Energy and Particle Flow measurements at HERA

- Hadronic final state at low-x
- Forward jet
- Resolved photon
- Instanton

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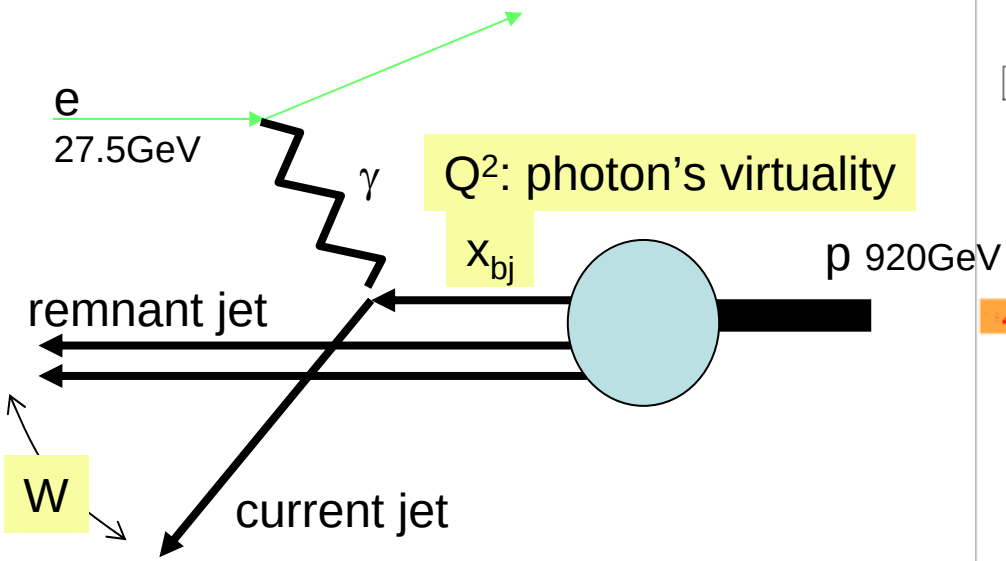
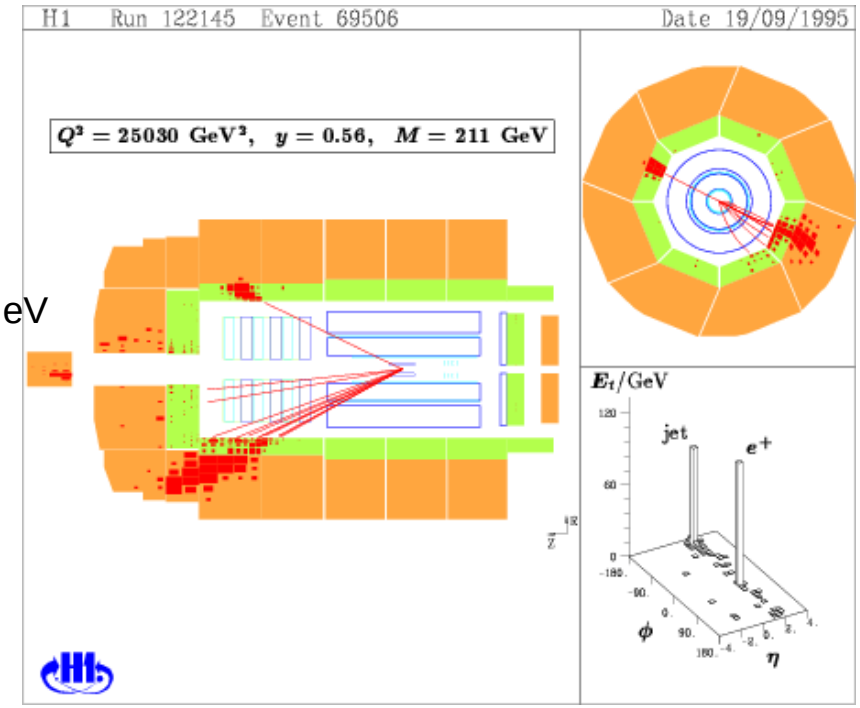
on behalf of H1 and ZEUS Collaborations

Jet Production in ep scattering

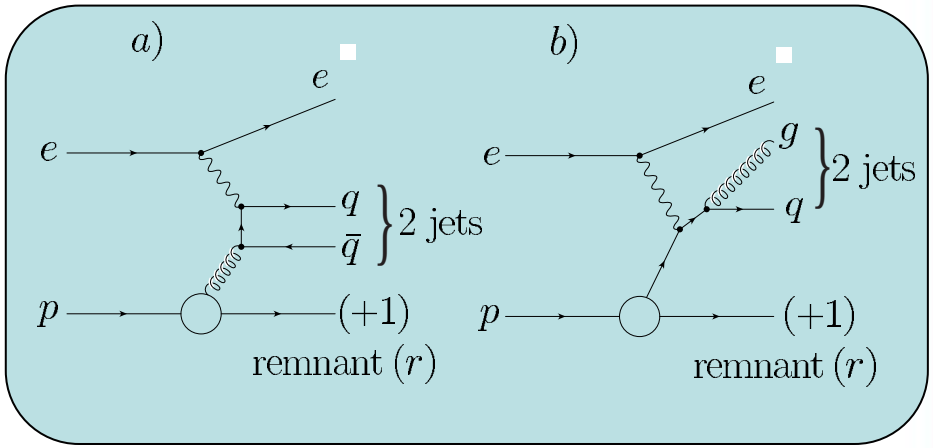


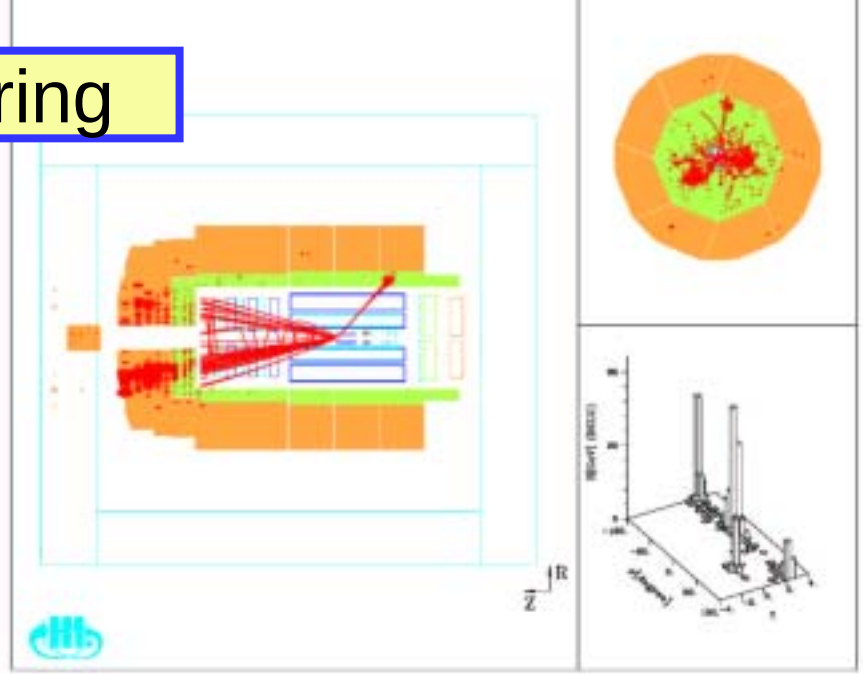


High Pt jet in ep collisions are at 0th order, the struck quark. (1+1 jet)

The jet pt is balanced with the scattered electron pt.
--> Jet measurement ~ Inclusive F_2 measurement

Jet Production in ep scattering





Topics in the studies of the hadronic final states

- Multi-jet production from BGF and QCDC
- Internal jet structures

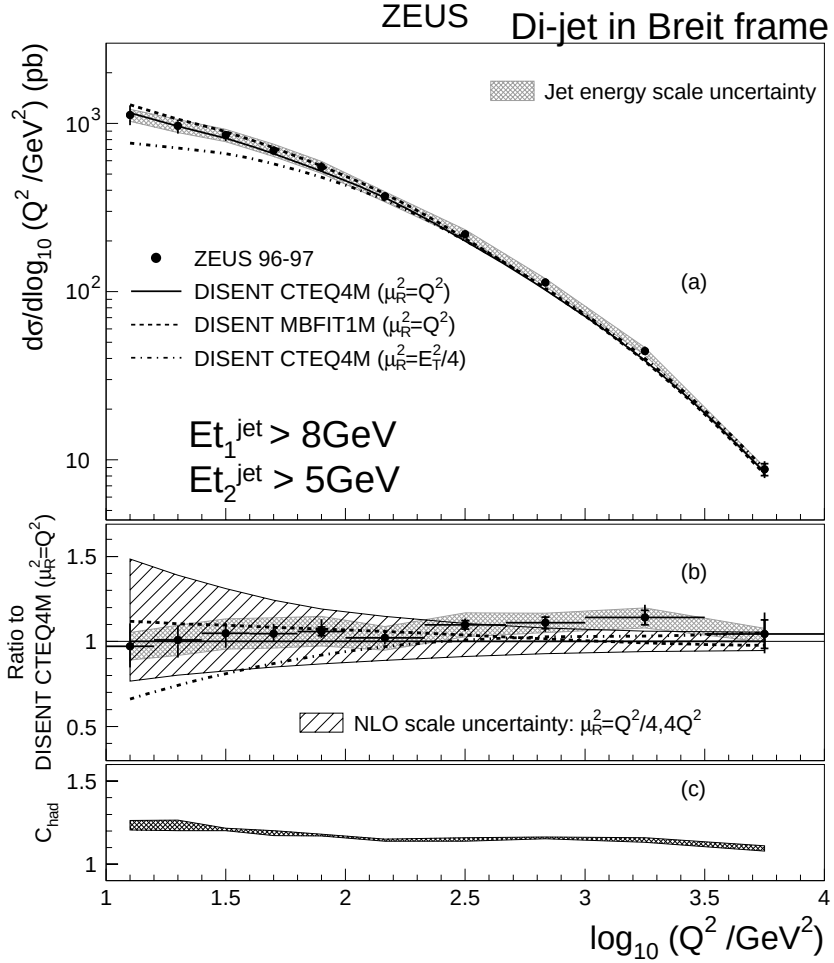
Jets are good test bed for pQCD.

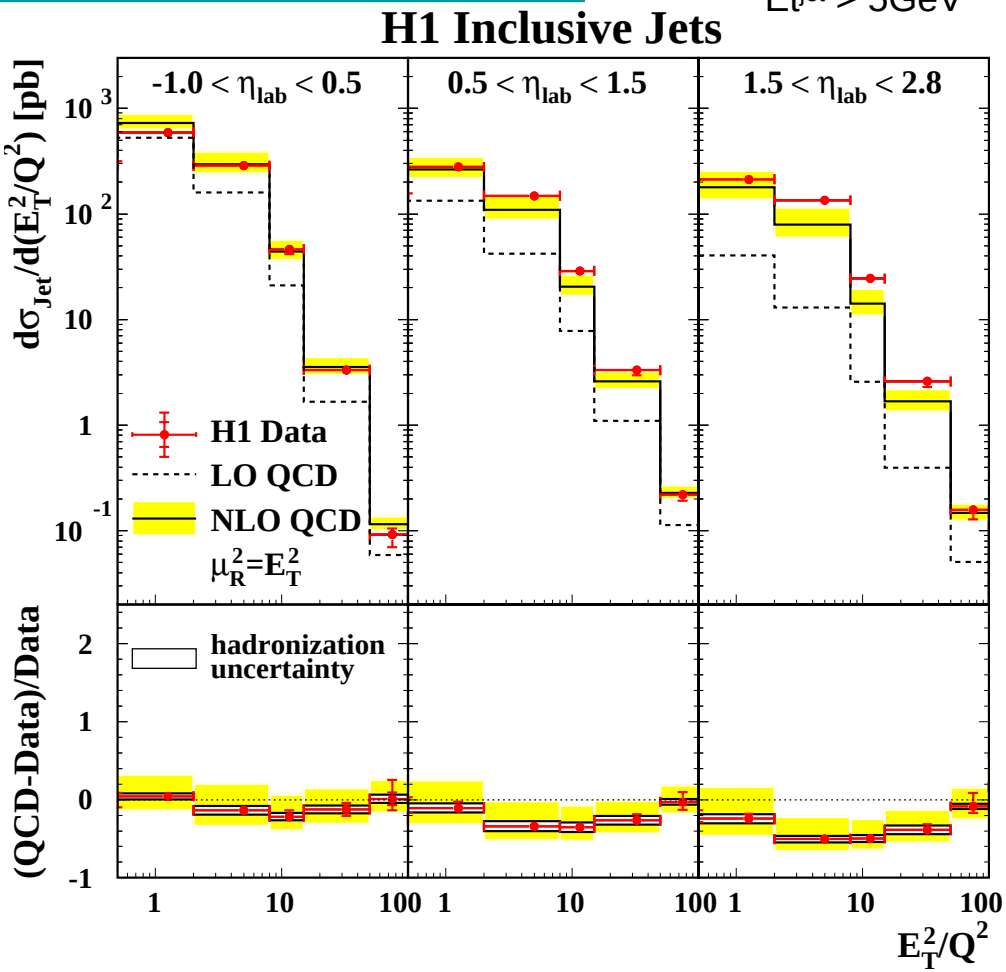
α_s measurements <-- Tomorrow's topic.

- At HERA, a large amount of events are in low-x and (relatively) low-Q^2 regions (and in photo production region), where the hadronic system is more complicated.

Jet production (comparison with NLO)

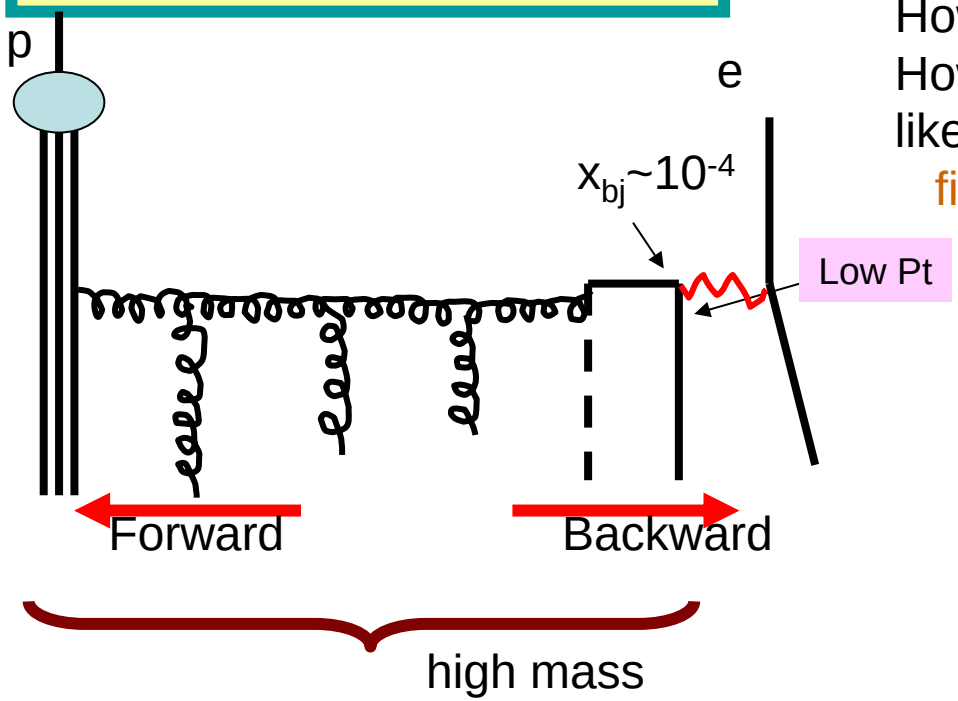
Breit frame
$Et^{jet} > 5GeV$





Generally, NLO describes the data well. But there are large scale uncertainty at low Q^2 . The agreement is worse for forward jets.

Parton Evolution



How is the parton evolution at low-x?
How initial state parton radiation looks like?

fixed order pQCD:

NLO (~α_s^2) : not enough

3 different types of QCD evolution

- DGLAP : Pt ordering
- CCFM : angular ordering
- BFKL : x ordering

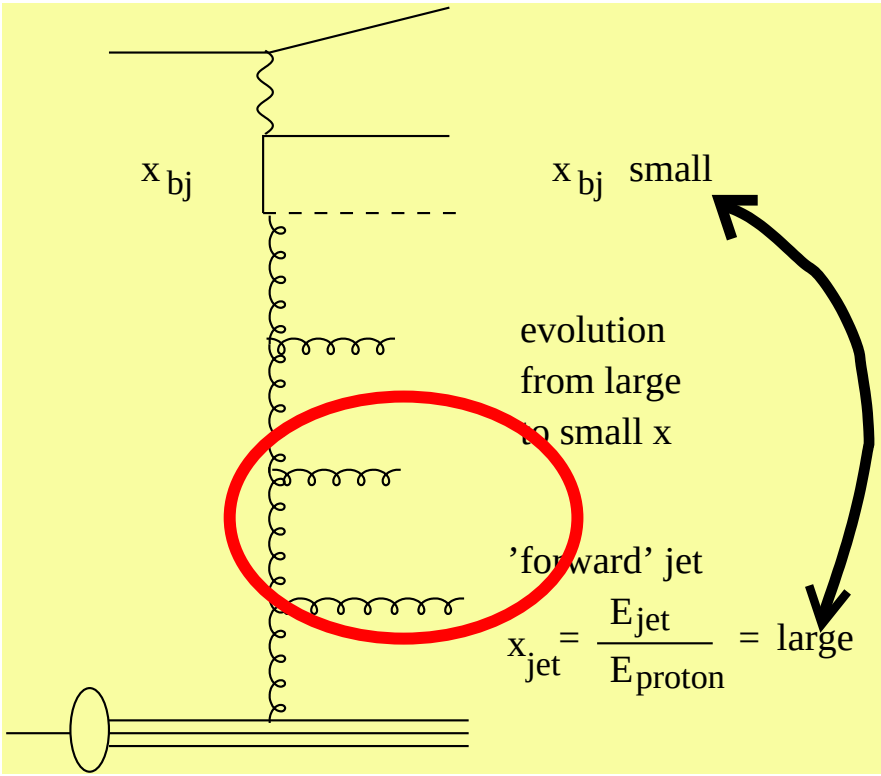
more high-pt radiation in the middle (fwd)

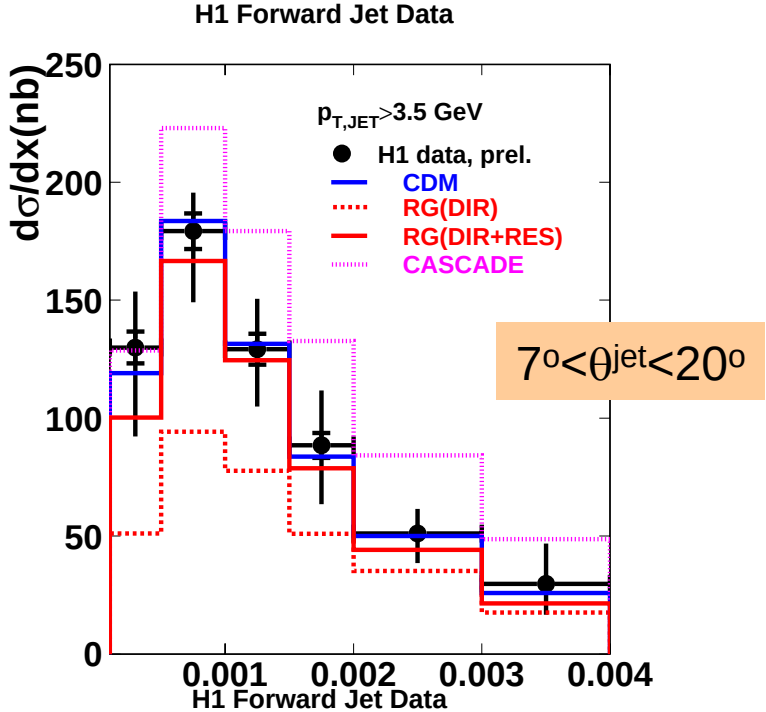
MC models

- Parton Shower in Lepto
- CASCADE
- (Colour Dipole Model)

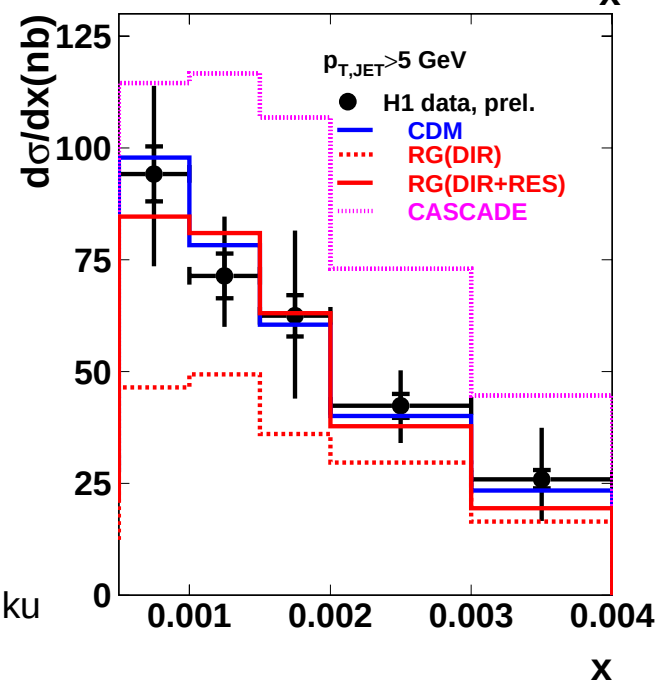
Study Energy flow (or jet) outside of "current-jet region" and compare with the different models

Forward Jets





$7^o < \theta^{jet} < 20^o$



Forward Jet production
- Too small for simple PS (DGLAP).
- Cascade (CCFM) overestimates.
- Colour dipole and Resolved photon model describe the data.

Forward particles (π^0)

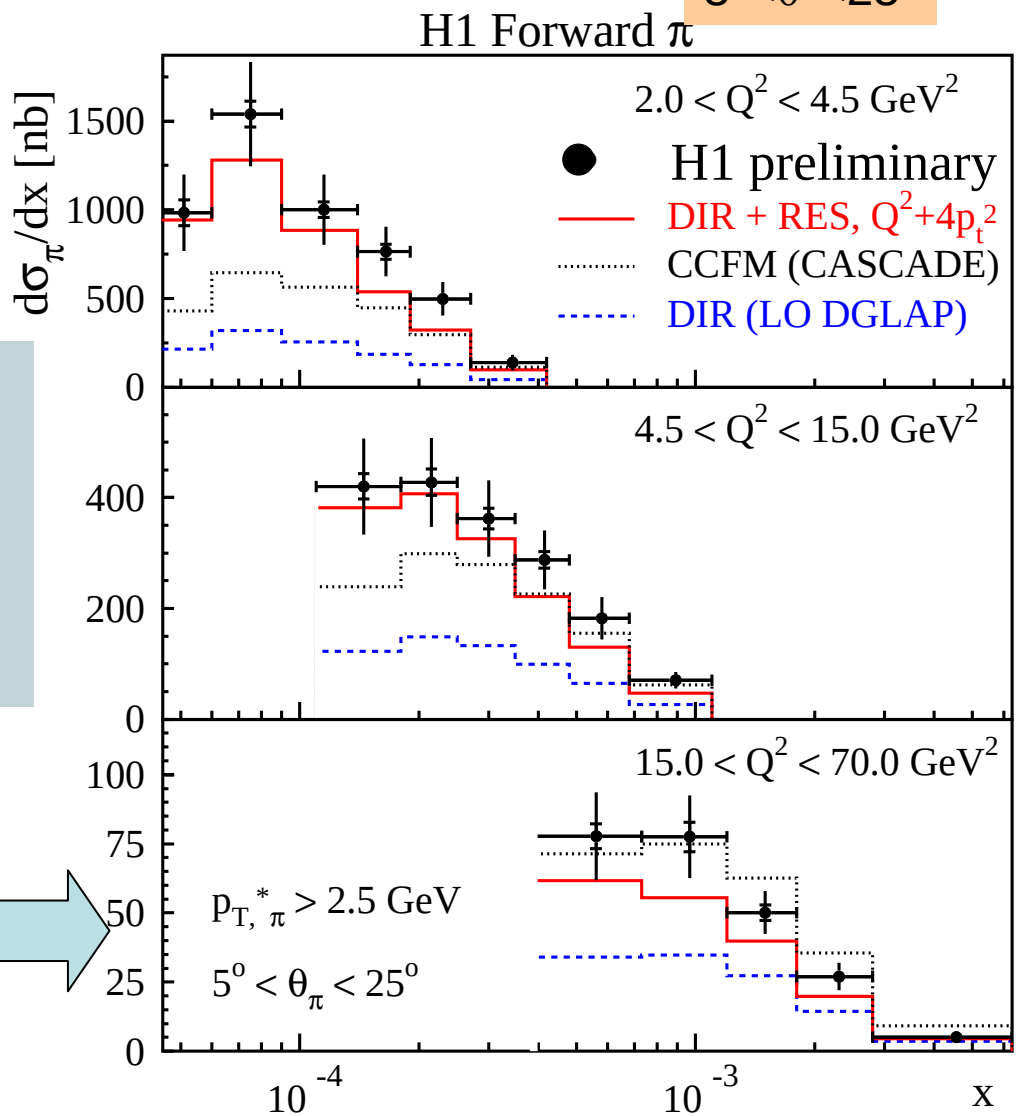
$5^o<\theta^\pi<25^o$

Single particle measurement is less sensitive to jet overlapping effect, but have extra uncertainty from the fragmentation function.

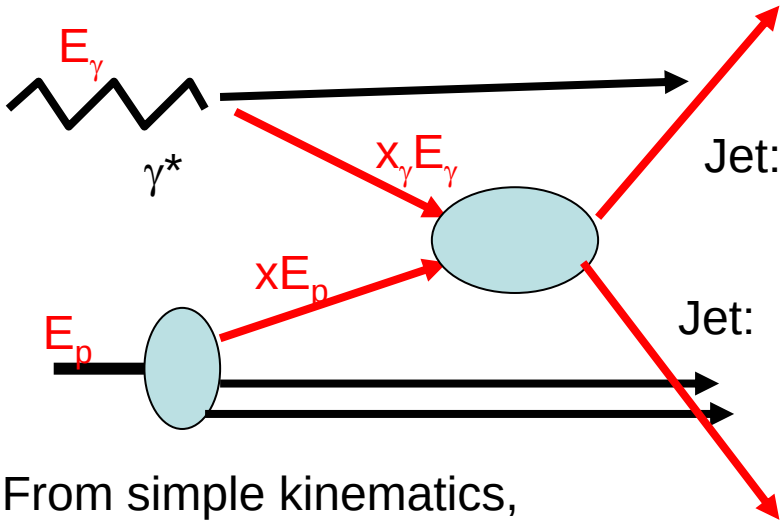
Similar results as Jet at higher-x. Model with Resolved photon gives reasonable agreement

CASCADE starts underestimating the yield at low-x

Similar x range as the jet measurement



Resolved photon picture



In a different view, low-x DIS event can be regarded as parton-parton scattering between the proton and the "resolved" photon

--> Photon remnant : BWD

--> Jet : FWD

From simple kinematics,

$$x_\gamma \Rightarrow \frac{\sum_{jet} (E - Pz)_{jet}}{2yEe}$$

$$= \frac{\sum Et_{jet} \exp(-\eta_{jet})}{2yEe} \equiv x_\gamma^{OBS}$$

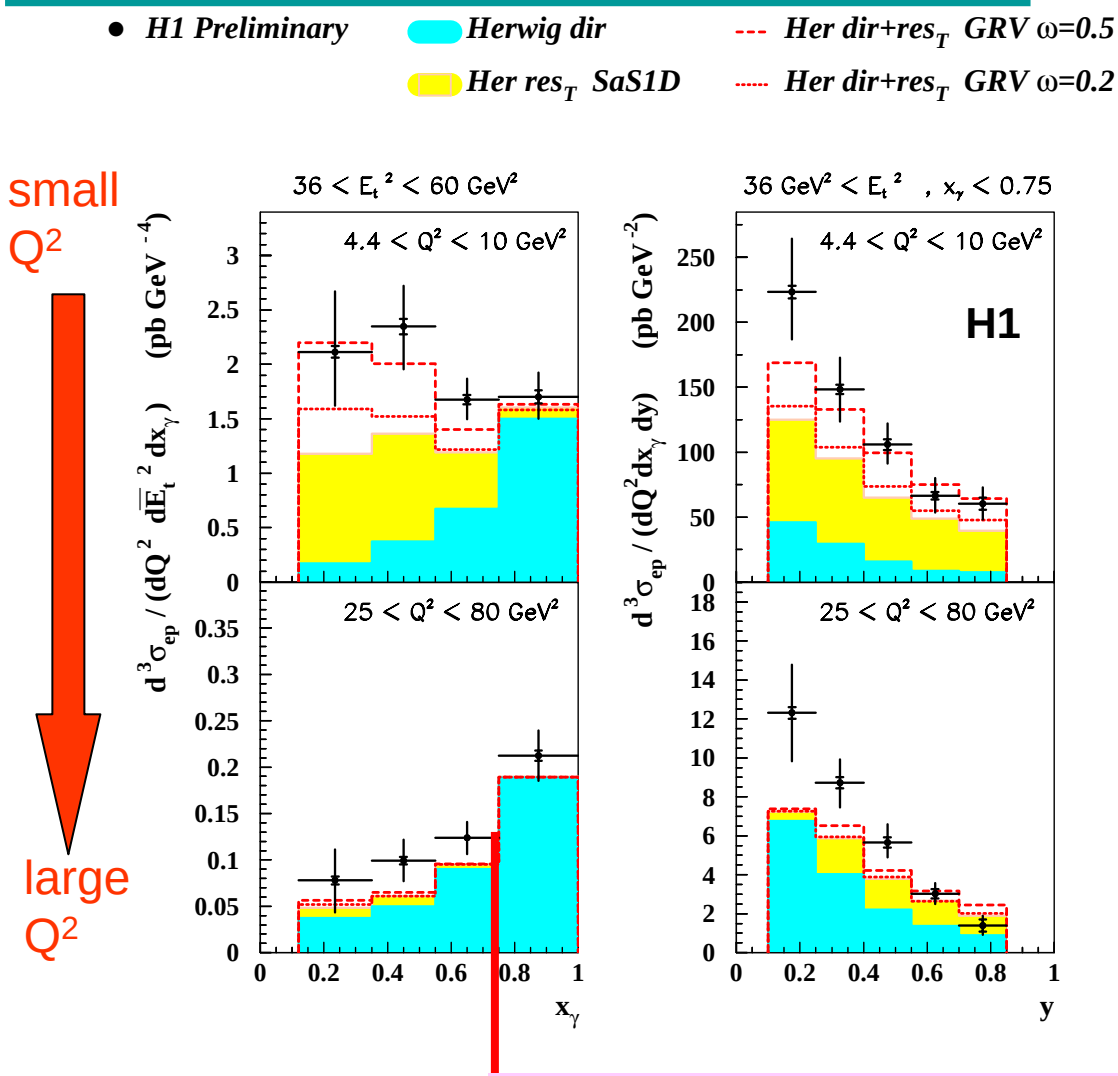
Estimator of $x\gamma$:

If Direct γ $X_\gamma^{obs} \sim 1$

If resolved, many events with $X_\gamma^{obs} < 1$

Virtual Photon Contribution

Direct x_γ^{OBS} measurement from dijet events



$$x_\gamma^{OBS} = \frac{\sum Et_{jet} \exp(-\eta_{jet})}{2yEe}$$

Comparison with MC:

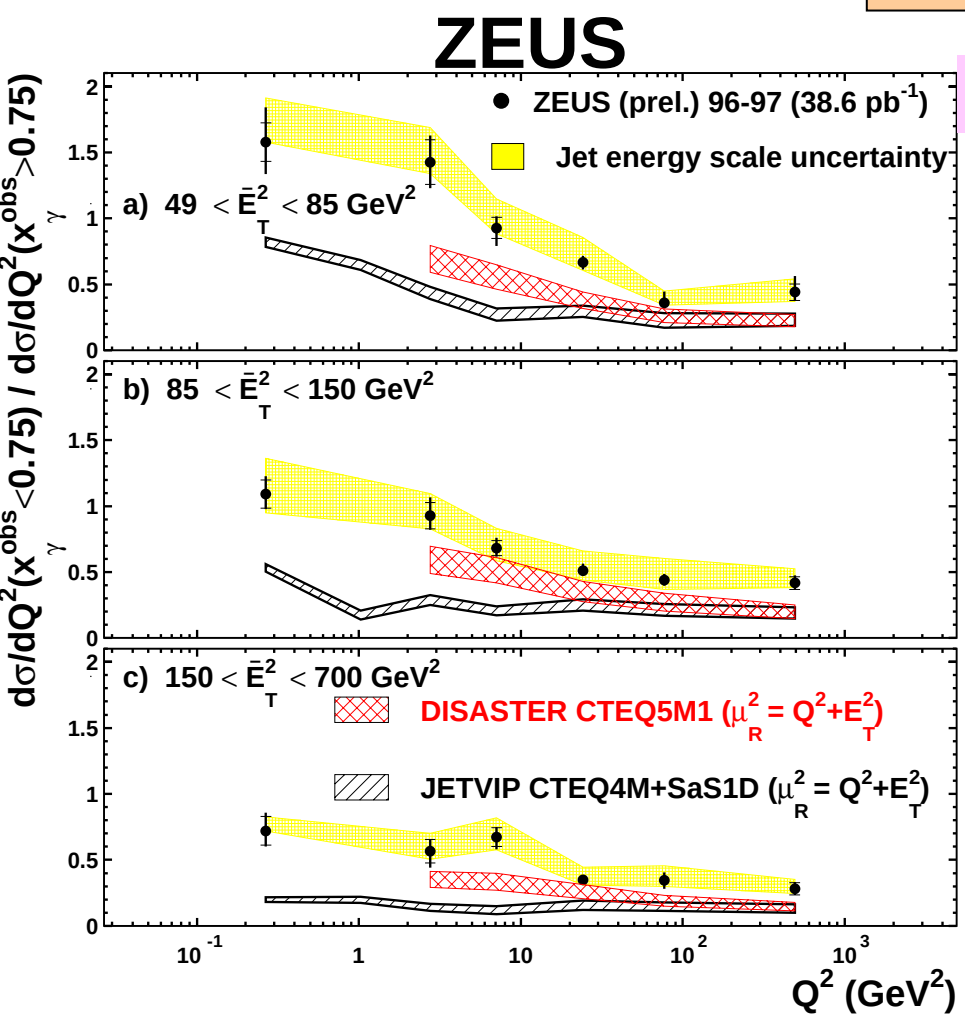
- Resolved processes need to be included.
- Sensitive to virtual photon PDF.

- Cascade: reasonable agreement (not shown)

To estimate, the ratio of Xγ>0.75 and Xγ<0.75 is used

Virtual Photon Contribution (Dijet cross section)

Comparison with NLO with Resolved photon



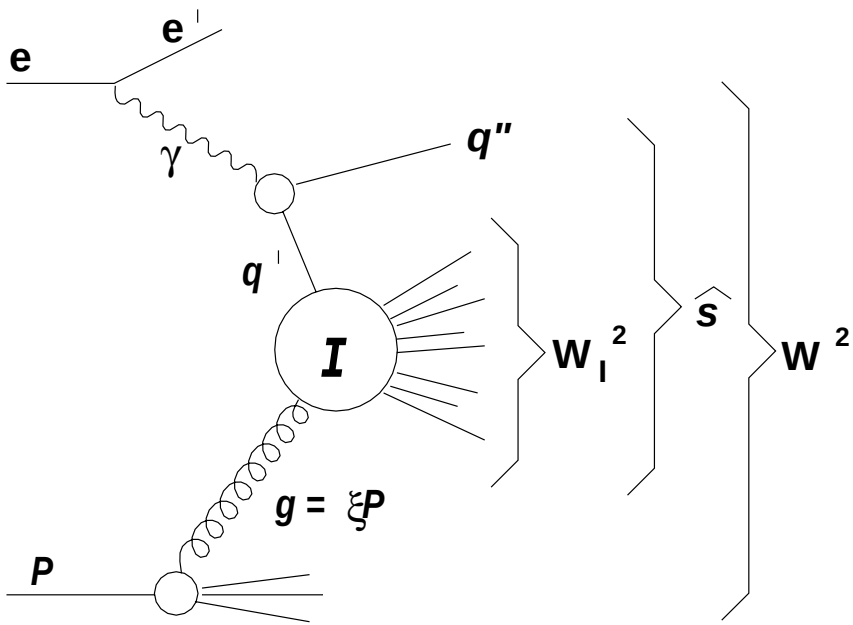
Small Et_{jet}

large Et_{jet}

- Small Et: A Large fraction of low x_γ events. It decreases as Q^2 increases, as expected from the resolved photon contribution.
- NLO calculation with virtual photon (JETVIP with CTEQ4M+SaS1D) agrees in shape but fails to describes the magnitude.

Probably tuning of photon parton distribution is needed.

Instanton



$$q + g \xrightarrow{I} \sum_{n_f} (q_R + \bar{q}_R) + ng$$

$$q + g \xrightarrow{\bar{I}} \sum_{n_f} (q_L + \bar{q}_L) + ng$$

In QCD, certain processes violate the conservation of chirality. – Instantons.

--> Non-perturbative fluctuation of the gluon field. Tunnelling between 2 vacuum states.

Ringwald and Schrempp pointed out that instanton-induced events can be seen in DIS. The cross section is calculable in a certain kinematical region (defined by q' and g--> instanton size (ρ)) . σ~ 100 pb.

Events are expected to have distinct signature.

- Many quark and gluons --> fireball like
- Flavour democratic --> many K

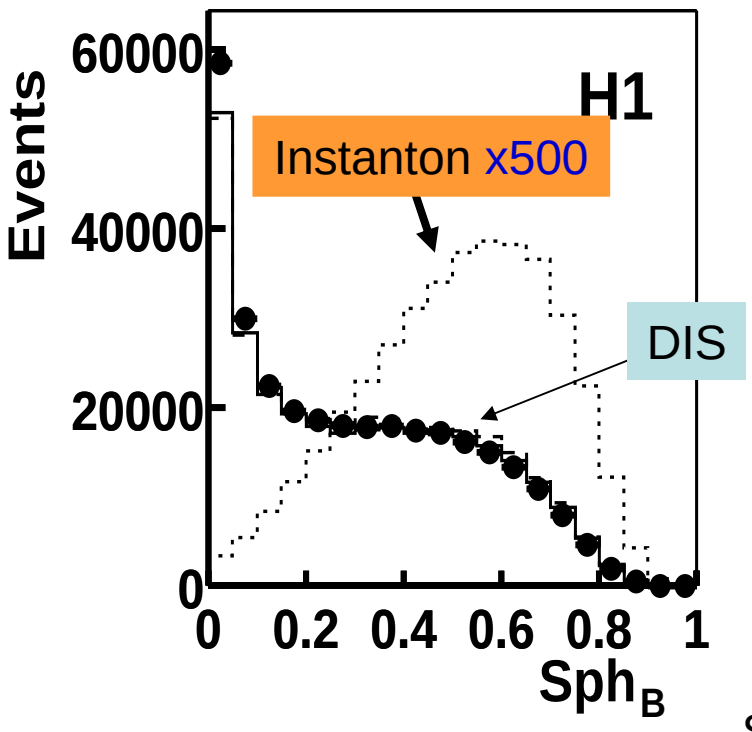
Instanton

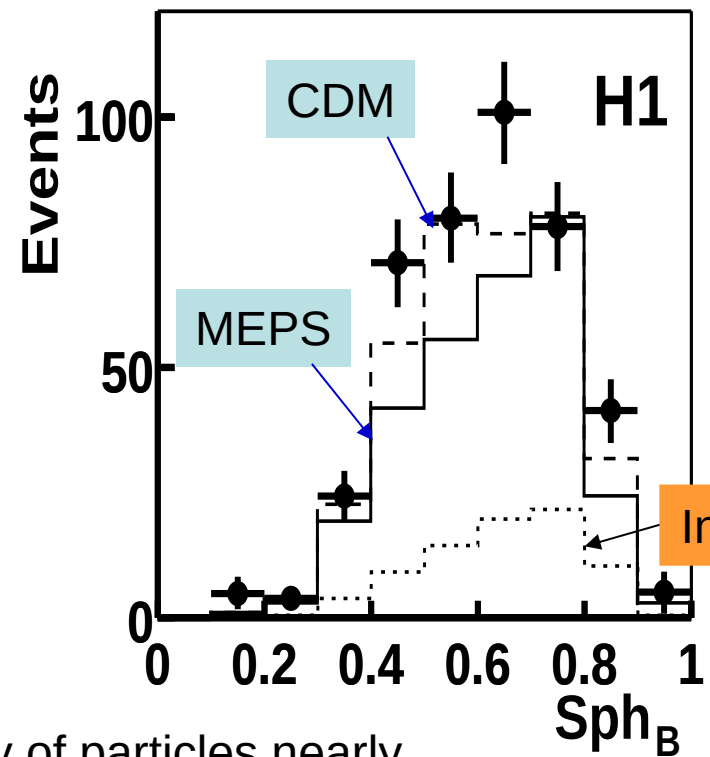
Instanton events have different particle emission patterns from the normal DIS. But the expected production rate is not so large

After the selection cut to enhance the instanton-like sample, the difference in the two normal-DIS MC's predictions are still large

One example

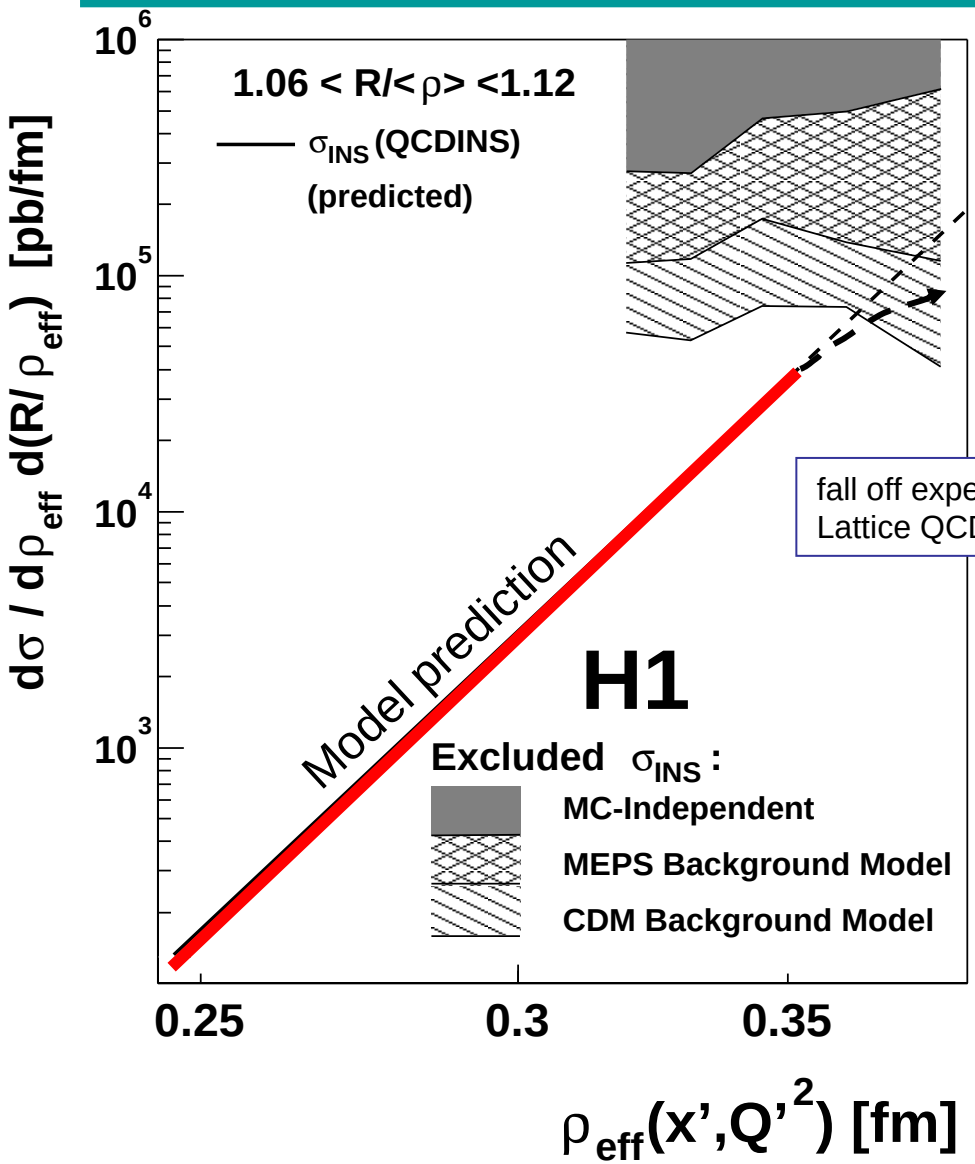
After Enrichment cuts.





Sphericity of particles nearly I-rest frame

Instanton



MC-Independent:
Assuming all remaining events are instanton-induced:
(very conservative)

If CDM is the "correct MC" for DIS we are closer to set limit.

Not yet give a stringent limit.

We need more understanding for the normal DIS process.

Summary

• The studies of the hadronic final state in ep collisions is a good testing ground of QCD.

• Particle and Jet distribution at low-x is not so simple as the naive QPM predicts.

•A lot of data on energy flow, jet, single particle are produced with the HERA-I data. In corresponding to this, many theoretical developments are performed in recent years.

- •fixed order NLO
- •Parton evolution at low-x
- •virtual photon structure
- ... and its implementation to MCs.

The comparisons is getting more and more precise. There is not a perfect model.

• Search for genuine QCD effect (such as Instanton-induced process) are going on. Also for such searches, we need to understand the normal DIS better.