QCD@LHC 2011

How **Universal** are the QCD MC Model **Tunes**?

Quantum Chromo-Dynamics

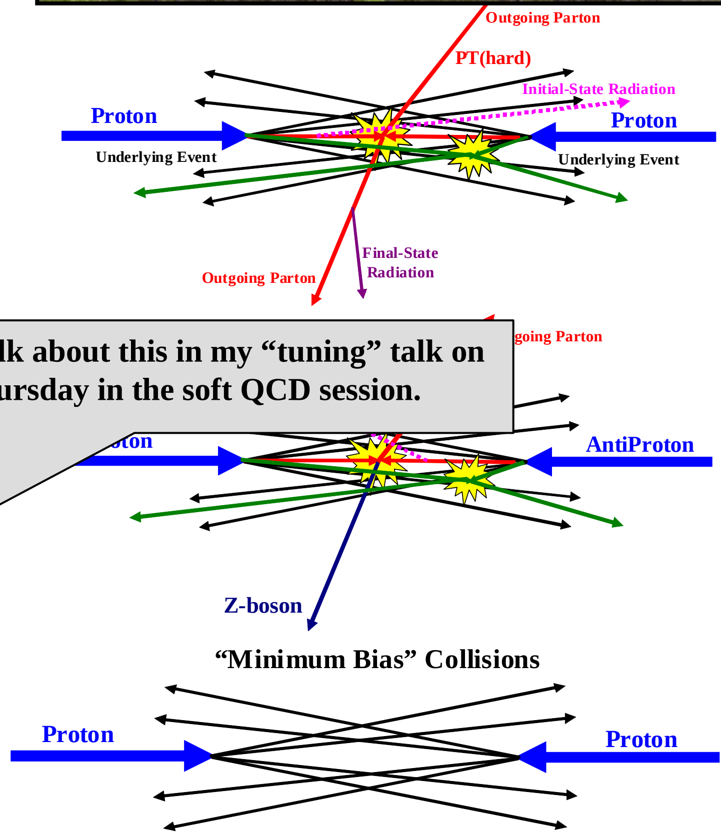
Rick Field

University of Florida

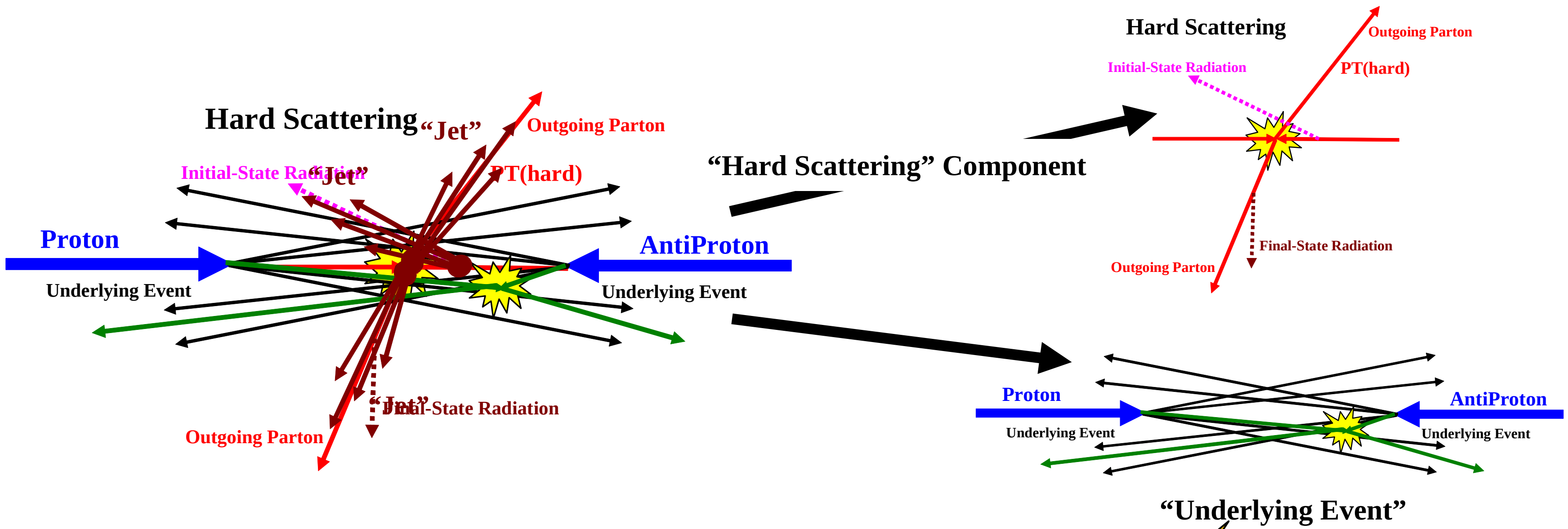
Outline

- Do we need a separate tune for **each center-of-mass energy**? **900 GeV, 1.96 TeV, 7 TeV, etc.**
- Do we need a separate tune for **each hard QCD subprocess**? **Jet Production, Drell-Yan Production, etc.**
- Do we need **separate tunes** for "Min-Bias" (**MB**) and the "underlying event" (**UE**) in a hard scattering process?
- Do we need **separate fragmentation tunes** for **e^+e^- and hadron-hadron** collisions?

I will talk about this in my "tuning" talk on Thursday in the soft QCD session.



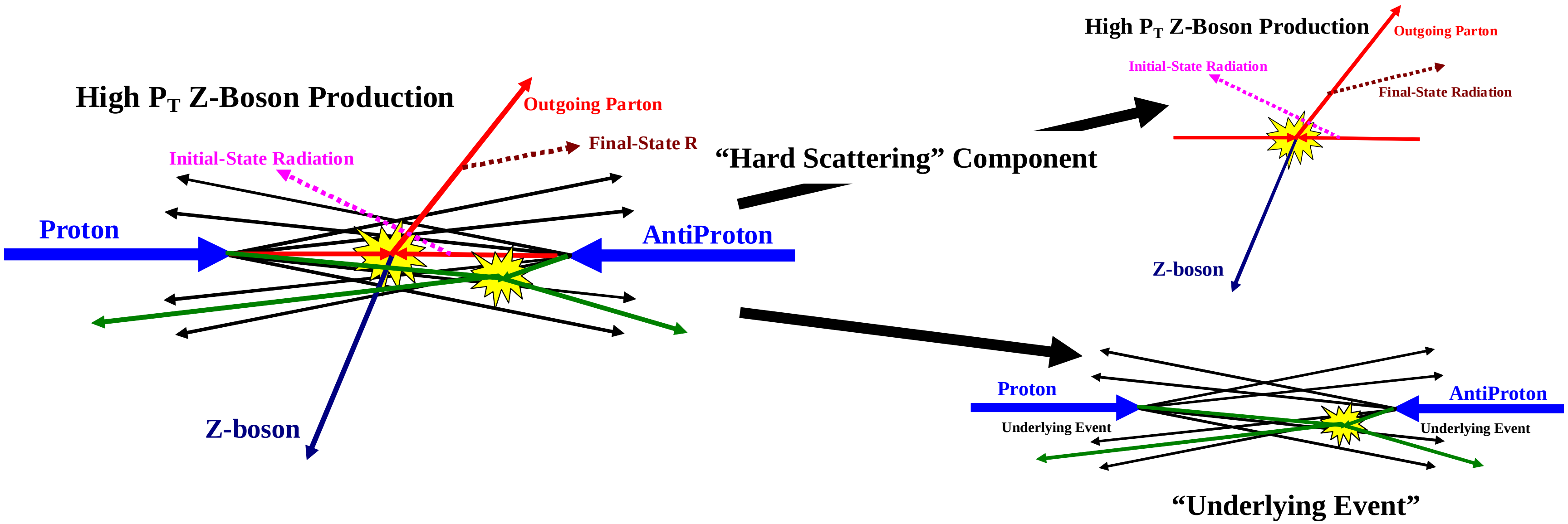
QCD Monte-Carlo Models: High Transverse Momentum Jets



- 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[...]

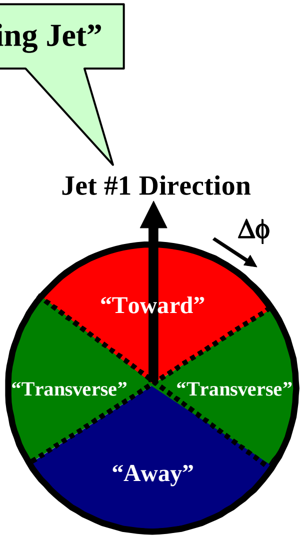
The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

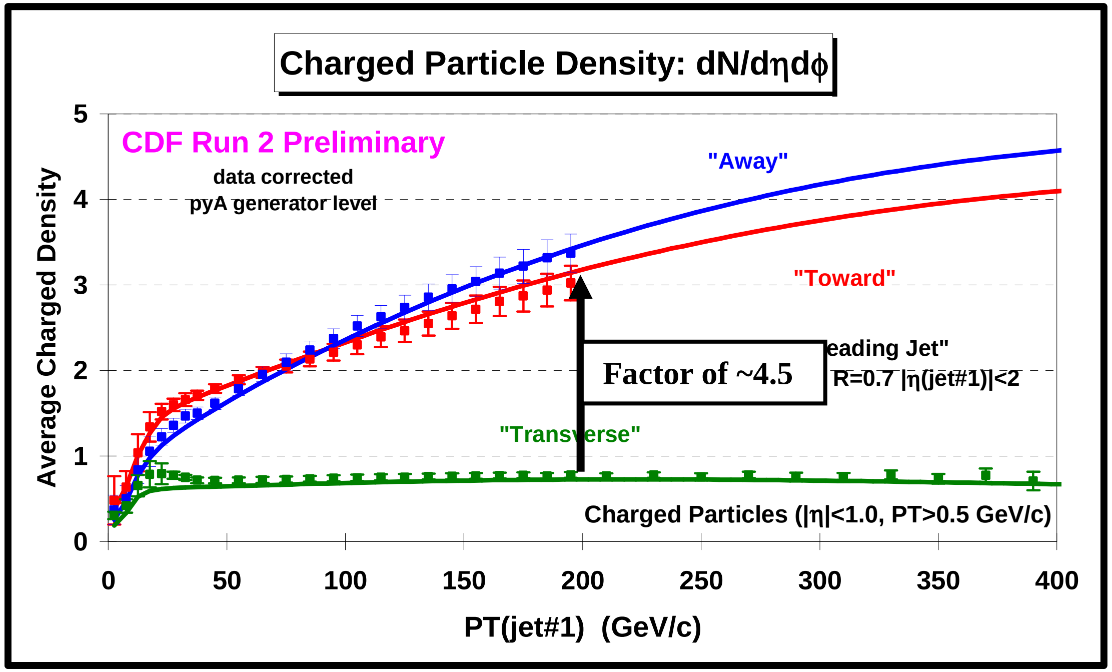
QCD Monte-Carlo Models: Lepton-Pair Production



- **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.**

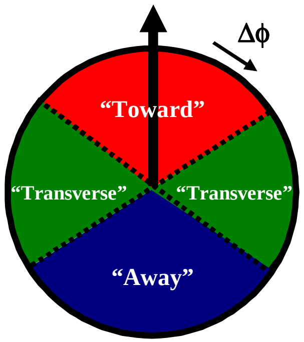
“Towards”, “Away”, “Transverse”

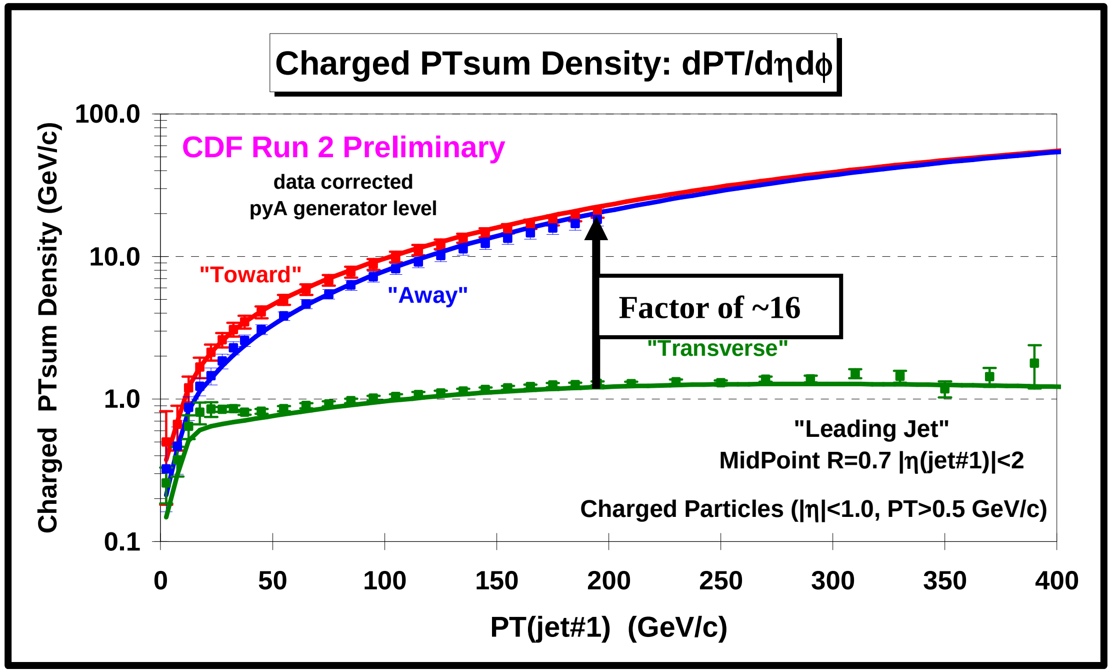




- **CDF data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical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

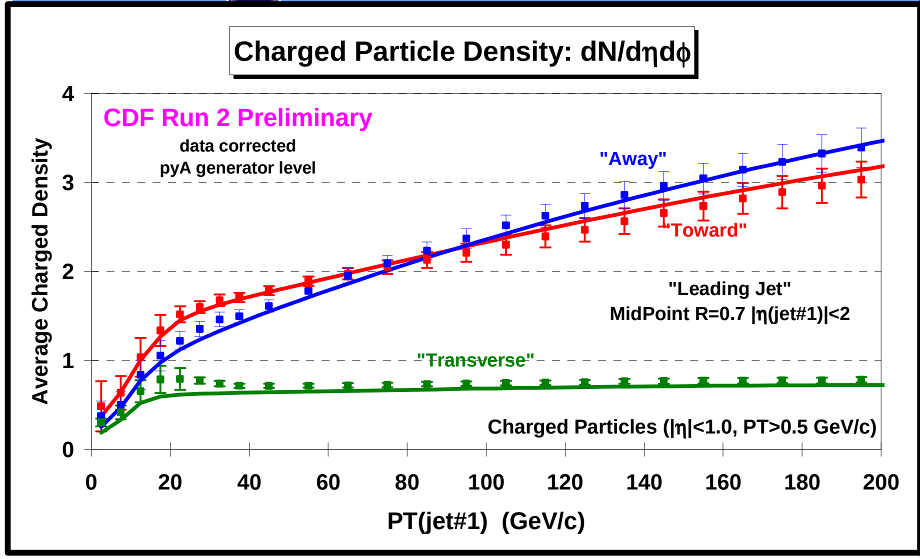
“Towards”, “Away”, “Transverse”

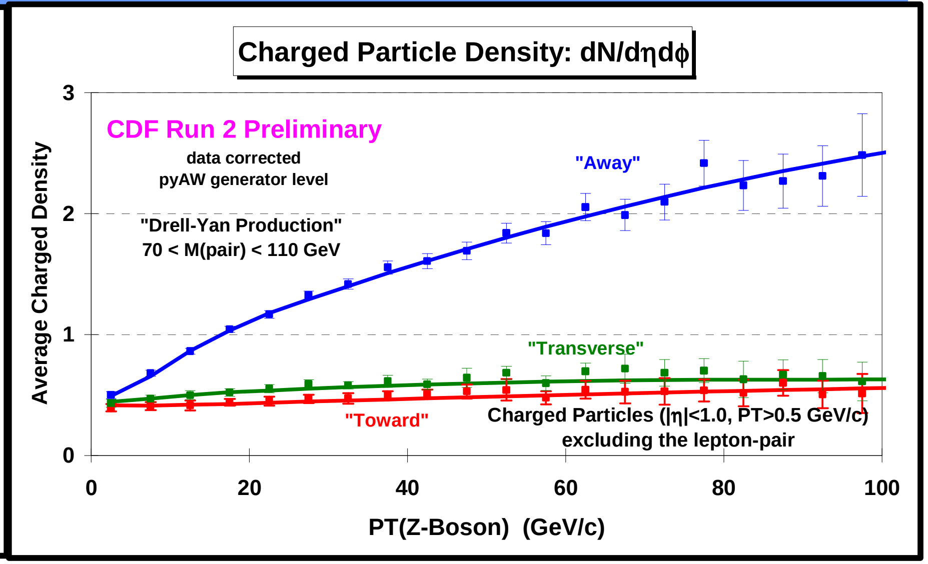


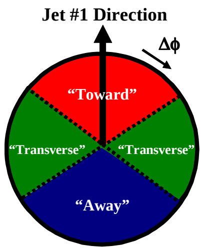


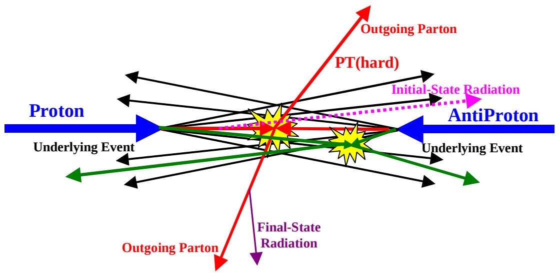
- **CDF data at 1.96 TeV** on the charged particle *scalar* p_T sum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (*with errors that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

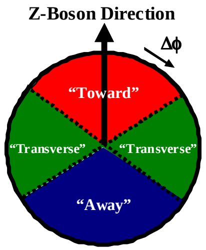
Charged Particle Density

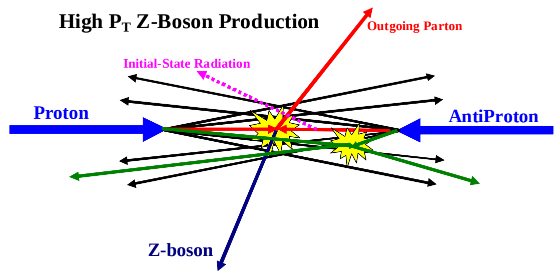






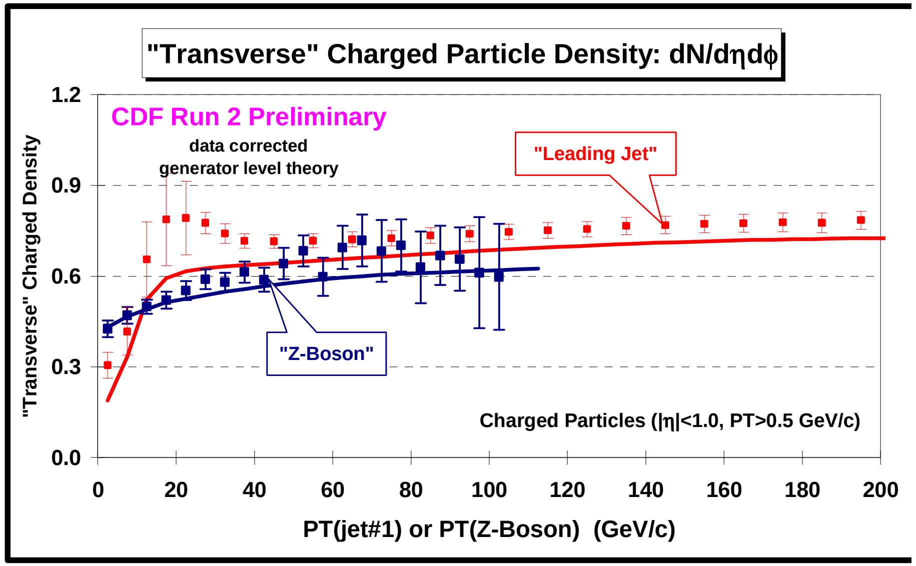


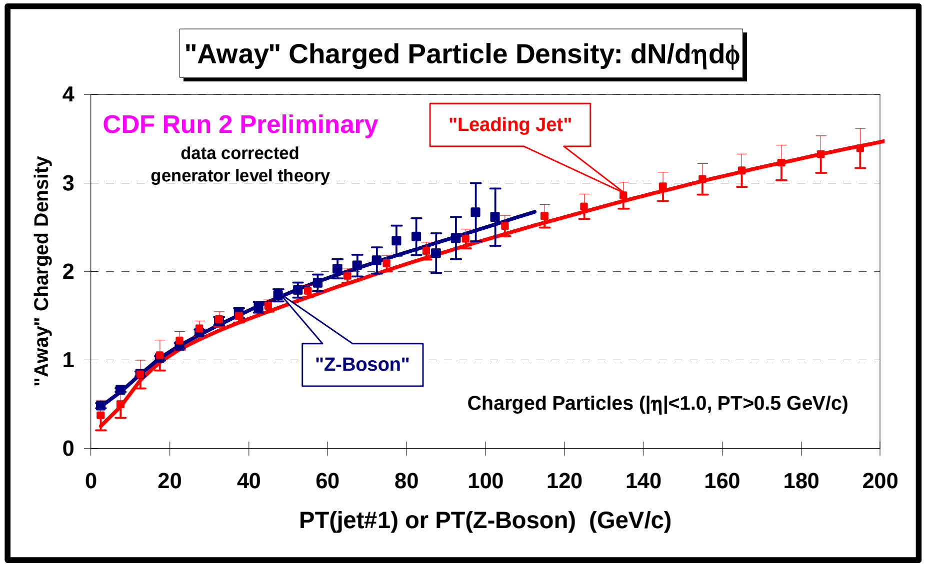


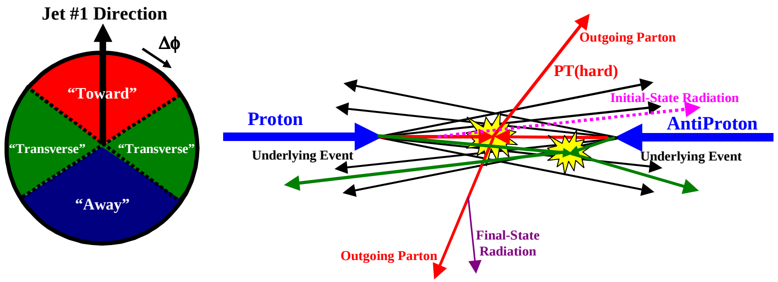


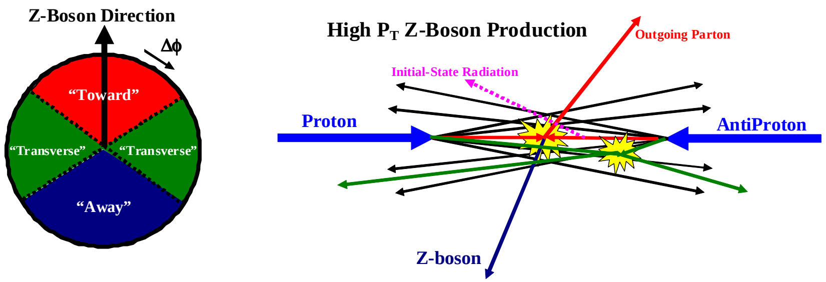
- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level and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

Charged Particle Density



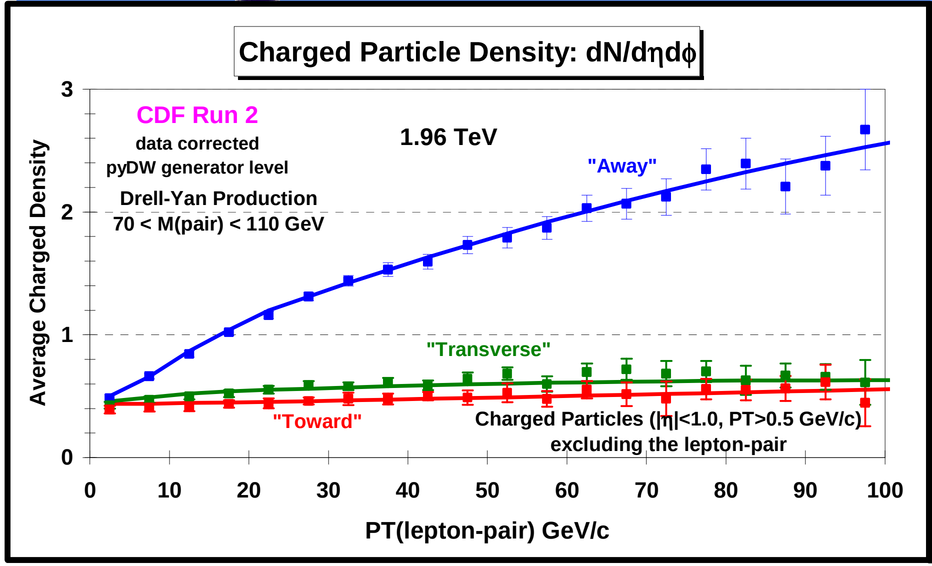


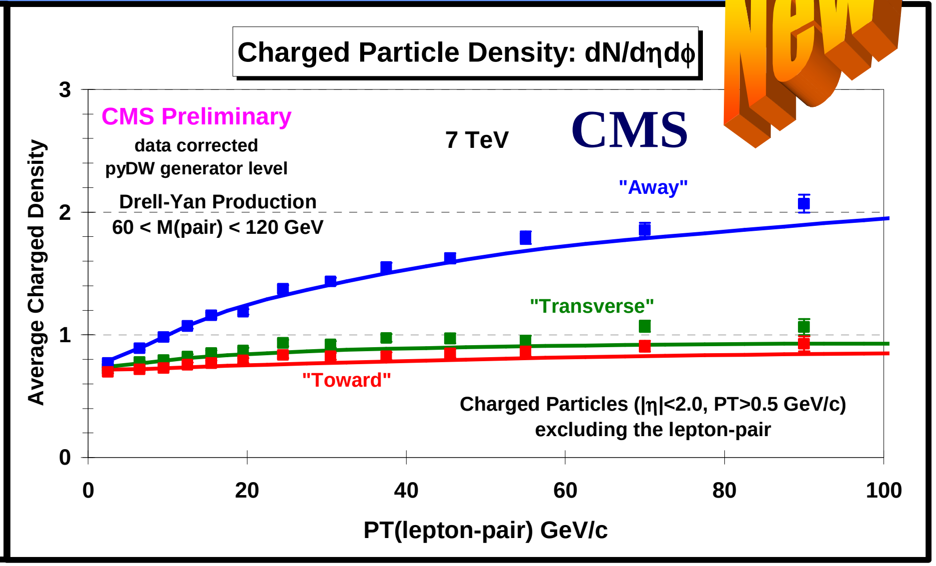


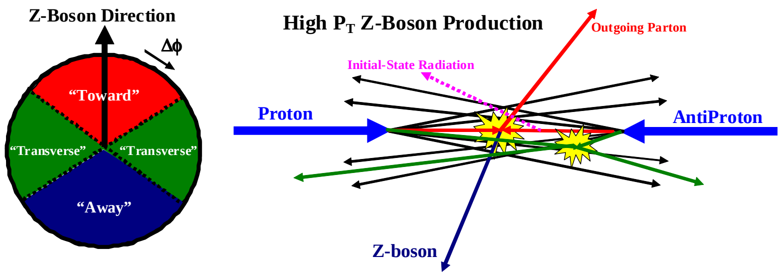


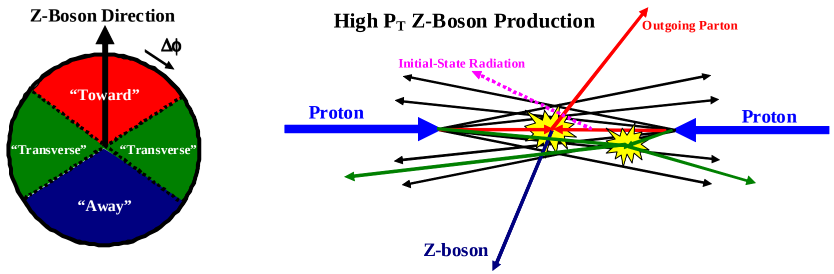
- **CDF data at 1.96 TeV** on the density of charged particles, $dN/d\eta d\phi$, with p_T > 0.5 GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the **"toward"**, **"away"**, and **"transverse"** regions. The data are corrected to the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

Charged Particle Density



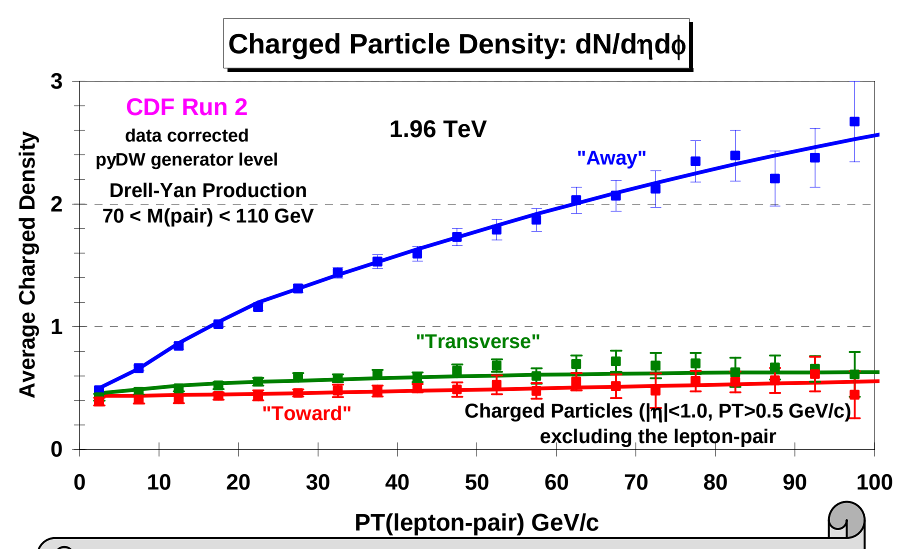


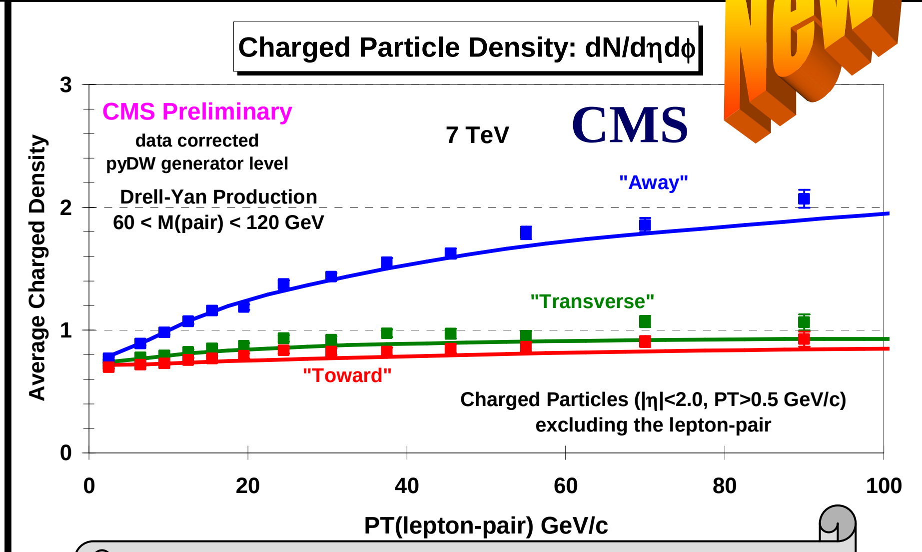




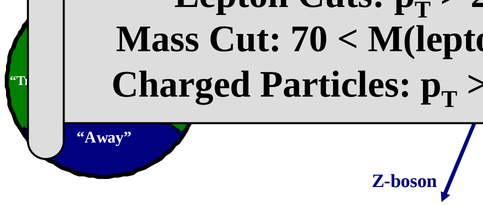
- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune DW**.
- **CMS data at 7 TeV** on the density of charged particles, dN/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune DW**.

Charged Particle Density

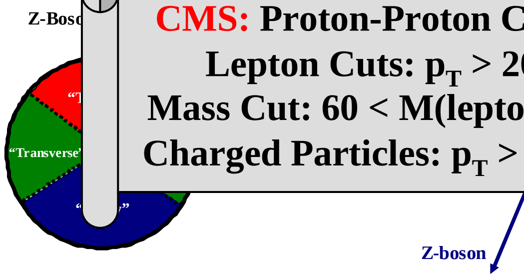




CDF: Proton-Antiproton Collisions at 1.96 GeV
Lepton Cuts: p_T > 20 GeV |η| < 1.0
Mass Cut: 70 < M(lepton-pair) < 110 GeV
Charged Particles: p_T > 0.5 GeV/c |η| < 1.0

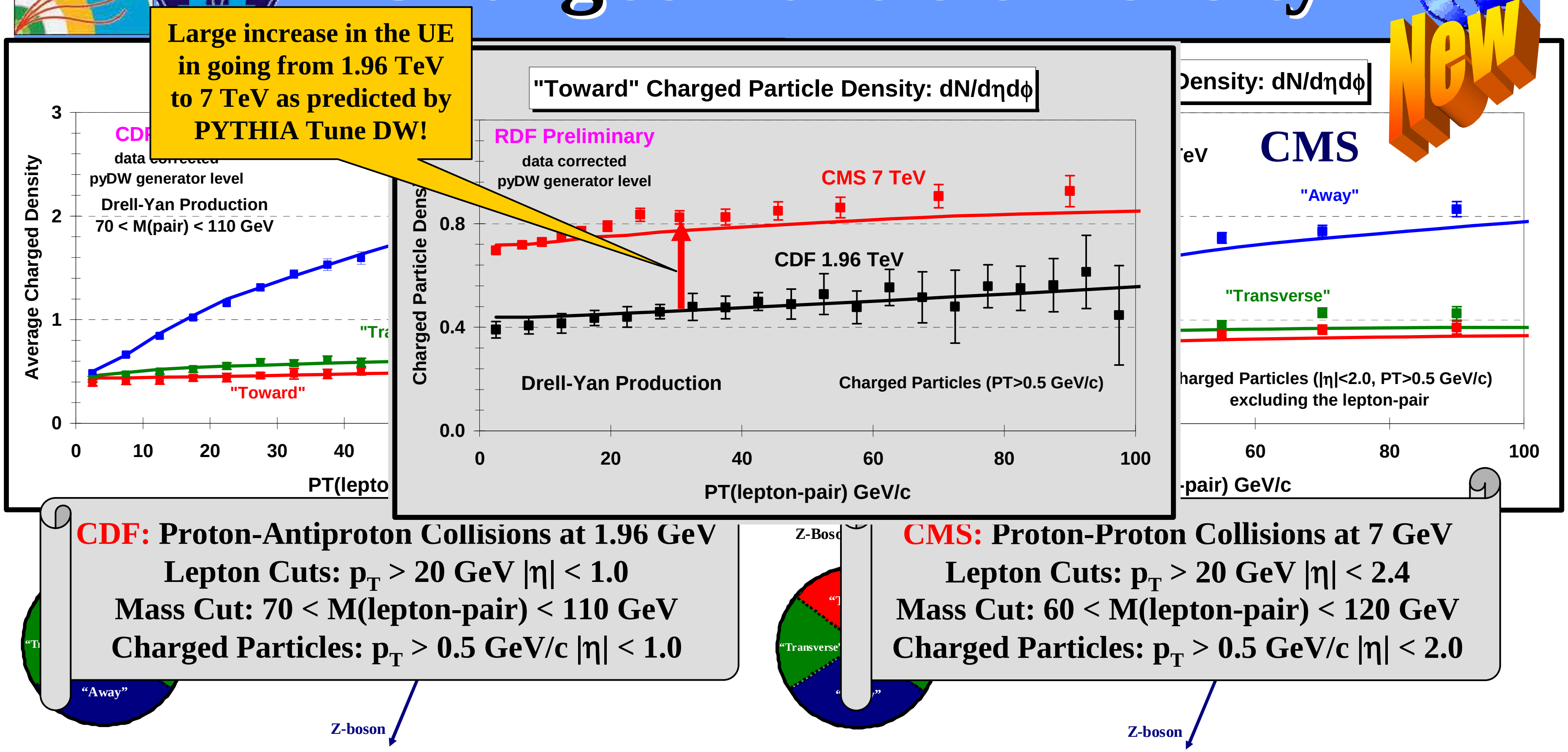


CMS: Proton-Proton Collisions at 7 GeV
Lepton Cuts: p_T > 20 GeV |η| < 2.4
Mass Cut: 60 < M(lepton-pair) < 120 GeV
Charged Particles: p_T > 0.5 GeV/c |η| < 2.0



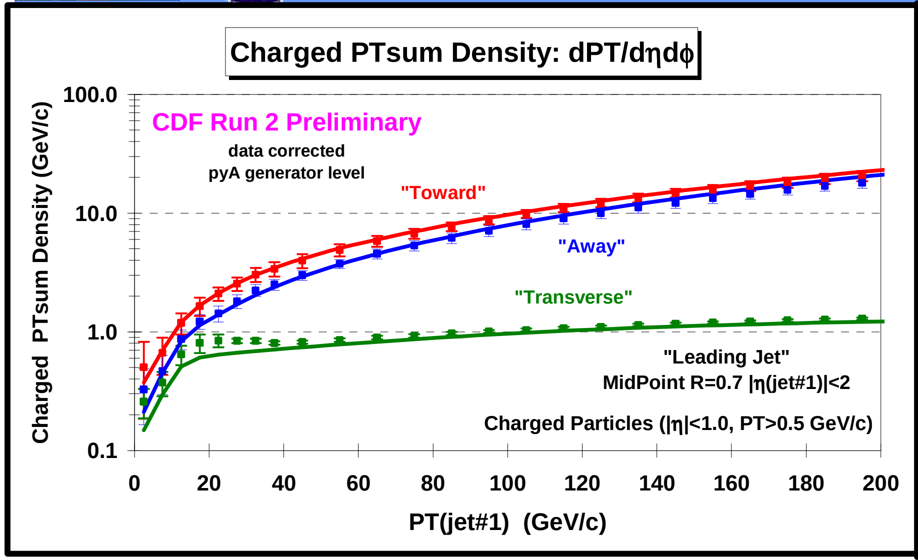
- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.
- **CMS data at 7 TeV** on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.

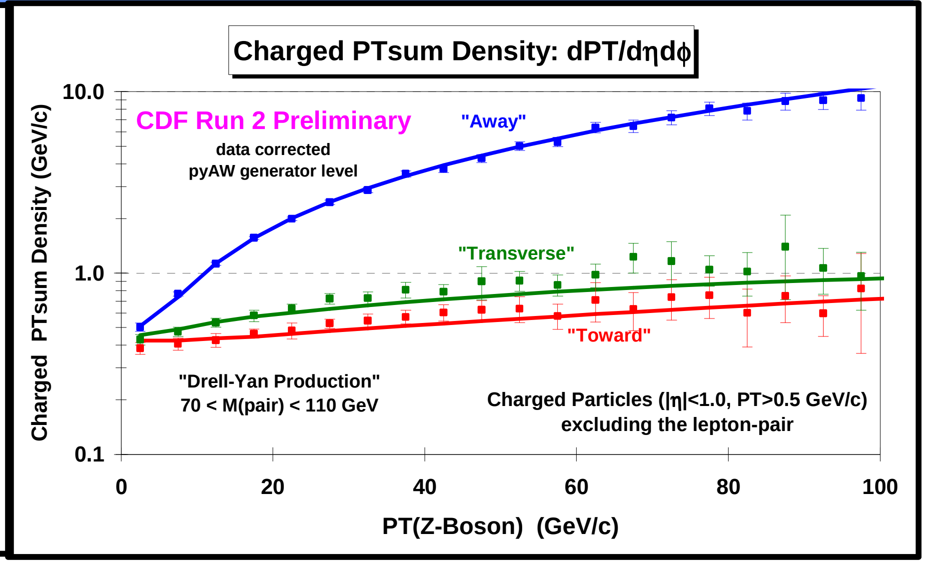
Charged Particle Density

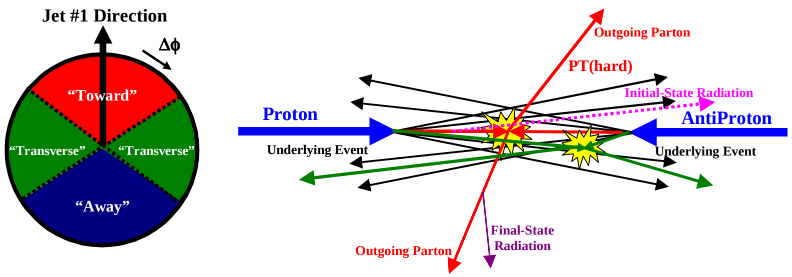


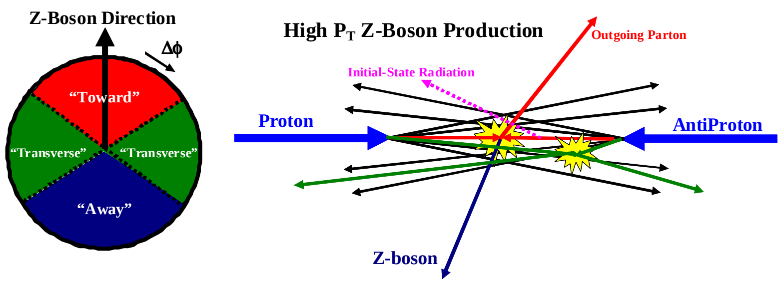
- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.
- **CMS data at 7 TeV** on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.

Charged PTsum Density



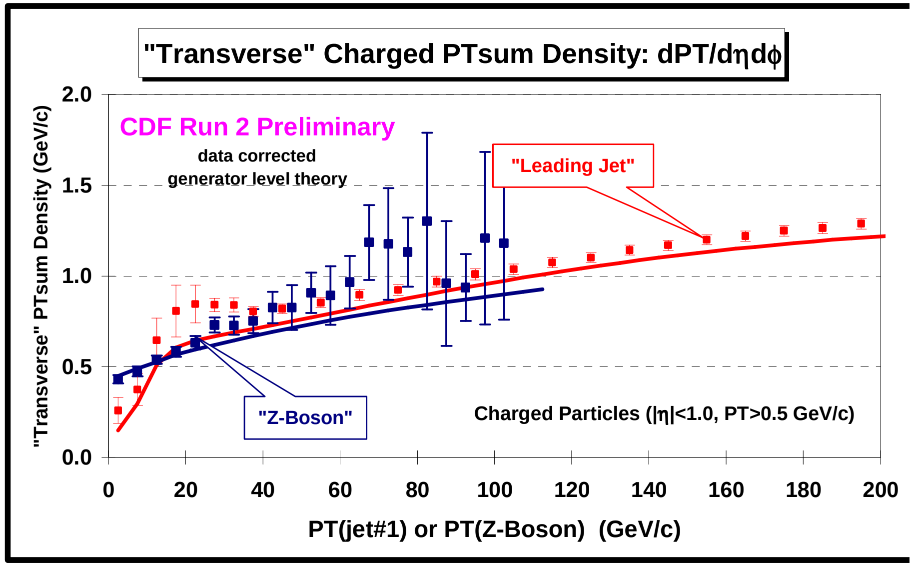


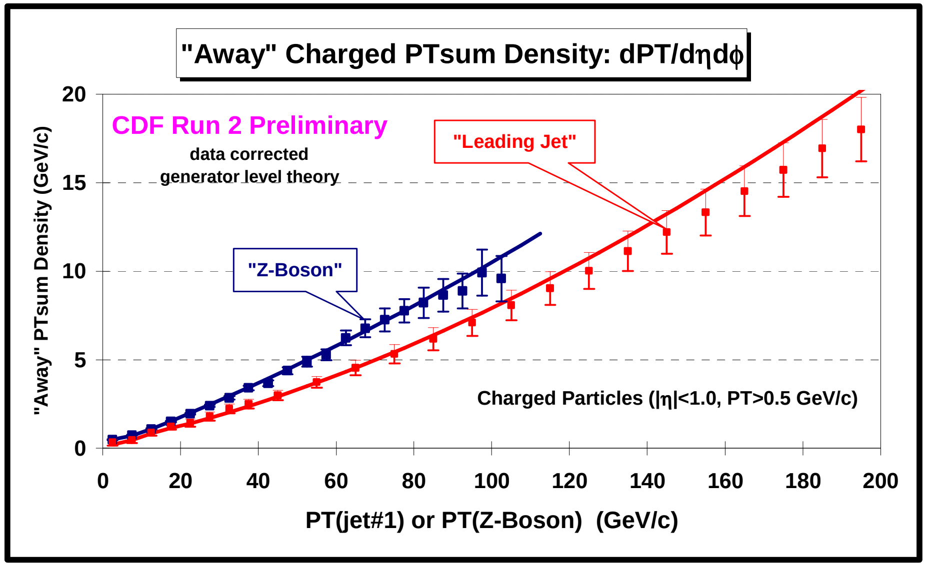


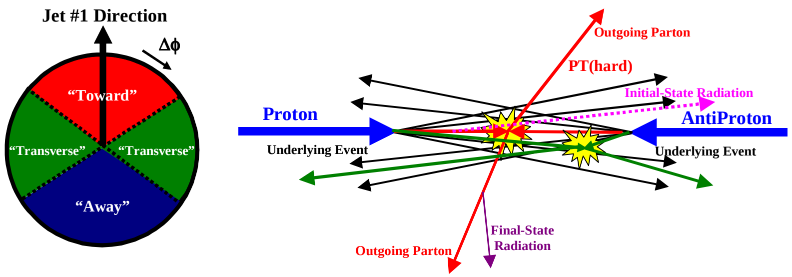


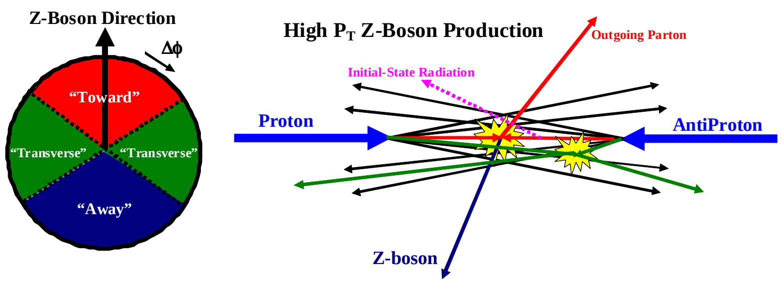
- **CDF data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

Charged PTsum Density



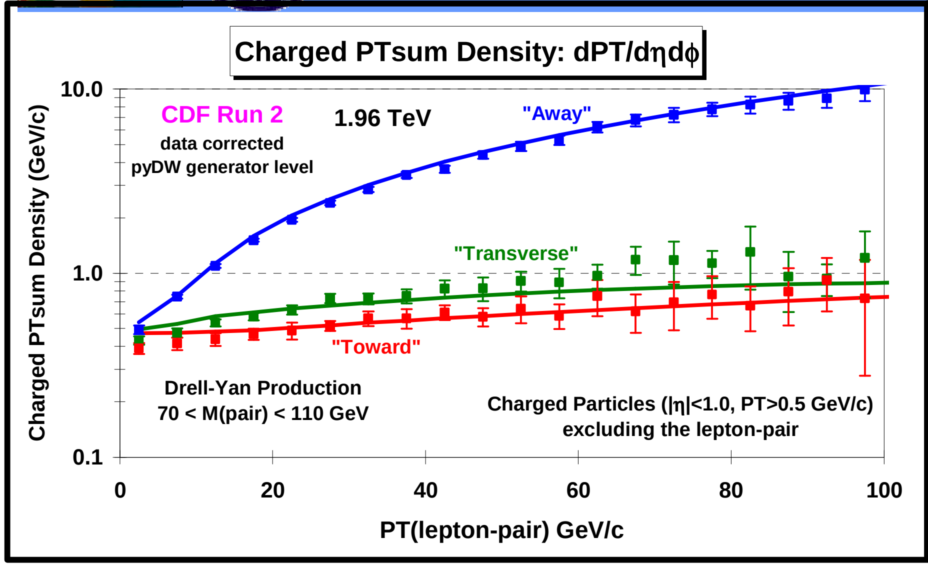


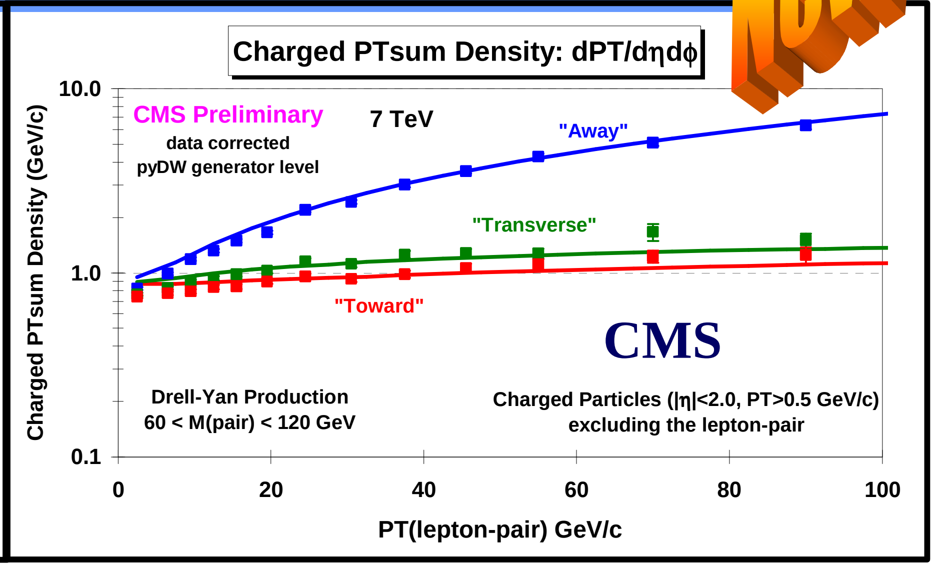


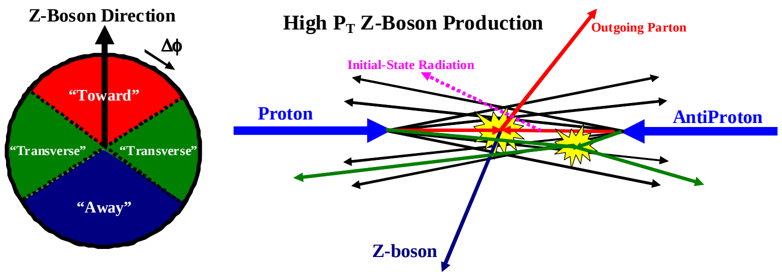


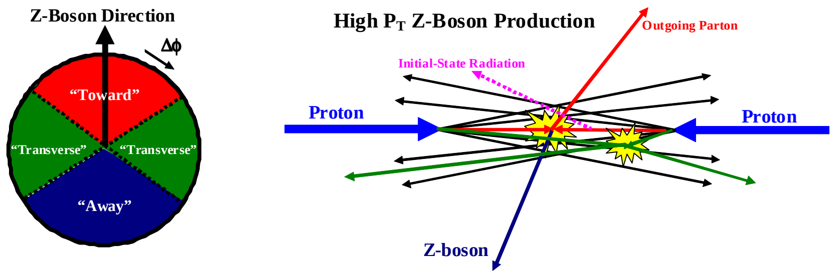
- **CDF data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

Charged PTsum Density



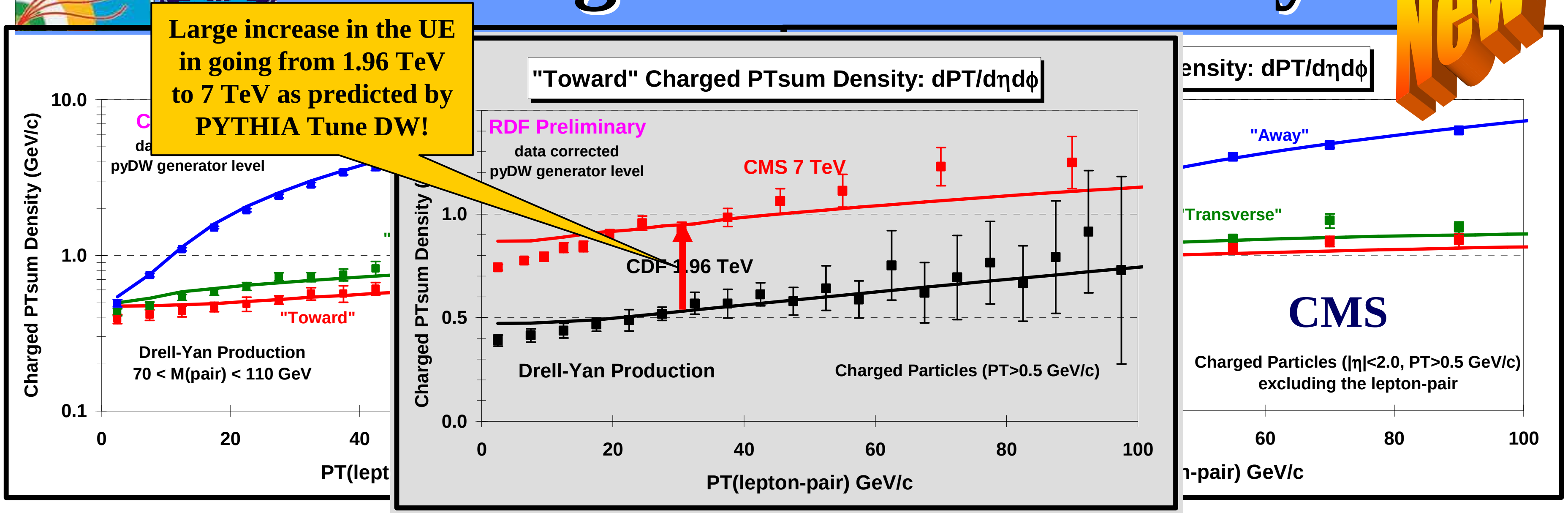


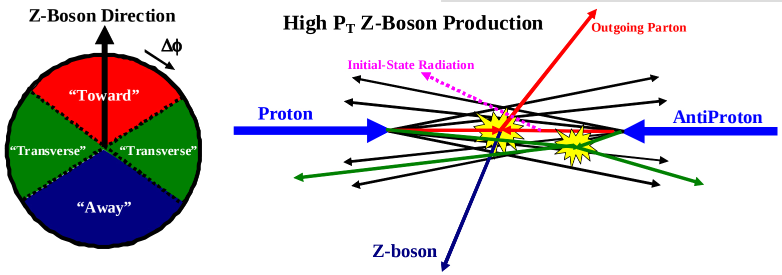


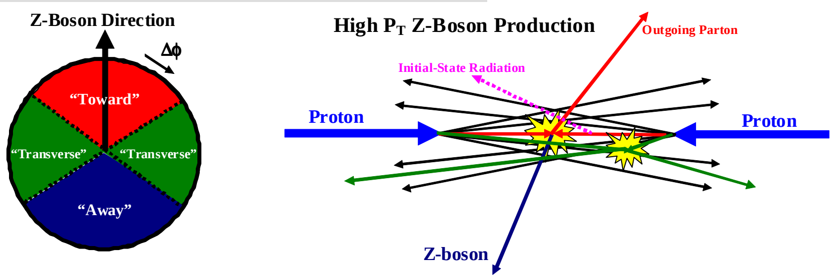


- **CDF data at 1.96 TeV** on the charged PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of PT(Z) for the **"toward"**, **"away"**, and **"transverse"** regions compared with PYTHIA Tune DW.
- **CMS data at 7 TeV** on the charged PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of PT(Z) for the **"toward"**, **"away"**, and **"transverse"** regions compared with PYTHIA Tune DW.

Charged PTsum Density

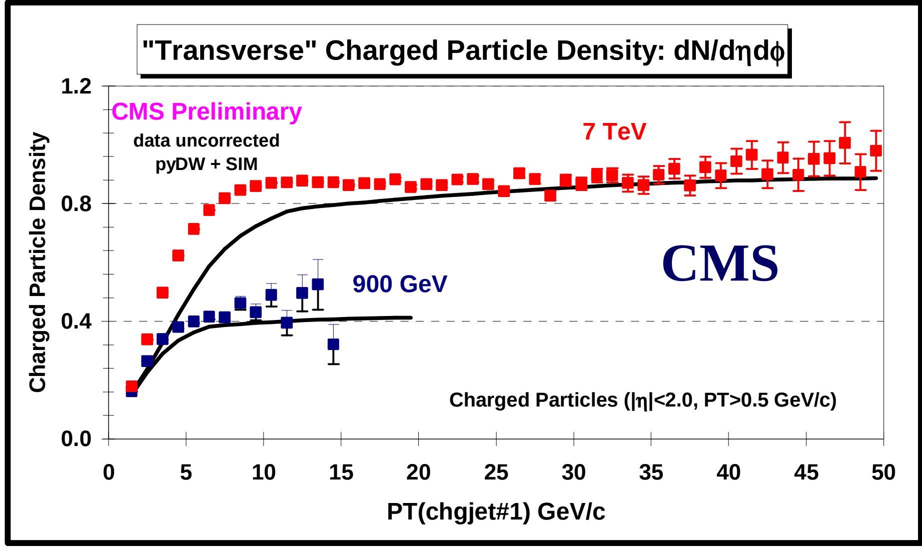


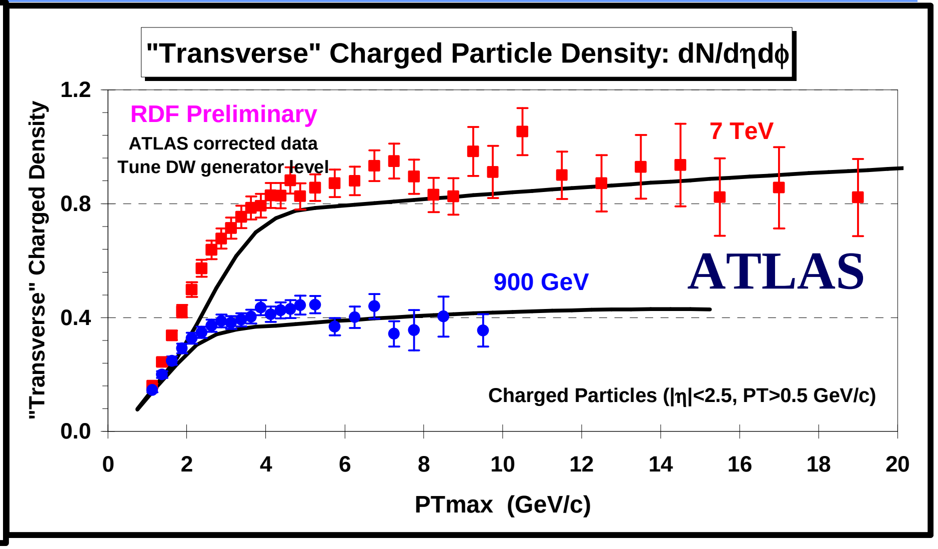




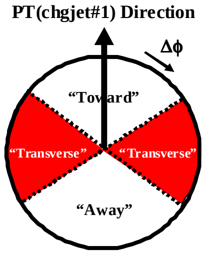
- **CDF data at 1.96 TeV on the charged PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of PT(Z) for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.**
- **CMS data at 7 TeV on the charged PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of PT(Z) for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.**

PYTHIA Tune DW

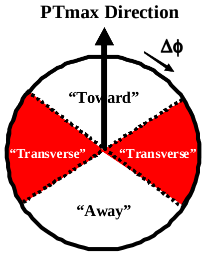




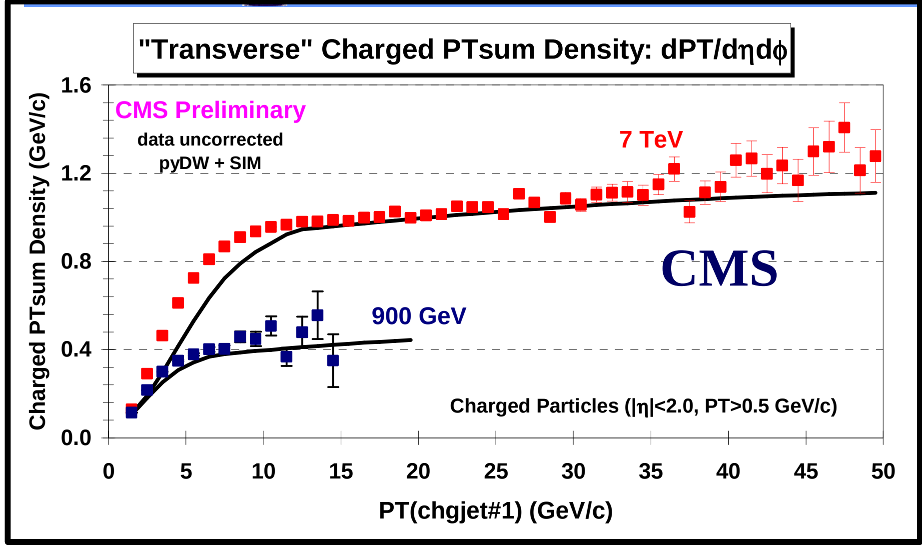
- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

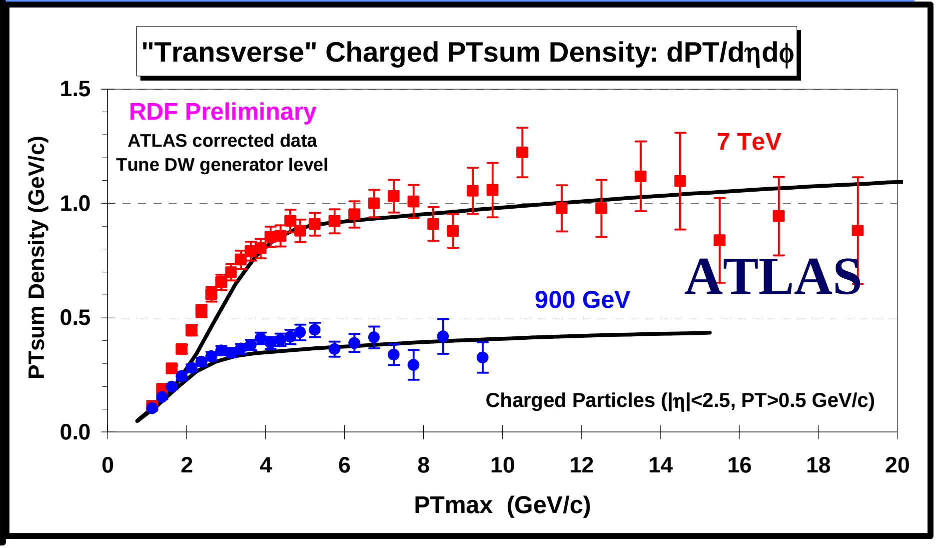


- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.**

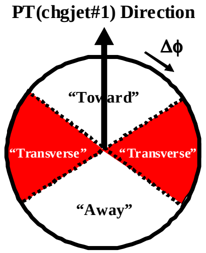


PYTHIA Tune DW

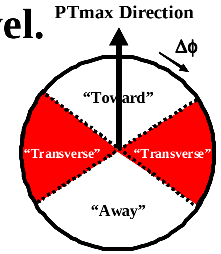




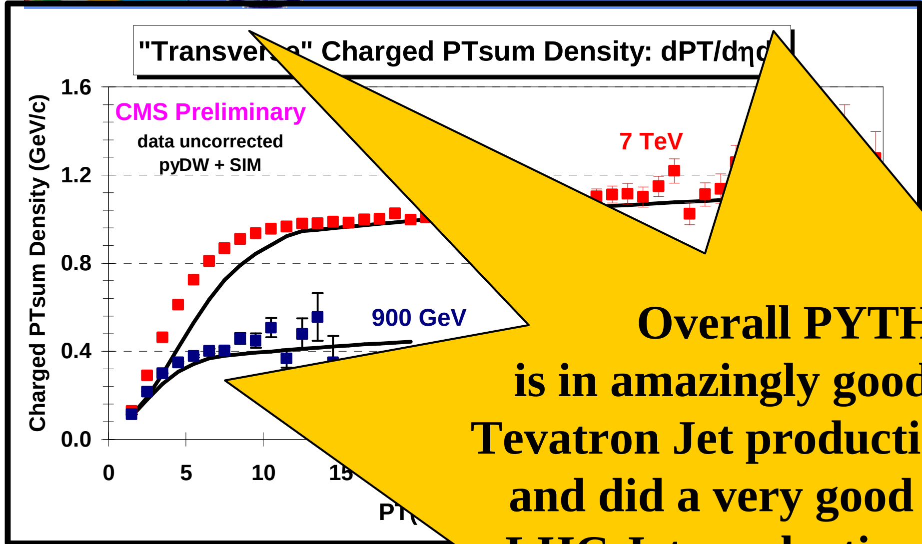
- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

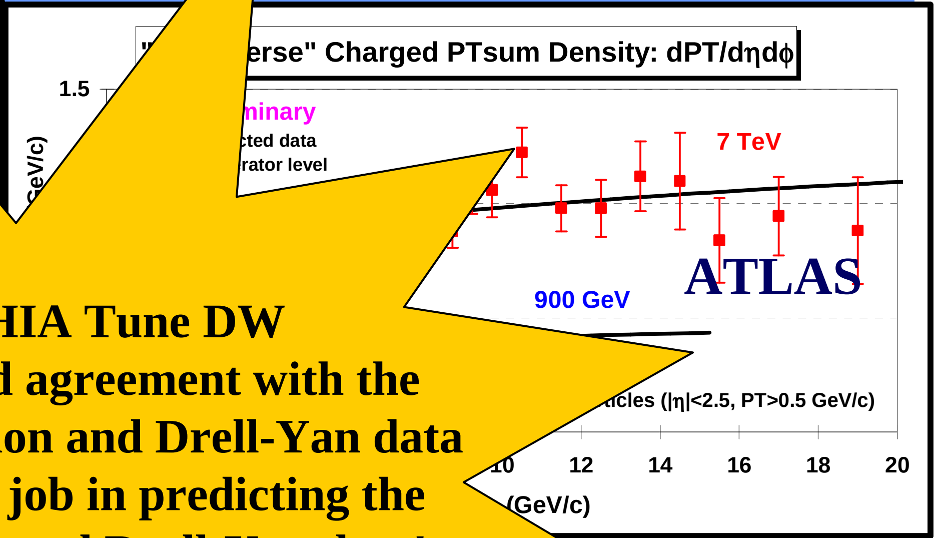


- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.**



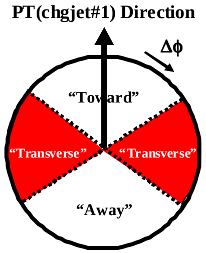
PYTHIA Tune DW



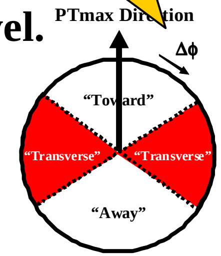


Overall PYTHIA Tune DW is in amazingly good agreement with the Tevatron Jet production and Drell-Yan data and did a very good job in predicting the LHC Jet production and Drell-Yan data! (although not perfect)

- **CMS preliminary d… TeV on the "tra… density, dPT… charged particle jet (chgjet#… particles with p_T > 0.5 GeV… The data are uncorrected a… compa… with PYTHIA Tune DW after detect… simulation.**

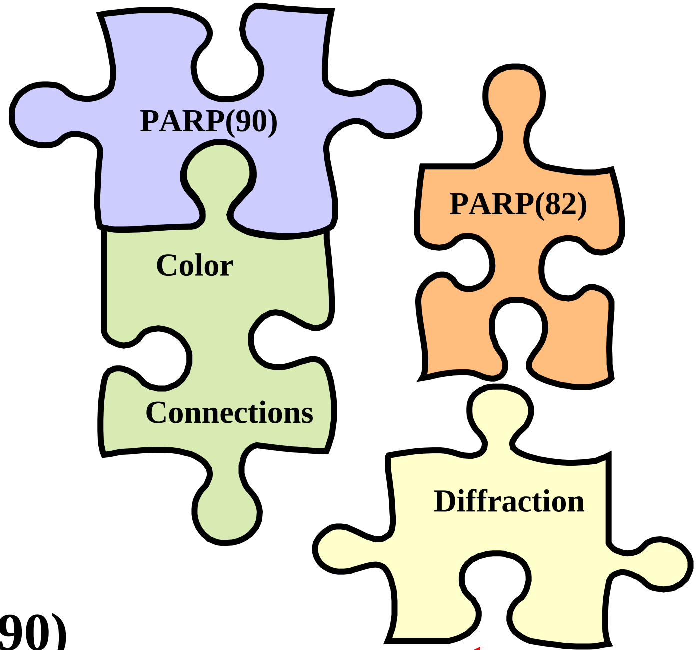


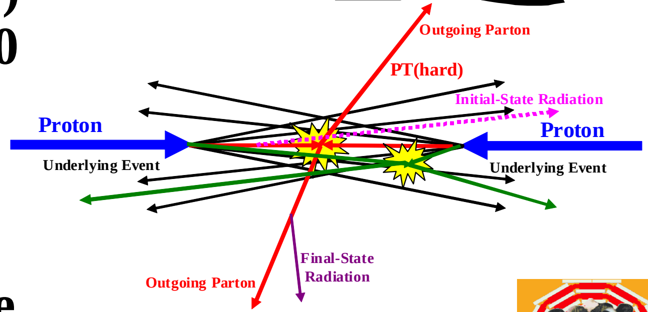
- **… 900 GeV and … ansverse" charged PTsum … , as defined by the … rticle (PTmax) for … d par… ith p_T > 0.5 GeV/c and … .5. The d… re corrected and … ared with PY… IA Tune DW at the g… ator level.**



PYTHIA Tune Z1

- **All my previous tunes (A, DW, DWT, D6, D6T, CW, X1, and X2) were PYTHIA 6.4 tunes using the old Q^2-ordered parton showers and the old MPI model (really 6.2 tunes)!**
- **I believe that it is time to move to PYTHIA 6.4 (p_T-ordered parton showers and new MPI model)!**
- **Tune Z1: I started with the parameters of ATLAS Tune AMBT1, but I changed LO* to CTEQ5L and I varied PARP(82) and PARP(90) to get a very good fit of the CMS UE data at 900 GeV and 7 TeV.**
- **The ATLAS Tune AMBT1 was designed to fit the inelastic data for Nchg ≥ 6 and to fit the PTmax UE data with PTmax > 10 GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!**





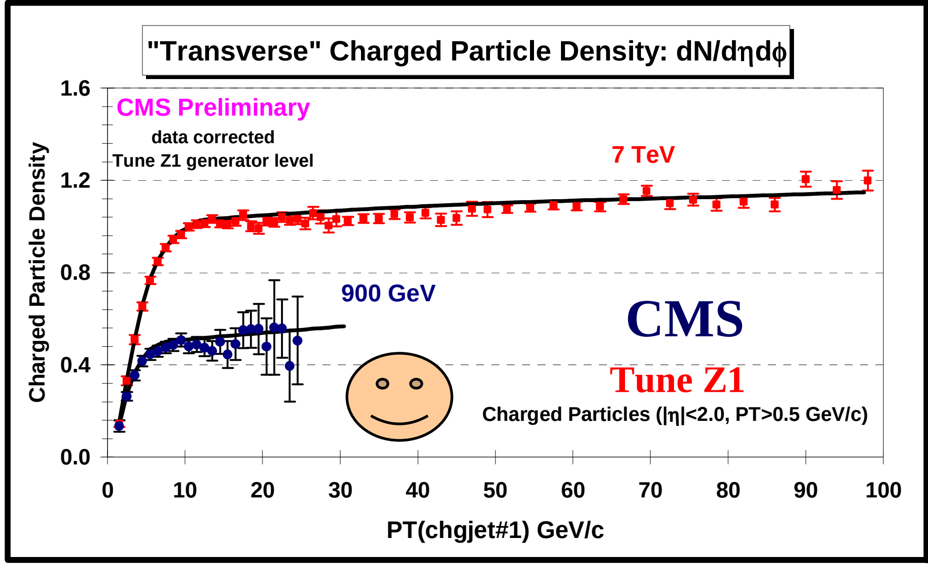
UE&MB@CMS

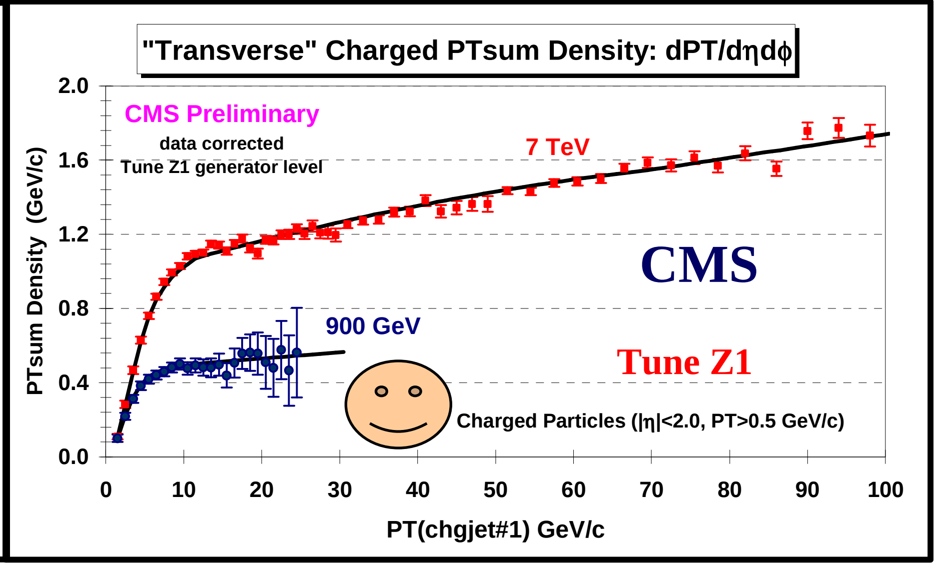
PYTHIA Tune Z1

Parameters not shown are the PYTHIA 6.4 defaults!

Parameter	Tune Z1 (R. Field CMS)	Tune AMBT1 (ATLAS)
Parton Distribution Function	CTEQ5L	LO*
PARP(82) – MPI Cut-off	1.932	2.292
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.25
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

CMS UE Data





- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

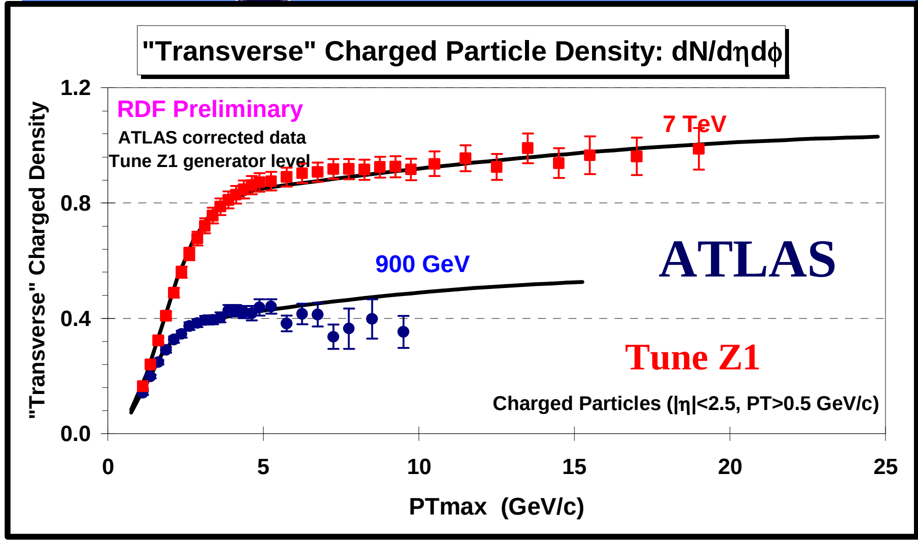
- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

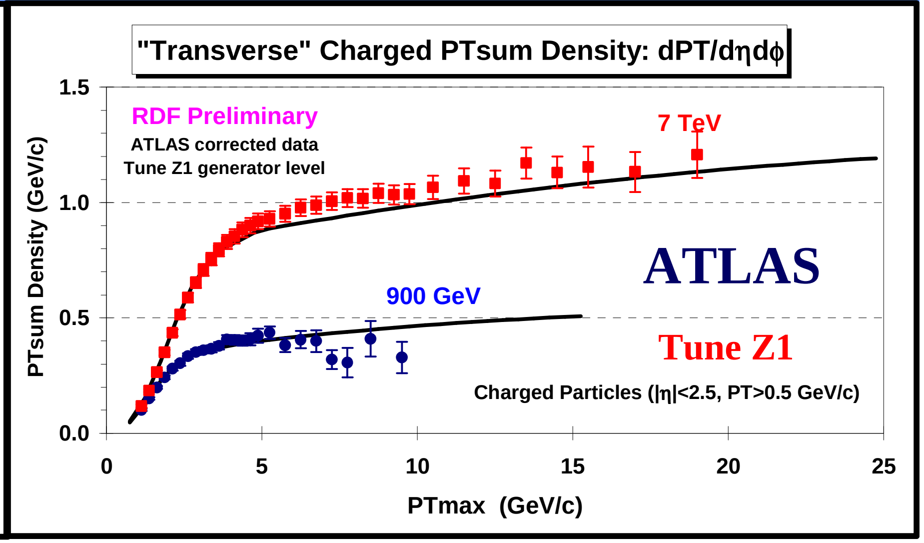
CMS corrected data!

Very nice agreement!

CMS corrected data!

ATLAS UE Data



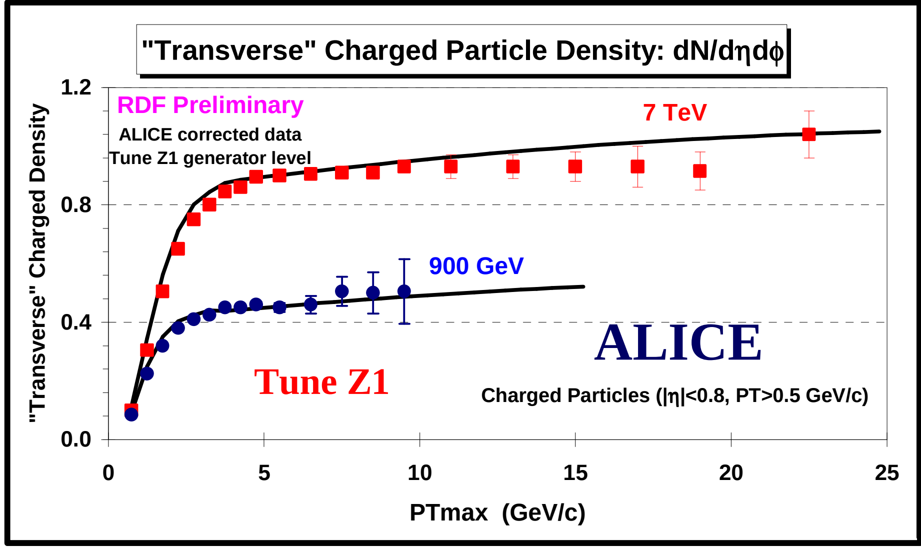


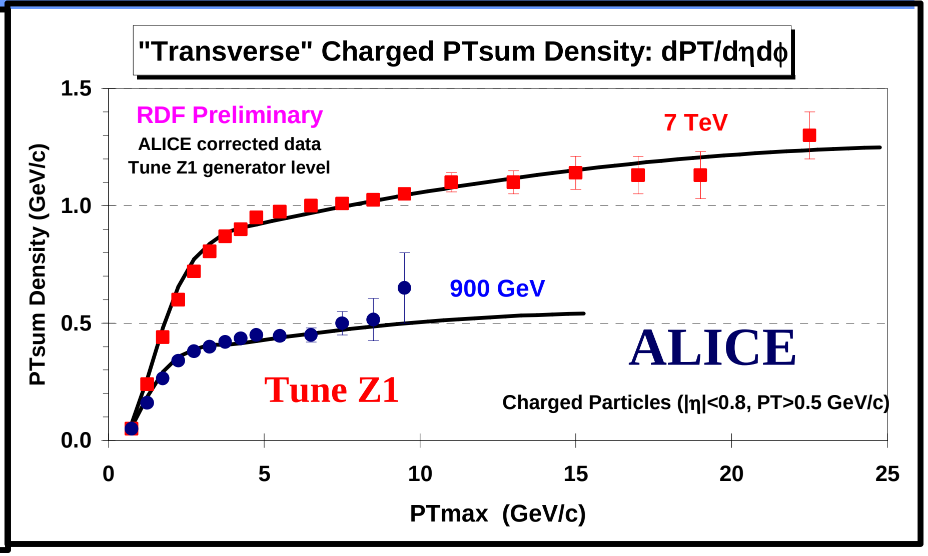
- **ATLAS published data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

- **ATLAS published data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the genererator level.**

ATLAS publication – arXiv:1012.0791
December 3, 2010

ALICE UE Data





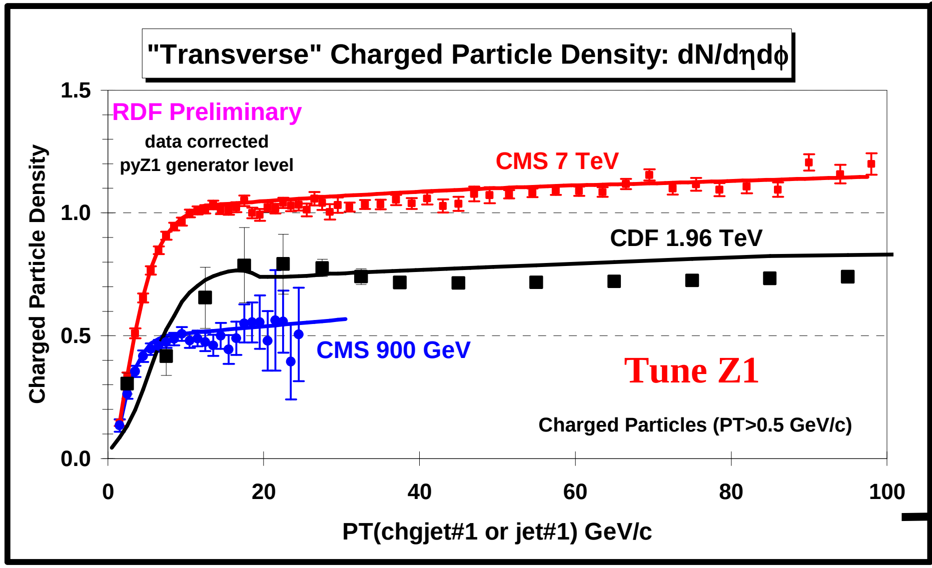
- **ALICE preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

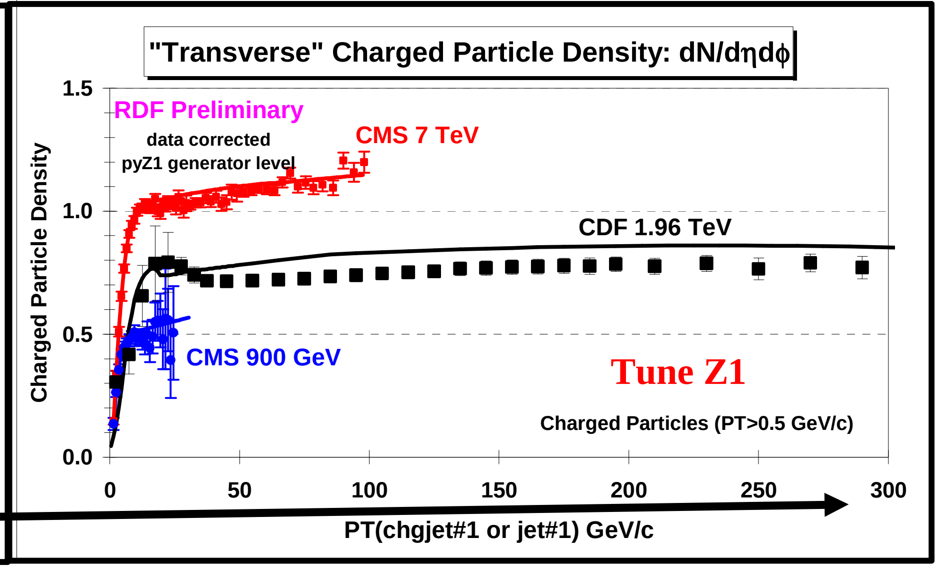
- **ALICE preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with PYTHIA Tune Z1 at the generrator level.**

I read the points off with a ruler!

ALICE UE Data: Talk by S. Vallero
MPI@LHC 2010 Glasgow, Scotland
November 30, 2010

PYTHIA Tune Z1

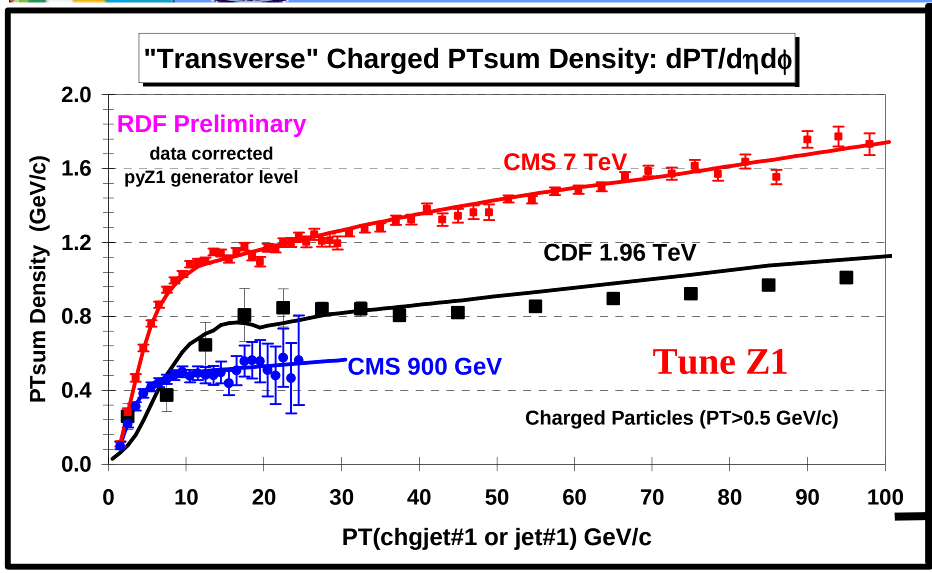


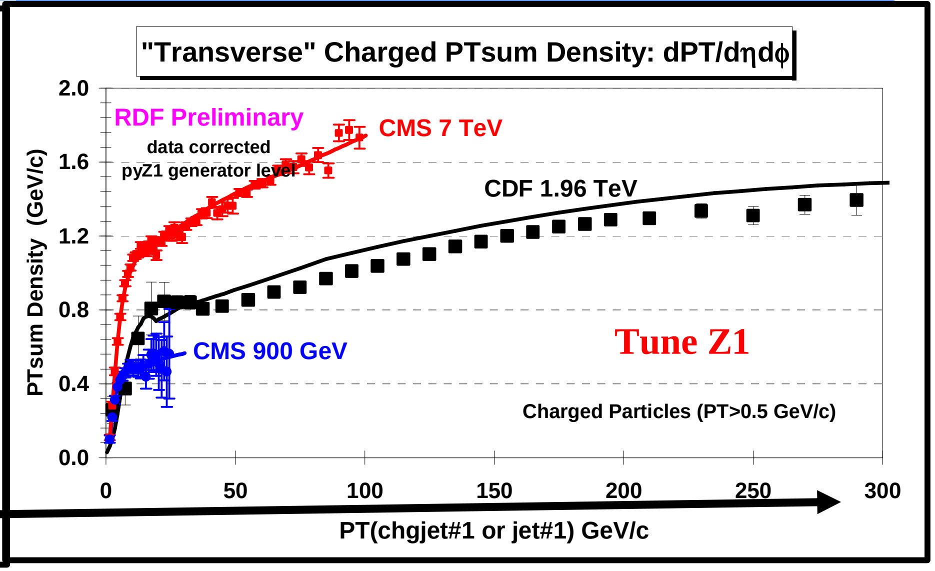


- **CMS data at 900 GeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

- **CDF data at 1.96 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading calorimeter jet (jet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

PYTHIA Tune Z1

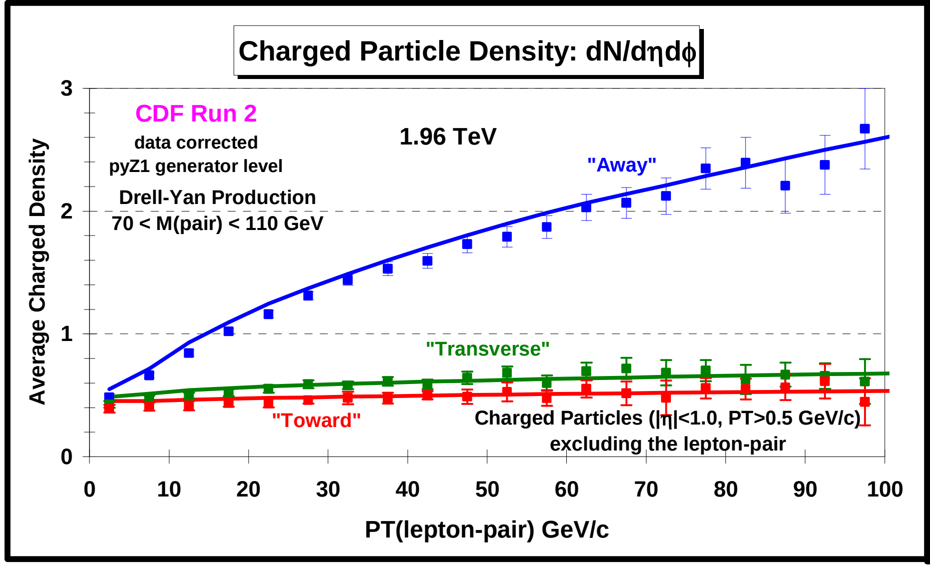


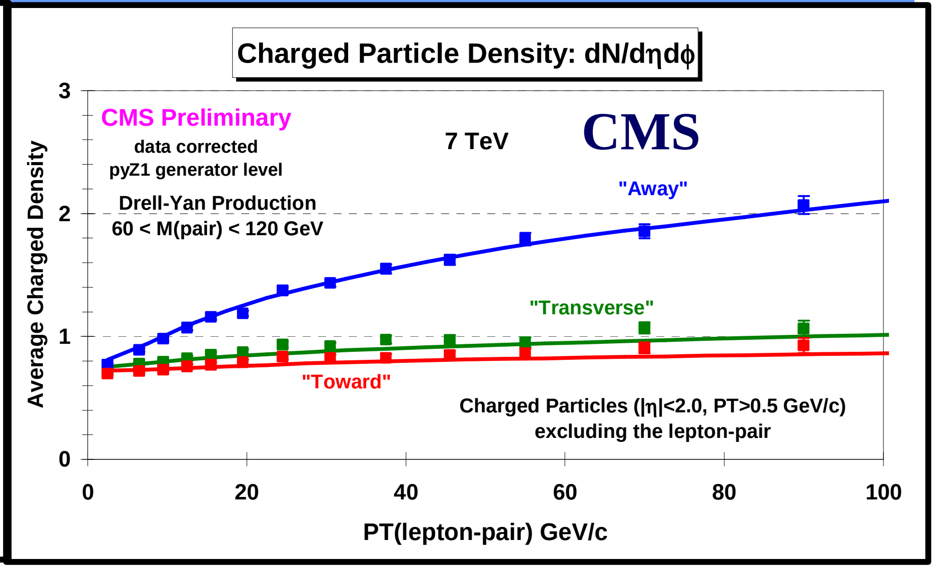


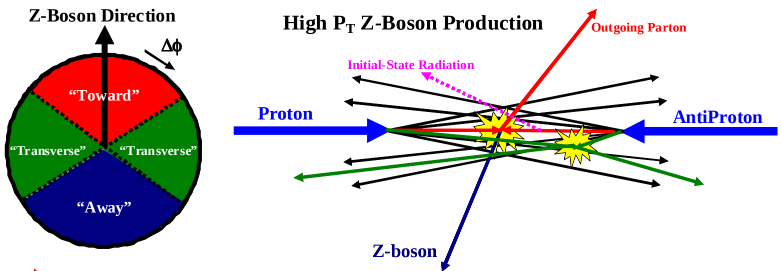
- **CMS data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

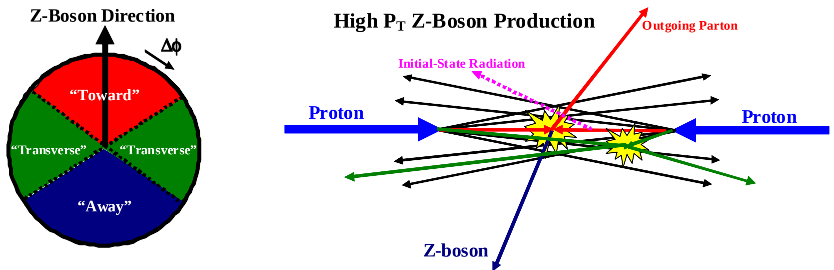
- **CDF data at 1.96 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading calorimeter jet (jet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

PYTHIA Tune Z1



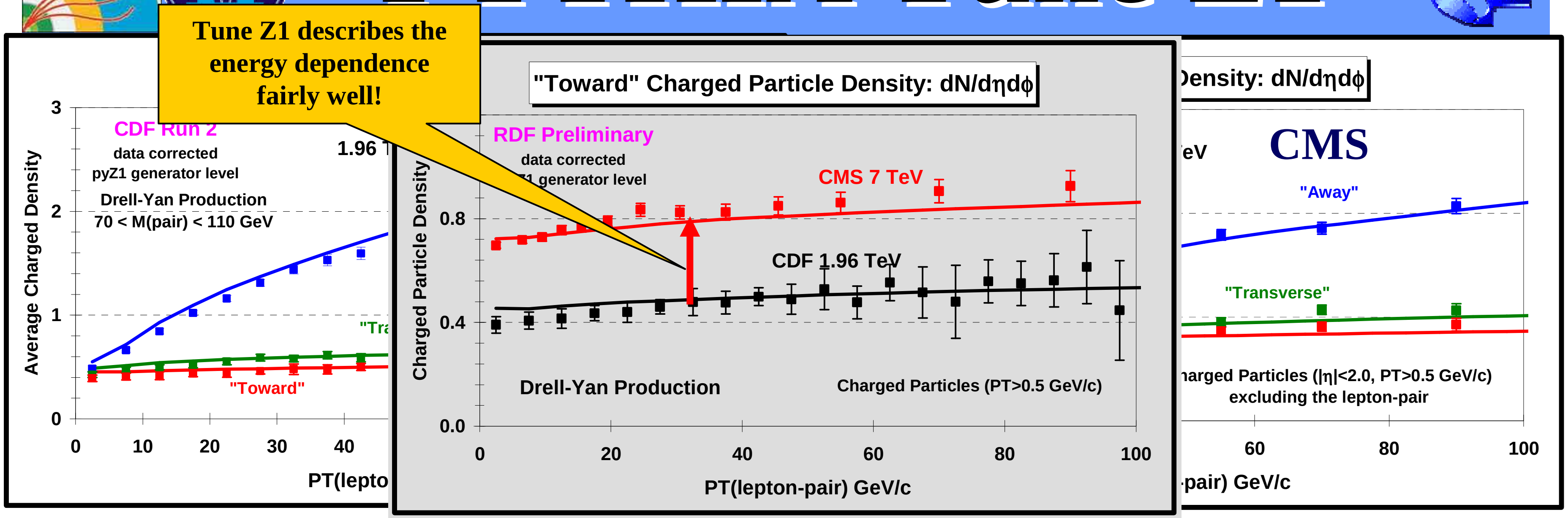


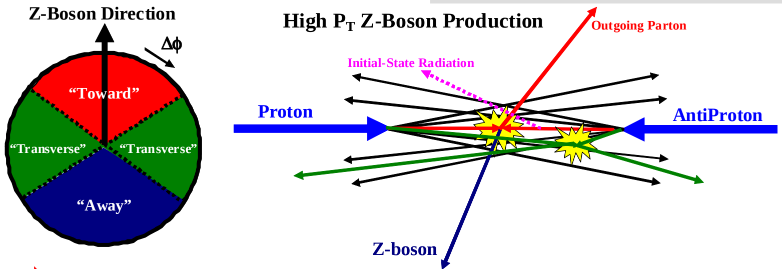


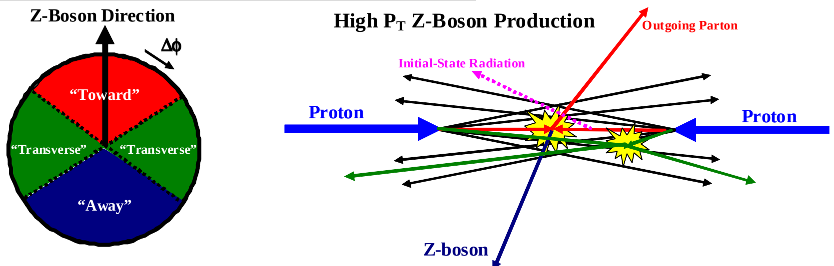


- **CDF data at 1.96 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.
- **CMS data at 7 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.

PYTHIA Tune Z1

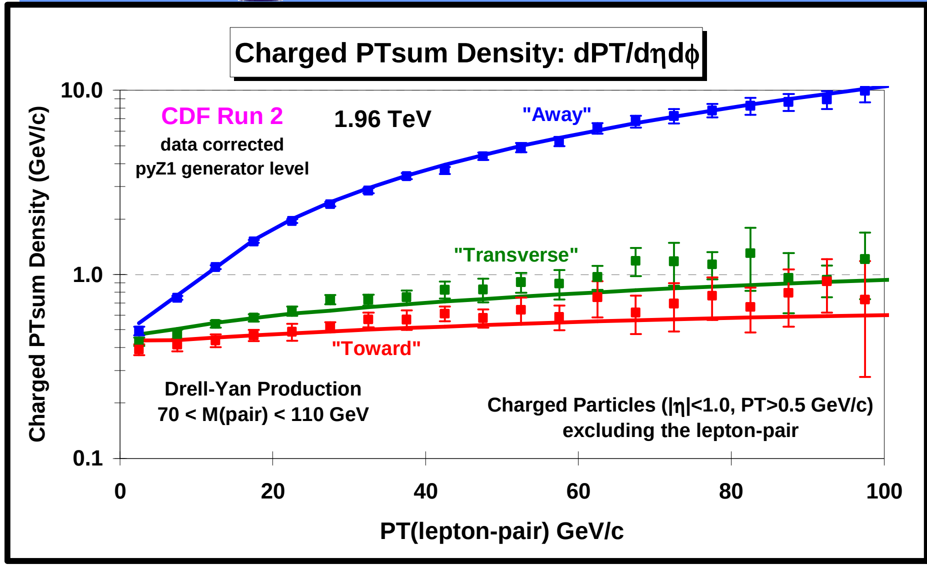


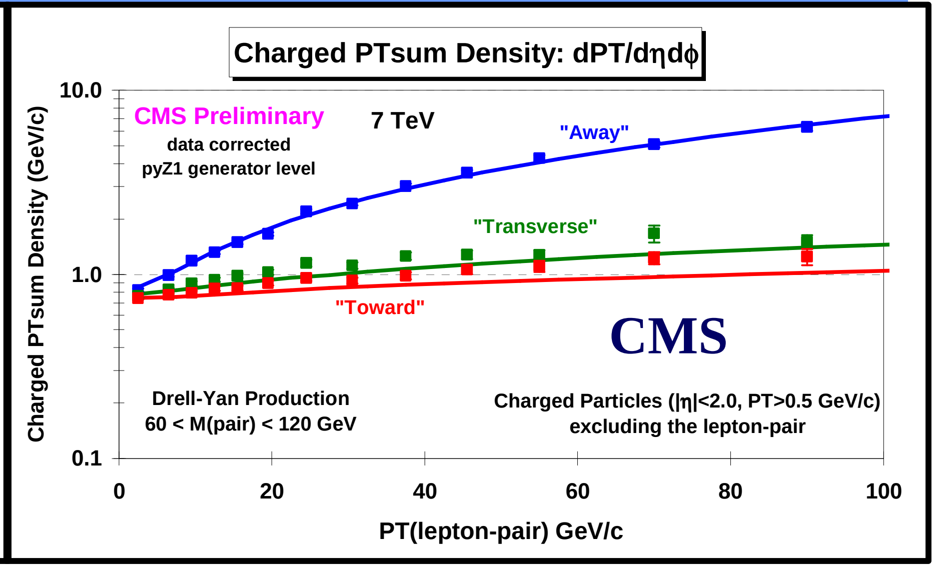


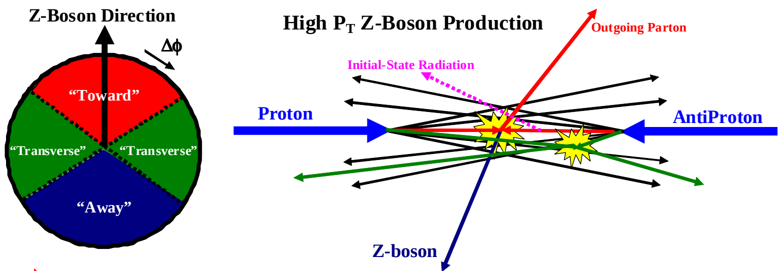


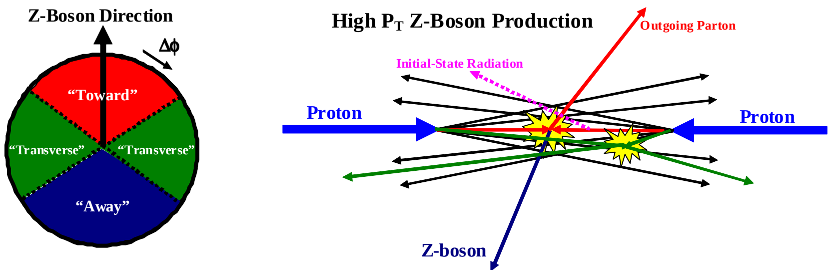
- **CDF data at 1.96 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune Z1**.
- **CMS data at 7 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune Z1**.

PYTHIA Tune Z1



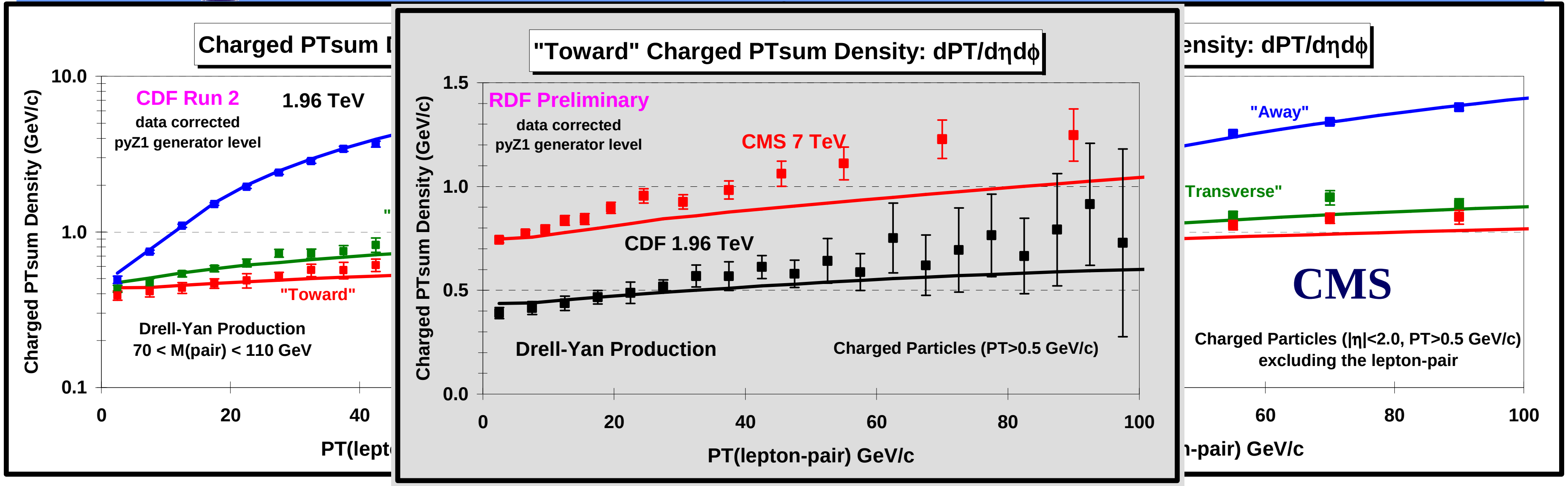


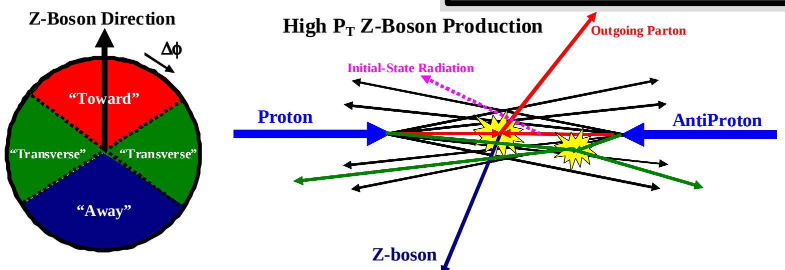


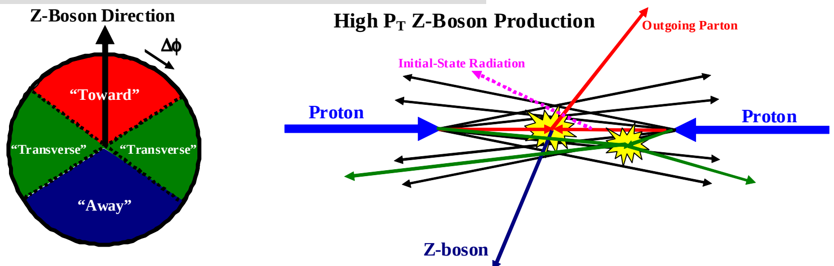


- **CDF data at 1.96 TeV** on the charged PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.
- **CMS data at 7 TeV** on the charged PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.

PYTHIA Tune Z1

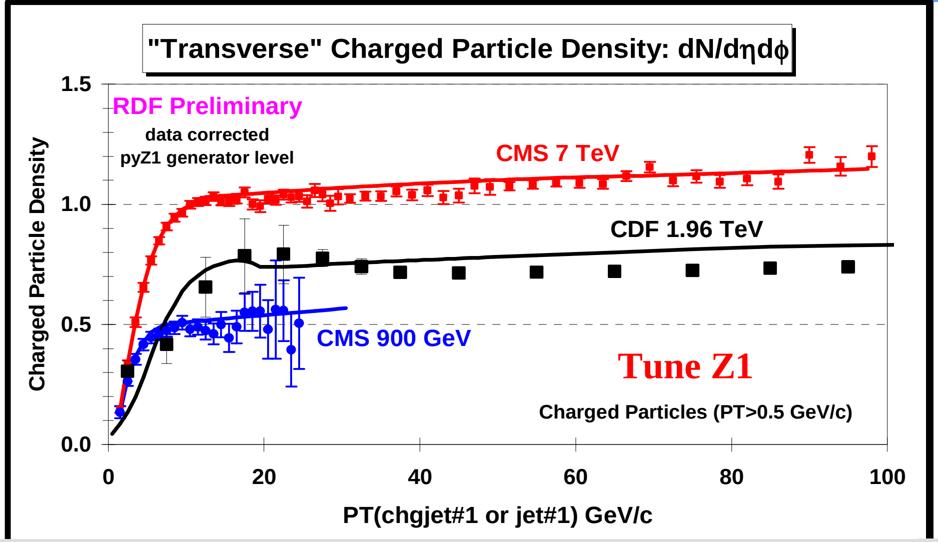


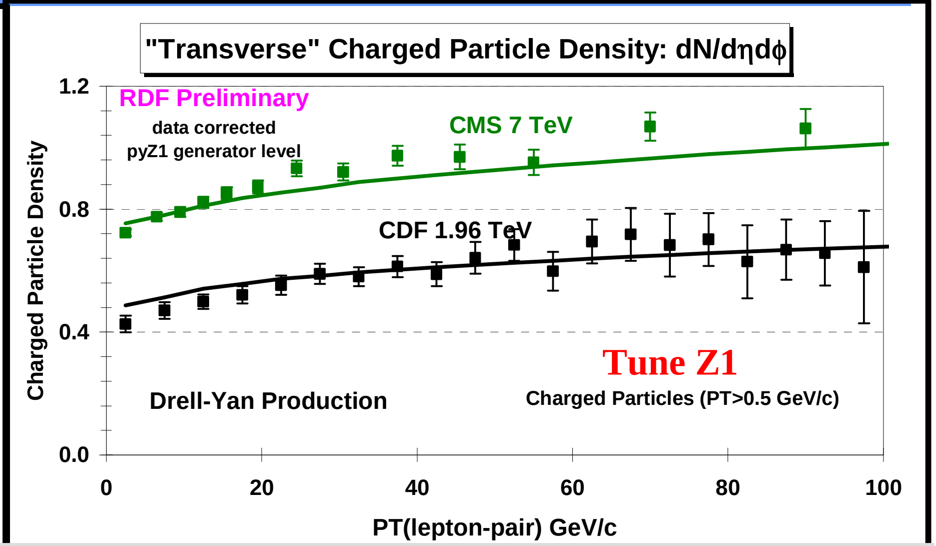


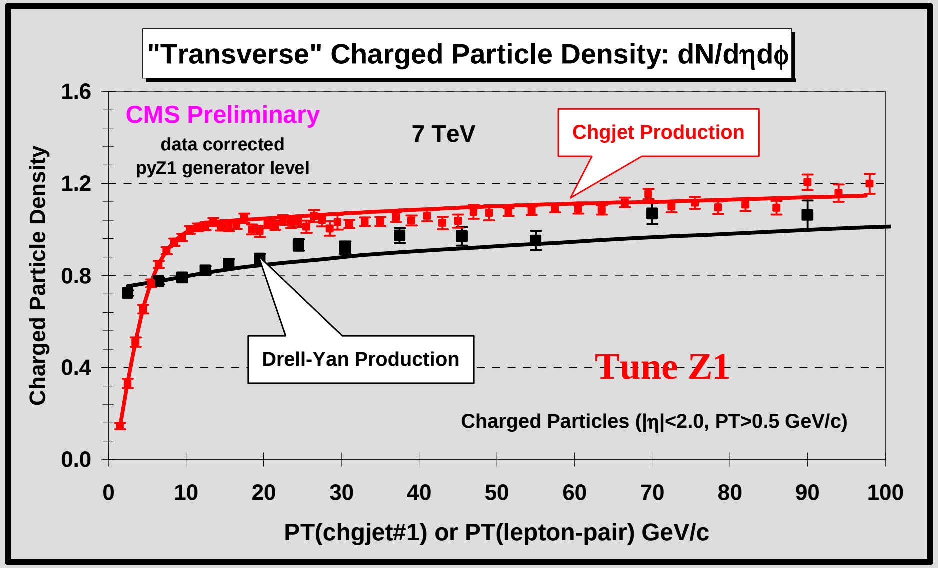


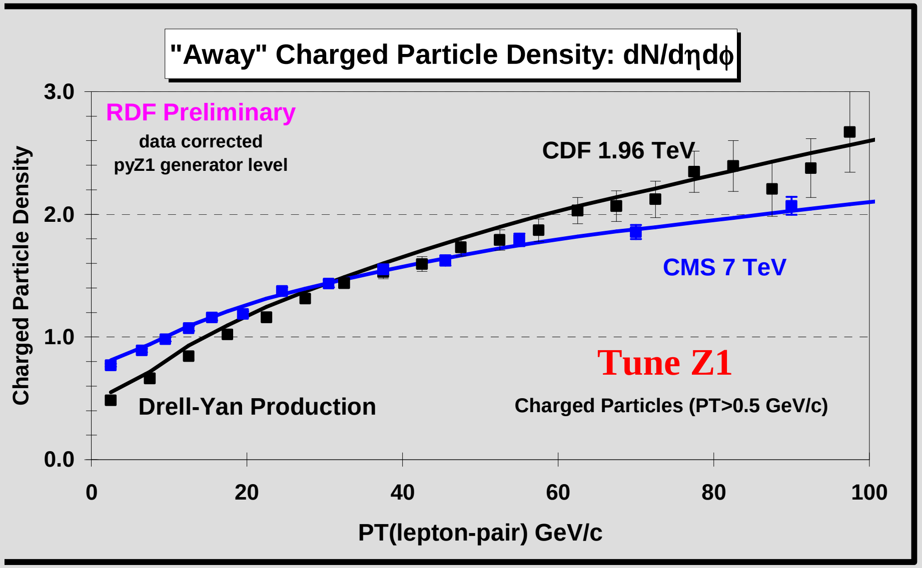
- **CDF data at 1.96 TeV** on the charged PTsum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.
- **CMS data at 7 TeV** on the charged PTsum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with PYTHIA Tune Z1.

PYTHIA Tune Z1

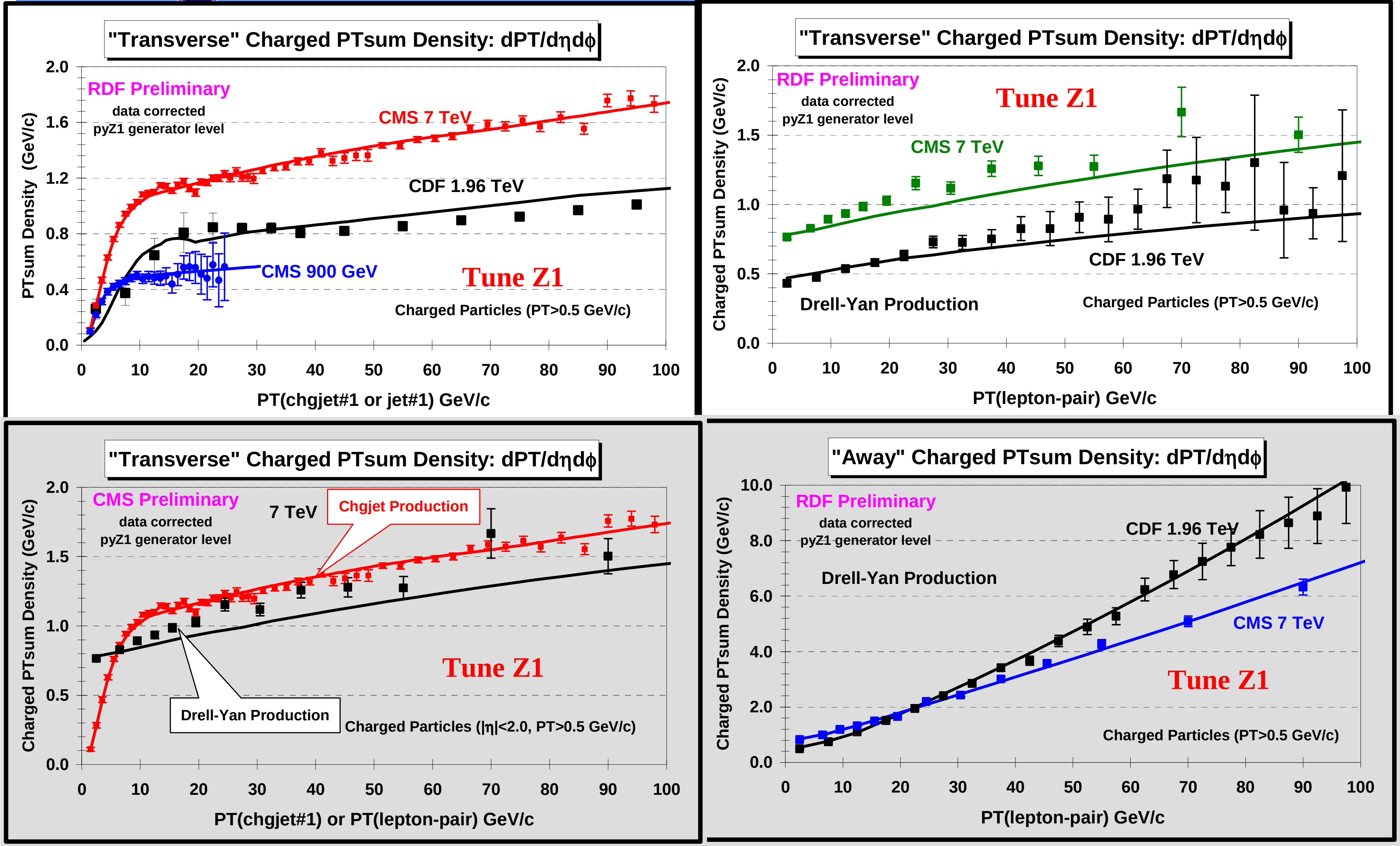




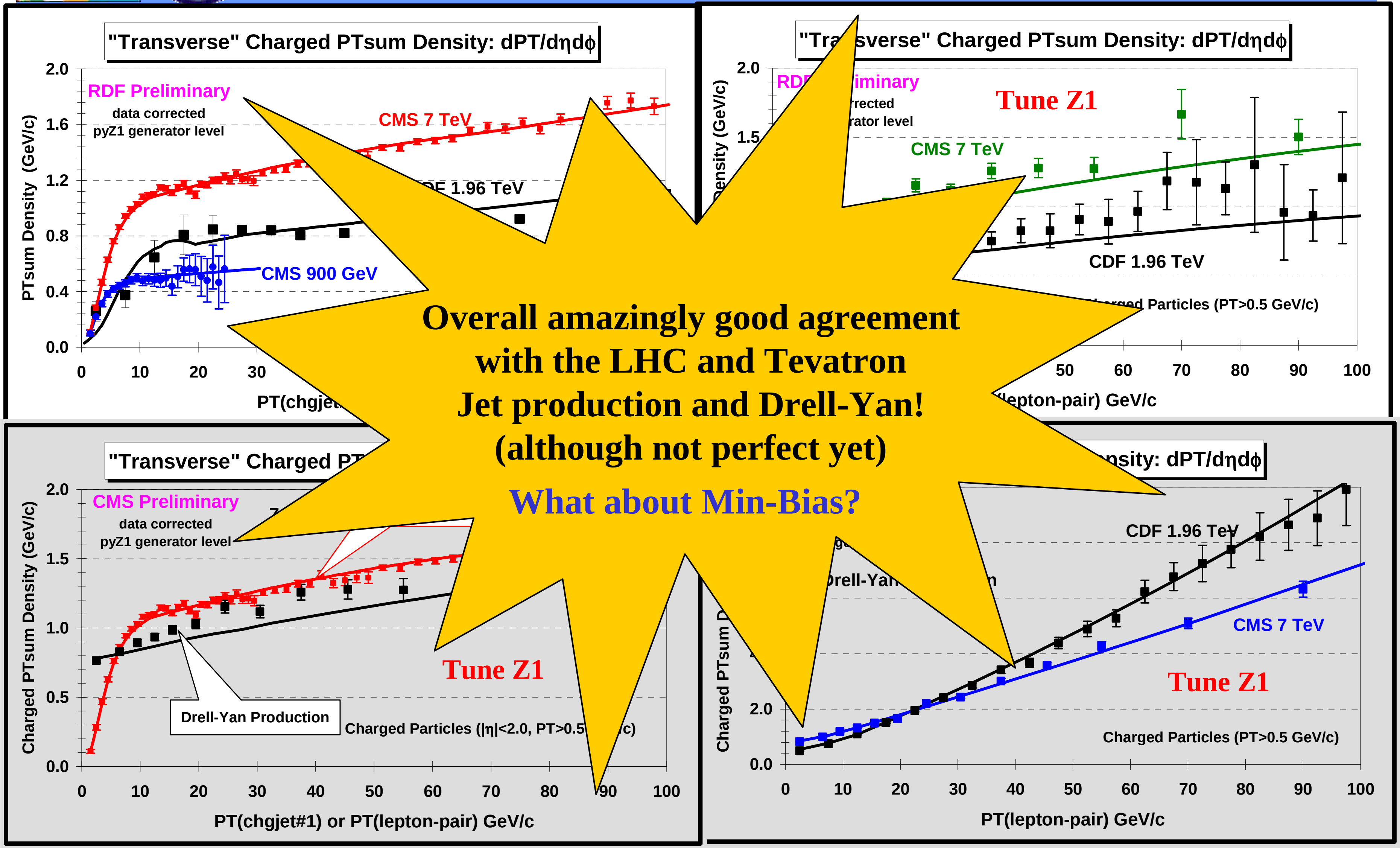




PYTHIA Tune Z1

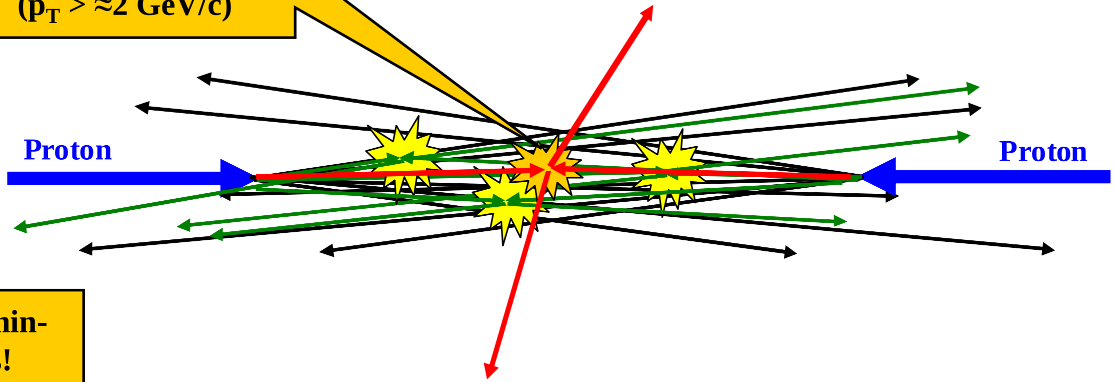


PYTHIA Tune Z1



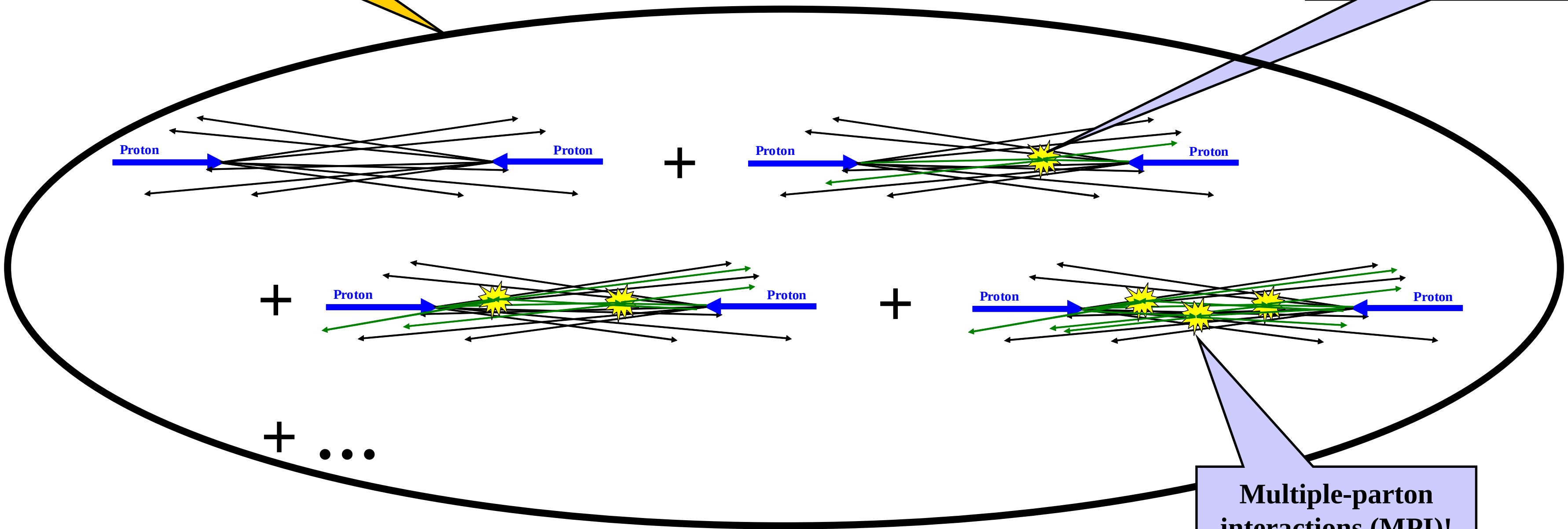
The Inelastic Non-Diffractive Cross-Section

Occasionally one of the parton-parton collisions is hard ($p_T > \approx 2$ GeV/c)



Majority of “min-bias” events!

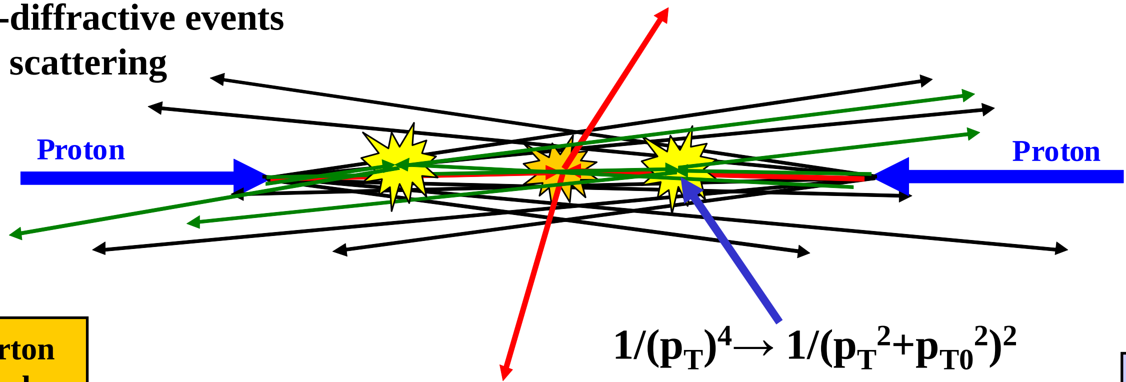
“Semi-hard” parton-parton collision ($p_T < \approx 2$ GeV/c)



Multiple-parton interactions (MPI)!

The "Underlying Event"

Select inelastic non-diffractive events that contain a hard scattering

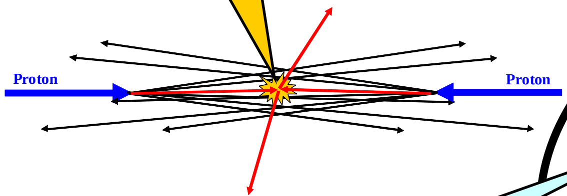


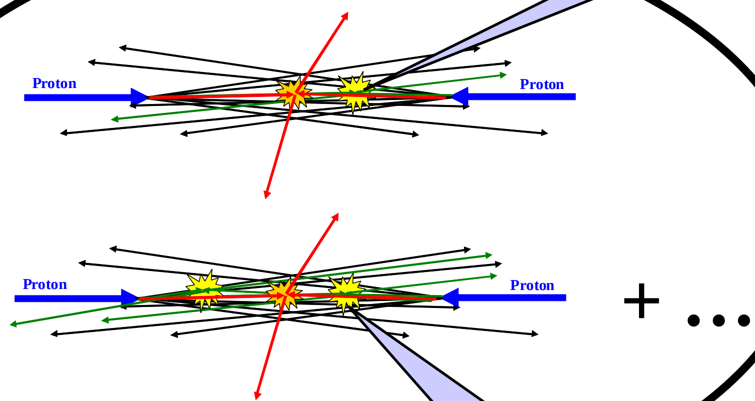
$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

Hard parton-parton collisions is hard ($p_T > \approx 2$ GeV/c)

The "underlying-event" (UE)!

"Semi-hard" parton-parton collision ($p_T < \approx 2$ GeV/c)



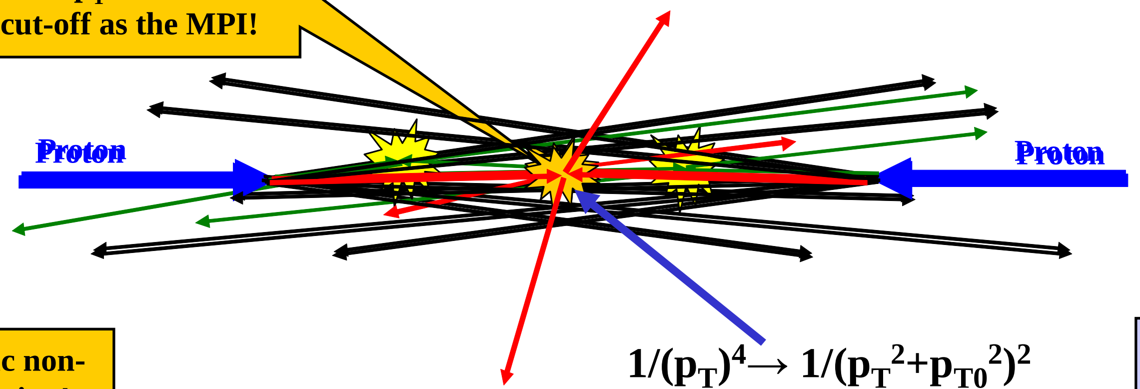


Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than "min-bias".

Multiple-parton interactions (MPI)!

Model of σ_{ND}

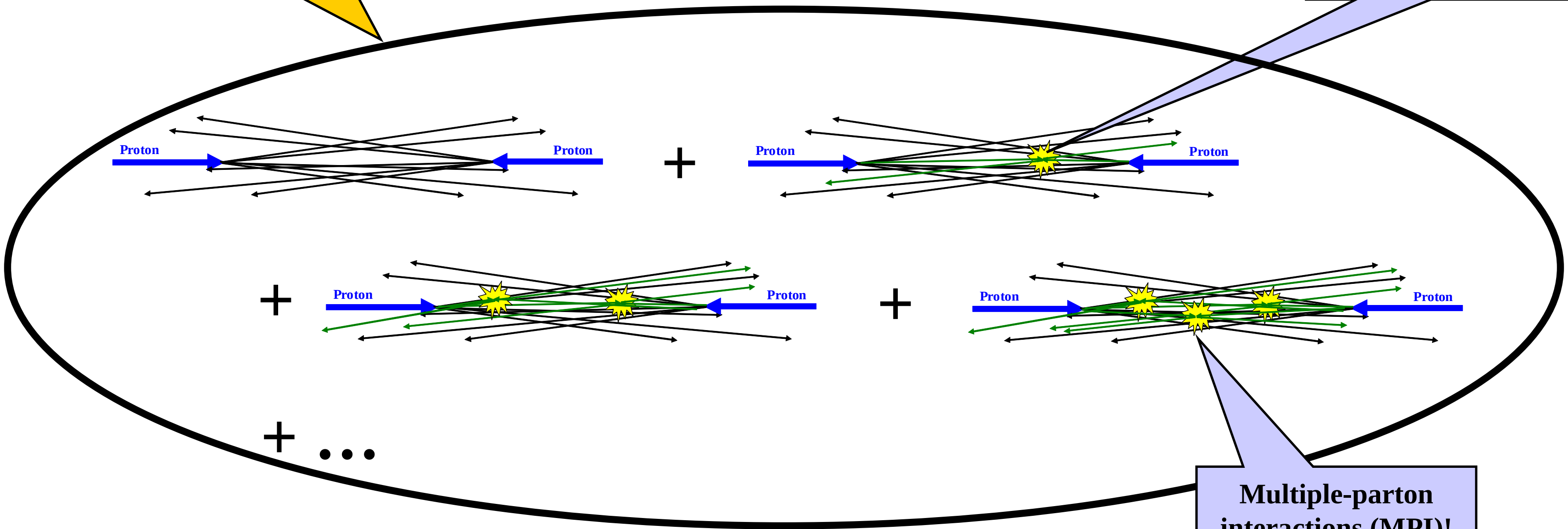
Allow leading hard scattering to go to zero p_T with same cut-off as the MPI!



$1/(p_T)^4 \rightarrow 1/(p_T{}^2+p_{T0}{}^2)^2$

Model of the inelastic non-diffractive cross section!

"Semi-hard" parton-parton collision ($p_T < \approx 2$ GeV/c)



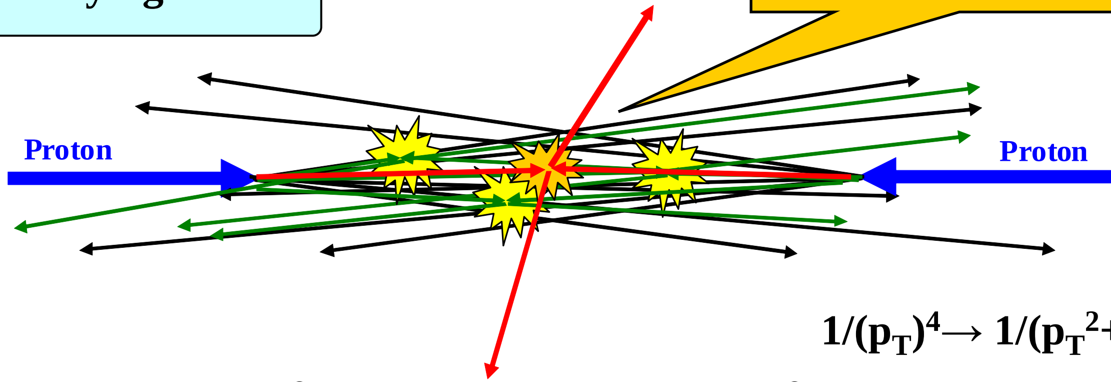
Multiple-parton interactions (MPI)!

UE Tunes

"Underlying Event"

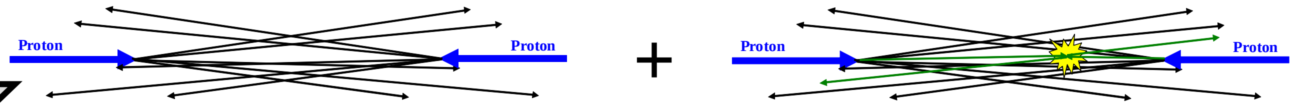
Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

Fit the "underlying event" in a hard scattering process.

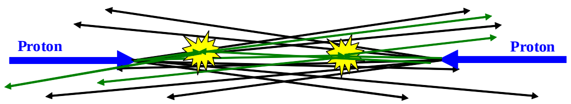


$$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$$

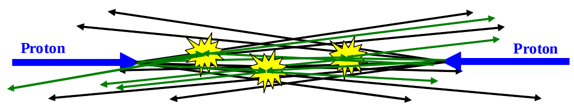
"Min-Bias" (add single & double diffraction)



+



+

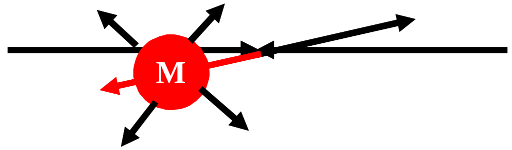


Predict MB (ND)!

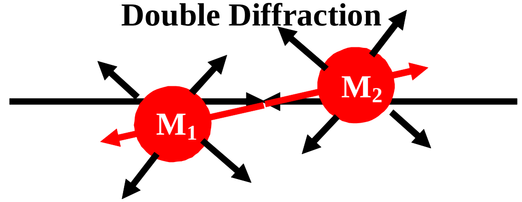
Predict MB (IN)!

+ ...

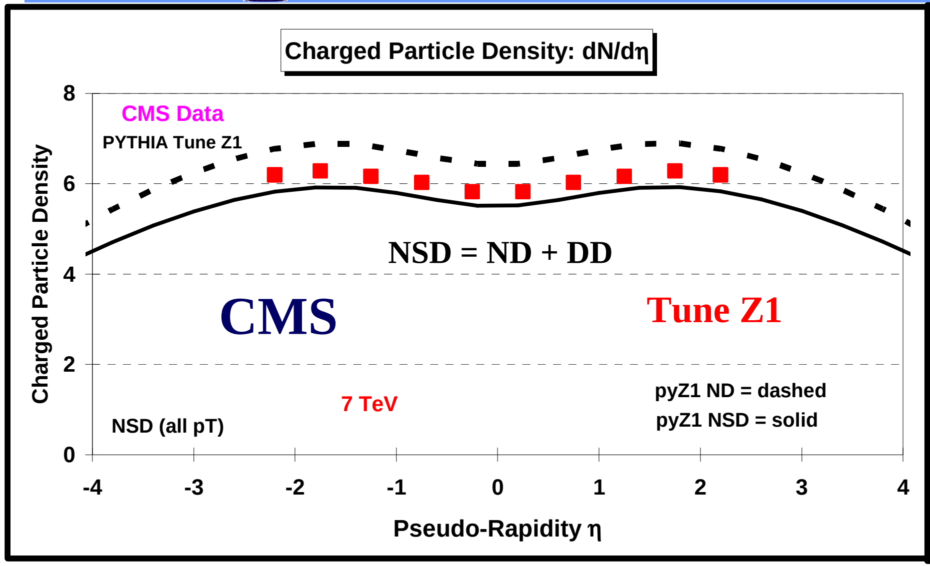
Single Diffraction

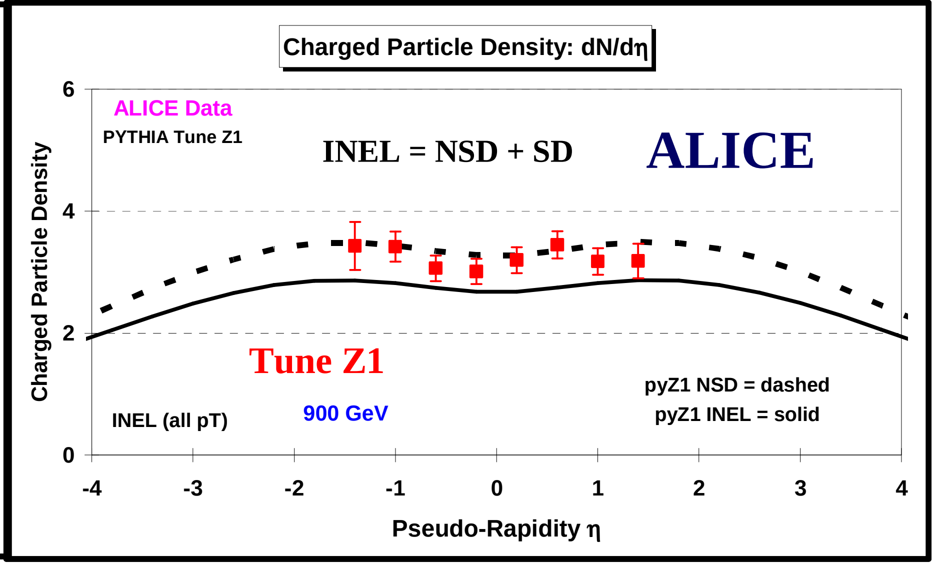


Double Diffraction



Min-Bias Collisions



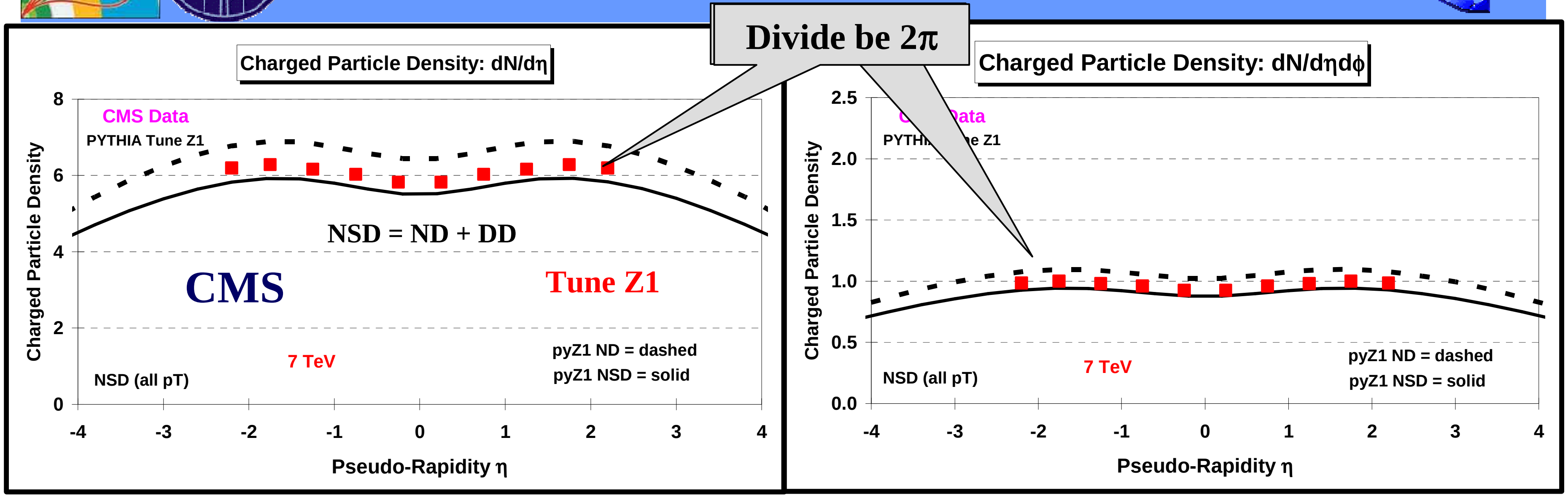


- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with **PYTHIA Tune Z1**. The plot shows the average number of particles per NSD collision per unit η, $(1/N_{NSD})\ dN/d\eta$.
- **ALICE NSD data** on the charged particle rapidity distribution at 900 GeV compared with **PYTHIA Tune Z1**. The plot shows the average number of particles per INEL collision per unit η, $(1/N_{INEL})\ dN/d\eta$.

"Minimum Bias" Collisions

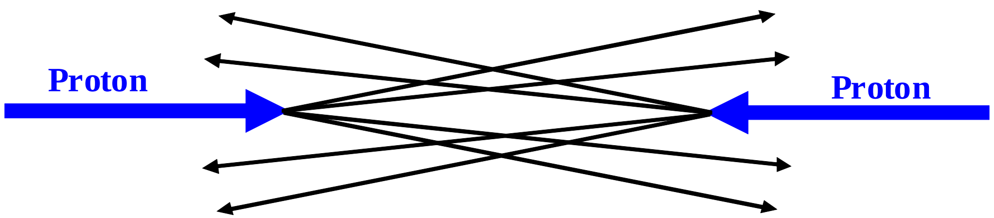
Okay not perfect, but remember we know that SD and DD are not modeled well!

MB versus UE

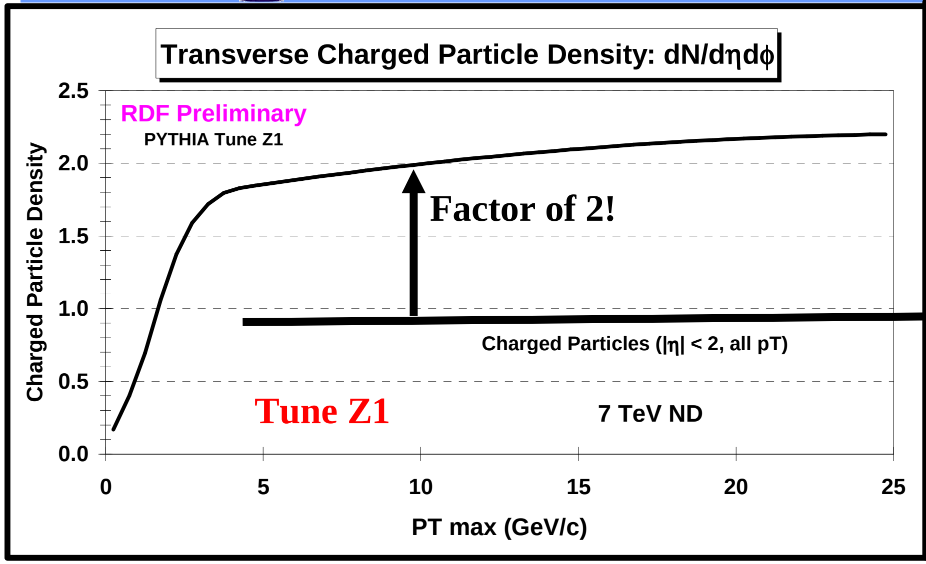


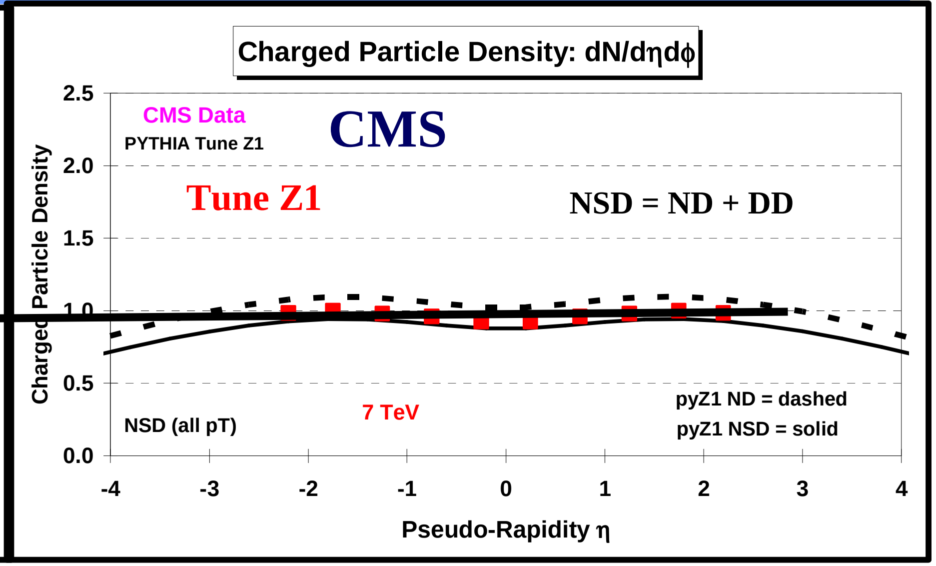
- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with **PYTHIA Tune Z1**. The plot shows the average number of charged particles per NSD collision per unit η, $(1/N_{NSD})\ dN/d\eta$.
- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with **PYTHIA Tune Z1**. The plot shows the average number of charged particles per NSD collision per unit η−ϕ, $(1/N_{NSD})\ dN/d\eta d\phi$.

"Minimum Bias" Collisions

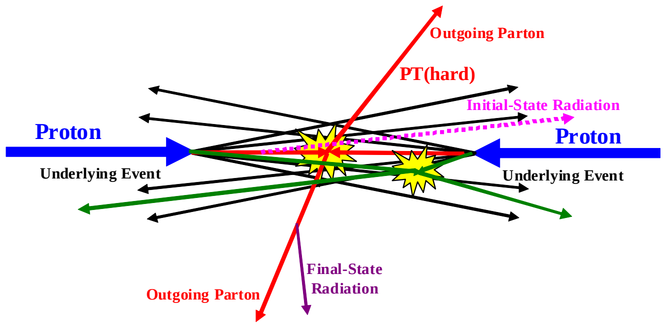


MB versus UE

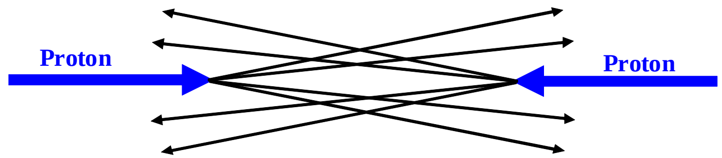




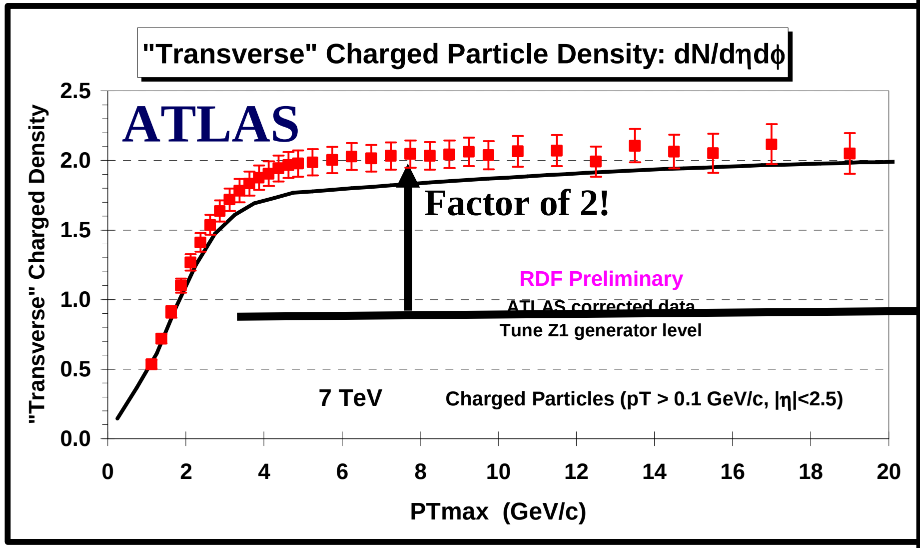
- Shows the density of charged particles in the **"transverse" region** as a function of PTmax for charged particles (All p_T, $|\eta| < 2$) at 7 TeV from PYTHIA **Tune Z1**.
- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with **PYTHIA Tune Z1**. The plot shows the average number of charged particles per NSD collision per unit $\eta-\phi$, $(1/N_{NSD})\, dN/d\eta d\phi$.

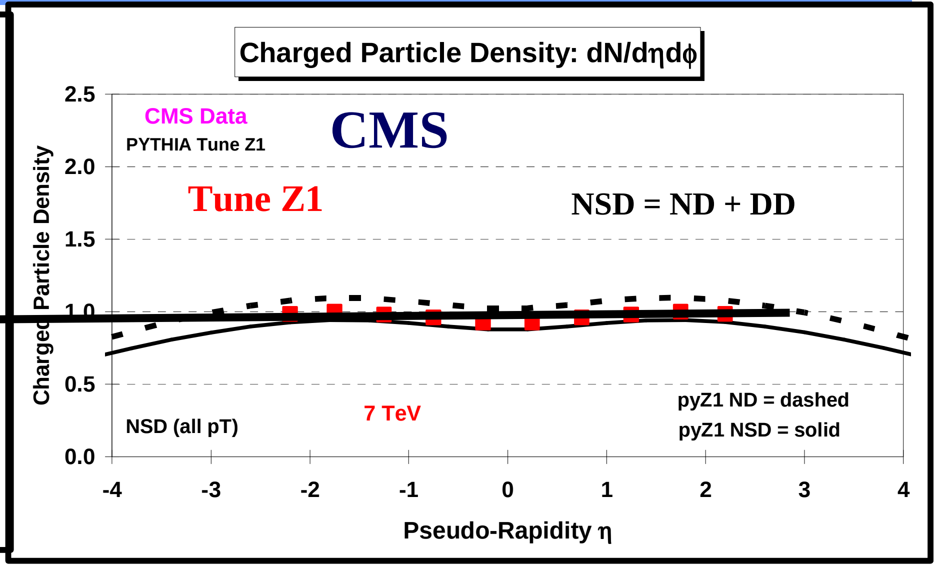


"Minimum Bias" Collisions

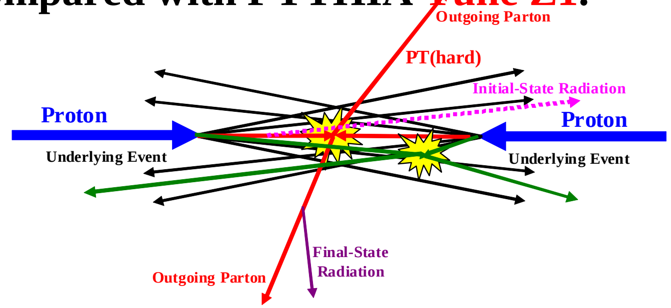


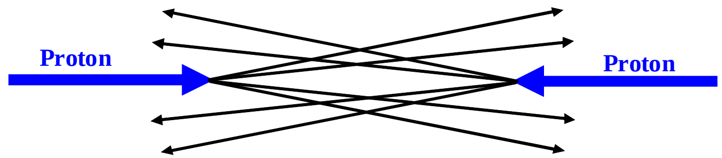
MB versus UE



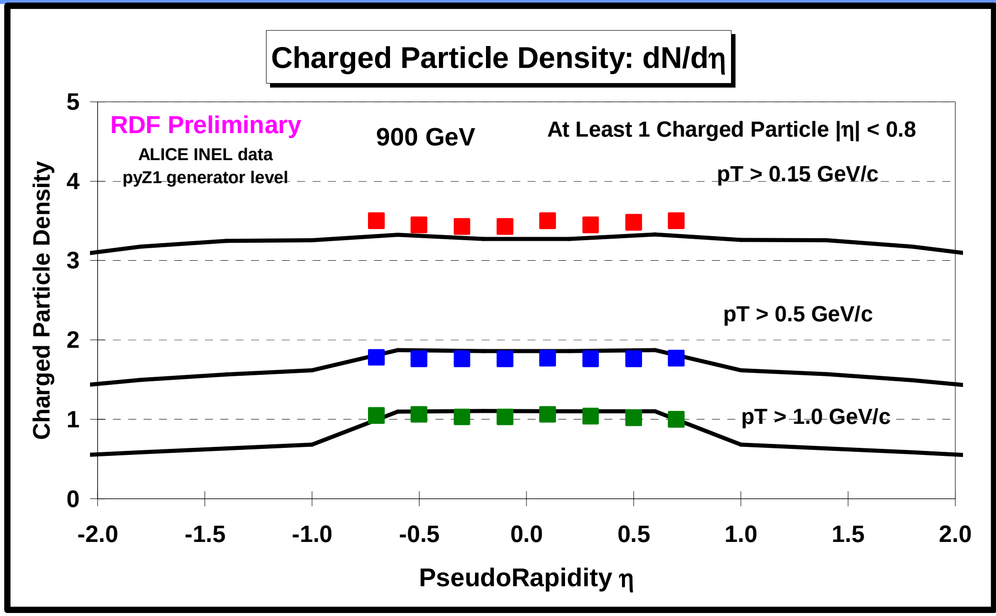


- **ATLAS data on the density of charged particles in the "transverse" region as a function of PTmax for charged particles (p_T > 0.1 GeV/c, |η| < 2.5) at 7 TeV compared with PYTHIA Tune Z1.**
- **CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η−φ, $(1/N_{NSD})$ dN/dηdφ.**





PYTHIA Tune Z1

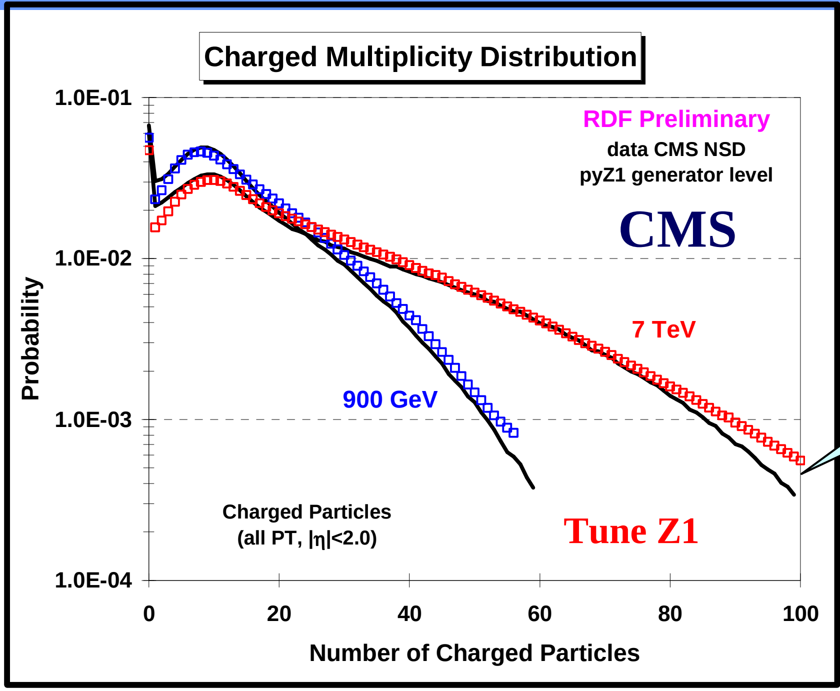


- **ALICE inelastic data at 900 GeV on the dN/dη distribution for charged particles (p_T > PTmin) for events with at least one charged particle with p_T > PTmin and |η| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level.**

"Minumum Bias" Collisions

Okay not perfect, but remember we do not know if the SD & DD are correct!

NSD Multiplicity Distribution



Difficult to produce enough events with large multiplicity!

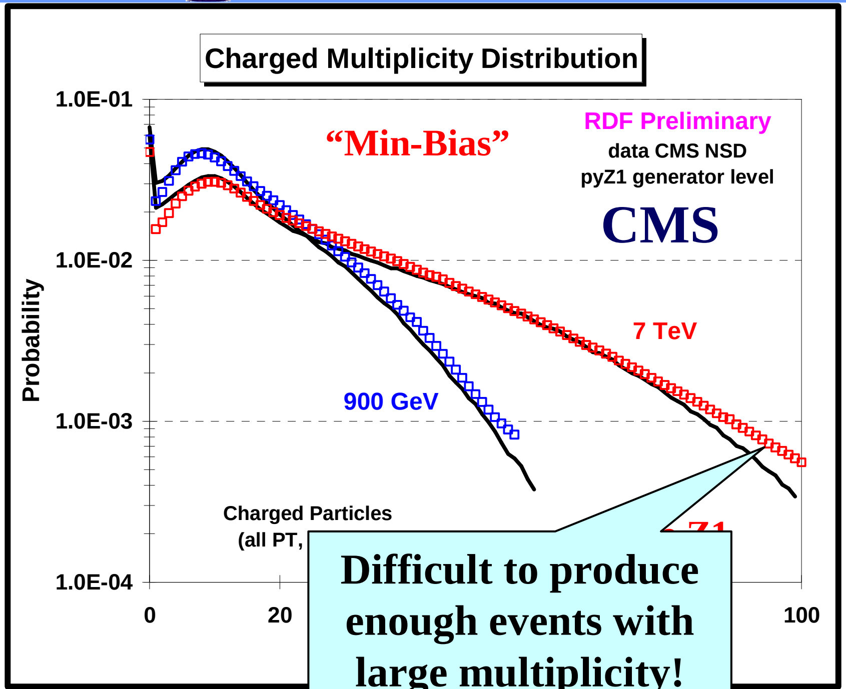
- Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

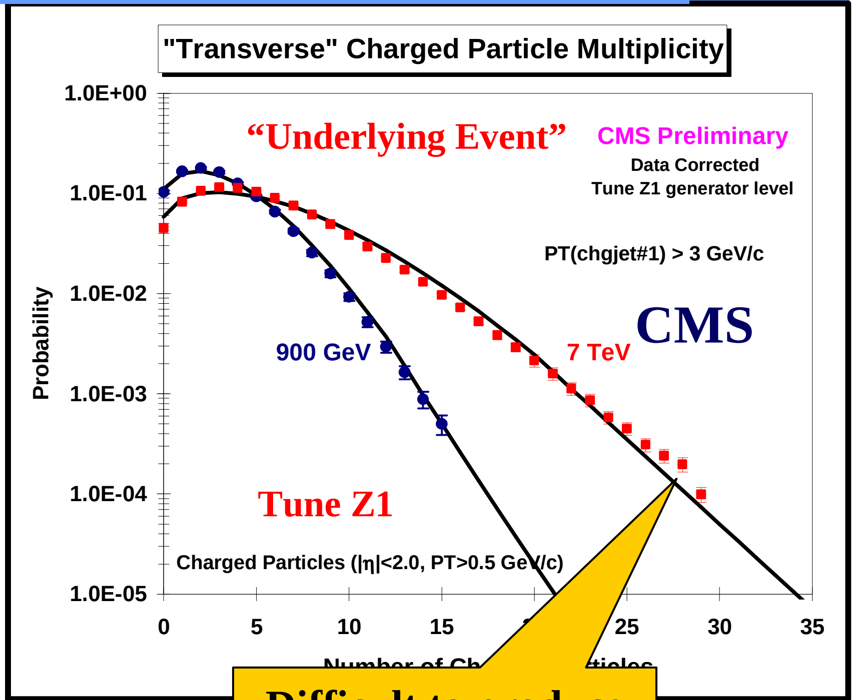
"Minumum Bias" Collisions

Proton Proton

Okay not perfect! But not that bad!

MB & UE





- **Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.**
- **CMS corr... and 7 TeV on th... iplicity distributi... egion for charged p..., |η| < 2) as defined ... particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1 at the generator level.**

How Universal are the Tunes?

- Do we need a separate tune for each center-of-mass energy? 900 GeV, 1.96 TeV, 7 TeV, etc.

> PYTHIA Tune DW did a nice (although not perfect) job predicting the LHC Jet Production and Drell-Yan UE data. I am still hoping for a single tune that will describe all energies!

- Do we need a separate tune for each hard QCD subprocess? Jet Production, Drell-Yan Production, etc.

> The same tune can describe both Jet Production and Drell-Yan!

- Do we need separate tunes for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

> PHTHIA Tune Z1 does fairly well at both the UE and MB, but you cannot expect such a naïve approach to be perfect!