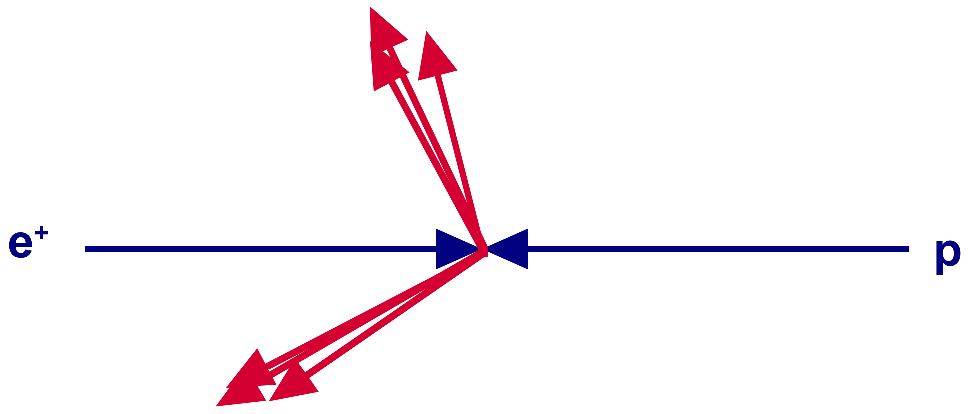
Preliminary Examination

Measurement of DiJet Cross Sections in Deep Inelastic Scattering at ZEUS



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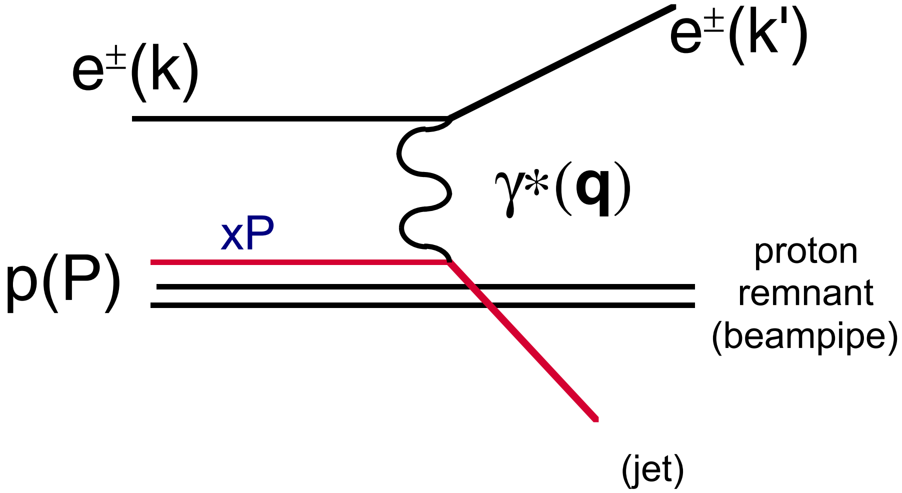
University of Wisconsin
20 December 1996

HERA

- **electron proton collider**
  - 820 GeV protons
  - 27 GeV electrons or positrons
  - center of mass energy = 300 GeV
    - equivalent to a 51 TeV fixed target
  - 220 bunches, 96 ns crossing time
  - L = 1.5 x 10^{31} $cm^{-2}s^{-1}$ (1.0 x 10^{31} this year)
  - e^{+-} current 58mA (40mA) p current 160mA (70mA)

Deep Inelastic Scattering



$$s = (P+k)^2 = 4E_pE_e = (300GeV)^2$$

$$Q^2 = -q^2 = -(k-k')^2 = sxy$$

the scale at which the proton is probed is proportional to 1/Q

$$x_{bj} = \frac{Q^2}{2P\bullet q}$$

fraction of the proton’s momentum carried by the struck quark

$$y = \frac{P\bullet q}{P\bullet k}$$

fraction of the electron’s energy transferred to the struck quark in the proton’s rest frame

DIS Cross Section

The differential cross section for photon exchange is:

$$\frac{d\sigma^2(ep \to eX)}{dxdy} = \frac{4\pi s\alpha_{em}^2}{Q^4}\left[(1-y+\frac{y^2}{2})F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

α_{em} is the electomagnetic coupling constant

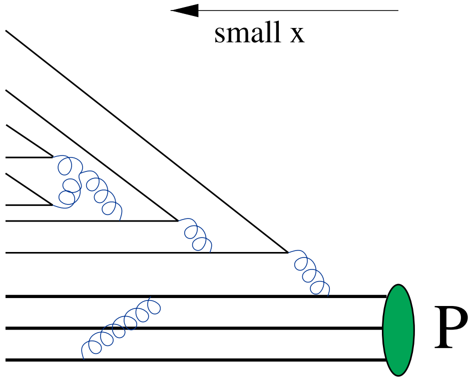
The structure function $F_2(x,Q^2)$ gives the interaction between transversely polarized photons and spin 1/2 partons. F_2 depends on the quark distributions of the proton.

The structure function $F_L(x,Q^2)$ gives the interaction due to longitudinally polarized photons that interact with the proton. The partons that interact have transverse momentum.

Scaling Violation

- **Naive parton model**
  - No parton - parton interactions
  - Partons have no transverse momentum
  - F_2 is only a function of x
  - Bjorken Scaling

But scaling is violated...



Parton-Parton interactions, mediated by the gluons, generate parton transverse momentum.

The stucture functions gain a Q^2 dependence.

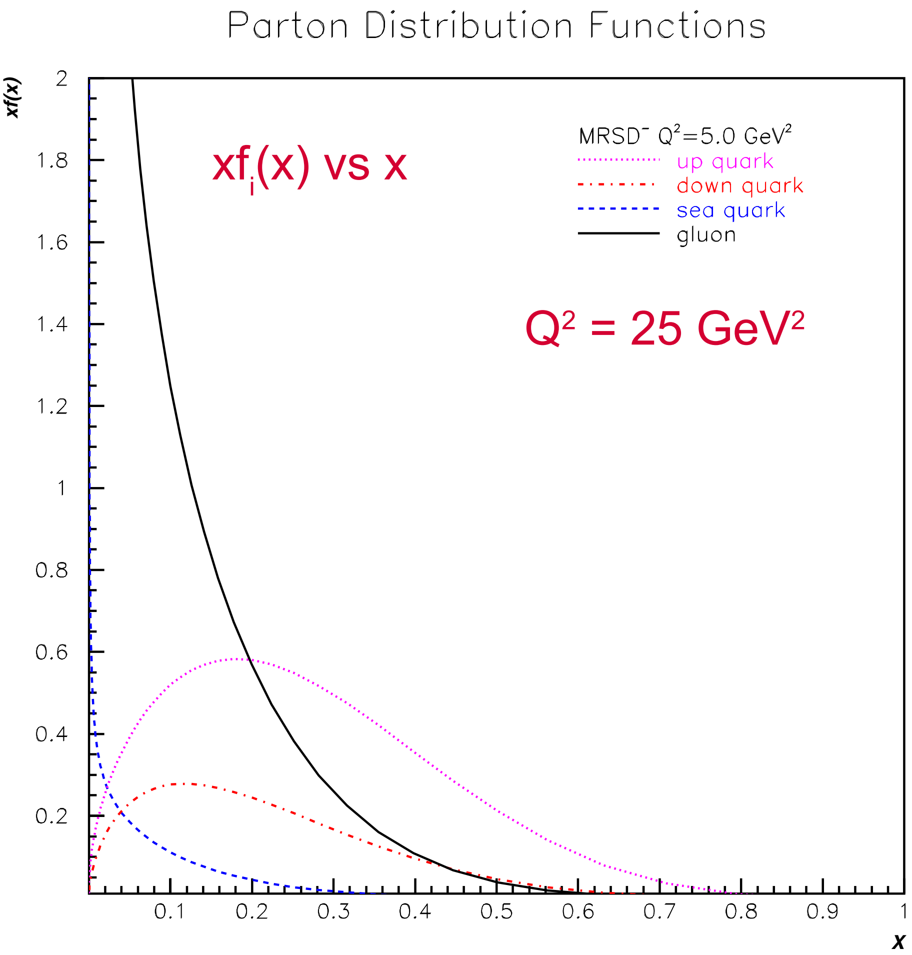
Parton Distribution Functions

$$f_i = f_i(x, Q^2)$$

$$i = q, \bar{q}, g$$

average number of partons of type i with momentum fraction between x and dx

The distribution functions are not calculated by theory. They must be determined from experiment.



Extracting Gluon Density From F_2

$$\frac{d\sigma^2(ep\to eX)}{dxdy} = \frac{4\pi s\alpha^2_{em}}{Q^4}\left[(1-y+\frac{y^2}{2})F_2(x,Q^2)-\frac{y^2}{2}F_L(x,Q^2)\right]$$

$$F_2(x,Q^2) = x\sum_q Q_q^2 f_q(x,Q^2)$$

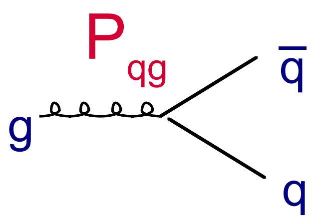
F_L depends on the gluon density.

- **F_2 measurement**
  - measure experimentally the differential cross section
  - estimate F_L from QCD

QCD predicts: (Altarelli-Parisi)

$$\frac{\partial F_2(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\left[2\sum_q Q_q^2 \int_x^1 \frac{dw}{w}\left(\frac{x}{w}\right)P_{qg}\left(\frac{x}{w}\right)wg(w,Q^2) + \int_x^1 \frac{dw}{w}\left(\frac{x}{w}\right)P_{qq}\left(\frac{x}{w}\right)F_2(w,Q^2)\right]$$

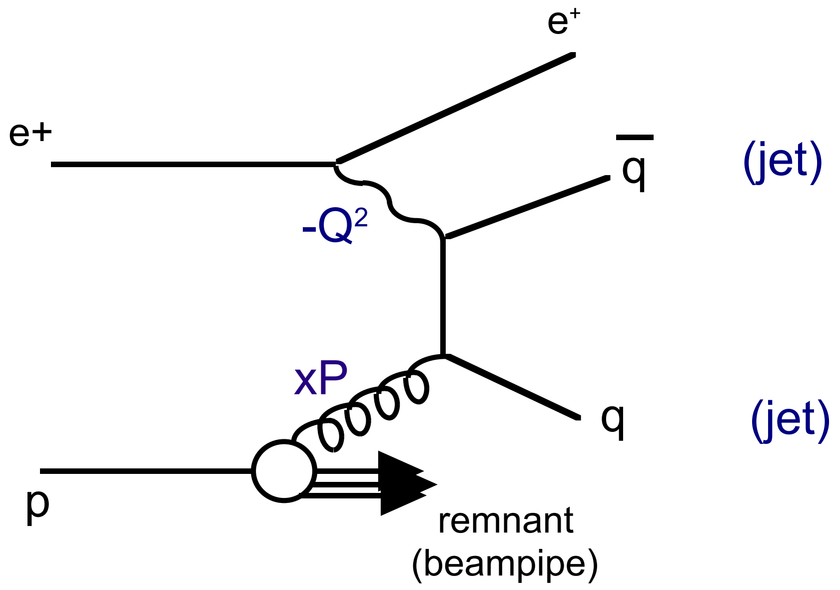
α_s is the strong coupling constant



related to the probability of g->qq

Dijet Process

Boson Gluon Fusion



$$x = x_{bj}\left(1 + \frac{M_{jj}^2}{Q^2}\right)$$

M_{jj}^2 is the invariant mass squared of the dijet system

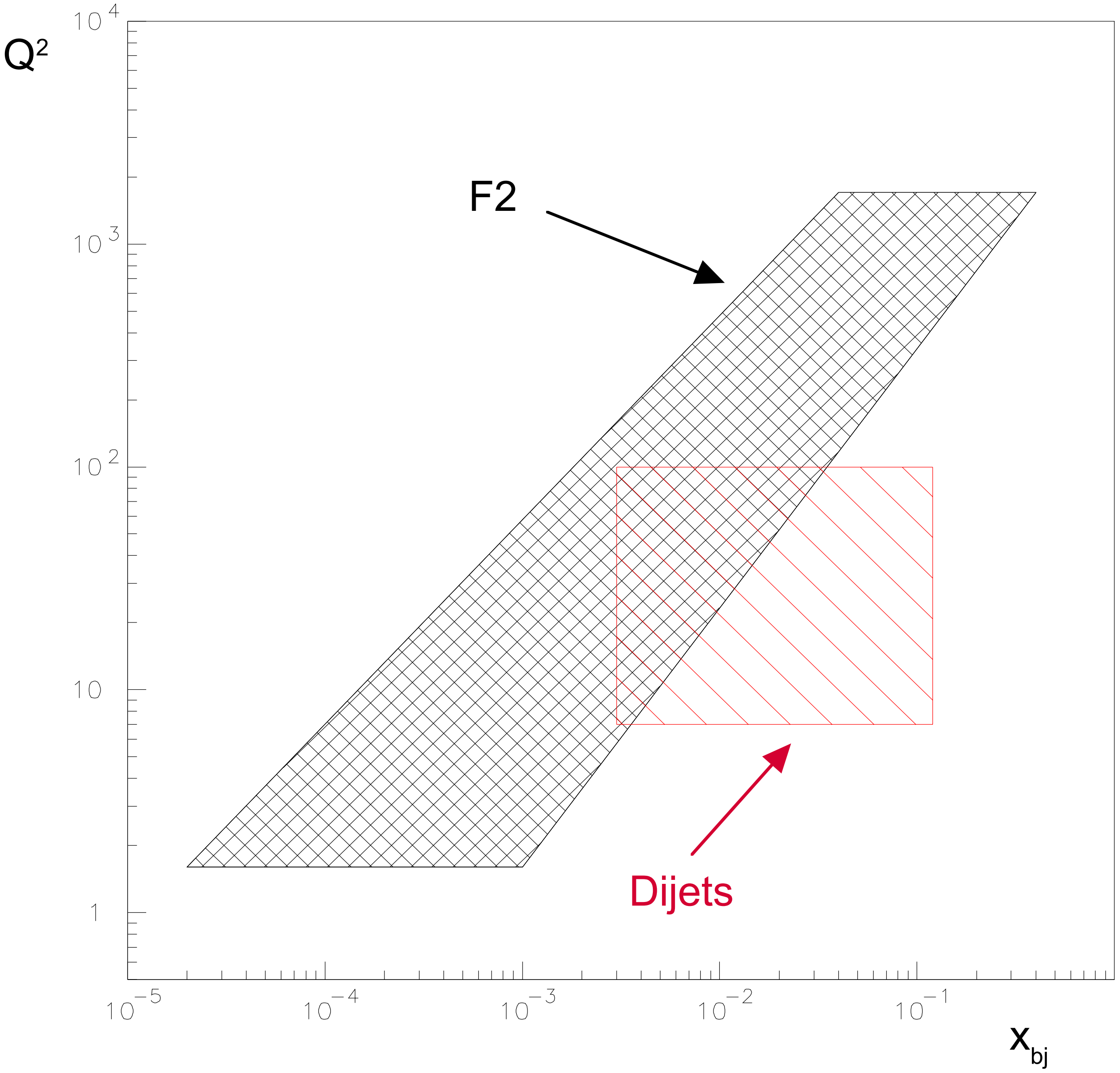
Rate depends directly on the gluon density in the proton.

At what scale is the proton probed in this process?

for $M_{jj}^2 >> Q^2$, then use p_T of the jets

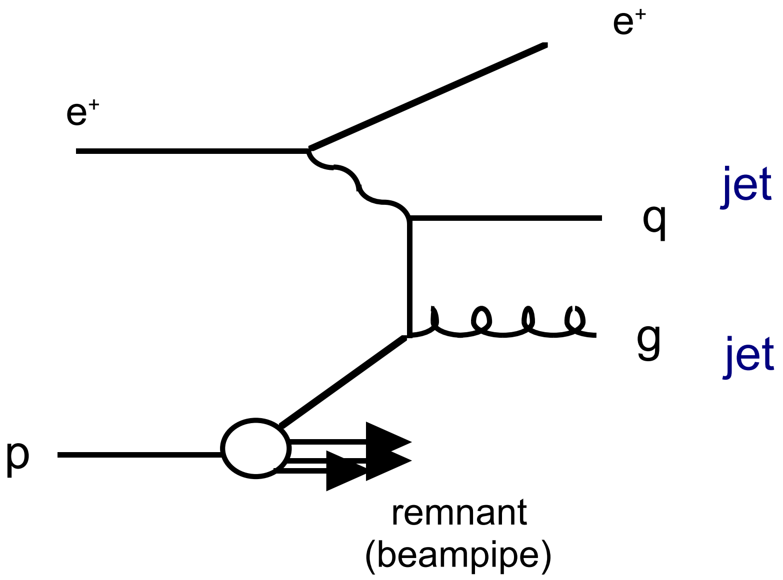
for $M_{jj}^2 \approx Q^2$, then use Q

Kinematic Range



Background Process

QCD Compton



For low x this process is dominated by the Boson Gluon Fusion process.

Getting at the Gluon via Dijets

Leading Order

$$\sigma_{dijet} \approx \sigma_{BGF} + \sigma_{QCDC}$$
$$\approx \hat{\sigma}_g(x)g(x,\mu^2) + \hat{\sigma}_q(x)f_q(x,\mu^2)$$

$$x = x_{bj}\left(1 + \frac{M_{jj}^2}{Q^2}\right)$$

$$g(x,\mu^2) \approx \frac{\sigma_{dijet}(x) - \hat{\sigma}_q(x)f_q(x,\mu^2)}{\hat{\sigma}_g(x)}$$

$f_q(x,\mu^2)$ and $g(x,\mu^2)$ are the densities of the quarks and gluons respectively. $f_q(x,\mu^2)$ from other experiments must be used.

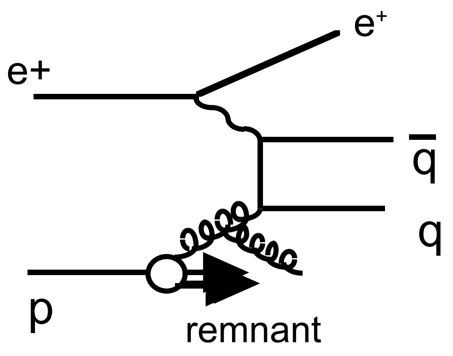
$\hat{\sigma}_q$ and $\hat{\sigma}_g$ are the partonic cross sections for processes initiated by the quarks and gluons respectively. They must be calculated by theory.

μ^2 is the scale at which the proton is probed. It is also called the factorization scale.

NLO

$$\hat{\sigma}(x) \rightarrow \hat{\sigma}(x,\mu^2)$$

NLO calculations reduce dependency on the factorization scale.



Selecting Scale

- **renormalization scale** $\alpha_s(\mu_r^2)$
  - scale at which the running coupling constant α_s is evaluated
- **factorization scale** $f_i(x,\mu_f^2)$
  - scale at which the parton densities are evaluated

$$\mu_f^2 = \mu_r^2 = \mu^2$$

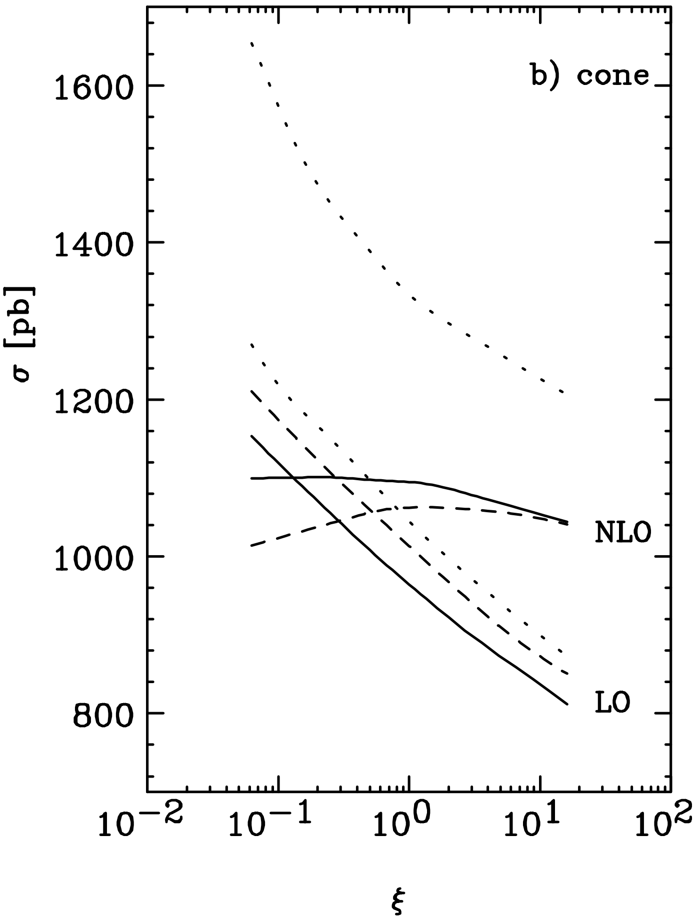
dijet choices:

$$Q^2, p_t^2, k_t^2, ???$$

$$\mu^2 = \xi Q^2$$

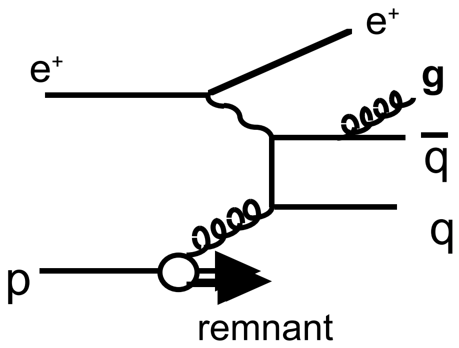
$$\mu^2 = \xi p_t^2$$

$$\mu^2 = \xi k_t^2$$



Other Concerns

- **final state recombination**



  - Jet definitions can be sensitive to the recombination scheme used.
  - A large effect on the cross section is possible.

- **calulated cross section and detector measured cross section comparison**
  - fragmentation of partons into hadrons
  - detector acceptances

Monte Carlo Generators

- **generate events at parton level**
  - inputs: parton distributions and scale
- **kinematic cuts**
- **jet finding**

Two NLO programs exist: MEPJET and DISENT

They differ in the methods of handling:

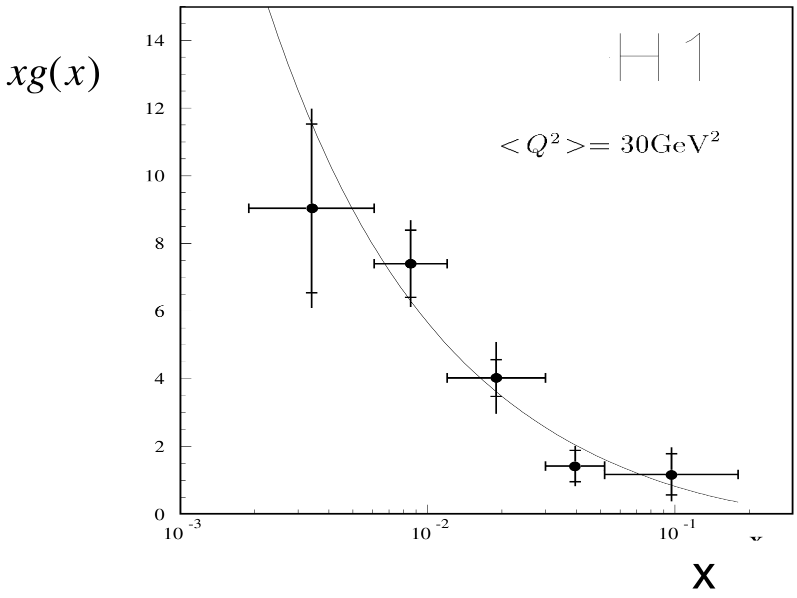
renormalization

factorization

final state recombination

Previous Dijet Gluon Results

LO



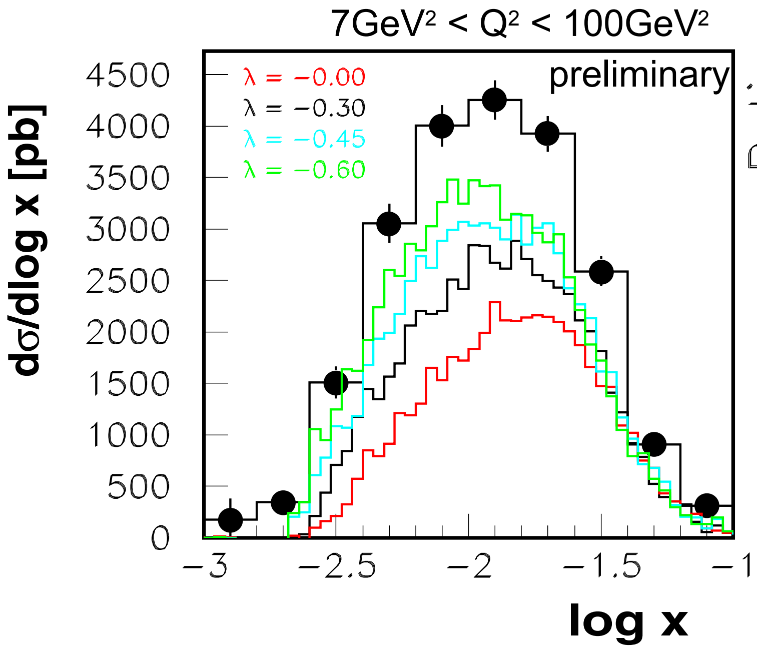
1993 H1 data

MC used: LEPTO

scale used: Q^2

results compatible with previous F_2 measurements

NLO



1994 ZEUS data

$$xg(x, \mu_o^2) \propto x^{\lambda}$$

measure λ

MC used: MEPJET

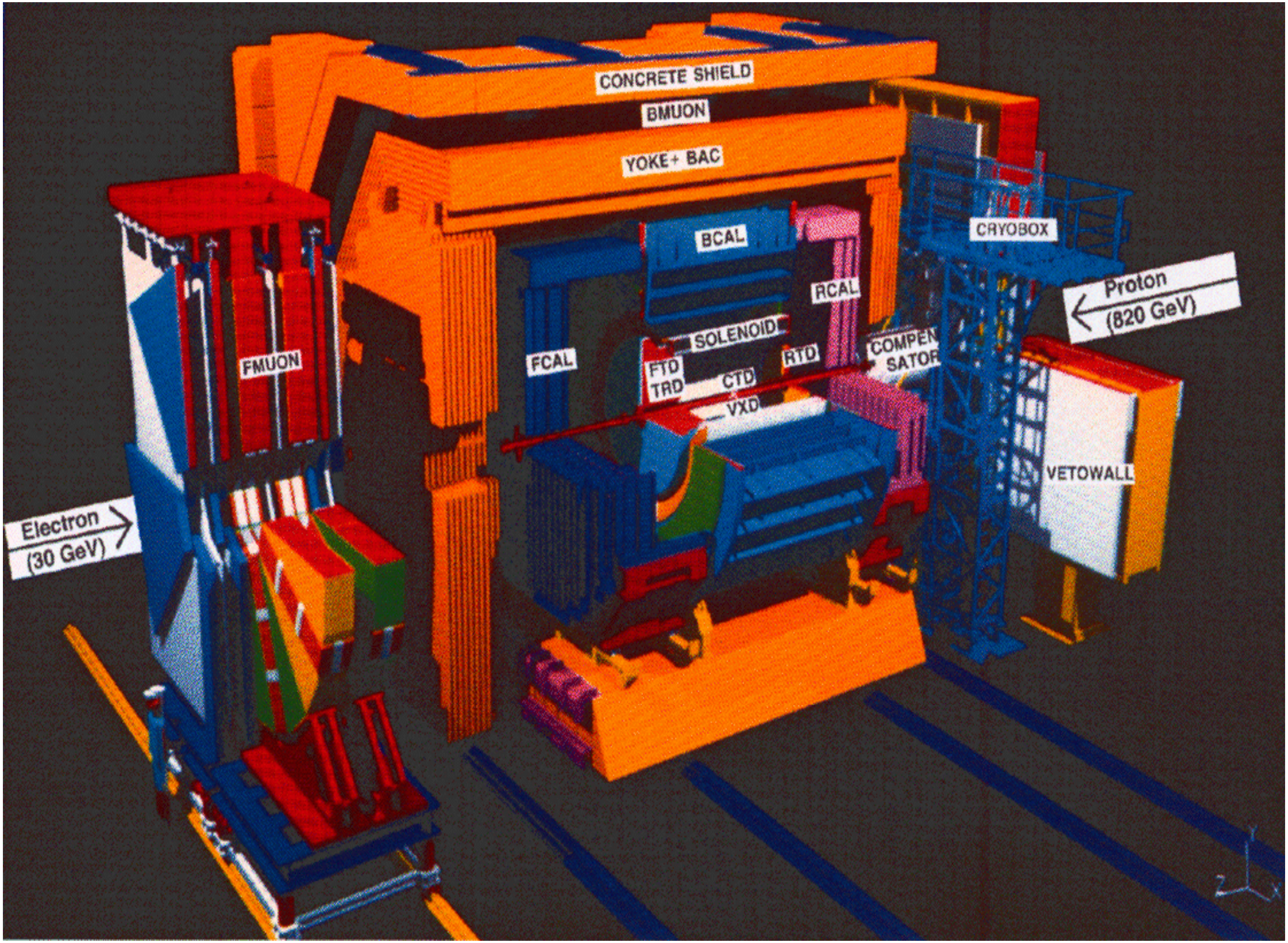
scale used: Q^2

Physics Motivation

proton structure

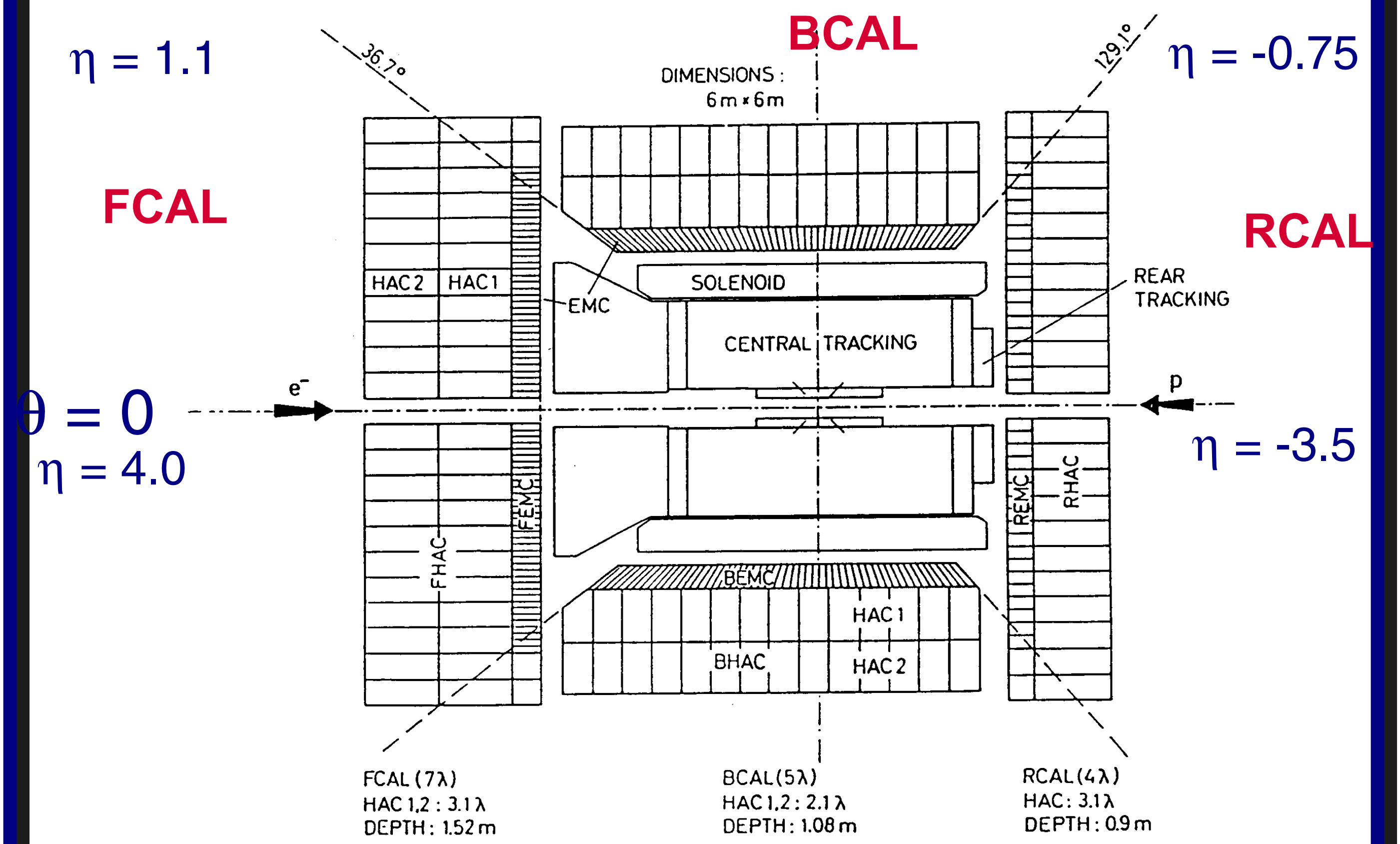
- 50% of the proton's momentum is carried by gluons
- the F_2 method is an indirect measurement of the gluon density
- the dijet cross section is directly proportional to the gluon density of the proton
- dijet method is sensitive in an extended region of x-Q^2

ZEUS


CONCRETE SHIELD
BMUON
YOKE+ BAC
BCAL
CRYOBOX
Proton
(820 GeV)
RCAL
SOLENOID
FMUON
FCAL
FTD
TRD
CTD
RTD
COMPENSATOR
VXD
VETOWALL
Electron
(30 GeV)
Z
Y
X

Calorimeter

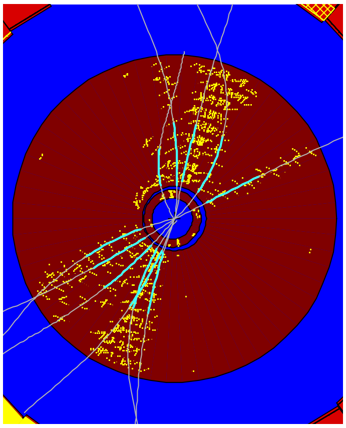
- **depleted uranium and scintillator**
  - 99.7% solid angle coverage
  - electron res: 18%/√E hadronic res: 35%/√E



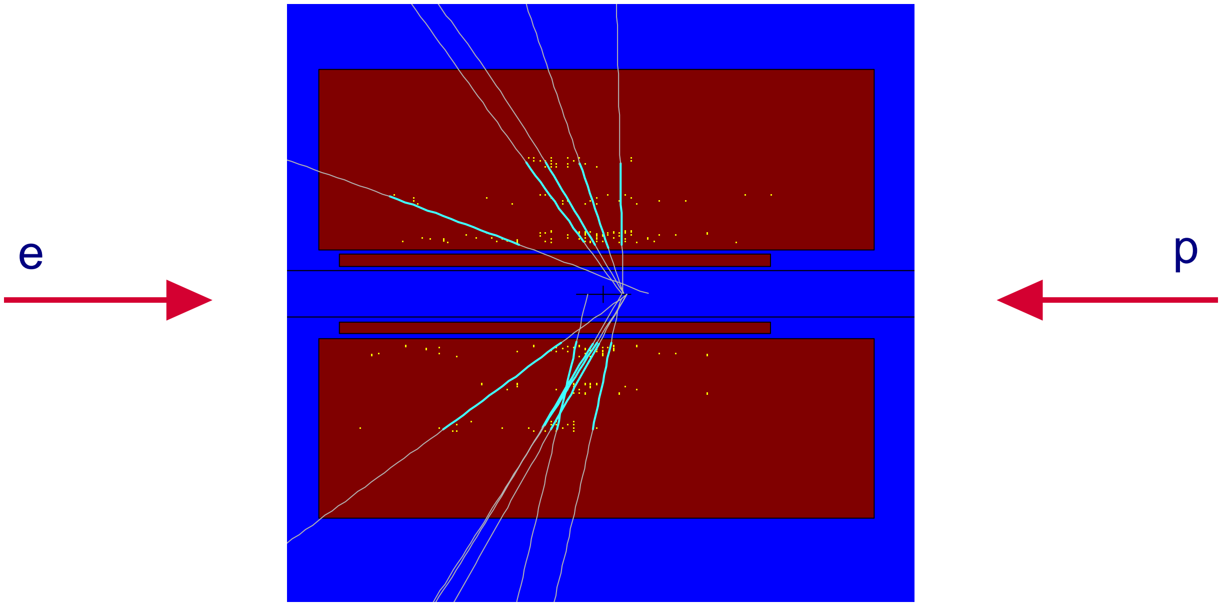
$$\eta = -\ln[\tan(\frac{\theta}{2})]$$

Central Tracking Detector

- **drift chamber**
- **1.43T solenoid**
- **vertex resolution**
    - 1mm transverse
    - 4mm in z

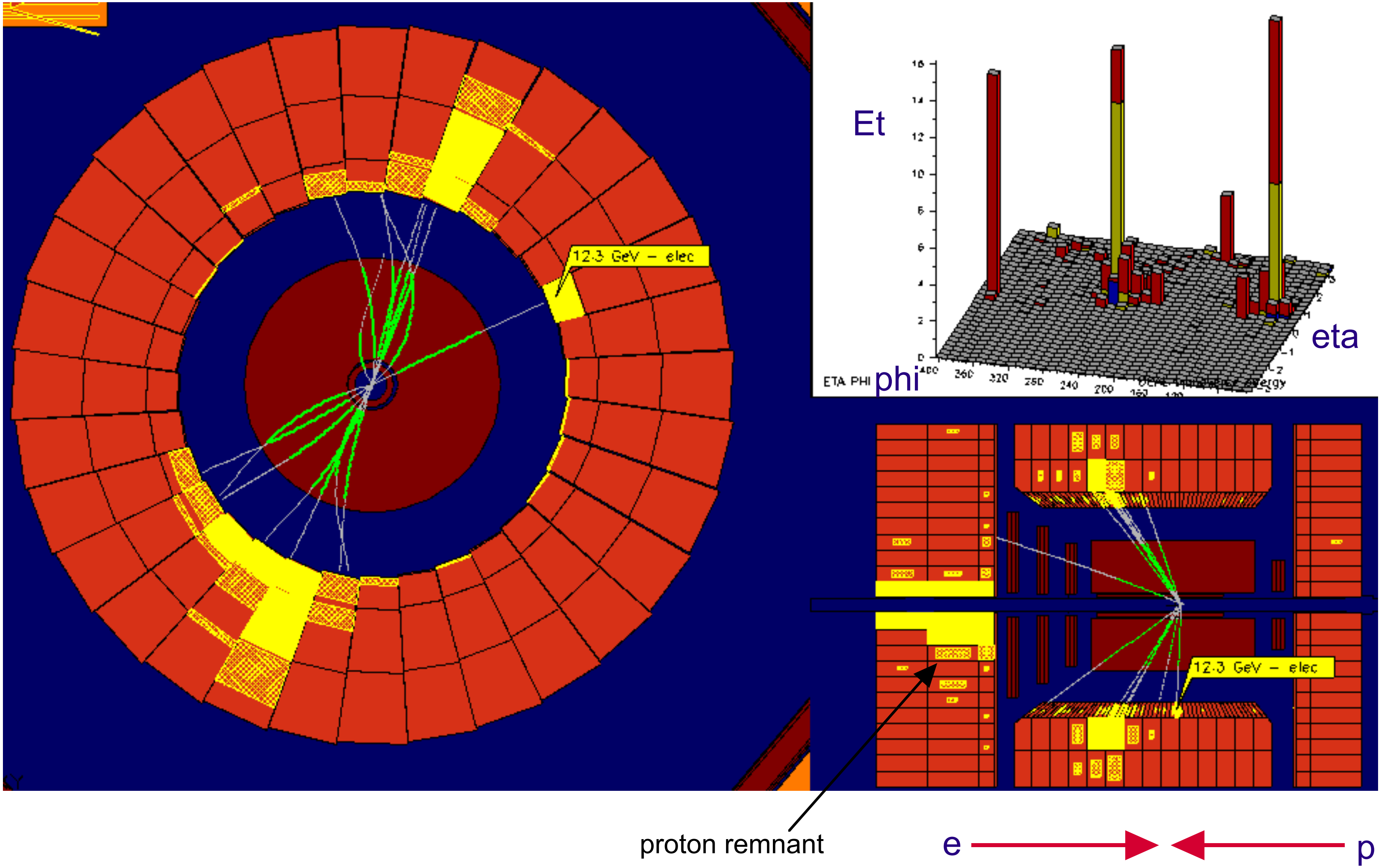


transverse view

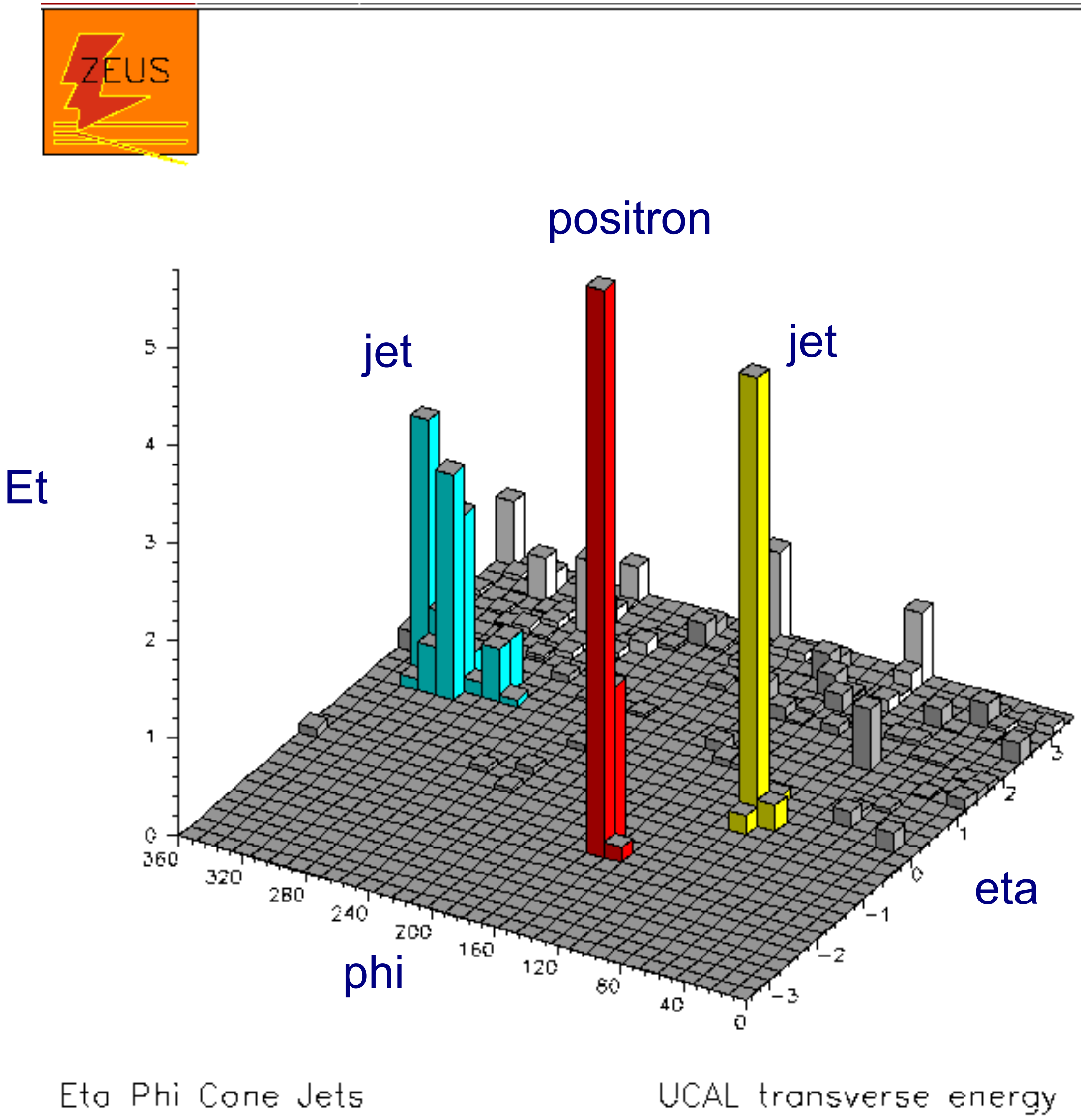


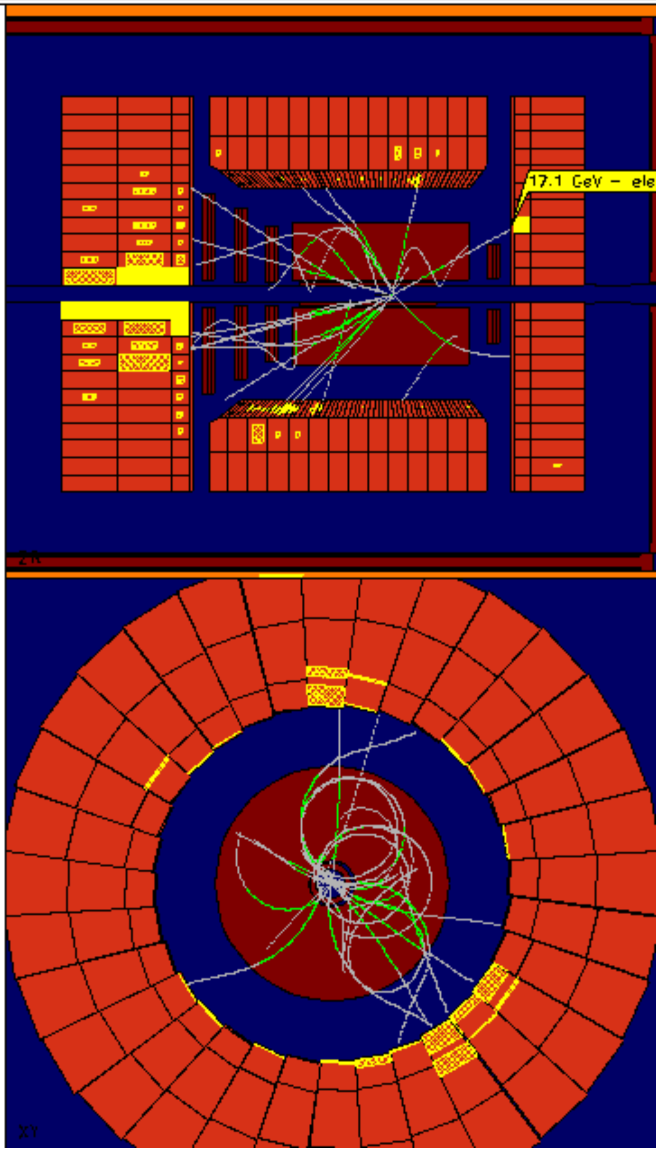
side view

DIS DIJET EVENT

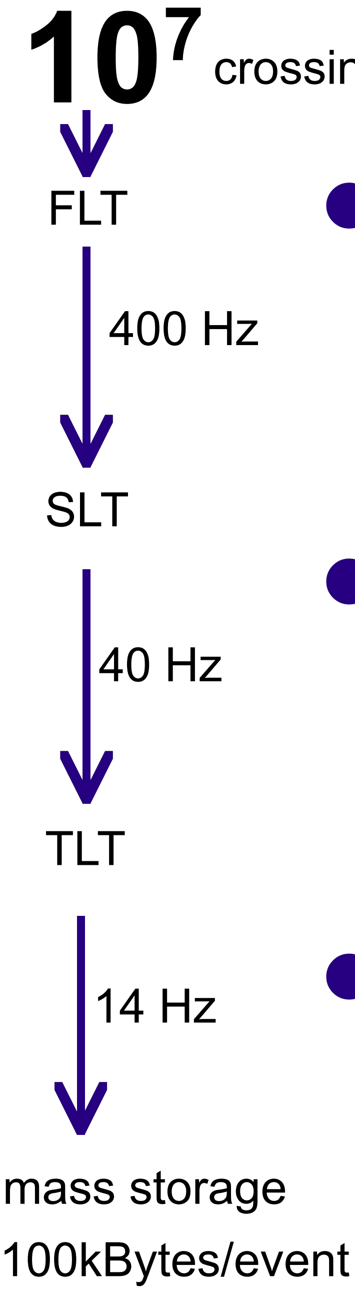


DIS DIJET EVENT Q^2=100 GeV^2





Trigger



10^7 crossings/sec

FLT

400 Hz

SLT

40 Hz

TLT

14 Hz

mass storage

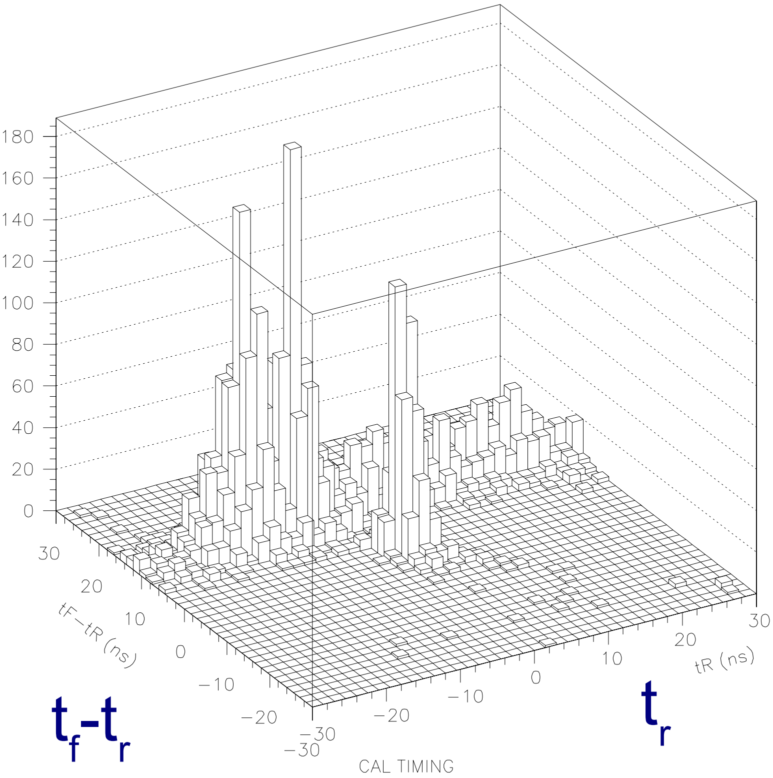
100kBytes/event

10^5 Hz background rate

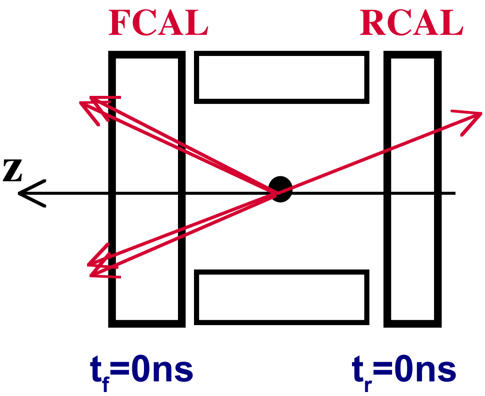
10 Hz physics rate

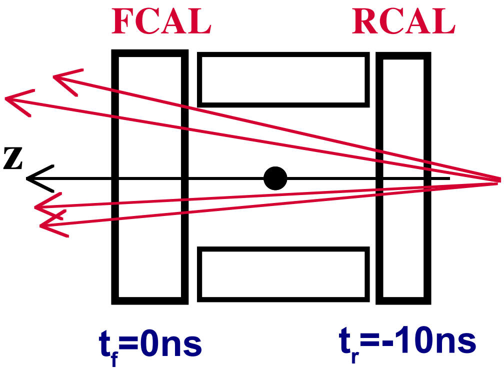
- **First level**
  - dedicated hardware
  - no deadtime
  - global and regional energy sums
  - isolated electron and muon recognition
  - tracking information
- **Second level**
  - timing cuts
  - $e-p_z$
  - simple physics filters
  - electron finding
  - additional tracking information
- **Third level**
  - full event information available
  - advanced physics filters
  - jet and electron finding

Timing and E-P_z



calorimeter timing resolution < 1ns

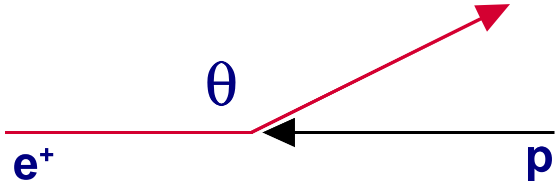




$$E - P_z = \sum_{cells} E(1 - \cos\theta)$$

Initially:

$$E_P - E_{pz} + E_e - (-E_{ez}) = 2E_e$$



measured value is conserved if no energy lost down rear beam pipe

Analysis Plan

- **apply cuts to detector data to select sample of dijet events**
  - 1996: 10.8 pb^{-1} integrated luminosity
  - a sample of 50k events are expected after cuts
- **measure cross section from data**
  - bin events in x
  - make corrections due to detector acceptances
- **generate Monte Carlo event samples and apply equivalent cuts**
- **compare MC with data**

Cone Jet Identification Alogorithm

First finds largest E_t cluster. Then it sums all clusters within

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1$$

The resulting combination is called a jet and removed.

Stops when the Et of the summed clusters is less than a specified value.

Lorentz invariant

Good in ZEUS central region, but overefficient in the ZEUS forward region. Proton remnant can be misidentified as a jet.

Currently used in the ZEUS third level trigger

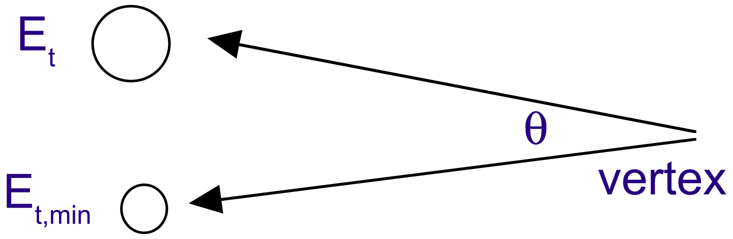
Relatively independent of the MC recombination scheme

Other Jet Identification Algorithms

k_t

First finds largest Et cluster

$$k_\perp = 2E_{t,\min}^2(1-\cos\theta)$$



The two clusters with minimum $k_\perp$ are found.

If $k_\perp$ larger than a threshold value then the largest cluster is called a jet and removed.

Otherwise the two clusters are combined, and the process is repeated.

Good in ZEUS forward region.

Relatively independent of the MC recombination scheme

JADE

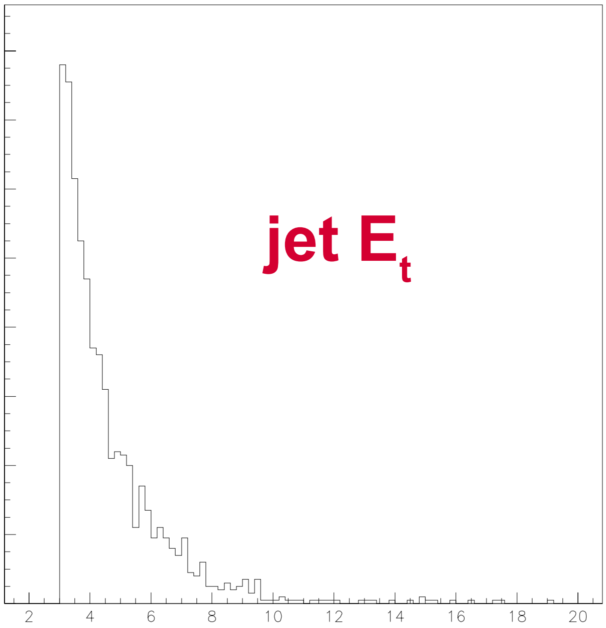
Similar to k_t, except the relevant quantity is

$$M = 2EE_{\min}(1-\cos\theta)$$

energy weighted combination

large recombination scheme dependence

Jet Properties

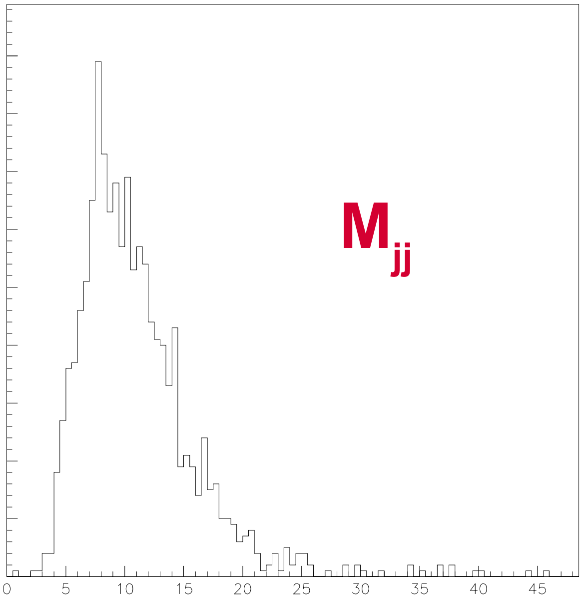


Transverse Energy (GeV)

jet E_t > 3GeV

2.5 < η < -3.0

cone algorithm



Energy (GeV)

Electron Identification

- **electron signature is**
  - energy deposit in electromagnetic calorimeter cells
  - energy contained in a few calorimeter cells
  - electromagnetic / hadronic energy ratio
- **ZEUS uses several finders**
  - use electron signature
  - primary finder is > 95% efficient for electron energy > 10 GeV
- **improvements can be made using additional components-- Small Rear Tracking Detector and the RCAL Presampler**
- **Calorimeter First Level Trigger is 99% efficient for isolated electrons above 5 GeV (RCAL)**

Variable Reconstruction - Electron Method

$$y = 1 - \frac{E'_e}{2E_e}(1-\cos\theta)$$

θ = positron scattering angle

E_e' = scattered positron energy

$$Q^2 = 2E'_e E_e (1+\cos\theta)$$

E_e = 27 GeV

E_p = 820 GeV

$$x_{bj} = \frac{E'_e(1+\cos\theta)}{2yE_p}$$

$$x = x_{bj}\left(1+\frac{M_{jj}^2}{Q^2}\right)$$

$$M_{jj}^2 = 2E_{jet1}E_{jet2}(1-\cos\theta_{jets})$$

best x resolution at low Q^2

sensitive to miscalibrations

General Dijet Cuts

- **positron found with E > 10 GeV**
  - good efficiency
- **x_{bj}, Q^2 and y determined from electron method**
  - best resolution
- **$E-P_z > 35$ GeV**
  - selects DIS events
- **$y > 0.04$**
  - uncertainty is large for small values of y
- **vertex cut $-40cm < z < 40cm$**
  - removes beamgas
- **7 $GeV^2 < Q^2 < 100$ GeV^2**
  - BGF dominant below 100GeV^2
  - above 7GeV^2 positron fully contained in RCAL
- **two jets found by cone algorithm**
  - $E_t > 3.0$ GeV
  - $-3.0 < \eta < 2.5$

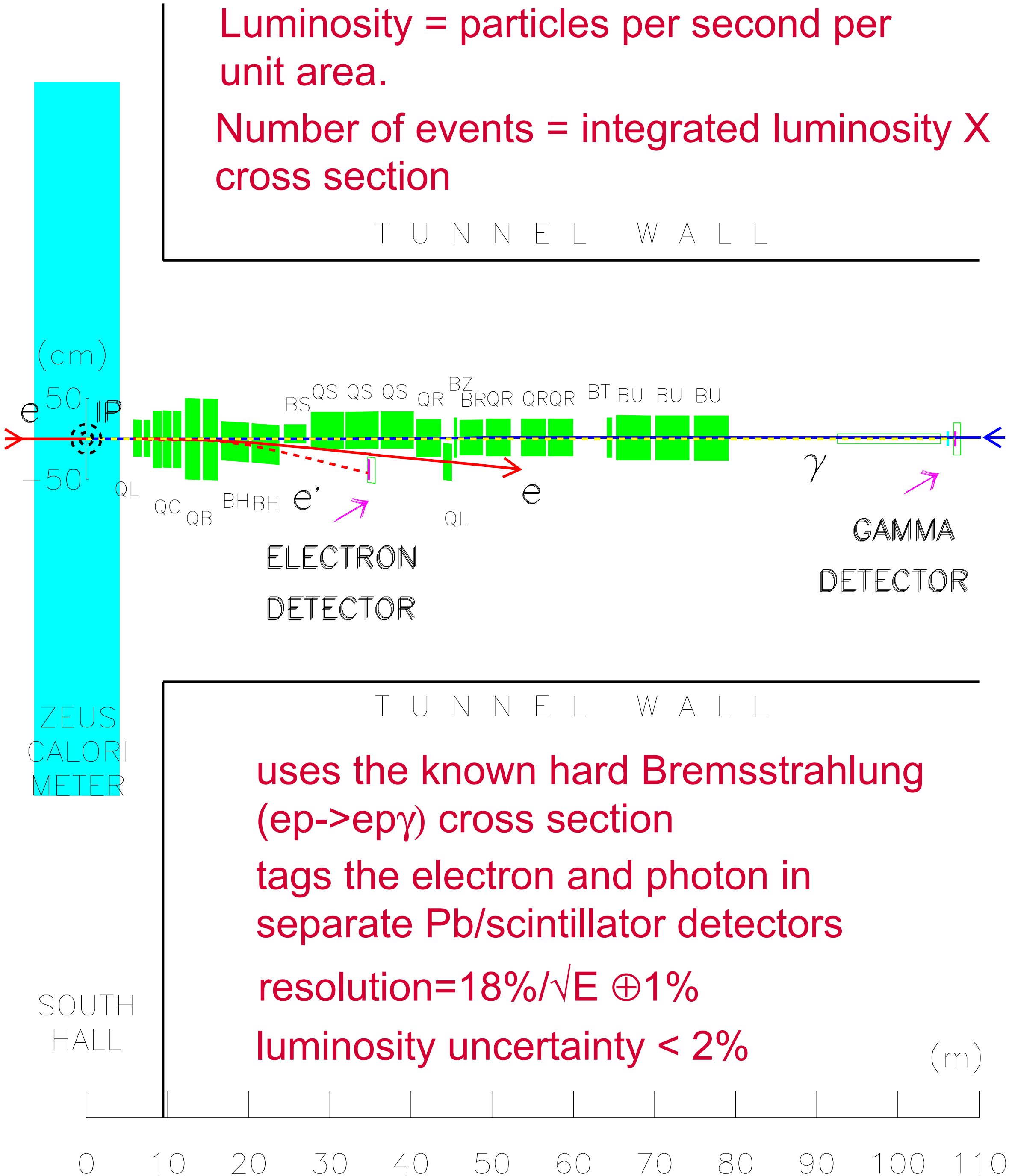
Measurement Uncertainties

- **event misidentification**
  - photoproduction events (scattered positron goes down rear beampipe)
    - a particle in a jet may mimic a scattered positron
    - observed E-Pz is not conserved
  - ~ 1% effect
- **y, x_{bj}, Q^2, and x resolution**
  - improvement over 1994 analysis
    - SRTD and RCAL presampler
- **jet energy resolution**
  - cross section uncertainty is very sensitive to energy scale uncertainty
  - improvements using tracking information possible

Conclusions

- **measure deep inelastic scattering dijet cross section using 1996 ZEUS data sample**
  - improved statistics and resolution
  - 1994: 3.2 pb^{-1}
  - 1995: 6.3 pb^{-1}
  - 1996: 10.8 pb^{-1}
- **determination of the gluon density of the proton**
  - dijet method: complementary measurement to the F_2 method
  - dijet cross section has direct dependence on gluon density
  - extended kinematic range

Luminosity Monitor



Luminosity = particles per second per unit area.

Number of events = integrated luminosity X cross section

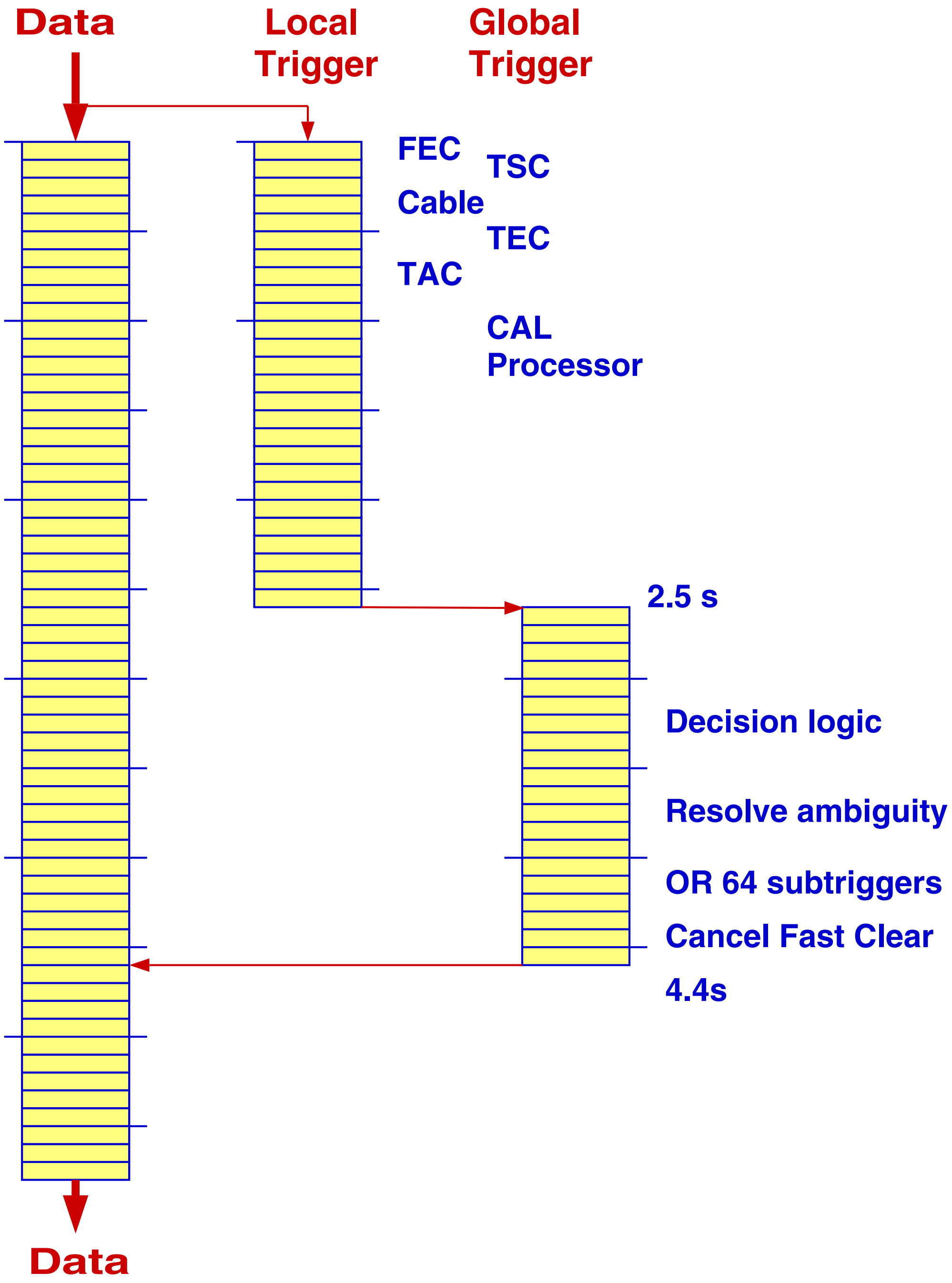
uses the known hard Bremsstrahlung (ep->epγ) cross section

tags the electron and photon in separate Pb/scintillator detectors

resolution=18%/√E ⊕1%

luminosity uncertainty < 2%

First Level Trigger



Data

Local Trigger

Global Trigger

FEC

TSC

Cable

TEC

TAC

CAL Processor

2.5 s

Decision logic

Resolve ambiguity

OR 64 subtriggers

Cancel Fast Clear

4.4s

Data

Pseudorapidity

$$rapdity = \frac{1}{2}\ln\left[\frac{E + p_{||}}{E - p_{||}}\right]$$

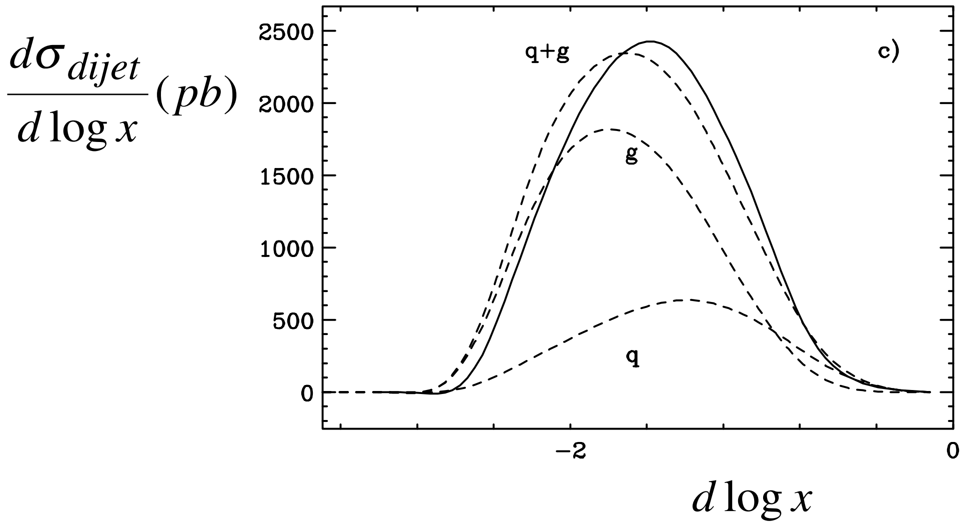
$$psuedorapidity = \eta = \frac{1}{2}\ln\left[\frac{|p| + p_{||}}{|p| - p_{||}}\right] = -\ln(\tan\frac{\theta}{2})$$

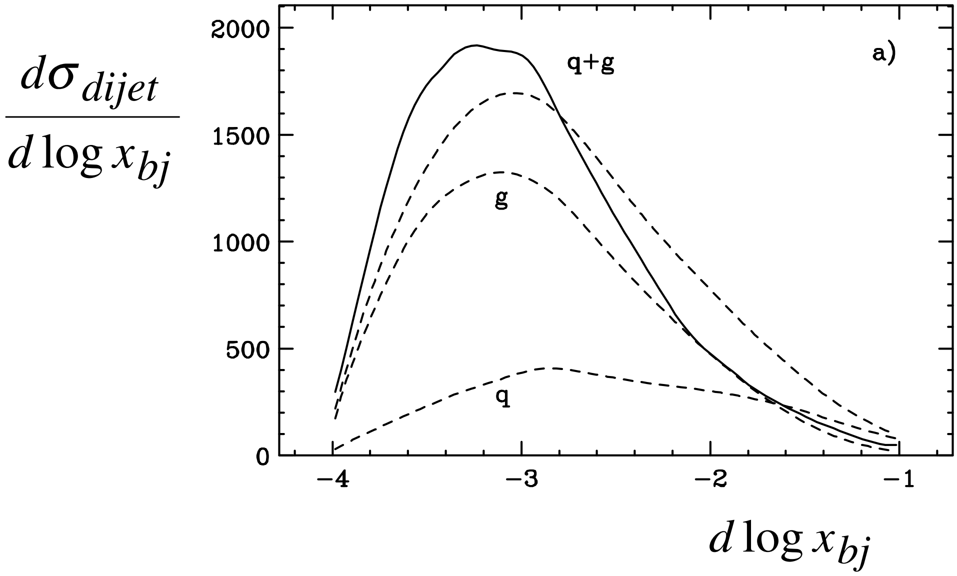
Lorentz boost along the beam direction

$$\eta' = \eta + f(v)$$

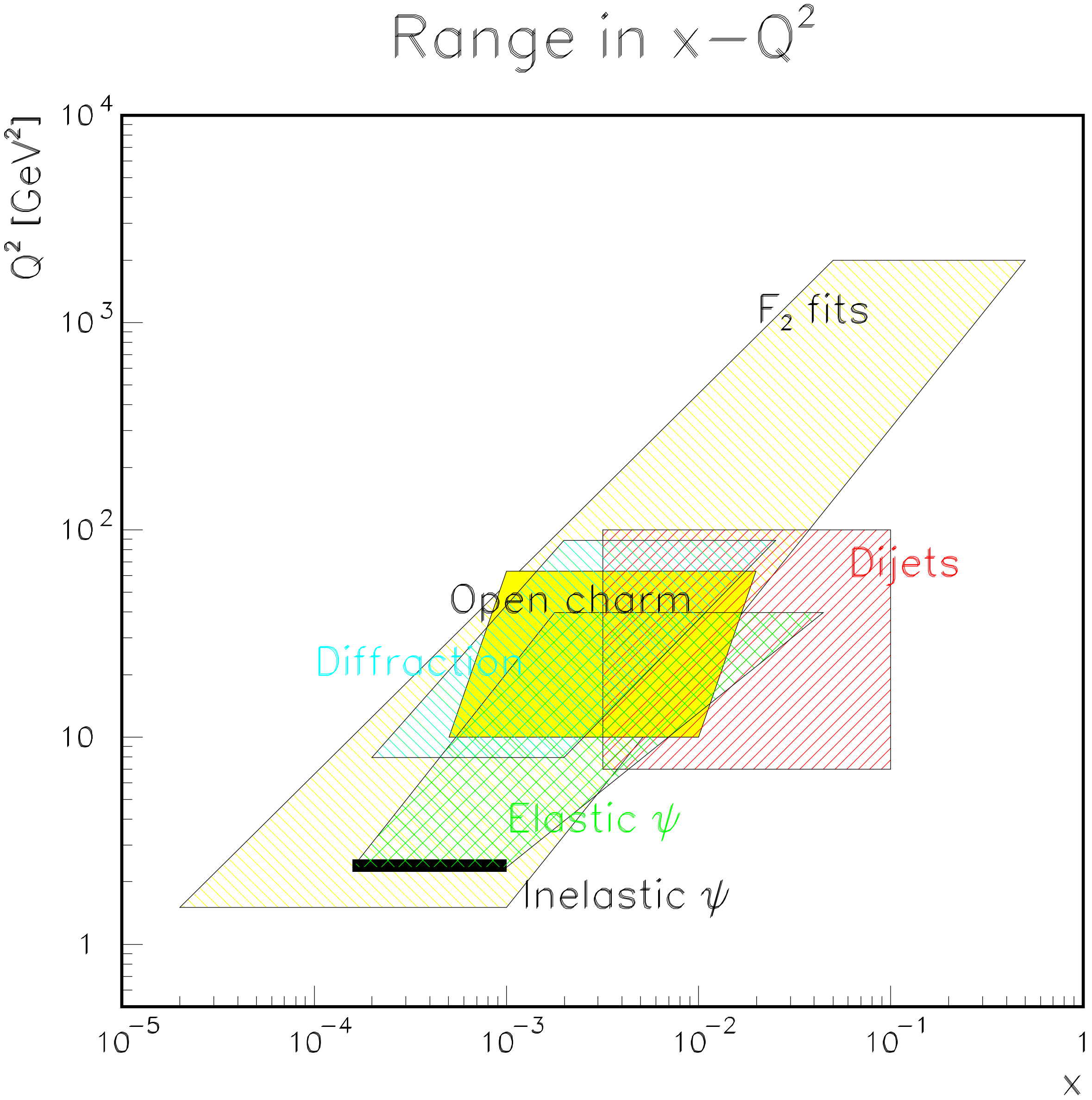
$\Delta\eta$ **is unaffected**

MEPJET Plots



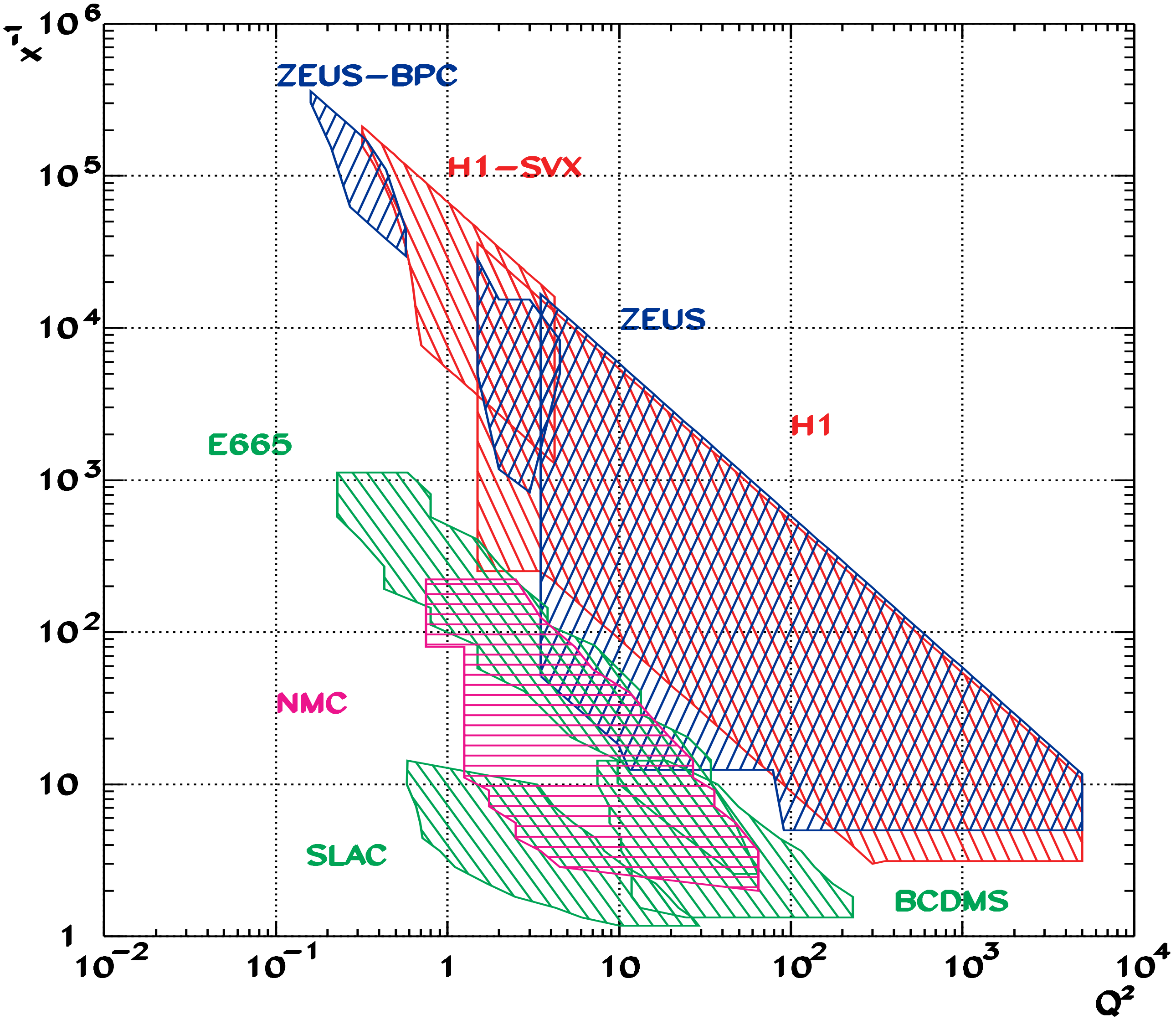


jose range



Altarelli-Parisi

wesley kinematic range



Double Angle Method

$$\cos\gamma = \frac{\left(\sum p_x\right)^2 + \left(\sum p_y\right)^2 - \left(\sum (E - P_z)\right)^2}{\left(\sum p_x\right)^2 + \left(\sum p_y\right)^2 + \left(\sum (E - P_z)\right)^2}$$

characterizes the momentum flow of the hadronic system

$$x_{DA} = \frac{E_e}{E_p} \frac{\sin\gamma + \sin\theta + \sin(\gamma+\theta)}{\sin\gamma + \sin\theta - \sin(\gamma+\theta)}$$

$E_e = 27$GeV

$E_p = 820$ GeV

θ = positron scattering angle

$$Q_{DA}^2 = \frac{4E_e^2 \sin\gamma(1+\cos\theta)}{\sin\gamma + \sin\theta + \sin(\gamma+\theta)}$$

$$y_{DA} = \frac{Q_{DA}^2}{s x_{DA}}$$

$$x = x_{DA}\left(1 - \frac{M_{jj}^2}{Q^2}\right)$$

Depends only on energy ratios so it is less sensitive to energy scale uncertainties.

better mean resolution over the entire x-Q^2 plane
define mjj here

junk

$$\frac{\partial f_i(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s(Q^2)}{8\pi^2} \sum_j \int_x^1 \frac{dw}{w} P_{ij}\left(\frac{x}{w}\right) f_j(w,Q^2)$$