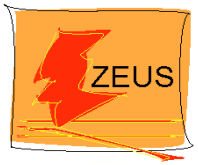
HERA Perspectives



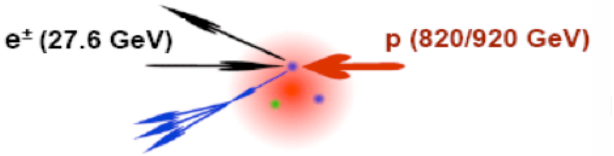
DESY Program Oriented Funding Meeting, February 26, 2009

Cristinel DIACONU
CPP Marseille & DESY

Outline

- Introduction
- HERA Achievements and Goals
- Strategy, organisation and plans
- Conclusions

HERA Experimental Complex



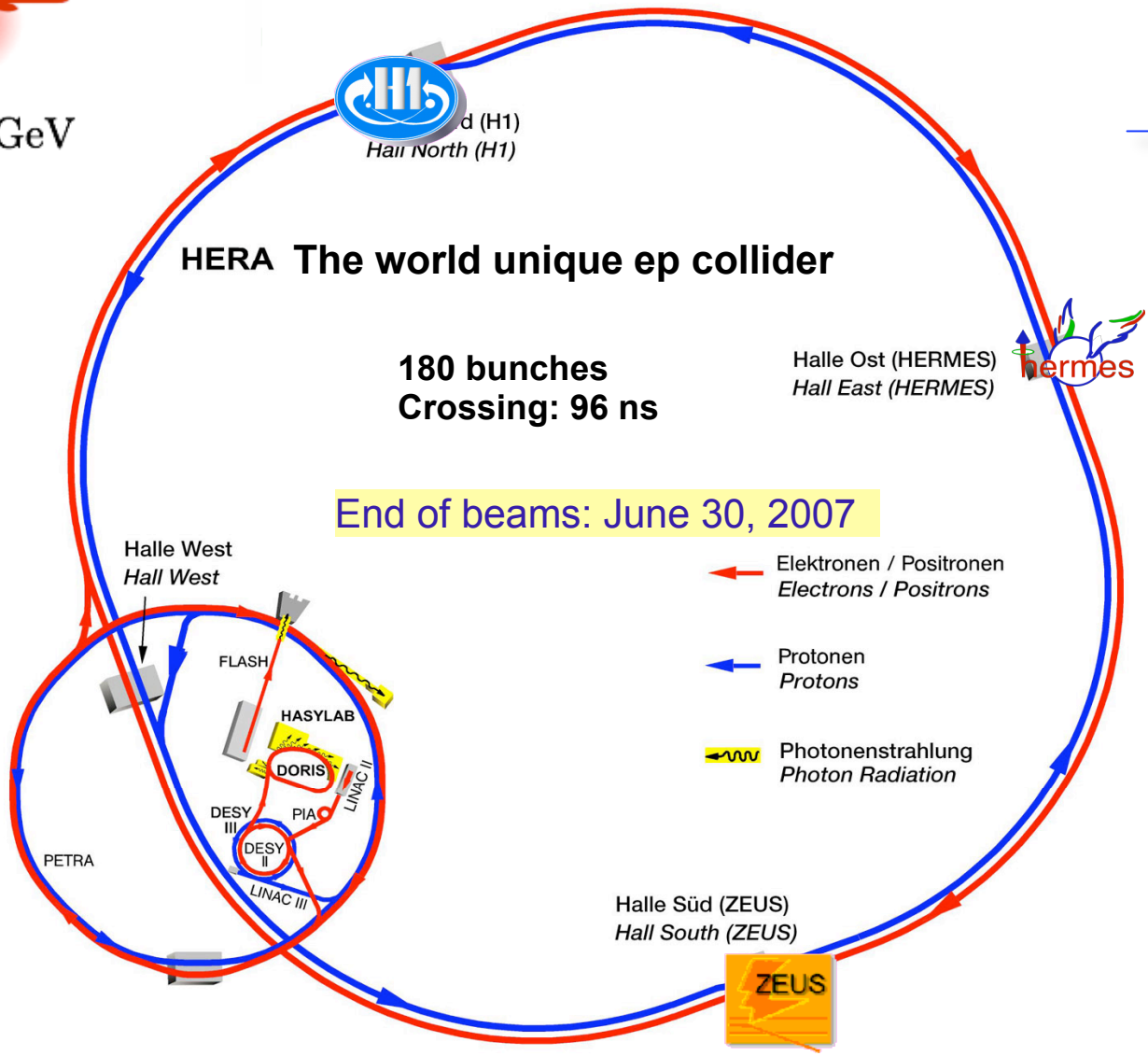
$E_{cm} = 320$ GeV

$E_{cm} = 7$ GeV

HERA **The world unique ep collider**

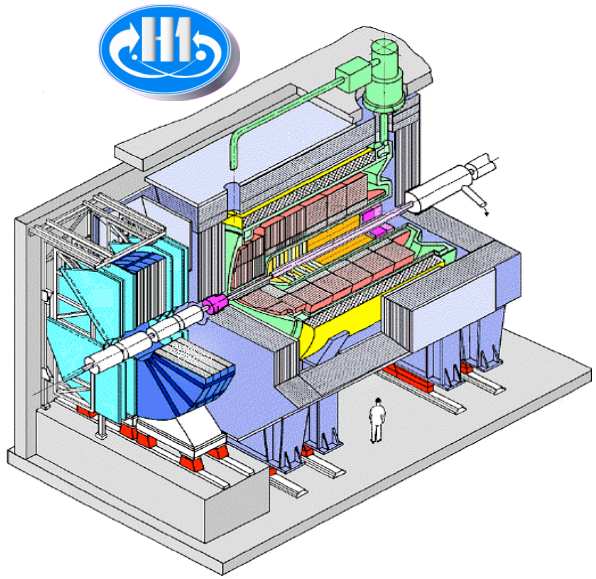
180 bunches
Crossing: 96 ns

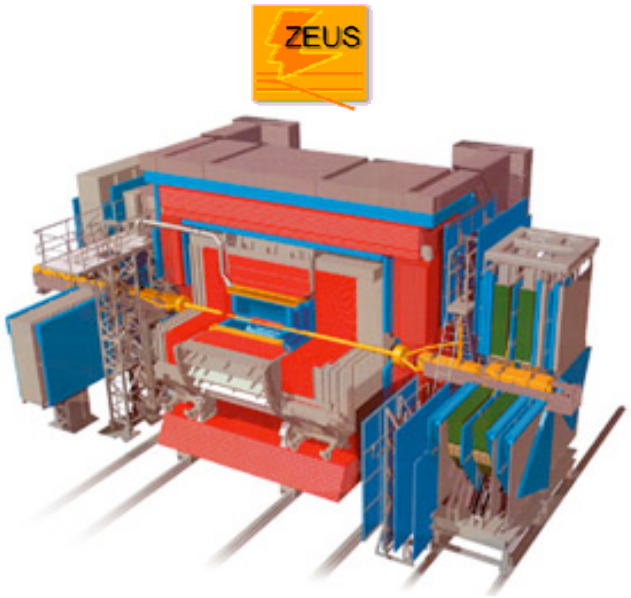
End of beams: June 30, 2007



The Detectors

Complex detectors, large international collaborations (~800 physicists)



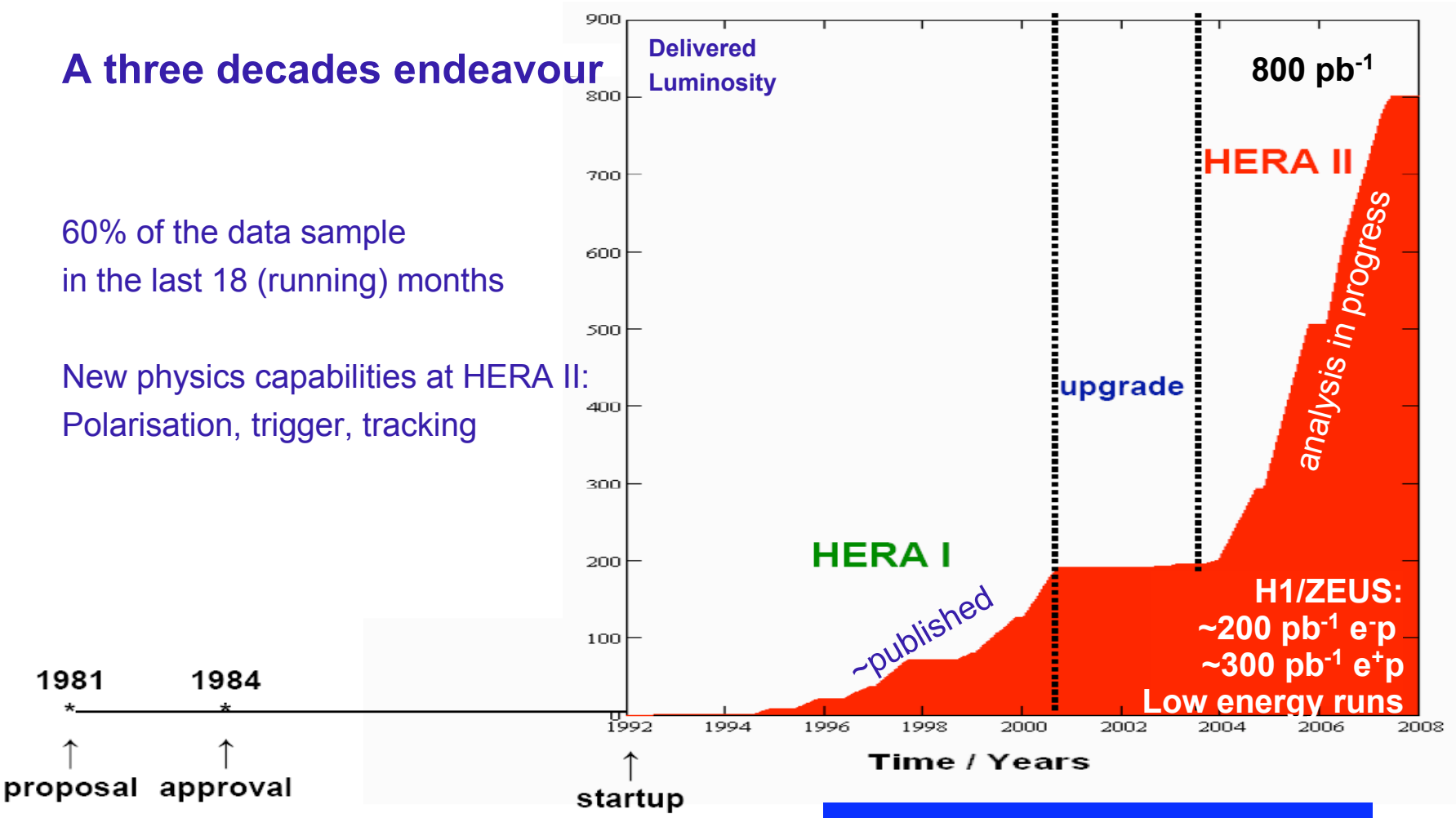


HERA Program

A three decades endeavour

60% of the data sample
in the last 18 (running) months

New physics capabilities at HERA II:
Polarisation, trigger, tracking

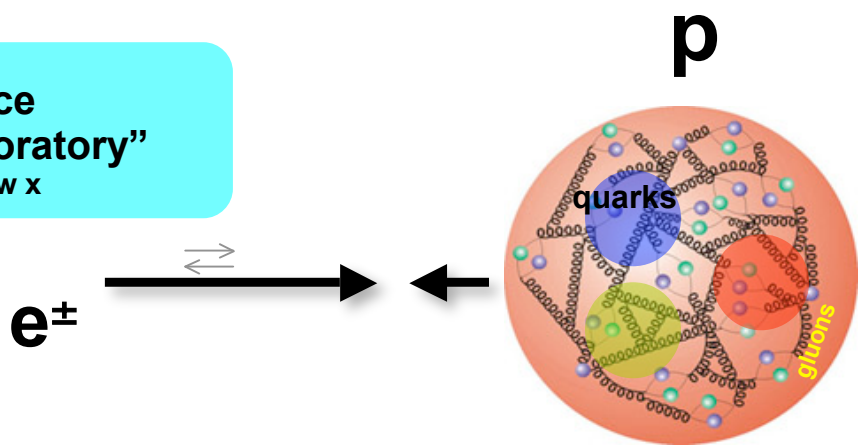


Goals of the next period:
Exploit the full HERA data
Provide the return of the investment

The Physics at HERA

The proton structure
with unprecedented precision
Parton distribution functions for the future

The strong force
in a clean "laboratory"
Jets, Diffraction, Low x

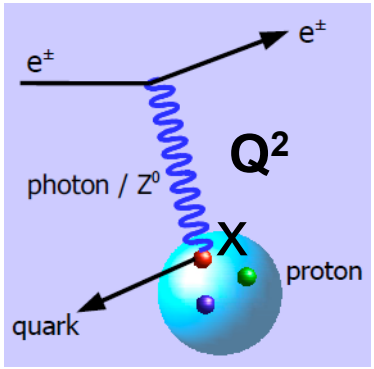


The proton spin surgery
Longitudinal and transverse spin measurements

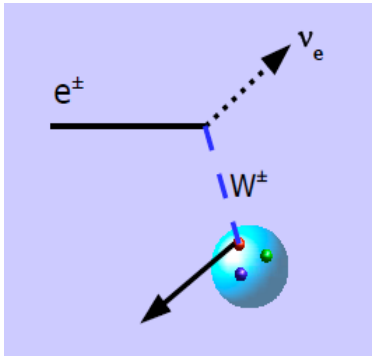
The new physics
at the energy frontier

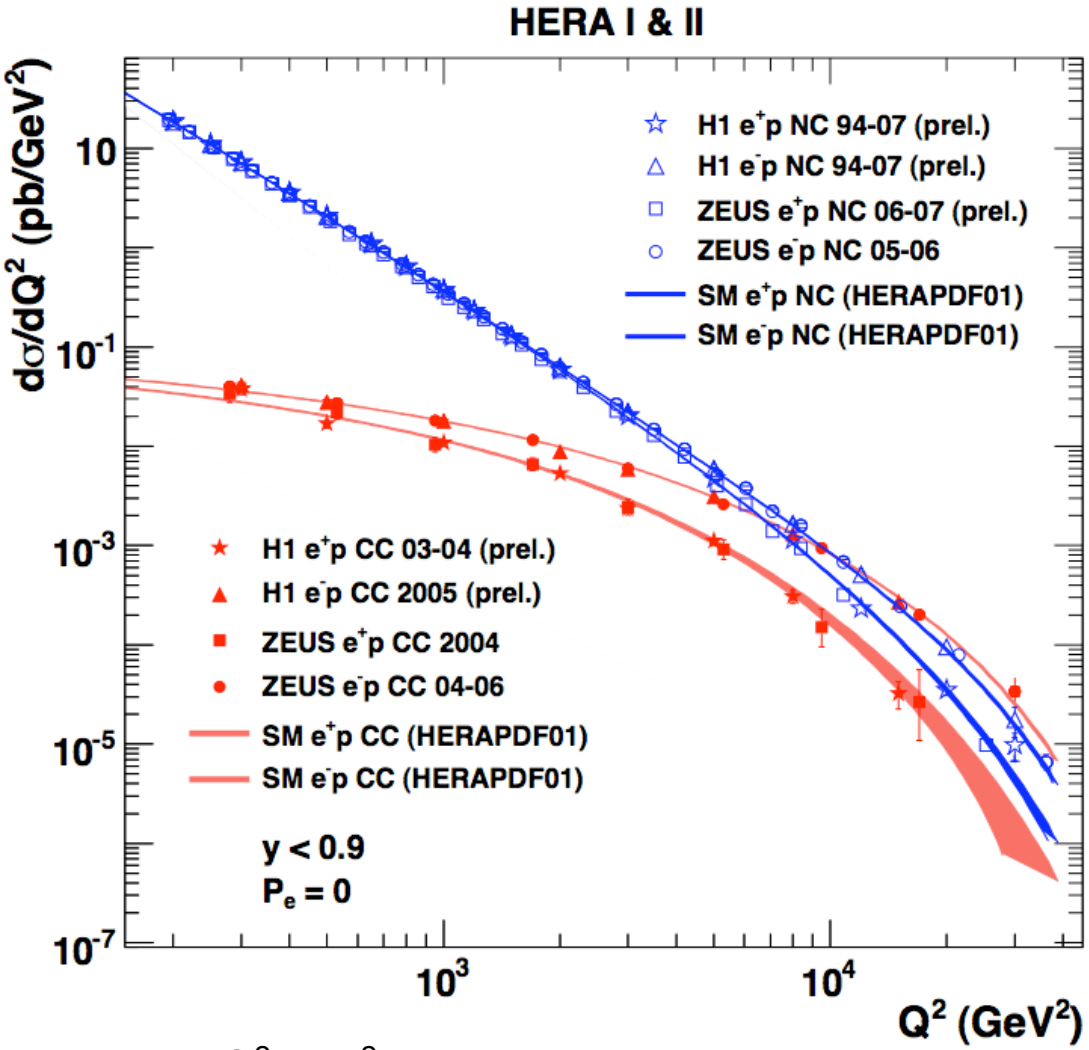
HERA Microscope

Neutral Current



Charged Current





x momentum fraction

Q^2 transfered momentum squared

$Q^2 \sim M^2_{W,Z}$ (electroweak regime)

$$\text{Resolution [fm]} = \frac{0.2}{Q[GeV]}$$

r_{quark}<0.001 fm

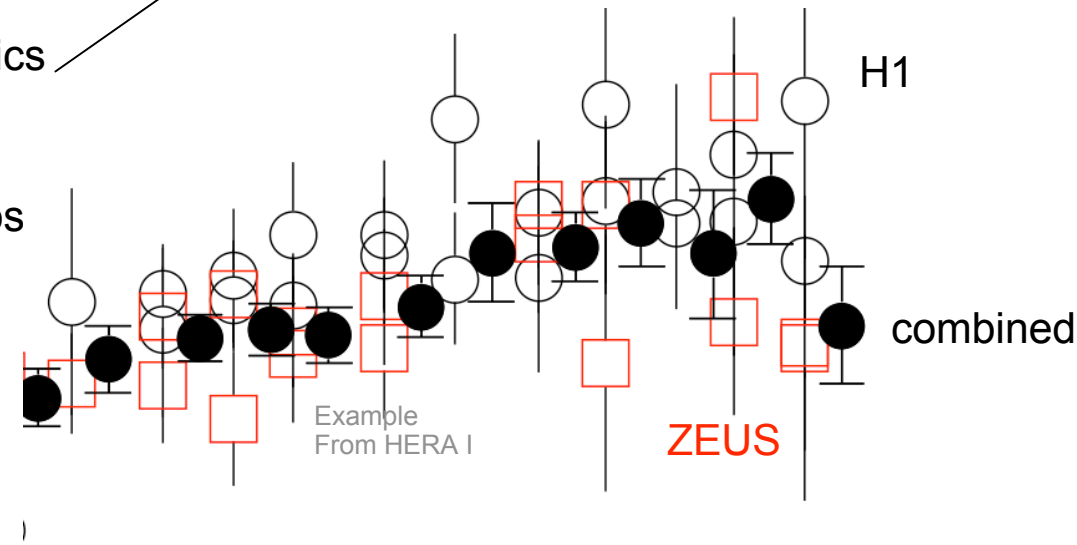
Sharpen the output: H1 and ZEUS data combination

"Double" the statistics

Extra-constrain the coherent systematics

H1 and ZEUS common working groups in all physics areas

$$\chi^2_{\text{exp}}\left(M^{i,\text{true}}, \alpha_j\right) = \sum_i \frac{\left[M^{i,\text{true}} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\alpha_j\right)\right]^2}{\delta_i^2} + \sum_j \frac{\alpha_j^2}{\delta_{\alpha_j}^2}$$

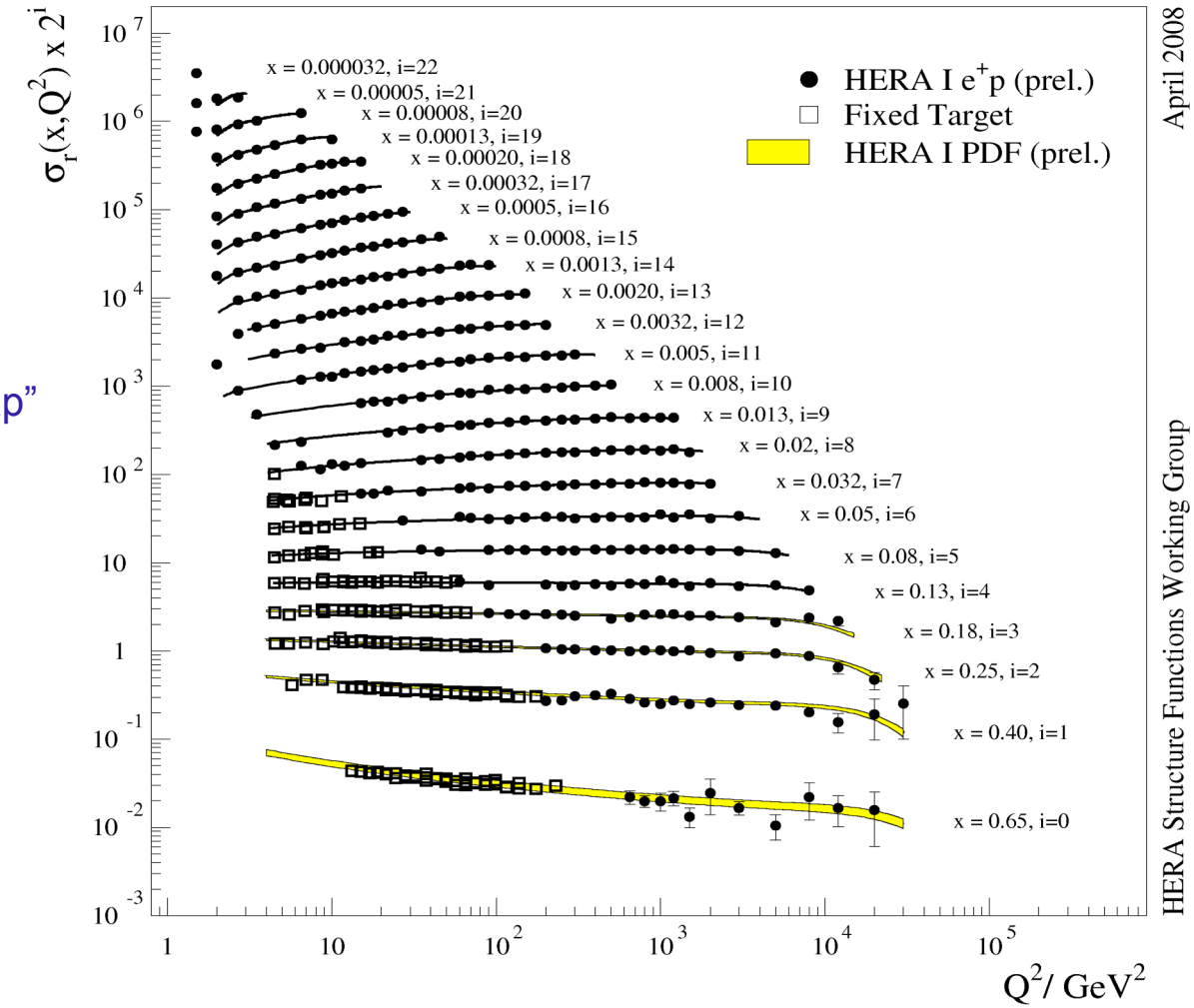


Goal: improve HERA output, coherent message from the unique ep collider

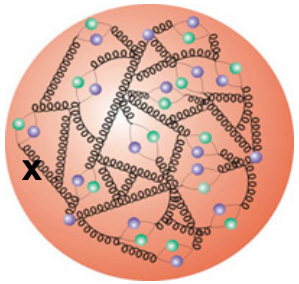
The combined HERA I data: towards the global view

Coherent data sets combined:
vast coverage of the proton “map”

Scaling violations reveal
the gluon content

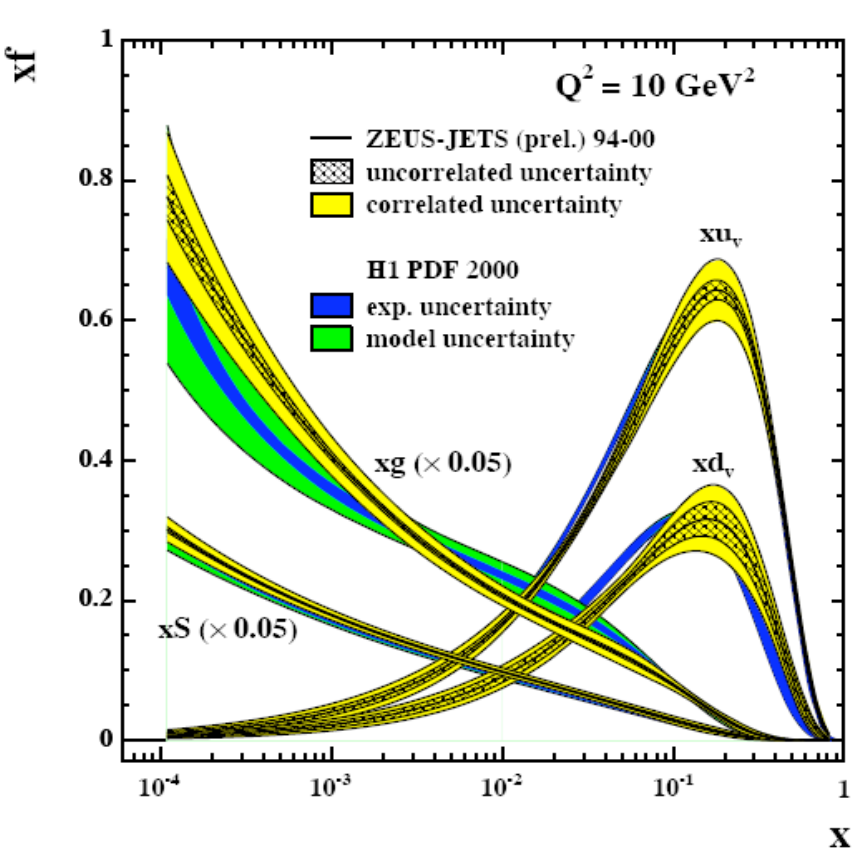


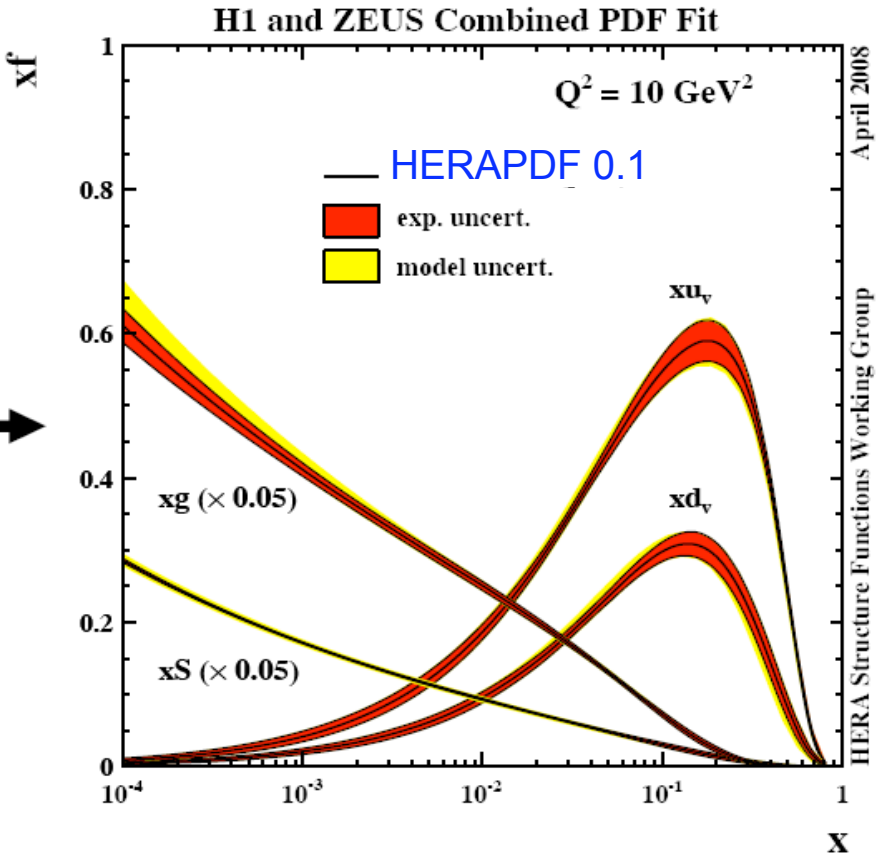
Goal: Produce a coherent and complete data set from HERA I+II



Partons in the proton: the power of HERA

Parton **D**istribution **F**unctions from HERA I data

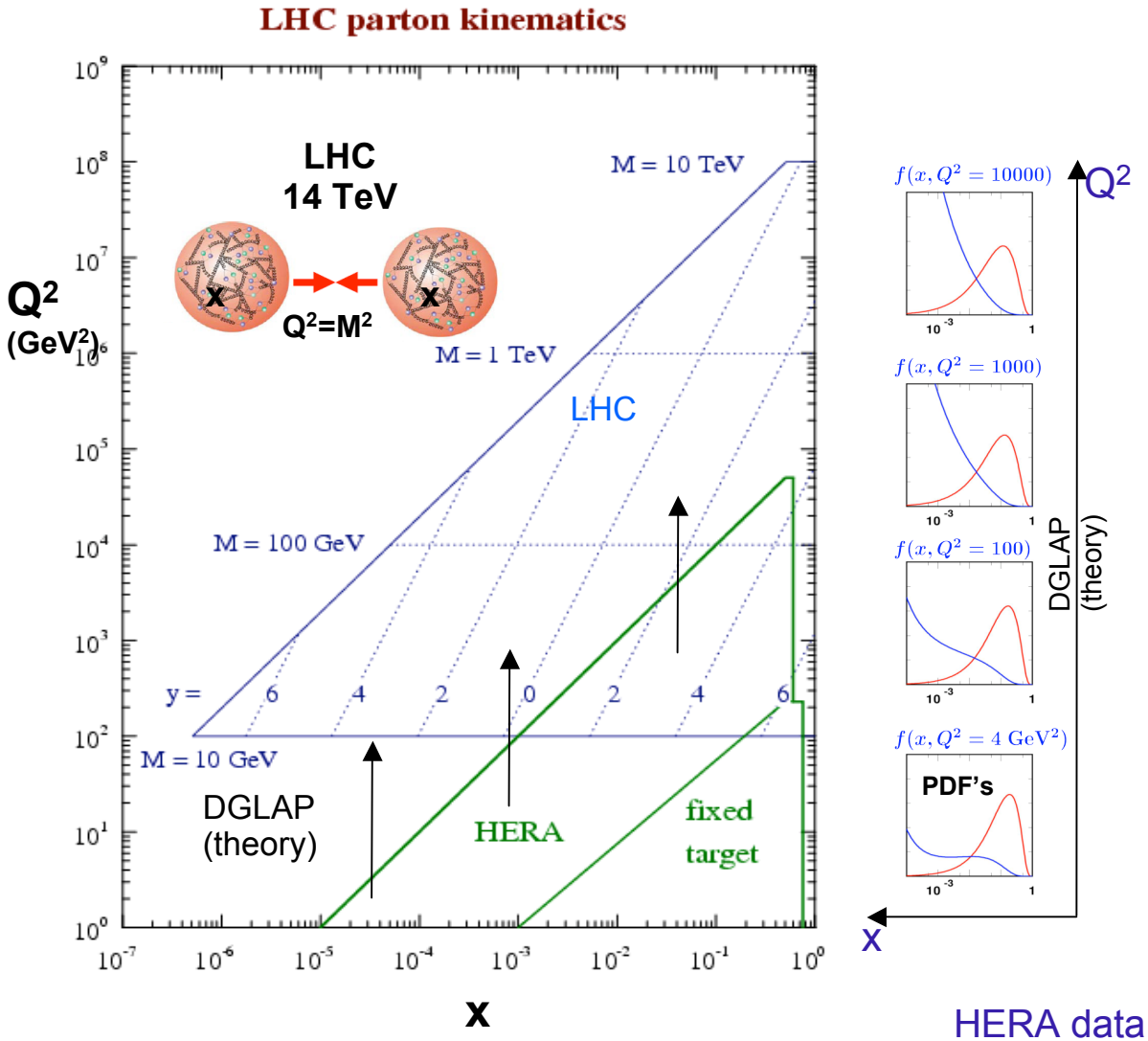




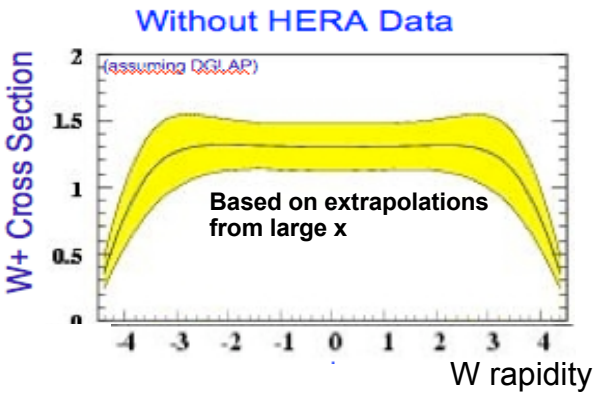
The power of the coherent data combination is visible
Much more to come: HERA II, heavy flavours, jets

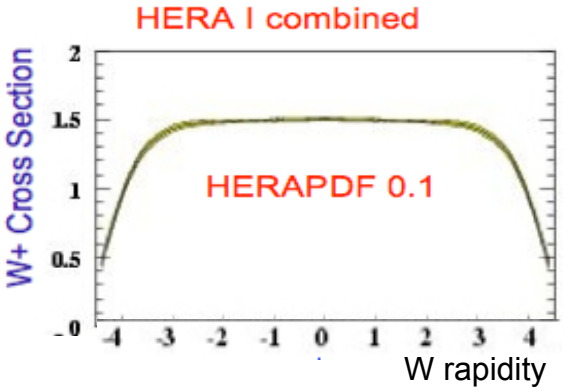
Goal:
Final HERAPDF

HERA and LHC



W+ Production at LHC

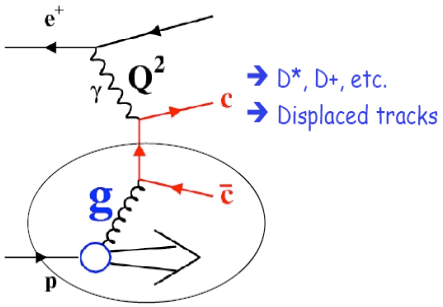




HERA data is essential for LHC
Final precision in PDF's is mandatory
for some areas of LHC physics

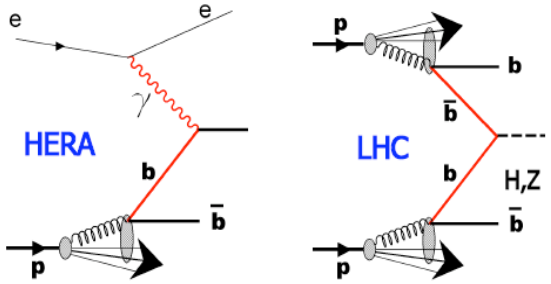
Proton's charm and beauty

Young Investigator Group:
Heavy Flavours HERA/LHC
Katerina Lipka

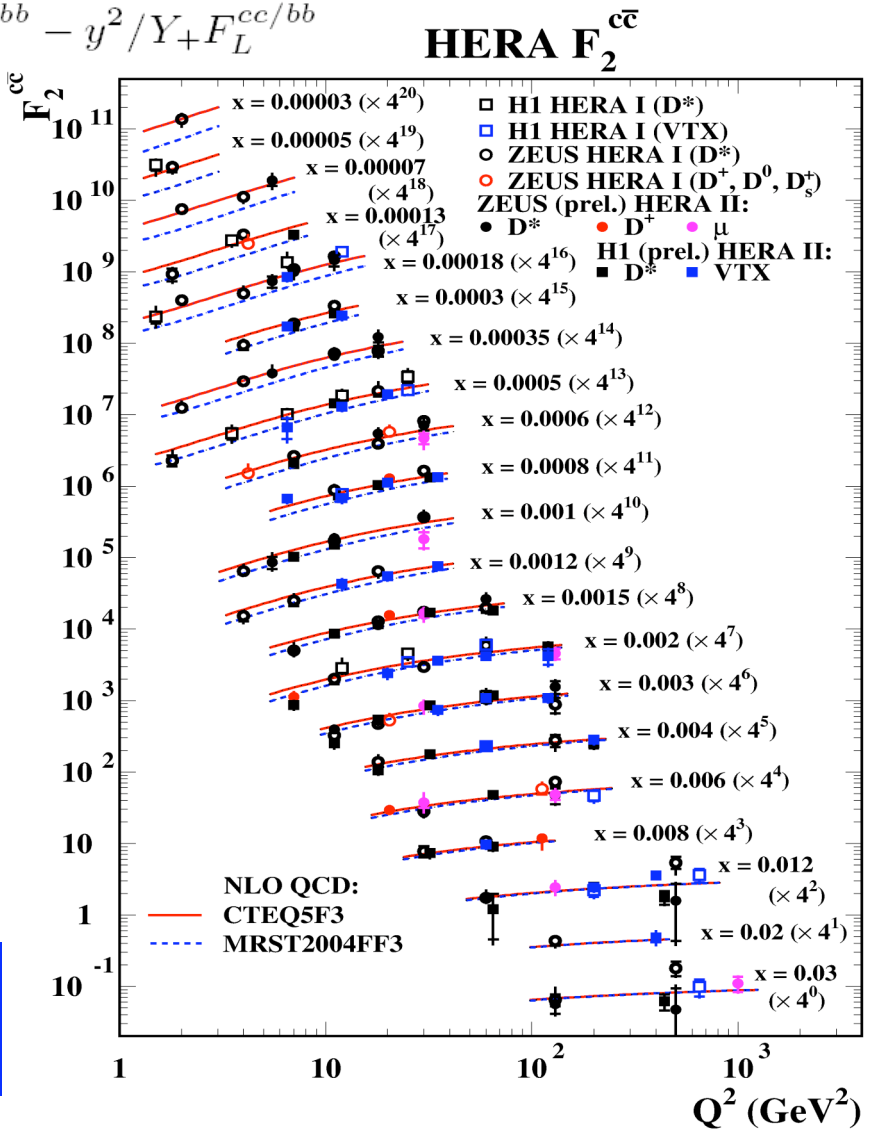


$$\sigma_r^{cc/bb} = F_2^{cc/bb} - y^2/Y_+ F_L^{cc/bb}$$

Present precision: charm 10%, beauty 20%

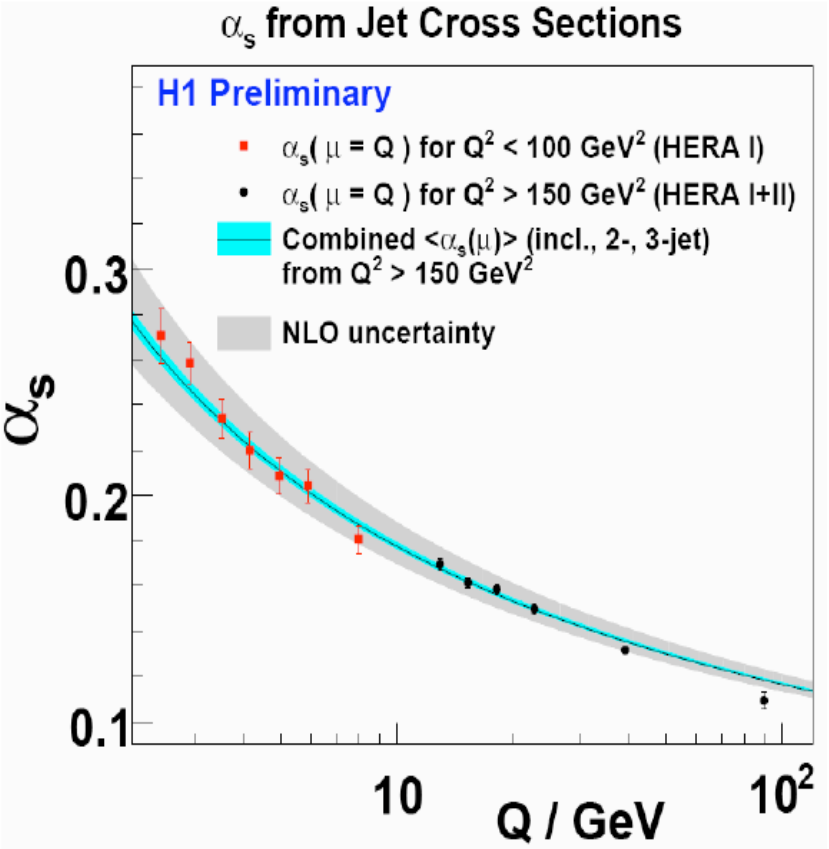


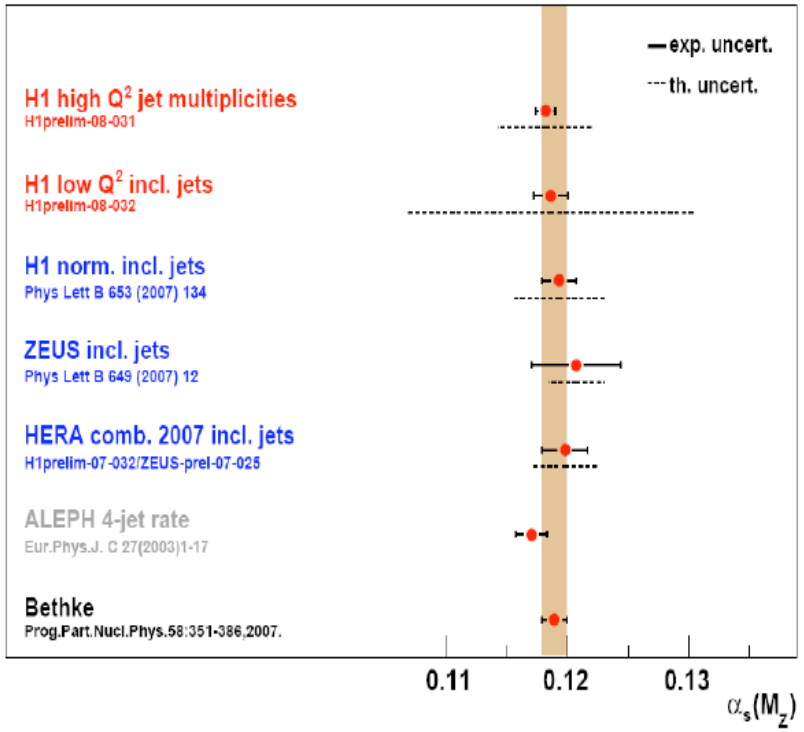
Goal:
More data, combinations: charm 5% , beauty 15%
Include in the final PDF's



Strong coupling

Jet production measurements access the strong coupling





At present:
1-2% experimental error
3-4% theoretical error

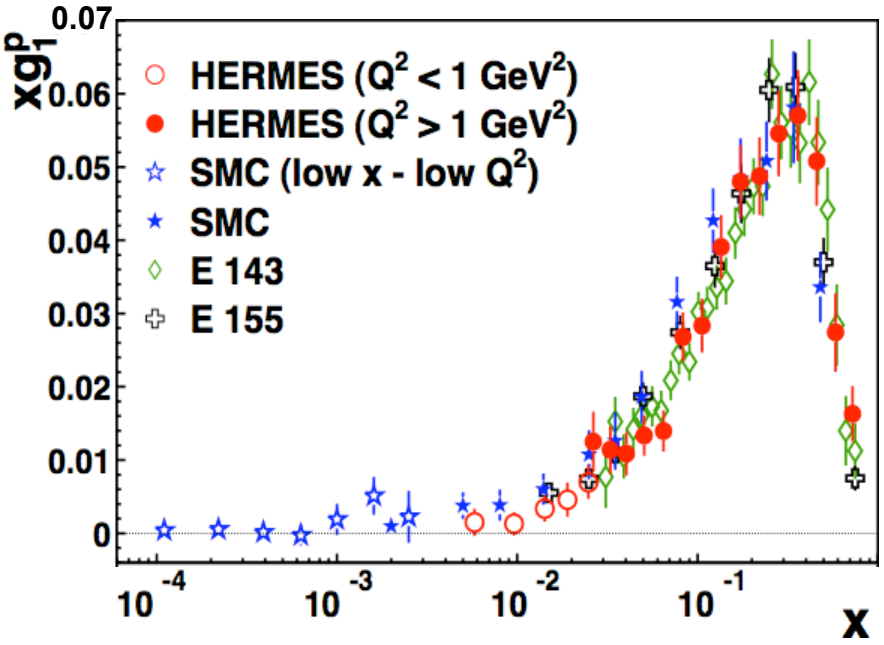
Goal: more data, combination: 0.5% experimental error
jet cross sections used for PDF's

Theoretical improvements are also needed

The Proton Spin

quarks gluons orbital angular momenta

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^G$$



HERMES:

$$\Delta\Sigma = 0.33 \pm 0.04$$

Inclusive DIS

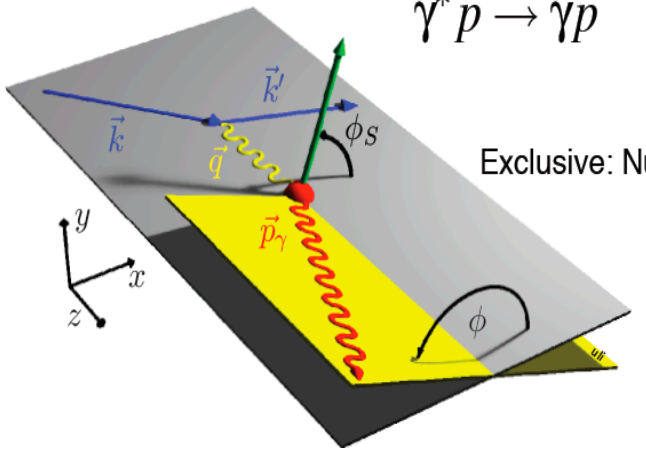
$$\Delta G/G = 0.07 \pm 0.13$$

Semi-inclusive DIS

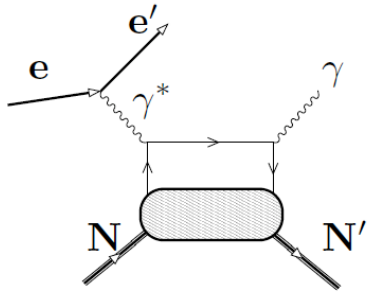
More measurements in order to further investigate L

Transverse target and beam charge asymmetries in DVCS

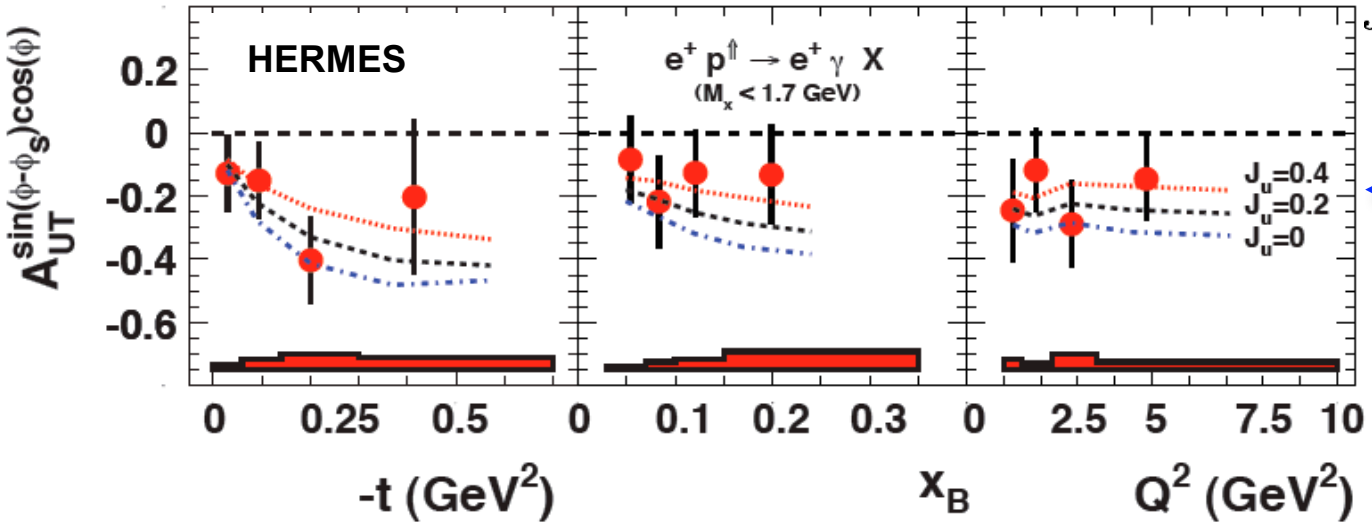
$\gamma^* p \rightarrow \gamma p$



Exclusive: Nucleon recoils intact



Generalised
Parton
Distributions



$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

← **J_q**

Goal: measure the transverse momentum distributions and access the angular momenta

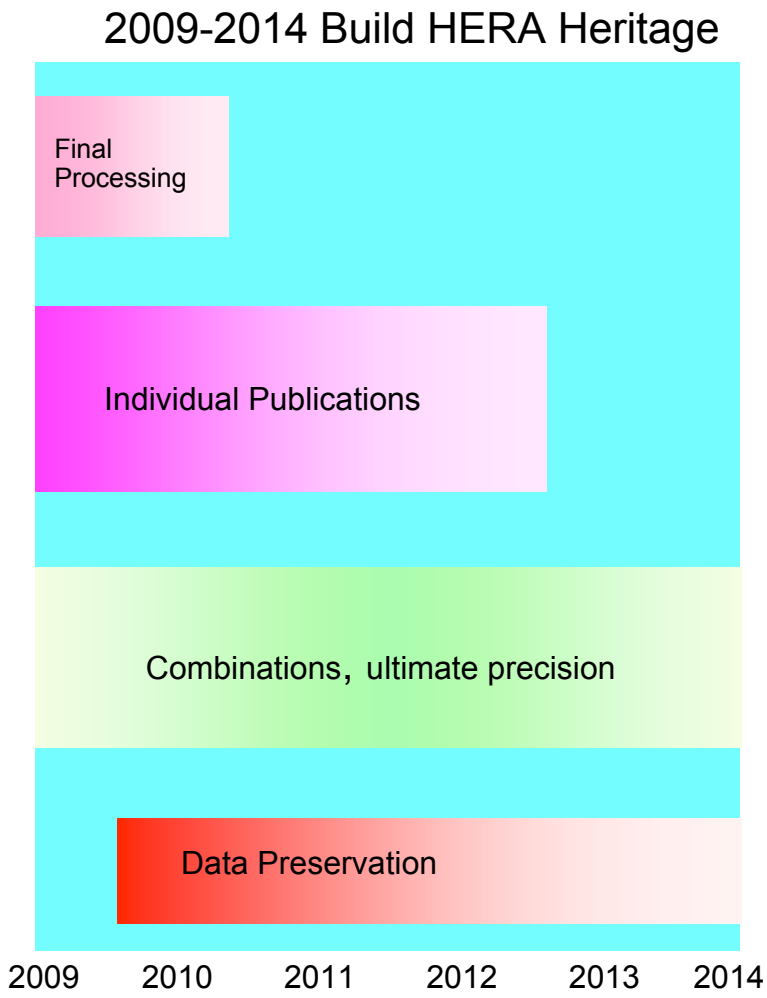
Plans for Final Results from HERA

	Achievement	Milestones		Goals
Proton Structure	HERAPDF 0.1 2-5%, FL	HERA I (low Q2) HERA II (high Q2) 2011	2009 2011	HERAPDF 1%
Heavy Flavours	10% charm 20% beauty	Cross sections Combinations	2010 2012	5% charm 15% beauty
Jets	Jets Cross sections α_S 1%	Cross sections Final Precision (th)	2010 2013	α_S 0.5% exp. improved theory
Diffraction	DPDF (HERAI) DVCS, Vector Mesons	Full HERA II Combinations	2010 2012	FLD, HERADPDF Exclusive Measurements
Searches for New Physics	Full HERA Data Explored	Combinations	2009	Publish before LHC
Proton Spin	Longitudinal spin program, quarks	Tensor charge GPD's and J_q	2012 2013	Angular Momenta Contributions

Final PDF's 2012-2014

Roadmap 2009-2014

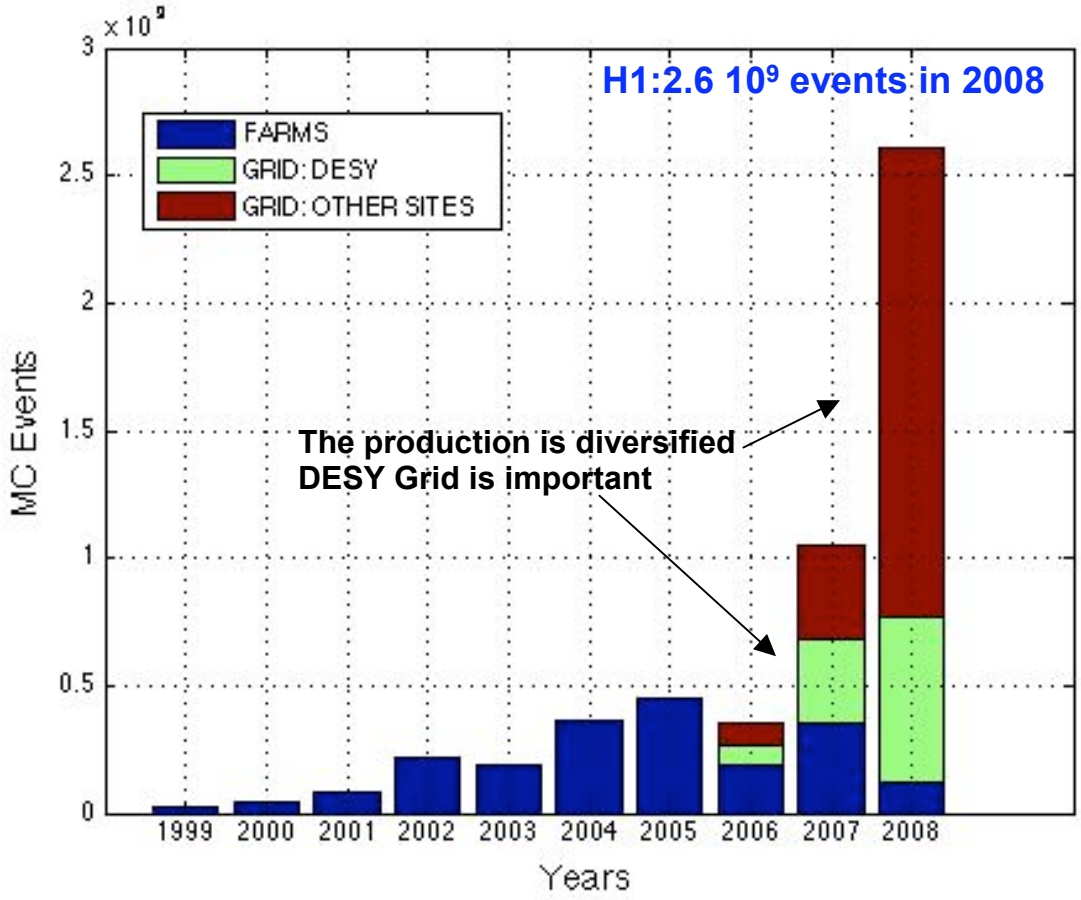
- Refine the instrumental precision
  - Exploit the full experimental capabilities (recent detectors)
  - Data reprocessing, improved Monte Carlo simulation
- Plan the publications
  - Taking into account the availabile human ressources
- Combine data and extract the best physics message for the future
  - H1 ZEUS Common working groups
- Preserve data and long term analysis capabilities



Monte Carlo Simulation

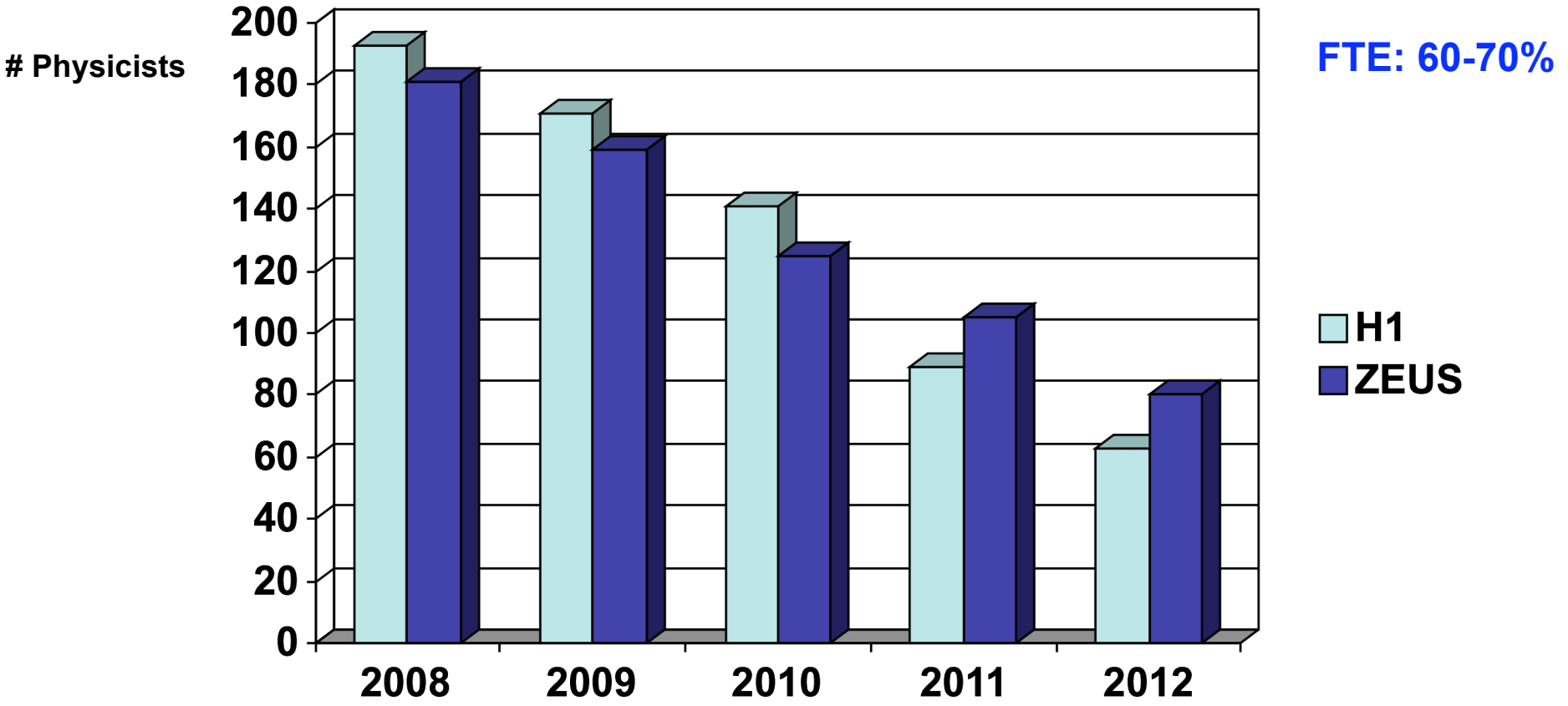
MC GRID Production: use LHC infrastructure for high statistics samples

HERA among the main users in a few big sites



Goal: refine the simulation and maintain production capability

Person power



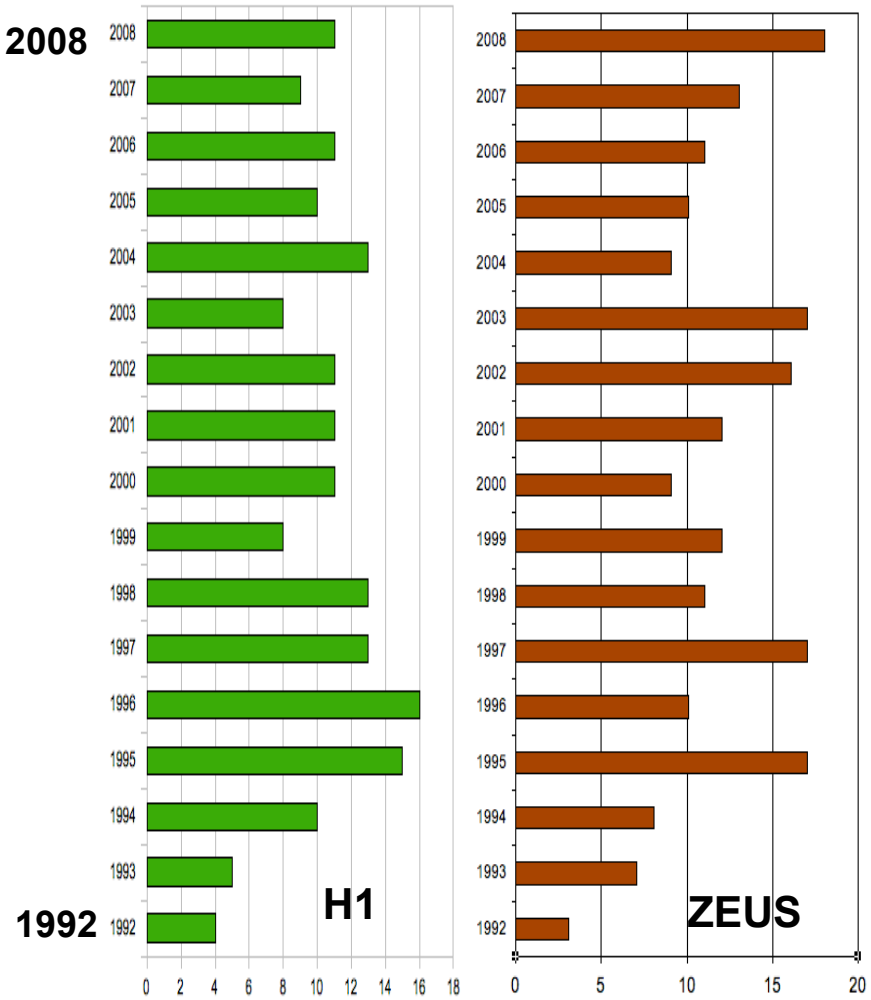
FTE: 60-70%

Strong commitment from most of the collaborating institutes: DESY contribution 20-30%
Postdocs and students are essential for the completion of the physics program

Goal: sustain the necessary collaborative effort

Publications planing in the next years

In the past: 10-15 papers/year



Planned 2009-2014:

H1: 50 publications
ZEUS: 60 publications
+10 combined publications

-2009-2012 rate of 15-20 papers /exp./year
-a few subjects for 2013-2014

HERMES: 40 papers
-transverse spin papers by 2011
-recoil data 2012-2014

Next few years will be very productive at HERA
Resources are essential for the publication plan

HERA Data Preservation Plans

HERA data is unique, no follow up experiments
All HERA experiments committed to preserve the data analysis capabilities

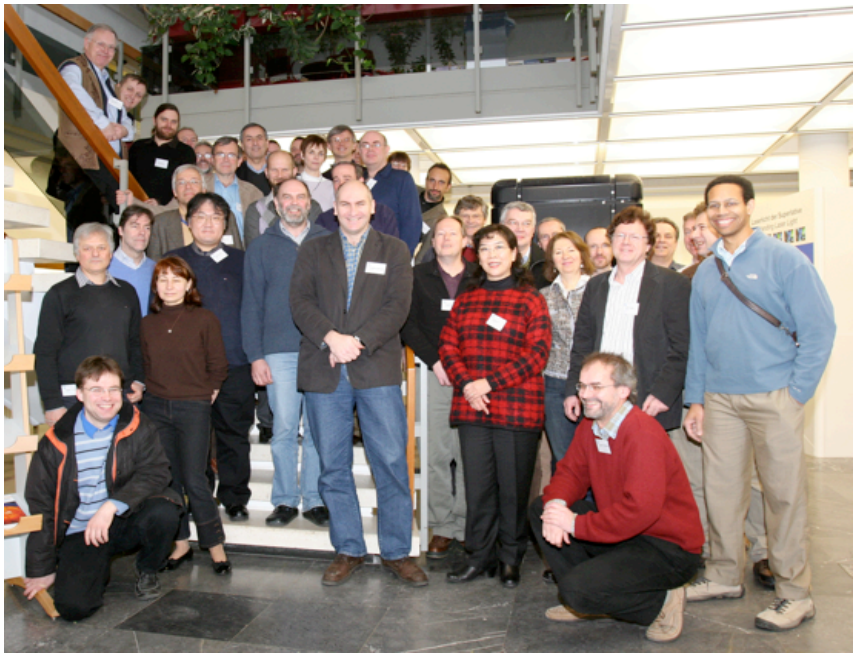
DPHEP Study Group for Data Preservation and Long Term Analysis in High Energy Physics

Inter-experiment Study Group
Large HEP labs and Computing Centers

Workshops in Desy 26-28 Jan. 2009
and SLAC june 2009

produce a blue-print as a reference
for further projects and collaborations

Within experiments: prepare data/software for preservation, consultations started



Goal: Long Term Analysis Capabilities

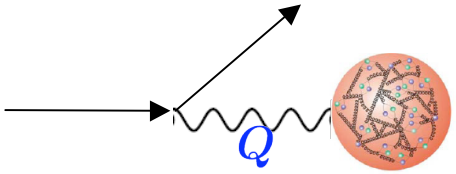
Conclusions and outlook

- HERA is an unique experimental facility:
  - Nucleon structure, precision QCD, electroweak, searches
  - Provides input for LHC physics
- The physics output from the final analyses 2009-2014 is essential:
  - Full detectors performance
  - Full HERA II data
  - Combination and ultimate precision: the HERA heritage
- **DESY is the core of this program:**
  - **Person power: in particular students and postdocs**
  - **Adequate computing and collaborative facilities**
  - **Data preservation: secure HERA heritage**

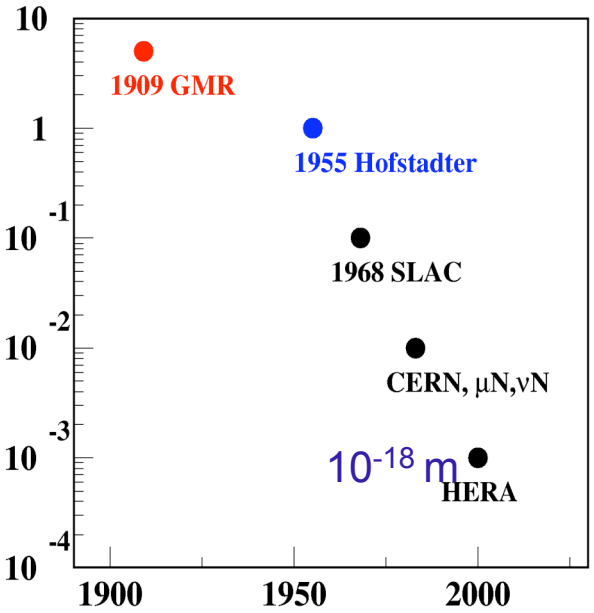
The significant investment in HERA program is exploited now

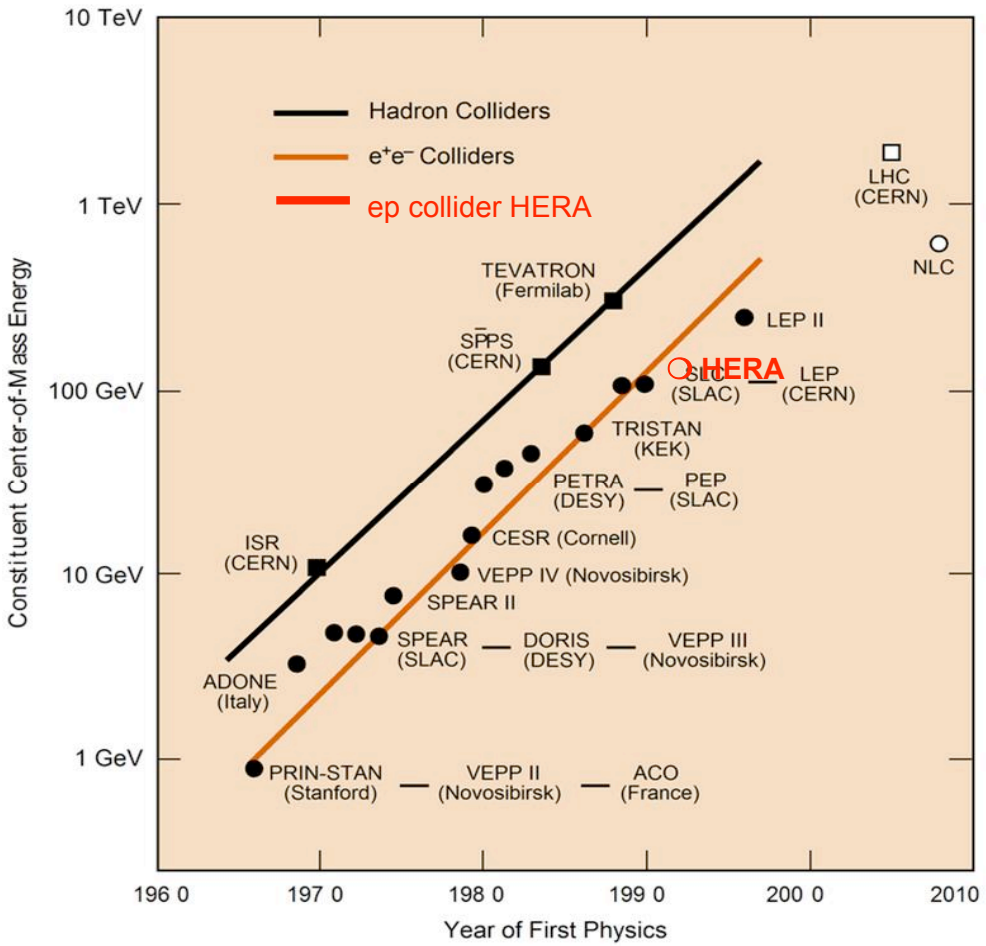
Backup

HERA: an unique collider at the energy frontier



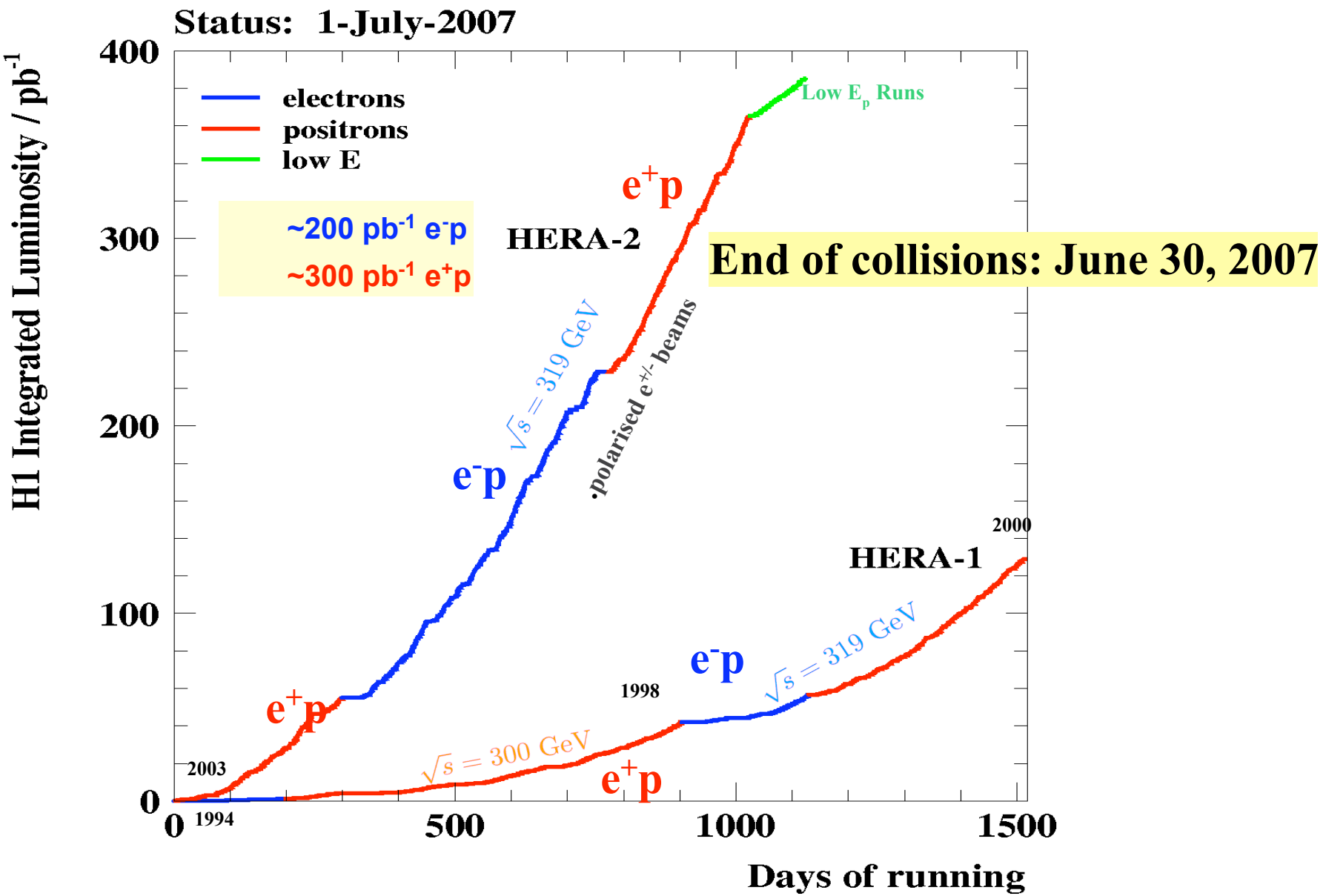
$$\delta\ [\mathrm{fm}] \simeq \frac{200\ \mathrm{MeV}}{Q}$$



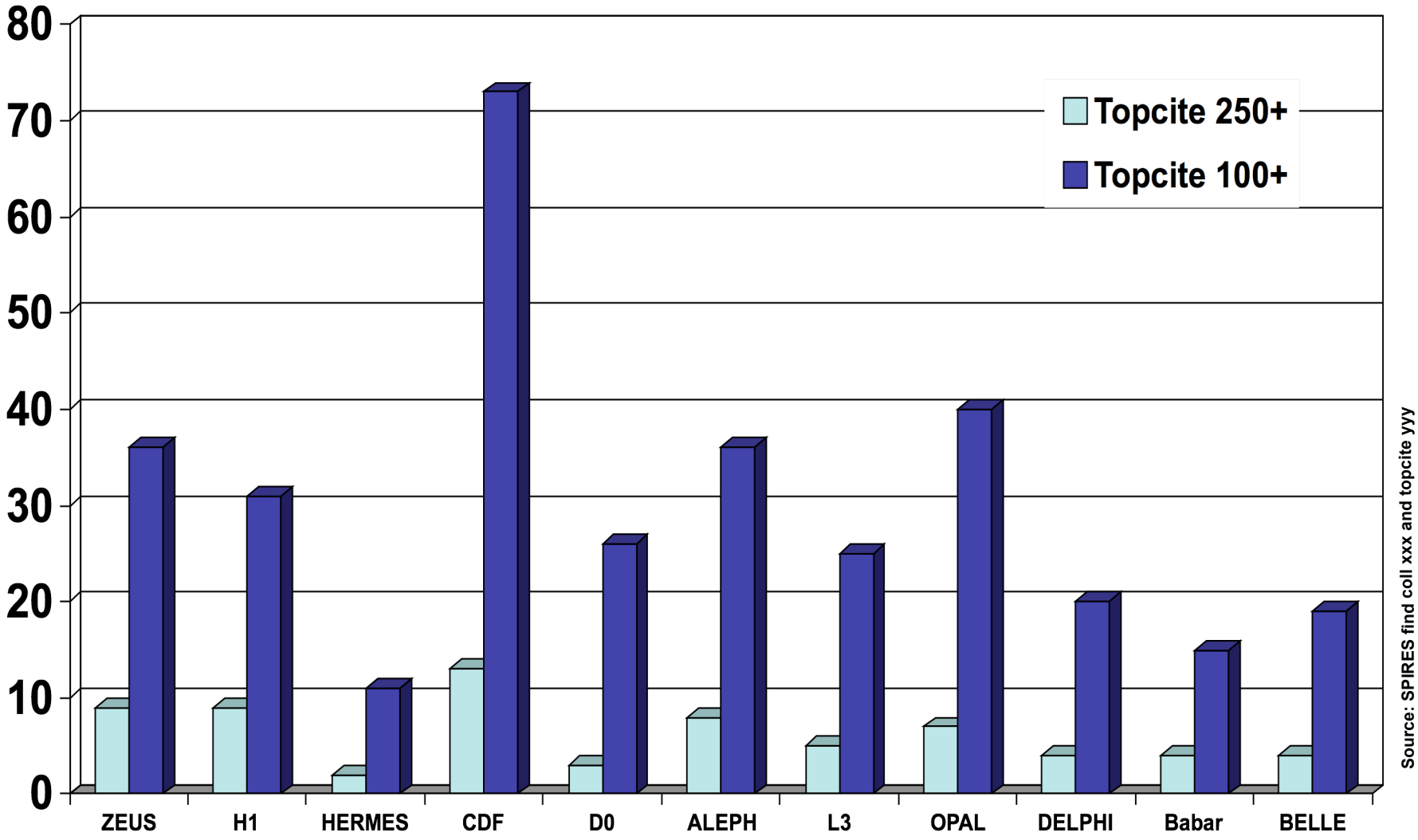


[polarised collisions since mid 70's]

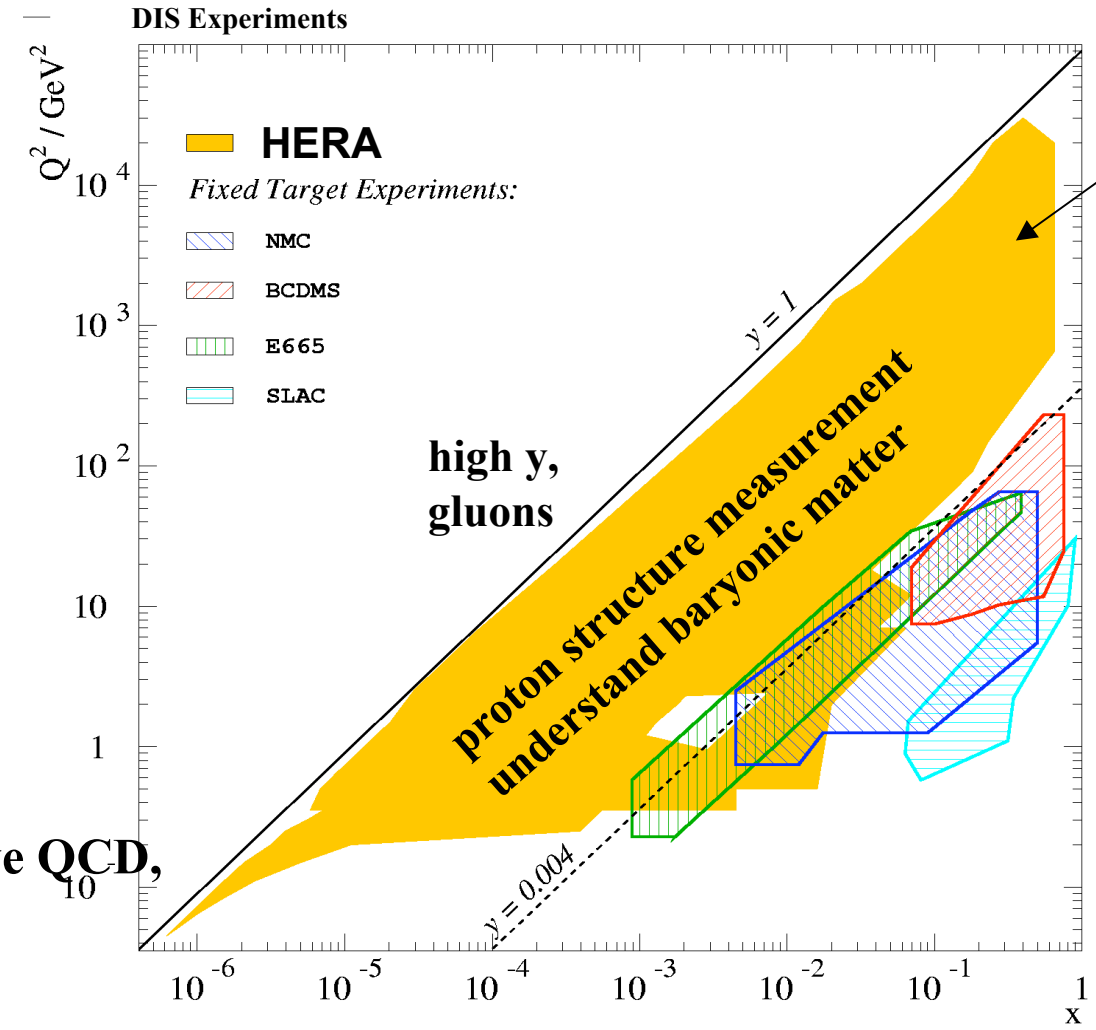
The Harvest from HERA Collider



HERA Results and Visibility

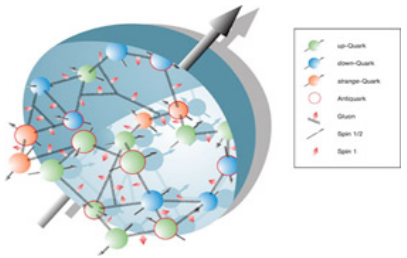


The proton map in the kinematic plane



Highest collision energy EW+searches

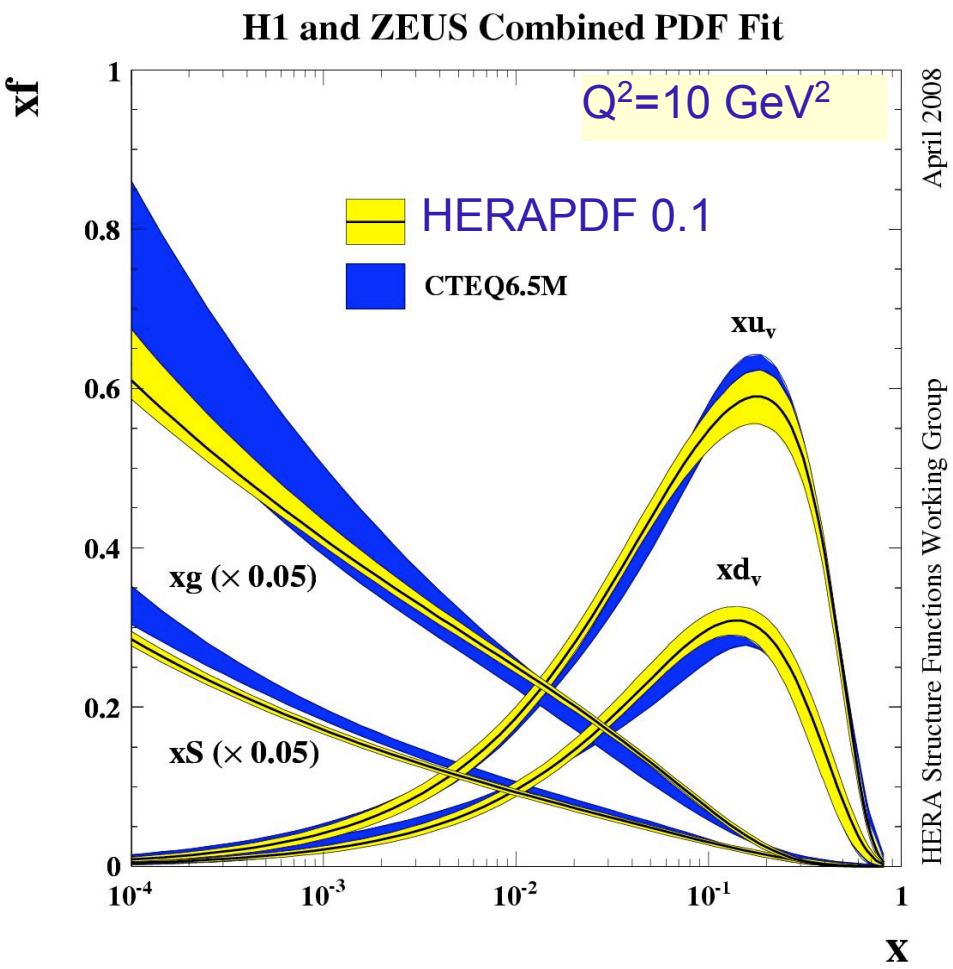
The proton spin surgery

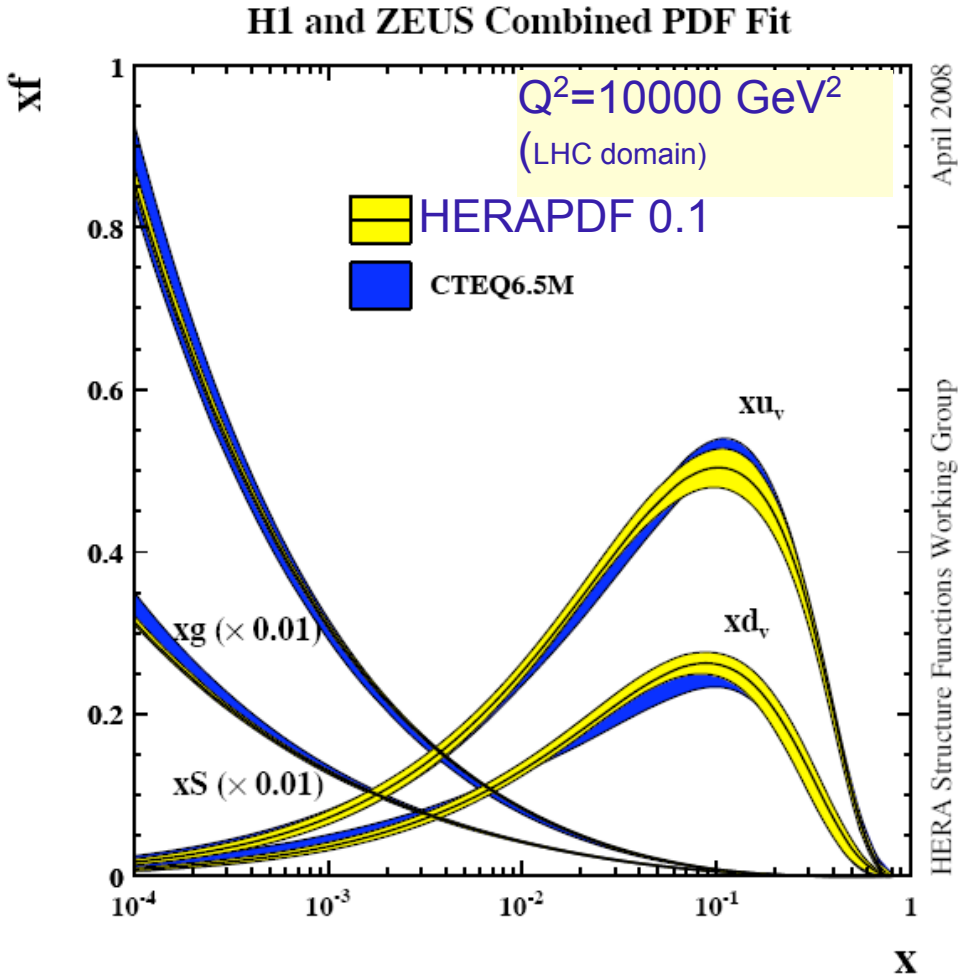


Non-perturbative QCD, transition

Use the final state processes (exclusive) for more on QCD, for finer phase space

Comparisons with global fits



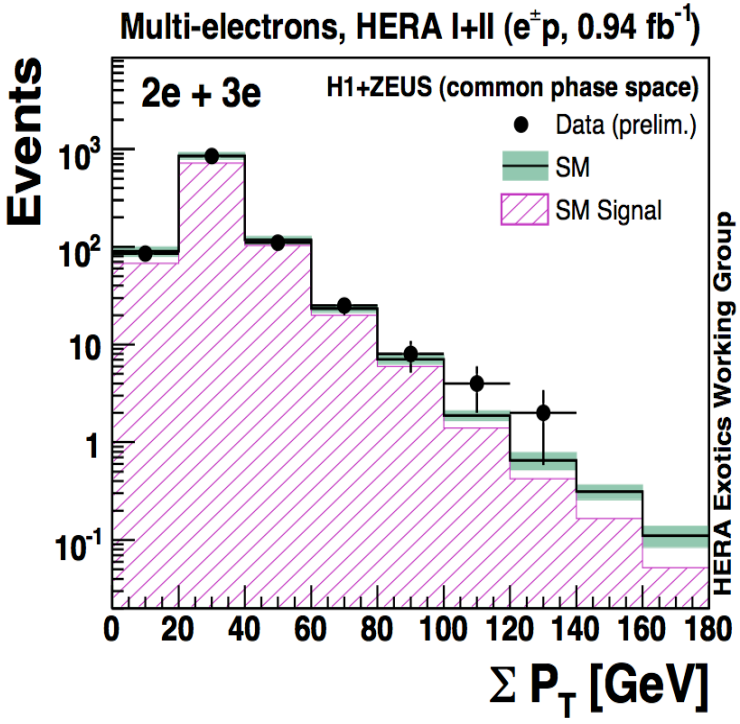


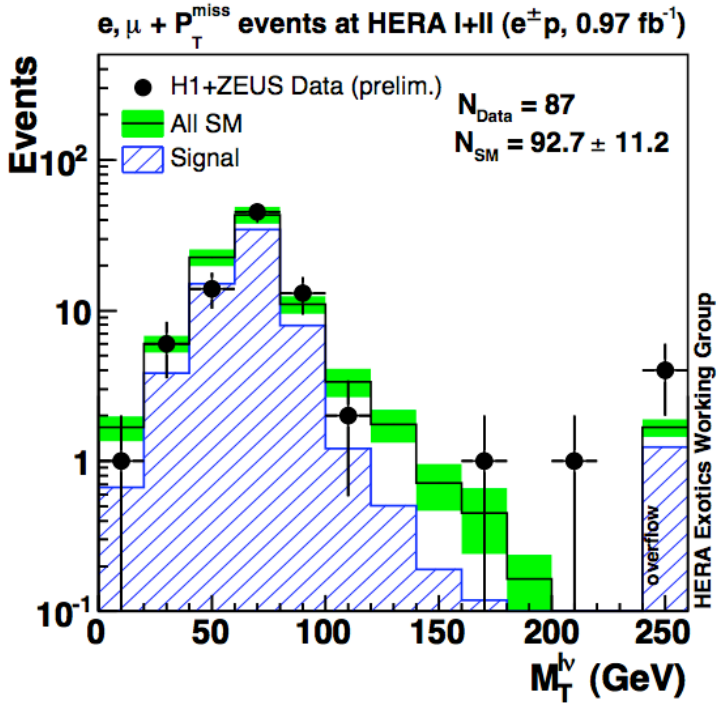
Improvement most notably at low x, holds for LHC domain (high Q^2)

Released in LHAPDF

Energy frontier tested with full HERA data

Searches for new physics combined H1 and ZEUS data **1 fb^{-1}**

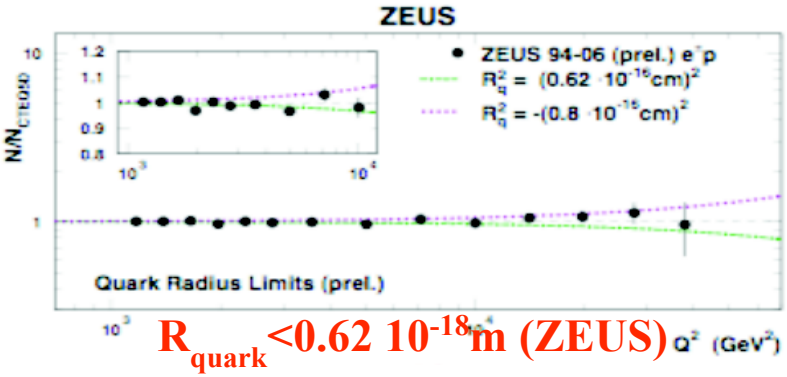




Goal: publish the full statistics searches, combined H1 and ZEUS analyses

Energy frontier tested with full HERA data

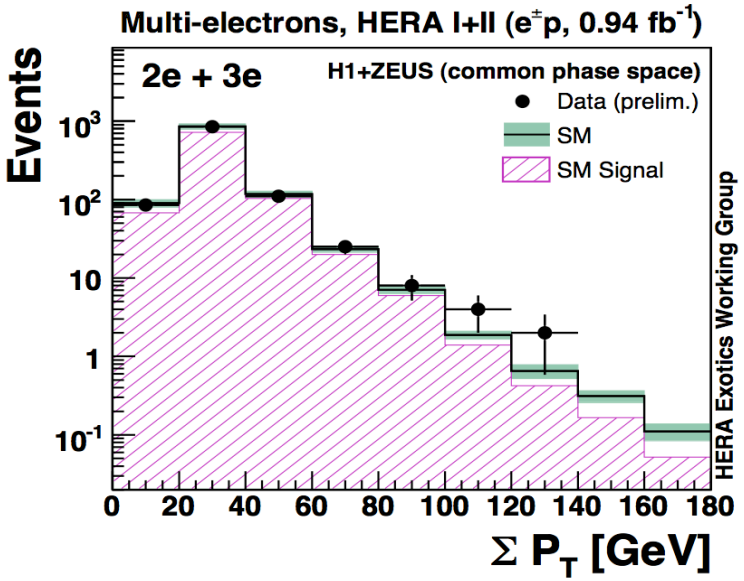
Deviations at high Q2?



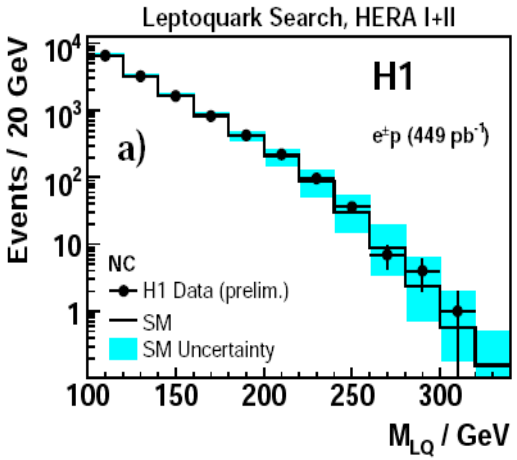
$R_{quark} < 0.62\ 10^{-18}$m (ZEUS)

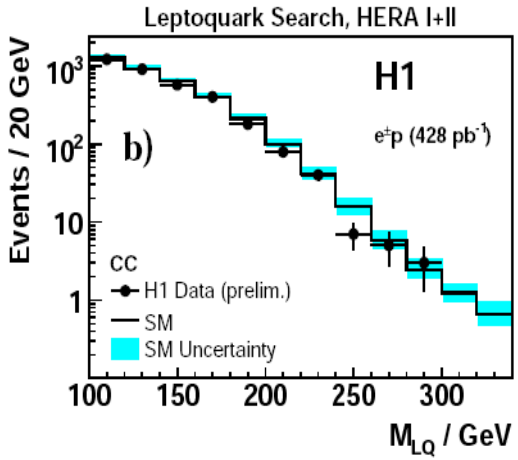
$R_{electron} < 0.28\ 10^{-18}$m (LEP)

High PT tails?

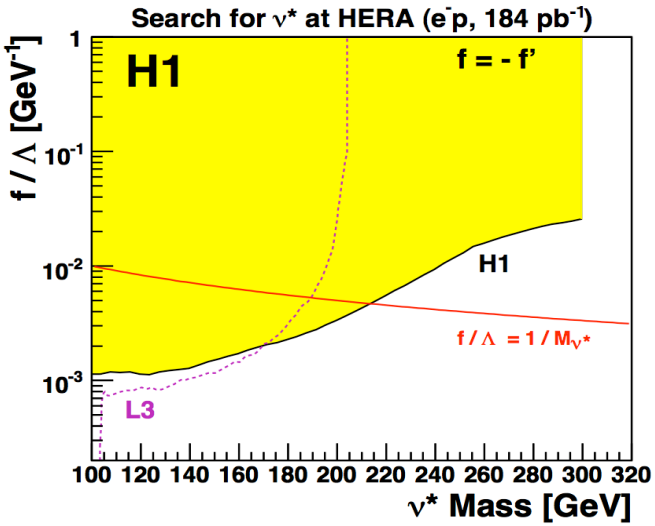


Mass peaks?



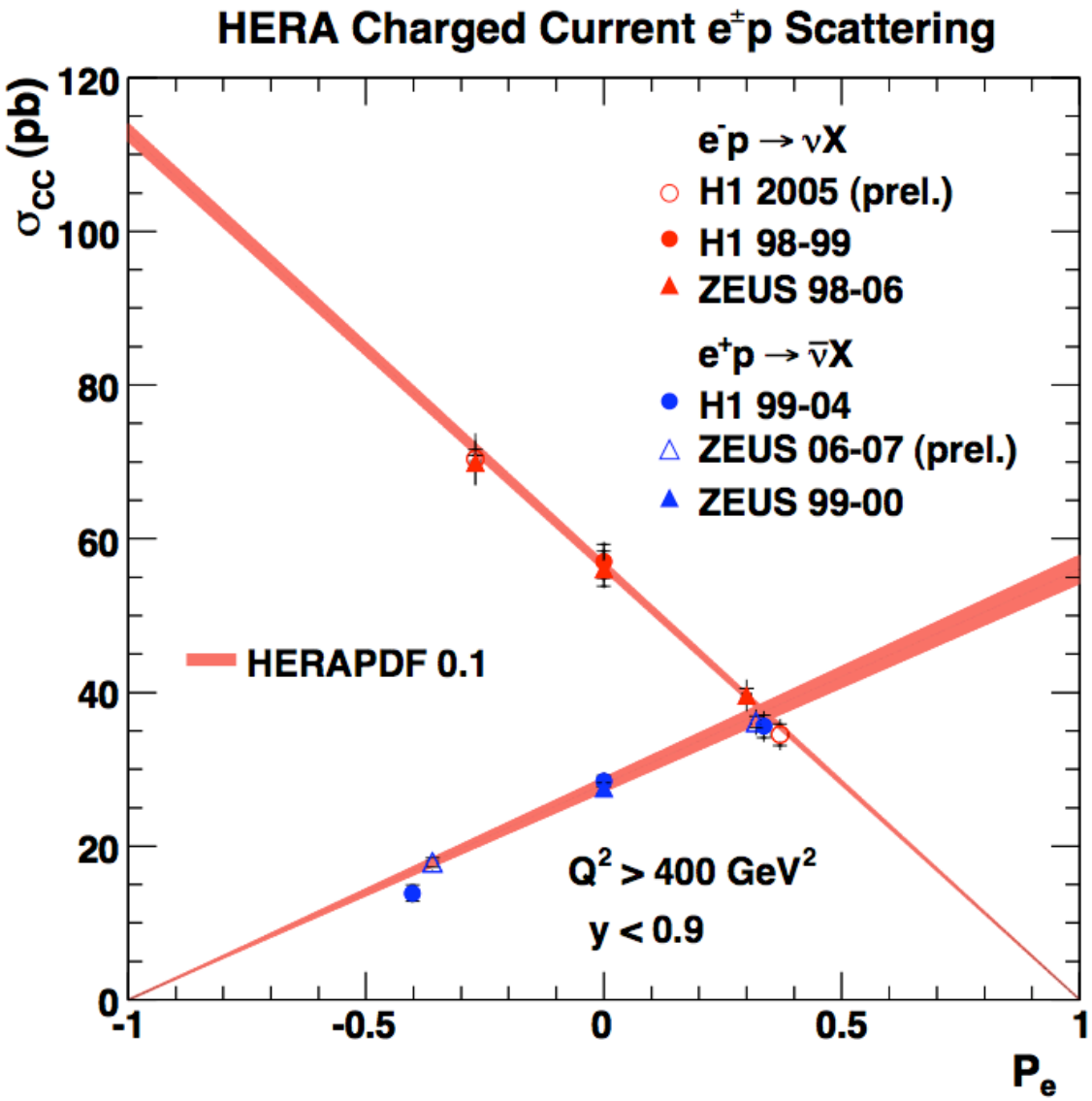


Complex signatures?



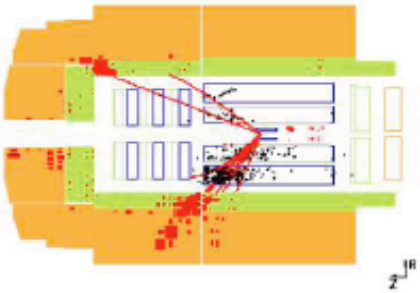
The V-A nature of the weak currents

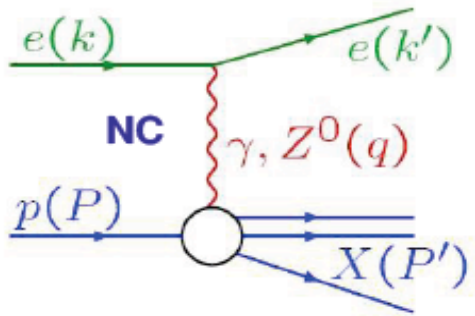
$$\sigma^{e^{\pm}p}(P) = (1 \pm P)\sigma^{e^{\pm}p}_{P=0}$$

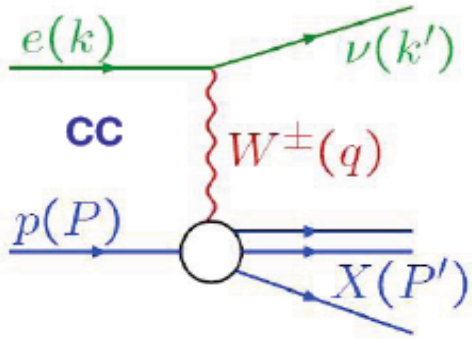


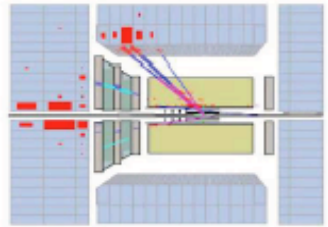
Deep-Inelastic Scattering at HERA

Partons = Quarks (+ Gluons = QCD improved quark parton model)









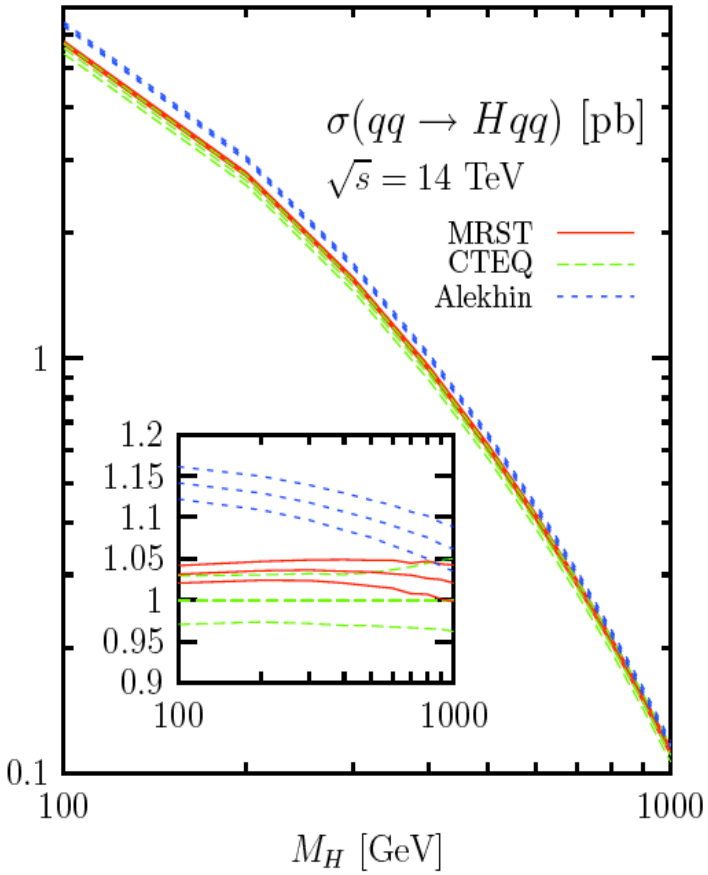
$$Q^2 = -q^2 = -(k - k')^2$$ **Boson Virtuality=1/Resolving power**

$$x = \frac{Q^2}{2qP}$$ **Momentum fraction of the scattered parton (Bjorken Scaling variable)**

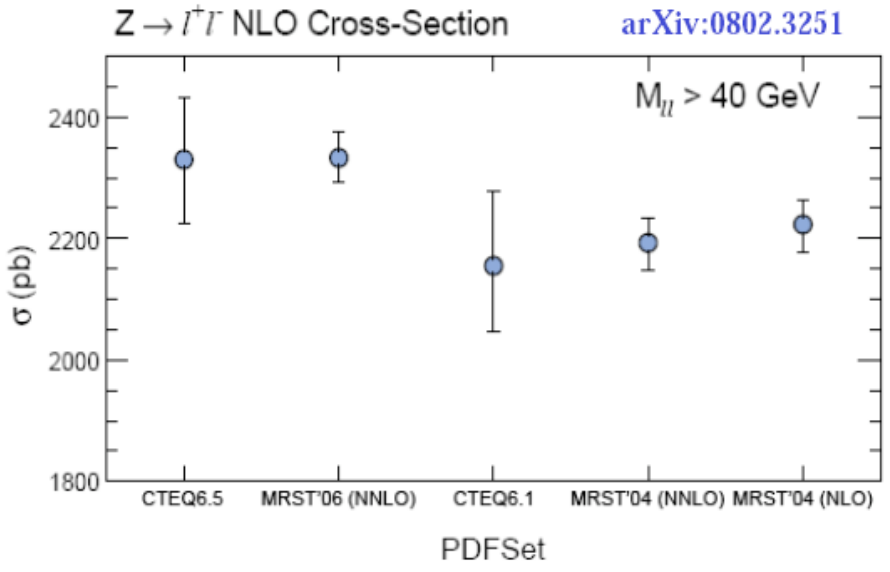
$$y = \frac{Q^2}{xs}$$ **Inelasticity**

$$\tilde{\sigma}^{\pm}_{NC} = \frac{\mathrm{d}^2\sigma^{e^{\pm}p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2 Y_+} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3, \quad Y_{\pm} = 1 \pm (1-y)^2$$

Predictions for LHC, some examples



N.Adam et al.
arXiv:0802.3251



Total Theoretical Uncertainty (%)

Uncertainty	Cross-Section $\Delta\sigma$	Acceptance ΔA
Missing O(α) EWK	0.38 ± 0.26	0.96 ± 0.21
Total QCD Uncertainty	1.51 ± 0.75	2.55 ± 0.79
PDF Uncertainty	3.79	1.32
Total Uncertainty	4.1 ± 0.3	3.0 ± 0.7

Various fits give incompatible results

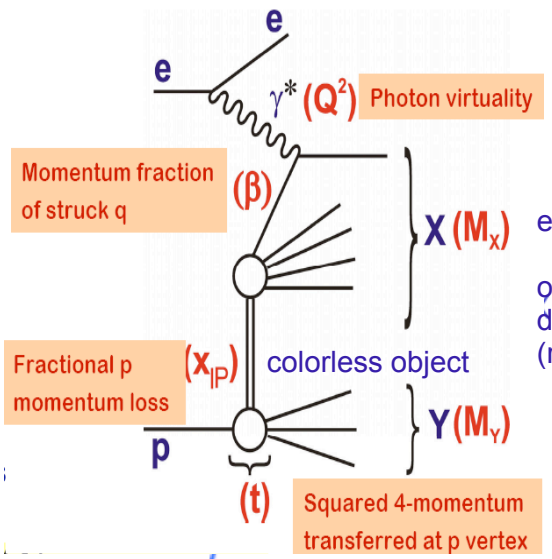
PDF error dominant for some standard signals

The variations in the P_T spectra due to PDF's can be limiting factor for non-resonant searches

More precise data for PDF's is the best medicine

Hard Diffraction at HERA

10% of DIS events are diffractive:
produced via the exchange of an coulouless exchange



empty rapidity region (gap)

or intact proton detected down the beampipe (roman pots)

$$\frac{d\sigma^{NC}_{diff}}{dx_{IP}dtd\beta dQ^2} \propto \frac{1}{Q^4} F_2^{D(4)}(x_{IP}, t, \beta, Q^2)$$

assuming factorisation:
structure of the diffractive echnage

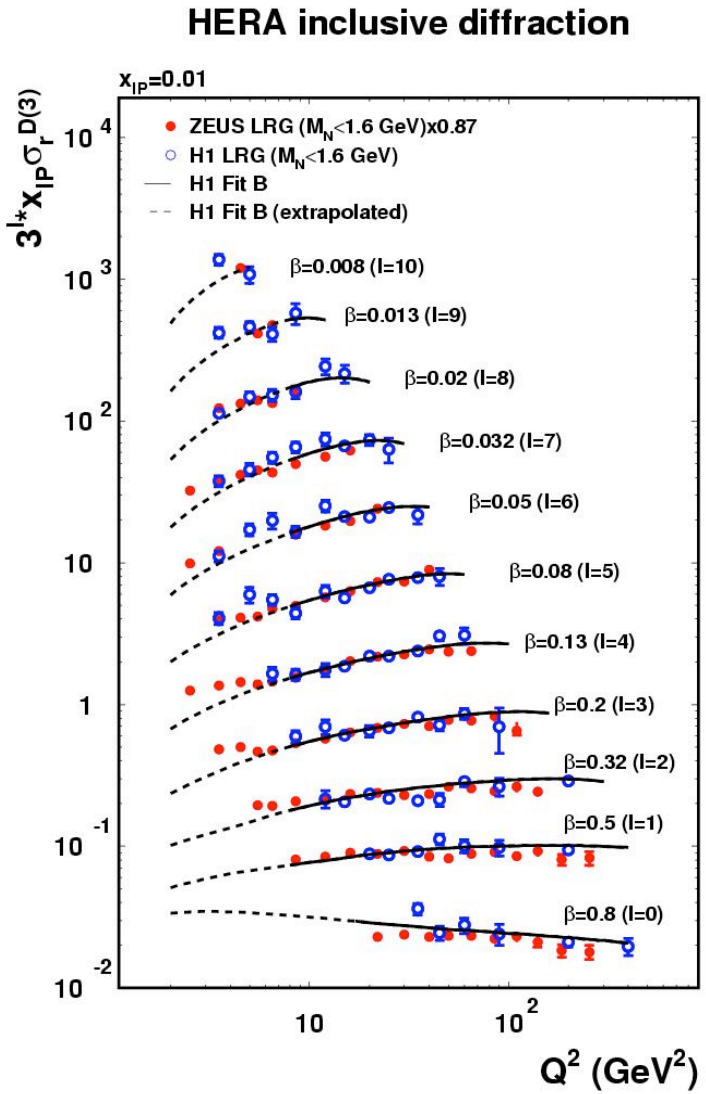
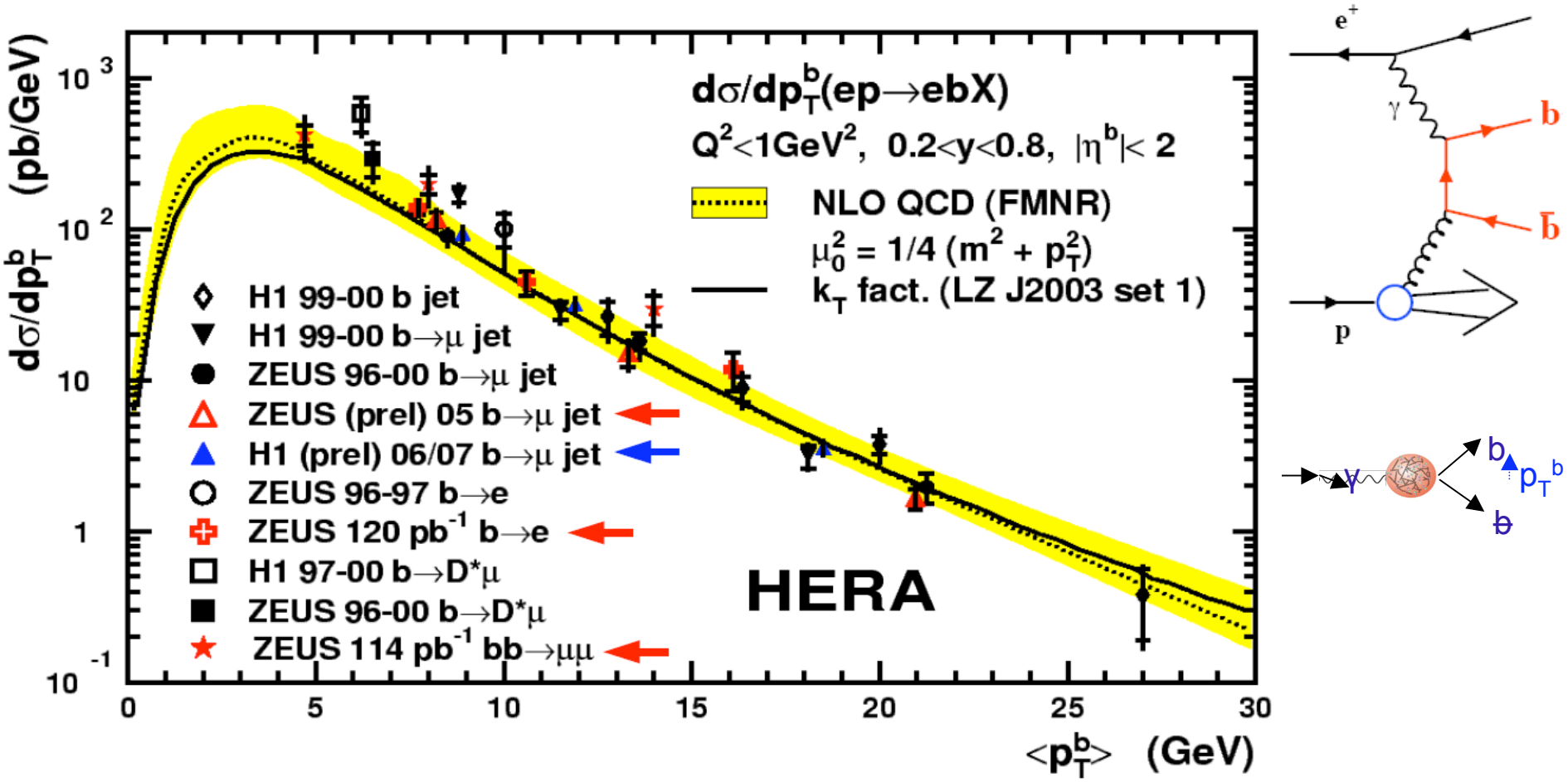
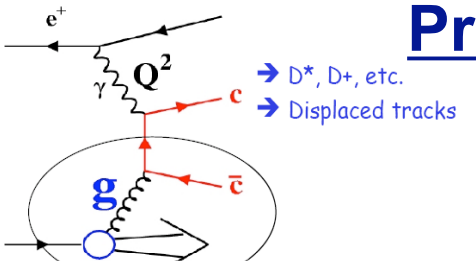


Photo-Produced Beauty

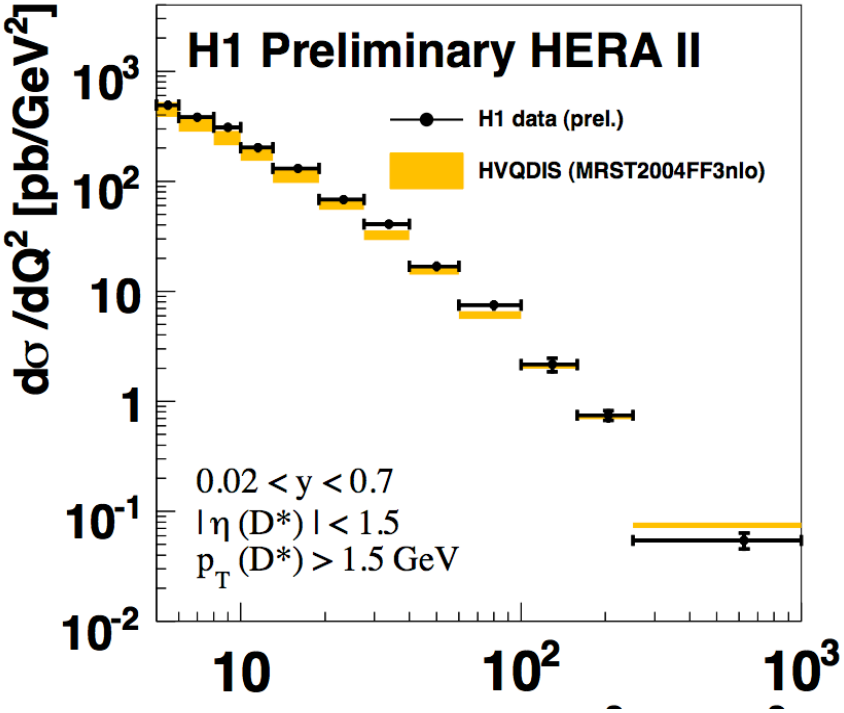


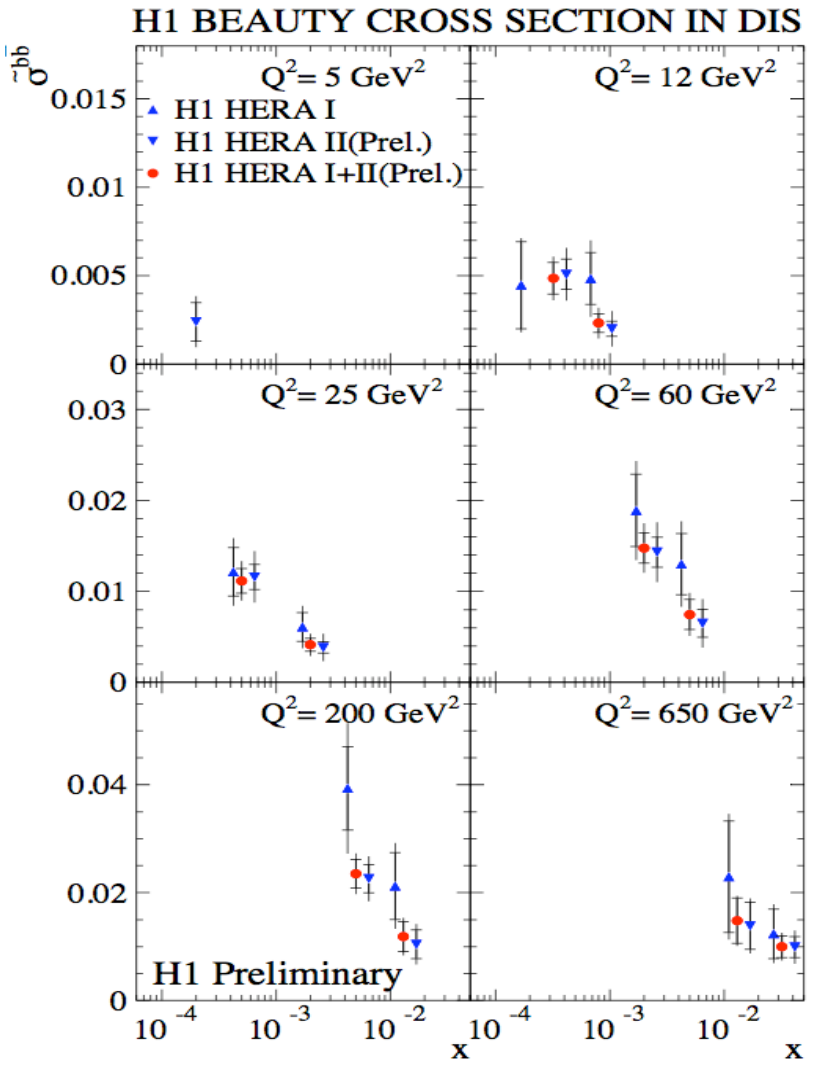
Recent precise H1 measurements in agreement with theory

Precision Measurements of the Heavy Flavours Production using HERA II Data



D* production in DIS

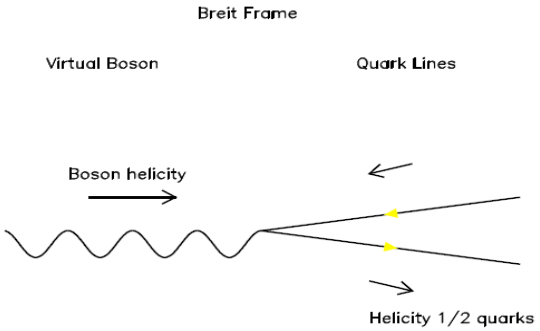




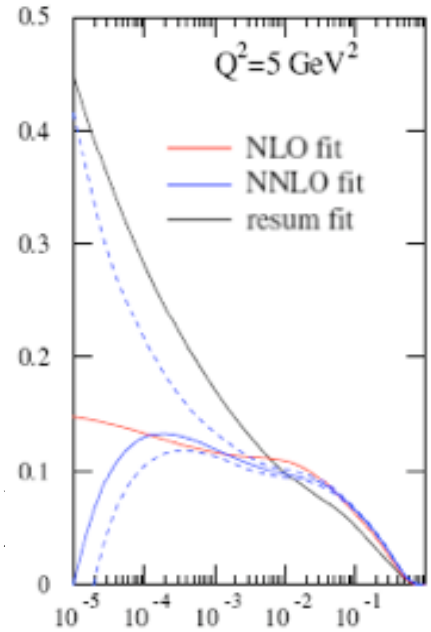
The potential of HERA II explored
Precision in tracking is crucial

The proton structure function F_L

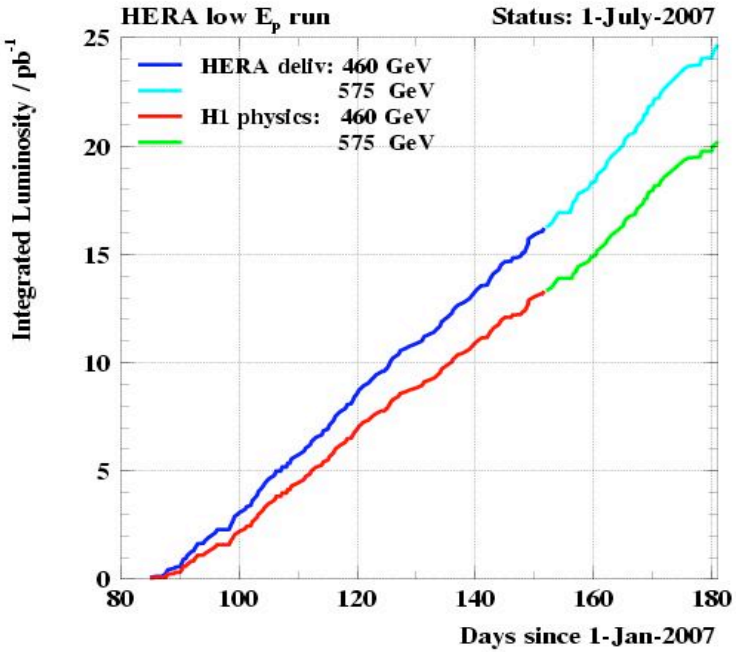
$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{Y_+} \cdot F_L(x, Q^2)$$

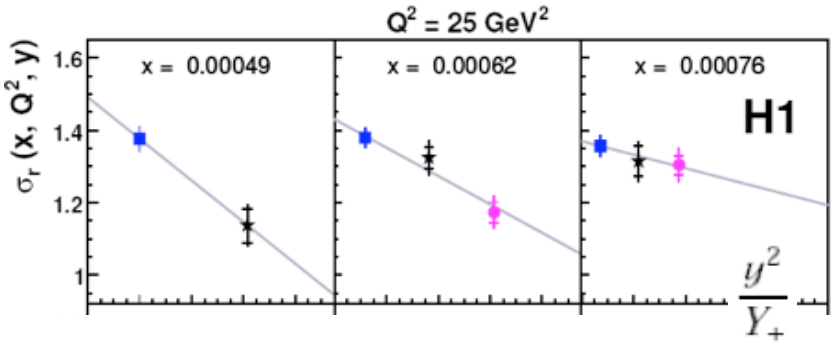


$$F_L(x, Q^2) \sim \alpha_s x g(x, Q^2$$



$$F_L \sim C(y) * (\sigma(E_p^1) - \sigma(E_p^2))$$

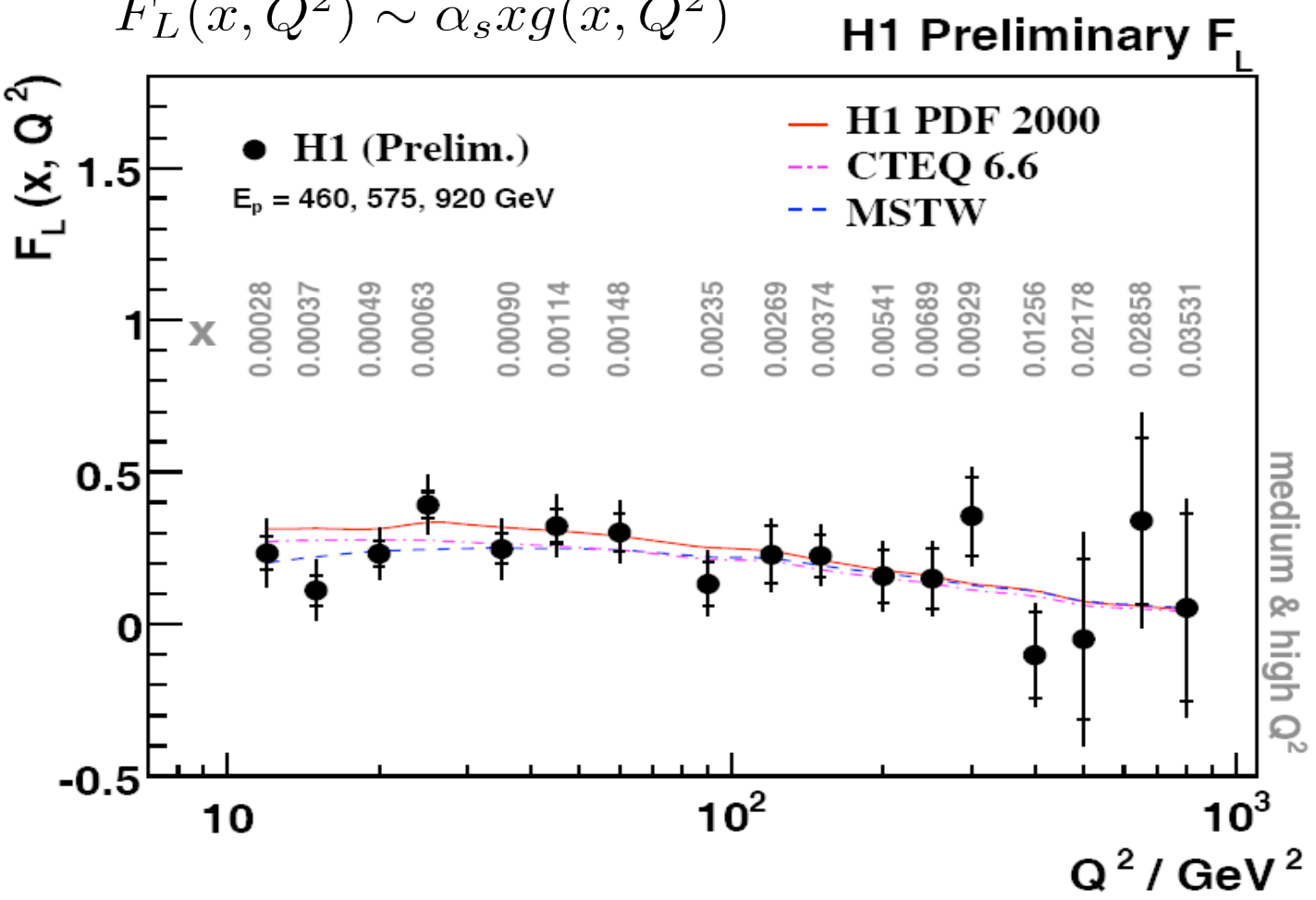




Fundamental form factor of the proton
Proportional to the gluon, important for PDF's
Discriminate between theoretical approaches

F_L averaged in each Q^2 bin

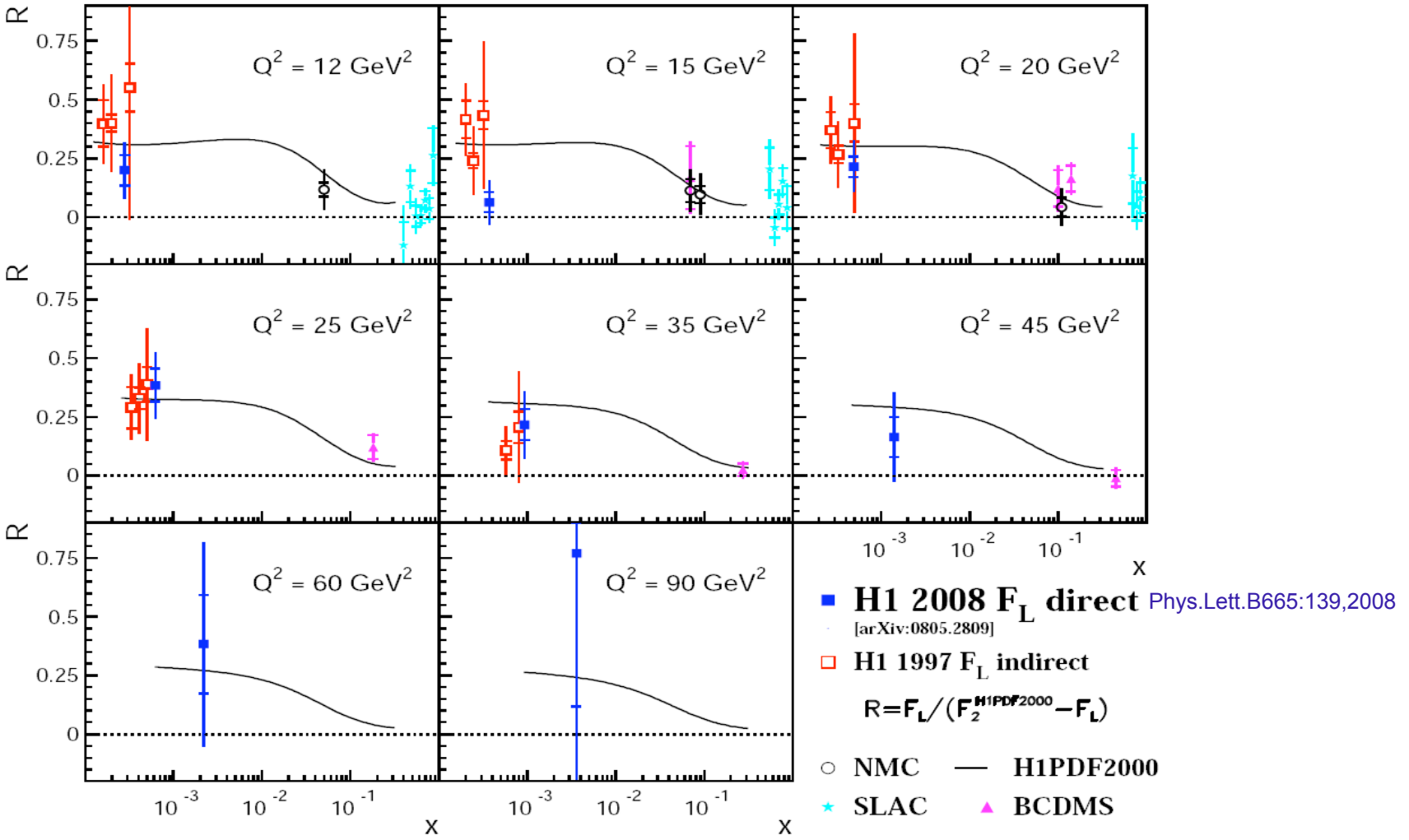
$$F_L(x, Q^2) \sim \alpha_s x g(x, Q^2)$$



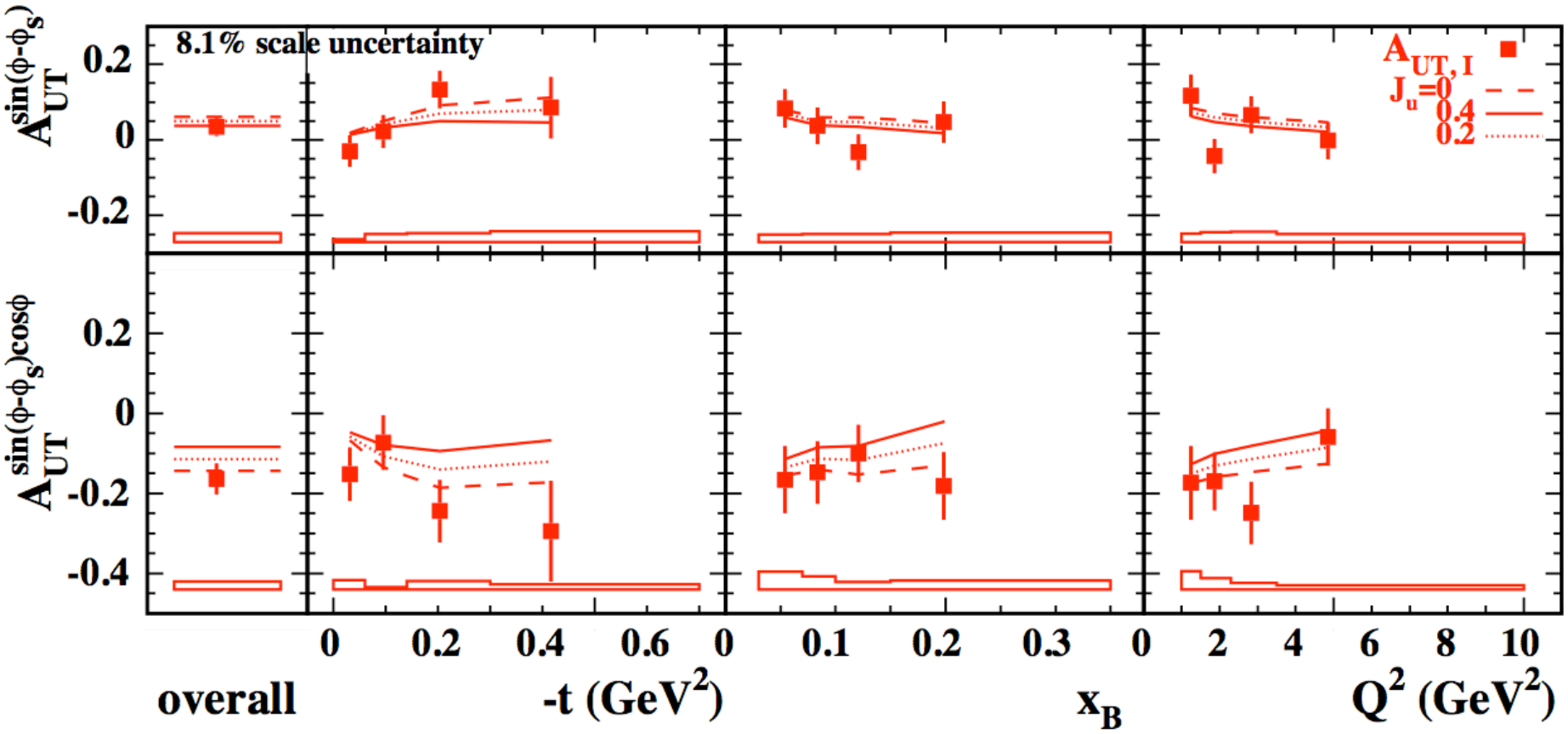
Work ongoing to extend to lower Q^2/x: test QCD, resummation, gluon

Comparison with target data and indirect determinations

Q^2 range of the first publication "medium Q^2"



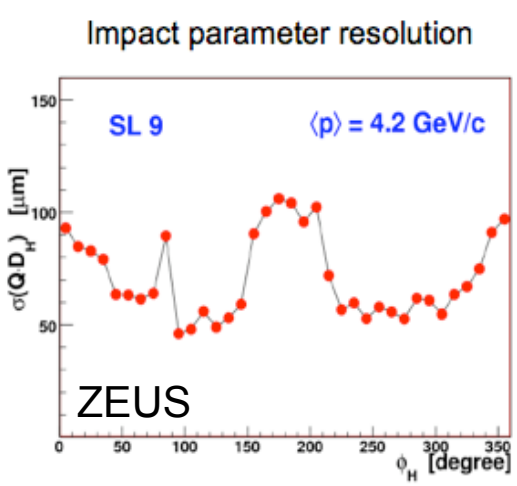
The gluon "turn-on" at low x clearly visible

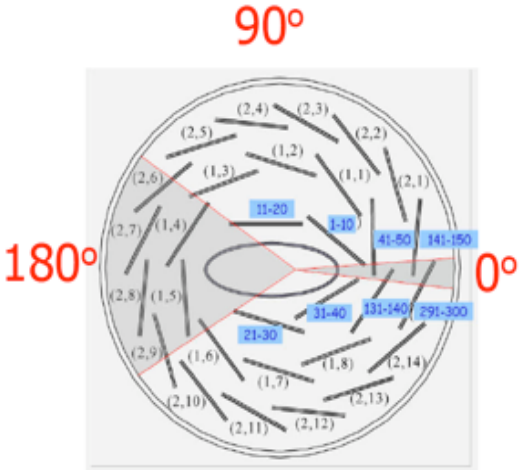

8.1% scale uncertainty
$A_{UT,I}$
J_u=0
0.4
0.2
$A_{UT}^{\sin(\phi-\phi_S)}$
$A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$
0.2
0
-0.2
-0.4
0
0.2
0.4
0.6
0.1
0.3
2
4
6
8
10
overall
-t (GeV^2)
x_B
Q^2 (GeV^2)

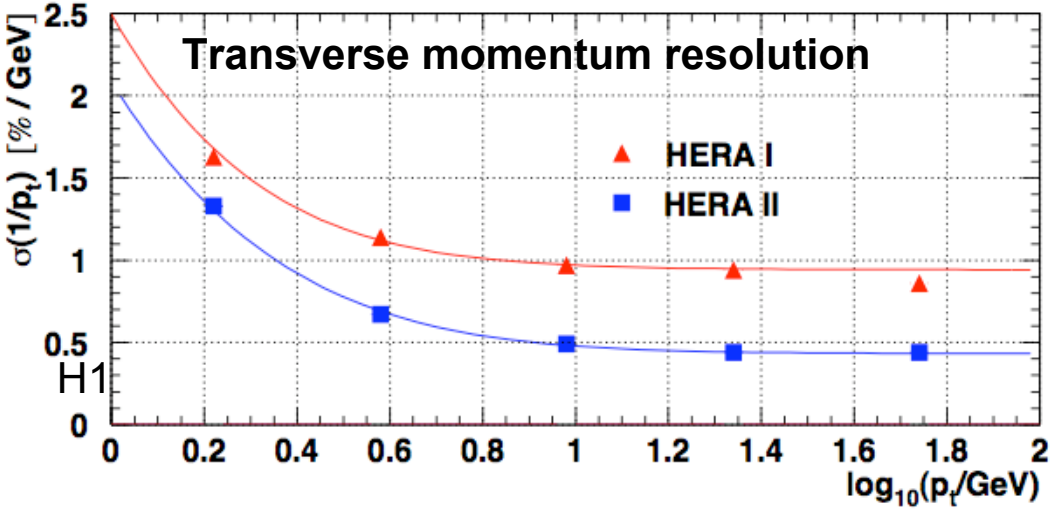
Data processing for ultimate precision

Understand the tracking to 0.5-1%

Calibrate calorimeters to 1-1.5%







Goal:
Reach the best precision
for heavy flavours and jets