QCD at the LHC

ECT* European Centre for Theoretical Studies in Nuclear Physics and Related Areas

LHC UE & MB MC Tunes

Rick Field

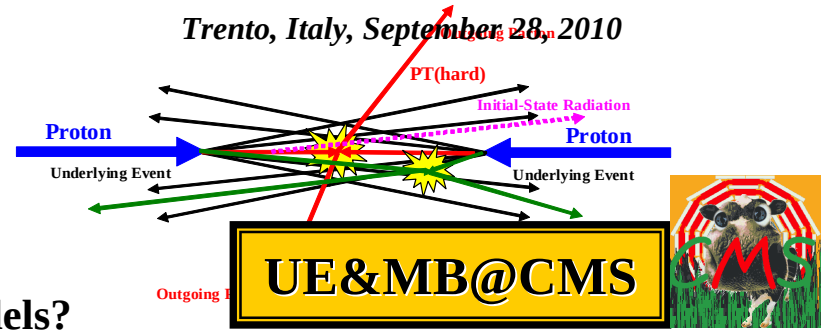
Quantum Chromo-Dynamics

University of Florida

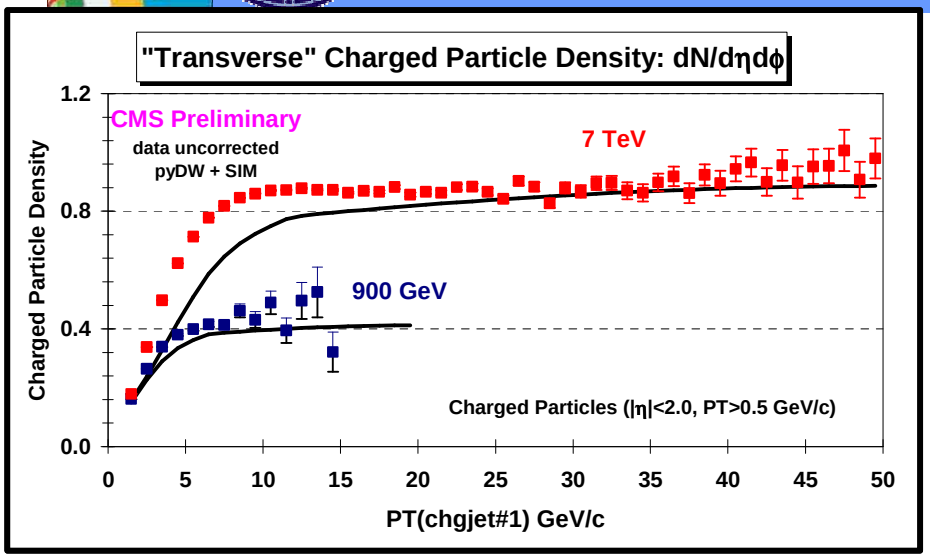
Trento, Italy, September 28, 2010

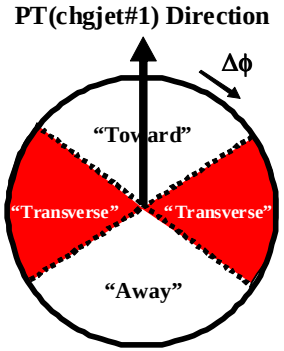
Outline of Talk

- **How well did we do at predicting the LHC UE data at 900 GeV and 7 TeV? A careful look.**
- **How well did we do at predicting the LHC MB data at 900 GeV and 7 TeV? A careful look.**
- **PYTHIA 6.4 Tune Z1: New CMS 6.4 tune (pT-ordered parton showers and new MPI).**
- **PYTHIA 8 Tune: New tune from Hendrik Hoeth.**
- **Long-Range Same-Side Correlations: Collective phenomena in pp collisions at 7 TeV?? New type of "underlying event"!**
- **Strange particle production: A problem for the models?**



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.**

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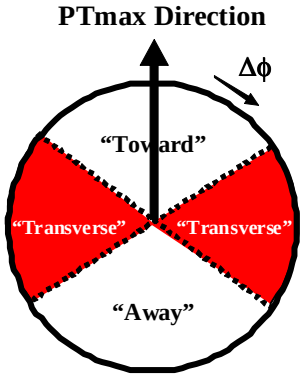

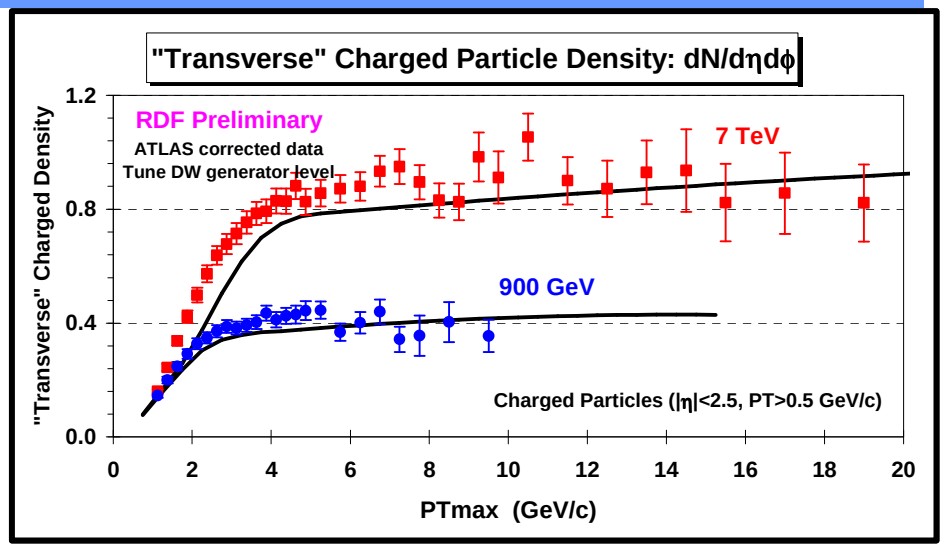

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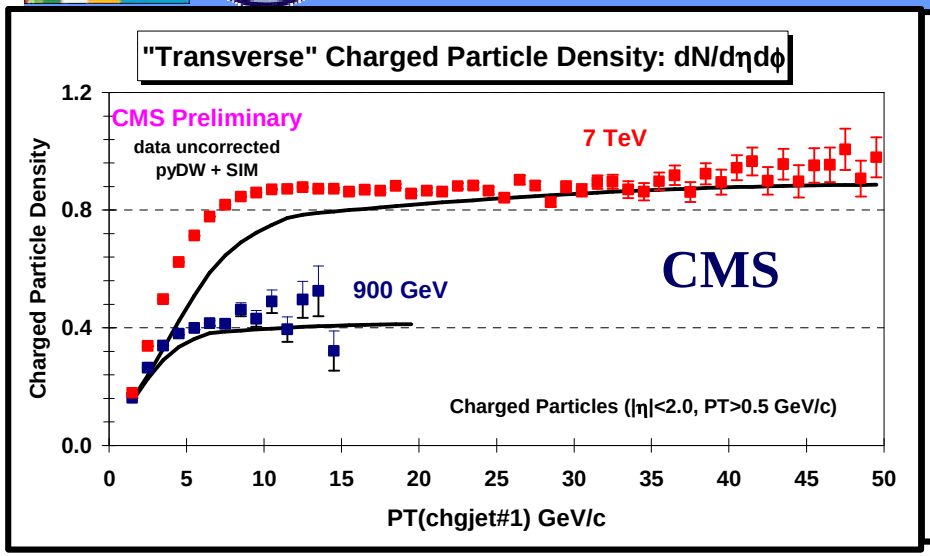

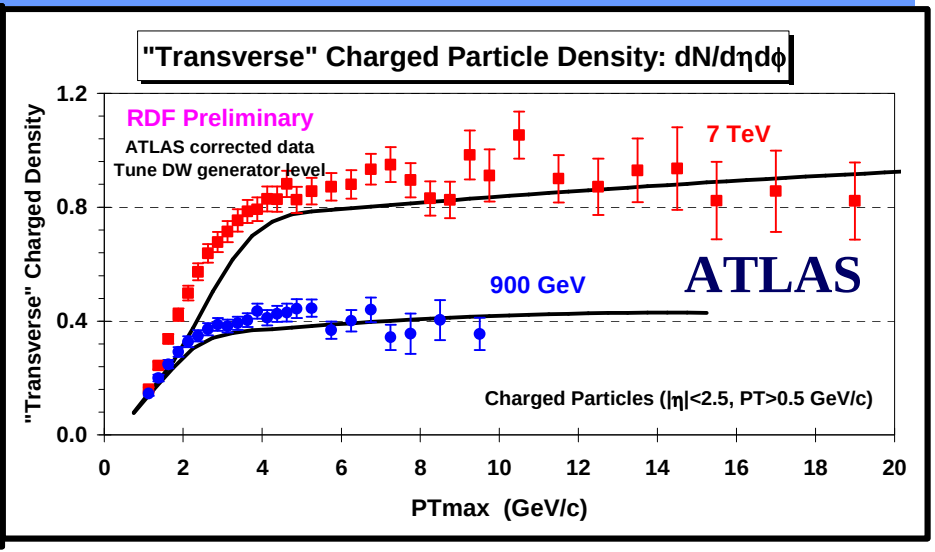

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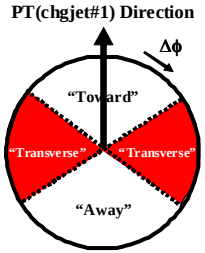

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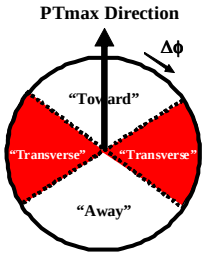

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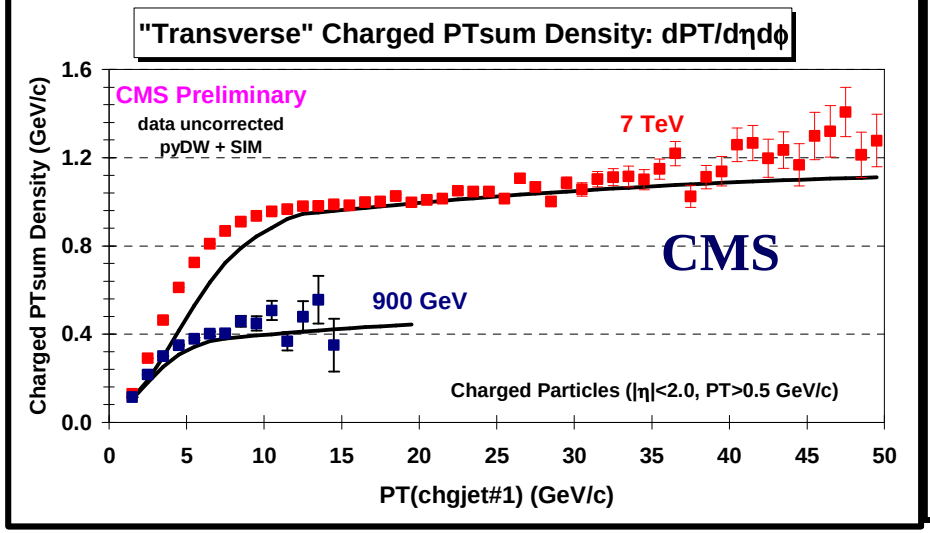

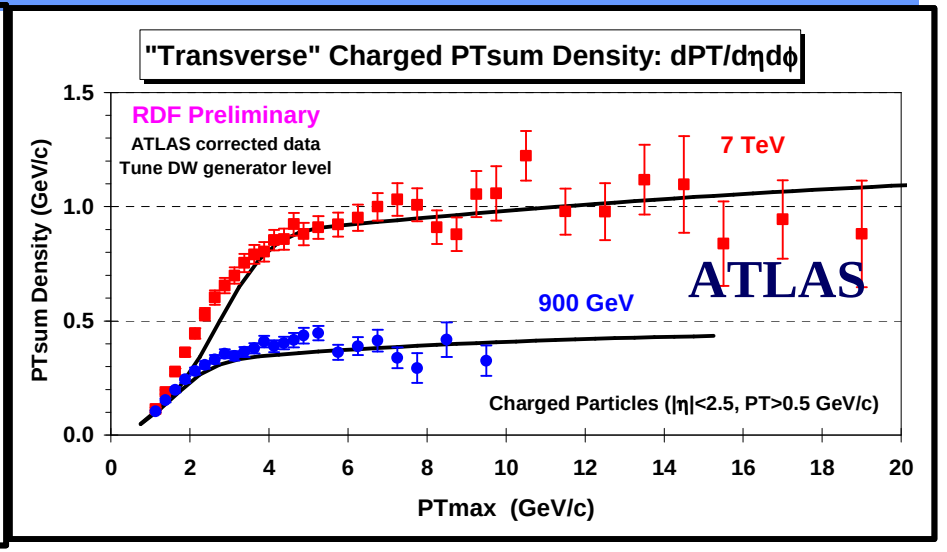

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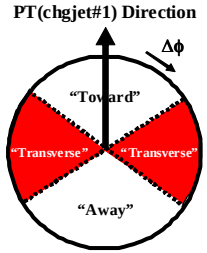

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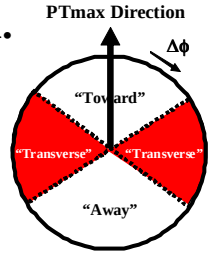

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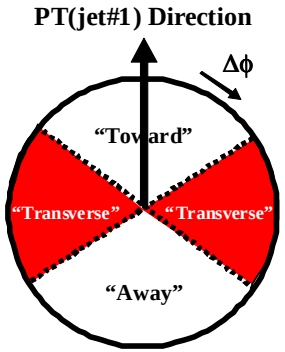

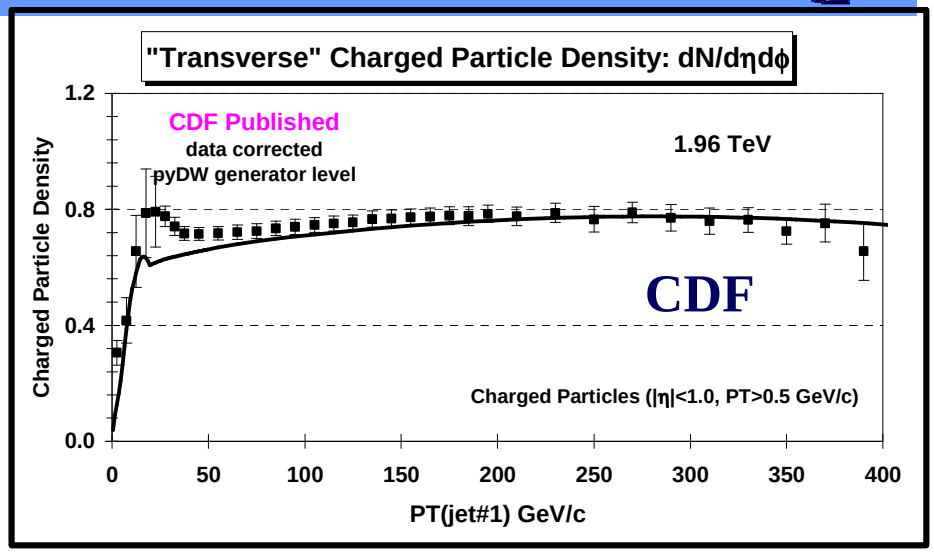

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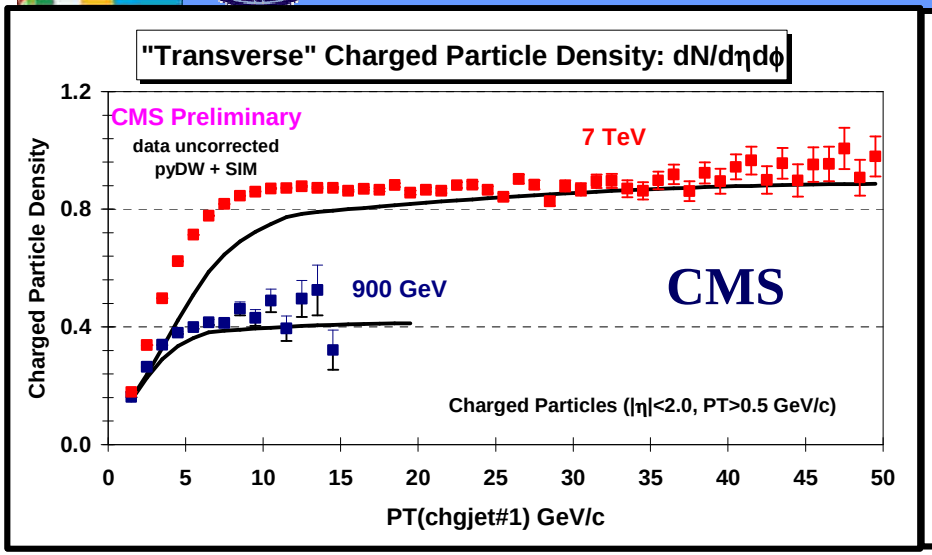

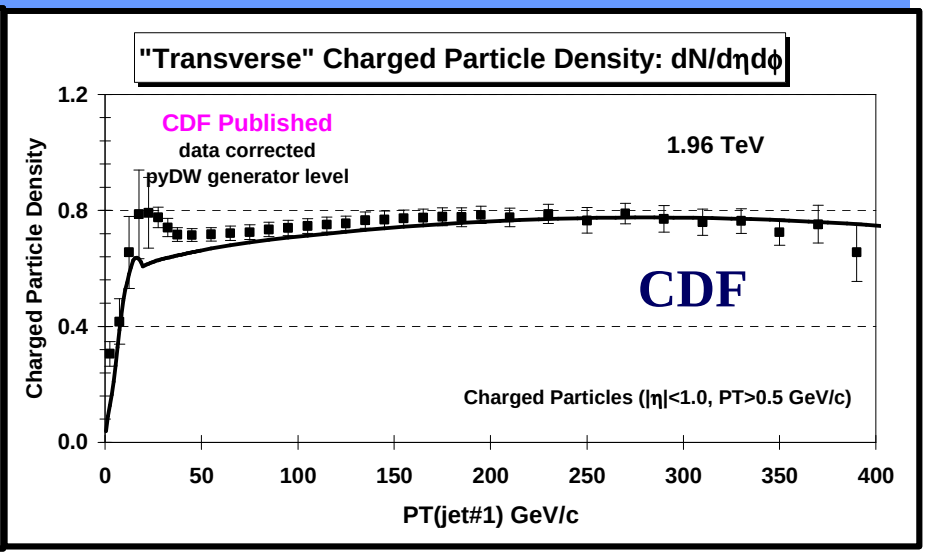

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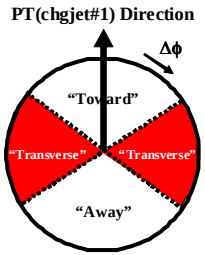

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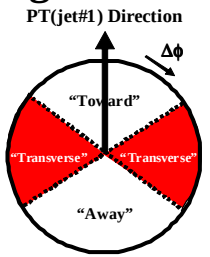

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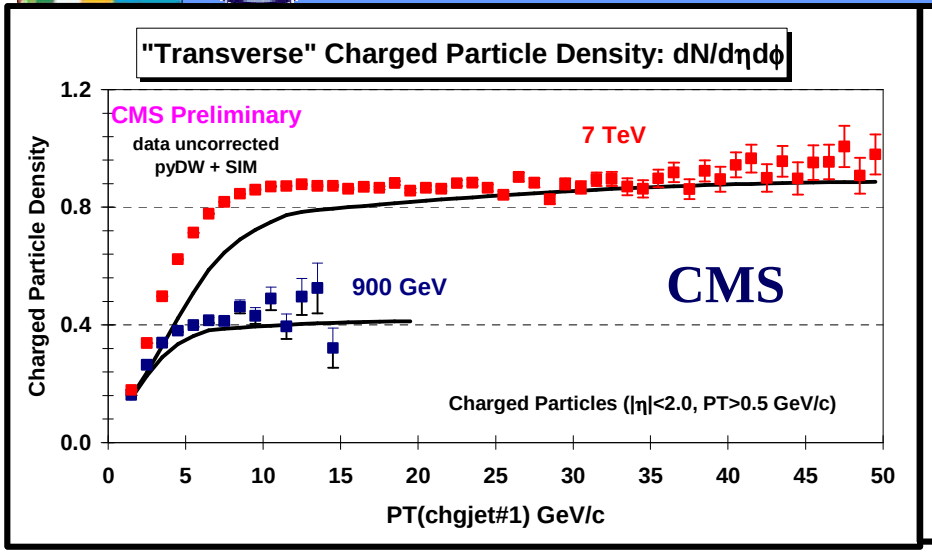

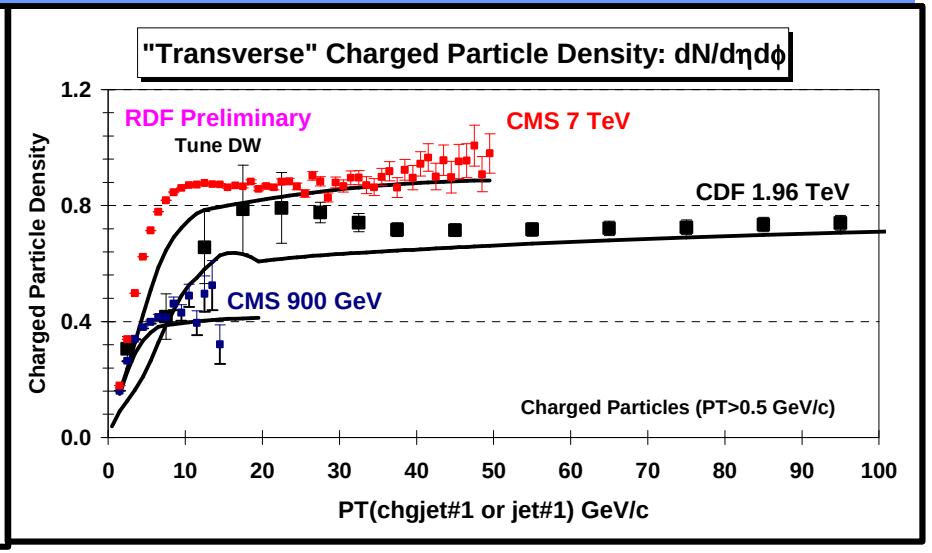

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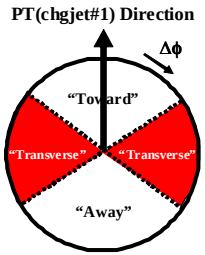

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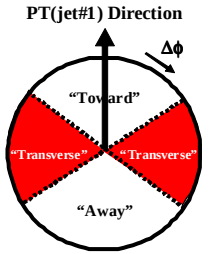
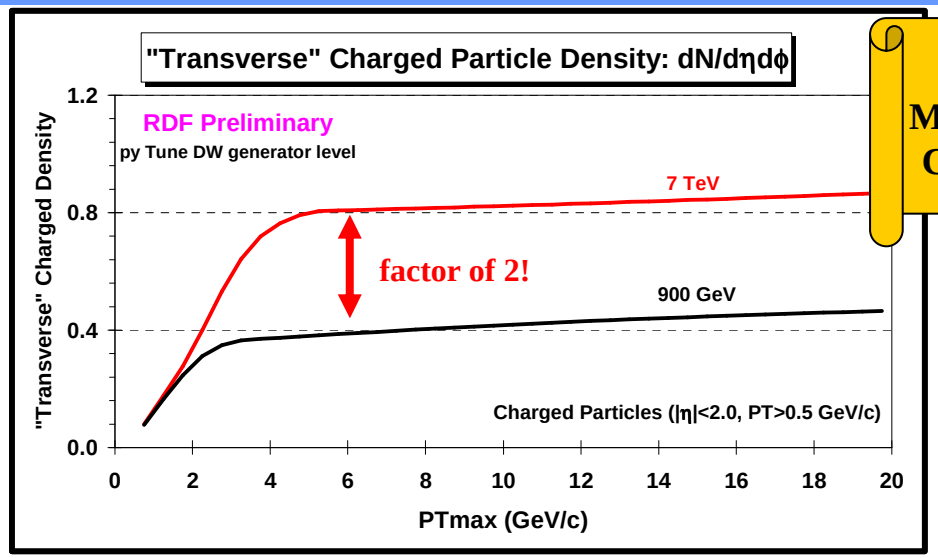
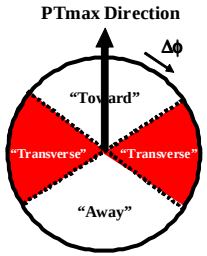


"Transverse" Charge Density



Rick Field
MB&UE@CMS Workshop
CERN, November 6, 2009

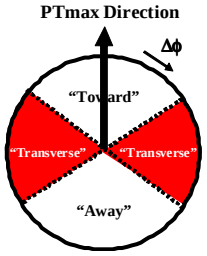
LHC 900 GeV



900 GeV → 7 TeV
(UE increase ~ factor of 2)

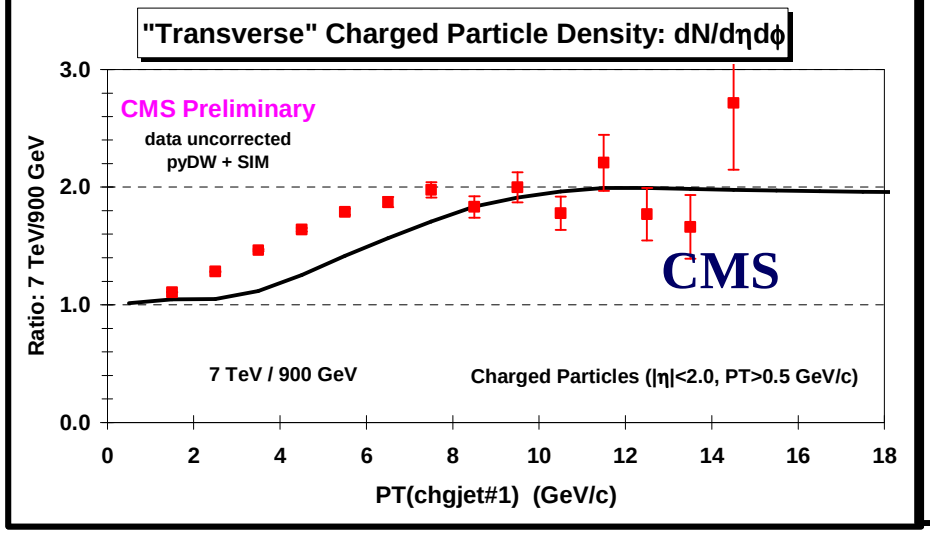
~0.4 → ~0.8

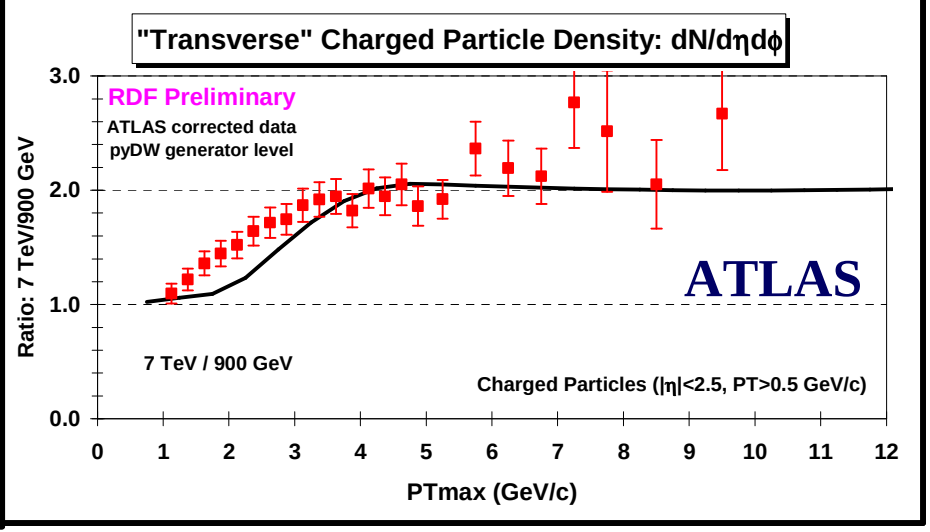
LHC 7 TeV



➡ **Shows the charged particle density in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) at 900 GeV and 7 TeV as defined by PTmax from PYTHIA Tune DW and at the particle level (*i.e.* generator level).**

PYTHIA Tune DW





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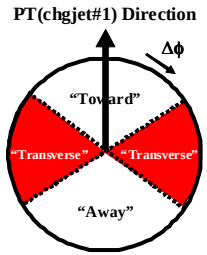

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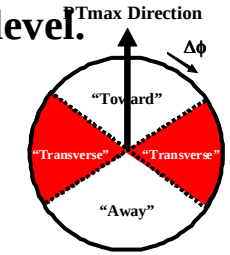

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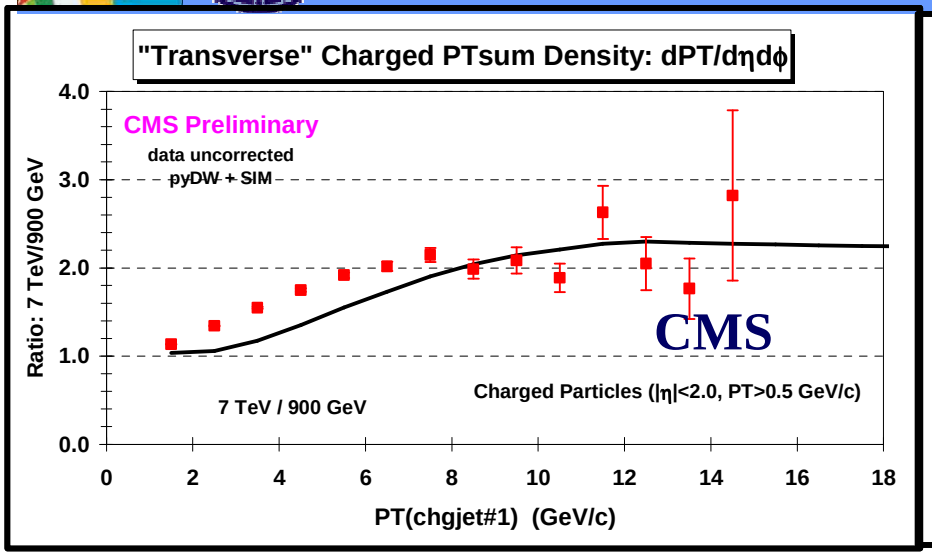

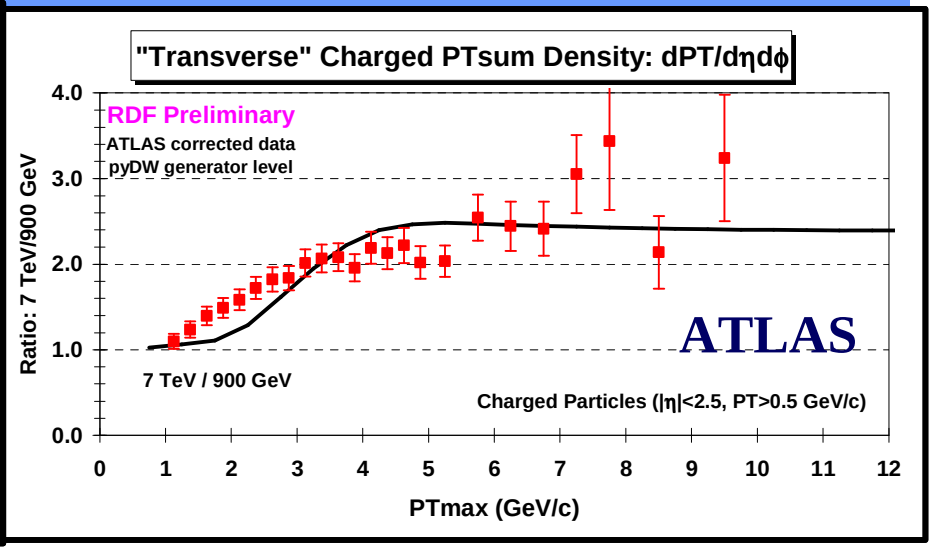

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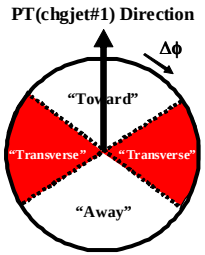

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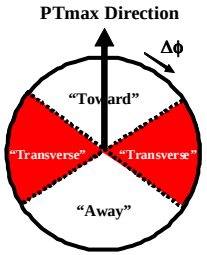
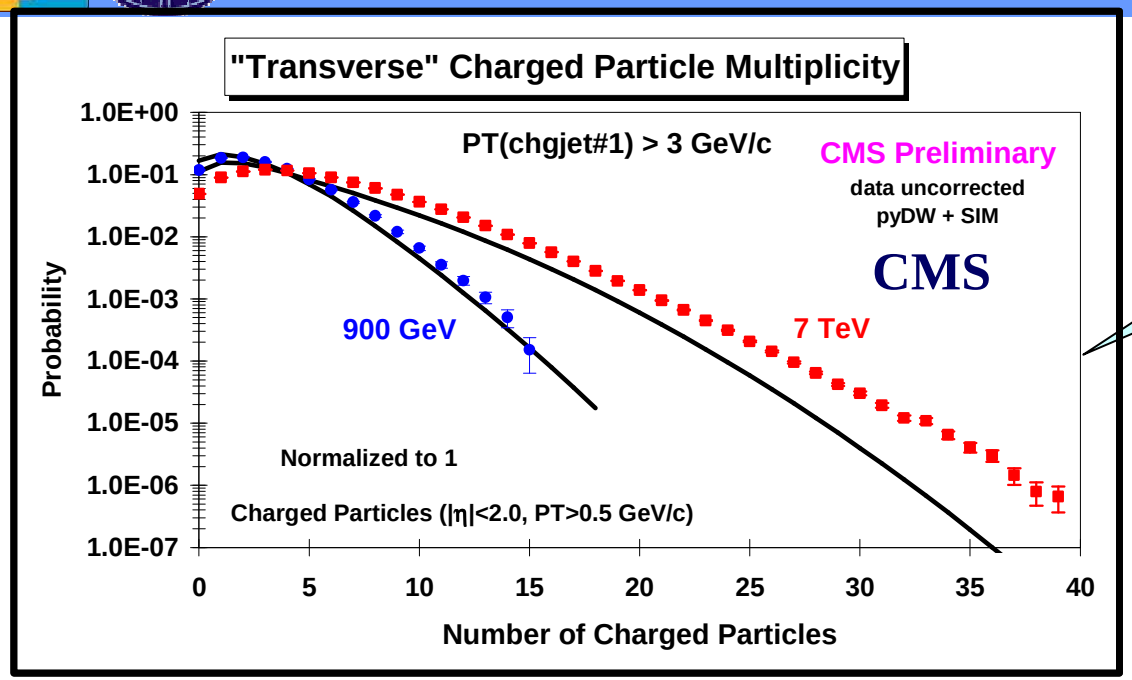
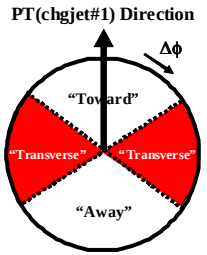


"Transverse" Multiplicity Distribution



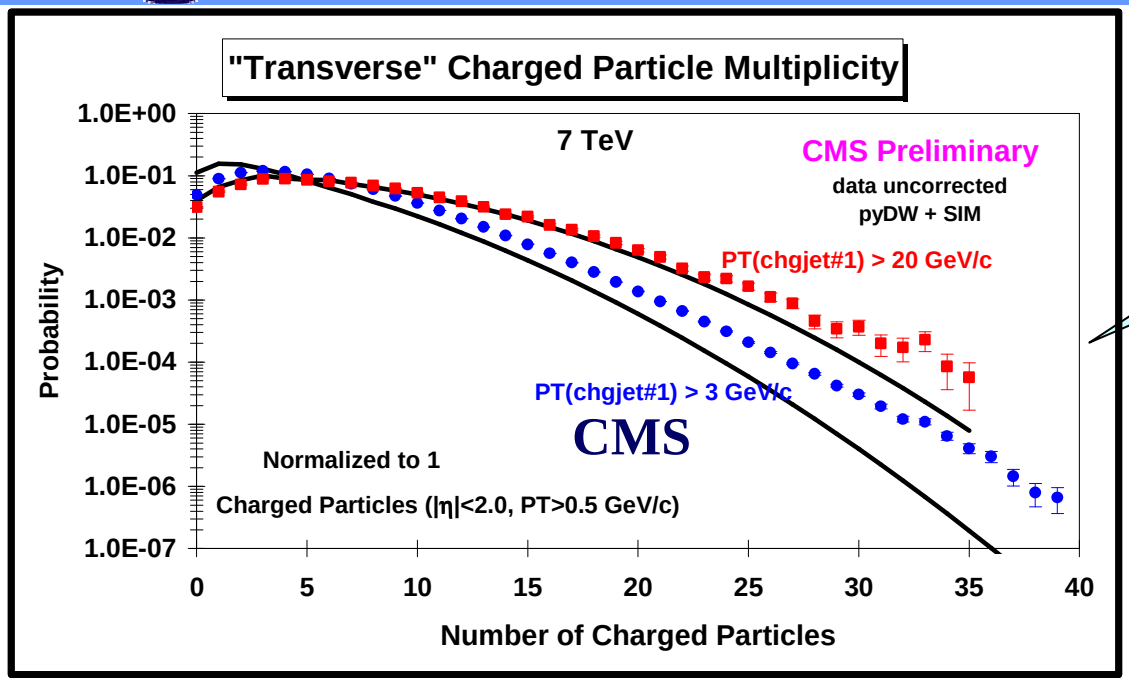
Same hard scale at two different center-of-mass energies!



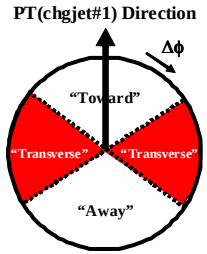
- **CMS uncorrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet, chgjet#1, with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune DW at the detector level (*i.e.* Theory + SIM).**

Shows the growth of the "underlying event" as the center-of-mass energy increases.

"Transverse" Multiplicity Distribution



Same center-of-mass energy at two different hard scales!

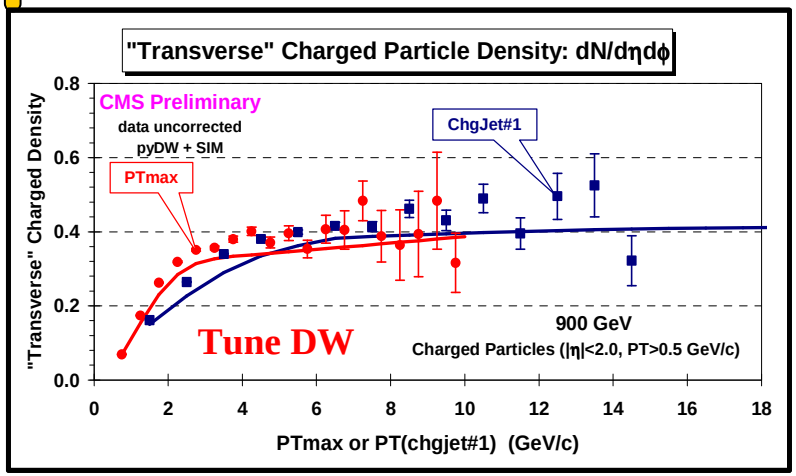


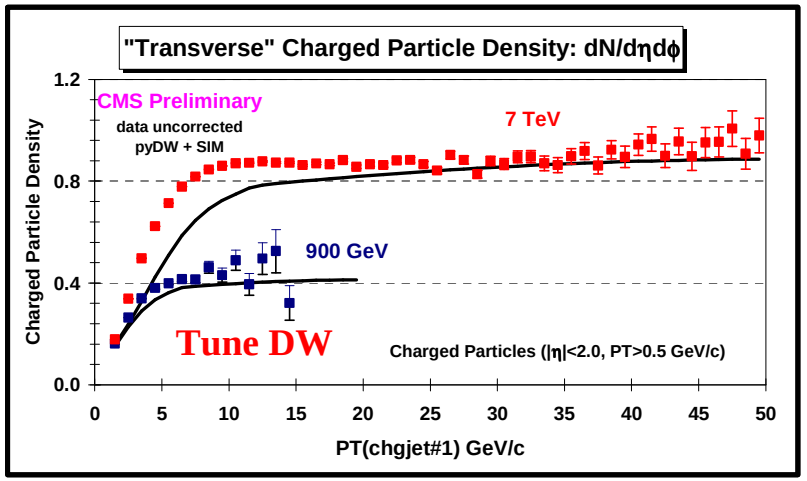
- **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet, chgjet#1, with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune DW at the detector level (*i.e.* Theory + SIM).**

Shows the growth of the "underlying event" as the hard scale increases.

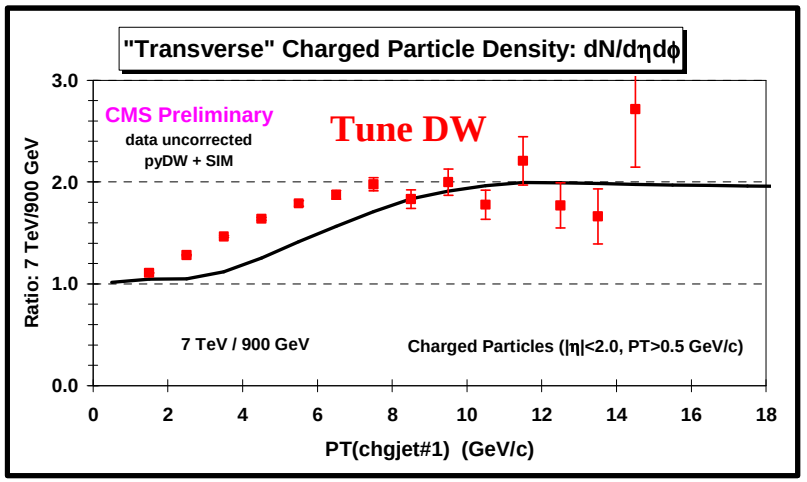
PYTHIA Tune DW

How well did we do at predicting the "underlying event" at 900 GeV and 7 TeV?



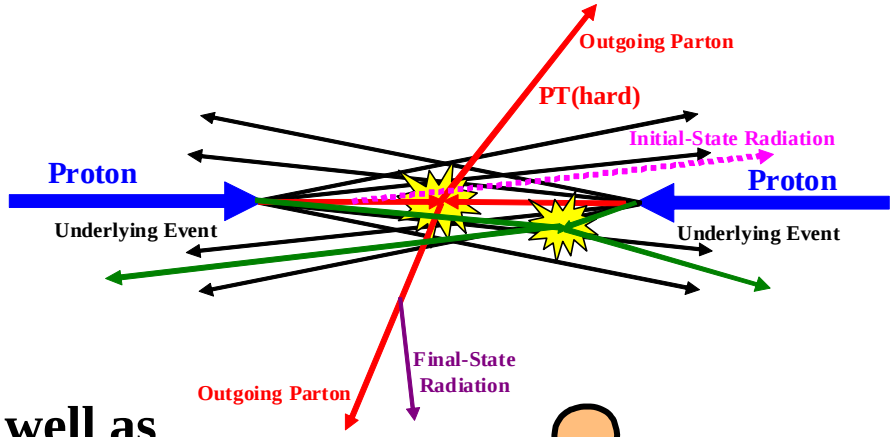


➡ **I am surprised that the Tunes did as well as they did at predicting the behavior of the "underlying event" at 900 GeV and 7 TeV!**

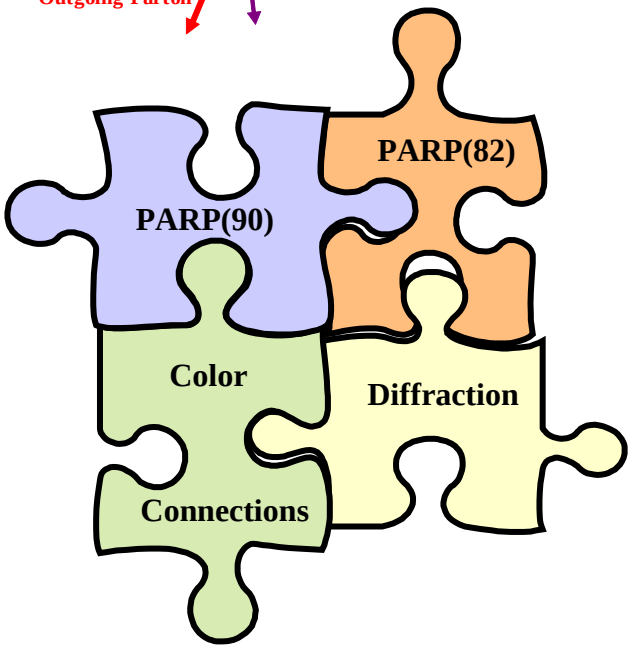


UE Summary

- The "underlying event" at 7 TeV and 900 GeV is almost what we expected! With a little tuning we should be able to describe the data very well (see Tune Z1 later in this talk).



- I am surprised that the Tunes did as well as they did at predicting the behavior of the "underlying event" at 900 GeV and 7 TeV! Remember this is "soft" QCD!



- "Min-Bias" is a whole different story! Much more complicated due to diffraction!

UE Summary

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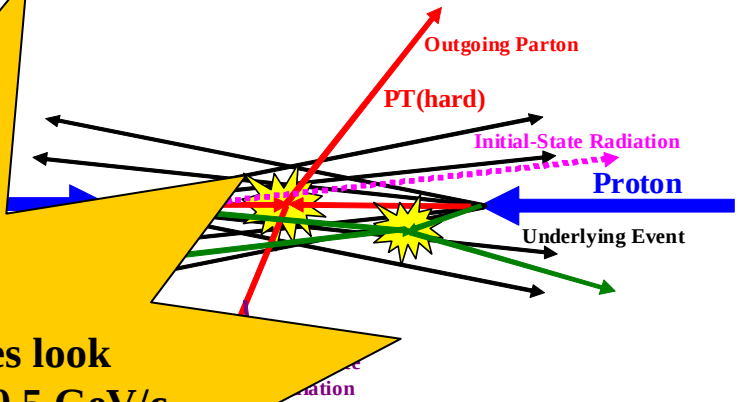
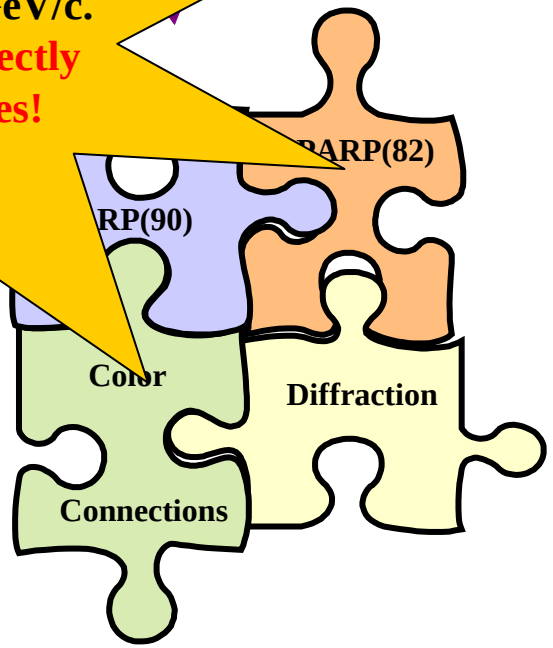
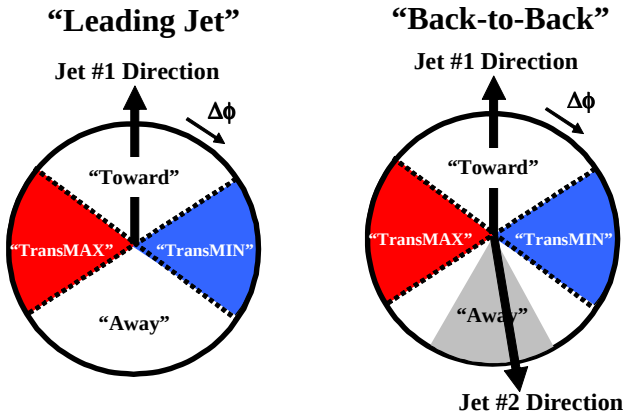
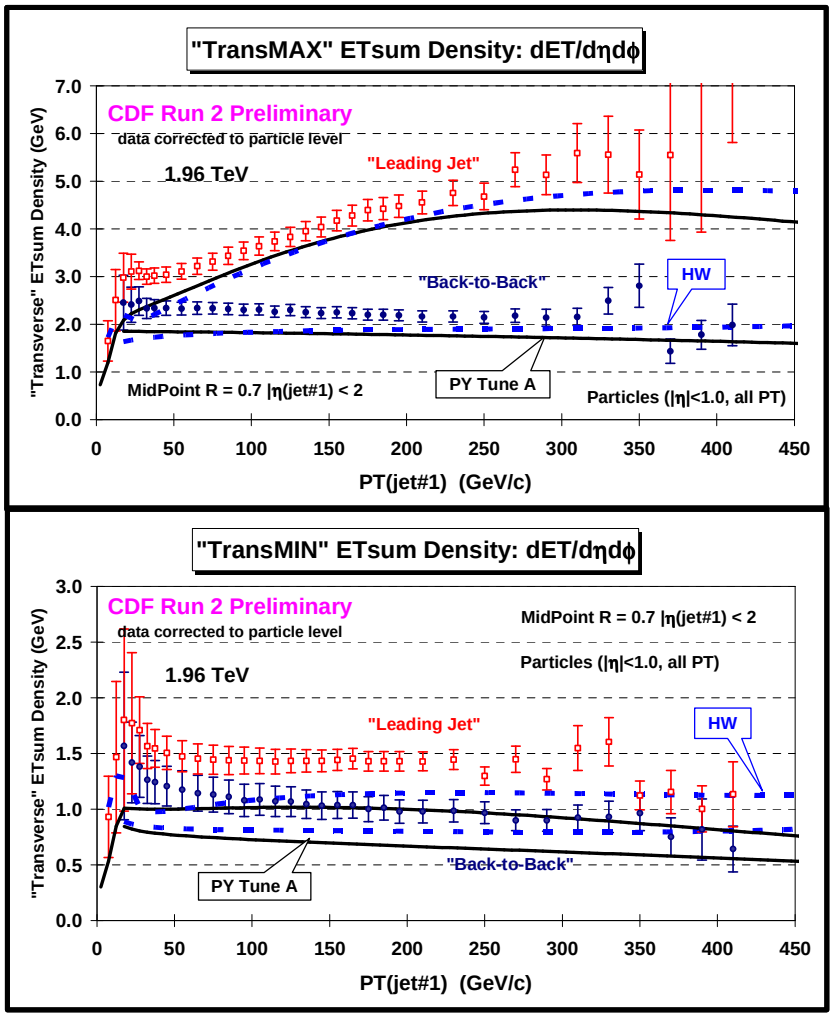


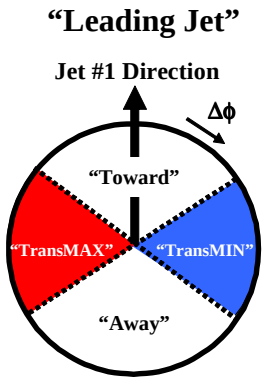
Warning! All the UE studies look at charged particles with $p_T > 0.5$ GeV/c. We do not know if the models correctly describe the UE at lower p_T values!

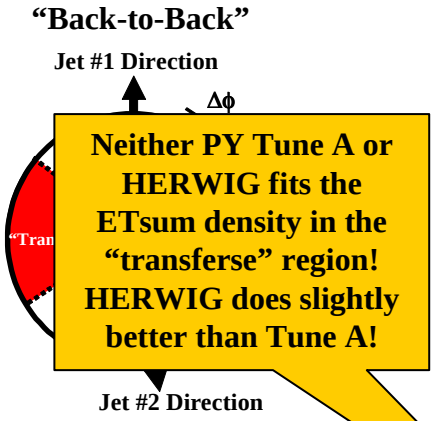




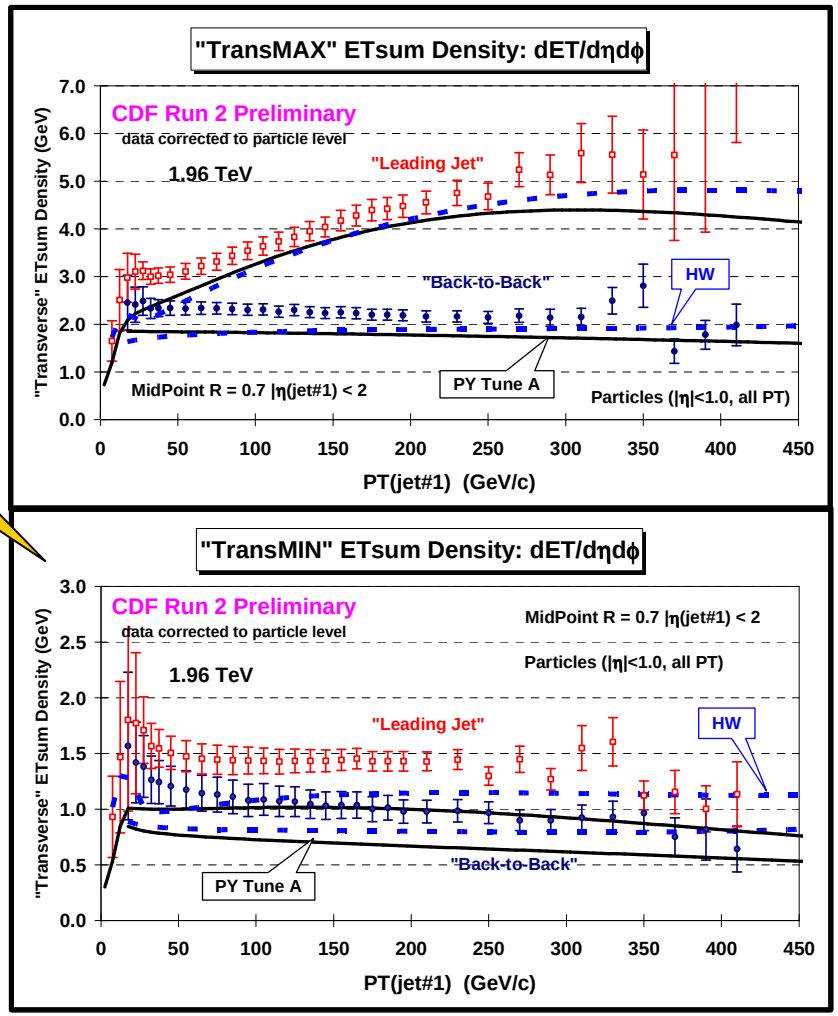
- **Shows the data on the tower ETsum density, $dET_{sum}/d\eta d\phi$, in the "transMAX" and "transMIN" region (E_T > 100 MeV, $|\eta| < 1$) versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.**
- **Compares the (*corrected*) data with PYTHIA Tune A (*with MPI*) and HERWIG (*without MPI*) at the particle level (all particles, $|\eta| < 1$).**







Neither PY Tune A or HERWIG fits the ETsum density in the "transferse" region! HERWIG does slightly better than Tune A!



- **Shows the data on the tower ETsum density, $dET_{sum}/d\eta d\phi$, in the "transMAX" and "transMIN" region ($E_T > 100$ MeV, $|\eta| < 1$) versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.**
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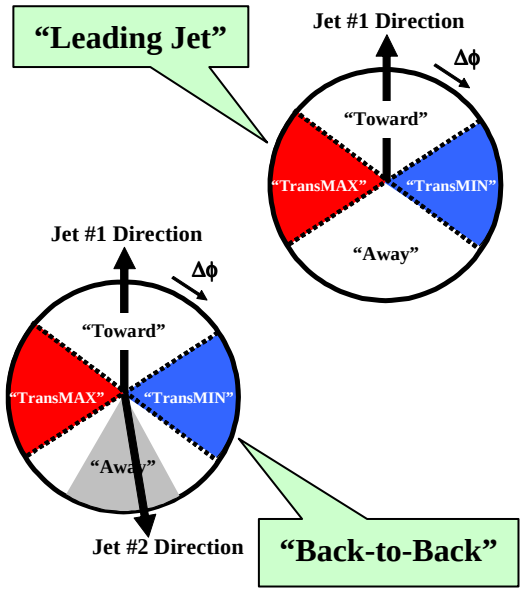
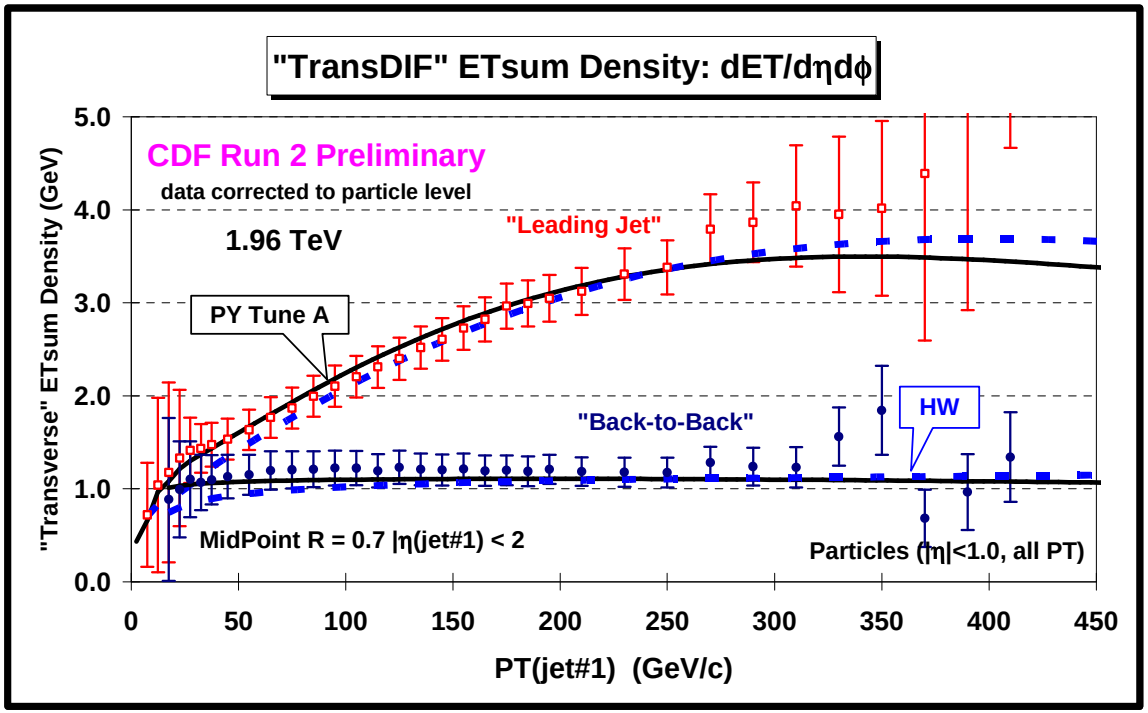
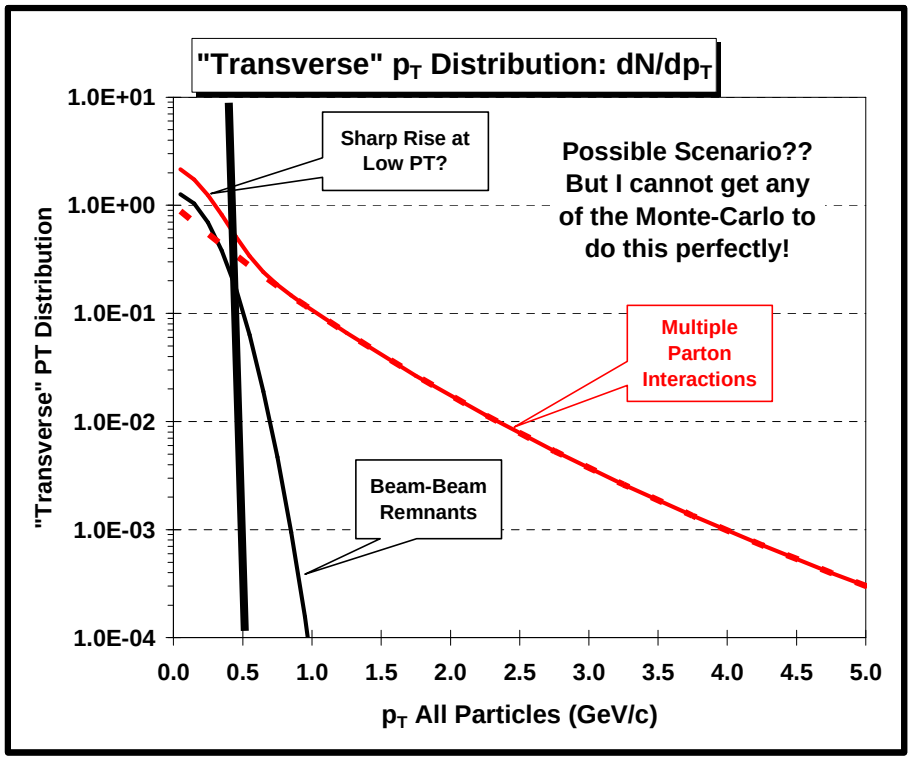




"transDIF" is more sensitive to the "hard scattering" component of the "underlying event"!

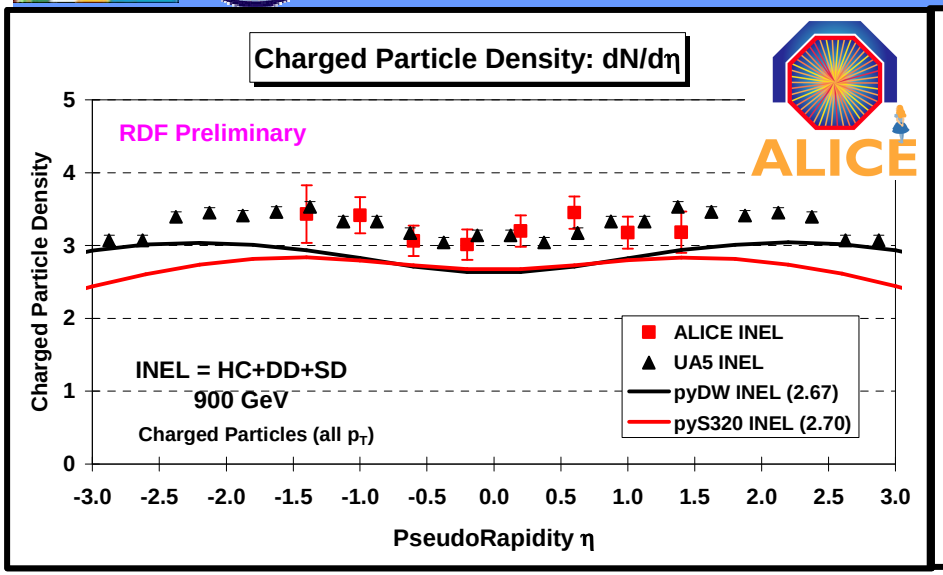
- **Use the leading jet to define the MAX and MIN "transverse" regions on an event-by-event basis with MAX (MIN) having the largest (smallest) charged PTsum density.**
- **Shows the "transDIF" = MAX-MIN ETsum density, $dET_{sum}/d\eta d\phi$, for all particles ($|\eta| < 1$) versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.**

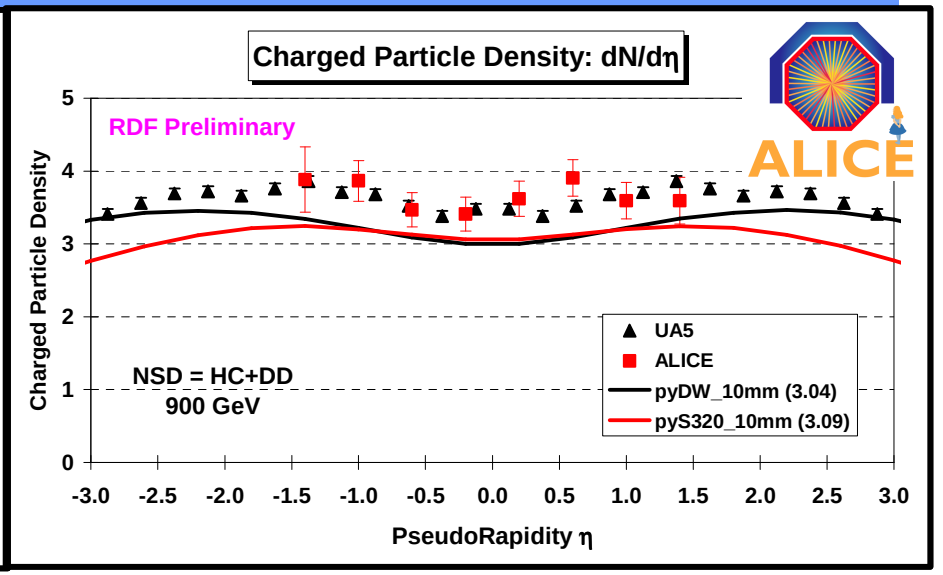
Possible Scenario??

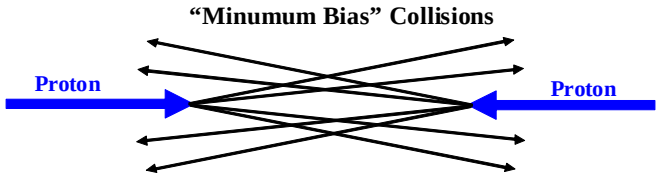


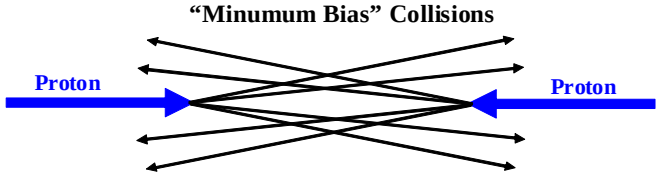
- **PYTHIA Tune A fits the charged particle PTsum density for $p_T > 0.5$ GeV/c, but it does not produce enough ETsum for towers with $E_T > 0.1$ GeV.**
- **It is possible that there is a sharp rise in the number of particles in the "underlying event" at low p_T (*i.e.* $p_T < 0.5$ GeV/c).**
- **Perhaps there are two components, a vary "soft" beam-beam remnant component (Gaussian or exponential) and a "hard" multiple interaction component.**

LHC MB Predictions: 900 GeV



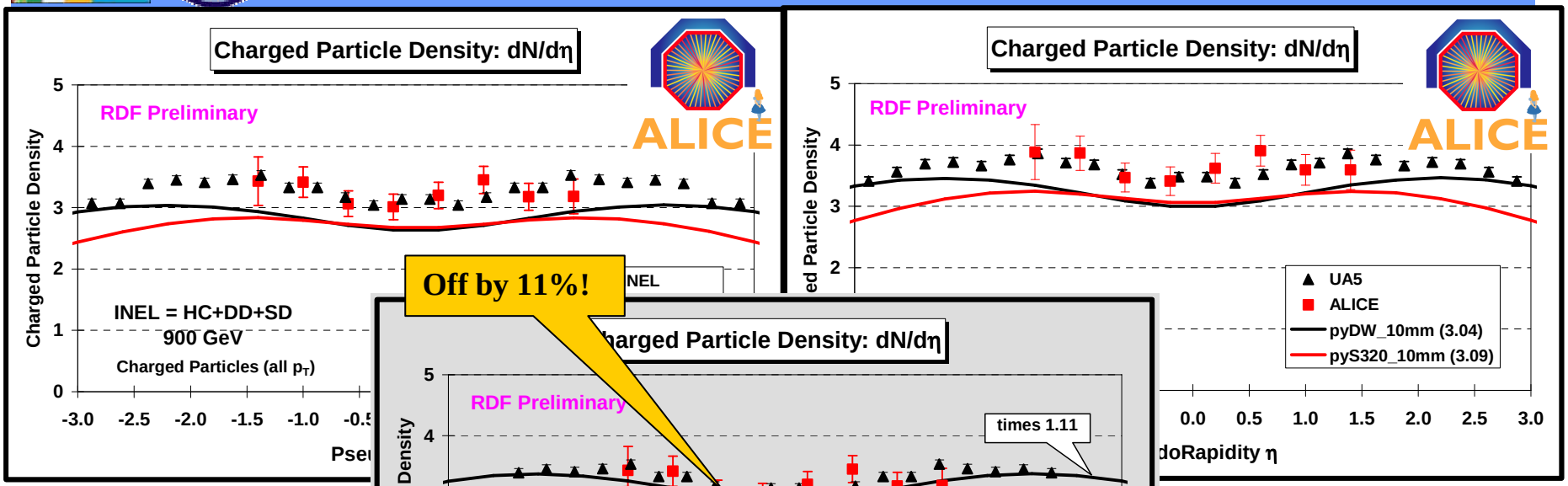






➡ **Compares the 900 GeV ALICE data with PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old Q^2-ordered parton shower and the old MPI model. Tune S320 uses the new p_T-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of dN/dη for the region $|\eta| < 0.6$.**

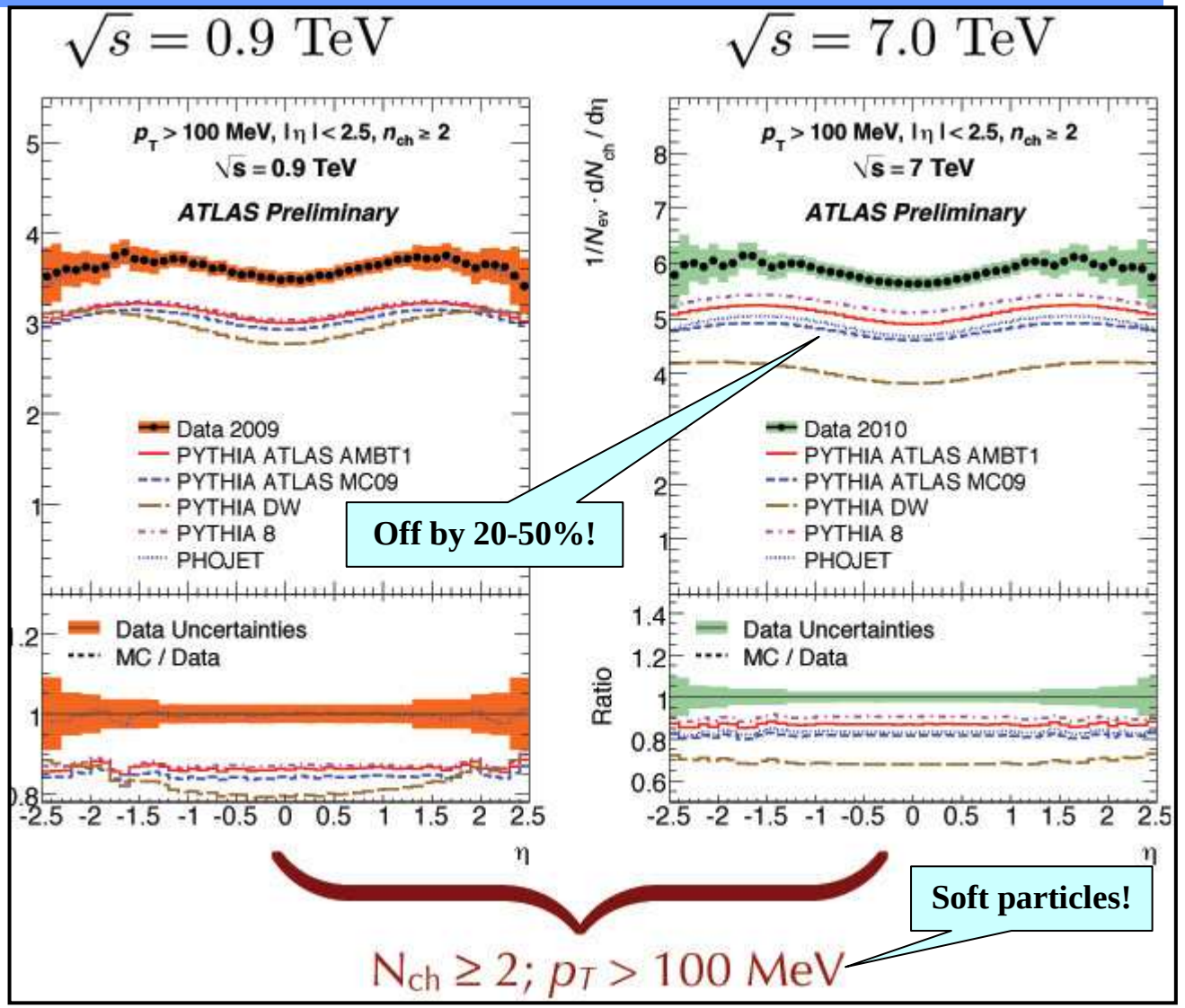
LHC MB Predictions: 900 GeV



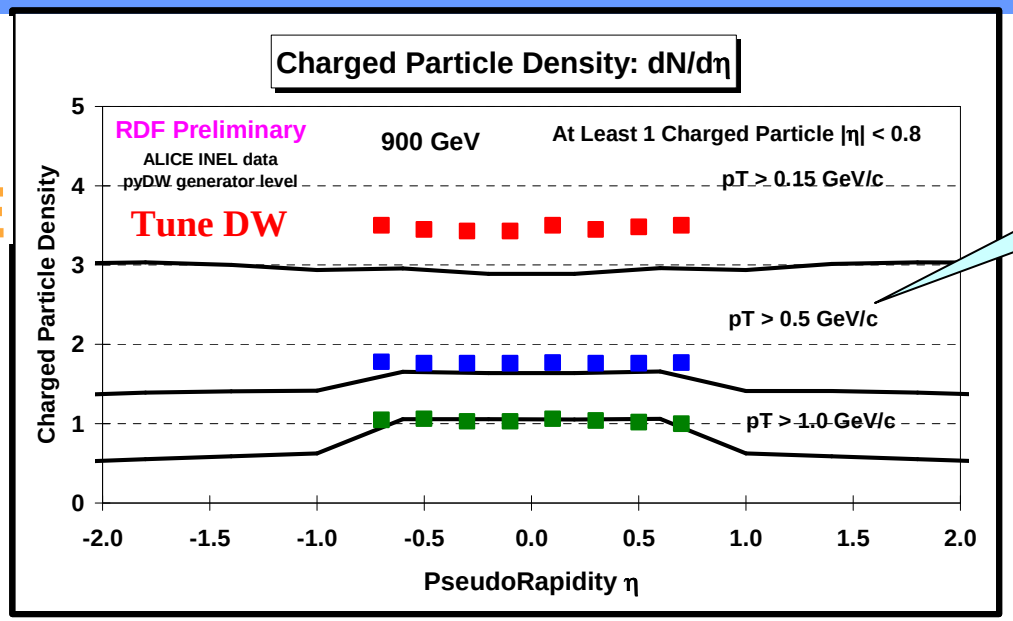
➡ **Compares the 90(… e S320 Perugia 0. Tune DW uses th… IPI model. Tune S320 uses the new p_T-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of dN/dη for the region |η| < 0.6.**

ATLAS INEL dN/dη

- None of the tunes fit the ATLAS INEL dN/dη data with PT > 100 MeV! They all predict too few particles.
- The ATLAS Tune AMBT1 was designed to fit the inelastic data for Nchg ≥ 6 with p_T > 0.5 GeV/c!



PYTHIA Tune DW

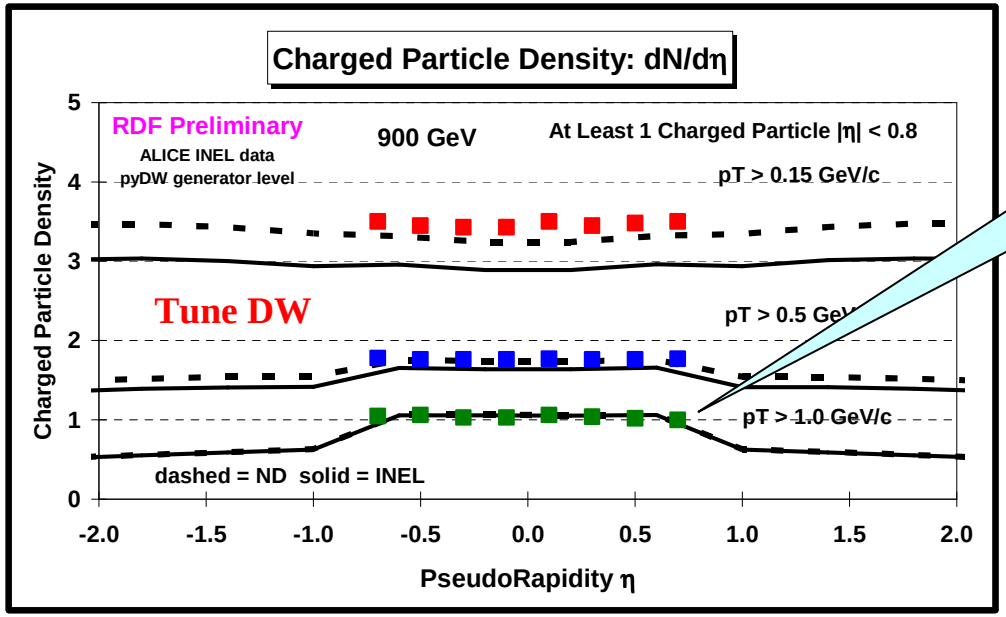


If one increases the hard scale the agreement improves!

➡ **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 DW at the generator level.**

The same thing occurs at 7 TeV!
ALICE, ATLAS, and CMS data coming soon.

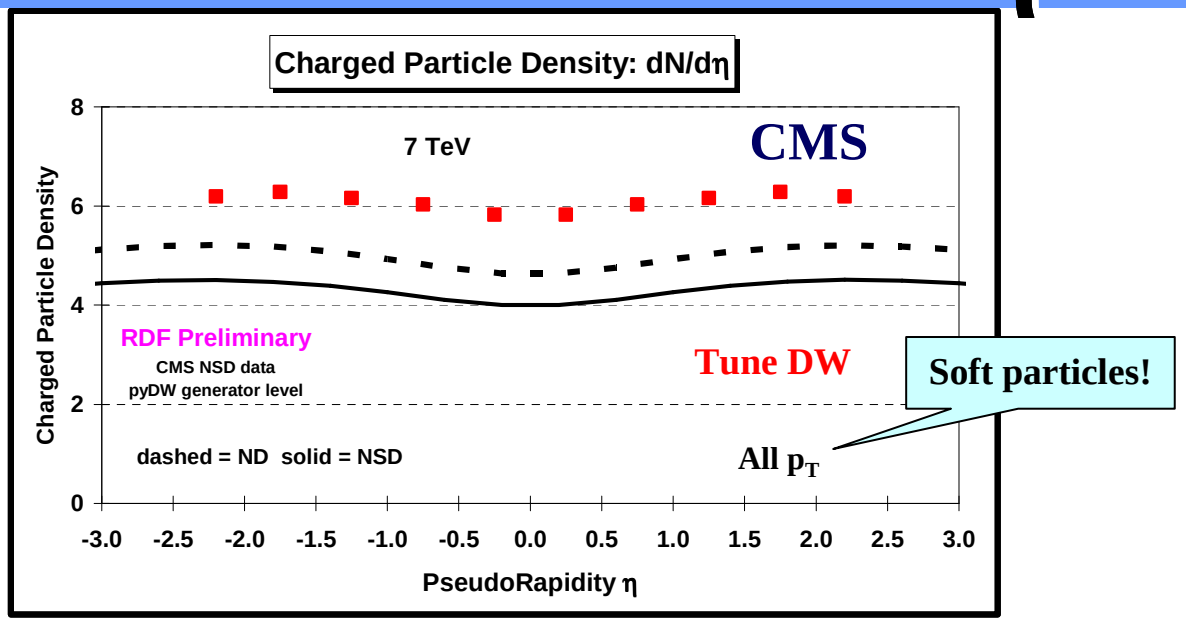
PYTHIA Tune DW



➡ **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 (dashed = ND, solid = INEL).**

Cannot trust PYTHIA 6.2 modeling of diffraction!

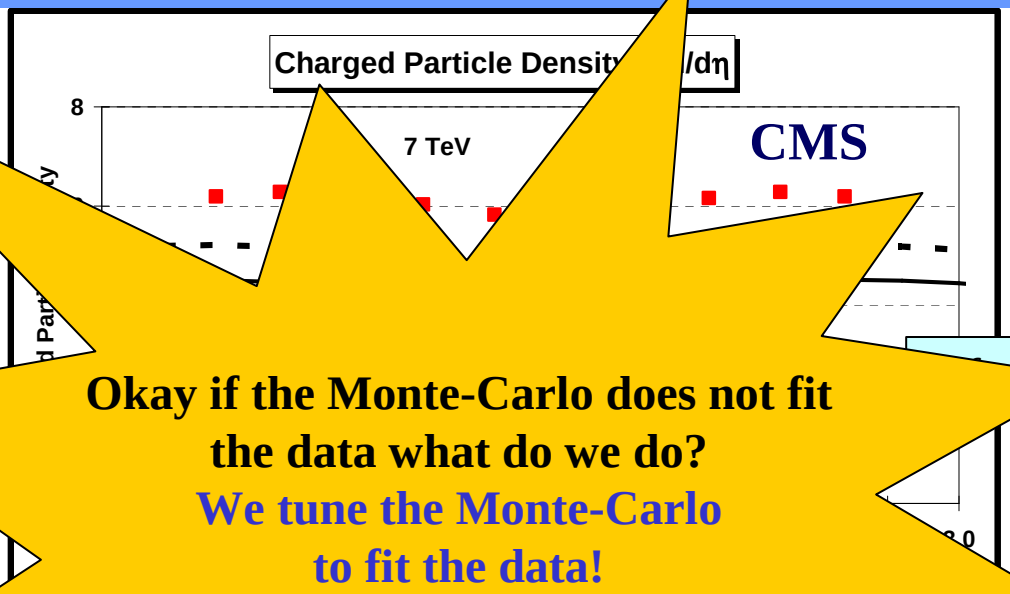
CMS dN/dη



➡ **Generator level dN/dη (all pT). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.**

Off by 50%!

CMS dN/dη

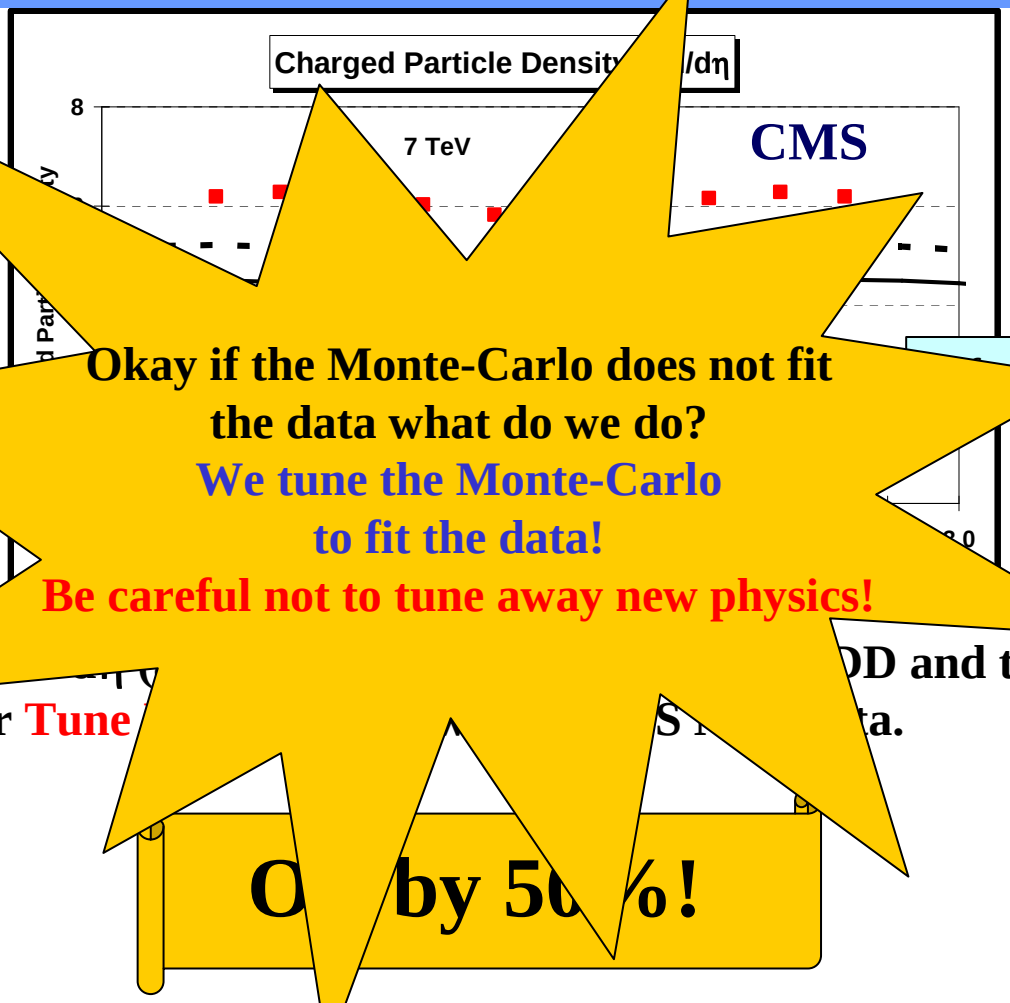


Okay if the Monte-Carlo does not fit the data what do we do?
We tune the Monte-Carlo to fit the data!

- **Generator l… OD and the HC = ND contributions for Tune … S 1… ta.**

O… by 50…%!

CMS dN/dη



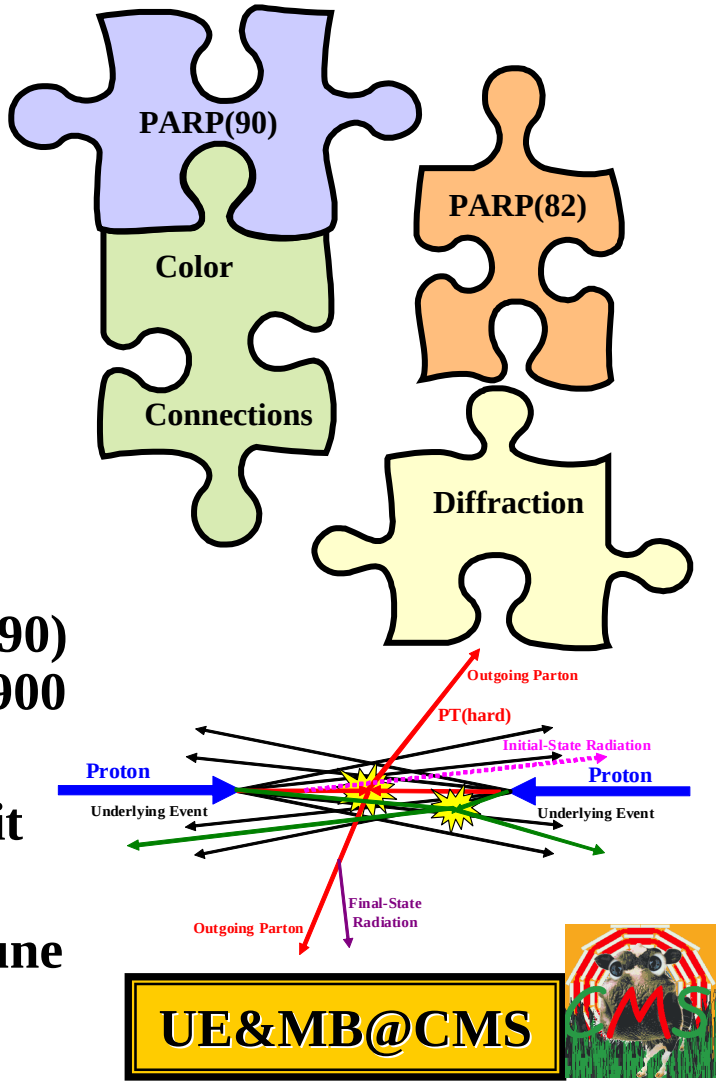
Okay if the Monte-Carlo does not fit the data what do we do?
We tune the Monte-Carlo to fit the data!
Be careful not to tune away new physics!

➡ **Generator**
DD and the HC = ND contributions for Tune
ta.

O by 50%!

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!

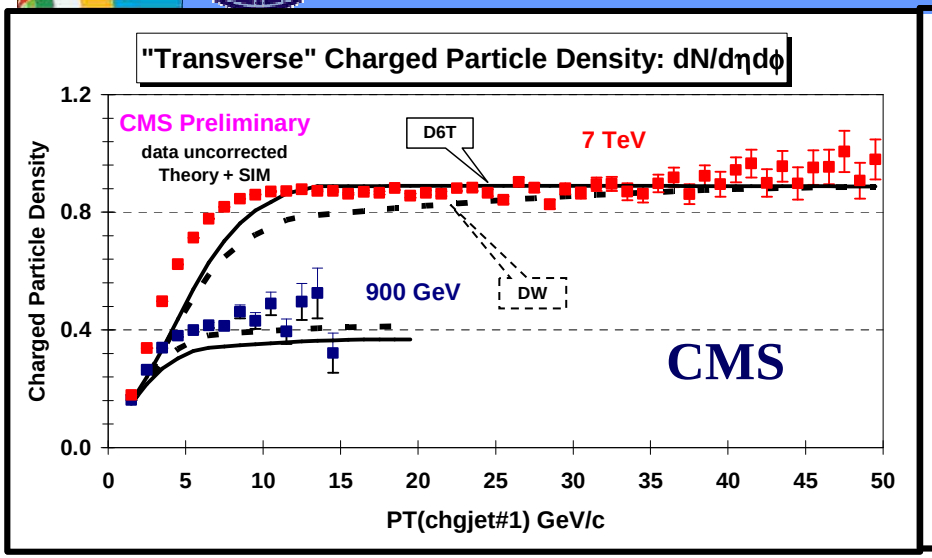


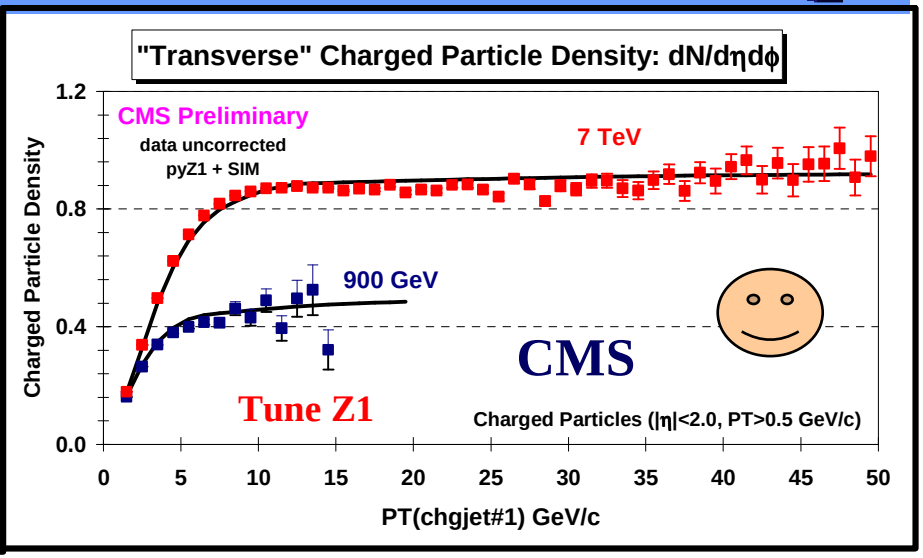
PYTHIA Tune Z1

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

PYTHIA Tune Z1





➡ **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 $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW and D6T after detector simulation (SIM).**

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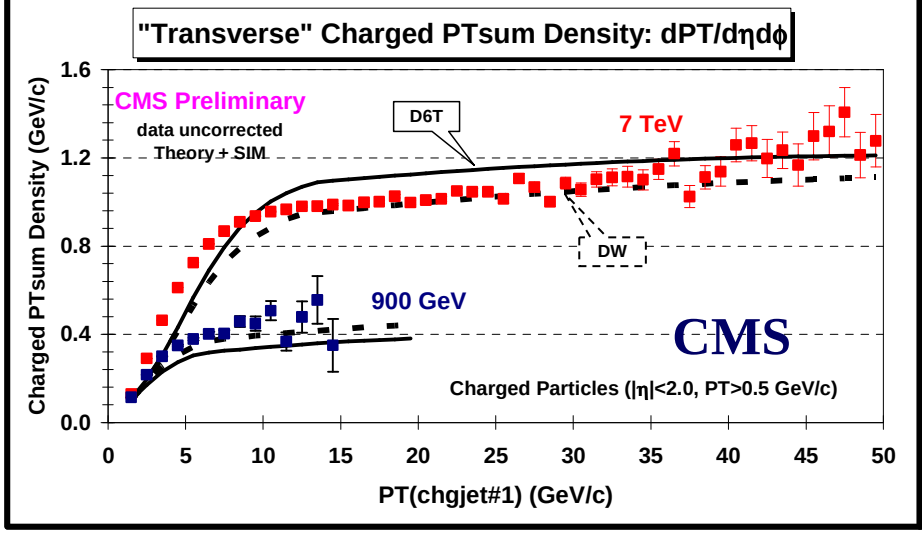
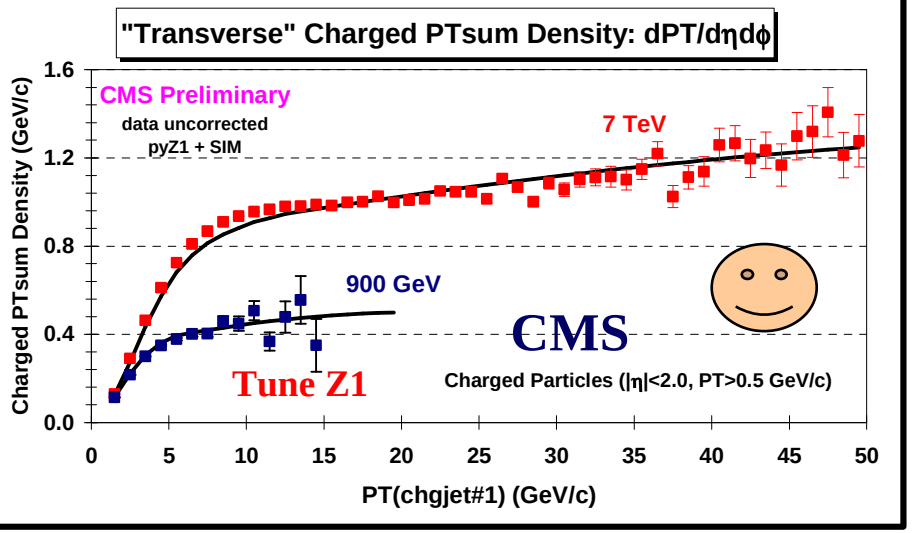
Color reconnection suppression.
Color reconnection strength.

Tune Z1 (CTEQ5L)
PARP(82) = 1.932
PARP(90) = 0.275
PARP(77) = 1.016
PARP(78) = 0.538

Tune Z1 is a PYTHIA 6.4 using p_T-ordered parton showers and the new MPI model!

PYTHIA Tune Z1





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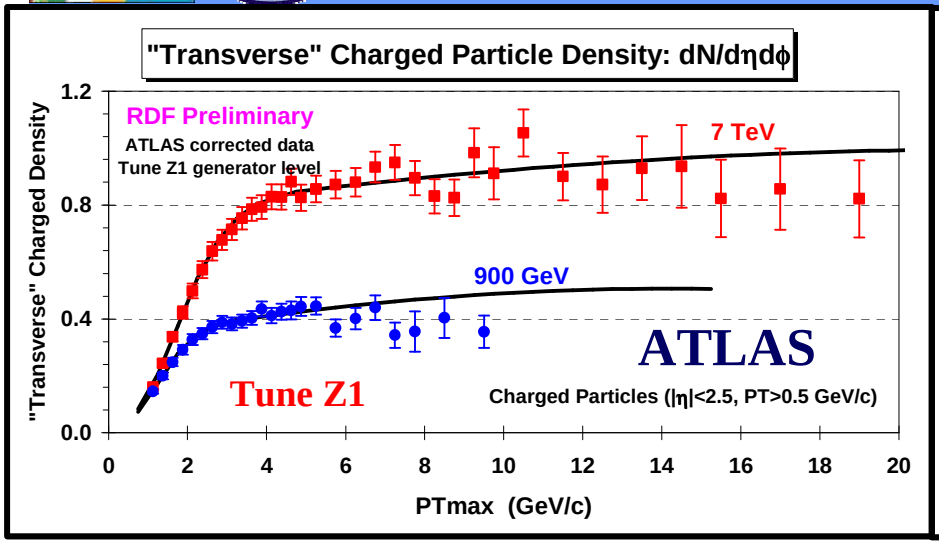
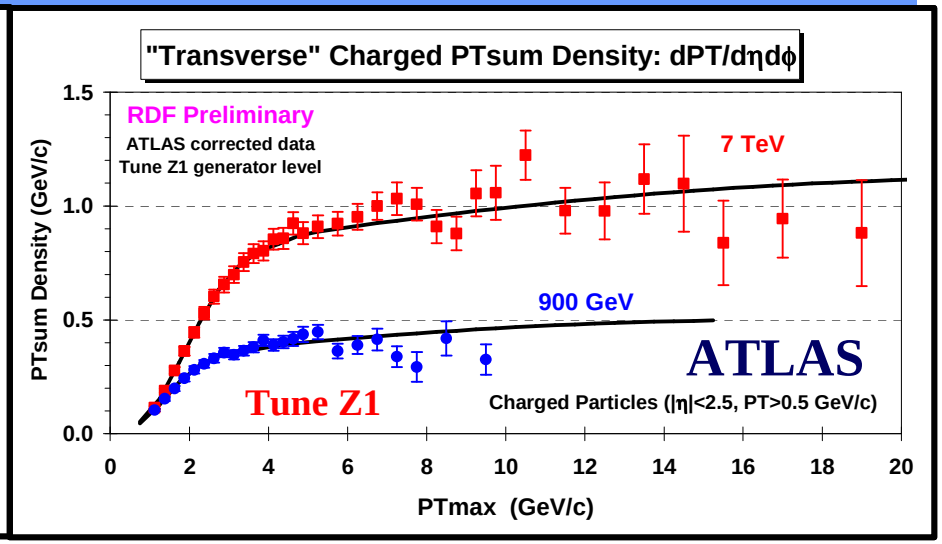
PYTHIA Tune Z1





➡ **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 Z1 at the generator level.**

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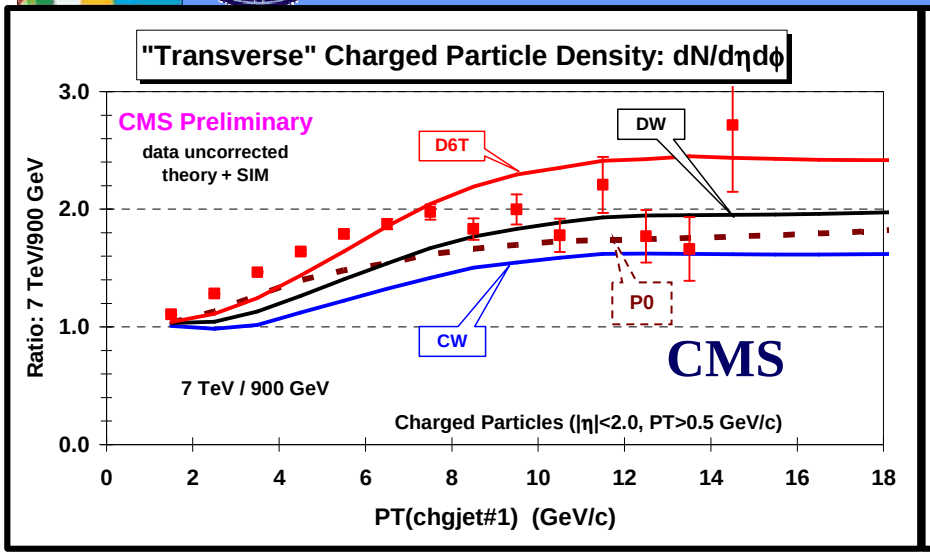

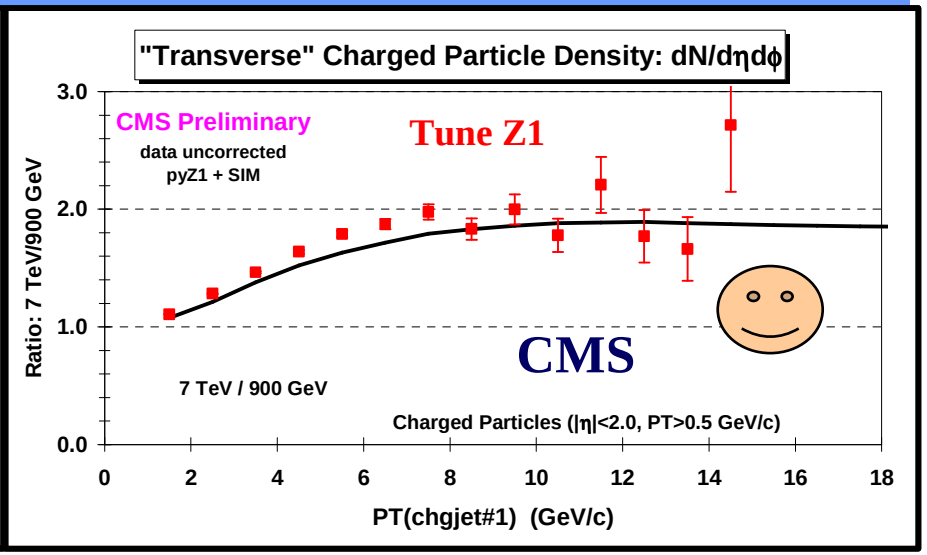

- **Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the "transverse" charged particle density as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW, D6T, CW, and P0 after detector simulation (SIM).**

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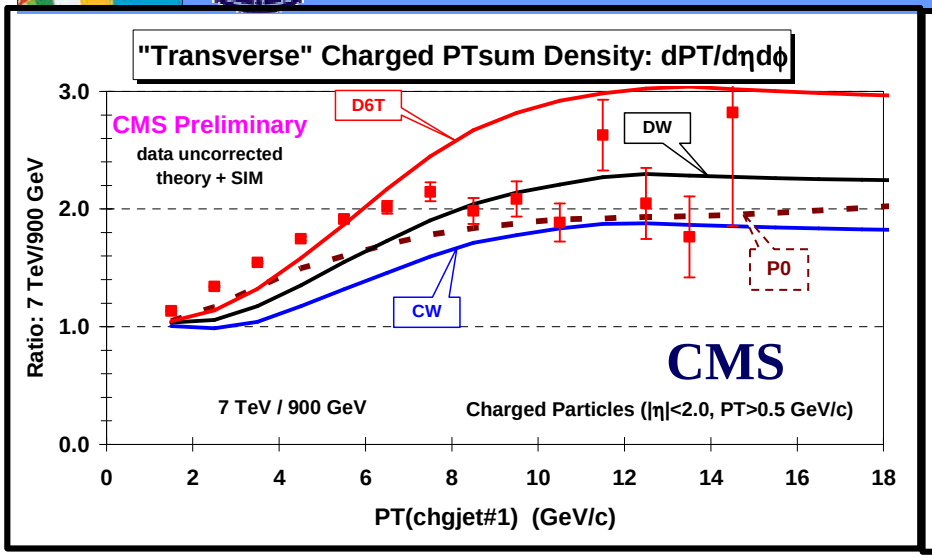
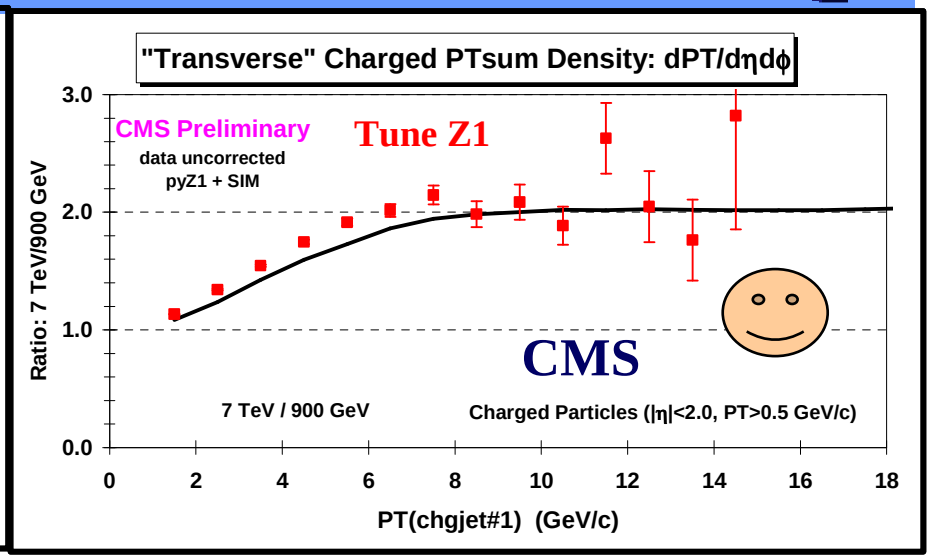
PYTHIA Tune Z1





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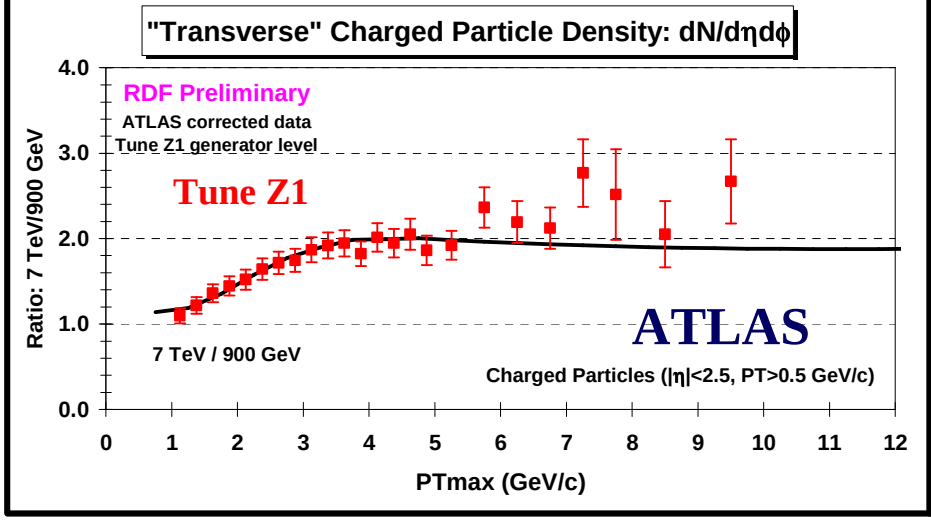
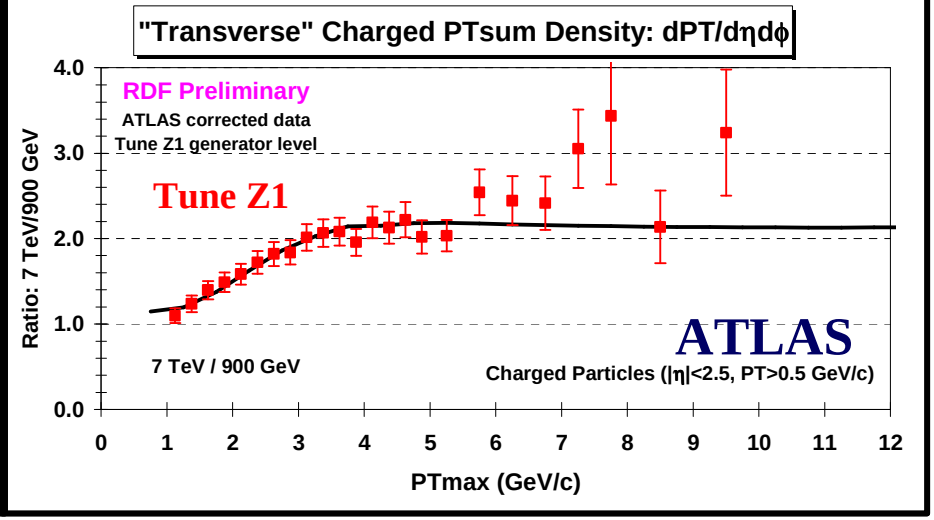
PYTHIA Tune Z1

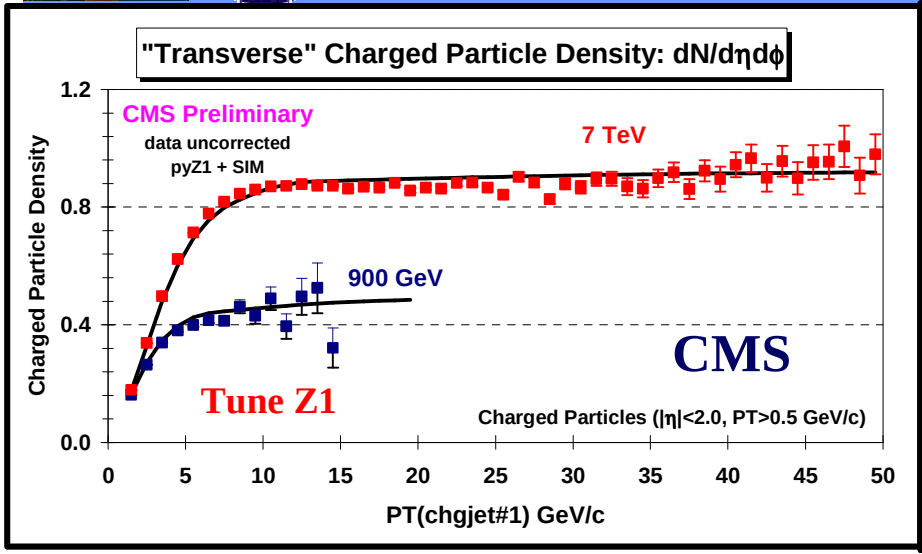


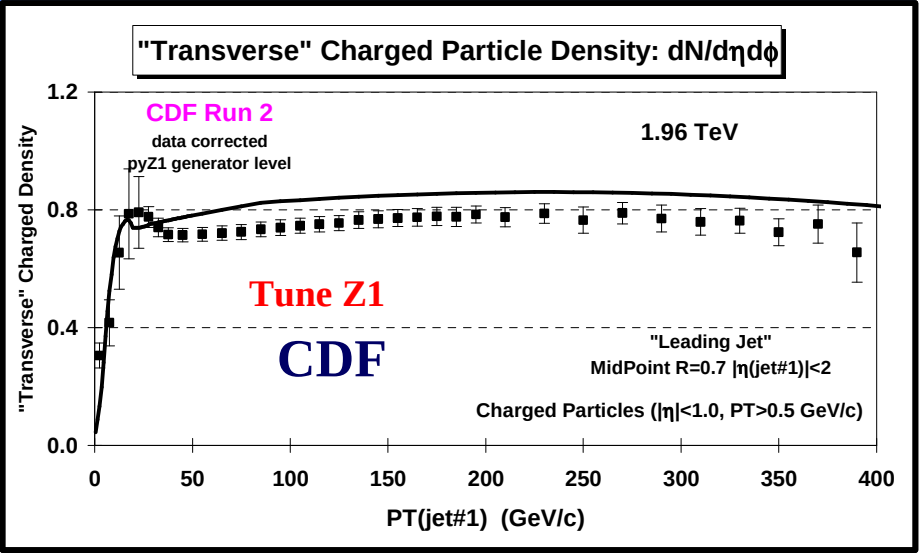


- **Ratio of the ATLAS preliminary data on the charged particle density in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2.5) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.**

- **Ratio of the ATLAS preliminary data on the charged PTsum density in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2.5) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.**

PYTHIA Tune Z1

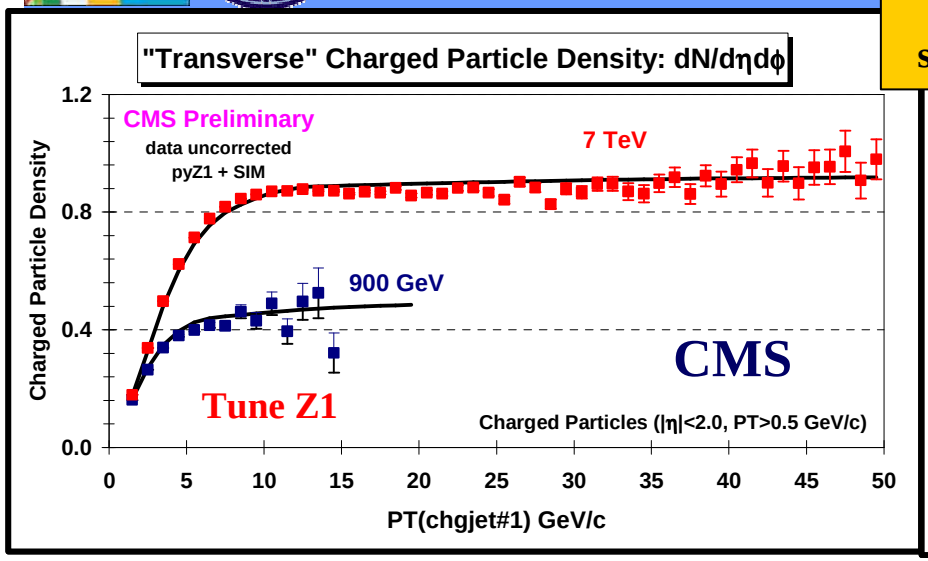




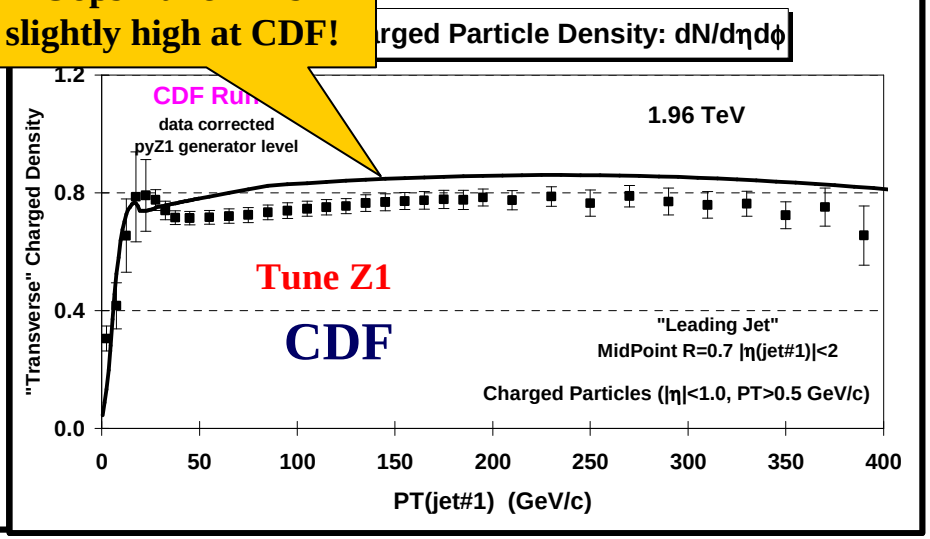
- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune Z1 after detector simulation.**

- **CDF published 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 $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

PYTHIA Tune Z1



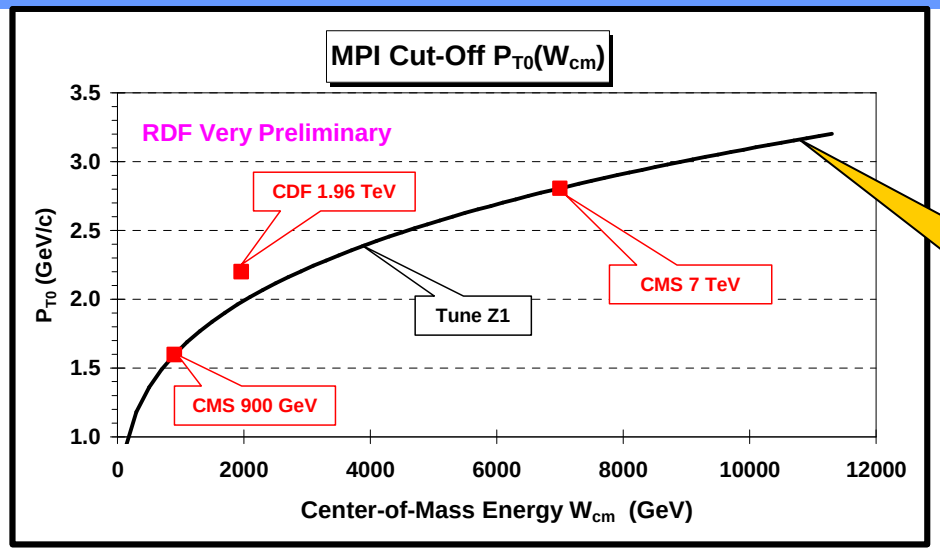
Oops Tune Z1 is slightly high at CDF!



- **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 Z1 after detector simulation.**

- **CDF published 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 $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

PYTHIA Tune Z1

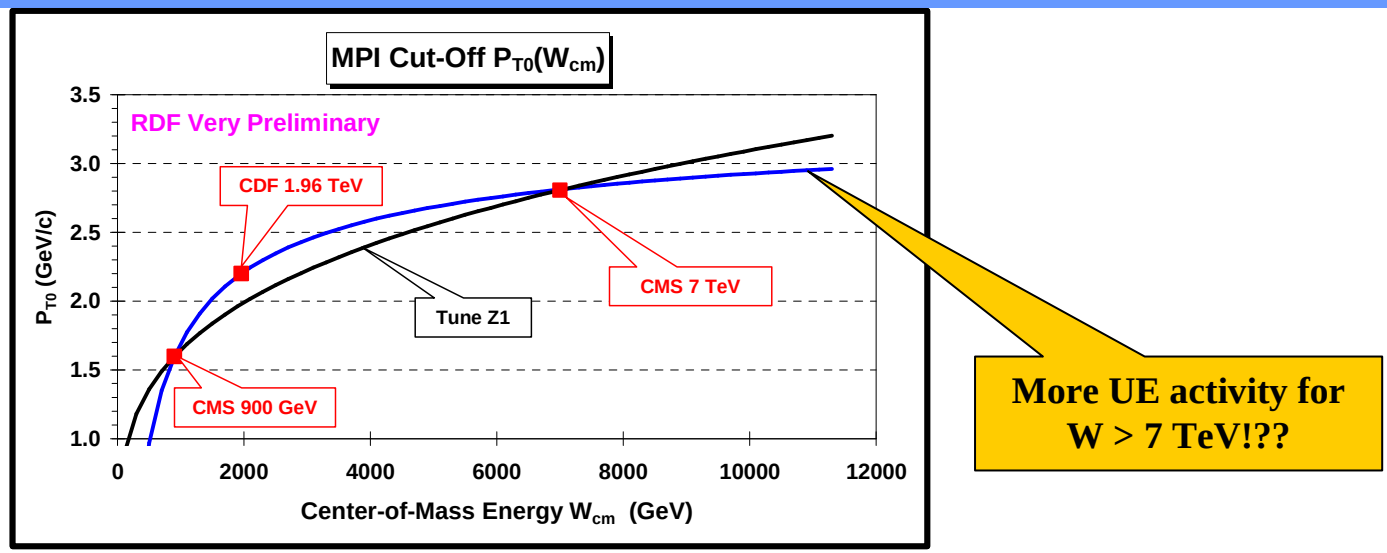


$p_{T0}(W)=p_{T0}(W/W0)^{e}$

➡ **MPI Cut-Off versus the Center-of Mass Energy W_{cm}: PYTHIA Tune Z1 was determined by fitting p_{T0} independently at 900 GeV and 7 TeV and calculating ε = PARP(90). The best fit to p_{T0} at CDF is slightly higher than the Tune Z1 curve. This is very preliminary! Perhaps with a global fit to all three energies (*i.e.* "Professor" tune) one can get a simultaneous fit to all three??**

$$p_{T0}(W)=p_{T0}(W/W_0)^{\varepsilon} \quad \varepsilon = \text{PARP(90)} \quad p_{T0} = \text{PARP(82)} \quad W = E_{cm}$$

PYTHIA Tune Z1



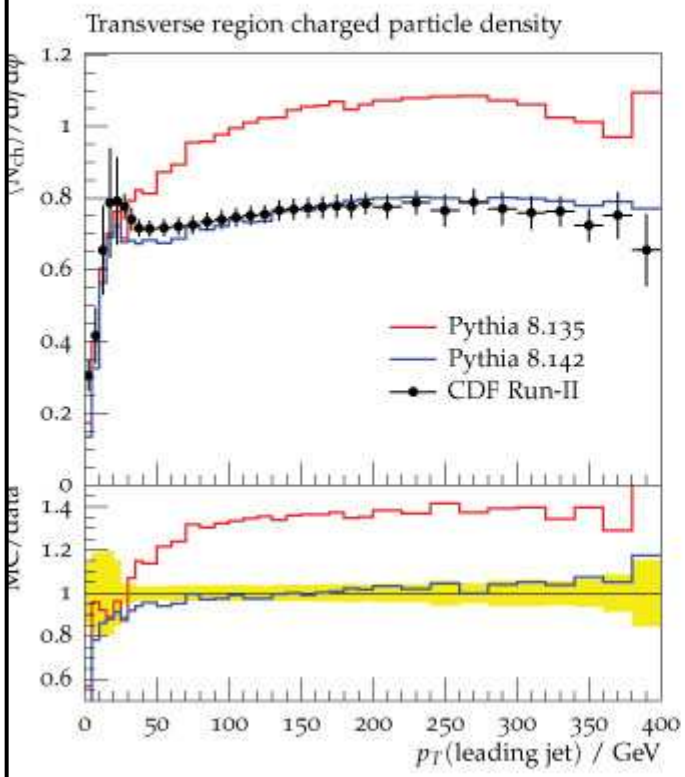
➡ **MPI Cut-Off versus the Center-of Mass Energy W_{cm}: PYTHIA Tune Z1 was determined by fitting p_{T0} independently at 900 GeV and 7 TeV and calculating ε = PARP(90). The best fit to p_{T0} at CDF is slightly higher than the Tune Z1 curve. This is very preliminary! Perhaps with a global fit to all three energies (*i.e.* "Professor" tune) one can get a simultaneous fit to all three??**

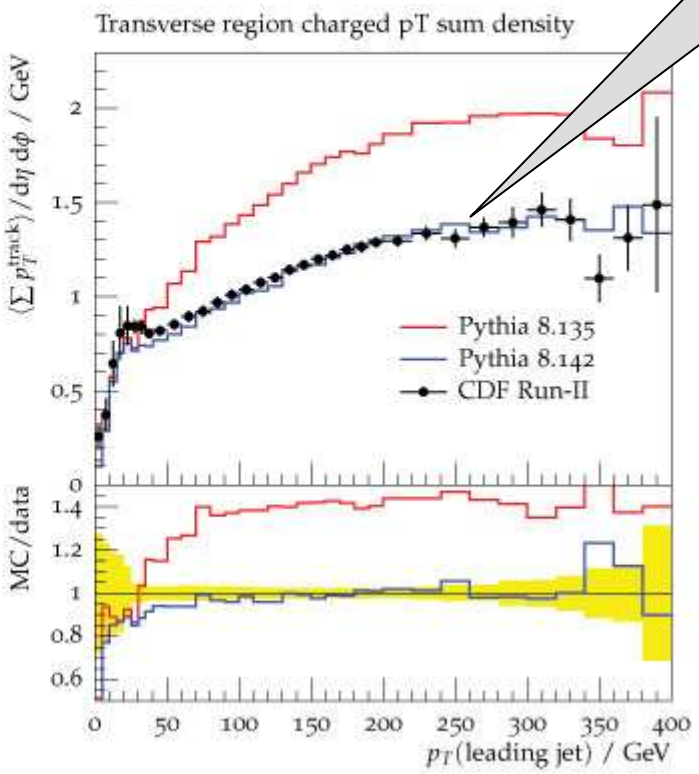
$$p_{T0}(W)=p_{T0}(W/W_0)^{\varepsilon} \quad \varepsilon = PARP(90) \quad p_{T0} = PARP(82) \quad W = E_{cm}$$

PYTHIA 8 Tunes

Pythia 8 – UE Hendrik Hoeth ISMD2010

Bug in versions older than 8.140, affecting hard QCD events.





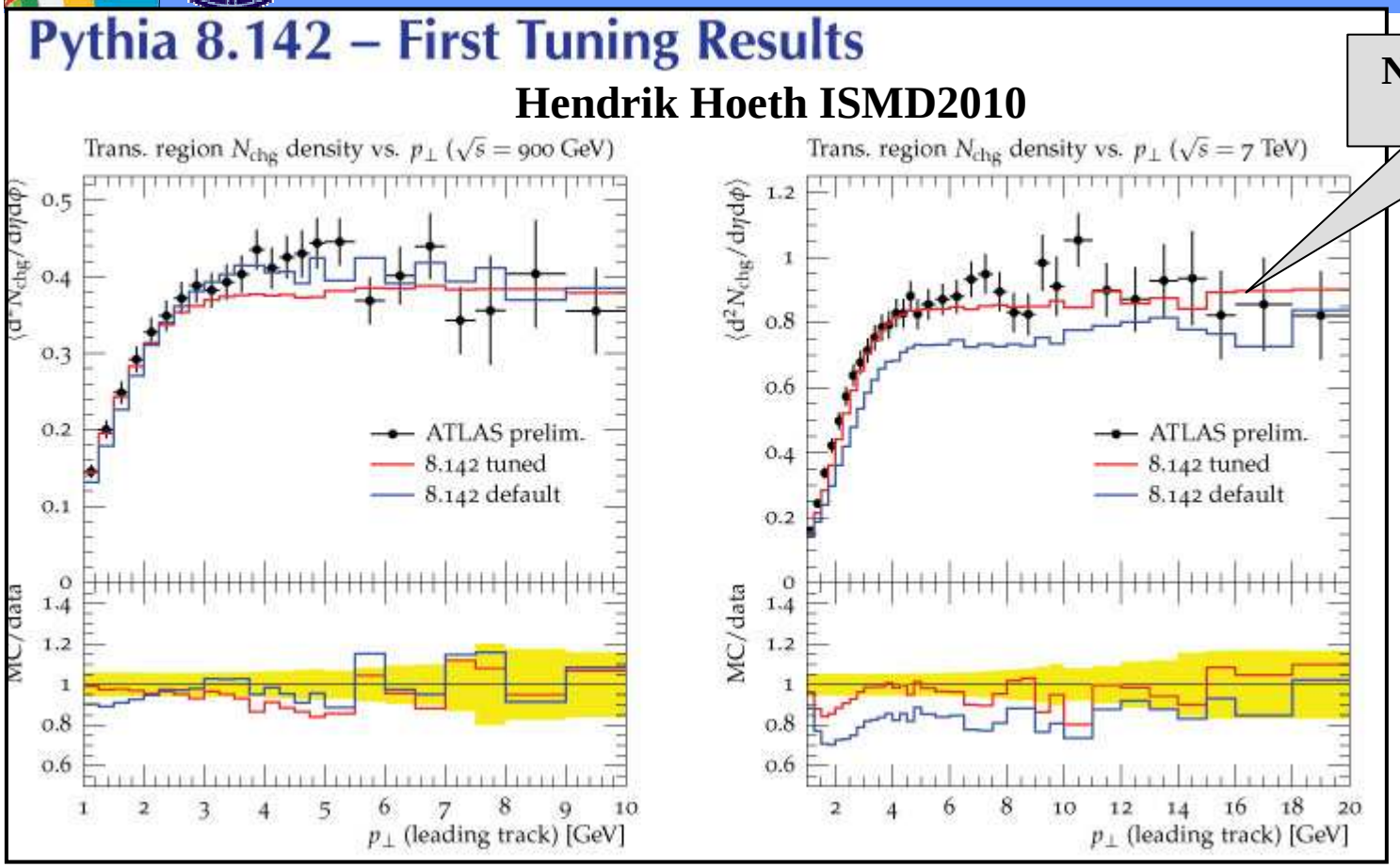
New PYTHIA 8 tune!

➡ **New PYTHIA 8.142 "professor" tune from Hendrik Hoeth.**

PYTHIA 8 Tunes

Pythia 8.142 – First Tuning Results

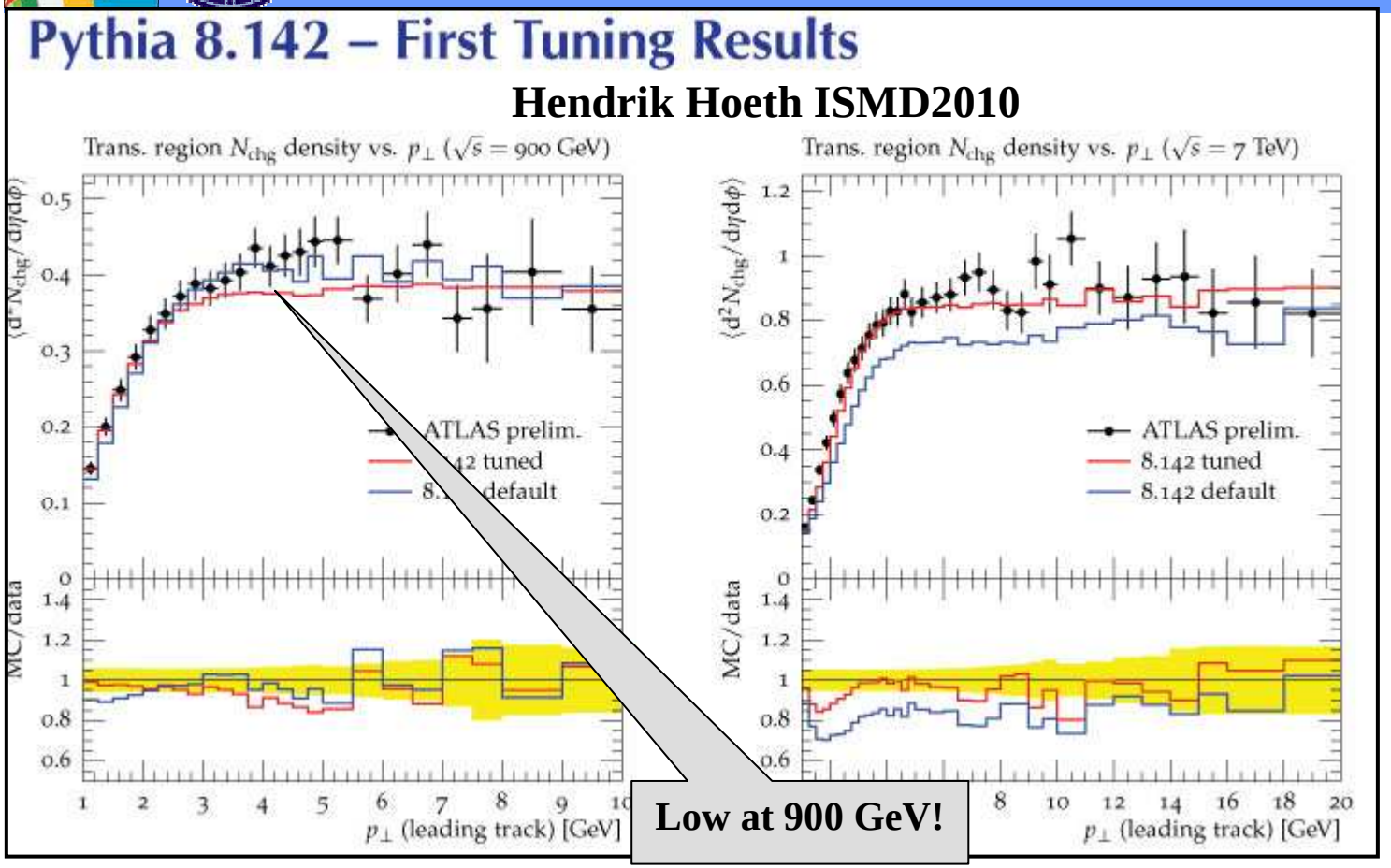
Hendrik Hoeth ISMD2010



New PYTHIA 8 tune!

➡ **New PYTHIA 8.142 "professor" tune from Hendrik Hoeth.**

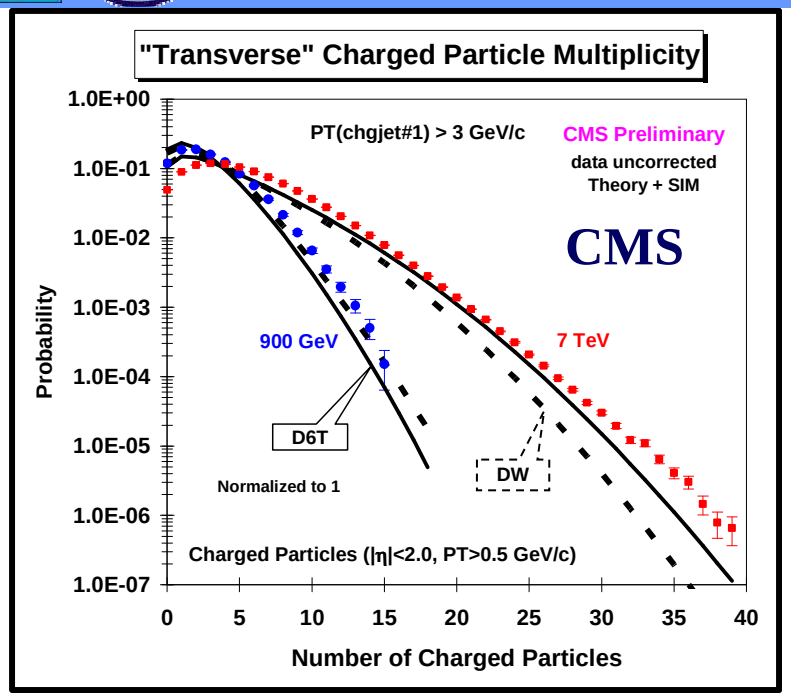
PYTHIA 8 Tunes

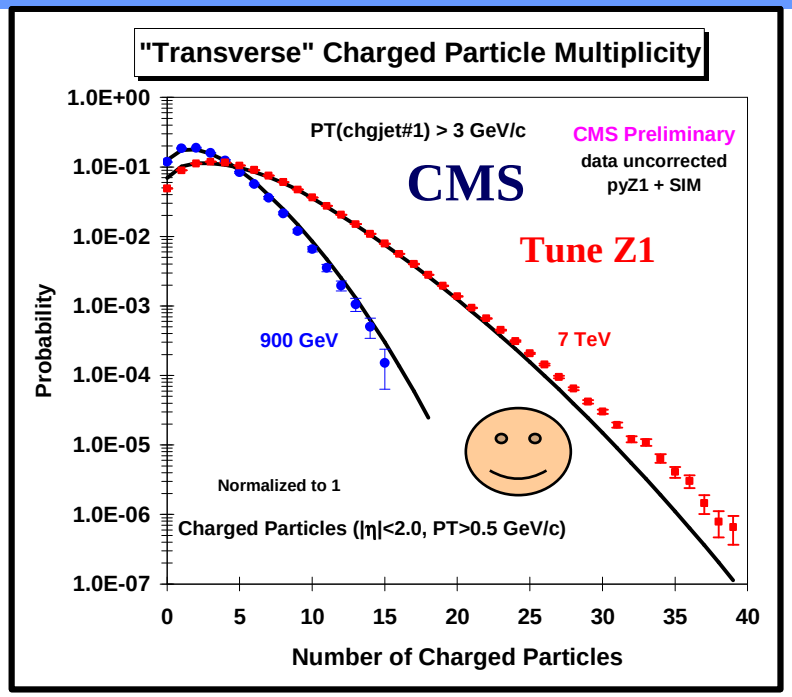


➡ **New PYTHIA 8.142 "professor" tune from Hendrik Hoeth.**

➡ **Fits nicely 1.96 TeV and 7 TeV, but is low at 900 GeV!**

"Transverse" Multiplicity Distribution

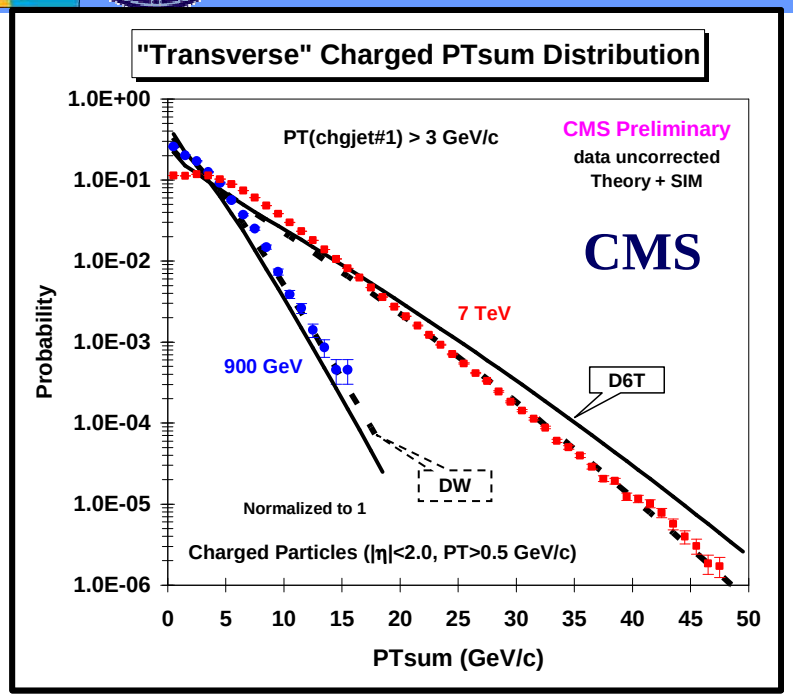


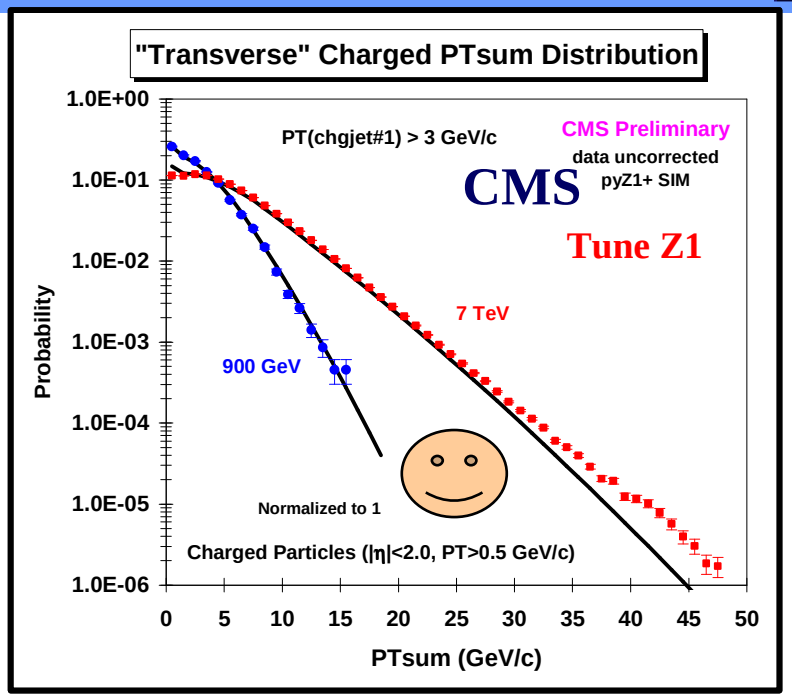


- **CMS uncorrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune DW and Tune D6T at the detector level (*i.e.* Theory + SIM).**

- **CMS uncorrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

"Transverse" PTsum Distribution

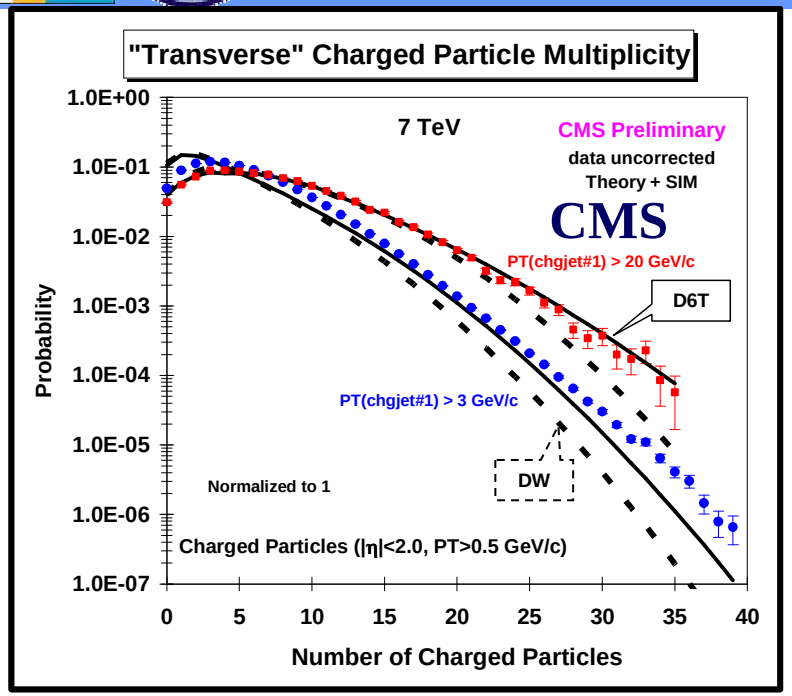


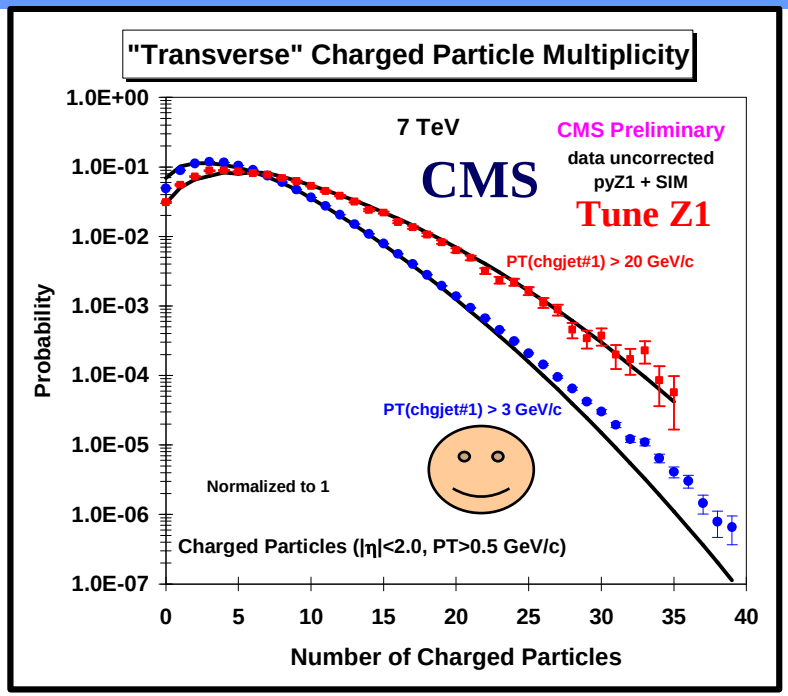


➡ **CMS uncorrected data at 900 GeV and 7 TeV on the charged scalar PTsum distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune DW, and Tune D6T at the detector level (*i.e.* Theory + SIM).**

➡ **CMS uncorrected data at 900 GeV and 7 TeV on the charged scalar PTsum distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1, at the detector level (*i.e.* Theory + SIM).**

"Transverse" Multiplicity Distribution

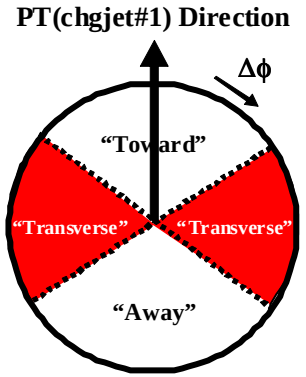


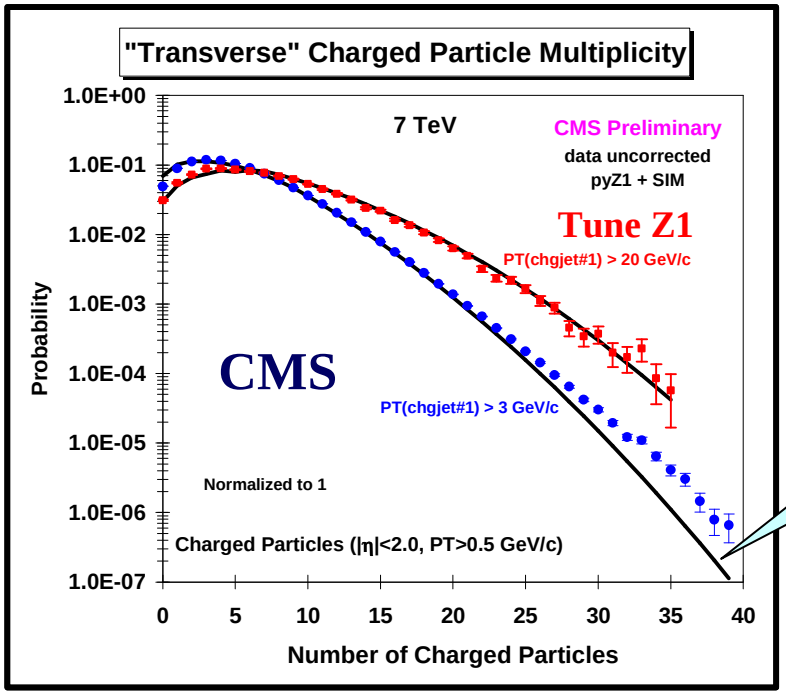


➡ **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune DW and Tune D6T at the detector level (*i.e.* Theory + SIM).**

➡ **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

"Transverse" Multiplicity Distribution

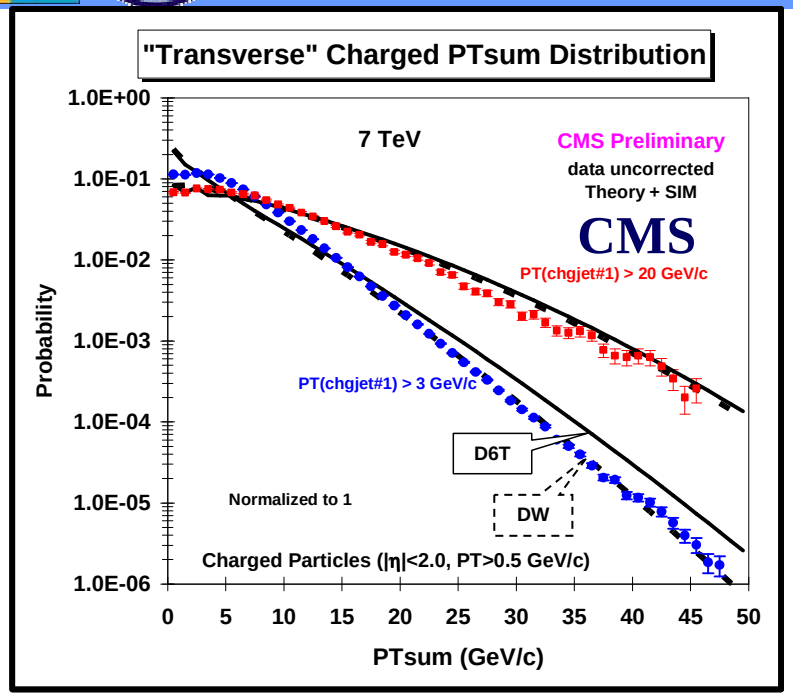


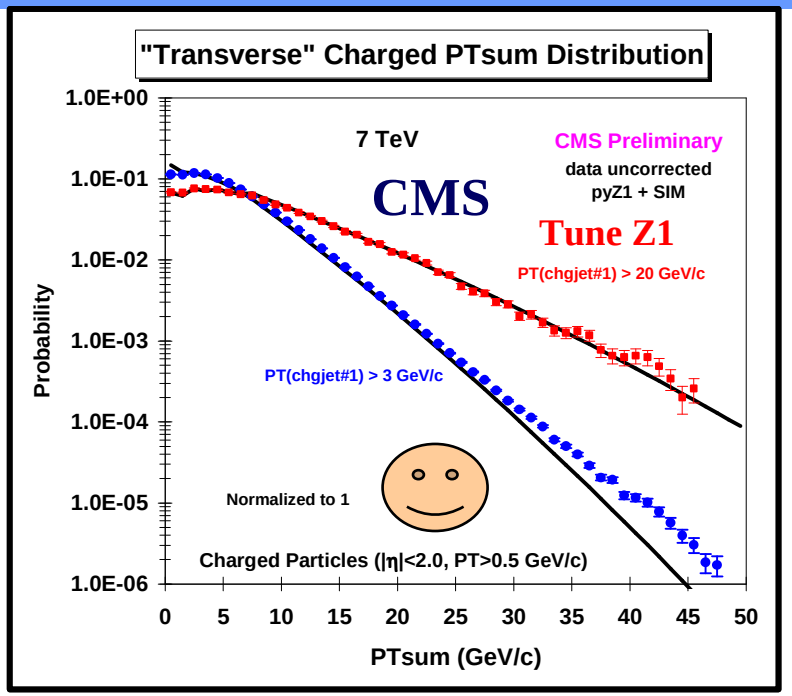


Difficult to produce enough events with large "transverse" multiplicity at low hard scale!

- **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet, chgjet#1, with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

"Transverse" PTsum Distribution

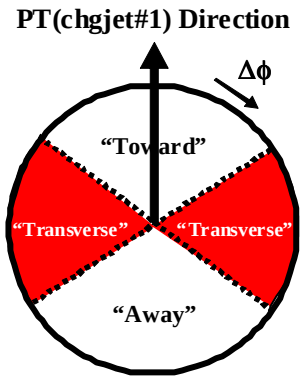


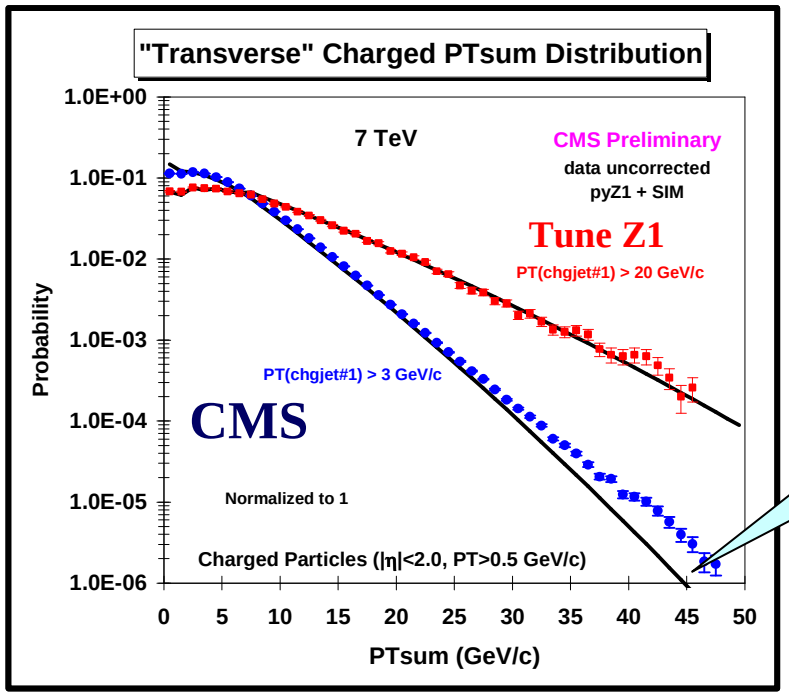


➡ **CMS uncorrected data at 7 TeV on the charged PTsum distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune DW and Tune D6T at the detector level (*i.e.* Theory + SIM).**

➡ **CMS uncorrected data at 7 TeV on the charged PTsum distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

"Transverse" PTsum Distribution

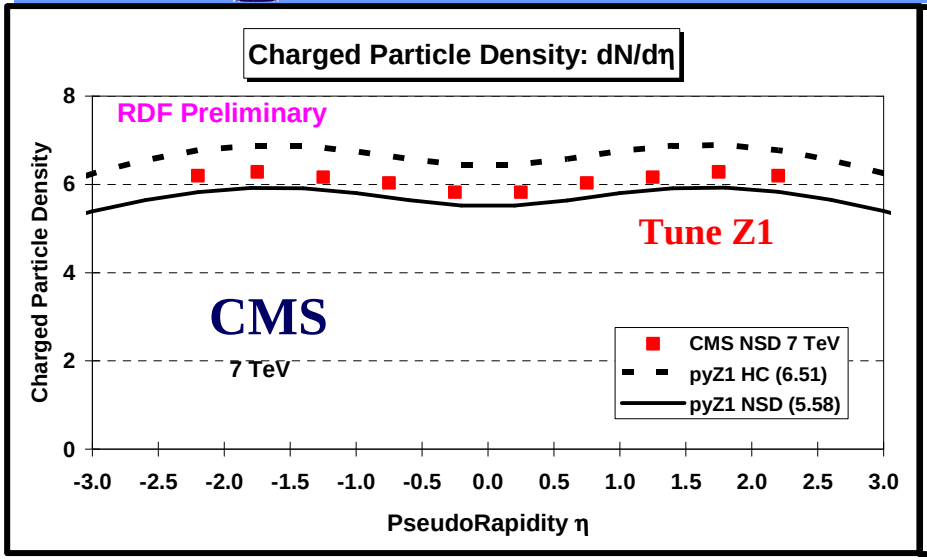


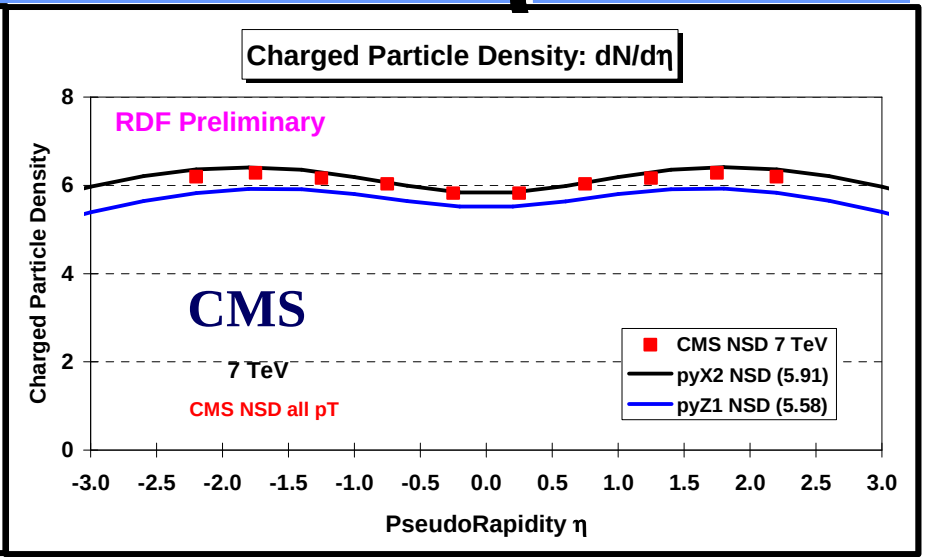


Difficult to produce enough events with large "transverse" PTsum at low hard scale!

➡ **CMS uncorrected data at 7 TeV on the charged PTsum distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet, chgjet#1, with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

CMS dN/dη



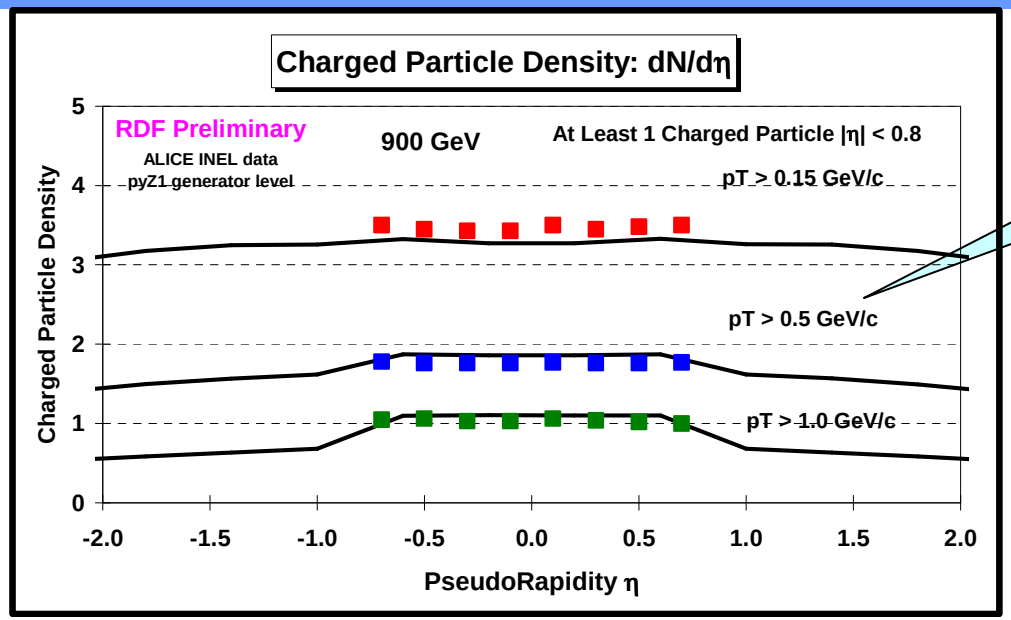


- Generator level dN/dη (all pT). Shows the NSD = HC + DD and the HC = ND contributions for Tune Z1. Also shows the CMS NSD data.

- Generator level dN/dη (all pT). Shows the NSD = HC + DD prediction for Tune Z1 and Tune X2. Also shows the CMS NSD data.

Okay not perfect, but remember we do not know if the DD is correct!

PYTHIA Tune Z1

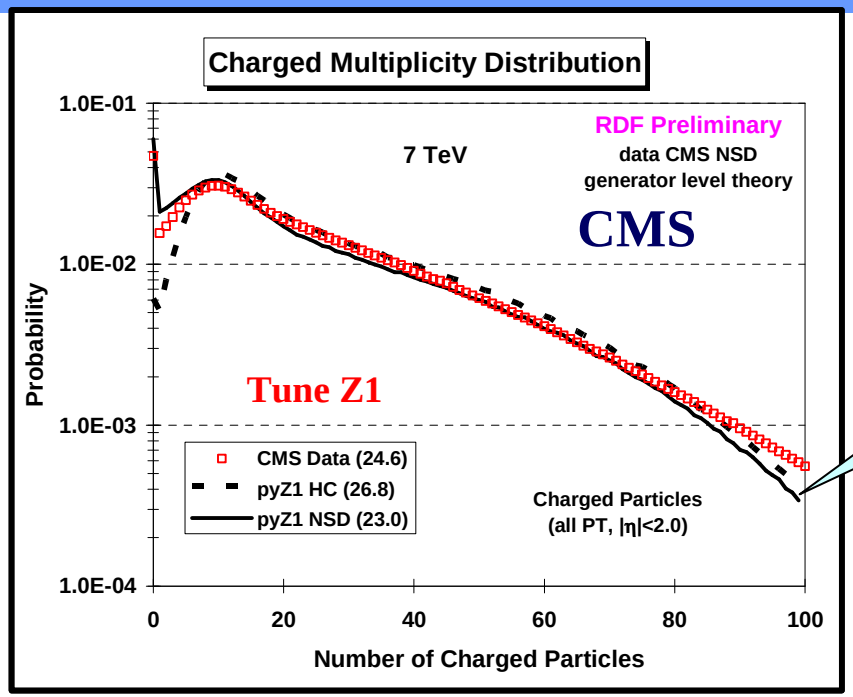


If one increases the hard scale the agreement improves!

- **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.**

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

NSD Multiplicity Distribution

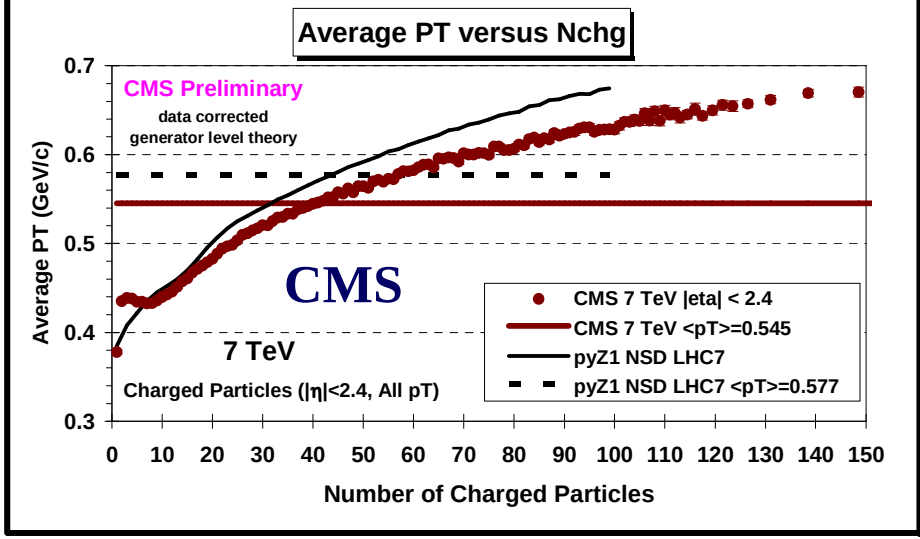


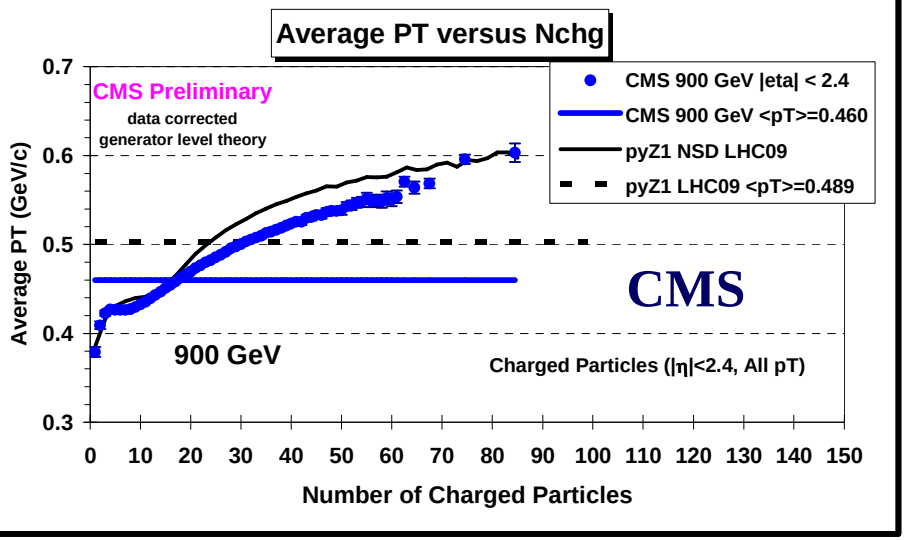
Difficult to produce enough events with large multiplicity!

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

Okay not perfect!
But not that bad!

NSD <pT> versus Nchg

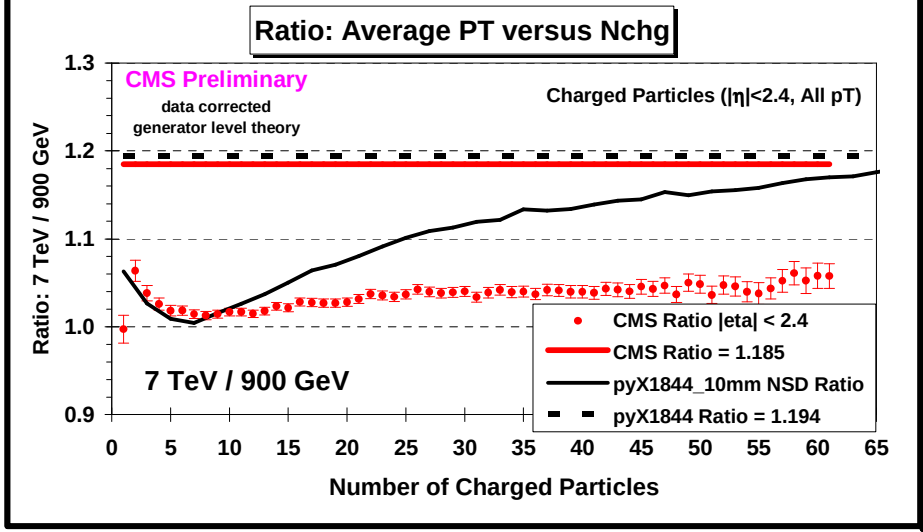


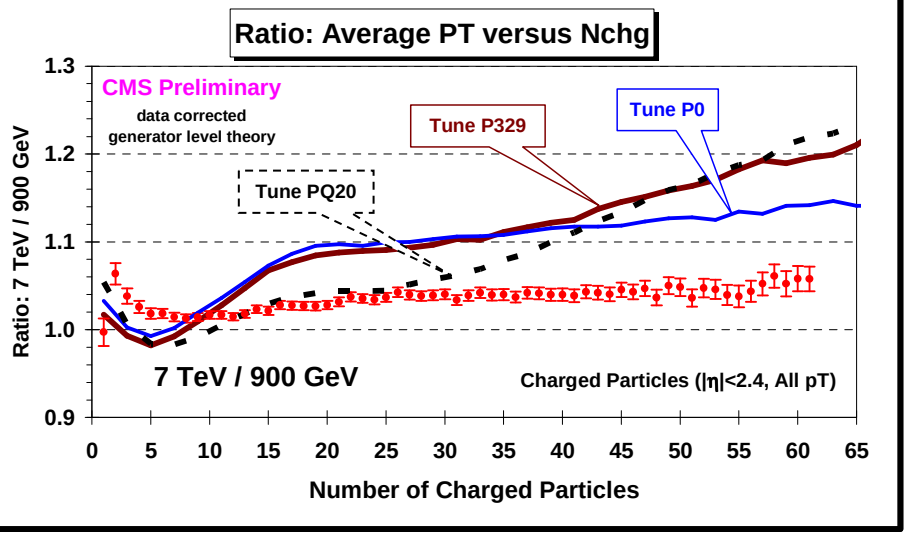


➡ **Shows the 7 TeV and 900 GeV CMS NSD corrected data on $\langle p_T \rangle$ versus Nchg (all p_T, $|\eta| < 2.4$) compared with Tune Z1.**

Okay not perfect!
But not that bad!

<p_T> versus Nchg

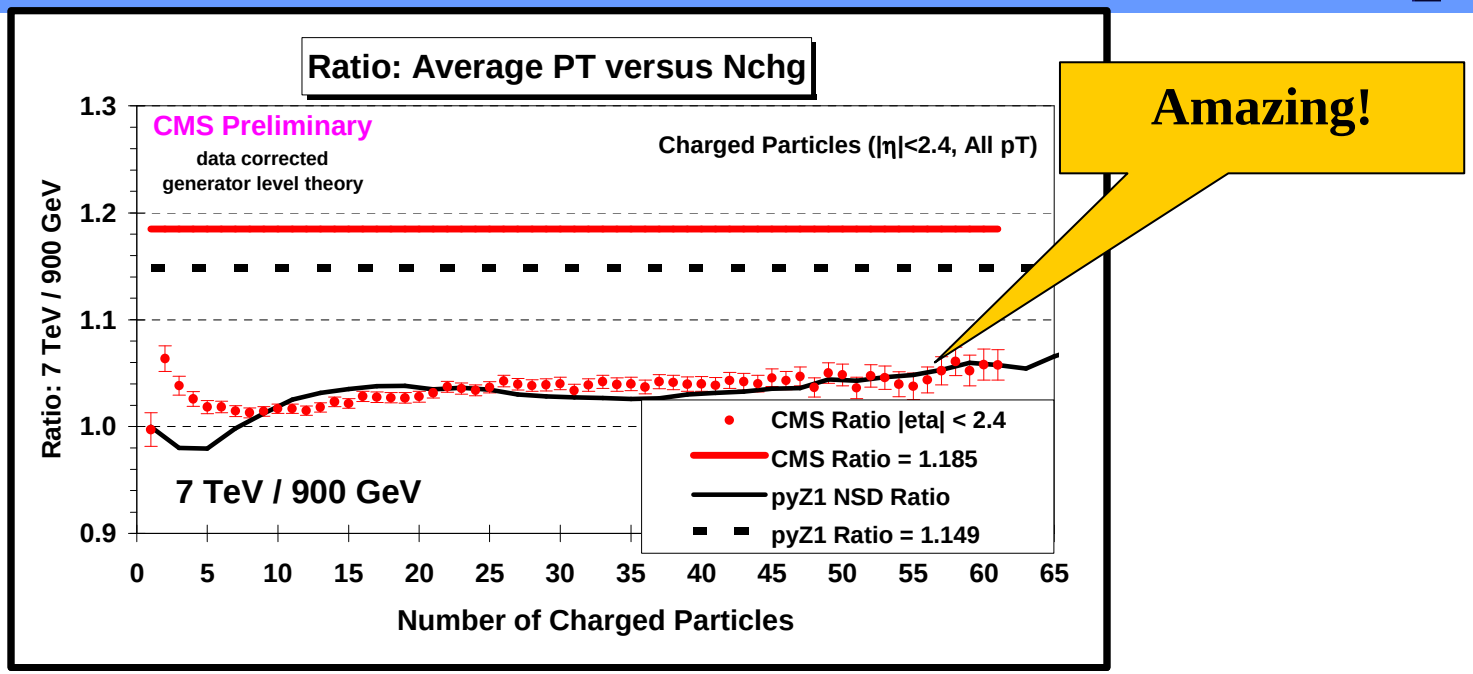




- (*left*) Shows the energy dependence of the CMS NSD corrected data on <p_T> versus Nchg (all p_T, $|\eta| < 2.4$) compared with Tune X2. Also shows the energy dependence of the overall <pT> compared with Tune X2.

- (*right*) Shows the energy dependence of the CMS NSD corrected data on <p_T> versus Nchg (all p_T, $|\eta| < 2.4$) compared with Tune P0, Tune PQ20, and Tune P329. **It will be interesting to see if any tune can get this right!**

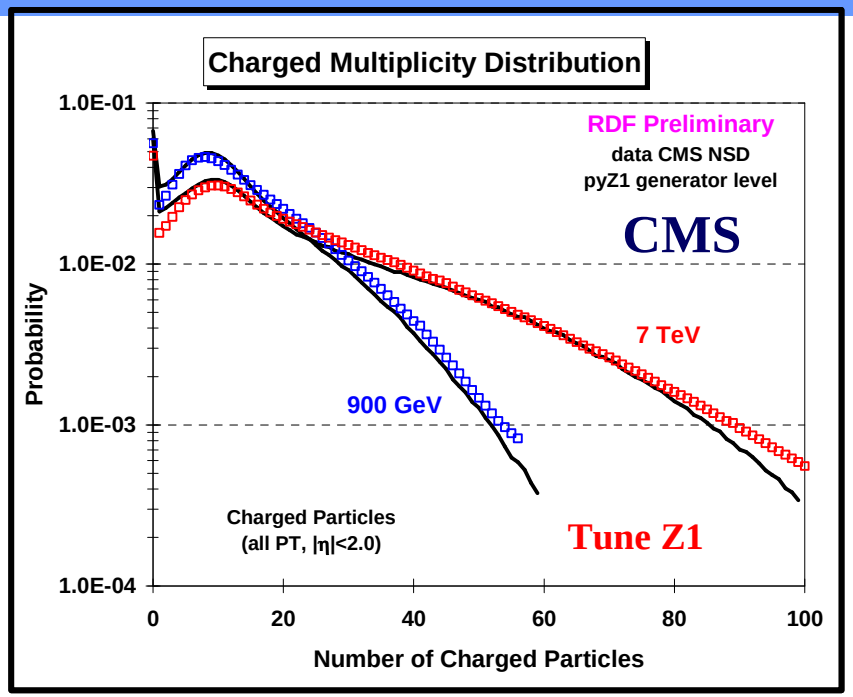
NSD <pT> versus Nchg



➡ **Shows the energy dependence of the CMS NSD corrected data on $\langle p_T \rangle$ versus Nchg (all p_T, $|\eta| < 2.4$) compared with Tune Z1. Also shows the energy dependence of the overall <pT> compared with Tune Z1.**

First Tune (except PhoJet) to come close here!

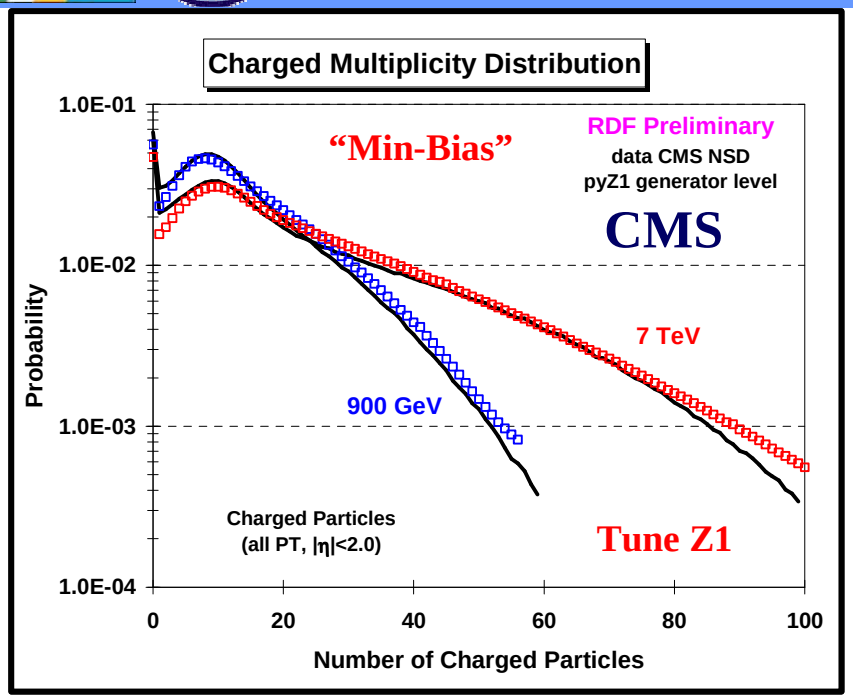
NSD Multiplicity Distribution

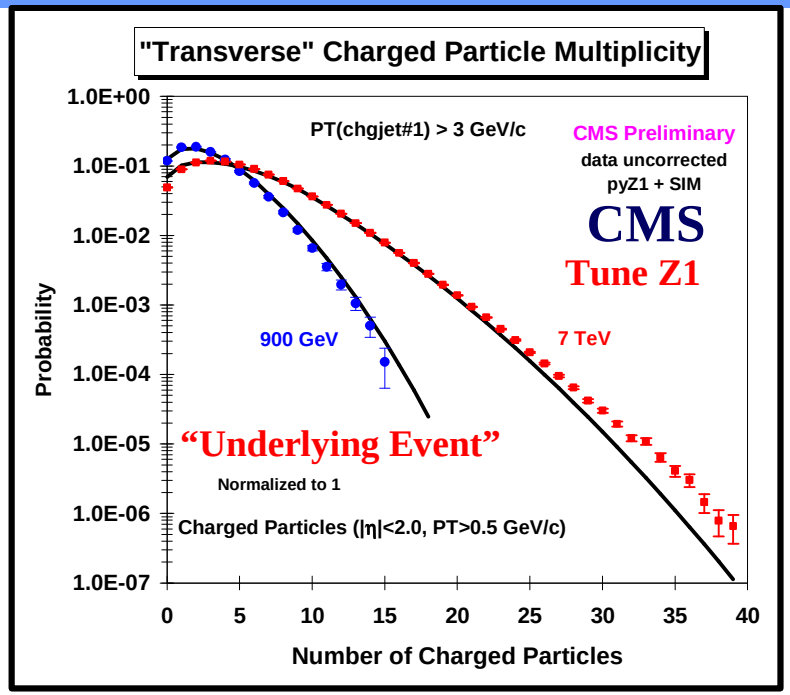


➡ **Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.**

Okay not perfect!
But not that bad!

NSD Multiplicity Distribution

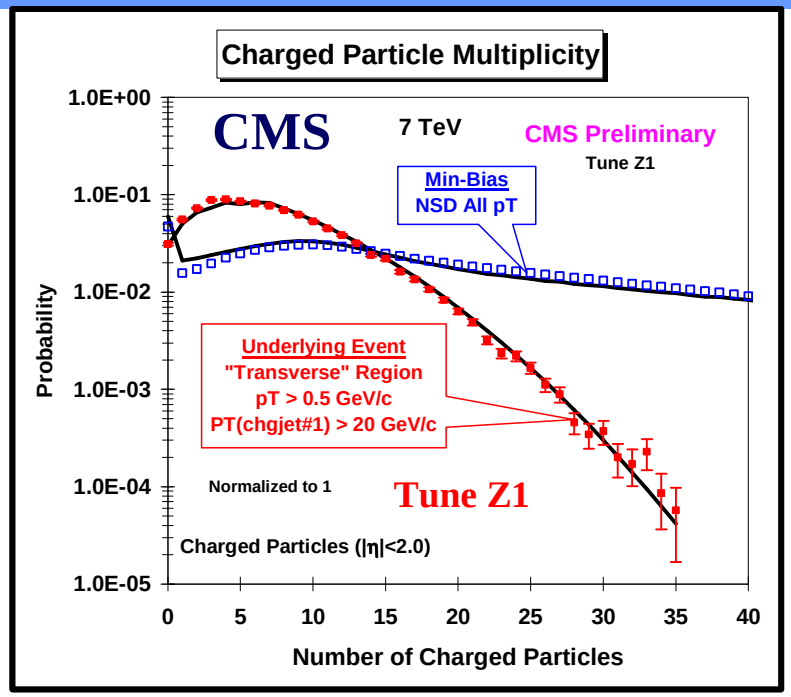




- **Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.**

- **CMS uncorrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM).**

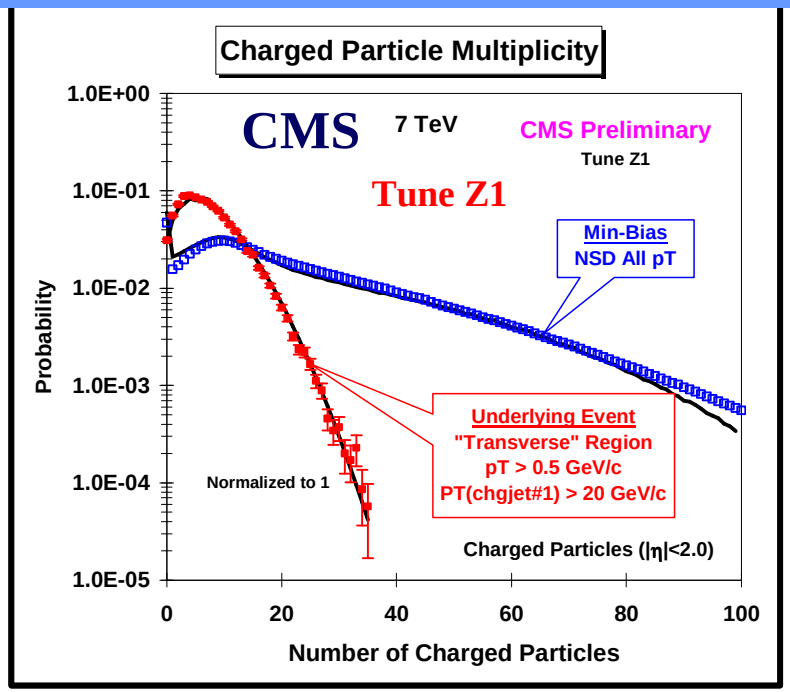
PYTHIA Tune Z1



➡ **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all pT, |η| < 2) compared with Tune Z1 at the generator.**

Amazing what we are asking the Monte-Carlo models to fit!

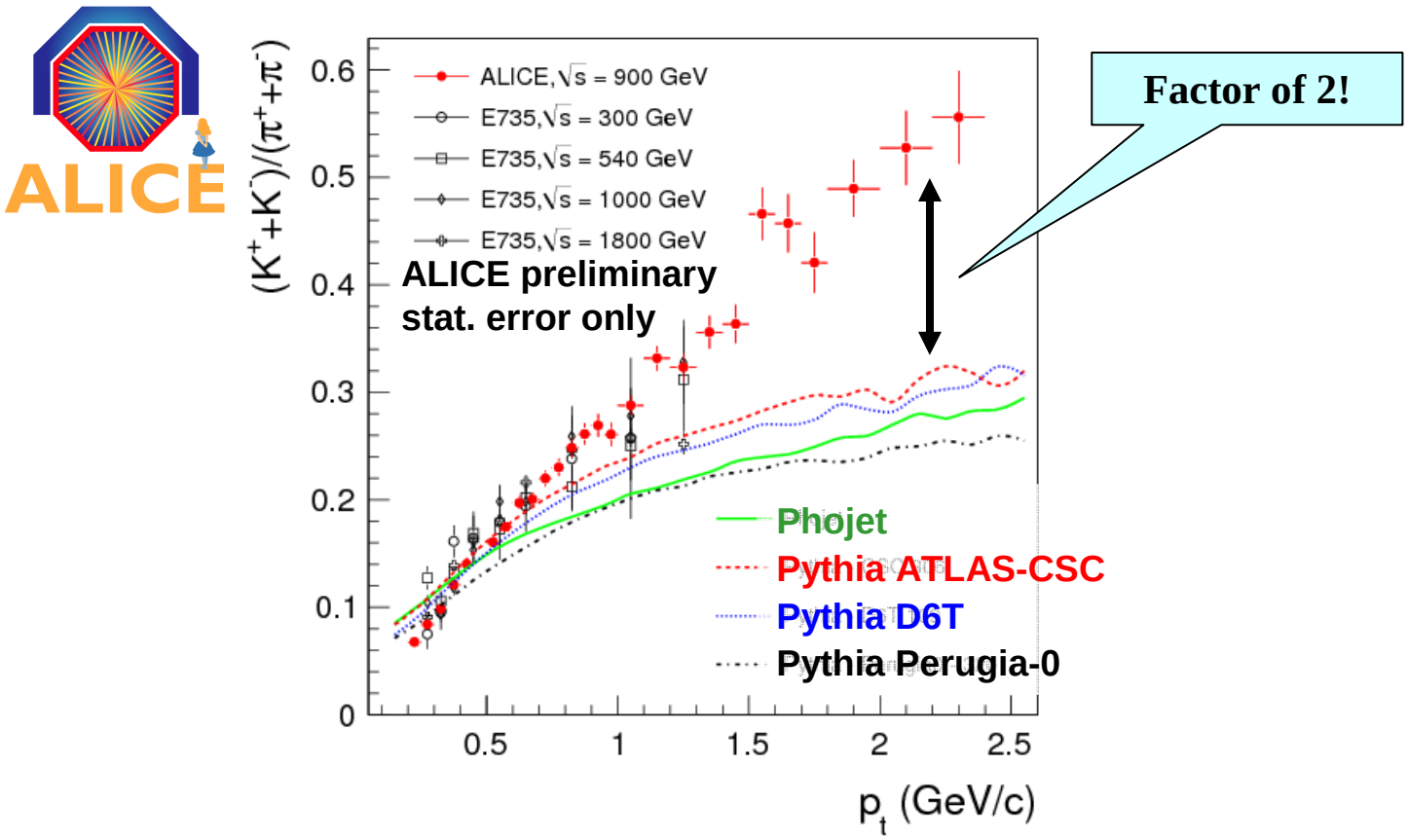
PYTHIA Tune Z1



➡ **CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) as defined by the leading charged particle jet with PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (*i.e.* Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all pT, |η| < 2) compared with Tune Z1 at the generator.**

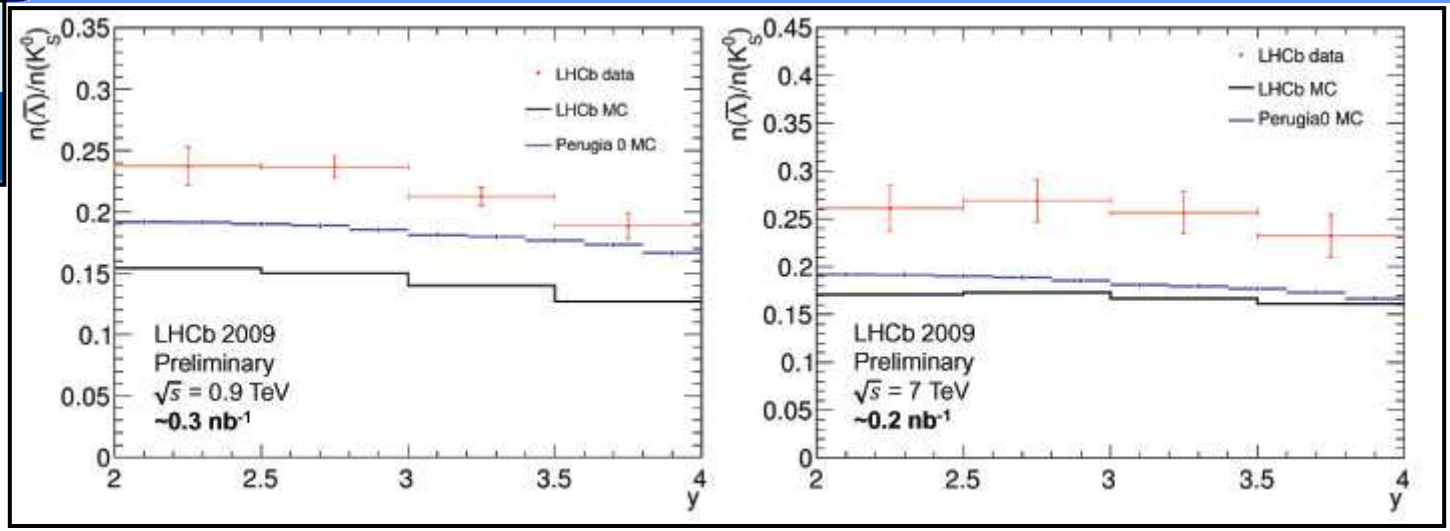
Amazing what we are asking the Monte-Carlo models to fit!

Strange Particle Production



- A lot more strange mesons at large p_T than predicted by the Monte-Carlo Models!
- K/π ratio fairly independent of the center-of-mass energy.

Strange Baryon Production

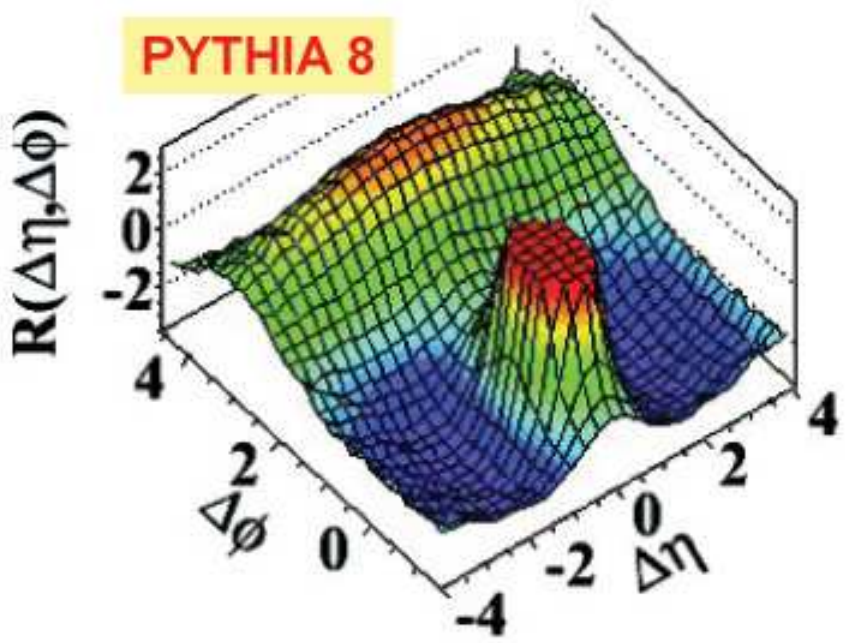


➡ **More strange baryons than expected!**

Long-Range Same-Side Correlations

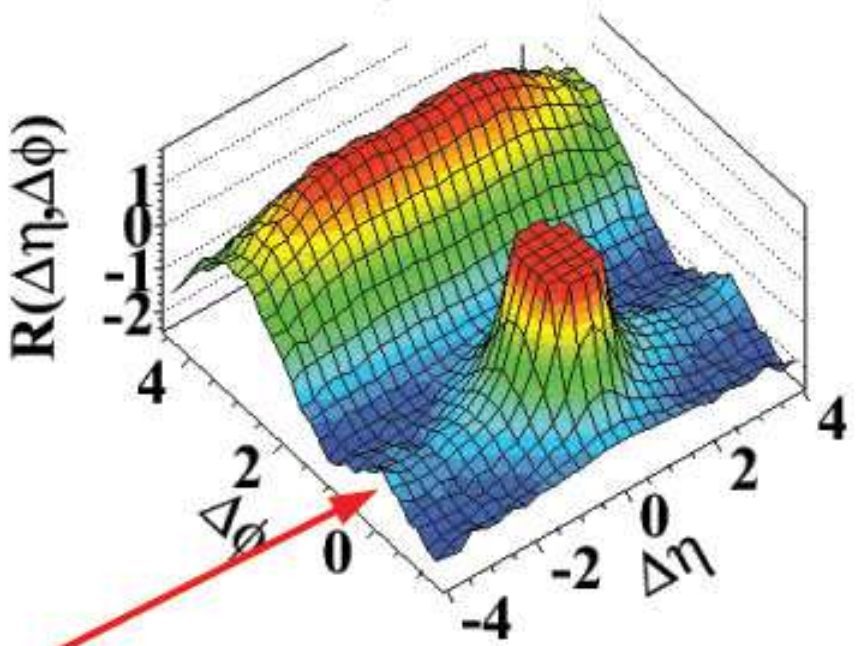
High Multiplicity "Min-Bias"

(d) N>110, 1.0GeV/c<p_T<3.0GeV/c



High Multiplicity "Min-Bias"

(d) N>110, 1.0GeV/c<p_T<3.0GeV/c



→ Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_T (Ridge at $\Delta\phi \sim 0$)

Not there in PYTHIA8! Also not there in PYTHIA 6 and HERWIG++!

Long-Range Same-Side Correlations

High Multiplicity "Min-Bias"

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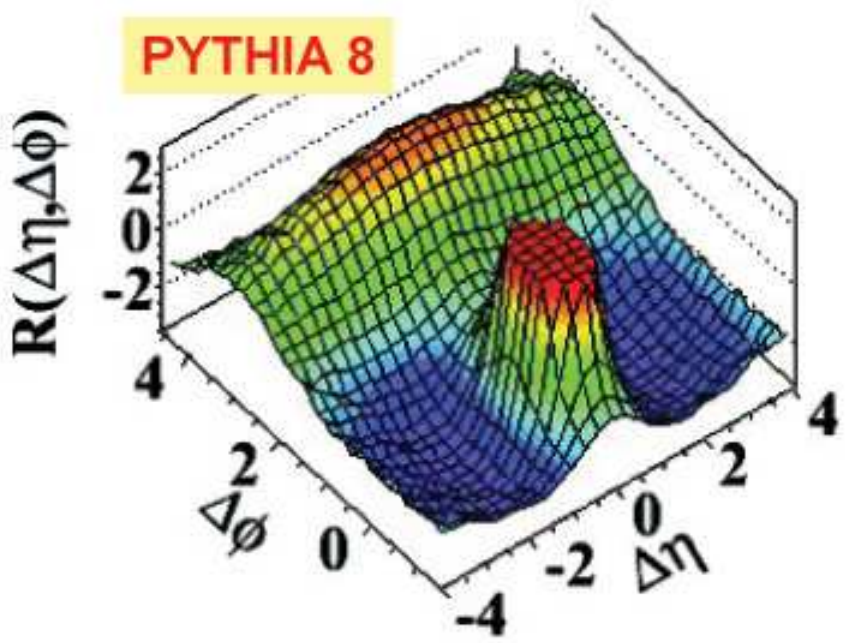

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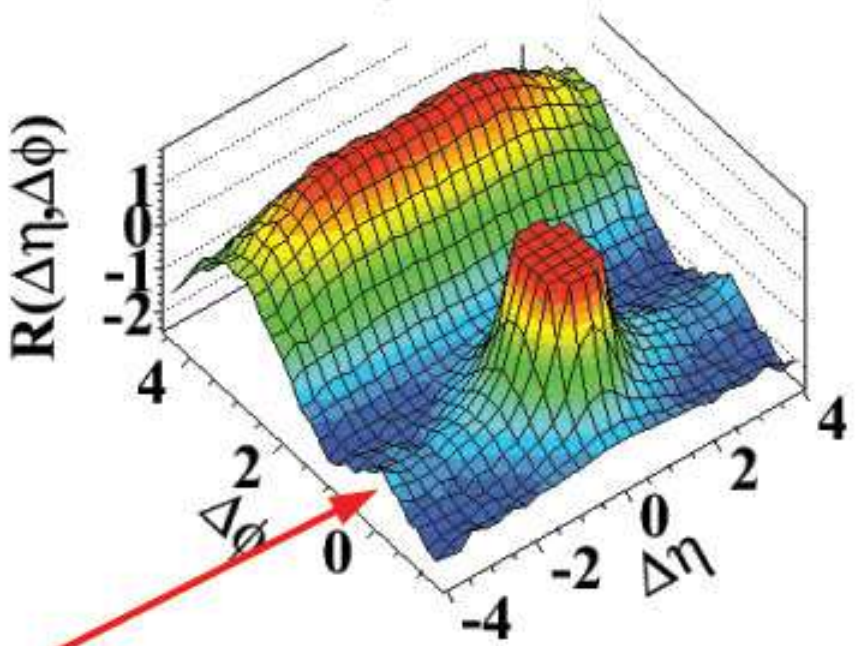
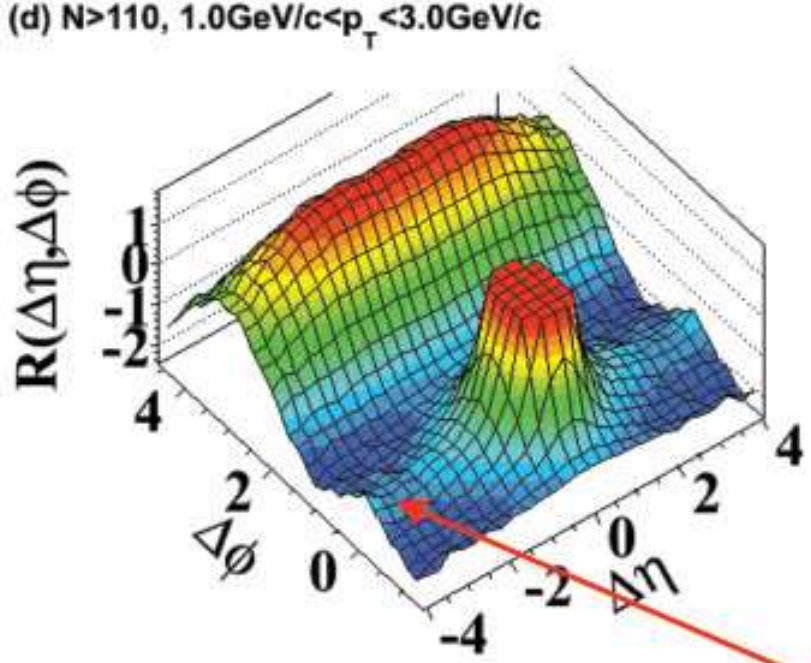


→ Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_T (Ridge at $\Delta\phi \sim 0$)

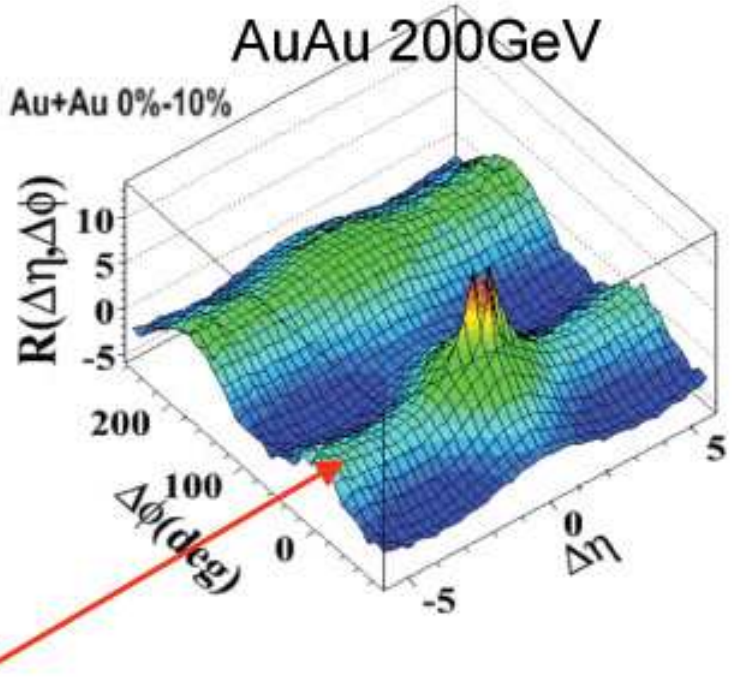
New type of "underlying event"! Would like to remove all the ordinary QCD jets and MPI from the event and look for a long range collective phenomena!

Proton-Proton vs Au-Au

Proton-Proton Collisions 7 TeV



Gold-Gold Collisions 200 GeV



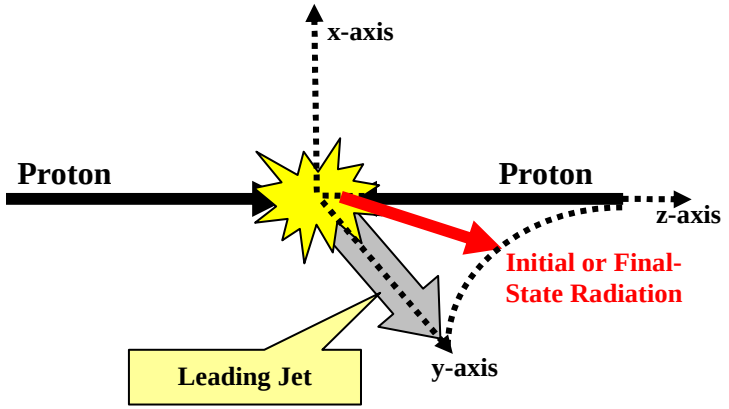
Similar "ridge" in high multiplicity pp
(even similar p_T dependence)

➡ **I am not ready to jump on the quark-gluon plasma bandwagon quite yet!**

Jet-Jet Correlations

- Are the "leading-log" or "modified leading-log" QCD Monte-Carlo Models missing an important QCD correlation?

- The leading jet and the incident protons form a plane (yz-plane in the figure). This is the plane of the hard scattering.

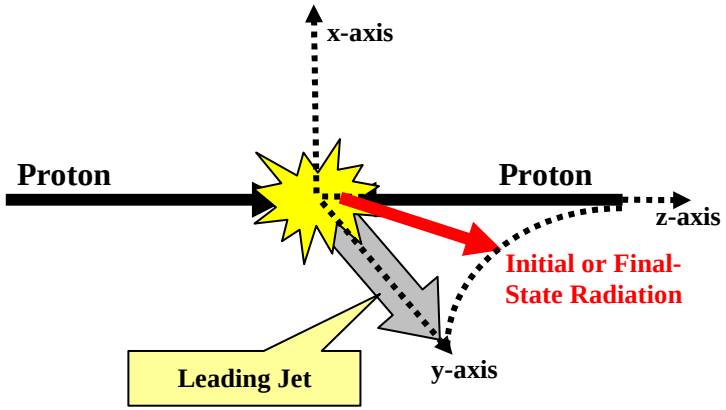


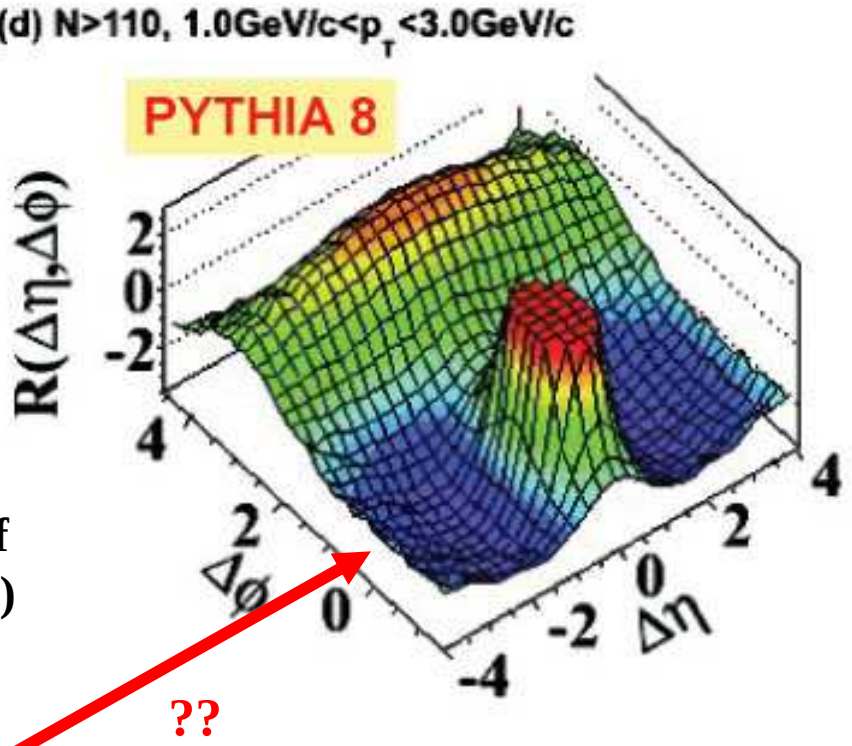
- Initial & final-state radiation prefers to lie in this plane. This is a higher order effect that you can see in the 2→3 or 2→4 matrix elements, but it is not there if you do 2→2 matrix elements and then add radiation using a naïve leading log approximation (*i.e.* independent emission).

- I do not know to what extent this higher order jet-jet correlation is incorporated in the QCD Monte-Carlo models.

- I would think that this jet-jet correlation would produce a long range (in $\Delta\eta$) correlation with $\Delta\phi \approx 0$ from two particles with one in the leading jet and one in the radiated jet. Why don't we see this in the Monte-Carlo models?

Jet-Jet Correlations



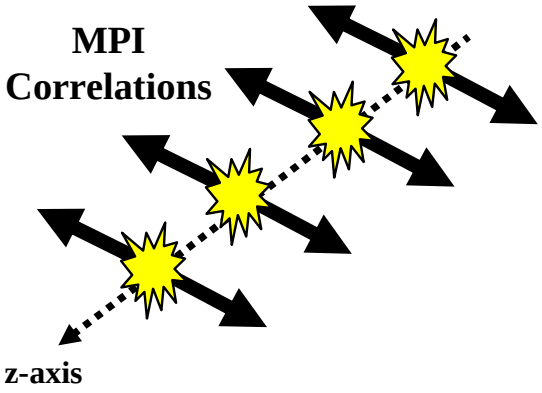


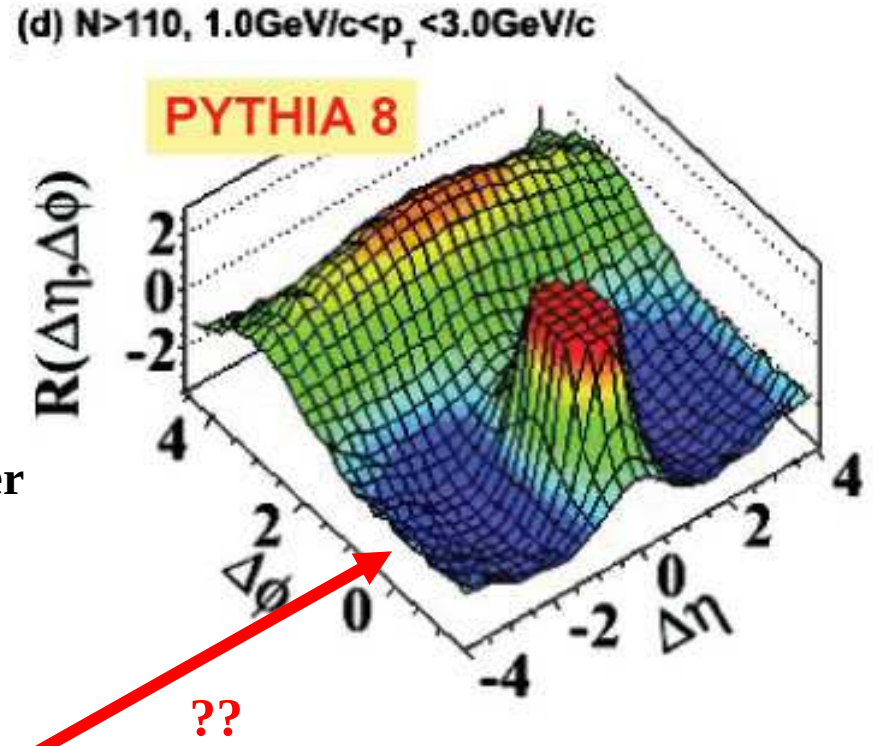
➡ **Initial & Final-State Radiation: There should be more particles "in-the-plane" of the hard scattering (yz-plane in the figure) than "out-of –the-plane".**

➡ **I do not understand why this does not result in a long-range same-side correlation?**

??

MPI Correlations?





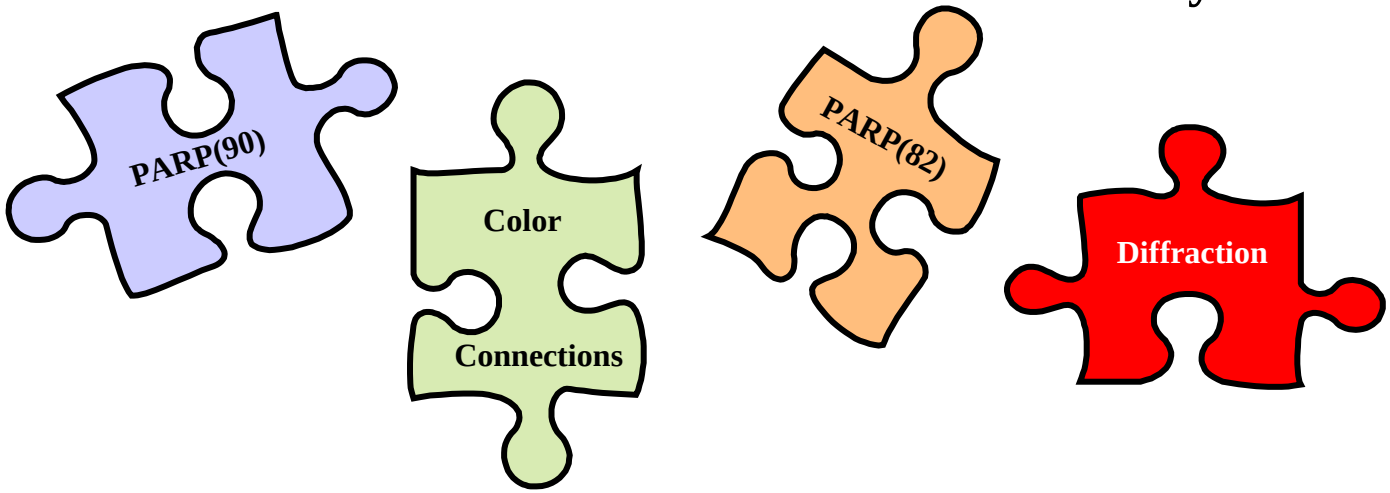
➡ **Large multiplicity implies a large number of multiple-parton interactions (MPI). Maybe there are MPI correlations (*i.e.* prefer to lie in a plane)?**

??

➡ **In the current MPI models the individual MPI are not correlated!**

Min-Bias Summary

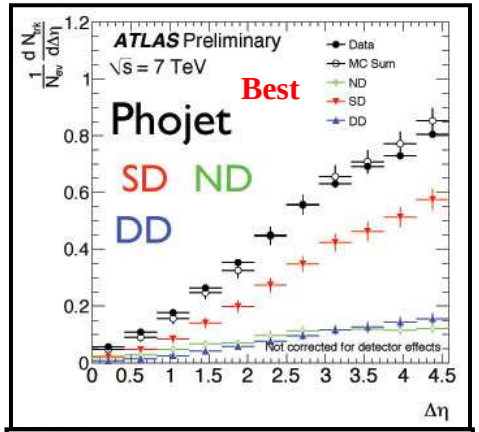
- **We are a long way from having a Monte-Carlo model that will fit all the features of the LHC min-bias data! There are more soft particles that expected!**
- **We need a better understanding and modeling of diffraction!**
- **It is difficult for the Monte-Carlo models to produce a soft event (*i.e.* no large hard scale) with a large multiplicity. There seems to be more "min-bias" high multiplicity soft events at 7 TeV than predicted by the models!**
- **The models do not produce enough strange particles! I have no idea what is going on here! The Monte-Carlo models are constrained by LEP data.**

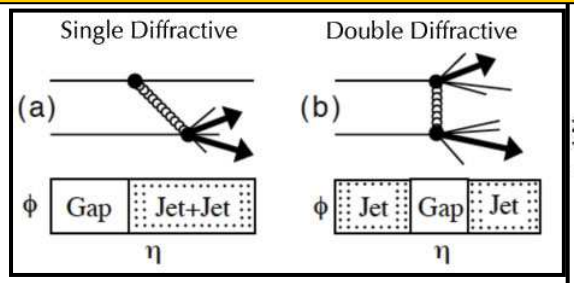


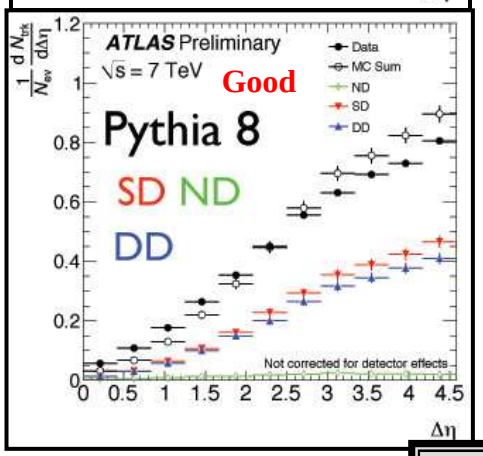
Min-Bias Summary

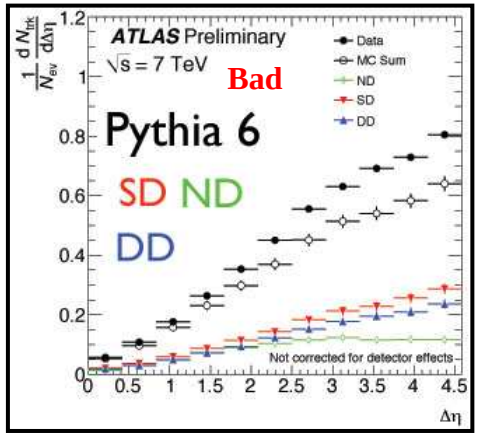
➡**We need a better understanding and modeling of diffraction!**

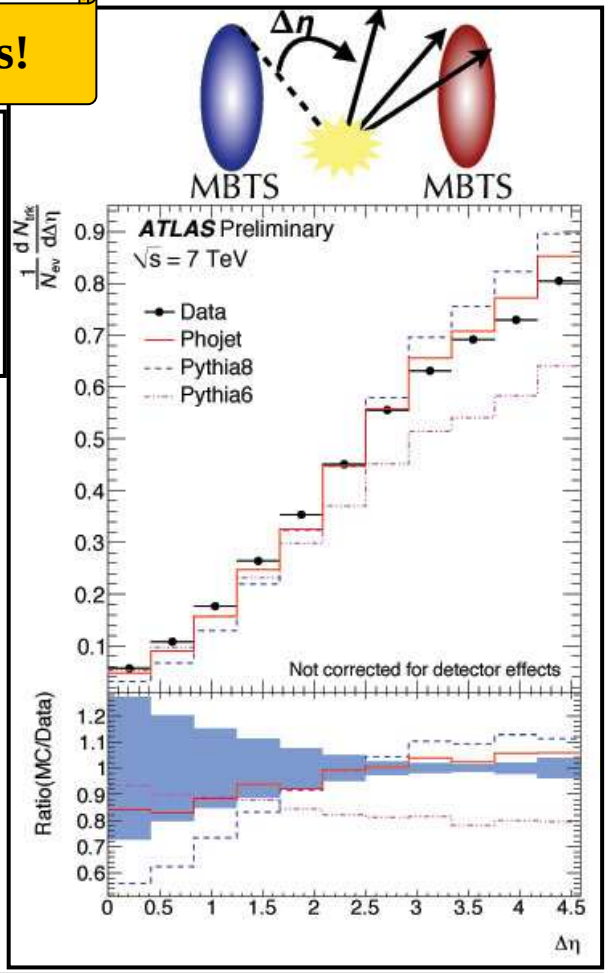
Explore by defining "diffractive enhanced" data samples!











See the talk by Lauren Tompkins at the LPCC MB&UE@LHC Meeting September 6, 2010,

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