



University
of Glasgow

Experimental
Particle Physics

Early QCD measurements with ATLAS

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University of Glasgow

Representing the ATLAS collaboration



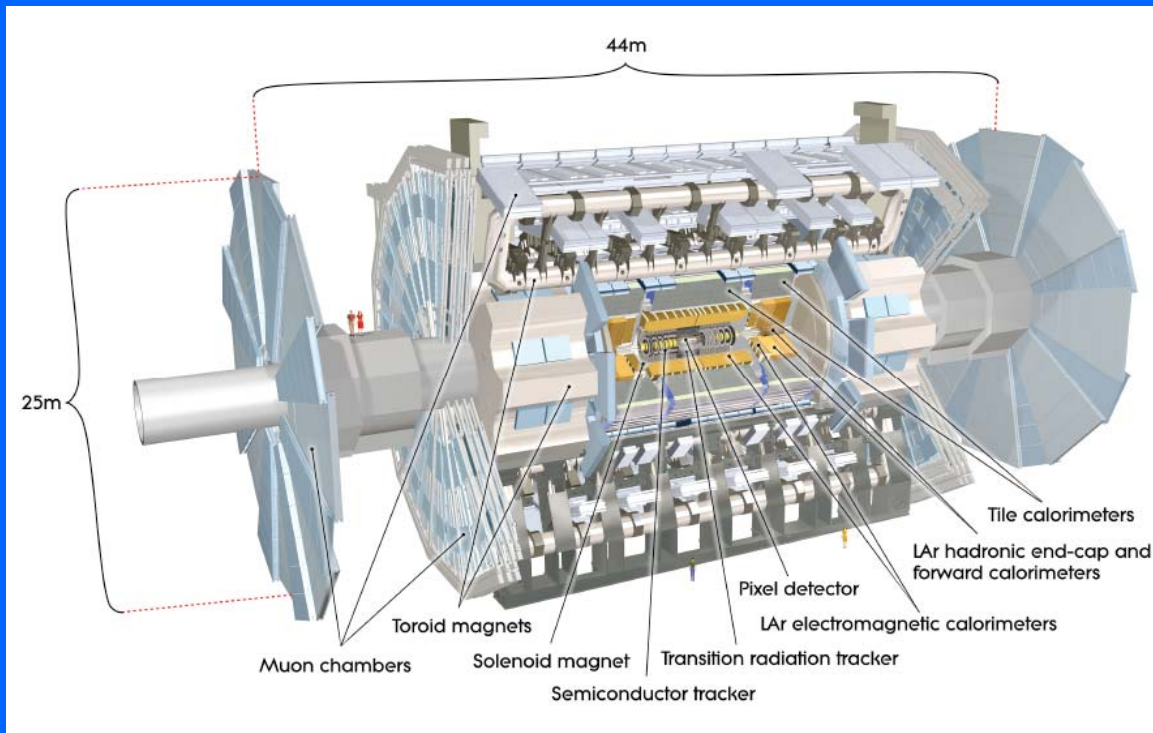
Outline

- Minimum bias
- Underlying event
- Di-jet azimuthal decorrelations
- Jets – high-x gluon pdf and jet energy scale

All results for 14TeV unless otherwise stated

Main reference (unless otherwise stated): Expected performance of the ATLAS experiment: detector, trigger and physics: arXiv 0901.0512

ATLAS: on one slide



See Alan Watson's talk for more details

Magnetic Field

2T solenoid plus air core toroid

Inner Detector

$\sigma/p_T \sim 0.05\% p_T(\text{GeV}) + 0.1\%$

Tracking in range $|\eta| < 2.5$

EM Calorimetry

$\sigma/E \sim 10\%/\sqrt{E(\text{GeV})} + 0.7\% \quad |\eta| < 3.2$

(Fine granularity up to $|\eta| < 2.5$)

Hadronic Calorimetry

$\sigma/E \sim 50\%/\sqrt{E(\text{GeV})} + 3\% \quad |\eta| < 3.2$

Calorimetry

Covers $|\eta| < 4.9$ for E_T

Muon Spectrometer

$\sigma/p_T \sim 2-7\%$

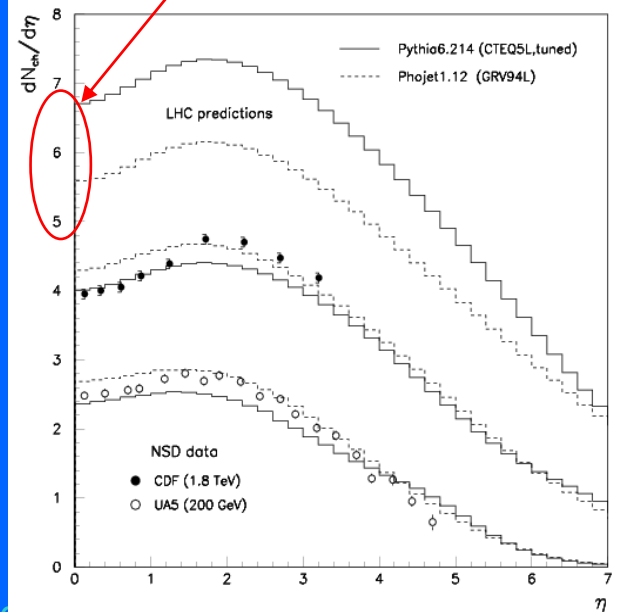
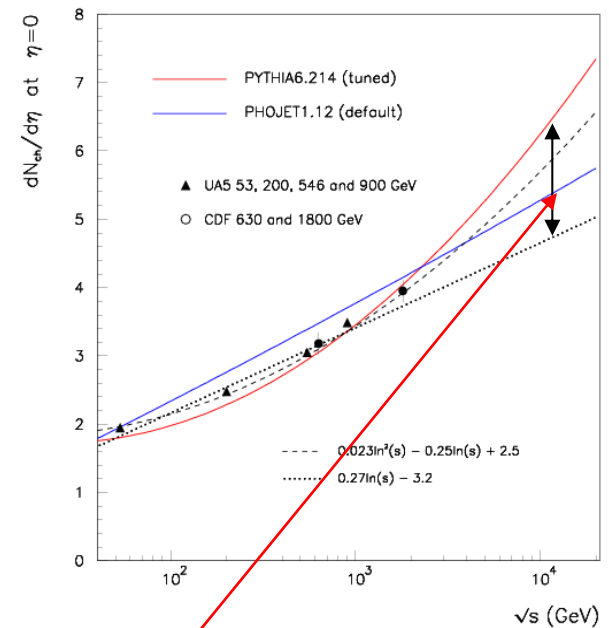
Covers $|\eta| < 2.7$

Precision physics in $|\eta| < 2.5$

Measurement of properties of minimum bias events

First measurement at LHC

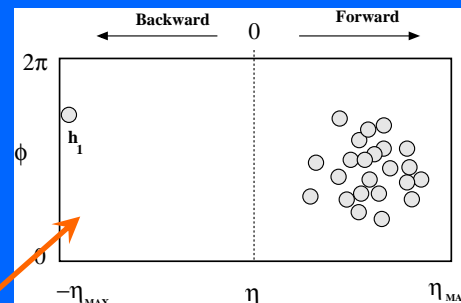
- Measure charged particle distributions: rapidity distribution and pt-spectrum
- Multiplicity distributions and $\langle pt \rangle$ as a function of multiplicity
- Overlap with underlying event studies
- Large uncertainties on model predictions



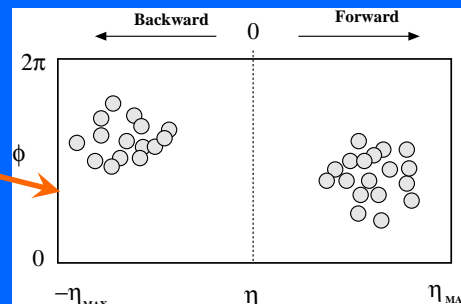
Soft pp collisions

pp collisions at $\sqrt{s} = 14\text{TeV}$	PYTHIA6.323	PHOJET1.12
σ_{tot}	101.5 mb	119.1 mb
σ_{elas}	22.2 mb	34.5mb
$2*\sigma_{\text{SD}}$	14.4mb	11.0mb
σ_{DD}	10.3mb	4.1mb
σ_{ND}	54.7mb	69.5mb

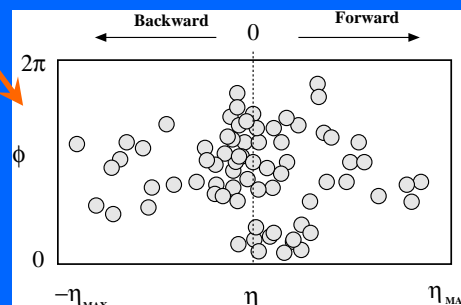
Minimum bias
Made up of
combination of
non-diffractive
and diffractive



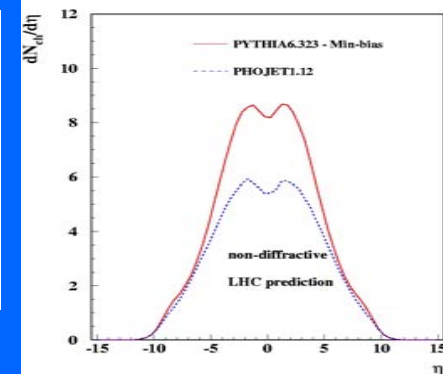
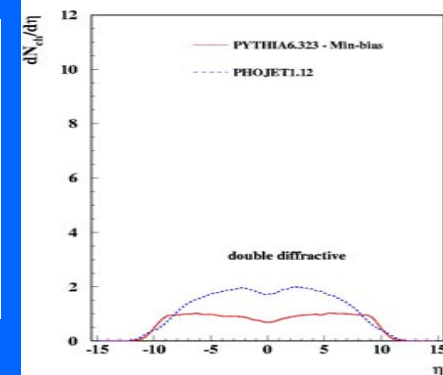
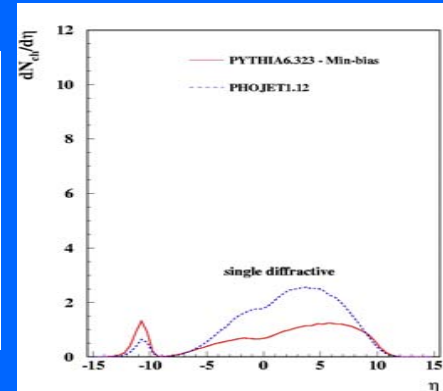
Single diffractive SD



Double diffractive DD

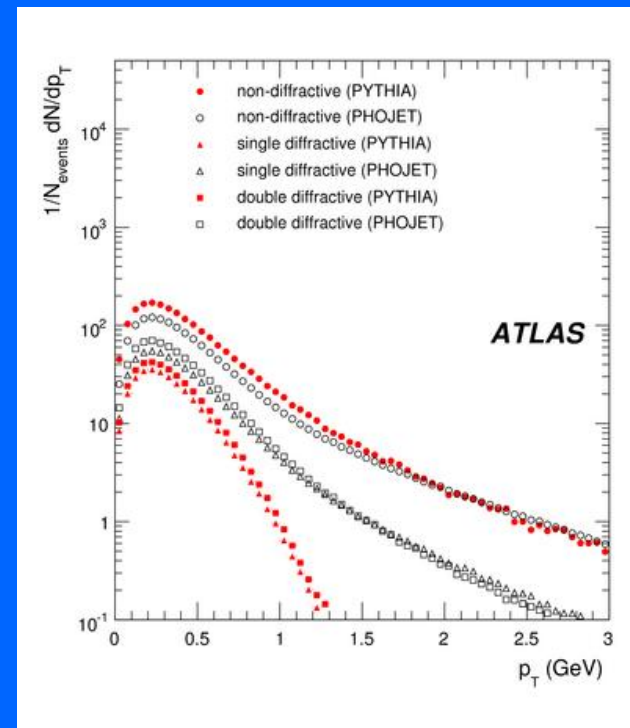
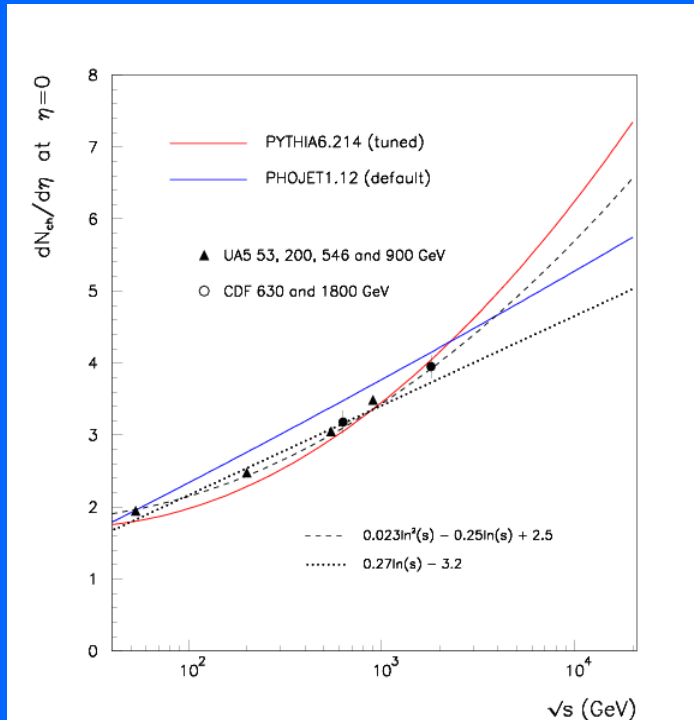


Non-diffractive ND



Early QCD measurements with ATLAS, DIS09

Model predictions for minimum bias at 14 TeV



Large uncertainties on predictions

σ_{inel} : 79-85mb $\sim 7\%$

$\sigma_{diff}/\sigma_{inel}$: 0.2-0.3 $\sim 50\%$

$dN_{ch}/d\eta_{l(nsd, \eta=0)}$: 5-7 $\sim 33\%$

$\langle p_T \rangle$ at $\eta=0$: 550-640MeV $\sim 15\%$

What are minimum bias events?

- Minimum bias are inelastic collisions of two protons
 - Includes very rare high-pt scatters and very common low-pt scatters
- Minimum bias is an experimental definition
 - Defined by experimental trigger and analysis
- Relation between experiment and physics is:

$$\sigma_{measured} = f_{sd} \sigma_{sd} + f_{dd} \sigma_{dd} + f_{nd-inelastic} \sigma_{nd-inelastic}$$

f_i are the efficiencies for different physics processes determined by the trigger

Need to understand what is measured to allow comparison to previous results often presented for non-single diffractive (NSD) events

ATLAS minbias triggers

For operating luminosity 10^{33} - $10^{34}\text{cm}^{-2}\text{s}^{-1}$ use random trigger

For early running up to $\sim 10^{30}\text{cm}^{-2}\text{s}^{-1}$, number of events/crossing $\ll 1$

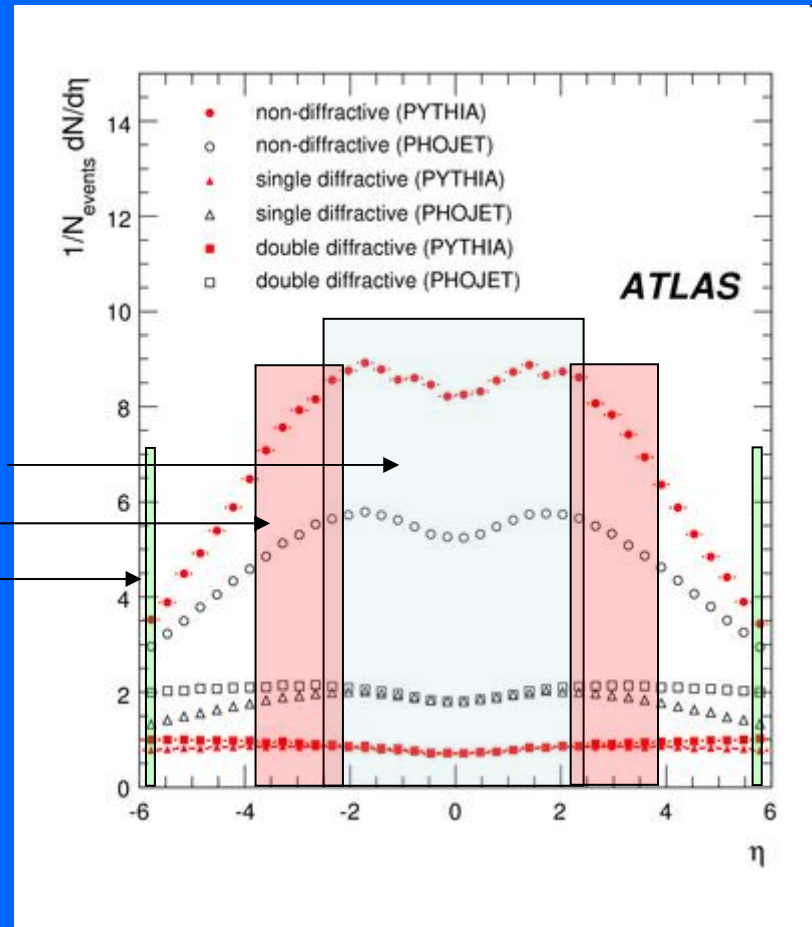
Require triggers for minimum bias

Inner detector spacepoints and tracks $|\eta| < 2.5$

Trigger scintillators (MBTS) $2.1 < |\eta| < 3.8$

LUCID $5.6 < |\eta| < 5.9$

ZDC $|\eta| > 8.3$



Trigger efficiencies

Results calculated using PYTHIA at 14TeV

Efficiency	MBTS_1_1	MBTS_2	SP+EF
ND	0.99	1.0	1.0
SD	0.45	0.69	0.57
DD	0.54	0.83	0.65

Trigger efficiency for different physics processes

MBTS_1_1=1 hit in each side – level 1
MBTS_2=2 hits on any side – level 1

SP+EF=

Random trigger – level 1

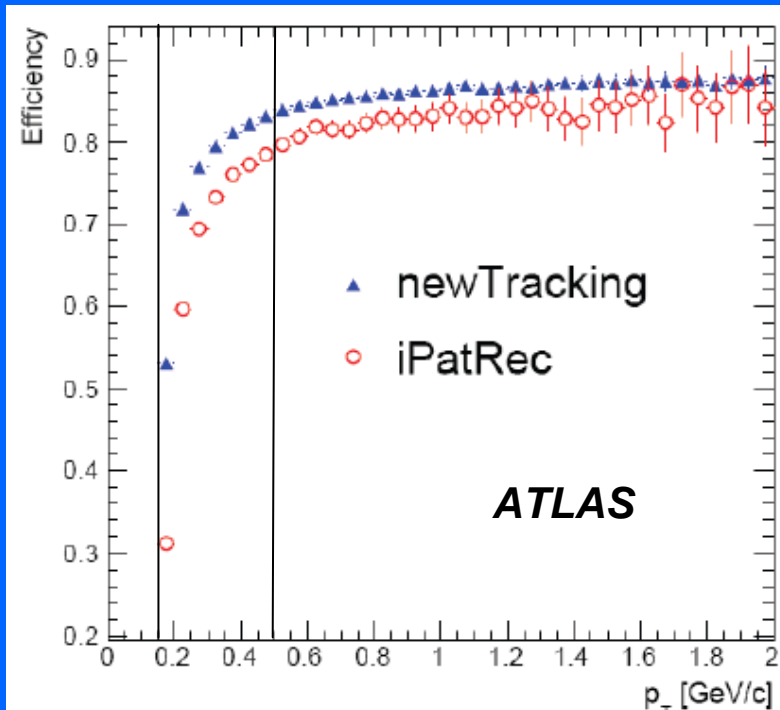
Inner detector spacepoints (level 2)+tracks
(event filter)

Acceptance	MBTS_1_1	MBTS_2	SP+EF
ND	0.69	0.70	0.70
SD	0.08	0.12	0.10
DD	0.07	0.10	0.08
Total	0.84	0.92	0.88
NSD/total	0.90	0.87	0.89

Trigger acceptance of different physics processes
(Efficiency scaled by fraction of total cross-section)

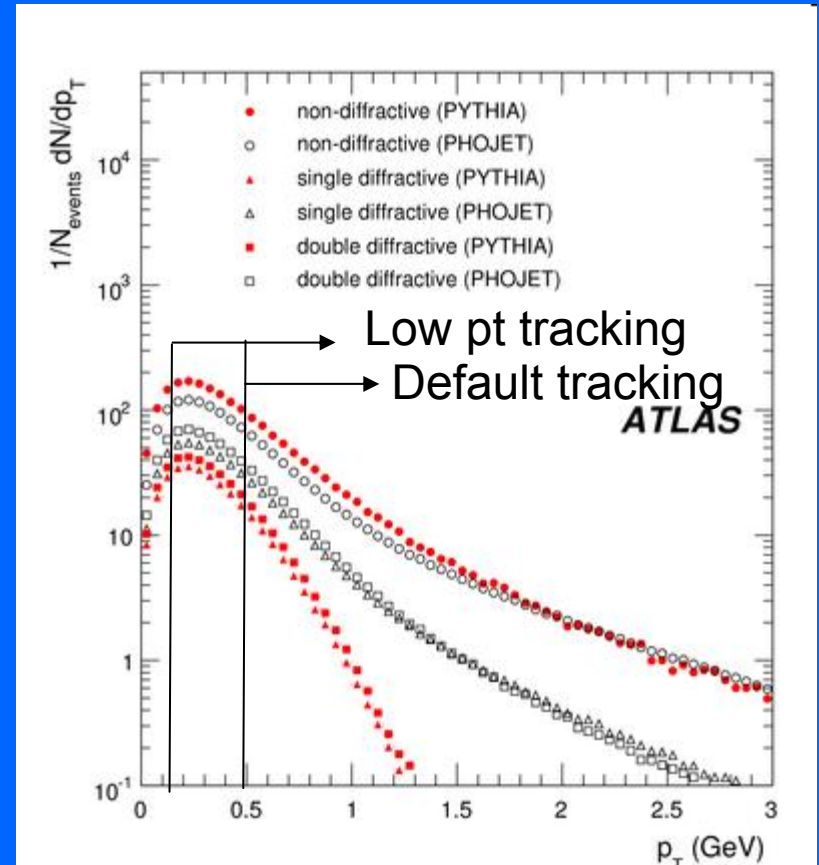
NSD Trigger acceptance ~90% of total rate

Low pt tracking

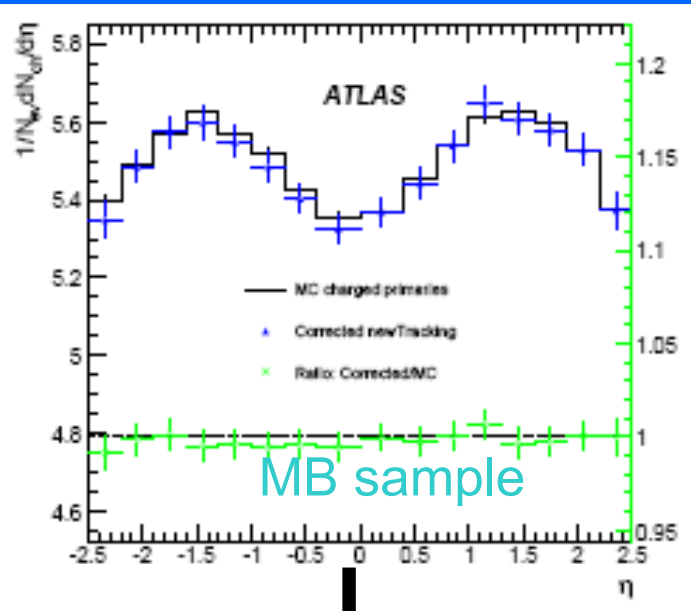


p_T problem

- Need to extrapolate by ~ 2
- Need to understand low p_T charged track reconstruction



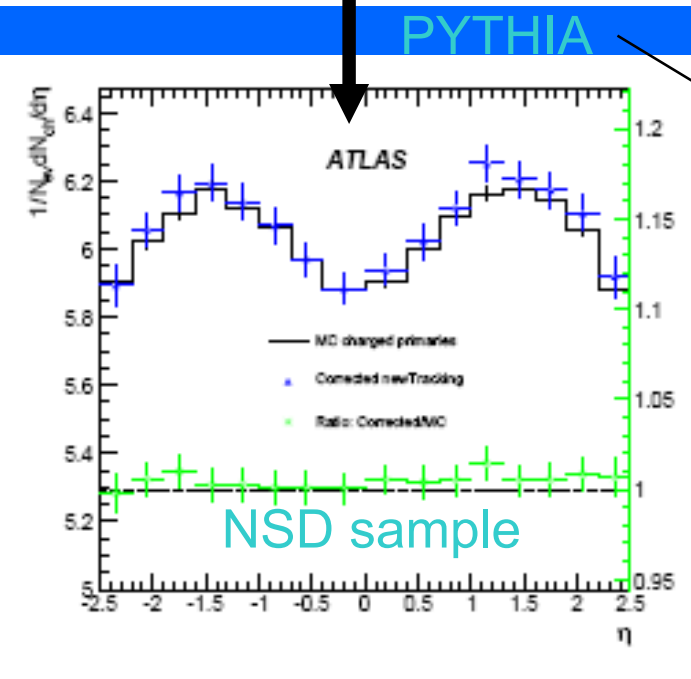
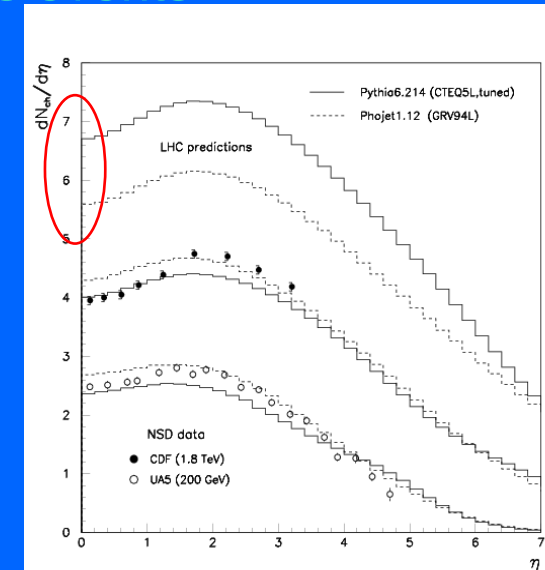
Minimum bias distributions



ATLAS has the tools to trigger on and reconstruct minimum bias events

Minimum bias sample
Selected by MBTS_2

- track reconstruction
- vertex reconstruction



Distributions have
 $p_T > 150 \text{ MeV}$

6%

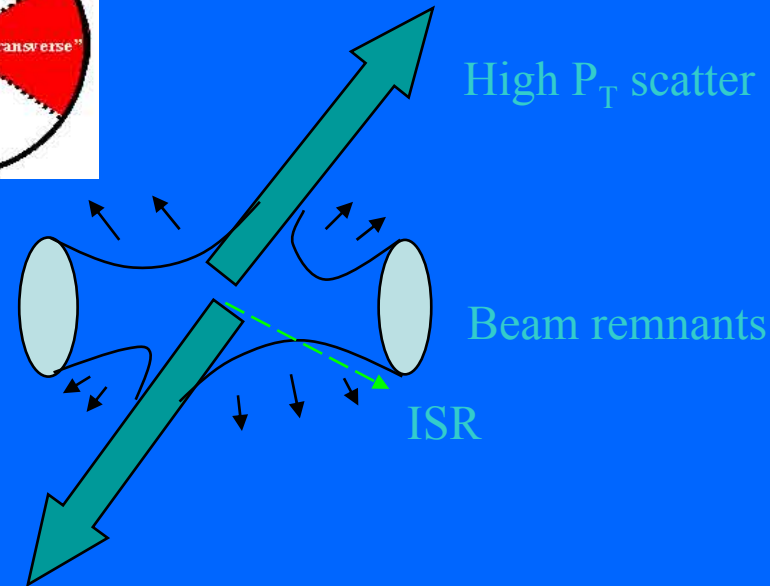
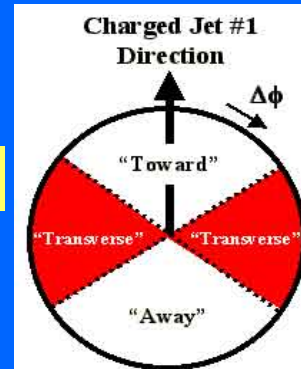
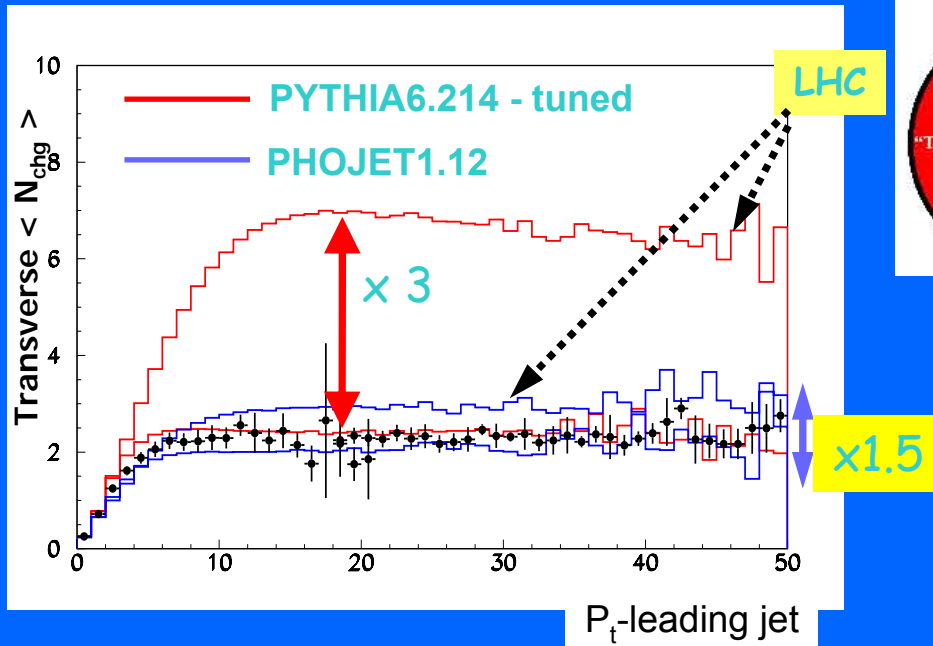
NSD sample
Corrected for trigger bias
-- change trigger bias

Track selection cuts	2%
Mis-estimate of secondaries	1.5%
Vertex reconstruction	0.1%
Mis-alignment	6%
Beam-gas & pile-up	1%
Particle composition	2%
Diffraction cross-sections	4%
Total:	8%

with ATLAS, DIS09, Madrid April 2009

The underlying event

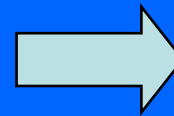
Average charged particle density in transverse region



Extrapolation of UE to LHC energies is unknown

The UE depends on

- Multiple interactions
- Radiation
- PDFs
- String formation



UE affects

- Lepton isolation
- Top
- Jet energy at low P_{T}

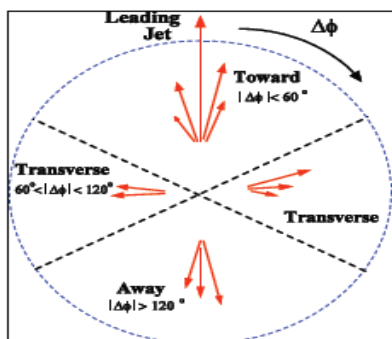
PYTHIA-(new)Tune vs Jimmy-Tune

PYTHIA6.416-(new)Tune vs Jimmy 4.3-Tune

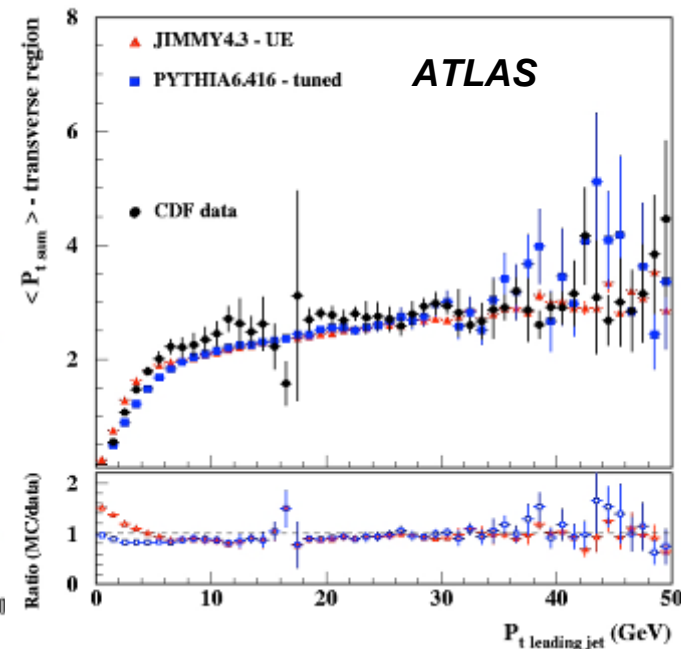
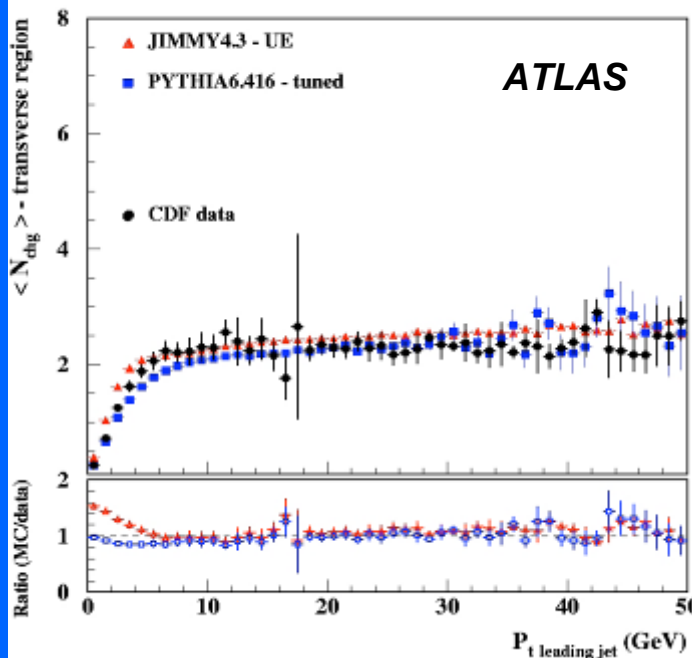
CDF - Run I "Style"

Charged particles:
 $p_T > 0.5 \text{ GeV}$ and $|\eta| < 1$

Cone jet finder: $R=0.7$



UE particles come from region transverse to the leading jet.

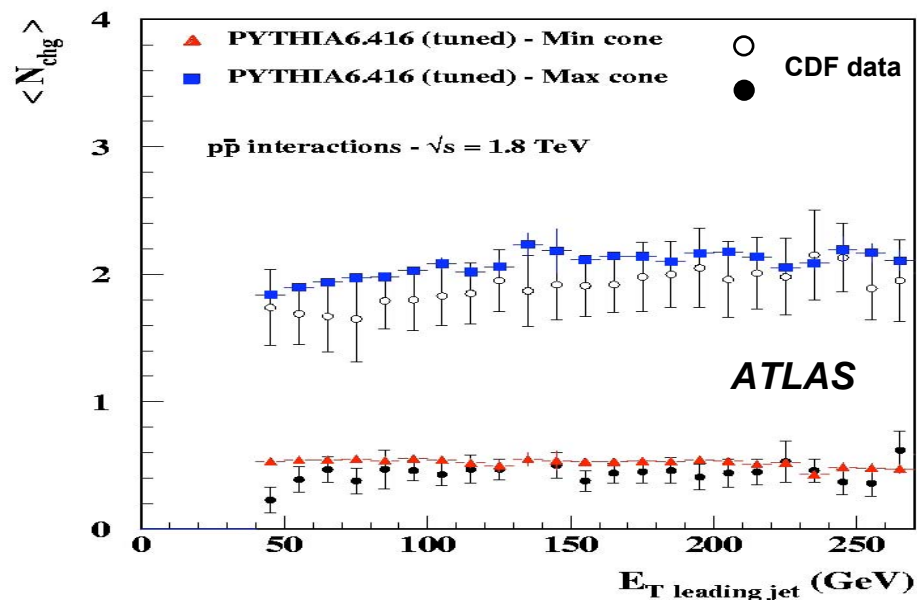


New PYTHIA tune (ATLAS-PHYS-PROC-2009-045)
 Shorter strings and change in matter distribution

Jimmy-Tune:
 Les Houches, 2005.
 hep-ph/0604120

Good agreement between PYTHIA6.416-Tuned and Jimmy4.3 for $P_{T}^{\text{leading jet}} > 6 \text{ GeV}$ at Tevatron Energies

- ## <N_{chg}> in TransMAX & TransMIN



▲ PYTHIA6.416 (tuned) - Min cone

■ PYTHIA6.416 (tuned) - Max cone

○ CDF data

● CDF data

$p\bar{p}$ interactions - $\sqrt{s} = 1.8$ TeV

ATLAS

E_T leading jet (GeV)

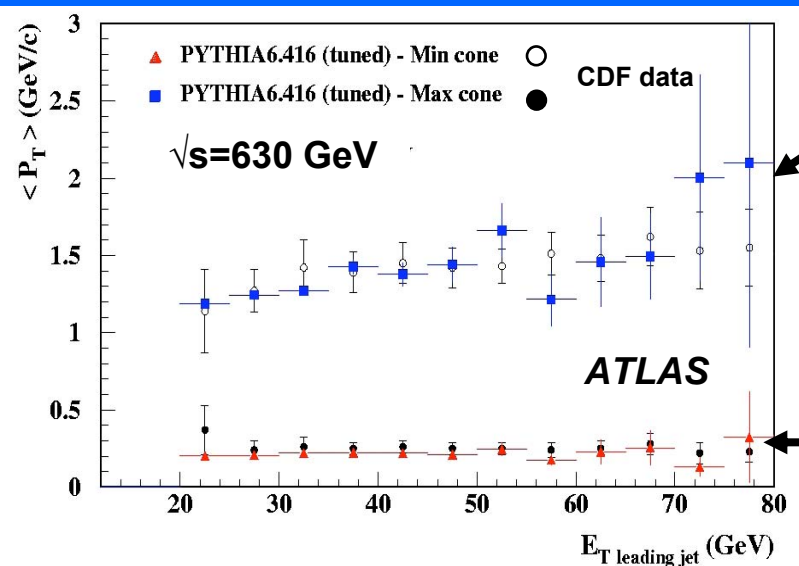
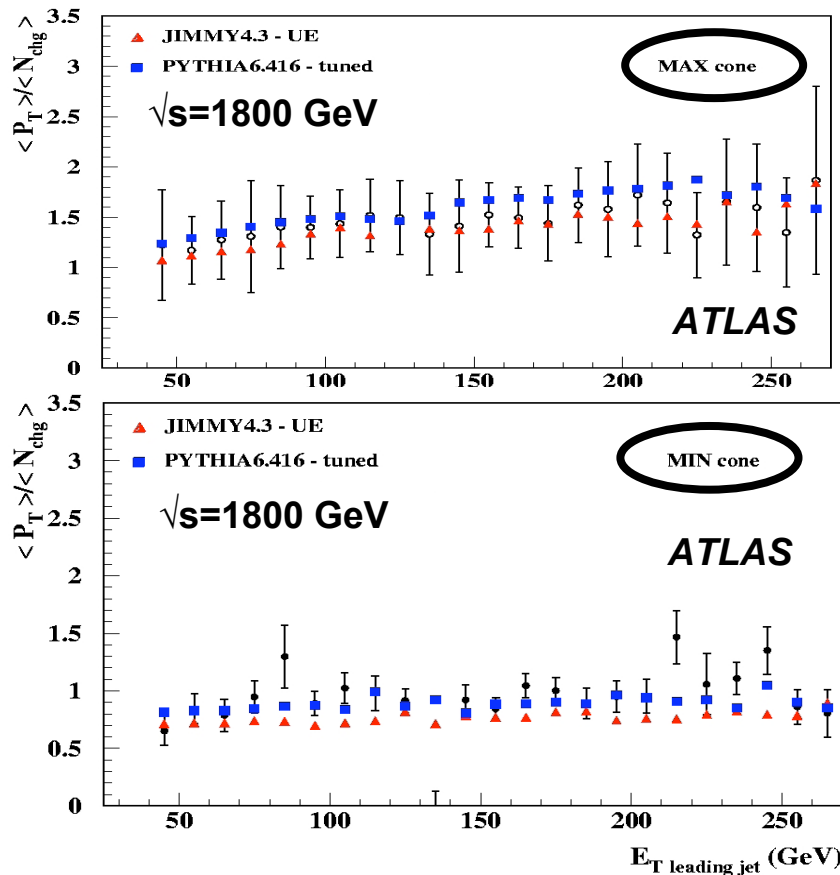
UE Energy Extrapolation

Comparison of PYTHIA(new-tune) to JIMMY in MAX/MIN regions

- Important to determine energy extrapolation of UE

• Extrapolate tuning at 1800 GeV to 630 GeV,

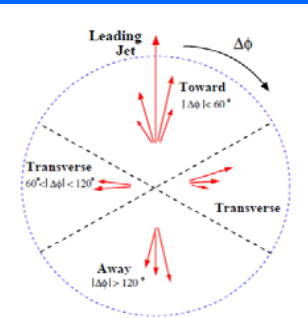
- Use MAX/MIN Analysis in Transverse Regions



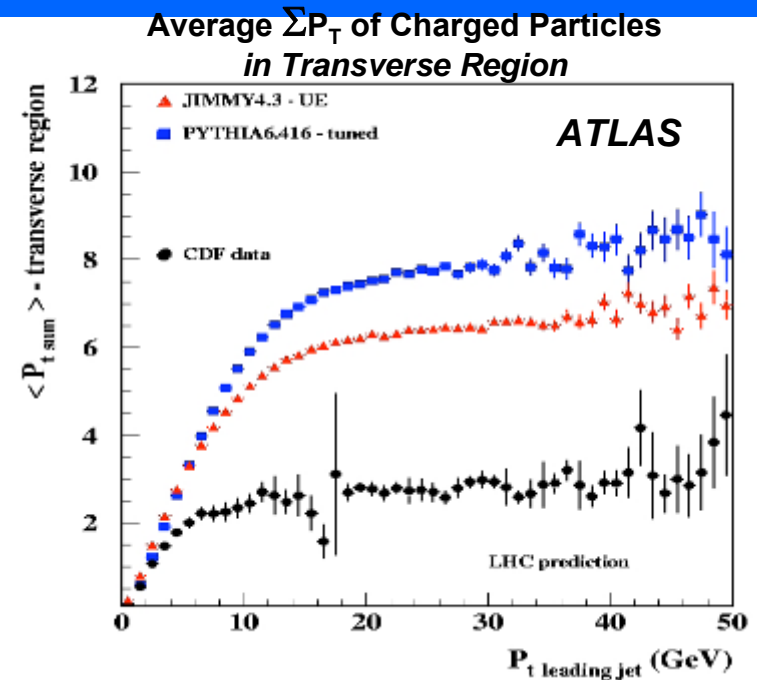
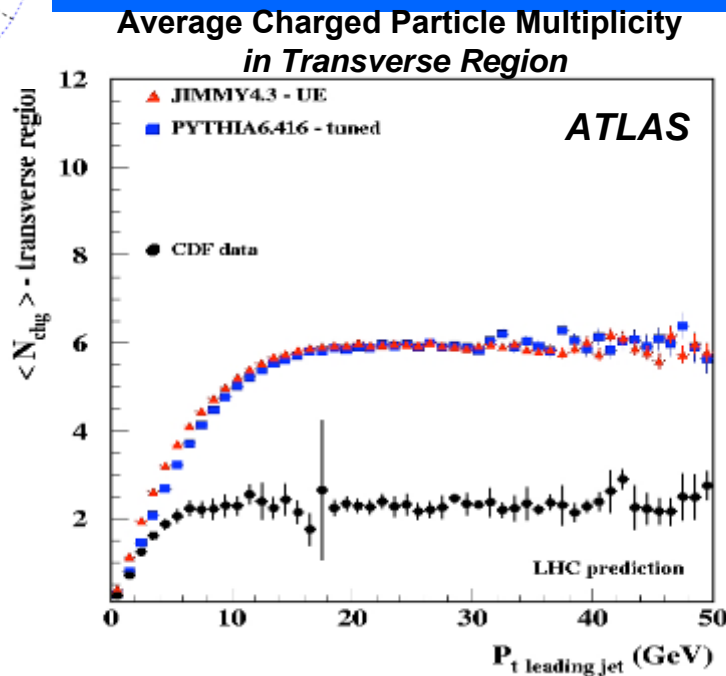
- Good agreement between PYTHIA-(new)Tune and Jimmy for both MAX/MIN Regions

- good extrapolation to lower energies

LHC Predictions at $\sqrt{s}=14$ TeV

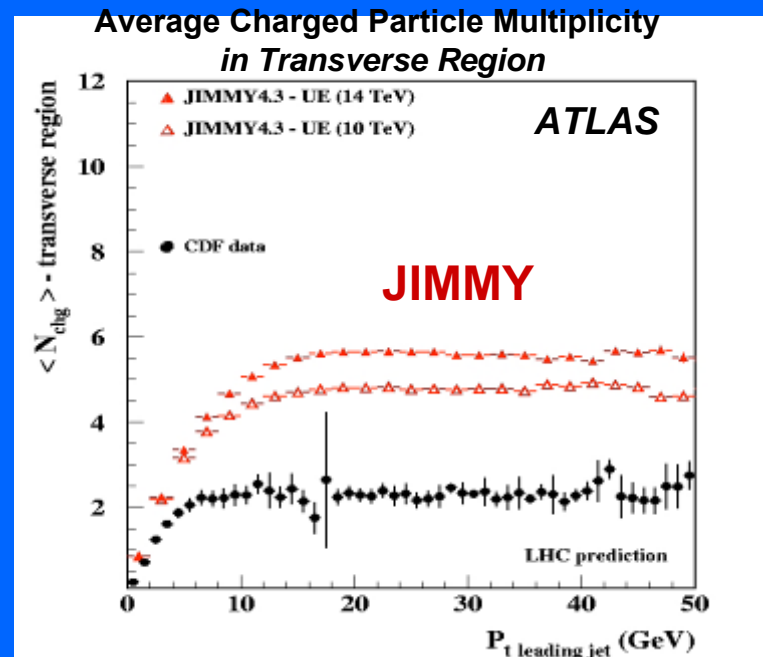
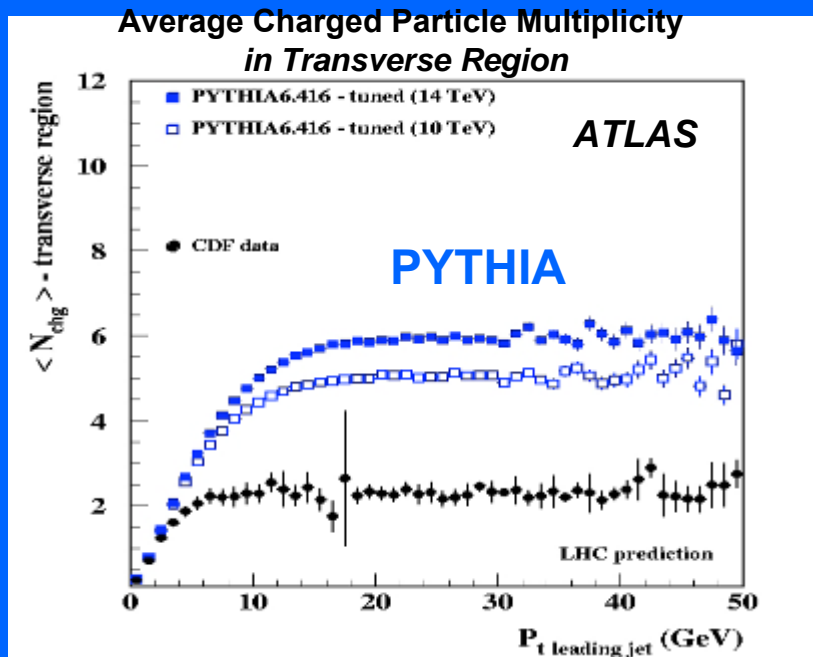


PYTHIA6.416-newTune vs Jimmy 4.3



- $\langle N_{\text{chg}} \rangle$ Predictions for LHC \rightarrow PYTHIA-newTune and Jimmy predict same particle density
- $\langle P_{\text{T sum}} \rangle$ Predictions for LHC \rightarrow PYTHIA-newTune predicts harder particles

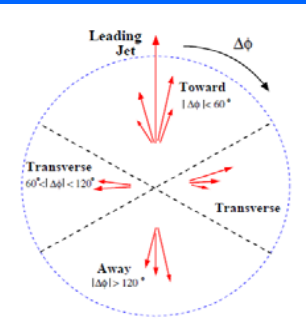
LHC Predictions at $\sqrt{s}=10$ TeV



Particle Density plateau at $\sqrt{s}=10$ TeV reduced by 16% wrt $\sqrt{s}=14$ TeV
1-10pb⁻¹ with minimum bias trigger probes to P_{T} -leading jet ~ 50 GeV

UE Reconstruction in ATLAS

ATL-PHYS-PUB-2005-015



Selecting the underlying event:

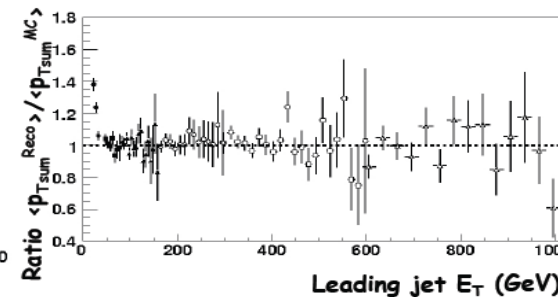
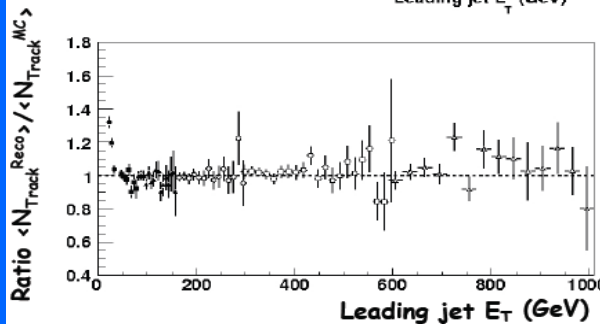
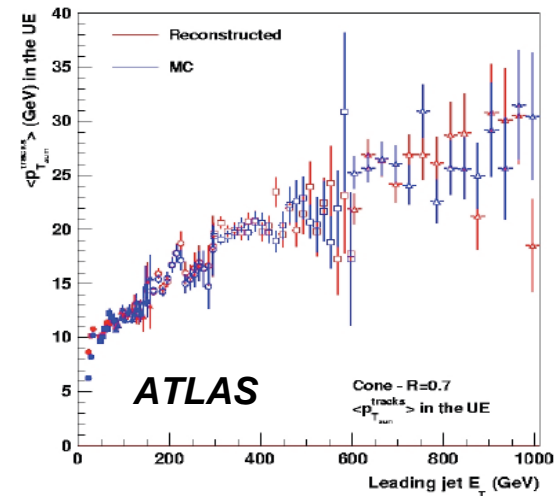
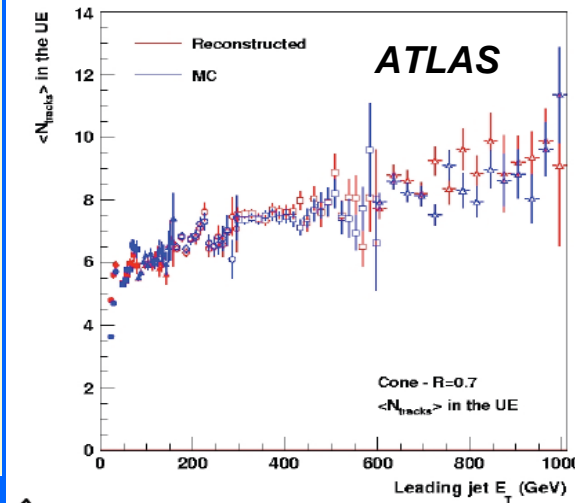
i. Jet events:

$$\begin{aligned} N_{\text{jets}} &> 1, \\ |\eta_{\text{jet}}| &< 2.5, \\ E_{\text{T,jet}} &> 10 \text{ GeV}, \end{aligned}$$

ii. Tracks:

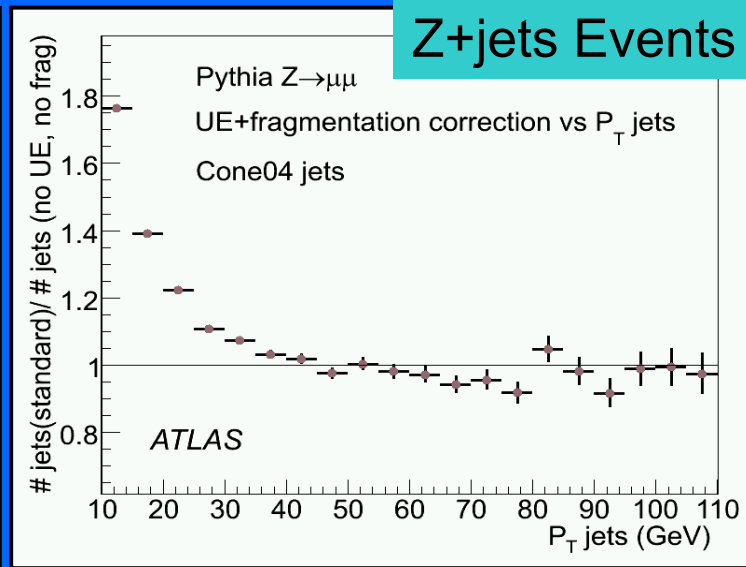
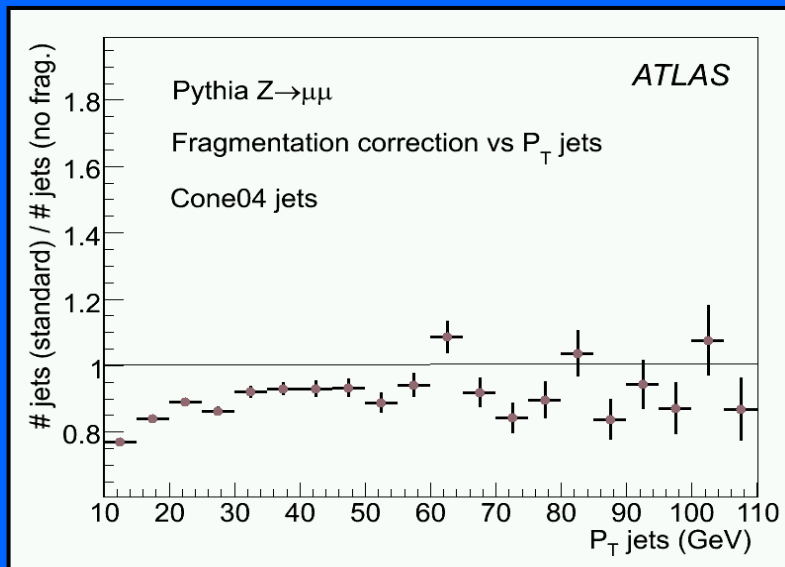
$$\begin{aligned} |\eta_{\text{track}}| &< 2.5, \\ p_{\text{T,track}} &> 1.0 \text{ GeV/c} \end{aligned}$$

ATLAS Reconstructed track distributions for the UE well reproduce the MC event generator predictions



Jet measurements of early data will extend considerably our knowledge of the UE

Effect of underlying event in jet reconstruction

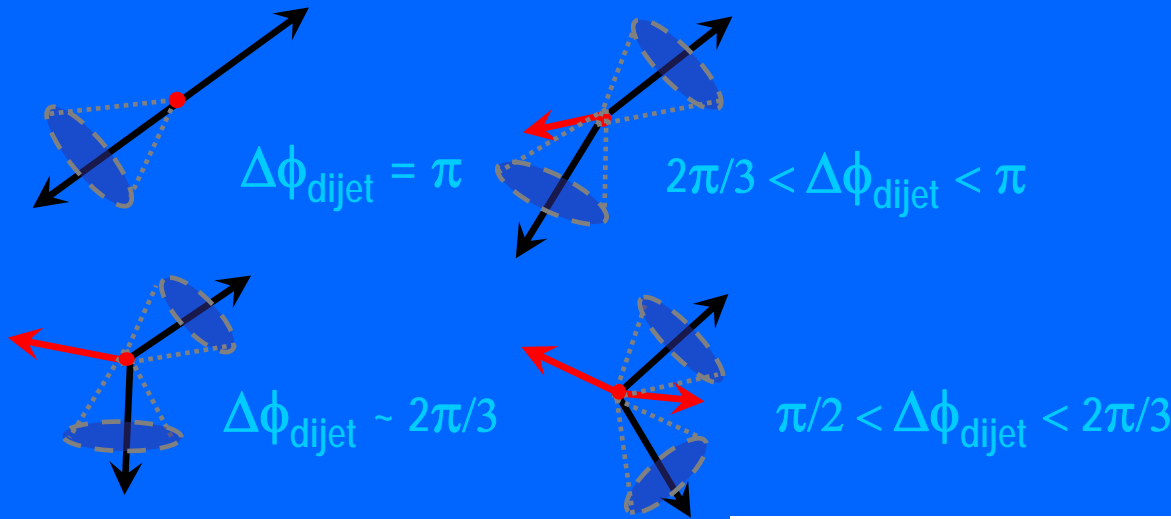


Fragmentation reduces the amount of energy in jet cone

UE adds energy to the hadron level jet

- Underlying event and fragmentation have the opposite effect
- Precise behaviour depends on the jet algorithm used
 - Frag. corrections for Cone DR=0.7 jets smaller than for Cone DR=0.4 jets, UE corrections larger due to the larger cone size
 - K_T D=0.4 shows the lowest combined corrections (Frag. and UE effects cancel out).
 - K_T D=0.6 jets is comparable to Cone DR=0.4 jets.
 - (Except for Cone DR=0.7 jets), non-perturbative effects are negligible for jets with $p_T > 40$ GeV (PYTHIA).

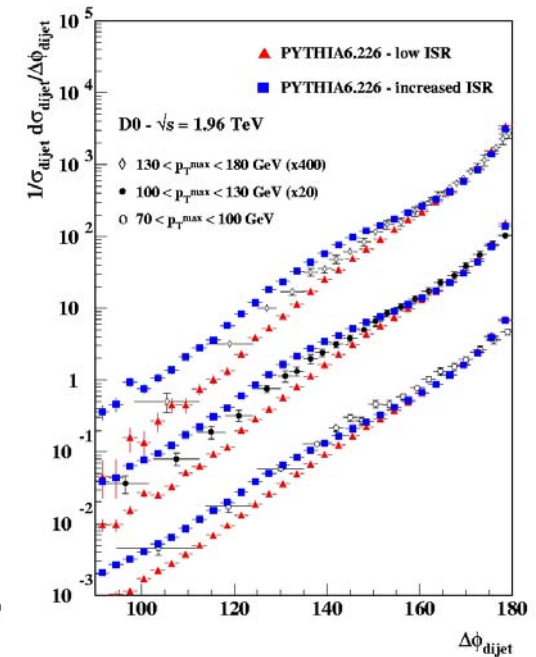
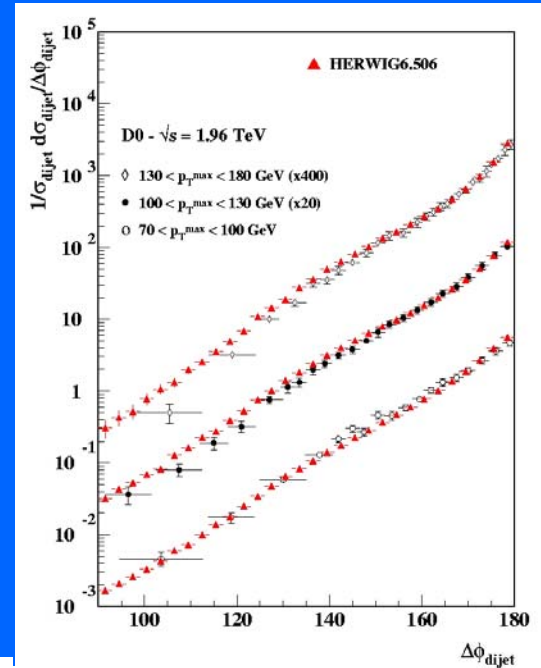
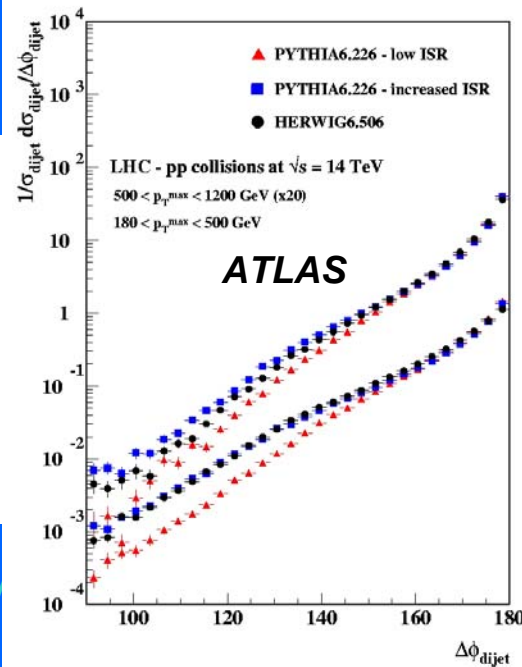
Azimuthal dijet decorrelation



Early measurement to benchmark generators particularly parton showers/higher orders

Early QCD measurements with

ATLAS-PHYS-PUB-2006-013



Reconstructed di-jet azimuthal decorrelations

Selecting di-jet events:

Cone jet algorithm ($R=0.7$)

$N_{\text{jets}} = 2,$

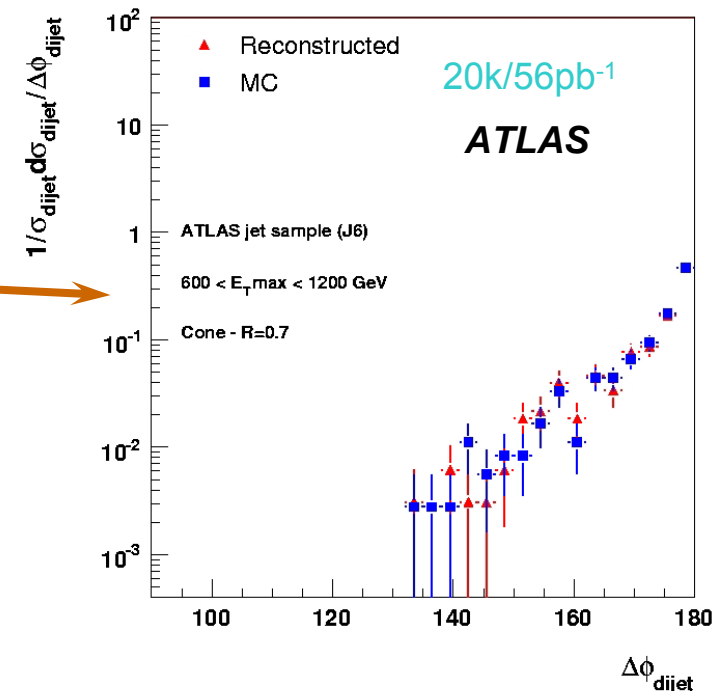
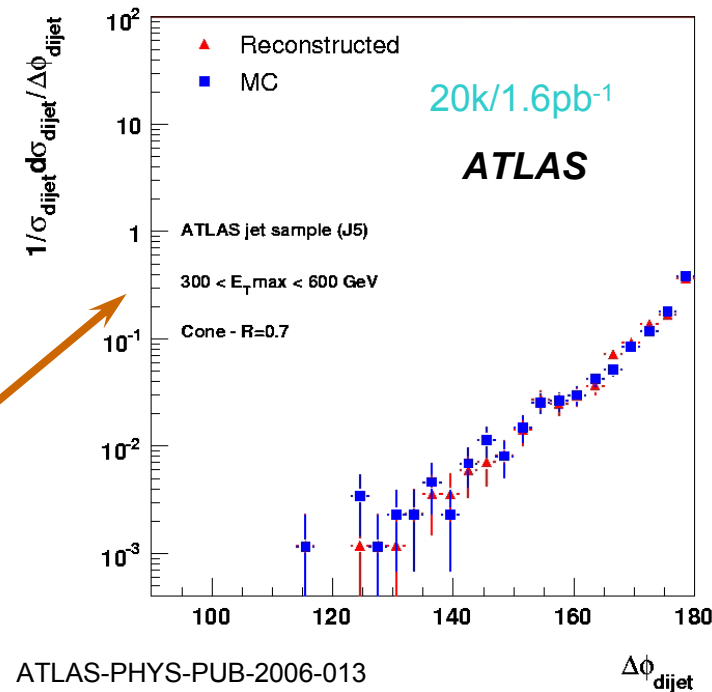
$|\eta_{\text{jet}}| < 0.5,$

$E_{\text{T}}^{\text{jet \#2}} > 80 \text{ GeV},$

Two analysis regions:

$300 < E_{\text{T}}^{\text{MAX}} < 600 \text{ GeV}$

$600 < E_{\text{T}}^{\text{MAX}} < 1200 \text{ GeV}$

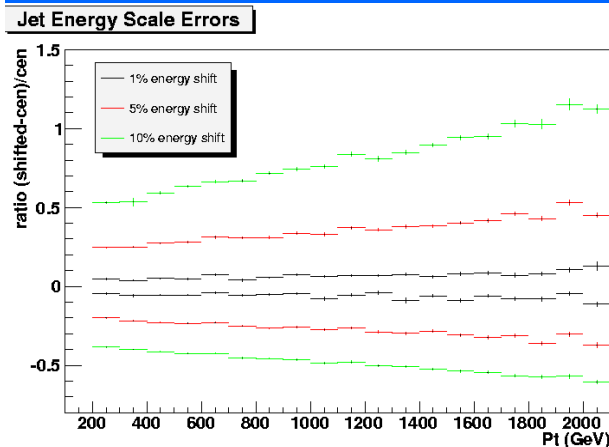
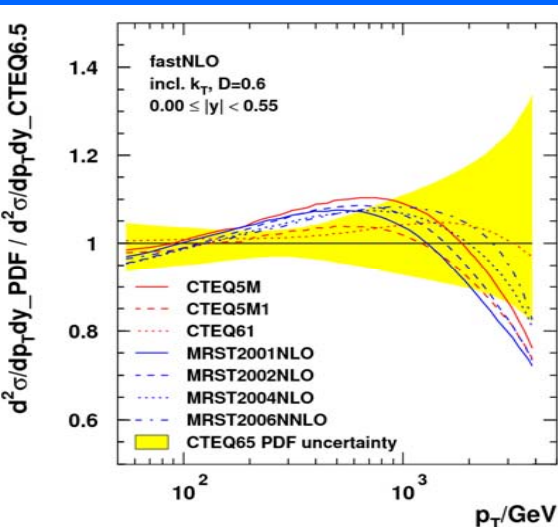


Jet cross-section and High-x gluon pdf

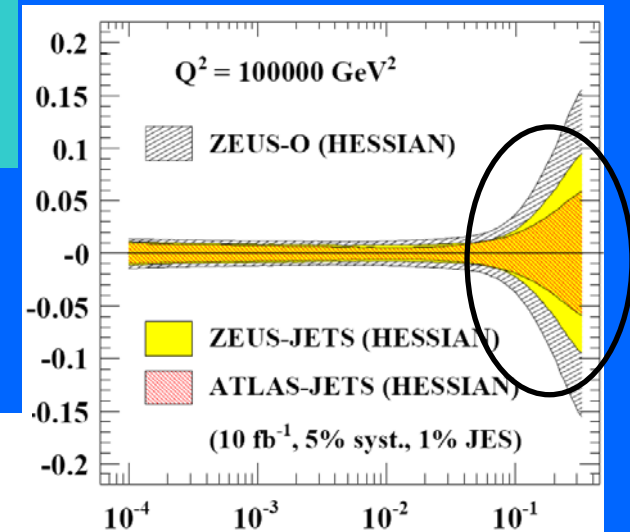
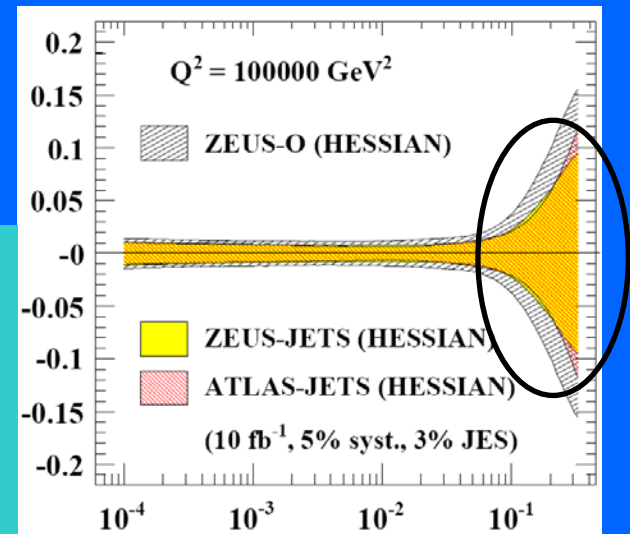
Jet cross-section theoretical uncertainty is dominated by high-x gluon pdf uncertainty

This limits the ability to search for new physics with high P_T jets

K. Rabbertz
4th LHC-HERA workshop



Gluon Fractional error

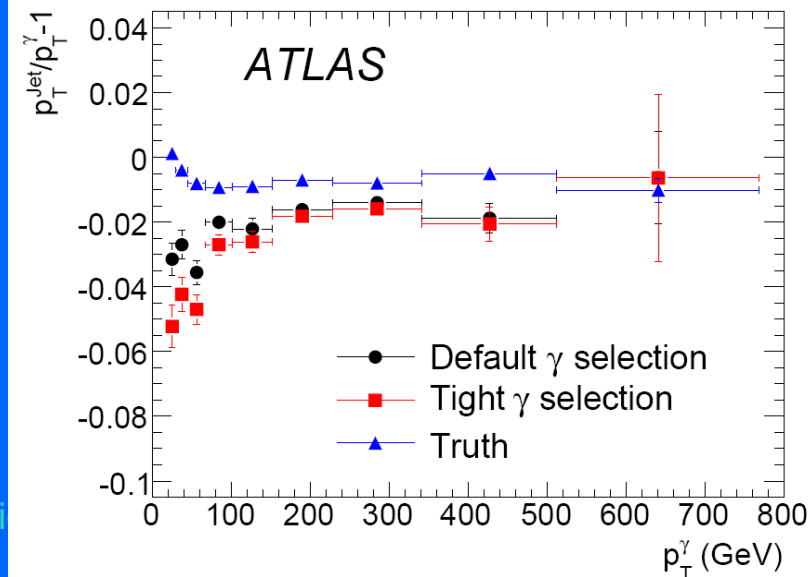
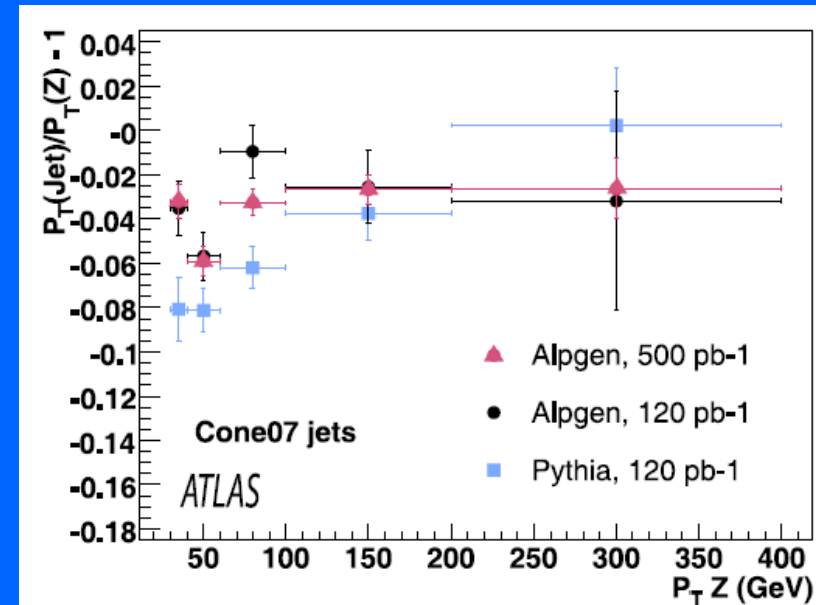


Biggest challenge is understanding jet energy scale for high P_T jets

Determining the jet energy scale

Determine jet-energy scale (JES) uncertainty using in-situ methods

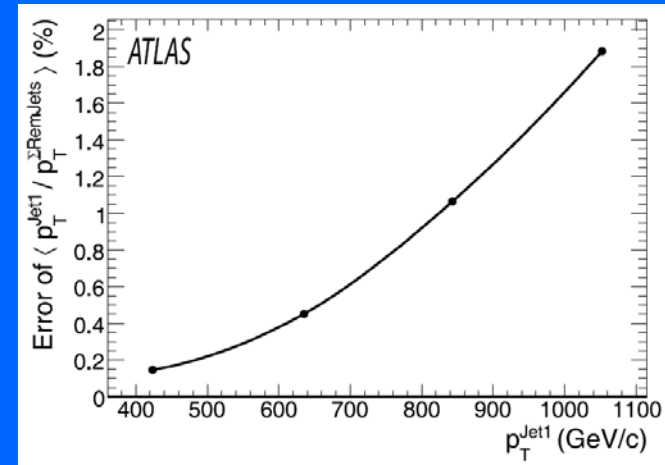
- Z-jets
 $10\text{GeV} < P_t < 100\text{-}200\text{GeV}$
 1% statistical uncertainty on JES with 300pb^{-1}
 Systematics: ISR/FSR+UE $\sim 5\text{-}10\%$ at low P_t , reducing to 1-2% for $P_t \sim 100\text{-}200\text{GeV}$
- γ -jets
 $100\text{-}200 < P_t < 500\text{GeV}$
 1-2% statistical uncertainty on JES with 100pb^{-1}
 systematics from physics effects:
 ISR/FSR+UE $\sim 1\text{-}2\%$



Jet energy scale

$P_t > 500\text{GeV}$

- Use multi-jet P_t -balance: balance low- P_t jets with known JES against high-pt jet with unknown JES
- Statistical uncertainty $\sim 2\%$ for 1fb^{-1}
- Systematics: JES uncertainty on low energy jets $P_t > 40\text{GeV} \sim 7\%$ for $400\text{--}1100\text{GeV}$
- So total uncertainty is $\sim 8\%$ dominated by low energy JES
- Makes measurement of high-x gluon pdf “challenging”
- Dominated by physics effects that may be better understood with data?



$$B'_\Sigma = \frac{p_T^{\text{jet1}}}{\text{non-leading jets } |\Sigma p_T|}$$



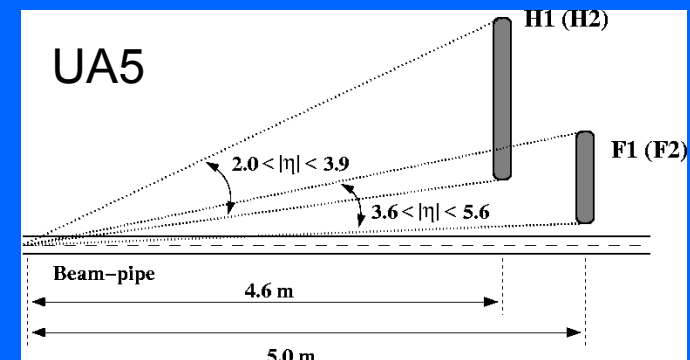
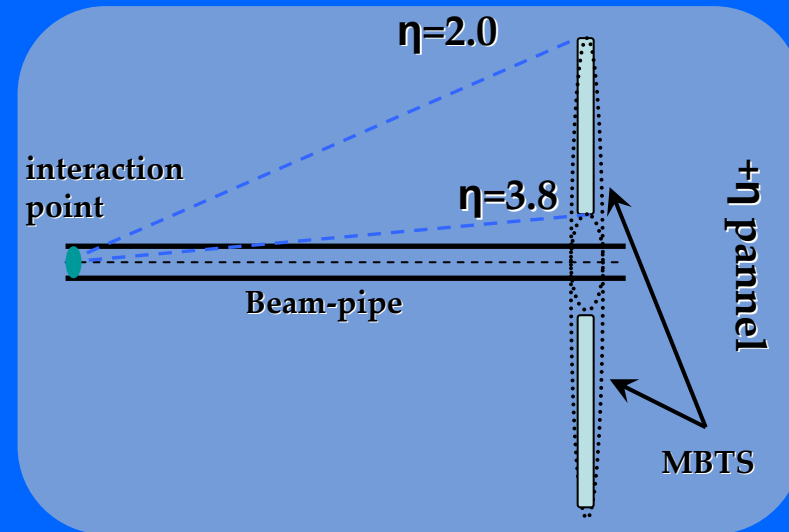
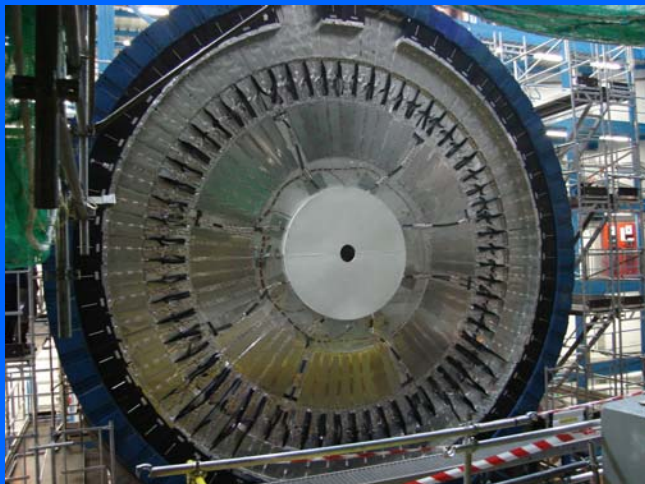
Summary and Conclusions

- Minimum bias distributions can be measured and compared to previous NSD data and can discriminate between models
- Underlying event models have been tuned using tevatron data for current physics studies
- Underlying event can be measured with early data and can discriminate between models
- Comparisons of underlying event and minimum bias data will allow the energy evolution of the soft processes to be measured
- Understanding the underlying event is important for jet reconstruction
- Azimuthal decorrelations can be used to benchmark Monte Carlos with early data
- Jet energy scale for high- P_t jets is challenging but can be improved with data
 - Extrapolation of jet energy scale to high P_t jet is limited by the understanding of low P_t jets
 - Measurements of underlying event and ISR/FSR from early data will help to improve this
- Thank you for your attention

Extra slides

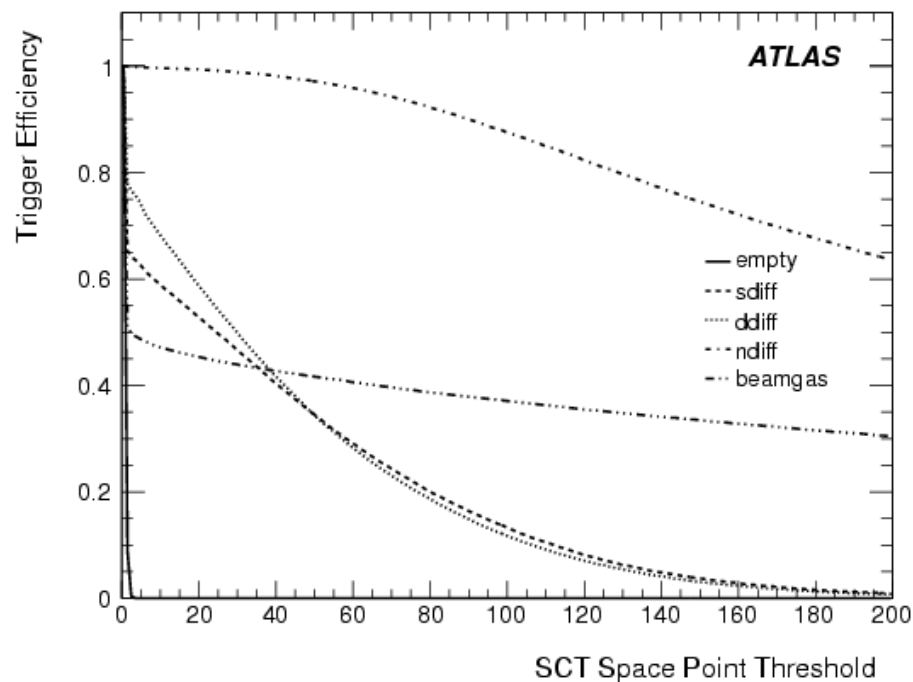
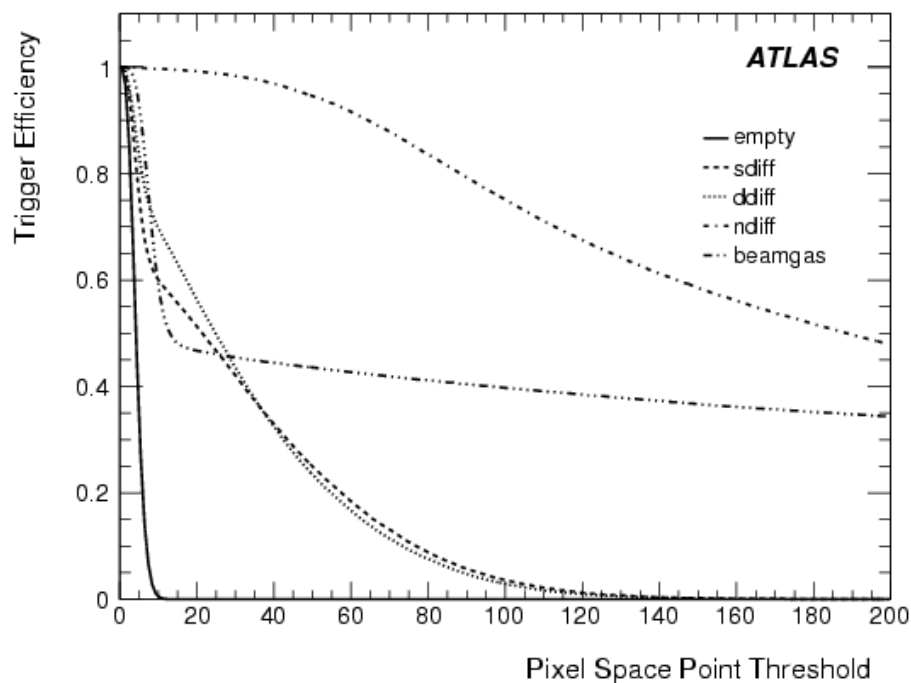
MBTS

- Trigger scintillation counters mounted on end of LAr calorimeter covering same radii as ID
 - Cover $2 < |\eta| < 4$
- Can be used for first data BUT!
 - Not rad-hard
 - Uses 1/8th of tilecal readout
 - Lifetime unknown
- At L1 S/N is 'modest'
 - Now in simulation can be tuned to measurement in the summer
- Can do better at L2 with precision readout



Inner Detector Trigger at L2

L1 random trigger



Use pixel and SCT spacepoints to
reject empty events
Empty:Interaction ~ 94:6
Still have large beamgas contribution

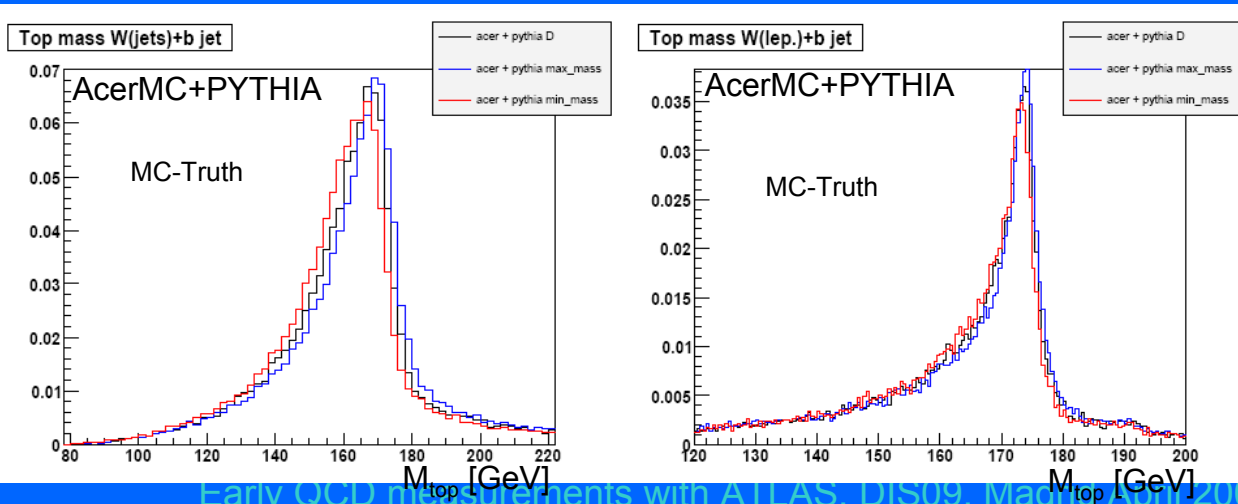
Top Physics – $t\bar{t}$

Main goal, so far, has been to estimate uncertainties on reconstructed top parameters from UE (MPI) and ISR/FSR (coupled together)

- variations on UE, ISR/FSR affect observables on which selections cuts are applied: jet multiplicity, particles p_T etc.
- potentially a serious impact on top reconstructed parameters (e.g. M_{top} , $\sigma_{t\bar{t}}$)

❑ ISR and FSR PYTHIA parameters have been varied to give smallest and largest values of reconstructed top mass

- ❑ Max ISR, Min FSR ($\Lambda_{ISR} * 2$, ISR cutoff $-0.5 * \text{ISR cutoff}$, $\Lambda_{FSR} * 0.5$) → Max M_{top}
- ❑ Min ISR, Max FSR ($\Lambda_{ISR} * 0.5$, ISR cutoff $+0.5 * \text{ISR cutoff}$, $\Lambda_{FSR} * 2$) → Min M_{top}
- ✓ up to ~10% change in the Selection Efficiency from Min-Max M_{top} samples
- ✓ contributing ~10% on syst. uncertainty on early data $\sigma_{t\bar{t}}$
- ✓ visible effect on reconstructed M_{top} :
 - ✓ MC-Truth: ~5 GeV (hadronic M_{top}) and ~1-2 GeV (leptonic M_{top})



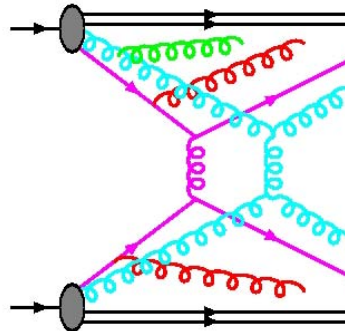
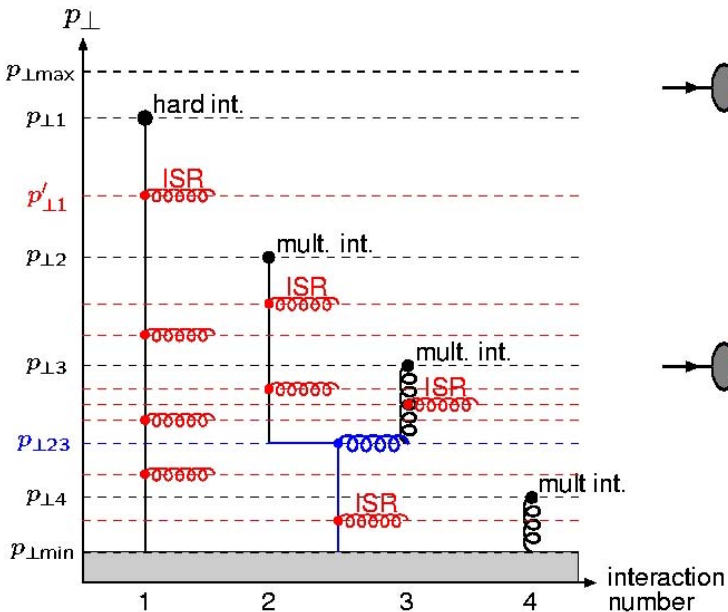
PYTHIA Params

- max. mass:
parp(61)=0.384, mstp(70)= 0 and
parp(62)=1.0, parj(81)=0.07
- min. mass:
parp(61)=0.096, mstp(70)=0 and
parp(62)=3.0, parj(81)=0.28.

MC-level Plots
For semi-leptonic $t\bar{t}$ events
(Cone $\Delta R=0.4$ truth jets)

New underlying event model: PYTHIA6.3

Interleaved Multiple Interactions



(hep-ph/0408302, hep-ph/0308153 and JHEP 03(2004) 053)

Why do we need a new UE model?

- hadron collisions are complex. Present models need to be improved! (more detail & more precision)
- extrapolations to the LHC energies require better physical insight. Simple parametrization is not enough!
- uncertainties in UE predictions for the LHC impact on cuts applied to possible discovery channels.

- New *ISR* and *FSR* parton showers
- new *model for multiple parton-parton interactions*
- description of parton showers & MPI has been unified