# Energy Dependence of the Mean Charged Multiplicity in Deep Inelastic Scattering with ZEUS at HERA

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# Standard Model

- Matter made of fermions:
  - quarks or leptons
- Each particle has anti-particle with opposite quantum numbers
- Quarks carry color “charge”
- Four fundamental forces
  - Electromagentic (EM) force
  - Weak force
  - Strong force
  - Gravity

**Fermions**

| Quarks (colored) | | |
|---|---|---|
| Flavor | Mass (GeV/c$^2$) | Charge (Q/e) |
| *u* | 0.003 | +2/3 |
| *d* | 0.006 | -1/3 |
| *c* | 1.3 | +2/3 |
| *s* | 0.1 | -1/3 |
| *t* | 175 | +2/3 |
| *b* | 4.3 | -1/3 |

| Leptons (not colored) | | |
|---|---|---|
| Flavor | Mass (GeV/c$^2$) | Charge (Q/e) |
| $\nu_e$ | < 1x $10^{-8}$ | 0 |
| $e$ | 5.11 x $10^{-3}$ | -1 |
| $\nu_\mu$ | <0.00002 | 0 |
| $\mu$ | 0.106 | -1 |
| $\nu_\tau$ | <0.02 | 0 |
| $\tau$ | 1.7771 | -1 |

# Standard Model (II)

**Bosons**

| Boson | Force | Types | Mass(GeV) | Charge (Q/e) | Color |
|---|---|---|---|---|---|
| $\gamma$ (photon) | Electromagnetic | 1 | 0 | 0 | No |
| $W^{\pm}$ | Weak | 2 | 80.4 | ±1 | No |
| $Z^0$ | Weak | 1 | 91.187 | 0 | No |
| *g* (gluon) | Strong | 8 | 0 | 0 | Yes |

- Strength of forces determined by coupling constant ($\alpha_{EM}$ and $\alpha_s$)
- forces mediated by exchange of bosons: $\gamma$, $W^{\pm}$, $Z^0$,g
- Gravity described at macroscopic scale by general relativity.
    - very weak, neglected in high energy particle physics
- Quantum Electrodynamics (QED): theory of EM, combined with weak ➔ Electro-weak theory
- Quantum Chromodynamics (QCD): theory of strong interaction
- Combined theories ➔ Standard Model

# Particle Scattering

- Study structure of proton and nature of strong force which binds the quarks inside together.
- Scattering via probe

Wavelength

$$\lambda = \frac{\hbar}{Q}$$

h : Plank's Constant

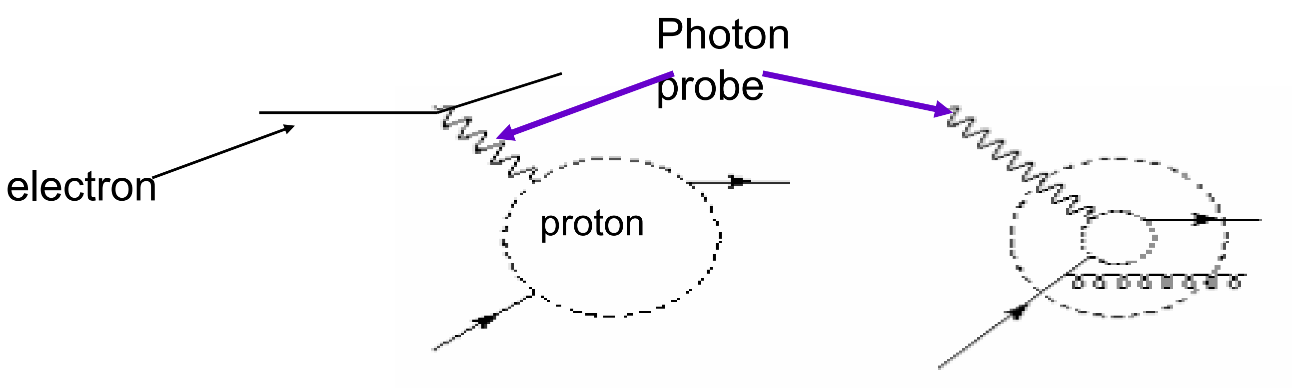
$Q^2$: related to momentum of probe

Large momentum = small wavelength = can probe more deeply into proton

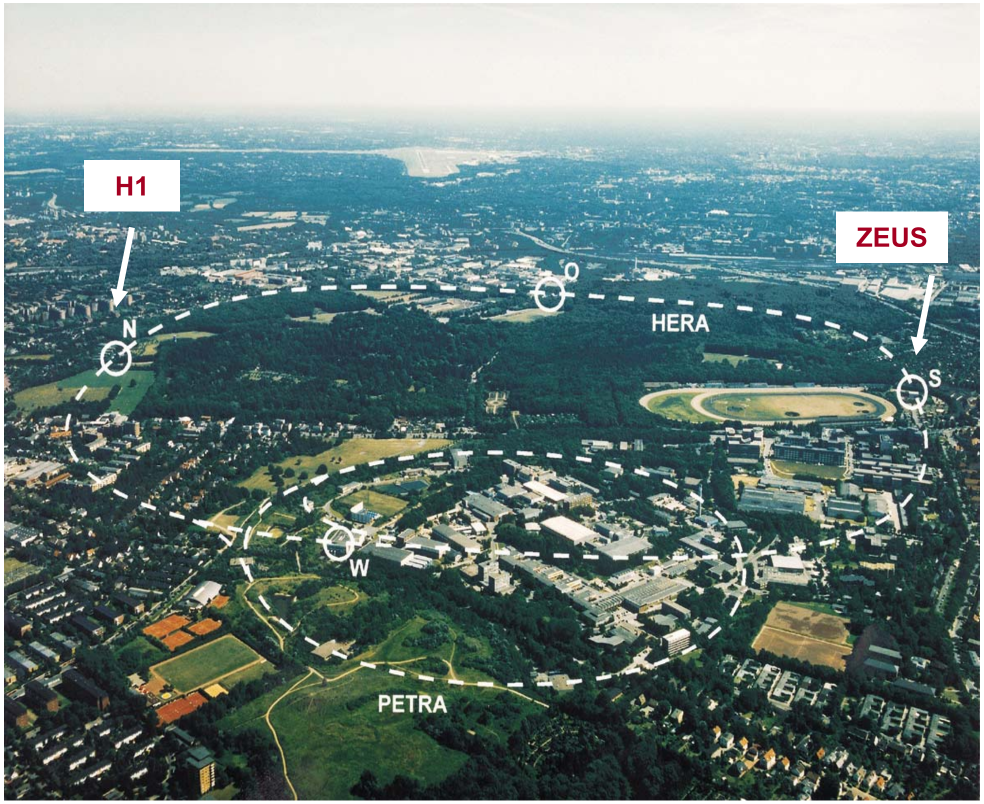
- Deep Inelastic Scattering (DIS) – $Q^2$ large

**For example:**

**High energy electron transfers momentum to a proton via photon probe**



# HERA Description

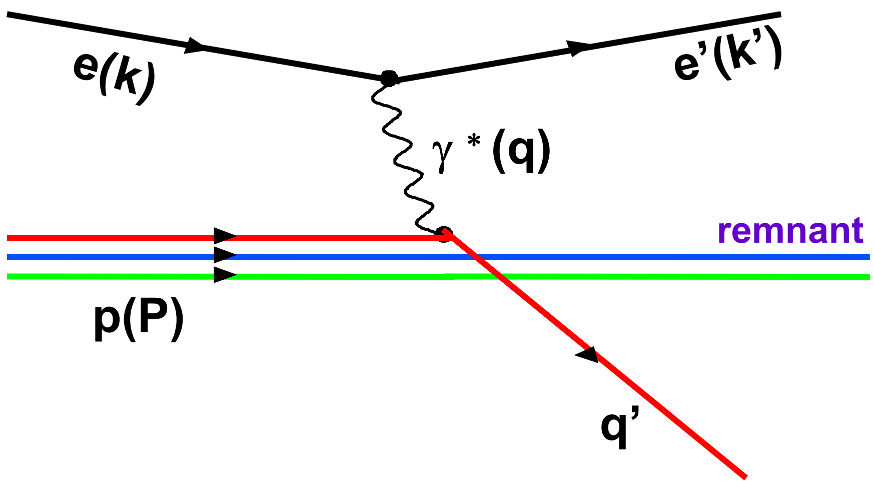



**DESY Hamburg, Germany**

**Unique opportunity to study hadron-lepton collisions**

- **920 GeV $p^+$**
  **(820 GeV before 1999)**
- **27.5 GeV $e^-$ or $e^+$**
- **318 GeV cms**
- **Equivalent to a 50 TeV Fixed Target**
- **HERA can probe to ~0.001fm**
  Size of proton ~ 1 fm
- **Instantaneous luminosity max: $1.8 \times 10^{31}$ $cm^{-2}s^{-1}$**
- **220 bunches**
- **96 ns crossing time**
- **$I_P$~90mA p**
- **$I_e$~40mA $e^+$**

# Kinematic Variables




**Virtuality of exchanged photon**

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

**Inelasticity: $0 \leq y \leq 1$** $\quad y = \dfrac{p \cdot q}{p \cdot k}$

**Fraction of proton momentum carried by struck parton** $\quad x = \dfrac{Q^2}{2q \cdot p}$

**$0 \leq x \leq 1$**

$\sqrt{s}$ **= Center of mass energy of the ep system** $\quad s = (p + k)^2 \cong 4E_e E_p$

**Center of mass energy of the $\gamma^*$P system** $\quad W^2 = (q + p)^2$

**Only two independent quantities** $\quad Q^2 = sxy$

# DIS cross-section and the Quark Parton Model→QCD

$$\frac{d^2\sigma(e^+p)}{dxdQ^2}(x,Q^2)=\frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right)F_2(x,Q^2)-y^2F_L(x,Q^2)-\left(1-(1-y)^2\right)xF_3(x,Q^2)\right]$$

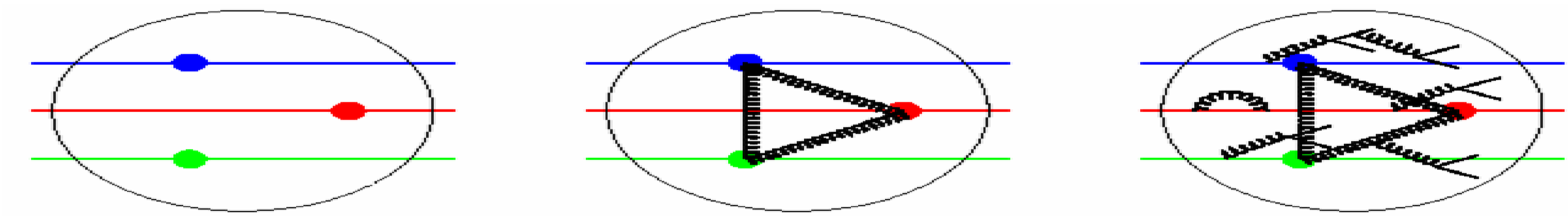
DIS cross-section can be written in terms of unit-less structure functions, F2, FL and xF3.

**Quark Parton Model (QPM):** The proton is made of quasi-free point-like constituents called partons, one parton participates in scattering

- Structure functions depend only on x, independent of $Q^2$ ← scaling
- Assuming spin ½ partons: $F_2(x) = 2xF_1(x)$ ➔ $F_L = 0$ (Callan-Gross)

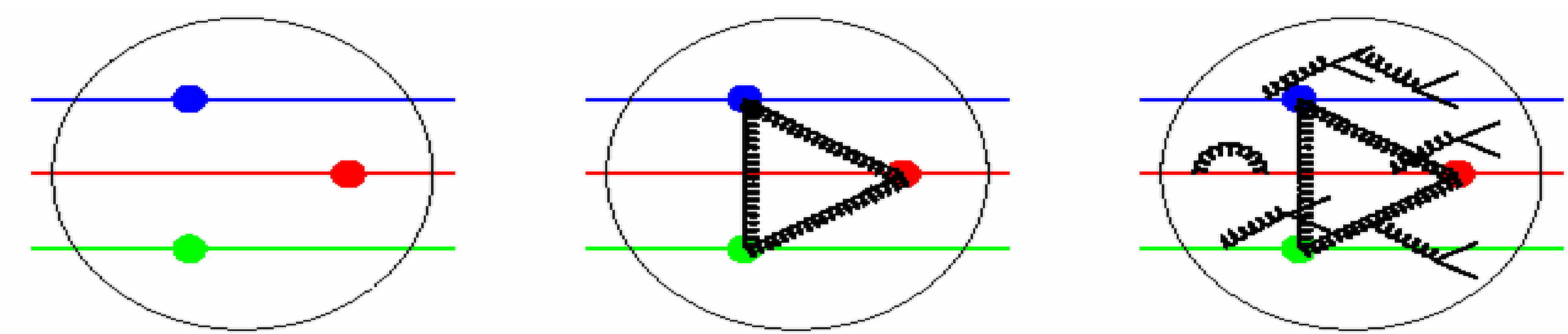
QPM: good in kinematic regions where effects of nuclear force negligible } Need QCD!

- Quarks carry ½ of protons momentum ➔ remainder taken by gluons
- Quarks radiate gluons, split into $q\bar{q}$ pairs: "sea quarks"
- Valence quarks carry higher momentum fraction, $F_2$ rises with $Q^2$ at low x. ← scaling violation



# QCD Theory

- QCD Quantum Chromodynamics
  - Strong force couples to color and is mediated by the gluon
  - Strong force increases as colored objects move apart: $\alpha_s$ "running"
  - Quarks confined within hadrons (color confinement) yet behave as free particles when probed at high energies
  - Gluons create quarks through pair production
  - Gluons themselves carry color, (a color charge and an anti-color)
  - The effect of polarization of virtual gluons in vacuum is to augment the color field. (anti-screening)



# Perturbative QCD

Leading Order (LO) → $A_1\alpha_S$ ; Next to Leading Order (NLO) → $A_2\alpha_S^2$

$$A = A_0 + A_1\alpha_S + A_2\alpha_S^2 + \ldots$$

## Perturbative QCD p(QCD)

Small $\alpha_s$ (hard scale)

Series expansion in $\alpha_s$ used to calculate observables

## Nonperturbative QCD

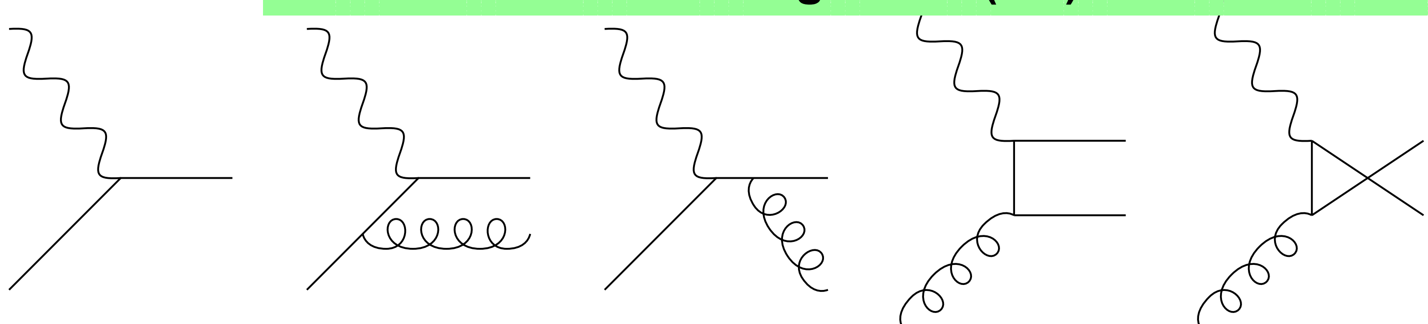
Large $\alpha_s$ (soft scale)

Series not convergent

**Each term in expansion consists of 1 or more integrals represented by a Feynman diagram**

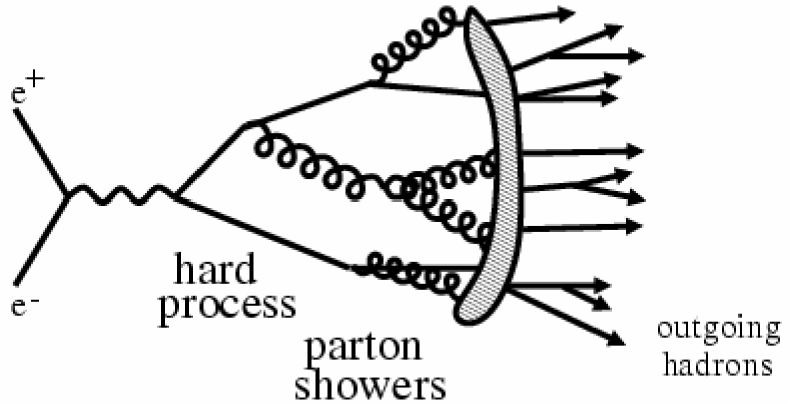
Lowest Order
no $\alpha_s$ vertex

Leading Order (LO)



QPM | QCD Compton (initial & final) | Boson gluon fusion

# From Partons to Hadrons




**hard scattering ⊗ parton showers ⊗ hadronization**

- Hard scattering: hard scale (short distance) perturbative process
- Parton showers: initial QCD radiation of partons from initial partons
- Hadronization: colorless hadrons produced from colored partons
  soft process (large distance) - not perturbatively calculable
  phenomenological models and experimental input

# Multiplicity and Energy Flow

- The hard scattering process determines the initial distribution of partons

- Parton Shower + Hadronization determine the number of charged particles produced

- Measure mean number of charged particles produced, (mean charged multiplicity, $\langle n_{ch} \rangle$), in ep DIS, versus the energy available for production of final state hadrons, study the mechanisms of hard scattering, parton showers and hadronization

- Universality of the hadronization process can be tested by comparison of measurements of the energy dependence of $\langle n_{ch} \rangle$ in reactions with different initial states: ep, e+e-, pp and fixed target DIS (μp & νp).

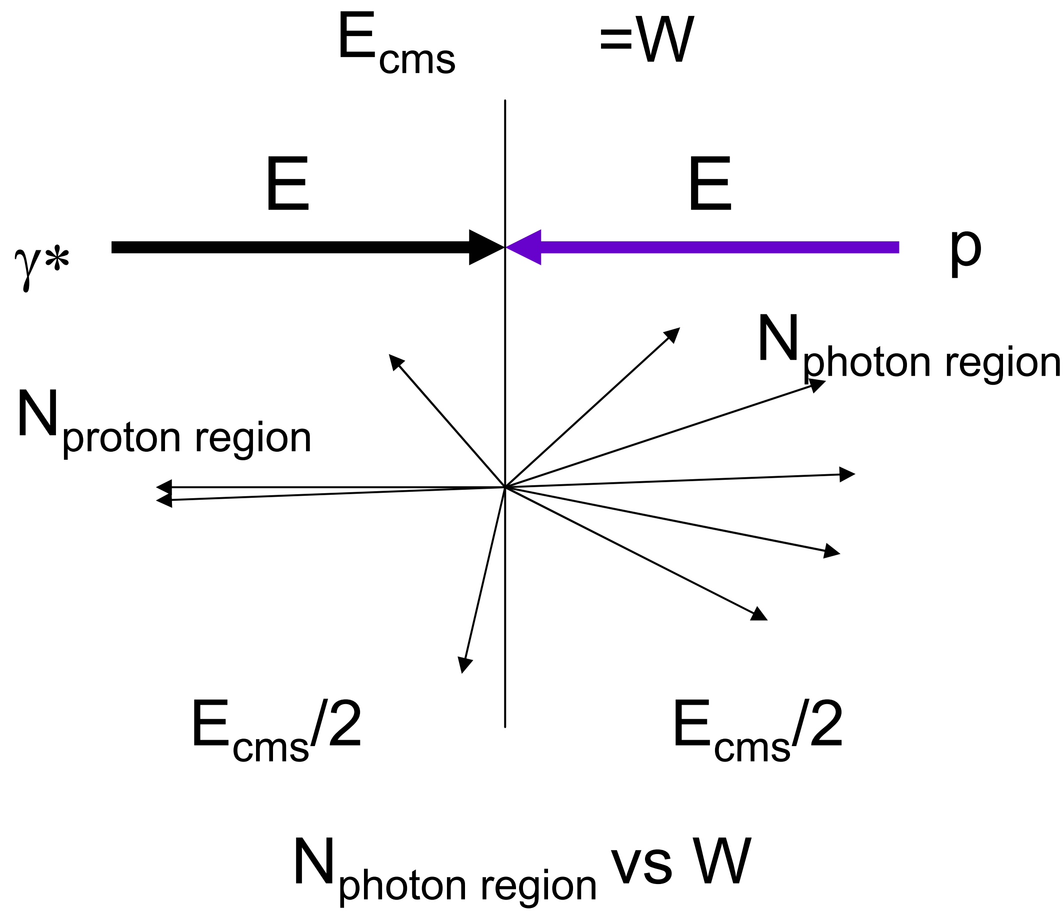
# Hadronic center of mass (HCM) frame

**Definition of HCM frame** $\vec{P} + \vec{q} = 0$

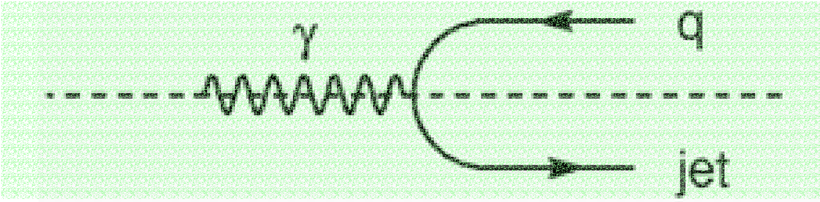
$$W = \sqrt{(q+P)^2}$$

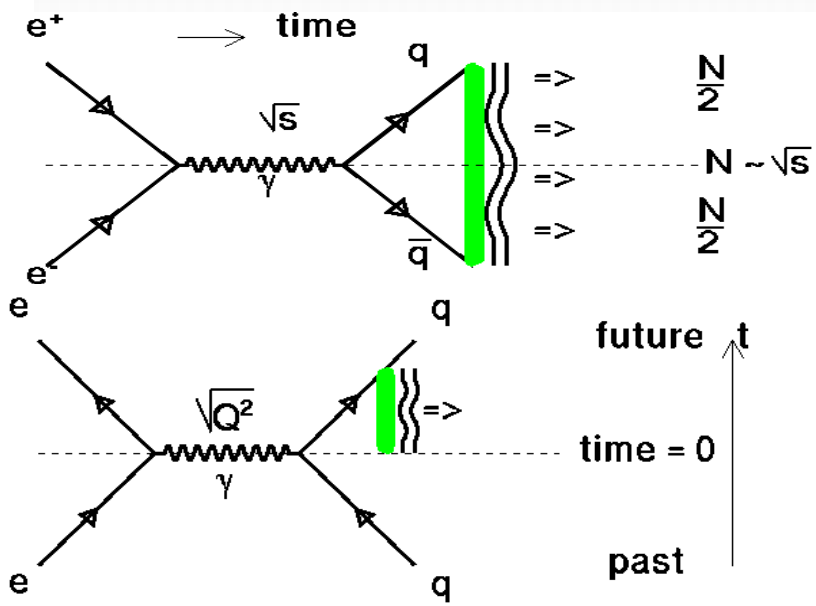
**Hadronic center of mass energy is W**

- **Forward moving particles: photon hemisphere**
- **Backward moving particles: proton hemisphere**
- **Incoming photon and proton E= W/2**
- **Final state: both hemispheres E=W/2**



# Breit Frame

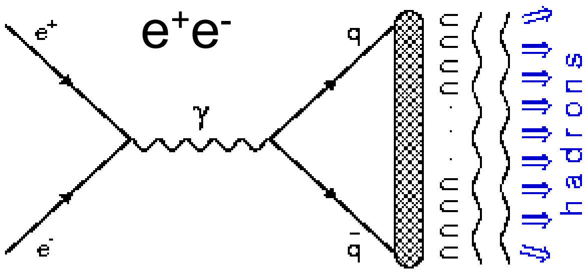


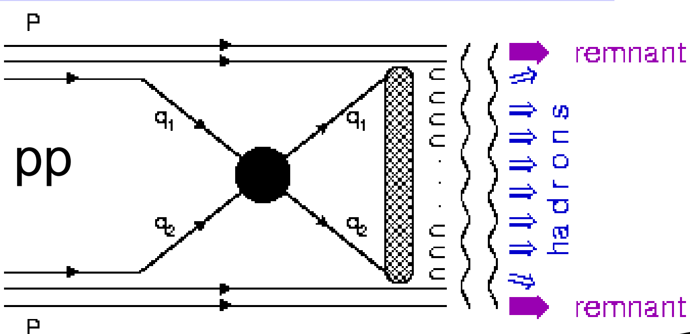

- "Brickwall" frame: incoming quark scatters off photon and returns along same axis
- Breit Frame definition: $2xP + q = 0$
- $p_Z<0$: current region, $p_Z>0$: target region
- Advantage: Current region is analogous to single hemisphere $e^+e^-$: diagrams are similar above dashed line
- In e+e- pair of quarks produced back to back with E=√s/2 each of them equiv. to the struck quark of E=Q/2 in DIS.
- ➔ Are they really the same?

**Mean charged multiplicity has been measured for various initial state interactions, e+e-, pp, ep DIS, and fixed target DIS, in both Breit and HCM frames**

# Previous Measurements: Multiplicity in $e^+e^-$ and pp




$$\sqrt{s_{e^+e^-}} = \sqrt{\left(p_{e^-} + p_{e^+}\right)^2}$$

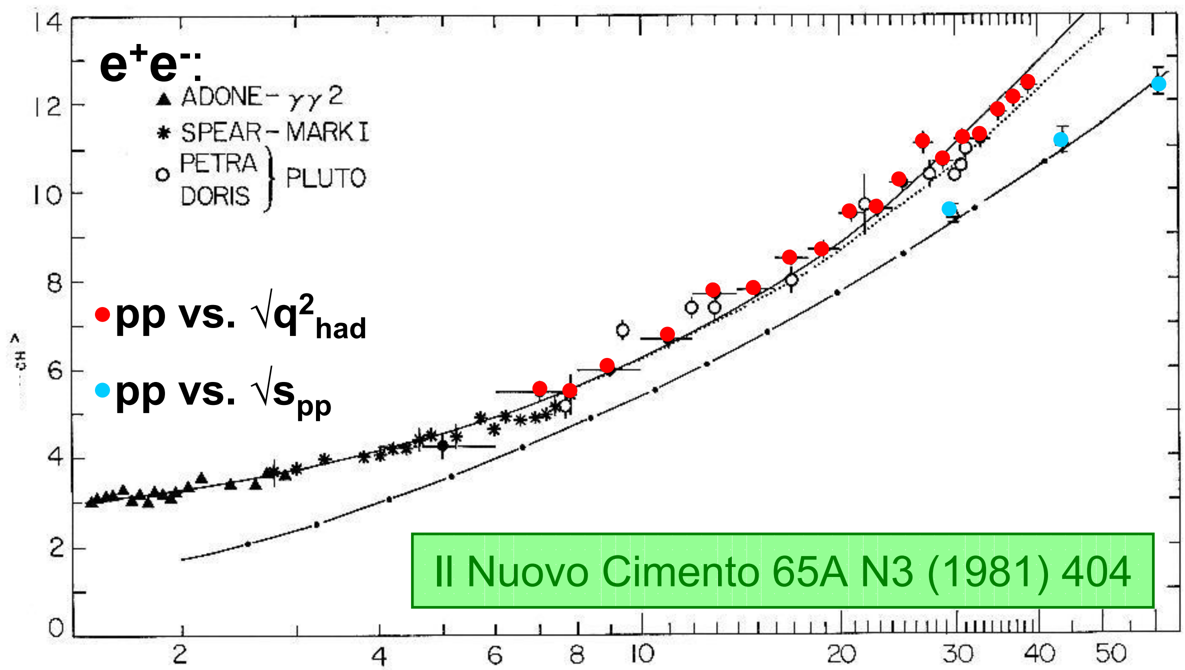



$$\sqrt{s_{pp}} = \sqrt{\left(p_p + p_p\right)^2}$$

Energy available for particle production

$$\sqrt{\left(q_{tot}^{had}\right)^2} = \sqrt{\left[\left(q_1^{inc} - q_1^{leading}\right) + \left(q_2^{inc} - q_2^{leading}\right)\right]^2}$$

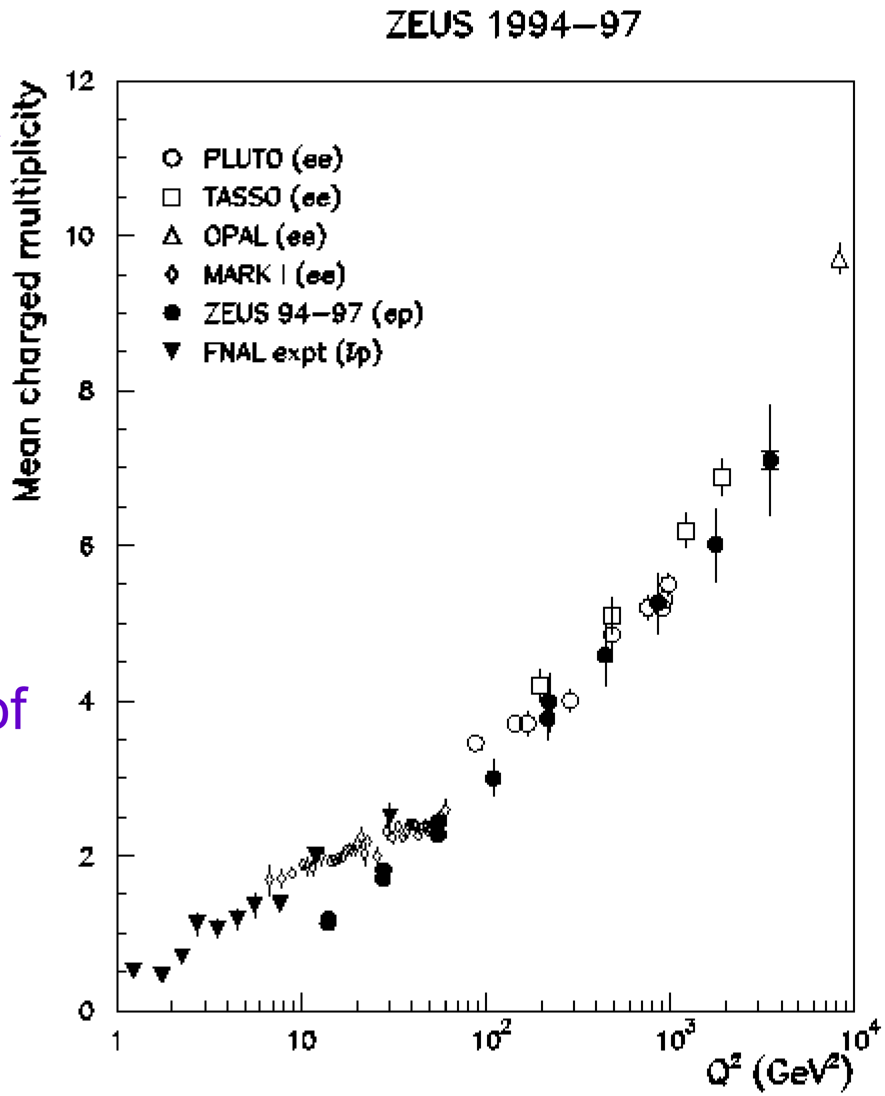
**$M_{inv}$ created within the detector**




- Agreement between $e^+e^-$ and pp plotted vs. $\sqrt{\left(q_{had}^2\right)^2}$

# Previous Measurements: Multiplicity vs. Q in Breit frame ep DIS

- Current region Breit frame multiplicity vs. $Q^2$ (hemisphere) shown along with $e^+e^-$ data (whole sphere divided by 2)
- Consistent with $e^+e^-$ data for high $Q^2$
  ➔ disagreement at $Q^2 < 80$ GeV$^2$
- ep has gluon radiation whereas $e^+e^-$ does not– (radiated gluons migrating out of current region-possible source of disagreement at low $Q^2$ )

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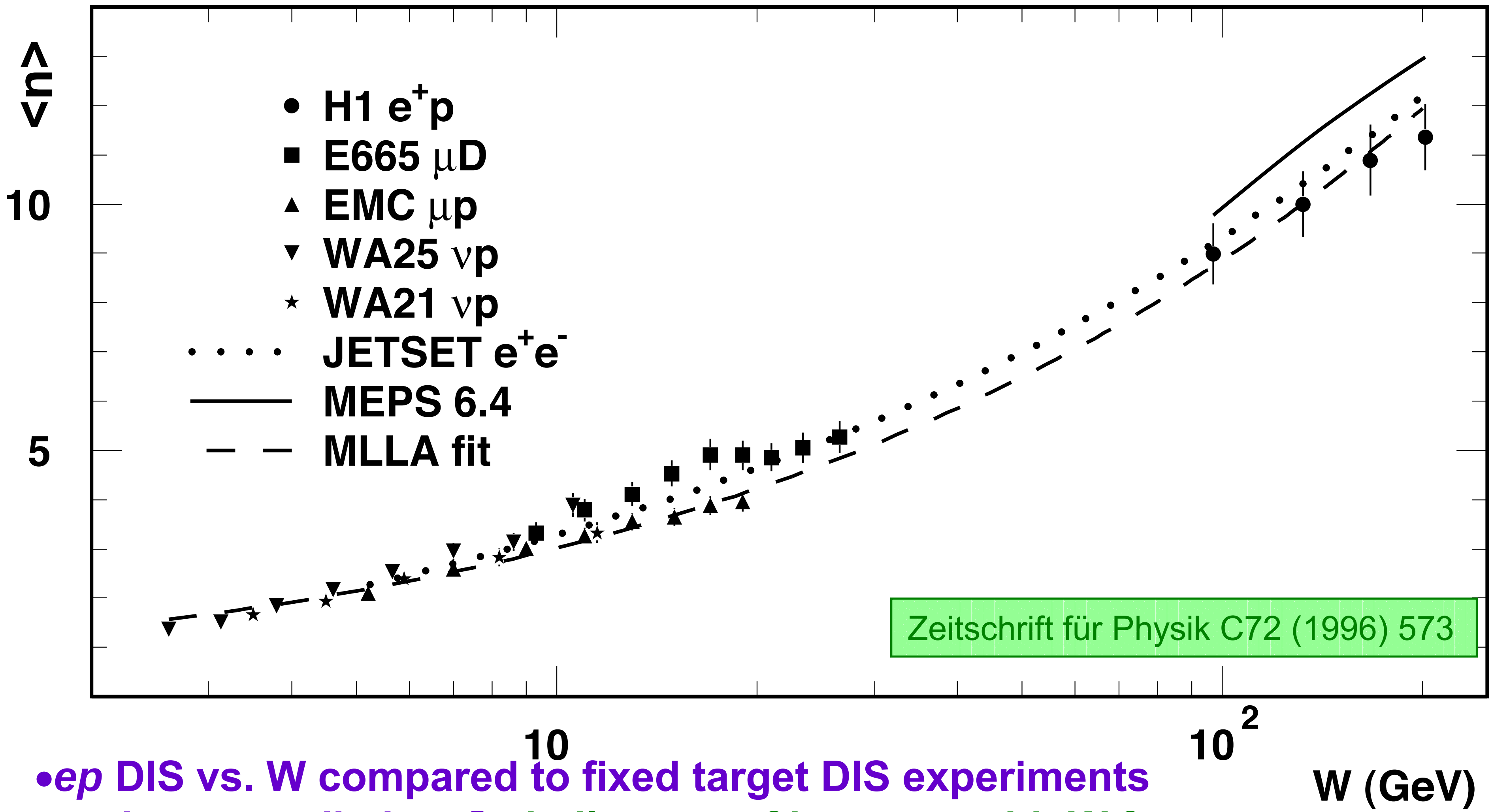
# Previous Measurements: Multiplicity vs. W in HCM frame ep DIS

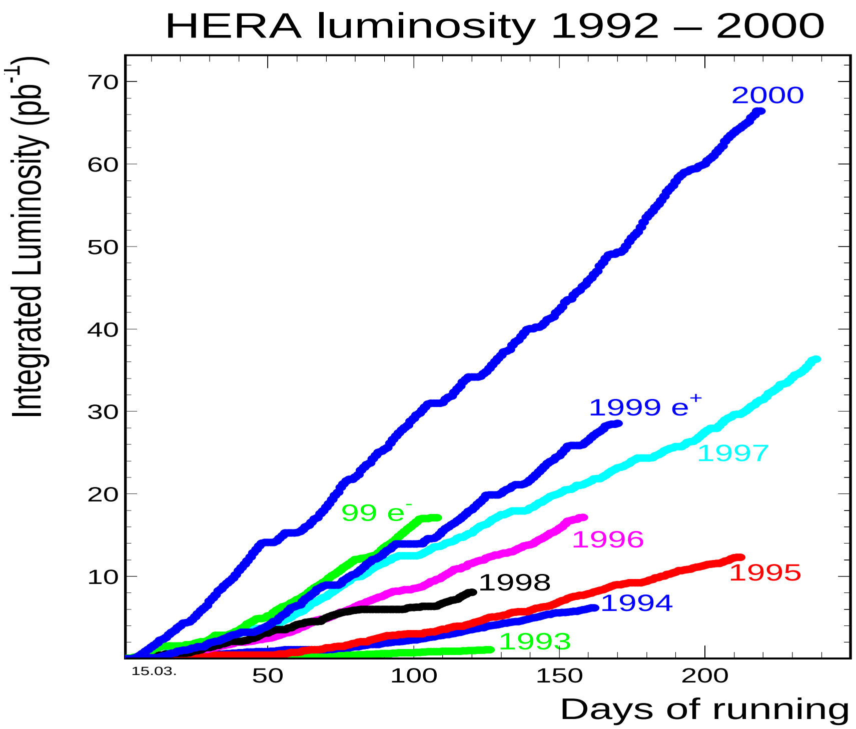



- *ep* DIS vs. W compared to fixed target DIS experiments and *e+e-* prediction ➔similar rate of increase with W for *ep* and *e+e-*

# Present Analysis

- Investigated energy dependence of <nch> in
  - photon region of HCM frame
    - compared to e+e-, pp and previous DIS
  - Breit Frame: current regions
    - compared to one hemisphere of e+e-: previous results show disagreement at low energies: used total energy in current region of Breit frame as a scale for comparison with e+e-
  - Laboratory frame: in bins of x and $Q^2$
  - Evaluated an alternative energy scale, the effective mass of hadronic system, $M_{eff}$
    - compared ep DIS $<n_{ch}>$ dependence on $M_{eff}$ in
      - current and target regions of Breit frame
      - current region Breit and photon region HCM frames

# HERA I Data



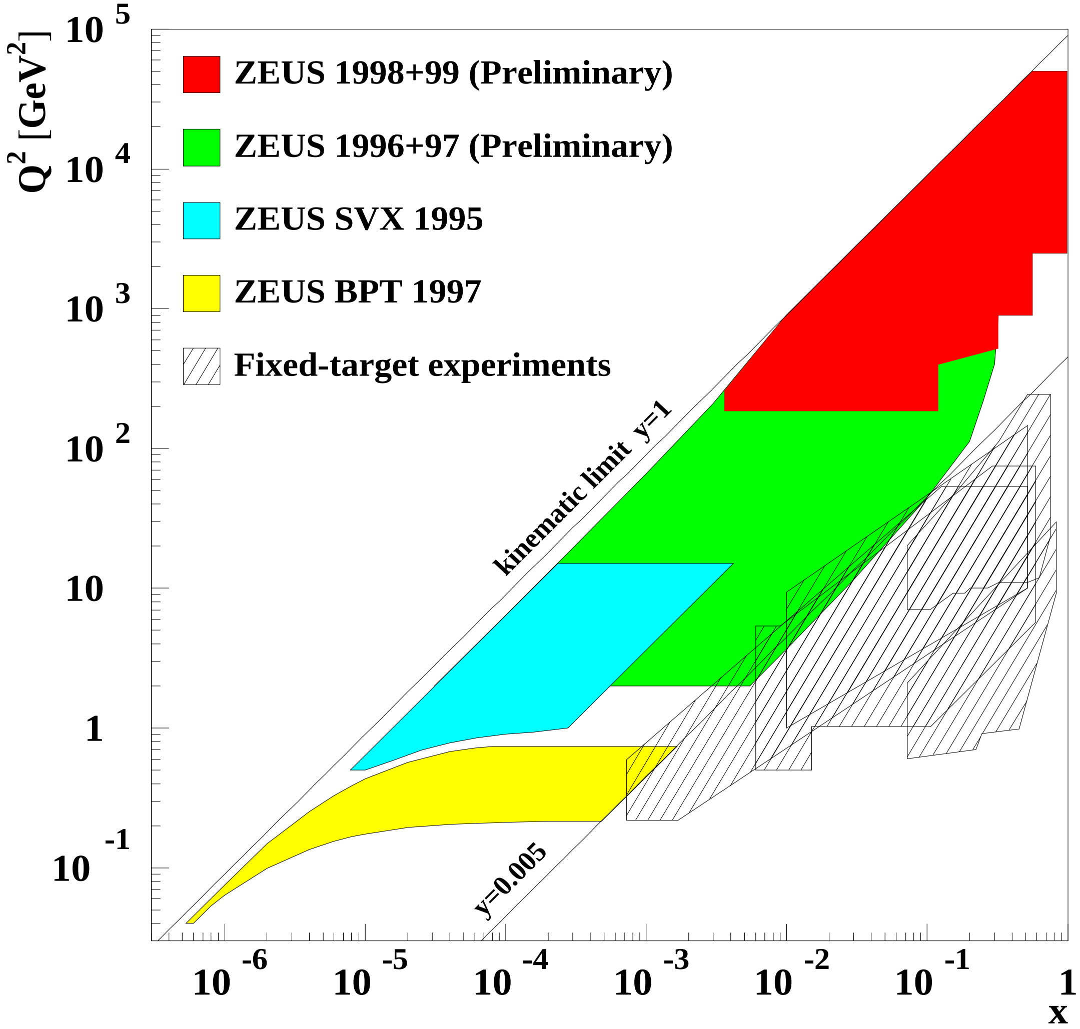

- Present Analysis not statistics limited
- Used well studied NC DIS sample of events taken in 1996-97
- positron–proton collisions
- Luminosity studied for this analysis: 38.58 $pb^{-1}$

**HERA II <u>Luminosity upgrade</u>**

- 5x increase in Luminosity

| ZEUS Luminosities ($pb^{-1}$) | | | # events ($10^6$) |
|---|---|---|---|
| Year | HERA | ZEUS on-tape | Physics |
| **$e^-$**: *93-94, 98-99* | 27.37 | 18.77 | 32.01 |
| **$e^+$**: *94-97, 99-00* | 165.87 | 124.54 | 147.55 |

# HERA Kinematic Range

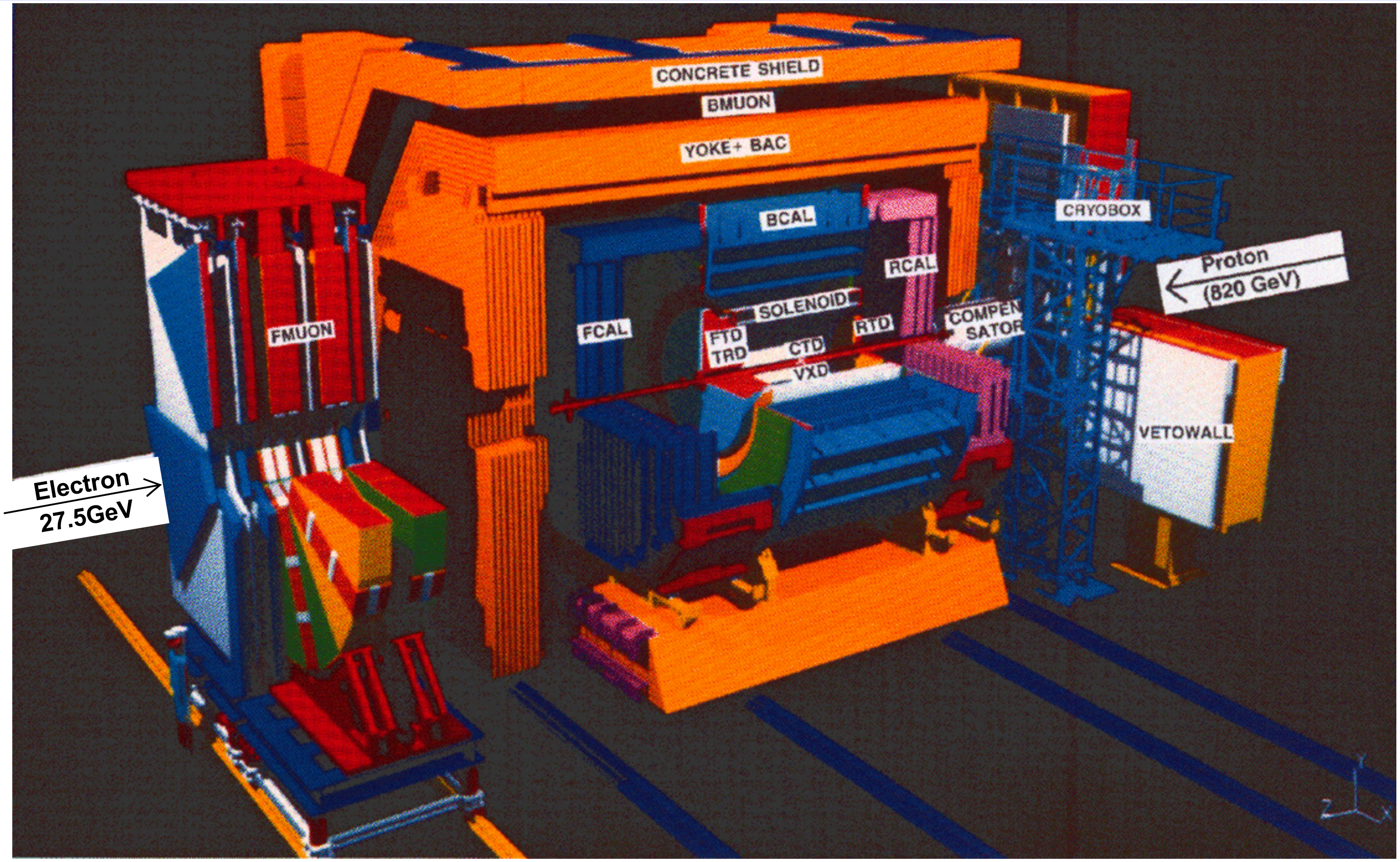



$Q^2 = sxy$

$0.1 < Q^2 < 20000\ GeV^2$

$10^{-6} < x < 0.9$

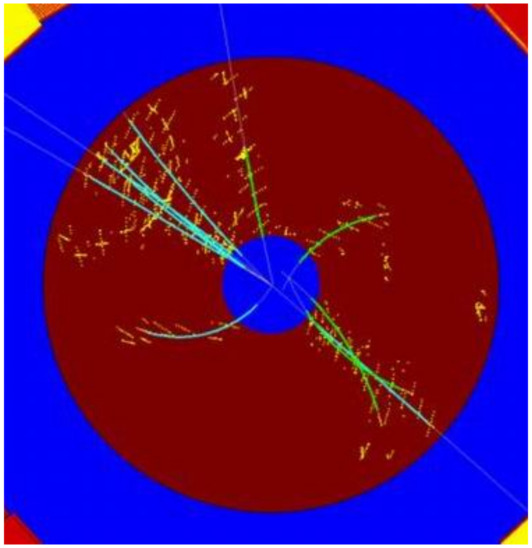
# ZEUS Detector




•General Purpose Detector •Almost hermetic

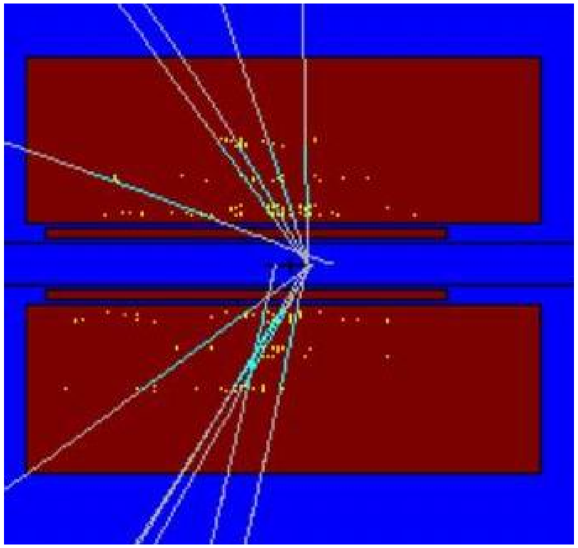
•Measure ep final state particles: energy, particle type and direction

# Central Tracking Detector



View Along Beam Pipe

e →



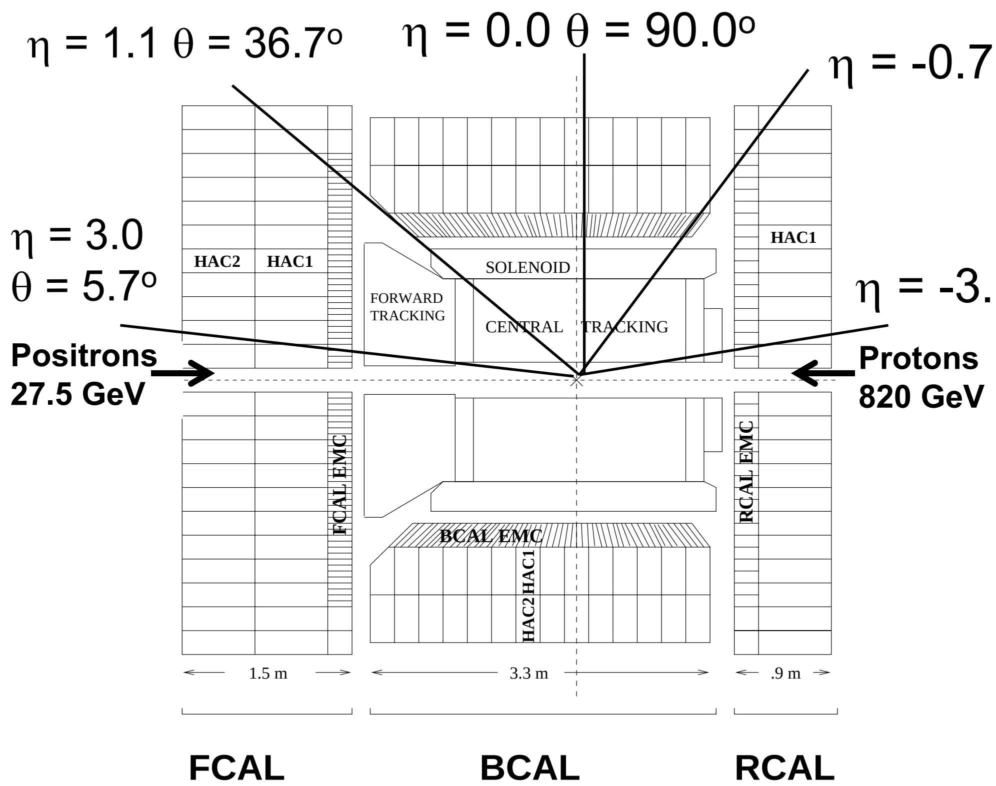
← p

Side View

- Drift Chamber inside 1.43 T Solenoid
- Can resolve up to 500 charged tracks
- Average event has ~20-40 charged tracks
- Determine interaction vertex of the event
- Measure number of charged particles (tracks)
- Region of good acceptance: -1.75 < η < 1.75

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

# Uranium-Scintillator Calorimeter (CAL)




- alternating uranium and scintillator plates (sandwich calorimeter)
- compensating - equal signal from hadrons and electromagnetic particles of same energy - e/h = 1
- Energy resolution $\sigma_e/E_e$= 18% / $\sqrt{E}$ $\sigma_h/E_h$= 35% / $\sqrt{E}$ , E in GeV
- covers 99.6% of the solid angle

- Depth of FCAL > RCAL due to $E_p > E_e$

Served as CAL calibration and data quality expert during time at ZEUS

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

# ZEUS Trigger

**$10^7$ Hz Crossing Rate, $10^5$ Hz Background Rate, 10 Hz Physics Rate**

## ➔First Level

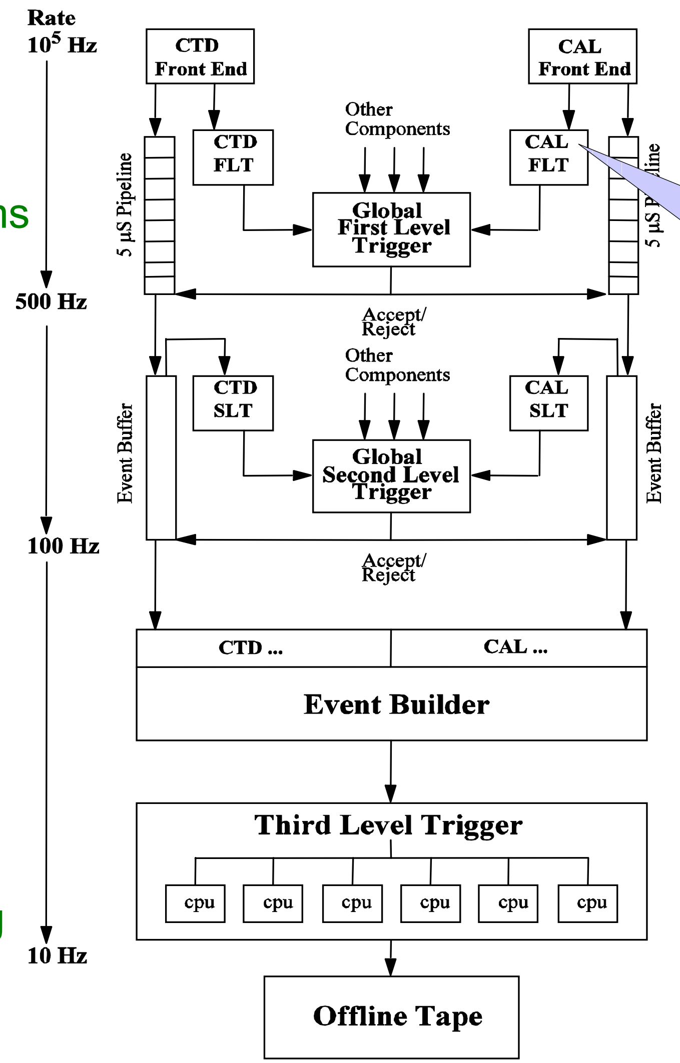
- Dedicated custom hardware
- Pipelined without deadtime
- Global and regional energy sums
- Isolated $\mu$ and $e^+$ recognition
- Track quality information

## ➔Second Level

- "Commodity" Transputers
- Calorimeter timing cuts
- E - $p_z$ cuts
- Vertex information
- Simple physics filters

## ➔Third Level

- Commodity processor farm
- Full event info available
- Refined Jet and electron finding
- Advanced physics filters




UW group responsible for CFLT

# Modeling DIS with Monte Carlo

**Event generators use algorithms based on QCD and phenomenological models to simulate DIS events**

- Hard subprocess: pQCD
- Parton Cascade
- Hadronization
- Detector Simulation
  - correct for detector effects: finite efficiency, resolutions & acceptances

**Hadronization Models**

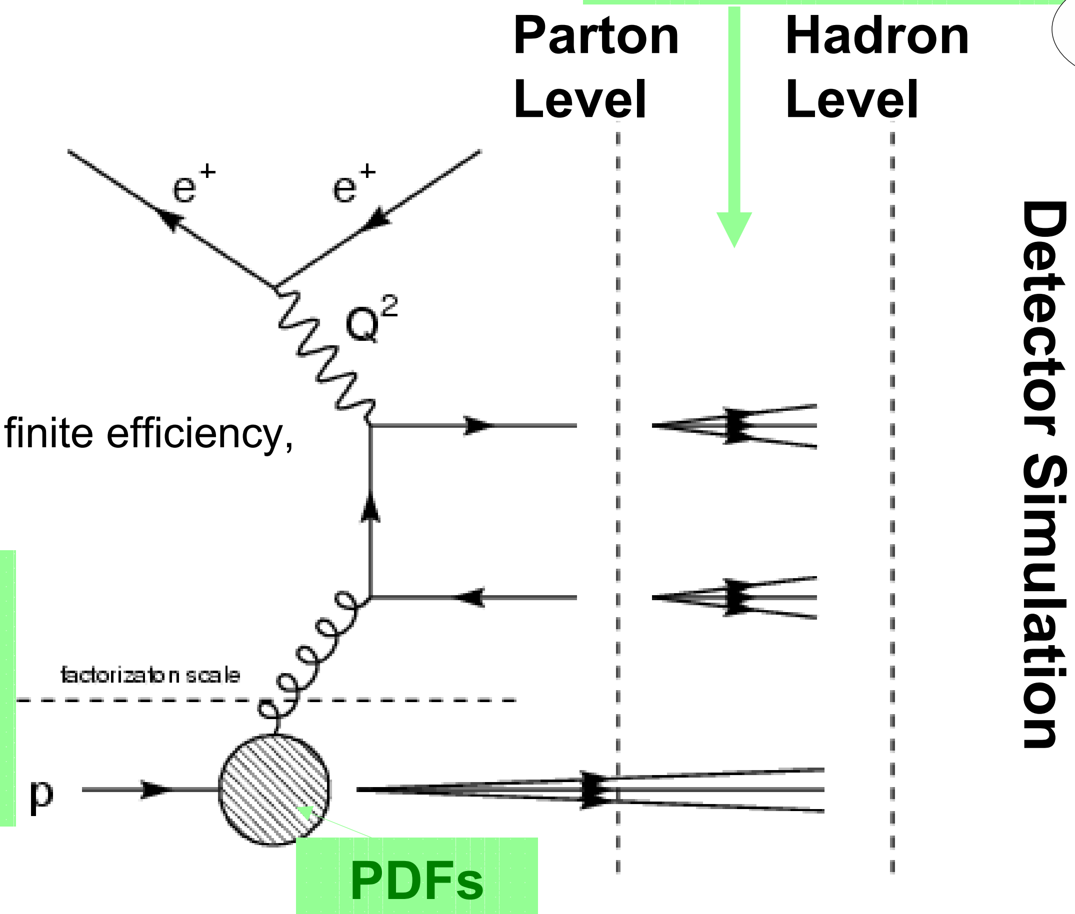
- **String Fragmentation (Lund)**
- **Cluster Model**

Next slide

**Parton Cascades**

- **LO Matrix Element + Parton Showers (MEPS)**
- **Color Dipole Model (CDM)**

Next slide

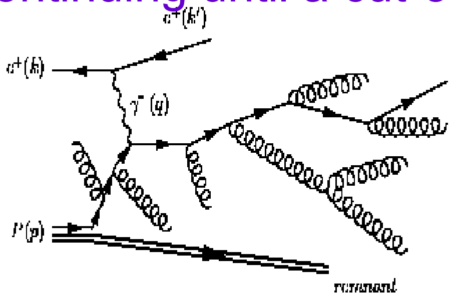


# Monte Carlo models: parton cascades and hadronization

## Models for parton cascades:

### Parton Shower Model:

- cascade of partons with decreasing virtuality continuing until a cut-off

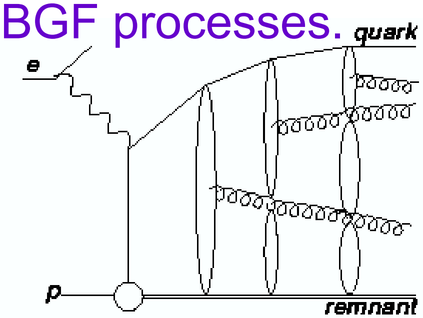



LEPTO
HERWIG

### Color Dipole Model:

- Gluons are emitted from the color field between quark-antiquark pairs, supplemented with BGF processes.

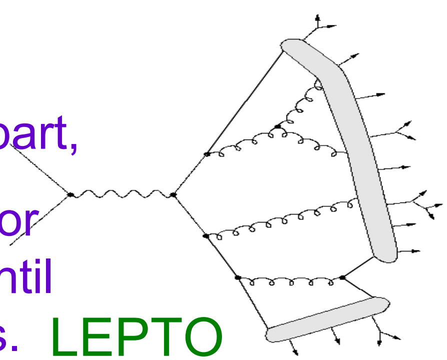
ARIADNE




## Hadronization models:

### Lund String Model:

- color "string" stretched between q and q moving apart,
- string breaks to form 2 color singlet strings, and so on until only on-mass-shell hadrons.



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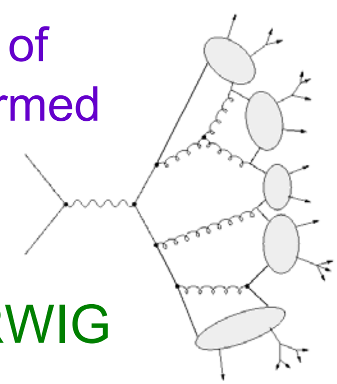
ARIADNE

### Cluster Fragmentation Model:

- color-singlet clusters of neighboring partons formed
- Clusters decay into hadrons

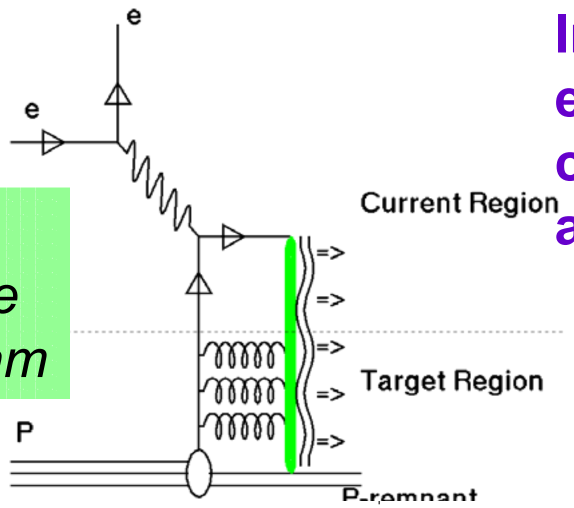
HERWIG



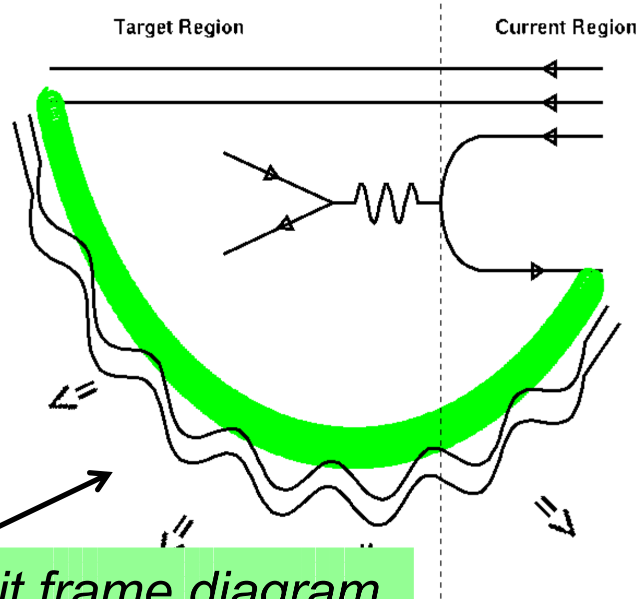
# 1996-97 Data sample

- **Event Selection**
  - Scattered positron found with $E > 12$ GeV
  - A reconstructed vertex with $|Z_{vtx}| < 50$ cm
  - Scattered positron position cut: radius > 25cm
  - 40 GeV < $E\text{-}p_z$ < 60 GeV
  - Diffractive contribution excluded by requiring $\eta_{max} > 3.2$
- **Track Selection**
  - Tracks associated with primary vertex
  - $|\eta| < 1.75$
  - $p_T > 150$ MeV
- **Physics and Kinematic Requirement**
  - $Q^2_{da} > 25$ GeV$^2$
  - $y_{el} < 0.95$
  - $y_{JB} > 0.04$
  - 70 GeV < W < 225 GeV **( $W^2 = (q + p)^2$ )**

# Analysis Methods: Breit Frame




Lab frame diagram



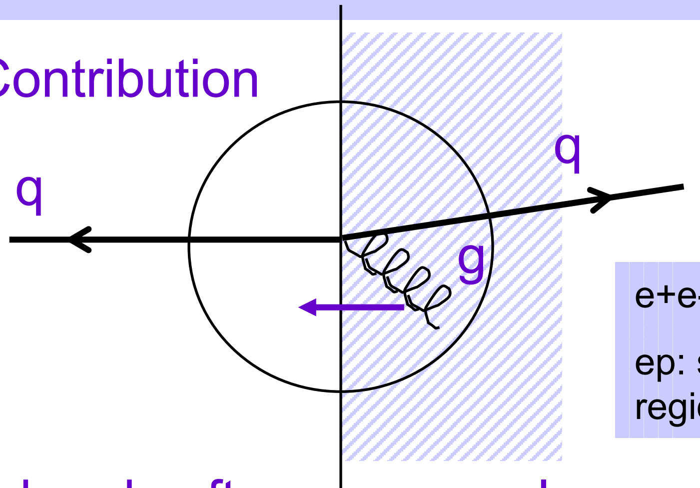

Breit frame diagram

**Investigated cause of disagreement between ep vs. Q and e+e- at low energies➔ look more closely at comparison of one hemisphere e+e- and current region Breit frame**

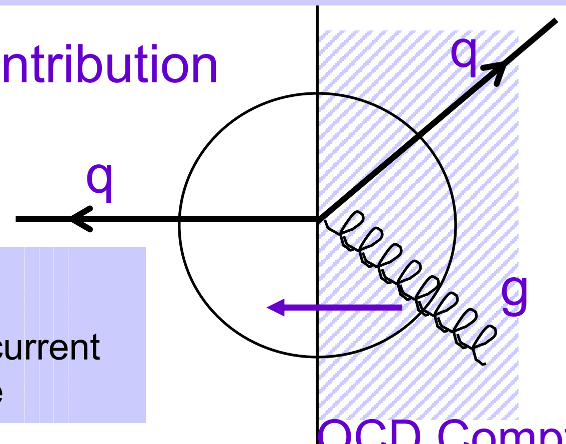
- ep: Split into Current and Target Region – one string two segments.
- In ep we have a color field between 2 colored objects the struck quark and the proton remnant
- When we use $Q^2$ as a scale we are assuming the configuration is as symmetric as it is in $e^+e^-$, but it isn't
- This asymmetric configuration leads to migration of particles from the current region to the target region

# Current region Breit Frame
# Q and 2*$E_{Breit}$

Soft Contribution




Hard Contribution




QCD Compton

e+e-: whole sphere

ep: shaded region: current region of Breit frame

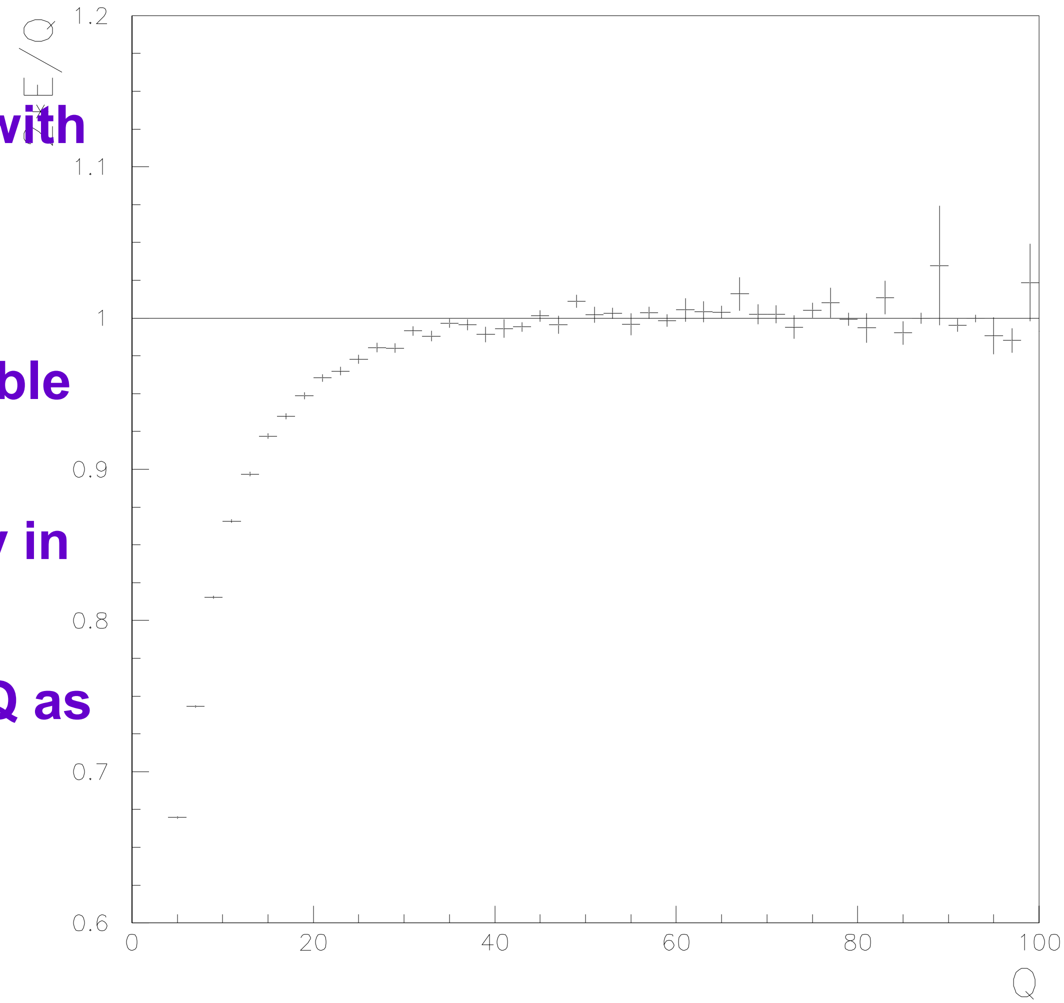
- In hard and soft processes gluon radiation occurs
- These gluons can migrate to target region
- Total energy in the current region of Breit frame and multiplicity are decreased due to these migrations ($Q^2$ is not)
- Effect is more pronounced for low $Q^2$ : more low energy gluons

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

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

# Effects of gluon migrations

- $2{*}E_{current}/Q$ as a function of Q with ARIADNE
- Higher energies: $2{*}E_{current} = Q$
  - ➔Gluon migrations negligible
- Lower energies: Q doesn't accurately reflect actual energy in hemisphere.
- Must Use $2{*}E_{current}$ instead of Q as a scale for comparing with $e^+e^-$



# Analysis Methods: photon hemisphere HCM frame

**Check migrations in HCM frame: Is it better to use $2*E_{photon}$ instead of W?**

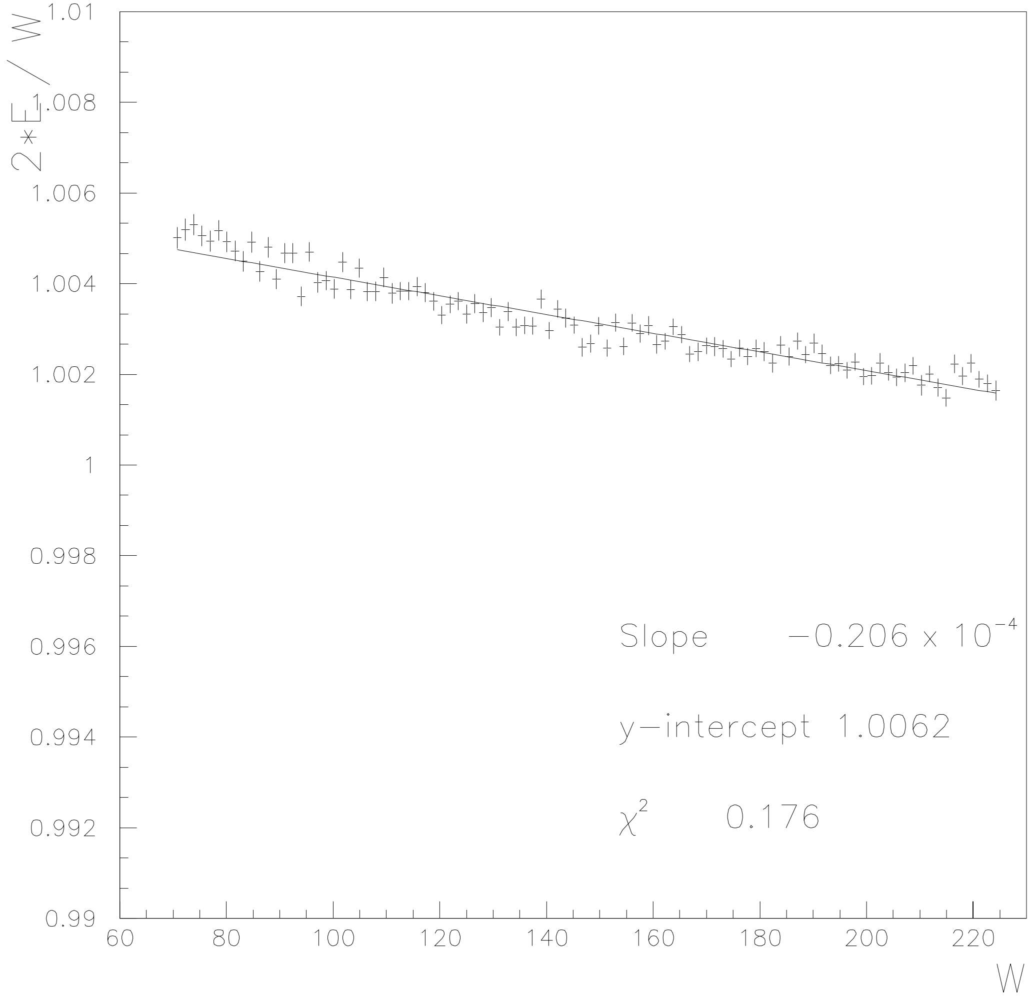
$2*E_{photon}/W$ as function of W with ARIADNE

Difference is negligible

Measure dependence of $\langle n_{ch} \rangle$ on energy available for particle production, $M_{inv}$, in HCM as was done in Breit frame

Migrations here are small ➔ $2*E_{photon} \approx W$

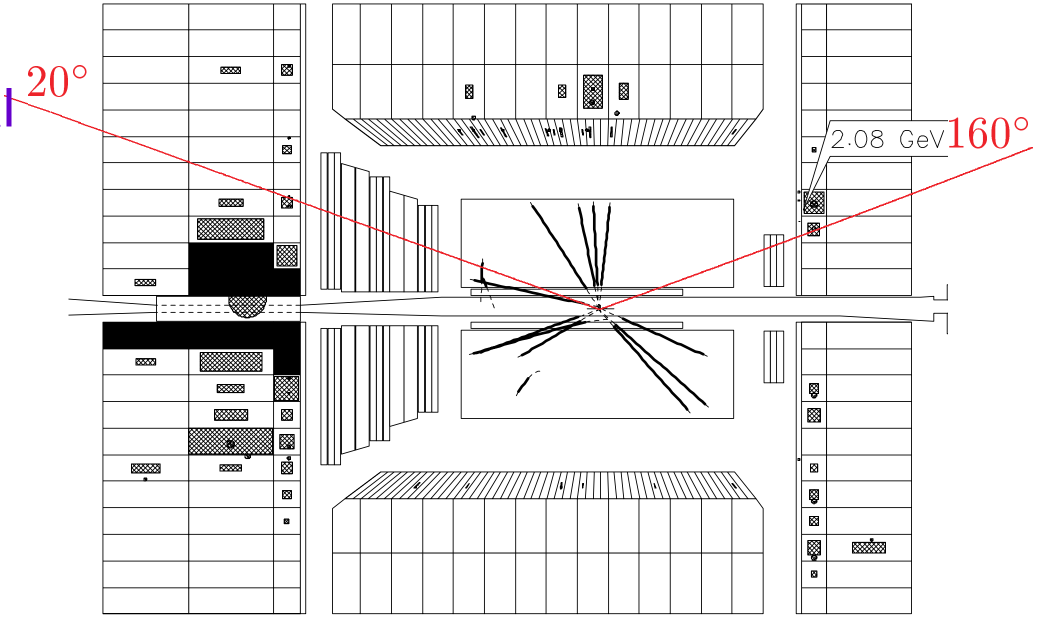
$M_{inv} = W$ ➔ use W as scale



# Invariant Mass of Hadronic System

**Following idea in pp: Use $M_{inv}$ created within the detector as a scale**

- Measure hadronic final state within $\Delta\eta$ for best acceptance in the central tracking detector (CTD)
- Measure # charged tracks, reconstruct number of charged hadrons
- Measure invariant mass of the system ($M_{eff}$) in corresponding $\Delta\eta$ region.
- Energy is measured in the Calorimeter (CAL)




$$M_{eff}^2 = (\sum_{i \neq e'} E^i)^2 - (\sum_{i \neq e'} p_x^i)^2 - (\sum_{i \neq e'} p_y^i)^2 - (\sum_{i \neq e'} p_z^i)^2$$

**Used as a scale to compare:**

**current and target regions of Breit frame**

**current region Breit frame to photon region HCM**

Study: $<n_{ch}>$ vs. $M_{eff}$

CTD (for $n_{ch}$)

CAL within the CTD acceptance (for $M_{eff}$)

# Corrections: detector level to hadron level

**ZEUS data: convolution of real physical quantities and detector effects**

**To understand underlying physics must remove effects specific to ZEUS detector**

**Bin-by-bin method: a correction factor (C) is calculated for each bin *i* which corrects for purity (p) <100% and efficiency (e) <100%**

**p = percentage of correctly detected events**

**e = percentage of generated events that are detected**

$$p = \frac{\text{had}_i \oplus \det_i}{\det_i} \qquad e = \frac{\text{had}_i \oplus \det_i}{\text{had}_i} \qquad C = \frac{p}{e} = \frac{\text{had}_i}{\det_i}$$

The correction factor, C, is a number for each bin which is multiplied by the data

Straight forward method for correcting cross sections. We correct the energy scale in this way, but to correct the track distributions must use other methods:

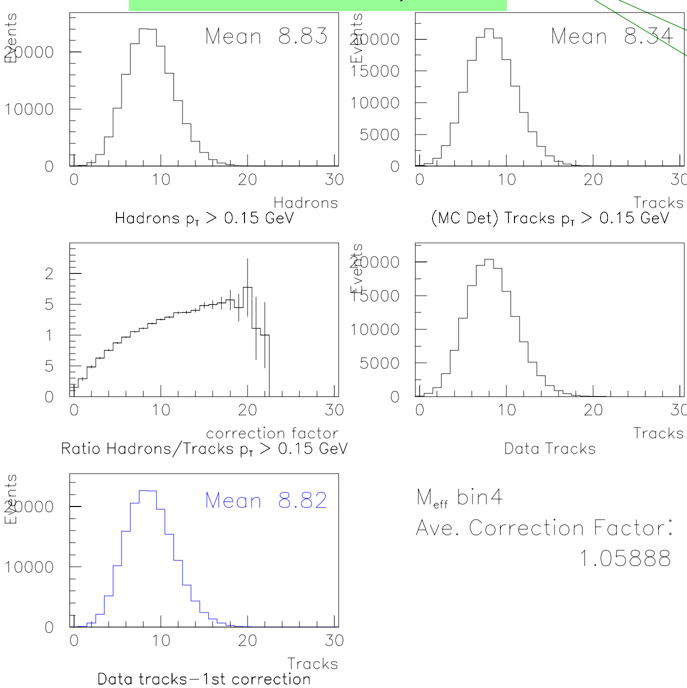
**modified bin-by-bin method and Matrix unfolding method**

# Detector level to hadron level: Modified bin-by-bin correction

**Part one**: correct to hadron level using only hadrons generated with $p_T$ > 0.15 GeV (Detector Effects)

$$C_{1,i} = \frac{n_{ch,i}^{GEN,0.15}}{n_{ch,i}^{DET}}$$

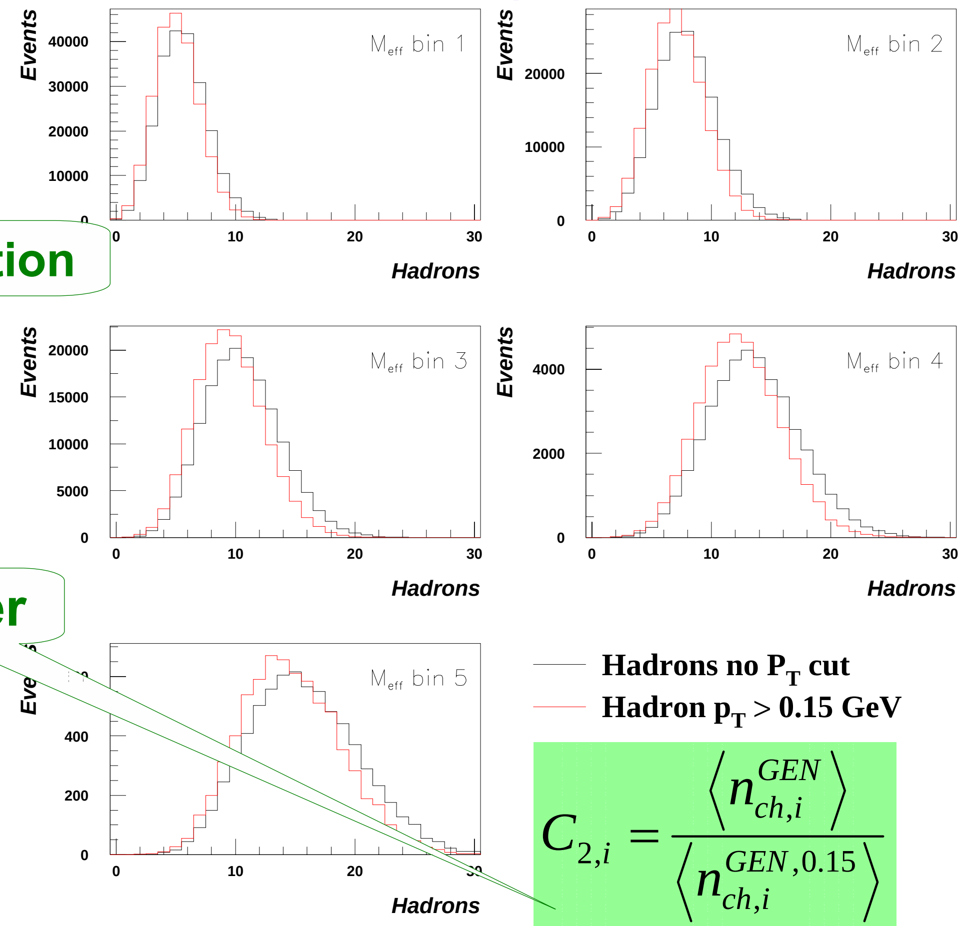
distribution




$$\langle n_{ch,i}^{corrected} \rangle = \langle n_{ch,i}^{DATA} \cdot C_{1,i} \rangle \cdot C_{2,i}$$

**Part two**: correct for hadrons with lower $p_T$, using ratio of <gen> with $p_T$ cut to <gen> no $p_T$ cut in each bin.

number




$$C_{2,i} = \frac{\langle n_{ch,i}^{GEN} \rangle}{\langle n_{ch,i}^{GEN,0.15} \rangle}$$

# Detector level to hadron level: Modified bin-by-bin correction

Average correction for detector effects: $\langle C_{1,i} \rangle$

$$C_{1,i} = \frac{n_{ch,i}^{GEN,0.15}}{n_{ch,i}^{DET}}$$

Correction of hadrons of $p_T > 0.15$ GeV to all hadrons

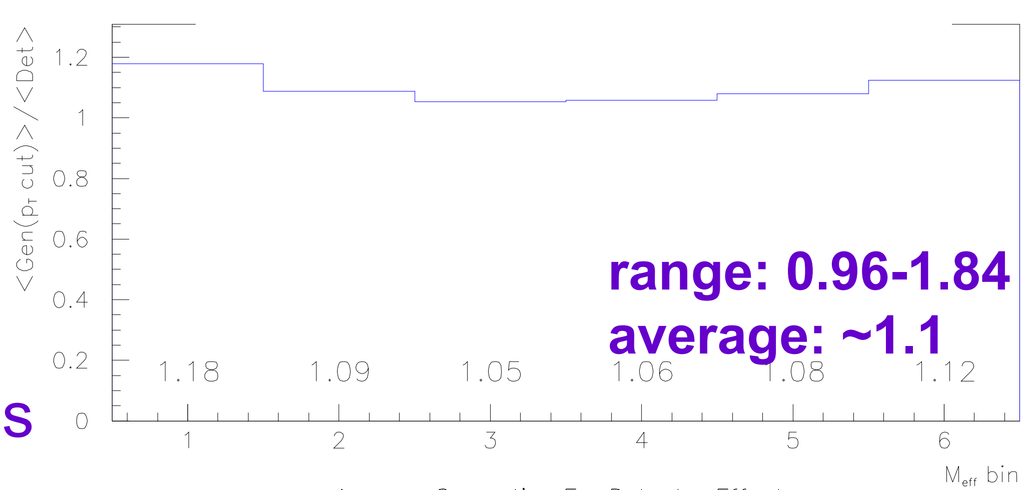
$$C_{2,i} = \frac{\langle n_{ch,i}^{GEN} \rangle}{\langle n_{ch,i}^{GEN,0.15} \rangle}$$

**Invariant Mass correction: normal bin-by-bin method:**

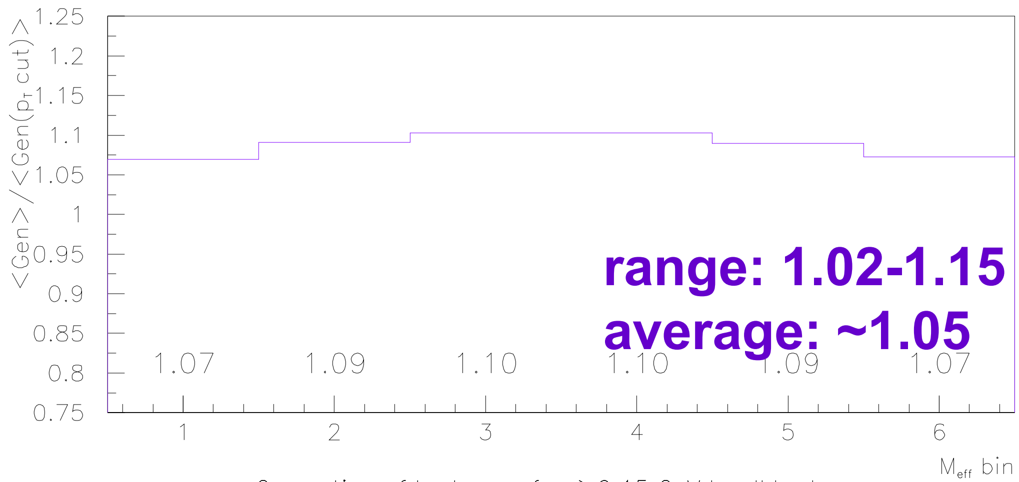
$$M_{inv} = \langle M_{inv}^{DATA} \rangle \frac{\langle M_{inv}^{GEN} \rangle}{\langle M_{inv}^{DET} \rangle}$$

**Average less than 2%**

**Example: lab frame vs. $M_{eff}$**




Average Correction For Detector Effects



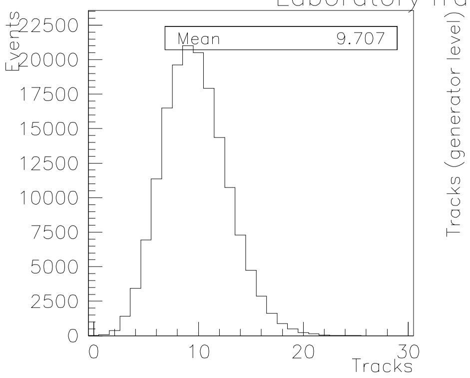

Correction of hadrons of $p_T$ >0.15 GeV to all hadrons

# Detector level to hadron level: Matrix Correction

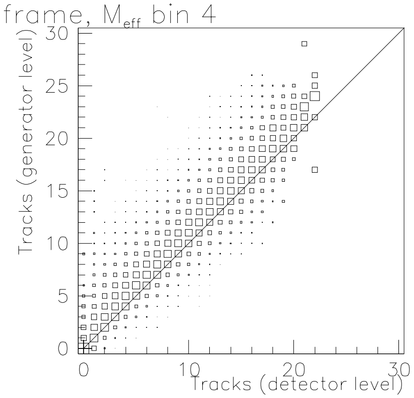
## Step 1: Correction Matrix:

$$M_{n_{GEN},n_{DET}} = \frac{\text{No. of events with } n_{ch}^{GEN} \text{ hadrons generated and } n_{ch}^{DET} \text{ tracks observed}}{\text{No. of events with } n_{ch}^{DET} \text{ tracks observed}}$$

Laboratory frame, $M_{eff}$ bin 4



a) Data distribution after Matrix correction

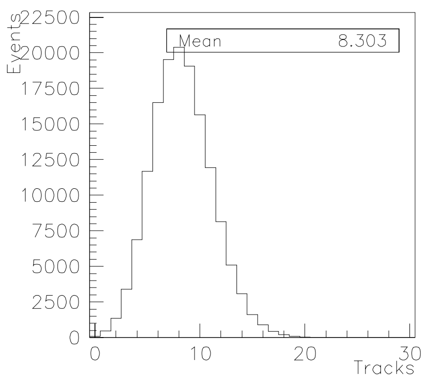


b) Correction Matrix

Starts at zero and runs through all possible n combinations

The matrix relates the observed to the generated distributions by:

$$P_{n_{GEN}} = \sum_{n_{DET}} M_{n_{GEN},n_{DET}} \cdot P_{n_{DET}}$$



c) Uncorrected data distribution

## Step 2: Correction for acceptance of event selection cuts in the bins

$$C = \frac{\rho_{GEN}}{\rho_{DET}}$$

$\rho_{GEN}$ :distribution with GEN level cuts

$\rho_{DET}$ :distribution with GEN level cuts

- Matrix corrects tracks to hadron level
- ρ corrects phase space to hadron level

# Detector level to hadron level: Matrix Correction

**To illustrate average size of 1st part of correction:**

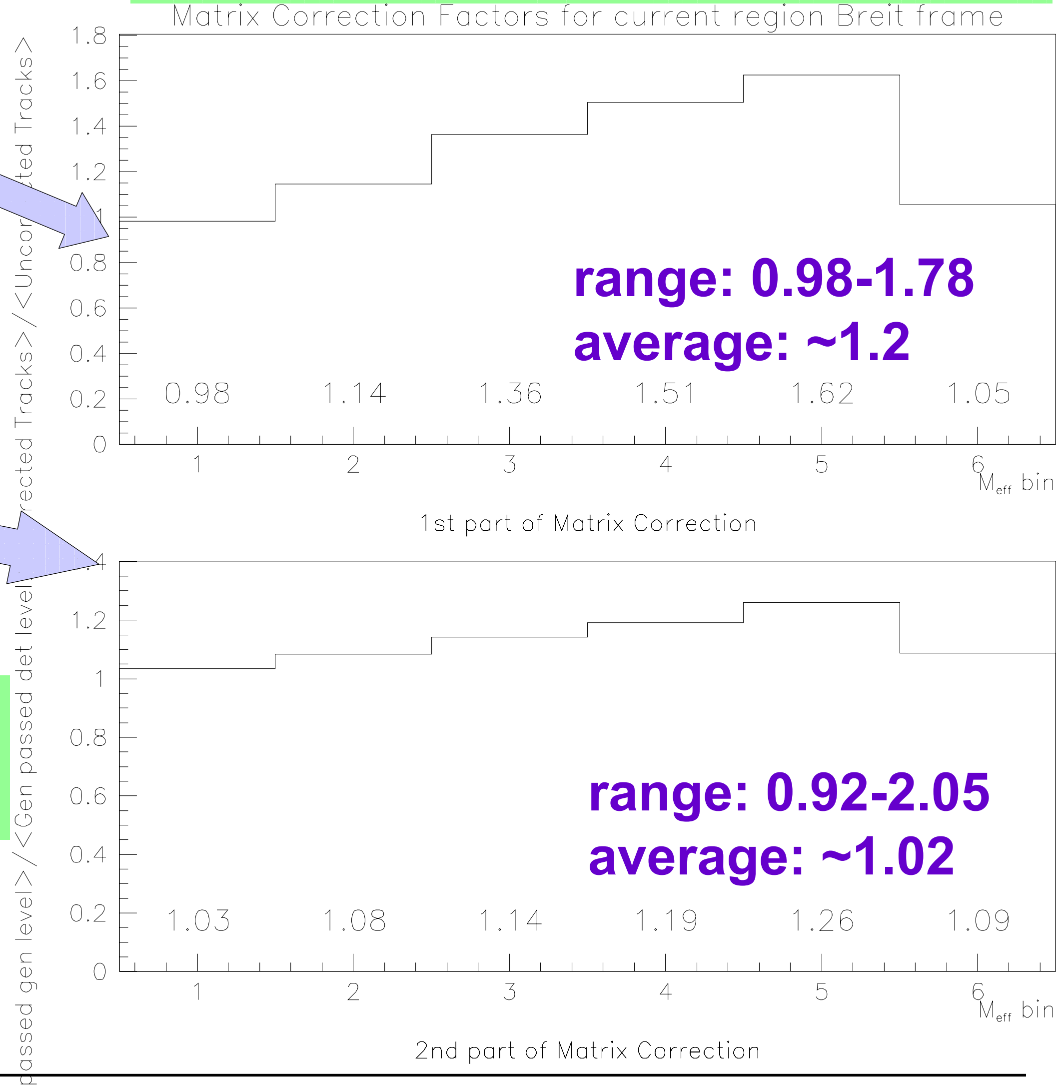
**Mean matrix correction factor:**

$$\frac{\langle \text{uncorrected tracks distribution} \rangle}{\langle \text{track distribution after matrix correction} \rangle}$$

Mean of *C* distributions:

$$P_{n_{corrected}} = C \cdot \sum_{n_{data}} M_{n_{GEN}, n_{data}} \cdot P_{n_{data}}$$

Example: current region of Breit frame vs. 2*E



# Acceptance correction: Current region of Breit frame:

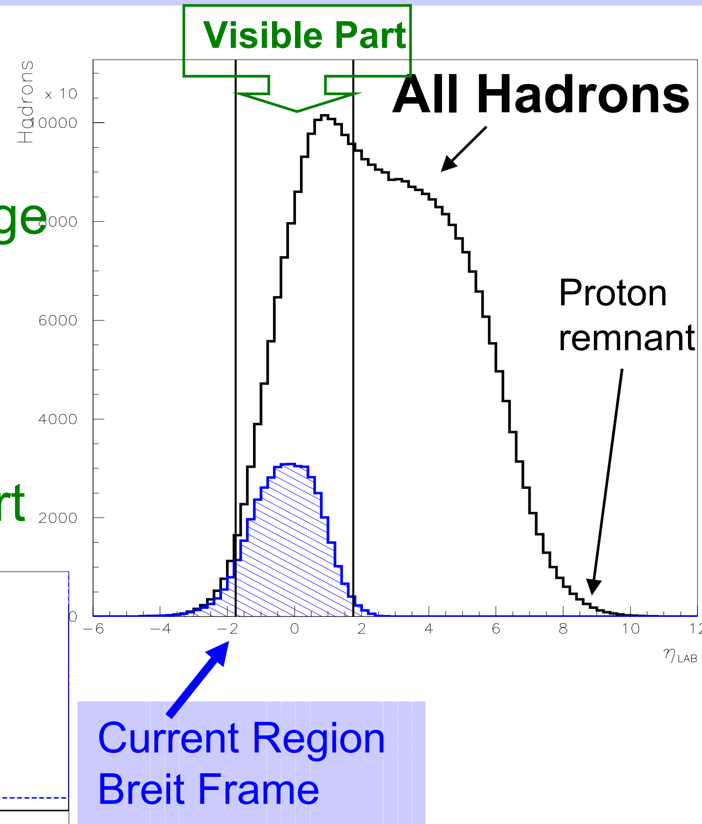
- **Breit Frame**: 95% of hadrons in current region visible in detector, only 30% of target region hadrons are visible

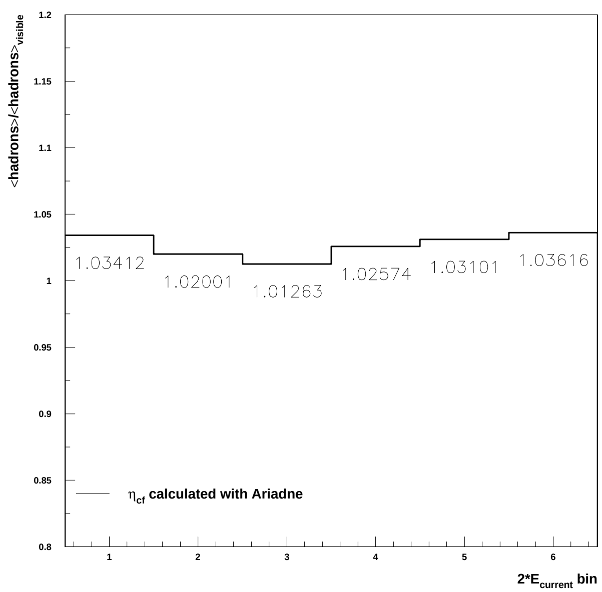
Generated in full η range

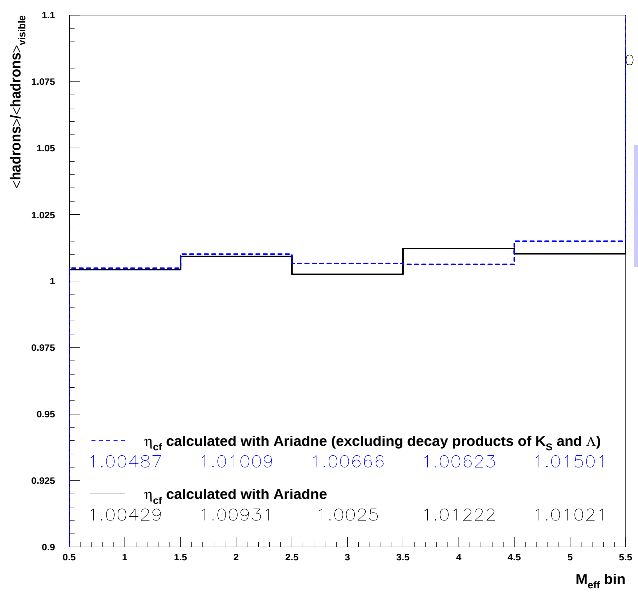
$$C_{\eta}^{hadrons} = \frac{\left\langle n_{ch}^{GEN} \right\rangle}{\left\langle n_{ch}^{GEN,visible} \right\rangle}$$

Generated in visible part

Multiplied by $\langle n_{ch} \rangle$



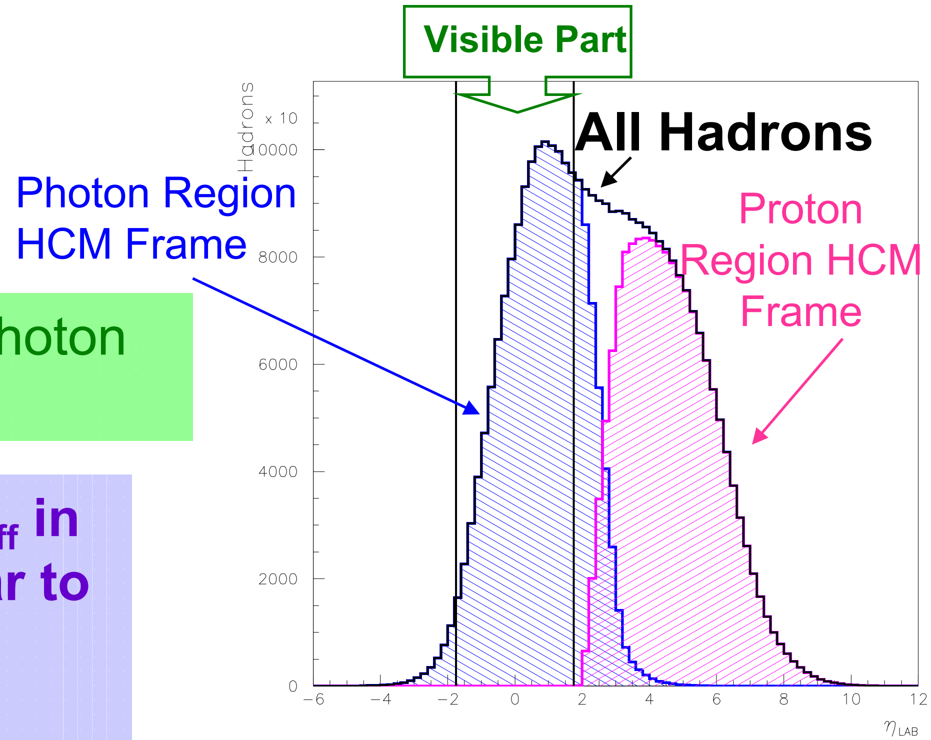




Large MC dependent corrections for target region.

# Acceptance correction: Photon region HCM

- **HCM Frame:** 60-80% Photon region HCM frame contained in visible part of detector.
  ➔ larger corrections.

Correction factors for <nch> vs. W in photon region HCM frame: **1.78, 1.42, 1.26**




**Additional correction needed for $M_{eff}$ in HCM: calculated in bins of W, similar to hadron acceptance correction:**

$$C_{\eta}^{M_{inv}} = \frac{\left\langle M_{eff}^{GEN} \right\rangle}{\left\langle M_{eff}^{GEN,visible} \right\rangle}$$

**Correction factors: 2.38, 1.73, 1.45**
**Applied on an event by event basis**

# Systematic Checks

| Systematic | Change |
| --- | --- |
| Ee' | ± 1 GeV |
| Radius Cut | ± 1cm |
| Track $p_T$ | +50 MeV |
| $Q^2$ | ± 2.25 $GeV^2$ |
| $y_{JB}$ | ± .008 |
| $y_{el}$ | ± .05 |
| $Z_{vtx}$ | ± 15 cm |
| W | ± 15 GeV<br>± 7 GeV |
| E - $p_z$ | ± 2 GeV |
| CAL energy scale | ± 3 % |
| Choice of correction method | |
| Choice of MC | |
| Removing the $\eta_{max}$ cut | |

**Dominant sources of systematic uncertainty:**

- Main uncertainty is choice of MC. Up to 5%. Average correction between LEPTO and ARIADNE taken for measurements
- In photon region HCM HERWIG fails to describe multiplicity distributions, and included in systematics

**Other sources (typical values in parenthesis)**

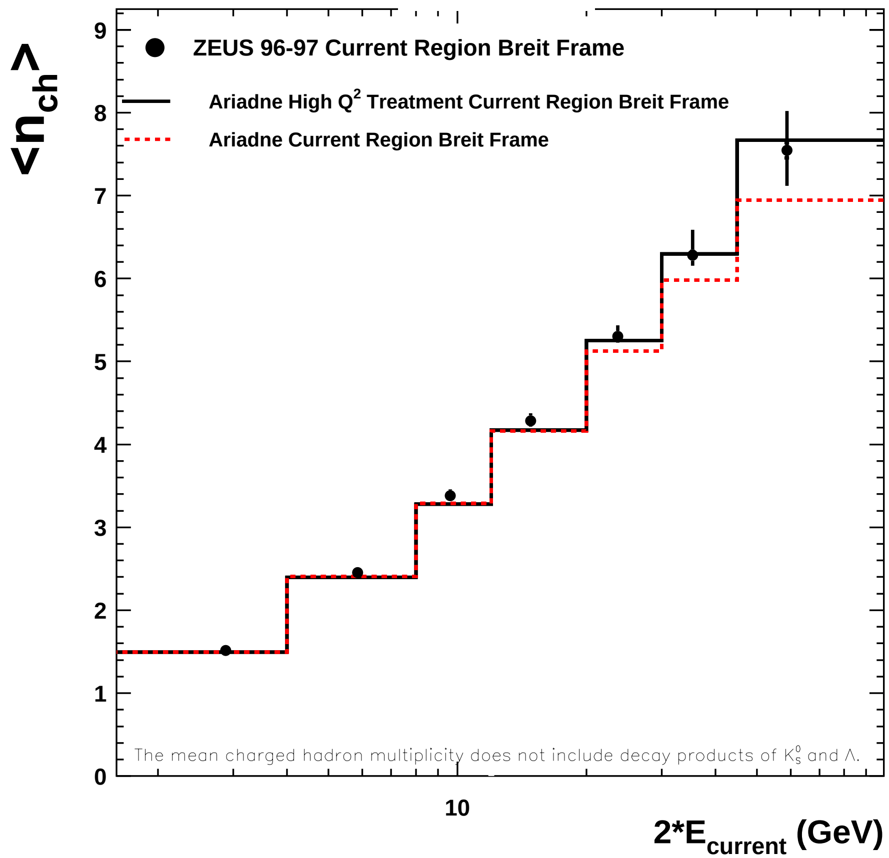
- CAL energy scale (1.5%)
- Event & Track reconstruction and selection (<0.5%)
- Method of correction: Matrix or Bin-by-bin (<1.5%)
- Contaminations due to migrations from $Q^2$<25 (< 1.7%)
- Uncertainty due to diffractive event contamination negligible

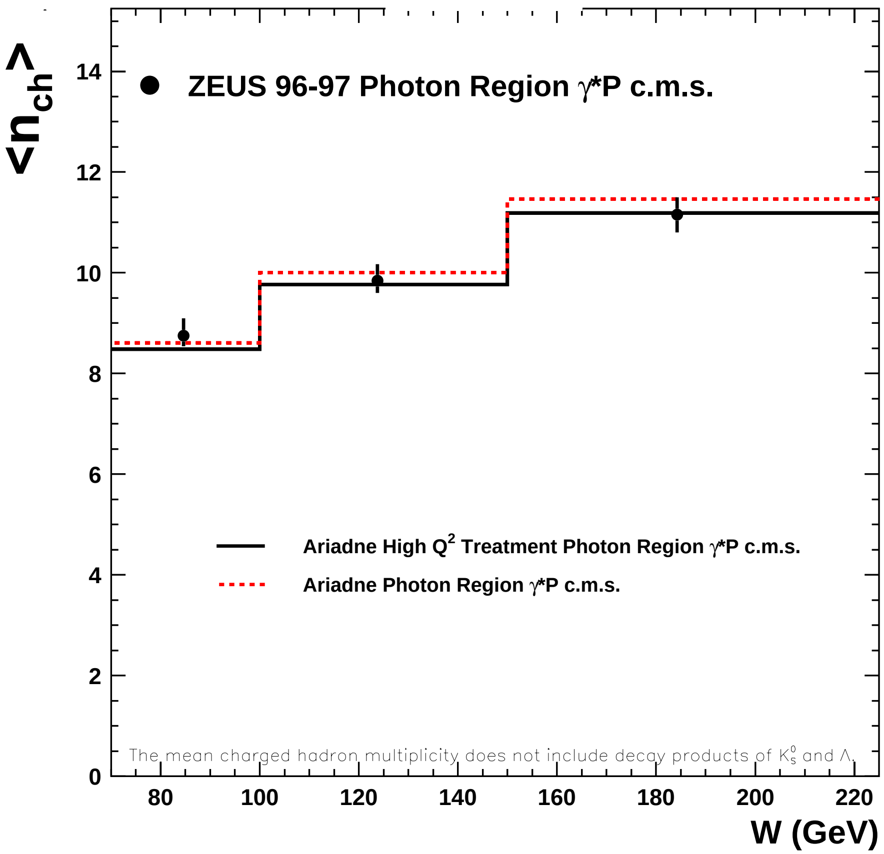
Systematics added in quadrature and shown on plots

CAL energy scale correlated between points: not shown

# Mean charged multiplicity
# Breit and HCM frames for ep DIS

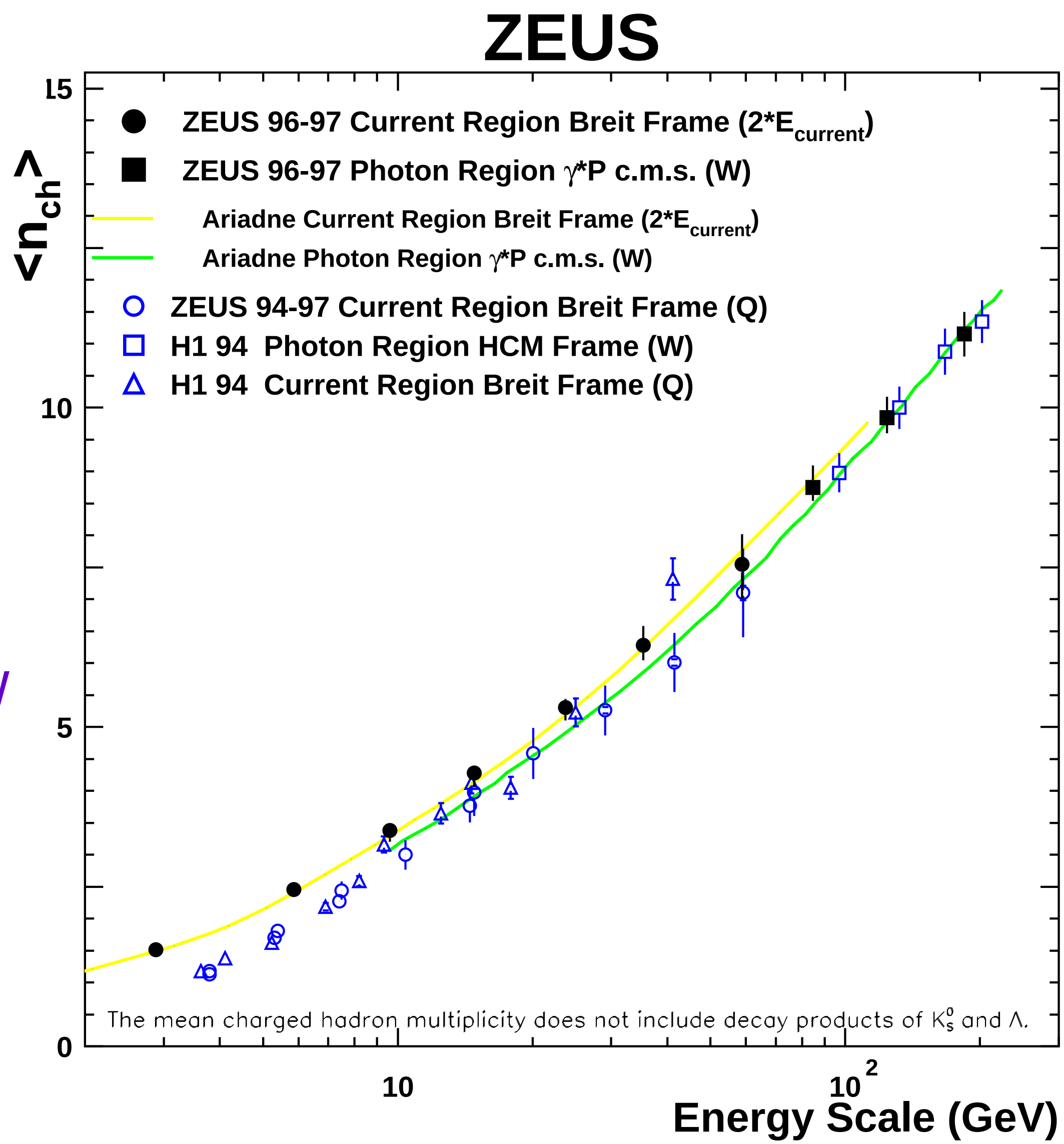
- Multiplicity in current region of Breit frame and photon region of HCM frame described by ARIADNE
- ARIADNE with "high Q2 treatment" gives better description in high energy bins



# Comparison to other multiplicity measurements at HERA

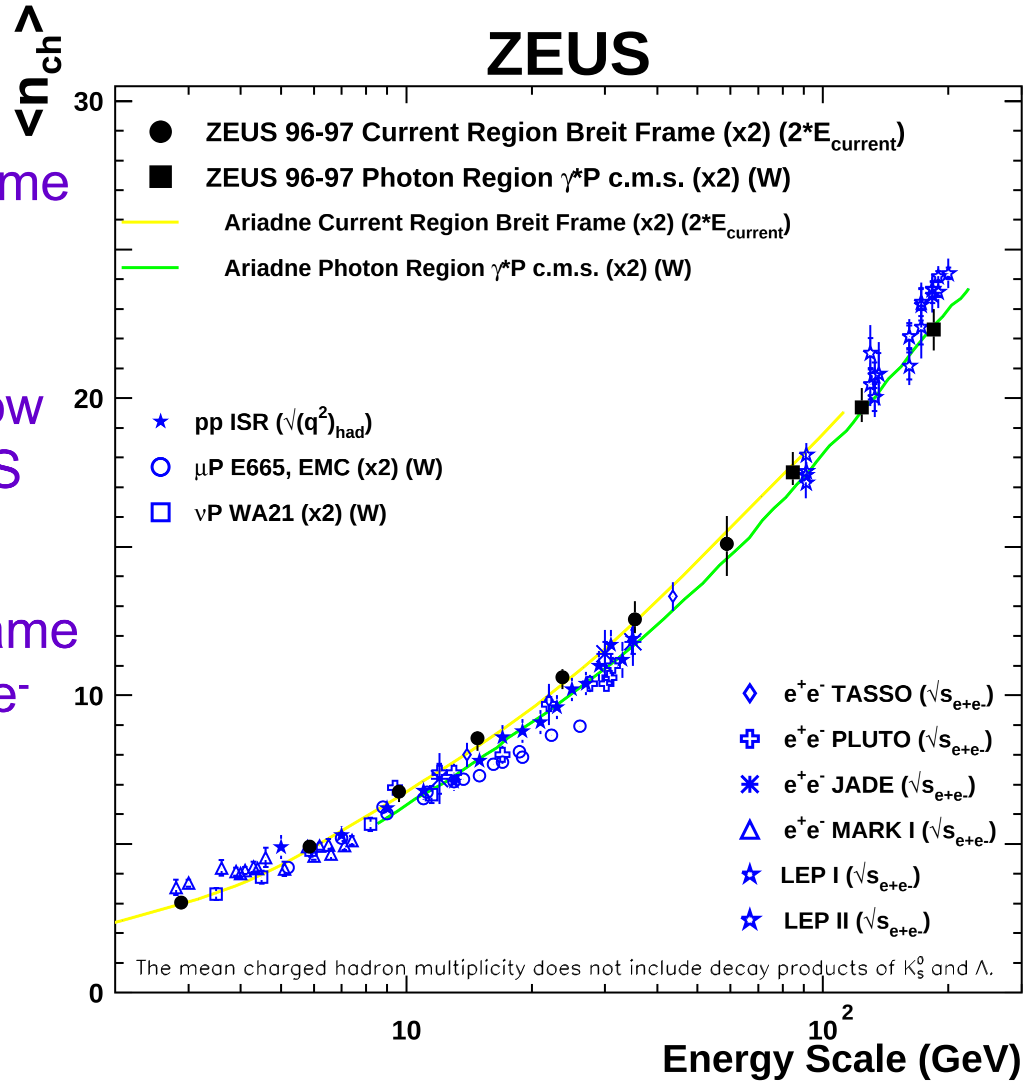
- $\langle n_{ch} \rangle$ in current region of Breit frame and photon region of HCM frame, and ARIADNE predictions plotted together
- photon region HCM ARIADNE agrees with $\langle n_{ch} \rangle$ measurements when extended to lower energies
- Results agree with previous measurements in HCM frame vs. W
- Measure higher multiplicities at lower energies than previous ep measurements as result of using $2^*E_{current}$.



# Comparison of ep multiplicity to other experiments

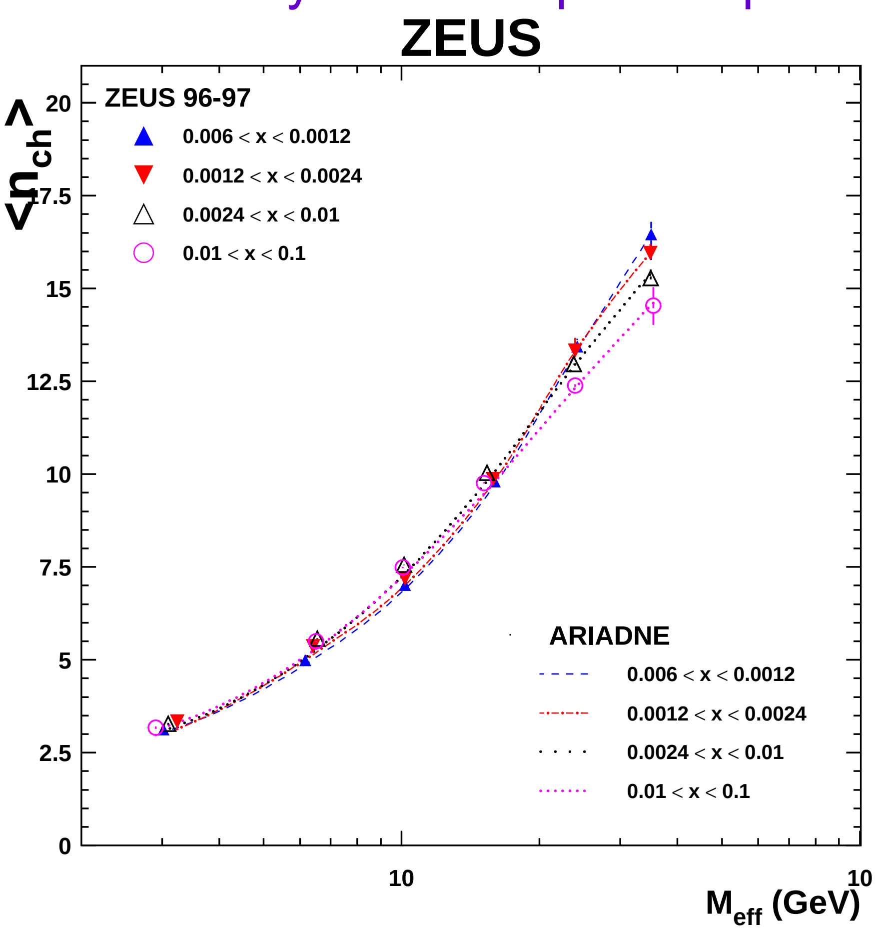
- $\langle n_{ch} \rangle$ in current region Breit frame agree with pp and $e^+e^-$.
- $1^{st}$ time lowest energy data in current region of Breit frame show agreement with $e^+e^-$, pp, and DIS fixed target.
- $\langle n_{ch} \rangle$ in photon region HCM frame are compared to high energy $e^+e^-$ (LEP & LEPII) data.

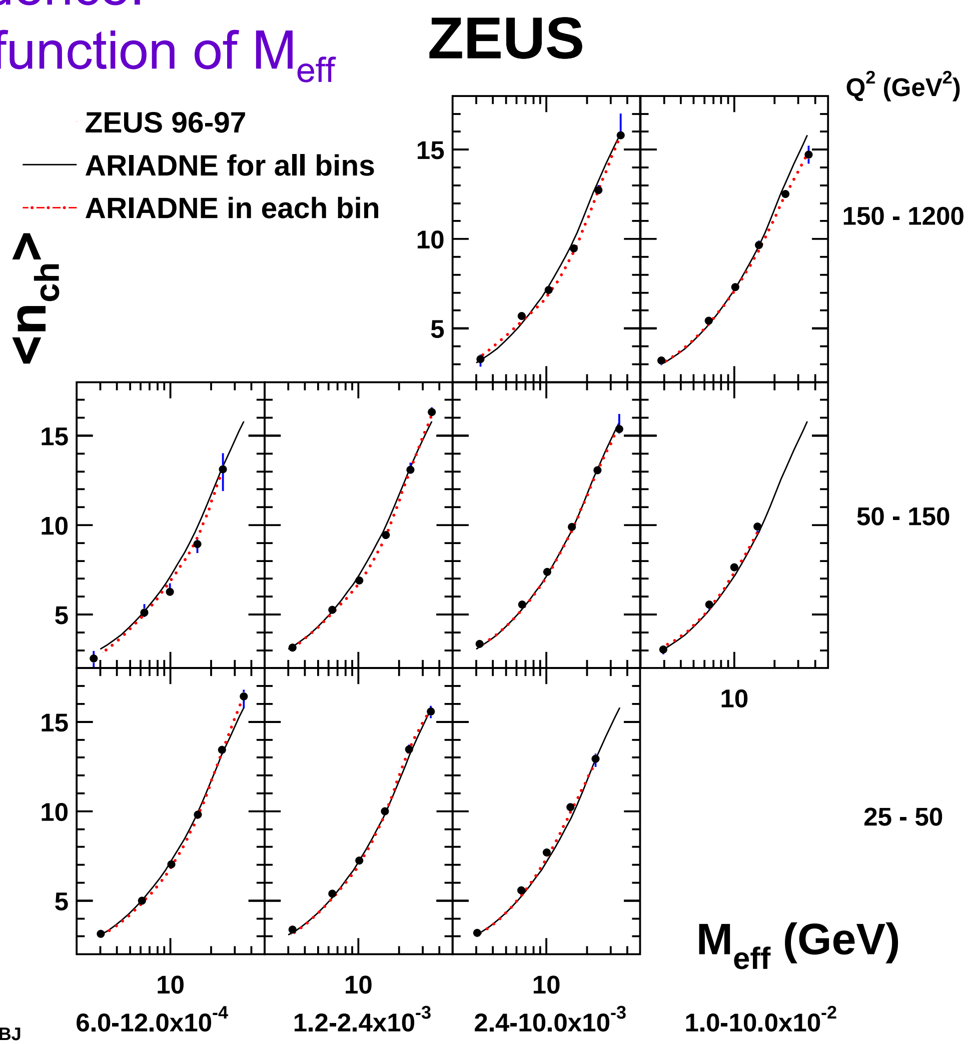
ep measurement agrees within errors of measurement



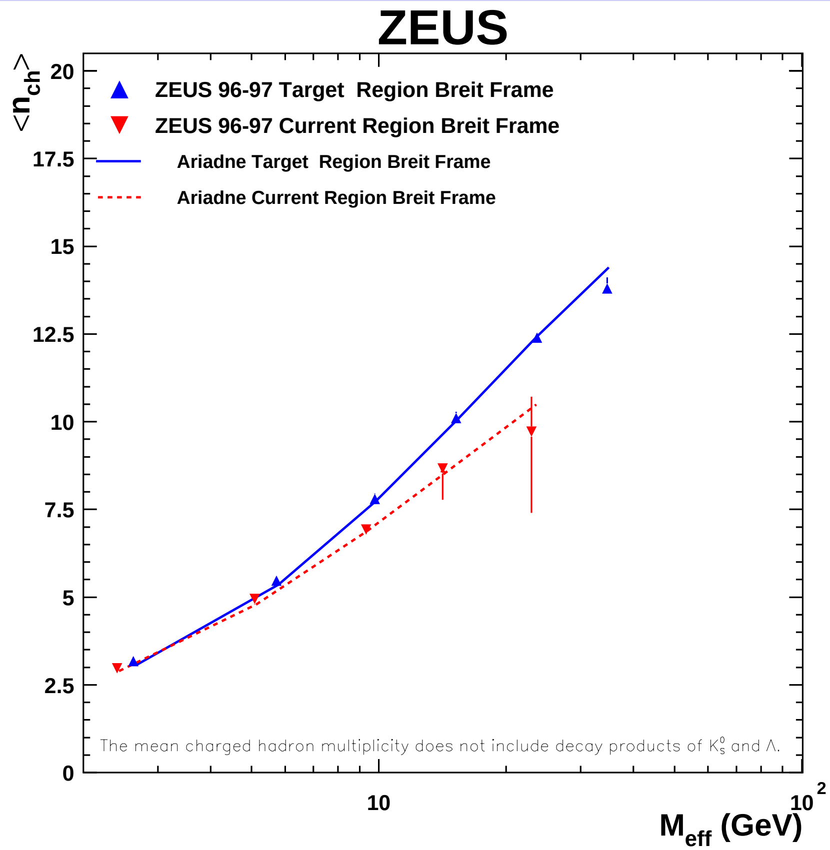
# $<n_{ch}>$ vs. $M_{eff}$ in x and $Q^2$ bins

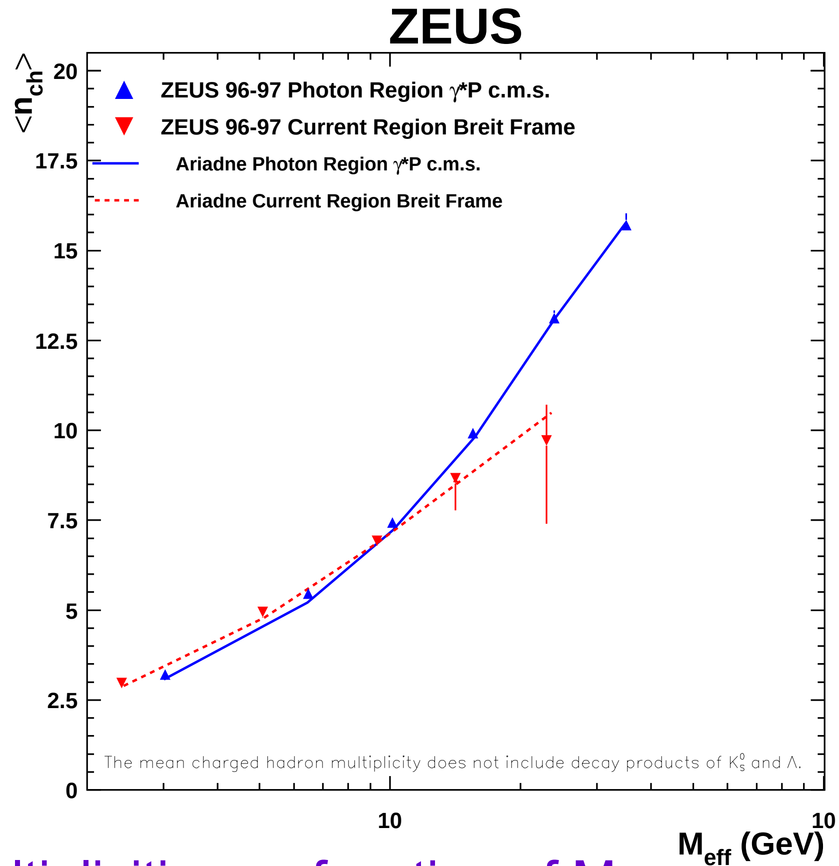
$<N_{ch}>$ shows only small x or $Q^2$ dependence:
confirms that comparison of <nch> as function of $M_{eff}$ not biased by choice of phase space.



# $\langle n_{ch} \rangle$ vs. $M_{eff}$ in Breit and HCM frames




Compare Breit frame current and target multiplicities as function of $M_{eff}$:
$\langle n_{ch} \rangle$ target is slightly above current ➔ bigger contribution of soft particles.

Compare current region BF and photon region HCM frame as function of $M_{eff}$:
behave similarly at low energies, $\langle n_{ch} \rangle$ increases faster in HCM than in Breit

# Summary and Conclusions

HFS investigated in NC ep DIS in range 25<q2 and 70< W< 225 in terms of <nch> , the center of mass energy, and the invariant mass, Meff

1st time, lower energy data of cr Breit frame shown to agree with e+e- and pp by using 2*E as energy scale

<nch> in photon region HCM agree with e+e-

Total energy region of analysis from 2 to 200

New energy variable used for comparison between diff e regions of ep HFS

<nch> scales with Meff in the same way as 2*E in cr Breit frame, (and therefore also same as e+e-), <nch> in photon region HCM rises faster as a function of Meff than <nch> in current region BF.

<nch> in photon region HCM show no dep. On x or Q