Real and virtual photon structure from dijet events

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H1 Collaboration

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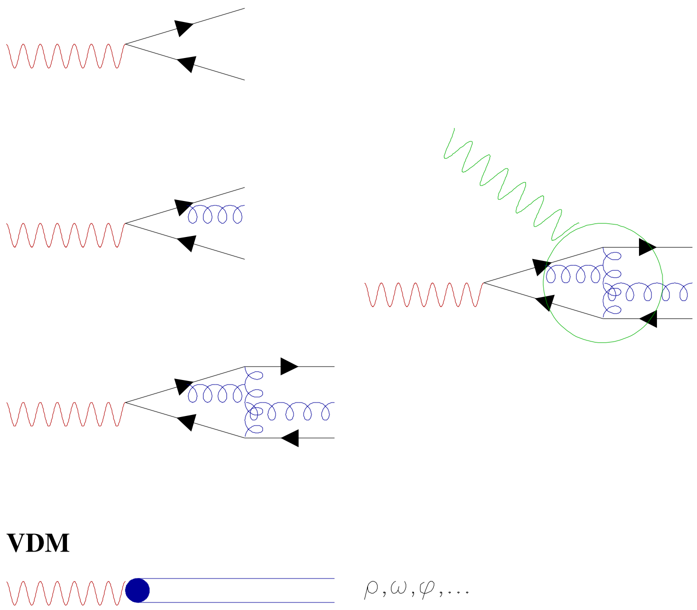
1. Introduction

Photon structure

- e^+e^- LEP at CERN, KEK and SLAC → deep inelastic scattering on an almost real photon
- ep HERA → di–jet production with almost real ($Q^2 < 10^{-2}$ GeV^2) and virtual photon ($1.4 < Q^2 < 80$ GeV^2)

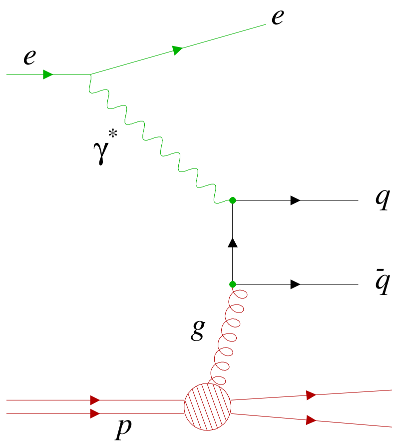


HERA is sensitive to the complicated internal structure of the photon!

Photon structure at HERA

e^+ (27.6 GeV) → ← p (820 GeV)

- Q^2 - virtuality of γ^* and y - inelasticity
- p_t - transverse momentum of jets
- x_γ - fraction of γ^*'s momentum in hard subprocess



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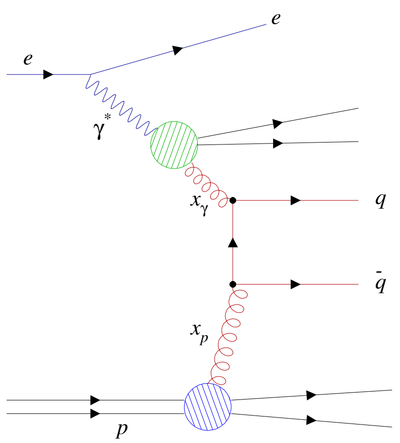


Resolved

- photon size $\sim 1/Q$
- parton from proton resolves structure of photon at scale $1/p_t$
- if $p_t^2 \gg Q^2$, structure of photon can be resolved

$Q^2(\mathrm{GeV}^2)$	y	purpose of analysis
$< 10^{-2}$	$0.5 - 0.7$	gluon density in real γ at low x_γ
$1.6 - 80$	$0.2 - 0.7$	virtual photon structure

Single effective subprocess approximation

Resolved photon cross section

$$\frac{d^5\sigma}{dy\, dQ^2\, dx_\gamma\, dx_p\, d\cos\theta^*} \sim$$

$$\frac{f_{\gamma/e}(y,Q^2)}{y} \sum_{i,j} \frac{f_{i/\gamma}(x_\gamma,Q^2,p_t^2)}{x_\gamma} \frac{f_{j/p}(x_p,p_t^2)}{x_p} |M_{ij}(\cos\theta^*)|^2$$

Use a single $M_{ij} \to M_{SES}$ and $f_{i/\gamma} \to f^\gamma_{eff}$ and $f_{j/p} \to f^p_{eff}$.

$f_{eff} = \sum_i^{N_f} (q_i + \bar{q}_i) + \frac{9}{4} g$ effective parton density

$$\frac{d^5\sigma}{dy\, dQ^2 ...} \sim \frac{f_{\gamma/e}(y,Q^2)}{y} \frac{f^\gamma_{eff}(x_\gamma,Q^2,p_t^2)}{x_\gamma} \frac{f^p_{eff}(x_p,p_t^2)}{x_p} |M_{SES}(\cos\theta^*)|^2$$

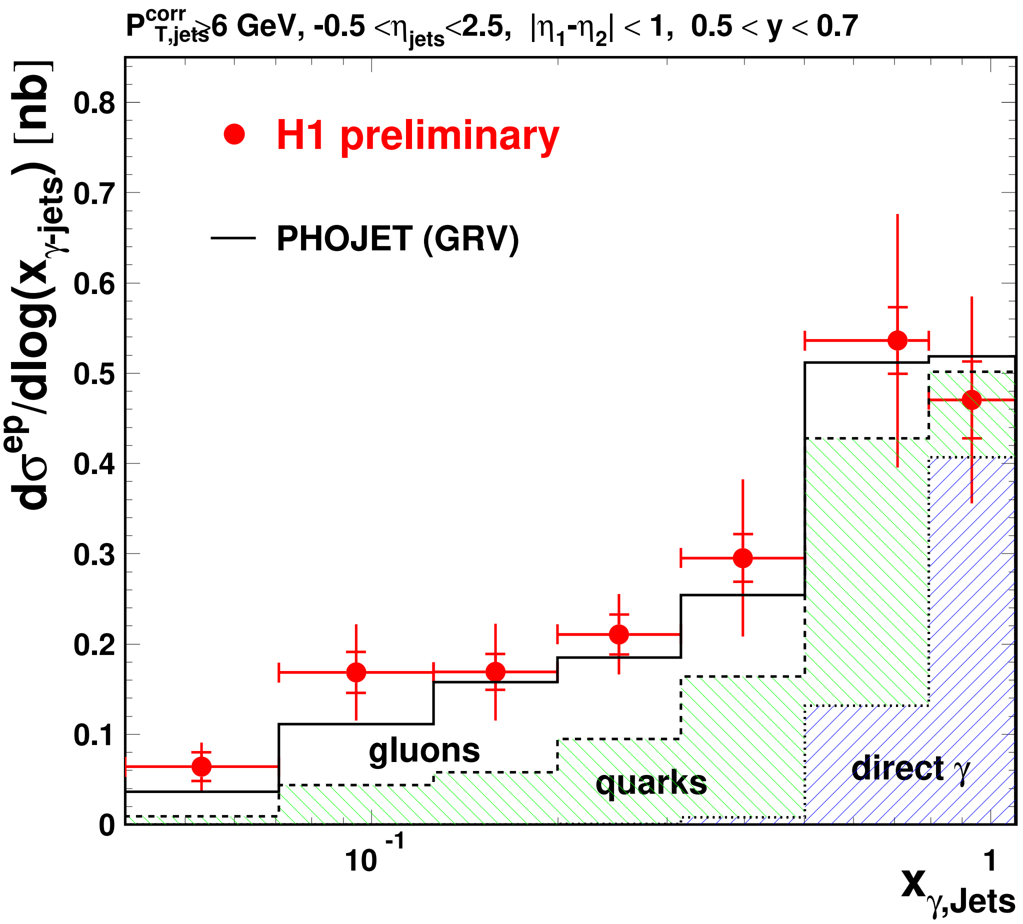
f^γ_{eff} is extracted from comparison of parton level cross sections in data and MC

$$x_\gamma = \frac{\sum_{jets} p_{t,i} e^{-\eta_i}}{2yE_e} \quad \text{or} \quad \frac{\sum_{jets}(p_{t,i}-p_{z,i})}{\sum_{had}(p_{t,h}-p_{z,h})}$$

2. Gluon structure of real photon

DIS on γ at LEP sensitive to the quark structure,
Jet production at HERA to quark and gluon structure of the photon.

Goal of the new analysis: Access to low x_γ where gluons dominate.
Cone algorithm with $R = 0.7$, two jets in the forward lab region

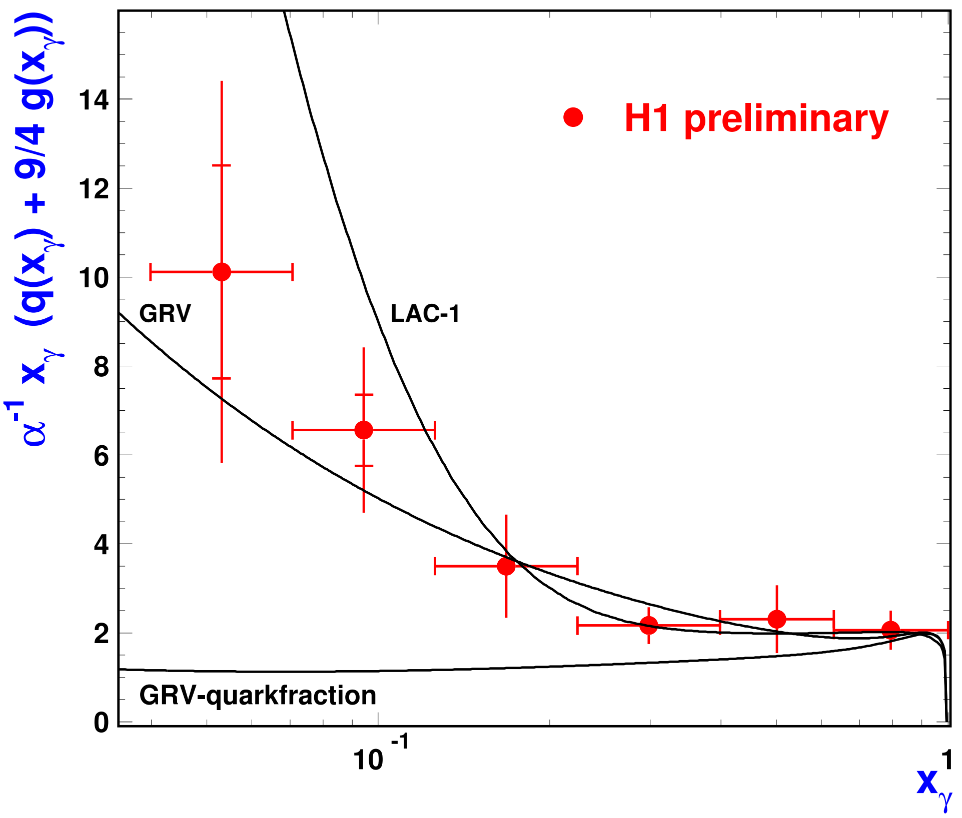


- precise measurement down to $x_\gamma = 0.04$
- good agreement with GRV parton density within PHOJET
- clear sensitivity to gluons in photon

Single effective parton density

To decrease the sensitivity to MC models:

- jet pedestals subtracted
- $p_t^{jet} > 6$ GeV after pedestal subtraction
- $\eta^{jet} > -0.9 - \ln(x_\gamma)$
- unfolding to parton level in x_γ
- systematics dominated by uncertainty in hadronic E scale 30% at low x_γ and MC dependence 25%

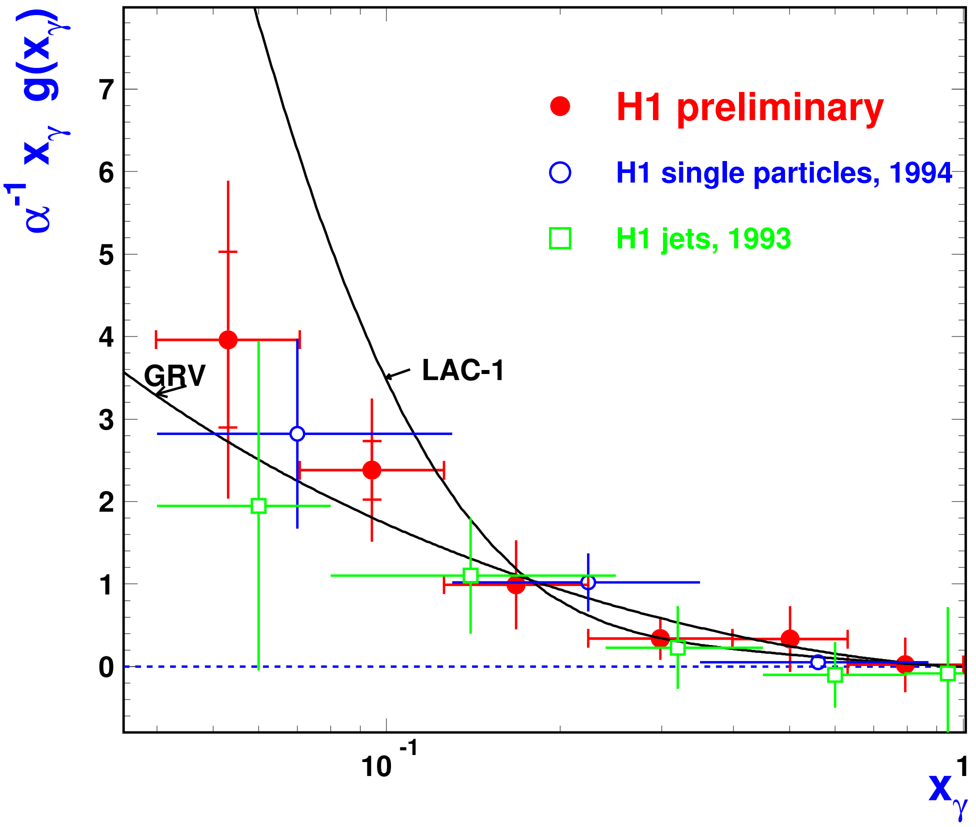


Best measurement of effective parton density so far made.
To get gluon density → quark density must be subtracted.

Real photon gluon density from H1

H1 measurements of gluon density of real photon:

1. Dijet analysis of 1993 data, $\int \mathcal{L}dt = 0.29\ \mathrm{pb}^{-1}$, Nucl. Phys. **B445** (1995) 195-218.
2. High p_t track inclusive analysis of 1994 data, $\int \mathcal{L}dt = 1.35\ \mathrm{pb}^{-1}$, DESY 98-148, subm. to Eur. Phys. J.
3. Dijet analysis of 1996 data, $\int \mathcal{L}dt = 7.2\ \mathrm{pb}^{-1}$, this analysis



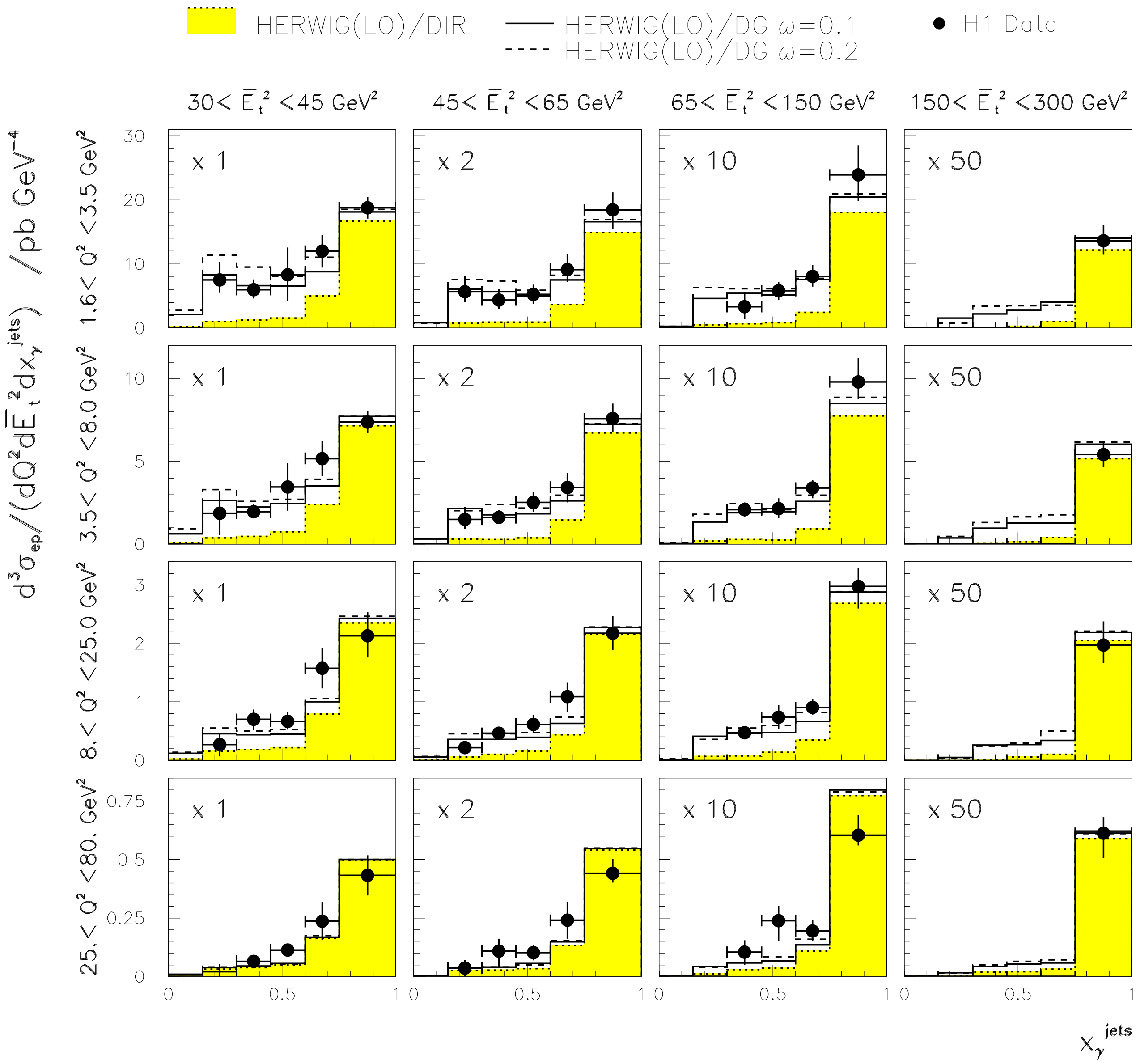
- good agreement between 3 different analysis
- agreement between jet and track analysis important - different systematics
- rise of gluon density at low x_γ established

3. Effective parton density of virtual photon

Triple differential dijet cross-section

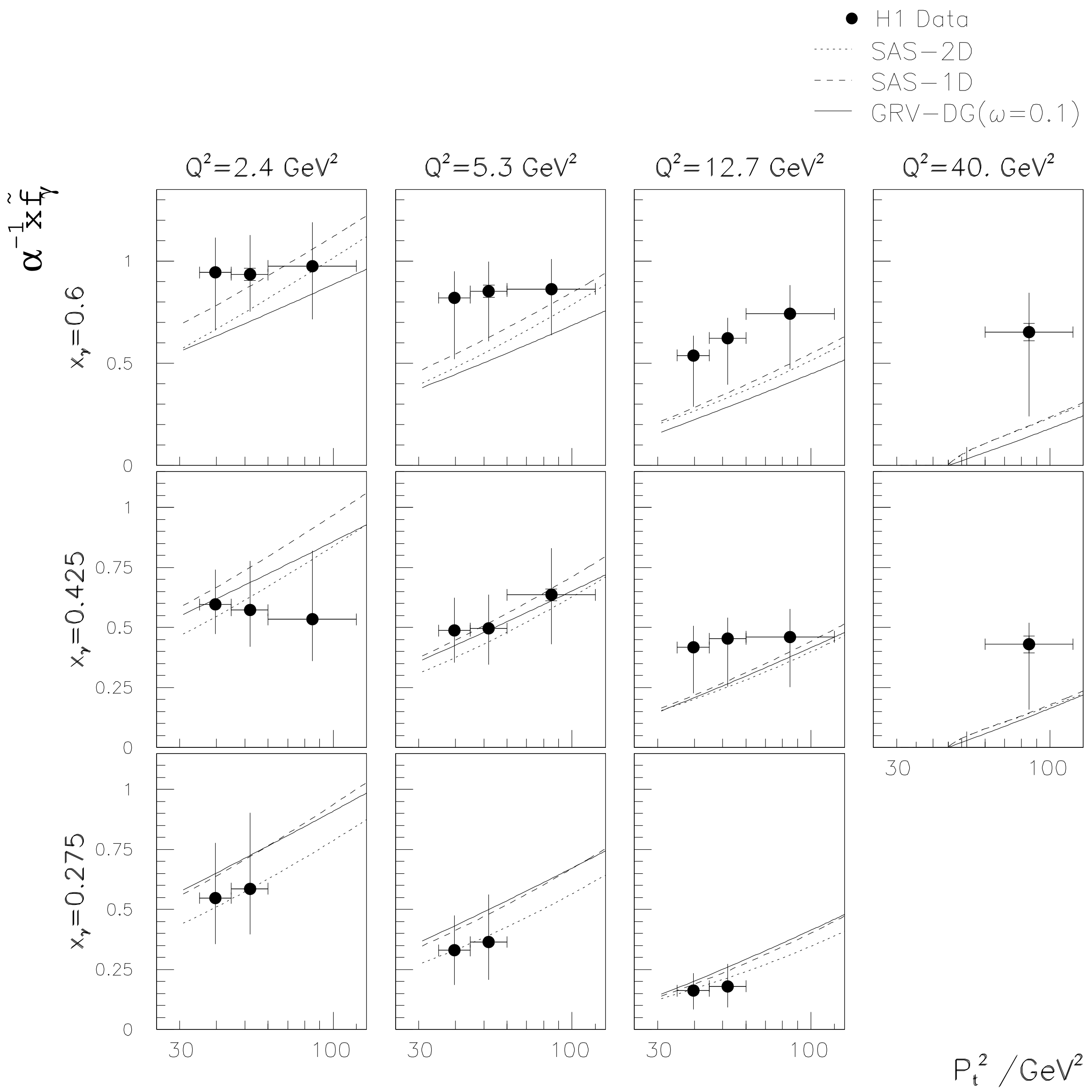
$\bar{E}_t^2$ →

Q^2 ↓



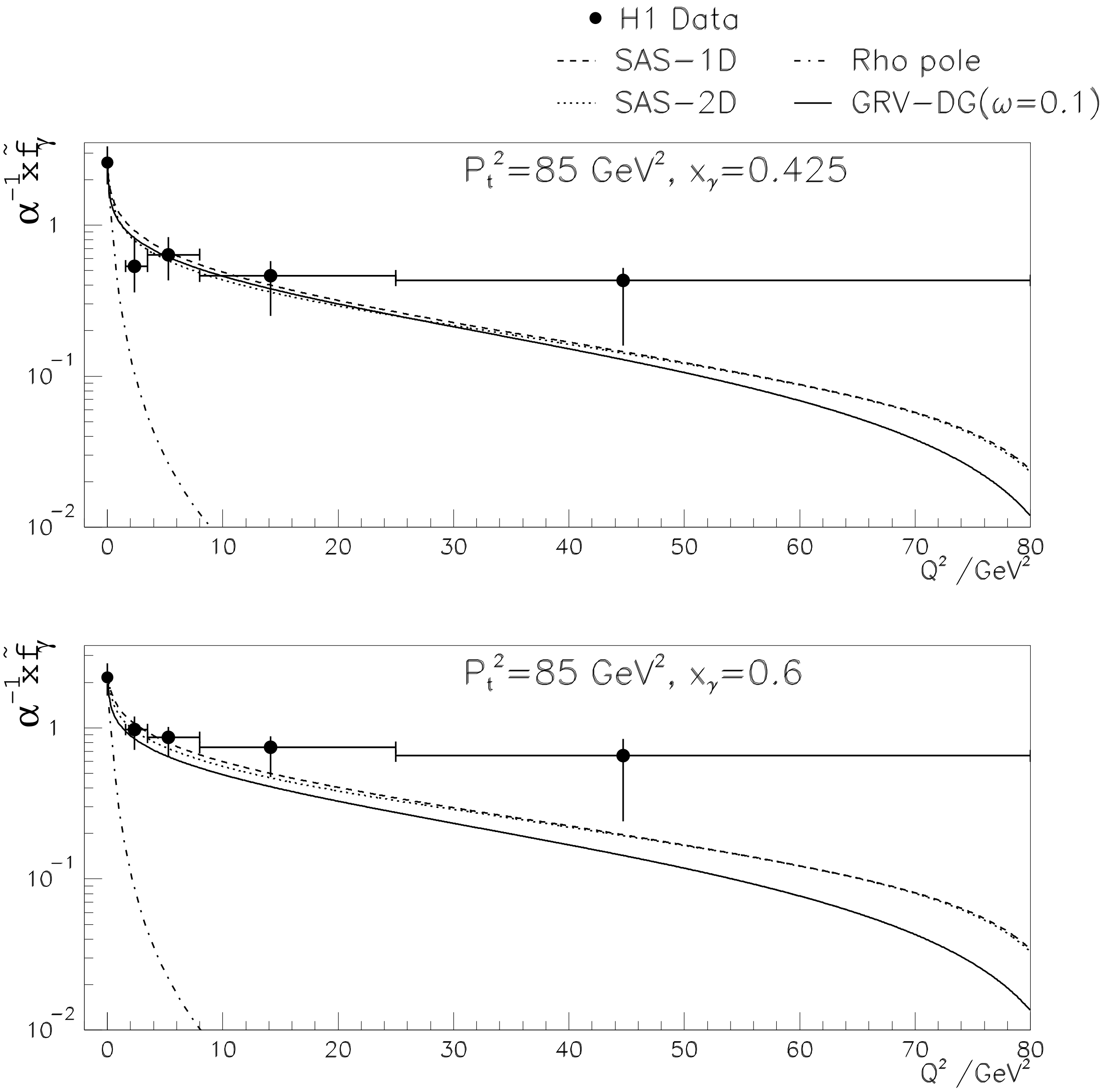
- measured how photon resolved contribution develops as a function of Q^2 and jets average $\bar{E}_t = (E_{t,1} + E_{t,2})/2$
- Q^2 suppression of γ^* parton density function tested

Effective parton density of virtual photon



- data roughly independent of (p_t^2)
- within large systematic errors consistent with $\log(p_t^2)$ dependence expected from pQCD for anomalous component of photon

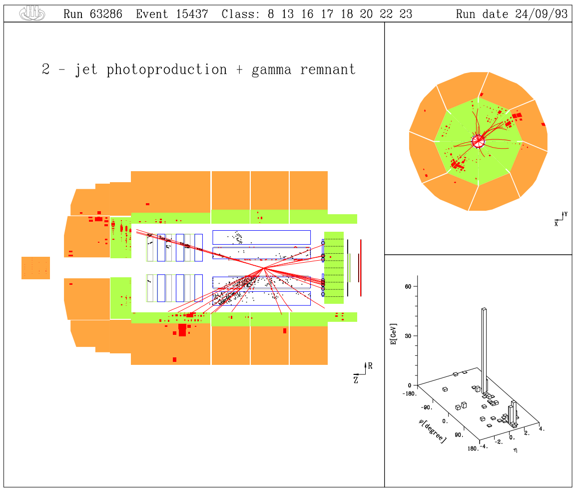
Q^2 suppression of parton density



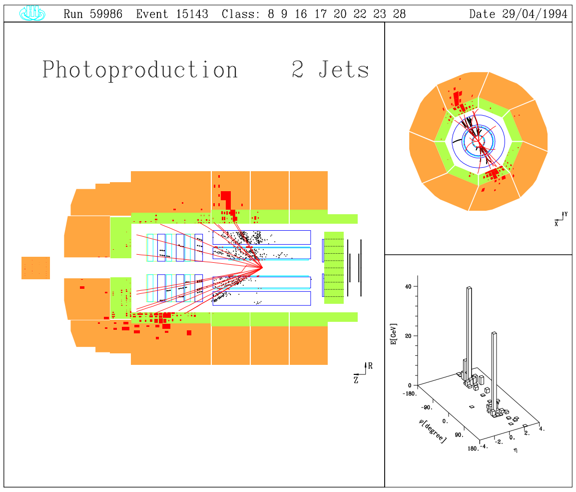
- VDM contribution important for real photon only
- Q^2 suppression measured and compared with existing parton densities

4. Photon remnant

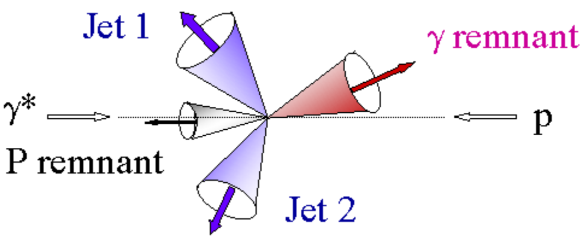
In LO resolved photon splits into parton and remnant.
What are the properties of the photon remnant?



resolved photon



direct photon



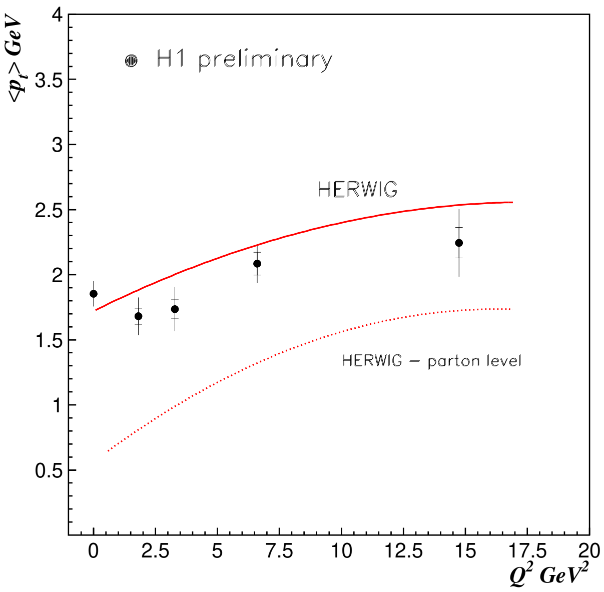
- Event decomposed into 4 jets
- Photon remnant defined as the jet closest to the γ^* direction in $\gamma^* p$ cms

Basic event selection: two highest p_T jets must satisfy

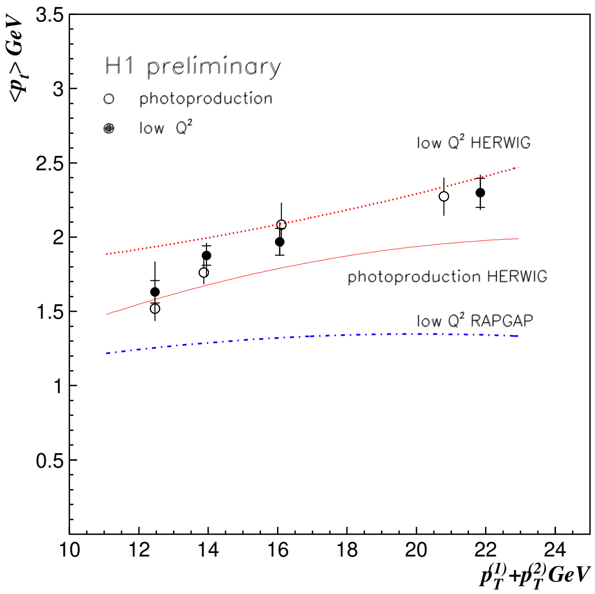
- $p_T > 5$ GeV and $p_{T,1} + p_{T,2} > 12$ GeV
- $-3 < \eta < 0$
- $x_\gamma < 0.75$

p_t dependence of photon remnant

- Photon remnant has large transverse momentum $p_t \sim 2$ GeV
- Remnant p_t dependence on $Q^2, p_{T,1} + p_{T,2}$ measured
- Data compared to HERWIG and RAPGAP; intrinsic k_t of partons in γ is gaussian: $\frac{dN}{dp_t^2} \sim \exp(-\frac{k_t^2}{k_0^2})$, $k_0 = 0.66$ GeV



Q^2 [GeV]



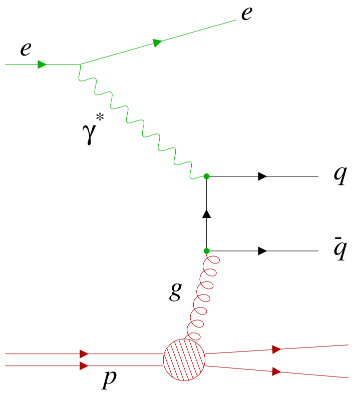
$p_{T,1} + p_{T,2}$ [GeV]

- weak increase of $\langle p_t \rangle$ with Q^2
- hadronisation changes normalisation only
- increase of $\langle p_t \rangle$ with $p_{T,1} + p_{T,2}$ of jets
- same for γp and $\gamma^* p$

Photon remnant correlated with hard jets

5. Dijet cross section and NLO comparison

LO



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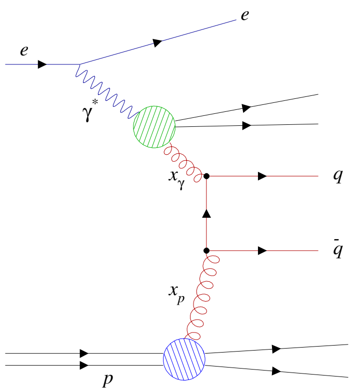
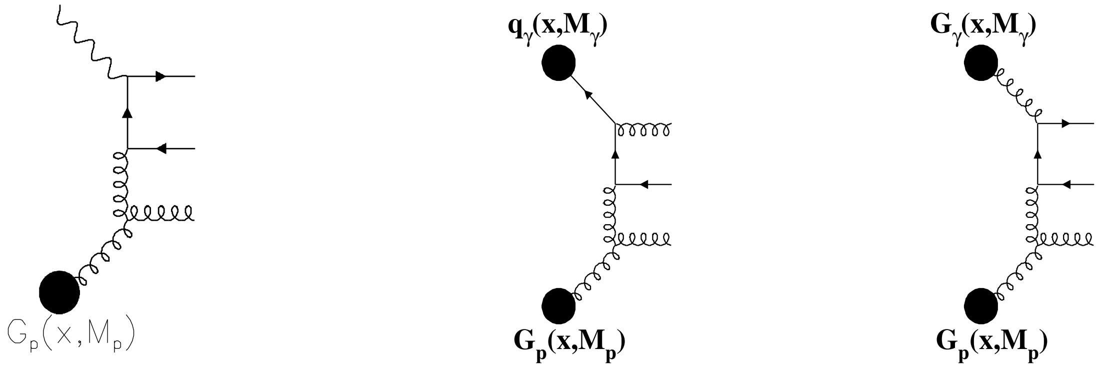


Resolved

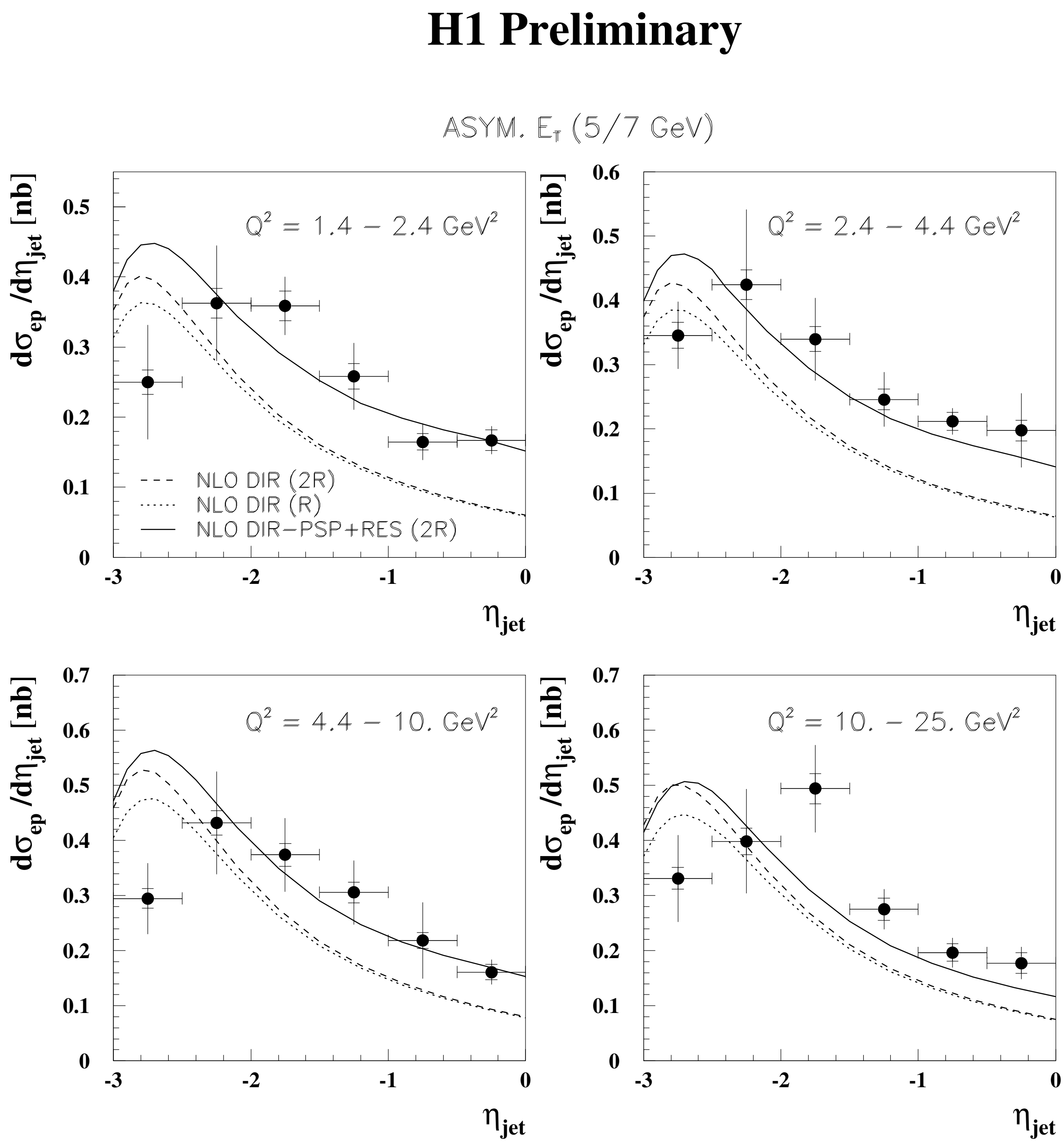


NLO

- program JETVIP (Kramer, Potter)
- p-pdf = CTEQ4M, γ^*-pdf = SaS1M
- $\mu_F = \mu_R = p_t^{jet}$
- dependence on scales μ_F, μ_R small

Dijet cross section and NLO comparison

- CDF cone alg., $R = 1$ in $\gamma^* p$ cms
- jets with $p_{T,1} > 7$, $p_{T,2} > 5$ GeV
- hadronization corr. $< 10\%$ for $\eta_{\text{jet}} > -2.5$



Significant resolved component needed, its importance decreases with increasing Q^2

Conclusions

- New measurement of gluon density of real photon confirms its rise at low x_γ
- Effective parton density of virtual photon measured for the first time. The scale dependence is not in contradiction with the predicted $\ln(p_t^2)$ behaviour
- $\langle p_t \rangle$ of photon remnant increases with hard scale defined by E_T of jets
- Dijet cross section at $Q^2 < 10\ \mathrm{GeV}^2$ needs significant resolved contribution from NLO resolved processes
- H1 operates a new detector which covers the region of $0.05 < Q^2 < 0.7\ \mathrm{GeV}^2$