ICHEP 2012

Energy Dependence of the UE

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University of Florida

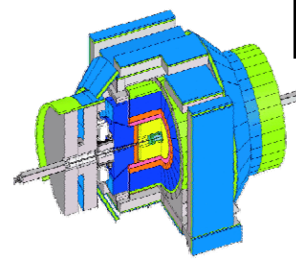
Quantum Chromo-Dynamics

ICHEP2012 Melbourne

Melbourne July 4-11, 2012

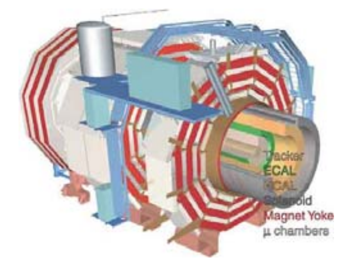
Outline of Talk

- CDF PYTHIA 6.2 Tevatron Tune DW predictions.
- CMS PYTHIA 6.4 LHC Tune Z1.
- LPCC MB&UE working group "common plots".
- New UE data at 300 GeV, 900 GeV, and 1.96 TeV from the Tevatron Energy-Scan.
- New comparisons with PYTHIA 6.2 Tune DW and PYTHIA 6.4 Tune Z1.
- Much more coming soon!



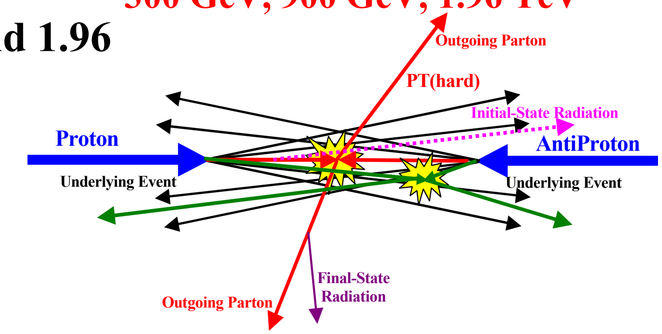
CDF Run 2

300 GeV, 900 GeV, 1.96 TeV

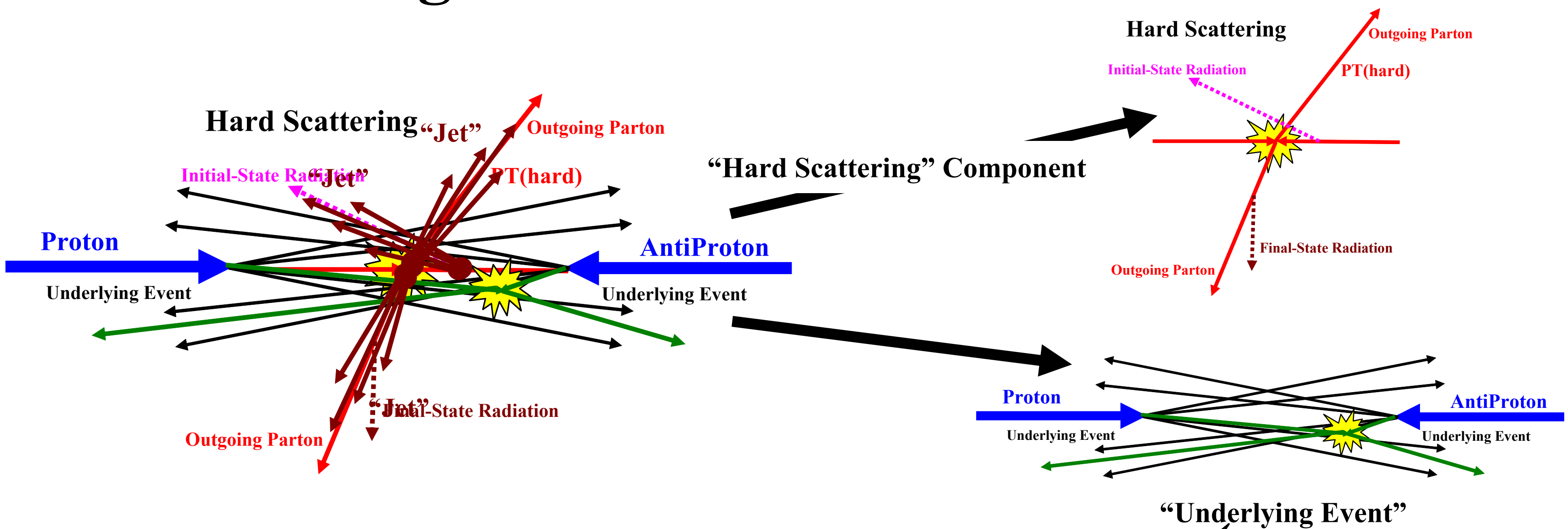


CMS at the LHC

900 GeV, 7 & 8 TeV



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[…] 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[…]

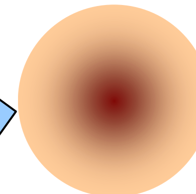
The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

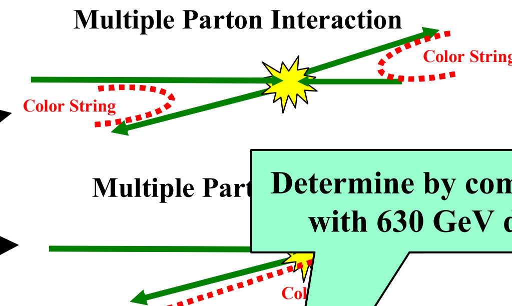
Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

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 … uces two gluons w … nearest neighbors.
PARP(86)	0.66	Prob … y that the MPI produces two gluons eit … s described by PARP(85) or as a closed … loop. The remaining fraction consists of … uark-antiquark pairs.
PARP(89)	1 Te…	Determines the reference energy E_0.
PARP(82)	…9 GeV/c	The cut-off P_{T0} that regulates the 2-to-2 scattering 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.

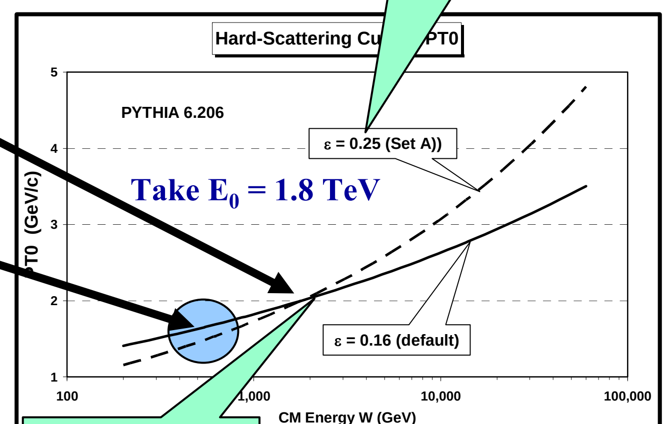
Determines the energy dependence of the MPI!

Hard Core





Determine by comparing with 630 GeV data!

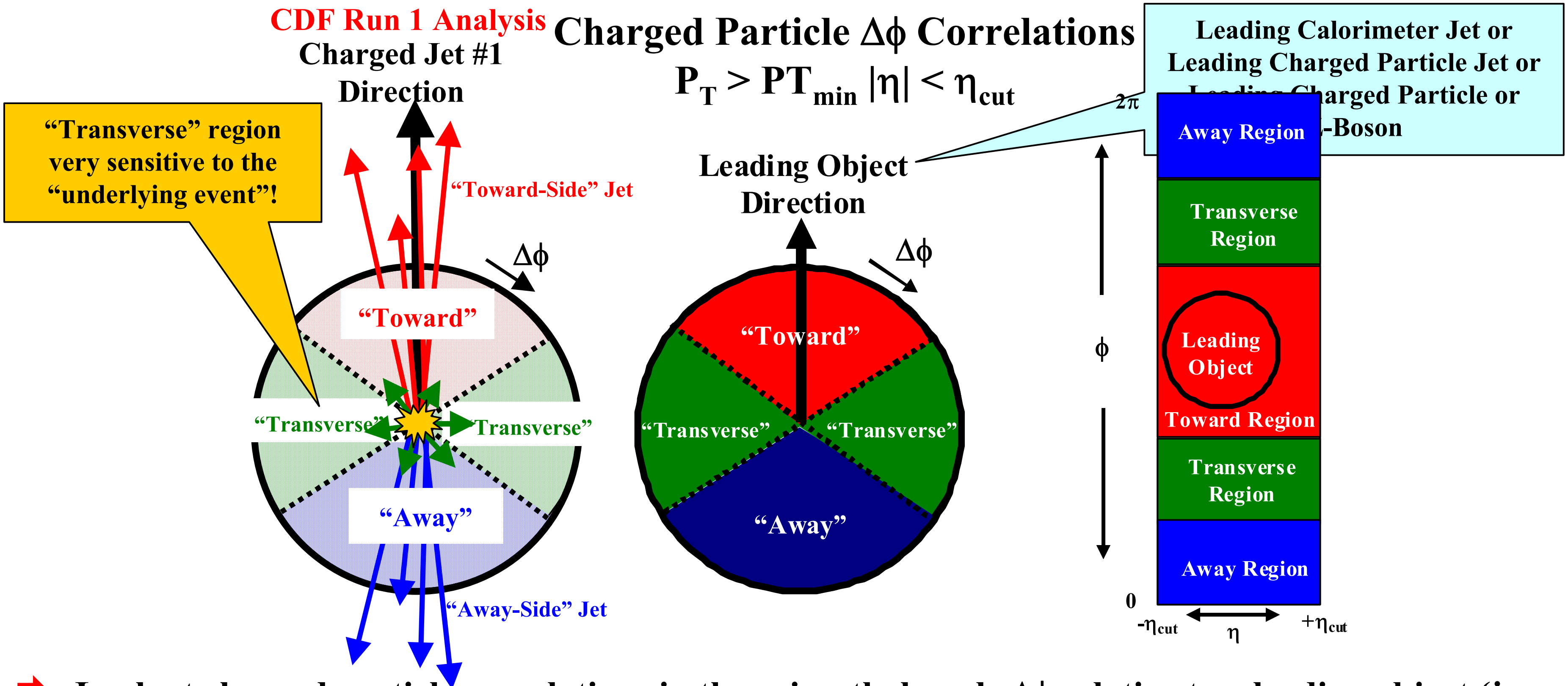


Reference point at 1.8 TeV

Traditional Approach

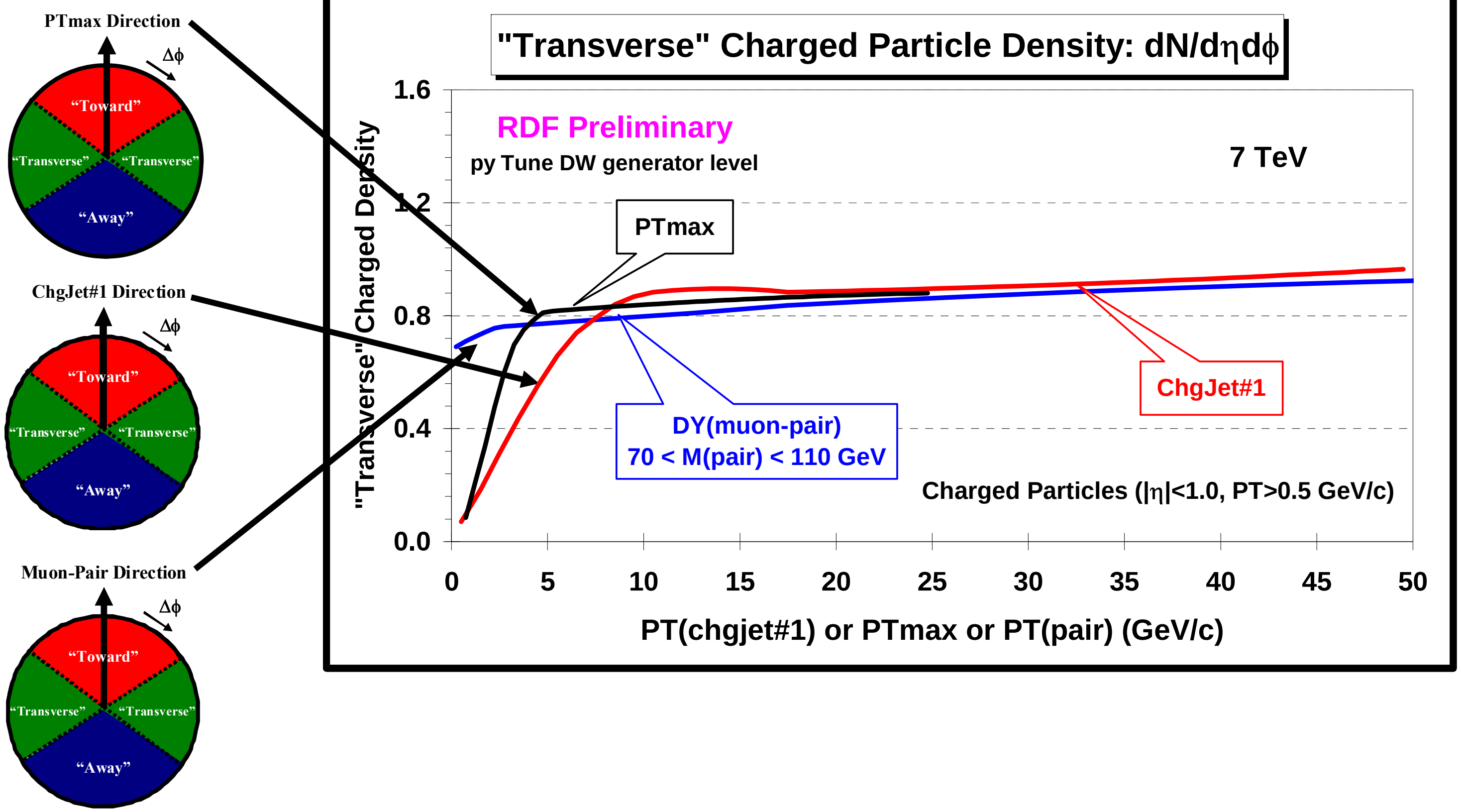
Charged Particle Δϕ Correlations

$P_T > PT_{min}$ $|\eta| < \eta_{cut}$



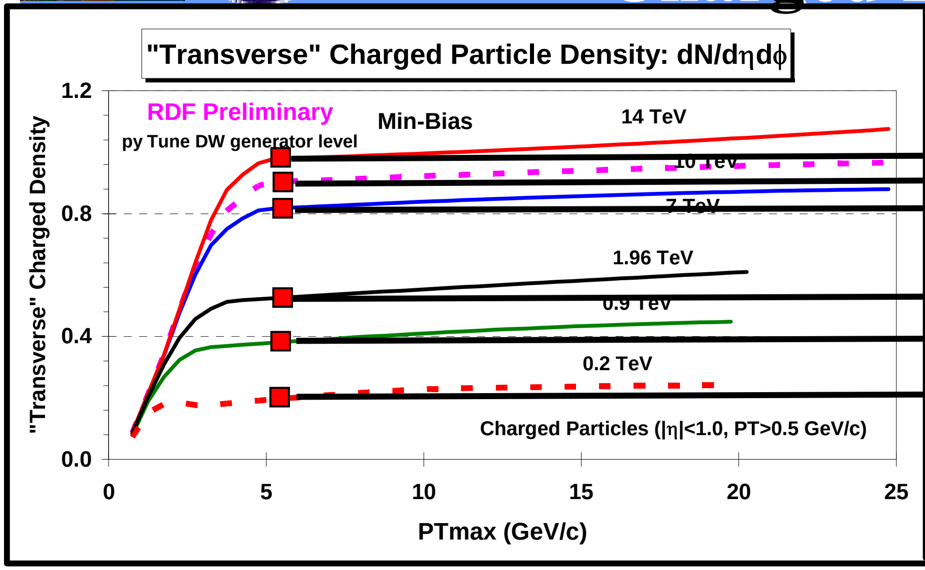
- Look at charged particle correlations in the azimuthal angle Δϕ relative to a leading object (*i.e.* CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c $\eta_{cut} = 1$.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same area in η-ϕ space, $\Delta\eta\times\Delta\phi = 2\eta_{cut}\times120^o = 2\eta_{cut}\times2\pi/3$. Construct densities by dividing by the area in η-ϕ space.

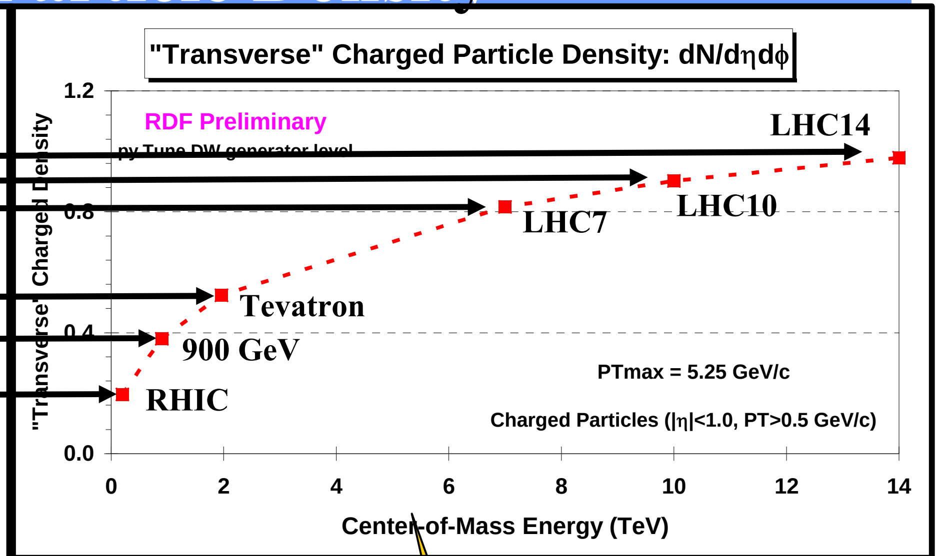
"Transverse" Charged Density



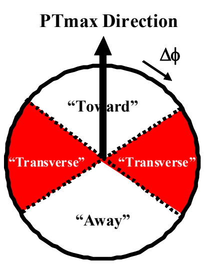
- Shows the charged particle density in the "transverse" region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) at 7 TeV as defined by PTmax, PT(chgjet#1), and PT(muon-pair) from PYTHIA Tune DW at the particle level (*i.e.* generator level). Charged particle jets are constructed using the Anti-KT algorithm with d = 0.5.

Min-Bias "Associated" Charged Particle Density



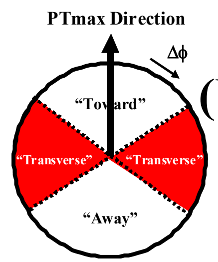


RHIC



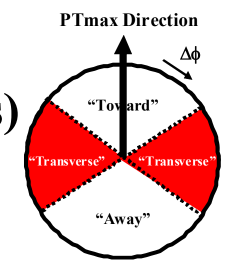
0.2 TeV → 1.96 TeV
(UE increase ~2.7 times)

Tevatron



1.96 TeV → 14 TeV
(UE increase ~1.9 times)

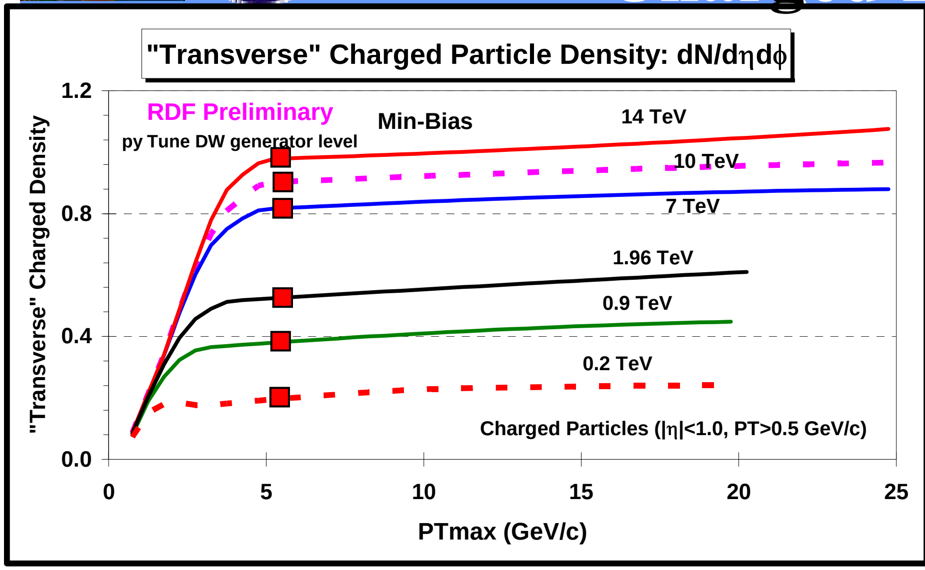
LHC

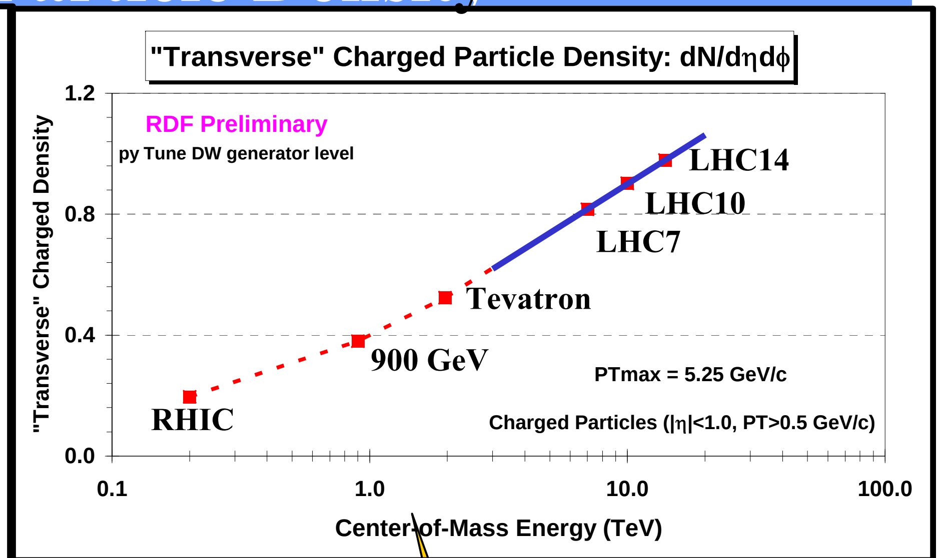


- **Shows the "associated" charged particle density in the "transverse" region a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) "min-bias" events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTH at the particle level (*i.e.* generator level).**

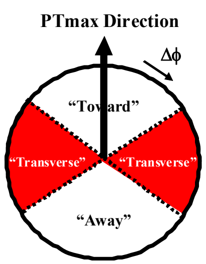
Linear scale!

Min-Bias “Associated” Charged Particle Density



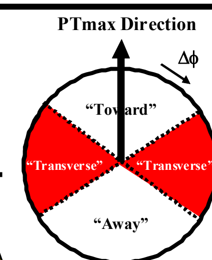


LHC7



7 TeV → 14 TeV
(UE increase ~20%)

LHC14

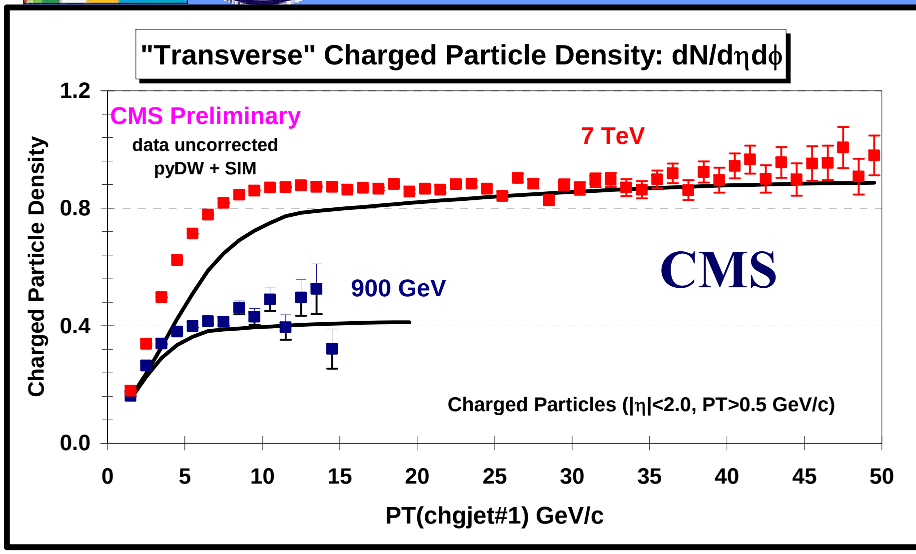


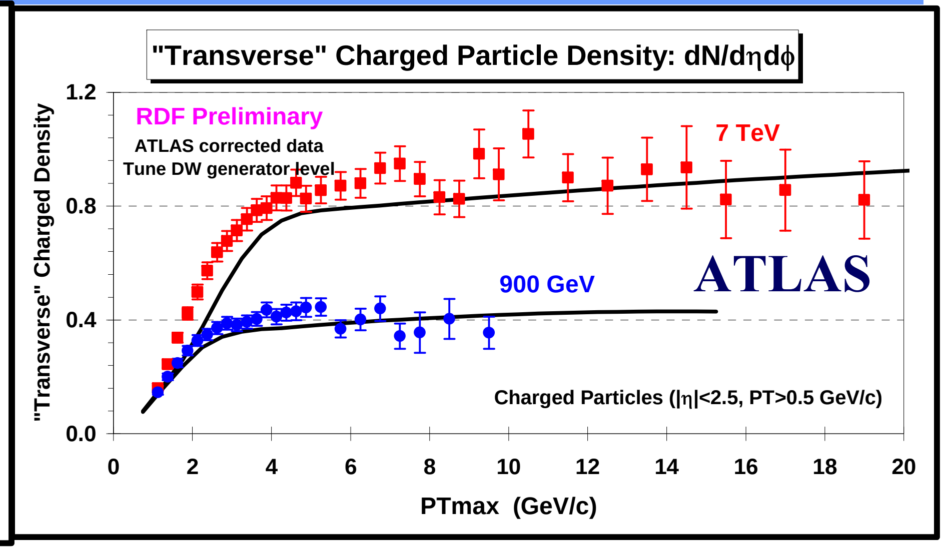
Linear on a log plot!

Log scale!

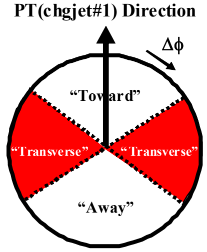
- **Shows the “associated” charged particle density in the “transverse” region … a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) … “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTH… at the particle level (*i.e.* generator level).**

PYTHIA Tune DW

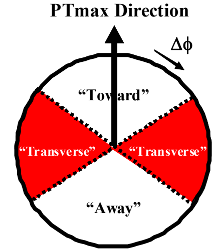




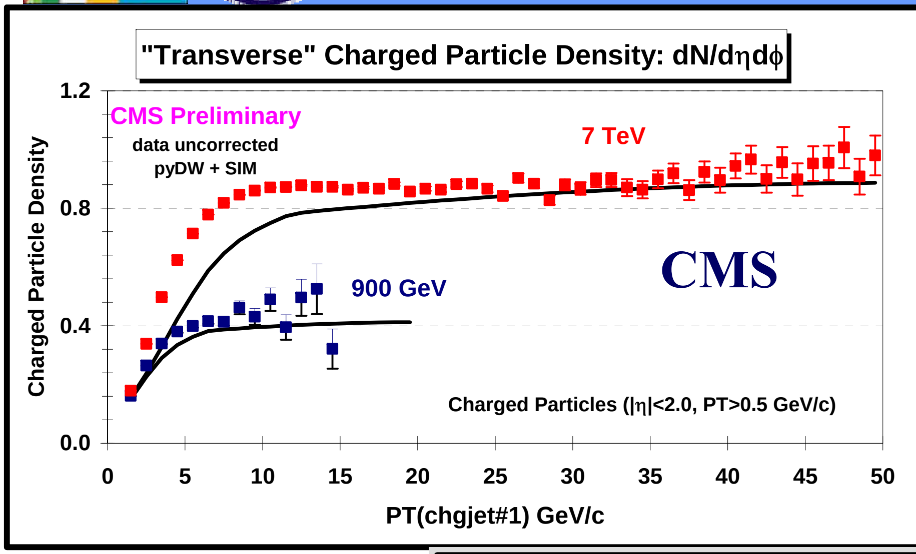
- **CMS preliminary data at 900 GeV and 7 TeV** on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA **Tune DW** after detector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

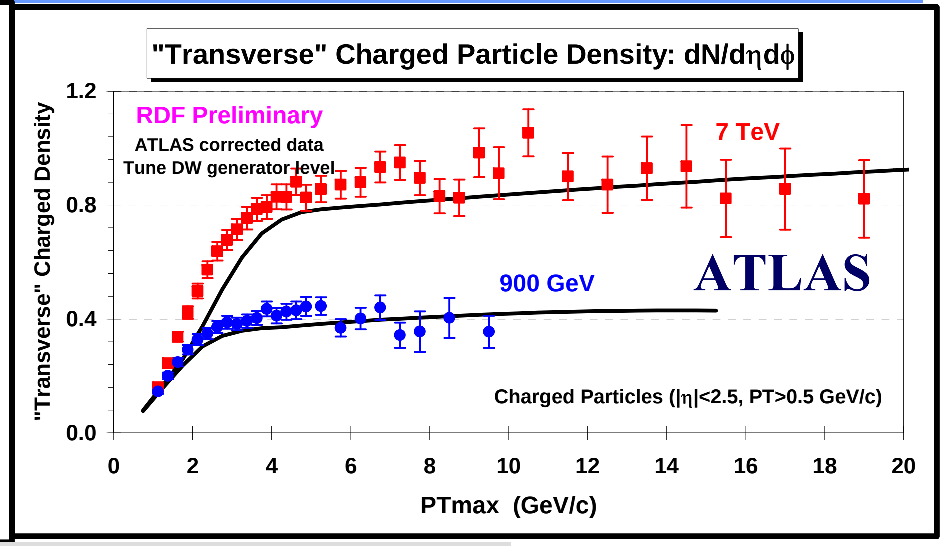


- **ATLAS preliminary data at 900 GeV and 7 TeV** on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA **Tune DW** at the generator level.

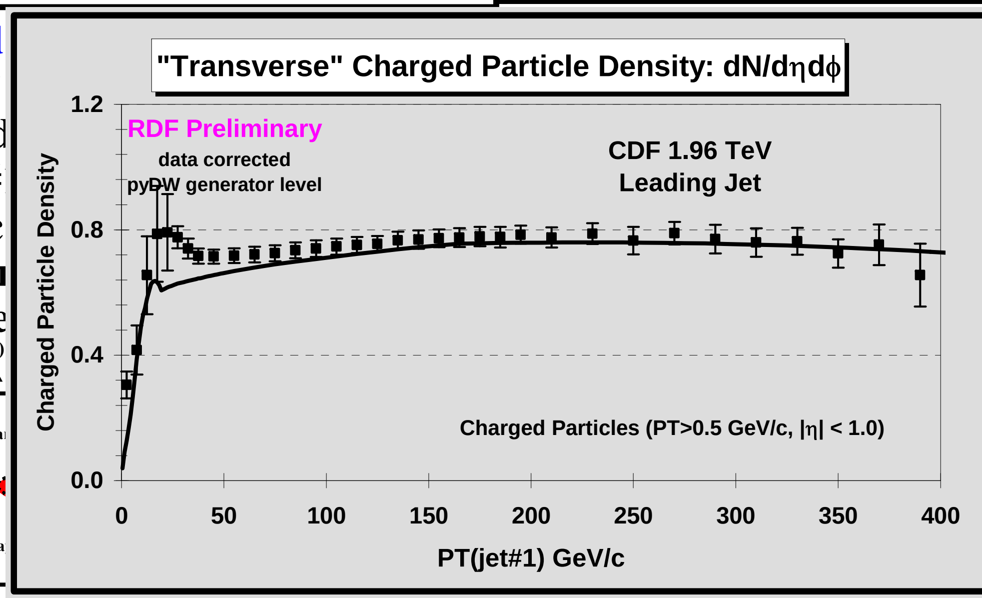


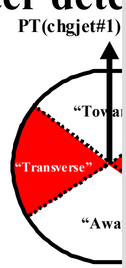
PYTHIA Tune DW

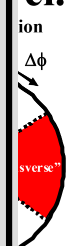




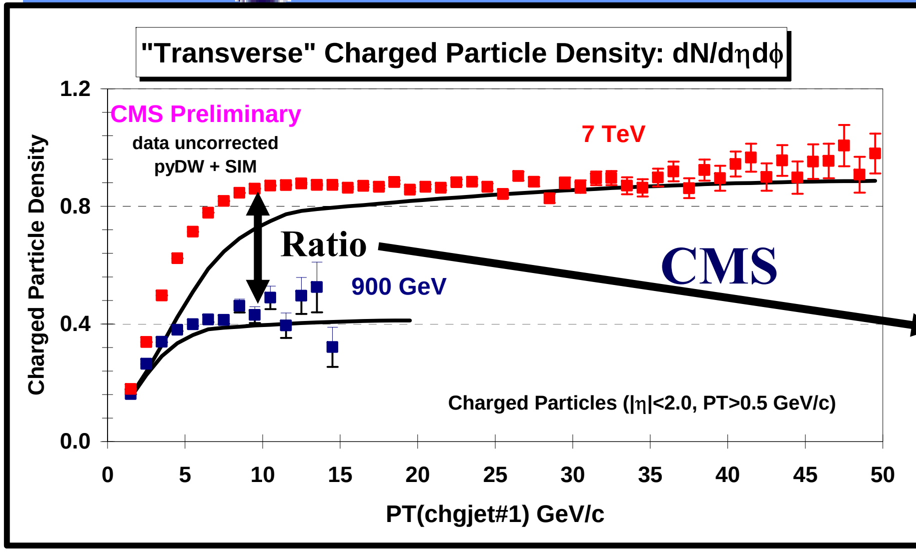
- **CMS preliminary d** … **ta at 900 GeV and 7**
  on the "transverse" … **' charged particle**
  dN/dηdϕ, as defined … **fined by the leading**
  particle jet (chgjet# … **x) for charged particles**
  with p_T > 0.5 GeV/c … **|η| < 2.5. The data are**
  uncorrected and co … **d with PYTHIA Tune**
  Tune DW after dete … **el.**

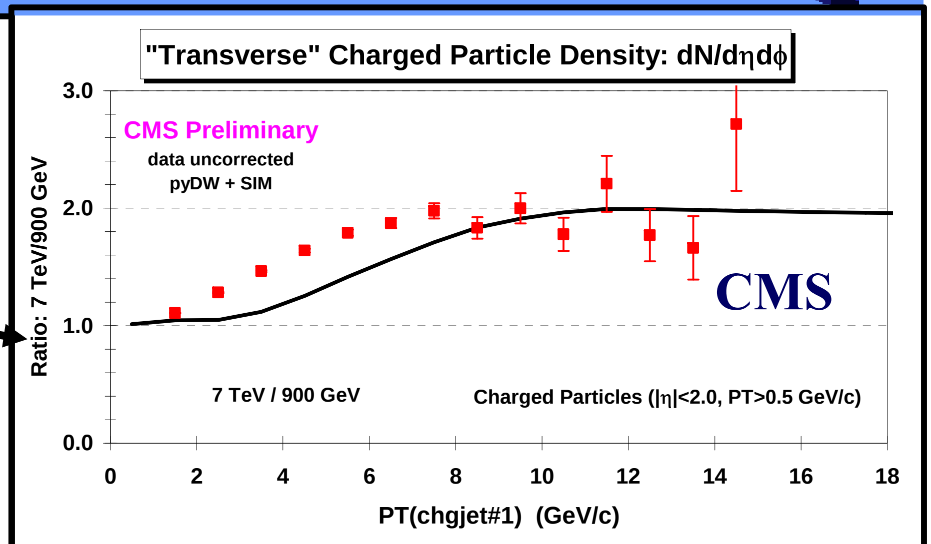




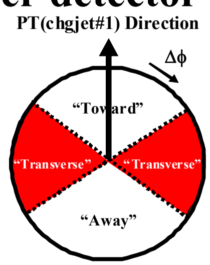


PYTHIA Tune DW

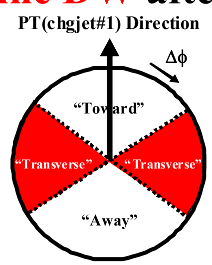




- CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

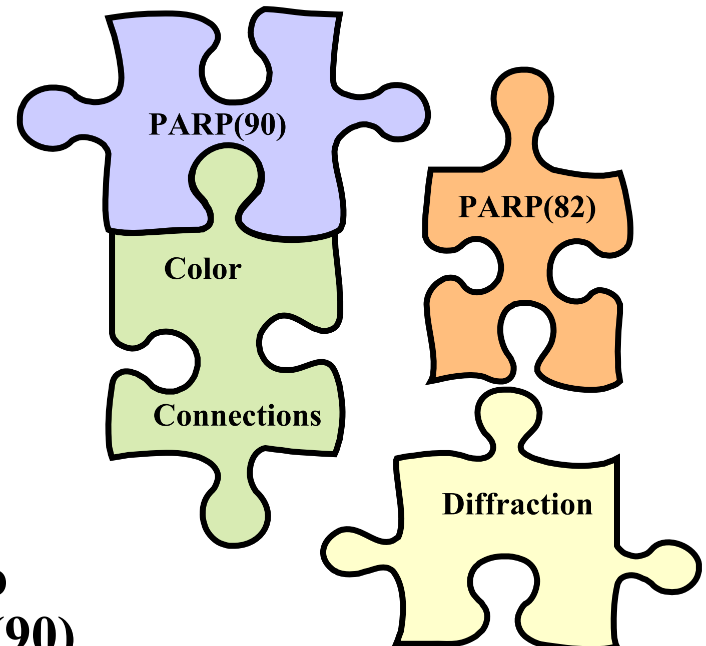


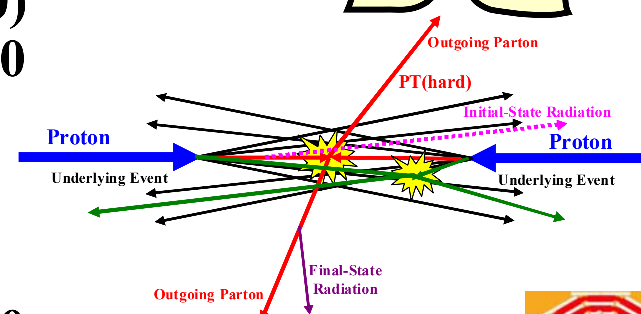
- Ratio of CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector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



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!**





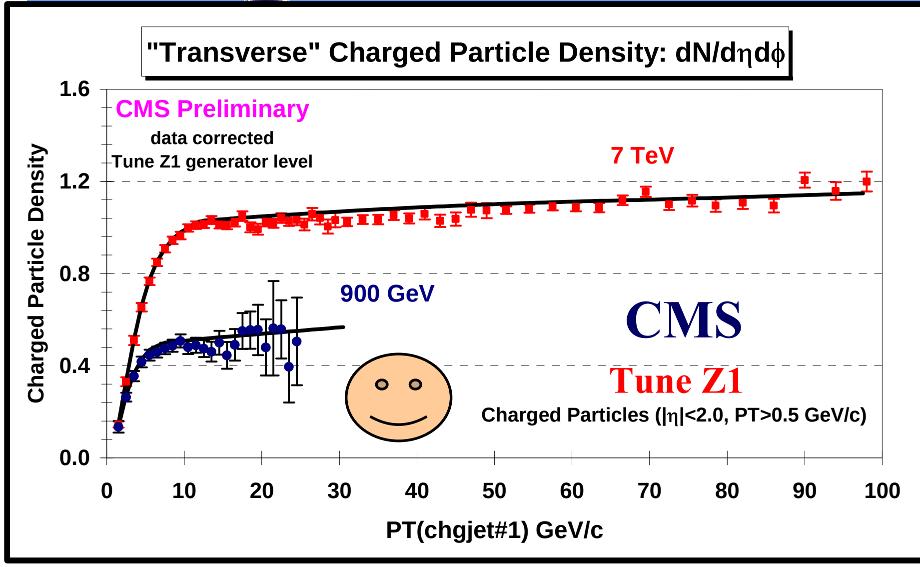
UE&MB@CMS

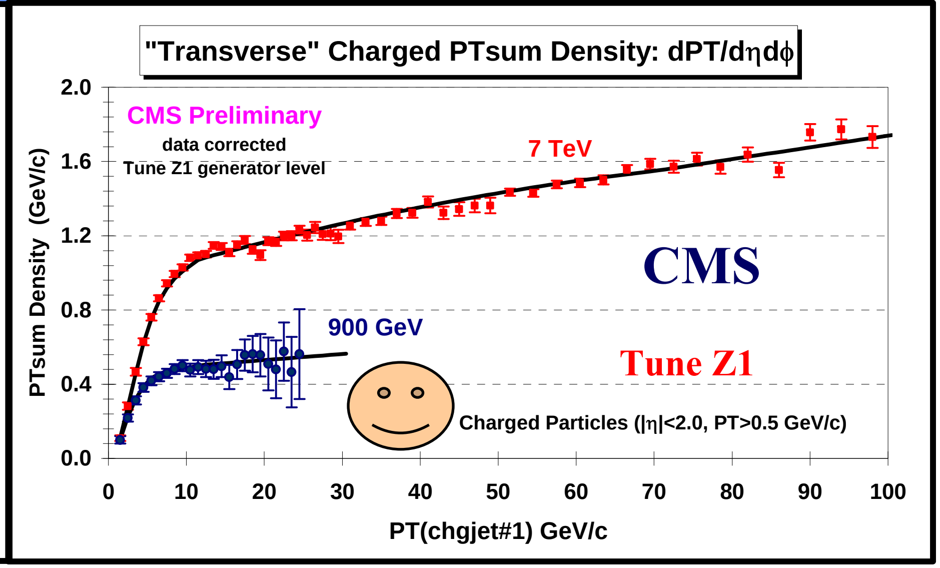
PYTHIA Tune Z1

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.**

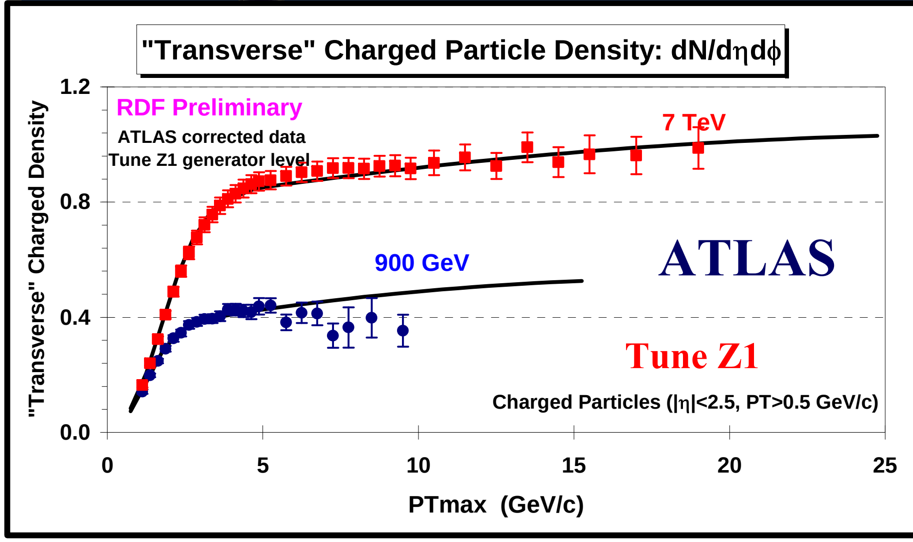
- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

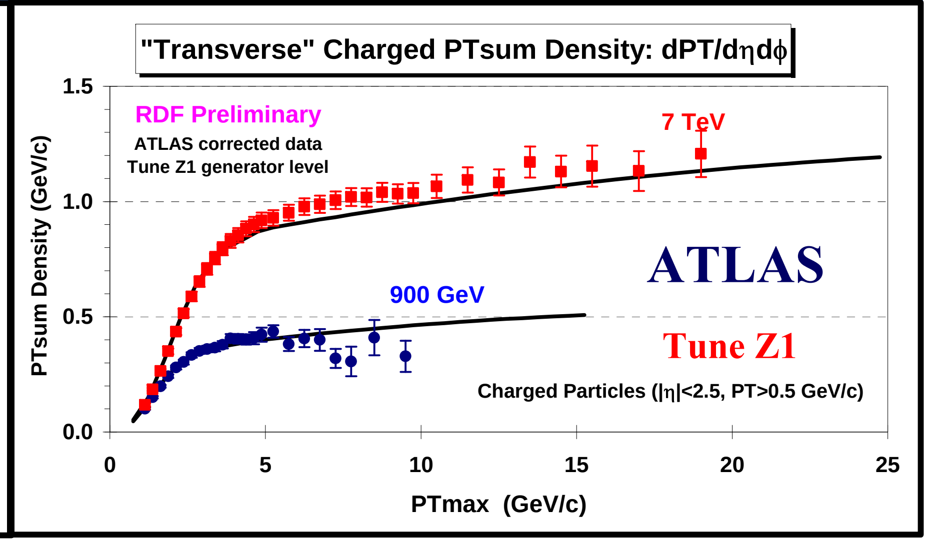
CMS corrected data!

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 generrator level.**

ATLAS publication – arXiv:1012.0791
December 3, 2010

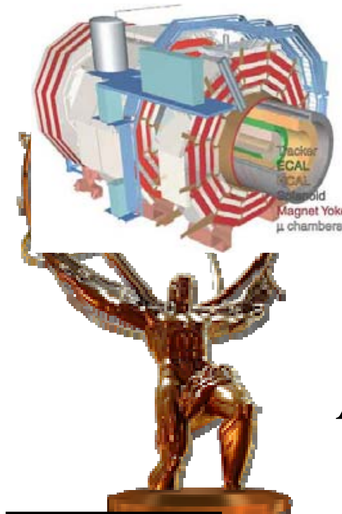
LPCC

MB&UE Working Group

LHC Physics Centre at CERN

MB & UE Common Plots

Quantum Chromo-Dynamics

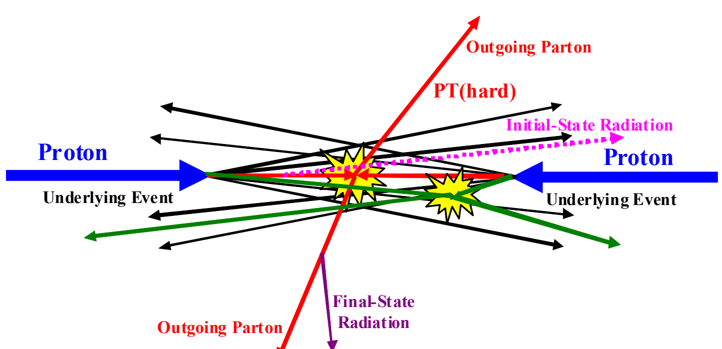


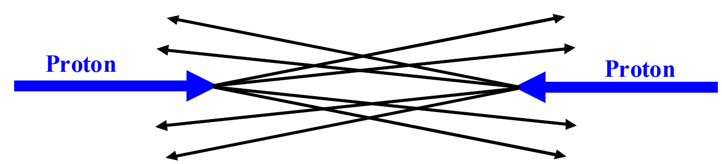
CMS

ATLAS

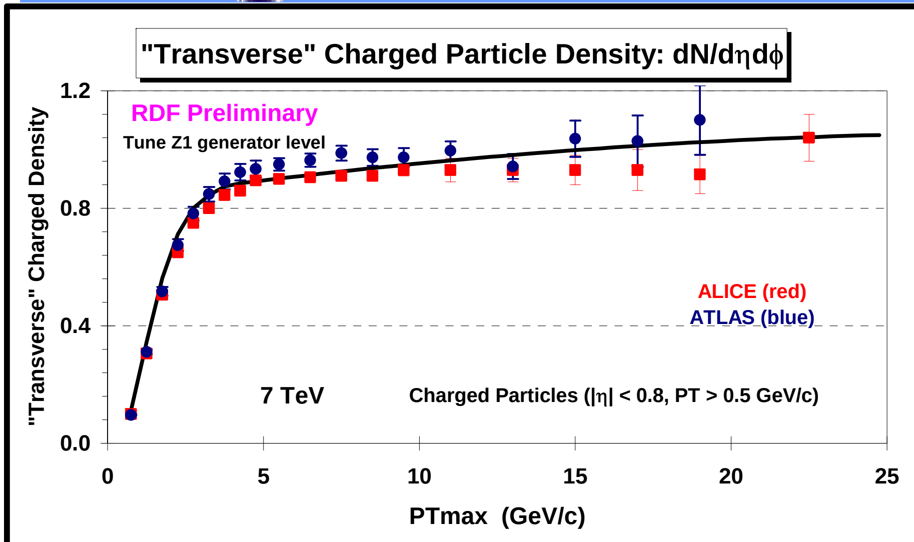
➡ **The LPCC MB&UE Working Group has suggested several MB&UE "Common Plots" the all the LHC groups can produce and compare with each other.**

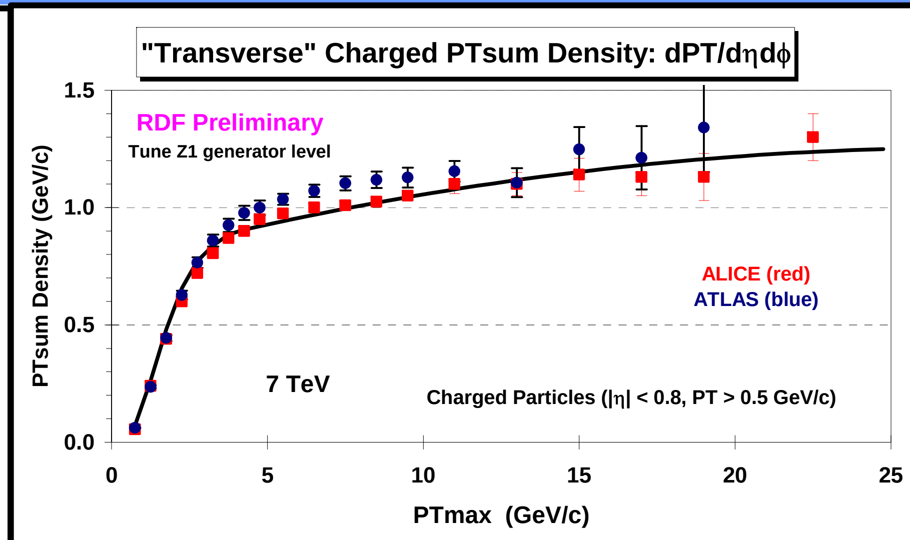
ALICE LHCb

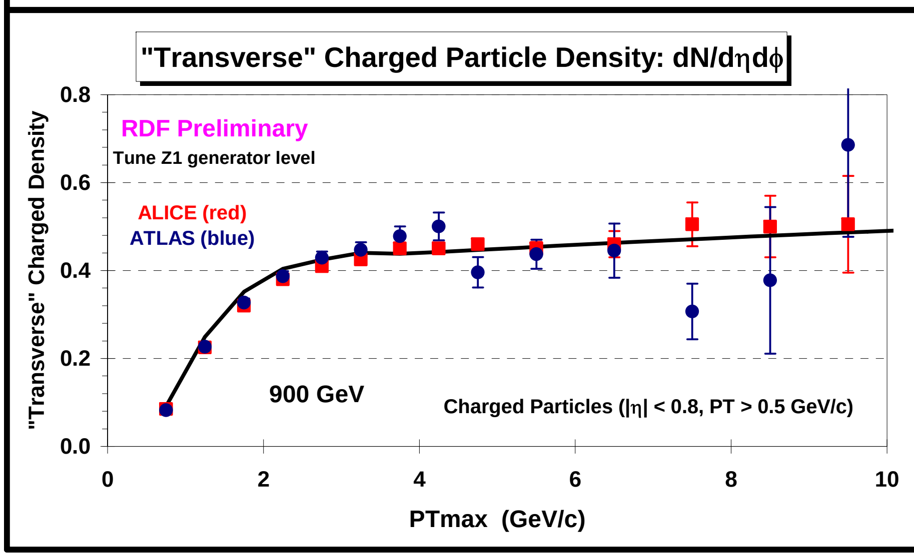


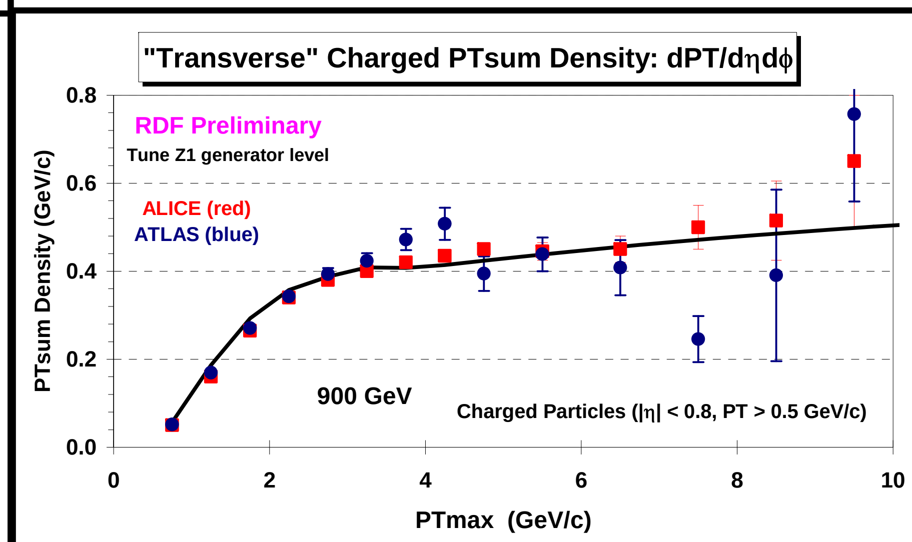


ALICE-ATLAS UE

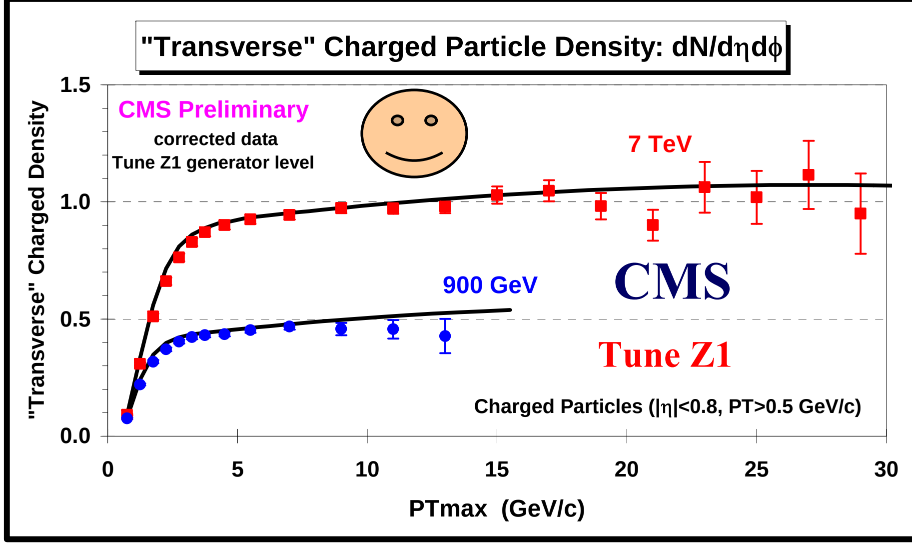


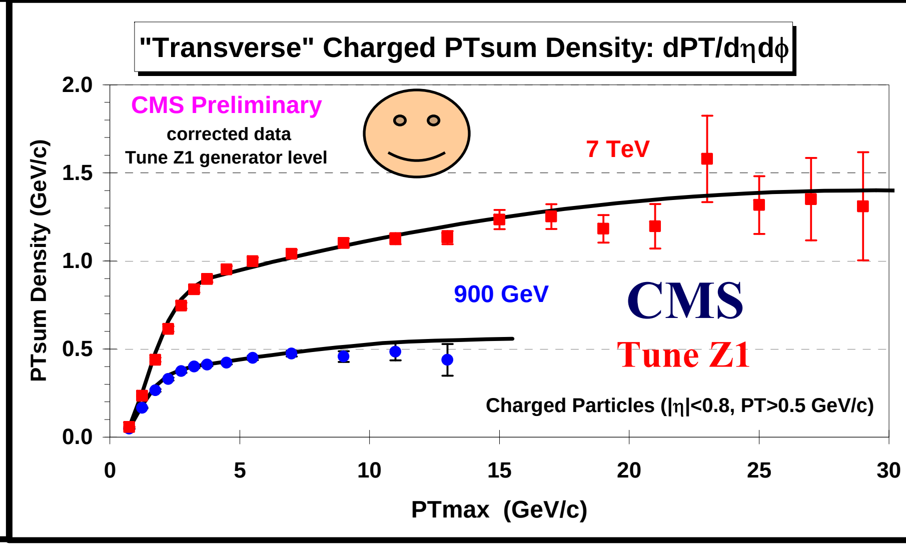






New CMS UE Data





- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (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.**

- **CMS 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 generator level.**

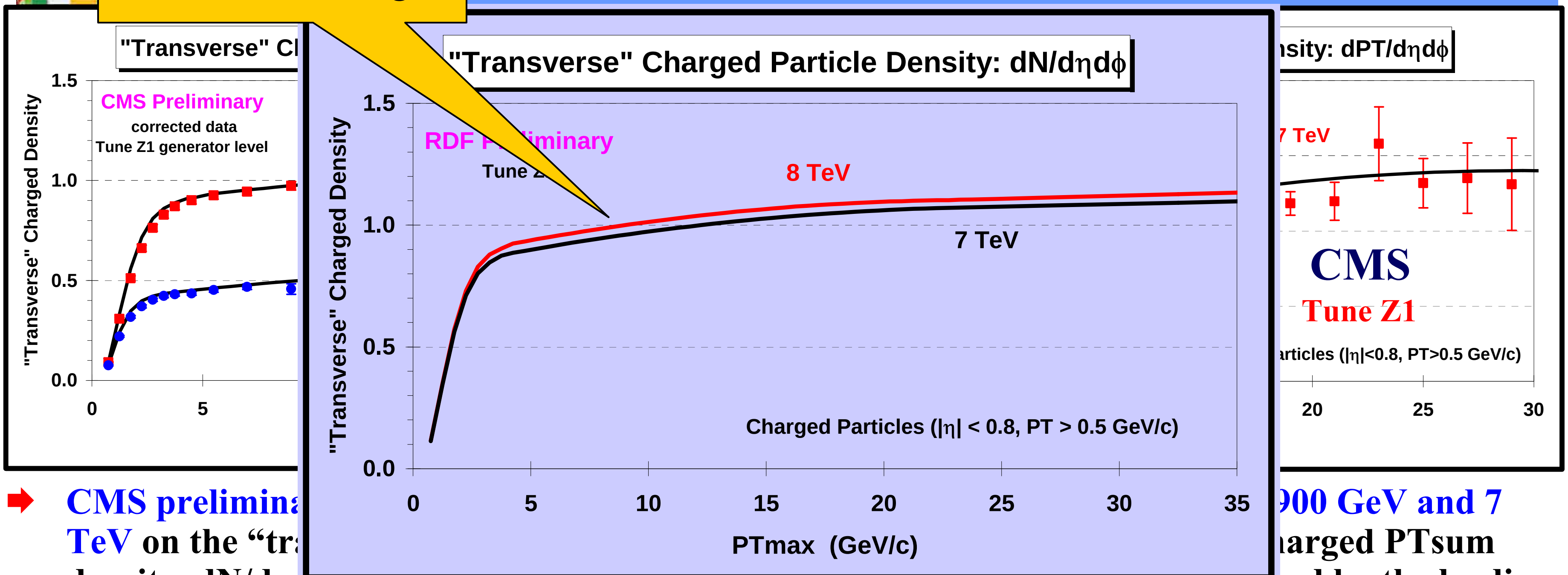
CMS corrected data!

Very nice agreement!

CMS corrected data!

New CMS UE Data

Less than 4% change!



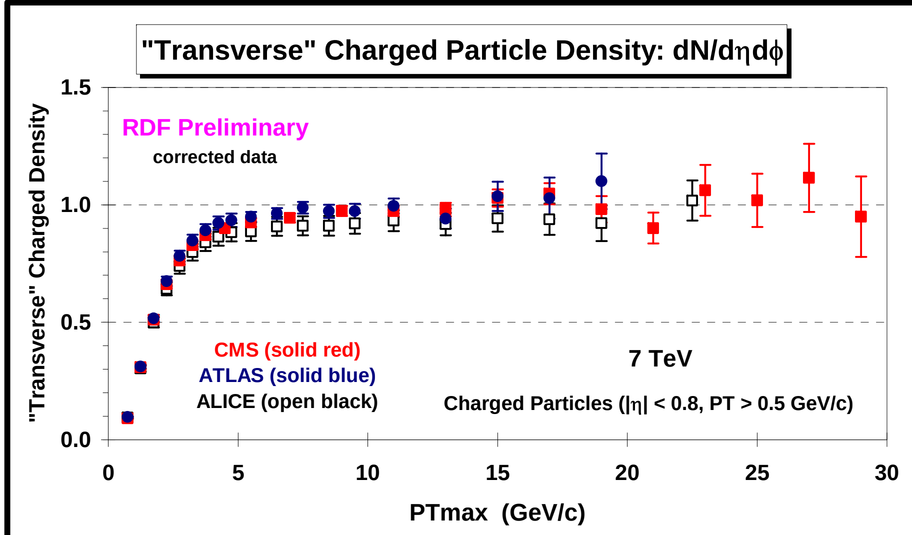
- **CMS prelimina**… **TeV** on the "tr… density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.
- …**900 GeV and 7** …harged PTsum density, dPT/dηdφ,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

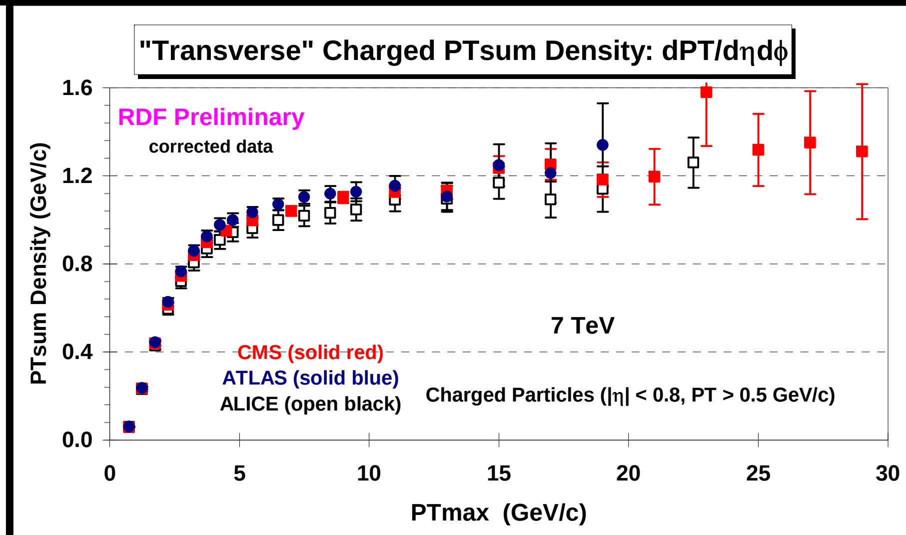
CMS corrected data!

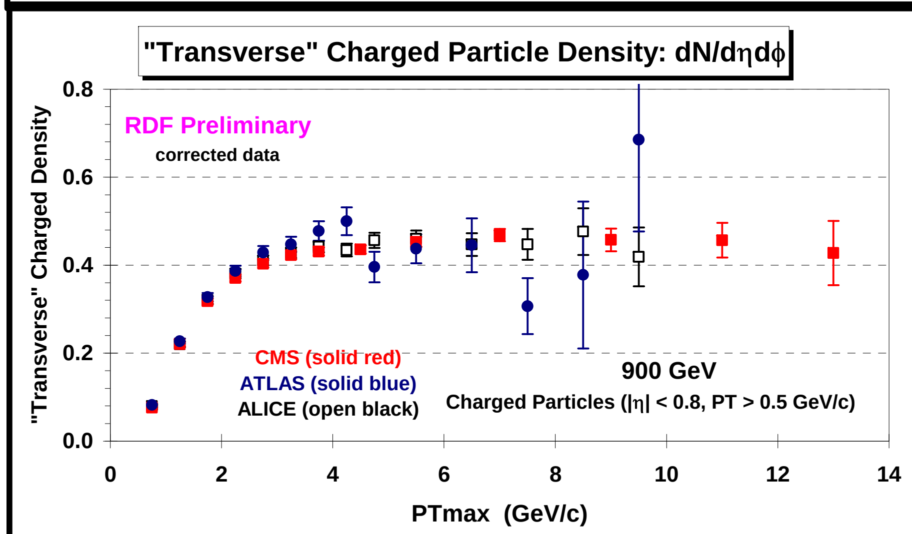
Very nice agreement!

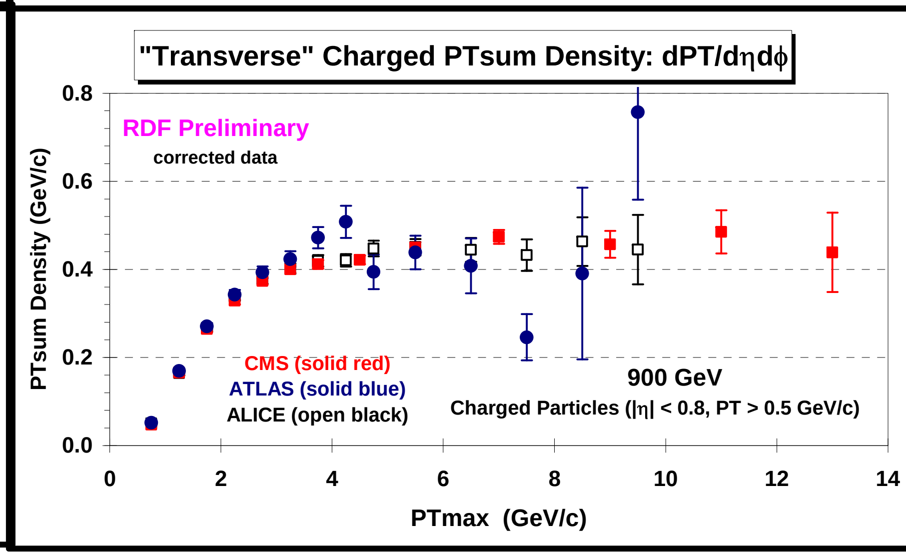
CMS corrected data!

UE Common Plots

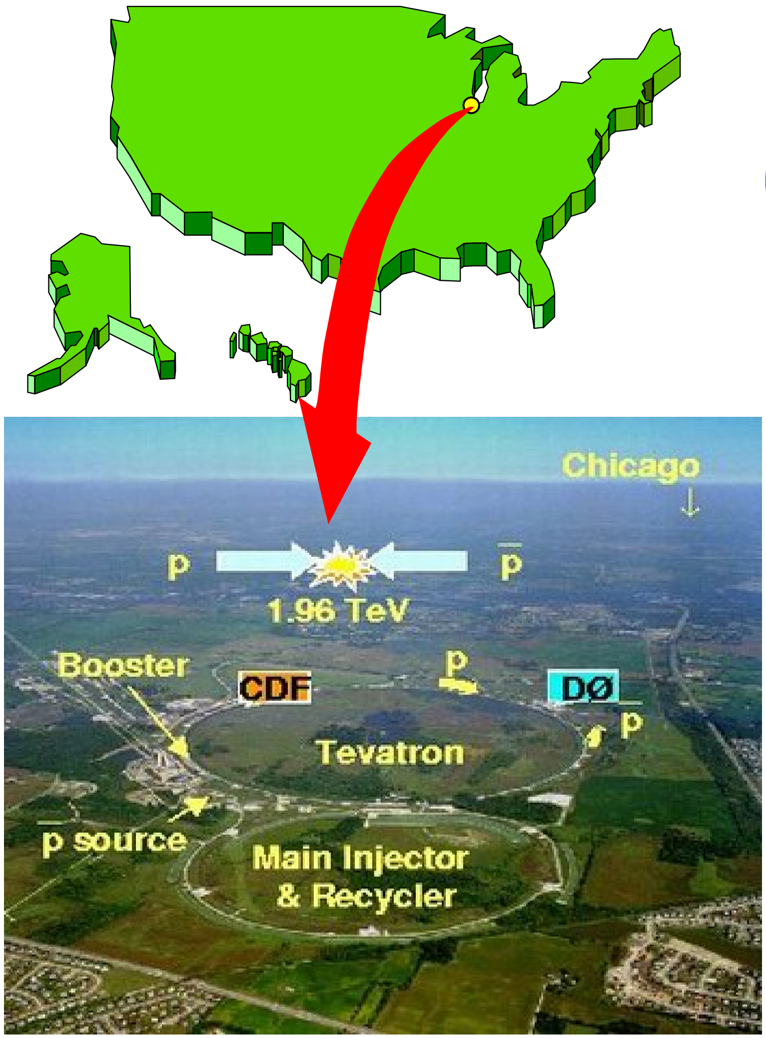


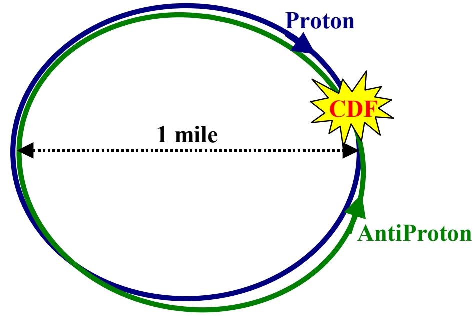






Tevatron Energy Scan



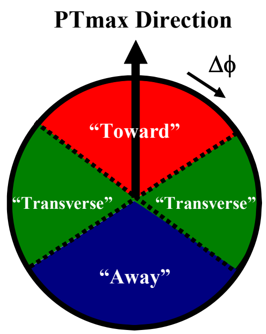


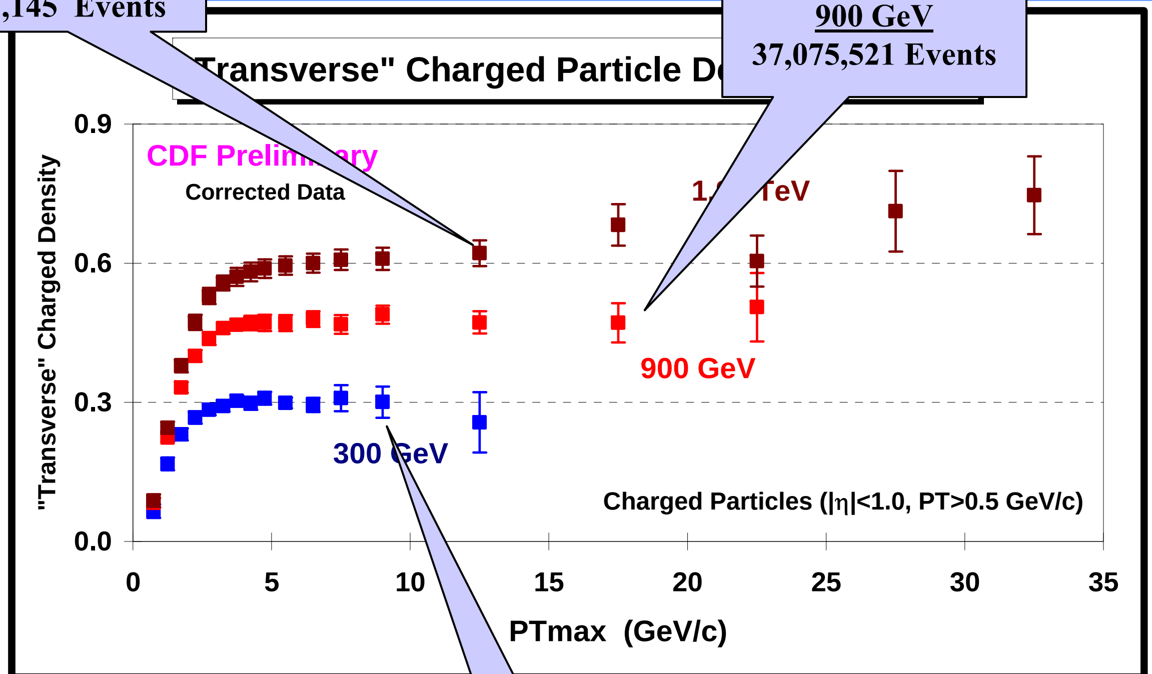
- Just before the shutdown of the Tevatron CDF has collected more than 10M "min-bias" events at several center-of-mass energies!

300 GeV 12.1M MB Events

900 GeV 54.3M MB Events

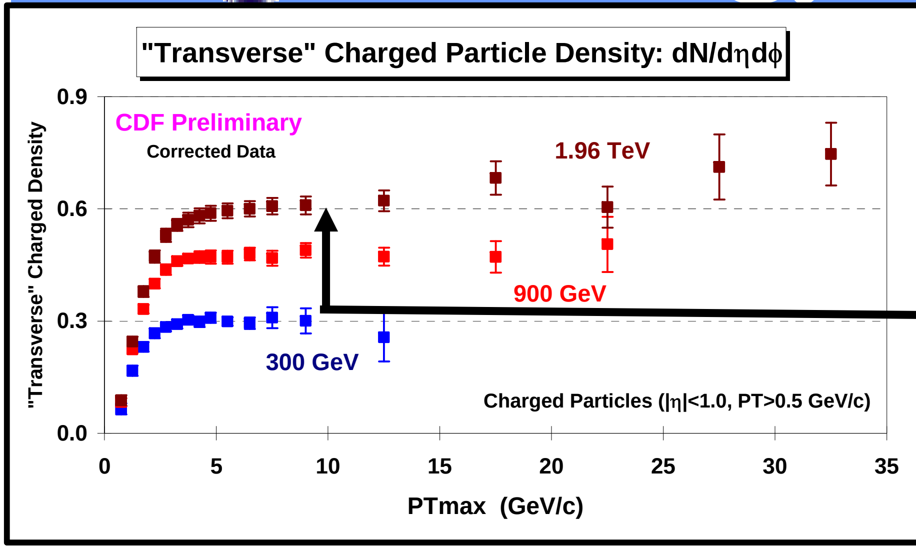
New CDF UE Data

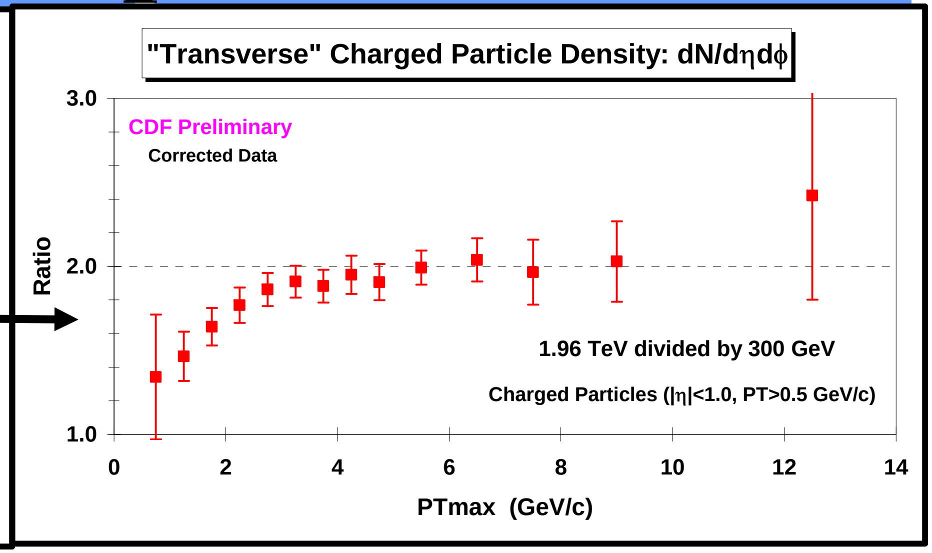




- New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$.

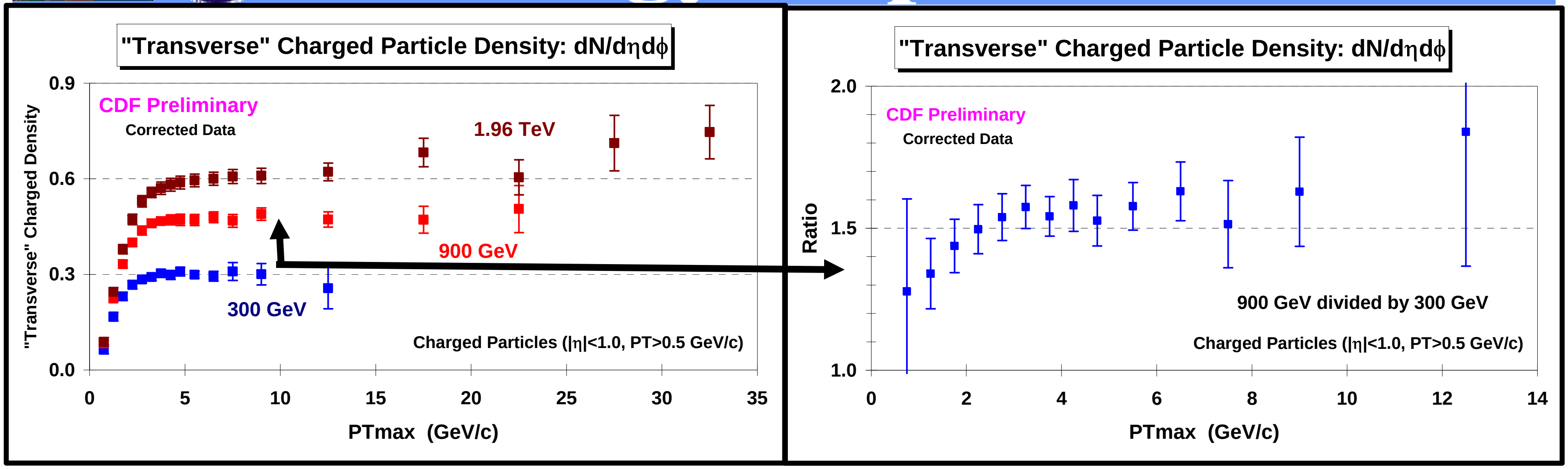
Energy Dependence





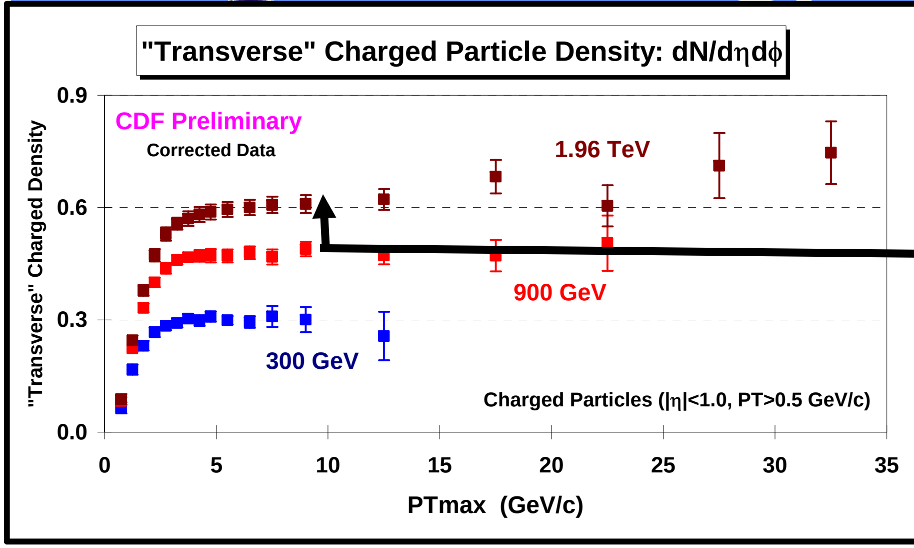
- **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0.**
- **Ratio of the CDF data at 300 GeV and 1.96 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0. Shows 1.96 TeV divided by 300 GeV.**

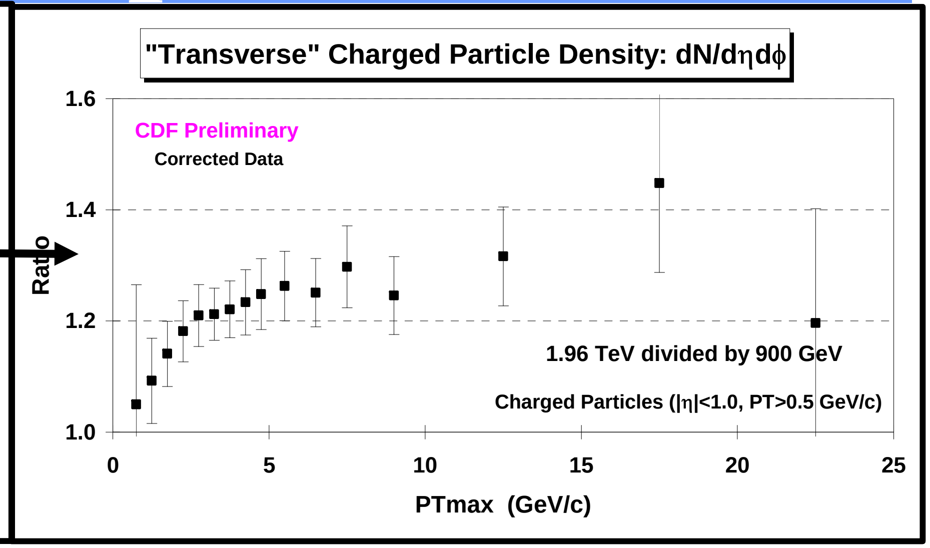
Energy Dependence



- New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 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| < 1.0.
- Ratio of the CDF data at 300 GeV and 900 GeV 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| < 1.0. Shows 900 GeV divided by 300 GeV.

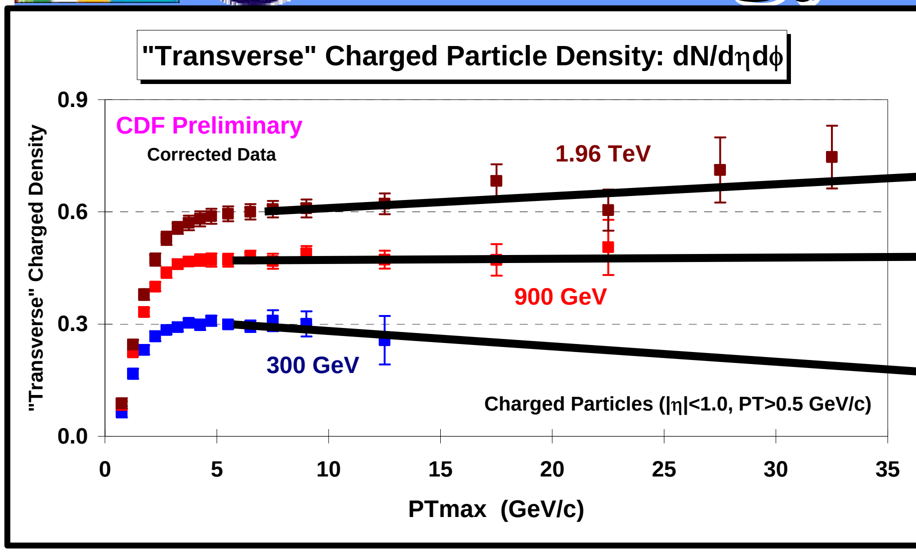
Energy Dependence

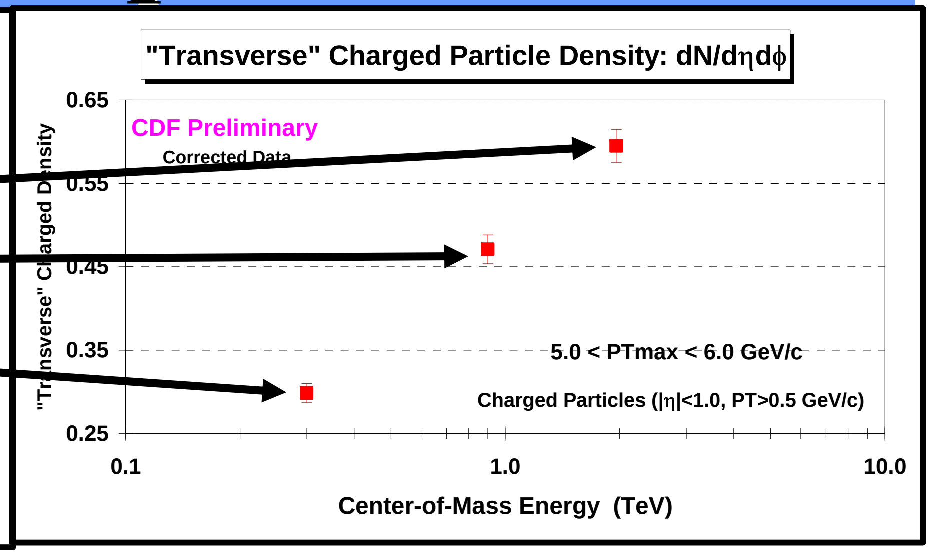




- New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0.
- Ratio of the CDF data at 900 GeV and 1.96 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0. Shows 1.96 TeV divided by 900 GeV.

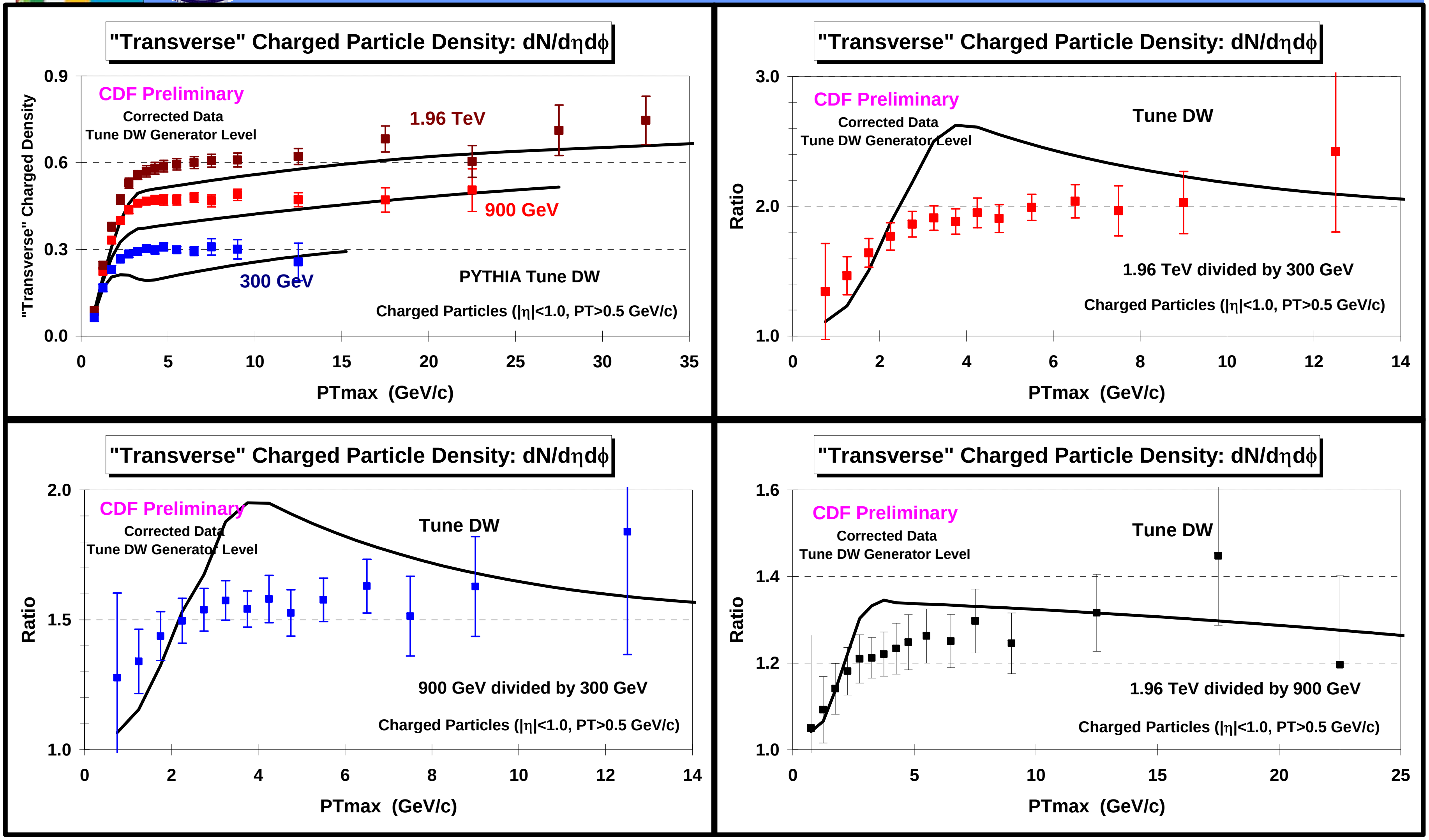
Energy Dependence



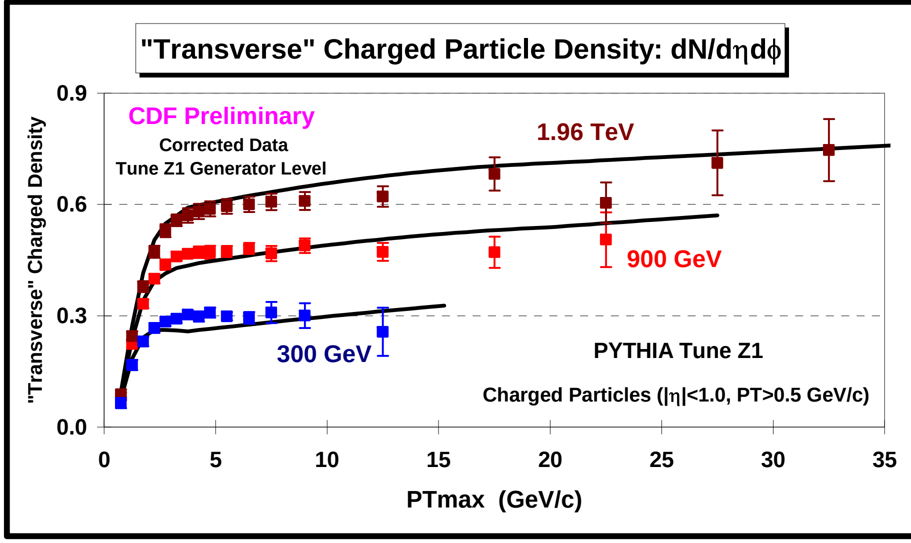


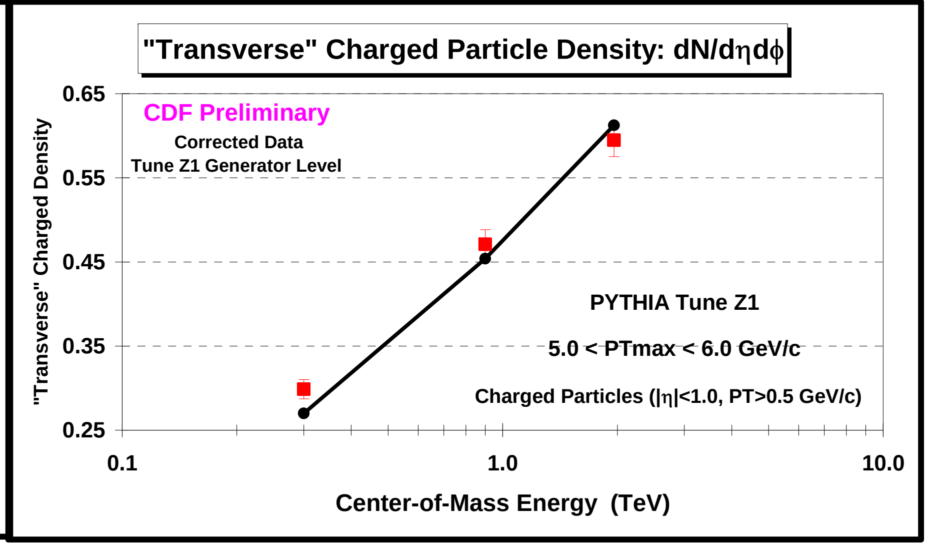
- New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0.
- New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" 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| < 1.0 for 5.0 < PTmax < 6.0 GeV/c.

PYTHIA 6.2 Tune DW

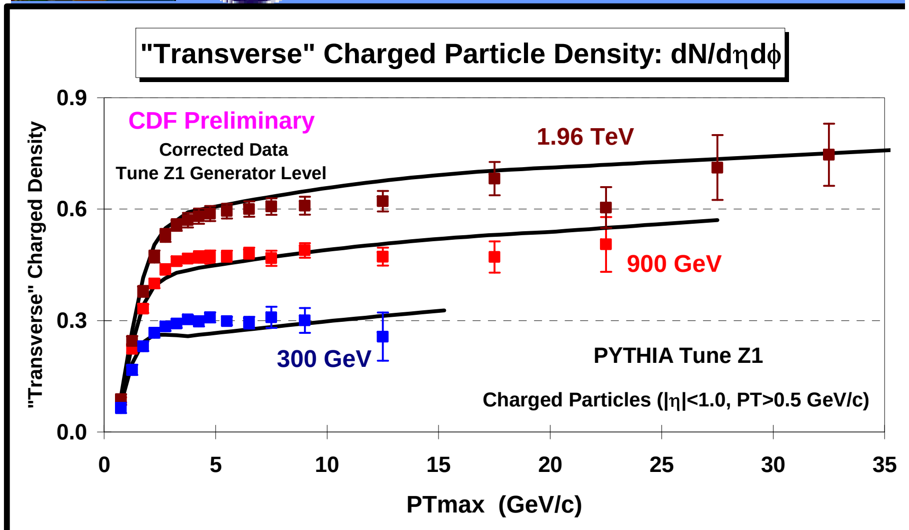


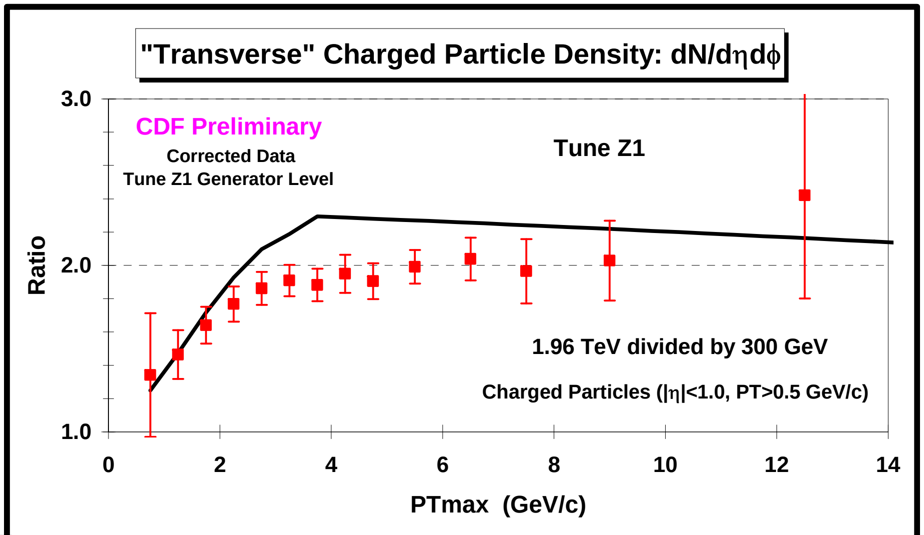
PYTHIA 6.4 Tune Z1

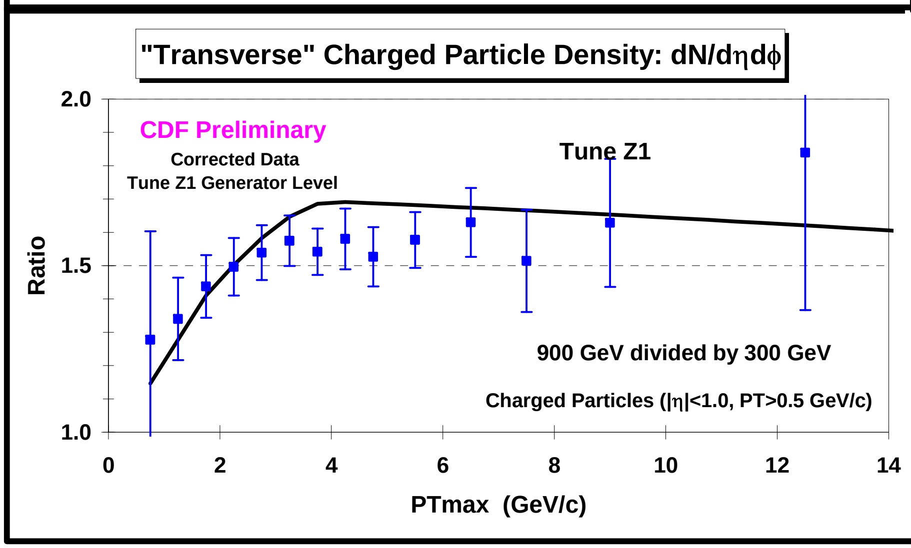


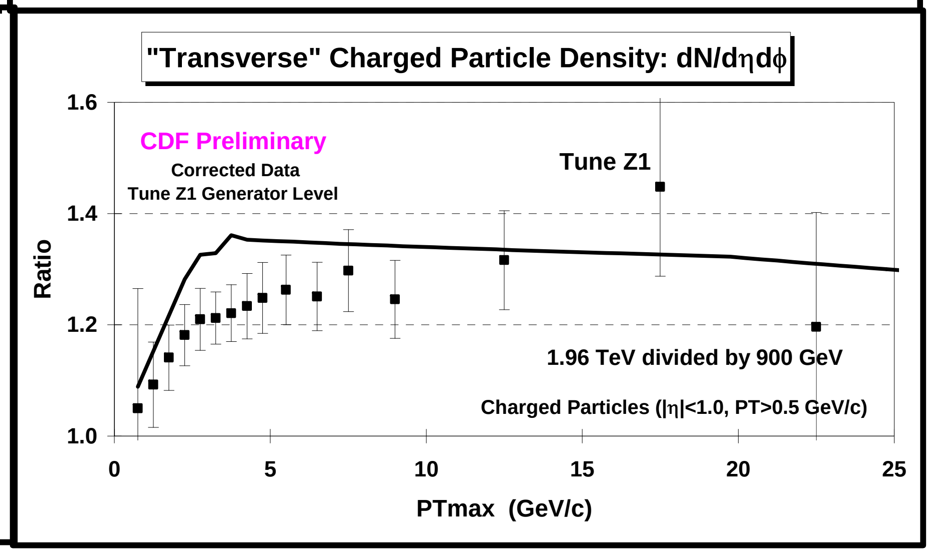


PYTHIA 6.4 Tune Z1

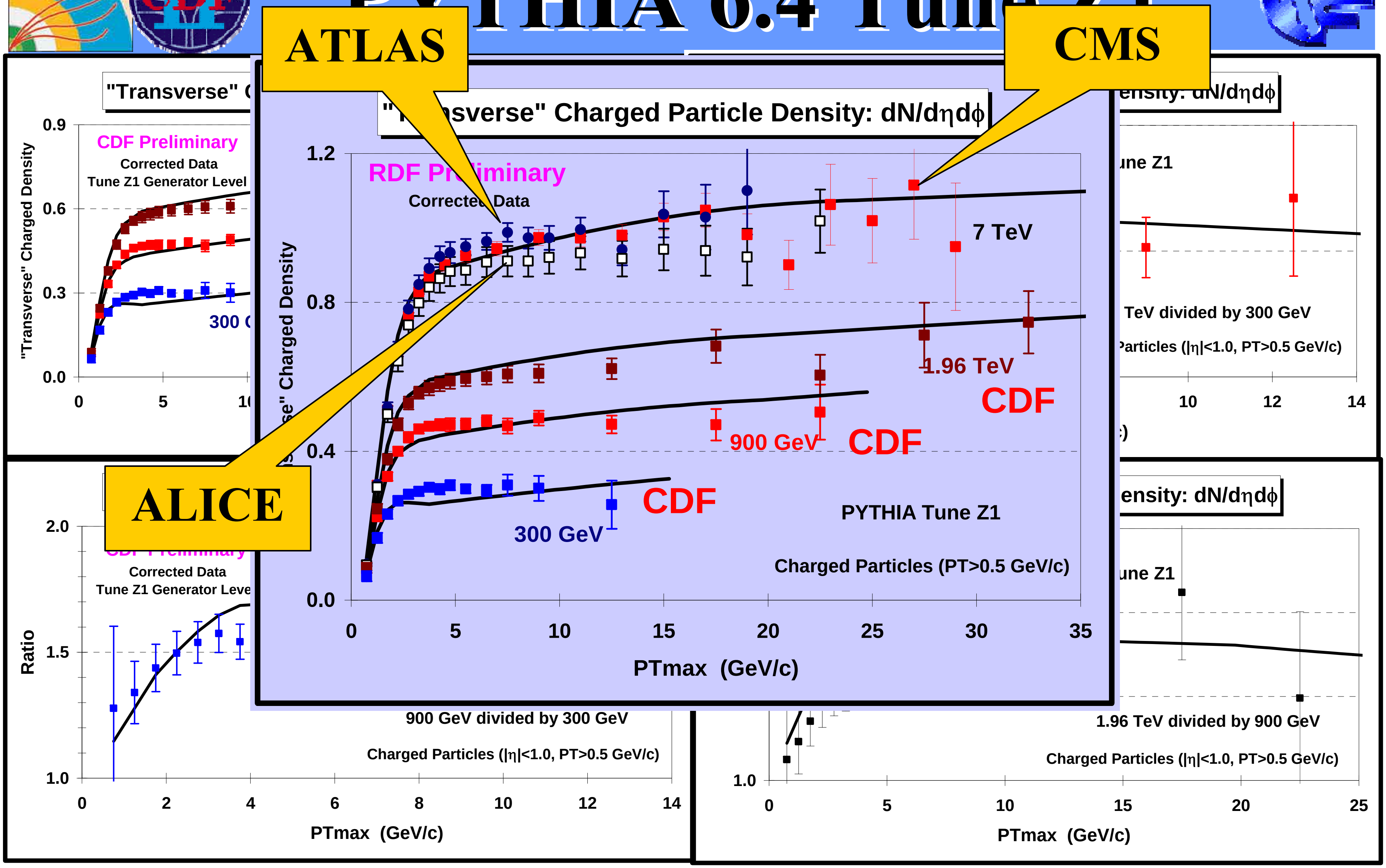




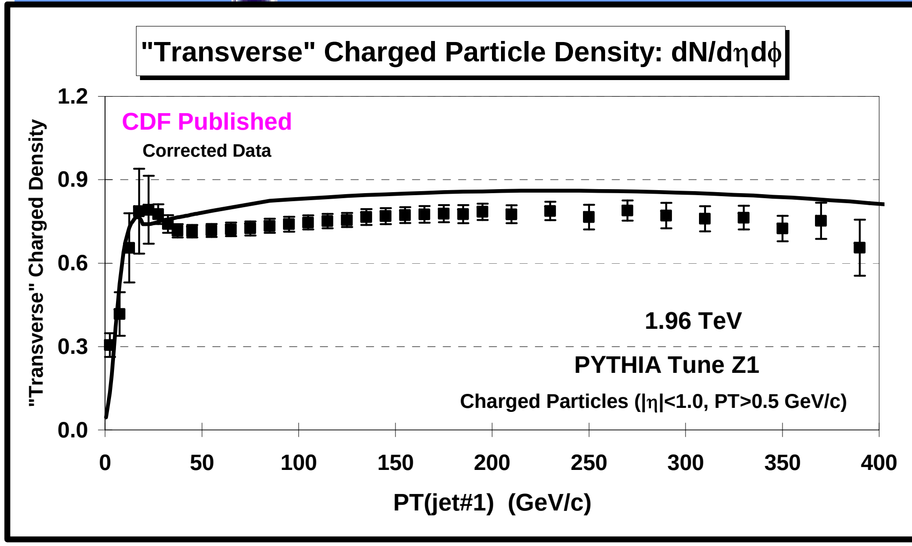


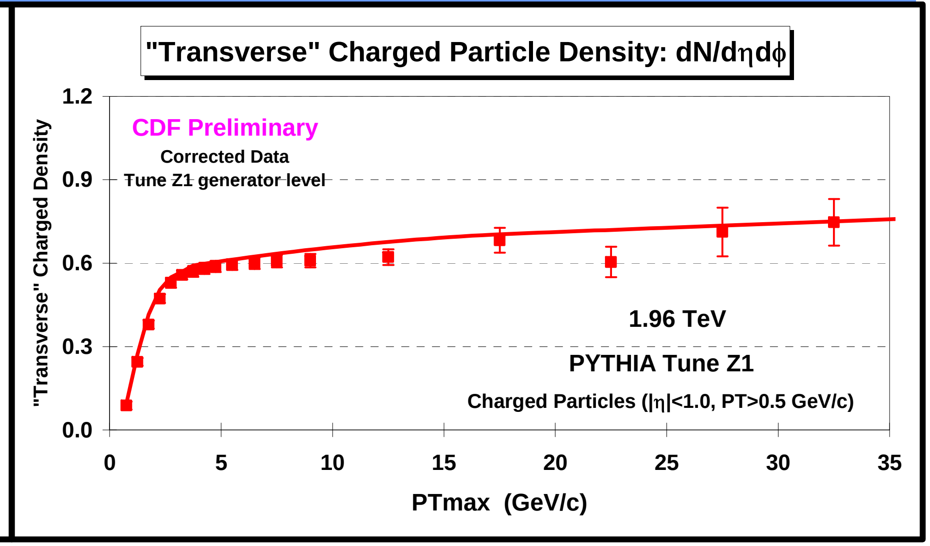


PYTHIA 6.4 Tune Z1



PTmax versus Leading Jet

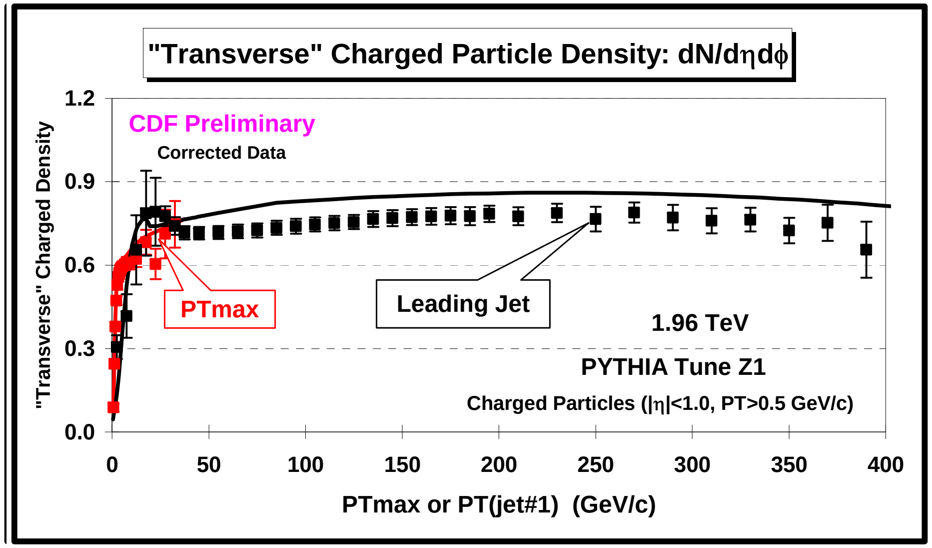


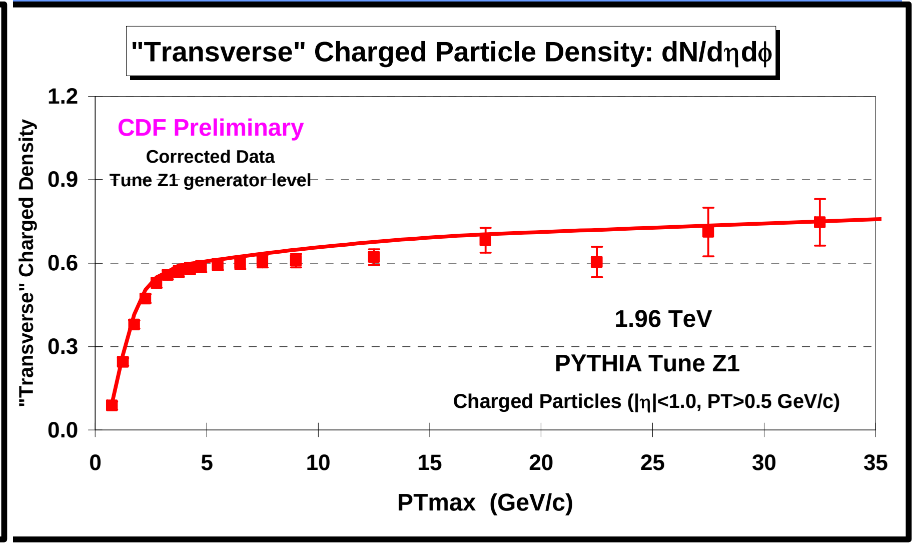


- **Published CDF Run 2 data at 1.96 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading calorimeter jet (jet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0 compared with PYTHIA Tune Z1.**

- **New CDF data 1.96 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| < 1.0 compared with PYTHIA Tune Z1.**

PTmax versus Leading Jet

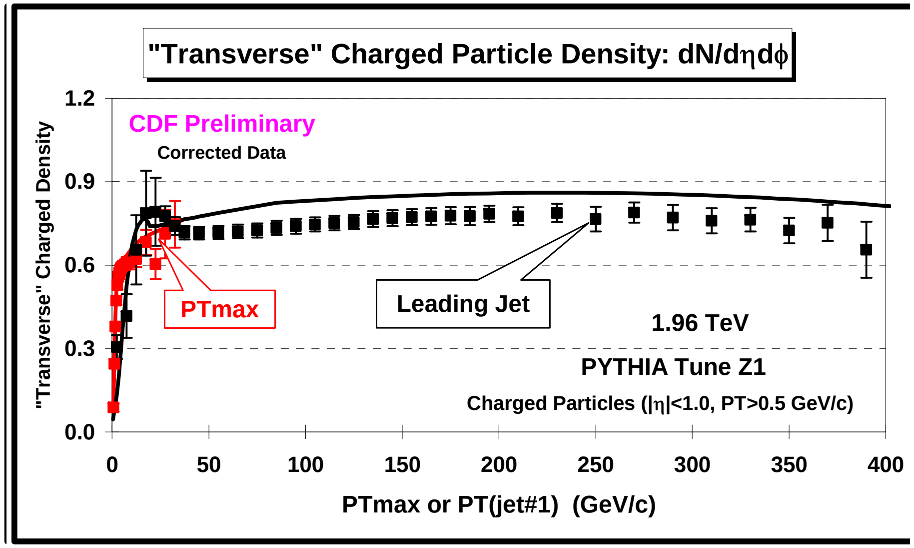


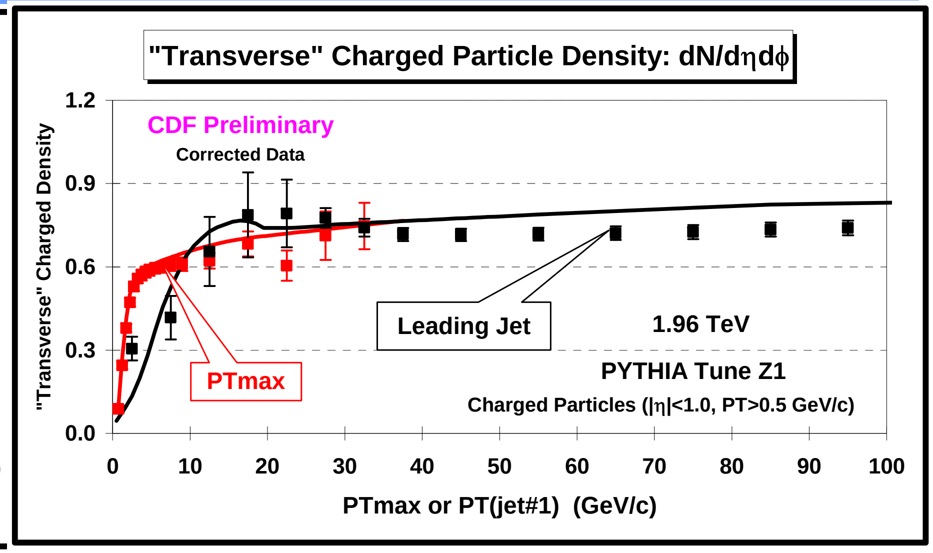


- Published CDF Run 2 data at 1.96 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading calorimeter jet (jet#1) for charged particles with $p_T > 0.5$ GeV/c and |η| ... with PYTHIA Tune Z1

- New CDF data 1.96 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| < 1.0 compared with PYTHIA Tune Z1.

PTmax versus Leading Jet

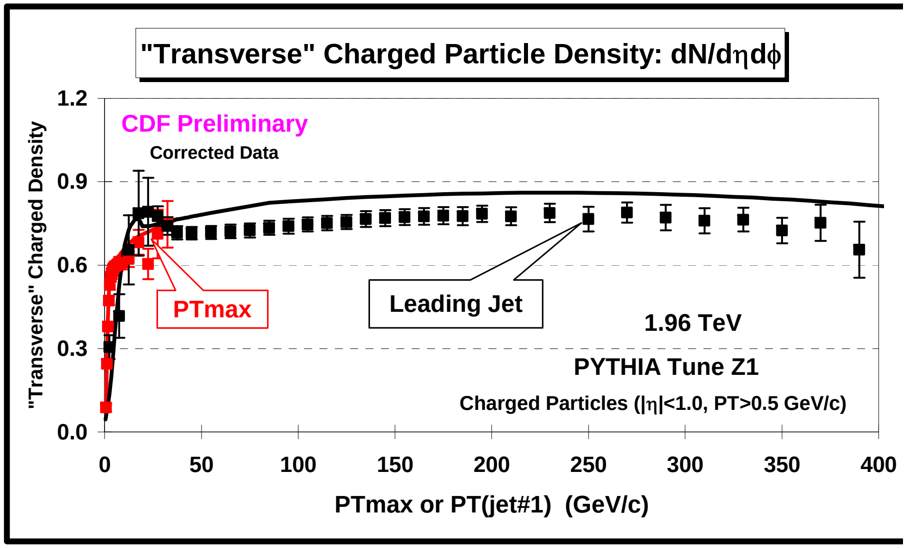


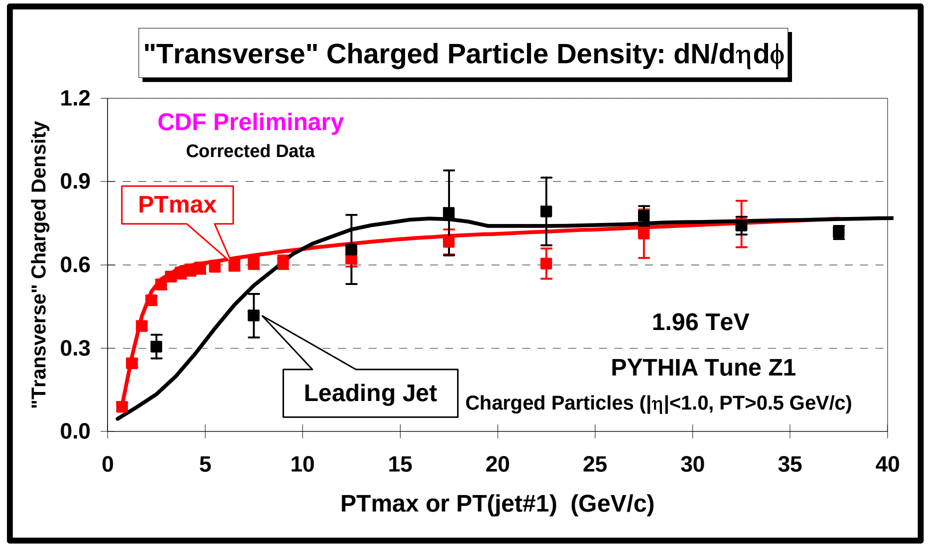


- **Published CDF Run 2 data at 1.96 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading calorimeter jet (jet#1) for charged particles with p_T > 0.5 GeV/c and |η| … with PYTHIA Tune Z1.**

- **New CDF data 1.96 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| < 1.0 compared with PYTHIA Tune Z1.**

PTmax versus Leading Jet



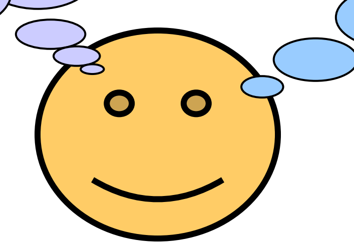


- **Published CDF Run 2 data at 1.96 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading calorimeter jet (jet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 1 ... d with PYTHIA Tune Z1**

- **New CDF data 1.96 T ... se” charged p ... d by the le ... charg ... < 1.0 c**

Yikes!
???

Okay
No inconsistency
But need to understand!



More Coming Soon!

- **CDF - Many More UE Observables:** Nchg density, PTsum density, average p_T, “toward”, “away”, “transverse”, “transMAX”, “transMIN”, distributions, etc..
- **CDF - Two η Ranges:** Must do ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) as well as ($p_T > 0.5$ GeV, $|\eta| < 1$).
- **CDF - Min-Bias:** Many MB observables: Multiplicity, dN/dη, p_T distribution, $\langle p_T \rangle$ versus Nchg, etc.

Soon we will have MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, 7 TeV, and 8 TeV! We can study the energy dependence more precisely than ever before!

More Coming Soon!

- **CDF - Many More UE Observables**: chg density, PTsum density, average p_T, "toward", "away", "transverse", "transMAX", "transMIN"...
- **CDF - Ty**... 0.8) as wel...
- **CDF - Min-**...ity, dN/dη, ...

What we are learning should allow for more precise predictions at the future LHC energy of 13 TeV!

Soon ... UE ... t 300 GeV, ... GeV, ... 6 Te... TeV, an... TeV! We can stud... e energ... dependence more prec... ly than ever before!