Soft-QCD Studies and Monte-Carlo Tuning in ATLAS

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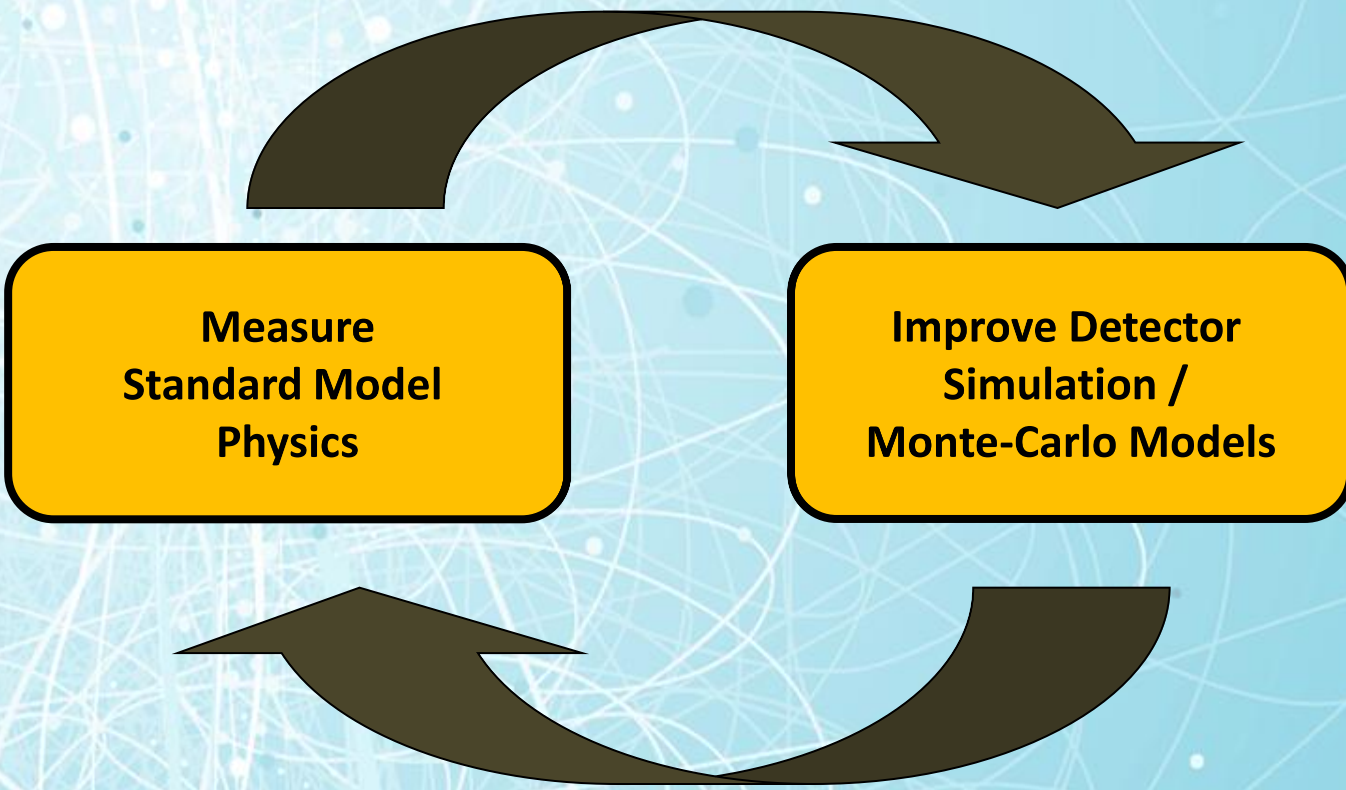
7th December 2011

PROLOGUE

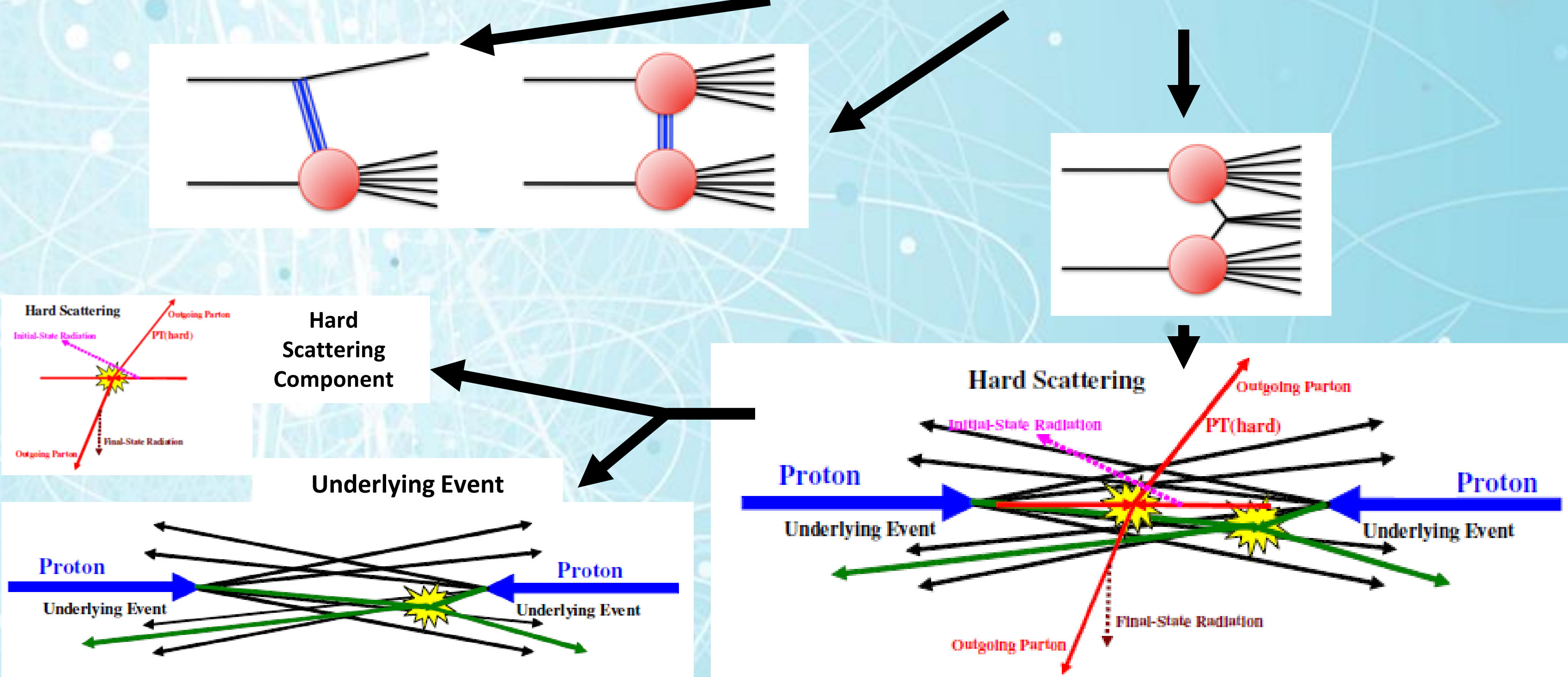

Measure
Standard Model
Physics
Improve Detector
Simulation /
Monte-Carlo Models

Soft-QCD in a new high energy and high multiplicity frontier …

- Bulk of the total cross-section, corresponding to soft and semi-hard processes is not well understood since non-perturbative physics is involved.
- Soft QCD processes are unavoidable background to all collider observables .
- Intricately tied to measurement of high p_T observables – *i.e.* inclusive jet and b-jet cross-sections, as well as missing energy, isolation cuts, top mass, among others.
- High Q^2 and low –x phenomenon, such as the effect of high parton densities and the interplay between perturbative and non perturbative regimes is not well understood.
- We have to use the soft QCD distributions to test the phenomenological models and "tune" the Monte-Carlo event generators to give the best description of the data.

“Soft” QCD: MB and UE

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



Minimum-Bias: generic term referring to events that are selected with a loose trigger, that accepts a large fraction of the inelastic cross-section.

Underlying Event: defined as everything except the hard scattered part.

Minimum Bias Measurements

- First physics result!
- Fully inclusive measurement *(not just charged hadrons).*
- No model dependent corrections or extrapolations *(not claimed to be a non-single-diffractive measurement, for example).*

Minimum-Bias Measurements

Inclusive distributions:

$$\frac{1}{N_{\mathrm{ev}}} \cdot \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta}, \quad \frac{1}{N_{\mathrm{ev}}} \cdot \frac{1}{2\pi p_{\mathrm{T}}} \cdot \frac{\mathrm{d}^2 N_{\mathrm{ch}}}{\mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}, \quad \frac{1}{N_{\mathrm{ev}}} \cdot \frac{\mathrm{d}N_{\mathrm{ev}}}{\mathrm{d}n_{\mathrm{ch}}} \quad \text{and} \quad \langle p_{\mathrm{T}} \rangle \text{ vs. } n_{\mathrm{ch}}$$

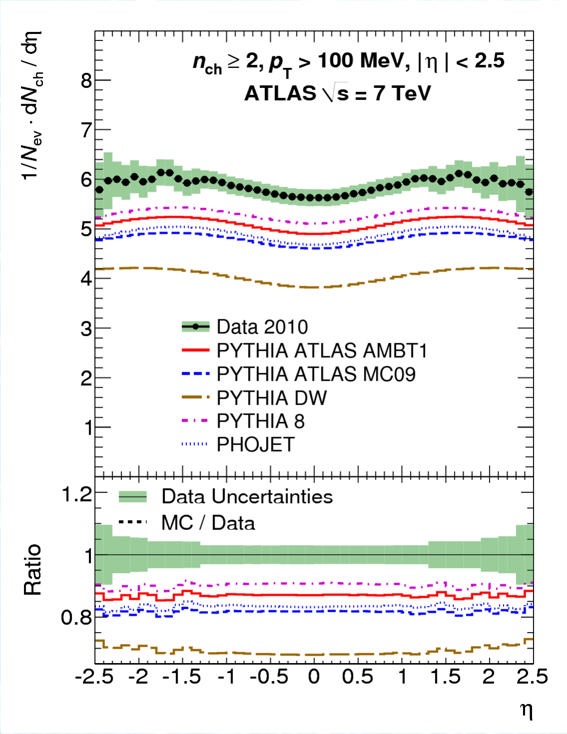
Going down to p_T > 100 MeV (requires ≥2 particles).

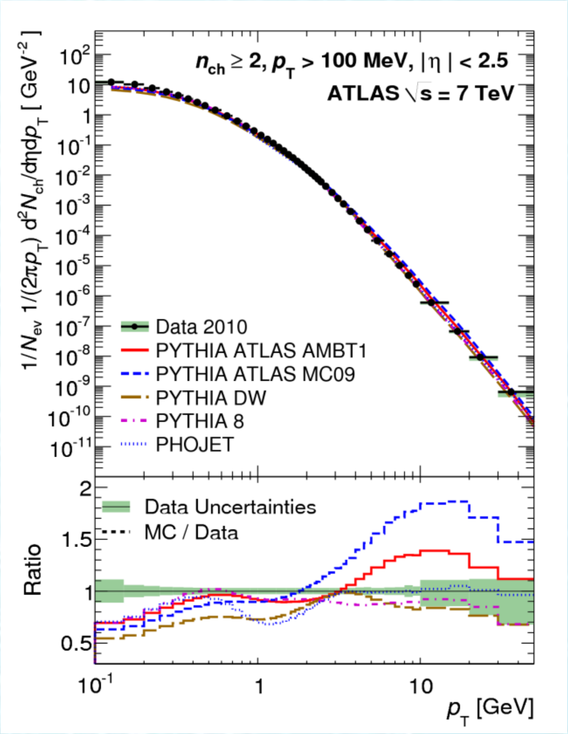
Previously with p_T > 500 MeV (required ≥1 particle).

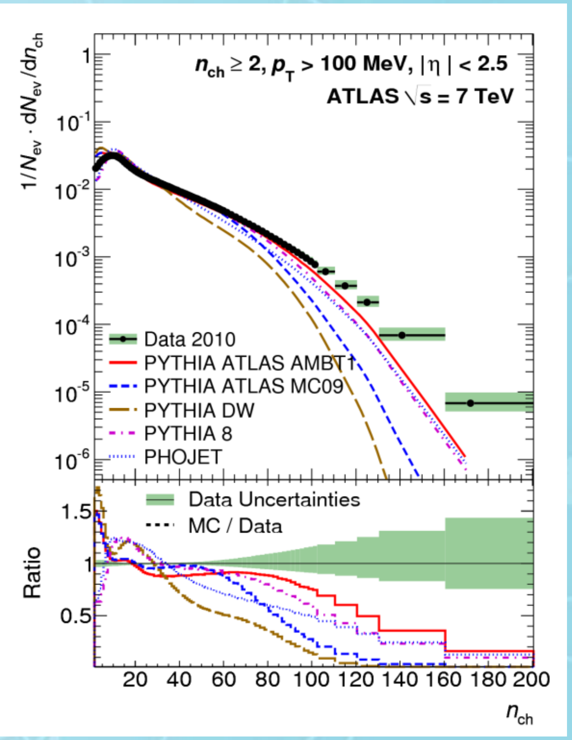
Also, diffraction suppressed distributions for tuning (requiring ≥6 particles).

Data corrected back to particle level by applying efficiency corrections and unfolding to account for migration.

Minimum-Bias Results

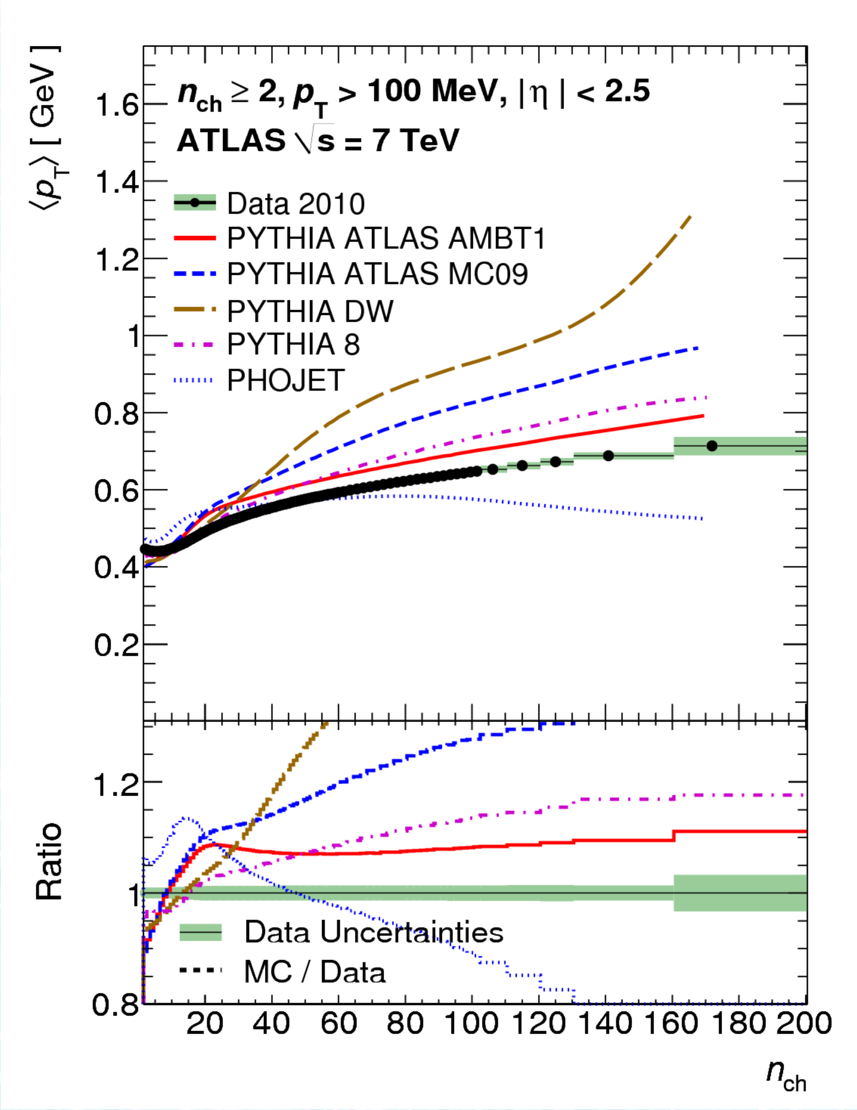






Shape described well, but not normalization by MC. Largest diffractive contribution in lower p_T region.

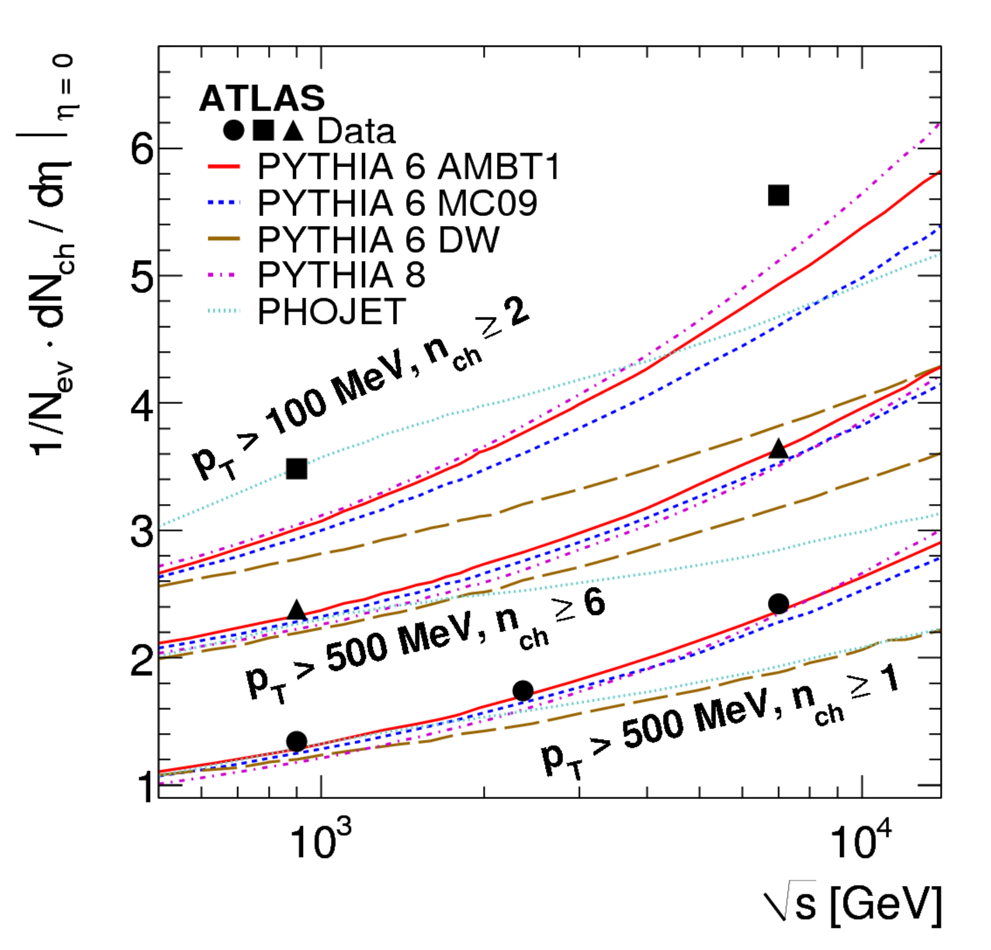
Charged particle <p_T> vs N_{ch}



All pre-LHC models disagree with data.
(except PYTHIA 8)

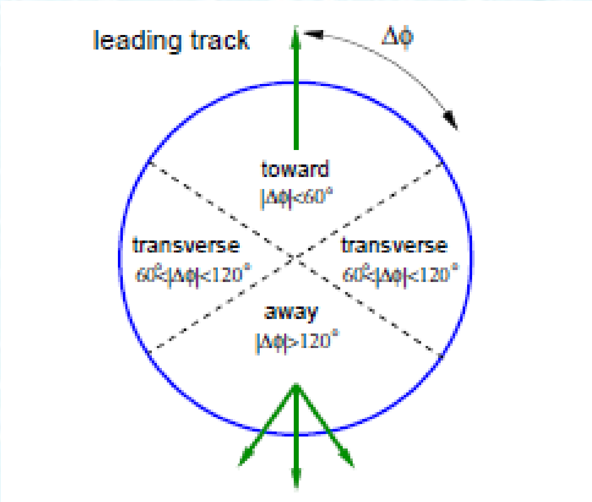
Low n_{ch} part affected by SD and DD component.

Charged particle multiplicity



Pythia 6 AMBT1 tune gives good description of energy dependence for phase spaces without low-pT region

Underlying Event Measurements



At low energies and with limited statistics, sufficient to use the leading track, (the leading track is usually found in the leading jet)

Taking advantage of the event topology – isolating regions with respect to the leading track.

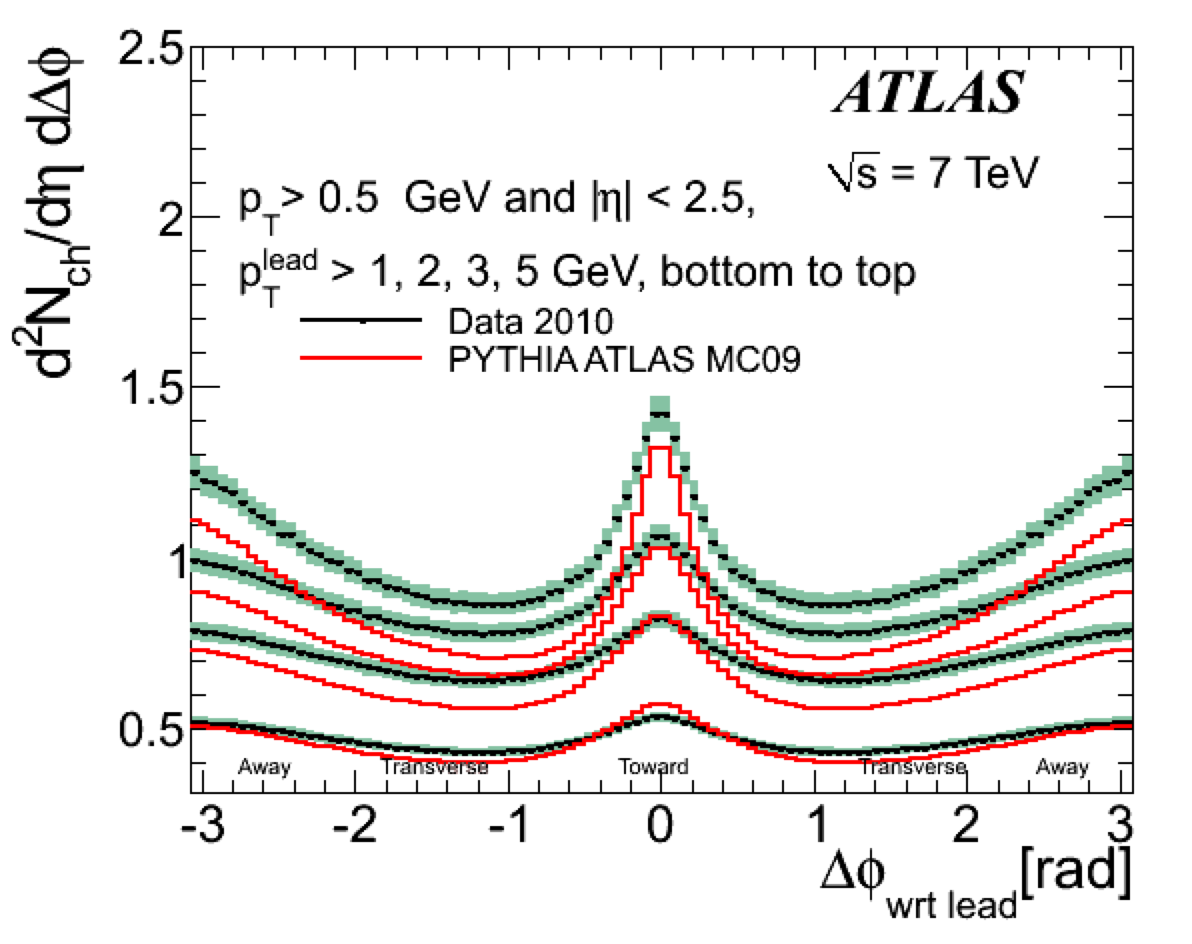
- 1 GeV leading track p_T requirement, *underlying event* tracks with p_T >500 MeV.
- Otherwise event and track selection, correction for vertex, trigger and tracking efficiency from minimum bias measurements.

Underlying Event Distributions

Profile		Abscissa	Ordinate
Number Density	Transverse	Lead Track p_T	Transverse Track Number / Transverse Area
	Away	Lead Track p_T	Away Track Number / Away Area
	Toward	Lead Track p_T	Toward Track Number / Toward Area
Trans. Num. Den. Standard Deviation		Lead Track p_T	S.D (Transverse Track Number / Transverse Area)
p_T Density	Transverse	Lead Track p_T	Transverse Track p_T / Transverse Area
	Away	Lead Track p_T	Away Track p_T / Away Area
	Toward	Lead Track p_T	Toward Track p_T / Toward Area
Trans. p_T Dens. Standard Deviation		Lead Track p_T	S.D. (Transverse Track p_T / Transverse Area)
Mean p_T	Transverse	Lead Track p_T	Transverse Track p_T / Transverse Track Number
	Away	Lead Track p_T	Away Track p_T / Away Track Number
	Toward	Lead Track p_T	Toward Track p_T / Toward Track Number
Angular Distributions		$\|\phi\|$ from Lead Track	Number Density of Tracks in $\|\phi\|$ Bin Interval
		$\|\phi\|$ from Lead Track	p_T Density of Tracks in $\|\phi\|$ Bin Interval

Phys. Rev. D 83, 112001

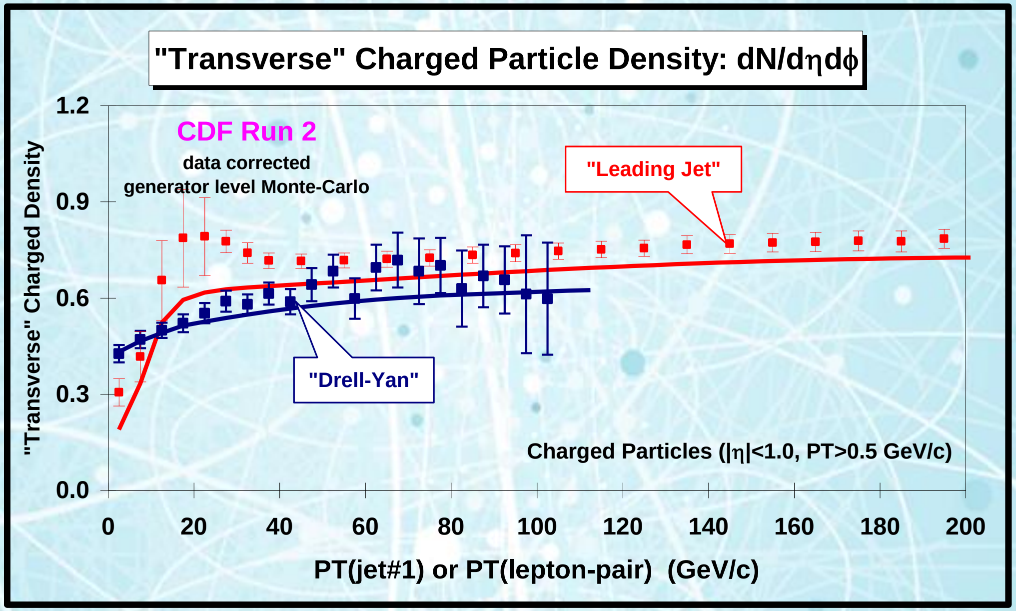
First UE Results



Significant difference in shape, sharper rise in transverse region compared to MC.

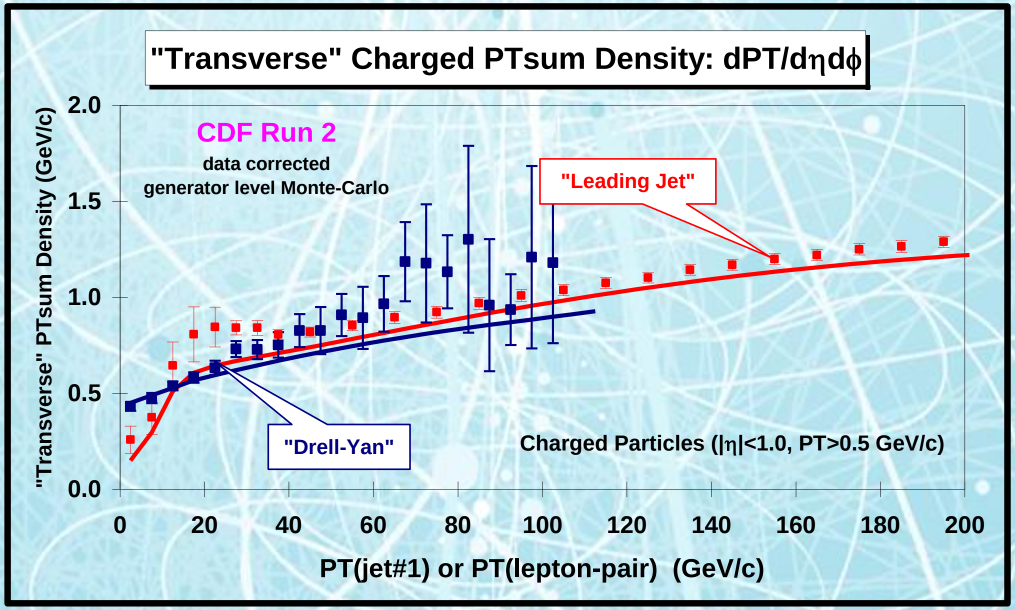
Phys. Rev. D 82 (2010) 034001.

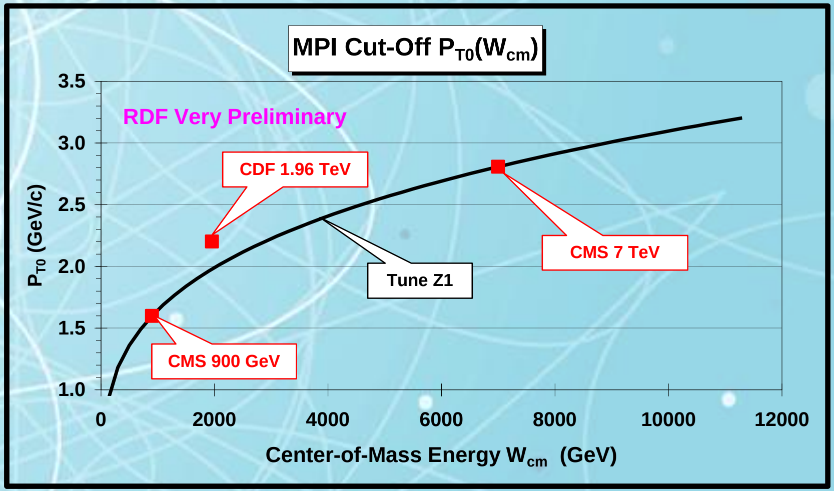
A Step Back: CDF Results



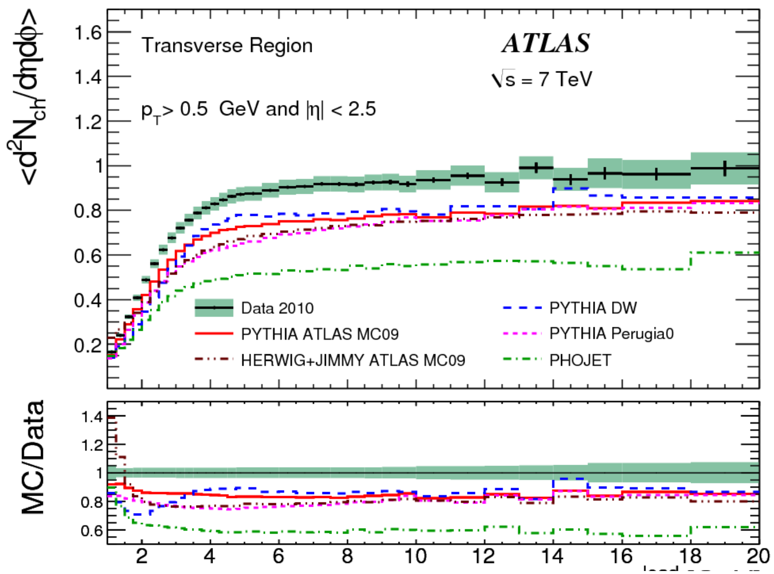
PYTHIA tune A described leading jet UE results reasonably well, and tune AW did so for the Drell-Yan UE.

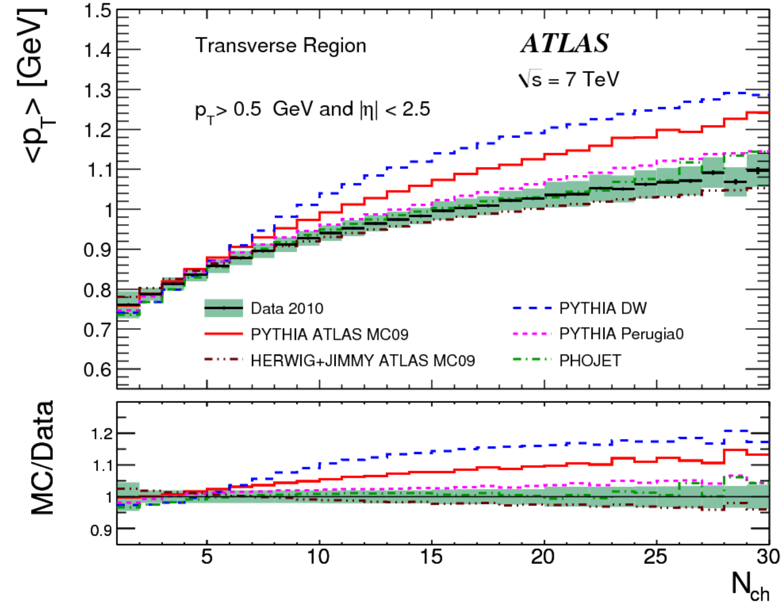
So what happened with LHC?

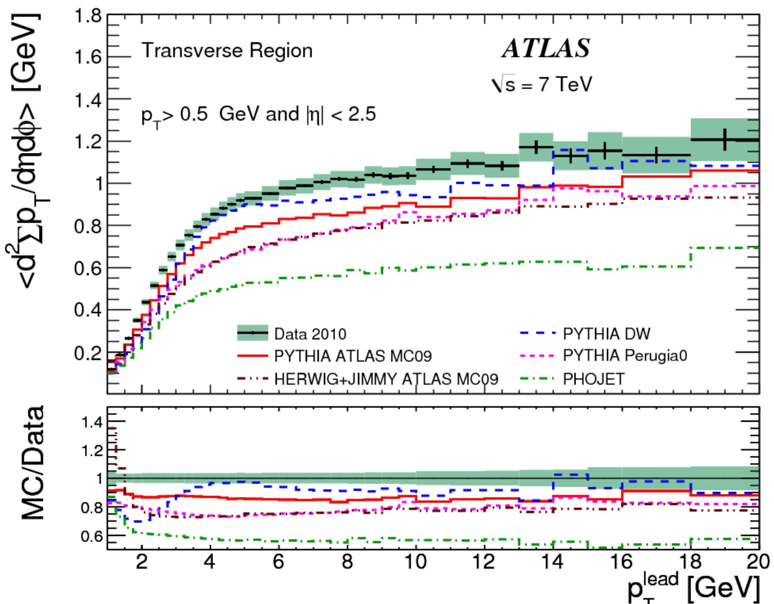




Leading Track UE Results



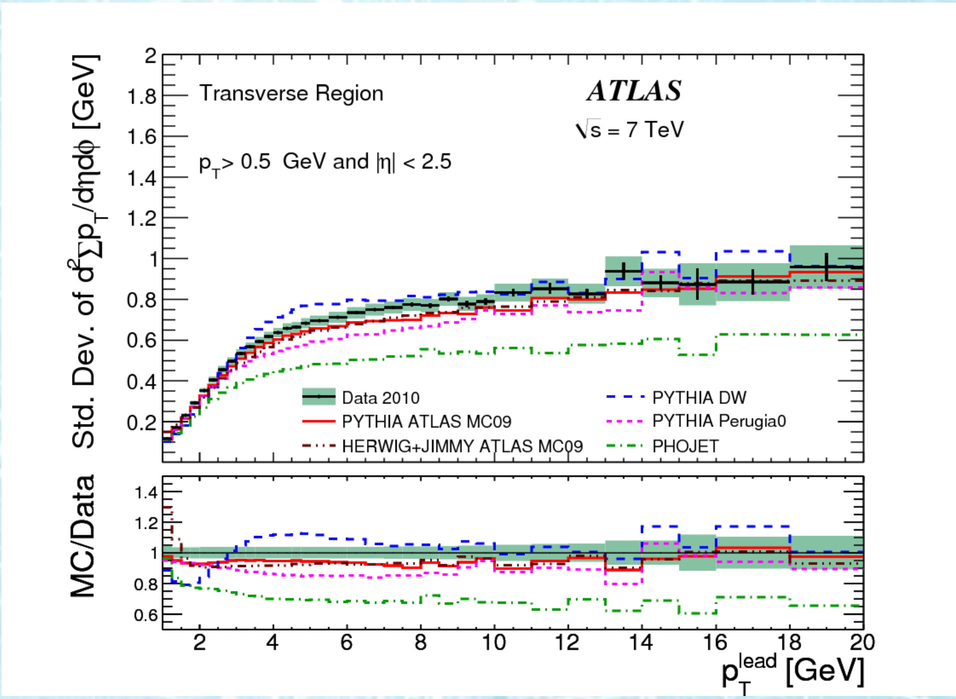


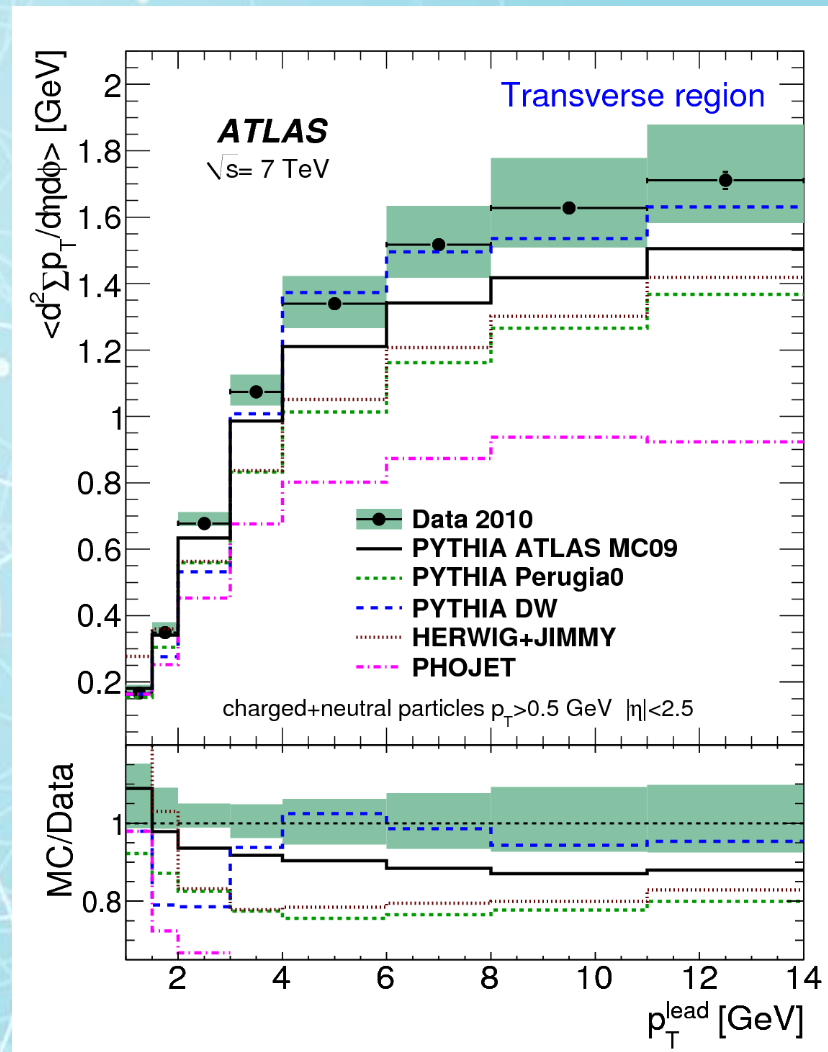


UE more active than predicted by Pre-LHC models, MC's mostly predict harder spectra at high multiplicity.

EPJC 71 (2011) 1636

"New" Measurements





- S.D. indicates that the subtraction of UE from jets must be done on an event by event basis.

- Cluster p_T sum is sensitive to complete proton-proton final state including neutral.

What is cooking?

- UE with leading jet (and possibly dijet) events, extending the pT scale upto 1 TeV.

- UE with inclusive Z-boson events, using the full 2011 data. Much cleaner probe of UE.

Monte-Carlo Models

- So we have to use the underlying event distributions to test the phenomenological models and “tune” the Monte-Carlo event generators to give the best description of the data.

- We gain deeper insight if data does not match up with Monte-Carlo predictions, which reflect our current “best-guess” understanding of these processes.

PYTHIA has "knobs” which can be *tuned* to obtain an optimal description of the data.

LHC Era Models

- Moved from old Q^2-ordered parton Showers to p_T-ordered parton showers and new MPI models in PYTHIA 6.

- Pythia 8 interleaved evolution for ISR, FSR and MPI, new high-mass diffractive framework.

- New parameter for soft interactions and color reconnection model HERWIG++ (end of the road for Jimmy?).

- Next major version of Sherpa (1.3.0 early next year) will contain changes in the physics, e. g. an improved soft physics model and improved hadronization.

- Increasing use of “hybrids”.


Model that?

ATLAS Tuning Technique

Moved from "by eye tuning" to use of statistical tools to optimize the MC fit to the reference data.

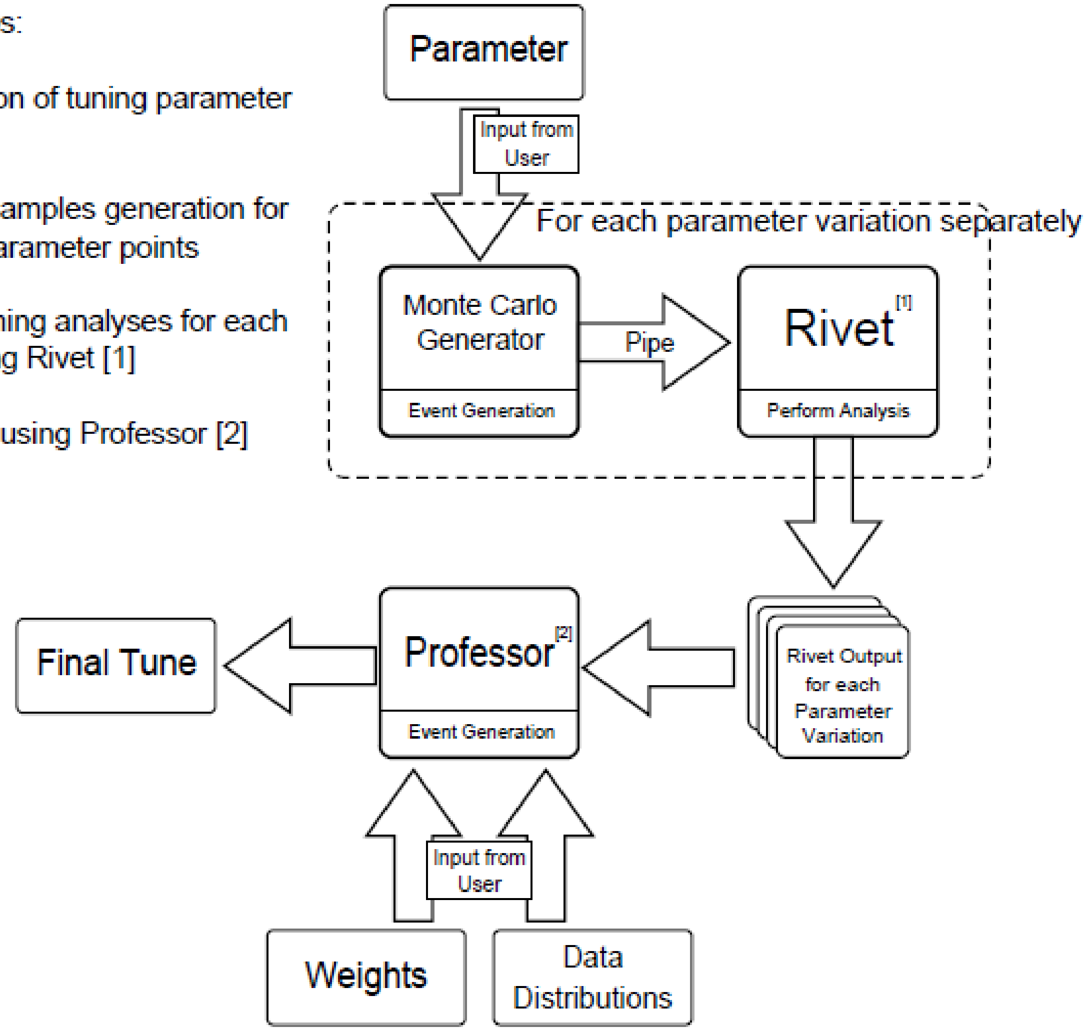
Main Steps:

1) Definition of tuning parameter space

2) Event samples generation for random parameter points

3) Performing analyses for each event using Rivet [1]

4) Tuning using Professor [2]



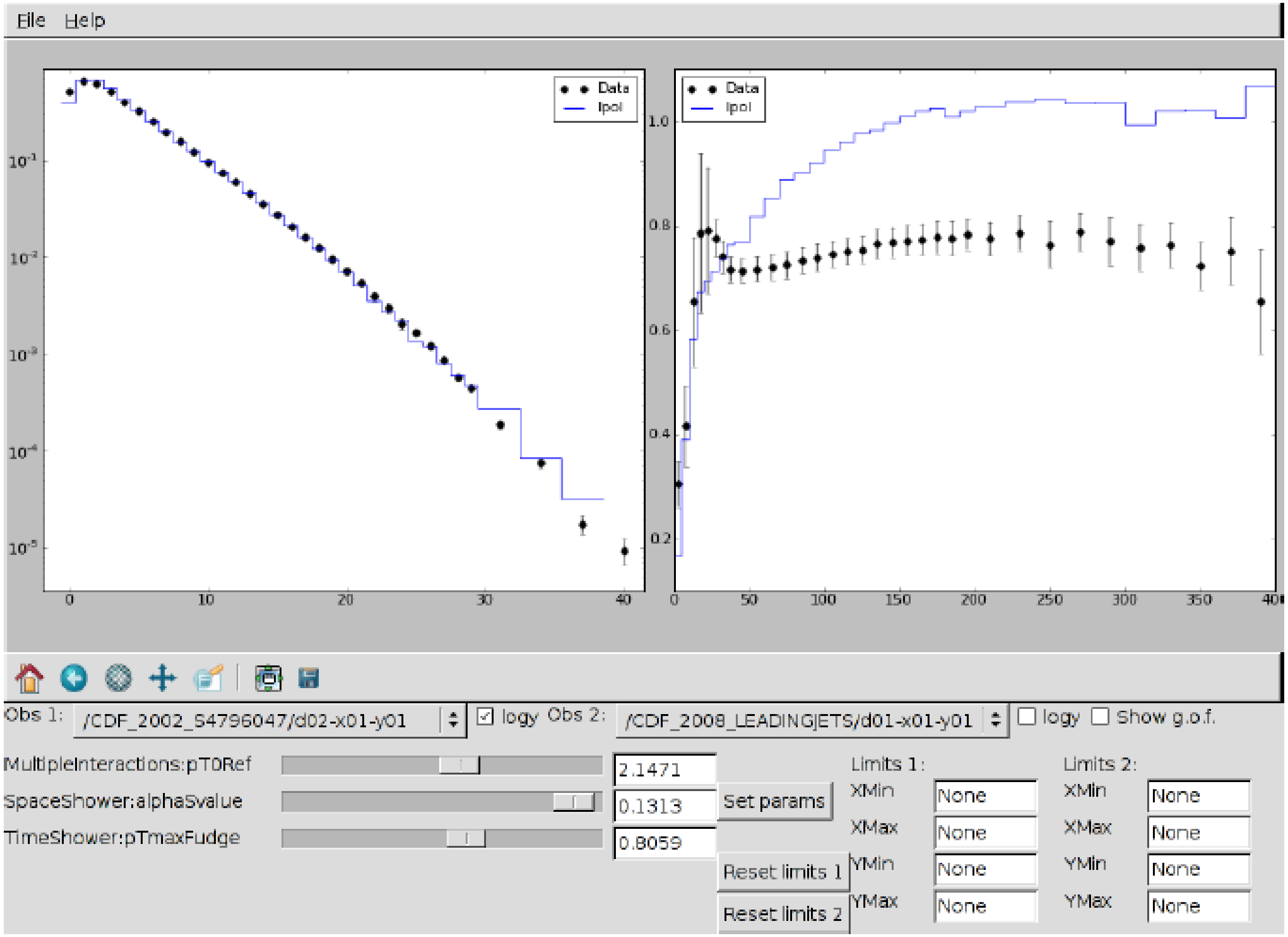
[1] A. Buckley, J. Butterworth, L. Lonnblad, H. Hoeth, J. Monk, et al., *Rivet user manual*, arXiv:1003.0694 [hep-ph]
[2] A. Buckley, H. Hoeth, H. Lacker, H. Schulz, and J. E. von Seggern, *Systematic event generator 199 tuning for the LHC*, arXiv:0907.2973 [hep-ph]

Professor: statistical tool which parameterizes observable responses to changes in MC parameters.

1. Sample N random MC runs from n-parameter hypercube using e.g. Rivet.
2. For each bin b in each distribution, use the N points to fit an interpolation function using a singular value decomposition.
3. Construct overall 2 function and (numerically) minimize.
4. Test optimized point by scanning around it in parameter and linear combinaion directions.

Interactive MC simulator!

prof-I



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Obs 2: /CDF_2008_LEADINGJETS/d01-x01-y01
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SpaceShower:alphaSvalue
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TimeShower:pTmaxFudge
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YMin None
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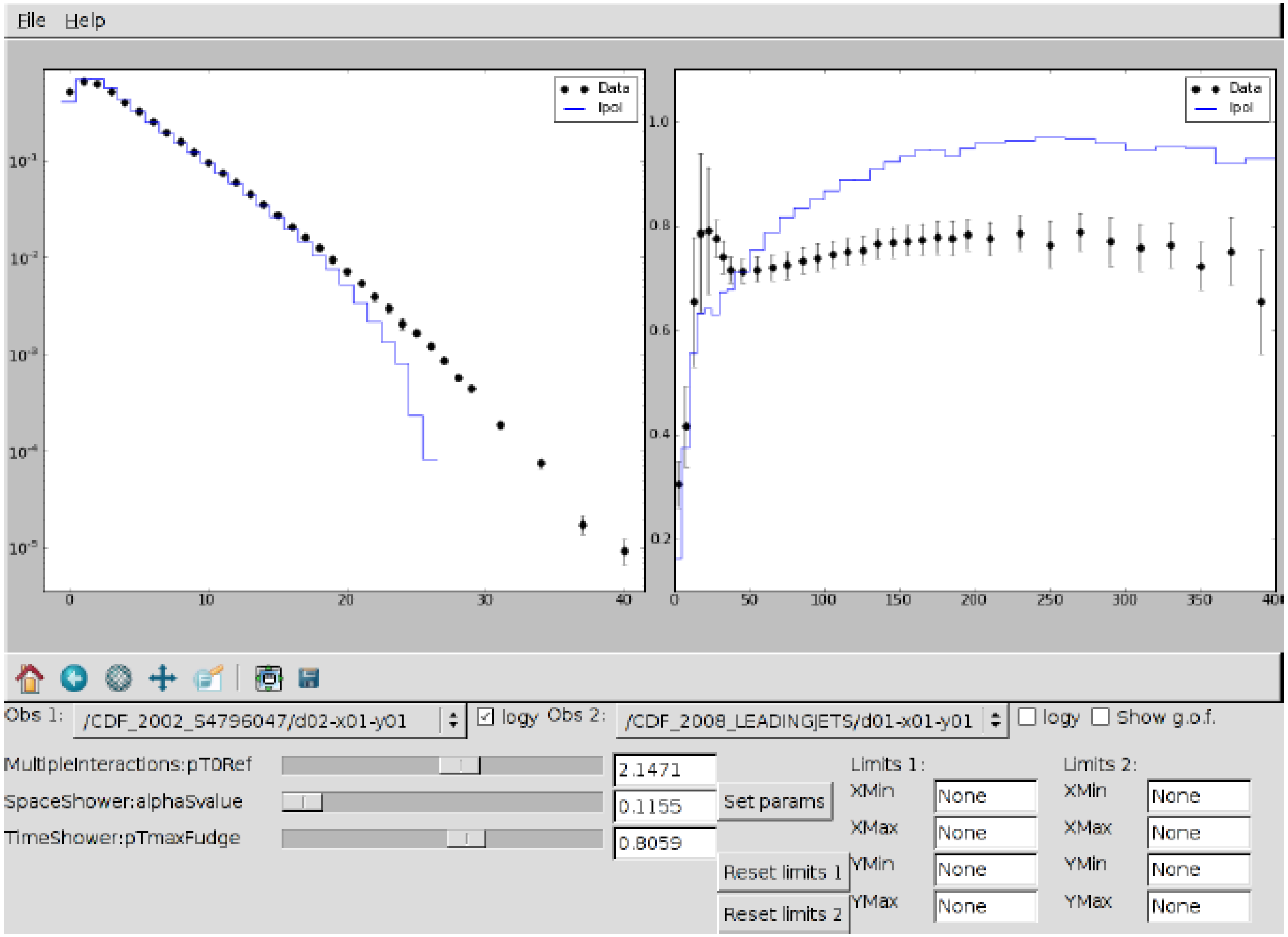
prof-I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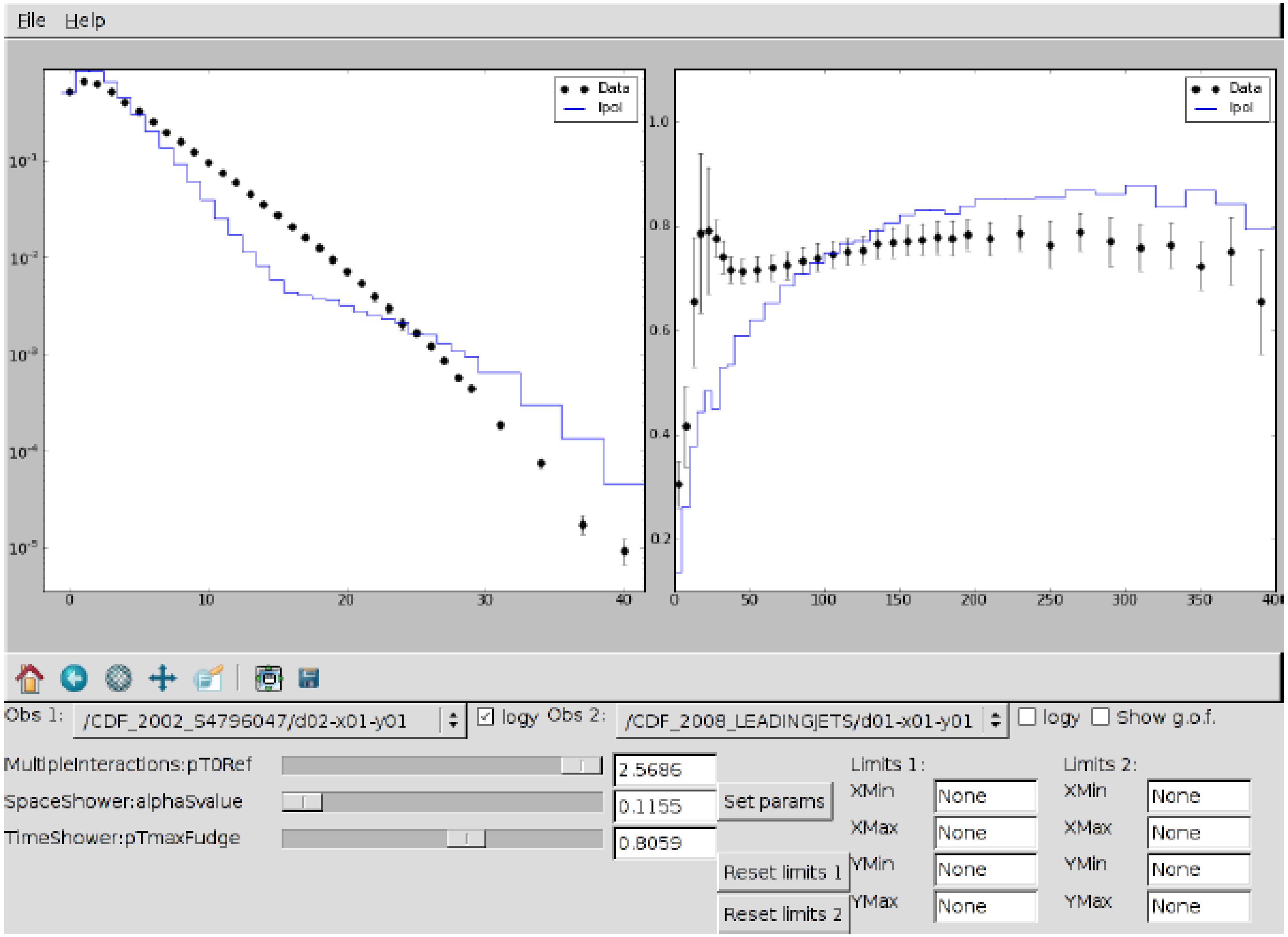

File Help
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TimeShower:pTmaxFudge
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Set params
Reset limits 1
Reset limits 2
Limits 1:
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YMin None
YMax None
Limits 2:
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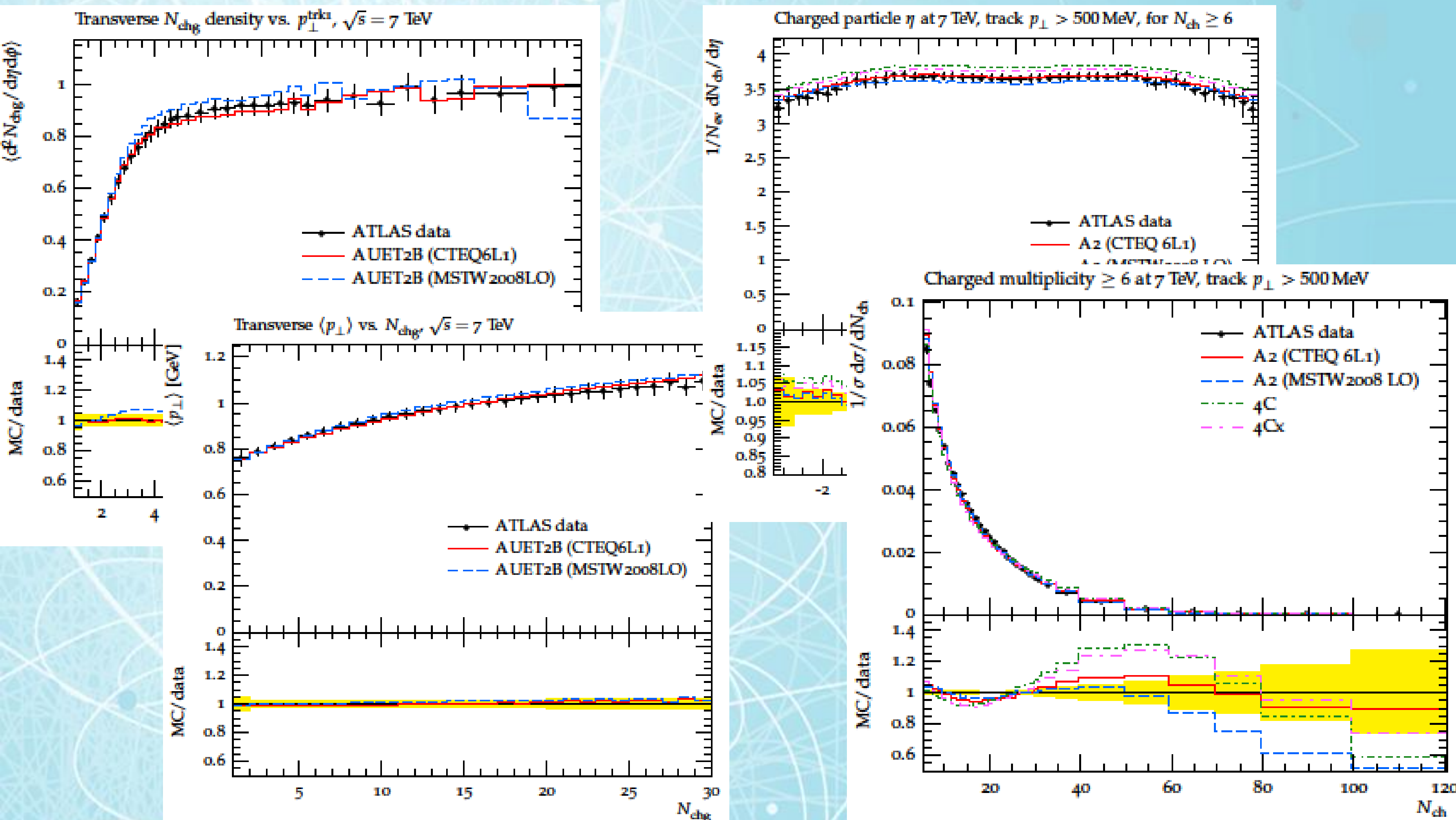
YMin None
YMax None

Tuning results: much better description of data now…



Parton Density Functions

- LO PDFs inadequate at low-x and high-x, shows up in W/Z rapidity distributions etc.

- The modified LO (mLO) PDFs attempt to address this by the use of the NLO QCD coupling, relaxing of the momentum sum rule, and (for LO**) by change in the scale used for the argument of α_S for high-x evolution.

- We are more and more using NLO parton shower Monte-Carlos for many of our processes, so should be consistent and use NLO PDFs for the LO parton shower Monte Carlo generation as well?

What do we see?

- For Pythia 8 LO PDFs, a common MB and UE tune can be obtained, while for NLO and mLO PDFs, only UE tunes were done. For PYTHIA 6, no common tune.
- (For PYTHIA 6) UE tunes made using LO PDFs were able to match both the shapes of the ramp and plateau region, while mLO tend to develop a steeper p_T sum plateau slope than seen in data.
- The description of UE data with these NLO PDF tunes is generally very good.
- NLO PDF tunes seem to demand a stronger color reconnection strength but somewhat lower MPI p_T cutoff and energy exponent .

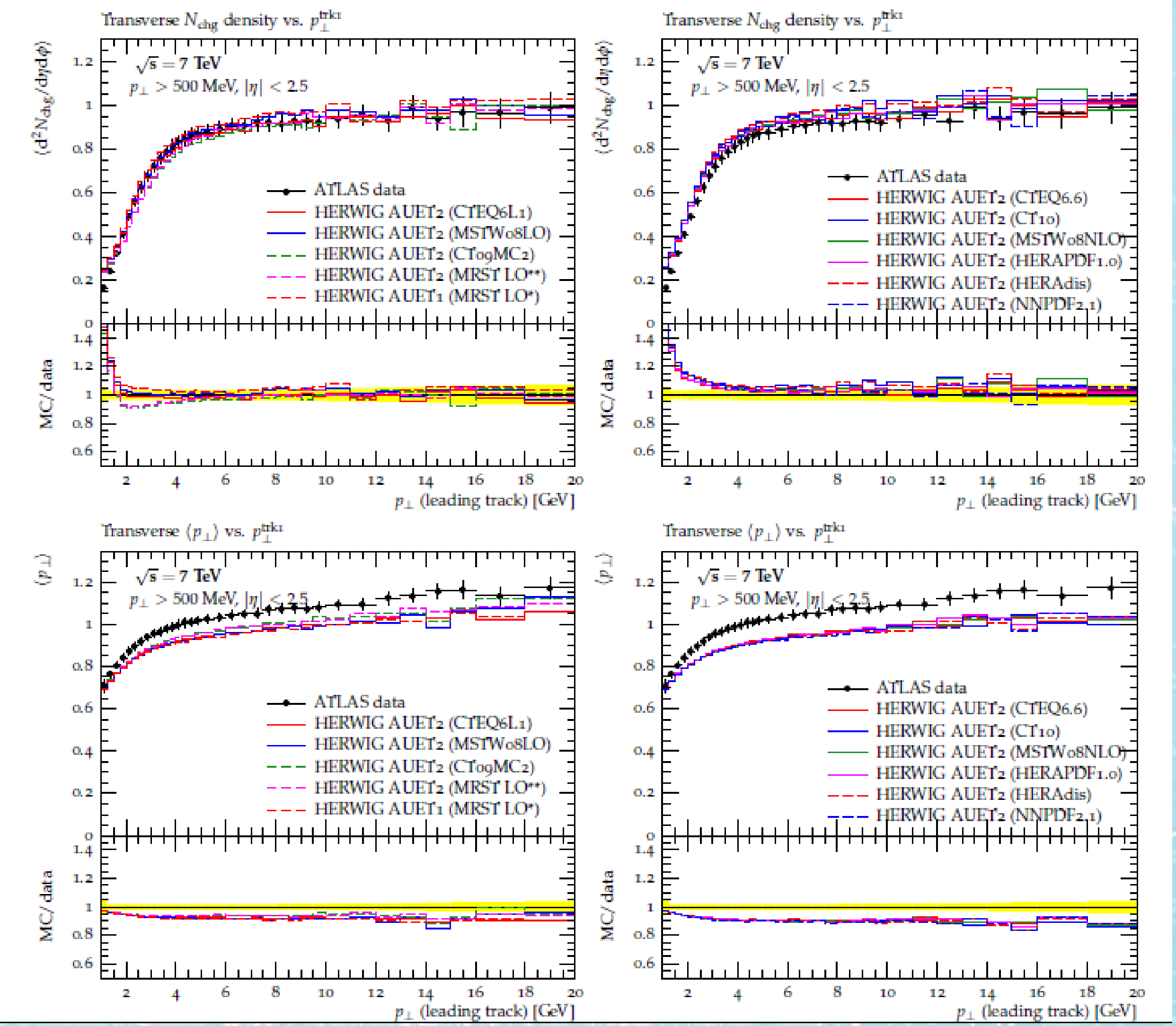
Summary:

- Pre-LHC models seen not to agree with most of the "soft"-QCD distributions.
- Many improvements in the models using these LHC data.

Road to discovery is through a good understanding of soft physics!

Supporting Material

HERWIG+JIMMY AUET2B

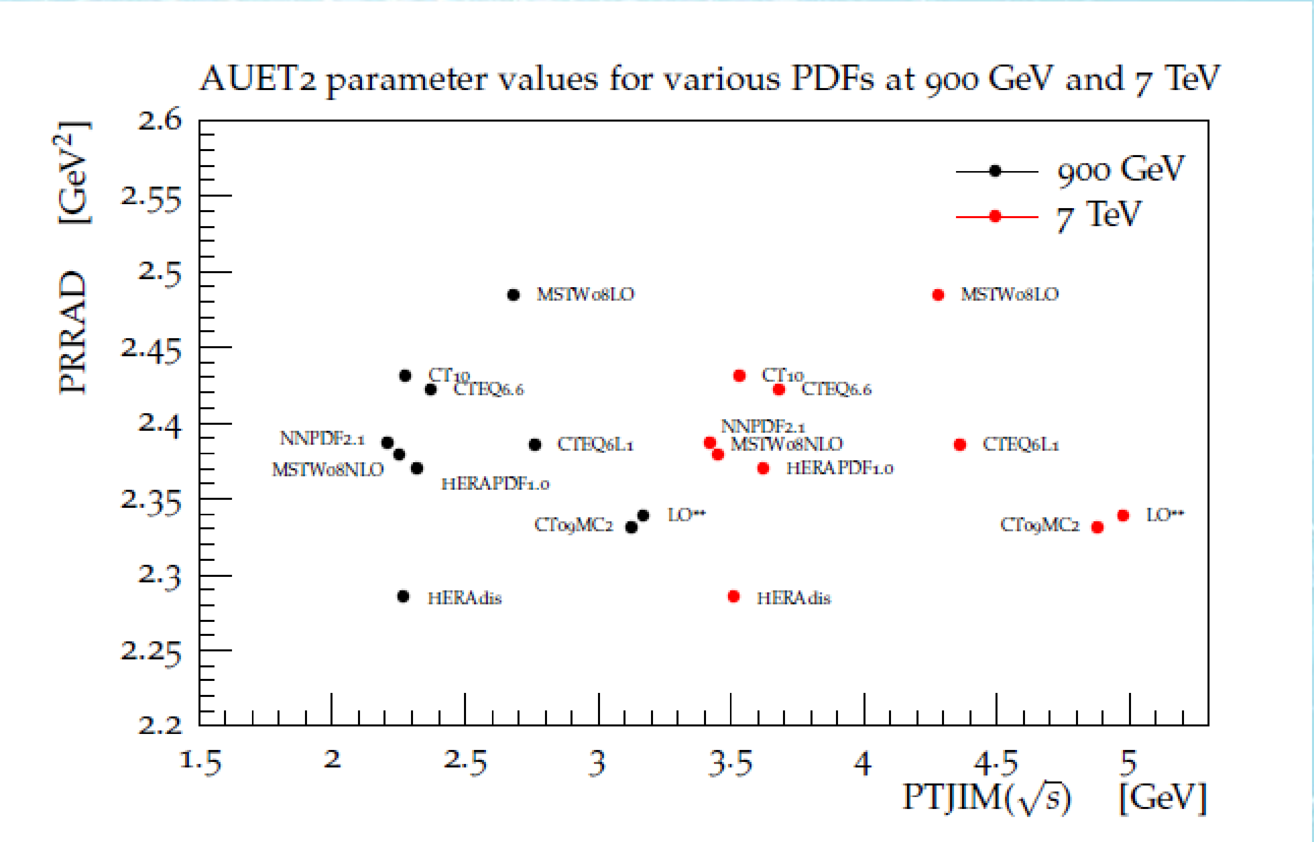


- Three parameter MPI tune.
- Good description of UE level, but MPI model is too restricted.

- **PTJIM**: cut-off for multiple parton interactions, similar energy dependence as for PYTHIA 6.

- **PRRAD**: hadronic form factor radius.

Parameter Grouping



The size of the MPI cutoff is ordered according to the typical value of the gluon PDF at low values of Björken x, with mLO PDFs favoring the highest values.

Scatter of MPI p_T cutoff highlights groupings by PDF type.

PYTHIA 6

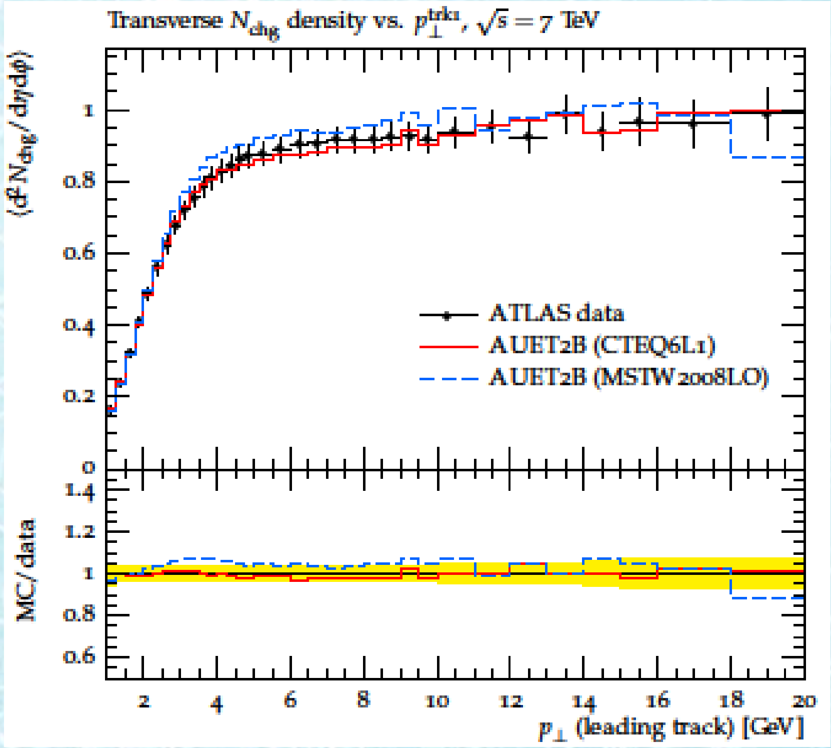
- Tunes include LEP data for hadronisation and FSR, and ATLAS and Tevatron data for the parton shower and MPI stages.

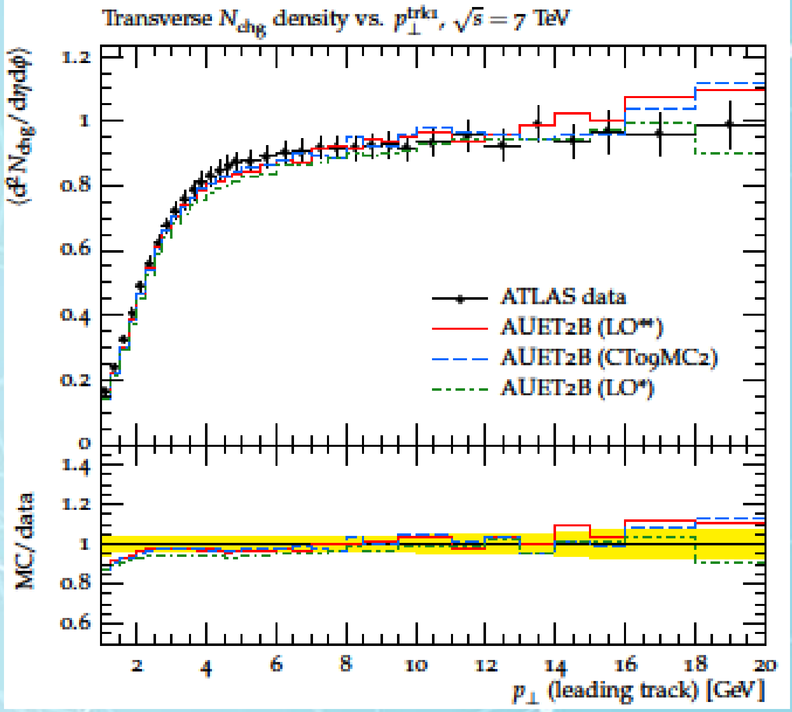
- Tuning workflow: first shower tune using jet shape (CDF and ATLAS), jet fragmentation (ATLAS)function, dijet decorrelation ATLAS, D0) data. (For LO** a MPI tune was done before due to absence of situable MPI configuration.)

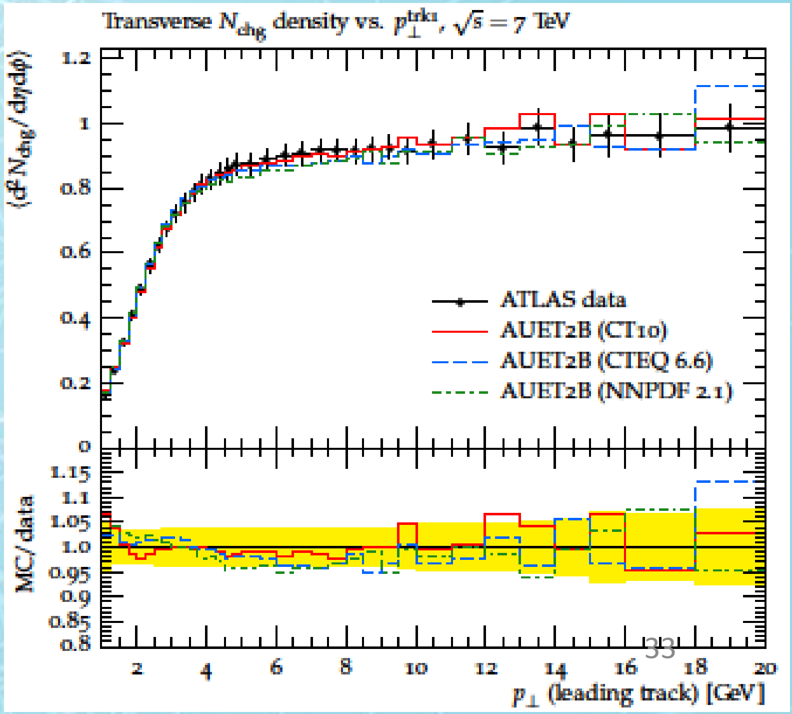
- Then MPI parameters using CDF and ATLAS MB and UE data:

PARP(82)	MPI p_T cut-off at the nominal reference energy of 1800 GeV.
PARP(90)	MPI cutoff energy evolution exponent.
PARP(83)	Double Gaussian hadronic matter distribution: parp(83)% of matter in radius parp(84).
PARP(84)	
PARP(77)	Suppression of color reconnection for high-p_T strings.
PARP(78)	Strength of color reconnection.

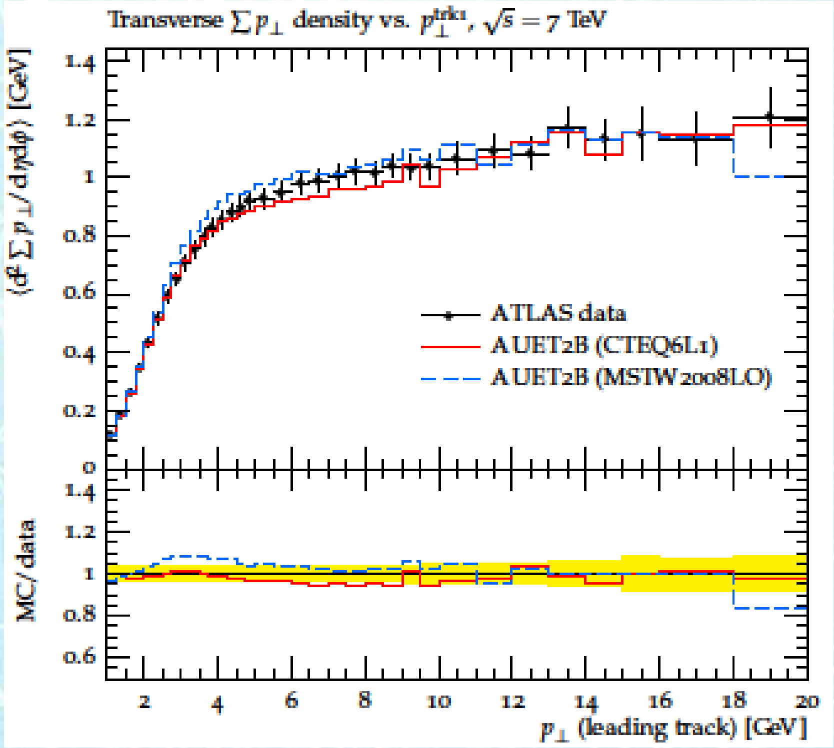
UE N_{chg} for AUET2B

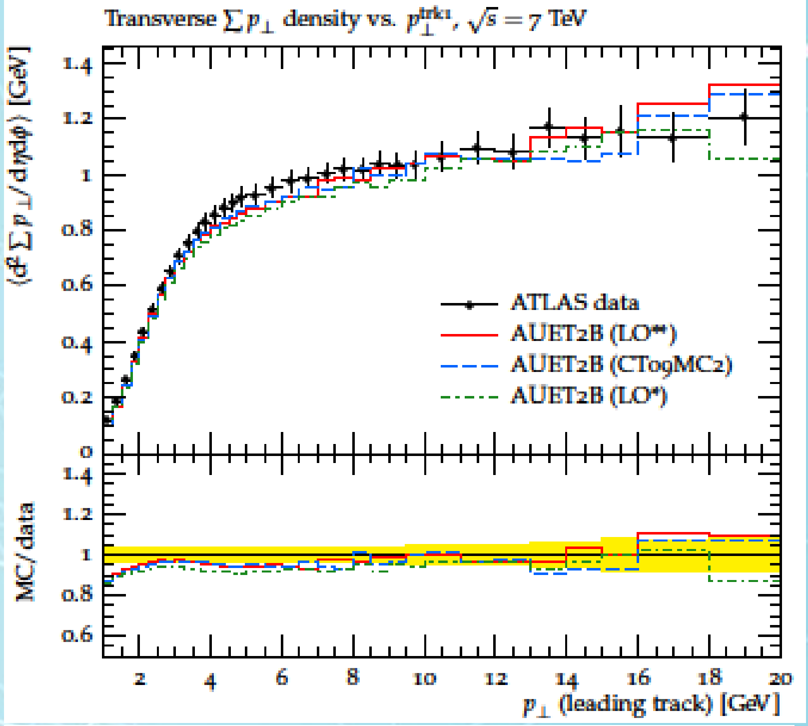


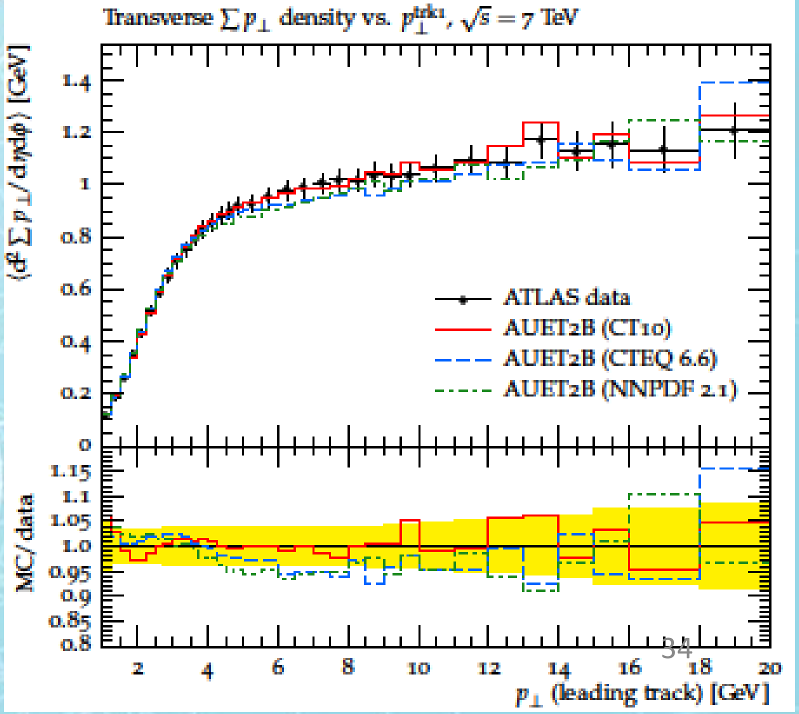




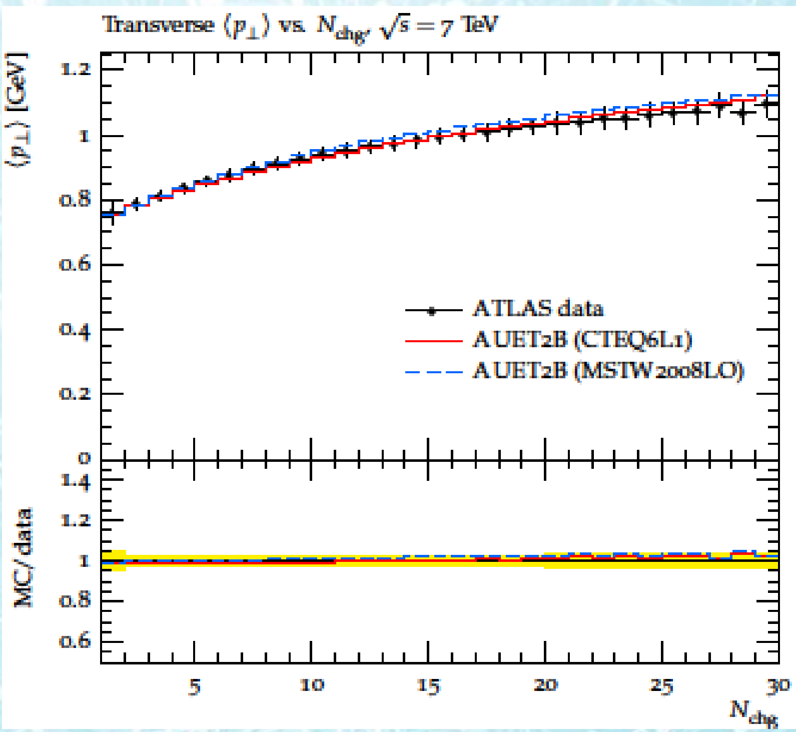
UE p_T Sum for AUET2B

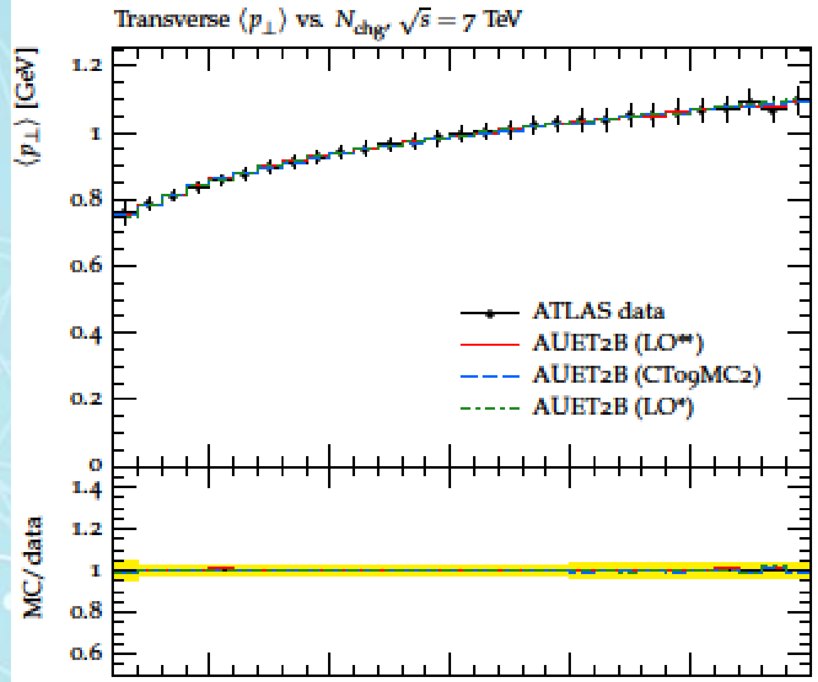


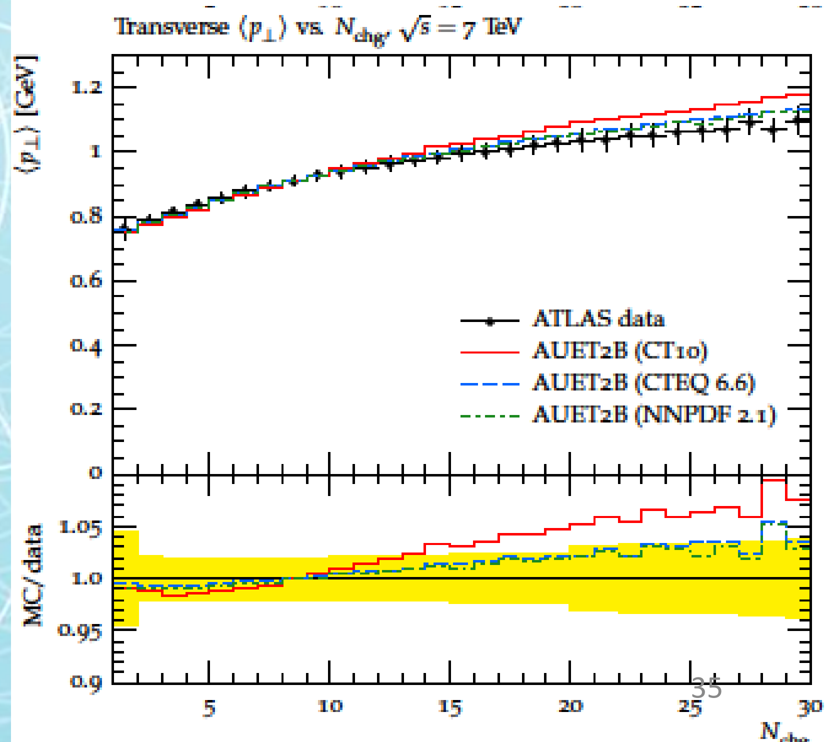




UE $<p_T>$ vs N_{chg} for AUET2B







Tune Results

	PARP(77)	PARP(78)	PARP(82)	PARP(84)	PARP(90)
CTEQ6L1	0.491	0.311	2.26	0.443	0.249
MSTW2008LO	0.597	0.371	1.99	0.499	0.266
MRST LO*	0.845	0.279	2.22	0.507	0.267
MRST LO**	0.901	0.309	2.44	0.560	0.241
CT09MC2	0.869	0.285	2.29	0.545	0.212
CTEQ6.6	0.505	0.385	1.87	0.561	0.189
CT10	0.125	0.309	1.89	0.415	0.182
NNPDF 2.1 NLO	0.498	0.354	1.86	0.588	0.177
PARP(83) is fixed to AMBT1 value of 0.356					

Pythia 8

- Better diffractive model, among other improvements.
- Used in ATLAS for pileup simulation, so describing MB data is important.
- Used the option where width of the transverse matter distribution varies depending on the momentum fraction of the interacting partons.
- Turned off SpaceShower:rapidityOrder, letting the shower get closer to the matrix-element results.

Tune Parameters

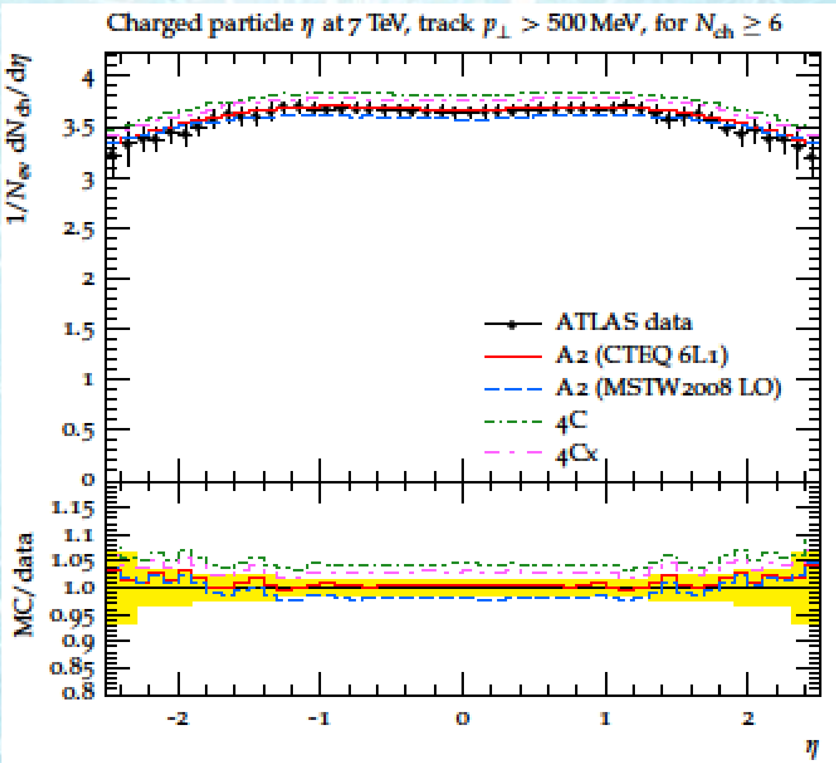
- MultipleInteractions:pT0Ref *[PARP(82)]*
- MultipleInteractions:ecmPow *[PARP(90)]*
- MultipleInteractions:bProfile *[MSTP(82)]*
- If above is 2 (double Gaussian), MultipleInteractions:coreFraction, *[PARP(83)]* MultipleInteractions:coreRadius *[PARP(84)]*
- If above is 4 (x-dependent), MultipleInteractions:a1
- BeamRemnants:reconnectRange *[PARP(77), PARP(78)]*

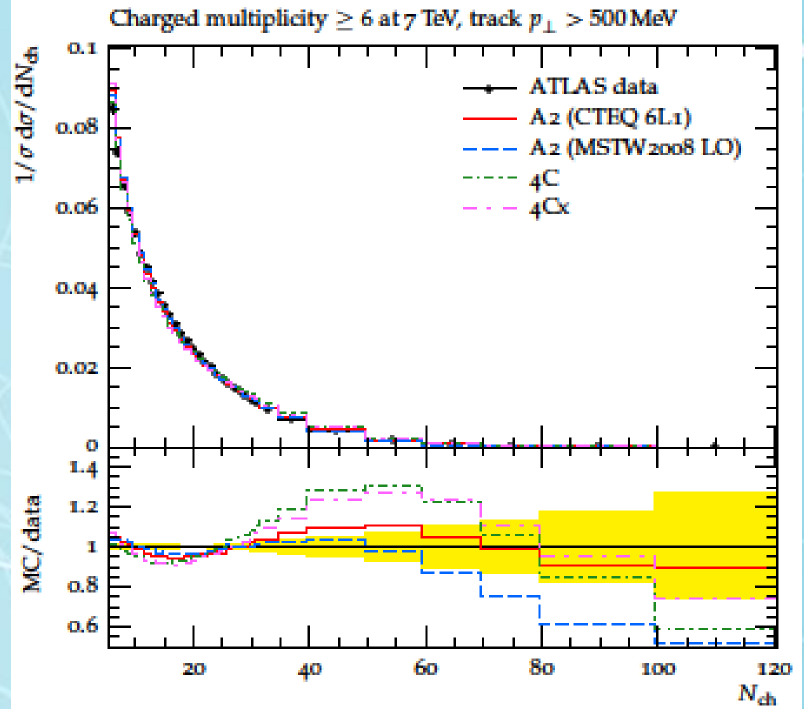
Author Tunes

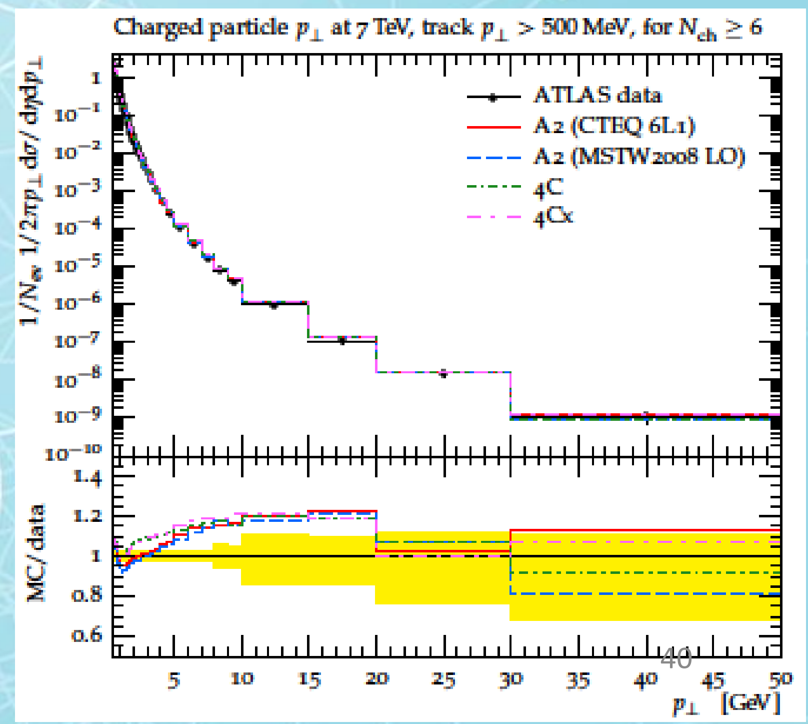
Parameter	2C	2M	4C	4Cx
SigmaProcess:alphaSvalue	0.135	0.1265	0.135	0.135
SpaceShower:rapidityOrder	on	on	on	on
SpaceShower:alphaSvalue	0.137	0.130	0.137	0.137
SpaceShower:pT0Ref	2.0	2.0	2.0	2.0
MultipleInteractions:alphaSvalue	0.135	0.127	0.135	0.135
MultipleInteractions:pT0Ref	2.320	2.455	2.085	2.15
MultipleInteractions:ecmPow	0.21	0.26	0.19	0.19
MultipleInteractions:bProfile	3	3	3	4
MultipleInteractions:expPow	1.60	1.15	2.00	N/A
MultipleInteractions:a1	N/A	N/A	N/A	0.15
BeamRemnants:reconnectRange	3.0	3.0	1.5	1.5
SigmaDiffractive:dampen	off	off	on	on
SigmaDiffractive:maxXB	N/A	N/A	65	65
SigmaDiffractive:maxAX	N/A	N/A	65	65
SigmaDiffractive:maxXX	N/A	N/A	65	65

R. Corke & TS, JHEP 03 (2011) 032, JHEP 05 (2011) 009

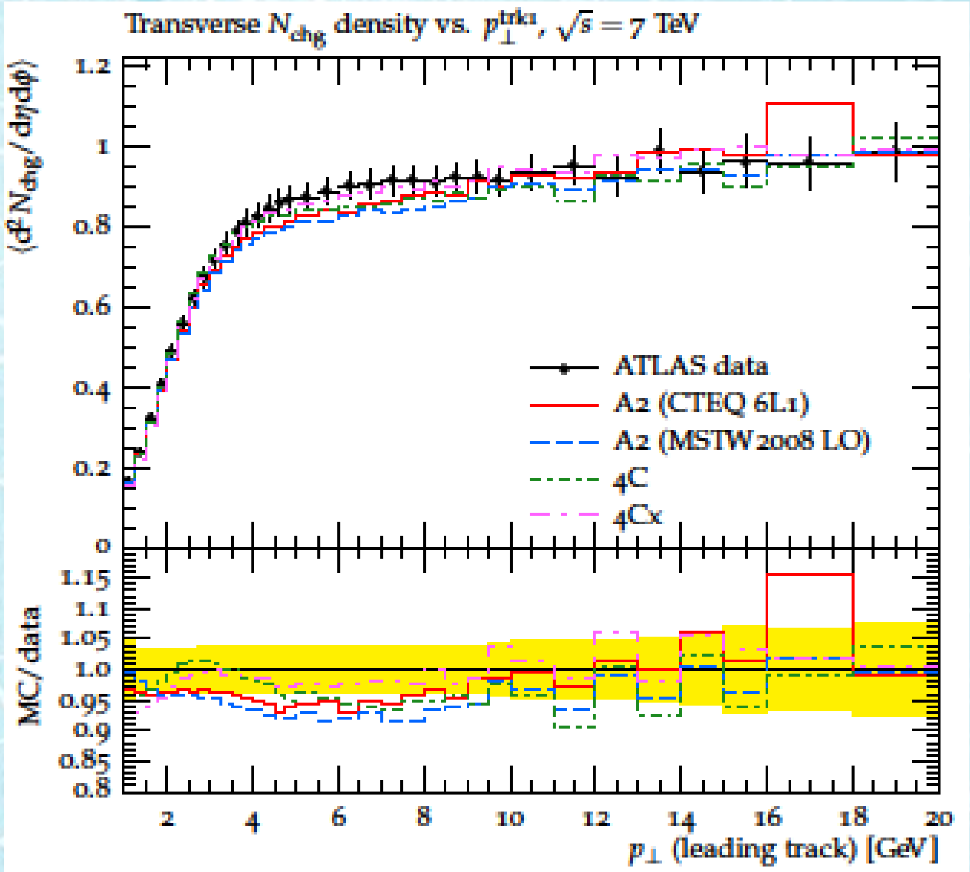
MB for Tune A2

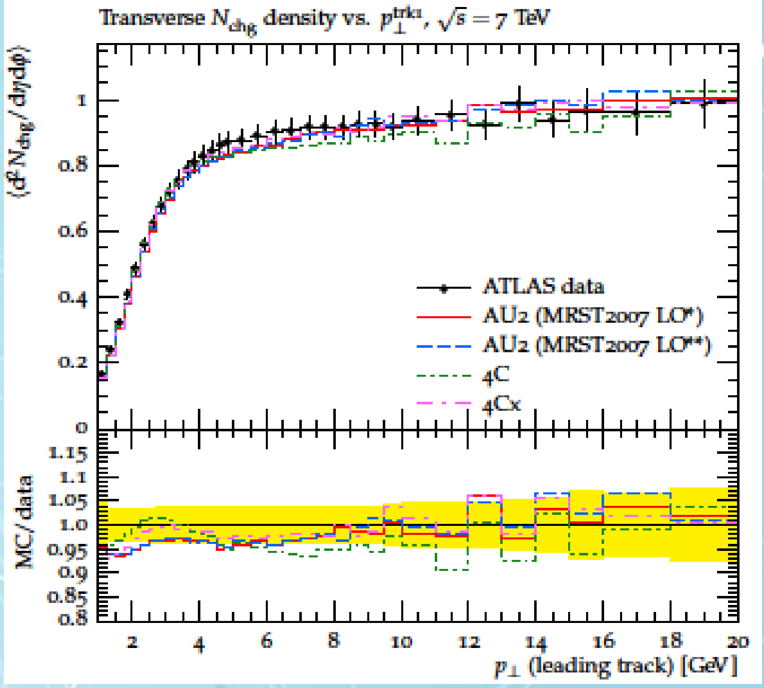


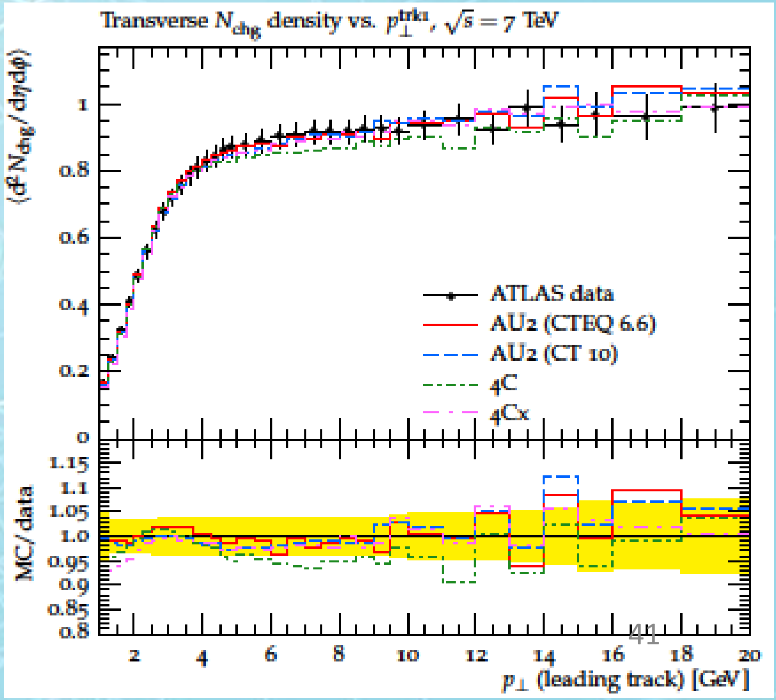




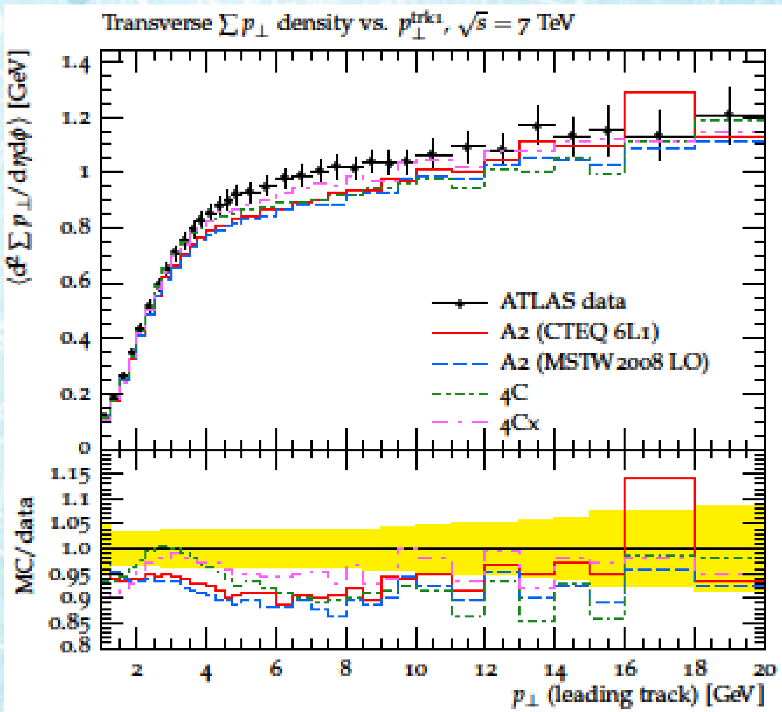
UE N_{chg} for A2/AU2

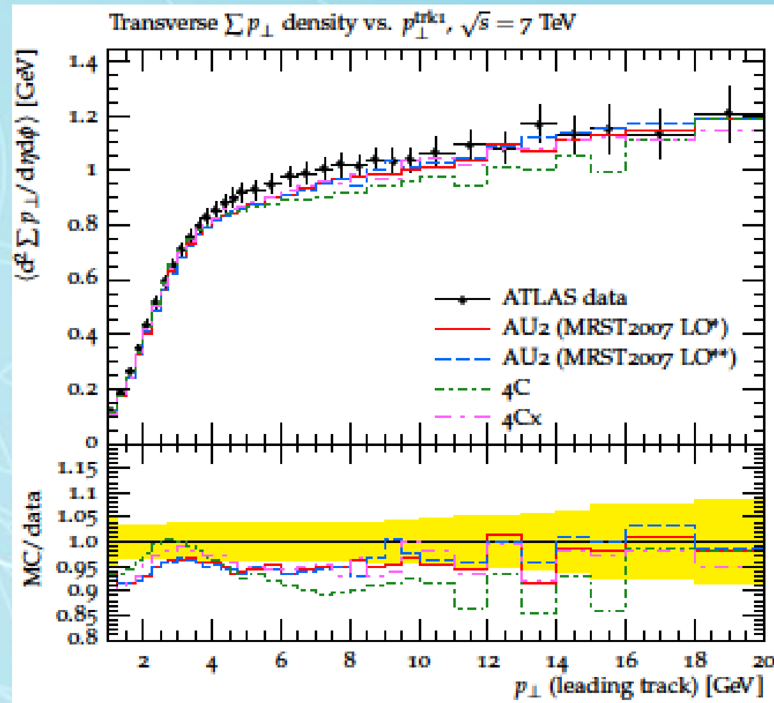


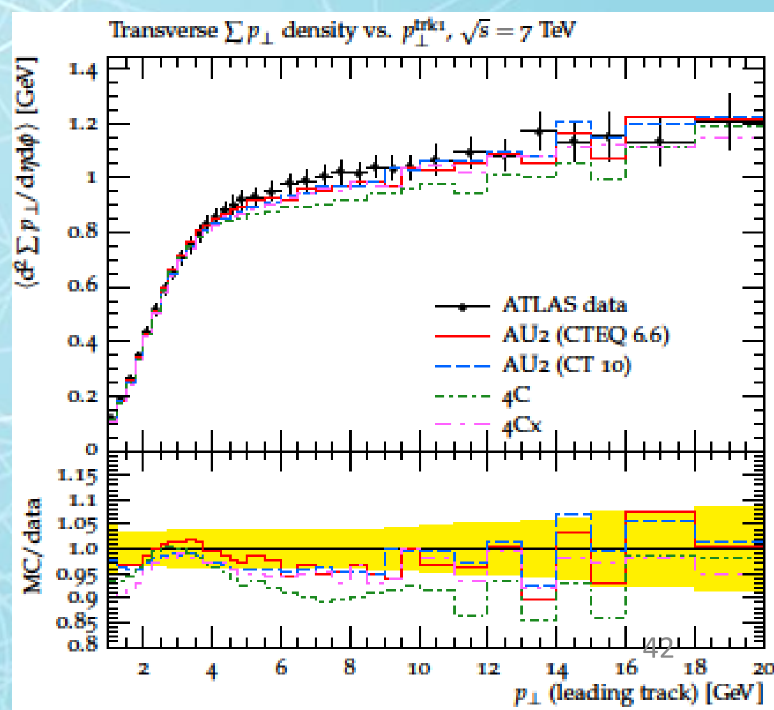




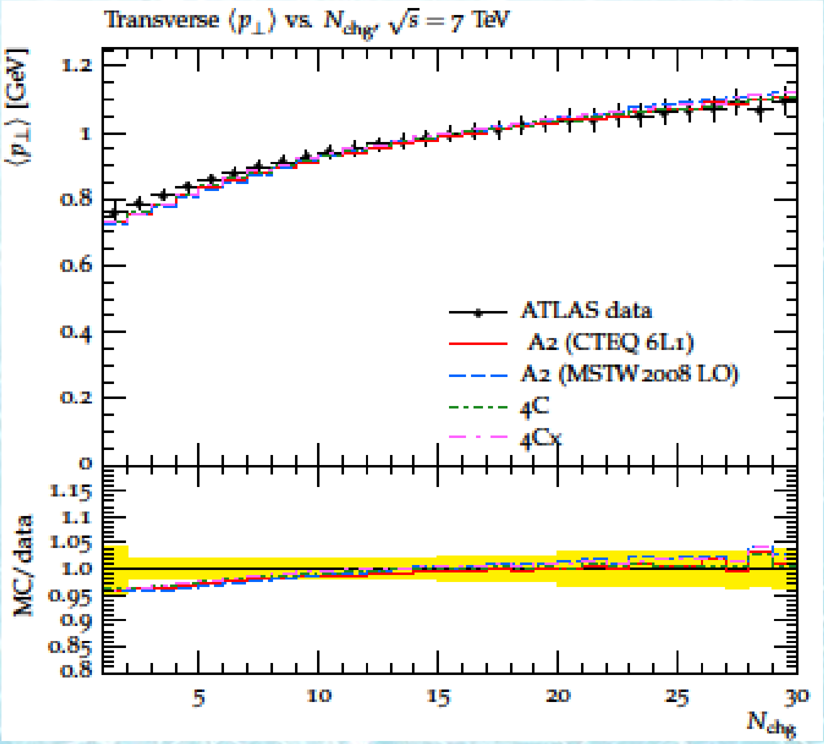
UE p_T sum for A2/AU2

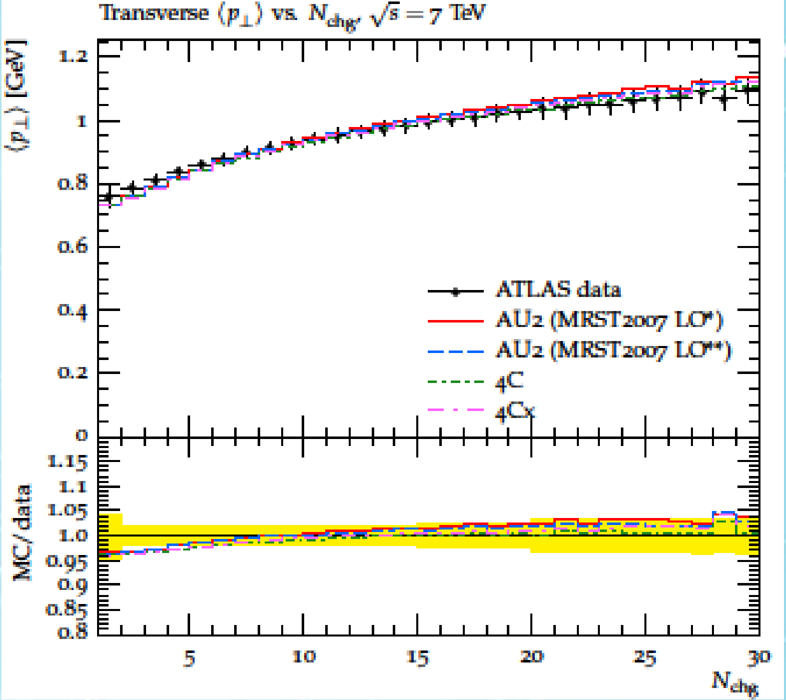


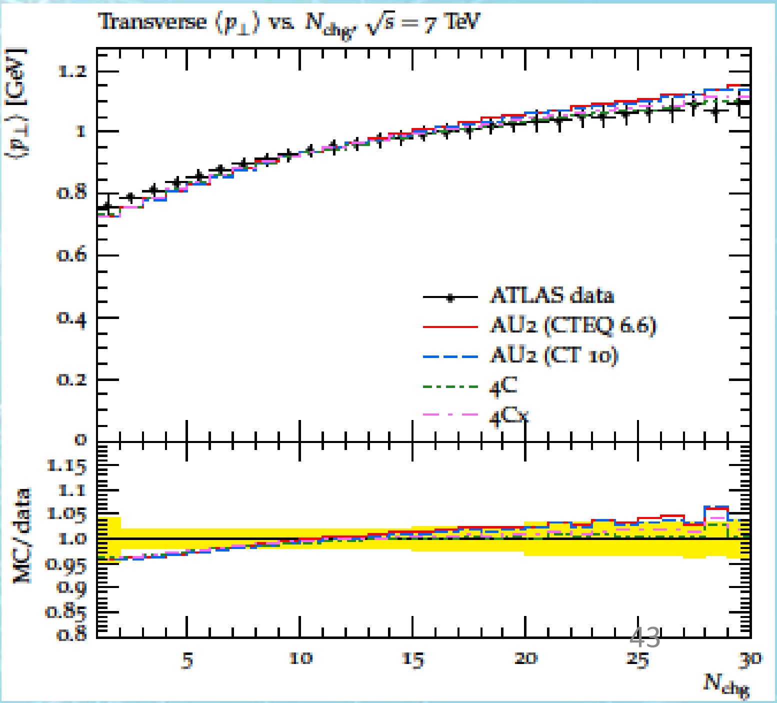




UE $<p_T>$ vs N_{chg} for A2/AU2







Tune Results

	pT0Ref	ecmPow	a1	reconnectRange
CTEQ 6L1	2.18	0.22	0.06	1.55
MSTW2008 LO	1.90	0.30	0.03	2.28
MRST2007 LO*	2.39	0.24	0.01	1.76
MRST2007 LO**	2.57	0.23	0.01	1.47
CTEQ 6.6	1.73	0.16	0.03	5.12
CT10	1.70	0.16	0.10	4.67

Observed: putting more weight on UE distributions results in the tune preferring much stronger color reconnection, which is not consistent at all with the MB and UE mean p_T against multiplicity distributions.

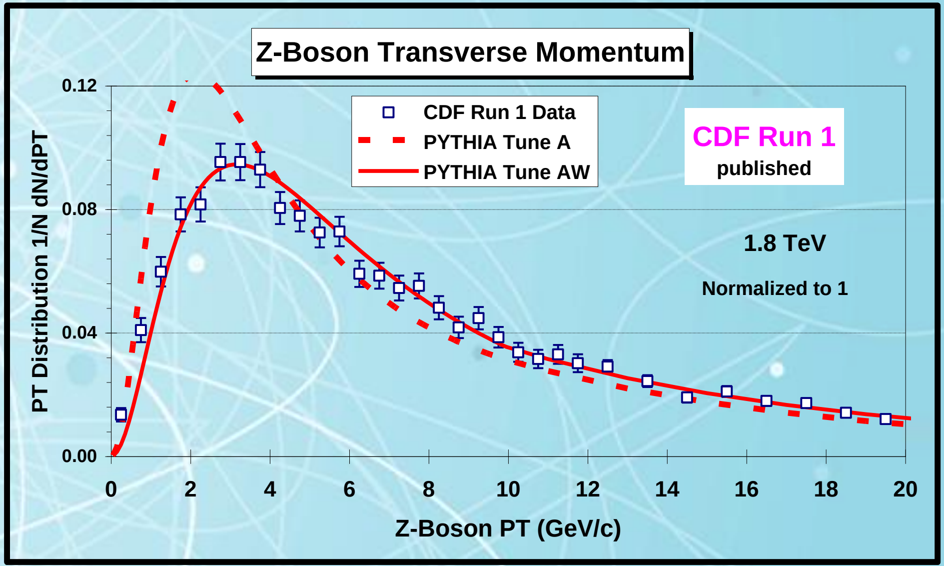
CDF Run 1 Tune (PYTHIA 6.2 CTEQ5L)

UE Parameters

ISR Parameters

Intrinsic KT

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0



Both tunes reveal a remarkably good agreement of the data and PYTHIA.

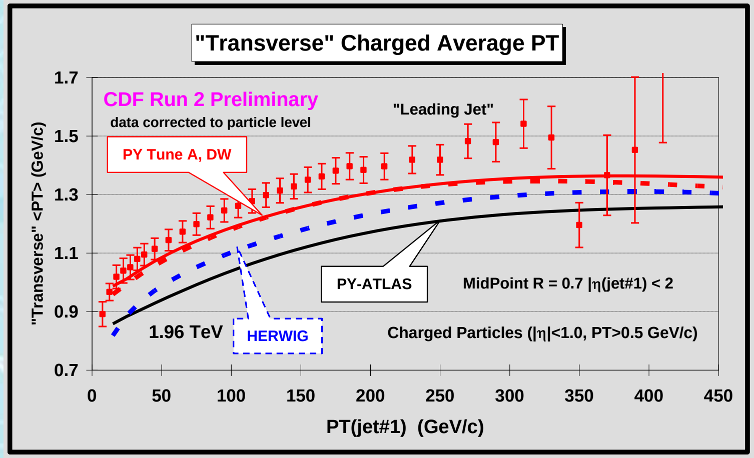
CDF Run 2 Tune (PYTHIA 6.206 CTEQ5L)

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune A	Tune DW	Tune DWT
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV
PARP(90)	0.25	0.25	0.16
PARP(62)	1.0	1.25	1.25
PARP(64)	1.0	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	1.0	2.1	2.1
PARP(93)	5.0	15.0	15.0



PYTHIA Tune DW is very similar to Tune A except that it fits the CDF $P_T(Z)$ distribution and it uses the DØ prefered value of PARP(67) = 2.5.