Color coherence Measurement at 7 TeV

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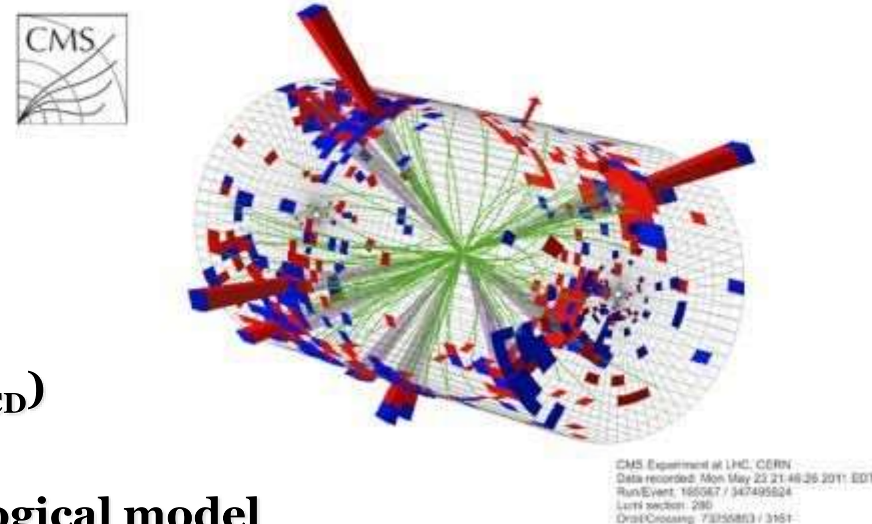
Introduction

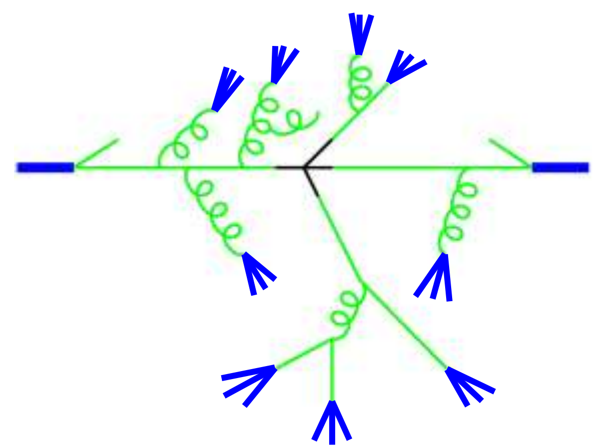
❑ Dominant features in High-PT hadron collision

- **Jet**
  - **Particles in collimation**
- **Jet production**
  - **High-Pt parton collision**
  - **Parton shower**
    - **pQCD, parton emision ($Q_o > \Lambda_{QCD}$)**
  - **Fragmentation, Hadronization**
    - **Non-perturvative, phenomenological model**



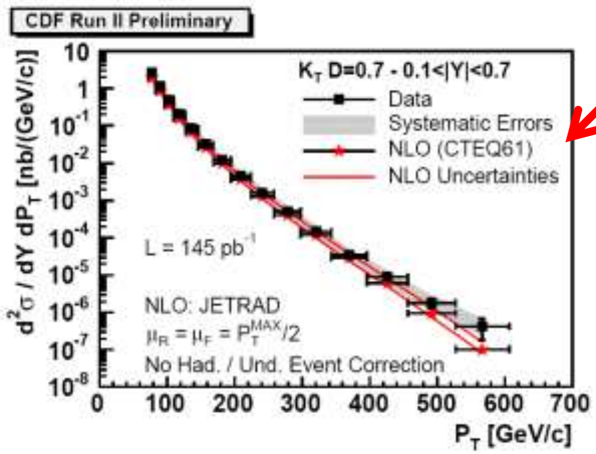
❑ QCD studies with jet

- **Jet production**
- **Jet shape**
- **Jet correlation**

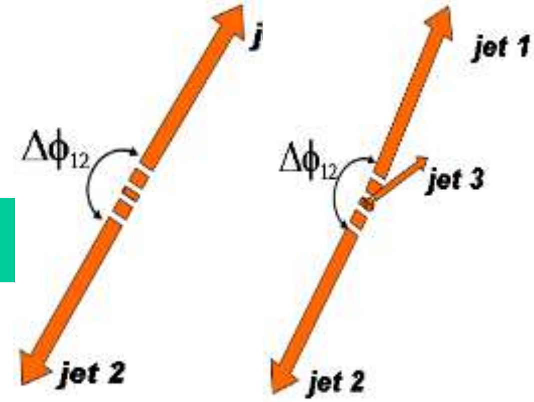


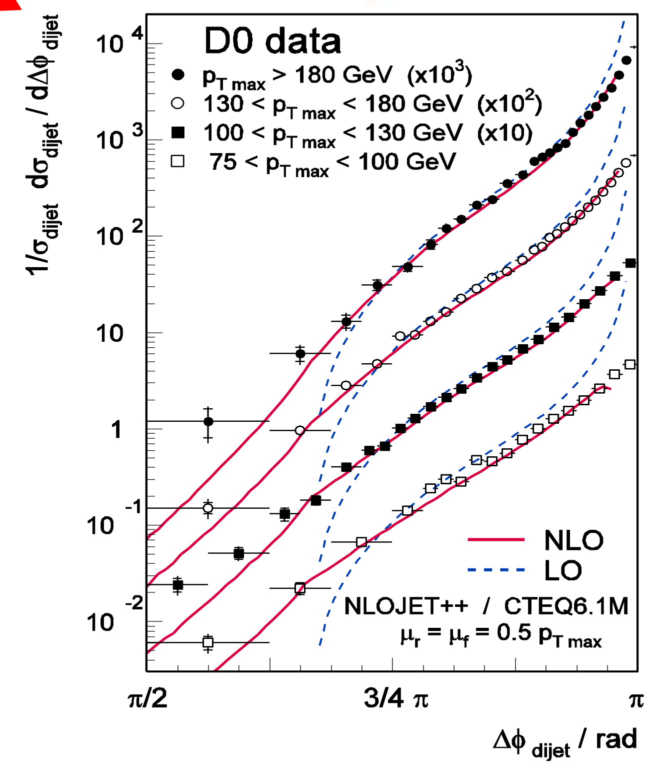
QCD studies with high p_T jets

Jet p_T spectrum

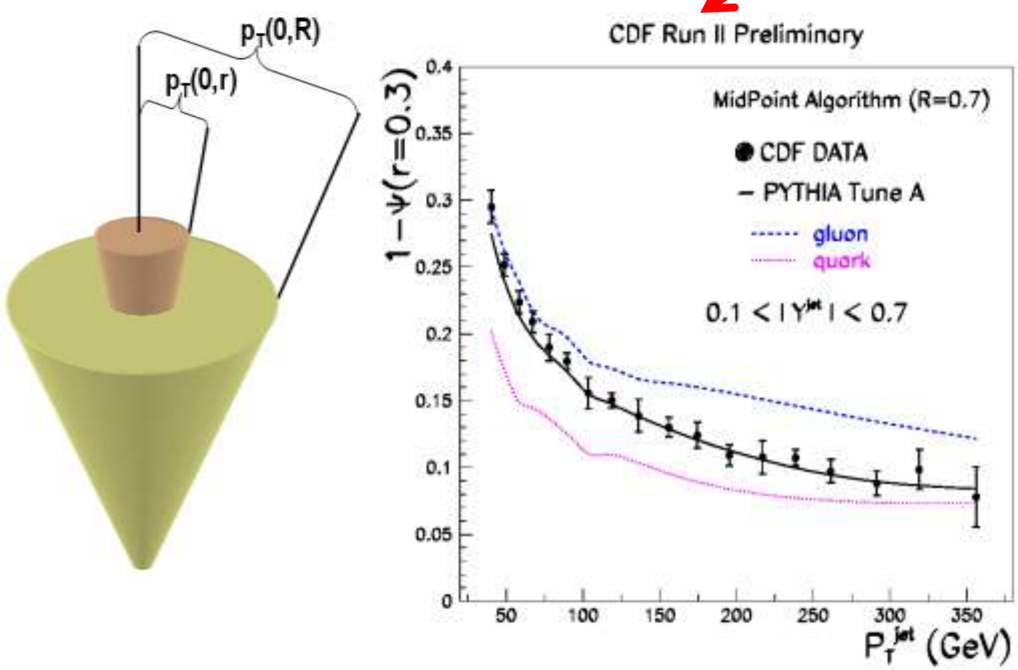


Jet angular correlation



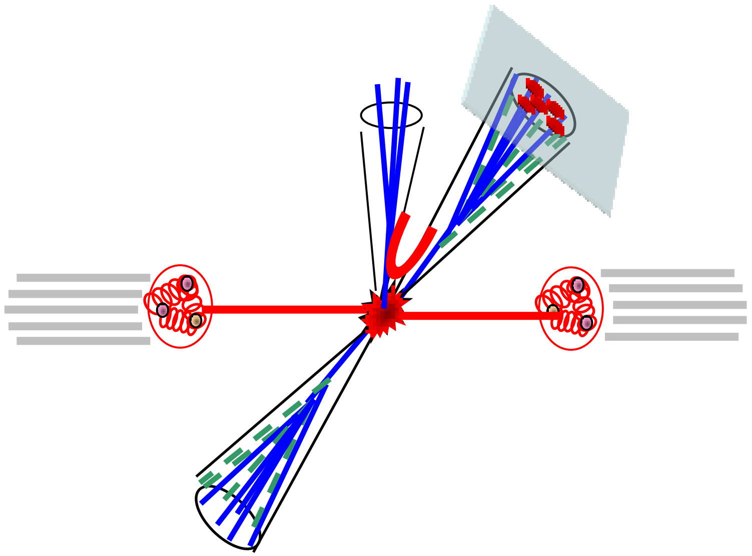


Jet shape



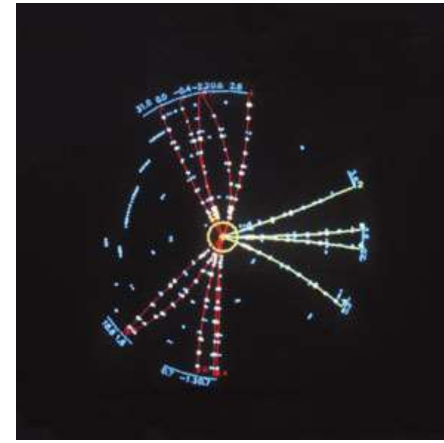
Color coherence

- QCD describes the pp collision as a hard interaction of their constituents that have color charge
- Color connection
  - Outgoing partons from the hard collision remains color connected at short distance and interfere with each other during their fragmentation process
- Symptom
  - Abundance of particles near color connected area
  - Deficiency of particles elsewhere

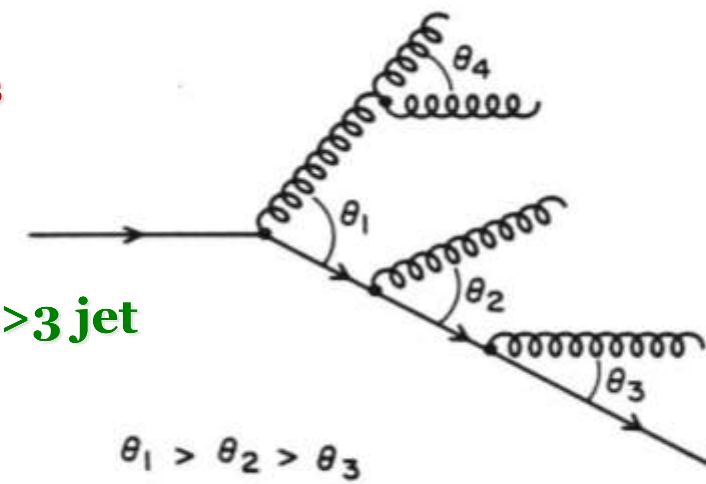


Jet production & coherence

- **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



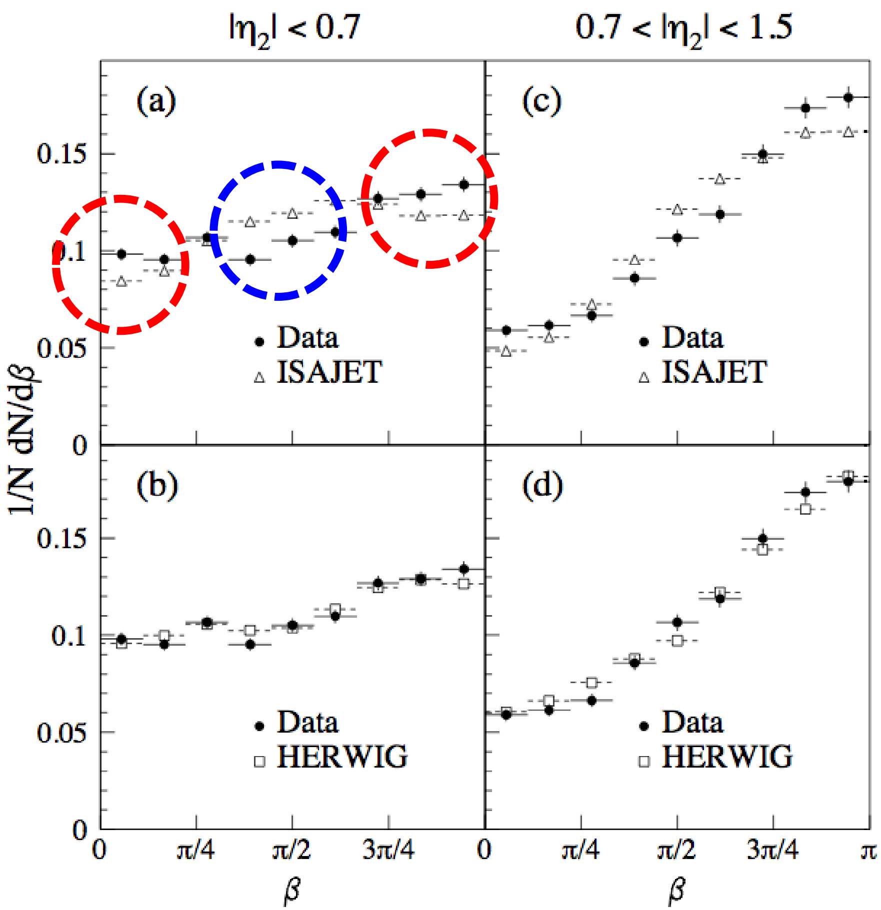
- **Intrajet coherence**
  - color coherence in partonic cascade
  - AO (Angular Ordering)
    - emission angle decreases → cone shape
    - hump-backed shape of particle spectra in jets
- **Interjet coherence**
  - string/drag effect
  - angular structure of soft particle flow for >3 jet
  - AO worked for Tevatron energy



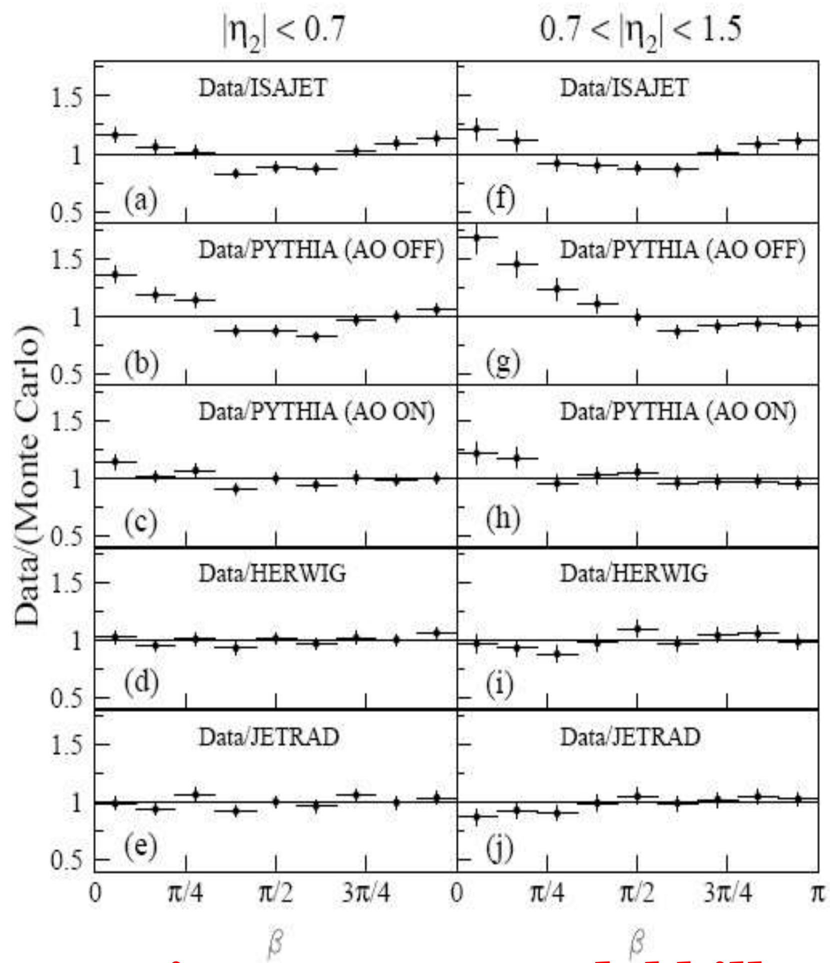
Angular Ordering

Tevatron measurements

- Both CDF & Do released the results



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



Acting as a MC model killer

Color coherence at LHC?

- **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
  - Higher coherence effects?
    - Break AO?
- **Question**
  - Is it smaller? Bigger?
  - Is the Tevatron fix still valid?

INTERESTING PHYISICS TOPIC

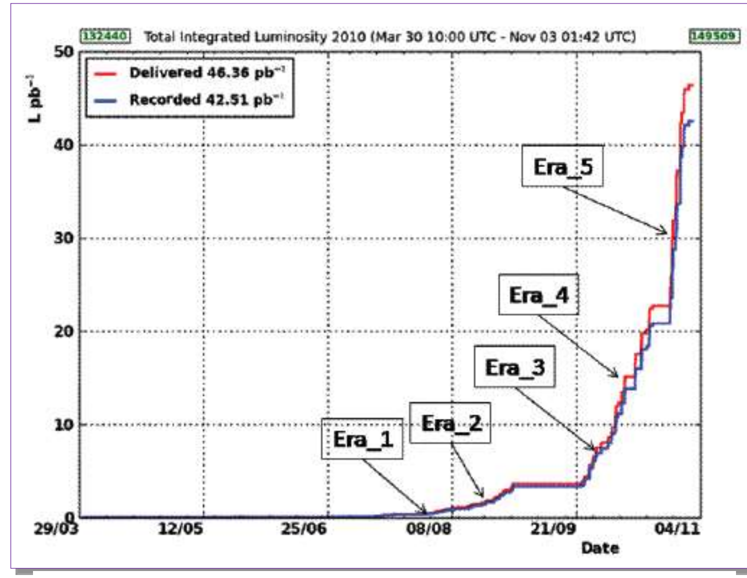
F. Hautmann & H. Jung, Nucl. Phys. B 186 (2009) 35-38

Color Coherence Measurement at 7 TeV

LHC 2010 Data sample

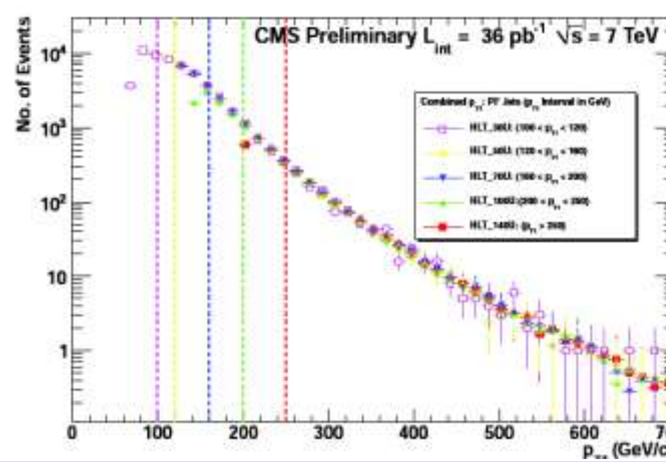
❑ Used 2010 data corresponding to 36 pb-1

Data era	Run range	Integrated Lumi. (pb^{-1})
era_1	136035-141881	0.28
era_2	141956-144114	2.90
era_3	146428-147116	5.06
era_4	147196-148058	9.5
era_5	148822-149294	18.3
		~36



❑ Data mix

HLT Jet Trigger	p_{T1} intervals (GeV)	Collected luminosity (pb^{-1})	Number of events total (central, forward)
HLT_Jet30U	100-120	0.35	4,511 (1,671, 2,840)
HLT_Jet50U	120-160	4.5	67,086 (27,069, 40,017)
HLT_Jet70U	160-200	9.2	50,071 (23,055, 27,016)
HLT_Jet100U	200-250	20	39,464 (18,987, 20,477)
HLT_Jet140U	250-	36	31,999 (16,728, 15,271)
All	100-		193,131 (87,510, 105,621)



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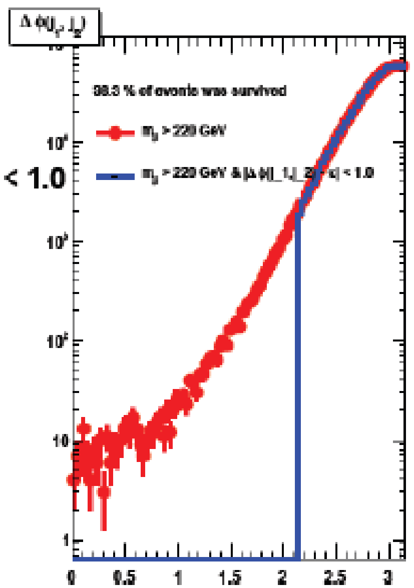
MC samples on the test-bench

- **PYTHIA 6 Tune Z2 :**
  - ME: 2 →2 LO, Parton Shower: p_T ordered.
    - Color Coherence for first branching in ISR and FSR using Angular Ordering (LUND string model)
- **PYTHIA 8 Tune 4C :**
  - ME: 2 →2 LO
    - Similar to PYTHIA 6 in what concerns us.
- **HERWIG++ Tune 23:**
  - ME: 2 → 2 LO, Parton Shower: angular ordered showers
    - Color Coherence through Angular Ordering – coherent branching algorithm.
- **MADGRAPH :**
  - ME: 2 → 2 and 2 → 3 LO
    - Matched to PYTHIA 6 for PS.

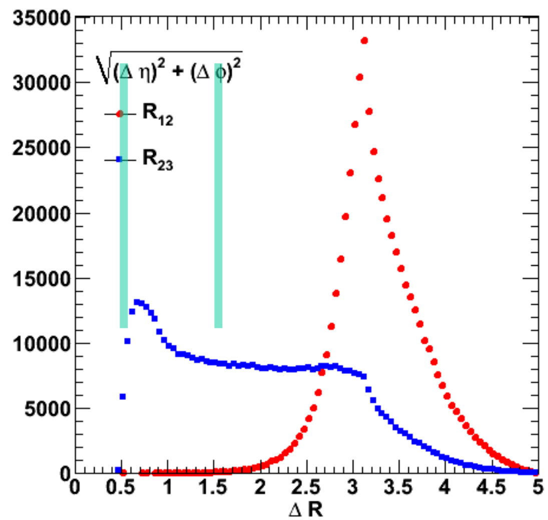
Event Selection & topology

- **Reconstruction**
  - **Particle Flow → FastJet → anti-kt (R=0.5)**
- **Event selection**
  - **3rd jet emitted by the second.**
  - **2nd jet “back-to back” with the 1st one**
    - **We request 3rd jet close to the second.**

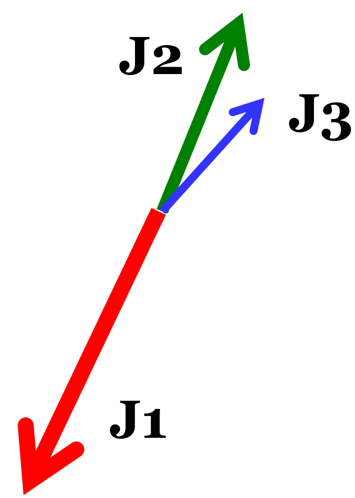
Jet 1	Jet 2	Jet 3
$p_T > 30$ GeV		
$\lvert\eta_{1,2}\rvert < 2.5$		
$M_{12} > 220$ GeV		
	$0.5 < \sqrt{\Delta\eta_{23}^2 + \Delta\phi_{23}^2} < 1.5$	



$M_{12} > 220$ GeV



$$0.5 < \sqrt{\Delta\eta_{23}^2 + \Delta\phi_{23}^2} < 1.5$$



$P_{T,J1} > P_{T,J2} > P_{T,J3}$

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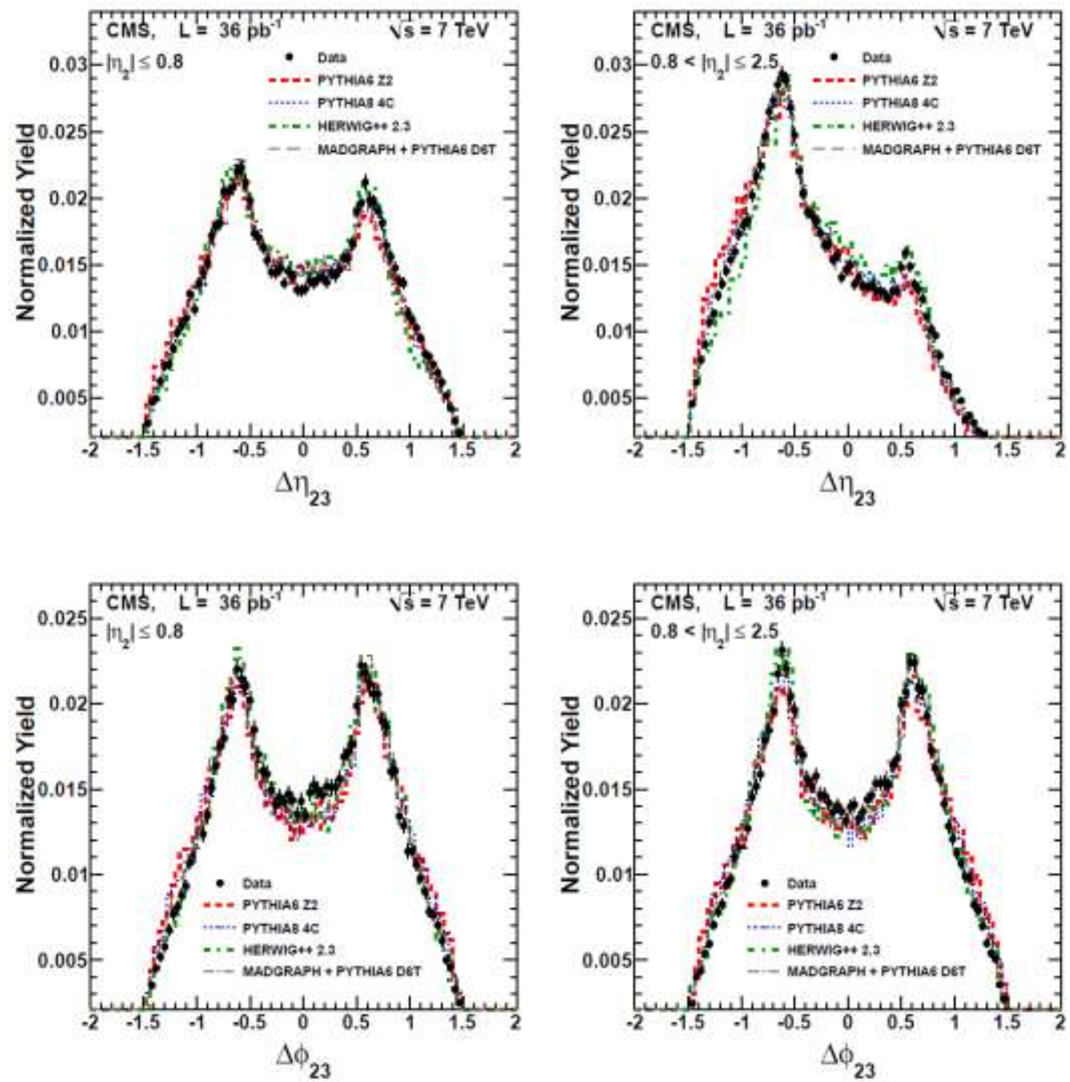
Data & MC comparison

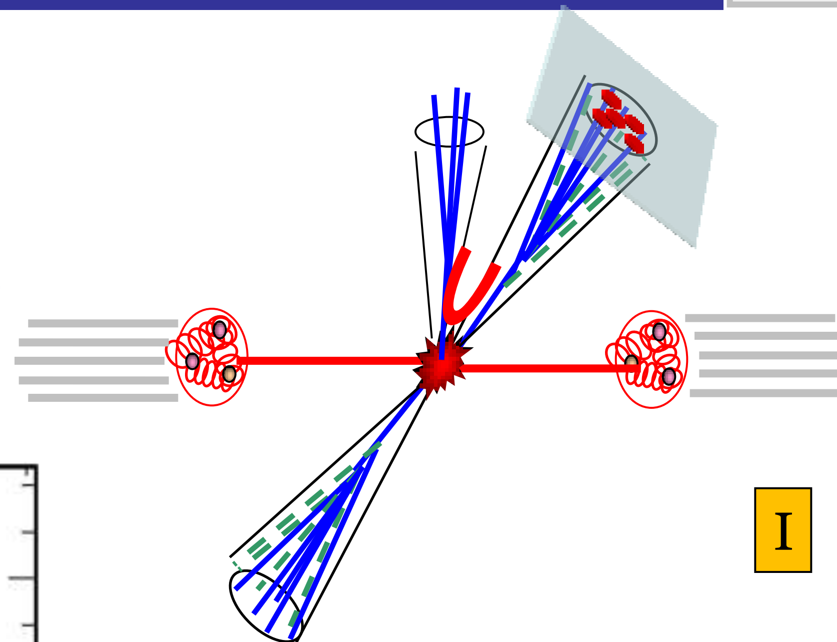
- **Comparisons**
  - $\eta_3 - \eta_2$
  - $\phi_3 - \phi_2$

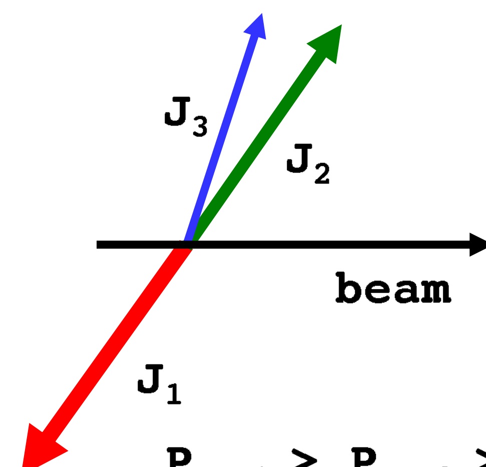
- **General features well described.**
  - Agreement is not expected to be perfect since color coherence is not perfectly modeled by the MC.



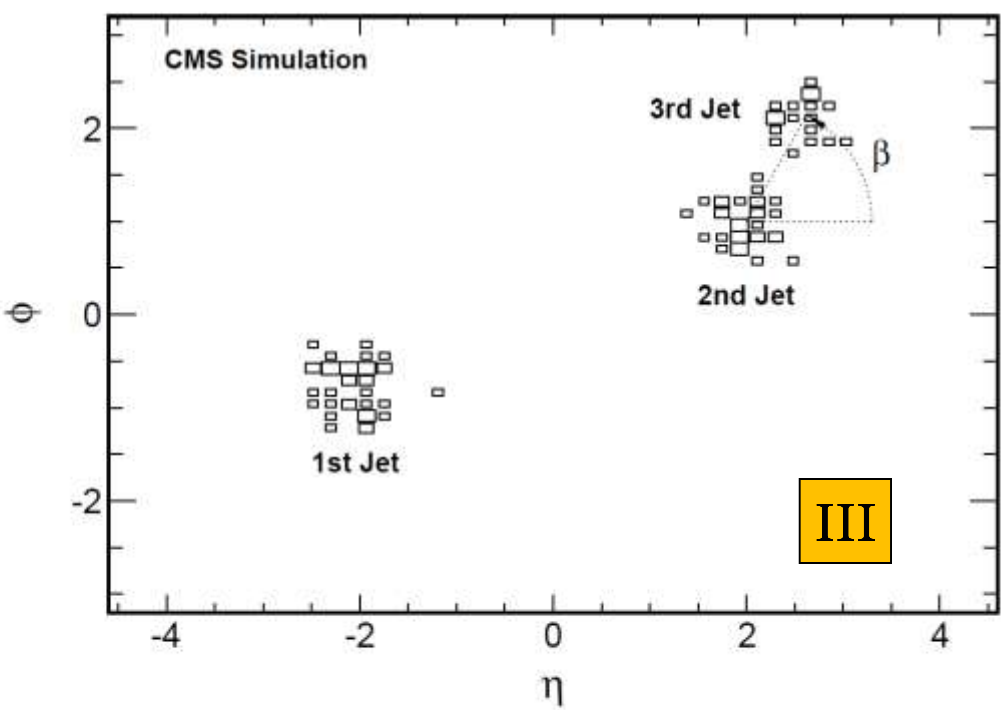
3-jet topology

- ❑ Jets are reconstructed
- ❑ sorted by p_T
- ❑ projected to the $\eta - \phi$ space
- ❑ Finally, calculate β





$P_{T,J1} > P_{T,J2} > P_{T,J3}$



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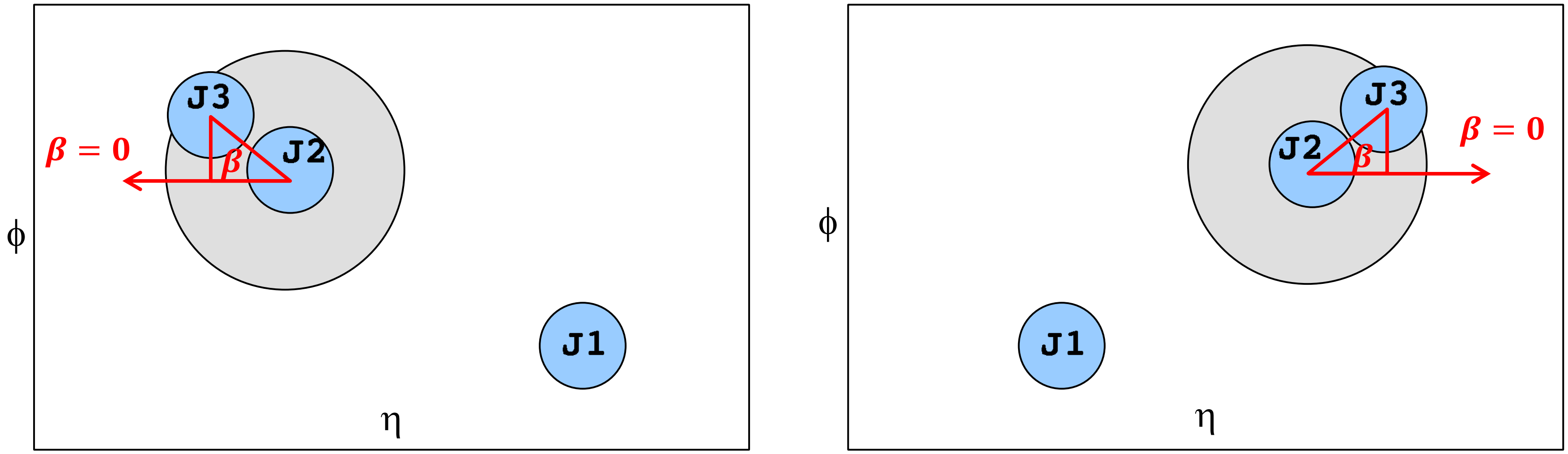
Definition of β

❑ Definition:

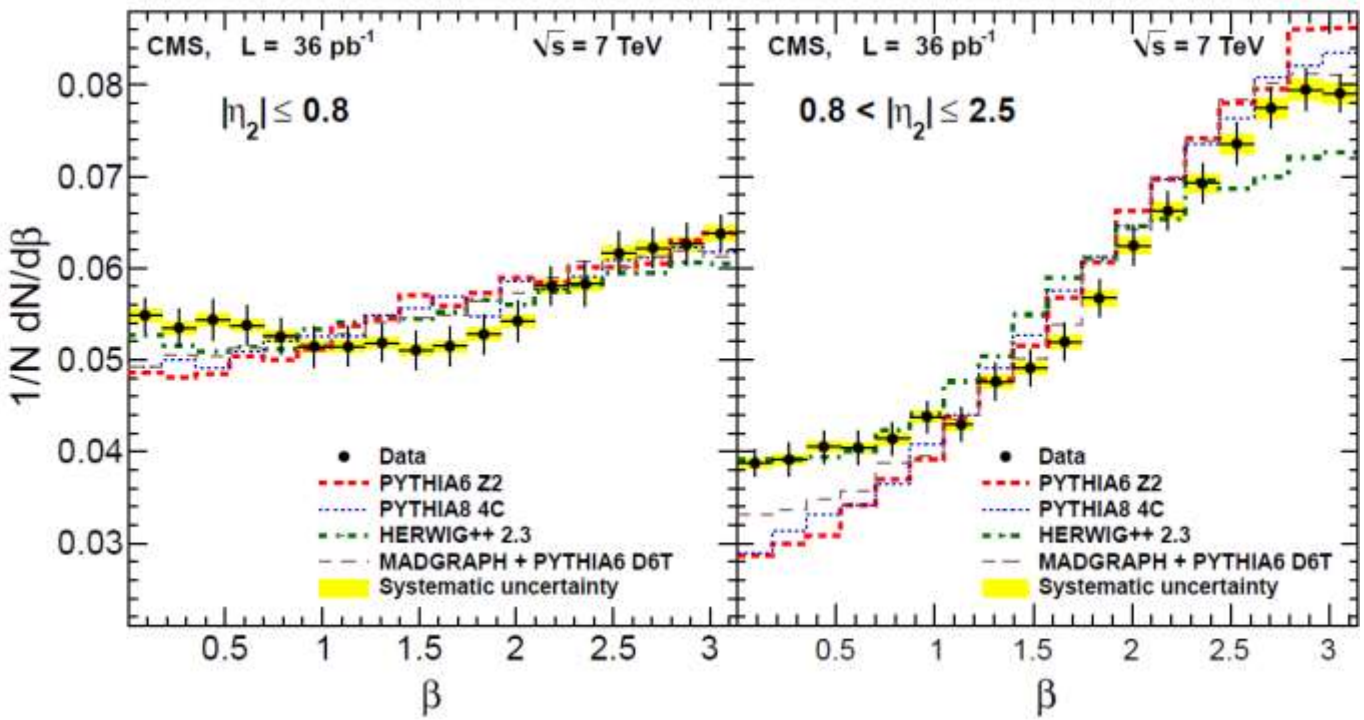
$$\beta = |\tan^{-1}[sign(\eta_2)\frac{\phi_3 - \phi_2}{\eta_3 - \eta_2}]|$$

– With sign(η_{J2}), β becomes symmetric
- When η(J2) > 0 (positive hemisphere)
- When η(J2) < 0 (negative hemisphere)

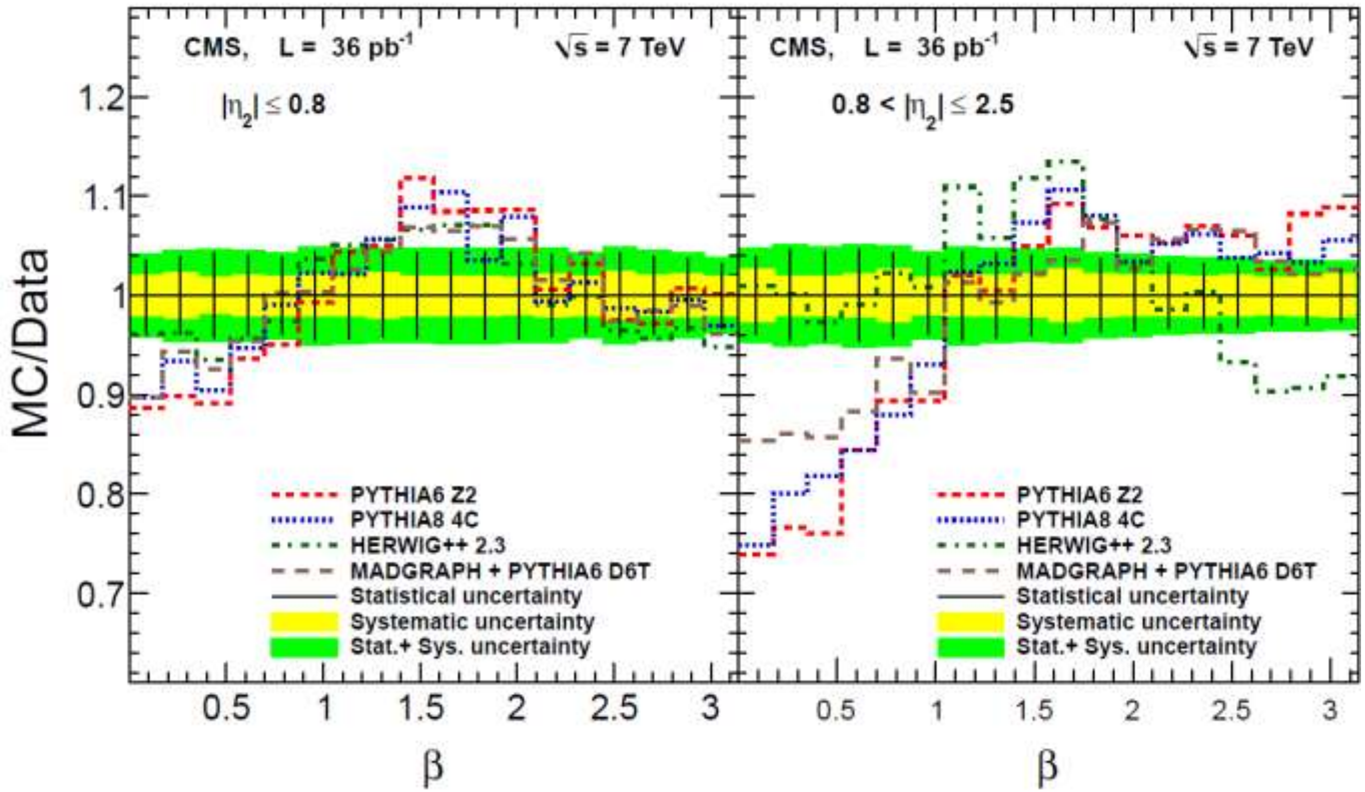


Beta measurements for data & 4 MCs

- The data show an enhancement in the event plane and a suppression in the out of plane
  - Bigger coherence effect



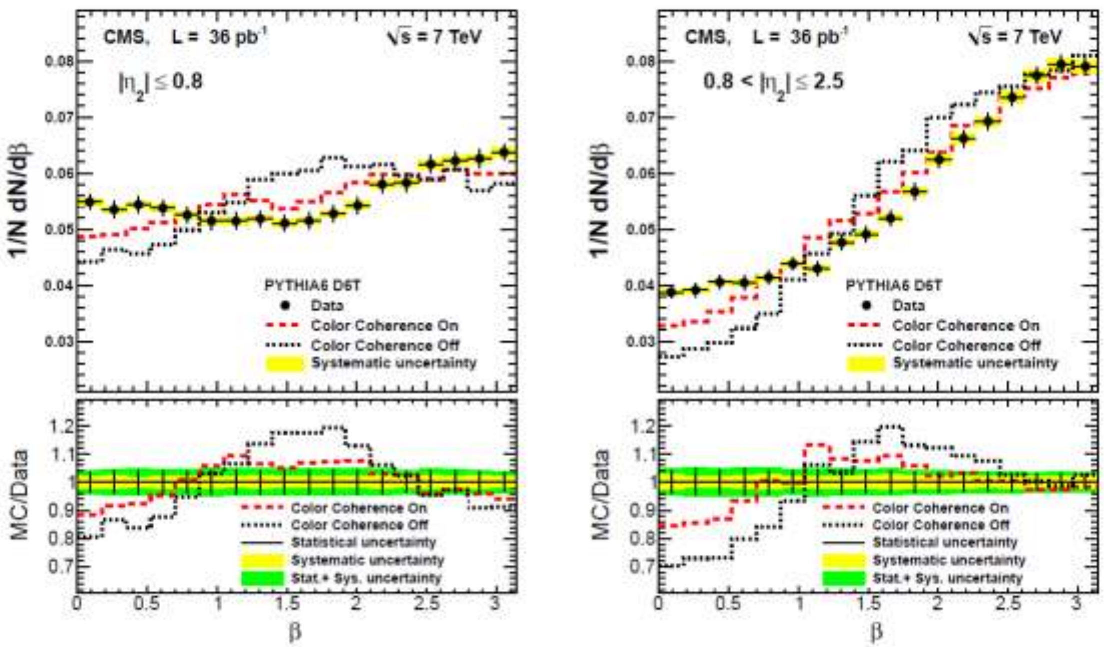
Results: ratio & chi2



χ^2/NDF	$\lvert\eta_2\rvert < 0.8$	$0.8 < \lvert\eta_2\rvert < 2.5$
PYTHIA 6 (Z2)	**2.5**	**8.1**
PYTHIA 8 (4C)	**1.7**	**6.4**
HERWIG ++ (2.3)	**1.2**	**3.5**
MADGRAPH (+PYTHIA 6 D6T)	**1.6**	**3.3**

Is this Color coherence effect?

- **Color coherence was switched on and off for the first parton emision in ISR and FSR in PYTHIA 6.**
  - **With Color coherence On reduces the difference between data/PYTHIA.**
  - **Effects of hadronization and UE was found to be negligible.**



χ^2/NDF (ON→OFF)
2.5 → 7.7 (central)
8.1 → 11.5 (forward)

Summary

- Color coherence effect was studied in multi-jet event from pp collisions with 36 pb-1 at sqrt(s) = 7 TeV
  - A variable(ß), the same as Tevatron analysis, is used
    - which shows the angular correlation between the second and the third energetic jets in eta-phi space
  - We have shown the variable (b) is sensitive to CC
- None of MCs describes the data satisfactorily
  - PYTHIA 6/8
    - need more color coherence effects
    - PYTHIA 8 exhibits a better agreement than PYTHIA 6
  - MADGRAPH
    - improves the situation w.r.t. PYTHIA6 due to exact 2 → 3 LO ME.
  - HERWIG
    - Describe the data well in central, but some discrepancy in forward