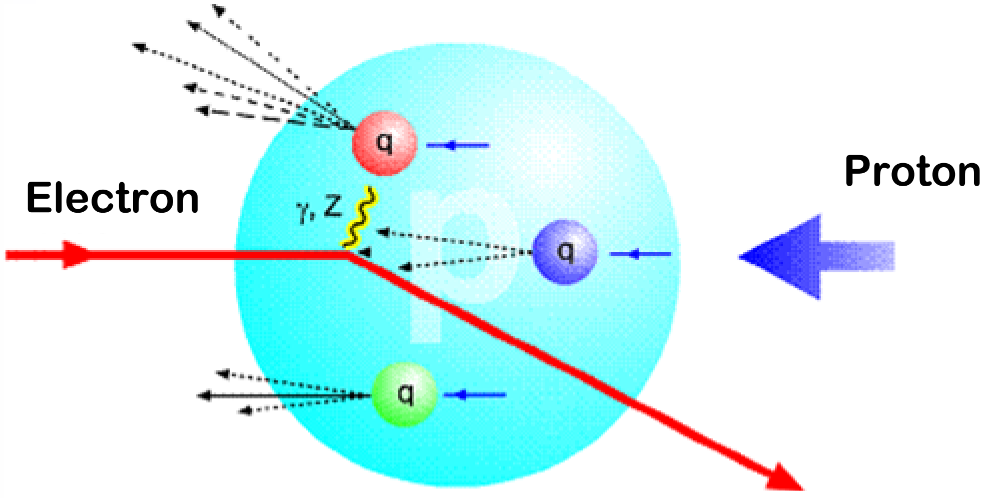
H1 & ZEUS

Status Report



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MPI Project Review

December 14 - 15, 2009

H1 & ZEUS MPI Group Members

Director
- A. Caldwell

External scientific member
- H. Abramowicz

Guest Scientist
- A Levy (ZEUS, Tel Aviv U.)

Staff scientists
- I. Abt (project leader ZEUS, ZEUS Physics coordinator)
- V. Chekelian (Project leader H1)
- G. Grindhammer (H1 QCD Convener, MPI@DESY)

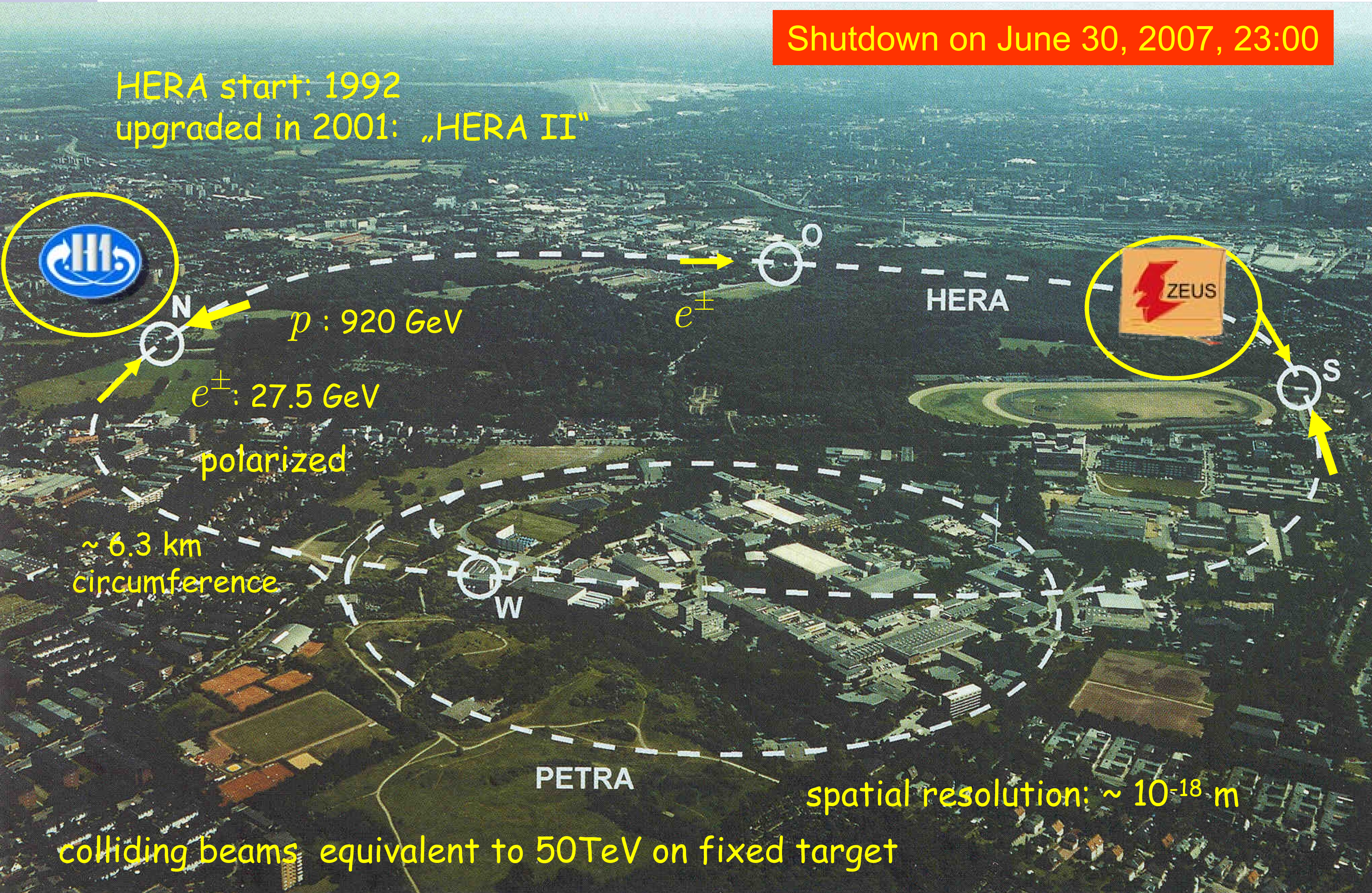
Post-docs
- B. Reisert (ZEUS, co-convener FL → SFEX+QCD)
- W. Schmidke (ZEUS)

PhD students
- R. Kogler (H1)
- A. Dossanov (H1)
- S. Shushkevich (H1)
- D. Britzger (H1, HH Uni, DESY)
- V. Drugakov (ZEUS, Minsk/DESY)
- P. Devgun (ZEUS, Punjab U.)
- I. Singh (ZEUS, Punjab U.)
- R. Aggarwal (ZEUS, Punjab U.)

Cooperation with former MPI PhD students and post-docs
- A. Dubak-Behrendt
- B. Olivier
- R. Placakyte
- A. Nikiforov

Administration & Support
F. Happel, M. Schaber

HERA – the world's largest electron microscope
(Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany)

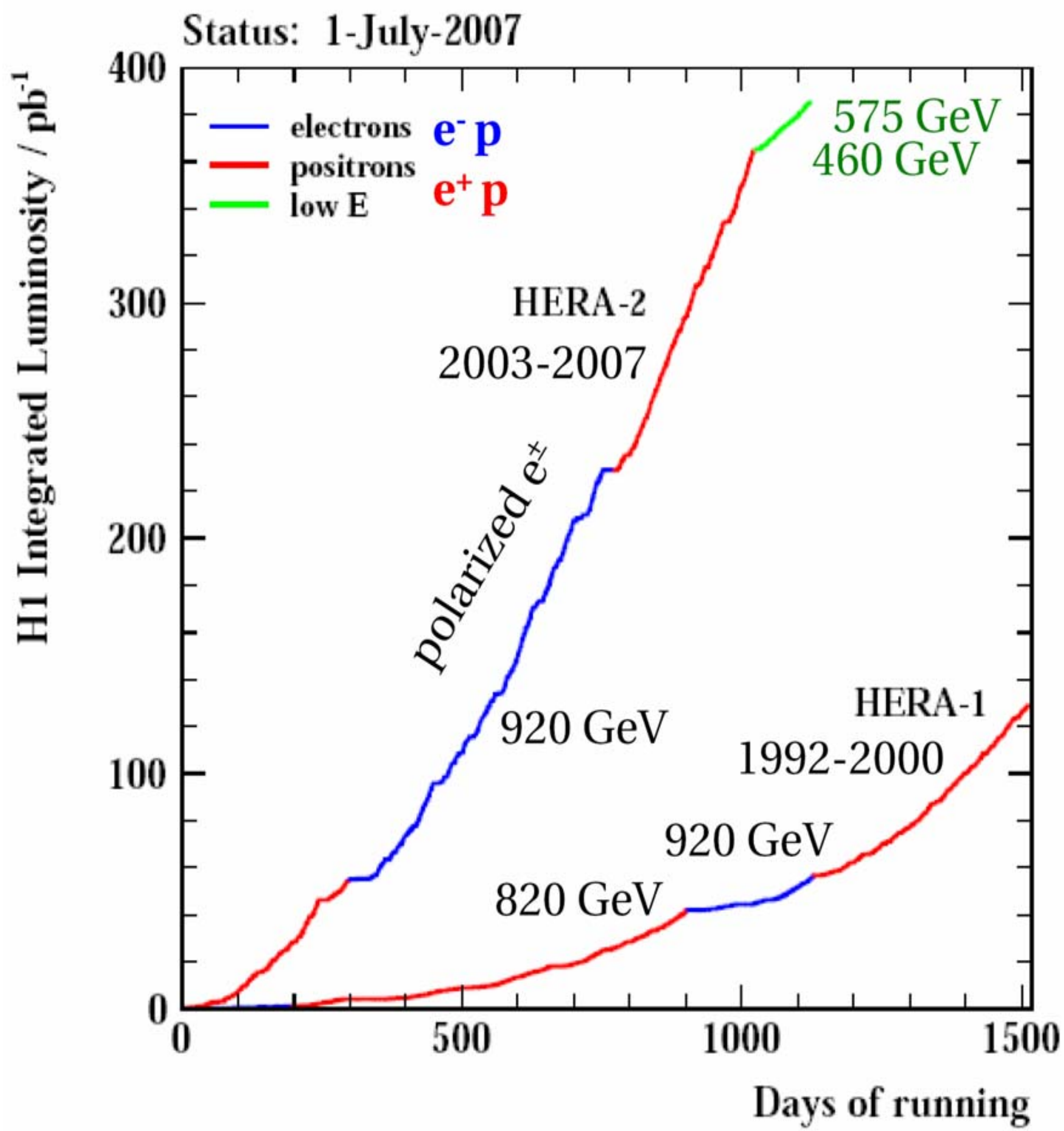


H1 & ZEUS Collaborations

Salute to our collaborators in H1 & ZEUS

Many thanks to our colleagues in the electronics and mechanics departments for their design, construction, commissioning, maintenance, decommissioning efforts of some 20 years.

Hera Luminosity



HERA I: 1992-2000

HERA II upgrade:

- luminosity
- longitudinal polarization of the lepton beams (spin rotator pairs around the interaction regions)
- massive upgardes also for the detectors
- running efficiently from 2003 onwards
- Luminosity
  L = 500 pb^{-1} per exp.

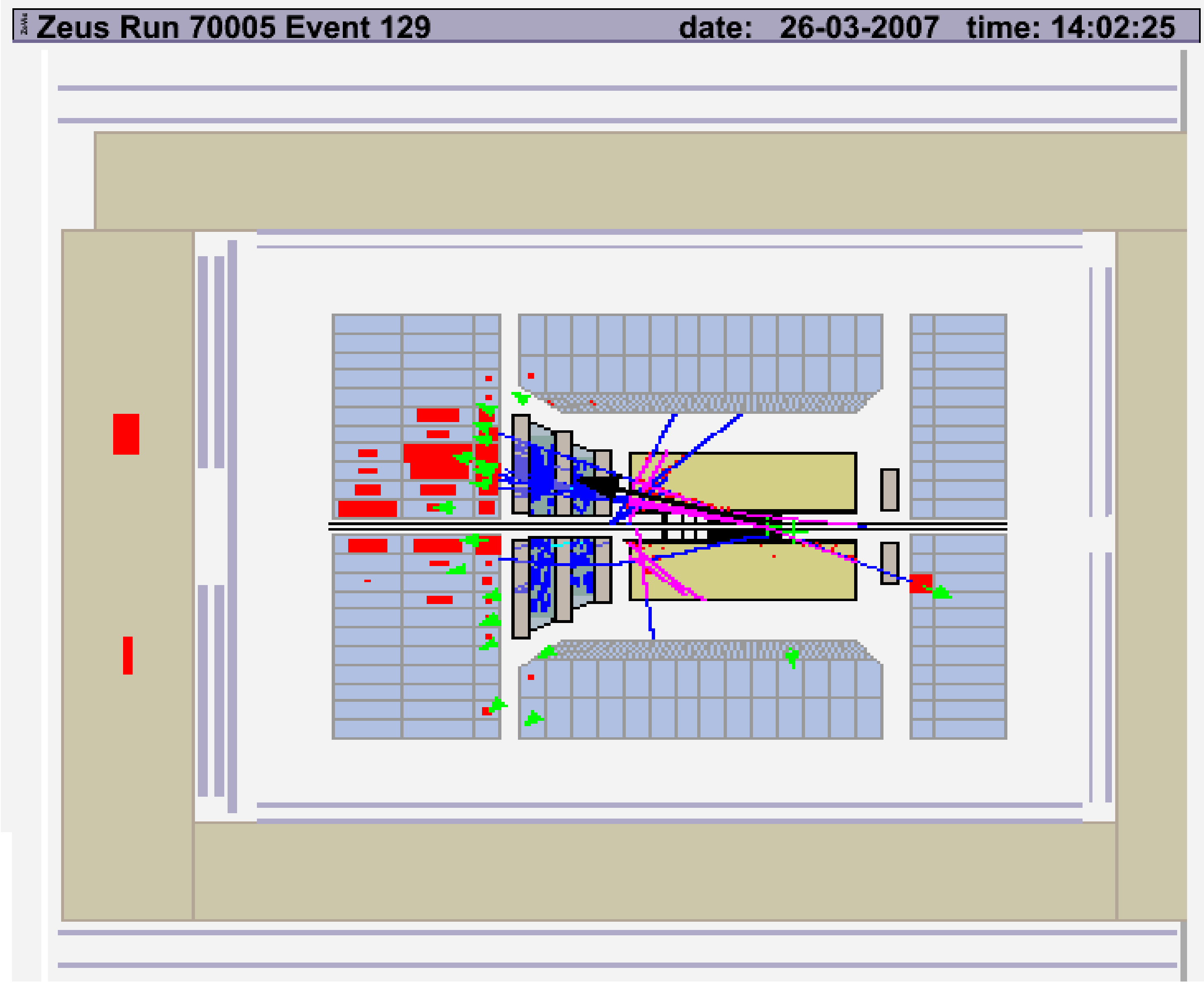
MPI Activities

Physics:
- Inclusive neutral & charged current cross sections and structure functions F2, xF3 and FL (H1, ZEUS)
- Inclusive jets in DIS and photoproduction (H1)
- γp total cross sections (ZEUS)
- Leading neutrons in di-jet photoproduction (ZEUS)
- Combination of H1 and ZEUS inclusive data & QCD Fits

Services:
- Improve jet energy reconstruction and calibration (H1)
- Coordination of H1 analysis software (H1OO)
- Improve calibration of electron and hadronic final state (ZEUS)
- Provide ultimate precision of luminosity measurement (ZEUS)

Organization:
- ZEUS Physics coordinator (paper output rate doubled, I. Abt's term ended this summer)
- Two physics working group conveners (H1 & ZEUS, one each)
- DIS09 working group convener
- Organization of H1 physics working group meeting at MPI

DIS Neutral Current Event



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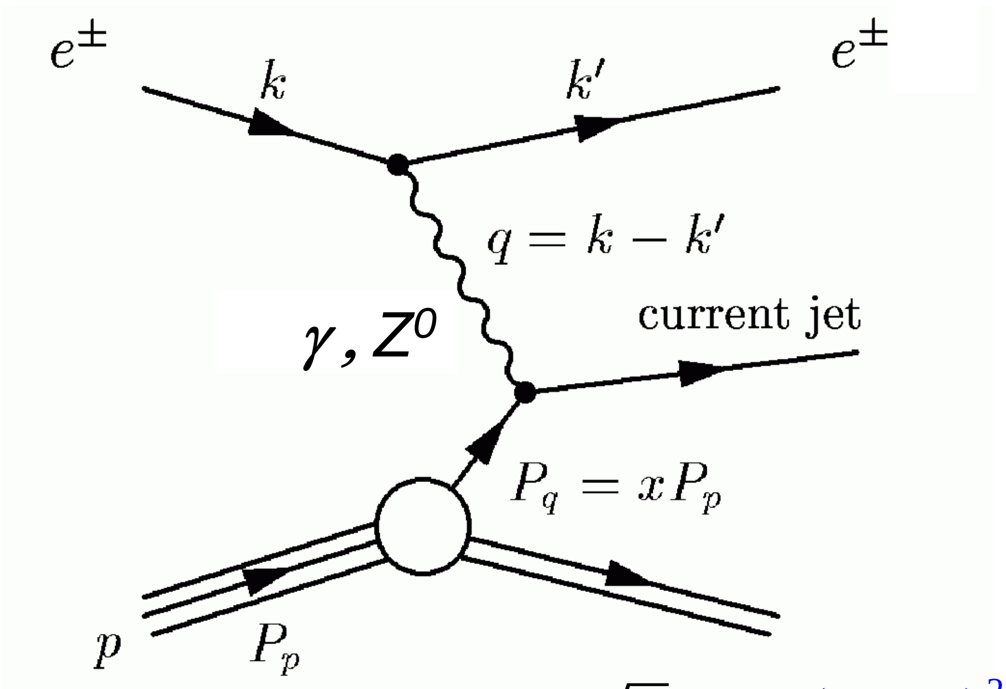
Deep Inelastic Scattering



Center of mass energy $\sqrt{s}$: $s = (k + p)^2$

Kinematic Variables

- **4-momentum transfer resolving power**
  $Q^2 = -q^2 = -(k - k')^2$
- **Bjørken scaling variable *x* momentum fraction of struck parton** $x = \frac{Q^2}{2p \cdot q}$
- **Inelasticity:** $y = \frac{p \cdot q}{p \cdot k}$

relation for fixed s: $Q^2 = sxy$

- **Neutral current DIS cross section expressed by structure functions:**

$$\frac{d^2\sigma^{e^\pm p \to e^\pm X}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \underbrace{\left(1 + (1-y)^2\right)}_{Y_\pm = 1 \pm (1-y)^2} \cdot \left(F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \mp \frac{Y_-}{Y_+} xF_3(x, Q^2) \right)$$

High Q² only

$\tilde{\sigma}$: Reduced cross section

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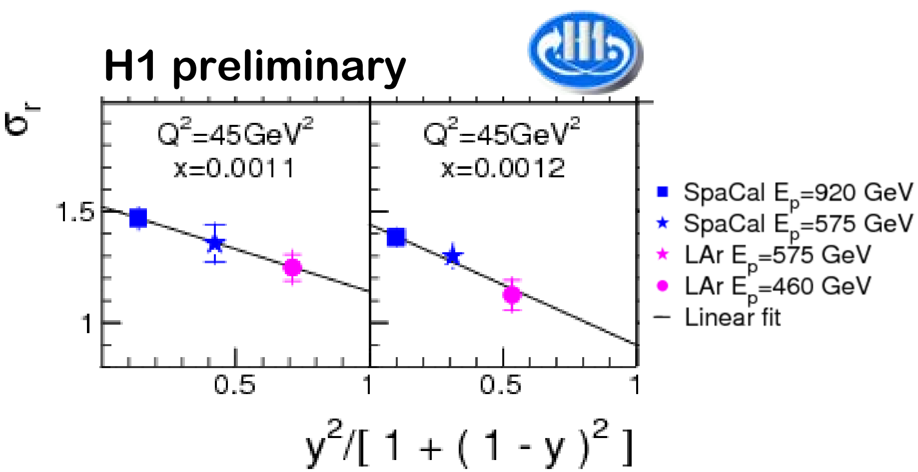
Cross Sections for direct FL extraction

Direct F_L measurement requires measurement of the reduced cross sections at **same x and Q^2 but different y:**

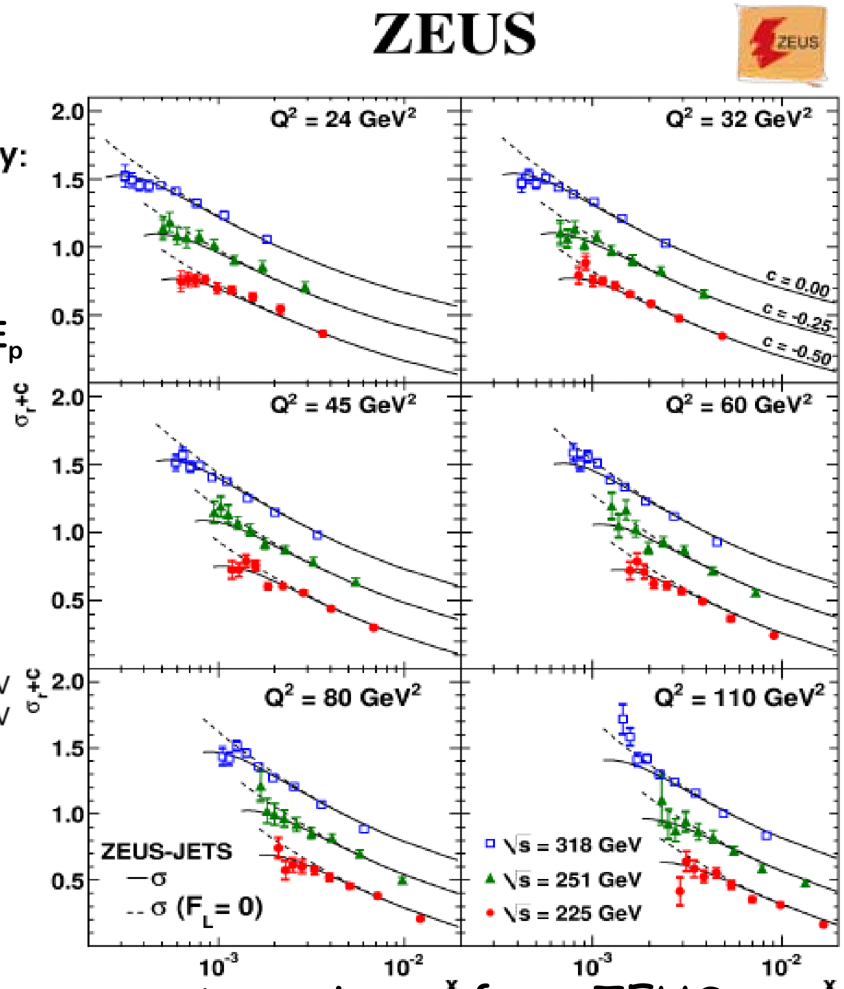
$$\sigma_r(x,Q^2,y) = F_2(x,Q^2) - \frac{y^2}{Y_+}\cdot F_L(x,Q^2)$$

$y = \frac{Q^2}{x \cdot s}$ different y → different s → different beam $\mathbf{E_p}$



Straight line fit of σ_r vs y^2/Y_+

F_L slope, F_2 intercept



most precise σ_r from ZEUS

Turnover due to F_L small but visible

Phys. Lett. B 682 (2009) 8-22

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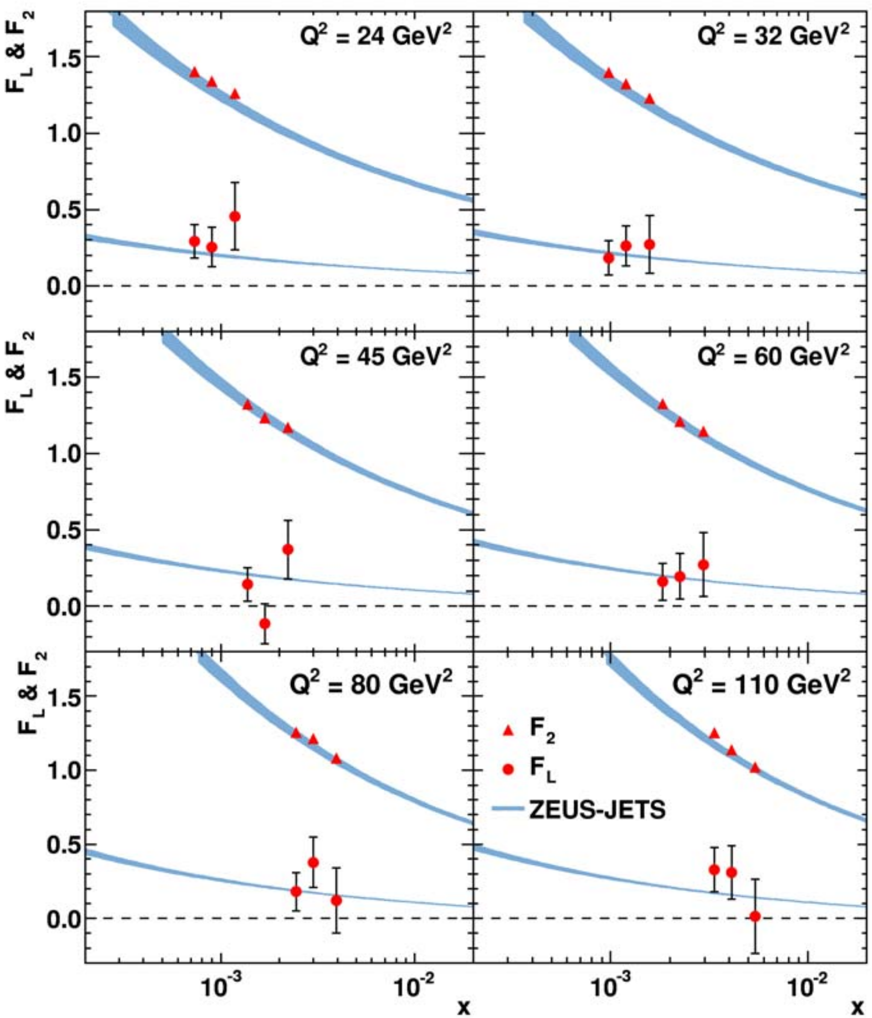
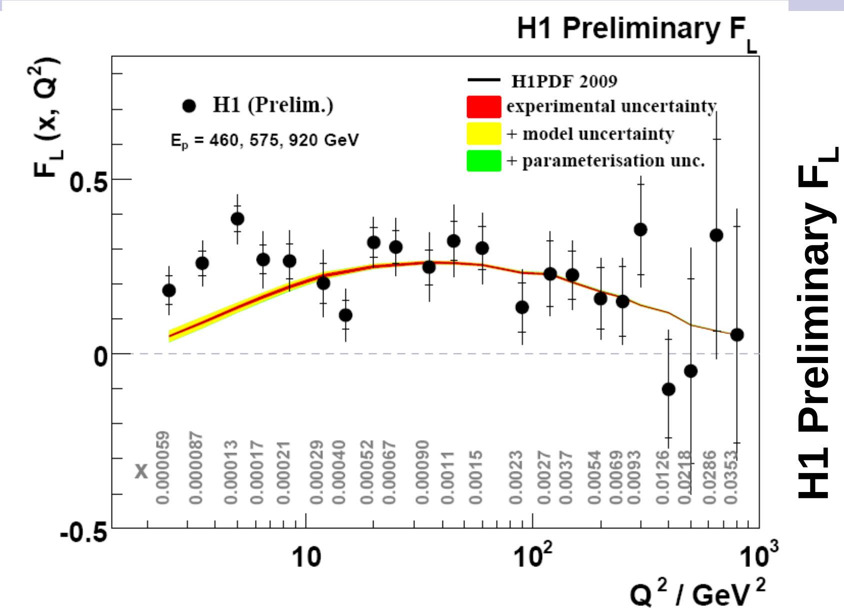
Extracted F_L and F_2 – ZEUS

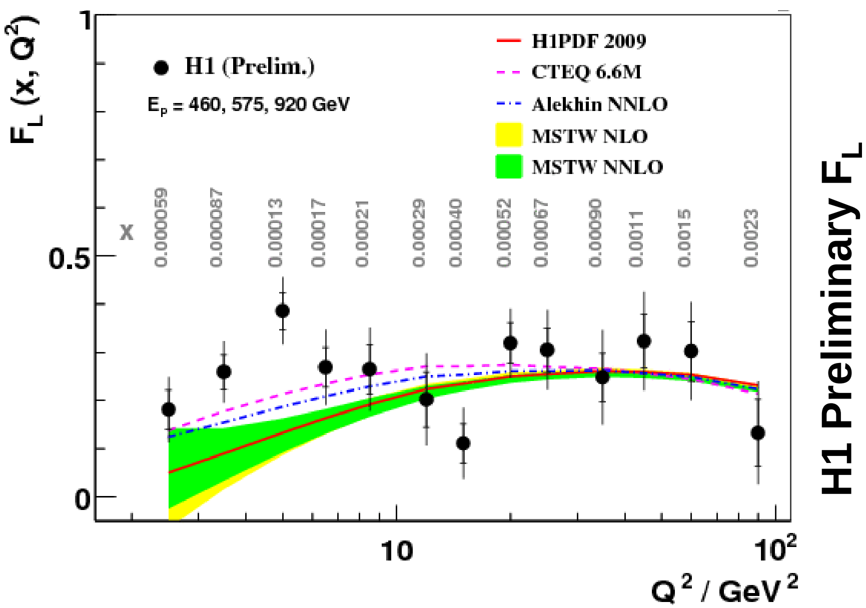


- Most precise F_2 measurement from ZEUS in kinematic region studied
- First F_2 measurement without assumptions on F_L
- Data support a non-zero F_L
- Predictions for F_2 and F_L are consistent with data

Phys. Lett. B 682 (2009) 8-22
Cross section and structure functions in Durham HEP database

Average F_L





- H1 measurements cover $2.5 \le Q2 \le 800$ GeV^2 and $0.00005 \le x \le 0.05$
- For $Q^2 \ge 10$ GeV^2, agree well with H1PDF 2009 prediction.
- MSTW and H1PDF 2009 predictions use the same heavy flavour scheme to calculate F_L.
- Data agree better with calculation of CTEQ (and Alekhin)
- Data is consistent with constant $R \sim 0.25$ (H1)
  $R = 0.18^{+0.07}_{-0.05}$ (ZEUS).
  $R = F_L/(F_2-F_L)$
- Color-Dipol Picture: R = 0.27 (D. Schildknecht)

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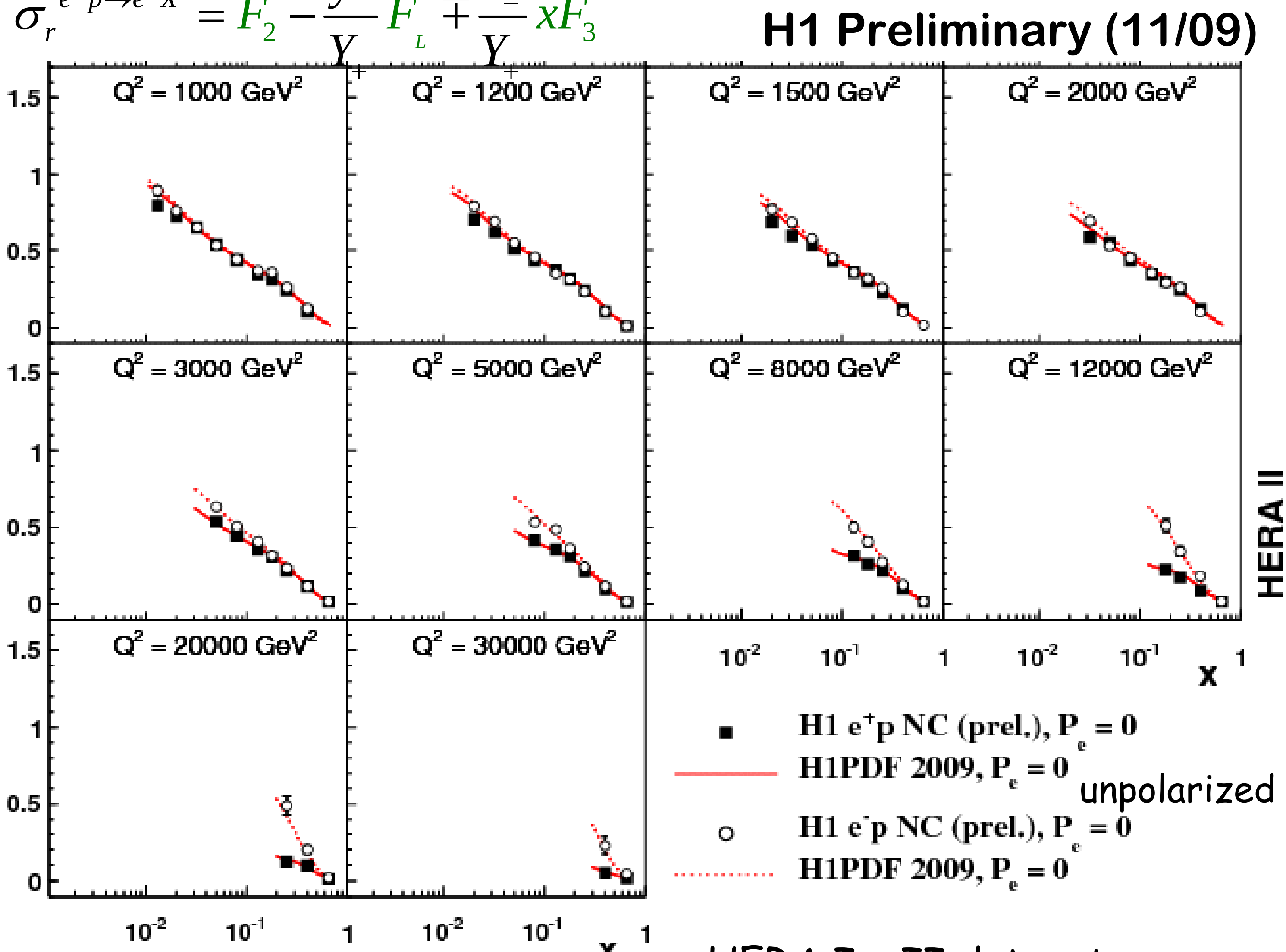
NC Cross Sections at High Q^2

$$\sigma_r^{e^\pm p \to e^\pm X} = F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} x F_3$$



unpolarized

HERA I + II datasets

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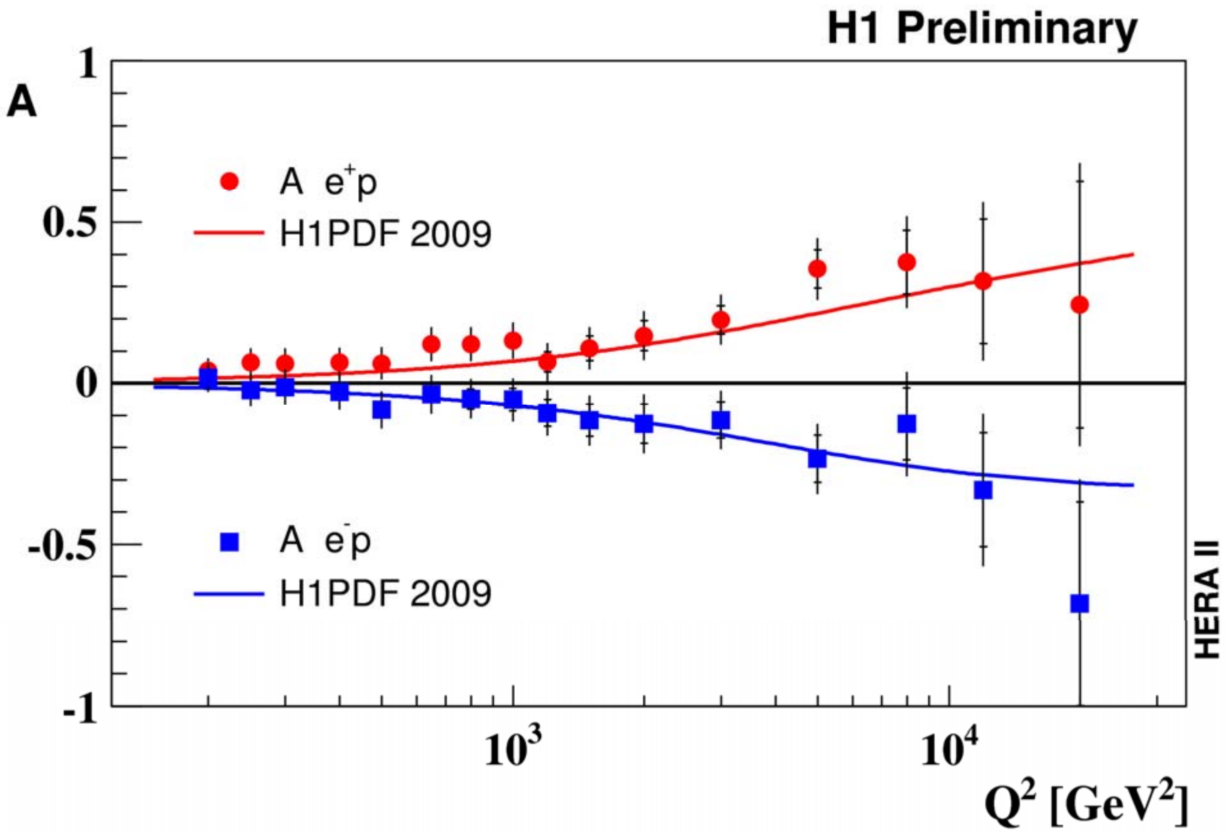
NC Cross Section Asymmetries

$$A_{\pm} = \frac{2}{P_R - P_L} \frac{\sigma_{\pm}(P_R) - \sigma_{\pm}(P_L)}{\sigma_{\pm}(P_R) + \sigma_{\pm}(P_L)}$$



Parity Violation due to γZ interference

At high x, assuming SM couplings

$$A_{\pm} \sim \frac{u_v + d_v}{4u_v + d_v}$$

constrain d/u

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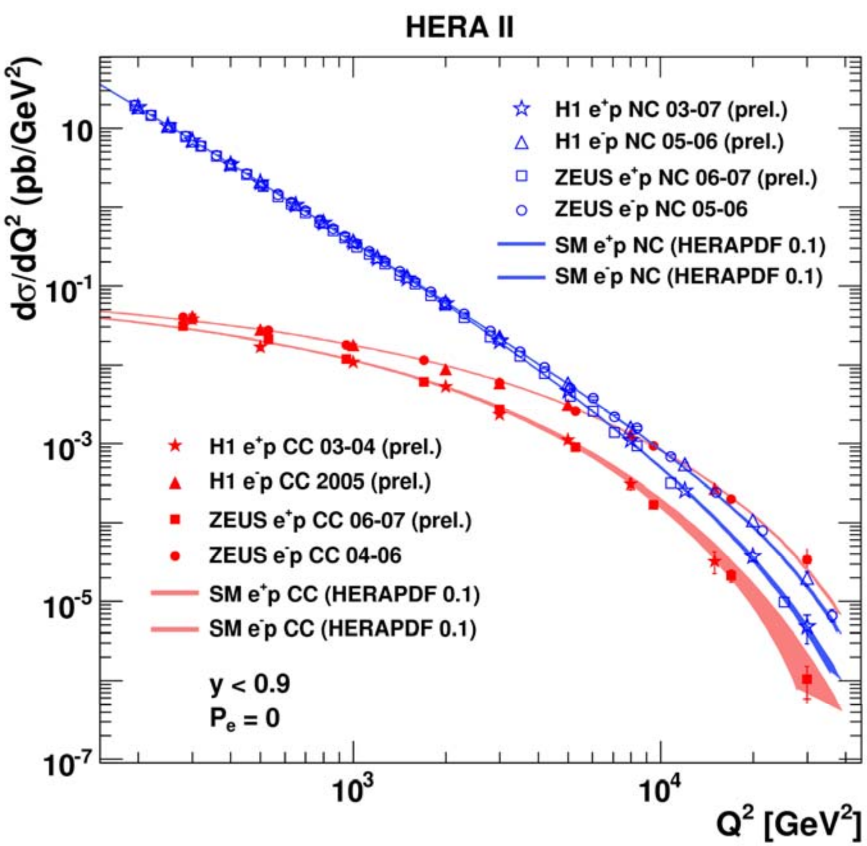
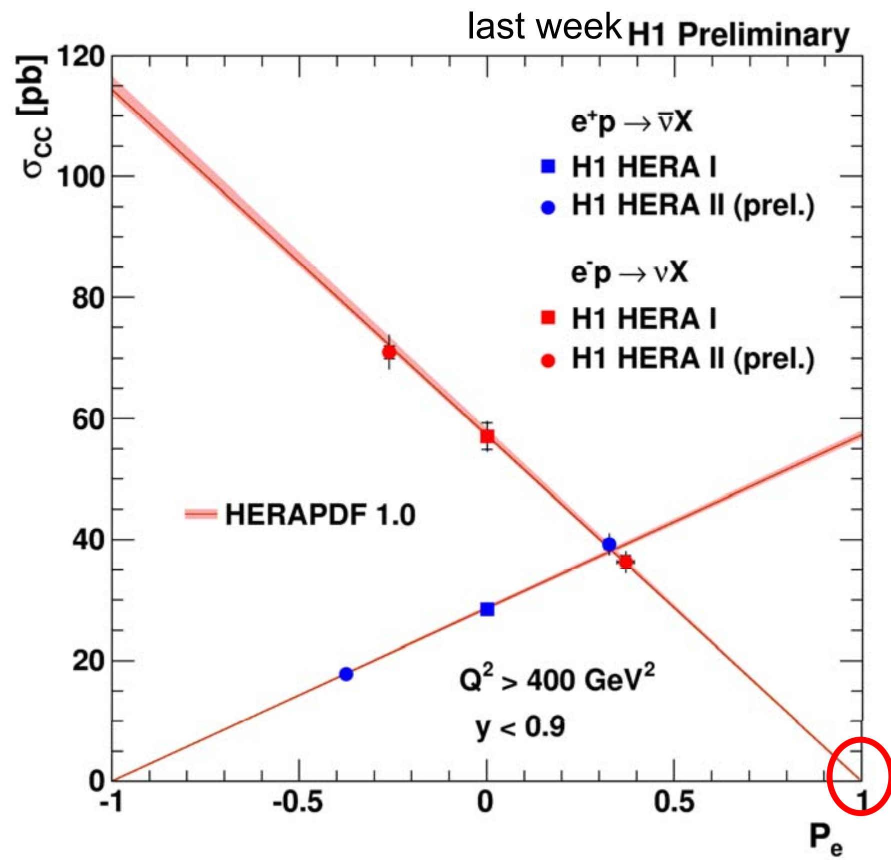
Charged Current Measurements





Manifestation of electroweak unification

Consistent with SM prediction $\sigma(CC_{RH}) = 0$

SM describes all HERA data: Impressive success of SM

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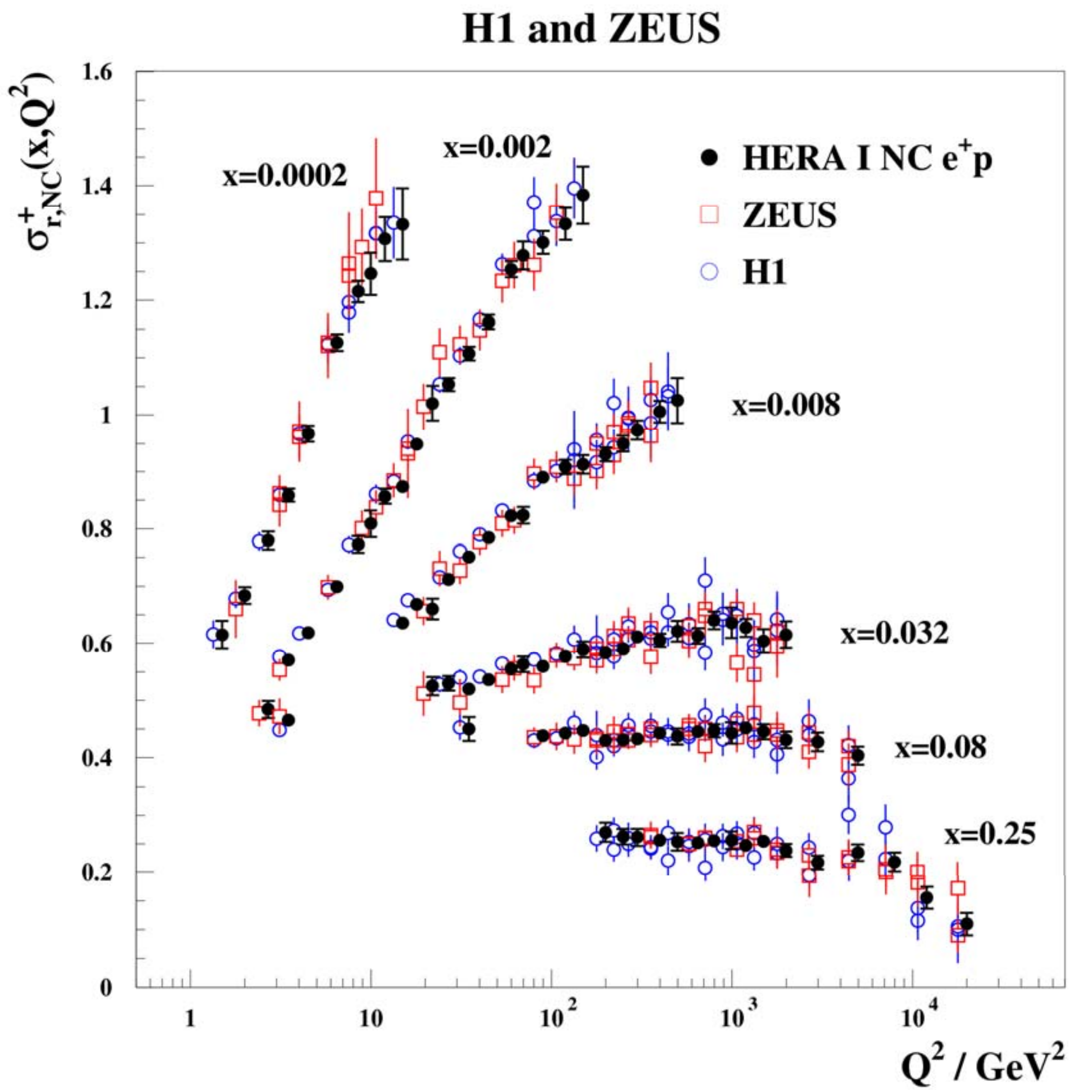
HERA Averaged NC cross sections

DESY Report 09-158
to be published in JHEP



- Precise measurements from two experiments
- For $Q^2 \leq 100$ GeV^2

  $\delta_{stat} \leq 1\%, \delta_{sys} \leq 3\%$

  for $Q^2 \geq 1000$ GeV^2

  $\delta_{stat} > \delta_{sys}$

- Combine datasets from both experiments:

  Key assumption

  H1 and ZEUS measure the same cross section at the same x, Q^2, y

- Improved precision of combined H1 and ZEUS datasets (stat and sys)

H1 and ZEUS combined QCD Fit

QCD Analysis of combined H1 & ZEUS HERA-I data to extract proton PDFs

PDF general form (Q_0^2=1.9):

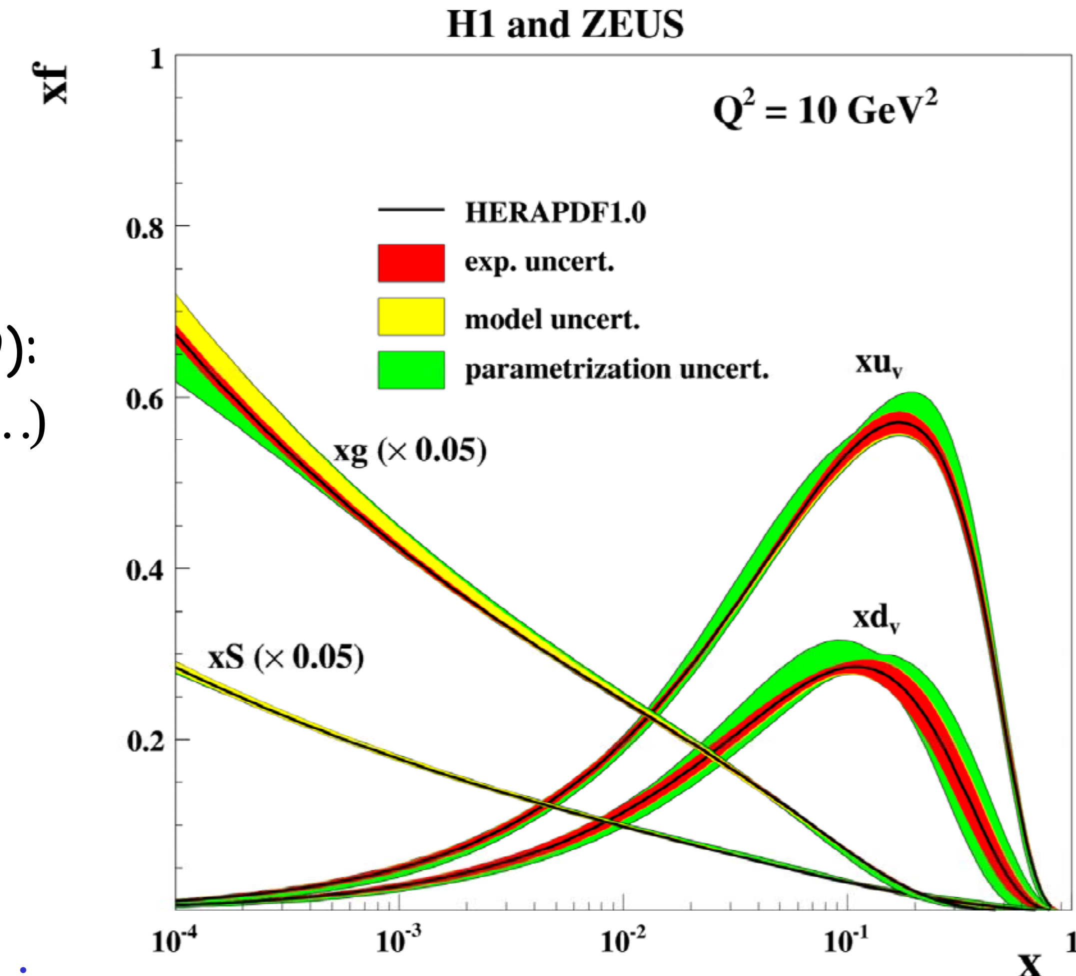
$$xPDF = Ax^B(1-x)^C \cdot (1+Dx+\ldots)$$

Parameterize:

g, u_v, d_v, U(=u+c), D(=d+s)

Impressive precision HERA alone competitive with global analysis

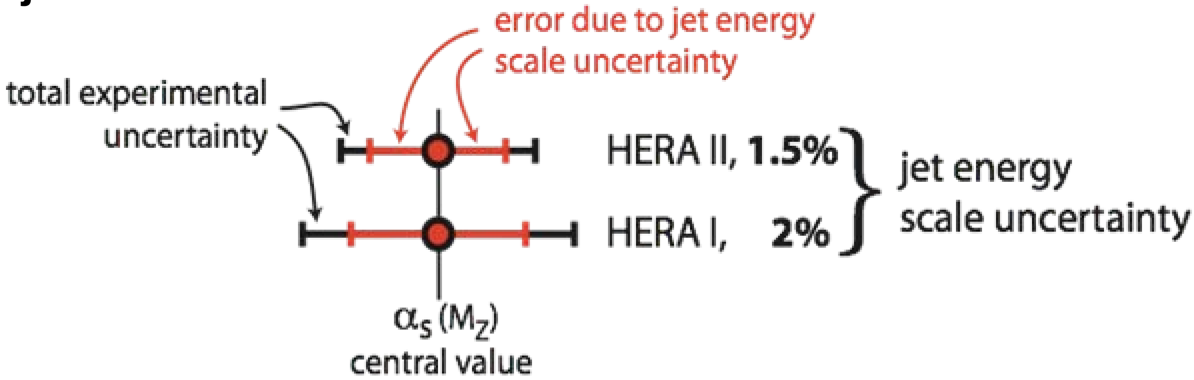
Expect even higher precision when including HERA-II



DESY Report 09-158
to be published in JHEP

H1: Improving the Jet Energy Scale Uncertainty

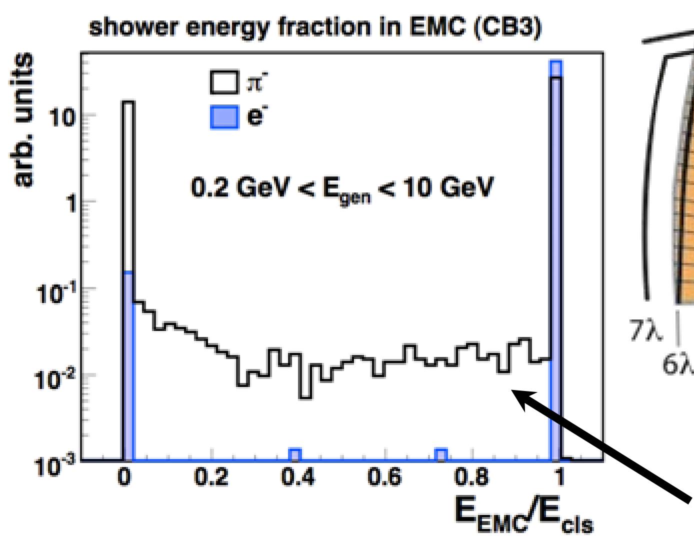
Jet energy scale uncertainty is one of the dominant uncertainties in jet measurements

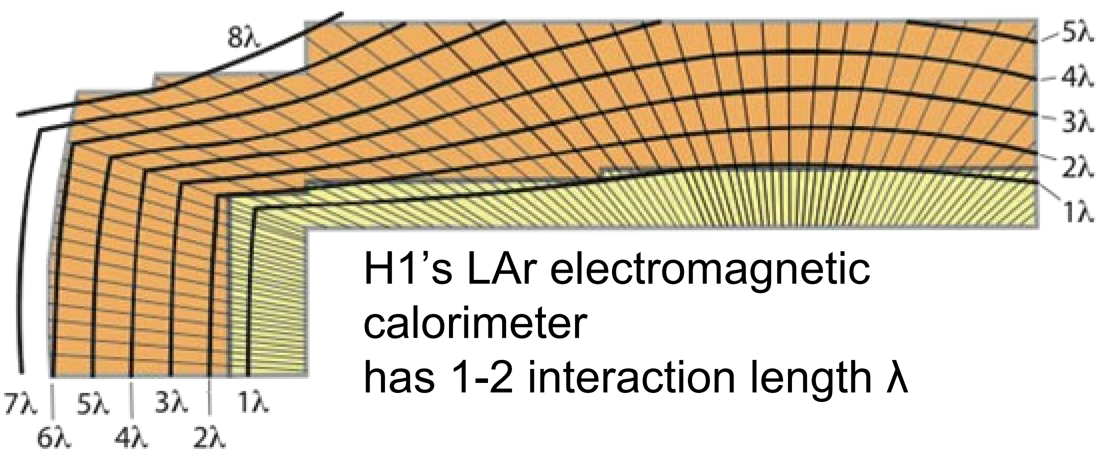


Status as of:

α_S from jets @ low Q^2: arXiv:0911.5678 [hep-ex]

α_S from jets @ high Q^2: arXiv:0904.3870 [hep-ex]





H1's LAr electromagnetic calorimeter
has 1-2 interaction length λ

Energy deposited in EMC from hadronic showers not negligible
Separation crucial for improved energy measurement

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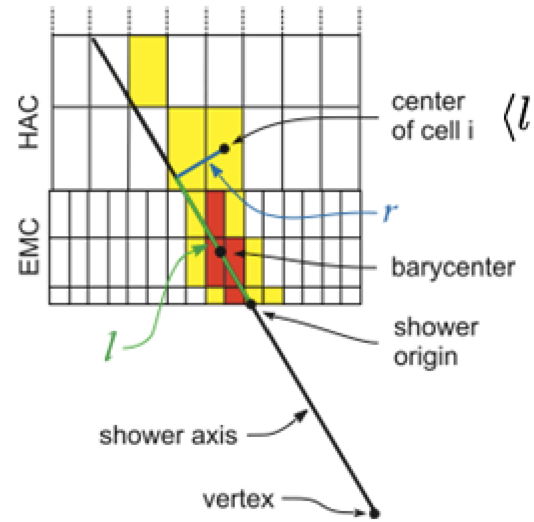
H1: Improving the Jet Energy Scale Uncertainty

1) Improved separation of hadronic and electromagnetic showers using several neural networks

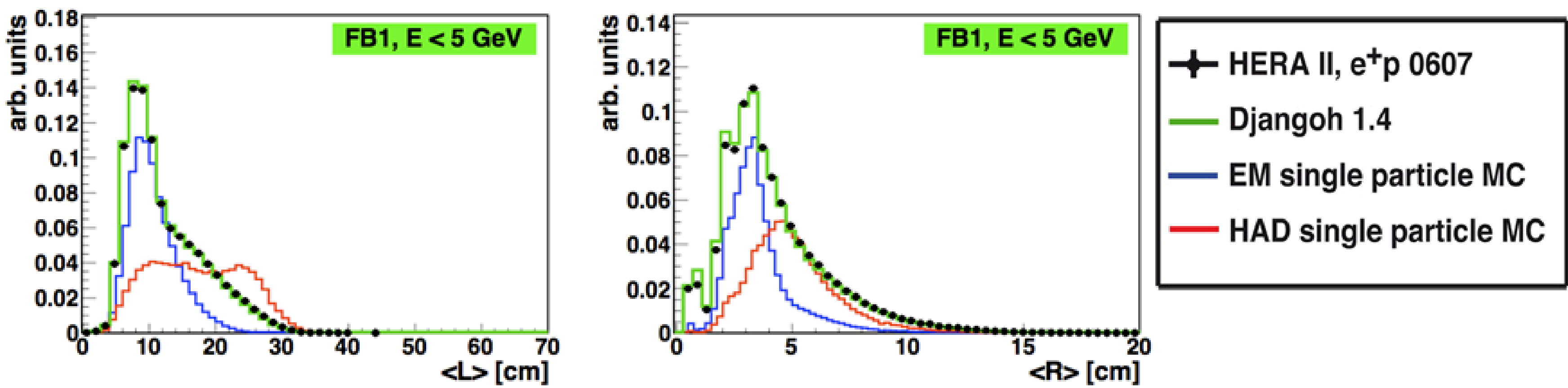
separation based on cluster shapes only

two neural networks per calorimeter wheel trained

track information used subsequently in reconstruction of hadronic final state objects



$$\langle l \rangle = \frac{1}{E}\int \mathrm{d}\boldsymbol{r}\, l\, f(\boldsymbol{r}) \approx \frac{\sum_i l_i w_i}{\sum_i w_i}$$



Input variables for the neural net are well simulated,
~10 shower shapes per calorimeter wheel used.

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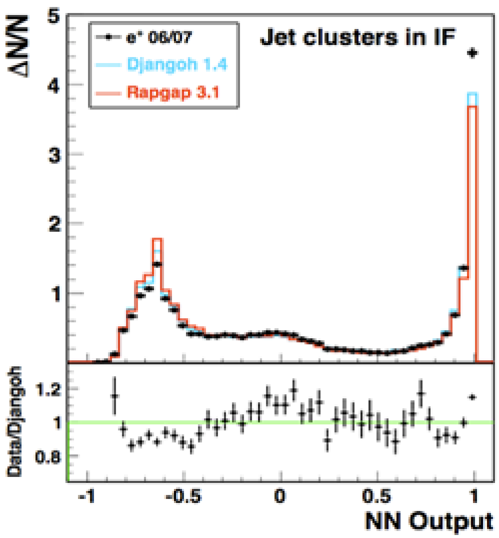
H1: Improving the Jet Energy Scale Uncertainty

Results from the shower separation



NN output can be interpreted as probability

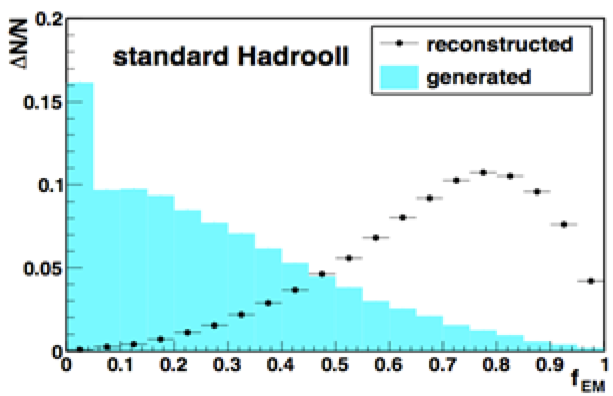
$$P_{em} = \frac{1-o}{2}$$

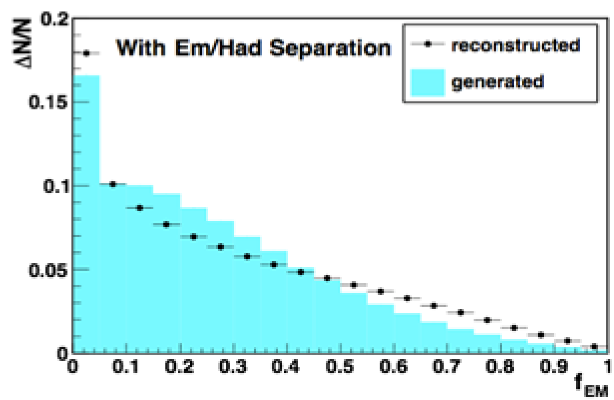
reconstructed jet's electromagnetic energy fraction:

$$f_{em}^{rec} = \left(\sum_{i=0}^{N_{cls}} P_{em}^{i} E_{i}^{cls} + \sum_{j=0}^{N_{em}} E_{j}^{em} \right) \Big/ E_{jet}$$

generated jet's electromagnetic energy fraction:

$$f_{em}^{gen} = \left(\sum E_{\gamma} + \sum E_{elecs} \right) \Big/ E_{jet}^{gen}$$





Excellent correspondence between gen. and rec. electromagnetic fraction
Improved energy resolution

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H1: Improving the Jet Energy Scale Uncertainty

2) New jet calibration after the improvements in the reconstruction

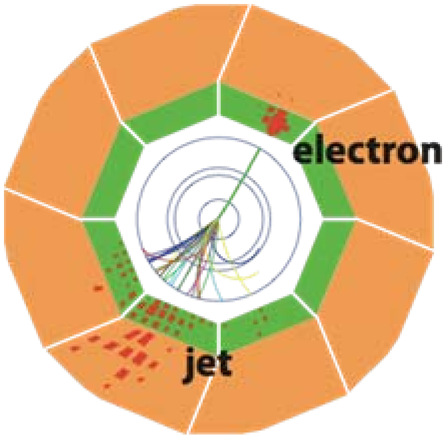
Definition of hadronic final state with cluster-wise calibration

$$hfs = \sum f^i\, cls^i_{jet} + \sum trk^i_{jet} \quad + \sum g^i\, cls^i_{out} + \sum trk^i_{out}$$

Using a well defined single-jet calibration sample, minimize

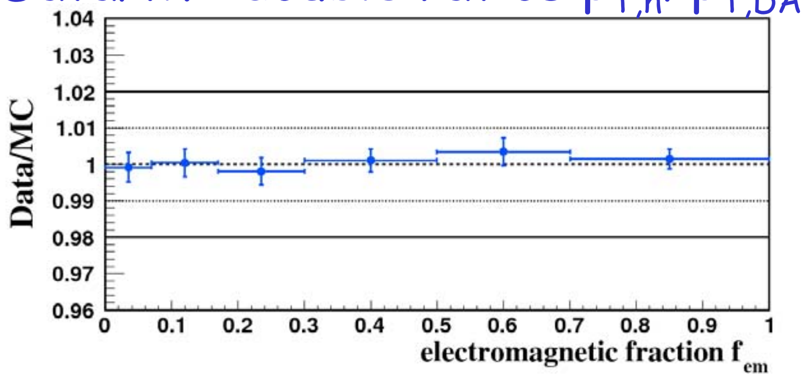
$$\chi^2 = \sum_{i=1}^{Nevts} \frac{\left(P_T^{h,i} - P_T^{da,i}\right)^2}{\sigma_i^2}$$

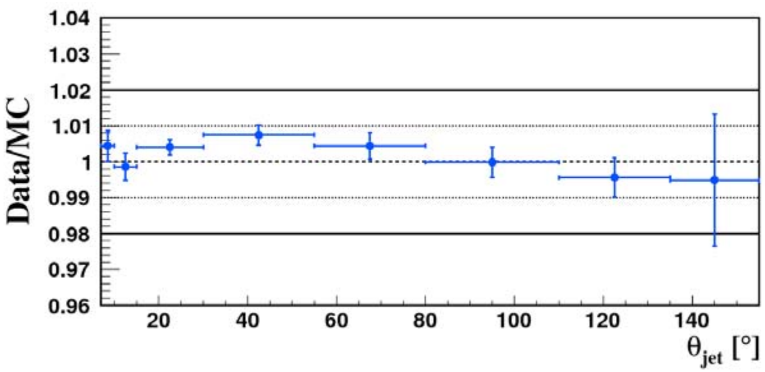
to get the calibration functions f and g.



dedicated 1-jet calibration sample

Data/MC double ratios $p_{T,h}/p_{T,DA}$

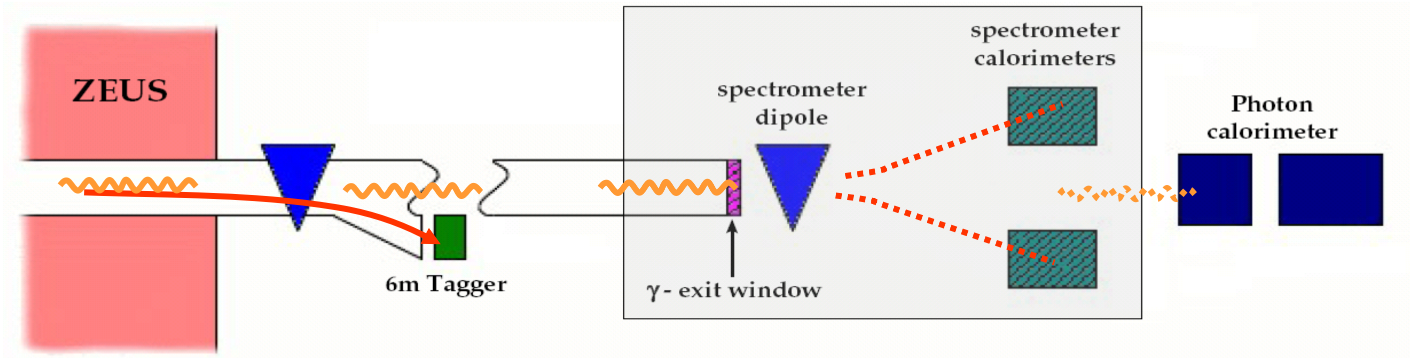




Jet energy scale uncertainty within 1% feasible - extended η range up to 2.5
Expect reduced syst. unc. for Jet measurements and as extraction

ZEUS: Precision Luminosity Measurement

LUMI @ ZEUS, Bethe-Heitler *ep→epg*, two measurements:
- Direct photon calorimeter (PCAL)
- Converted pair spectrometer
- agree ~1%, sys. unc. ~2.6% dominated by P(conversion)



MPI responsible

Ongoing work to reduce sys. unc.

Measure spectrometer Acceptance with 6m Tagger:
- Tag e from ep→epγ
- Count g in spectrometer
- Need rad. corr. Calculation ep→epγγ, ep →epe$^+$e$^-$

Improve uncertainty of P(conversion)
- Measure composition of window
- Compare GEANT ←→ s(γ→e$^+$e$^-$) measured to <1% in 1968
- Already discrepancy found, unc. on P(conversion) significantly reduced

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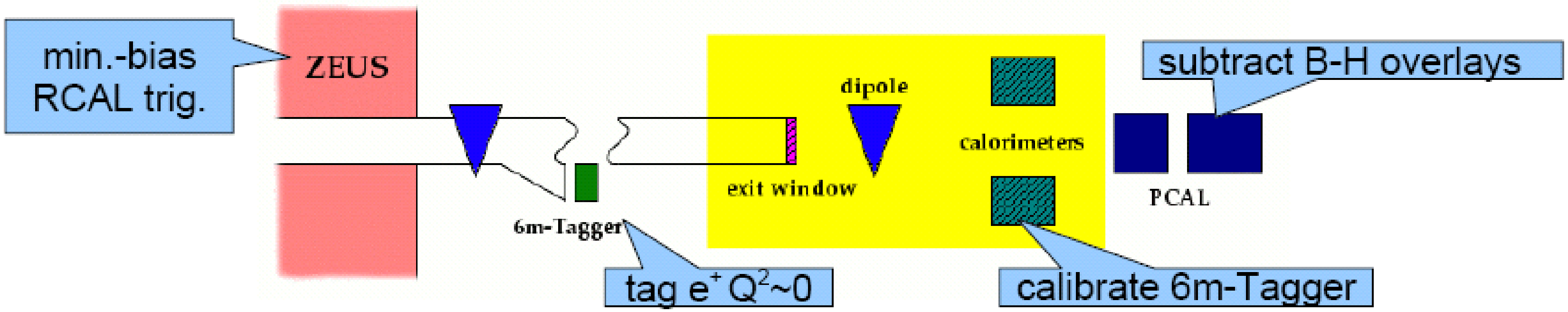
ZEUS: Energy Dependence of $\sigma_{tot}(\gamma p)$

- Dedicated trigger: energy in RCAL & positron in 6m-Tagger
- Data taken @ E_p = 920, 460, 575 GeV



<u>Progress so far:</u>

- Eliminate intense beam-induced min.-bias trigs.
- Subtract overlays of untagged-gp & Bethe-Heitler e^+ (high rate)
- Precise measure of energy in 6m-Tagger

<u>Work in progress:</u>

- Determine precise 6m-Tagger acceptance (untagged γp trigs.)
- Tune Pythia w/ measured data $\rightarrow$ precise acceptance A_{CAL}
- Prospect for best ever $\sigma_{tot}(\gamma p)$ and energy dependence

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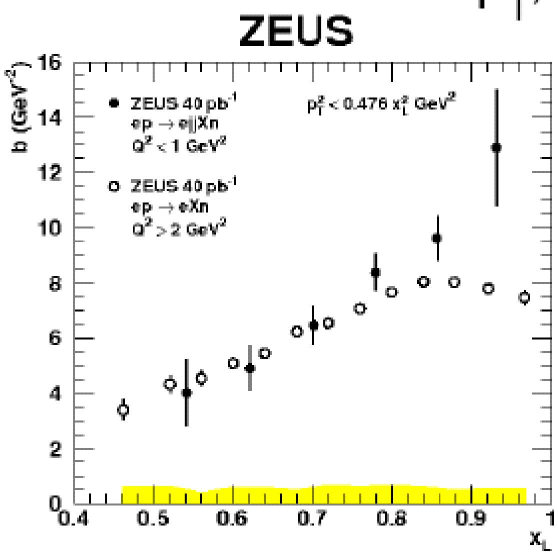
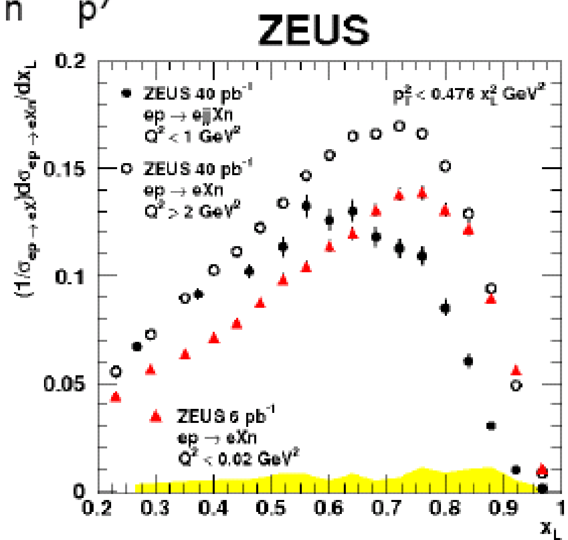
ZEUS: Leading Neutron Production in di-jet photoproduction

Nucl. Phys. B 827 (2010) 1

- Study of leading neutrons in $e + p \rightarrow e + jet + jet + n$, $Q^2 \sim 0$
- Focus on neutron p_T, energy ($x_L = E_n/E_p$) measurements:





- 1st ever measure of p_T^2 slopes b

  $d\sigma/dp_T^2 \sim \exp(-b\, p_T^2)$ this process
- Dijet-γp b (solid) similar to DIS (open)

➔ similar production mechanism

- In γp w/o jet requirement (red) LN suppressed rel. to DIS (open) @ low x_L

  ⇔ rescattering models
- In γp with high E_T jets (solid) LN suppressed rel. to DIS @ high x_L shown to be kinematic constraints

  ⇒ no clear sign of rescattering

Summary & Outlook

- HERA experiments H1 and ZEUS passed through the transition from active data taking to pure physics analysis
- Ongoing efforts improving reconstruction algorithms and calibrations taking advantage of full data samples.
- Steady stream of physics output, i.e. papers.
- Both MPI groups, H1 and ZEUS, enjoy high visibility within the HERA communinty