Northwest Terascale Workshop
Parton Showers and Event Structure at the LHC

Review of the QCD Monte-Carlo Tunes

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Quantum Chromo-Dynamics

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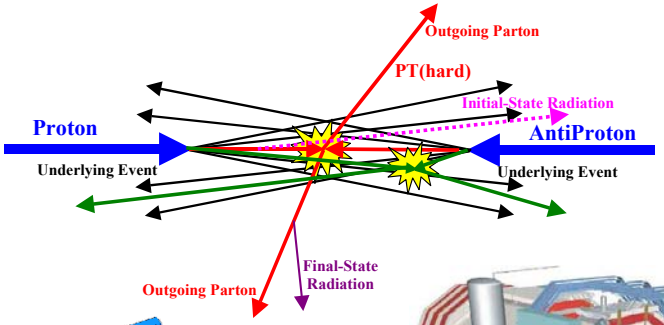
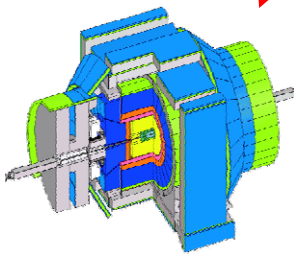
University of Oregon February 23, 2009

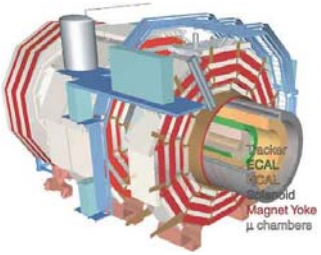
Outline of Talk

- **Review some of what we have learned about "min-bias" and the "underlying event" in Run 1 at CDF.**
- **Review the various PYTHIA "underlying event" QCD Monte-Carlo Model tunes.**
- **Show some things I do not understand about the CDF data.**
- **Show some extrapolations to the LHC.**



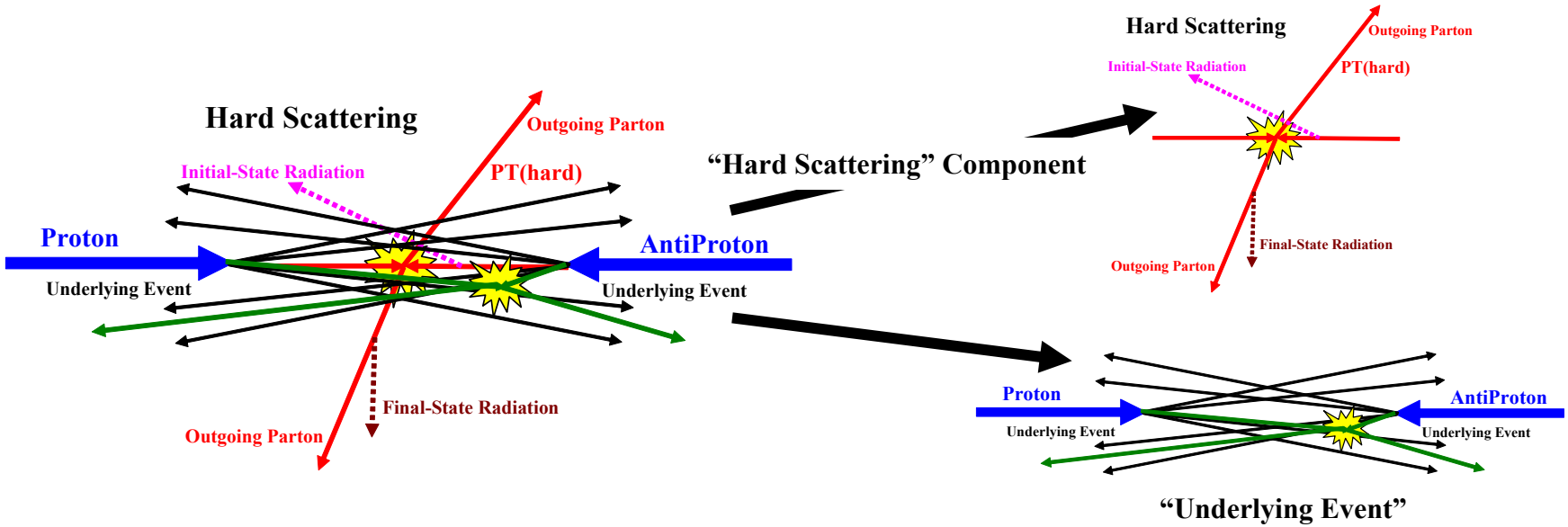


CDF Run 2



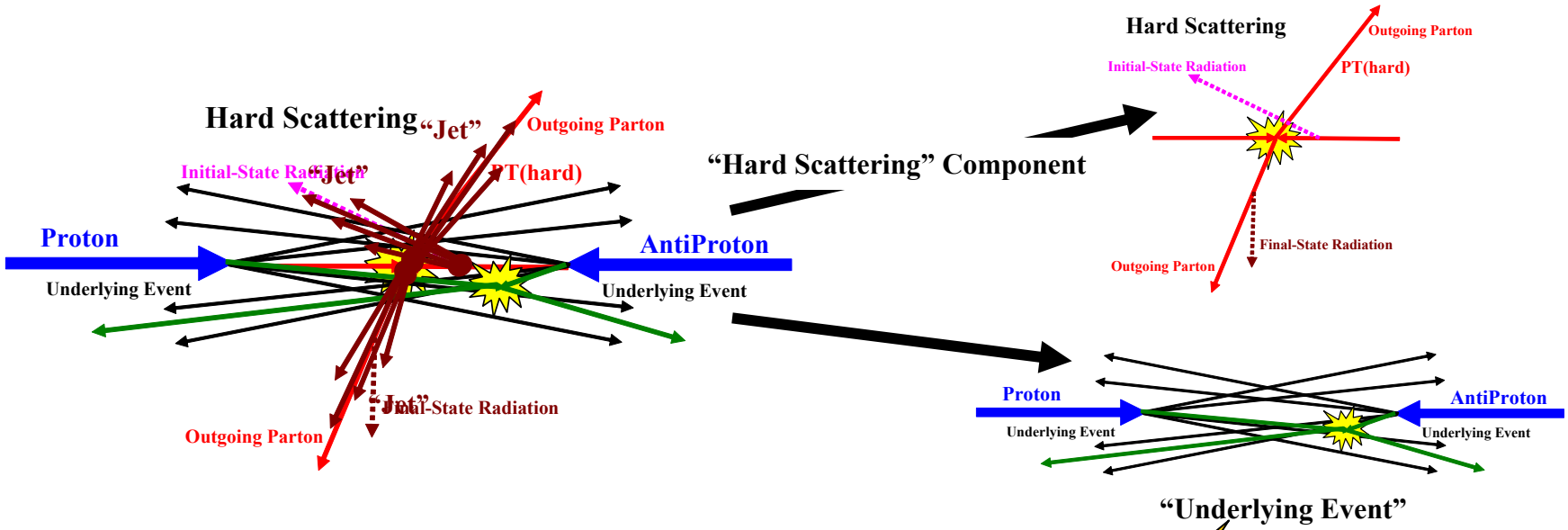
CMS at the LHC

QCD Monte-Carlo Models: High Transverse Momentum Jets



- Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).
- The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).
- Of course the outgoing colored partons fragment into hadron "jet" and inevitably "underlying event" observables receive contributions from initial and final-state radiation.

QCD Monte-Carlo Models: High Transverse Momentum Jets



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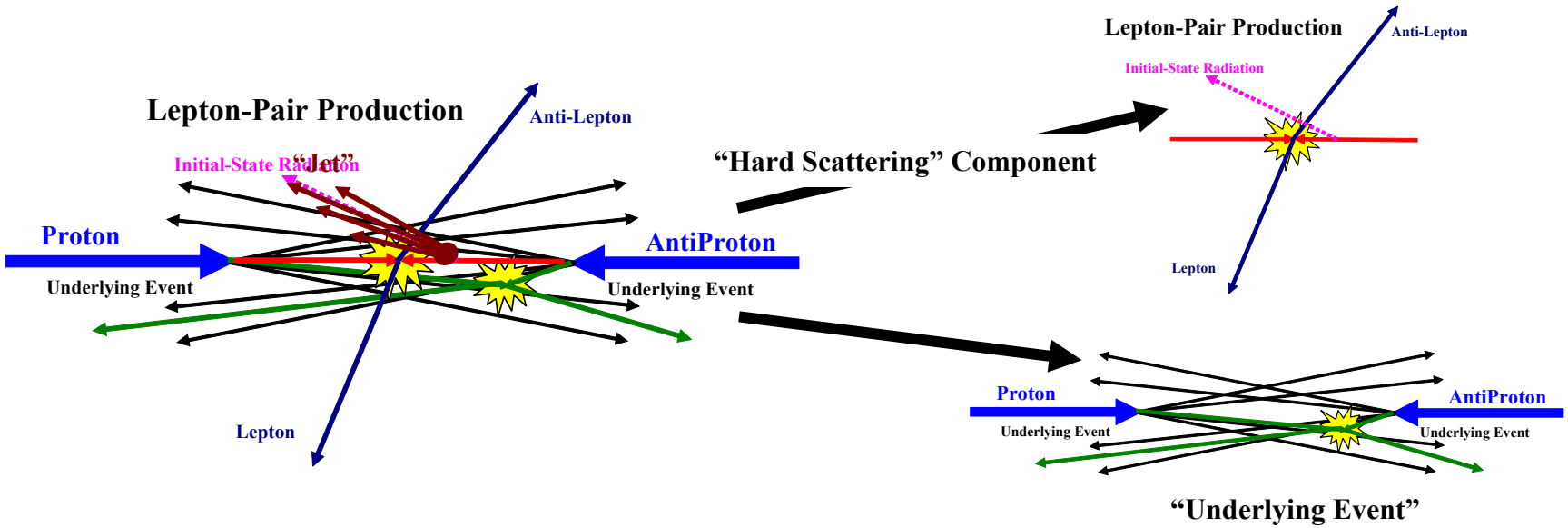
The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

QCD Monte-Carlo Models: Lepton-Pair Production



- Start with the perturbative Drell-Yan muon pair production and add initial-state gluon radiation (in the leading log approximation or modified leading log approximation).
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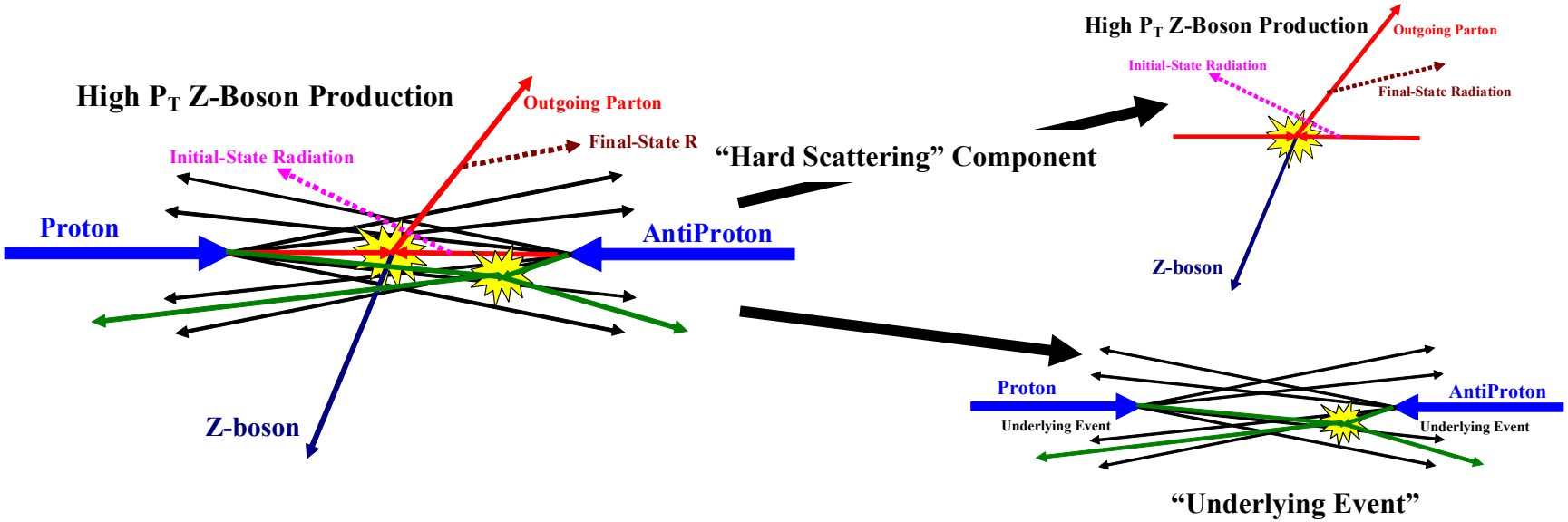

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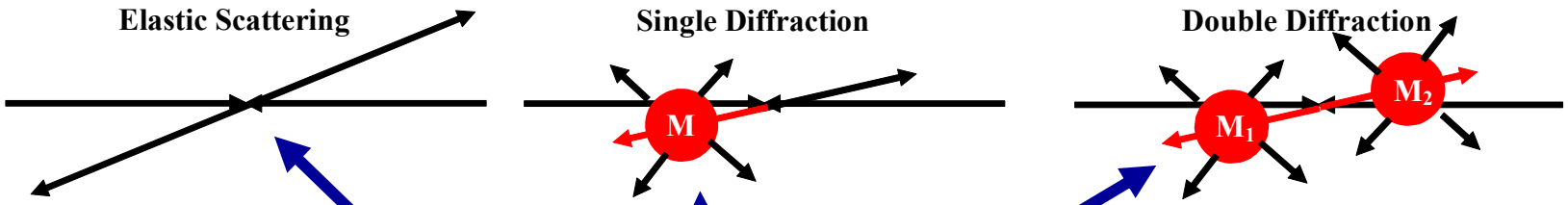
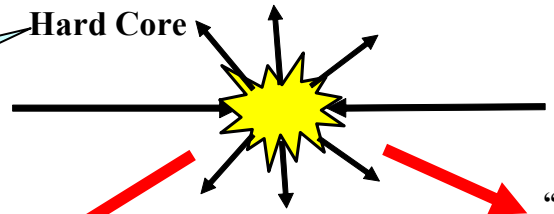
Proton-AntiProton Collisions at the Tevatron

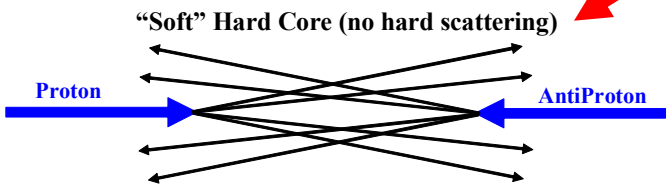


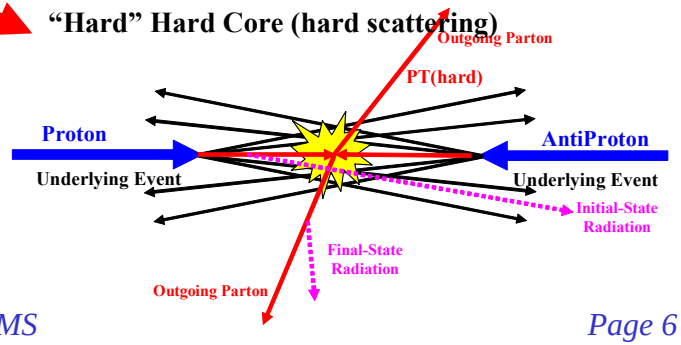
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC}$$

1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

The "hard core" component contains both "hard" and "soft" collisions.

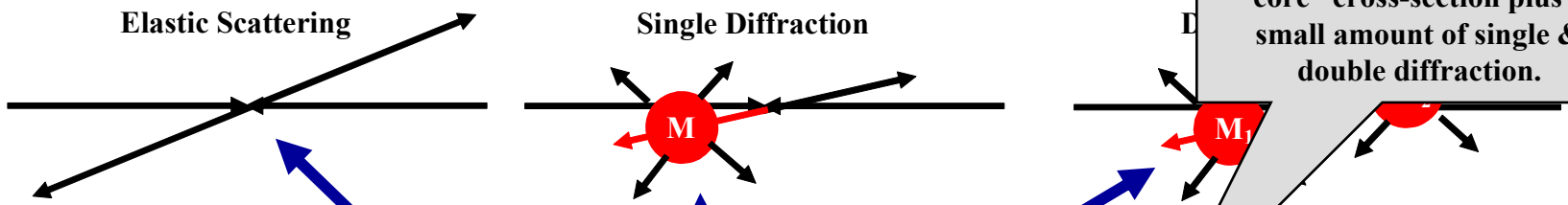






Proton-AntiProton Collisions at the Tevatron

The CDF "Min-Bias" trigger picks up most of the "hard core" cross-section plus a small amount of single & double diffraction.



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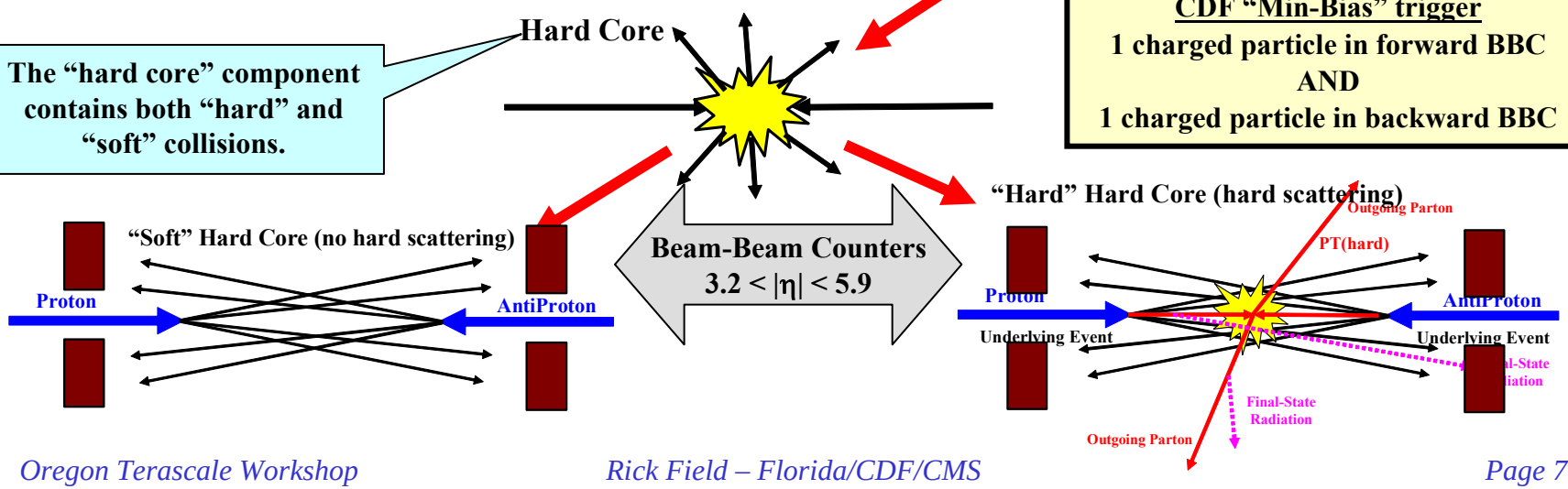
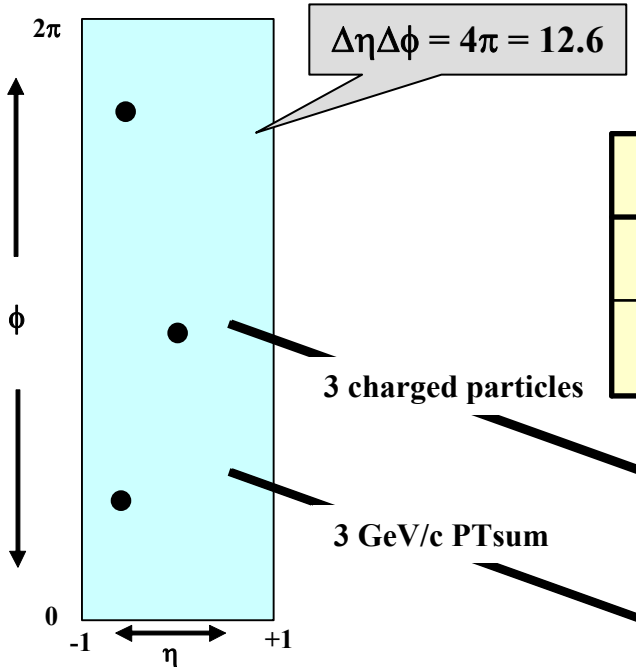
The "hard core" component contains both "hard" and "soft" collisions.

CDF "Min-Bias" trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC



Particle Densities



Charged Particles
$p_T > 0.5$ GeV/c $|\eta| < 1$

CDF Run 2 "Min-Bias"

	CDF Run 2 "Min-Bias" Observable	Average	Average Density per unit η-φ
Nchg	Number of Charged Particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$)	3.17 +/- 0.31	0.252 +/- 0.025
PTsum (GeV/c)	Scalar p_T sum of Charged Particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$)	2.97 +/- 0.23	0.236 +/- 0.018

Divide by 4π

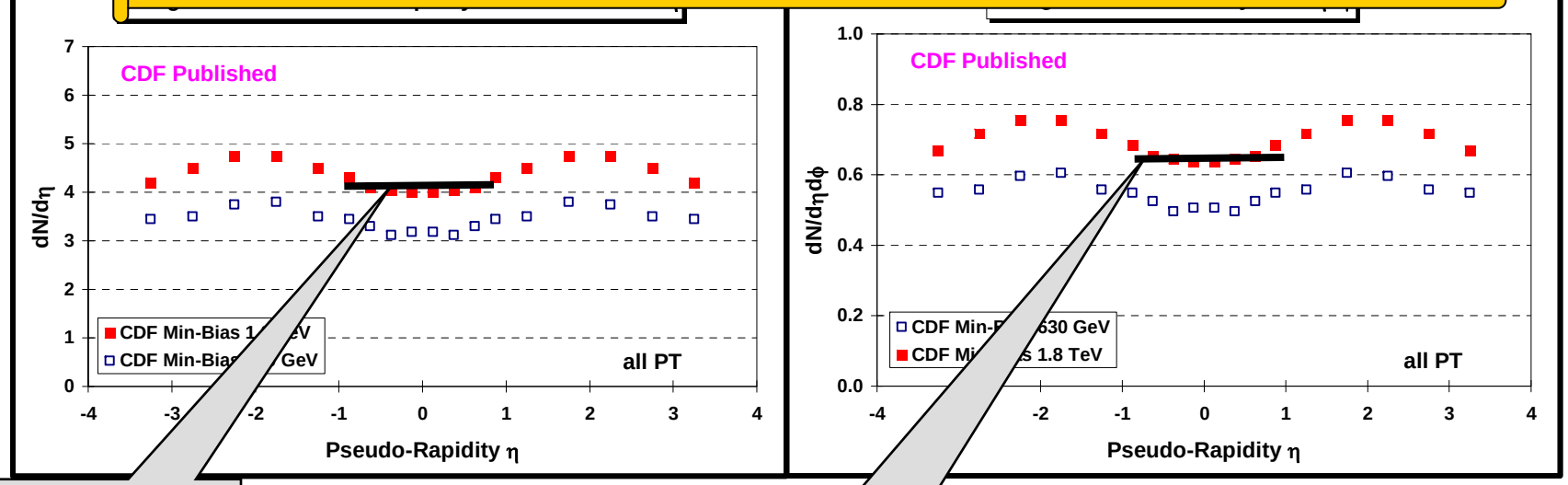
$dN_{chg}/d\eta d\phi = 3/4\pi = 0.24$

$dPT_{sum}/d\eta d\phi = 3/4\pi$ GeV/c = 0.24 GeV/c

➡ **Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{chg}/d\eta d\phi$, and the charged scalar p_T sum density, $dPT_{sum}/d\eta d\phi$.**

CDF Run 1 "Min-Bias" Data
Charged Particle Density

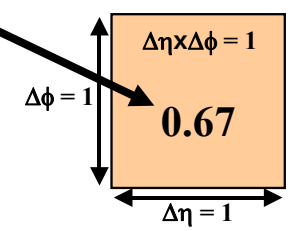
I will talk about "min-bias" and "pile-up" tomorrow!



$\langle dN_{chg}/d\eta \rangle = 4.2$

$\langle dN_{chg}/d\eta d\phi \rangle = 0.67$

- Shows CDF "Min-Bias" data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about **4.2 charged particles per unit η in "Min-Bias" collisions at 1.8 TeV** ($|\eta| < 1$, all p_T).
- Convert to charged particle density, $dN_{chg}/d\eta d\phi$, by dividing by 2π. There are about **0.67 charged particles per unit η-φ in "Min-Bias" collisions at 1.8 TeV** ($|\eta| < 1$, all p_T).



CDF Run 1 "Min-Bias" Data
Charged Particle Density

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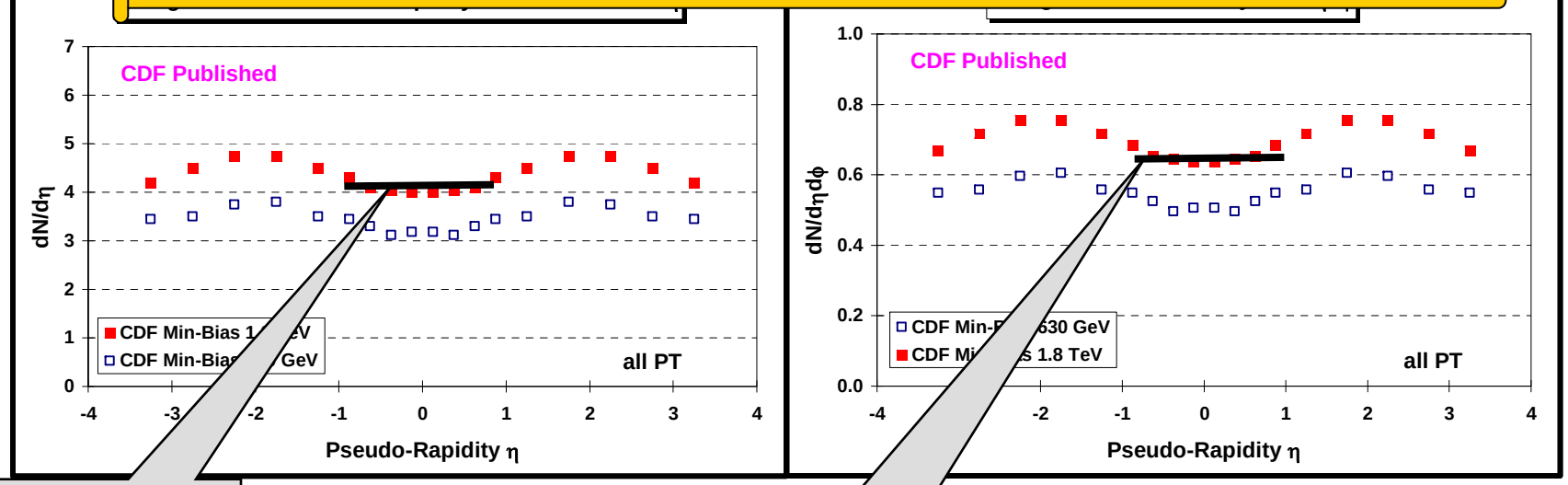

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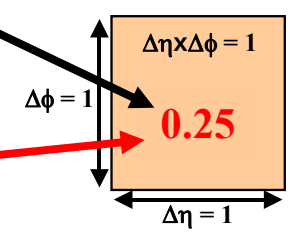
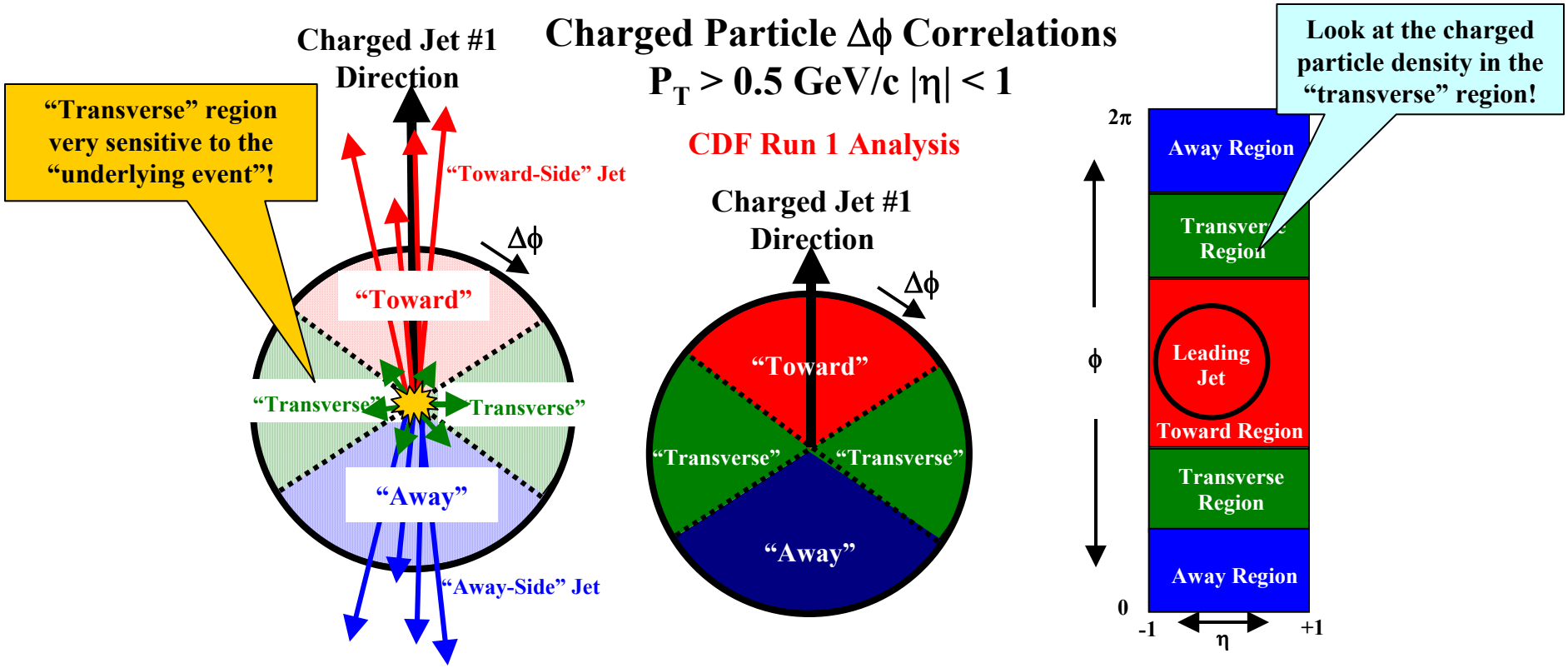
- There are about **0.25 charged particles per unit η-ϕ in "Min-Bias" collisions at 1.96 TeV** ($|\eta| < 1$, $p_T > 0.5$ GeV/c).

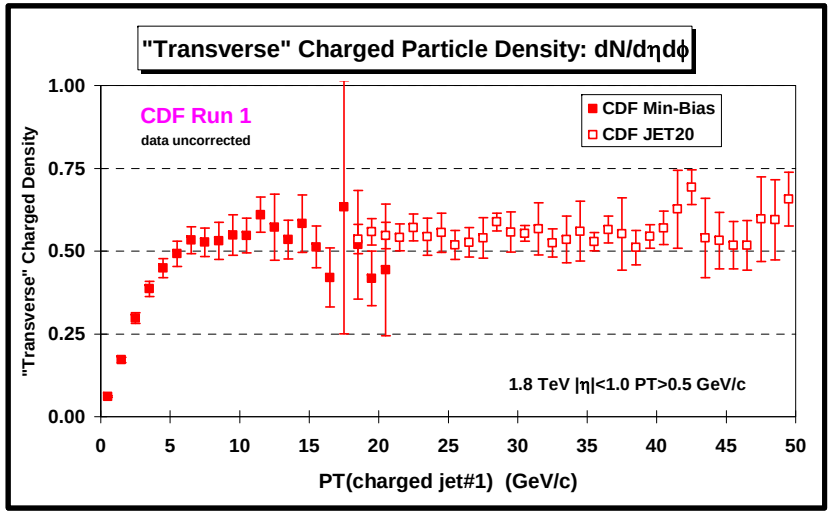


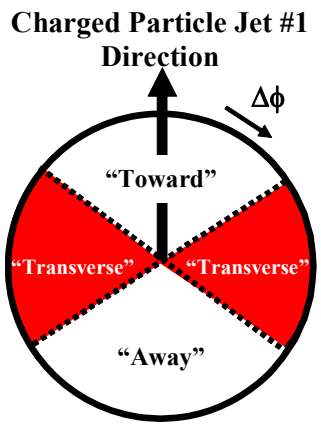
CDF Run 1: Evolution of Charged Jets "Underlying Event"



- Look at charged particle correlations in the azimuthal angle Δϕ relative to the leading charged particle jet.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same size in η-ϕ space, $\Delta\eta x\Delta\phi = 2x120^o = 4\pi/3$.

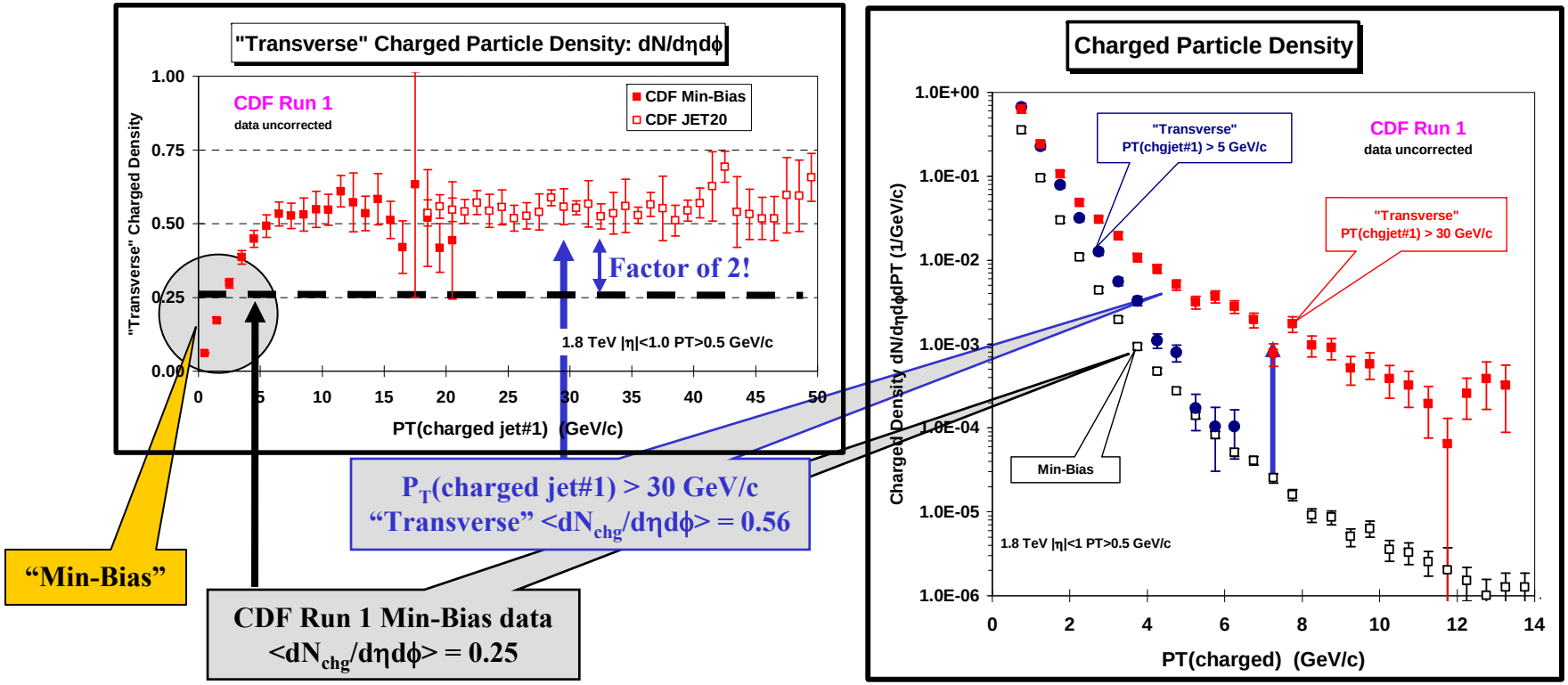
Run 1 Charged Particle Density "Transverse" p_T Distribution





- **Compares the average "transverse" charge particle density with the average "Min-Bias" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV). Shows how the "transverse" charge particle density and the Min-Bias charge particle density is distributed in p_T.**

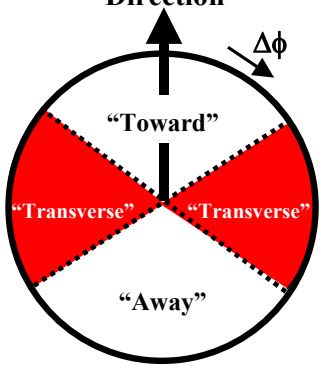
Run 1 Charged Particle Density "Transverse" p_T Distribution

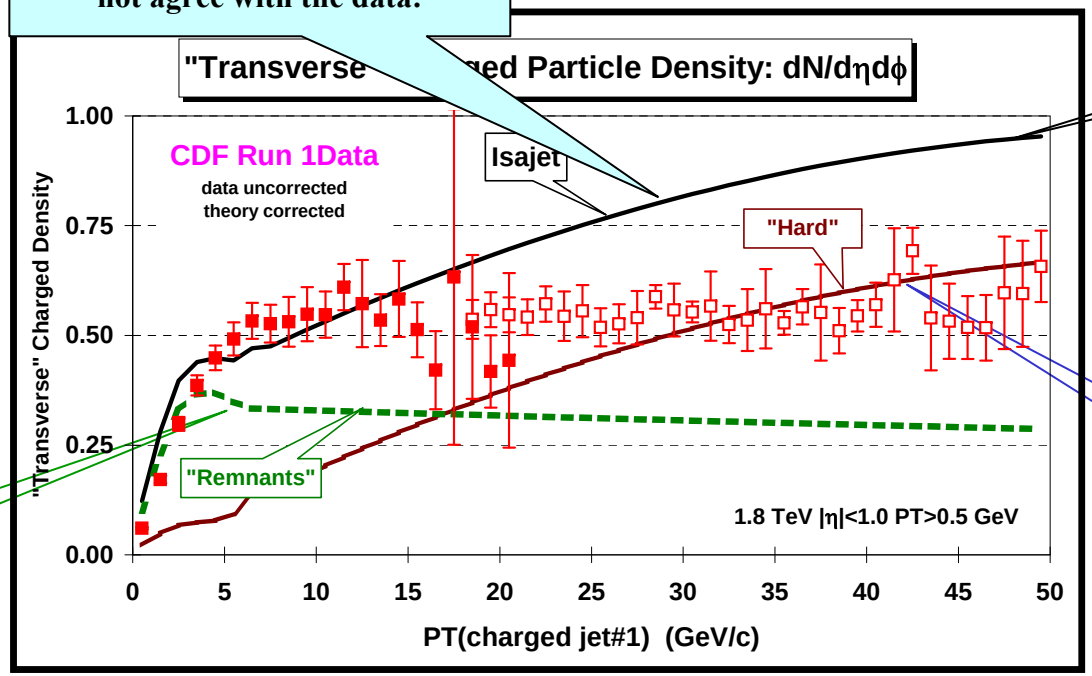


➡ **Compares the average "transverse" charge particle density with the average "Min-Bias" charge particle density (|η|<1, p_T>0.5 GeV). Shows how the "transverse" charge particle density and the Min-Bias charge particle density is distributed in p_T.**

ISAJET 7.32
"Transverse" Density

ISAJET uses a naïve leading-log parton shower-model which does not agree with the data!





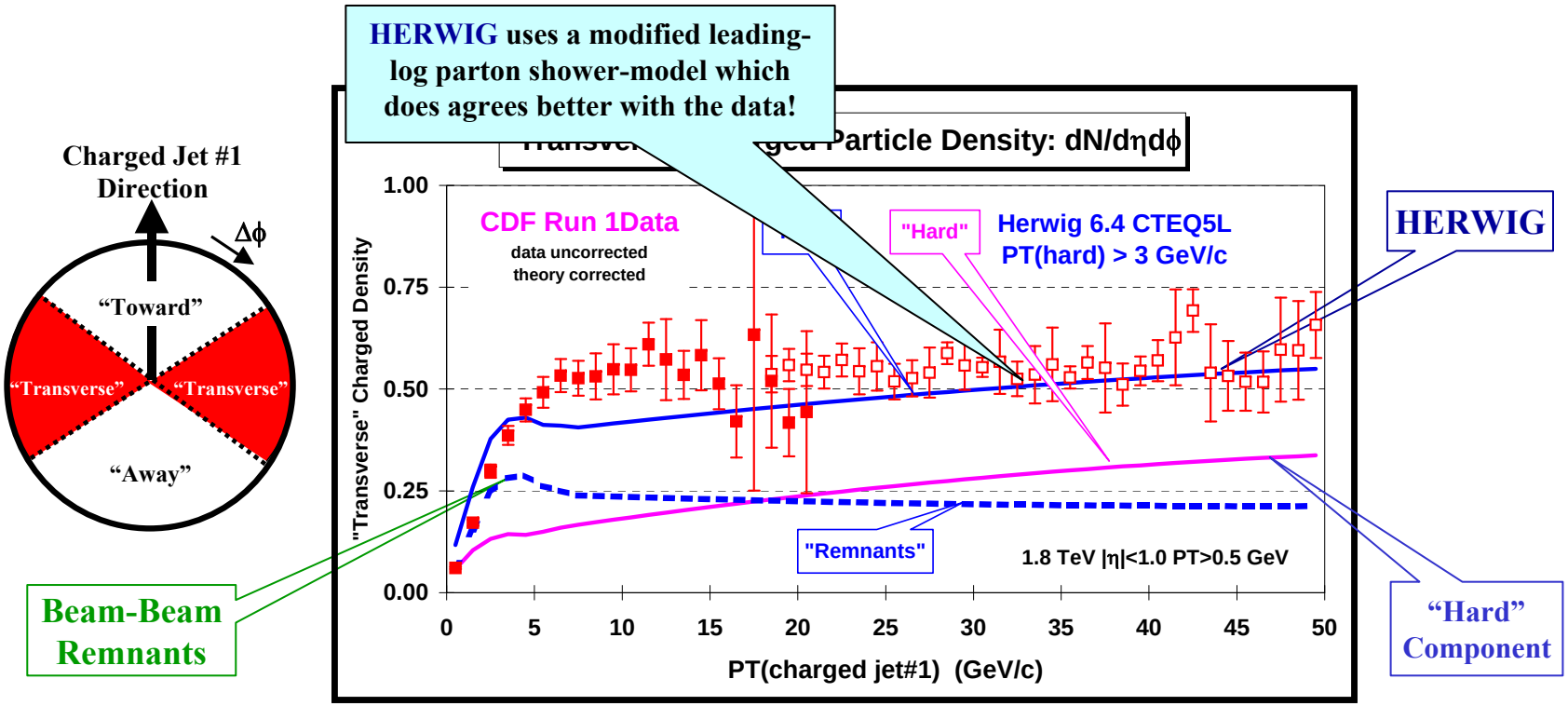
ISAJET

"Hard" Component

Beam-Beam Remnants

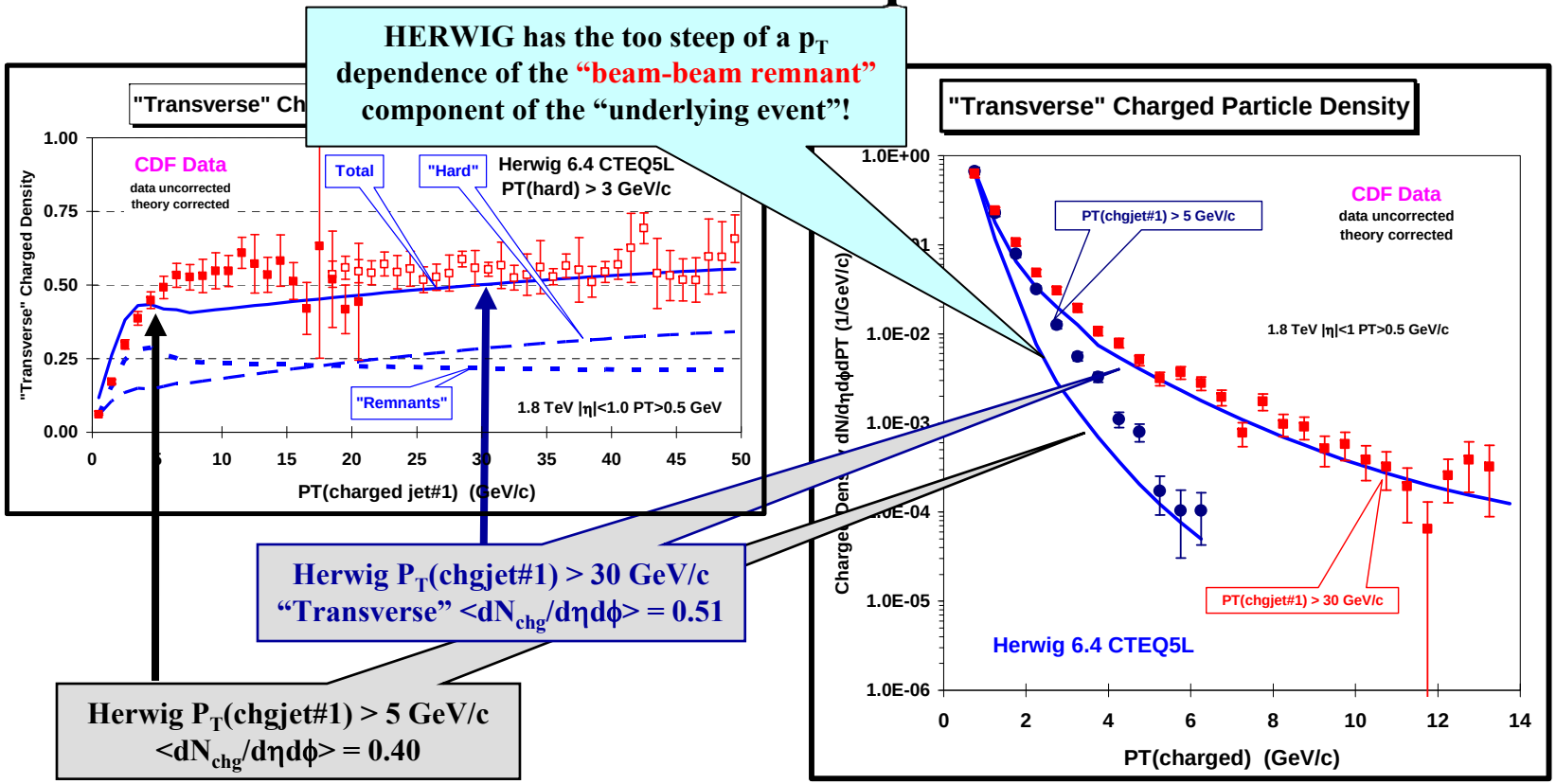
- **Plot shows average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of ISAJET 7.32 (default parameters with P_T(hard)>3 GeV/c) .**
- **The predictions of ISAJET are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).**

HERWIG 6.4
"Transverse" Density



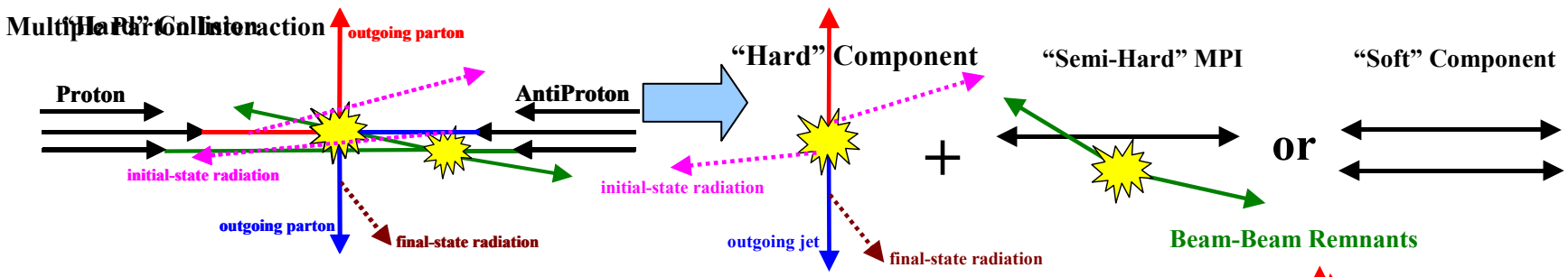
- Plot shows average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of HERWIG 5.9 (default parameters with P_T(hard)>3 GeV/c).
- The predictions of HERWIG are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).

HERWIG 6.4
"Transverse" P_T Distribution

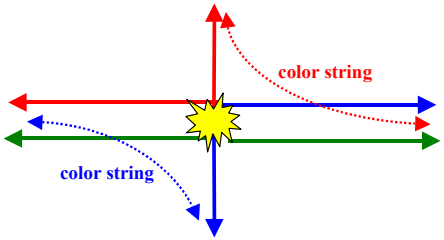


➡ **Compares the average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) versus P_T(charged jet#1) and the p_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of HERWIG 6.4 (default parameters with P_T(hard)>3 GeV/c. Shows how the "transverse" charge particle density is distributed in p_T.**

MPI: Multiple Parton Interactions



- PYTHIA models the "soft" component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (MPI) in which one interaction is hard and the other is "semi-hard".

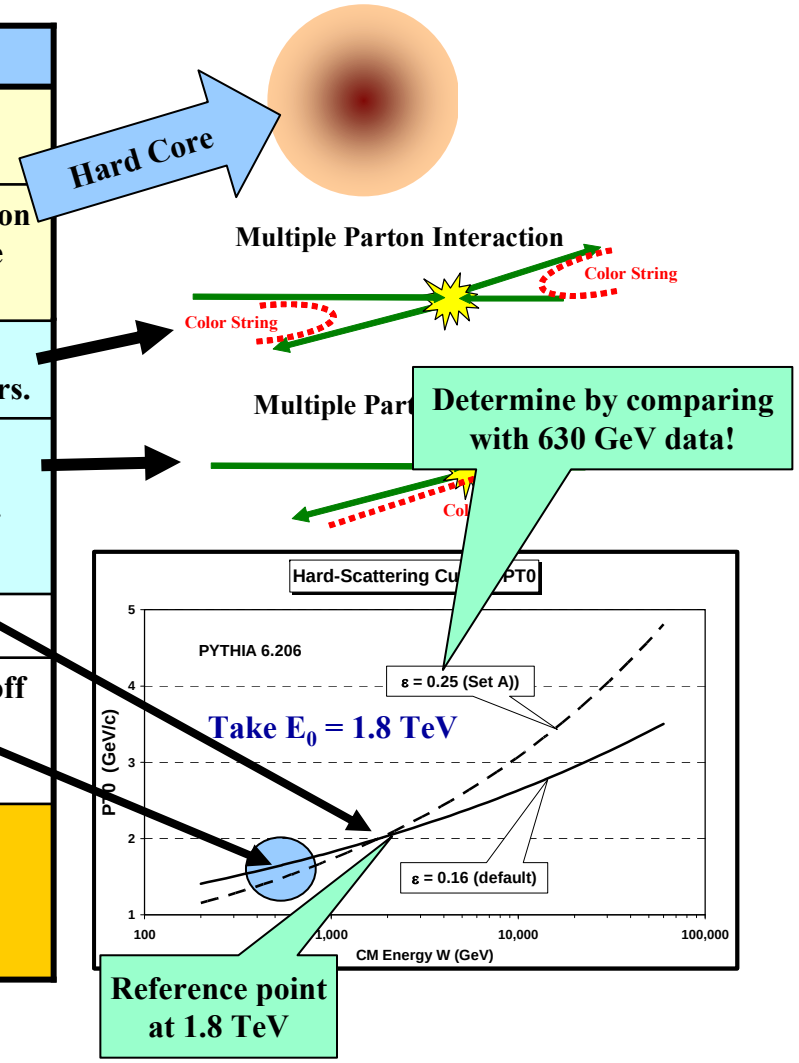


- The probability that a hard scattering events also contains a semi-hard multiple parton interaction can be varied but adjusting the cut-off for the MPI.
- One can also adjust whether the probability of a MPI depends on the P_T of the hard scattering, P_T(hard) (constant cross section or varying with impact parameter).
- One can adjust the color connections and flavor of the MPI (singlet or nearest neighbor, q-qbar or glue-glue).
- Also, one can adjust how the probability of a MPI depends on P_T(hard) (single or double Gaussian matter distribution).

Tuning PYTHIA:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the "nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed g fraction consists of
PARP(89)	1 TeV	D mes the reference energy E_0.
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

Affects the amount of initial-state radiation!

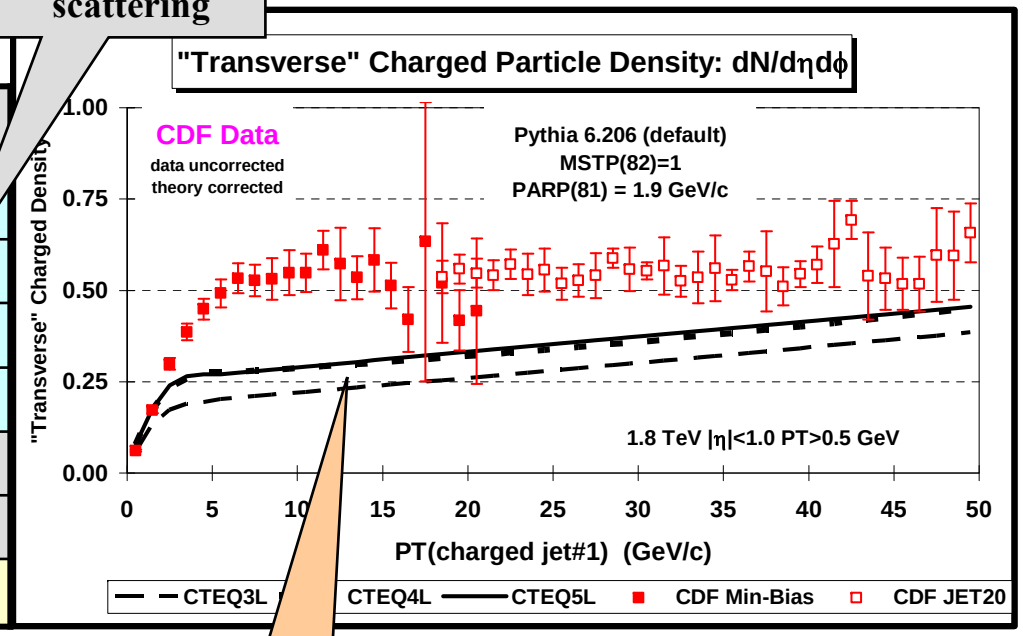


PYTHIA 6.206 Defaults

PYTHIA default parameters

Parameter	6.115	6.125	6.158	6.206
MSTP(81)	1	1	1	1
MSTP(82)	1	1	1	1
PARP(81)	1.4	1.9	1.9	1.9
PARP(82)	1.55	2.1	2.1	1.9
PARP(89)		1,000	1,000	1,000
PARP(90)		0.16	0.16	0.16
PARP(67)	4.0	4.0	1.0	1.0

MPI constant probability scattering



➡ **Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of PYTHIA 6.206 (P_T(hard) > 0) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.**

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

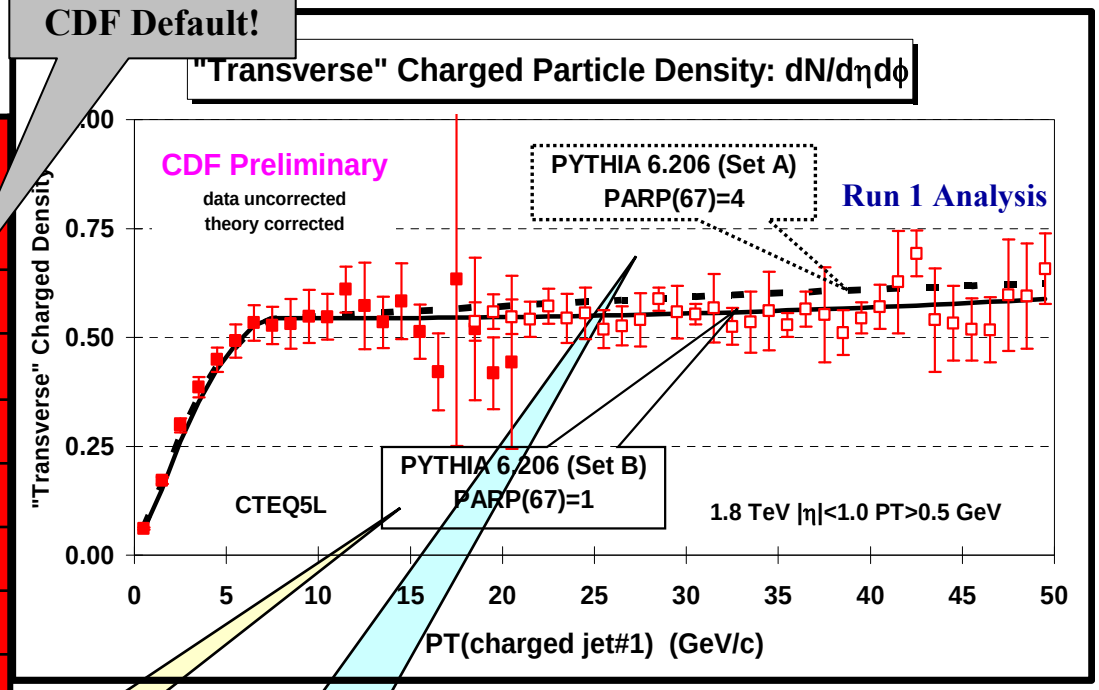
Default parameters give very poor description of the "underlying event"!

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

Parameter	Tune B	Tune A
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

CDF Default!

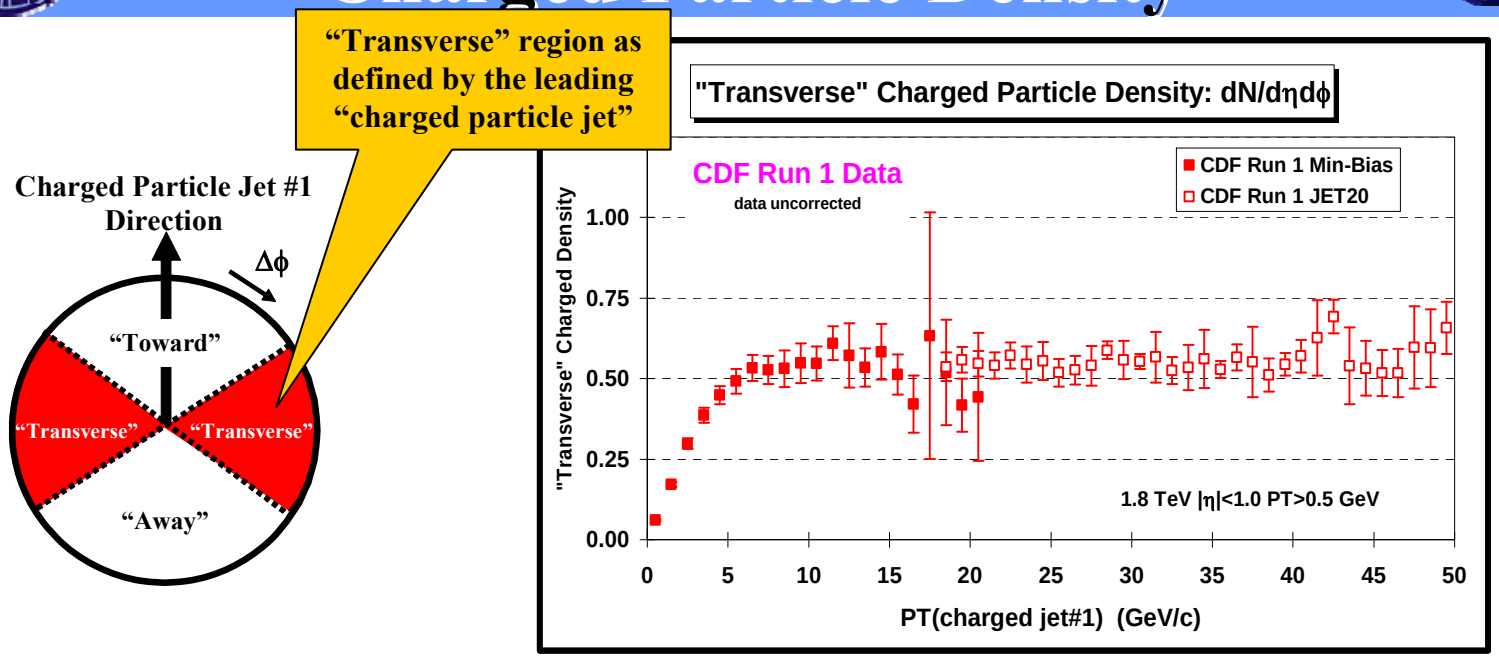


➡ **Plot shows the "transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).**

New PYTHIA default (less initial-state radiation)

Old PYTHIA default (more initial-state radiation)

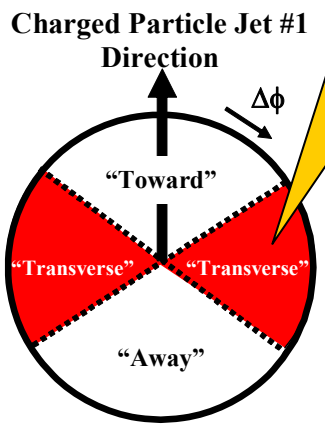
Run 1 vs Run 2: "Transverse" Charged Particle Density

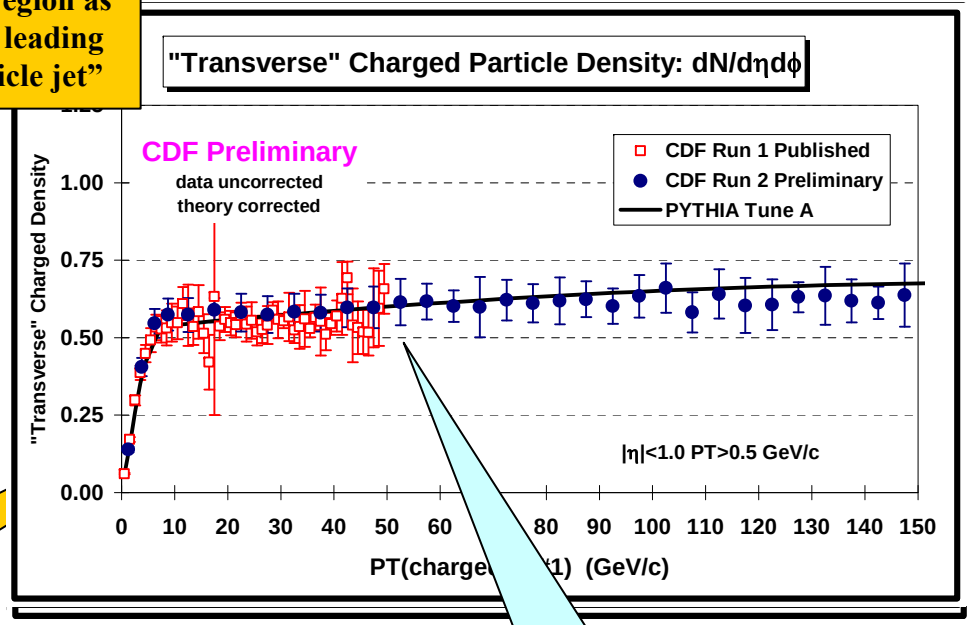


- Shows the data on the average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) as a function of the transverse momentum of the leading charged particle jet from Run 1.
- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (*uncorrected*) Run 2 data include both statistical and correlated systematic uncertainties.
- Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

Run 1 vs Run 2: "Transverse" Charged Particle Density

"Transverse" region as defined by the leading "charged particle jet"





Excellent agreement between Run 1 and 2!

- Shows the ransverse" charge particle dens |η|<1, p_T>0.5 GeV) as a function of the transverse momentum of the leading charged pa jet from Run 1.
- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET10 Run 1. The errors on the (*uncorrected*) Run 2 data include both statistical a systematic uncertainties.
- Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

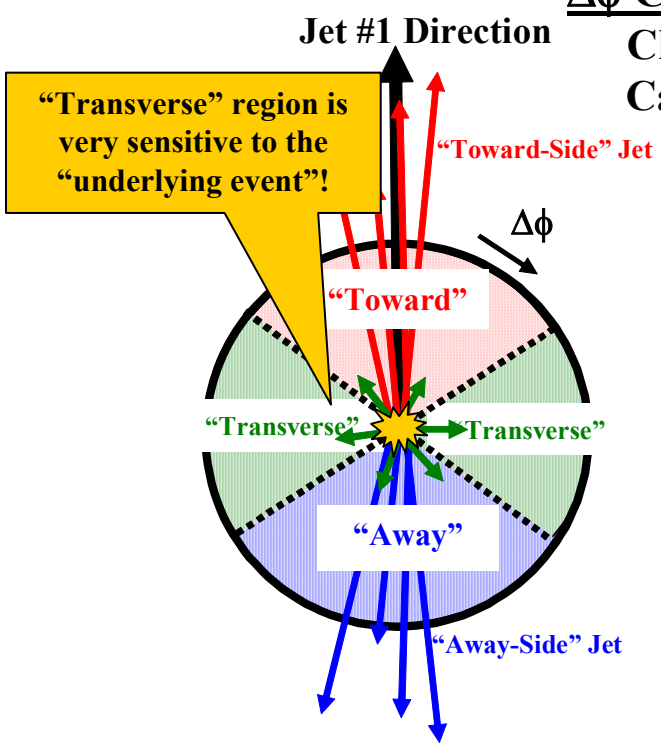
PYTHIA Tune A was tuned to fit the "underlying event" in Run I!

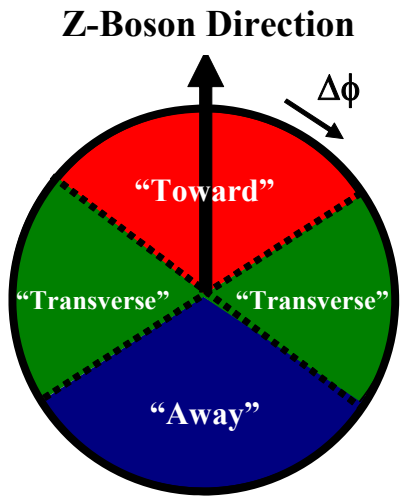
"Towards", "Away", "Transve

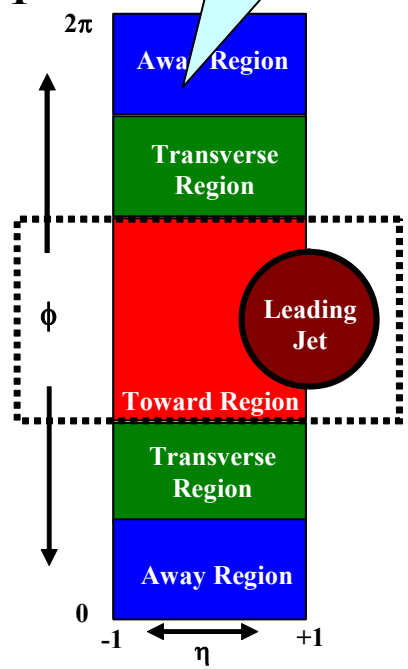
Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

Δϕ Correlations relative to the leading jet

Charged particles $p_T > 0.5$ GeV/c $|\eta| < 1$
Calorimeter towers $E_T > 0.1$ GeV $|\eta| < 1$



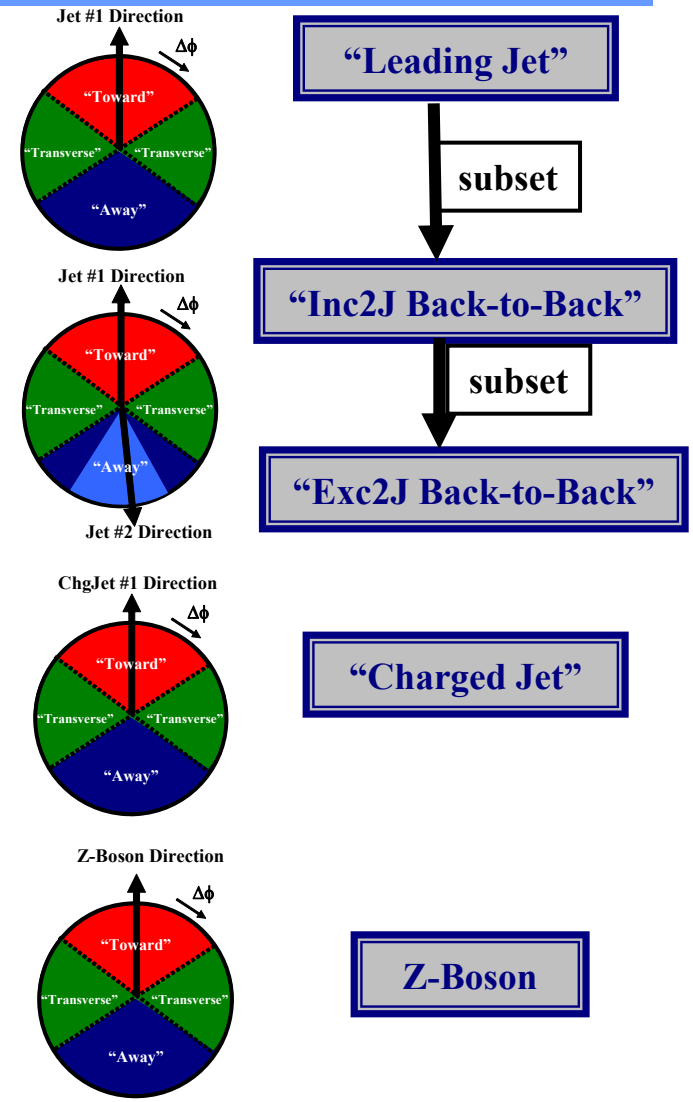




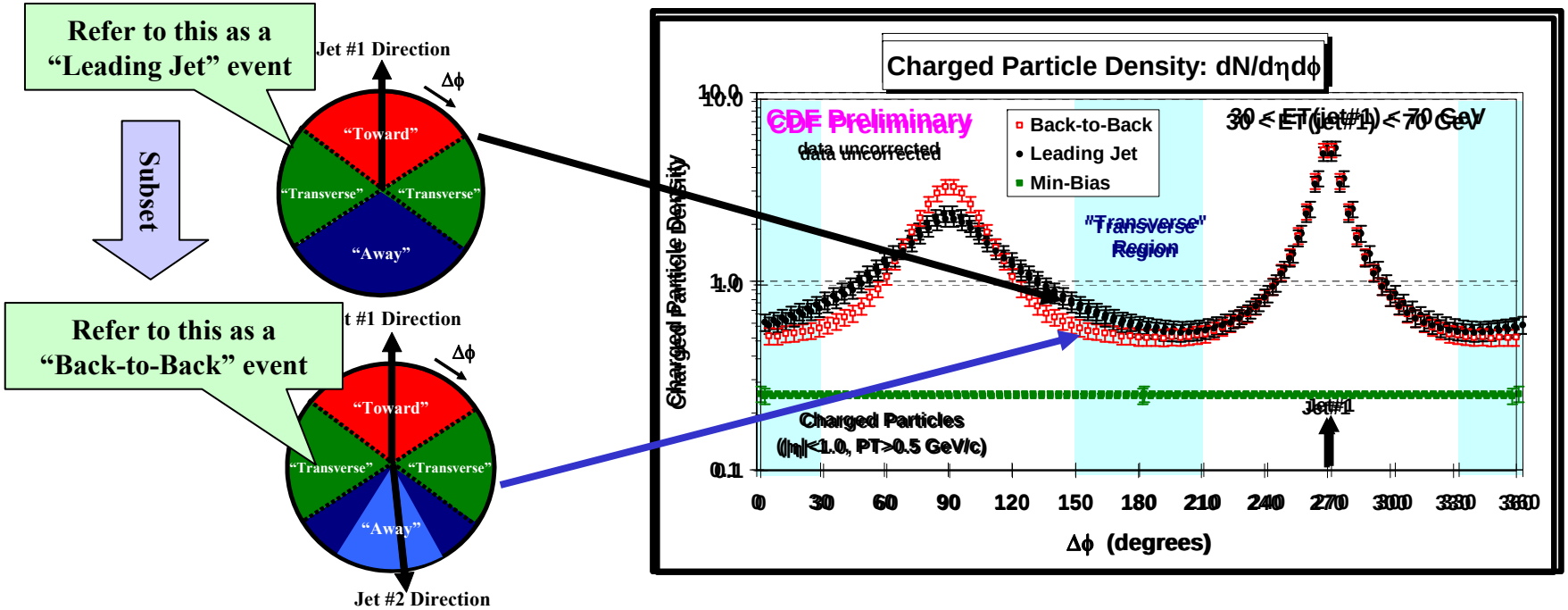
- Look at correlations in the azimuthal angle Δϕ relative to the leading charged particle jet ($|\eta| < 1$) or the leading calorimeter jet ($|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse ", and $|\Delta\phi| > 120^o$ as "Away". Each of the three regions have area $\Delta\eta\Delta\phi = 2\times120^o = 4\pi/3$.

Event Topologies

- **"Leading Jet"** events correspond to the leading calorimeter jet (MidPoint R = 0.7) in the region $|\eta| < 2$ with no other conditions.
- **"Inclusive 2-Jet Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (P_T(jet#2)/P_T(jet#1) > 0.8) with no other conditions .
- **"Exclusive 2-Jet Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (P_T(jet#2)/P_T(jet#1) > 0.8) and P_T(jet#3) < 15 GeV/c.
- **"Leading ChgJet"** events correspond to the leading charged particle jet (R = 0.7) in the region $|\eta| < 1$ with no other conditions.
- **"Z-Boson"** events are Drell-Yan events with 70 < M(lepton-pair) < 110 GeV with no other conditions.

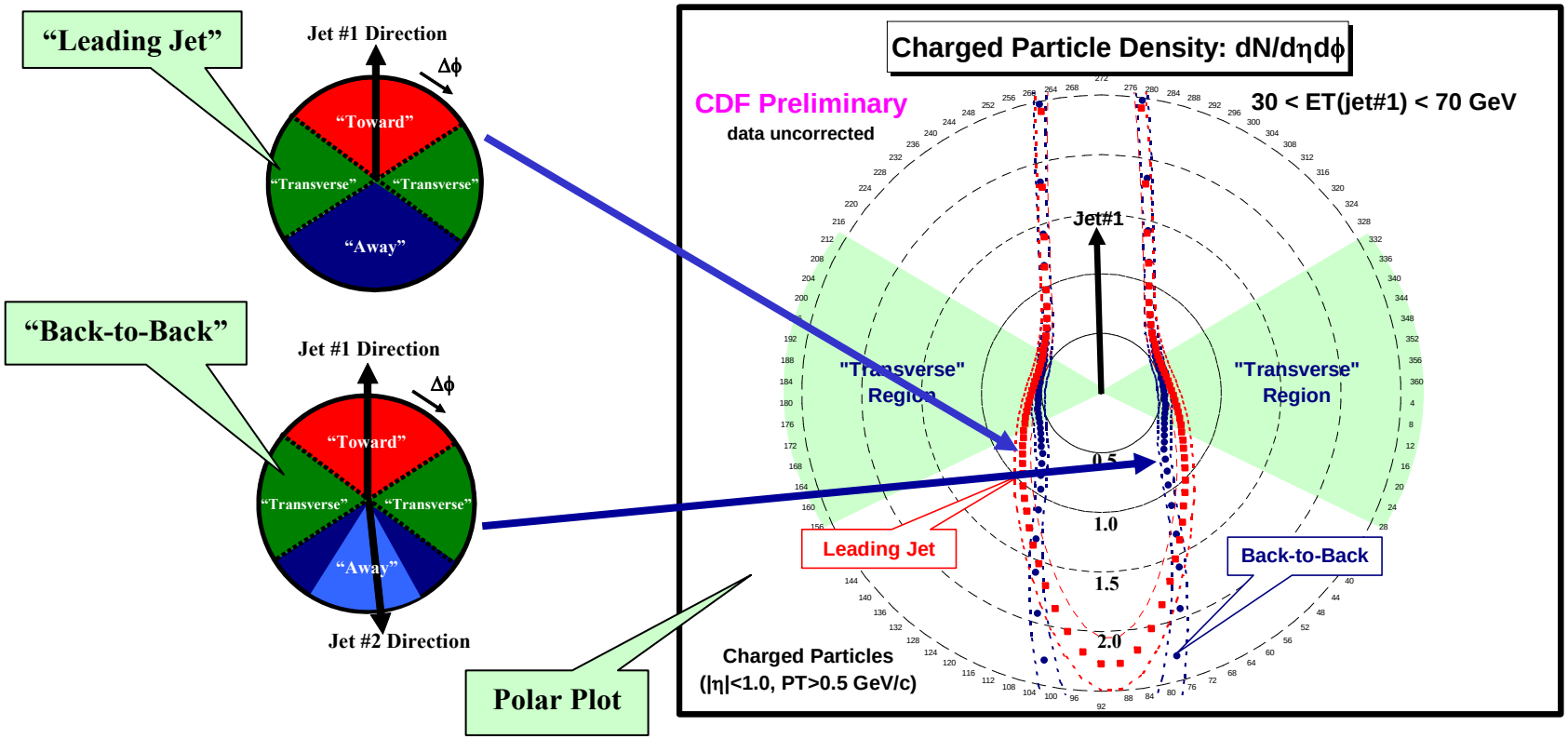


Charged Particle Density Δϕ Dependence



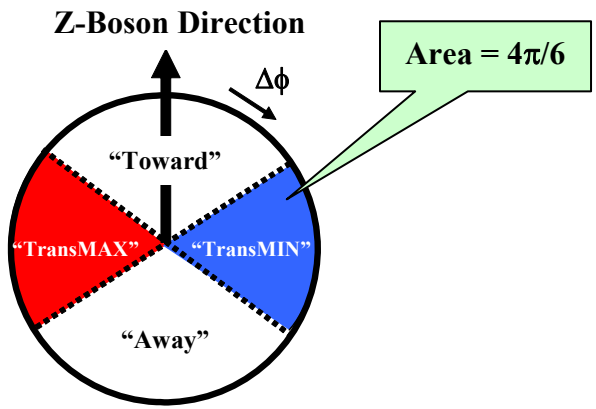
- Look at the "transverse" region as defined by the leading jet (JetClu R = 0.7, $|\eta| < 2$) or by the leading two jets (JetClu R = 0.7, $|\eta| < 2$). "Back-to-Back" events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (E_T(jet#2)/E_T(jet#1) > 0.8) and with E_T(jet#3) < 15 GeV.
- Shows the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for 30 < E_T(jet#1) < 70 GeV for "Leading Jet" and "Back-to-Back" events.

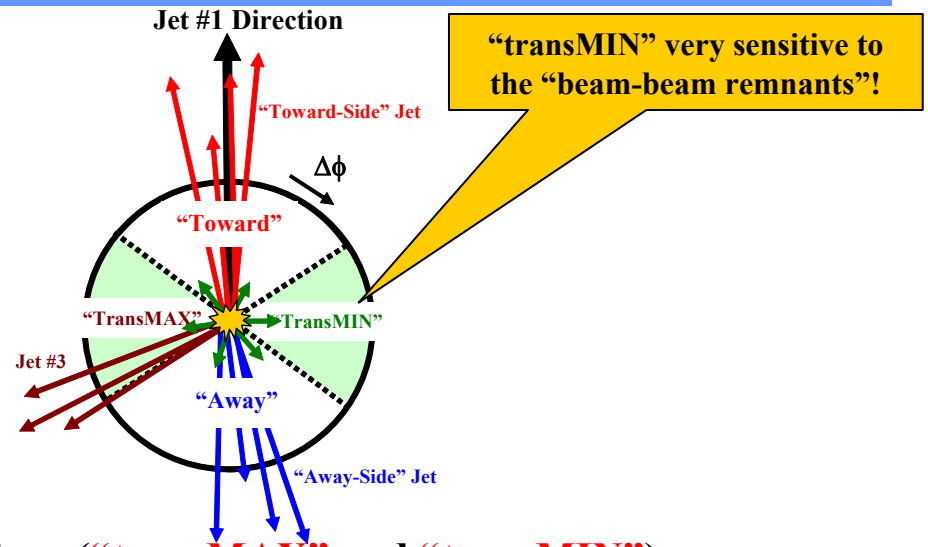
Charged Particle Density Δϕ Dependence



➡ **Shows the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for 30 < E_T(jet#1) < 70 GeV for "Leading Jet" and "Back-to-Back" events.**

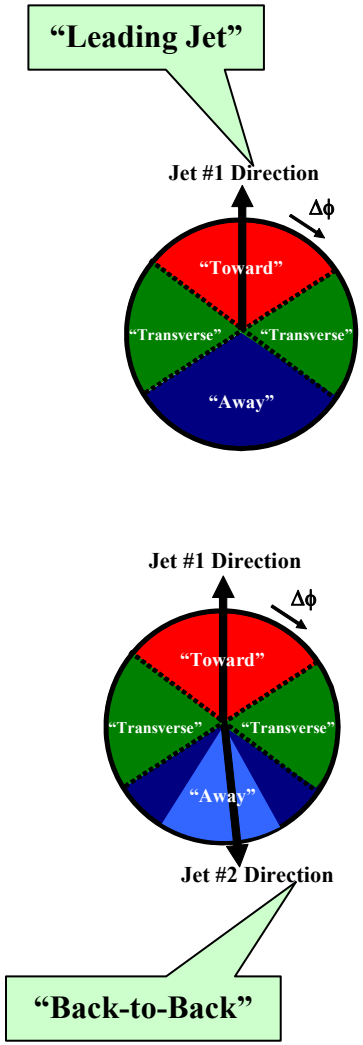
"transMAX" & "transMIN"





- **Define the MAX and MIN "transverse" regions ("transMAX" and "transMIN") on an event-by-event basis with MAX (MIN) having the largest (smallest) density. Each of the two "transverse" regions have an area in η-ϕ space of 4π/6.**
- **The "transMIN" region is very sensitive to the "beam-beam remnant" and the soft multiple parton interaction components of the "underlying event".**
- **The difference, "transDIF" ("transMAX" minus "transMIN"), is very sensitive to the "hard scattering" component of the "underlying event" (*i.e.* hard initial and final-state radiation).**
- **The overall "transverse" density is the average of the "transMAX" and "transMIN" densities.**

Observables at the Particle and Detector Level



Observable	Particle Level	Detector Level
dNchg/dηdφ	Number of charged particles per unit η-φ (p_T > 0.5 GeV/c, |η| < 1)	Number of "good" charged tracks per unit η-φ (p_T > 0.5 GeV/c, |η| < 1)
dPTsum/dηdφ	Scalar p_T sum of charged particles per unit η-φ (p_T > 0.5 GeV/c, |η| < 1)	Scalar p_T sum of "good" charged tracks per unit η-φ (p_T > 0.5 GeV/c, |η| < 1)
$\langle p_T \rangle$	Average p_T of charged particles (p_T > 0.5 GeV/c, |η| < 1)	Average p_T of "good" charged tracks (p_T > 0.5 GeV/c, |η| < 1)
PTmax	Maximum p_T charged particle (p_T > 0.5 GeV/c, |η| < 1) Require Nchg ≥ 1	Maximum p_T "good" charged tracks (p_T > 0.5 GeV/c, |η| < 1) Require Nchg ≥ 1
dETsum/dηdφ	Scalar E_T sum of all particles per unit η-φ (all p_T, |η| < 1)	Scalar E_T sum of all calorimeter towers per unit η-φ (E_T > 0.1 GeV, |η| < 1)
PTsum/ETsum	Scalar p_T sum of charged particles (p_T > 0.5 GeV/c, |η| < 1) divided by the scalar E_T sum of all particles (all p_T, |η| < 1)	Scalar p_T sum of "good" charged tracks (p_T > 0.5 GeV/c, |η| < 1) divided by the scalar E_T sum of calorimeter towers (E_T > 0.1 GeV, |η| < 1)

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

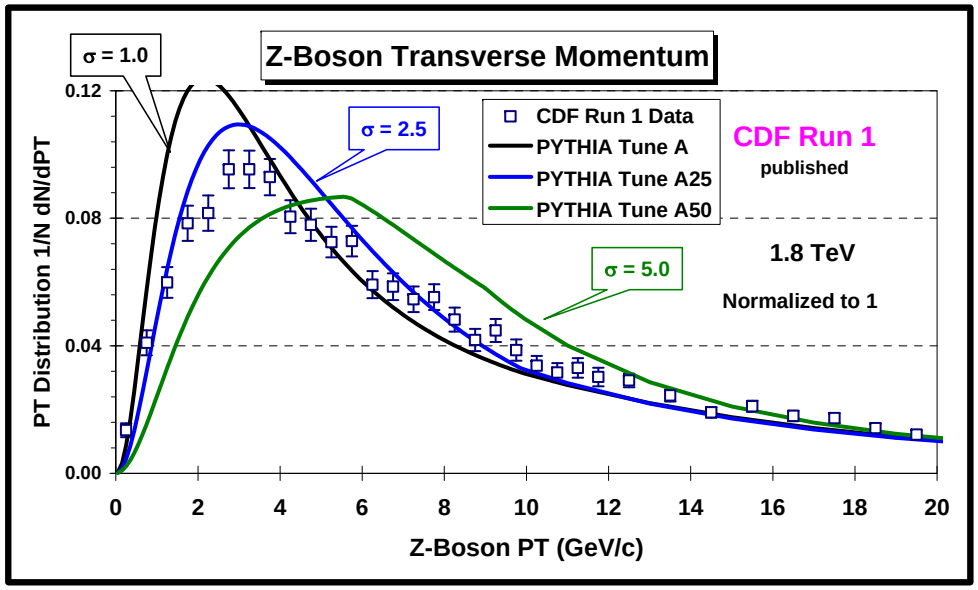
UE Parameters

ISR Parameter

Intrinsic KT

Pa			ne A50
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	0.9	0.9
PARP(86)	0.95	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(67)	4.0	4.0	4.0
MSTP(91)	1	1	1
PARP(91)	1.0	2.5	5.0
PARP(93)	5.0	15.0	25.0

Vary the intrensic KT!



- Shows the Run 1 Z-boson p_T distribution ($\langle p_T(Z)\rangle \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($\langle p_T(Z)\rangle = 9.7$ GeV/c), Tune A25 ($\langle p_T(Z)\rangle = 10.1$ GeV/c), and Tune A50 ($\langle p_T(Z)\rangle = 11.2$ GeV/c).

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

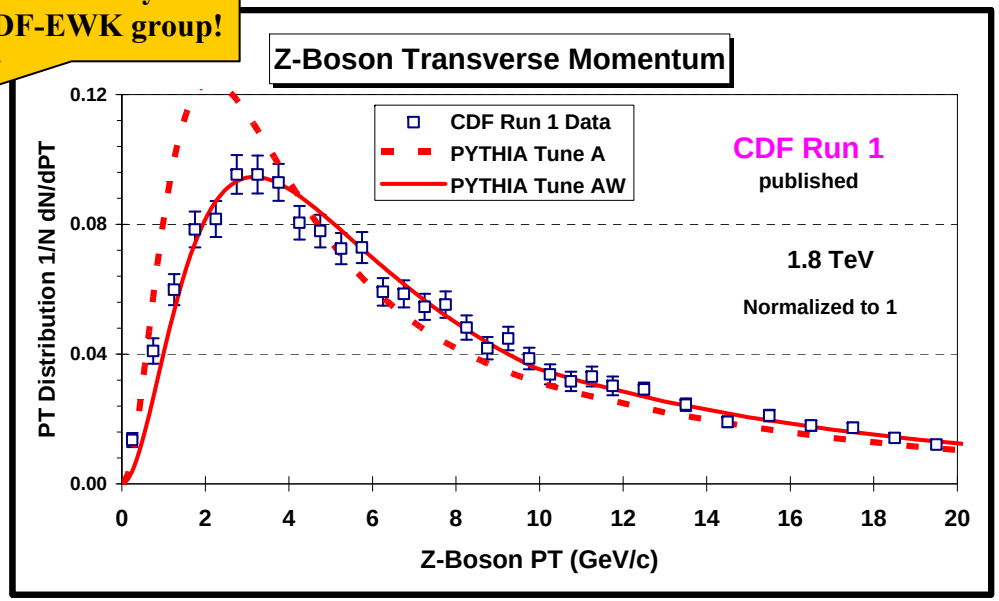
Tune used by the CDF-EWK group!

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0

UE Parameters

ISR Parameters

Intrensic KT



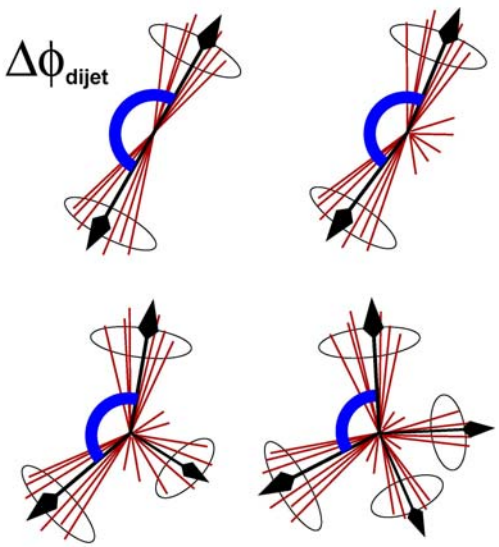
➡ **Shows the Run 1 Z-boson p_T distribution ($\langle p_T(Z)\rangle \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($\langle p_T(Z)\rangle = 9.7$ GeV/c), and PYTHIA Tune AW ($\langle p_T(Z)\rangle = 11.7$ GeV/c).**

Effective Q cut-off, below which space-like showers are not evolved.

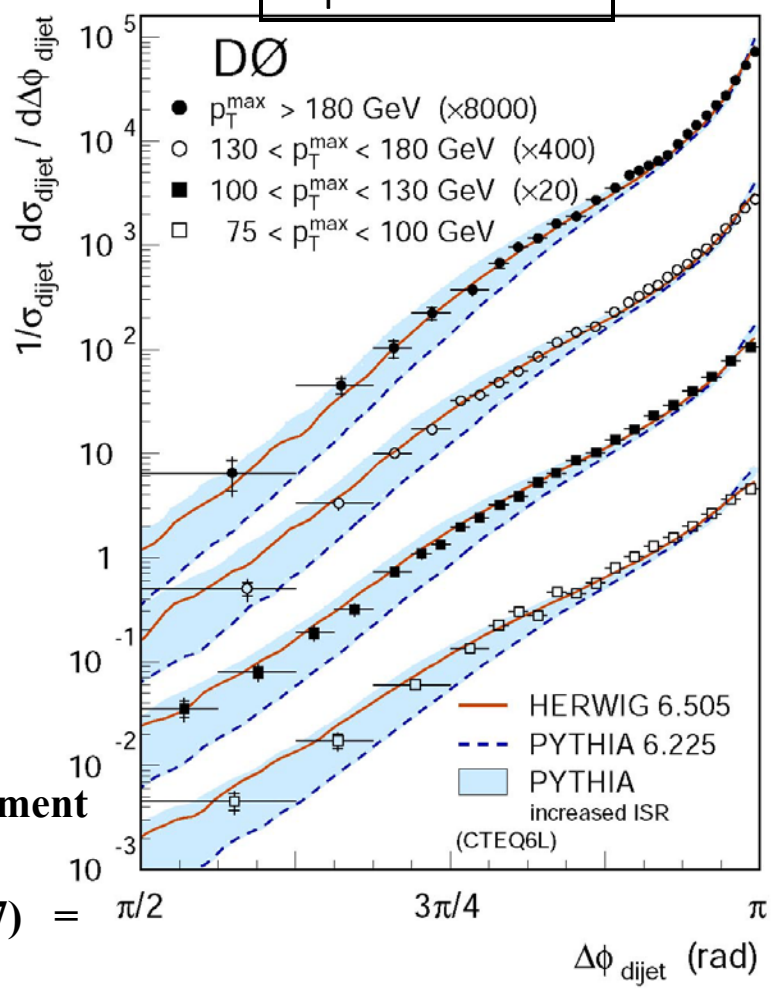
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

Jet-Jet Correlations (DØ)

Jet#1-Jet#2 Δϕ Distribution



Δϕ Jet#1-Jet#2



- **MidPoint Cone Algorithm (R = 0.7, f_{merge} = 0.5)**
- **$\mathcal{L}$ = 150 pb^{-1} (Phys. Rev. Lett. 94 221801 (2005))**
- **Data/NLO agreement good. Data/HERWIG agreement good.**
- **Data/PYTHIA agreement good provided PARP(67) = 1.0→4.0 (i.e. like Tune A, best fit 2.5).**

CDF Run 1 $P_T(Z)$

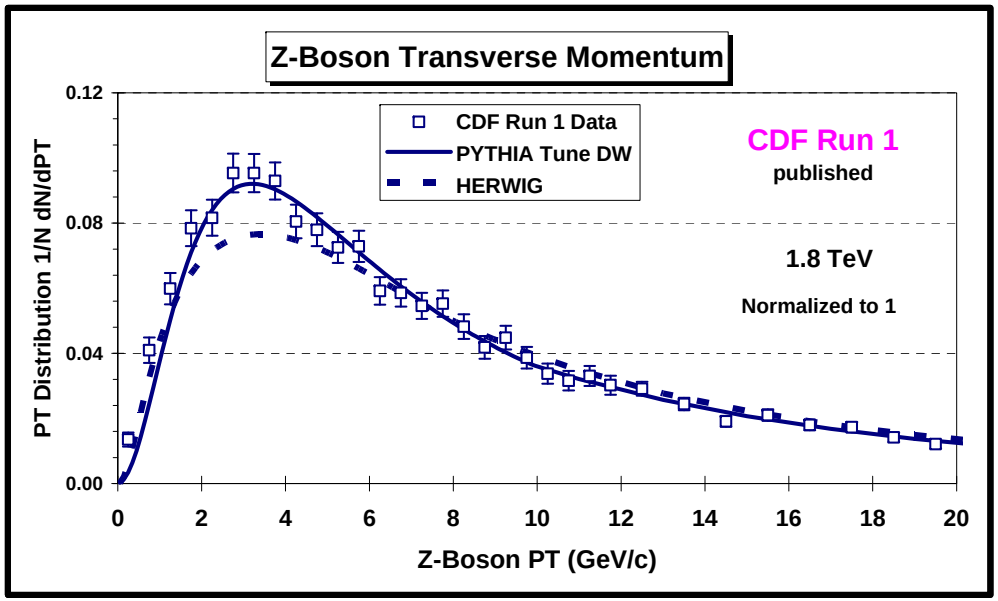
PYTHIA 6.2 CTEQ5L

Parameter	Tune DW	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.25	1.25
PARP(64)	0.2	0.2
PARP(67)	2.5	4.0
MSTP(91)	1	1
PARP(91)	2.1	2.1
PARP(93)	15.0	5.0

UE Parameters

ISR Parameters

Intrensic KT



➡ **Shows the Run 1 Z-boson p_T distribution ($\langle p_T(Z)\rangle \approx 11.5$ GeV/c) compared with PYTHIA Tune DW, and HERWIG.**

Tune DW uses D0's perfered value of PARP(67)!

Tune DW has a lower value of PARP(67) and slightly more MPI!

MIT Search Scheme: Vista/Sleuth

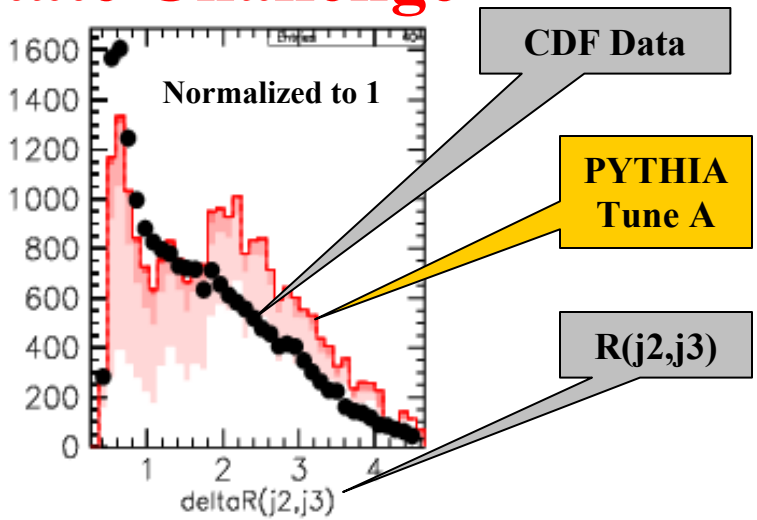
Exclusive 3 Jet Final State Challenge

Bruce Knuteson

At least 1 Jet ("trigger" jet)
(P_T > 40 GeV/c, |η| < 1.0)

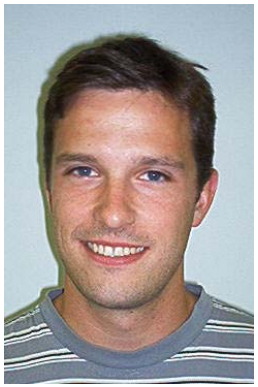
Exactly 3 jets
(P_T > 20 GeV/c, |η| < 2.5)

Order Jets by P_T
Jet1 highest P_T, etc.



Khaldoun Makhoul

Georgios Choudalakis



Markus Klute

Conor Henderson

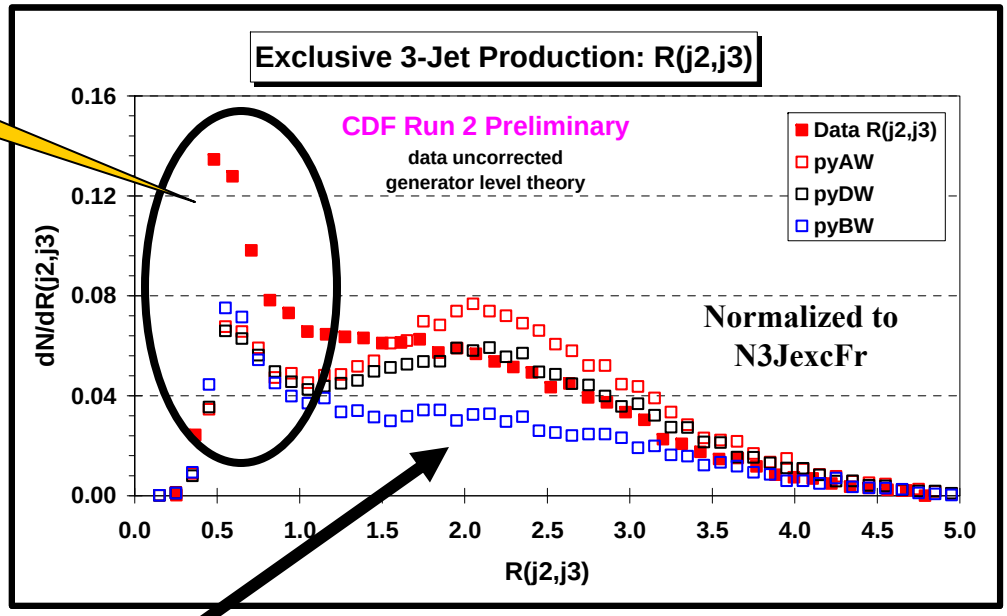
Ray Culbertson

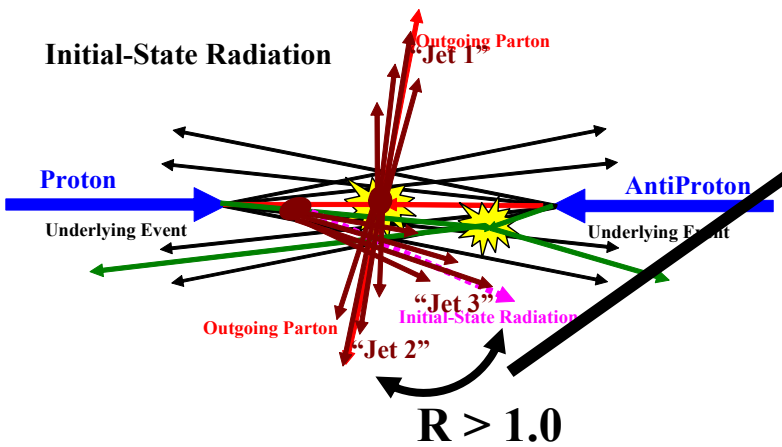
Gene Flanagan

3 Jexc R(j2,j3) Normalized

The data have more 3 jet events with small R(j2,j3)!?

- Let Ntrig40 equal the number of events with at least one jet with $P_T > 40$ GeV and $|\eta| < 1.0$ (this is the "offline" trigger).
- Let N3Jexc20 equal the number of events with exactly three jets with $P_T > 20$ GeV/c and $|\eta| < 2.5$ which also have at least one jet with $P_T > 40$ GeV/c and $|\eta| < 1.0$.
- Let N3JexcFr = N3Jexc20/Ntrig40. The is the fraction of the "offline" trigger events that are exclusive 3-jet events.

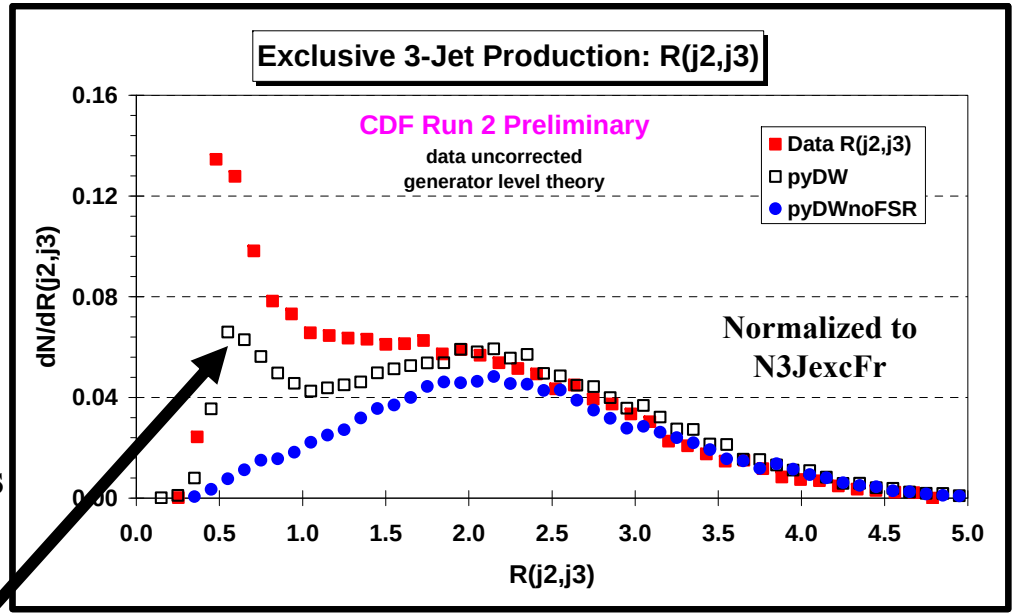


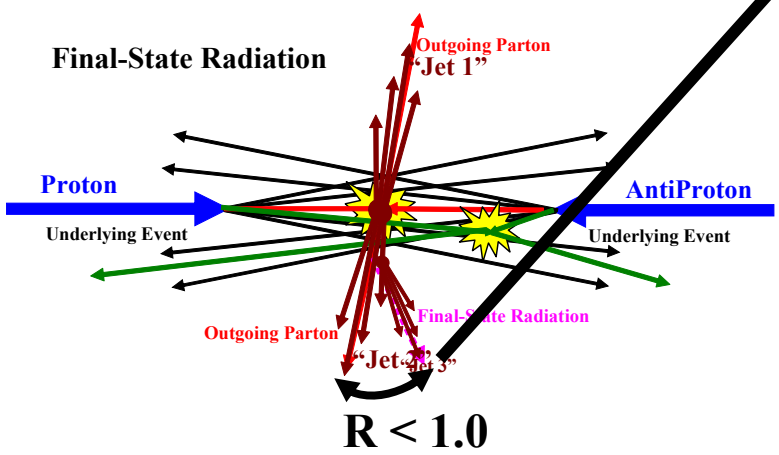


- The CDF data on dN/dR(j2,j3) at 1.96 TeV compared with PYTHIA Tune AW (PARP(67)=4), Tune DW (PARP(67)=2.5), Tune BW (PARP(67)=1).
- PARP(67) affects the initial-state radiation which contributes primarily to the region R(j2,j3) > 1.0.

3Jexc R(j2,j3) Normalized

- Let Ntrig40 equal the number of events with at least one jet with $P_T > 40$ geV and $|\eta| < 1.0$ (this is the "offline" trigger).
- Let N3Jexc20 equal the number of events with exactly three jets with $P_T > 20$ GeV/c and $|\eta| < 2.5$ which also have at least one jet with $P_T > 40$ GeV/c and $|\eta| < 1.0$.
- Let N3JexcFr = N3Jexc20/Ntrig40. The is the fraction of the "offline" trigger events that are exclusive 3-jet events.

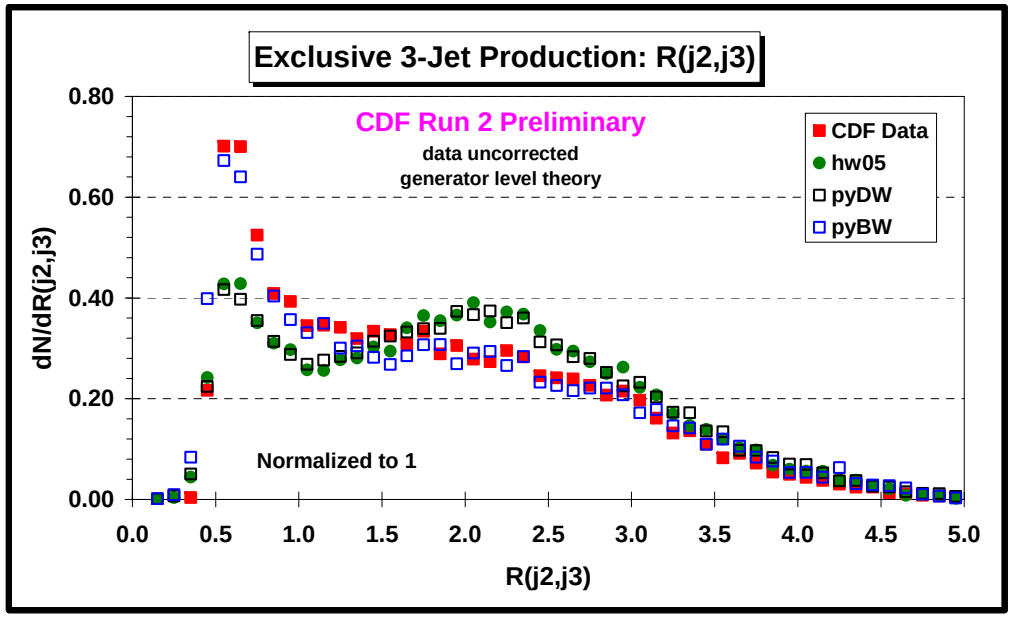


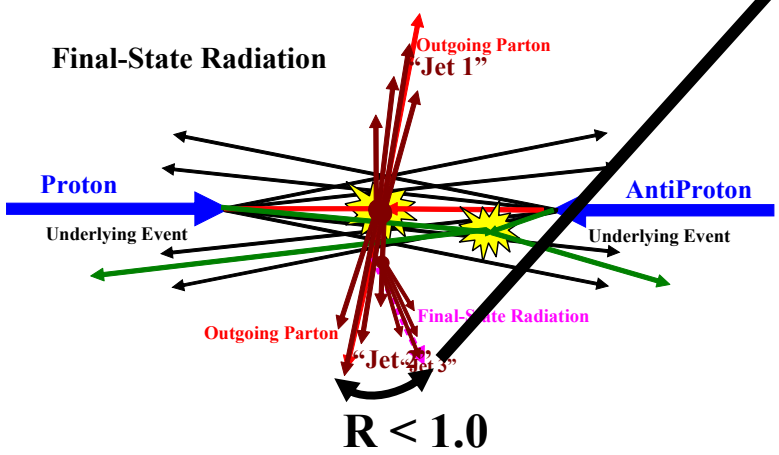


- The CDF data on dN/dR(j2,j3) at 1.96 TeV compared with PYTHIA Tune DW (PARP(67)=2.5) and HERWIG (*without MPI*).
- Final-State radiation contributes to the region R(j2,j3) < 1.0.
- If you ignore the normalization and normalize all the distributions to one then the data prefer Tune BW, but I believe this is misleading.

3Jexc R(j2,j3) Normalized

- Let Ntrig40 equal the number of events with at least one jet with $P_T > 40$ geV and $|\eta| < 1.0$ (this is the "offline" trigger).
- Let N3Jexc20 equal the number of events with exactly three jets with $P_T > 20$ GeV/c and $|\eta| < 2.5$ which also have at least one jet with $P_T > 40$ GeV/c and $|\eta| < 1.0$.
- Let N3JexcFr = N3Jexc20/Ntrig40. The is the fraction of the "offline" trigger events that are exclusive 3-jet events.

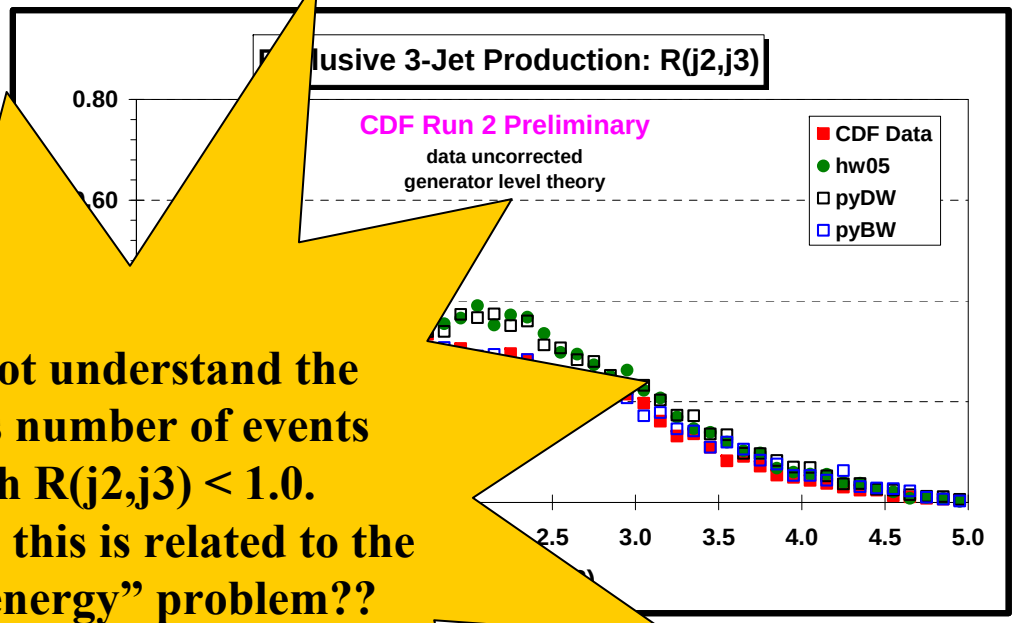




- The CDF data on dN/dR(j2,j3) at 1.96 TeV compared with PYTHIA Tune DW (PARP(67)=2.5) and HERWIG (*without MPI*).
- Final-State radiation contributes to the region R(j2,j3) < 1.0.
- If you ignore the normalization and normalize all the distributions to one then the data prefer Tune BW, but I believe this is misleading.

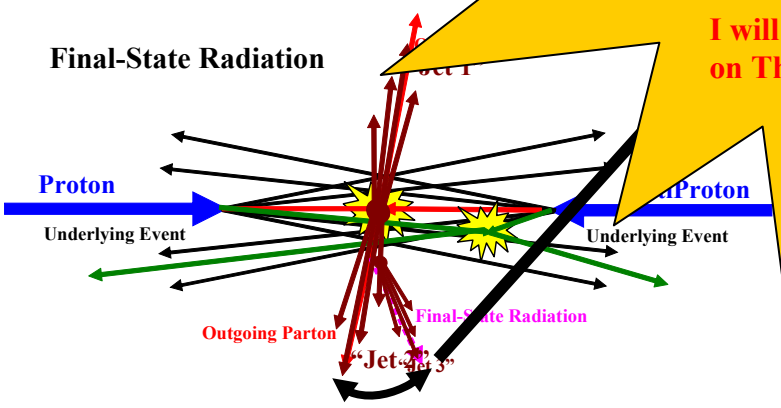
3Jexc R(j2,j3) Normalized

- Let Ntrig40 equal the number of events with at least one jet w[illegible]th $P_T > 40$ GeV and $|\eta| < 1.0$ (this is the "off[illegible]" trigger).
- Let N3Jexc20 equal the nu[illegible] of event[illegible] with exactly three jets with P[illegible] and $|\eta| < 2.5$ which also have at[illegible] jet with $P_T > 40$ GeV/[illegible]
- Let N3JexcFr = N3Jexc[illegible] the fraction of the "offline" [illegible] that are exclusive 3-jet even[illegible]



I do not understand the excess number of events with R(j2,j3) < 1.0. Perhaps this is related to the "soft energy" problem??

I will show you a lot more on Thursday!



R < 1.0

[illegible]R(j2,j3) at 1.96 TeV compared [illegible]V (PARP(67)=2.5) and [illegible]R [illegible]*thou*[illegible]).

[illegible]nal-St[illegible]adiation c[illegible]tributes to the region [illegible](j2,j3) < [illegible]).

- If you ignore the normalization and normalize all the distributions to one then the data prefer Tune BW, but I believe this is misleading.

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

Parameter	Tune AW	Tune DW	Tune D6
PDF	CTEQ5L	CTEQ5L	CTEQ6L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0

Uses CTEQ6L

Tune A energy dependence!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

ATLAS energy dependence!

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	1.9409 GeV	1.8387 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.5
PARP(85)	1.0	1.0	0.33
PARP(86)	1.0	1.0	0.66
PARP(89)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.2	0.2	1.0
PARP(67)	2.5	2.5	1.0
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	1.0
PARP(93)	15.0	15.0	5.0

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(81)	1.9409 GeV	1.8387 GeV	1.8 GeV
[illegible]	0.5	[illegible]	0.5
[illegible]	0.4	[illegible]	[illegible]
[illegible]	1.0	[illegible]	0.33
[illegible]	1.0	[illegible]	0.66
PARP(89)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.2	0.2	1.0
PARP(67)	[illegible]	2.5	1.0
MSTP(91)	[illegible]	1	[illegible]
PARP(91)	[illegible]	2.1	[illegible]
PARP(93)	[illegible]	15.0	[illegible]

Tune A

Tune AW

Tune B

Tune BW

Tune D

Tune DW

Tune D6

Tune D6T

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

Parameter	Tune	WT	Tune D6T	LAS
PDF	CT		CTEQ6	EQ5L
MSTP(81)			1	1
PARP(6				
PARP(				1.6
MSTP				
PAR			2.	
PARP			15.0	

UE Parameters

Tune A

Parameter

BW

Tune D

Tune

Tune D6

Tune D6T

These are "old" PYTHIA 6.2 tunes!
There are new 6.4 tunes by
Arthur Moraes (ATLAS)
Hendrik Hoeth (MCnet)
Peter Skands (Tune S0)

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

Q^2 ordered showers, old MPI!

Parameter	Tune H(6.418)	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	2.1 GeV	1.9409 GeV	1.8387 GeV	1.8
PARP(83)	0.84	0.5	0.5	0.
PARP(84)	0.5	0.4	0.4	0.
PARP(85)	0.82	1.0	1.0	0.33
PARP(86)	0.91	1.0	1.0	0.66
PARP(89)	1.0	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.17	0.16	0.16	0.16
PARP(62)	2.97	1.25	1.25	1.0
PARP(64)	0.12	0.2	0.2	1.0
PARP(67)	2.74	2.5	2.5	1.0
MSTP(91)	1	1	1	1
PARP(91)	2.0	2.1	2.1	1.0
PARP(93)	5.0	15.0	15.0	5.0

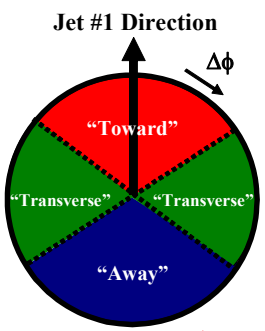
JIMMY at CDF

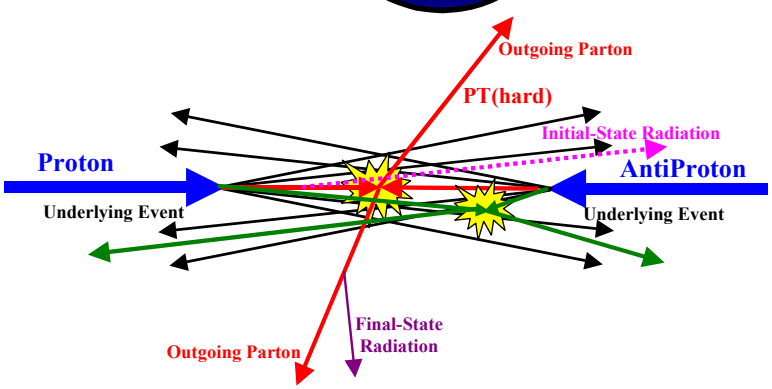
JIMMY
Runs with HERWIG and adds multiple parton interactions!

JIMMY was tuned to fit the energy density in the "transverse" region for "leading jet" events!

The Energy in the "Underlying Event" in High P_T Jet Production

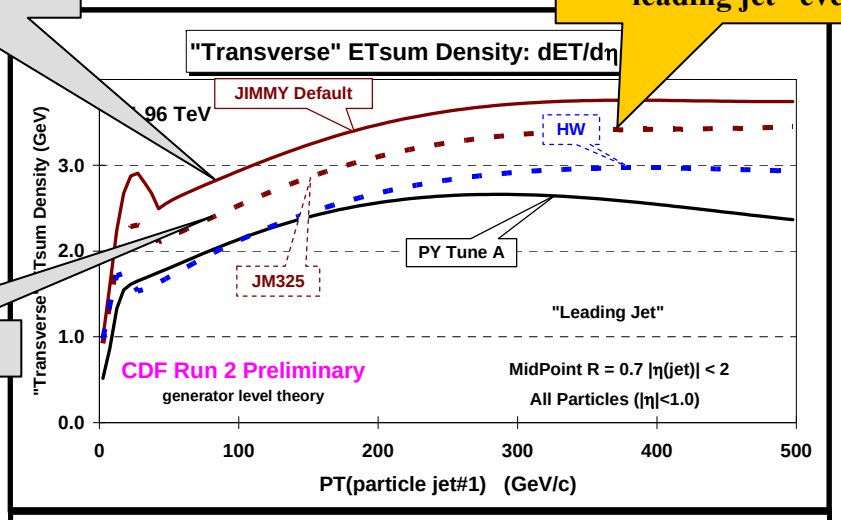
JIMMY: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

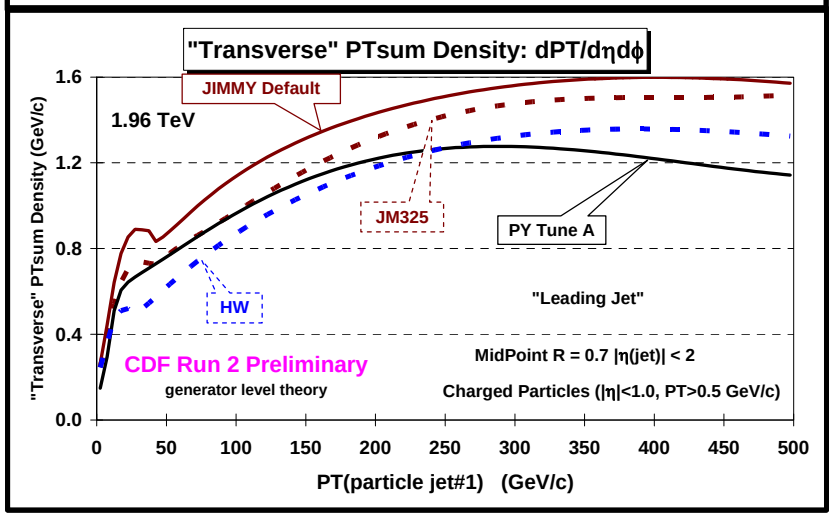




PT(JIM)= 2.5 GeV/c.

PT(JIM)= 3.25 GeV/c.





"Transverse" <Densities> vs P_T(jet#1)

JIMMY at CDF

JIMMY
Runs with HERWIG and adds multiple parton interactions!

PT(JIM)= 2.5 GeV/c.

JIMMY was tuned to fit the energy density in the "transverse" region for "leading jet" events!

The Energy in the "Underlying Event" in High P_T Jet Production

JIMMY: MPI
J. M. Butterworth
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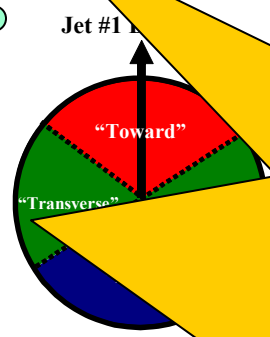
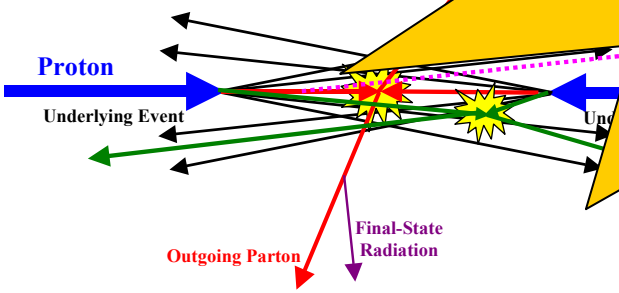
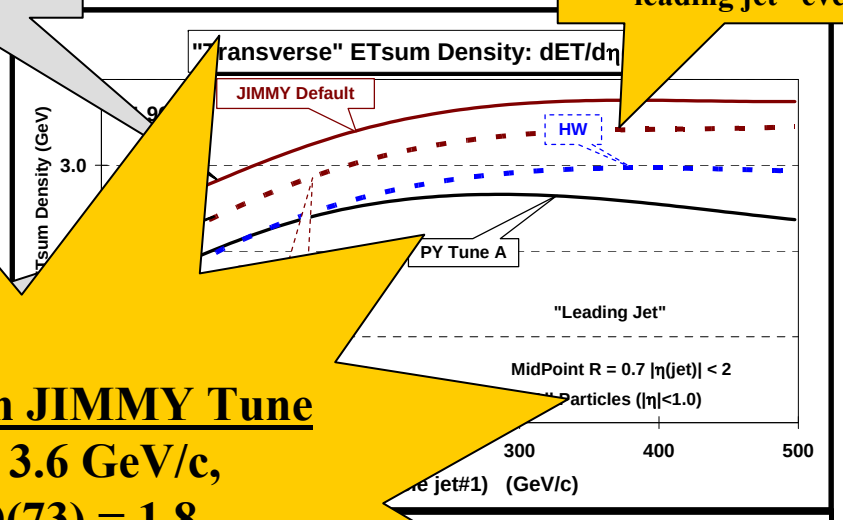
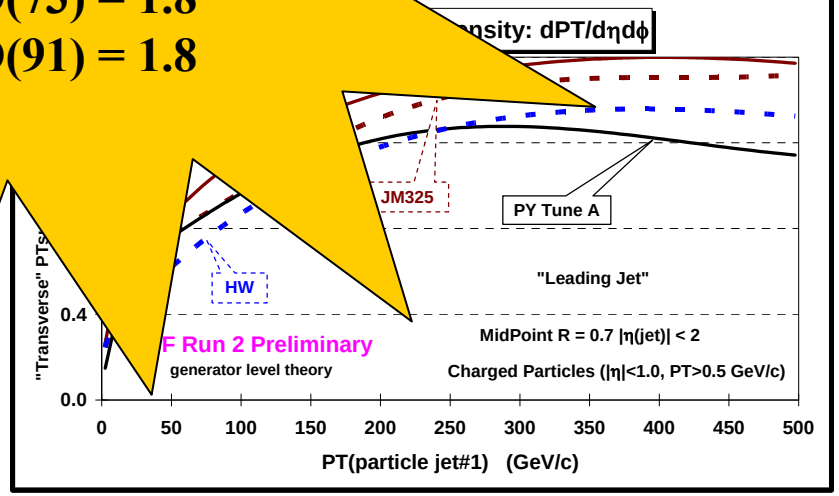




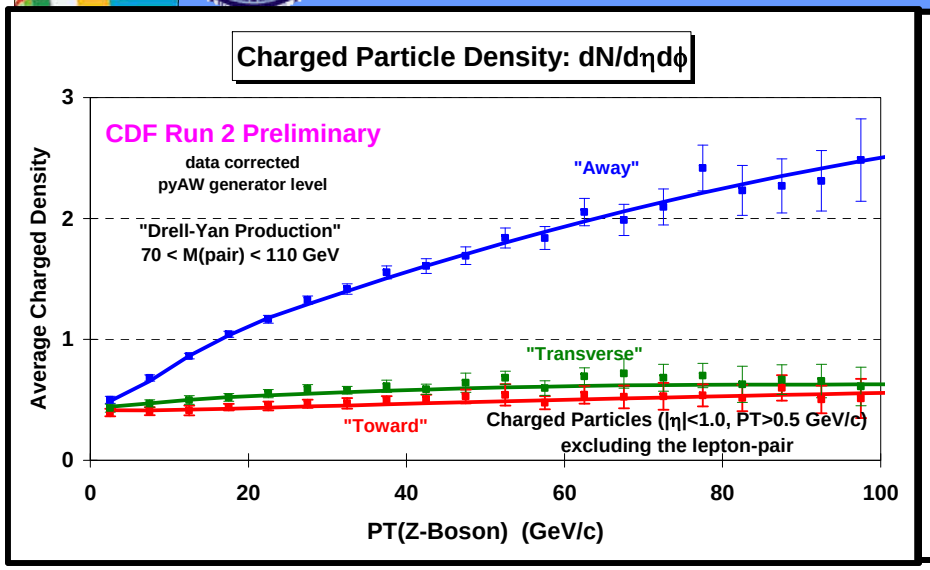
The Drell-Yan JIMMY Tune
PTJIM = 3.6 GeV/c,
JMRAD(73) = 1.8
JMRAD(91) = 1.8

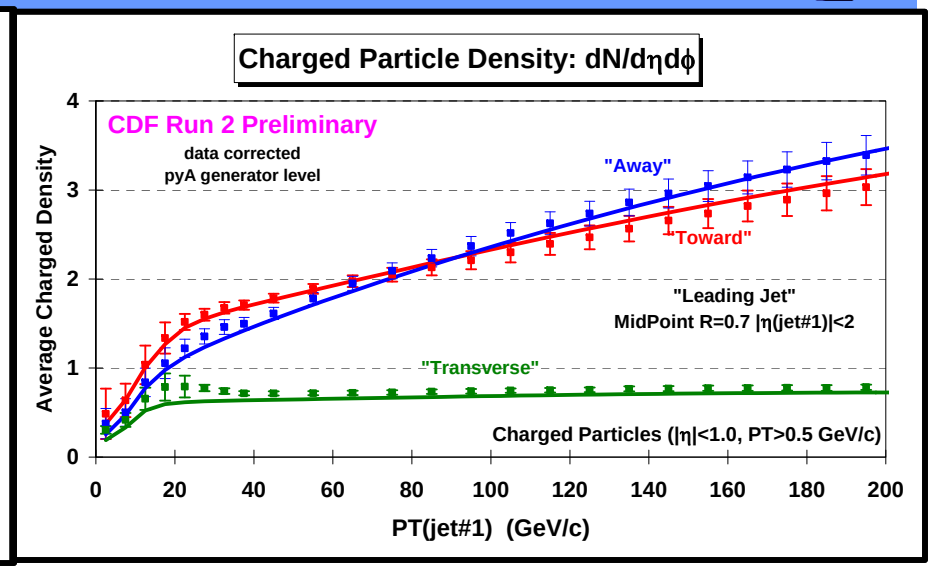


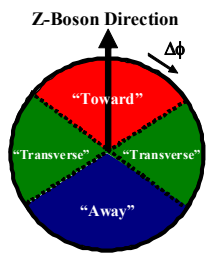


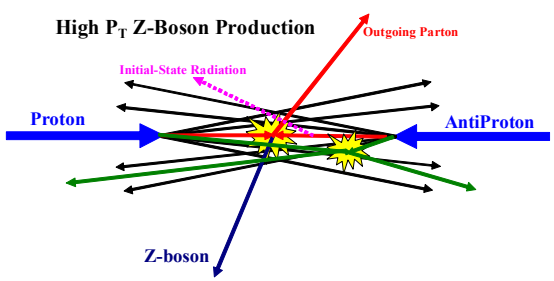
"Transverse" <Densities> vs P_T(jet#1)

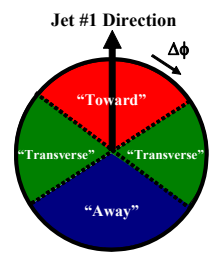
Charged Particle Density

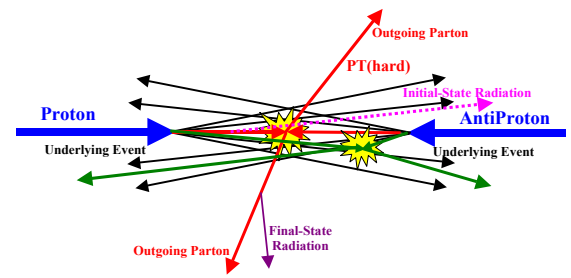






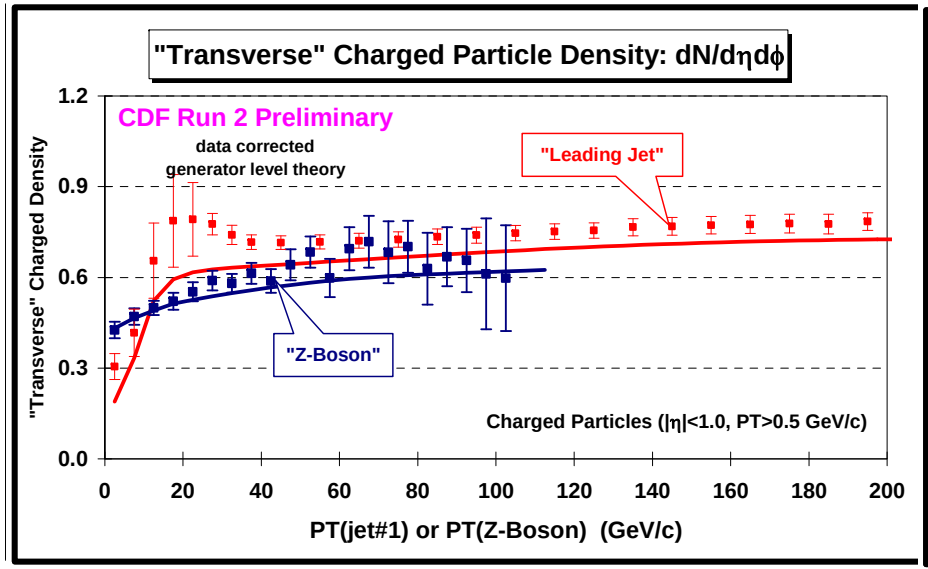


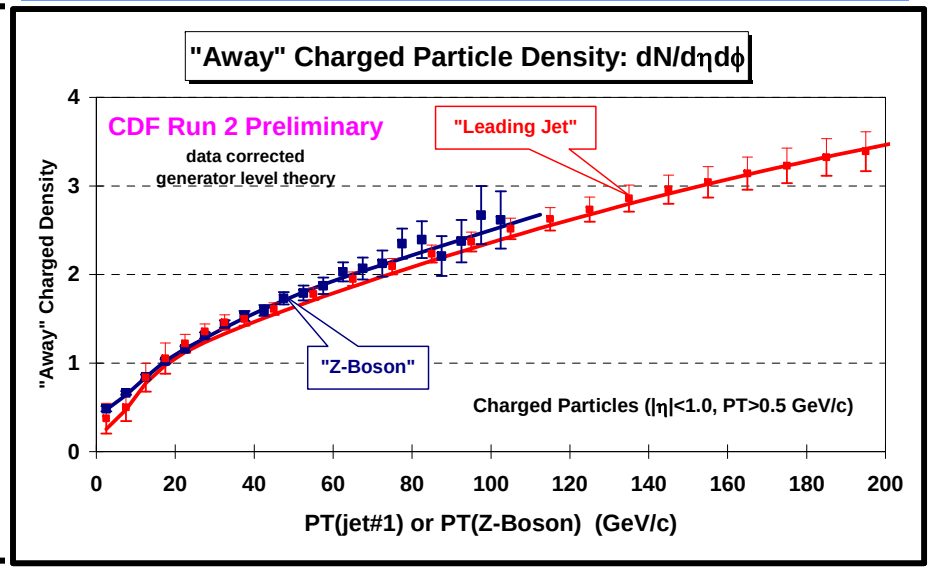


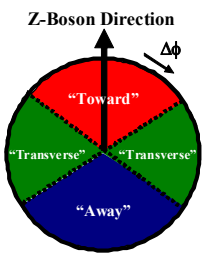


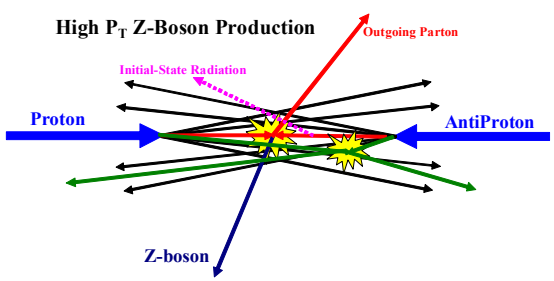
➡ **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

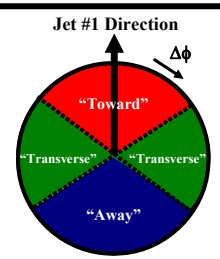
Charged Particle Density

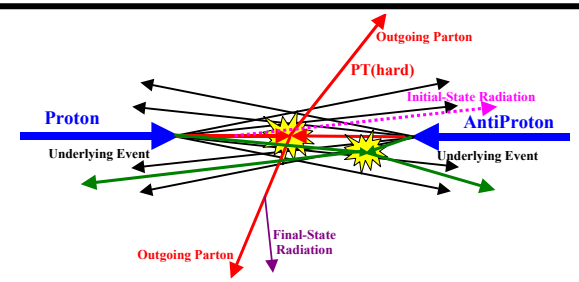






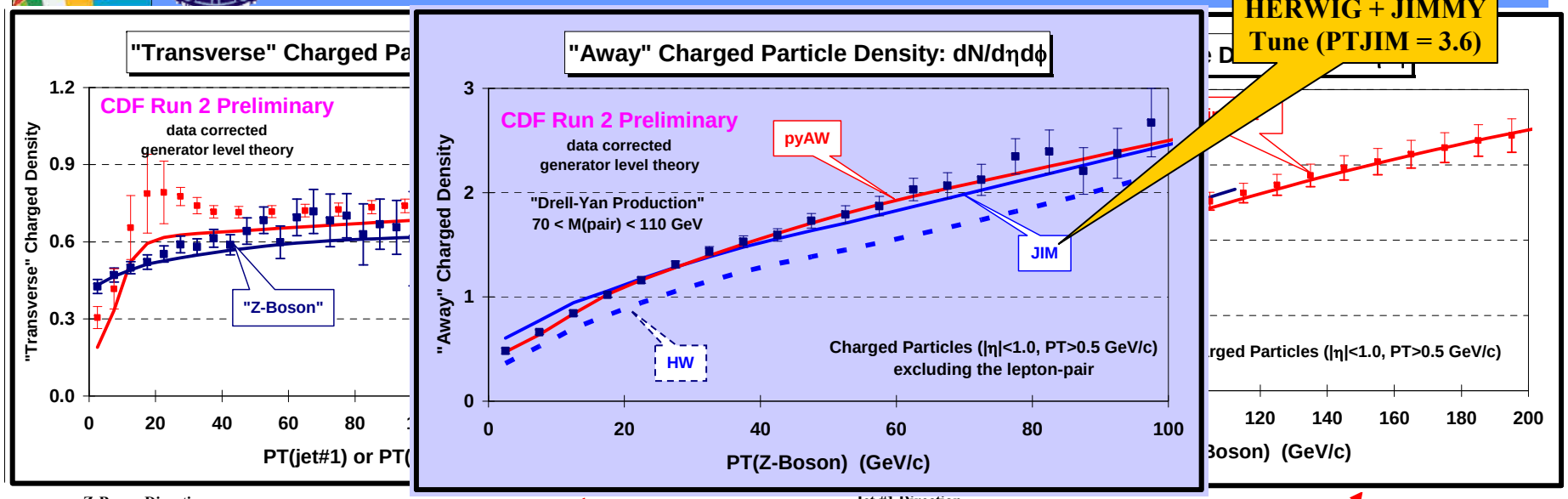


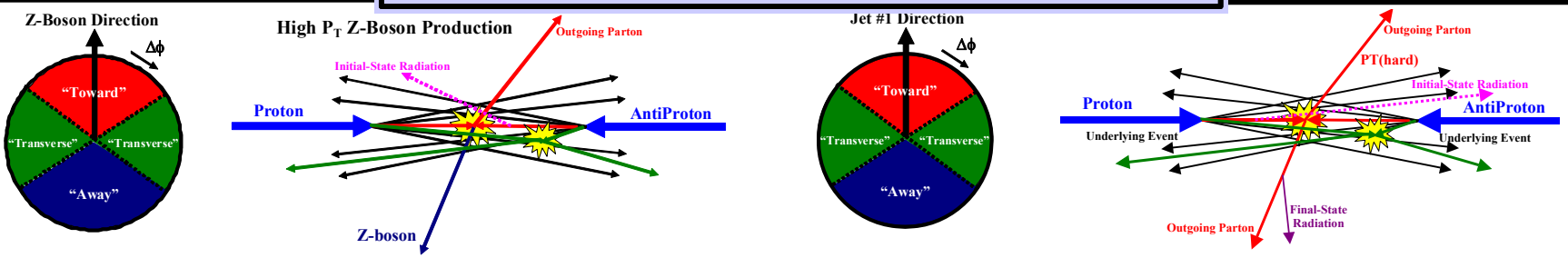




➡ **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

Charged Particle Density



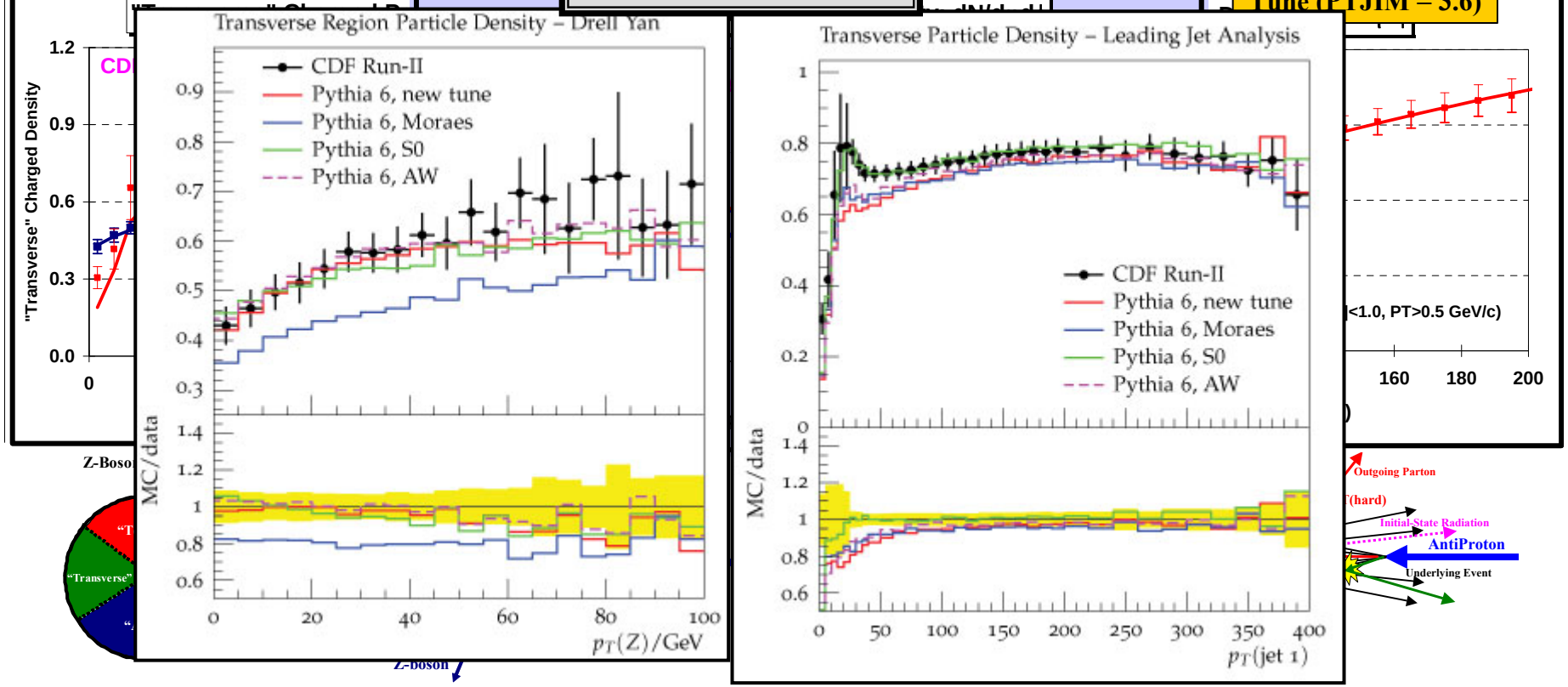


➡ **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

Charged Particle Density

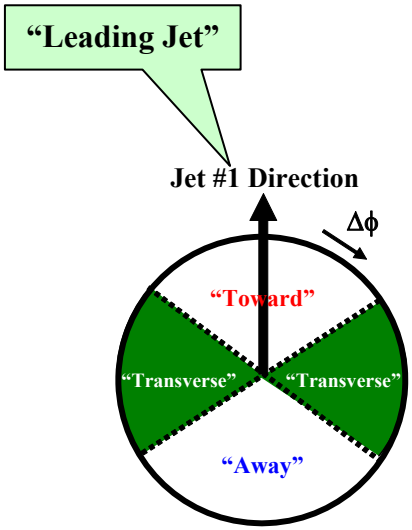
H. Hoeth, MPI@LHC08

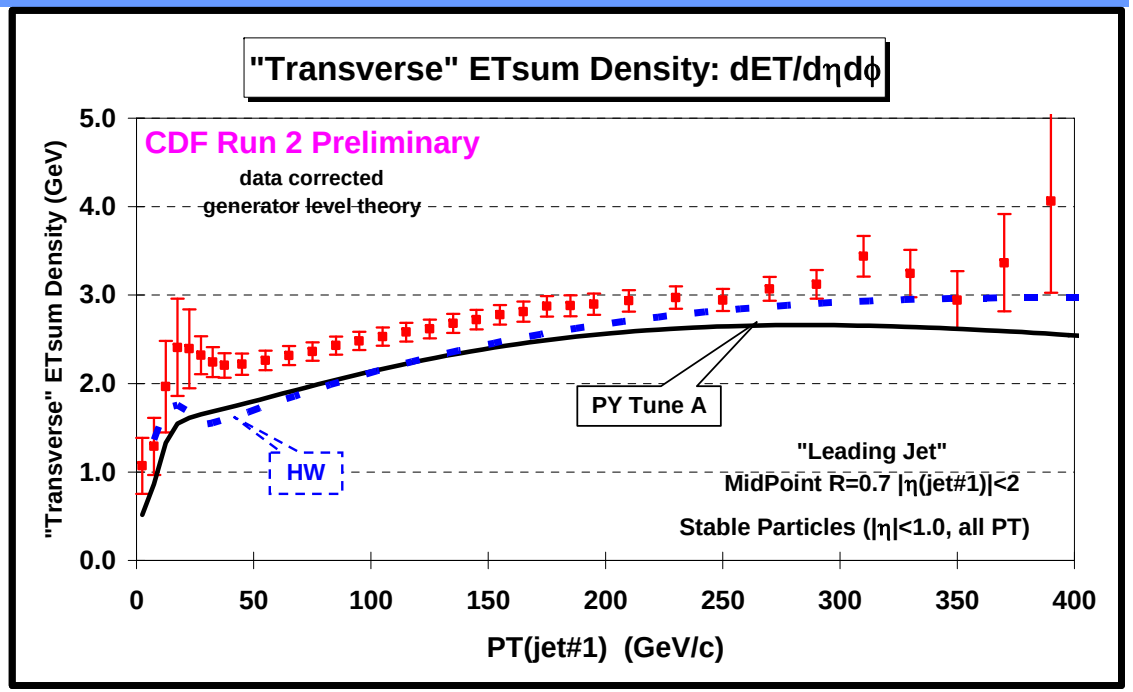
HERWIG + JIMMY Tune (PTJIM = 3.6)



➡ **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

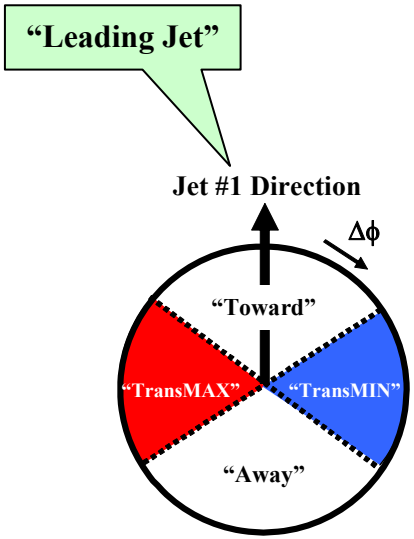
The "Transverse" Region

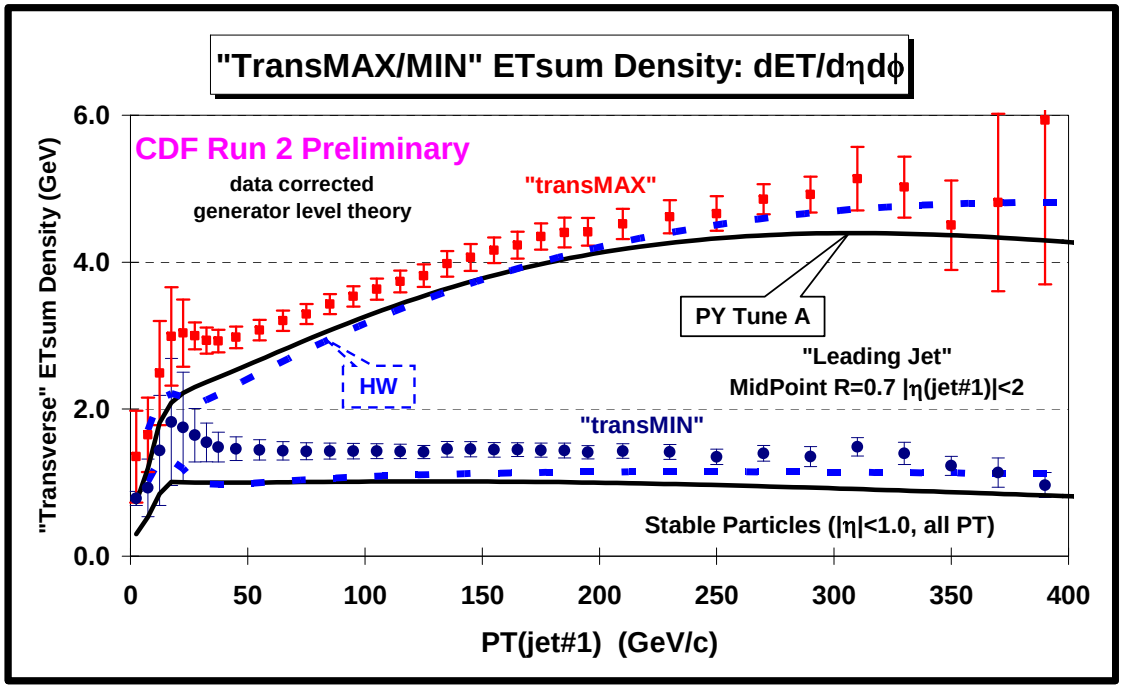




➡ **Shows the Data - Theory for the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).**

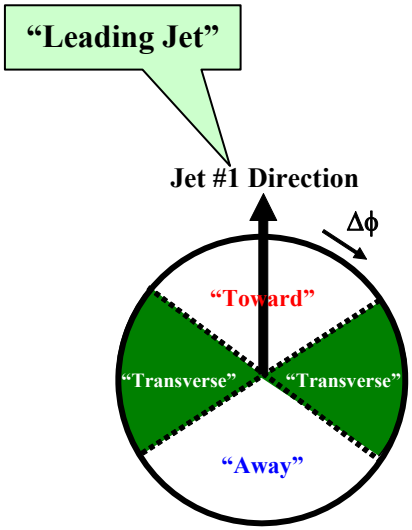
The "TransMAX/MIN" Regions

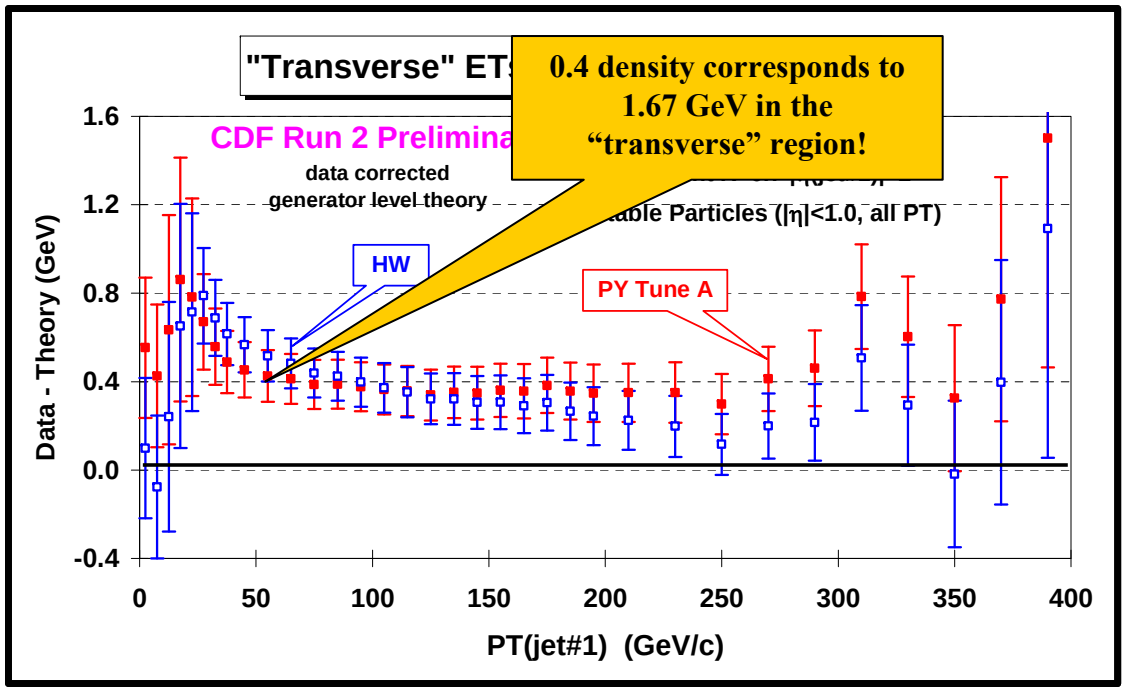




➡ **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for "transDIF" = "transMAX"-"transMIN. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

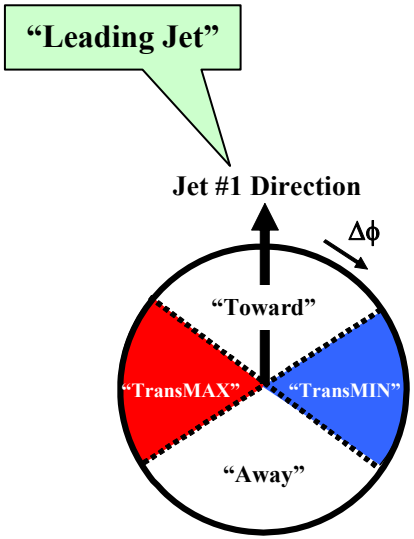
The "Transverse" Region

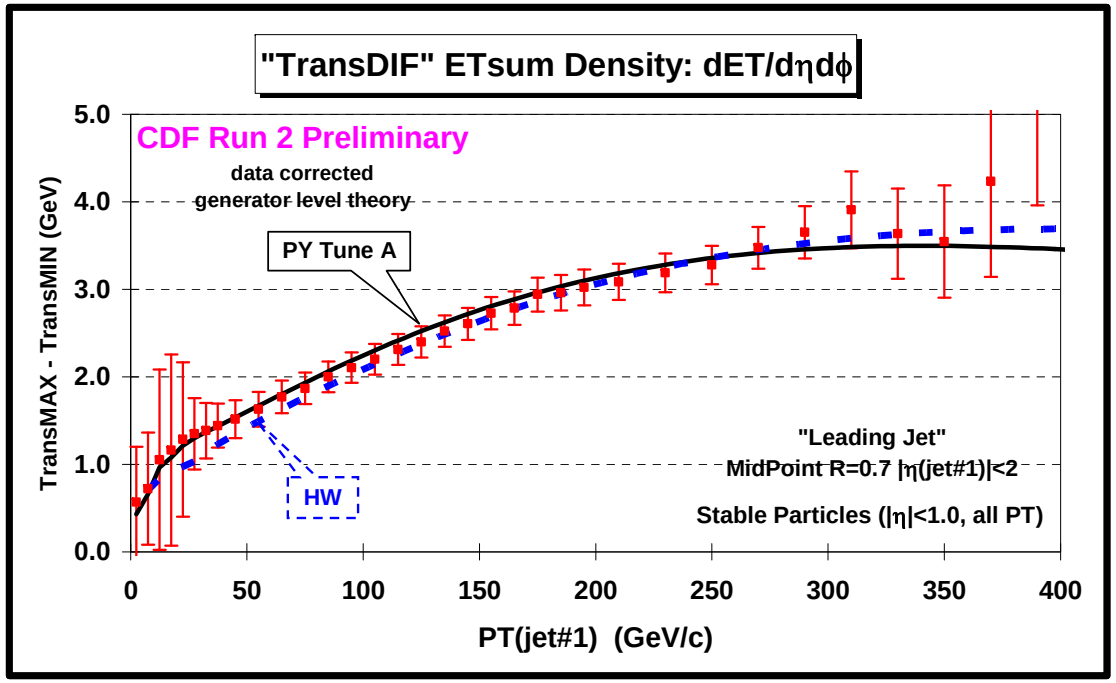




➡ **Shows the Data - Theory for the *scalar* E_T sum density, $dET/d\eta d\phi$, with $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).**

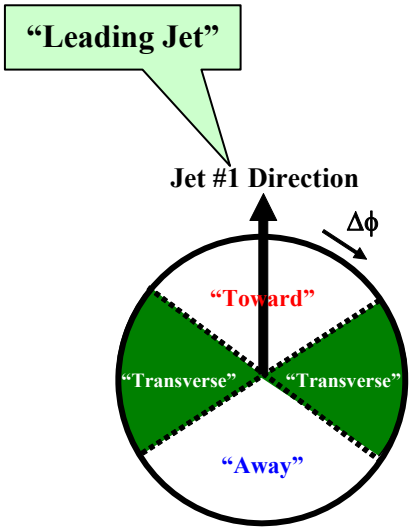
The "TransMAX/MIN" Regions

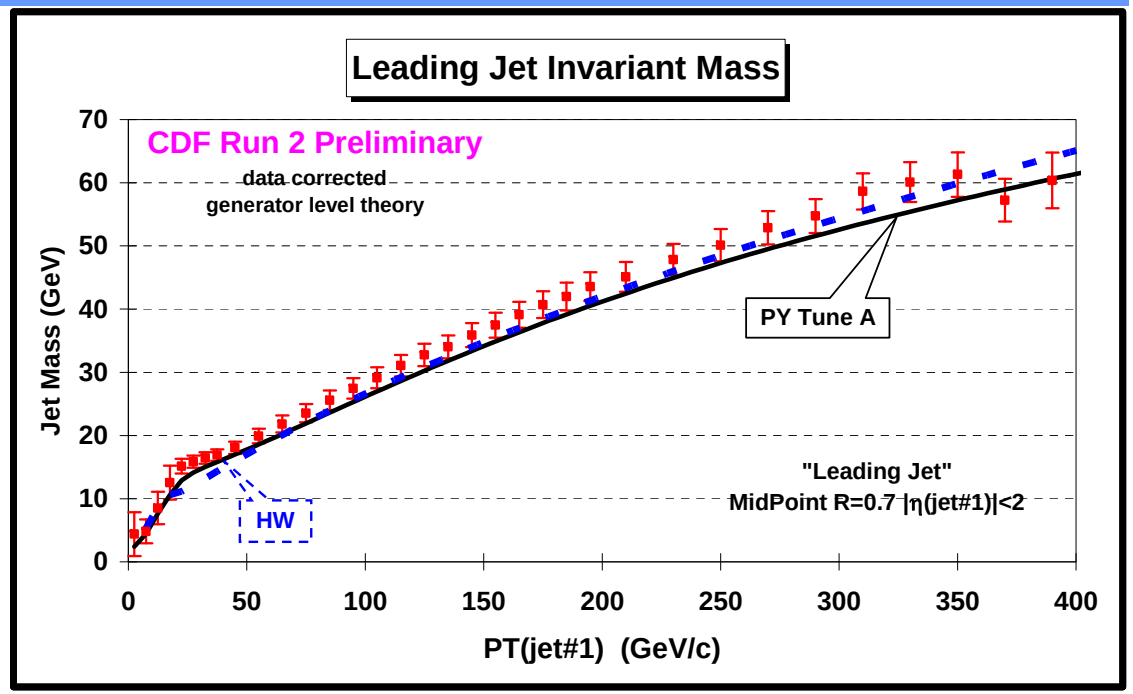




- **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for "transDIF" = "transMAX"-"transMIN. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

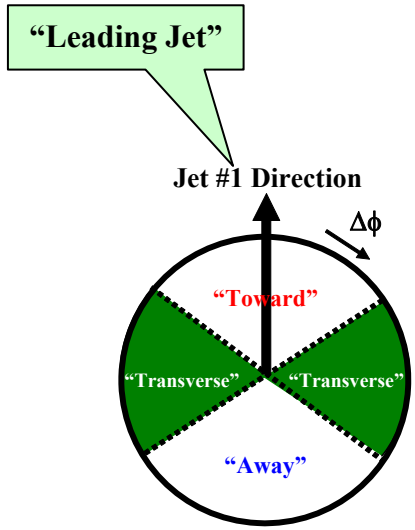
The Leading Jet Mass

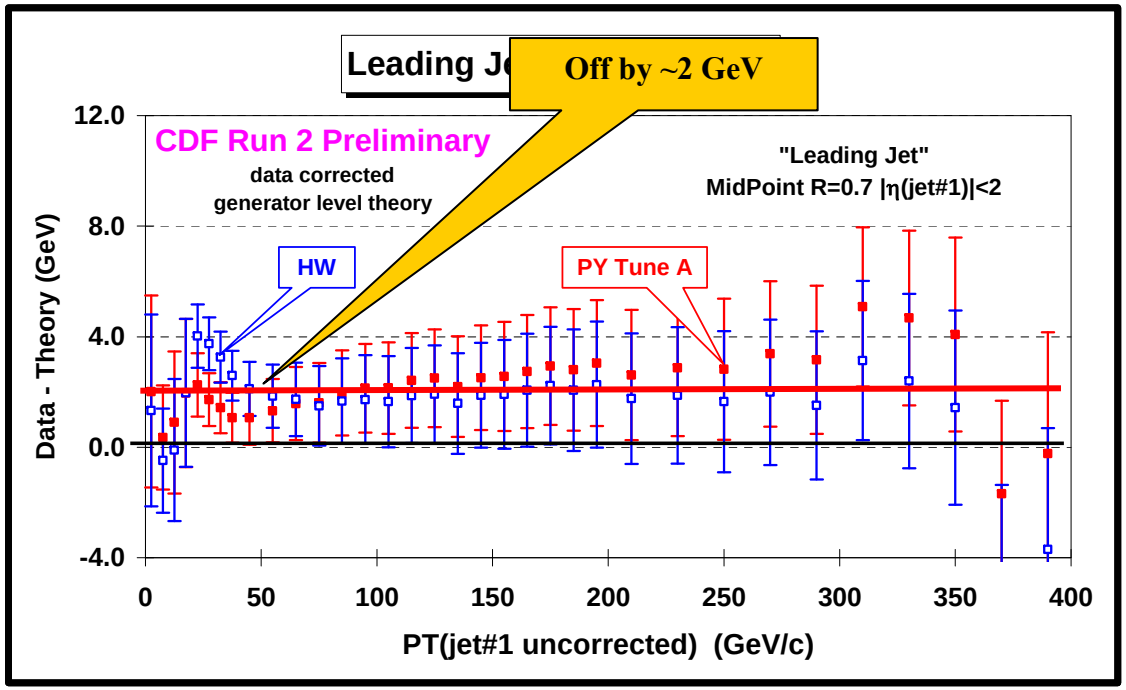




➡ **Shows the Data - Theory for the leading jet invariant mass for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).**

The Leading Jet Mass

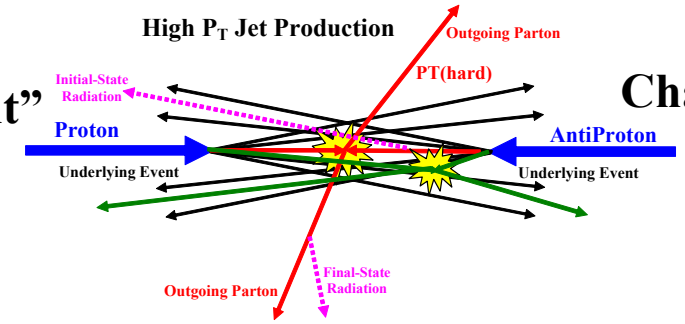




➡ **Shows the Data - Theory for the leading jet invariant mass for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).**

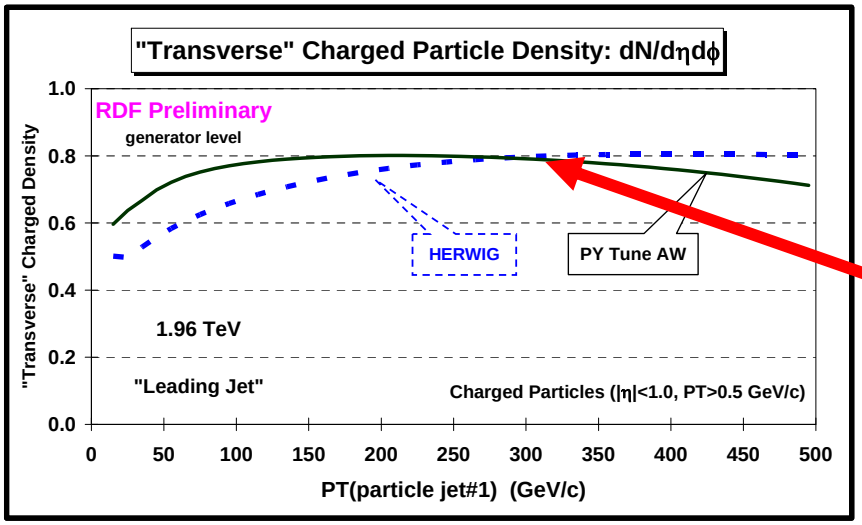
The "Underlying Event" in High P_T Jet Production (LHC)

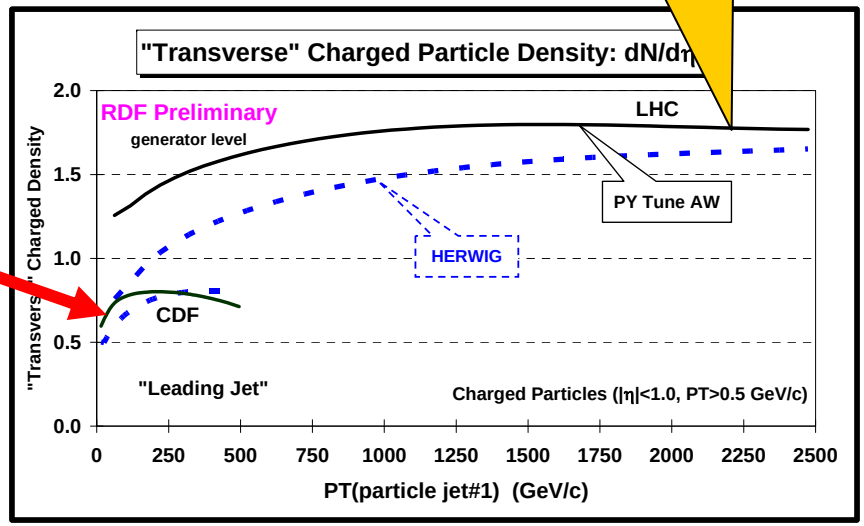
The "Underlying Event"



Charged particle density versus P_T(jet#1)

"Underlying event" much more active at the LHC!

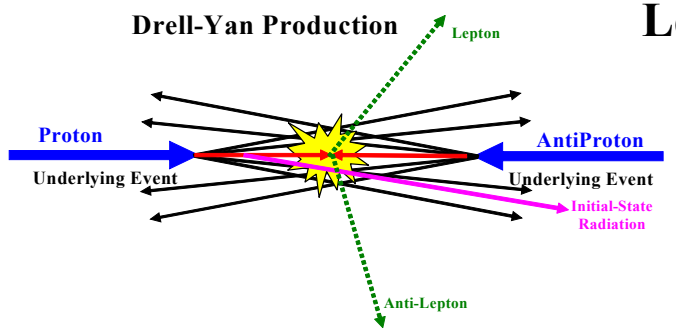




➡ Charged particle density in the "Transverse" region versus P_T(jet#1) at 1.96 TeV for PY Tune AW and HERWIG (*without MPI*).

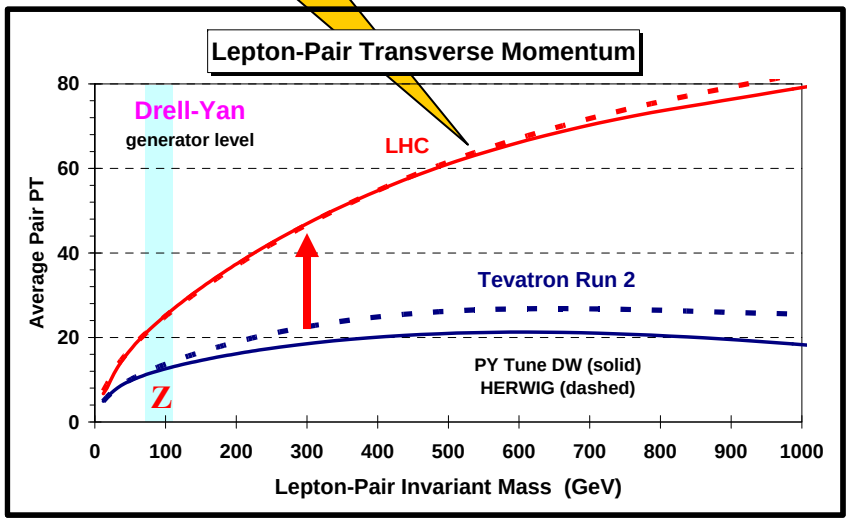
➡ Charged particle density in the "Transverse" region versus P_T(jet#1) at 14 TeV for PY Tune AW and HERWIG (*without MPI*).

Drell-Yan Production (Run 2 vs LHC)

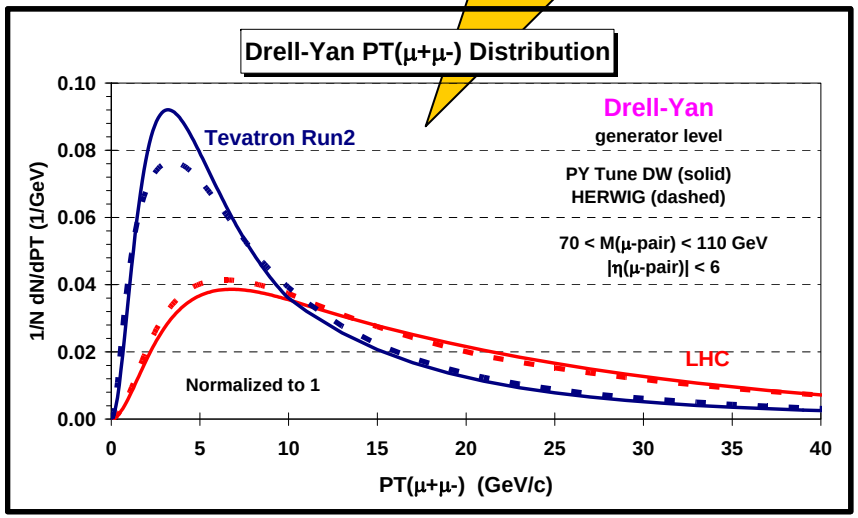


Lepton-Pair Transverse Momentum

$<p_T(\mu^+\mu^-)>$ is much larger at the LHC!



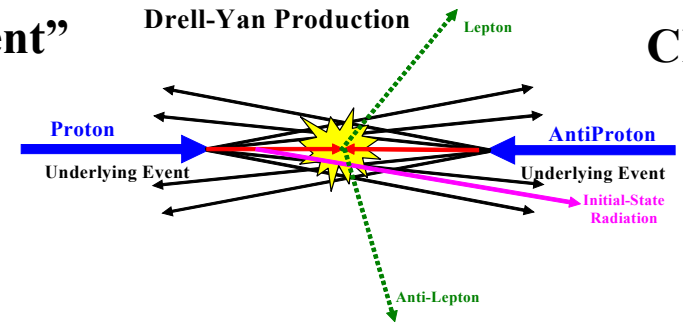
Shapes of the $p_T(\mu^+\mu^-)$ distribution at the Z-boson mass.



- Average Lepton-Pair transverse momentum at the Tevatron and the LHC for PYTHIA Tune DW and HERWIG (*without MPI*).
- Shape of the Lepton-Pair p_T distribution at the Z-boson mass at the Tevatron and the LHC for PYTHIA Tune DW and HERWIG (*without MPI*).

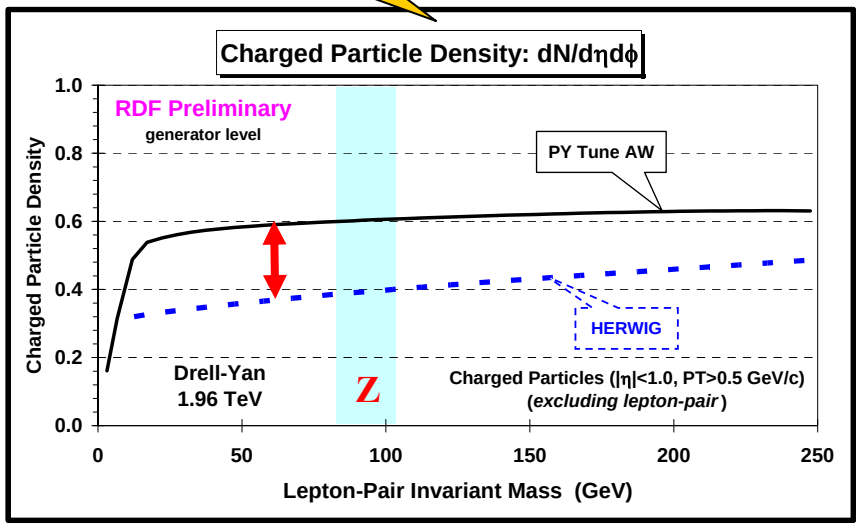
The "Underlying Event" in Drell-Yan Production

The "Underlying Event"

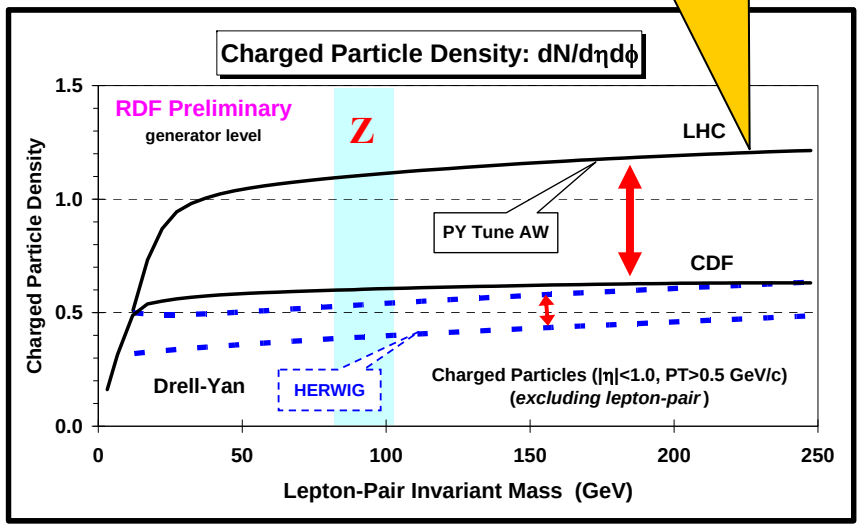


Charged particle density versus M(pair)

HERWIG (*without MPI*) is much less active than PY Tune AW (*with MPI*)!



"Underlying event" much more active at the LHC!



- Charged particle density versus the lepton-pair invariant mass at 1.96 TeV for PYTHIA Tune AW and HERWIG (*without MPI*).
- Charged particle density versus the lepton-pair invariant mass at 14 TeV for PYTHIA Tune AW and HERWIG (*without MPI*).

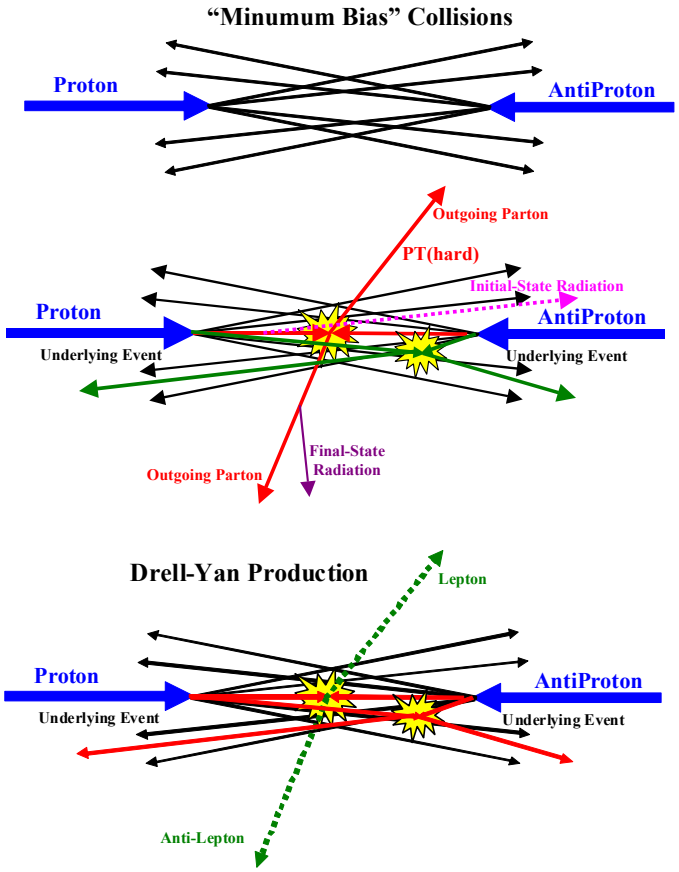
Summary

- We are making good progress in modeling "min-bias" collisions! I will talk more about this tomorrow.
- We are making good progress in understanding and modeling the "underlying event" high transverse momentum jet production and in Drell-Yan production. I will talk much more about this tomorrow.
- There are still some things we do not fully understand!

** Soft Underlying Event Energy ** ** Jet Mass **

** R(J2,J3) **

I will talk much more about this on Thursday!



- **AND we really do not know how to extrapolate to the LHC!**