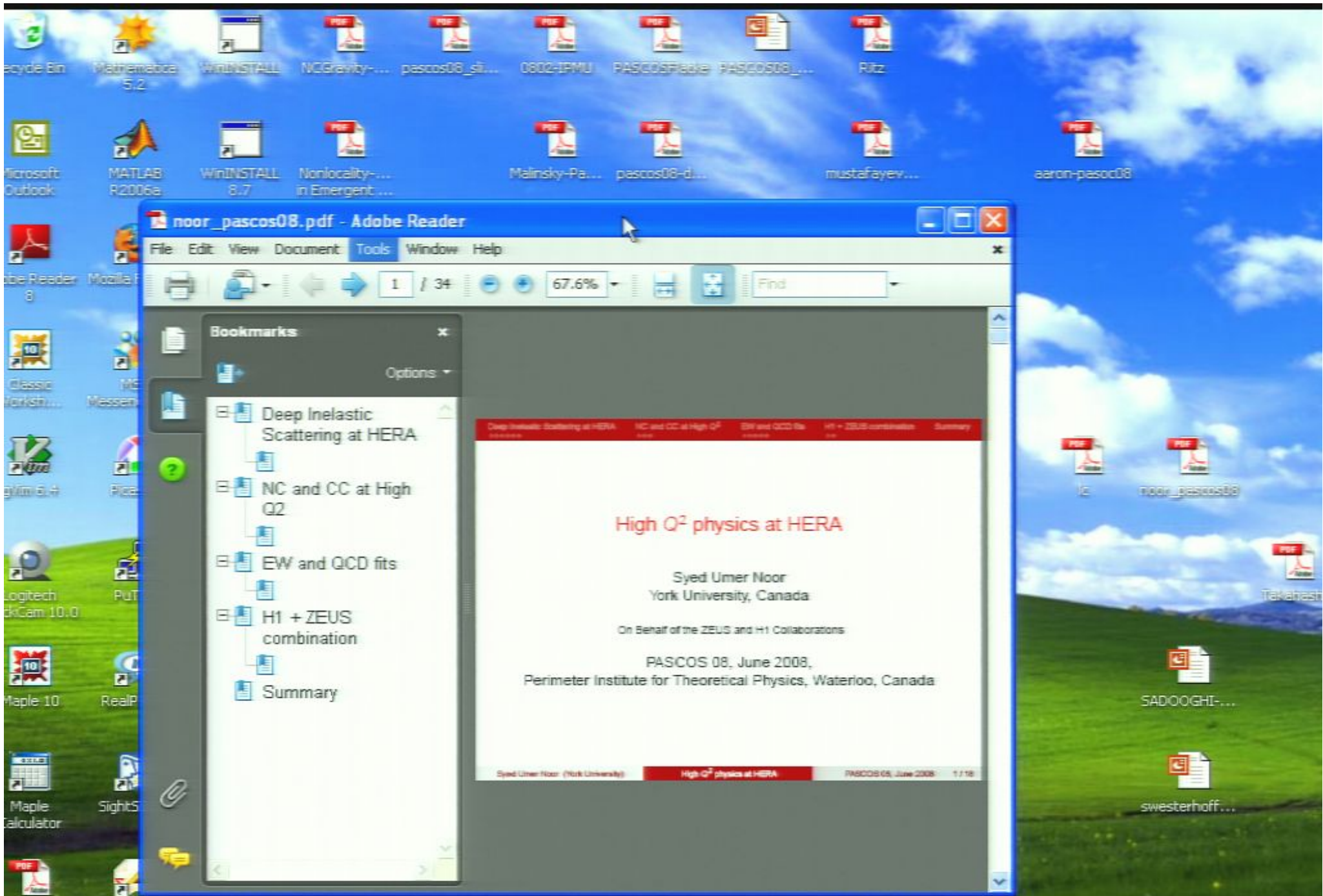


Title: High Q^2 physics at HERA

Date: Jun 05, 2008 02:45 PM

URL: <http://pirsa.org/08060105>

Abstract: Proton structure measurements at high Q^2 performed by the H1 and ZEUS collaborations at the HERA collider, are reviewed. Neutral and charged current deep inelastic scattering cross sections and structure functions are presented. The review also discusses improvements to the parton density measurements using jet cross section data and recent high Q^2 inclusive cross section measurements.



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- Deep Inelastic Scattering at HERA
 - NC and CC at High Q^2
 - EW and QCD fits
 - H1 + ZEUS combination
- Summary

Deep Inelastic Scattering at HERA NC and CC at High Q^2 EW and QCD fits H1 + ZEUS combination Summary

High Q^2 physics at HERA

Syed Umer Noor
York University, Canada

On Behalf of the ZEUS and H1 Collaborations

PASCOS 08, June 2008,
Perimeter Institute for Theoretical Physics, Waterloo, Canada

Syed Umer Noor (York University) High Q^2 physics at HERA PASCOS 08, June 2008 1 / 18



High Q^2 physics at HERA

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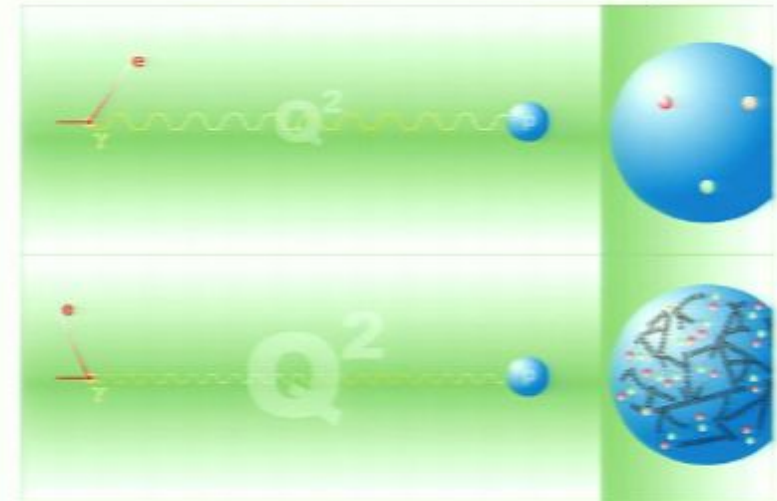
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HERA - the world's only $e^\pm p$ collider



- Collides protons with e^\pm
- e^\pm beam: 27.5 GeV
- p beam: 920 GeV
- Centre-of-mass energy $\sqrt{s} = 320$ GeV

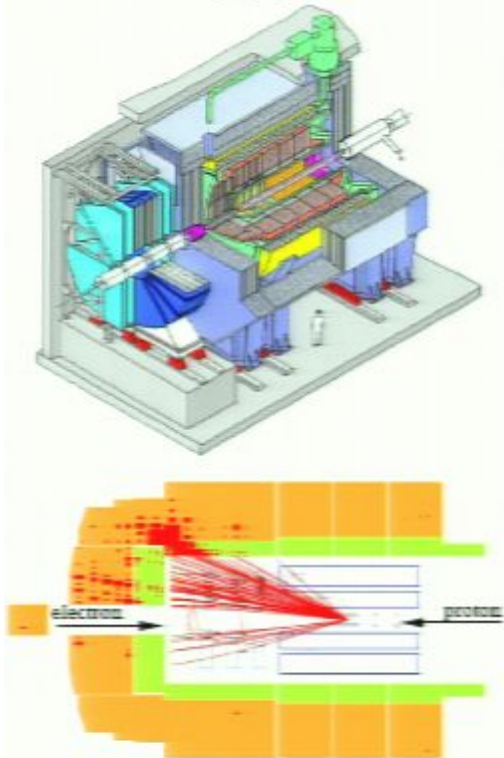
The HERA microscope!



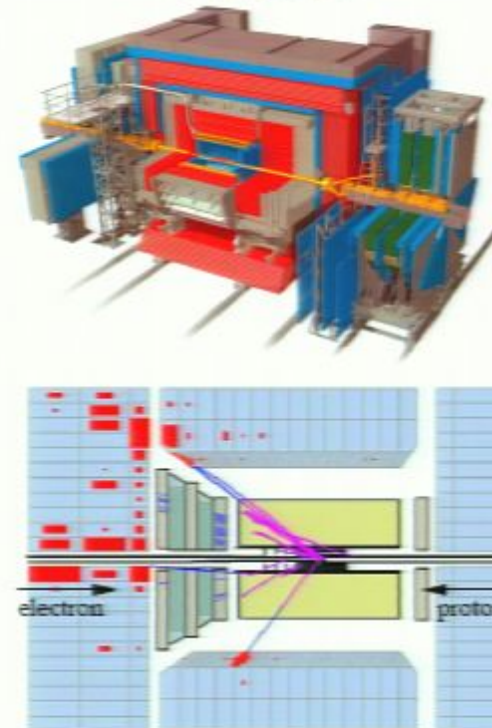
- Q^2 corresponds to the spatial resolution (wavelength λ) of the probe
- $\lambda \sim 1/\sqrt{Q^2}$
- $Q_{max}^2 \sim 10^5 \text{ GeV}^2$ (set by s)
- $\lambda_{min} \sim 10^{-18} \text{ m} \sim R_{\text{proton}}/1000$

The collider detectors at HERA

H1

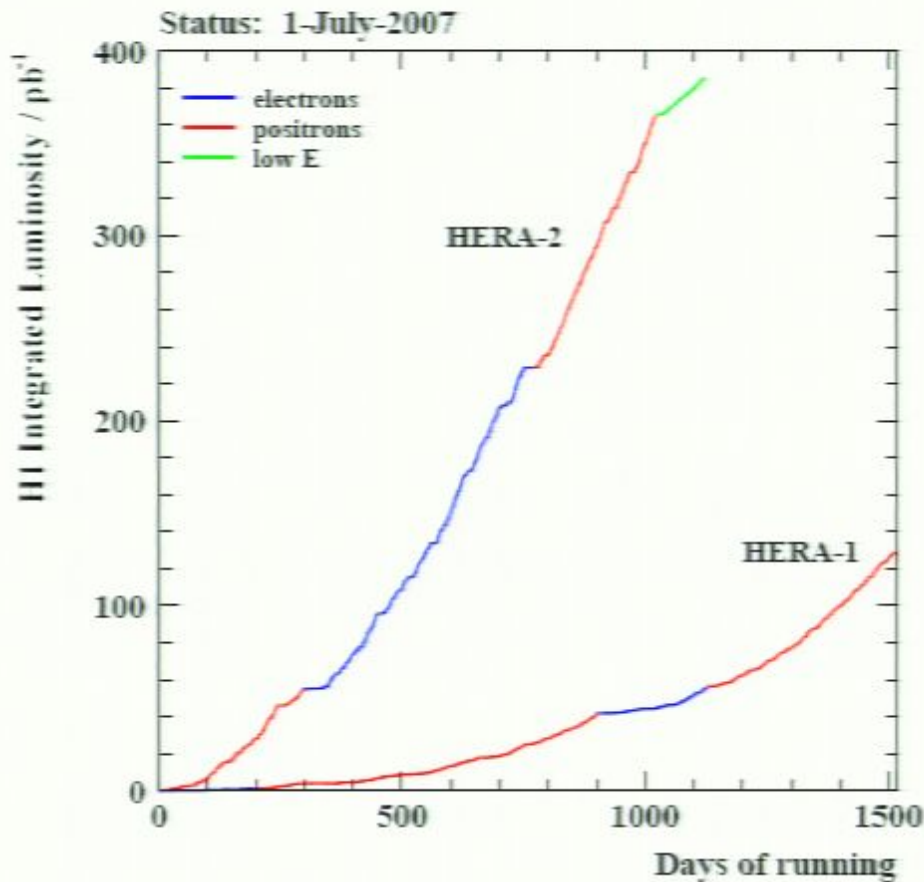


ZEUS

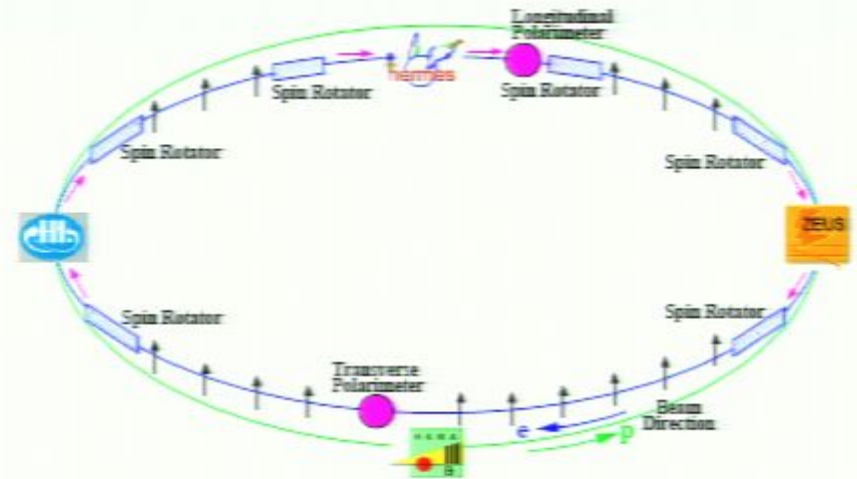


- Compensated Uranium Calorimeter (ZEUS), Liquid Argon Calorimeter (H1)
- Tracking and vertex detectors
- Silicon micro-strip detectors

HERA Operation

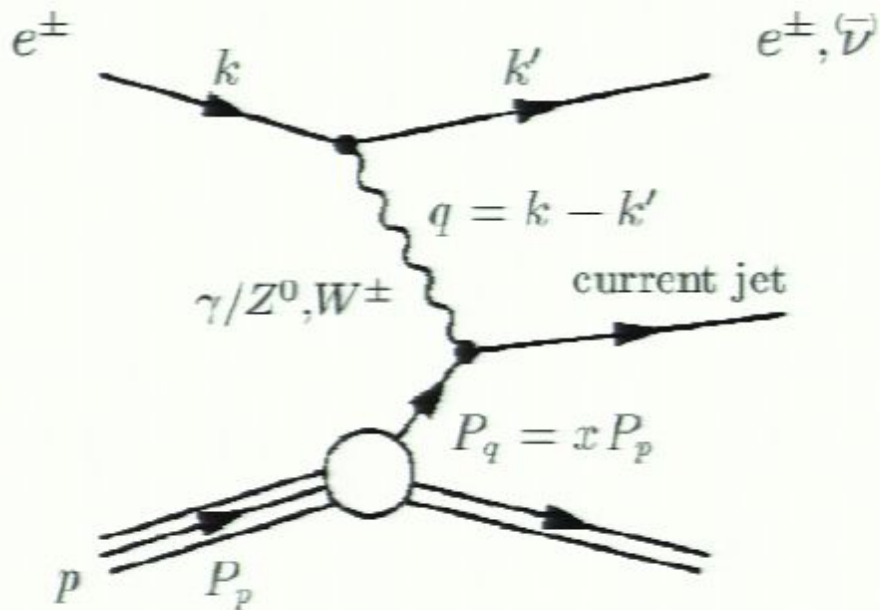


- Approximately 1 fb^{-1} of data collected by H1 + ZEUS



- Transverse polarisation builds up naturally (Solokov Ternov effect)
- Spin rotators installed in HERA II, providing longitudinally polarised leptons
- $$P_e = \frac{N_R - N_L}{N_R + N_L}$$

Deep Inelastic Scattering at HERA



Two processes

- Neutral Current (NC):
Exchange of γ or Z^0
- Charged Current (CC):
Exchange of W^\pm

Q^2 : Probing power

$$Q^2 = -q^2 = -(k - k')^2$$

x : Mom. fraction of struck quark

$$x = \frac{Q^2}{2p \cdot q}$$

y : Energy fraction transferred from lepton in p rest frame

$$y = \frac{p \cdot q}{p \cdot k}$$

NC DIS Cross Sections

$$\tilde{\sigma}_{NC}^{e^\pm p} = \frac{xQ^4}{2\pi\alpha^2} \frac{1}{Y_+} \frac{d^2\sigma(e^\pm p)}{dx dQ^2} = F_2 \mp \frac{Y_-}{Y_+} xF_3 - \frac{y^2}{Y_+} F_L$$

- $Y_\pm \equiv 1 \pm (1 - y)^2$
- **Structure functions**
 - F_2 : dominant contribution

$$F_2 \propto \sum(q + \bar{q})$$

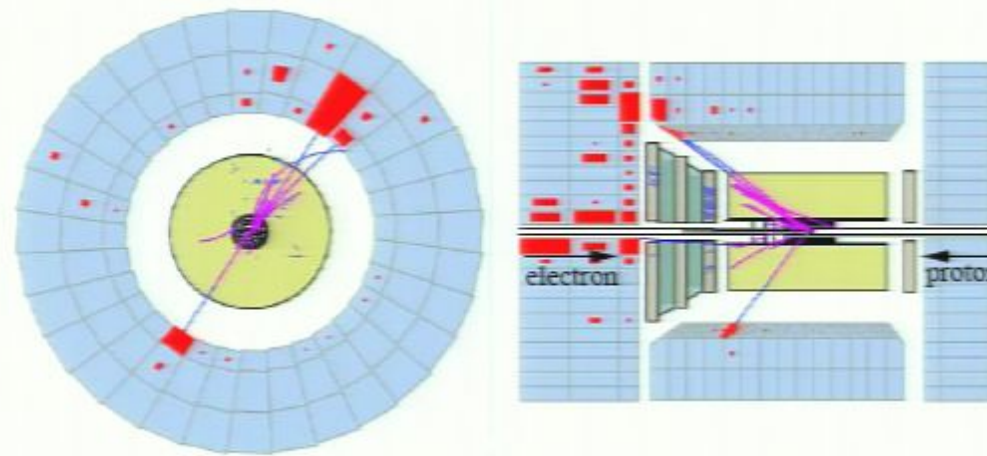
- xF_3 : sensitive at high Q^2

$$xF_3 \propto \sum(q - \bar{q})$$

- F_L : sensitive at high y

$$F_L \propto \alpha_s xg(x, Q^2)$$

ZEUS, NC event



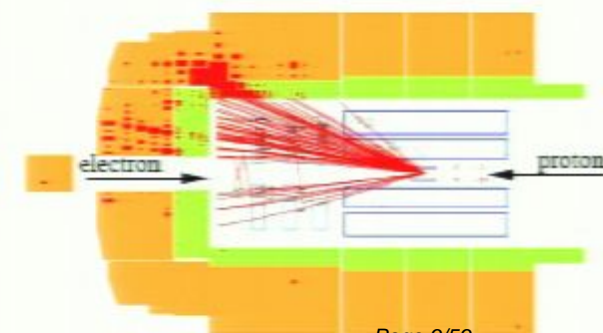
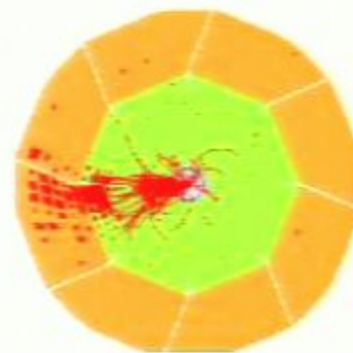
CC DIS Cross Sections

$$\frac{d^2\sigma_{CC}(e^-p)}{dx dQ^2} = (1 - P_e) \frac{G_F^2}{2\pi} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 [u + c + (1 - y)^2(\bar{d} + \bar{s})]$$

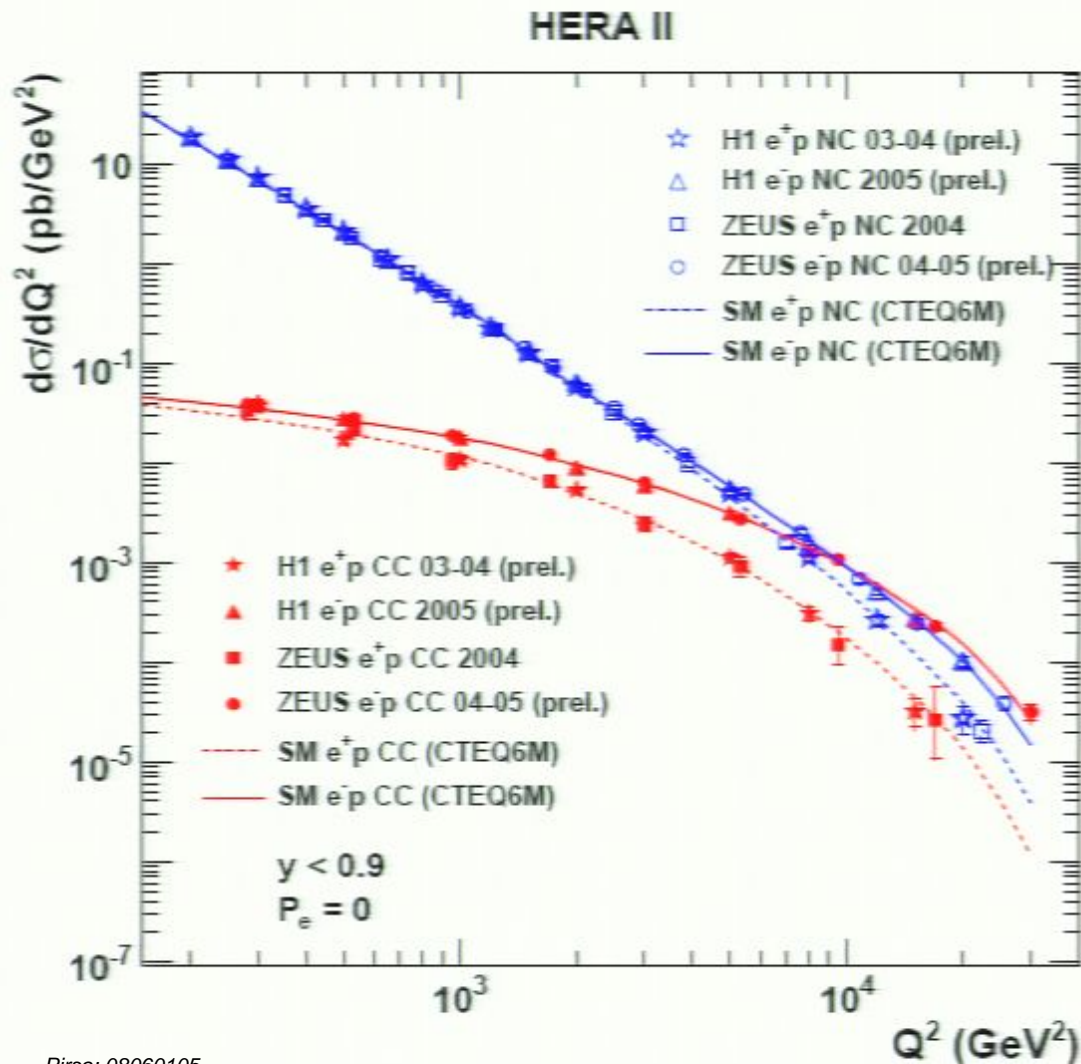
$$\frac{d^2\sigma_{CC}(e^+p)}{dx dQ^2} = (1 + P_e) \frac{G_F^2}{2\pi} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 [\bar{u} + \bar{c} + (1 - y)^2(d + s)]$$

- Linear polarisation dependence
- Sensitive to u and d valence quarks
 - Flavour dependent probe of proton structure

H1, CC event



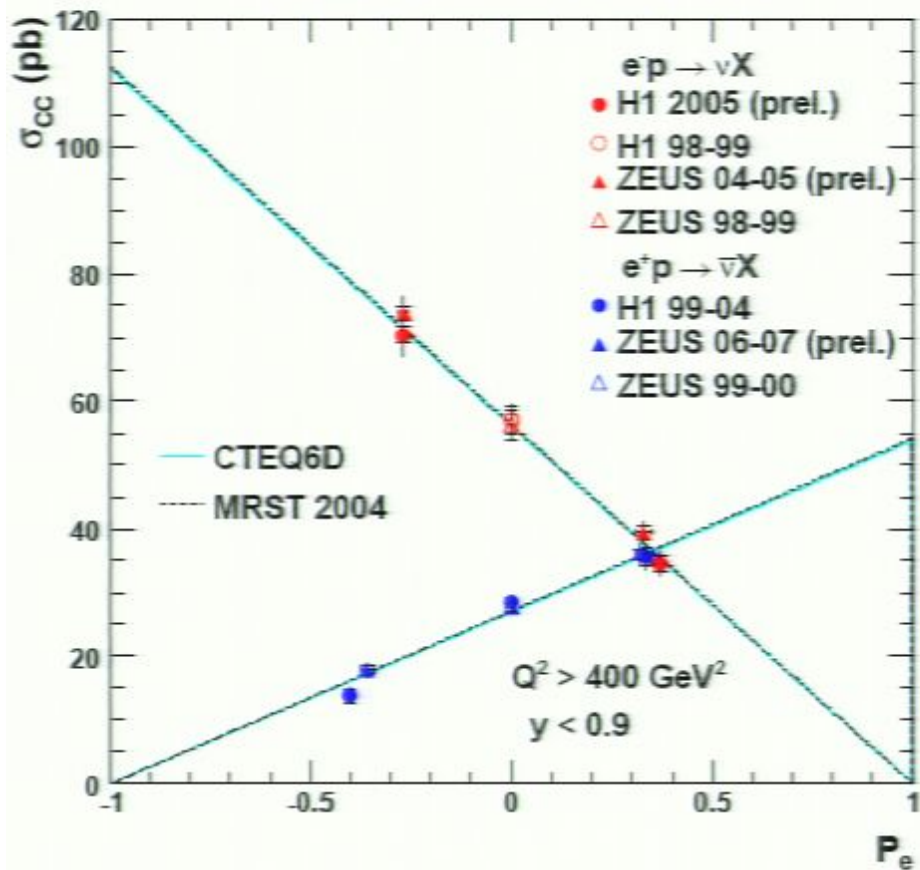
NC & CC Unpolarised Cross Sections



- NC cross section dominated by photon exchange
- Sensitive to the massive Z^0 contribution at high Q^2
- EW unification as NC and CC cross sections become similar

CC Polarised Cross Sections

Charged Current $e^\pm p$ Scattering

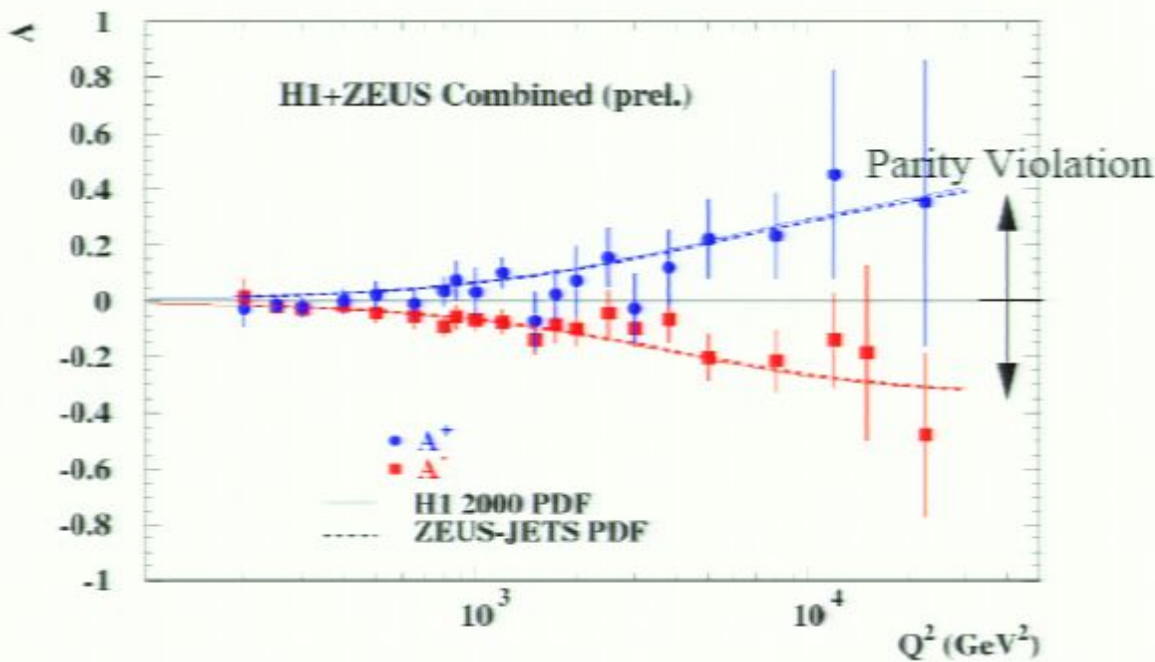


$$\sigma_{CC}^{e^\pm p}(P_e) = (1 \pm P_e) \sigma_{CC}^{e^\pm p}(P_e = 0)$$

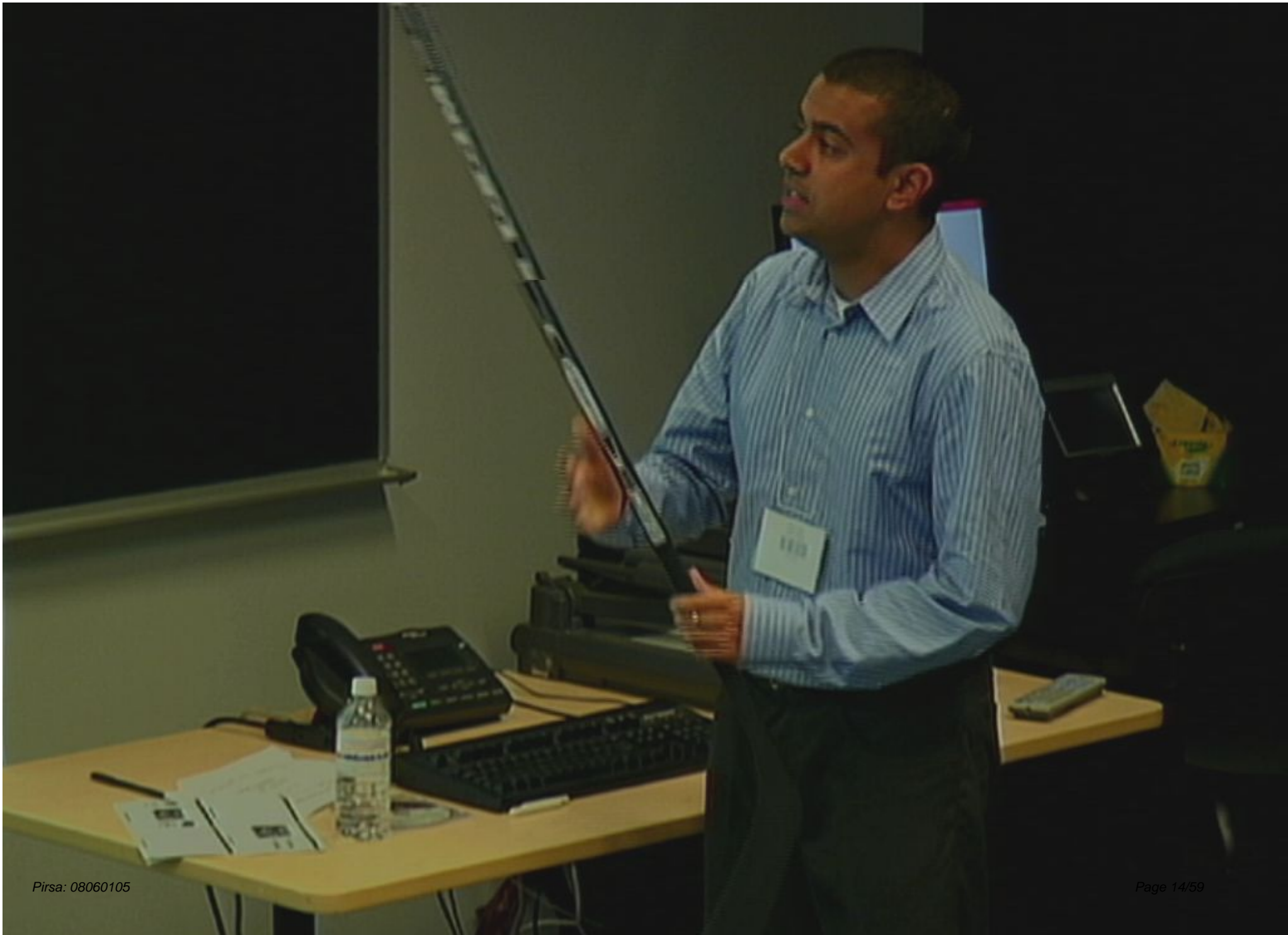
- Linear dependence with lepton polarisation
- No evidence of right-handed currents

NC Polarisation Asymmetry

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

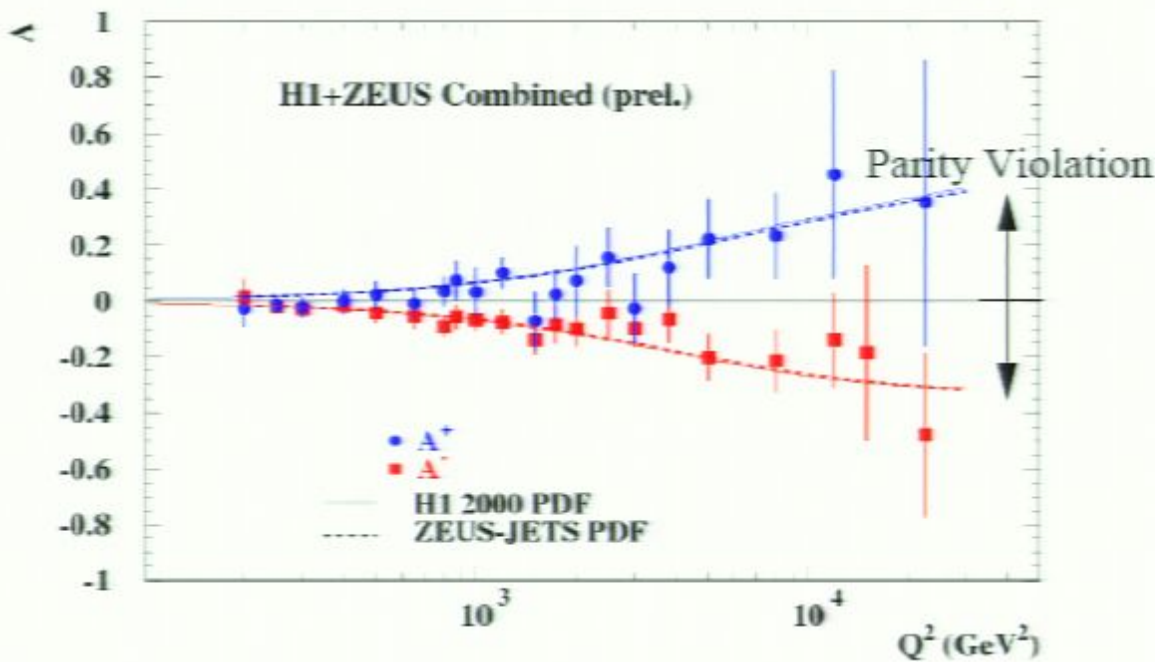


- Observe $A^{\pm} \neq 0$
- First evidence of parity violation in NC $e^{\pm}p$ scattering at high Q^2 ($\sim 10^{-18}\text{m}$)



NC Polarisation Asymmetry

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

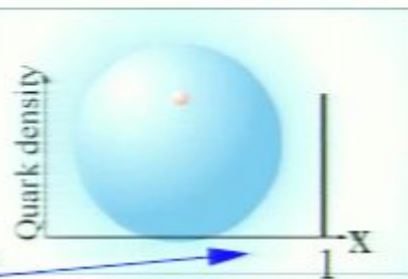


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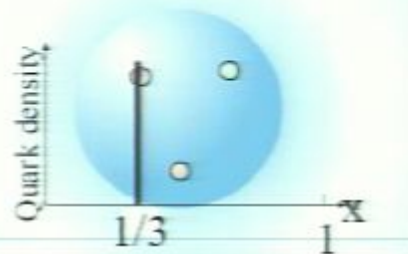
Structure of the proton

A single particle

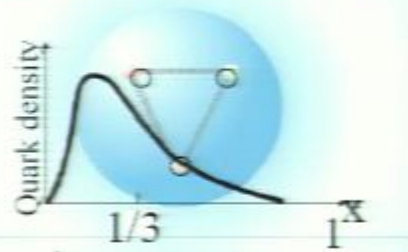
Proton momentum fraction x



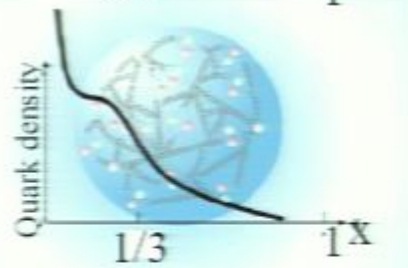
Three valence quarks



Three valence quarks with interactions



Valence and sea quarks with interactions

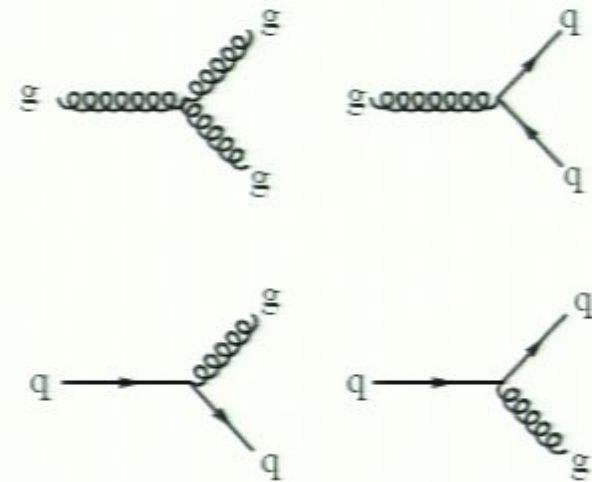
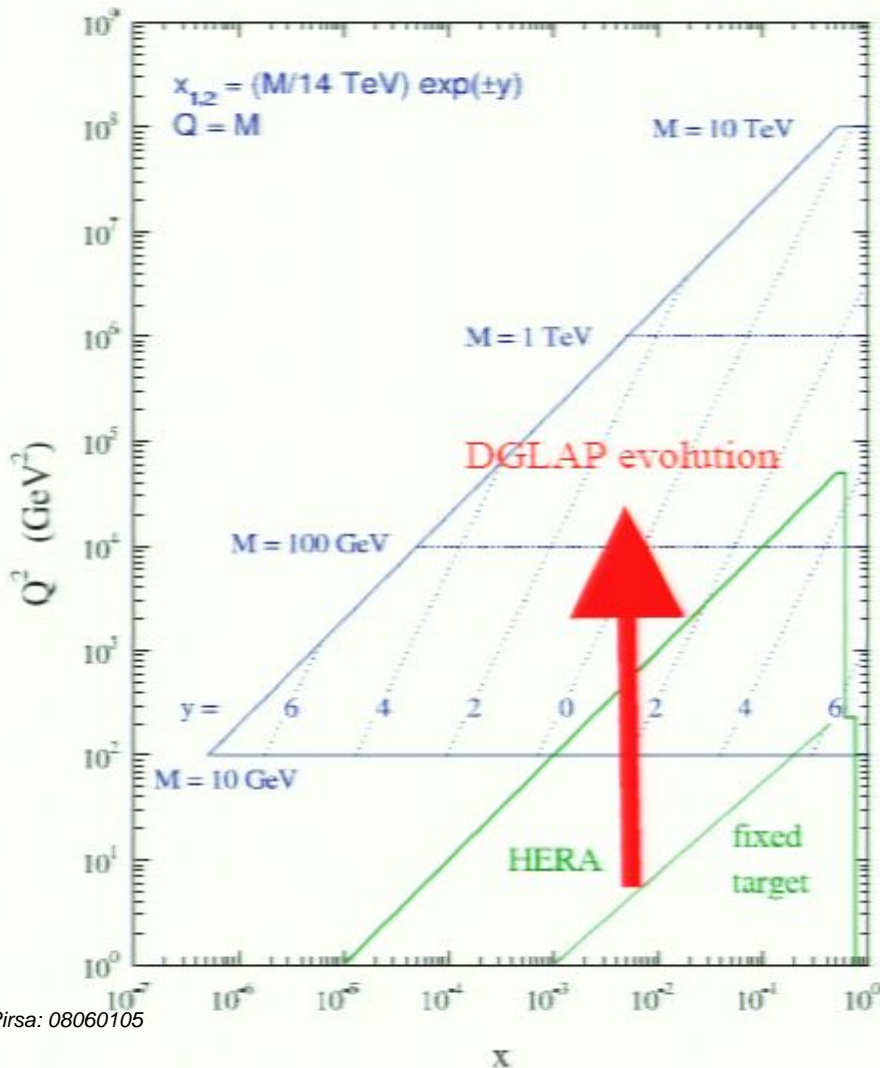


Wavelength of probe
Increasing resolution

- Structure depends on resolution (Q^2)
- Quark density = Probability that a quark carries momentum fraction x
- Known as Parton Density Functions (PDFs)
- Extracted from fits to data (QCD fits)

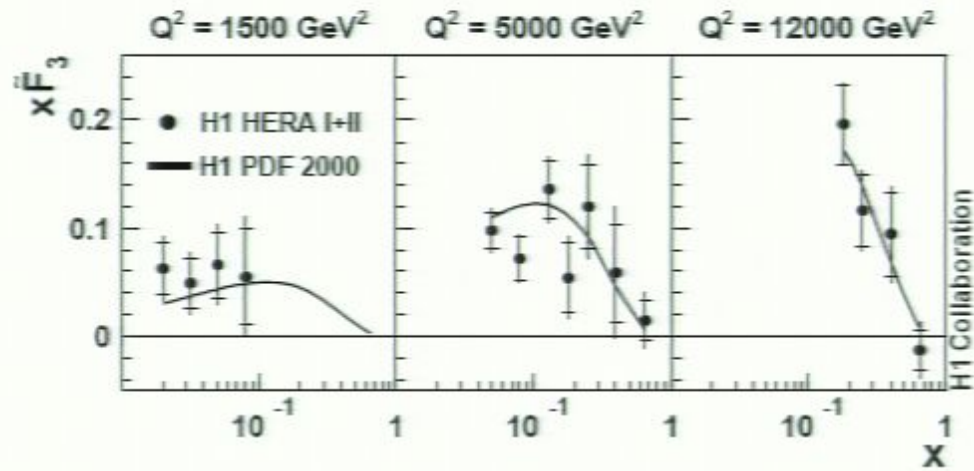
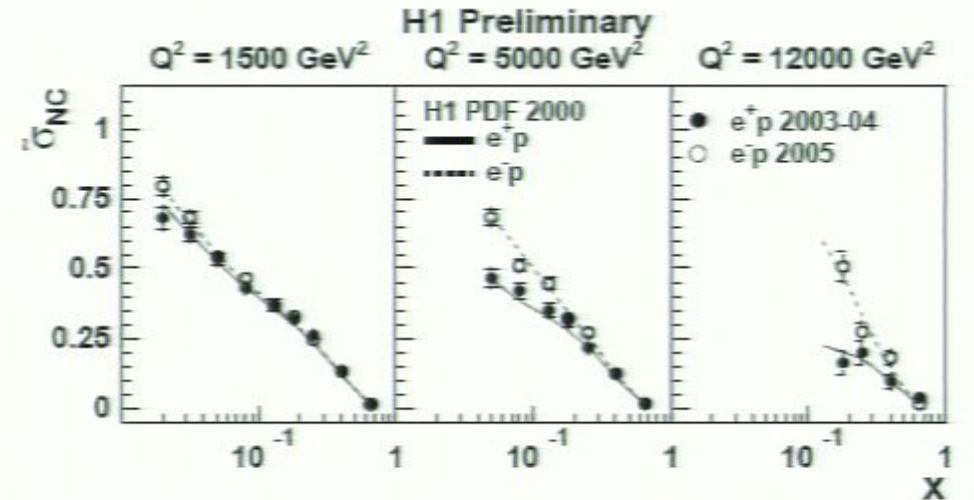
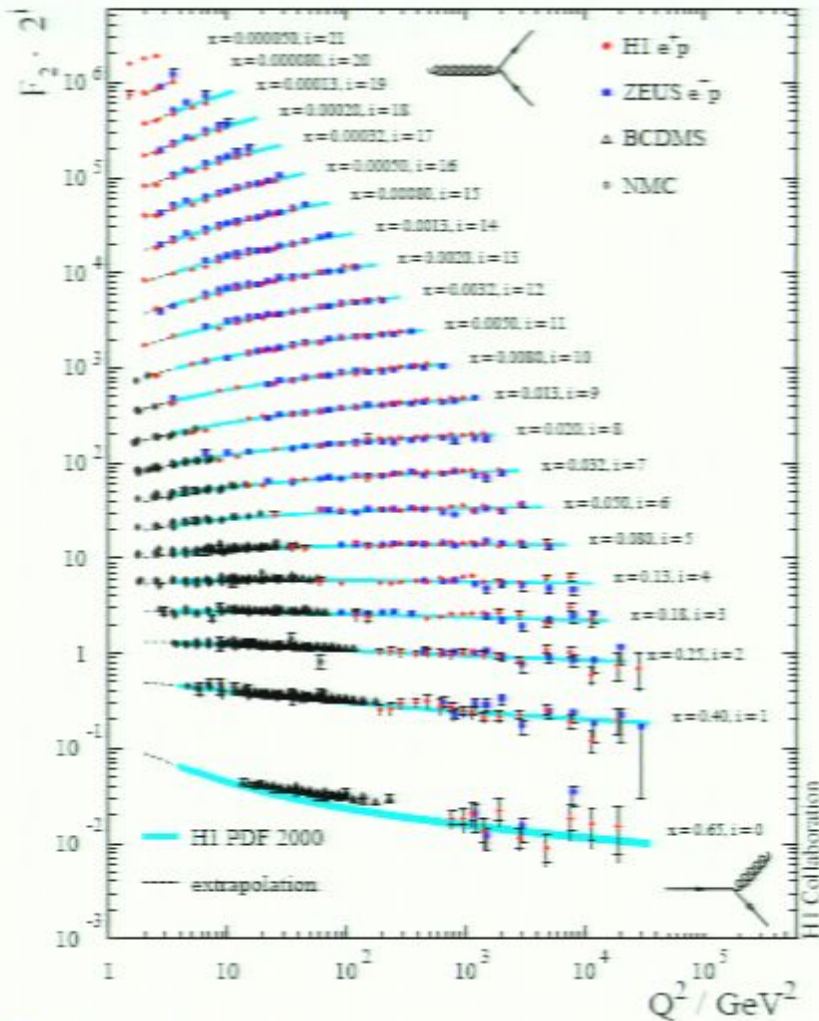
HERA - LHC Kinematic Plane

LHC parton kinematics



- DGLAP QCD evolution provides Q^2 dependence but x dependence comes from data
- HERA covers a very important region for the LHC
- Reliable PDFs needed to describe the proton structure

An example of the cross sections used for fits

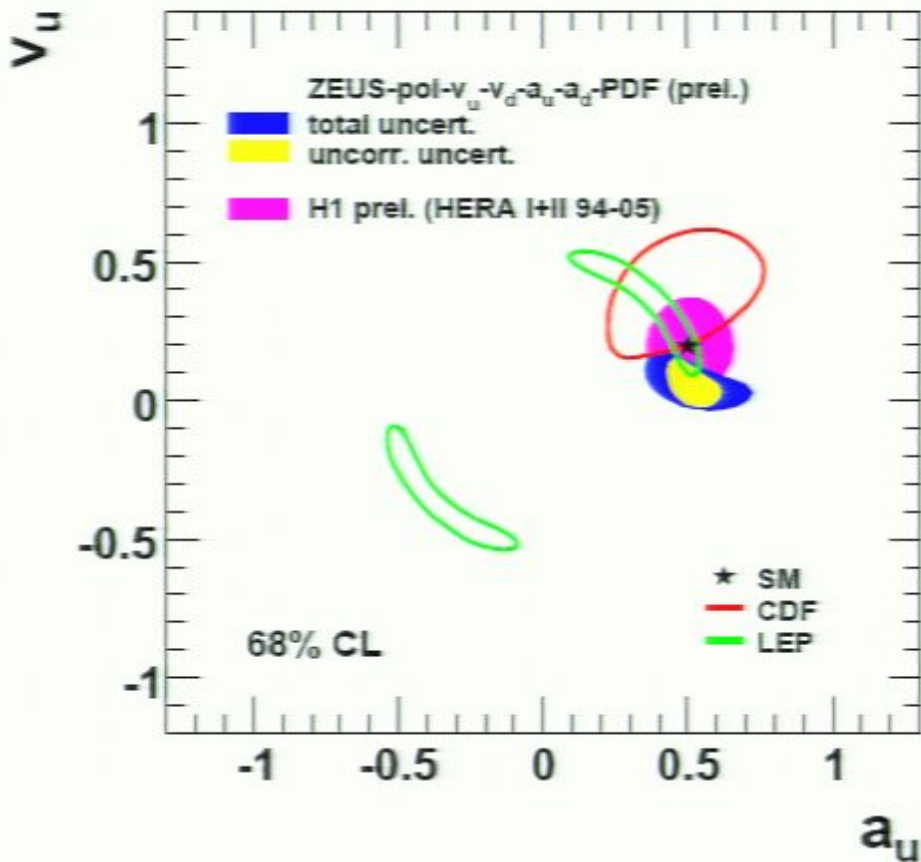


■ Scaling violation

■ Low-x sea and gluons precisely determined

■ Able to extract $xF_3 \propto \sum (q - \bar{q})$

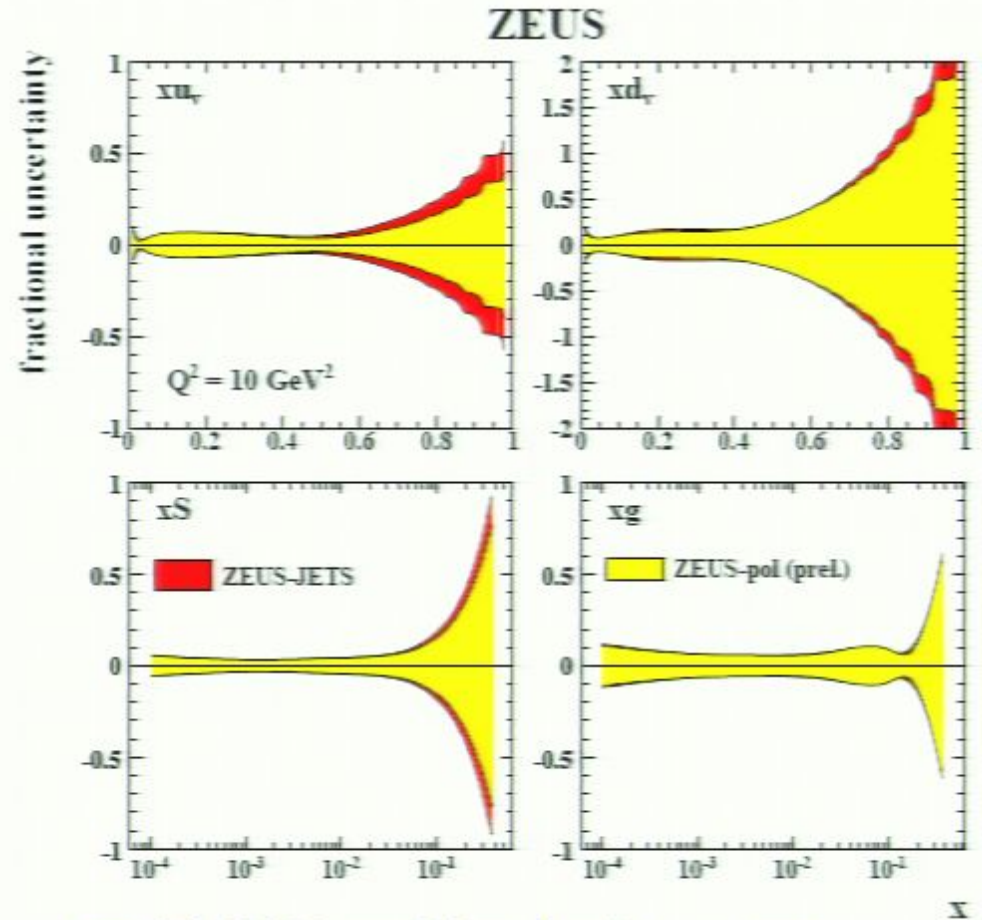
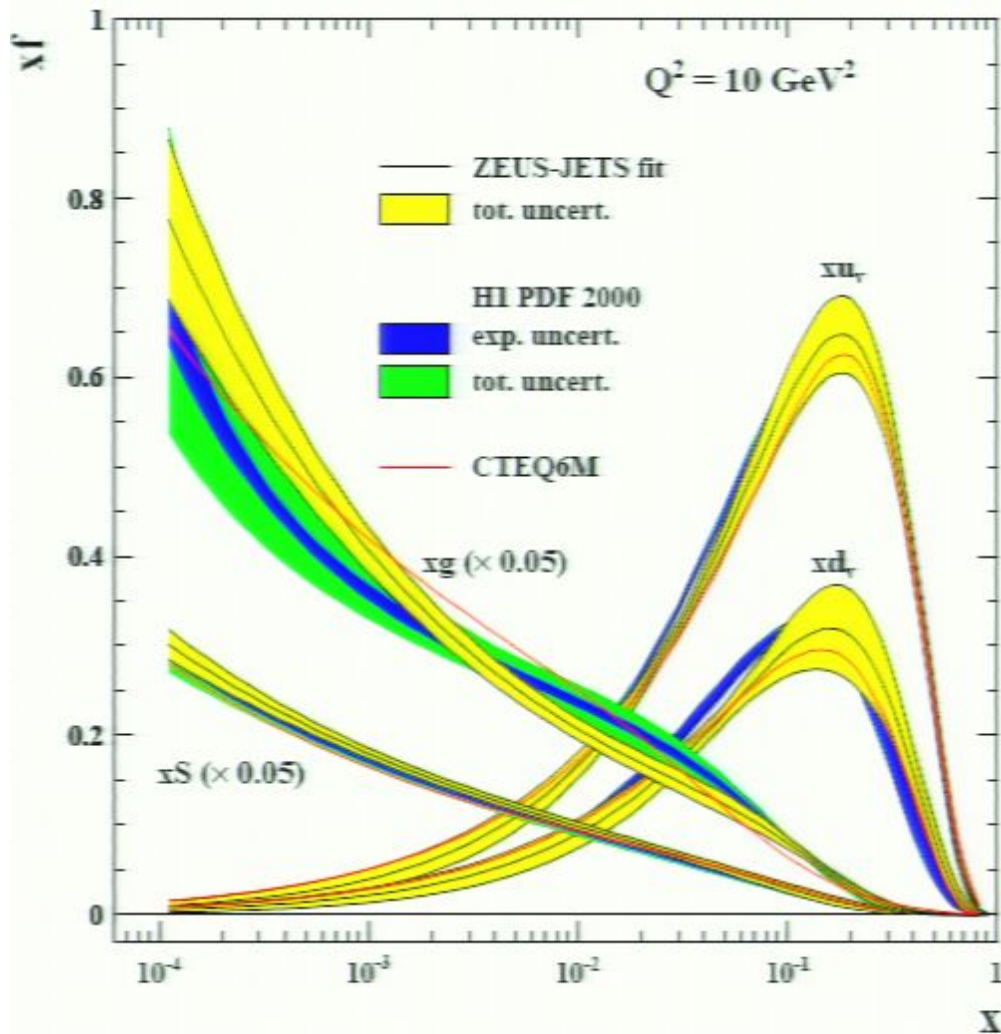
H1 and ZEUS EW fits



$$F_{2,3} = F_{2,3}(v_e, a_e, v_q, a_q)$$

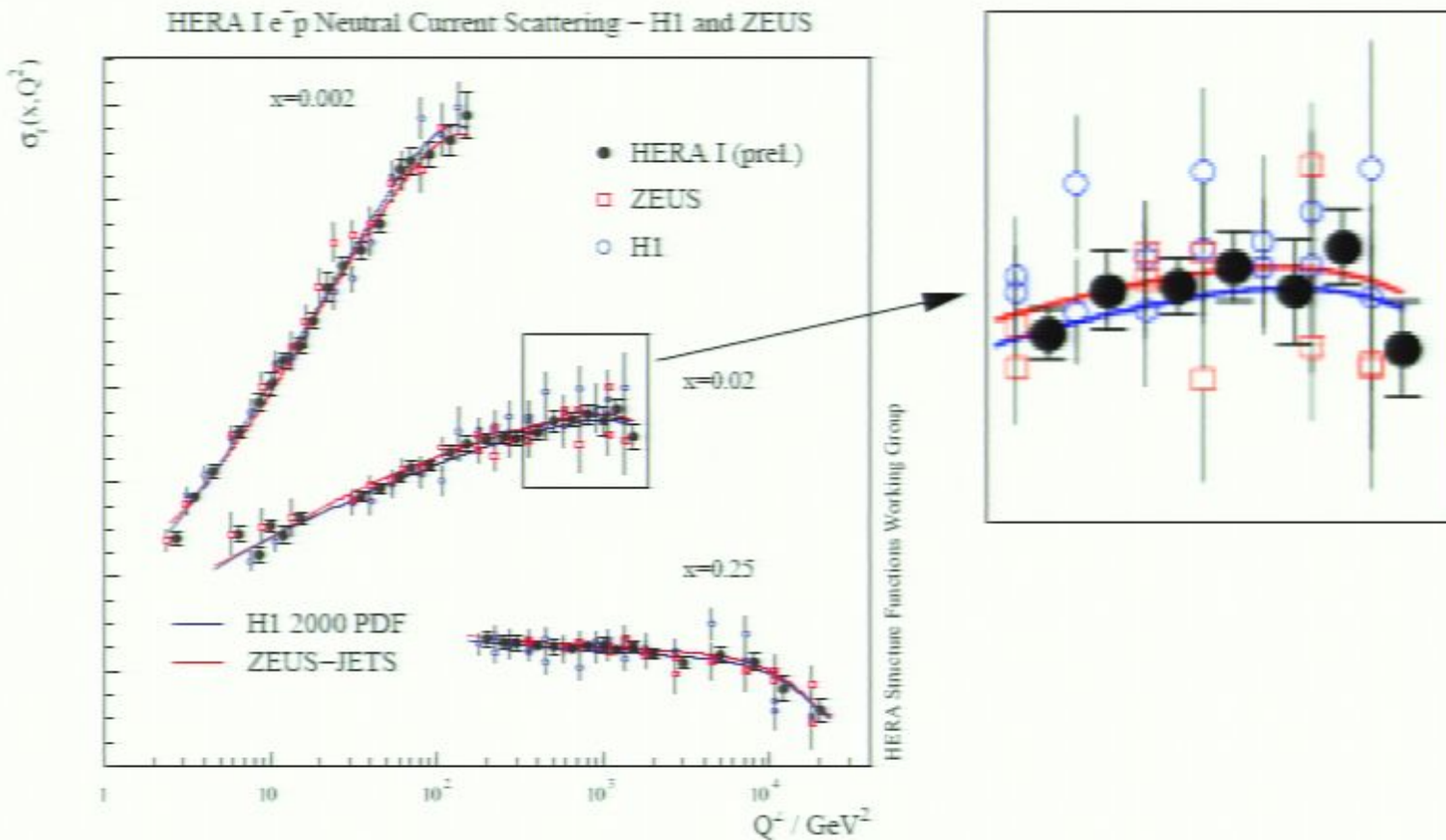
- Leave the light-quark couplings to the Z^0 free in fit
- Extract vector (v) and axial vector (a) couplings
- Competitive with Tevatron and LEP results

H1 and ZEUS PDF fits



- ZEUS-pol includes new polarised data
- Improved uncertainties

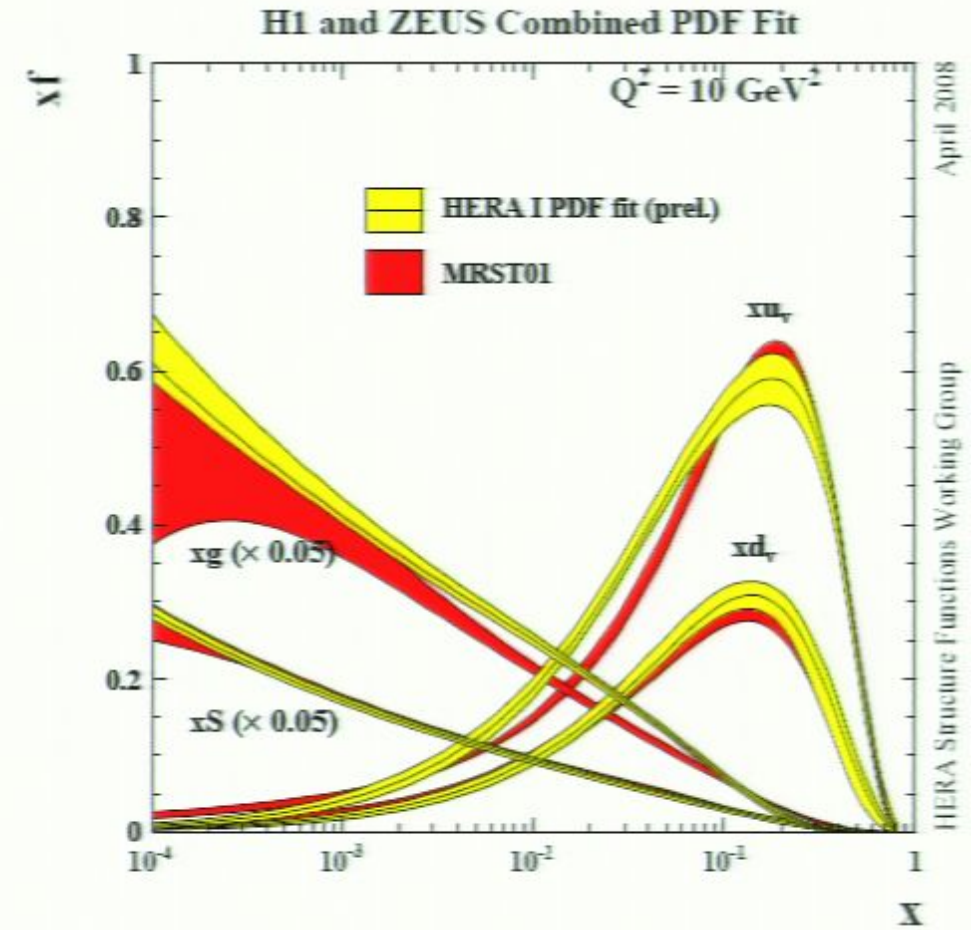
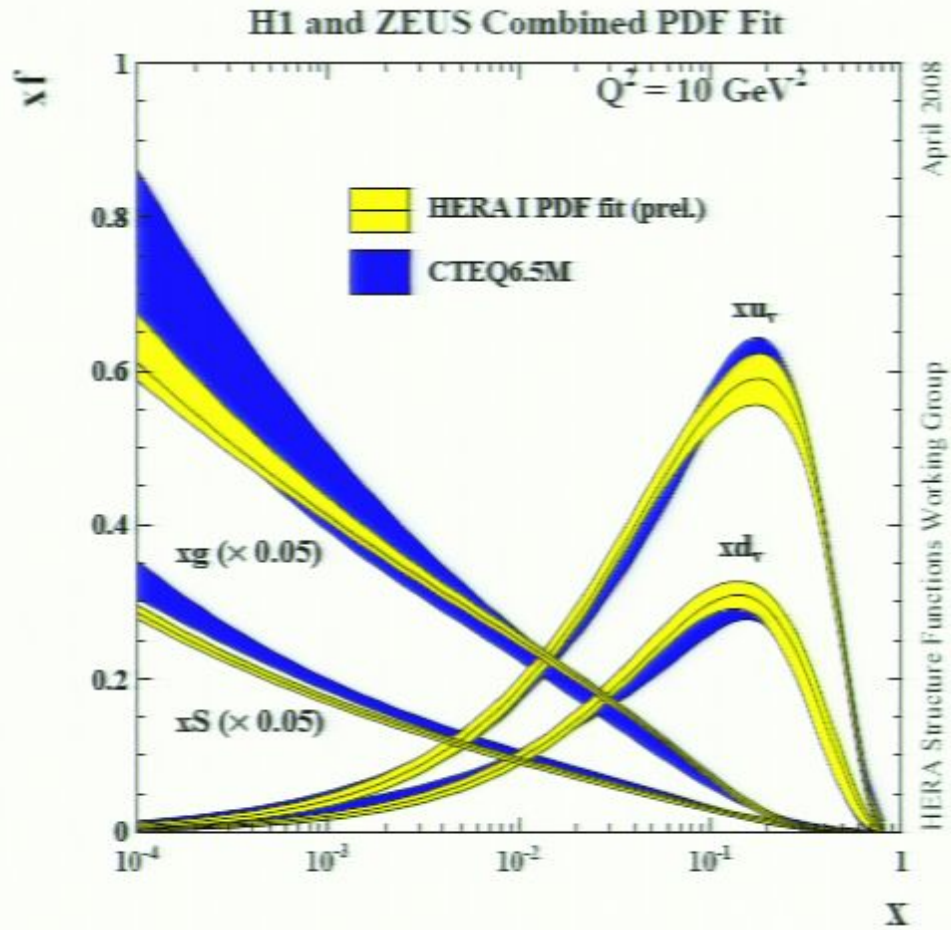
HERA I combined CC and NC results



- H1 and ZEUS are very active in combining DIS results
- Experiments “cross calibrate” each other

Pirsa: 08060105 ■ Uncertainties improved by more than $\sqrt{2}$ in some regions Page 21/59

HERA I PDF



- HERA I PDF fitted using combined H1 and ZEUS data
- Impressive precision compared to global fits

Summary

- HERA is providing significant tests to the electroweak model and improving our knowledge of the proton structure
- No evidence of right-handed CC
- First time that parity violation observed in NC DIS at high Q^2
- Determination of the light quark couplings to the Z^0
- Improvements to PDF uncertainties using HERA II data and through H1 & ZEUS combination
- Outlook
 - Analysis of complete HERA data, $\approx 1\text{fb}^{-1}$, to come

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Deep Inelastic Scattering at HERA NC and CC at High Q^2 EW and QCD fits H1 + ZEUS combination Summary

Sped Usher-Roar (York University) High Q^2 physics at HERA PASCOS 08, June 2008 18 / 18







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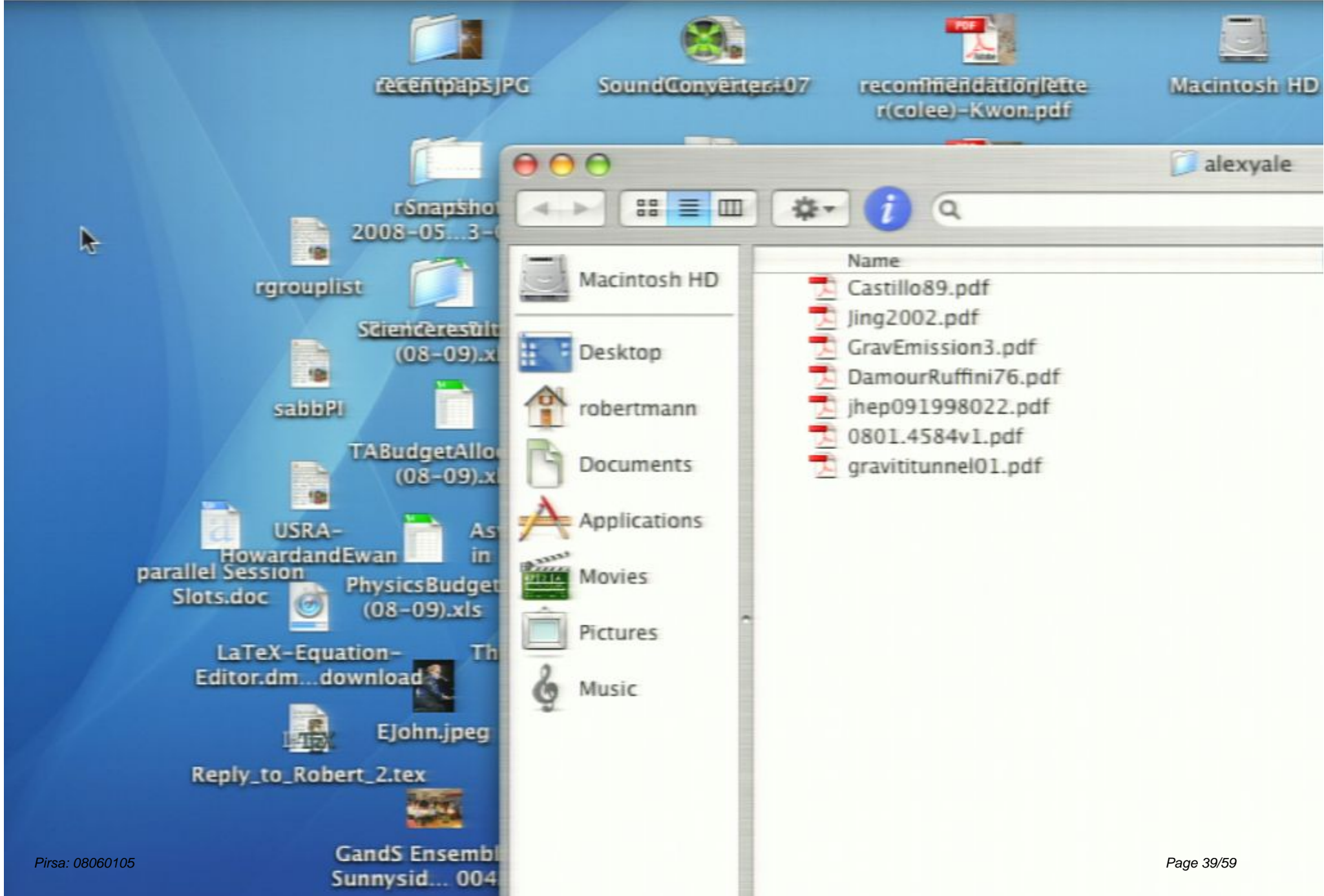


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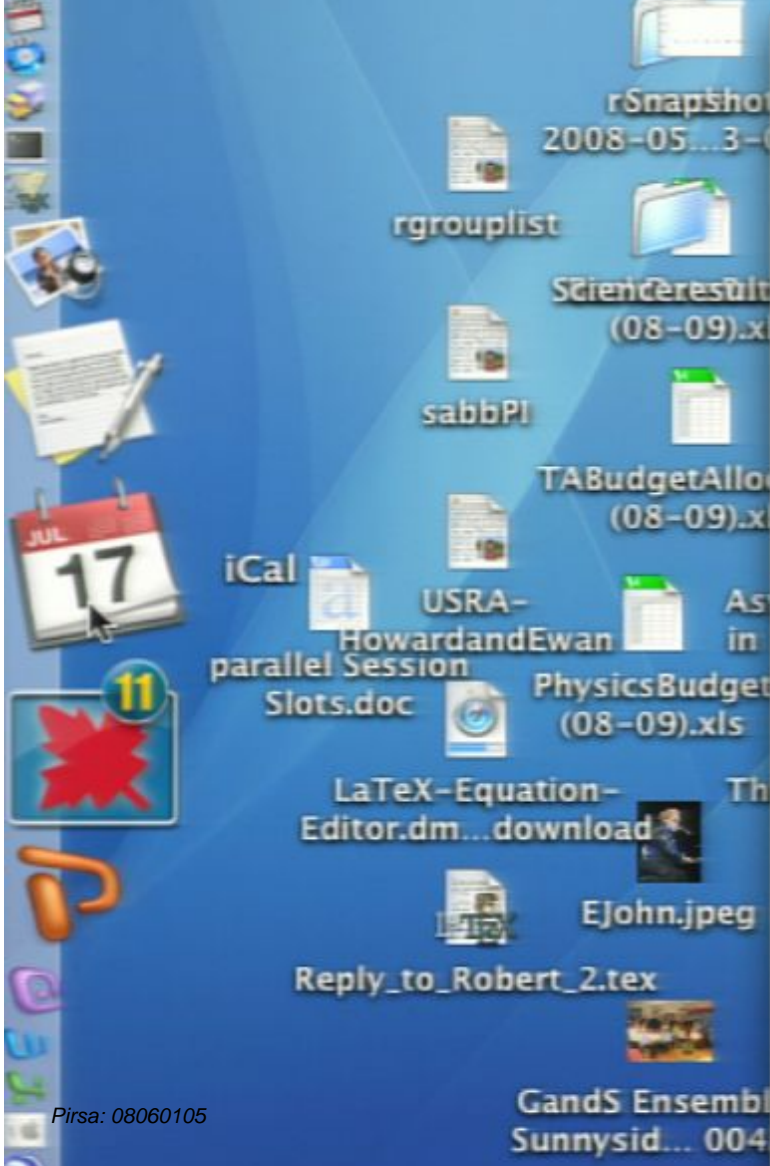
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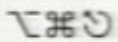
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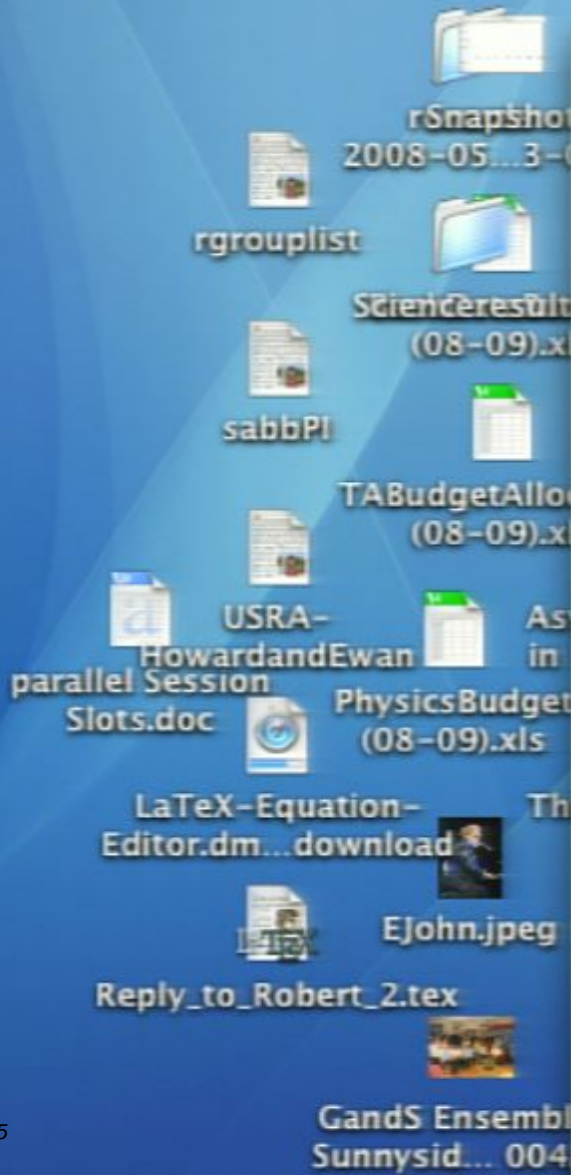
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Photo Booth	25-May-07, 1:05 PM
PCalc	29-Oct-05, 7:00 PM
OmniOutliner	25-May-07, 1:02 PM
Office 2004 for Mac Test Drive	23-Dec-05, 10:02 PM
MPEG Streamclip	30-Dec-06, 4:38 AM
Microsoft Office 2004	19-May-08, 10:06 PM
Microsoft AutoUpdate	22-Sep-04, 6:27 PM
MathType 5	29-May-07, 9:50 PM
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MacTheRipper	10-Mar-05, 7:45 AM
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LaTeXiT	24-Aug-07, 7:28 AM
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iWork '06	3-Sep-07, 11:47 AM
iWeb	25-May-07, 1:15 PM
iTunes	5-Apr-08, 1:47 AM

Applications

Macintosh HD Desktop robertmann Documents Applications Movies Pictures Music

Name	Date Modified
Sherlock	25-May-07, 1:01 PM
Safari	1-May-08, 10:16 PM
QuickTime Player	5-Apr-08, 1:47 AM
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Macintosh HD	
Desktop	
Address Book	
robertmann	
Documents	
Applications	
Movies	
Pictures	
Music	
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Search box: Type a word and begin searching.

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Dashboard

Applications

Navigation and search controls including back/forward arrows, view modes (grid, compare, web), settings gear, information icon, and search field.

Name	Date Modified
Macintosh HD	
Desktop	
robertmann	
Documents	
Applications	
Movies	
Pictures	
Music	
Stierlock	25-May-07, 1:01 PM
Safari	1-May-08, 10:16 PM
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- About This Mac
- Software Update...
- Mac OS X Software...
- System Preferences...
- Dock ▶
- Location ▶
- Recent Items ▶
- Force Quit... ⌘⇧⌘
- Sleep
- Restart...
- Shut Down...
- Log Out Robert Mann... ⌘⇧⌘

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- Movies
- Pictures
- Music

- About This Mac
- Software Update...
- Mac OS X Software...
- System Preferences...
- Dock
- Location
- Recent Items**
- Force Quit...
- Sleep
- Restart...
- Shut Down...
- Log Out Robert Mann...

- Applications
 - Adobe Reader
 - Keynote
 - Microsoft Excel
 - Microsoft Word
 - QuickTime Player
 - Safari
 - Terminal
 - TeXShop
 - TextEdit
 - Transmit
- Documents
 - BackDataBudget(08-09).xls
 - Higgs Portal
 - numerics graph.pdf
 - parallel Session Slots.doc
 - PhysicsBudget(08-09).xls
 - rrkN2figs.tar.gz
 - rrkN5.tex
 - rrkNmorefigs.tar.gz
 - TABudgetAllocation(08-09).xls
 - unitrot41-submitted
- Servers

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Applications

Macintosh HD

Desktop

robertmann

Documents

Applications

Movies

Pictures

Music

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Opening...



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- robertmann
- Documents
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