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

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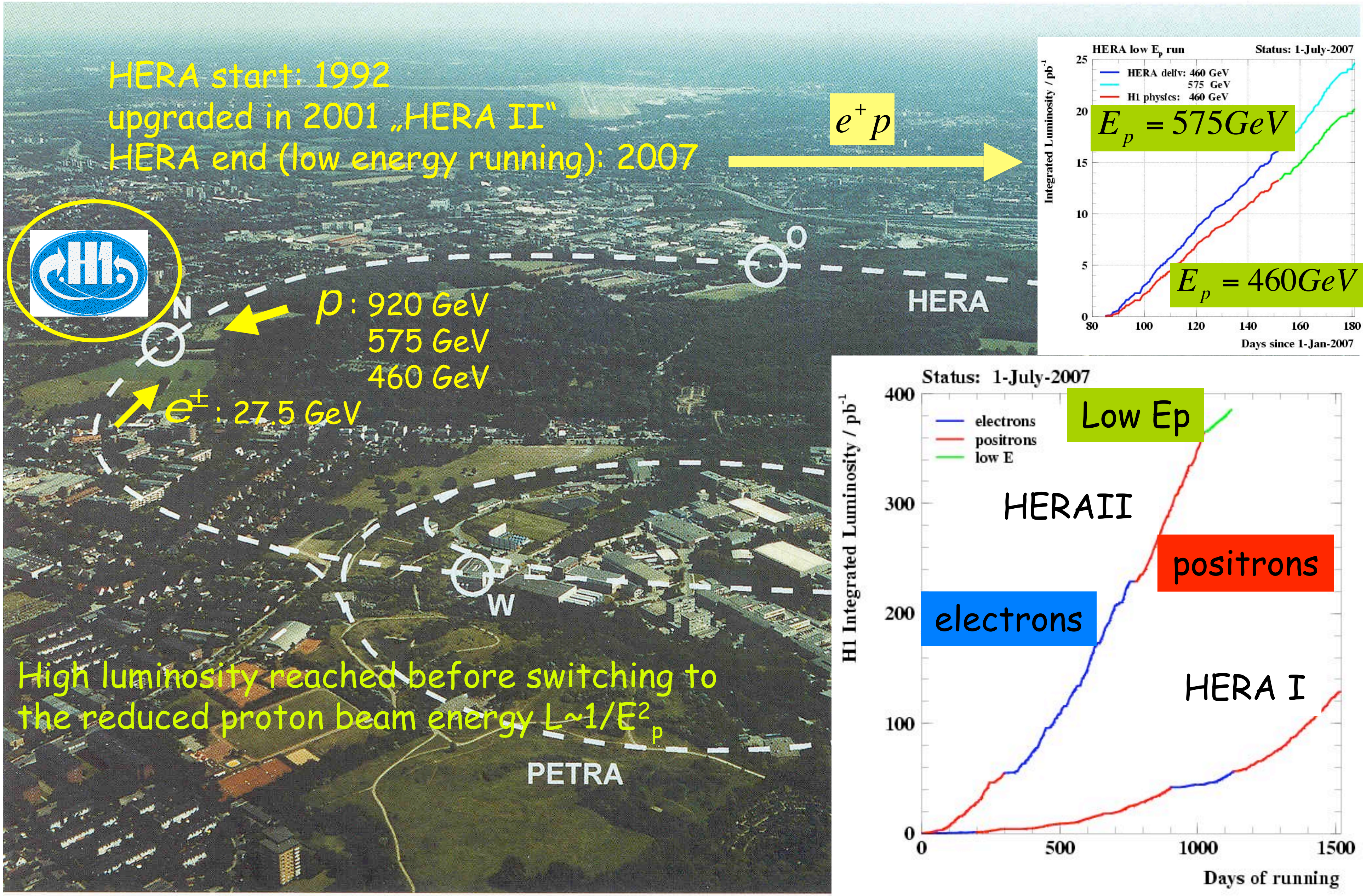
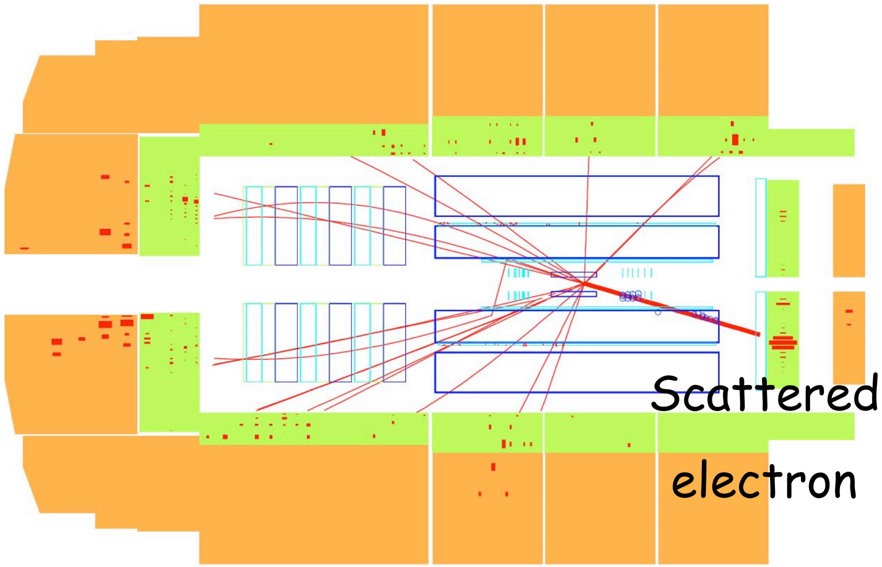
Outline

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

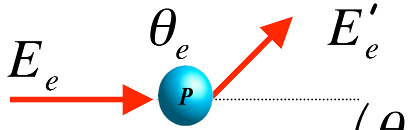
HERA – Unique Electron-Proton Collider
(Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany)



Deep Inelastic Scattering (DIS) in the H1 Detector



Determination of kinematics using electron method



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

$$y = 1 - \frac{E_e'}{E_e}\sin^2\left(\frac{\theta_e}{2}\right)$$ Inealsticity

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

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

$Y_+ = 1 + (1-y)^2$

xF_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,Q2) 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

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

the slope=> F_L

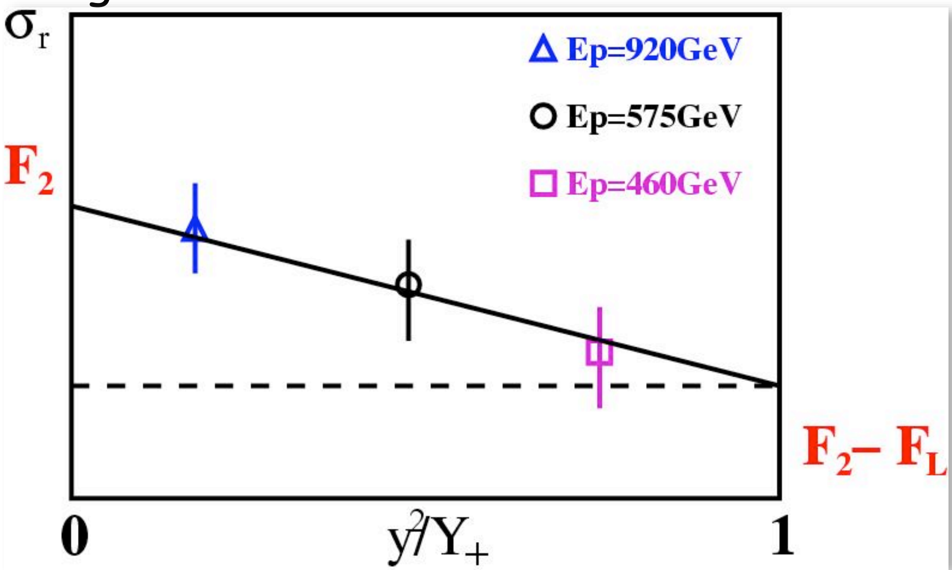
the intercept with y axis=> F_2

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

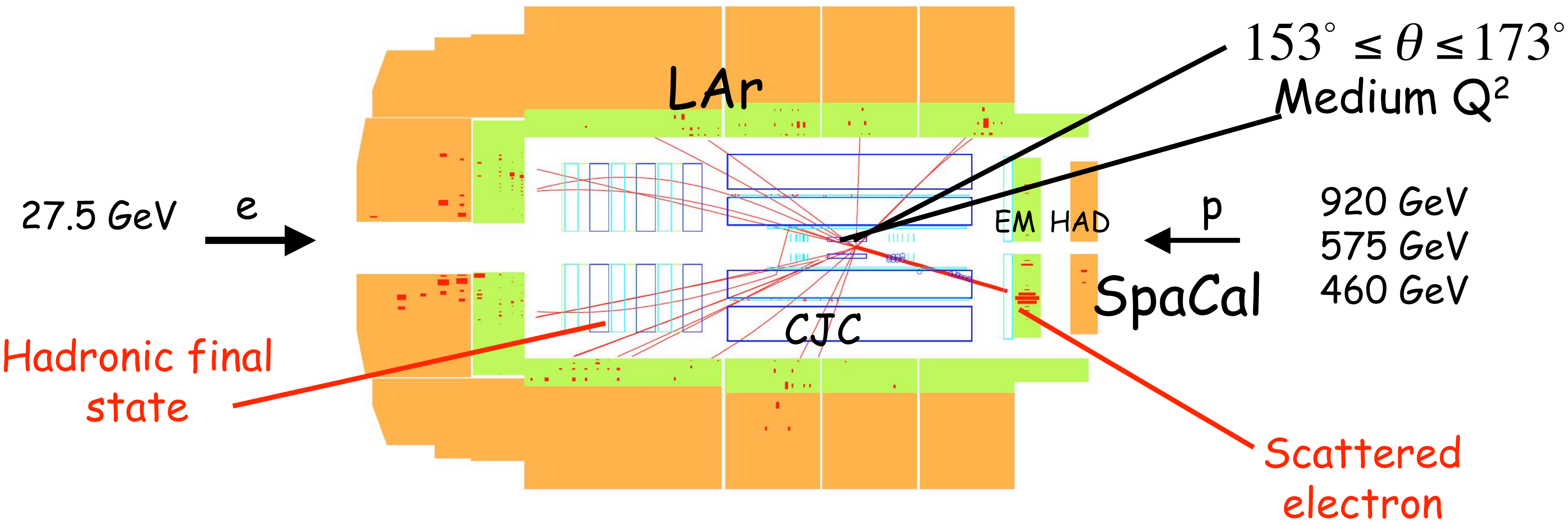
1) largest possible beam energy difference

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:

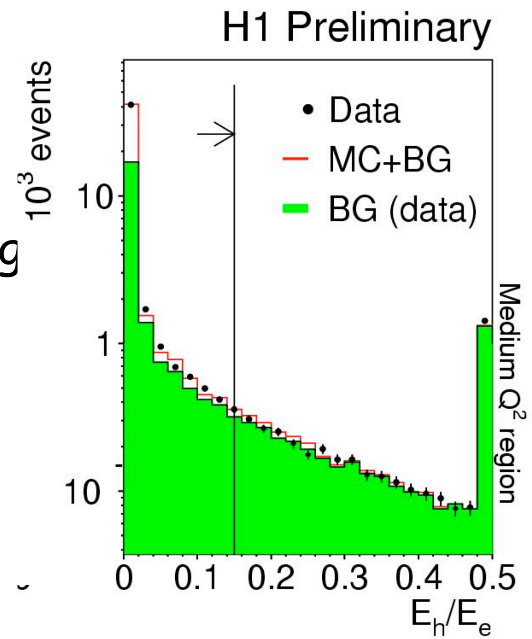
 =>As corresponds to the combined acceptance of the SpaCal and Central Jet Chamber (CJC)

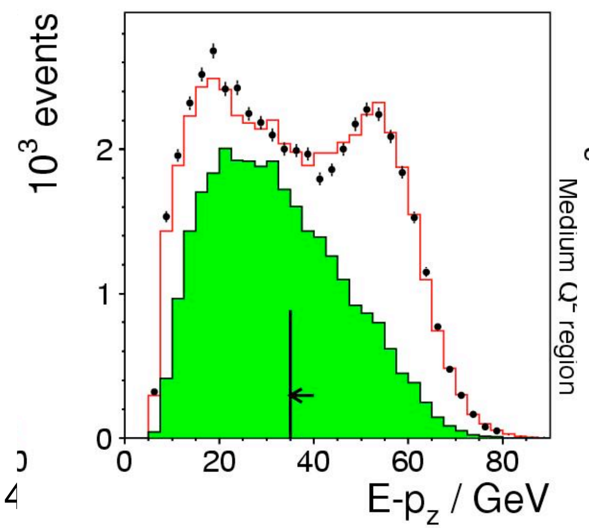
 =>Trigger events an low energy deposition of 2GeV in SpaCal and track requirement for the energy <7GeV (trigger efficiency~99%)

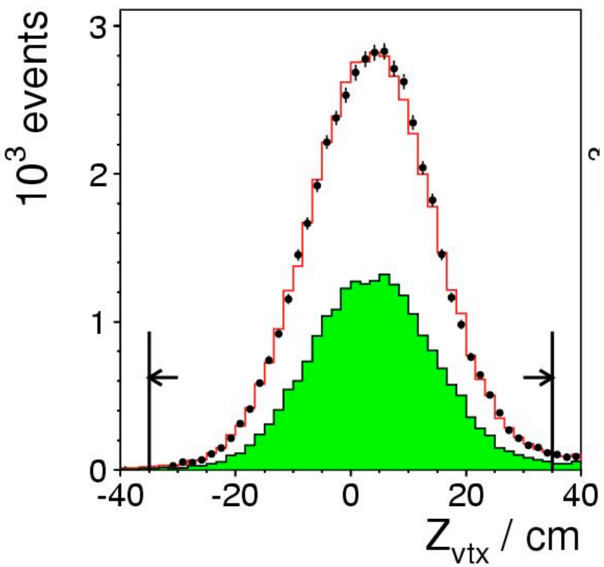
 =>H1 has preliminary results (DIS07) at high y (2003-2006) in the same phase space (experimental issues well known)

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
  - =>$E-p_z$>35GeV (suppress radiative events)
  - =>Well reconstructed central vertex







- 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 $E_p = 460GeV$ and $E_p = 575GeV$

  $0.1 < y < 0.5$ for $E_p = 920GeV$

  High y

  $0.38 < y < 0.9$ for $E_p = 460GeV$ and $E_p = 575GeV$

- High (low) beam energy=>low (high) y

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

- Example of y bin:

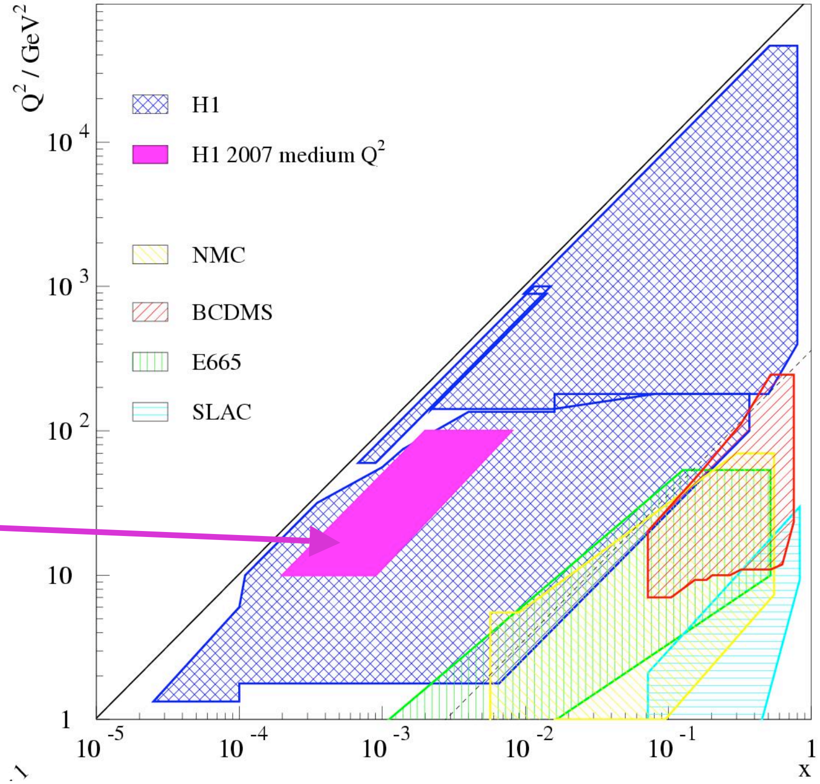
  $0.90 - 0.80 \; E_p = 460GeV$

  $0.64 - 0.72 \; E_p = 575GeV$

  $0.45 - 0.40 \; E_p = 920GeV$

Medium Q2

$12 < Q^2 < 90GeV^2$



Event Selection at Low y

❑Low y

$$0.1 < y < 0.38 \text{ for } E_p = 460GeV \text{ and } E_p = 575GeV$$
$$0.1 < y < 0.5 \text{ for } E_p = 920GeV$$

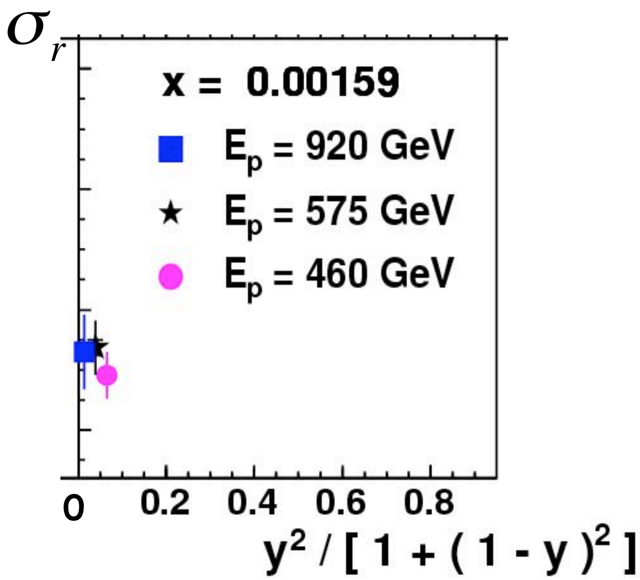
❑Low y data are used:

- To measure the cross sections for E_p=920GeV
- 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=>high Ee)

=>Do not require track-cluster matching

=>Lower SpaCal radii R>20cm

=>Estimate (small) background using MC

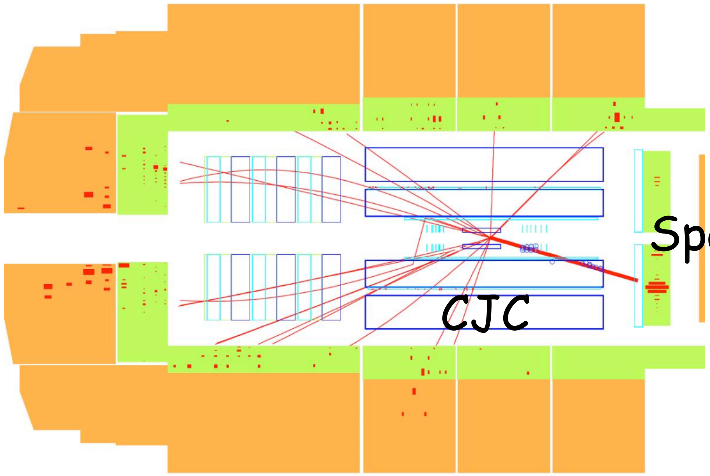
Event Selection at High y

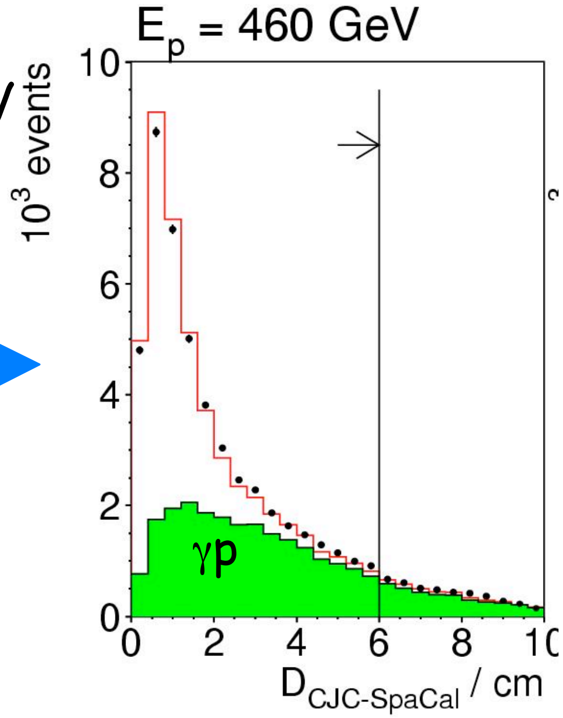
- High y:

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

- High γp background contribution

=>Cluster in SpaCal matched to the track in CJC





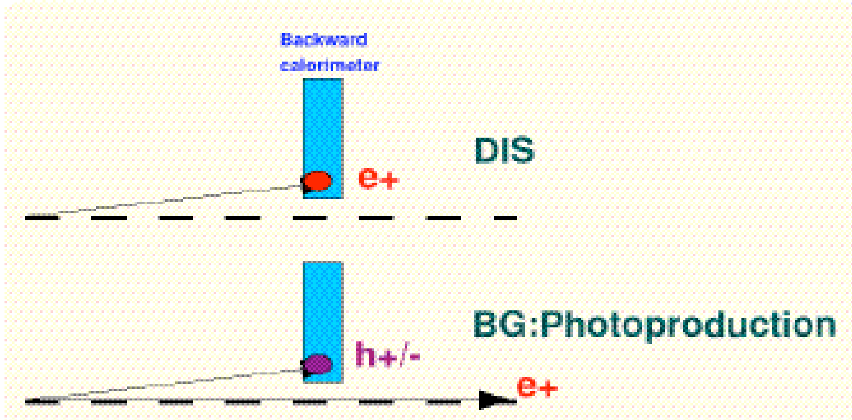
=>Lowest scattered electron energy required $E_e \geq 3.4\text{GeV}$

=>Background estimated from data directly

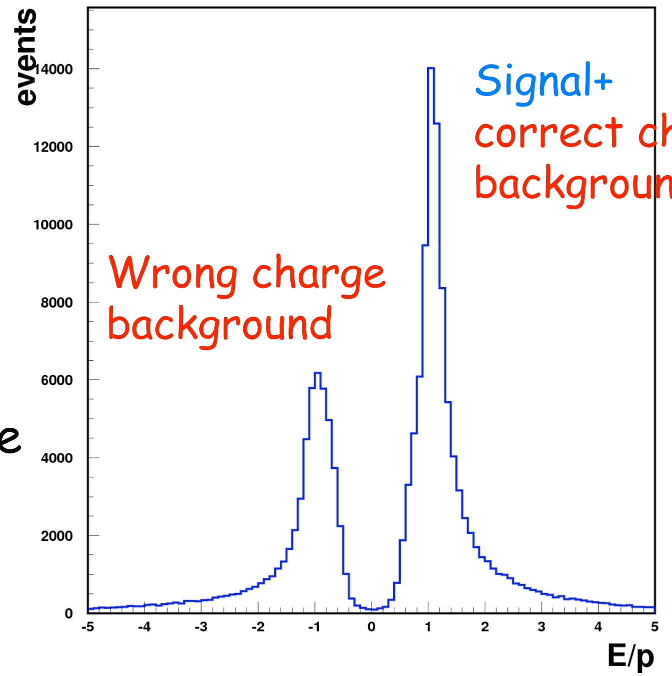
$$y \approx 1 - \frac{E'_e}{E_e}$$

Background Determination

- At high y there is a large γp 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 depositied 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 γp 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:

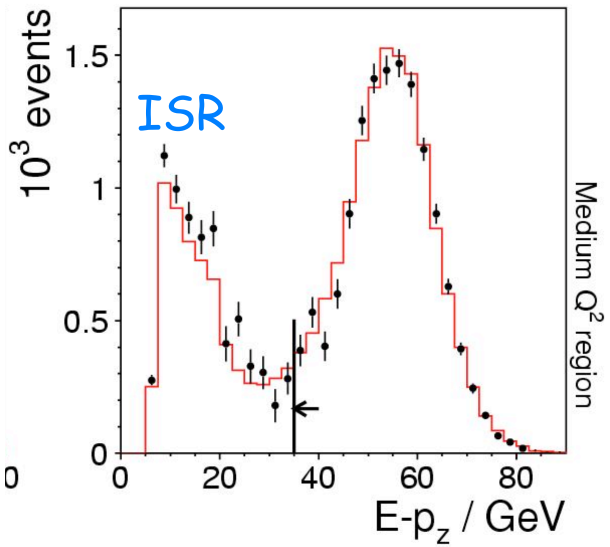
$$(E-p_z)_{meas} = (E-p_z)_{HFS} + (E-p_z)_e \approx 2E_e^{beam}$$

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

->γp event with the electron scattered below the SpaCal acceptance

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

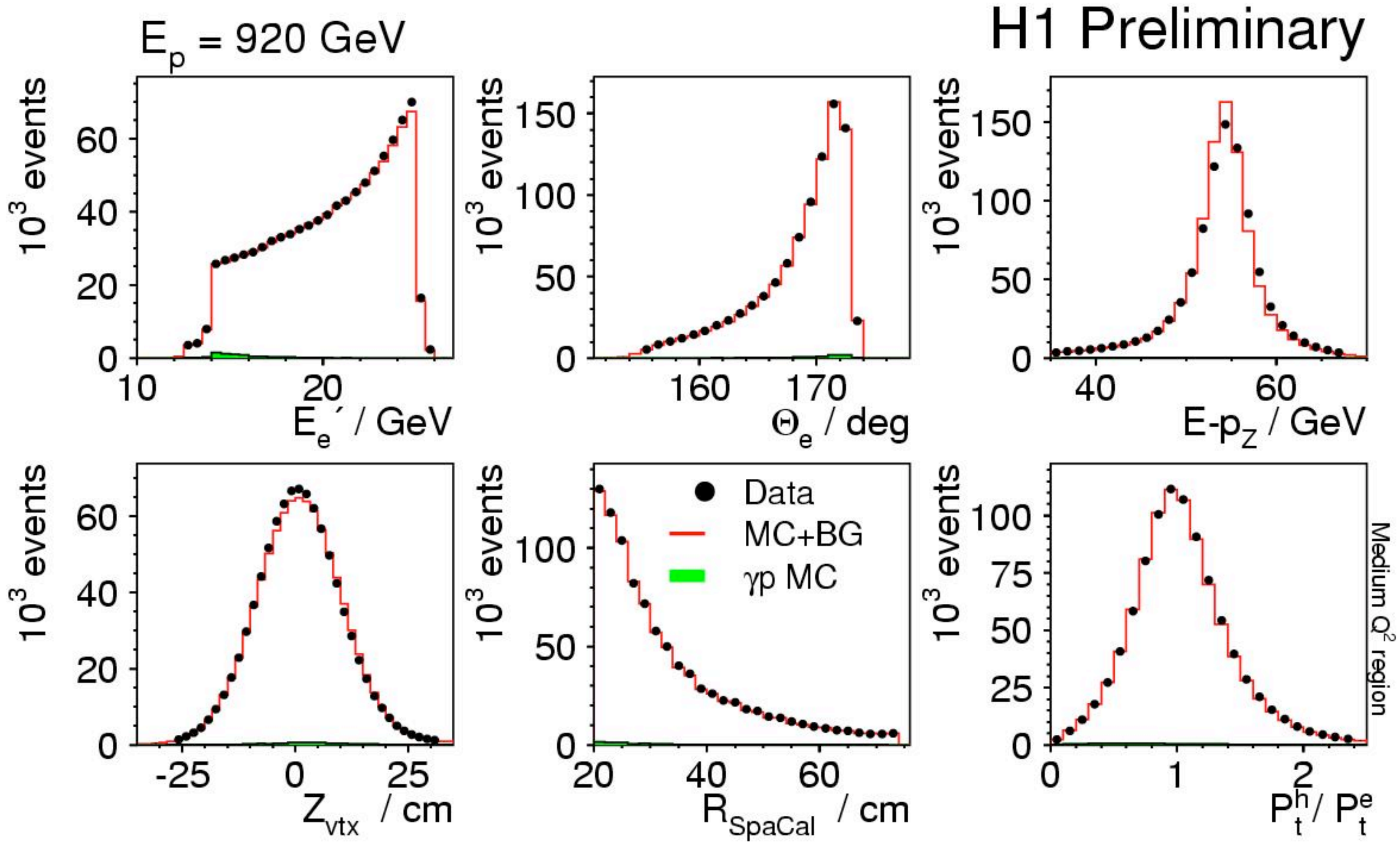
after γp bg subtraction



$E-p_z$>35GeV effective cut

Uncertainty on radiative corrections is <1%

Control Plots for E_p=920GeV (low y)

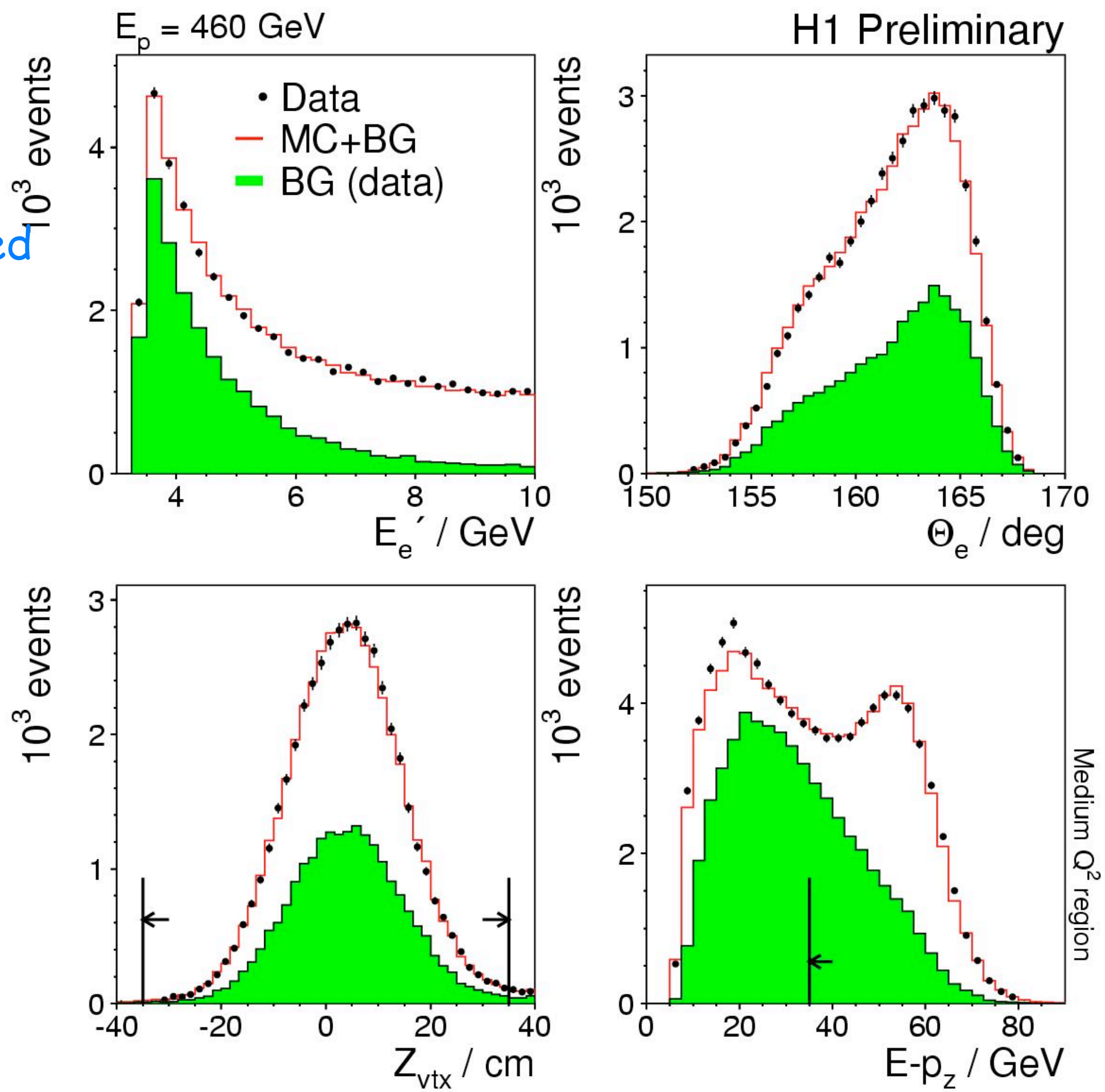


- Low y 0.1<y<0.5, BG estimated using PHOJET MC
- Kinematic variables are well described by MC

Control Plots for E_p=460GeV (high y)

- Before background subtraction

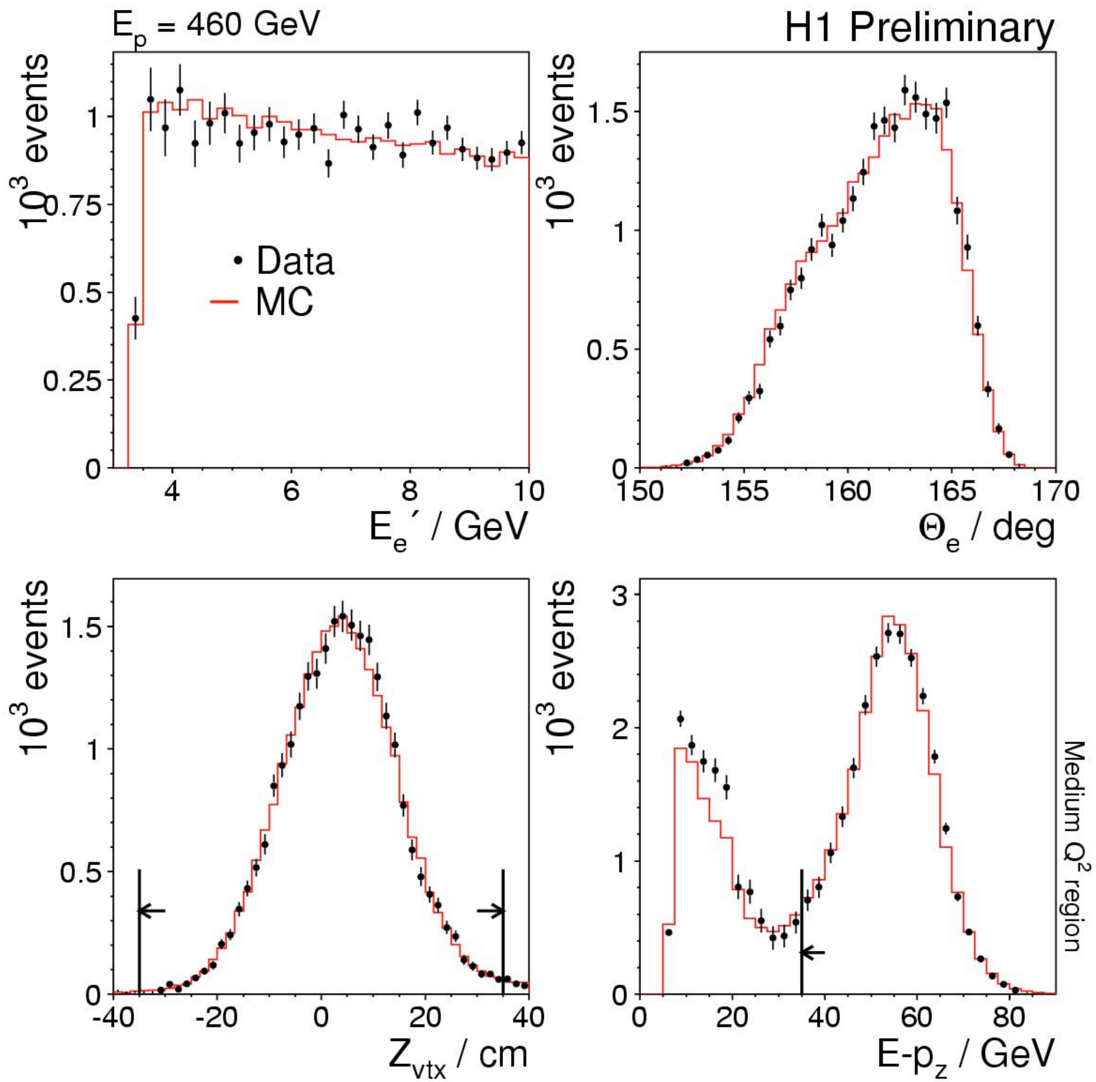
- Background determined from data directly



Control Plots for E_p=460GeV (high y)

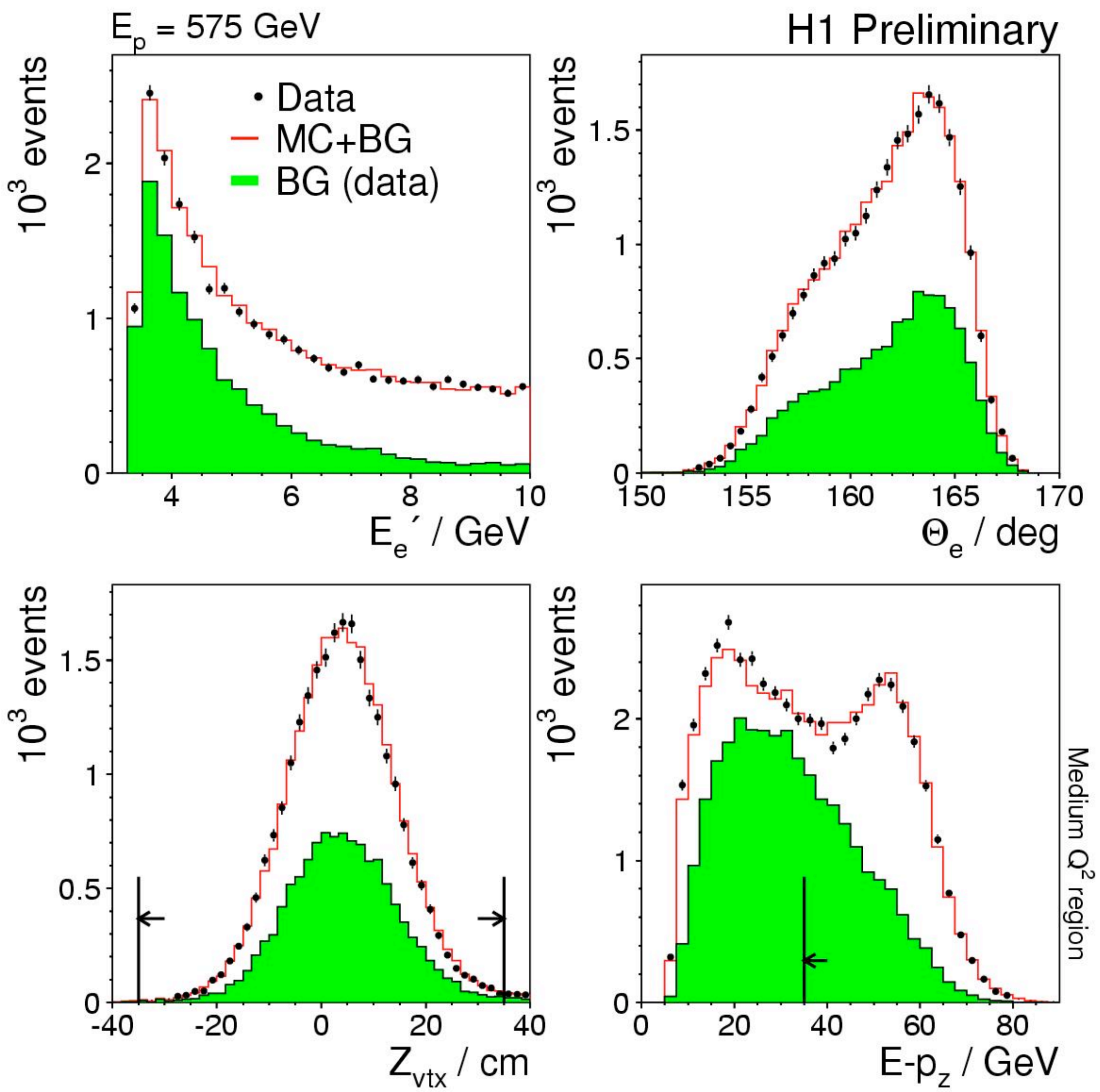
- After background subtraction taking into account asymmetry fator

- Good description of the data by MC



Control Plots for E_p=575GeV (high y)

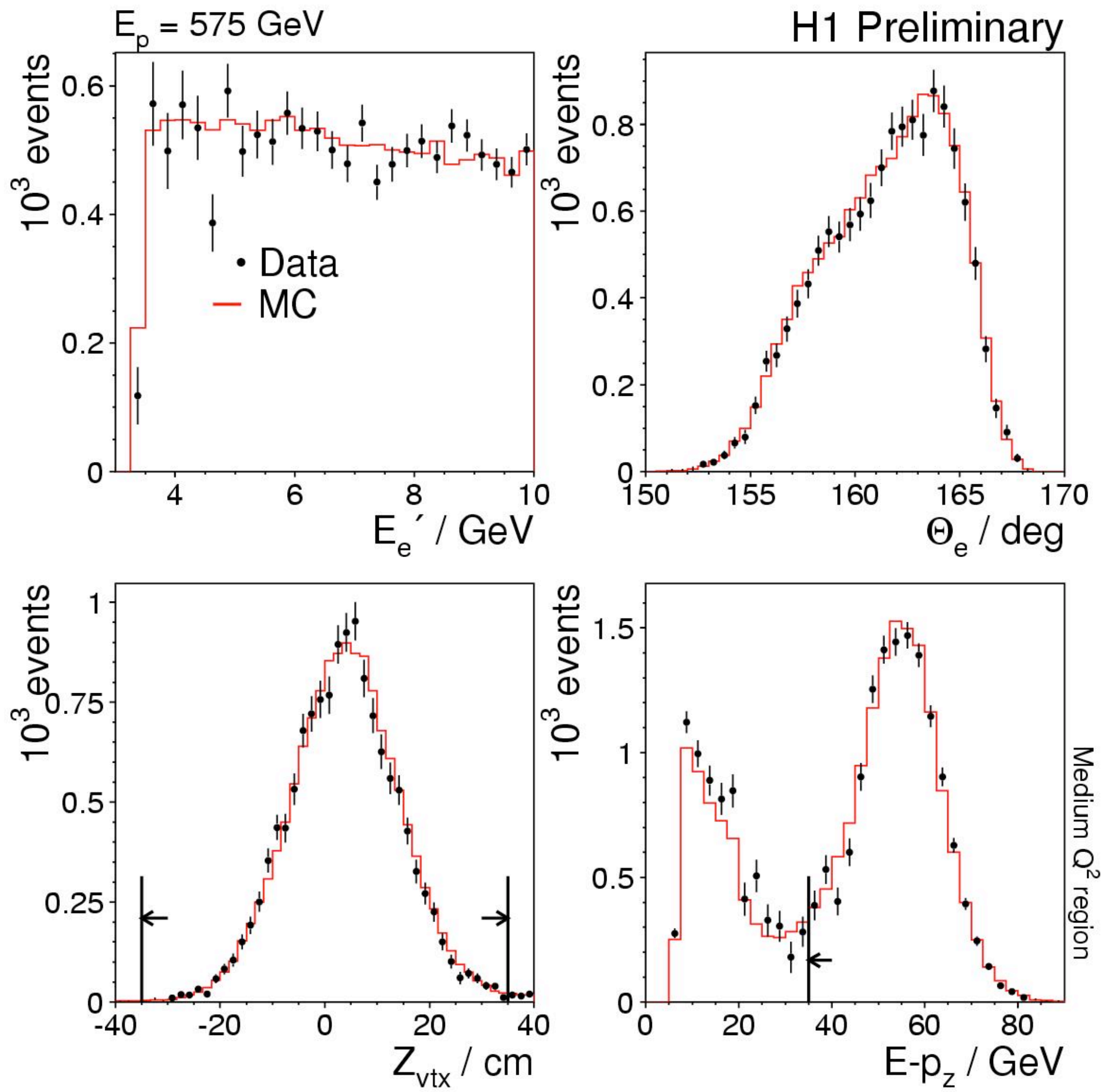
- ❑Before background subtraction
- ❑ Background determined from data directly



Control Plots for E_p=575GeV (high y)

- After background subtraction taking into account asymmetry fator

- Good description of the data by MC

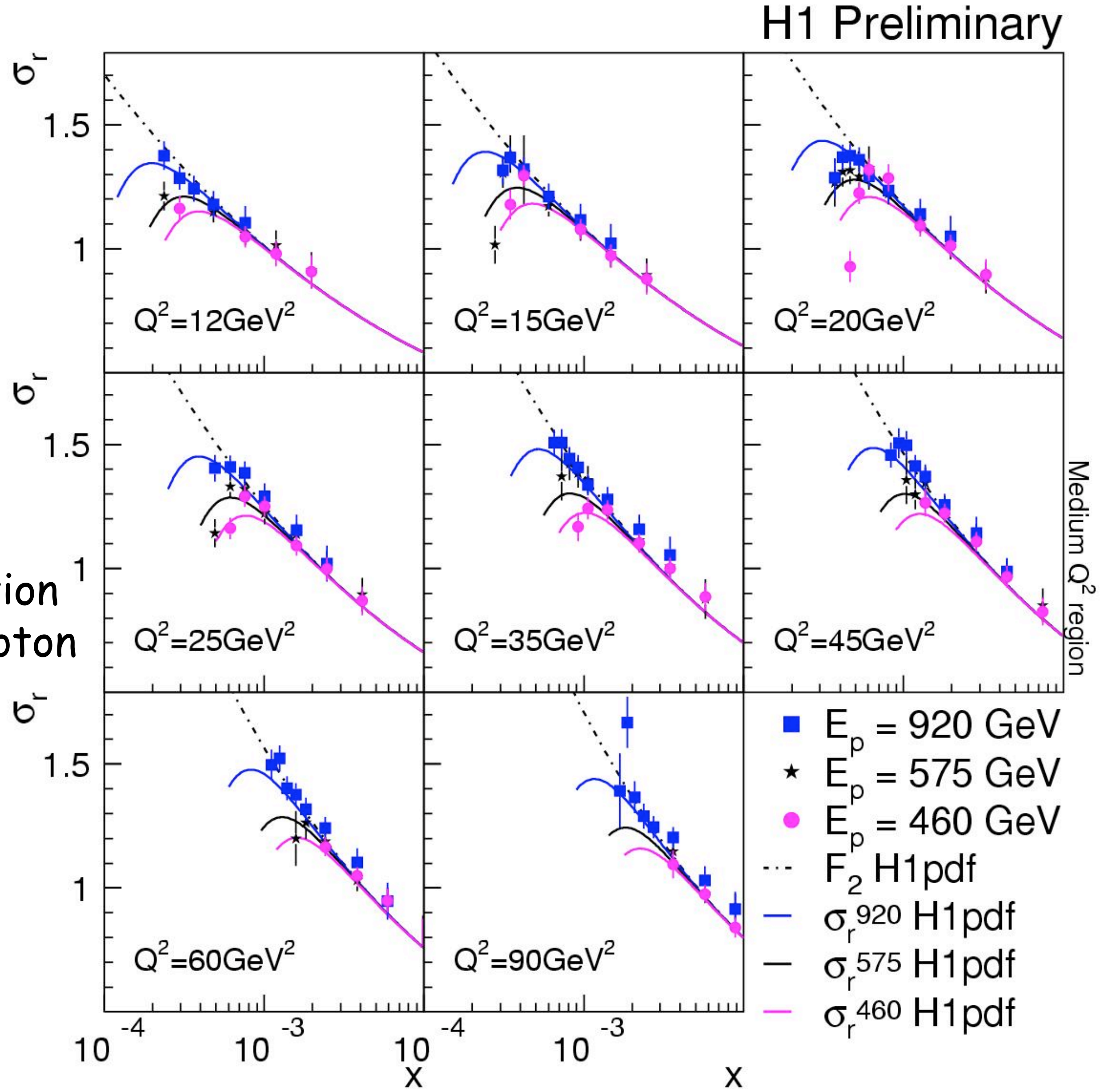


Double differential cross sections

- 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

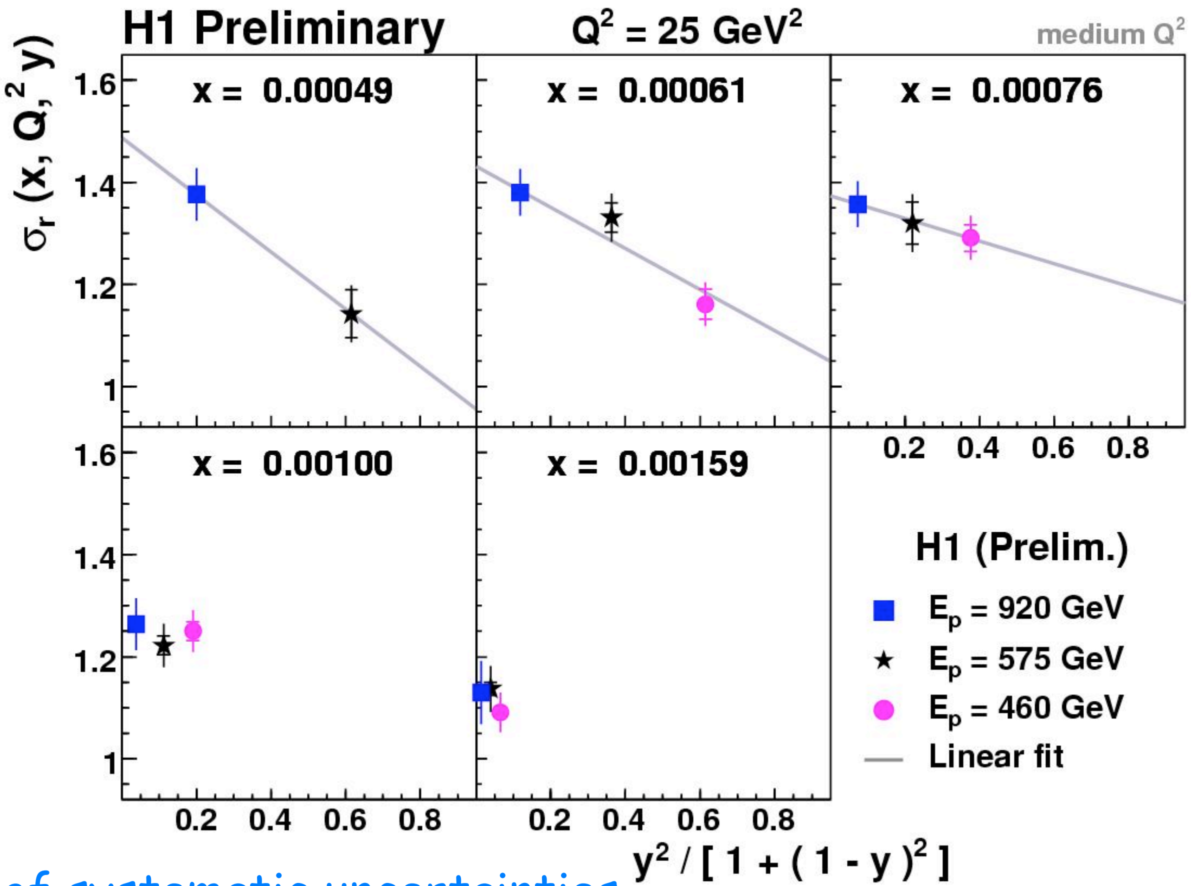


Extraction of F_L

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

- Linear fit to points of different CME
  - Intercept at y axis =>F_2
  - Slope => F_L

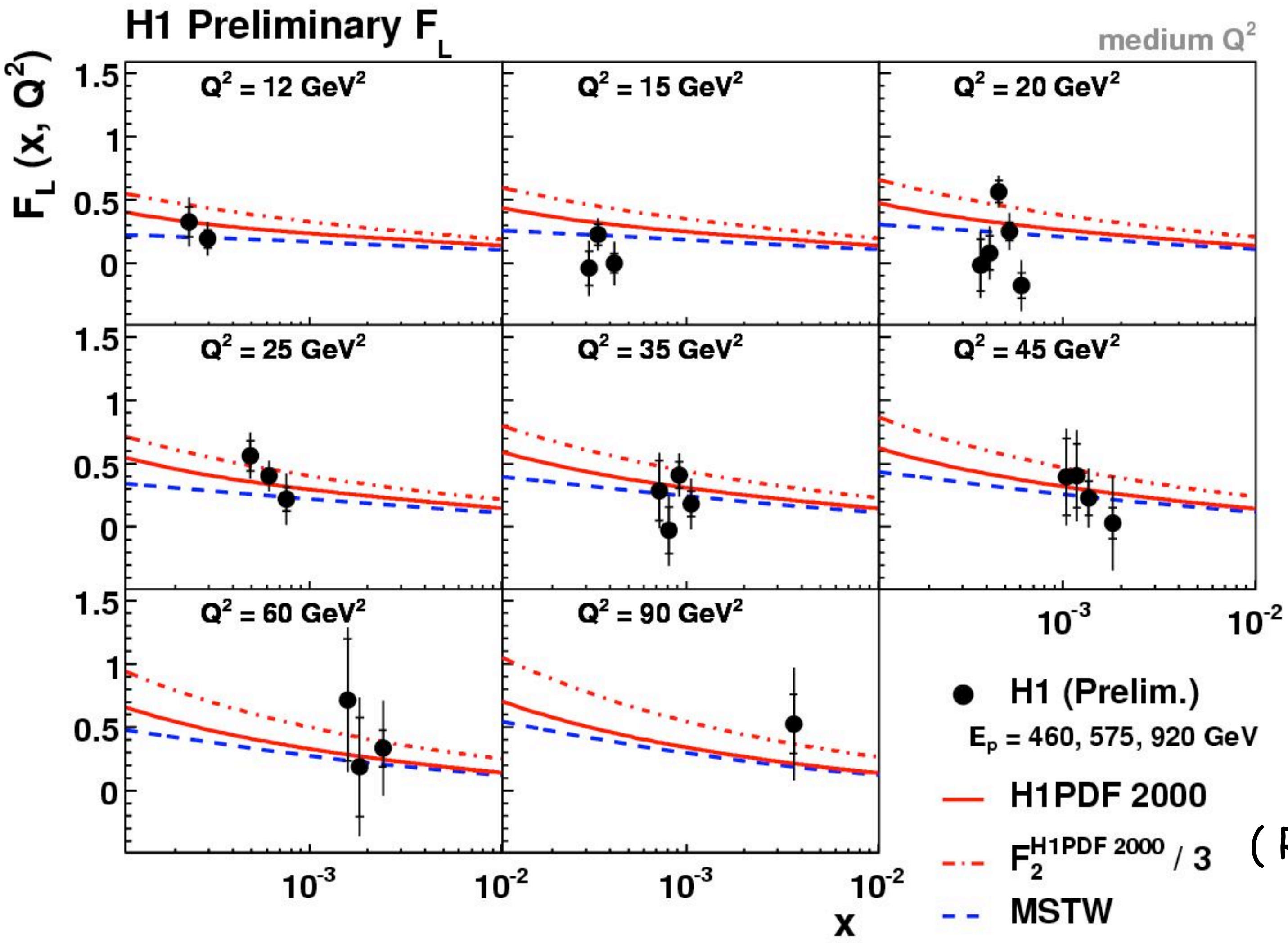
- Relative normalization derived from low y gives 1% uncertainty



- E_p=575GeV =>cross check of systematic uncertainties
  =>additional x bins

Longitudinal Structure Function F_L

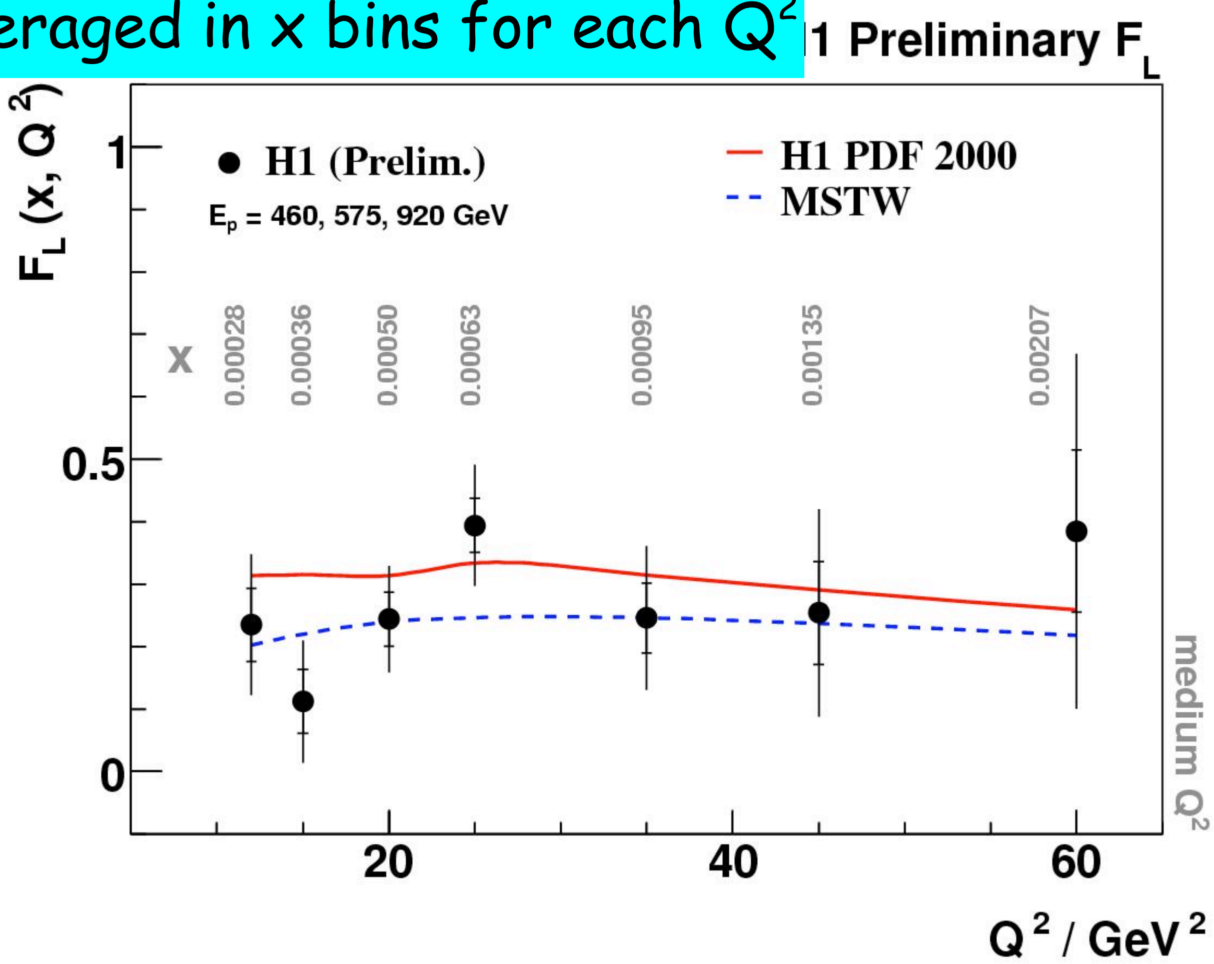
First direct measurement of the F_l at low x



(R=0.5)

F_L Averaged in x Bins

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



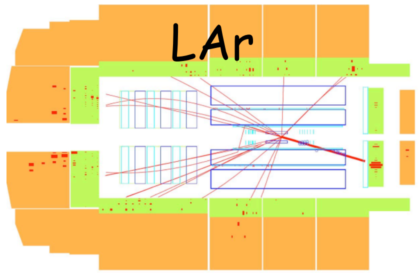
- F_L predicted by higher order QCD fits using gluon that was derived from scaling violations of F_2 is consistent with the measurement.

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 (12-90GeV^2)

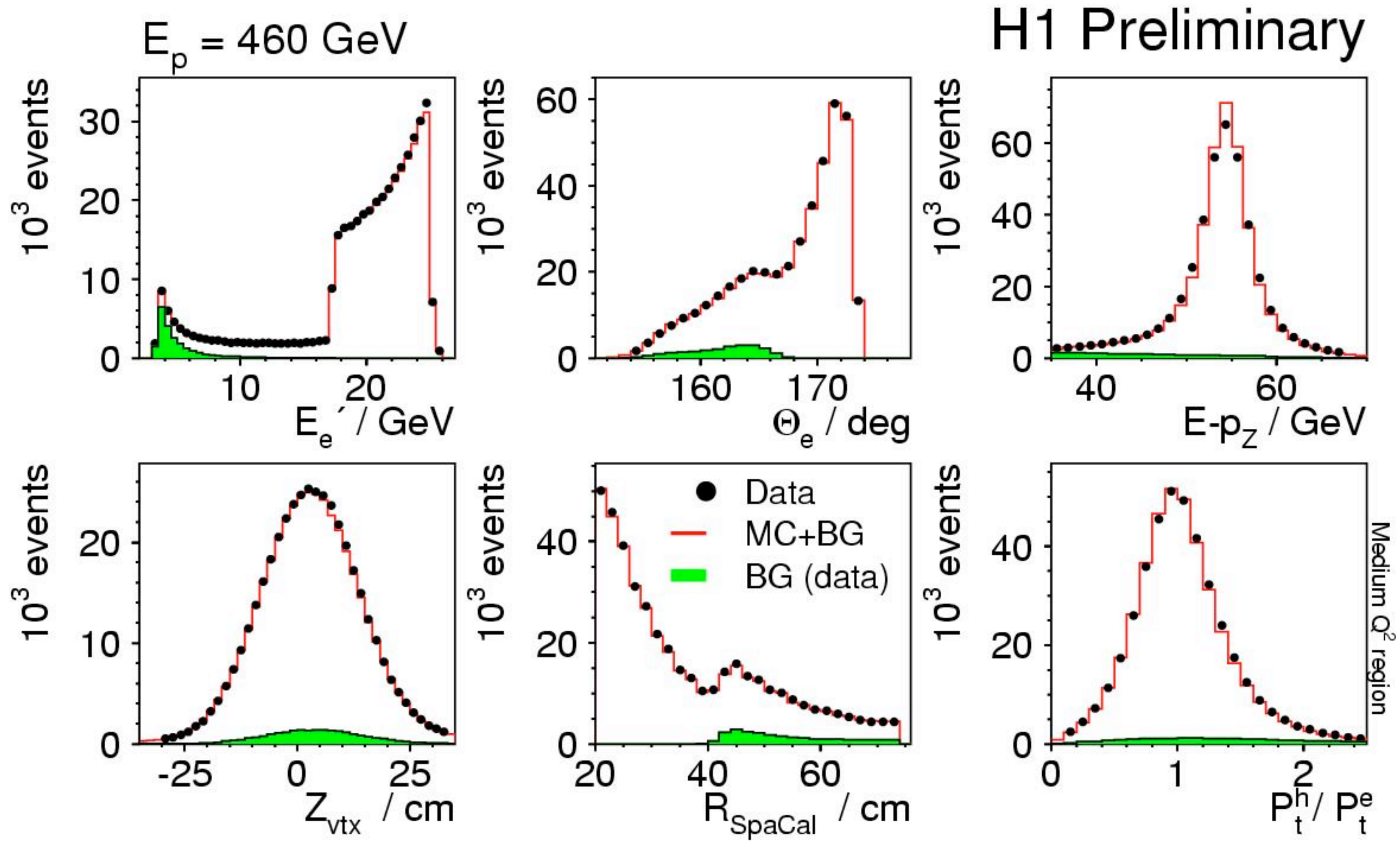
- Measured F_L is in agreement with higher order QCD expectations, based on HERA low x measurements of the scaling violations of F_2

- 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)



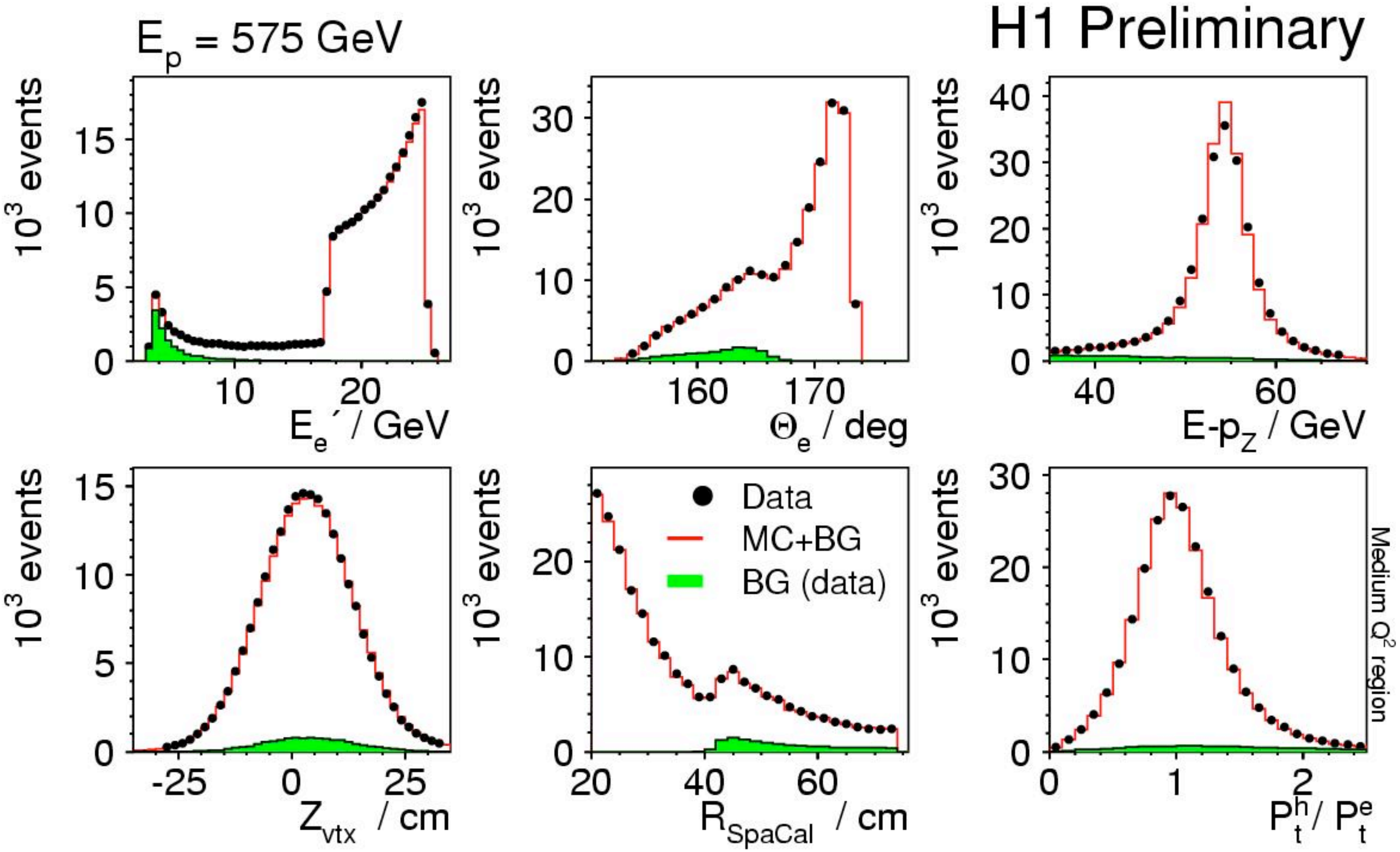
Backup slides

Control Plots for E_p=460GeV (low y & high y)



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

Control Plots for E_b=575GeV (low y & high y)



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