HEP Seminar

Tevatron Energy Scan: Findings & Surprises

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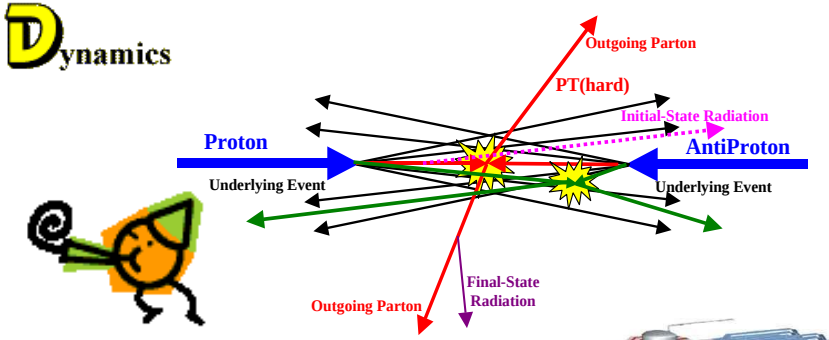
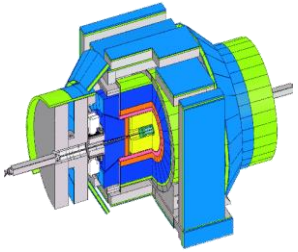
Quantum Chromo-Dynamics

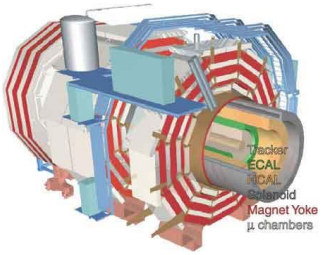
Outline of Talk

- **CDF data from the Tevatron Energy Scan.**
- **The overall event topology for events with at least 1 charged particle.**
- **The "transMAX", "transMIN", "transAVE" and "transDIF" UE observables.**
- **Mapping out the energy dependence: Tevatron to the LHC!**
- **Comparisions with PYTHIA 6.4 Tune Z1 & Z2* and PYTHIA 8 Tune 4C*.**
- **Summary & Conclusions.**



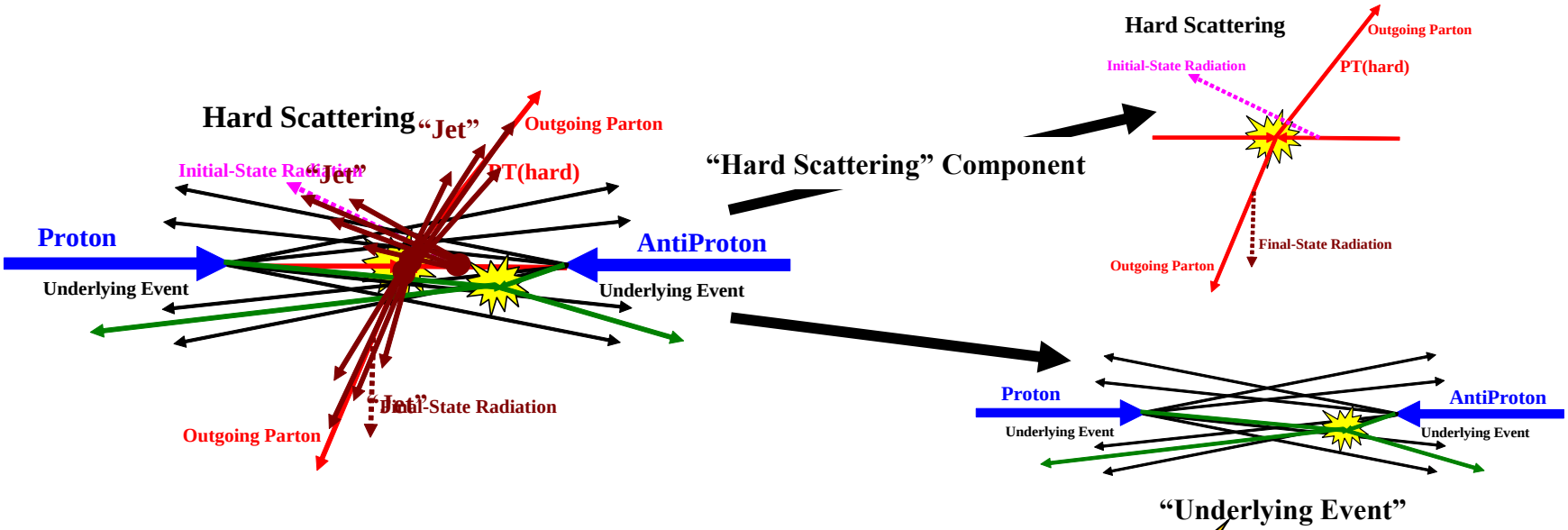


CDF Run 2
300 GeV, 900 GeV, 1.96 TeV



CMS at the LHC
900 GeV, 7 & 8 TeV

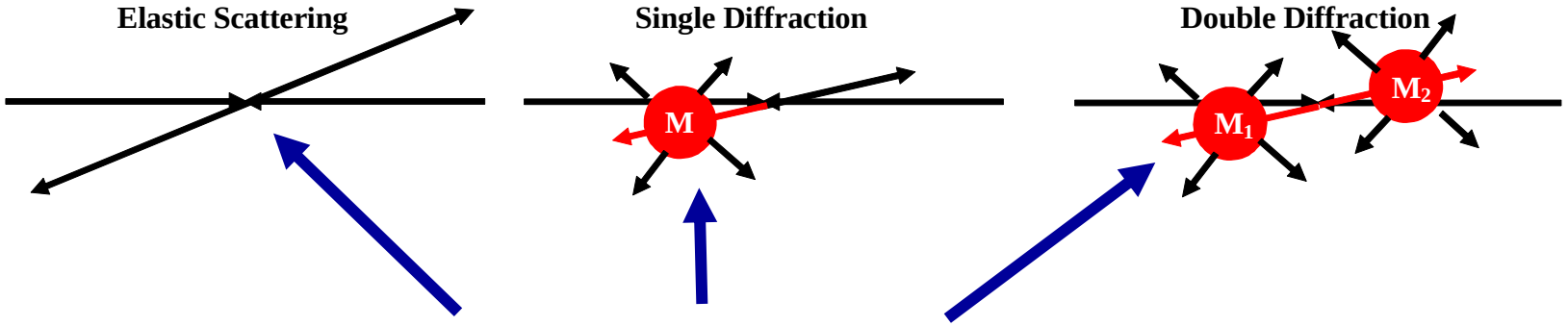
QCD Monte-Carlo Models: High Transverse Momentum Jets



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

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

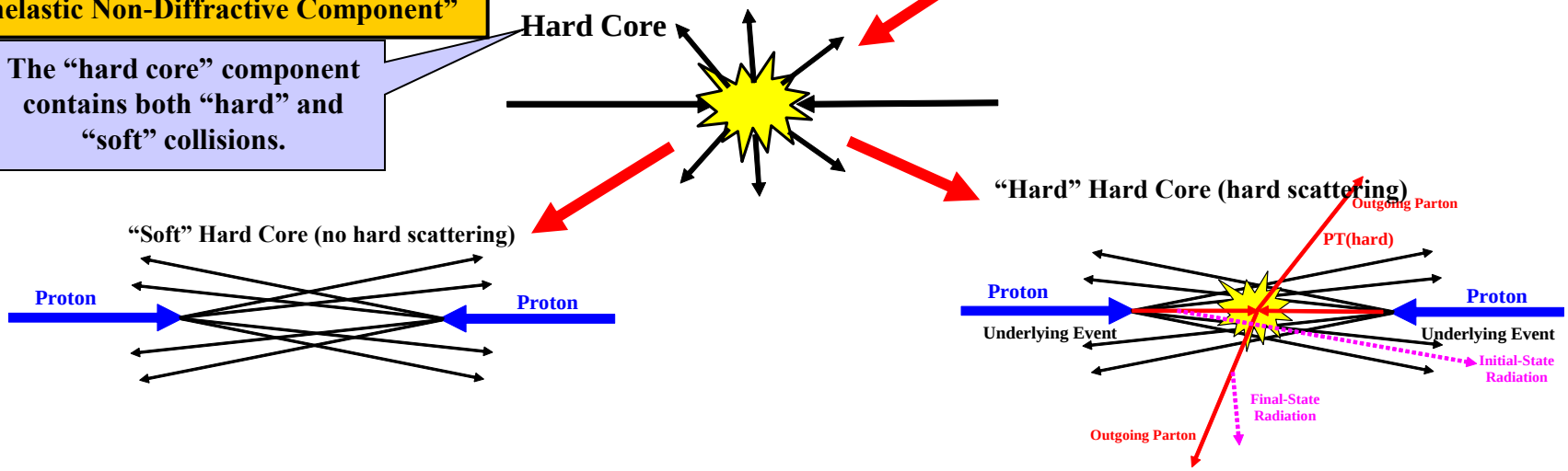
Proton-Proton Collisions



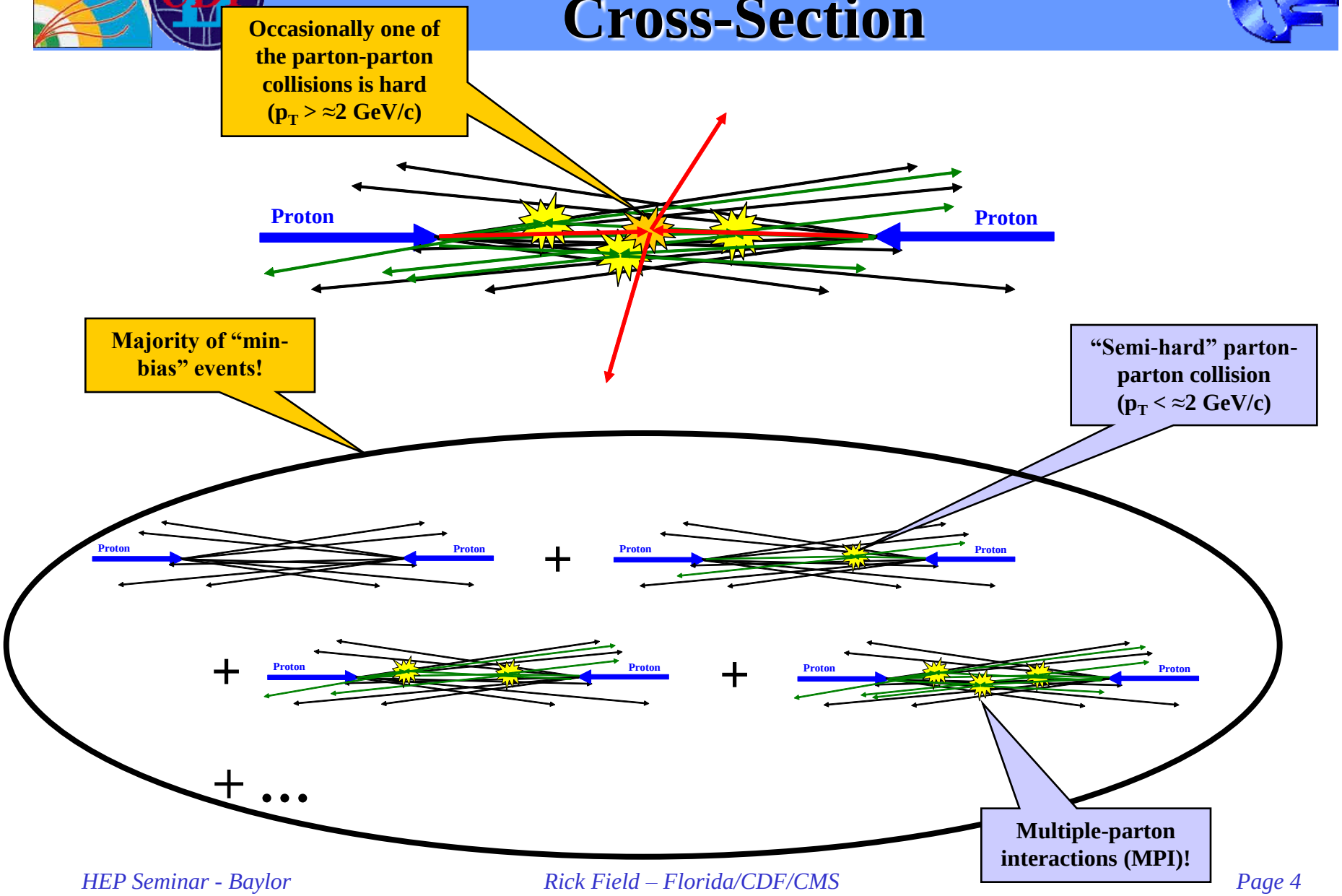
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$

"Inelastic Non-Diffractive Component"

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

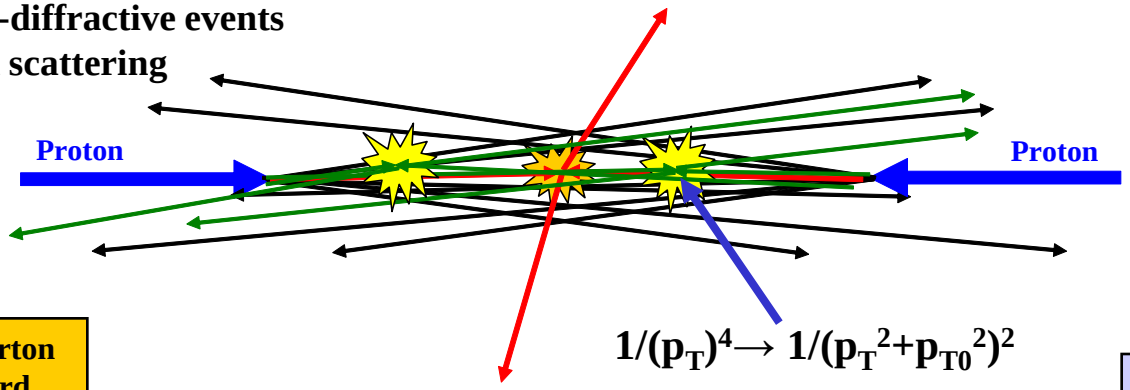


The Inelastic Non-Diffractive Cross-Section



The "Underlying Event"

Select inelastic non-diffractive events that contain a hard scattering

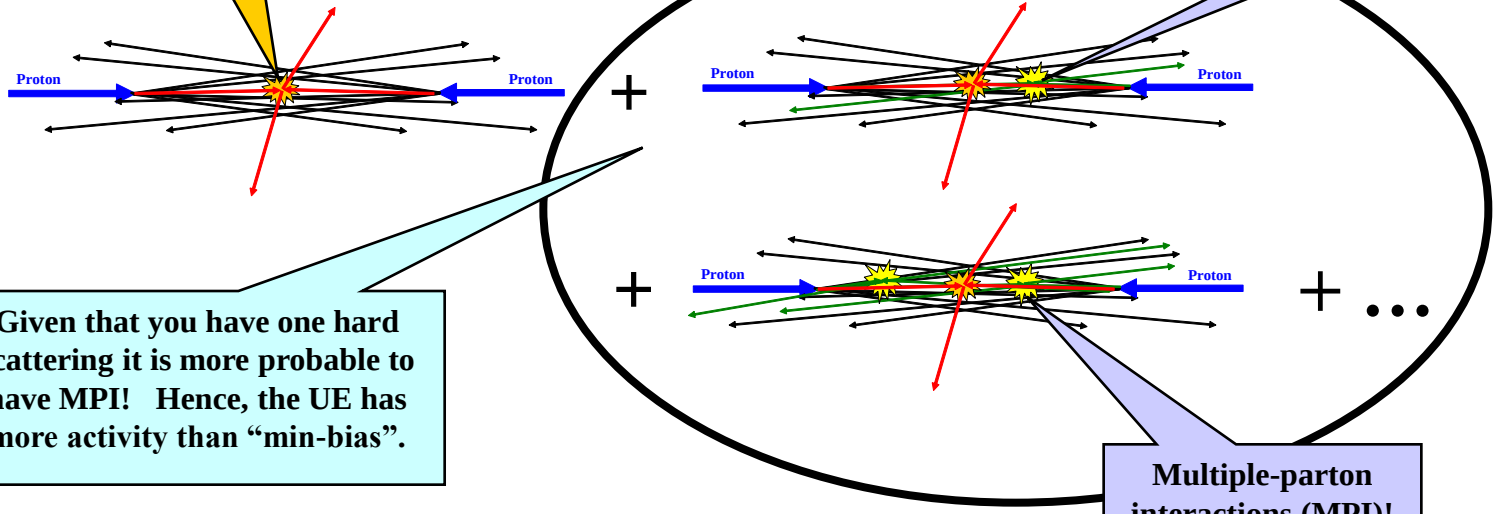


$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

Hard parton-parton collisions is hard (p_T > ≈2 GeV/c)

The "underlying-event" (UE)!

"Semi-hard" parton-parton collision (p_T < ≈2 GeV/c)

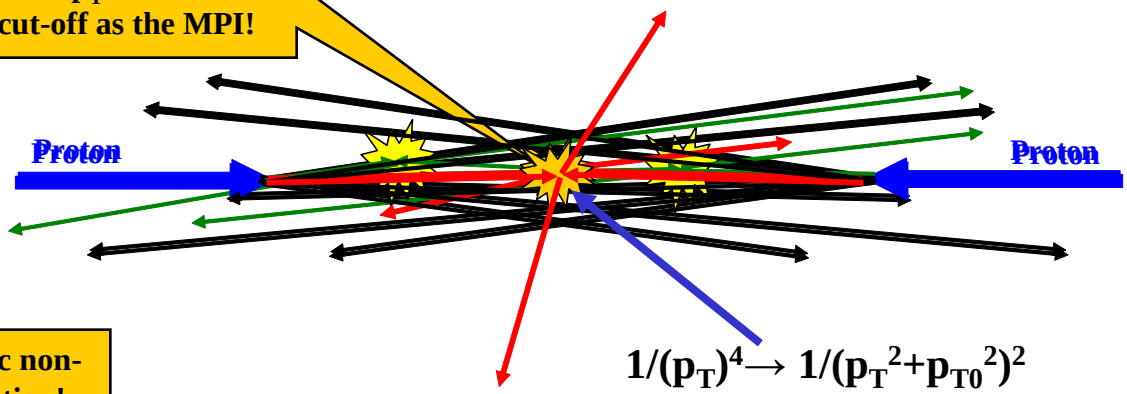


Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than "min-bias".

Multiple-parton interactions (MPI)!

Model of σ_{ND}

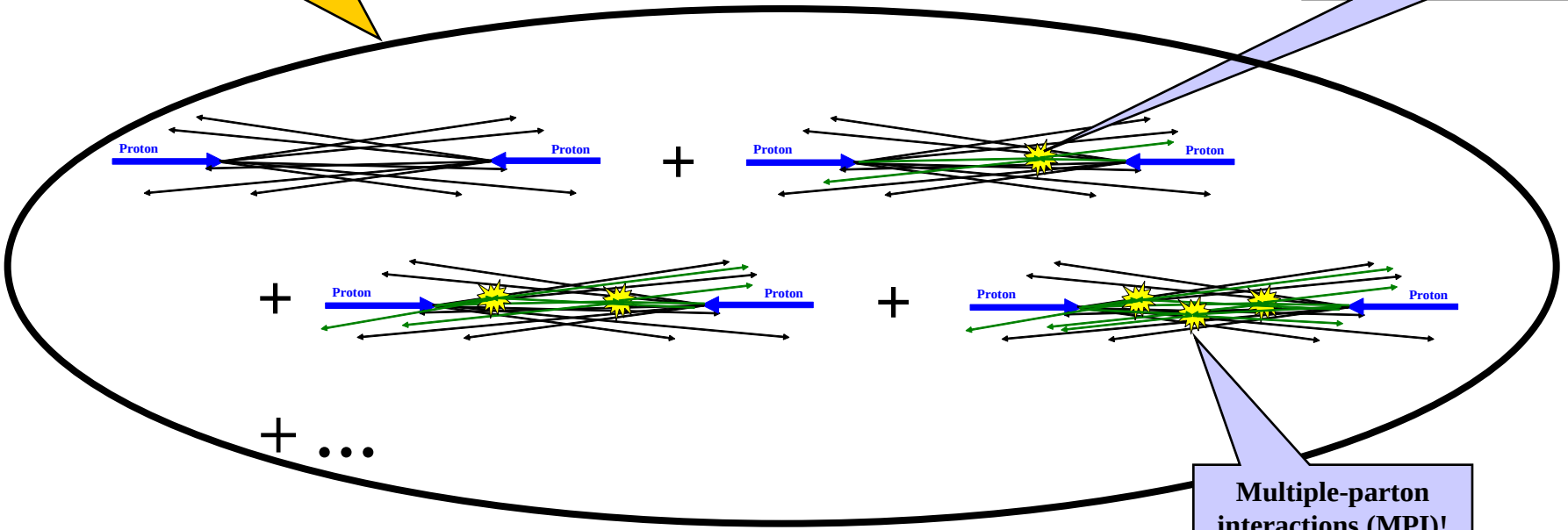
Allow leading hard scattering to go to zero p_T with same cut-off as the MPI!



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

Model of the inelastic non-diffractive cross section!

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



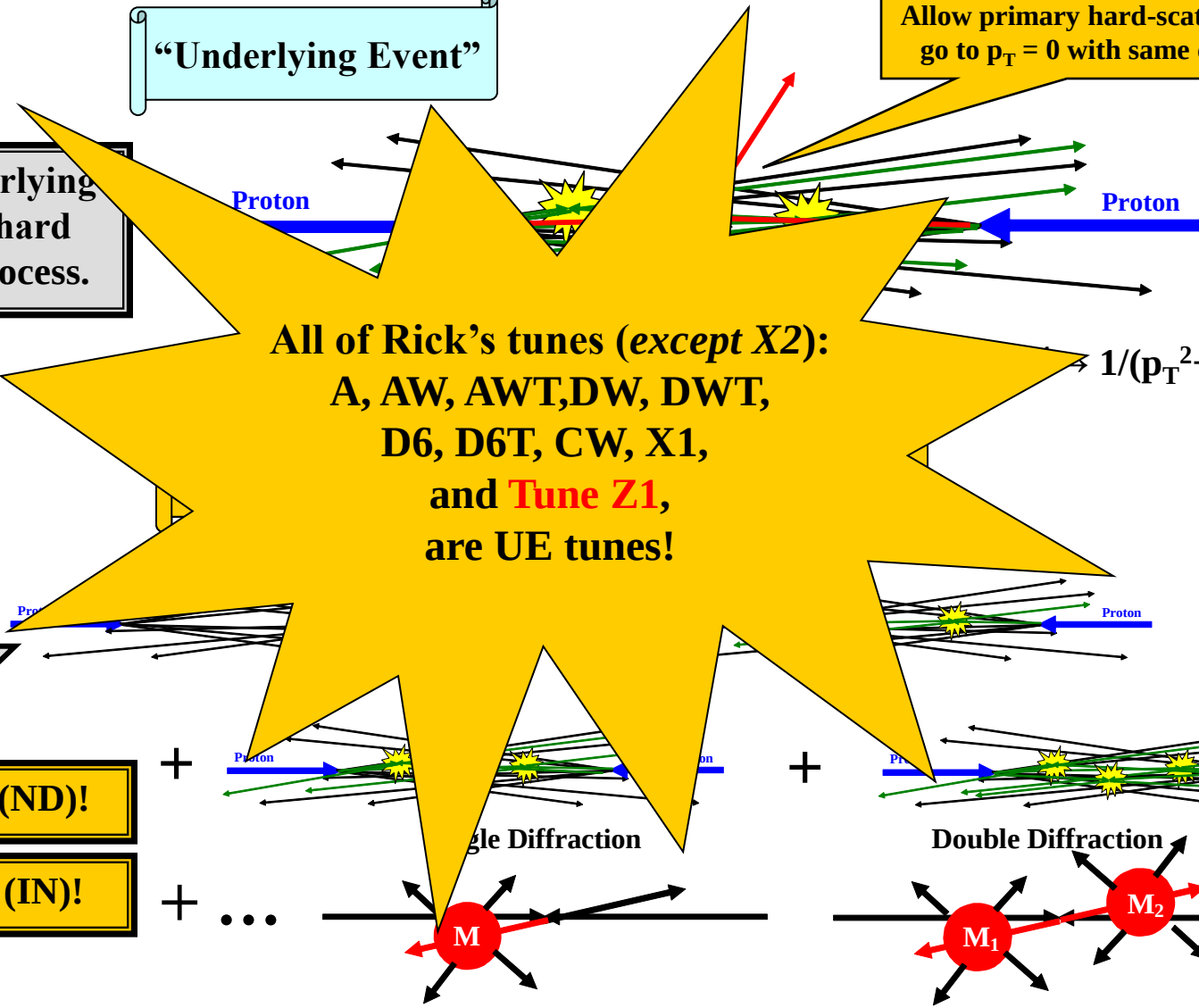
Multiple-parton interactions (MPI)!

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.

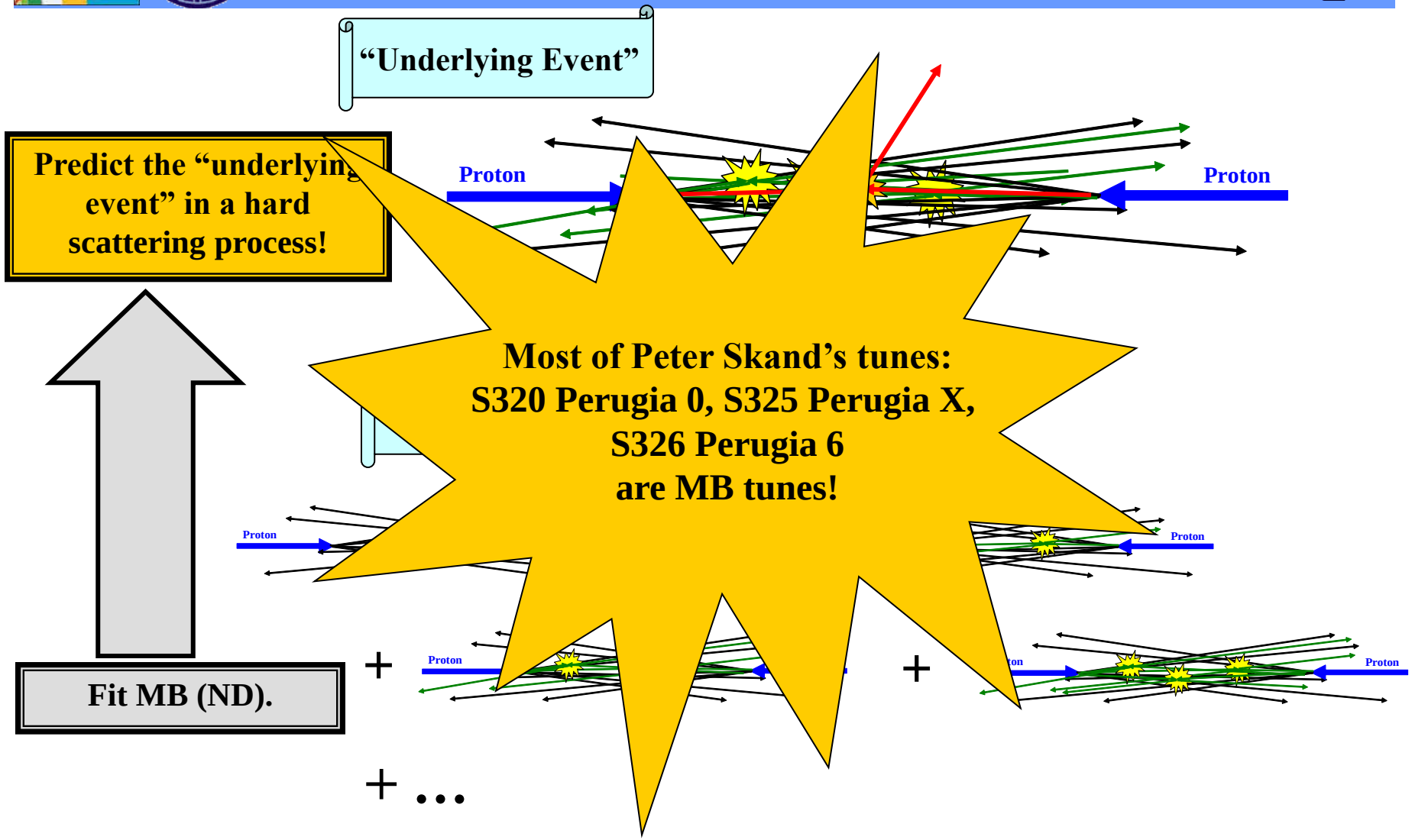


All of Rick's tunes (*except X2*):
A, AW, AWT,DW, DWT,
D6, D6T, CW, X1,
and Tune Z1,
are UE tunes!

Predict MB (ND)!

Predict MB (IN)!

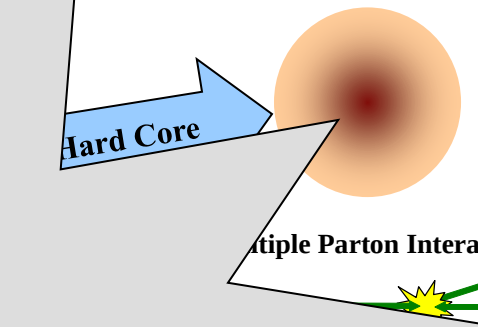
MB Tunes


"Underlying Event"
Predict the "underlying event" in a hard scattering process!
Most of Peter Skand's tunes:
S320 Perugia 0, S325 Perugia X,
S326 Perugia 6
are MB tunes!
Fit MB (ND).
Proton
Proton
Proton
Proton
Proton
Proton
+
+
+ …

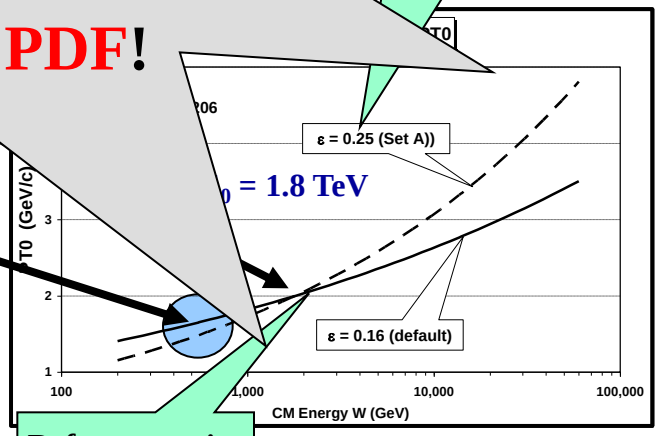
Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

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

Remember the energy dependence of the "underlying event" activity depends on both the ε = PARP(90) and the PDF!

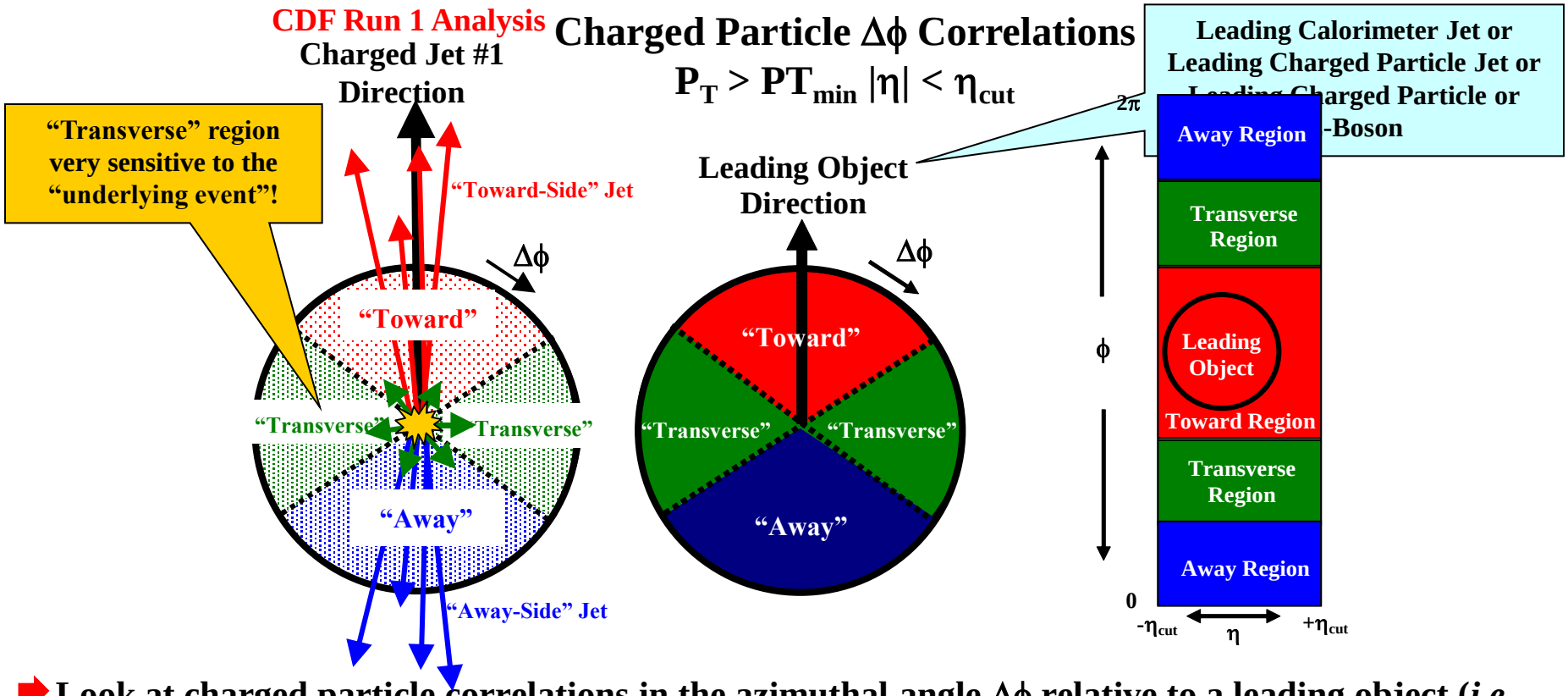


Determine by comparing with 630 GeV data!



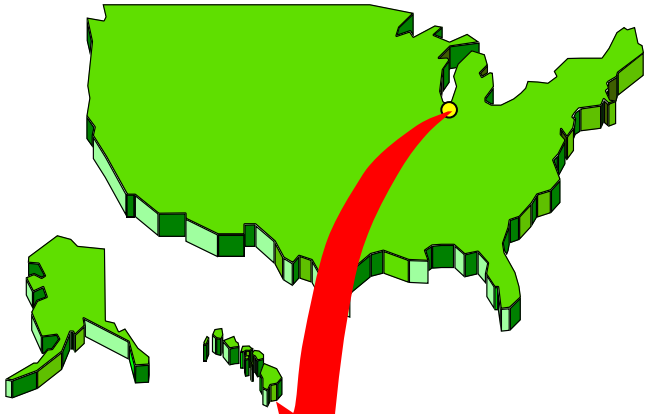
Reference point at 1.8 TeV

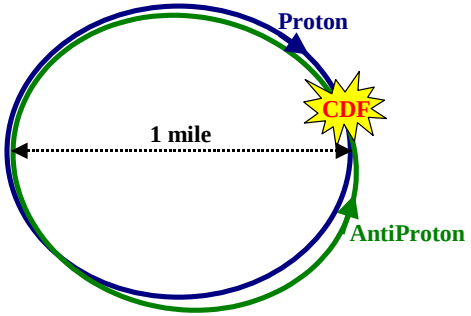
Traditional Approach



- 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, $\Delta\eta \times \Delta\phi = 2\eta_{cut} \times 120^o = 2\eta_{cut} \times 2\pi/3$. Construct densities by dividing by the area in η-ϕ space.

Tevatron Energy Scan





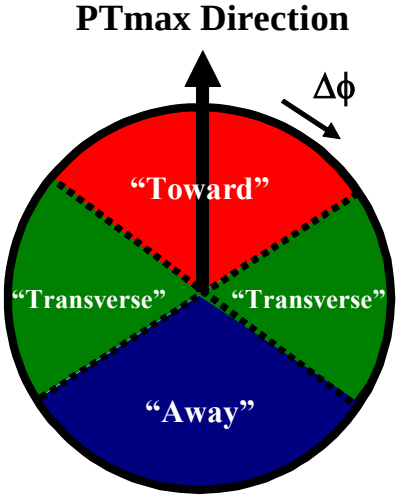
- **Just before the shutdown of the Tevatron CDF has collected more than 10M "min-bias" events at several center-of-mass energies!**

300 GeV 12.1M MB Events

900 GeV 54.3M MB Events

Jet Observables

➡ **"Toward" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "toward" region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



➡ **"Toward" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "toward" region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **"Away" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "away" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

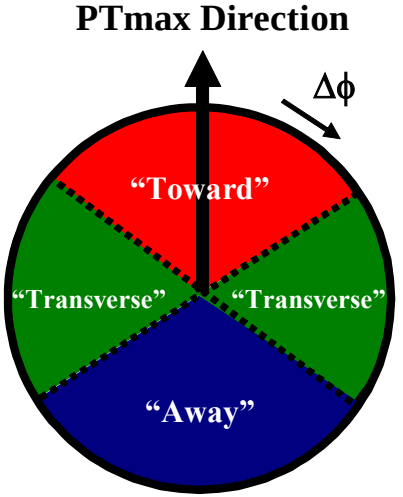
➡ **"Away" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "away" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

$\eta_{cut} = 0.8$

UE Observables

➡ **"Transverse" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **"Transverse" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



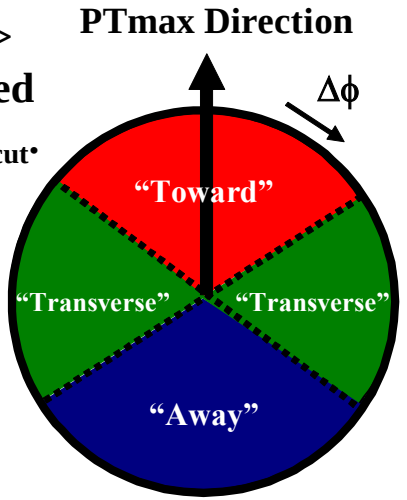
➡ **"Transverse" Charged Particle Average P_T:** Event-by-event $\langle p_T \rangle$ = PTsum/Nchg for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, averaged over all events with at least one particle in the "transverse" region with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **Zero "Transverse" Charged Particles:** If there are no charged particles in the "transverse" region then Nchg and PTsum are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$. However, if there are no charged particles in the "transverse" region then the event is not used in constructing the "transverse" average p_T.

$\eta_{cut} = 0.8$

Observables

➡ **Total Number of Charged Particles:** Number of charged particles (p_T > 0.5 GeV/c, $|\eta| < 0.8$, including PTmax) as defined by the leading charged particle, PTmax, with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



➡ **Overall "Associated" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$, not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **Overall "Associated" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$, not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

$\eta_{cut} = 0.8$

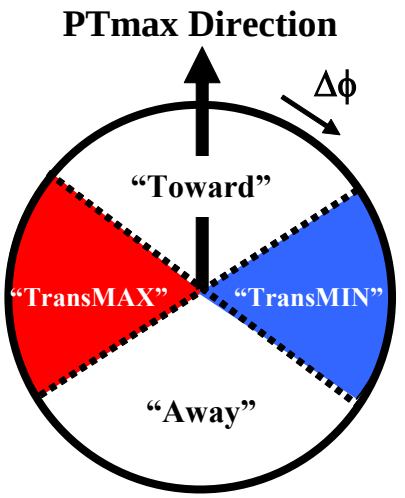
Note: The overall "associated" density is equal to the average of the "Towards", "Away", and "Transverse" densities.

Overall "Associated" Density = ("Towards" Density + "Away" Density + "Transverse" Density)/3

UE Observables

➡ **"transMAX" and "transMIN" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **"transMAX" and "transMIN" Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



$\eta_{cut} = 0.8$

Overall "Transverse" = "transMAX" + "transMIN"

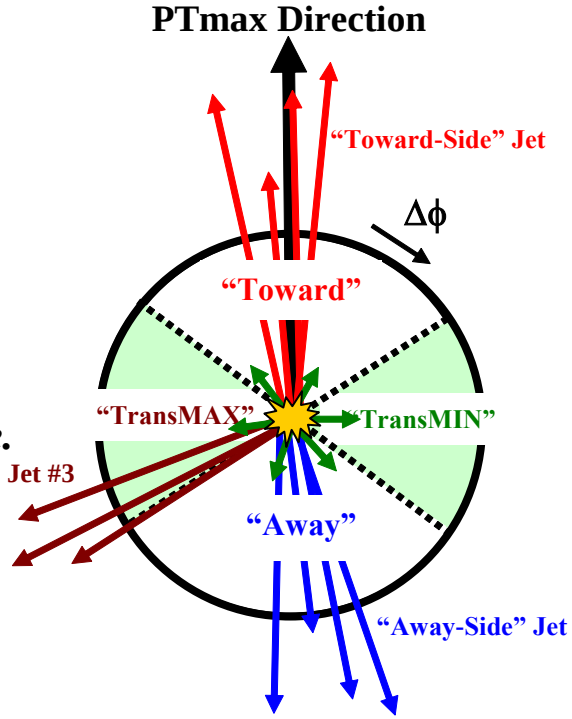
Note: The overall "transverse" density is equal to the average of the "transMAX" and "TransMIN" densities. The "TransDIF" Density is the "transMAX" Density minus the "transMIN" Density

"Transverse" Density = "transAVE" Density = ("transMAX" Density + "transMIN" Density)/2

"TransDIF" Density = "transMAX" Density - "transMIN" Density

"transMIN" & "transDIF"

- The "toward" region contains the leading "jet", while the "away" region, on the average, contains the "away-side" "jet". The "transverse" region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the "underlying event". For events with large initial or final-state radiation the "transMAX" region defined contains the third jet while both the "transMAX" and "transMIN" regions receive contributions from the MPI and beam-beam remnants. Thus, the "transMIN" region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the "transMAX" minus the "transMIN" (*i.e.* "transDIF") is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).



"TransMIN" density more sensitive to MPI & BBR.

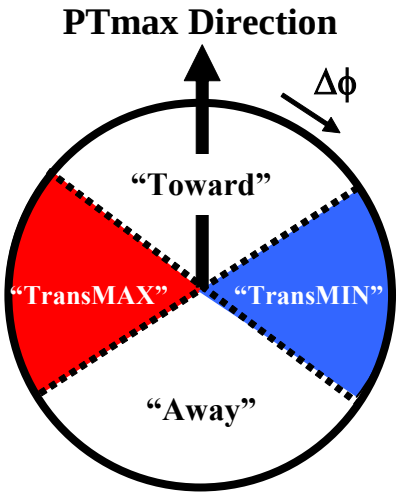
"TransDIF" density more sensitive to ISR & FSR.

0 ≤ "TransDIF" ≤ 2×"TransAVE"

"TransDIF" = "TransAVE" if "TransMIX" = 3×"TransMIN"

PTmax UE Data

➡ **CDF PTmax UE Analysis: "Towards", "Away", "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV (R. Field analysis).**



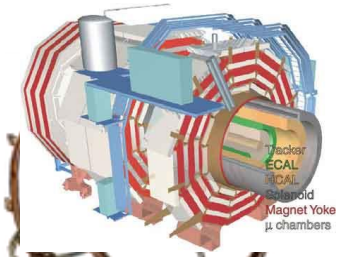
➡ **CMS PTmax UE Analysis: "Towards", "Away", "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in proton-proton collisions at 900 GeV and 7 TeV (Mohammed Zakaria Ph.D. Thesis, CMS PAS FSQ-12-020).**

➡ **CMS UE Tunes: PYTHIA 6.4 Tune Z1 (CTEQ5L) and PYTHIA 6.4 Tune Z2* (CTEQ6L) and PYTHIA 8 Tune 4C* (CTEQ6L). All 3 were tuned to the CMS leading chgjet "transAVE" UE data at 900 GeV and 7 TeV.**

Similar to Tune 4C by Corke and Sjöstrand!

MB & UE Common Plots

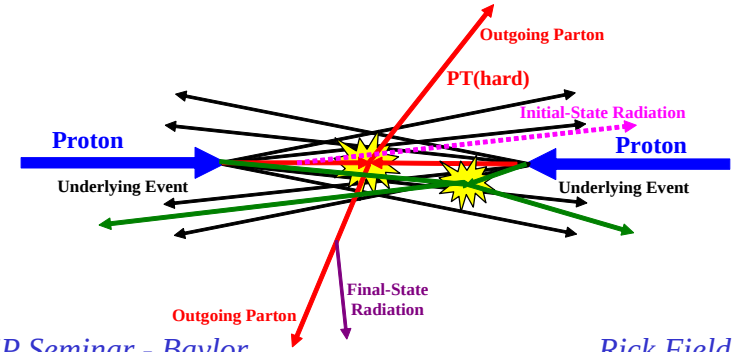
Quantum Chromo-Dynamics

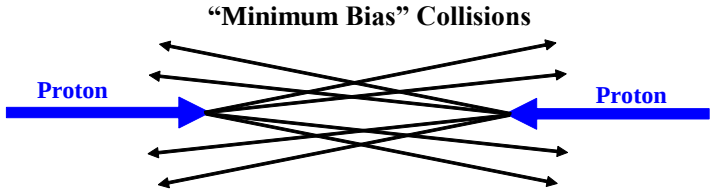


CMS

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.**





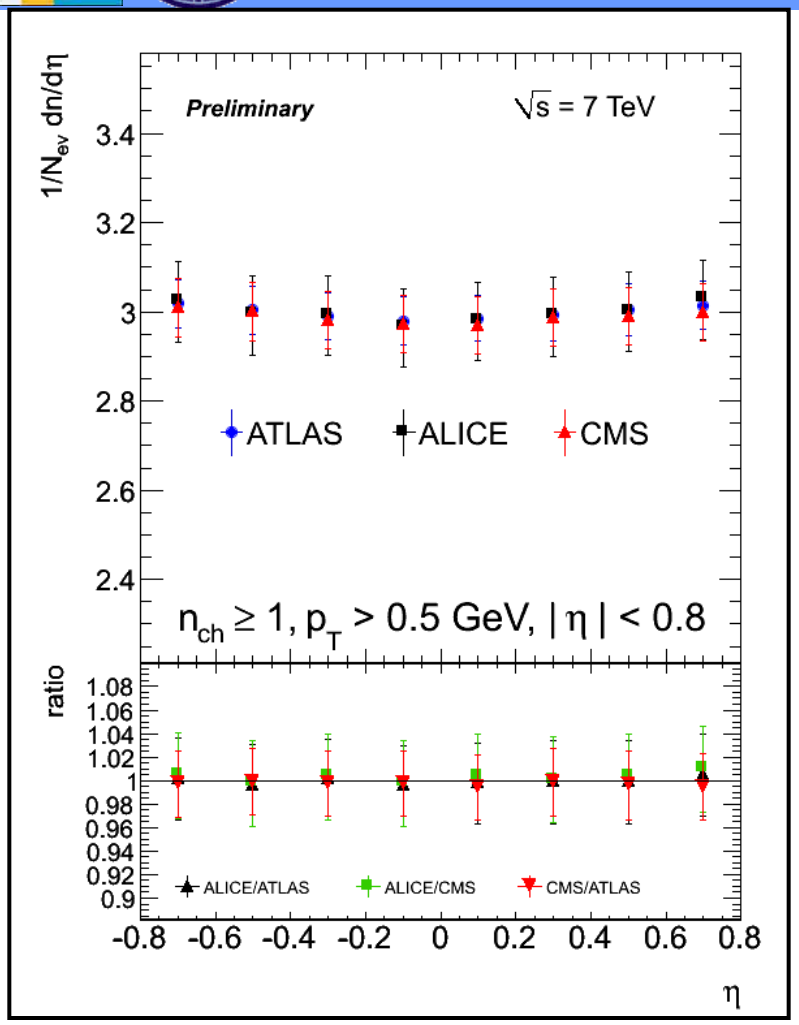
CMS Common Plots

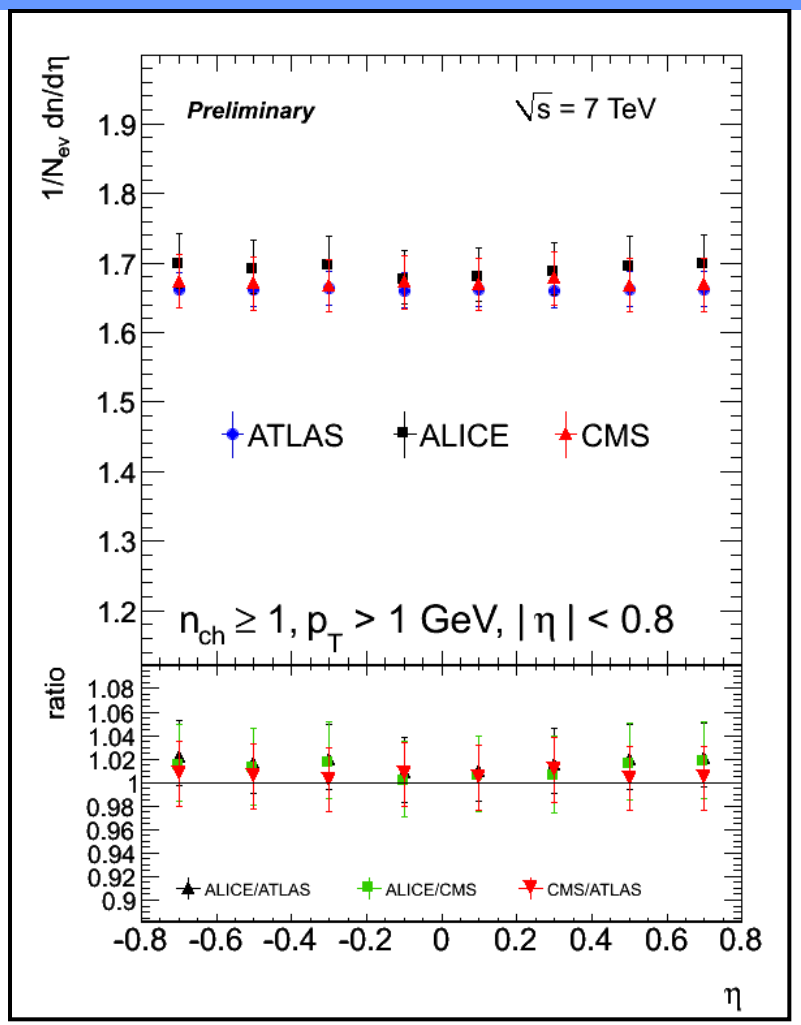
Observable	900 GeV	7 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$	Do	Done
$\|\eta\| < 0.8$ $p_T >$ /c & 1.0 C	QC	0-024
MB2: dN_{chg}/dp_T		talled
MB		
$\|\eta\| < 0.8$ p		
MB4: $\langle p_T \rangle$ ver		cs
$\|\eta\| < 0.8$ $p_T >$		
UE1: Transverse Nchg defined by the leading particle, PTmax		one
$\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 G	FSQ	F 2-020

Note that all the "common plots" require at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$!
This done so that the plots are less sensitive to SD and DD.

Direct charged partic (including leptons) corrected to the particle level with o corrections for SD or DD.

MB Common Plots 7 TeV





Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

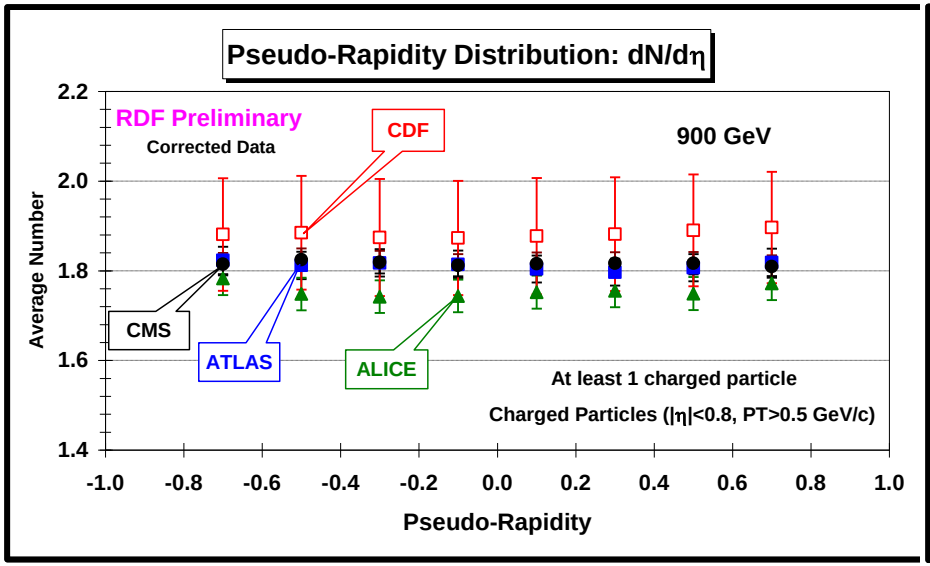
CDF Common Plots

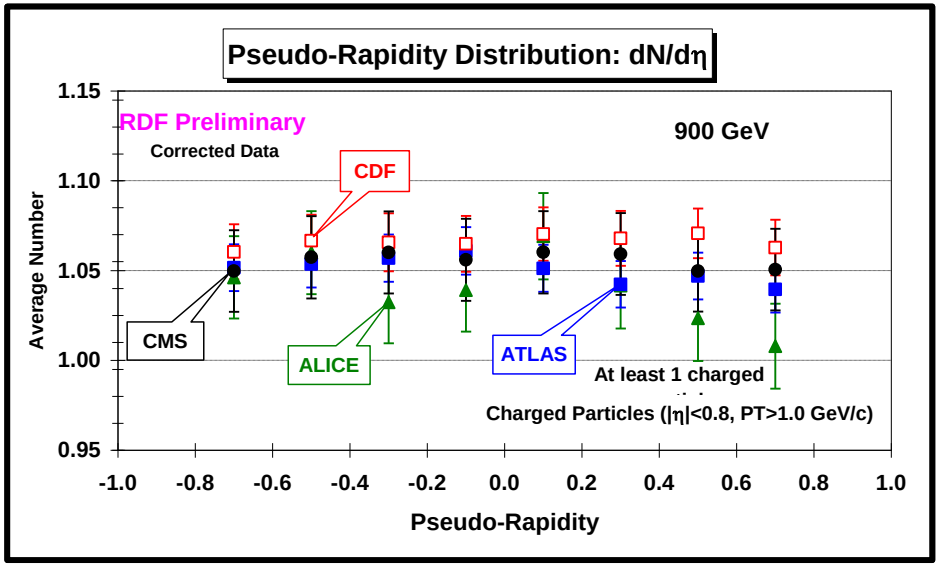
Observable	300 GeV	900 GeV	1.96 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T > 0.5$ Gev/c & 1.0 GeV/c	Done	Done	Done
MB2: dN_{chg}/dp_T $N_{chg} \geq 1$ $\|\eta\| < 0.8$	In progress	In progress	In progress
MB3: Multiplicity Distribution $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
MB4: $<p_T>$ versus Nchg $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done

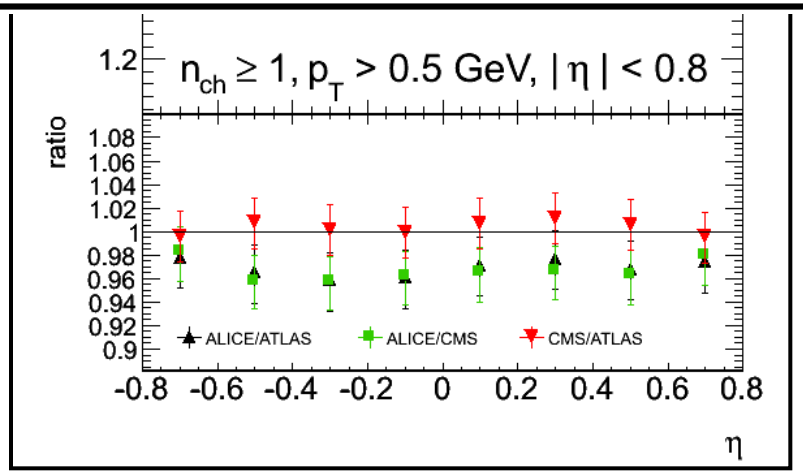
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

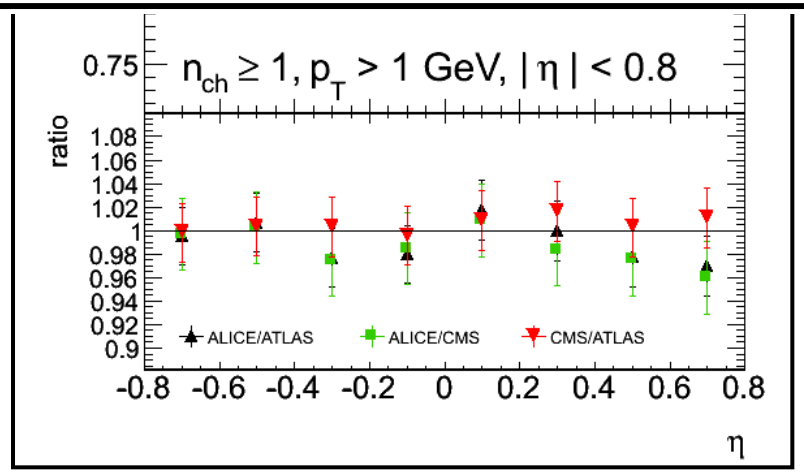
R. Field, C. Group, and D. Wilson.

MB Common Plots 900 GeV



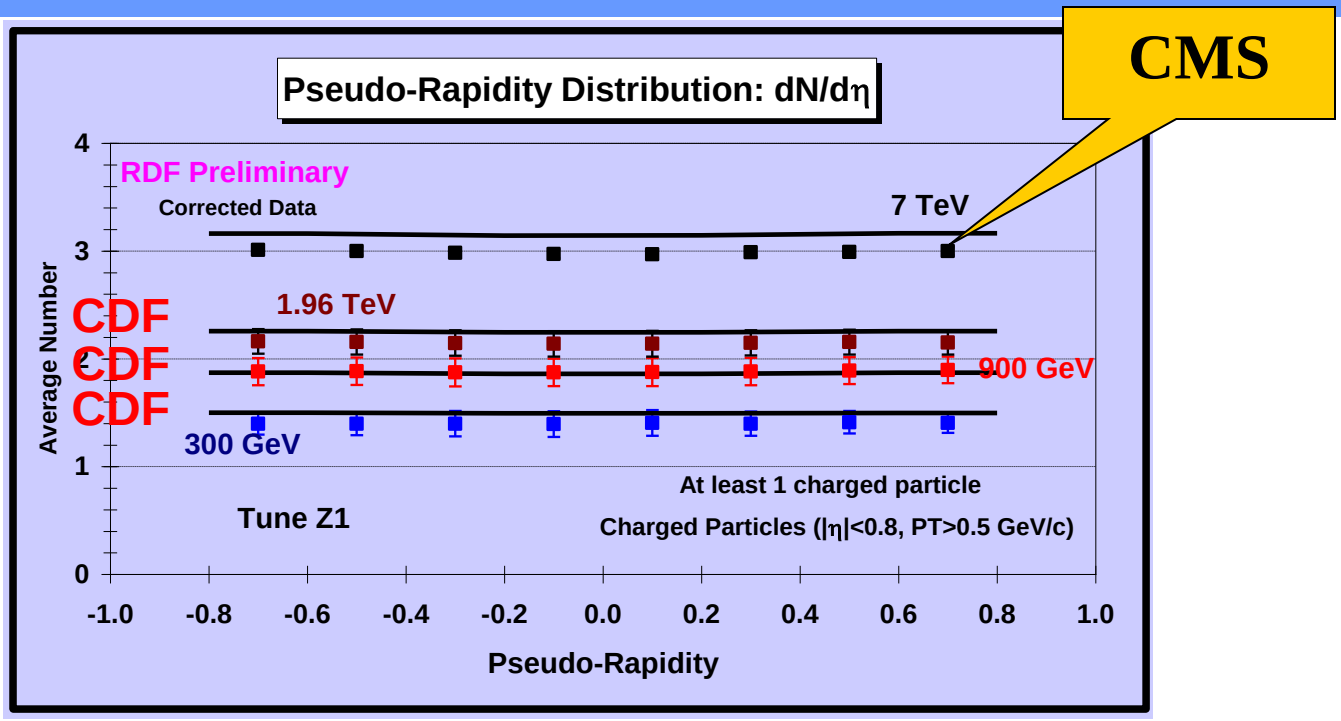






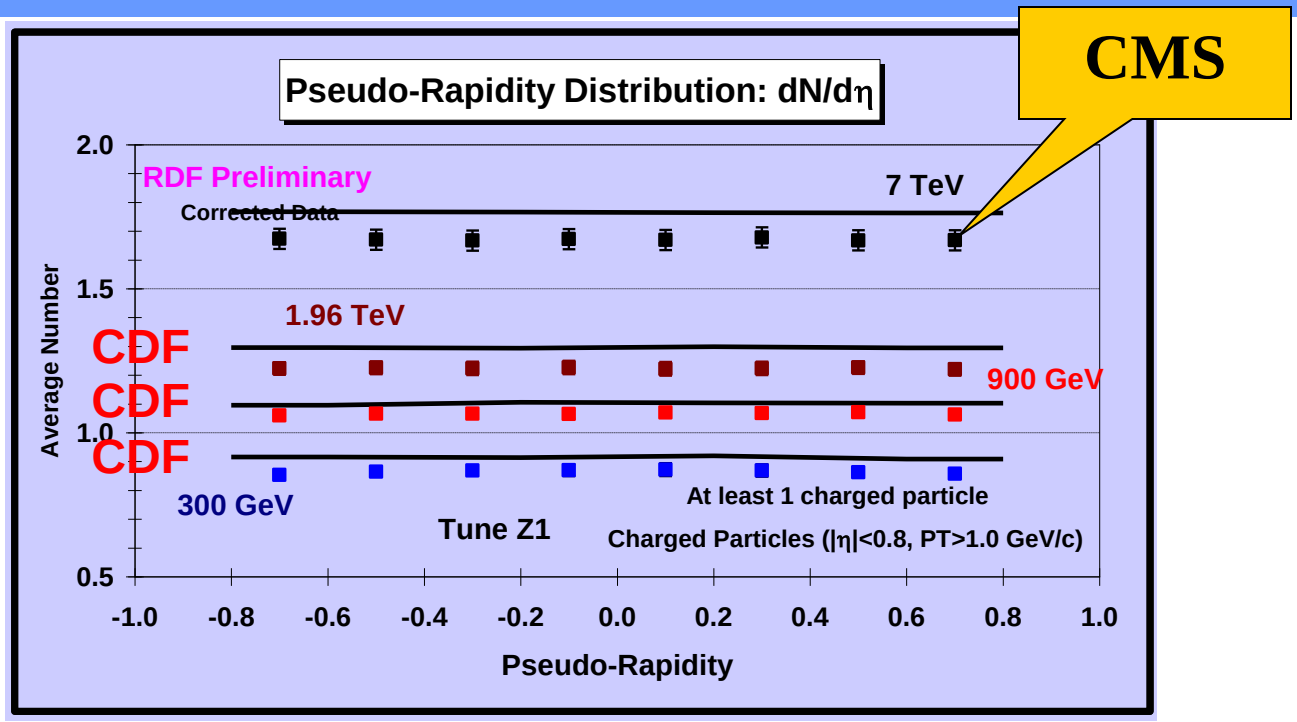
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

New CDF MB Data



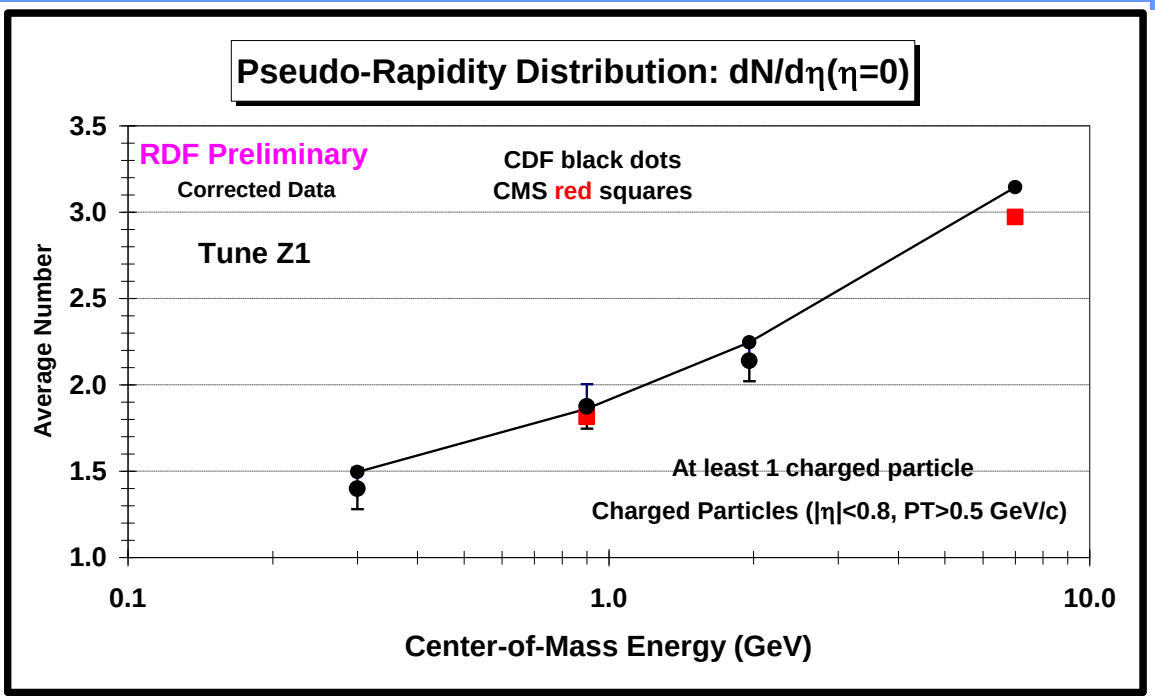
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with $p_T > 0.5$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



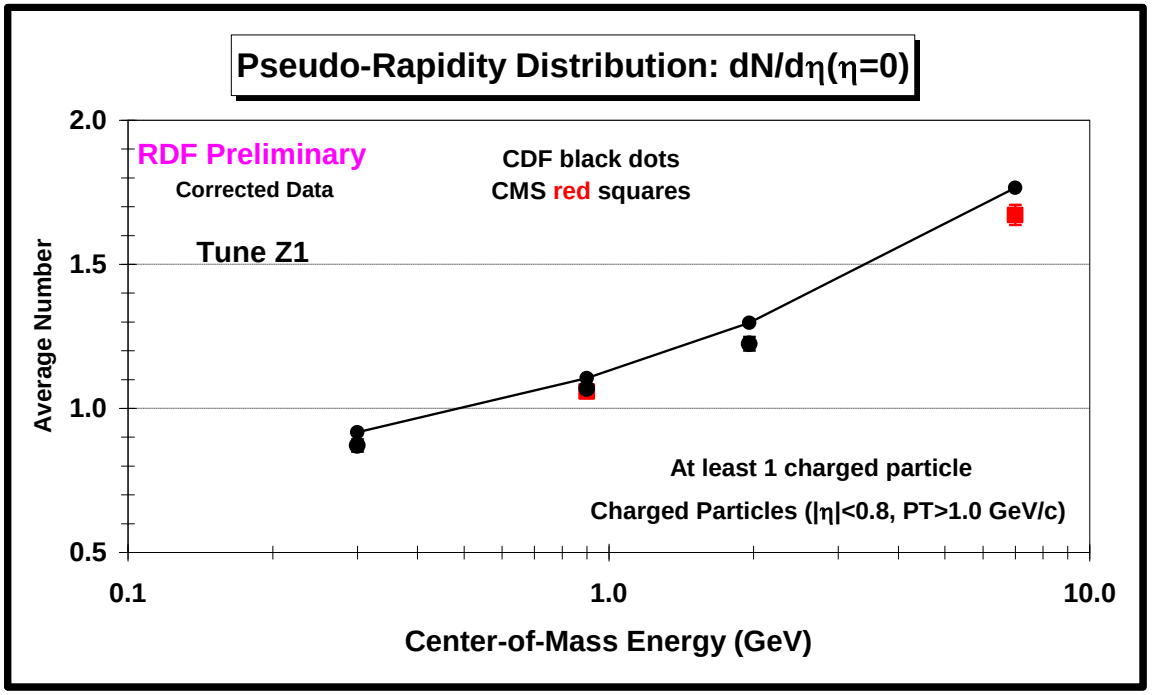
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with $p_T > 1.0$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 1.0$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Energy Dependence dN/dη



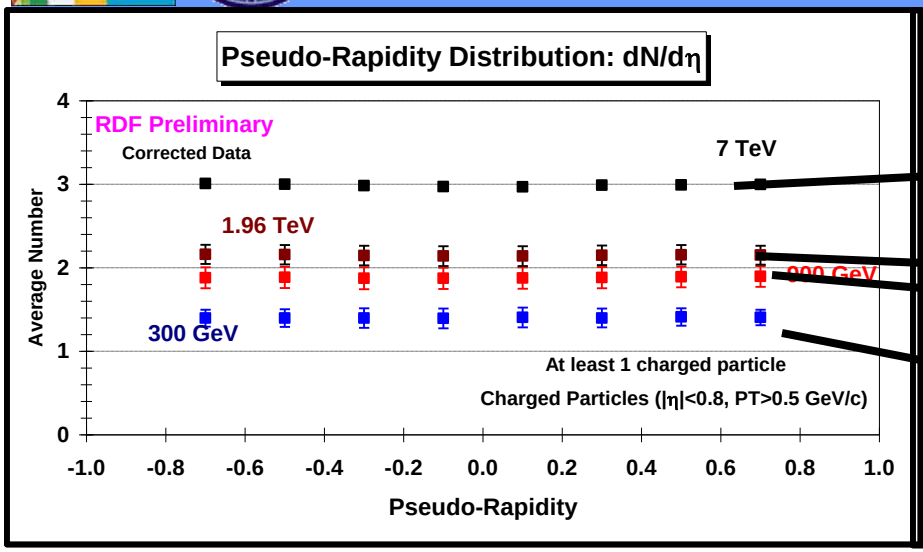
➡ **CMS data at 7 TeV and 900 GeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on dN/dη at η = 0 with p_T > 0.5 GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 0.5 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

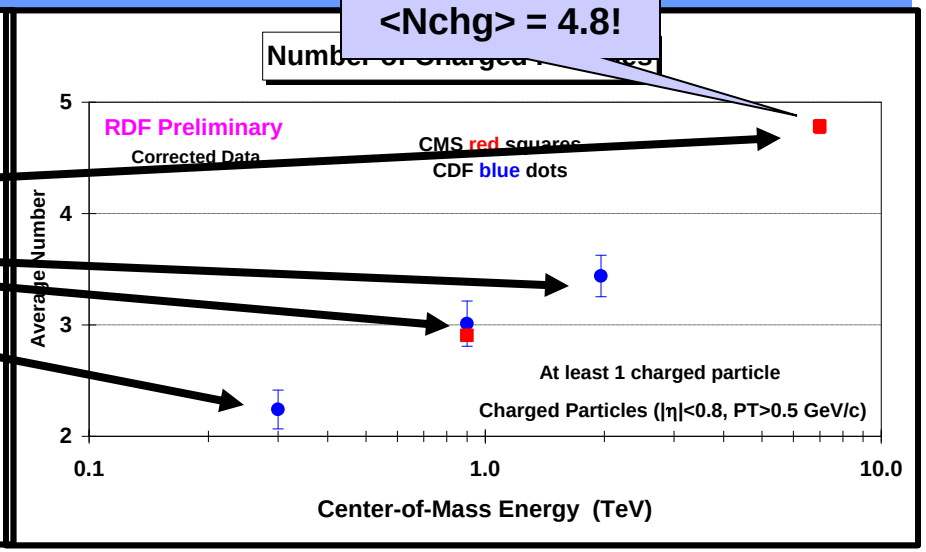
Energy Dependence dN/dη



➡ **CMS data at 7 TeV and 900 GeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on dN/dη at η = 0 with p_T > 1.0 GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 1.0 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Total Number of Charged Particles





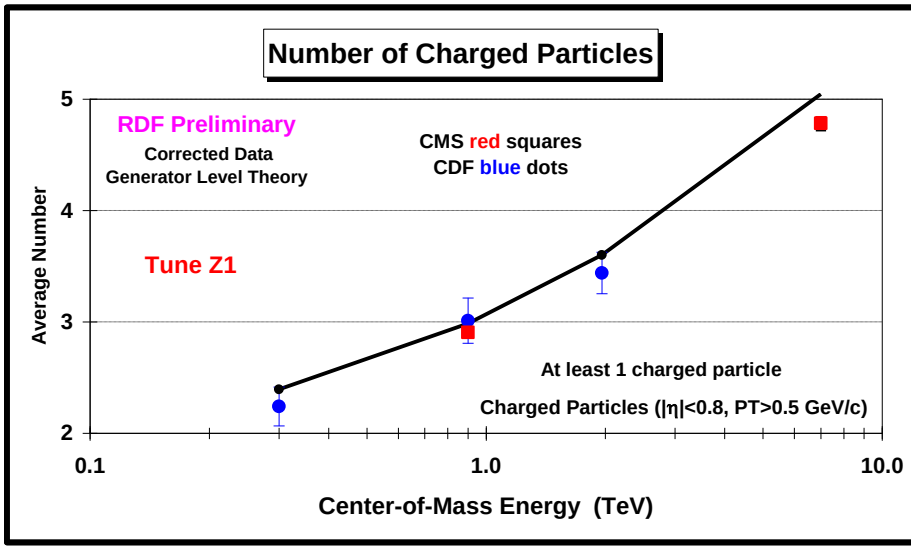
➡ **CDF and CMS data on the pseudo-rapidity distribution, dN/dη, for charged with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$.**

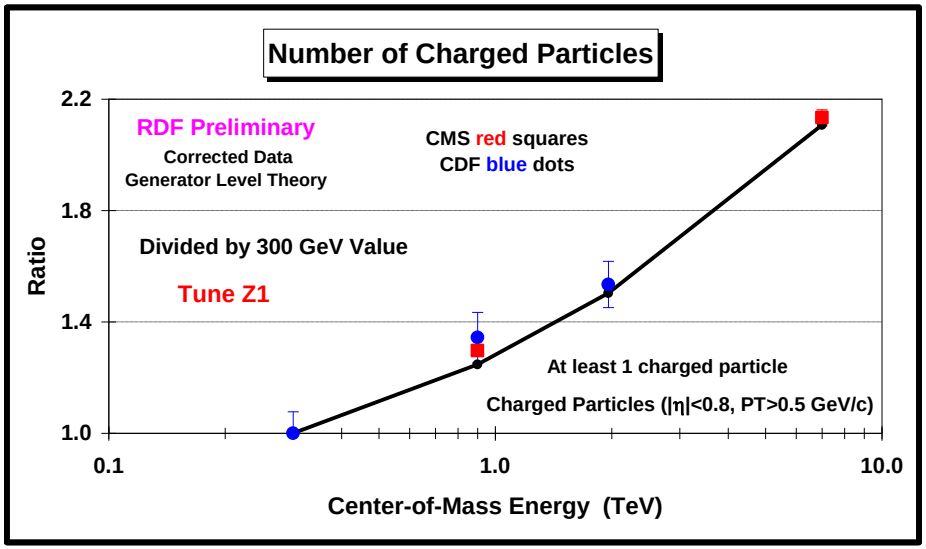
Ecm	Nchg	error	NchgDen	error
300 GeV	2.241	0.175	0.223	0.017
900 GeV	3.012	0.203	0.300	0.020
1.96 TeV	3.439	0.186	0.342	0.019
7 TeV	4.782	0.063	0.476	0.006

➡ **CDF and CMS data total number of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

$$N_{chg} = \int_{-0.8}^{0.8} \frac{dN}{d\eta} d\eta$$

Total Number of Charged Particles



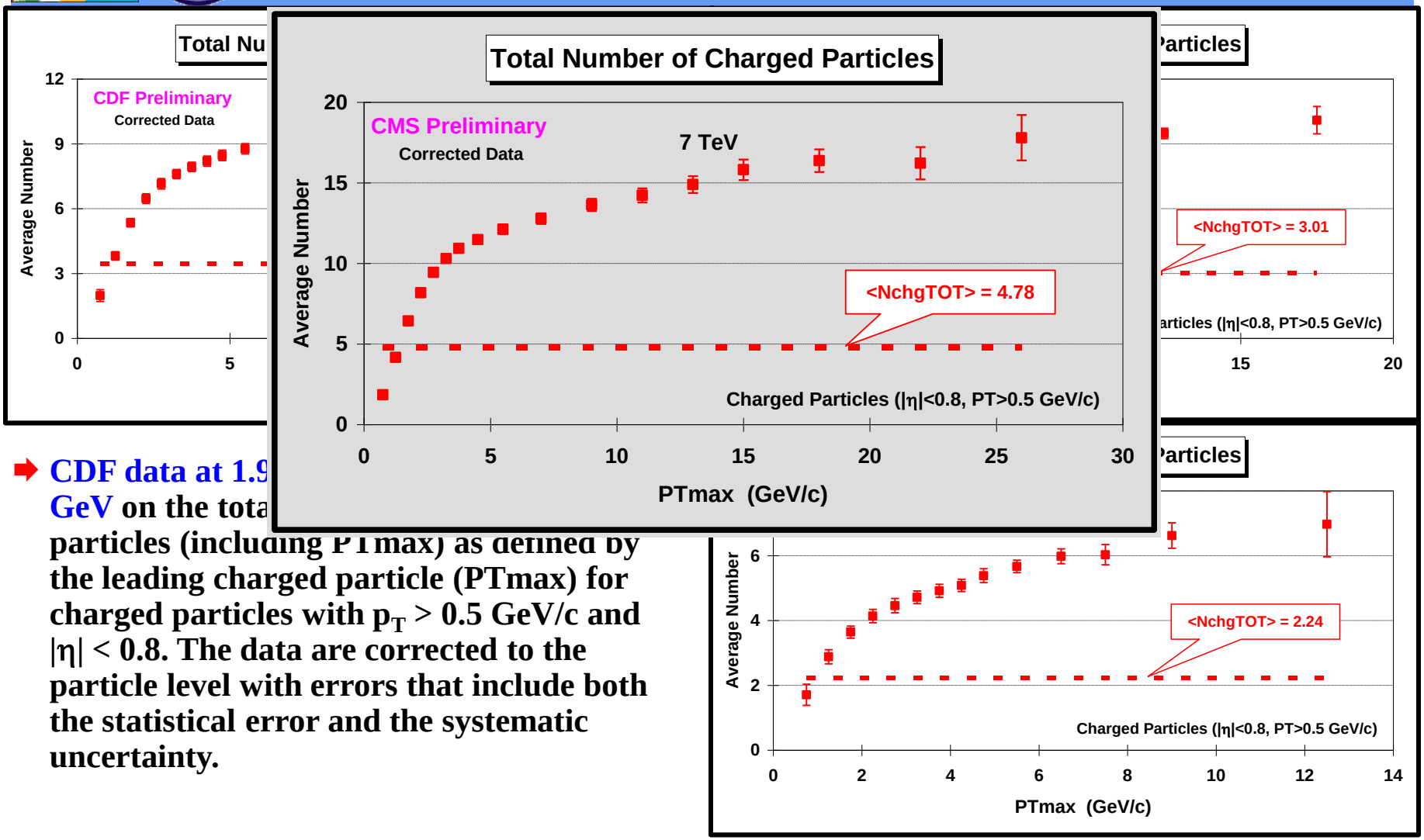


➡ **CDF and CMS data total number of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **CDF and CMS data ratio of the total number of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are divided by the value at 300 GeV.**

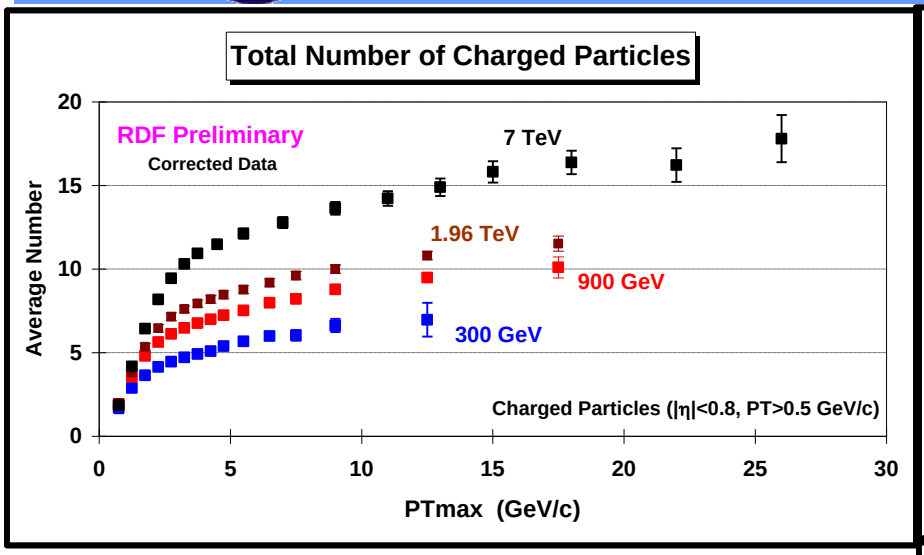
The data are compared with PYTHIA 6.4 Tune Z1

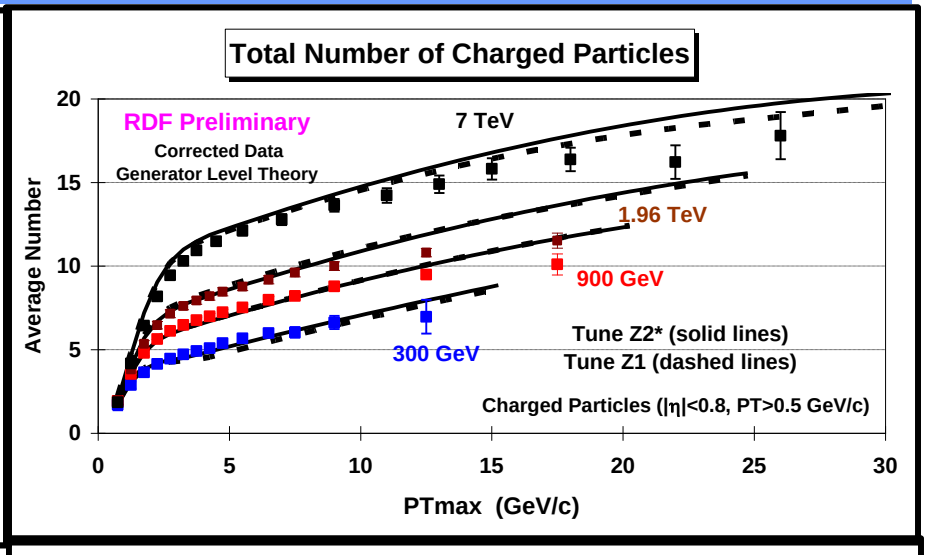
Total Number of Charged Particles



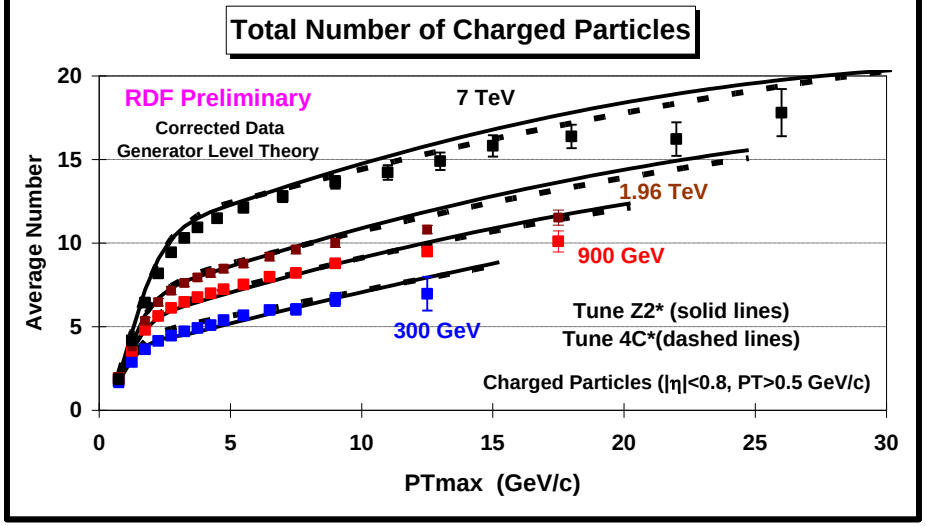
➡ **CDF data at 1.9 GeV on the tota particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Total Number of Charged Particles

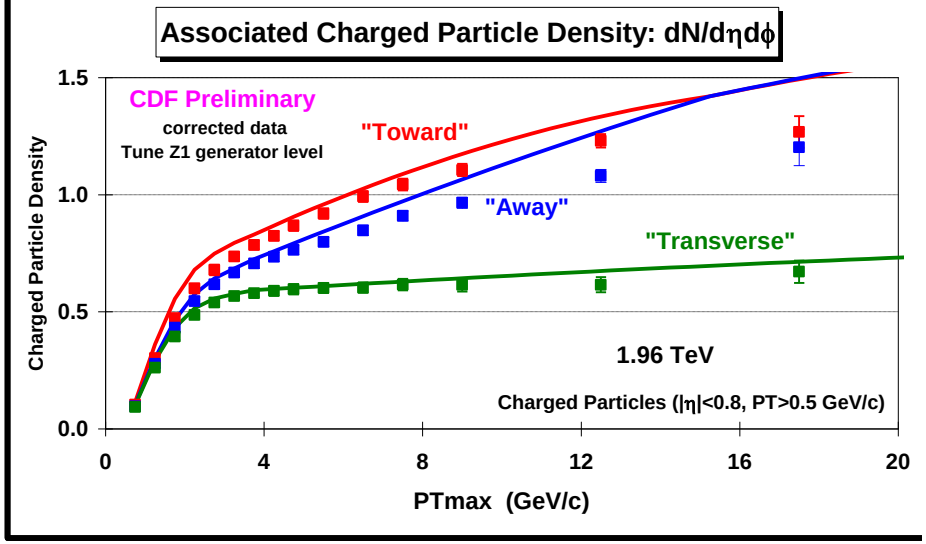


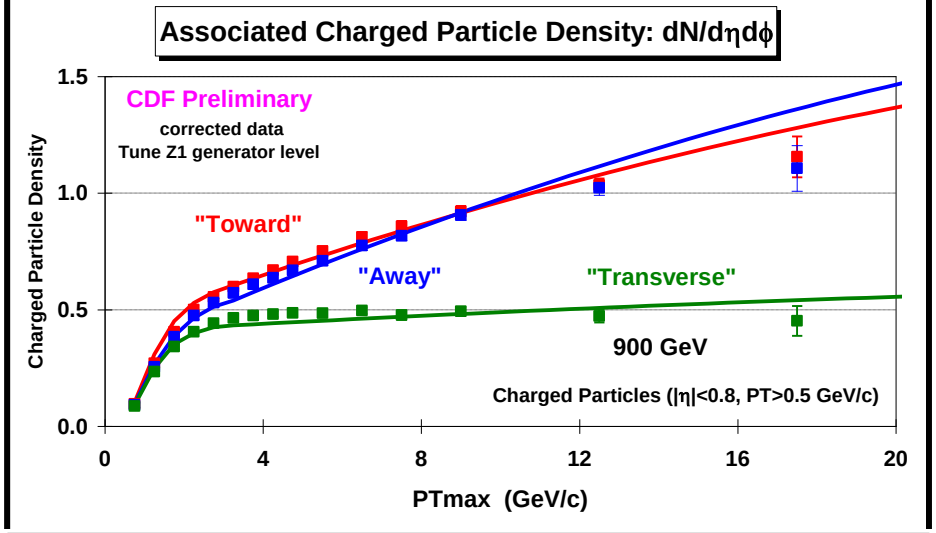


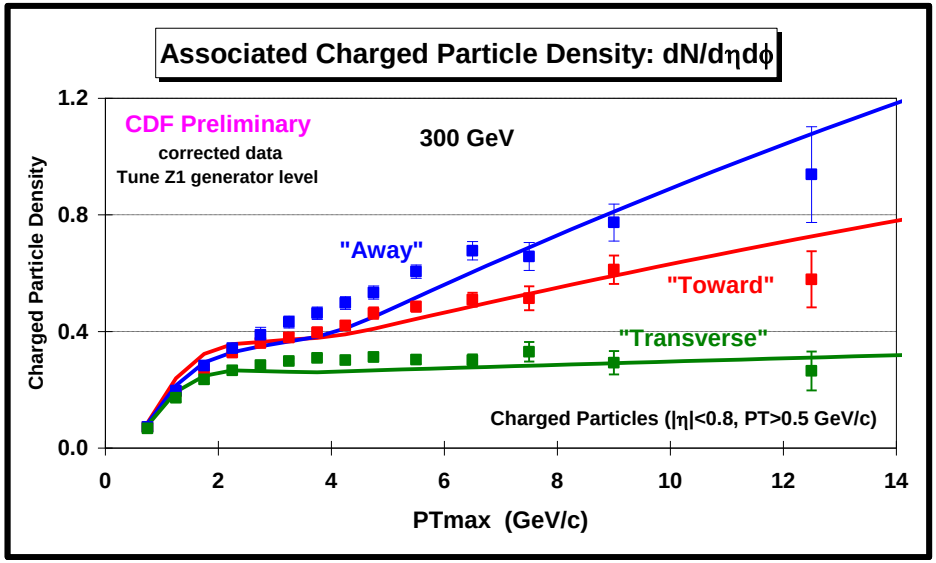
➡ **CMS and CDF data on the total number of charged particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"Associated" Charged Particle Density



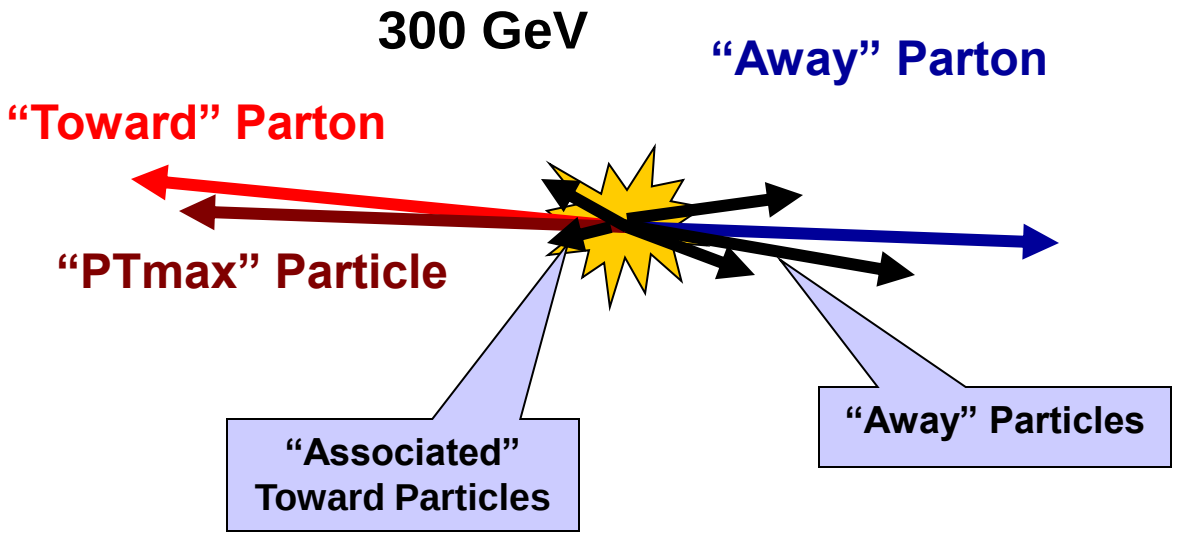




➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

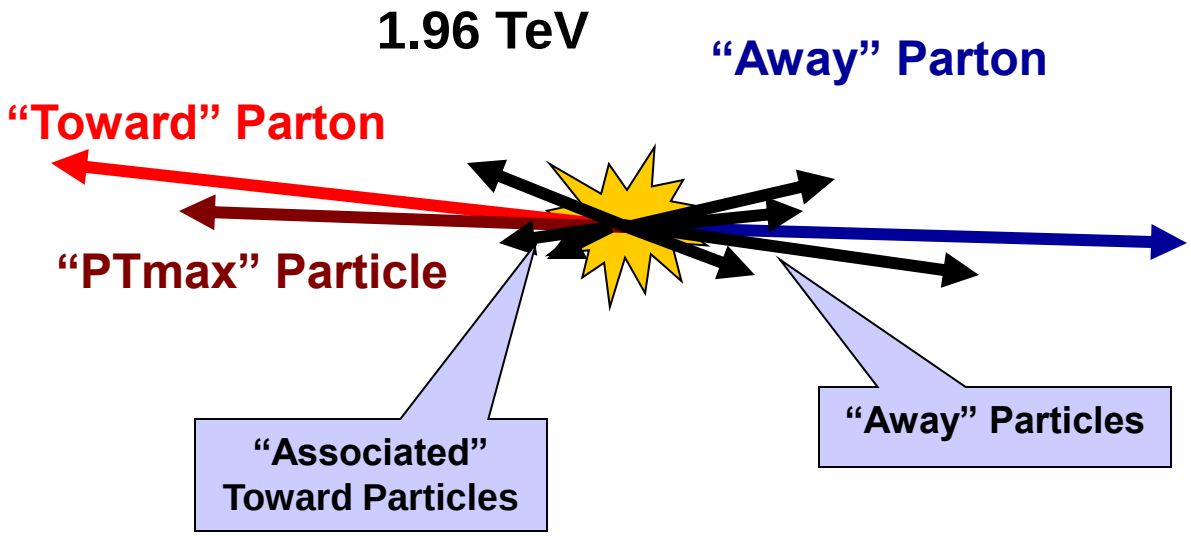
The data are compared with PYTHIA Tune Z1.

"Toward" Associated Density



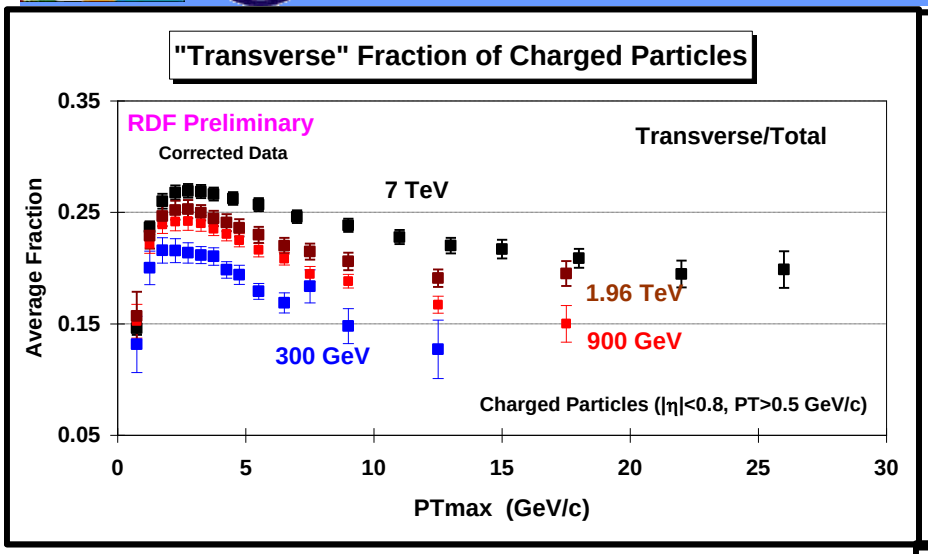
- **At low center-of-mass energies PTmax carries almost all the momentum of the "toward" parton (*i.e.* z ≈ 1) leaving very little momentum for the other particles in the "jet".**

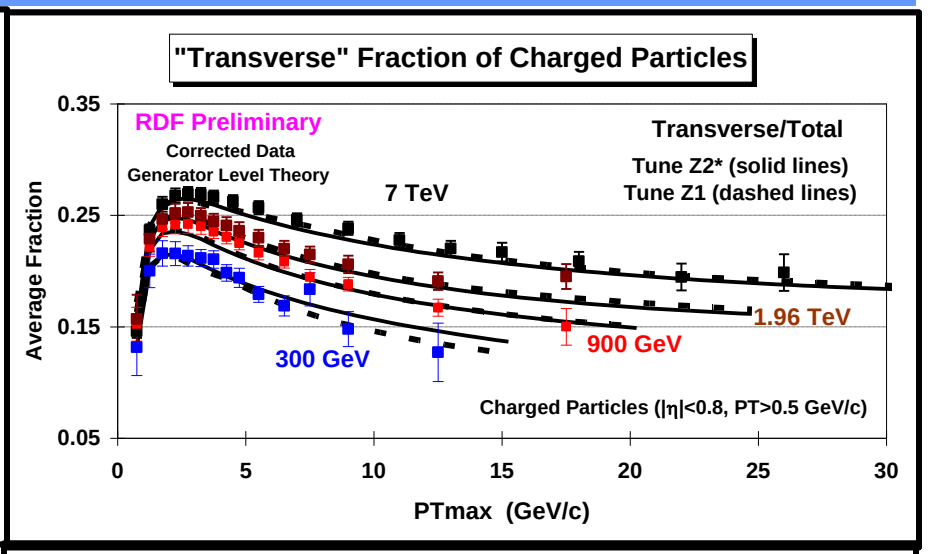
"Toward" Associated Density



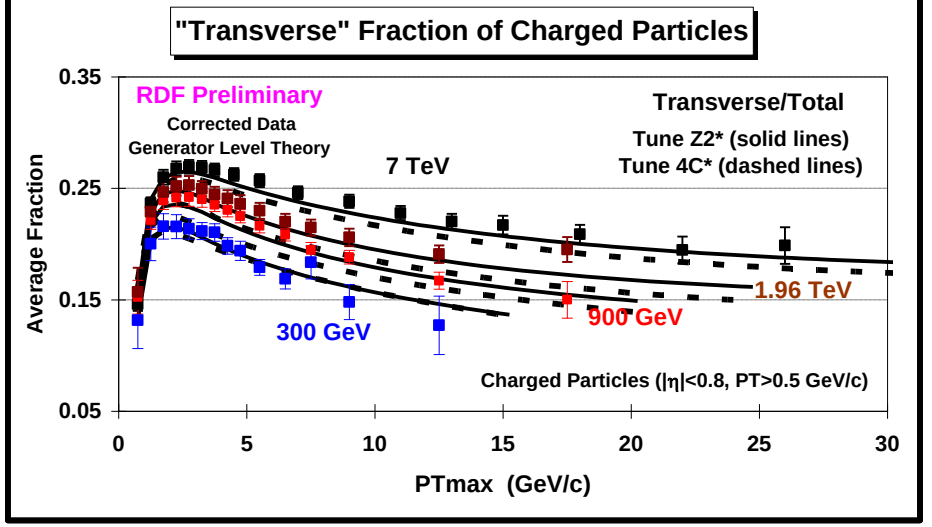
- **At higher center-of-mass energies the same PTmax carries less of the momentum of the "toward" parton (*i.e.* z < 1) leaving more momentum for the other particles in the "jet".**

"Transverse" Charge Particle Fraction

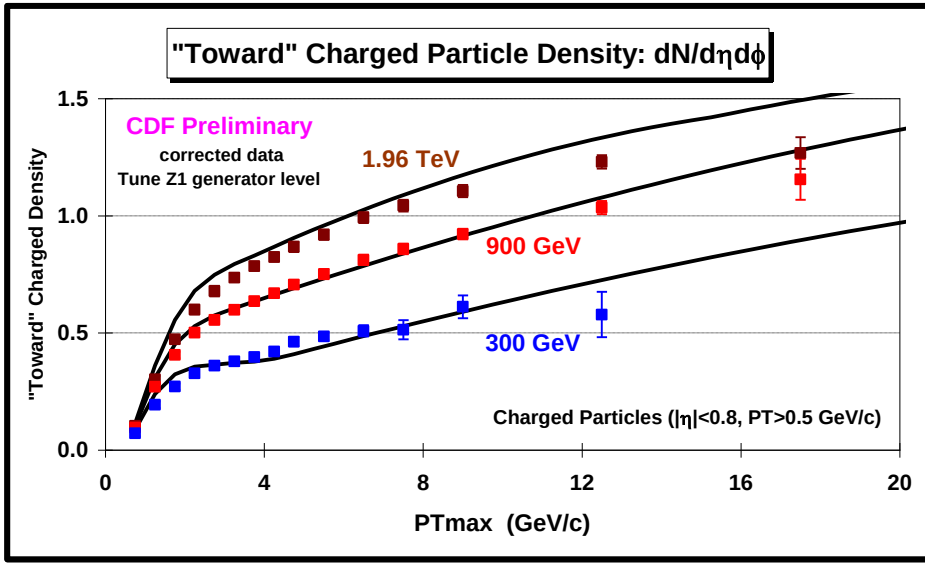


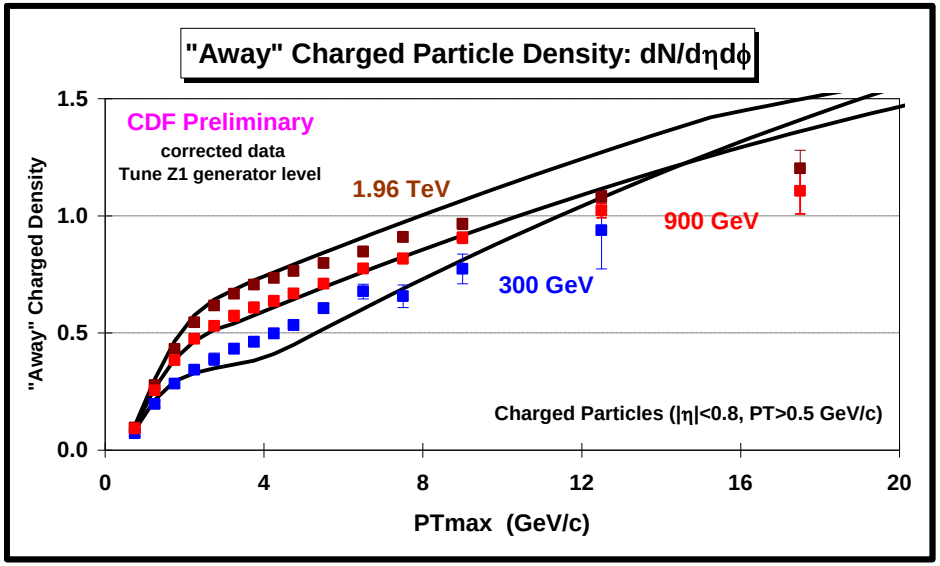


- **CMS and CDF data on the fraction of charged particle in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The plot shows the "transverse" Nchg divided by the total Nchg. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



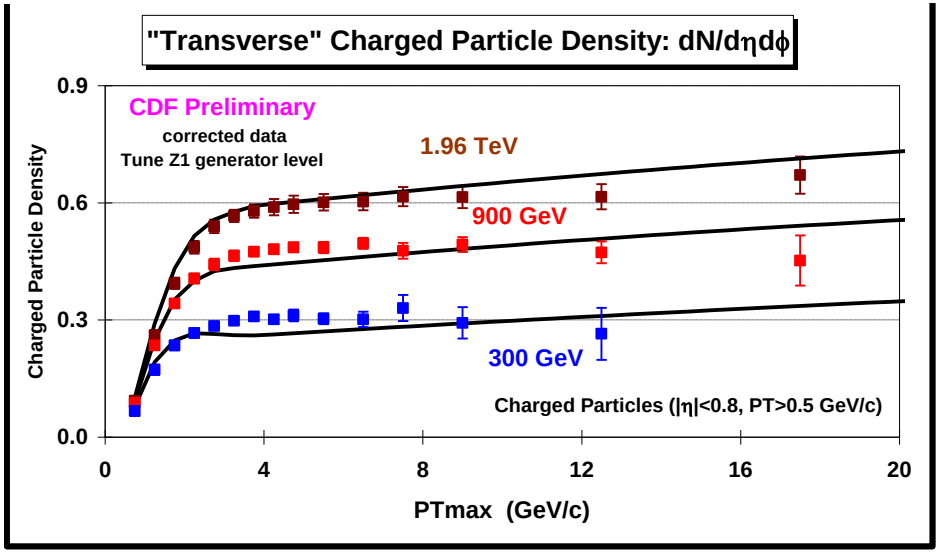
"Associated" Charged Particle Density



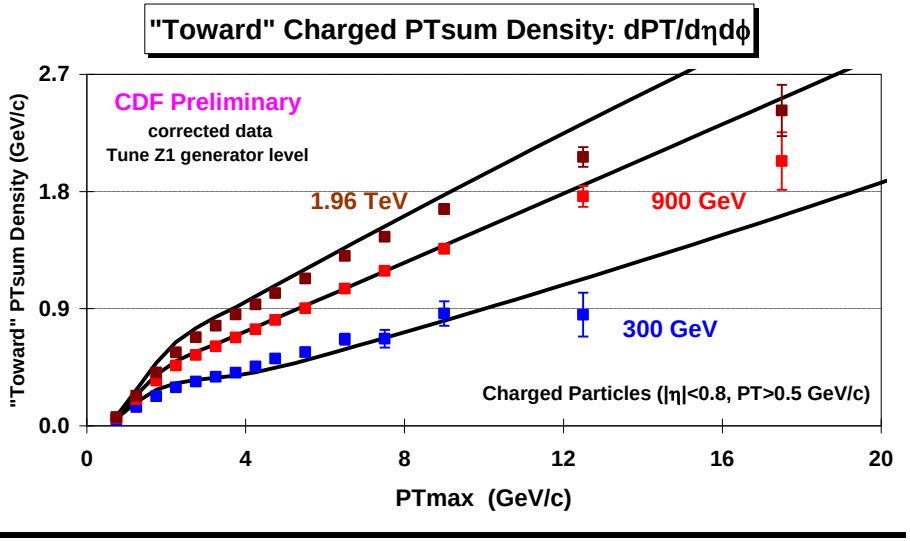


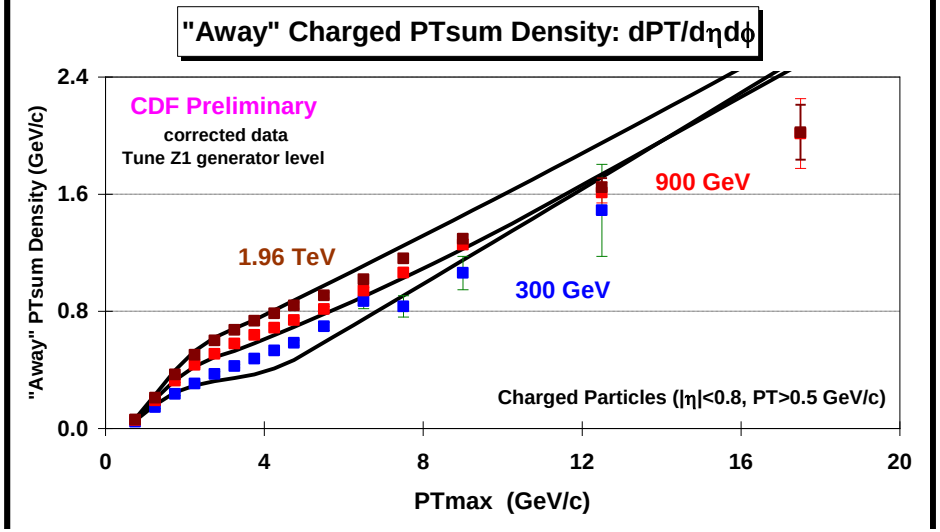
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

The data are compared with PYTHIA Tune Z1.



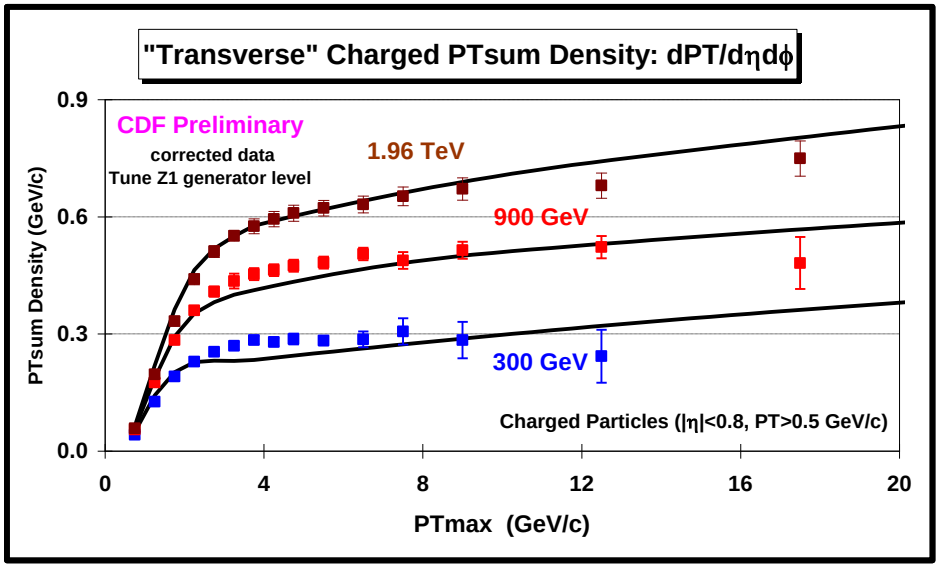
"Associated" Charged PTsum Density



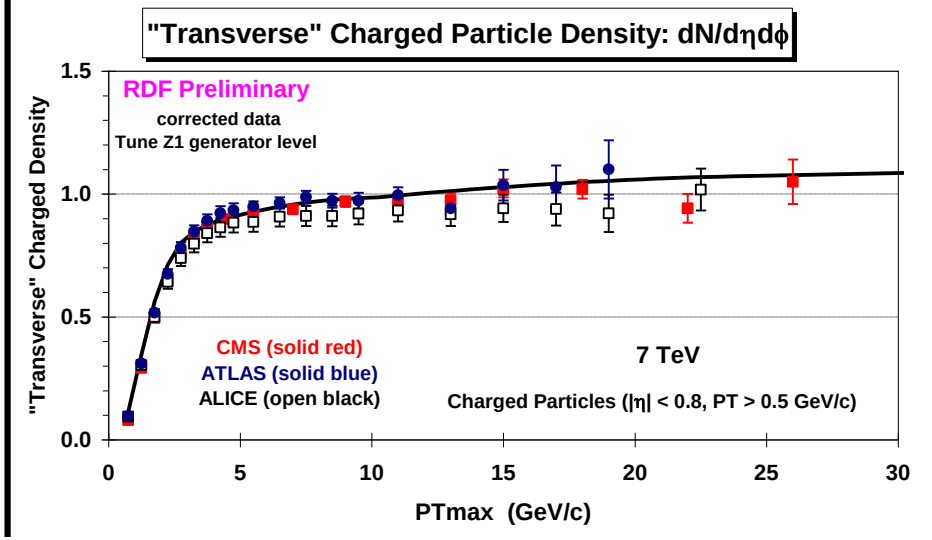


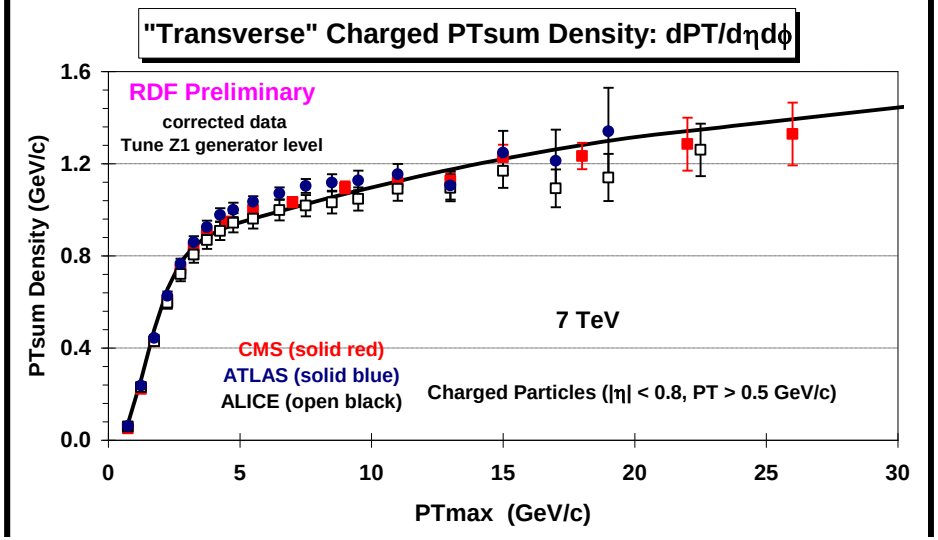
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged PTsum density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

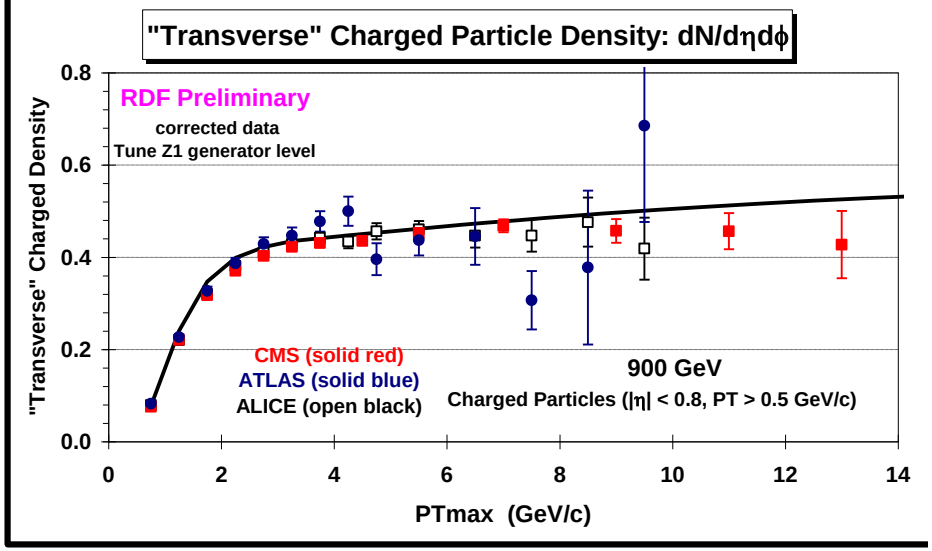
The data are compared with PYTHIA Tune Z1.

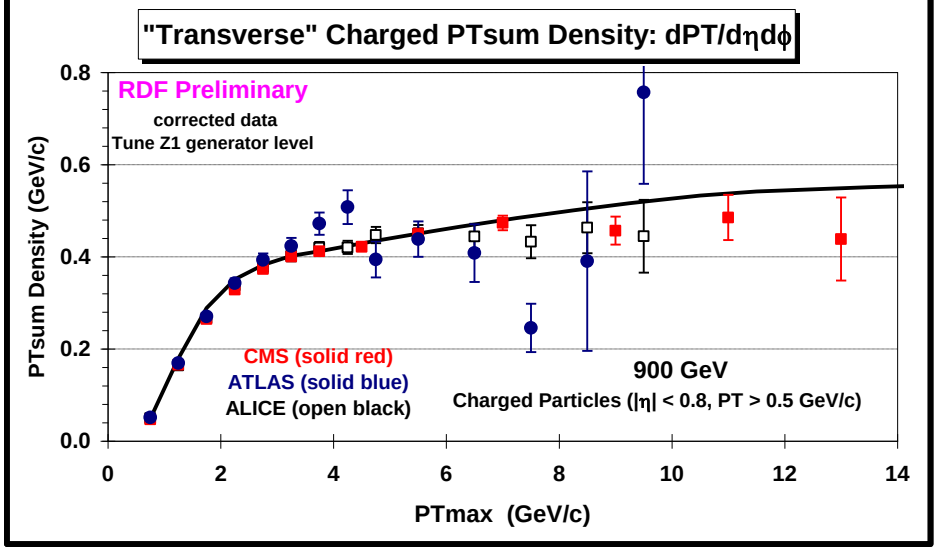


UE Common Plots

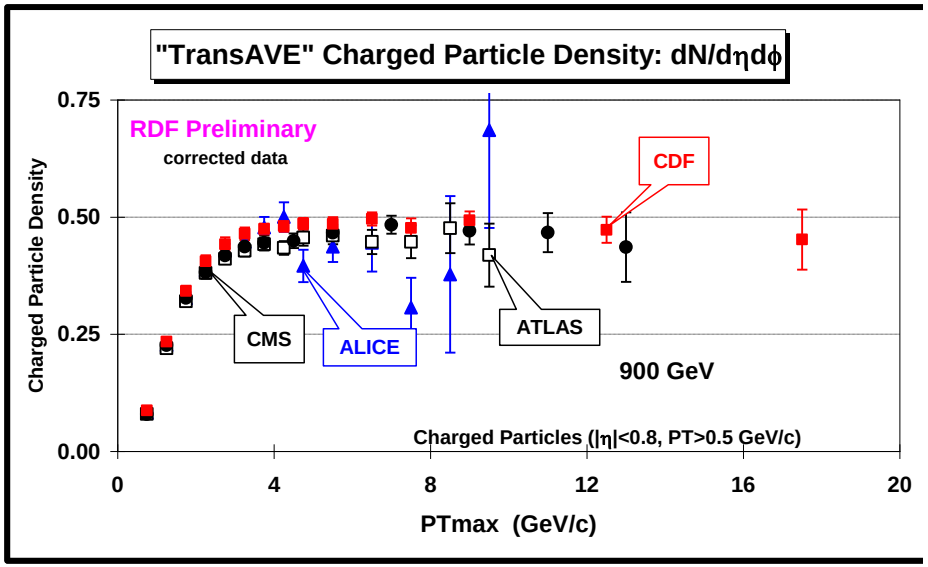


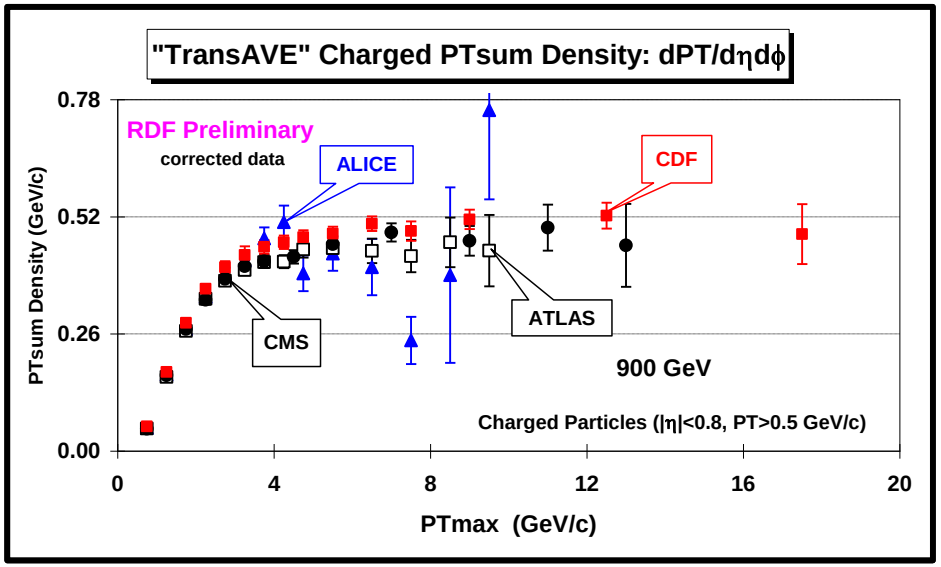






CDF versus LHC

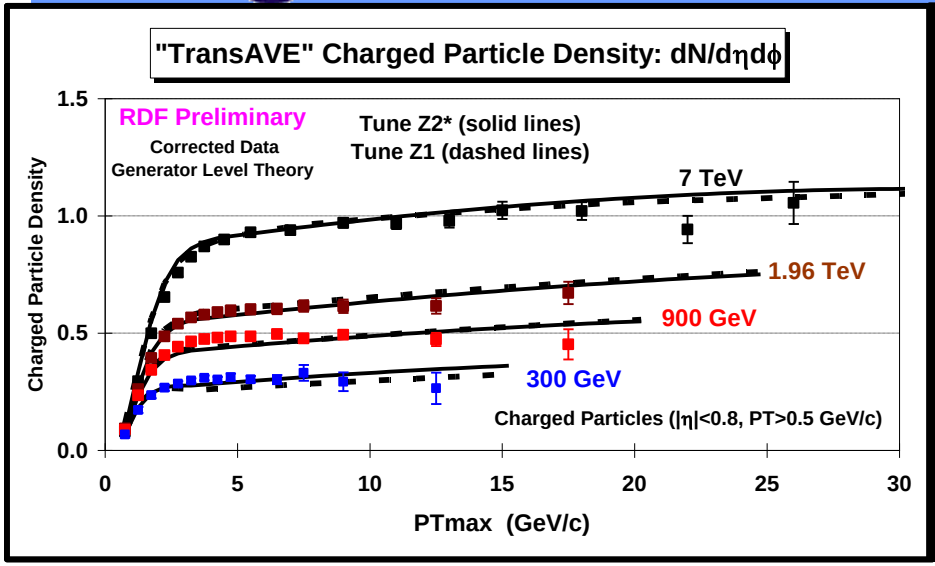


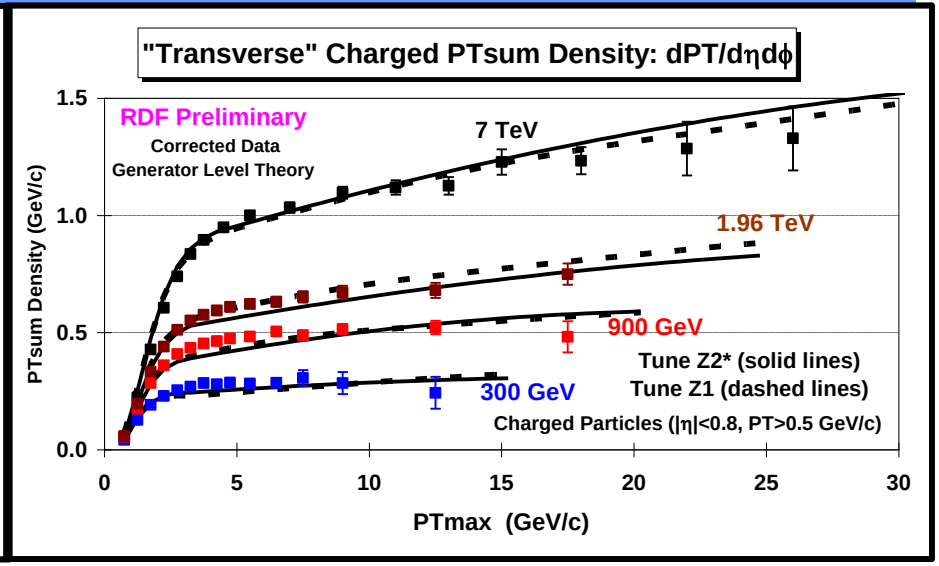


➡ **CDF and CMS data at 900 GeV/c on the charged particle density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **CDF and CMS data at 900 GeV/c on the charged PTsum density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

"TransAVE" Density

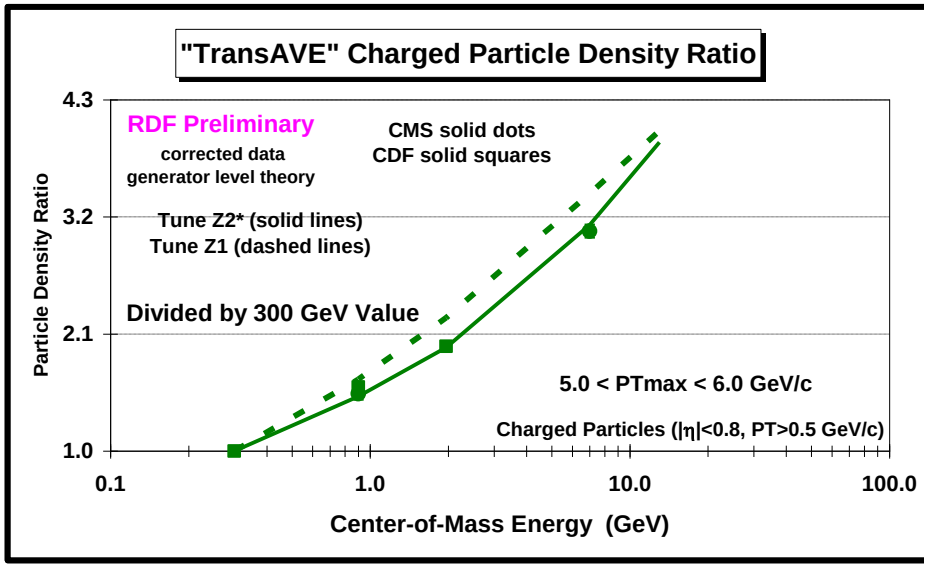


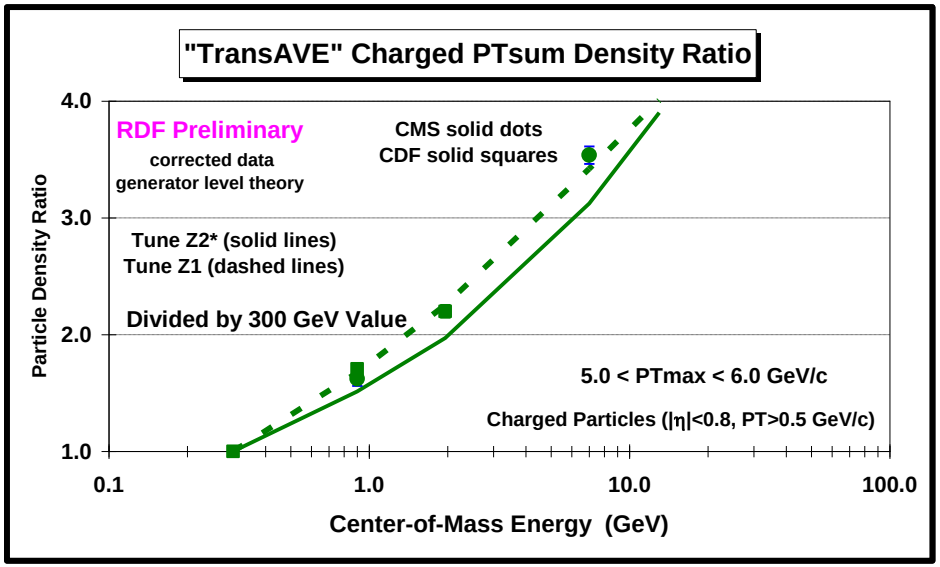


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

"TransAVE" vs E_{cm}



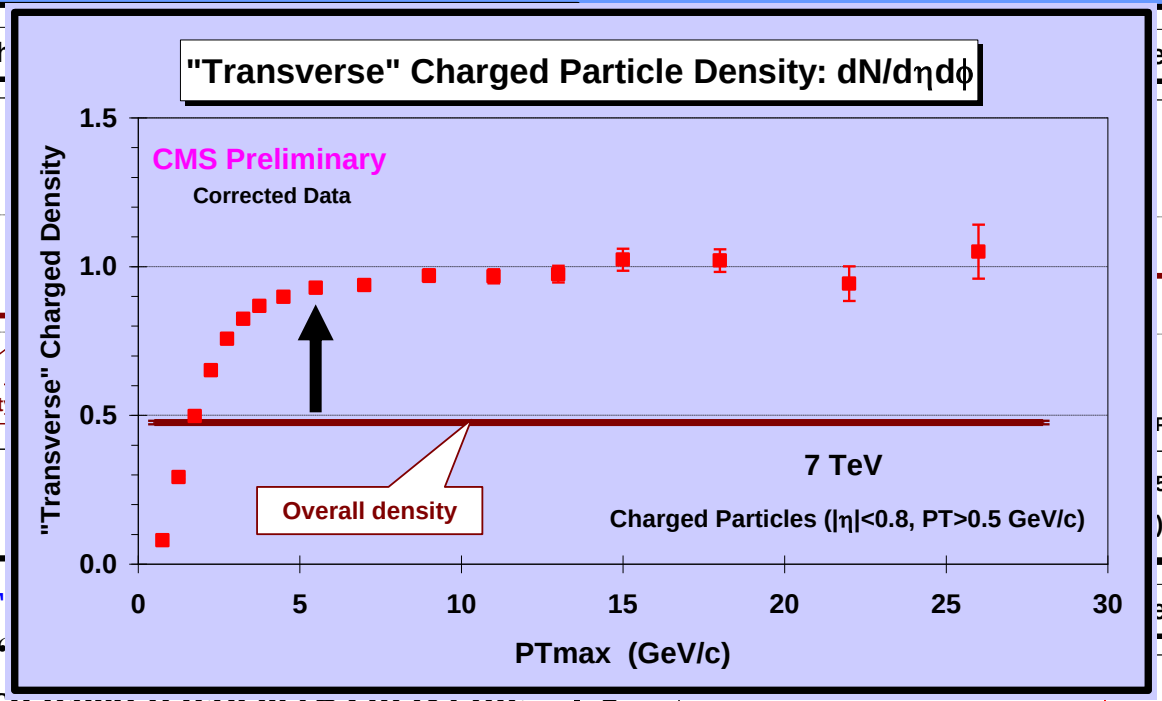


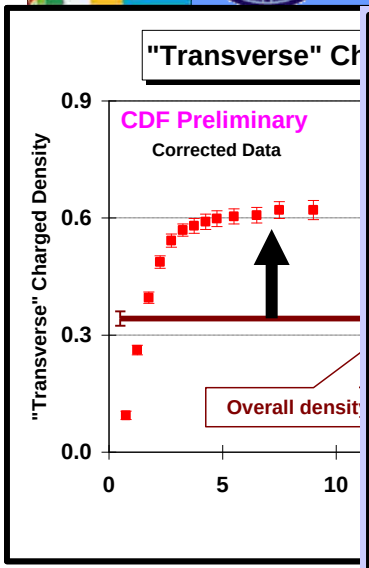
➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

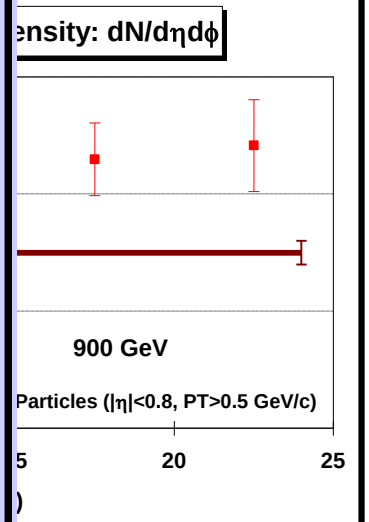
➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

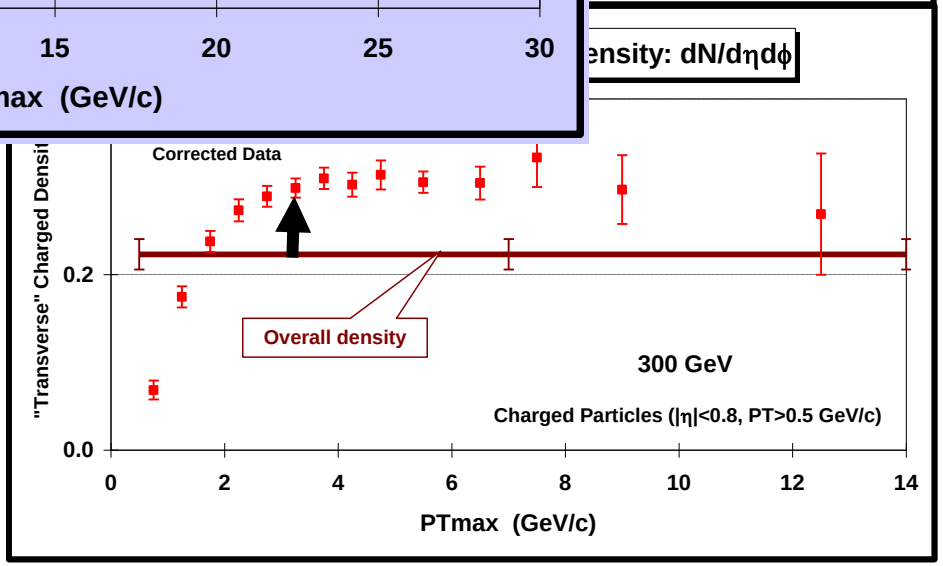
The data are "normalized" by dividing by the corresponding value at 300 GeV.

MB versus the UE



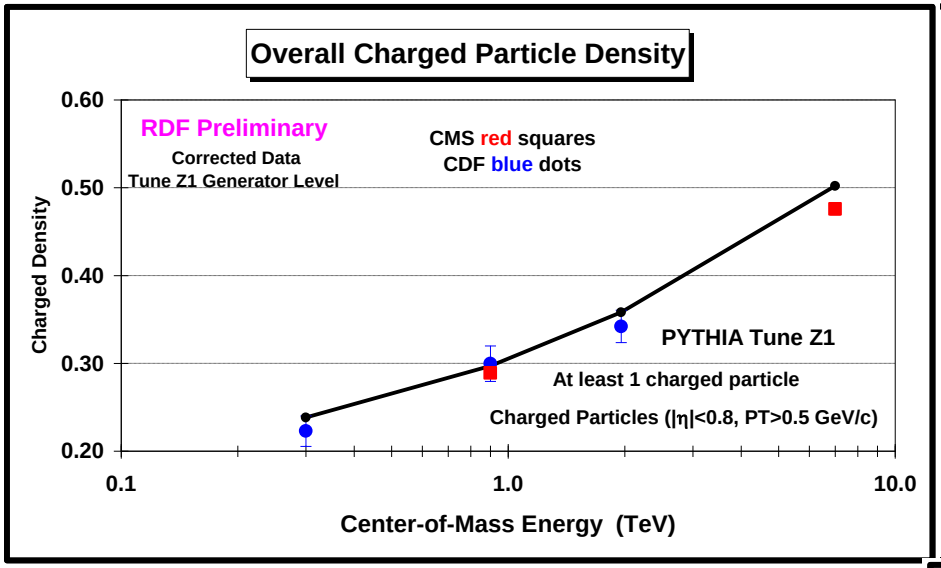


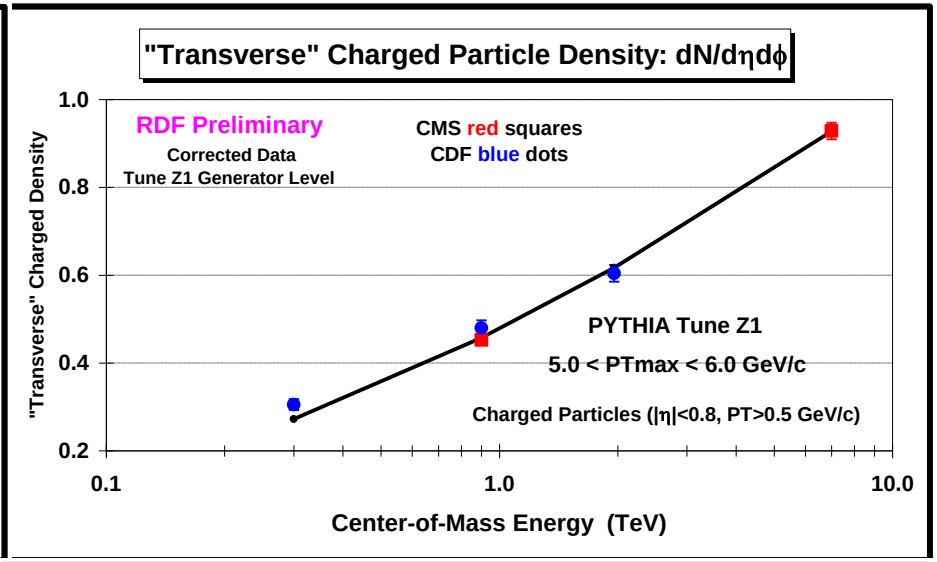




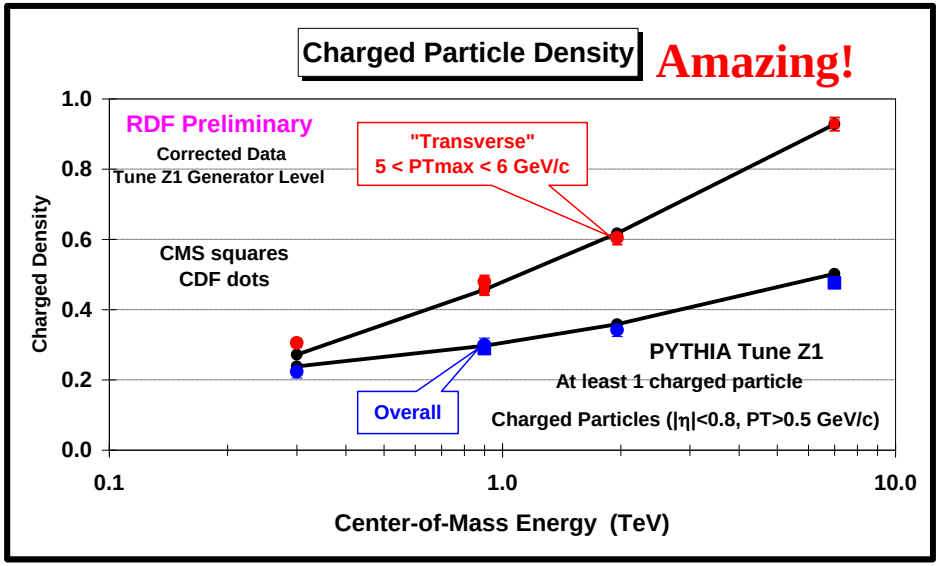
➡ **Corrected CDF … density, in the "… by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty and are compared with the overall charged particle density (*straight lines*).**

MB versus the UE

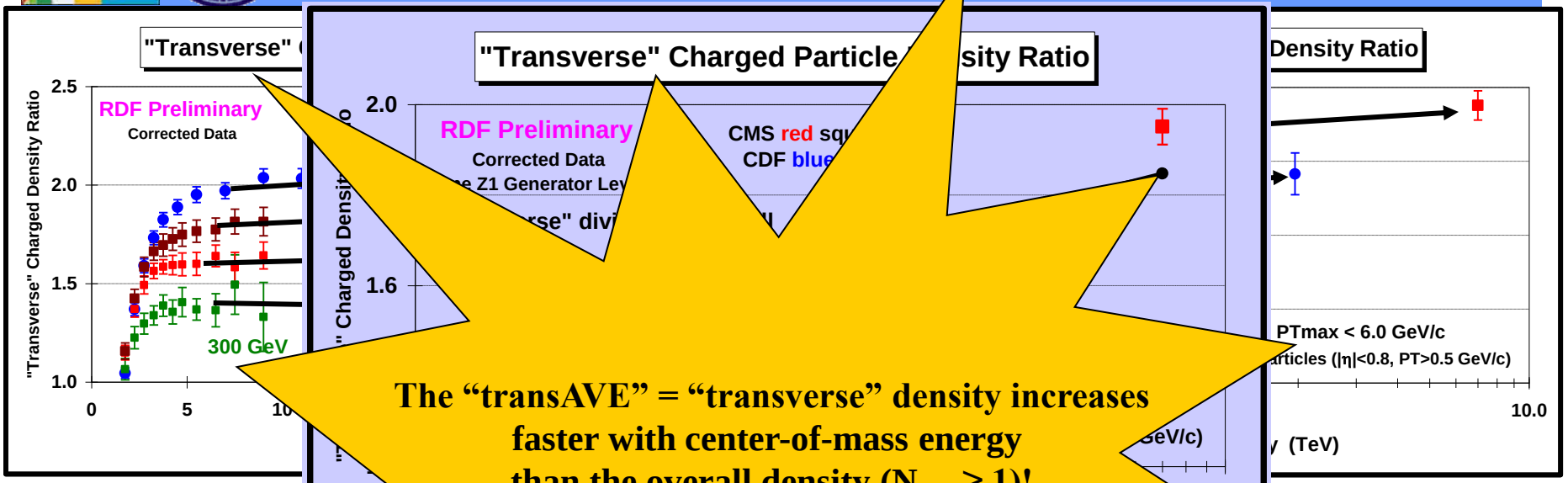




➡ **Corrected CDF and CMS data on the overall density of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**



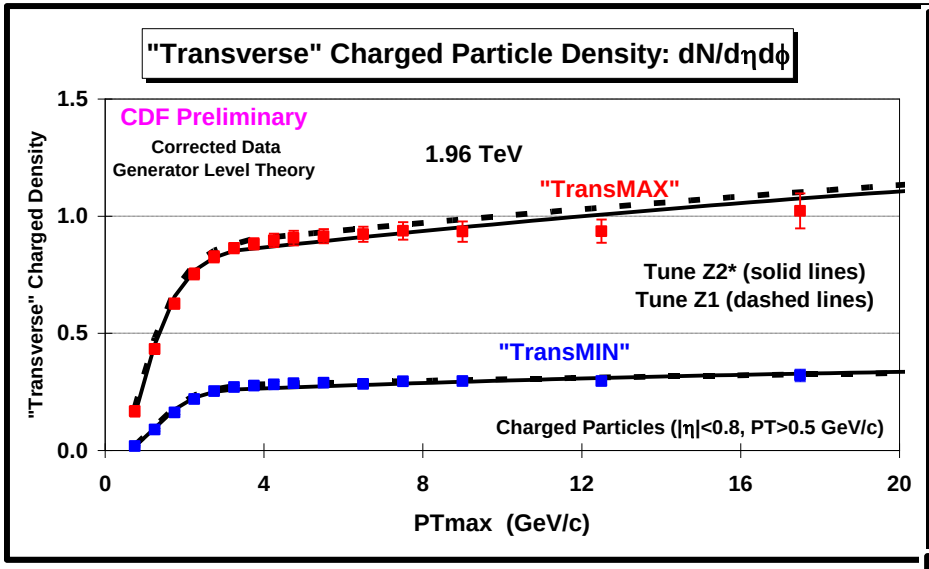
"Transverse"/Overall

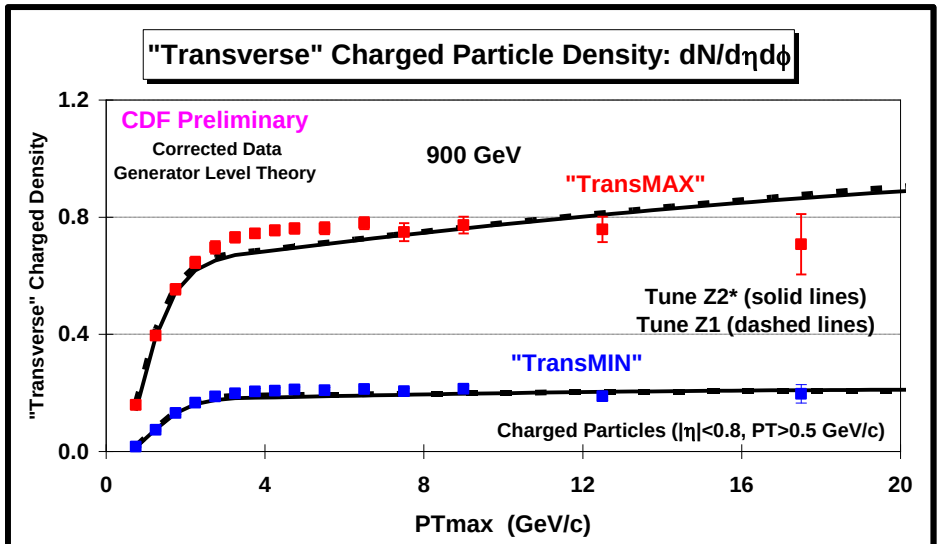


The "transAVE" = "transverse" density increases faster with center-of-mass energy than the overall density ($N_{chg} \geq 1$)!

➡ **Corrected CDF ta on the charged particl , in the "transverse" re on as defined by the leading charged part (PTmax) for particles with p_T > 0.5 GeV/c es 0.5 GeV/c and |η| < 0.8 for The ratio corresponds to the nsv max < /c. The ratio corresponds charged particle density div d by t "transver charged particle density overall charged particle density (N_{chg} d by the ove ll charged particle de ty ($N_{chg} \geq 1$). The data are plotted versus the enter-of-mass energy (*log scale*).**

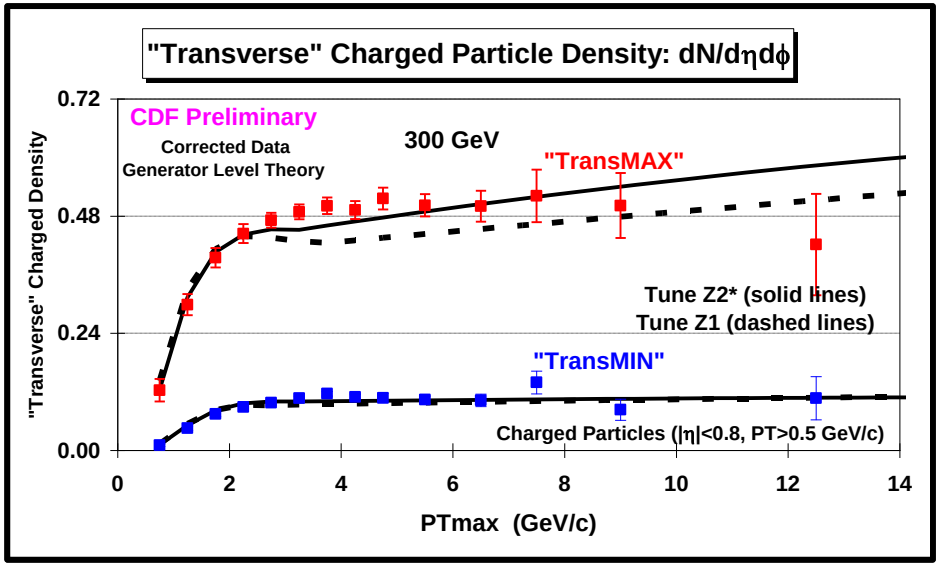
"transMAX/MIN" NchgDen



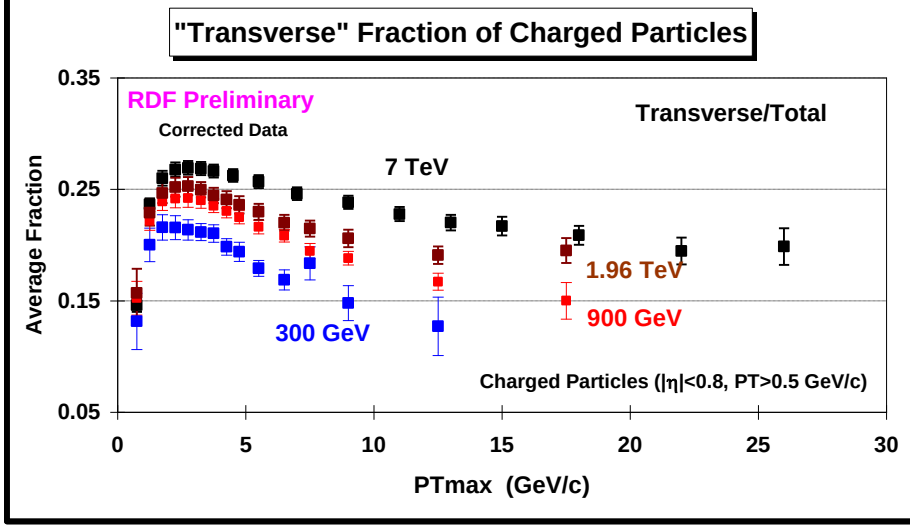


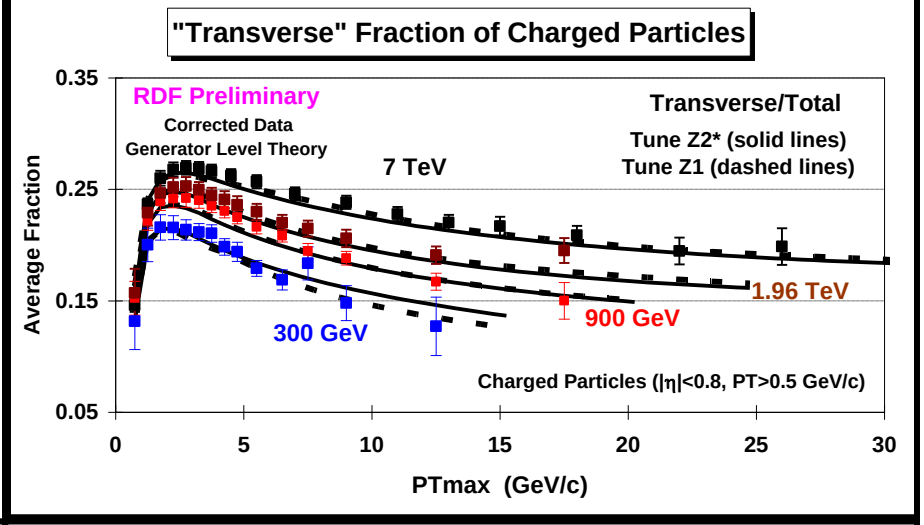
- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.

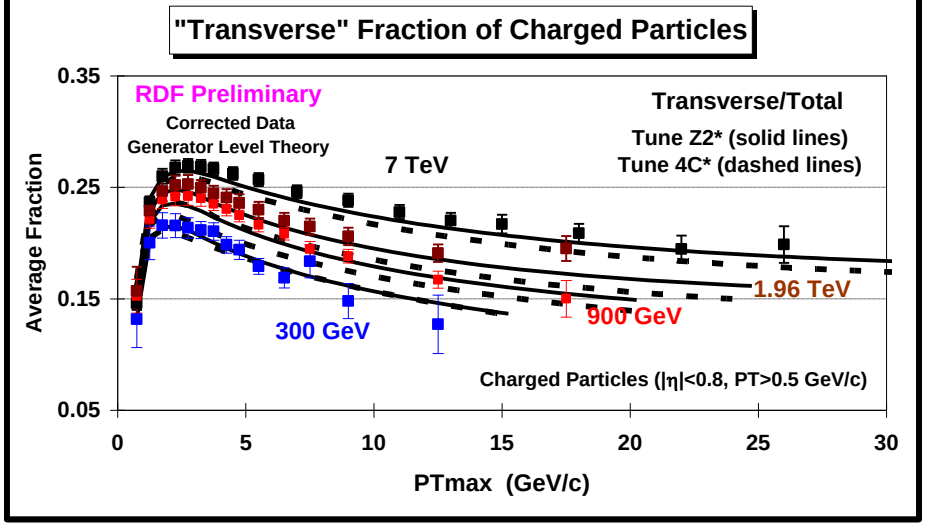


"tranMIN" Nchg Fraction

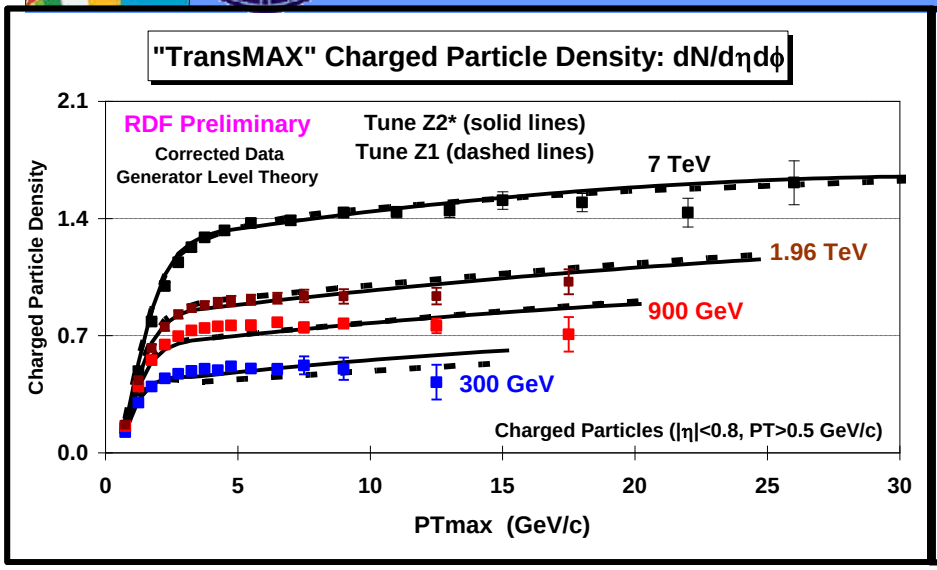


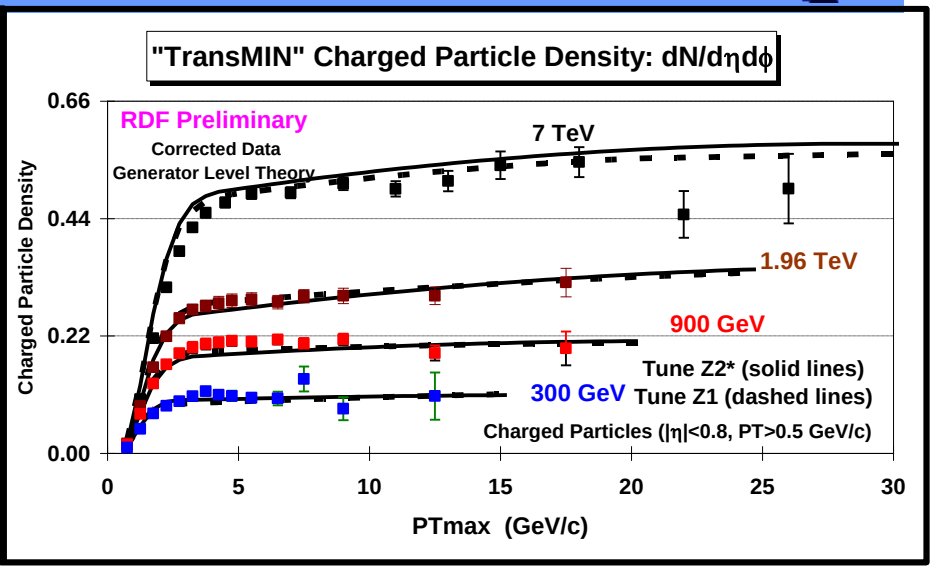


- **CMS and CDF data on the fraction of charged particles in the "transMIN" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The plot shows "transMIN" Nchg divided by the overall "transverse" Nchg. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"transMAX/MIN" NchgDen

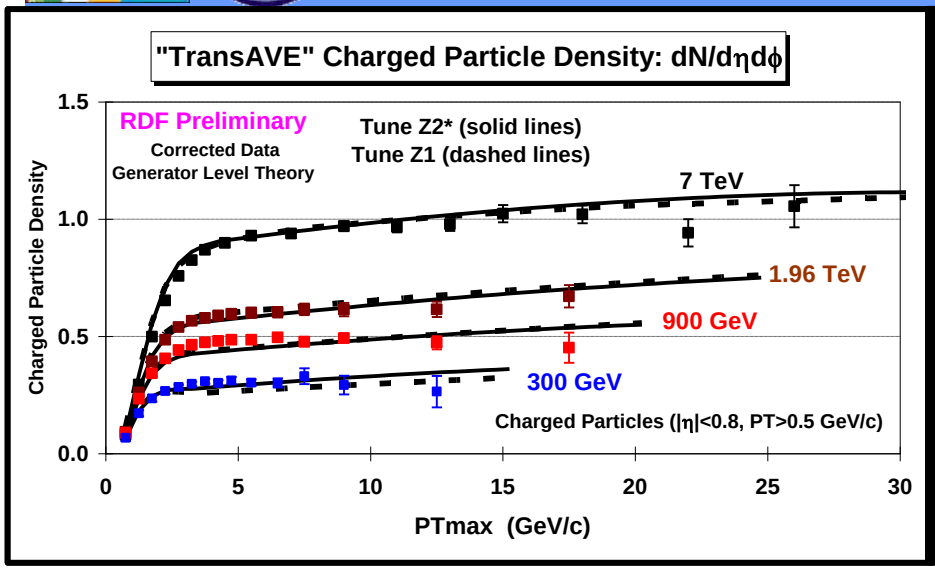


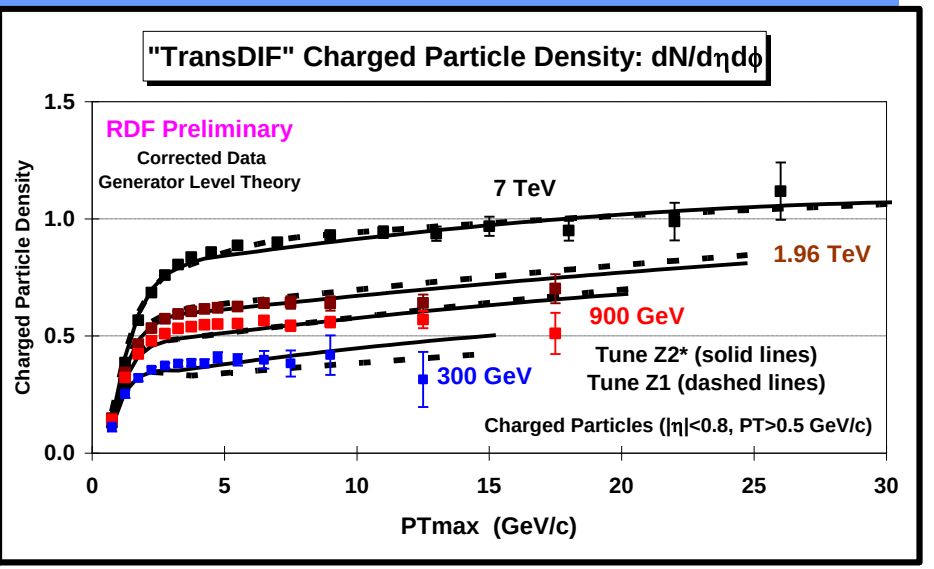


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMIN" region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

"transDIF/AVE" NchgDen

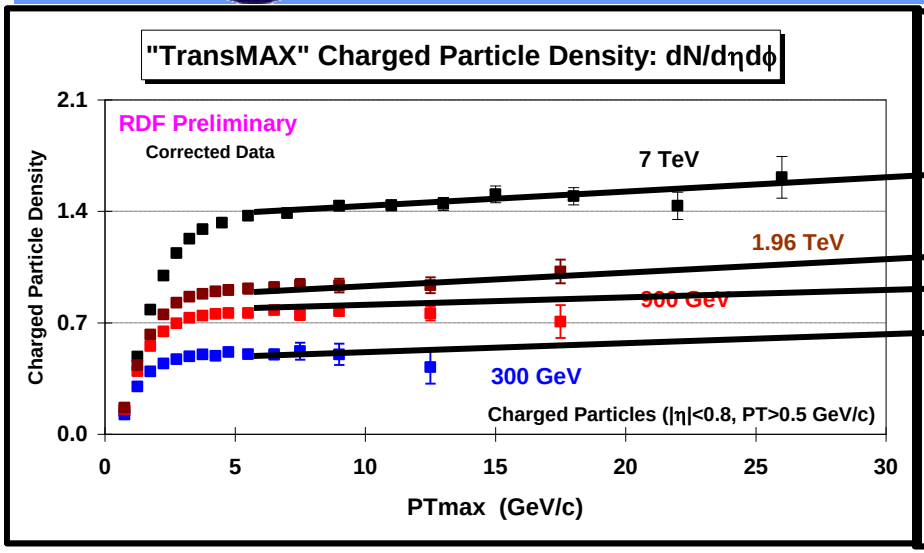


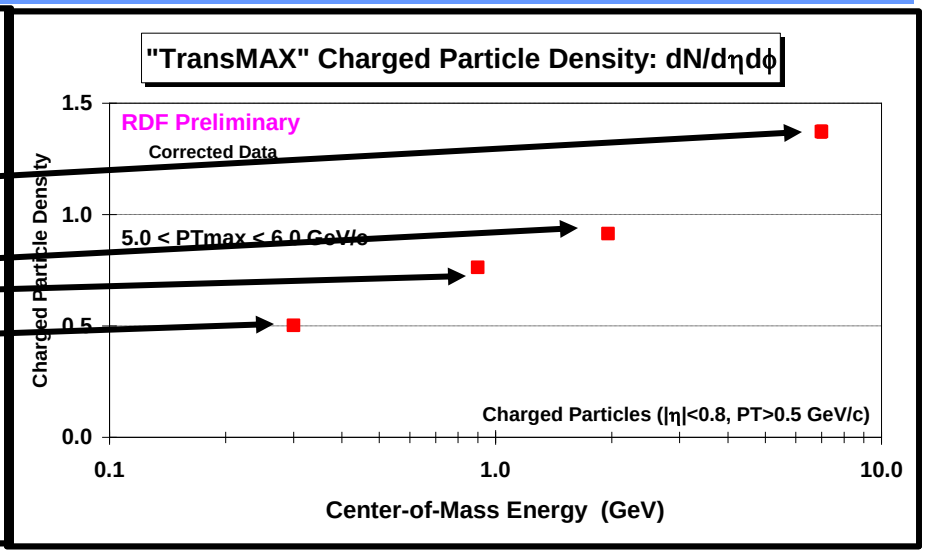


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transDIF" region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

"transMAX" NchgDen vs E_{cm}

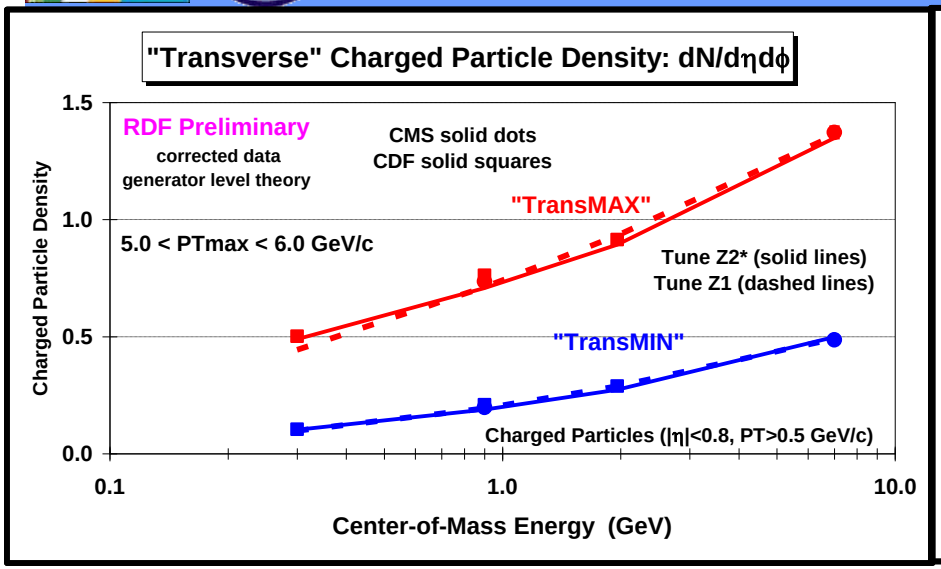


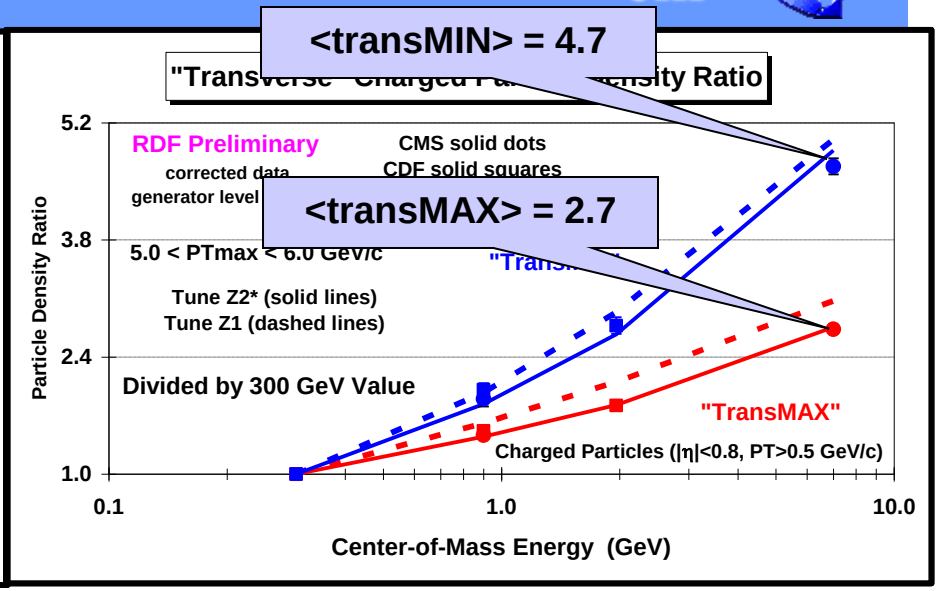


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **Corrected CMS and CDF data on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

"Transverse" NchgDen vs E_{cm}



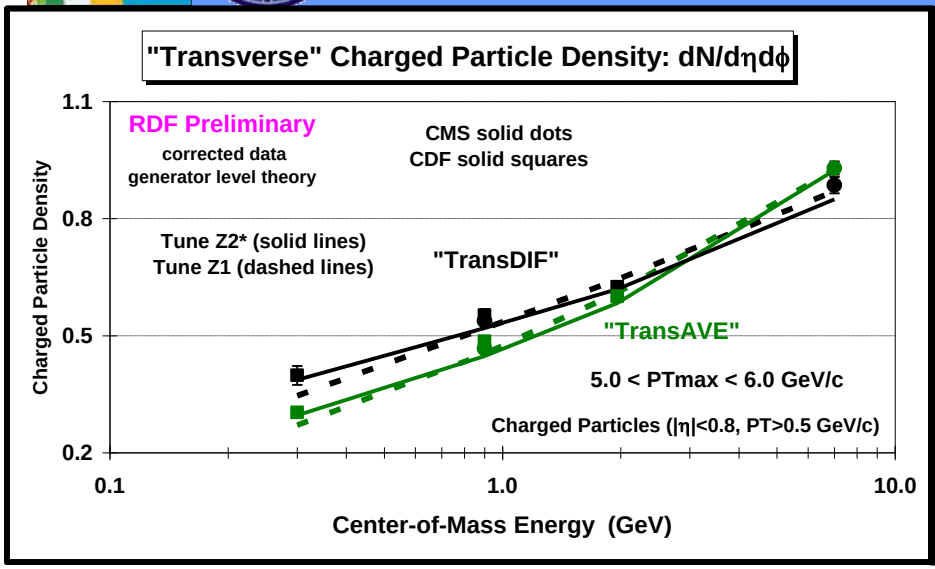


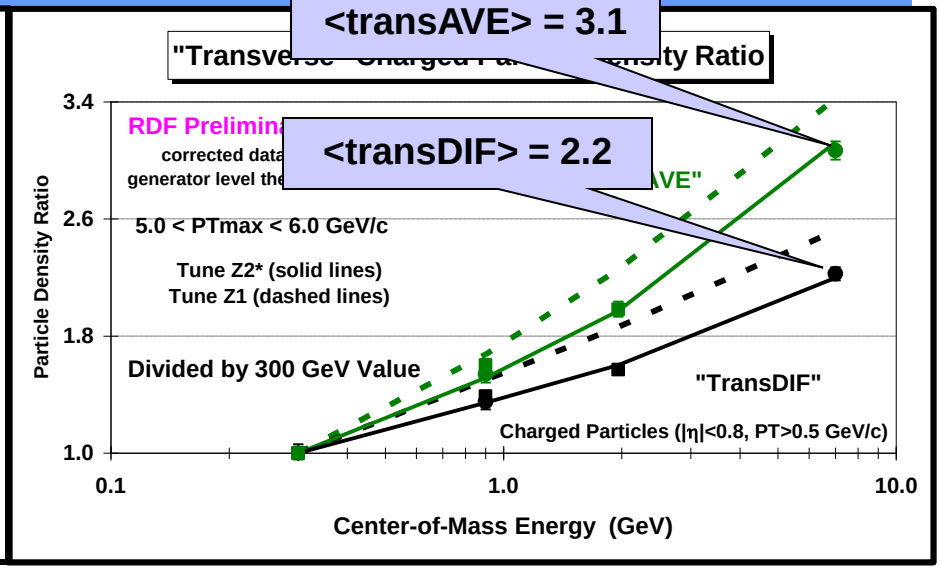
➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➡ **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"Transverse" NchgDen vs E_{cm}



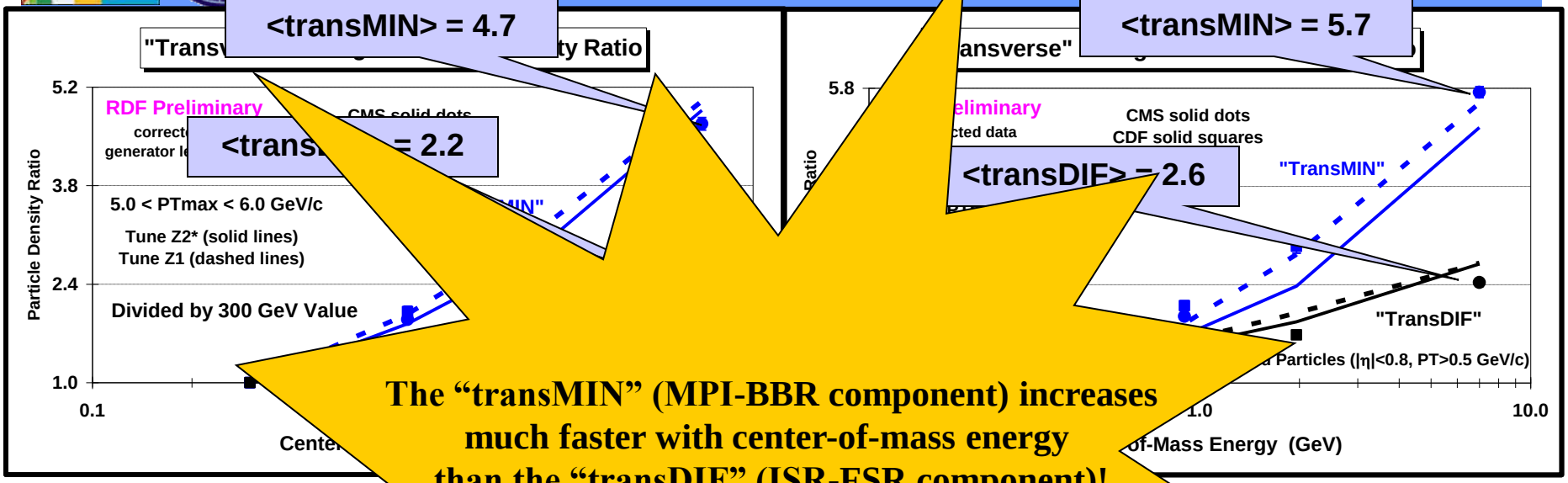


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➡ **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"TransMIN/DIF" vs E_{cm}

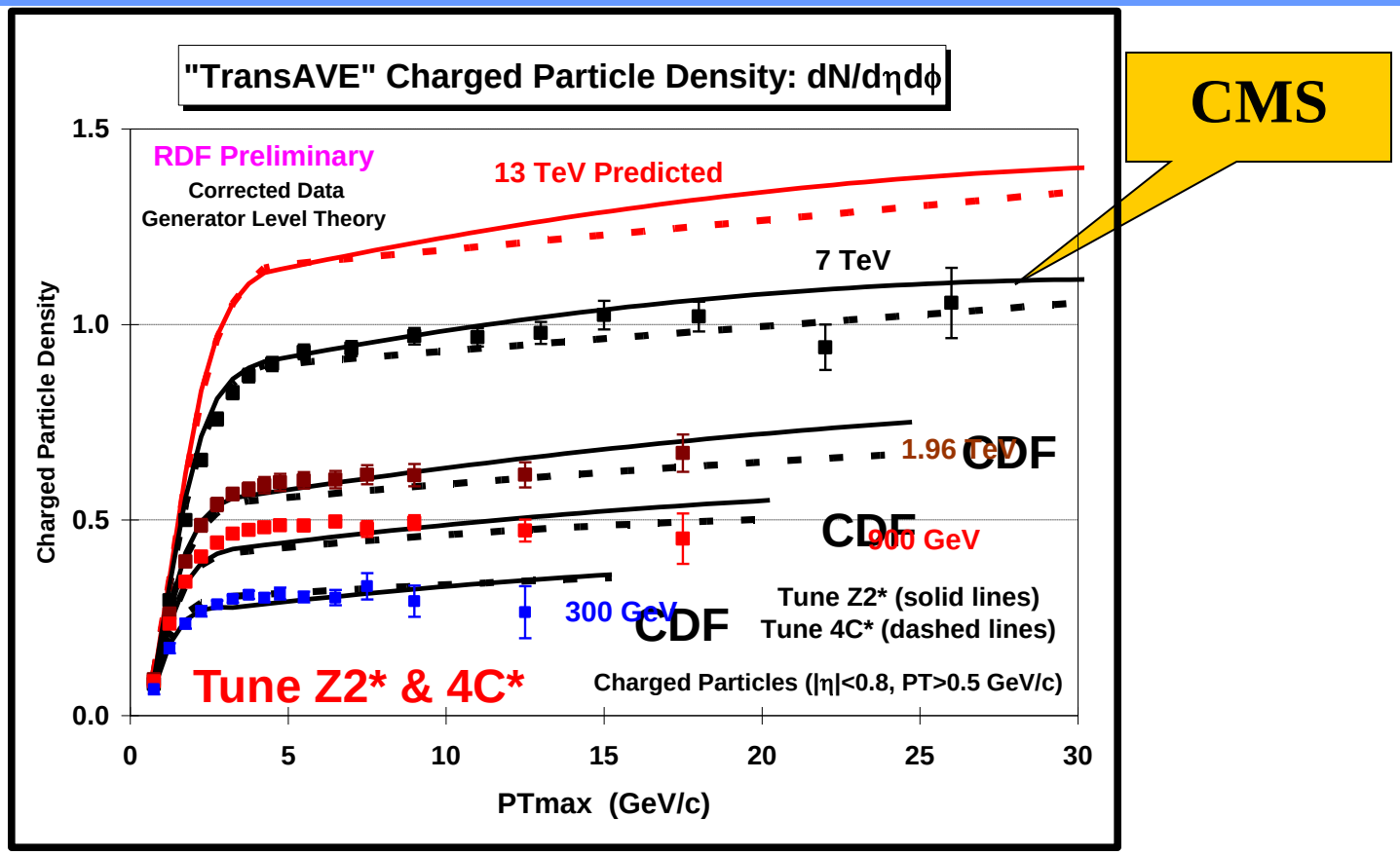


The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)! Duh!!

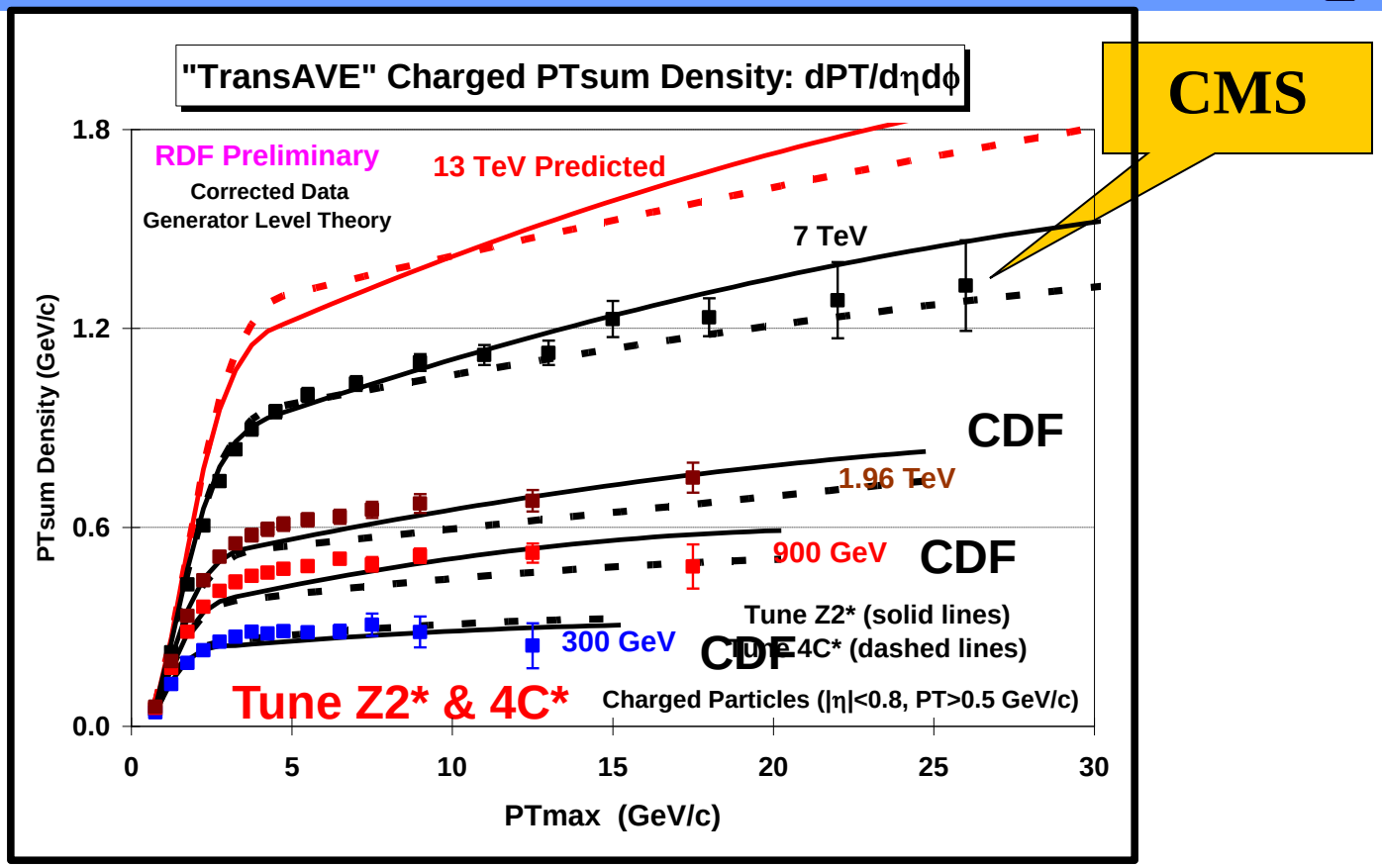
➡ **Ratio of CMS data at 7 … TeV and CDF data at 1.96 TeV, 900 GeV, a… GeV to the value at 300 GeV for th… charged PTsum density in the "transMIN", "transDI… and "transDIF" regions as defined by the leading charge… by …ding charged particle (PTmax) for charged particle… p_T …x) for …ed particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 <$ …max … and $|\eta| <$ … with $5 <$ PTmax < 6 GeV/c. The data are plotted versus the … c. The data are plotted versus the center-of-mass energy (*log scale*). … r-of-mass energy (*log scale*).**

The data are compared … ith PYTHIA Tune Z1 and Tune Z2*.

"Tevatron" to the LHC



"Tevatron" to the LHC



Summary & Conclusions

- The "transverse" density increases faster with center-of-mass energy than the overall density (Nchg ≥ 1). However, the "transverse" = "transAVE" region is not a measure of the energy dependence of the MPI since it receives large contributions from
- The "transMIN" density increases with center-of-mass energy. Previously we only knew that
- PYTHIA 6.4 Tune AW does a really good job in describing the data. Room for improvement. $(p_T/p_{T0})^{\varepsilon}$ seems to work!

What we are learning should allow for a deeper understanding of MPI which will result in more precise predictions at the future LHC energies of 13 & 14 TeV!

We now have data on the UE at 300 GeV, 900 GeV, 1.96 TeV and 7 TeV! We can study the energy dependence more precisely than ever before!