A.M. Baldin seminar series

XXI Baldin Seminar Retrospective

A few historical remarks by

Lee Pondrom

Dubna International Seminars on problems in high energy physics

- The first seminar was held in 1969, and about every two years since then.
- My first visit to Dubna was in 1970, at the Instrumentation Conference following the ‘Rochester’ conference in Kiev.
- The early conferences had simultaneous Rus-Eng translators. In 1988 the conference remained bilingual, but by 1998 it had switched to English.

Dubna International Seminars

- Professor Baldin was an organizer of the conference for many years. He was also a mountain climber.
- Field theory and its product QCD have been central themes of the seminars.
- Heavy ions and QCD plasma have been important subjects recently

A few personal recollections

- I gave a number of experimental reports over the years, starting with the Fermilab fixed target hyperon beams and continuing with Fermilab CDF collider work.
- The seminars are a good place to meet people. Frankfurt and Strikman, Gerasimov, Shirkov, Neudachin, Baldin, Pontecorvo, et al.
- I look forward to an interesting week, and I wish the organizers good fortune in continuing the series.

Search for double parton interactions in Z->μμ events from p-$\bar{p}$ collisions at 1.96 TeV

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for the CDF Collaboration

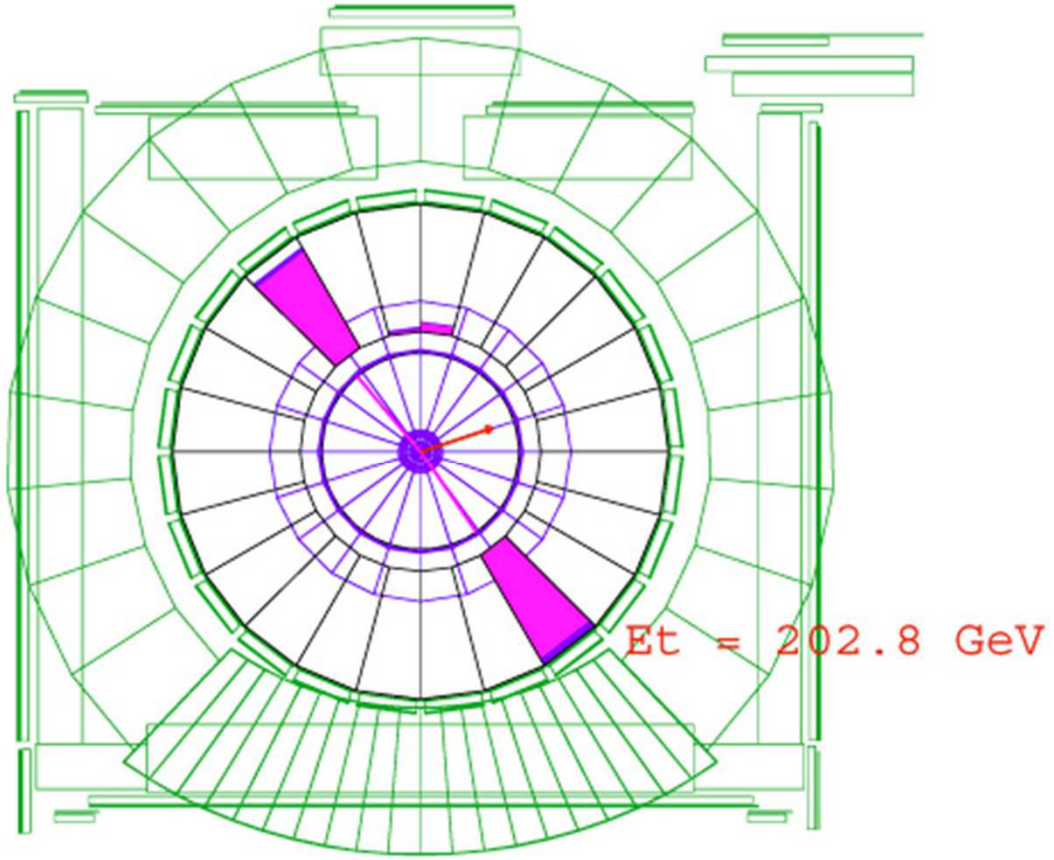
XXI International Baldin Seminar
September 10-15, 2012

Old Moscow-Kitai Gorod in the 17th century

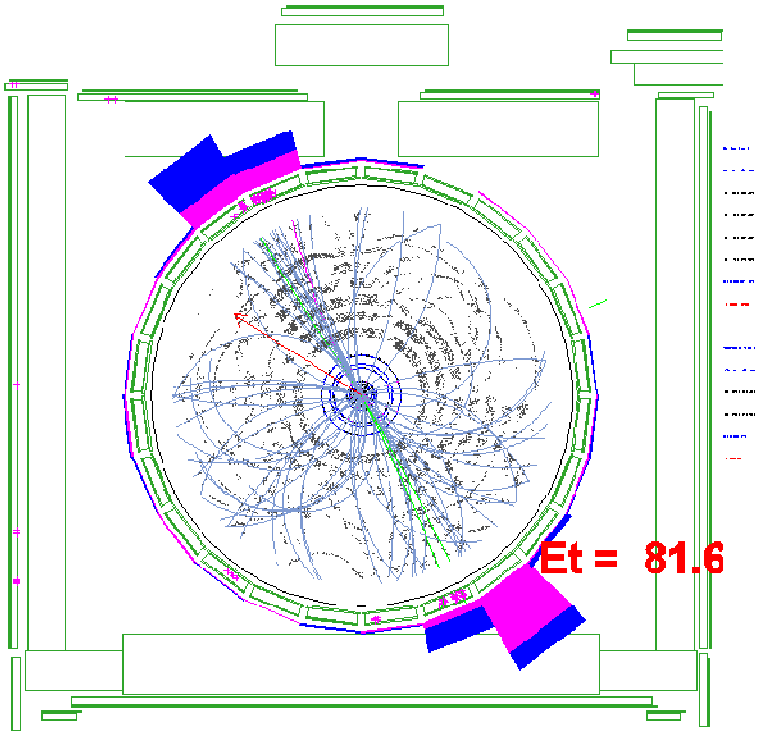
Parts of CDF for this analysis

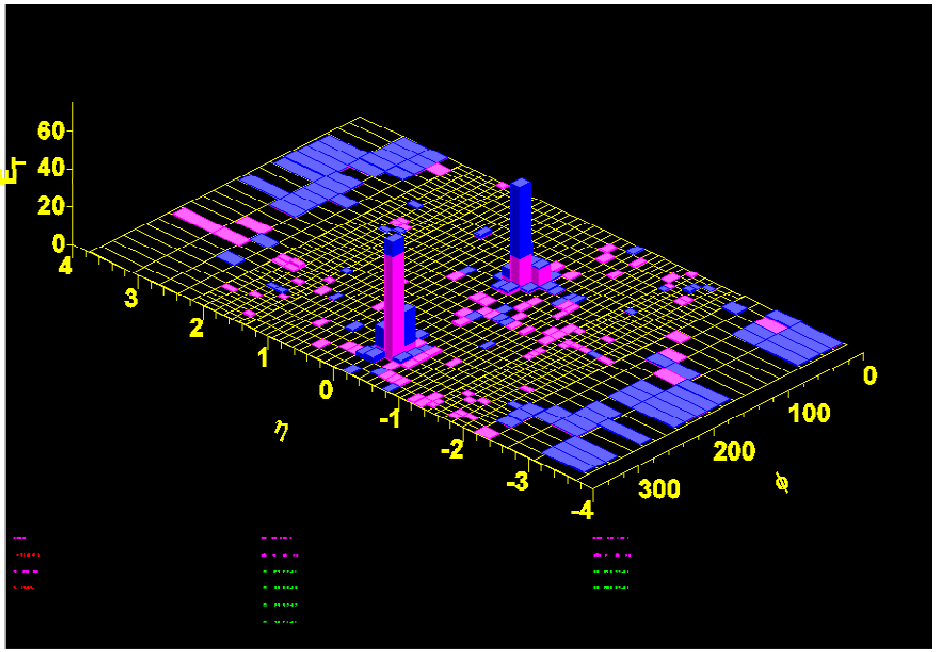
- Charged particle central tracker
- Central electromagnetic and hadronic calorimetry
- Central muon detectors
- Polar coordinates; origin at center of the detector, z axis in proton direction, $\eta = -\log(\tan(\theta/2))$, φ in plane perpendicular to the z axis.

CDF RunII dijet end view



Typical dijet event display

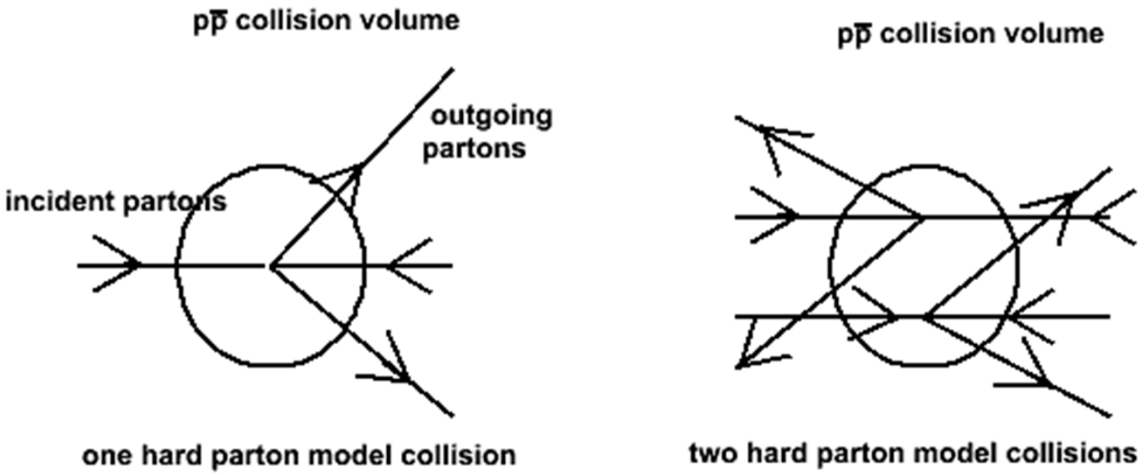




The parton model is indispensable for understanding hadron collisions

- Monte Carlo programs like Pythia base their analysis on the parton model, and are very successful in explaining observations.
- Pbar-p interactions are described by 2->2 simple parton-parton scattering, folded into parton distribution functions determined by lepton-hadron scattering.

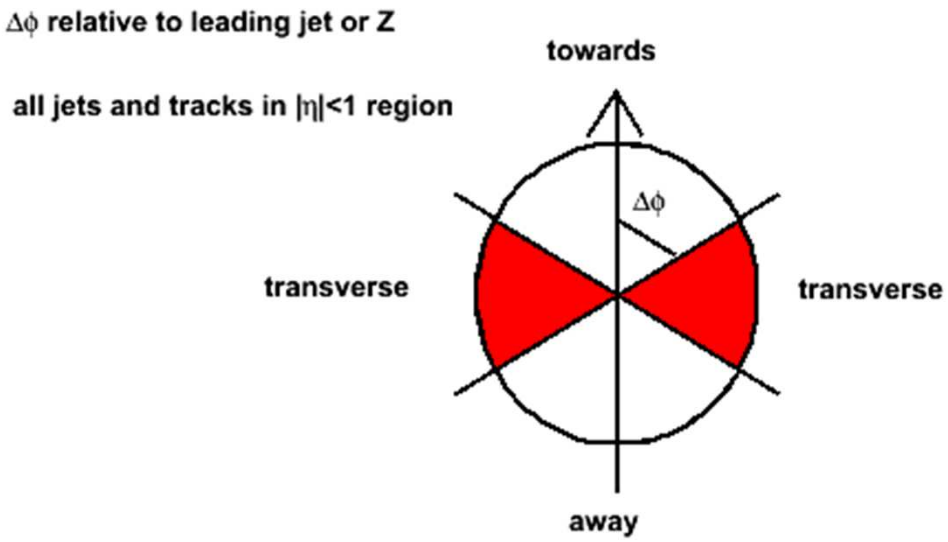
In a double parton interaction this process occurs twice



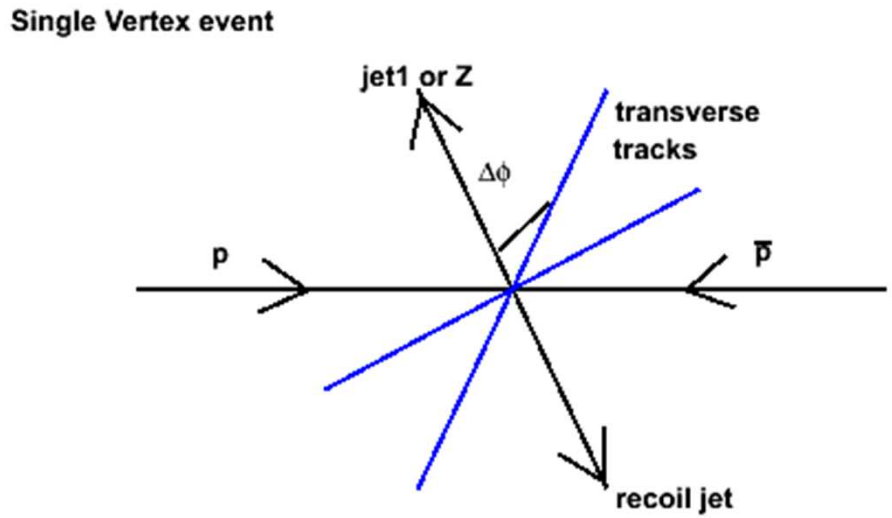
Signature of DPI

- The two hard scatters are perturbative.
- The two hard scatters are independent, consistent with the conservation laws.
- If the momentum fractions and energies involved in the two scatters are modest, independence should be obtained.
- Two hard scatters in a single interaction can be modeled by two separate interactions (vertices) in the same event.

Single hard scatter and the ‘underlying event’



Single vertex dijet or Z+jet event

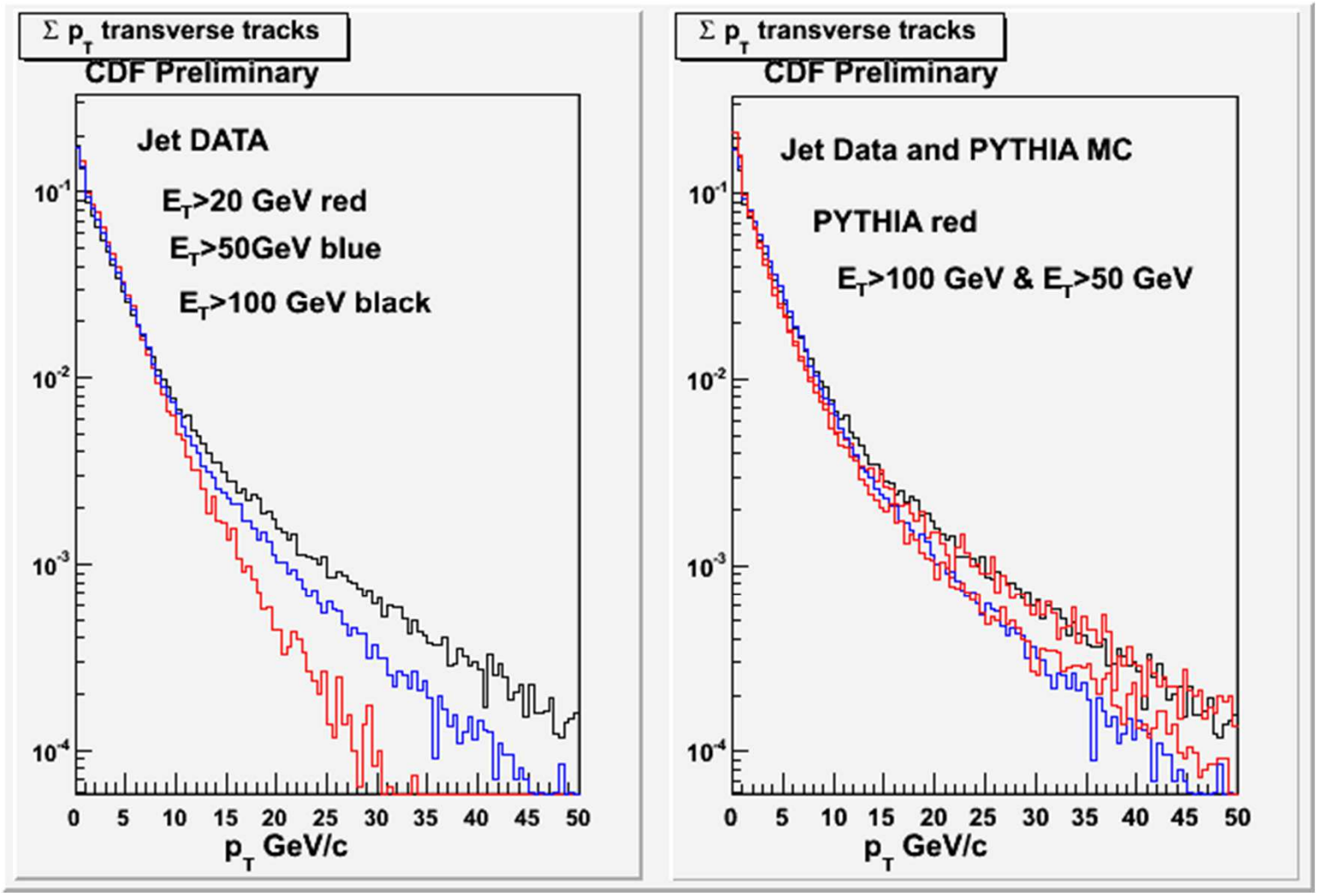


Charged tracks in the transverse region

- CDF studied the underlying event in the region transverse to Z production.
- PYTHIA was tuned to match the charged track distribution.(PRD82,034001,2010)).

  Track p_T > .5 GeV, track |η|<1
- Parameters track multiplicity, scalar sum track p_T, max p_T.
- The PYTHIA tune has been widely used.

Quick check of underlying event with dijet data



Transverse track activity depends slowly on p_{TZ} or jet1 E_T

- About 90% of the $\sum p_T$ plots are energy independent. PYTHIA agrees with data.
- Underlying event activity is the same for $p_{TZ} \approx$ jet1E_T
- If double parton interactions exist, a good place to look for them would be in the transverse region.

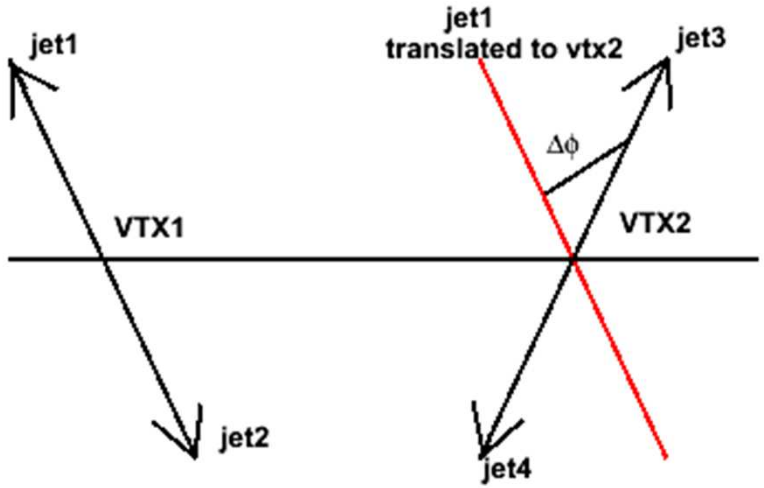
This suggests a new technique to look for DPI

- Look in the transverse region in φ, where the main event is relatively quiet.
- Use the high pt transverse tracks as a ‘trigger’ signature of a second hard interaction.
- Impose the arbitrary requirement $\sum \text{transtrack} p_T > 15$ GeV/c as the trigger

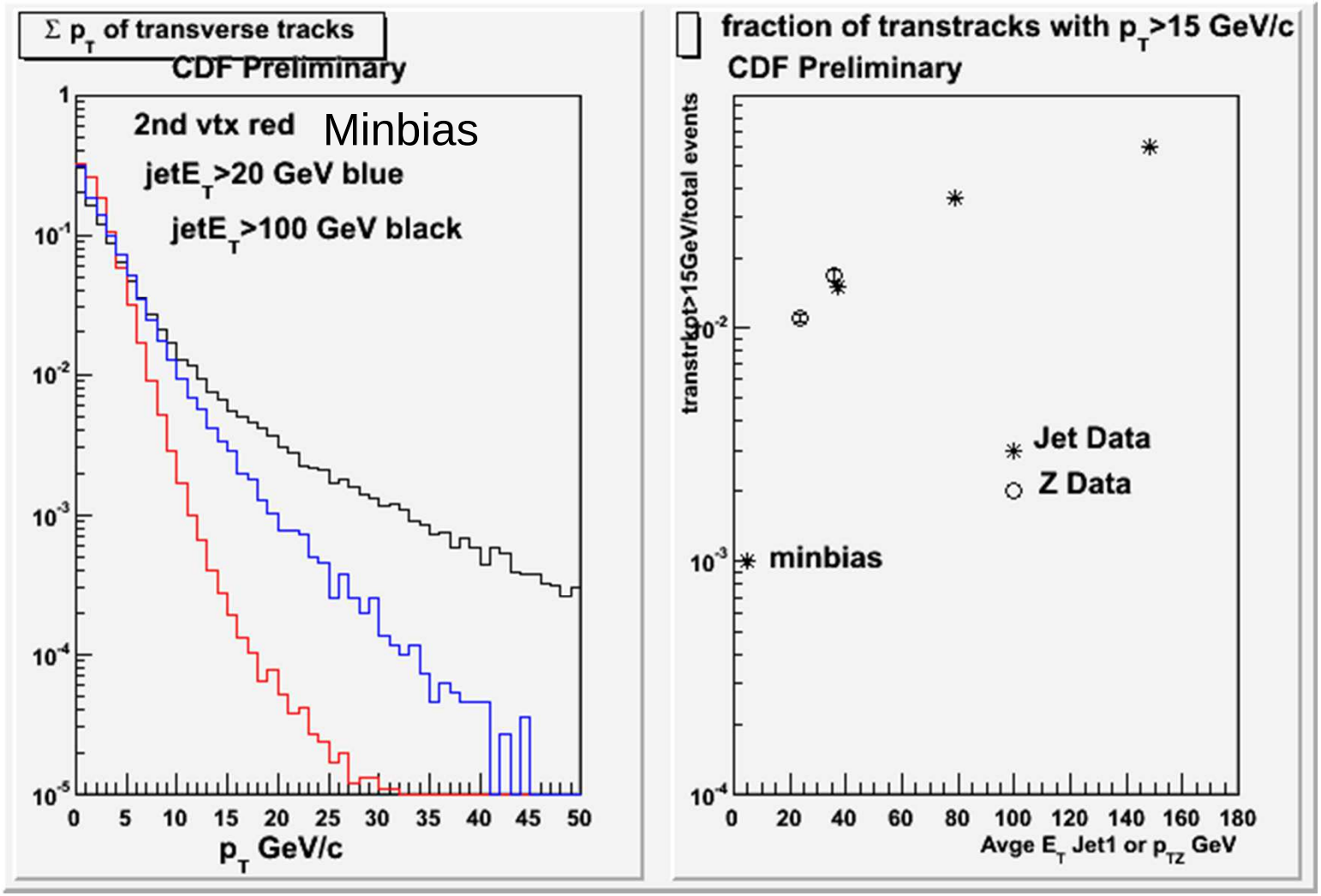
look at jet events with two vertices to test the idea

- Use dijet E_T>100 GeV data
- Require jets one and two to be on the first vertex. Exactly two vertices per event.
- Extra jets three and four can be anywhere
- Separate the two vertices by at least 10 cm.
- Require vtx2 to have at least 3 charged tracks, with p_T>.5 GeV and |η|<1.
- Second vtx σ ≈ 12 mb, called ‘minbias’.

Two vertex event with 2 jets on primary vtx and 2 jets on 2nd vtx



Transverse tracks on the 2nd vtx



Transverse track activity

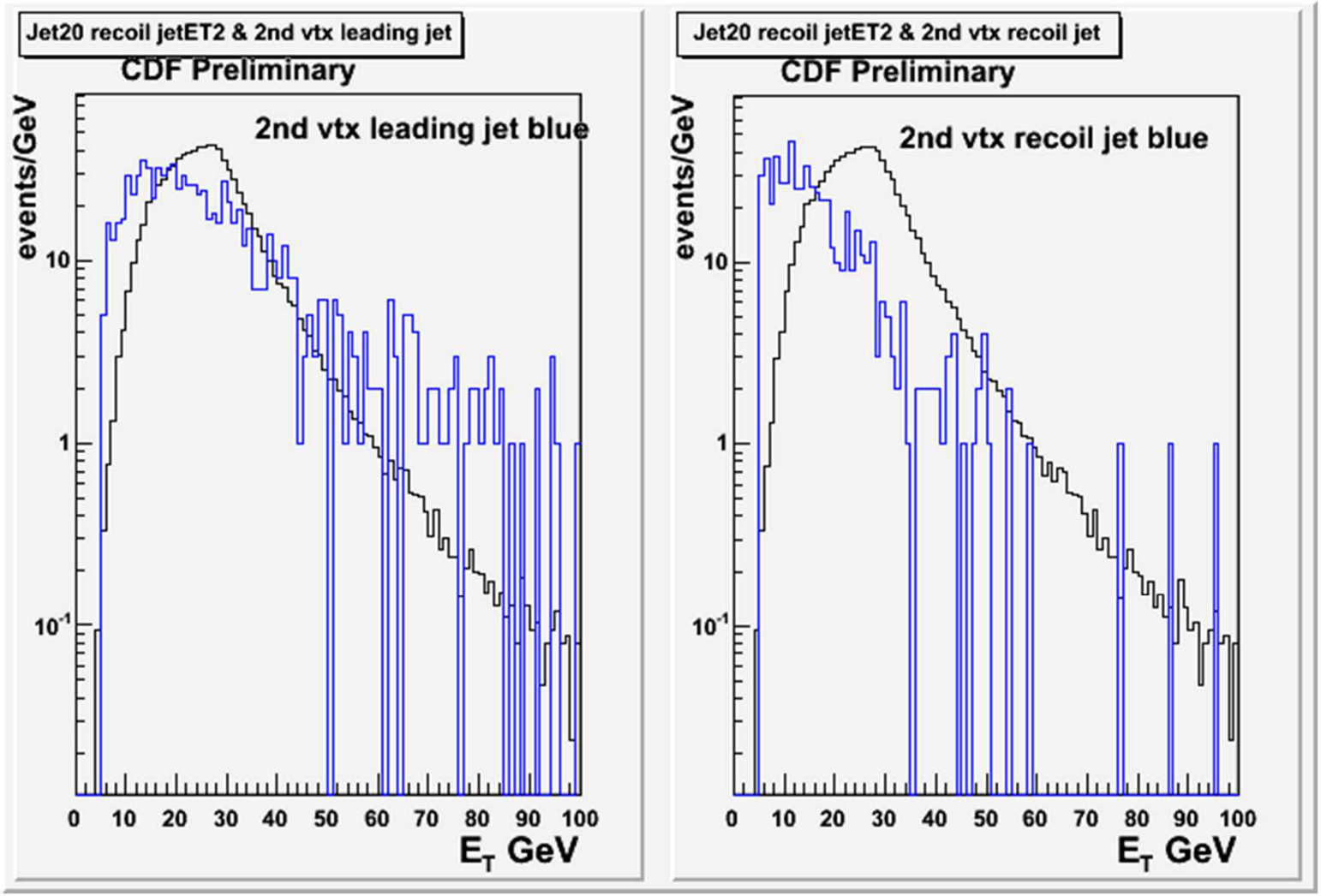
- The first vertex transverse tracks are defined with respect to the azimuth φ of the highest E_T jet: $\pi/3<\Delta\varphi(\text{jet-track})<2\pi/3$
- second vertex transverse tracks are defined in the same way with respect to the same jet – highest E_T jet on vtx1, track on vtx2.
- ~60% of all ‘triggers’ have a pair of transverse jets with $E_T>5$ GeV on 2^{nd} vtx.

$\sum$transtrackp_T>15 GeV

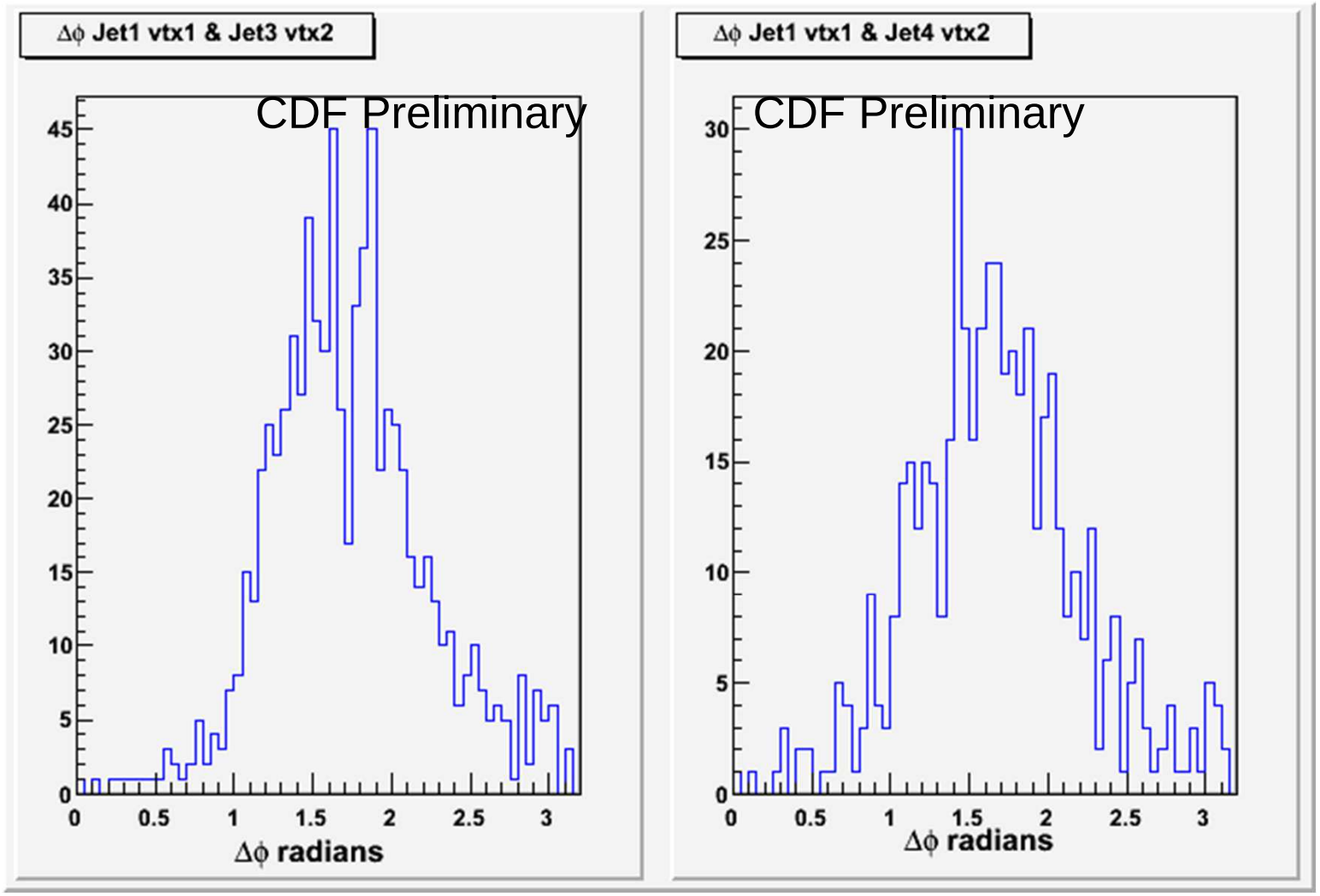
- Note that the fraction increases from .001 to .015 going from minbias (plotted as E_T=5GeV) to jet E_T>20 GeV

Using $\sigma \approx 12$ mb for the 2nd vertex, the effective cross section for the $\sum p_T$>15 GeV 'trigger' is $\sigma \approx 12$ μb.

Recoil jet E_T against E_T>20 GeV compared to 2nd vtx jets



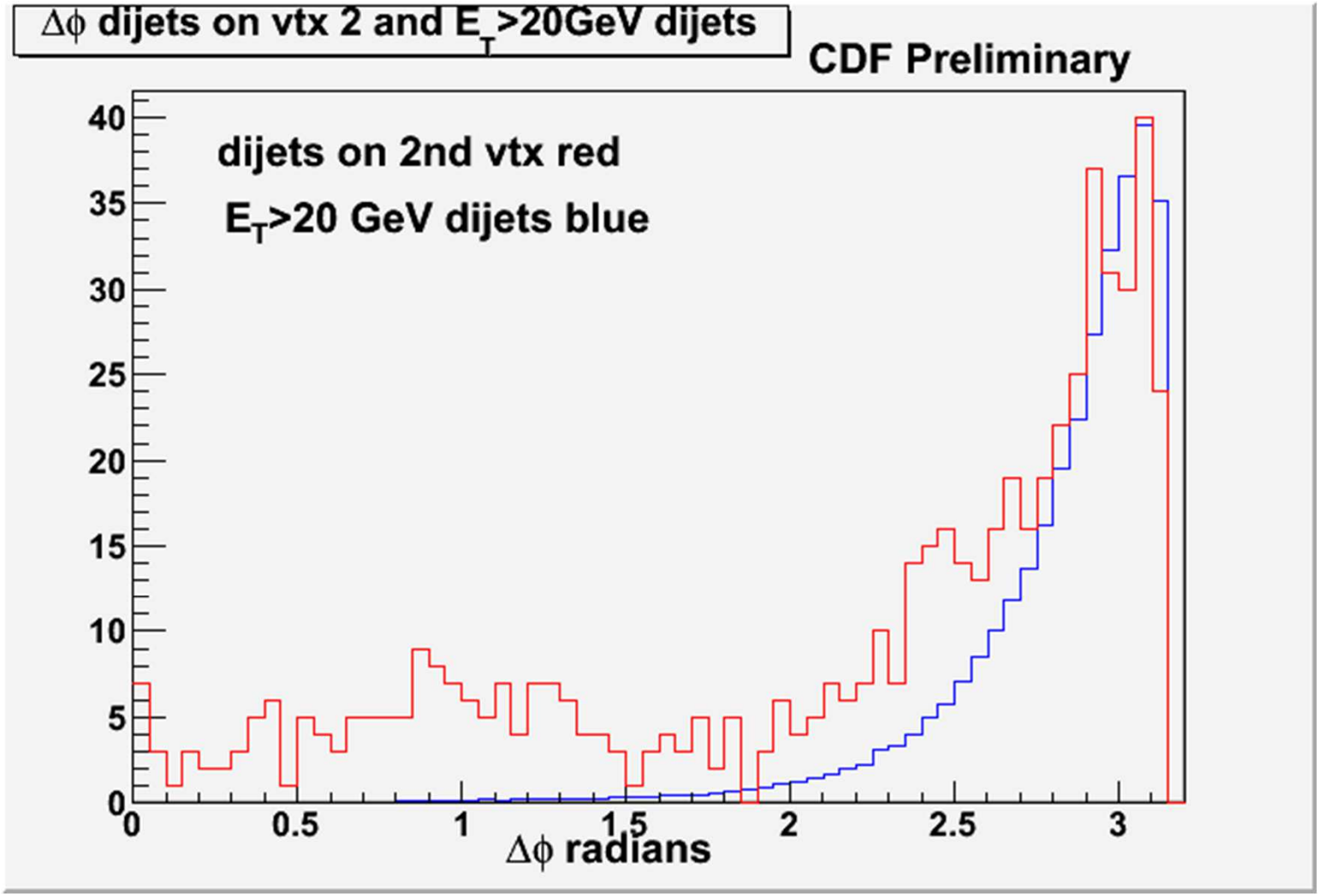
Δφ for 2nd vtx jets relative to jet1 on 1st vtx



2^{nd} vtx ‘trigger’ jets

- The $\sum$transtrackp_T>15GeV ‘trigger’ creates two jets on the second vertex which are softer than jet20 (the lowest E_T CDF jet trigger).
- The two jets created by the trigger are in the transverse region in φ relative to jet1, which is on the first vertex.

Δφ of jet pair on 2nd vtx created by ∑transtrackp$_T$>15 GeV/c



$\Delta\varphi$ for jet pair on 2nd vtx

- There is a clear back-to-back signal for the jet pair created in the transverse region in φ of the leading jet pair on the first vertex.
- The $\Delta\varphi$ resolution is broader than for jetE_T>20 Gev, which has on average higher E_T jets.

DPI search strategy

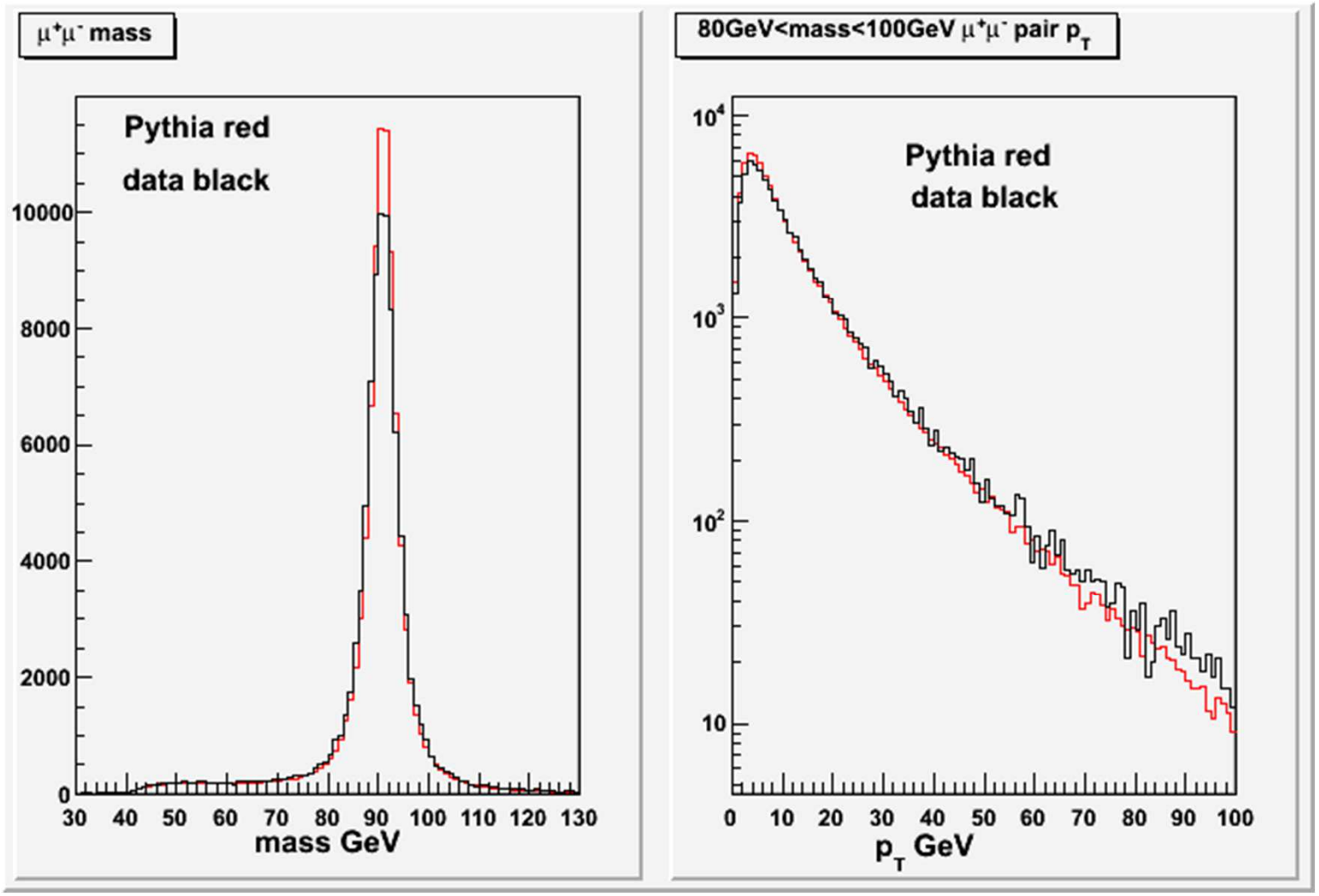
- Use Z->μμ data to define the φ region transverse to p_{TZ}.
- Require only one vertex in the event
- Apply the ∑transtrackp_T>15 GeV ‘trigger’
- Look for a pair of back to back jets like those found on the second vertex.

Use entire $\int$Ldt=9/fb high p_T muon dataset

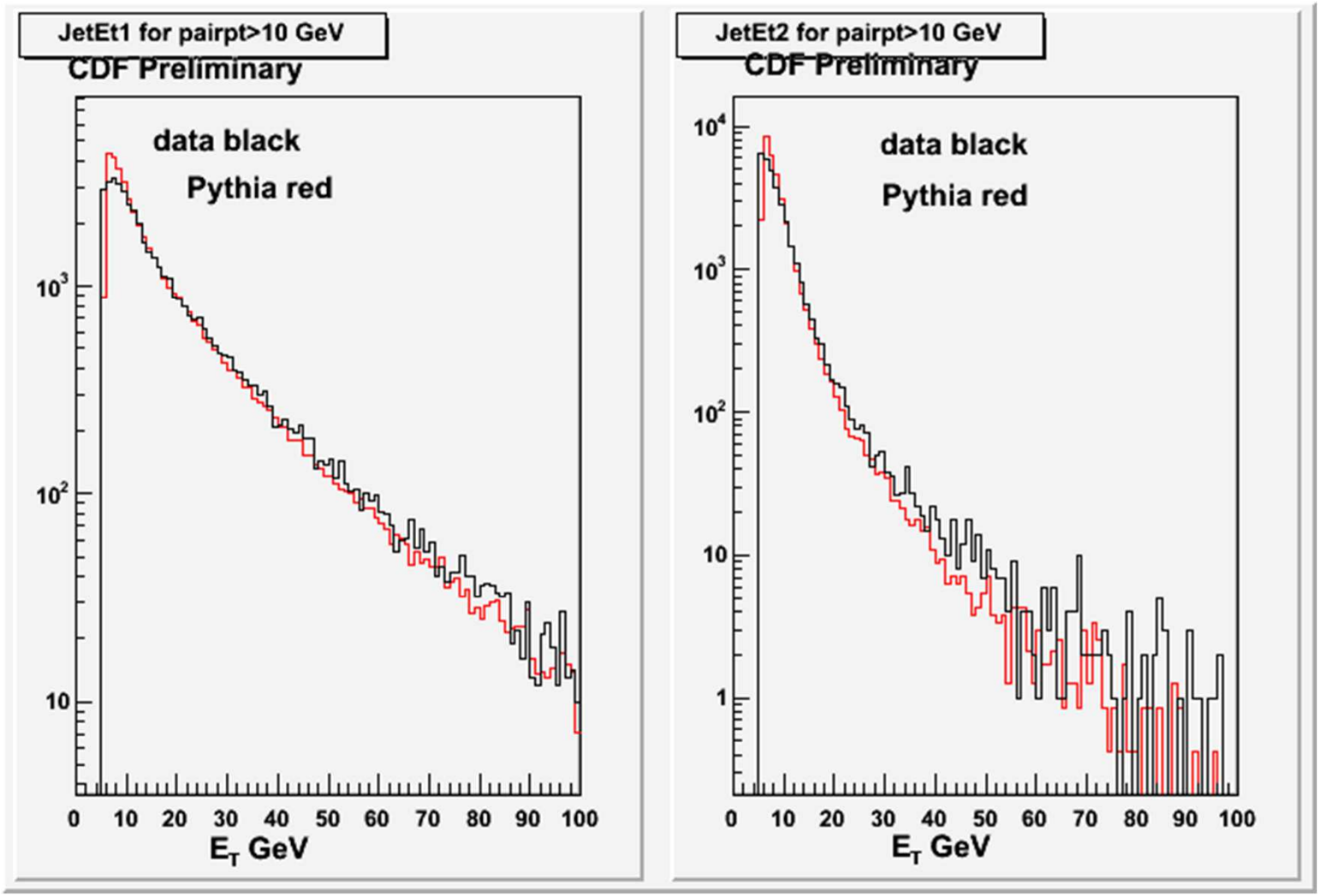
- Require two muons opposite charge $|\eta|<1$.
- Eliminate events with cosmic rays
- Require at least one good quality central muon

  215589 events 30GeV<mμμ<130GeV
- 176351 events 80GeV<mμμ<100 GeV
- Require at least one jet with E_T>5 GeV
- 45738 events Z pair p_T>10 GeV
- 21443 events Z pair p_T>20 GeV

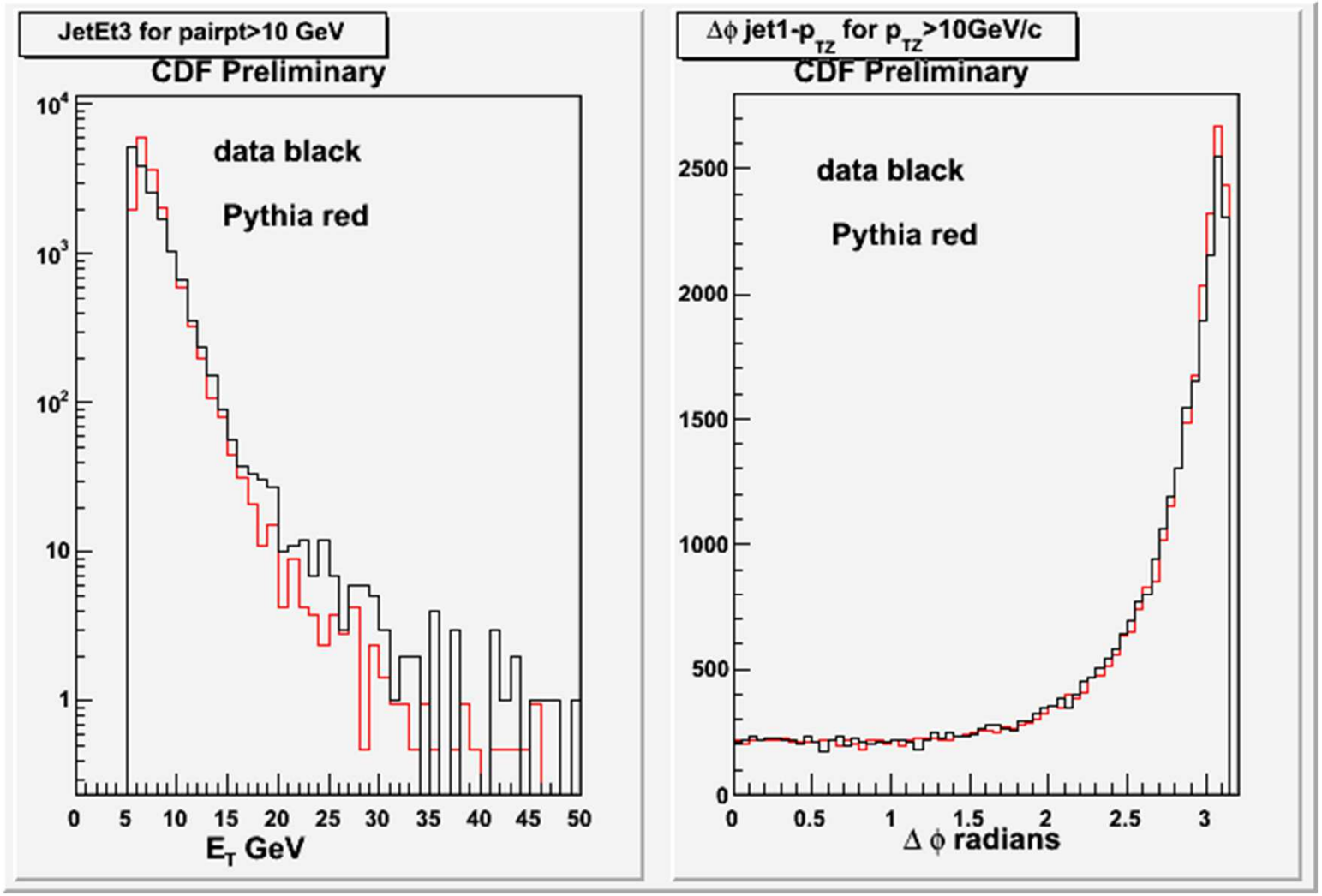
Z->μμ kinematics data and Pythia
CDF Preliminary



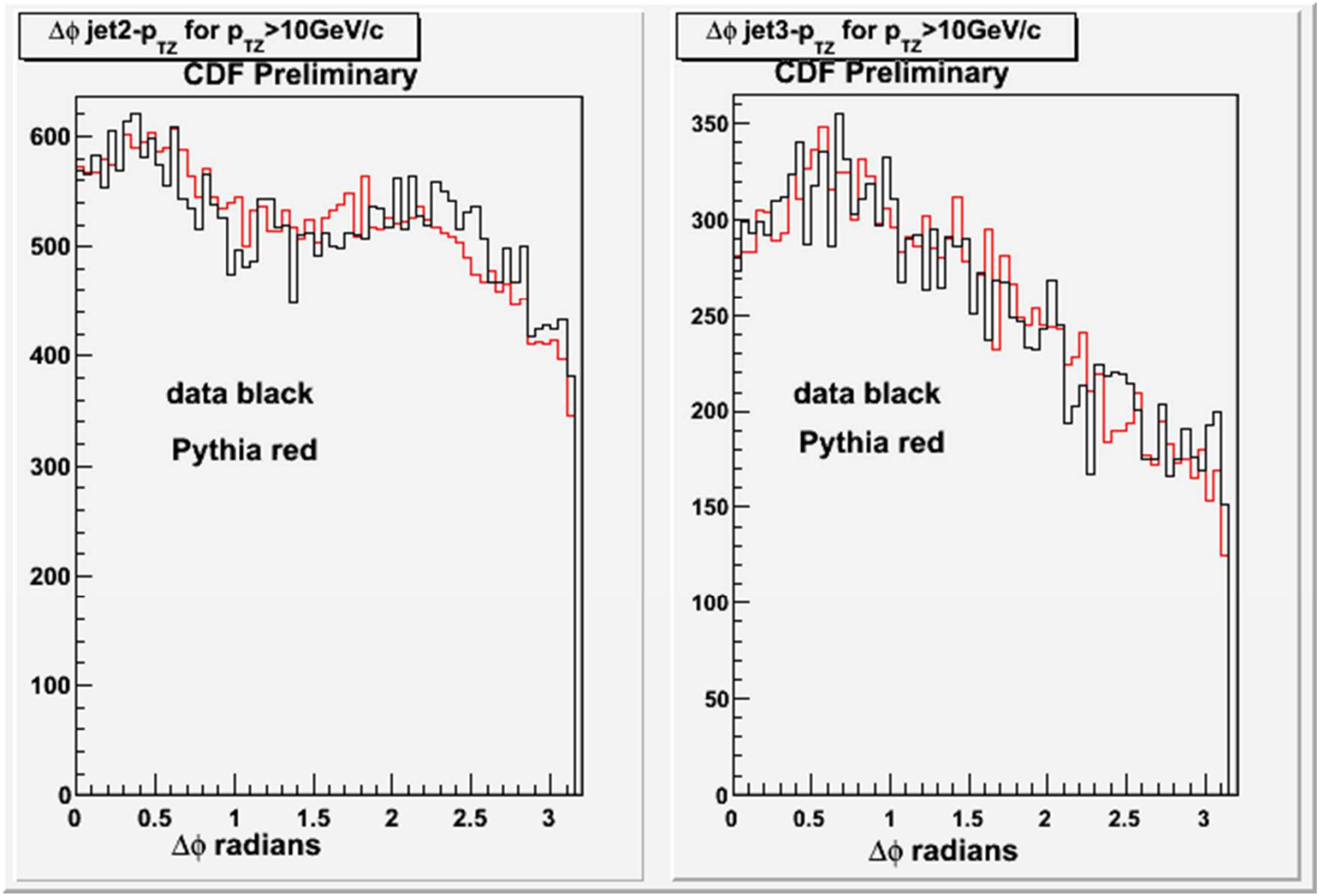
E_T jets 1&2 data and Pythia



E_T jet3 and $\Delta\varphi$ jet1-p_{TZ}



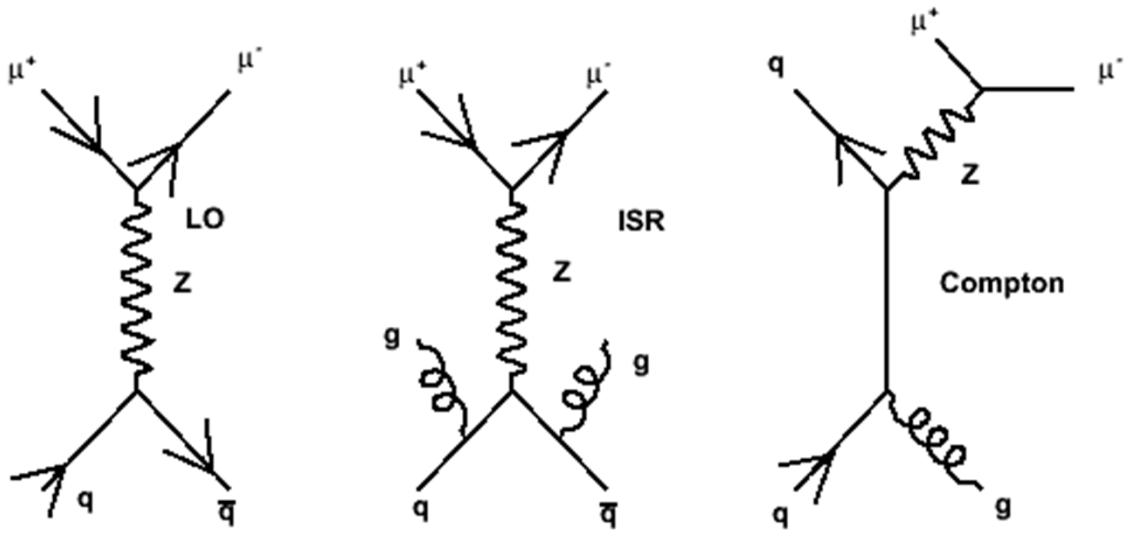
$\Delta\varphi$ jets-p_{TZ}



$\Delta\varphi$ p_{TZ} and recoil jets

- Jet1 has a strong peak near $\Delta\varphi \approx \pi$, but also has a long flat tail.
- Jets2 and 3 have a slight preference to be close to the p_{TZ} vector direction!
- All three jets can occupy the transverse region.
- Pythia agrees with data regarding these features.

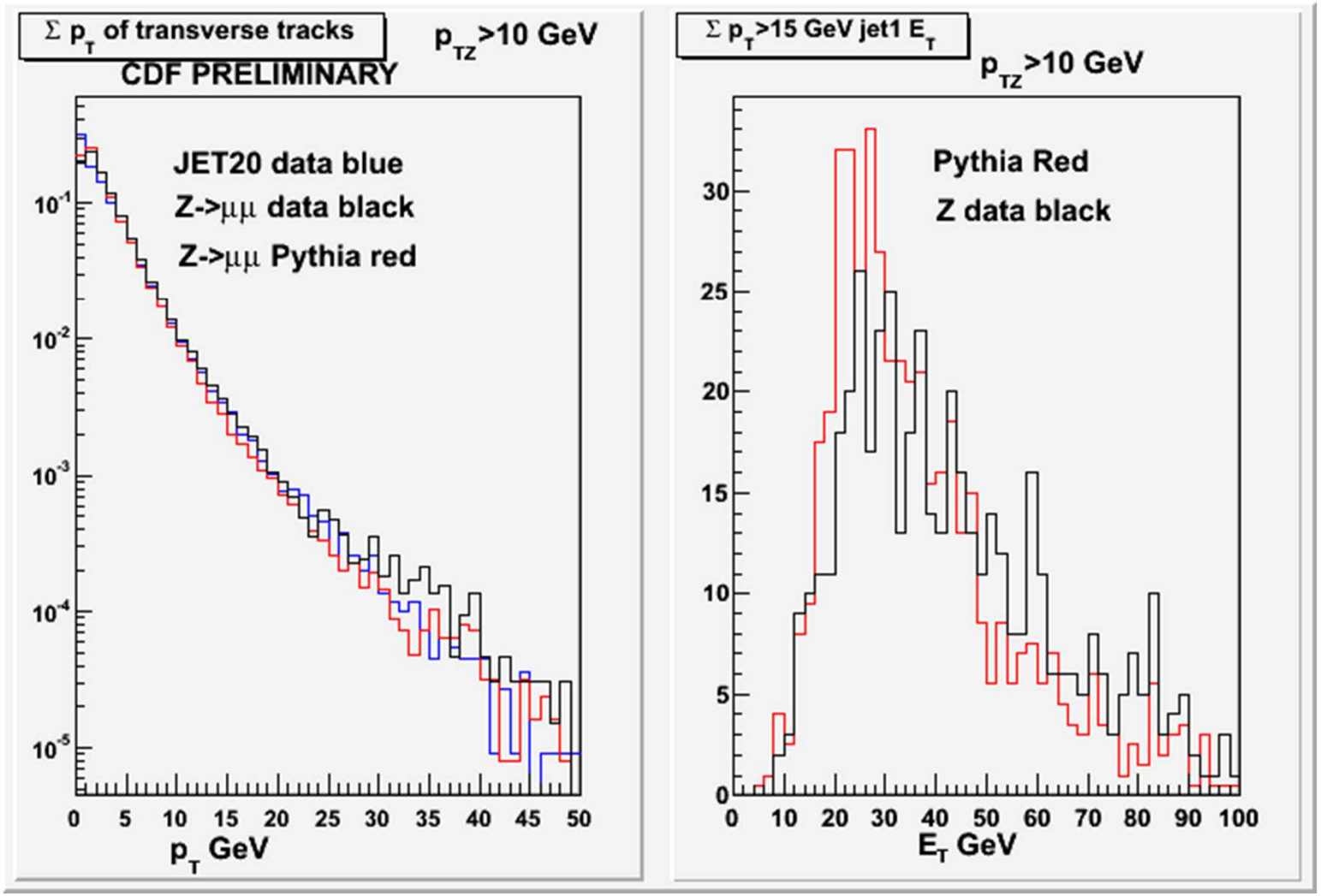
Drell-Yan mechanism and p_{TZ}



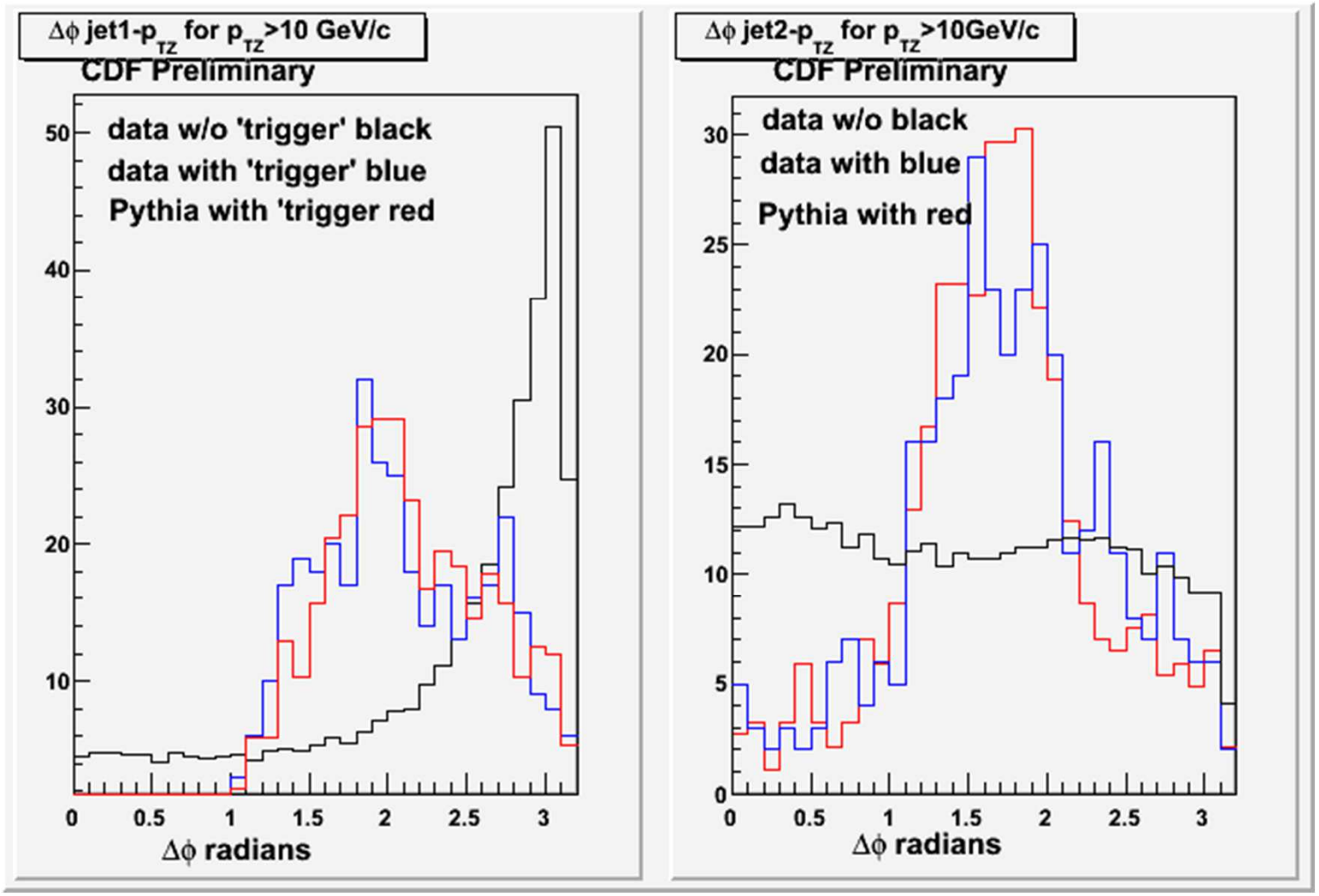
Drell-Yan mechanism and p_{TZ}

- Lowest order diagram has p_{TZ}=0.
- Initial state radiation by either incident quark can give low p_{TZ}, but soft multijets can cancel each other out.
- There are several variations of the Compton diagram, which dominate at higher p_{TZ}.. Extra jets can radiate from anywhere.

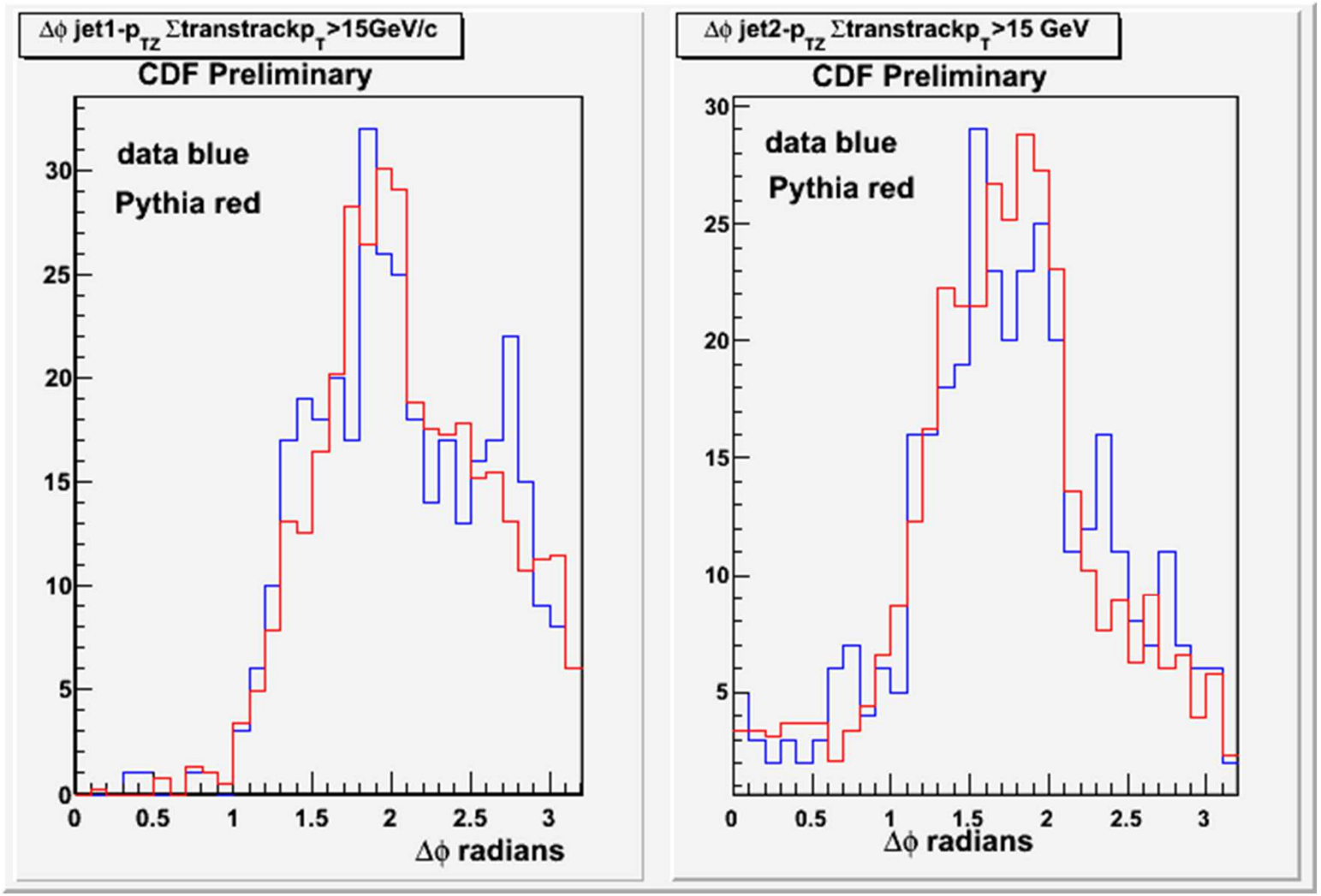
$\sum$transtrackp_T for p_{TZ}>10GeV



‘Trigger’=∑transtrackp_T>15GeV/c. 3 jets required with E_T>5GeV



Δφ jets p_{TZ} data and Pythia



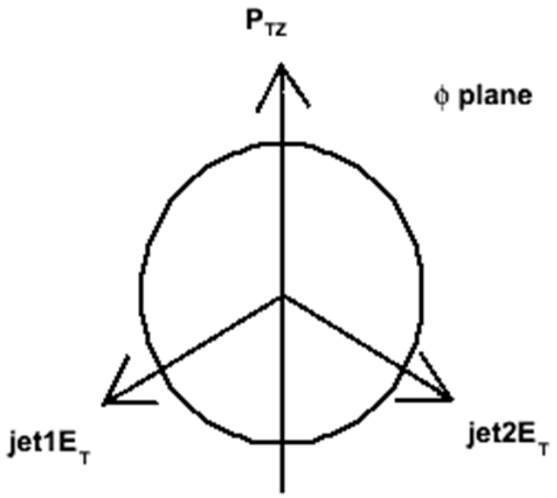
$\sum$transtrackp_T>15 GeV

- Jet E_T distributions are broader after the ‘trigger’, the opposite of DPI expectations.
- Jets 1 and 2 both move into the transverse region in φ!
- This is not supposed to happen in double parton scattering. Jet 1 stays put to balance the Z.

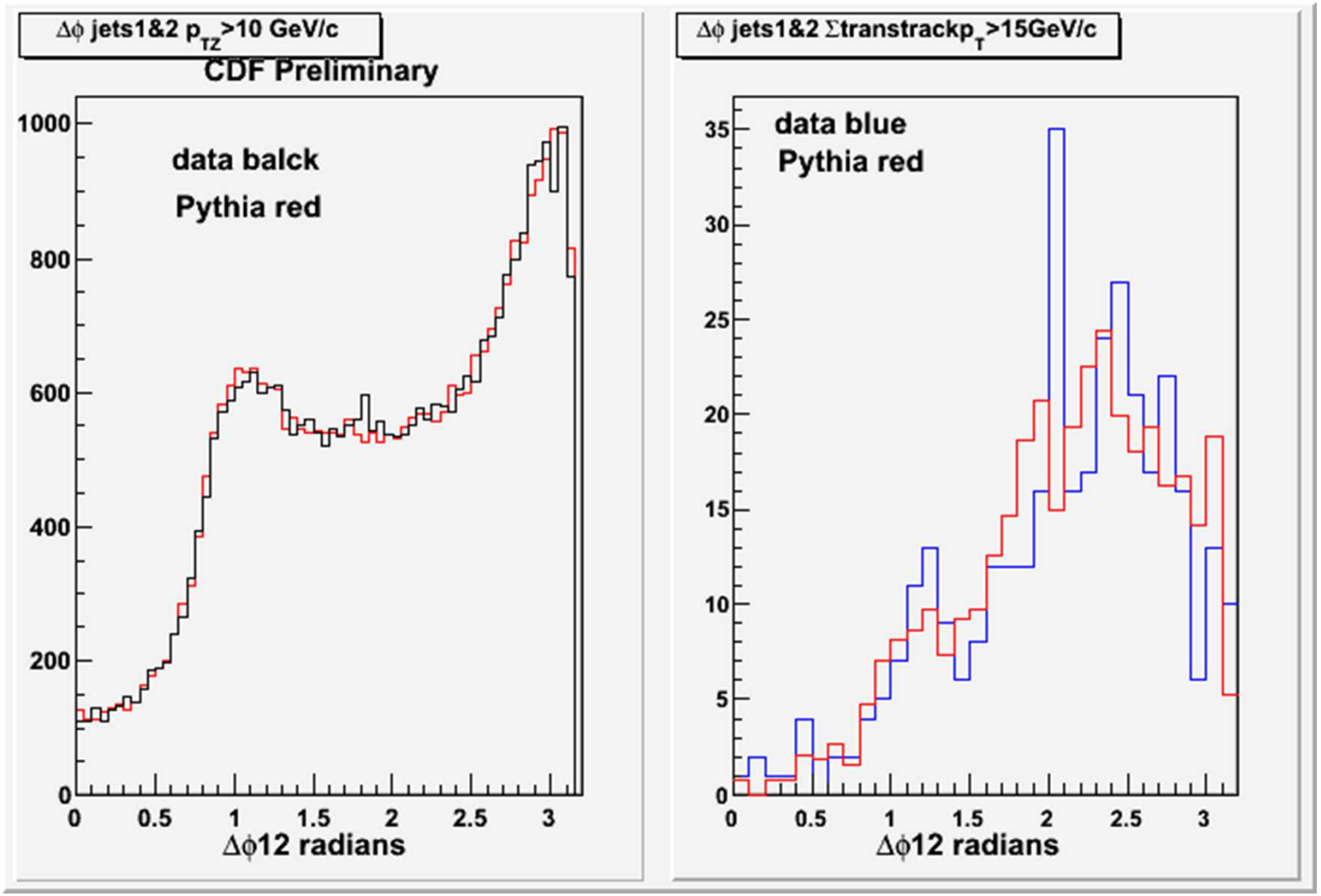
$\sum$transtrackp_T>15 GeV

- The ‘trigger’ has little effect on jet3.
- The ‘trigger’ moves both jets 1&2 into the transverse φ region relative to p_{TZ}.
- Δφ12 then favors ~140 degrees, forming a Mercedes Benz pattern in φ: p_{TZ}-E_{Tj1}-E_{Tj2}
- Jet3 can be anywhere.

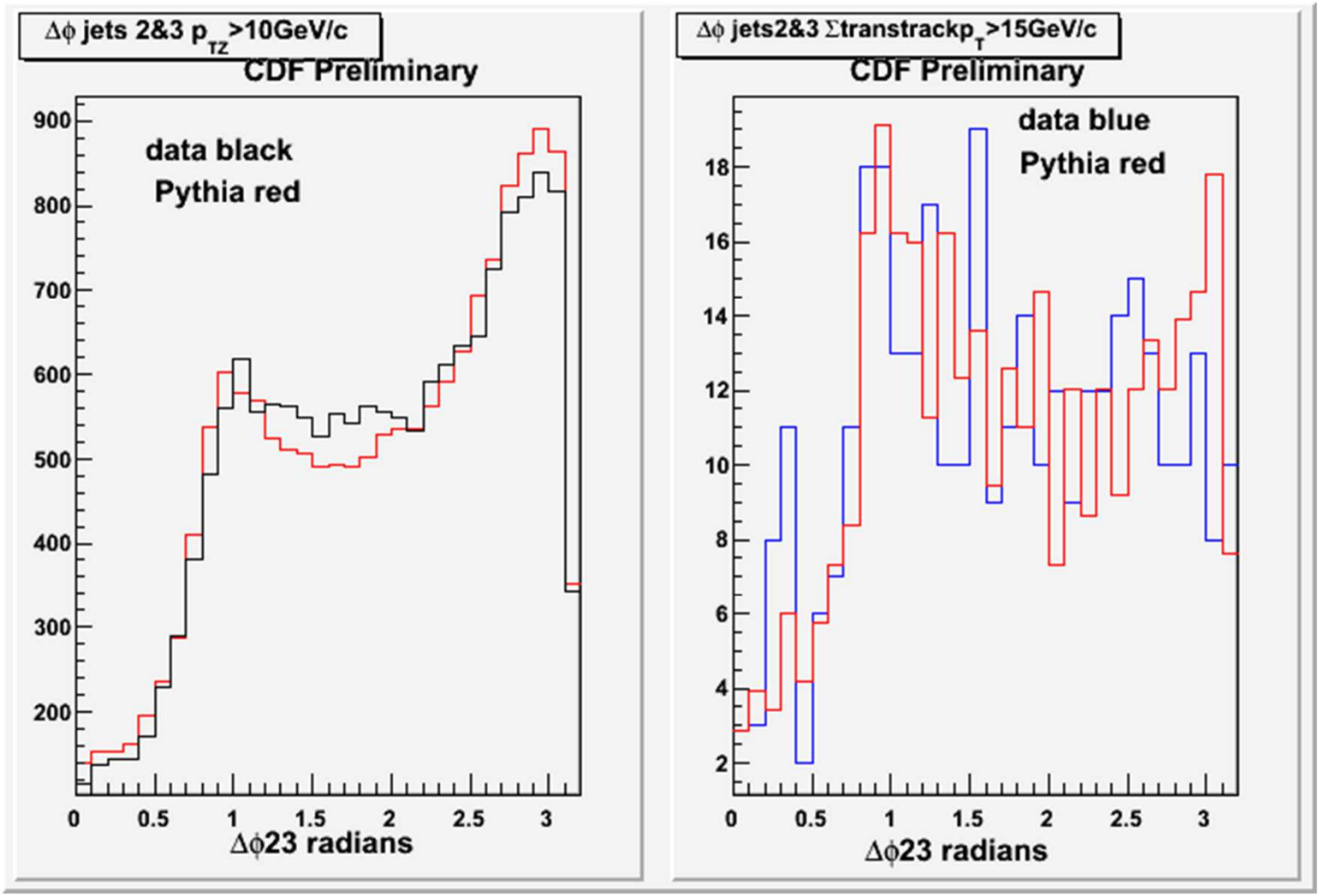
Jets 1 and 2 combine to balance $p_{TZ,}$, jet 3 is anywhere



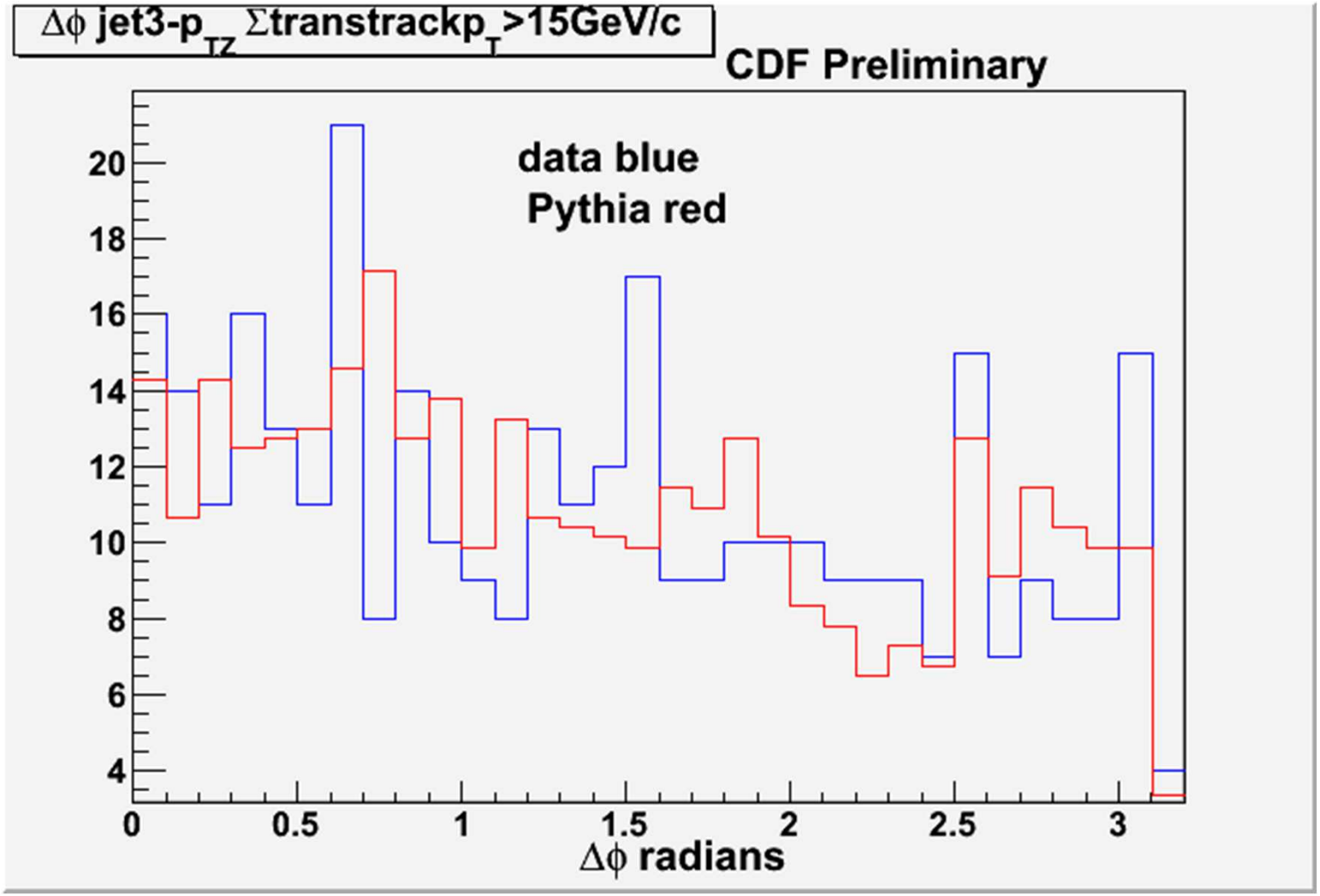
Δφ12 data and Pythia



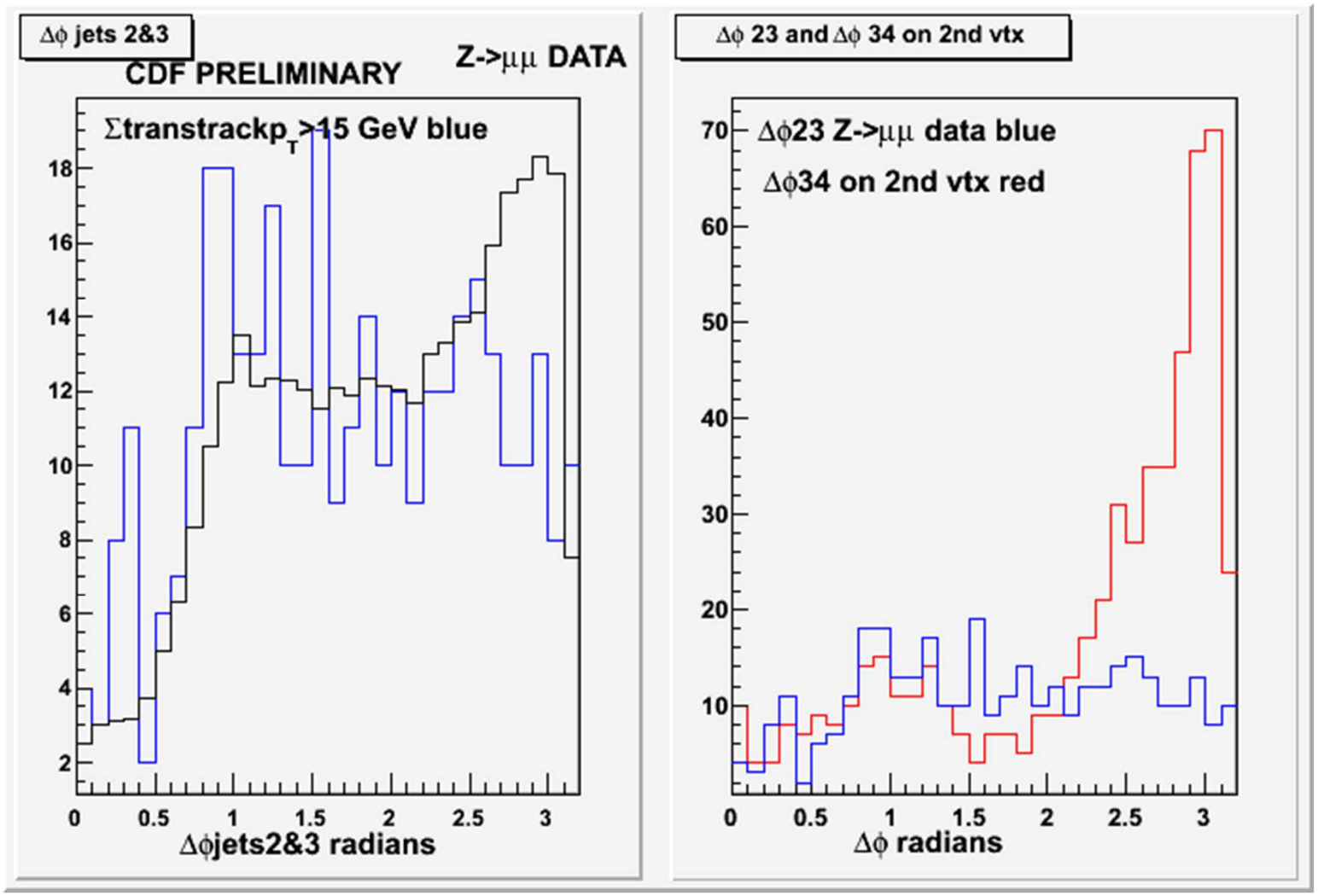
Δφ23 data and Pythia



Δφ jet3 p_{TZ} data and Pythia



Search for DPI in recoil jets 2&3



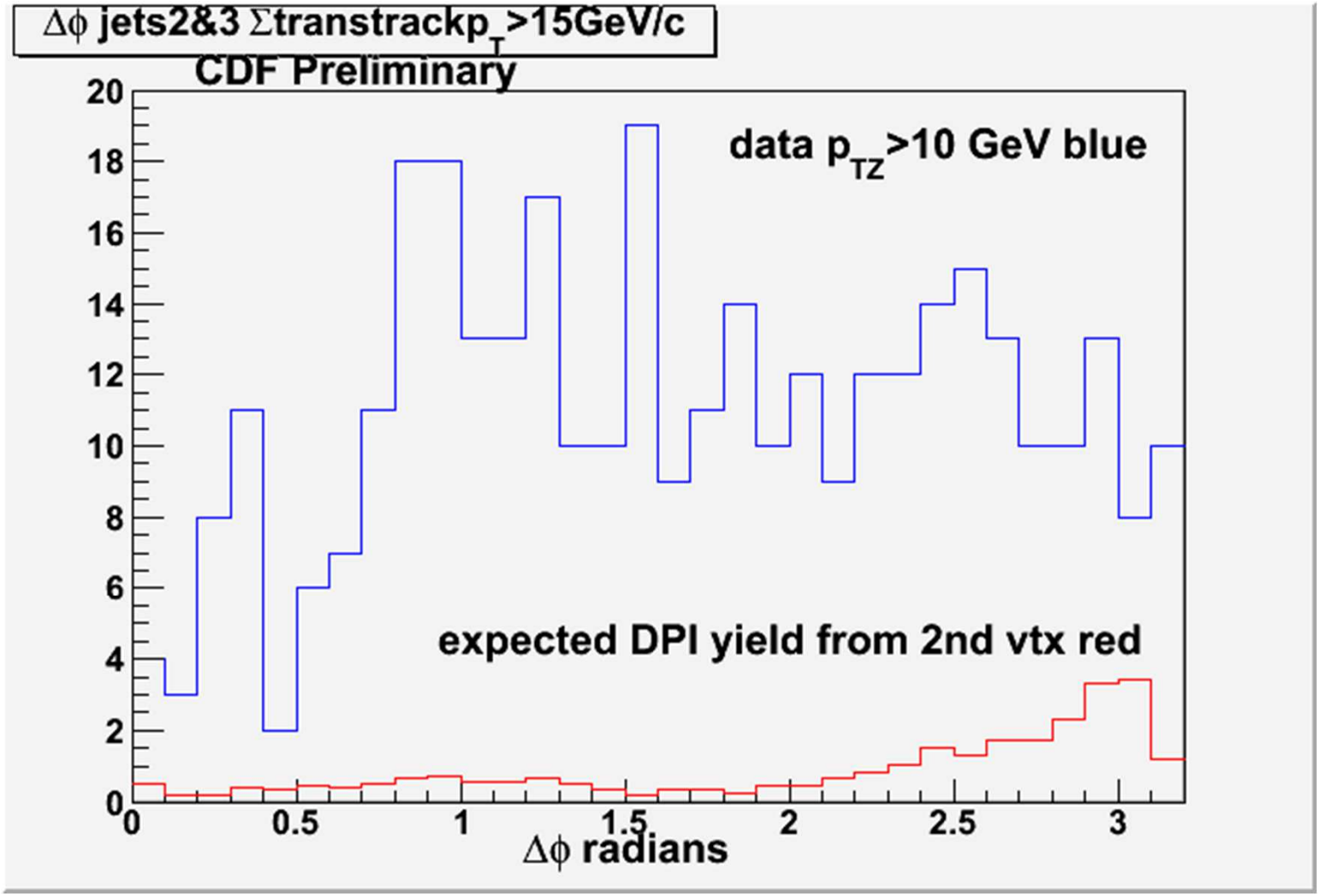
Effect of the trigger on jets 2&3

- Pythia agrees with data regarding the behavior of jet3, given limited statistics.
- The true shape of $\Delta\varphi 23$ without DPI is unknown.
- DPI should enhance $\Delta\varphi 23$ near π radians
- No enhancement is observed.

Expected DPI yield

- Assume that each Z production event contains a DPI vertex as defined by the two vertex study.
- Then .0006 of all Z production events should have two extra back to back jets.
- Given 46,000 events implies 28 DPI events on the Δφ jets2&3 plot.

Expected DPI yield



Outlook

- Pythia and Z + jets data agree very well.
- Data show no sign of DPI.
- Z production is a clean environment- minimal color flow, no jets along p_{TZ}, although there is jet activity ‘transverse’.
- The new technique of $\sum$transtrackp_T>15GeV/c, which gives dijets on a 2nd vertex, simply rearranges the kinimatics of the Z production.