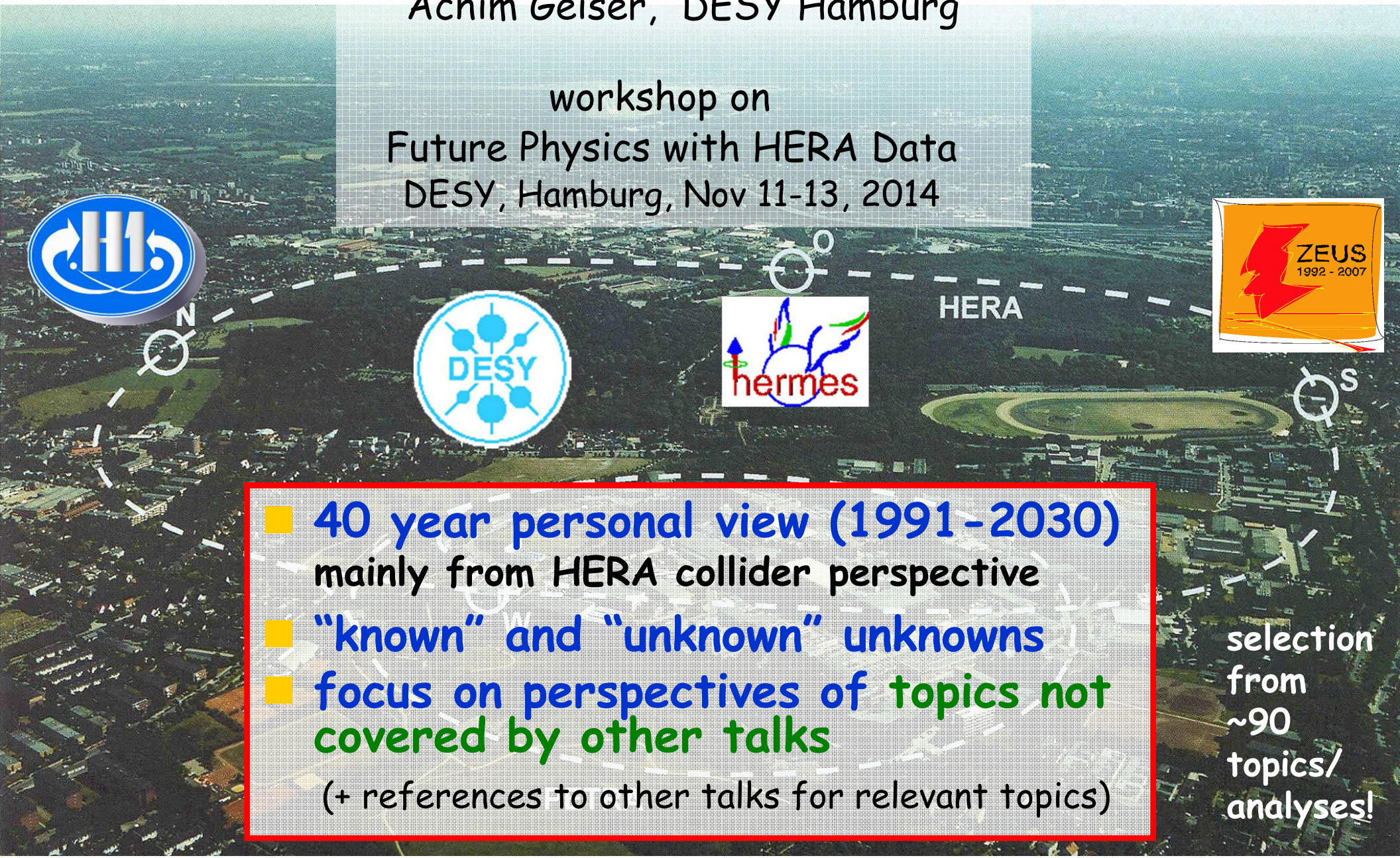
# Possible Future HERA Analyses

Achim Geiser, DESY Hamburg

workshop on
Future Physics with HERA Data
DESY, Hamburg, Nov 11-13, 2014



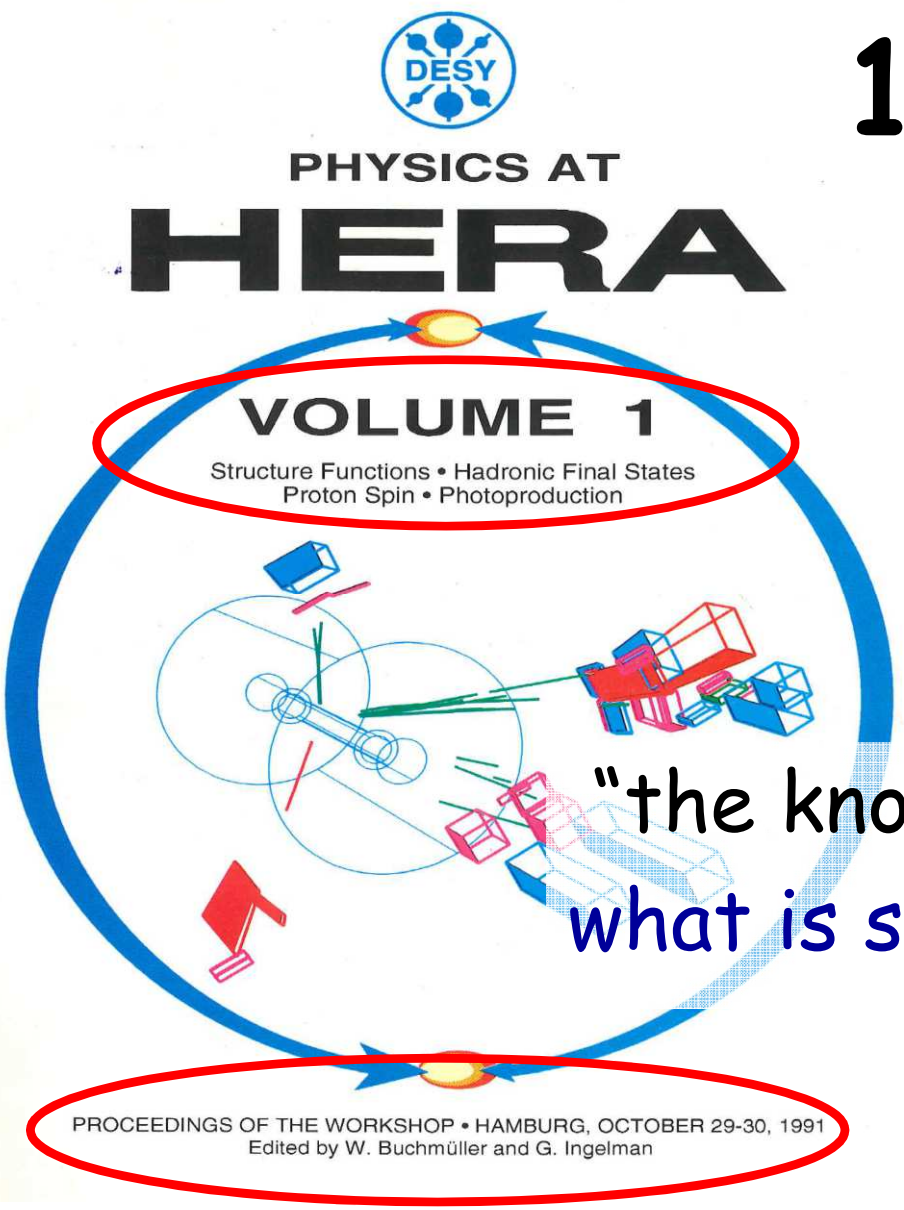

- **40 year personal view (1991-2030)**
  mainly from HERA collider perspective
- **"known" and "unknown" unknowns**
- **focus on perspectives of topics not covered by other talks**

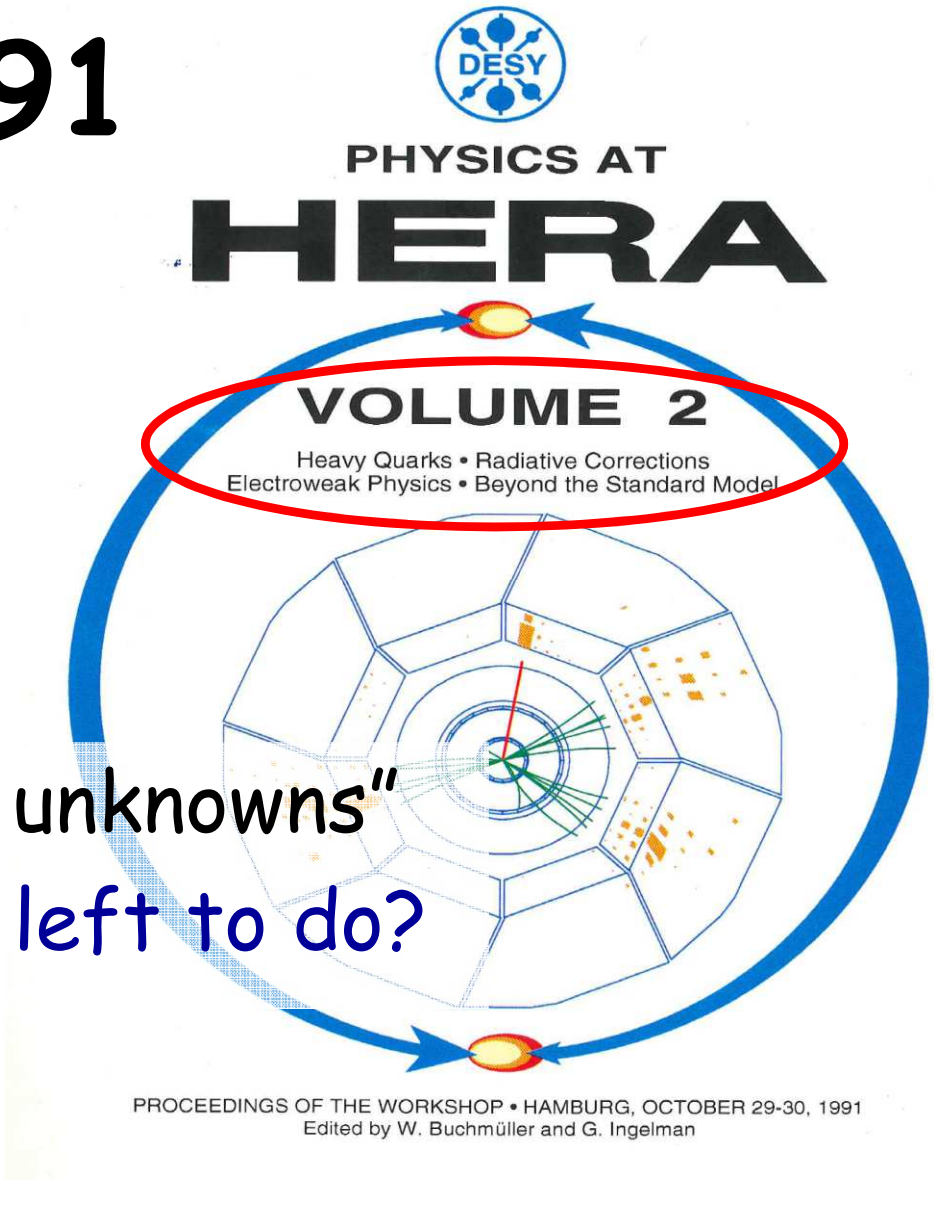
(+ references to other talks for relevant topics)

selection from ~90 topics/ analyses!

# Workshop on Physics at HERA

## 1991




"the known unknowns"

what is still left to do?

# 1991: HERA, structure functions

B. Wiik: "it is the first electron proton collider ever"

… and presumably still the only at least for the next decade -> **unique physics**

J. Engelen/M. Klein/R. Rückl (structure functions):

"the very high energies will allow to extend the range of momentum transfers … corresponding to a spatial resolution of about $10^{-18}$ m" -> achieved

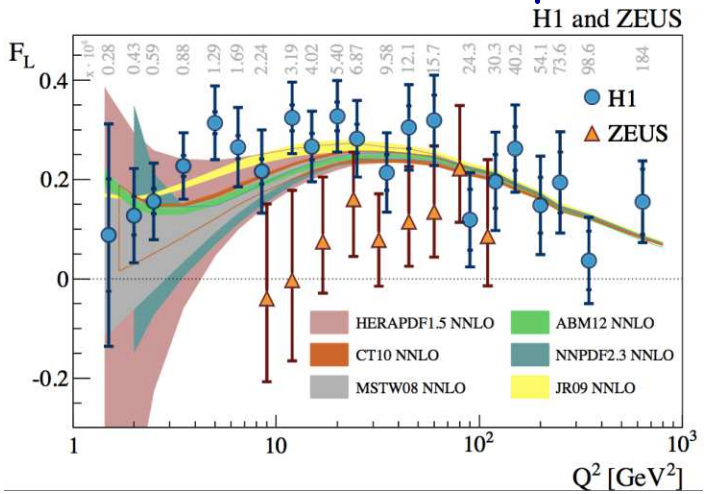
"HERA … will provide us … with structure function data for $1 < Q^2 < 10^5$ GeV$^2$ and $10^{-5} < x < 1$. These will represent an enourmously powerful constraint on the theory and phenomenology of strong interactions." -> HERAPDF2.0

-> talks A. Levy, R. Thorne, S. Moch, A. Cooper-Sarkar, … but not completed

e.g. high x -> talks A. Caldwell, A. Levy

"The machine must be operated both at maximum and at lowest possible energies … in order to measure the longitudinal structure function $F_L$"

-> achieved, but dedicated final $F_L$ combination from H1 and ZEUS still left to be done.



# 1991: structure functions, low x

J. Engelen/M. Klein/R. Rückl (structure functions):

"For the first time deep inelastic scattering experiments will measure virtual photon-quark collisions down to $x \sim 10^{-5}$. [ ] At very small x the model of quasifree, noninteracting partons … is bound to fail because the predicted rise of $F_2$ or $G(x)$ at lower x conflicts with unitarity limits. This may be satisfied allowing for nonlinear, 'screening' interactions between quarks and gluons …" -> the rise of gluons at low x was predicted, but not believed to be true

-> we still do not have firm evidence for hitting this unitarity limit, DGLAP still alive and well

J. Bartels/J. Feltesse (QCD at low x):

"In conclusion, it should be emphasized that, if the estimates turn out to be correct, HERA should be seen as a strong challenge for solving QCD in the nonperturbative region"

J. Bartels/M. Besancon/A. de Roeck:

"However, deviations may be small, and it might be difficult to draw unambigous conclusions"

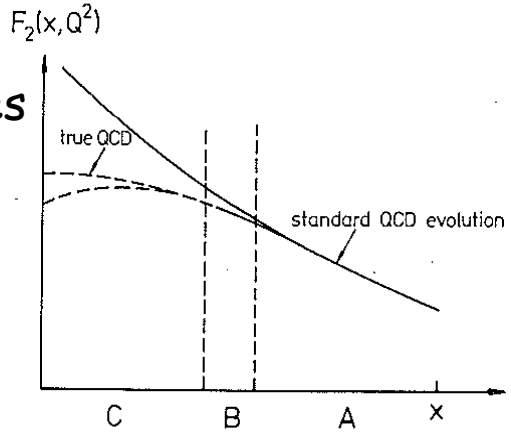



Figure 2: *Small-x behavior of the structure function: standard QCD evolution versus "true QCD" evolution. A is the perturbative region, B the transition region, C the nonperturbative region.*

-> **low x physics at HERA still very hot topic**

Are we starting to hit the nonperturbative limit?

Can we make further decisive measurements from existing data? Improved theoretical interpretations of existing results? Maybe even evidence for new physics?

-> see talks A. Cooper-Sarkar, M. Ruspa, J. Bartels, L. Motyka, H. Kowalski, …

# 1991: diffraction

## G. Ingelman/K. Janson-Prytz (QCD at low x):

"The diffractive ep scattering cross section is calculated based on the pomeron structure function $F_2^P$, [...] This effect is predicted to be large and observable at HERA."

... but it turned out to be even larger

**reanalyse HERA I data for some topics?**

**finish analysis of HERA II data, + combination**

-> see talks A. Volkarova, M. Ruspa, L. Motyka, ...

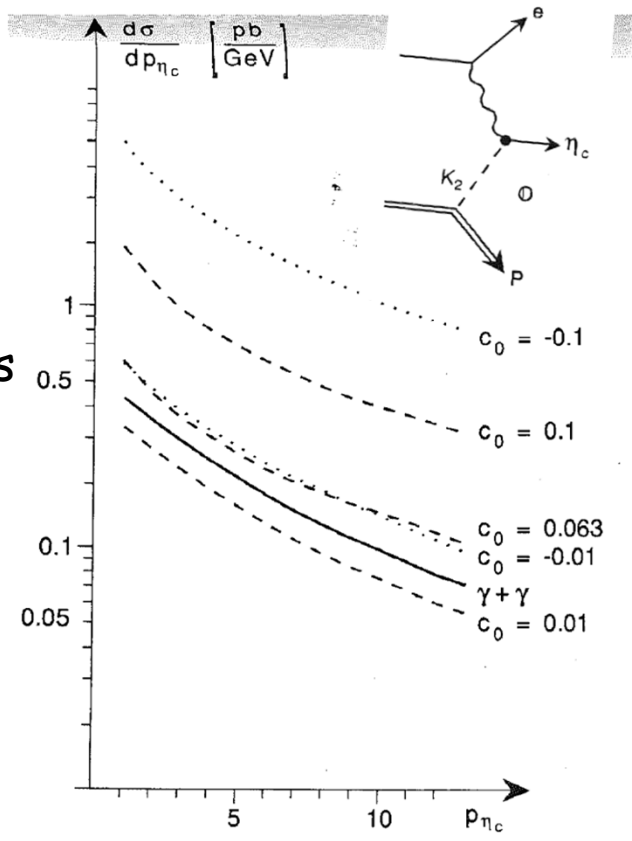
## A. Schäfer/L. Mankiewicz/O. Nachtmann:

"The diffractive production of $\eta$, $\eta'$, and $\eta_c$ can serve as a probe of the odderon, while diffractive J/psi, and psi' production tests the universality of the pomeron. [...] the ratio of $\eta$ to $\eta'$ should be a good test for the existence of an odderon. The total cross sections we got are of the order nanobarn and thus should be measurable without too many problems."

-> J/psi and psi' mostly done (H1)/ongoing (ZEUS).

**$\eta$, $\eta'$, $\eta_c$ not yet achieved; should be feasable**

-> also see talks R. McNulty, M. Sauter, ...



# 1991: jets and hadronic final states

## D. Graudenz/N. Magnussen (Jets and hadronic final states):

"The measurement of jet cross sections at HERA will offer the possibility to study aspects of perturbative QCD in deeply inelastic electron-proton scattering. […] for (1+1), (2+1), and (3+1)-jet production."

## M. Crombie/A. Wegner:

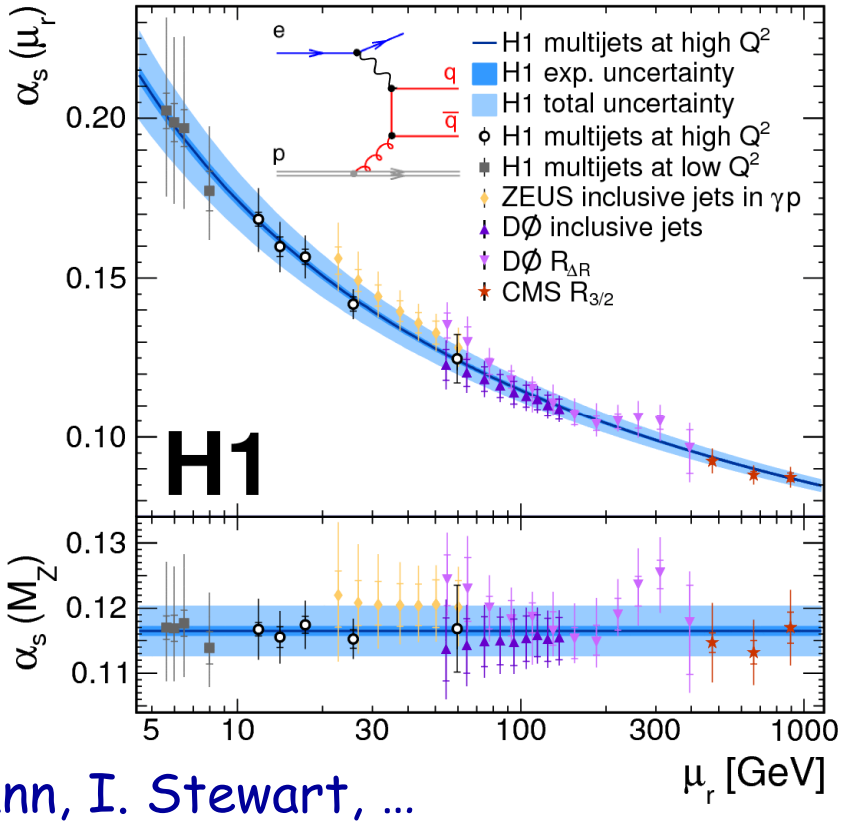
"An outline of the basic theoretical issues associated with a well-defined measurement of the effective strong coupling constant using jet ratios is given."

measurements only partially completed

-> to be completed and combined

data precision typically 3-5 times better than theory predictions

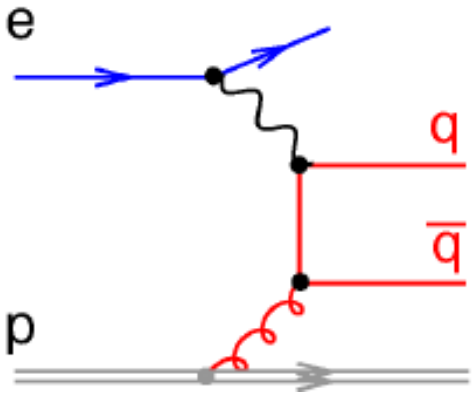
-> NNLO calculations urgently needed !

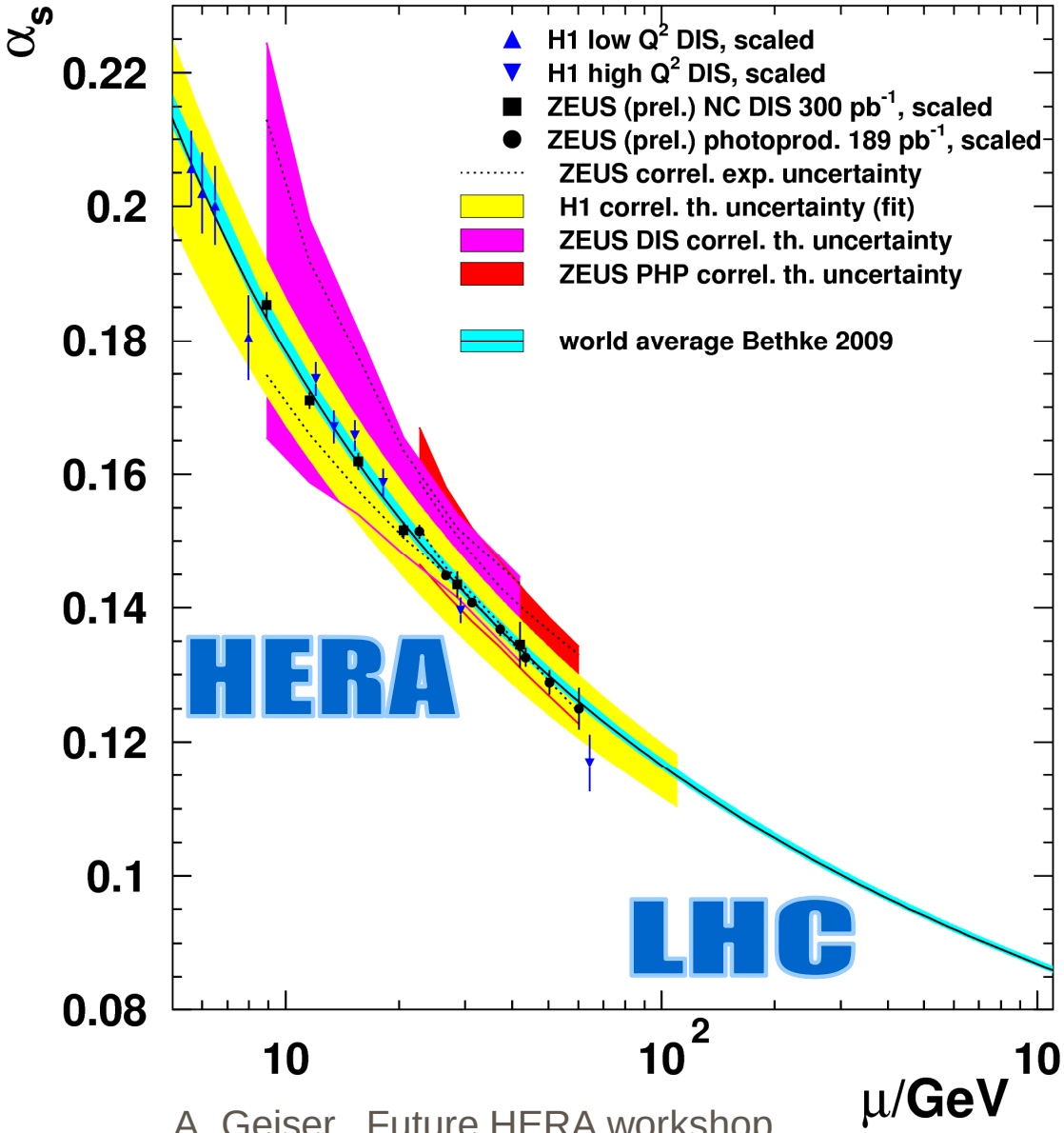



-> see talks A. Volkarova, R. Thorne, T. Gehrmann, I. Stewart, …

Hadronic final states: see talk H. Jung

# $\alpha_s$ from the HERAscale to the Terascale

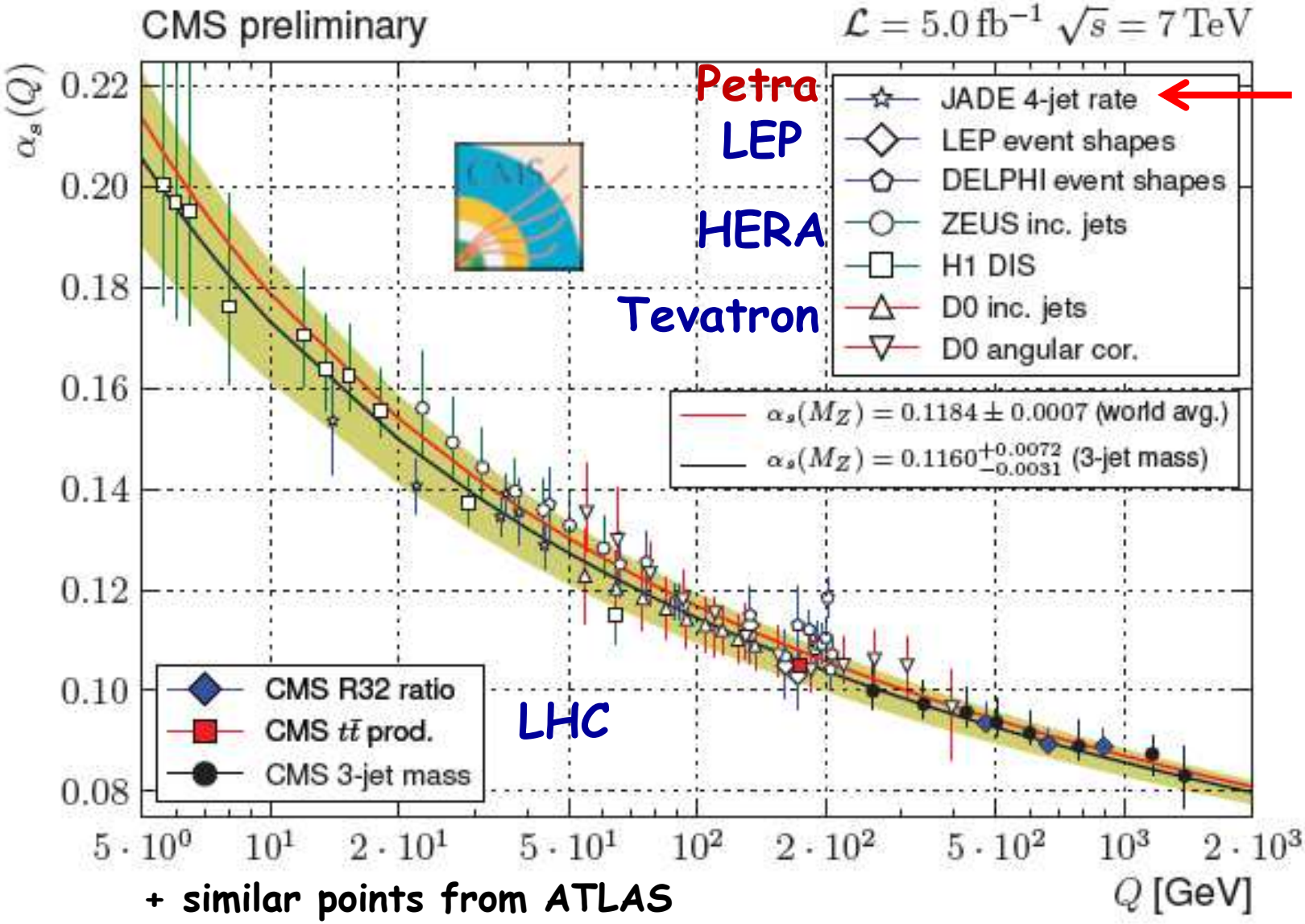



**DESY brochure Particle Physics 2010**

example for "Unknown unkown" (as of 1991)

# $\alpha_s$ running from jets (EPS 13)




from preserved data!

to do: quantitatively test consistency between HERA and LHC

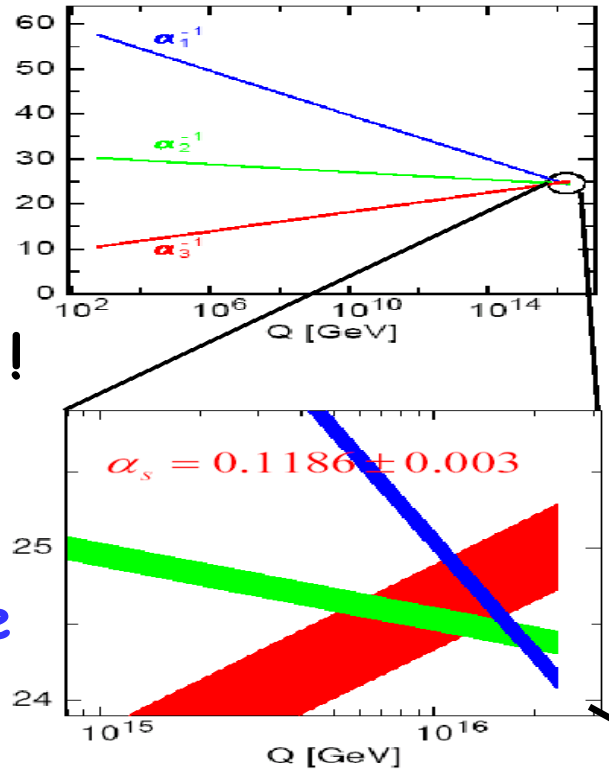
+ similar points from ATLAS

# reminder: $\alpha_s$ and grand unification

error on $\alpha_s$ dominates (theory!)

=> need NNLO QCD !

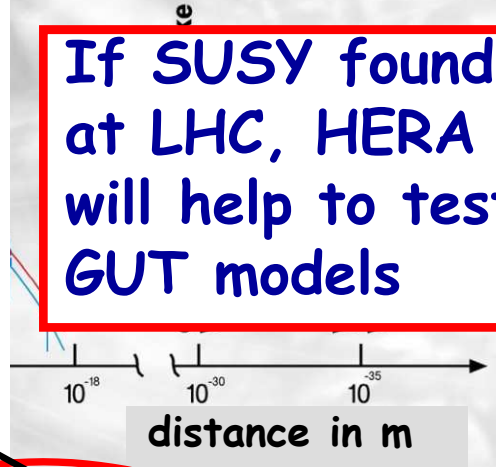
=> HERA would yield most precise $\alpha_s$ value ( O(1-2%) )

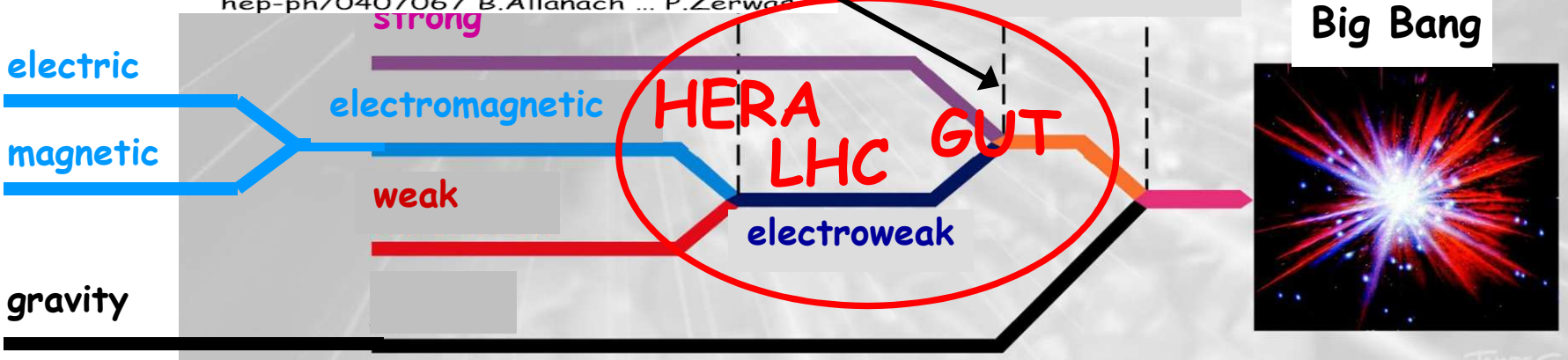



SUSY Grand Unification

reanalyse whenever NNLO predictions become available

If SUSY found at LHC, HERA will help to test GUT models



# 1991: pol. struct. funct., electroweak

J. Engelen/M. Klein/R. Rückl (structure functions):

"The structure function programme at HERA will be complete only with electron-deuteron data, and, perhaps, polarization of the electrons and protons"

G. Altarelli (proton spin, polarized structure functions):

"the experimental program on polarised structure functions is a very important part of the HERA physics program"

-> electron polarization achieved,

proton polarisation and deuterons achieved with HERMES,

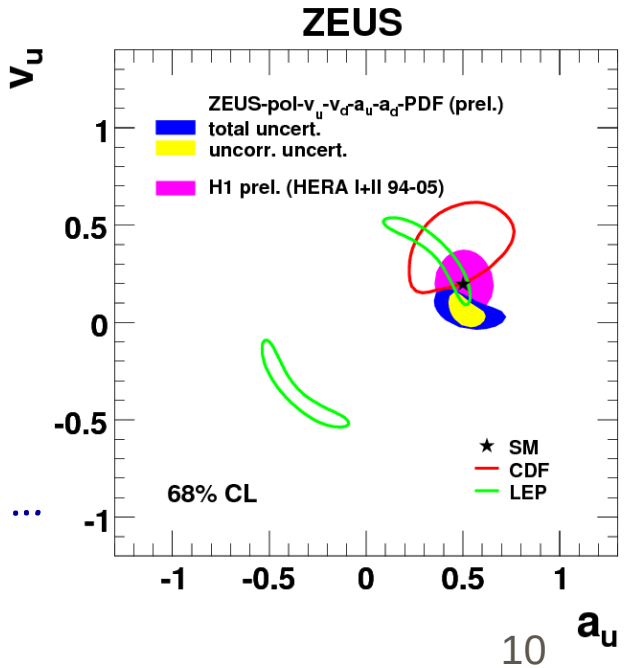
left for future accelerator for collider mode

-> see talks C. van Hulse, E. Aschenauer, P. Kroll, A. Bacchetta, E. Nocera, …

V. Brisson et al. (electroweak physics) :

"The measurement of electroweak parameters in deep inelastic scattering at HERA is discussed …"

-> see talks R. Thorne, H. Spiesberger, K. Wichmann, …



# 1991: intrinsic charm

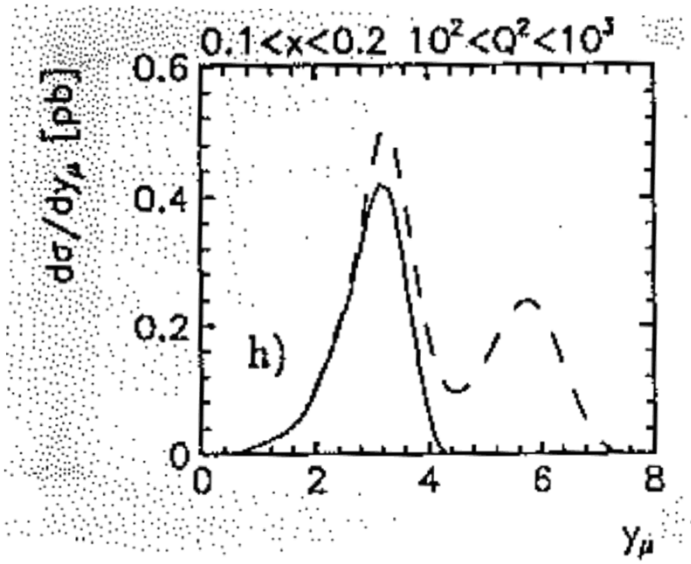
G. Ingelmann/L. Jonsson/M. Nyberg (hadronic final states):

"We investigate the feasibility to use deep inelastic scattering at HERA to probe a possible intrinsic charm quark component [...] resulting in acceptable signal/background ratios using [forward] muons to tag charm. [...] with statistics of, say, 500 $pb^{-1}$ [...] it should be possible to probe the intrinsic charm component of the proton down to a level of 0.1%, i.e. somewhat below the level indicated by the analysis of the EMC data [0.3%]."

"Intrinsic charm", i.e. charm pairs not originating from perturbative (single) gluon splitting, could originate from the "Brodsky" fock-state mechanism, or from QCD instantons (could this be the same thing?).

Current upper limit of order 1% (CTEQ). Standard H1/ZEUS charm analyses can not cover relevant kinematic range, thus no sensitivity. Forward muons are difficult (but not impossible) to detect.

**Could a combined H1/ZEUS dedicated forward muon analysis do the job?**



# 1991: photon structure

## G. Schuler (photoproduction):

"A central theme of low-$Q^2$ studies at HERA is the photon, whose nature can be probed in a new kinematical regime in high energy photon-proton collisions."

## A. Levy:

"The photon, though being the gauge particle mediating electromagnetic interactions, exhibits features similar to those of normal hadrons. […] Thus the HERA measurements, which extend into this new x domain, will enable the study of the gluon distribution in the photon."

distinguish between
- leading order "resolved photon" picture
(includes e.g. perturbative splitting of a photon into cc pair)
- NLO (or higher order) "hadron-like resolved photon" picture
-> only nonperturbative parts of hadron-like aspects of photon are absorbed into photon PDFs.

leading order picture partially explored,

**explicit measurement of NLO photon PDFs essentially uncharted territory**
(absence of interest due to the absence of an active high energy e+e- collider. Will this change if the ILC gets approved? FCC e+e- option?)

# 1991: radiative corrections

~10% of the 1991 workshop dedicated to radiative corrections!

Kramer/Spiesberger:

"Ever since electron scattering experiments have been performed to obtain information on the internal electromagnetic structure of atoms, nuclei, nucleons, or leptons, it was necessary to separate radiative effects from the lowest order Born cross section."

Are radiative corrections in current PDF analyses (can be as large as ~50% in some regions of phase space!) really fully under control?

Photon PDF of the proton (+other electroweak corrections)

-> completely new paradigm for PDF input data: must undo the "usual" correction to Born level QED. Start of a new era of PDF fitting?

-> also see talk H. Spiesberger

# 1991: heavy flavour production

## A. Ali/D. Wyler (heavy flavours):

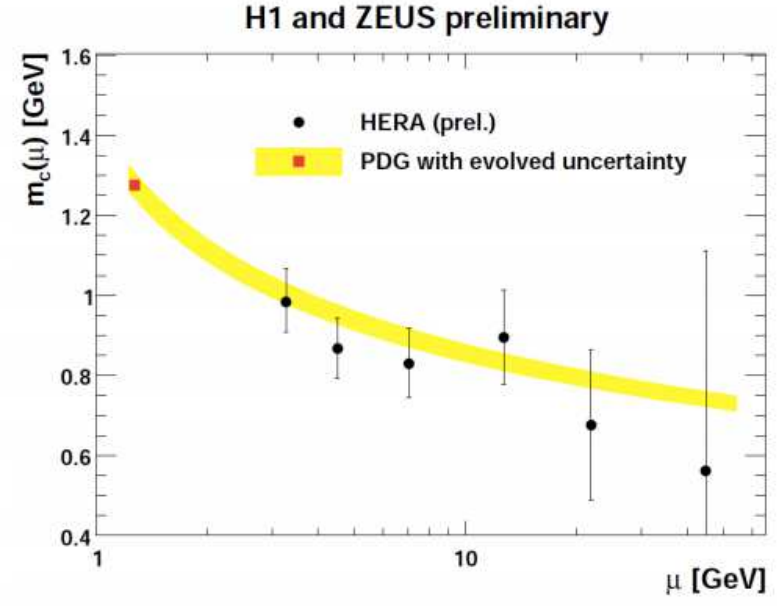
"We particularly emphasize the large charmed quark production cross section at HERA […]. The topics studied in detail include […] improved perturbative QCD treatement of heavy quark photo- and leptoproduction, […] determination of the gluon density […]"

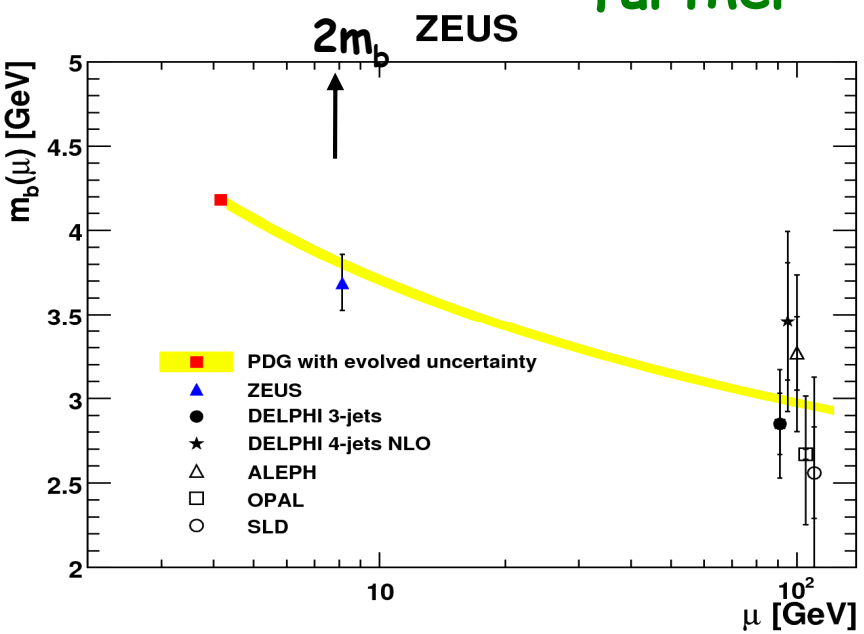
achieved

but one of the currently most interesting aspects, measurements of charm and beuaty quark masses and their running, was not anticipated

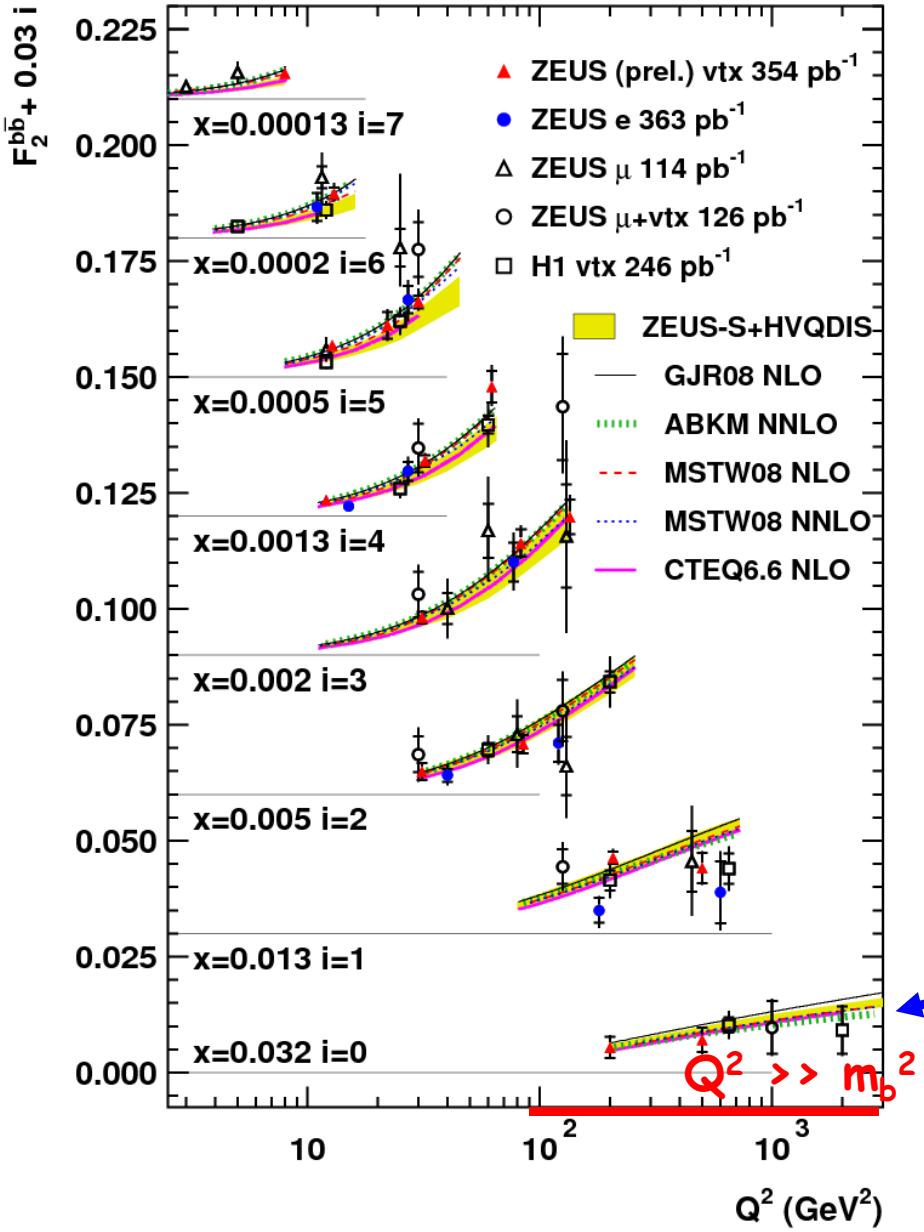
-> see talks A. Levy, R. Thorne, J. Blümlein

**can be improved further**



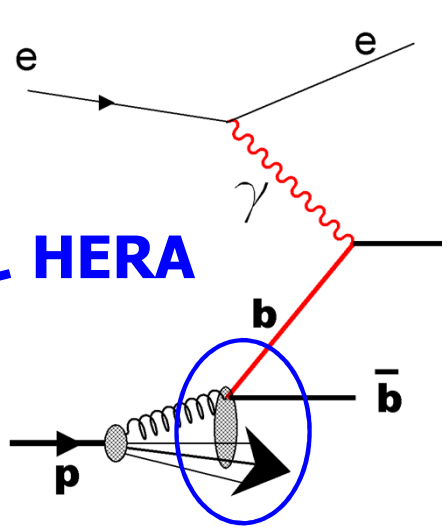
# beauty contribution to $F_2$




data in agreement with NLO and NNLO

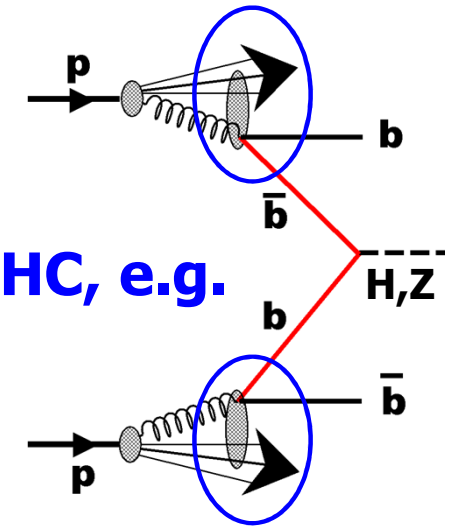
combine!

check „b in proton" for LHC: Z, Higgs



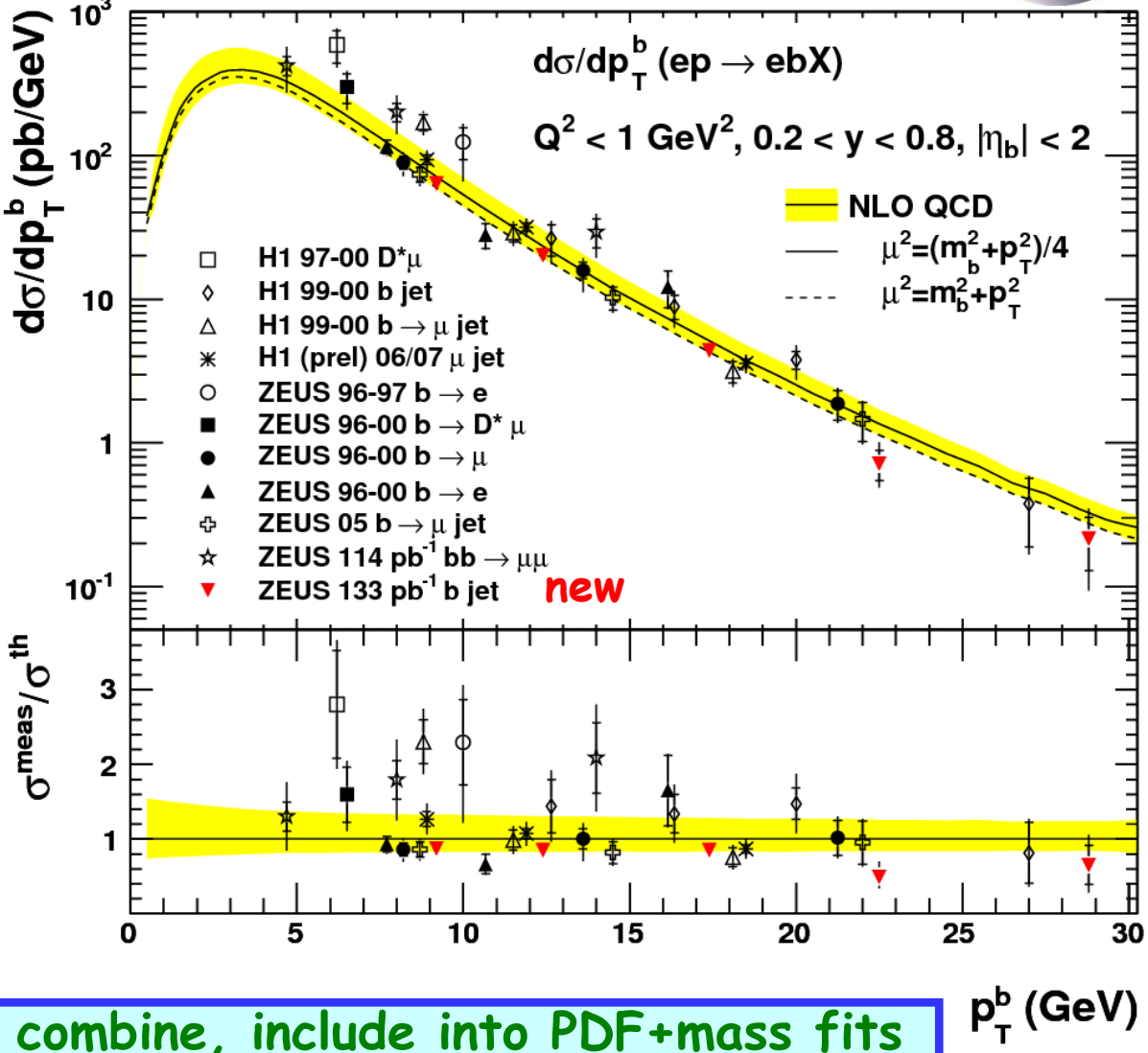

HERA

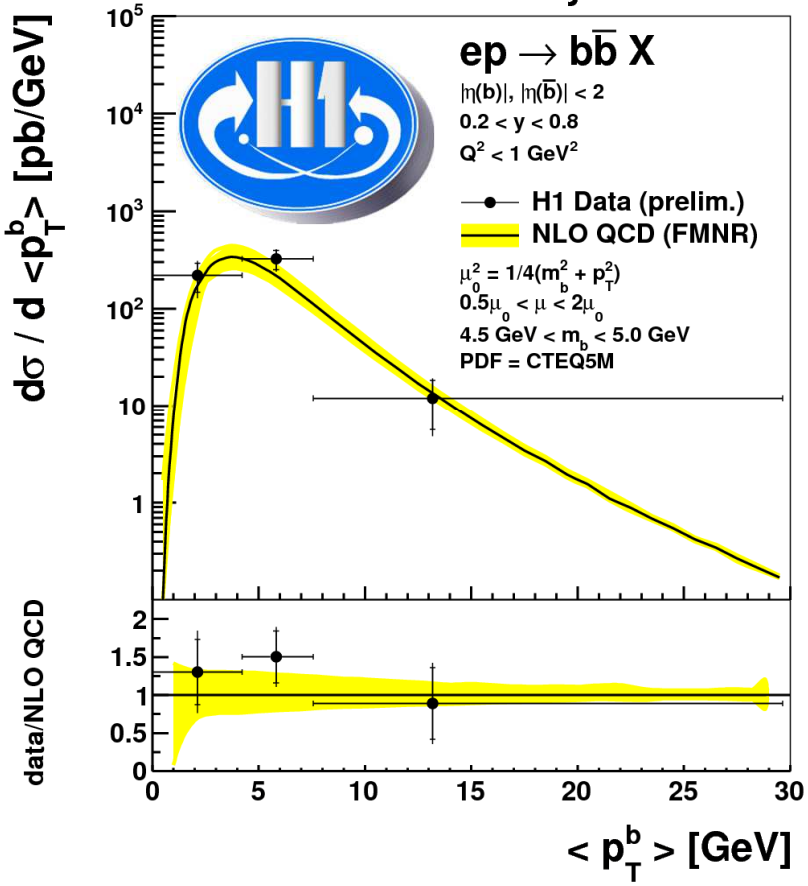
LHC, e.g.



# beauty in photoproduction

HERA



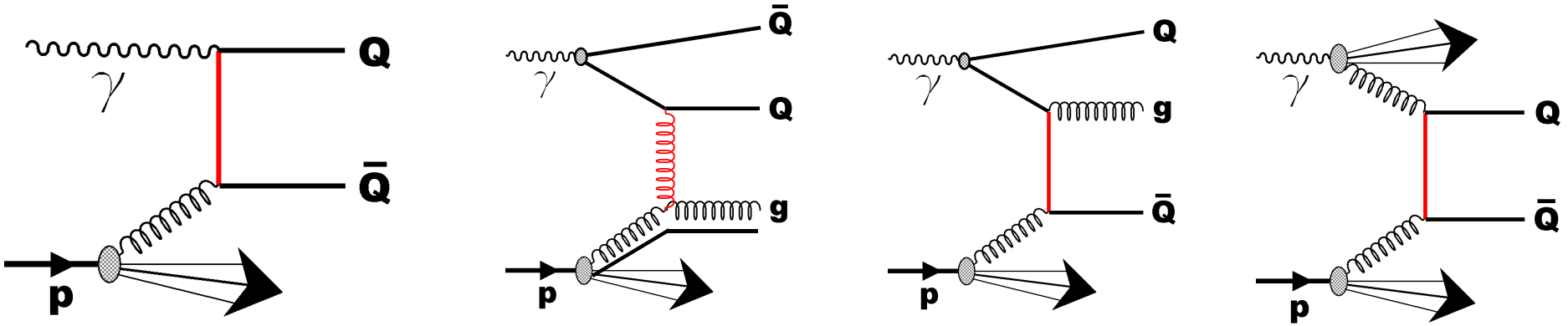




combine, include into PDF+mass fits

reasonably described by NLO QCD down to threshold

# Why measure QQbar correlations?

- some NLO diagrams (massive scheme), **Q**=b,c




- 3rd jet not always detected (forward or low $E_T$)
- single tag measurement does not distinguish **Q** and g/q for 2nd jet
- double tag measurement does

=> test and understand NLO QCD

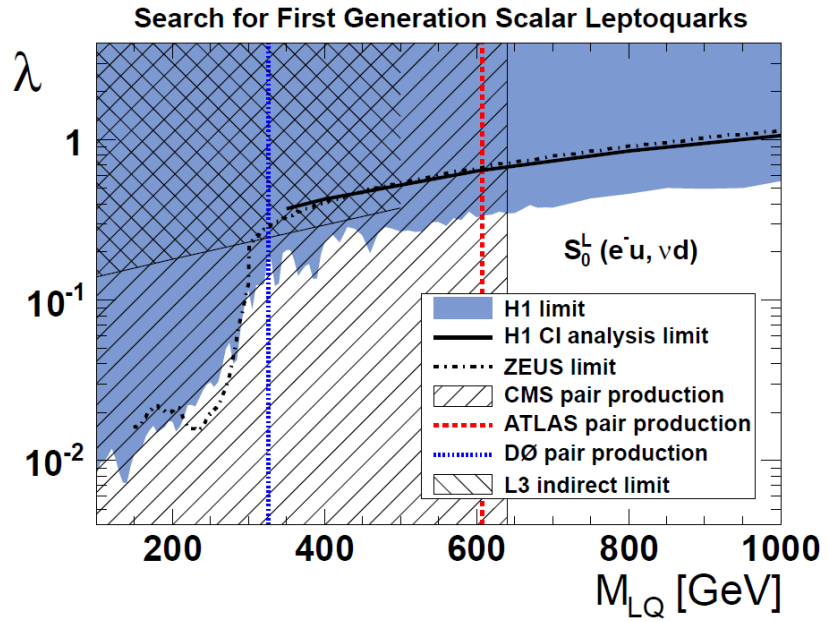
use result to e.g. reliably measure NLO gluon distribution in photon

- go for multi-differential measurement !

# 1991: BSM physics

~10% of the workshop dedicated to BSM searches

Most searches successfully completed (unfortunately with negative results)
For most current beyond the standard model searches LHC offers much better sensitivity (much higher centre-of-mass energy).
But few topics might be left
-> see talks R. Thorne, K. Wichmann

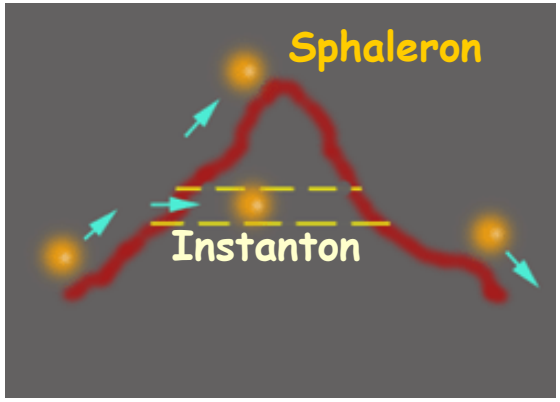



Revert argument: All results from HERA guaranteed to be free of new physics (e.g. PDFs), therefore unbiased benchmark for searches at LHC !

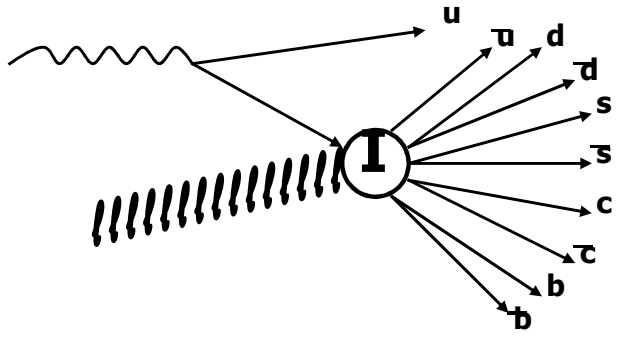
-> see e.g. talks M. Cooper-Sarkar, S. Glazov, …

# contribution to the antimatter puzzle from HERA?

- CP violation measured so far not strong enough to explain matter-antimatter asymmetry
- way out: CP violation in neutrino oscillations and/or strong lepton number asymmetry in early universe.
- Standard Model predicts baryon and lepton number violation through so-called „sphaleron" process: converts 3 leptons into 3 baryons!




- rare process at very high energy -> not observable so far
- related process: QCD „instantons"
- in principle observable at HERA!
- investigate new analysis strategies



# My dream:

- Simultaneous analysis of inclusive HERA I+II DIS over full phasespace,

  + charm and beauty contributions, jets

  + s,u,d contributions (leading $\phi$, leading charged particles, calibrated with inclusive PhP dijets)

  => direct measurement of b,c,s,u,d fractions

  => ultimate and fully correlated information on flavour composition + gluon

- + merger with LHC data

  (see PROSA contribution tomorrow)

# Selection of some other topics:

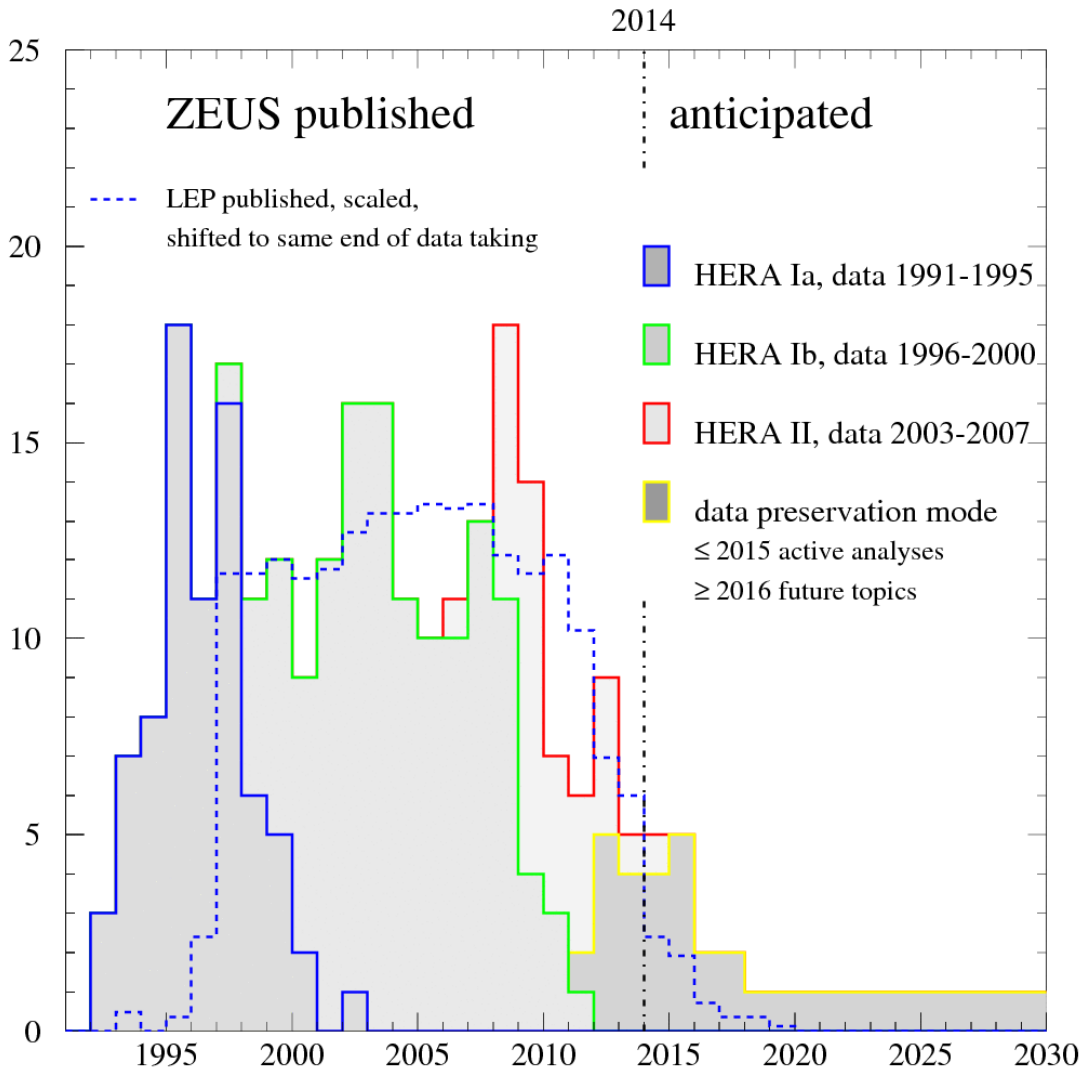
- DVCS measurements not completed
- exclusive vector meson measurements not completed
- charm fragmentation function measurements not completed
- measurement of charm in CC not completed (constrain strangeness in proton)
- prompt photon measurements not completed

  -> see talk P. Bussey
- pentaquark searches not completed

  -> see talk U. Karshon
- measurement of total $\gamma p$ cross section not completed
- test higher order QED corrections "a la Olympus" using Bethe-Heitler dimuons
- …
- new theory developments (beyond those already mentioned) might require reanalysis of data

# published papers per year

**Example: ZEUS compared to LEP (rescaled)**



# Conclusions and Outlook

- HERA data are unique and exciting !

- many of the topics of interest more than 20 years ago are still of interest today, and quite a few are still not finished
- more have been added

  -> will continue to be of interest for the next decade

- HERA physics analysis is in full swing and will hopefully continue for a long time, although at strongly reduced pace, based on the data preservation scheme

- bottleneck: manpower after end of (so far very generous) DESY support

  purpose of this meeting: motivate that it is worthwhile finding manpower/funding from (so far) unconventional sources in order to finish the great physics program