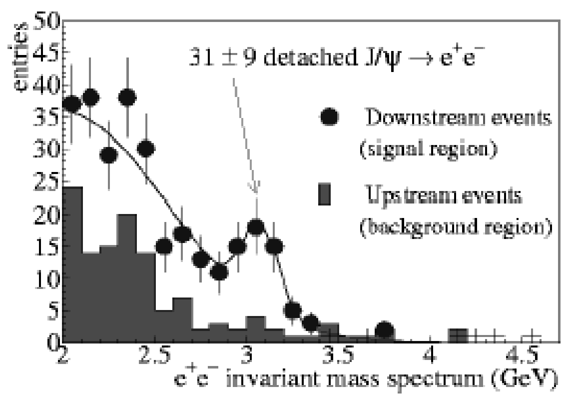




Analysis in progress. Expectation: 15-20% precision on $\sigma(b\bar{b})$, incl. systematics

40% of sample, after vertex cuts

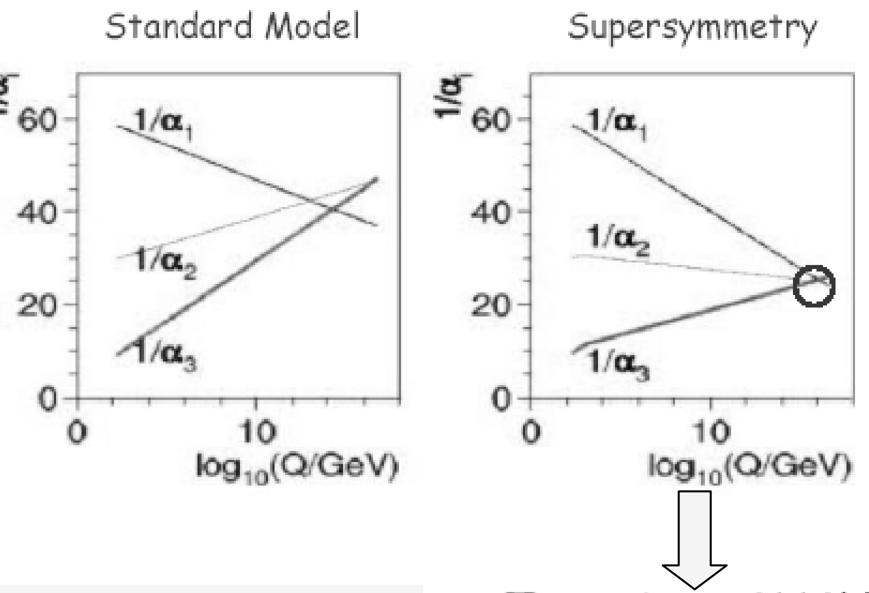


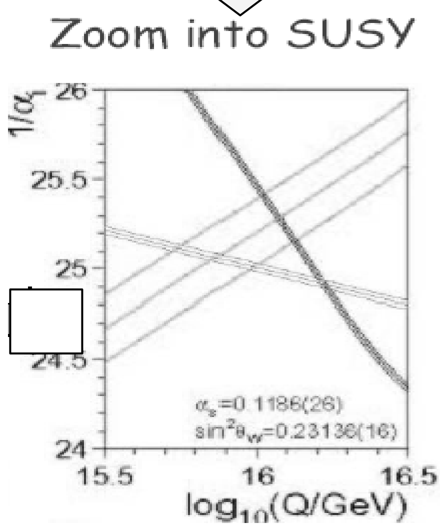


Data taking HERA-B completed

Strong coupling constant α_s

α_s determination - how good?



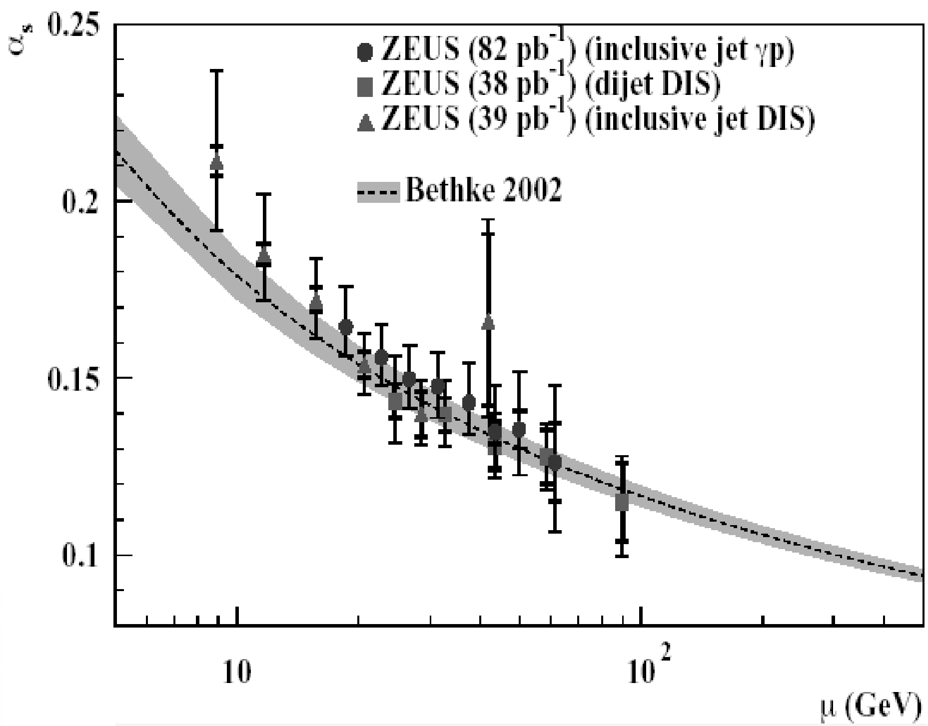


- **as precise as possible !**

+

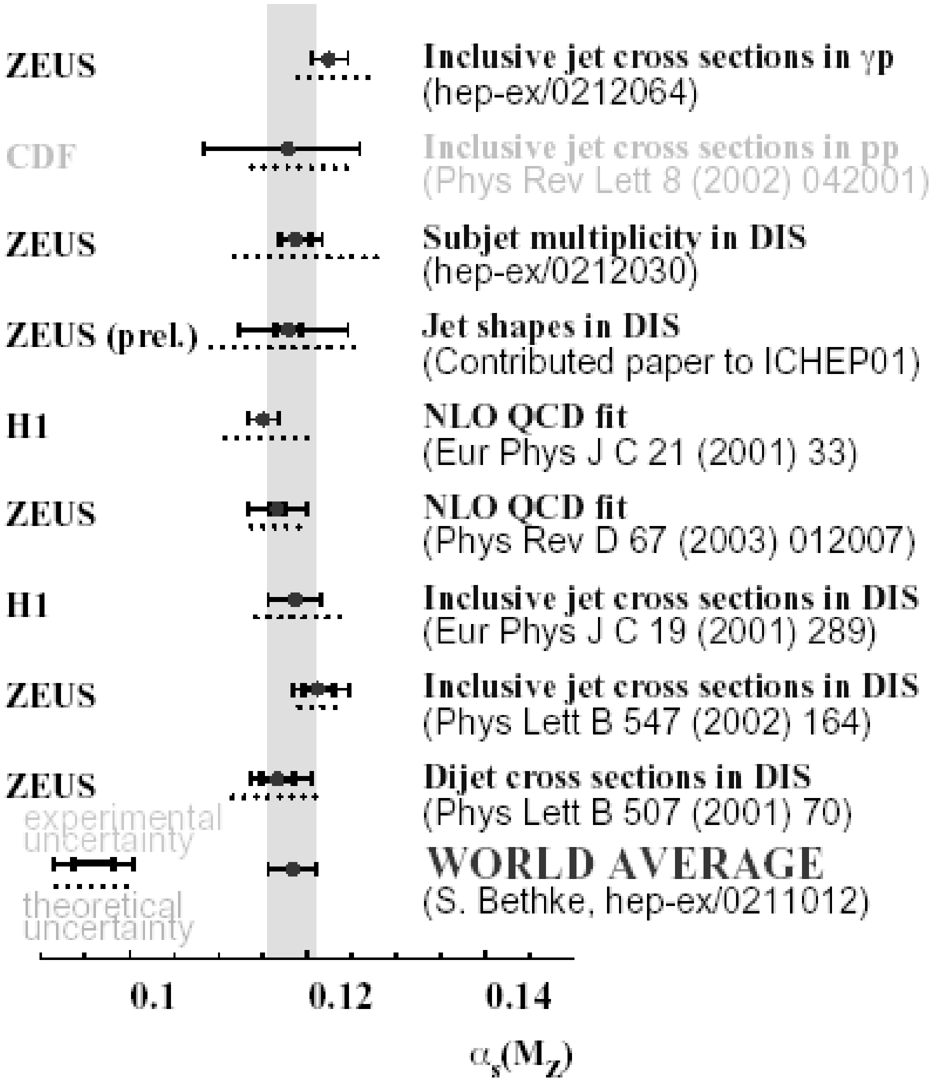
- **consistency checks QCD**
- **needed for cross sections**

one example from HERA: single and di-jet production in γp and DIS



- **running over one order in μ in a single experiment**
- **consistency between different analyses**

Summary of α_s measurements at HERA I

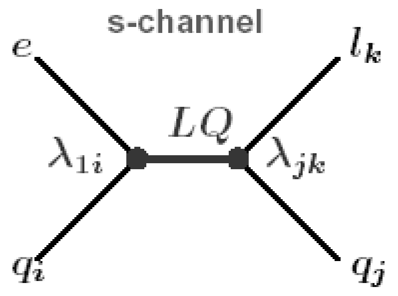


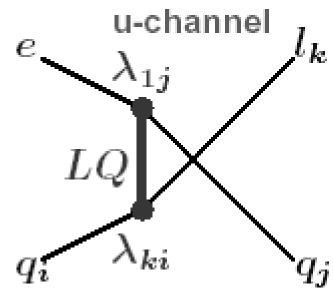
- very different measurements agree with each other within errors
- measurements from HERA are consistent with world average
- precision competitive with world data
- in most cases experimental errors smaller than theoretical errors
- need higher orders
- NNLO calculation under way ...

HERAII + NNLO:
aim for O(1%) precision

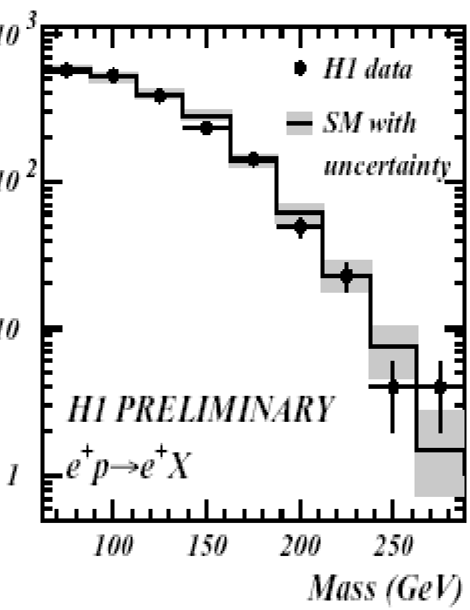
BSM: Leptoquarks

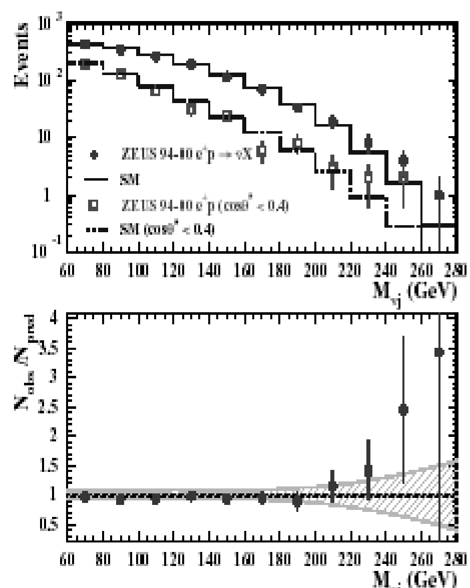
LQ-production at HERA $\sigma \sim f(\lambda, m_{LQ})$



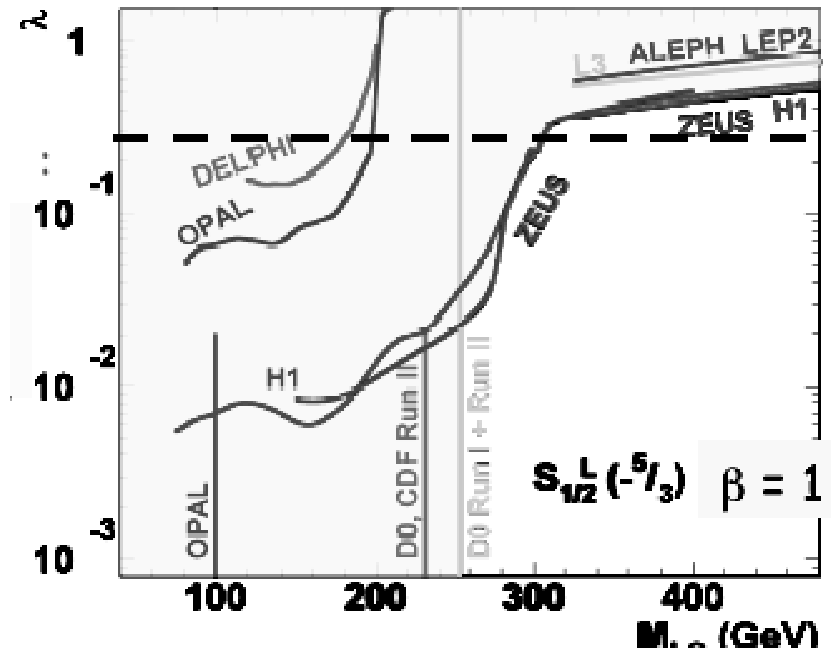


from agreement of high-Q^2 NC and CC DIS-data with SM predictions:





for $\lambda = \sqrt{4\pi\alpha_{em}} = 0.3$ HERA:
m_{LQ} > 290 GeV @ 95% CL



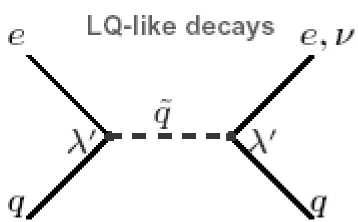
- Tevatron probes large masses for large β (LQ → eq) independently of λ
- HERA better probes LQs with small β provided that λ not too small

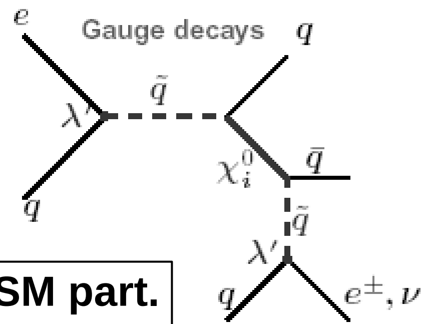
→ Complementarity of both facilities

NB : at HERA, e^+ / e^- + polarisation could help in disentangling the LQ quantum nb

More BSM

R_P-violating MSSM from HERA:





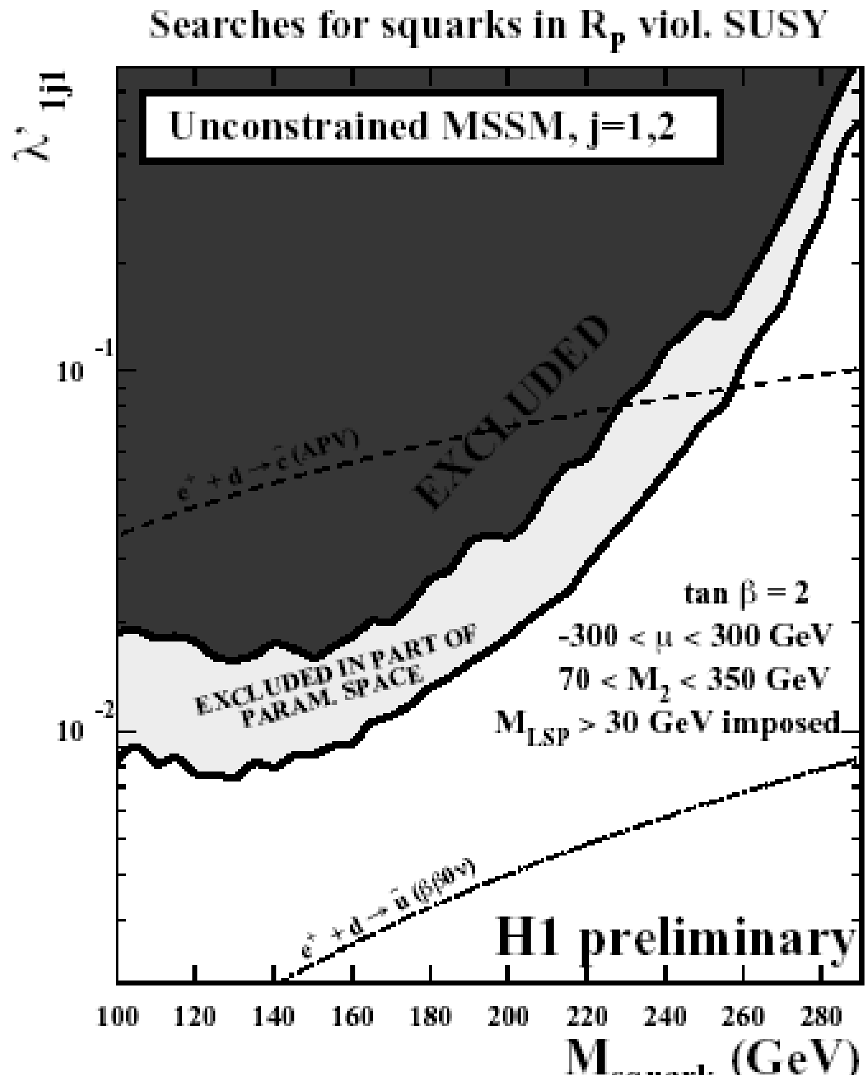
$R_P=(-1)^{3B+L+2S}$	= +1 SM part.
	= -1 SUSY p.

R_P-violation: SUSY can be singly produced + LSP instable

Many more searches – no significant signals found → limits for BSM for:

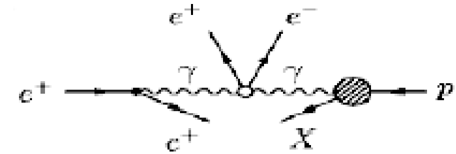
- **leptoquarks**
- **Lepton flavour violation**
- **R_P violating SUSY**
- **excited fermions**
- **contact interactions,**
- **large extra dimensions**
- **an. top production and FCNCs NCs**
- **monopole search**

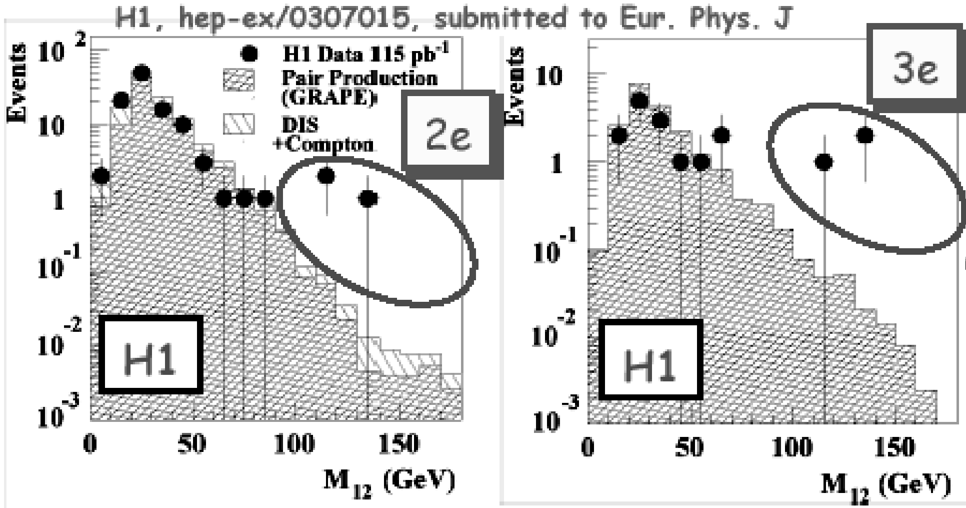
masses up to 270 GeV excluded for λ' = 0.3



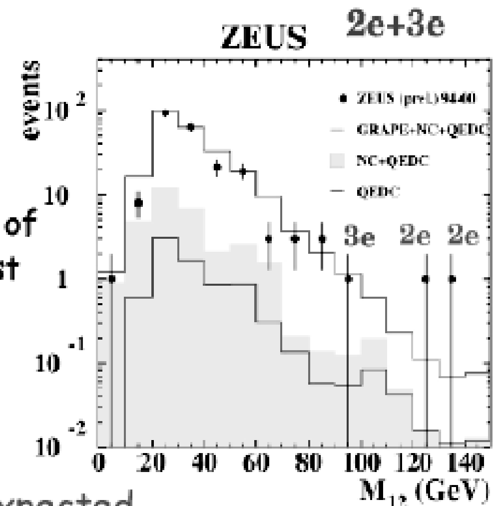
HERA multilepton events

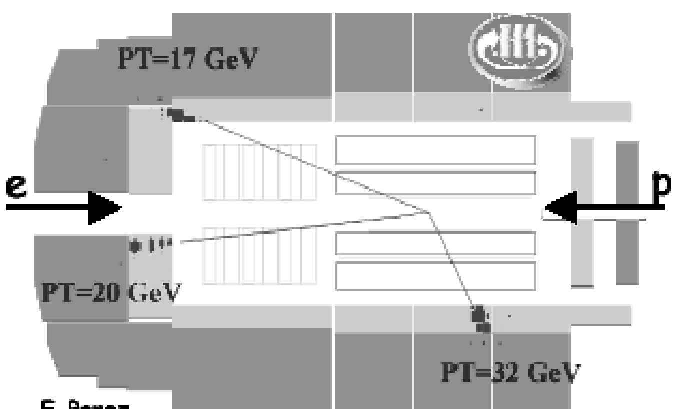
Search for events with several leptons in final state
Mainly produced via $\gamma\gamma$ collisions





M_{12} = mass of two highest P_T e





observed / expected

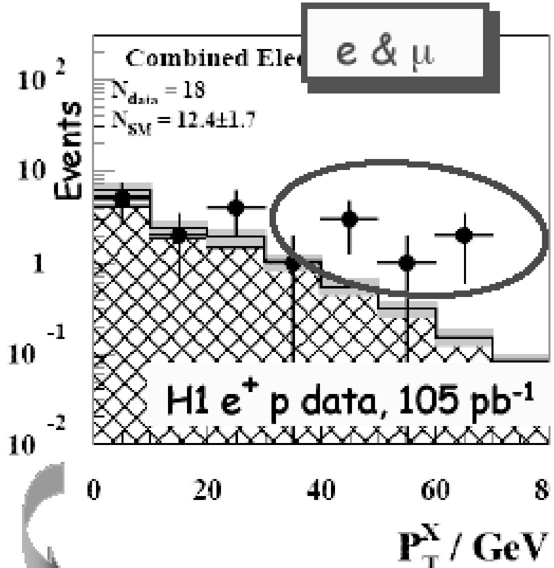
selection \ expt	H1 (115 pb^{-1})	ZEUS (130 pb^{-1})
2e, M > 100 GeV	3 / 0.30 ± 0.04	2 / 0.77 ± 0.08
3e, M > 100 GeV	3 / 0.23 ± 0.04	0 / 0.37 ± 0.04

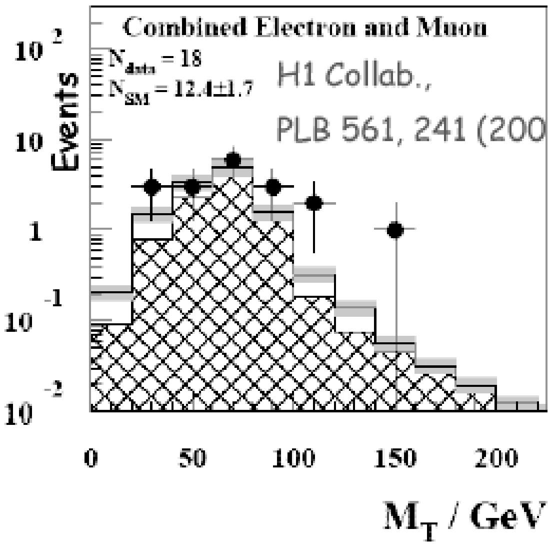
(different angular ranges in H1 / ZEUS analyses)

No excess in $ep \rightarrow \mu\mu X$

E. Perez 8 LP' 03, 08 / 11 / 03

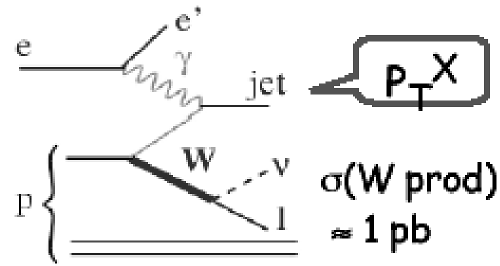
HERA events with isolated lepton + $P_{T,miss}$





$e\,p \rightarrow l + \text{jet} + P_{T,miss}$

Main SM contribution :

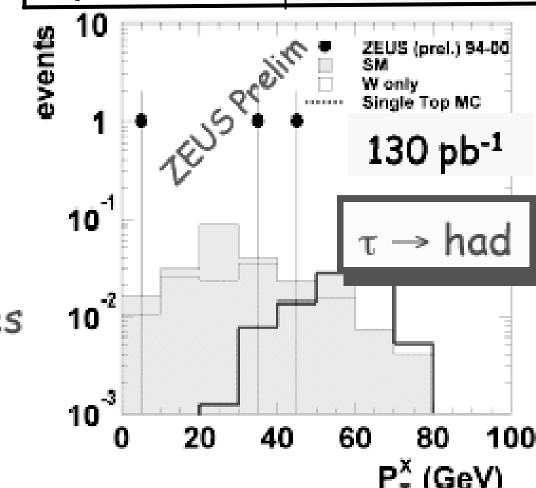


σ(W prod) ≈ 1 pb

ZEUS $e^{\pm}$ p data	τ channel
$P_T^X > 25$ GeV	2 / 0.12 ± 0.02
$P_T^X > 40$ GeV	1 / 0.06 ± 0.01

observed / expected

H1 e^+ p data	e channel	μ channel	Combined e & μ
$P_T^X > 25$ GeV	4 / 1.48 ± 0.25	6 / 1.44 ± 0.25	10 / 2.92 ± 0.49
$P_T^X > 40$ GeV	3 / 0.54 ± 0.11	3 / 0.55 ± 0.12	6 / 1.08 ± 0.22



- No excess in H1 e^- p data **(15 pb^{-1} vs 120 pb^{-1} !)**
- No excess in ZEUS data in e & μ channels, τ candidates
- **Agreement in the had. channel (but large bckgd)**
- W prod : full NLO corrections **included (recently available)**

E. Perez

9

HERA I (O(100pb^{-1}) ep):

- high precision structure of proton, (polarised and unpolarised),
- precision measurements of α_S,
- QCD radiation and diffraction at high energy,
- check (develop) understanding QCD, in final states (jets, heavy flavour, …),
- many limits on BSM,
- EW-sector barely touched.

HERA II (O(1fb^{-1}) + e+/e- polarised):

H1 + ZEUS

- high statistics at high Q^2 and high E_T,
- high x partons from high Q^2 DIS,
- jets at high Q^2 and high ET,
- heavy flavours (det. improvements),
- diffraction (detector improvements),
- EW-coupling of light quarks,
- m_W measurement in CC-DIS,
- BSM and HERA zoo events, }
- exclusive channels (DVCS,…). }

HERMES

- transversity distributions,
- more long. polarised data,

HERA II status:

- upgrade HERA + detectors completed in summer 2001,
- HERAII achieved most design goals
  - specific luminosity,
  - polarised positrons (for 3 expt.),
- but could not run at nominal currents mainly because of BG in expts.,
- begin 2003: BG largely understood → shutdown March-July 2003,
- start to tune for luminosity: 1. Oct. 03 so far situation promising

HERA II and beyond:

- aim HERAII: 1 fb^{-1} e+/e- polarised (ep) + pol.eN + exclusive data (HERMES) by 2006/07
- then stop HERA programme to:
  - PETRA → synchr.rad.source
  - make resources available for PETRAIII, XFEL and prepare for an e^+e^- linear collider

See: "Consensus document"

http://sbhep1.physics.sunysb.edu/~grannis/wwlc_report.html

Understanding Matter, Energy, Space and Time :
The Case for the e^+e^- Linear Collider

A world-wide consensus has formed for a baseline LC project in which *positrons* collide with *electrons* at energies from M_Z to 500 GeV, with polarized e^- and collecting 500 fb^{-1} in the first 4 years.

The energy should be upgradable to ~1 TeV and 500 fb^{-1}/ year.

Above this firm baseline, several options - depending on the nature of the discoveries made at the LHC and in the initial LC operation.

- **e^+ polarisation at GigaZ of ~ 60 %**
- **e^-e^- ~ easy (luminosity ~1/3 e^+e^-)**
- gg, g**e more involved**

The consensus document is presently being signed by scientists all around the world. `http://www-flc.desy.de/lcsurvey/`

Why do we need an LC?

- **to provide the full picture on a SM/MSSM Higgs,**
- **to provide an answer on EW symmetry breaking, even in difficult or unexpected scenarios (heavy Higgs, reduced Higgs cross-section, …)**
- **to access the SUSY symmetry breaking mechanism with LC+LHC measurements,**
- **to predict precisely within SUSY $O_{DM}h^2$,**
- **to interpret unambiguously an unexpected discovery at the LHC (e.g. Z‘ or Kaluza-Klein)**
- **to estimate the mass scale beyond the reach of LC/LHC:**
  - **precision measurements on Higgs couplings translated into deviations from e.g. m_A, m_H or $m_{Z'}$,**
  - **test of the theory at the quantum level which could reveal new mass scales (à la LEP/SLD and m_H),**
- **discovery potential for the unexpected.**

Detector R&D efforts for a Linear Collider

The goal: develop technology for a LC detector

- **excellent tracking**
- **highly granular calorimeter to separate neutral and charged clusters**

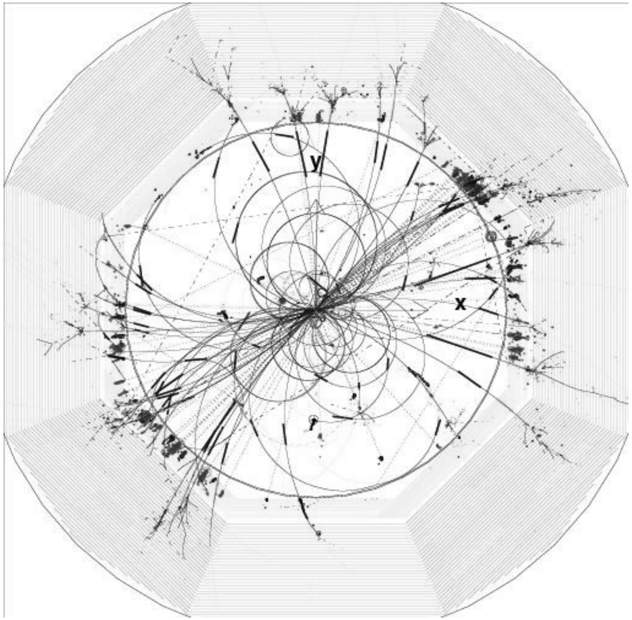
Several R&D groups have formed:

- **VTX developments**
- **TPC developments**
- **calorimeter: CALICE, LCCAL**
- **forward detectors**

Interact through regional and international workshops:

ECFA workshop (Montpellier Nov 2003)
ACFA workshop (Mumbai Dec 2003)
ALCPG workshop (SLAC Jan 2004)

Higgs to top decay at the LC reconstructed in the “TESLA detector”



Milestones towards the LC:

2004 Selection of Collider Technology (warm or cold) by committee of wise persons and setting up of an international project team with branches in America, Asia and Europe.

Continuation of discussion between funding agencies.

Further studies of organisation structures.

2005 Start of work of project teams (‚Pre GLC‘).

2006 Completion of the project layout including costing.

2007 Decision in principle by governments to go ahead with LC.

2015 Start of commissioning

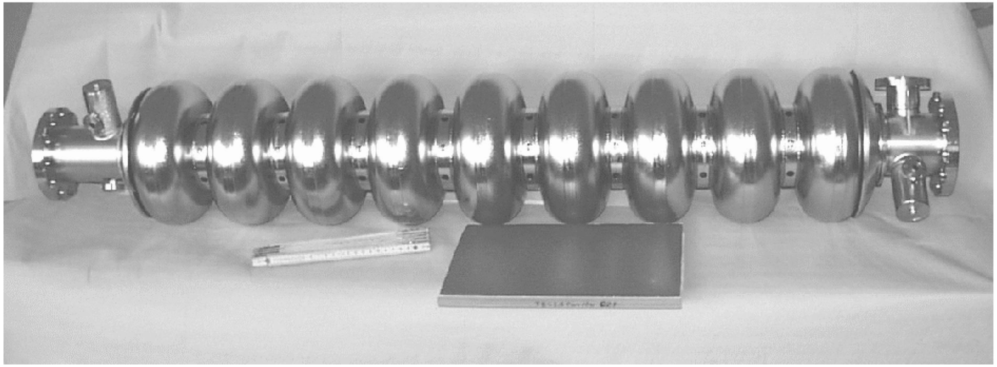
Germany – ministry of science (bmbf):

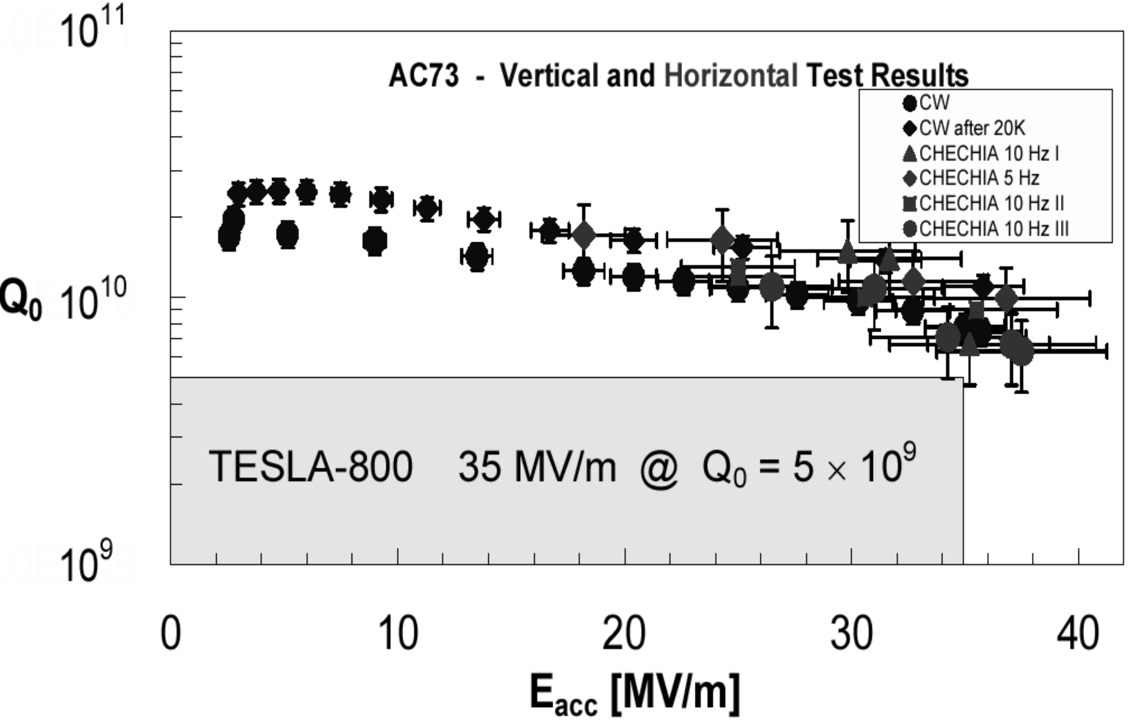
Dr. H. Schunck, EPS HEP conference in Aachen, July 2003:

“The TESLA linear collider has been one of the proposals evaluated by the Wissenschaftsrat. The judgement of the Wissenschaftsrat on the scientific perspectives of the project has indeed been very positive. The Wissenschaftsrat has strongly suggested hat the linear collider should be realized as a genuine global project.

The German government has decided to follow this and as a consequence not to proceed nationally and at this moment not to propose a German site for TESLA. We have to wait for the international development. But we will continue our efforts to be able to participate in a global linear collider project. Let me underline: my government is the first one to have announced to be principally committed to participating in the project. “

High gradient programme:





High power test of a **complete electro-polished nine-cell cavity**

- 1/8th of a TESLA cryomodule
- 5 Hz, 500 ms fill, 800 ms flat-top
- 33→ >35 MV/m

  with no interruption related to cavity-coupler-klystron for more than 1000 hours.
- No field emission

very important achievement for the choice of technology

HERA I: rich physics harvest
HERA II: getting under way
LC: major progress