Summary of the HFS Working Group

This talk: Part I: Experimental Aspects

(PartII: Theory aspects – Pavel Nadolsky)

Pavel Nadolsky

Claudia Glasman

Steve Maxfield

~40 talks covering wide range of Hadronic Final State physics

Obviously impossible to do justice to them all

Will try to provide snap-shot of the various analyses

Apologies in advance for leaving out 'favourite' results

Please look at the wealth of detail in the full presentations

Puzzling Pentaquarks

- New studies from H1, ZEUS, HERMES, BABAR and CLAS.
  - Strange and Charm pentaquark at HERA
  - HERMES θ^{+}, θ^{++} and Ξ^{--}
  - BABAR θ^{+}, θ^{++}, Ξ^{-} and Ξ^{0}
  - CLAS θ^{+}

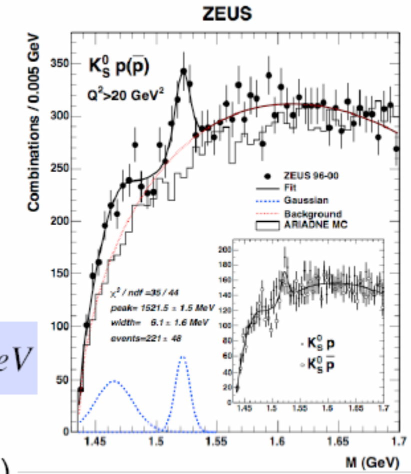
$\Rightarrow$

Strange Pentaquark H1 and ZEUS

Observation of Θ^+

ZEUS Collaboration: S. Chekanov et al.
Physics Letters B 591 (2004) 7-22

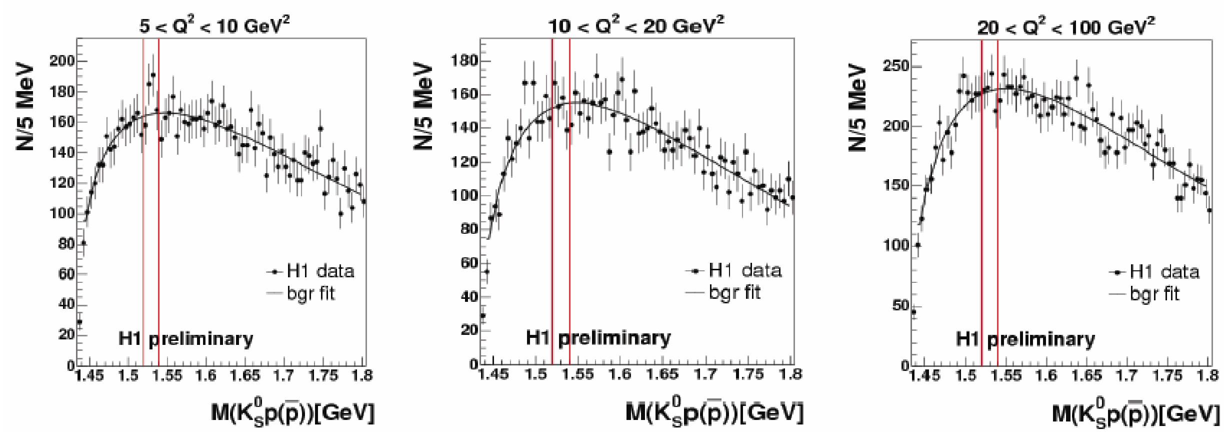
- Kinematics range
  $Q^2 > 20 GeV^2$
  $P_T(\Theta^+) > 0.5 GeV, |\eta(\Theta^+)| < 1.5$
- A signal with ~4.6 σ statistical significance was observed at
  $M = 1521.5 \pm 1.5(stat)^{+2.8}_{-1.7}(syst) MeV$
- Gaussian width 6.1±1.5 MeV (experimental resolution ~2 MeV)



ZEUS ✓

…but is there really a contradiction?

H1 ✗



no significant signal in the interesing mass range 1.52 to 1.54 GeV

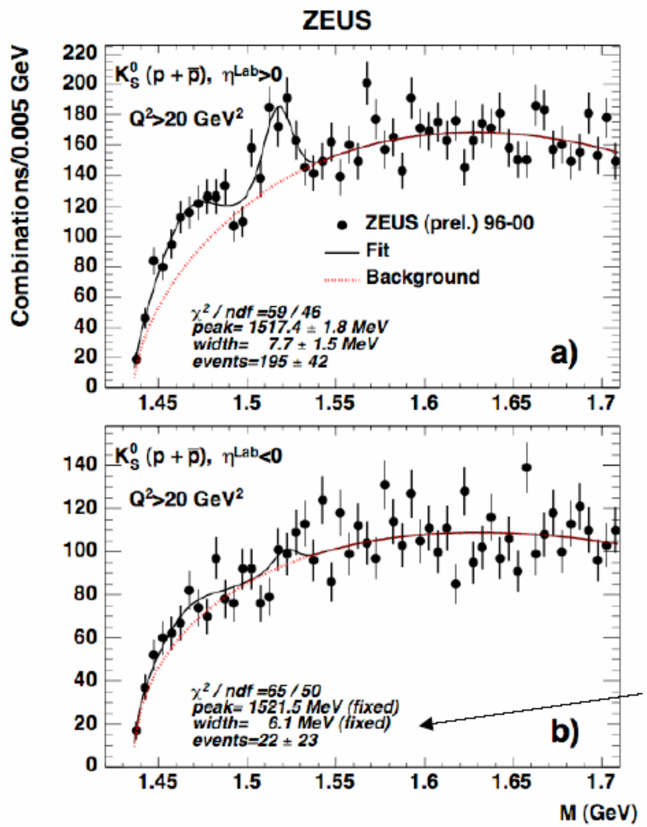
Both experiments have taken a closer look…

ZEUS *Zhenhai Ren*

- Published already
  - Non-observation of Ξ^{--} in $\Xi^-\pi^-$
  - Observation of $\Theta^+ \rightarrow K^0{}_sP$
  - $\sigma(ep \rightarrow e\Theta + X): 125 \pm 27(stat)^{+36}_{-28}(syst)\,pb$

Goal of new ZEUS studies

- Look at various kinematics regions
  - Understand the production mechanism?
- check statistical sensitivity to established states



- Θ^+ May favor proton-remnant fragmentation origin
  - Production rate is higher at forward region than rear region
  - Production rate is higher for particle than for anti-particle
    - however the statistics is too small to make strong conclusion

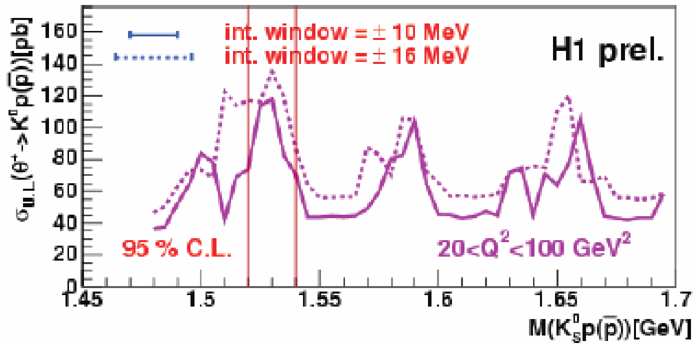
H1: extraction of upper limit for θ^+ cross section

Christiane Risler

Comparison with ZEUS:

low-momentum dE/dx selection
$20<Q^2<100$ GeV^2
$0.1 < y < 0.6$

M=1.52 GeV $\sigma_{U.L.} \sim 100$ pb *



ZEUS observation:
Q2>20 GeV2, 0.04 < y <0.95, p_T>0.5, |η|<1.5
σ(ep->e +X->eK^{0}pX)=125 ± 27(stat) +36 -28 (syst.) pb (prel.)

$\sigma_{U.L.} \sim 100$ pb not in contradiction with ZEUS measured cross section

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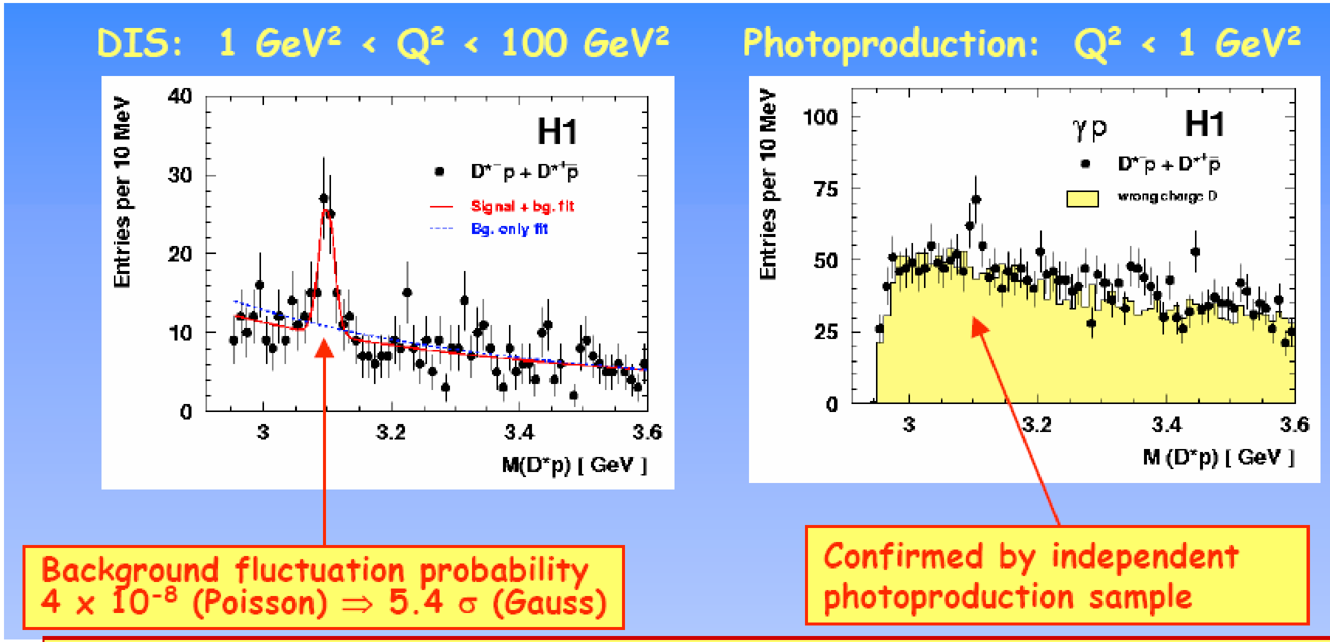
* at M=1.522 GeV assuming a resolution of 5 (8) MeV
$\sigma_{U.L.}$ = 89.6 (116.3) pb

Charm Pentaquark at HERA

Karin Daum /Yehuda Eisenburg

Seen by H1…



H1 Preliminary:

$$R_{cor}(D^*p(3100)/D^*) = 1.59 \pm 0.33\% ^{+0.33}_{-0.45}\%$$

…but negative results (in different processes) from ALEPH, FOCUS, CDF, BELLE

…and ZEUS same process

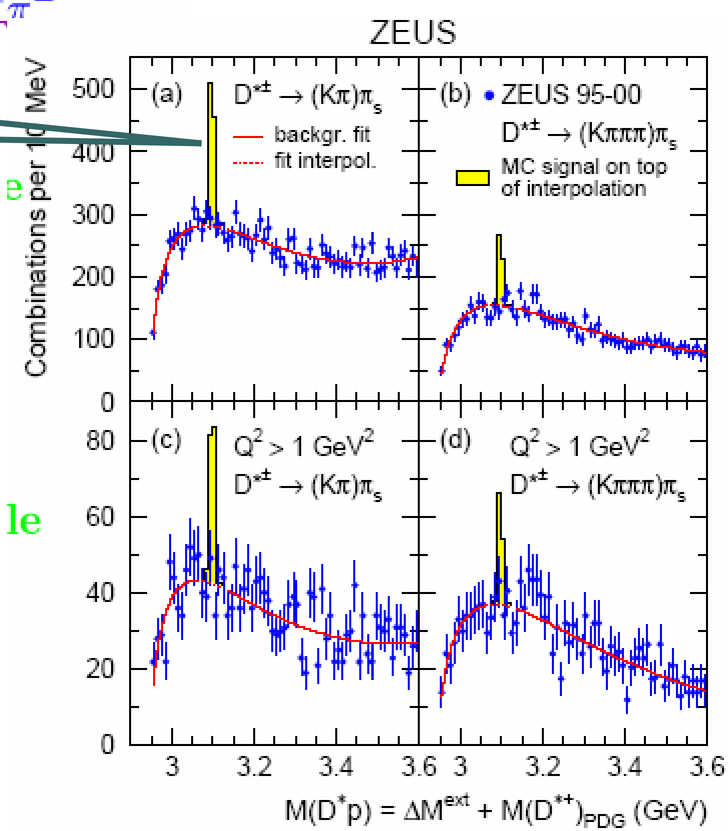
ZEUS have performed a careful evaluation of upper limits…

Yehuda Eisenberg

$$M(D^{*}p) = M(K\pi\pi_{s}p) - M(K\pi\pi_{s}) + M(D^{*+})_{\mathrm{PDG}}$$

$$D^{0} \rightarrow K^{-}\pi^{+} \qquad D^{0} \rightarrow K^{-}\pi^{+}\pi^{+}\pi^{-}$$

MC normalised to $\theta_c/D^* = 1\%$



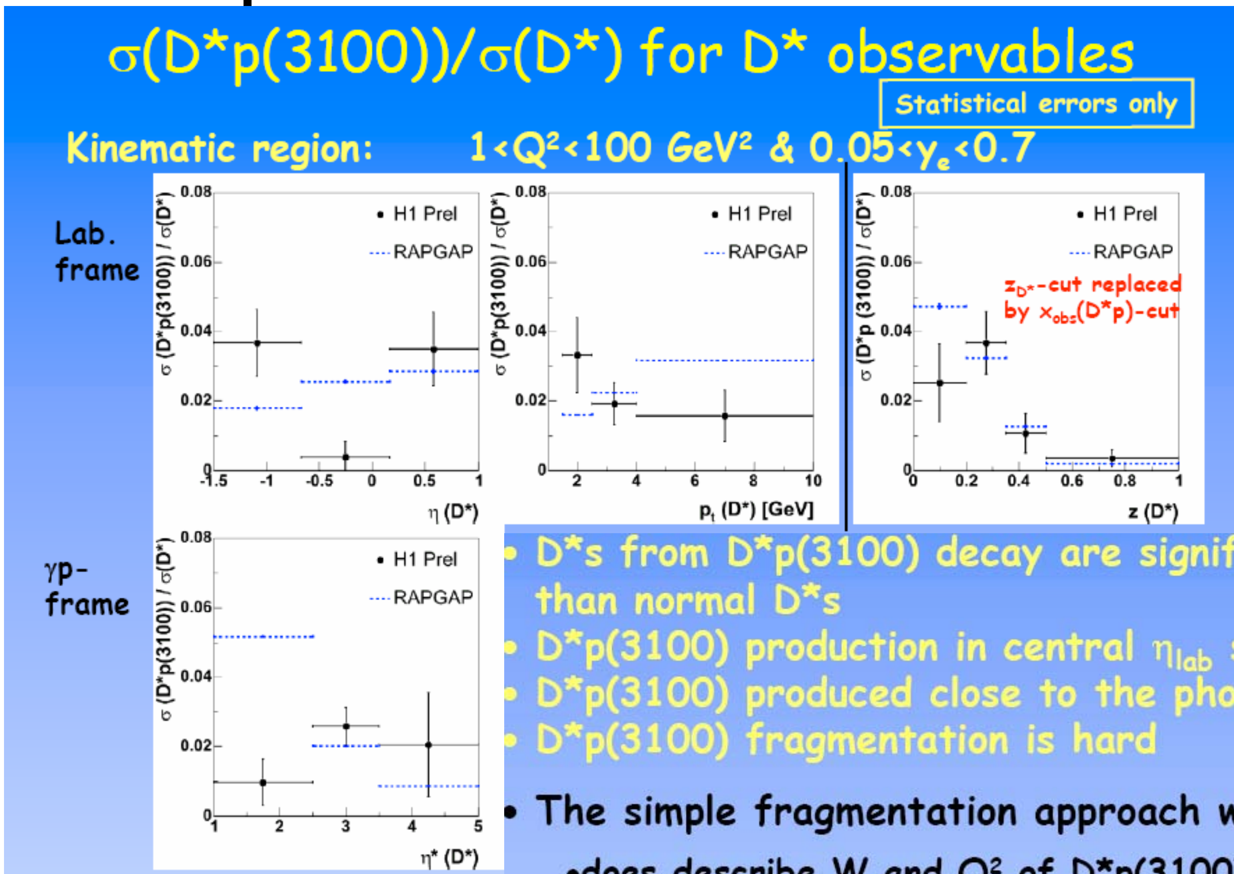
95% C.L. upper limit on $R(\theta_c \rightarrow D^*p/D^*)$ in D^* window

R<0.23% (0.35% for DIS)

0.37%(0.51%) acceptance corrected

H1 More detailed look taken….

σ(D*p(3100))/σ(D*) vs Event kinematics, D* and D*p variables



< Example

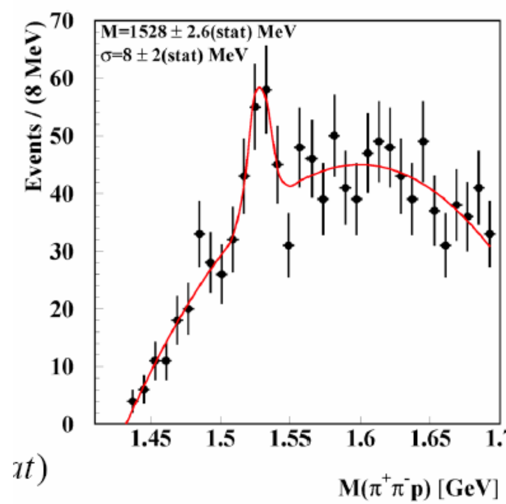
- D*s from D*p(3100) decay are significantly softer than normal D*s
- D*p(3100) production in central η_{lab} suppressed
- D*p(3100) produced close to the photon direction
- D*p(3100) fragmentation is hard

- The simple fragmentation approach with isotropic decay
  - does describe W and Q^2 of D*p(3100) production
  - does not describe D* properties from D*p(3100) decay
  - does reasonably well for properties of D*p(3100), except for η_{lab} and η^*

HERMES pentaquark searches

Avetik Airapetian

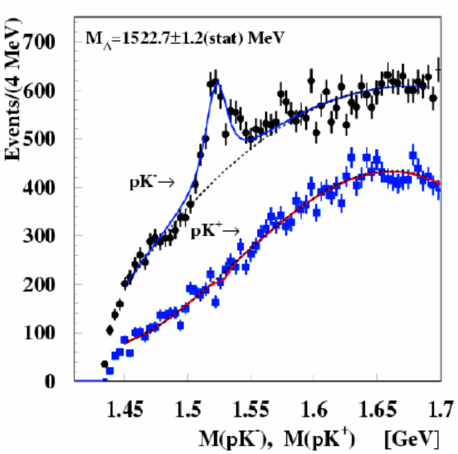
► $\Theta^+ \to pK^0_S$ Previously published result:



Check θ⁺ for

•Kinematic reflections, detector acceptance cuts. Is it a Σ^{*+}, Still there with additional π?

Θ^+ Isospin



- Well established $\Lambda(1520) \to pK^-$ with acceptance: 1.5% $\sigma(\Lambda(1520)) = 62 \pm 11(stat)nb$
- No peak structure for $\Theta^{++} \to pK^+$ zero counts at 91% CL

→ Θ^+ not isotensor probably **isoscalar**

Conclusions

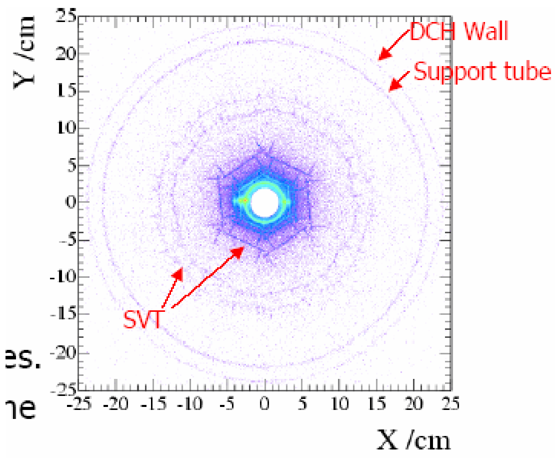
- Direct reconstruction of Θ^+ invariant mass
- Confirmation of Θ^+ (results carefully checked)
- No peak in $\Theta^{++} \to pK^+$:probably isoscalar
- Third π improves signal → :production mechanism?
- Ξ^{--} is not seen → $\sigma_{\Xi^{--}} < 2.1nb(90\%C.L.)$

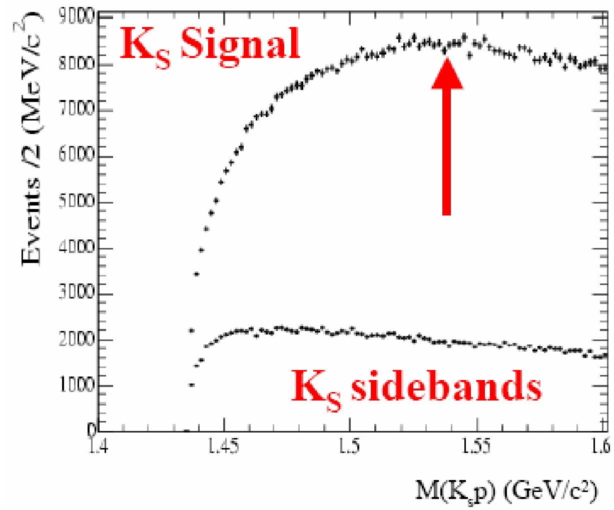
Searches for Pentaquarks at BaBar

Eric Eckhart

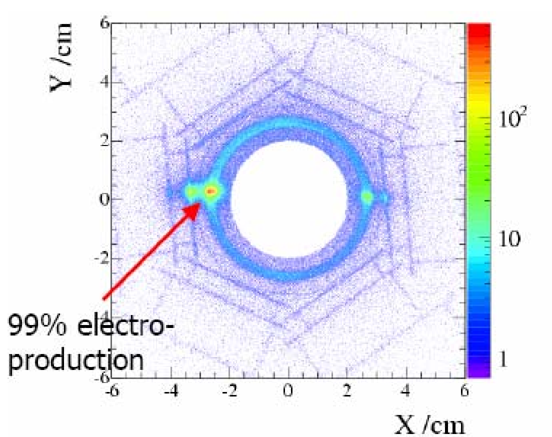
Inclusive searches for θ^+(in e^+e^- and electro-production), Ξ^{--}, Ξ^0

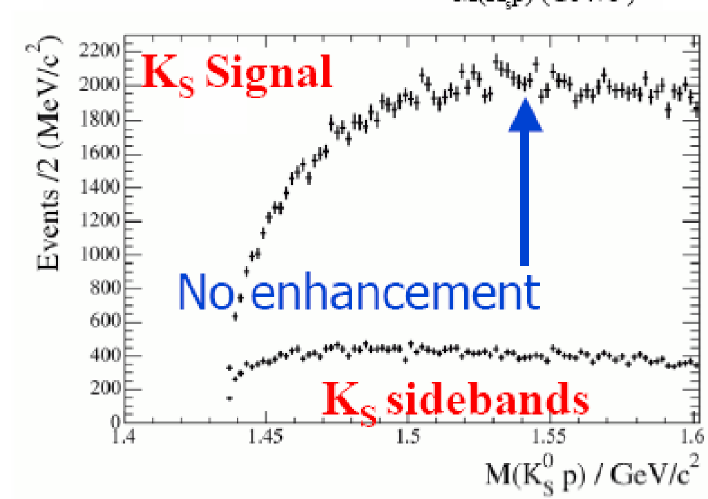
x-y location of pKs vertices ⇒ electro-, hadro-production off detector material



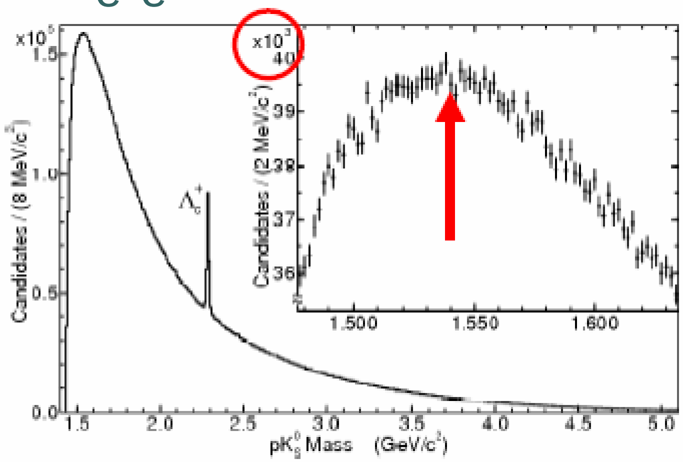


Electro-production only





e^+e^-



- No enhancement near 1540 GeV/c^2;
- Clear $\Lambda_c^+ \rightarrow pK_s$ signal with 98,000 candidates;
- Mass resolution (HWHM) is 2 MeV/c^2 at 1540 MeV/c^2.

Conclusions:

- There is copious production Λ^0, Ξ^-, Ξ^{*0}, Ω^-, Ξ_c^0, Λ_c^+ baryons at BaBar;
- There is no evidence for $\Theta(1540)^+ \rightarrow pK_s$ in e^+e^- interactions, or electro- or hadro-production in the detector material;
- There is no evidence for $\Xi_5(1860)^{--}$ or $\Xi_5(1860)^0$ states;
- Limits on $\Theta(1540)^+$ and $\Xi_5(1860)^-$ production are well below baryons of similar mass;
- There is no evidence for $\Theta^{*++} \rightarrow pK^+$ in $B^+ \rightarrow p\bar{p}K^+$.

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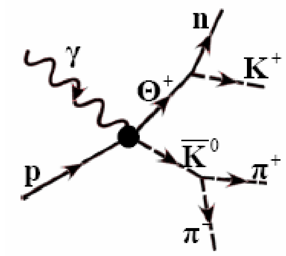
New results from CLAS

Marco Battaglieri

g11 proton $E_\gamma \sim 1.6\text{–}3.8$ GeV
data taking completed in 2004

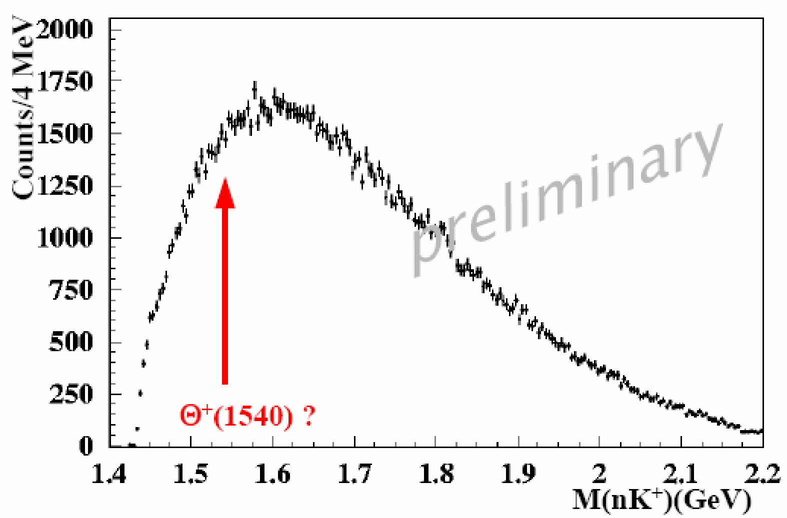
‣ Run in May–July 2004, with a total of $7 \cdot 10^9$ triggers recorded (Luminosity ~70 pb^{-1})

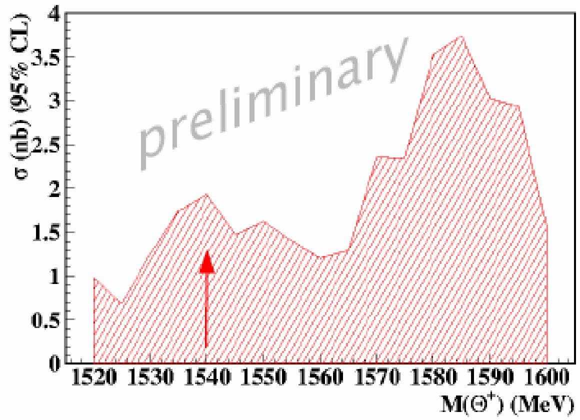
$\gamma p \rightarrow \Theta^+ \overline{K}^0$



$\Theta^+ \rightarrow nK^+$

$\overline{K}^0 \rightarrow K_S \rightarrow \pi^+\pi^-$





Upper limit (95% CL)

$\sigma_{\gamma p \rightarrow \Theta^+ K^0} < 1\text{–}4$ nb

c.f.

SAPHIR

$\sigma_{\gamma p \rightarrow \Theta^+ K^0} \sim 300$ nb
reanalysis 50 nb

To come:

- More channels
- Higher energy run

Conclusions on Pentaquark results:

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Perturbative QCD and Jets

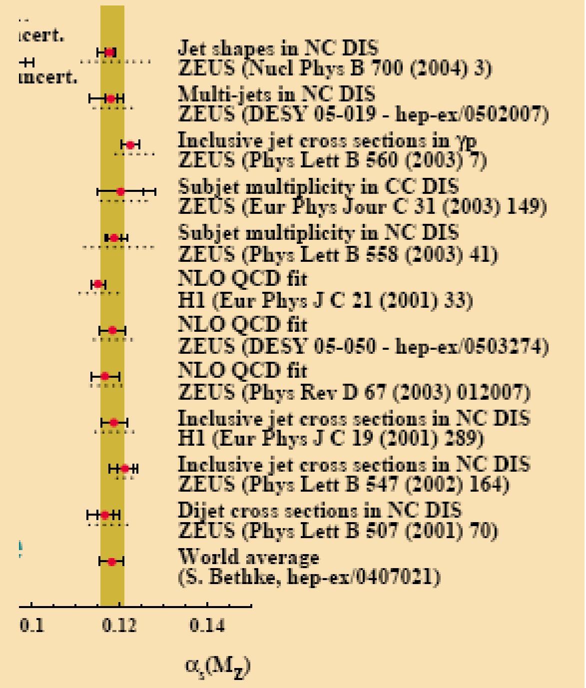
$$\Rightarrow$$

Precision Measurements of α_S *Claudia Glasman*

- Review of α_S determinations from H1 and ZEUS experiments.
- Evaluation of HERA averages of $\alpha_S(M_Z)$ and scale dependence of α_S.

Process	Coll.	Value	Stat.	Experim.	Theory	Total
Dijet NC DIS	ZEUS	0.1166	0.0019	$^{+0.0024}_{-0.0033}$	$^{+0.0057}_{-0.0044}$	$^{+0.0065}_{-0.0058}$
Inc. Jet NC DIS	ZEUS	0.1212	0.0017	$^{+0.0023}_{-0.0031}$	$^{+0.0028}_{-0.0027}$	$^{+0.0040}_{-0.0044}$
Inc. Jet NC DIS	H1	0.1186	$\rightarrow$	$^{+0.0030}_{-0.0030}$	$^{+0.0051}_{-0.0051}$	$^{+0.0059}_{-0.0059}$
3/2 Jet NC DIS	ZEUS	0.1179	0.0013	$^{+0.0028}_{-0.0046}$	$^{+0.0064}_{-0.0046}$	$^{+0.0071}_{-0.0066}$
3/2 Jet NC DIS	H1	0.1175	0.0017	$^{+0.0050}_{-0.0050}$	$^{+0.0054}_{-0.0068}$	$^{+0.0076}_{-0.0086}$
Subjet NC DIS	ZEUS	0.1187	0.0017	$^{+0.0024}_{-0.0009}$	$^{+0.0093}_{-0.0076}$	$^{+0.0097}_{-0.0078}$
Jet Shape NC DIS	ZEUS	0.1176	0.0009	$^{+0.0009}_{-0.0026}$	$^{+0.0091}_{-0.0072}$	$^{+0.0092}_{-0.0077}$
Subjet CC DIS	ZEUS	0.1202	0.0052	$^{+0.0060}_{-0.0019}$	$^{+0.0065}_{-0.0053}$	$^{+0.0103}_{-0.0077}$
NLO QCD Fit	ZEUS	0.1183	$\rightarrow$	$^{+0.0028}_{-0.0028}$	$^{+0.0051}_{-0.0051}$	$^{+0.0058}_{-0.0058}$
NLO QCD Fit	H1	0.1150	$\rightarrow$	$^{+0.0017}_{-0.0017}$	$^{+0.0051}_{-0.0050}$	$^{+0.0054}_{-0.0053}$
Inc. Jet γp	ZEUS	0.1224	0.0001	$^{+0.0022}_{-0.0019}$	$^{+0.0054}_{-0.0042}$	$^{+0.0058}_{-0.0046}$

experimental uncertainties: $\sim 3\%$
theoretical uncertainties: $\sim 4\%$ (jet cross sections and NLO QCD fits)
$\sim 8\%$ (internal structure of jets)



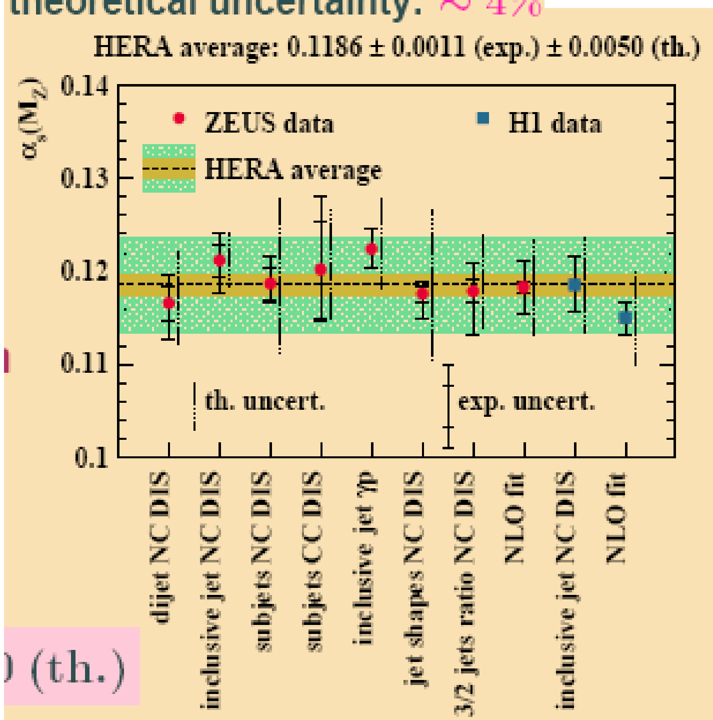
Most precise determinations used in averages

- Averaging must take proper account of *correlations* in e.g
  - Energy-scale uncertainties, PDFs, hadronisation corrections, terms beyond NLO

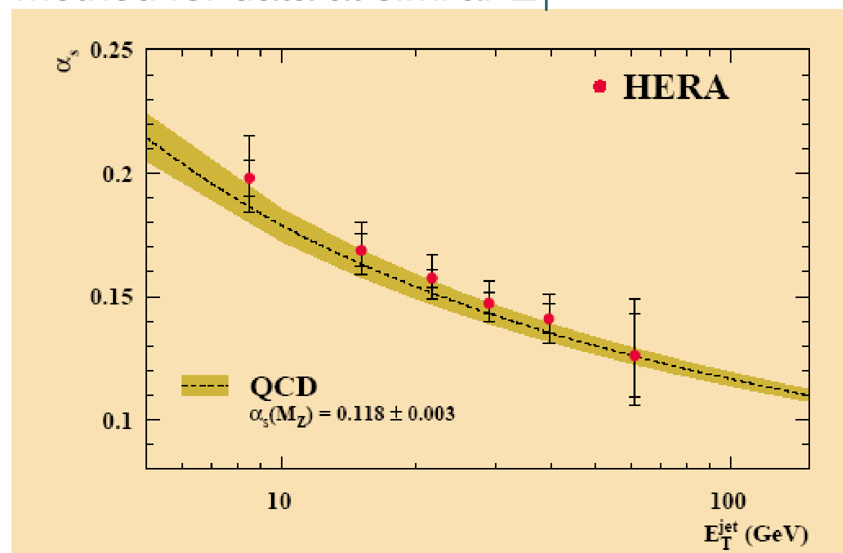
$$\rightarrow \overline{\alpha_s(M_Z)} = 0.1186 \pm 0.0011\ (\text{exp.}) \pm 0.0050\ (\text{th.})$$

experimental uncertainty: $\sim 0.9\%$

theoretical uncertainty: $\sim 4\%$



Combined running of α_s using correlation method for data at similar E_T

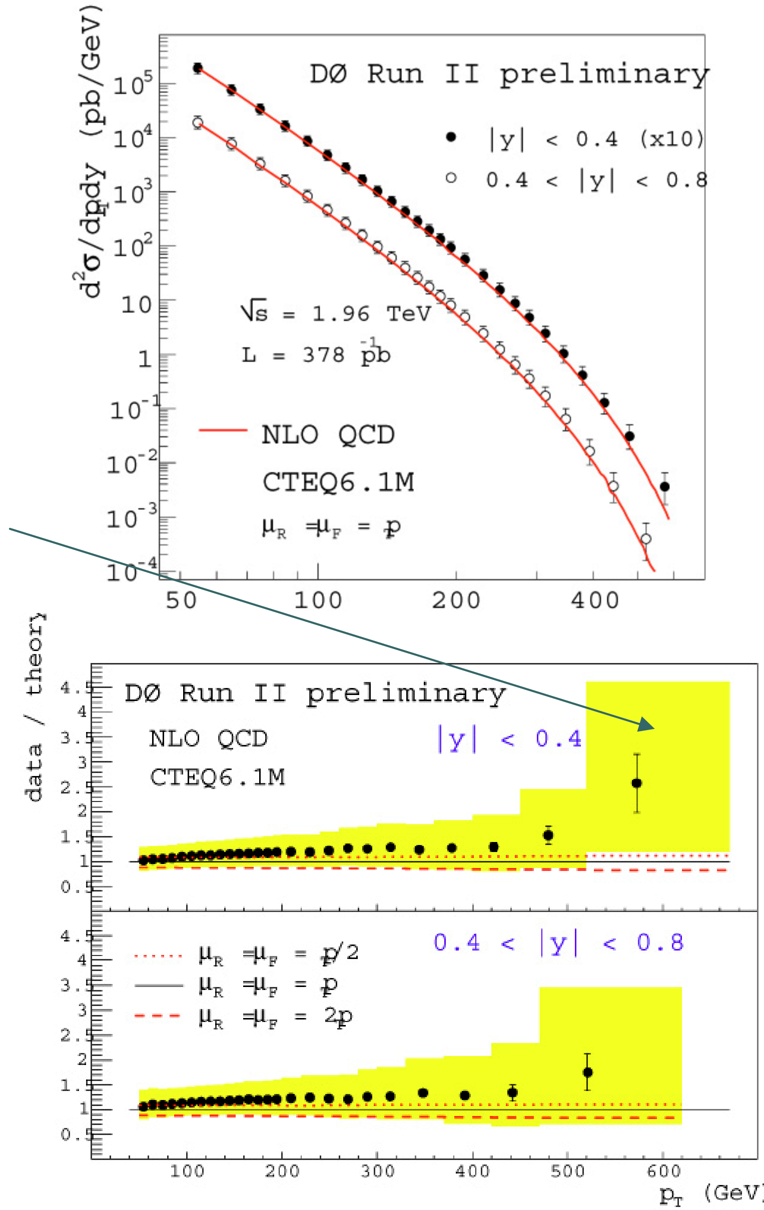


…Next steps will need NNLO

Inclusive jet and dijets from D0

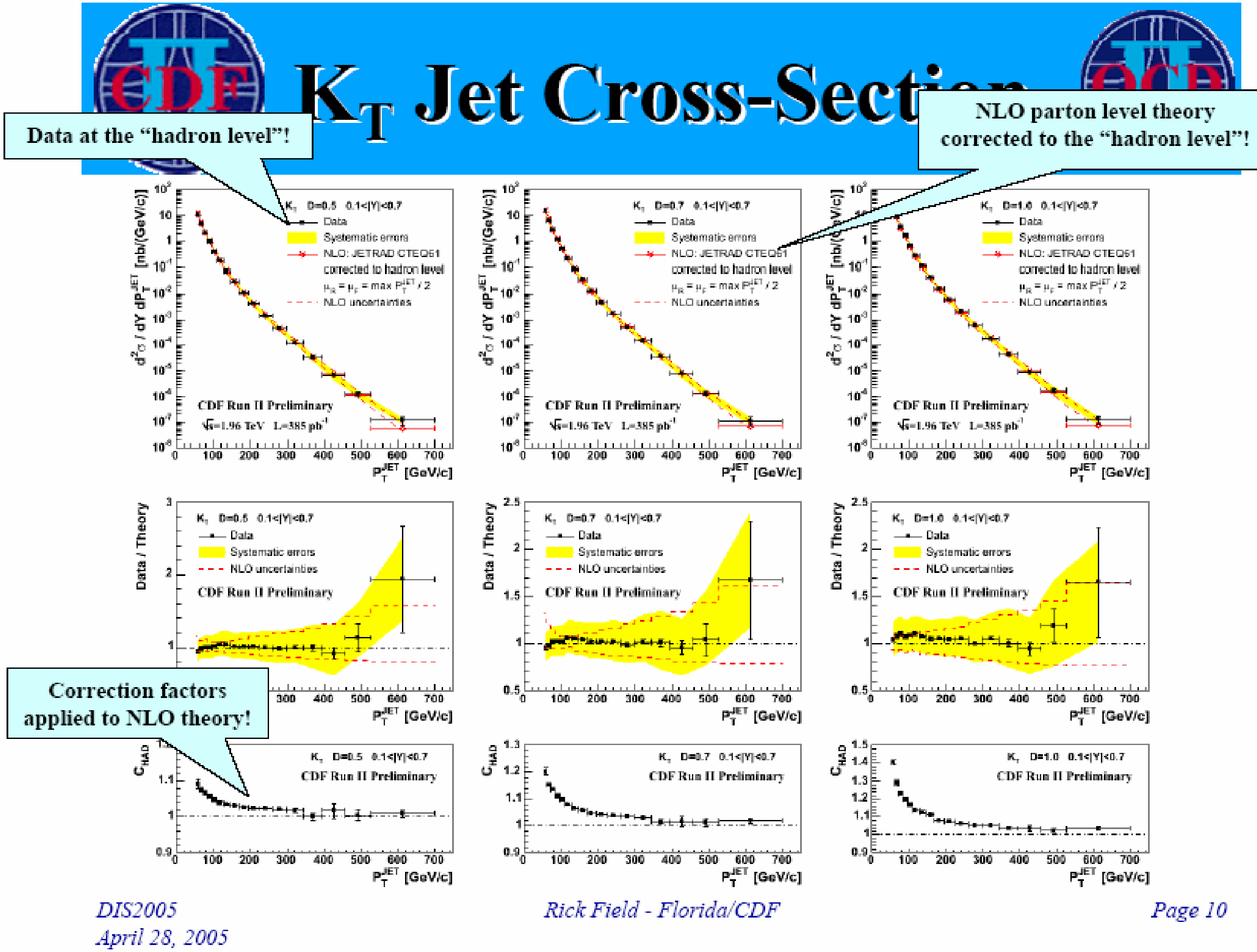
Brian Davies

- Run II has ~0.7 fb^{-1} (~half being analysed here)
- Increased beam energy $\Rightarrow$ extended p_T reach promising sensitivity to gluon at high x
- New cone algorithm IR safe
- Dominant experimental systematic from jet energy scale (~5%) – still understanding new detector components
- Also looking at flavour tagging of jets with μs (vertex tagging to come) and ϕ decorrelations



Jet measurements at CDF

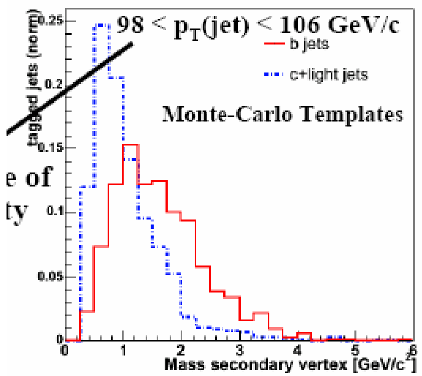
Rick Field

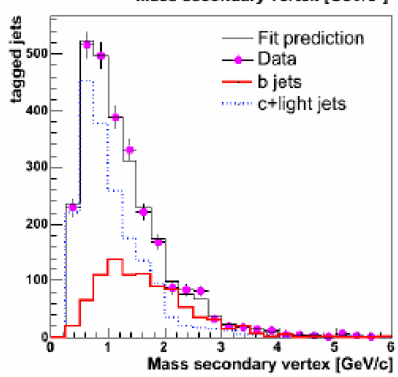


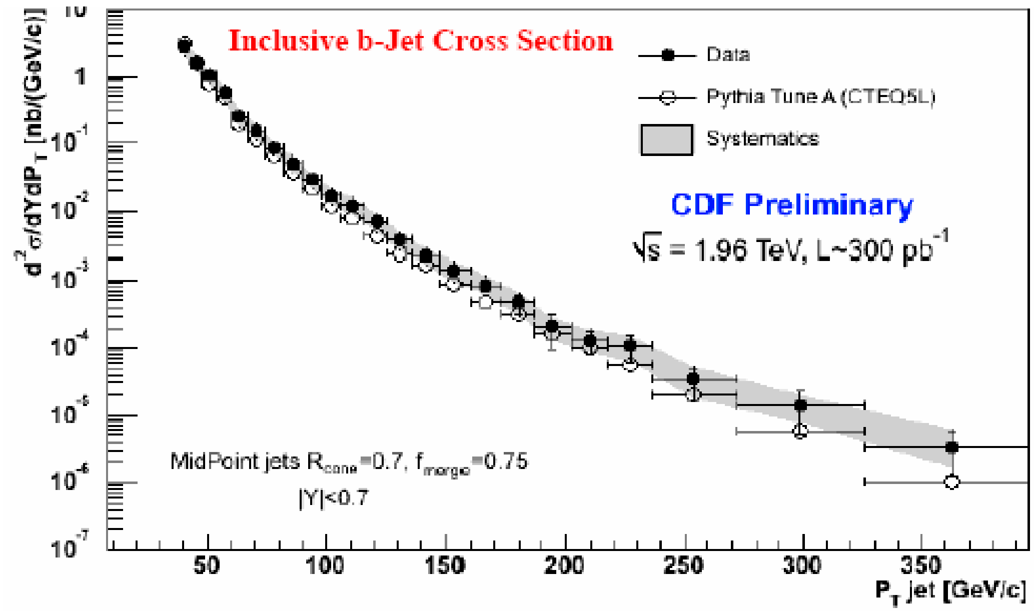
- Now using k_T
- RDF preferred procedure for data/theory comparison
- Future-proofing your results

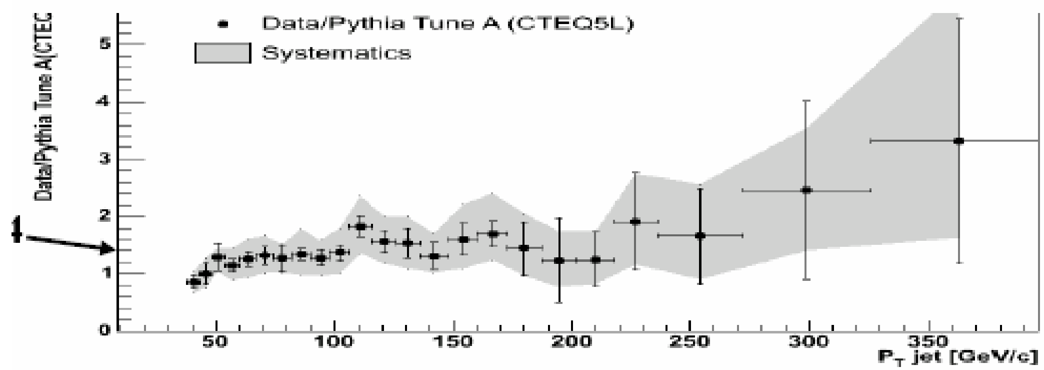
CDF Inclusive b-jet cross-section

Use shape of secondary vertex mass as discriminator









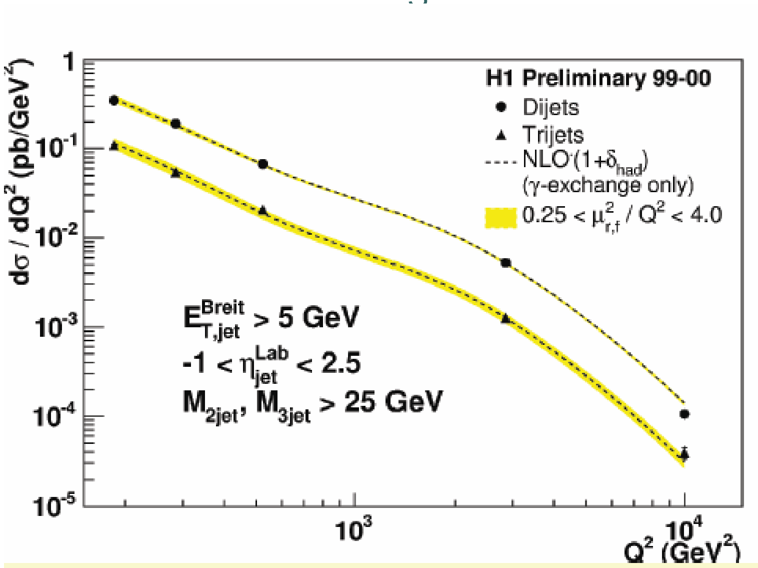
- The data are compared with PYTHIA (tune A)! Data/PYA ~ 1.4
- Comparison with MC@NLO coming soon!

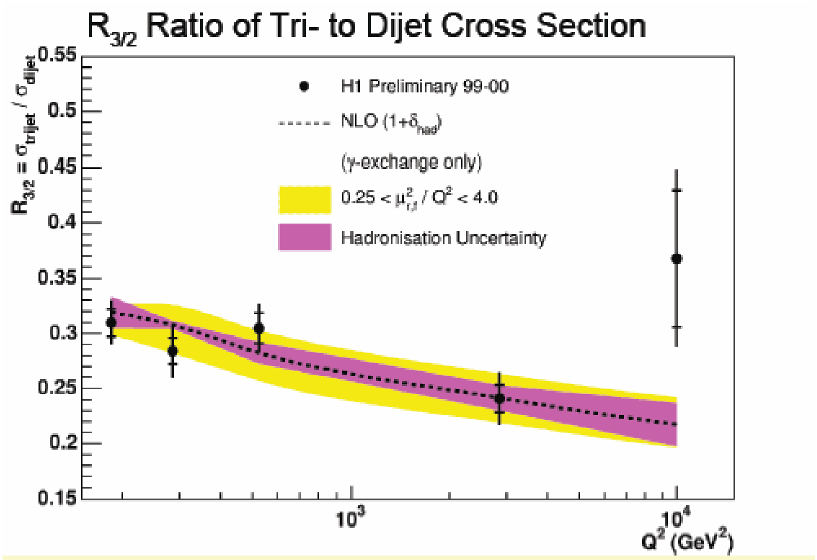
* For CDF underlying event studies -> Pavel

Jet Production at High Q^2 (H1)

Thomas Kluge

- Measure 2- and 3-jet cross sections at high Q^2 - 150 < Q2 < 15000 GeV^2
- Use to make α_S determination



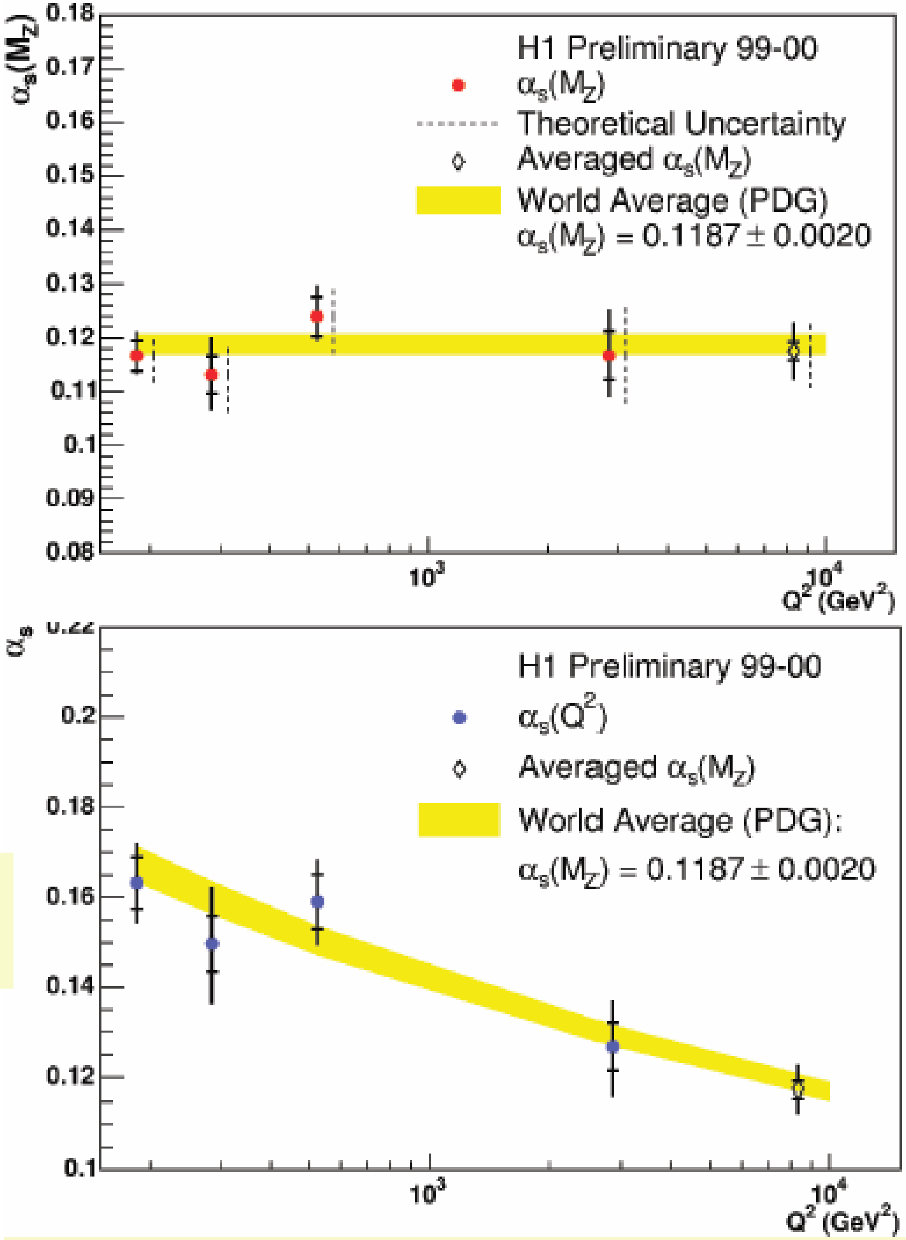


Highest bin needs electroweak corrections from Z exchange. Not used

•Measure cross section ratio $R_{3/2}$

•Reduced experimental and theory uncertainties (e.g. μ_R dependence reduced to ~5%)

$\alpha_s(m_Z)=0.1175\pm0.0017\pm0.005\,^{+0.0054}_{-0.0068}$ (stat.+syst.+theo.)

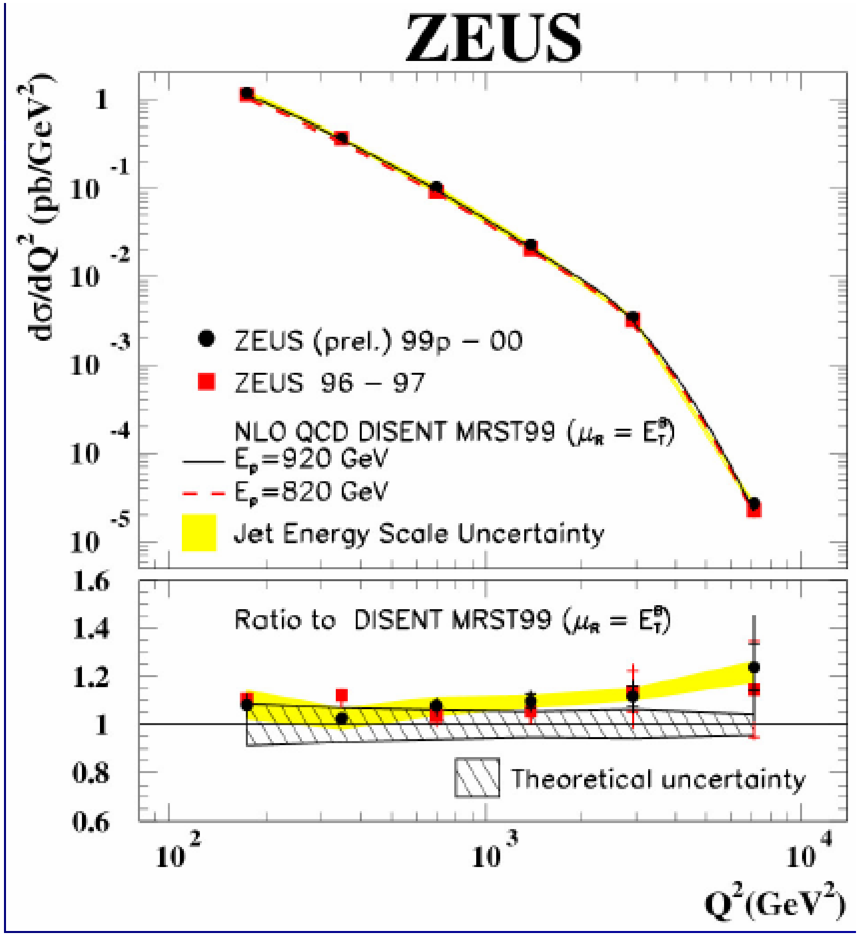


Inclusive Jet Cross-Sections in Neutral Current DIS Events Using the Breit Frame

Jeff Standage

New measurement with 1999/2000 ZEUS data

- Data points consistent with NLO prediction within the uncertainties.
- This measurement is directly sensitive to value of $\alpha_s(M_z)$ and the scale dependence of α_s.
- Consistent with NLO predicted ~10% increase in cross-section

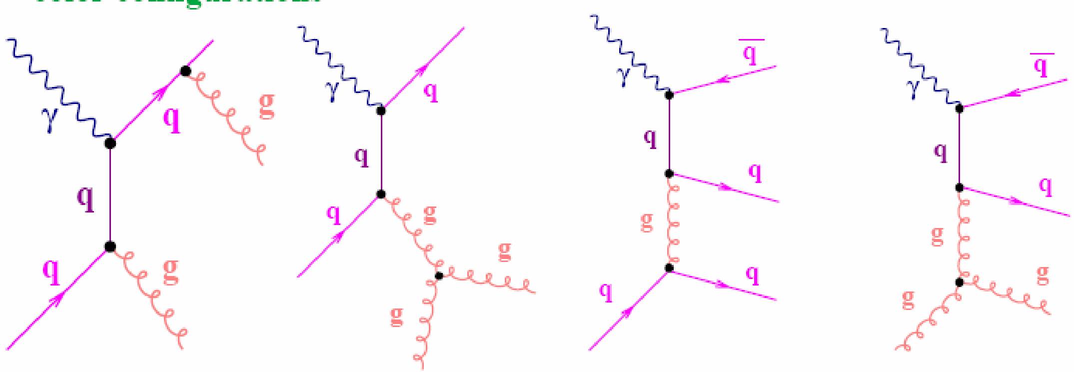


Colour dynamics in photoproduction of jets (ZEUS)

Juan Terron

Photoproduction of Three-Jet Events

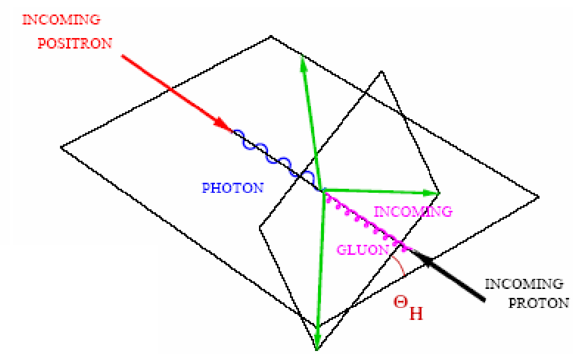
- Direct processes provide a clean way to study the effects of the different color configurations



C_F^2 | $C_F \cdot C_A$ | $C_F \cdot T_F$ | $T_F \cdot C_A$

- The predicted cross section at $\mathcal{O}(\alpha\alpha_s^2)$ can be written as

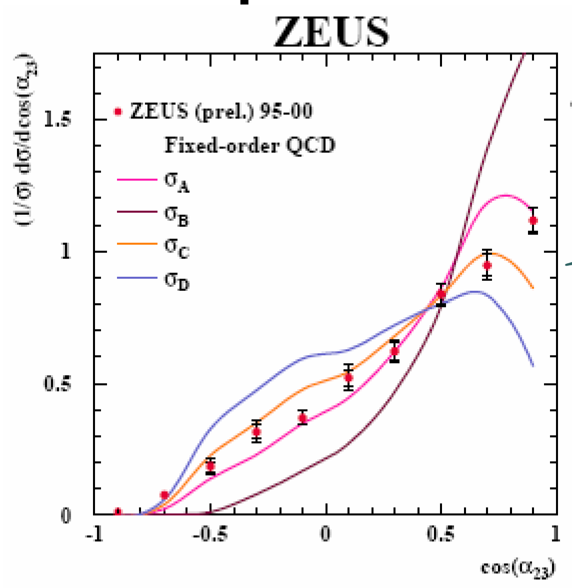
$$\sigma_{ep\to 3\text{jets}} = C_F^2{\cdot}\sigma_A + C_F C_A{\cdot}\sigma_B + C_F T_F{\cdot}\sigma_C + T_F C_A{\cdot}\sigma_D$$



Use angular variables to distinguish the different processes

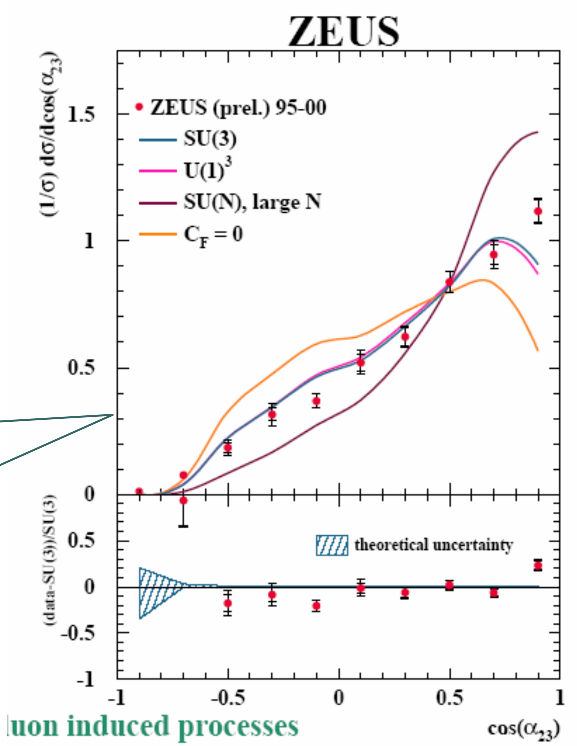
Colour dynamics in photoproduction of jets (ZEUS)

Juan Terron



Different shapes.
e.g. α_{23} $C_F C_A$ very different.

But only 10%contribution predicted in SU(3)



Fixed order calculations (Klasen, Kleinwort, Kramer) based on various symmetry groups. $(\mathcal{O}(\alpha\alpha_s^2))$
Consistent with SU(3)

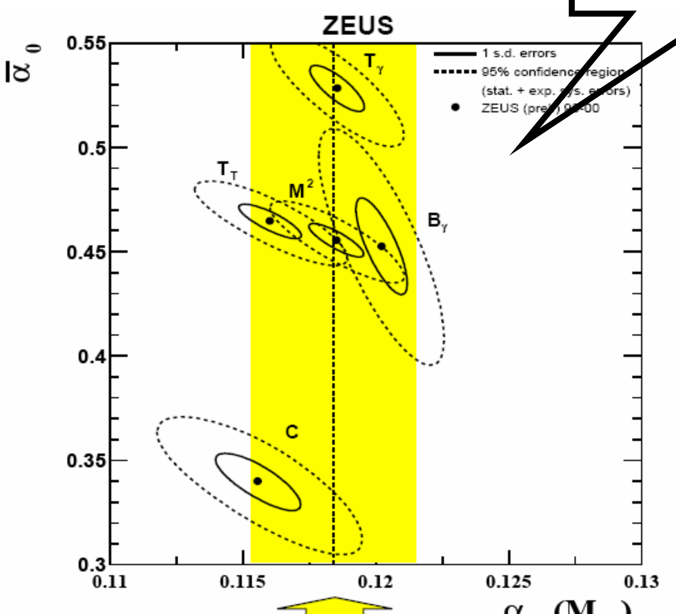
New variables needed (esp. for senstivity to 3-g vertex)

Event shapes from ZEUS

Adam Everett

- Choose IR- and collinear-safe event shape variables.
- Compare with NLO + power corrections (Dokshitzer, Webber)
  (+ resummation for differential distributions)

1/n dn/dF



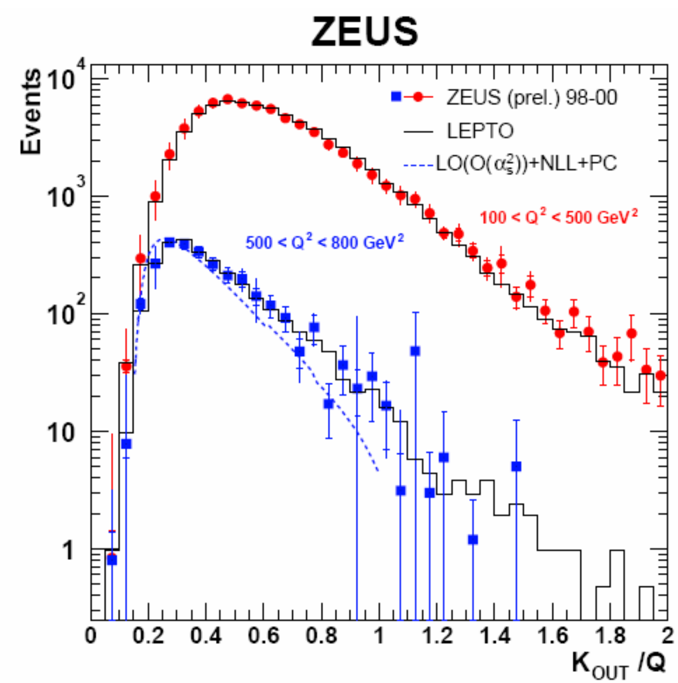
- $\alpha_0 \approx 0.45 - 0.5$

Momentum out of plane

$$K_{out} = \sum_i |\vec{p}_i|$$

Higher order process

Calculations LO for this



No fits performed up to now

First comparison with LO+NLL+PC is shown

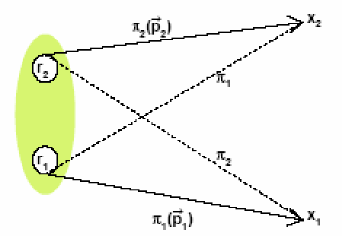
- $\alpha_s(M_Z) = 0.118$
- $\alpha_0=0.52$

Waiting on generalized resummation program

ZEUS 98-00 (82.2 pb^{-1})
$Q^2 > 100$ GeV^2

Neutral and Charged Kaon Bose-Einstein Correlations in DIS

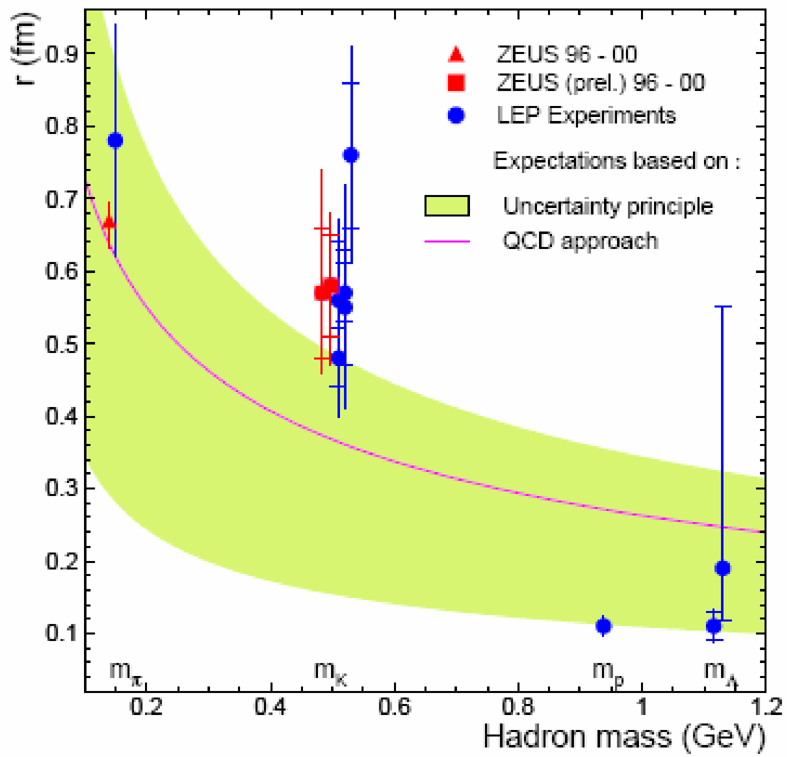
Anna Galas



π_1, π_2 - bosons

$$R(Q_{12}) = \alpha(1 + \lambda e^{-Q_{12}^2 r^2})(1 + \delta Q_{12})$$

r = source size



ZEUS DIS event sample

$$2 < Q^2 < 15000\ GeV^2$$

$$r(m_\pi) > r(m_K) > r(m_\Lambda)$$

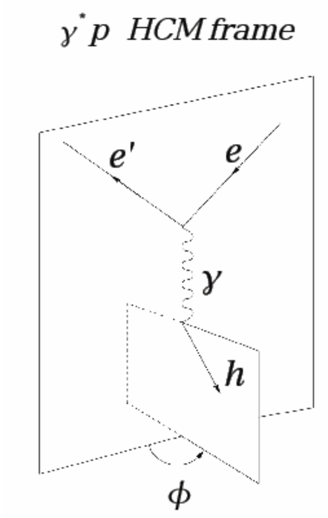
Conclusions

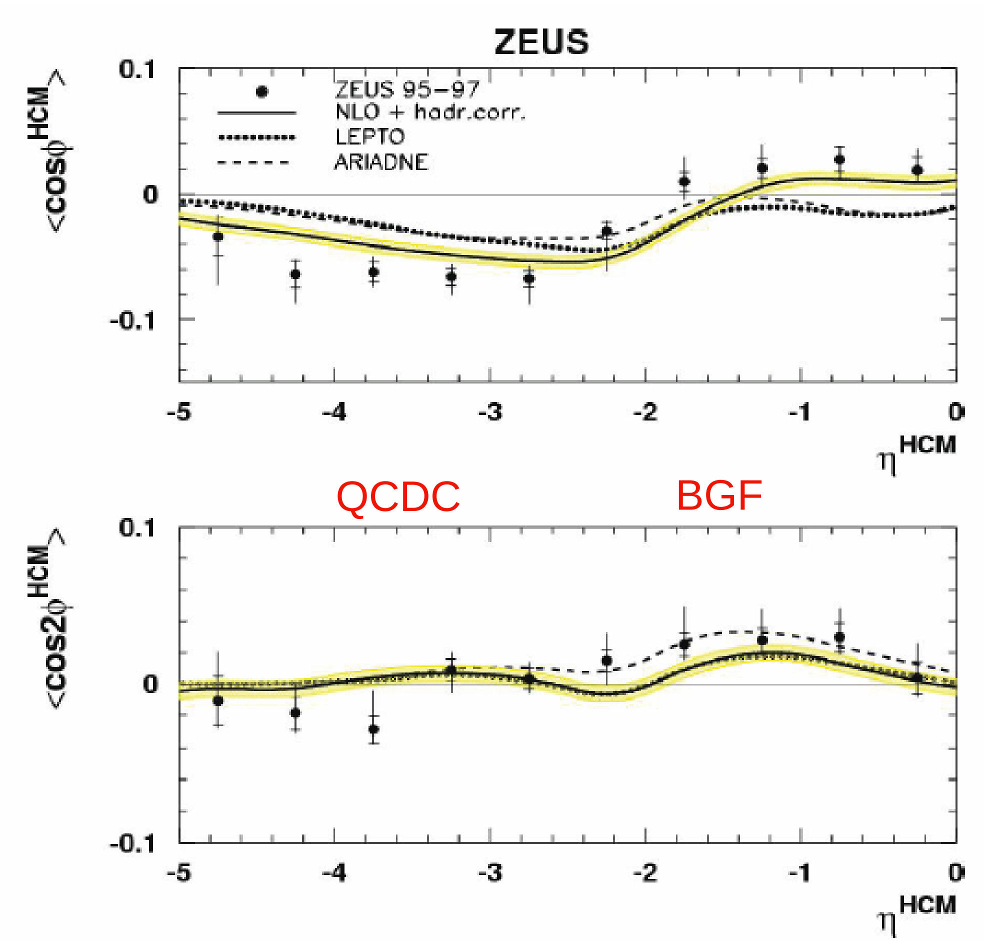
- Still not clear situation.
- We need more precise r measurements for the source size to better explore $r(m)$ behavior.
- We need more mesurements for heavier particles (proton, $\Lambda \Rightarrow$ DIS - ZEUS).

Azimuthal Asymmetries in DIS (ZEUS)

Artur Ukleja

$$\frac{d\sigma^{ep\rightarrow ehX}}{d\phi}=A+B\cos(\phi)+C\cos(2\phi)+D\sin(\phi)+E\sin(2\phi)$$





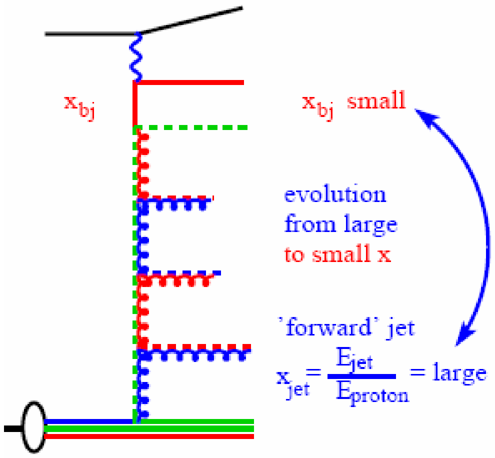
New method: use Energy Flow Objects

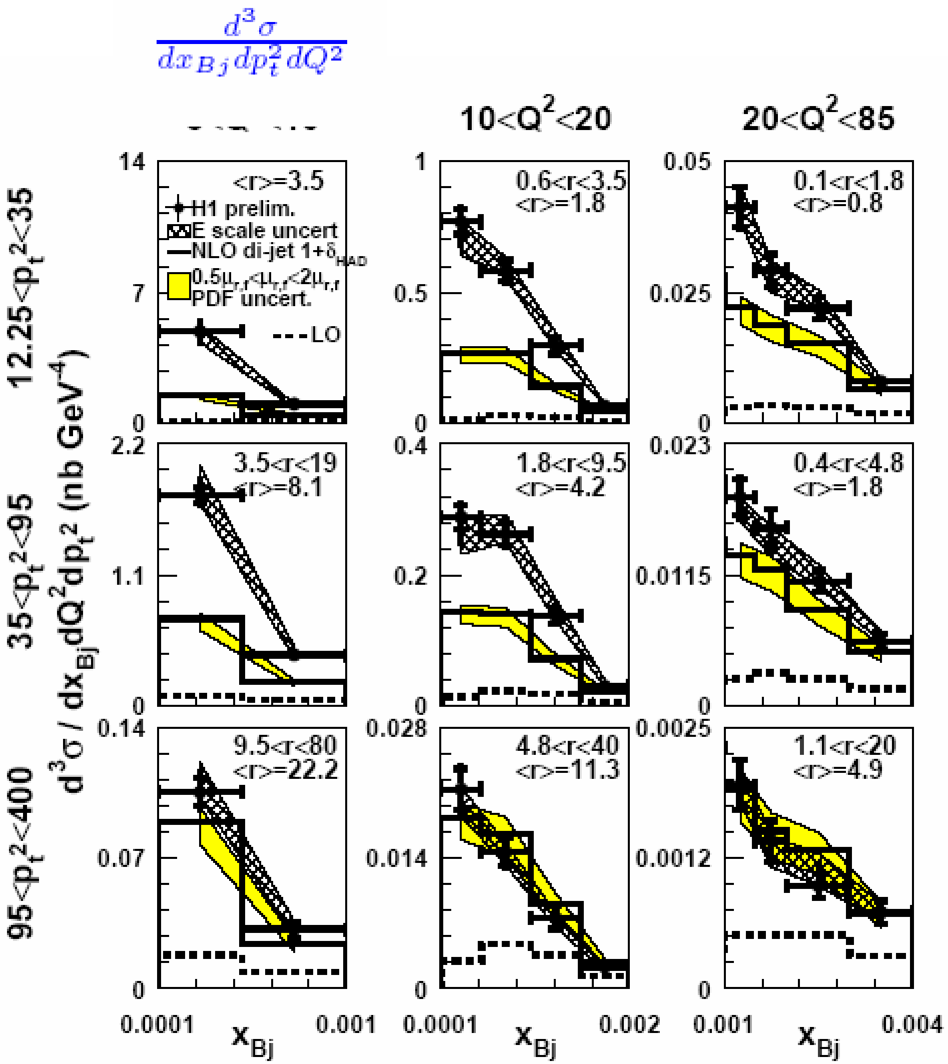
(weight particle directions by their energy)

(better pQCD behaviour)

Measurement of Forward Jet Production at low x in DIS (H1)

Albert Knutsson





Large x_{Bj}, Q^2 and p_t^2 $\Rightarrow$

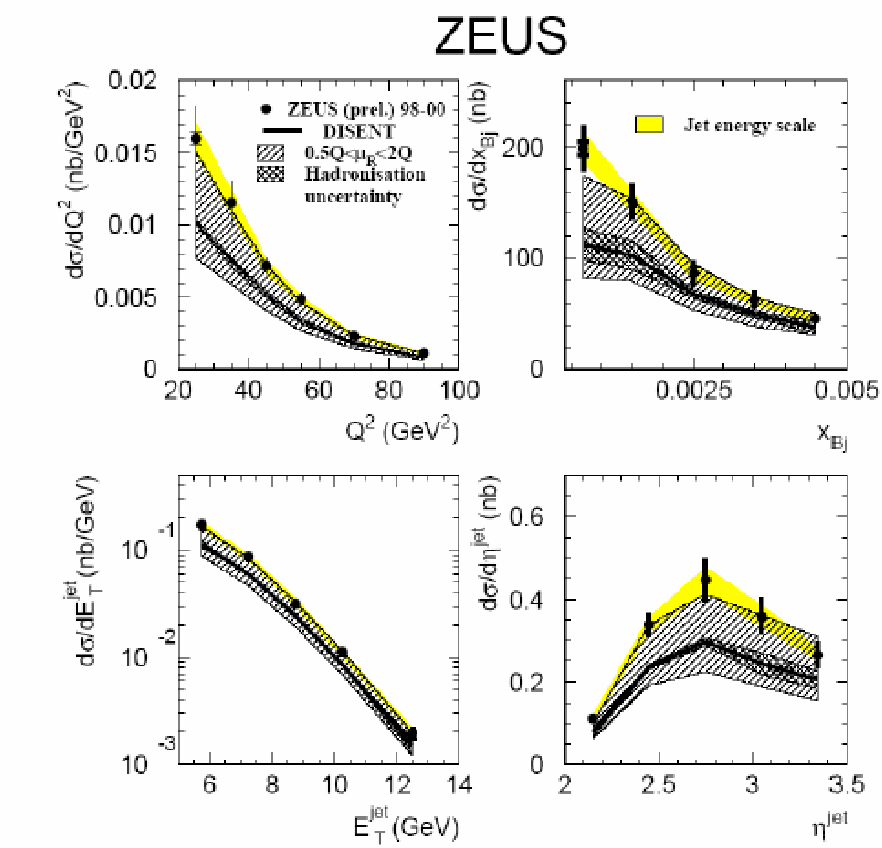
NLO describes data

Smaller x_{Bj}, Q^2 and p_t^2 $\Rightarrow$

NLO insufficient

Inclusive Forward Jet production in DIS (ZEUS)

Nicolai Vlasov



- Average hadronisation correction obtained with LEPTO and ARIADNE
- Proton PDF CTEQ5D
- NLO predictions lower than data but within theoretical uncertainties (except very low x_{Bj})
- Theory has too large uncertainty
- No disagreement with NLO DGLAP has been observed for forward jets

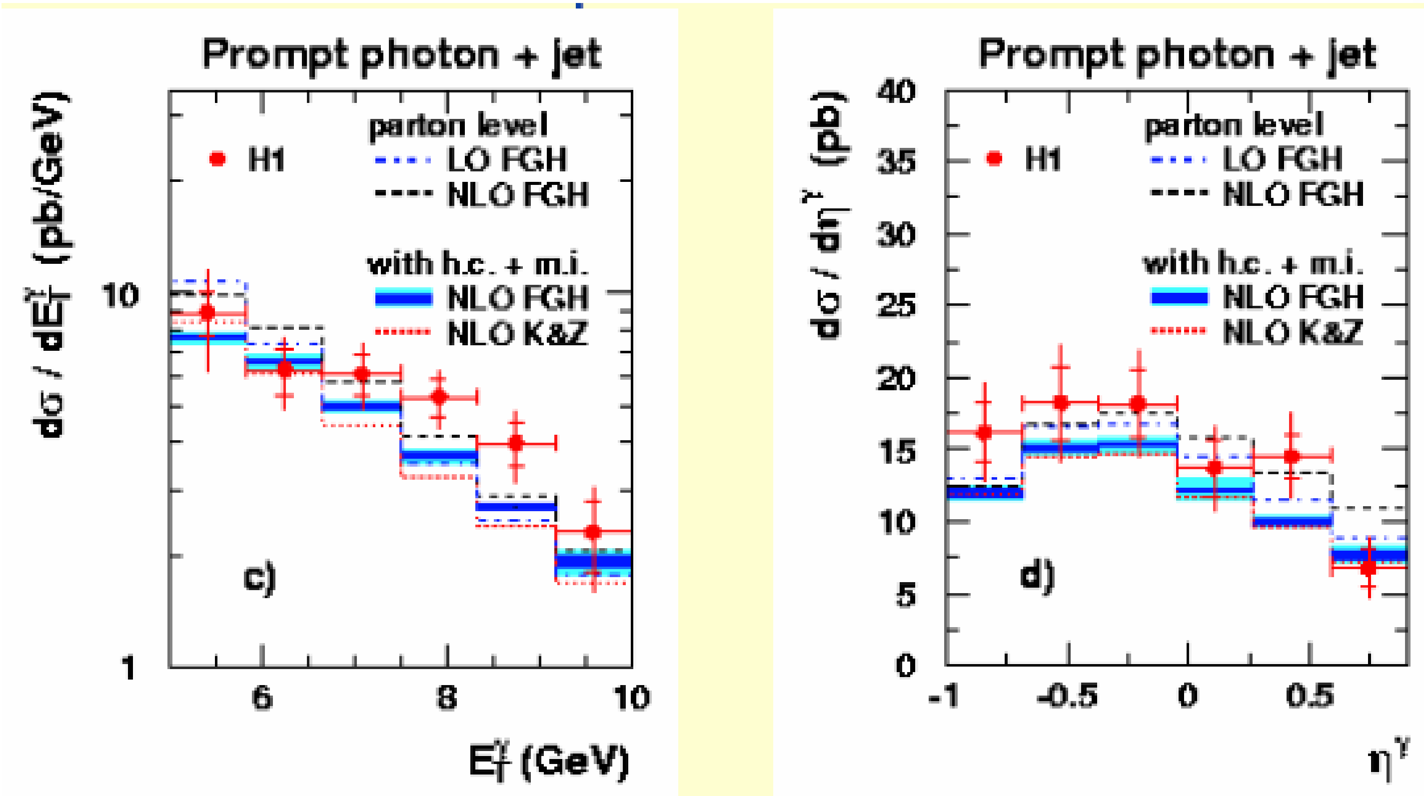
Different way of estimating scale uncertainty?

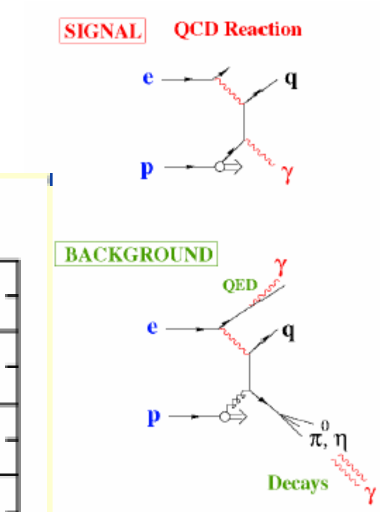
Prompt Photon Cross section in Photoproduction (H1)

Josef Ferencei

1996-2000 data: 105 pb^{-1}

Use combination of shower shape variables to discriminate against π^0,η



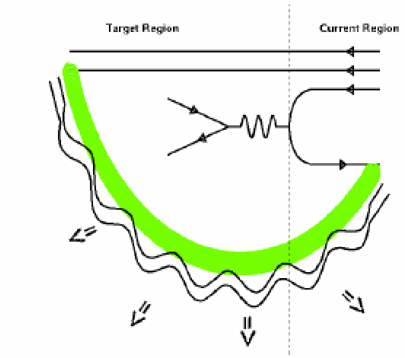


NLO does reasonably well (better with jet)

Charged multiplicity distributions (ZEUS)

Breit Frame analysis of multiplicities

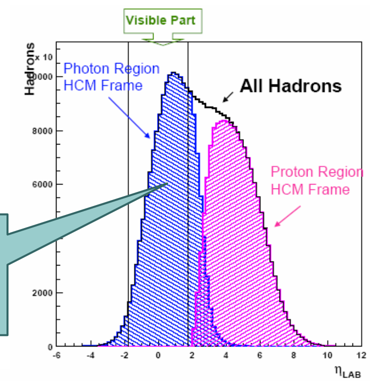
Careful look at: current region in B.F. ≡ one e^+e^- hemisphere

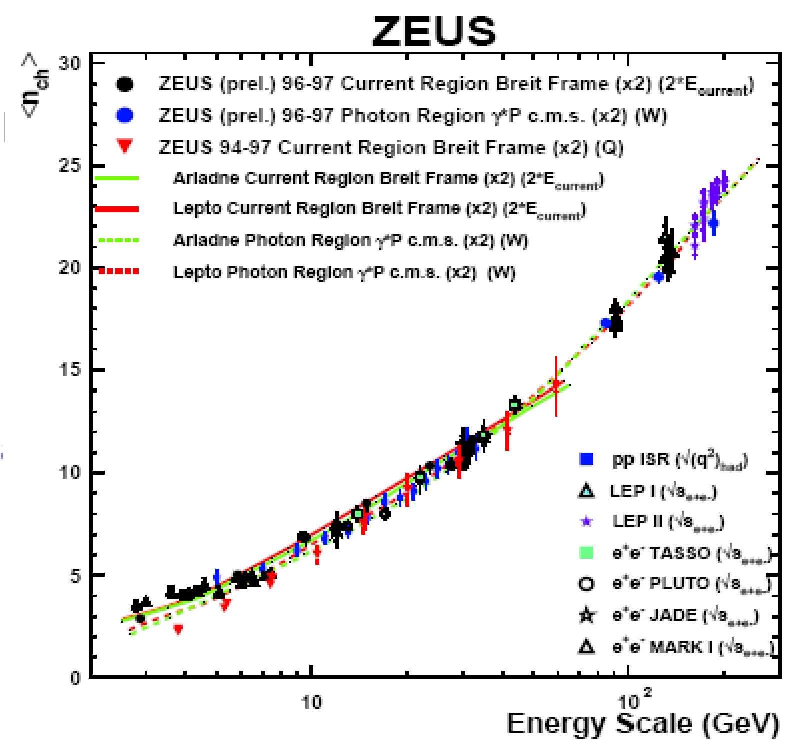


No migrations: $E_{Breit} = \frac{\sqrt{Q^2}}{2}$

With migrations: $\begin{cases} N < N_{expected} \\ E_{Breit} \langle \frac{\sqrt{Q^2}}{2} \end{cases}$

Photon region in HCM mostly target region in BF



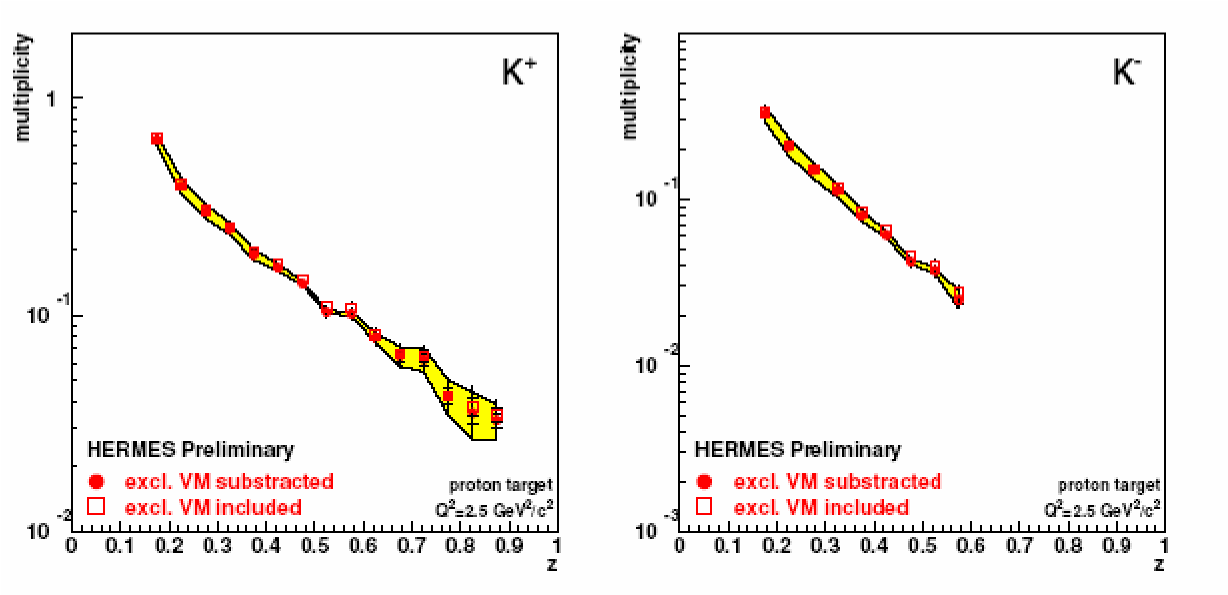


- Measurement in current region of the Breit frame shows similar dependence to e^+e^- if $2{*}E_{current}$ is used as the scale
- The same dependence is observed for the photon region of the HCM frame vs. W.

Fragmentation Process in HERMES

Bino Maiheu

- Flavour separated multiplicity distributions – RICH
- Test factorisation and validity of e^+e^- FFs down to low Q^2 ($2.5 GeV^2$)
- Must cope with low HERMES acceptance



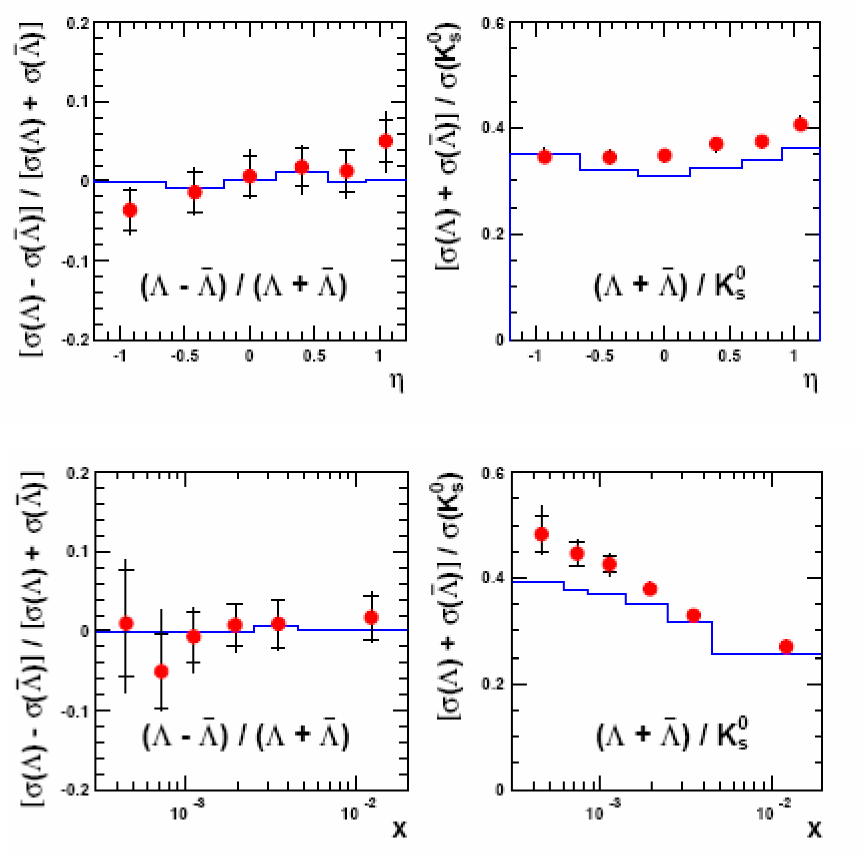
Systematics from RICH

Polarization and Asymmetries in Neutral Strange Particle Production (ZEUS)

Andrew Cottrell

Investigate Λ, $\bar{\Lambda}$ and K_s^0

- Strange quark polarisation (origin of s)
- Baryon/meson ratio
- Baryon number (how transferred?)



c.f. Ariadne

Conclusions:

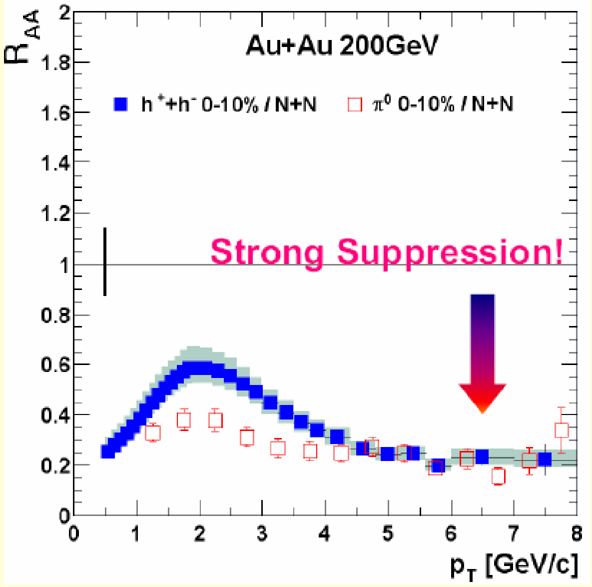
- Transverse Λ pol consistent with 0
- Longitudinal also – sensitivity for HERAII
- No Λ–Λbar asymmetry – starts to limit baryon number transport models
- Baryon/Meson ratio between e^+e^- and Heavy Ion - strong decrease with x

π^0, η and direct γ production in Au+Au and p+p collisions

PHENIX *Terry Awes*

Au-Au with p+p
Nuclear modification factor

$$R_{AA} = \frac{\text{Yield}_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{\text{Yield}_{pp}}$$



Partons from hard scattering exit through dense strongly interacting medium ⇒ "jet quenching"

π^0 and charged hadrons exhibit:

Strong suppression ⇒ high gluon densities and energy densities

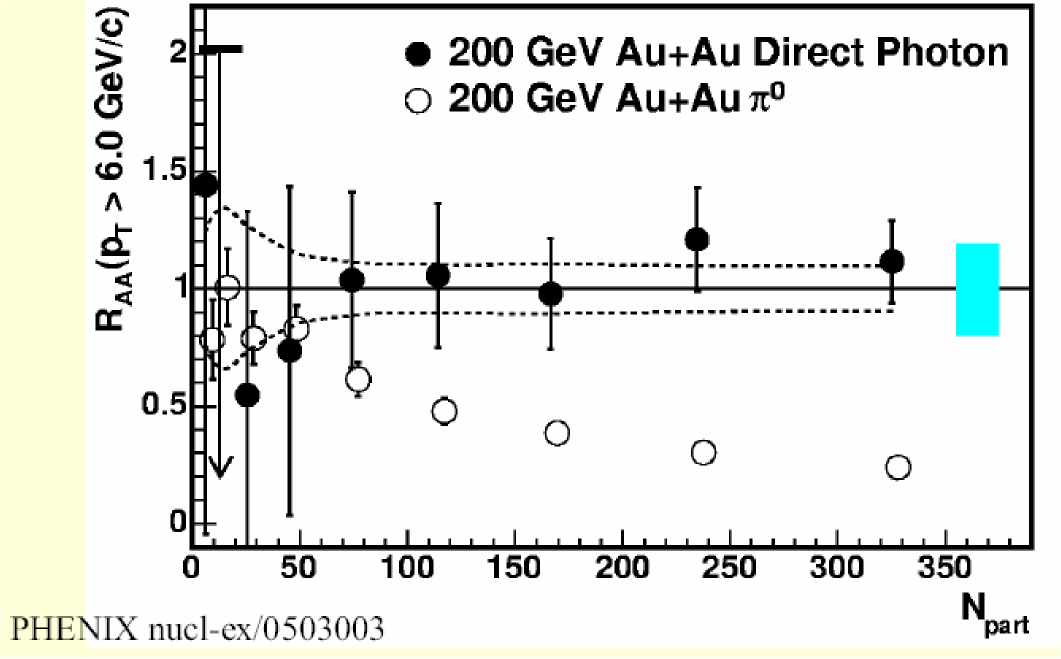
Suppression increasing with overlap (so with increasing density and pathlength

But must distinguish initial state effects – modifications to PDFs (shadowing, saturation etc)

From final state effects of QGP (+etc)

So look at direct γ production – once produced escape unscathed

No suppression seen!

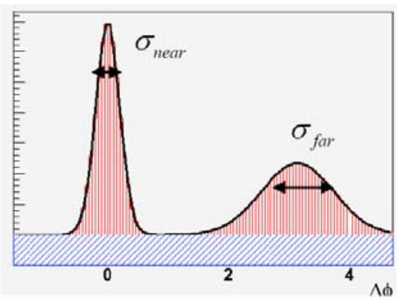


Strong confirmation hadron suppression due to QGP rather than PDF modification

Jet properties from di-hadron correlations in pp and dAu

PHENIX *Jiangyong Jia*

- Access properties of dijet system through 2-particle correlation in $\Delta\phi$



$$\frac{1}{N^0_{trig}}\frac{dN_0}{d\Delta\phi} = \lambda + \frac{Yield_{Near}}{\sqrt{2\pi}\sigma_N} e^{\frac{-\Delta\phi^2}{2\sigma_N^2}} + \frac{Yield_{Far}}{\sqrt{2\pi}\sigma_F} e^{\frac{-(\Delta\phi-\pi)^2}{2\sigma_F^2}}.$$

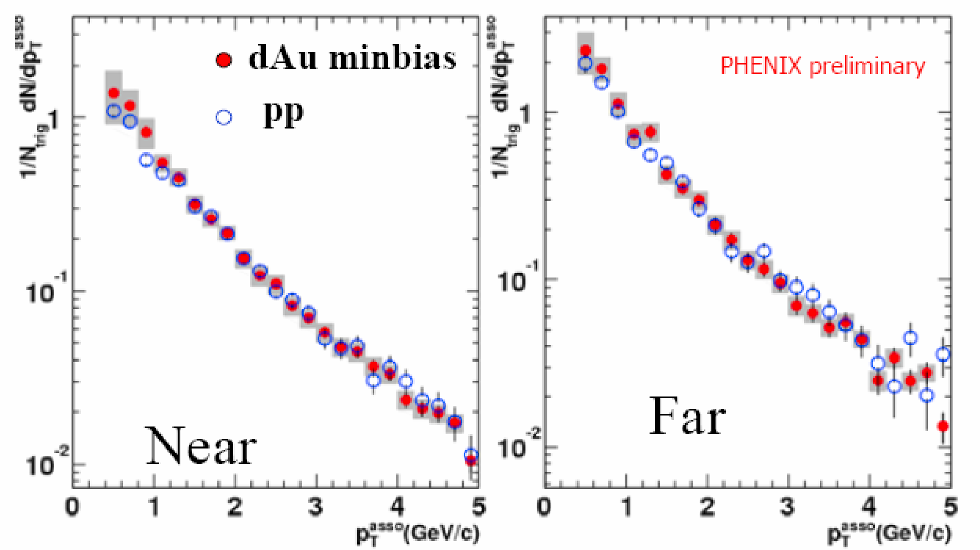
Underlying event — Near side jet — Far side jet

Relatively insensitive to multiplicity and limited PHENIX acceptance

Look at Jet shape, yield, underlying event.

e.g. Jet yield $\Rightarrow$

…showing pp, dAu agree within errors.



Conclusion

- Experimental studies of the hadronic final state alive and active
- Developments in “traditional” jet cross-section and QCD studies.
- New and exciting results from JLAB and RHIC
- Still huge amount to learn before (and after) LHC turns on

Many thanks to all the HFS speakers!