



# CMS

## *Color Coherence Effect at LHC*

**Heavy Ion Meeting  
Oct. 6, 2012**

**Inkyu PARK, Chawon PARK  
Dept. of Physics, University of Seoul**

**Intro**



# Happy 20 years anniversary



- ❑ **1992-1995 (LEP-I) : ALEPH (e+ e-)**
  - **Tau lepton lifetime** / Tracking software
- ❑ **1995-1996 (LEP-II): ALEPH**
  - **Low-x scattering PDF** / Luminosity monitor
- ❑ **1996-1998 (LHC): ATLAS (p-p)**
  - **Jet algorithm, Jet performance for TDR** / Hadron calorimeter
- ❑ **1999-2004 (RHIC): PHOBOS (Au-Au)**
  - **Particle elliptic flow phenomenon** / Software engineering
- ❑ **2004-2007:**
  - **Computational physics on EM, Medical, Display, ...** / Teaching
- ❑ **2007-present (LHC): CMS (p-p, Pb-Pb)**
  - **QCD Jet study** / More management work
    - **Today's talk**

## □ With pp

### – Low-pT QCD

- Min Bias Physics
- Charged hadron spectra

### – Mid-pT QCD

- Multiple parton interaction

### – High-pT QCD

- Hadronic jet shape
- Inclusive jet
- Di-jet de-correlation

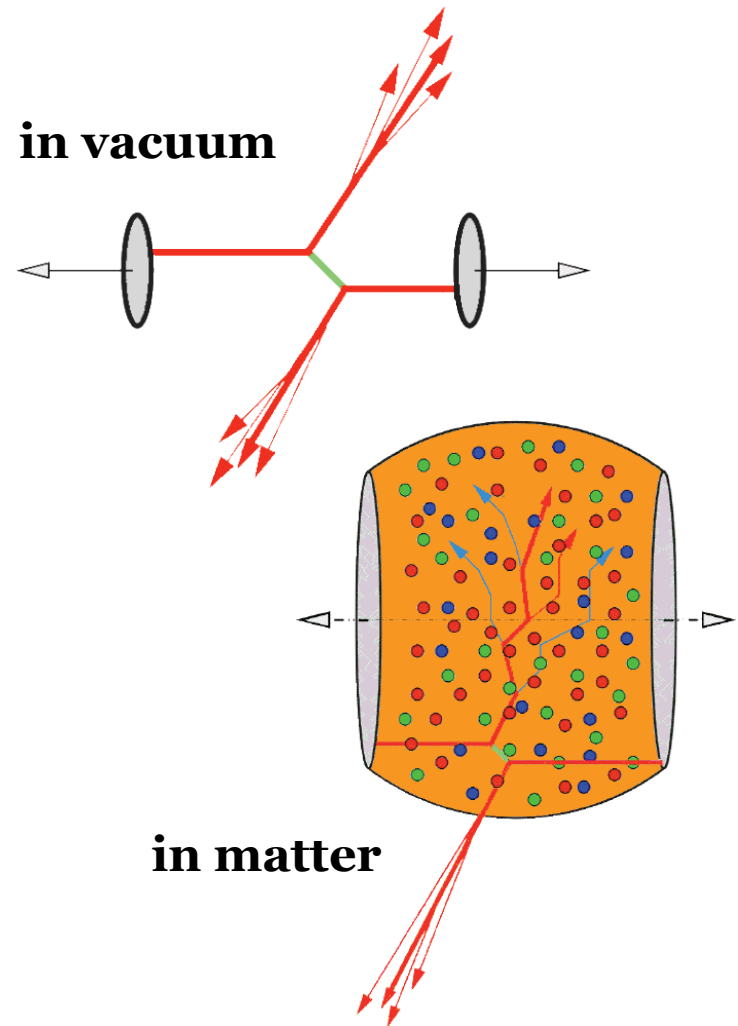
### – Photon Physics

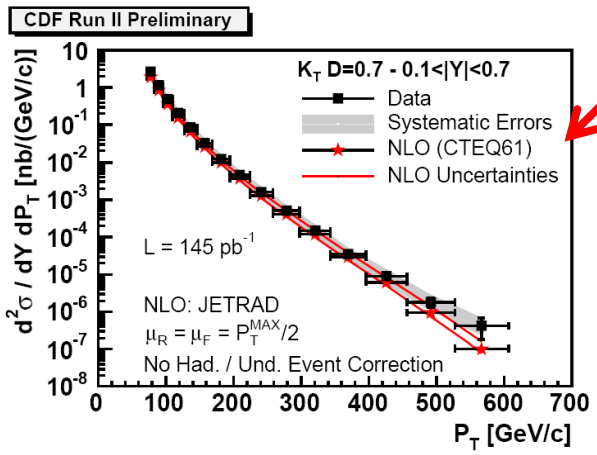
### – Forward Physics

## □ With HI

### – QGP

- hot & dense matter
- jet queching, flow, HBT

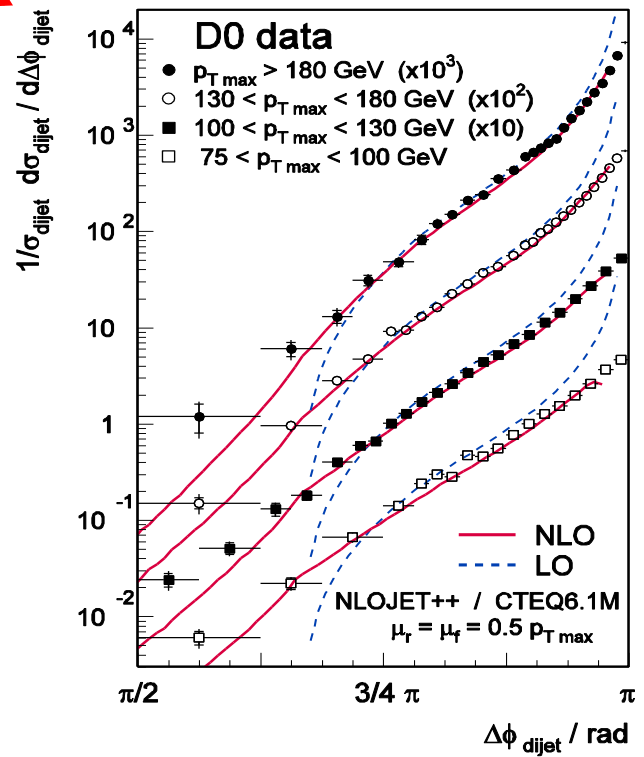
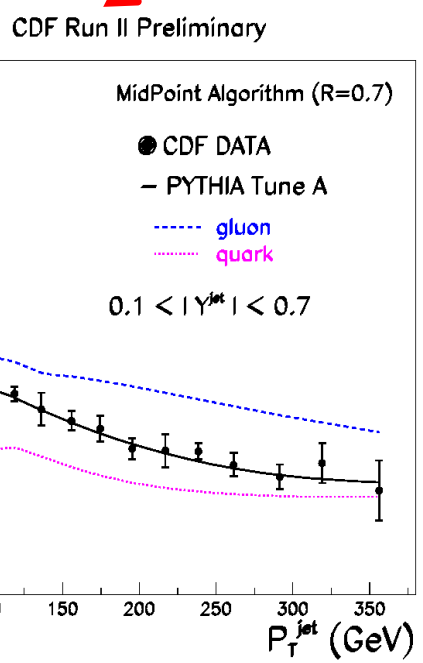
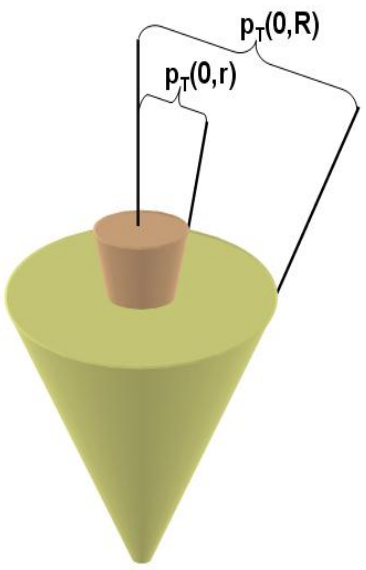
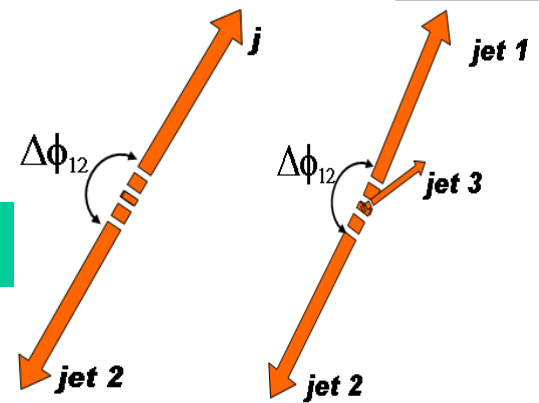




**Jet  $p_T$  spectrum**

**Jet angular correlation**

**Jet shape**



## □ Standard parton shower generation

– HERWIG, PYTHIA

- jet developing with small angle gluon emission, Angular Ordering
- carrying longitudinal momentum fraction  $x \sim O(1)$

## □ At Tevatron

– dominant LO QCD processes

– well described by collinear emission (HERWIG, PYTHIA) + NLO

## □ At LHC

– emission not collinearly ordered become not negligible

- non collinear emission

– coherence effects : space-like partons carry “ $x \ll 1$ ”

- coherence with space-like branching

F. Hautmann & H. Jung, Nucl. Phys. B 186 (2009) 35-38

## □ Situation in 2009:

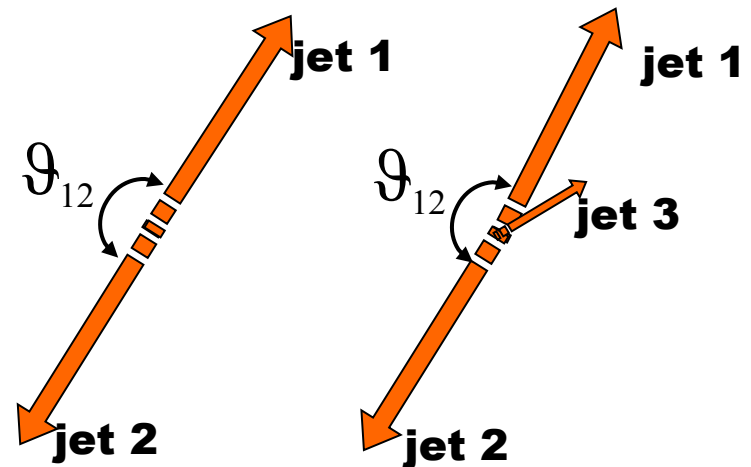
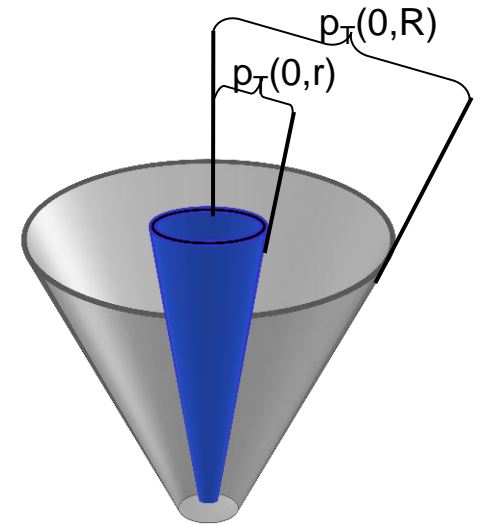
### – QCD Subgroup analyses

- QCD High PT subgroup contents


- Dijet Azimuthal Decorrelations in pp Collisions at 10 TeV
- Transverse Energy Distribution within Jets in pp collisions at 14 TeV
- Pseudorapidity distributions of charged hadrons in minimum bias p-p collisions at 14 TeV
- Hadronic Event Shapes at CMS
- Study of jet transverse structure using the second moment of Pt radial distribution
- Measurement of inclusive jet cross sections with CMS at LHC

- many more , almost all studies were on-going

– no rooms were available!




- ❑ **Quantum Chromodynamics: High Energy Experiments and Theory (Chap 11)**
  - **G. Dissertori, I. Knowles, M. Schmelling**
- ❑ **Color coherence in multi-jet final states**
  - **F. Hautmann, H. Jung, Nucl. Phys. B 186, 35-38 (2009)**
- ❑ **A summary of recent color coherent results**
  - **Nikos Vareles, arXiv hep-ex:980919 (1998)**
- ❑ **Color coherent radiation in multijet events from ppbar Collisions at sqrt(s)=1.8TeV**
  - **Do Collaboration, Phys. Lett. B 414-419 (1997)**



**Nuclear Physics B - Proceedings Supplements**

Volume 186, January 2009, Pages 35–38


Proceedings of the QCD 08, 14th High-Energy Physics International Conference On Quantum ChromoDynamics



**Color coherence in multi-jet final states**


F. Hautmann<sup>a</sup>, H. Jung<sup>b</sup>

<sup>a</sup> University of Oxford, Theoretical Physics, Oxford OX1 3NP  
<sup>b</sup> Deutsches Elektronen Synchrotron, D-22603 Hamburg



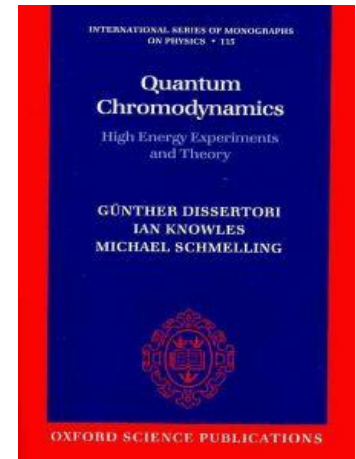
**Physics Letters B**

Volume 414, Issues 3–4, 27 November 1997, Pages 419–427



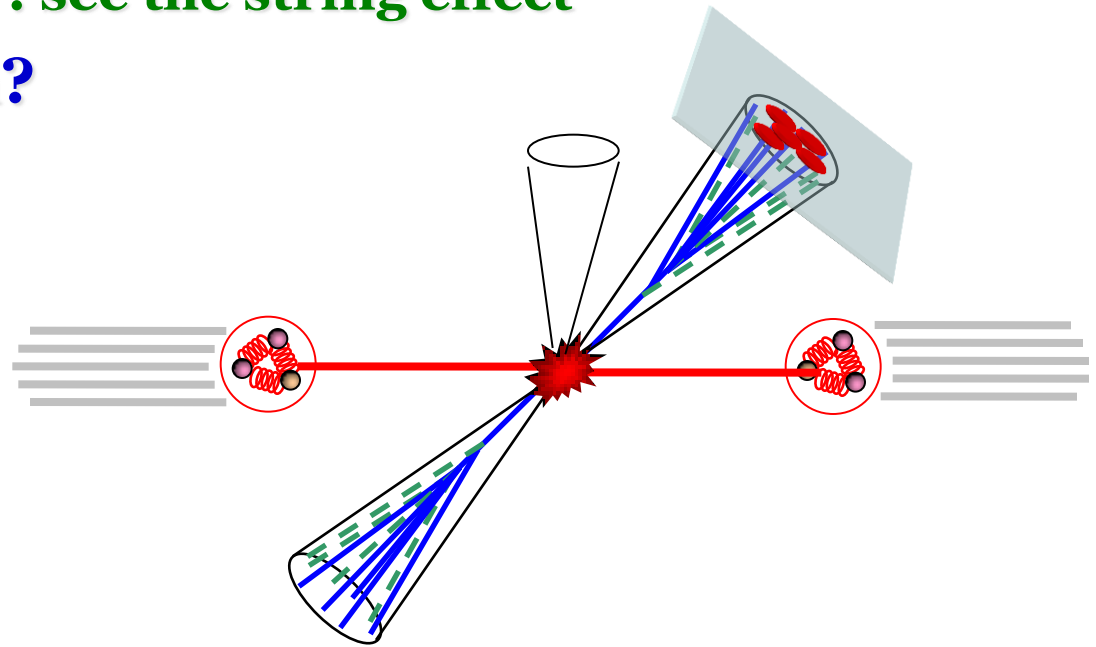
**Color coherent radiation in multijet events from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.8 \text{ TeV}$**

DØCollaboration, B. Abbott<sup>ac</sup>, M. Abolins<sup>z</sup>, B.S. Acharya<sup>ar</sup>, I. Adam<sup>l</sup>, D.L. Adams<sup>ad</sup>, M. Adams<sup>g</sup>, S. Ahn<sup>o</sup>, H. Aihara<sup>y</sup>, G.A. Alves<sup>i</sup>, E. Amidi<sup>bd</sup>, N. Amos<sup>f</sup>, E.W. Anderson<sup>s</sup>, R. Astur<sup>aq</sup>, M.M. Baarmand<sup>ag</sup>, A. Baden<sup>k</sup>,





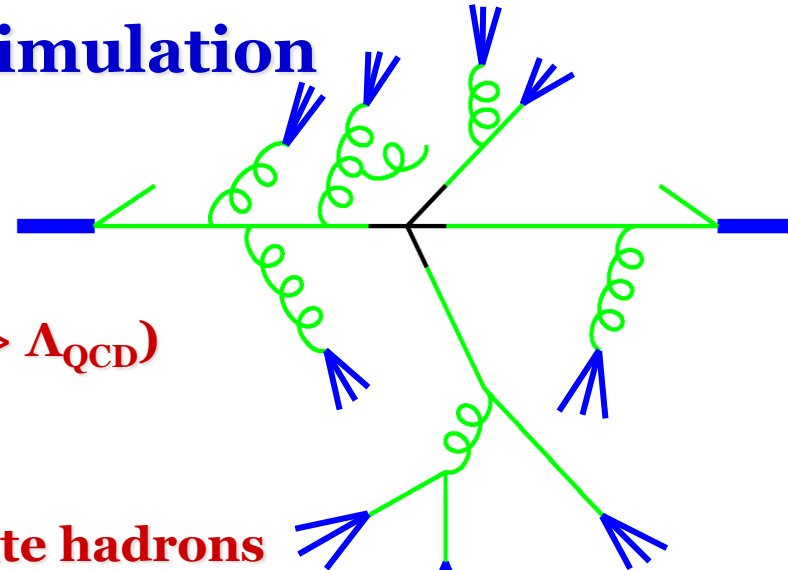
- ❑ **Intra-jet color coherence**
  - fragmentation function → intra-jet coherence
- ❑ **Inter-jet color coherence**
  - distribution of particles lying between jets → Inter-jet
  - usually with three jets : see the string effect
- ❑ **Something between?**
  - a new measurement
  - help other physics



[http://www-cdf.fnal.gov/physics/new/top/2009/mass/meatv3\\_p19\\_public/index.html](http://www-cdf.fnal.gov/physics/new/top/2009/mass/meatv3_p19_public/index.html)

# **Coherence effect in intrajet**

- **High  $P_T$  processes  $\rightarrow$  hadronic final states, jets**
  - **understanding color interaction**
- **Main tool to describe the jet production is pQCD**
  - **However, relies on phenomenological models to explain the partonic cascade**
- **Pictures implemented in MC simulation**
  - **hard process**
  - **parton shower**
    - **pQCD, gluon & quark emission**
    - **until a cut-off  $k_T$  scale ( $Q_0 \sim 1\text{GeV} \gg \Lambda_{\text{QCD}}$ )**
  - **Fragmentation, hadronization**
    - **non-perturbative**
    - **cluster the partons into the final state hadrons**
    - **described by phenomenological fragmentation models**
      - **need to be tuned to the data**



LUND String model, Cluster fragmentation model, etc.

- A purely analytical approach giving quantitative predictions of hadronic spectra is based on the concept of **LPHD** (Local Parton Hadron Duality)
  - key assumption: conversion of partons into hadrons occurs at the order of hadronic masses,  $\sim 200\text{MeV}$ 
    - independent of the scale of the primary hard process
    - i.e. involves only low momentum transfers
  - results obtained for partons apply to hadrons as well
  - only two parameters are involved
    - QCD scale  $\Lambda_{\text{QCD}}$ , transverse momentum cut-off  $Q_0$
  - Within the **LPHD** approach, pQCD calculations have been carried out in **DLA** (Double Log Assumption) or in **MLLA** (Modified Leading Log Approximation)

## □ Intrinsic property of QCD

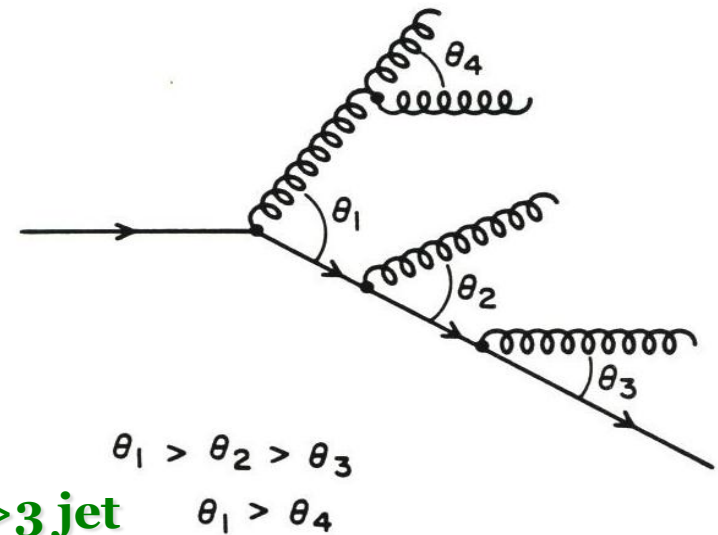
- well established in early 80' e+e- experiments
- It arises from interference between the soft gluons radiated from quarks and gluons
  - should be observed after hadronization (predicted by LPHD)

## □ Intrajet coherence

- color coherence in partonic cascade
- AO (Angular Ordering)
  - emission angle decreases → cone shape
  - hump-backed shape of particle spectra in jets

## □ Interjet coherence

- string/drag effect
- angular structure of soft particle flow for >3 jet

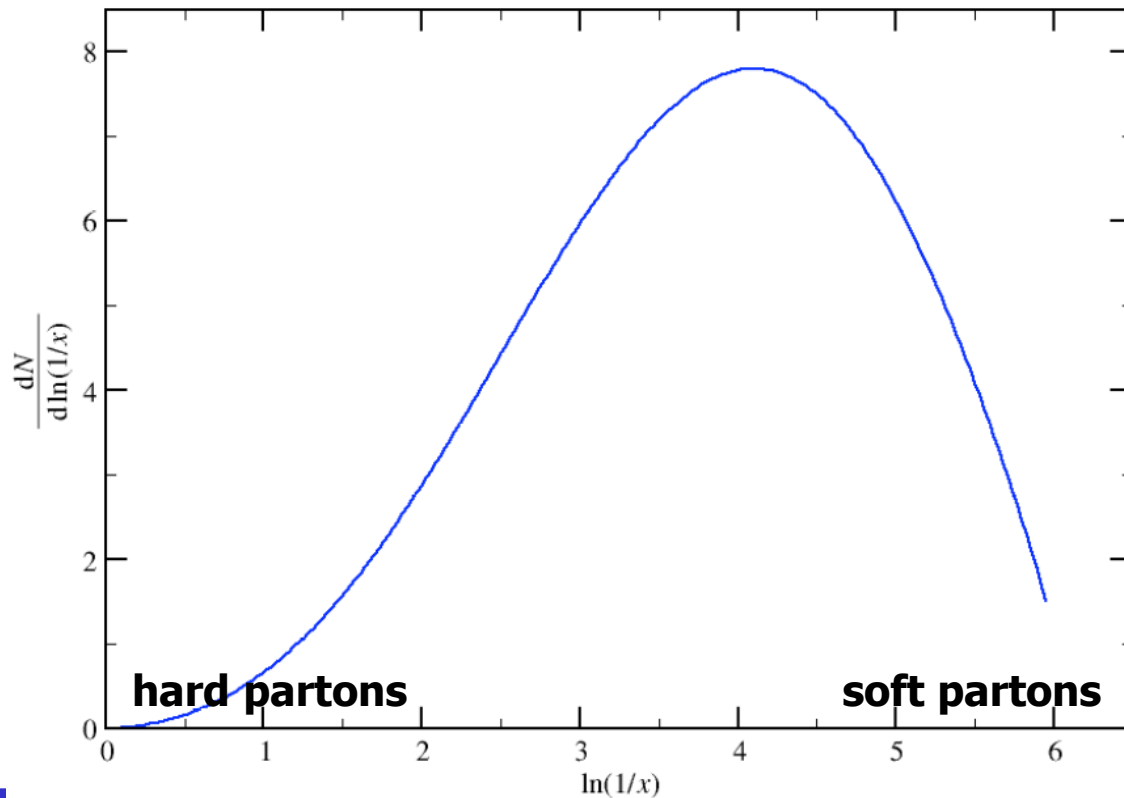


Angular Ordering

## □ A striking prediction of pQCD/LPHD/MLLA

– depletion of soft particle production

- **Hump-Backed Plateau**
- **approximately Gaussian shape in the variable  $\xi$**



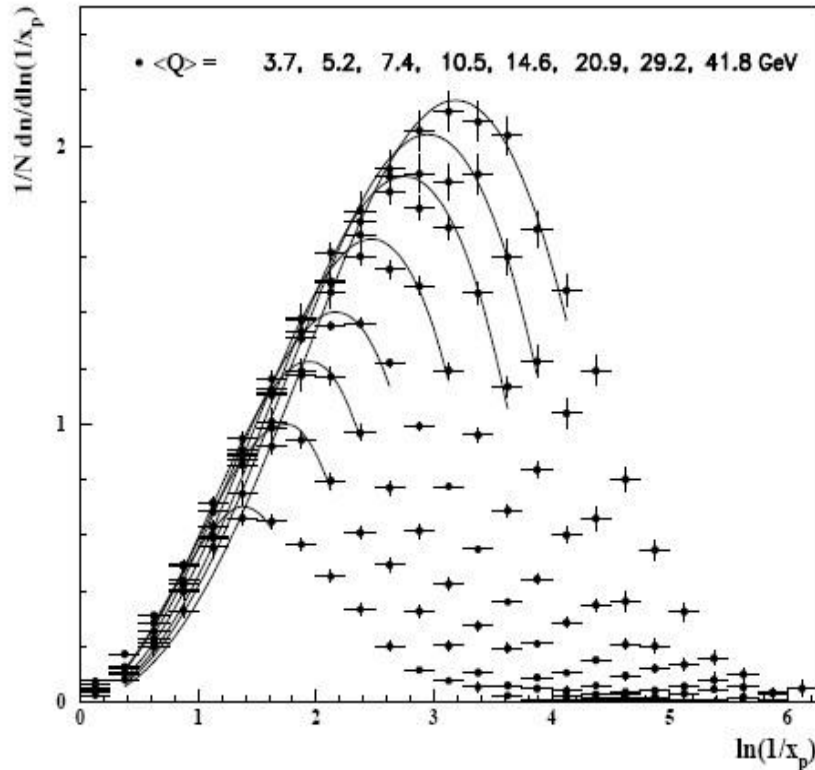
$$\xi = \log(E_{jet} / p) = \log(1/x_p)$$

$$\frac{1}{\sigma} \frac{d\sigma}{d\xi} = Const \cdot f_{MLLA}(\xi, Y, \lambda)$$

$$Y = \log \frac{E_{jet}}{Q_0}$$

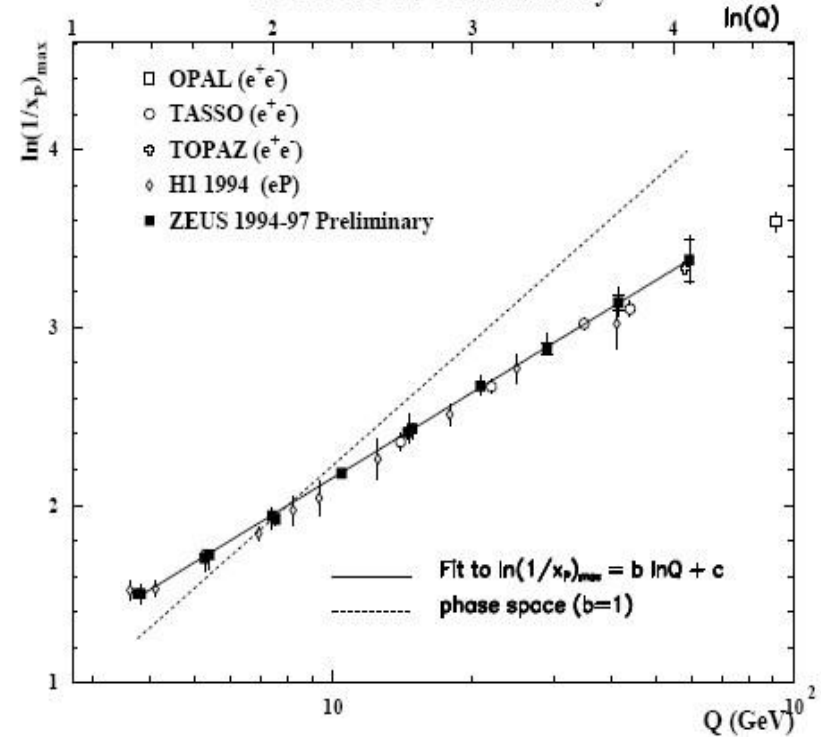
$$\lambda = \log \frac{Q_0}{\Lambda}$$

ZEUS 1994-97 Preliminary



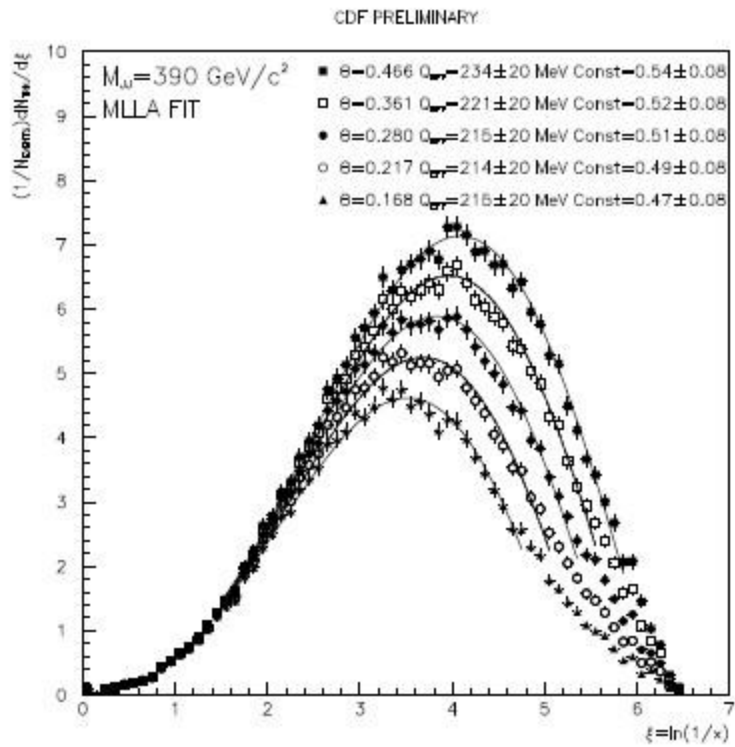
(a) Evolution of the  $1/N dn/d \log(1/x_p)$  distributions with  $Q$ . The curves are MLLA fits.

ZEUS 1994-97 Preliminary

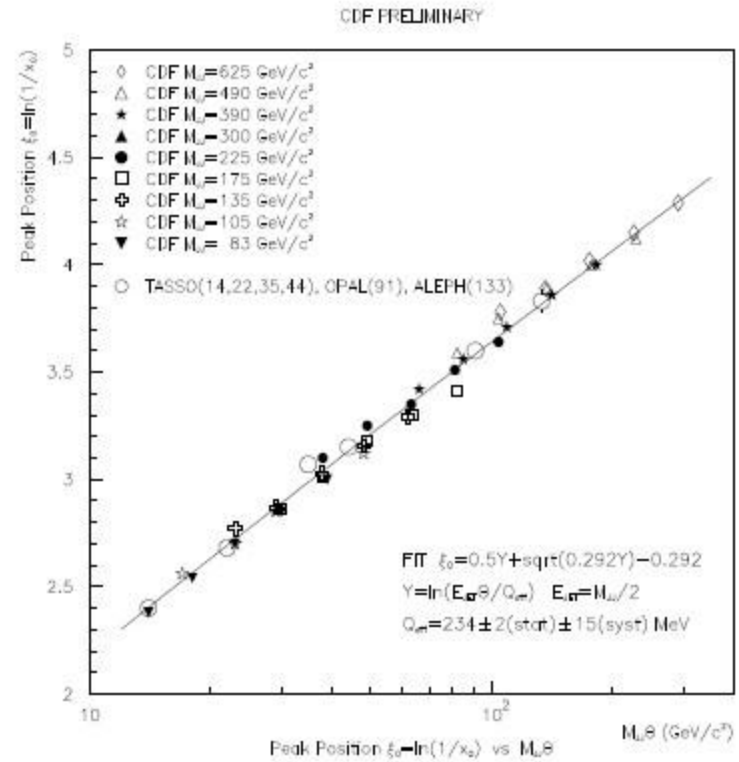


(b) Evolution of the peak position  $\log(1/x_p)_{max}$  with  $Q$ .





(a) Evolution of  $\xi$  with jet opening angle,  $\Theta$ , for  $M_{JJ} = 390 \text{ GeV}$ .

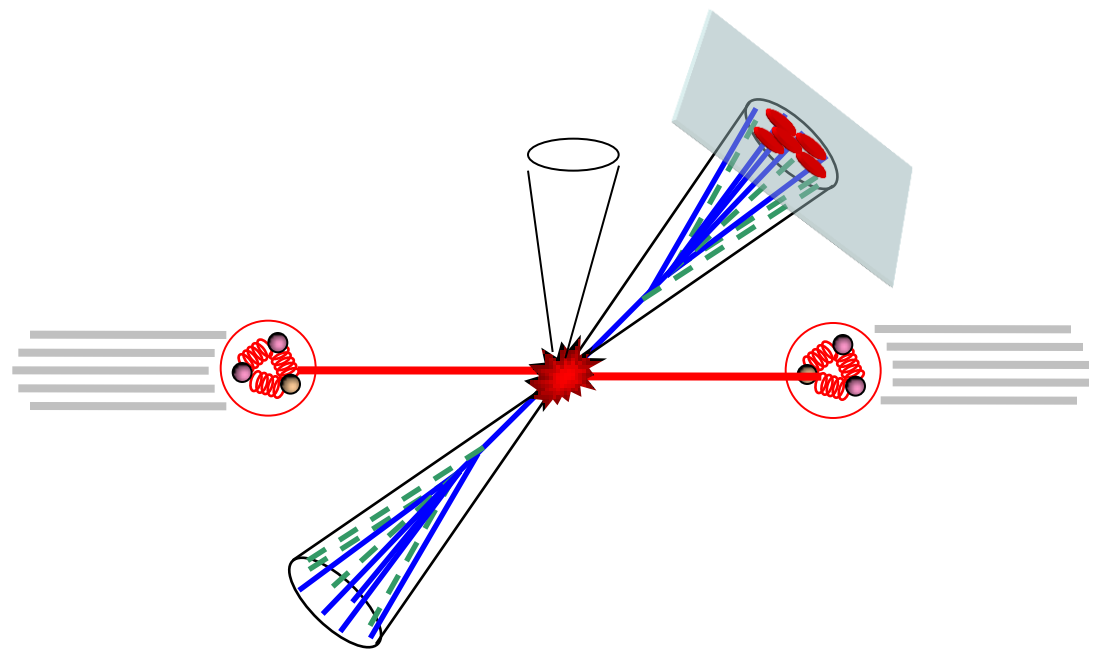


(b) Evolution of the peak position with  $M_{JJ}\Theta$ .



# **Coherence effect in interjet**

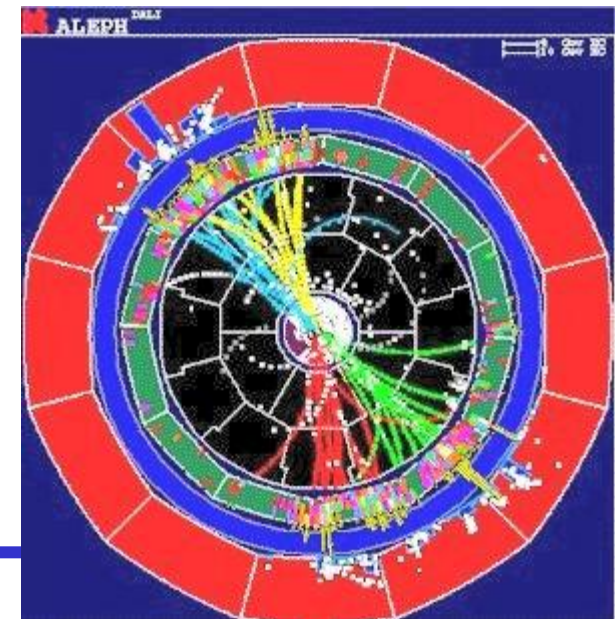
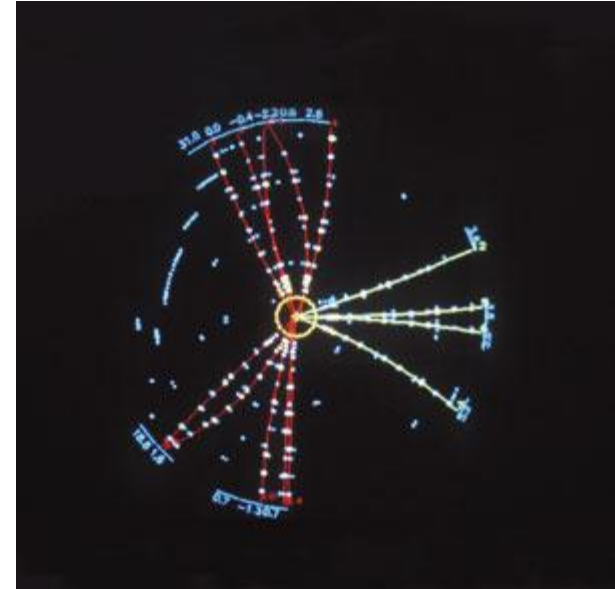
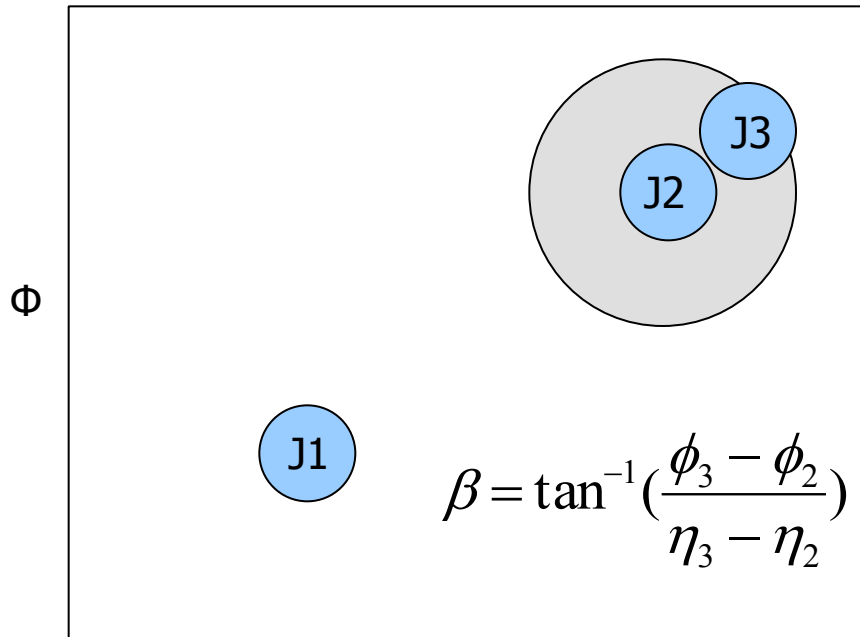
- In pp, coherence effects becomes complicate
  - colored constituents in both the initial and final states
  - transfer of color between interacting partons
  - interference effects in the initial states, in the final states, between the initial and final states

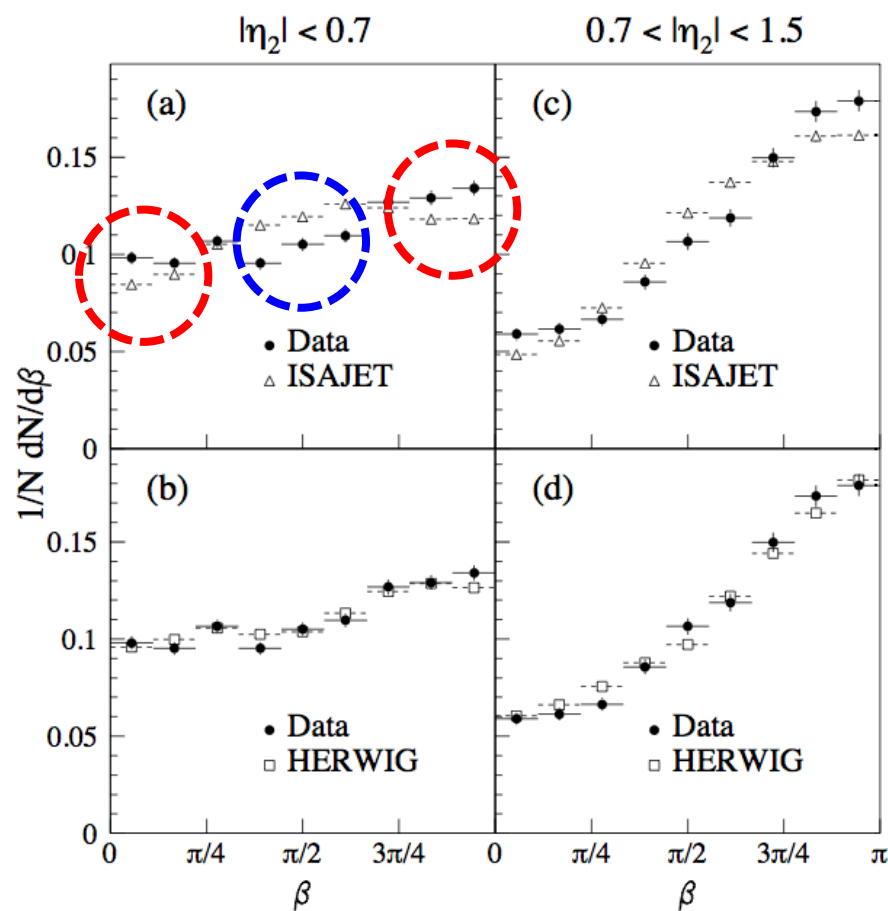


## □ Typical analysis with multijets

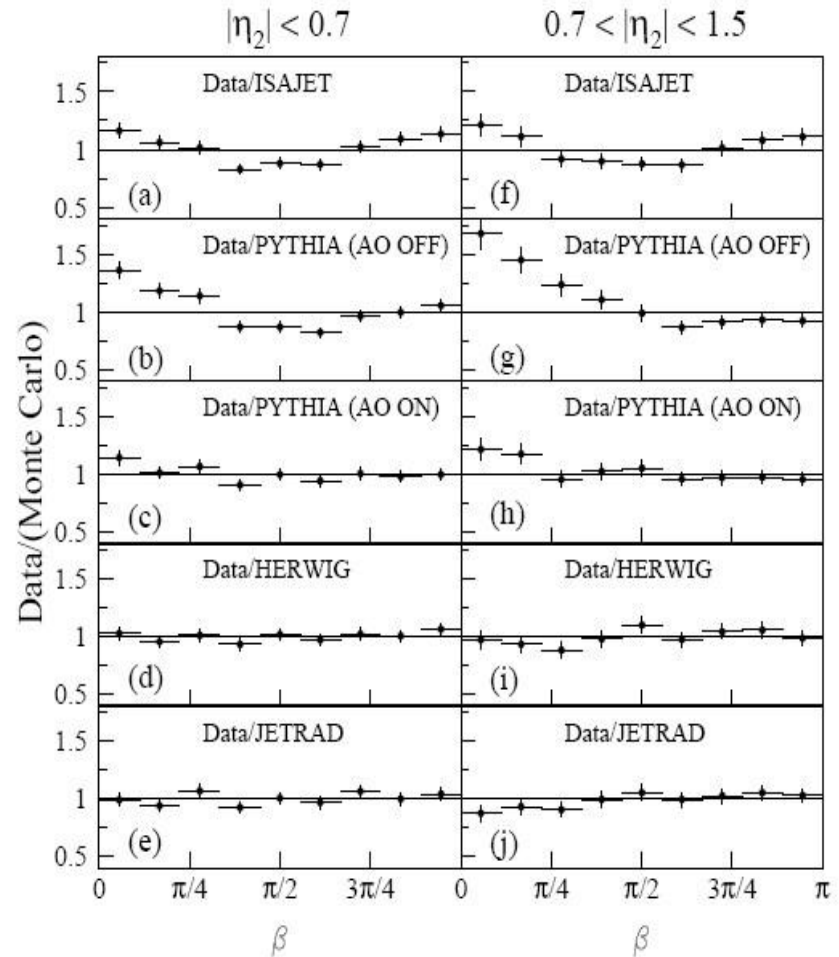
### – Using 3-jet events

- define  $J_1, J_2, J_3$  ( $E_1 > E_2 > E_3$ )
- $J_3$  in R around  $J_2$  ( $0.6 < R < \pi/2$ )
- define beta angle





D0 Collaboration, Phys. Lett. B 414 419 (1997)



**Acting as a MC model killer**