Physics in Collision

Min-Bias and the **Underlying Event** at the **LHC**

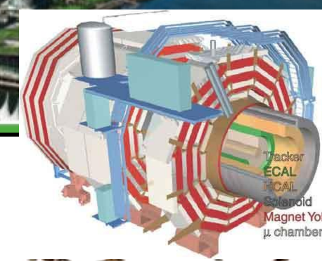
Rick Field

University of Florida

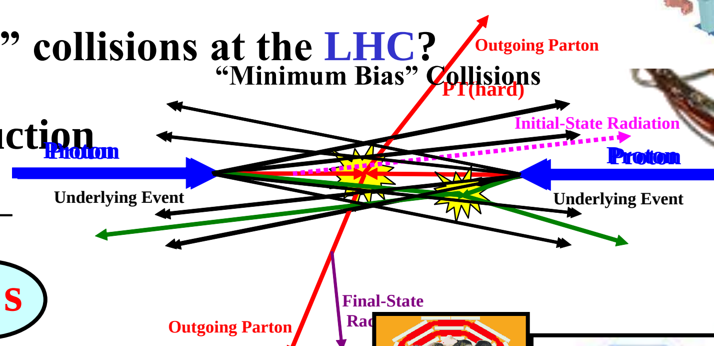
Quantum
Chromo-
Dynamics

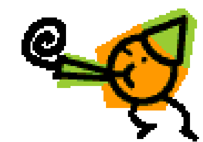
Outline

- How well did we do at predicting the behavior of the "underlying event" at the LHC (900 GeV and 7 TeV)?
- How **universal** are the QCD Monte-Carlo model tunes?
- Examine the connection between the "underlying event" in a hard scattering process (UE) and "min-bias" collisions (MB).
- How well can we predict "min-bias" collisions at the LHC?
- **Strange particle** and **baryon** production at the LHC.



CMS





ATLAS

K^+: u $\bar{s}$

K_{short}: d $\bar{s}$ + $\bar{d}$ s

p: uud

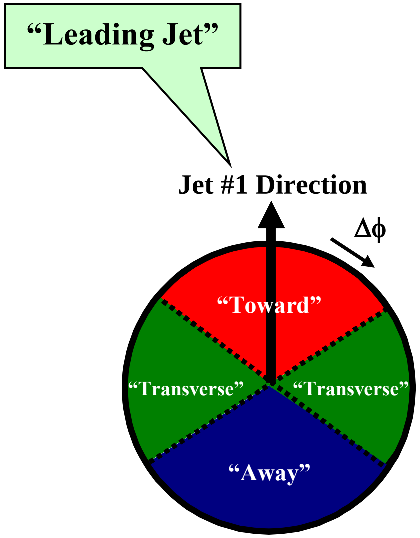
Ξ^-: dss

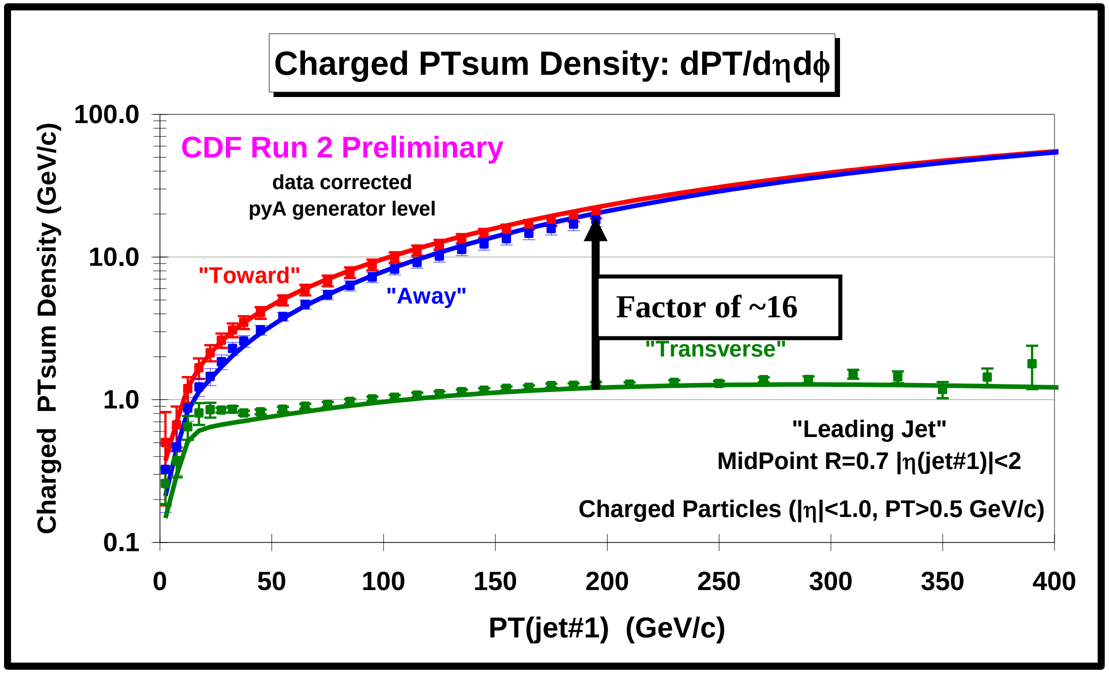
K^-: $\bar{u}$ s

Λ: uds

UE&MB@CMS

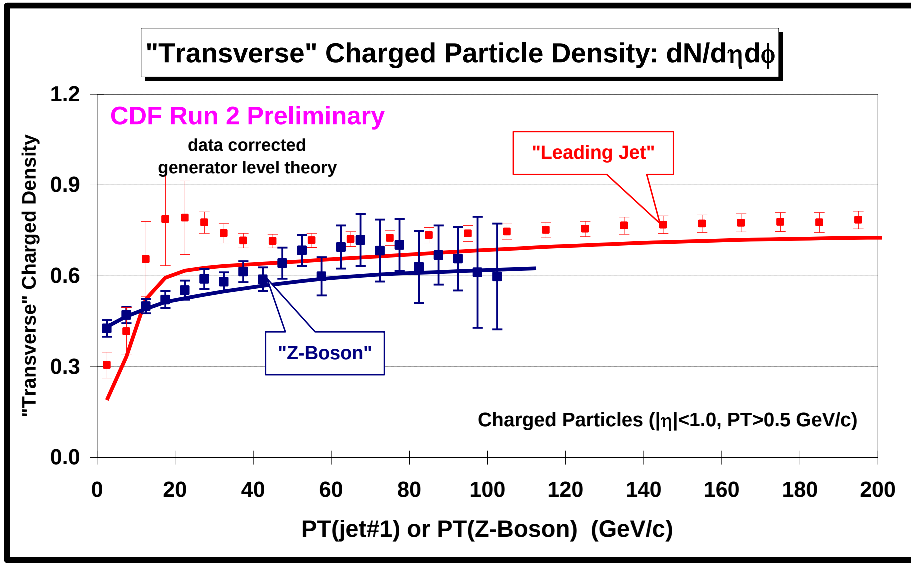
"Towards", "Away", "Transverse"

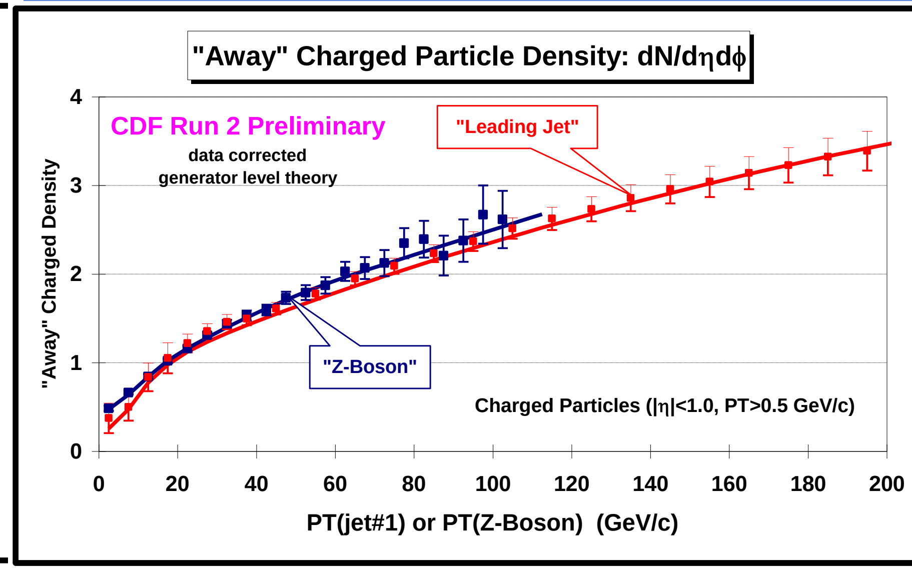


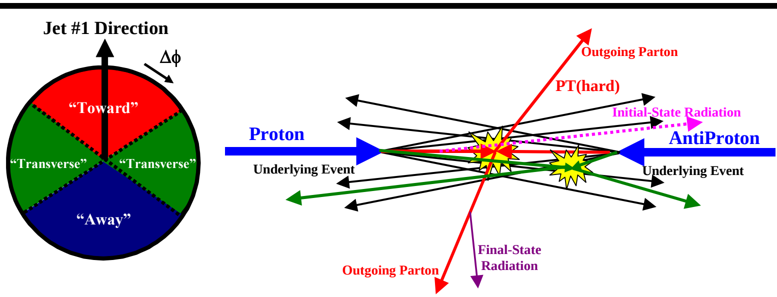


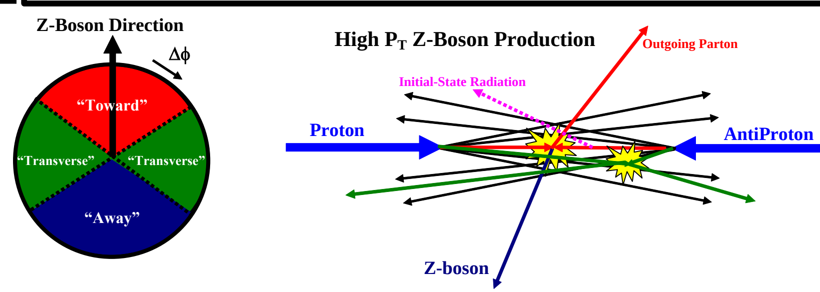
- **CDF data at 1.96 TeV** on the charged particle *scalar* p_T sum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that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

Charged Particle Density





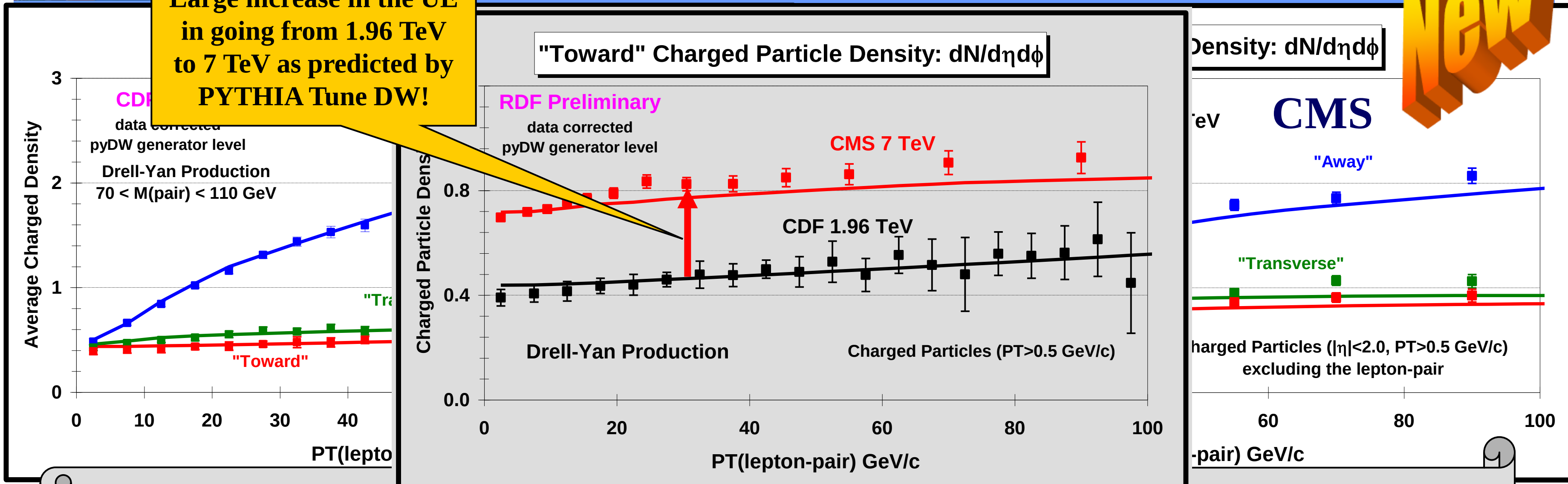




- **CDF data at 1.96 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the **"toward"**, **"away"**, and **"transverse"** regions. The data are corrected to the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

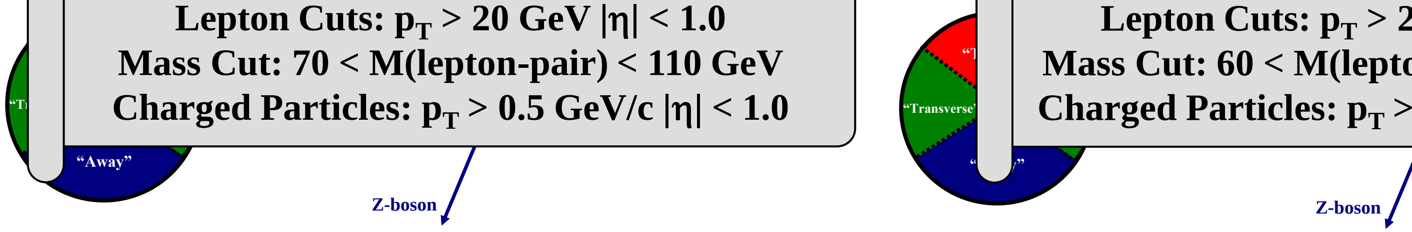
Charged Particle Density

Large increase in the UE in going from 1.96 TeV to 7 TeV as predicted by PYTHIA Tune DW!



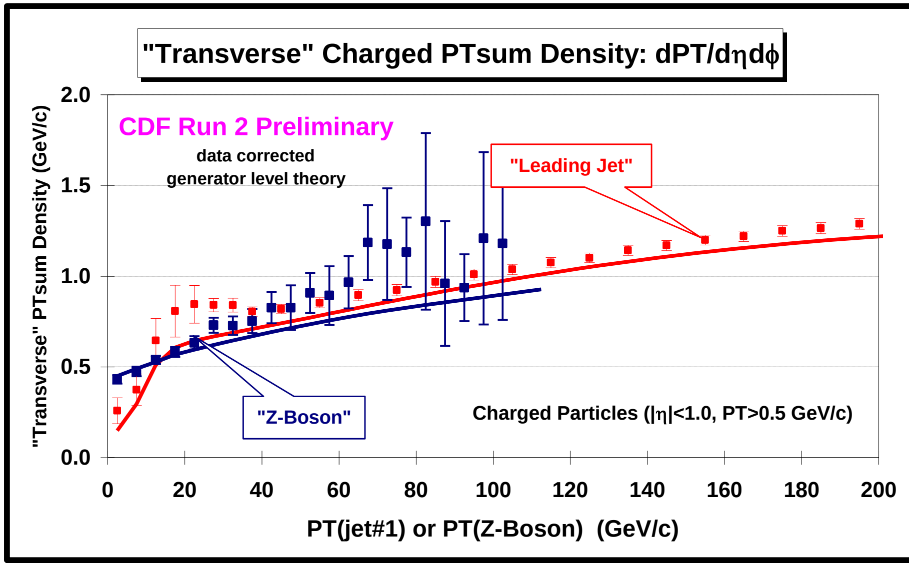
CDF: Proton-Antiproton Collisions at 1.96 GeV
Lepton Cuts: $p_T > 20$ GeV $|\eta| < 1.0$
Mass Cut: 70 < M(lepton-pair) < 110 GeV
Charged Particles: $p_T > 0.5$ GeV/c $|\eta| < 1.0$

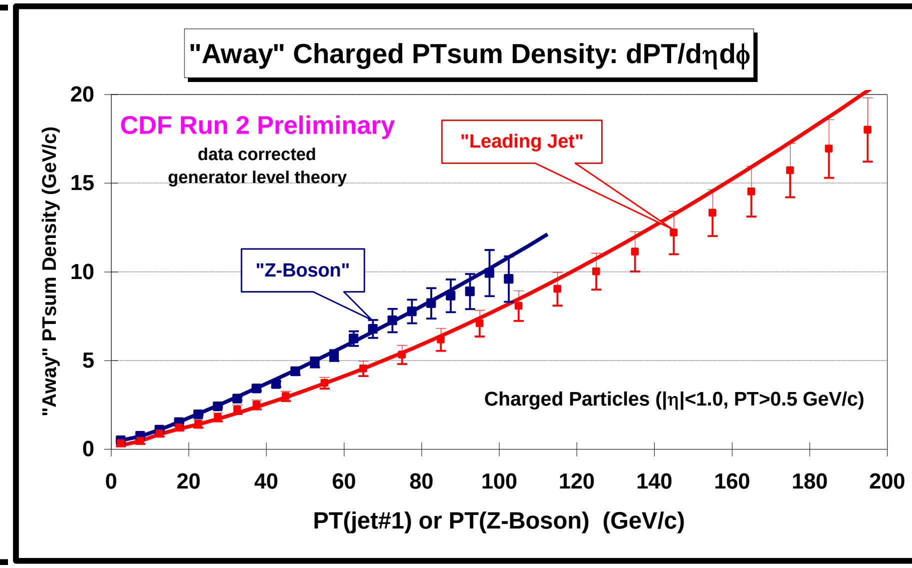
CMS: Proton-Proton Collisions at 7 GeV
Lepton Cuts: $p_T > 20$ GeV $|\eta| < 2.4$
Mass Cut: 60 < M(lepton-pair) < 120 GeV
Charged Particles: $p_T > 0.5$ GeV/c $|\eta| < 2.0$

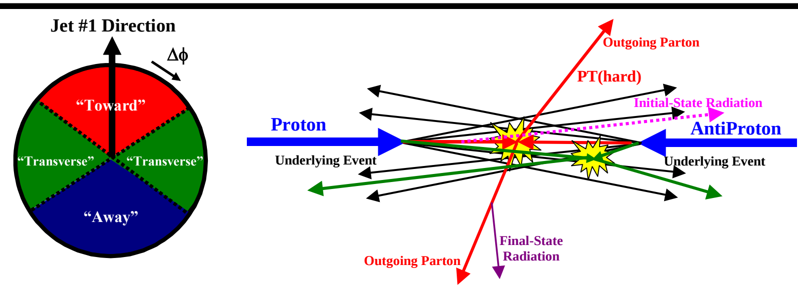


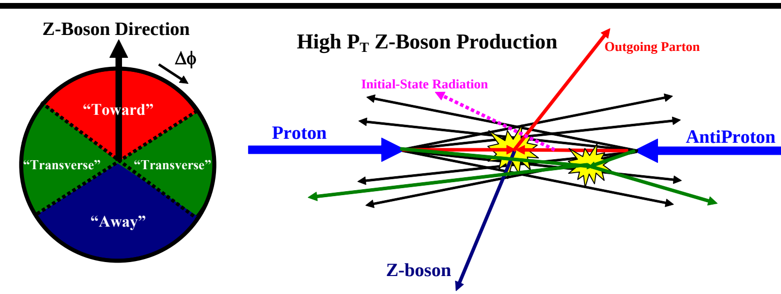
- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune DW**.
- **CMS data at 7 TeV** on the density of charged particles,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

Charged PTsum Density



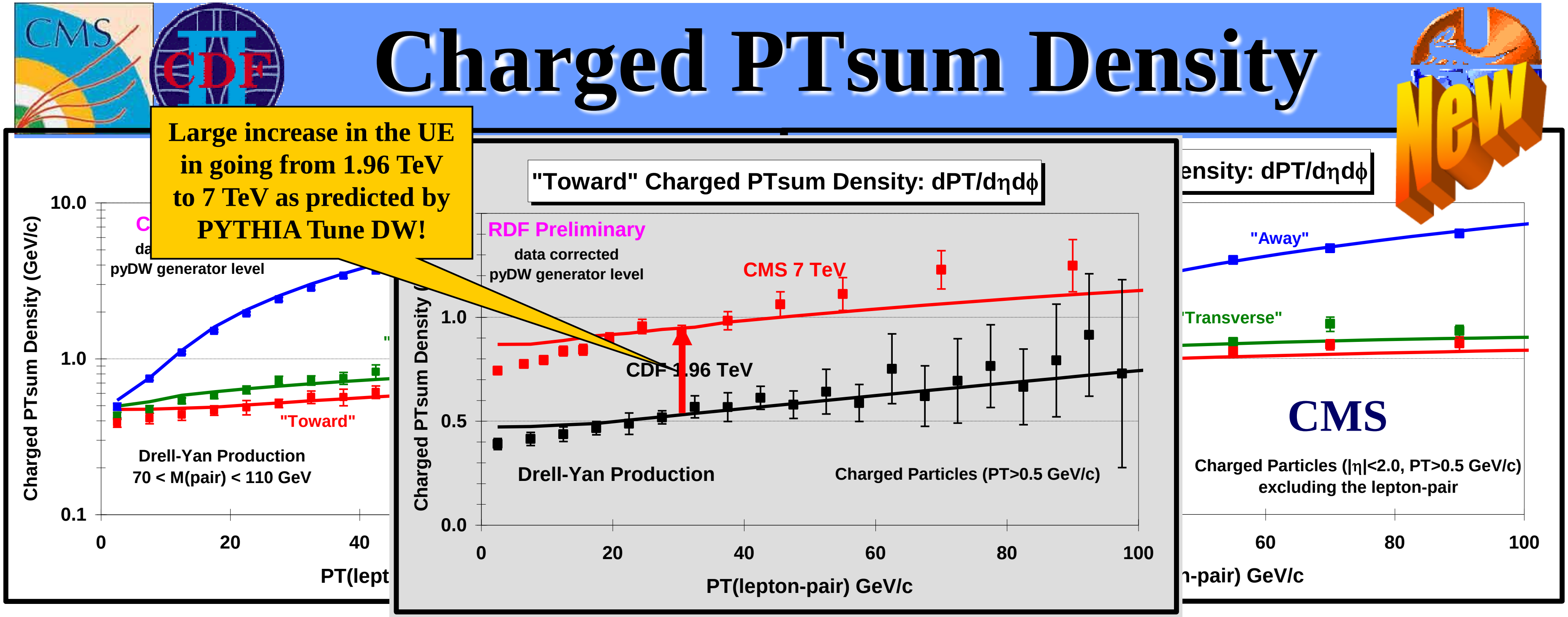


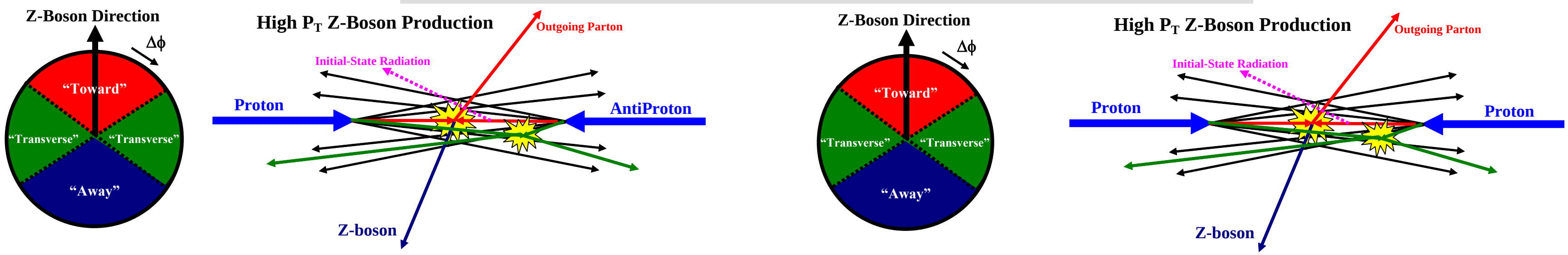




- **CDF data at 1.96 TeV** on the charged *scalar* PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level and are compared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

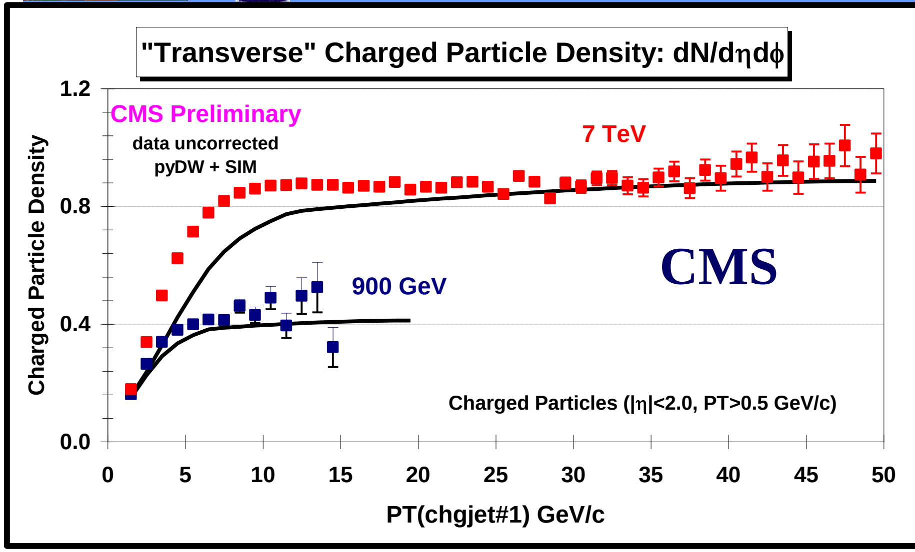
Charged PTsum Density

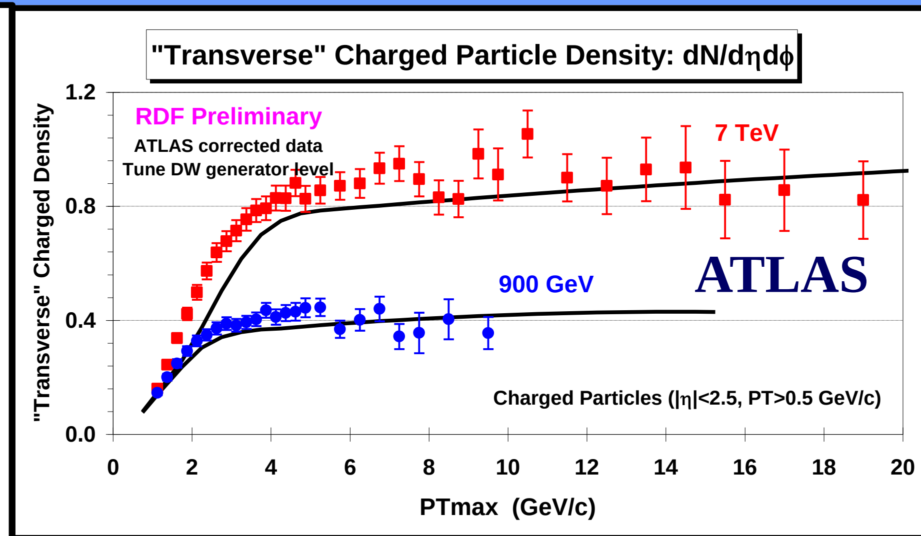




- **CDF data at 1.96 TeV** on the charged PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of PT(Z) for the "toward", "away", and "transverse" regions compared with PYTHIA Tune DW.
- **CMS data at 7 TeV** on the charged PTsum density, dPT/dηdφ, with p_T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

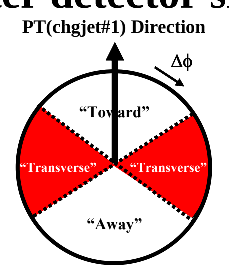
PYTHIA Tune DW

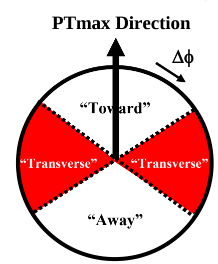


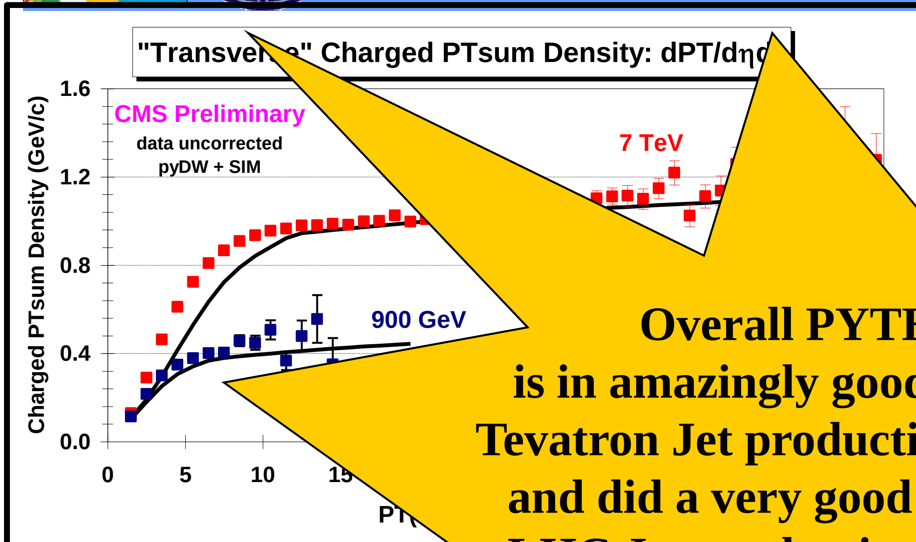


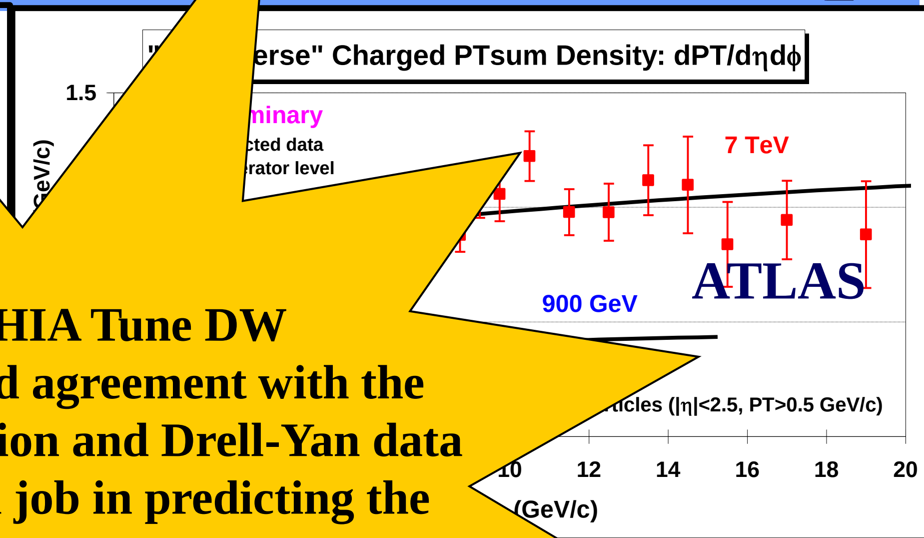
- **CMS preliminary data at 900 GeV and 7 TeV** on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA **Tune DW** after detector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

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



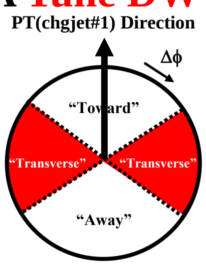


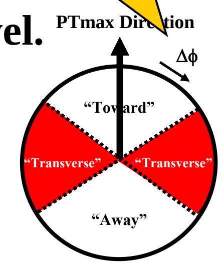




Overall PYTHIA Tune DW is in amazingly good agreement with the Tevatron Jet production and Drell-Yan data and did a very good job in predicting the LHC Jet production and Drell-Yan data! (although not perfect)

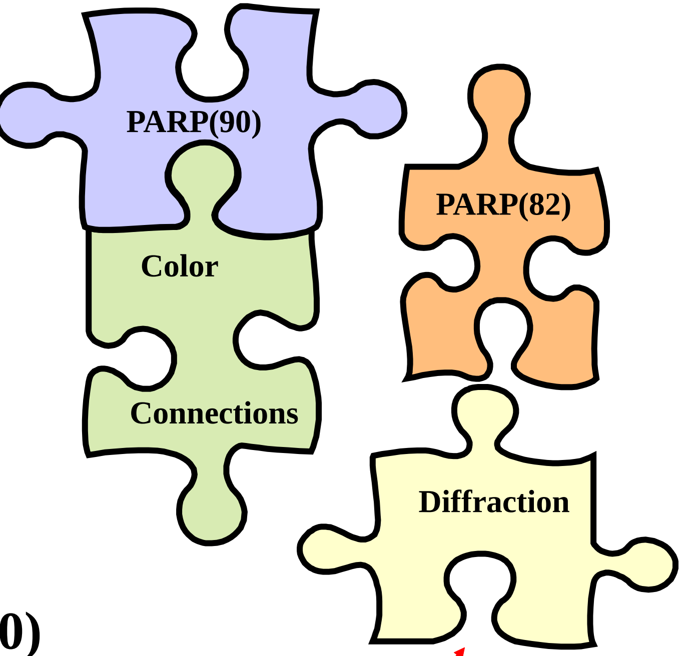
- **CMS preliminary d... 900 GeV and ... TeV on the "tra... ...d PTsum density, dPT... ..., as defined by the ... charged particle jet (chgjet#... ...rticle (PTmax) for ... particles with p_T > 0.5 GeV... ...d par... ...ith p_T > 0.5 GeV/c and ... The data are uncorrected a... compa... ...5. The d... ...re corrected and ... with PYTHIA Tune DW a...er detecto... ...ared with PY...IA Tune DW at the ... simulation. ... g...ator level.**

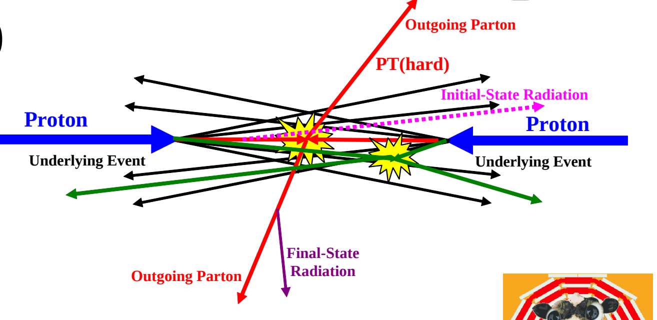




PYTHIA Tune Z1

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



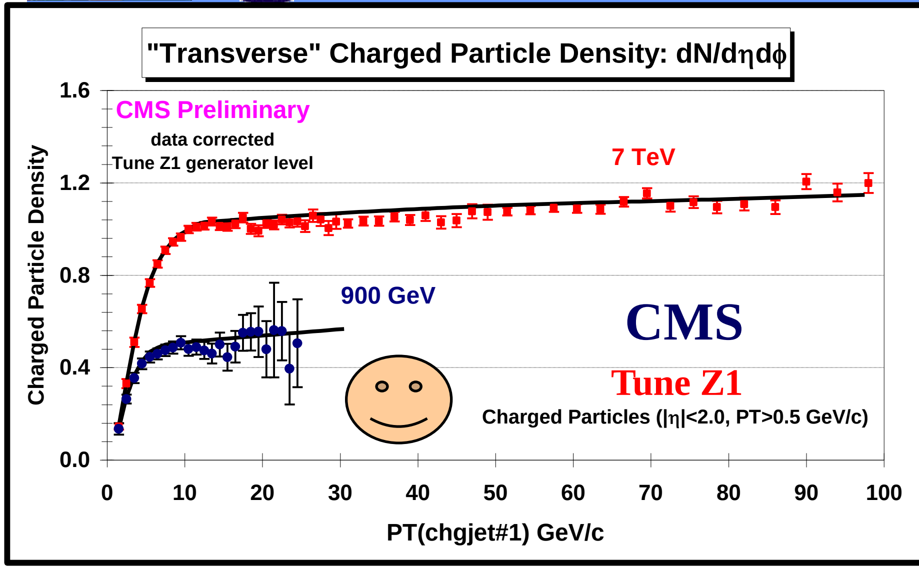


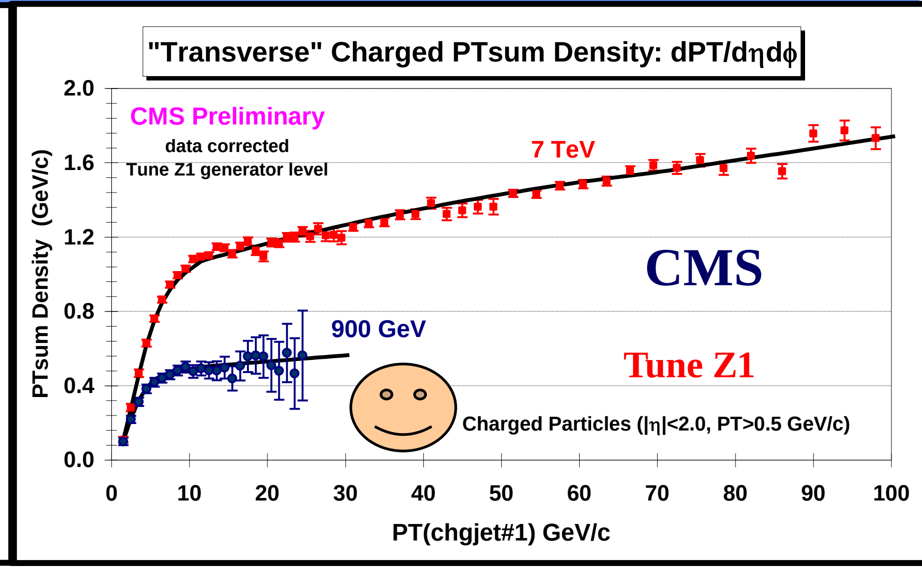
PYTHIA Tune Z1

Parameters not shown are the PYTHIA 6.4 defaults!

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

CMS UE Data





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

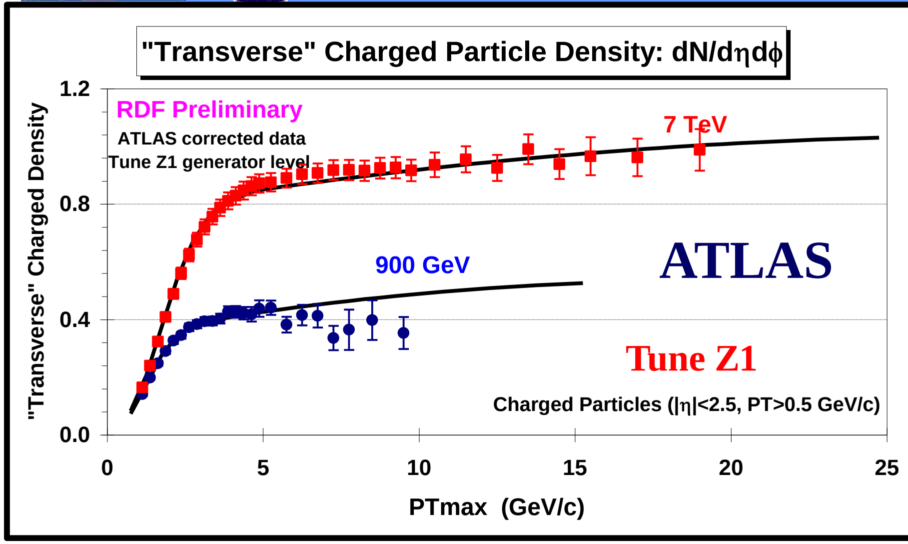
- **CMS preliminary data at 900 GeV and 7 TeV** on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

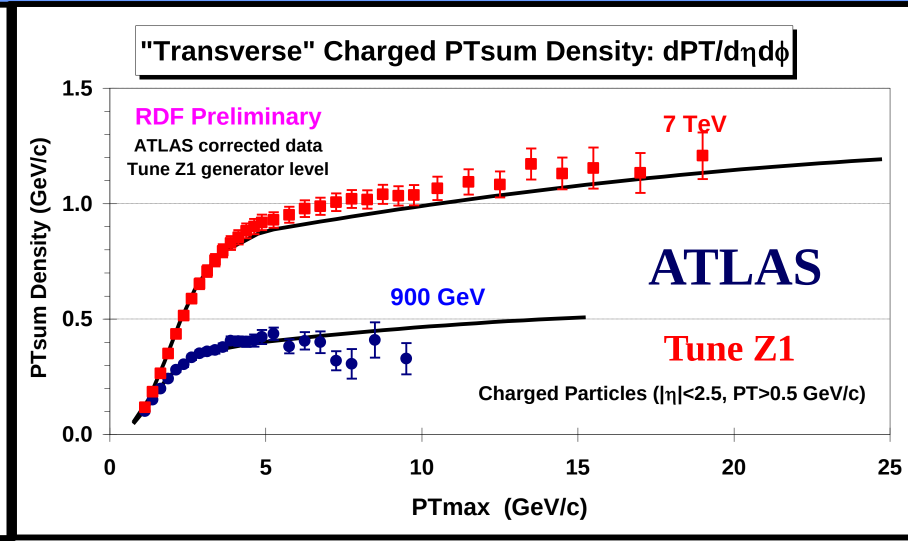
CMS corrected data!

Very nice agreement!

CMS corrected data!

ATLAS UE Data



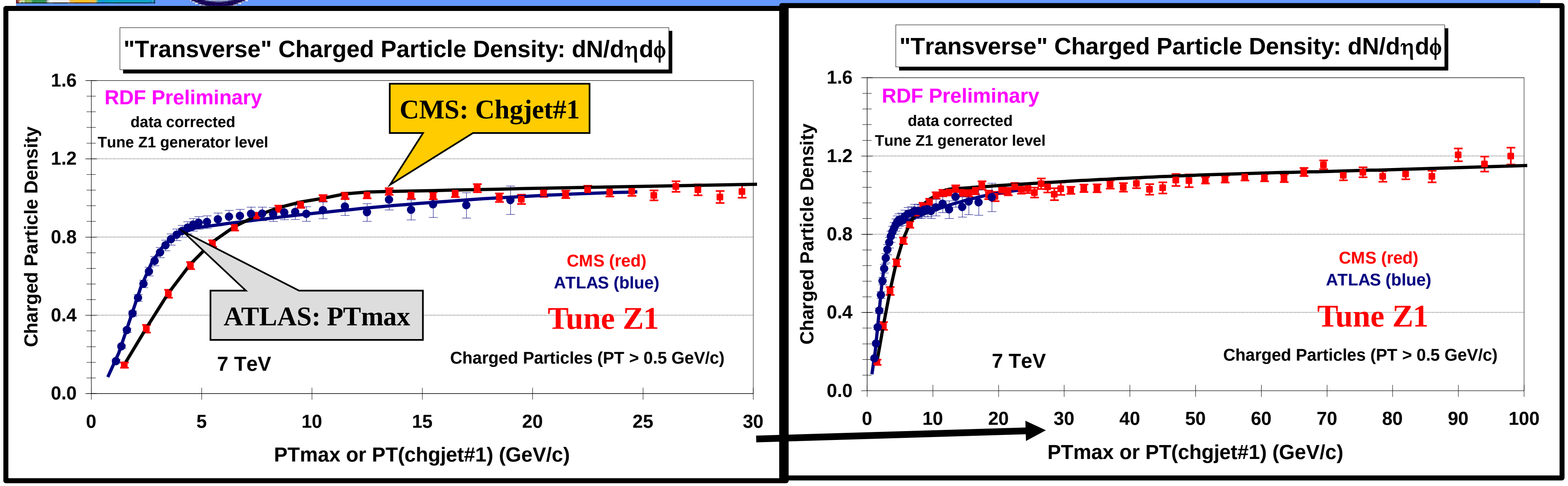


- **ATLAS published data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

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

ATLAS publication – arXiv:1012.0791
December 3, 2010

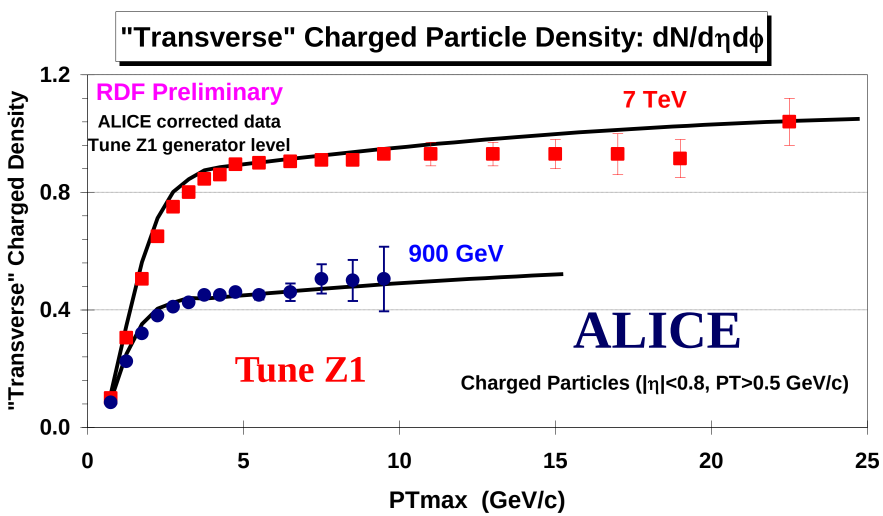
CMS-ATLAS UE Data

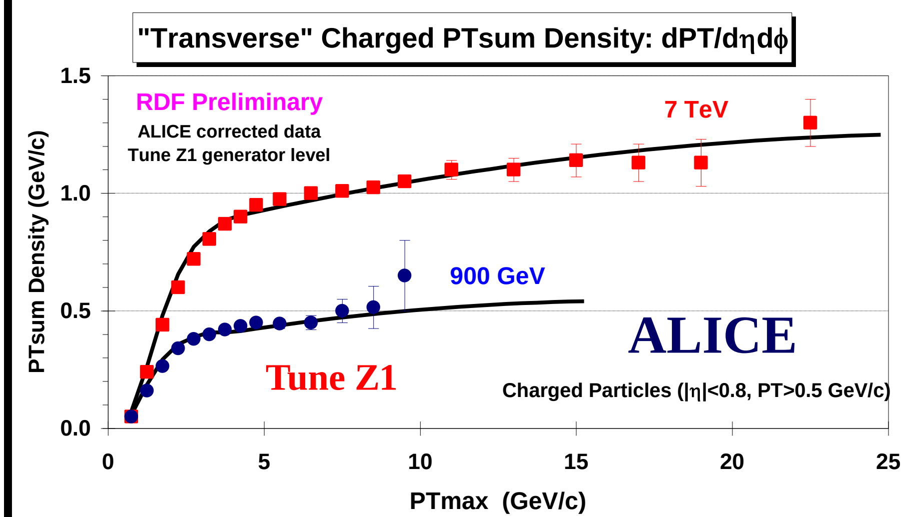


- **CMS preliminary data at 7 TeV** on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$ together with the **ATLAS published data at 7 TeV** on the "transverse" charged particle 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.

Amazing agreement!

ALICE UE Data





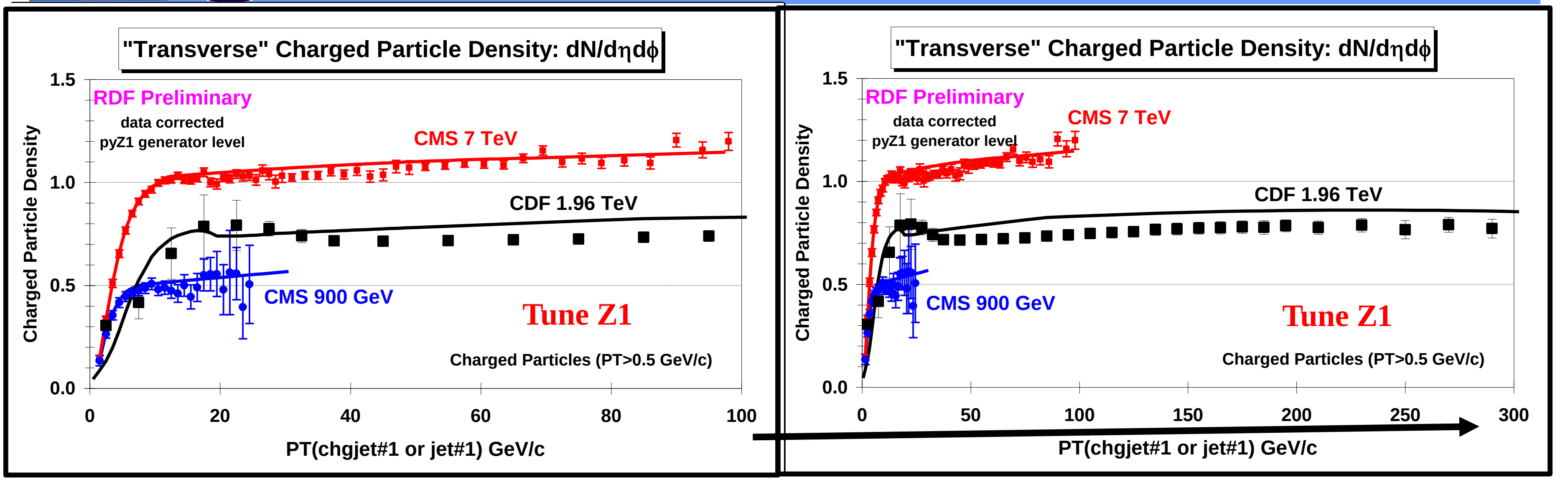
- **ALICE preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

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

I read the points off with a ruler!

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

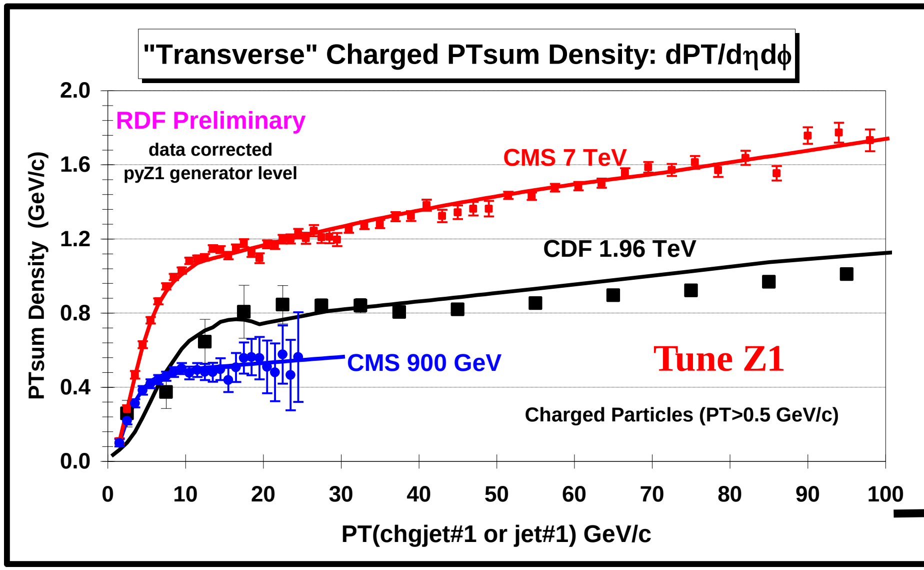
PYTHIA Tune Z1

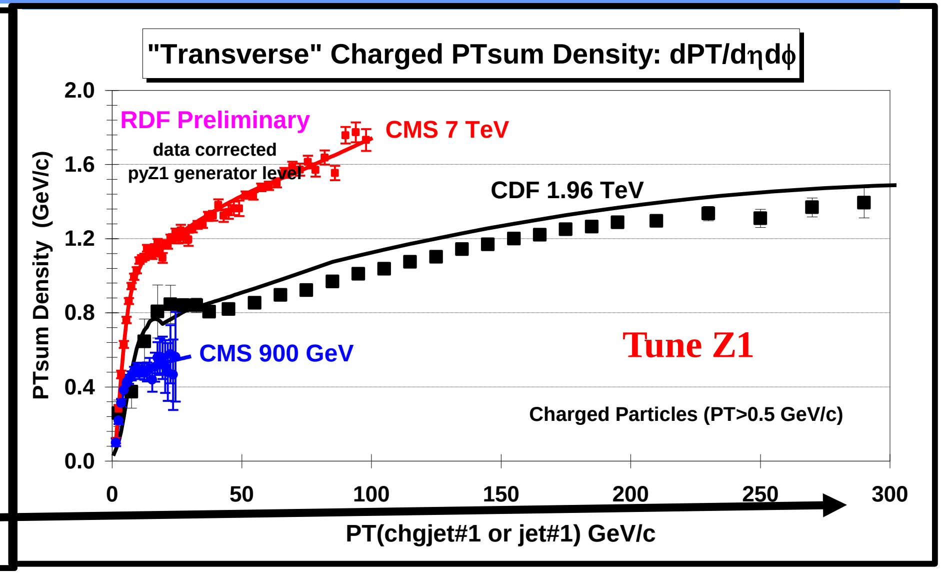


- **CMS data at 900 GeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

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

PYTHIA Tune Z1





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

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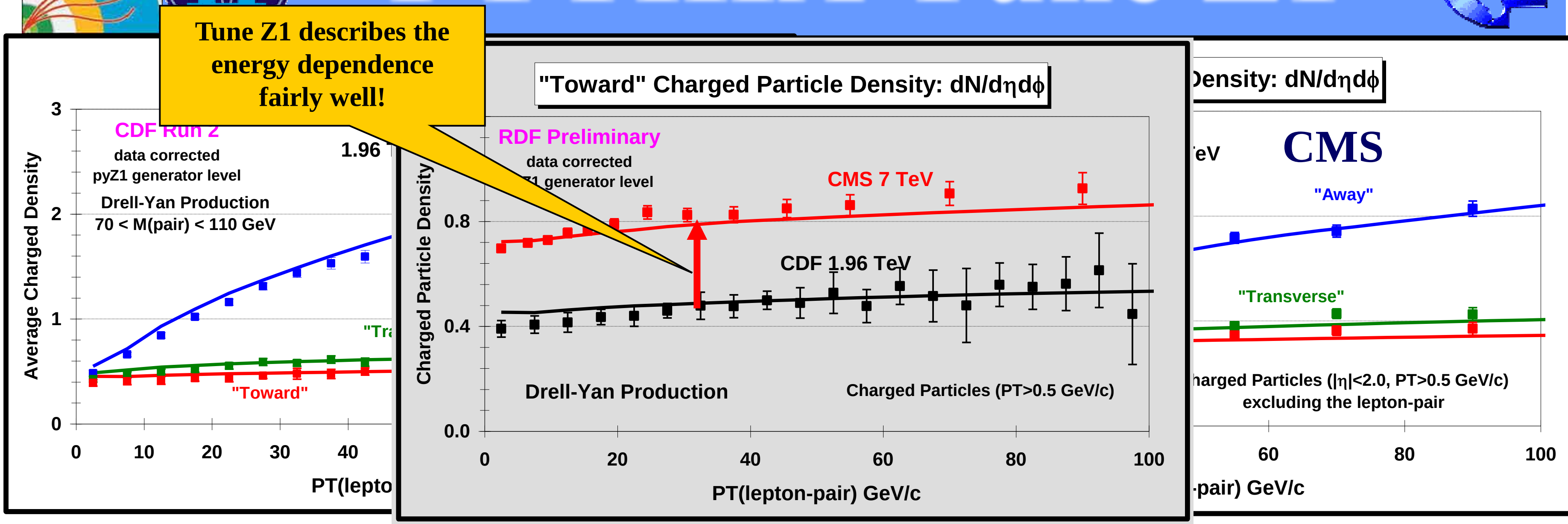
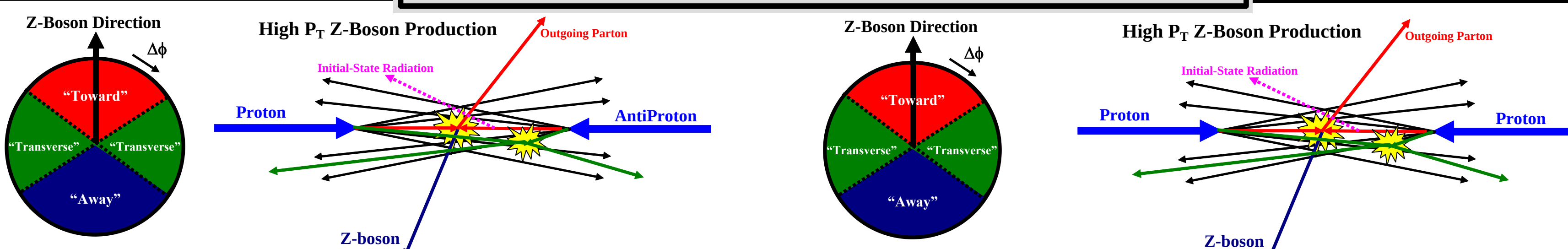
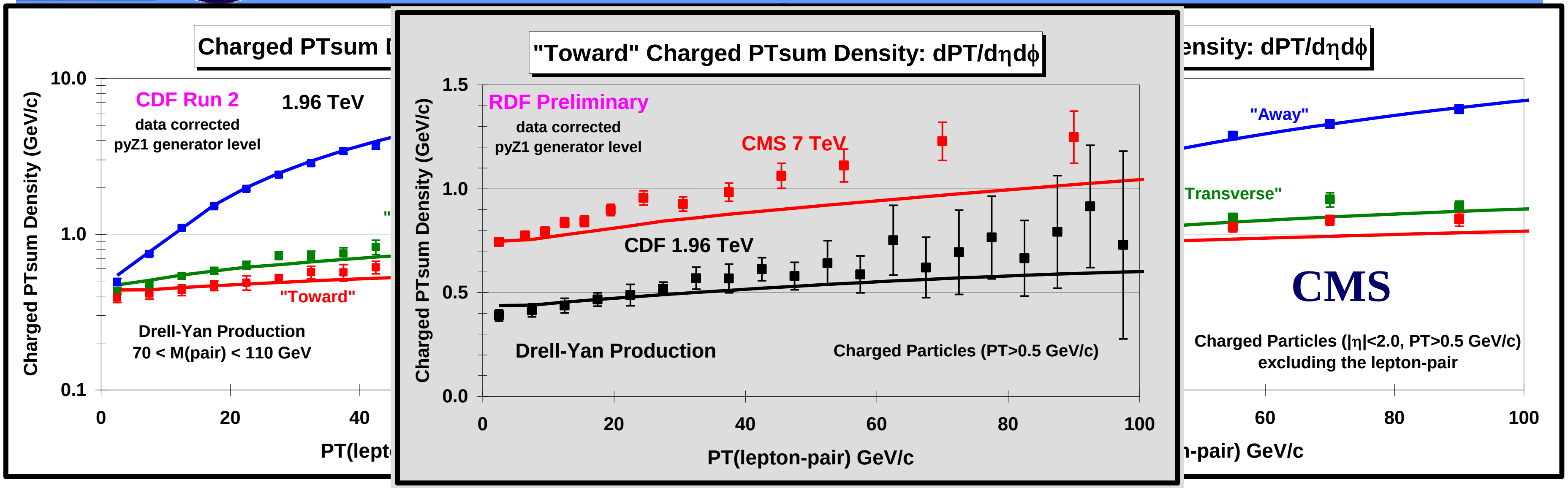
PYTHIA Tune Z1

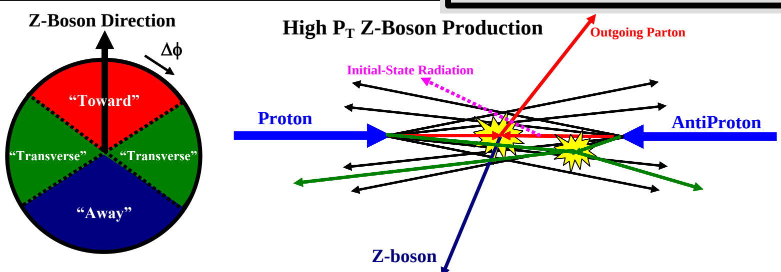


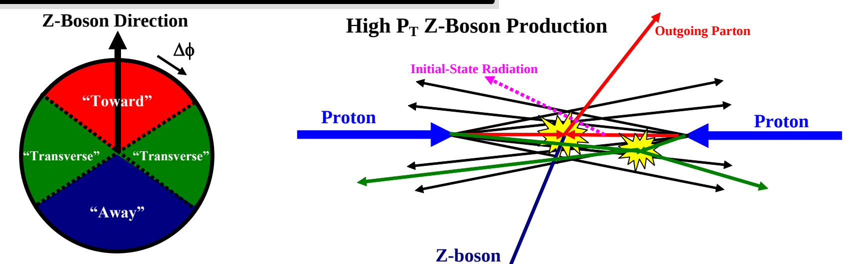


- **CDF data at 1.96 TeV** on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune Z1**.
- **CMS data at 7 TeV** on the density of charged particles,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

PYTHIA Tune Z1

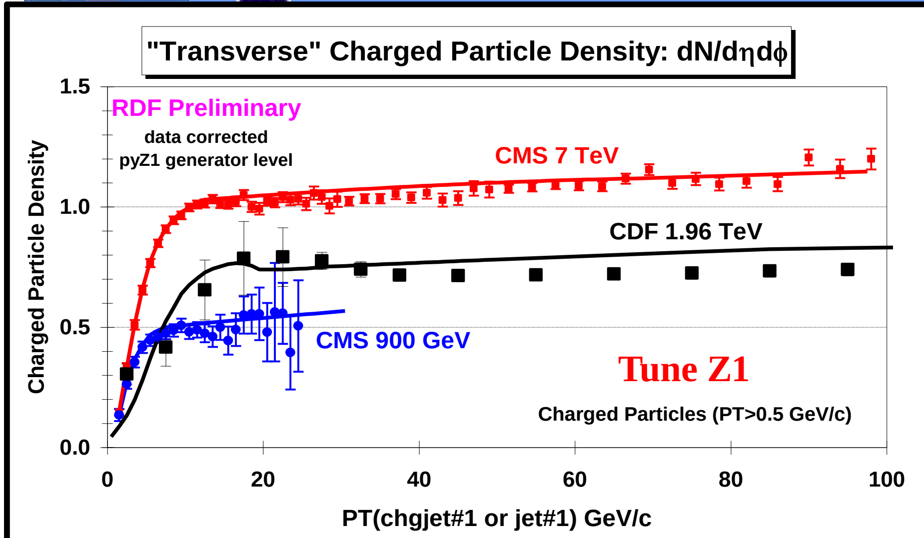


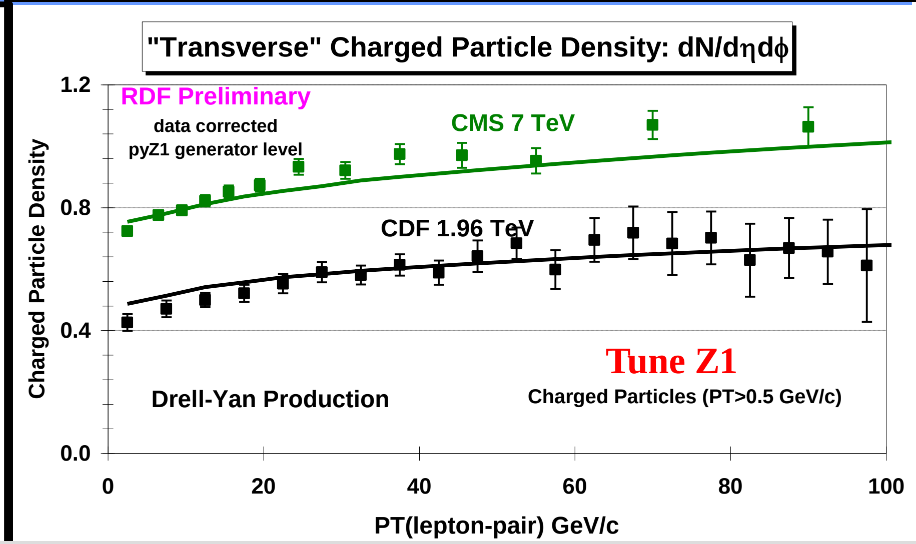


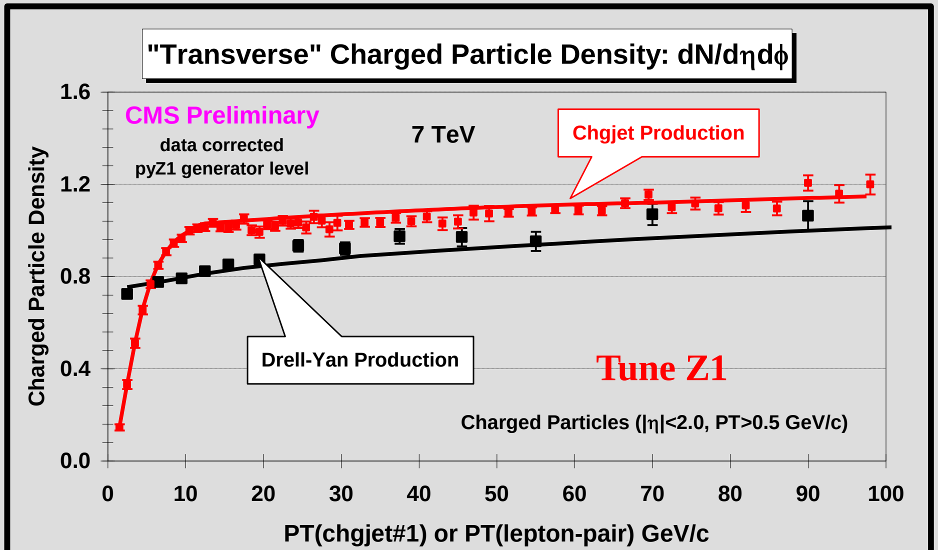


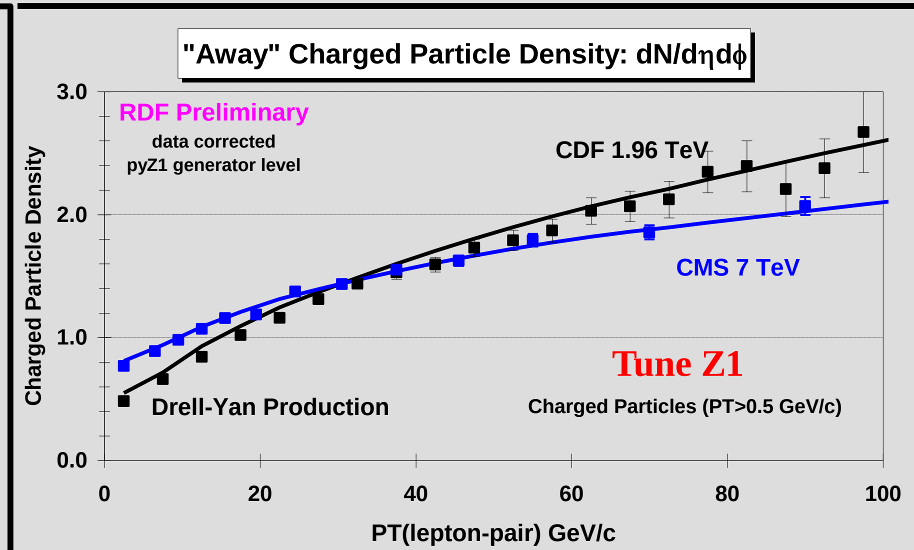
- **CDF data at 1.96 TeV** on the charged PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the "toward", "away", and "transverse" regions compared with **PYTHIA Tune Z1**.
- **CMS data at 7 TeV** on the charged PTsum density, dPT/dηdϕ, with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

PYTHIA Tune Z1

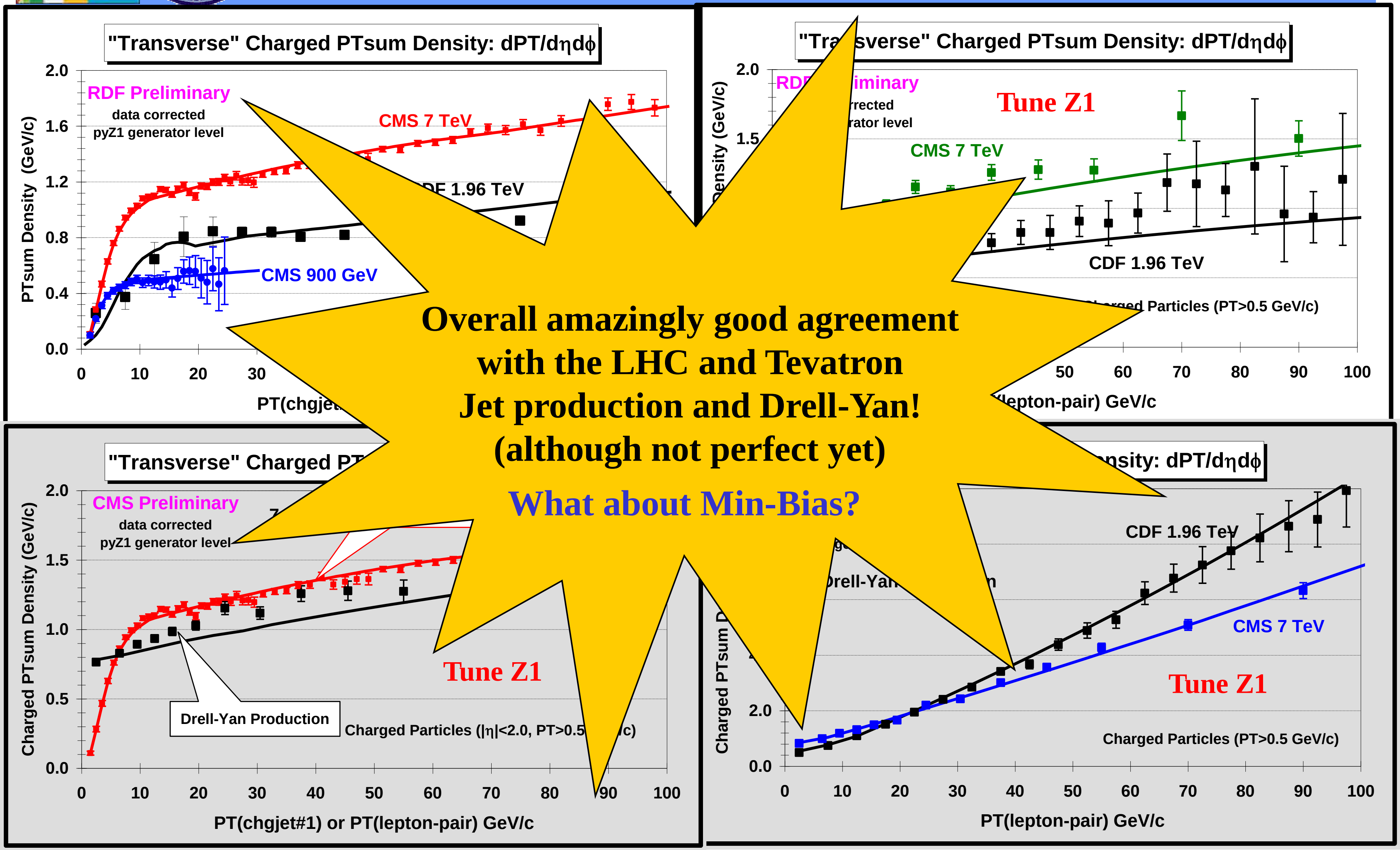




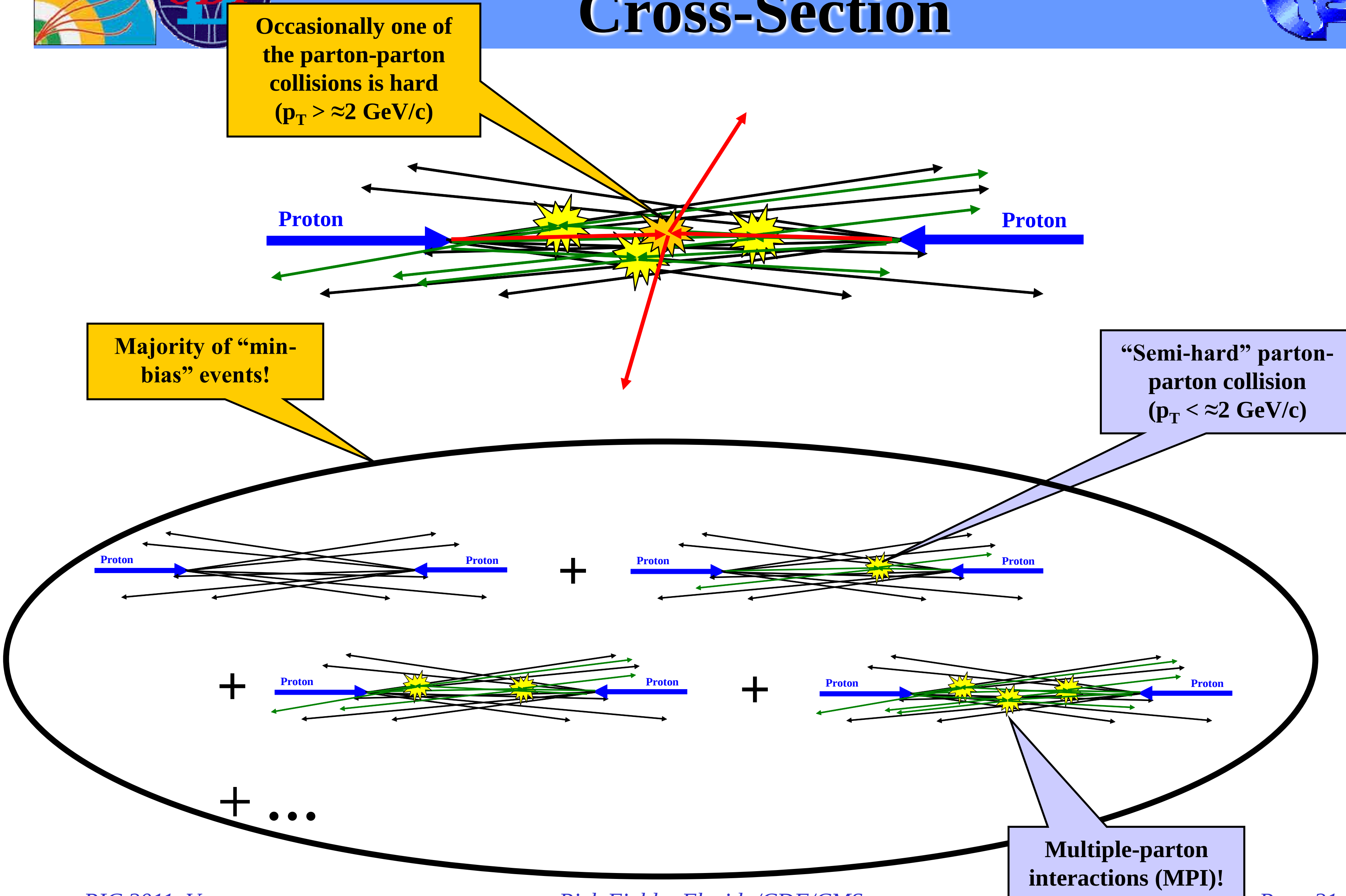




PYTHIA Tune Z1

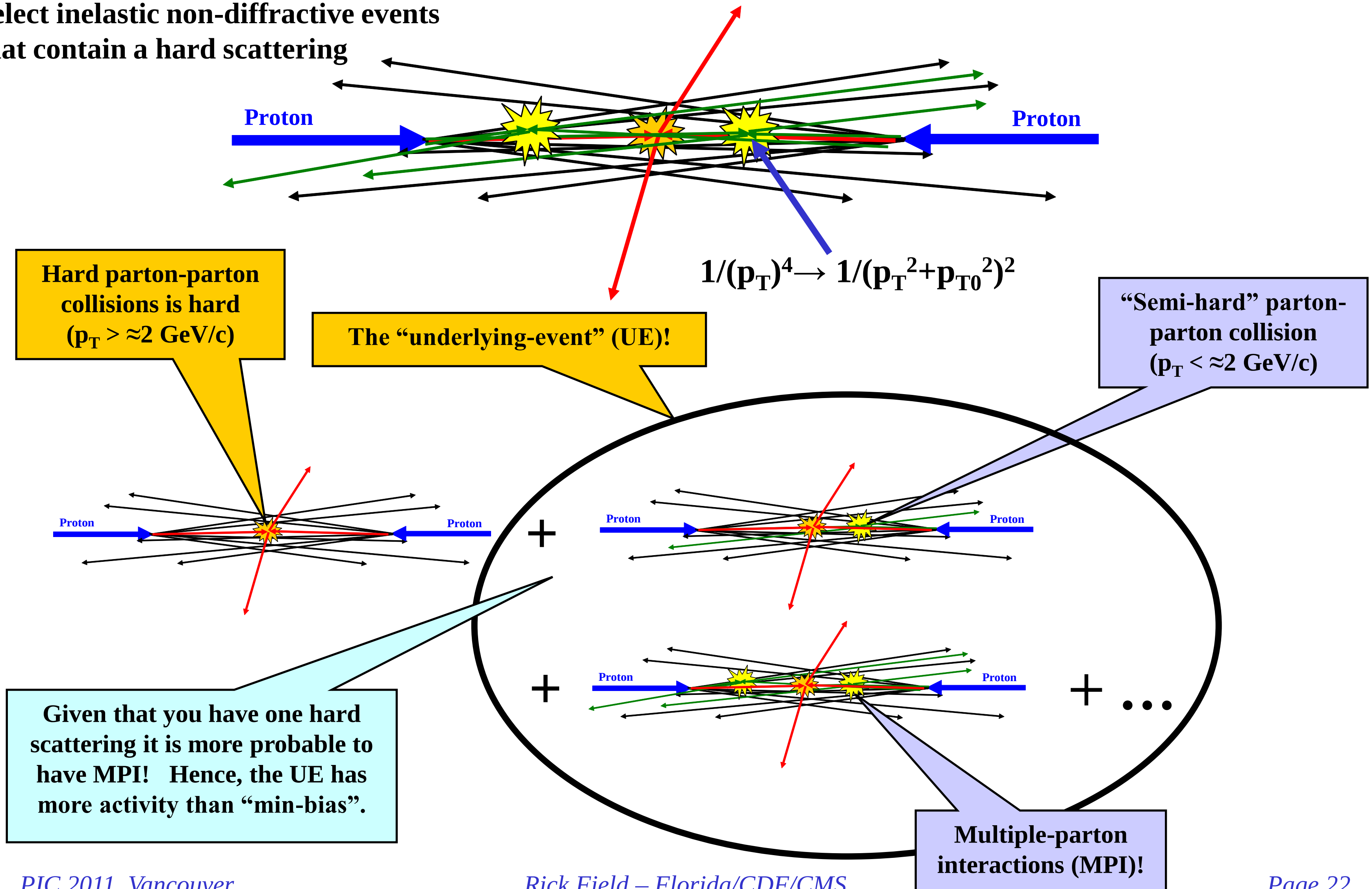


The Inelastic Non-Diffractive Cross-Section

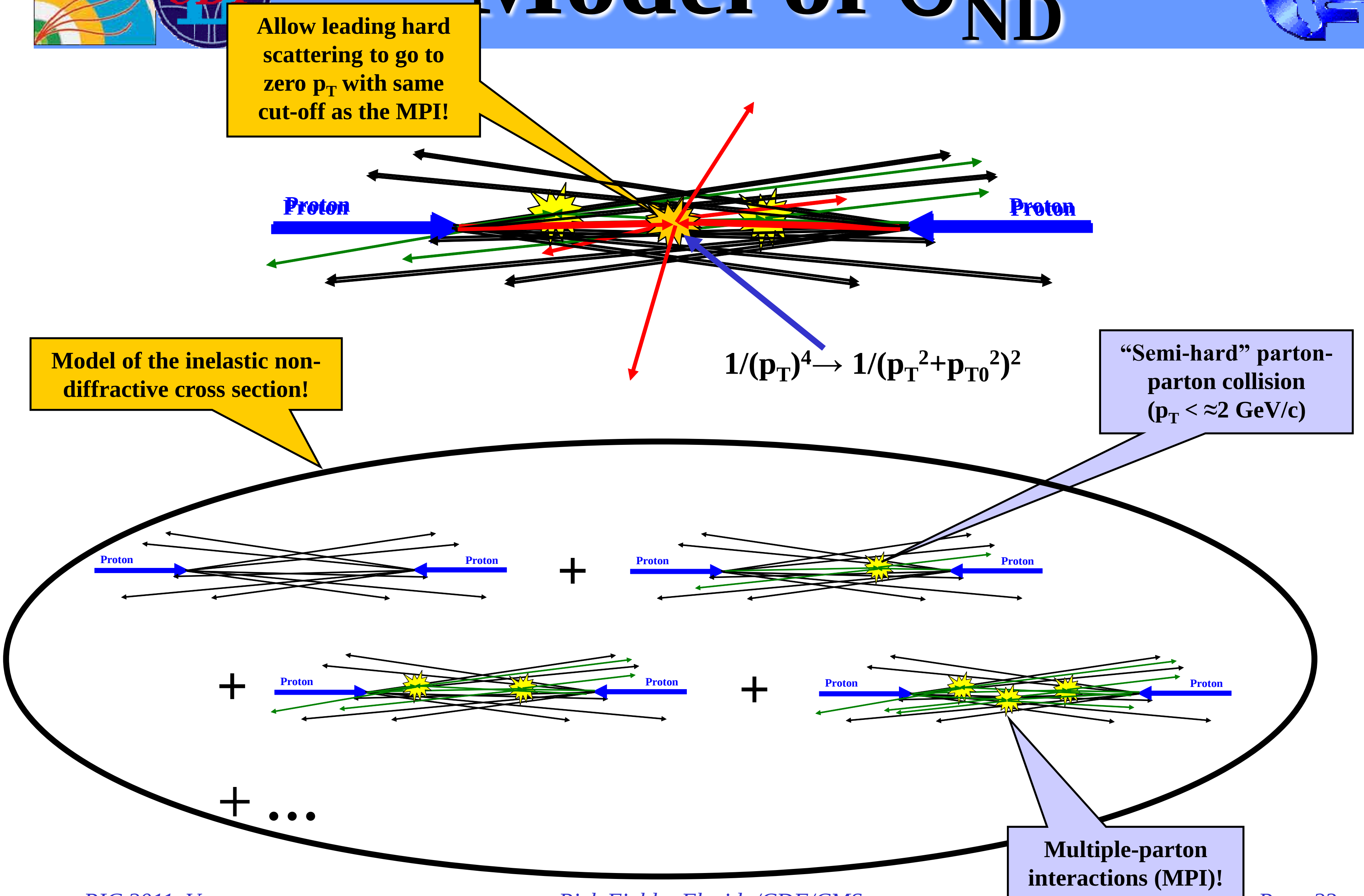


The “Underlying Event”

Select inelastic non-diffractive events that contain a hard scattering



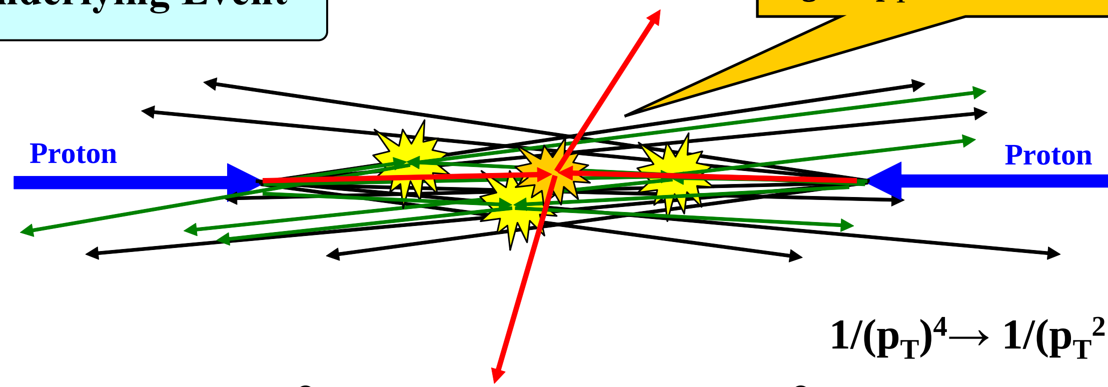
Model of σ_{ND}



UE Tunes

"Underlying Event"

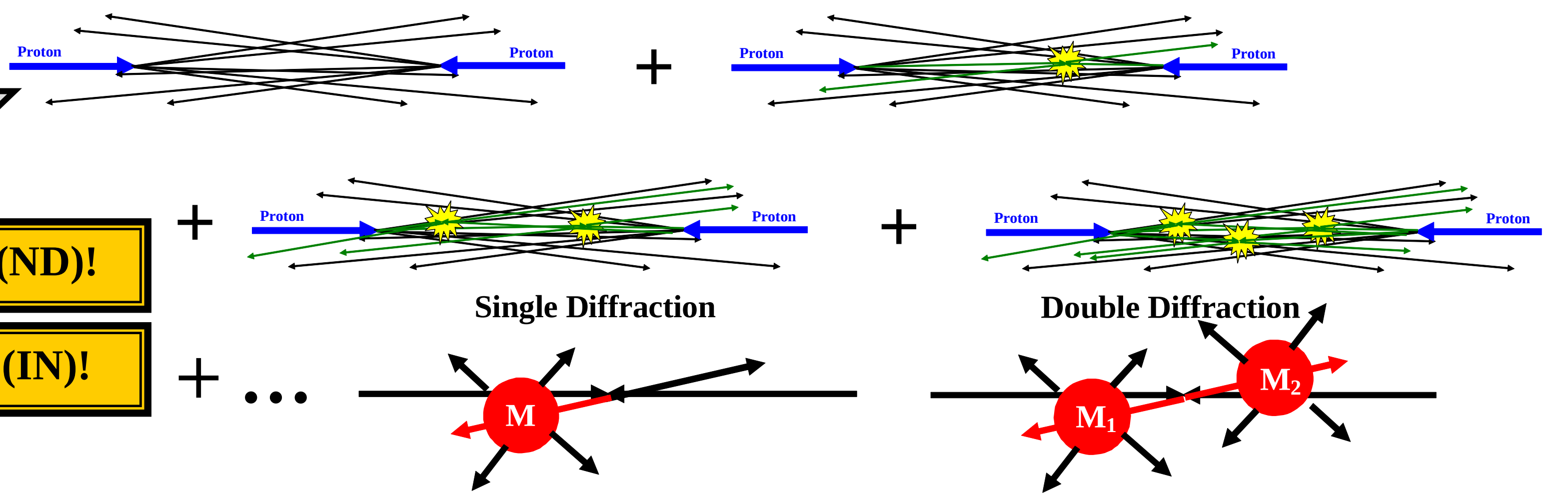
Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!



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

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

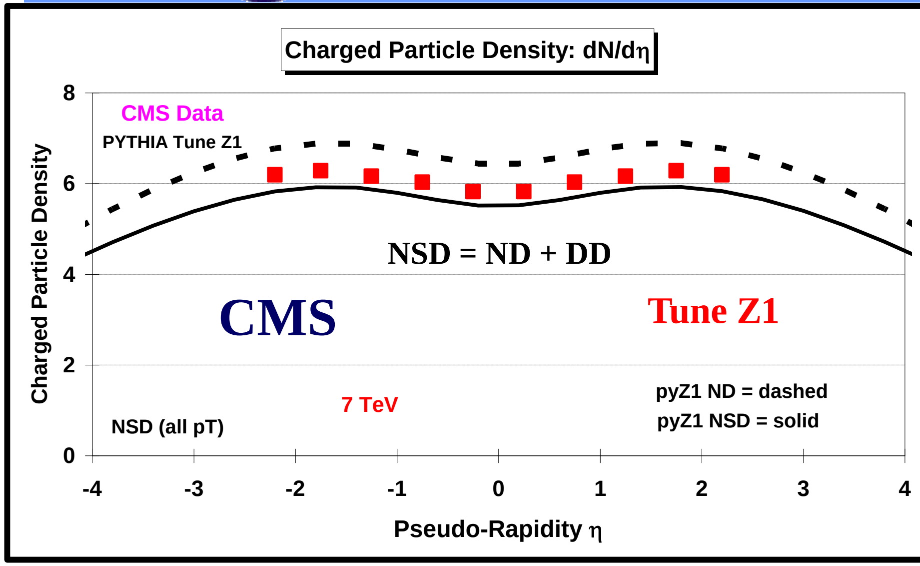
"Min-Bias" (add single & double diffraction)

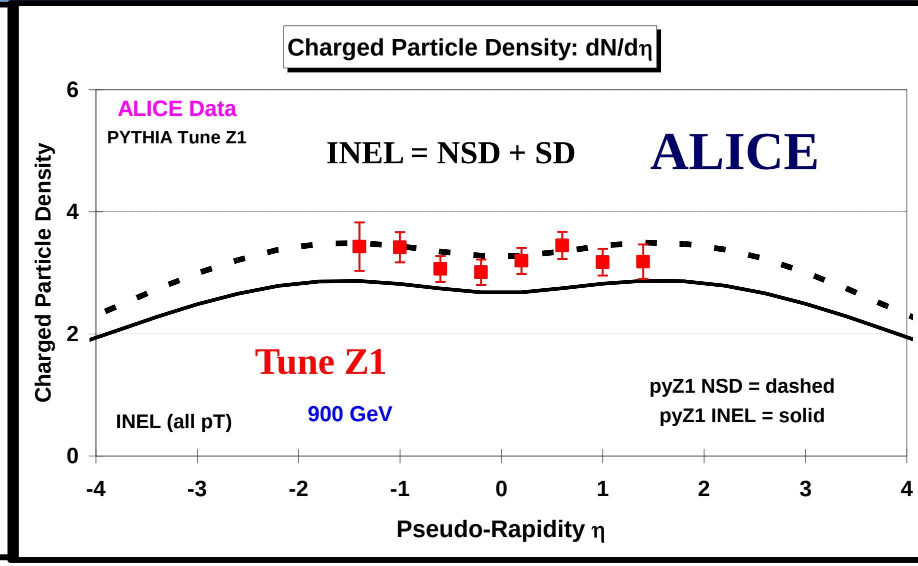


Predict MB (ND)!

Predict MB (IN)!

Min-Bias Collisions





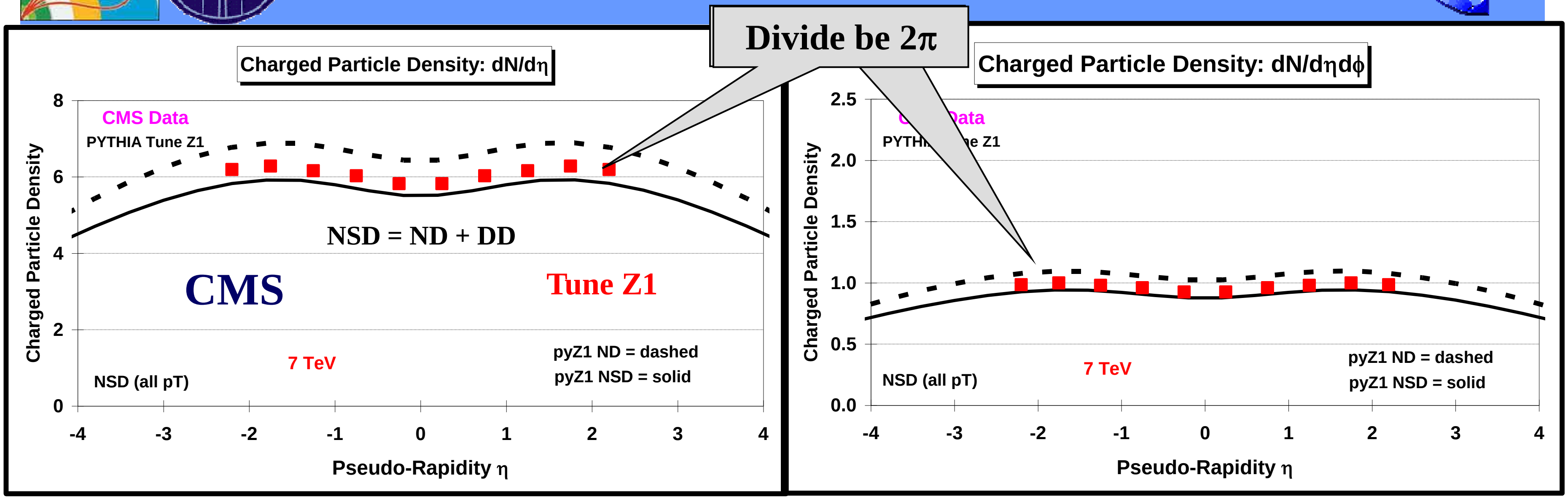
- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with **PYTHIA Tune Z1**. The plot shows the average number of particles per NSD collision per unit η, $(1/N_{NSD})\ dN/d\eta$.

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

"Minimum Bias" Collisions

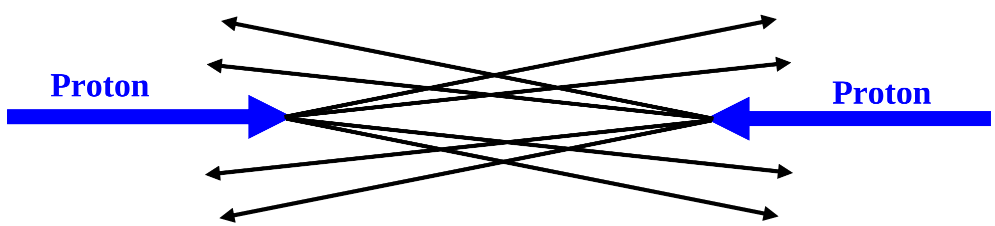
Okay not perfect, but remember we know that SD and DD are not modeled well!

MB versus UE

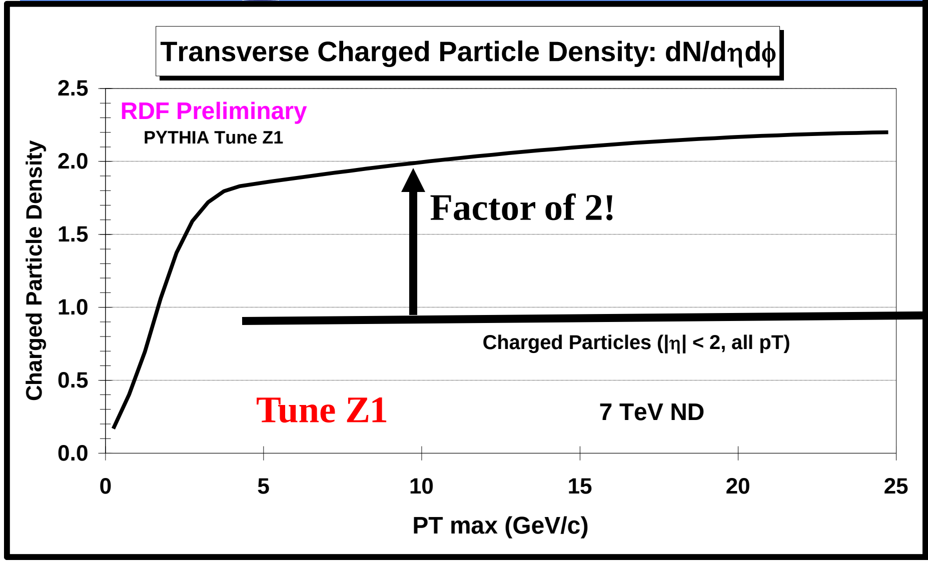


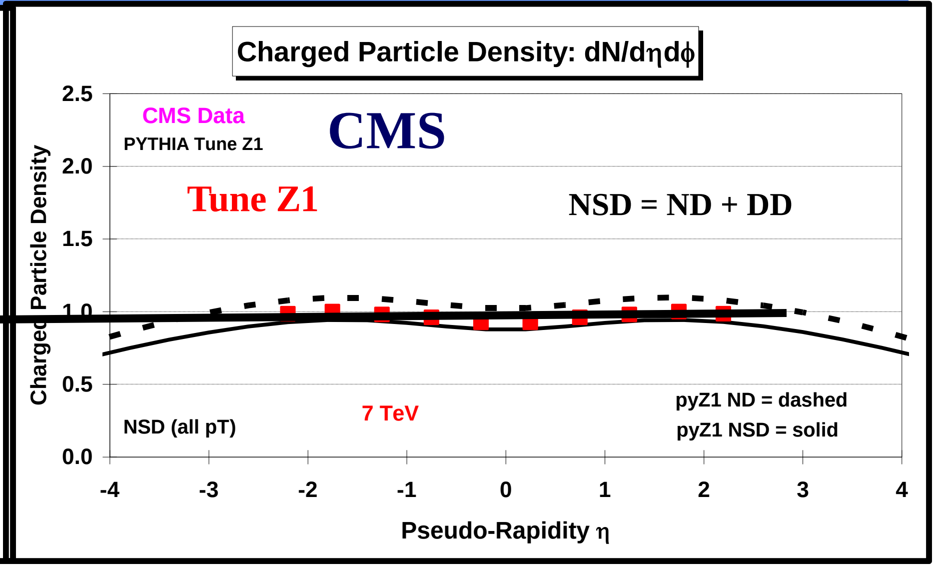
- **CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η, $(1/N_{NSD})\ dN/d\eta$.**
- **CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA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

"Minimum Bias" Collisions

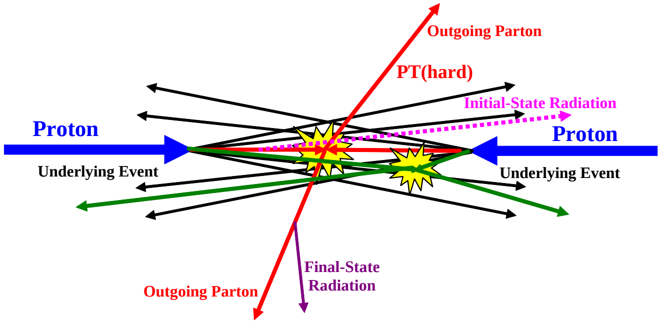


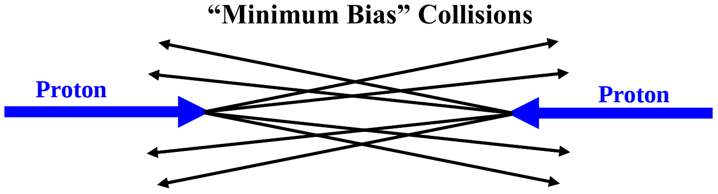
MB versus UE



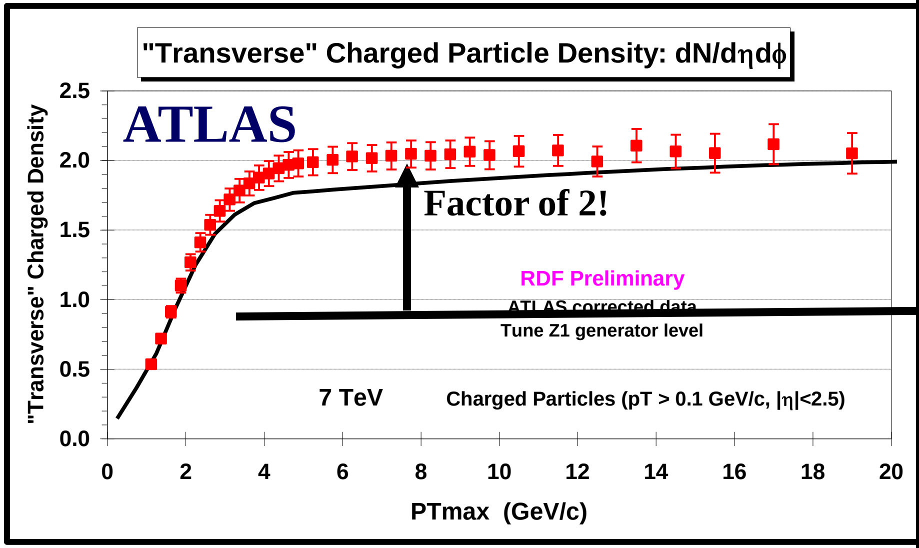


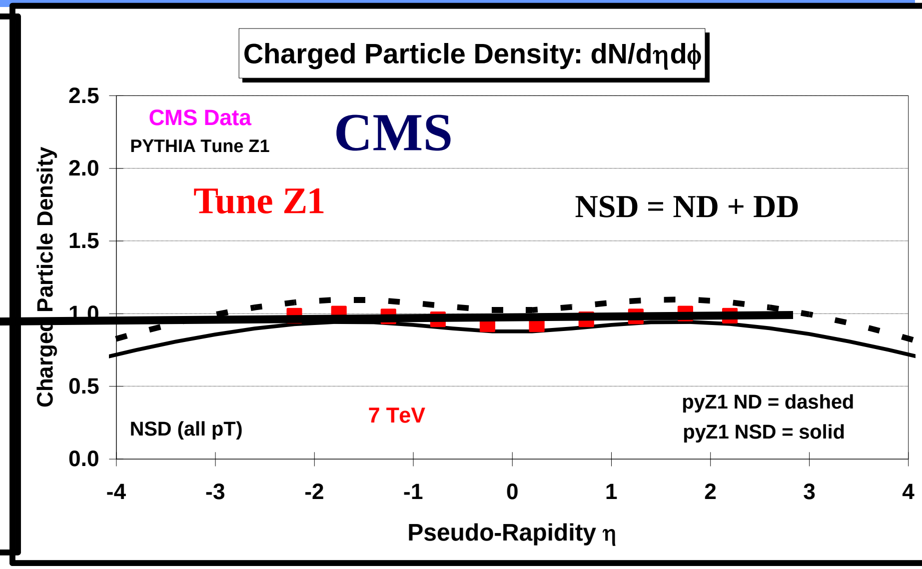
- Shows the density of charged particles in the "transverse" region as a function of PTmax for charged particles (All p_T, $|\eta| < 2$) at 7 TeV from PYTHIA Tune Z1.
- CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number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





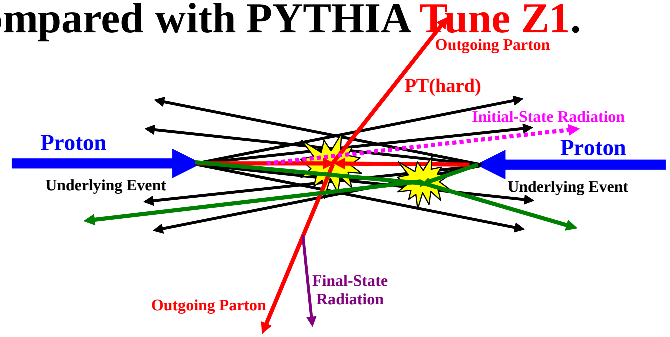
MB versus UE

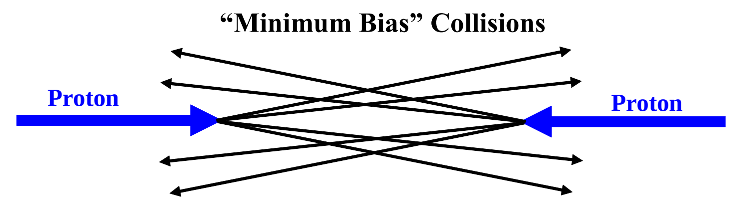




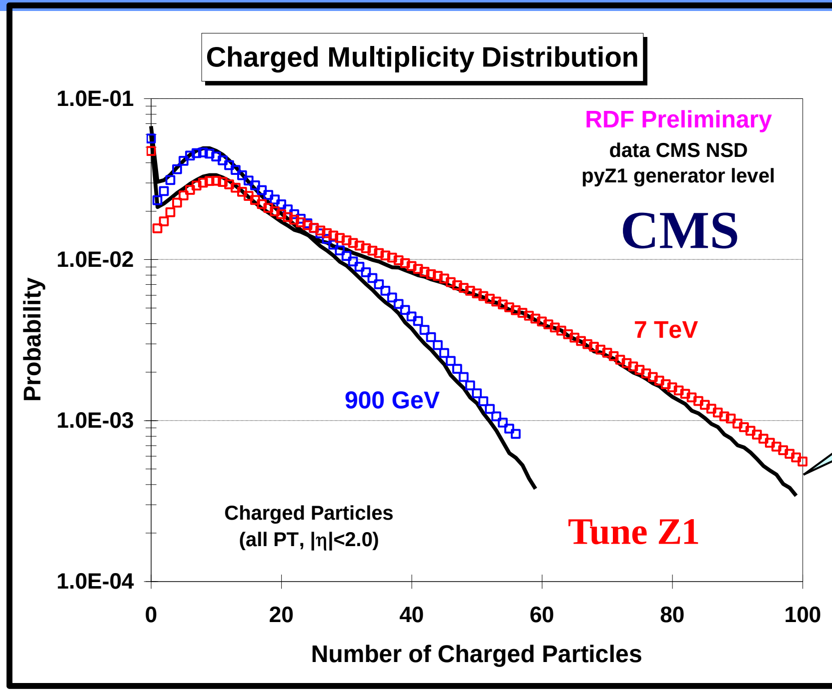
- **ATLAS data** on the density of charged particles in the **"transverse" region** as a function of PTmax for charged particles ($p_T > 0.1$ GeV/c, $|\eta| < 2.5$) at 7 TeV compared with PYTHIA **Tune Z1**.

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





NSD Multiplicity Distribution



Difficult to produce enough events with large multiplicity!

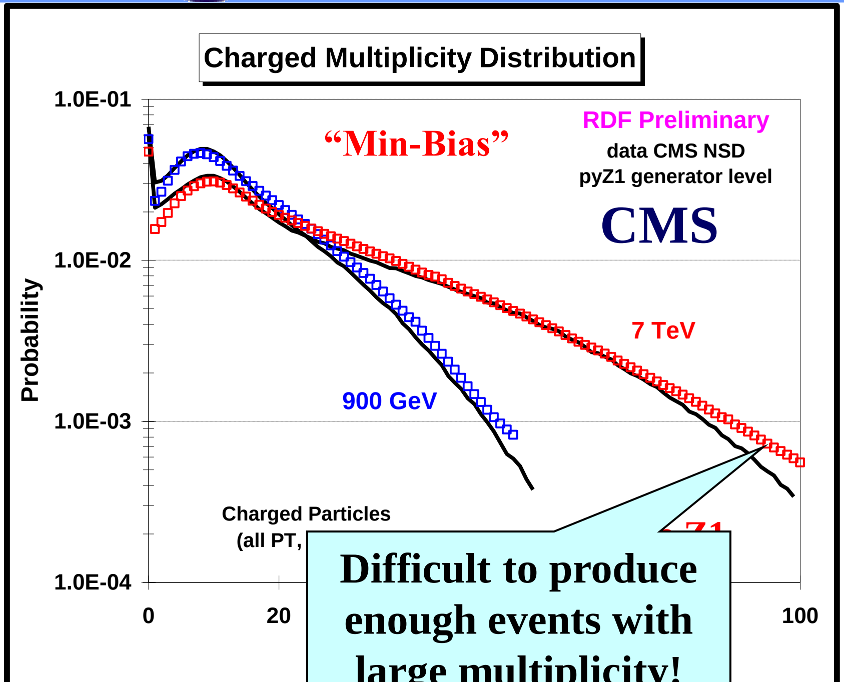
- **Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.**

"Minumum Bias" Collisions

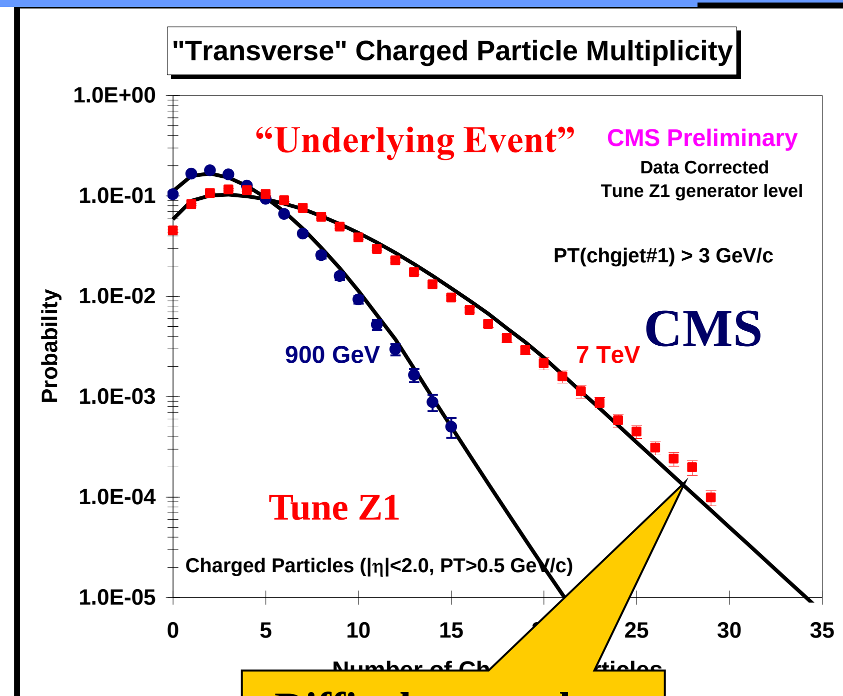
Proton **oton**

Okay not perfect!
But not that bad!

MB & UE



Difficult to produce enough events with large multiplicity!



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

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

- CMS corr… and 7 TeV on the cha…ty distributi…egion for charged p…, $|\eta| < 2$) as defined …l particle jet with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1 at the generator level.

How Universal are the Tunes?

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

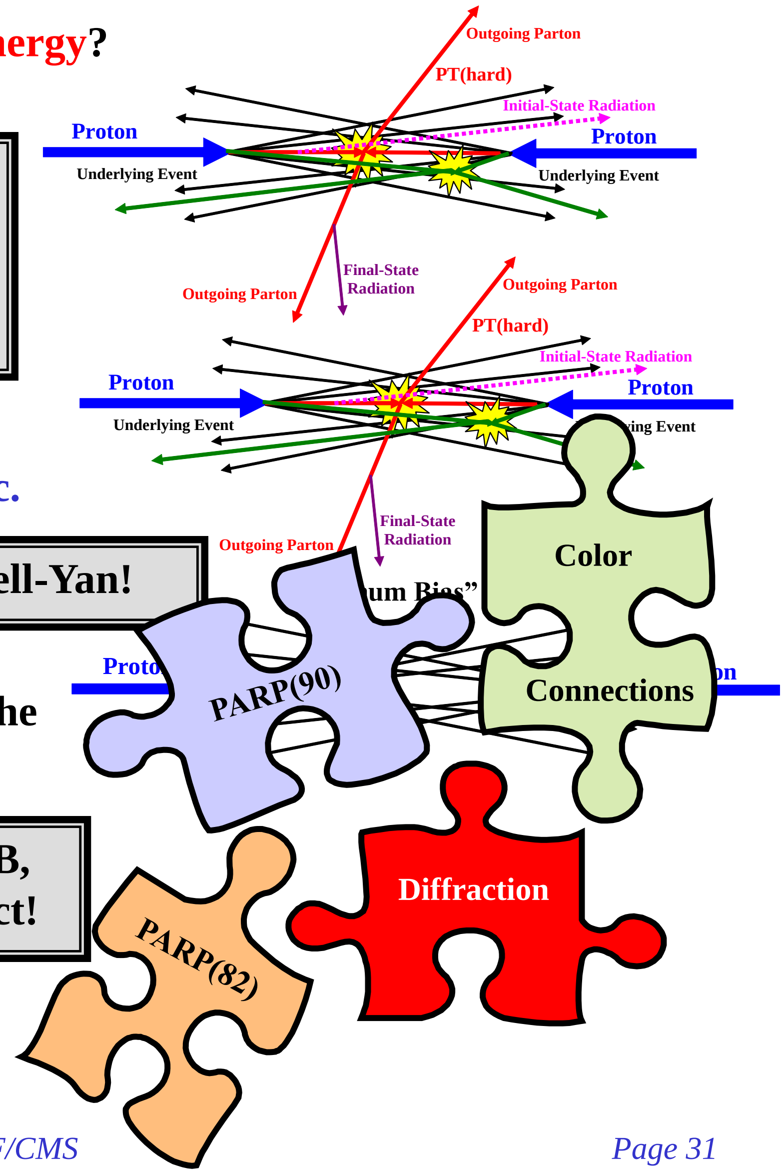
> **PYTHIA Tune DW did a nice (although not perfect) job predicting the LHC Jet Production and Drell-Yan UE data. I am still hoping for a single tune that will describe all energies!**

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

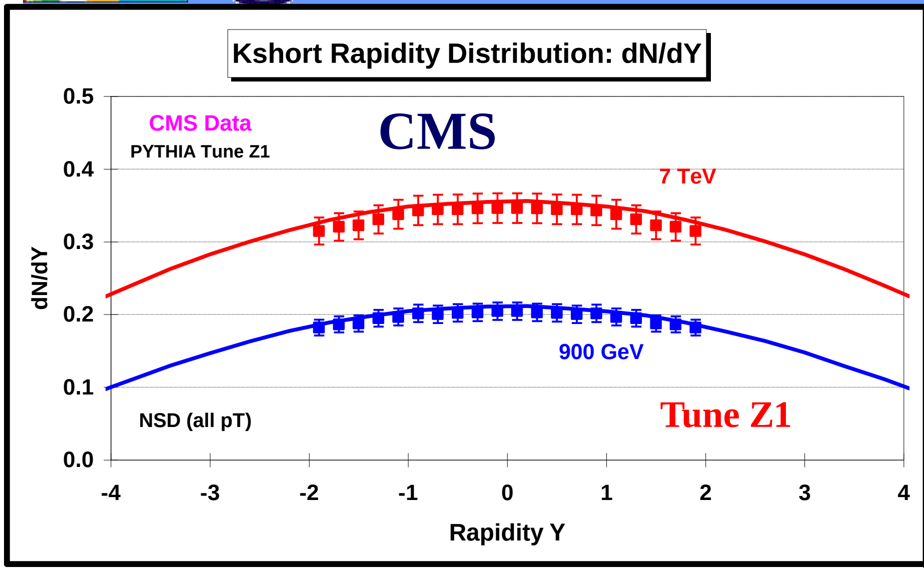
> **The same tune can describe both Jet Production and Drell-Yan!**

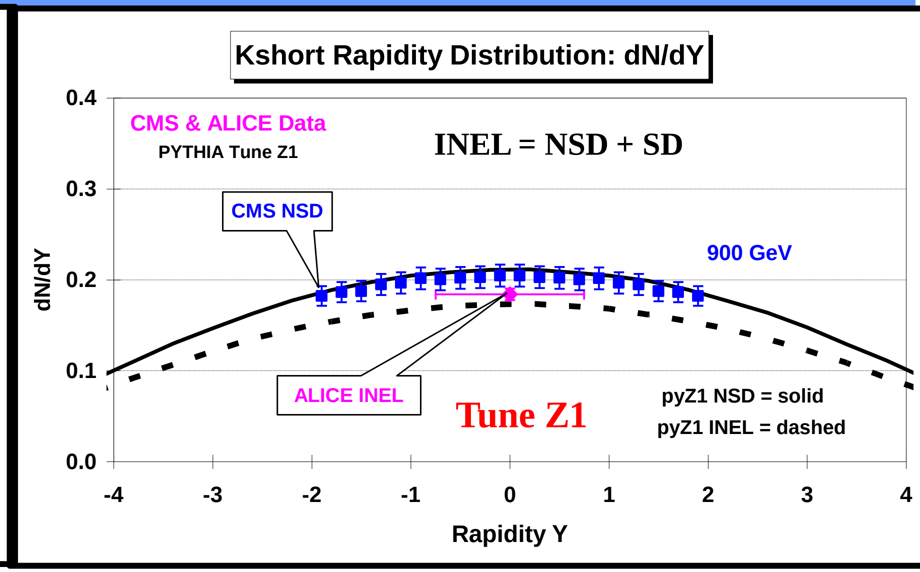
- Do we need **separate tunes** for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

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



Kaon Production





- **CMS NSD data on the K_{short} rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of K_{short} per NSD collision per unit Y, $(1/N_{NSD})$ dN/dY.**

- **CMS NSD data on the K_{short} rapidity distribution at 900 GeV and the ALICE point at Y = 0 (INEL) compared with PYTHIA Tune Z1. The ALICE point is the average number of K_{short} per INEL collision per unit Y at Y = 0, $(1/N_{INEL})$ dN/dY.**

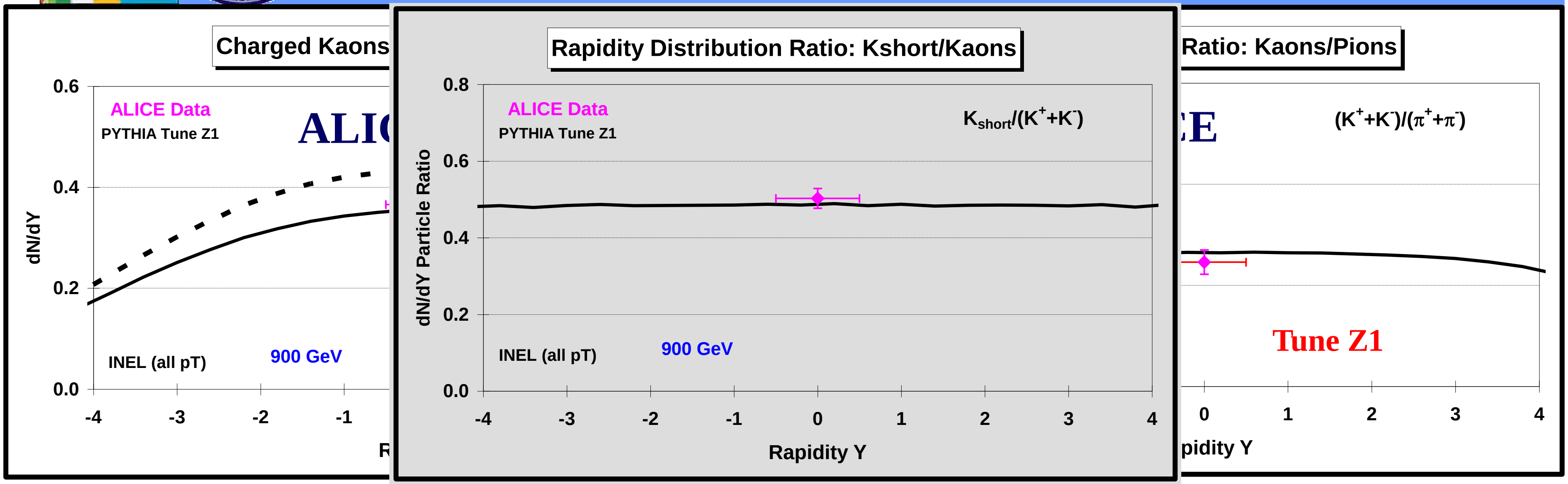
"Minimum Bias" Collisions

K_{short}: $d\bar{s} + \bar{d}s$

No overall shortage of Kaons in PYTHIA Tune Z1!

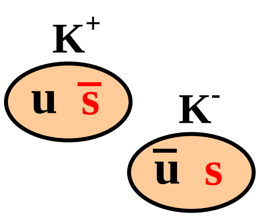
K_{short}: $d\bar{s} + \bar{d}s$

Kaon Production



- **ALICE INEL data** on the charged kaon rapidity distribution at 900 GeV compared with **PYTHIA Tune Z1**. The plot shows the average number of charged kaons per INEL collision per unit Y at Y = 0, $(1/N_{INEL})$ dN/dY.
- **ALICE INEL data** on the charged kaon to charged pion rapidity ratio at 900 GeV compared with **PYTHIA Tune Z1**.

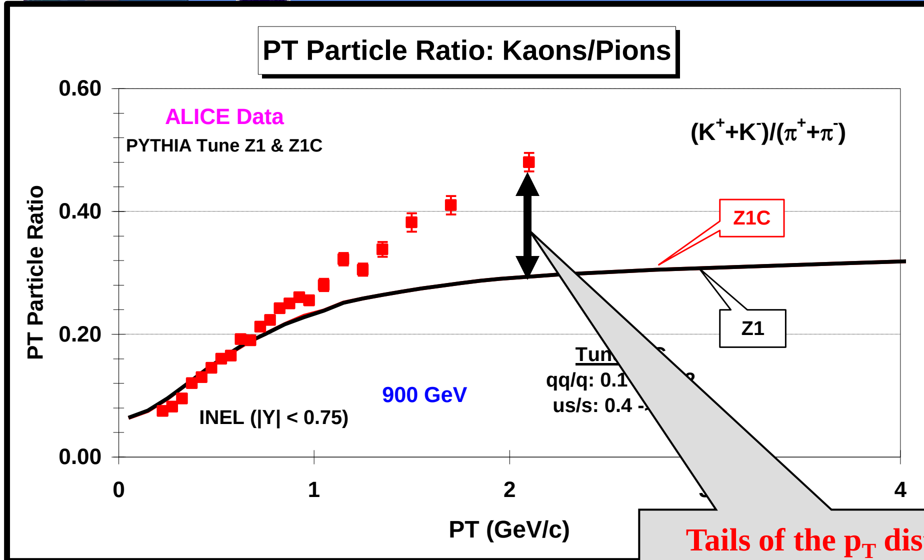
$$\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)} = \frac{\text{Strange Meson}}{\text{Non-strange Meson}}$$

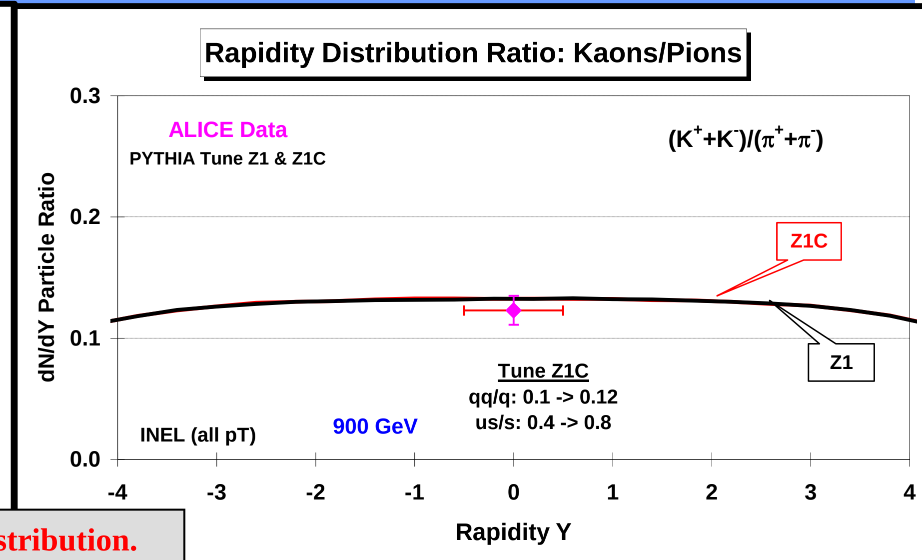


"Minimum Bias" Collisions

No overall shortage of Kaons in PYTHIA Tune Z1!

Particle Ratios versus PT

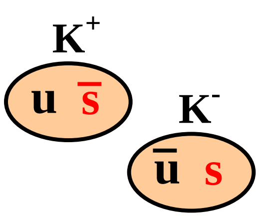




Tails of the p_T distribution.
Way off due to the wrong p_T!

- ALICE INEL data on the charged kaons to charged pions ratio versus p_T at 900 GeV (|Y| < 0.75) compared with PYTHIA Tune Z1 & Z1C.
- ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with PYTHIA Tune Z1.

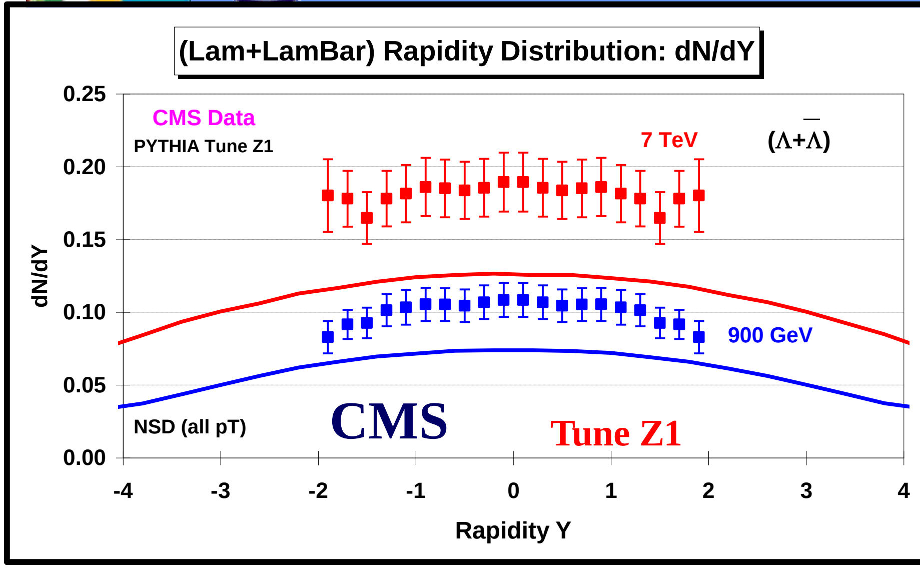
$$\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)} = \frac{\text{Strange Meson}}{\text{Non-strange Meson}}$$

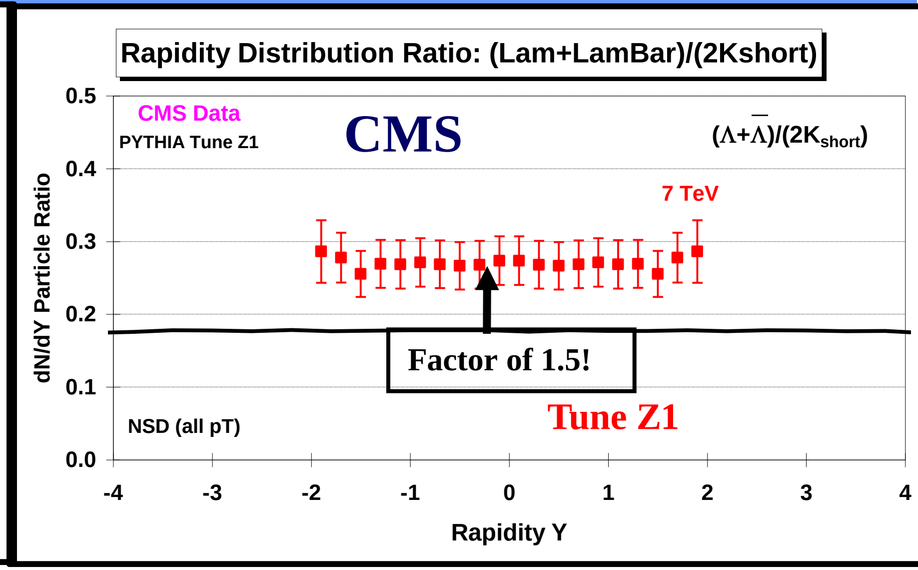


"Minimum Bias" Collisions

PYTHIA p_T dependence off on Kaons!

Lambda Production





- **CMS NSD data** on the Lambda+AntiLambda rapidity distribution at 7 TeV and 900 GeV compared with **PYTHIA Tune Z1**. The plot shows the average number of particles per NSD collision per unit Y, $(1/N_{NSD})$ dN/dY.
- **CMS NSD data** on the Lambda+AntiLambda to 2Kshort rapidity ratio at 7 TeV compared with **PYTHIA Tune Z1**.

$$\frac{(\Lambda + \bar{\Lambda})}{2K_{short}} = \frac{\text{Single-strange Baryon}}{\text{Strange Meson}}$$

"Minimum Bias" Collisions

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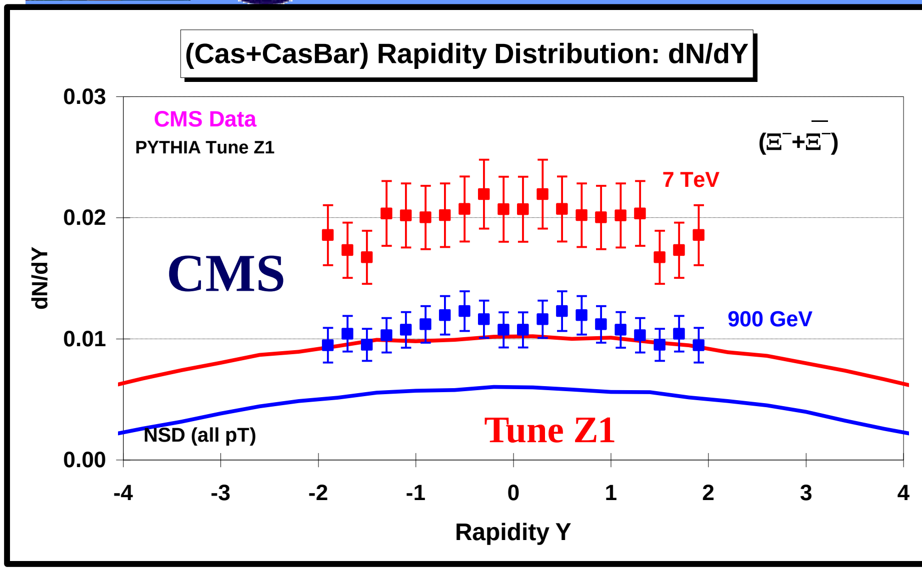
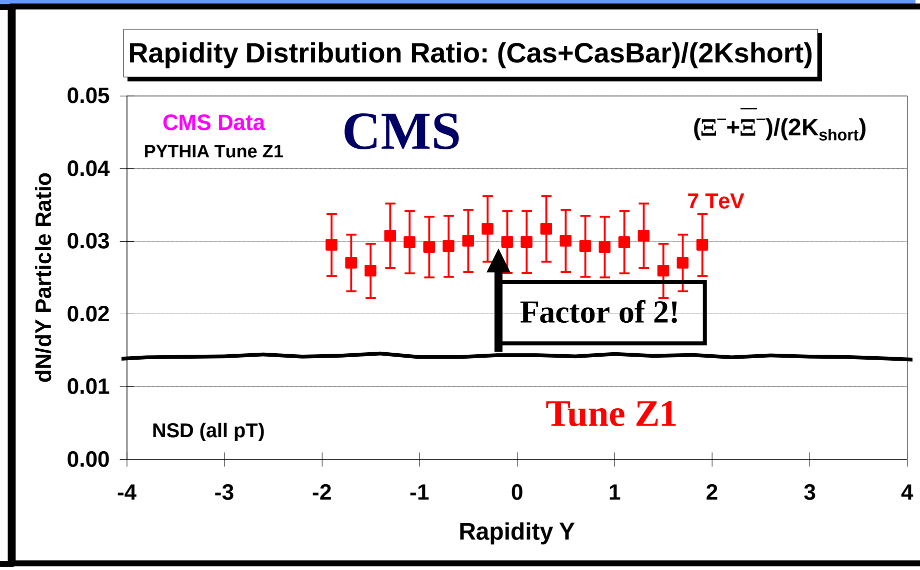
Oops! Not enough Lambda's in PYTHIA Tune Z1!

Cascade Production



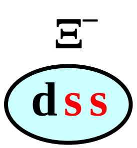


- **CMS NSD data** on the Cascade$^-$ +AntiCascade$^-$ rapidity distribution at 7 TeV and 900 GeV compared with **PYTHIA Tune Z1**. The plot shows the average number of particles per NSD collision per unit Y, $(1/N_{NSD})\, dN/dY$.

- **CMS data** on the Cascade$^-$+AntiCascade$^-$ to 2Kshort rapidity ratio at 7 TeV compared with **PYTHIA Tune Z1**.

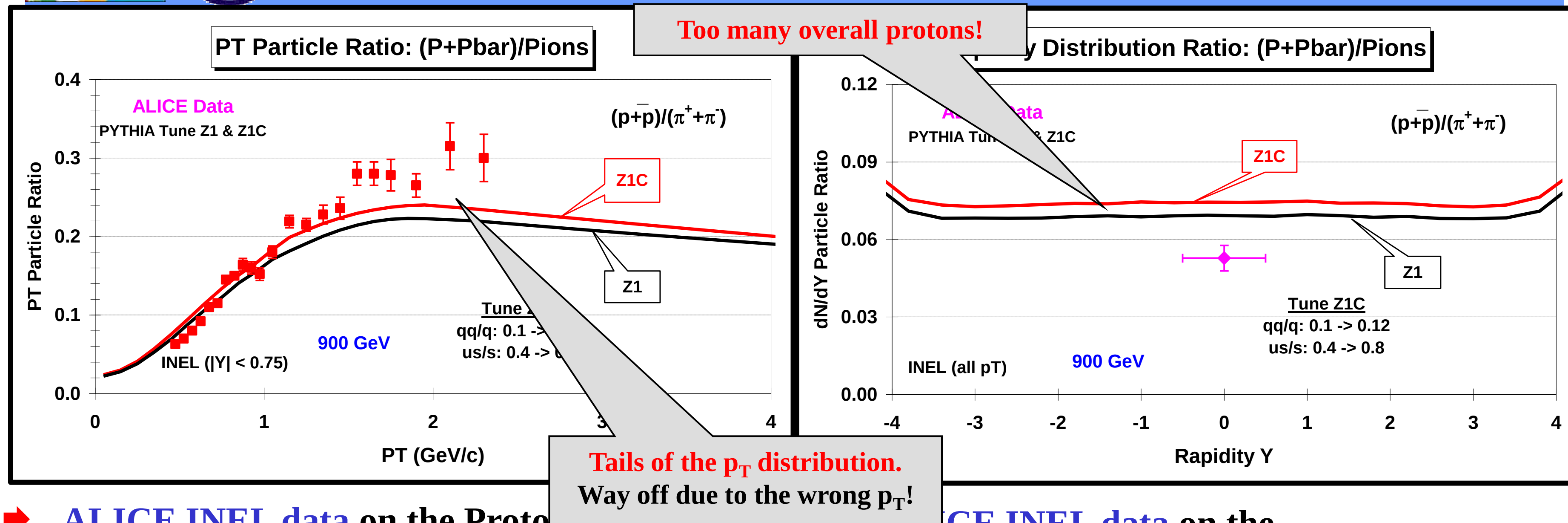
$$\frac{(\Xi + \bar{\Xi})}{2K_{short}} = \frac{\text{Double-strange Baryon}}{\text{Strange Meson}}$$

"Minimum Bias" Collisions



Yikes! Way too few Cascade's in PYTHIA Tune Z1!

Particle Ratios versus PT



- **ALICE INEL data** on the Proton+AntiProton to charged pions ratio versus p_T at 900 GeV ($|Y| < 0.75$) compared with **PYTHIA Tune Z1 & Z1C**.

$$\frac{(p + \bar{p})}{(\pi^+ + \pi^-)} = \frac{\text{Non-strange Baryon}}{\text{Non-strange Meson}}$$

- **ALICE INEL data** on the Proton+AntiProton to charged pion rapidity ratio at 900 GeV compared with **PYTHIA Tune Z1 & Z1C**.

"Minimum Bias" Collisions

p

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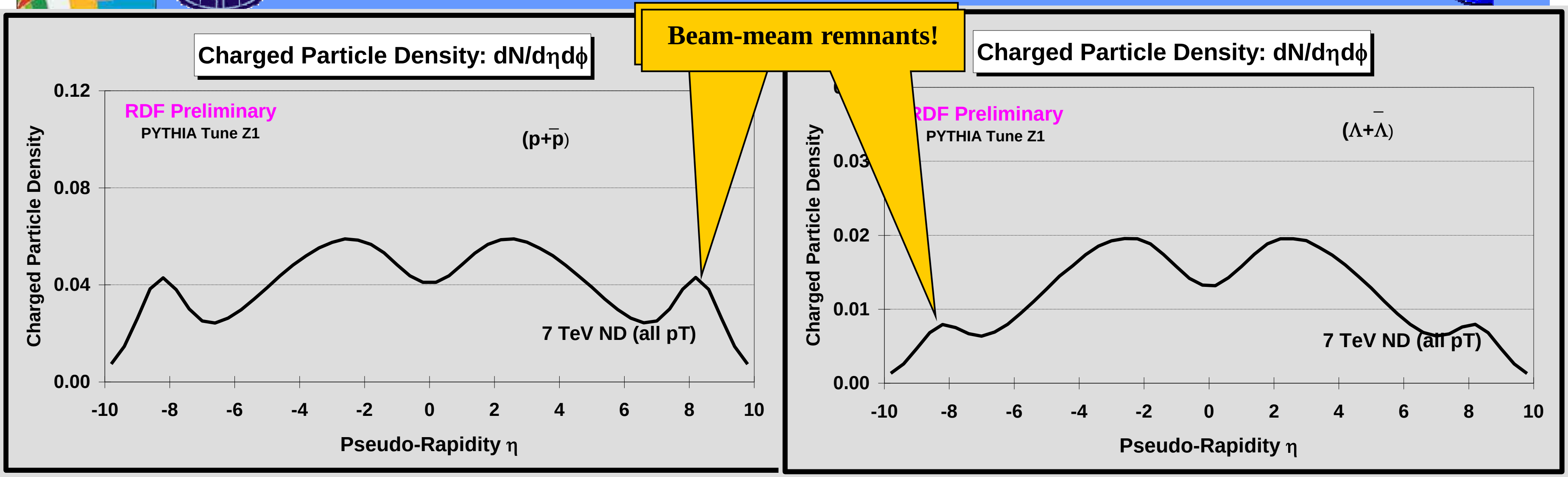
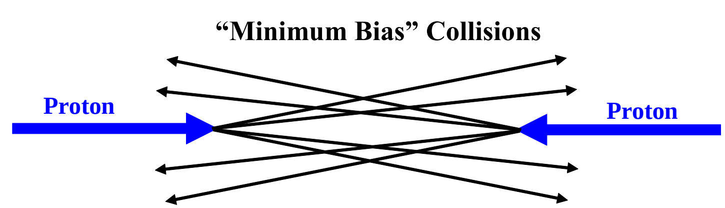
PYTHIA way off on the p_T dependence of Protons!

Fragmentation Summary



looks at particle ratios at large p_T you can see big discrepancies between data and MC (out in the tails of the distributions)!

- **Factorization: Are we seeing a breakdown in factorization between e^+e^- annihilations and hadron-hadron collisions! Is something happening in hadron-hadron collisions that does not happen in e^+e^- annihilations?**



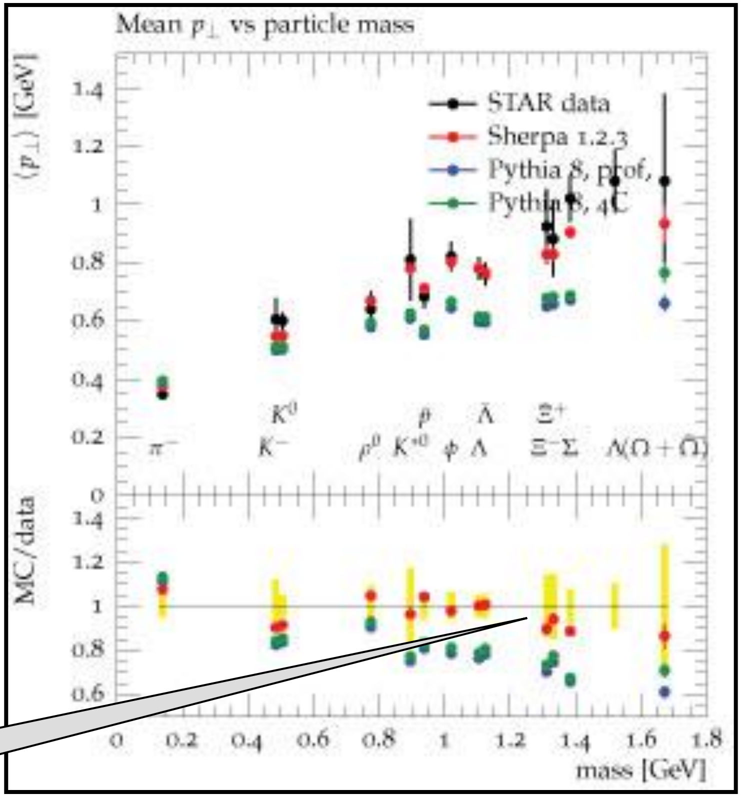
- **Herwig++ & Sherpa: Before making any conclusions about fragmentation one must check the predictions of Herwig++ and Sherpa carefully!**

Sherpa versus PYTHIA

$\langle p_T \rangle$ versus Mass

- Before making any conclusion about e^+e^- versus pp collisions one must check the predictions of Herwig++ and Sherpa!

Strange particle production in pp at 200 GeV (STAR_2006_S6860818)



Sherpa does better than PYTHIA 8!

Hendrik Hoeth
http://users.hepforge.org/~hoeth/STAR_2006_S6860818/