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(virtual) Photon Structure at HERA (H1 + ZEUS)

- Intro
- parton dynamics at small x

  resolved γ's $\left\{\begin{array}{l}\text{forward jets}\\ \text{di-jet x-section}\end{array}\right\}$ Q^2 dependence
- what did we learn?
- present picture of DIS

NOT: structure of real γ !

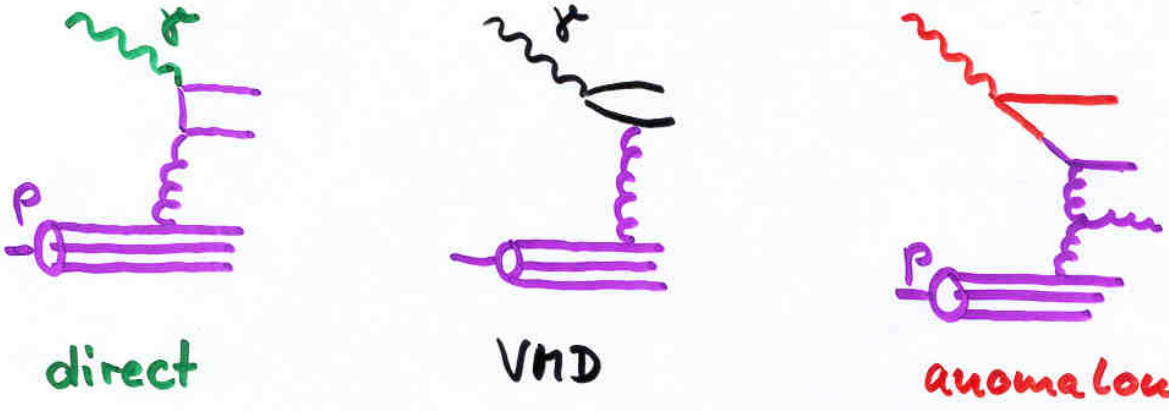
all data presented before, some now final!

Summary Moriond 1999: resolved virtual γ's – really proper way?

the structure of the photon

physical γ = bare = direct + VMD + $q\bar{q}$ anomalous

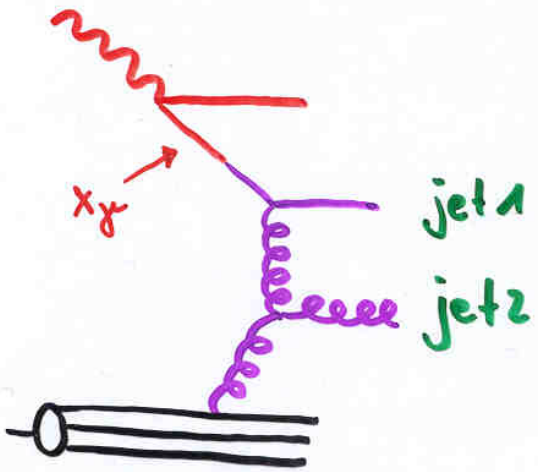
processes:



direct VMD anomalous

→ resolve structure of γ, if scale of hard process is larger Q^2 of γ. (1/size ~ Q^2 = virtuality of γ in DIS)

→ jet production



momentum fraction of parton in photon

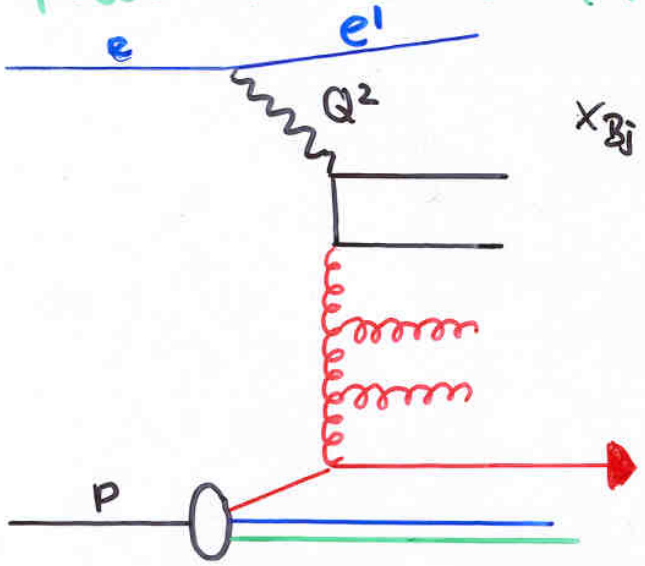
$$x_\gamma = \frac{E_{T1} e^{-\eta_1} + E_{T2} e^{-\eta_2}}{2 \cdot y \cdot E_e}$$

→ studied extensively in γ-prod. ($Q^2 \sim 0$)

→ what about virtual γ's (DIS) ?

forward jet production in DIS – parton dynamics at small x_{Bj}

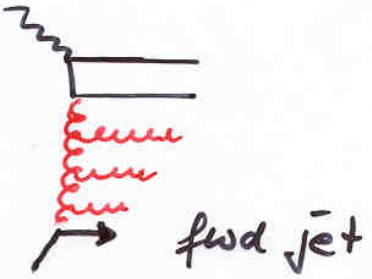
- proposed measurement (A. Mueller)



$$x_{Bj} = \frac{Q^2}{y \cdot s}$$

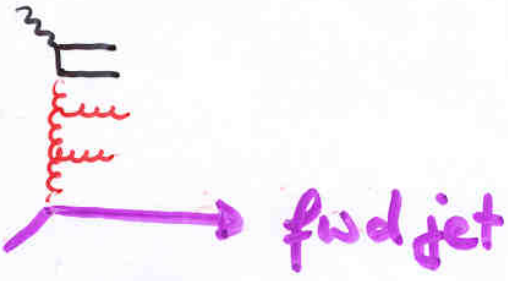
"forward" jet at large $x_{jet} \gg x_{Bj}$

- $p_{T\,jet}^2 < Q^2 \rightarrow$ "direct γ" region ("standard" DIS)



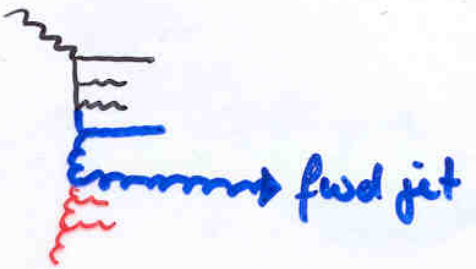
- $p_{T\,jet}^2 \sim Q^2 \rightarrow$ **BFKL region**

difficult region: 2 scales



- $p_{T\,jet}^2 > Q^2$

"resolved γ^*" region



→ learn much on parton dynamics by scan p_T^2/Q^2 (fwd jet → large phase space)

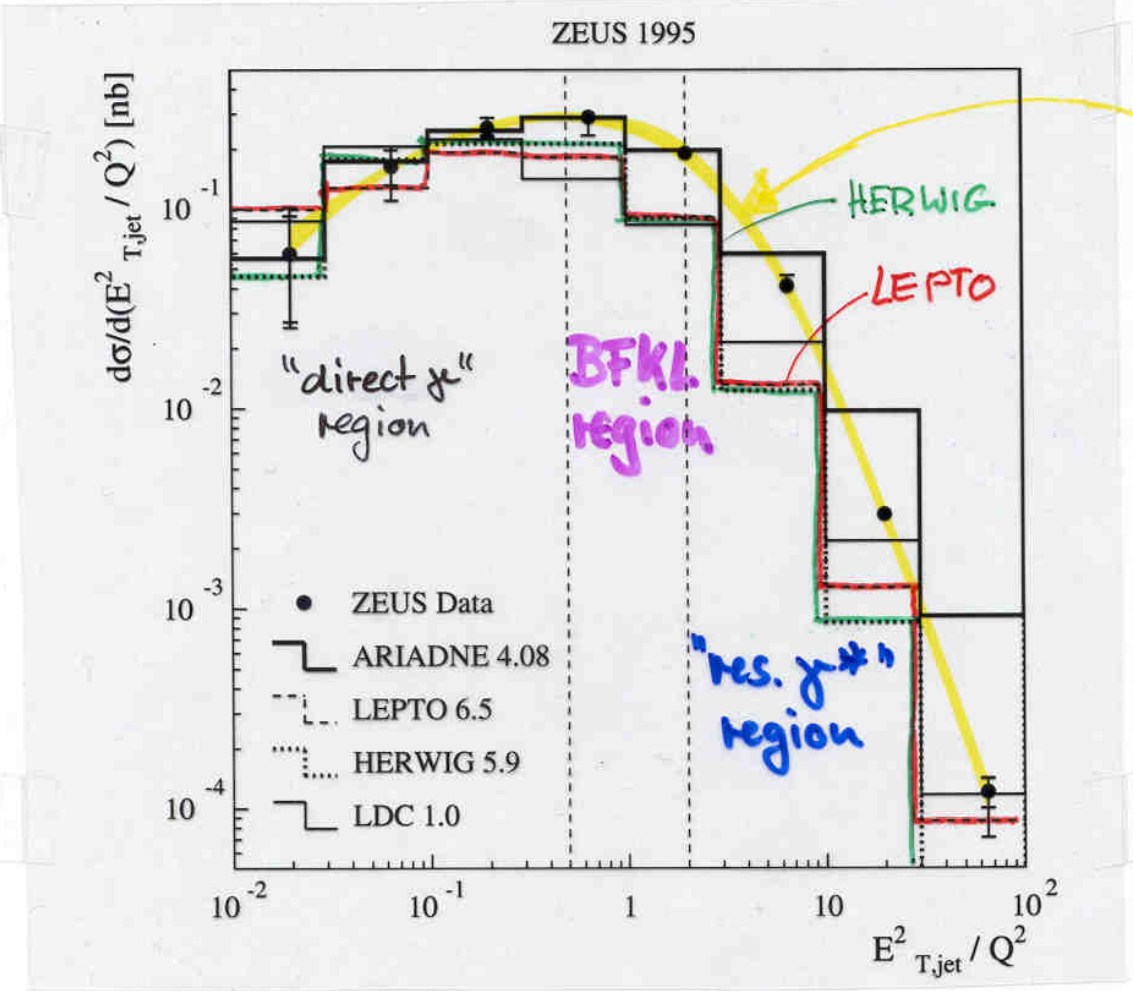
fwd jet prod.: E_T^2/Q^2 dependence

- fwd jets → BFKL effects $E_T^2 \sim Q^2$
- event selection:

$Q^2 > 10\ \text{GeV}^2$ $(y > 0{,}1\ ,\ E_e' > 10\ \text{GeV})$

$\eta_{jet} < 2{,}6 \ \hat{=}\ \theta_{jet} > 8{,}5^\circ$
$E_{T\,jet} > 5\ \text{GeV}$
} jets with cone algo.

$x_{jet} = \frac{p_{z\,jet}}{p_{beam}} > 0{,}036$, $p_{z\,Breit} > 0$ (avoid jets from scatt. quarks at large x)

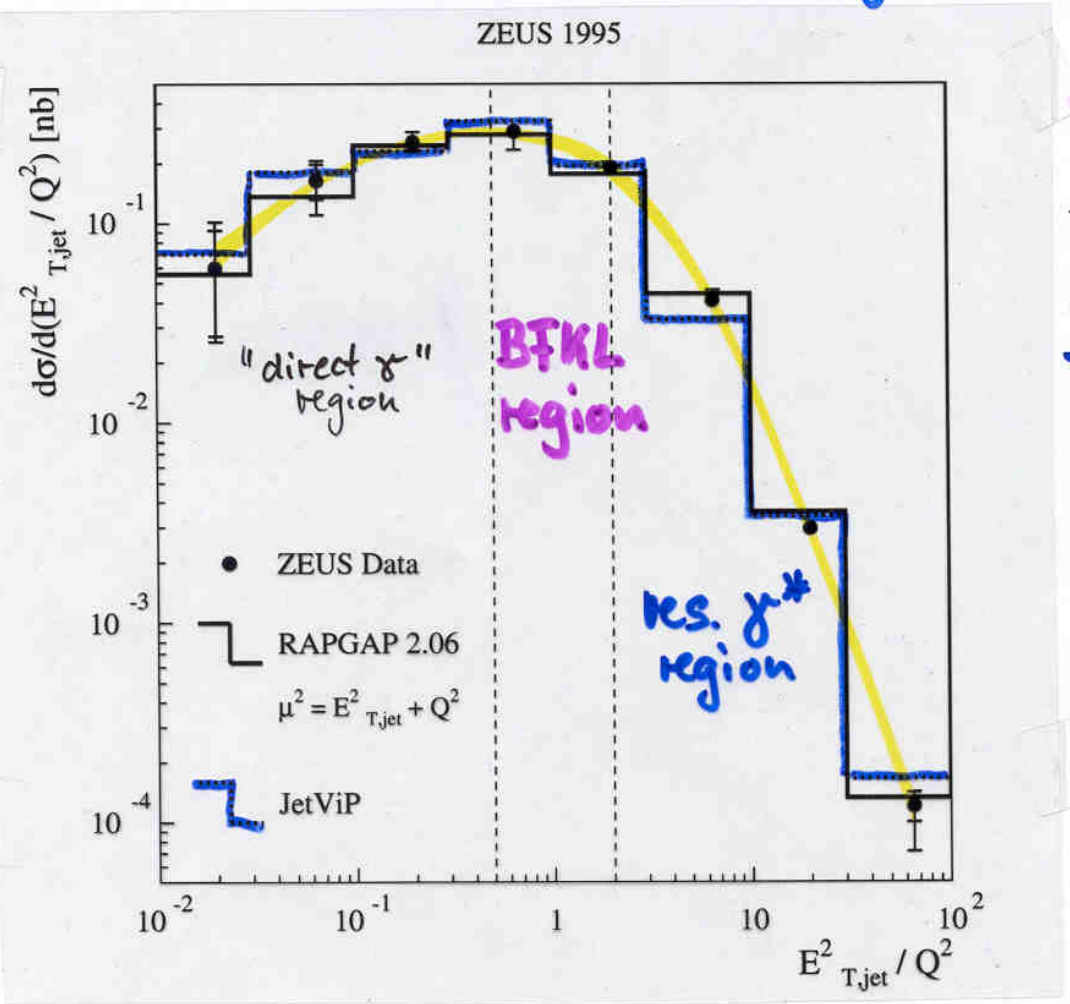


→ Something in addition to standard direct γ (LO) predictions needed !

→ resolved virtual γ's ?

fwd jets - resolved virtual γ's

- include resolved virtual γ's (via photon pdf)
  - → in LO hadron level MC
  - → in NLO calculation (res. γ's also in NLO)



- had level MC
- NLO calculation

→ "direct γ" region still ok !

→ "res. γ" region $E_T^2/Q^2 \gg 1$ described !

→ BFKL region also described !

- virtual γ pdf: anomalous contribution dominant !
  - ~~< calculable in QCD → small uncertainty
- Question: what is the scale ? $Q^2 + p_T^2$? (in MC + NLO)

virtual γ structure: dijet x-section

- study region $Q^2 < E_T^2$ (one scale problem)

$0.1 < y < 0.7$

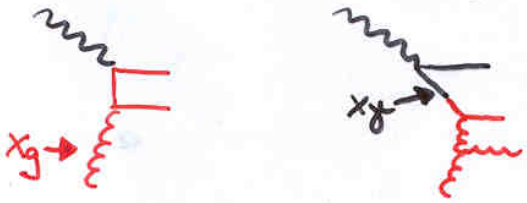
$1.6 < Q^2 < 80\ \mathrm{GeV}^2$

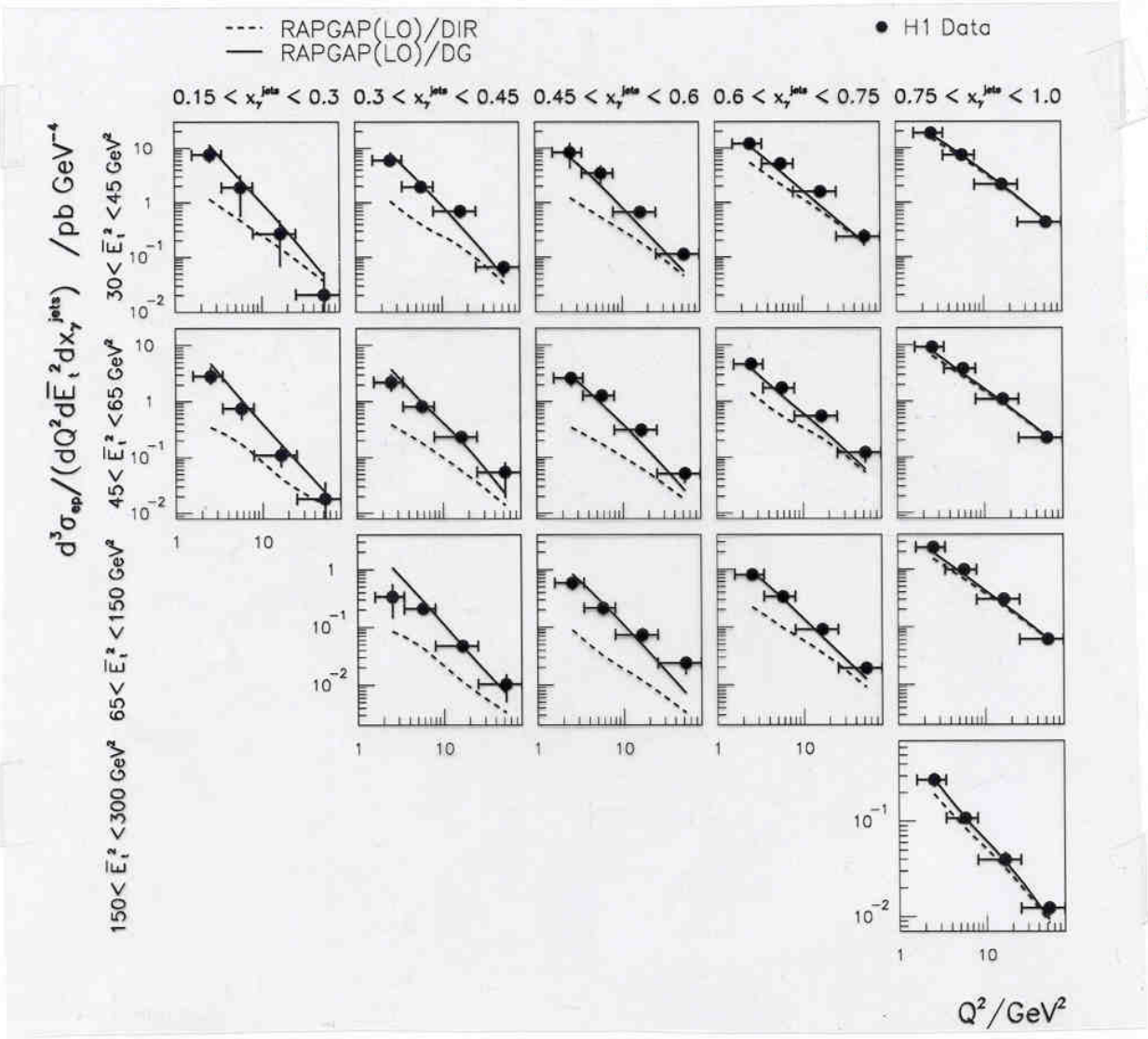
inclusive k_T algo ⇒ 2 jets

$|\Delta\eta| < 1$

$\bar{E}_T^2 > 30\ \mathrm{GeV}^2$

⇒ $E_{T1} > 4$, $E_{T1} + E_{T2} > 11$





main syst. error from model dependence

(MC scale: P_T^2)

→ direct γ contribution too small !

→ resolved virtual γ's needed !

→ stronger Q^2 dependence observed, than expected from direct γ's

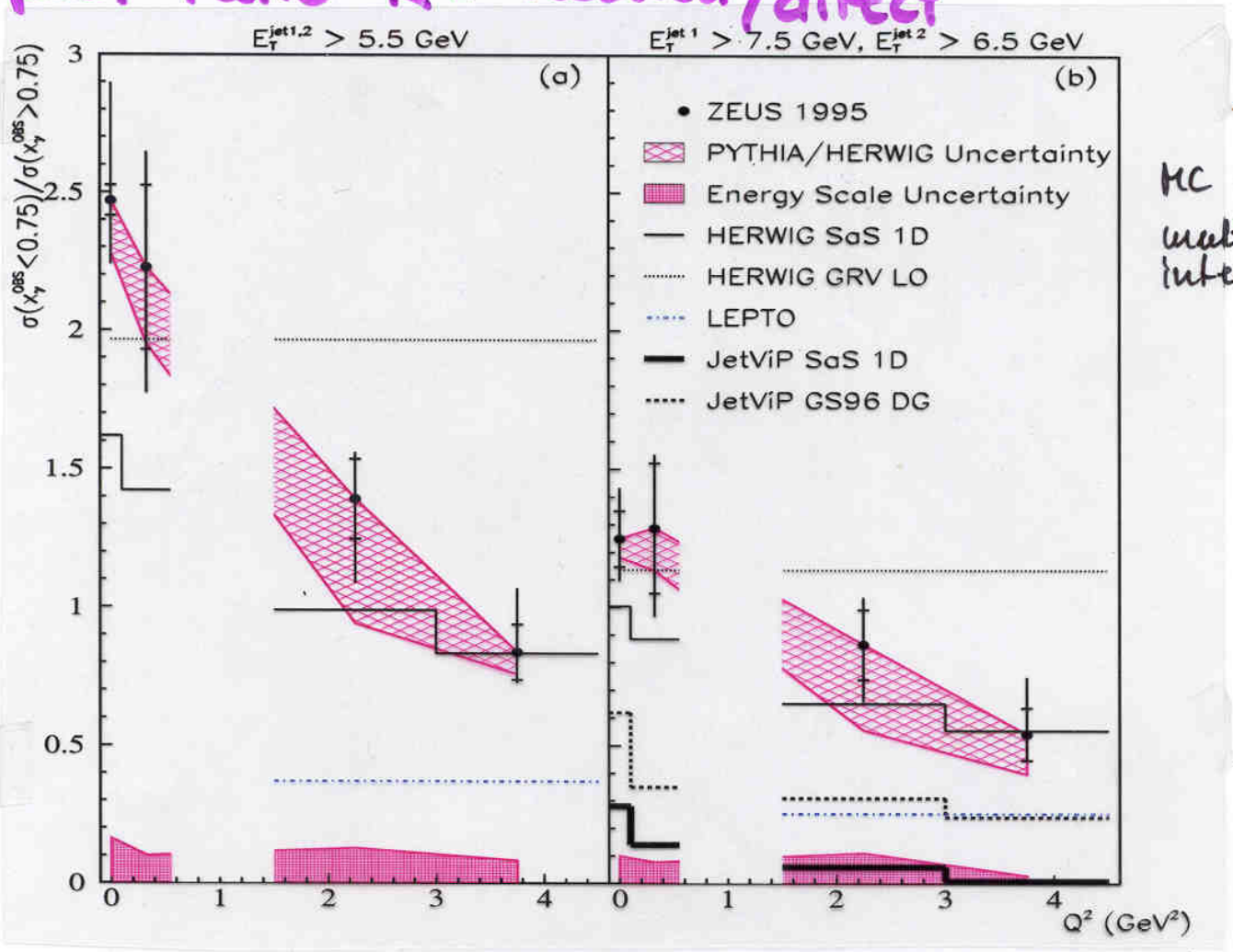
→ resolved γ's die out at large Q^2 !

Q^2 dependence of dijet x-section

- event selection: $0{,}2 < y < 0{,}55$, $0 < Q^2 < 4{,}5\ \text{GeV}^2$
  long. inv. $k_\perp$ algo: $E_{T1} > 5{,}5$ GeV, $-1{,}125 < \eta_{jet} < 2.2$
  two samples: **low E_{T1}: $E_{T1} > 5.5$** (sensitive to mult. interaction)
  high E_{T1}: $E_{T1} > 7{,}5$, $E_{T2} > 6{,}5$ (not sensitive to mult. interactions)

measure: "direct" x-section ($x_\gamma^{OBS} > 0{,}75$)
"resolved" x-section ($x_\gamma^{OBS} < 0{,}75$)

plot ratio R = resolved/direct



MC w/o mult. interact.

- from real γ-production to DIS!
- significant res. γ contribution suppressed at large Q^2!

what did we learn ?

- real γ-production jets
  one scale problem : scale = $E_\perp^2$

- virtual γ's : jet x-sections
  two scale problem: scales = Q^2, $E_\perp^2$
  - need more than direct γ-interaction
    (even with NLO calculations)

  different regions:

- $E_\perp^2 \ll Q^2$ direct γ- contribution (standard DIS)

- $E_\perp^2 \gg Q^2$ analogy to real γ-prod.
  → structure of virtual γ
  → measurement of x-sections
  Q^2 dep., effective pdf's....
  (mainly anomalous comp. relevant. hadr. comp. dies out with Q^2)

- $E_\perp^2 \sim Q^2$ also described by dir + res. γ^*
  if scale = $Q^2 + p_\perp^2$, or $4 \cdot p_\perp^2$
  (some have doubts, that this is proper choice)

also described by BFKL !

present picture of DIS

- if relevant scale of hard subprocess is $\sim p_\perp^2$

→ 3 different contributions needed for DIS:

DIS = direct γ's + BFKL + resolved γ's

($E_\perp^2 \ll Q^2$) ($E_\perp^2 \sim Q^2$) ($E_\perp^2 \gg Q^2$)

→ what about intermediate regions ?

$E_\perp^2 \to Q^2$?

→ adding further contributions ?

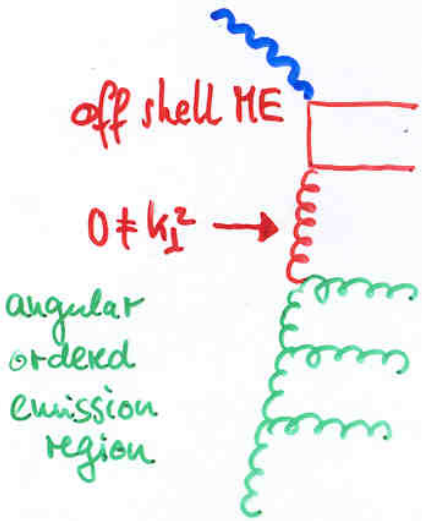
→ double counting ?

→ too complicated !

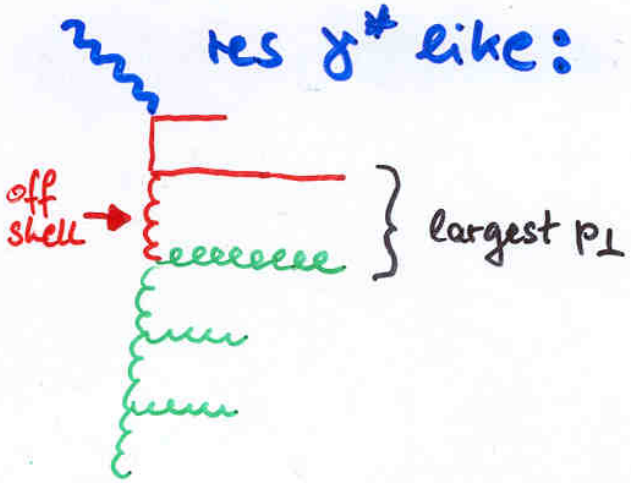
→ **Unification needed !**

$k_\perp$-factorisation + GCFM parton evolution !

→ reproduces BFKL $x \to 0$, DGLAP for large x !

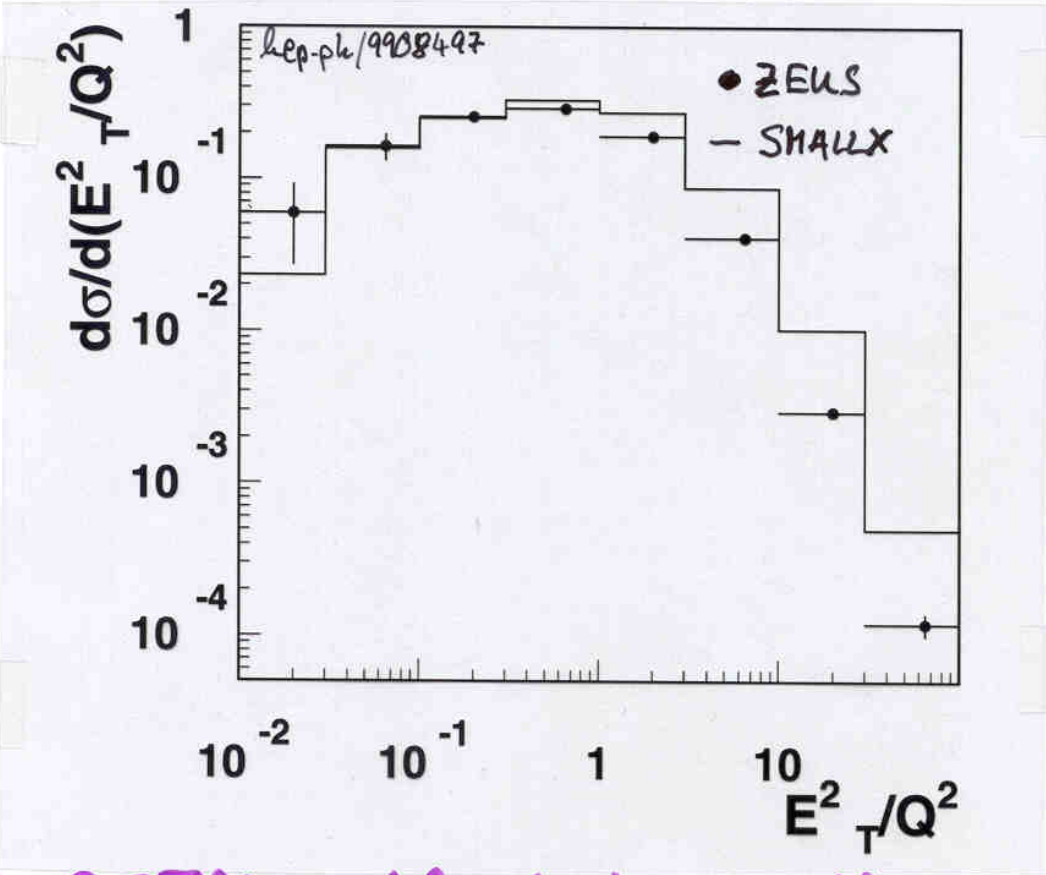


res γ^* like:



towards a unified picture of DIS !?

- fwd jet x-section: E_T^2/Q^2 dependence



– parton level, only gluons, describes F_2.

still to be improved !

→ CCFM: unified description of
"direct γ" region
BFKL region
"resolved γ" region (anomalous γ's only)

→ may also help in real γ-production

→ studies of photon structure important for understanding of high energy interactions !