Transverse jet shape measurement @ LHC

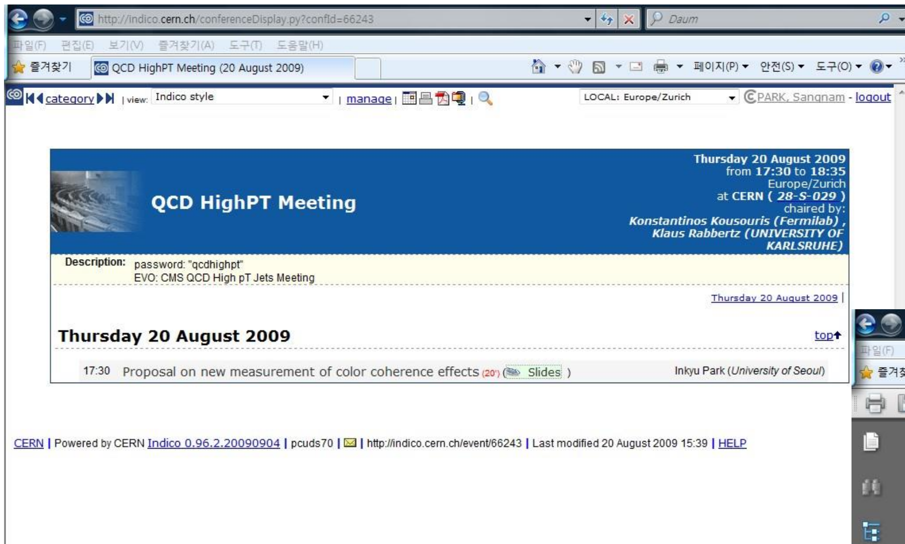
HIM @ Pohang, Sep. 25, 2009

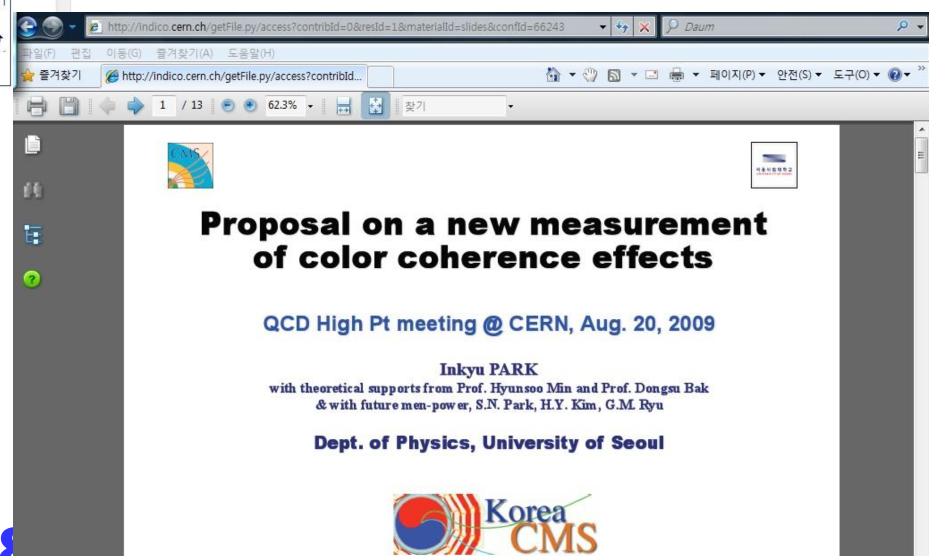
Inkyu PARK
Dept. of Physics, University of Seoul

% much based on hep-ex/9809019v1 of Nikos Valelas and a talk of Nicolas Borghini

Summer work in 2009 @ CERN

- Have spent a wonderful summer vacation @ CERN in 2009, studying QCD…

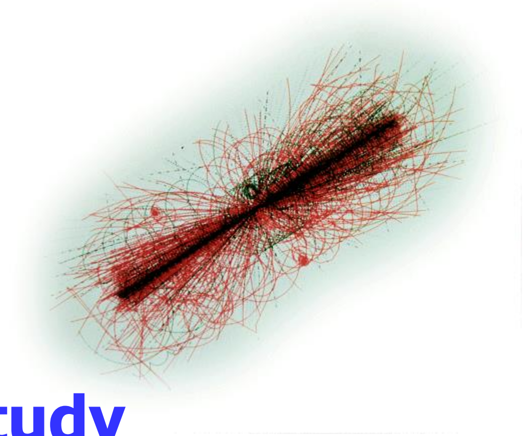




- Baseline of this talk.
- With CMS QCD convener & experts.

Contents

1. QCD study @ LHC
2. Coherence effects in Intra-jet
3. Coherence effects in Inter-jet
4. Coherence effects in dense matter
5. Korea CMS activities toward the jet study



See the talk of Prof. B.S.Hong for the detail of the CMS detector & performance

No CMS specifics here!!

starting with references …

- Quantum Chromodynamics: High Energy Experiments and Theory
  - 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
  - D0 Collaboration, Phys. Lett. B 414-419 (1997)
- Jets in Heavy Ion Collisions
  - Nicolas Borghini, Quantum fields in extreme environments, Saclay & Paris (2009)

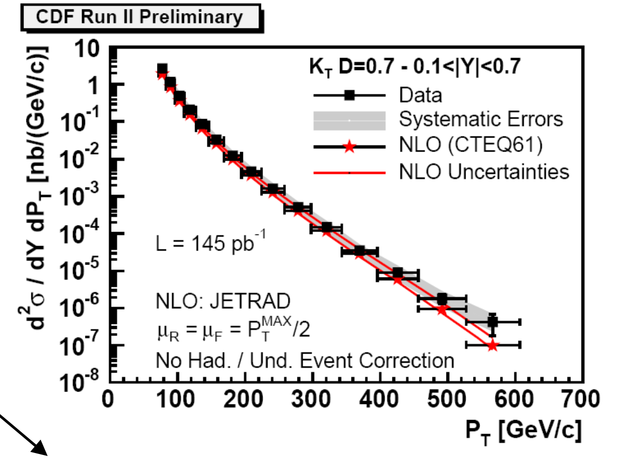
Not mentioning CMS notes

QCD study @ LHC

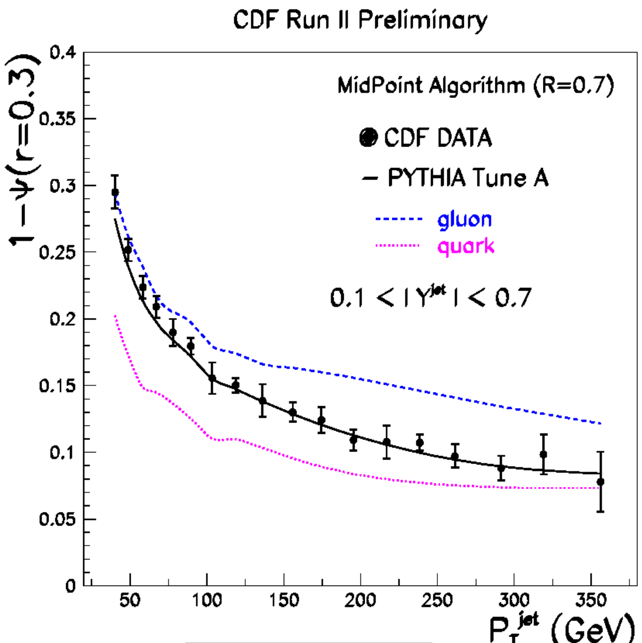
LHC QCD Physics menu

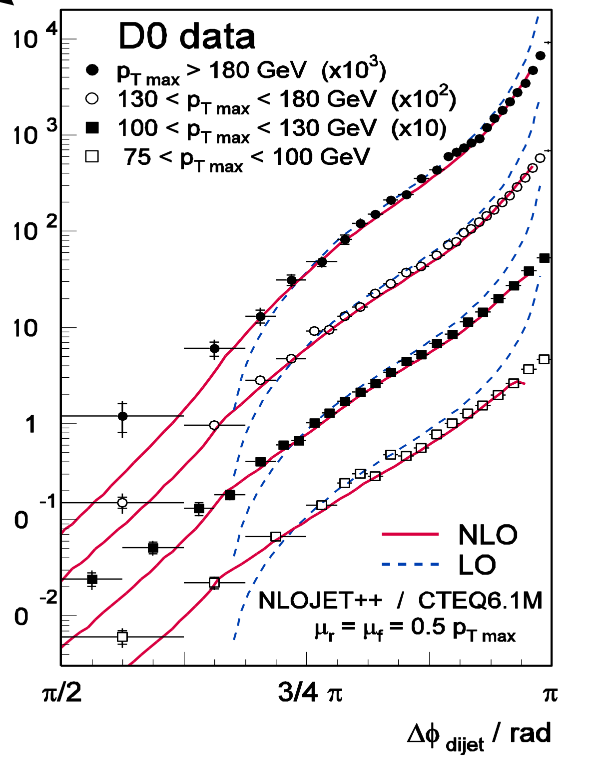
- **With pp**
  - **Low-pT QCD**
    - **Min Bias Physics**
    - **Charged hadron spectra**
  - **Mid-pT QCD**
    - **Multiple parton interaction**
  - **High-pT QCD**
    - **Hadronic jet shape**
    - **Inclusive jet**
    - **Di-jet de-correlation**
  - **Photon Physics**
  - **Forward Physics**
- **With HI**
  - **QGP**
    - **hot & dense matter**
    - **jet queching, flow, HBT**

Jetspectra



Di-jet correlation





Jet shape

- **Standard parton shower generation**
  - **HERWIG, PYTHIA**
    - **jet developing with small angle gluon emission, Angular Ordering**
    - **carrying longitudinal momentum fraction x ~ O(1)**
- **At Tevatron**
  - **dominant LO QCD processes**
  - **well described by collinear emission (HERWIG, PYTHIA) + NLO**
- **At LHC**
  - **emission not collinearly ordered becomes not negligible**
    - **non collinear emission**
  - **coherence effects become more important**
    - **coherence with space-like branching**

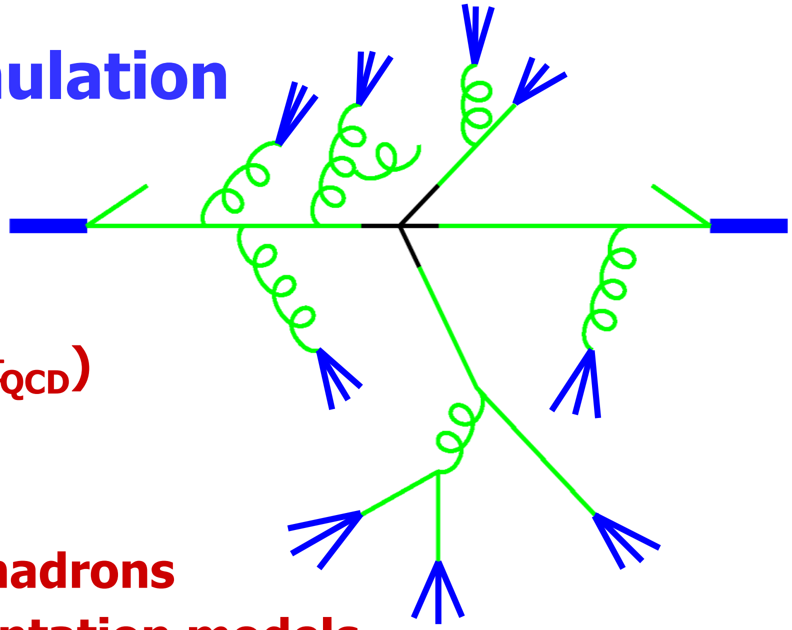
F. Hautmann & H. Jung, Nucl. Phys. B 186 (2009) 35-38

Coherence effect in intrajet

Understanding Jet

- **High P_T processes → 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 ~ 1GeV >> Λ_{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



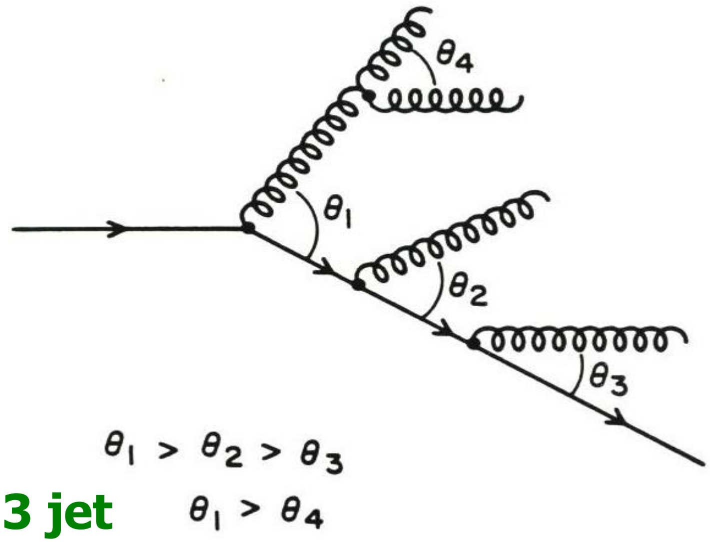
LUND String model, Cluster fragmentation model, etc.

Theoretical understanding

- **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, ~ 200MeV**
    - **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 Λ_{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)**

Color coherence

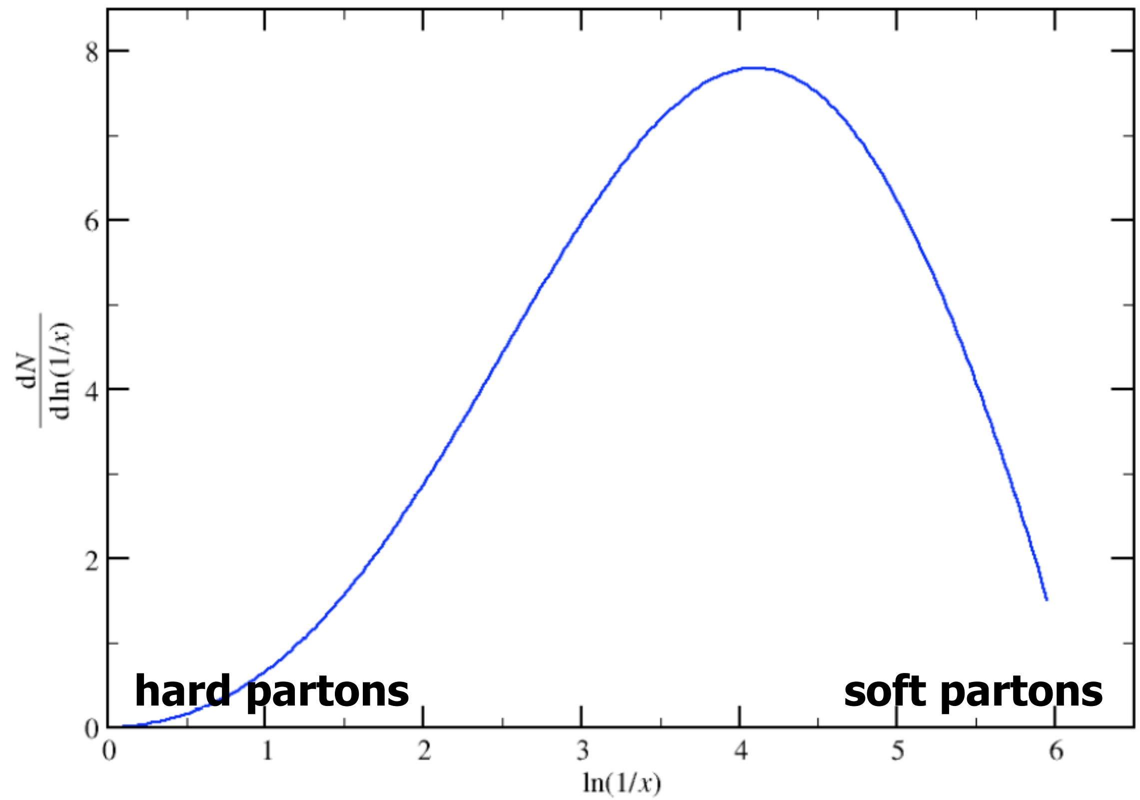
- **Intrinsic property of QCD**
  - **well established in early 80' e+e- experiments**
  - **It arises from interference between the soft gluons radiated from quarks and gluons**
    - **should be observed after hadronization (predicted by LPHD)**
- **Intrajet coherence**
  - **color coherence in partonic 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

MLLA prediction

- **A striking prediction of pQCD/LPHD/MLLA**
  - **depletion of soft particle production**
    - **Hump-Backed Plateau**
    - **approximately Gaussian shape in the variable ξ**



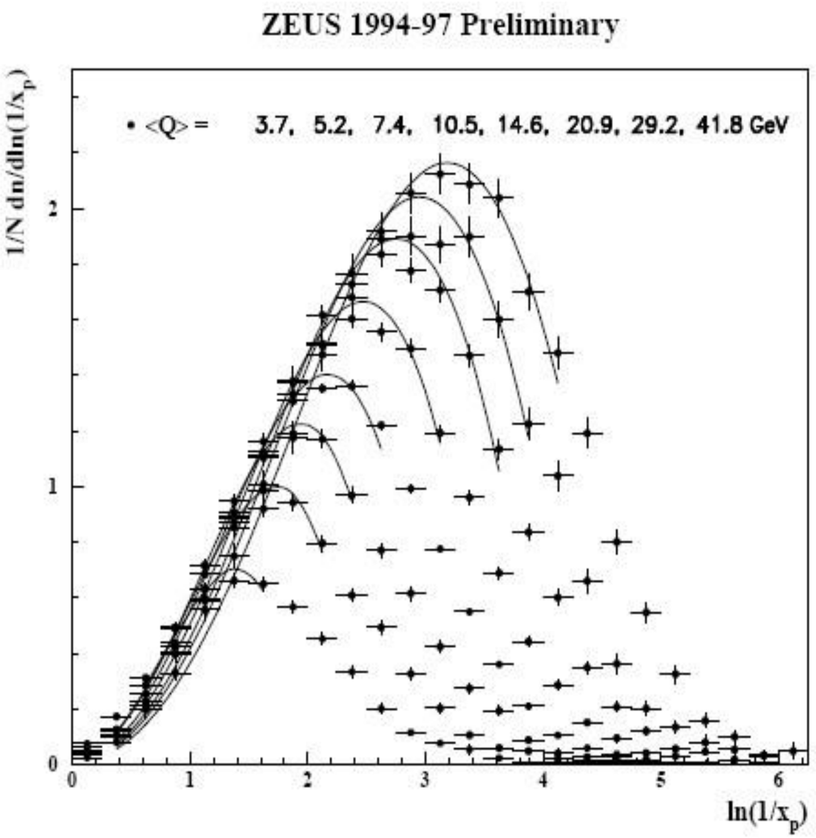
$$\xi = \log(E_{jet}/p) = \log(1/x_p)$$

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

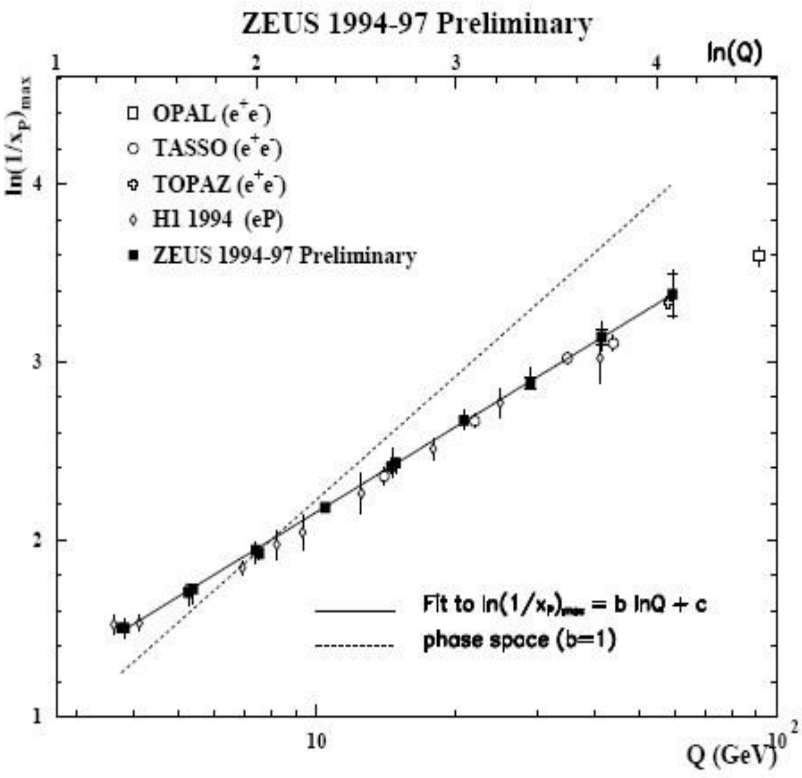
$$Y = \log\frac{E_{jet}}{Q_0}$$

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

Intrajet results in ee,ep

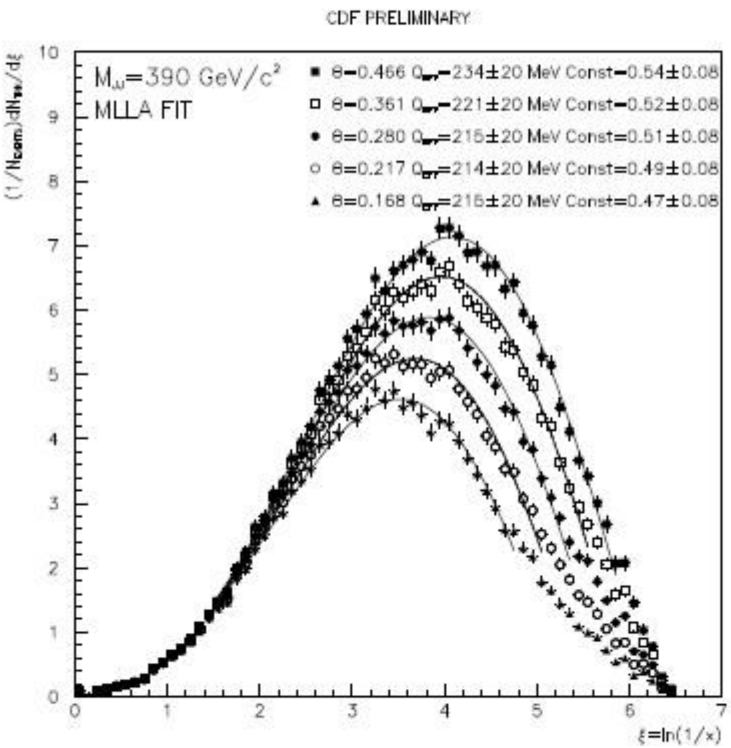


(a) Evolution of the $1/N dn/d\log(1/x_p)$ distributions with Q. The curves are MLLA fits.

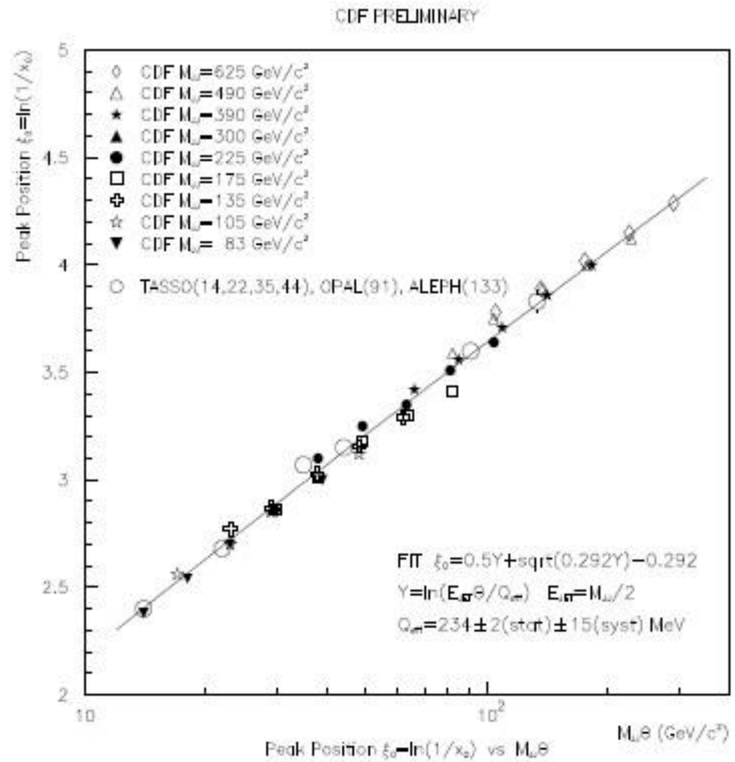


(b) Evolution of the peak position $log(1/x_p)_{max}$ with Q.

intrajet results in pp



(a) Evolution of ξ with jet opening angle, Θ, for $M_{\rm JJ} = 390$ GeV.

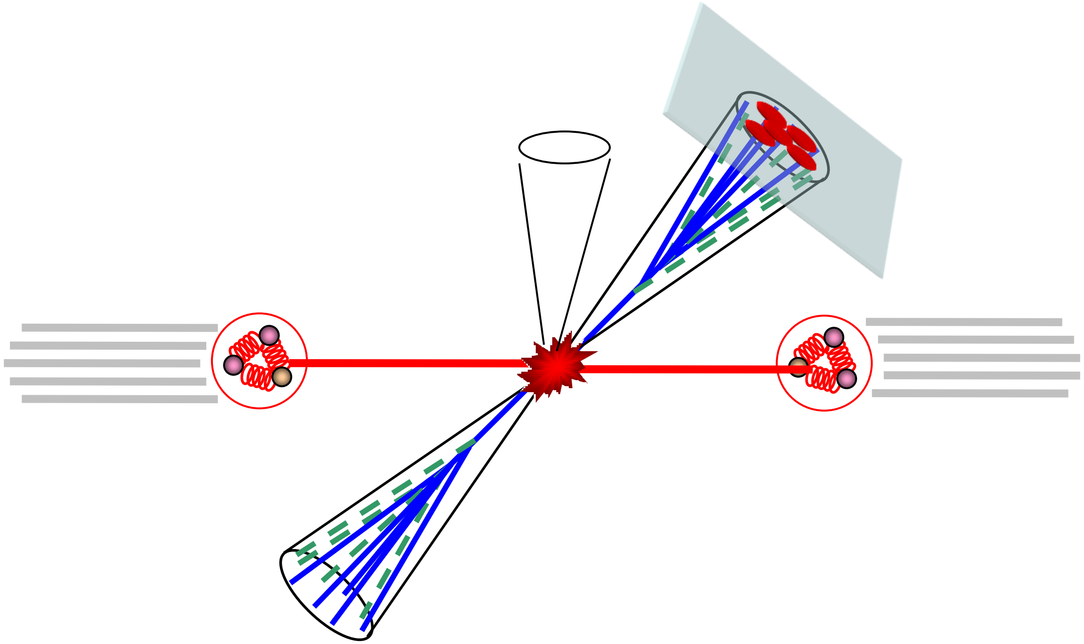


(b) Evolution of the peak position with $M_{\rm JJ}\Theta$.

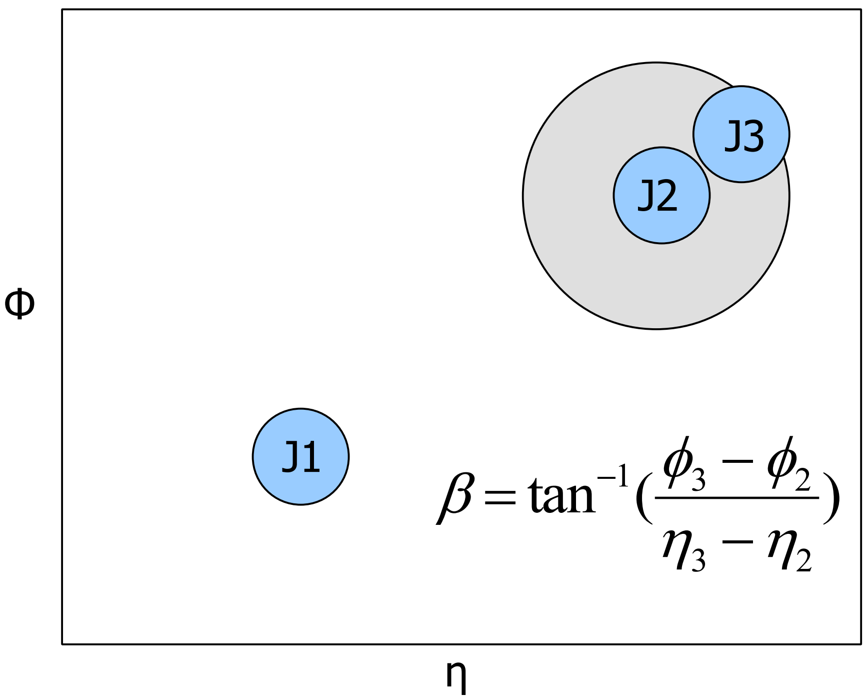
Coherence effect in interjet

Interjet coherence effects in pp

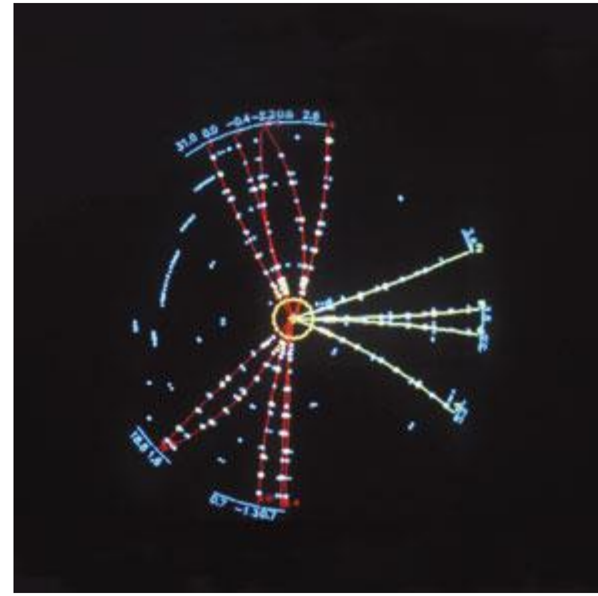
- In pp, coherence effects becomes complicate
  - colored constituents in both the initial and final states
  - transfer of color between interacting partons
  - interference effects in the initial states, in the final states, between the initial and final states

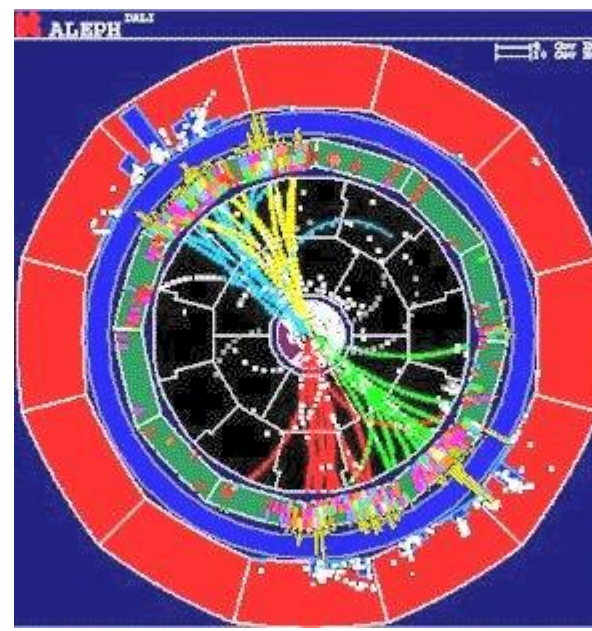


- **Typical analysis with multijets**
  - **Using 3-jet events**
    - **define J1, J2, J3 (E1>E2>E3)**
    - **J3 in R around J2 (0.6 < R < π/2)**
    - **define beta angle**

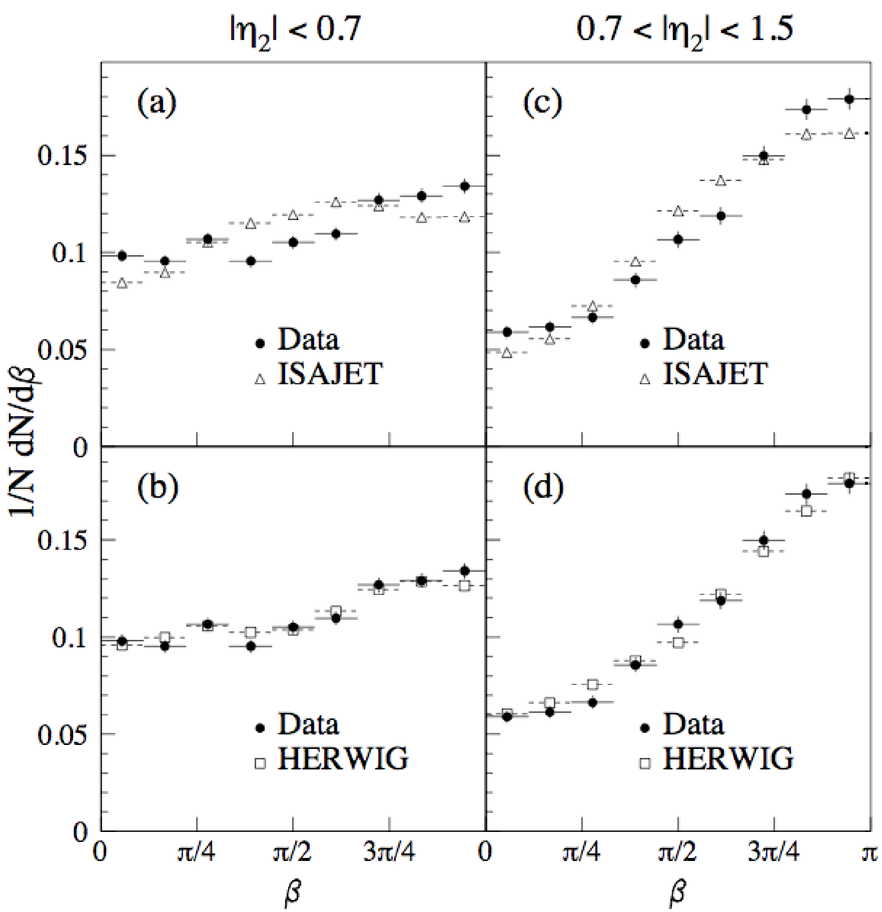


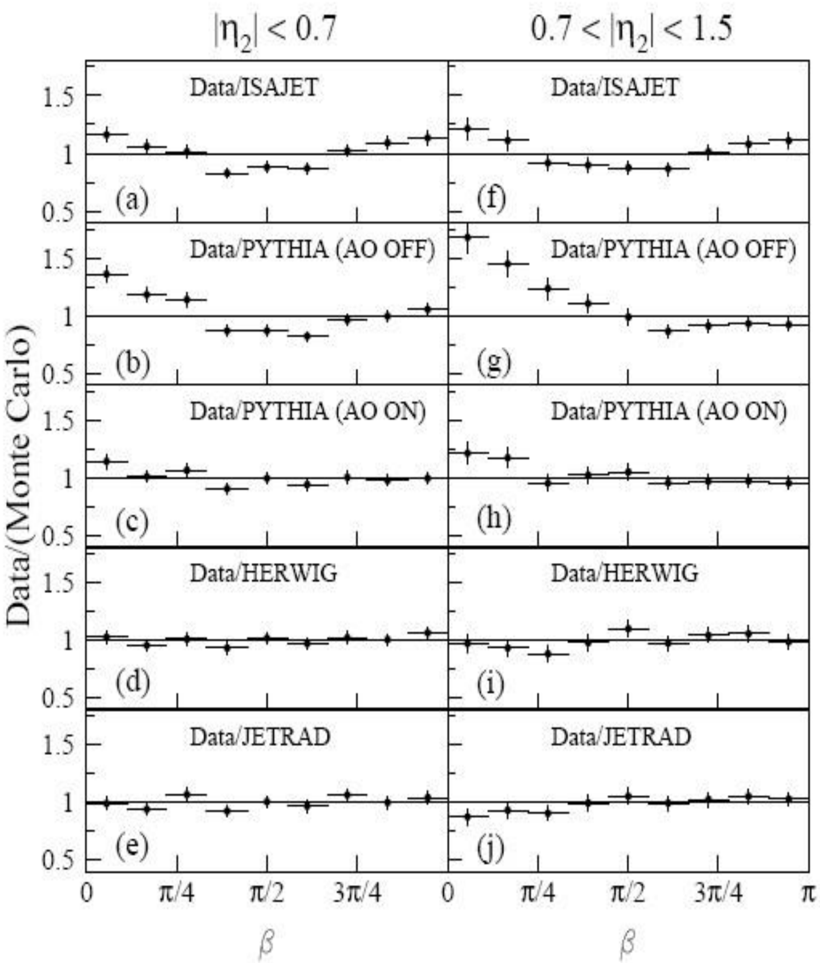
$$\beta = \tan^{-1}\left(\frac{\phi_3 - \phi_2}{\eta_3 - \eta_2}\right)$$





Interjet analysis results



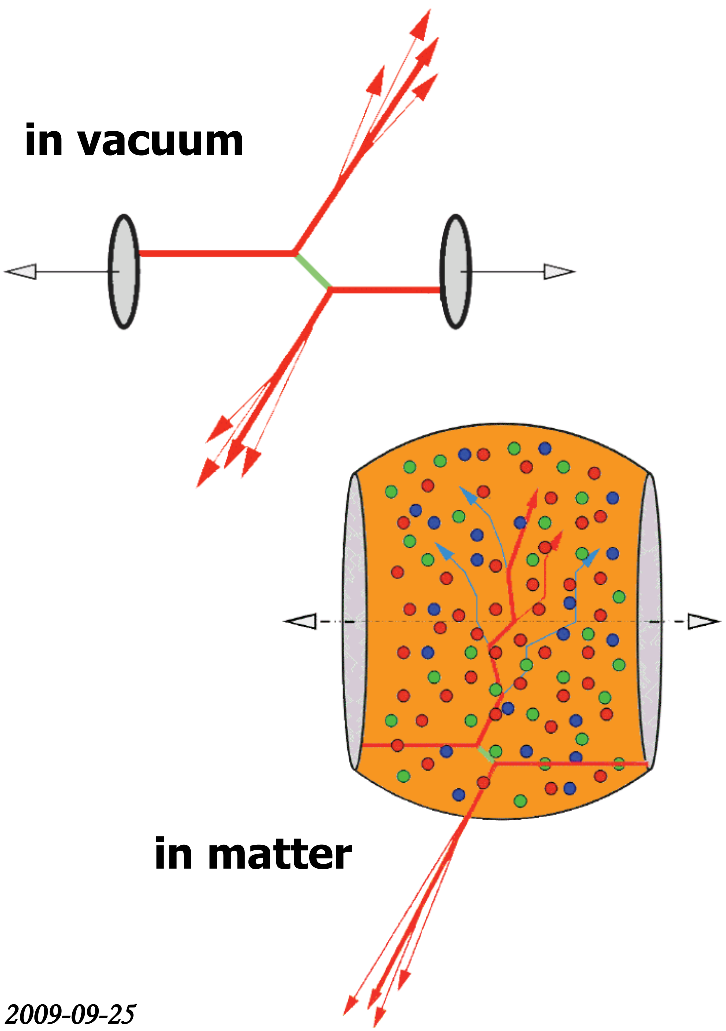


D0 Collaboration, Phys. Lett. B 414 419 (1997)

Coherence effect
in
dense matter

Jet Quenching

- **Extinction of jets**
  - **Bjorken proposed**
  - **a la Bethe-Bloch**



Fermi National Accelerator Laboratory

FERMILAB-Pub-82/59-THY
August, 1982

Energy Loss of Energetic Partons in Quark-Gluon Plasma:
Possible Extinction of High p_T Jets in Hadron-Hadron Collisions.

J. D. BJORKEN
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

Abstract

High energy quarks and gluons propagating through quark-gluon plasma suffer differential energy loss via elastic scattering from quanta in the plasma. This mechanism is very similar in structure to ionization loss of charged particles in ordinary matter. The dE/dx is roughly proportional to the square of the plasma temperature. For hadron-hadron collisions with high associated multiplicity and with transverse energy dE_T/dy in excess of 10 GeV per unit rapidity, it is possible that quark-gluon plasma is produced in the collision. If so, a produced secondary high-p_T quark or gluon might lose tens of GeV of its initial transverse momentum while plowing through quark-gluon plasma produced in its local environment. High energy hadron jet experiments

- **Yield of high-pT hadrons are reduced by 80% in Au-Au**
  - **normalized by pp data**
  - **not in d-Au**
- **Azimuthal correlation of jet**
  - **leading particle at RHIC**

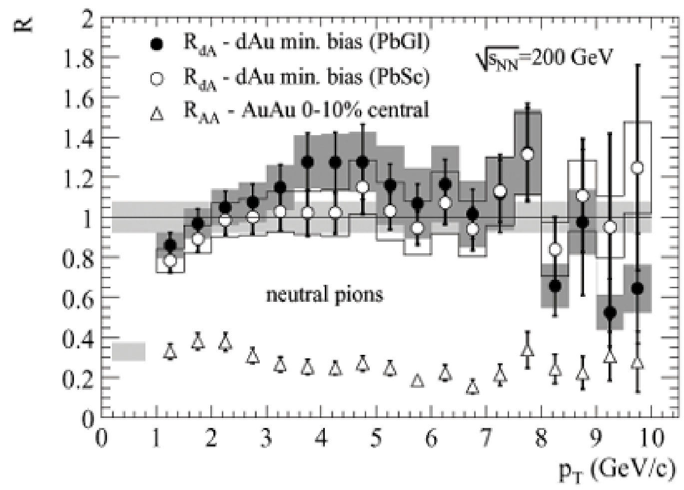
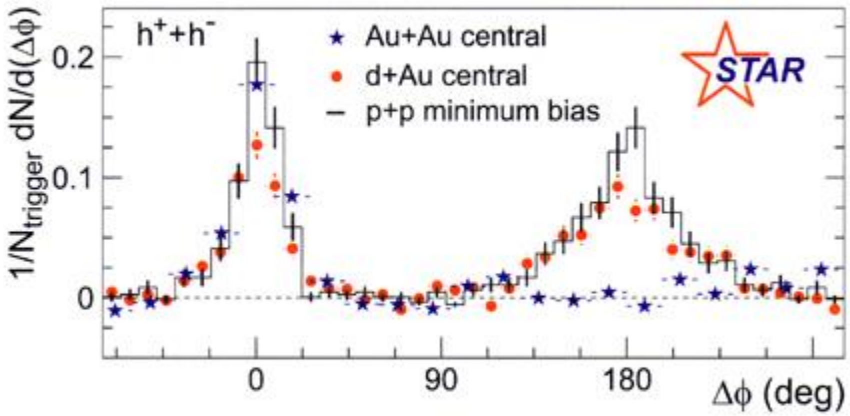


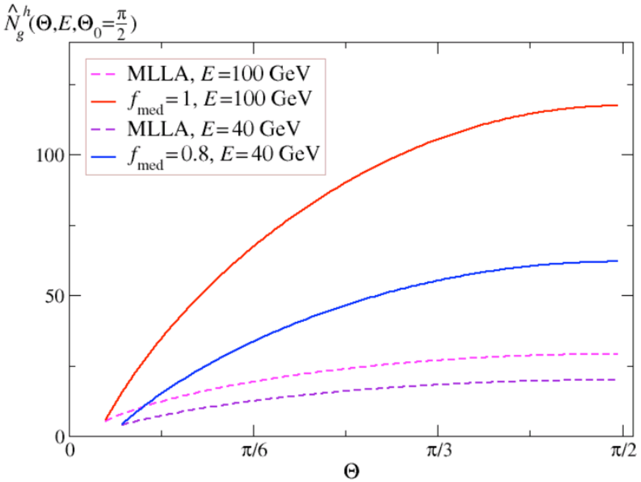
FIG. 1: PHENIX measurements [6] of nuclear modification factors $R_{AB}(p_T)$ for minimum bias d+Au and central Au+Au collisions illustrate the strong suppression of pion yields in central Au+Au collisions, in comparison to the expectations from pp collisions, scaled by the number of contributing binary collisions. No suppression is observed in the d+Au data.



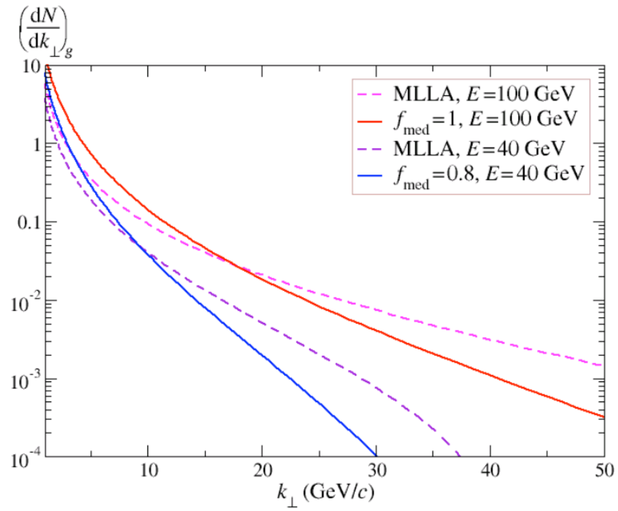
Jets in medium

- **one can expect the emission of soft gluons increases much in medium → medium modified splitting function**
  - **N. Borghini, Wiedemann, P. Arnold, C. Dogan, etc.**
- **Modeling by modifying the parton splitting functions**

angular distribution: "jet broadening"

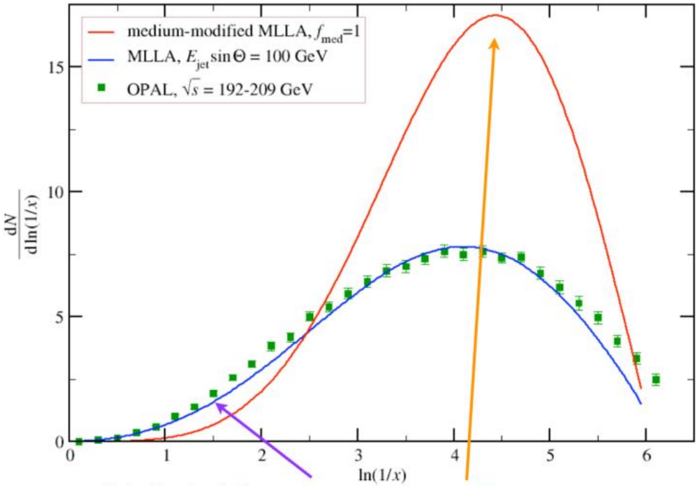


transverse momentum distribution: "jet softening"



NB 2009

inclusive longitudinal distribution



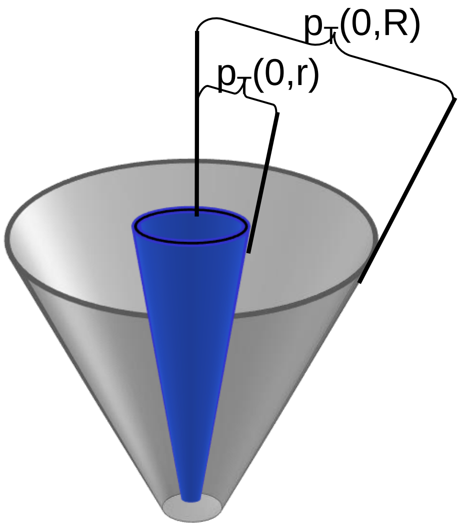
Partons are redistributed from large x to small x.

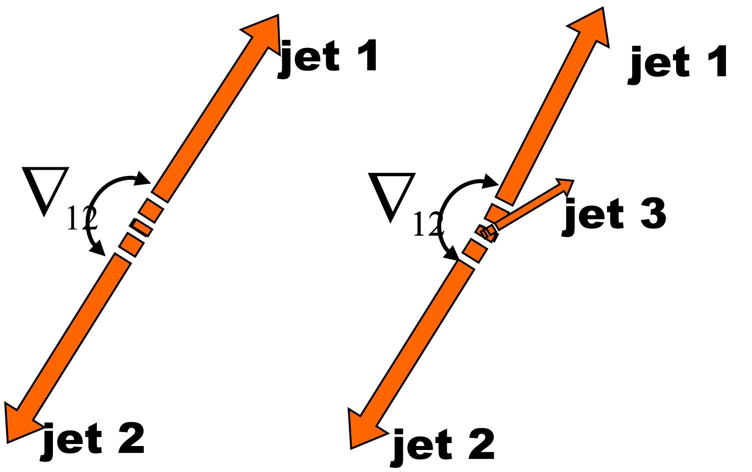
NB & Wiedemann, 2005

Korea CMS Activities toward the jet study

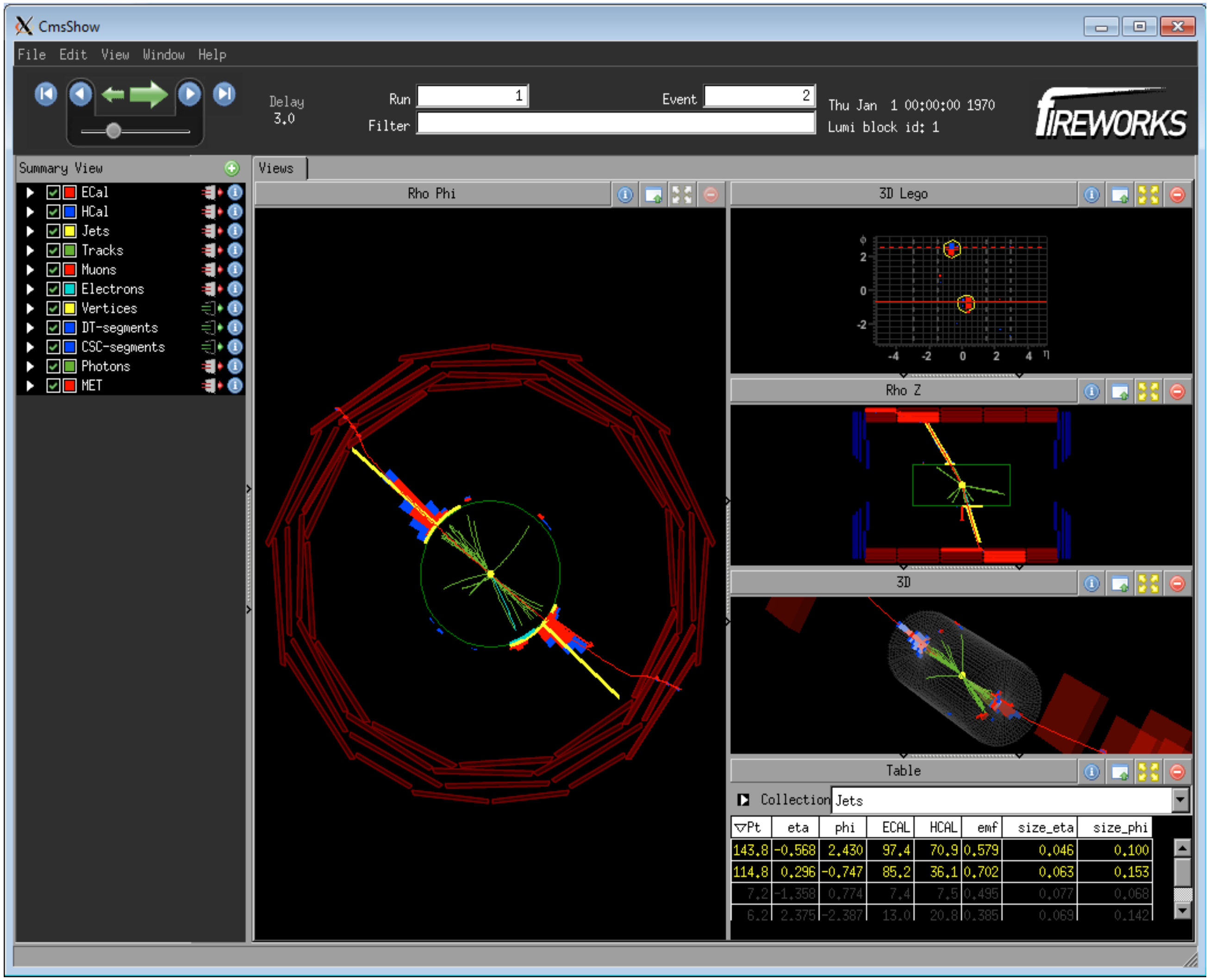
Current menu in CMS-QCD

- **QCD Analysis in CMS**
  - **current QCD High PT 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**
    - **etc. etc.**
- **we also work for CMS-HI**
  - **elliptic flow**
  - **Jet-flow correlation in HI**





Jets generated & simulated by KCMS

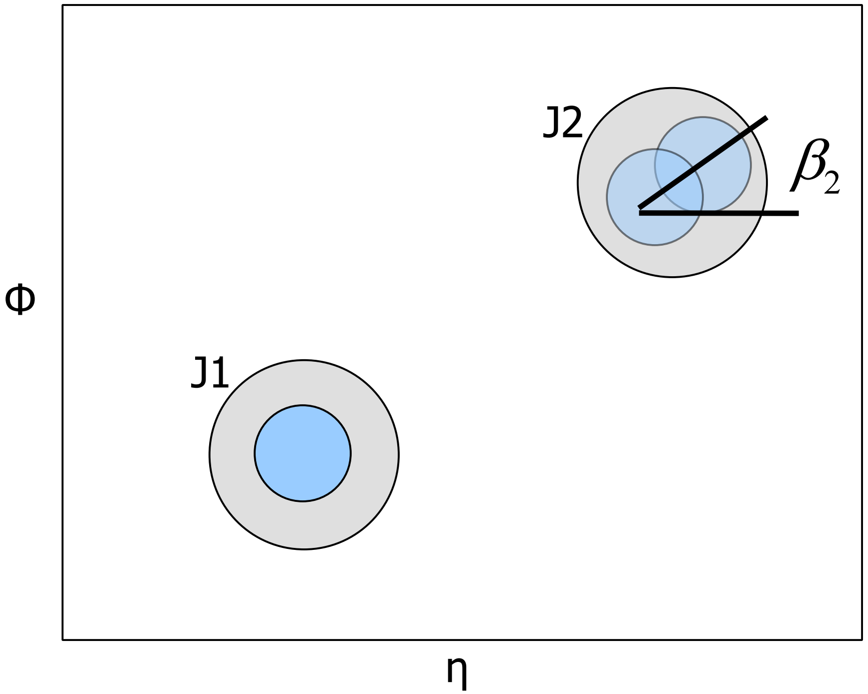


GEN-SIM-DIGI-RECO all done in our local CMS facility! → We are ready to go!

A new observable: underlying idea

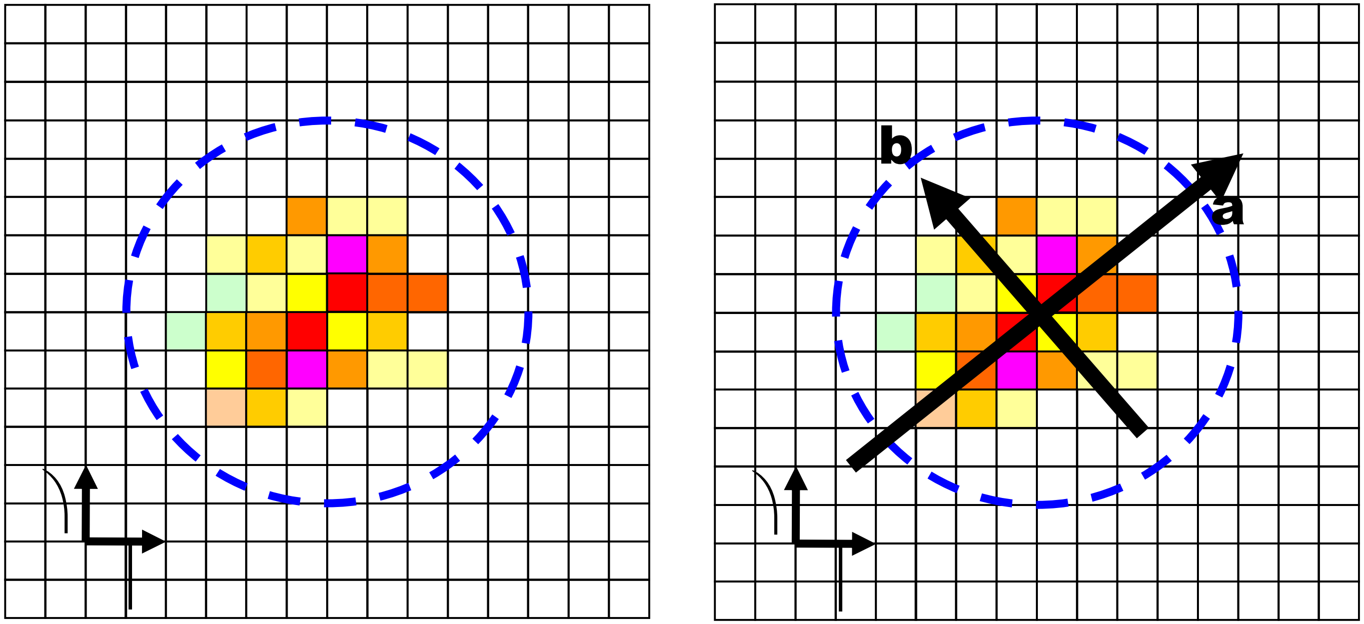
- **Imagine a 2.5 jet event:**
  - **fragmentation**
    - **gluon radiation, Angular Ordering**
  - **color strings produced**
    - **from the initial state or in the final state**
  - **affect on jet cluster shape**
    - **asymmetric shape**
  - **create correlation in di-jets**
    - **shape correlation**
- **Shape is nothing but fluctuation?**
  - **average out, need flattening**

$$\beta_i = \tan^{-1}\left(\frac{\sum |\phi_c - \phi_J|}{\sum |\eta_c - \eta_J|}\right)$$



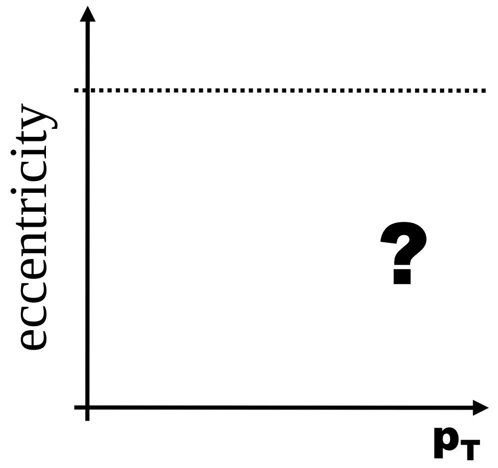
- **Define a major axis and a minor axis**
  - **1) eccentricity, 2) orientation (beta i)**
- **Be Careful!**
  - **event-by-event OR jet-by-jet**
    - **It's just 1) statistical, 2) phase space, 3) detector effect, 4) B-field effect, etc. or many more which can never be corrected**

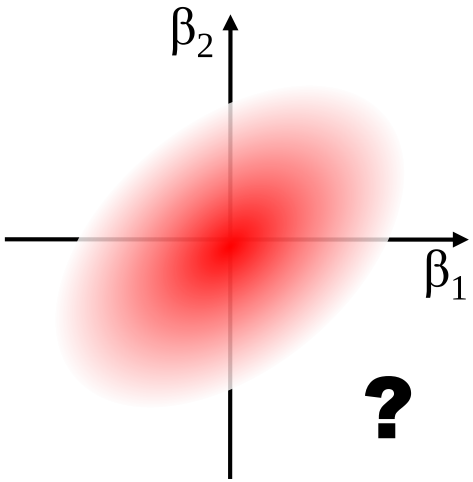
$$\varepsilon_i = \frac{size(b)}{size(a)} \qquad \beta_i$$

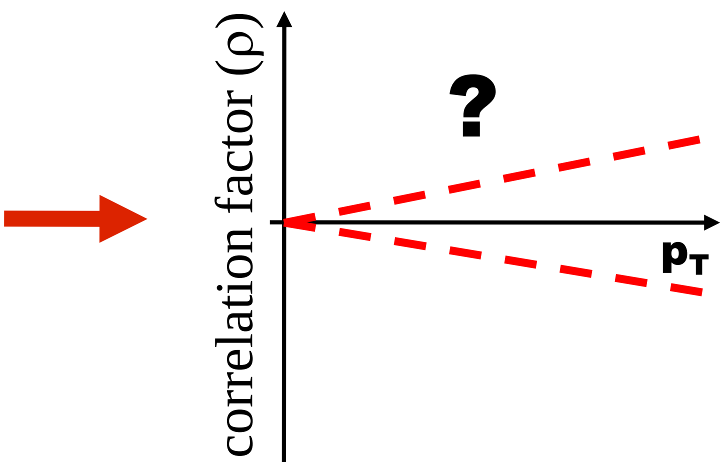


What could be the physics outputs?

- **After correcting all the effects**
  - **we expect a circular shape of jet on average (e.g. spin/polarization sum)**
    - **average eccentricity vs pt**
    - **look at two hemisphere correlation**
    - **more to imagine**







Physics expectation

- **MC calibration:**
  - **see whether MCs describe Data**
    - **feed back to MC**
- **In 2-jet evens**
  - **see the contribution of color coherence effects at LHC**
    - **new coherence measurement**
- **In 3-jet events**
  - **perform typical beta measurement**
    - **compare Tevatron vs LHC**
  - **J3 (~2/3 gluon) may have larger eccentricity**
    - **one of our theoretical supporters' guess (new physics out)**

Manpower and facility

- **Manpower from UOS**
  - **Inkyu Park will be stationed at CERN for a year**
    - **2010/03-2011/02, on leave as a sabbatical year**
  - **Prof. Hyunsoo Min & Prof. Dongsu Bak will do theoretical supports**
  - **SN Park (Ph.D. course student) will work together for data analysis for his Ph.D. thesis**
  - **HY Kim & GM Ryu (MS students) are warming up in the bullpen**
- **Facility**
  - **Exploit the Seoul Supercomputer Center (SSCC) as a dedicated computing resource**
    - **Tier2 level facility, MC production, data analysis**

Plan

- **Plan**
  - **task 1: MC GEN level study (fall/winter 2009)**
    - for example, Z→qqbar, di-jet correlation
    - 6 months: set-up variable, MC study (PYTHIA, HERWIG, etc)
  - **task 2: follow the Di-jet event reco & selection (spring 2010)**
    - 6 months: with some jet-algorithm work
  - **task 3: perform typical 3-jet color coherence study (2010-2011)**
    - 1 year + more : physics out
  - **task 4: real data analysis, systematics**
    - 2 years or more: publication and Ph.D. thesis (~ 2012, 2013)

Conclusion

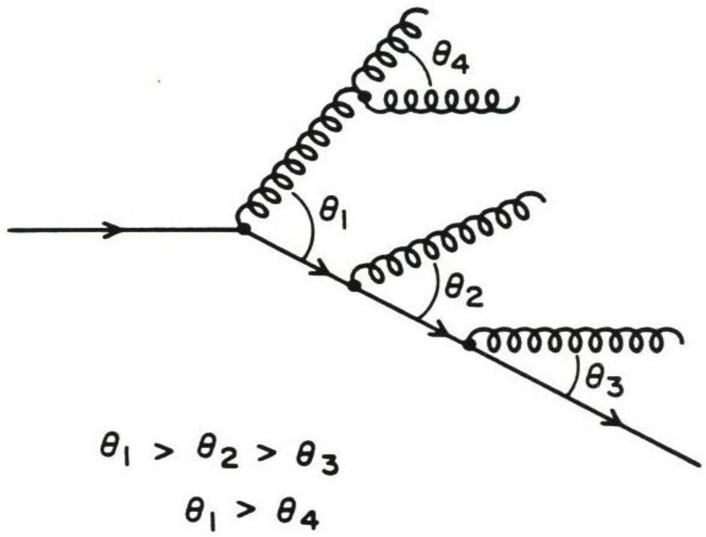
Conclusion

- Color coherence effects in Intra-jet, in Inter-jet, and Jet modification in dense matter were reviewed
  - color coherence effect →hump-backed plateau
  - string/drag effect in 3 jets
  - expected jet broadening, jet softening in HI
- These measurements with jets are very straitforward at LHC/CMS
  - extremely interesting in contrast with Tevatron, e+e- results
  - contribute to tune MC
- Jet spectrum and Jet shape are modified in dense matter
  - important knowledge to understand the hot and dense matter
  - contribute to confirm the existence of QGP

Backup slides

MLLA's main features:

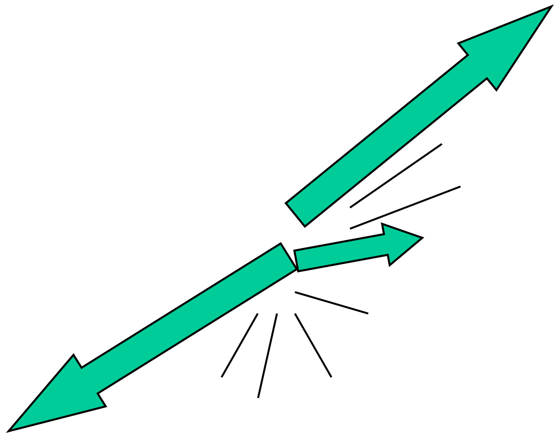
- resummation of double and single logarithms in ln(1/x)
- consider the running α_s along the parton shower development
- consider the color coherence effects such as AO
  - AO (Angular Ordering) : the angle between mother and offspring partons decreases along the fragmentation step
- includes next-to-leading order corrections

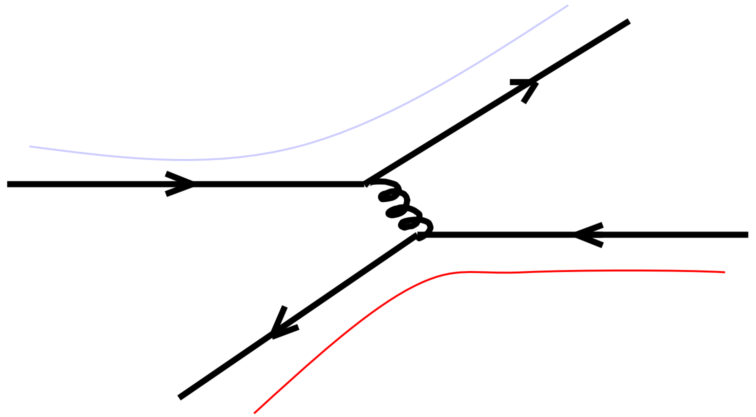


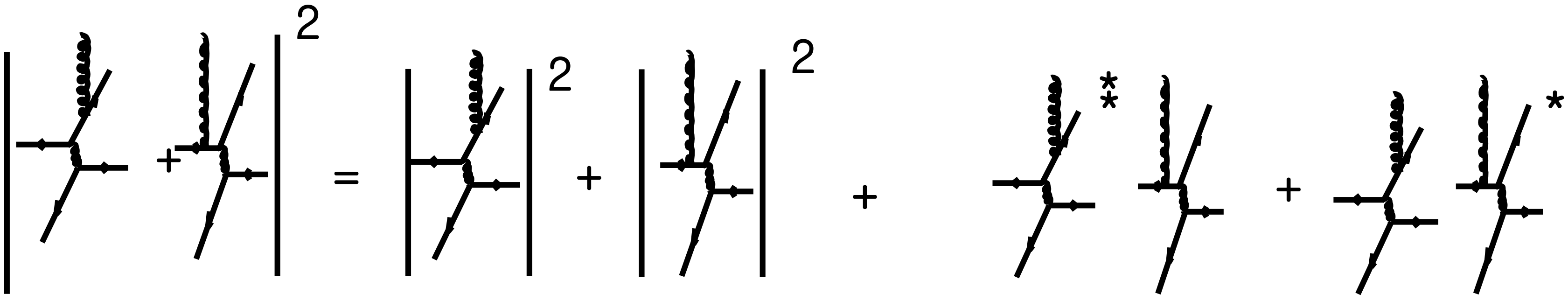
AO

- **AO (Angular Ordering) approximation**
  - **suppress of soft gluon radiation in partonic cascade in some phase space**
  - **emission angles of soft gluons decrease monotonically as the partonic cascade evolves**

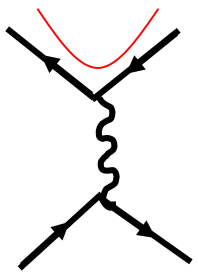
String or Drag effect





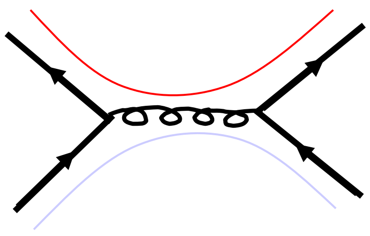


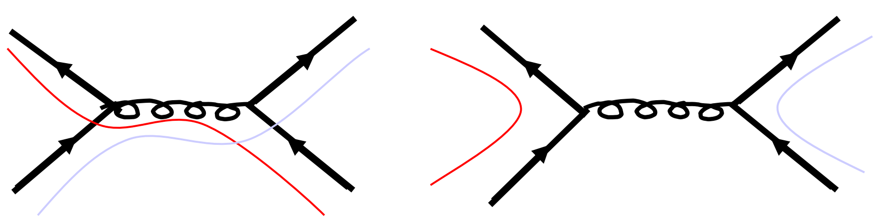
$$\xi^* = Y\left(1/2 + \sqrt{C/Y} - C/Y\right) + F_h(\lambda)$$



$$C = \left(\frac{11N_c/3 + 2n_f/3N_c^2}{4N_c}\right)^2 \cdot \frac{N_c}{11N_c/3 - 2n_f/3}$$

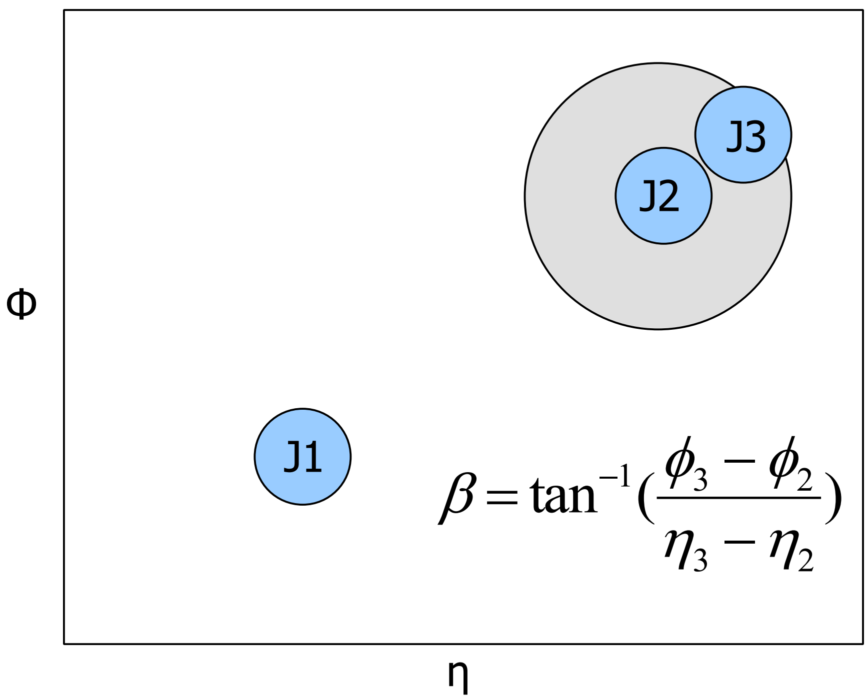
$$F_h(\lambda) = -1.46\lambda + 0.207\lambda^2 \pm 0.06$$

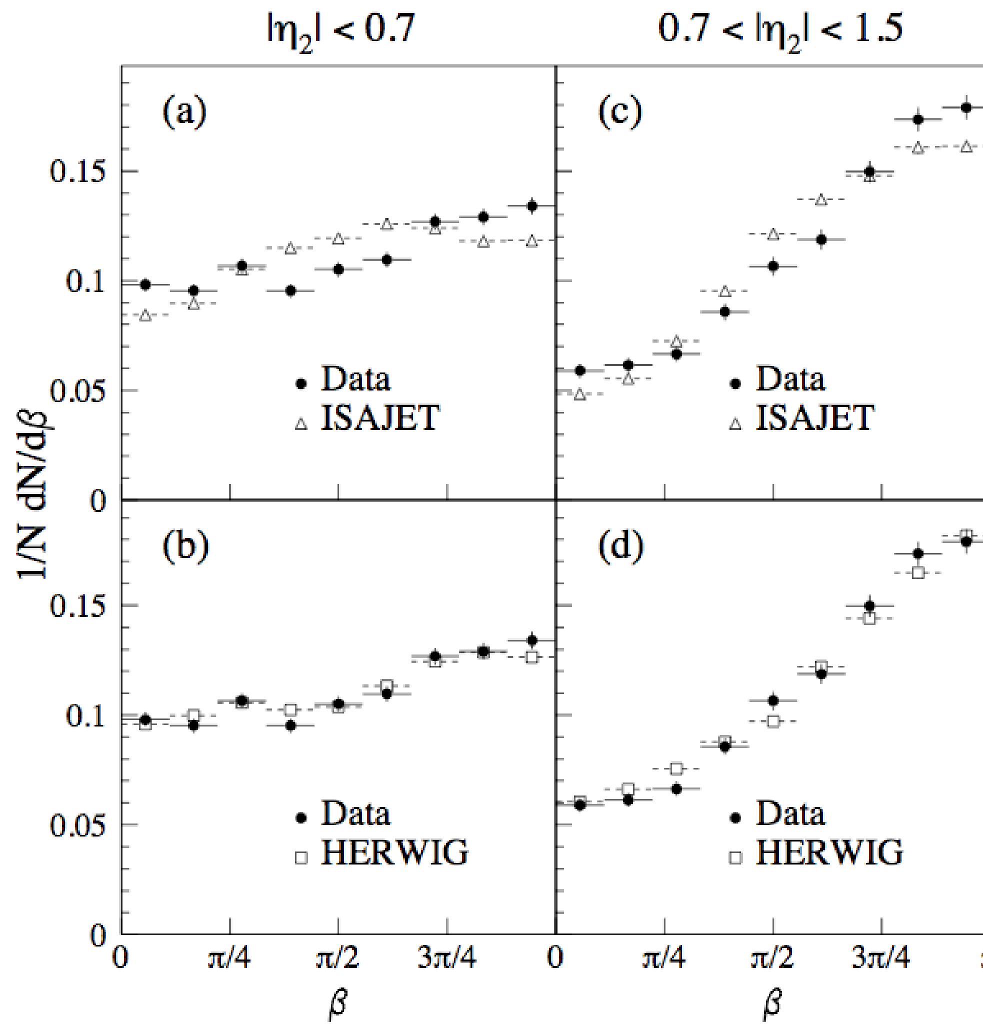




A typical coherent measurement

- Using 3-jet events
  - define J1, J2, J3
    - E1>E2>E3
  - J3 in R around J2
    - 0.6 < R < □/2
  - define beta angle





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

* Initial–to–final state coherence

$$p\bar{p} \rightarrow 3\,jets + X$$

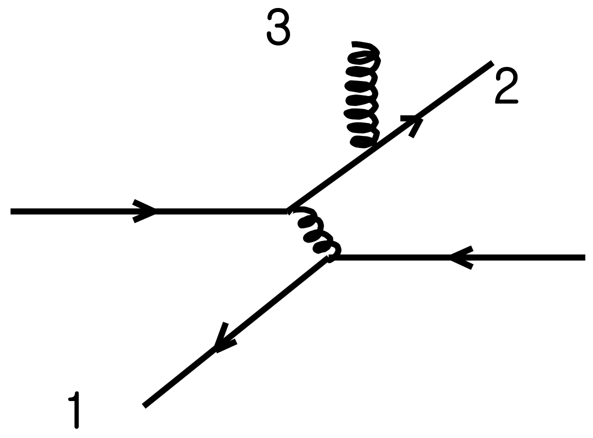
$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

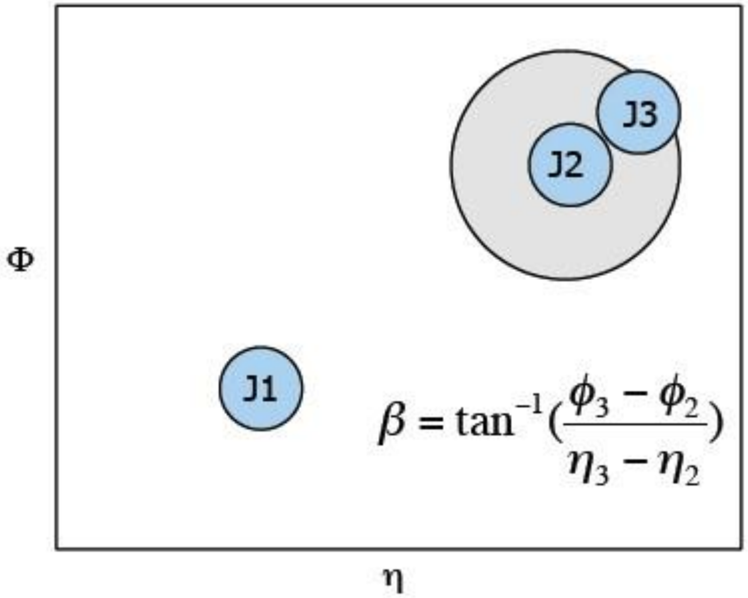
$$\beta = \tan^{-1}\left(\frac{sign(\eta_2)\cdot\Delta\phi}{\Delta\eta}\right)$$

$$\eta = -\ln\left[\tan(\theta/2)\right]$$

$$\Delta\eta = \eta_3 - \eta_2$$

$$\Delta\phi = \Delta\phi_3 - \Delta\phi_2$$





B. W + Jets

Angular distributions of tower above 250 GeV

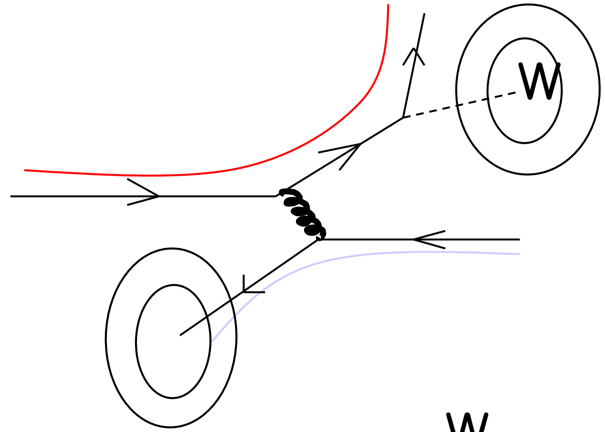
Tower : $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

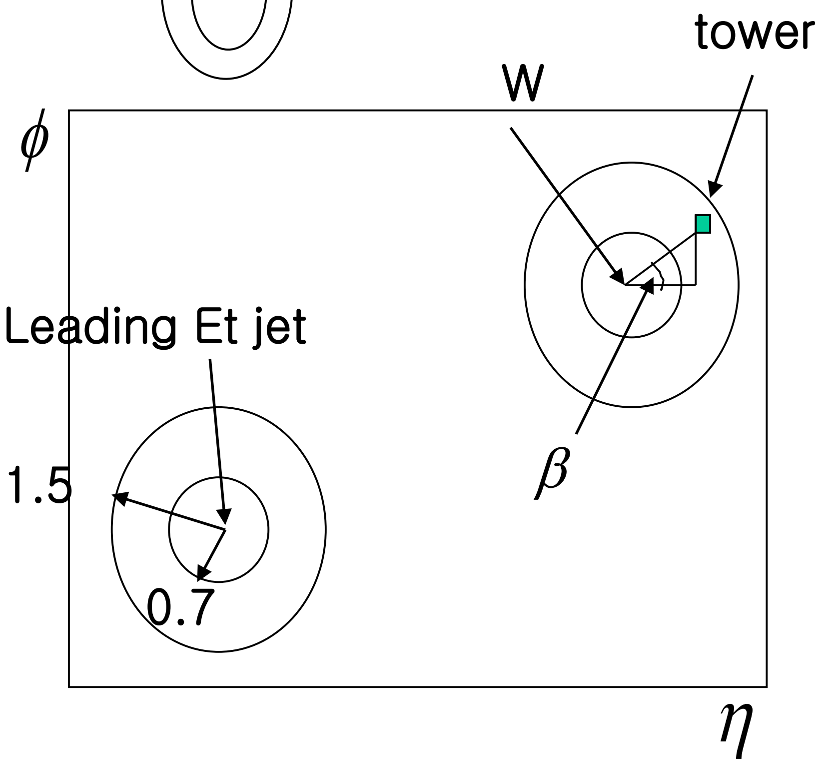
$$0.7 < R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.5$$

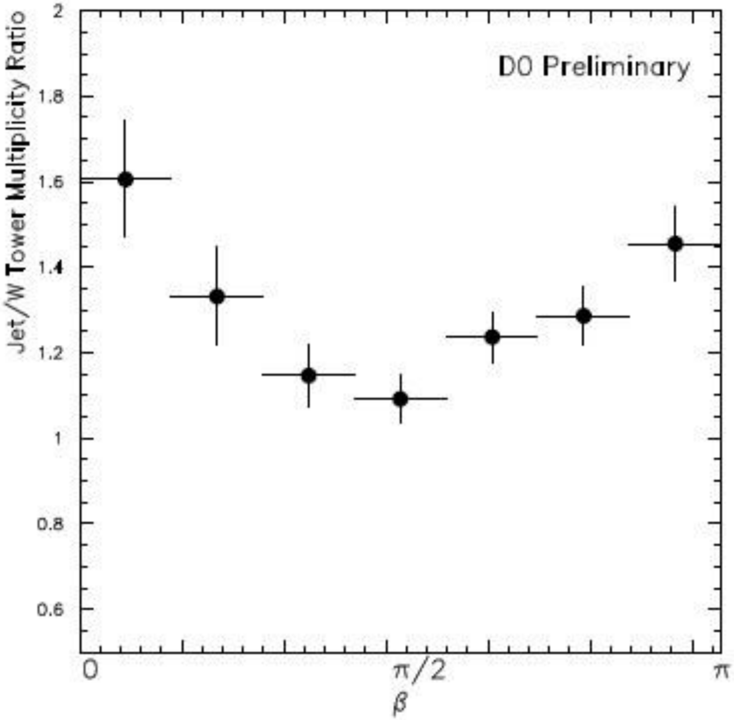
$$\beta_{W,Jet} = \tan^{-1}\left(\frac{sign(\eta_{W,Jet}) \cdot \Delta\phi_{W,Jet}}{\Delta\eta_{W,Jet}}\right)$$

$$\Delta\eta_{W,Jet} = \eta_{Tower} - \eta_{W,Jet}$$

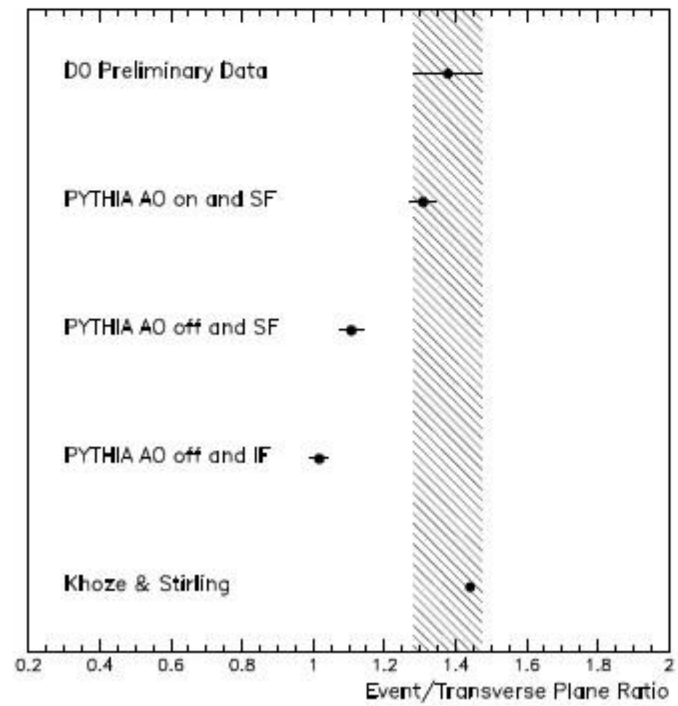
$$\Delta\phi_{W,Jet} = \Delta\phi_{Tower} - \Delta\phi_{W,Jet}$$







(a) Jet/W tower multiplicity ratio as a function of β.



(b) Ratio of event plane to transverse plane of Jet/W tower multiplicity for DØ data, PYTHIA with various coherence implementations, and a MLLA QCD calculation. The errors are statistical only.

FIG. 7. DØ preliminary results on $W+$ Jets coherence.

For any $\beta_i = \tan^{-1}\left(\frac{\sum|\phi_c - \phi_J|}{\sum|\eta_c - \eta_J|}\right)$