Particle Production and Fragmentation

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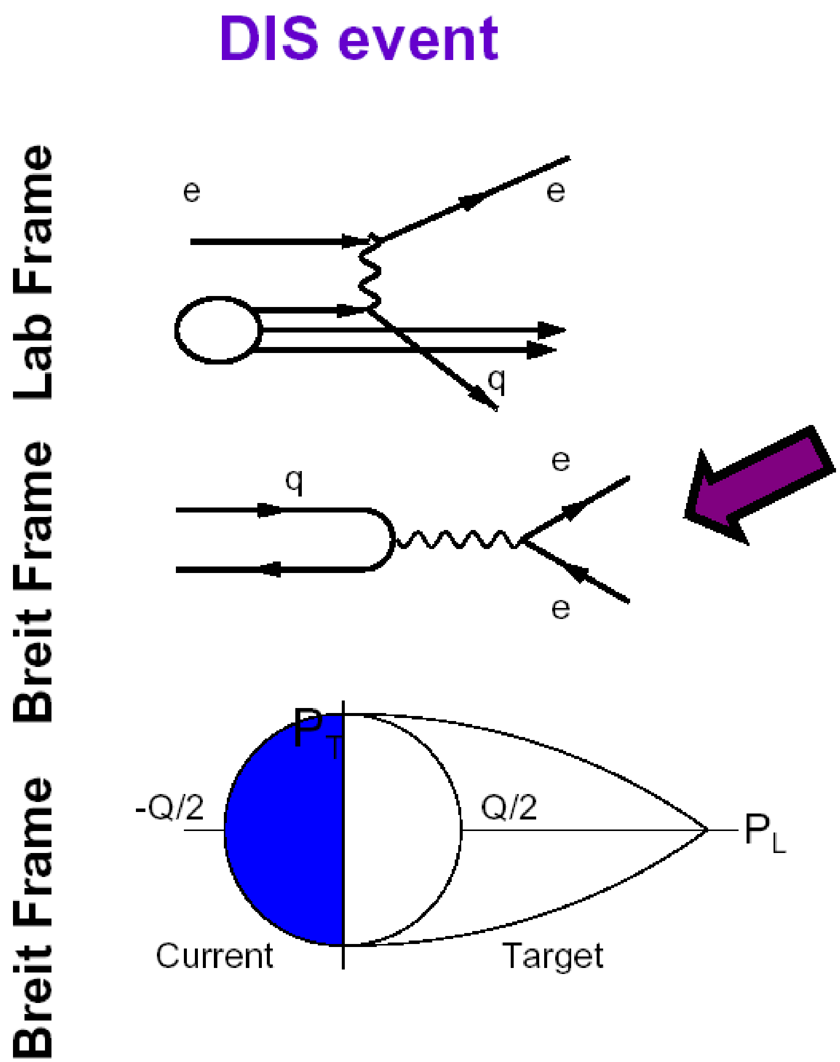
H1 & ZEUS data. New theory.

Charged Multiplicities in DIS and DDIS
Inclusive photoproduction of non-strange mesons
Strange Particle production
Charm fragmentation
Baryons decaying to strange particles
Antideuteron production
KK Bose Einstein correlations
Prompt photon production in DIS

DIS particle multiplicities: use of Breit frame

(De Wolf)



- Use Breit frame to compare multiplicity in ep to (one hemisphere) of e^+e^-
- Breit Frame definition:

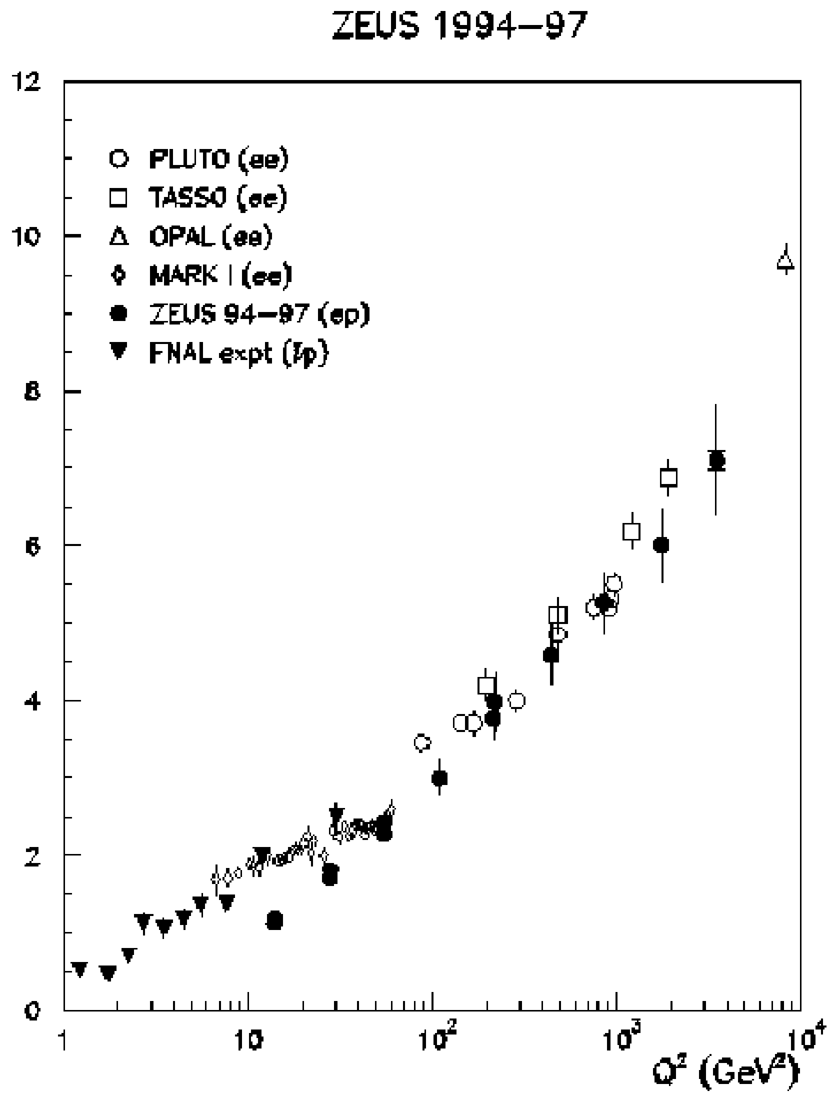
$$2xP + q = 0$$

- "Brick Wall frame": incoming quark scatters off photon and returns along same axis.
- Current region (CR) of Breit Frame is analogous to e^+e^- in 0^{th} order pQCD =Quark-Parton Model and energy = Q/2
- But: QCD Compton and Boson-Gluon Fusion processes → Particle migration out of current region

K.H.Streng et al. ZPC 2 (1979) 237; S. Chekanov J.Phys. G (1999) 59, hep-ph/9806511; 9810477

- Energy in CR < Q/2
- **ZEUS: use measured energy in CR of Breit Frame as energy scale**

$<n_{ch}>$: *ep* (Breit frame) v e^+e^-



e^+e^- data divided by 2

Similar within largeish errors at high Q^2

ep result lower at lowest Q^2

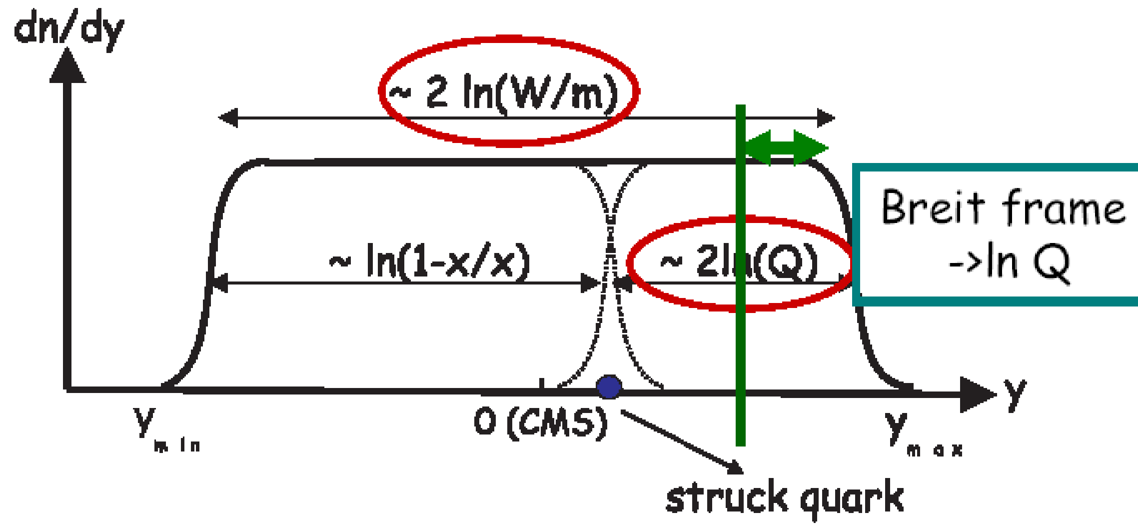
Only looking at a fraction of each event.

Can we look at more of each event?

DIS

$W^2 \sim Q^2/x$

$Y_{max} = \ln(W/m_\pi)$

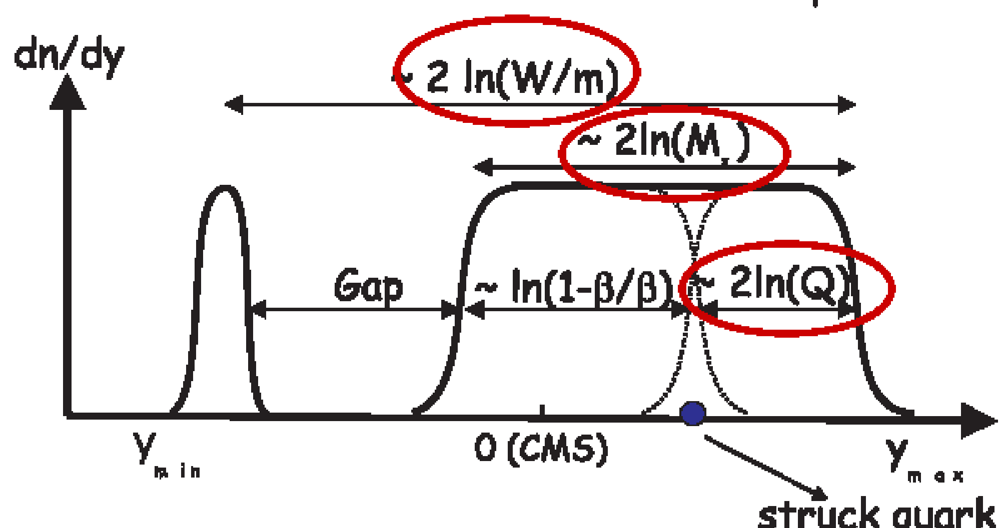


In DDIS β plays role of x in DIS

DDIS

$$M_X^2 = Q^2 \frac{1-\beta}{\beta}$$

$$\text{gap} \sim \ln \frac{1}{x_{IP}}$$

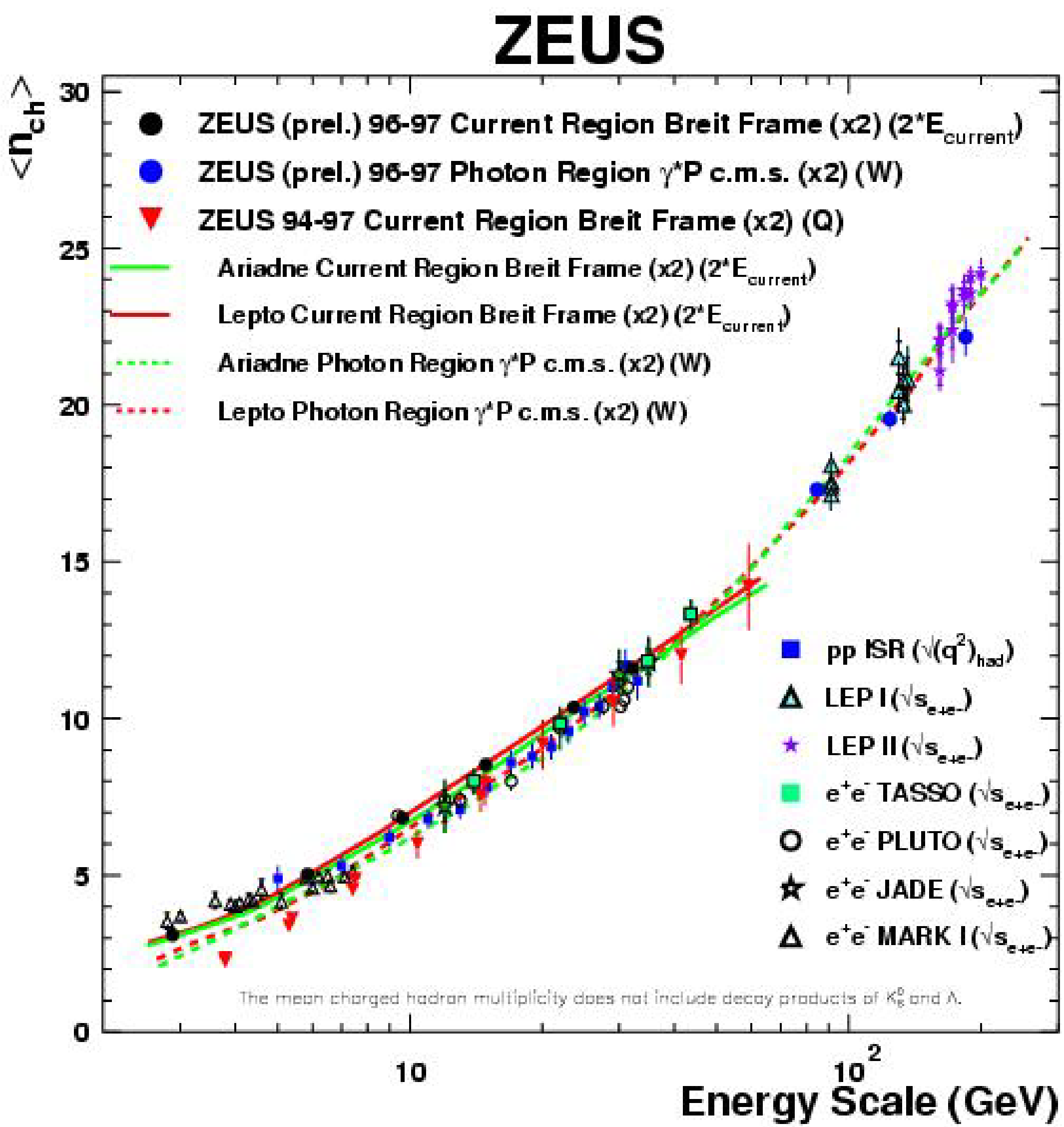


(De Wolf)

$<n_{ch}>$: *ep* (Breit, $\gamma^* p$ c.m.s.) v e^+e^-

excludes K^0, Λ decay products

$2*<n_{ch}>$ for *ep*



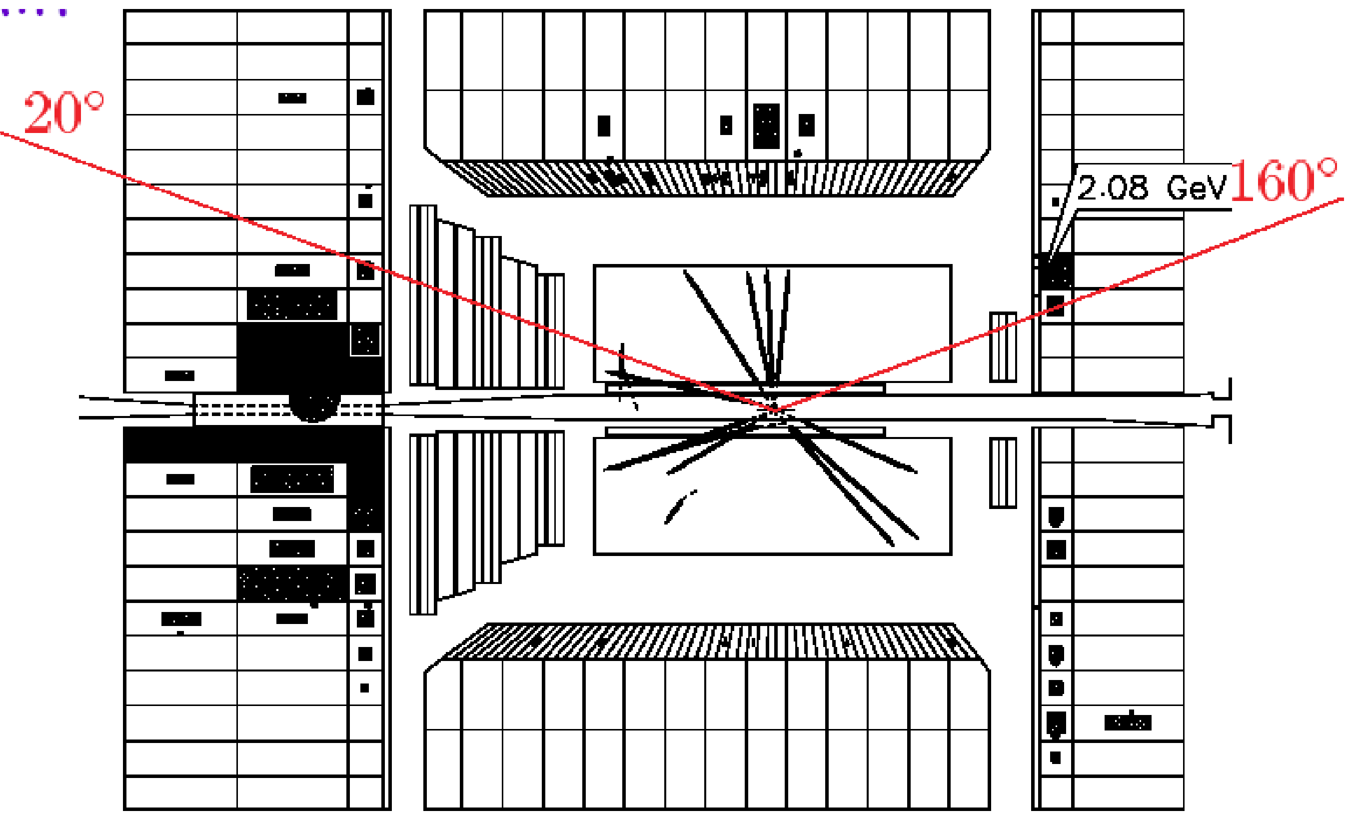
Breit frame:

Closer to e^+e^- if $2*E_{\text{current}}$ used as scale – black dots

$\gamma^* p$ c.m.s. current region:

close to e^+e^- over wide range using W as scale – blue dots

ZEUS: M_{eff} using best part of central tracker



Exclude scattered electron

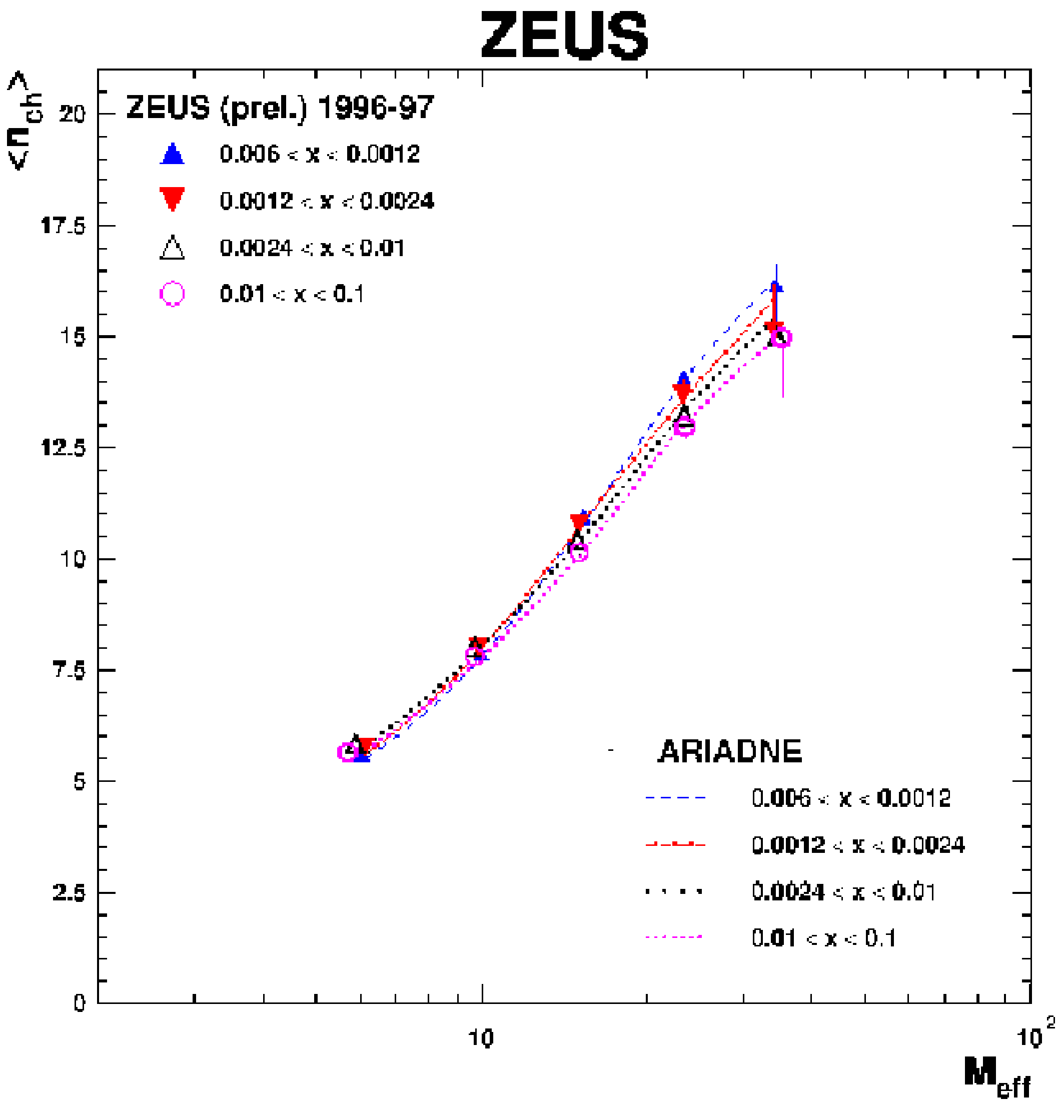
Use best angular range for counting tracks

Use same angular range in calorimeter for

$$M^2_{eff} = (\Sigma E)^2 - (\Sigma \boldsymbol{p})^2$$

↑ vector

$\langle n_{ch} \rangle$ v M_{eff} in x-bins

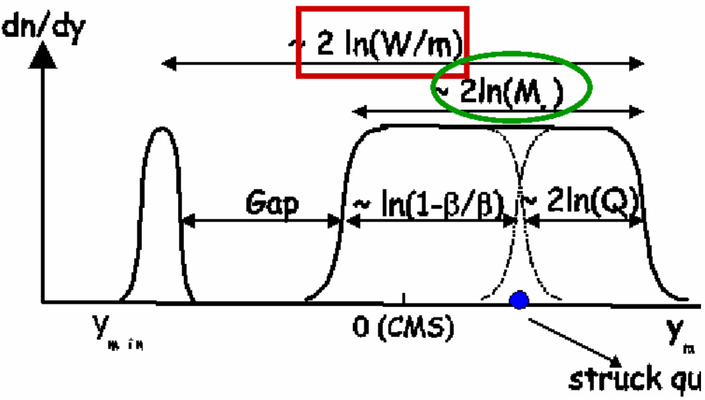


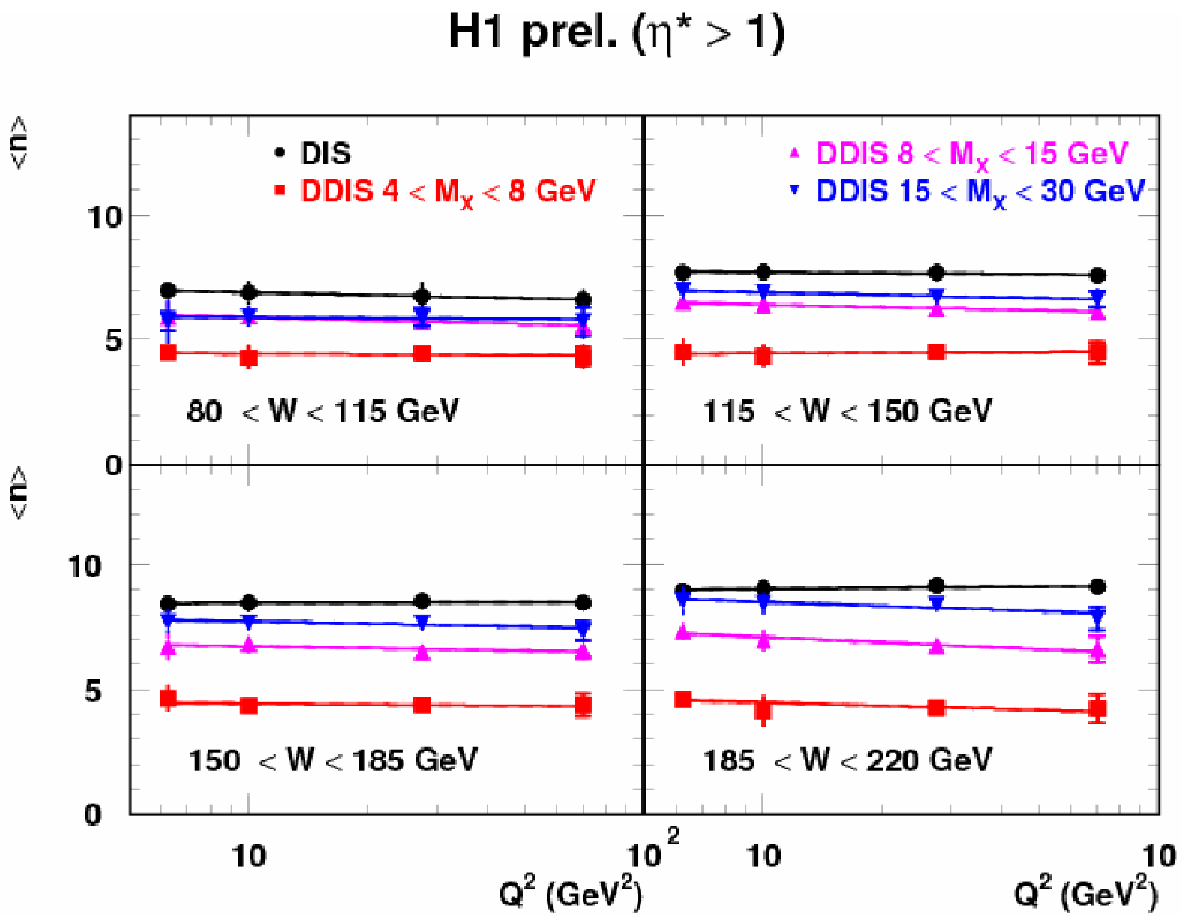
Lab frame measurement agrees well with Ariadne

Weak-x_{Bj} dependence

No Q^2 dependence observed

H1: $<n_{ch}>$ v Q^2 in DIS and DDIS at fixed W





DIS data + DDIS at fixed M_x

No statistically significant dependence on Q^2

Weak W-dependence in DDIS

Rapidity spectra v weak Q^2 dependence (not shown)

$<n_{ch}>$ v W at fixed M_x in DDIS (De Wolf)

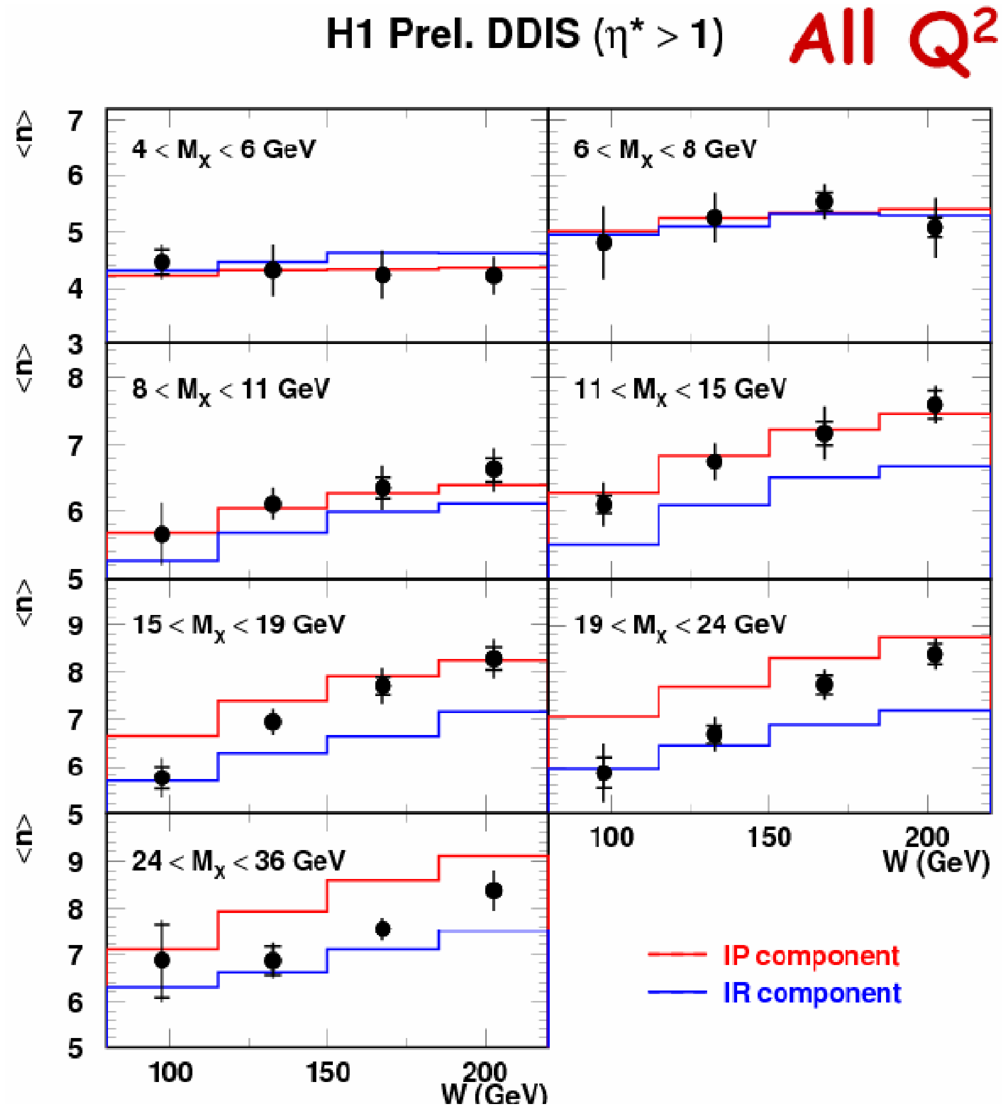
At fixed M_X : changing W means changing gap and x_{IP}

Regge factorization means diffractive pdf's AND Final state properties independent of x_{IP}

W-dependence = breaking of Regge factorization

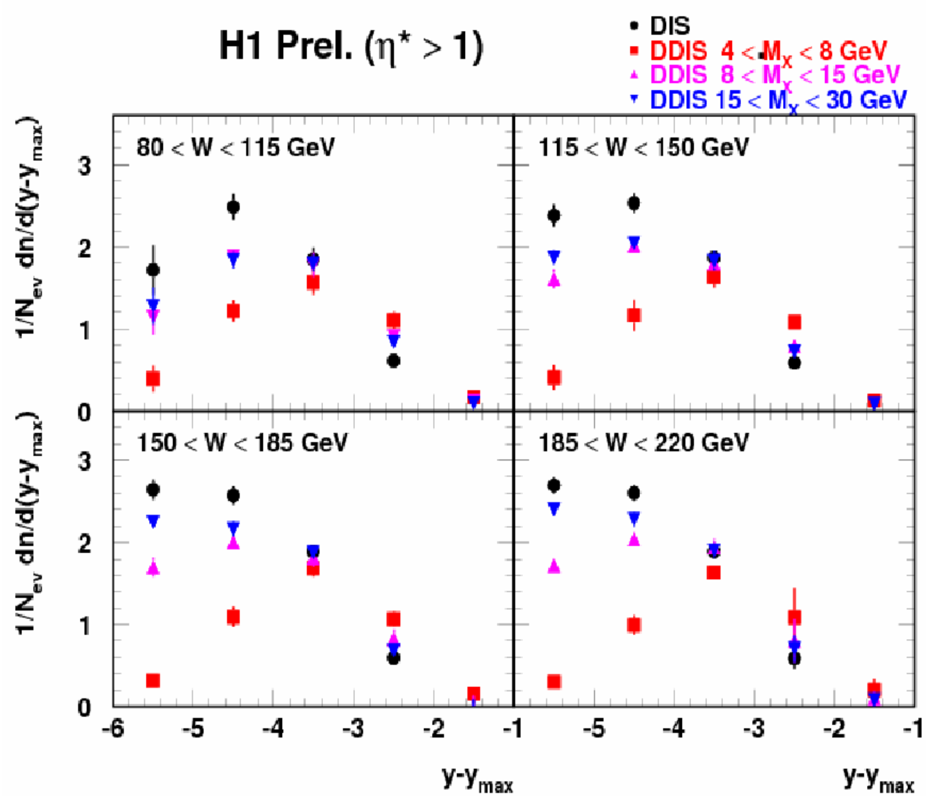
In resolved Pomeron model: pomeron + reggeon

Large M_X : Data move from Reggeon to Pomeron as W grows



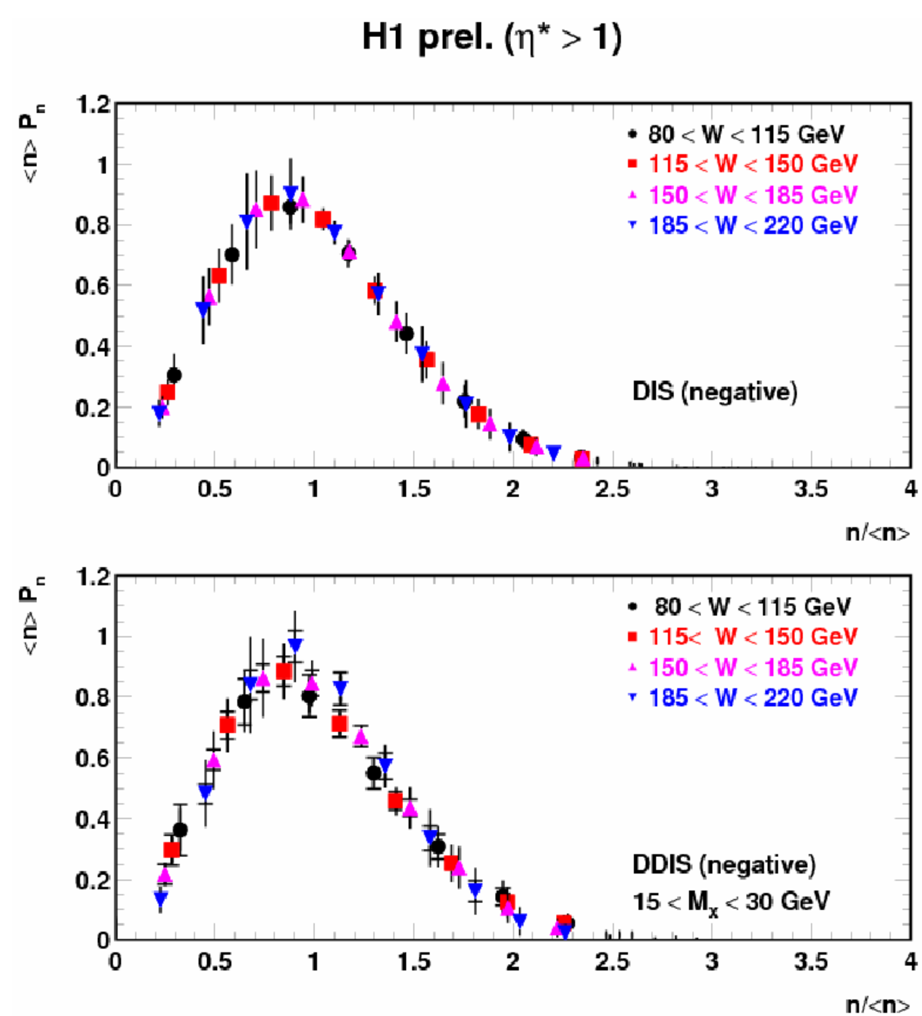
DIS v DDIS:

Rapidity distribution

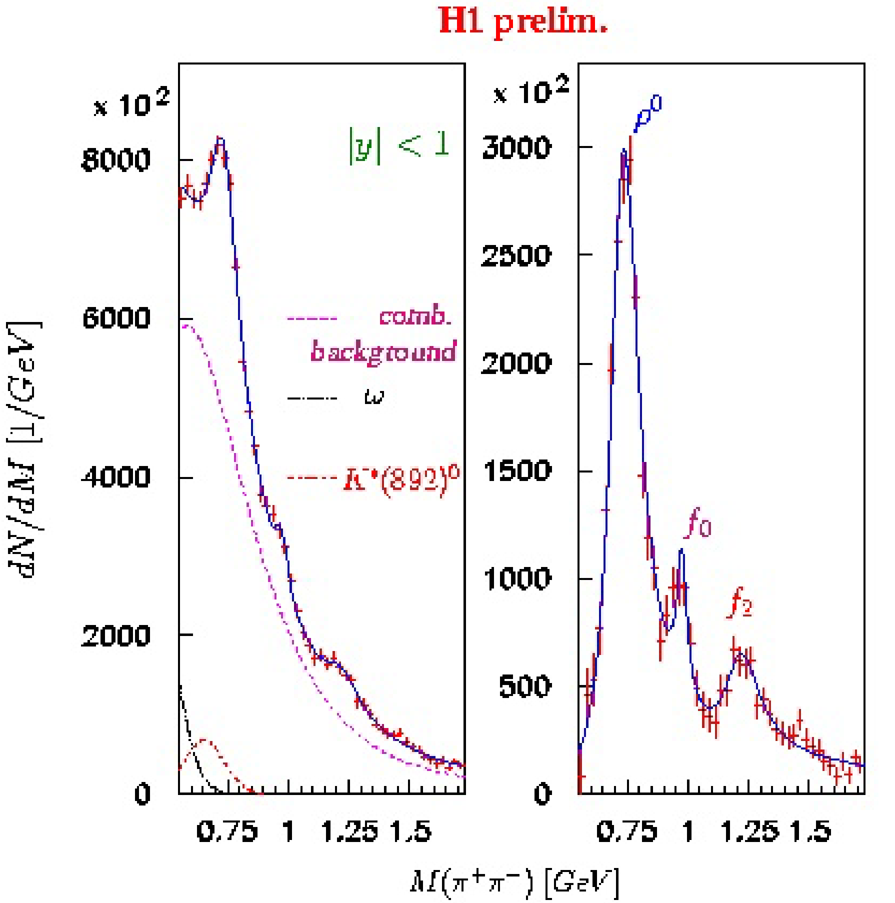


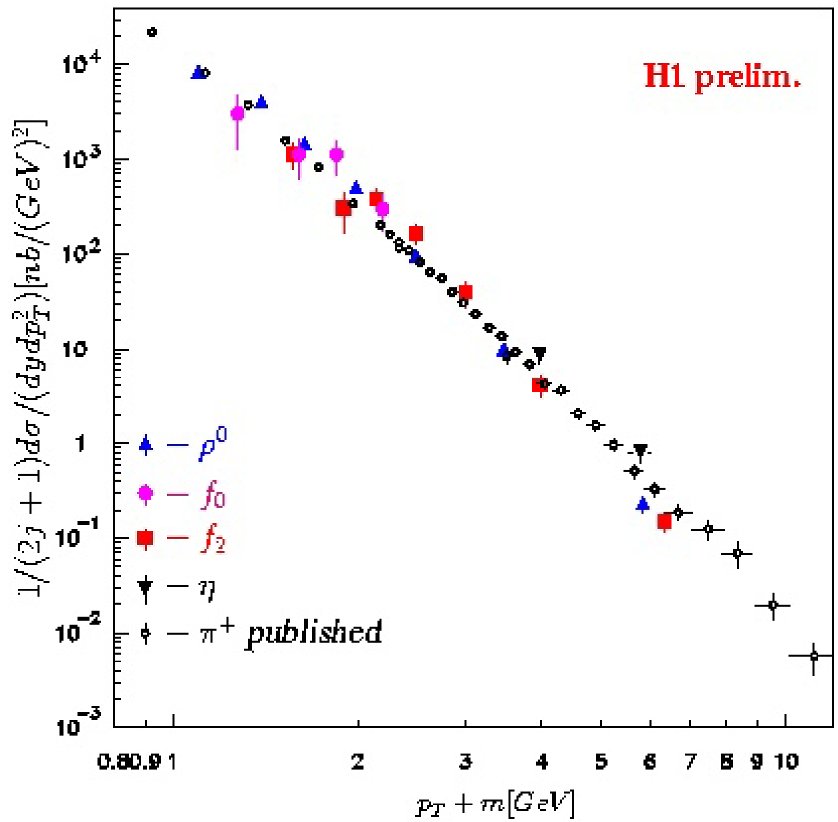
Similar rapidity density at high M_x.
DDIS gluon rich presumably

KNO scaling



$\rho^0, f_0, f_2, \eta, \pi^{\pm}$ inclusive photoproduction

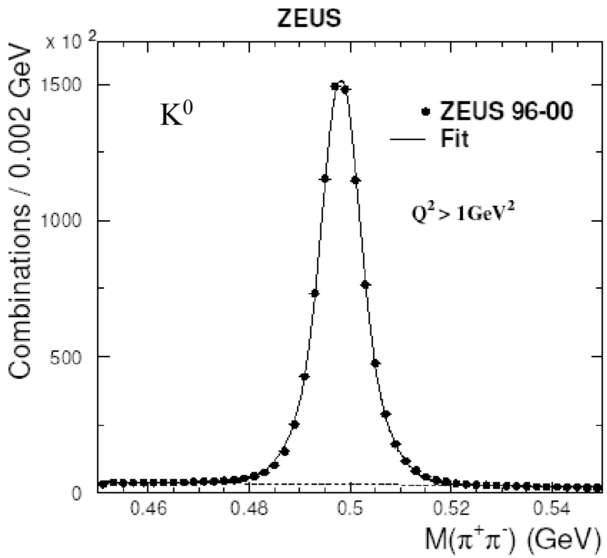


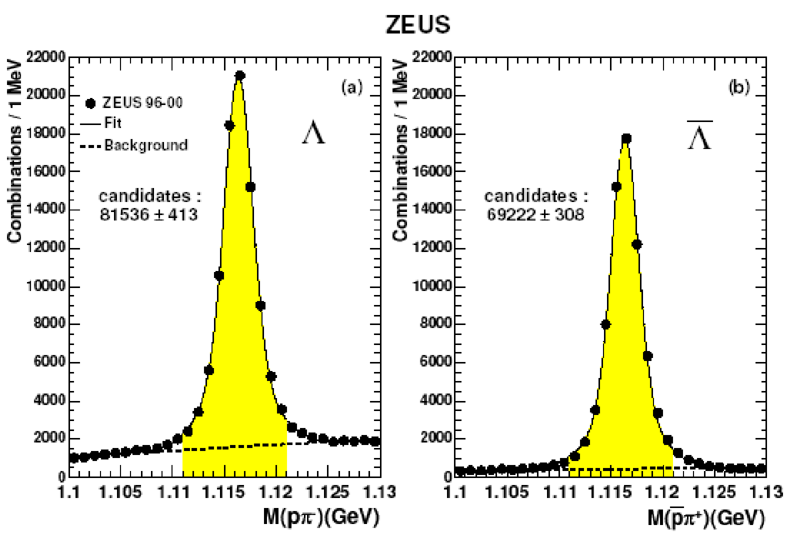


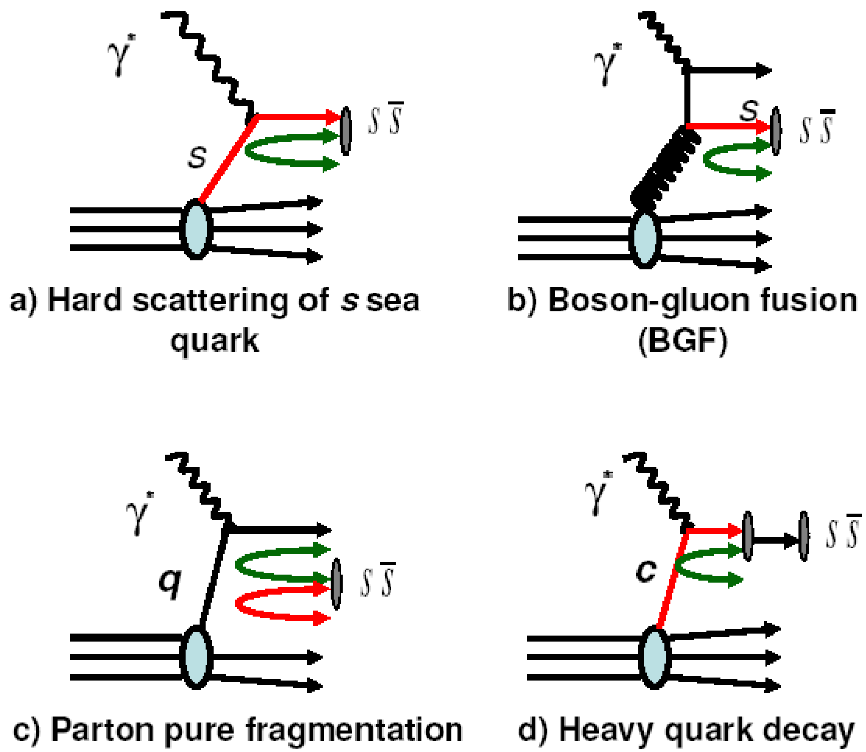
Tricky background & reflection removal

Universal curve plotted against (p_T+m)

$K^0, \Lambda^0, \bar{\Lambda}^0$ production

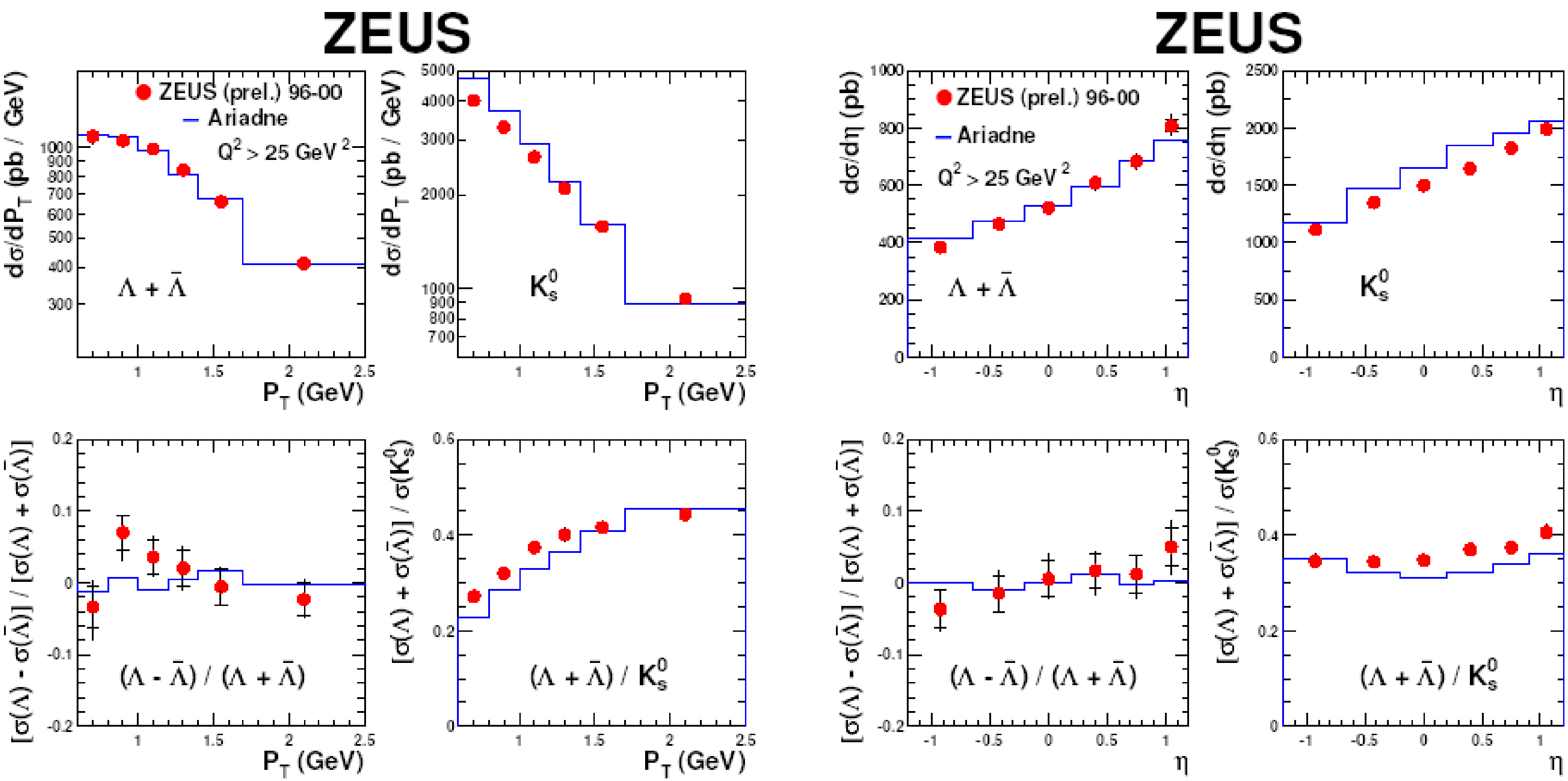






(C Liu)

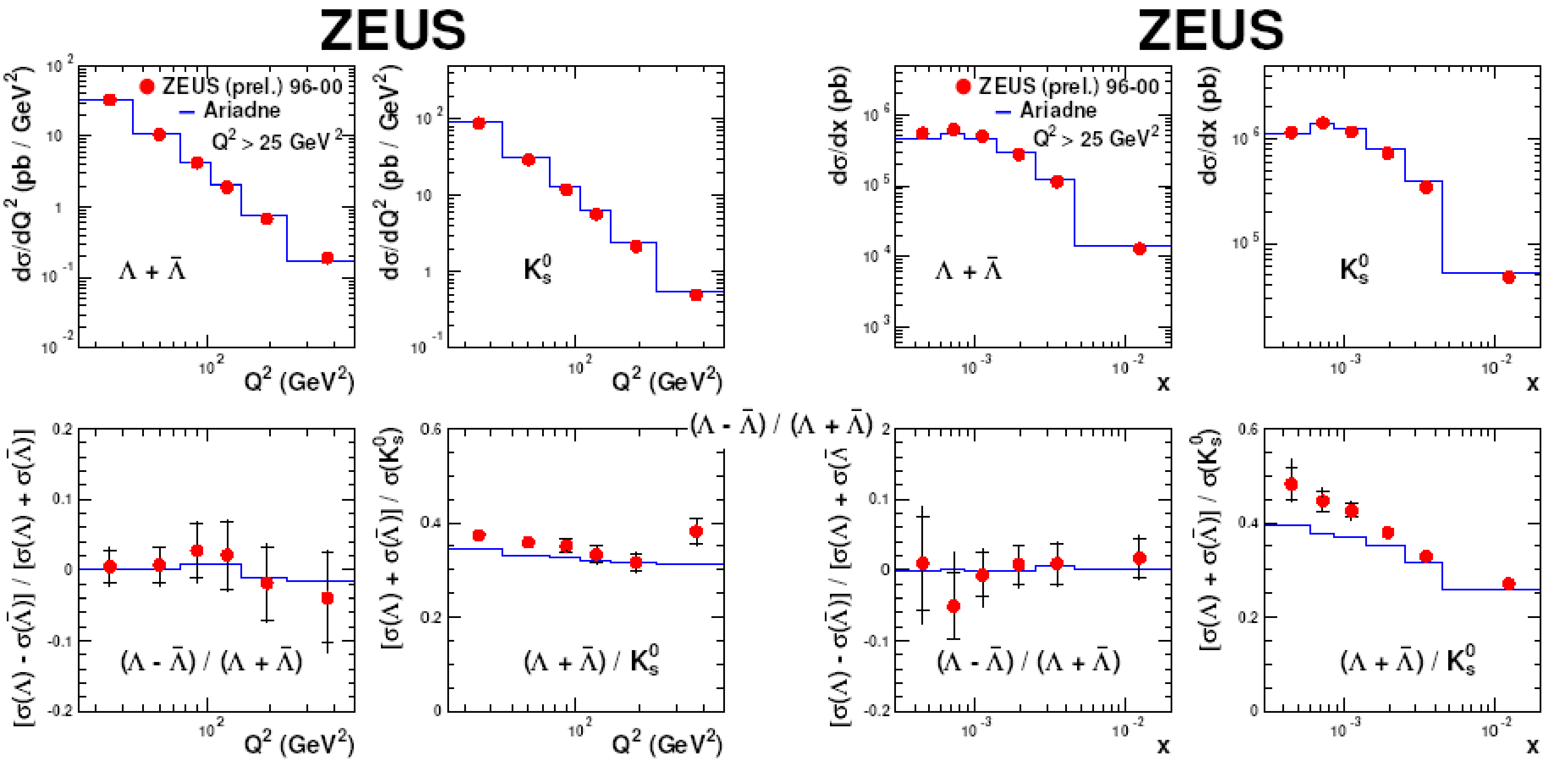
K^0, Λ^0, $\bar{\Lambda}^0$: p_T and η



Ariadne mostly OK: overestimates K^0 rate. Favours smaller *s/u* ratio (0.22?)

Λ – Λbar: no significant asymmetry

$K^0, \Lambda^0, \bar{\Lambda}^0$: Q^2 and x

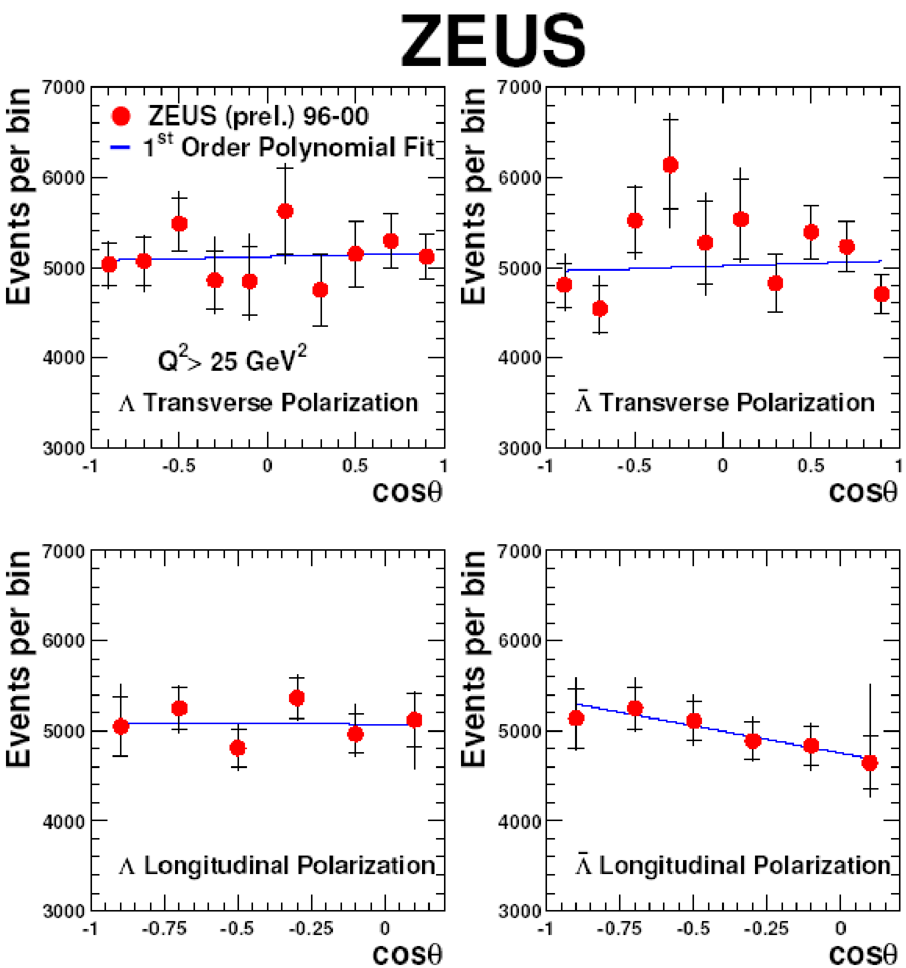


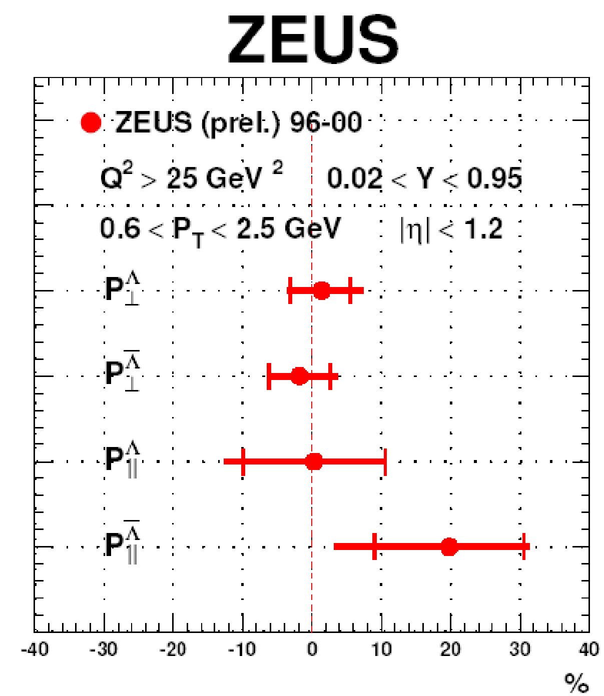
Ariadne: Λ/K poor at low x

$\Lambda - \Lambda$bar: no significant asymmetry

$\Lambda,\bar{\Lambda}$ polarisation

Angular distribution of $\Lambda \to \pi^- p$ decay in Λ rest-frame $(1 + \alpha P \cos\theta)$: $\alpha = 0.642$



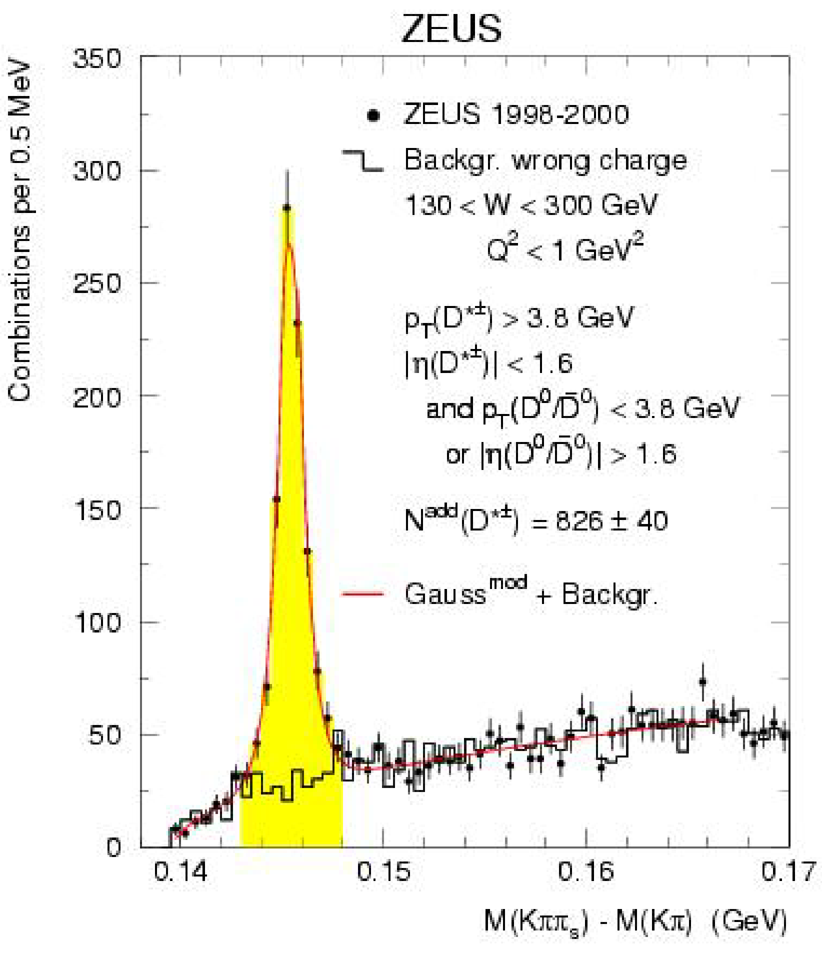


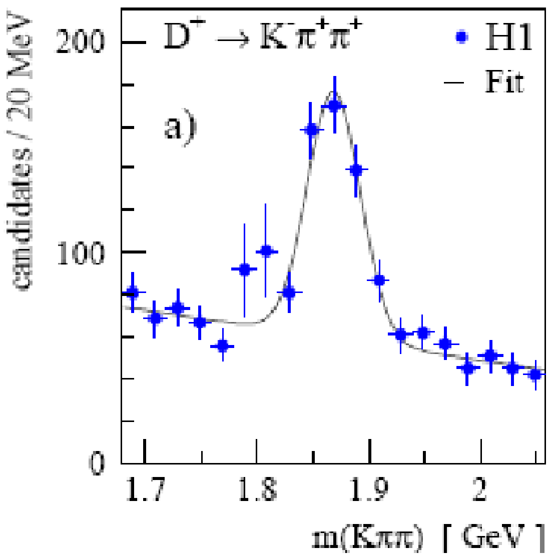
No Λ,Λ bar polzn with unpolarised $e^{\pm}$

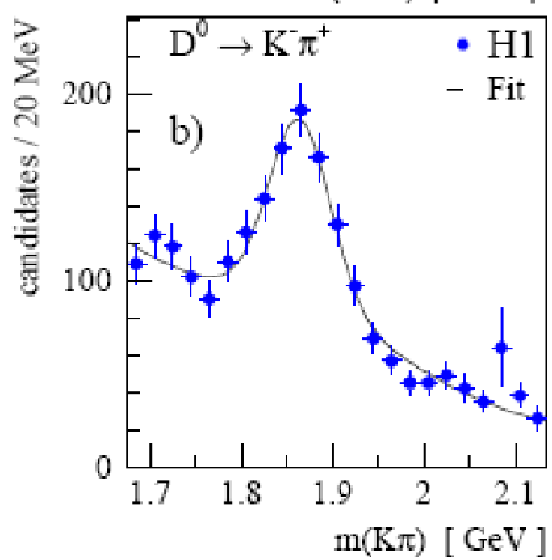
?polarised beams at HERA-II

Charm production

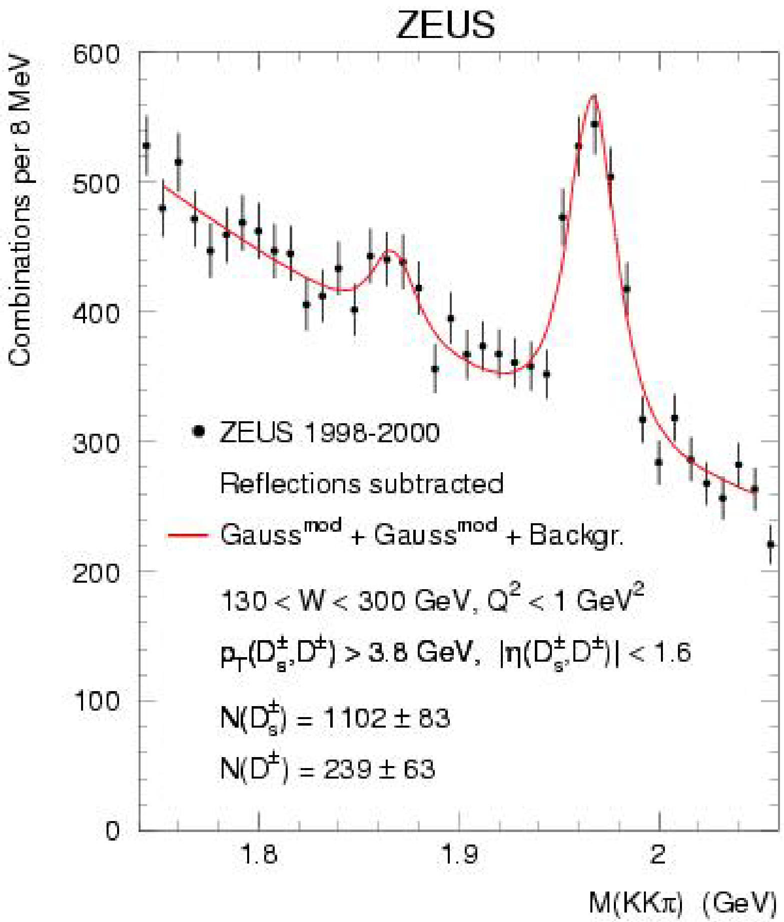
D^{*+}, D^{+}, D^{0}, D_s^{+}, Λ^{+}_{c} observed

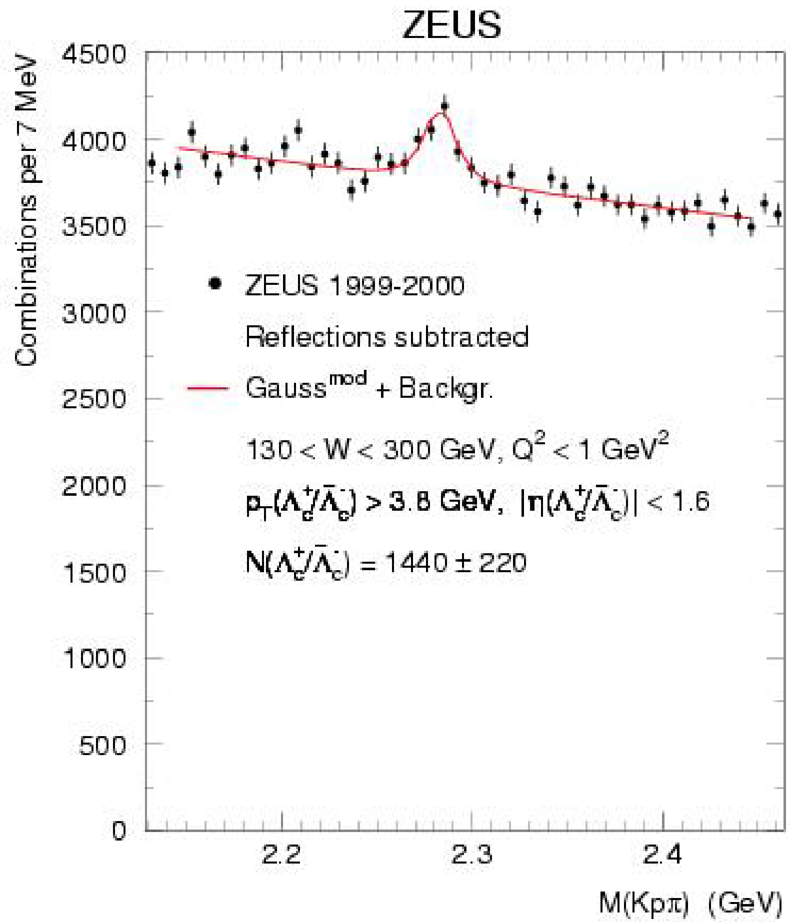






$D_s^{\pm} \to \phi\pi^{\pm}, \phi \to K^+K^-$: $\Lambda_c^+ \to pK^-\pi^+$ signals

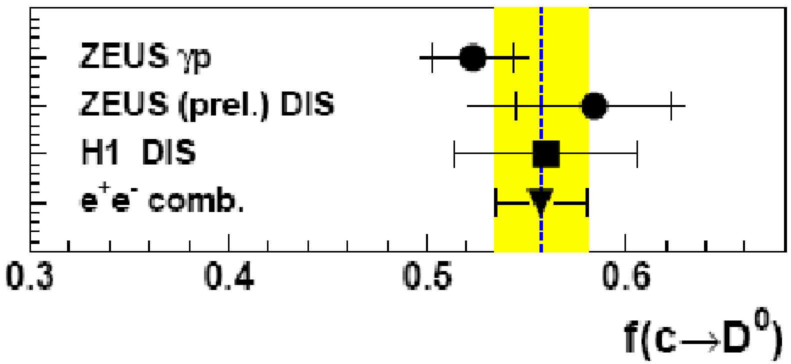


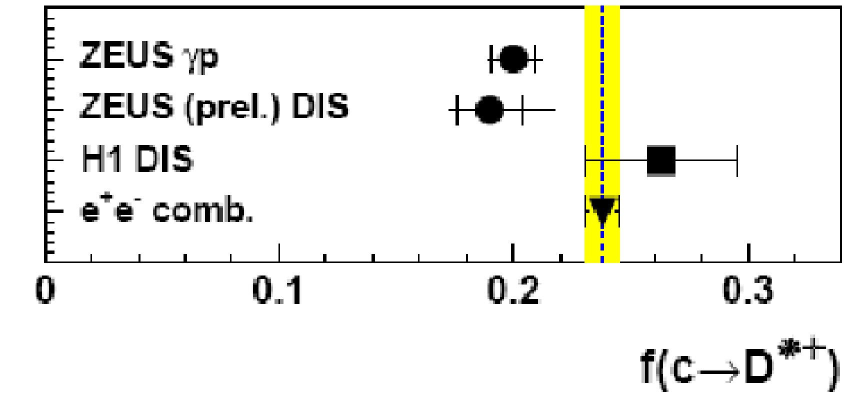


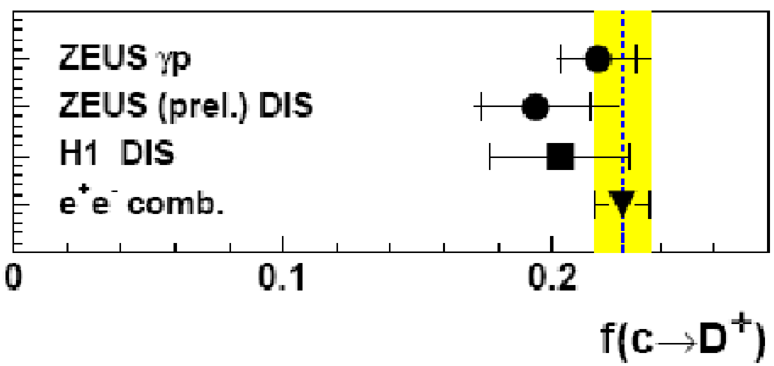
M(KK) within 8 MeV of ϕ mass

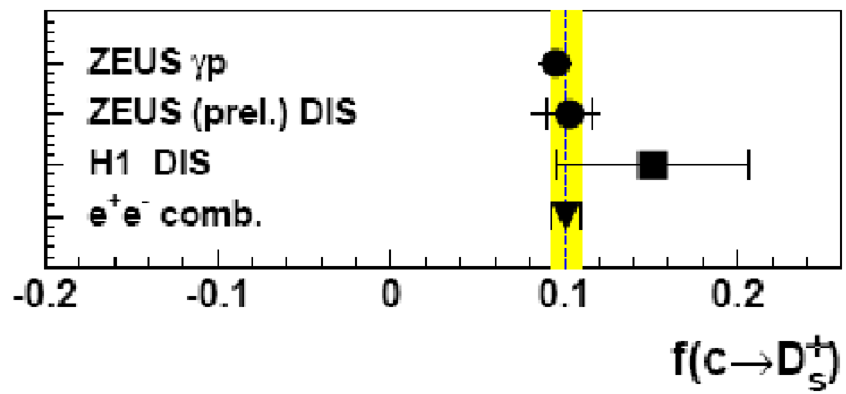
dE/dx info used for particle ID

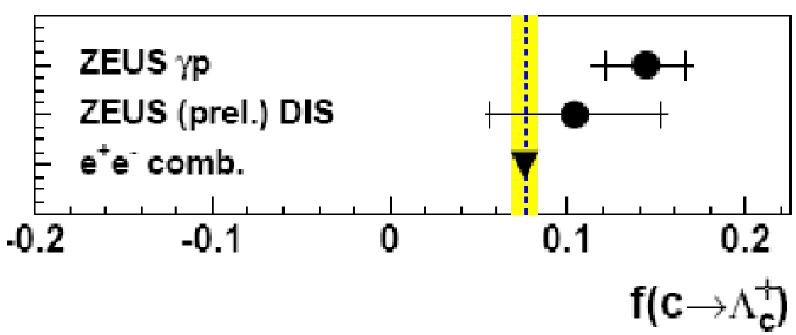
Charm fragmentation supports universality





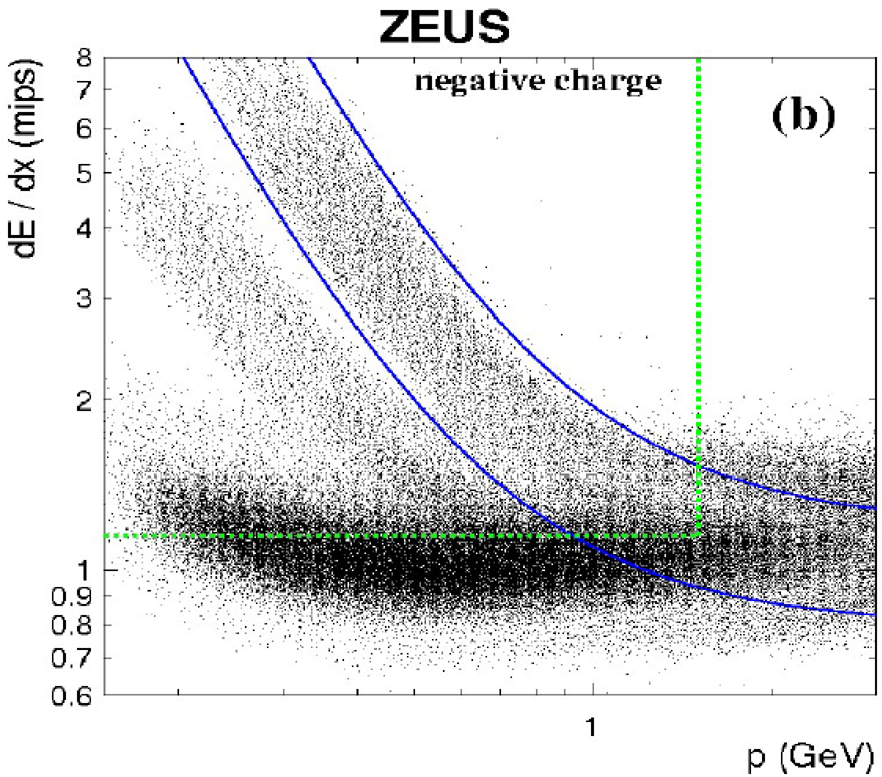






DIS, photoprod, e^+e^- annihilation similar

Baryons decaying to strange particles



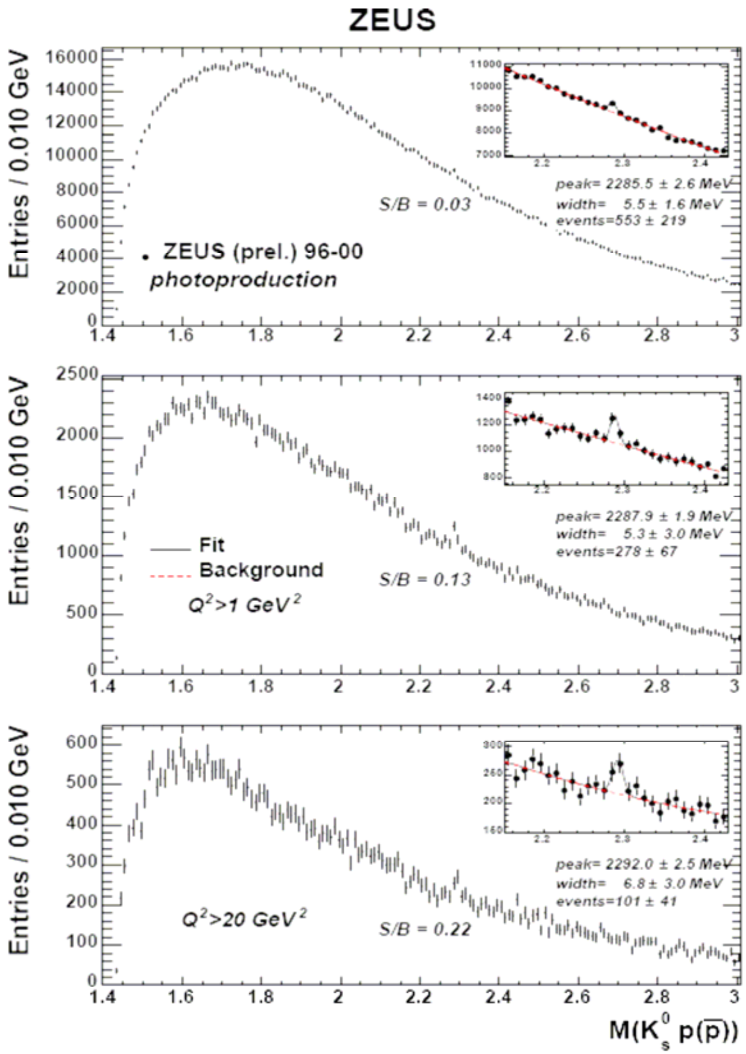
p, $\bar{p}$, K^+, K^- reconstruction:
tracks from primary vertex
dE/dx identification:
ZEUS – region method
in blue band
and *dE/dx* > 1.5 mips
and $p < 1.5$ GeV

H1 – likelihood method

$K^0_s \rightarrow \pi^+\pi^-$: secondary vertex.
$p_T(K^0_s) > 0.3$ GeV, $|\eta(K^0_s)| < 1.5$
exclude Dalitz pairs, γ-conversions
exclude Λ candidates

$K^0_s p$ mass resolution
ZEUS 2.4, H1 5 MeV

$K^0_s p$ mass spectra ($\Lambda^*, \Sigma^*, \Lambda_c$, pentaquark)



Combinatorial backgrounds higher in γp ($<n_{ch}>$ higher) & low Q^2

Mass peaks:

Θ^+(1520) candidate in DIS (see separate talk)

Λ_c(2286) in PHP and DIS

seen equally in *Kp, Kpbar*

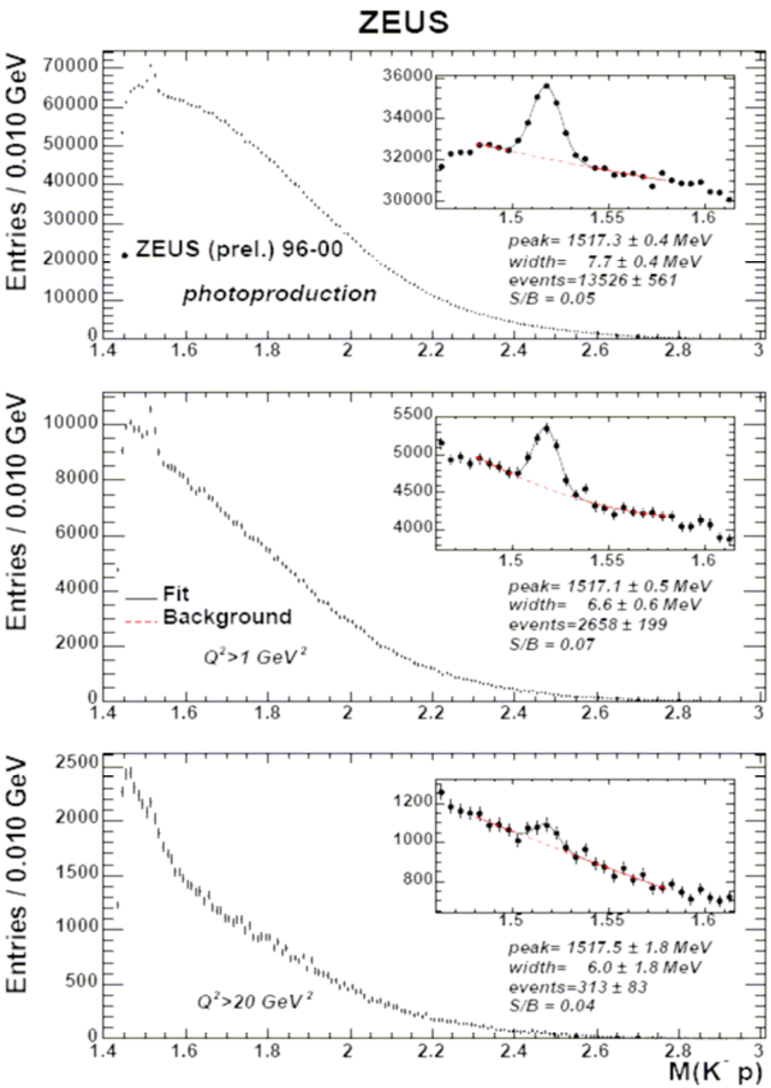
(162±36, 116±38 ev)

seen equally $\eta > 0$, $\eta < 0$

(131±40, 145±34 ev)

Consistent with $\gamma^* g \rightarrow c\bar{c}$

K^-p, $K^+\bar{p}$ mass spectra (Λ(1520))



Mass peak:

Λ (1520) in PHP and DIS

seen equally in *Kp, Kpbar*

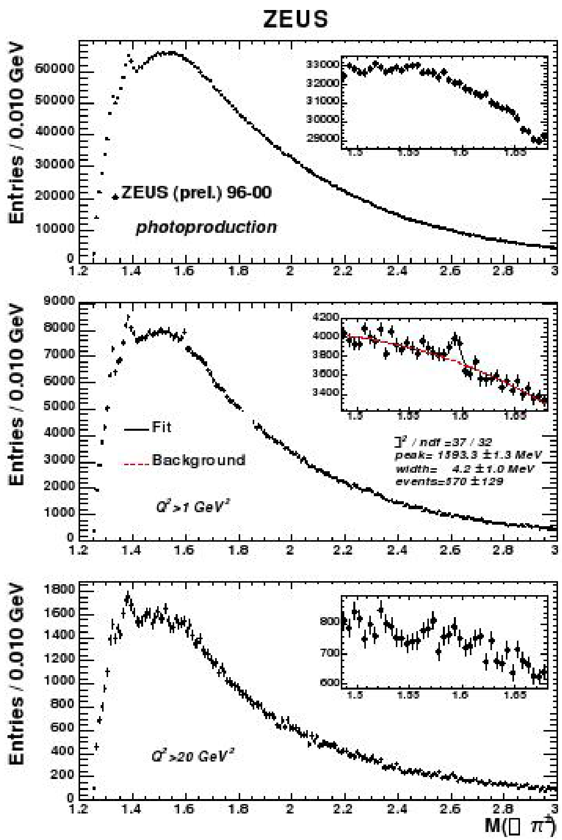
(1207±143, 1402±142 ev)

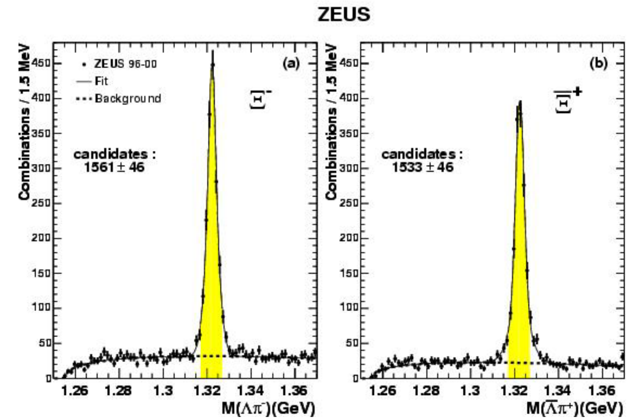
seen equally η>0, η<0

(1337±151, 1246±127 ev)

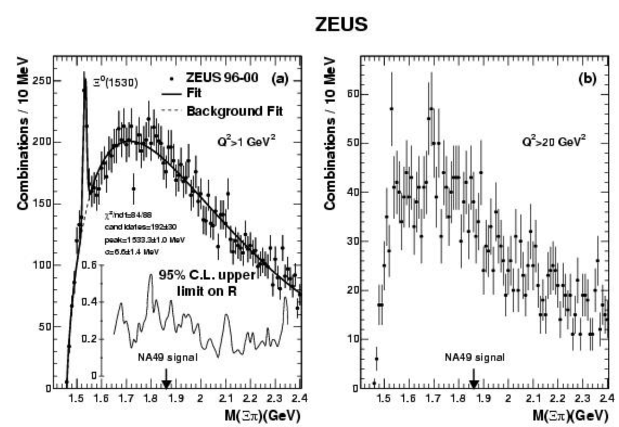
Consistent with $\gamma^* g \rightarrow q\bar{q}$

$\Lambda^0\pi^\pm$ mass spectra (Ξ,Σ*, pentaquark)





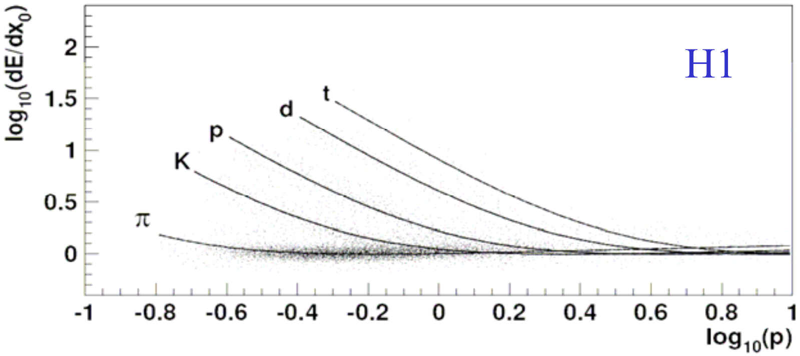
Demand decay vtx: see $\Xi^-\to\Lambda\pi^-$, also $\Xi^*\to\Xi\pi$

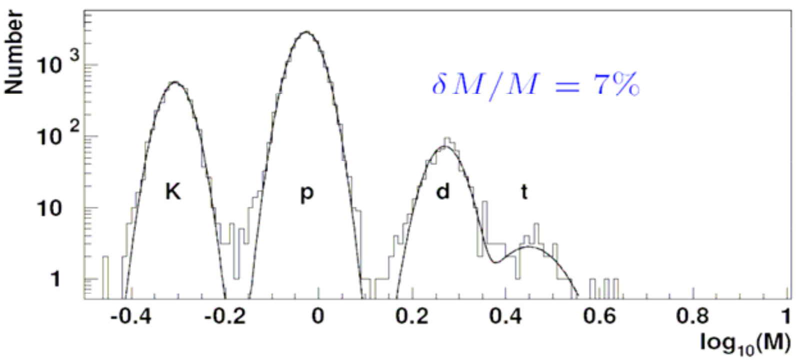


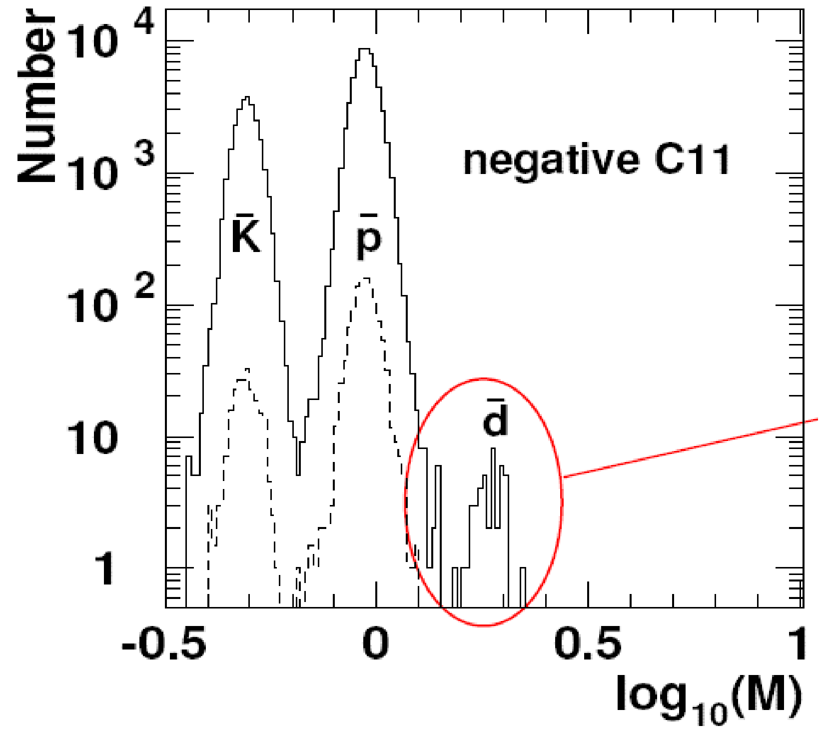
Observe: Ξ(1320) Σ*(1385)
No peak in Θ^+(1520) region

4.4σ peak near 1600 MeV for
$Q^2 > 1$ DIS: Σ(1580)? Σ(1620)?

Anti-deuteron production and heavy particle search





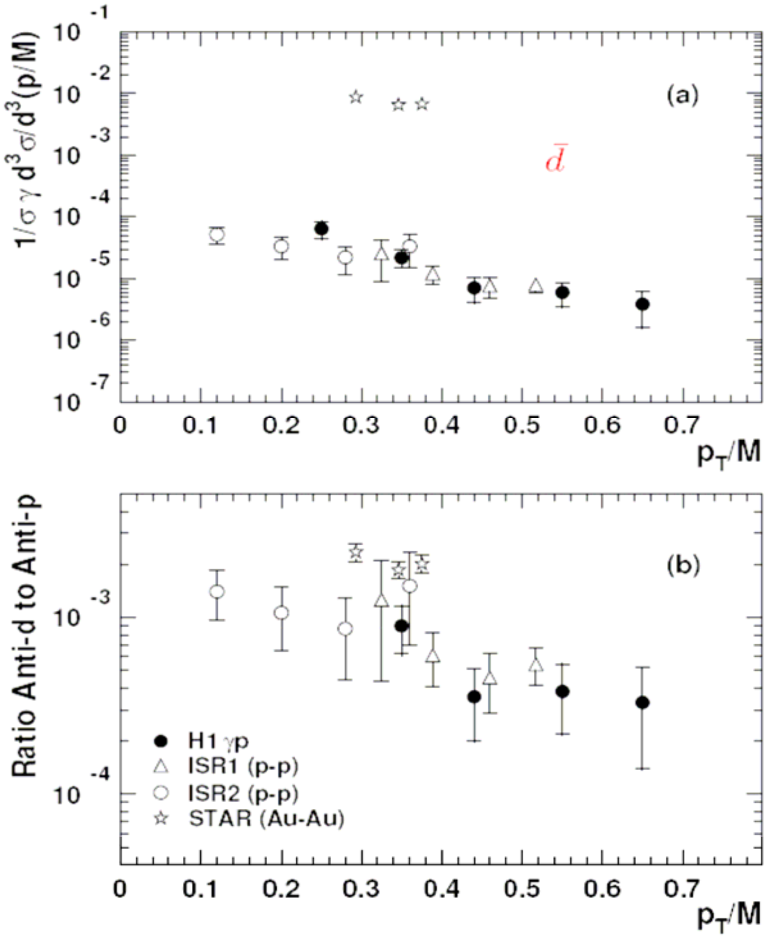


d,t mainly from background
Nothing heavier than *t* seen.

anti-*d*: physics beyond standard fragmentation
45 anti-*d* in 5.5 pb^{-1}
0 anti-*t*, 0 heavier

$\langle W_{\gamma,p} \rangle = 200$ GeV, $0.2 < p_t/M < 0.7$, $-0.4 < y_{lab} < 0.4$

anti-d production: compare γp, pp, $AuAu$



$\sigma(\bar{d})$ = 2.7 $\pm$ 0.5 $\pm$ 0.2 nb
$\sigma(M_{-/+} > M_{\bar{d}/t}) < 0.19$ nb @ 95% C.L.

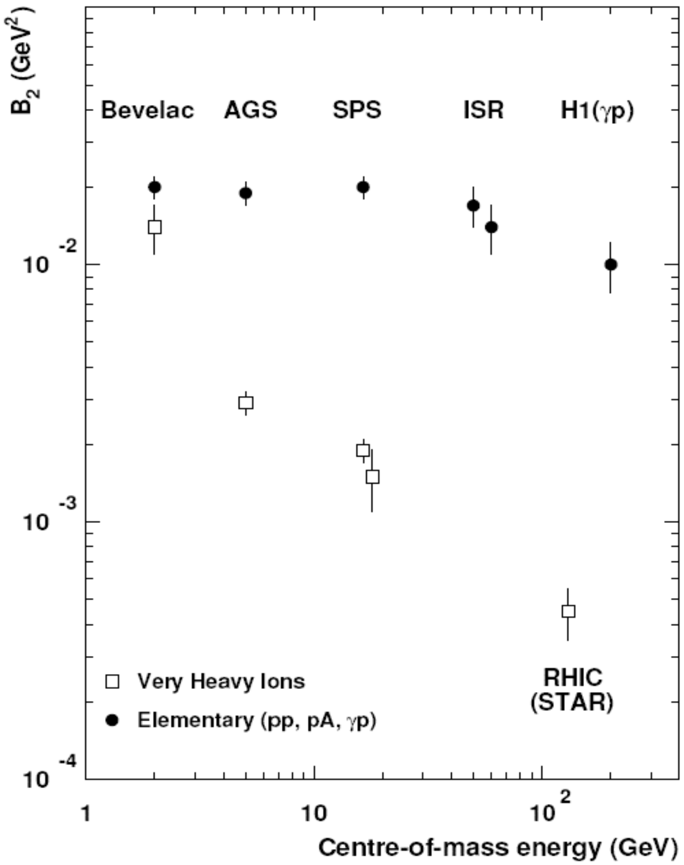
0.2$< p_t/M <$0.7, $|\, y_{lab} \,| <$0.4

Normalised invariant cross-sections:

γp, pp good agreement
AuAu much higher

$\bar{d}/\bar{p}$ ratio higher in *AuAu* also

anti-*d* production: compare *γp, pp, AuAu*



Coalescence model:

$$\frac{1}{\sigma}\frac{d^3\sigma(d)}{d^3p} = B_2\left(\frac{1}{\sigma}\frac{d^3\sigma(p)}{d^3p}\right)\left(\frac{1}{\sigma}\frac{d^3\sigma(n)}{d^3p}\right)$$

B_2 inversely proportional to size of interaction region.

γp: $B_2 = 0.010 \pm 0.002 \pm 0.001$

Similar values in *pp, pA*

Much lower values in *AuAu*

(Very heavy ions):
Bevalac (*NeAu*), AGS (*AuPt*), SPS(*PbPb*)

Bose-Einstein correlations: $K^0_s K^0_s$ and $K^\pm K^\pm$

ZEUS

Study space-time structure of particle source via, $f(Q_{12})$, its Fourier transform

Earlier shown BEC independent of Q^2

Correlation function: $R(p_1,p_2) = \rho(p_1,p_2)/\rho(p_1)\rho(p_2) = |\, 1 + f(Q_{12})\,|^2$

where $Q_{12} = p_1 - p_2$

Fit function: $R(Q_{12}) = \alpha(1+\delta Q_{12})(1 + \lambda \exp[-r^2 Q_{12}{}^2])$

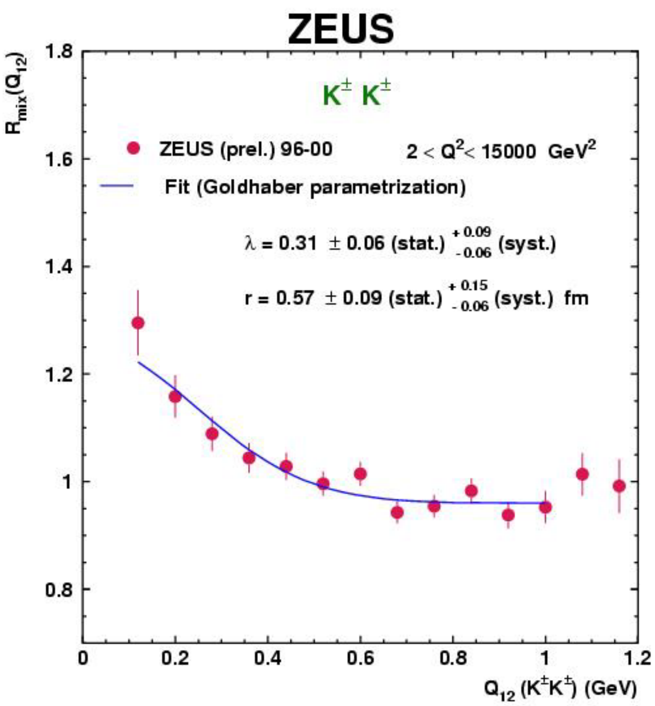
r = source radius, $0< \lambda < 1$

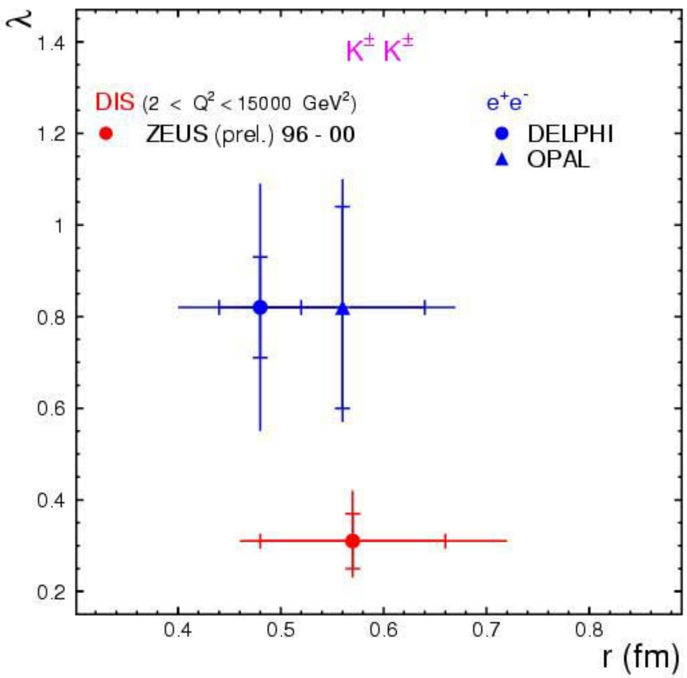
Measure $R(Q_{12})$ in data by event-mixing double ratio

$R = \{ P(\text{data})/P_{\text{mix}}(\text{data})\} / \{P(\text{MC})/P_{\text{mix}}(\text{MC})\}$

All evaluated at the same Q_{12}. MC has no BE correlations

Bose-Einstein correlations: $K^{\pm}K^{\pm}$





r-value similar to charged pions

$\pi^{\pm}\pi^{\pm}$: $r = 0.666 \pm 0.009^{+0.022}_{-0.036}$

$K^{\pm}K^{\pm}$: $r = 0.57 \pm 0.09^{+0.015}_{-0.06}$

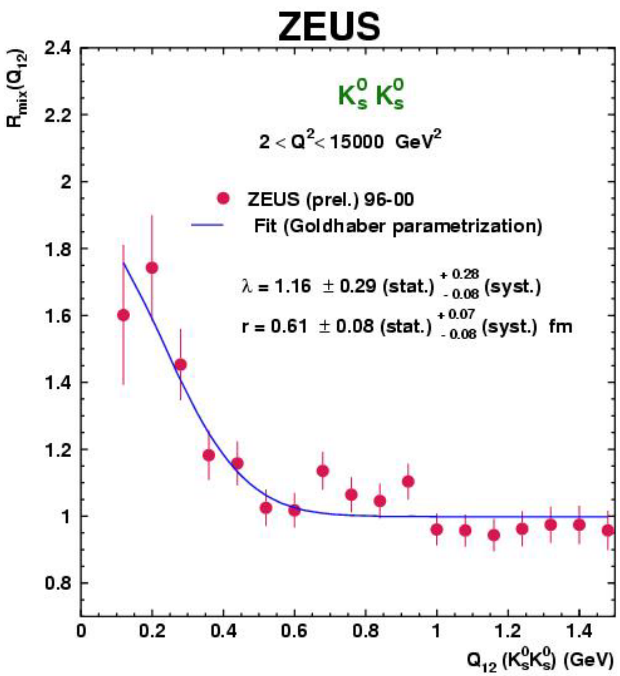
r-value agrees with LEP

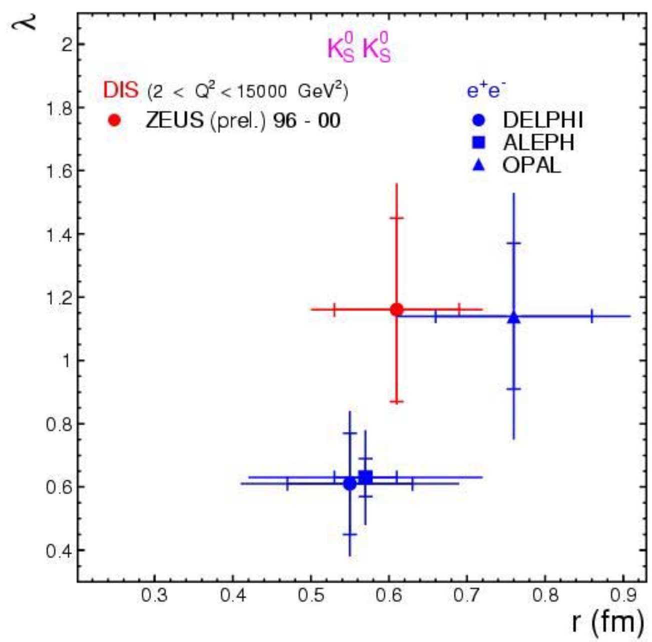
λ-value is lower. Reasons:

?different fragmentation,

?ϕ^0(1020) decay in *p*-fragmentation region

Bose-Einstein correlations: $K^0_s K^0_s$





LEP: clear hierarchy $r(\pi^\pm) > r(K^\pm) > r(\Lambda)$

ZEUS: $r(\pi\pm) \sim r(K^\pm) \sim r(K^0_s)$

$\pi^\pm\pi^\pm$: $r = 0.666 \pm 0.009\ ^{+0.022}_{-0.036}$ fm

$K^\pm K^\pm$: $r = 0.57 \pm 0.09\ ^{+0.15}_{-0.06}$ fm

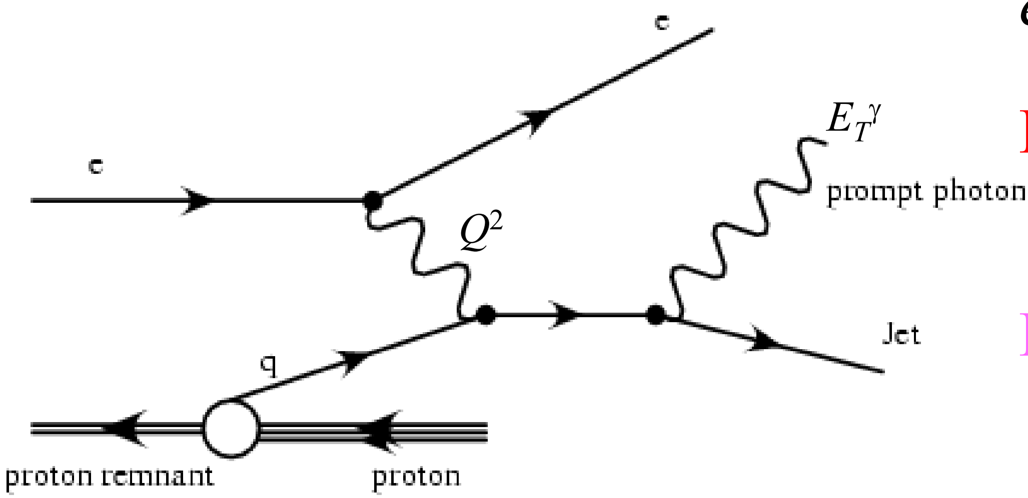
$K^0_s K^0_s$: $r = 0.61 \pm 0.08\ ^{+0.07}_{-0.08}$ fm

r (DIS) ~ r (LEP)

λ (DIS) > λ (LEP)

reasons: ? $f_0(980) \to K^0_s K^0_s$
affects λ at low Q_{12}
(ALEPH,DELPHI removed
$f_0(980)$ effects

Prompt photon production: γ radiation from quark line



$eq \rightarrow eq\gamma$

DIS: isolated e,γ (incl.)
isolated e,γ,jet

Photoprod'n (Q^2<1 GeV^2)
e unobserved
isolated γ,
jet balancing p_T

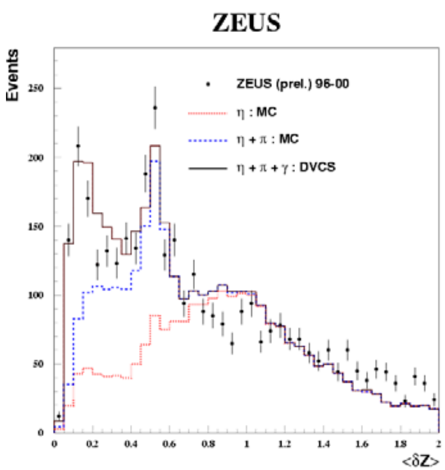
Backgrounds: γ radiation from initial state, final state e (DIS)
γ from jet fragmentation
γ from π^0, η^0 decay

γ signal – π^0 and η^0 backgrounds

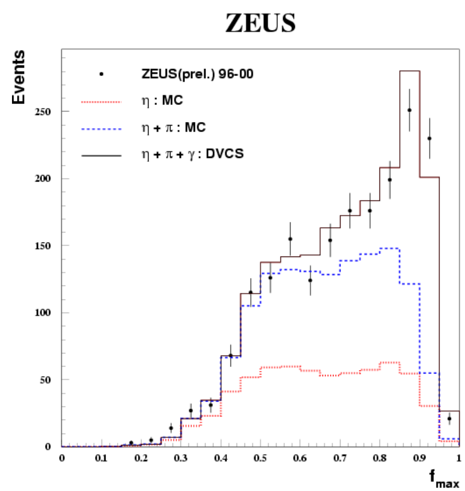
Use e.m. calorimeter shower shape

ZEUS DIS

Shower width



Hot core fraction

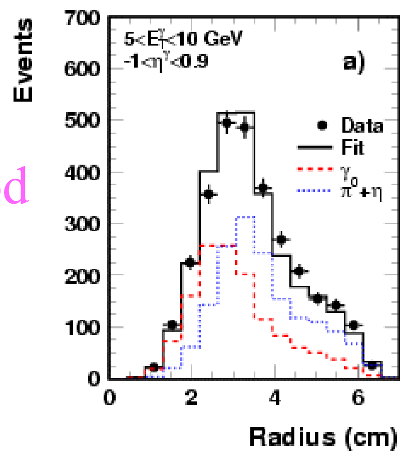


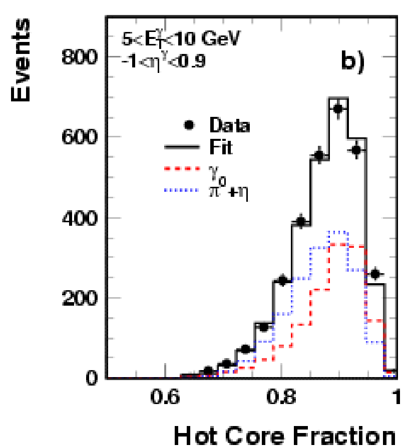
ZEUS z-strips

γ shape from DVCS data
π^0,η^0 shapes from MC
Fit for γ,π^0,η^0 fractions

Background subtraction is rather stable against errors in γ shape.

H1 photoprod



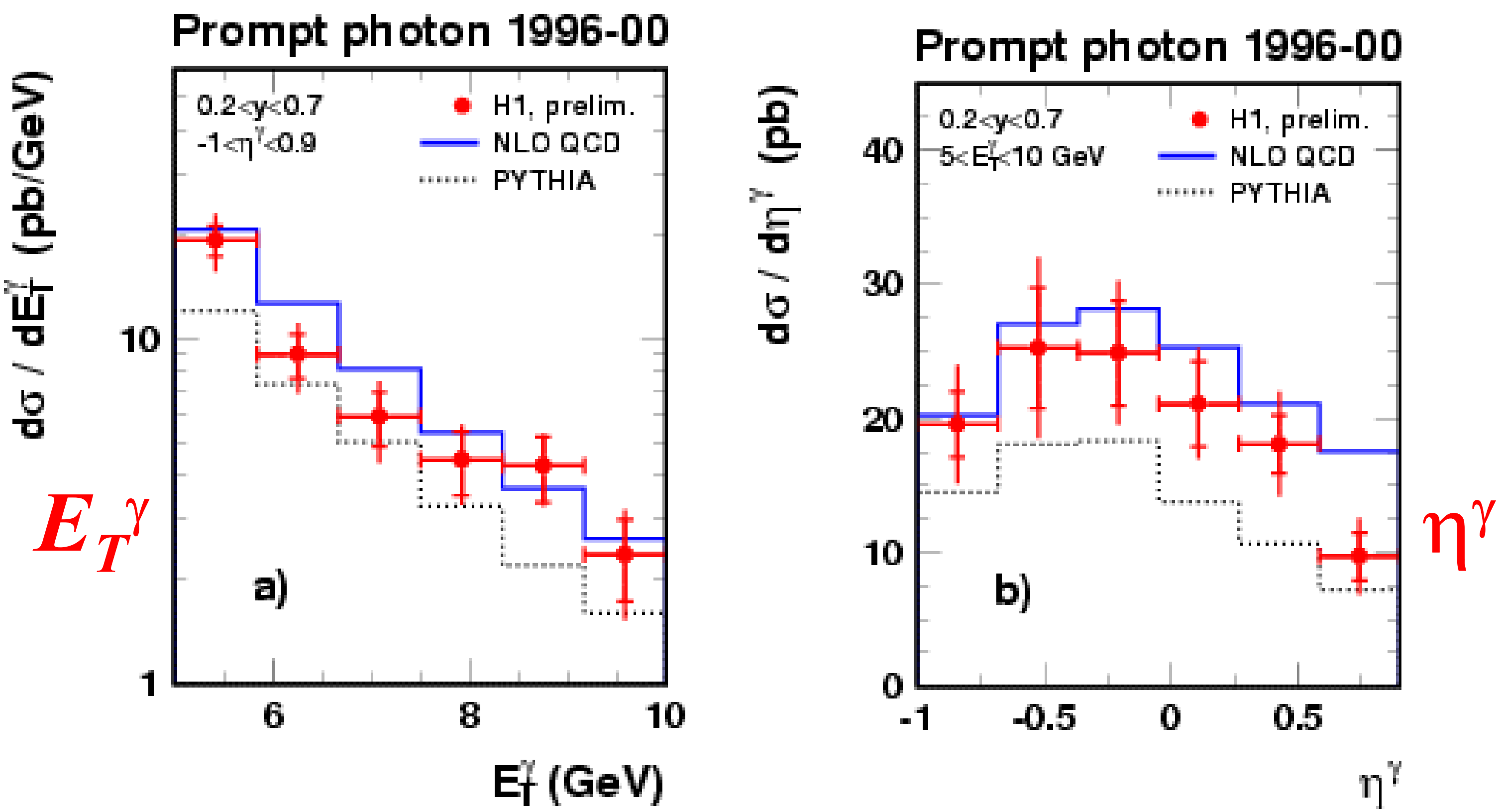


H1 cells

$\gamma,(\pi^0+\eta^0)$ shapes from MC
Likelihood discriminator in (E_T,η) bins

Photoproduction:

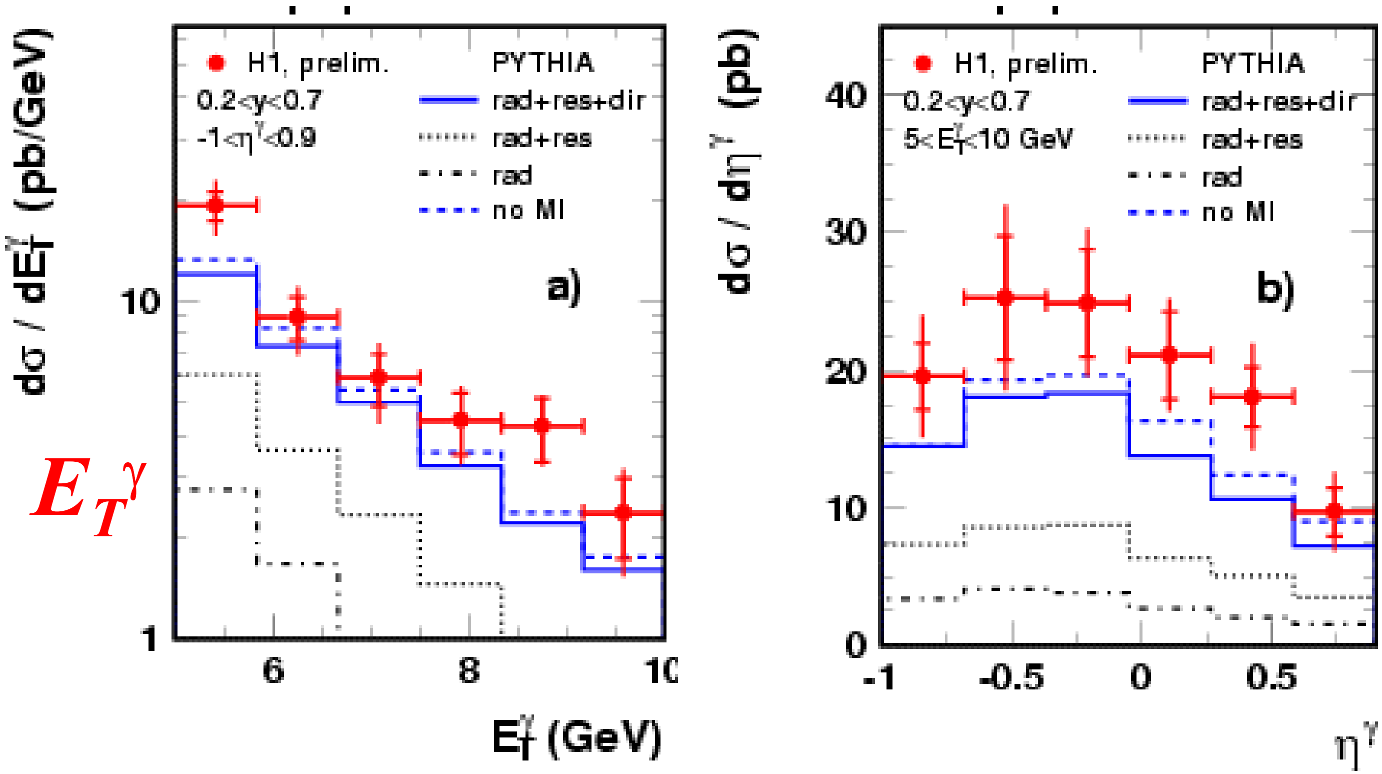
H1: compare to NLO and PYTHIA



pQCD (NLO, Fontannaz *et al*) agrees within errors
PYTHIA: describes shapes but a bit low.

Photoproduction:

PYTHIA – origin of prompt γ



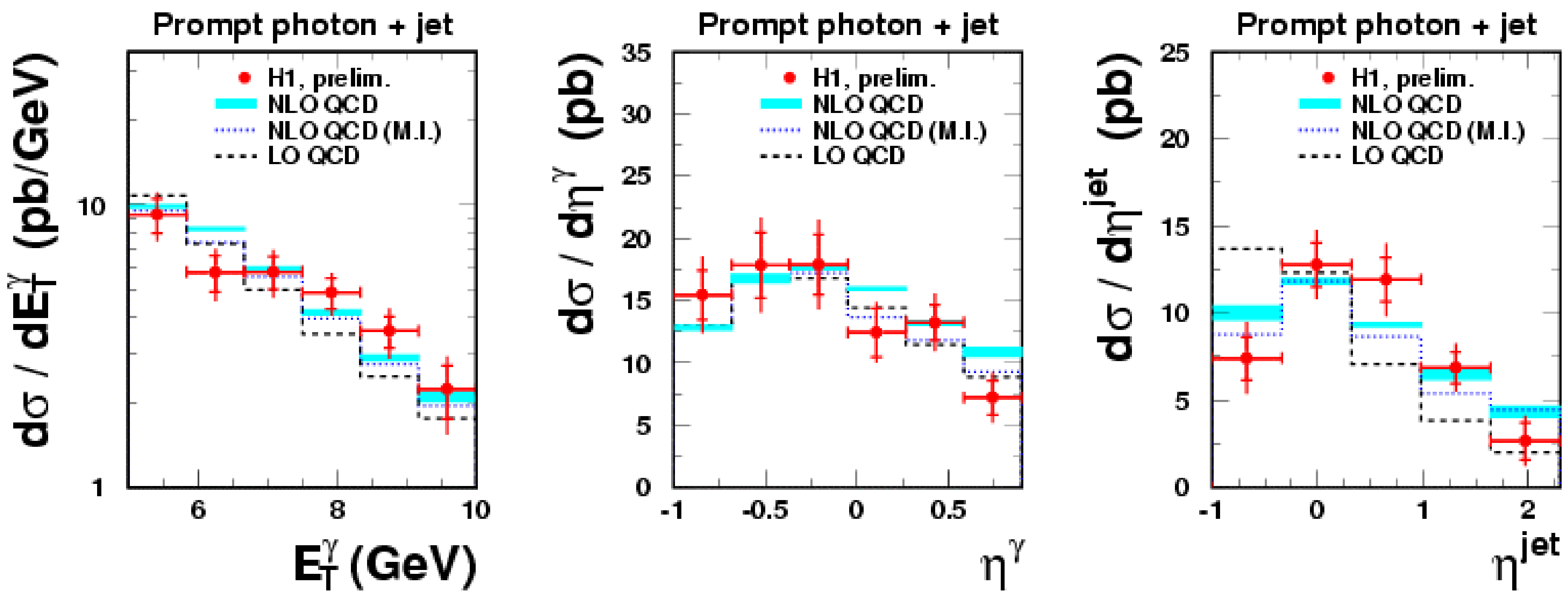
E_T^γ η^γ

- >50% direct exchanged γ.
- Radiation from electron line small
- Multiple interactions hurt photon isolation cut and so reduce the cross-section

Photoproduction:

γ+jet – compare to LO and NLO (Fontannaz *et al*)

(NLO scale variation 0.5 E^{γ}_{T} to 2 E^{γ}_{T})



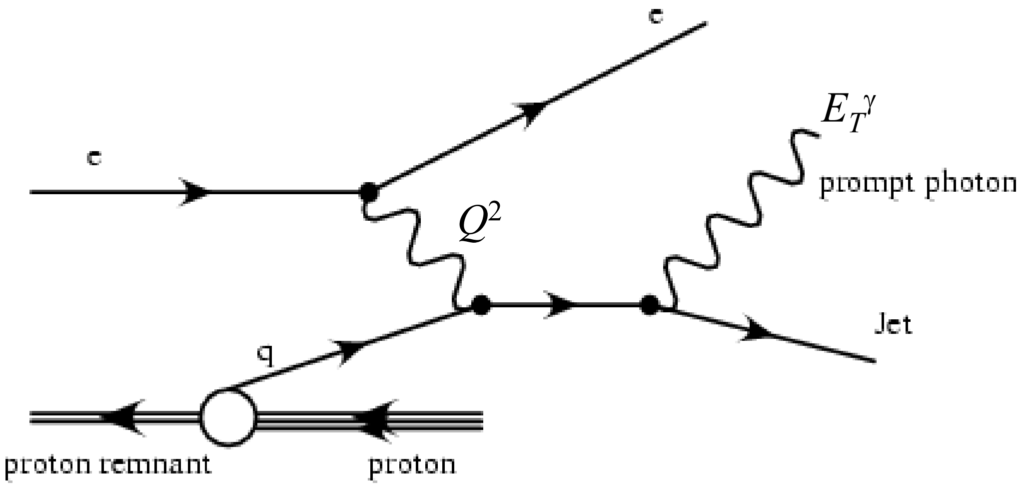
Correction to NLO for multiple interactions applied by PYTHIA

– improves fit at large η^{γ}

Large negative NLO corrections at $\eta^{jet} < 0$

NLO describes the data within errors

$eq \rightarrow eq\gamma$ in Deep Inelastic Scattering



Minimise ISR, FSR

($139.8^o < \theta_e < 171.9^o$) far from γ

Two hard scales:

(Q^2, E_T^γ) hard for MC to simulate

PYTHIA v6.206 (new)

HERWIG v6.1

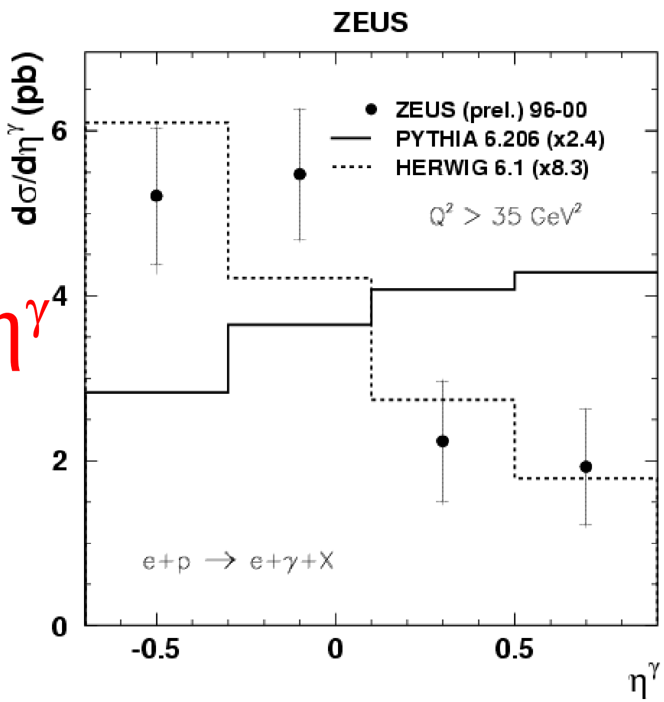
Comparisons available for $e\gamma X$, $e\gamma$jet

NLO calculations $O(\alpha^3\alpha_s)$ by Kramer and Spiesberger

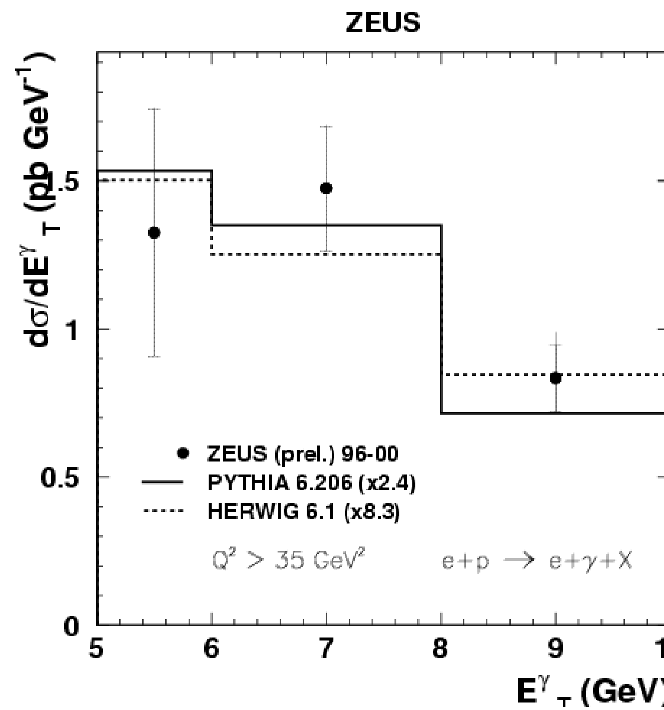
Based on A. Gehrmann-de Ridder,K,S Nucl. Phys. **B578** (2000) 326

- includes ISR, FSR, vertex diagrams, all interferences,
- predictions for (e+γ+one jet) including renorm. scale uncertainty

DIS: $eq \rightarrow e\gamma X$ (inclusive)



η^{γ}

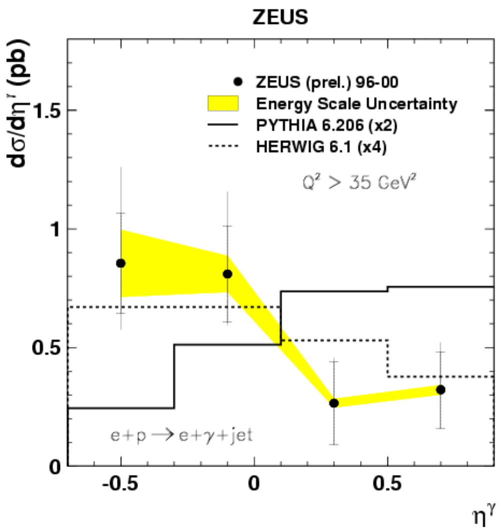


E_T^{γ}

	$<Q^2>$(GeV^2)	$<x_{Bj}>$	η^{γ} shape	E_T^{γ} shape	normalisation factor needed
Data	87	0.0049			
PYTHIA	87	0.0047	BAD	OK	2.4
HERWIG	62	0.0017	OK	OK	8.3

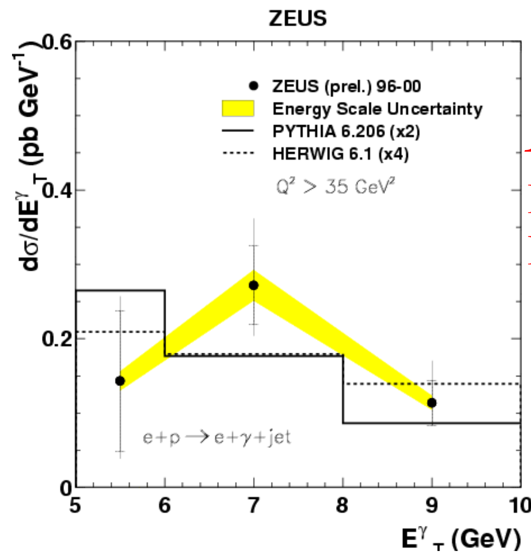
NEITHER IS A GOOD DESCRIPTION OF THE DATA.

DIS: *eq* → *eγ* + one jet



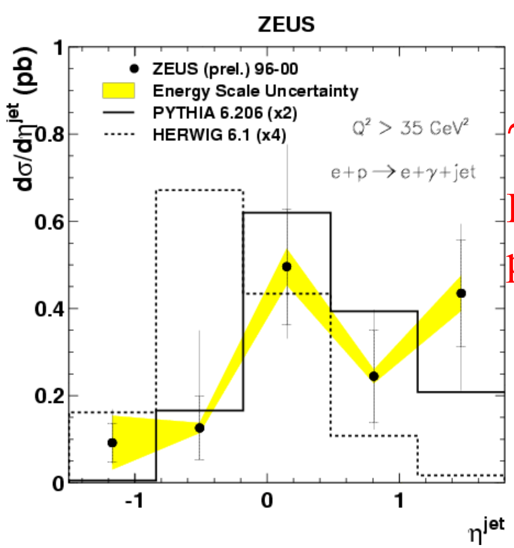
η^{γ}

HERWIG preferred



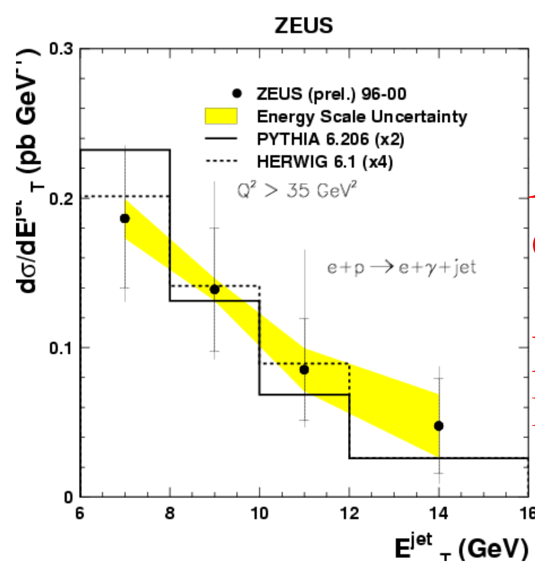
E_T^{γ}

Data uneven.
MC's similar



η^{jet}

PYTHIA preferred



E_T^{jet}

OK

Normalisation:

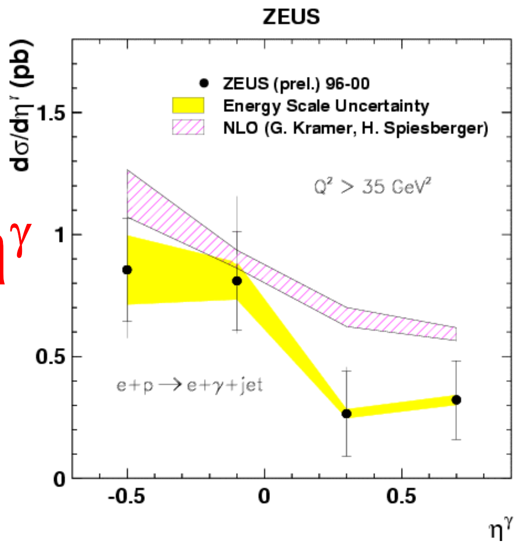
Both poor

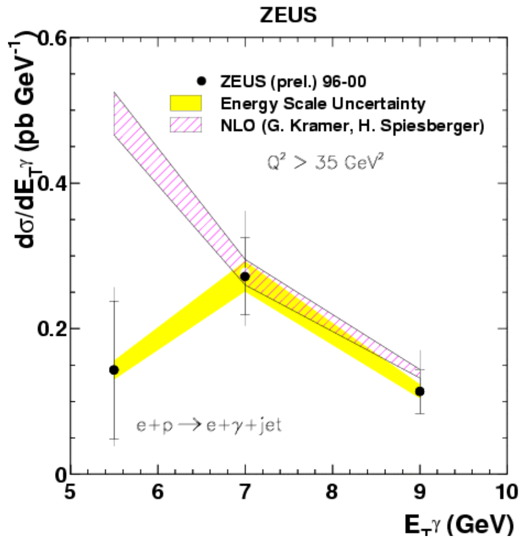
DIS: $eq \rightarrow e\gamma$ + one jet

Comparison to NLO calculations

(Kramer & Spiesberger)

η^γ

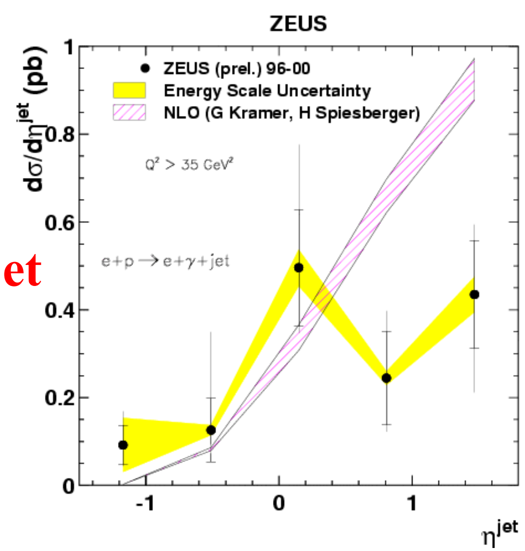


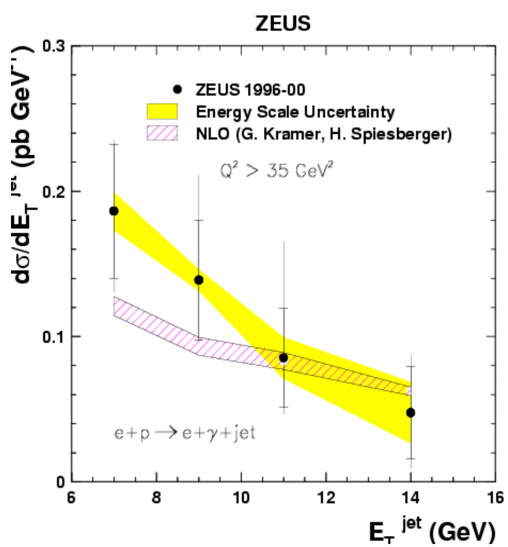


E_T^γ

Total cross section:
Data slightly below theory
(1.7 S.D.)

η^{jet}



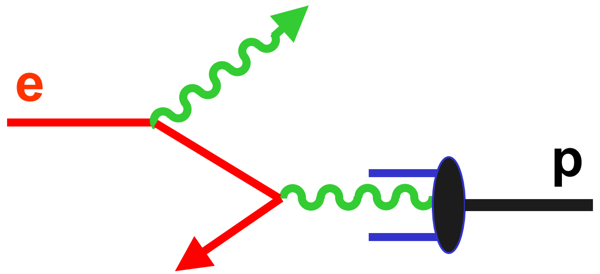


E_T^{jet}

Overall: 'fair' agreement
rates well predicted

MRST:

first measurement of $\gamma_p(x,Q^2)$?



ZEUS: "Observation of high E_T photons in deep inelastic scattering", hep-ex/0402019

$\sqrt{s}$ = 318 GeV, Q^2 > 35 GeV^2, E_e > 10 GeV

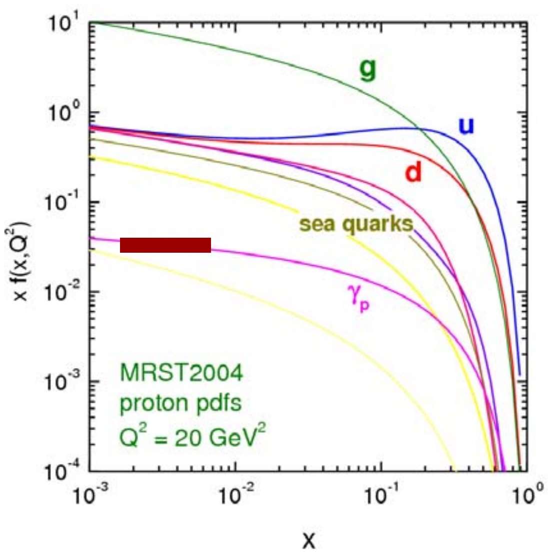
$139.8^o < \theta_e < 171.8^o$

$5 < E_T^\gamma < 10$ GeV, $-0.7 < \eta^\gamma < 0.9$

$\sigma(ep \to e\gamma X) = 5.64 \pm 0.58\ (stat.) \pm^{0.47}_{0.72}\ (syst.)$ pb

prediction using MRST2004 QEDpdfs:

$\sigma(ep \to e\gamma X) = 6.2 \pm 1.2$ pb (scale dependence)

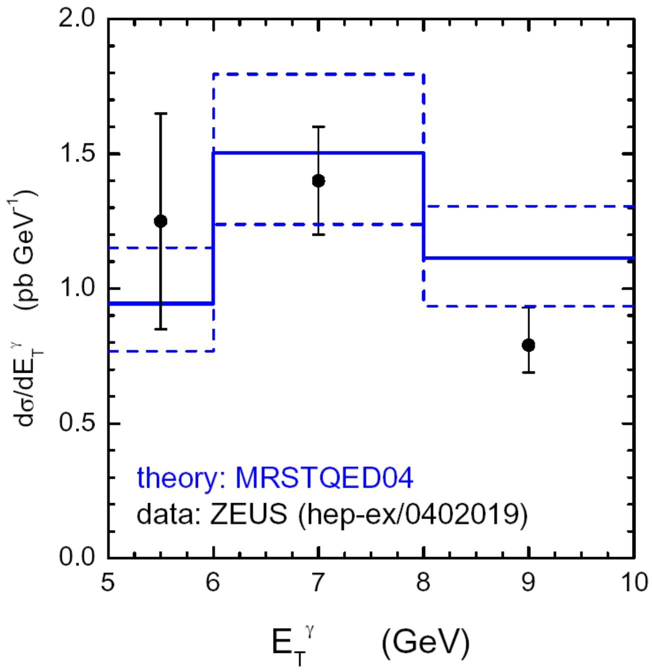


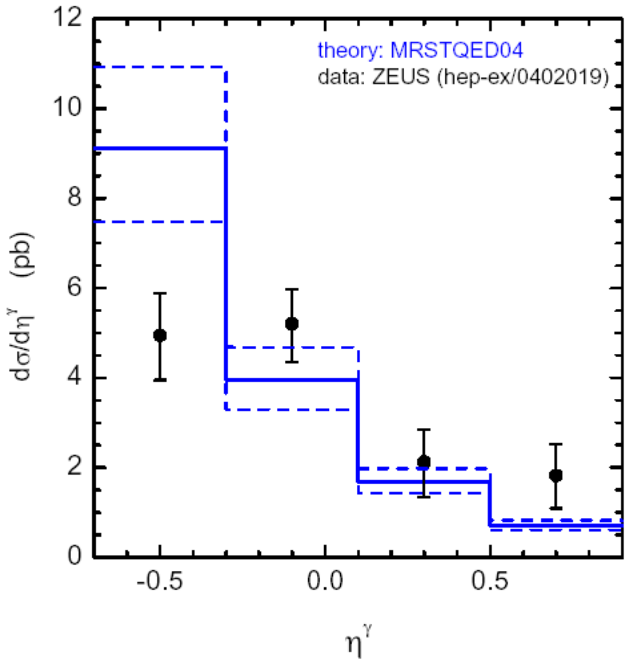
Note: exchanged e* carries the Q^2

MRST: lowest order theory. No jets prediction. $p_t(e) = p_t(\gamma)$

$$e\,\gamma_p(x,Q^2) \rightarrow e\,\gamma$$

Absolute rate prediction





$<Q^2> = 75$ (*cf* data 87). Would increase with higher orders

Encouraging agreement. Can they predict (γ + jets) distributions?

Summary

Charged Multiplicities in DIS and DDIS

use of W, $E_{current}$: unified look at DIS, DDIS

Inclusive photoproduction of non-strange mesons

universal rate as function of (p_T+m)

Strange Particle production

p_T,η,Q^2,x, Λ polarisation

Charm fragmentation

universality: DIS, photoproduction, e^+e^-

Baryons decaying to strange particles

dE/dx for $K^{\pm}$,p: resonances seen, pentaquark search

Antideuteron production

dE/dx. Coalescence model

KK Bose-Einstein correlations

compare LEP, $f_0(980)$ issues

Prompt photon production in DIS

first measurement of $\gamma p(x,Q^2)$?

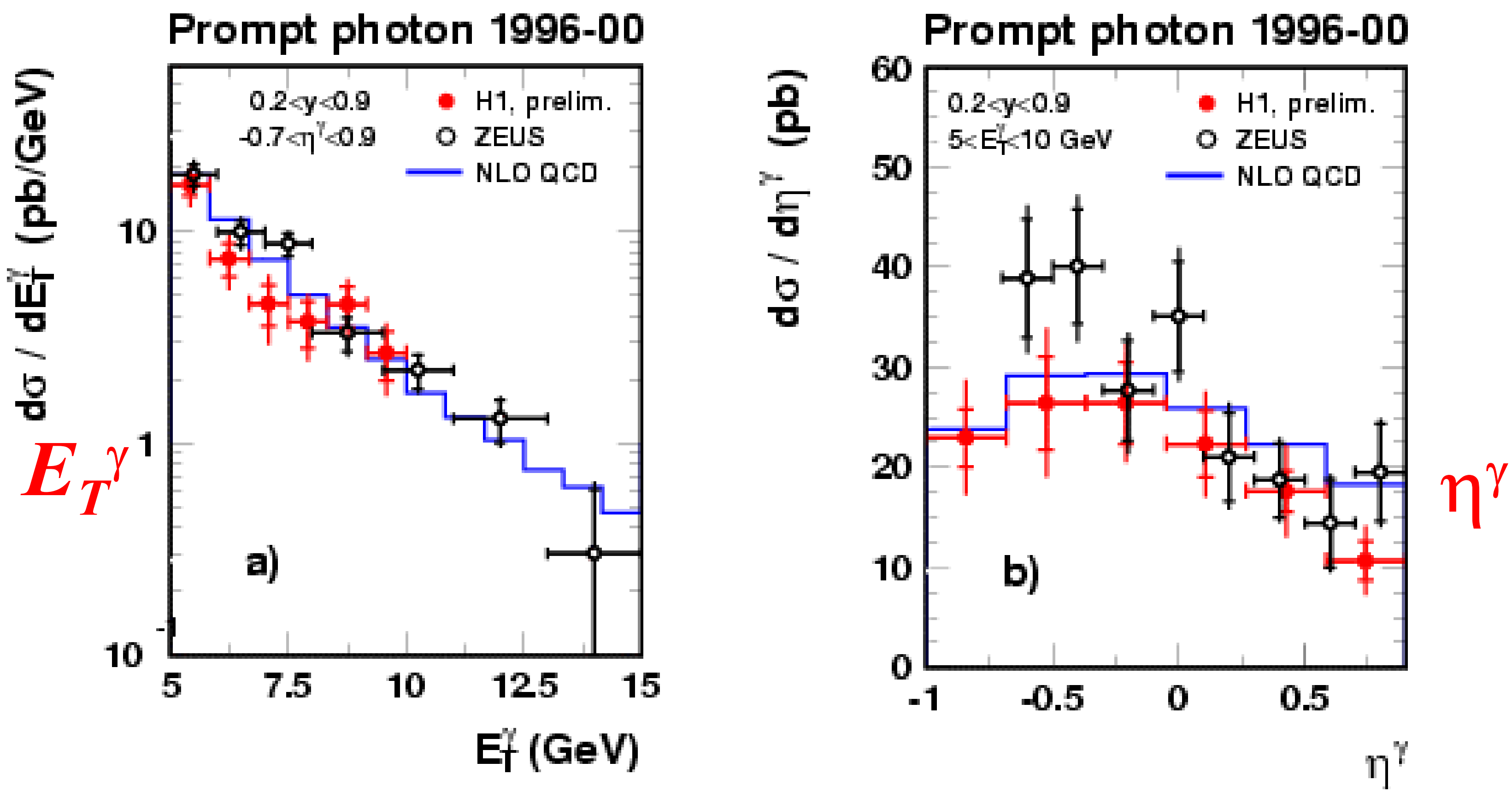
Kinematic region

H1 photoproduction	ZEUS photoprod'n (old)	ZEUS DIS
96-00 data (105 pb^{-1})	96-97 data (38 pb^{-1})	96-00 data (121 pb^{-1})
$Q^2 < 1$ GeV^2		$Q^2 > 35$ GeV^2
$5 < E_T^{\gamma} < 10$ GeV (15 GeV for ZEUS photo $d\sigma/d\,E_T^{\gamma}$)		
$-1.0 < \eta^{\gamma} < 0.9$	$-0.7 < \eta^{\gamma} < 0.9$	
$122 < W < 266$ GeV	$134 < W < 285$ GeV	31(69)%@300(318)GeV
Isolation: $E_t^{\gamma}/ E_t^{total} > 0.9$ in cone of $\Delta R = (\Delta\Phi^2+\Delta\eta^2)^{1/2} = 1$		
Prompt photon + jet		
Inclusive k_T		Cone $\Delta R = 0.7$
$E_t^{jet} > 4.5$ GeV	$E_t^{jet} > 5$ GeV	$E_t^{jet} > 6$ GeV
$-1.0 < \eta^{jet} < 2.3$	$-1.5 < \eta^{jet} < 1.8$	

Table after Lemrani

Photoproduction:

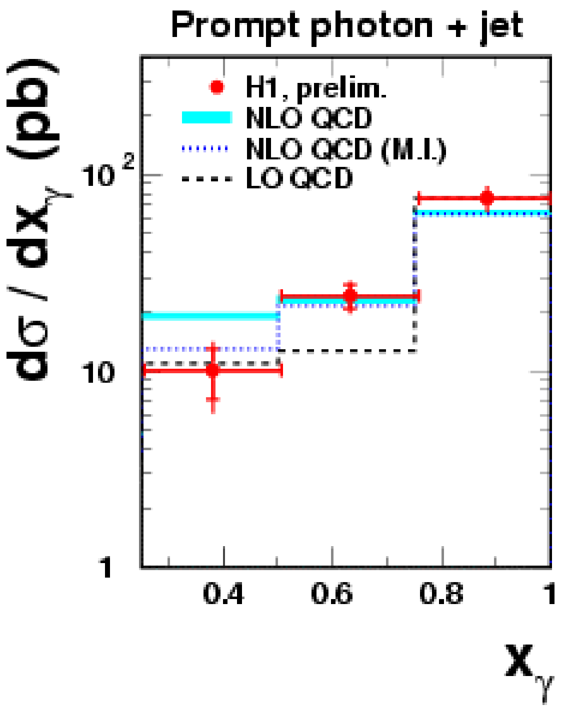
Inclusive prompt photon cross section



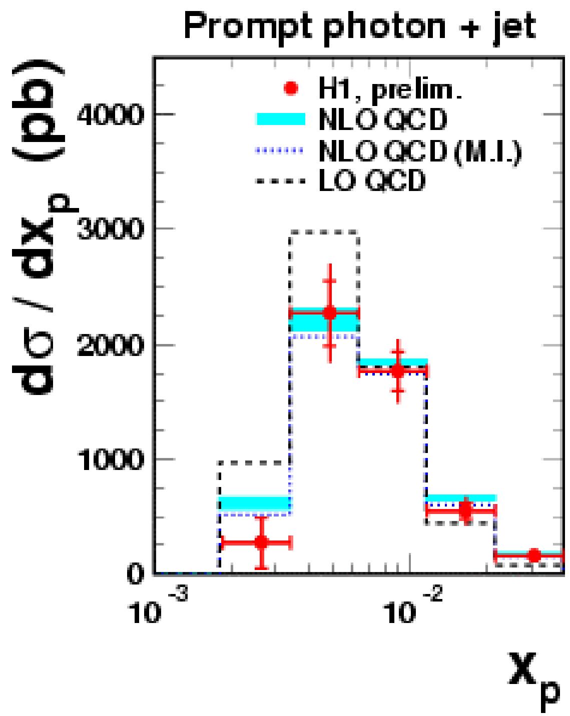
Data consistent within errors.

Photoproduction:

(γ+jet) σ *vs.* x_γ, x_p



$x_\gamma = (E_T^{jet}e^{-\eta(jet)} + E_T^{\gamma}e^{-\eta(\gamma)})/2yE_e$

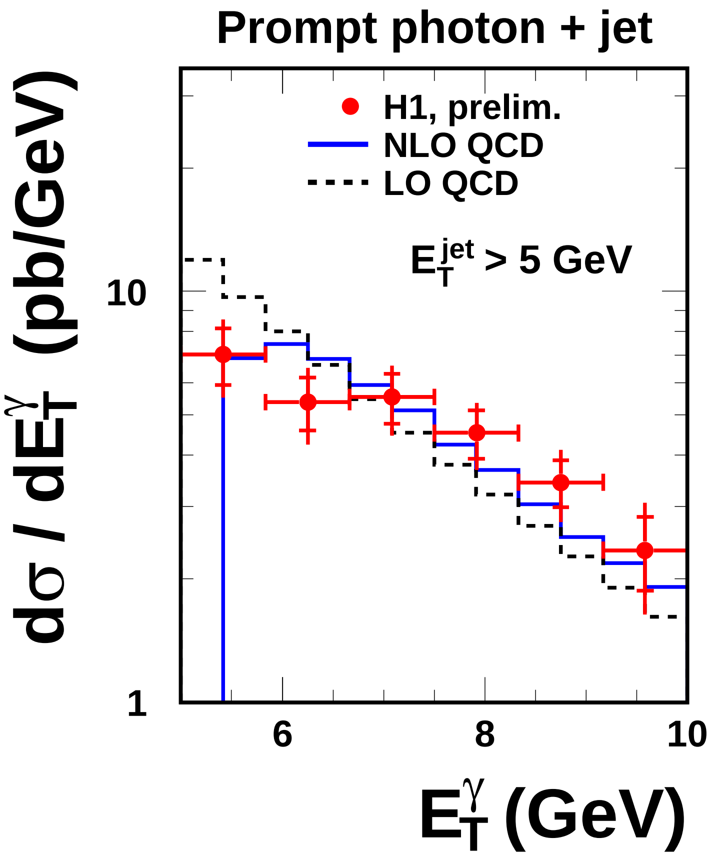


$x_p = (E_T^{jet}e^{\eta(jet)} + E_T^{\gamma}e^{\eta(\gamma)})/2E_p$

- Multiple interactions matter at $x_\gamma < 0.5$ (resolved γ region)
- NLO + MI describes the data

Photoproduction

(γ+jet) Avoid symmetric E_T cuts



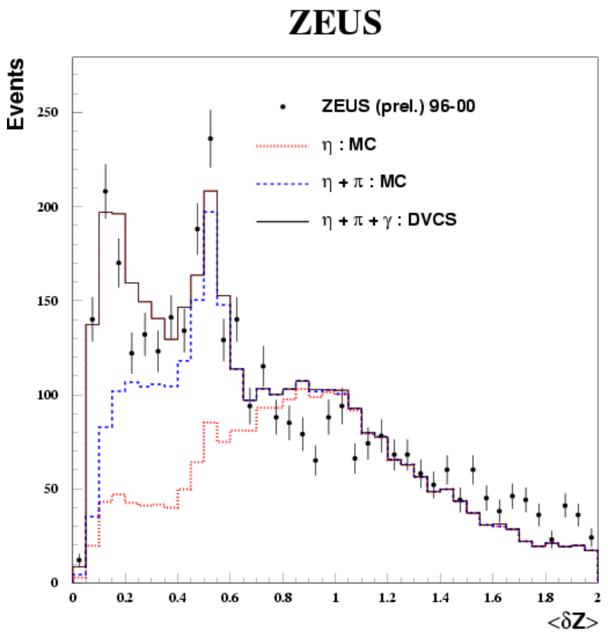
Fontannaz *et al:*

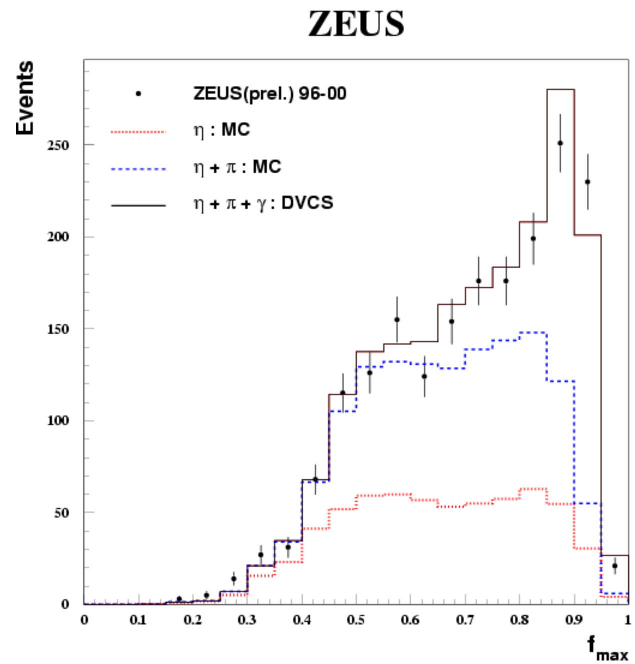
NLO infrared instabilities with symmetric cuts *e.g.*
$E^{jet}{}_{T,min} = E^{\gamma}{}_{T,min} = 5$ GeV

Unphysical drop in prediction just above cut (similar to dijets)

γ signal extraction in ZEUS

Shower shape variables for γ (from DVCS data), π^0,η (from MC)
Using 5 cm z-strips in Barrel e.m. calorimeter (-0.7 < η < 0.9)
$\delta Z = \Sigma_i E_i . |Z_i - <Z>| / \Sigma_i E_i$ f_{max} = fraction of γ energy in highest cell





(use δZ>0.65 only)

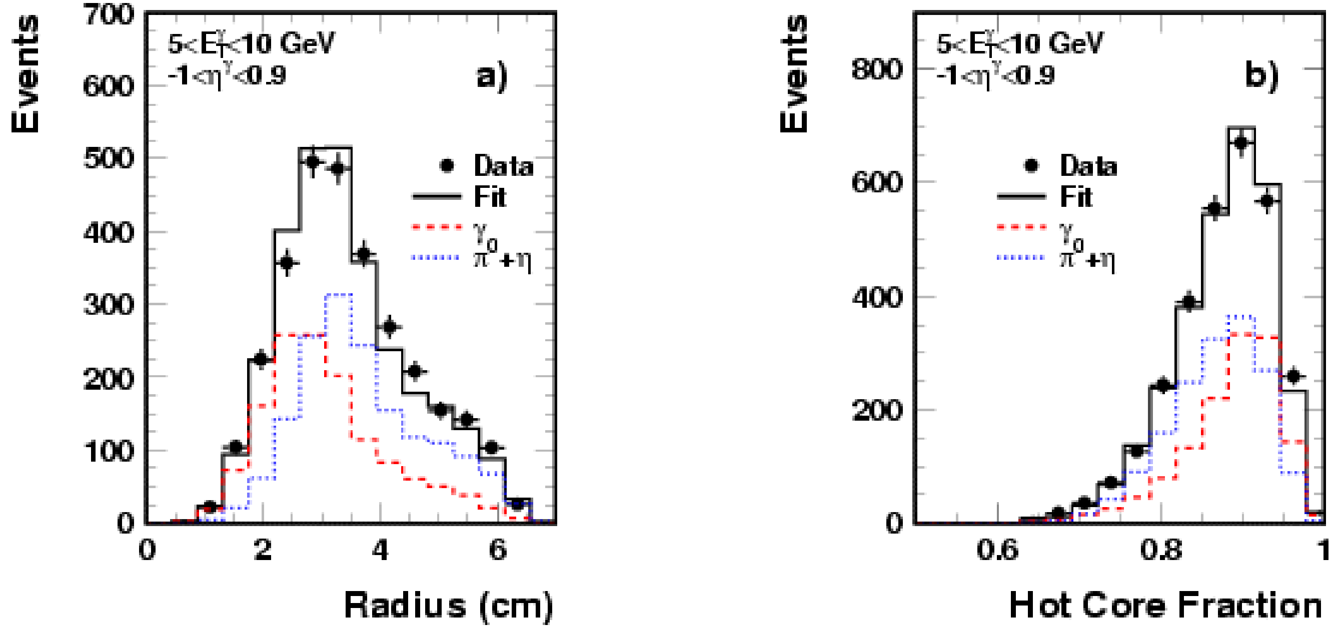
S/B~0.44

η fraction fixed from background at $\delta Z > 0.65$
Background subtraction from f_{max} plot. Rather insensitive to errors in modelling showers (included in systematic errors)

γ signal extraction in H1

Use shower shape variables for γ, (π^0 +η) (η fraction from MC)

Radius = $\Sigma_{\text{cells}}\, w_i r_i / \Sigma_{\text{cells}}\, w_i$ *Hot core fraction*= E_{core}/E_{tot}



Likelihood discriminator used in (E_T,η) bins to allow for energy dependence and varying calorimeter granularity.

- Shower shape variables well described.
- photoproduction S/B ~ 1