



# Measurement of the Longitudinal Structure Function $F_L$ at Low $x$ in the H1 Experiment at HERA

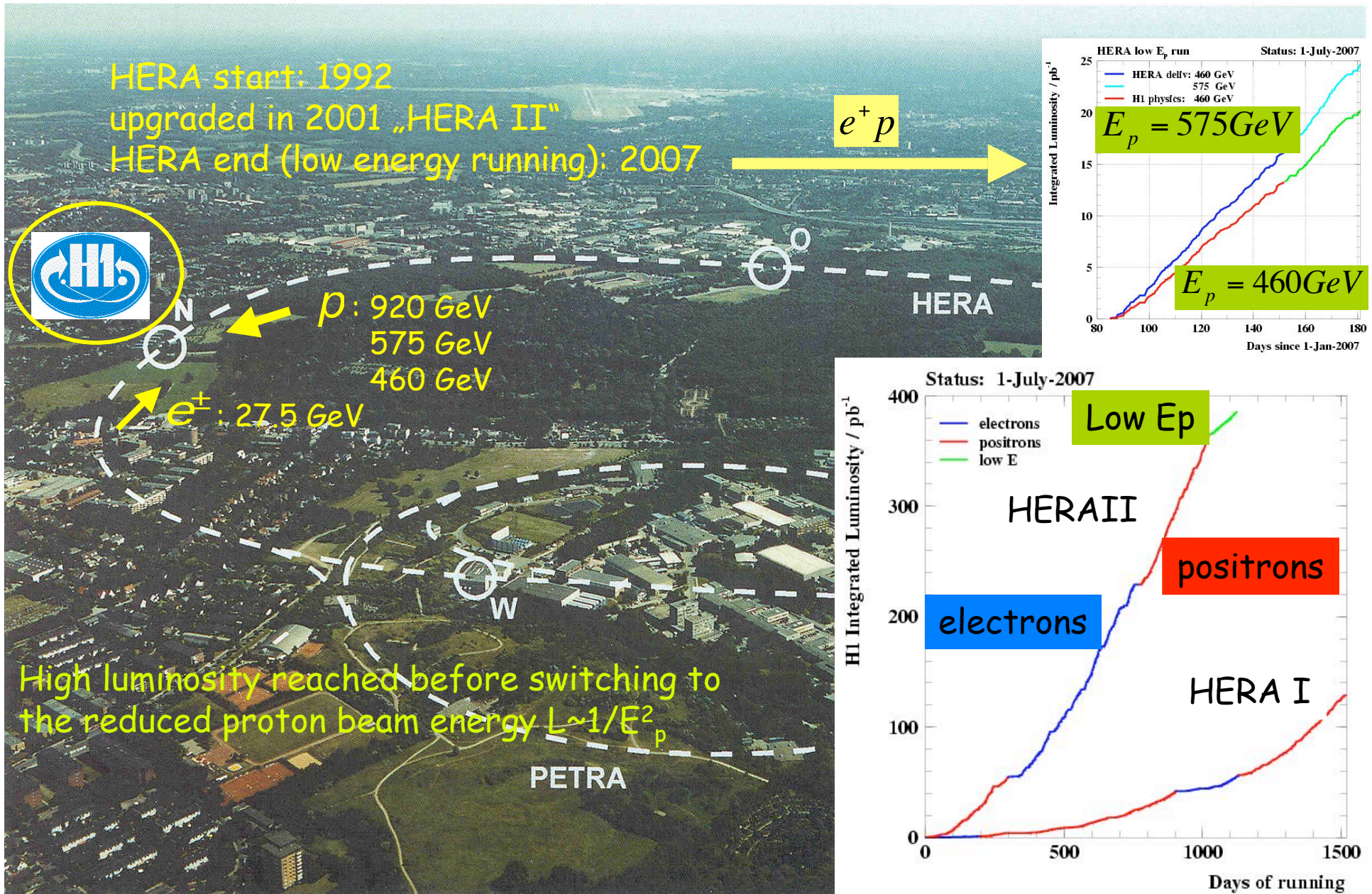
Biljana Antunović, DESY  
on behalf of the H1 Collaboration

DIS08, London, 7-11<sup>th</sup> April 2008

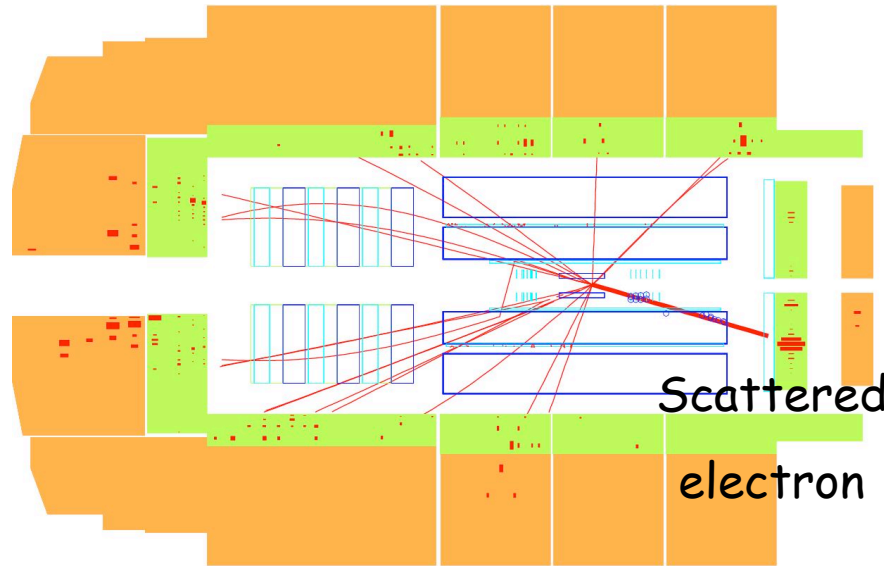
## Outline

- HERA and DIS
- Physics Motivation
- Analysis Strategy
  - Results
  - Summary

# HERA - Unique Electron-Proton Collider (Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany)



# Deep Inelastic Scattering (DIS) in the H1 Detector



Determination of kinematics  
using electron method

The diagram shows an incoming electron with energy  $E_e$  (red arrow) and a scattered electron with energy  $E'_e$  (red arrow) at an angle  $\theta_e$  relative to the proton target (blue circle labeled 'P').

$$Q^2 = 4 E_e E'_e \cos^2\left(\frac{\theta_e}{2}\right) \text{ (Momentum transfer)}^2$$

$$y = 1 - \frac{E'_e}{E_e} \sin^2\left(\frac{\theta_e}{2}\right) \text{ Inelasticity}$$

$$x = \frac{Q^2}{sy} \text{ Bjorken } x$$

□ DIS at HERA provides:

=> unique tool to study the structure of the proton (PDFs)

=> test of pQCD and validity of DGLAP evolution equations at low  $x$  and  $Q^2$

# Physics Motivation

- Reduced NC DIS ep cross-section at low  $Q^2$

$$\sigma_r(x, y, Q^2) = \frac{Y_+ Q^4}{2\pi\alpha^2} \frac{d^2\sigma}{dx dQ^2} = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

$Y_+ = 1 + (1 - y)^2$   
 $x F_3$  negligible

- $F_2$  dominant, **sensitivity to  $F_L$  only at high  $y$**
- Measurement of  $F_L$  completes study on inclusive DIS at HERA
- $F_L$  and  $F_2$  provide crucial tests of pQCD at high orders at low  $x$ , both  $dF_2/d\ln(q^2)$  and  $F_L$  are measures of  $xg$
- Previous determinations of  $F_L$  with assumptions on  $F_2$ , and theoretical pdf analyses lead to expectation of  $F_L$  to be large, **reflecting the dominance of  $xg$  at low  $x$**

# Direct Measurement of FL

## Measurement Strategy:

=> Measure reduced cross sections for the same  $(x, Q^2)$  at different  $y$  (CME)

=> Collect data with **3 different proton beam energies with enough luminosity**

=> Perform straight line fit of cross section to extract  $F_2$  and  $F_L$

$$\sigma_r(x, Q^2, y) = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \quad Y_+ = 1 + (1 - y)^2$$

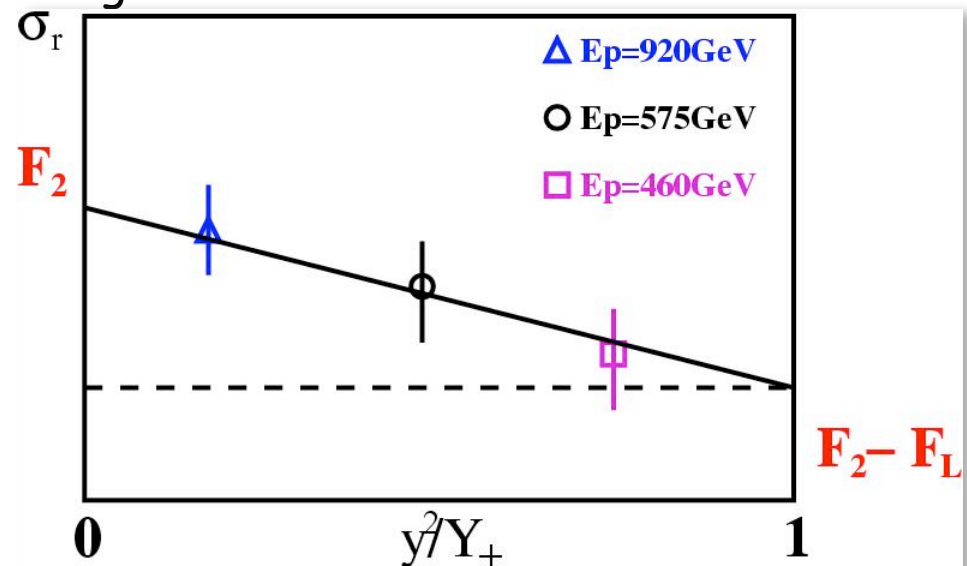
the slope =>  $F_L$

the intercept with  $y$  axis =>  $F_2$

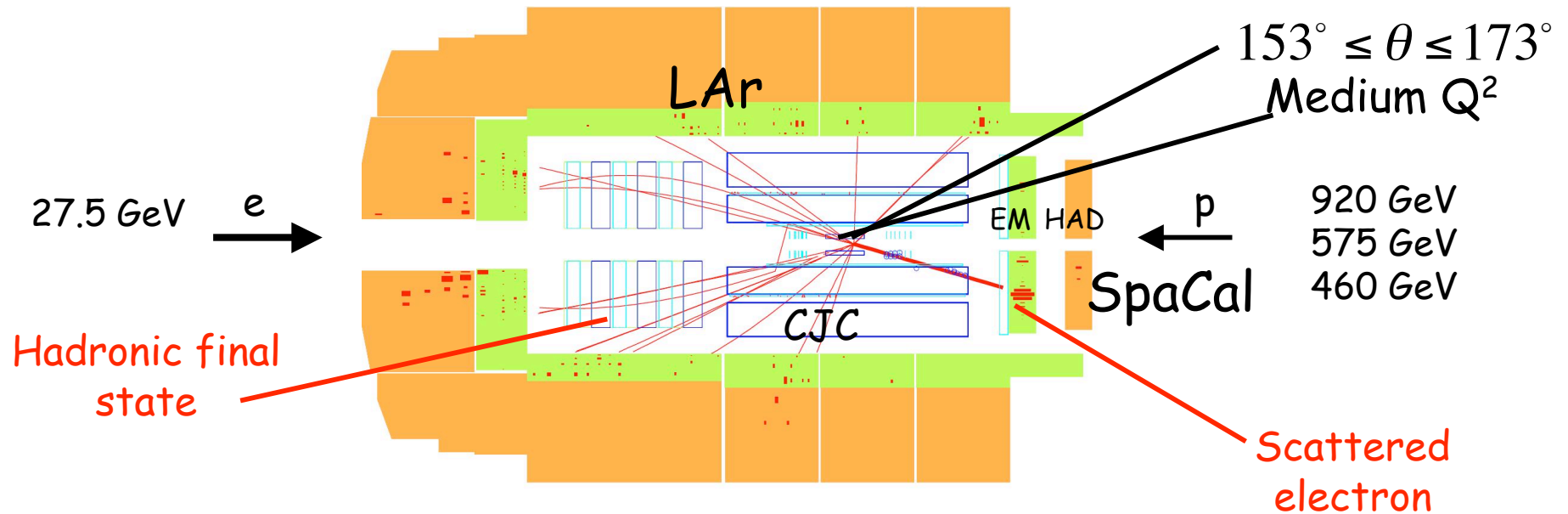
=> The largest spread in  $y^2/Y_+$  is achieved by two means:

- 1) largest possible beam energy difference
- 2) highest possible  $y$  at low beam energies

$E_p$ [GeV]	$\sqrt{s}$ [GeV]	$L$ [ $pb^{-1}$ ]
920	319	21.9
575	252	6.2
460	225	12.4



# Analysis Strategy



□ Measurement performed in a **medium  $Q^2$**  region:

=>As corresponds to the combined acceptance of the SpaCal and Central Jet Chamber (CJC)

=>Trigger events an low energy deposition of 2GeV in SpaCal and track requirement for the energy  $<7\text{GeV}$  (trigger efficiency~99%)

=>H1 has preliminary results (DIS07) at high  $y$  (2003-2006) in the same phase space (experimental issues well known)

# Electron Identification

□ Scattered electron identification by:

=>An energy cluster in the SpaCal fulfilling event selection

=>A cut on the shower shape profile by requiring small transverse extension of the cluster

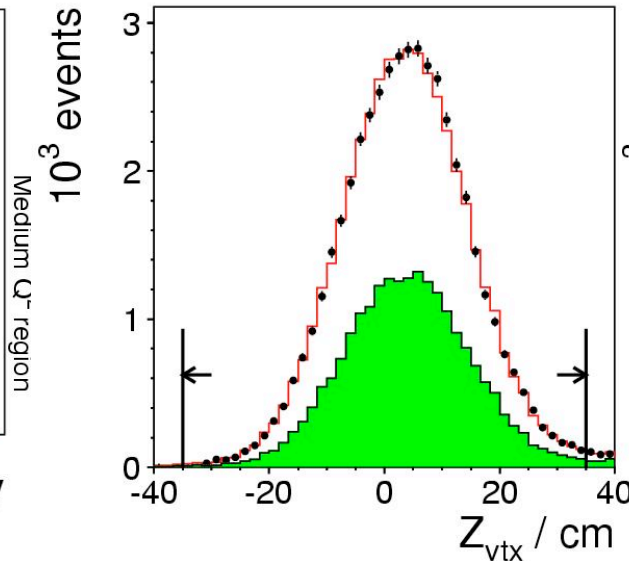
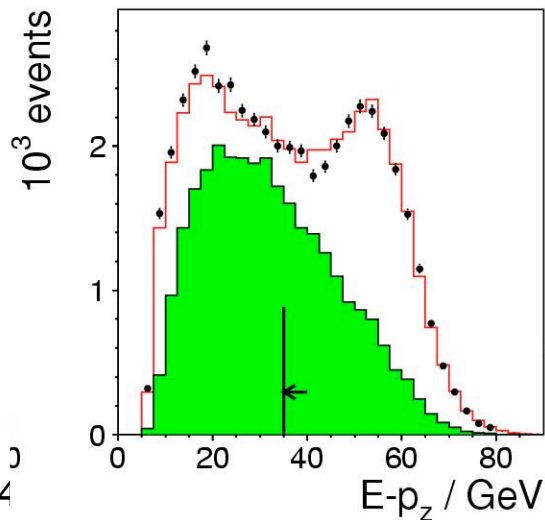
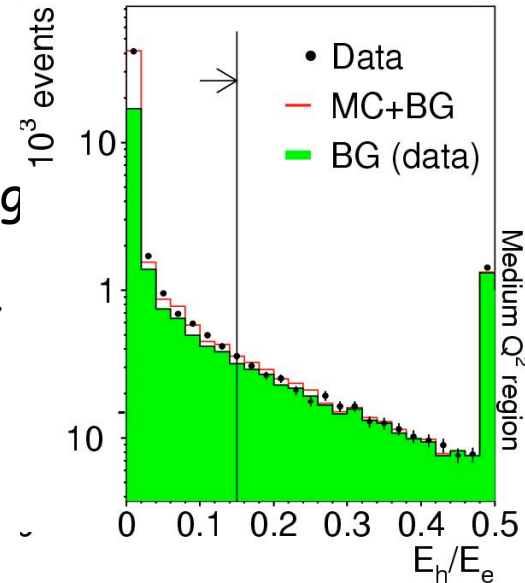
=>A small hadronic energy measured behind the electromagnetic cluster  $E_h/E_e > 15\%$

=>Electric charge of the electron candidate

=> $E-p_z > 35\text{GeV}$  (suppress radiative events)

=>Well reconstructed central vertex

H1 Preliminary



□ Electron identification efficiency between data and MC agrees up to 1%

# Kinematics

□ Measure cross sections at same  $(Q^2, x)$ , different CME => different  $y$  ranges:

Low  $y$

$0.1 < y < 0.38$  for  $E_p = 460\text{GeV}$  and  $E_p = 575\text{GeV}$

$0.1 < y < 0.5$  for  $E_p = 920\text{GeV}$

High  $y$

$0.38 < y < 0.9$  for  $E_p = 460\text{GeV}$  and  $E_p = 575\text{GeV}$

□ High (low) beam energy => low (high)  $y$

$$y = \frac{Q^2}{sx}$$

□ Example of  $y$  bin:

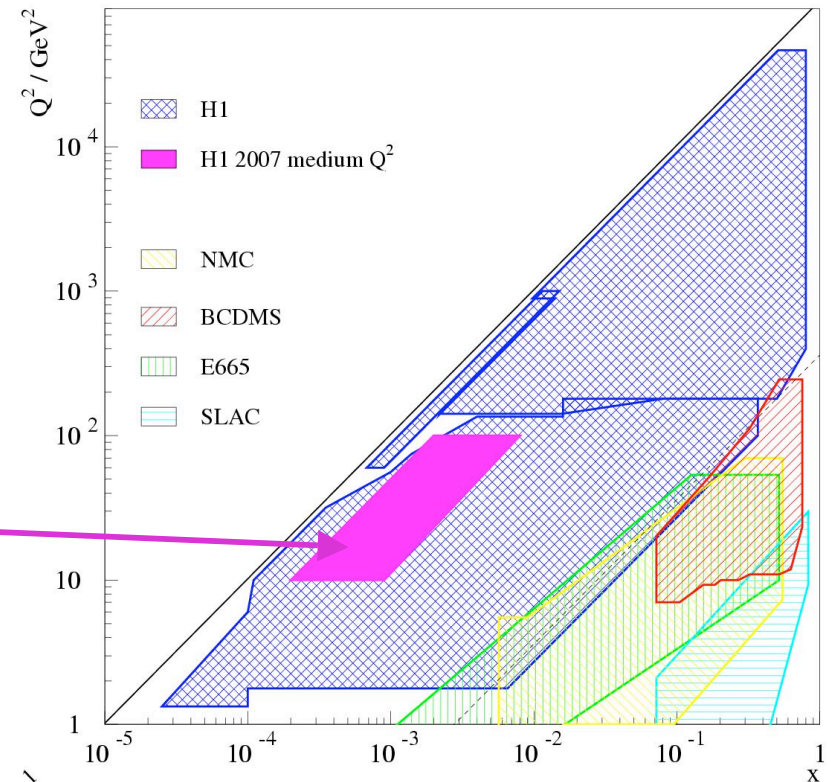
$0.90 - 0.80$   $E_p = 460\text{GeV}$

$0.64 - 0.72$   $E_p = 575\text{GeV}$

$0.45 - 0.40$   $E_p = 920\text{GeV}$

Medium  $Q^2$

$$12 < Q^2 < 90\text{GeV}^2$$





# Event Selection at Low $y$

## □ Low $y$

$0.1 < y < 0.38$  for  $E_p = 460\text{GeV}$  and  $E_p = 575\text{GeV}$

$0.1 < y < 0.5$  for  $E_p = 920\text{GeV}$

## □ Low $y$ data are used:

○ To measure the cross sections for  $E_p = 920\text{GeV}$

○ To control normalization between different proton beam energies:

=> Cross sections agree for different proton beam energies at low  $y$

=> No background contribution

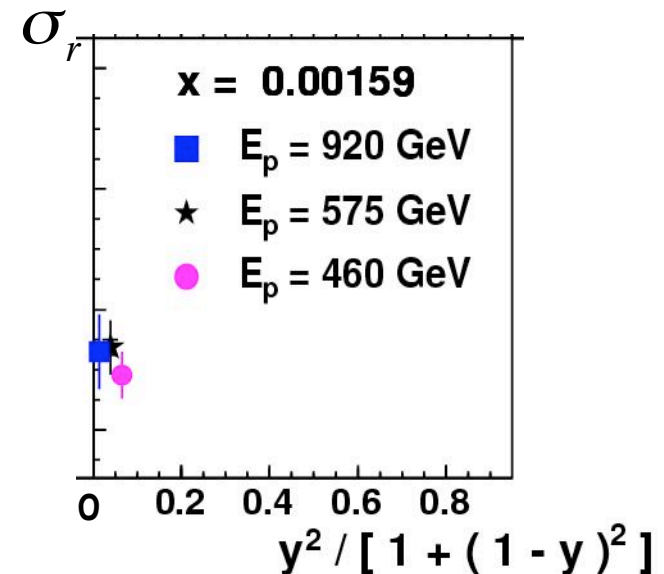
=> No sensitivity to  $F_L$

## □ Background free area (low $y \Rightarrow$ high $E_e$ )

=> Do not require track-cluster matching

=> Lower SpaCal radii  $R > 20\text{cm}$

=> Estimate (small) background using MC



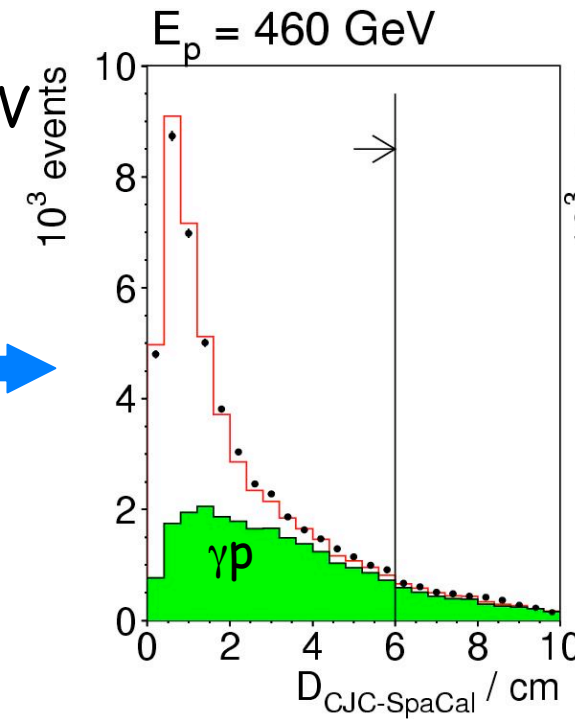
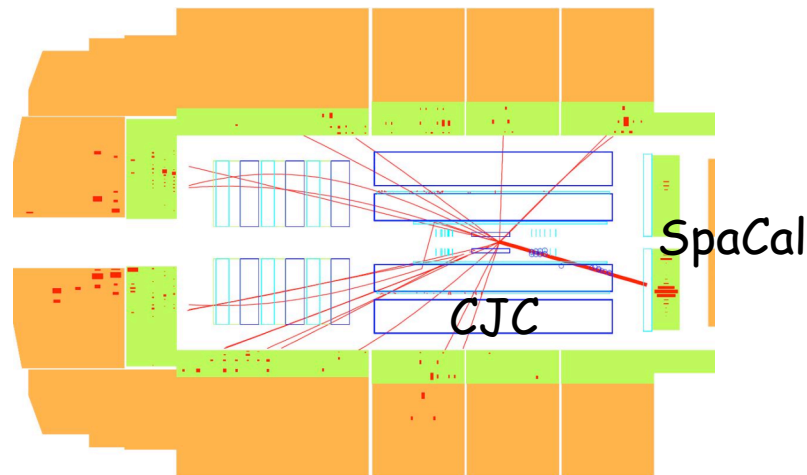
# Event Selection at High $y$

□ High  $y$ :

$0.38 < y < 0.9$  for  $E_p = 460\text{GeV}$  and  $E_p = 575\text{GeV}$

□ High  $\gamma p$  background contribution

=> Cluster in SpaCal matched to the track in CJC

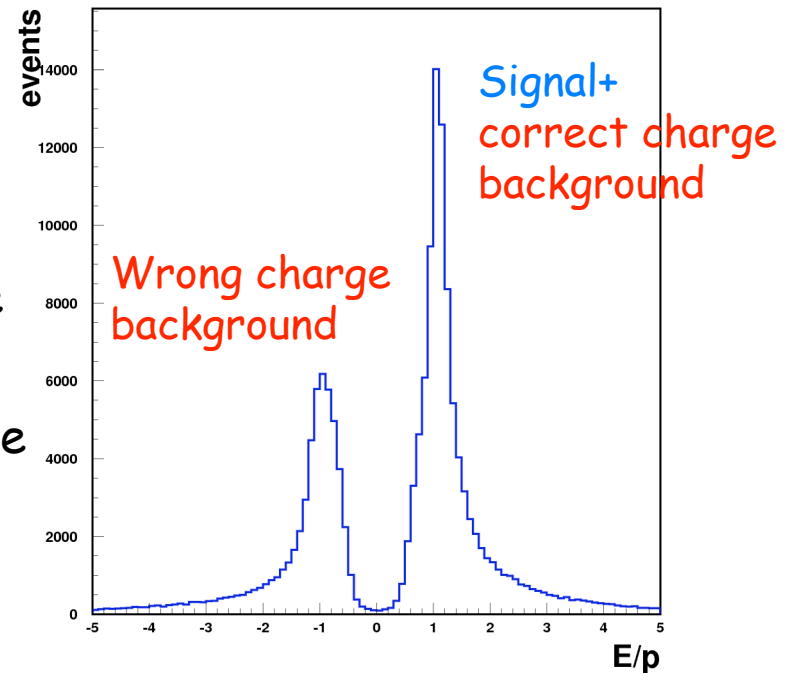
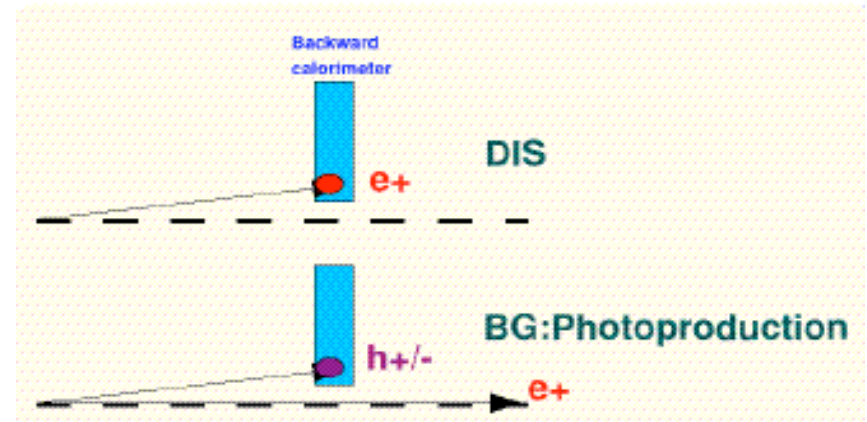


=> Lowest scattered electron energy required  $E_e \geq 3.4\text{GeV}$   
 => Background estimated from data directly

$$y \approx 1 - \frac{E'_e}{E_e}$$

# Background Determination

- At high  $y$  there is a large  $\gamma p$  background
- The background determination using charge of the tracks relies on the charge measurement in the CJC
- The CJC resolution improves at low  $E'_e$
- Terminology:
  - =>Correct charge electron has same charge as the incoming lepton beam charge
  - =>Wrong charge electron has charge opposite to the incoming lepton beam charge
- Good separation between different charges



## Background Determination (cont.)

- A charge asymmetry ( $k$ ):

=>caused by the enhanced energy deposited by  $\bar{p}$  vs  $p$  is observed  
=>the most accurately measured by comparing unlike charge distributions at small energies in electron and positron DIS events using high statistics of 2003-2006 data (prel. DIS07)

$$k = 1.057 \pm 0.005$$

=>determined charge asymmetry is in a very good agreement with tagged  $\gamma p$  data leading to the charge asymmetry

$$k = 1.06 \pm 0.01$$

- Background subtraction is done accounting for the charge asymmetry  $k$ :

$$N_+^{sig} = N_+^+ - kN_+^-$$

Track charge

Lepton beam charge

# Electromagnetic Energy Calibration

- Energy calibration:  
cell-by-cell performed using double angle method (DA)
- The results of DA calibration are checked by comparing distribution in the data and MC for the standard selection in the kinematic peak
- Calibration of low energy clusters is checked using  $J/\psi \rightarrow e^+e^-$  and  $\pi^0 \rightarrow \gamma\gamma$  candidate events with electrons reconstructed in SpaCal
- Electron calibration described at least up to 1%

# Radiative Corrections and Longitudinal Momentum Balance

□ Radiative corrections are estimated using DJANGO MC and cross checked using HECTOR

□ Due to energy and longitudinal momentum conservation for DIS event:

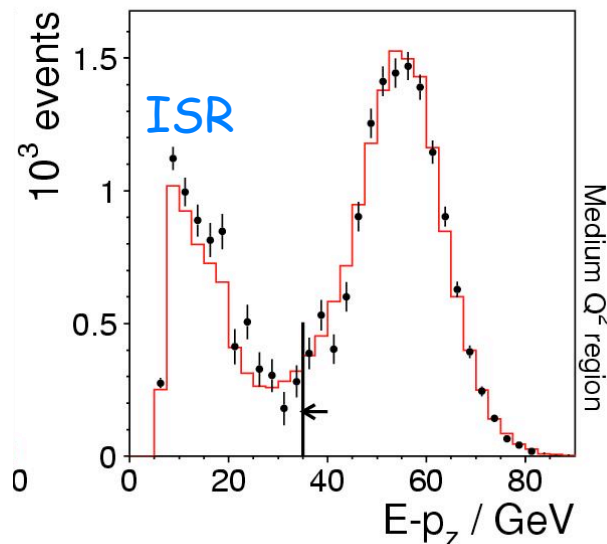
$$(E - p_z)_{meas} = (E - p_z)_{HFS} + (E - p_z)_e \approx 2E_e^{beam}$$

□  $E - p_z$  values much smaller than  $2E_e^{beam}$  are characteristic for:

->  $\gamma p$  event with the electron scattered below the SpaCal acceptance

-> initial state radiation (ISR) with a photon escaping down the beam pipe

after  $\gamma p$  bg subtraction

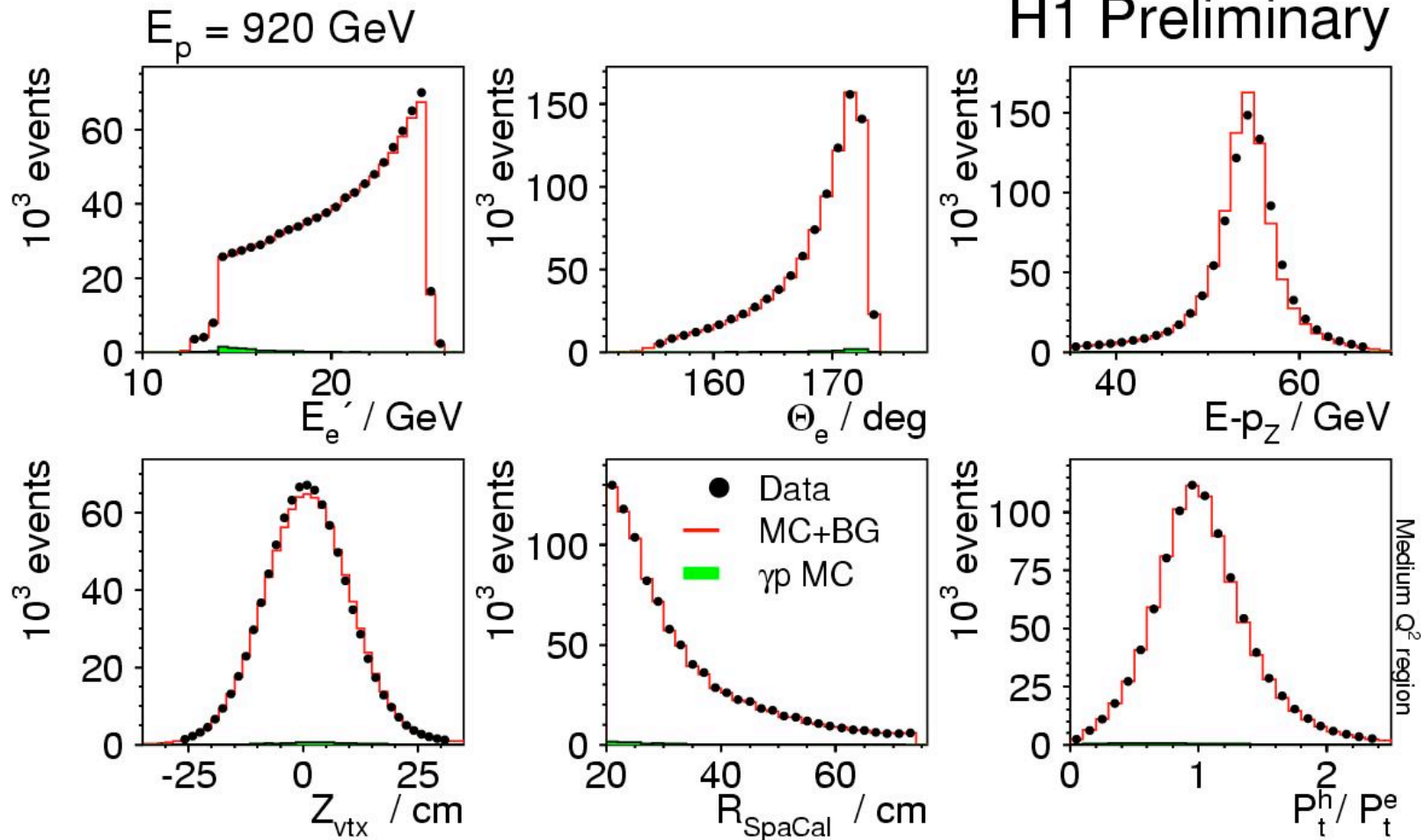


$E - p_z > 35 \text{ GeV}$  effective cut

Uncertainty on radiative corrections is  $< 1\%$

# Control Plots for $E_p=920\text{GeV}$ (low $y$ )

H1 Preliminary



- Low  $y$   $0.1 < y < 0.5$ , BG estimated using PHOJET MC
- Kinematic variables are well described by MC

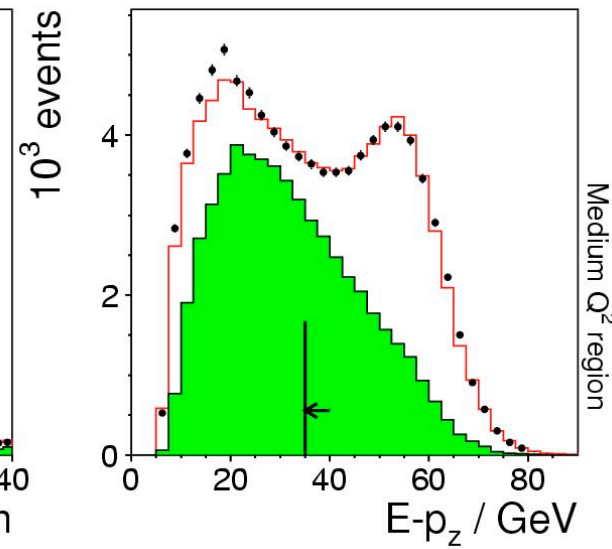
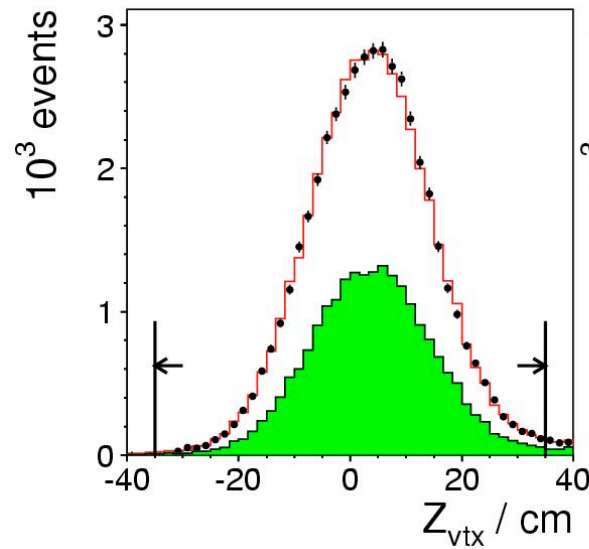
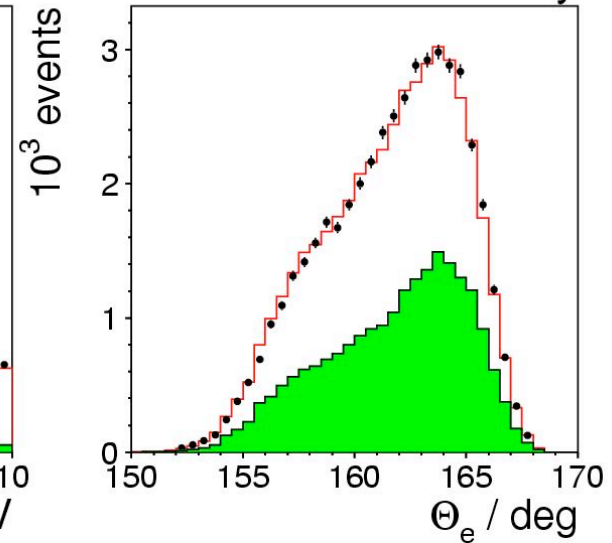
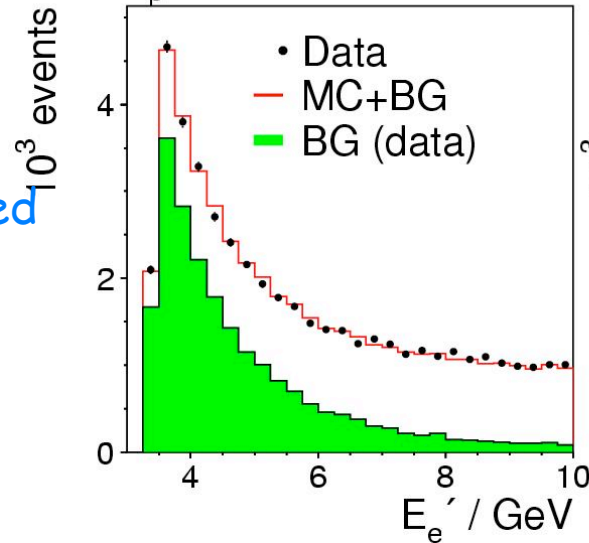
# Control Plots for $E_p=460\text{GeV}$ (high $\gamma$ )

□ Before background subtraction

□ Background determined from data directly

$E_p = 460\text{ GeV}$

H1 Preliminary



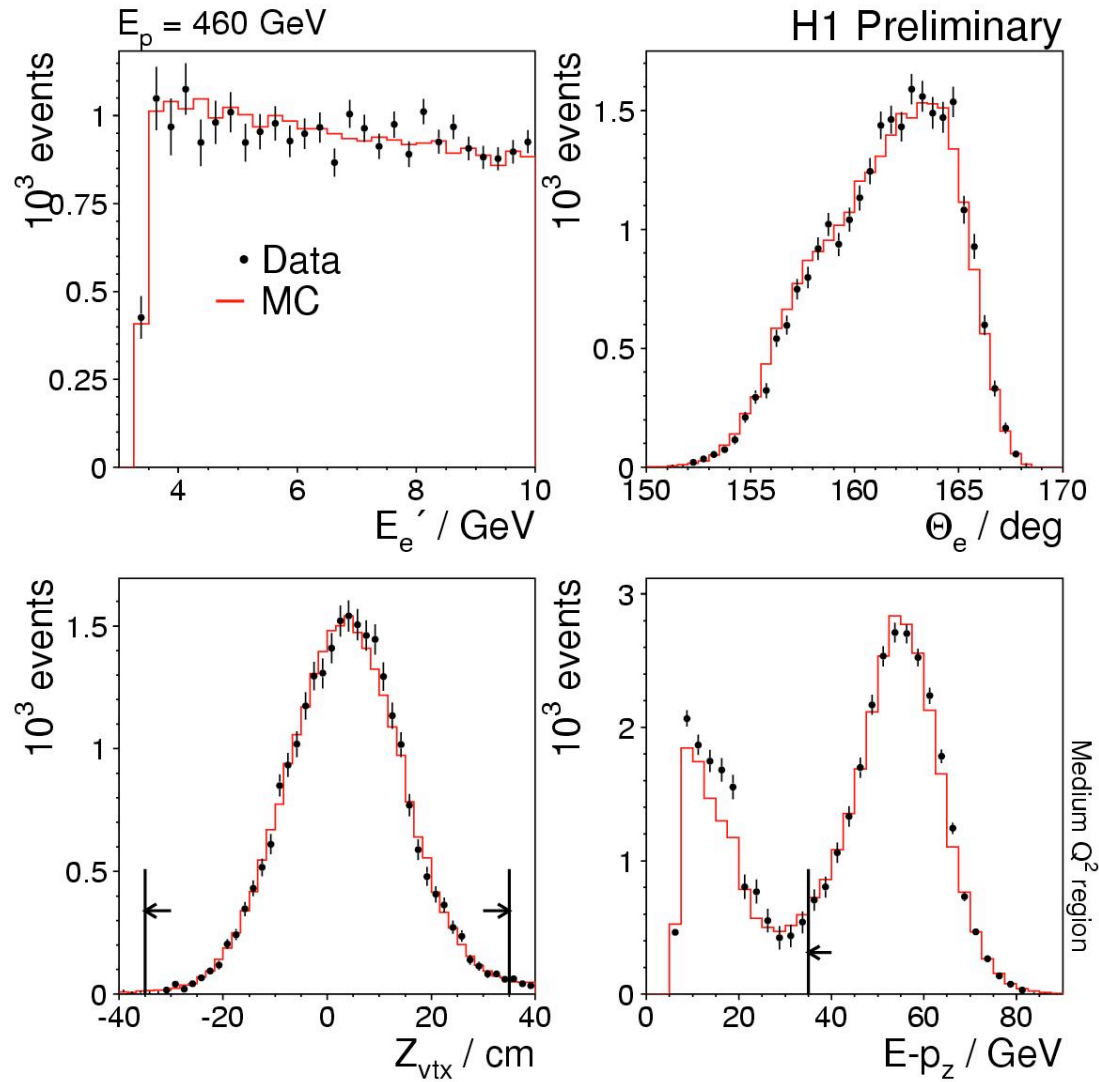
Medium  $Q^2$  region



# Control Plots for $E_p=460\text{GeV}$ (high $y$ )

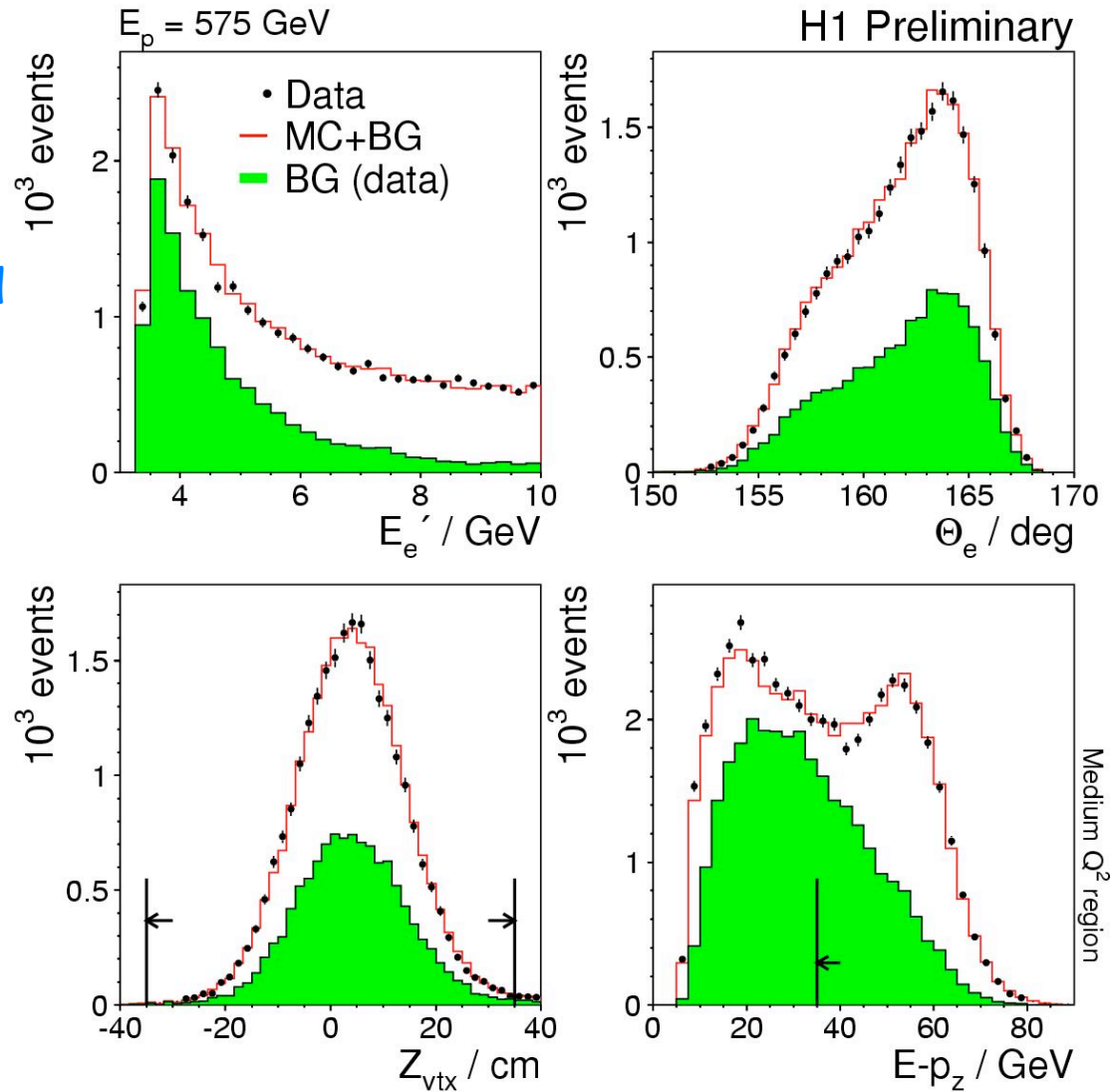
□ After background subtraction taking into account asymmetry factor

□ Good description of the data by MC



# Control Plots for $E_p=575\text{GeV}$ (high $y$ )

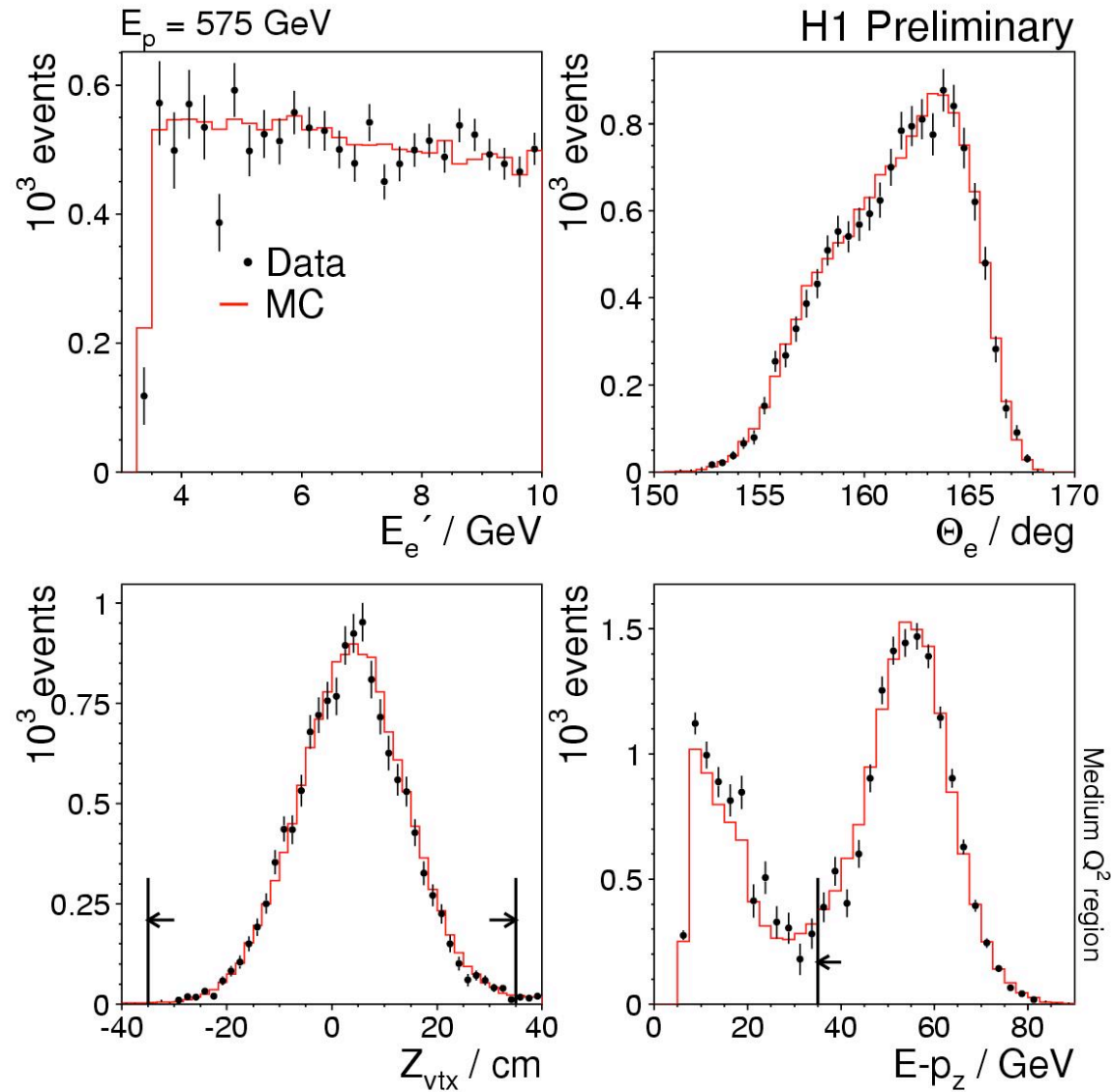
- Before background subtraction
- Background determined from data directly



# Control Plots for $E_p=575\text{GeV}$ (high $y$ )

□ After background subtraction taking into account asymmetry factor

□ Good description of the data by MC



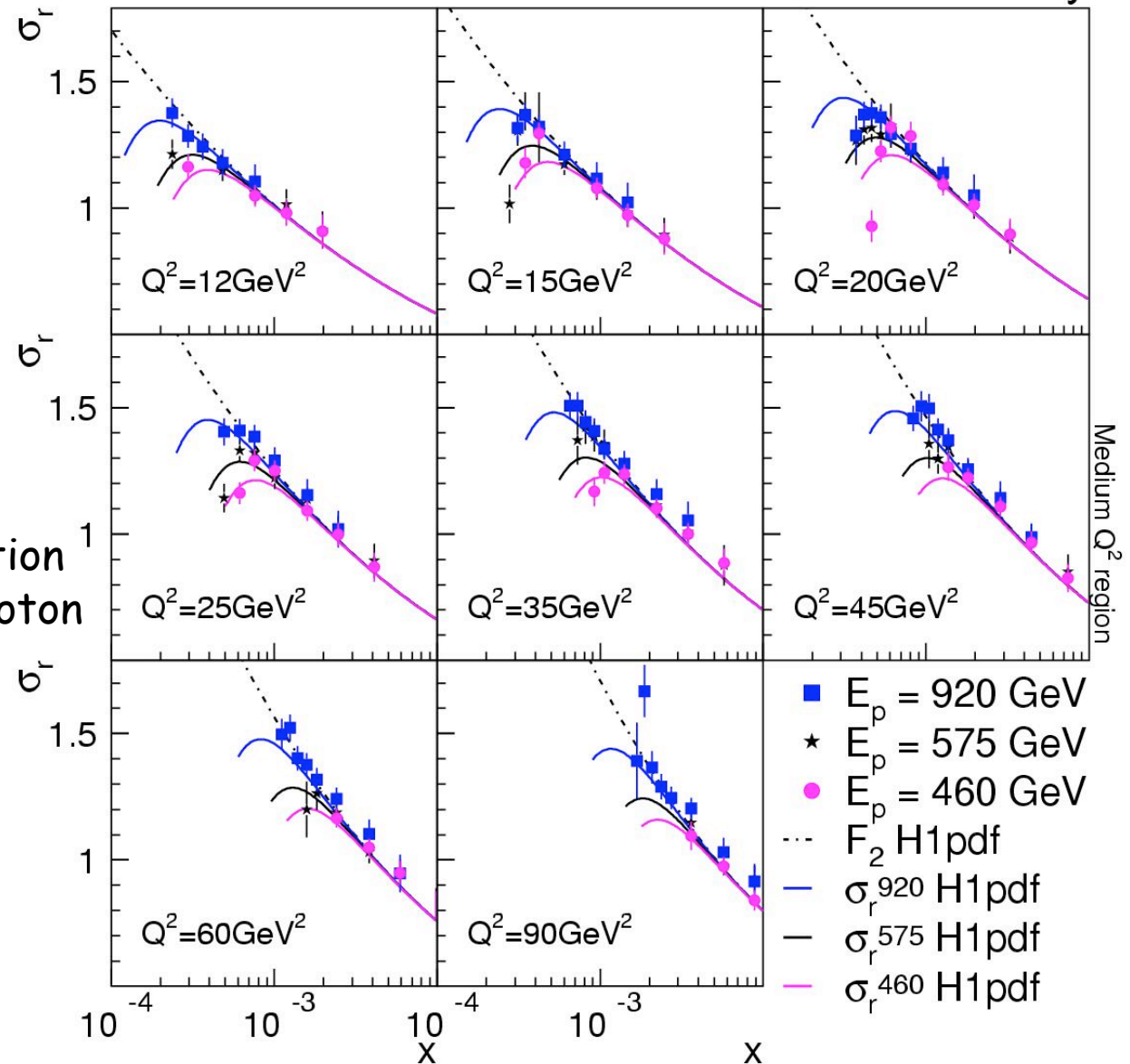
# Double differential cross sections

H1 Preliminary

Same  $Q^2$  and  $x$   
different  $y$  ( $E_p$ )

Turn over in the cross  
section at low  $x$  due to  
 $F_L$  contribution

Use relative normalization  
at low  $y$  for different proton  
beam energies



# Extraction of $F_L$

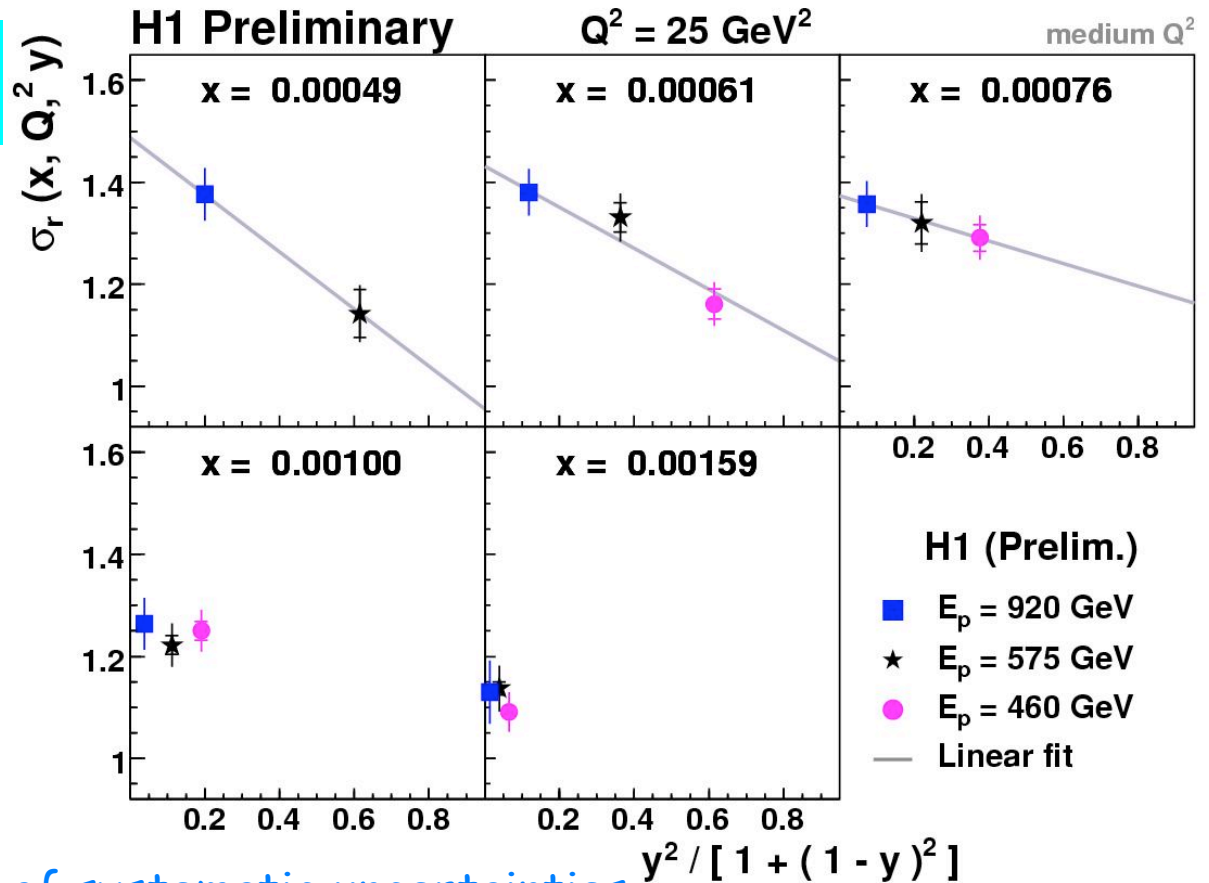
$$\sigma_r(x, y, Q^2) = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

Linear fit to points of different CME

- Intercept at y axis  $\Rightarrow F_2$
- Slope  $\Rightarrow F_L$

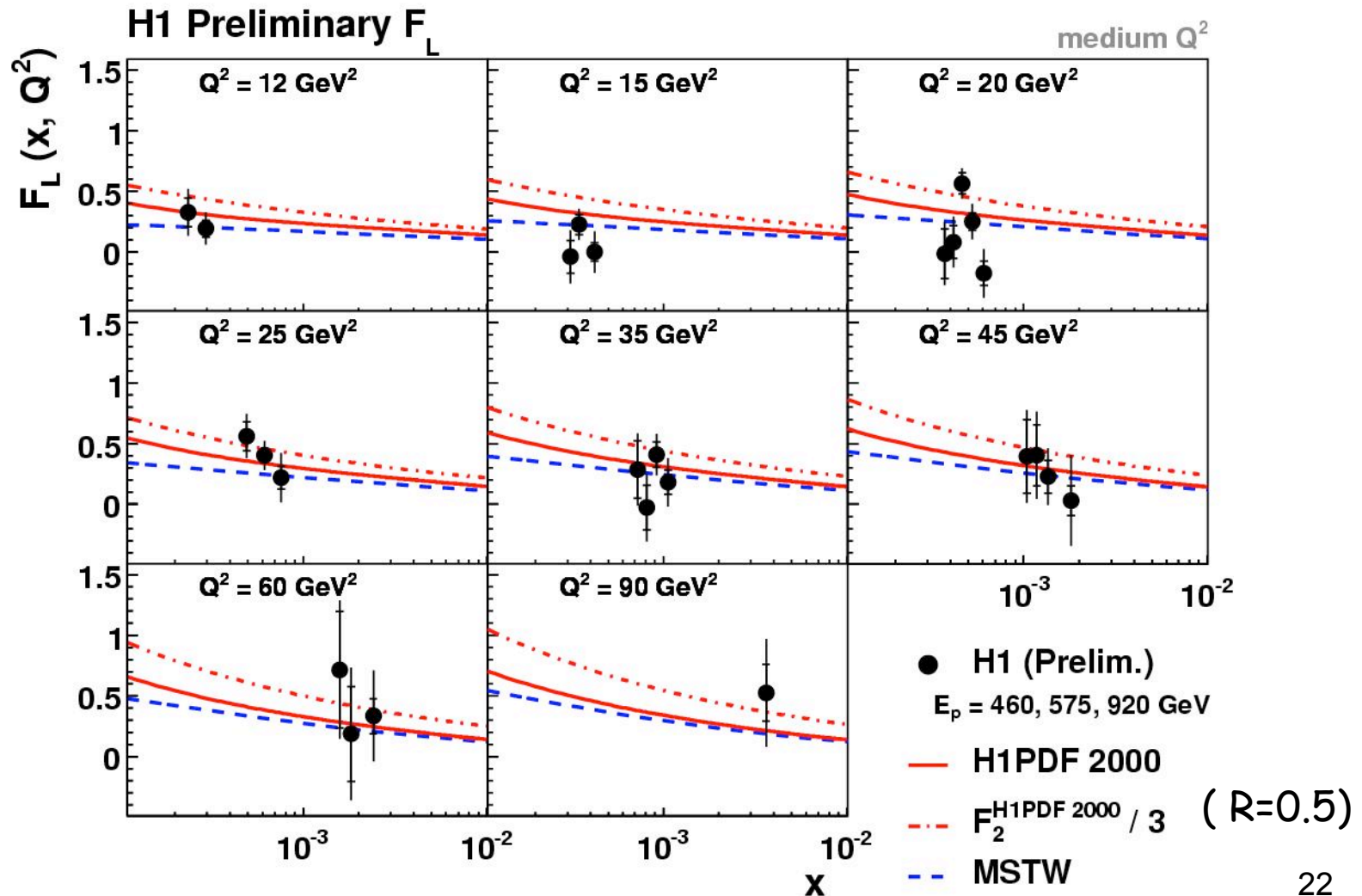
Relative normalization derived from low y gives 1% uncertainty

$E_p = 575 \text{ GeV} \Rightarrow$  cross check of systematic uncertainties  $\Rightarrow$  additional x bins



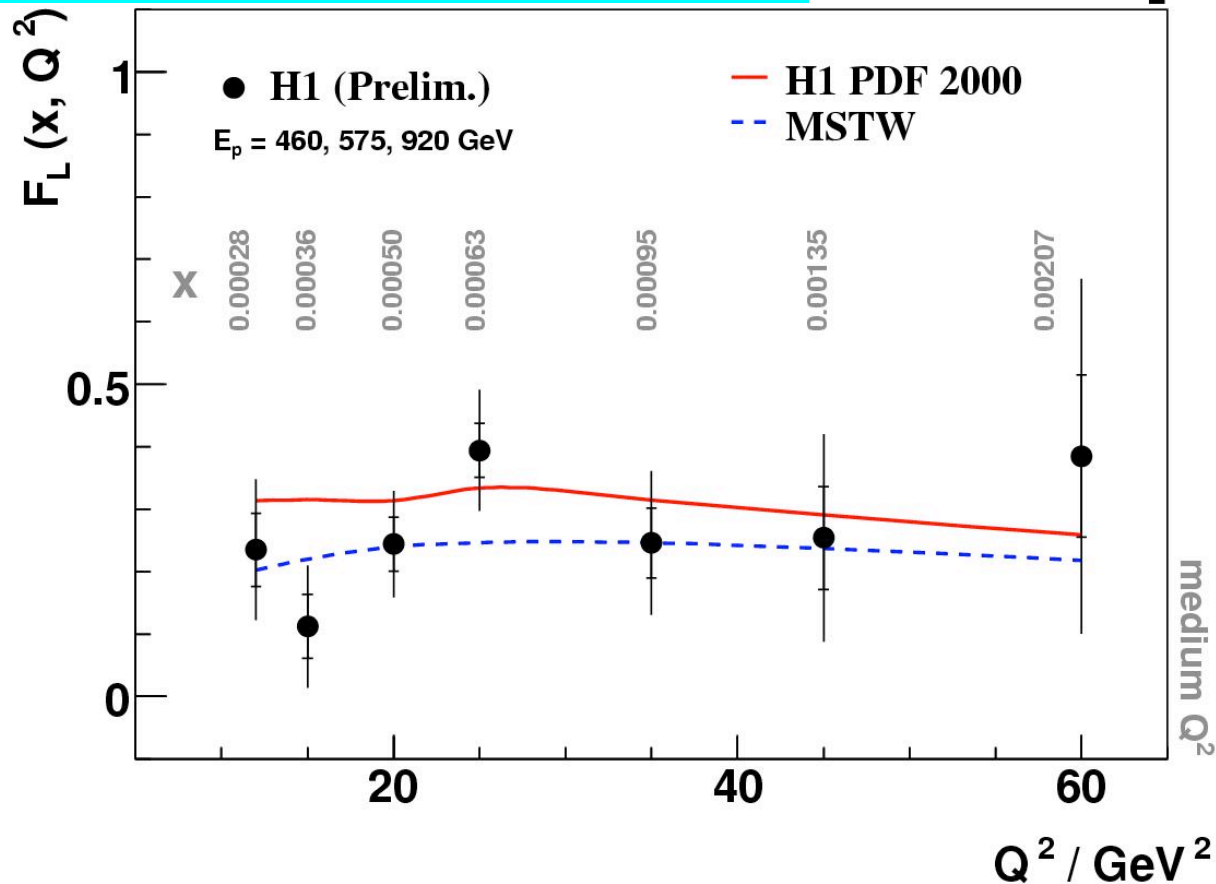
# Longitudinal Structure Function $F_L$

First direct measurement of the  $F_L$  at low  $x$



# $F_L$ Averaged in $x$ Bins

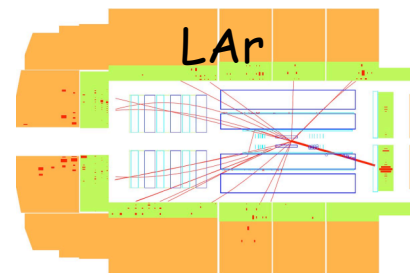
$F_L(x, Q^2)$  averaged in  $x$  bins for each  $Q^2$  Preliminary  $F_L$



□  $F_L$  predicted by higher order QCD fits using gluon that was derived from scaling violations of  $F_2$  is consistent with the measurement.

# Summary

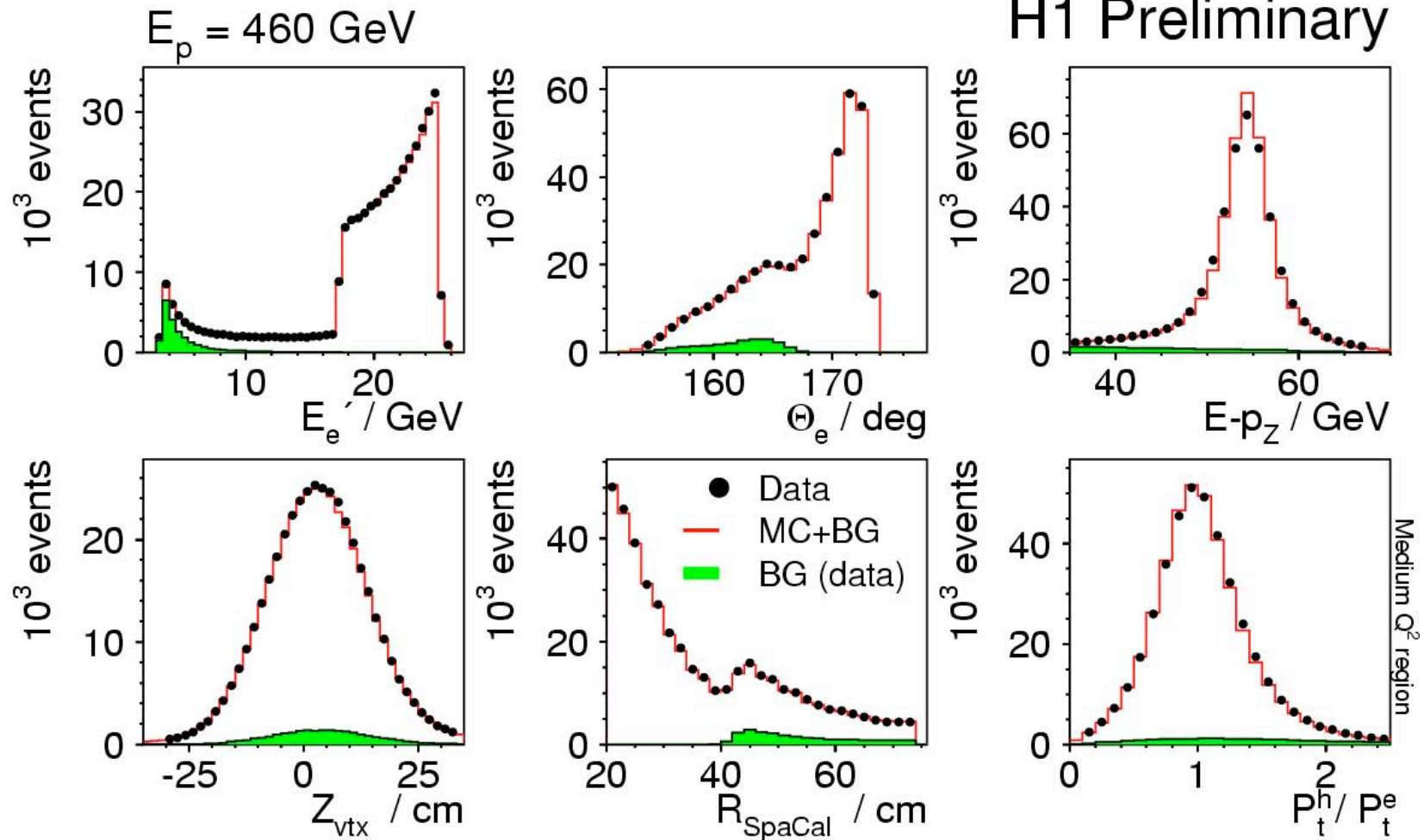
- First preliminary measurement of the longitudinal proton structure function  $F_L(x, Q^2)$  at low  $x$  at HERA by H1
  - > based on data taken in  $e+p$  collisions in 2007 at different CME
  - > performed in a range of medium  $Q^2$  (12-90 GeV<sup>2</sup>)
- Measured  $F_L$  is in agreement with higher order QCD expectations, based on HERA low  $x$  measurements of the scaling violations of  $F_2$
- Extension of the measurement:
  - => to lower  $Q^2$  is expected (using backward silicon tracker)
  - => to higher  $Q^2$  has been performed
  - (see talk by V. Shekelian )





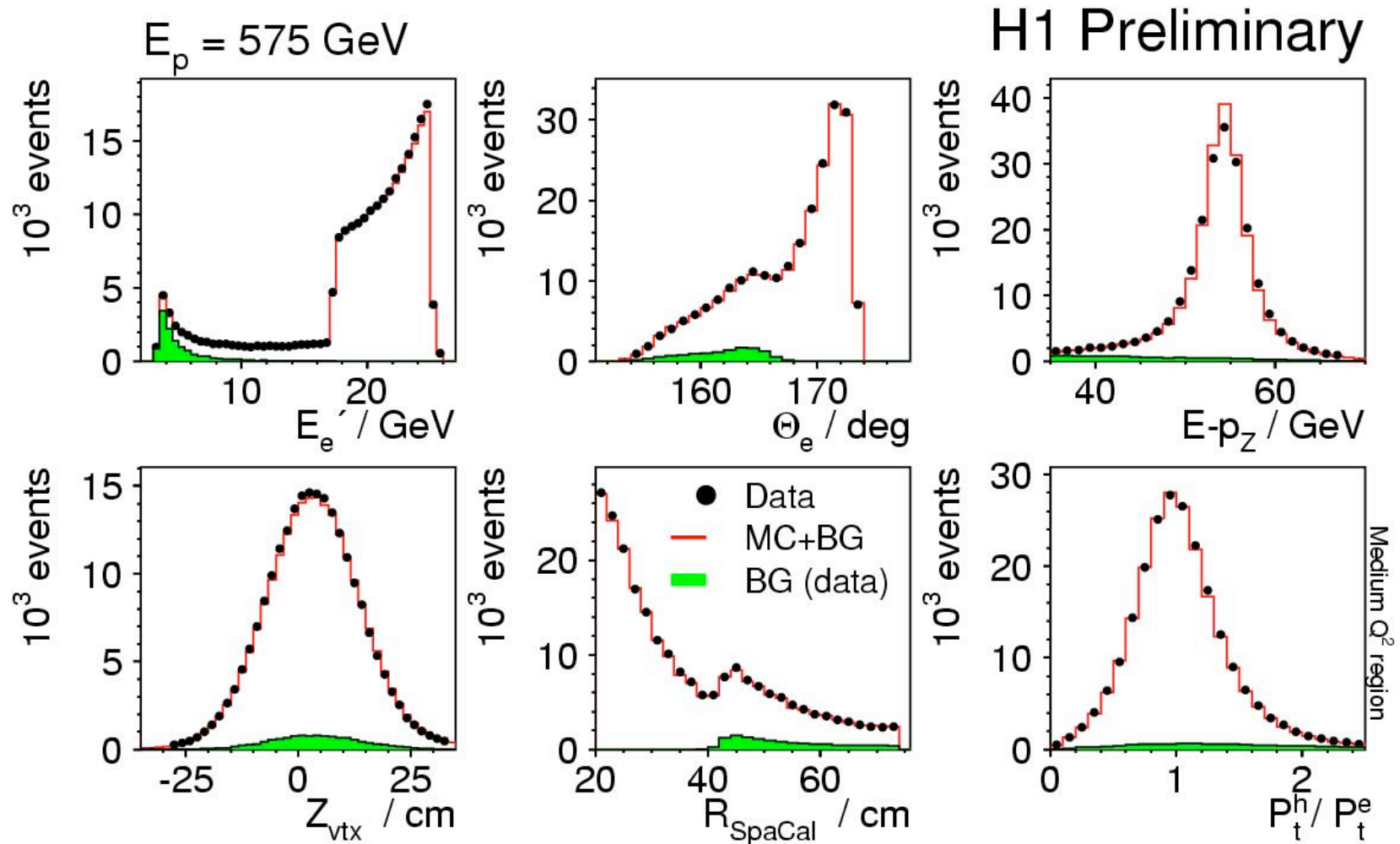
# Backup slides

# Control Plots for $E_p=460\text{GeV}$ (low $y$ & high $y$ )



- High and low  $y$  ( $0.1 < y < 0.9$ )
- Good description of the data by MC

# Control Plots for $E_p=575\text{GeV}$ (low $y$ & high $y$ )



□ High and low  $y$  ( $0.1 < y < 0.9$ )

□ Good description of the data by MC