Measurements of minimum bias and underlying event distributions and Monte Carlo generator tuning with ATLAS

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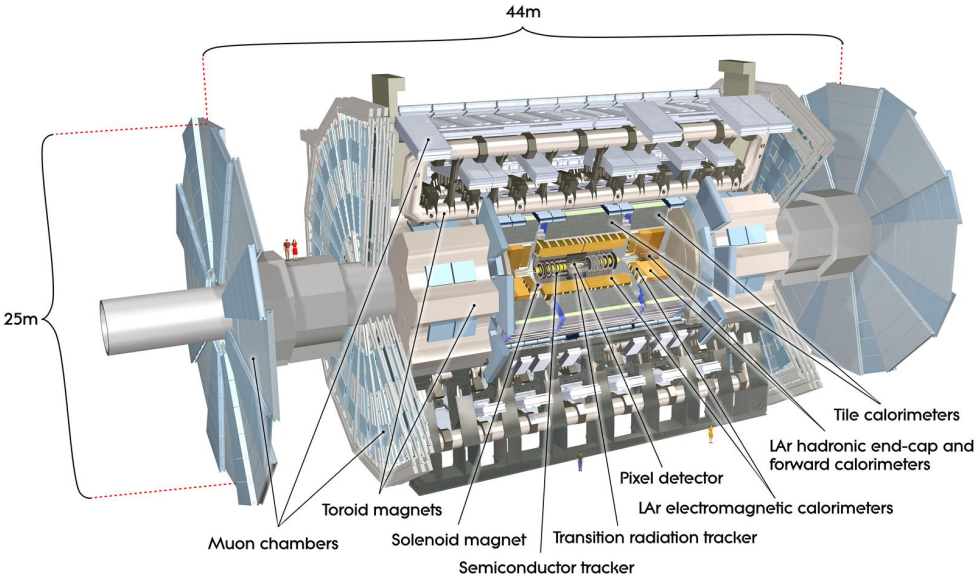
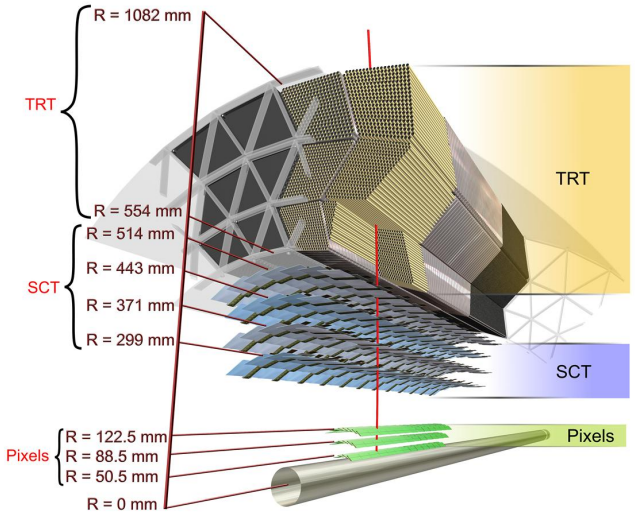
Introduction

- QCD well known where perturbation theory applies
- But: 'soft effects' (Underlying event (UE), hadronisation...)
  $\rightarrow$ Monte-Carlo (MC) generators
- MC predictions used to
  - estimate experimental efficiencies, uncertainties, backgrounds
- Models often phenomenological $\Rightarrow$ tuneable parameters (a priori unknown)
- Reliable predictions $\Rightarrow$ simulate events that look like real data $\Rightarrow$ tuning!
- Very important at LHC: Underlying Event models

- High precision MB and UE data from ATLAS motivates and allow for new UE tunes
- Will present new ATLAS tunes for workhorses Pythia 6 & Jimmy/Herwig

ATLAS detector



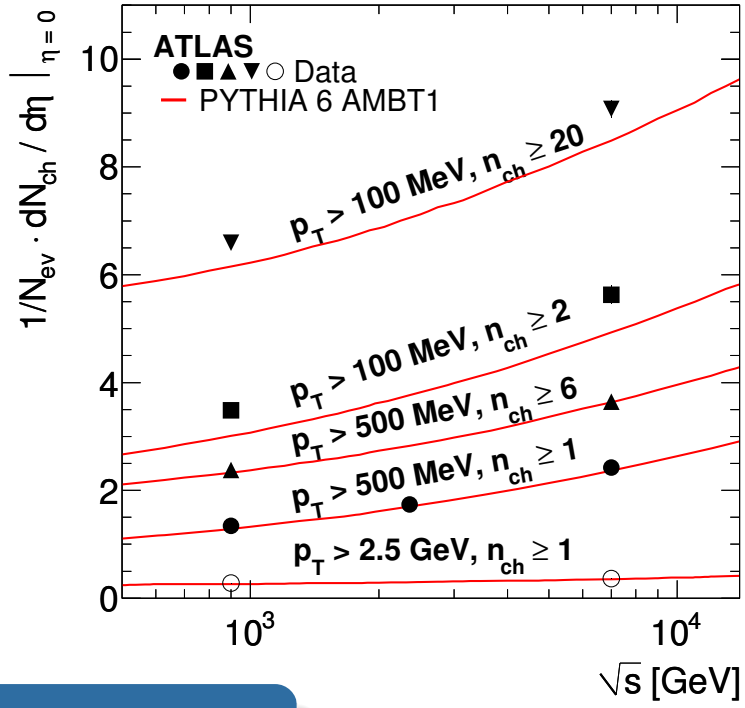


- Multi-purpose 4π detector
- From inside to outside: tracking system ($|\eta| < 2.5$), calorimeters, muon system
- MB & UE measurements presented in this talk only use:
  - MB trigger (MBTS)
  - tracking system and/or calorimeters

ATLAS MB & UE measurements

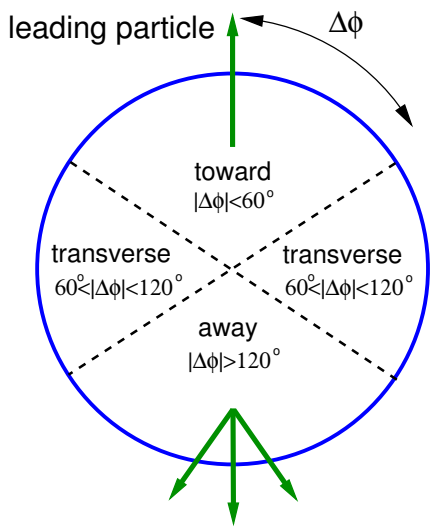
MinBias at $\sqrt{s} = 0.9$ & 7 TeV

- arXiv:1012.5104 [hep-ex]
- $\frac{dN}{dp_\perp}$, $\frac{dN}{dN_{ch}}$, $\frac{dN}{d\eta}$, $\langle p_\perp \rangle$ vs. N_{ch} distributions
- $p_\perp$ cuts: 100 and 500 MeV for charged particles
- Multiplicity cuts: $N_{ch} \geq 1, 2, 6, 20$

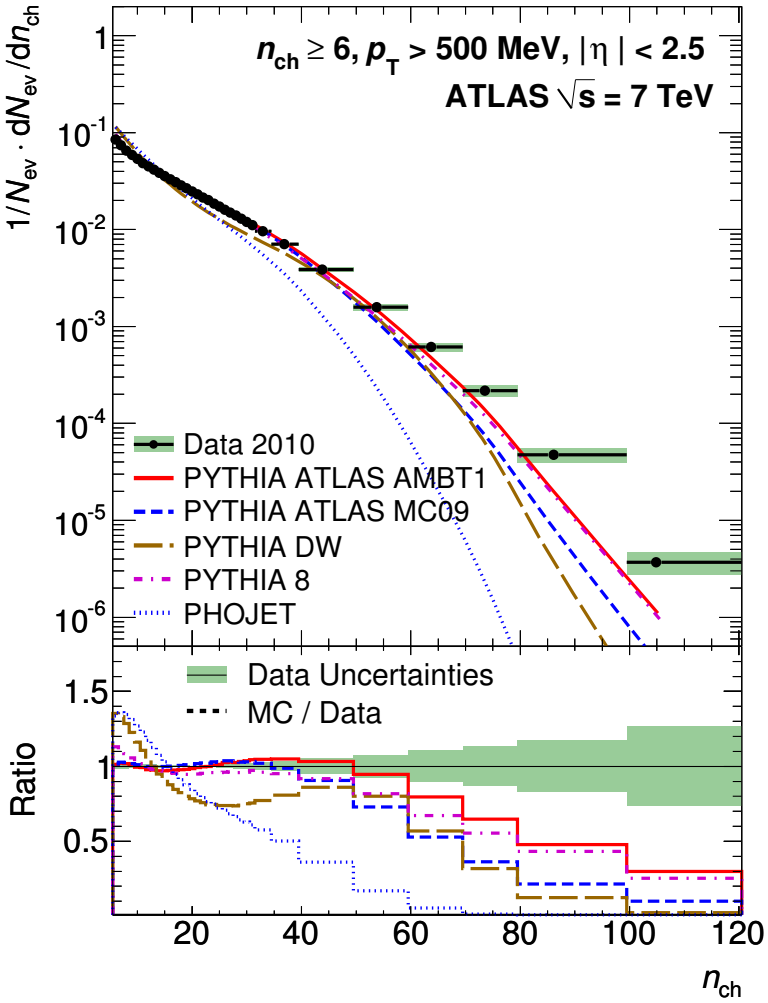


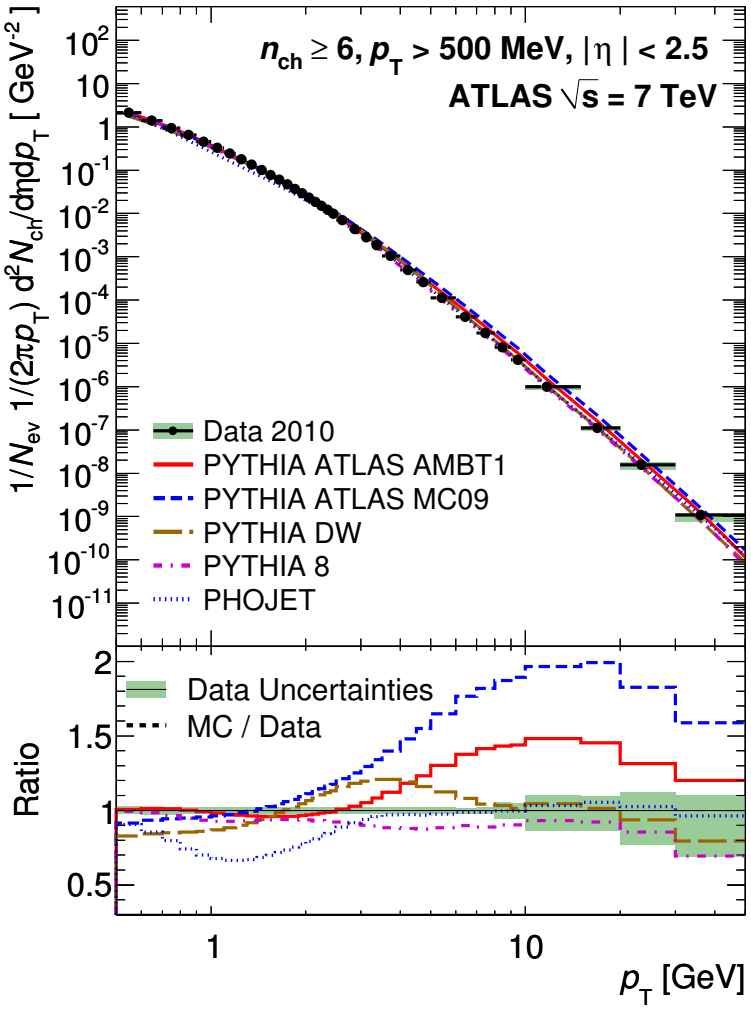
UE measurements at $\sqrt{s} = 0.9$ & 7 TeV

- Leading track: $p_\perp \geq 1$ GeV, $|\eta| \leq 2.5$
- Divide Φ space in 3 regions, measure N_{ch}, $\sum p_\perp$
- `arXiv:1012.0791 [hep-ex]`: charged particles, $p_\perp^{track} \geq 100$ or 500 MeV
- `arXiv:1103.1816 [hep-ex]`: charged and neutral particles, $p_\perp^{clust} \geq 500$ MeV



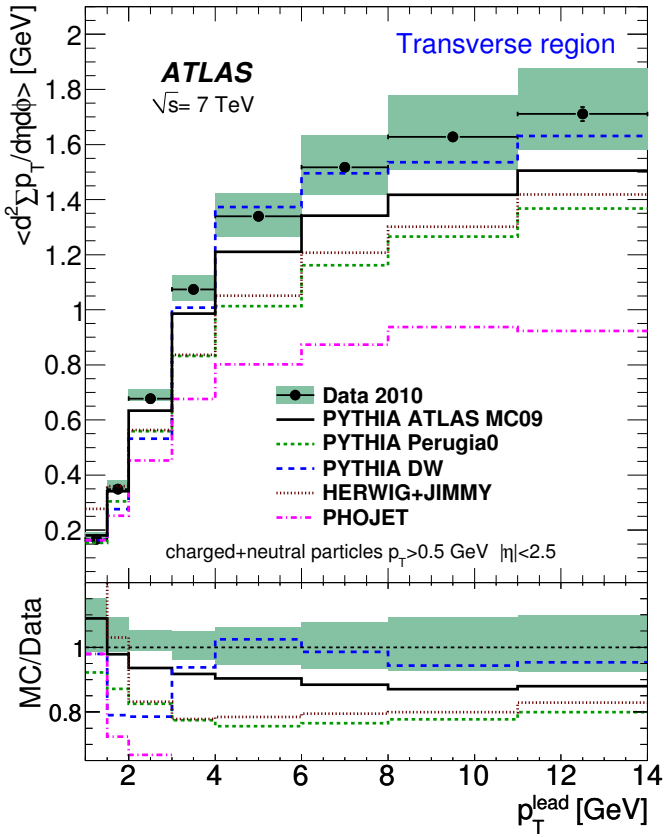
ATLAS MB results

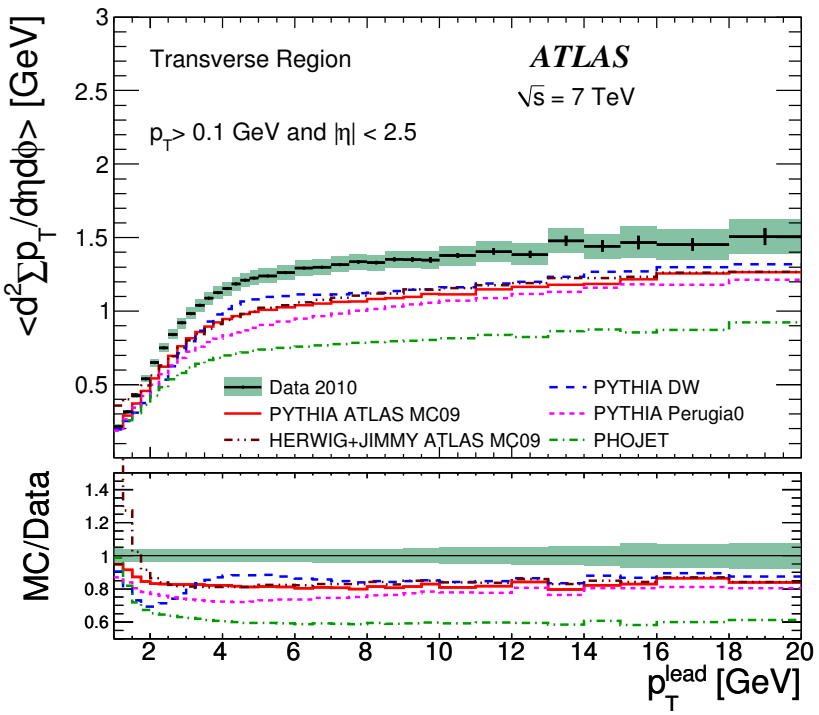




- Models unable to describe data, especially high N_{ch}, $p_\perp$
- Even when included in tuning (red line "AMBT1", previous ATLAS tune)

ATLAS UE results





- l.h.s.: UE with charged and neutrals, r.h.s. UE with charged particles
- Data shows much higher UE activity than predicted by models

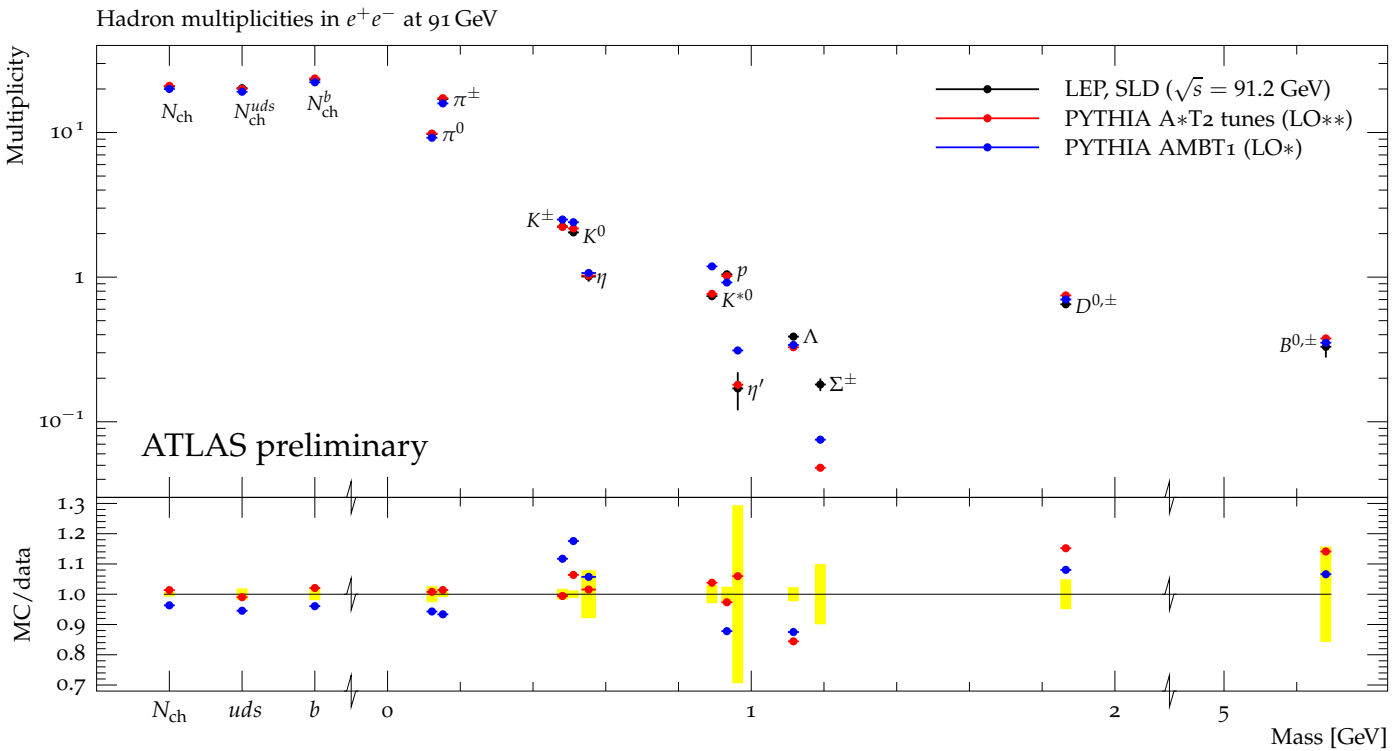
New ATLAS tunings

- Pythia6
  - New central PDF in ATLAS: MRSTMCal (LO**)
  - Use ISR settings as in Perugia2010 tune
  - ATLAS Minimum Bias Tune 2 (AMBT2)
  - ATLAS Underlying Event Tune 2 (AUET2)
  - Tuned a total of 25 parameters to hundreds of LEP, Tevatron, ATLAS observables
  - Intrinsic $k_\perp$, flavour, hadronisation, ISR, MPI cut-off, colour-reconnection ...
- Jimmy/Herwig
  - No soft physics in model
  - ATLAS Underlying Event Tune 2 (AUET2)
  - Tuned 3 MPI parameters to $\mathcal{O}(50)$ CDF & ATLAS observables
  - Finalised tuning for 10 PDFs
- Used Rivet (`arXiv:1003.0694 [hep-ph]`) and Professor (`Eur.Phys.J.C65:331-357,2010`) tools for tuning

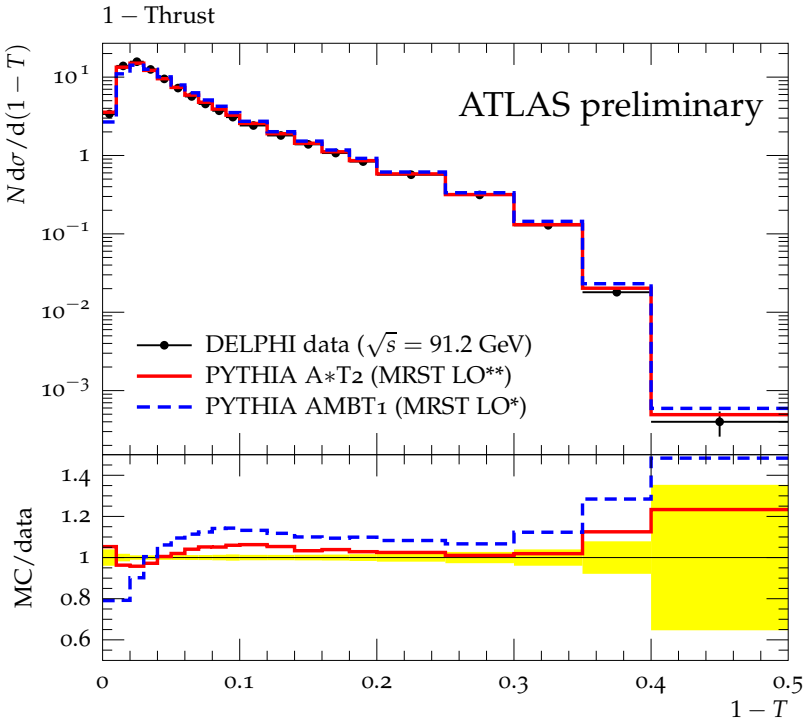
Pythia 6 tuning

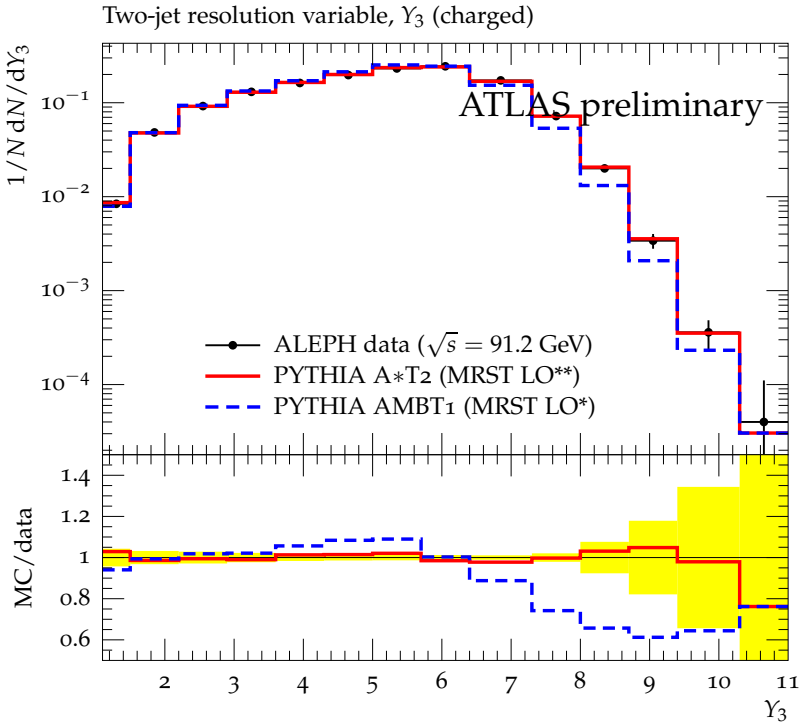
- Stepwise tuning strategy
  1. Tune 9 flavour parameters to LEP/SLD data (hadr. multiplicities)
  2. Tune 6 FSR parameters to LEP data (event shapes)
  3. Tune 5 ISR parameters to jet shapes, jet fragmentation data
  4. Tune 5 MPI parameters to MinBias & UE data

New tuning in red - nice improvement



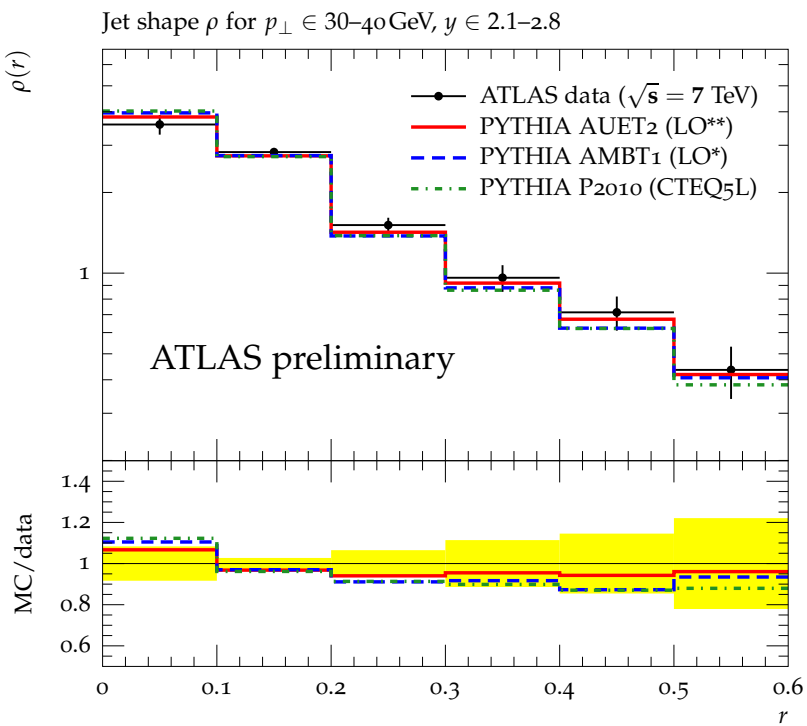
Pythia 6 FSR tuning

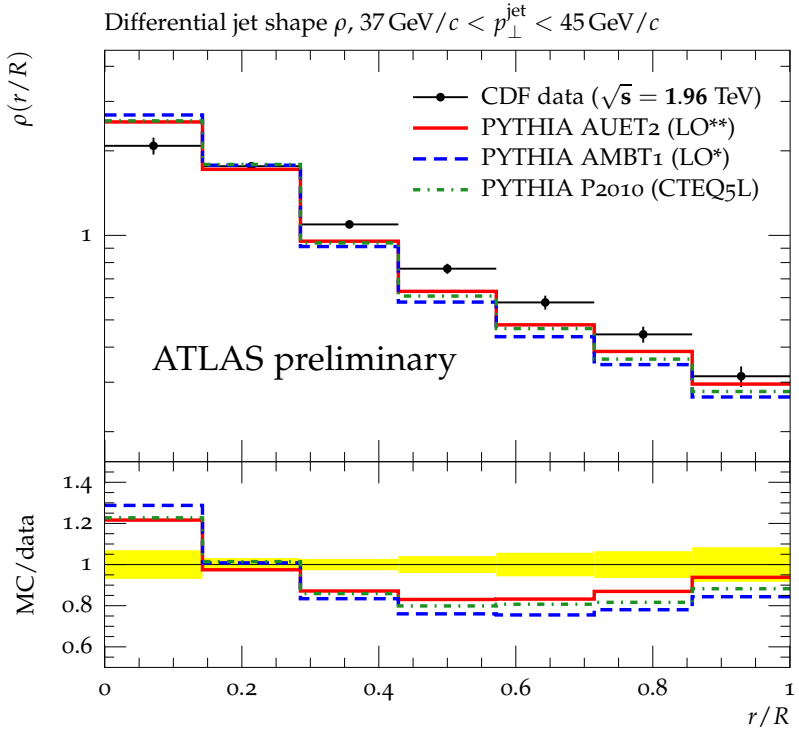




- FSR parameters tuned to LEP event shape data
- All event shapes have improved w.r.t. previous tuning "AMBT1"

Pythia 6 ISR tuning

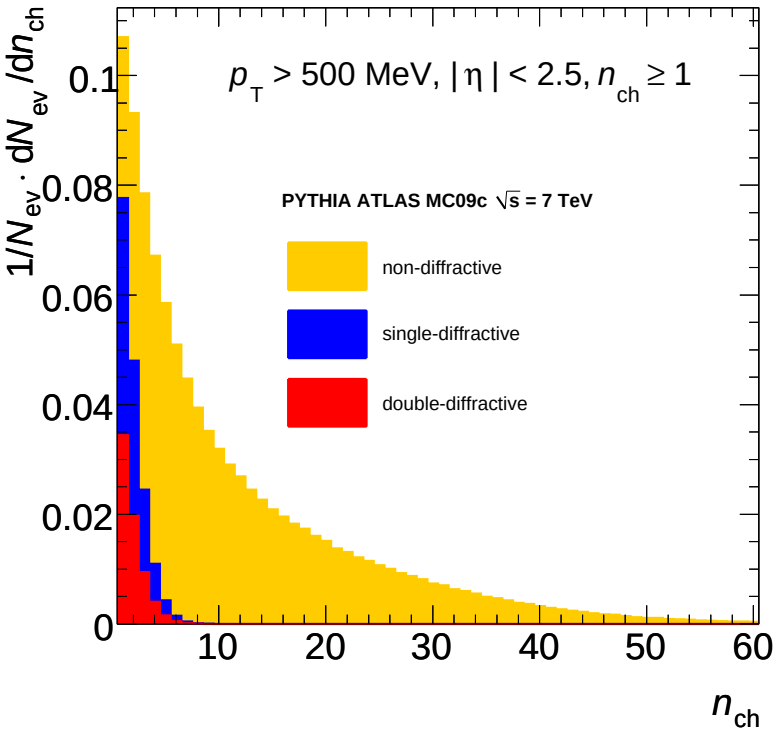




- Switched to Perugia2010 setup for ISR due to back then best description of jet shapes
- Tune parameters to data from CDF and ATLAS
- Some improvements w.r.t. AMBT1 but not dramatic

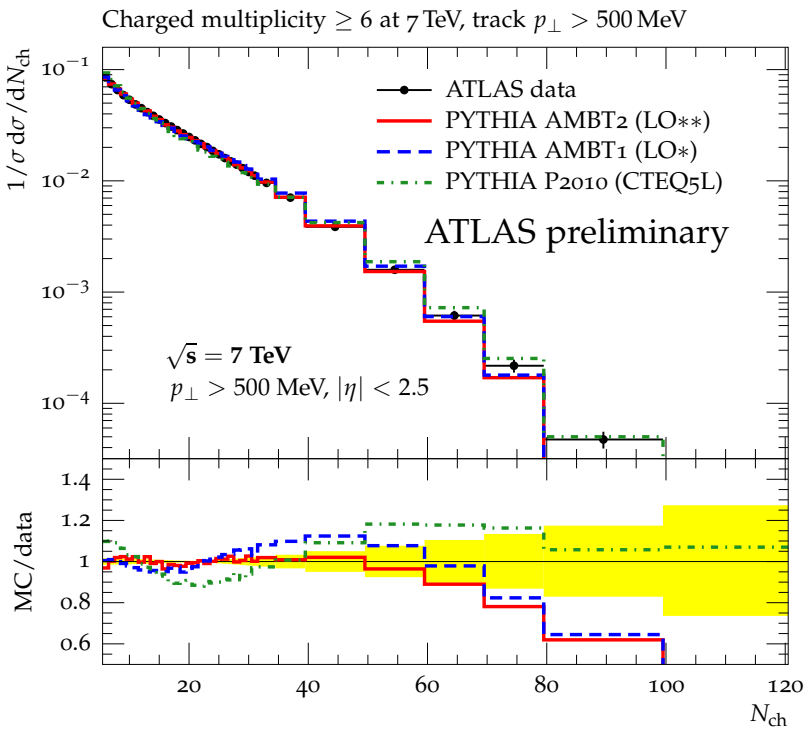
Pythia 6 MPI tuning

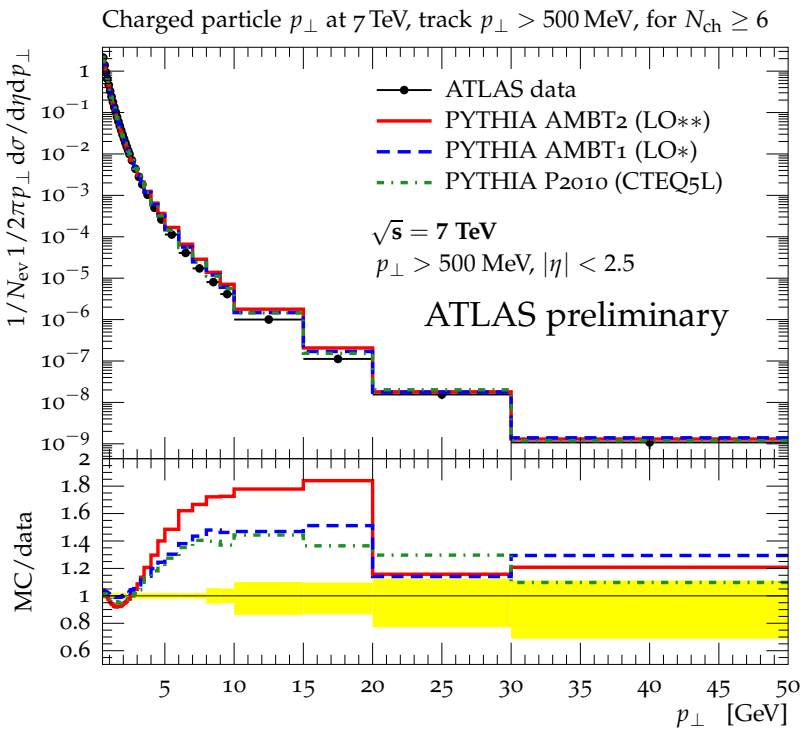
- MPI parameters tuned to UE and MinBias data from Tevatron and ATLAS:
  - ATLAS Minimum Bias w. diffraction reduced phase-space $N_{ch} \geq 6$ helped a lot since diffractives badly modelled in Pythia 6
  - Underlying event with tracks or calorimeters, $p_{\perp}^{track} \geq 100, 500$ MeV



- In this tuning attempt it was not possible to resolve MB and UE at the same time, hence we have to different tunes AMBT2 (tune to MB only) and AUET2 (tune to UE only)

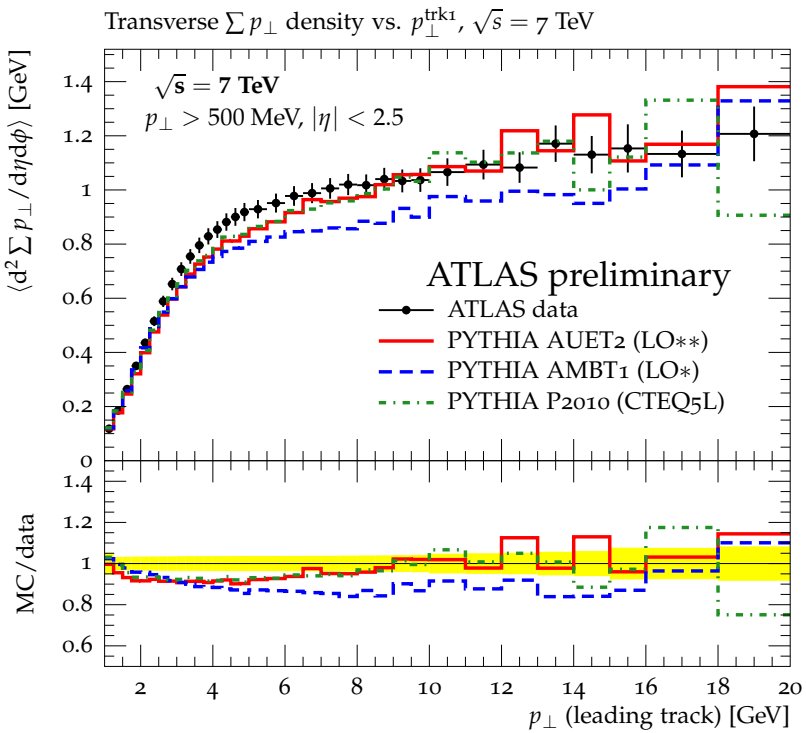
New Pythia 6 tune to ATLAS data: AMBT2

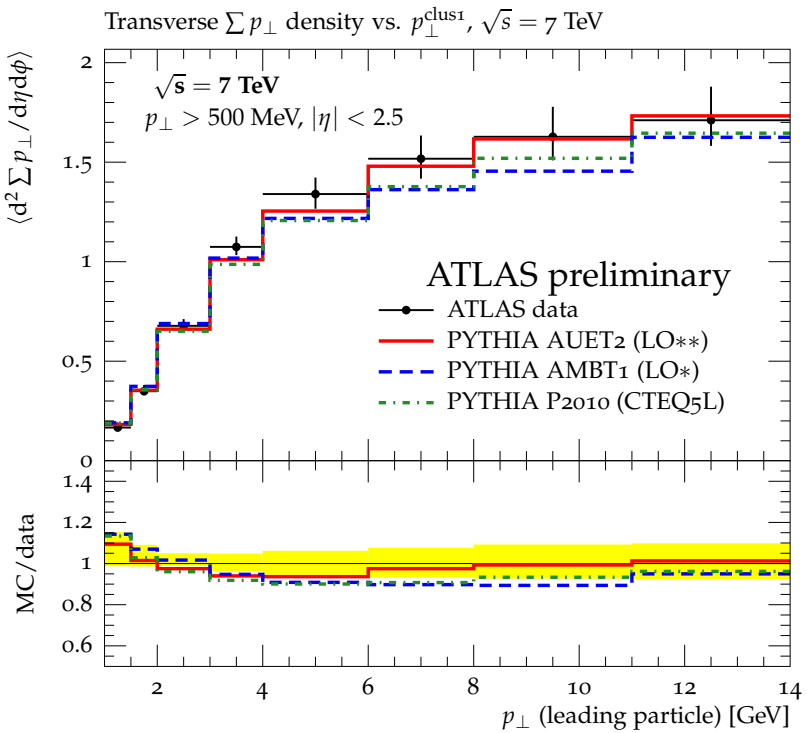




- N_{ch} distribution improved in statistically significant region
- $p_\perp$ distribution found impossible to describe with chosen ISR setup

New Pythia 6 tune to ATLAS data: AUET2





- Improvement w.r.t. AMBT1, "turn-over region" undershot
- Similar agreement for track- and calorimeter based UE measurements

Herwig/Jimmy tuning

- Only MPI tuning to UE data from ATLAS (7 TeV) and CDF (1.96 and 1.8 TeV)
- Tuned parameters:
  - Proton radius: PRRAD
  - Multiple parton interactions (MPI) cut-off scale, PTJIM, borrow Pythia's ansatz for energy dependence with meta-parameters:

$$\boxed{\mathtt{PTJIM}(\sqrt{s}) = \mathtt{PTJIM}_0 \cdot \left(\frac{\sqrt{s}}{1800\ \text{GeV}}\right)^{\mathtt{EXP}}}$$

- Tuning performed for a total of 10 PDF sets

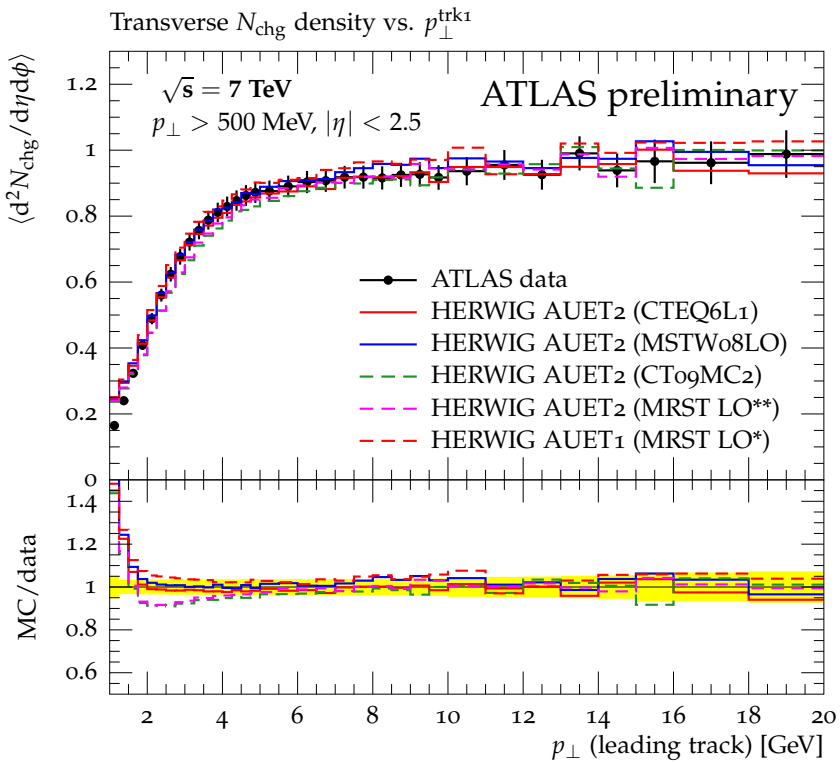
PDF type	PDF set	lhapdf code
Leading order (LO)	CTEQ6L1 MSTW08LO	10042 21000
Modified leading order (mLO)	MRSTMCal (LO**) CT09MC2	20651 10772
Next-to leading order (NLO) (for use with MC@NLO)	CTEQ6.6 CT10 MSTW08NLO HERAPDF1.0 HERAdis NNPDF2.1	10550 10800 21100 60500 USERGRID 192800

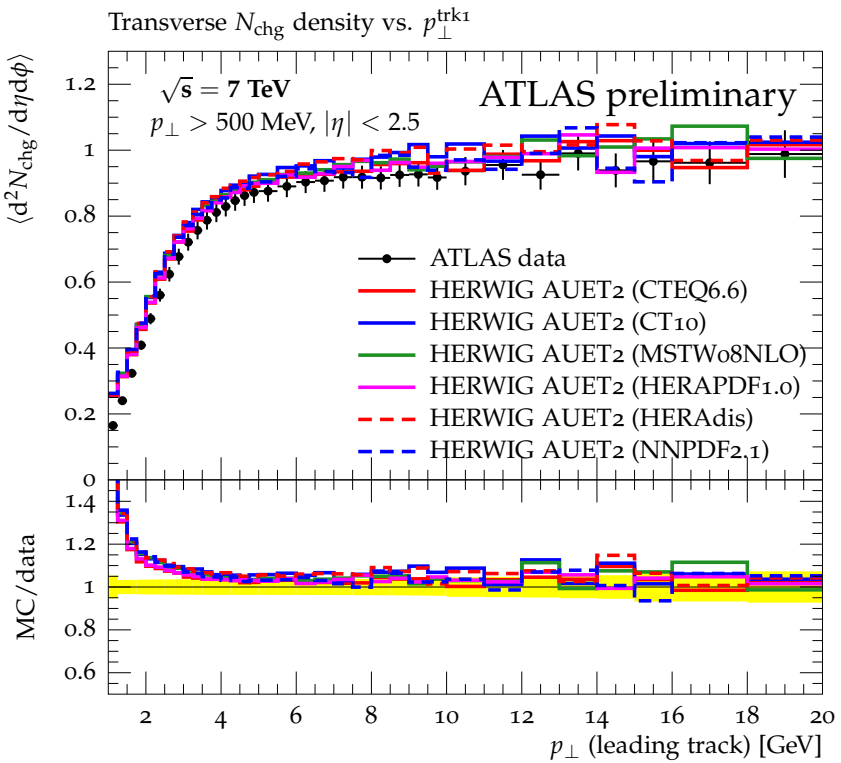
Observations made during tuning

- Impossible to fit model to all data with ansatz above, thus no 630 and 900 GeV data in fit, more precisely, fit to two energies possible, regardless of the experiments
- Impossible to get $\sum p_\perp$ and N_{ch} described at the same time (no colour reconnection)
- Impossible to describe ATLAS UE data with $p_\perp \geq 100$ MeV
- Impossible to get shape of UE plots right (only height changes)

- Herwig++ looks promising, active development, more advanced model (e.g. colour reconnection)

7 TeV ATLAS UE, $p_\perp^{\mathrm{TRACK}} > 500$ MeV TRACKS





- l.h.s: LO and mLO PDFs r.h.s: NLO PDFs
- PDF can almost be "tuned away" in UE
- Tuning results cluster in MPI cut-off `PTJIM` as function of PDF-type

Summary

- Large amounts of detector corrected ATLAS MinBias and UE high precision data available at $\sqrt{s} = 0.9$ and 7 TeV
- Immediately incorporated into generator tuning

- Pythia 6 setup adopted from Perugia2010: require separate UE and MB tunes, AUET2 and AMBT2
- Large improvements in many observables for Pythia 6, probably best FSR/ISR tune for Pythia 6

- ATLAS data clearly breaks the very stretched Herwig/Jimmy model — probably the last tunings in ATLAS, future tunings possibly focus on Herwig++
- Herwig/Jimmy tunes performed for LO, mLO and NLO PDFs

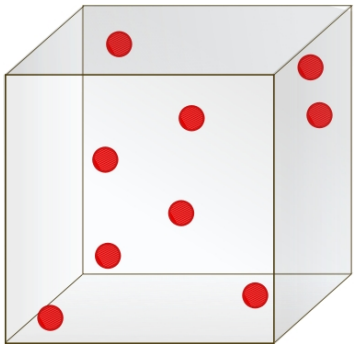
- ATLAS public note in preparation, $\mathcal{O}(1 \text{ week})$
- After successful 2.76 TeV LHC run we expect to stretch models even further

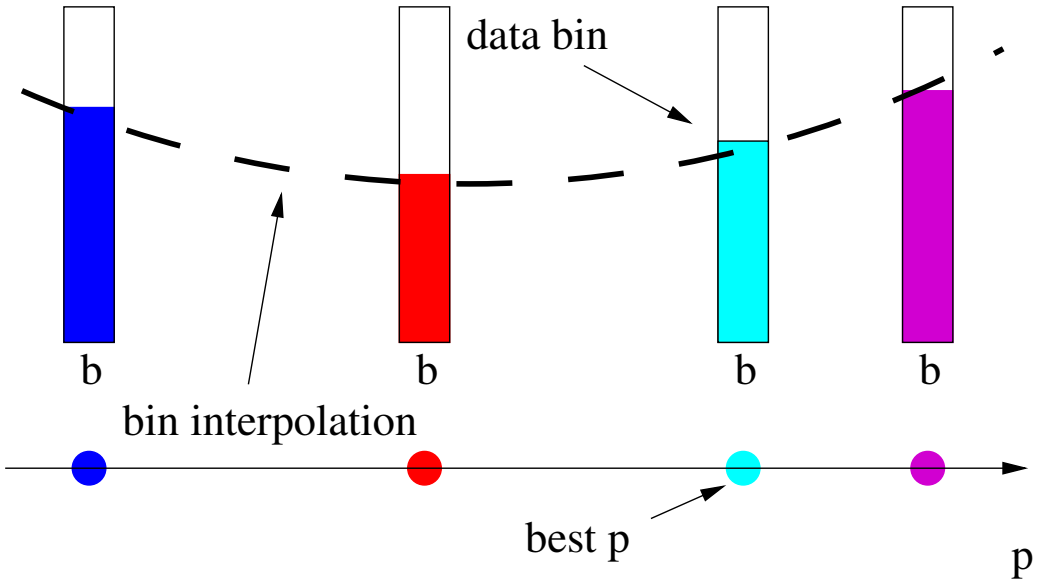
Thank you!

Backup

Tuning procedure in Professor (1D, 1Bin)

1. Random sampling: N parameter points in n-dimensional space
2. Run generator and fill histograms using Rivet
3. For each bin: use N points to fit interpolation (3rd order polynomial)
4. Construct overall (now trivial) $\chi^2 \approx \sum_{bins} \frac{(interpolation - data)^2}{error^2}$
5. Numerically *minimise* using `pyMinuit`

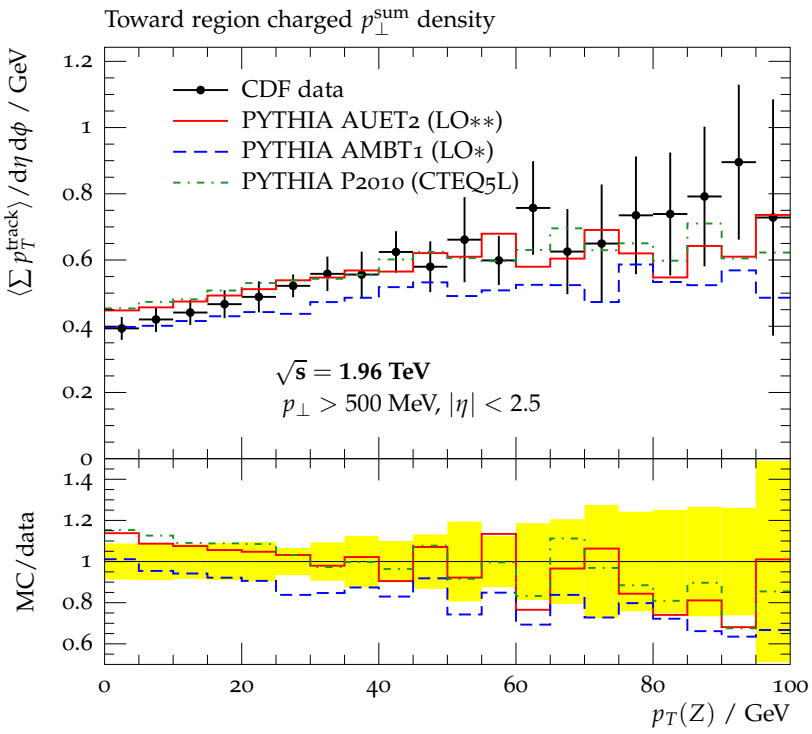


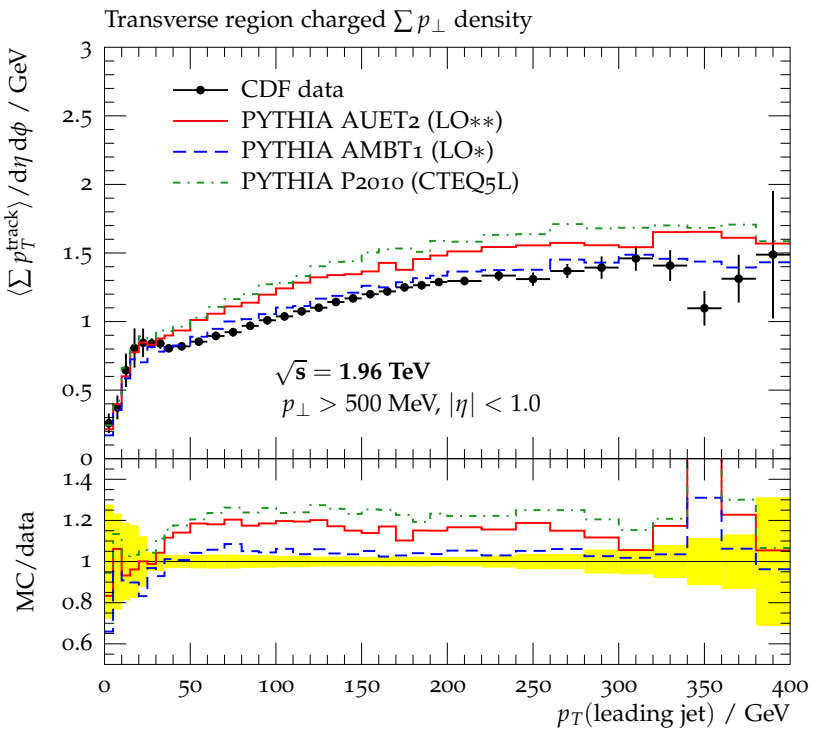


Observables and weights

- This is what Professor minimises: $\chi^2(\vec{p}) = \sum_{\mathcal{O}} \sum_{b \in \mathcal{O}} w_b \frac{(f^{(b)}(\vec{p}) - \mathcal{R}_b)^2}{\Delta_b^2}$
- Slightly more art than science
- Garbage in, garbage out
- Use weights w_b to:
  - emphasize certain observables, e.g. $\langle N_{\mathrm{ch}} \rangle$
  - emphasize certain bins of an observable
  - exclude bins from the fit

New Pythia 6 tune to ATLAS data: AUET2





- CDF Run-II UE leading jet data not well described with chosen ISR setup

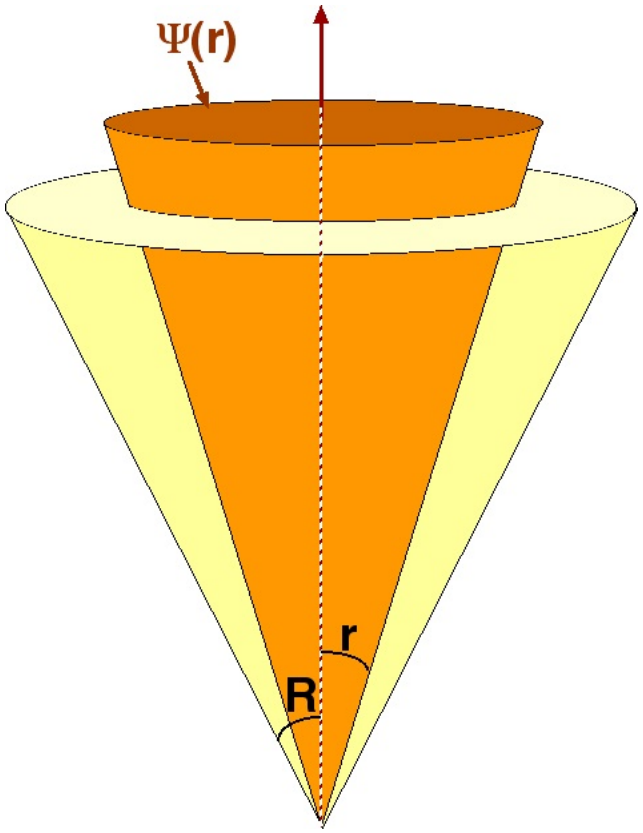
ATLAS jet shapes [1]
ATLAS dijet decorrelations [2]
ATLAS track jets [3]
ATLAS W plus jets [4]
CDF Z^0 $p_\perp$ and total cross-section in Z $\rightarrow$ e$^+$e$^-$ [5]
CDF jet shapes [6]
D0 dijet ϕ decorrelations [7]

TABLE: Observables and tuning weights used for tuning of the Pythia shower and intrinsic $k_\perp$ parameters.

Observable $\sqrt{s}$	Weight
Track-based minimum bias at 900 GeV and 7 TeV in ATLAS [8]	
CDF Run II minimum bias [9]	

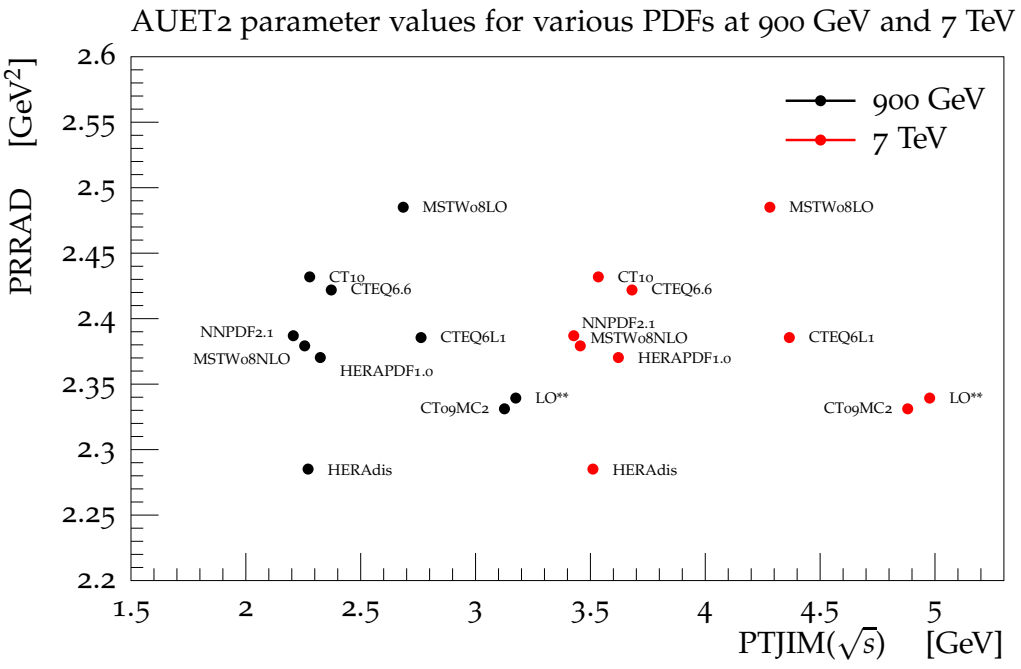
TABLE: Observable–weight combinations used for the AMBT2 MPI tuning.

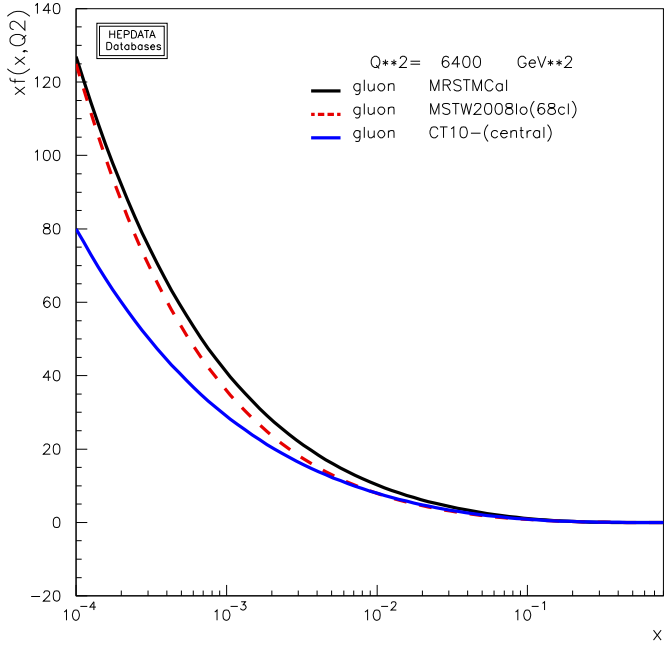
Jet shapes



- Differential jet shape $\rho(r)$, $r = \sqrt{\Delta y^2 + \Delta\Phi^2}$: avg. fraction of jet $p_\perp$ in annulus $[r - \Delta r/2; r + \Delta r/2]$ with $\Delta r = 0.1$ and $R = 0.6$

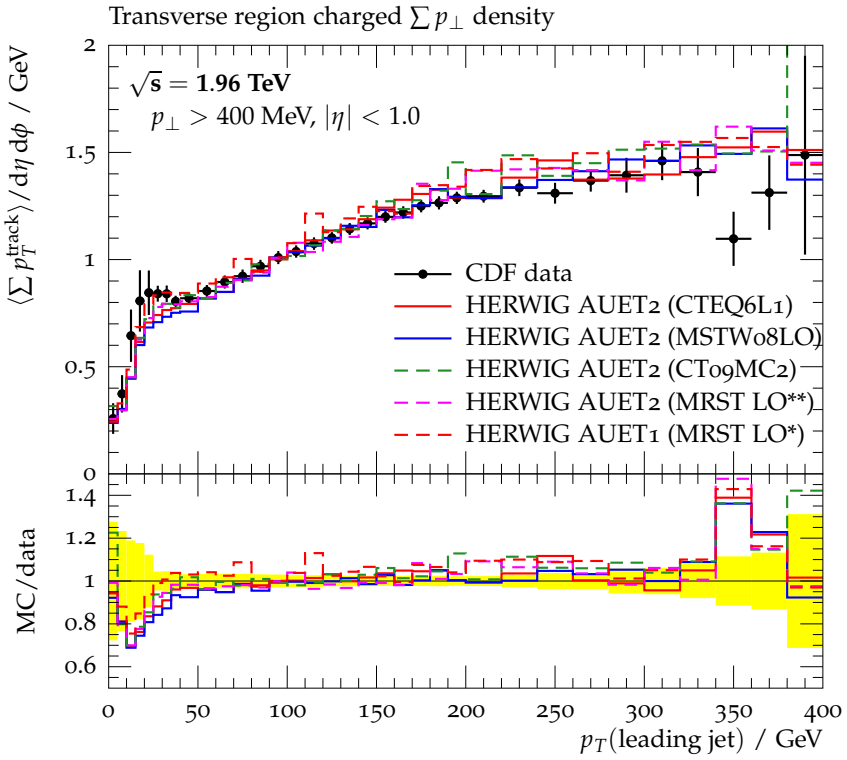
Jimmy/Herwig results: grouping by PDF-type

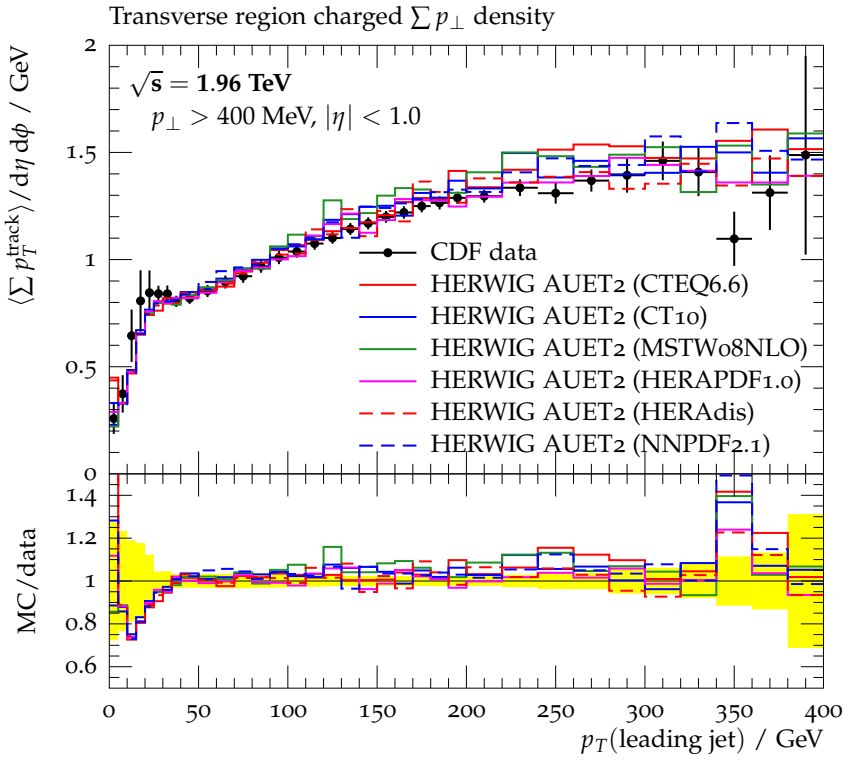




Left: Observed grouping of tuning results for PTJIM by PDF-type. Right: Gluon density distributions ($Q^2 = 6400$ GeV) for LO (MSTW08LO), mLO (MRSTCAL, LO**) and NLO PDFs (CT10) illustrating the augmented gluon activity at low x for mLO PDFs (plot generated at http://hepdata.cedar.ac.uk/pdfs)

CDF Run2, 1.96 TeV UE in leading jet events

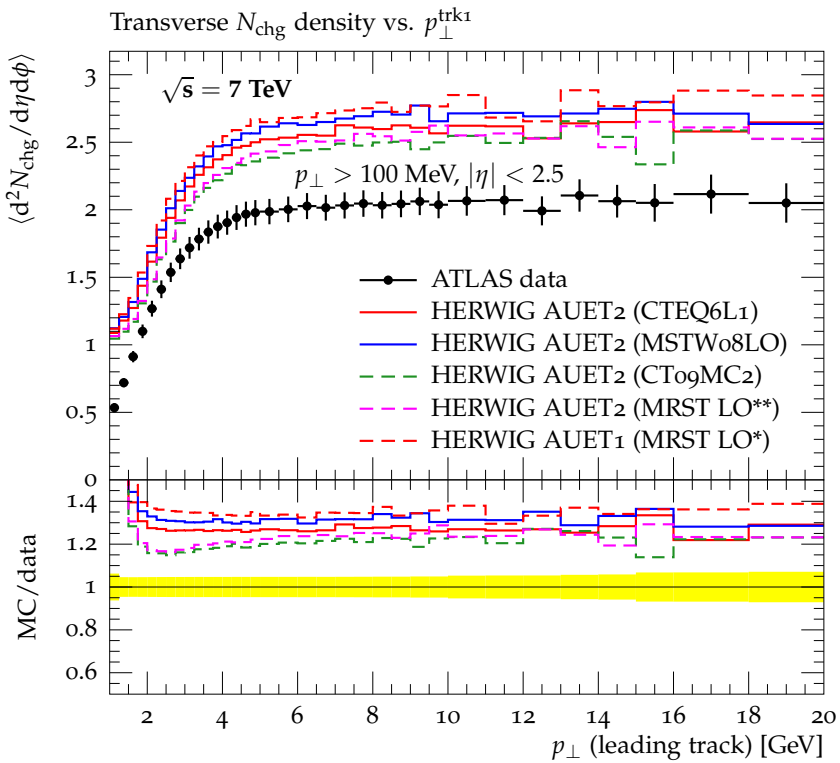


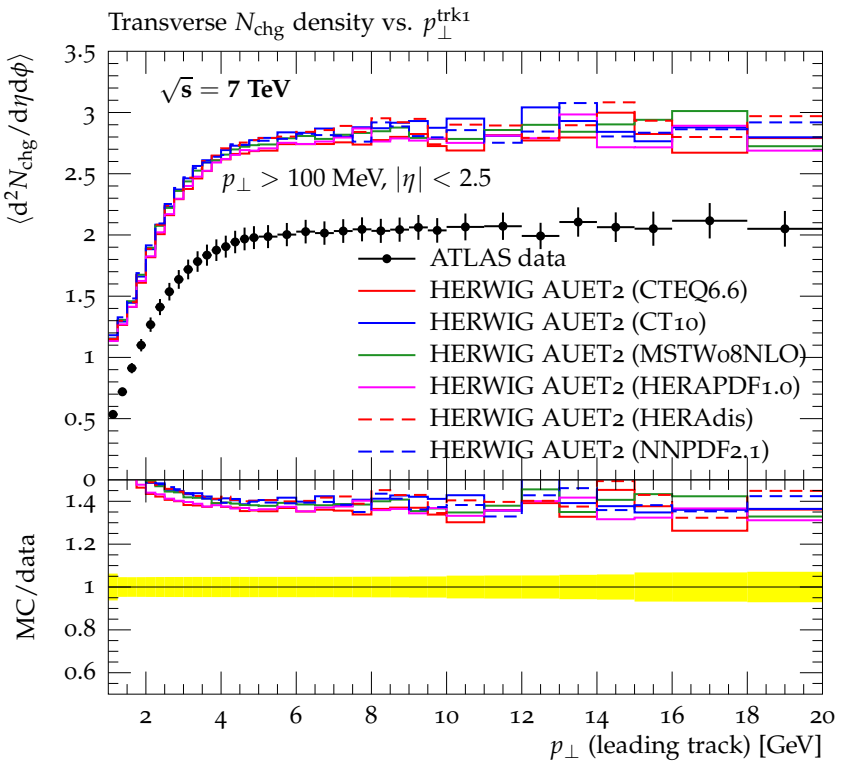


- l.h.s: LO and mLO PDFs

r.h.s: NLO PDFs

7 TeV ATLAS UE, $p_\perp^{\mathrm{TRACK}} > 100$ MeV TRACKS

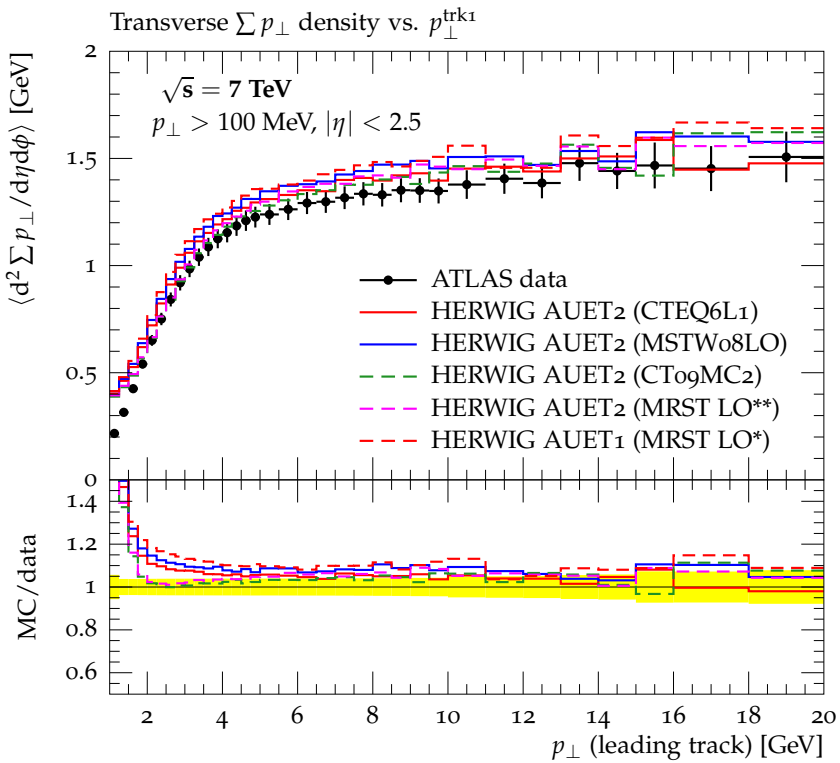


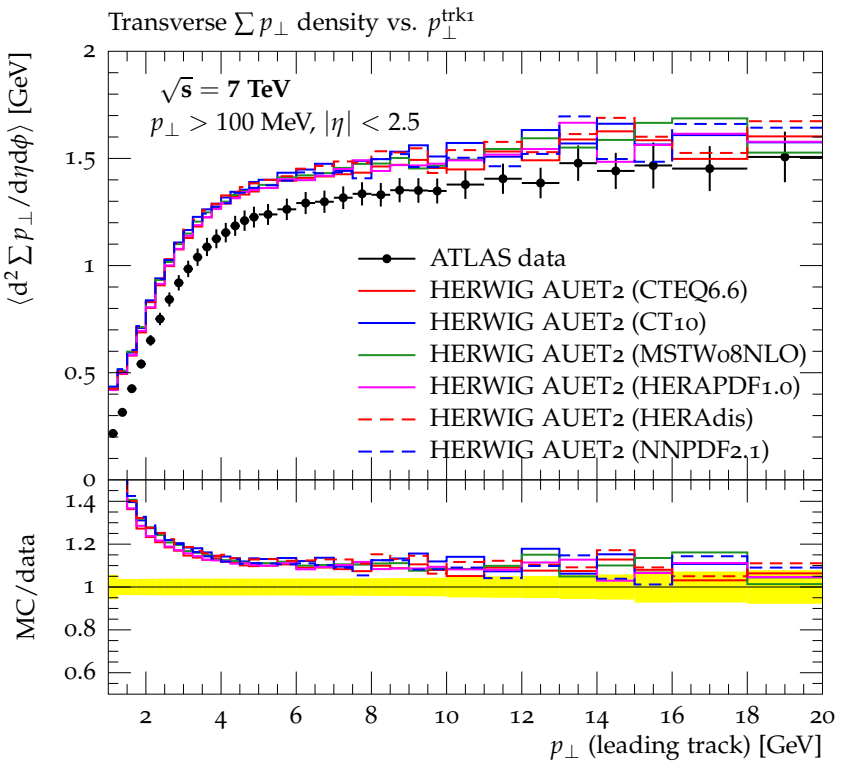


- l.h.s: LO and mLO PDFs

r.h.s: NLO PDFs

7 TeV ATLAS UE, $p_\perp^{\mathrm{TRACK}} > 100$ MeV TRACKS

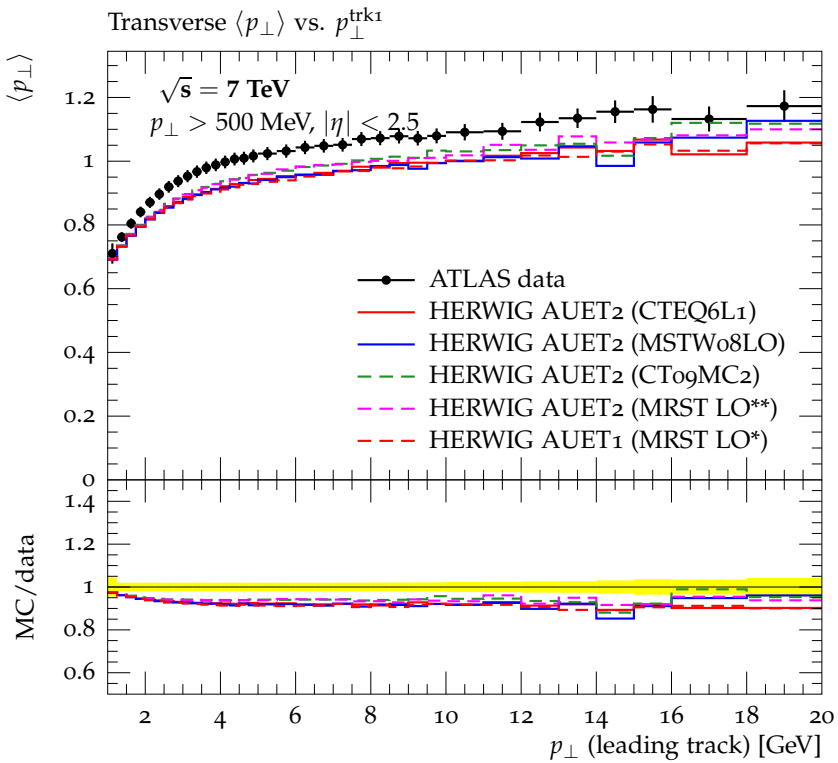


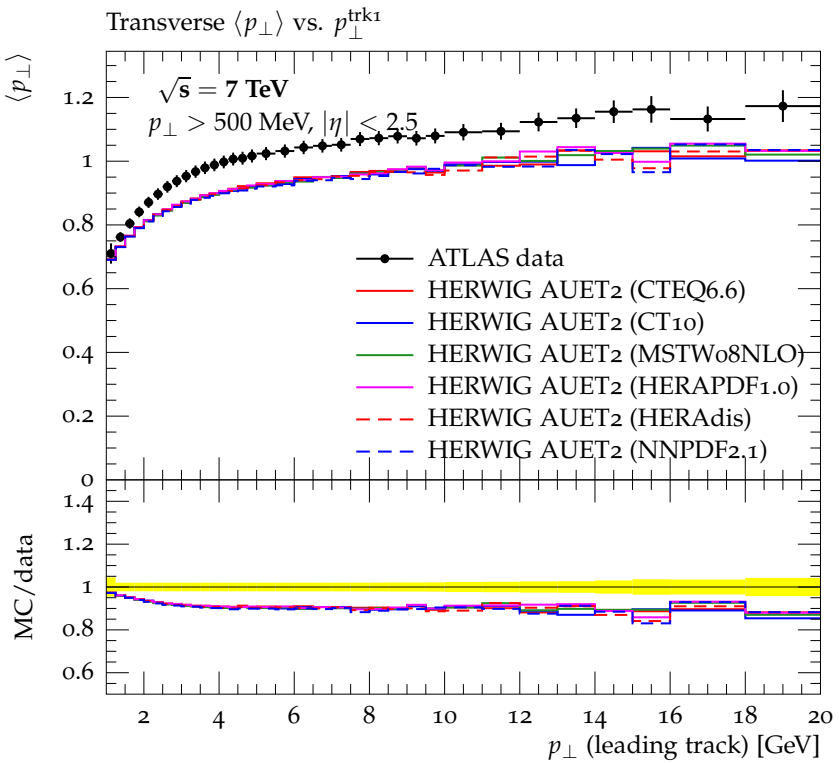


- l.h.s: LO and mLO PDFs

r.h.s: NLO PDFs

7 TeV ATLAS UE, $p_\perp^{\mathrm{TRACK}} > 100$ MeV TRACKS





- l.h.s: LO and mLO PDFs

r.h.s: NLO PDFs

Observable	$\sqrt{s}$	Fitrange	Weight
Track-based underlying event at 900 GeV and 7 TeV in ATLAS[10]			
Transverse region N_{chg} density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	40.0
Toward region N_{chg} density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	10.0
Away region N_{chg} density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	10.0
Transverse region $\sum p_{\perp}$ density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	60.0
Toward region $\sum p_{\perp}$ density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	10.0
Away region $\sum p_{\perp}$ density vs. $p_{\perp}$ (leading track)	7 TeV	$\geq$ 6 GeV	10.0
Transverse N density vs. $p_{\perp}^{\mathrm{clus1}}$	7 TeV	$\geq$ 4 GeV	50.0
Transverse $\sum p_{\perp}$ density vs. $p_{\perp}^{\mathrm{clus1}}$	7 TeV	$\geq$ 6 GeV	100.0
Cluster-based underlying event at 900 GeV and 7 TeV in ATLAS [11]			
Transverse N density vs. $p_{\perp}^{\mathrm{clus1}}$	7 TeV	$\geq$ 4 GeV	50.0
Transverse $\sum p_{\perp}$ density vs. $p_{\perp}^{\mathrm{clus1}}$	7 TeV	$\geq$ 6 GeV	100.0
Field & Stuart Run I underlying event analysis. [12]			
N_{ch} (toward) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
N_{ch} (transverse) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
N_{ch} (away) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
N_{ch} (toward) for JET20	1800 GeV		1.0
N_{ch} (transverse) for JET20	1800 GeV		2.0
N_{ch} (away) for JET20	1800 GeV		1.0
$p_{\perp}^{\mathrm{sum}}$ (toward) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
$p_{\perp}^{\mathrm{sum}}$ (transverse) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
$p_{\perp}^{\mathrm{sum}}$ (away) for min-bias	1800 GeV	$\geq$ 4 GeV	1.0
$p_{\perp}^{\mathrm{sum}}$ (toward) for JET20	1800 GeV		1.0
$p_{\perp}^{\mathrm{sum}}$ (transverse) for JET20	1800 GeV		2.0
$p_{\perp}^{\mathrm{sum}}$ (away) for JET20	1800 GeV		1.0
$p_{\perp}$ distribution (transverse, $p_{\perp}^{\mathrm{lead}} > 5$ GeV)	1800 GeV		1.0
$p_{\perp}$ distribution (transverse, $p_{\perp}^{\mathrm{lead}} > 30$GeV)	1800 GeV		1.0

Observable	$\sqrt{s}$	Fitrange	Weight
Transverse cone and 'Swiss cheese' underlying event studies [13]			
Transverse cone $\langle p_\perp^{\mathrm{max}} \rangle$ vs. $E_\perp^{\mathrm{lead}}$	1800 GeV		1.0
Transverse cone N_{max} vs. $E_\perp^{\mathrm{lead}}$	1800 GeV		1.0
Swiss Cheese $p_\perp^{\mathrm{sum}}$ vs. $E_\perp^{\mathrm{lead}}$ (2 jets removed)	1800 GeV		1.0
Swiss Cheese $p_\perp^{\mathrm{sum}}$ vs. $E_\perp^{\mathrm{lead}}$ (3 jets removed)	1800 GeV		1.0
CDF Run 2 underlying event in leading jet events [14]			
Transverse region charged particle density	1960 GeV	$30 \leq x \leq 300$ GeV	3.0
TransMAX region charged particle density	1960 GeV	$30 \leq x \leq 300$ GeV	1.0
TransMIN region charged particle density	1960 GeV	$30 \leq x \leq 300$ GeV	1.0
TransDIF region charged particle density	1960 GeV	$30 \leq x \leq 300$ GeV	1.0
Transverse region charged $\sum p_\perp$ density	1960 GeV	$30 \leq x \leq 300$ GeV	6.0
TransMAX region charged $\sum p_\perp$ density	1960 GeV	$30 \leq x \leq 300$ GeV	2.0
TransMIN region charged $\sum p_\perp$ density	1960 GeV	$30 \leq x \leq 300$ GeV	2.0
TransDIF region charged $\sum p_\perp$ density	1960 GeV	$30 \leq x \leq 300$ GeV	2.0
CDF Run 2 underlying event in Drell-Yan [14]			
Toward region charged particle density	1960 GeV	$\geq$ 10 GeV	2.0
Transverse region charged particle density	1960 GeV	$\geq$ 10 GeV	1.0
TransMAX region charged particle density	1960 GeV	$\geq$ 10 GeV	1.0
TransMIN region charged particle density	1960 GeV	$\geq$ 10 GeV	1.0
TransDIF region charged particle density	1960 GeV	$\geq$ 10 GeV	1.0
Away region charged particle density	1960 GeV	$\geq$ 10 GeV	1.0
Toward region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	4.0
Transverse region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	2.0
TransMAX region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	2.0
TransMIN region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	2.0
TransDIF region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	2.0
Away region charged $p_\perp^{\mathrm{sum}}$ density	1960 GeV	$\geq$ 10 GeV	2.0

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