The LHC Physics Environment

Talk 1: What We Have Learned at the Tevatron

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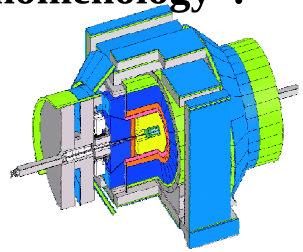
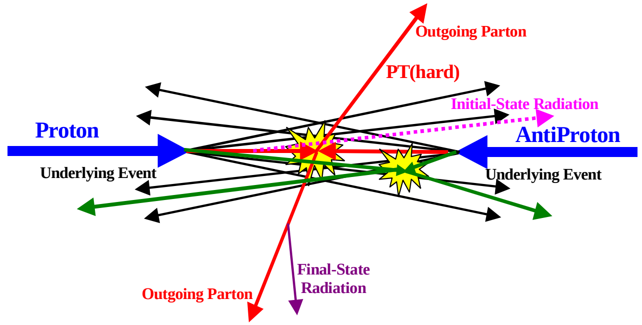
June 24th – July 2nd, 2009

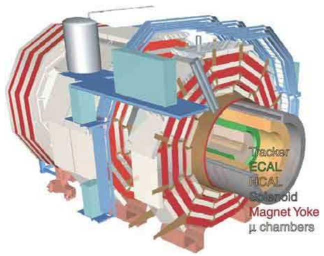
Outline of Talk

- The old days of "Feynman-Field Phenomenology".
- Review what we learned about "min-bias", the "underlying event", and "event topologies" in Run 1 at CDF.
- Review the CDF Run 2 "underlying event" studies in high transverse momentum jet production and in "Drell-Yan" production.
- Describe the QCD Monte-Carlo models that are used to simulate hadron-hadron collisions.
- Examine some extrapolations from the Tevatron to the LHC.



CDF Run 2

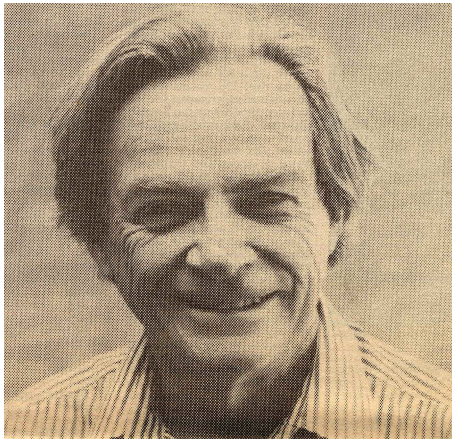


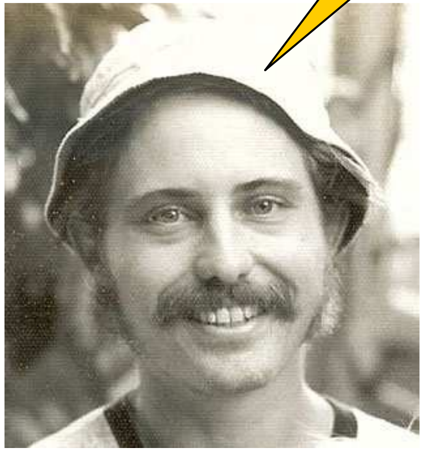


CMS at the LHC

UE&MB@CMS

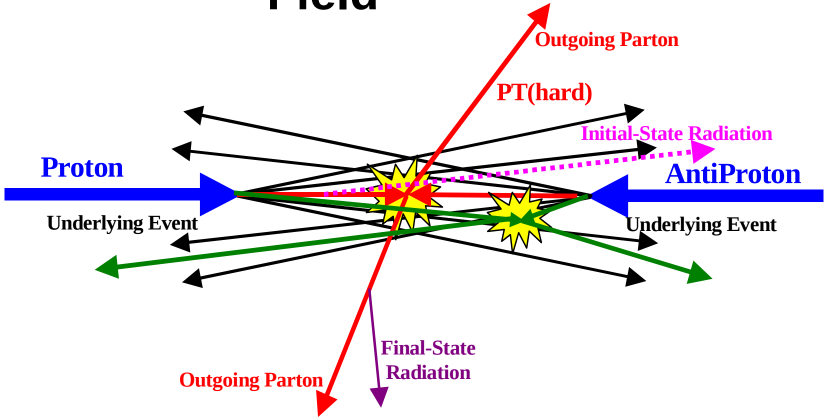
Feynman-Field Phenomenology





Feynman **and** **Field**

- **From 7 GeV/c π^0's to 600 GeV/c Jets. The early days of trying to understand and simulate hadron-hadron collisions.**

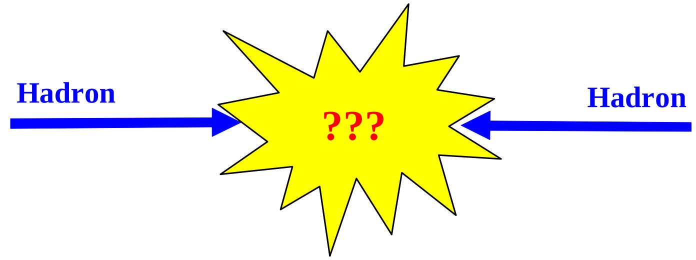


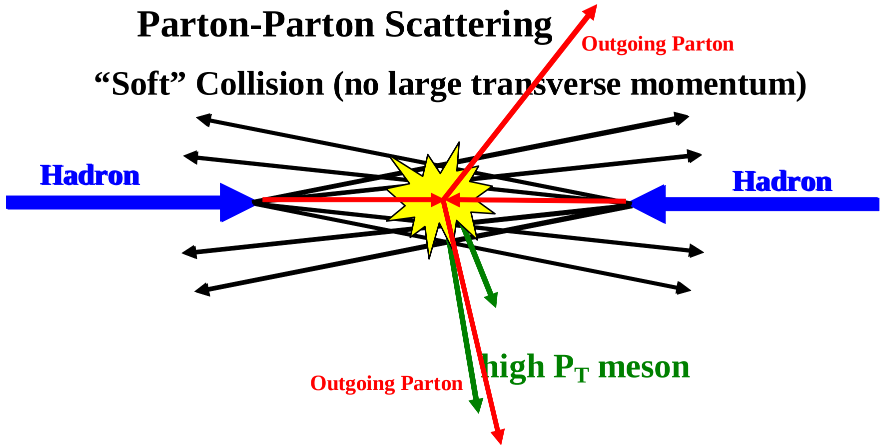
Hadron-Hadron Collisions

FF1 1977

- **What happens when two hadrons collide at high energy?**
- **Most of the time the hadrons ooze through each other and fall apart (*i.e.* no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton.**
- **Occasionally there will be a large transverse momentum meson. Question: Where did it come from?**
- **We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!**

"Black-Box Model"





Hadron-Hadron Collisions

FF1 1977

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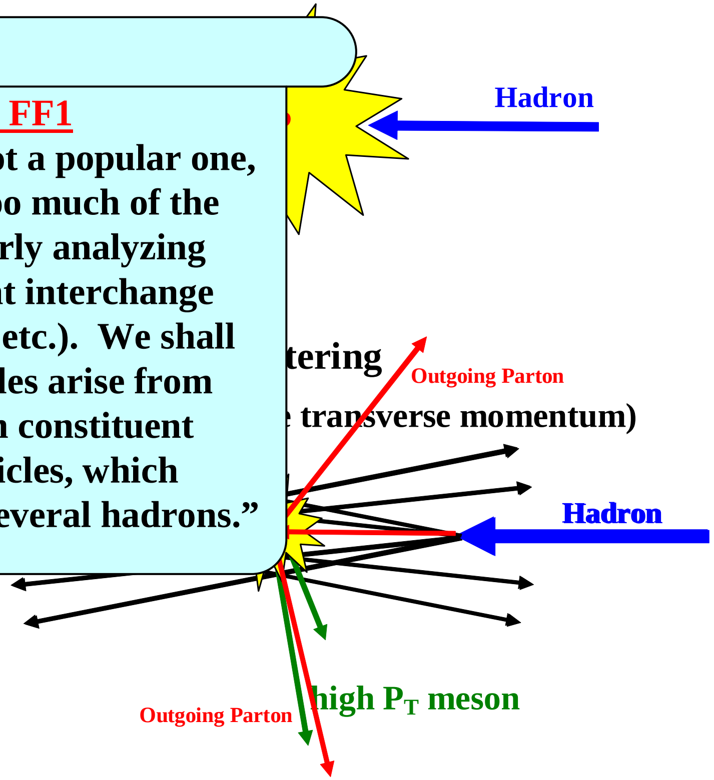
Feynman quote from FF1

"The model we shall choose is not a popular one, so that we will not duplicate too much of the work of others who are similarly analyzing various models (e.g. constituent interchange model, multiperipheral models, etc.). We shall assume that the high P_T particles arise from direct hard collisions between constituent quarks in the incoming particles, which fragment or cascade down into several hadrons."



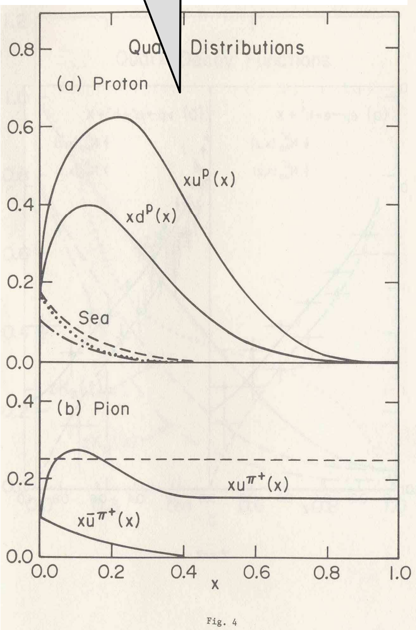
"Black-Box Model"

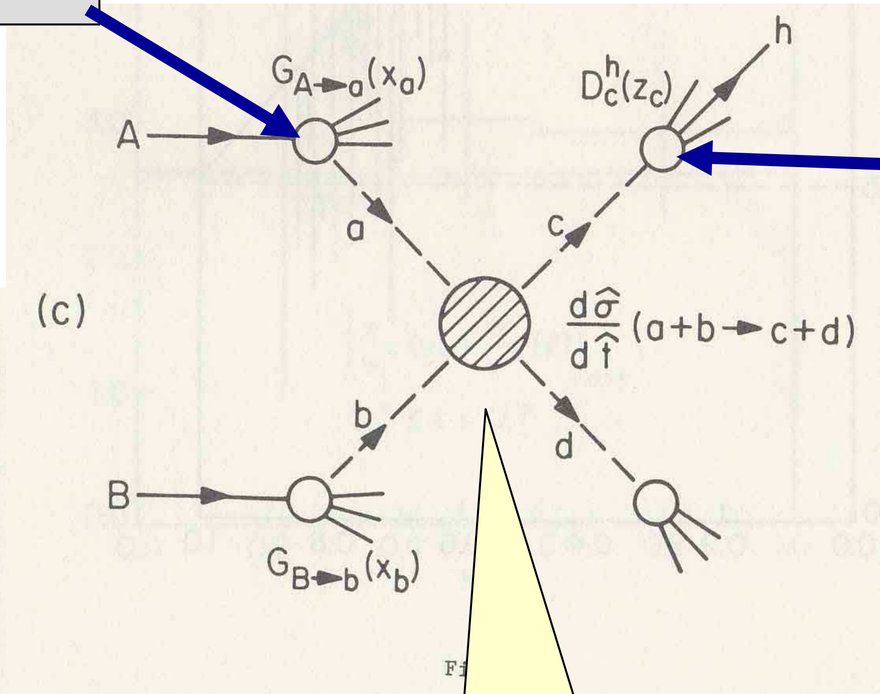
Quark-Quark Black-Box Model

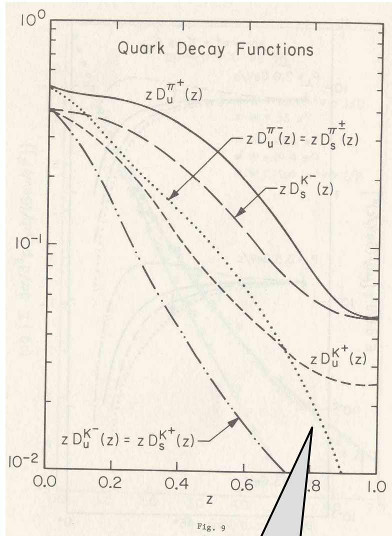
FF1 1977

No gluons!

Quark Distribution Functions
determined from deep-inelastic lepton-hadron collisions







Quark Fragmentation Functions
determined from e^+e^- annihilations

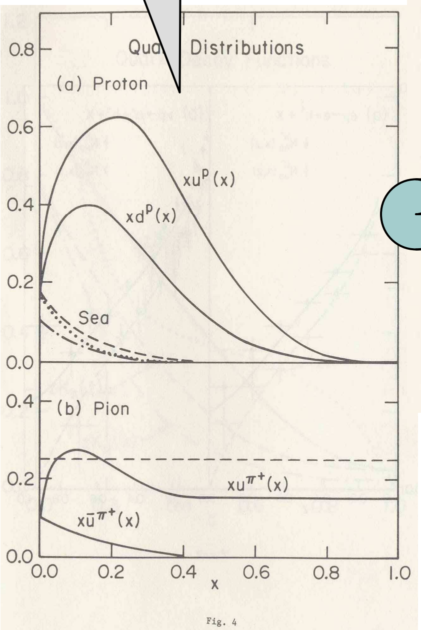
Quark-Quark Cross-Section
Unknown! Deteremined from hadron-hadron collisions.

Quark-Quark Black-Box Model

No gluons!

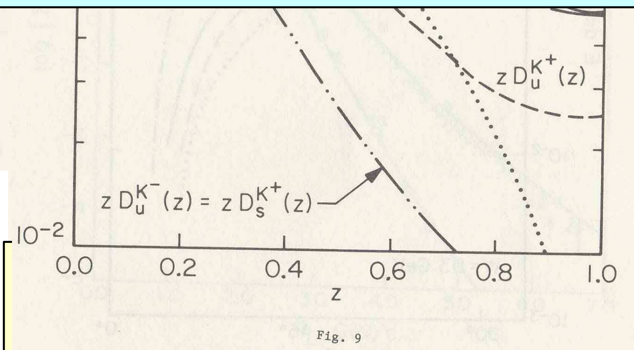
FF1 1977

Quark Distribution Functions determined from deep-inelastic lepton-hadron collisions

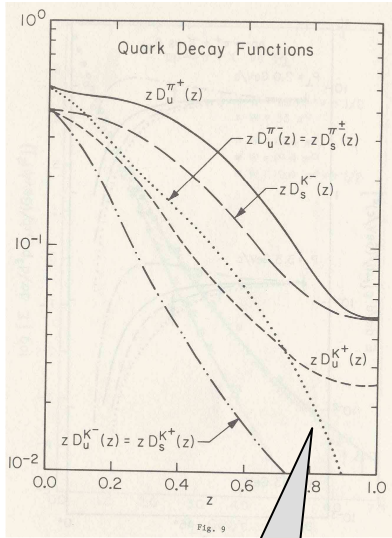


Feynman quote from FF1

"Because of the incomplete knowledge of our functions some things can be predicted with more certainty than others. Those experimental results that are not well predicted can be "used up" to determine these functions in greater detail to permit better predictions of further experiments. Our papers will be a bit long because we wish to discuss this interplay in detail."



hadron-hadron collisions.

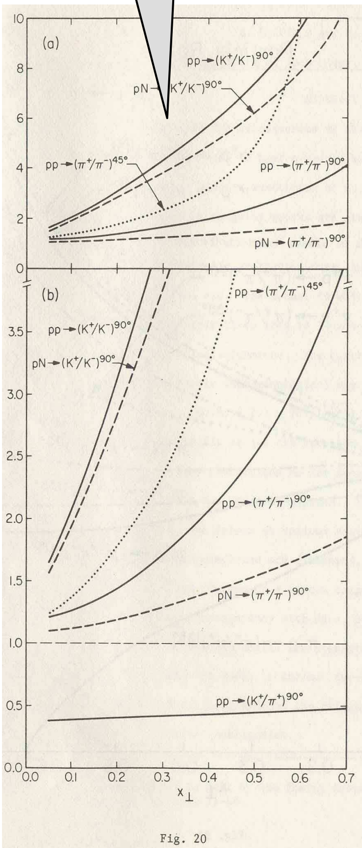


Quark Fragmentation Functions etermined from e^+e^- annihilations

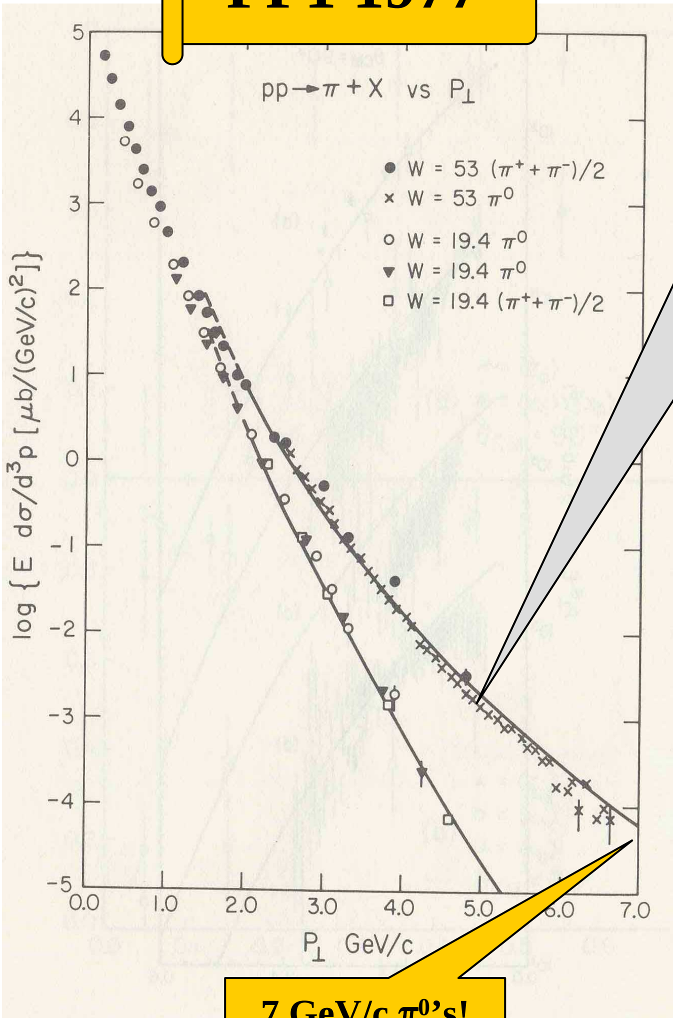
Quark-Quark Black-Box Model

FF1 1977

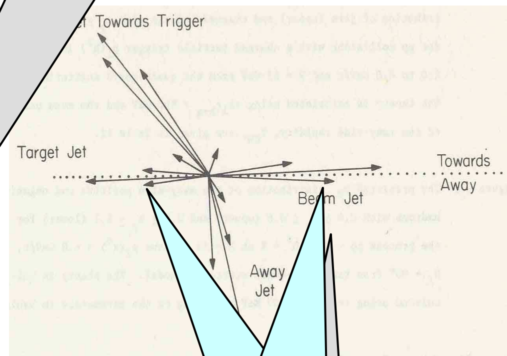
Predict particle ratios



Predict increase with increasing CM energy W



7 GeV/c π^0's!



The "underlying event" (Beam-Beam Remnants)!

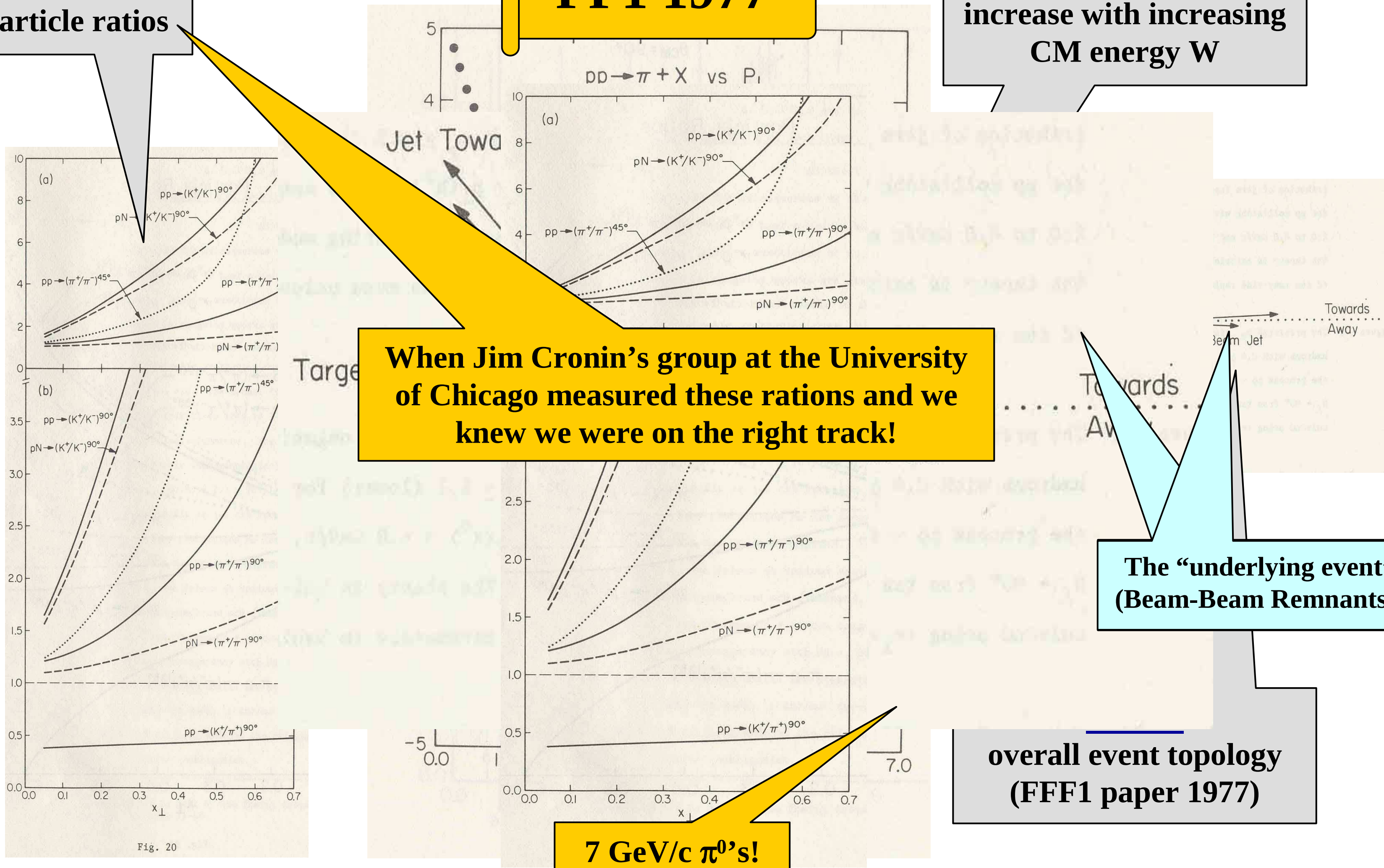
Predict overall event topology (FFF1 paper 1977)

Quark-Quark Black-Box Model

FF1 1977

Predict
particle ratios

Predict
increase with increasing CM energy W



When Jim Cronin's group at the University of Chicago measured these rations and we knew we were on the right track!

The "underlying event" (Beam-Beam Remnants)!

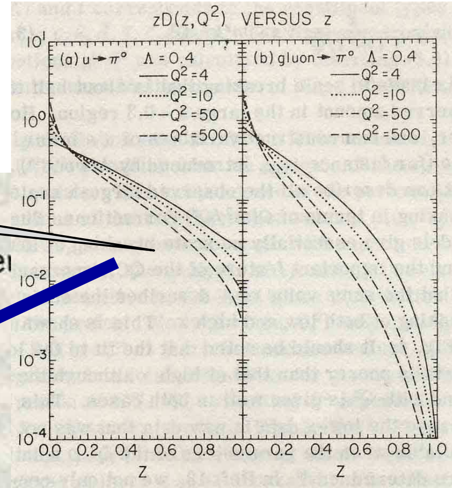
overall event topology (FFF1 paper 1977)

7 GeV/c π^0's!

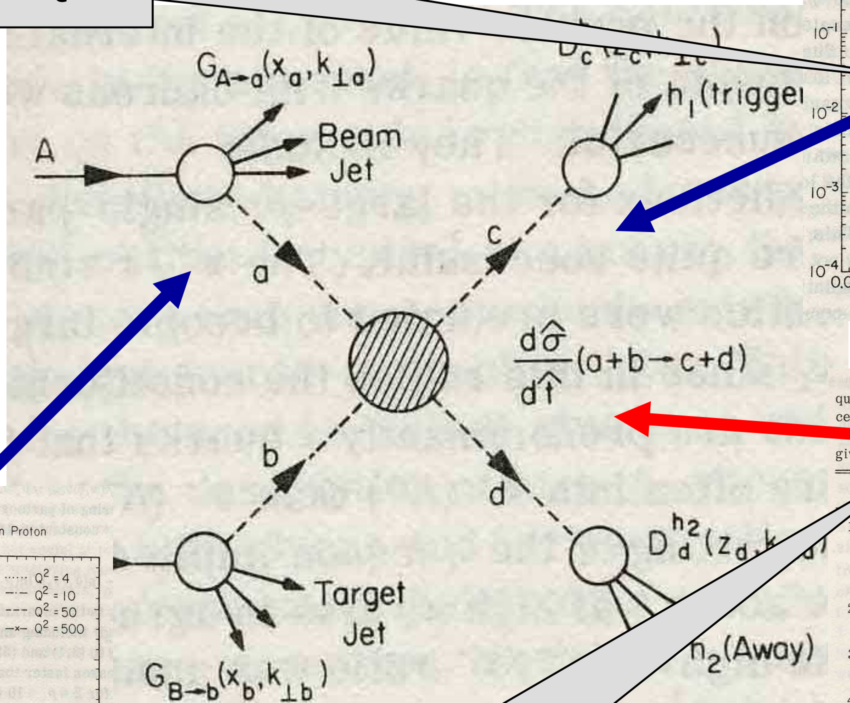
QCD Approach: Quarks & Gluons

FFF2 1978

Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD



Parton Distribution Functions
Q^2 dependence predicted from QCD



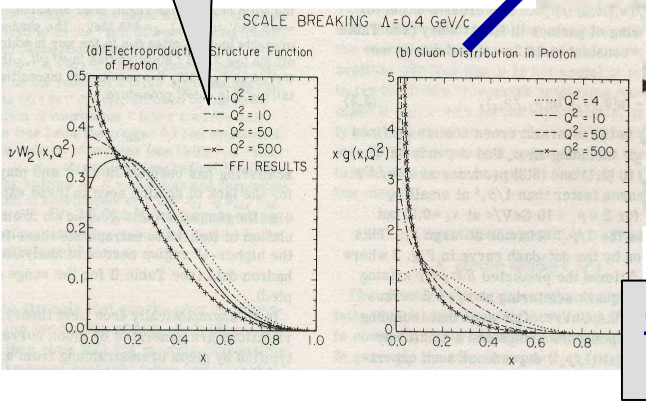


TABLE I. Cross sections for the various constituent quark-quark, quark-gluon, and gluon-gluon subprocesses.[a] The differential cross section is given by $d\hat{\sigma}/d\hat{t} = \pi\alpha_s^2(Q^2)|A|^2/\hat{s}^2$, where $\alpha_s(Q^2)$ is the effective coupling given by Eq. (3.1).

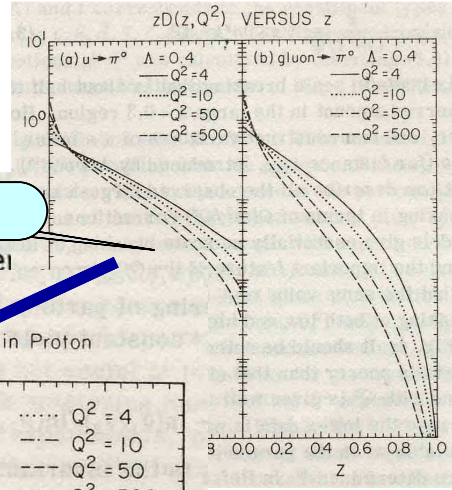
	Subprocess	$\|A\|^2$
1.	$q_iq_j \to q_iq_j$, $q_i\bar{q}_j \to q_i\bar{q}_j$ $(i \neq j)$	$\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$
2.	$q_iq_i \to q_iq_i$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right)-\frac{8}{27}\frac{\hat{s}^2}{\hat{u}\hat{t}}$
3.	$q_i\bar{q}_i \to q_i\bar{q}_i$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)-\frac{8}{27}\frac{\hat{u}^2}{\hat{s}\hat{t}}$
4.	$q_i\bar{q}_i \to gg$	$\frac{32}{27}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}}\right)-\frac{8}{3}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right)$
5.	$gg \to q_i\bar{q}_i$	$\frac{1}{6}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}}\right)-\frac{3}{8}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right)$
6.	$q_ig \to q_ig$	$-\frac{4}{9}\left(\frac{\hat{u}^2+\hat{s}^2}{\hat{u}\hat{s}}\right)+\left(\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}\right)$
7.	$gg \to gg$	$\frac{9}{2}\left(3-\frac{\hat{u}\hat{t}}{\hat{s}^2}-\frac{\hat{u}\hat{s}}{\hat{t}^2}-\frac{\hat{s}\hat{t}}{\hat{u}^2}\right)$

Quark & Gluon Cross-Sections
Calculated from QCD

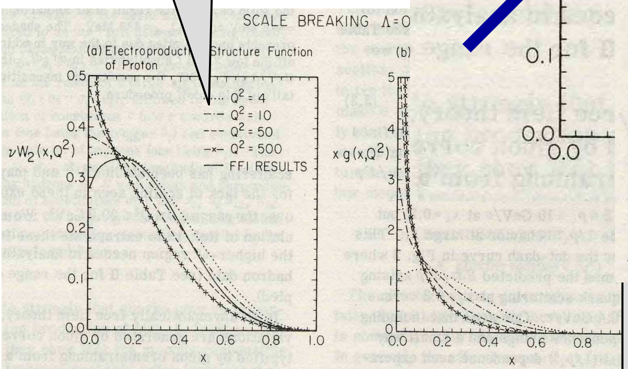
QCD Approach: Quarks & Gluons

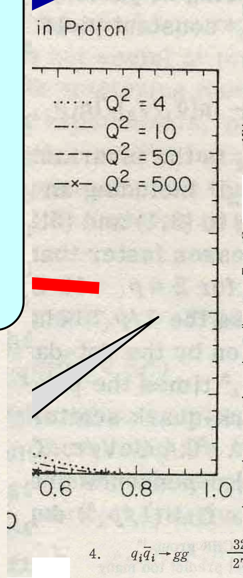
FFF2 1978

Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD



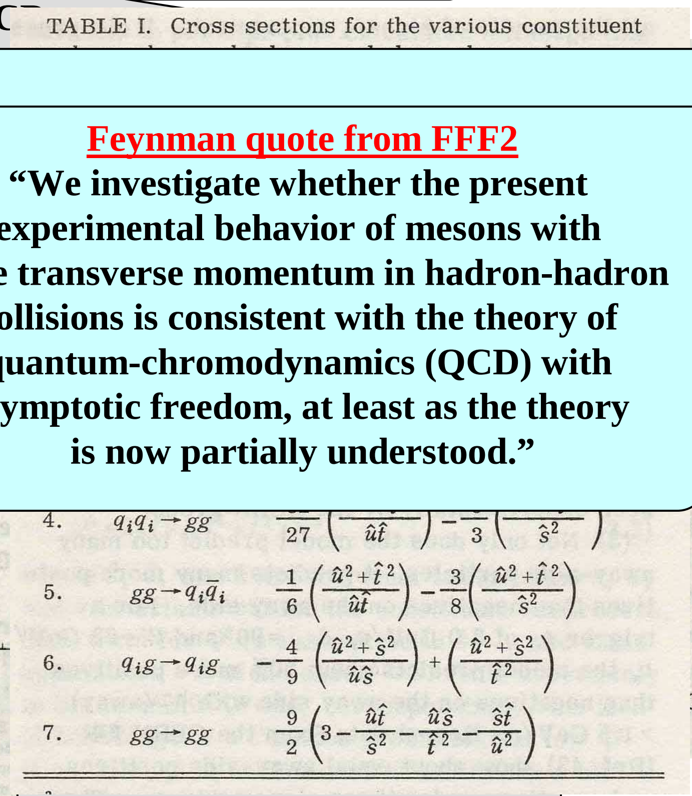
Parton Distribution Functions
Q^2 dependence predicted from QCD

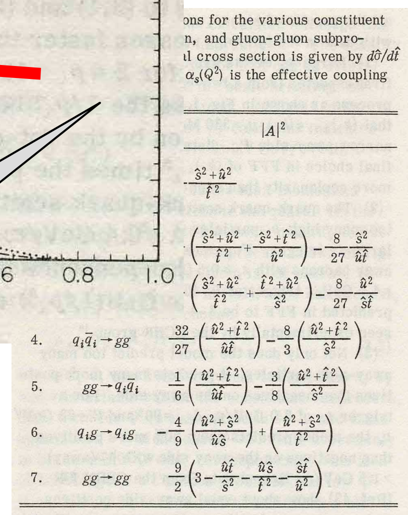




Feynman quote from FFF2

"We investigate whether the present experimental behavior of mesons with large transverse momentum in hadron-hadron collisions is consistent with the theory of quantum-chromodynamics (QCD) with asymptotic freedom, at least as the theory is now partially understood."

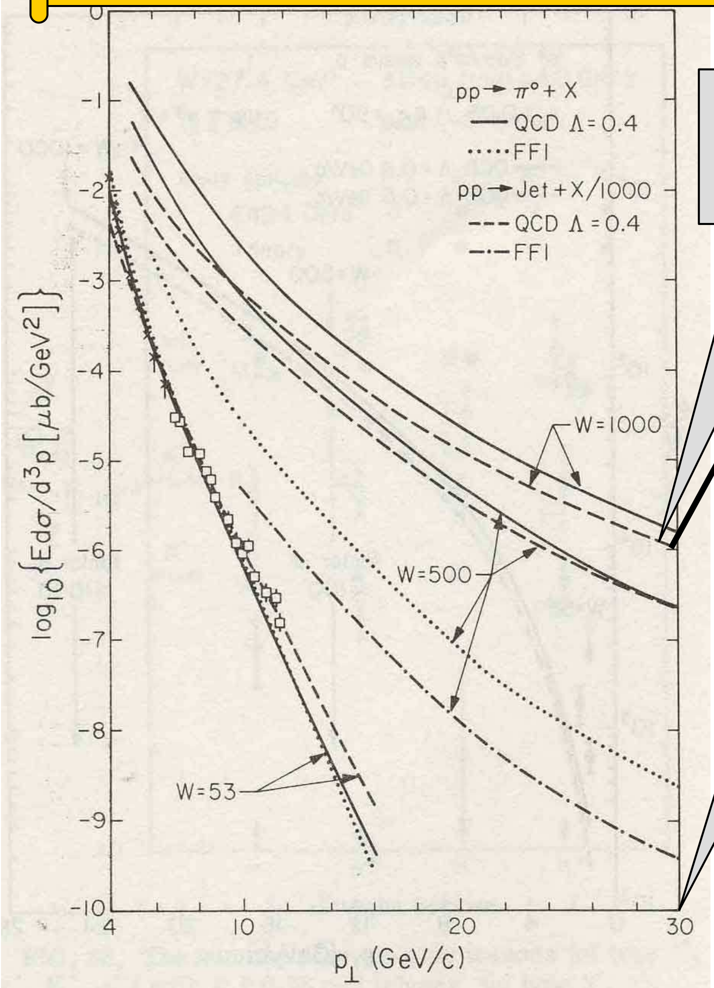




Quark & Gluon Cross-Sections
Calculated from QCD

High P_T Jets

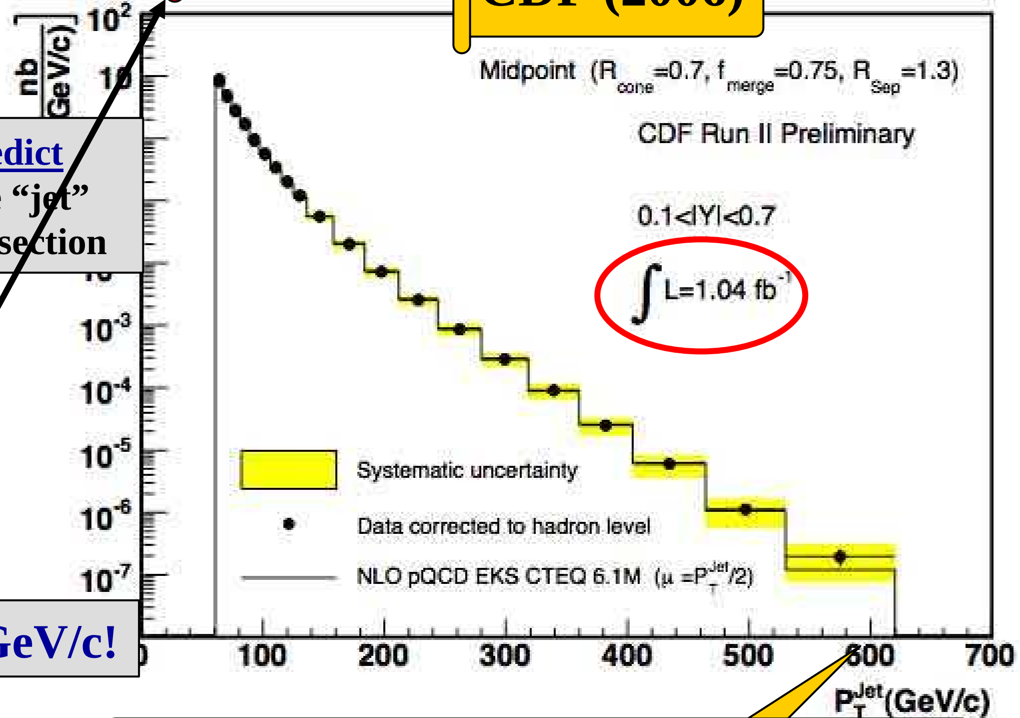
Feynman, Field, & Fox (1978)



Predict large "jet" cross-section

30 GeV/c!

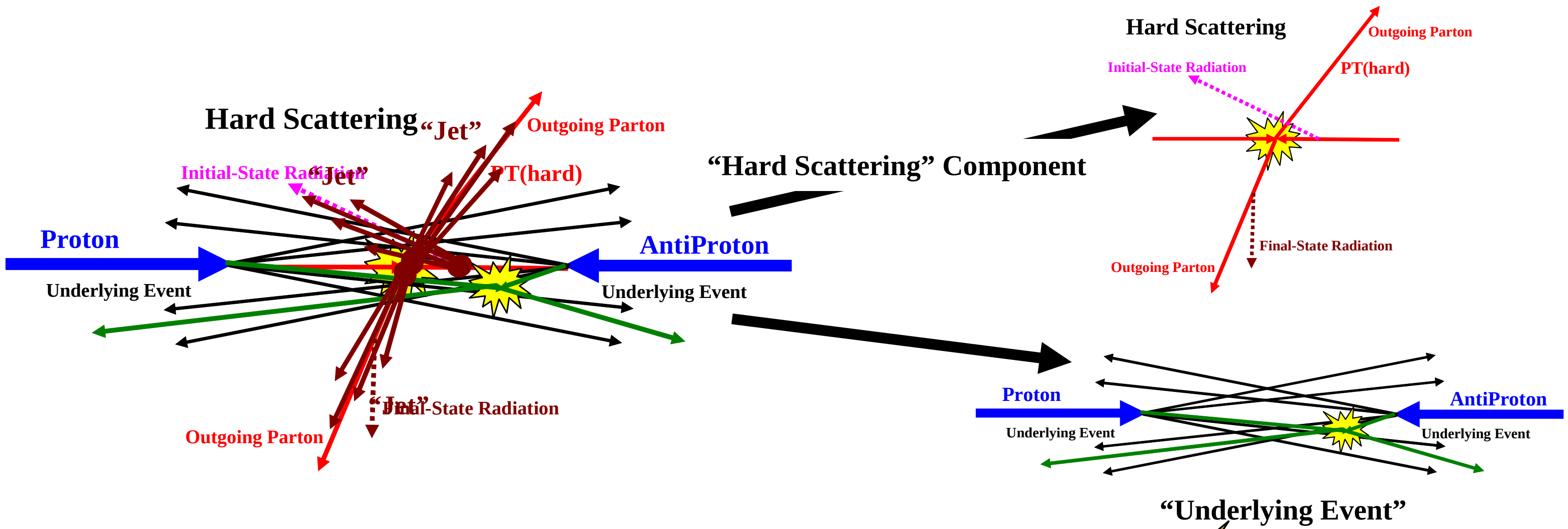
CDF (2006)



Feynman quote from FFF

"At the time of this writing, there is still no sharp quantitative test of QCD. An important test will come in connection with the phenomena of high P_T discussed here."

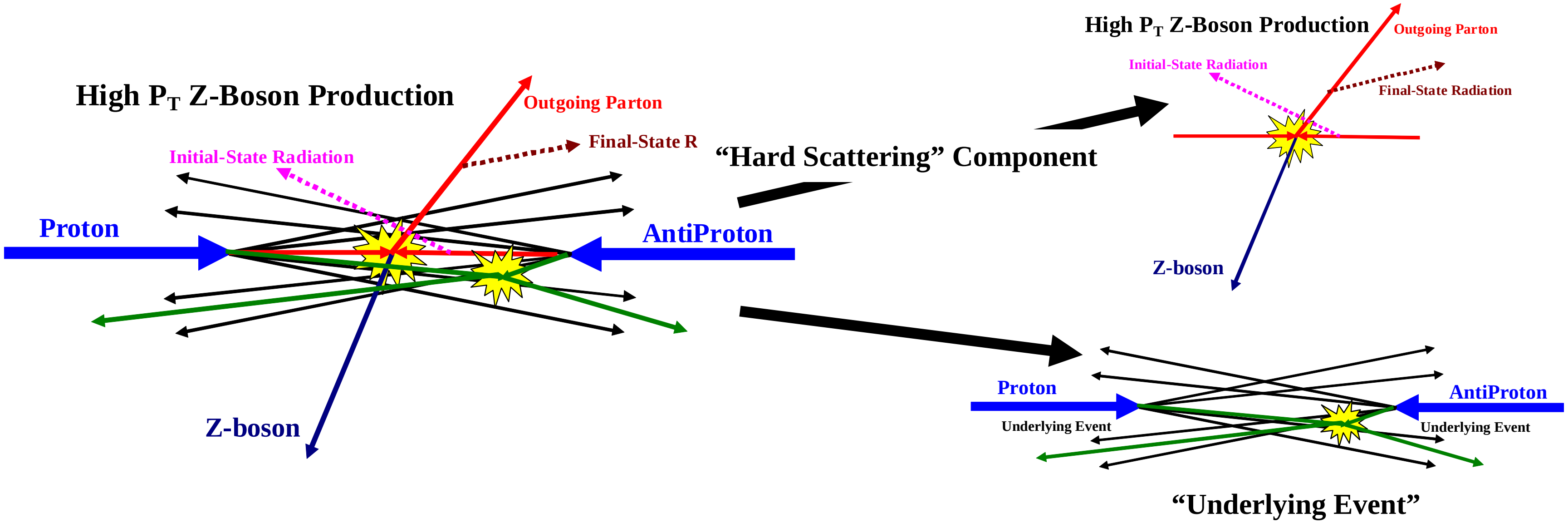
QCD Monte-Carlo Models: High Transverse Momentum Jets



- **Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scatter g and add initial and final-state gluon radiation (in the leading log approximation or modified leadin g approximation).**
- **The "underlying event" consists of the "beam-beam remnants" and articles arising from soft or semi-soft multiple parton interactions (MPI).**
- **Of course the outgoing colored parton bly "underlying event" observables receive contributions fron**

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

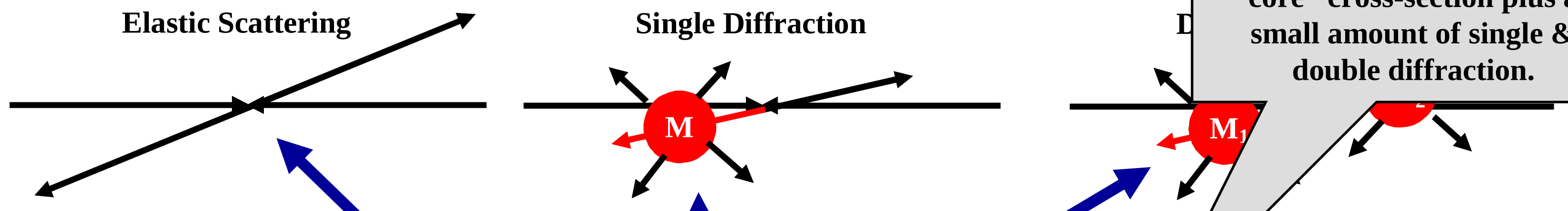
QCD Monte-Carlo Models: Lepton-Pair Production



- **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).**
- **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-state radiation.**

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.

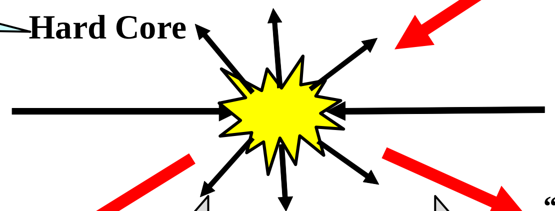


$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC}$$

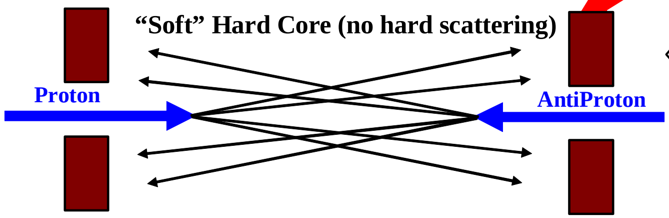
1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

The “hard core” component contains both “hard” and “soft” collisions.

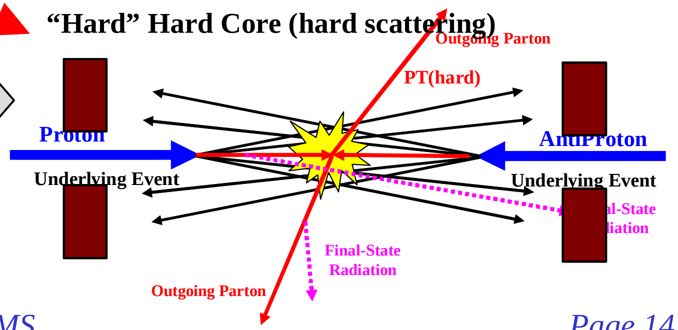
“Inelastic Non-Diffractive Component”



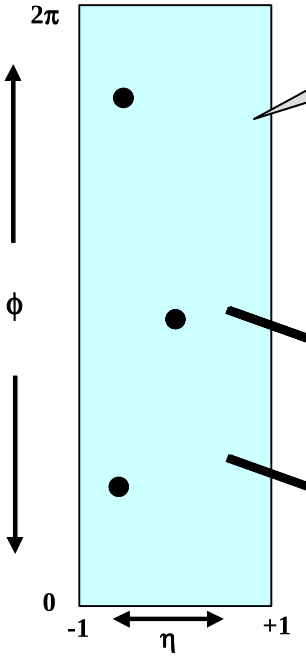
CDF “Min-Bias” trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC



Beam-Beam Counters
$3.2 < |\eta| < 5.9$



Particle Densities



$\Delta\eta\Delta\phi = 4\pi = 12.6$

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

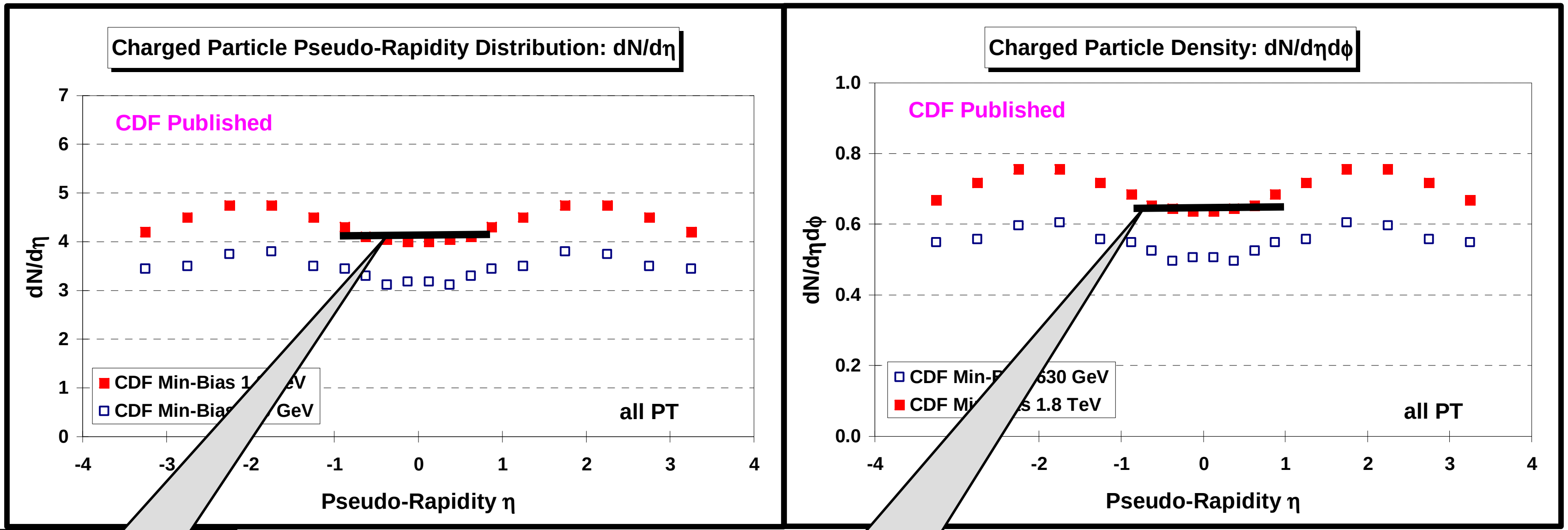
Divide by 4π

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

3 GeV/c PTsum → $dPT_{sum}/d\eta d\phi = 3/4\pi$ 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, $dPT_{sum}/d\eta d\phi$.**

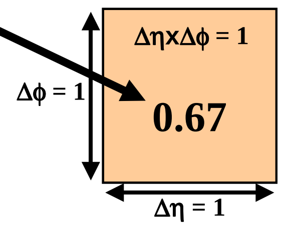
CDF Run 1 "Min-Bias" Data Charged Particle Density



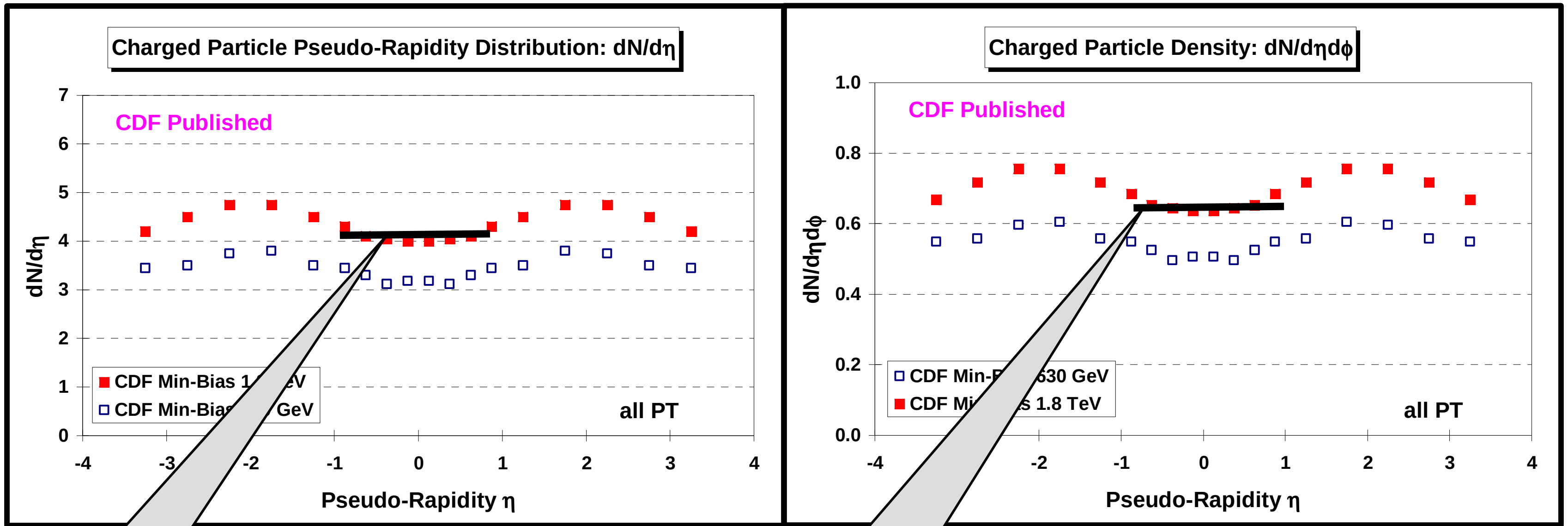
$<dN_{chg}/d\eta> = 4.2$

$<dN_{chg}/d\eta d\phi> = 0.67$

- 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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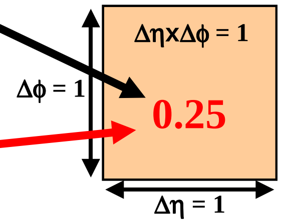
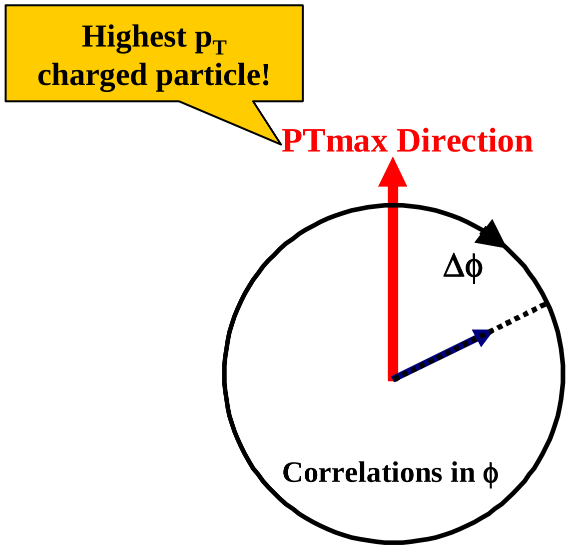
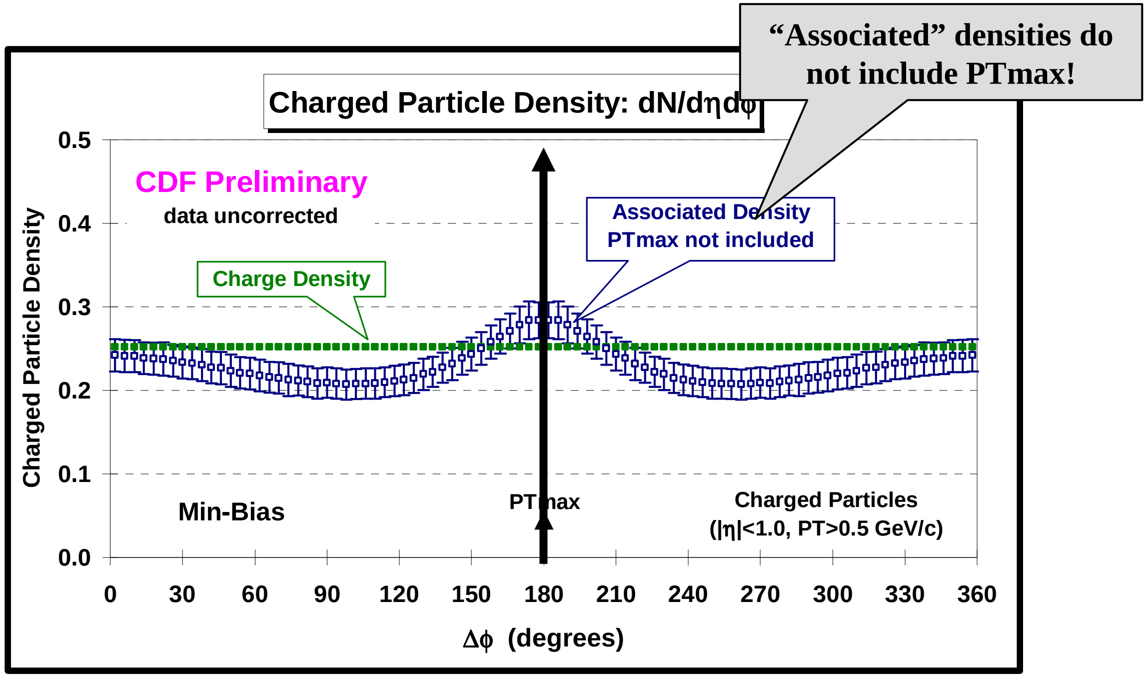
- Convert to charged particle density, $dN_{chg}/d\eta d\phi$, by dividing by 2π. There are about **0.67 charged particles per unit η-φ in "Min-Bias" collisions at 1.8 TeV (|η| < 1, all p_T)**.
- There are about **0.25 charged particles per unit η-φ in "Min-Bias" collisions at 1.96 TeV (|η| < 1, p_T > 0.5 GeV/c)**.



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

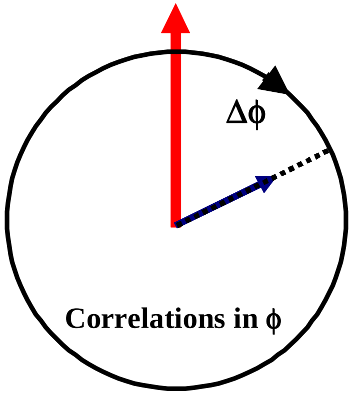




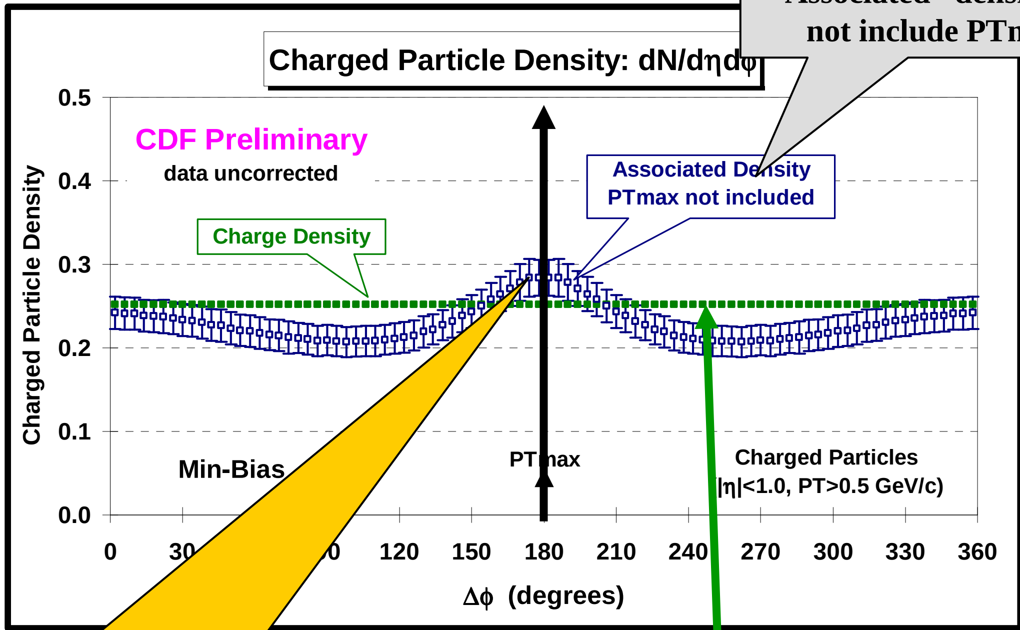
- Use the **maximum p_T charged particle in the event, PTmax**, to define a direction and look at the the "associated" density, dNchg/dηdϕ, in **"min-bias" collisions** (p_T > 0.5 GeV/c, |η| < 1).
- Shows the data on the **Δϕ dependence of the "associated" charged particle density**, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events**. **Also shown is the average charged particle density, dNchg/dηdϕ, for "min-bias" events.**

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

Highest p_T charged particle!



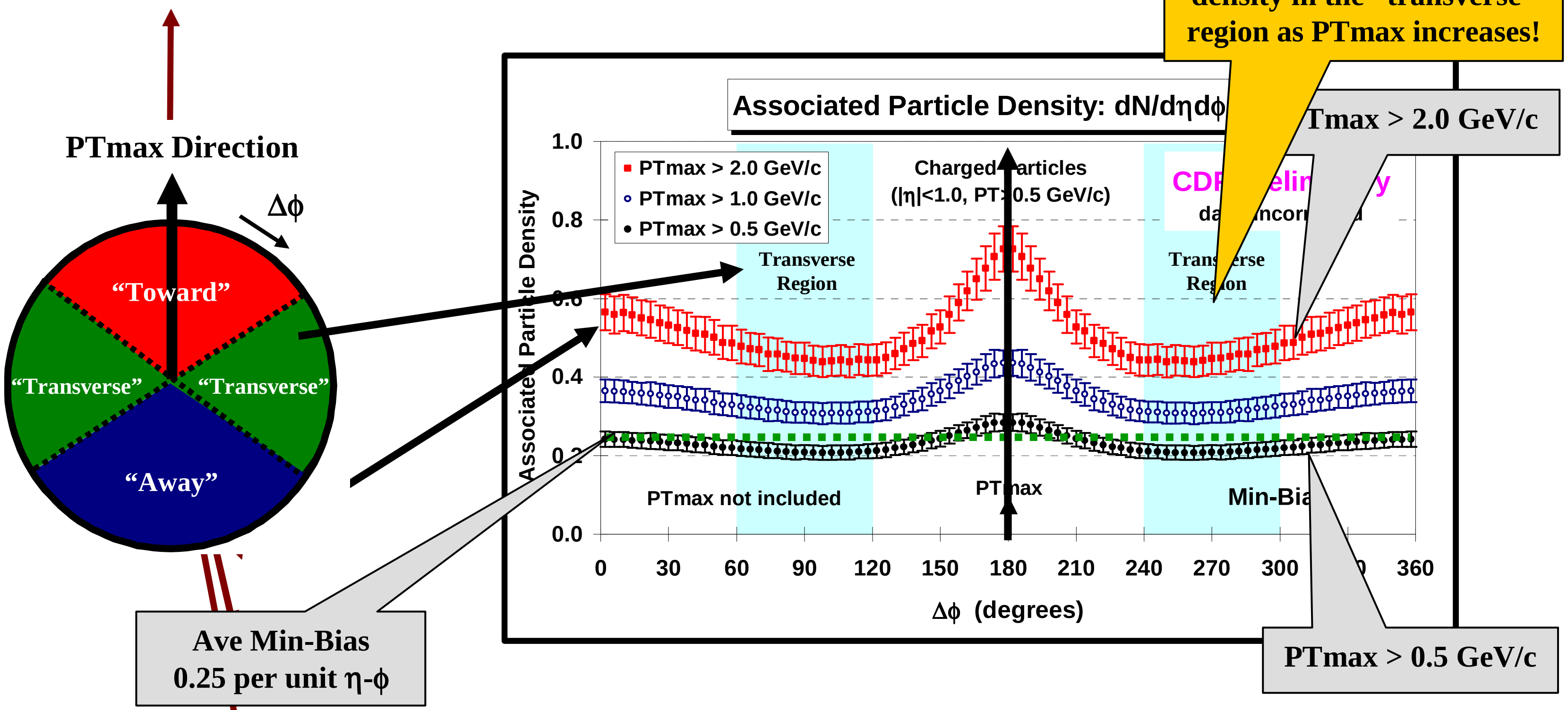
"Associated" densities do not include PTmax!



It is more probable to find a particle accompanying PTmax than it is to find a particle in the central region!

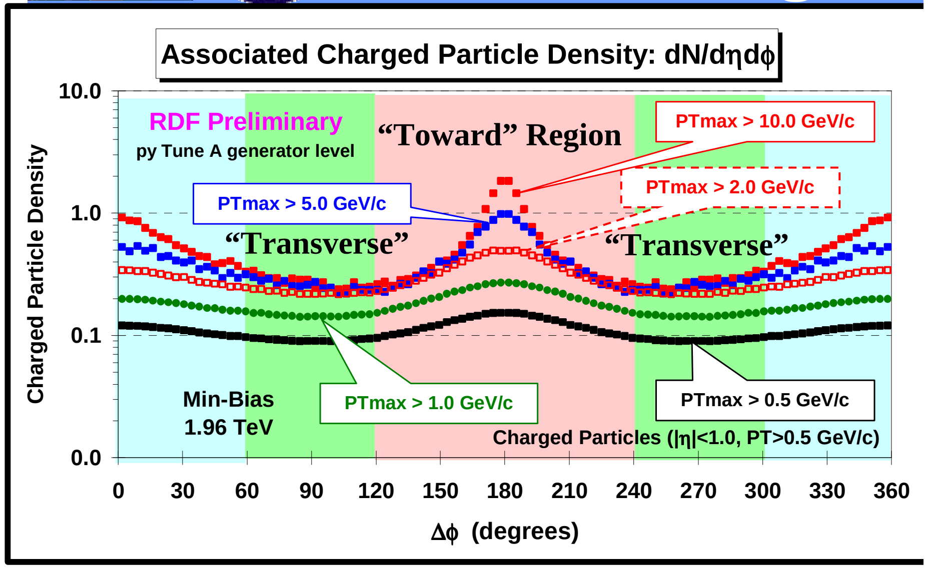
- Use the maximum p_T charged particle in the event, PTmax, to define a direction and look at the the "min-bias" collisions (p_T > 0.5 GeV/c, |η| < 1).
- Shows the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events. Also shown is the average charged particle density, $dN_{chg}/d\eta d\phi$, for "min-bias" events.

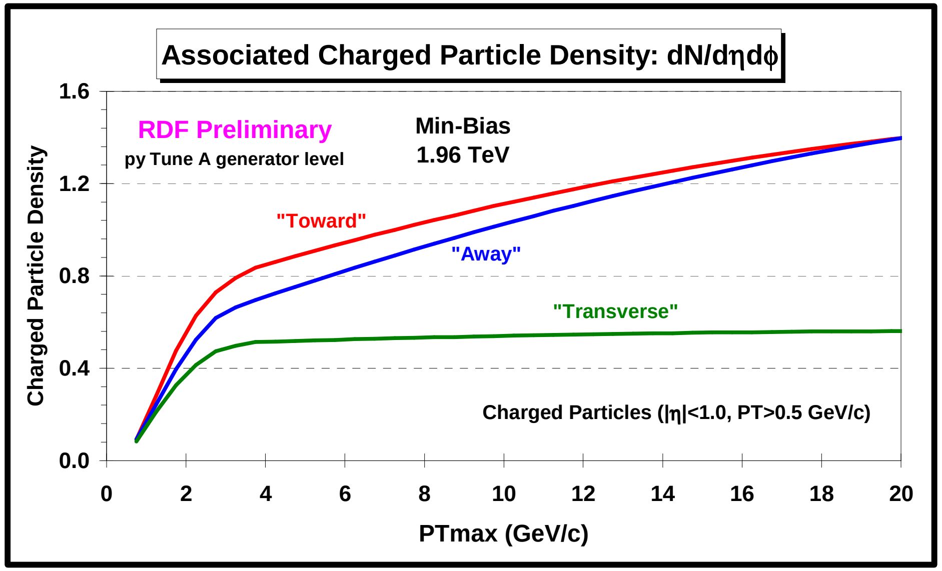
CDF Run 1 Min-Bias "Associated" Charged Particle Density



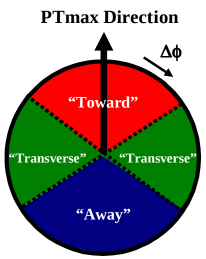
- Shows the data on the Δϕ dependence of the "associated" charged particle density, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.
- Shows "jet structure" in "min-bias" collisions (*i.e.* the "birth" of the leading two jets!).

Min-Bias "Associated" Charged Particle Density



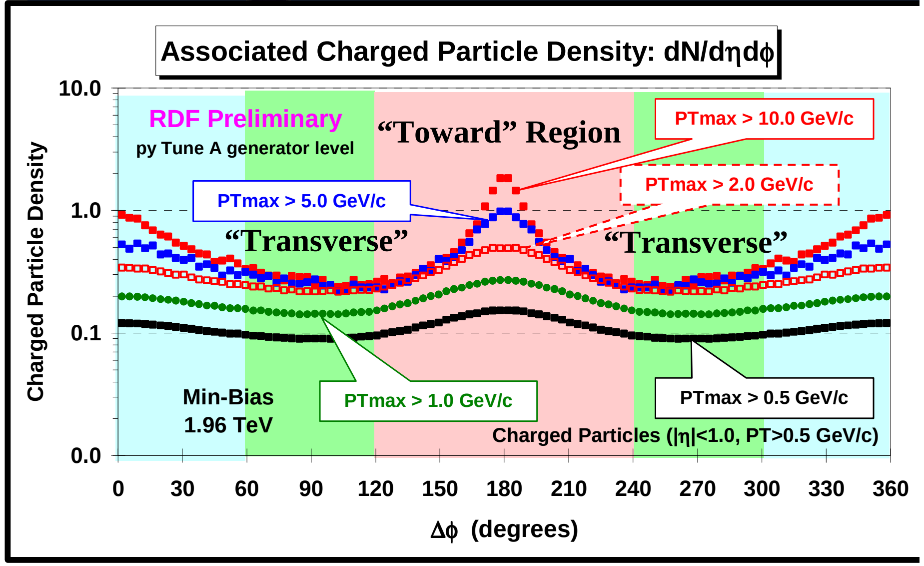


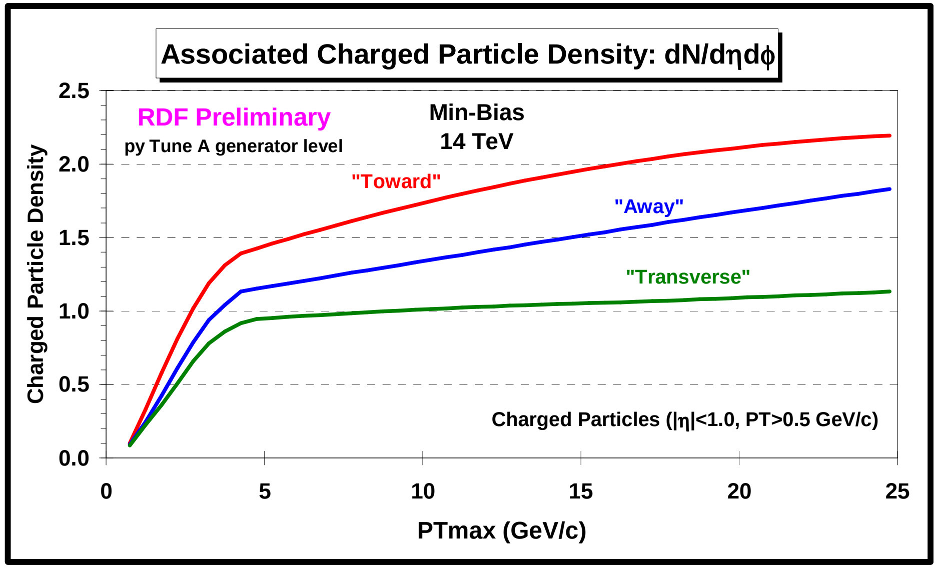
- Shows the **Δϕ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events at 1.96 TeV** with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from **PYTHIA Tune A** (generator level).



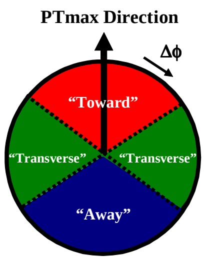
- Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) for **"min-bias" events at 1.96 TeV** from **PYTHIA Tune A** (generator level).

Min-Bias "Associated" Charged Particle Density



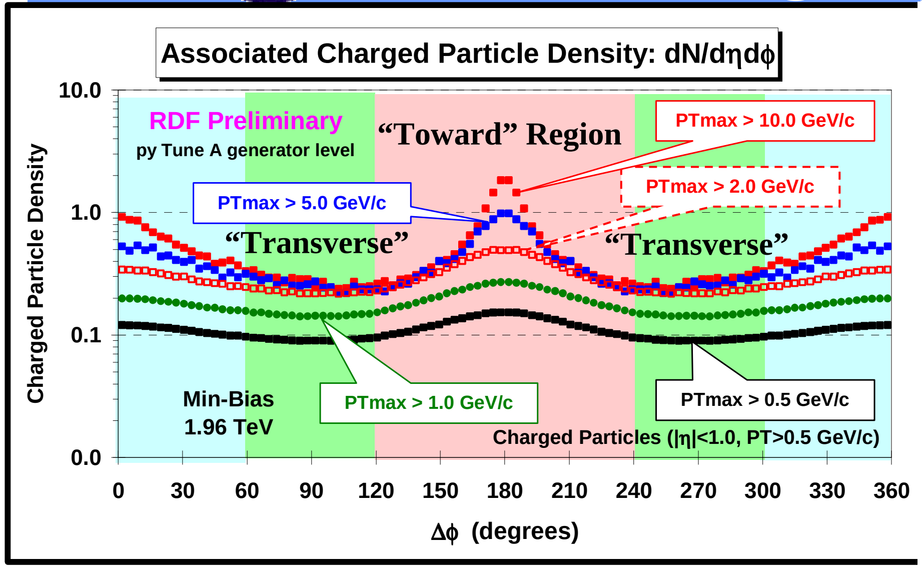


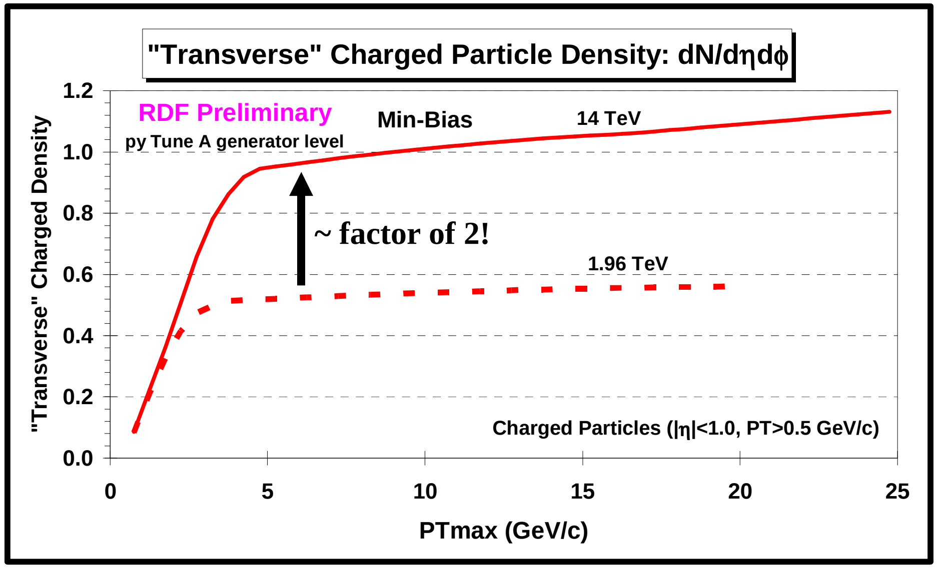
- **Shows the $\Delta\phi$ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from PYTHIA Tune A (generator level).**



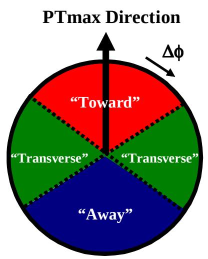
- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A (generator level).**

Min-Bias "Associated" Charged Particle Density



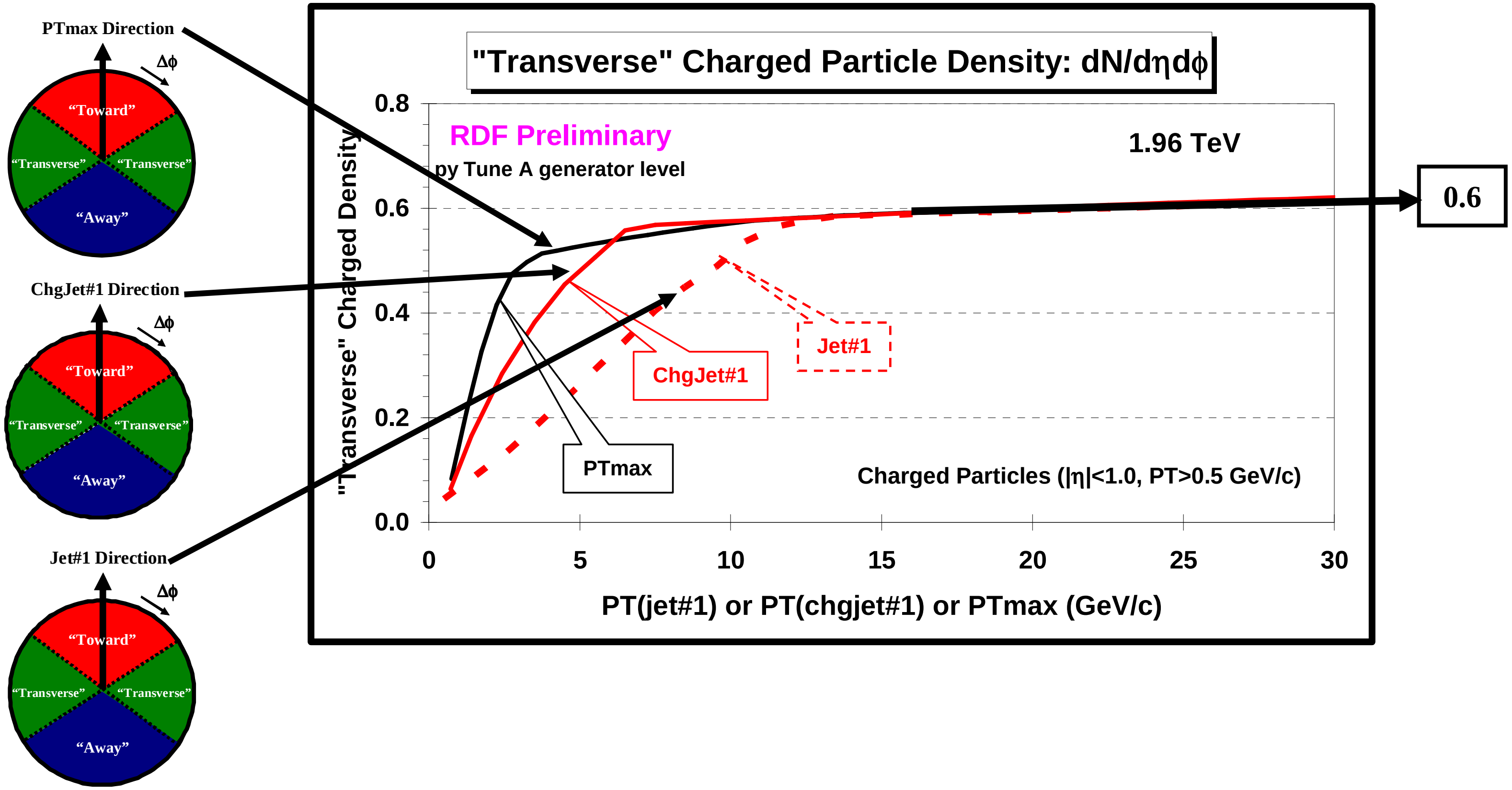


- **Shows the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from PYTHIA Tune A (generator level).**



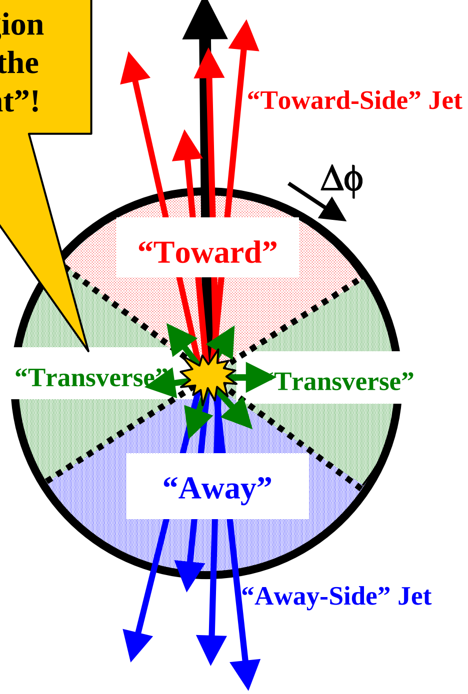
- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A (generator level).**

"Transverse" Charged Density



➡ Shows the charged particle density in the "transverse" region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) at 1.96 TeV as defined by PTmax, PT(chgjet#1), and PT(jet#1) from PYTHIA Tune A at the particle level (*i.e.* generator level).

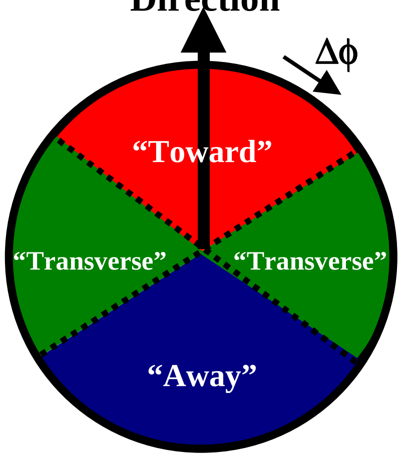
CDF Run 1: Evolution of Charged Jets "Underlying Event"



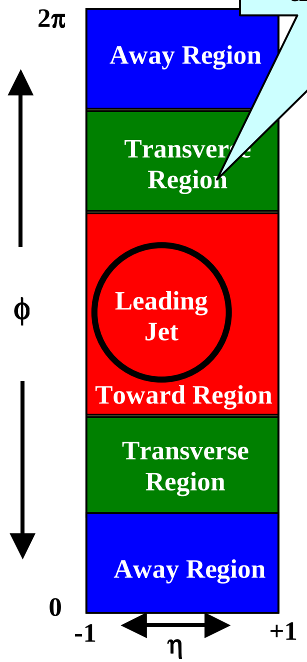
Charged Particle Δϕ Correlations

$P_T > 0.5$ GeV/c $|\eta| < 1$

CDF Run 1 Analysis

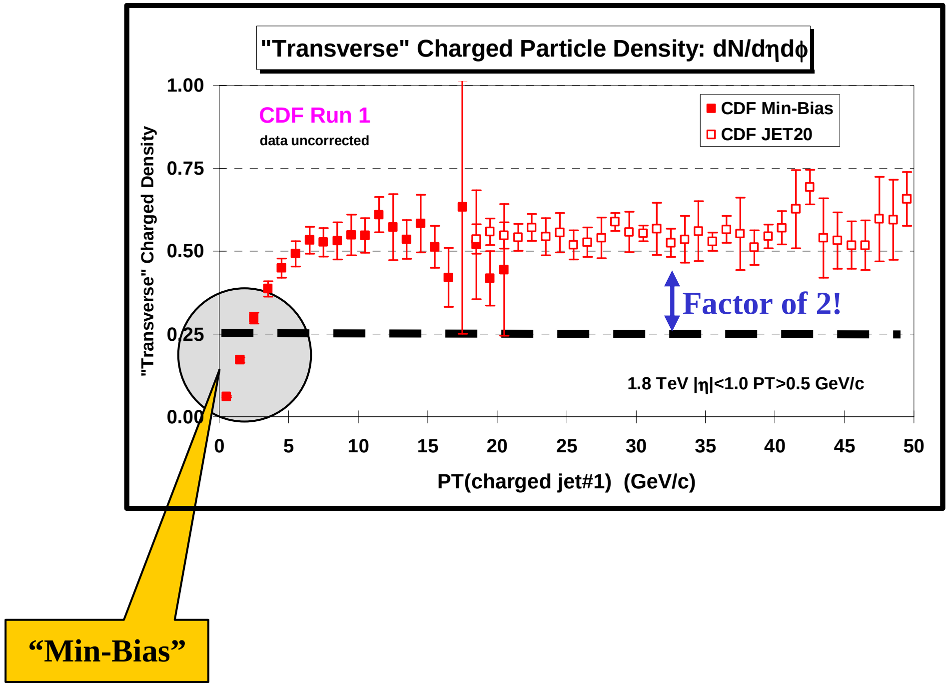


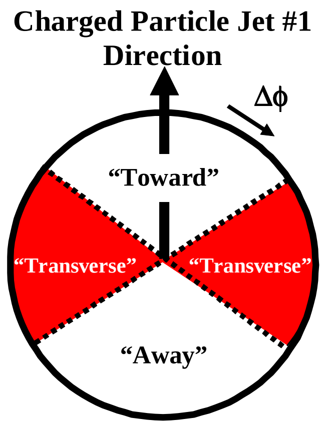
Look at the charged particle density in the "transverse" region!



- 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, $\Delta\eta \times \Delta\phi = 2 \times 120^o = 4\pi/3$.

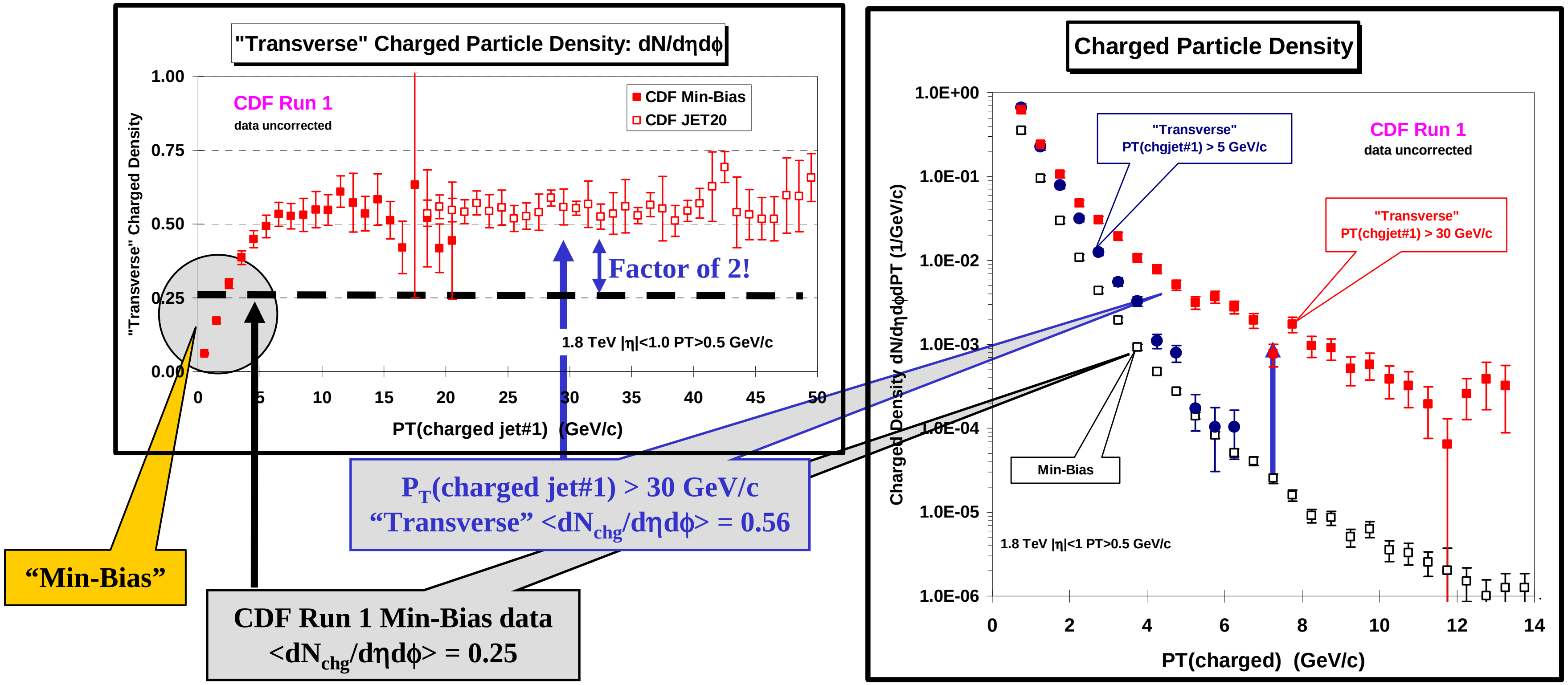
Run 1 Charged Particle Density "Transverse" p_T Distribution





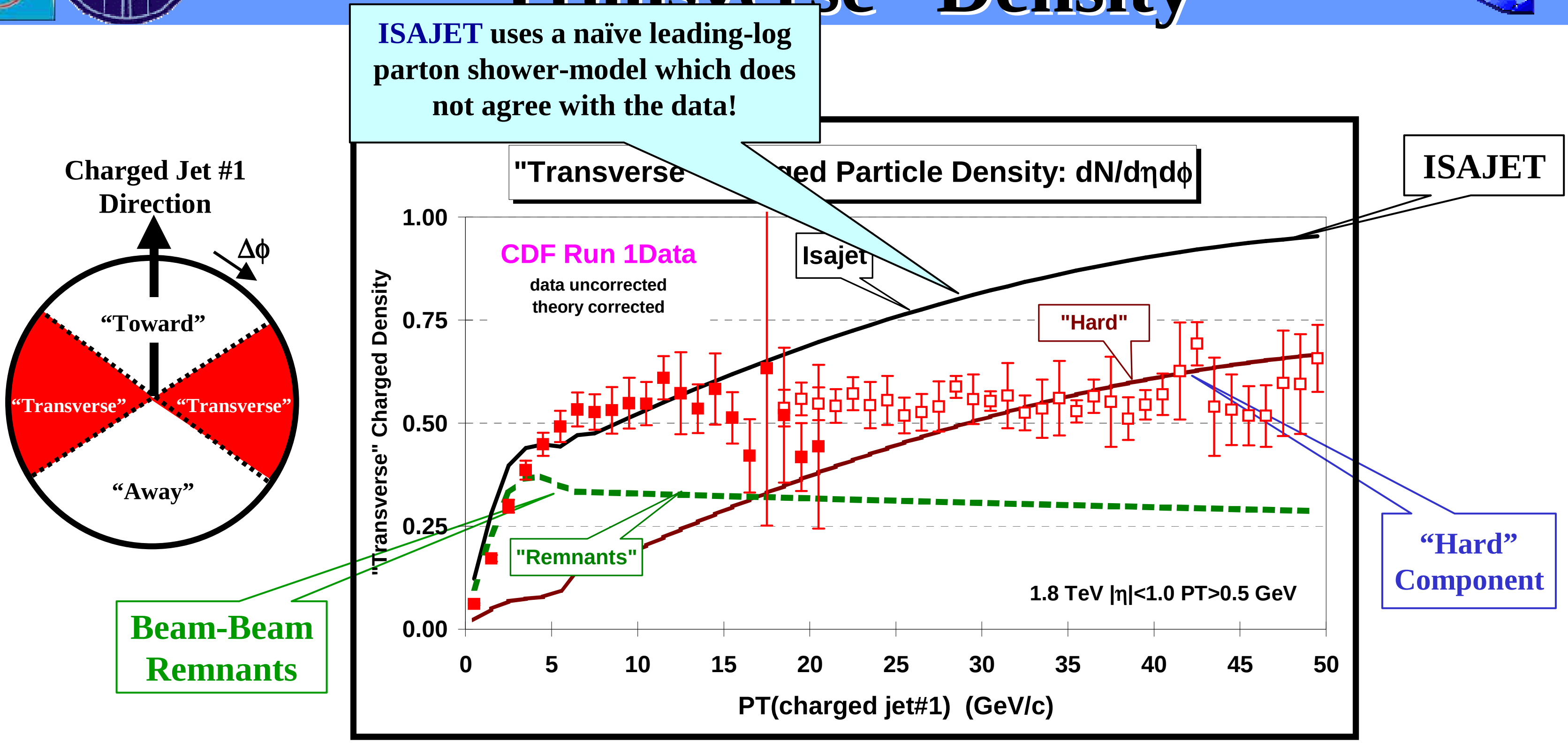
- Compares the average "transverse" charge particle density with the average "Min-Bias" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV). Shows how the "transverse" charge particle density and the Min-Bias charge particle density is distributed in p_T.

Run 1 Charged Particle Density “Transverse” p_T Distribution



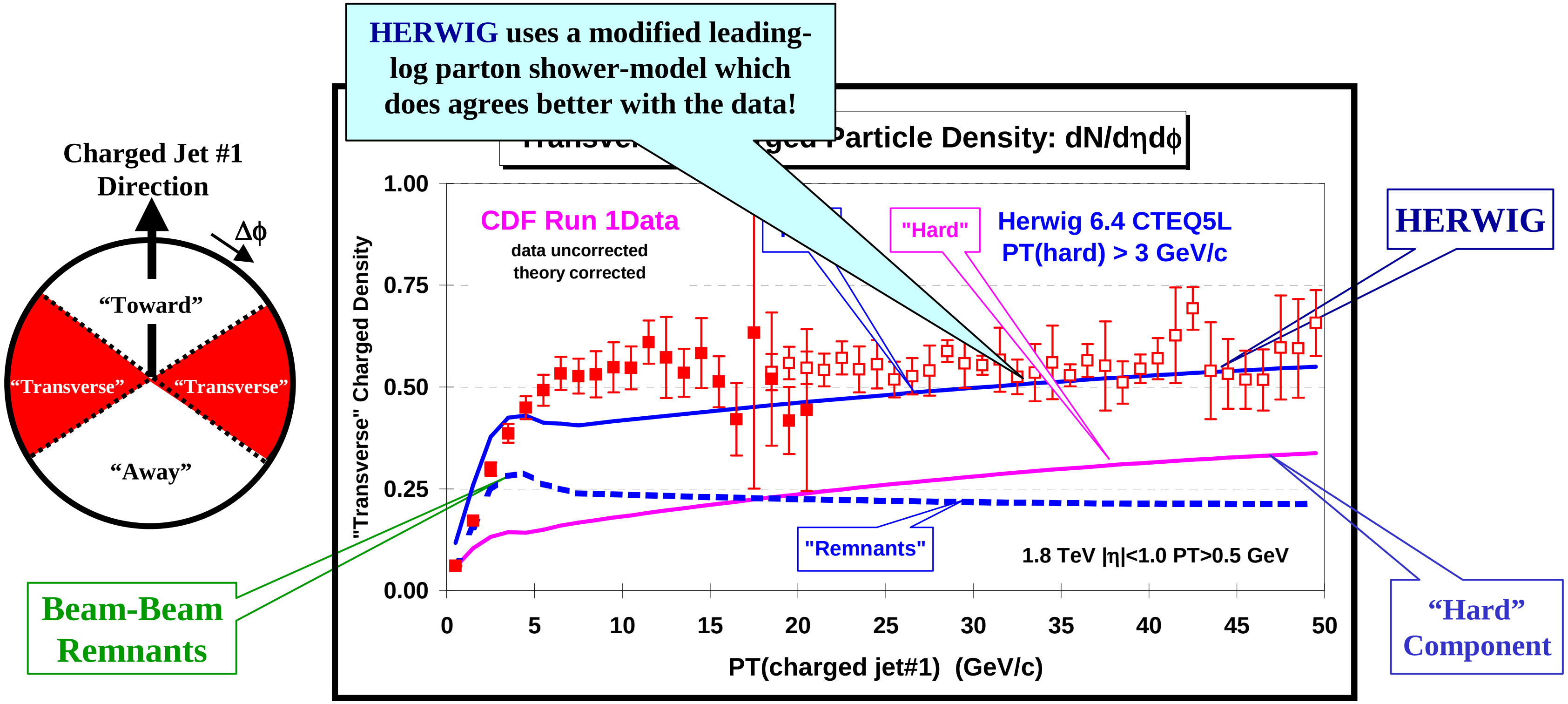
- Compares the average “transverse” charge particle density with the average “Min-Bias” charge particle density ($|\eta|<1$, $p_T>0.5$ GeV). Shows how the “transverse” charge particle density and the Min-Bias charge particle density is distributed in p_T.

ISAJET 7.32 "Transverse" Density



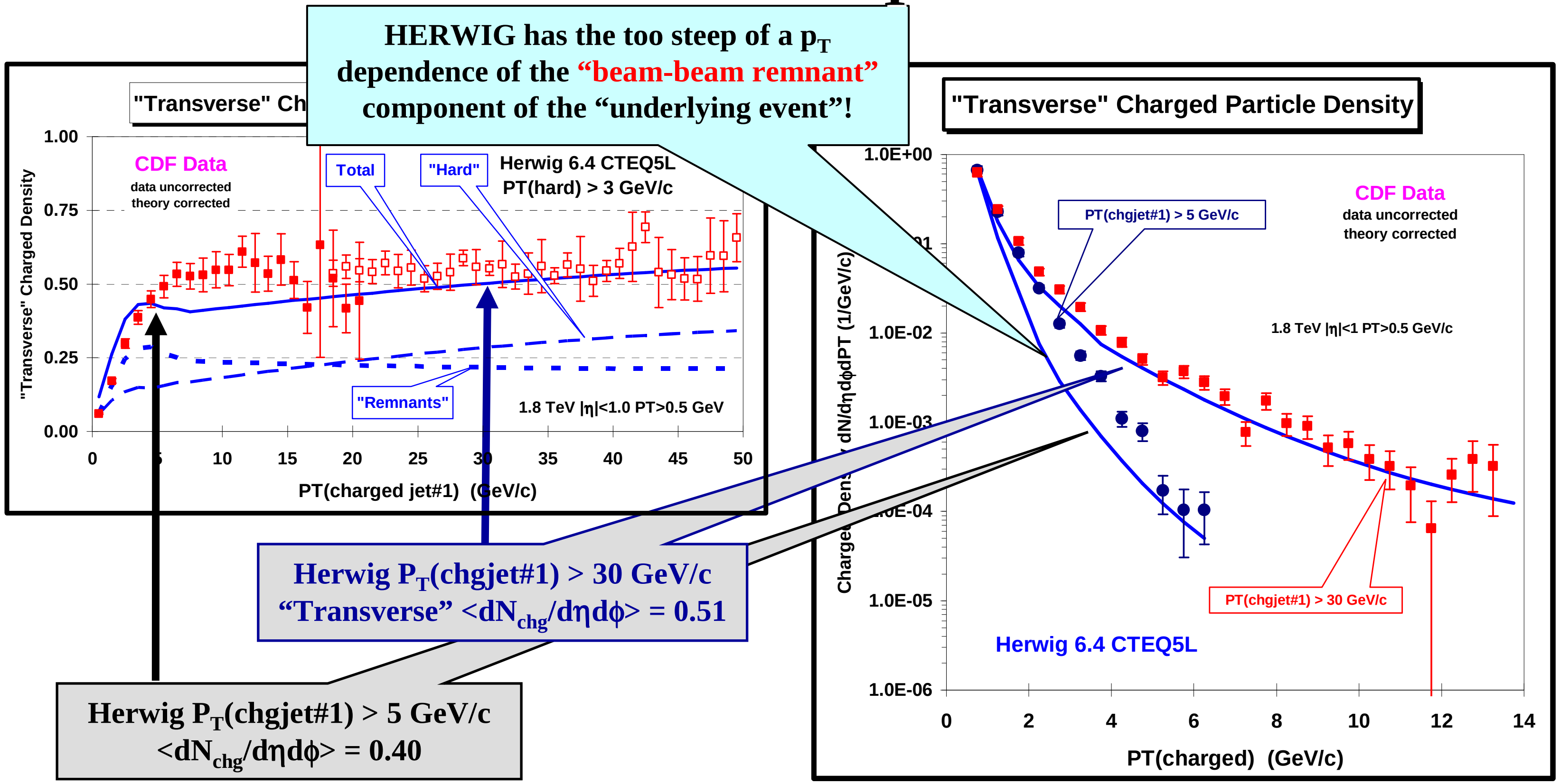
- Plot shows average "transverse" charge particle density (|η|<1, p_T>0.5 GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of ISAJET 7.32 (default parameters with P_T(hard)>3 GeV/c) .
- The predictions of ISAJET are divided into two categories: charged particles that arise 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



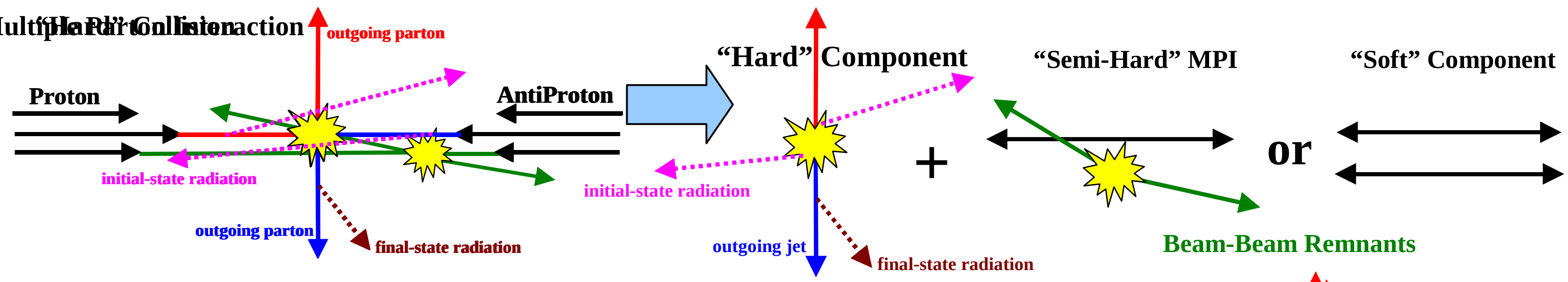
- Plot shows average "transverse" charge particle density (|η|<1, p_T>0.5 GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of **HERWIG 5.9** (default parameters with P_T(hard)>3 GeV/c).
- The predictions of HERWIG are divided into two categories: charged particles that arise 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

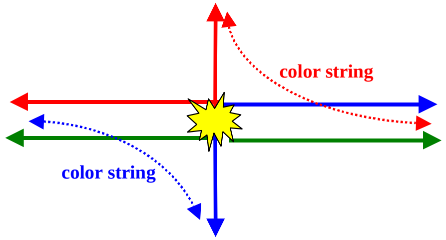


- Compares the average "transverse" charge particle density (|η|<1, p_T>0.5 GeV) versus P_T(charged jet#1) and the p_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of HERWIG 6.4 (default parameters with P_T(hard)>3 GeV/c. Shows how the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

MPI: Multiple Parton Interactions



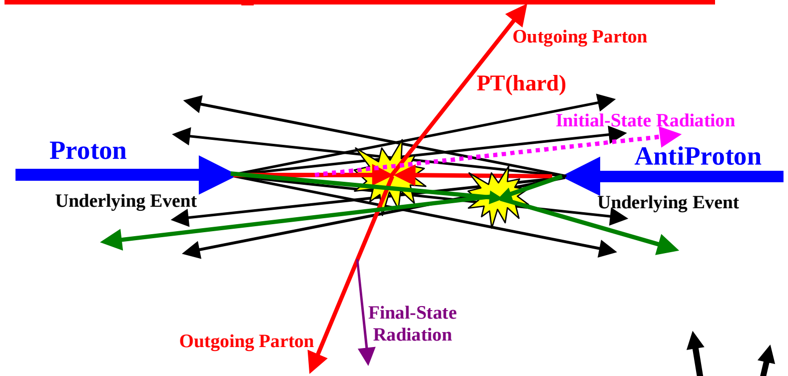
- PYTHIA models the "soft" component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (**MPI**) in which one interaction is hard and the other is "semi-hard".



- 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**).

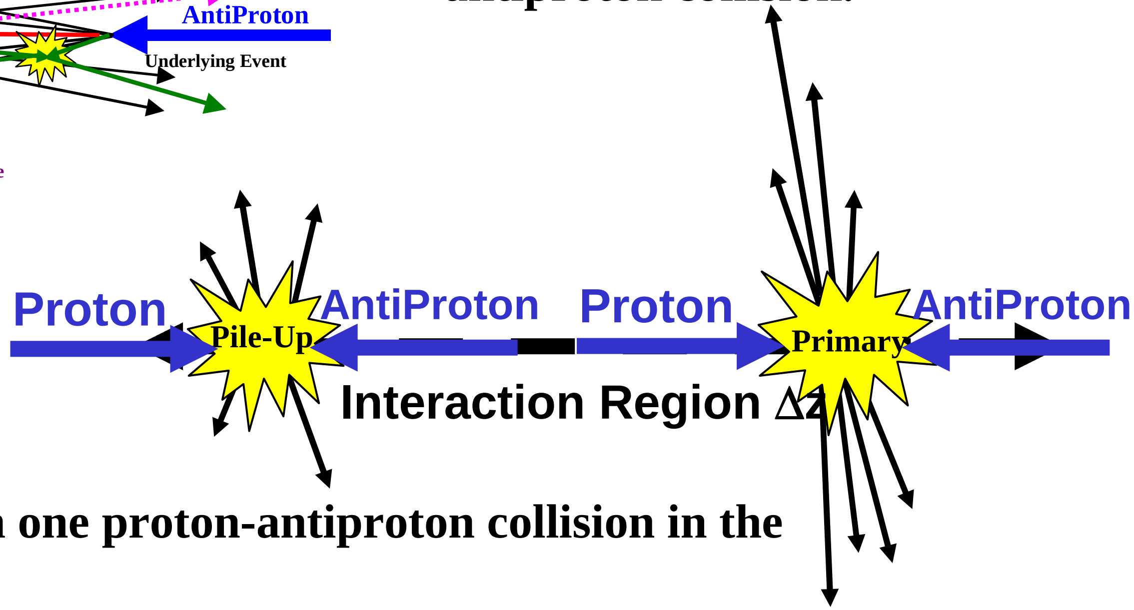
MPI, Pile-Up, and Overlap

MPI: Multiple Parton Interactions



- MPI: Additional 2-to-2 parton-parton scatterings within a single proton-antiproton collision.

Pile-Up



- Pile-Up: More than one proton-antiproton collision in the beam crossing.

Overlap

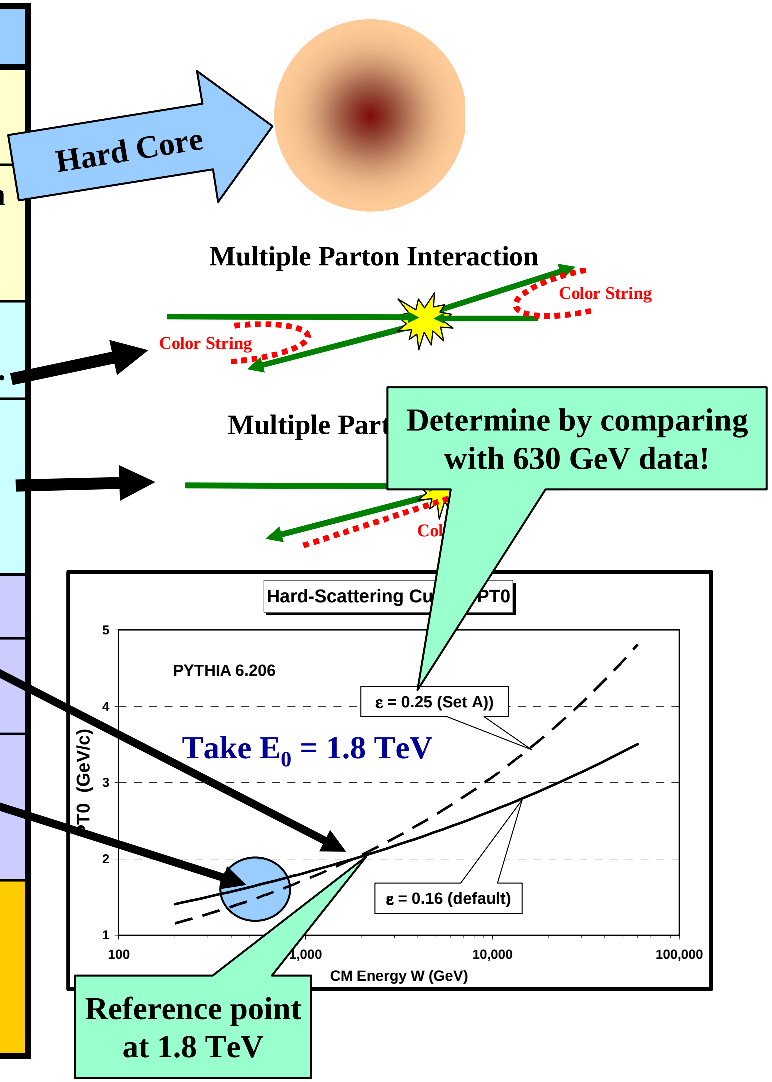
- Overlap: An experimental timing issue where a proton-antiproton collision from the next beam crossing gets included in the proton-antiproton collision from the current beam crossing because the next crossing happened before the event could be read out.

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	Pr[illegible] uces two gluons w[illegible] nearest neighbors.
PARP(86)	0.66	Prob[illegible] luons eit[illegible] s des[illegible] closed [illegible] loop. [illegible] ists of [illegible] ark-antiqua[illegible] s.
PARP(89)	1 Te[illegible]	Determin[illegible] reference energy E_0.
PARP(82)	[illegible].9 GeV/c	The c[illegible] off P_{T0} that regulates the 2-to-2 sc[illegible] ring divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
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.

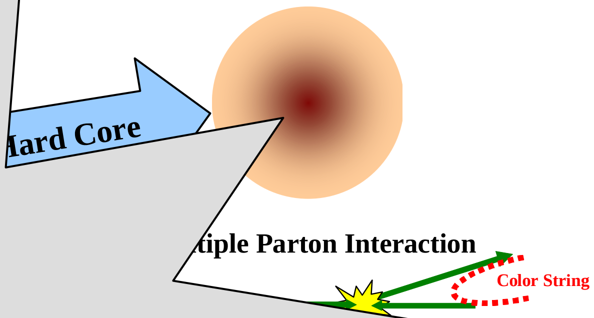
Determines the energy dependence of the MPI!

Affects the amount of initial-state radiation!



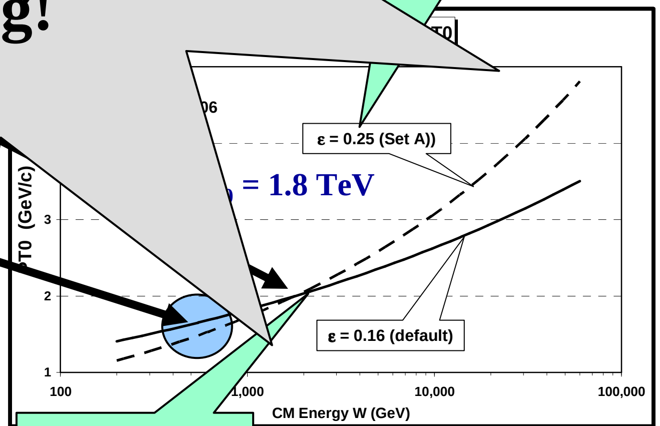
Tuning PYTHIA:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.	Double-Gaussian: Frac... total hadroni... ...r within PARP(8...
PARP(84)	0.2	...ian: Fr... ...en... ra... total
PARP(85)	0.33	P...
PARP(86)		
PARP(89)	1 Te...	
PARP(82)	... GeV/c	sc... ...ring d...
PARP(90)	0.16	Determine... ...of P_{T0} as foll... $_{T0}(E_{cm})$ ... $E_0)^\varepsilon$ w... ε = PAR... ...0)
PARP(67)	1.0	A scale factor that deter... ...he maximum parton virtuality for spa... ...e showers. The larger the value of PARP... the more initial-state radiation.



I will talk more about the energy dependence of MPI tomorrow morning!

Determine by comparing with 630 GeV data!



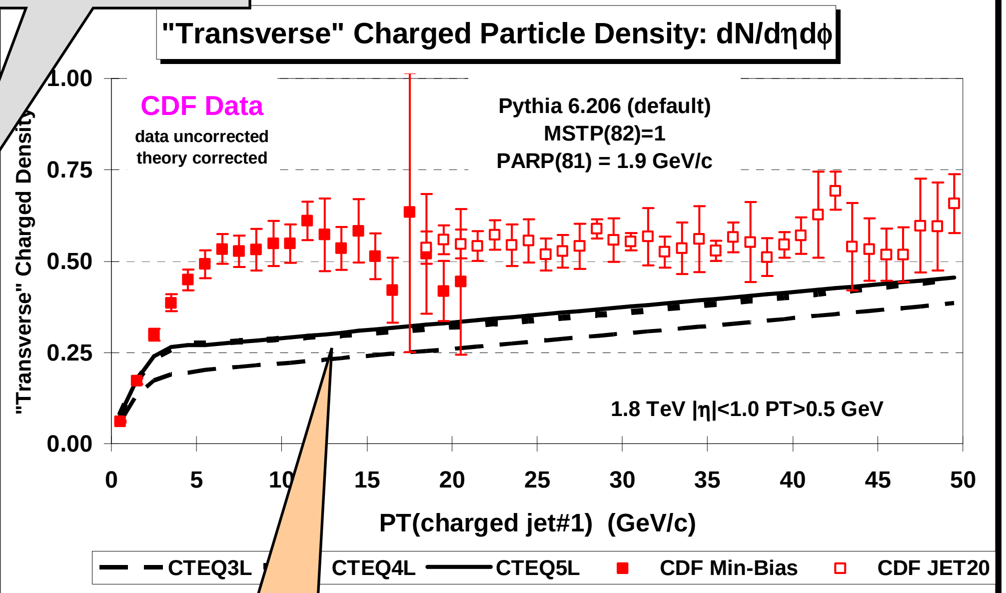
Reference point at 1.8 TeV

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

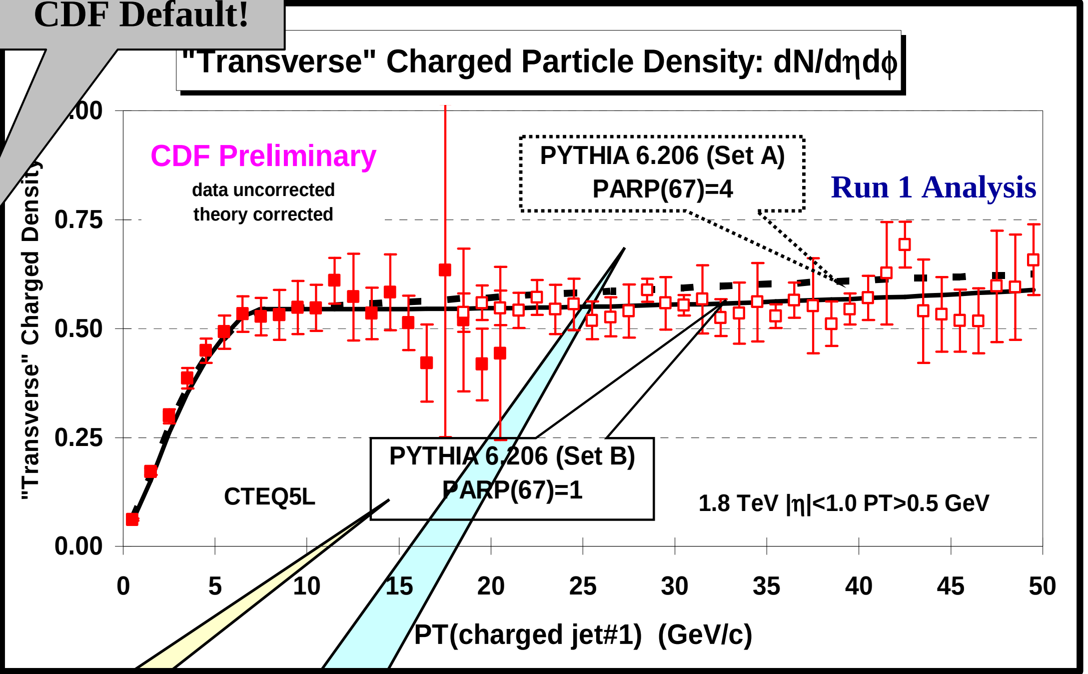
Parameter	Tune B	Tune A
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

CDF Default!

Not the default!

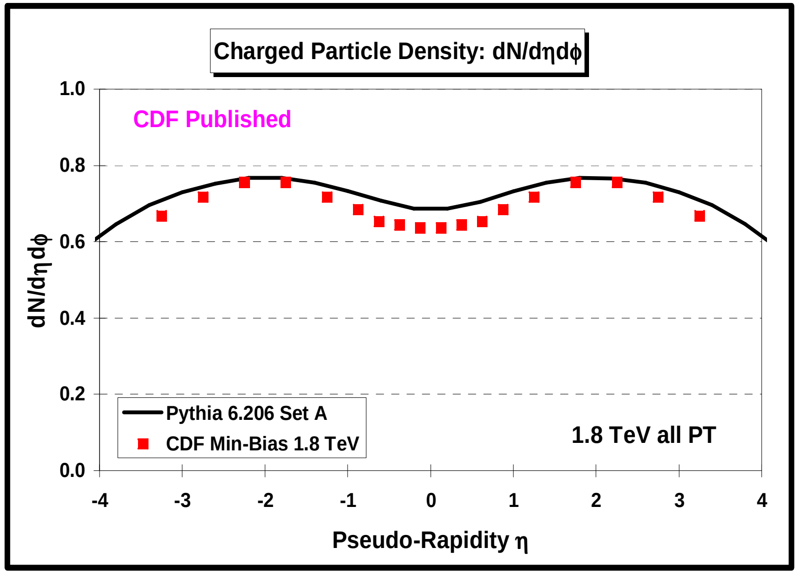
New PYTHIA default
(less initial-state radiation)

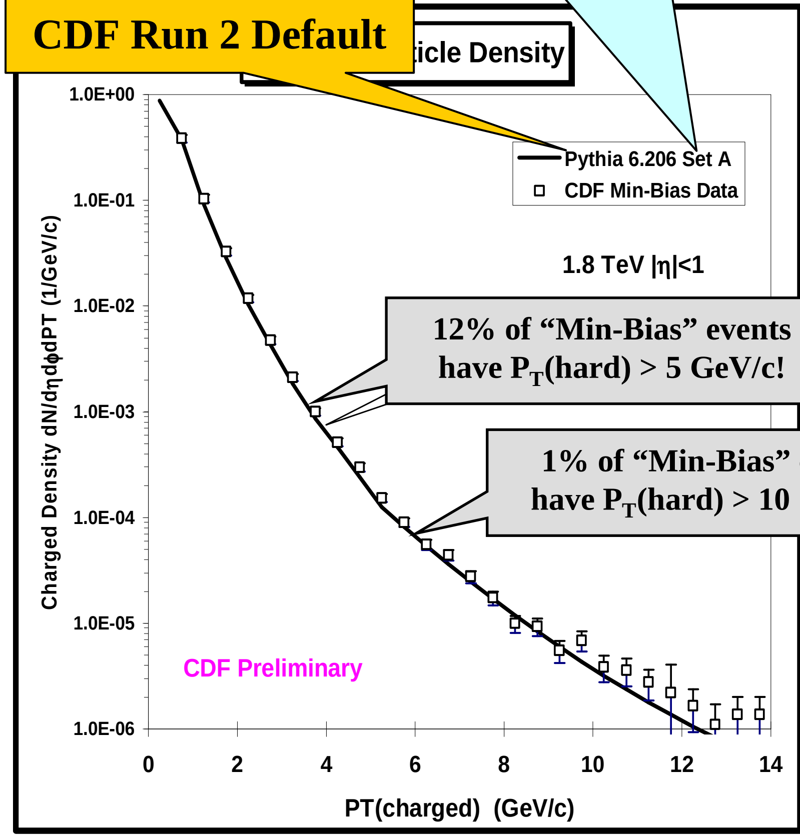
Old PYTHIA default
(more initial-state radiation)



- 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)).

PYTHIA Tune A Min-Bias "Soft" + "Hard"





PYTHIA Tune A
CDF Run 2 Default

Tuned to fit the CDF Run 1 "underlying event"!

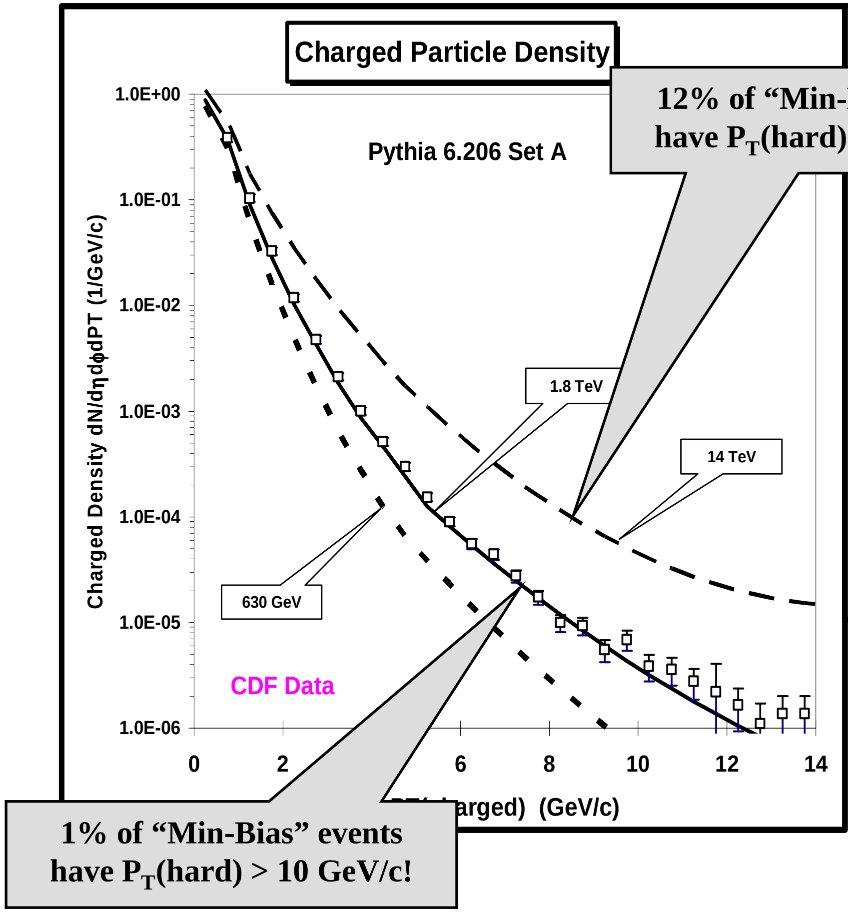
12% of "Min-Bias" events have P_T(hard) > 5 GeV/c!

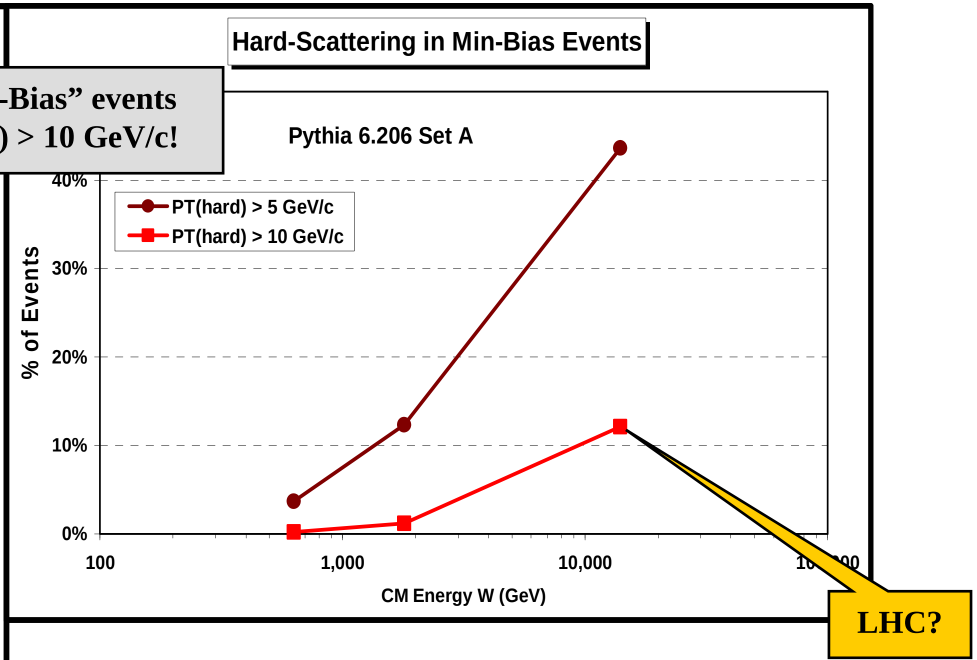
1% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

Lots of "hard" scattering in "Min-Bias" at the Tevatron!

- PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off parameters which allow one to run with P_T(hard) > 0. One can simulate both "hard" and "soft" collisions in one program.
- The relative amount of "hard" versus "soft" depends on the cut-off and can be tuned.
- This PYTHIA fit predicts that 12% of all "Min-Bias" events are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 5 GeV/c (1% with P_T(hard) > 10 GeV/c)!

PYTHIA Tune A
LHC Min-Bias Predictions





- Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions compared with PYTHIA Tune A with P_T(hard) > 0.

- PYTHIA Tune A predicts that 1% of all "Min-Bias" events at 1.8 TeV are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 10 GeV/c which increases to 12% at 14 TeV!

“Towards”, “Away”, “Transv

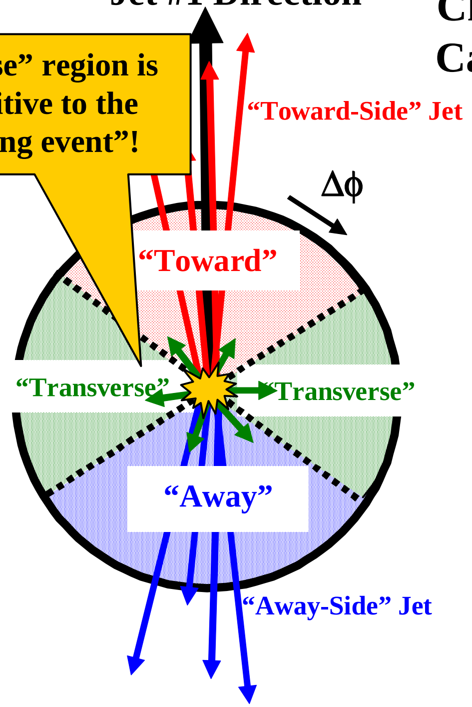
Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

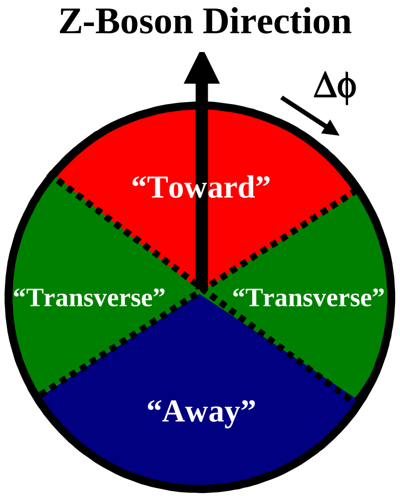
$\Delta\phi$ Correlations relative to the leading jet

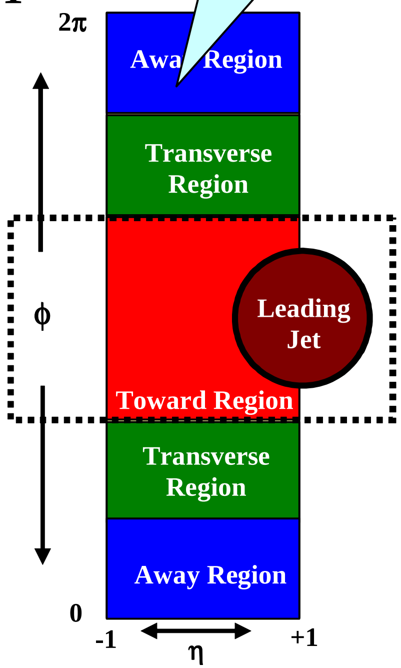
Charged particles $p_T > 0.5$ GeV/c $|\eta| < 1$

Calorimeter towers $E_T > 0.1$ GeV $|\eta| < 1$

“Transverse” region is very sensitive to the “underlying event”!



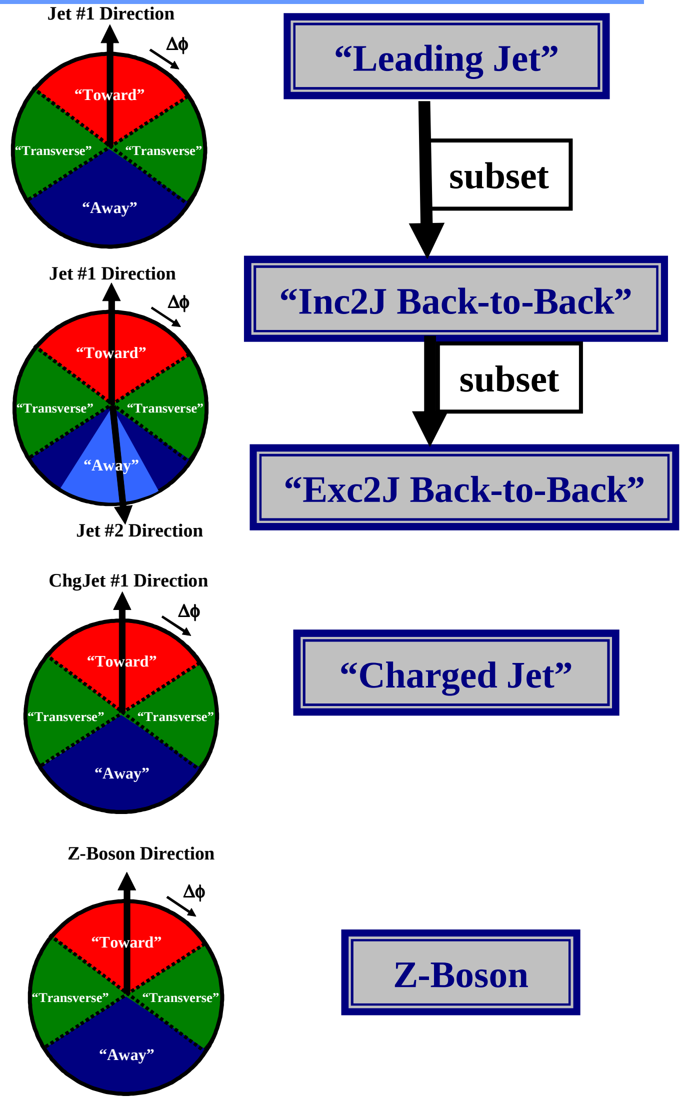




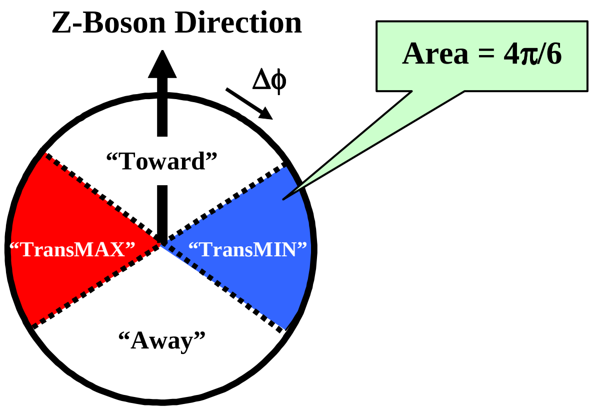
- Look at correlations in the azimuthal angle $\Delta\phi$ relative to the leading charged particle jet ($|\eta| < 1$) or the leading calorimeter jet ($|\eta| < 2$).
- Define $|\Delta\phi| < 60^{o}$ as “Toward”, $60^{o} < |\Delta\phi| < 120^{o}$ as “Transverse ”, and $|\Delta\phi| > 120^{o}$ as “Away”.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

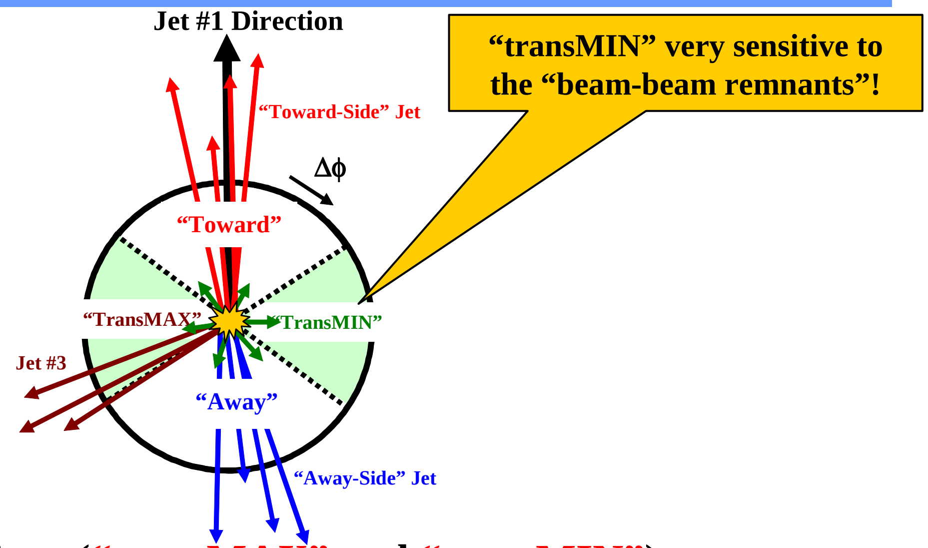
Event Topologies

- **"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.

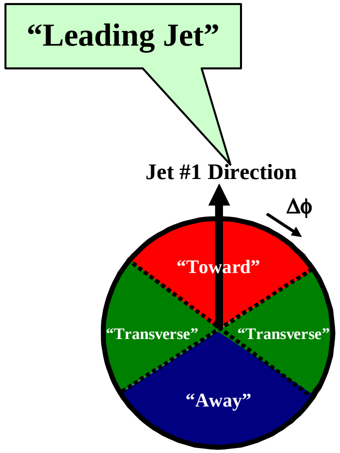


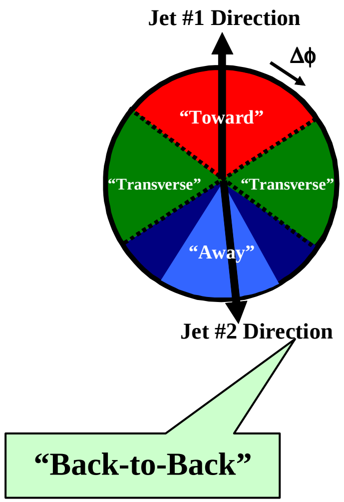
"transMAX" & "transMIN"





- **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.**





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

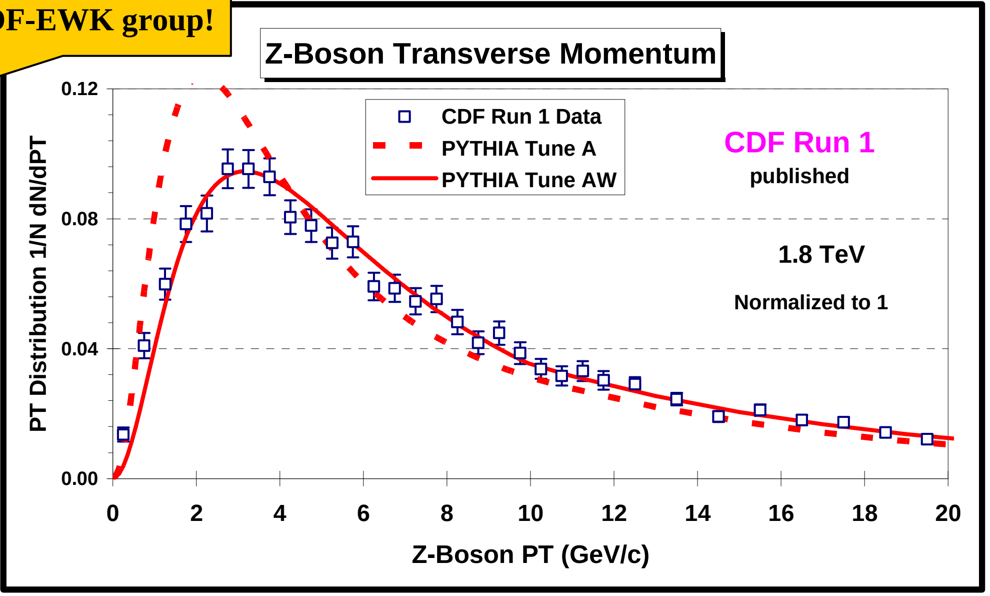
Tune used by the CDF-EWK group!

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



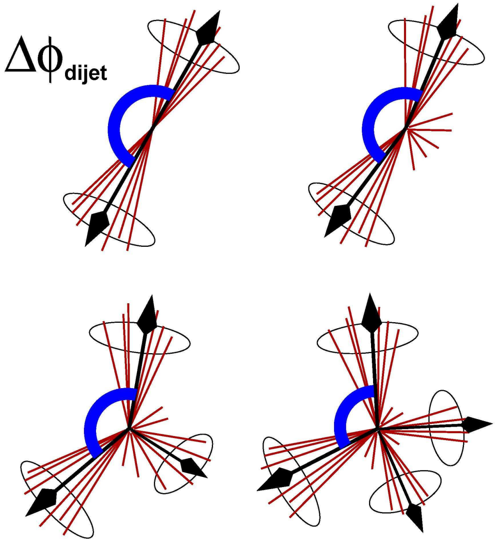
- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($<p_T(Z)> = 9.7$ GeV/c), and PYTHIA Tune AW ($<p_T(Z)> = 11.7$ GeV/c).

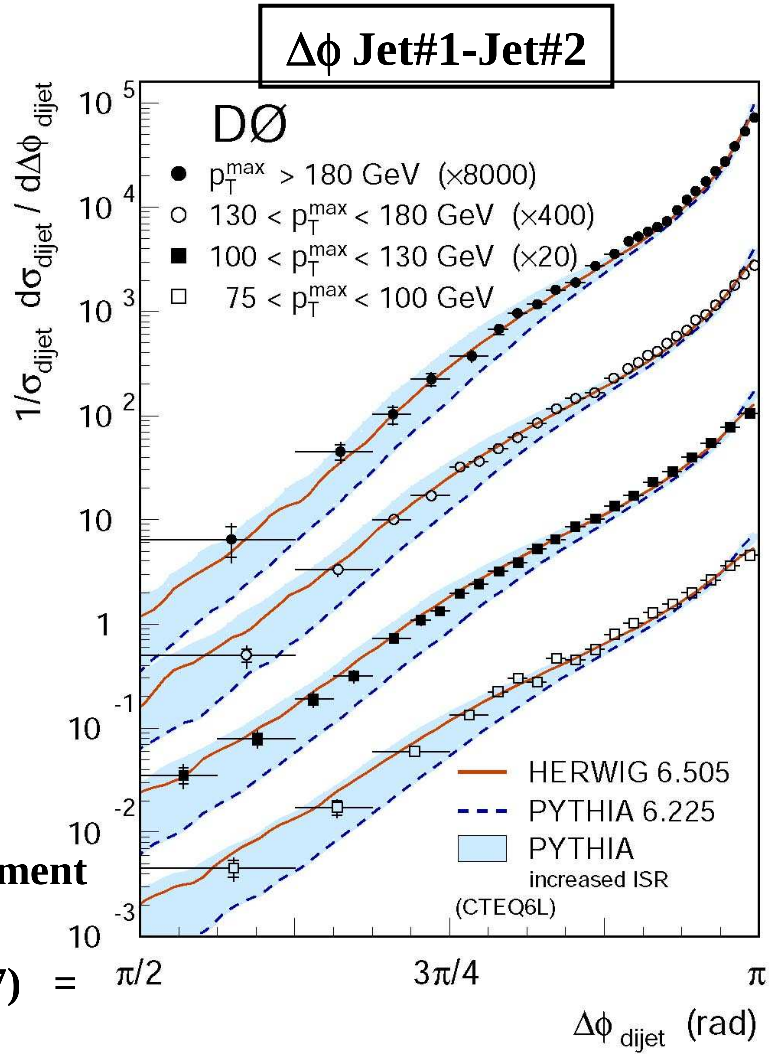
Effective Q cut-off, below which space-like showers are not evolved.

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





- **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 $P_T(Z)$

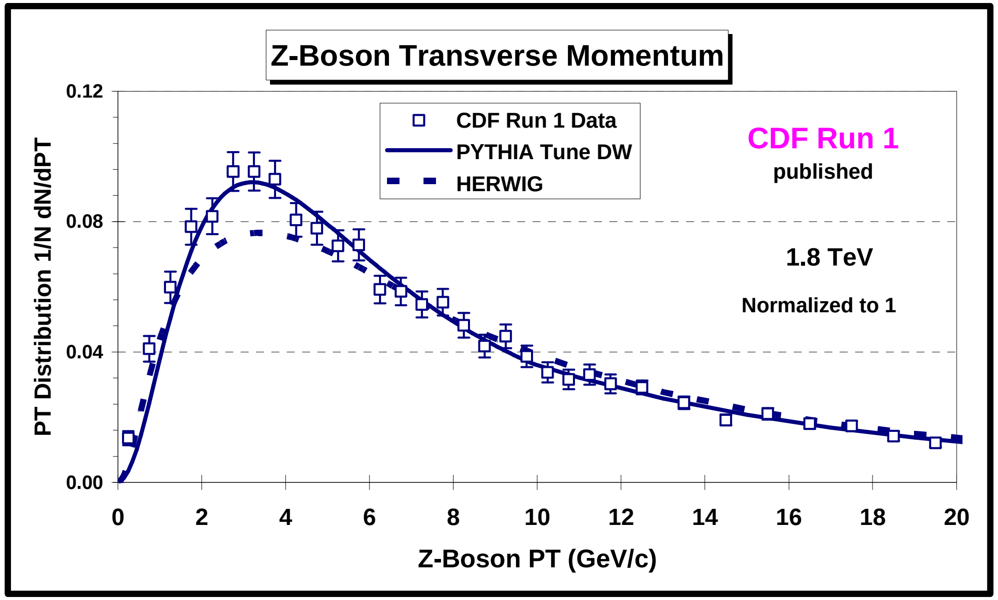
PYTHIA 6.2 CTEQ5L

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	[illegible]

UE Parameters

ISR Parameters

Intrensic KT



- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ 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!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

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

UE Parameters

ISR Parameter

Intrinsic KT

Uses CTEQ6L

Tune A energy dependence! (not the default)

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

ATLAS energy dependence! (PYTHIA default)

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

[illegible]arameter

ATLAS energy dependence! (PYTHIA default)

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
[illegible]	1.9409 GeV	1.8387 [illegible]eV	1.8 GeV
[illegible]	0.5	[illegible]	0.5
[illegible]	0.4	[illegible]	[illegible]5
[illegible]	1.0	[illegible]	[illegible].33
[illegible]5)	1.0	1.[illegible]	[illegible]66
[illegible]ARP([illegible]9)	1.96 TeV	1.96 T[illegible]V	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.[illegible]	0.2	1.0
PARP(6[illegible]	[illegible]	2.5	1.0
MSTP(91)	[illegible]	1	[illegible]
PARP(9[illegible]	[illegible]	2.1	[illegible]
PAR[illegible]	[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!

UE Parameters

Parameter	Tune DWT	Tune D6T
PDF	CT[illegible]	CTEQ6L
MSTP(81)		1
MSTP(82)		4

S energy dependence!

Tune A

Tune BW

Tune D

Tune D6

Tune D6T

These are "old" PYTHIA 6.2 tunes!

There are new 6.420 tunes by

Peter Skands (Tune S320, update of S0)

Peter Skands (Tune N324, N0CR)

Hendrik Hoeth (Tune P329, "Professor")

JIMMY at CDF

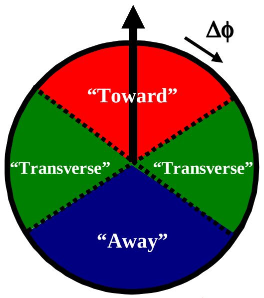
JIMMY
Runs with HERWIG and adds multiple parton interactions!

PT(JIM)= 2.5 GeV/c.

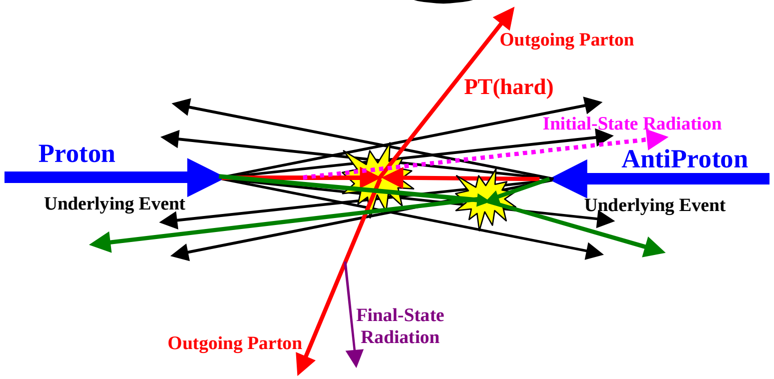
JIMMY was tuned to fit the energy density in the "transverse" region for "leading jet" events!

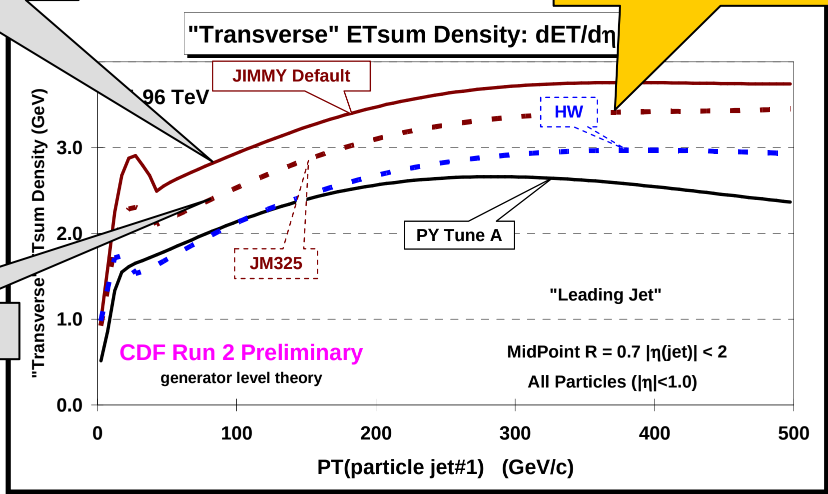
The Energy in the "Underlying Event" in High P_T Jet Production

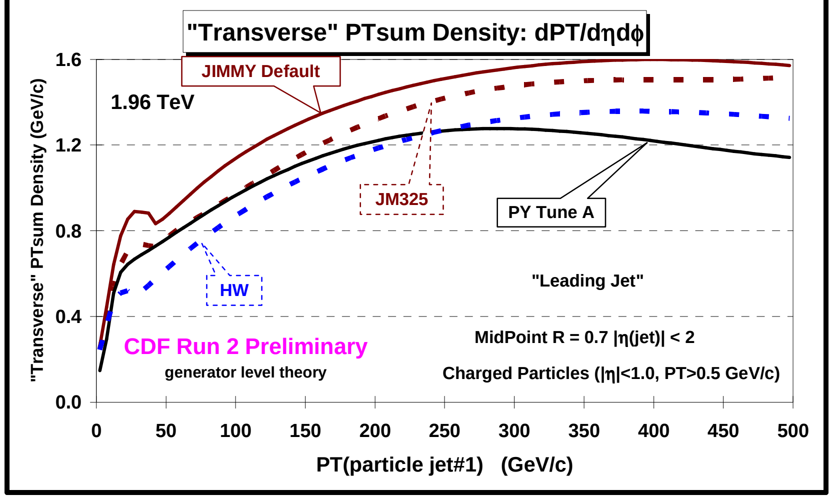
JIMMY: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour



PT(JIM)= 3.25 GeV/c.







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

JIMMY at CDF

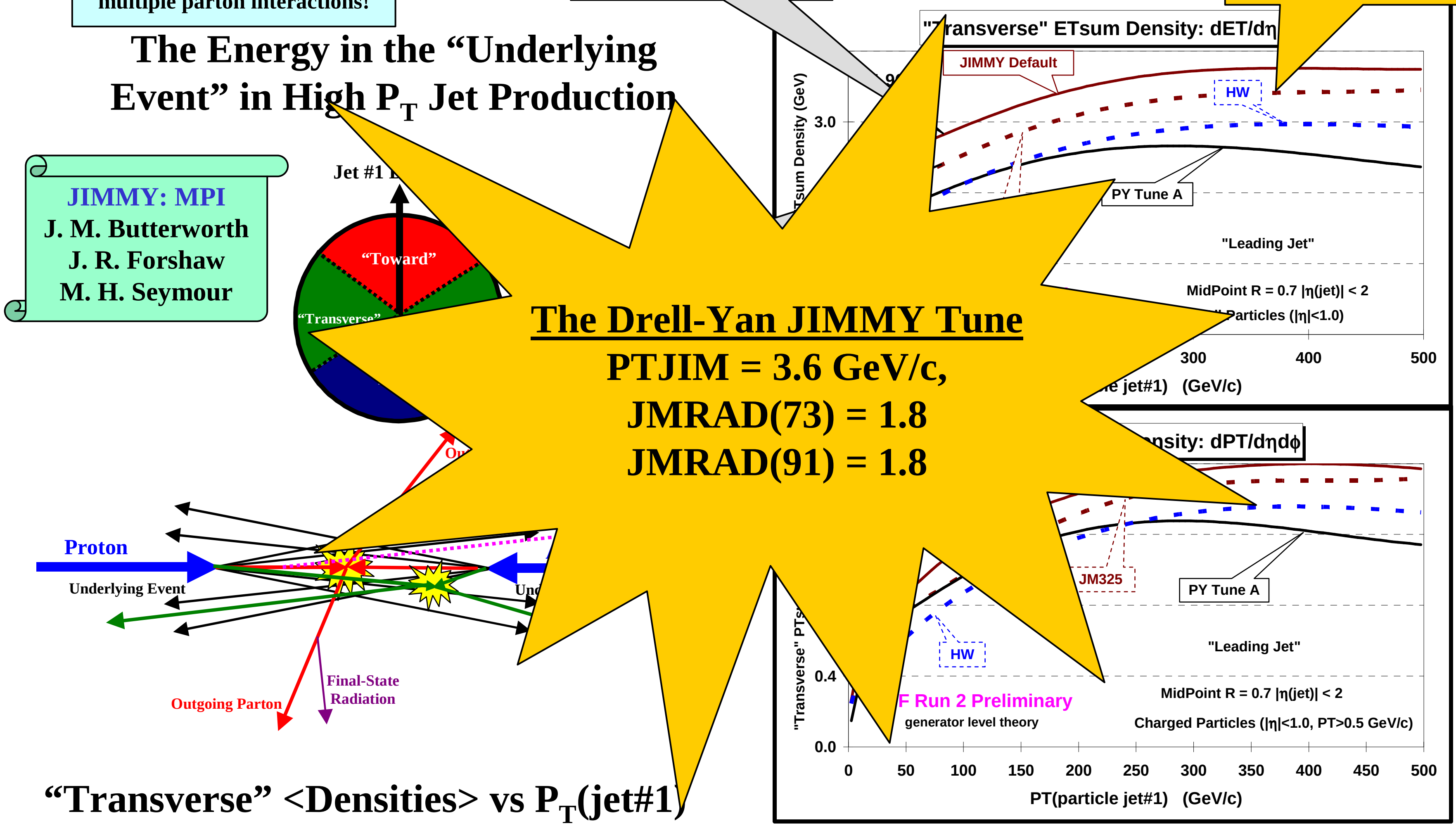
JIMMY
Runs with HERWIG and adds multiple parton interactions!

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

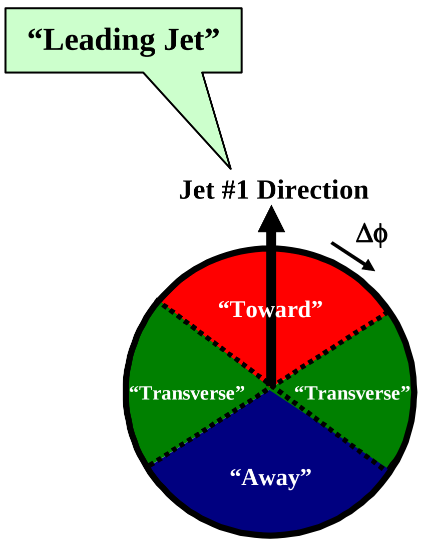
JIMMY: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

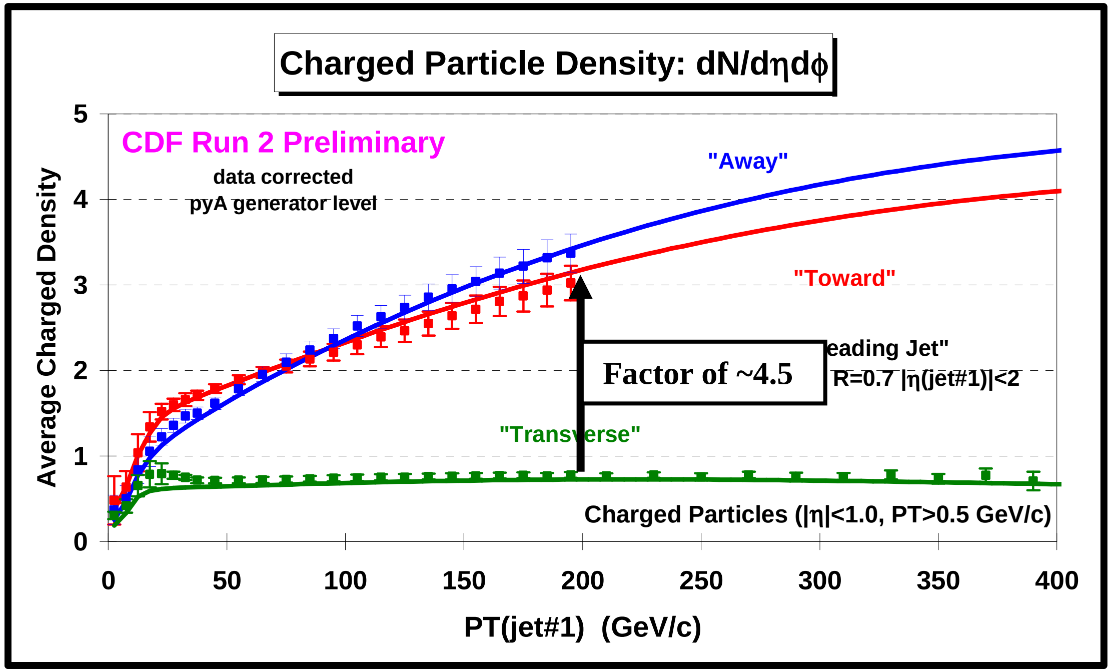


The Drell-Yan JIMMY Tune
PTJIM = 3.6 GeV/c,
JMRAD(73) = 1.8
JMRAD(91) = 1.8

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

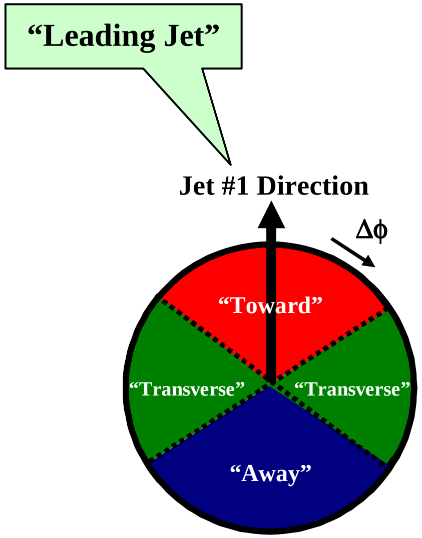
“Towards”, “Away”, “Transverse”

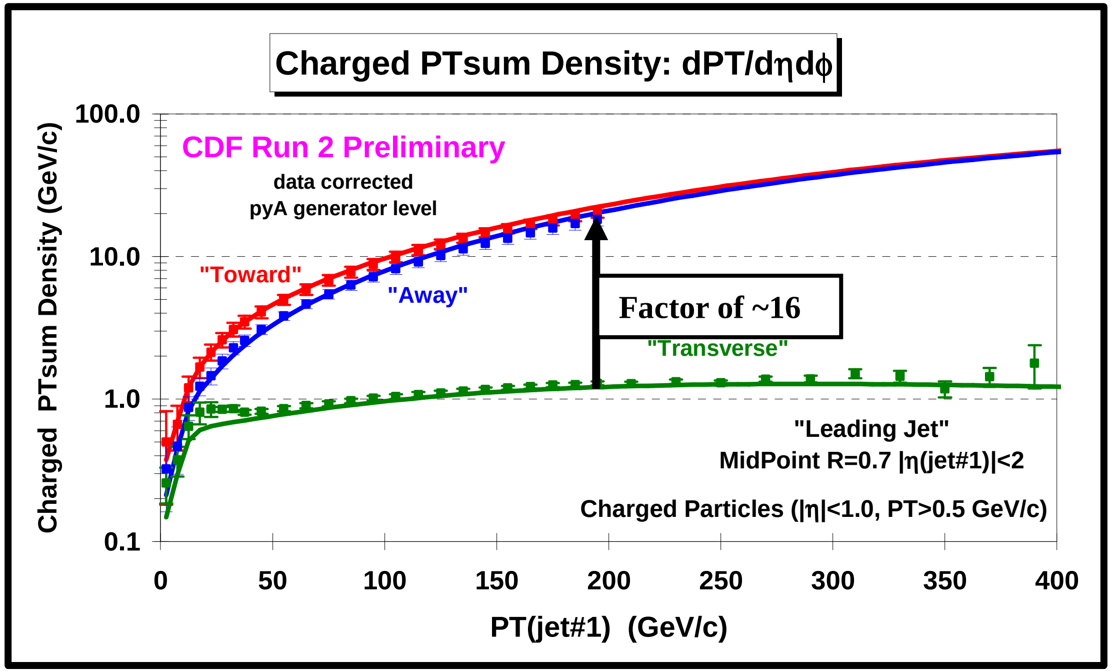




- Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical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

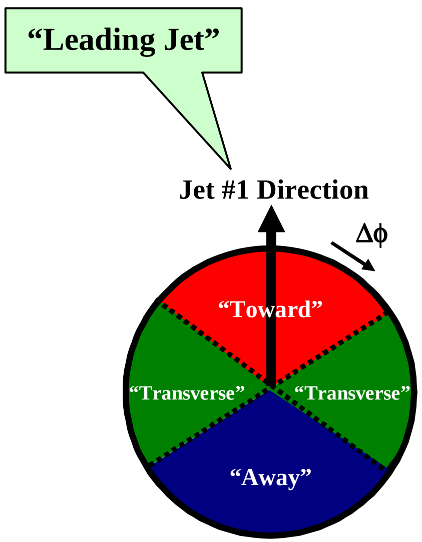
“Towards”, “Away”, “Transverse”

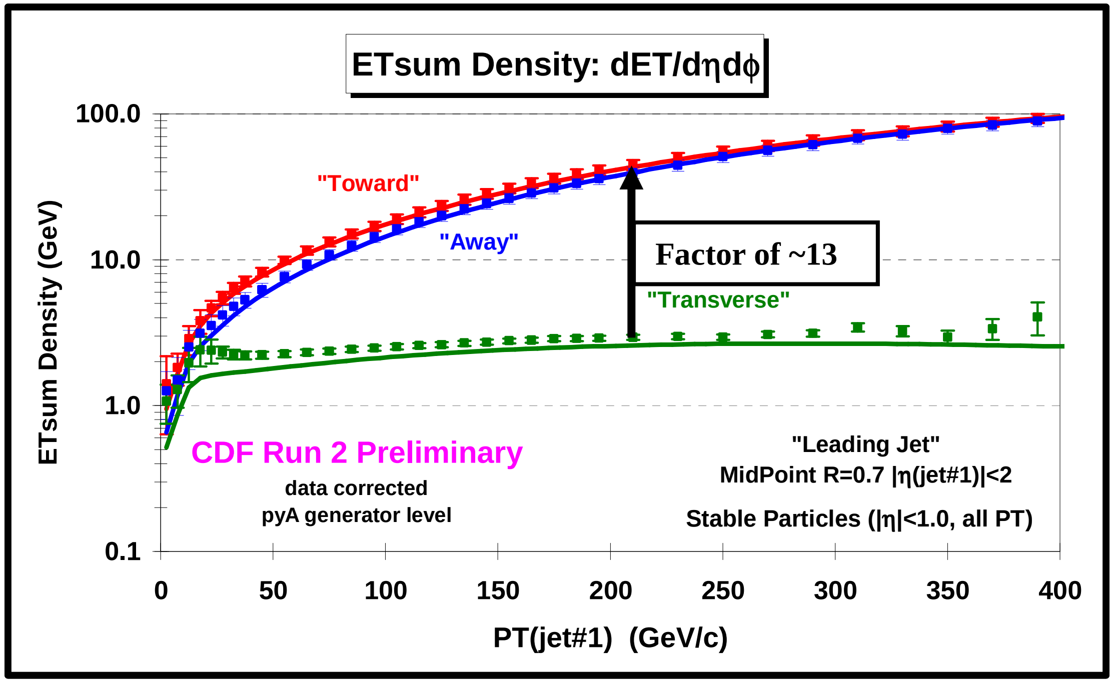




- Data at 1.96 TeV on the charged particle *scalar* p_T sum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).

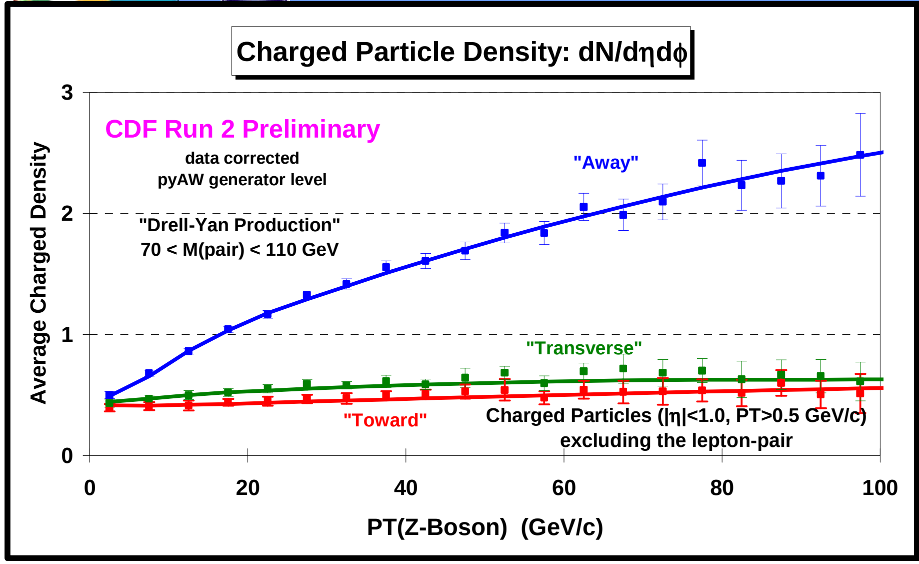
"Towards", "Away", "Transverse"

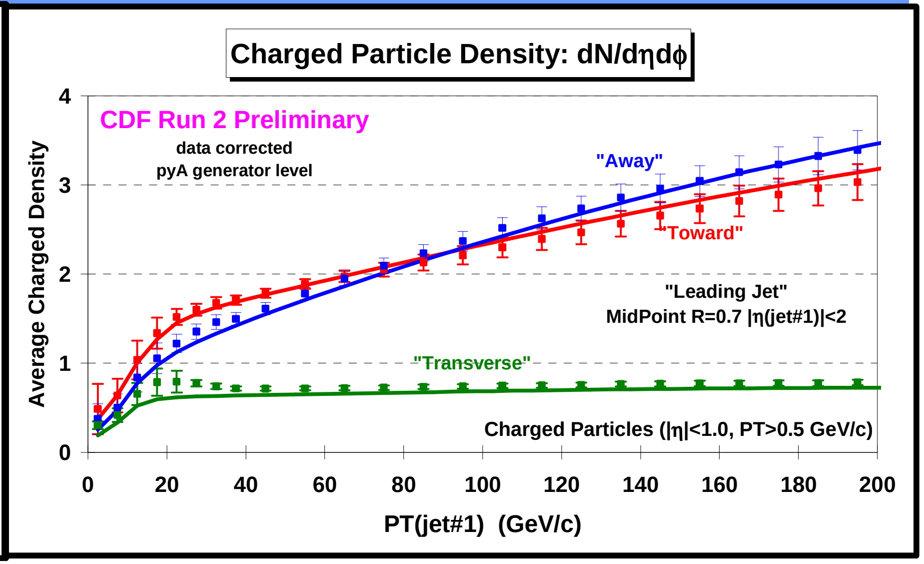


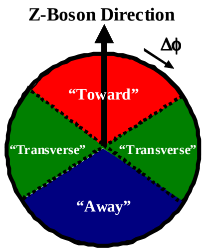


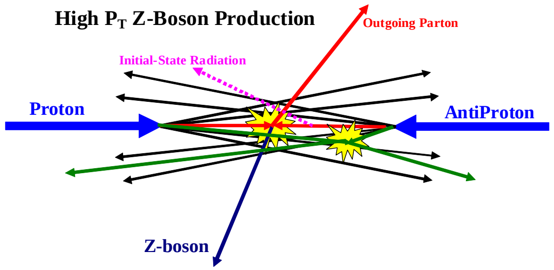
- **Data at 1.96 TeV on the particle *scalar* E_T sum density, dET/dηdϕ, for |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).**

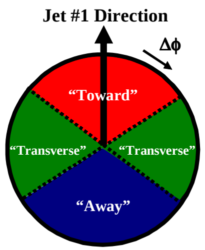
Charged Particle Density

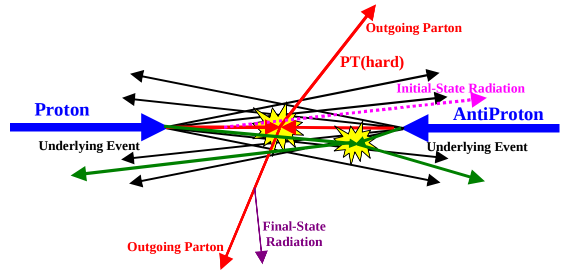






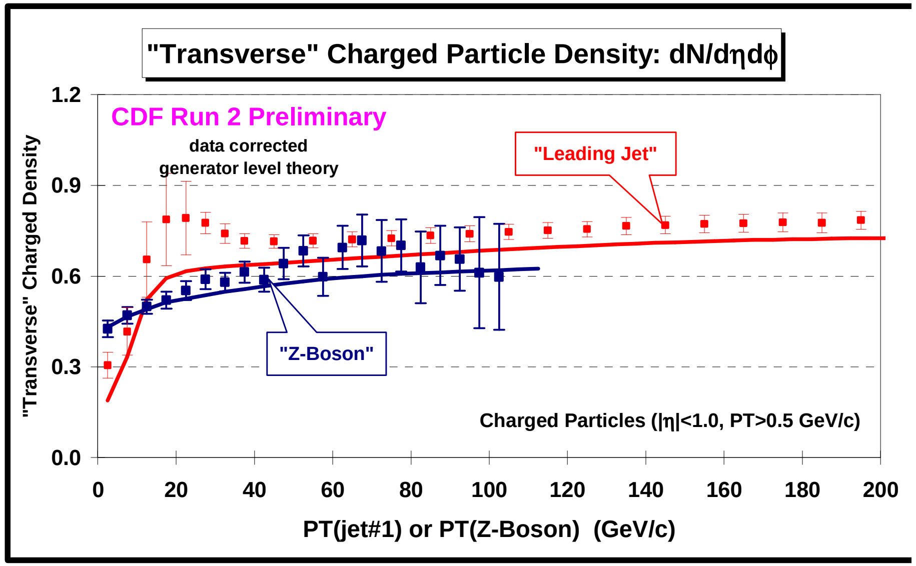


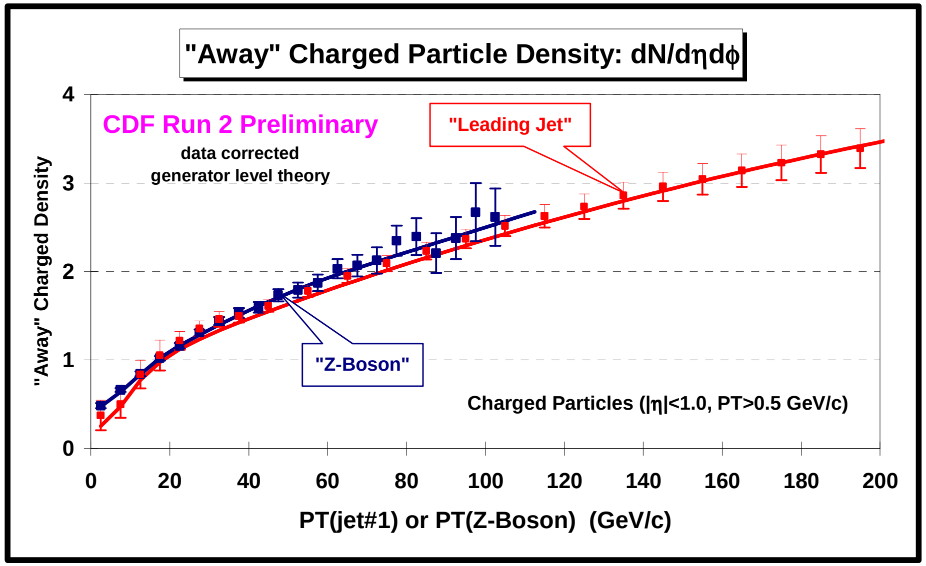


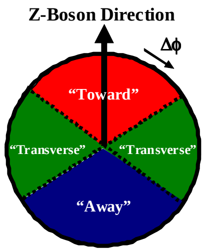


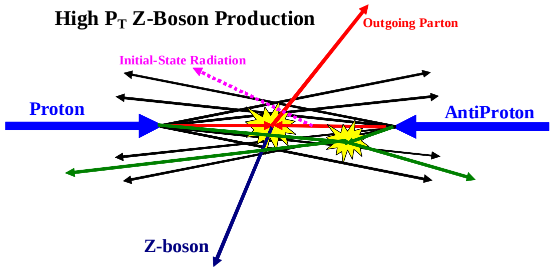
- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that 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).**

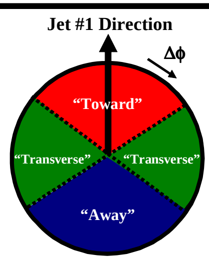
Charged Particle Density

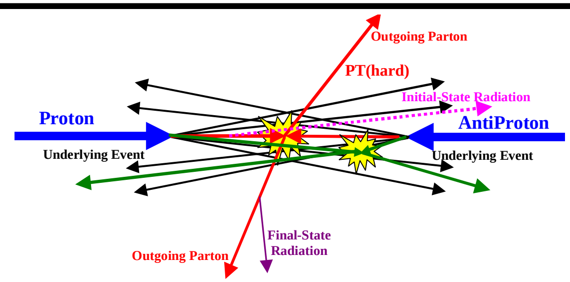






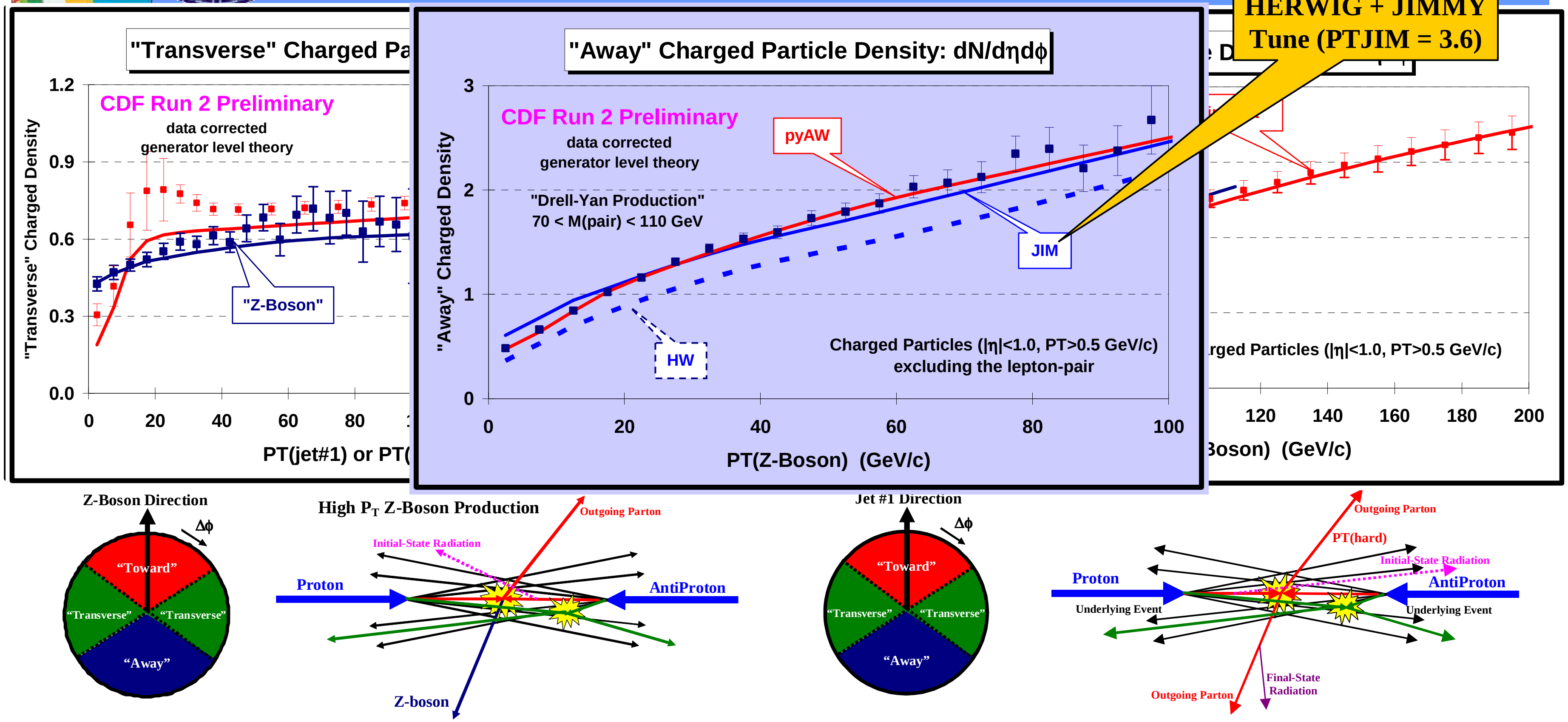






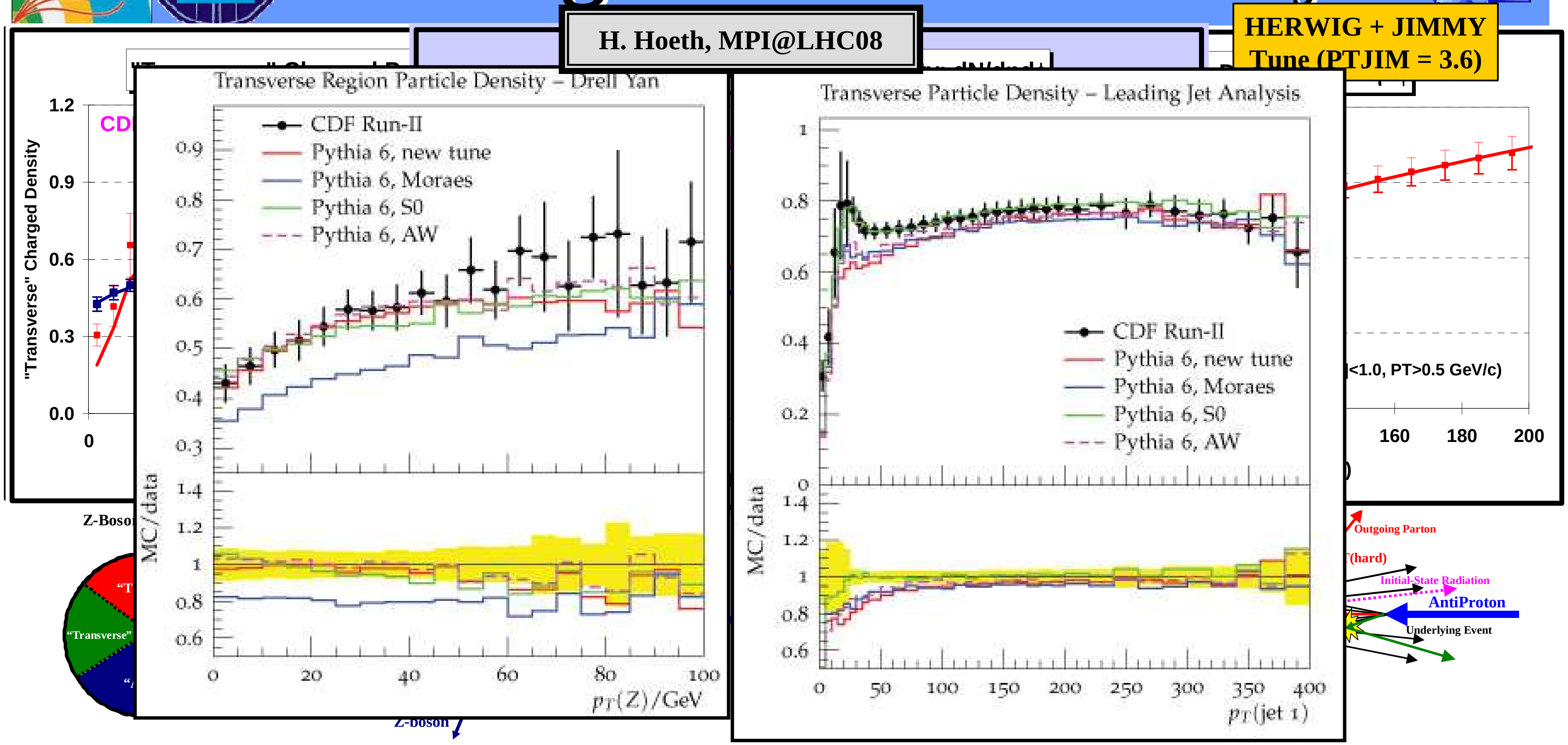
- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that 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



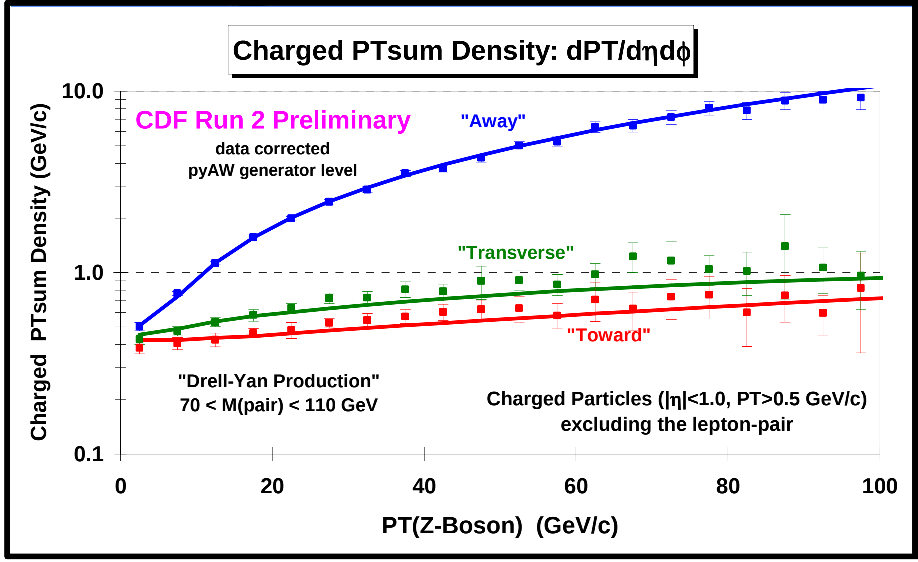
- Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors 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).

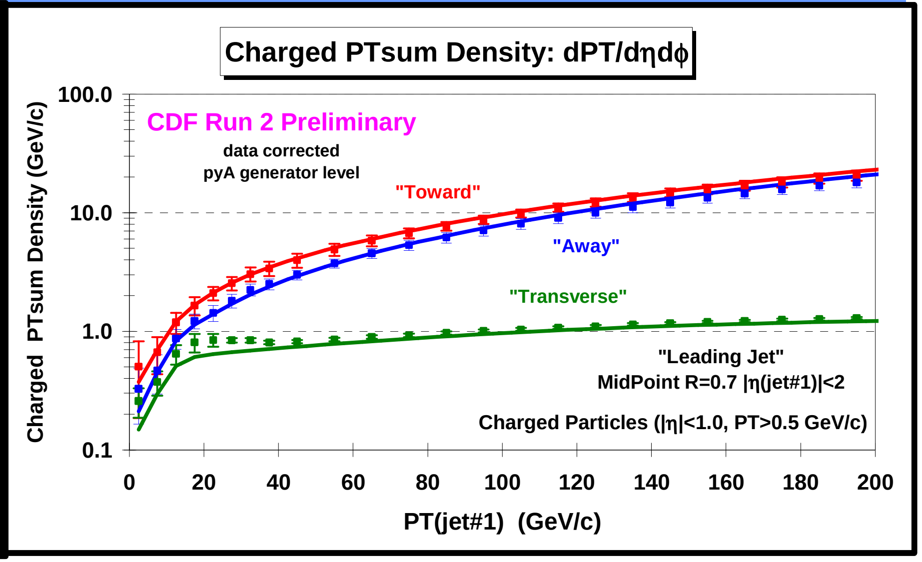
Charged Particle Density

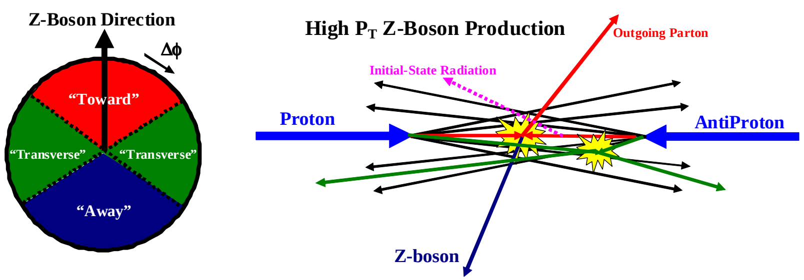


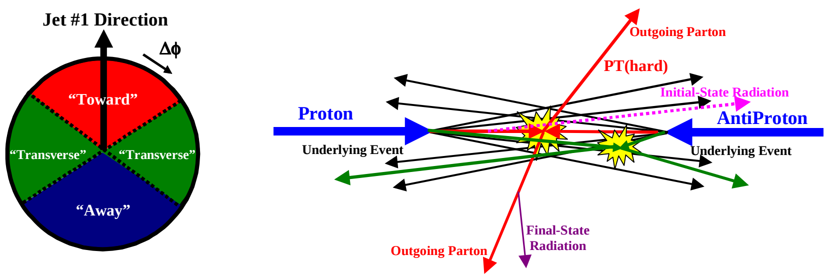
- Data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with 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 PTsum Density









- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/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).**

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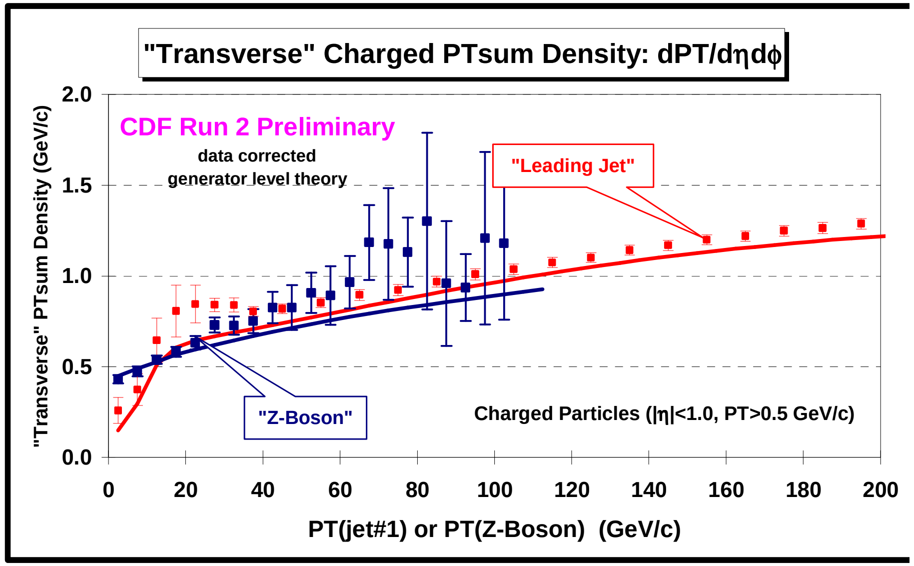

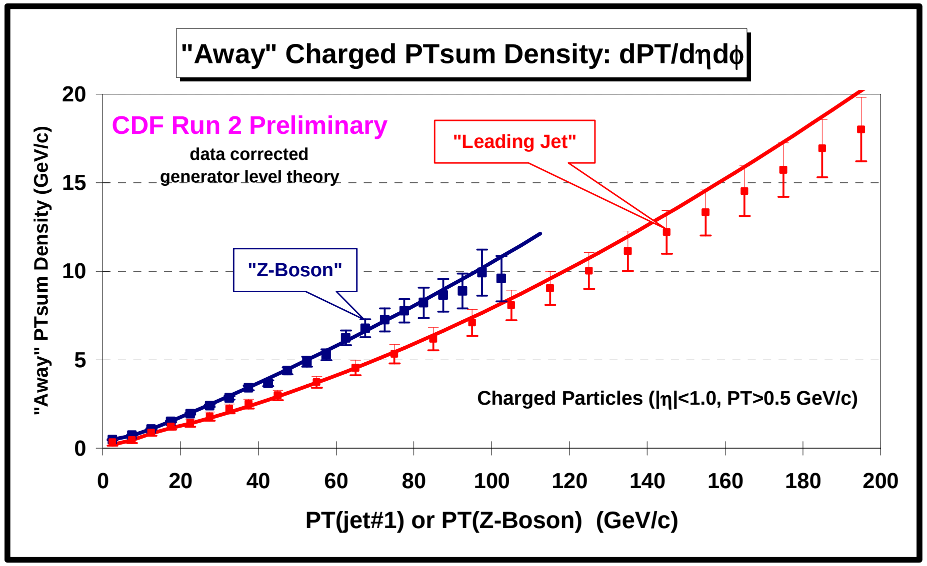

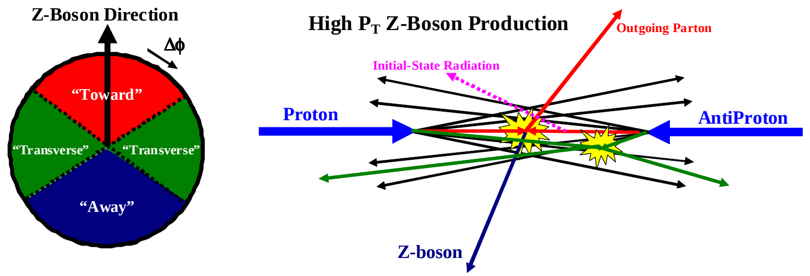

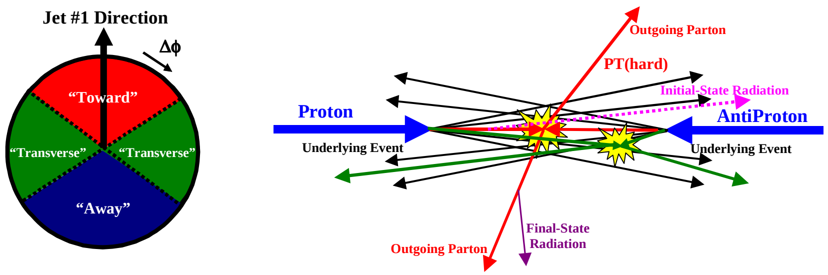

- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that 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).**

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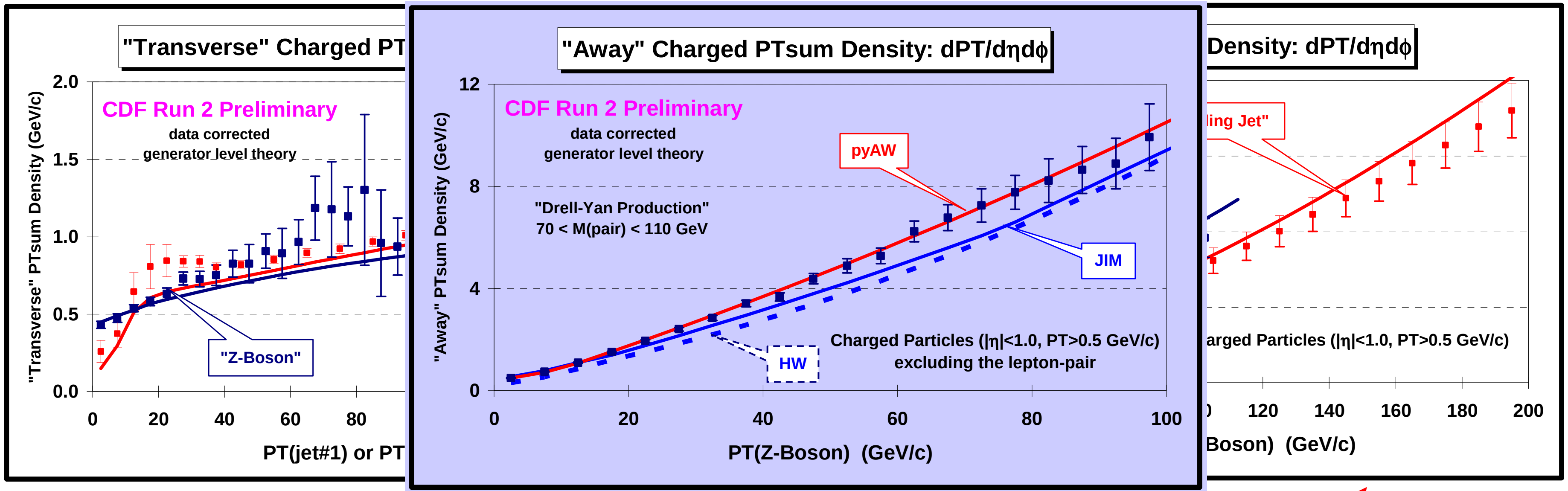

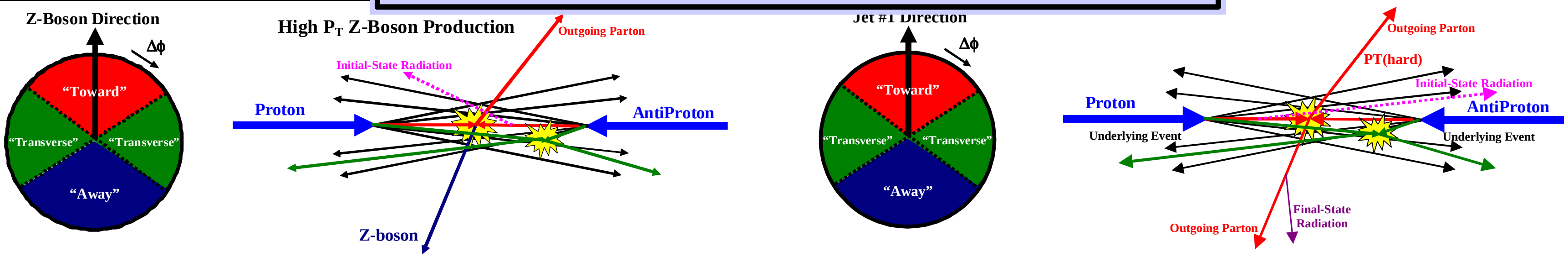

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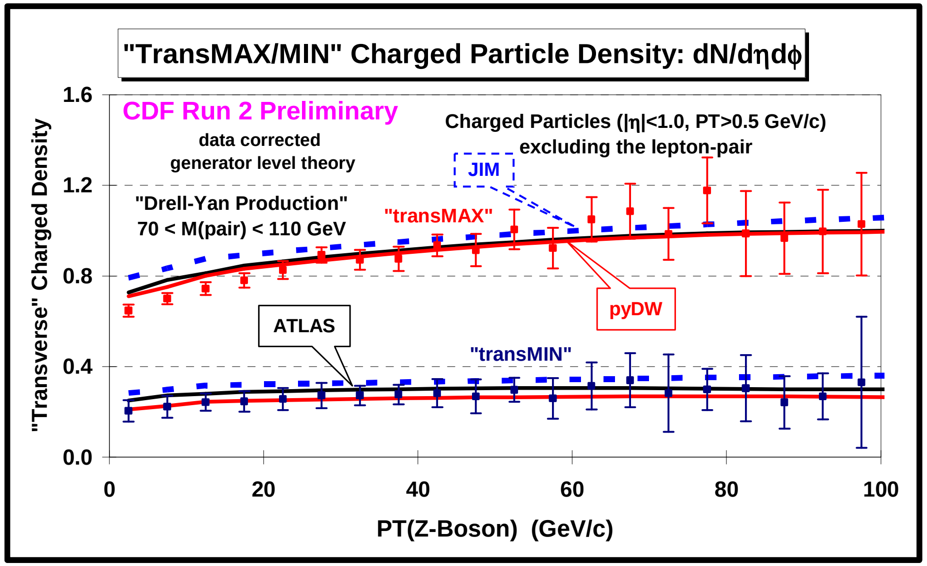
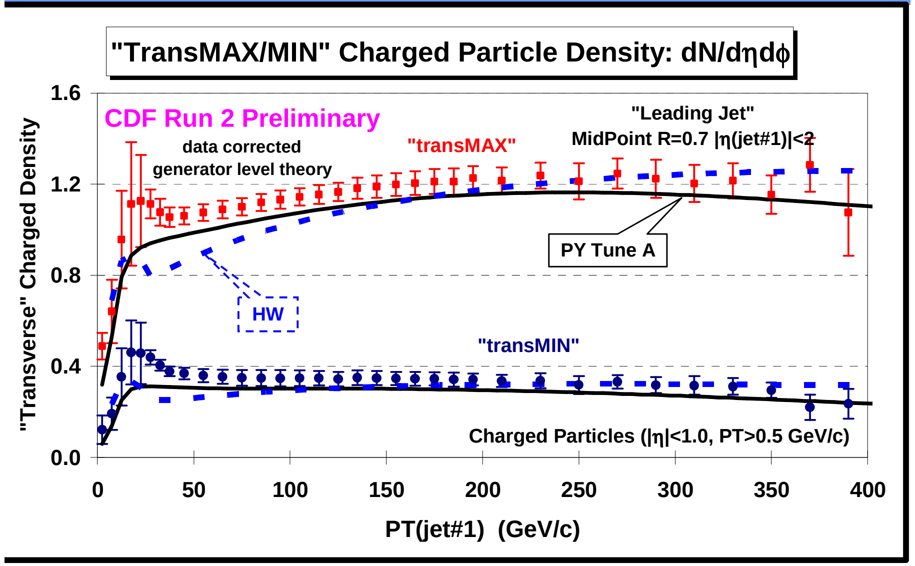
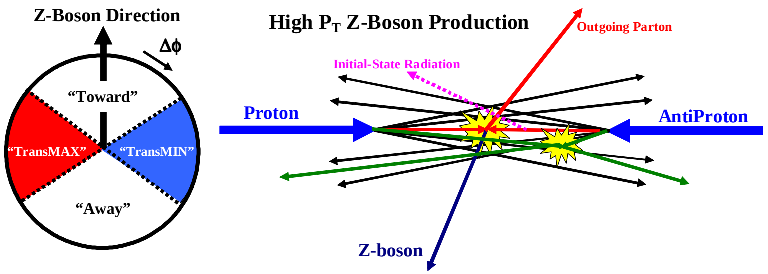
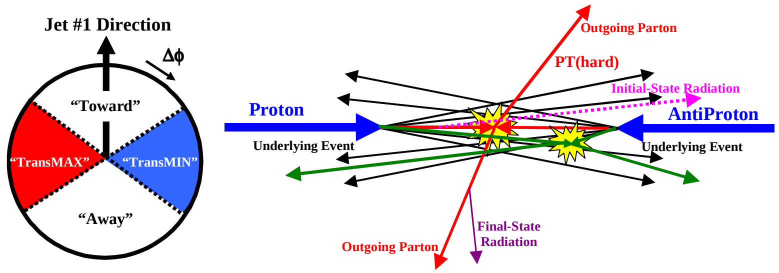
The "TransMAX/MIN" Regions









- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T and for Z-Boson events as a function of P_T(Z) for "TransDIF" = "transMAX" minus "transMIN" 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 A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

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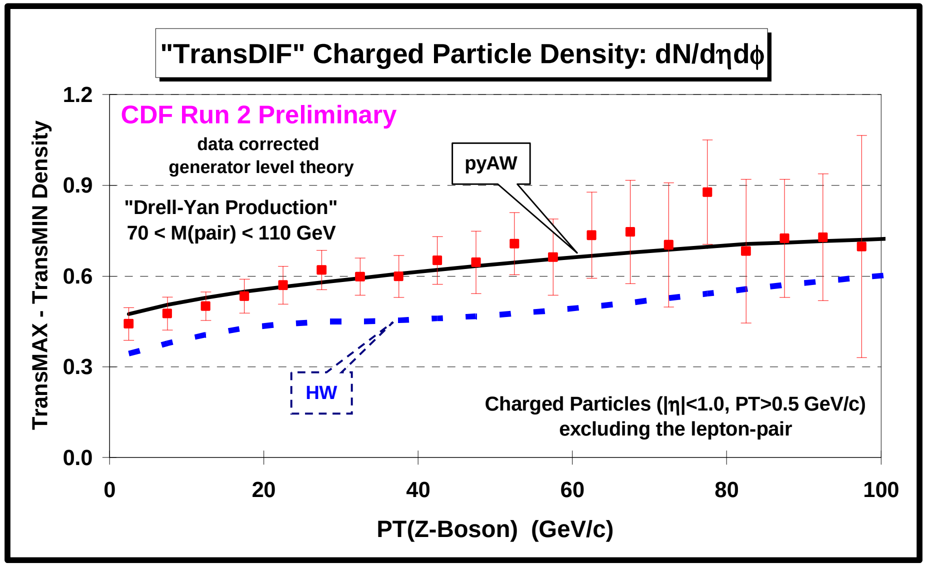

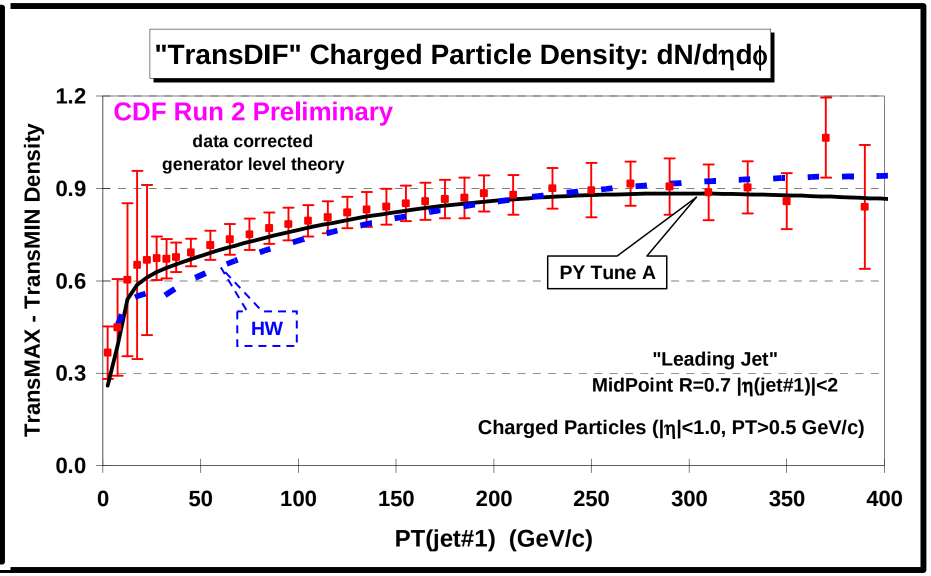

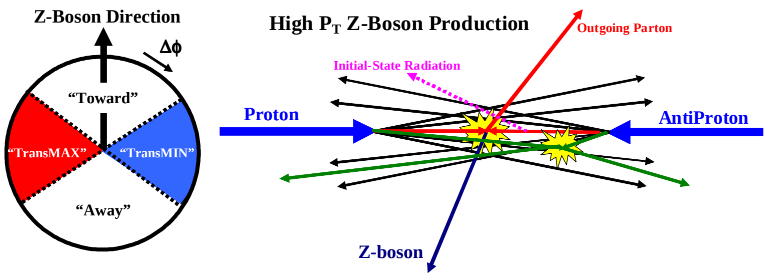

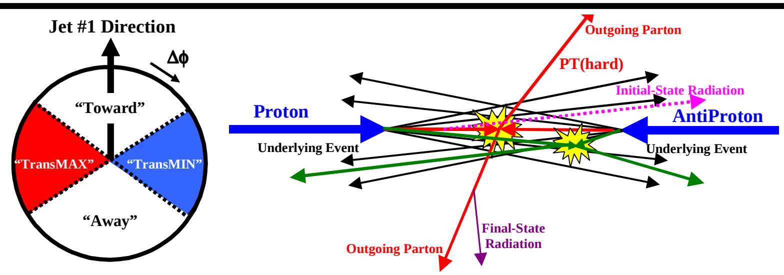

- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T and for Z-Boson events as a function of P_T(Z) for "TransDIF" = "transMAX" minus "transMIN" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

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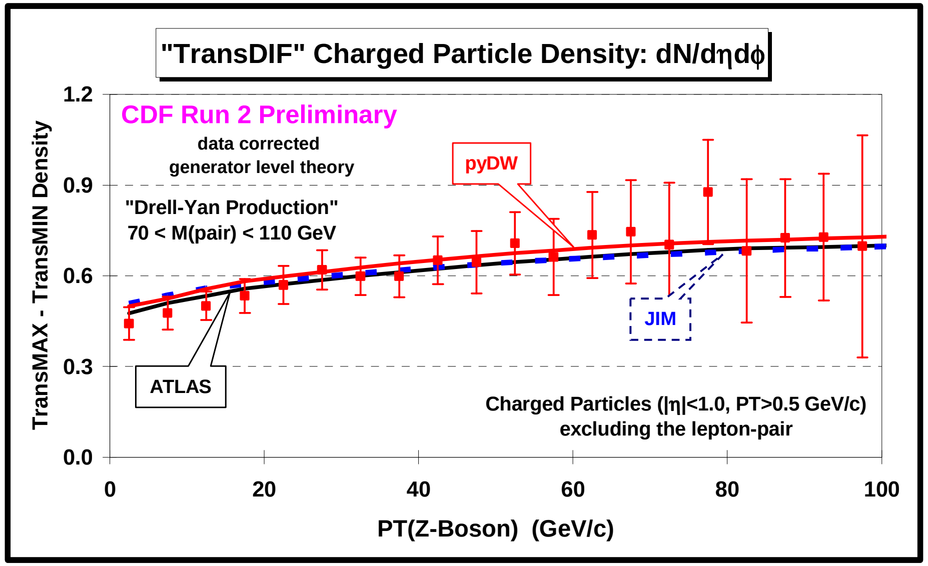

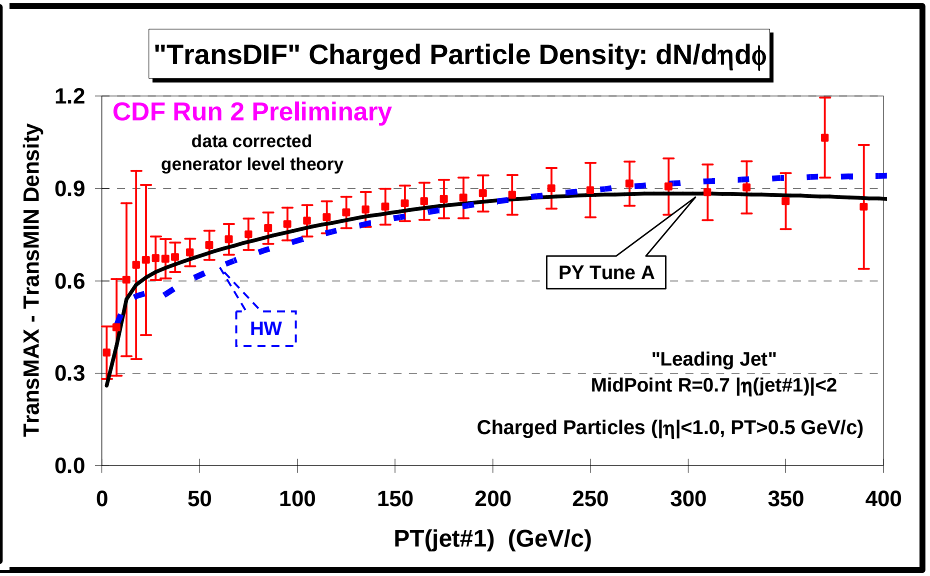

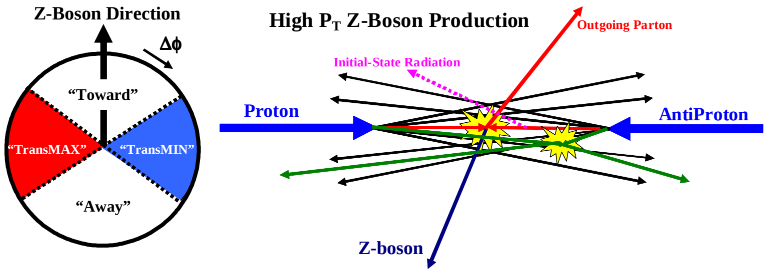

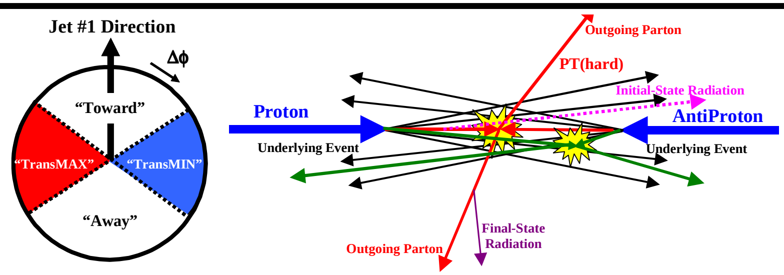

- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T and for Z-Boson events as a function of P_T(Z) for "TransDIF" = "transMAX" minus "transMIN" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

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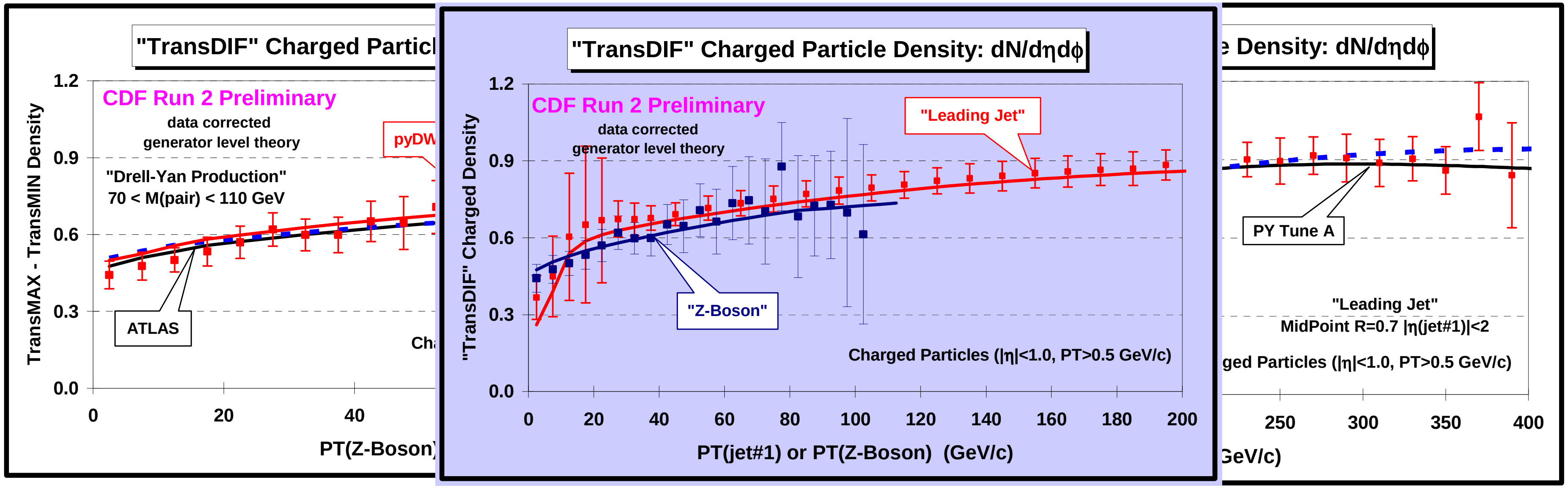

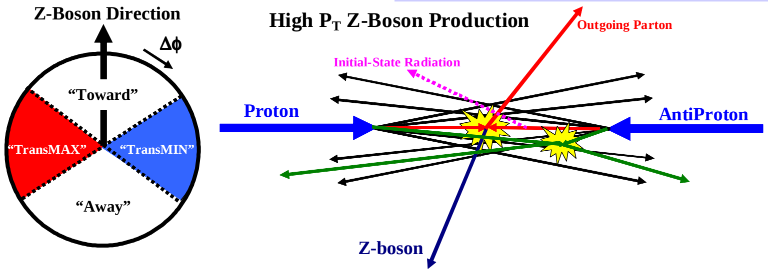

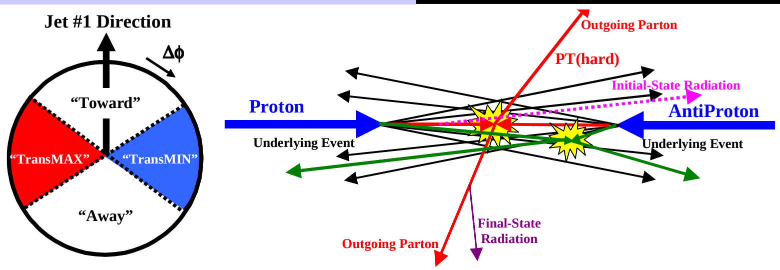

- Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T and for Z-Boson events as a function of P_T(Z) for "TransDIF" = "transMAX" minus "transMIN" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

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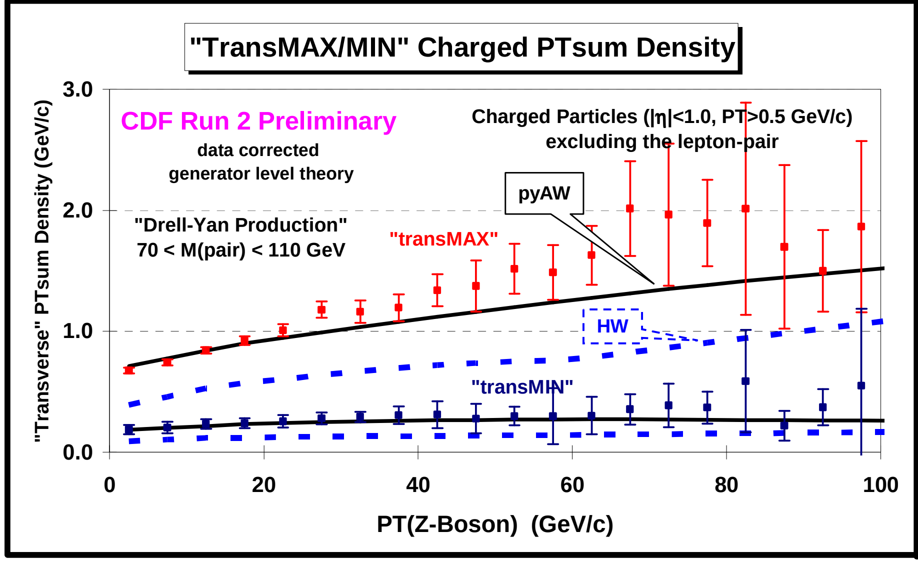

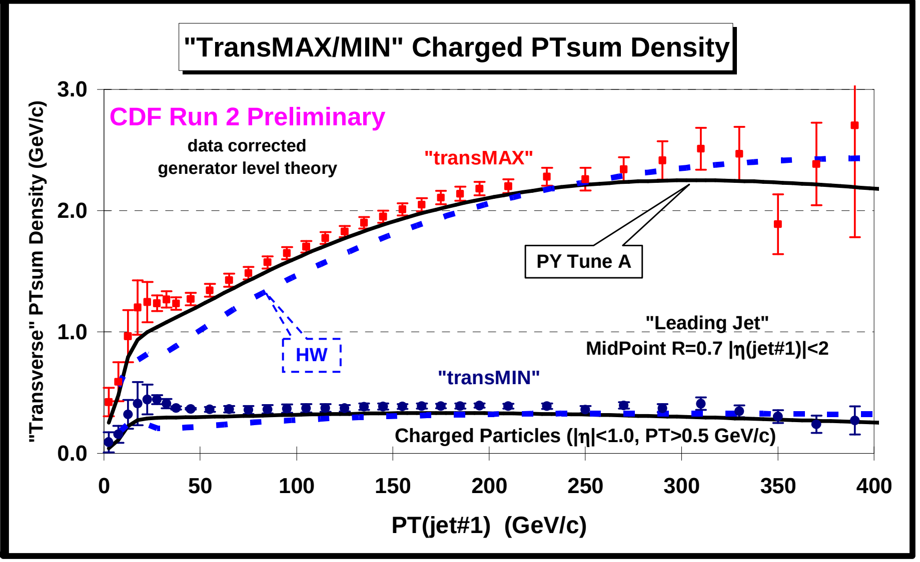

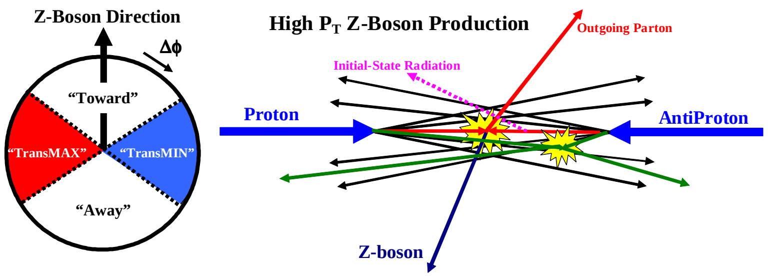

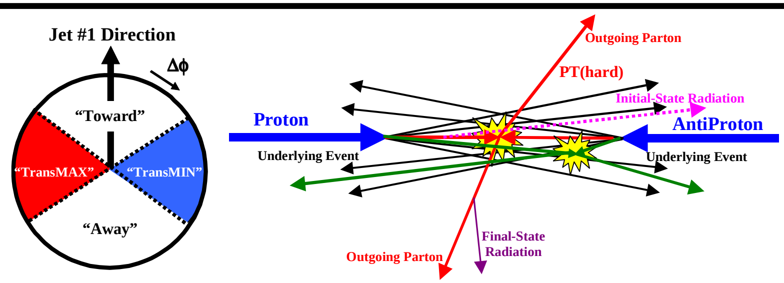

- Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T and for Z-Boson events as a function of $P_T(Z)$ for "TransDIF" = "transMAX" minus "transMIN" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

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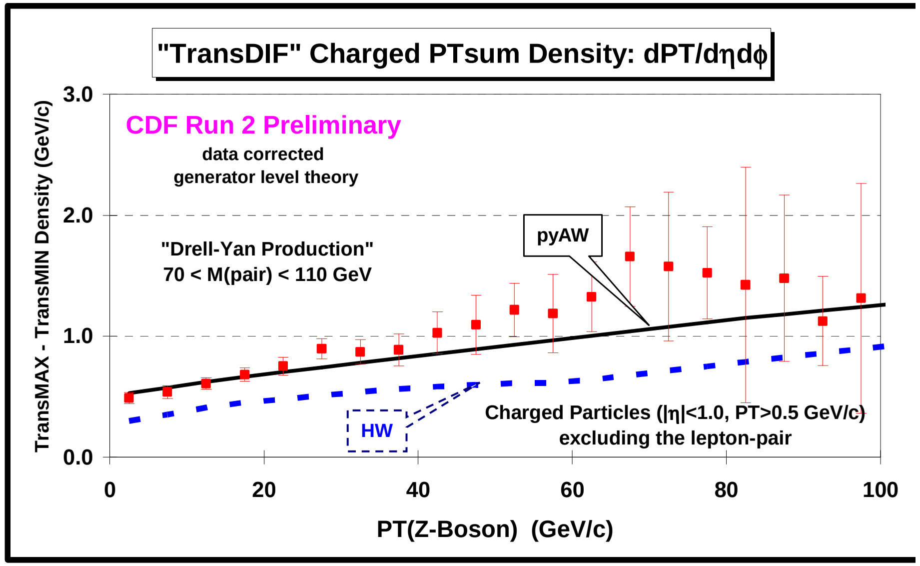

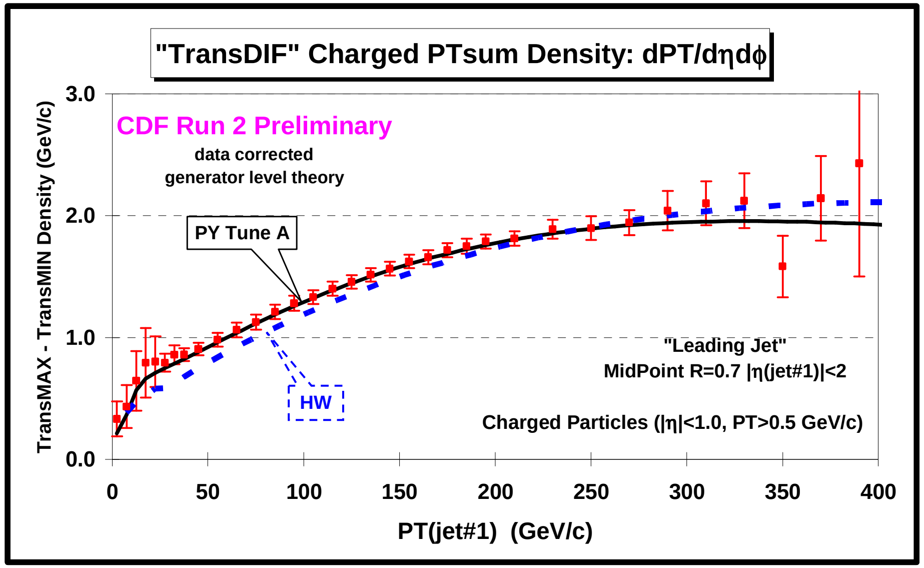

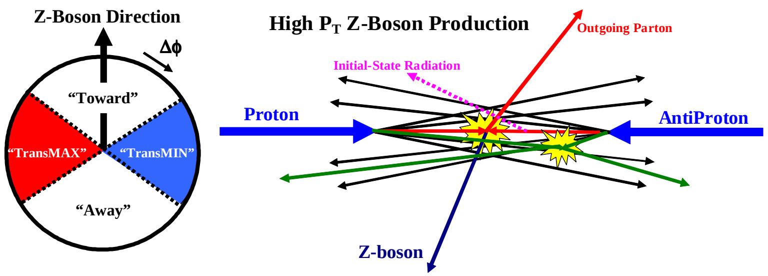

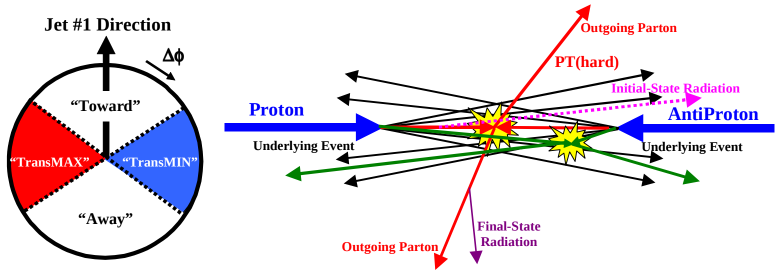

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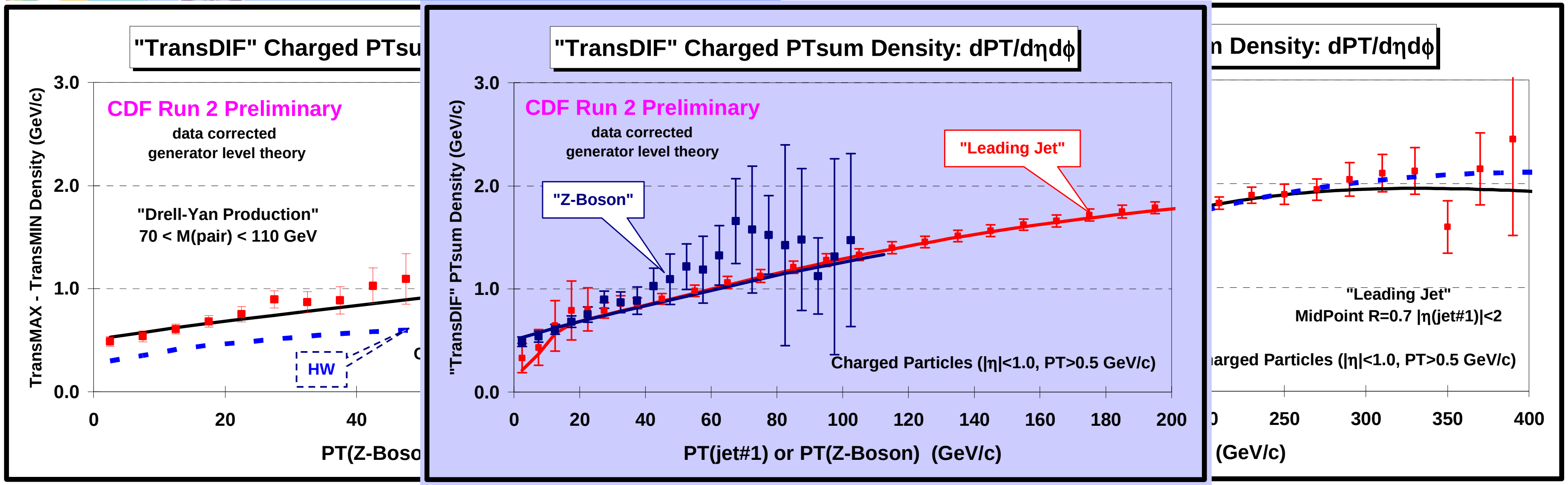

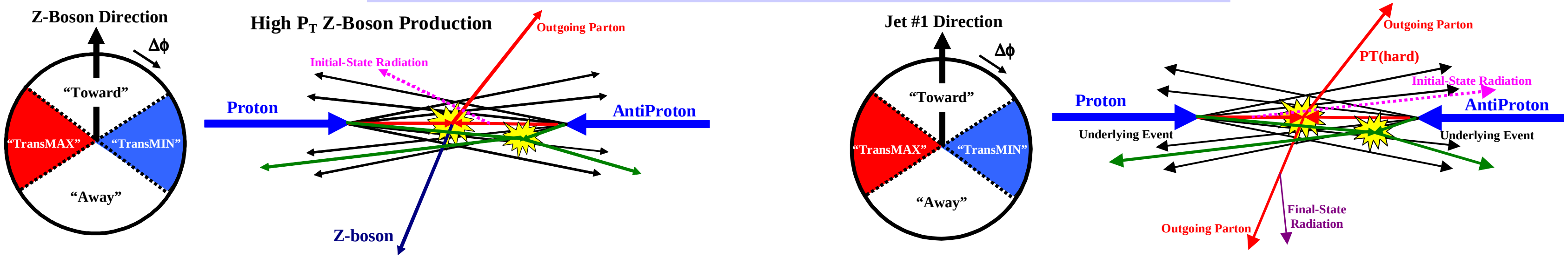

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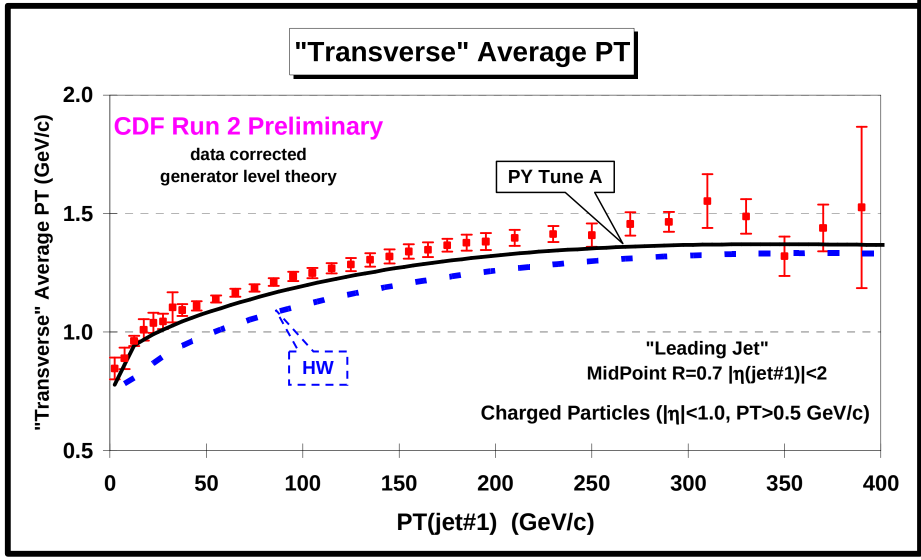
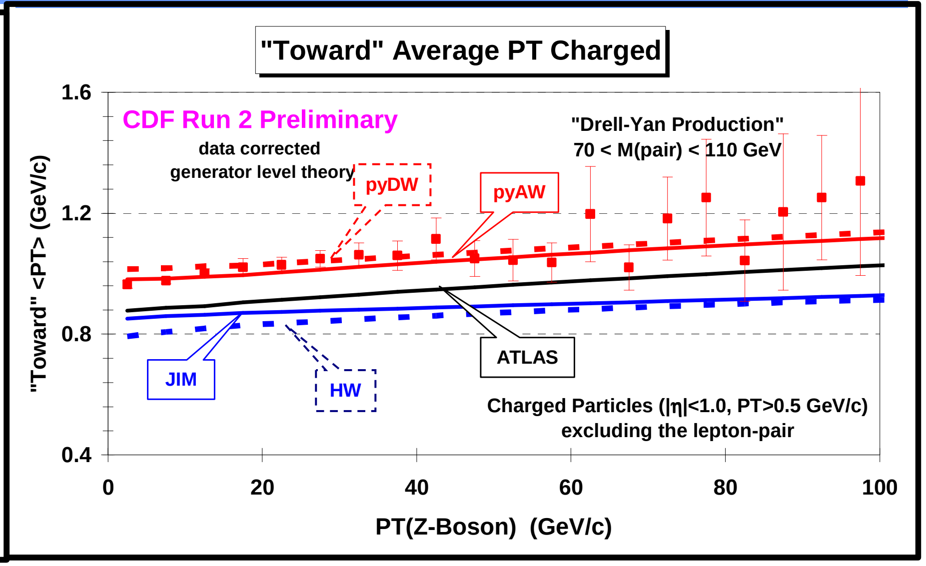
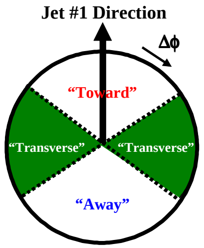
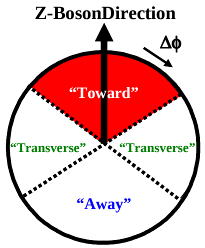
Charged Particle $<p_T>$





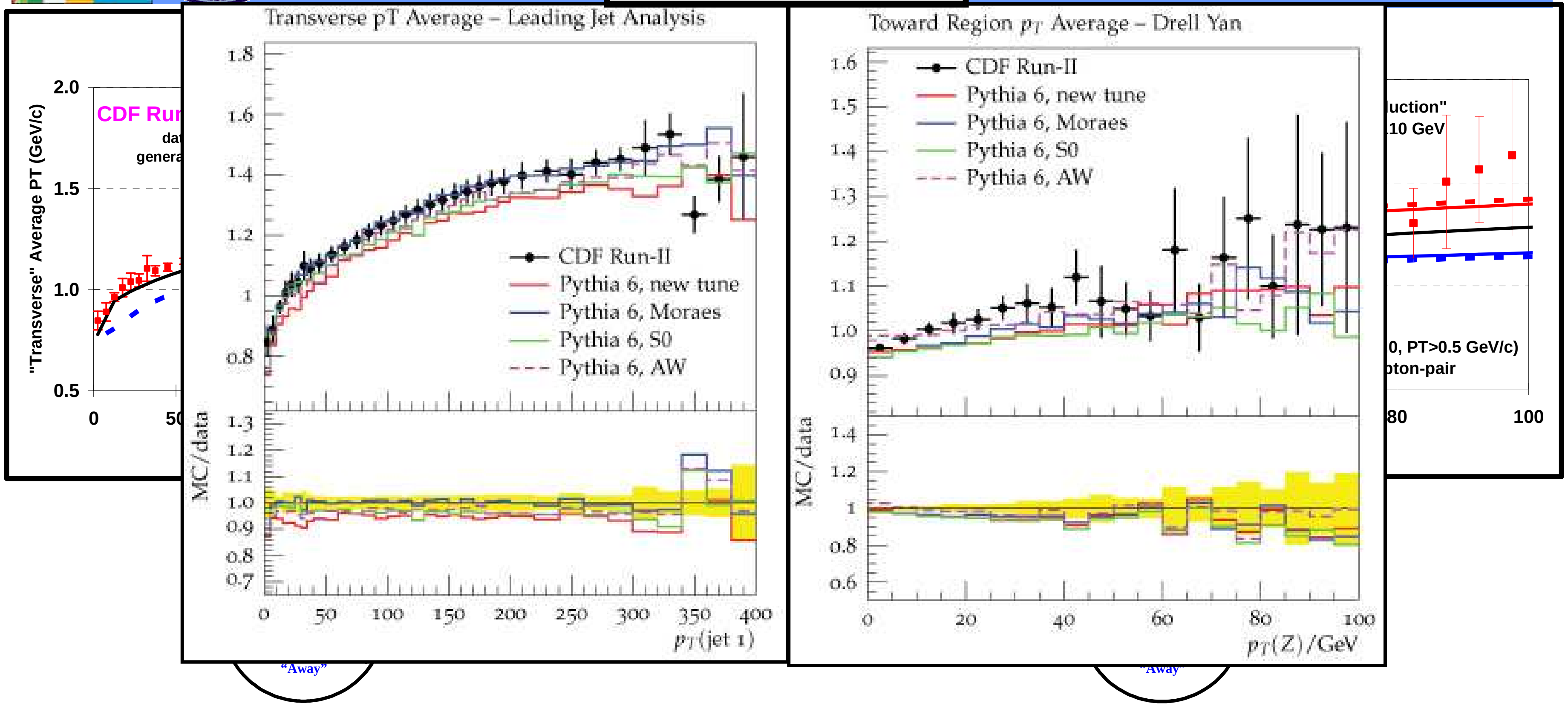




- **Data at 1.96 TeV on the charged particle average p_T, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for the "toward" region for "Z-Boson" and the "transverse" region for "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$. The data are corrected to the particle level (*with errors that 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 Z-Boson data are also compared with PYTHIA Tune DW, the ATLAS tune, and HERWIG (without MPI)**

Charged Particle <p_T>

H. Hoeth, MPI@LHC08



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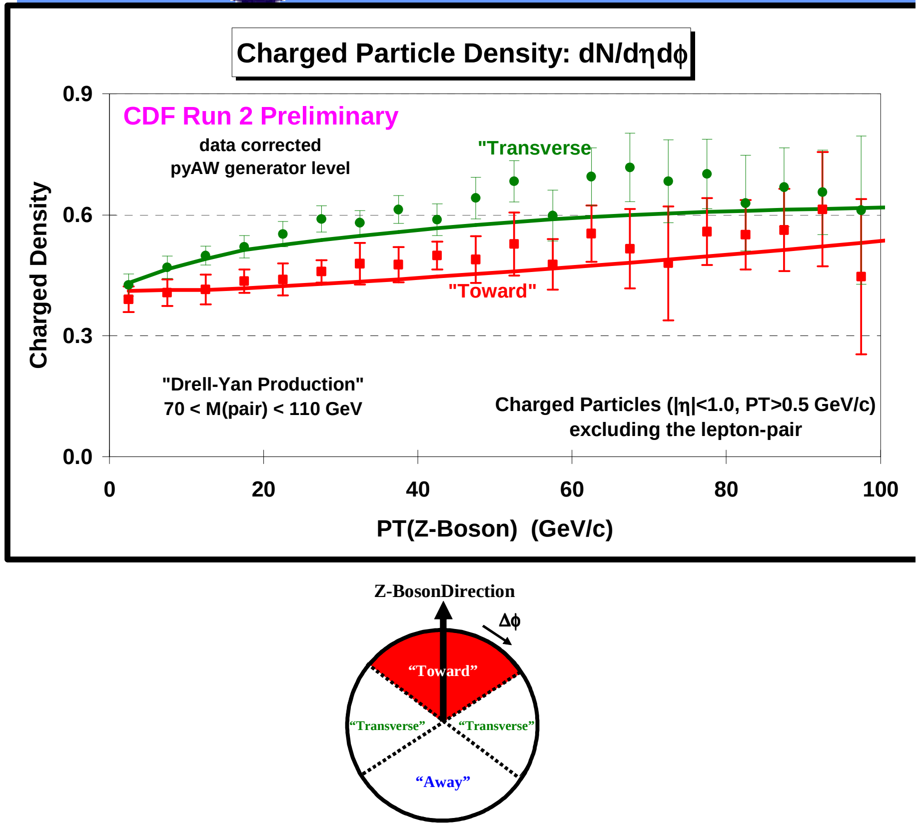
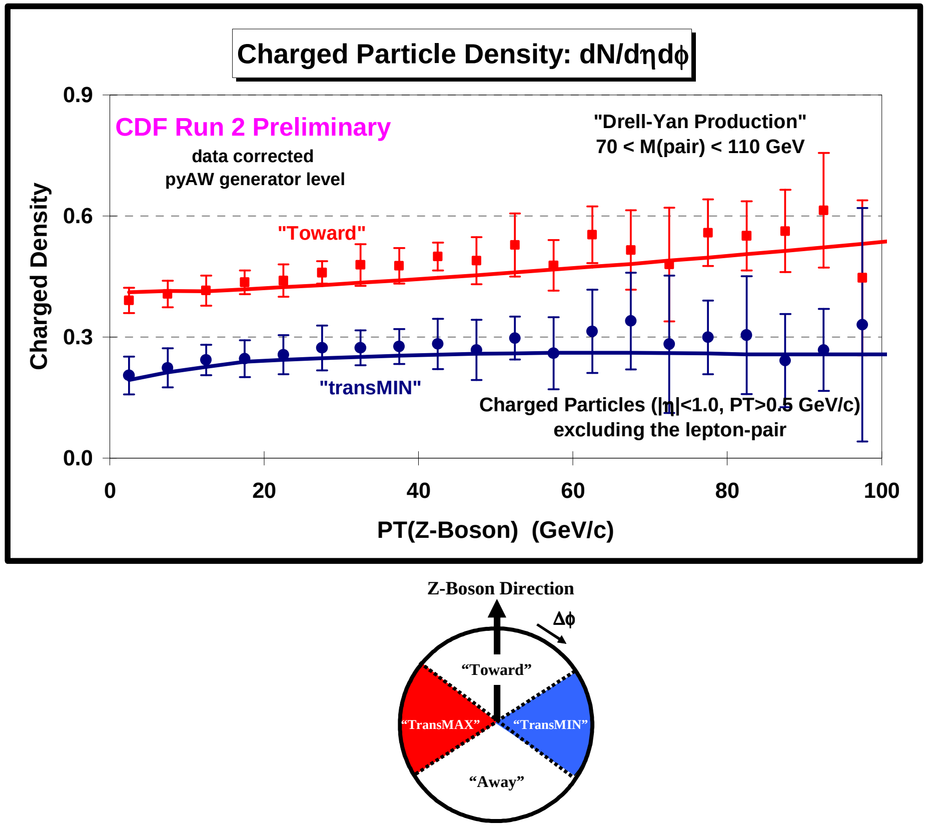
Z-Boson: "Towards", Transverse", & "TransMIN" Charge Density





- 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" events as a function of P_T(Z) for the "toward" 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 HERWIG (without MPI) at the particle level (*i.e.* generator level).

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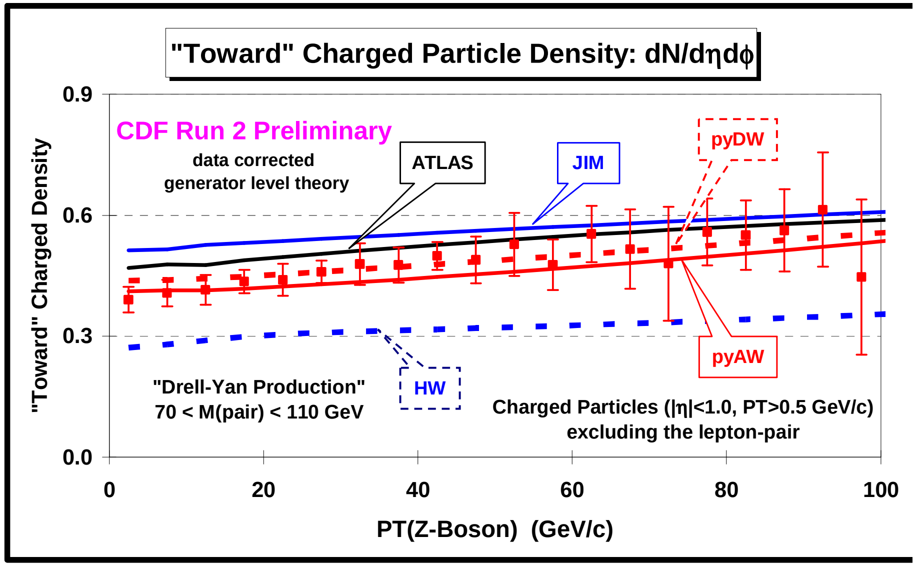

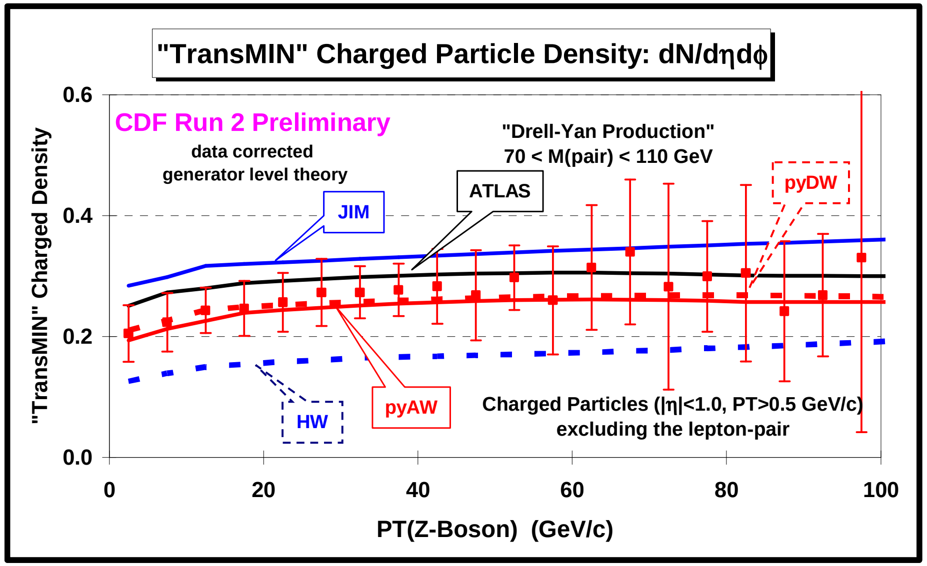

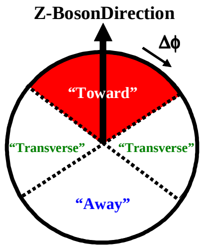

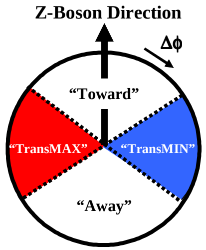

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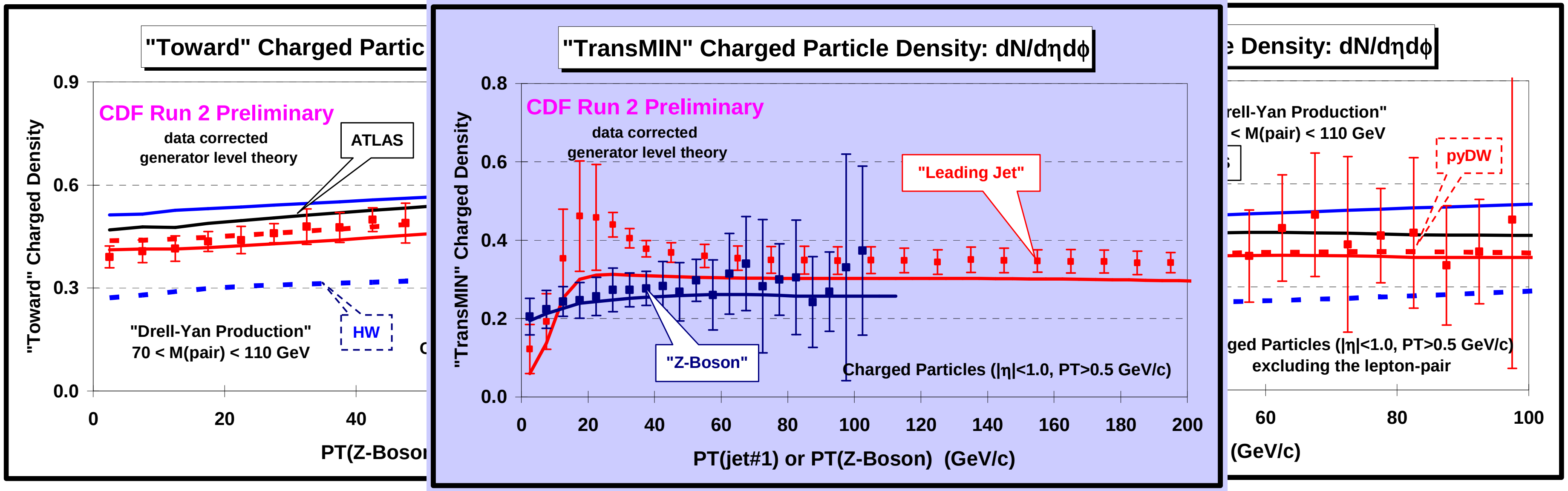

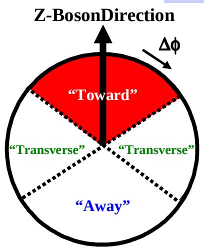

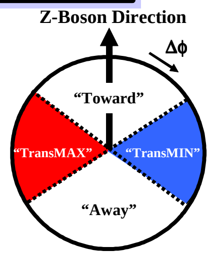

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Z-Boson: “Towards”, Transverse”, & “Tra arge Density

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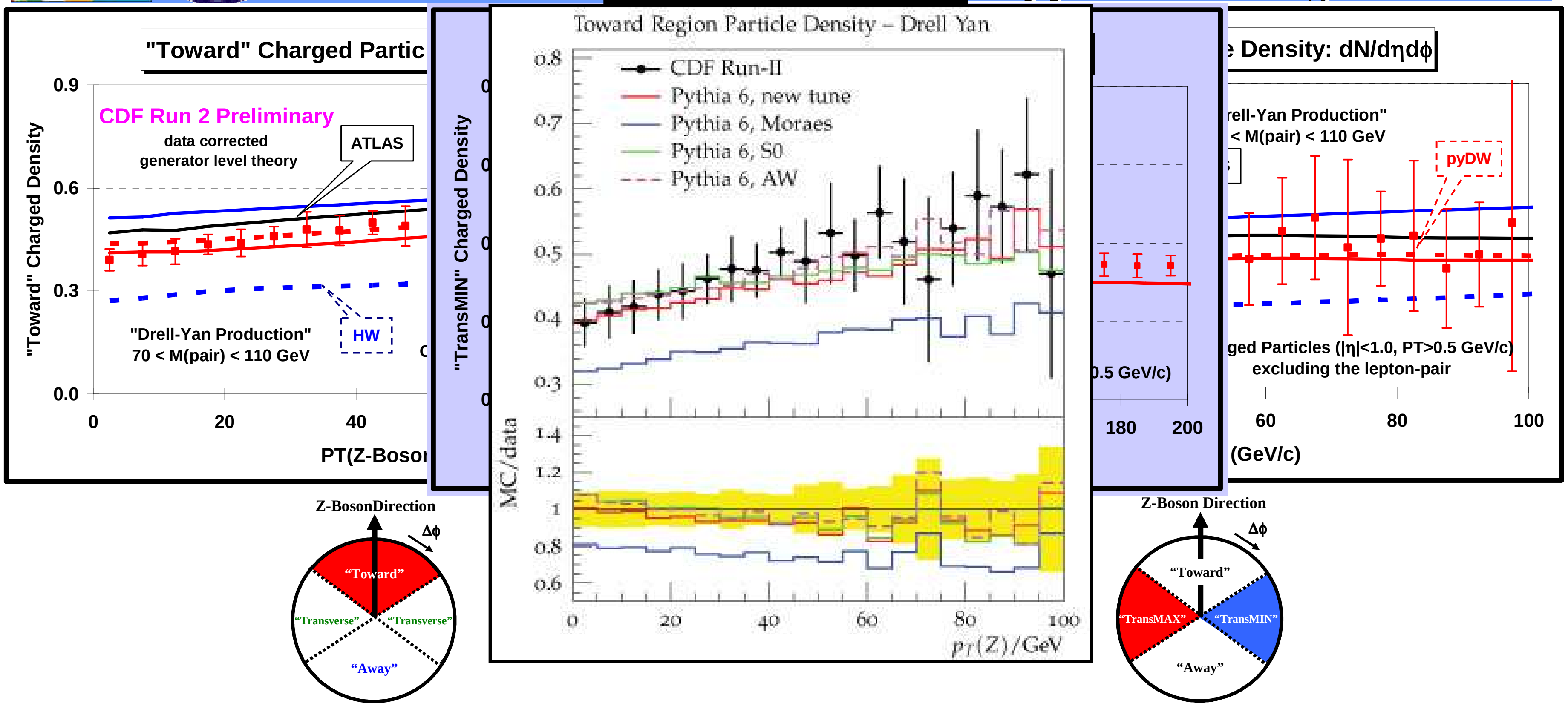

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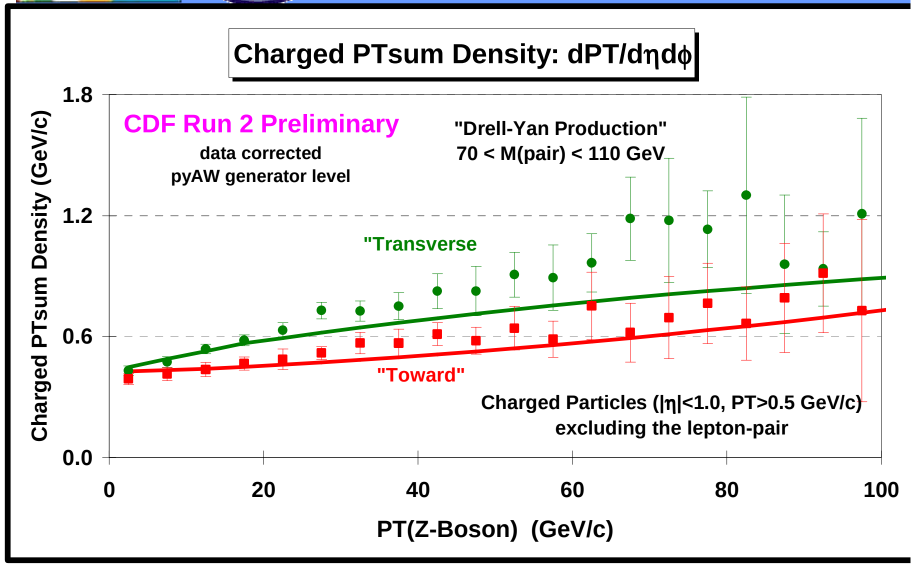
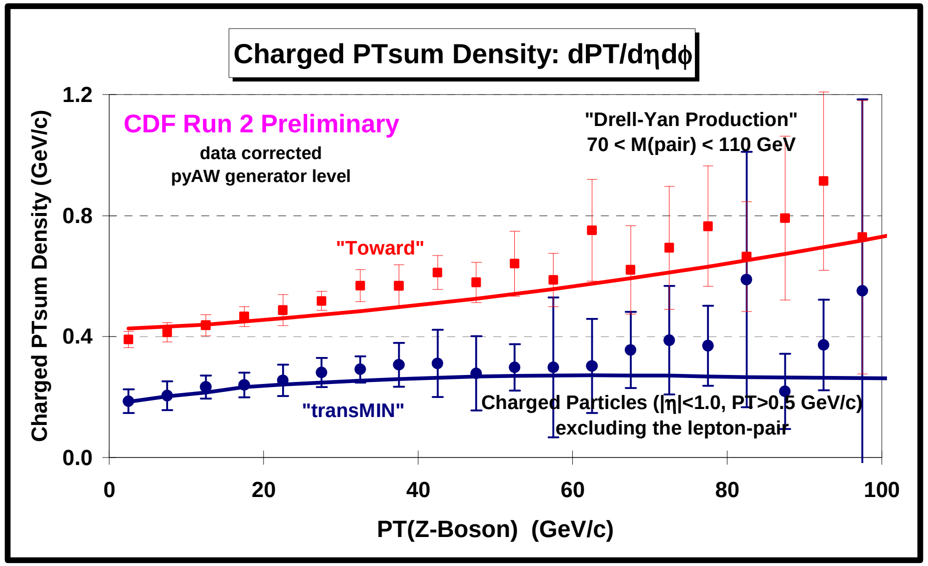
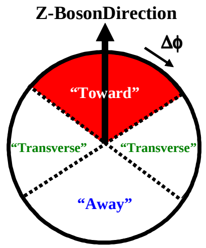
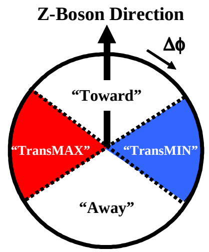


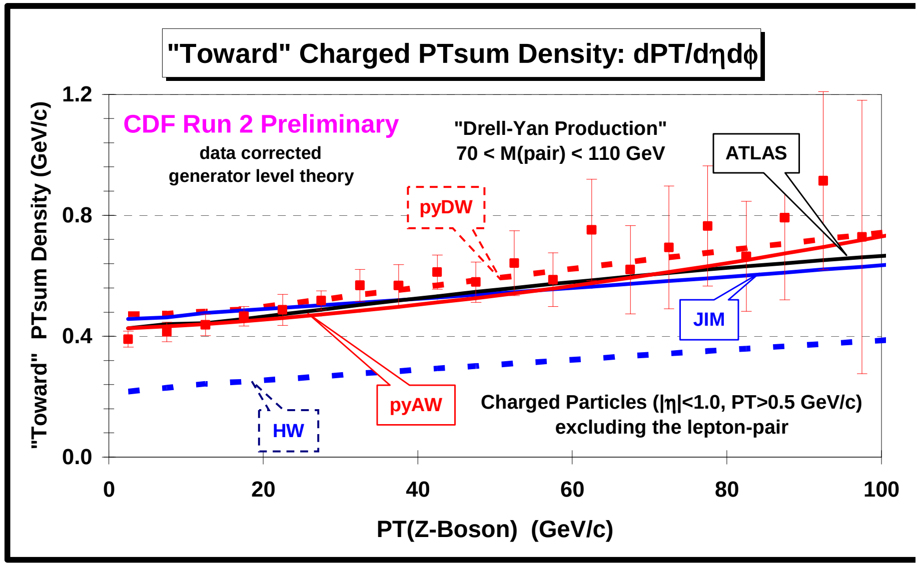


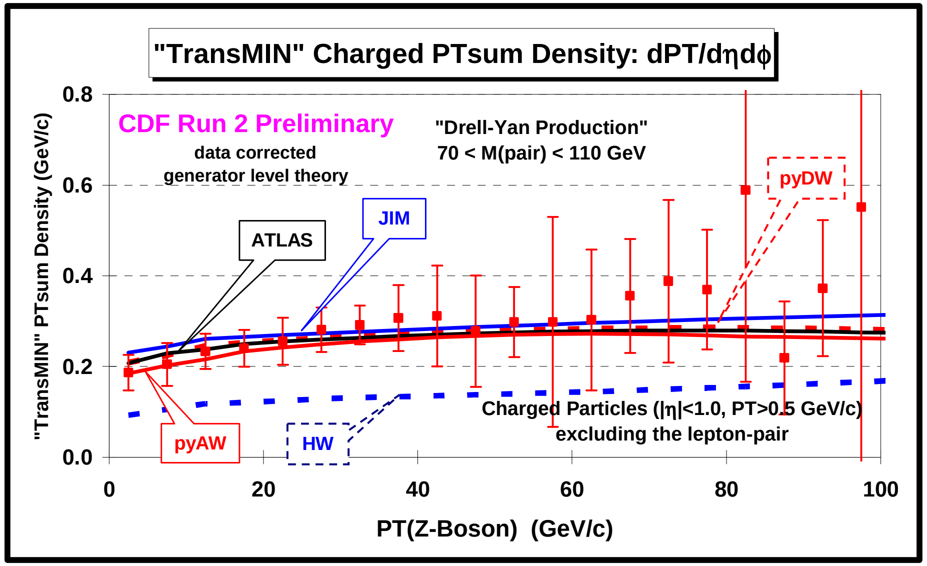


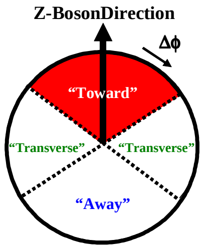


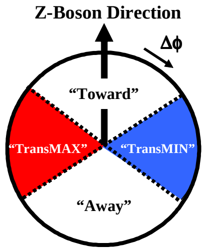
- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

Z-Boson: "Towards", Transverse", & "TransMIN" Charge Density



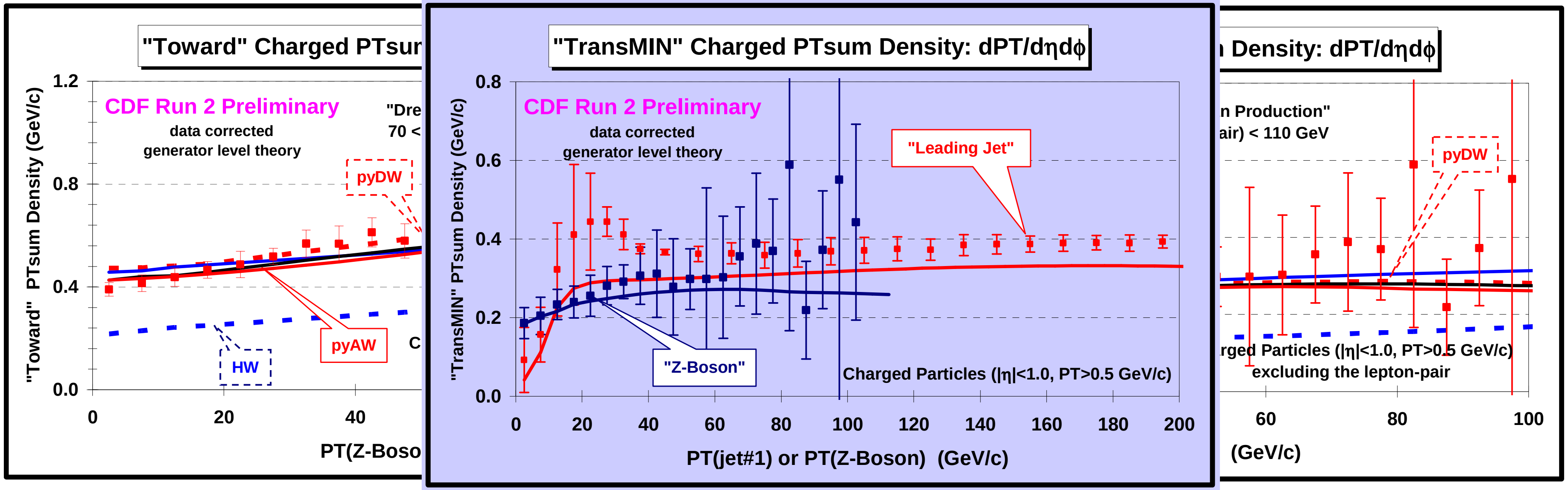


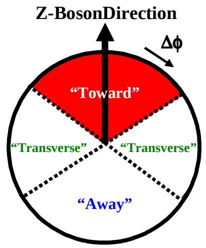


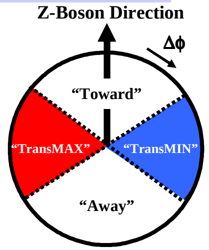


- Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of P_T(Z) for the "toward" and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).

Z-Boson: "Towards", Transverse", & "TransMIN" Charge Density

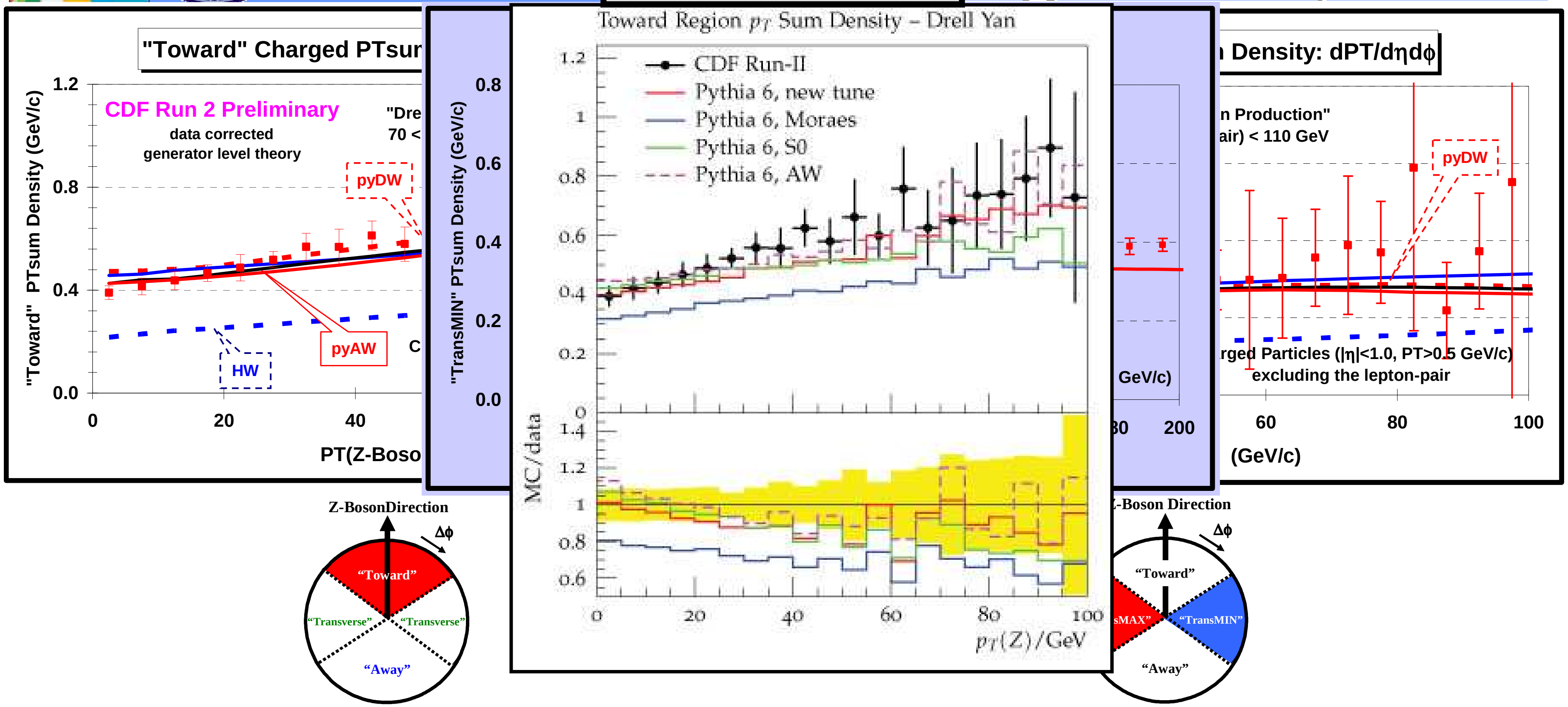






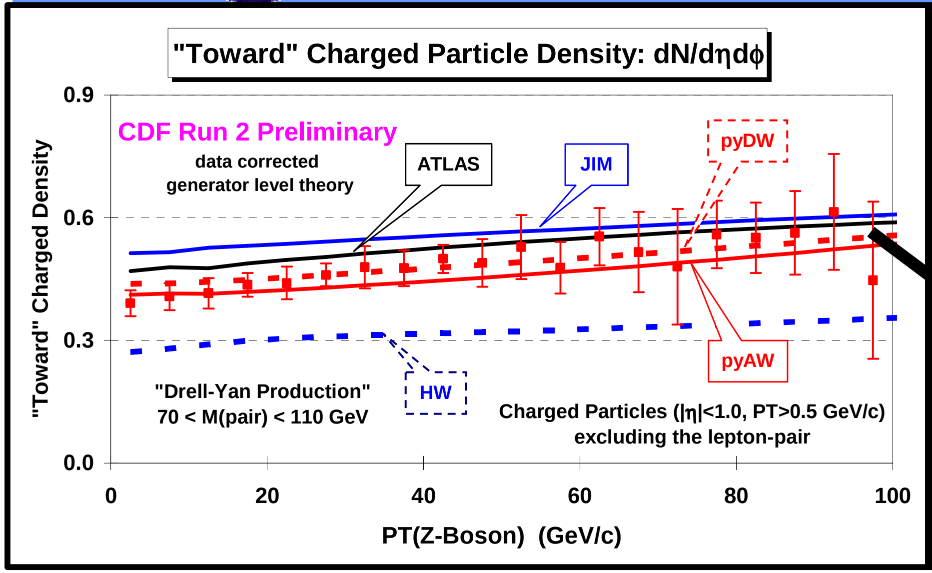
- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of P_T(Z) for the "toward" and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

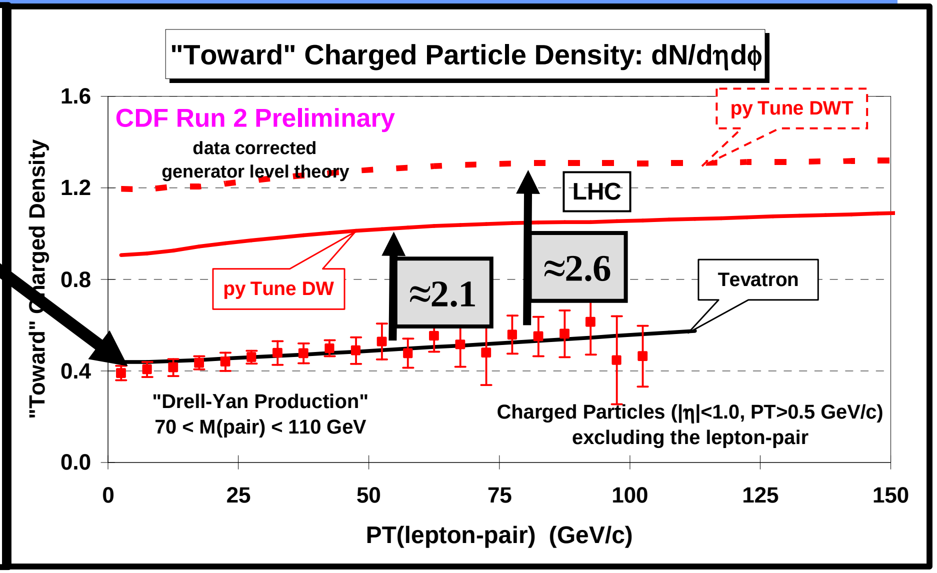
Z-Boson: "Towards", Transverse", & "Tra… …arge Density



- Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" 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 HERWIG (without MPI) at the particle level (*i.e.* generator level).

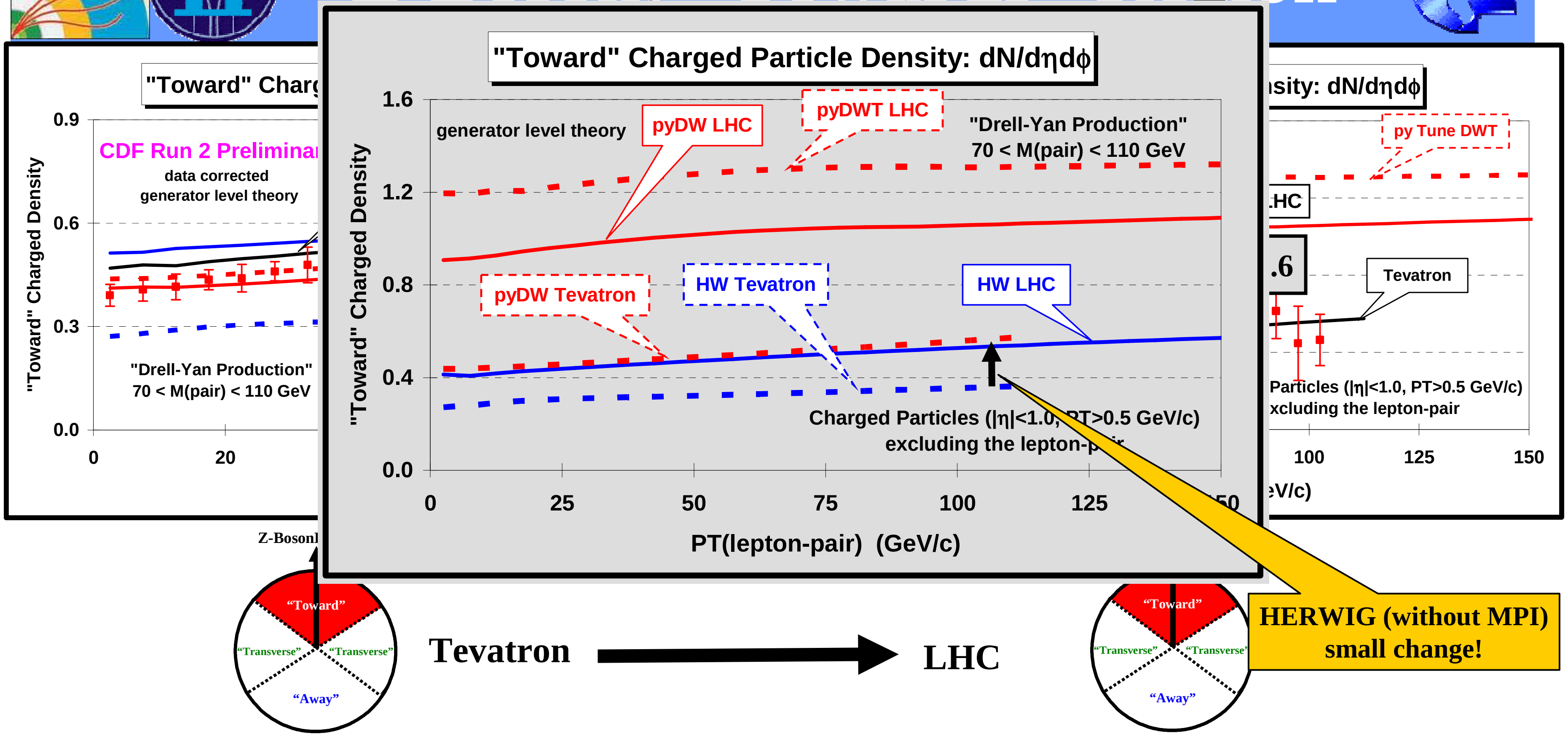
Z-Boson: "Towards" Region





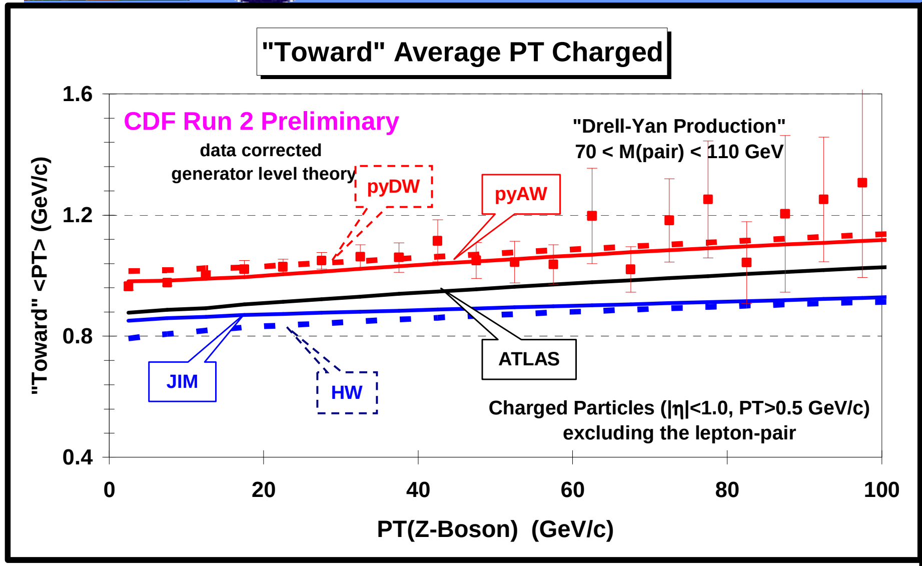
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW, Tune DW, PYTHIA ATLAS Tune, HERWIG (without MPI), and HERWIG (with JIMMY MPI) at the particle level (*i.e.* generator level).**

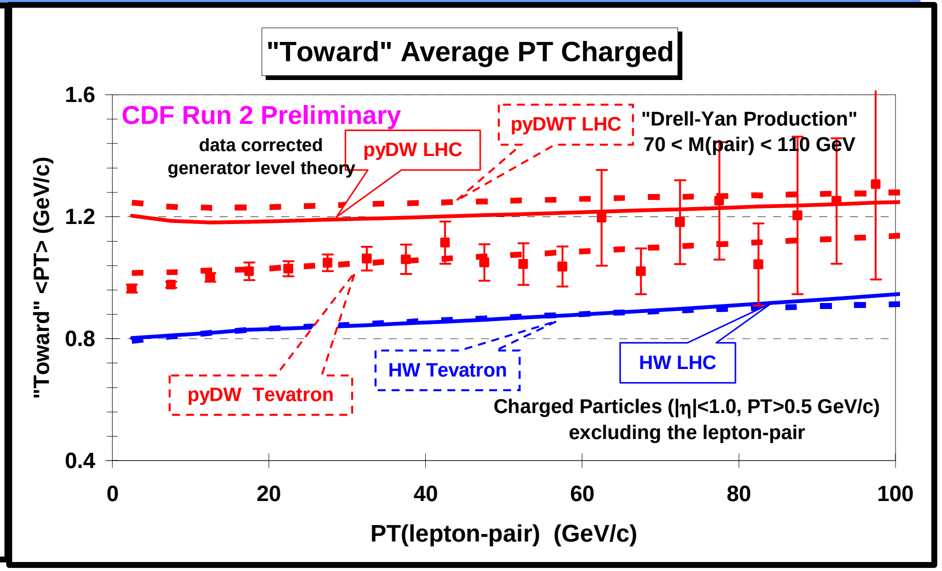
Z-Boson: "Towards" Region



- 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" events as a function of P_T(Z) for the "toward" region. 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, Tune DW, PYTHIA ATLAS Tune, HERWIG (without MPI), and HERWIG (with JIMMY MPI) at the particle level (*i.e.* generator level).

Z-Boson: “Towards” Region

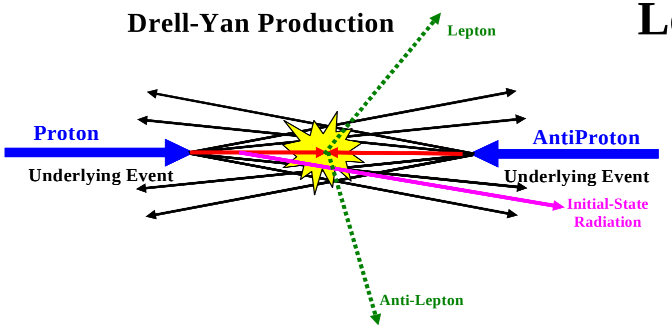




- **Data at 1.96 TeV on the the average p_T of charged particles with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” events as a function of $P_T(Z)$ for the “toward” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW, Tune DW, PYTHIA ATLAS Tune, HERWIG (without MPI), and HERWIG (with JIMMY MPI) at the particle level (*i.e.* generator level).**

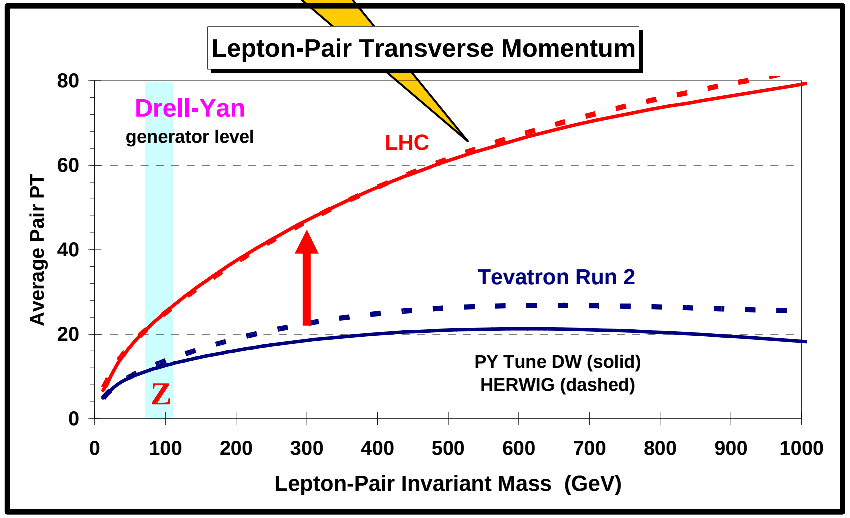
Drell-Yan Production
Tevatron vs LHC

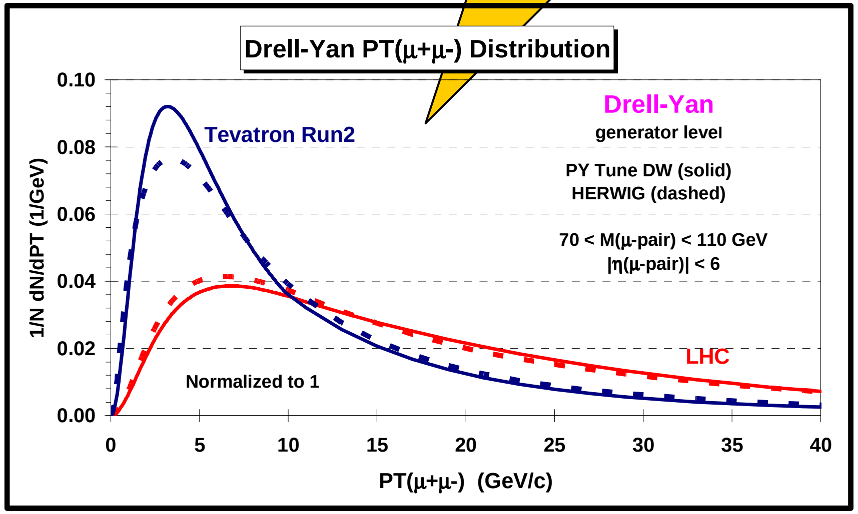
Lepton-Pair Transverse Momentum



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

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

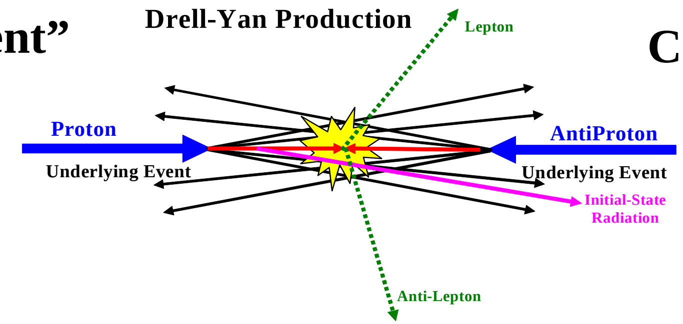




- Average Lepton-Pair transverse momentum at the Tevatron and the LHC for **PYTHIA Tune DW** and **HERWIG (*without MPI*)**.
- Shape of the Lepton-Pair p_T distribution at the Z-boson mass at the Tevatron and the LHC for **PYTHIA Tune DW** and **HERWIG (*without MPI*)**.

The "Underlying Event" in Drell-Yan Production

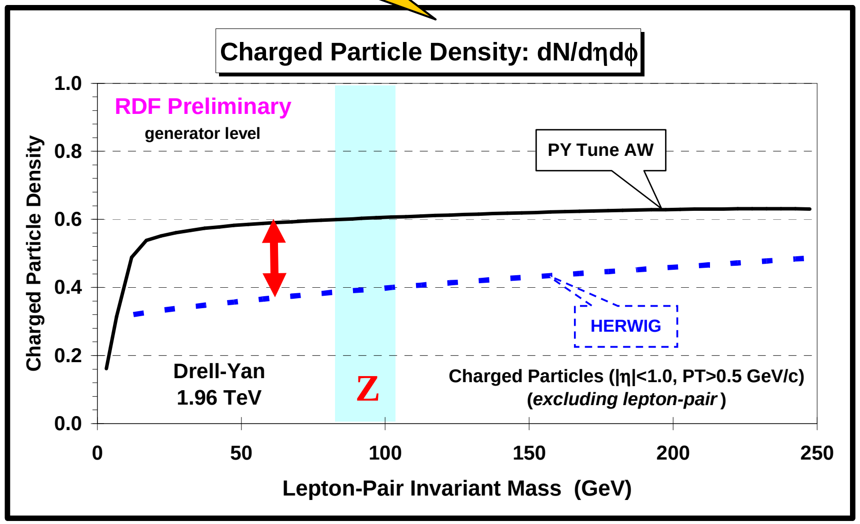
The "Underlying Event"

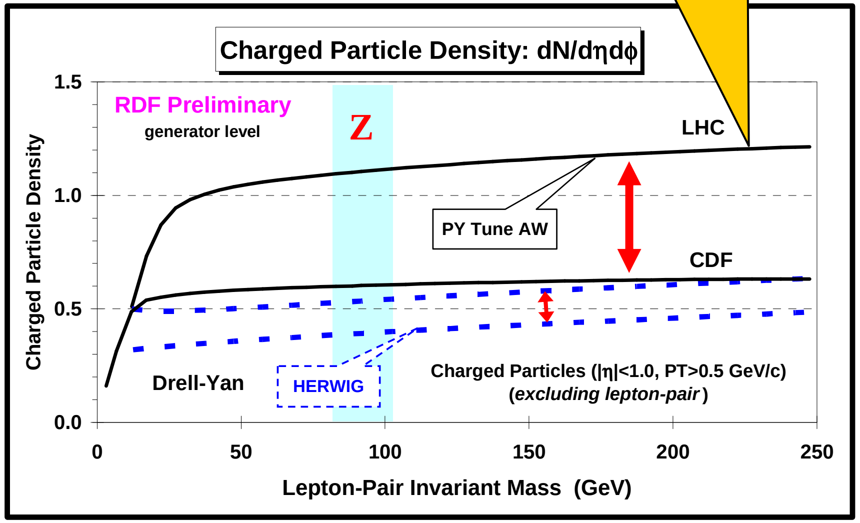


Charged particle density versus M(pair)

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

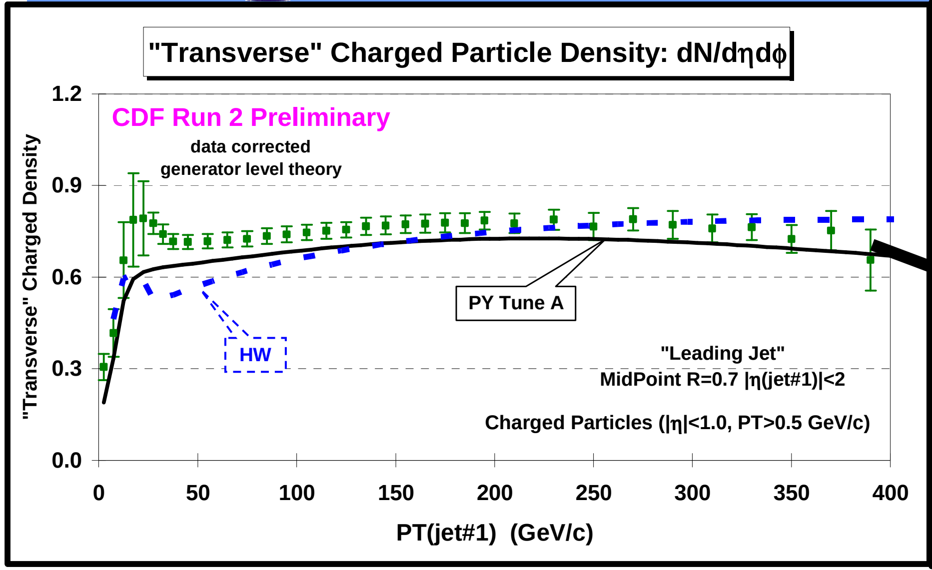
"Underlying event" much more active at the LHC!

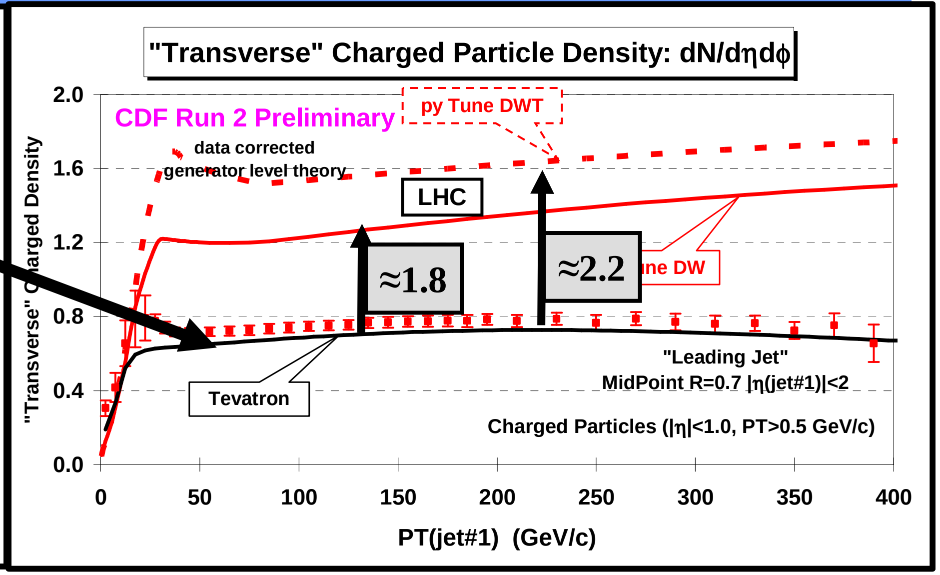


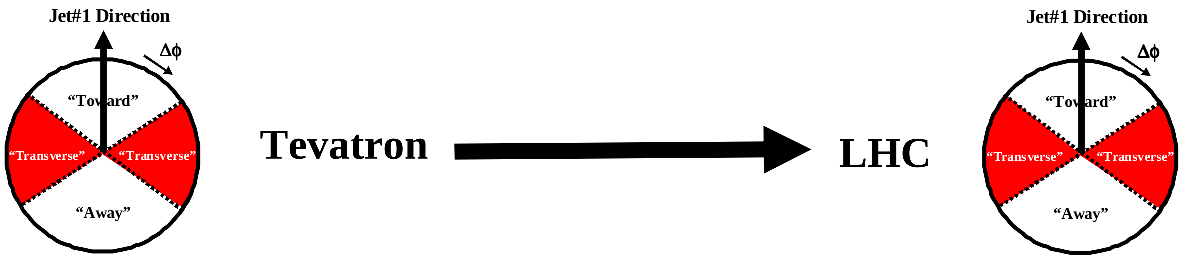


- **Charged particle density versus the lepton-pair invariant mass at 1.96 TeV for PYTHIA Tune AW and HERWIG (*without MPI*).**
- **Charged particle density versus the lepton-pair invariant mass at 14 TeV for PYTHIA Tune AW and HERWIG (*without MPI*).**

Leading Jet: “Transverse” Region







- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for “Leading Jet” events as a function of P_T(jet#1) for the “transverse” region. 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).**

Tomorrow Morning Talk

Talk 2: Extrapolations from the Tevatron to RHIC and the LHC

C T E Q

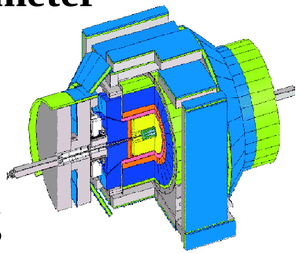
Rick Field

University of Florida

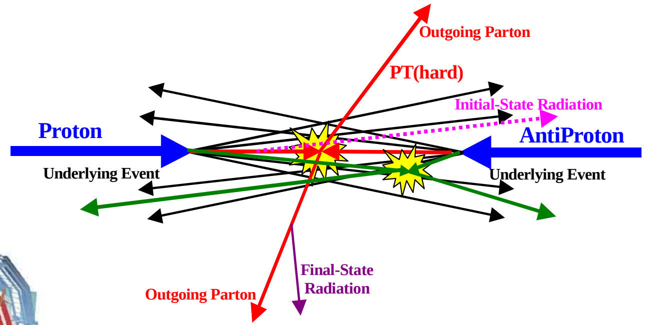
Quantum **C**hromo-**D**ynamics

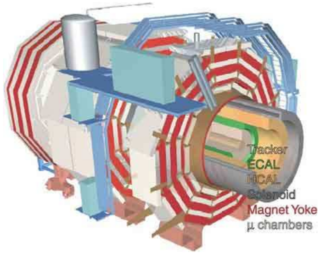
Outline of Talk

- The Pythia MPI energy scaling parameter PARP(90).
- The "underlying event" at STAR. Extrapolations to RHIC.
- LHC predictions for the "underlying event" (hard scattering QCD & Drell-Yan).
- "Min-bias" and "pile-up" at the LHC.
- Correlations: charged particle $<p_T>$ versus the charged multiplicity in "min-bias" and Drell-Yan.
- Summary & Conclusions.



CDF Run 2





CMS at the LHC

UE&MB@CMS