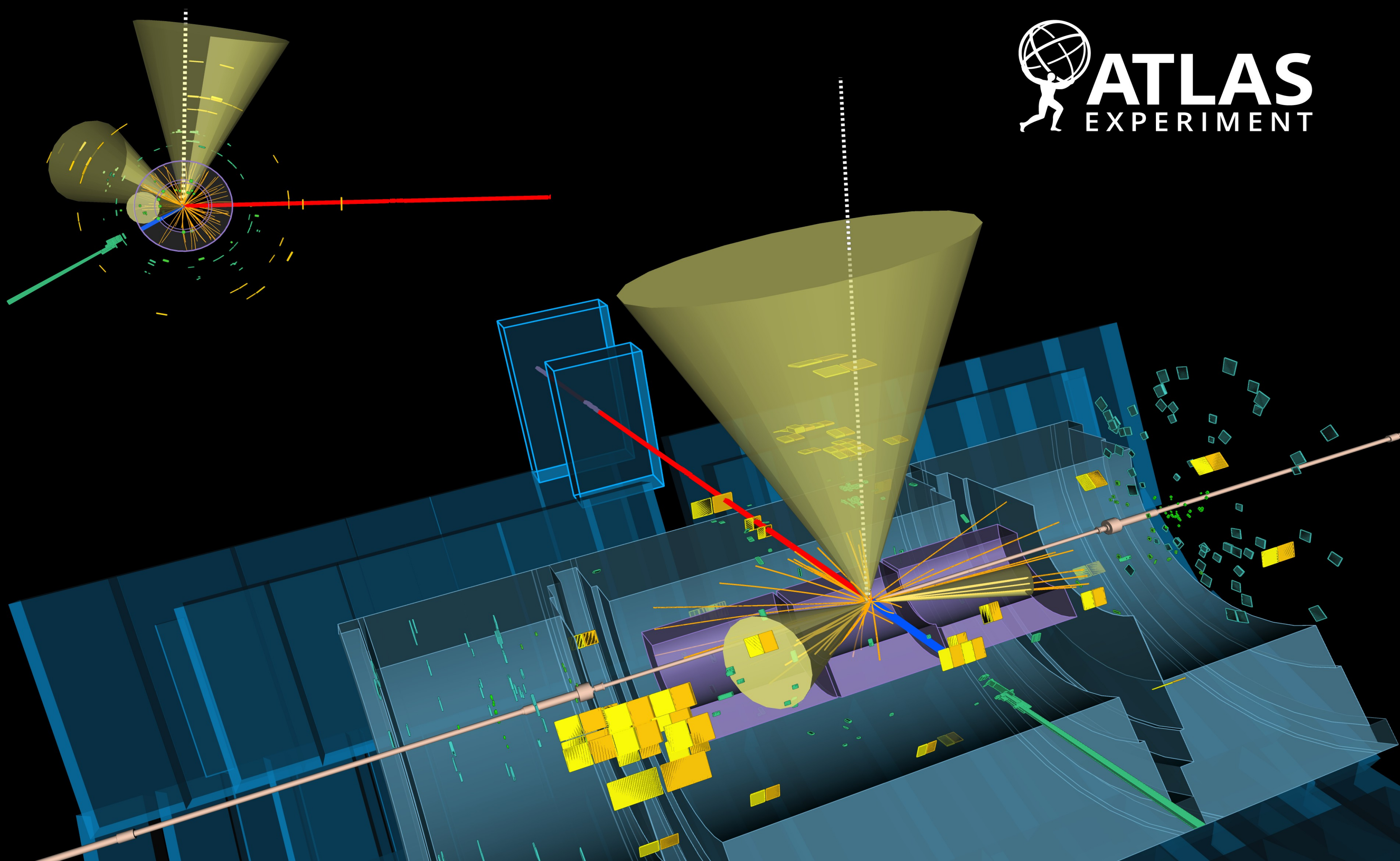
MC Tuning @ ATLAS

Stephen Jiggins on behalf of the ATLAS Collaboration
University College London (UCL)



Contents:

1) Monte Carlo models/event generation

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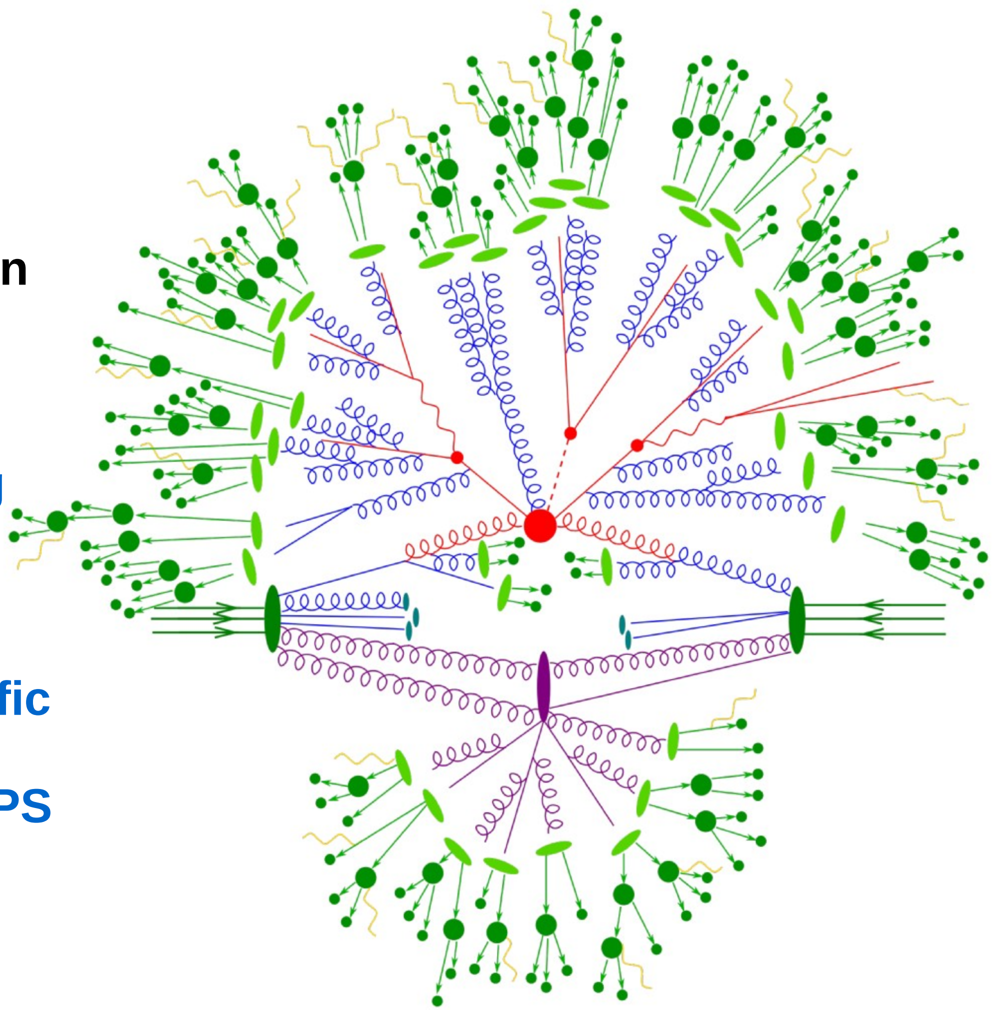
3) “A2” tune series → Pileup Modelling

4) “A14” Pythia8 tune → PS + MPI tune

5) “ATTBAR-...” NLO+PS → ttbar specific

6) “aMC@NLO+Pythia8” tune → NLO+PS general tune

7) Conclusion



Monte Carlo Event Model

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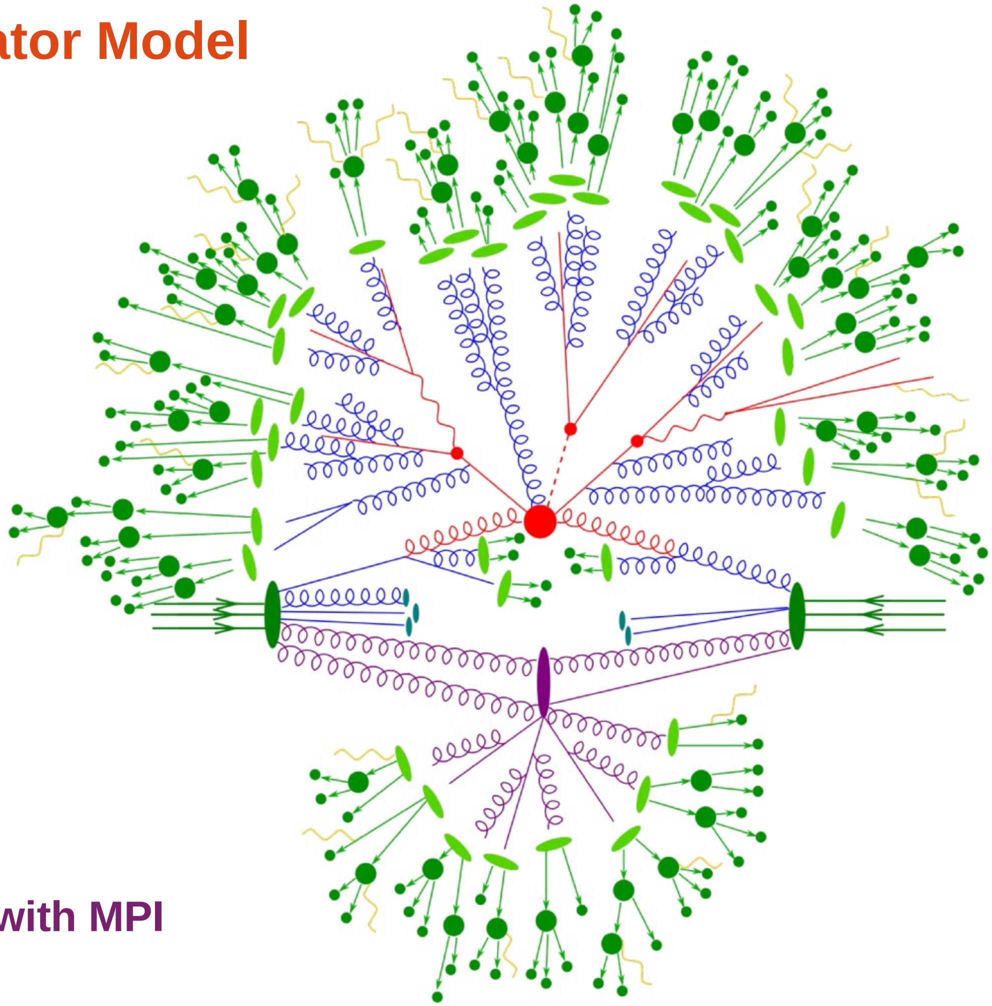
Monte Carlo Event Generator Model

Order of Generation

- ***Hard Scattering***
- ***Beam Remnants***
- ***Parton Shower → ISR + FSR***
- ***Multi-Parton Interaction (MPI)***
- ***Colour Reconnection (CR)***
- ***Hadronisation***
- ***Decays***

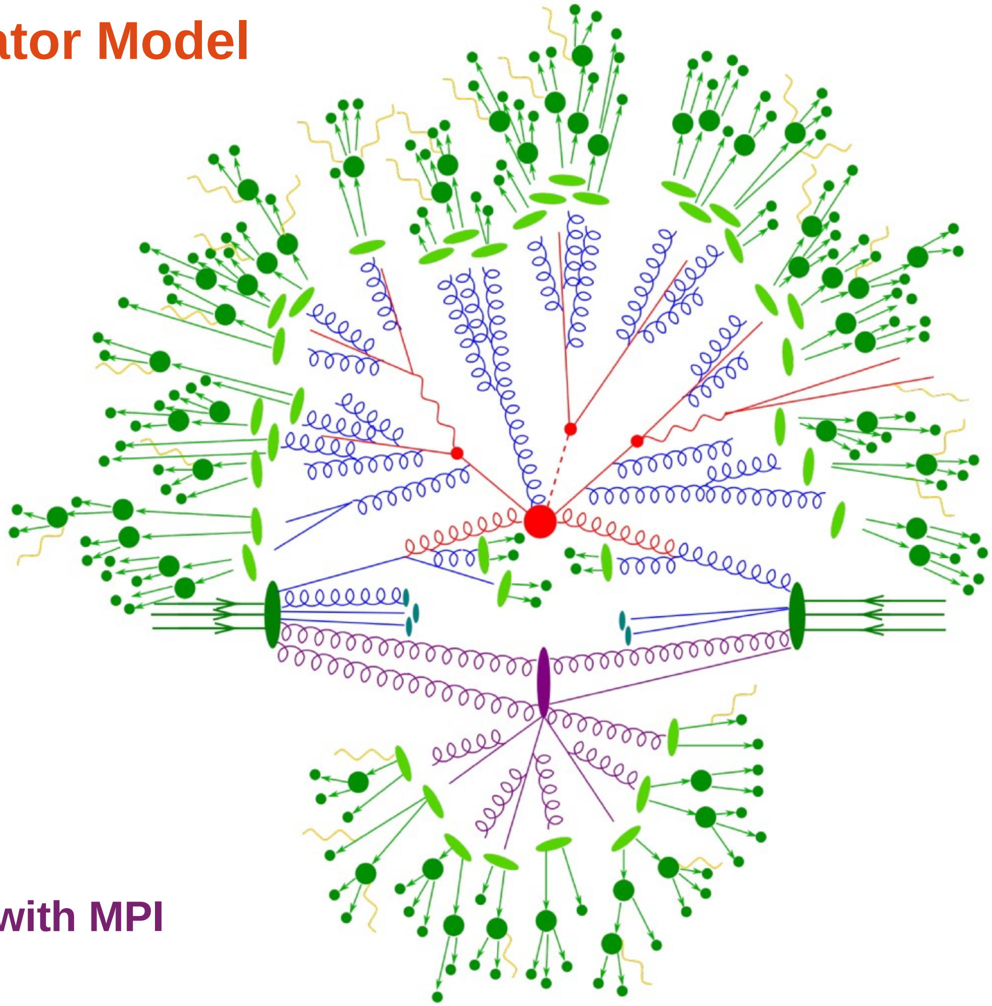


Caveat → Interleaved ISR/FSR with MPI

Monte Carlo Event Generator Model

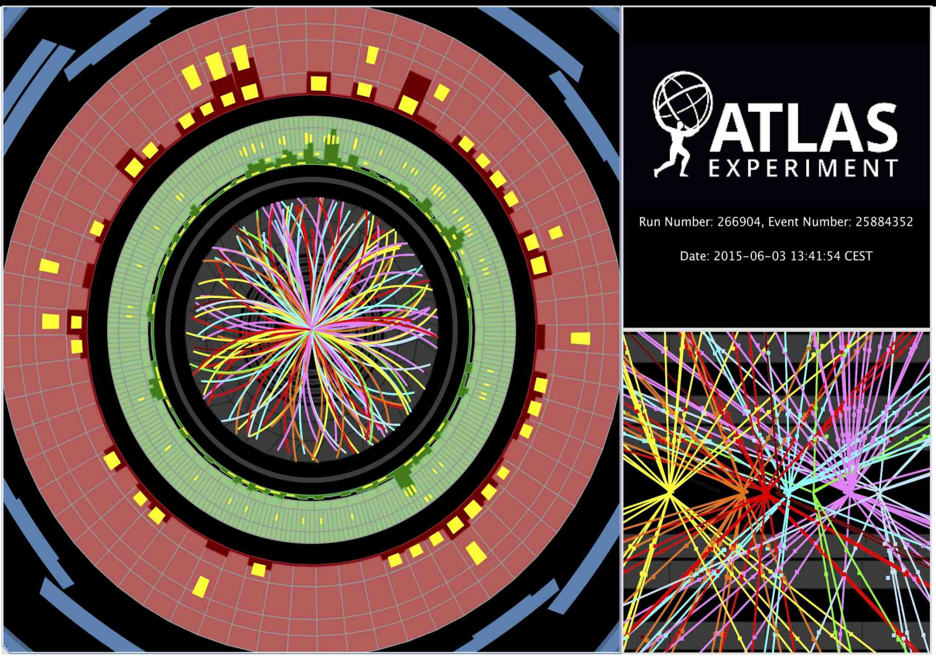
First Principles {
- *Hard Scattering*

Tuneable {
- *Beam Remnants*
- *Parton Shower → ISR + FSR*
- *Multi-Parton Interaction (MPI)*
- *Colour Reconnection (CR)*
- *Hadronisation*
- *Decays*



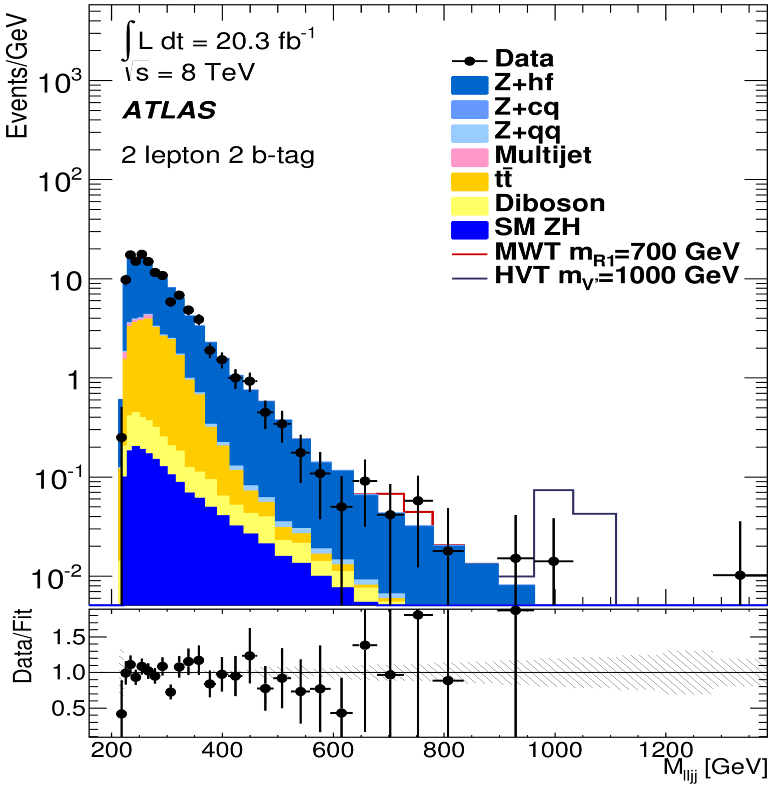
Caveat → Interleaved ISR/FSR with MPI

Monte Carlo Uses at ATLAS



Pile-up simulation + Calibration:

- Overlay hard event with '*n*' inclusive inelastic scatters → **Pile-up**
- Jet identification and calibration sensitive to pileup. → **Diffuse noise in reconstructed jets**



Unfolding:

- Extrapolation from Reconstruction to Particle Level

Background Estimates:

- Data control regions often define background **normalisation**
- MC define differential cross-section **shapes**.
- Over-tuning of non-perturbative parameters may hide **New Physics**

Tuning methodology → The Basics

Methodology:

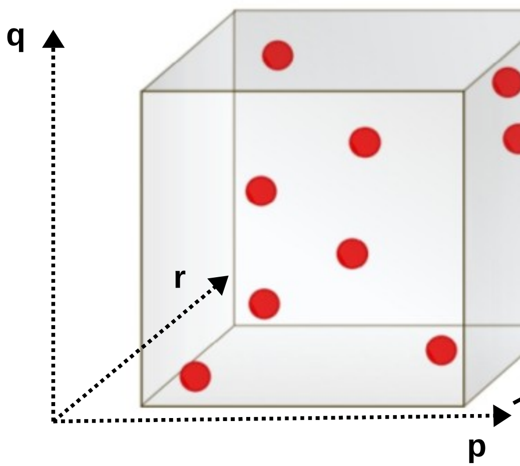
1. Choose parameter & parameter ranges
2. Choose relevant experimental data
   Process & fiducial cuts
   Sensitive Observables
3. Sample N-parameter hypercube
4. Generate samples for 'n' anchor points
5. Analytic approx of observable response to parameter changes.
6. X^2 minimisation of analytic approximation over full MC parameter space in MC/Data comparison.

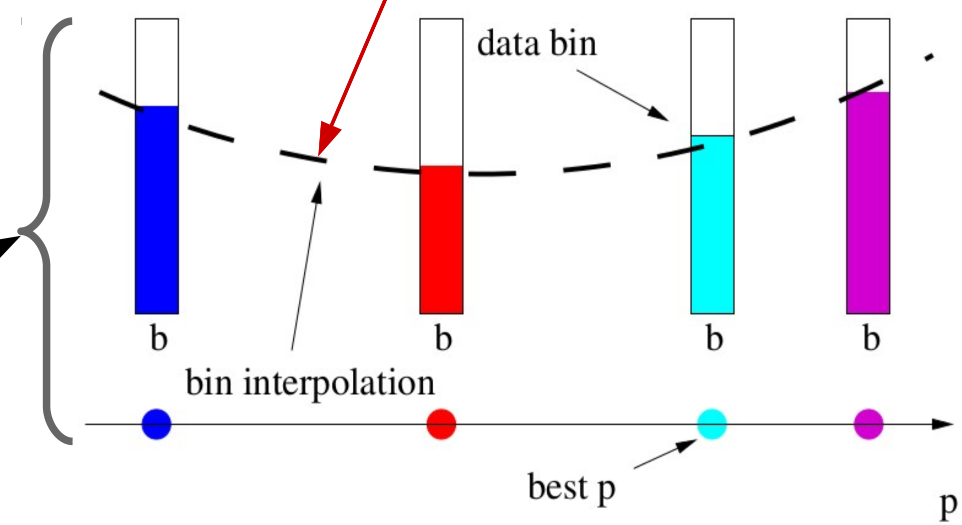
Tools

- Human intuition
- Rivet Tool Kit
  - Particle Level Analysis
  - Data Analysis repository
- Professor
  - Random Sampling of parameter hypercube
  - Analytic approximation of observable response to parameters

$$f_b(\vec{P}) = a_0^b + \sum_i B_i^b p'_i + \sum_{i \leqslant j} C_{ij}^b p'_i p'_j + \dots$$

  - χ^2 minimisation





“A2” Tunes

UE/MB Tunes

ATL-PHYS-PUB-2012-003

“A2” Tune → UE/MB Tune

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- Dedicated Pythia8 pile-up tune. “A2” has two sub-sets “**AU2**” & “**AM2**”. UE and Min-Bias respectively.

- Based on Pythia8 4C tune, with x-dependent matter profile (like 4Cx tune):

$$\rho(r,x) \propto \frac{1}{a_3(x)} \exp\left(\frac{-r^2}{a^2(x)}\right)$$ Where: $a(x) = a_0(1 + a_1 \ln(1/x))$ } **Pythia8.153 “bprofile = 4”**

- ATLAS data at 900GeV & 7TeV
  → Models for energy extrapolation incapable of tuning to LHC & Tevatron data at 3 CMS energies.
  → **Tevatron data ignored.**

- MPI & Colour Reconnection parameters tuned are:

MPI parameter	Sampling Range
pT0Ref	1.50 – 2.80
ecmPow	0.14 – 0.30
reconnectRange	0.00 – 9.00
bProfile	–

$$pT0 = pT0(\sqrt{s}) = pT0Ref \times (\sqrt{s}/1800)^{ecmPow}$$

MPI cut-off for low p_T divergence (smooth dampening)

Matter distribution profile

"A2" Tune → UE/MB Tune

- 200 anchor points chosen each 1M events.
- Observables used: **N_{ch}, charged track p_T, <p_T>, η**.
- Studied dependence of tuned parameters on several LO & NLO PDF sets:

PDF	pT0Ref	ecomPow	a1	reconnectRange	Tune:pp
Minimum-bias tunes: A2					
CTEQ 6L1	2.18	0.22	0.06	1.55	7
MSTW2008 LO	1.90	0.30	0.03	2.28	8
Underlying event tunes: AU2					
CTEQ 6L1	2.13	0.21	0.00	2.21	9
NNPDF 2.1 LO	1.98	0.18	0.04	3.63	–
MSTW2008 LO	1.87	0.28	0.01	5.32	10
NNPDF 2.1 NLO	1.74	0.17	0.08	8.63	–
CTEQ 6.6	1.73	0.16	0.03	5.12	–
CT10	1.70	0.16	0.10	4.67	11
MSTW2008 NLO	1.51	0.19	0.28	5.79	–
MRST2007 LO*	2.39	0.24	0.01	1.76	–
MRST2007 LO**	2.57	0.23	0.01	1.47	–

Recommended tune → MSTW2008 LO (A2)

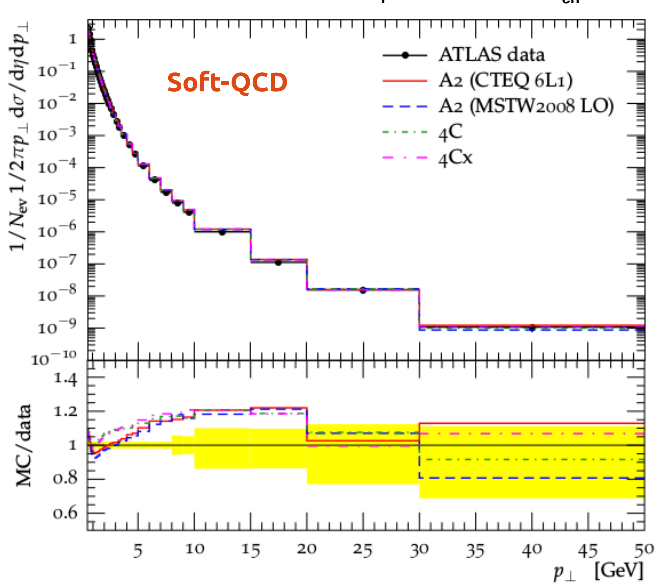
LO PDF's only for AM2 tune

LO, mLO & NLO PDF's for AU2 tune

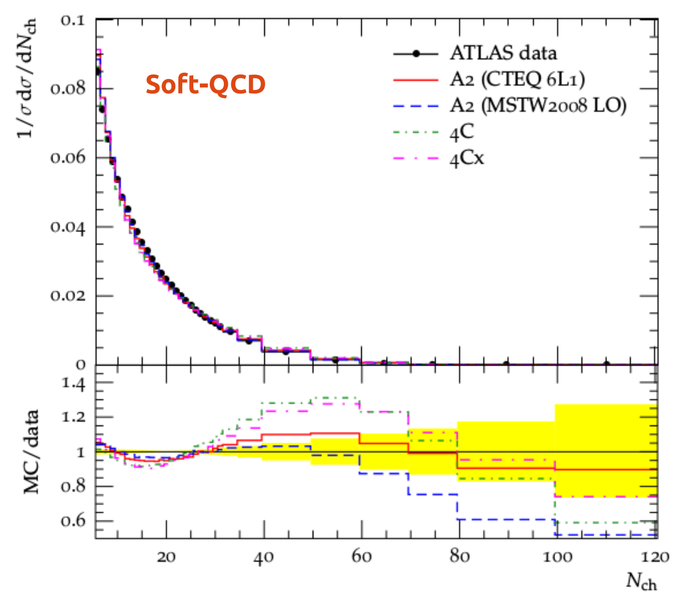
- **Results:**

  → AM2 tune demonstrates improvement over author 4C(x) tunes.
  → Improved Pile-up simulation.
  → Reference for MB and UE (AU2) modelling @ ATLAS.

Charged particle p_T at 7TeV, for $N_{ch} \geq 6$



Charged Multiplicity ≥ 6 at 7TeV, track p_T > 500MeV



“A14” Tunes (Global Tune)

MPI & Parton Shower Tune

ATL-PHYS-PUB-2014-021

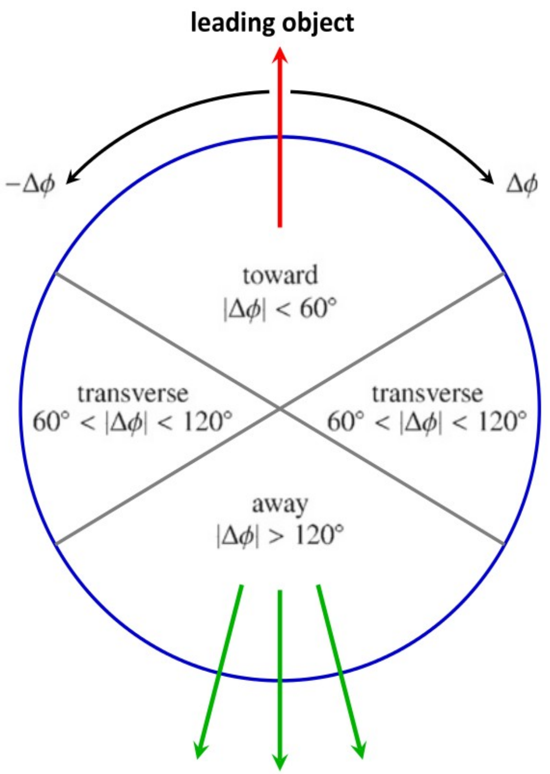
"A14" Global Tune → MPI & PS

- Only considered MPI tuning at present → **"A2" tunes**
  - Many observables sensitive to both MPI & PS parameters → **p^Z_T (ISR + MPI), 3/2 jet ratio (ISR + FSR)**
  - Especially for Pythia8 where showering & MPI are **interleaved.**

- Parton Shower modelling → **Phenomenological components**
  - Parameter value choice → **α_s values for ISR/FSR, evolution cut-offs, ...**

- "A14" tune performs simultaneous MPI & Shower tuning

- Tuning with ATLAS run 1 data @ √s = 7TeV.
  - **UE** in transverse region defined by leading p_T track/calorimeter jets → **<p_T>, N_{ch}, $\sum p_T$, etc...**
  - **FSR:** Jet structure → **track jet p_T, jet mass, jet shapes in inclusive jet/ttbar samples, etc...**
  - **ISR:** Additional jet emissions → **Di-Jet Decorrelation, 3/2 jet ratio, ttbar gap fractions**



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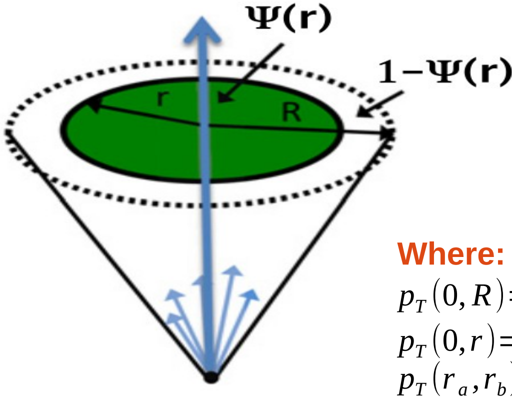


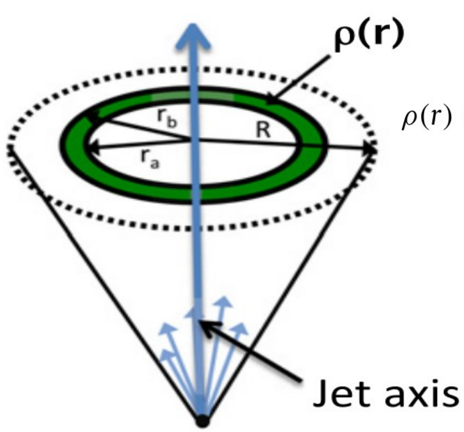
$$\psi(r) = \frac{1}{N_{jets}} \cdot \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}.$$

Where:

$p_T(0,R)$ = jet p_T

$p_T(0,r)$ = integral of p_T from jet center to radius r

$p_T(r_a, r_b)$ = integral of p_T from jet radius r_a to r_b



$$\rho(r) = \frac{1}{\delta r} \cdot \frac{1}{N_{jets}} \cdot \sum_{jets} \frac{p_T(r_a, r_b)}{p_T(0,R)}$$

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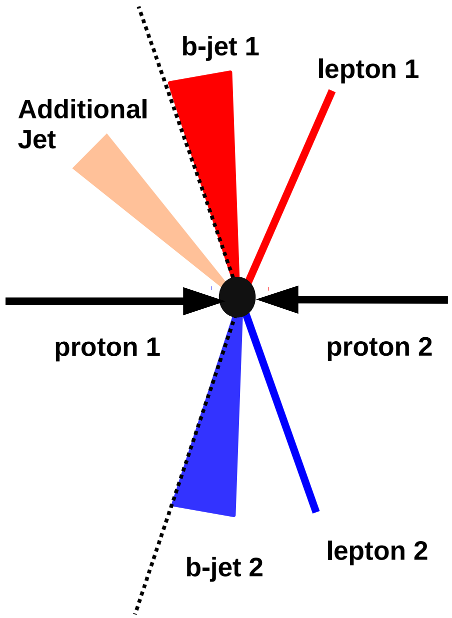
Gap Fraction defined as:

$$f(Q_0) = n(Q_0)/N$$

Where:

$n(Q_0)$ = number of events with no additional jet with p_T > Q_0 in a central rapidity region

N = number of ttbar events



“A14” Global Tune → MPI & PS

- Tuning based on Pythia8.186 Monash tune + simultaneous variation of **10 parameters:**

Parameter	Definition	Sampling range	
SigmaProcess:alphaSvalue	The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15	**Hard Scatter**
SpaceShower:pT0Ref	ISR p_T cutoff	0.75 – 2.5	**Parton Shower**
SpaceShower:pTmaxFudge	Mult. factor on max ISR evolution scale	0.5 – 1.5	
SpaceShower:pTdampFudge	Factorisation/renorm scale damping	1.0 – 1.5	
SpaceShower:alphaSvalue	ISR α_S	0.10 – 0.15	
TimeShower:alphaSvalue	FSR α_S	0.10 – 0.15	
BeamRemnants:primordialKThard	Hard interaction primordial $k_\perp$	1.5 – 2.0	**Non-Perturbative**
MultipartonInteractions:pT0Ref	MPI p_T cutoff	1.5 – 3.0	
MultipartonInteractions:alphaSvalue	MPI α_S	0.10 – 0.15	
BeamRemnants:reconnectRange	CR strength	1.0 – 10.0	

- Standard tuning methodology applied
  - → **Each observable bin parametrised as a 10-dimensional 3rd order polynomial.**
  - → **...**
- Tune performed for a set of 4 PDF's → **CTEQ6L1, MSTW2008LO, NNPDF23LO & HERAPDF15LO**

“A14” Global Tune → MPI & PS

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Parameter	Definition	Sampling range			CTEQ	MSTW	NNPDF	HERA
`SigmaProcess:alphaSvalue`	The α_S value at scale $Q^2 = M_Z^2$	0.12	–	0.15	0.144	0.140	0.140	0.141
`SpaceShower:pT0Ref`	ISR p_T cutoff	0.75	–	2.5	1.30	1.62	1.56	1.61
`SpaceShower:pTmaxFudge`	Mult. factor on max ISR evolution scale	0.5	–	1.5	0.95	0.92	0.91	0.95
`SpaceShower:pTdampFudge`	Factorisation/renorm scale damping	1.0	–	1.5	1.21	1.14	1.05	1.10
`SpaceShower:alphaSvalue`	ISR α_S	0.10	–	0.15	0.125	0.129	0.127	0.128
`TimeShower:alphaSvalue`	FSR α_S	0.10	–	0.15	0.126	0.129	0.127	0.130
`BeamRemnants:primordialKThard`	Hard interaction primordial $k_\perp$	1.5	–	2.0	1.72	1.82	1.88	1.83
`MultipartonInteractions:pT0Ref`	MPI p_T cutoff	1.5	–	3.0	1.98	2.22	2.09	2.14
`MultipartonInteractions:alphaSvalue`	MPI α_S	0.10	–	0.15	0.118	0.127	0.126	0.123
`BeamRemnants:reconnectRange`	CR strength	1.0	–	10.0	2.08	1.87	1.71	1.78

- **α_s** tuning results similar for all PDFs

  Hard process α_s higher than default 0.1265

  α_s(FSR) < α_s(default/Monash) tune → Tension in LEP vs LHC jet observables?

“A14” Global Tune → MPI & PS

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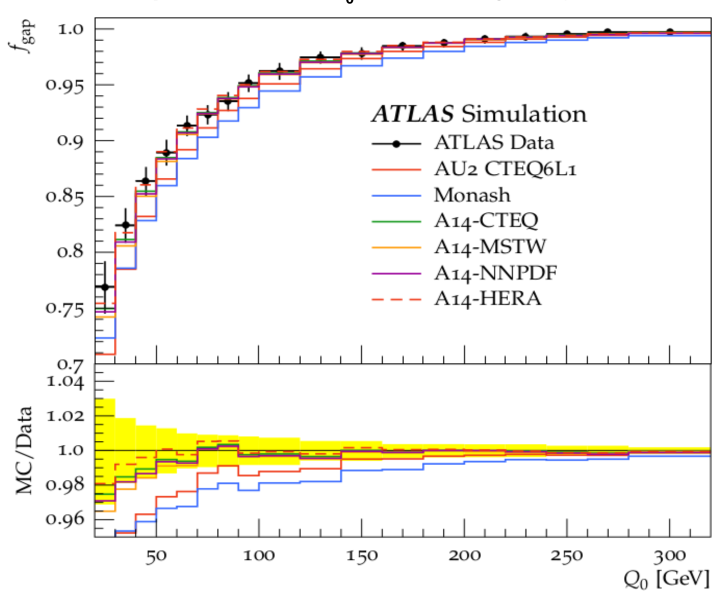
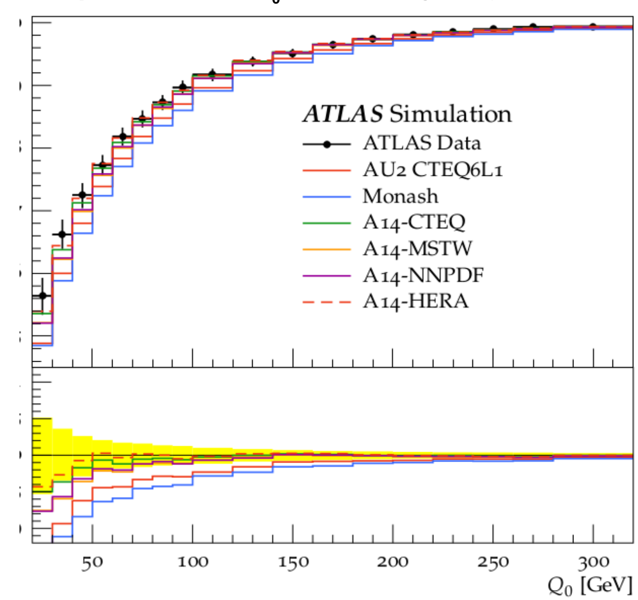
  - **α_s(FSR) < α_s(default/Monash) tune → Tension in LEP vs LHC jet observables?**

- Damped Shower in ttbar process includes some emissions above factorisation scale. → **Improved agreement in ttbar gap fraction.**

Gap Fraction vs Q_0 for veto region, y ≤ 0.8



Gap Fraction vs Q_0 for veto region, y ≤ 2.1

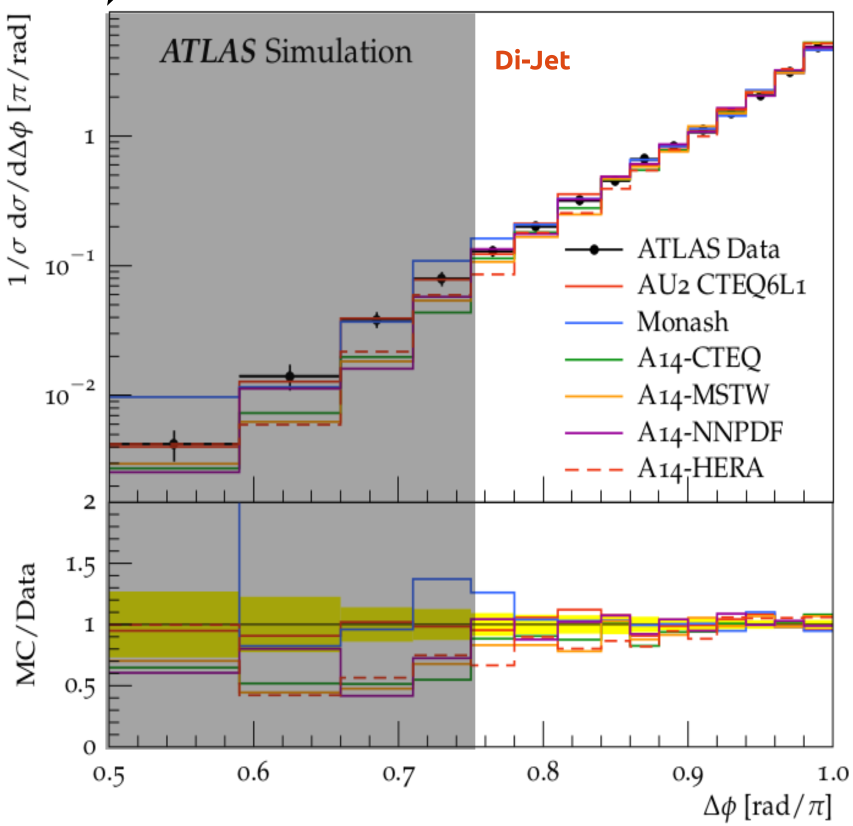


"A14" Global Tune: Results

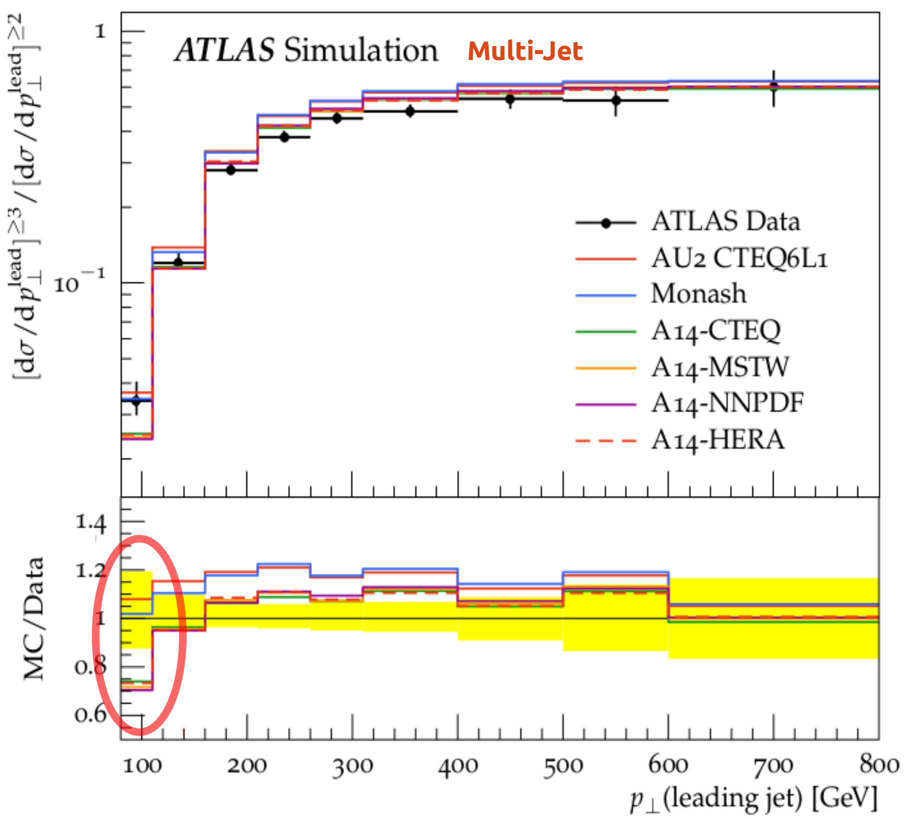
- Back-to-back configurations favoured → Excludes regions sensitive to multiple emissions at ME

- 3-to-2 jet ratio improvement
  → **at expense of σ_3/σ_2 ratio in soft events ($p_{T\ lead}$ < 100Gev).**
  → **BSM use case, so sacrificed here.**

Dijet azimuthal decorrelation for 210 < p_T^{Max} < 260GeV



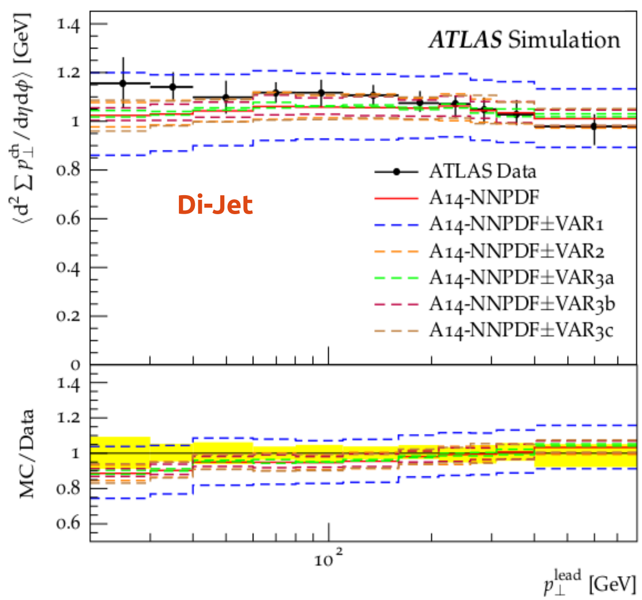
3-to-2 jet ratio for p_T > 60GeV (R=0.6)



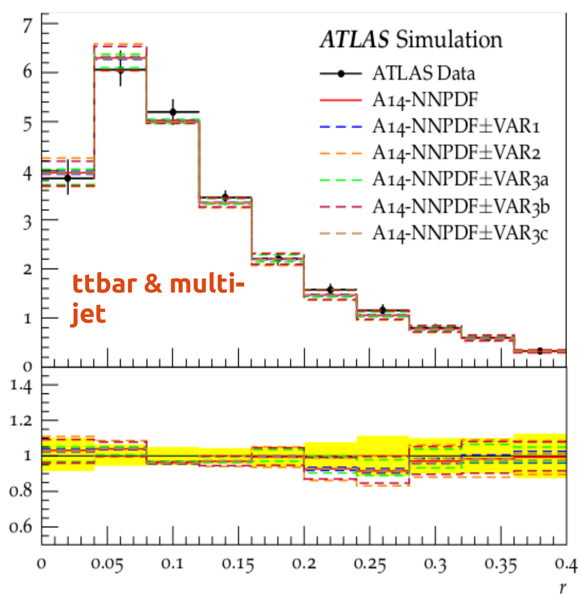
"A14" Global Tune: Systematic Variations

- Systematic variations for A14-NNPDF tune performed using eigentune Professor toolkit.
  - NNPDF chosen because it was most recent PDF & had error set.
  - (10 parameters) x (2 variations per parameter) → **Total: 20 variations**
- 20 variations too unwieldy.
  - Reduce to a subset of tune variations
  - 1 pair for Underlying Event → **UE**
  - 1 pair for Jet Structure → **FSR**
  - 3 pairs for extra jet production → **ISR**
- ISR uncertainties could not be reduced to a smaller subset. → **Reduction is physics dependent.**

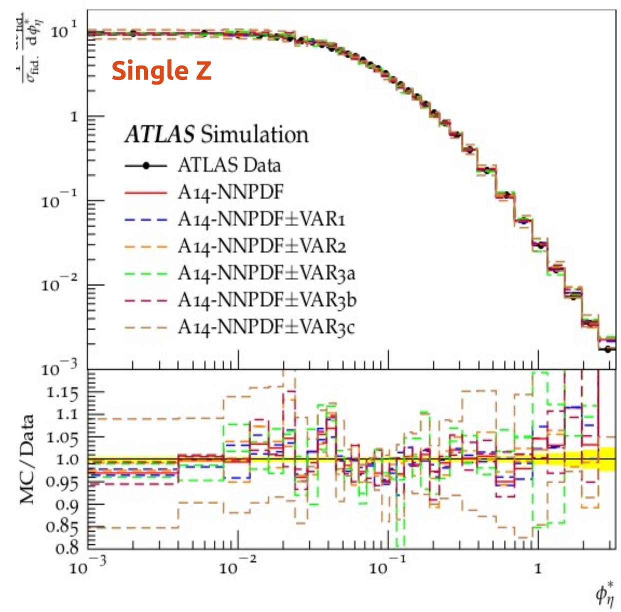
Transverse $\sum p_T^{CH}$ vs p_T^{lead} in $|\eta| < 2.5$, excl dijet events



Differential jet shape for b-jets with 30GeV < p_T < 40GeV



Φ^*_n spectrum, Z → ee (bare)



“ATTBAR” Tunes

Parton Shower & NLO ME (ttbar)

ATL-PHYS-PUB-2015-007

ATTBAR Tune → PS + NLO ME tune

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- ttbar receives significant corrections at NLO.
  - → Pythia8 approx NLO corrections via $dP_{ISR}/dp_T^2 \propto \frac{1}{p_T^2} \cdot \frac{k^2 M^2}{k^2 M^2 + p_T^2}$

  $k^2 = p^{ISR}_{T,min}$ tuned

- LO+PS often not sufficient for many process, ttbar especially.

- LHC measurements @ √s = 7TeV accurate enough for ttbar tuning.
  - → **Compare results to global ("A14"), dedicated Z (AZNLO) or even LEP tuning**
  - → **ttbar gluon-gluon dominated production**
  - → **Z is quark-quark dominated production**

  } **Testimony to "universality"?**

- ATLAS measurements of:
  - → **Jet multiplicities/p_T**
  - → **Central Gap Fractions**
  - → **ttbar jet shapes**

- **Tuning in 2 steps:**
  - → **Tuning of Pythia 8.201 (normalised to data)**
    - Measure sensitivity of observables to ISR/FSR & tune separately
    - Factorisation of ISR & FSR not exact
      - → **Combined tuning**
  - → **Application of tune to matched to Powheg/MG_aMC@NLO.**
    - Powheg **hdamp** factor for ISR real radiation.
    - aMC@NLO **upper/lower scale factor** for real radiation subtraction term.

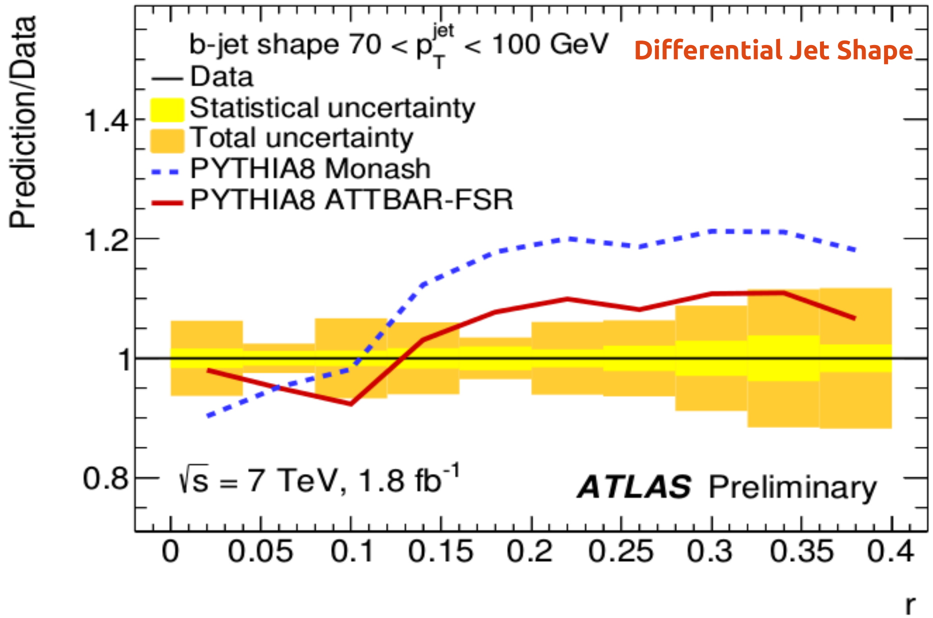
ATTBAR Tune → PS + NLO ME tune

- b-jet modelling also identified as an issue in Pythia 8.201.
  - → α^{FSR}_{s} value tension for light vs b-jets.
  - → χ^2/dof of light-jet closer to unity than b-jet. Indicates b-jet mismodelling
  - → **Therefore simultaneous tune only uses light jet shapes**

Parameter	light-jet shapes	*b*-jet shapes	4C
$\alpha_s^{FSR}(m_Z)$	0.131 ± 0.001	0.126 ± 0.001	0.1383
$\chi^2_{min}/\mathrm{dof}$	64/49	284/49	

Parameter	light-jet shapes	*b*-jet shapes	Monash
$\alpha_s^{FSR}(m_Z)$	0.125 ± 0.001	0.121 ± 0.001	0.1365
$\chi^2_{min}/\mathrm{dof}$	71/49	219/49	

Deviation from unity indicates modelling issues of b-jets



- Pythia8 standalone tune is based on **4C & Monash** tunes.
  - → **"ATTBAR" is based on Monash with NNPDF23LO PDF**
  - → **Other is 4C tune with CTEQ6L1 PDF**

- Correlated experimental uncertainties considered for first time.
  - → Taken into account in MC tuning via the χ^2 definition
  - → **Reduces uncertainties**

- Parameters tuned for Pythia 8.201 are ISR/FSR parameters:

Parameter	ATTBAR	Tune without uncertainties correlations
$\alpha_s^{ISR}(m_Z)$	0.121 ± 0.004	$0.118^{+0.007}_{-0.006}$
$p_{T,damp}^{ISR}$	$1.18^{+0.08}_{-0.07}$	$1.17^{+0.10}_{-0.09}$
$\alpha_s^{FSR}(m_Z)$	0.137 ± 0.003	$0.138^{+0.006}_{-0.005}$
$p_{T,min}^{FSR}$ [GeV]	1.26 ± 0.17	1.35 ± 0.35
χ^2_{min}/dof	92/85	13/85

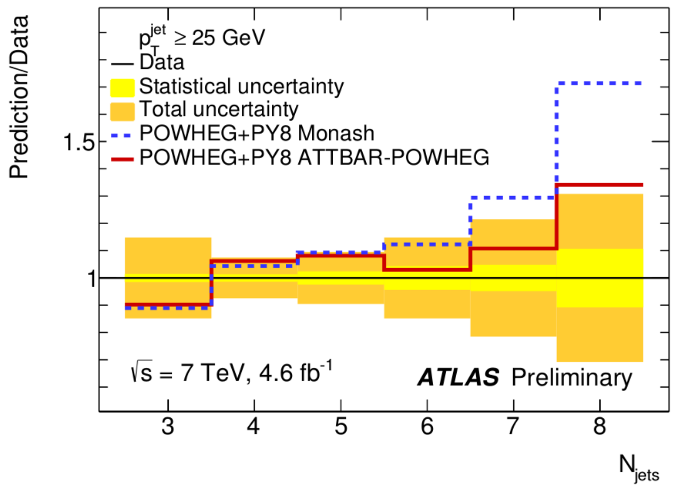
Indicative of over estimation of errors

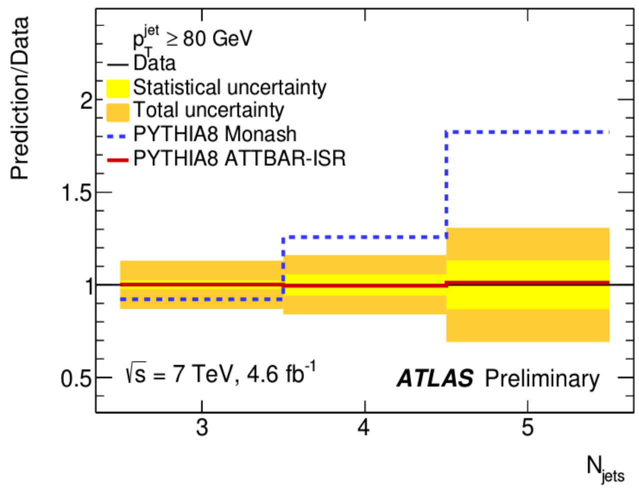
- Powheg+Pythia 8.201 (**"ATTBAR-POWHEG"**)
  - → **hdamp = h x m_{top} factor:** "**h**" is tunable parameter
  - → **Result:** **$h = 1.8^{+0.4}_{-0.3}$**

- MadGraph5_aMC@NLO + Pythia 8.201 tuning ("**ATTBAR-MG5aMC@NLO**")
  - → **f ≡ frac_upp = frac_down**
  - → **Result:** **f = 0.58 (+- 0.03) "*Global Recoil*" or f = 0.54 (+- 0.03) "*Local Recoil*"**

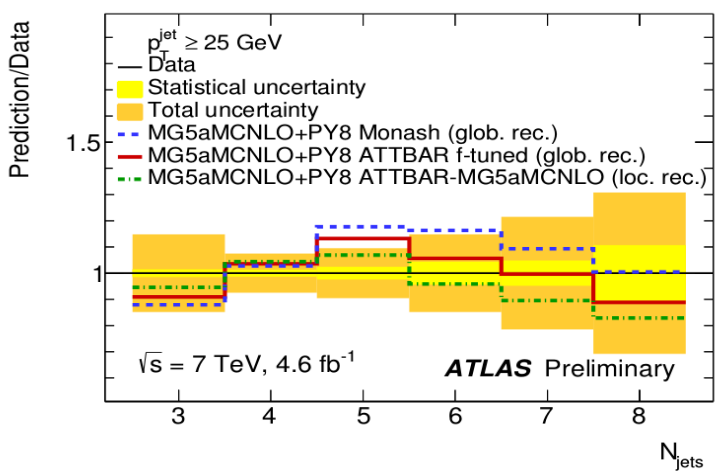
ATTBAR Tune → PS + NLO ME tune

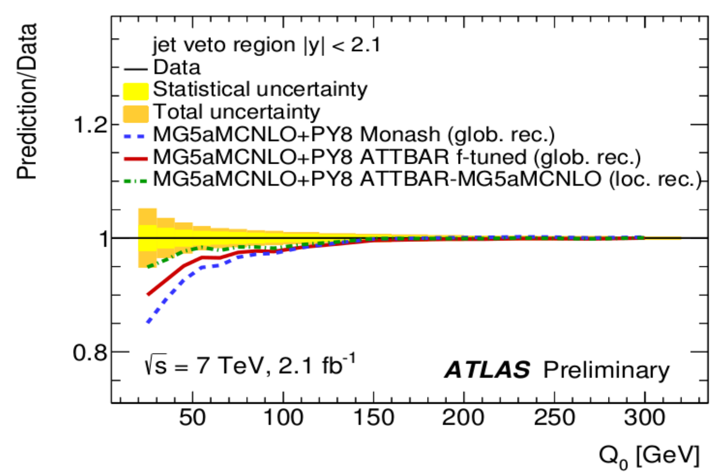
- Powheg+Pythia 8.201 tuning to jet multiplicity, jet p_T & gap fraction (Q_0) offered optimal tuned value:





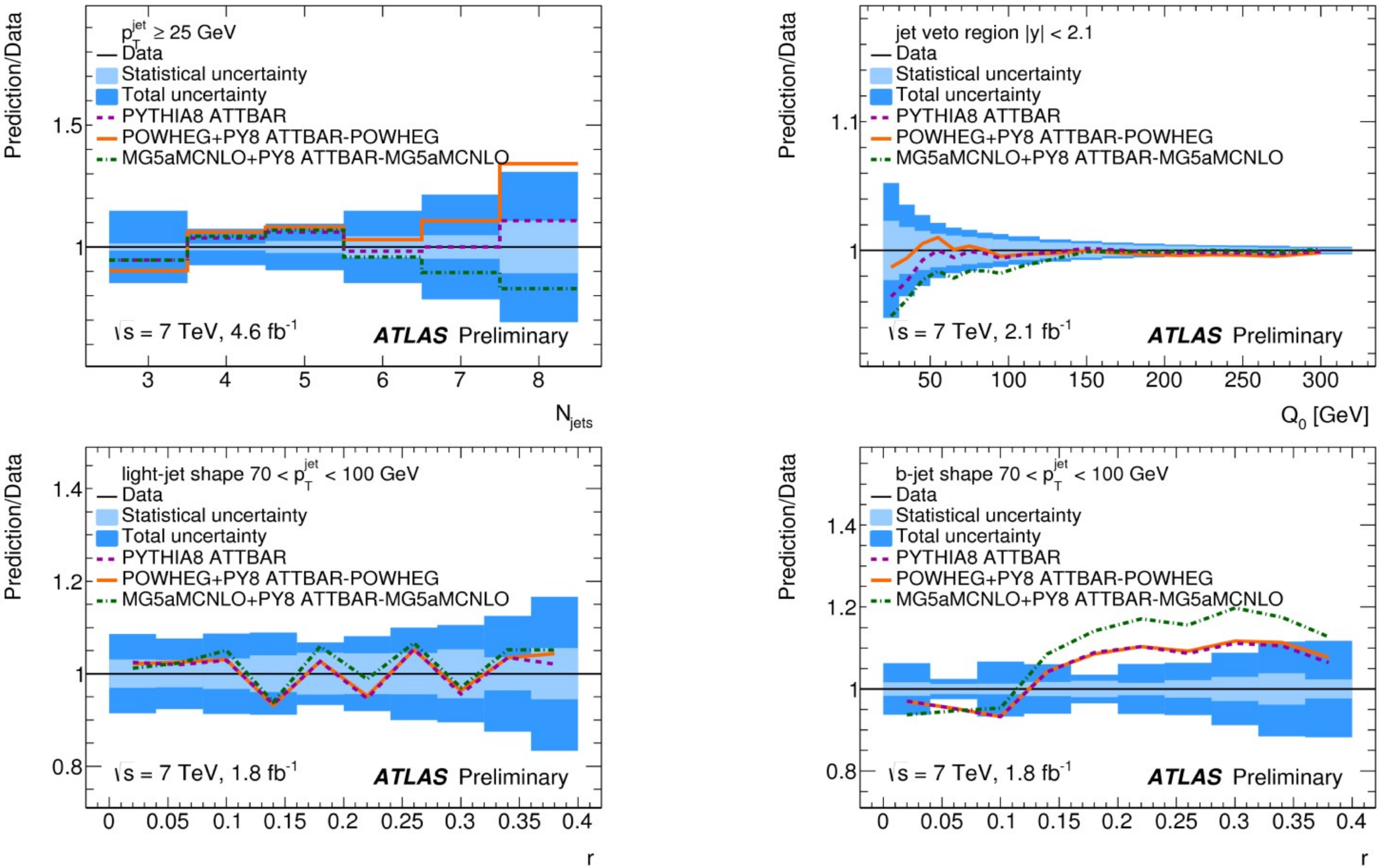
- MadGraph5_aMC@NLO tuned using both "*global recoil*" & "*local recoil*".
  - → **Global recoil favoured theoretically, but local recoil models data more accurately.**
  - → **χ^2/dof closer to unity in local recoil case**





ATTBAR Tune → PS + NLO ME tune

- Powheg+Pythia 8.201 comparison of ATTBAR, ATTBAR-Powheg & ATTBAR-aMC@NLO:



“MG5aMC@NLO(-TTBAR)” Tunes

Parton Shower & MPI tune with NLO ME attachment

ATL-PHYS-PUB-2015-048

MG5aMC@NLO(-TTBAR)

- Dedicated tune of Pythia 8.186 PS + MPI, when matched to the NLO ME generator MadGraph5_aMC@NLO.

- Two tunes available, “MG5aMC@ NLO“ & “MG5aMC@NLO-TTBAR”.
  → **General tune to inclusive jet, ttbar & Z events.**
  → **“***-TTBAR” tune to ttbar events.**
  → **Based on “A14” global tune.**

- Z & ttbar events tuned using √s = 7TeV 2011 data
  Inclusive jet events tuned using √s = 7TeV 2010 data (stats limited)

- Observables categorised into 3 categories:

  ttbar:
  →**Jet shapes, differential jet multiplicity/p_T & gap fraction.**

  Z Events:
  → **Z→ee uses Φ^*_η & Z→μμ uses p_T**
  → **N_{ch}, Σp_T.**

  Inclusive Jets:
  → **jet shapes, dijet decorrelation, jet rapidity etc...**

- 2 PDFs used:
  → **CT10 used for MG5_aMC@ NLO (NLO PDF)**
  → **NNPDF23LO for Pythia 8.186 (LO PDF).**

MG5aMC@NLO(-TTBAR)

- 7 parameters entered into tune:

Parameter	Pythia8 settings	Definition	Sampling range
$p_{\mathrm{T0,Ref}}^{\mathrm{ISR}}$ [GeV]	`SpaceShower:pT0Ref`	ISR p_{T} cutoff	0.75 – 2.5
α_S^{ISR}	`SpaceShower:alphaSvalue`	ISR α_S	0.115 – 0.140
$p_{\mathrm{T,min}}^{\mathrm{FSR}}$ [GeV]	`TimeShower:pTmin`	FSR p_{T} cutoff	0.5 – 2.0
α_S^{FSR}	`TimeShower:alphaSvalue`	FSR α_S	0.115 – 0.15
$p_{\mathrm{T0,Ref}}^{\mathrm{MPI}}$ [GeV]	`MultipartonInteractions:pT0Ref`	MPI p_{T} cutoff	1.5 – 3.0
α_S^{MPI}	`MultipartonInteractions:alphaSvalue`	MPI α_S	0.115 – 0.140
P. $k_{\mathrm{T,hard}}$ [GeV]	`BeamRemnants:primordialKThard`	Hard interaction primordial $k_{\perp}$	1.5 – 2.0

- Matter profile uses 2D Gaussian model where $\langle k_T \rangle^2 = \sigma^2$
  → **I.e square of the mean primordial k_T functions as width of 2D Gaussian matter profile**

- Following recommendations of authors "*Global Recoil*" is set.
  → **Despite previous tunes showing better agreement, theoretical consistency was favoured.**

- Standard Tuning Methodology
  → **500 parameter points sample 7-dimensional hypercube**
  → **3rd order polynomial for each dimension**
  → **...**

- Larger weights applied to Z & ttbar events
  → **Non-correlated observables offer significant control in tuning**
  → **E.g Drell-Yan process perfect for ISR tuning. No FSR overlap. Thus higher weight.**

MG5aMC@NLO(-TTBAR)

- 7 parameters entered into tune → **A15 Tune results**:

Parameter	A14	ATTBAR	AZ	A15-MG5aMCNLO	A15-MG5aMCNLO-TTBAR
α_S^{FSR}	0.127	0.137	(0.1383)	0.1385	0.122
$p_{T,min}^{FSR}$ [GeV]	(0.5)	1.26	(0.4)	1.18	1.0
α_S^{ISR}	0.127	0.121	0.1237	0.1267	0.119
$p_{T0,Ref}^{ISR}$ [GeV]	1.56	(2.0)	0.59	0.87	0.7
α_S^{MPI}	0.126	(0.130)	(0.135)	0.124	0.115
$p_{T0,Ref}^{MPI}$ [GeV]	2.09	(2.16)	(2.18)	2.06	1.7
P. $k_{T,hard}$ [GeV]	1.88	(1.8)	1.71	1.74	(1.88)
R. range	1.71	(1.8)	(1.5)	(1.71)	(1.71)

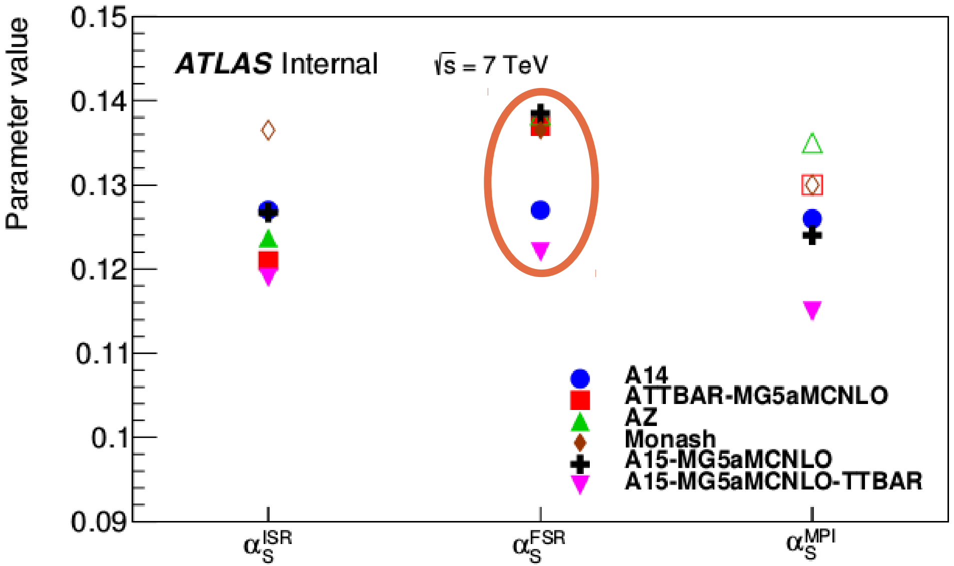
Global tune of PS+MPI using Z & ttbar events

ATTBAR-MG5aMC@NLO+Pythia8 tune *(Local Recoil)*

Z/γ* tune dedicated to ISR & MPI cut off tuning in low p_T Z production.

What to Take away

- One "A14" feature was a small α_s^{FSR} value, compared to LEP observables.
  → **Tune restores α_s^{FSR} back to LEP value.**
  α_s^{FSR}(A15) = 0.1385
  α_s^{FSR}(Monash) = 0.1365



MG5aMC@NLO(-TTBAR)

What to Take away

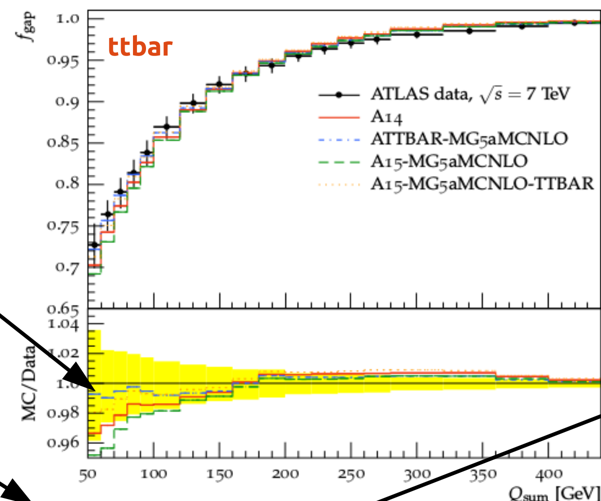
- Marginal improvement in modelling from previous tunes.
  - → **However several key features address previous tensions observed.**

- Dedicated tunes to ttbar events model gap fraction far better.
  - → **ISR tuning, to ttbar events, facilitates better agreement for gap fraction**

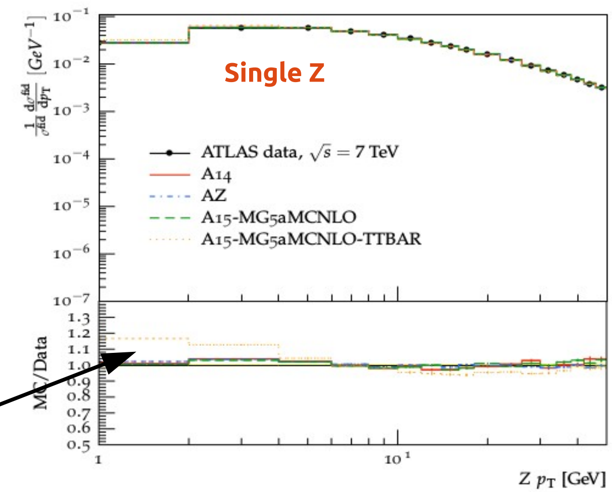
- MG5aMC@NLO general tune, models jet shapes best.

- Poor description of UE properties by "TTBAR" variant → **No MPI tuning performed in TTBAR sample**

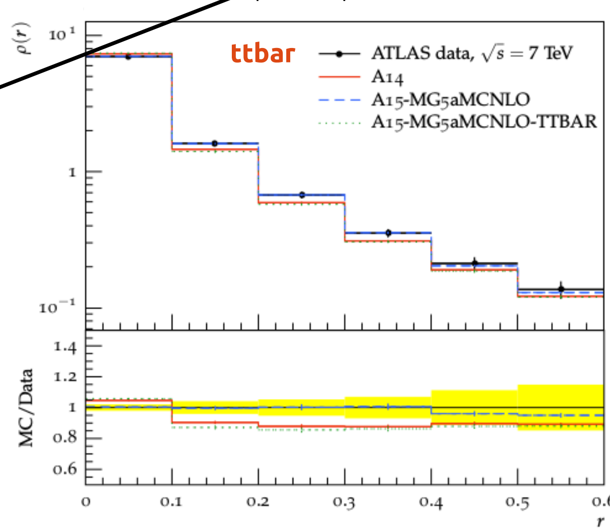
Gap Fraction vs Q_{sum} for veto region, |y| < 2.1



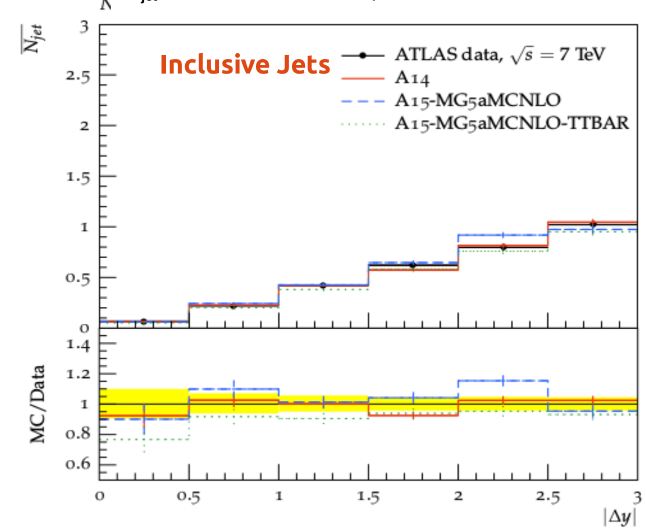
Z → μμ "dressed", Inclusive



Jet shape ρ for p_T 210 < p_T < 260GeV, 0 <y< 2.8



N_{jet} vs |Δy| for 150 < p_T < 180, Fwd/Bwd



Conclusion

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  - → **Forms basis of pileup modelling @ ATLAS**
  - → **Therefore concerned with MB tuning over UE**

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  - → **Systematic Error sets for UE, FSR & ISR**

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- ATTBAR series:
  - → **First dedicated ttbar tune**
  - → **First time experimental correlations considered**
  - → **Identified b-jet mismodelling concerns → Resolved A14 & LEP α_s disagreement**
  - → **MG5_aMC@NLO demonstrated local recoil offers better agreement to data**
  - → **Most accurate tune for ttbar events**

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  - → Most accurate tune for ttbar events

- A15 resolves many issues observed over the previous tunes:
  - → "ME + PS(tuned)" ≈ "{ME + PS}(tuned)" (doesn't matter which)
  - → α_s(FSR) between A14 & LEP rectified ~ b-jet modelling & weight of FSR sensitive observables
  - → MG5aMC@NLO global recoil tune only
  - → Offers the best general purpose tune for inclusive, ttbar & Z events.

Backup

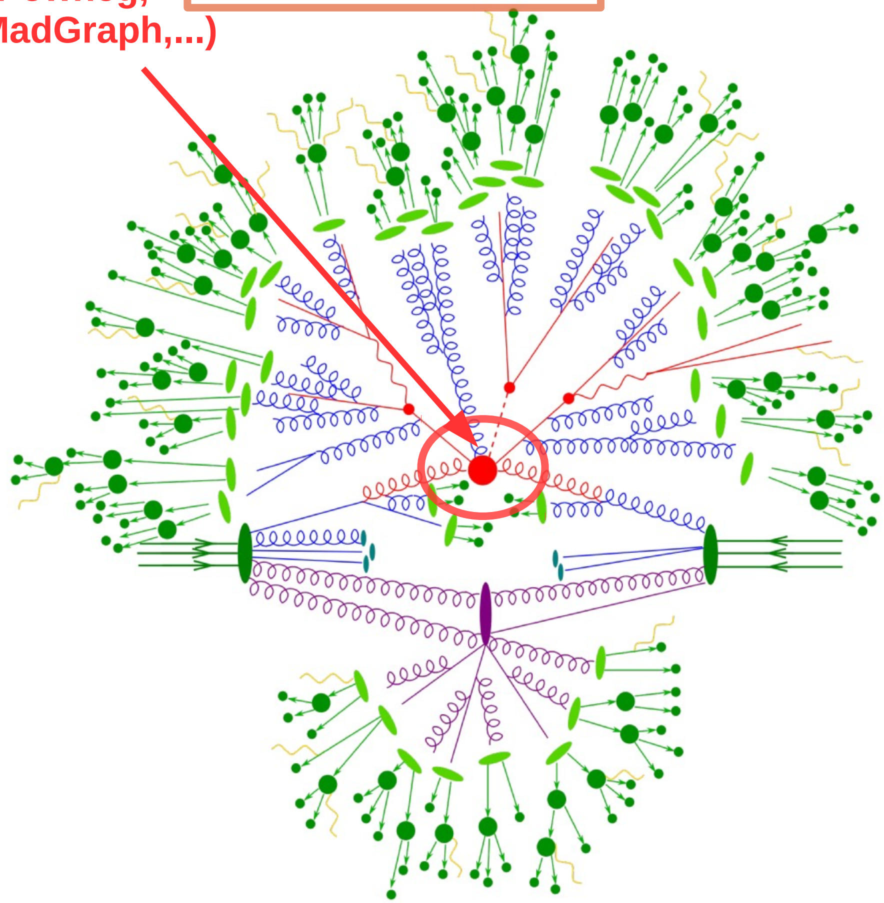
Monte Carlo Event Model

Perturbative QCD/QED:

Hard Scattering:

- Fixed Order (Powheg, aMC@NLO, MadGraph,...)

Derived from first principles → Do not want to tune.



Monte Carlo Event Model

Perturbative QCD/QED:

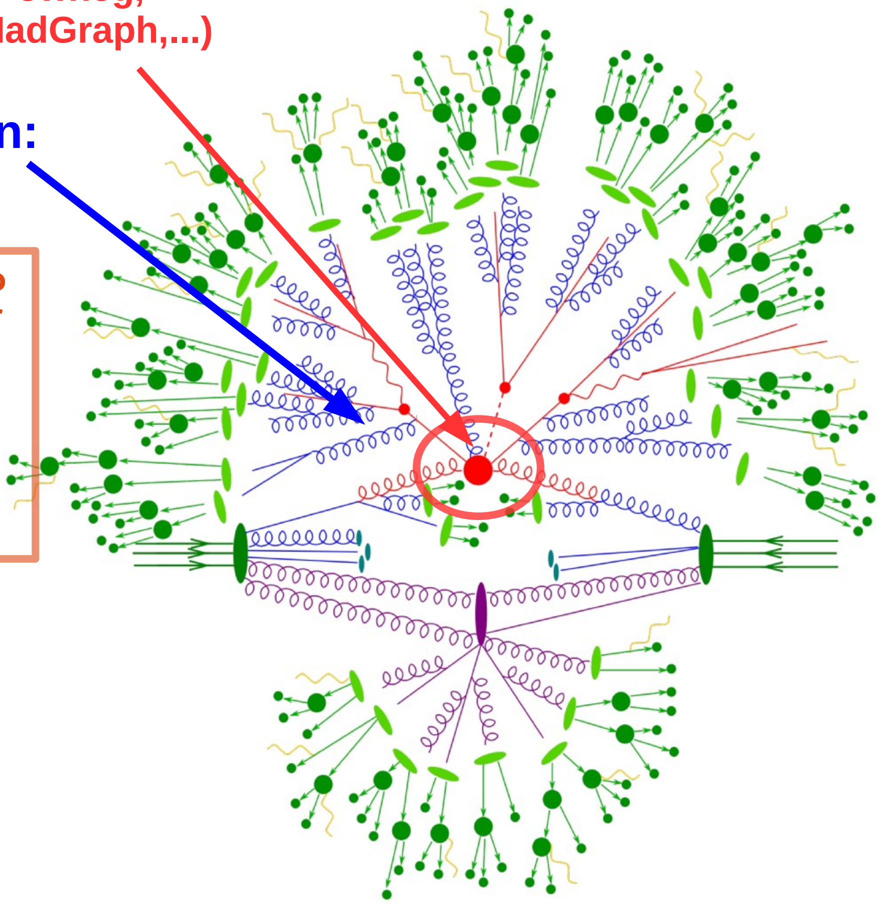
→ **Hard Scattering:**
- Fixed Order (Powheg, aMC@NLO, MadGraph,...)

→ **Fragmentation:**

Parton Shower
ISR & FSR

By ISR & FSR, I refer to radiation added under the parton shower scheme, unless otherwise noted.

Limited number of tunable parameters



Monte Carlo Event Model

Perturbative QCD/QED:

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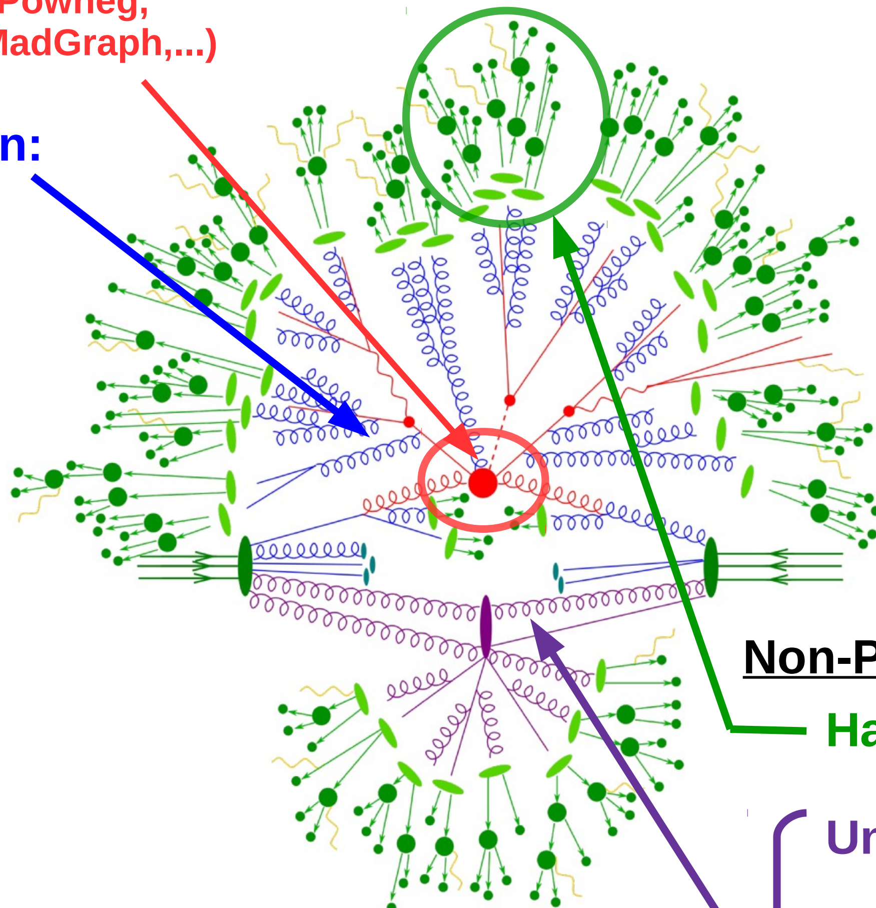

Empirical models.
Must be tuned to data.

Non-Perturbative QCD (npQCD):

Hadronisation: String/Cluster

Underlying Event:
MPI, SD, DD

Colour Reconnection

Beam Remnants

Monte Carlo Event Model

Perturbative QCD/QED:

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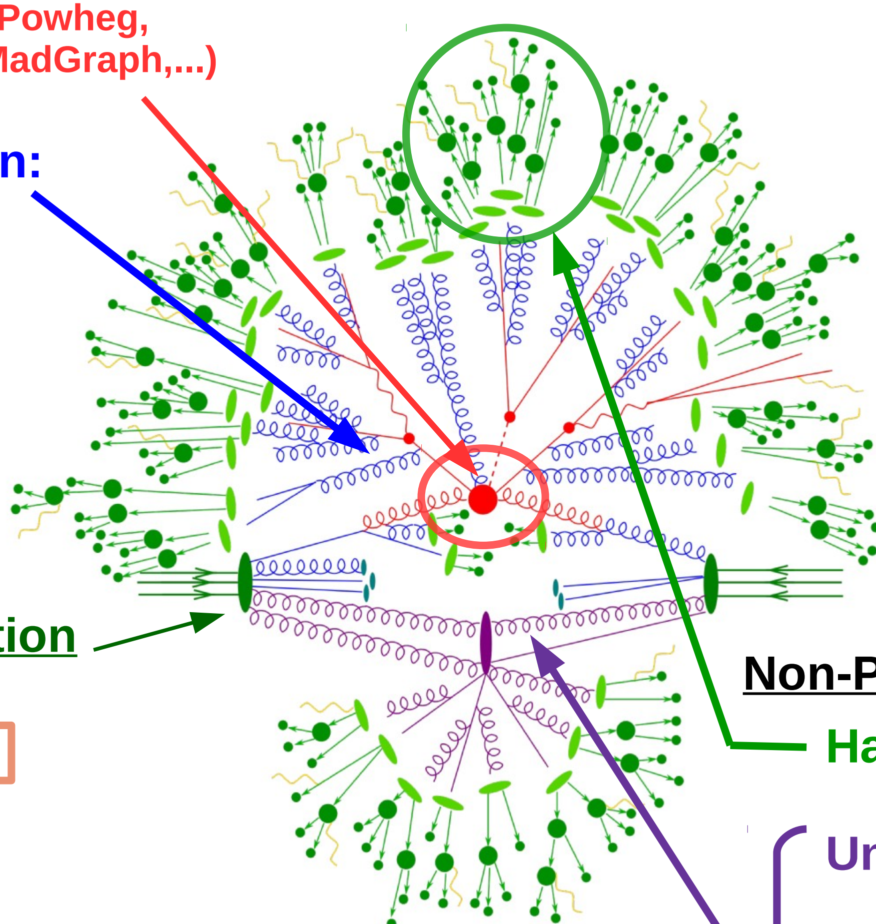


Parton Distribution Function (PDF)

Not Tuned

Non-Perturbative QCD (npQCD):

Hadronisation: String/Cluster

Underlying Event:

MPI, SD, DD

Colour Reconnection

Beam Remnants

Tuning Aspects of Monte Carlo

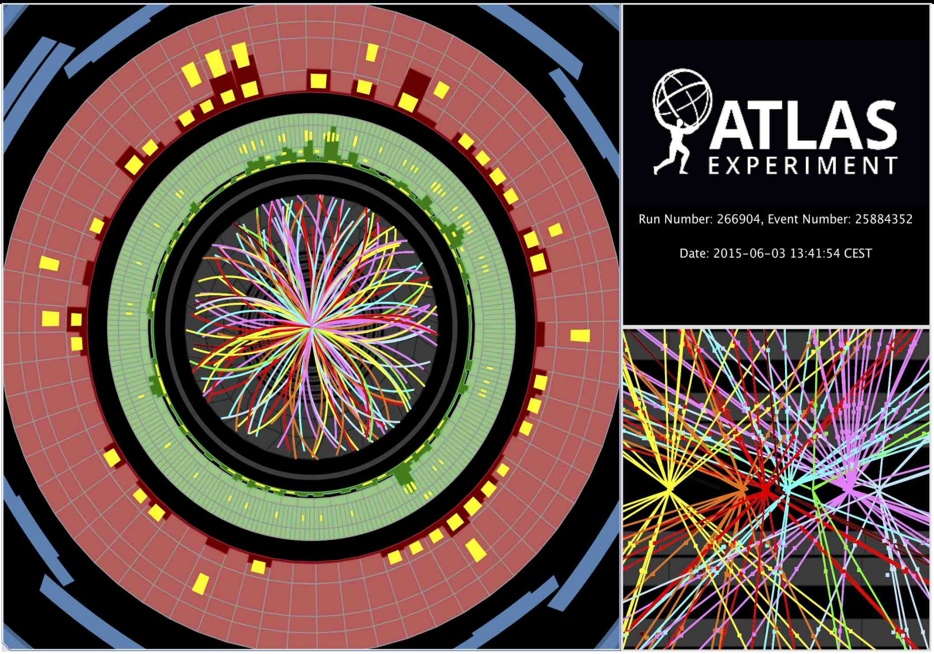
UCL

What can we tune then?

- Non-perturbative parameters can not be derived from first principles, so require tuning. √
- Higher order corrections absorbed into physical parameters → E.g ISR/FSR renormalisation scale tuned via α_s values, or Powheg hdamp. √
- Regions of high p_T important for new physics → **Modelled by first principles.** X

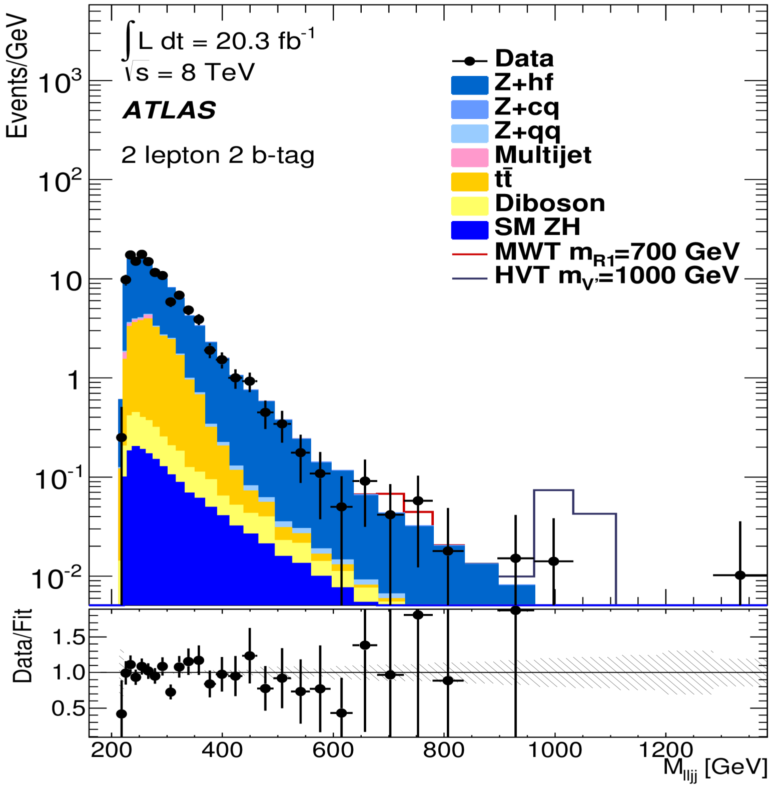
	Parameters:	*Sensitive Observables:*
Hard Scattering	μ_f, μ_r scales, hdamp, etc...	Ideally predicted by first princples → Scale variation to account for HO corrections
Beam Remnants	Primordial k_T, impact 'b',...	Tune with Z candle p^Z_T < 5GeV
Parton Shower (ISR, FSR)	$\alpha_s(M_Z)$, shower IR cutoff (p^{ISR}_T, ...), ...	Jet Shapes, p^Z_T, $p^{jet}_{T, ...}$ Tuned With LEP & LHC data
Multi-Parton Interactions (MPI)	infrared cut-off, α_s (MPI), ...	Hadron collider data using MB and UE observables
Color Reconnection	Range, Probability, ….	Underlying Event, MB & ttbar
Hadronisation	Fragementation function, HF fragmentation fraction, ...	LEP data for ee → Z → hadrons (light/HF)
Decays	Lifetime & Decay widths	PDG validated with data

Monte Carlo Uses at ATLAS



Pile-up simulation + Calibration:

- Overlay hard event with '*n*' inclusive inelastic scatters → **Pile-up**
  - Useful for measuring pileup systematic uncertainties
  - Zero bias overlay as possible pileup simulation alternative.
- Jet identification and calibration sensitive to pileup. → **Diffuse noise in reconstructed jets**



Unfolding:

- Extrapolation from Reconstruction to Particle Level

Background Estimates:

- Data control regions often define background **normalisation**
- MC define differential cross-section **shapes**.
- Over-tuning of non-perturbative parameters may hide **New Physics**

Methodology:

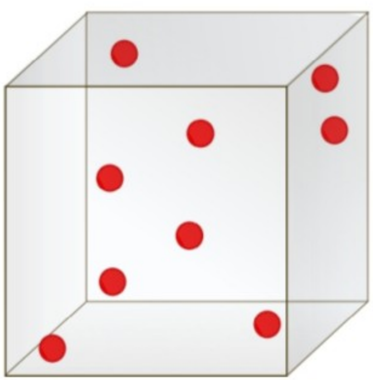
1. Choose parameter & parameter ranges
2. Choose relevant experimental data
   i. Process & fiducial cuts
   ii. Sensitive Observables
3. Sample N-parameter hypercube → Anchor Points
4. Generate samples for 'n' anchor points
5. Analytic approx of observable response to parameter changes.
6. X^2 minimisation of analytic approximation over full MC parameter space in MC/Data comparison.

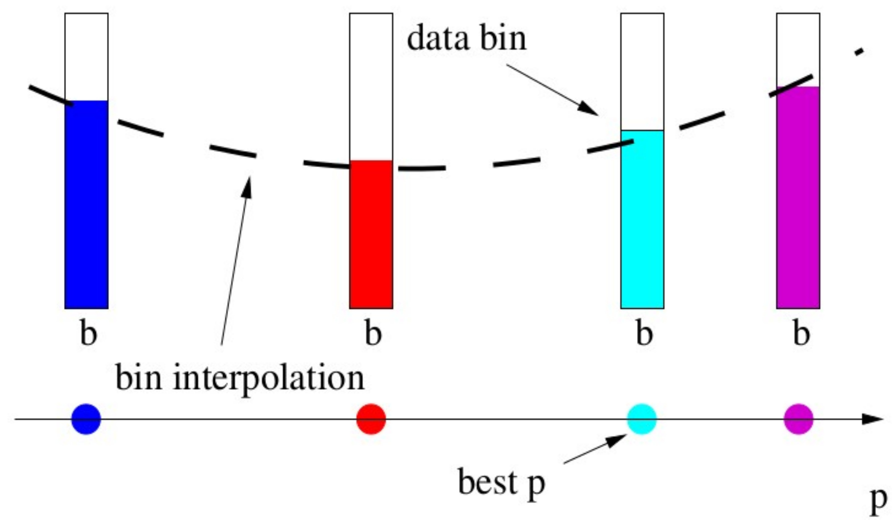
Tools

- **Human intuition**
- **Rivet Tool Kit**
  - **Particle Level Analysis**
  - **Data Analysis repository**
- **Professor**
  - **Random Sampling of parameter hypercube**
  - **Analytic approximation of observable response to parameters**

$$f_b(\vec{P}) = a_0^b + \sum_i B_i^b p'_i + \sum_{i \leq j} C_{ij}^b p'_i p'_j + \ldots$$

  - **Minimisation procedure for optimal parameter values**



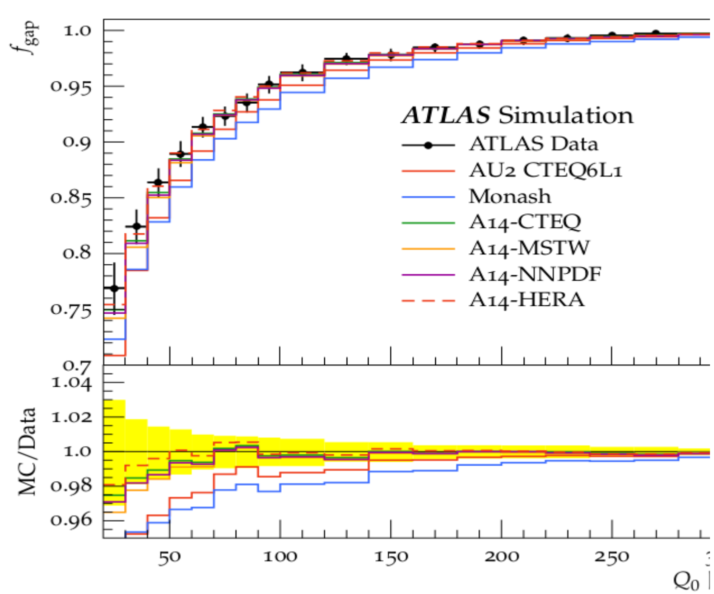


“A14” Global Tune: Results

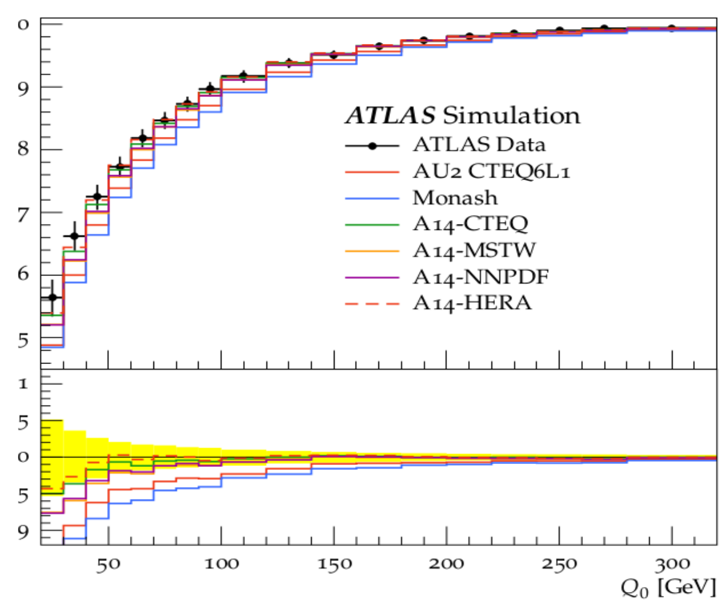
Parameter	Definition	Sampling range	EQ	MSTW	NNPDF	HERA
SigmaProcess:alphaSvalue	The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15	44	0.140	0.140	0.141
SpaceShower:pT0Ref	ISR p_T cutoff	0.75 – 2.5	30	1.62	1.56	1.61
SpaceShower:pTmaxFudge	Mult. factor on max ISR evolution scale	0.5 – 1.5	95	0.92	0.91	0.95
SpaceShower:pTdampFudge	Factorisation/renorm scale damping	1.0 – 1.5	21	1.14	1.05	1.10
SpaceShower:alphaSvalue	ISR α_S	0.10 – 0.15	25	0.129	0.127	0.128
TimeShower:alphaSvalue	FSR α_S	0.10 – 0.15	26	0.129	0.127	0.130
BeamRemnants:primordialKThard	Hard interaction primordial $k_\perp$	1.5 – 2.0	72	1.82	1.88	1.83
MultipartonInteractions:pT0Ref	MPI p_T cutoff	1.5 – 3.0	98	2.22	2.09	2.14
MultipartonInteractions:alphaSvalue	MPI α_S	0.10 – 0.15	18	0.127	0.126	0.123
BeamRemnants:reconnectRange	CR strength	1.0 – 10.0	08	1.87	1.71	1.78

- **α_s** tuning results similar for all PDFs
  - **Hard process α_s higher than default 0.1265**
  - **α_s(FSR) < α_s(default/Monash) tune → Tension in LEP vs LHC jet observables?**
- Damped Shower in ttbar process includes some emissions above factorisation scale. → **Improved agreement in ttbar gap fraction.**

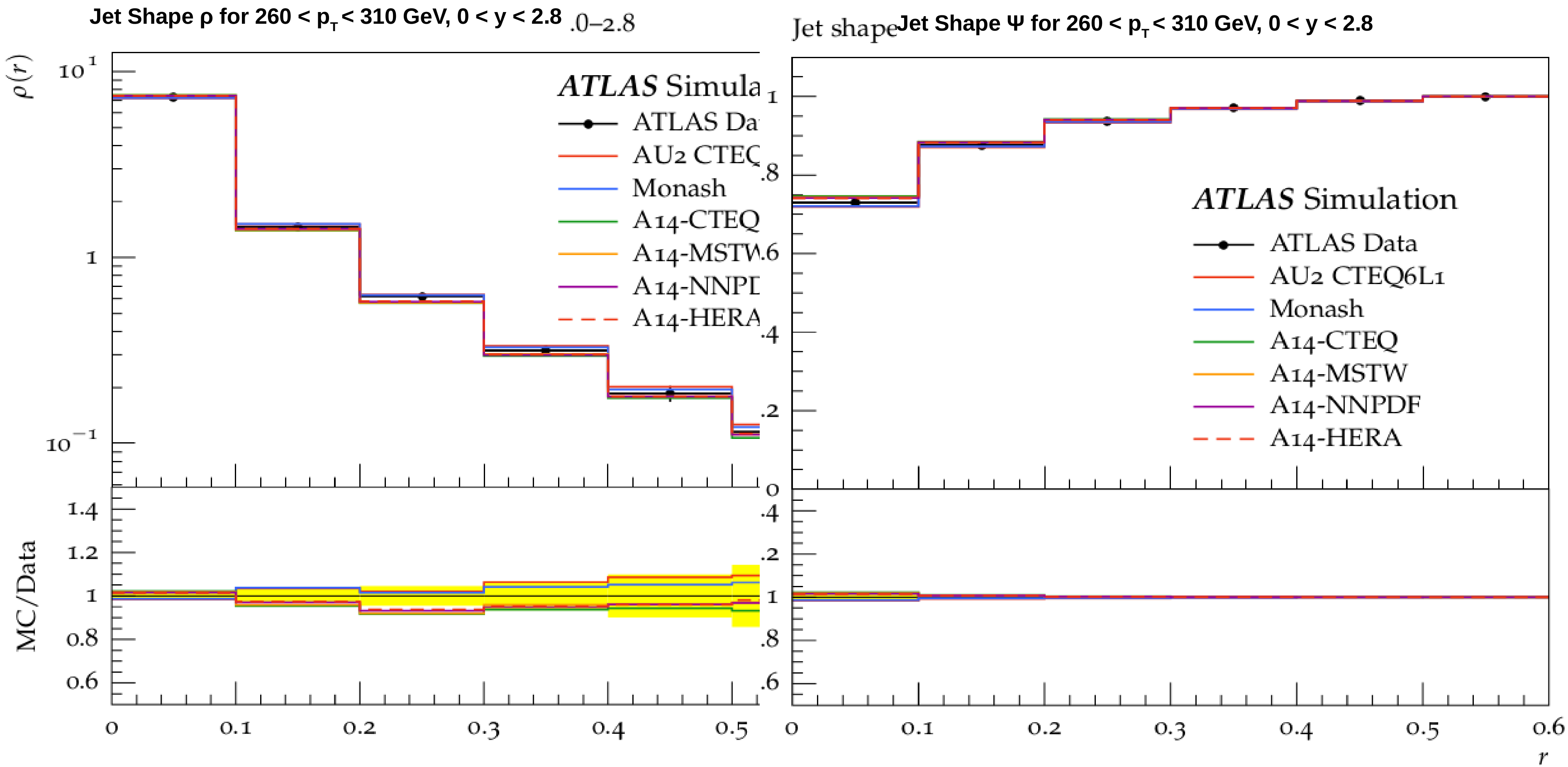
Gap Fraction vs Q_0 for veto region, y ≤ 0.8



Gap Fraction vs Q_0 for veto region, y ≤ 2.1



“A14” Global Tune: Results

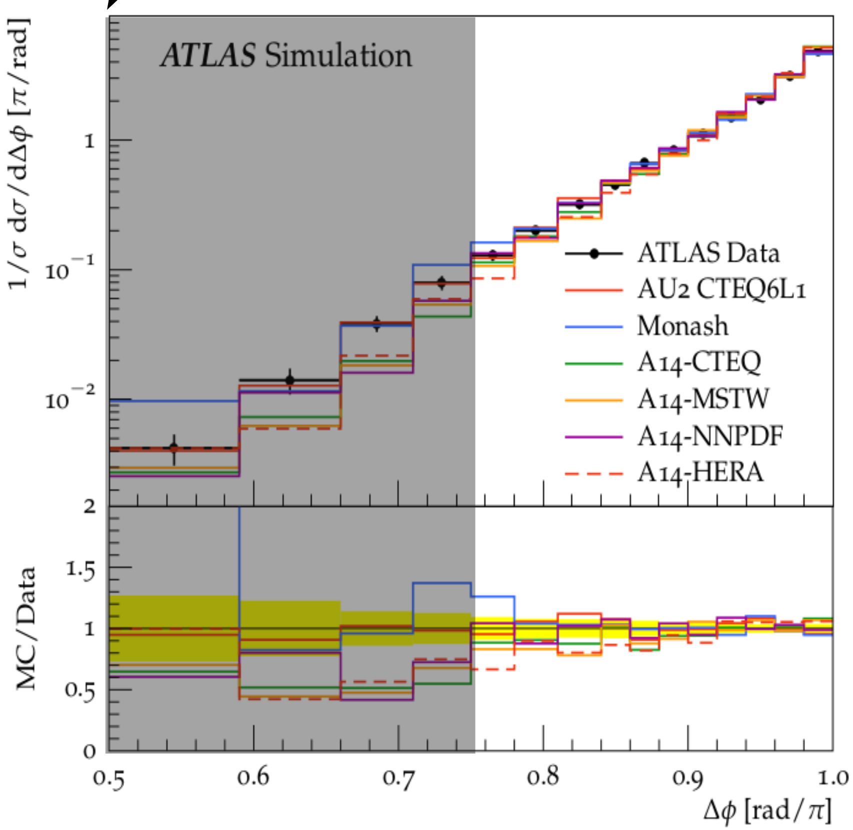


"A14" Global Tune: Results

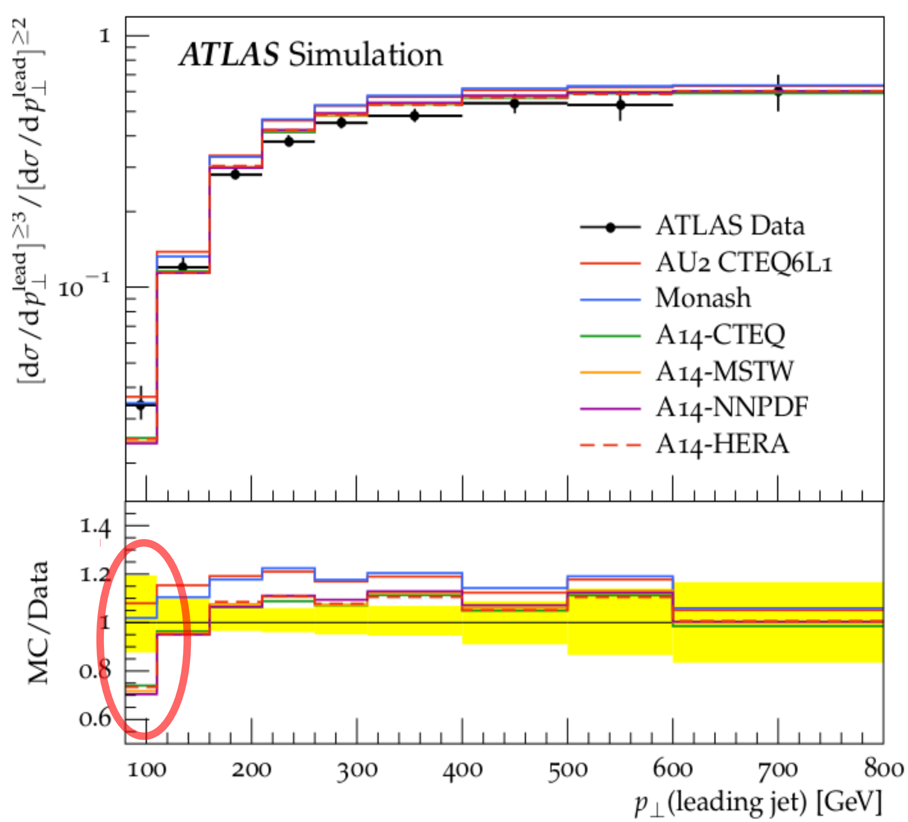
- Back-to-back configurations favoured → Excludes regions sensitive to multiple emissions at ME

- 3-to-2 jet ratio improvement
  → **at expense of σ_3/σ_2 ratio in soft events ($p_{T\ lead}$ < 100Gev).**
  → **BSM use case, so sacrificed here.**

Dijet azimuthal decorrelation for 210 < p_T^{Max} < 260GeV



3-to-2 jet ratio for p_T > 60GeV (R=0.6)

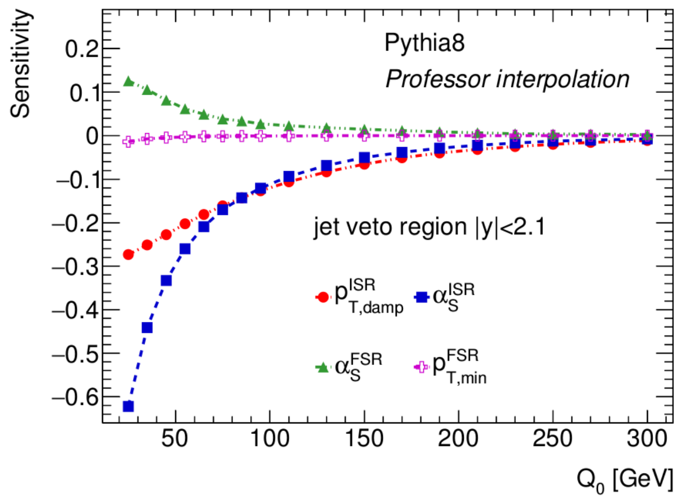


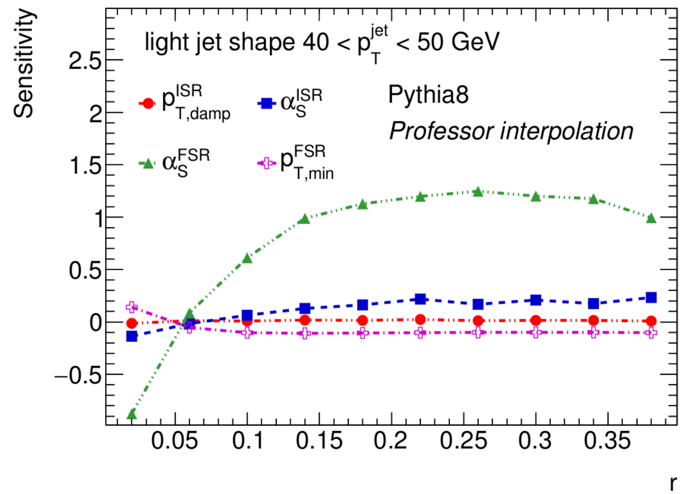
ATTBAR Tune → PS + NLO ME tune

- Sensitivity studies in single ISR/FSR tuning, using the definition:

$$S_i = \frac{\partial MC(\vec{p})}{\partial p_i} \times \frac{|p_{0,i}| + ew_{p_i}}{|MC_{p_0}| + ew_{MC}}$$

- Demonstrates the sensitivity of observables to ISR, FSR components:





- b-jet modelling also identified as an issue in Pythia 8.201.
  - → α^{FSR}_s value tension for light vs b-jets.
  - → χ^2/dof of light-jet closer to unity than b-jet. Indicates b-jet mismodelling
  - →**Therefore simultaneous tune only uses light jet shapes**

Parameter	light-jet shapes	*b*-jet shapes	4C
$\alpha_s^{FSR}(m_Z)$	0.131 ± 0.001	0.126 ± 0.001	0.1383
χ^2_{min}/dof	64/49	284/49	

Parameter	light-jet shapes	*b*-jet shapes	Monash
$\alpha_s^{FSR}(m_Z)$	0.125 ± 0.001	0.121 ± 0.001	0.1365
χ^2_{min}/dof	71/49	219/49	

Deviation from unity indicates modelling issues of b-jets