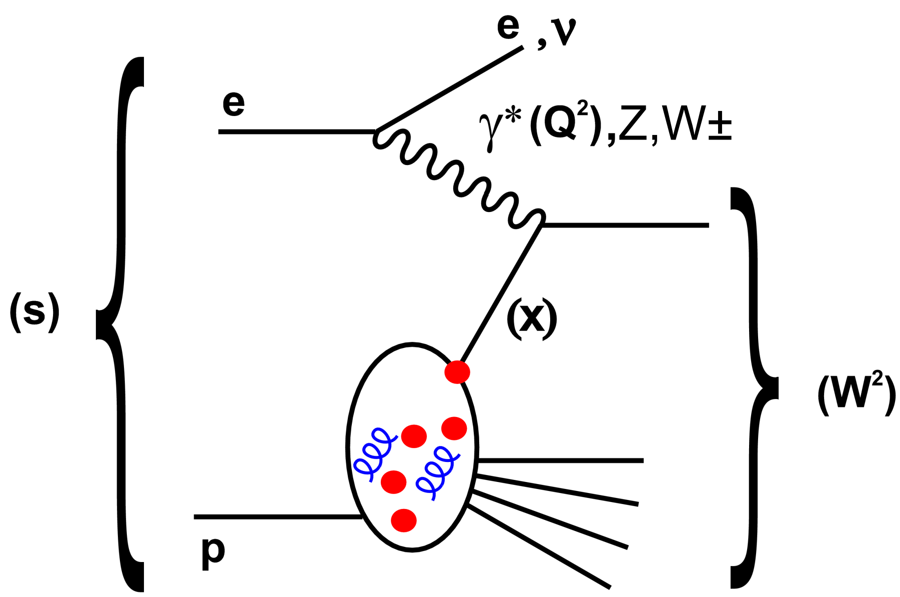
QCD and Hadronic Final State measurements at HERA

Boris Levchenko, SINP MSU

(on behalf of the ZEUS & H1 collaborations)

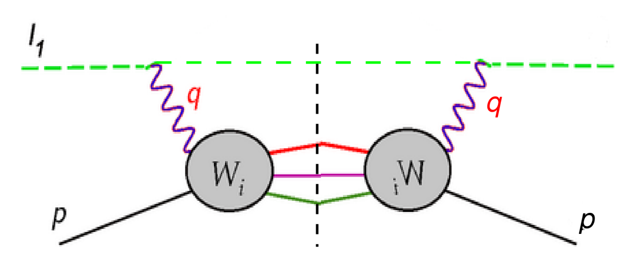


HFS — hadronic final state
is characterised by
- multiplicity
- space-time distribution of patricles (jets, etc)
- energy-momentum distribution
- composition of FS (particle species)
- how all these quantities varies with s, x, Q^2, W

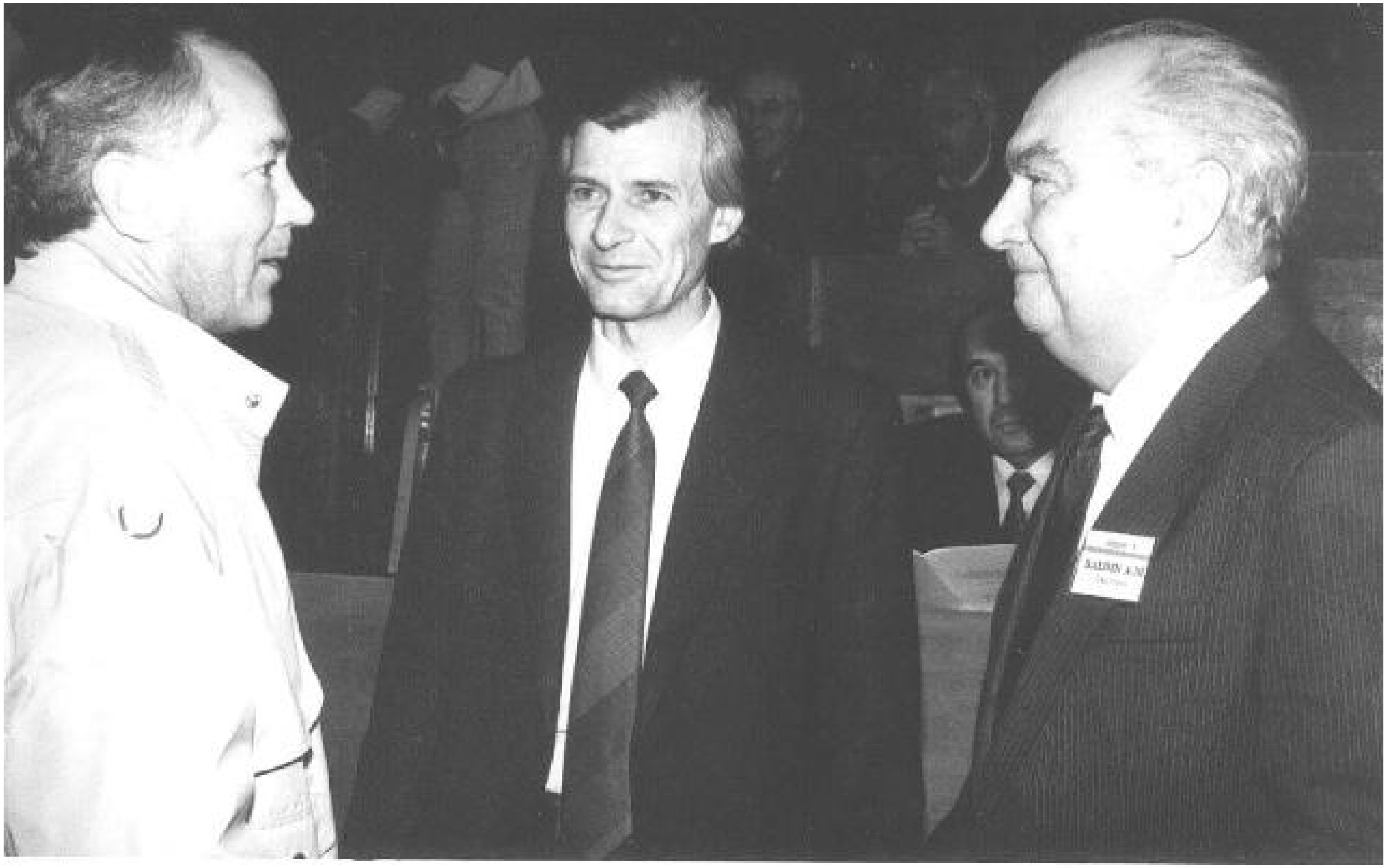
- Structure functions, talk by S. Shushkevich

$Q^2 \sim 0$ GeV², Photoproduction (PHP)

$Q^2 > 0.05$ GeV², DIS



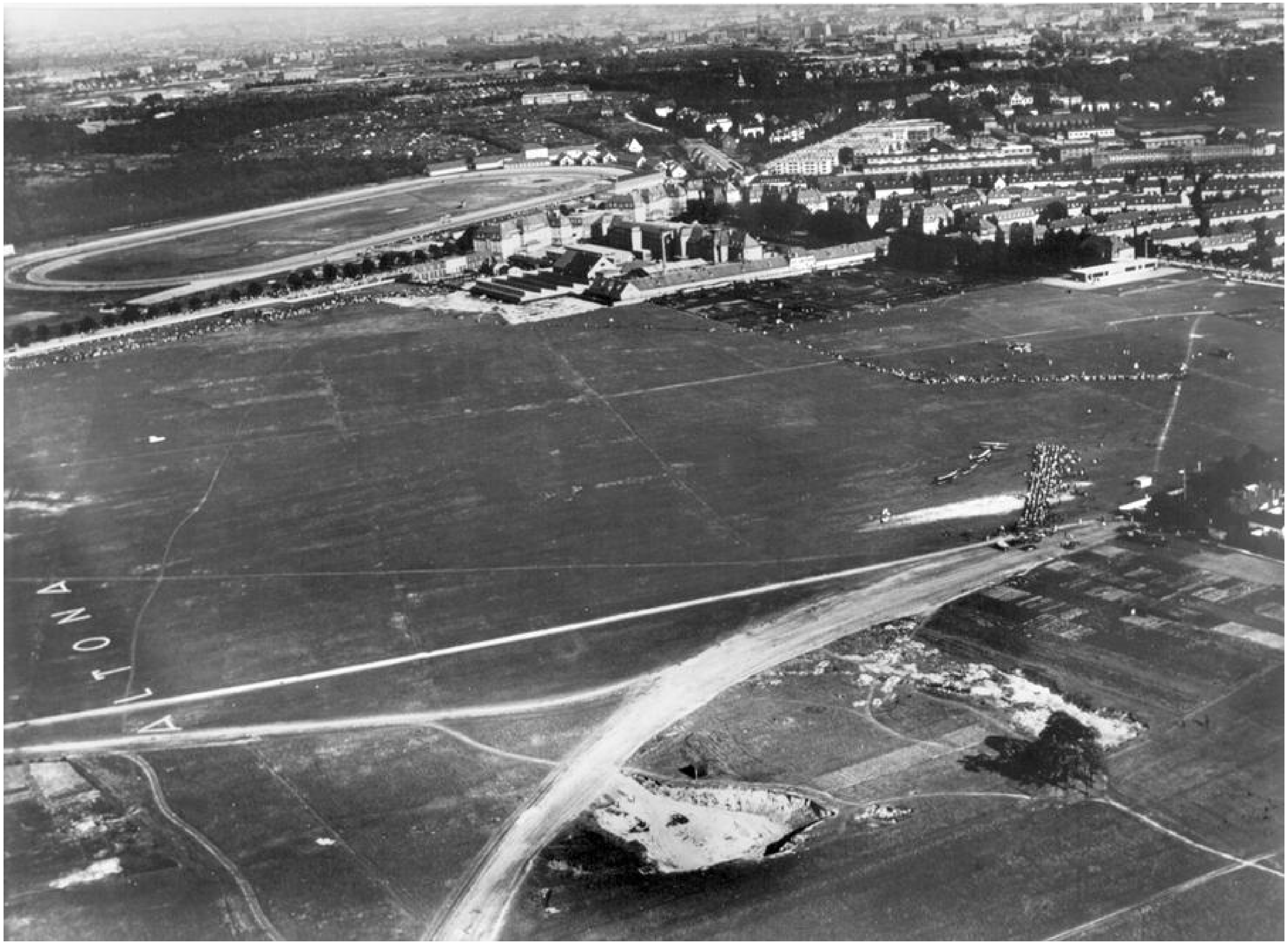
ISHEPP VI, 1981



N. P. Zotov, A. D. Kovalenko, A. M. Baldin

DESY

Hamburg racecourse



Hamburg-Bahrenfeld, Altona airport — future place for DESY and HERA (1957)

HERA (1992-2007)

German: Hadron-Elektron-RingAnlage,
English: Hadron-Electron Ring Accelerator

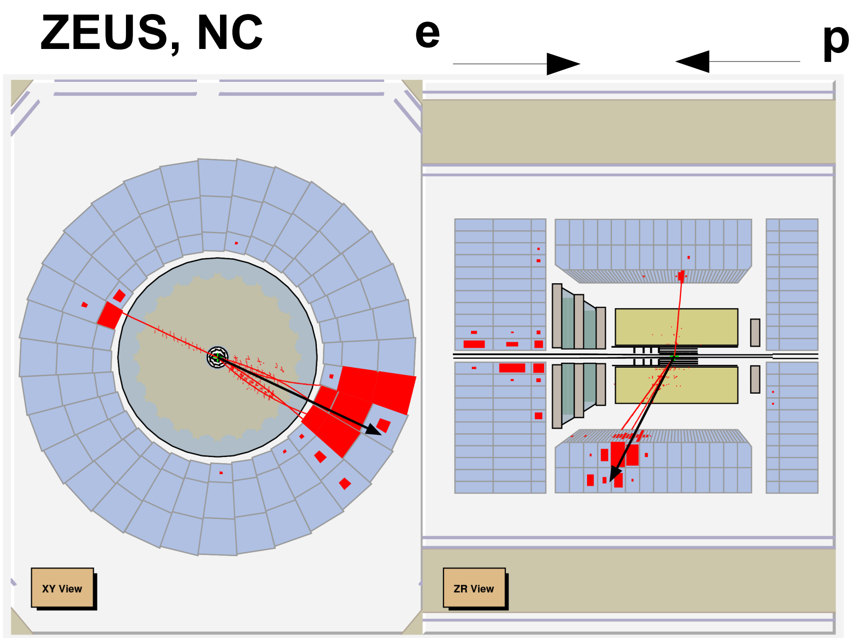
H1

ZEUS

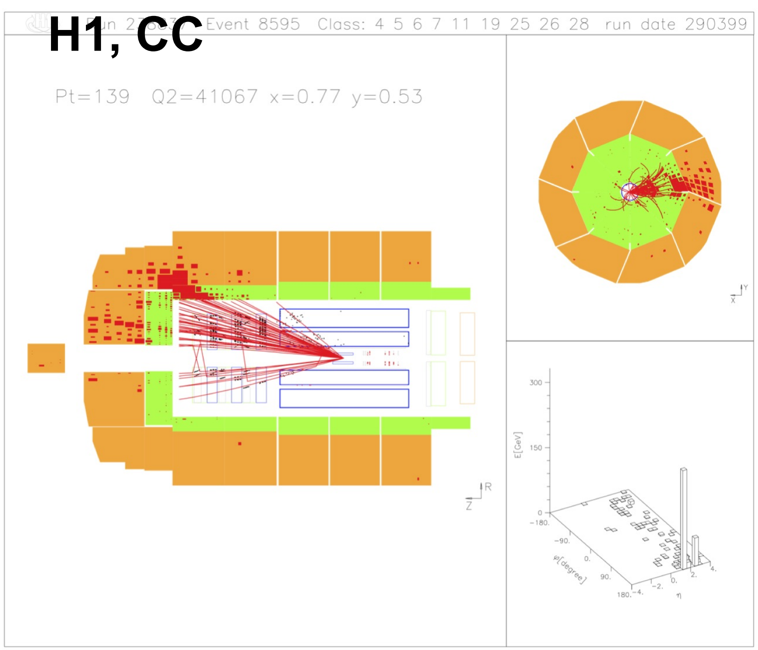
The storage ring was located in a tunnel of length 6.3 km

HERA collider experiments

ZEUS, NC



H1, CC



On May 31st 1992, the two HERA experiments **H1** and **ZEUS** observed for the first time electron - proton collisions

On June 30 2007, HERA was shut down.

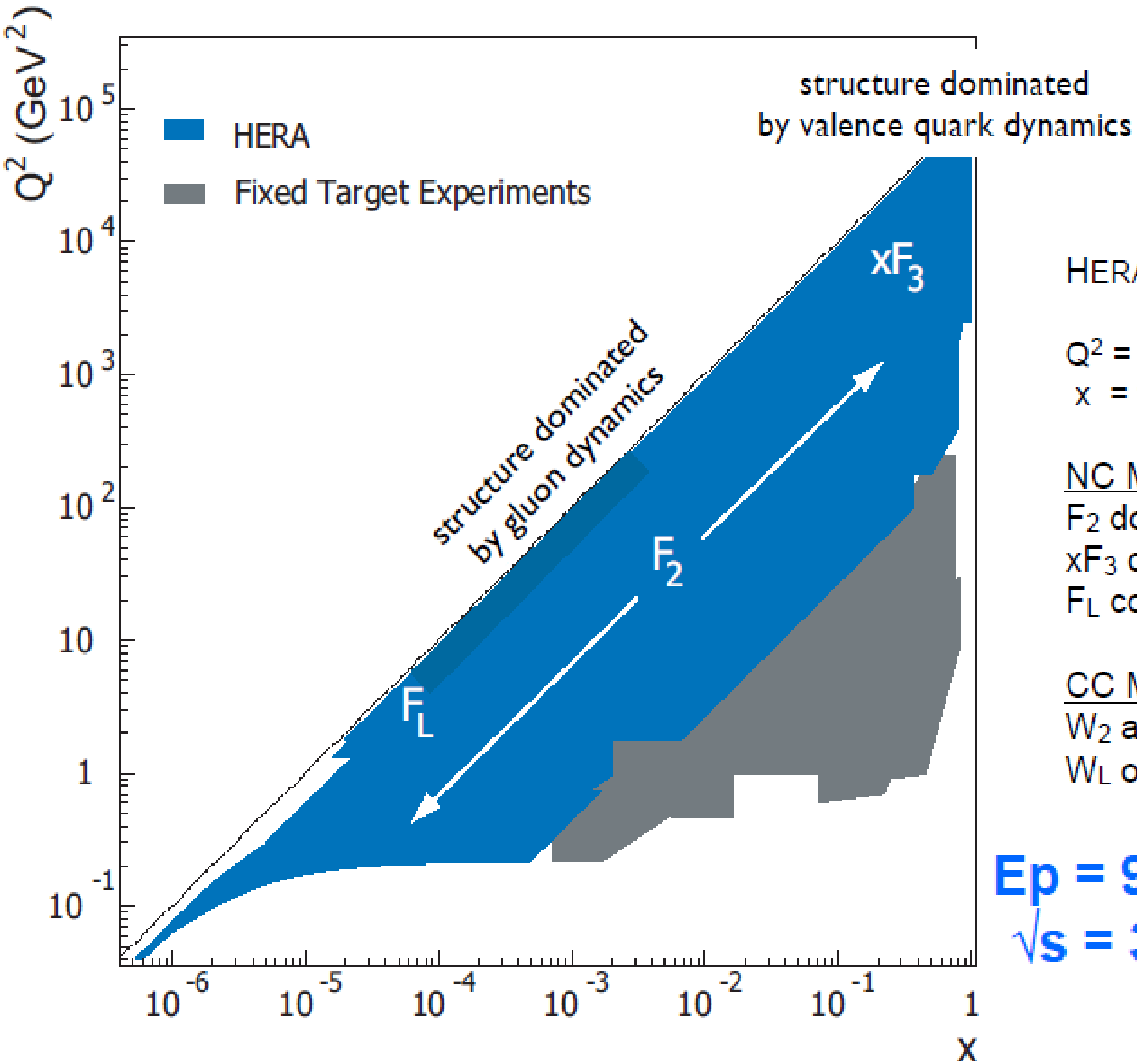
The data were taken at proton beam energies of **820, 920, 575** and **460** GeV and an electron beam energy of **27.5** GeV: $\sqrt{s} \leq 318\,\mathrm{GeV}$

Change the centre of mass energy of the **e-p** collision allows to extract **F_L**.

Collected data of ~1 fb^{-1}

470+ papers

HERA Kinematic Plane



HERA data cover wide region of x, Q^2

Q^2 = boson virtuality
x = fractional momentum of struck quark

NC Measurements
F_2 dominates most of Q^2 reach
xF_3 contributes in EW regime
F_L contributes only at highest y

CC Measurements
W_2 and xW_3 contribute equally
W_L only at high y

Ep = 920, 820, 575, 460 GeV
$\sqrt{s}$ = 320, 300, 251, 225 GeV

$0.045 < Q^2 < 50000$ GeV^2 $6.\ 10^{-7} < x_{Bj} < 0.65$

QCD — Quantum Chromo Dynamics

A part of more the general Electroweak Theory (SM), the output from the local gauge invariance principle and broken symmetries.

The SM Largangian provide rules for interactions of elementar partons.

However the proton and a vitual photon are more complicated systems.

Two branches:

1)The analytical perturbative approach (APA=pQCD + LHPD): MLLA, NNLO, …

2) QCD MC models — essential ingredients:

- running α_s (asymptotic freedom)
- quarks and gluons as the particle constituents
- partonic cascade
- color coherence -> angular ordering
- parton fragmentation/hadronization into hadrons
- energy-momentym, electrical and colour charge conservation

- FS particles as input for the detector responce simulation with the GEANT package

That is

LO ME + LL PS + Fragmentation + Conservation Laws

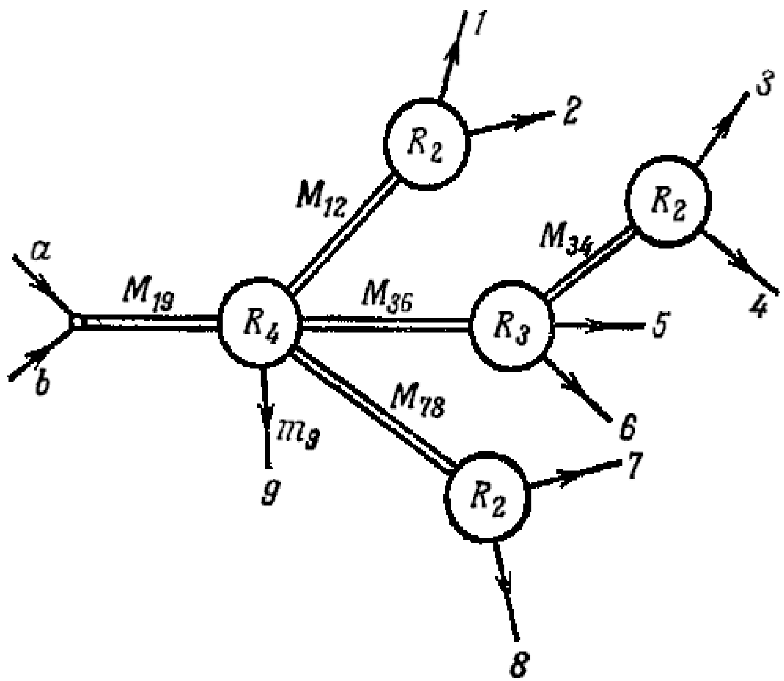
However, it is misleading if LL showers are equated with LL analytical calculations.

In particular, the latter contain no constraints from energy–momentum conservation: the radiation off a quark is described in the approximation that the quark does not lose any energy when a gluon is radiated, so that the effects of multiple emissions factorize.

Therefore energy–momentum conservation is classified as a next-to-leading-log correction.

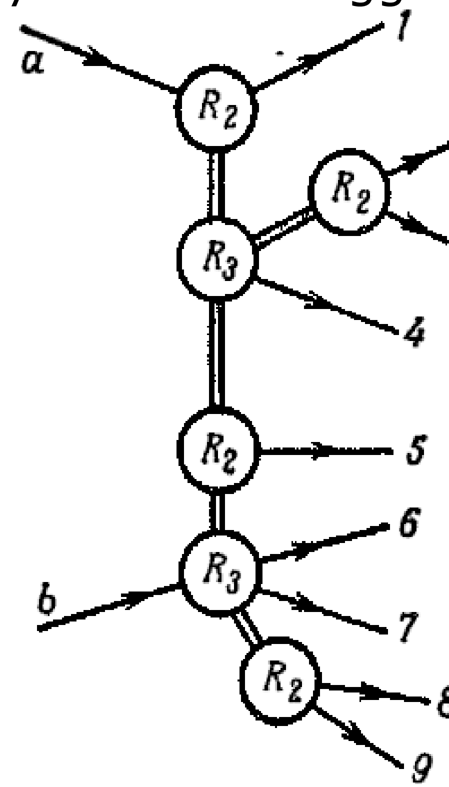
Space–time picture of fragmentation

Timelike cascade
(fireball type)



HERWIG

Space-like cascade,
multiperiferal type
(very succesful Regge approach)

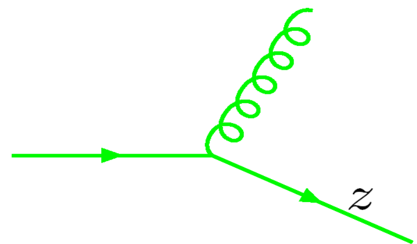


Lund MC family:Pythia, Lepto, Ariadne
(The fragmentation is based on the Lund string model)

Splitting kernels — Elemental parts of PS

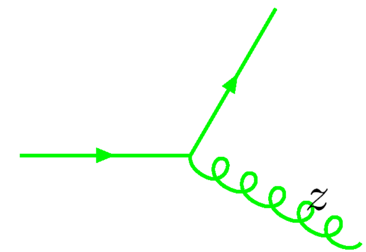
DGLAP LL evolution

Dokshitzer-Gribov-Lipatov-Altarelli-Parisi splitting kernel: dependent on flavour and spin



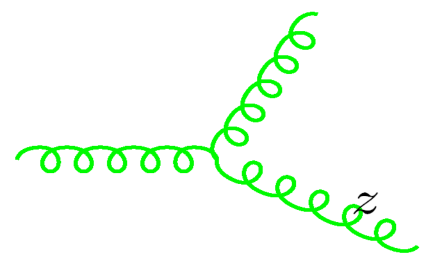
$q \to qg$

$C_F \frac{1+z^2}{1-z}$



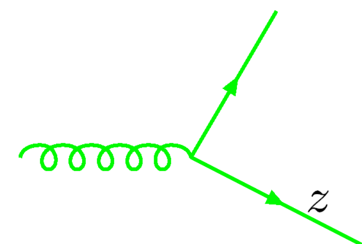
$q \to gq$

$C_F \frac{1+(1-z)^2}{z}$



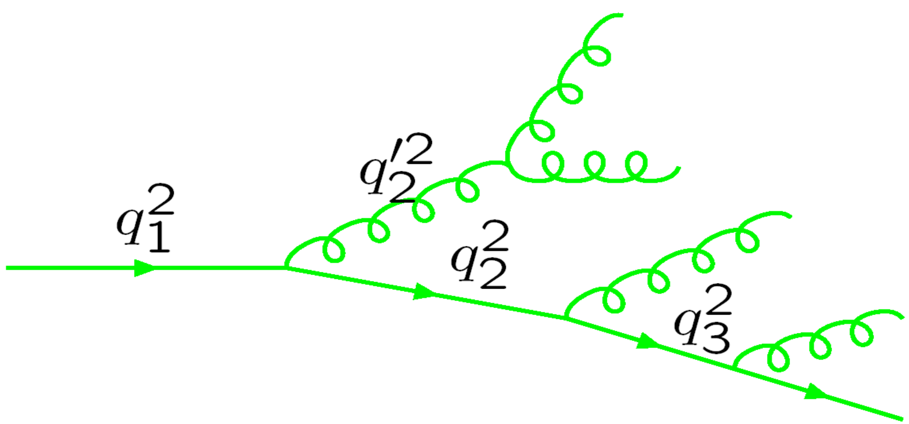
$g \to gg$

$C_A \frac{z^4+1+(1-z)^4}{z(1-z)}$



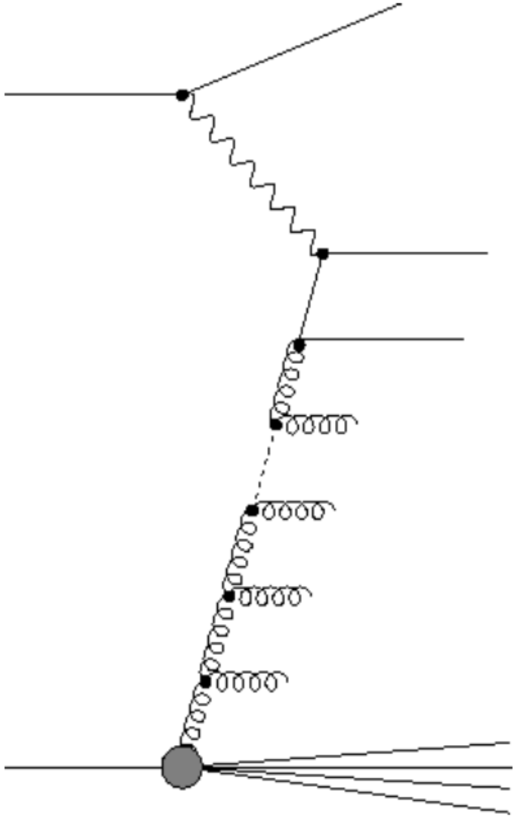
$g \to q\bar{q}$

$T_R \left(z^2 + (1-z)^2\right)$



$$q_1^2 > q_2^2 > q_3^2 > \dots$$
$$q_1^2 > q_2'^2 \dots$$

DGLAP evolution equations



A diagram with *n* gluon rungs

$$(\alpha_s \log(Q^2))^n \qquad Q^2 \gg k_{Tn}^2 \gg \dots \gg k_{T1}^2$$

$$\frac{dq_i(x,Q^2)}{d\log(Q^2)} = \frac{\alpha_s}{2\pi}\int_x^1 \left(q_i(z,Q^2)P_{qq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{qg}\left(\frac{x}{z}\right)\right)\frac{dz}{z},$$

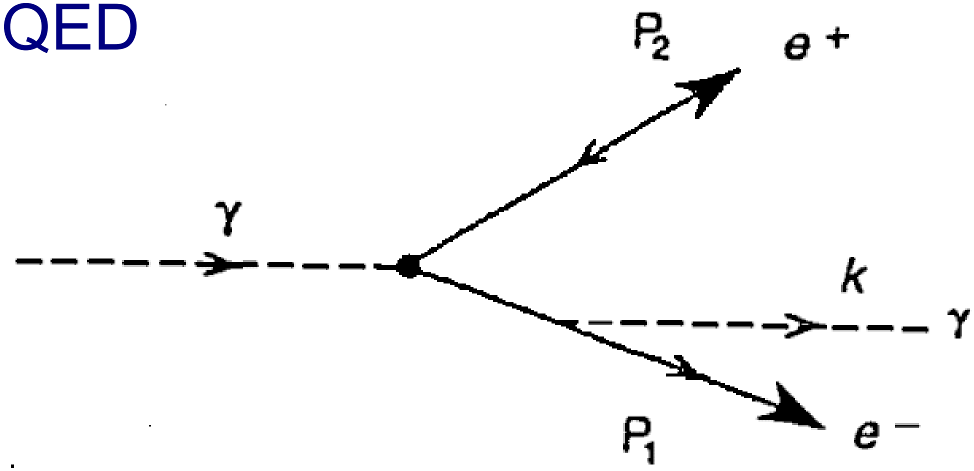
$$\frac{dg(x,Q^2)}{d\log(Q^2)} = \frac{\alpha_s}{2\pi}\int_x^1 \left(\sum_i q_i(z,Q^2)P_{gq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{gg}\left(\frac{x}{z}\right)\right)\frac{dz}{z}$$

$q(z,Q^2_0)$ should be parametrized ad hoc

$P_{a\to bc}(z)$ is interpreted as the branching probability for the original parton a.

Color Coherence and Angular Ordering

QED



$\Theta_{\gamma e^-} < \Theta_{e^+e^-}$ or $\Theta_{\gamma e^+} < \Theta_{e^+e^-}$

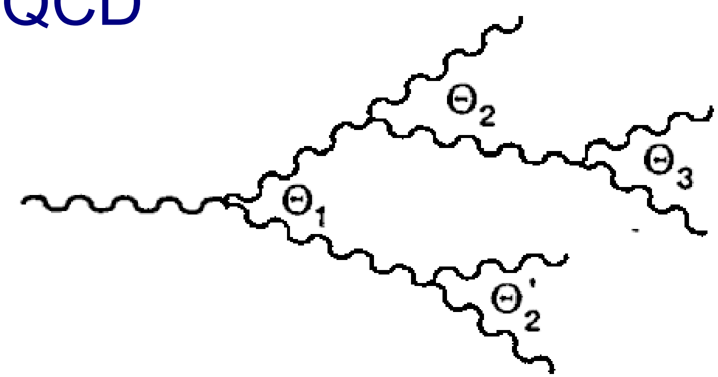
«Chudakov effect»

$\Theta_{\gamma e^-} \approx \Theta_{\gamma e^+} \gg \Theta_{e^+e^-}$

Small transverse separation
effective charge ~0, no radiation
γ to be strongly suppressed

e+ and e- can emit photons independently

QCD



effective color charge

$\Theta_1 > \Theta_2 > \Theta_3 \ldots, \Theta_1 >$

So appears MLLA

a soft gluon singularity cures by the Sudakov FF

Monte Carlo implementation

Can generate branching according to

$$\frac{d\sigma}{dt\,dz} = \Delta(Q,t)\frac{\alpha_s}{2\pi}\frac{1}{t}P_{qq}(z) \approx \exp\left(-\frac{\alpha_s}{2\pi}C_F \ln^2\frac{t}{Q} + \cdots\right)\frac{1}{t}\frac{\alpha_s}{2\pi}C_F\frac{1+z^2}{1-z}$$

The Sudakov factor Δ(t0, t) as the probability of finding no gluons between the scales t and t0.

The Sudakov factor is equivalent to performing the leading logarithmic resummation in QCD.

It has the important qualitative effect of sending the cross section for producing a gluon at t = 0 from σ = ∞ to σ = 0

Hadronization

Partons are not physical particles: they cannot freely propagate.
Hadrons are.

Hadronization cannot be calculated from first principles.
Need a model of partons' confinement into hadrons: hadronization.

Simplest : LHPD $$N_{hadrons} = K_{LPHD} \times N_{partons}$$

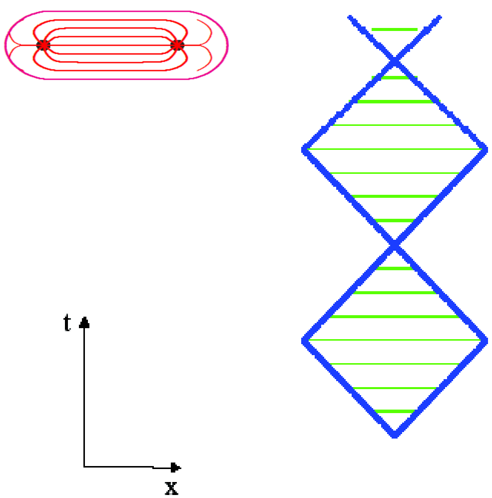
LHPD - Local Hadron Parton Duality

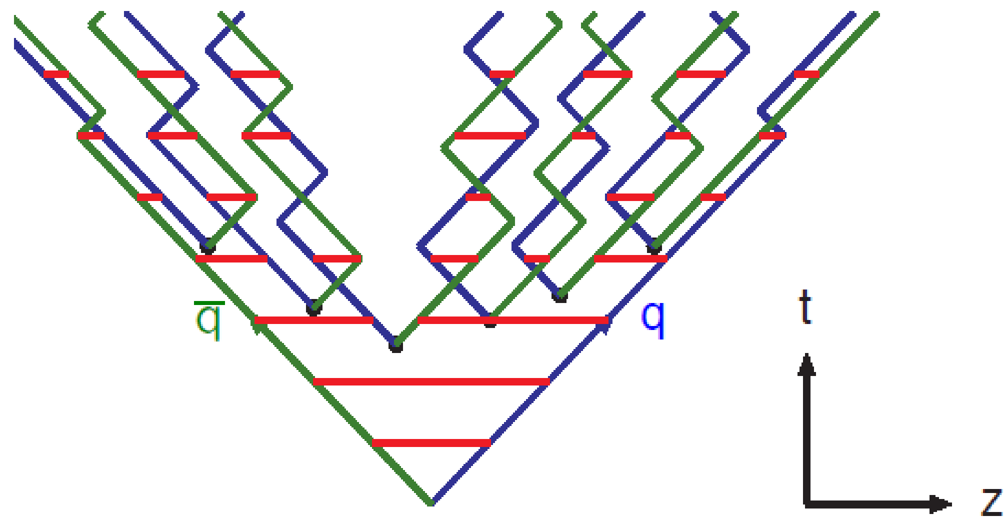
Fragmentation - The Lund String Model

Start by ignoring gluon radiation:
e+e- annihilation = pointlike source of qq pairs
Intense chromomagnetic field within string →qq pairs created by tunnelling. Analogy with QED:

$$\frac{d(\text{Probability})}{dx\,dt} \propto \exp(-\pi m_q^2/\kappa)$$

Expanding string breaks into mesons long before yo-yo point.



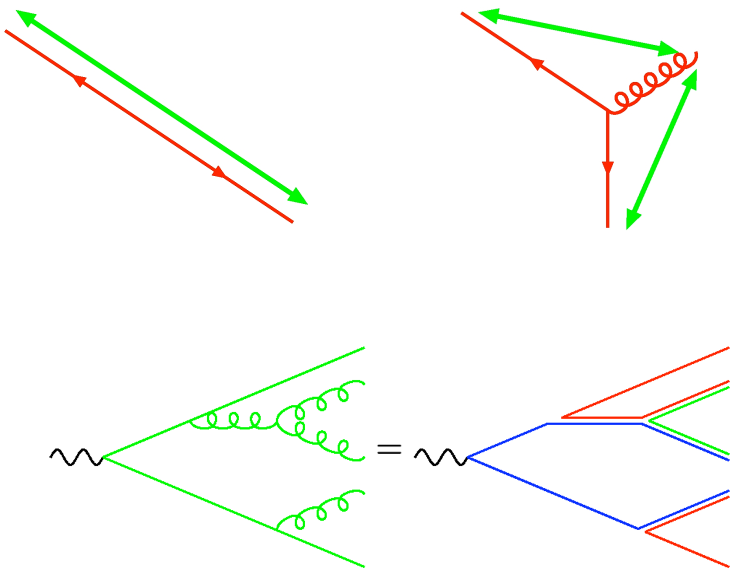


Light quarks connected by string.

ARIADNE - The Colour Dipole Model

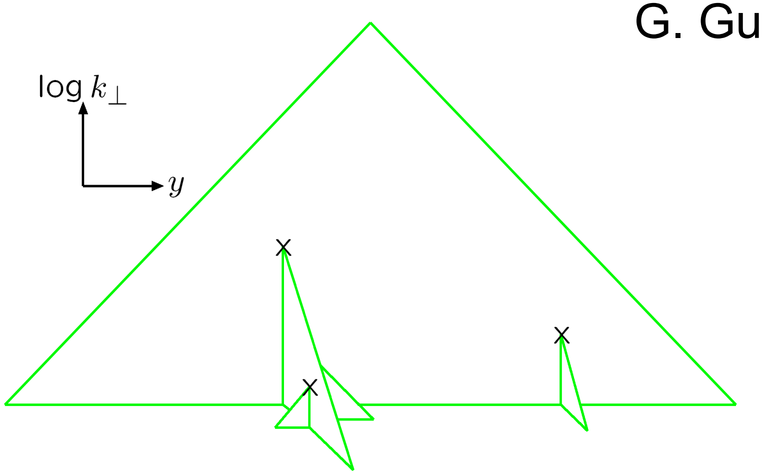
Leif Lönnblad

Emission of soft gluons from colour-anticolour dipole.
Subsequent dipoles continue to cascade
c.f. parton shower: one parton → two
CDM: one dipole → two = two partons → three



Kinematics is represented in 'origami diagram':

G. Gustafson



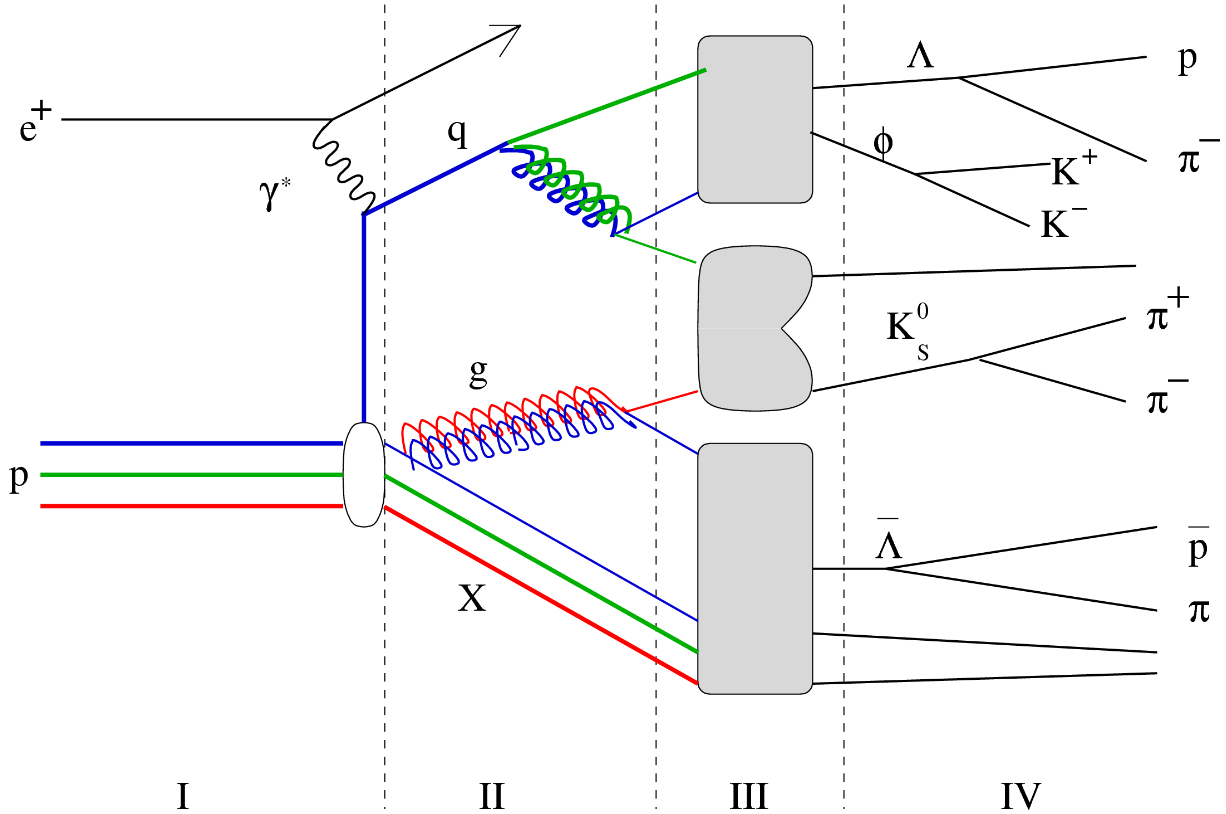
No Kt ordering (ala BFKL evolution)

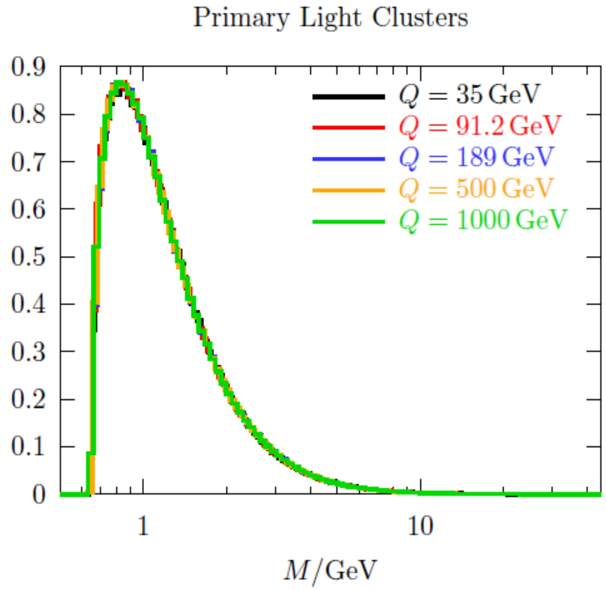
Hadronization according to the Lund String Model

HERWIG

Bryan Webber

LL PS

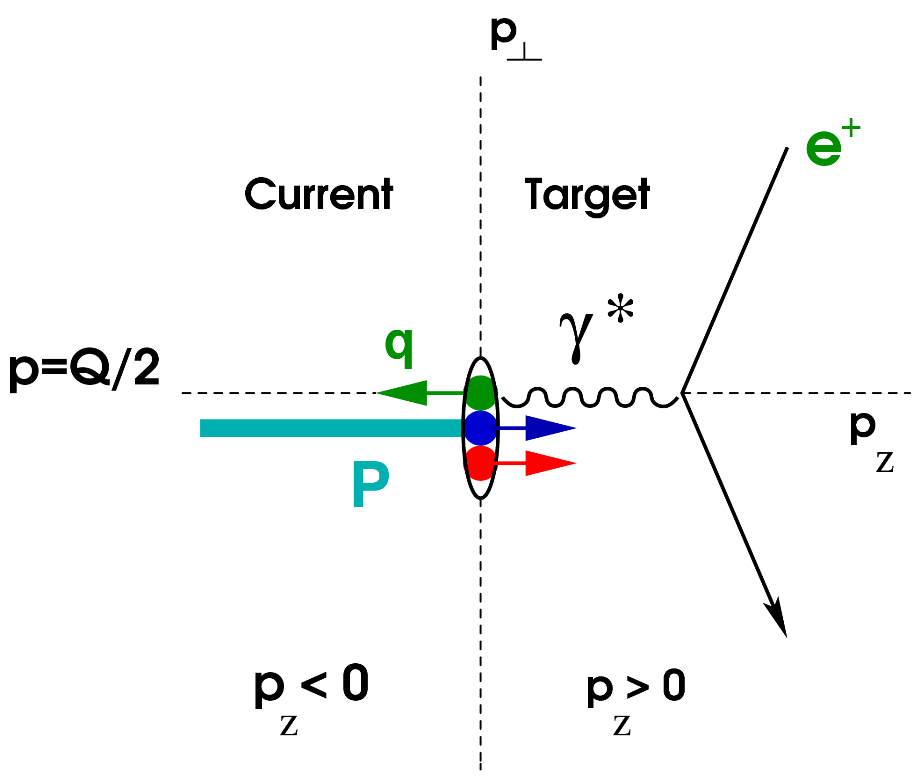




The cluster hadronization model is based on the preconfinement property of parton showers, which leads to colour-singlet parton clusters with a universal mass distribution at low scales.

1-st generation	2-nd generation
PYTHIA 5.7 / JETSET 7.4 Dec 1993	LEPTO
PYTHIA 8.2 Present	RAPGAP
ARIADNE 2 1988	DJANGO
ARIADNE version 4.12, present	CASCADE
HERWIG 5.1 1992	SHERPA
HERWIG 7 present , author list new	
HERWIG++	

Briet frame (BF)



HCM

$$\vec{P}_{\gamma^*} + \vec{P}_p = 0$$

Current, $P_z^* > 0$

Target, $P_z^* < 0$

Large asymmetry of the beam energies at HERA, a large fraction of the hadronic final state close to the proton direction lies outside the detector acceptance. Only hadrons belonging to CR of BF or HCM used in analyses

Modified Leading Log Approximation
MLLA/LPHD expectations

Average multiplicity of hadrons $< n_{ch}(s) >= a\alpha_s(s)^{b_1} \exp[b_2/\sqrt{\alpha_s(s)}]$

Momentum distribution $\frac{1}{\sigma}\frac{d\sigma^{e^+e^-}}{d\ln(1/x_p)} = \mathcal{N}(Y)\left(\frac{36N_C}{\pi^2 bY^3}\right)^{1/4} \exp\left[-\sqrt{\frac{36N_C}{b}}\frac{(l-\ln(1/x_{max}))^2}{Y^{3/2}}\right]$

where $l = \ln(1/x_p),\ Y = \ln(\sqrt{s}/2\Lambda_{eff})$ $\qquad b = \frac{11}{3}N_c - \frac{2}{3}N_f$

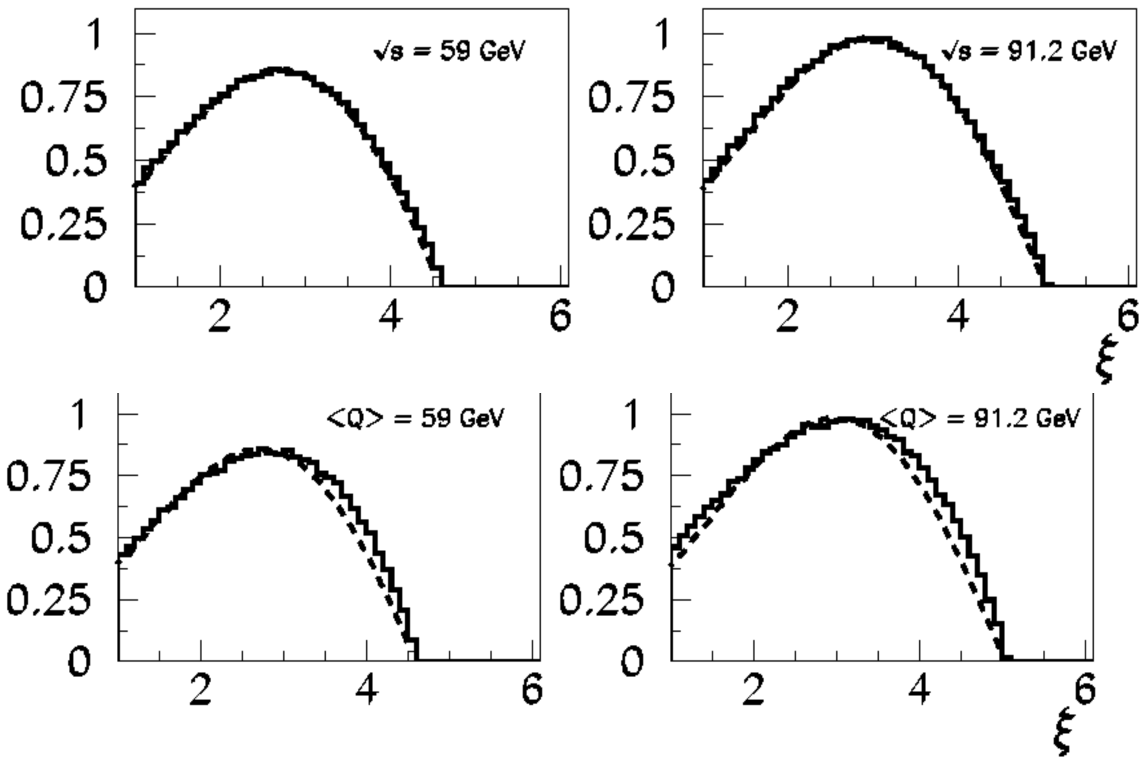
$$\mathcal{N}(Y) = K^{ch}Y^{1/4-B/2} \exp\sqrt{\frac{16N_c}{b}Y}$$

The position of the maximum of the distribution

$$\ln(1/x_{max}) = 0.5Y + B\sqrt{\frac{b}{16N_C}}\sqrt{Y} + \mathcal{O}(1)$$

Access to the main parameters of QCD

MLLA .vs. MC



e+e-

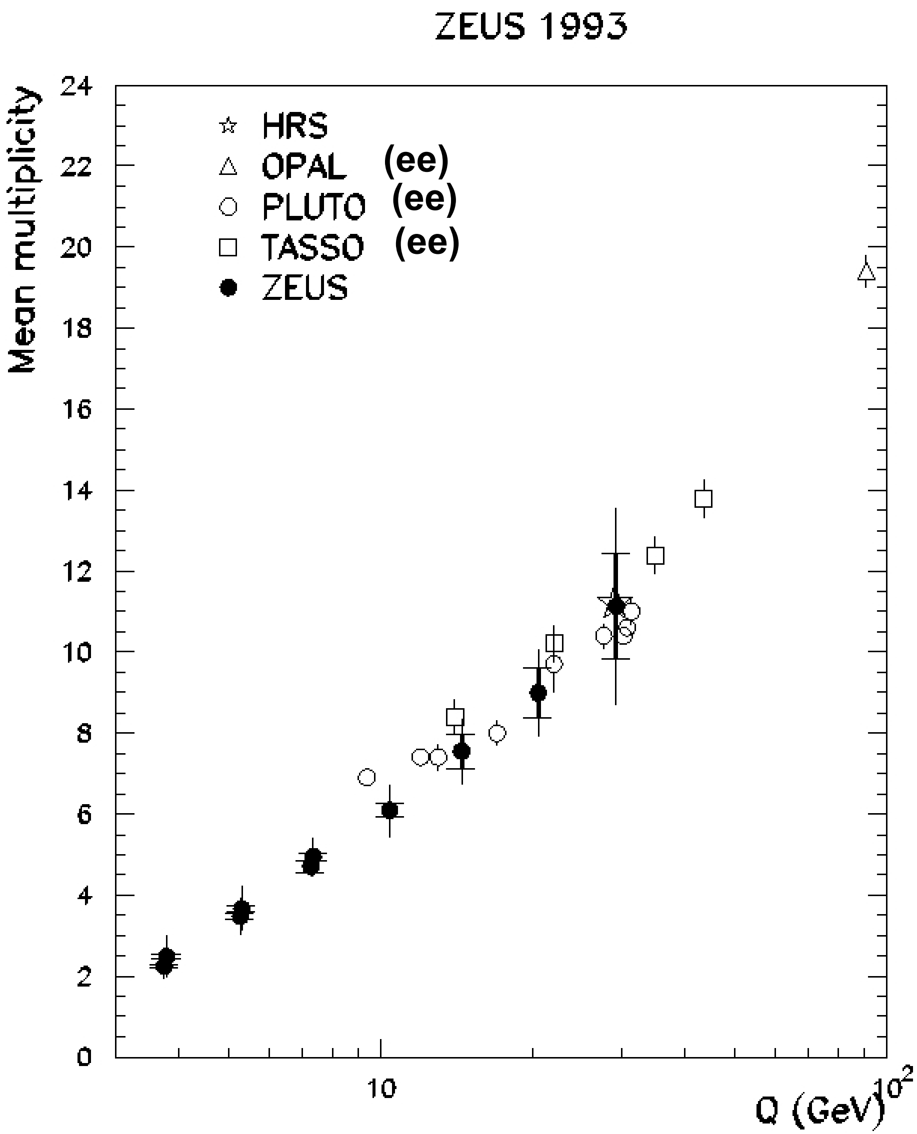
ARIADNE

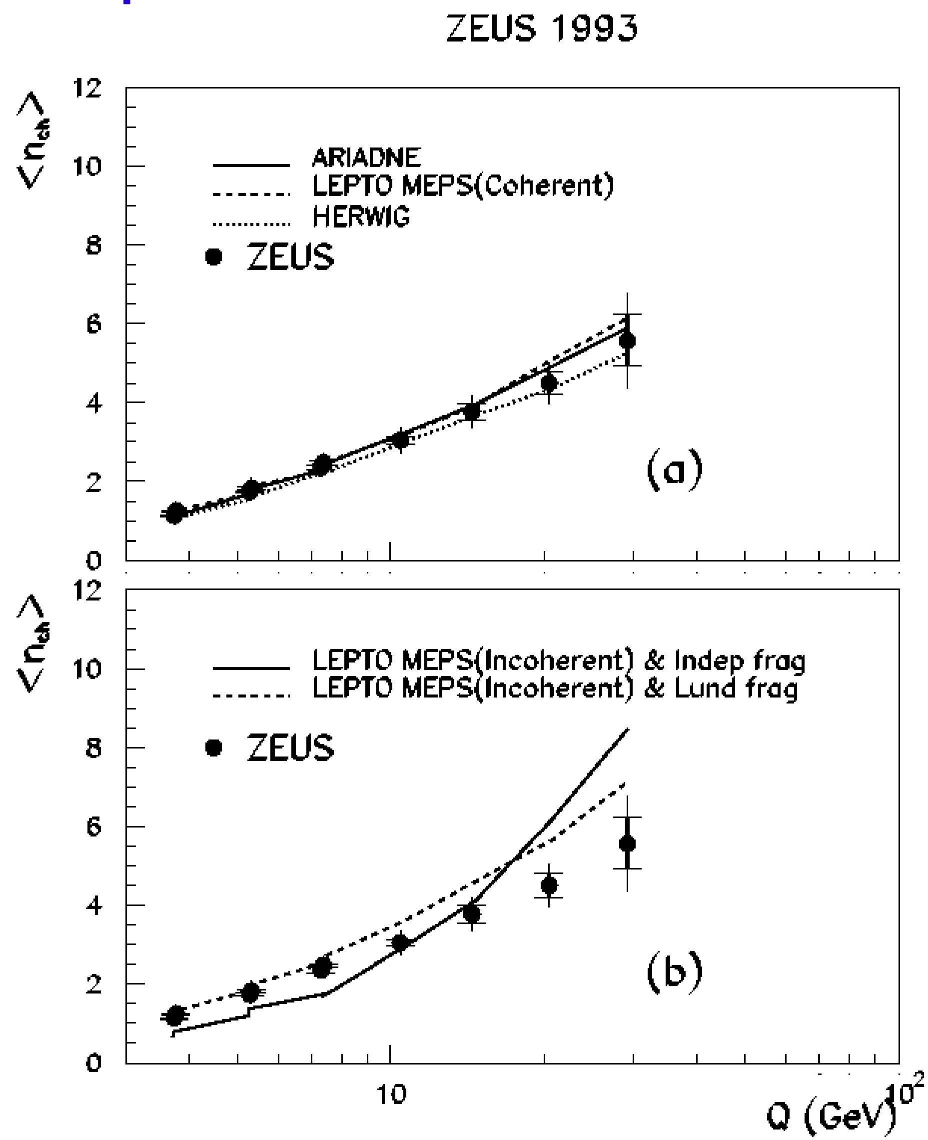
The logarithmic scaled momentum distributions, ξ

ep, DIS

The same was done with LEPTO and HERWIG in pre-HERA

Mean multiplicities

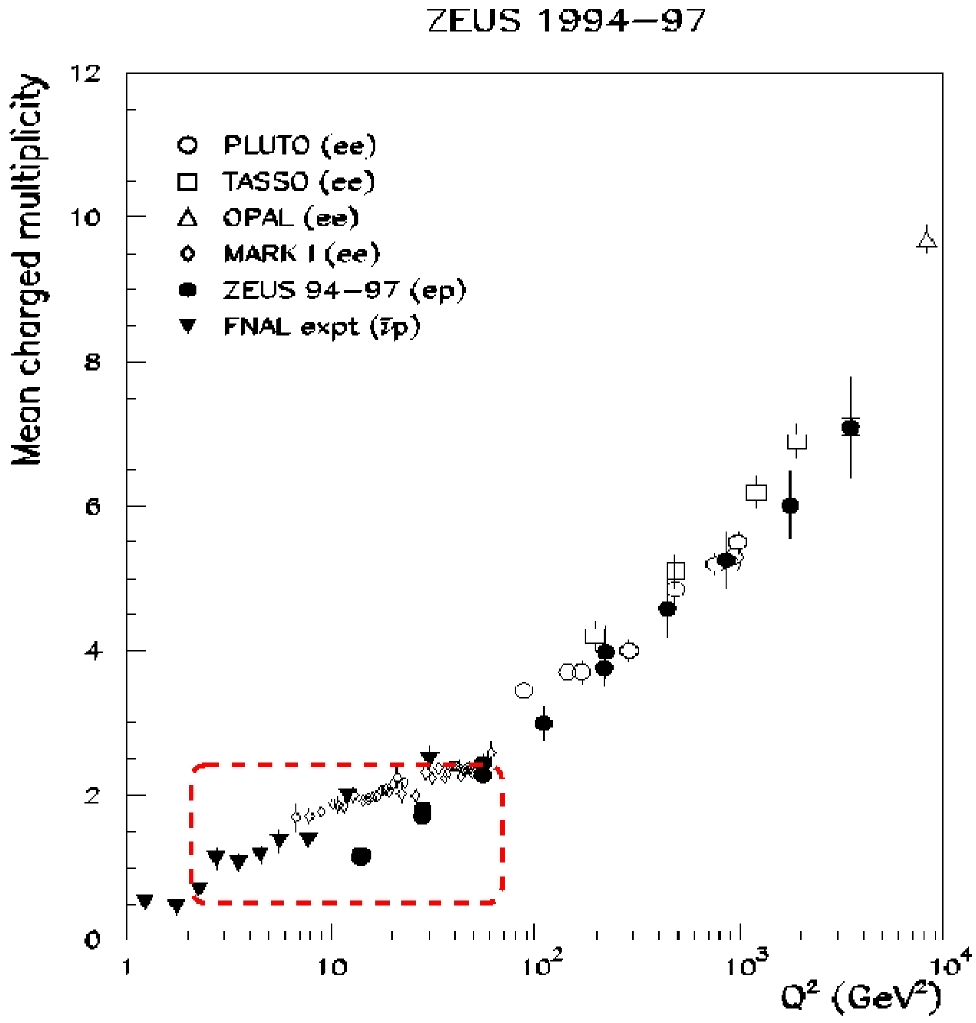


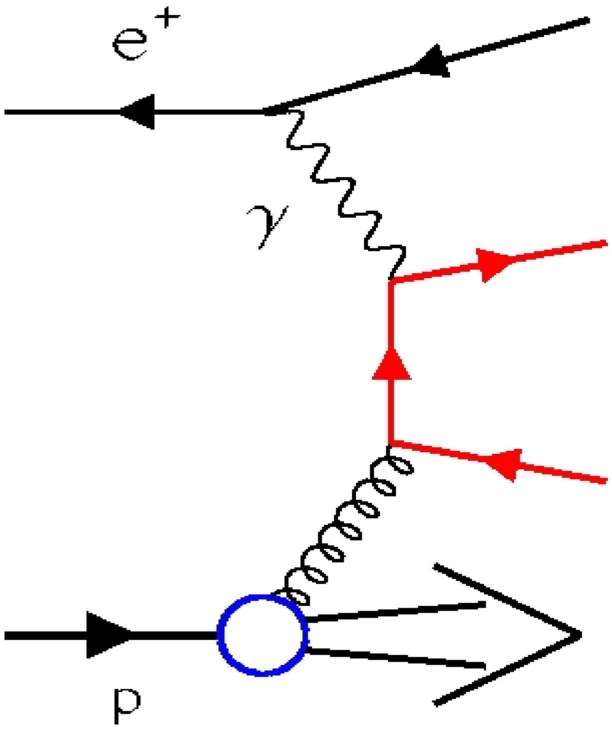


Universality of the quark fragmentation

Importance of coherence and connections between partons

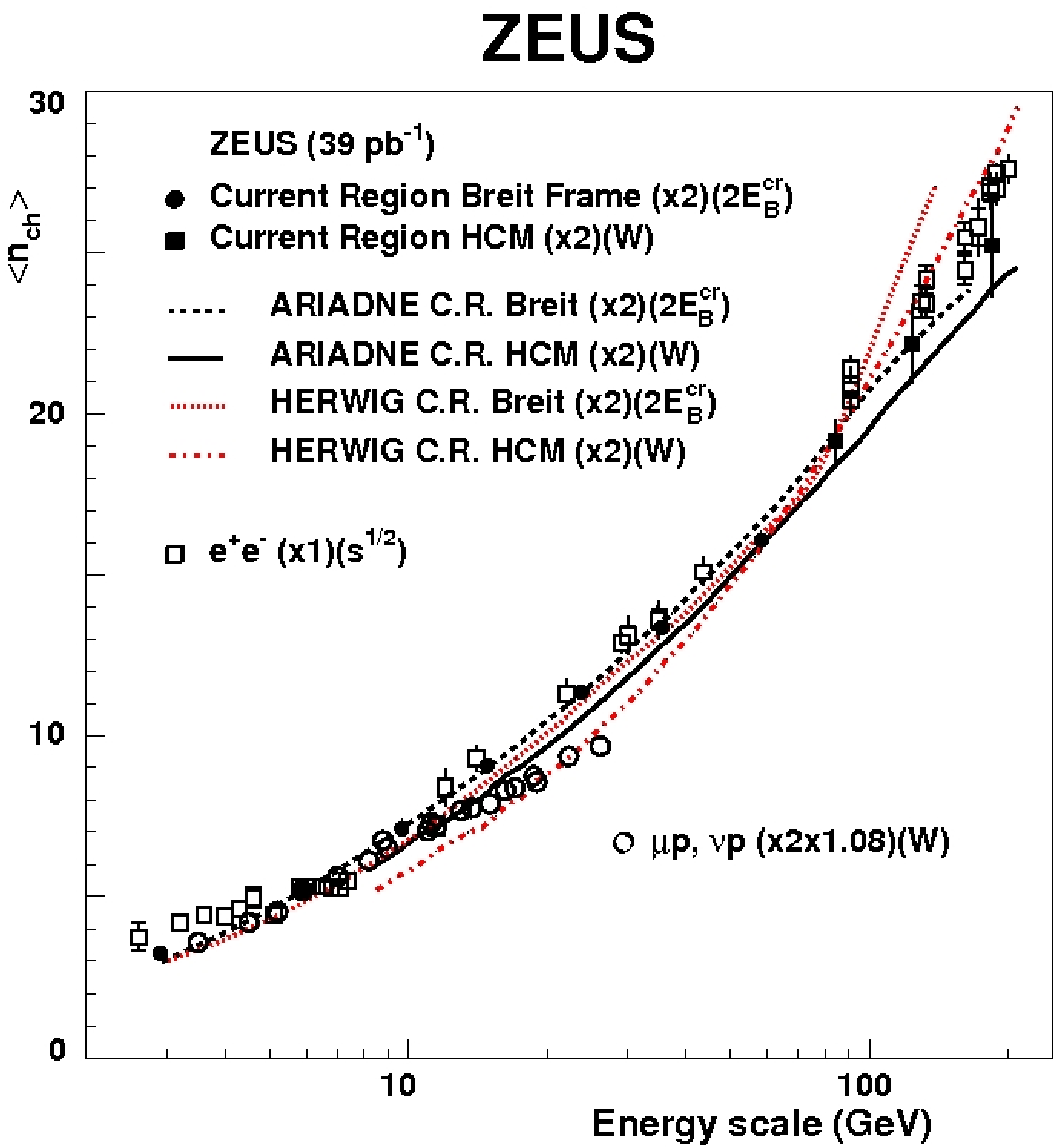
Universality of the quark fragmentation in e+e- and ep





BGF is absent in e+e- and νp

Universality of the Quark Fragmentation: Scale and Frame Dependence

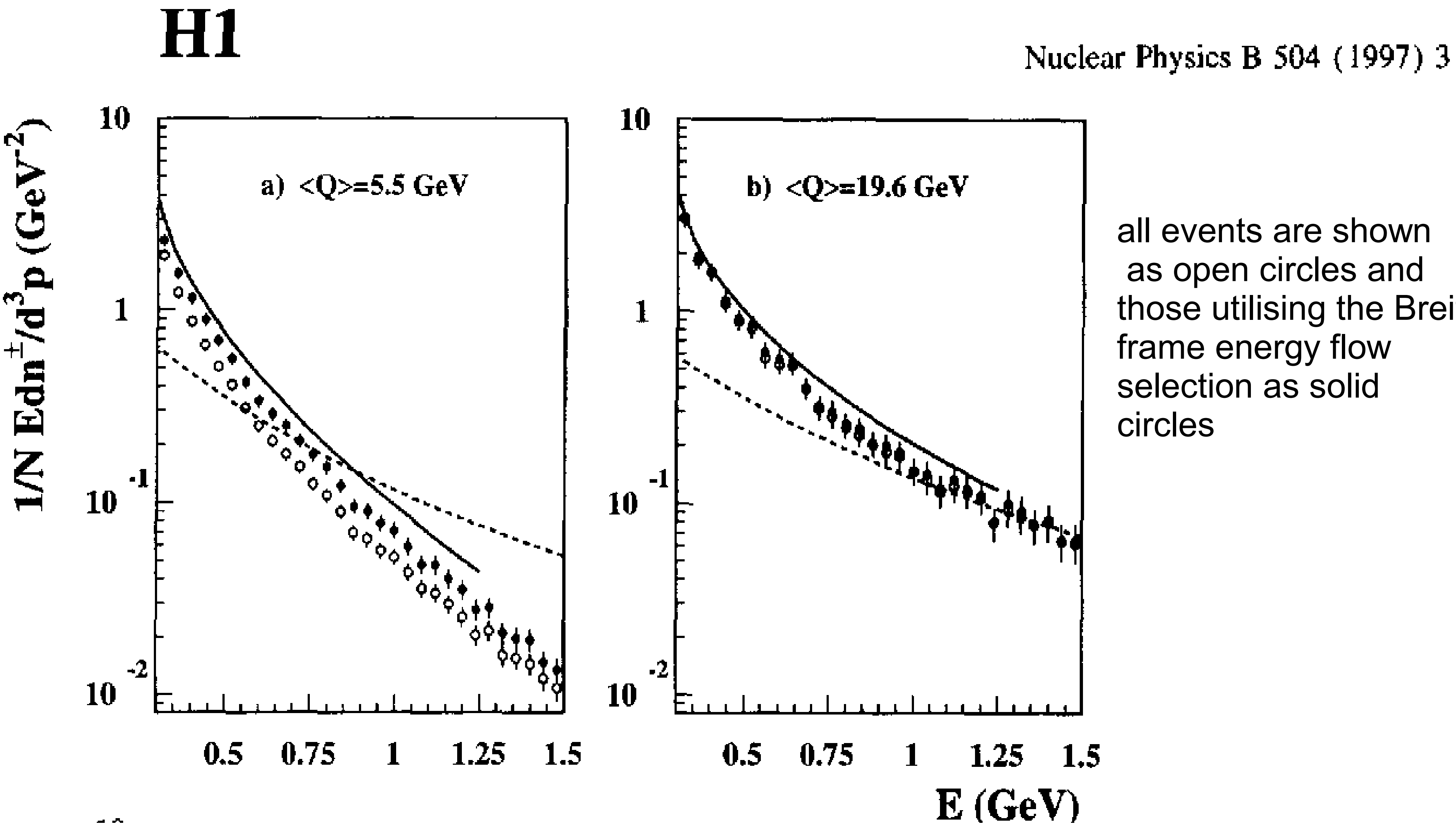


- DIS
- Measurements are performed in HCM and BF

-Scales: W in HCM, $2 \cdot E_{\rm B}^{\rm cr}$ in BF

DESY–08–036

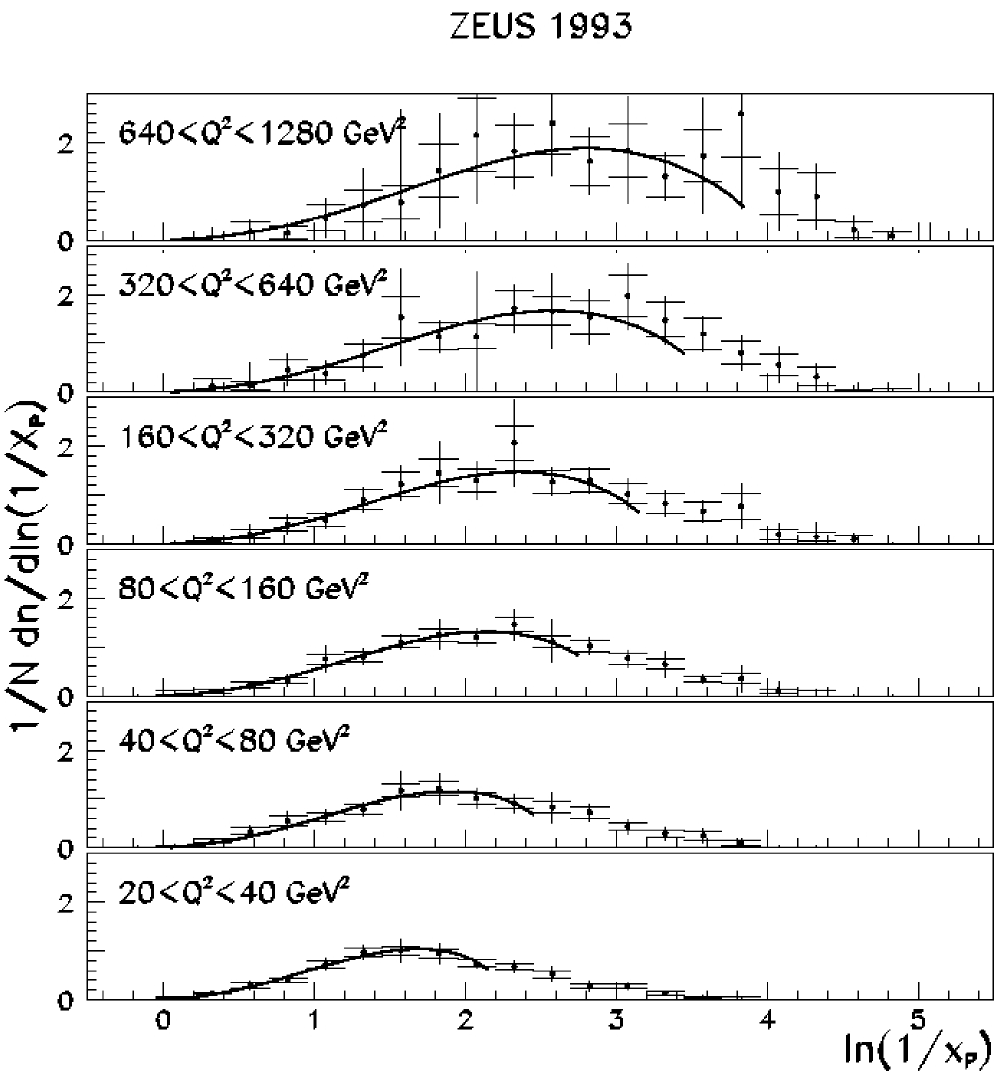
Invariant charged Hadron Energy Spectrum in the Current Hemisphere



all events are shown as open circles and those utilising the Breit frame energy flow selection as solid circles

The solid line is the prediction of MLLA/LPHD and the dashed line is the corresponding expectation for a non-running coupling constant, α_s

Momentum Distributions

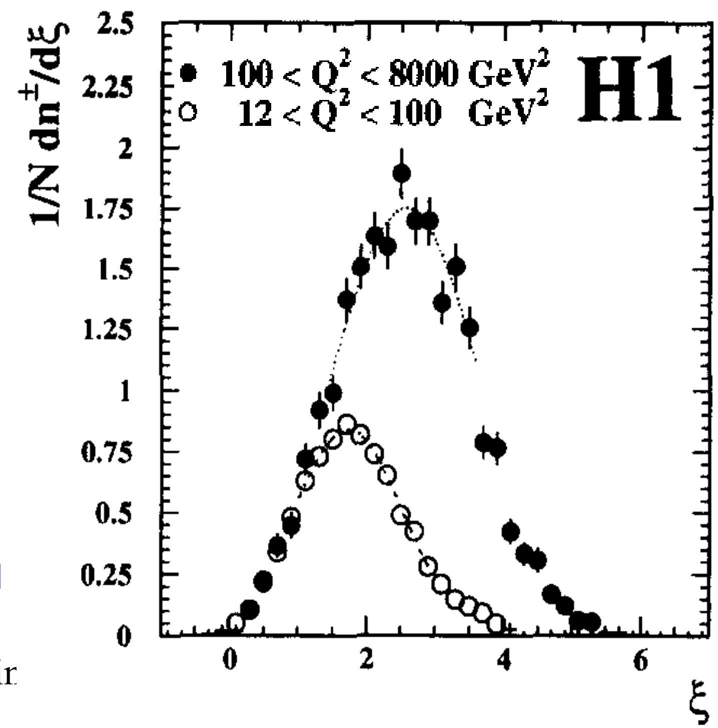


The logarithmic scaled momentum distributions, ξ

$$\xi = \log \frac{1}{x}, x = p_{track}/E_{jet}$$

Guassian shape

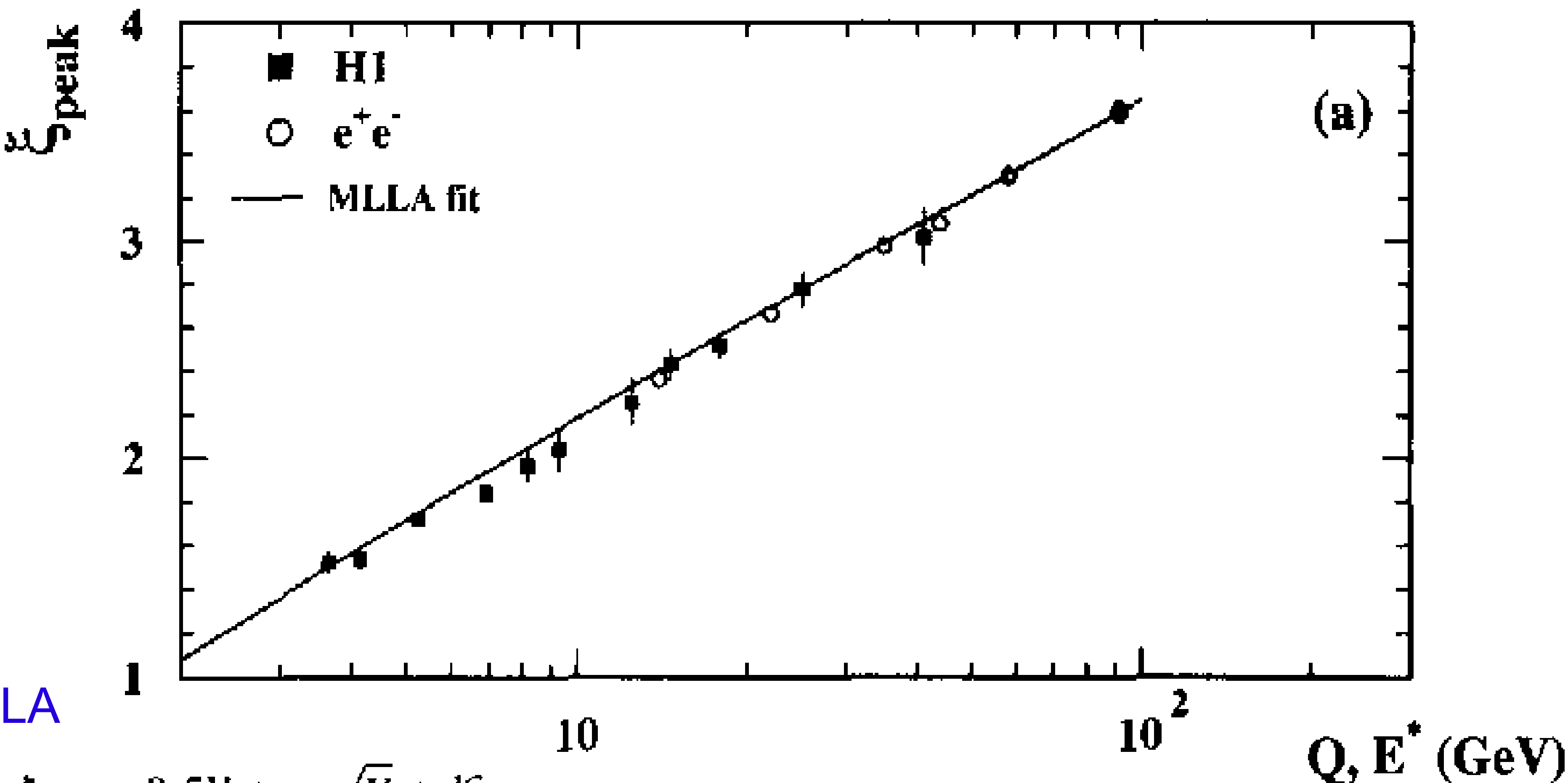
Peak position moves



Hump-Backed QCD Plateau

Evolution of the Peak

Nuclear Physics B 504 (1997) 3



MLLA

$$\xi_{peak} = 0.5Y + c_2\sqrt{Y} + \mathcal{K},$$

$$Y = \ln(Q/\Lambda_{eff})$$

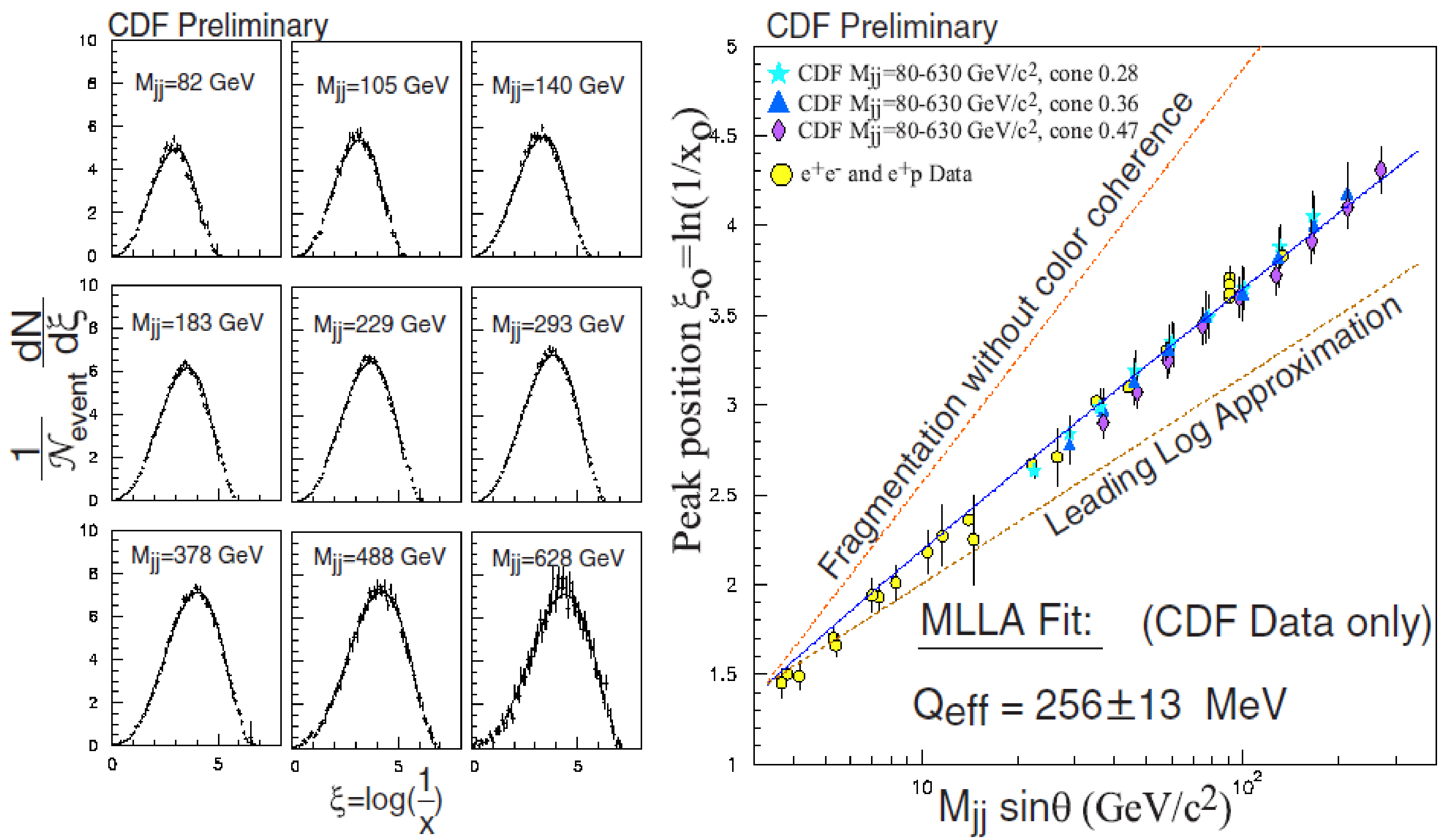
$$\Lambda_{eff} = 0.21 \pm 0.02 \text{ GeV}$$

as in e+e- data

Evolution of the Peak at Tevatron

$$N_{hadrons} = K_{LPHD} \times N_{partons}$$

Local Parton-Hadron Duality



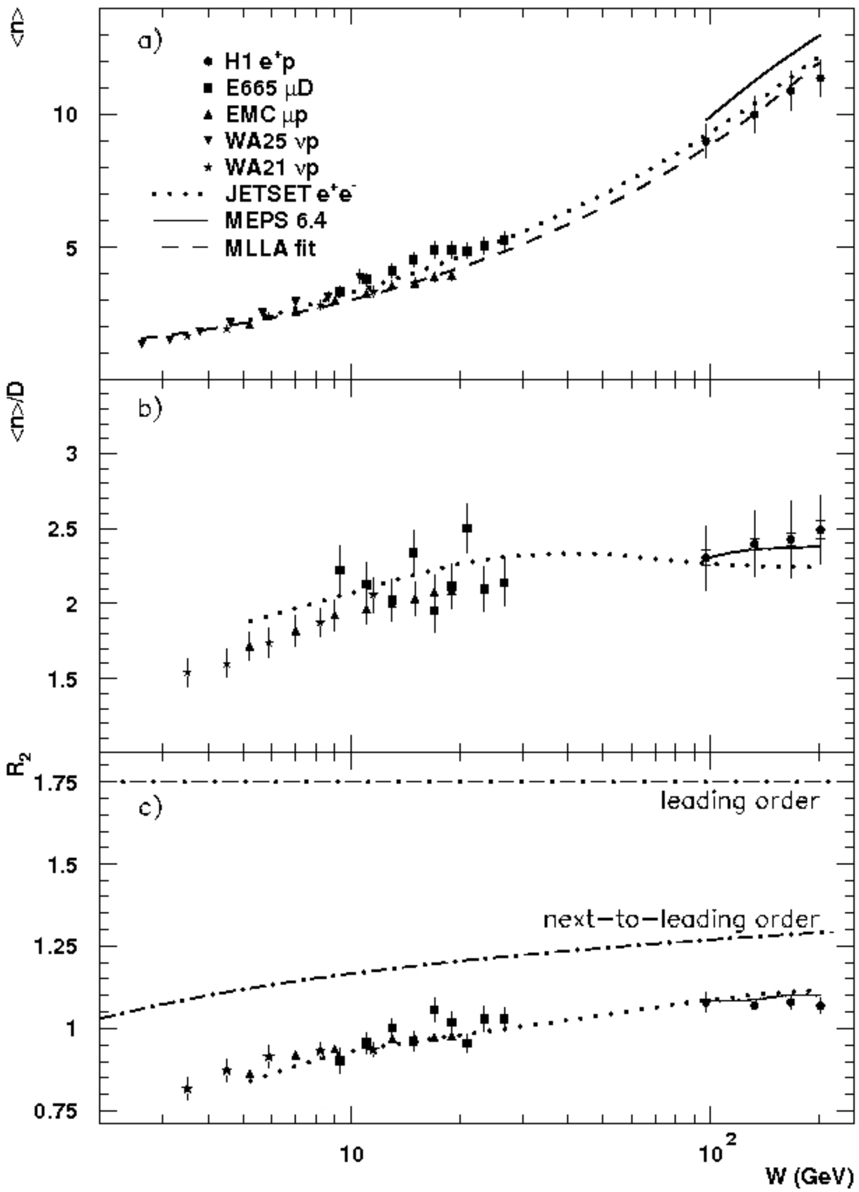
$$\xi = \log \frac{1}{x}, x = p_{track}/E_{jet}$$

$$\xi_{peak} = 0.5Y + c_2\sqrt{Y} + \mathcal{K},$$

Tracks were counted in restricted cones of sizes 0.47 around the jet axis.

Mean, Dispersion etc.

B. R. Weber



$$\langle n \rangle = a\,\alpha_s^b \exp\left(c/\sqrt{\alpha_s}\right)\left[1 + d \cdot \sqrt{\alpha_s}\right]$$

Two-loop expression

$$\frac{\alpha_s(W^2)}{4\pi} = \frac{1}{\beta_0 \ln(W^2/\Lambda^2)} - \frac{\beta_1 \ln\ln(W^2/\Lambda^2)}{\beta_0^3 \ln^2(W^2/\Lambda^2)}$$

$$R_2 = \langle n(n-1)\rangle / \langle n \rangle^2$$

Mini conclusions

- Universality of the quark fragmentation ✔
- Running strong coupling ✔
- Color coherence ✔
- Shower picture ✔
- Independent fragmentation —
- MLLA predictions well confirmed by MC and data ✔

Bose–Einstein Correlations (BEC)

Pairs of like-sign identical particles had a tendency to have smaller opening angles than pairs of unlike-sign one.

The effect of BEC between identical final-state particles is the true quantum nature of the hadronization process.

The detailed BE physics is not that well understood

No dependence of the source size on the kinematic variables, including Q^2.

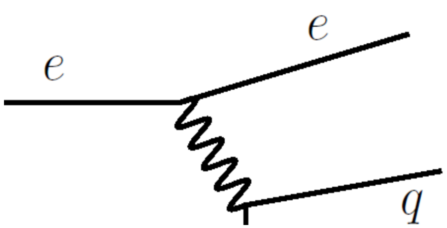
Within the DIS regime,Bose–Einstein interference in ep scattering does not depend significantly on the details of the hard process.

Process	Experiment	r (fm)
e^+e^-	AMY	$0.73 \pm 0.05 \pm 0.20$
	TASSO	$0.82 \pm 0.06 \pm 0.04$
	MARK II	$0.75 \pm 0.03 \pm 0.04$
	LEP	$0.78 \pm 0.01 \pm 0.16$
Previous DIS	EMC	0.84 ± 0.03
	BBCNC	0.80 ± 0.04
HERA	H1	$0.68 \pm 0.04^{+0.02}_{-0.05}$
	ZEUS	$0.666 \pm 0.009^{+0.022}_{-0.036}$
	H1 (diffractive)	$0.59 \pm 0.13^{+0.05}_{-0.05}$
	ZEUS ($K^\pm K^\pm$)	$0.57 \pm 0.09^{+0.15}_{-0.08}$
	ZEUS ($K^0_S K^0_S$)	$0.63 \pm 0.09^{+0.11}_{-0.08}$

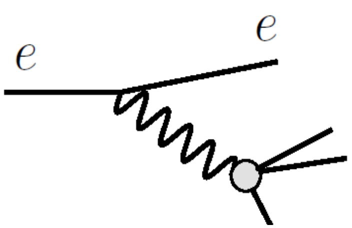
In MC, BEC implemented by force because operates with probabilities but not with amplitudes

Strange particle production

How well MC generators simulate
s-quark production with λ_s=const ?

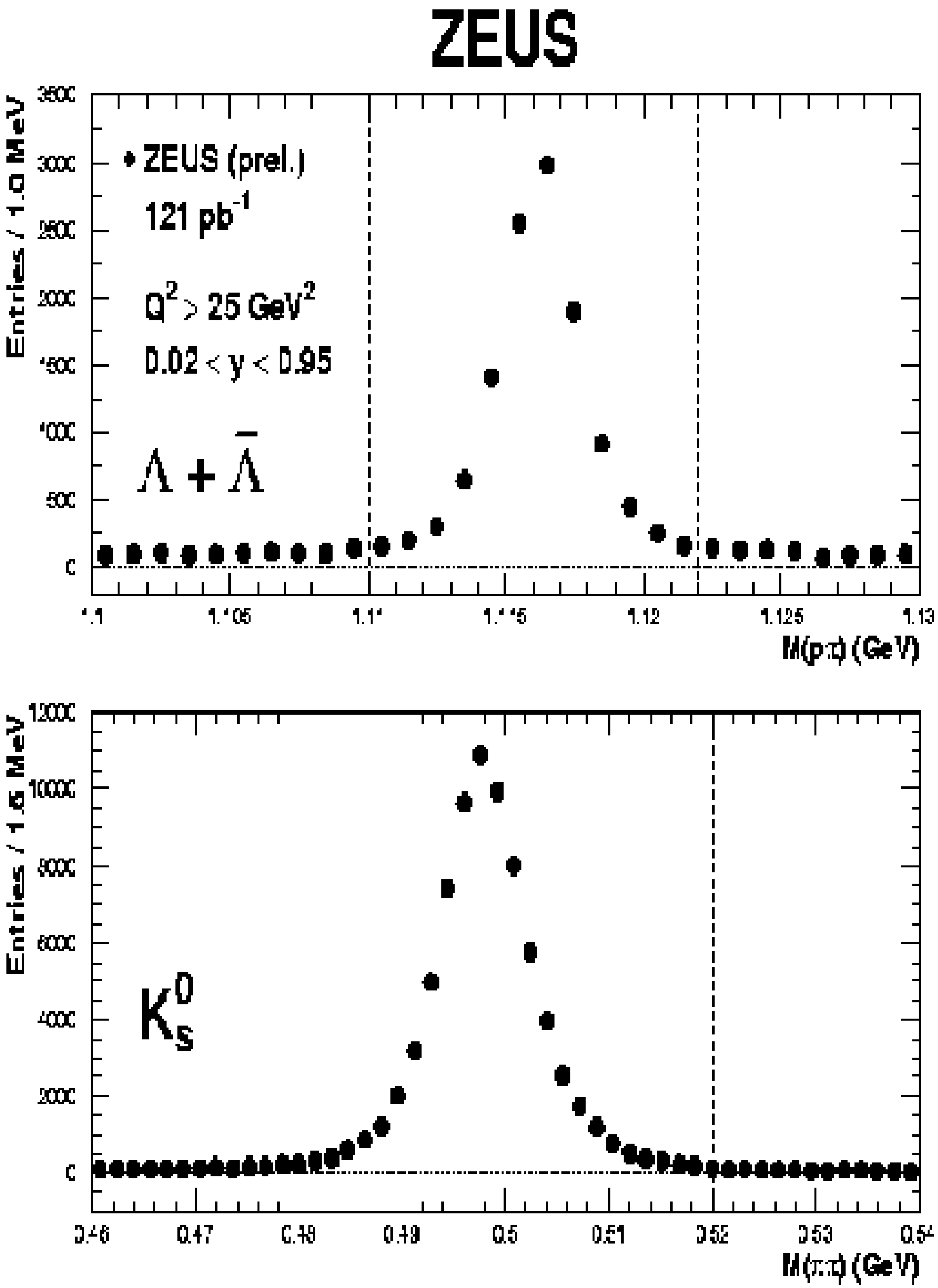


Direct



Resolved

K^0_s and Λ reconstruction



Background at the level of ~ 6% in Λ and ~3% in the K^0_s sample

MC

To study physics and determine the response of the detector and obtain the correction factors

DIS

CDM ARIADNE 4.1

MEPS LEPTO 6.5

PHP

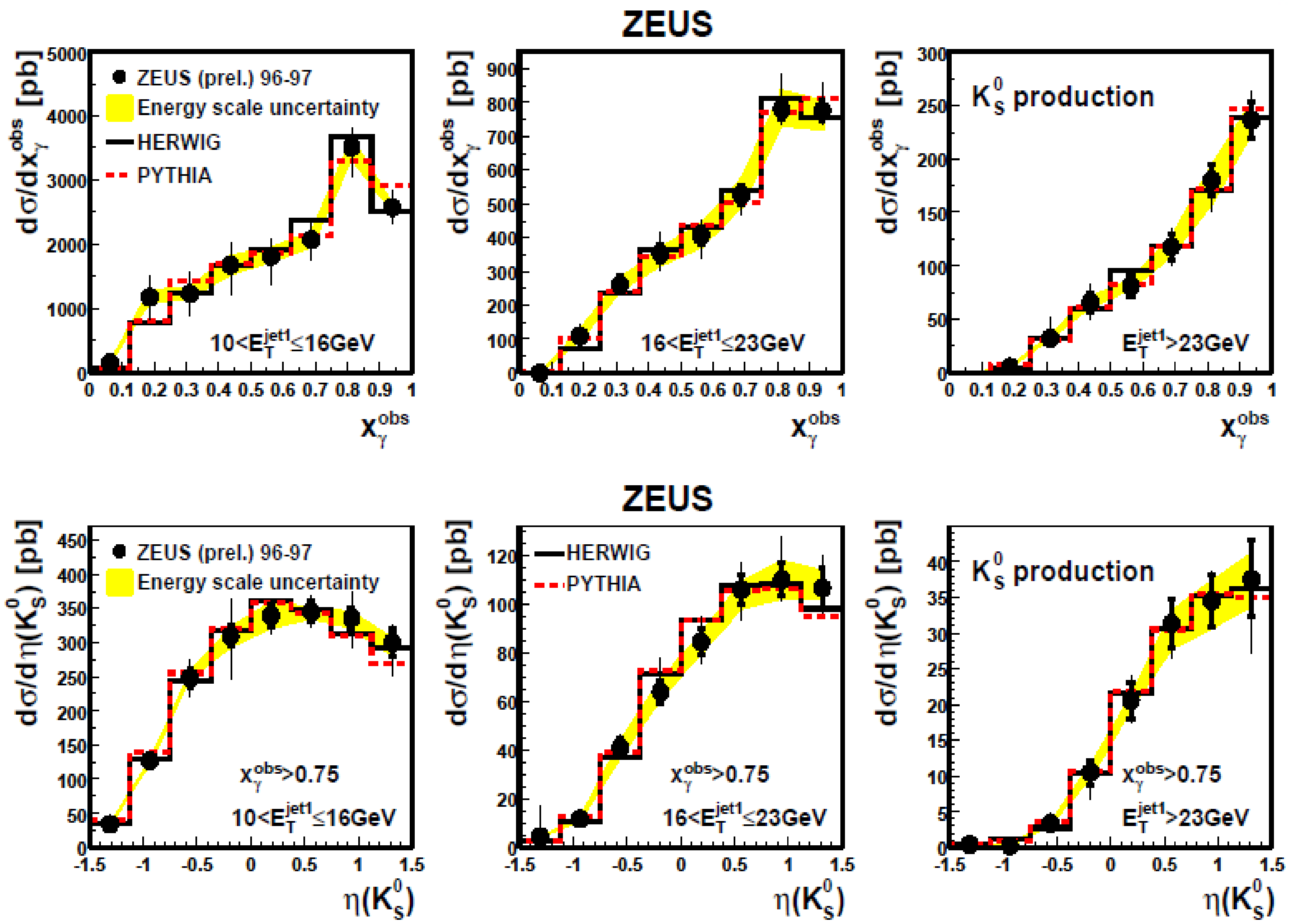
PYTHIA 6.1

$$\lambda_s = P(s)/P(u)$$

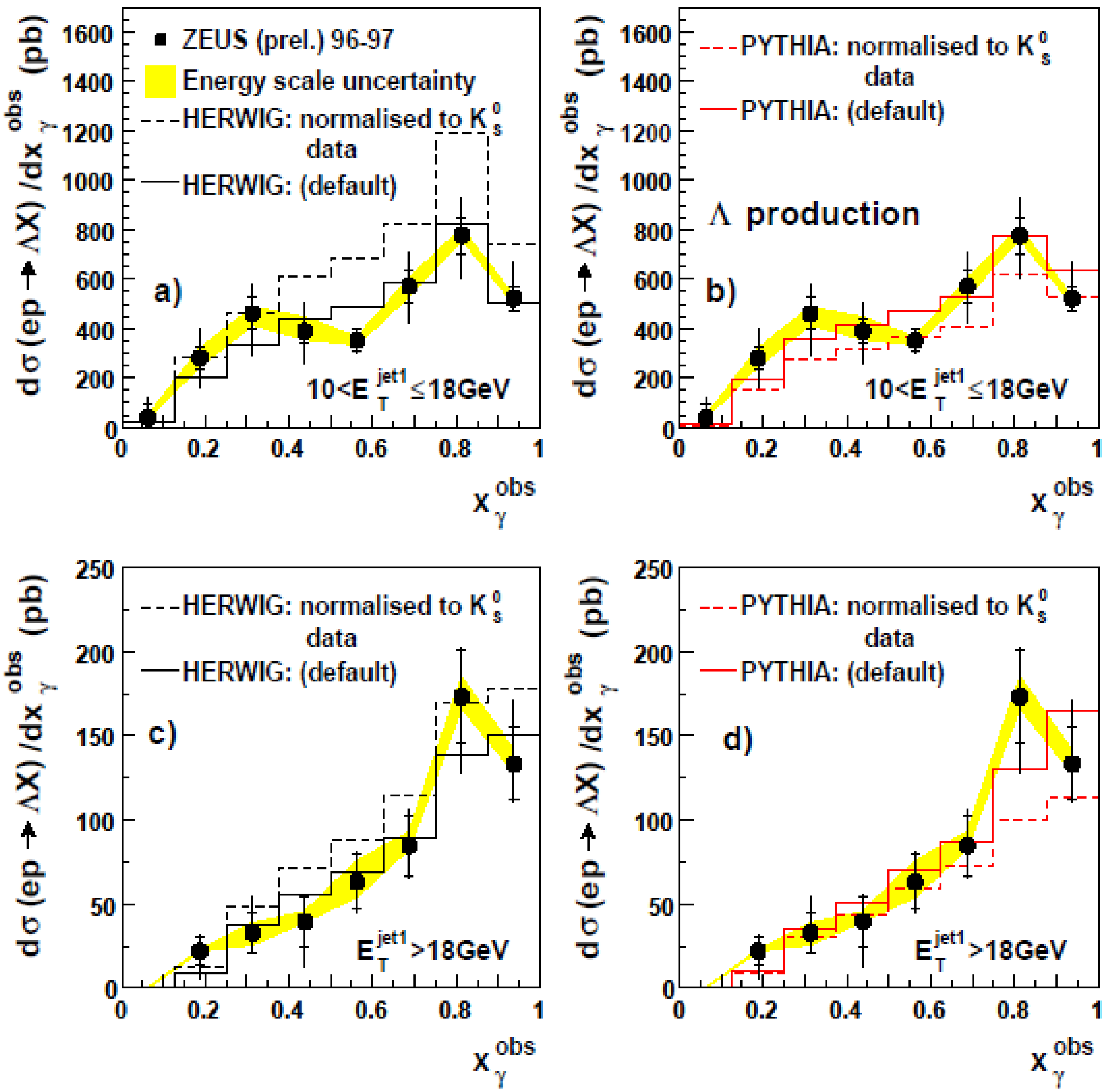
- strangeness suppression factor

K^0_s in photoproduction

$$x_\gamma^{\rm OBS} = \frac{\sum E_T^{\rm jet} e^{-\eta^{\rm jet}}}{2 y_{\rm JB} E_{\rm e}^{\rm beam}}$$

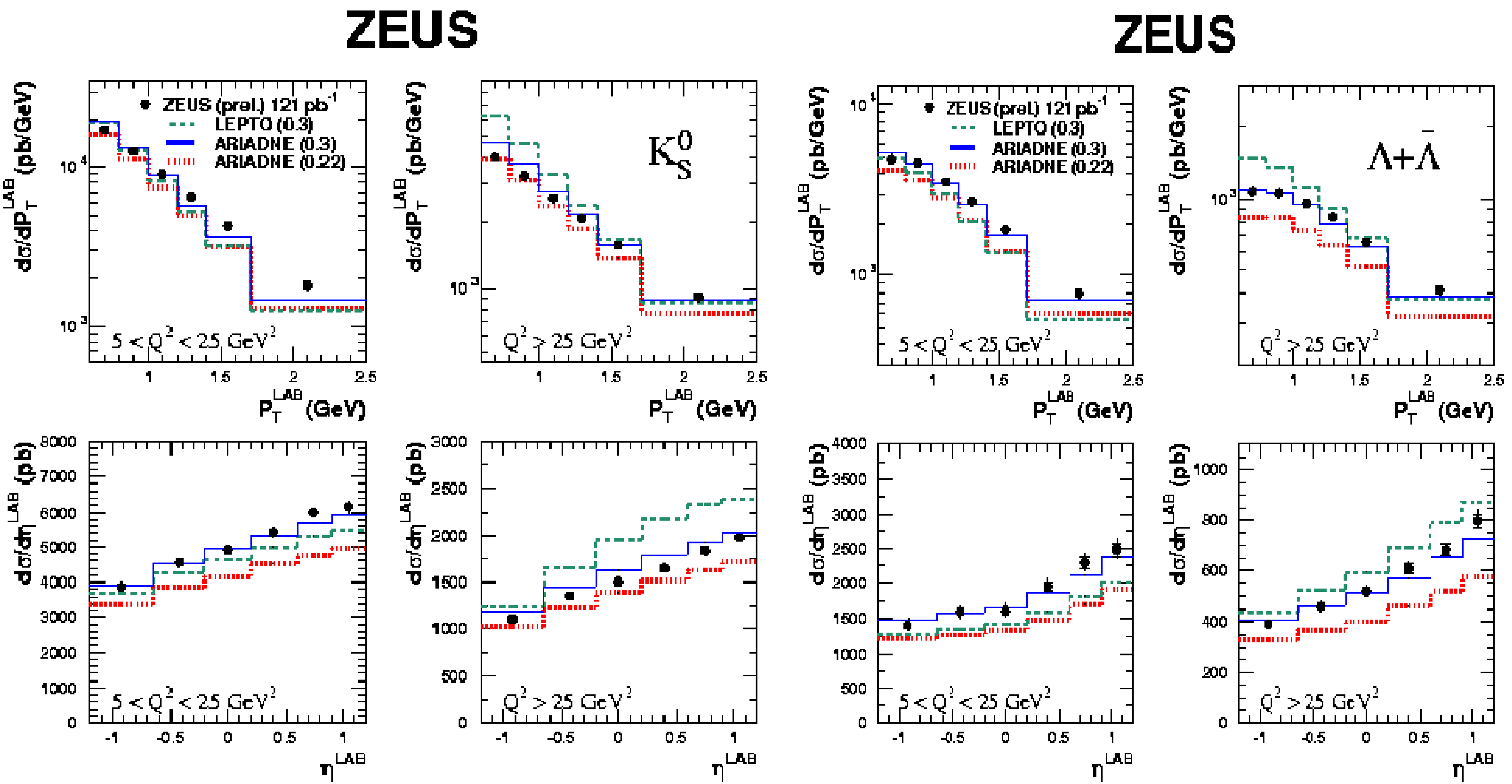


Λ in photoproduction



D=0.3

DIS cross-sections: Differential features



K^0_s: All model predicts steeper p_T slopes

Λ: ARIADNE with λ_s=0.3 describes data well, 0.22 less satisfactory
LEPTO fails to describe the data (too fast growth of dσ/dη with Q^2)

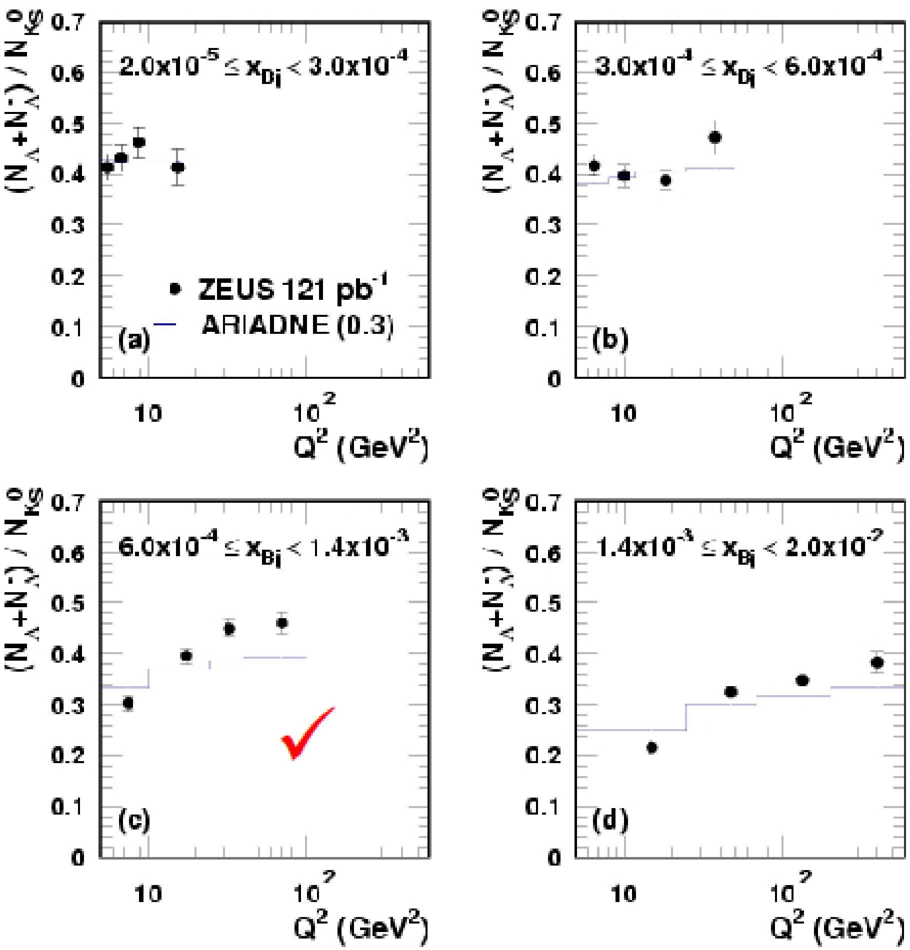
Baryon - to - meson ratio

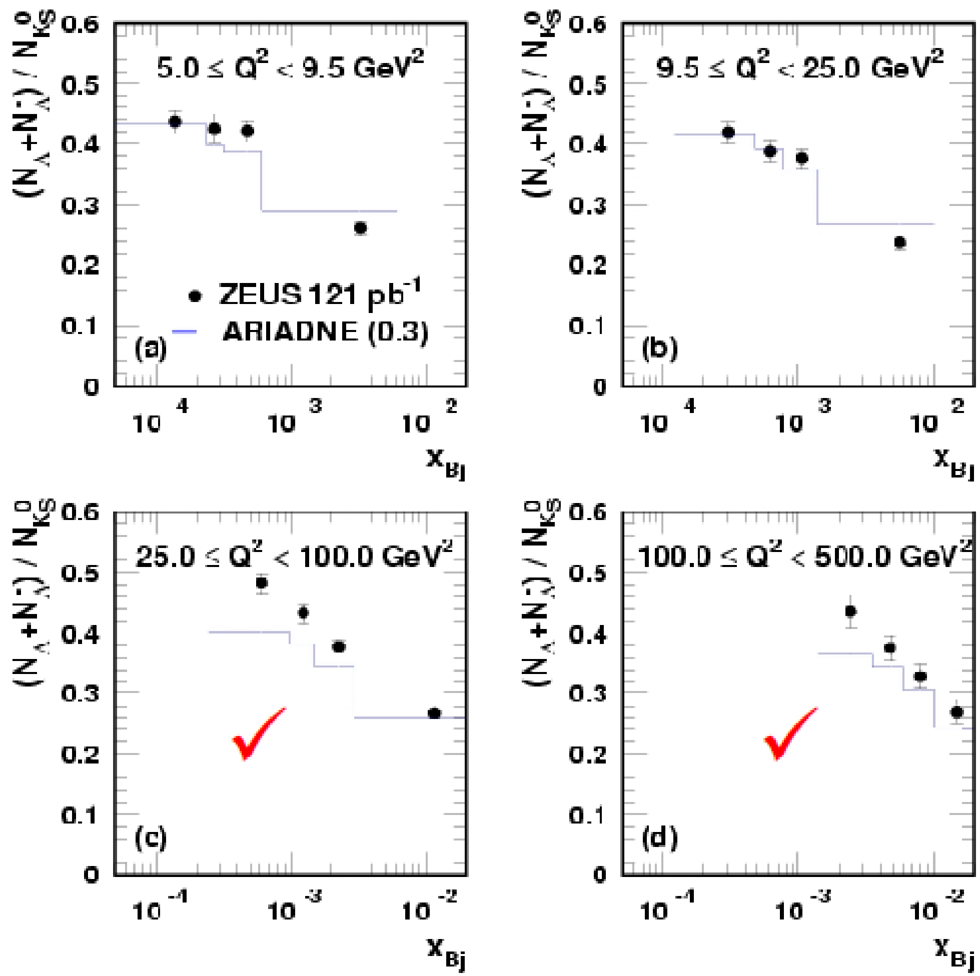
$$\frac{N_{\Lambda} + N_{\bar{\Lambda}}}{N_{K_s^0}}$$

ZEUS

Fixed bins in x ,Q²

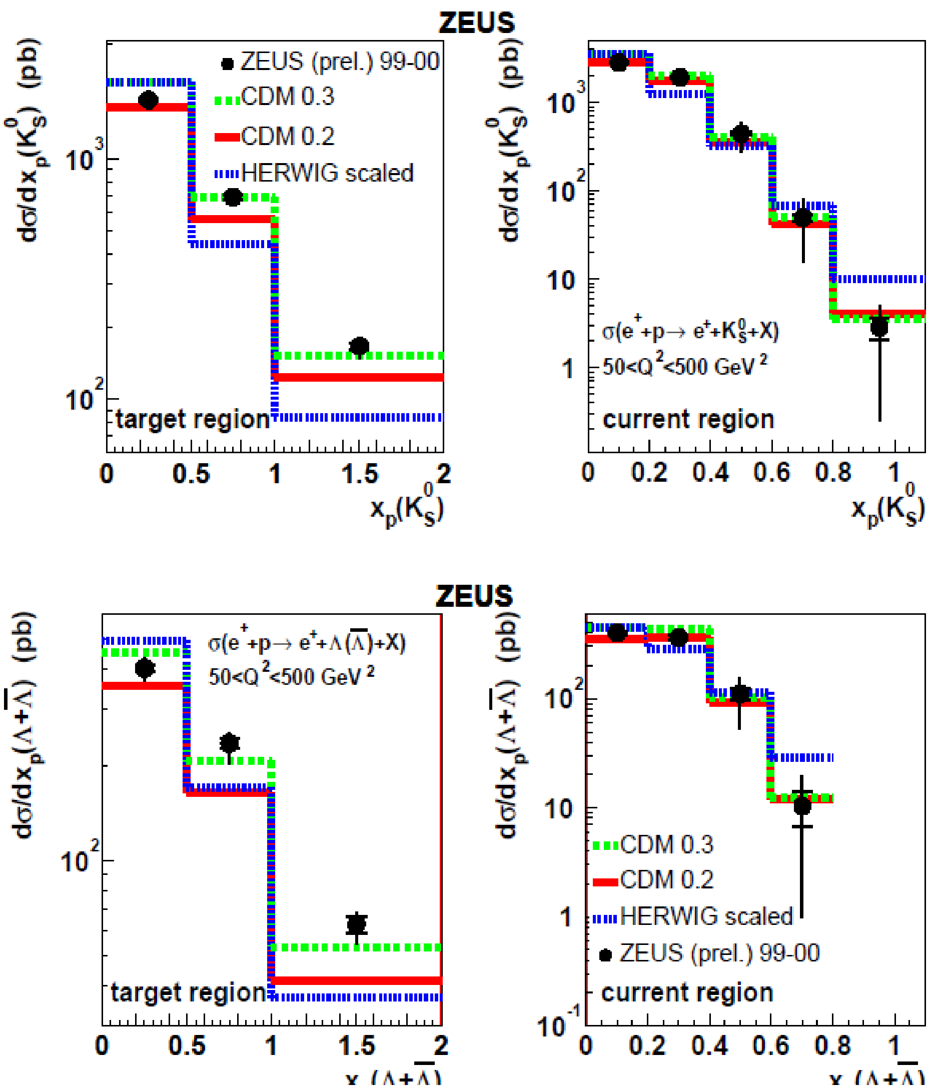
ZEUS





✓ ARIADNE underestimates the data at high Q² by up to 20%; Ratios are similar to those from ee and pp.

Cross Sections in Breit Frame



- Current region: weak sensitivity to λ_s
  - HERWIG does not fall steeply enough
  - ARIADNE describe the data with any $\lambda_s = 0.2 \div 0.3$

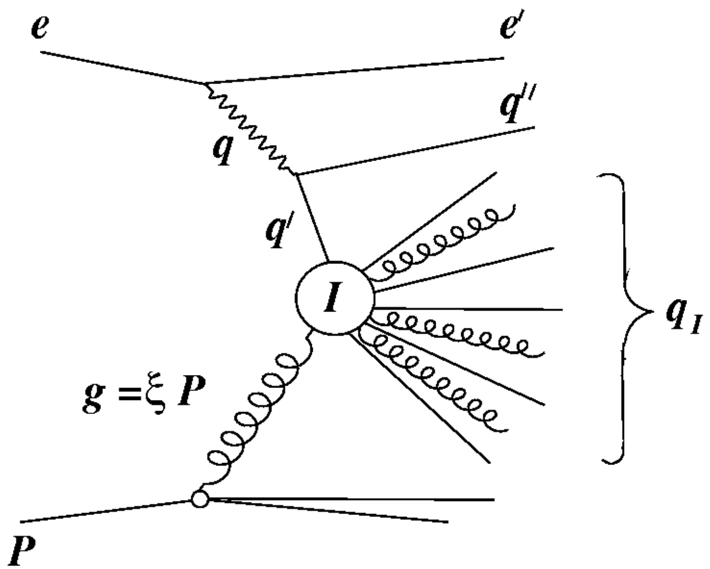
- Target region: $\frac{d\sigma}{dx_p} \sim e^{c\lambda_s}$ (cascade)

  λ_s value is sensitive to the particle mass

  $$\lambda_s(m_\Lambda) > \lambda_s(m_{K^0_s})$$

  - ARIADNE: $\lambda_s \geq 0.3$ at $x_p > 0.5$ and $\lambda_s \sim 0.22 - 0.25$ at $x_p < 0.5$
  - HERWIG falls too steeply

Non-perturbative phenomena: Search for QCD-instanton in DIS



Existence of instantons is required by the Standard Model.

Ringwald and Schrempp: MC QCDINS, less than 1% of σ (NC DIS)

For the description of parton showers and hadronisation, HERWIG 5.9 is used.

H1 — neural network O(50), PDERS

(Probability Density Estimator with Range Search)

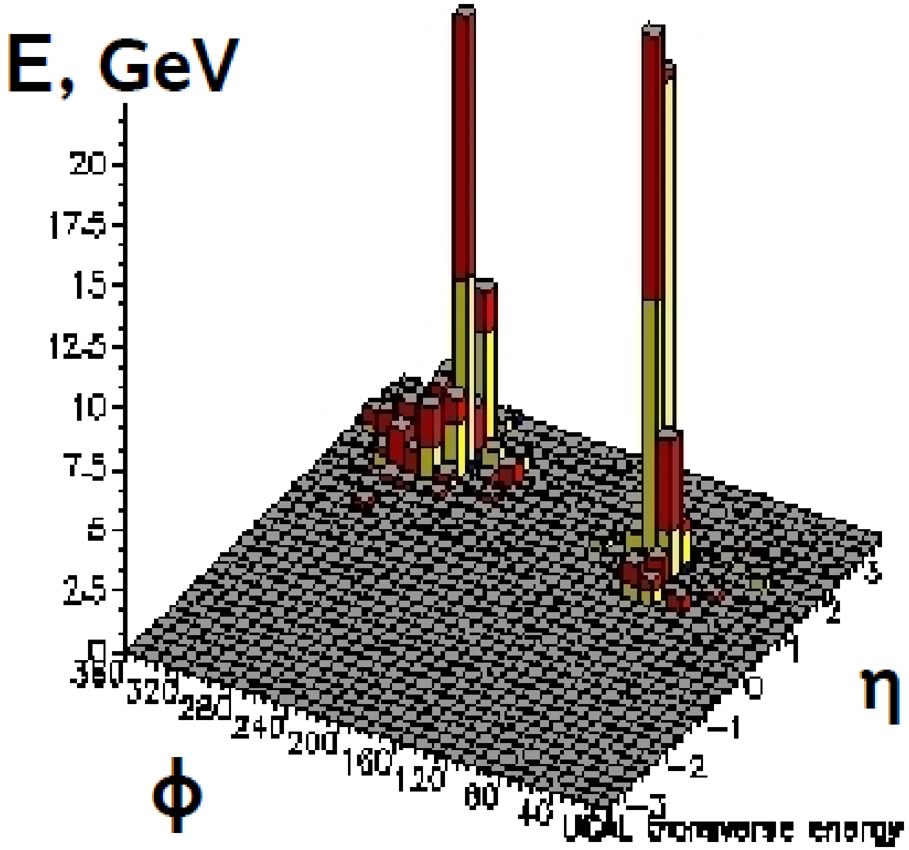
ZEUS - the Fisher discriminant O(6)

The problem: the background MC HERWIG (w/o instantons) generate fireball like events

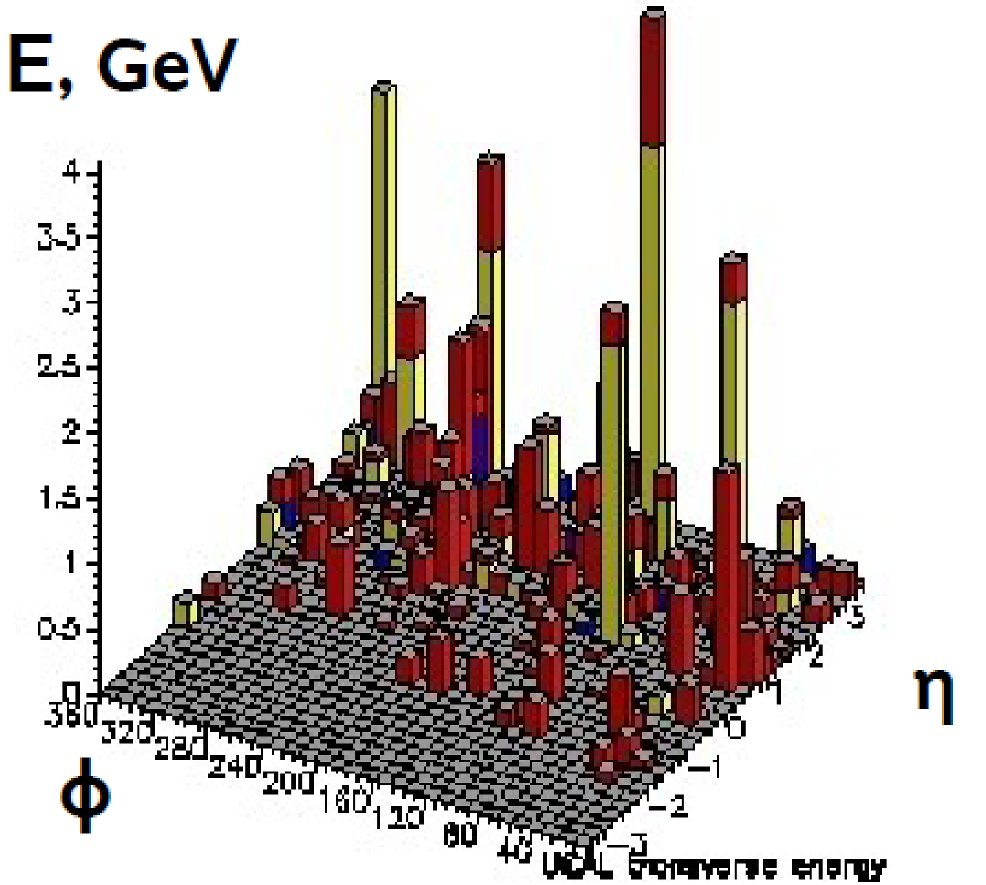
ZEUS,2003: Upper limit on the instanton cross section of 26 pb at a 95% c.l. has been set. The theory predicts the cross section of 8.9 pb.

H1, 2016: No evidence for the production of QCD instanton-induced events is observed. Upper limits on the cross section for instanton-induced processes between 1.5~pb and 6~pb

Photoproduction



event with 2 jets



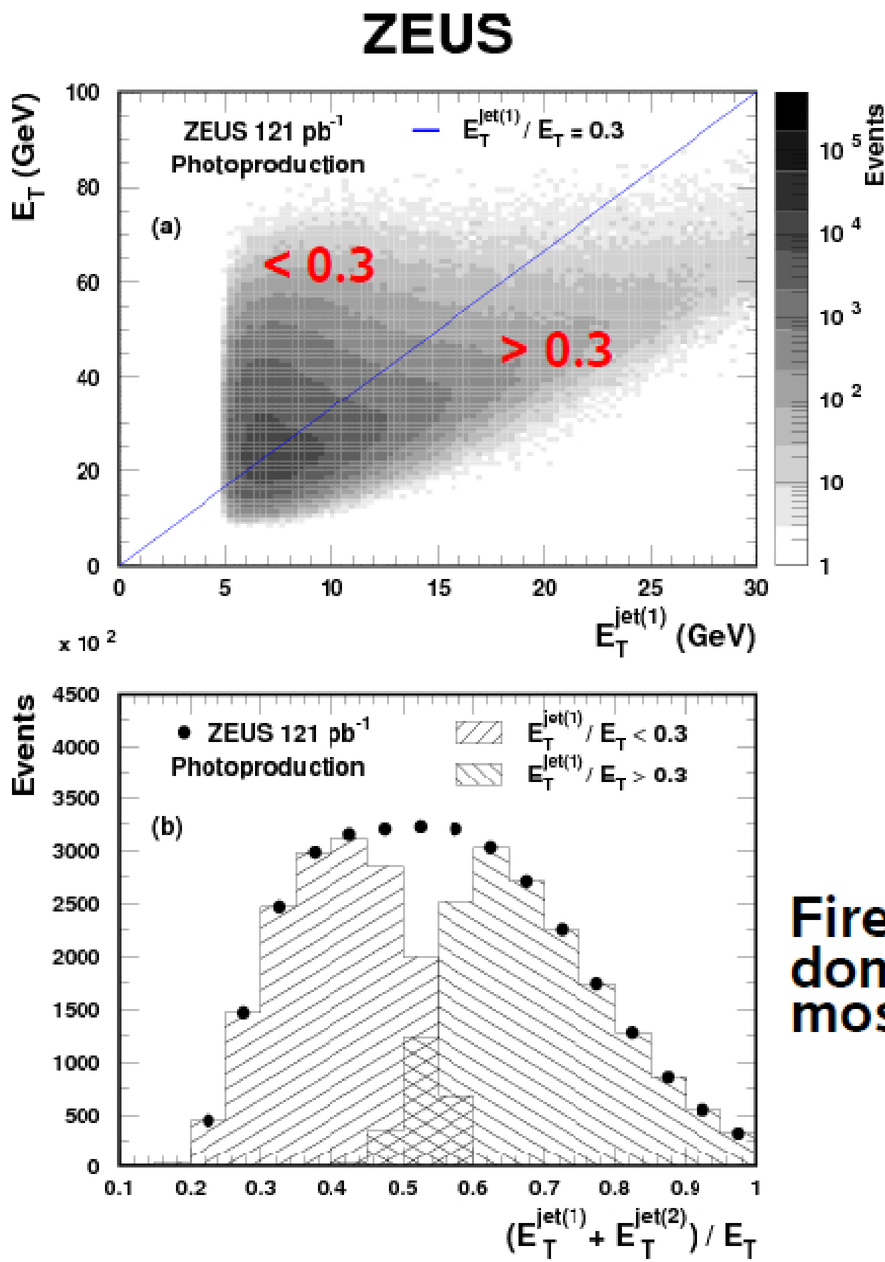
fireball-like event

Fireball sample selection in PHP

Total transverse energy

Fireball-enriched

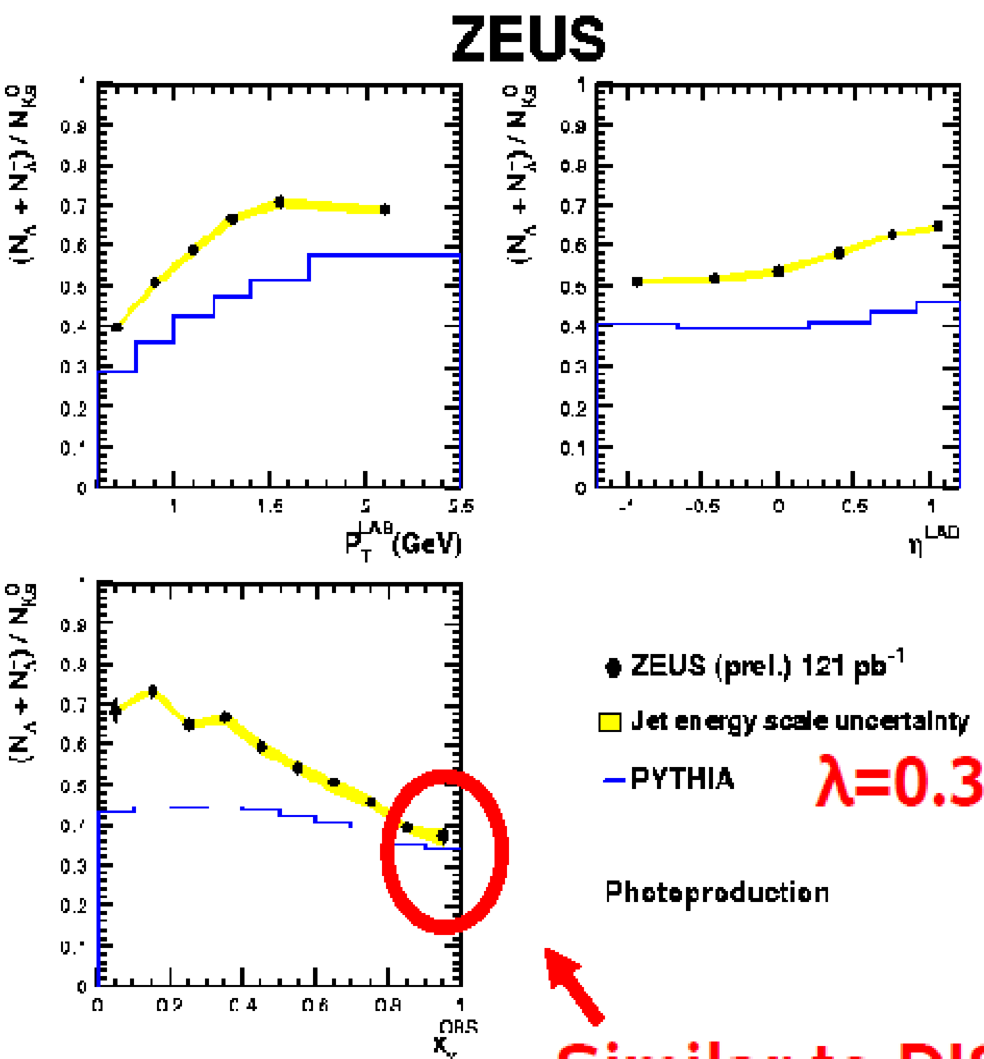
$$E_T^{jet(1)} / E_T < 0.3$$

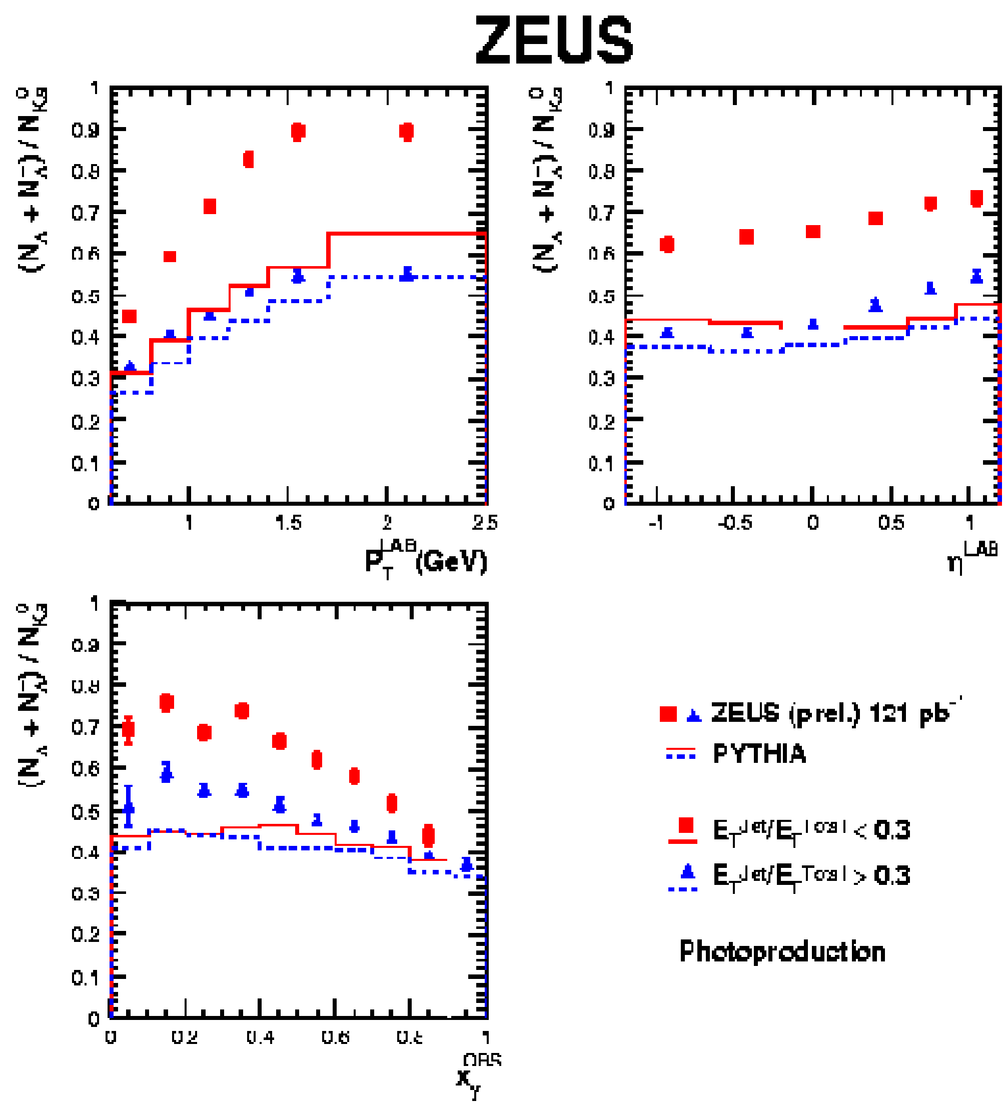


Highest transverse energy jet

Fireball-depleted events dominated by jj carrying most of E_T

PHP: Baryon-to-meson ratio $\frac{N_{\Lambda}+N_{\bar{\Lambda}}}{N_{K_s^0}}$





Similar to DIS

PYTHIA fails to describe the data

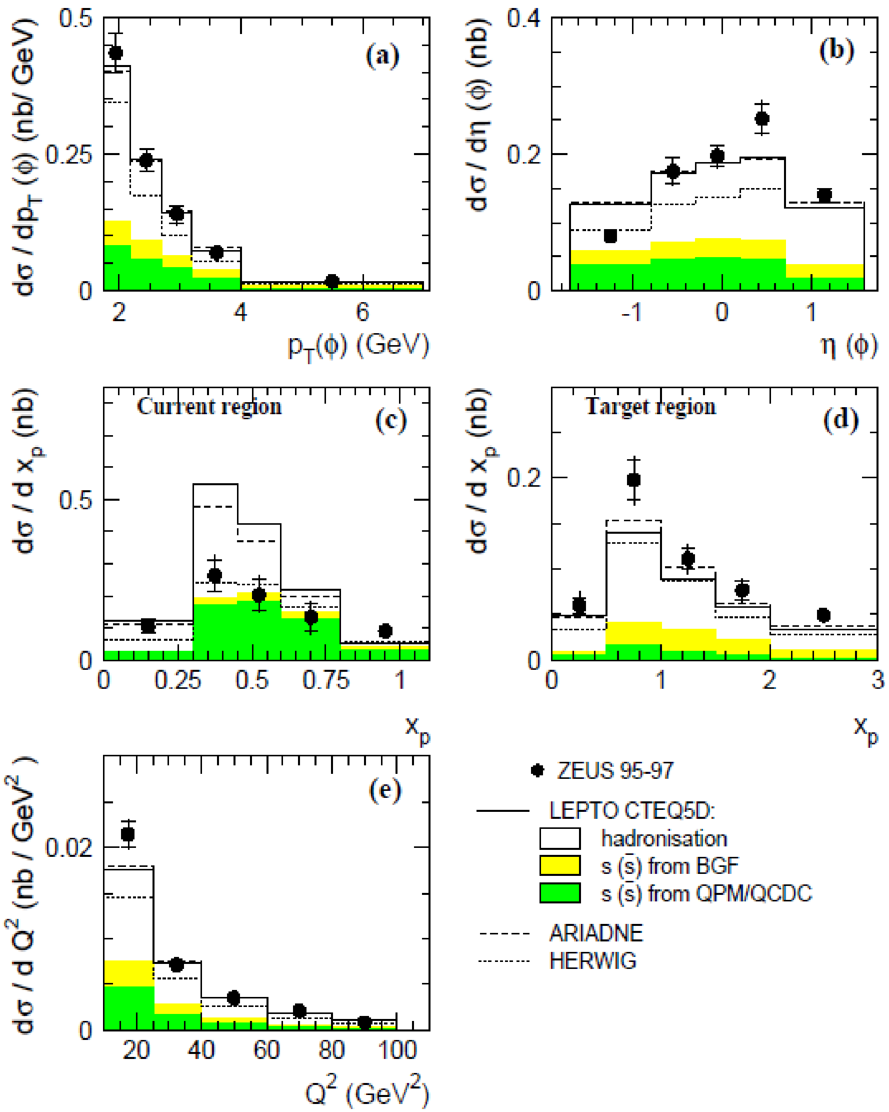
MI makes several independent jets

Mini conclusions

- ARIADNE and PYTHIA satisfactorily describe some of the distributions with λ_s in the range [0.22-0.3], however λ_s value depends on Q^2, x_{Bj}, p_T and η;

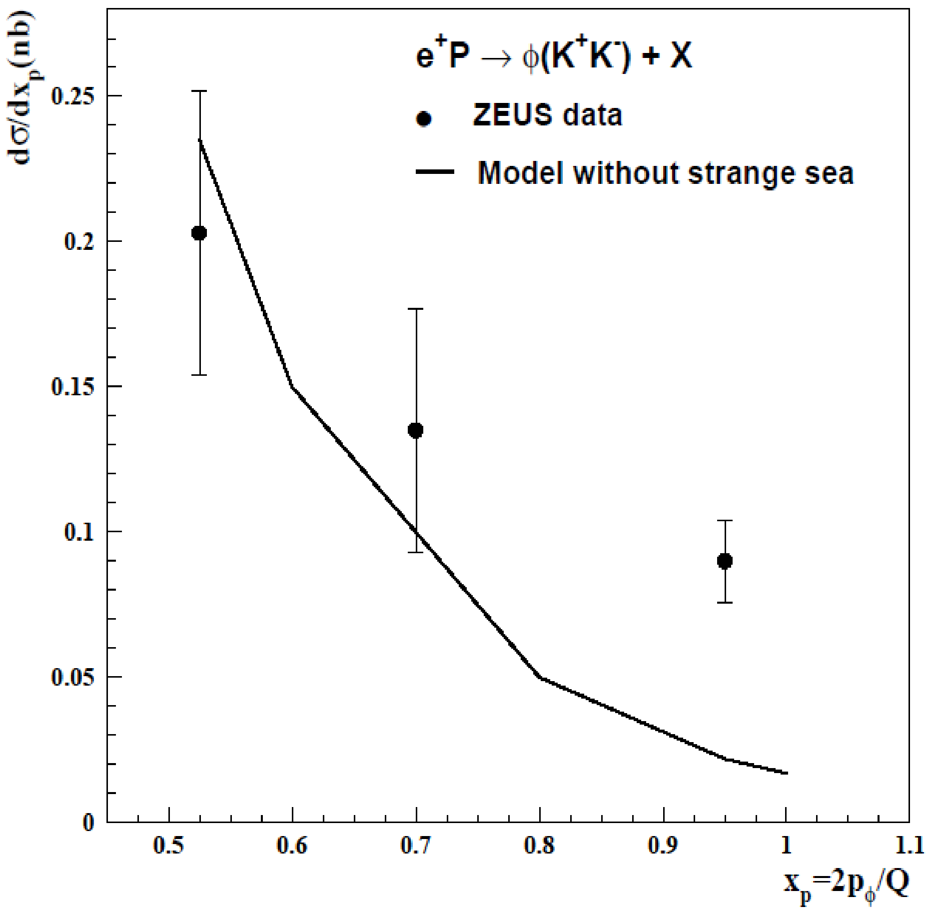
- The ratio of baryons to mesons is large in the PHP resolved region and in the fireball PHP region much larger than in e+e- and is not described by PYTHIA ;

ϕ(1020) in the K+K- decay mode



- cross sections as functions of $p_t(\phi)$, $\eta(\phi)$, $x_p(\phi)$ and Q^2, compared to MC models with λ_s=0.22 values and the CTEQ5D parton densities.
  - $s\bar{s}$ pairs from QPM and QCDC (green shaded band)
  - $s\bar{s}$ pairs from BGF (yellow shaded band)
- Current region of the Breit frame contains a significant fraction of events due to the hard scattering on the strange sea
- Relative contribution from hard QCD increases with $p_t(\phi)$
- Lund Monte Carlo models fail to describe x_p, $\eta(\phi)$ distributions and the cross section in the Breit frame.

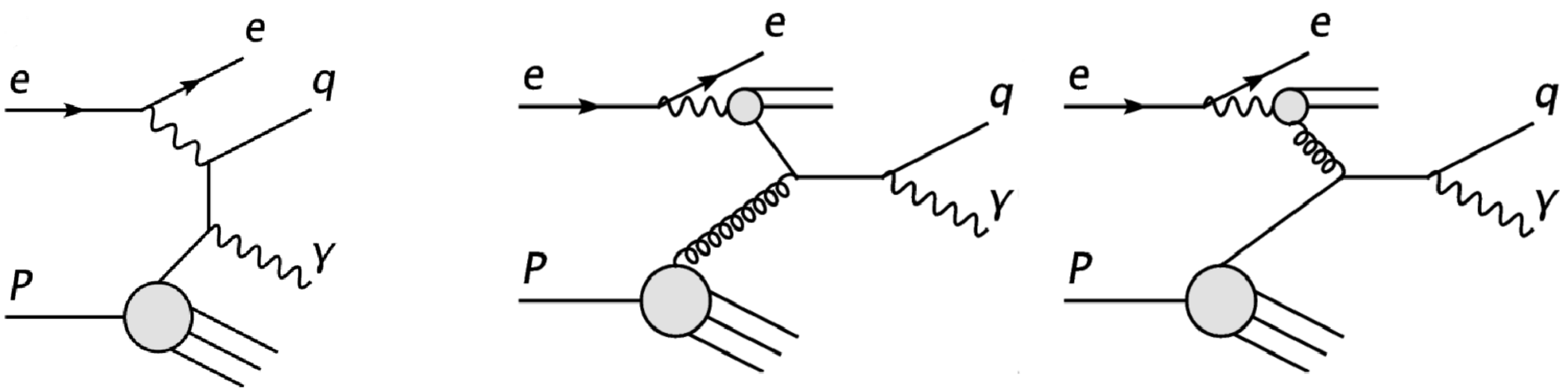
Strange sea in the proton



- High-momentum ϕ mesons (x_p >0.8) in the current region of the Breit frame give clear evidence for the strange sea in the proton.

Prompt photons

Isolated photons emerge without the hadronization phase

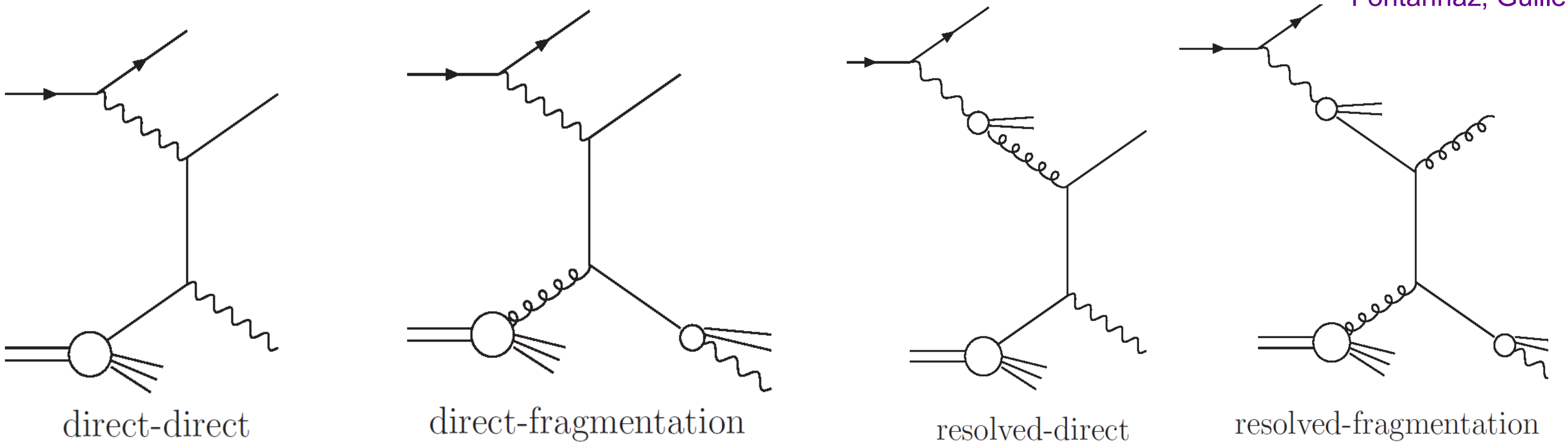


An access to the quark and gluon content of the proton and the hadronic nature of the resolved photon.

A comparison to MC models, as well as to NLO QCD (DGLAP) and the kT -factorization approaches.

Prompt photons: NLO, collinear factorization

Fontannaz, Guillet, Heinrich



$$d\sigma^{ep\to\gamma X}(P_p, P_e, P_\gamma) = \sum_{a,b,c} \int dx_e \int dx_p \int dz\, F_{a/e}(x_e, M) F_{b/p}(x_p, M_p) D_{\gamma/c}(z, M_F)$$

$$d\hat{\sigma}^{ab\to cX}(x_p P_p, x_e P_e, P_\gamma/z, \mu, M, M_p, M_F)\ ,$$

scales are set equal to p**γ**T

Unique to PHP is the possibility to "switch on/off" the res. **γ** by suppressing/enhancing large xγ.

As $x_\gamma = 1$ - dir. **γ**

$x^\gamma_{obs} \leq 0.9$ res. **γ**

Or place cuts on pT

$$x^\gamma_{obs} = \frac{p_T^\gamma\, e^{-\eta^\gamma} + p_T^{\rm jet}\, e^{-\eta^{\rm jet}}}{2E^\gamma}$$

$$x^p_{obs} = \frac{p_T^\gamma\, e^{\eta^\gamma} + p_T^{\rm jet}\, e^{\eta^{\rm jet}}}{2E^p}$$

suppress the contribution from the res. **γ**

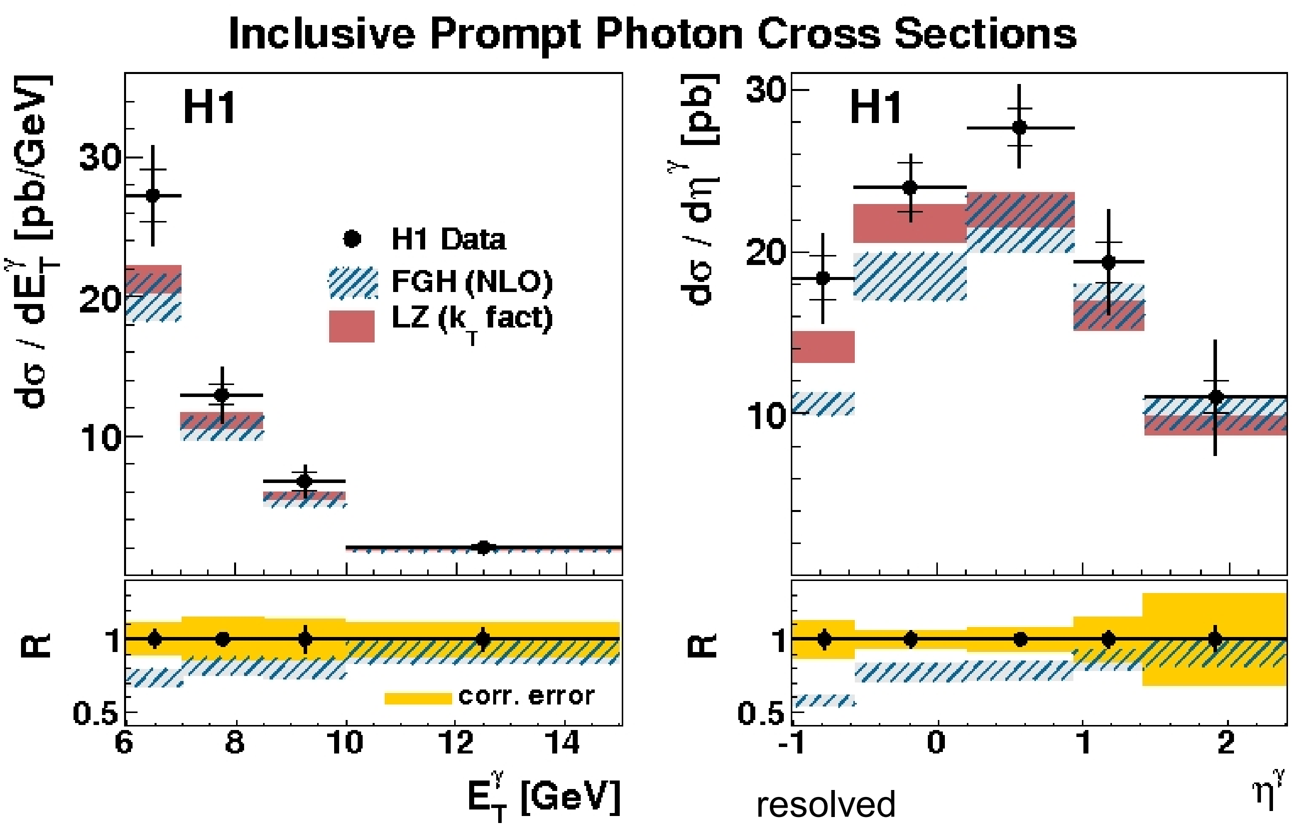
Prompt photons: kT-factorization

A. Lipatov, N. Zotov

Relies on parton distribution functions where the kT -dependence has not been integrated out.

kT of incoming partons is generated in the course of non-collinear parton evolution

Kimber-Martin-Ryskin (KMR) unintegrated parton densities (UPD)



resolved
photon region

H1 Prompt Photon Phase Space	
Inclusive cross section	$6 < E_T^\gamma < 15$ GeV $-1.0 < \eta^\gamma < 2.4$ ✔ $z = E_T^\gamma / E_T^{\gamma-\text{jet}} > 0.9$ $Q^2 < 1$ GeV^2 $0.1 < y < 0.7$
Jet definition	$E_T^{\text{jet}} > 4.5$ GeV $-1.3 < \eta^{\text{jet}} < 2.3$

ZEUS

$Q^2 < 1\,\text{GeV}^2,\ 5 < E_T^\gamma < 16\ \text{GeV}$

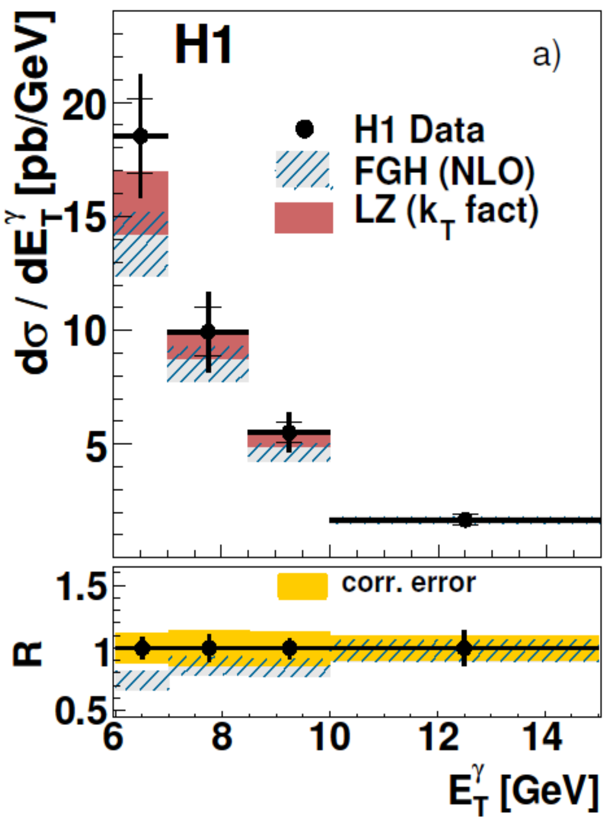
$-0.74 < \eta^\gamma < 1.1$ ✔

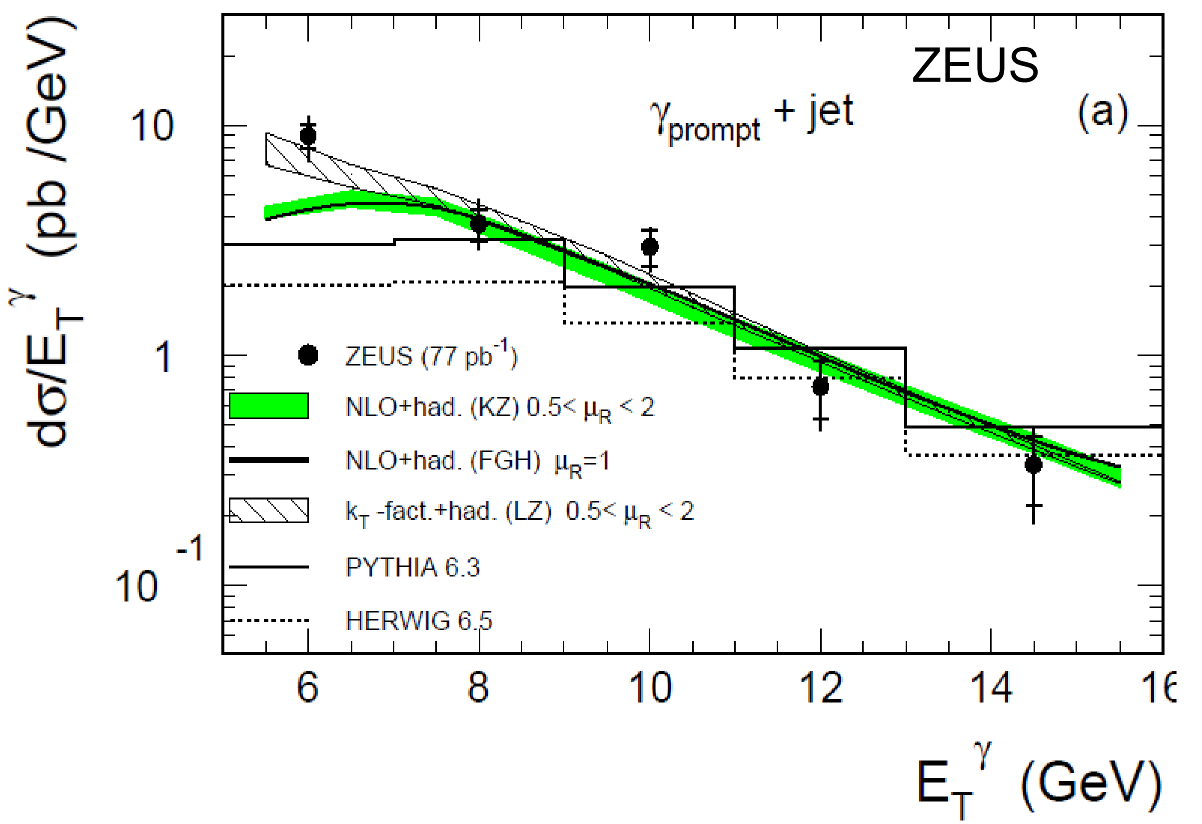
$E_T^{\gamma,(\text{true})} > 0.9\, E_T^\gamma \quad 0.2 < y < 0.8,$

$6 < E_T^{\text{jet}} < 17\ \text{GeV}$ ✔

$-1.6 < \eta^{\text{jet}} < 2.4$

Prompt photons: comparison to data





σtot for the process $ep \to e + \gamma_{\text{prompt}} + \text{jet} + X$

$$\sigma(ep \to e + \gamma_{\text{prompt}} + \text{jet} + X) = 33.1 \pm 3.0\,(\text{stat.})\,^{+4.6}_{-4.2}(\text{syst.})\text{ pb}$$ ZEUS

$23.3^{+1.9}_{-1.7}\text{ pb (KZ)}$

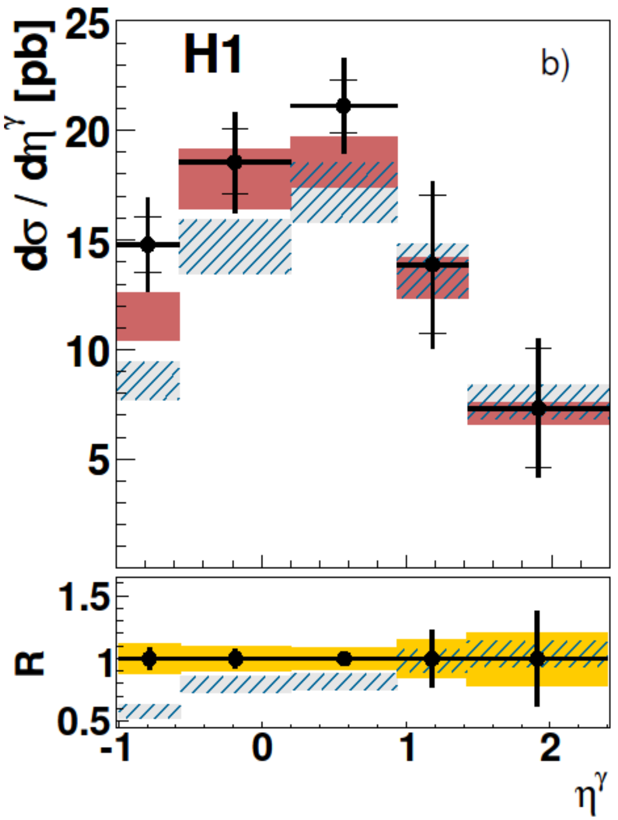
$30.7^{+3.2}_{-2.7}\text{ pb (LZ)}$

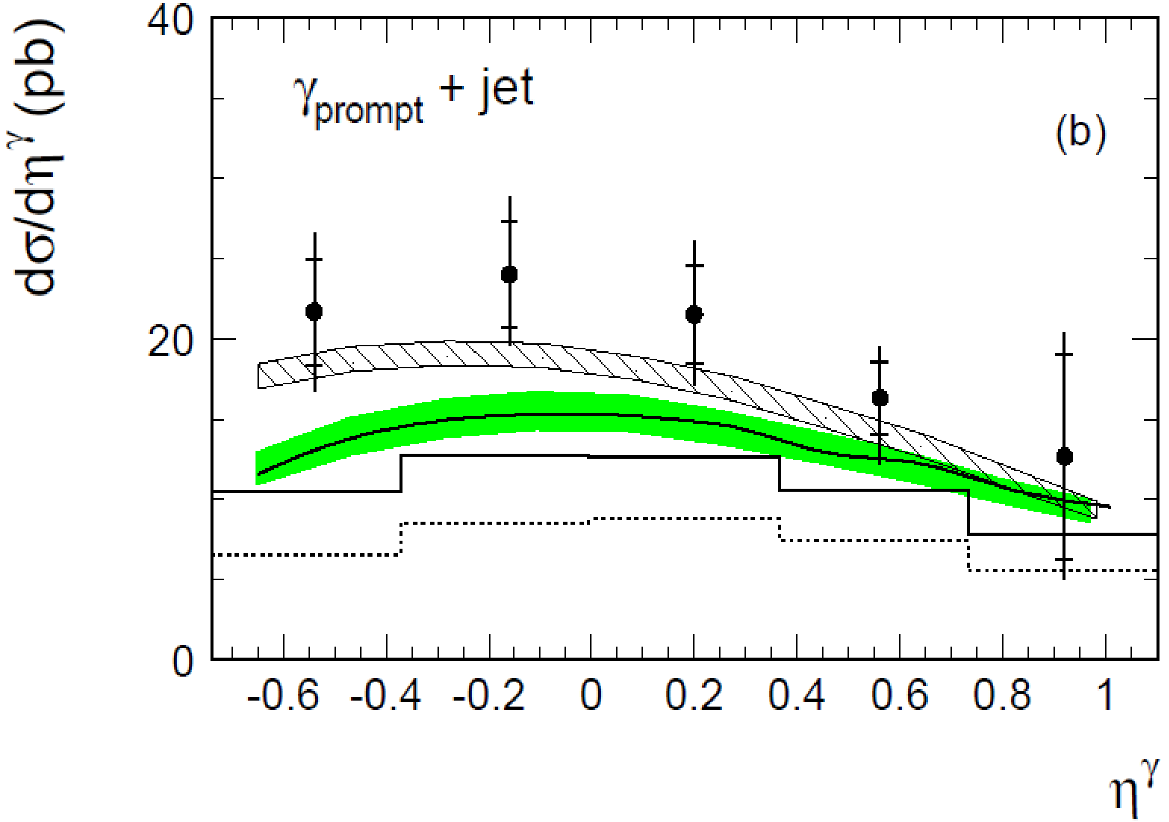
PYTHIA 20 pb

$23.5^{+1.7}_{-1.6}\text{ pb (FGH)}$

HERWIG 13.5 pb

Prompt photons: comparison to data





The QCD calculation based on the kT -factorization and KMR prescription for UPD, gives the best description of the E_T and η cross sections,
However, such calculations have larger theoretical uncertainties (scale dependence). LL MC underestimate xs by 30%

Conclusions

We briefly overviewed only a small part the HERA measurements on HFS.

These results confirms all basic features of QCD.

The HERA data favours the MC models with PS and the Lund hadronization.

However the data also indicate that PS should be improved by corrections beyond LL and the kT-ordering (BFKL-type evolution).

H1Zeus - HERA Combined Results

8 papers

www.desy.de/h1zeus/combined_results/

HERA Heritage

226+ H1 publications: www-h1.desy.de/publications/H1_sci_results.shtml

H1 Theses: www-h1.desy.de/publications/H1_sci_results.shtml

253+ ZEUS publications: www-zeus.desy.de/zeus_papers/

ZEUS Theses: zeusdp.desy.de/zeus_theses/index.html

Reviews (only recent):

-The Hadronic Final State at HERA,
P.R. Newman, M. Wing, Rev. Mod. Phys. 86, 1037 (2014)

-Charm, Beauty and Top at HERA,
O. Behnke, A. Geiser, M. Lisovyi,Prog.Part.Nucl.Phys. 84,1 (2015)

-Summary of workshop on Future Physics with HERA Data,
A. Bacchetta, J. Blümlein, O. Behnke et.al, arXiv.org/abs/1601.01499
indico.desy.de/conferenceDisplay.py?ovw=True&confId=10523

HERA Data: Open Access is under discussion

In memory of two outstanding personalities

Nikolay Zotov

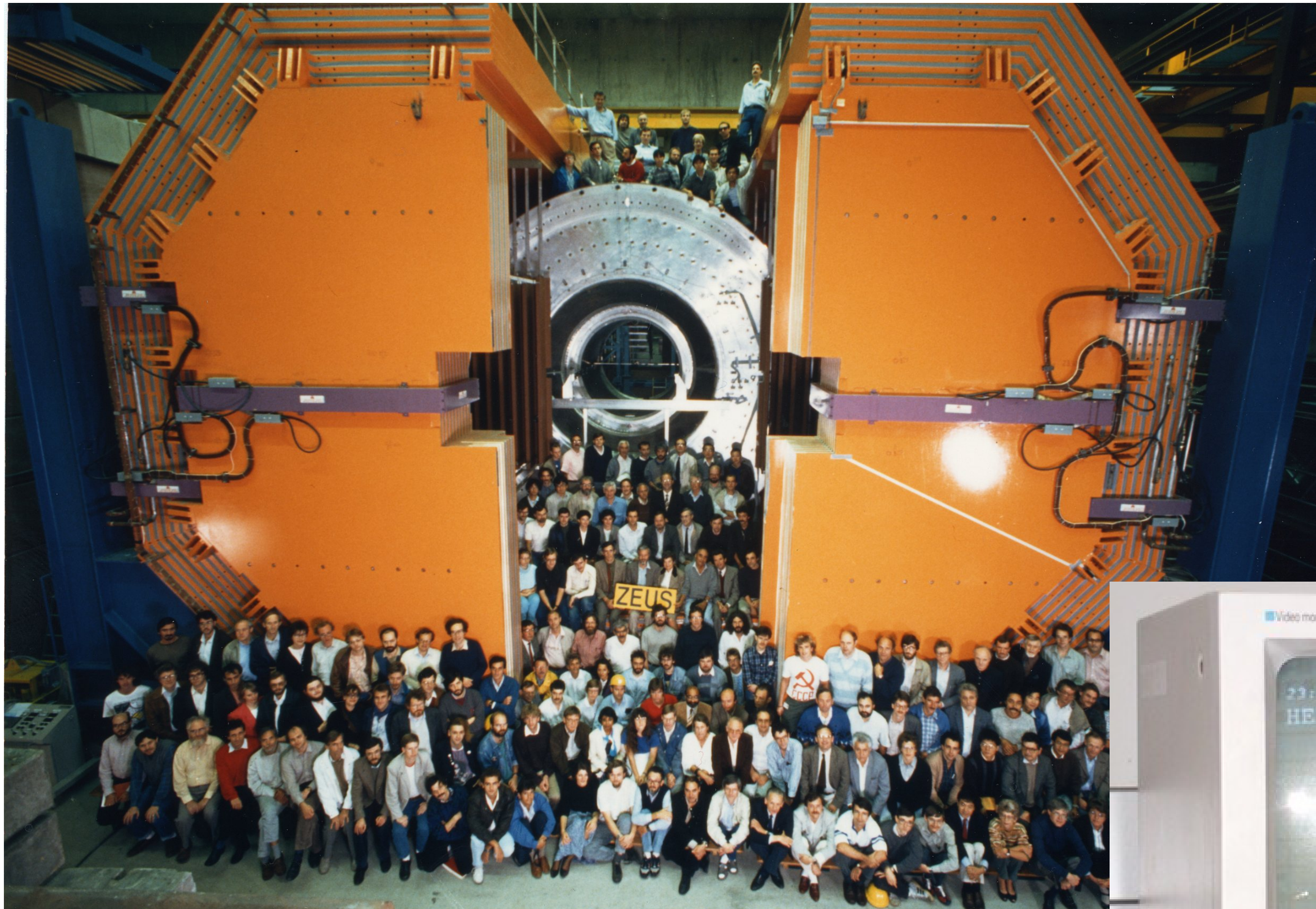
Pavel Ermolov,

Head and the Founder of DEHEP at SINP MSU

And the great scientific journey we undertook together ...

DESY,Hamburg, 30.06.2007

... with the grandiose equipment, people



The ZEUS detector + The ZEUS Collaboration

+ QCD

DESY, Hamburg, 30.06.2007