
# H1 Results

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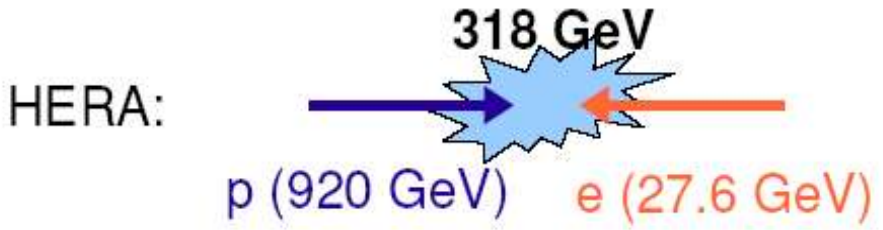
**and Deutsches Elektronen Synchrotron Hamburg**

**April 16, 2007, DIS Plenary**

# H1 and the HERA program




- **HERA 1: 1992-2000 ~120 pb$^{-1}$/expt**
- **HERA 2: 2003-2007 luminosity upgrade**

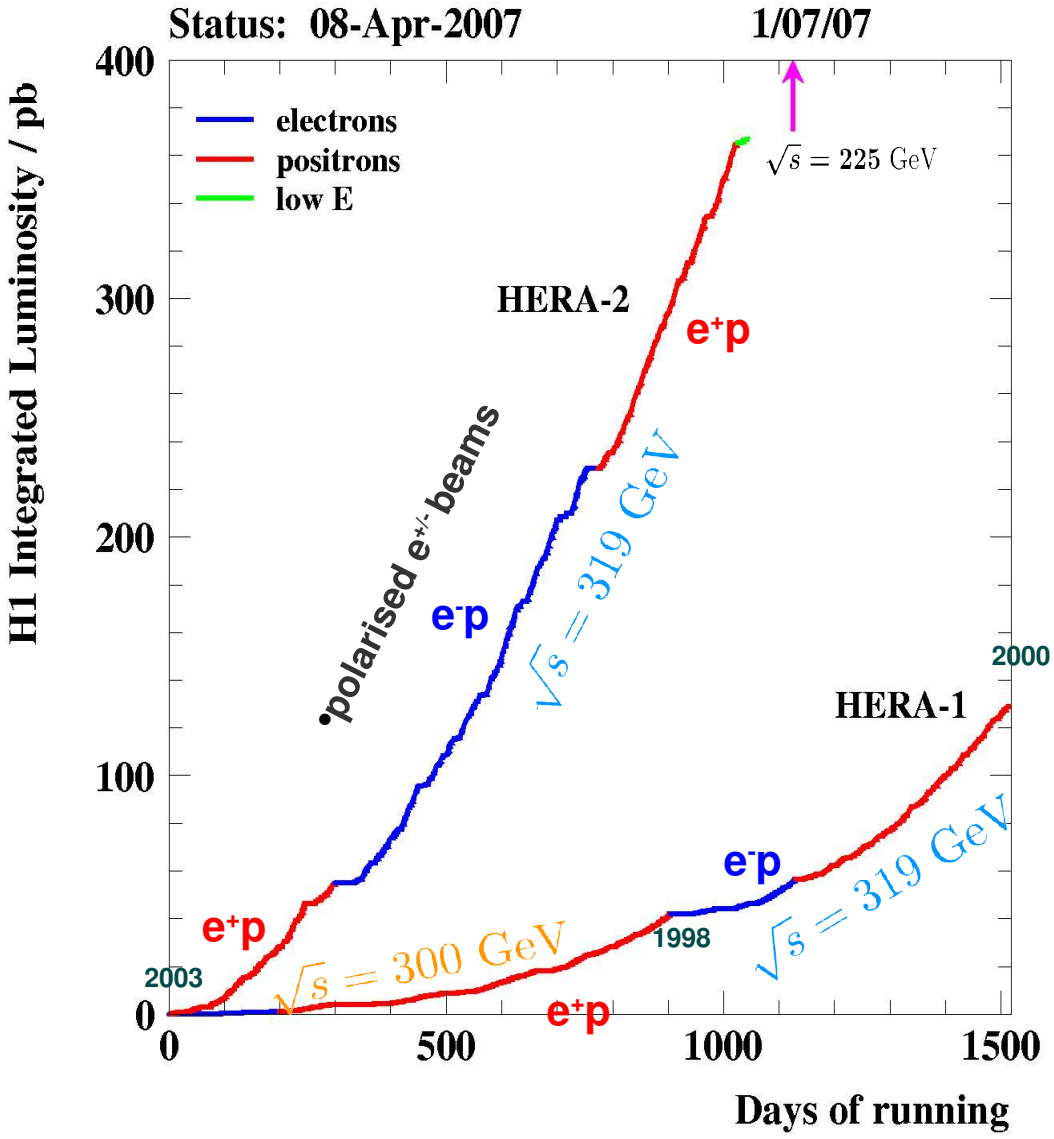
**End of High Energy run**
**March 20 2007**

**H1 Harvest at HERA 1+2: ~478pb$^{-1}$**

- **~184 pb$^{-1}$ e$^-$p**
- **~294 pb$^{-1}$ e$^+$p**

**Since April 2007: Low Energy Run**
**$E_p$=460 GeV**

**HERA program entering**
**an exciting period: final analyses**



# The expectations from the HERA program

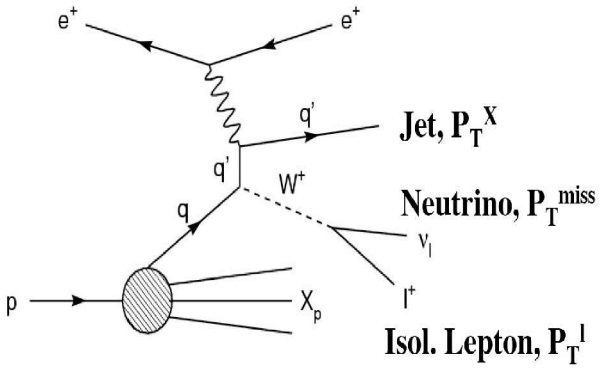
and an outline of this talk

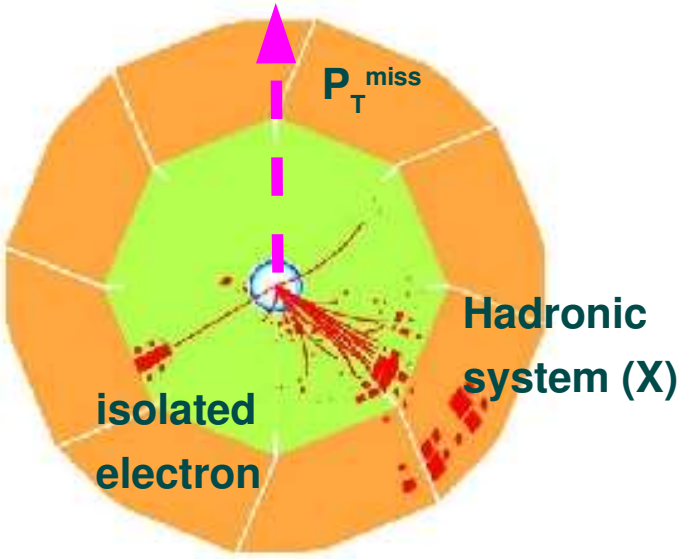
- Search for the "rare" and the "unexpected": HERA as a frontier collider
  - L~0.5 $fb^{-1}$ search for processes with $\sigma \leq 1pb$
- Proton structure with highest precision: HERA as a proton imaging device
  - PDF's with best precision high Q2 and low Q2
  - The longitudinal structure function $F_L$
- QCD studies in a clean high energy laboratory: HERA as a QCD machine
  - Exclusive final states: $\alpha_S$ from jets, charm, photons, DVCS
- News from the $E_p$=460 GeV run

# Event with isolated e or μ and $P_T^{miss}$

SM W: Total Cross Section ~1.3 pb

=> ~5 events/100pb$^{-1}$with e or μ

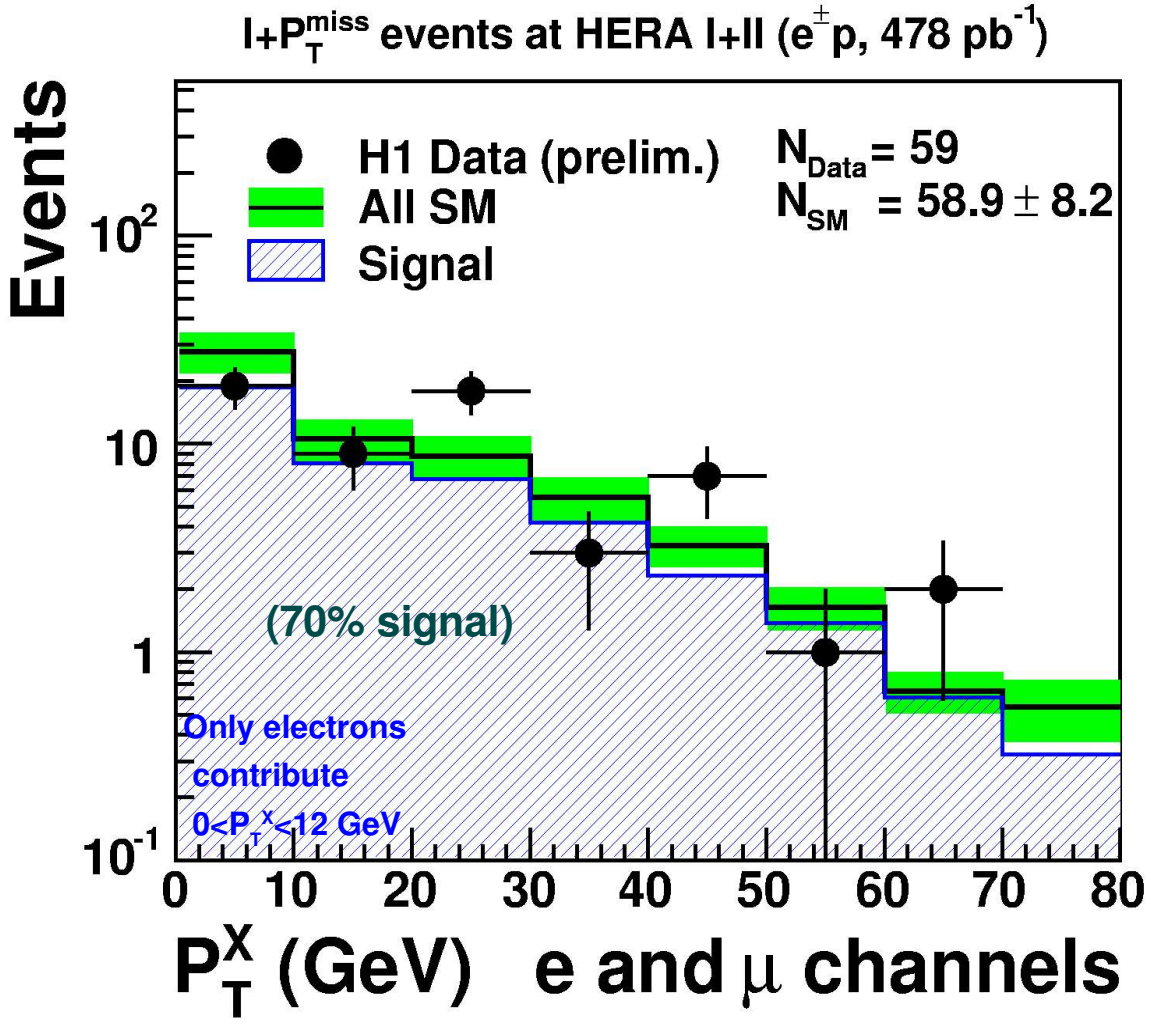



**H1 HERA 1 (118 pb$^{-1}$, mainly e$^+$p)**

**$P_T^X$>25 GeV 11 (Data) / 3.5±0.6 (SM) (3σ)**

**Full HERA Luminosity**

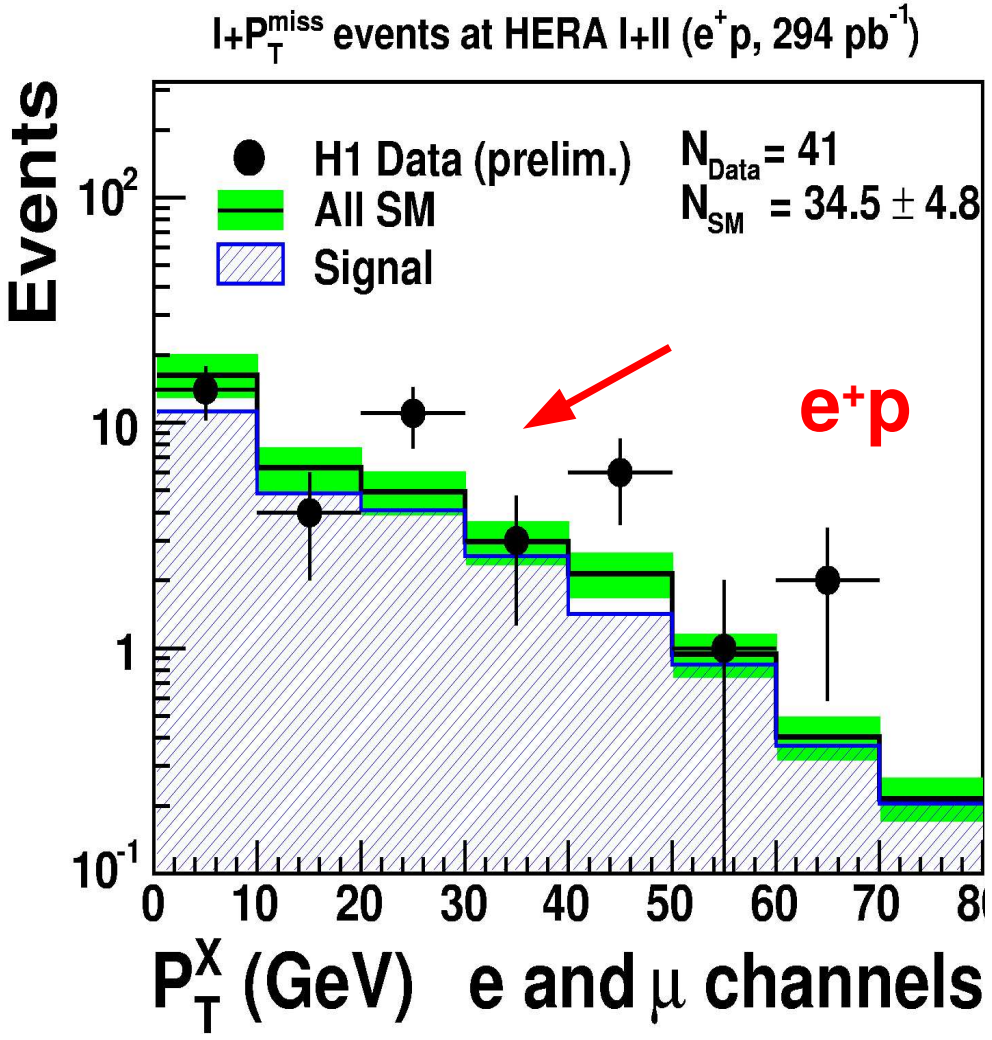


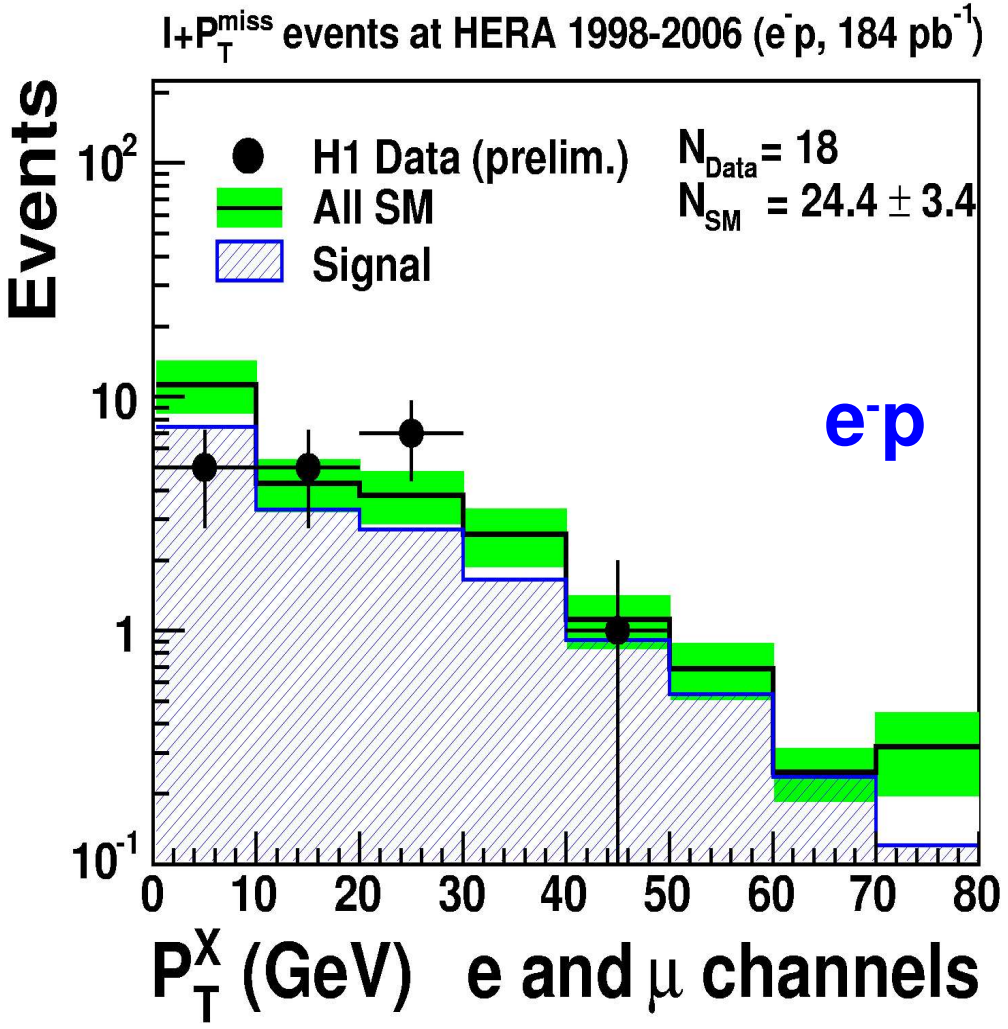

**Evidence for W production at HERA**

**Continue to observe events at high $P_T^X$**

**=>Look more differentially in e$^+$p/e$^-$p data samples**

# H1 Results (e and μ) $e^+p$ vs. $e^-p$ data




- Different observations in $e^+p$ and $e^-p$.

# H1/ZEUS results at $P_T^X$>25 GeV

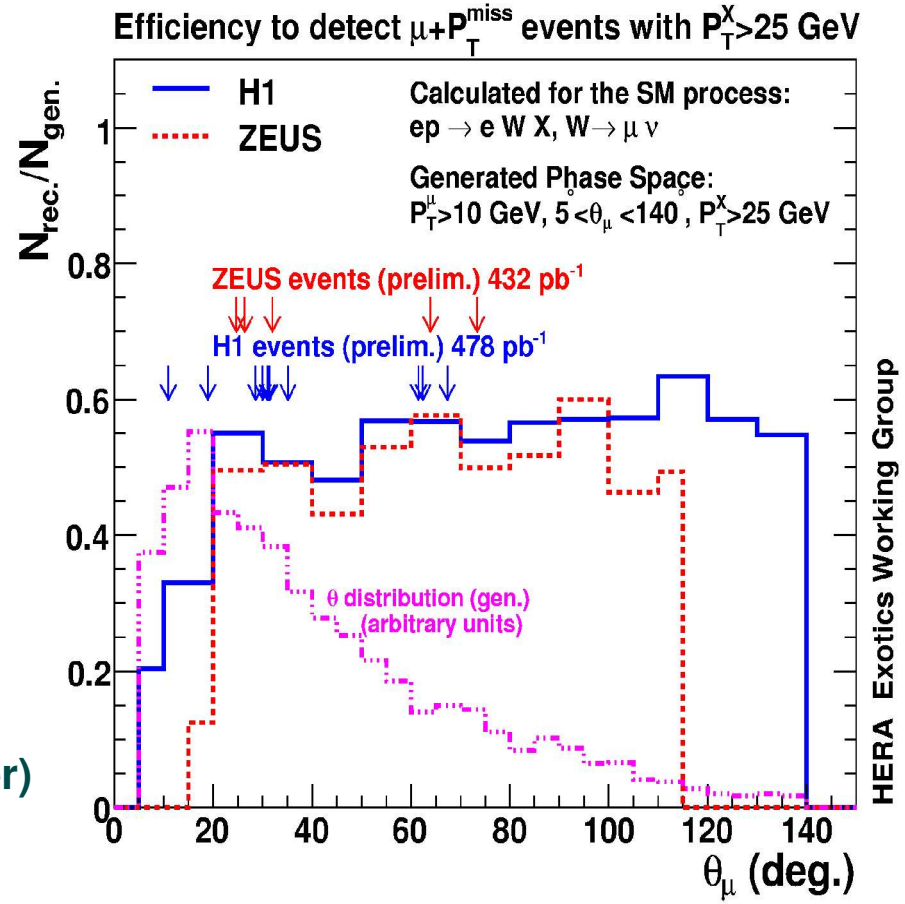
| | $P_T^X$> 25 GeV | | electrons Data/SM | muons Data/SM |
|---|---|---|---|---|
| $e^+p$ | H1 | 294 pb$^{-1}$ | 11/4.7±0.9 | 10/4.2±0.7 |
| | ZEUS | 228 pb$^{-1}$ | 1/3.2±0.4 | 3/3.1±0.5 |
| $e^-p$ | H1 | 184 pb$^{-1}$ | 3/3.8±0.6 | 0/3.1±0.5 |
| | ZEUS | 204 pb$^{-1}$ | 5/3.8±0.6 | 2/2.2±0.3 |

**$e^+p$ H1 observation: 21/8.9±1.5 (3.0σ)**

no events in excess observed by ZEUS

**$e^-p$ Agreement with SM (H1 and ZEUS)**

Most of H1 events in ZEUS acceptance (though smaller)




**H1 excess remains at high $P_T^X$ in $e^+p$ data at 3.0σ level,**

**not clarified with HERA II data**

[similar for electrons]

**In the full phase space: W production in ep collisions measured,**

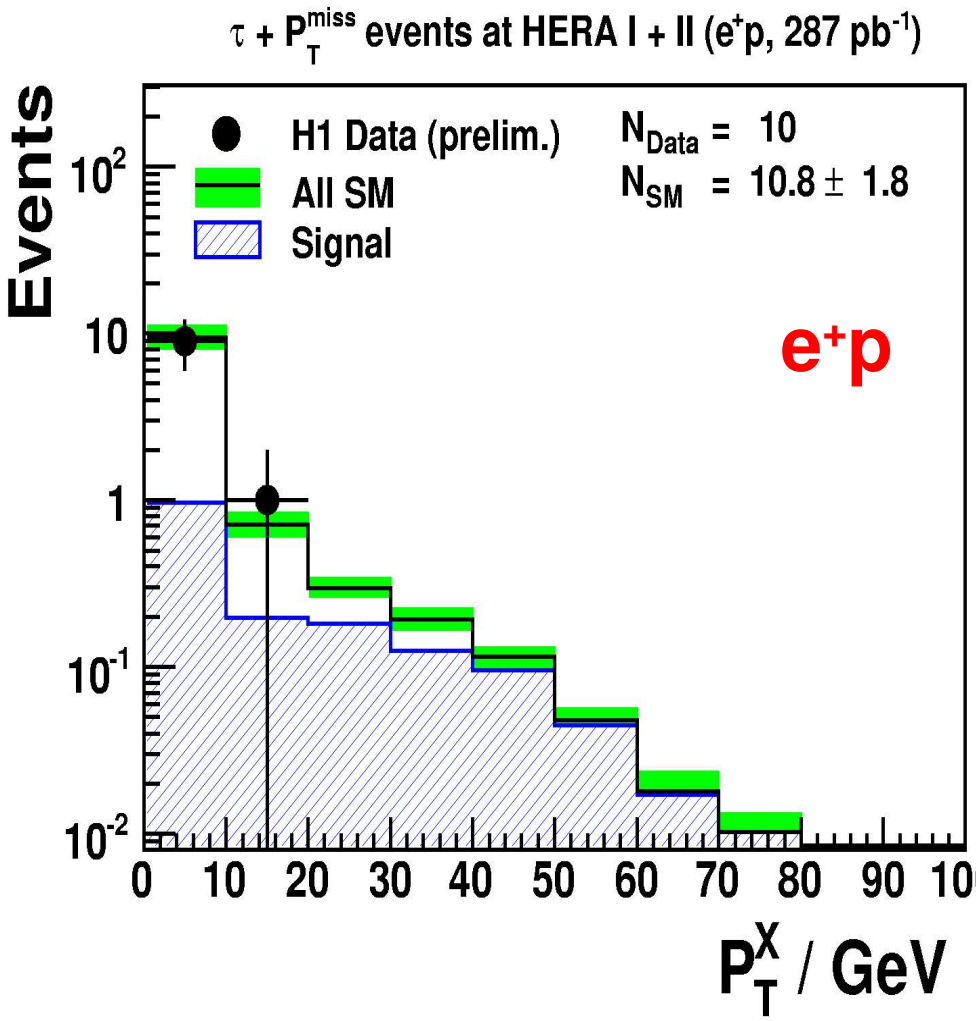
**To be further studied with a statistics of ~80 events (H1+ZEUS)**

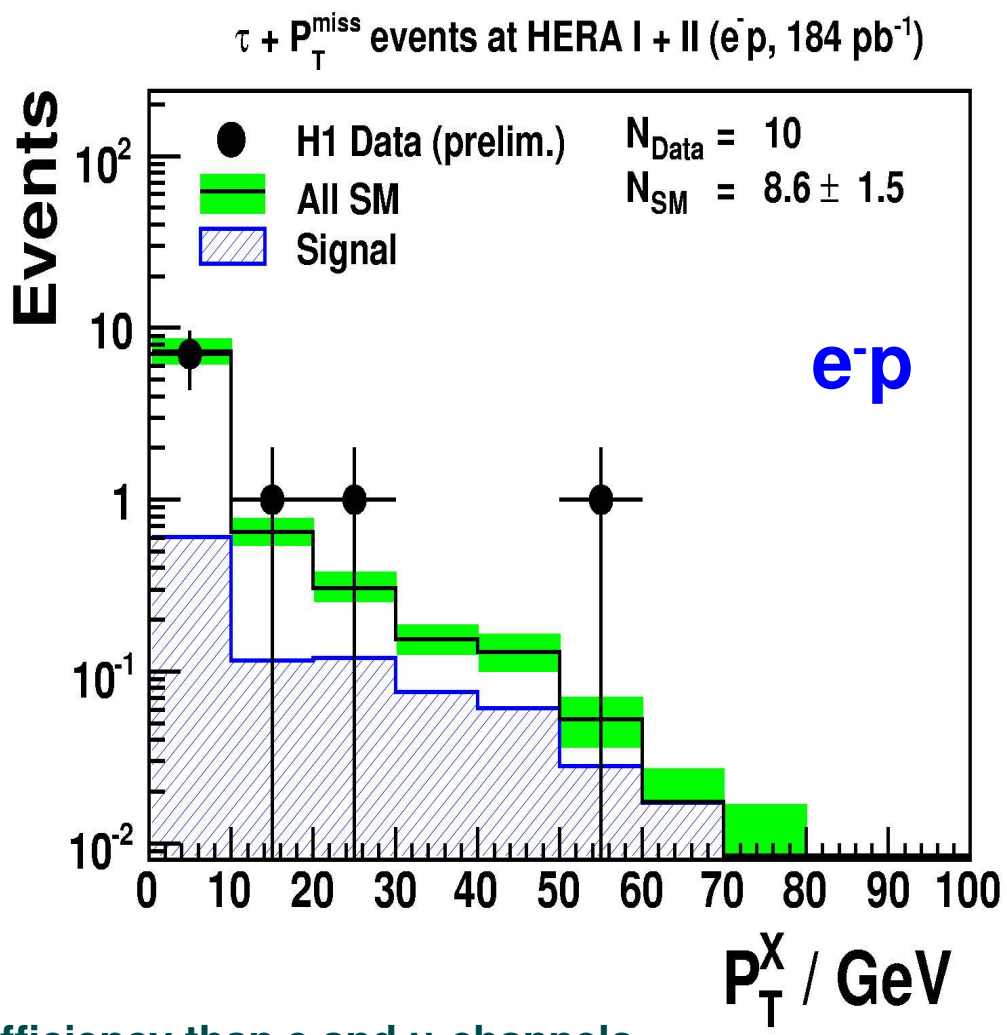
New Result
Full HERA statistics

# $\tau + P_T^{miss}$ $e^+p$ vs. $e^-p$ data

τ leptons identified in the hadronic (one-prong) decay channel

Jets with single tracks in CC events




Large background (CC), much lower efficiency than e and μ channels

- No excess detected in $e^+p$ and $e^-p$.

[talk Y. de Boer]

New Result
Full HERA statistics

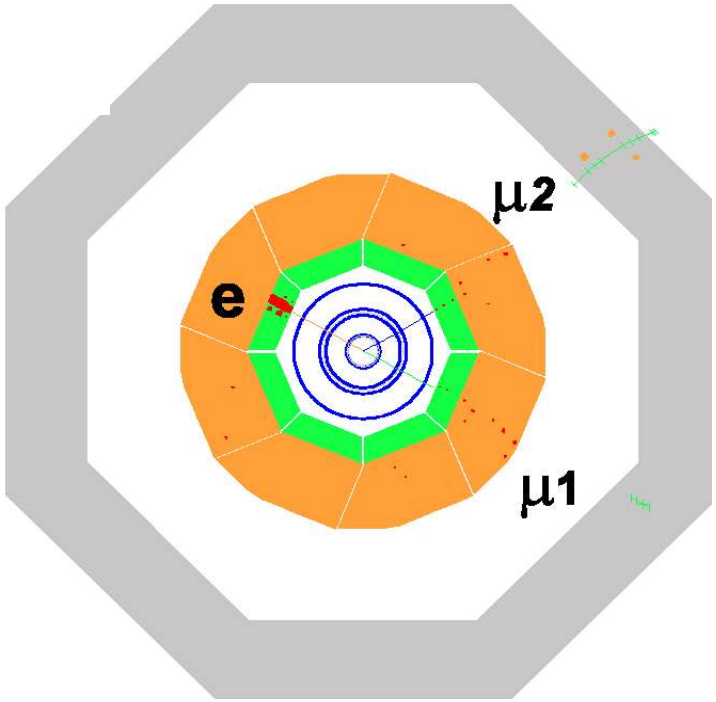
# Multilepton events

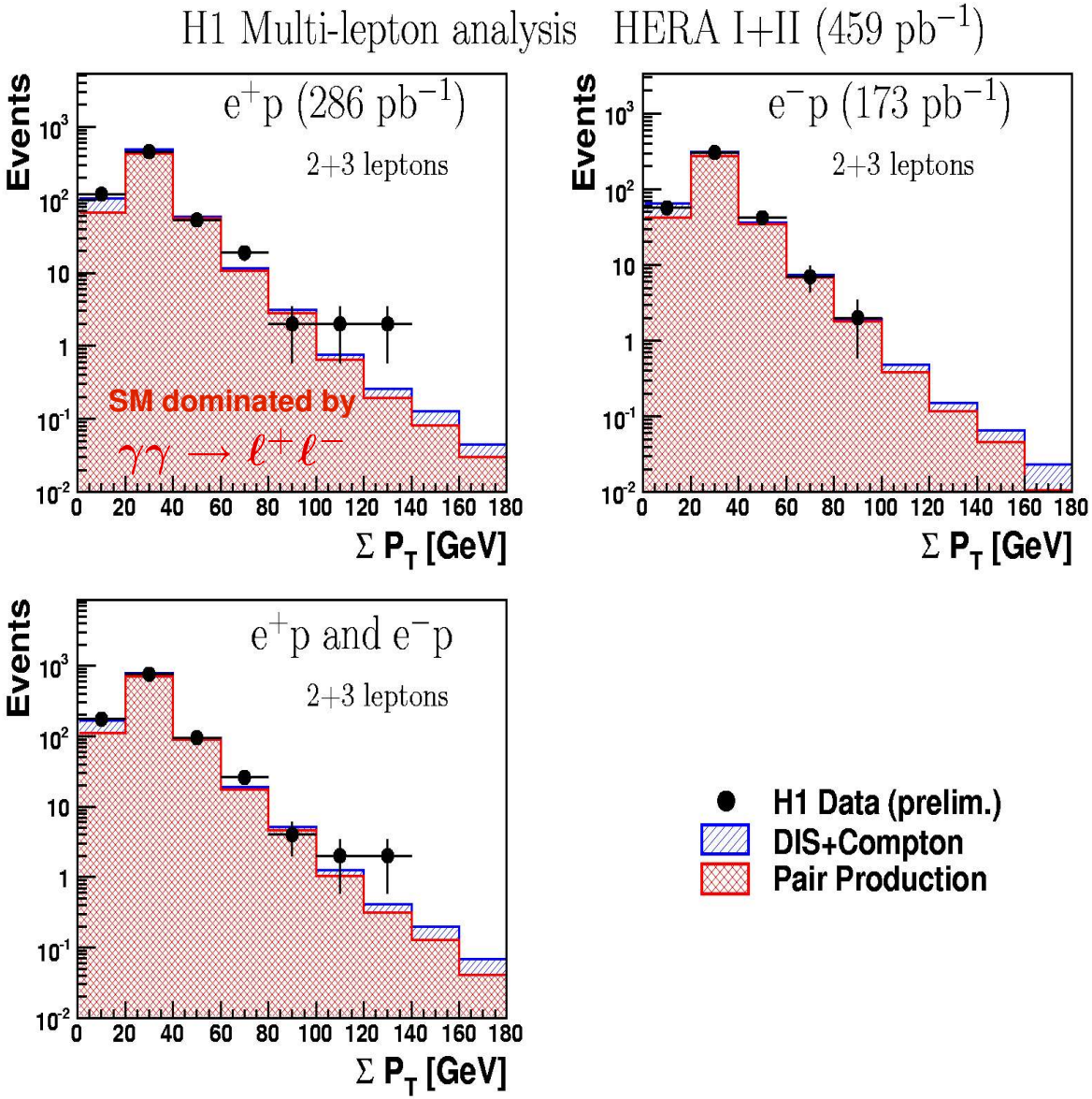
**H1/HERA I: observation of multi-electrons at high mass**

**Include muons; combinations:**

**ee, eμ, μμ, eee, eμμ**

**$\Sigma P_T$: "hardness" of the events**




**For $\Sigma P_T$>100 GeV, $e^+p$ data: 4/1.2±0.**

[talk G.Brandt]

# General Searches

New result
Full HERA II

- Search for isolated particles at high $P_T$
- Electrons ,Photons, Muons, Hadronic Jets, Neutrinos

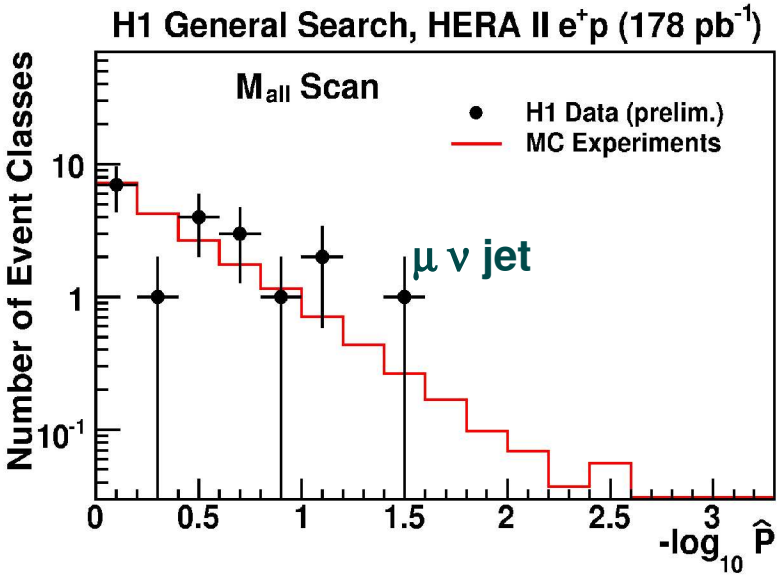
- Unique phase space:

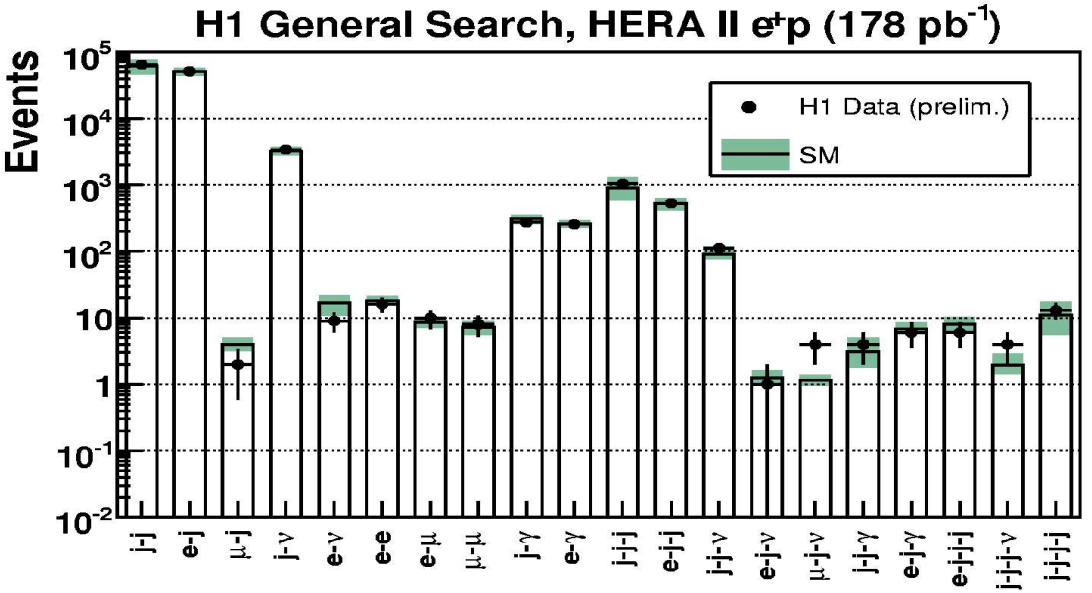
$P_T$ >20 GeV

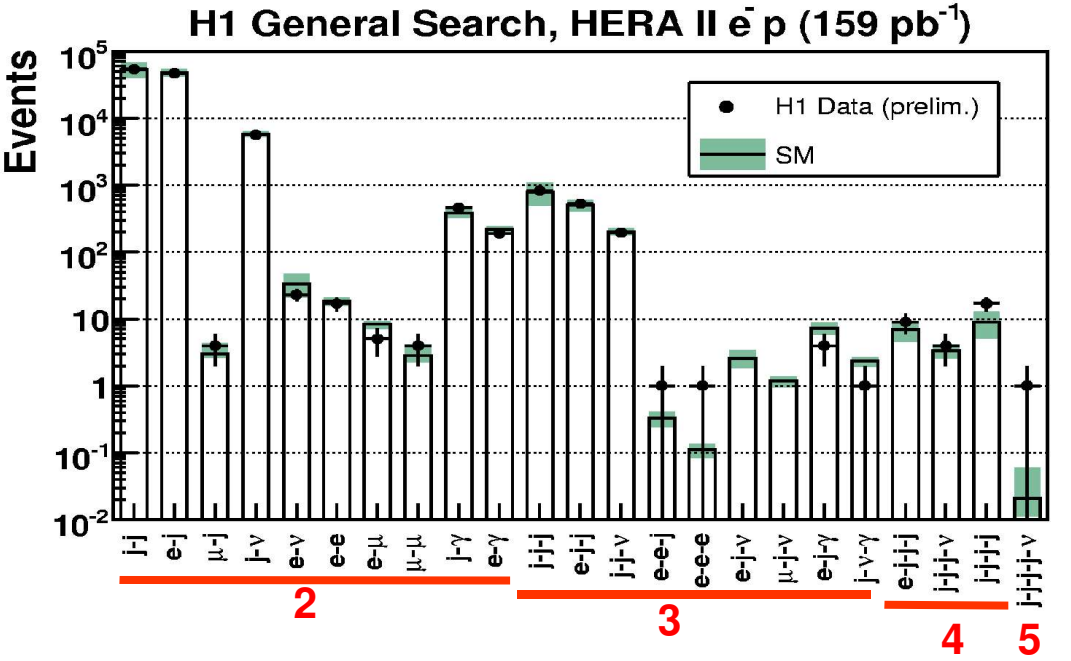
$10^o<\theta<140^o$

D0, PRD64, 012004 (2001)
H1, Phys Lett B602 (2004) 14

- Investigate Mass and $\Sigma P_T$
- Statistical Analysis (search for deviations)



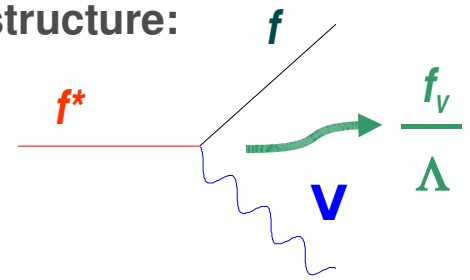

[talk E.Sauvan]

# Search for lepton-boson resonances

full HERA $E_{cm}$=320 GeV luminosity

Unambiguous signature for matter substructure:

direct observation of excited states



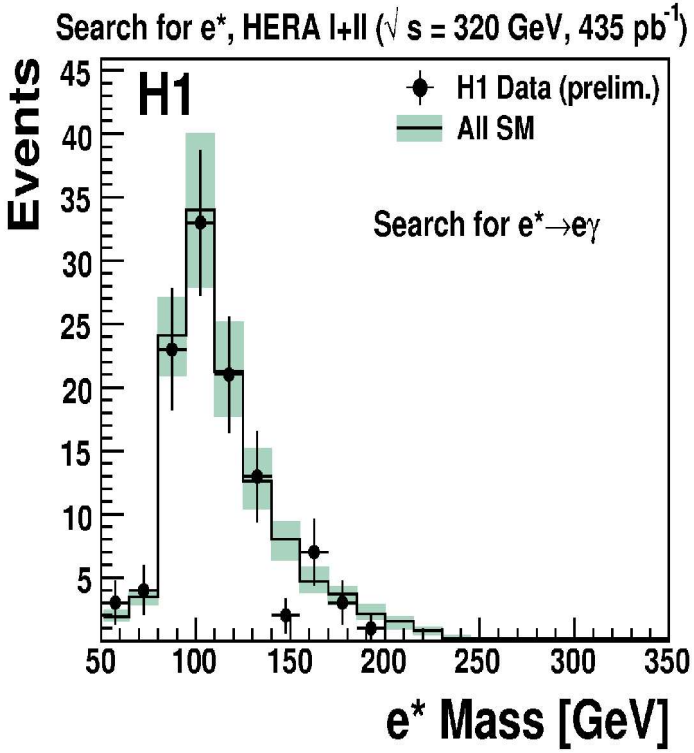

$\Lambda \approx$ compositeness scale

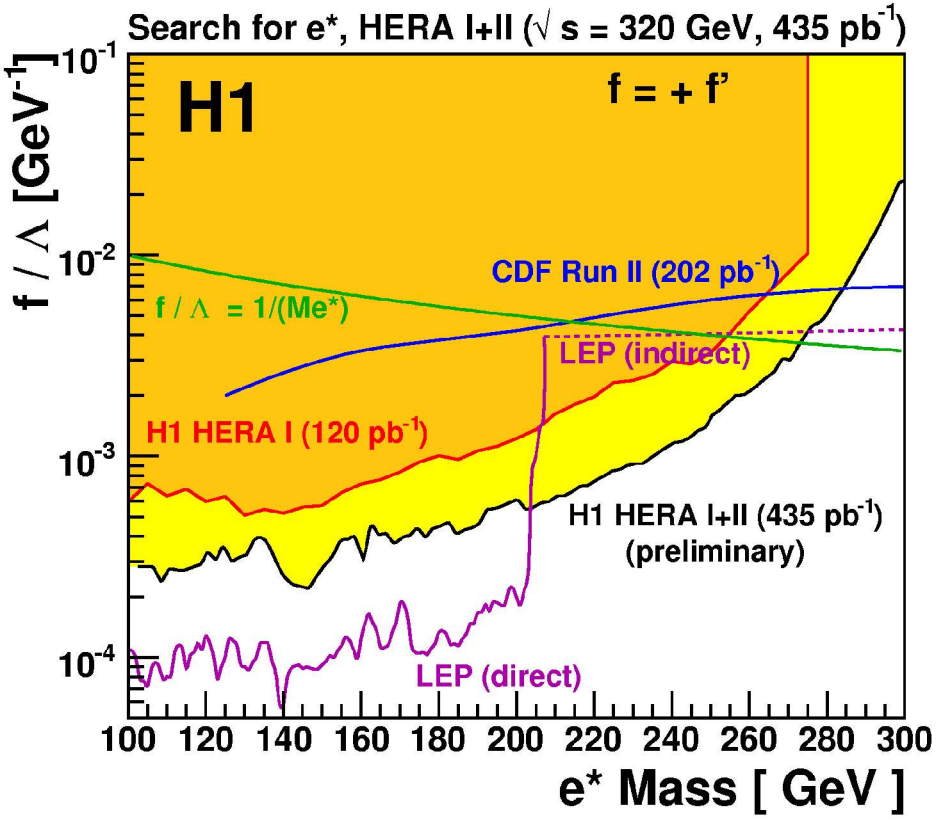
Relative strength $\gamma$, Z,g :

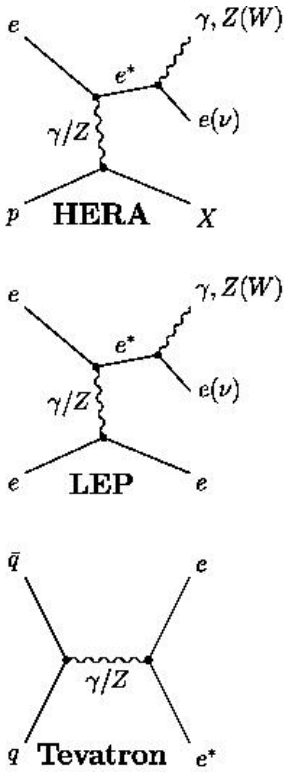
couplings f, f ', $f_s$

**Lepton-Boson Resonances**

**e$\gamma$, $\nu$W, eZ**



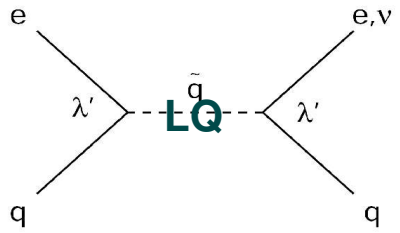

$f/\Lambda = 1/M_{e*}$

$M_{e*} < 273$ GeV excluded @ 95% C.L.

$\nu$* also explored [talk N. Trihn]

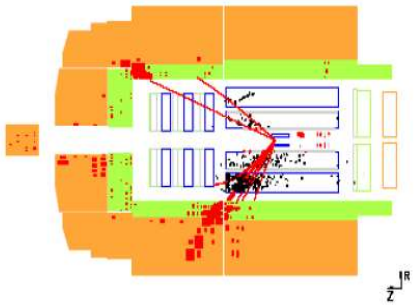
# Leptoquarks: new domain explored

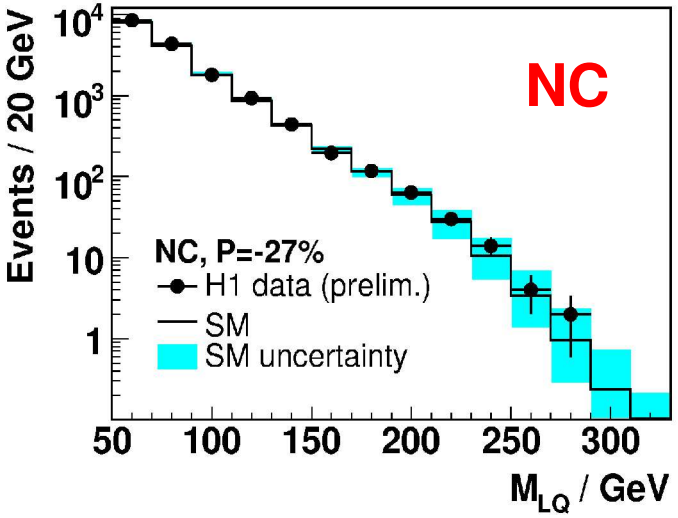
Lepton-jet resonance



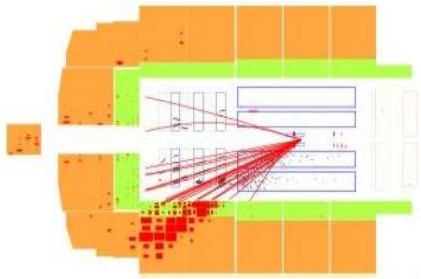

HERA II, $e^-p$, 92 $pb^{-1}$

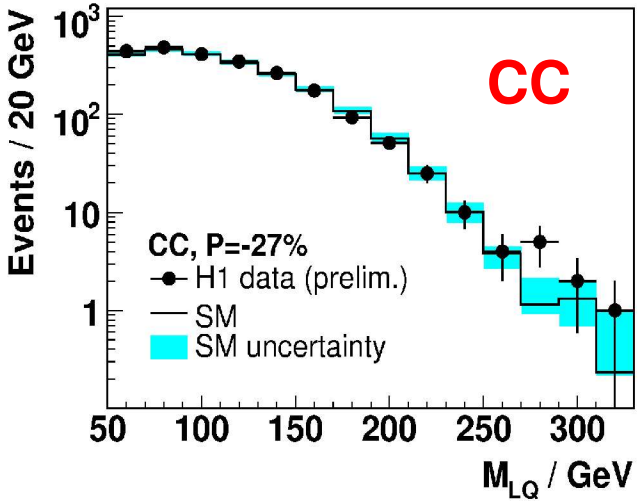
e+jet

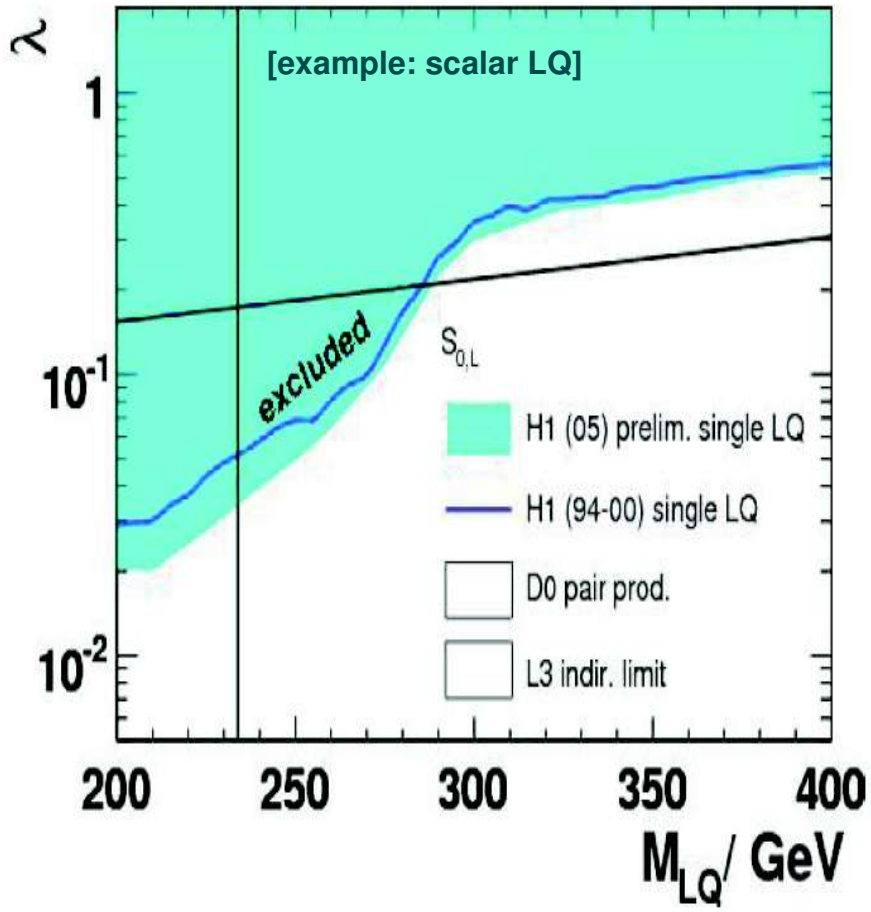





$P_T^{miss}$+jet






More data, $e^+/e^-p$, (x2)

final domain to explore

[talk A.Dubak]

# Proton structure at high Q2: $xF_3$

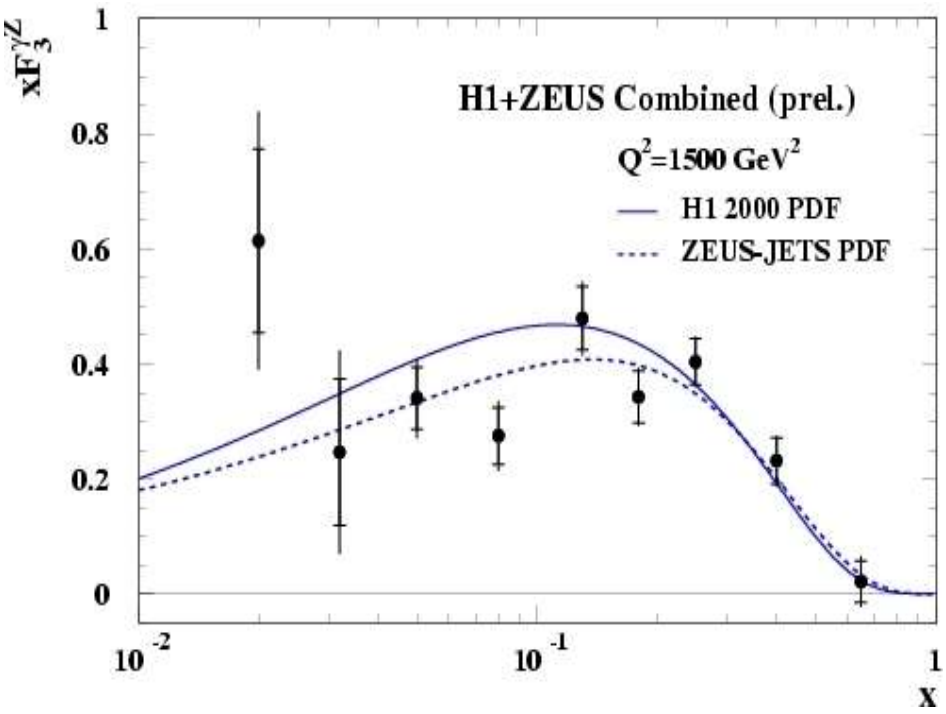
$$\frac{d^2\sigma_{\rm NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left[\tilde{F}_2(x,Q^2) \mp \frac{Y_-}{Y_+} x\tilde{F}_3(x,Q^2) - y^2 F_L\right] \quad \Rightarrow \quad x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left[\tilde{\sigma}^-(x,Q^2) - \tilde{\sigma}^+(x,Q^2)\right]$$

**dominated by photon-Z interference**

$$xF_3^{\gamma Z} = \frac{x}{3}[2u_v + d_v + \Delta]$$
$$\Delta = 2(u_{sea} - \bar{u} + c - \bar{c}) + (d_{sea} - \bar{d} + s - \bar{s})$$

**sensitive to valence quarks @ low x**

**combining H1 and ZEUS data**
**L=270(H1)+209(ZEUS) pb$^{-1}$**

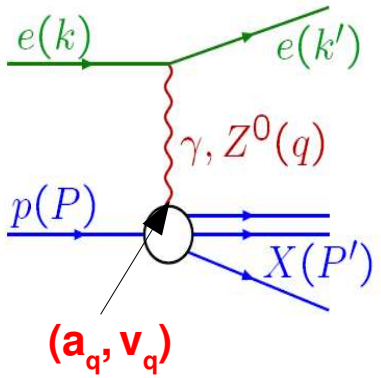



**Improvement expected from full HERA data**
**L(H1+ZEUS)=1fb$^{-1}$**

**error reduction by another 30%**

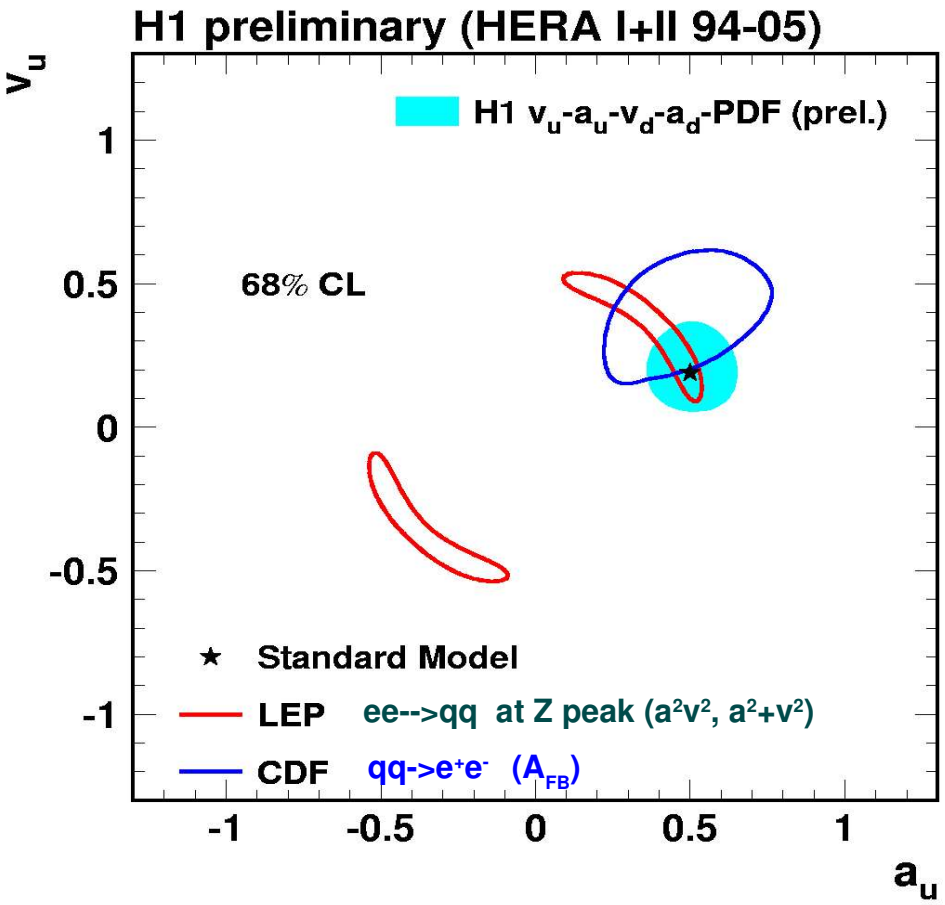
**more on e-beam polarisation asymmetry in Massimo's talk**

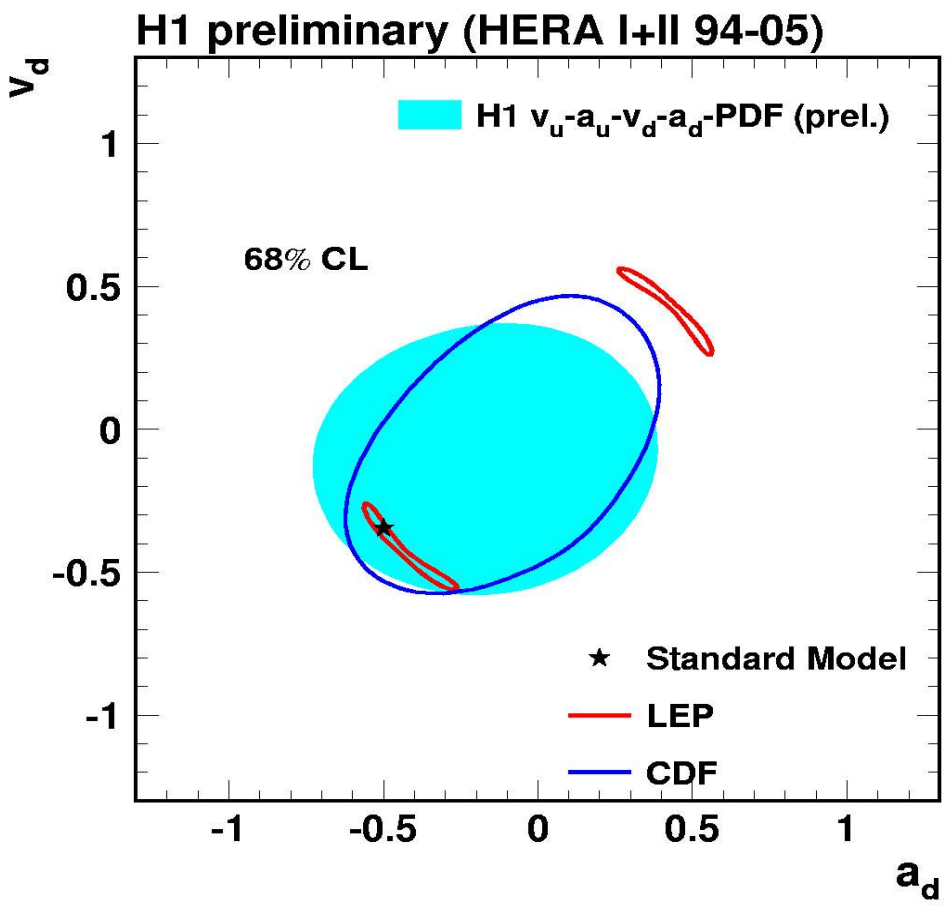
# Light quark couplings to Z




NC/CC data=> full QCD/EW Fit: PDF's+light quarks couplings

Now taking advantage of polarisation @HERA II : new fit




Best precision for u-couplings (factor 2 improvement wrt HERA 1)

A factor 2 increase in ($e^+p$) luminosity still to go

[talk G. Li]

# Low $Q^2$ measurements

**High precision in the low $Q^2$ regime obtained via special runs**

**MB** minimum bias (high trigger rate)

**SVX** shifted collision vertex

(increase acceptance at lowest Q2)

**$Q^2$: 0.2 – 12 GeV$^2$**

**x:4•10$^{-6}$ – 0.02**

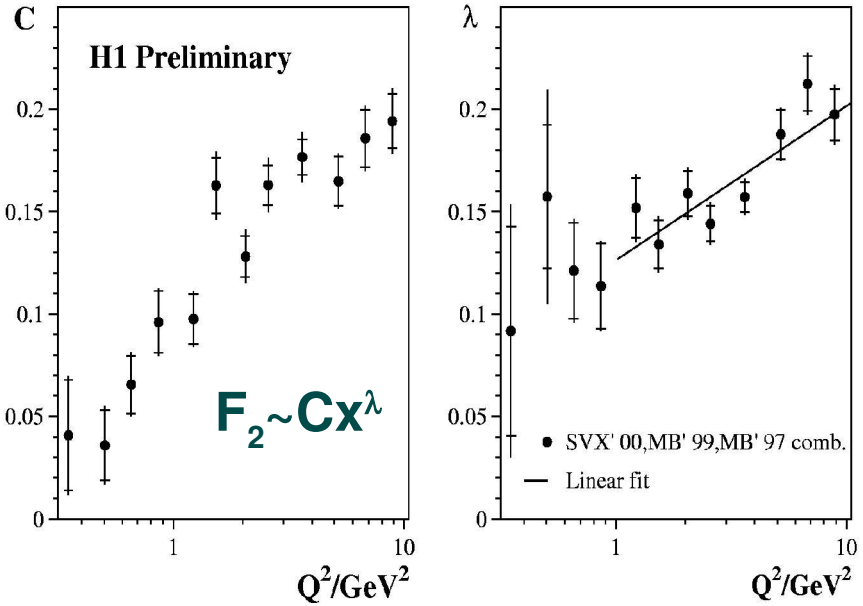
**New: datasets combined**

**2-3% precision** (systematics limited)

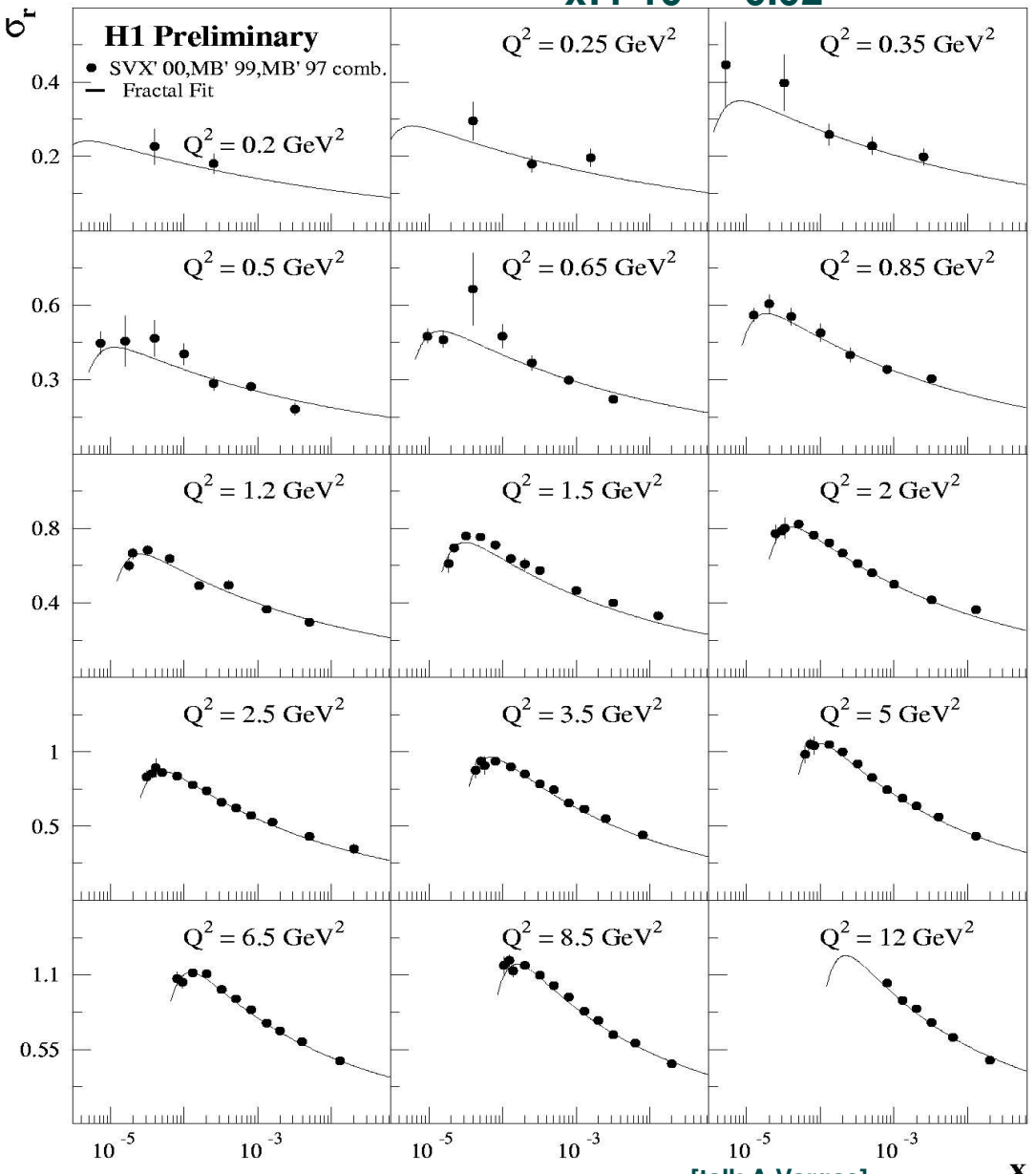
$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+}\cdot F_L(x,Q^2)$$

**Soft hadronic to DIS transition**

**F2: empirical predictions: fractal fit, power law...**




**...and $F_L$**




[talk A.Vargas]

# High y regime and $F_L$

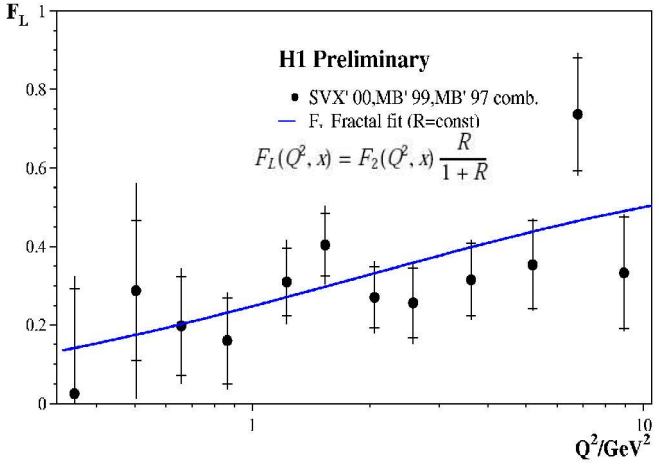
$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+}\cdot F_L(x,Q^2)$$

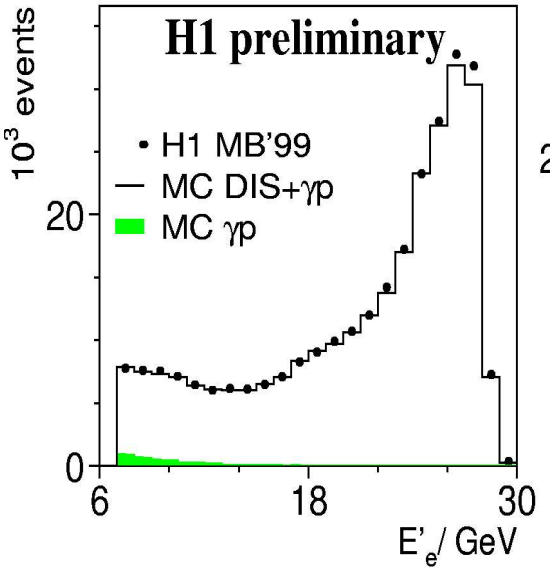
$$F_L(x,Q^2) \sim \alpha_s x g(x,Q^2)$$

**To extract $F_L$**

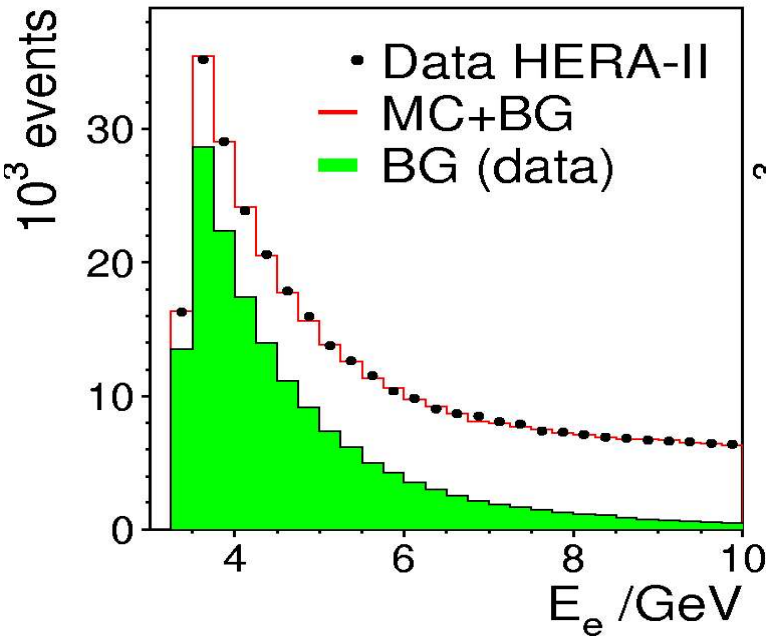
$$\sigma_r(Q^2,x) = c(Q^2)\,x^{-\lambda(Q^2)} - \frac{y^2}{Y_+}F_L(Q^2)$$

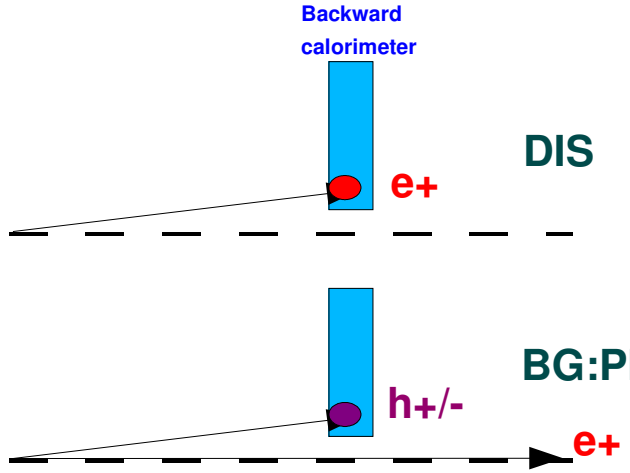
$$y \simeq \frac{E_e - E_e^0}{E_e}$$ **high y = low $E_e$**




## New analysis (HERA II) $e^+p/e^-p$ Data



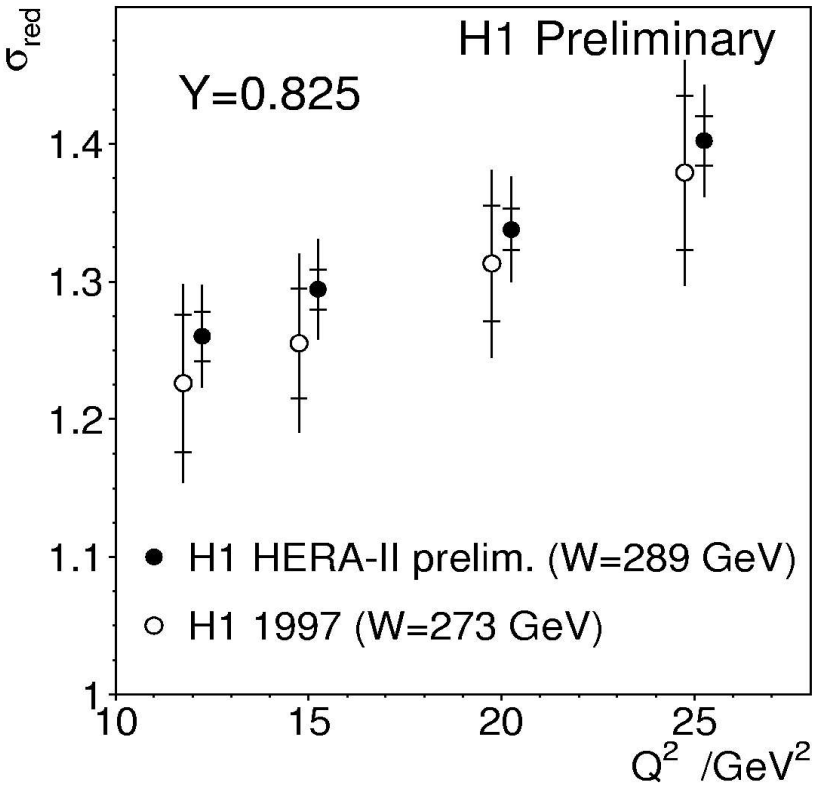



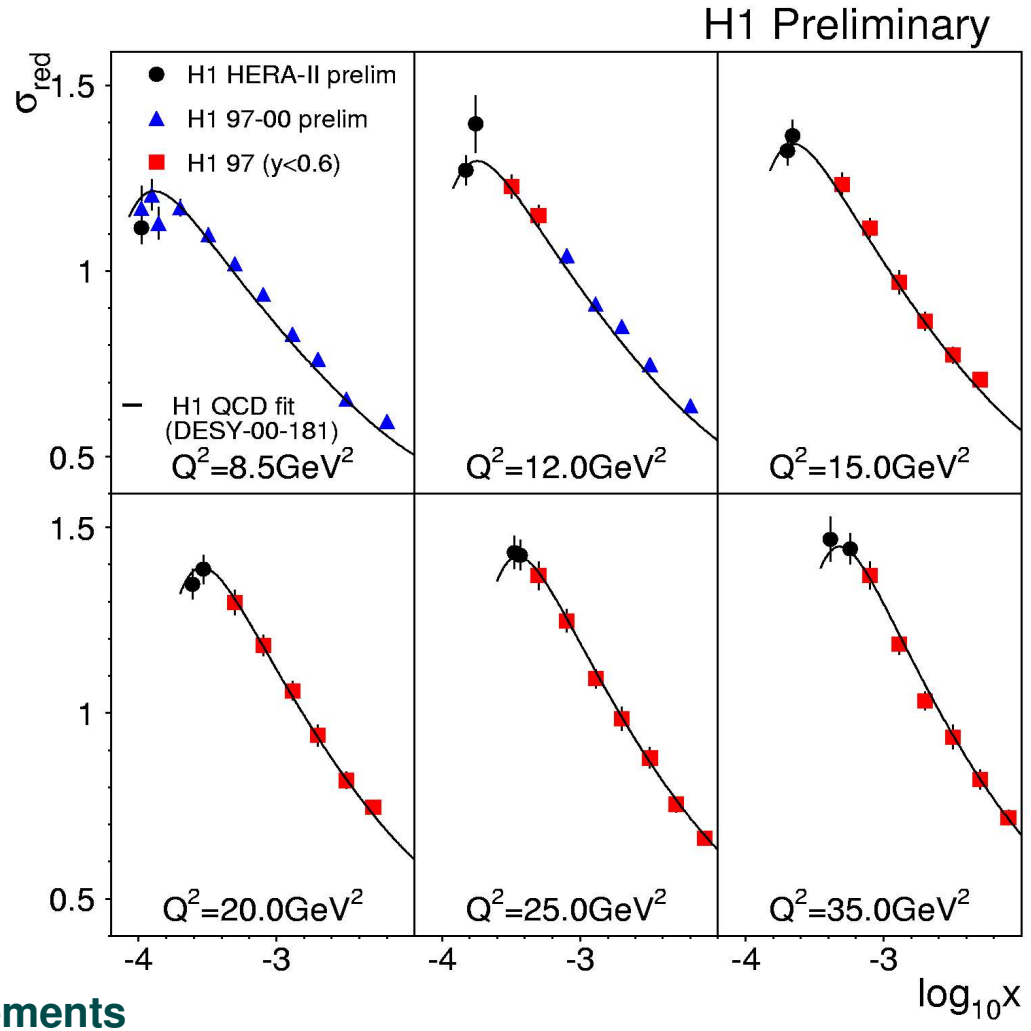

**Background subtracted using charge tag**

**$e^+p/e^-p$ samples complement/compare**

# High y measurement for $Q^2$=8.5 – 35 GeV²

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




**HERA II data used in precision measurements**

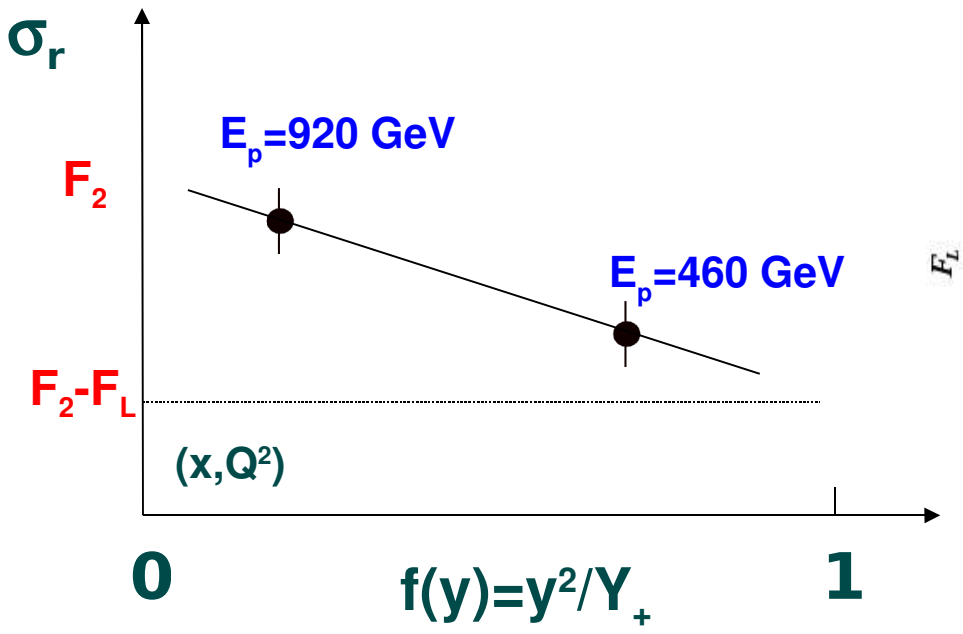
**Uncertainties divided by a factor of 2**

[talk N.Raicevic]

# Direct $F_L$ measurement

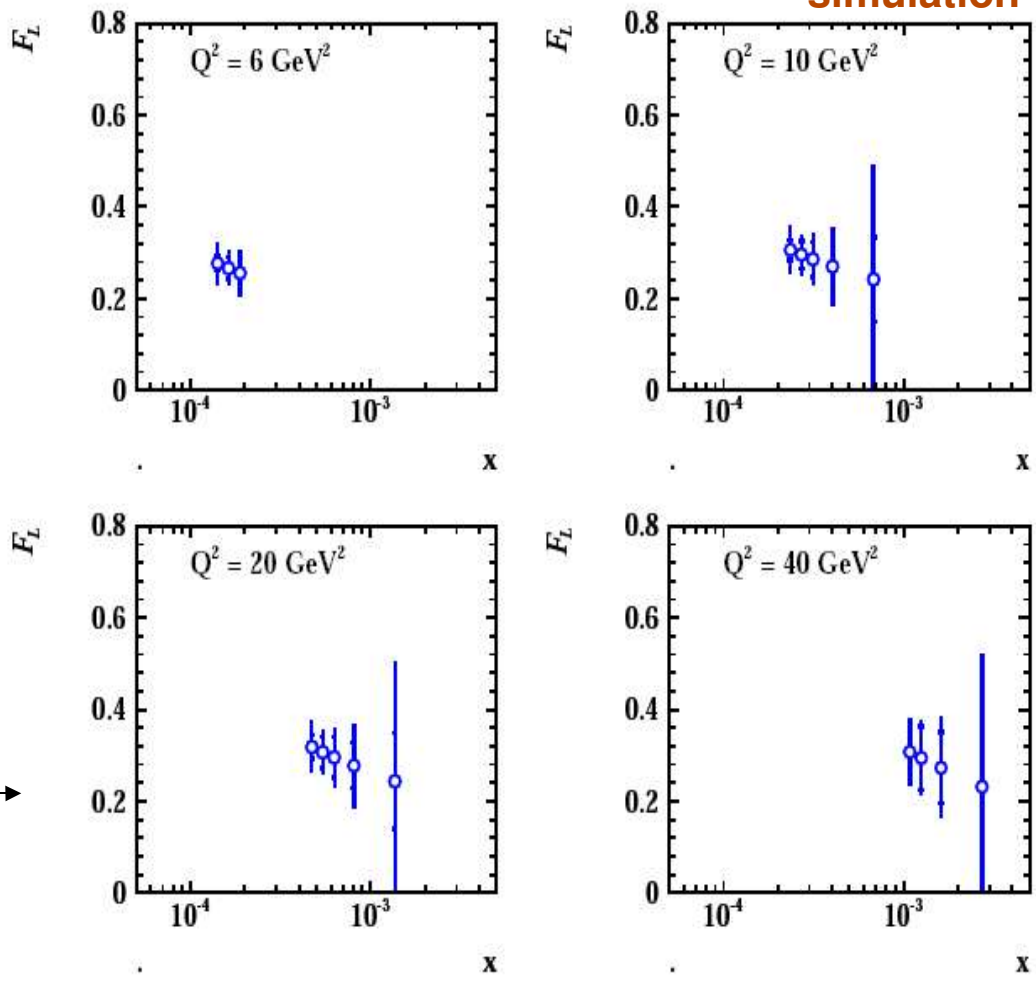
$$\sigma \sim F_2(x,Q^2) + f(y)\, F_L(x,Q^2)$$

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




**Special Run $E_p$=460 GeV : ongoing**

**simulation**

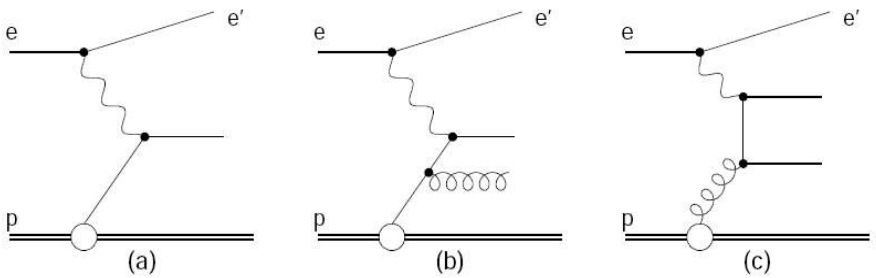


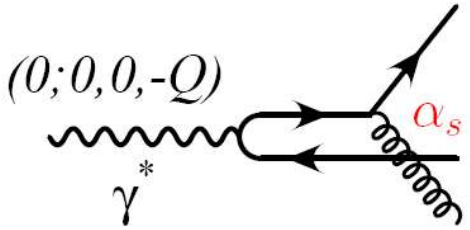

**ys=y's'=$Q^2$/x**

**At low $E_p$ , same (x,Q2) mean lower energy of the detected electron**

**"high y" analysis very important to establish the measurement technique @ s=225² GeV²**

# Jet production in DIS: high $Q^2$

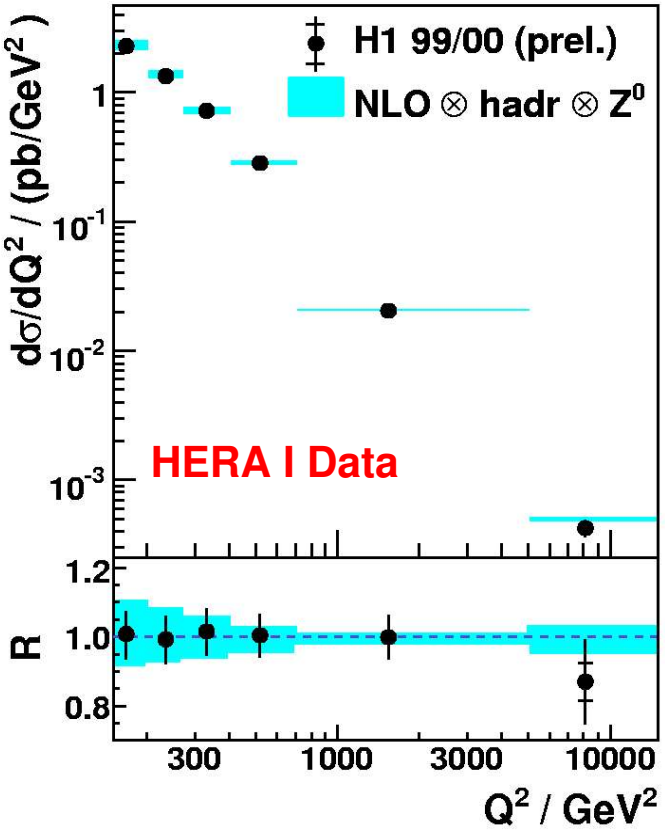


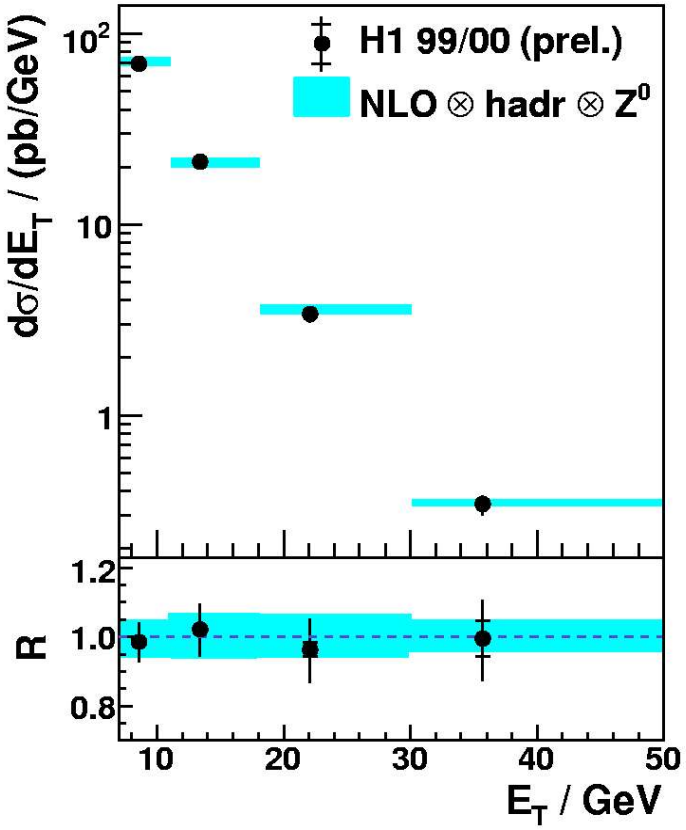




**Inclusive Jet Cross Section**

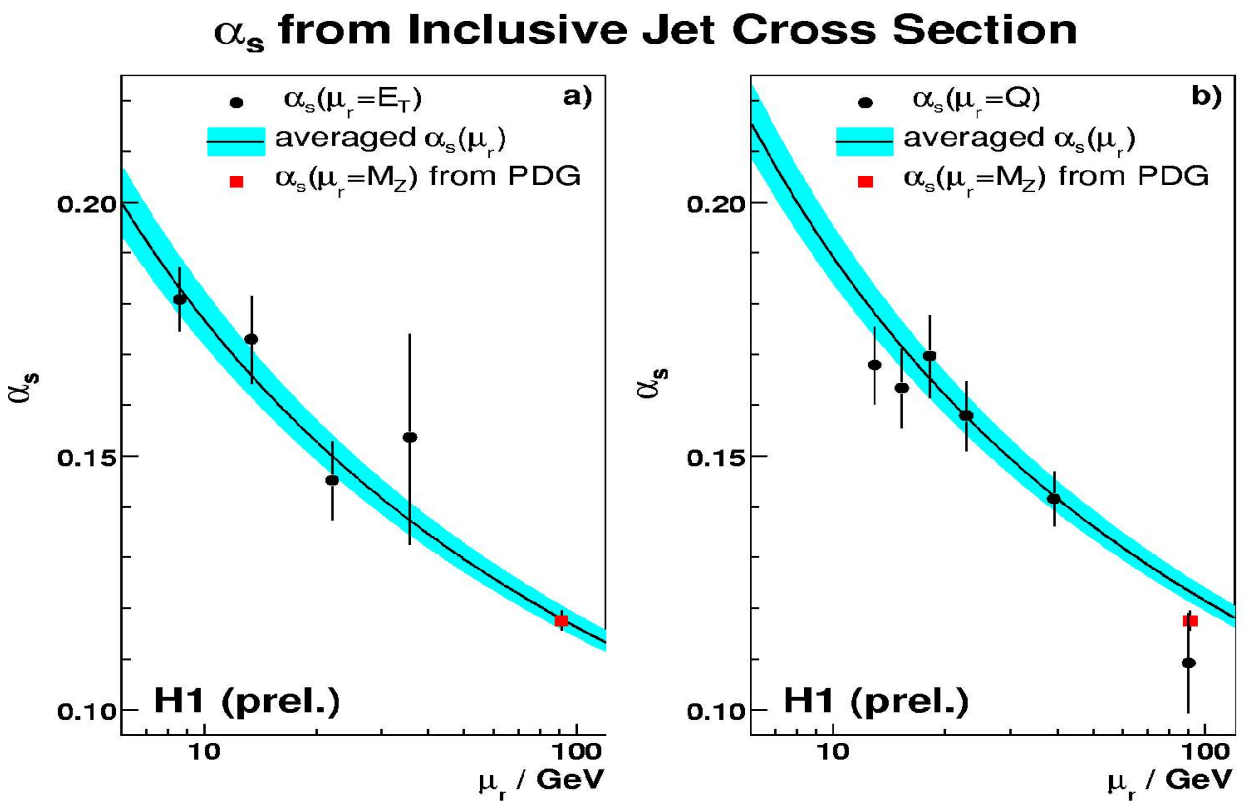
$$150 < Q^2 < 15000 \text{ GeV}^2 ,$$

$$0.2 < y < 0.7 ,$$



# Strong coupling measurement




**Most precise values obtained from the ratio σ(jets)/σ(inclusive)**

$$\alpha_s(M_Z) = 0.1193 \pm 0.0014\,(\text{exp.})\ ^{+0.0046}_{-0.0032}\,(\text{th.}) \pm 0.0016\,(\text{pdf.})$$

$$\alpha_s(M_Z) = 0.1176 \pm 0.0020 \quad \textbf{(PDG)}$$

**Theory error is reduced at high $Q^2$, experimental error increases**

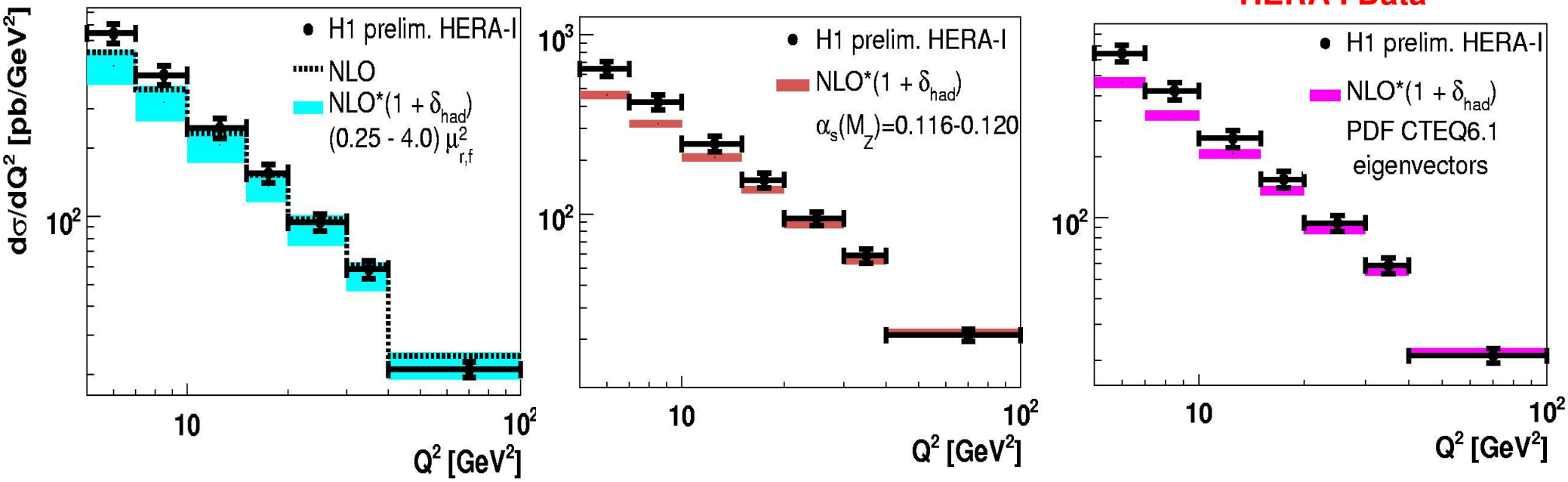
$$700 < Q^2 < 5000\,\text{GeV}^2 \quad \alpha_s(M_Z) = 0.1172 \pm 0.0021\,(\text{exp.})\ ^{+0.0032}_{-0.0017}\,(\text{th.}) \pm 0.0010\,(\text{pdf.})$$

**Improvement expected with full data (/2), theory?**

[talk T.Kluge]

# Jet Production at low Q2

**HERA I data: single and double differential cross sections measured**
**increased statistics and better precision**



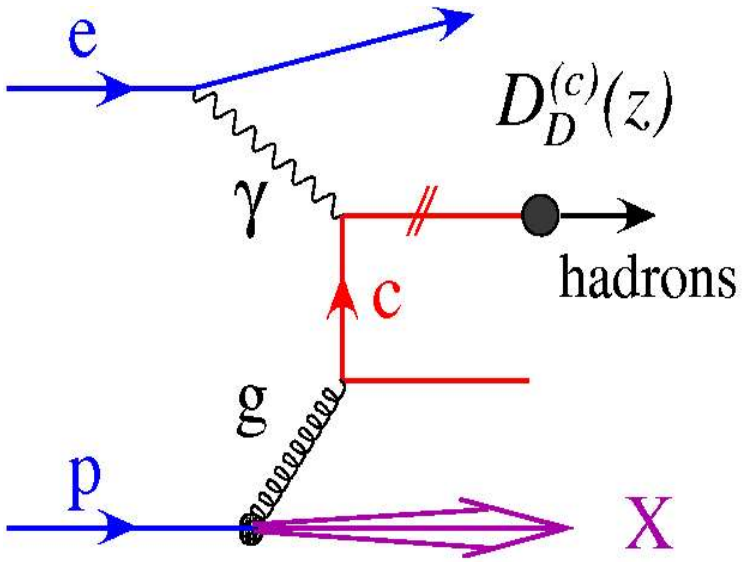

**Sensitivity to the strong coupling, scale dependence still the issue (NNLO needed)**

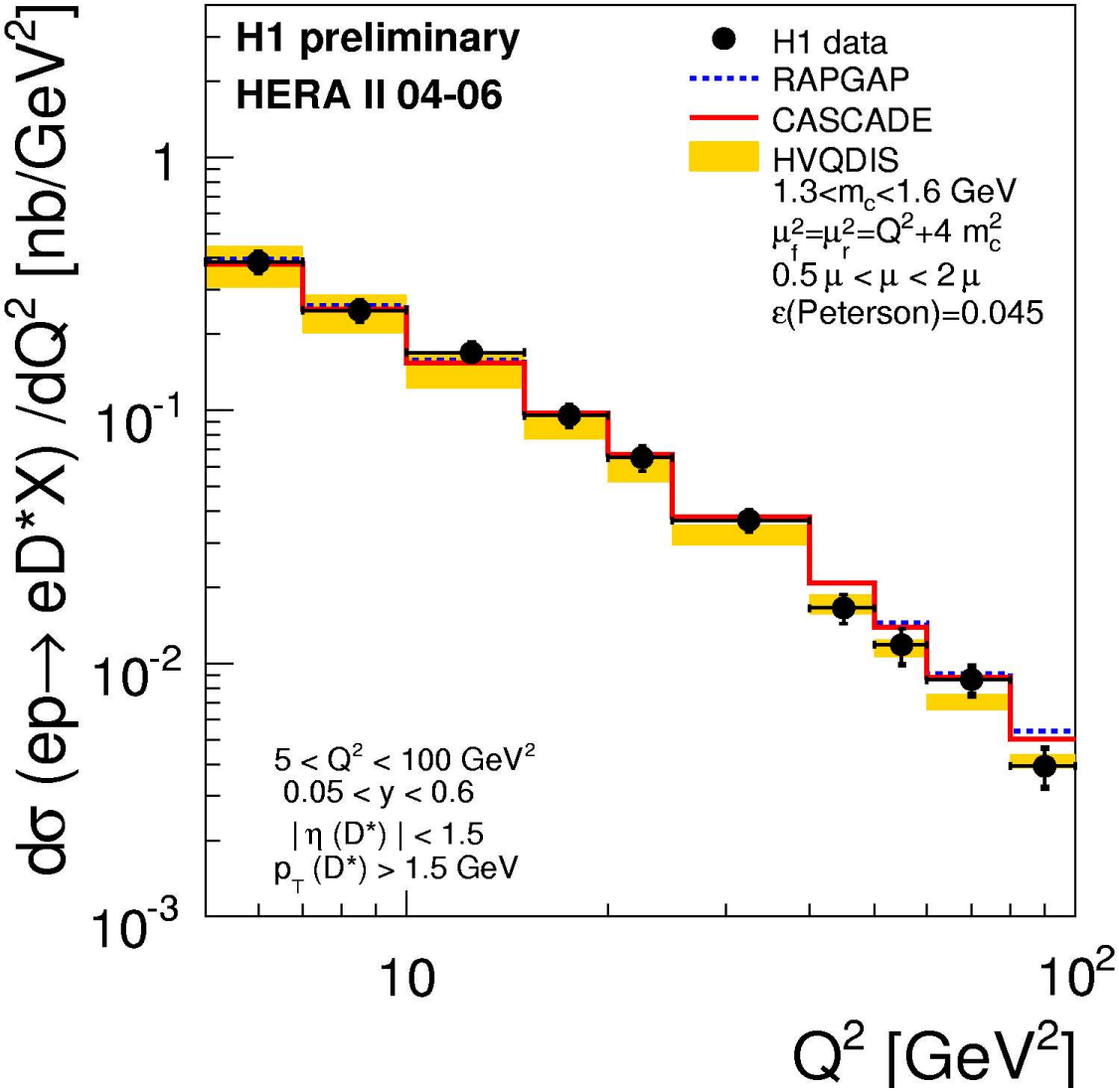
[talk A. Baghdasarian]

# Charm Production in DIS

HERA II data

$L=222\ pb^{-1}$



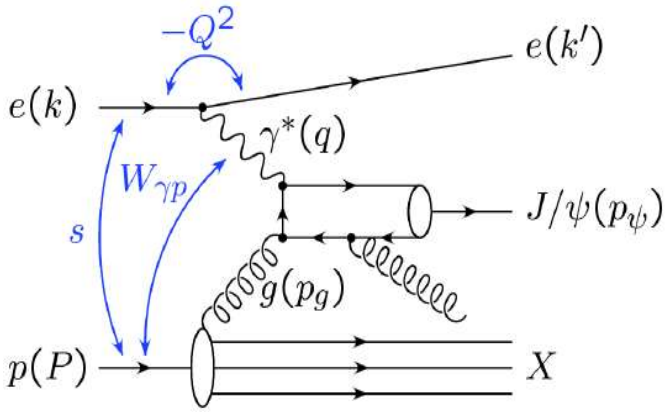

**High precision measurements**

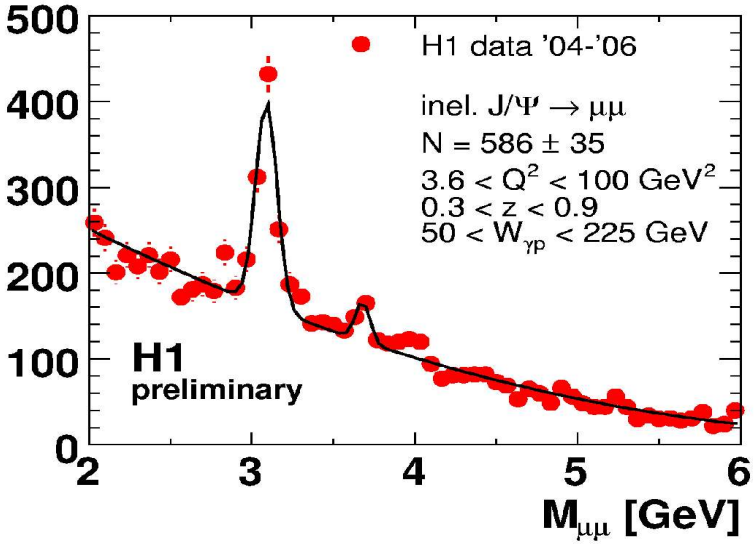
**test QCD and is sensitive to the gluon**

[talk K.Lipka]

# J/Psi electroproduction

HERA II data
L=260 pb$^{-1}$

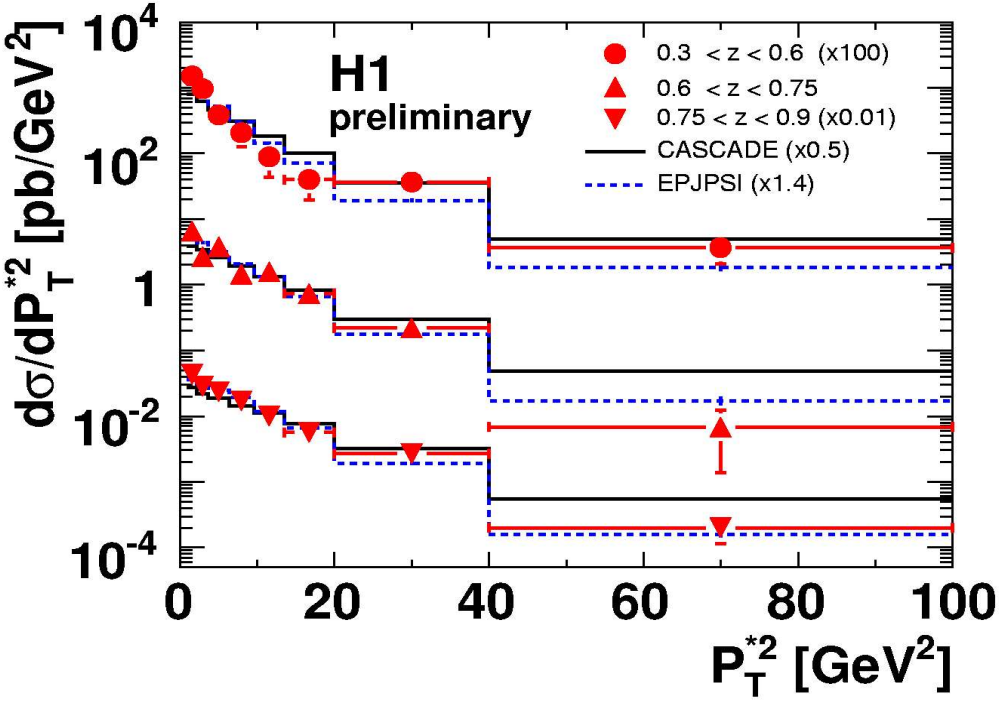



J/ψ→e⁺e⁻
also used

**short distance($Q^2$) ⊗ long distance(J/Psi)**

$$z = \frac{p_\psi \cdot P}{q \cdot P} = \frac{E^*_\psi}{E^*_\gamma} \text{ in } p \text{ rest frame}$$




**MC programs fail to describe data**
**New, precise measurement ready**
**to confront with theory**

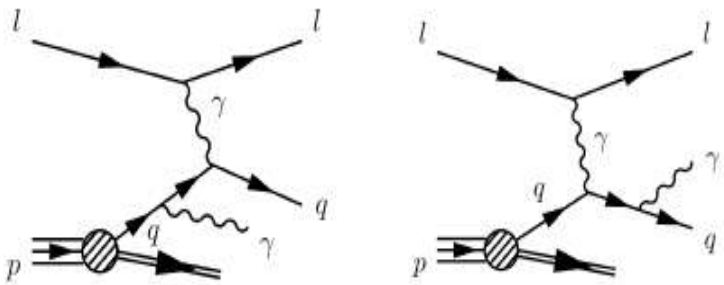
[talk M.Steder]

# Isolated photon production

HERA I+II Data
226 pb$^{-1}$

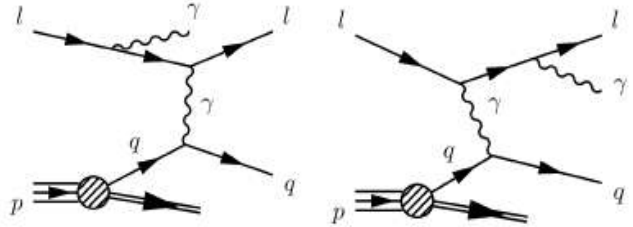
Radiation from the quark

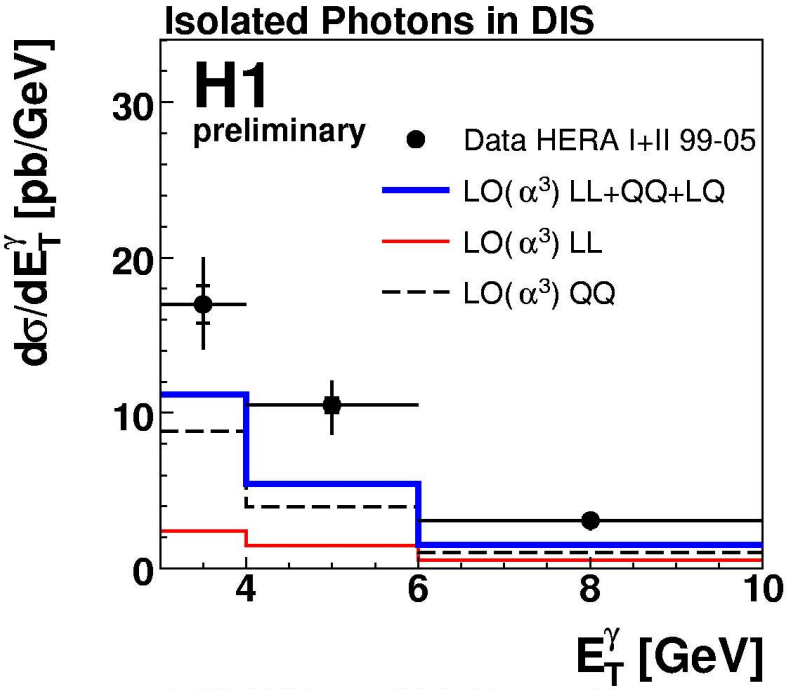
QQ

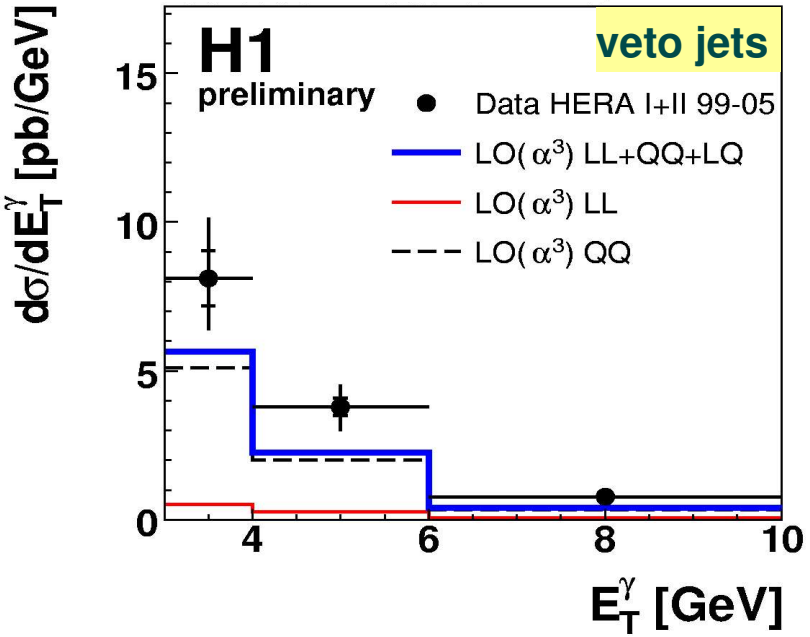


Radiation from the electron

LL






QQ contribution enhanced (inelastic production)

LO calculation underestimates the measurements

NLO needed

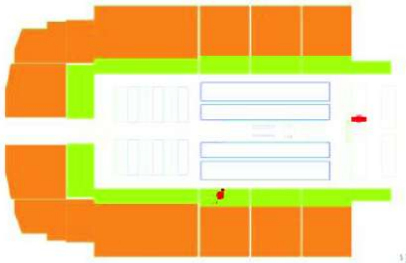
[talk K.Mueller]

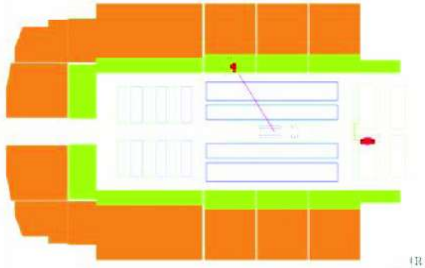
# Deeply Virtual Compton Scattering

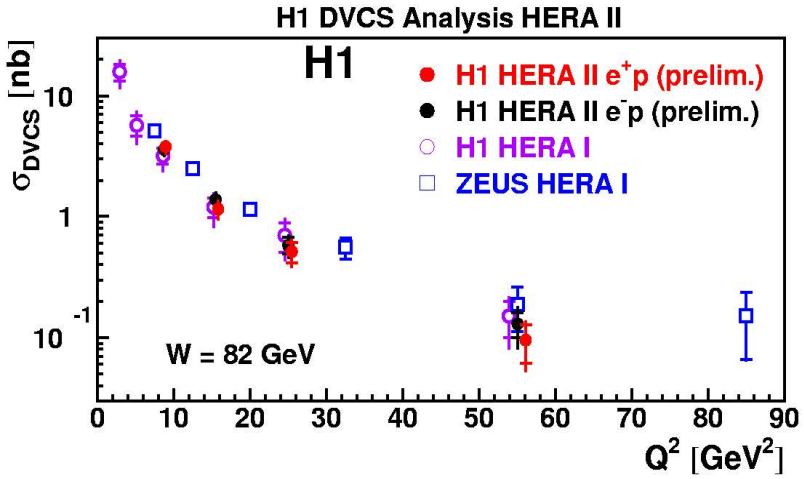
HERA II
$e^+p$ 145 $pb^{-1}$
$e^-p$ 146 pb-1

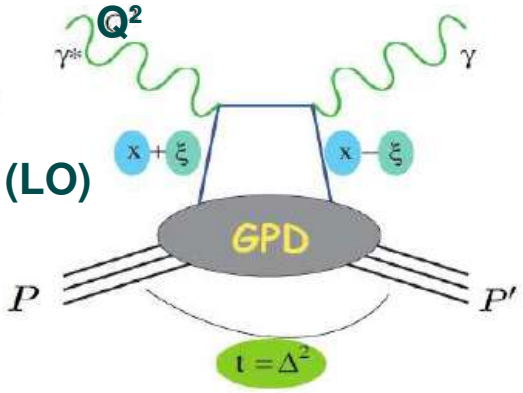
Deeply Virtual Compton Scatering

Bethe-Heitler

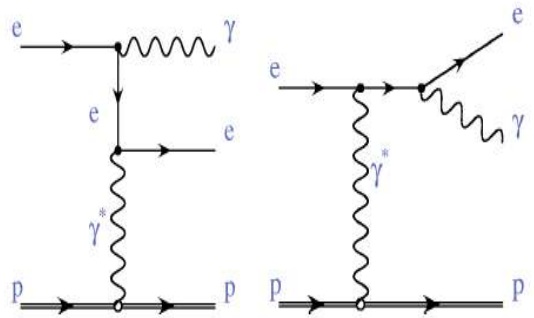




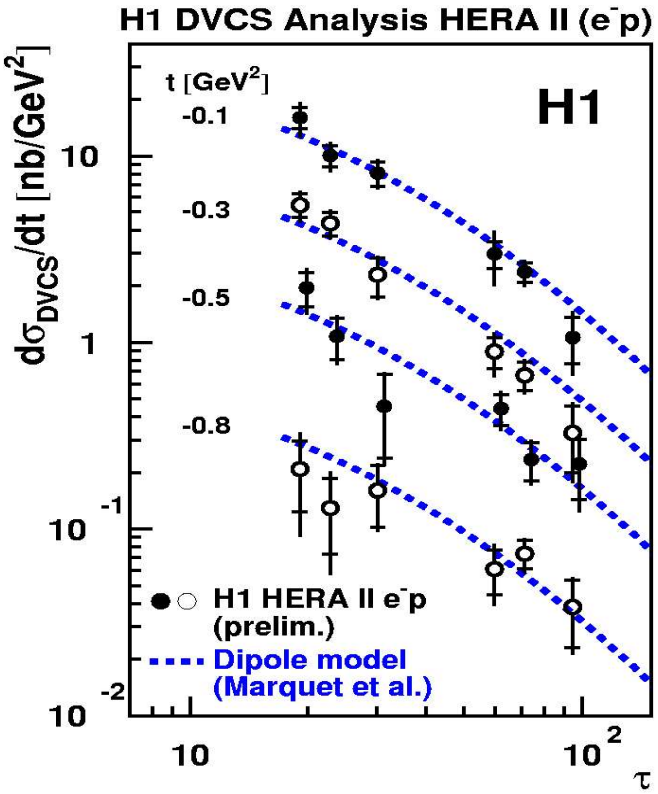



(LO)



$W=E_{cms}(\gamma^* p)$




Access the GPD's

Investigate soft interactions (color dipole model)

$$\sigma(\gamma^* p \to \gamma p)(x, Q^2) = \sigma(\gamma^* p \to \gamma p)(\tau = Q^2/Q_s^2(x)).$$

geometric scaling

# DVCS: $e^+p/e^-p$ asymmetry

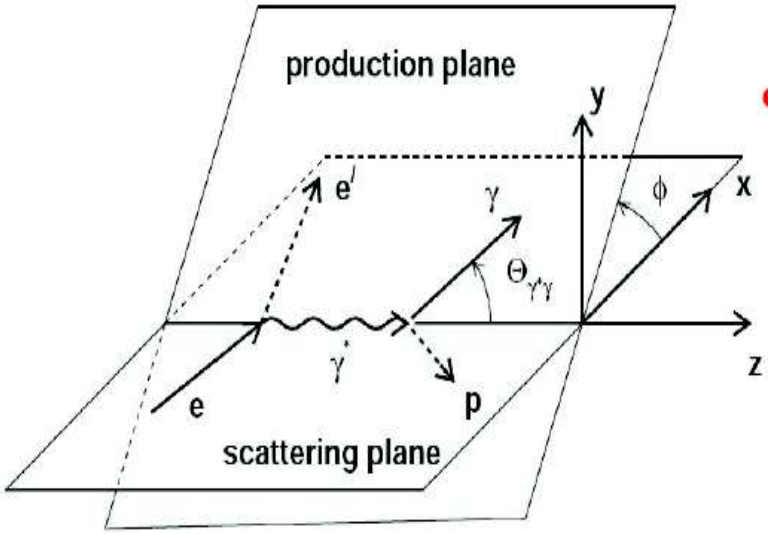
**Interference as "extractor" of new effects**

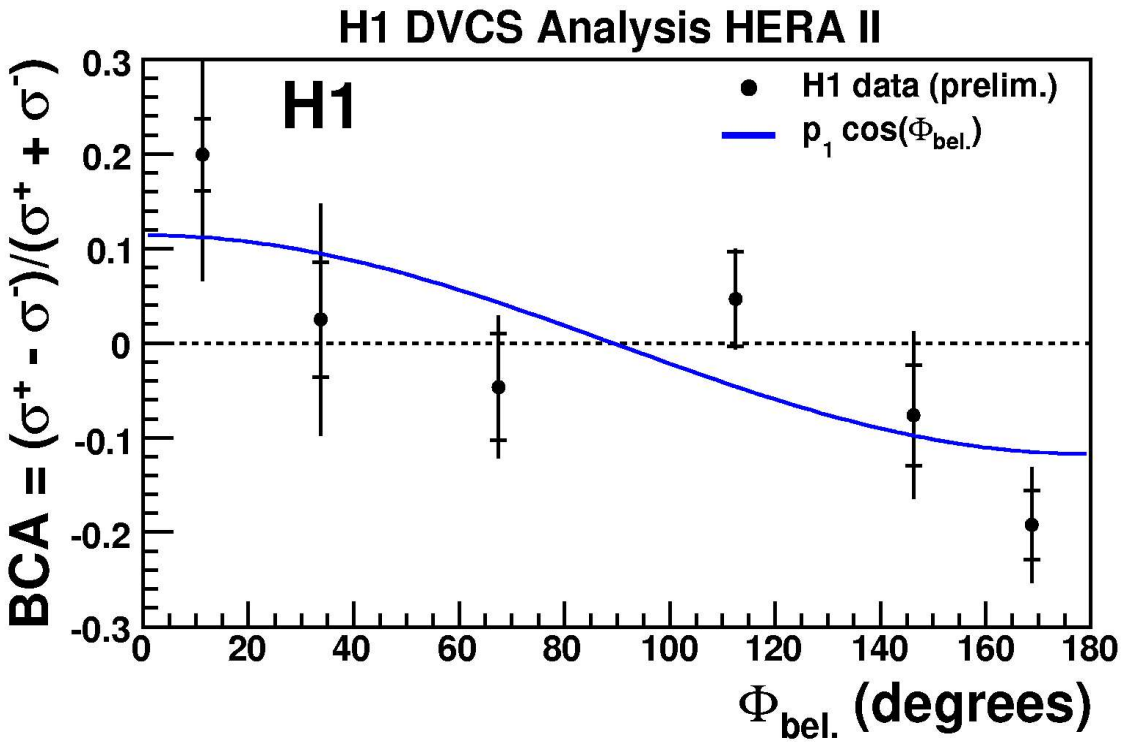
$$d\sigma_{ep\to ep\gamma} \simeq d\sigma^{BH} + d\sigma^{DVCS} + A^{BH} Re A^{DVCS}$$

e-beam charge dependent component

$$BCA = \frac{\sigma^{e^+p} - \sigma^{e^-p}}{\sigma^{e^+p} + \sigma^{e^-p}} = f(\Phi_{BEL}) \simeq \sum_{n=1,3} p_n \cos n\Phi_{BEL}$$

Complementary information, direct access to GPD's




**First measurement in collision mode at HERA**

[talk L.Schoeffel]

**Not covered in this talk**

**Diffractive Charm** [talk Paul Thompson]

**Diffractive Dijets** [talk Matthias Mozer]

**Status of the H1 VFPS** [talk Laurent Favart]

**Minijet Production in DIS** [talk Sakar Osman]

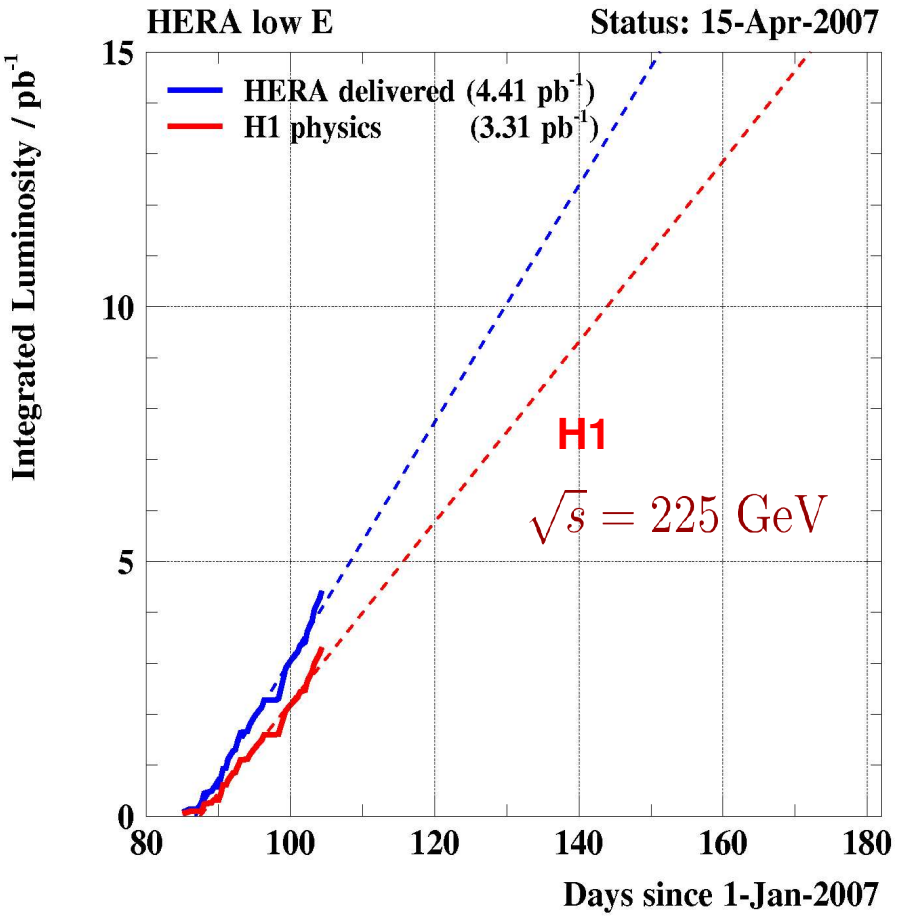
**Xi-pi Baryon Search** [talk Marc Del Degan]

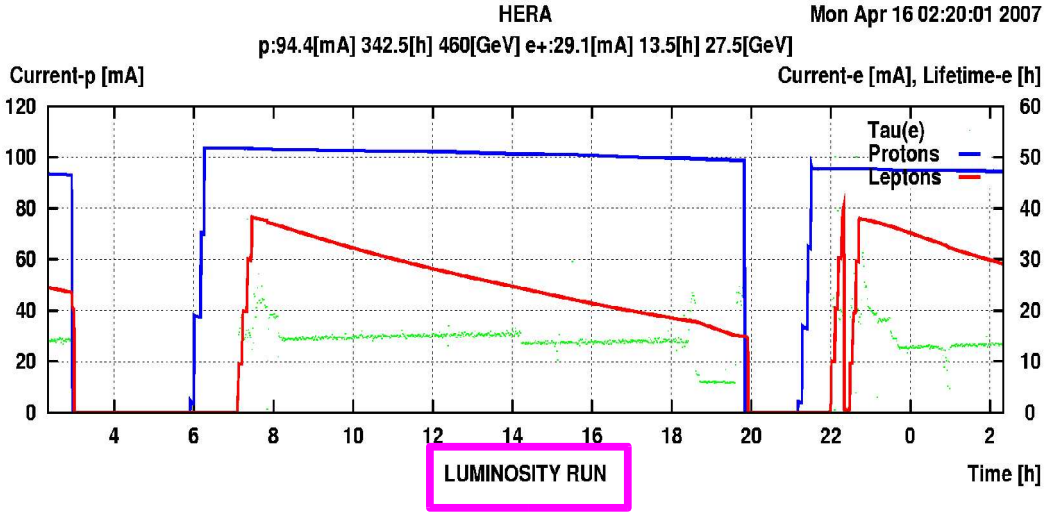
**3-jet Production in DIS** [talk Grazina Nowak]

**Charm Production with Jets** [talk Sebastian Schmidt]

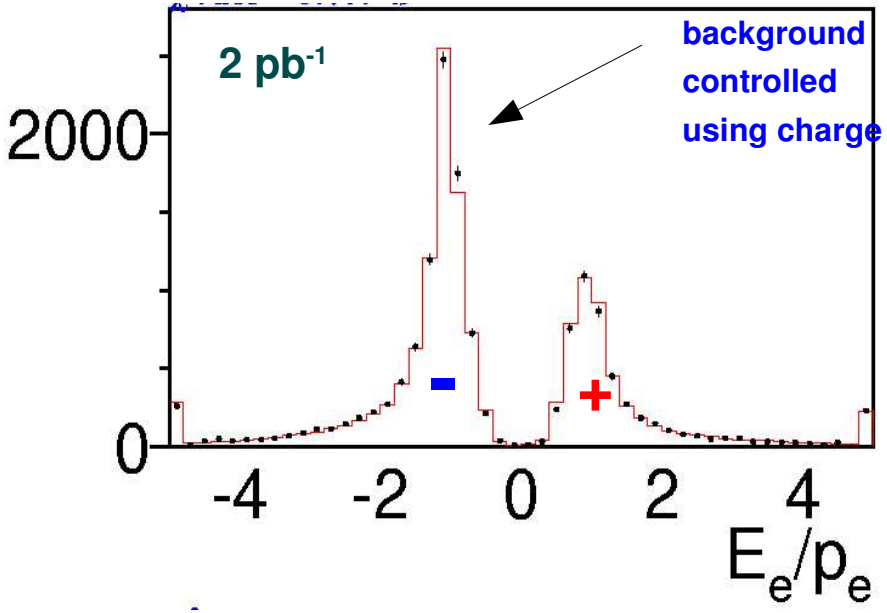
# News from the low energy run

- Started 21.03, measurement goal 10 $pb^{-1}$
- Now regular operation, luminosity production
- Excellent detector performance




phase space of the high y analysis




[talk Max Klein]

# Conclusions and outlook

- H1 collected ~0.5 $fb^{-1}$ at $E_{cm}$ ~320 GeV
  - Searches for new physics ongoing, full statistics exploited
    - 3$\sigma$ effect on isolated leptons remains
  - High $Q^2$ measurements: PDF constraints and EW effects from fits
  - Low Q2: best precision approached using now HERA II data
  - QCD studies: HQ production, jets, $\alpha_S$,diffraction...
- Low energy run ongoing
  - $F_L$ fundamental measurement, independent constraint on gluon density
- New step in HERA program: end of collisions 07/2007
  - plethora of new results expected from HERA in the next years
    - improvements in statistics, systematics challenges
    - H1+ZEUS combination
- Rich legacy to LHC and beyond is being built now