ATLAS studies of diffraction, soft particle production and double parton scattering.

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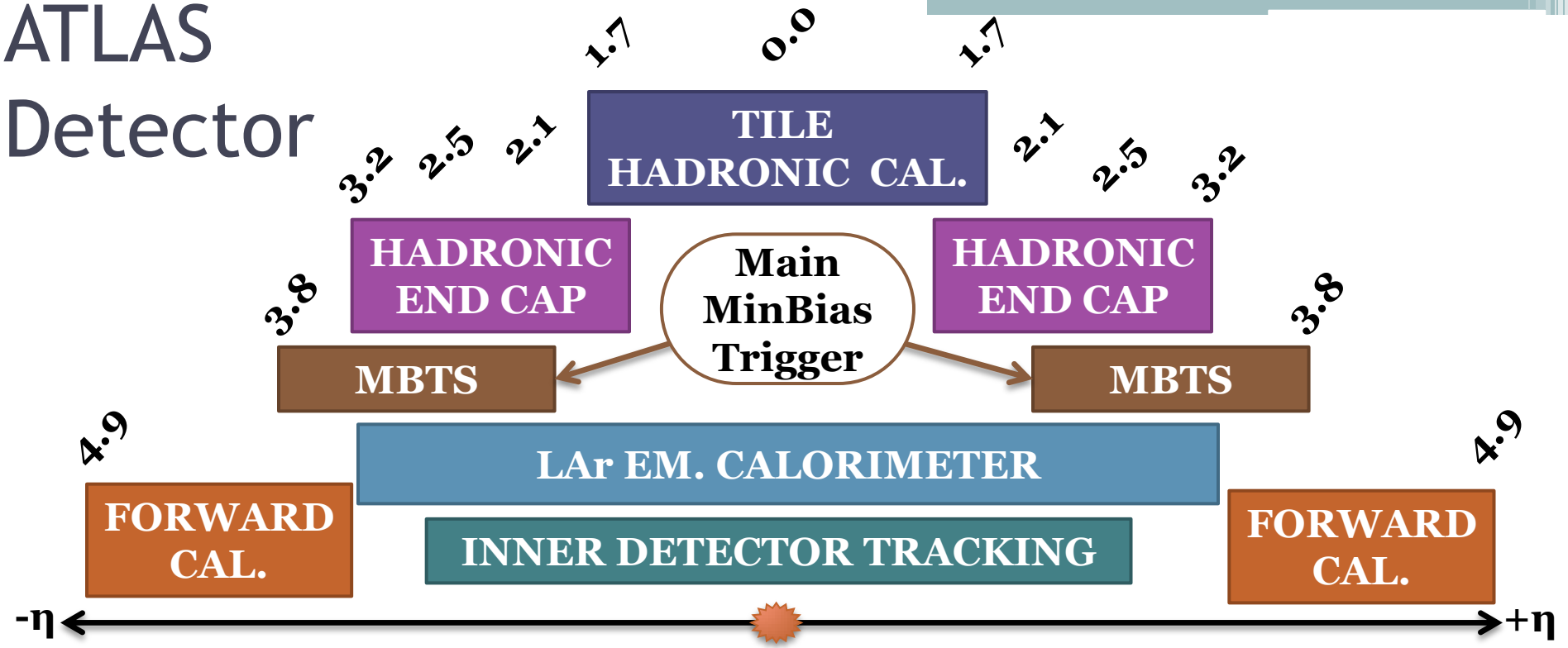
On behalf of the ATLAS Collaboration

UNIVERSITY OF BIRMINGHAM

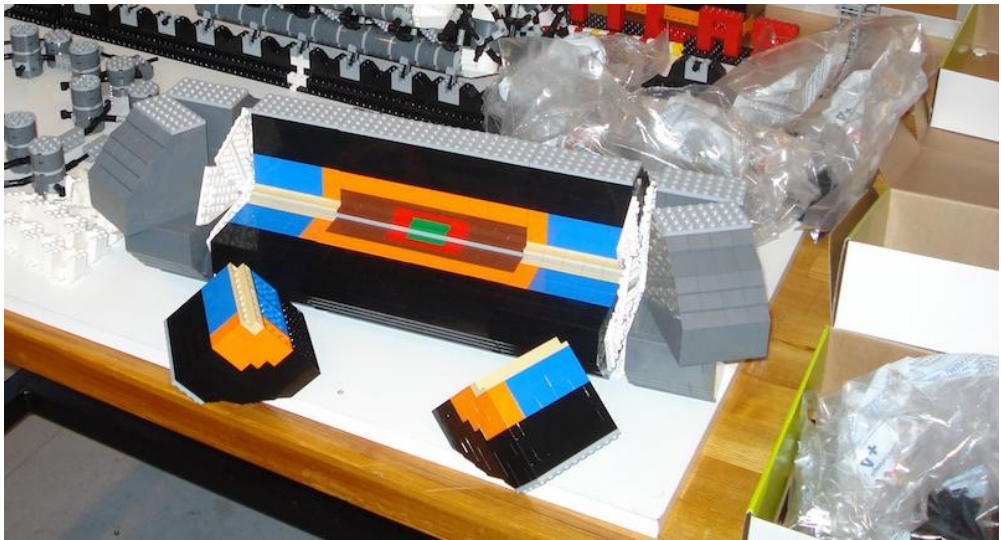
Overview


Inelastic & Diffractive Cross Sections
Forward-Backward Correlations
Azimuthal Correlations
Track Jet Underlying Event
NeW!
NeW!
Transverse Energy Flow
Event Shapes
NeW!
Double Parton Interactions in W → lν + 2 jet
Azimuthal Ordering
Λ Properties & Two Particle Correlations

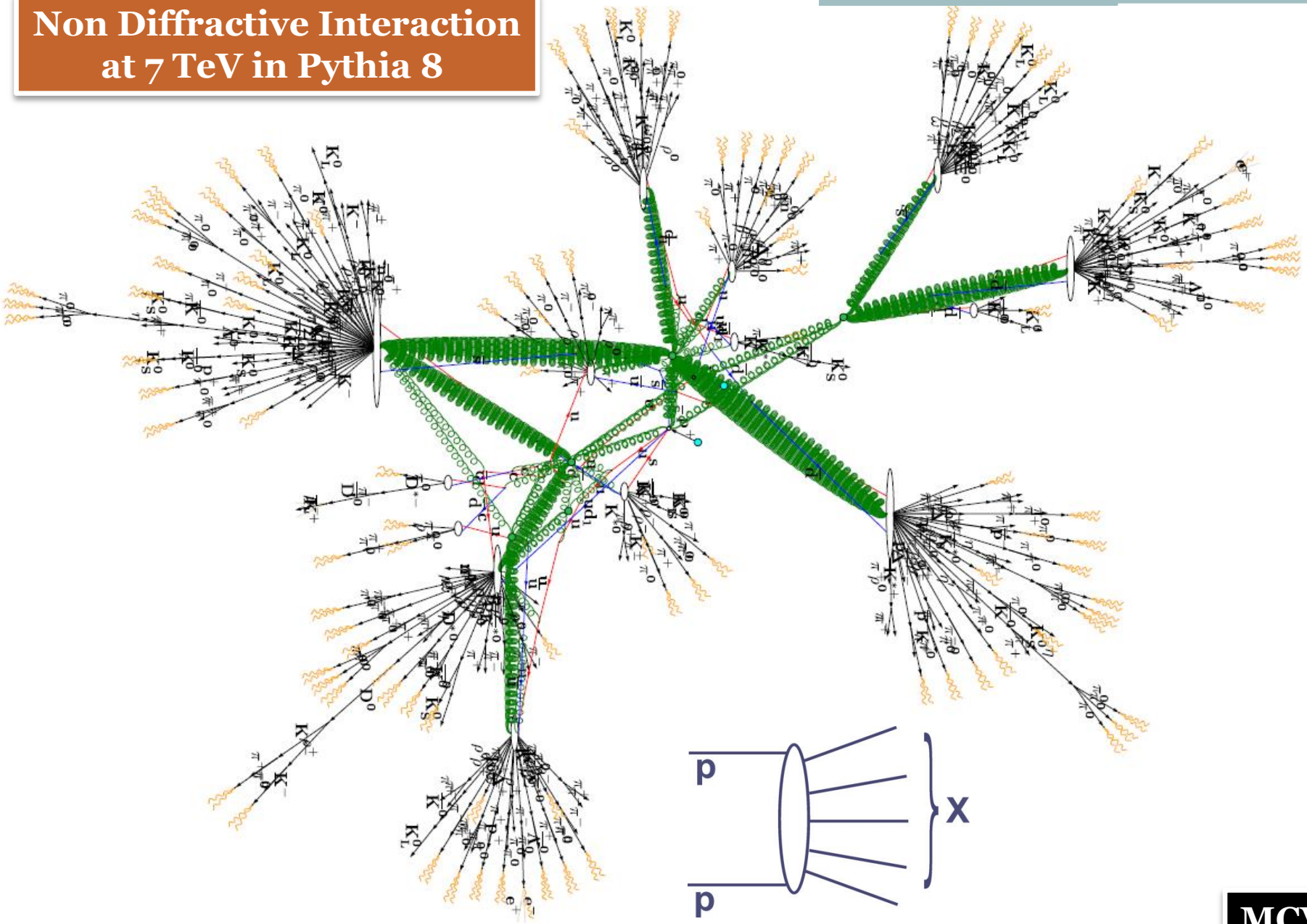
ATLAS Detector



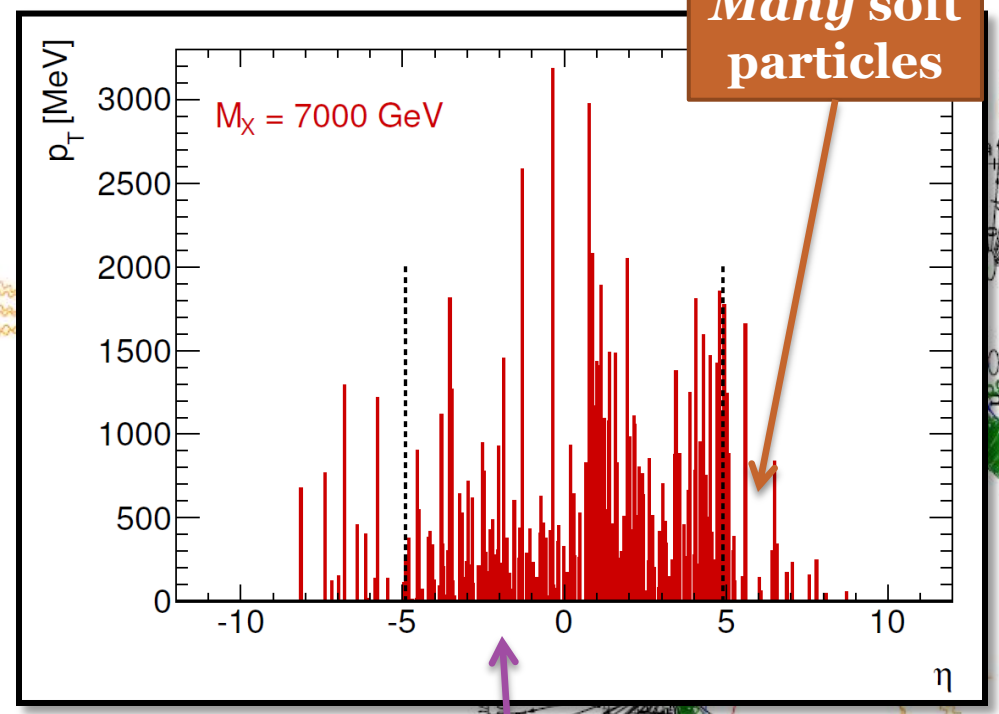
Following analyses use a combination of Inner Detector Tracking and ATLAS calorimetry.



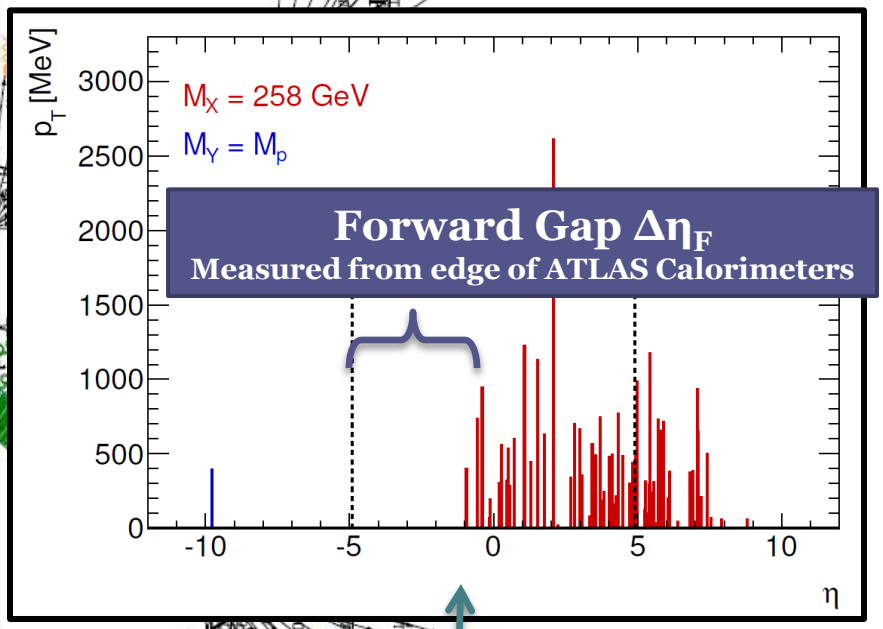
Non Diffractive Interaction at 7 TeV in Pythia 8



MCViz



***Many* soft particles**



Forward Gap $\Delta\eta_F$
Measured from edge of ATLAS Calorimeters

~75% of all inelastic interactions at the LHC are non-diffractive.

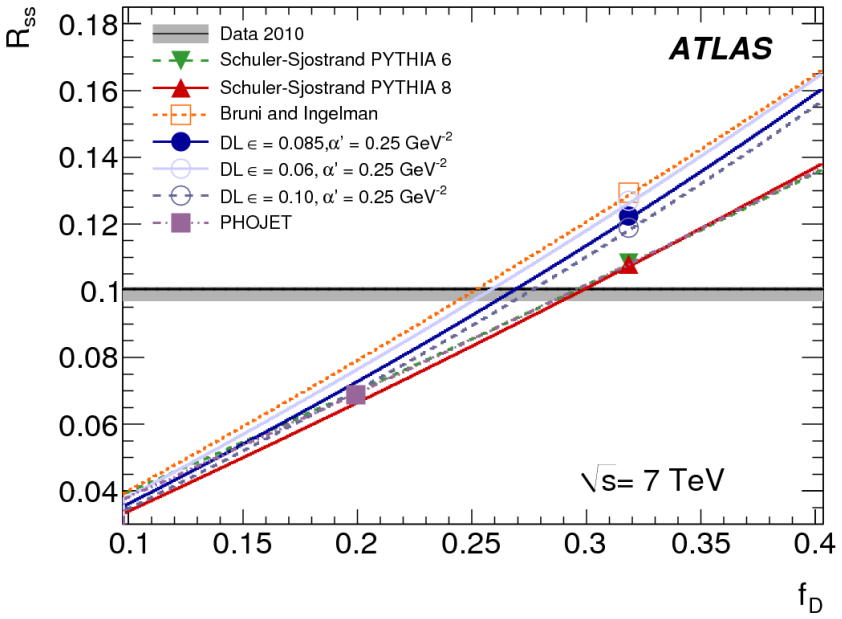
~25% of the time the inelastic interaction is *diffractive* which can result in a characteristic rapidity gap.

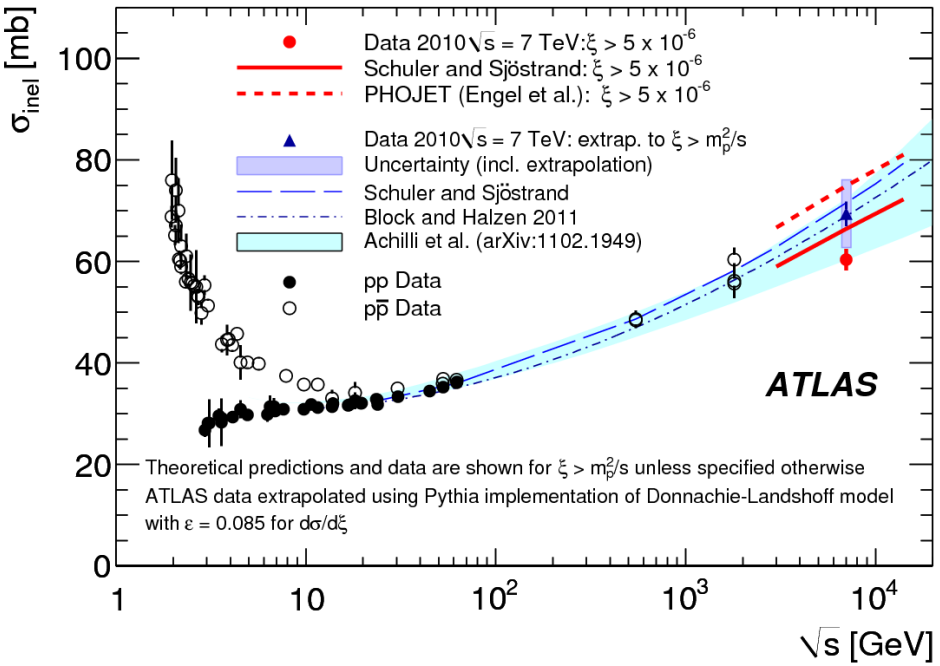
$\sigma_{Inelastic}$

- **Inelastic *pp* cross section** measured over acceptance of **ATLAS Minimum Bias Trigger Scintillators**.

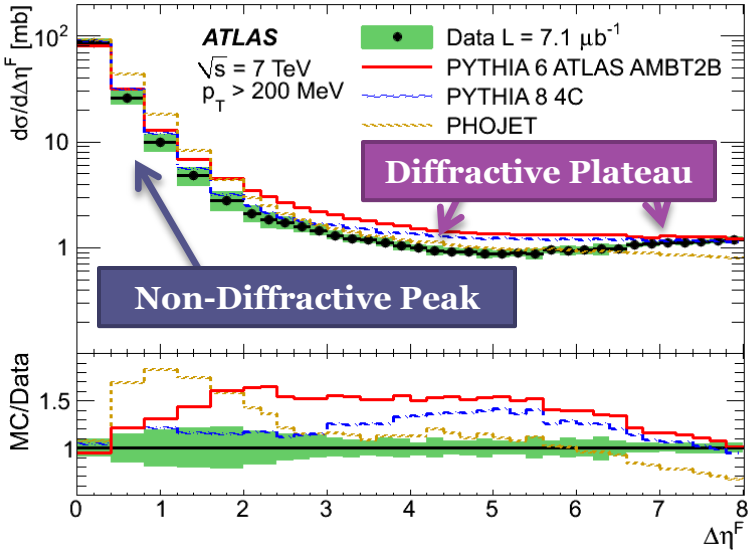
$\sigma_{inel.}$ = 69.4 ± 2.4(exp.) ± 6.9(extrap.)

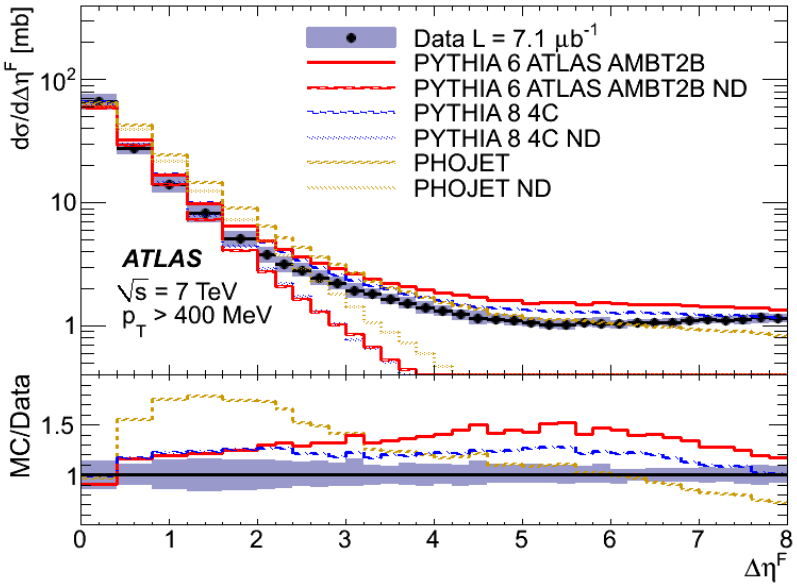
- **MC model uncertainty** dominates **extrapolation to full phase space**.
- Also measured the ratio of **exclusively single sided MBTS** triggered events.
- Sensitive to the magnitude of the **diffractive component**.

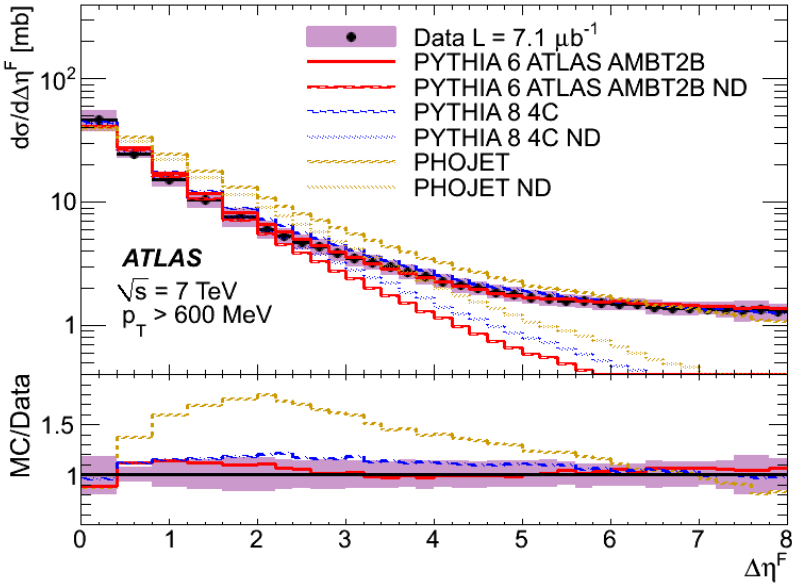


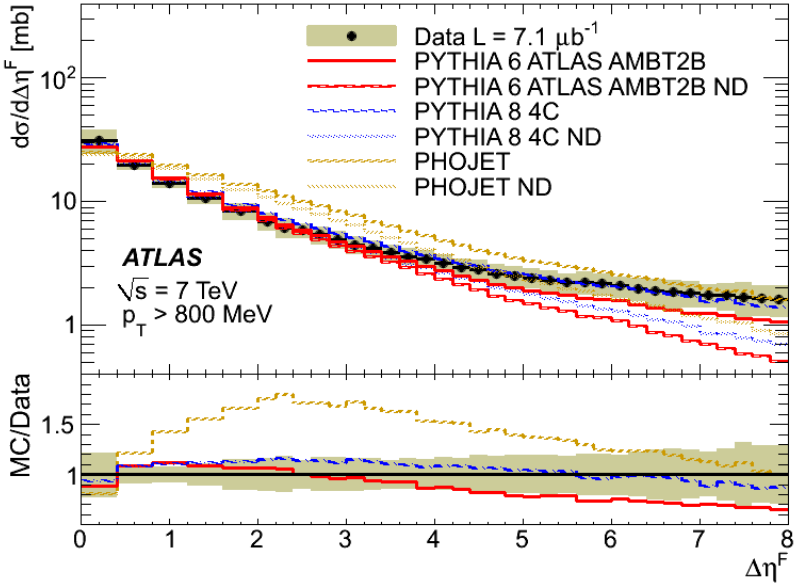


$\sigma_{Inelas.}$ as a function of $\Delta\eta^F$









$\Delta\eta_F$ = largest, empty η interval from edge of detector at η=±4.9

Corrected to charged & neutral particles p_T > 200, 400, 600 & 800 MeV

Bayesian unfolding technique

Particle Correlations

- **Forward-Backward** multiplicity and p_T correlations in η.

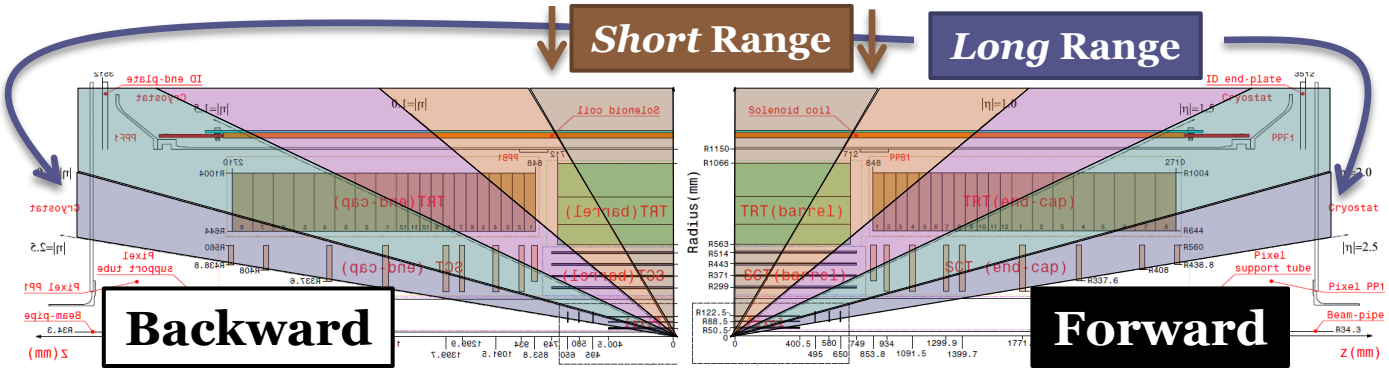
Deviation of fwd(bkwd) multiplicities from their mean.

Sum over events

$$\rho^n_{fb} = \frac{\sum x^n_f x^n_b}{N \sigma^n_f \sigma^n_b}$$

N Events

Standard deviation of fwd(bkwd) distributions about their mean.



ρ^n_{fb} = in a forward-backward η region is the normalised covariance between the two distributions, relative to the mean value of each.

Deviation of fwd(bkwd) scalar p_T sum of all accepted tracks from their mean.

$$\rho^{p_T}_{fb} = \frac{\sum x^{p_T}_f x^{p_T}_b}{N \sigma^{p_T}_f \sigma^{p_T}_b}$$

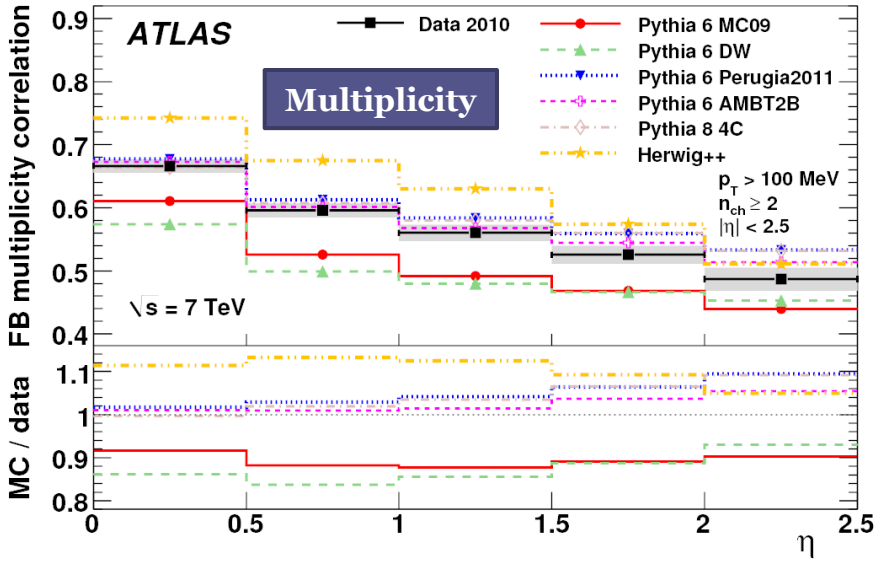
Detector level distributions are corrected to the hadron level using linear regression technique with different MC models.

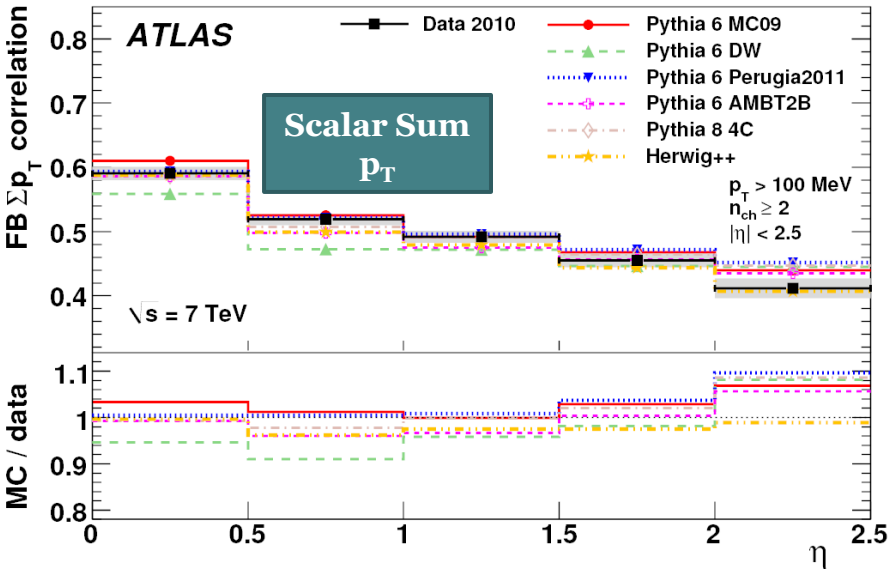
$$\rho_{had} = \alpha + \beta \rho_{det}$$

Trigger & Vertex Eff. : α = 0.07±0.03

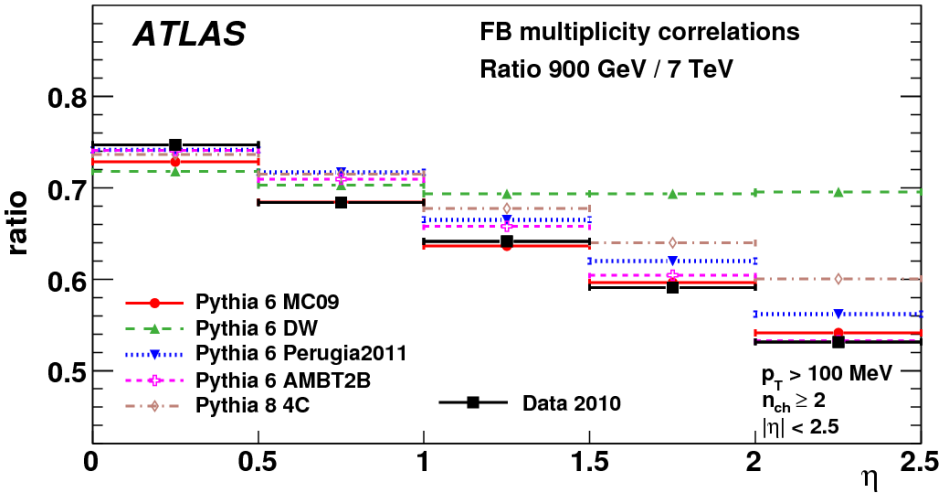
Track Reconstruction Eff. : β = 0.96-0.97

Results for ρ^{n}_{fb} & $\rho^{p_T}_{fb}$

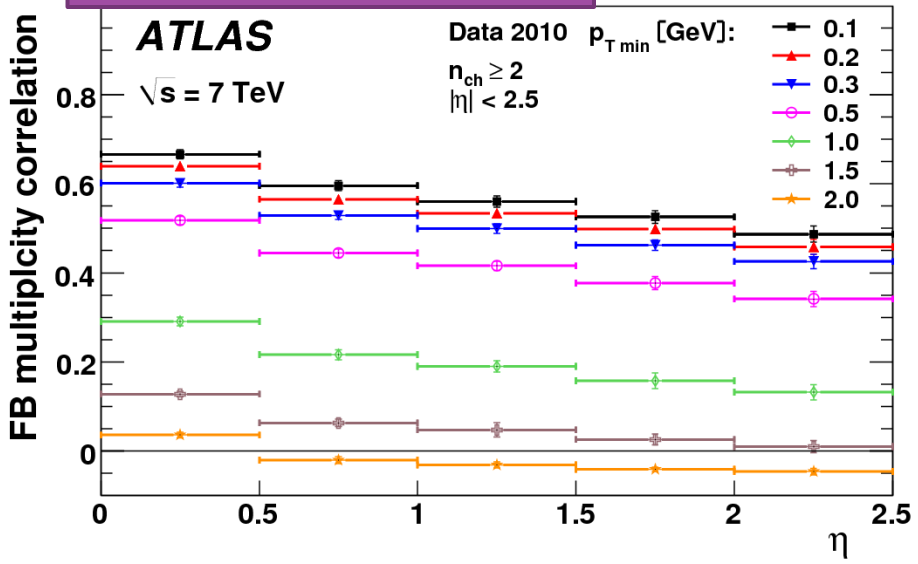




Centre of mass dependence

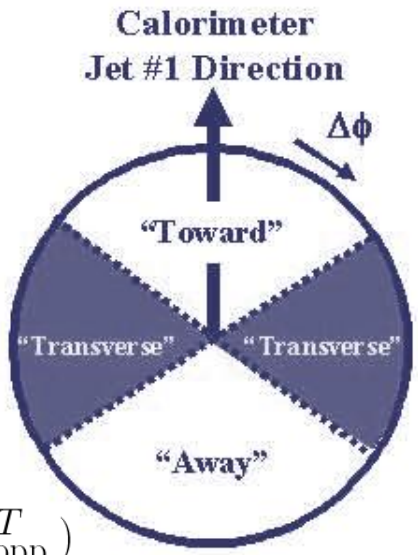


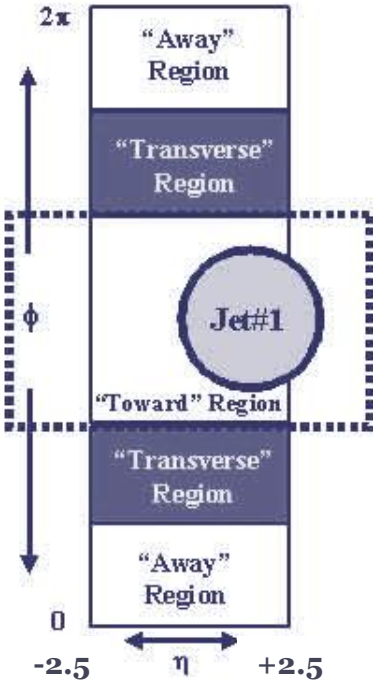
Minimum p_T dependence



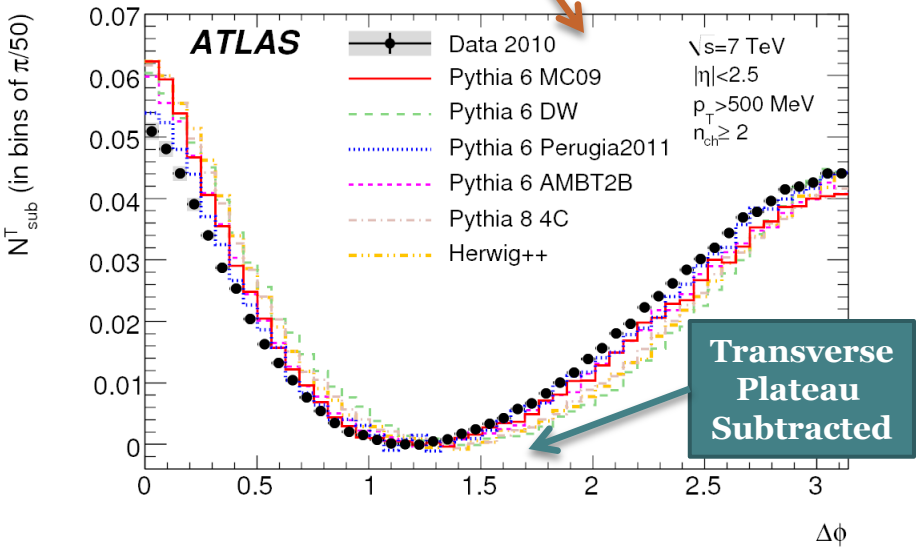
Azimuthal Correlations

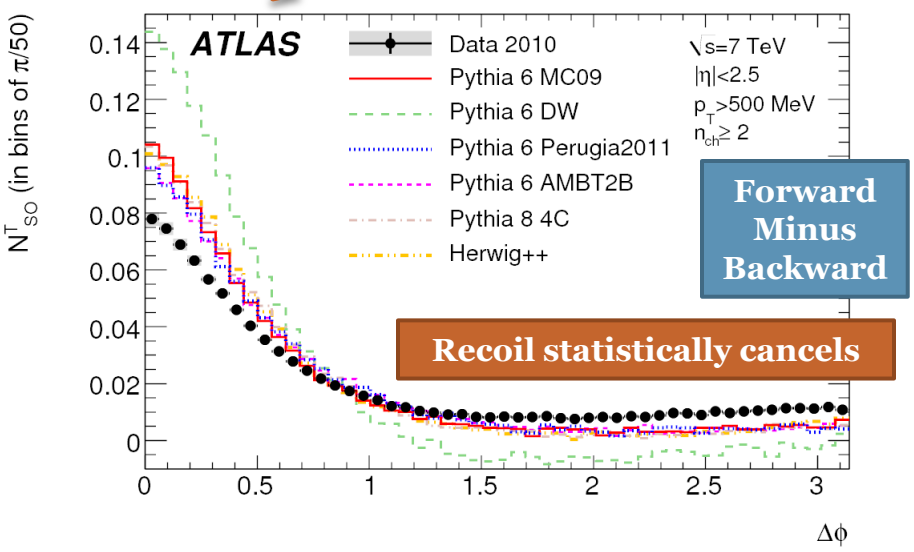
- Investigated as a function of η **region** and **fwd/bkwd correlation**.
- Primarily looking at the `**toward**' region.
- **Subtract** away the `**transverse**' region plateau for **data and MC**.
- The difference **Δφ** is plotted here vs. the **leading** (highest p_T) **track** in the event.





$$N^T_{sub} = \frac{(N^T - N^T_{min})}{\sum_{\text{Bins}}(N^T - N^T_{min})} \qquad N^T_{SO} = \frac{(N^T_{\text{same}} - N^T_{\text{opp.}})}{\sum_{\text{Bins}}(N^T_{\text{same}} - N^T_{\text{opp.}})}$$





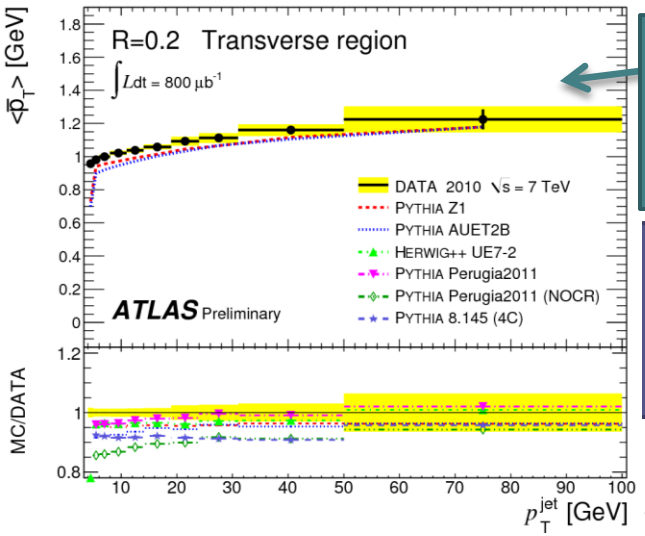
NeW!

Track-jet Underlying Event

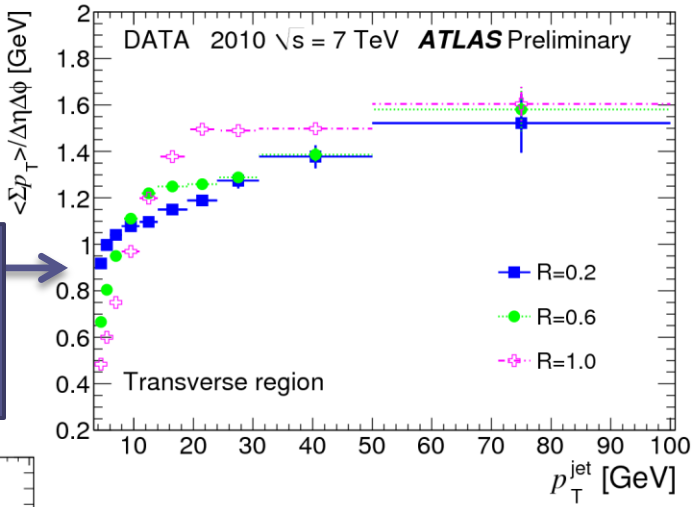
Huge quantity of tuning data, much too much to show here.

- **N_{ch}, $\Sigma|p_T|$ and $\langle p_T \rangle$. Plus as a function of p_T^{jet} in the range $4 < p_T^{Jet} < 100$ GeV**
- **For Anti-k_T Track jets with R = 0.2, 0.4, 0.6, 0.8, 1.0**
- **In the *Transverse* and *Away* regions.**

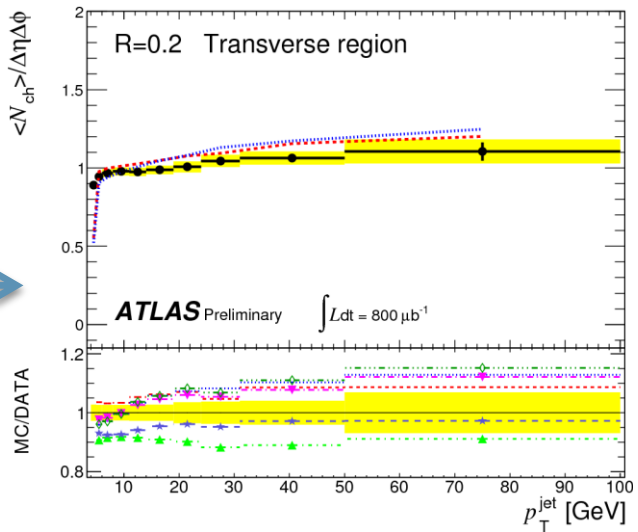
Average of mean p_T as function of p_T^{Jet} for R=0.2

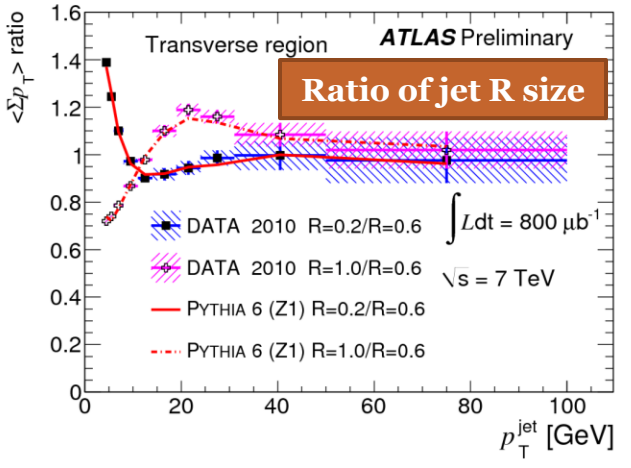


Average of Sum p_T per unit (η,φ) as function of p_T^{Jet} for R=0.2-1.0



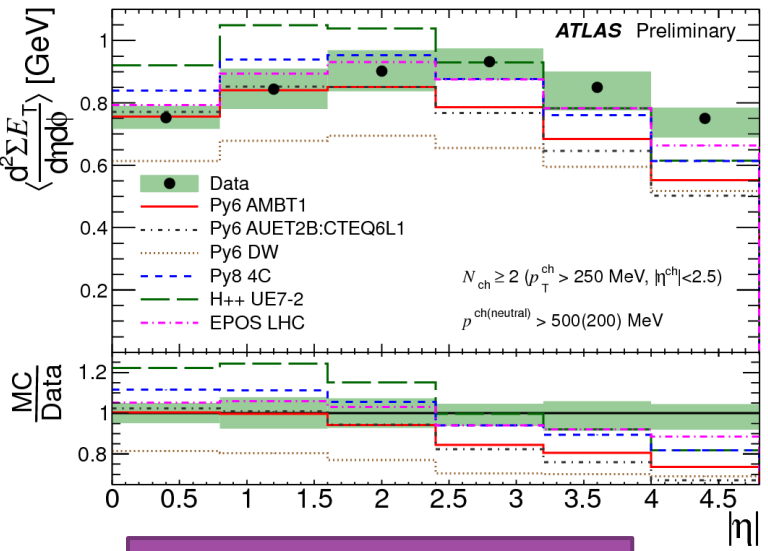
Average of N_{ch} per unit (η,φ) as function of p_T^{Jet} for R=0.2





NeW!

Differential Transverse Energy Density

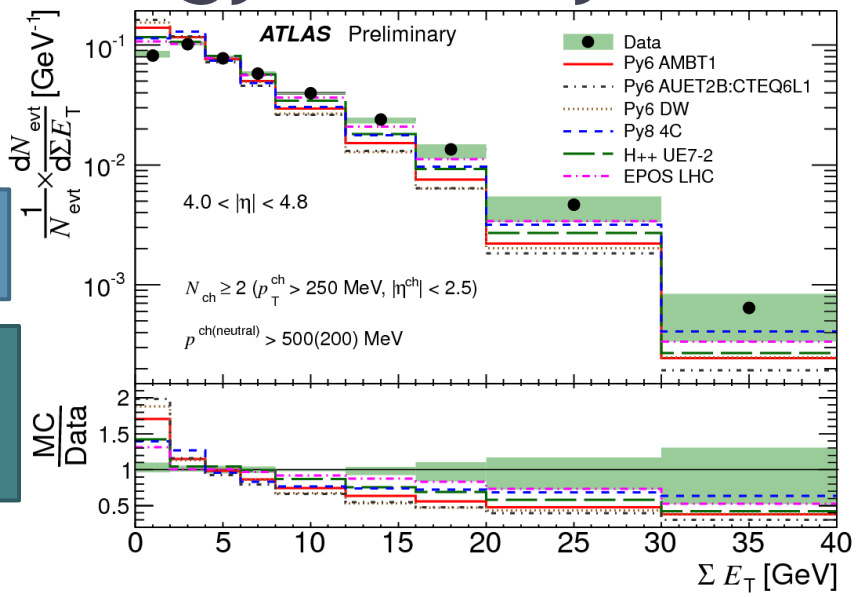


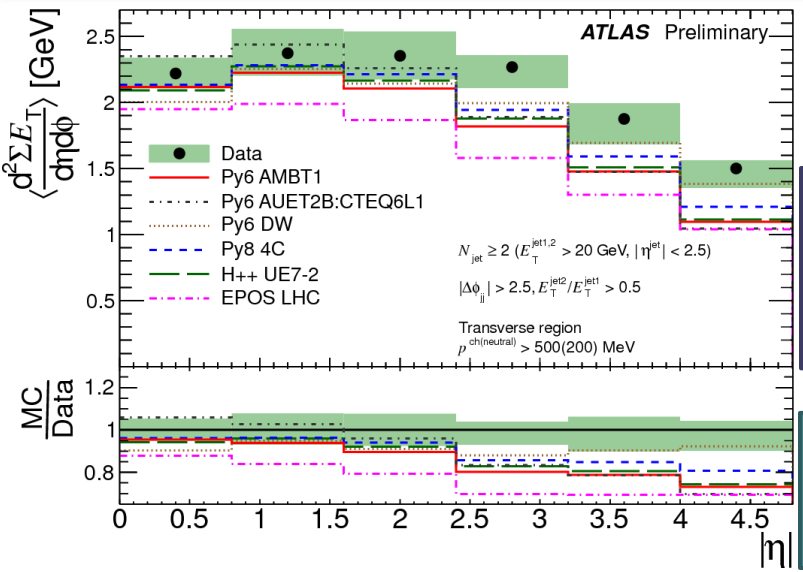
MinBias

Mid η dip from p_T cuts.

Forward flow underestimated Best soft model *EPOS*

Bayesian Unfolding Technique

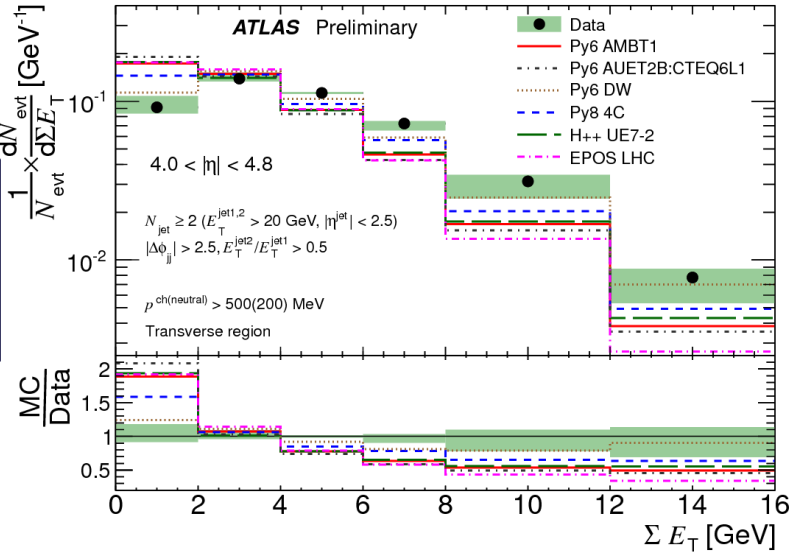




Underlying Event

Transverse region to di-jet system only.

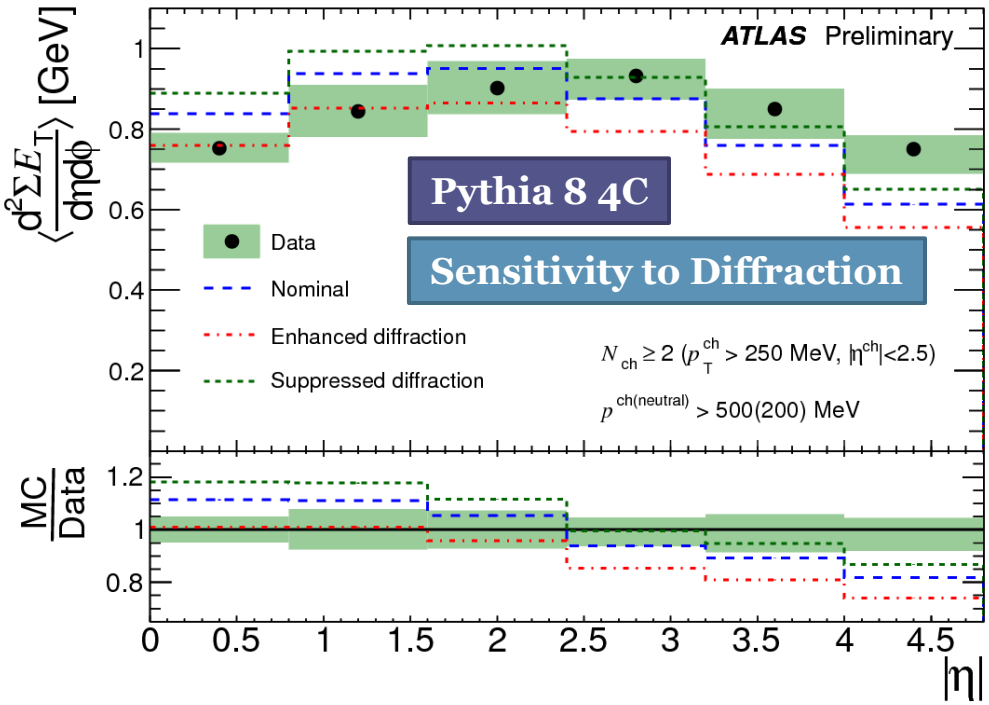
Best UE model *Pythia 6 DW*

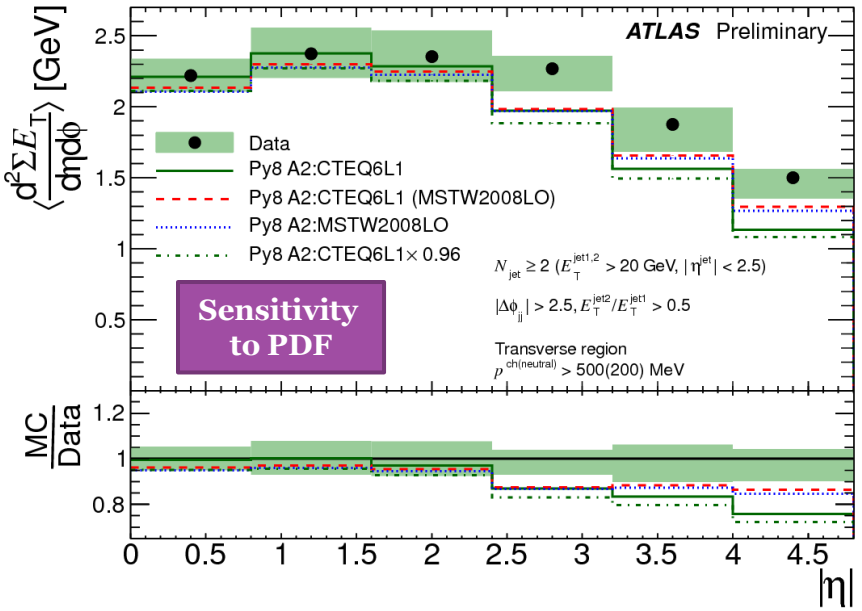


NeW!

Differential Transverse Energy Density

- **Diffractive** contributions **halved** and **doubled**.
- Affects the **amount of activity** (diffractive events are **softer on average**).
- Has **little effect on the shape**.





- In **MSTW2008 LO**, changes to the gluon PDF ***decreases* central** but ***increases* forward** energy.

NeW!

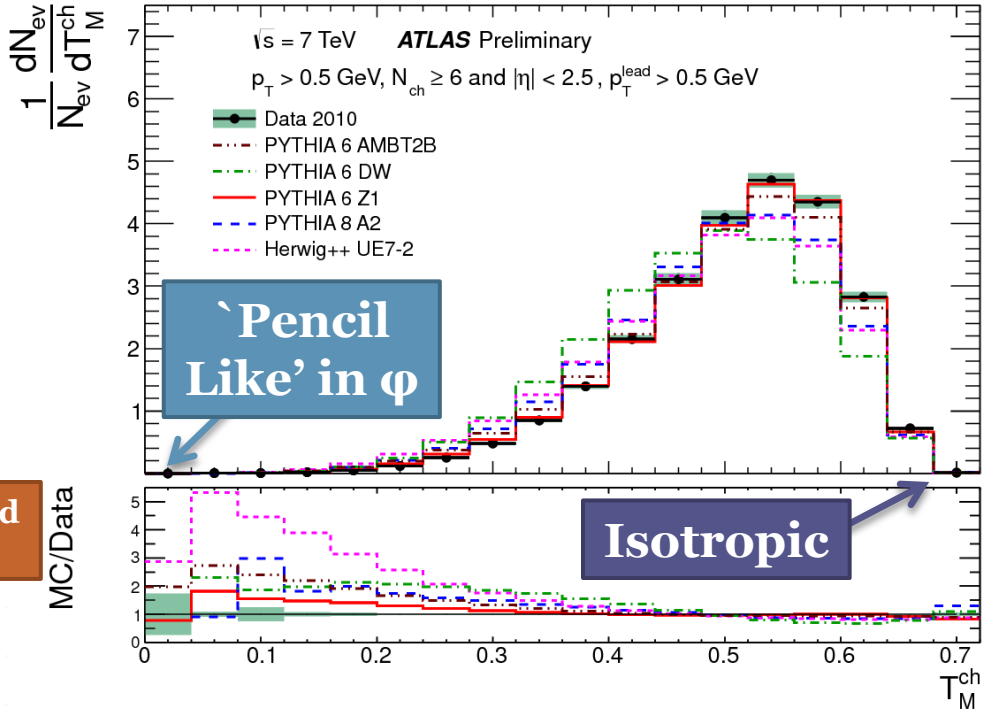
Event Shapes

Transverse Thrust:

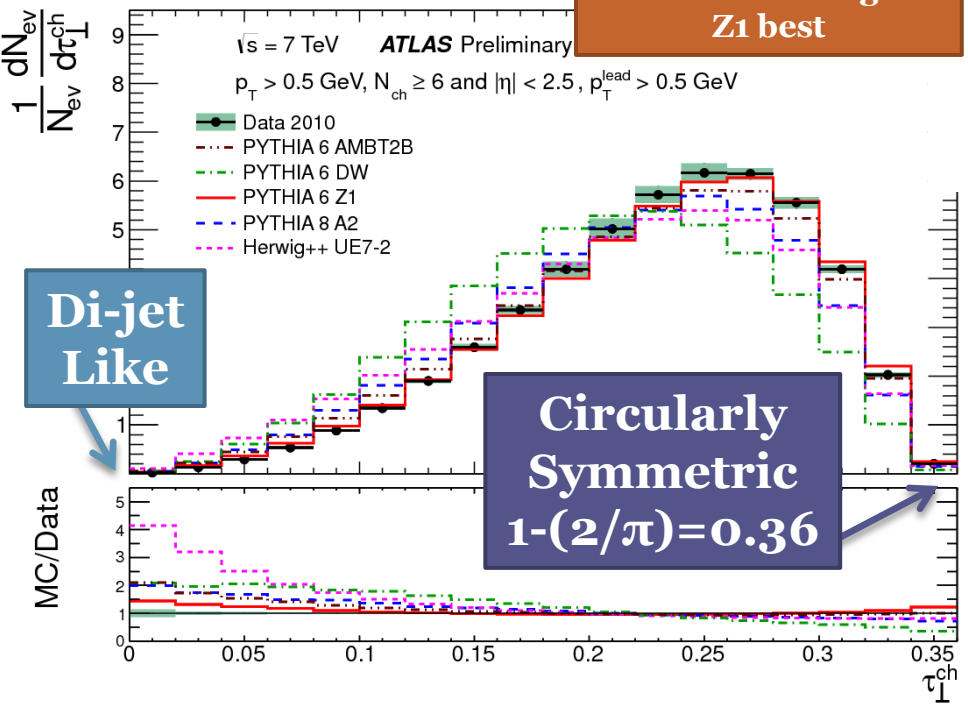
$$\tau_\perp = 1 - T_\perp$$

For Thrust Axis, unit vec. $\hat{n}_T$ for which:

$$\max_{\hat{n}} \frac{\sum_i |\vec{p}_T^{\,i} \cdot \hat{n}|}{\sum_i |\vec{p}_T^{\,i}|}$$



AMBT2B not so good
Z1 best



Thrust Minor:

Out of event plane energy flow.

$$\hat{n}_M = \hat{n}_T \times \hat{z}$$

Defined by *thrust axis* ($\hat{n}_T$) and *beam axis* ($\hat{z}$)

$$T_M = \frac{\sum_i |\vec{p}_T^{\,i} \cdot \hat{n}_M|}{\sum_i |\vec{p}_T^{\,i}|}$$

NeW!

Event Shapes

Transverse Sphericity:

A measure of the transverse summed p_T^2 with respect to the event axis.

Shown here as a function of p_T^{lead}

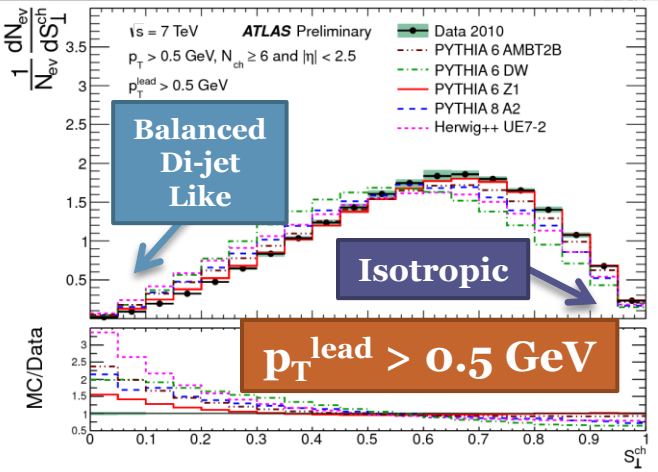
Derived from the **eigenvectors ($\lambda^{xy}_2 < \lambda^{xy}_1$)** of the **transverse** components of the **event momentum tensor**:

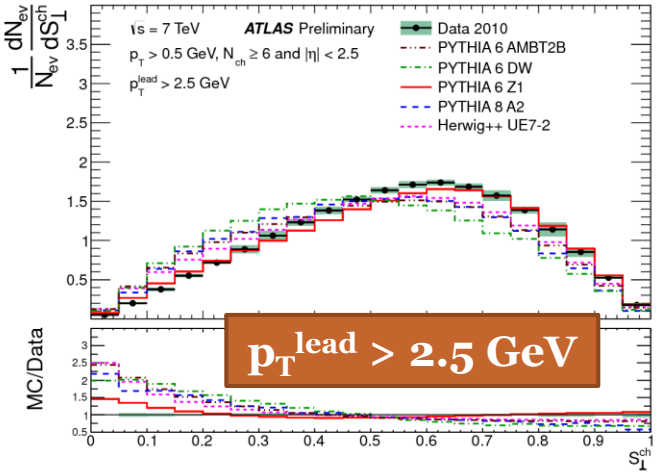
$$S^{xy} = \sum_i \begin{bmatrix} p_x^{2,i} & p_x^i p_y^i \\ p_x^i p_y^i & p_y^{2,i} \end{bmatrix} \qquad S_\perp = \frac{2\lambda_2^{xy}}{\lambda_1^{xy} + \lambda_2^{xy}}$$

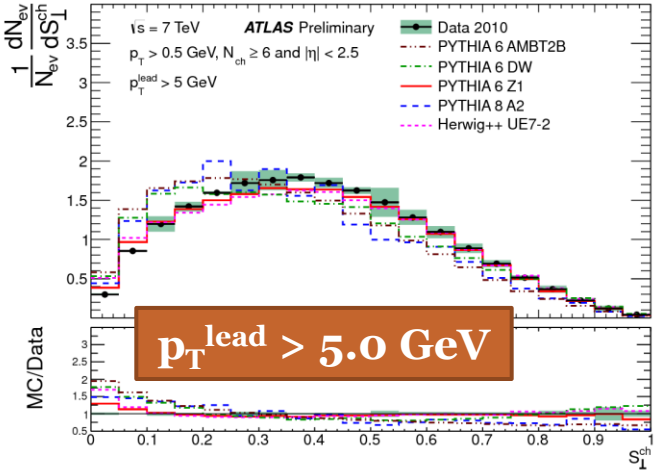
Transverse thrust, thrust minor and transverse sphericity measured for leading particle.

p_T^{lead} > 0.5, 2.5, 5.0 GeV

Along with *average values* as a function of N_{ch} and Σp_T

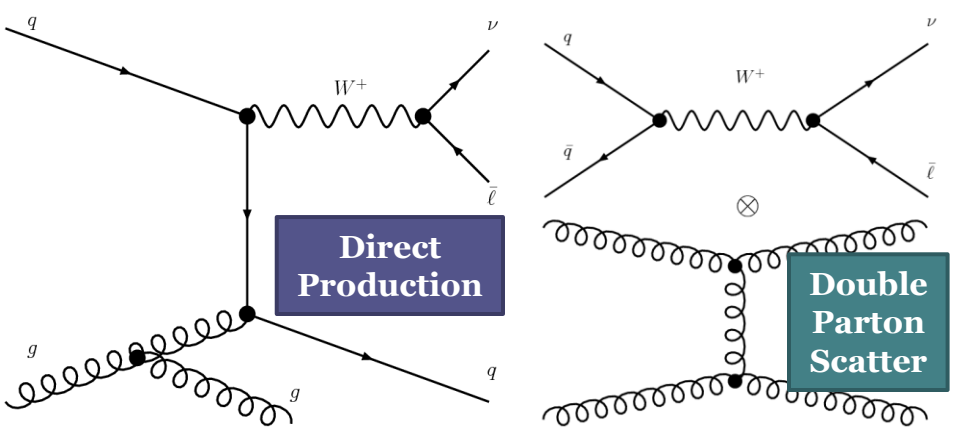


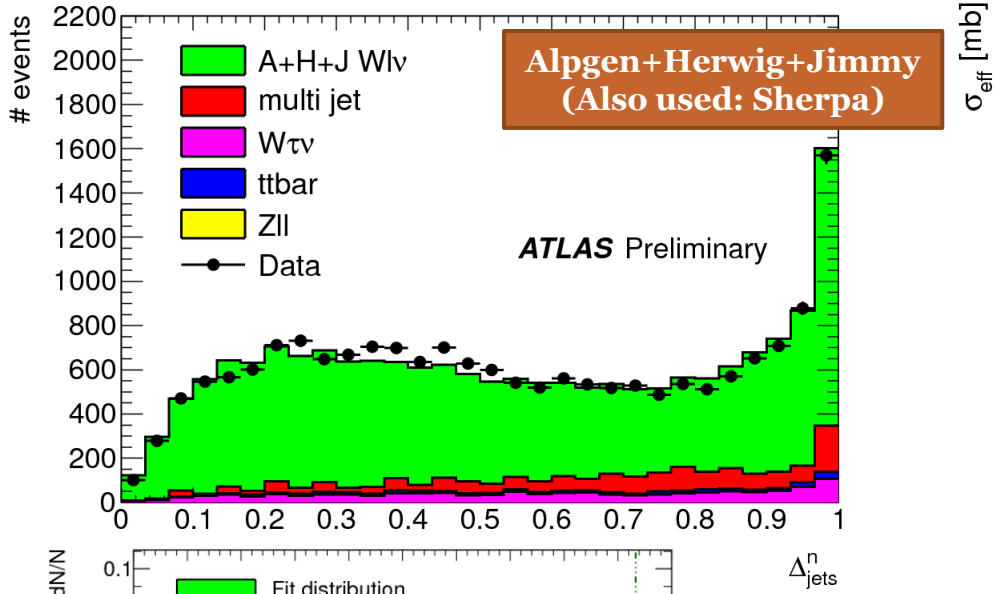


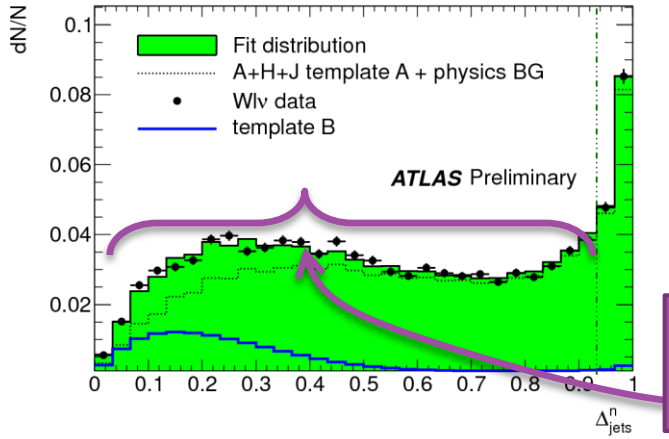


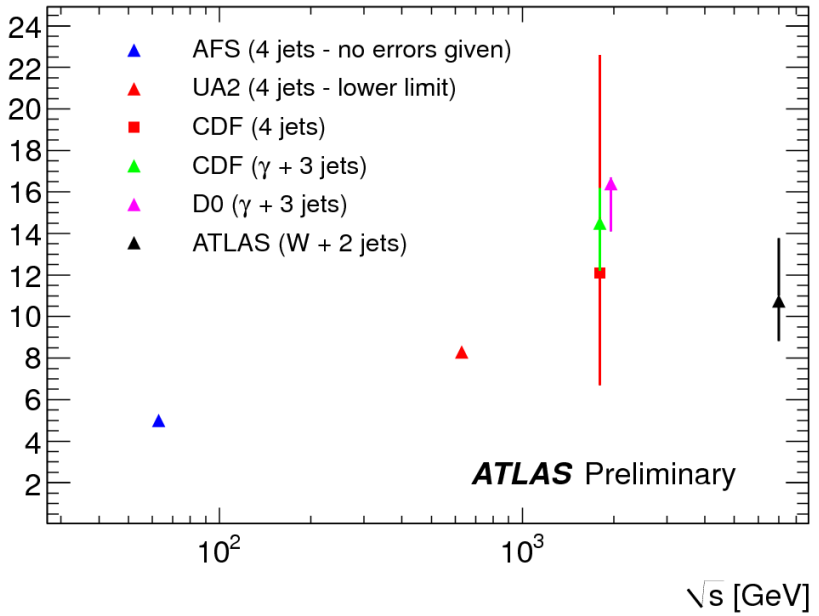
Hard DPI: W→lν+jj

$$\Delta^{n}_{jets} = \frac{|\vec{p}_{T1} + \vec{p}_{T2}|}{|\vec{p}_{T1}| + |\vec{p}_{T2}|}$$









Template A: Non-DPI MC

Template B: Di-jet Data

Templated χ² minimisation

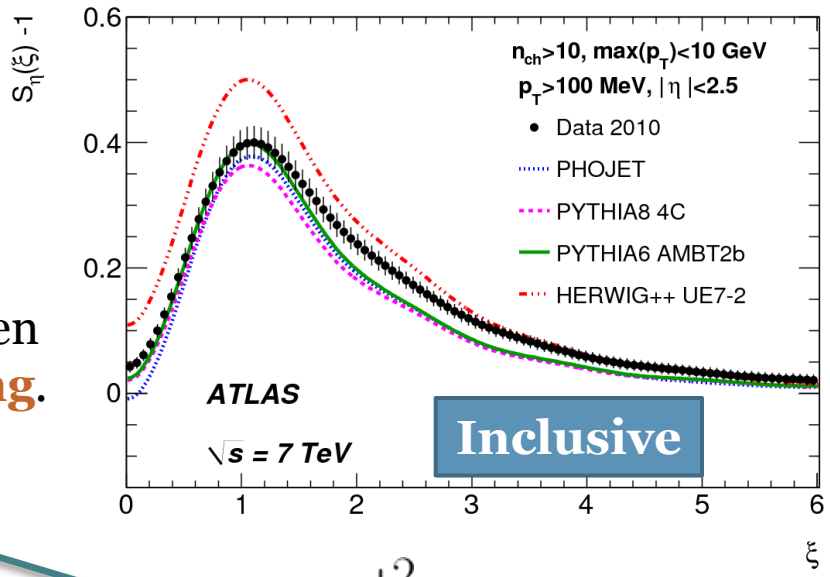
Template extracted fraction of DPI:
f^{R}_{DPI} = 0.16±0.01 (stat)±0.03 (sys)

Subsequently evaluated DPI cross section:
σ_{DPI}^{eff}(7 TeV) = 11±1(stat)$^{+3}_{-2}$(sys) mb

Is the gluon field helical?

Corrected via HBOM [arXiv:1111.4896v2]

- An **efficient way to pack soft gluons** into a **Lund string** formalism under **helicity conservation requirement** is the formation of a **helix structure** at the end of the parton cascade. [***Is there screwiness at the end of the QCD cascades?*** **arXiv:hep-ph/9807541v1**]
- **Correlations** in **the break points** of a **helically ordered string** will manifest as observables in the **p_T distribution and azimuthal ordering** of hadrons produced **directly from string fragments**.
- Assuming string breakup through **tunneling**, φ direction of **initial hadron p_T coincides with the phase of the helix string**.
- φ opening angle of **two direct hadrons** will then **measures the phase difference** between **two corresponding points along the string**.



Assumes helix winding is proportional to the rapidity difference between hadrons

φ and η of j_{th} hadron.

$$S_\eta(\xi) = \frac{1}{N_{\mathrm{Ev}}} \sum_{\mathrm{Events}} \frac{1}{n_{\mathrm{Ch}}} \left| \sum_{j}^{n_{\mathrm{Ch}}} e^{i(\xi\eta_j - \phi_j)} \right|^2$$

ξ is a scale parameter.

Is the gluon field helical?

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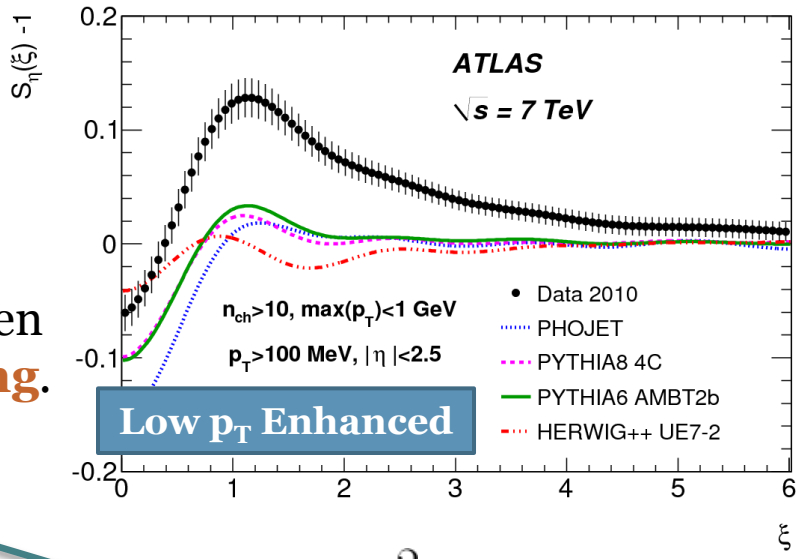
New Pythia8 Helix Model projects.hepforge.org/helix



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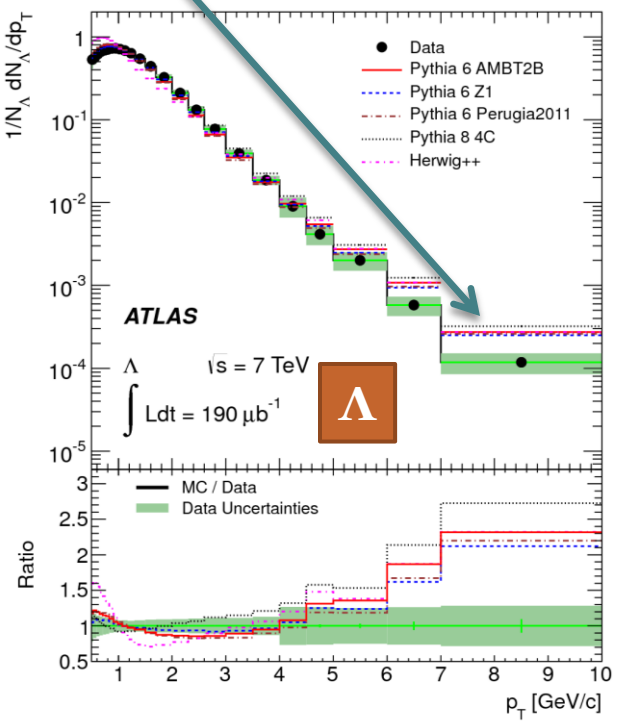
K^0_S and Λ

All tunes struggle to describe Λ data at high p_T

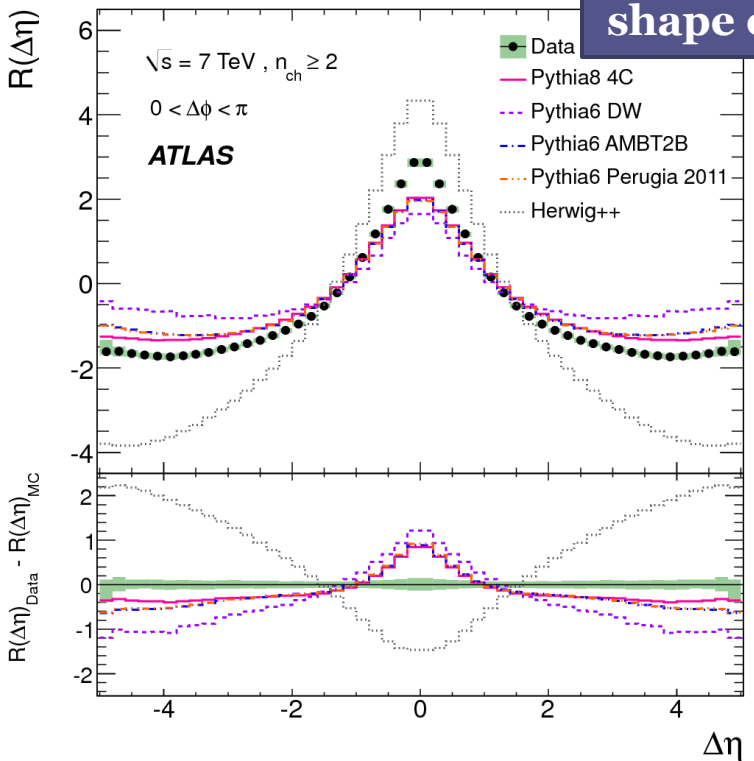


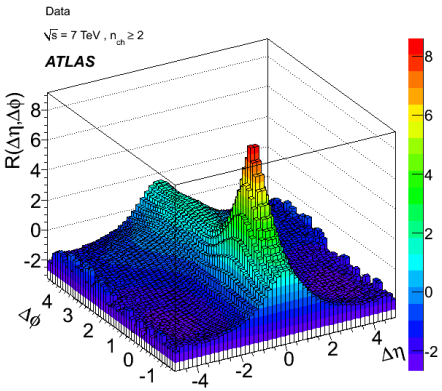
Two Particle Correlations

- **Δη and Δφ correlations** between **all particles** in an event.
- **Background subtracted** by combining two particles from **different** events.
- **Normalised** to be **independent of per event particle multiplicity**.

Corrected via HBOM [arXiv:1111.4896v2]

Most models (except Herwig++) reasonably predict the shape of the correlations.





Conclusion

- **A wealth of data from ATLAS on event characteristics, particle properties and correlations are available *at the hadron level*.**
- *Measurement of charged-particle event shape variables in sqrt(s) = 7 TeV proton-proton interactions with the ATLAS detector* **[Coming soon!]**
- *Measurements of the pseudorapidity dependence of the total transverse energy in proton-proton collisions at sqrt(s)=7 TeV with ATLAS* **[Coming soon!]**
- *Measurement of charged-particle event shape variables in sqrt(s) = 7 TeV proton-proton interactions with the ATLAS detector* **[Coming soon!]**
- *Measurement of the azimuthal ordering of charged hadrons with the ATLAS detector at the LHC* **[**arXiv:1203.0419**]**
- *Measurement of Inclusive Two-Particle Angular Correlations in pp Collisions with the ATLAS Detector at the LHC* **[**arXiv:1203.3549 **]**
- *Forward-backward correlations and charged-particle azimuthal distributions in pp interactions using the ATLAS detector* **[**arXiv:1203.3100 **]**
- *Rapidity Gap Cross Sections in pp Interactions at sqrt(s) = 7 TeV measured with the ATLAS detector* **[**arXiv:1201.2808 **]**
- *Kshort and Lambda production in pp interactions at sqrt(s) = 0.9 and 7 TeV measured with the ATLAS detector at the LHC* **[**arXiv:1111.1297 **]**
- *Measurement of the Inelastic Proton-Proton Cross-Section at sqrt(s) = 7 TeV with the ATLAS Detector* **[**arXiv:1104.0326**]**
- *A measurement of hard double-partonic interactions in W --> l nu + 2 jet events with the ATLAS detector at the LHC* **[ATLAS-CONF-2011-160]**

BACKUP

Is the gluon field helical? Part II

- One possibility, **a static, regular helix** with **helical phase difference Δφ** proportional to the **stored energy** in the string.

κ is string energy density

$$\Delta\phi = \mathfrak{L}\kappa\Delta l = \mathfrak{L}\Delta E$$

***Δl* & *ΔE* are length and energy separation in string rest frame.**

- ***ΔE* is not directly observable**, but we can **approximate the string as a chain of hadrons, ordered in η**.
- Define a **second power spectrum**, based on **φ** and the **position in the chain, *X*** defined as:

$$X_j = 0.5\ E_j + \sum_{k=0}^{k<j} E_k$$

***E*$_k$ is the energy of the *k*$_{th}$ hadron in the string.**

$$S_E(\omega) = \frac{1}{N_{\mathrm{Ev}}} \sum_{\mathrm{Events}} \frac{1}{n_{\mathrm{Ch}}} \left| \sum_{j}^{n_{\mathrm{Ch}}} e^{i(\omega X_j - \phi_j)} \right|^2$$

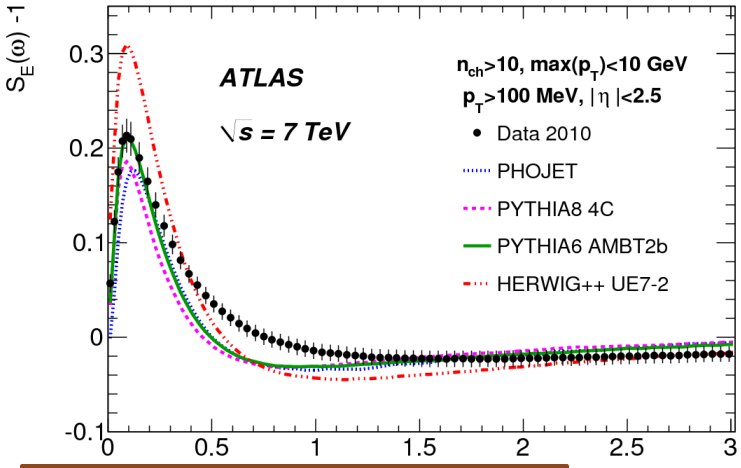
Very similar form factor, but probing a different structure in the QCD field.

ω is a scale parameter.

Helical ordering will appear as a peak in the power spectrum, location = winding density.

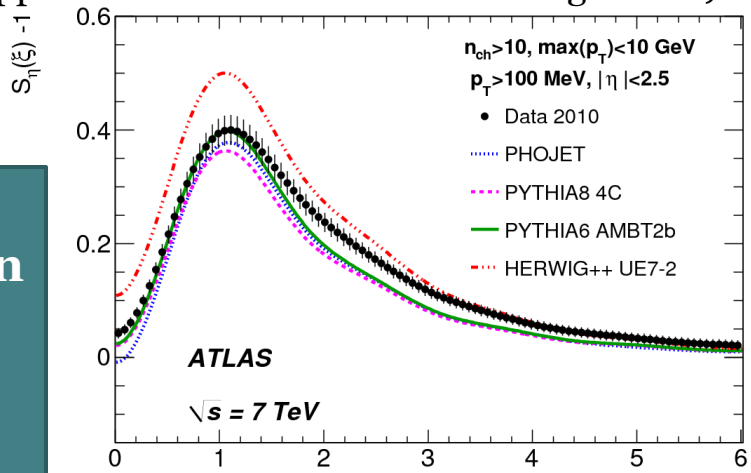
More results for $S_E(\omega)$ & $S_\eta(\xi)$

- Data **corrected to hadron level** via **HBOM** [**arXiv:1111.4896v2**]
  (Backward extrapolation from the parametrisation of repeated applications of the detector smearing matrix)



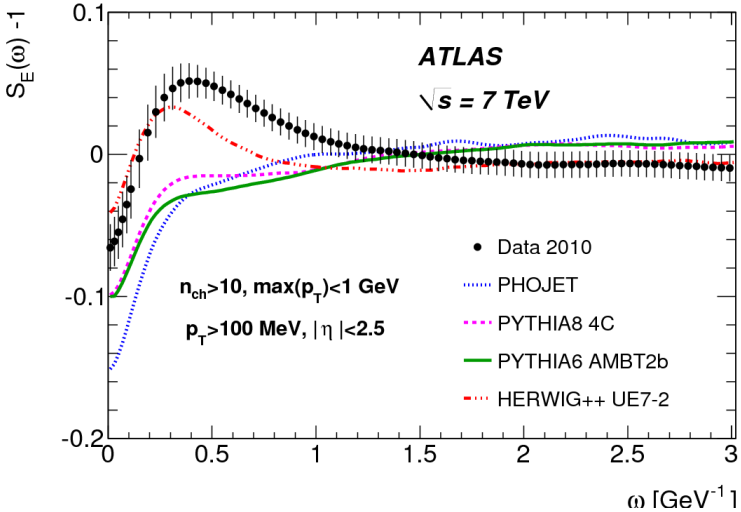
Inclusive MinBias

Lund string fragmentation model roughly reproduces the data.



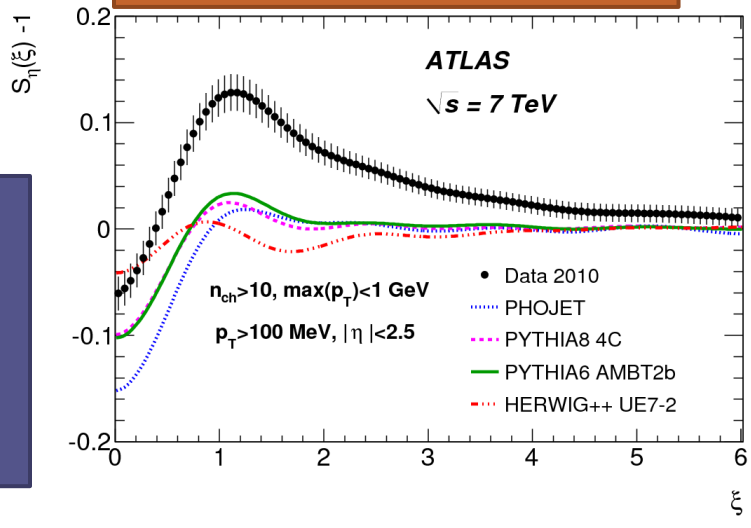
ω:Helix proportional to stored energy in string

ξ:Helix proportional to particle rapidity difference



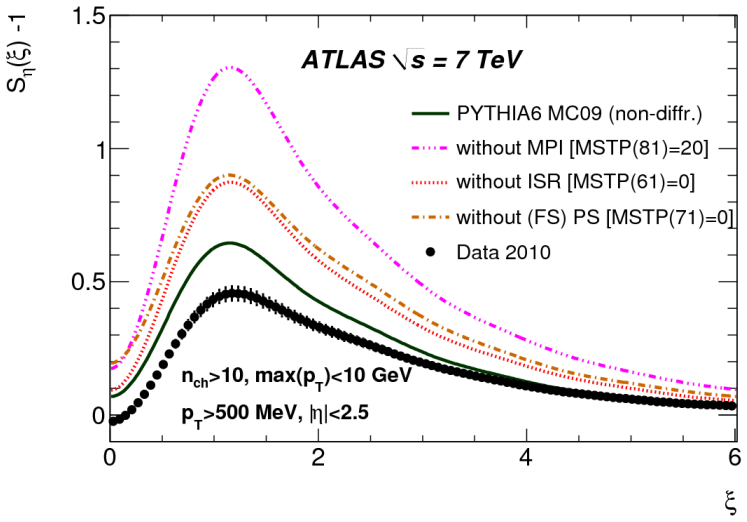
Low p_T Enhanced

Models unable to sufficiently describe the data.



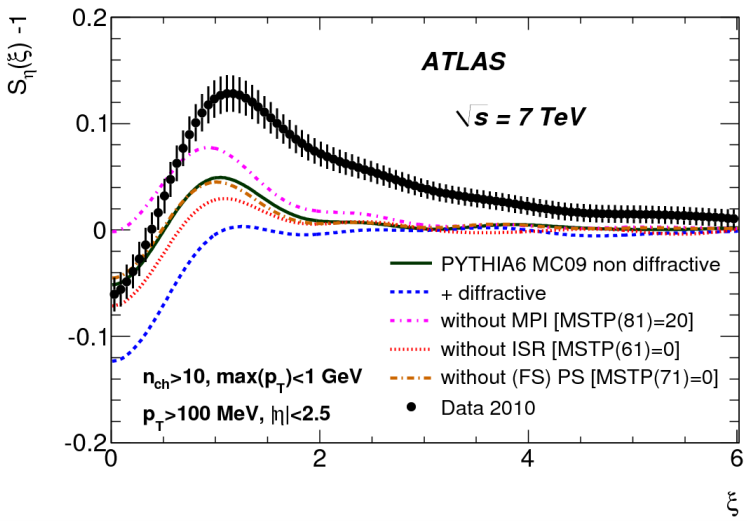
More results for $S_E(\omega)$ & $S_\eta(\xi)$

Low p_T Depleted

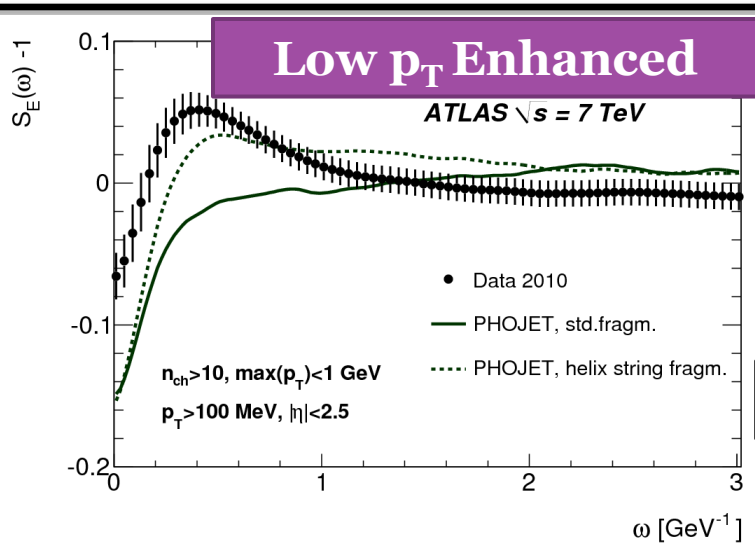


Model Parameter Sensitivity

Low p_T Enhanced



Low p_T Enhanced

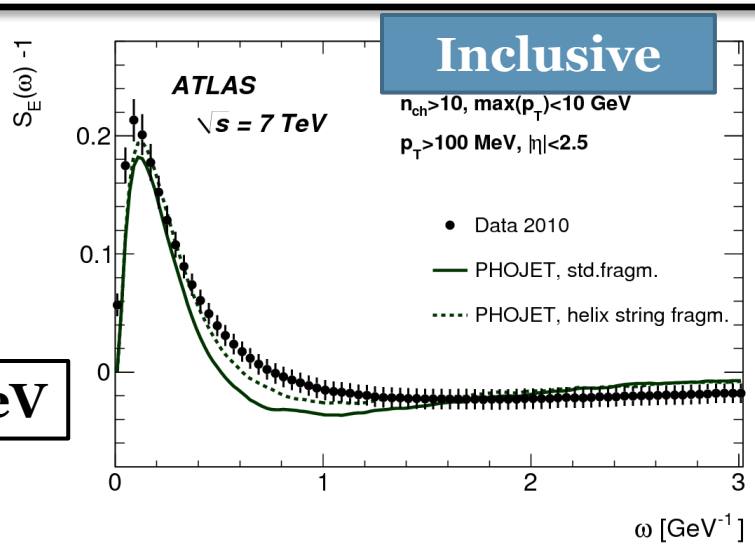


PHOJET Helix

S_E Definition

$\mathfrak{L}$ = 0.7 rad/GeV

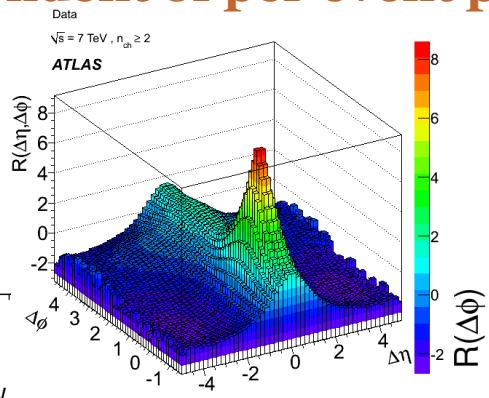
Inclusive



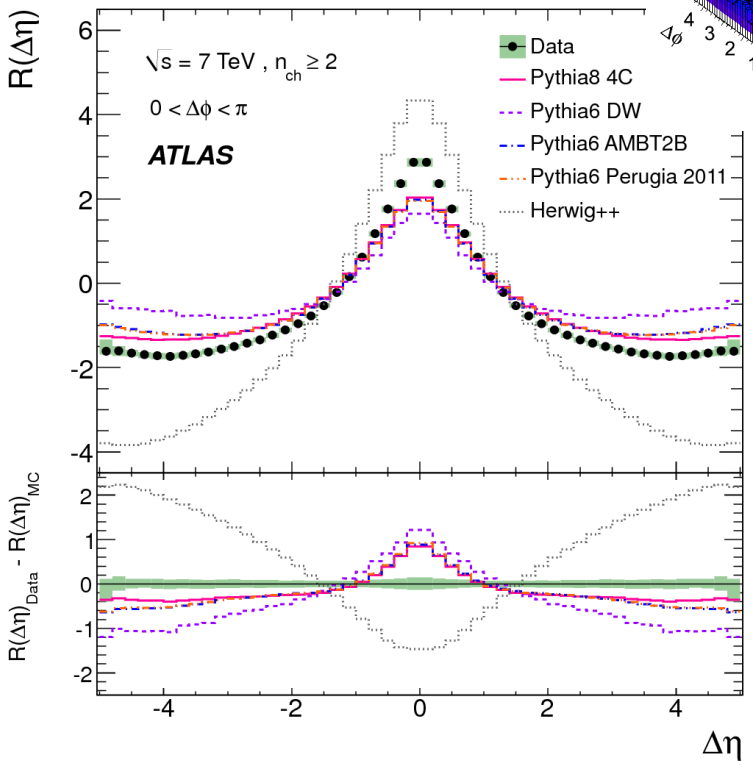
Two Particle Correlations

- **Δη and Δφ correlations** between **all particles** in an event.
- **Background subtracted** by combining two particles from **different** events.
- **Normalised** to be **independent of per event particle multiplicity**.

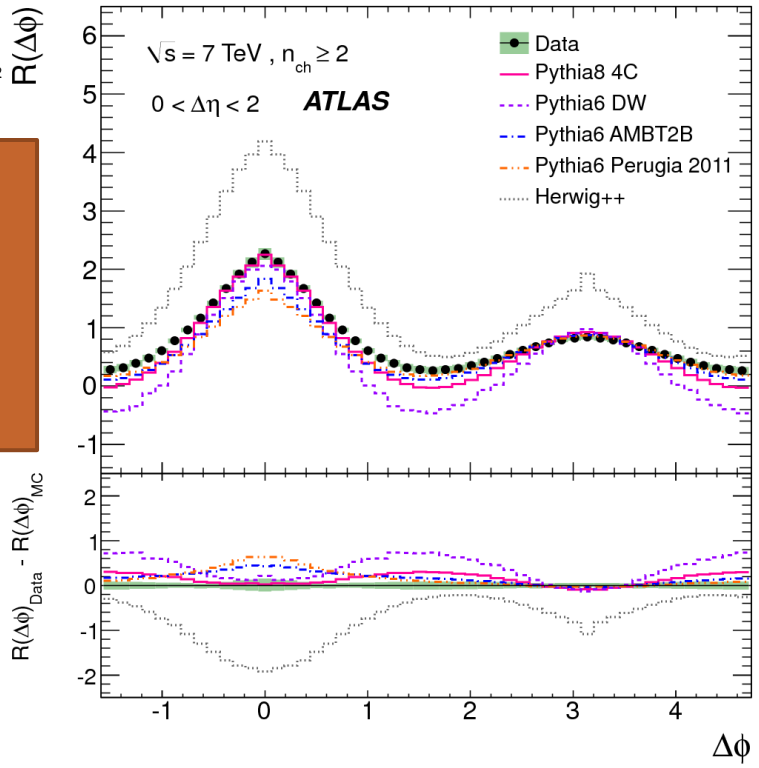
Most models (except Herwig++) reasonably predict the shape of the correlations.



The strength of correlations is less well predicted.

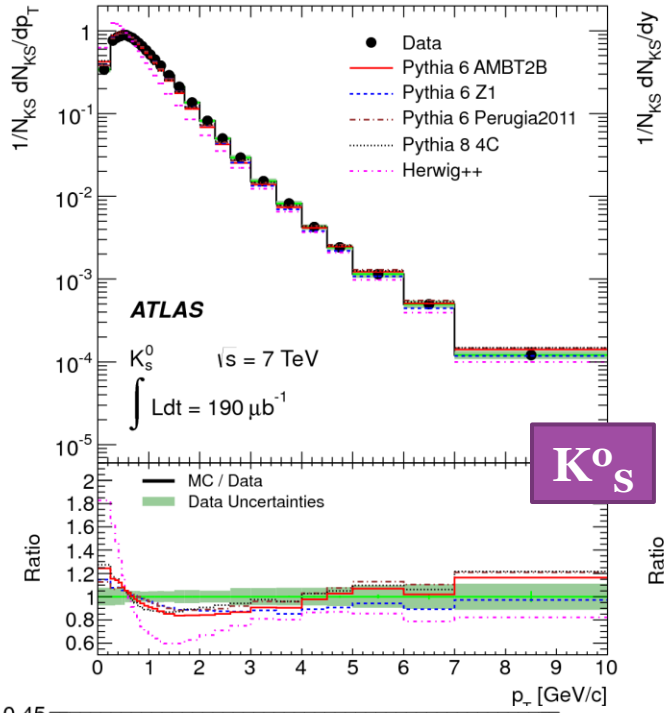


Data corrected using HBOM method

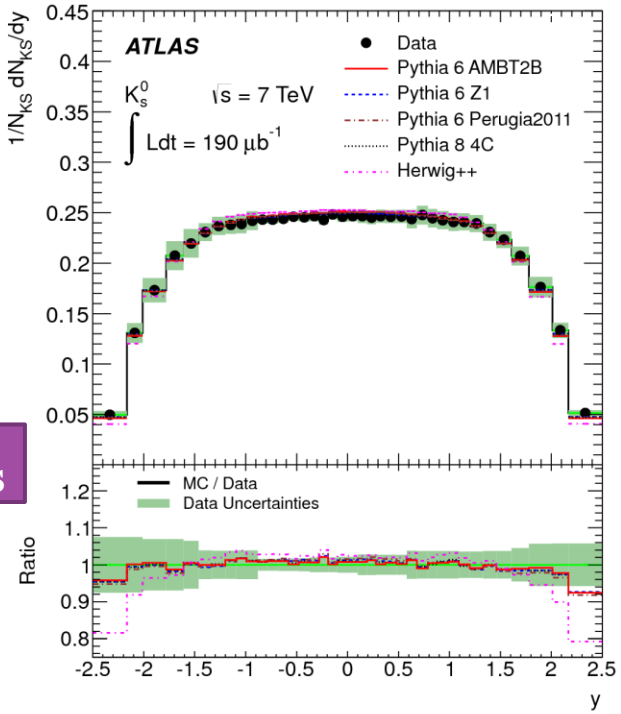


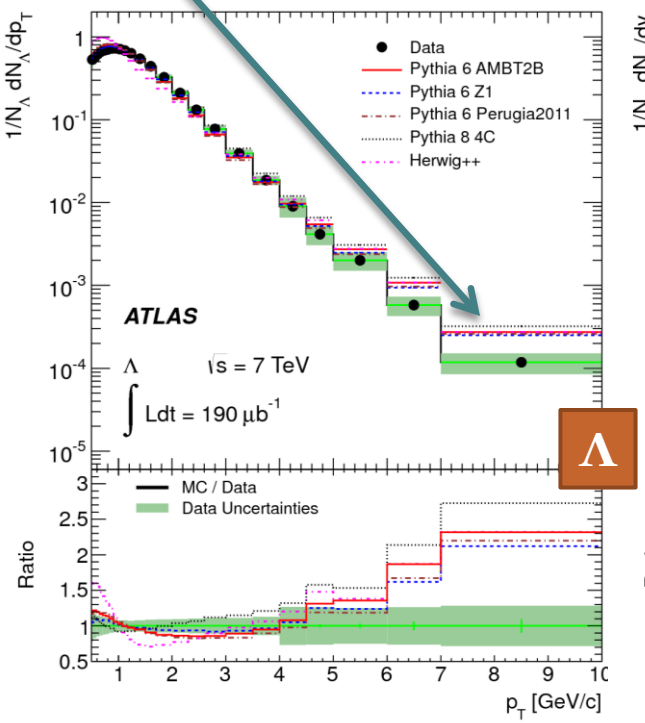
K^0_S and Λ

All tunes struggle to describe Λ data at high p_T

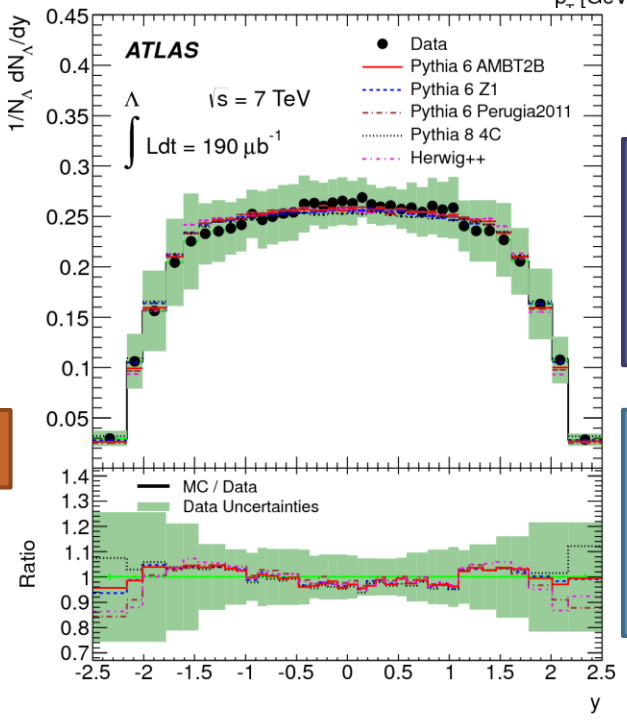


K^0_S





Λ

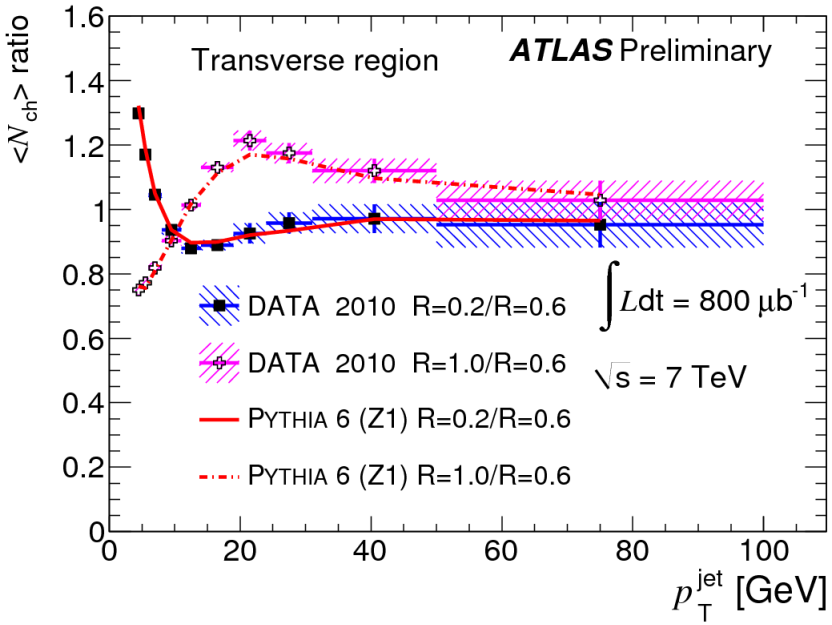


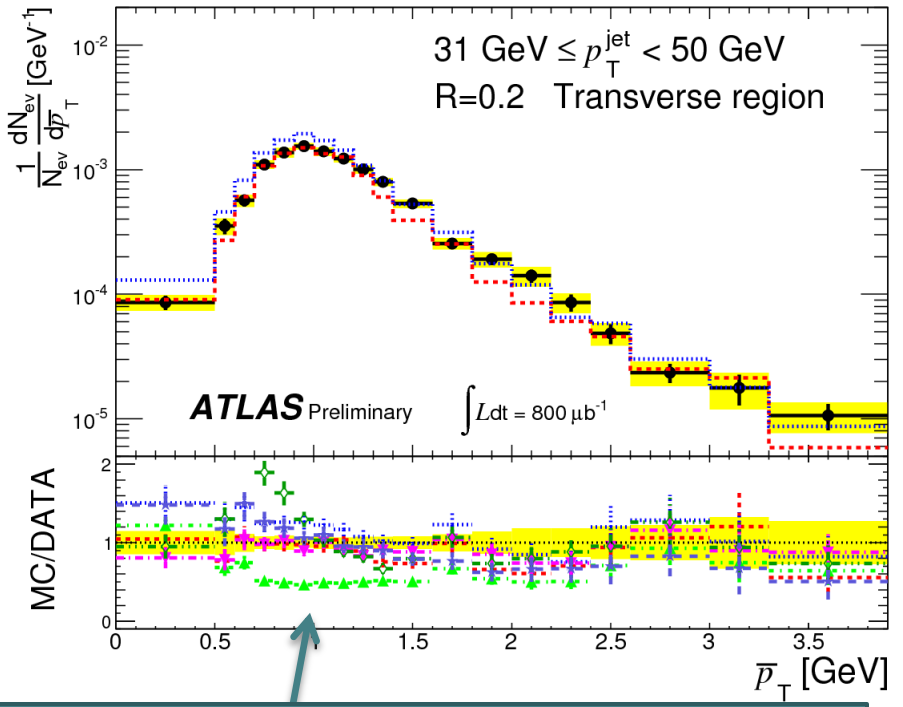
K^0_S: Flight distance between **4 - 450 mm**
Decay to two charged pions with **$|\eta| < 2.5$, $p_T > 100$ MeV**

Λ: $p_T > 500$ MeV, flight distance between **17 mm - 450 mm**
Decay to a proton and a pion with **$|\eta| < 2.5$, $p_T > 100$ MeV**

Track-jet Underlying Event

Ratio of mean N_{ch} for R=0.2/R=0.6 and R=1.0/R=0.6 as function of p_T^{Jet}





Event normalised average p_T for R=0.2 and $31 \le p_T^{jet} < 50$ GeV

DATA 2010 $\sqrt{s}$ = 7 TeV
PYTHIA (Z1)
PYTHIA (AUET2B)
HERWIG++ (UE7-2)
PYTHIA (Perugia2011)
PYTHIA (Perugia2011 NOCR)
PYTHIA 8.145 (4C)

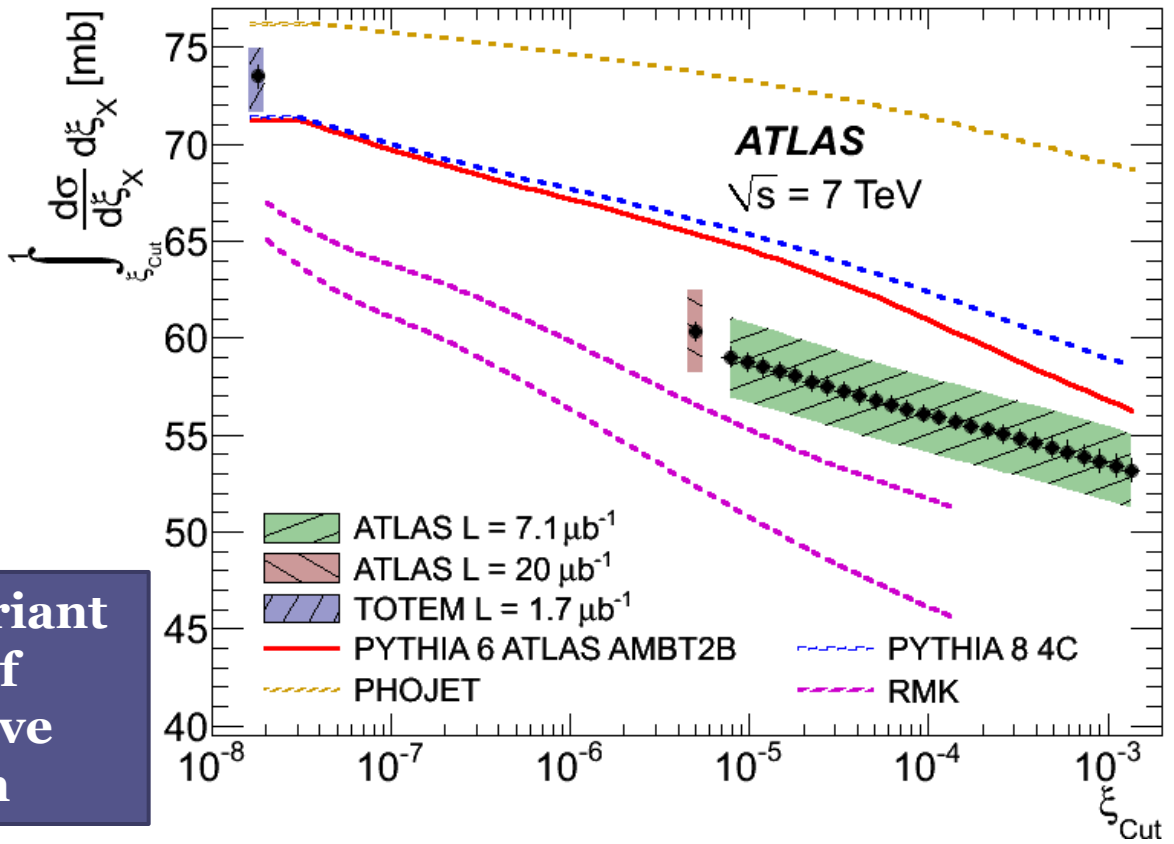
$p_T^{track} \ge 0.5$ GeV $|\eta^{track}| \le 1.5$
anti-k_t jets: $|\eta^{jet}| \le 1.5$

$\int \sigma_{Inelas}(\xi)\, d\xi$

- Measure the **total inelastic cross section which produces particles in the main ATLAS detector**. Can **integrate** up to a cut point.
- Apply all **correlated systematics symmetrically** plus additional **correction** from $\Delta\eta^F$ to ξ derived from **MC**, at most **1.1±1.1%**
- **Luminosity error** dominates.
- Comparison with published **ATLAS** paper good to **0.8%**, this is the measured **run-to-run lumi** error.
- Also included, **TOTEM**.
- And **Durham RMK** prediction.

$$\xi = \frac{M_X^2}{s}$$

M_X = Invariant mass of diffractive system



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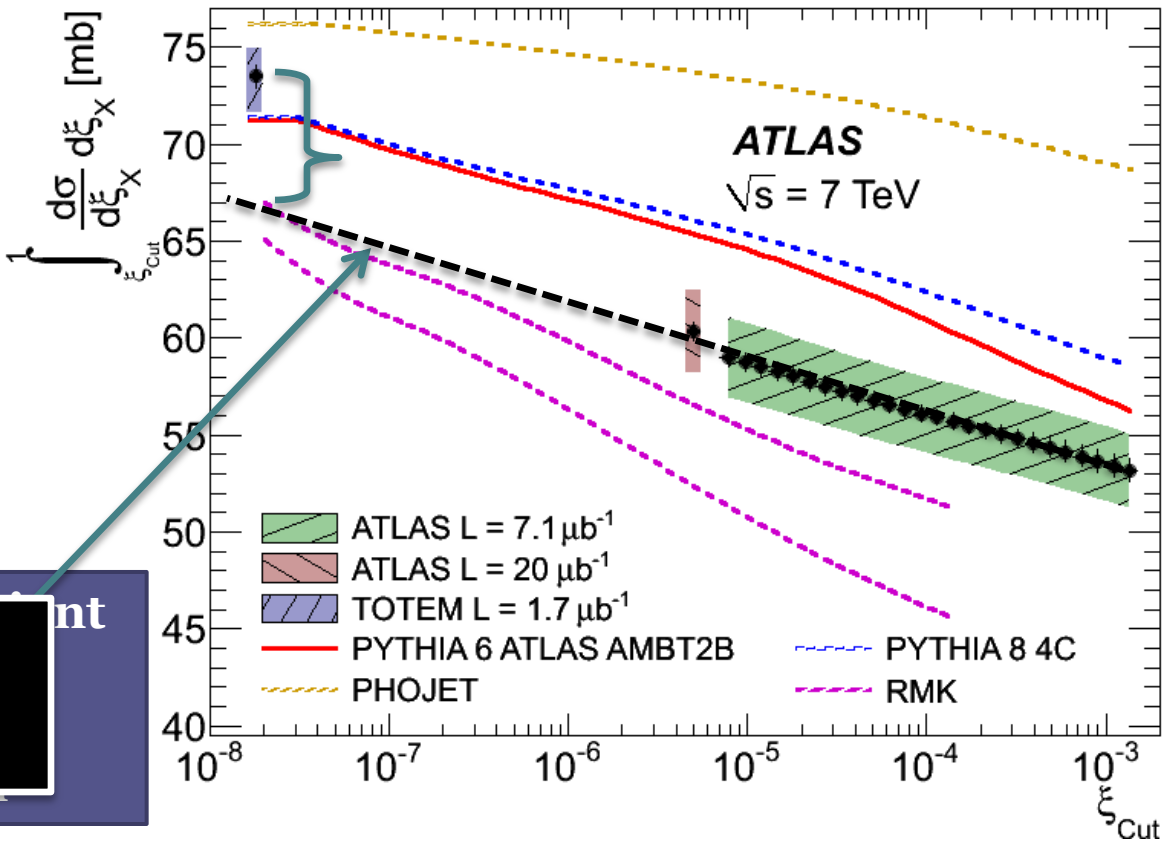
Tension of ~7 mb of low mass diffractive cross section.



Particle Correlations

- **Forward-Backward** multiplicity and p_T correlations in η.

Deviation of fwd(bkwd) multiplicities from their mean.

Sum over events

$$\rho_{fb}^{n} = \frac{\sum x_f^n x_b^n}{N \sigma_f^n \sigma_b^n}$$

N Events

Standard deviation of fwd(bkwd) distributions about their mean.

Deviation of fwd(bkwd) scalar p_T sum of all accepted tracks from their mean.

$$\rho_{fb}^{p_T} = \frac{\sum x_f^{p_T} x_b^{p_T}}{N \sigma_f^{p_T} \sigma_b^{p_T}}$$