"Min-Bias" Physics: Jet Evolution & Event Shapes

CDF Note with David Stuart will appear soon

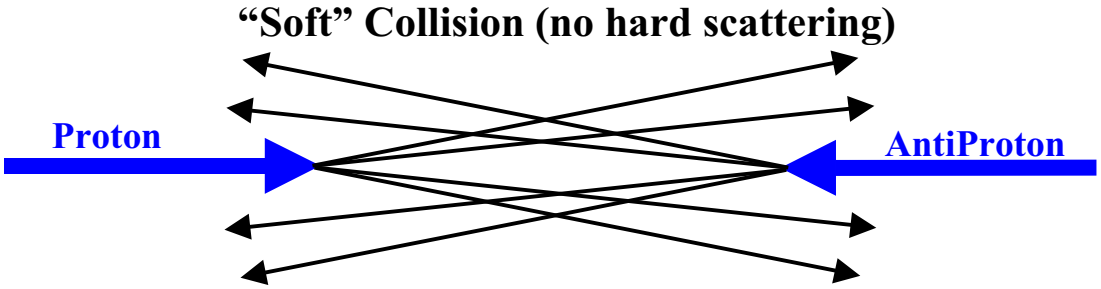
100 plots!

- Study the CDF "min-bias" data with the goal of finding a Mone-Carlo generator that will describe the data.
- Would like to describe (approximately) all the features of the inelastic ("hard core") cross section at both low and high PT.
- Look at data (plot many observables) and compare with "soft" scattering models of Isajet, Herwig, and MBR; and the QCD "hard" scattering models of Herwig, Isajet, and Pythia.
- The "min-bias" data are a mixture of "soft" and "hard" scattering. Fitting the data requires a superposition of "hard" and "soft" Monte-Carlo models.

We are working on this!

www.phys.ufl.edu/~rfield/cdf/

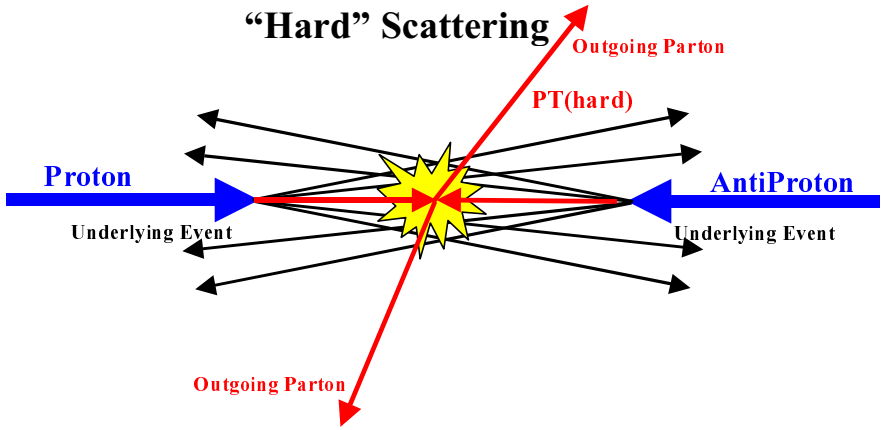
"Soft" Proton-Antiproton Collisions



Isajet and Herwig "min-bias" and MBR are "Soft" scattering models

- In a "soft" collision the proton and antiproton ooze through each other and break apart with no hard scattering.
- Isajet "min-bias", Herwig "min-bias" and the Rockefeller MBR program are models (*i.e.* parameterizations) of "soft" collisions.
- At 1.8 TeV the "Soft" models have about 4 charged particles per unit rapidity with a <PT> of around 500 MeV and no correlations except for resonances and momentum conservation.

"Hard" Proton-Antiproton Collisions



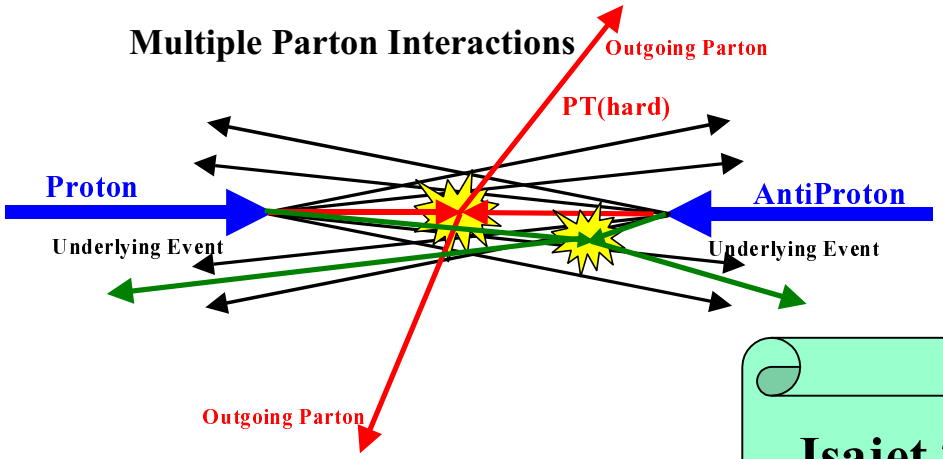
The "underlying event" consists of the beam-beam remnants and initial-state radiation

- Illustration of a proton-antiproton collision in which a "hard" 2-to-2 parton scattering with transverse momentum, PT(hard), has occurred (take PT(hard) > 3 Gev).
- Isajet, Herwig, and Pythia are QCD "hard" scattering Monte-Carlo models.

Isajet 7.32
Herwig 5.9
Pythia 6.115
Pythia 6.125
Pythia No MS
Pythia 4097

CDF Note 4097 parameters

Multiple Parton Interactions



- **Pythia uses multiple parton scattering to enhance the underlying event.**
- **Isajet and Herwig do not include multiple parton interactions.**

Pythia uses multiple parton interactions to enhace the underlying event.

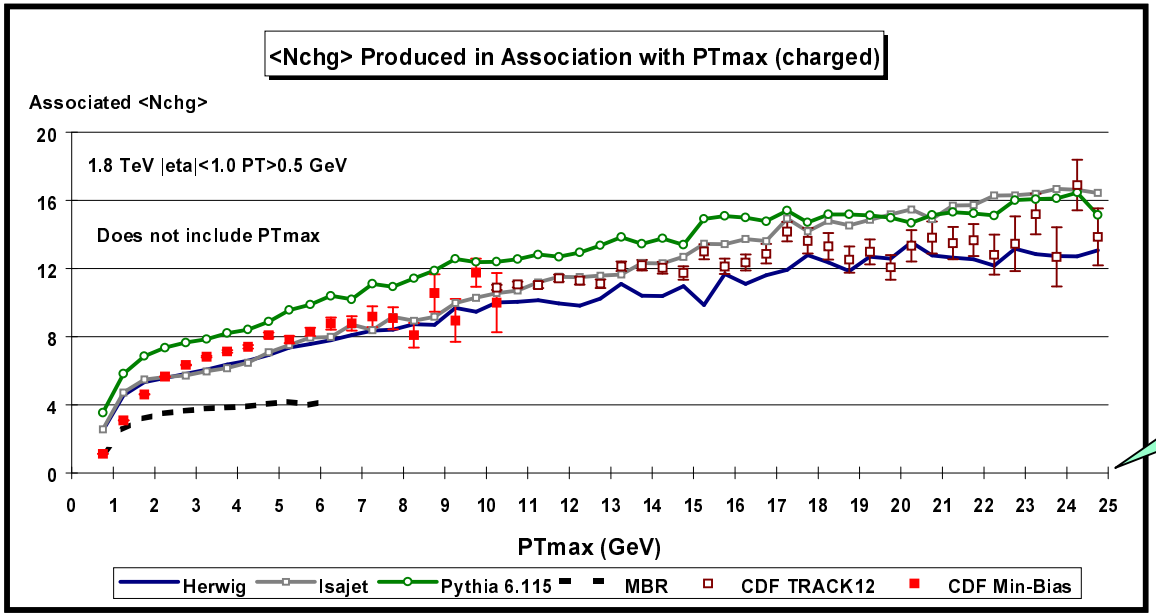
Isajet 7.32
Herwig 5.9
Pythia 6.115
Pythia 6.125
Pythia No MS
Pythia 4097

Pythia 6.115 and 6.125 differ in the amount of multiple parton interactions.

No multiple parton interactions.

Lots of multiple parton interactions.

The Transition Between "Soft" & "Hard" Scattering

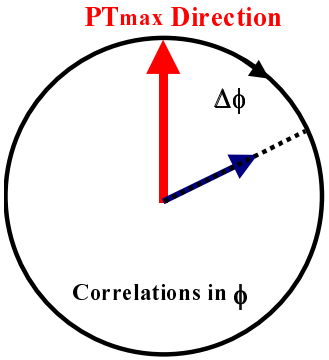


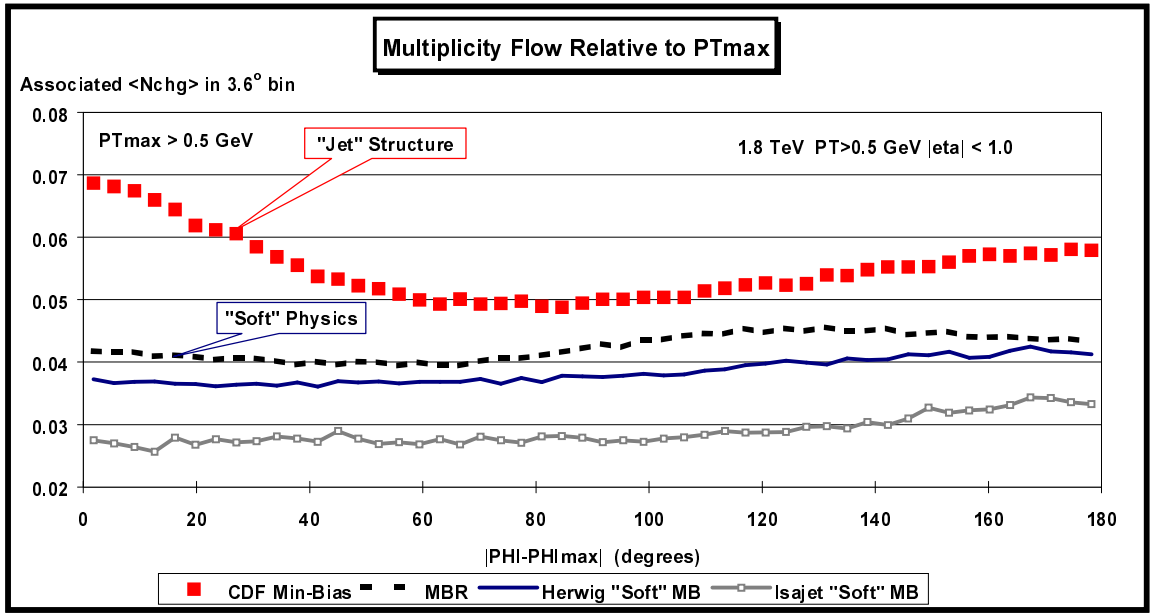
QCD "hard" scattering predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115, and the "soft" scattering MBR model

Global Observable

- **Plot shows "associated" <Nchg> versus PTmax. Each point corresponds to the <Nchg> in a 0.5 GeV bin (*not including PTmax*).**
- **Only consider charged particles with $|\eta| < 1$ and $P_T > 0.5$ GeV where the efficiency is good and use TRACK12 data to extend to large PTmax (highest PT charged particle in the event).**
- **Theoretical Monte-Carlo predictions must satisfy the CDF "min-bias" trigger and have been corrected for efficiency.**

Distribution of Nchg Relative to PTmax





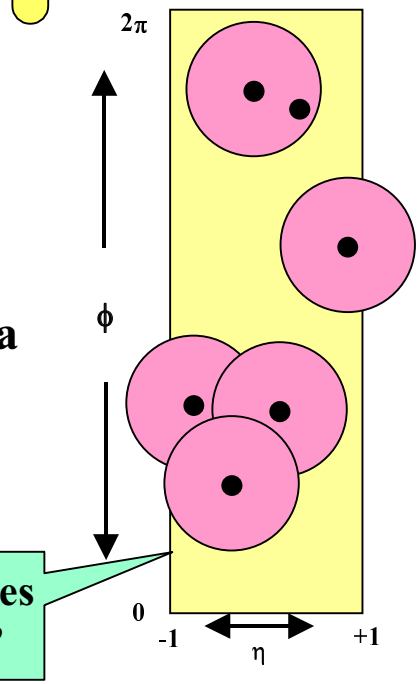
<PTmax> = 1.2 GeV

- **Define PTmax to be the highest PT charged particle in the event ($|\eta| < 1$ $P_T > 0.5$ GeV) and look at correlations in ϕ.**
- **Plot shows the associated charged particle multiplicity flow in ϕ relative to PTmax as a function of $|\phi - \phi max|$. Each point corresponds to the <Nchg> in a 3.6^o bin (*not including PTmax*).**
- **"Soft" scattering models have no correlations (except resonances and momentum conservation).**

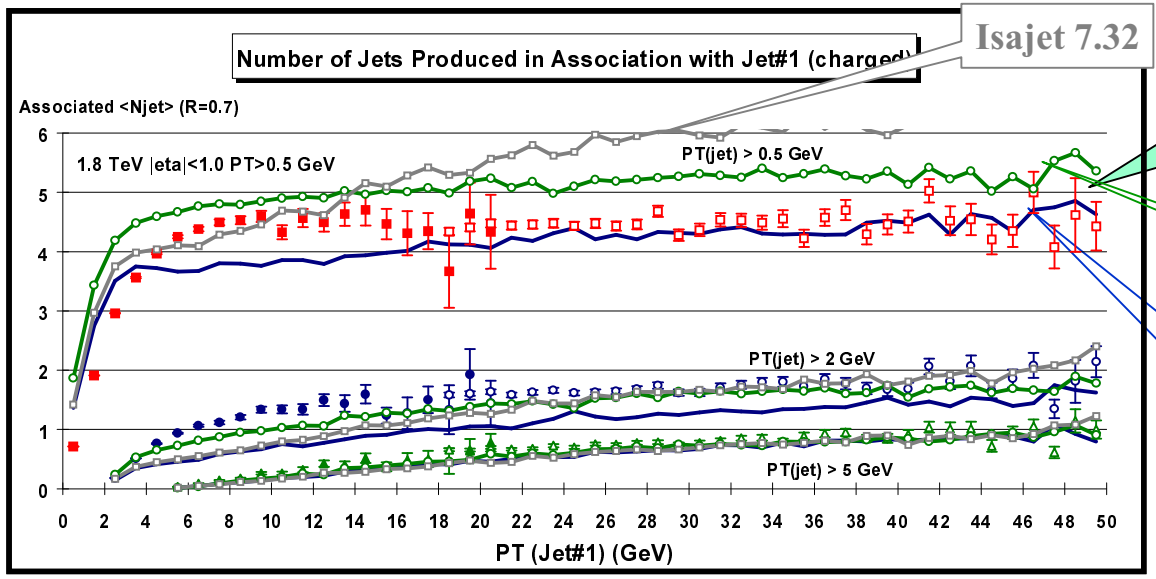
Define "Jets" as Circular Regions in η-φ Space

- Order Charged Particles in P_T ($|\eta| < 1$ $P_T > 0.5$ GeV).
- Start with highest P_T particle and include in the "jet" all particles ($|\eta| < 1$ $P_T > 0.5$ GeV) within radius R = 0.7.
- Go to next highest P_T particle (not already included in a previous jet) and include in the "jet" all particles ($|\eta| < 1$ $P_T > 0.5$ GeV) within radius R = 0.7 (not already included in a previous jet).
- Continue until all particles are in a "jet".
- Maximum number of "jet" is about $2(2)(2\pi)/(\pi(0.7)^2)$ or 16.

"Jets" contain particles from the underlying event in addition to particles from the outgoing partons.

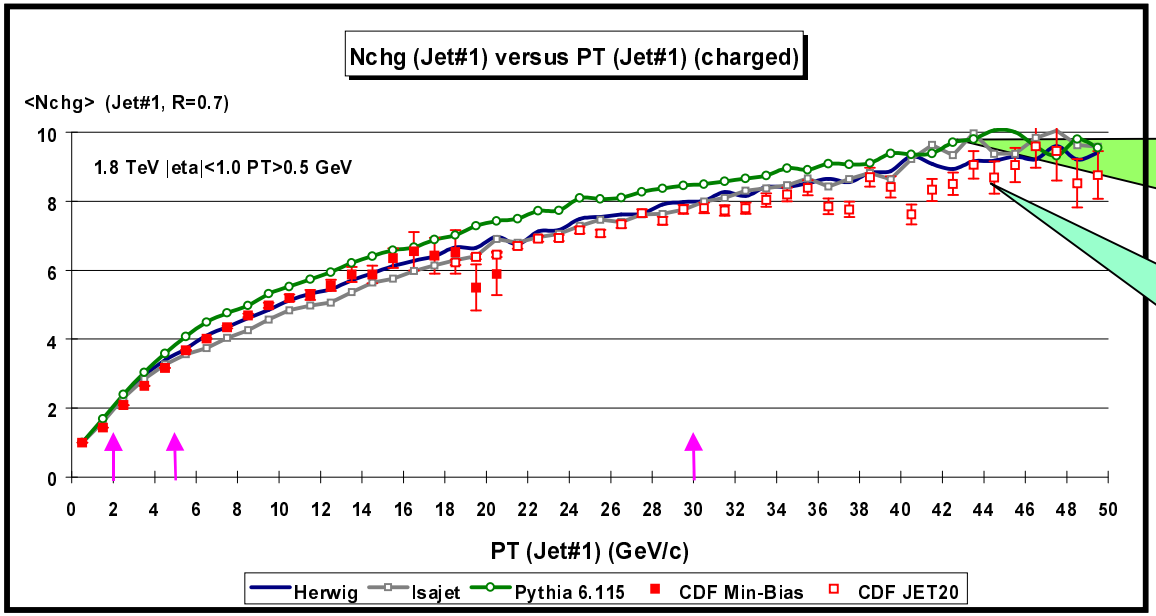


Number of "Jets" Produced with Jet#1



- Plot shows the number of jets (R = 0.7) produced in association with jet#1 (leading jet) vs PT(jet#1). Use the JET20 data to extend the range to $0.5 < PT(jet\#1) < 50$ GeV.
- Only charged particles with $|\eta| < 1$ and $P_T > 0.5$ GeV are included and the theory has been corrected for efficiency.
- Plot shows <Njet> (not counting jet#1) in a 1 GeV bin for the three cases: PT(jet) > 0.5, 2, and 5 GeV compared with the QCD "hard" scattering Monte-Carlo predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115.

The Evolution of "Jets" from 0.5 to 50 GeV



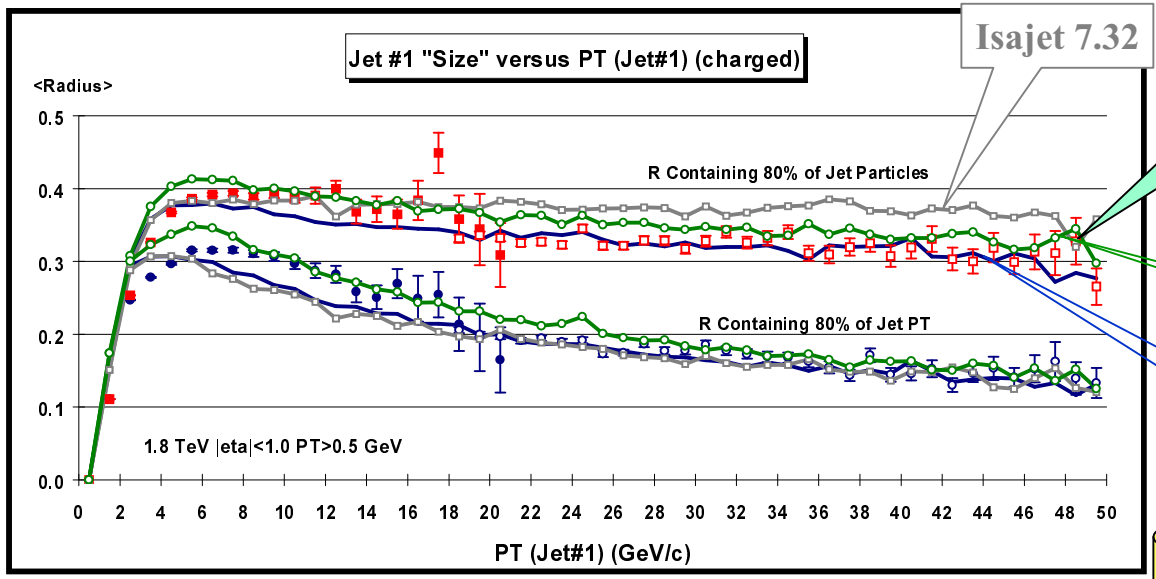
QCD "hard" scattering predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115

JET20 data connects on smoothly to the Min-Bias data

Local "Jet" Observable

- **Compares data on the average number of charged particles within Jet#1 (leading jet, R = 0.7) with the QCD "hard" scattering predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115.**
- **Use the JET20 data to extend the range to 0.5 < PT(jet#1) < 50 GeV. Plot shows <Nchg(jet#1)> versus PT(jet#1).**
- **Only charged particles with $|\eta| < 1$ and $P_T > 0.5$ GeV are included and the theory has been corrected for efficiency.**

Jet#1 "Size" vs PT(jet#1)



Isajet 7.32

JET20 data connects on smoothly to the Min-Bias data

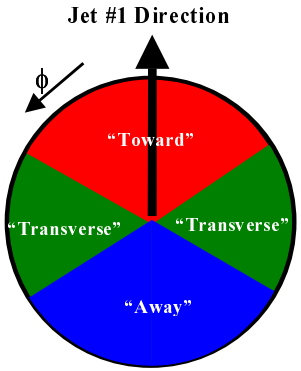
Pythia 6.115

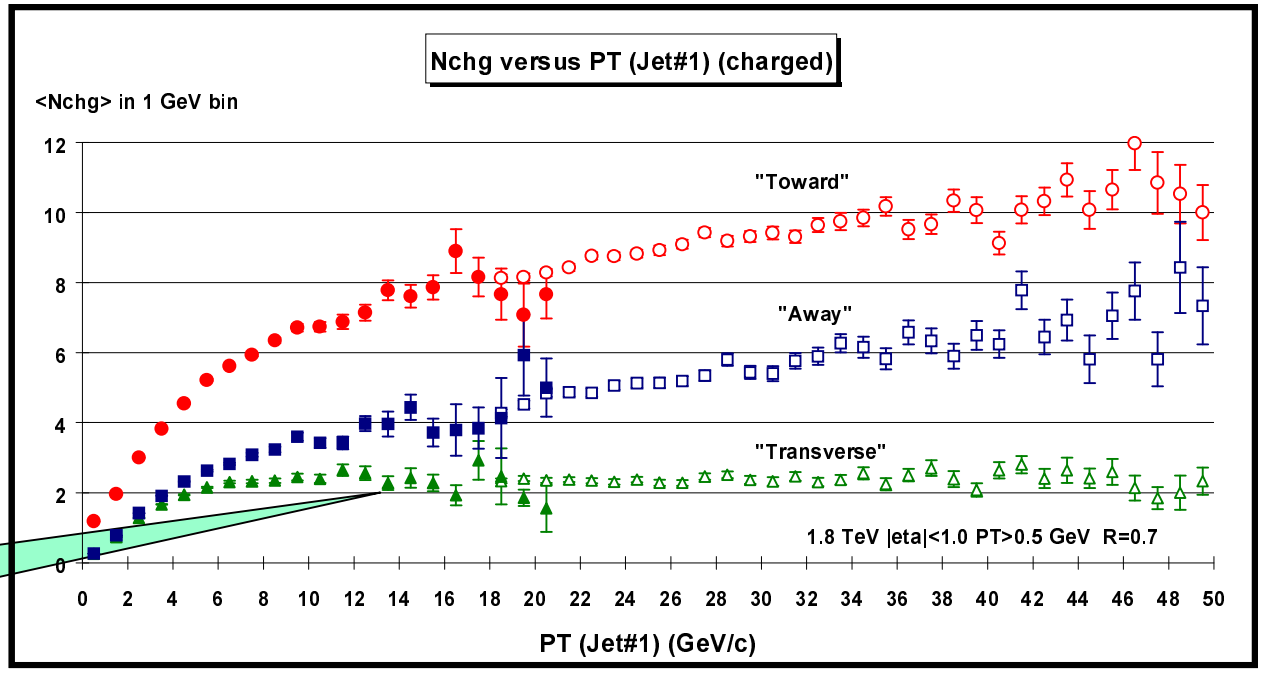
Herwig 5.9

Local "Jet" Observable

- Compares data on the average radius containing 80% of the particles and 80% of the PT of Jet#1 (leading jet) with the QCD "hard" scattering predictions of Herwig 5.9.
- Use the JET20 data to extend the range to 0.5 < PT(jet#1) < 50 GeV. Plot shows <R(jet#1)> versus PT(jet#1).
- Only charged particles with $|\eta| < 1$ and $P_T > 0.5$ GeV are included and the theory has been corrected for efficiency.

Distribution of Nchg Relative to Jet#1

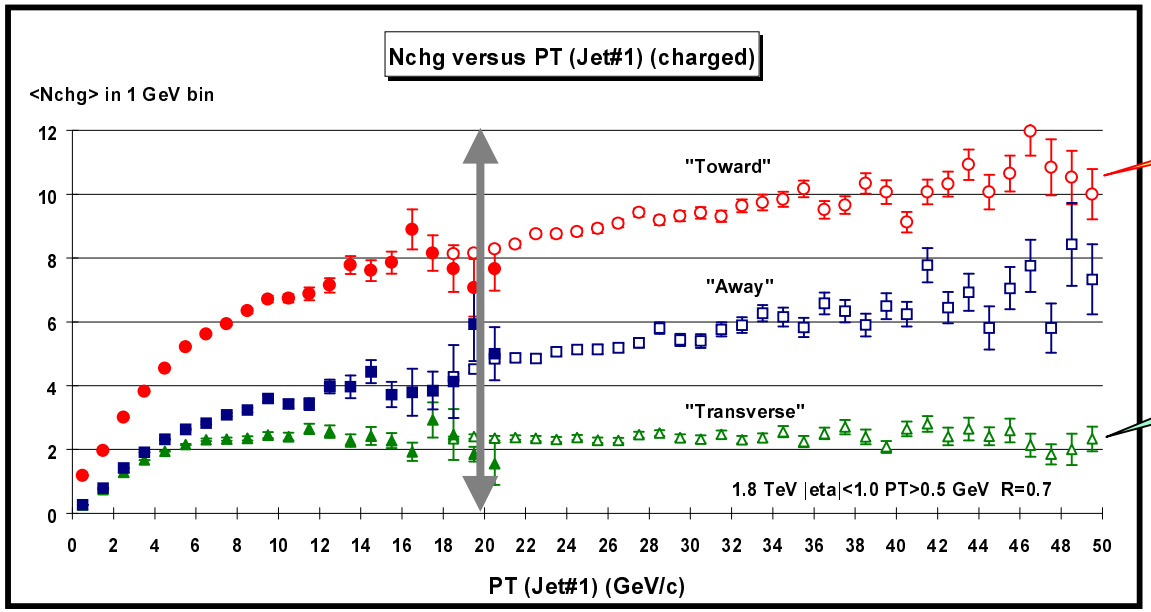




Underlying event "plateau"

- **Look at the charged multiplicity flow in ϕ relative to the direction of jet#1 ($|\eta| < 1$ $P_T > 0.5$ GeV). Use the JET20 data to extend the range to $0.5 < PT(jet\#1) < 50$ GeV.**
- **Define "Toward" $|\phi - \phi_{jet}| < 60^o$ (includes jet#1), "Transverse" $60^o < |\phi - \phi_{jet}| < 120^o$, and "Away" $|\phi - \phi_{jet}| < 120^o$ region.**
- **Plot shows <Nchg> in the three regions versus PT(jet#1).**

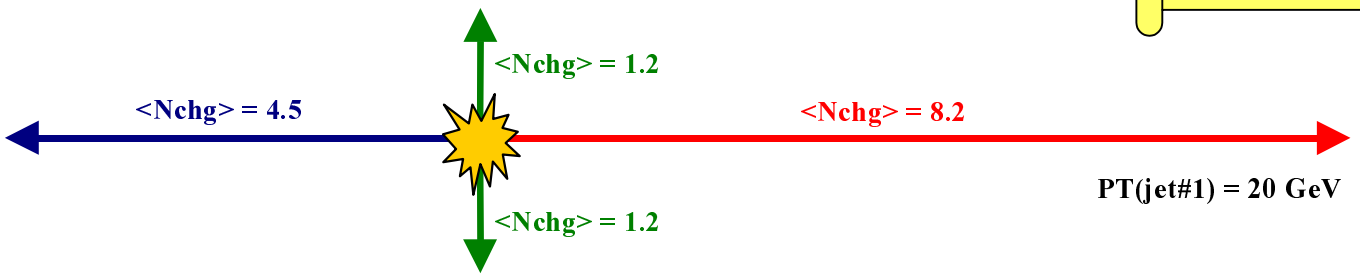
Shape of an Average Event with PT(jet#1) = 20 GeV



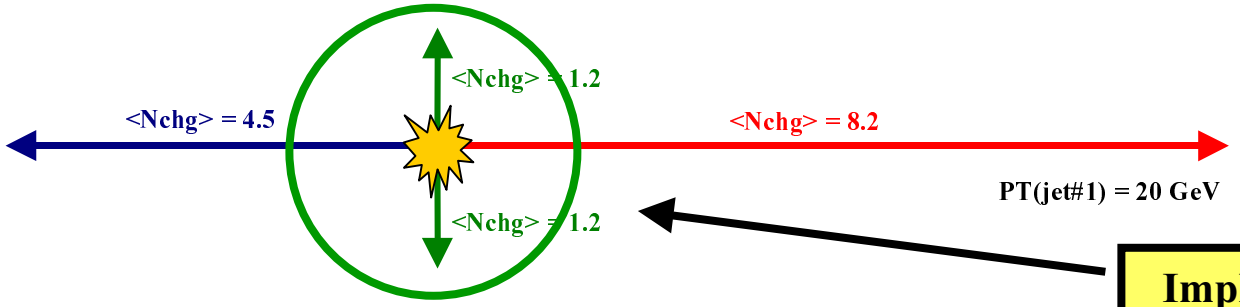
Includes Jet#1

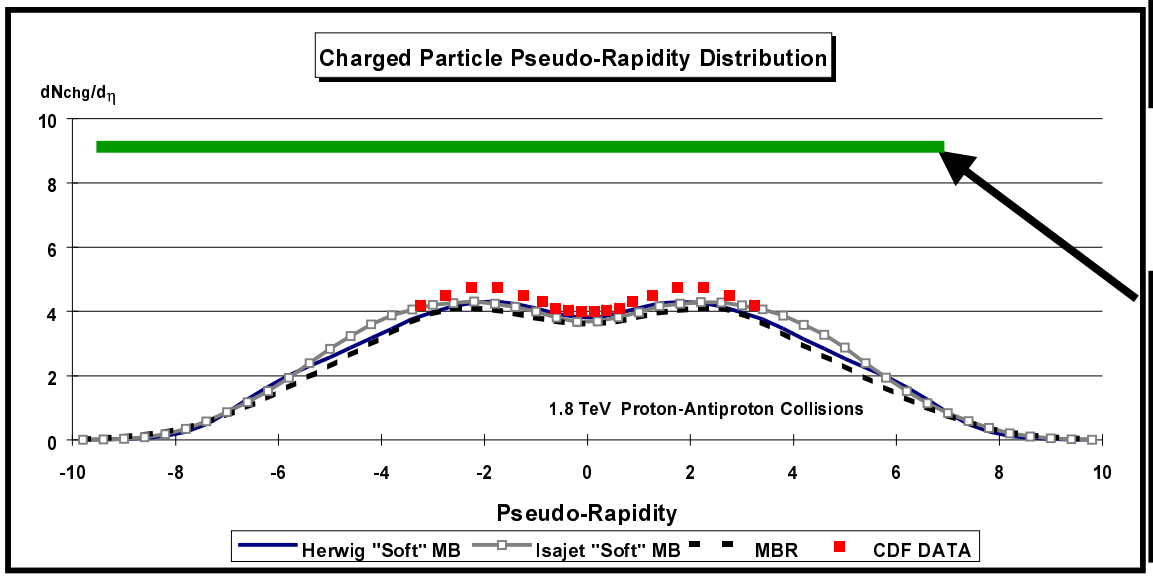
Underlying event "plateau"

Remember $|\eta| < 1$ $P_T > 0.5$ GeV



"Height" of the Underlying Event "Plateau"

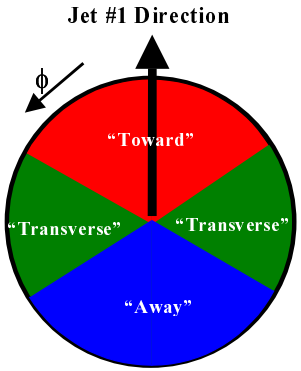


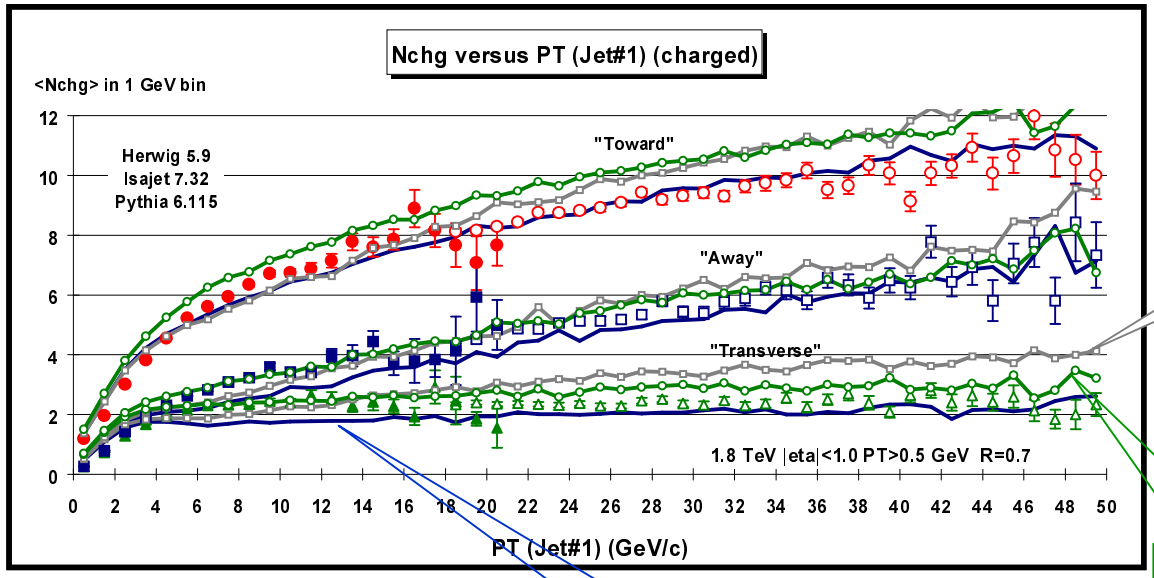


Implies 1.09*3(2.4)/2 = 3.9 charged particles per unit η with PT > 0.5 GeV.

Implies 2.3*3.9 = 9 charged particles per unit η with PT > 0 GeV which is a factor of 2 larger than "soft" collisions.

Distribution of Nchg Relative to Jet#1





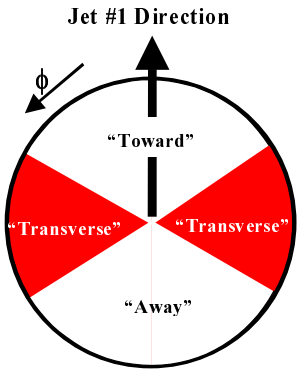
Isajet 7.32

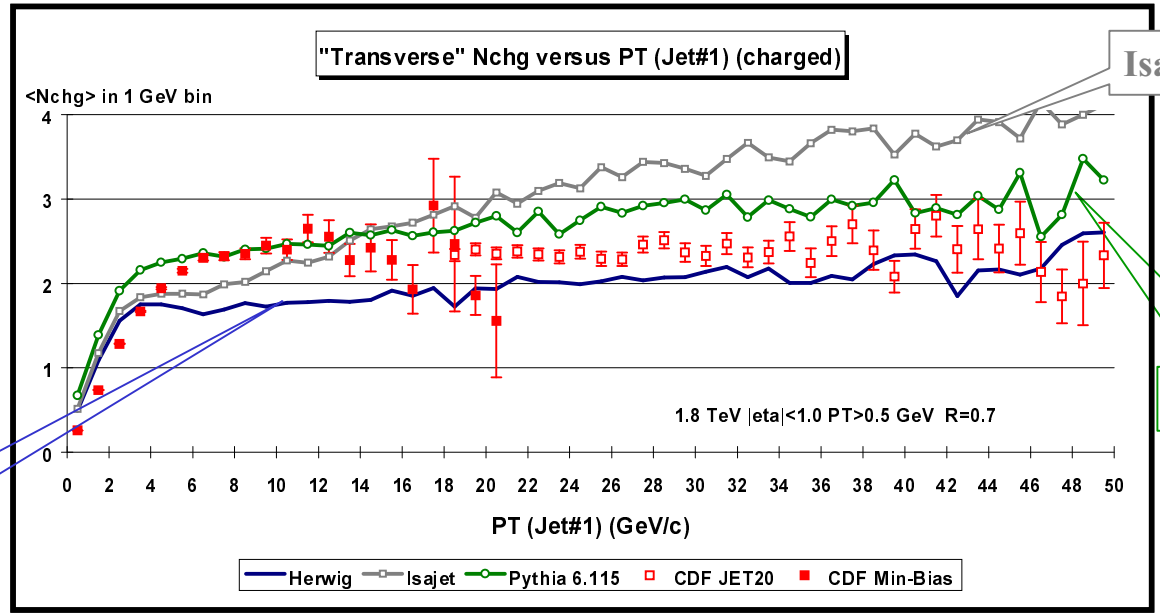
Pythia 6.115

Herwig 5.9

- Look at the charged multiplicity flow in ϕ relative to the direction of jet#1 ($|\eta| < 1$ $P_T > 0.5$ GeV). Use the JET20 data to extend the range to $0.5 < PT(jet\#1) < 50$ GeV.
- Define "Toward" $|\phi - \phi jet| < 60^o$ (includes jet#1), "Transverse" $60^o < |\phi - \phi jet| < 120^o$, and "Away" $|\phi - \phi jet| < 120^o$ region.
- Plot shows <Nchg> in the three regions versus PT(jet#1) compared with the QCD "hard" scattering predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115.

"Transverse" Nchg versus PT(jet#1)





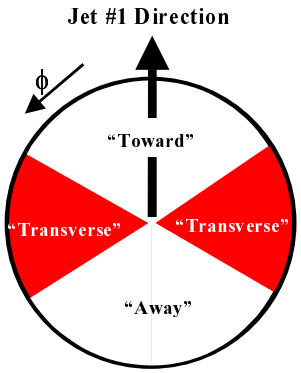
Isajet 7.32

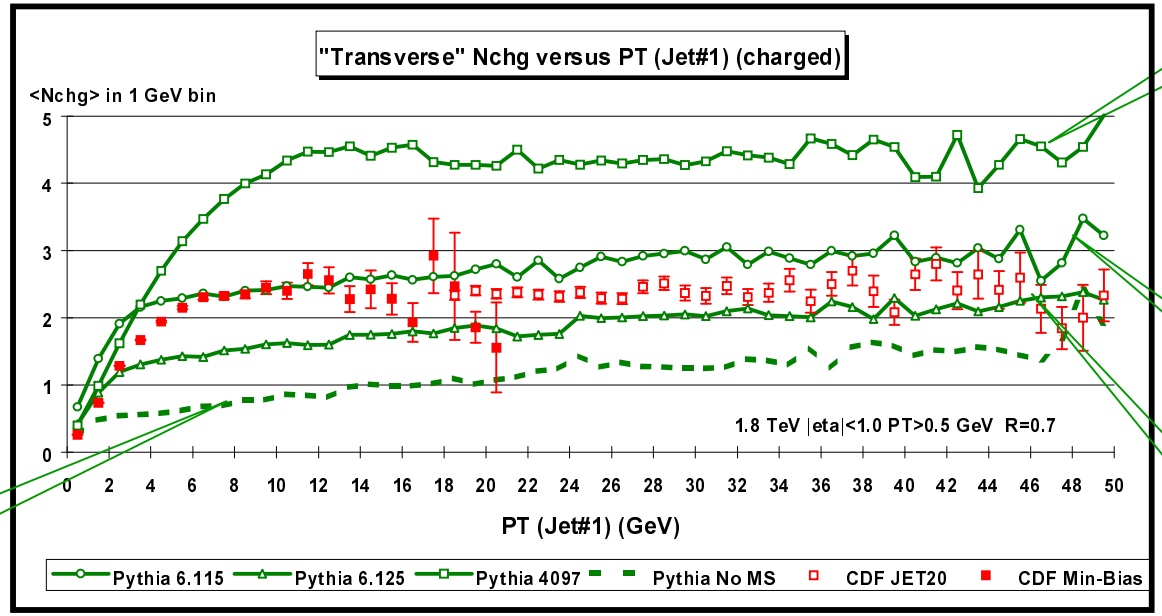
Pythia 6.115

Herwig 5.9

- Look at the charged multiplicity flow in ϕ relative to the direction of jet#1 ($|\eta| < 1$ $P_T > 0.5$ GeV). Use the JET20 data to extend the range to 0.5 < PT(jet#1) < 50 GeV. Define "Transverse" $60^o < |\phi - \phi jet| < 120^o$.
- Plot shows "Transverse" <Nchg> in the vs PT(jet#1) compared to the QCD "hard" scattering predictions of Herwig 5.9, Isajet 7.32, and Pythia 6.115.

"Transverse" Nchg versus PT(jet#1)





Note 4097

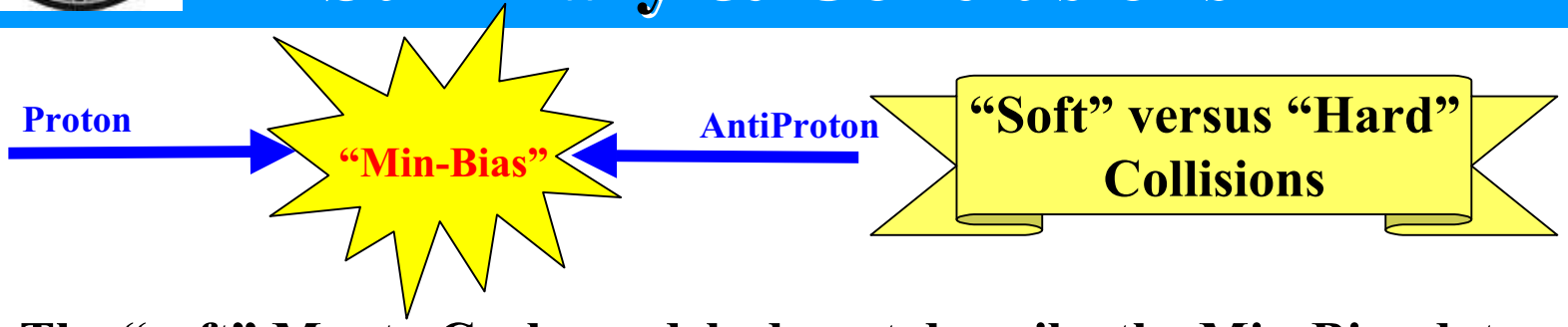
6.115

6.125

No multiple scattering

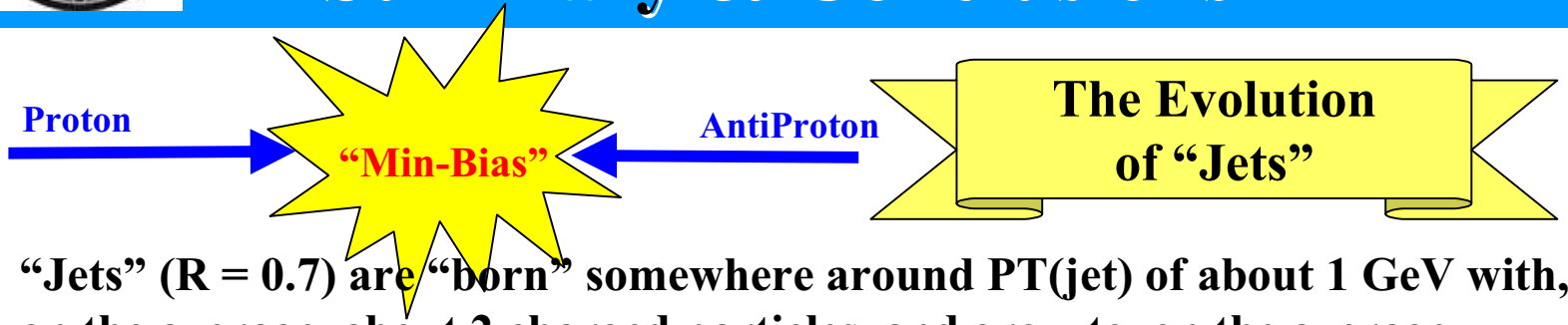
- Look at the charged multiplicity flow in ϕ relative to the direction of jet#1 ($|\eta| < 1$ $P_T > 0.5$ GeV). Use the JET20 data to extend the range to 0.5 < PT(jet#1) < 50 GeV. Define "Transverse" $60^o < |\phi - \phi jet| < 120^o$.
- Plot shows "Transverse" <Nchg> in the vs PT(jet#1) compared to the QCD "hard" scattering predictions of four versions of Pythia (6.115, 6.125, no multiple interactions, and CDF note 4097).

"Min-Bias" Physics: Summary & Conclusions



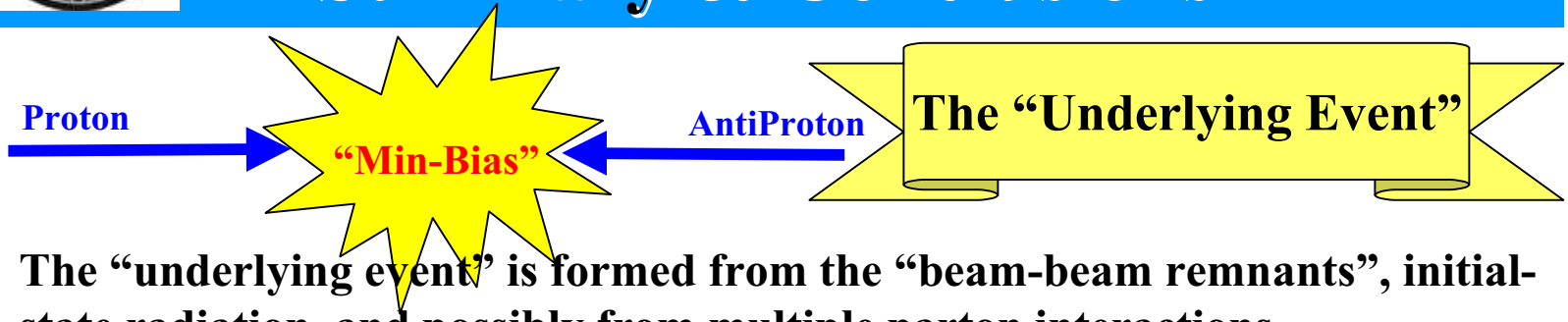
- **The "soft" Monte-Carlo models do not describe the Min-Bias data because the "soft" models have no "hard" scattering and no "jets" and the data show "jet" structure for PTmax > 1 GeV.**
- **The QCD "hard" scattering models (with PT(hard) > 3 GeV) qualitatively fit the data for PTmax or PTjet greater than about 2 GeV.**
- **Below 2 GeV that data are a mixture of "hard" and "soft" and to describe this region we will have to combine a model for the "soft" collisions with a QCD perturbative Monte-Carlo model of the "hard" collisions. We are working on this!**

"Min-Bias" Physics: Summary & Conclusions



- **"Jets" (R = 0.7) are "born" somewhere around PT(jet) of about 1 GeV with, on the average, about 2 charged particles, and grow to, on the average, about 10 charged particles at 50 GeV.**
- **The QCD "hard" scattering Monte-Carlo models agree qualitatively well with the multiplicity distribution of the charged particles within a "jet", the flow of charged multiplicity and PTsum around the jet direction, the "size" of the jets, and with the jet "fragmentation functions". They agree as well with 2 GeV "jets" as they do with 50 GeV "jets"!**
- **The "jets" in the Min-Bias data are simply the extrapolation (*down to small* P_T) of the high transverse momentum "jets" observed in the JET20 data. Our analysis suggests that at 1.8 TeV "hard" scattering makes up at least one-half of the "hard core" inelastic cross section. At the LHC, lots of "min-bias" events will contain 20 GeV "jets"!**

"Min-Bias" Physics: Summary & Conclusions



- **The "underlying event" is formed from the "beam-beam remnants", initial-state radiation, and possibly from multiple parton interactions..**
- **The Min-Bias data show that the charged multiplicity in the "underlying event" grows very rapidity with PTmax or with P_T(jet#1) and then forms an approximately constant "plateau". The height of this "plateau" is at least twice that observed in "soft" collisions at the same corresponding energy.**
- **None of the QCD Monte-Carlo models correctly describe the structure of the underlying event seen in the data. Herwig 5.9 and Pythia 6.125 do not have enough activity in the underlying event. Pythia 6.115 has about the right amount of activity in the underlying event, but as a result produces too much overall multiplicity. Isajet 7.32 has a lot of activity in the underlying event, but with the wrong dependence on P_T(jet#1). Pythia 4097 produces way too much activity in the underlying event.**