A Pythia8 tune to Ttbar observables

top LHC WG (20th May 2015)

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for the ATLAS Collaboration

Motivation

- At the LHC, for the first time, measurements of ttbar production have reached enough accuracy to be used in MC tuning
- The modelling of ISR and FSR radiation in ttbar production is one of the dominant uncertainties in the measurement of the top mass
  - The latest D0 measurement of the top mass constraints the ISR/FSR radiation from Drell-Yan events. While at the Tevatron DY and ttbar are qqbar initiated, at the LHC ttbar is mostly produced through gg, and the universality of the parton shower between Z and ttbar production must be verified

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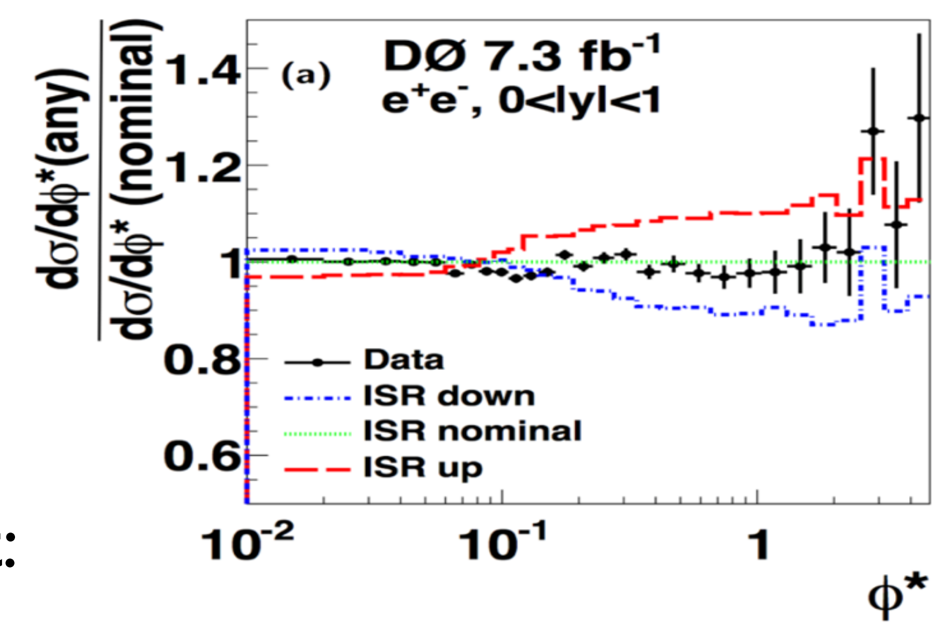


- This study is focused on **Pythia8** and aims at:
  - Investigate the compatibility of the PS parameters between ttbar production and other processes used in tuning (Z p_T, LEP event shapes)
  - Improve the **Pythia8** description of ISR and FSR for ttbar production
- NLO+PS generators are also expected to benefit from an improved tune, and to this purpose, the **Pythia8** tune is applied to the **Powheg** and **MadGraph5_aMC@NLO** generators

Methodology

- The tunes are performed with the Professor-v1.4 framework
- For the first time correlations are considered in a MC tune
  - To improve the sensitivity of the data to the MC parameters, and to obtain *statistically meaningful uncertainties* on the tuned parameters
  - Correlations of the experimental uncertainties are considered both between bins of the same observable and among different observables, but we did not correlate among analyses as the sys. treatment is different
- Observables have been chosen from three ATLAS measurements of ttbar production at 7 TeV:
  - tt+jets *[1407.0891]*:

    The distribution of the leading and 5th jet p_T and the number of jets for jets with p_T>25 and p_T>80 GeV
  - tt jet shapes *[1307.5749]*:

    The distributions of differential jet shapes for jets with 30<p_T<150 GeV (5 observables) for light- and b-jets separately.
  - tt gap fraction *[1203.5015]*:

    The inclusive gap fraction as function of the leading jet p_T threshold, Q_0

Tuning steps:

1. *Randomly sample the n-dimension parameter space*
2. *Create an analytic interpolation of the generator response (we used 3rd order polynomials)*
3. *Obtain the optimised values with a chi2 minimization (MINUIT) of the interpolated prediction*

Setup

- The optimisation is performed independently using Monash (NNPDF23LO) and 4C (CTEQ6L1) as baseline tunes
- 50,100,200 or 400 points are randomly sampled depending on the number of parameters considered
- 10/2M of semi-/di-leptonic ttbar events are generated per point with **Pythia8.201** and Rivet2.2 for the analyses implementation
- For each point the observables for the ttbar+jets analysis have been rescaled to the data, to account for the LO cross-section in **Pythia8**

Tuned parameters:

Parameter	Pythia8 setting	Variation range	4C	Monash
$\alpha_s^{\mathrm{ISR}}(m_Z)$	SpaceShower:alphaSvalue	0.110 – 0.140	0.137	0.1365
ISR damping	SpaceShower:pTdampMatch	1 (fixed)	0	0
$p_{T,\mathrm{damp}}^{\mathrm{ISR}}$	SpaceShower:pTdampFudge	0.8 – 1.8	-	-
$\alpha_s^{\mathrm{FSR}}(m_Z)$	TimeShower:alphaSvalue	0.110 – 0.150	0.1383	0.1365
$p_{T,\mathrm{min}}^{\mathrm{FSR}}$	TimeShower:pTmin	0.1 – 2.0	0.4	0.5

Fudge factor has been considered also for FSR, but no sensitivity found

Tune Strategy

- After computing the sensitivity of each observable to the different parameters the following tune strategy is defined:
  - Tune the **Pythia8** ISR parameters to the gap fraction and tt+jets
  - Tune the **Pythia8** FSR parameters to the jet shapes in ttbar
  - Combine tune of both ISR and FSR parameters to all the measurements
  - Retune the MPI cut-off to maintain the description of UE data
  - Apply the **Pythia8** tune to NLO+PS generators, tuning additional parameters sensitive to the extra radiation to the gap fraction and tt+jets

ISR tune results

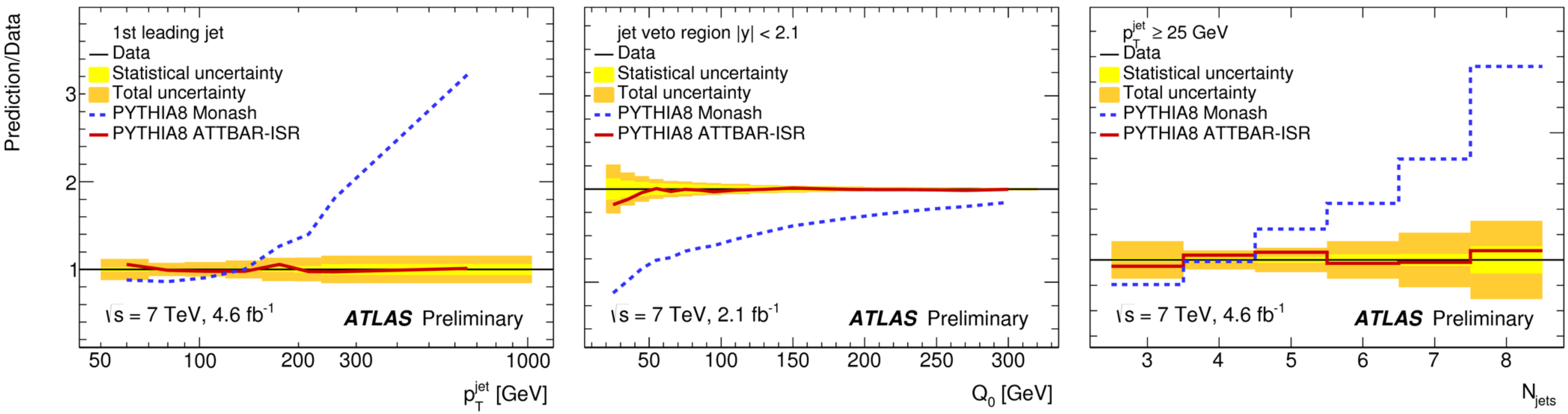
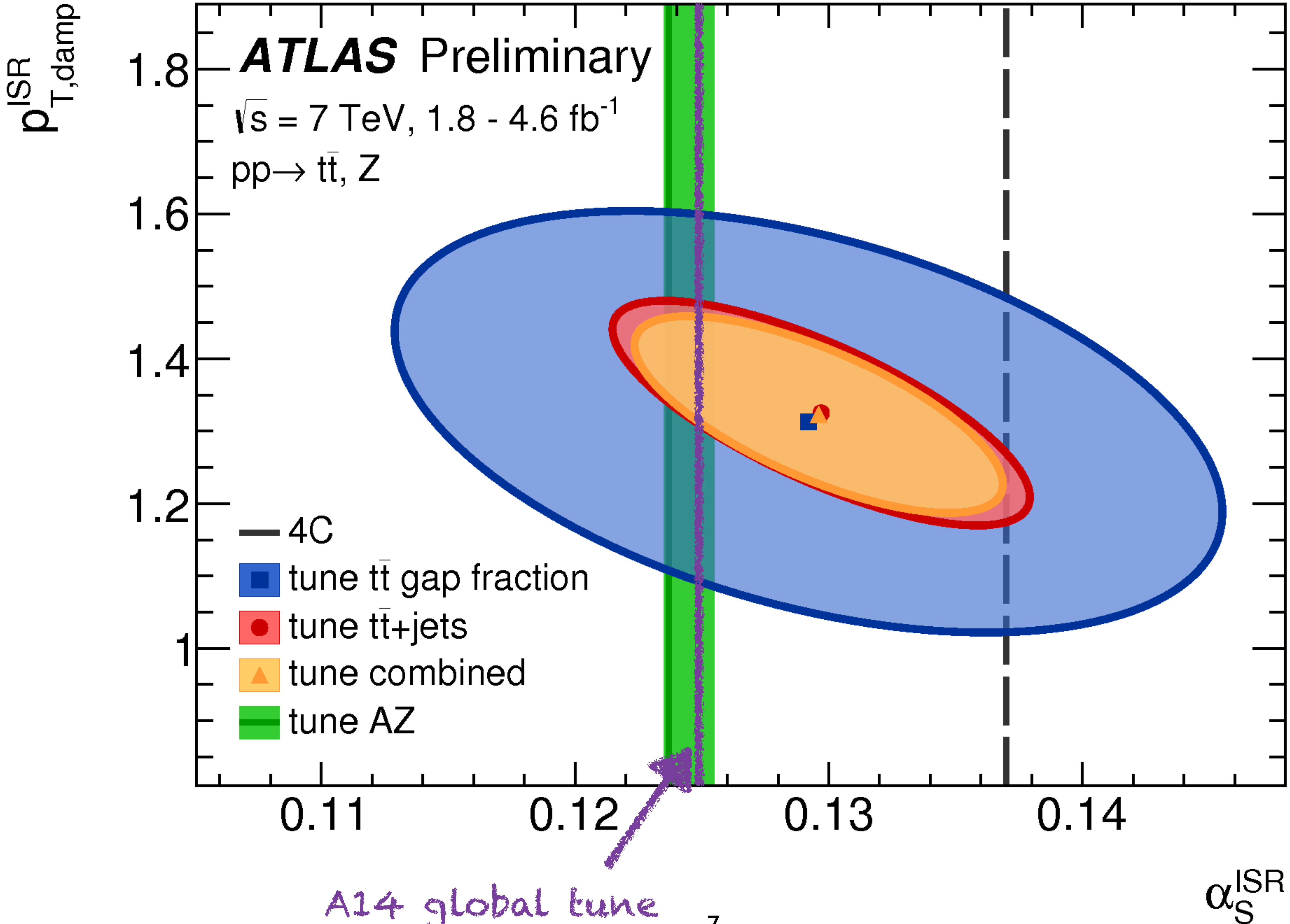


Table 4: Tuning results of $\alpha_s^{\mathrm{ISR}}(m_Z)$ and $p_{T,\mathrm{damp}}^{\mathrm{ISR}}$ to the differential $t\bar{t}$ cross sections as functions of jet multiplicity and jet transverse momentum ($t\bar{t}$+jets), and to the gap fraction as a function of Q_0 ($t\bar{t}$ gap fraction), using the Monash tune as baseline.

Parameter	$t\bar{t}$+jets	$t\bar{t}$ gap fraction	$t\bar{t}$+jets and $t\bar{t}$ gap fraction	Monash
$\alpha_s^{\mathrm{ISR}}(m_Z)$	0.124 ± 0.006	0.124 ± 0.010	$0.124^{+0.005}_{-0.006}$	0.137
$p_{T,\mathrm{damp}}^{\mathrm{ISR}}$	1.13 ± 0.09	$1.19^{+0.17}_{-0.15}$	1.14 ± 0.08	-
$\chi^2_{\mathrm{min}}/\mathrm{dof}$	24/19	10/16	34/37	

Optimised values of α_S^{ISR} are smaller than in the baseline tunes, and close to the value obtained in the AZ tune to Z p_T and phi*

ISR Tunes Consistency



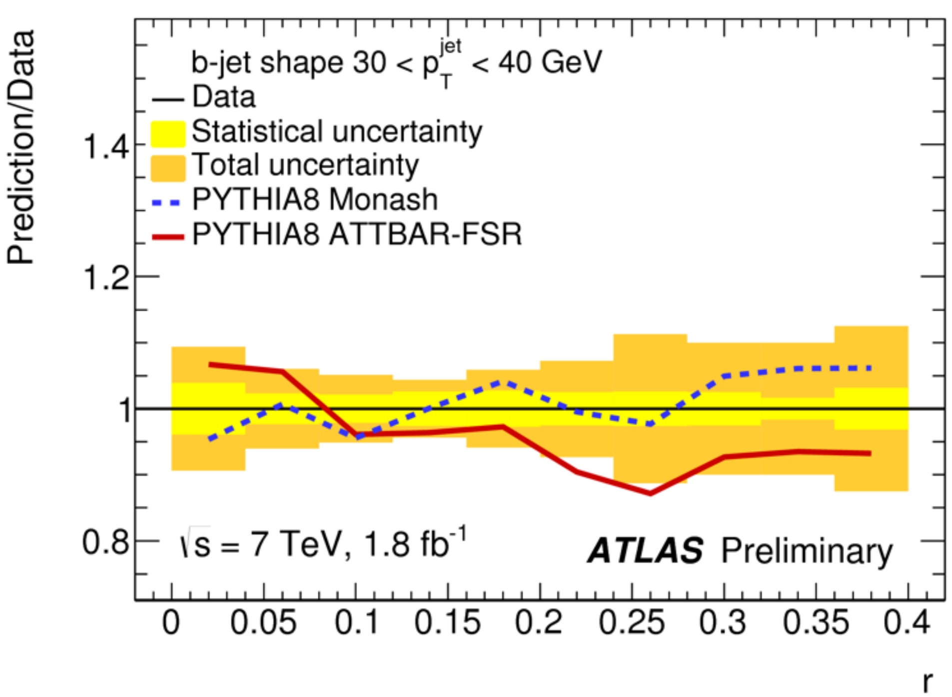
FSR TUNE

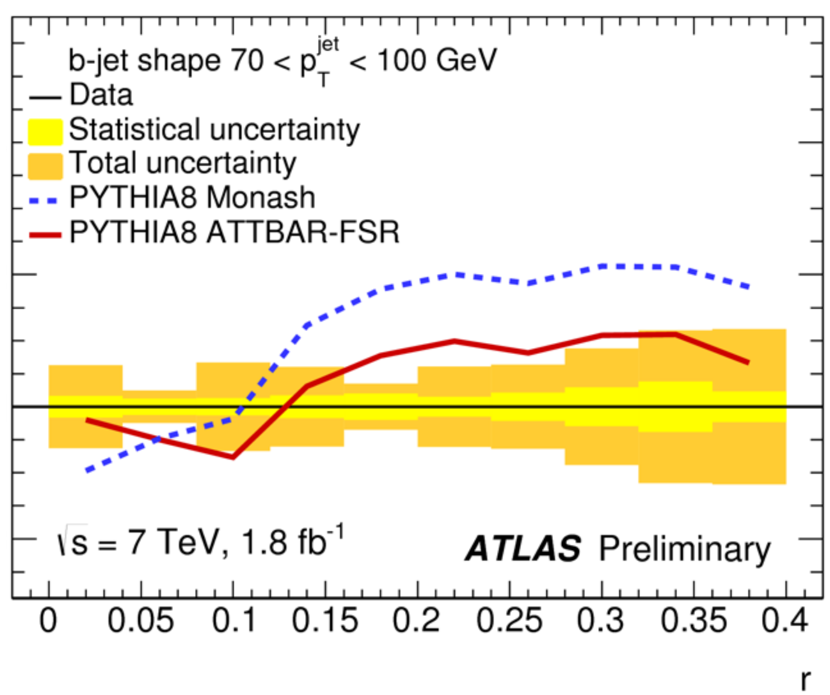
- Tuning α_s^{FSR} returns different values for the light- and b-jet shapes
  - The b-jet shapes prefer a lower value, close to α_s^{ISR} (as found in the A14 tune), that would be incompatible with LEP determinations, in the range of 0.13-0.14
  - Light-jet shapes prefer higher values, but still smaller than in the baseline tunes

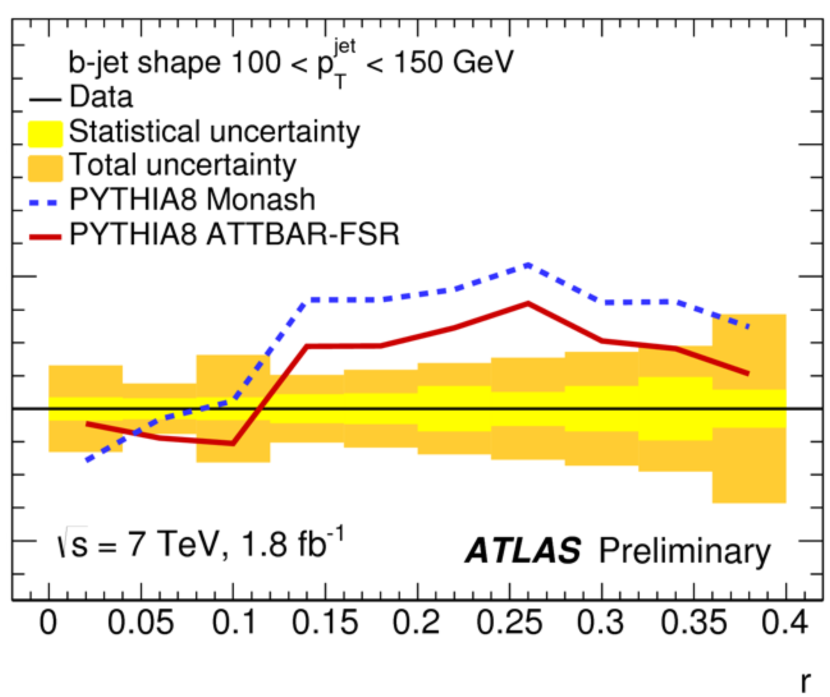
Parameter	light-jet shapes	b-jet shapes	Monash
$\alpha_s^{FSR}(m_Z)$	0.125 ± 0.001	0.121 ± 0.001	0.1365
χ^2_{min}/dof	71/49	219/49	

The tune return a very high chi2 and the b-jet shapes are poorly described

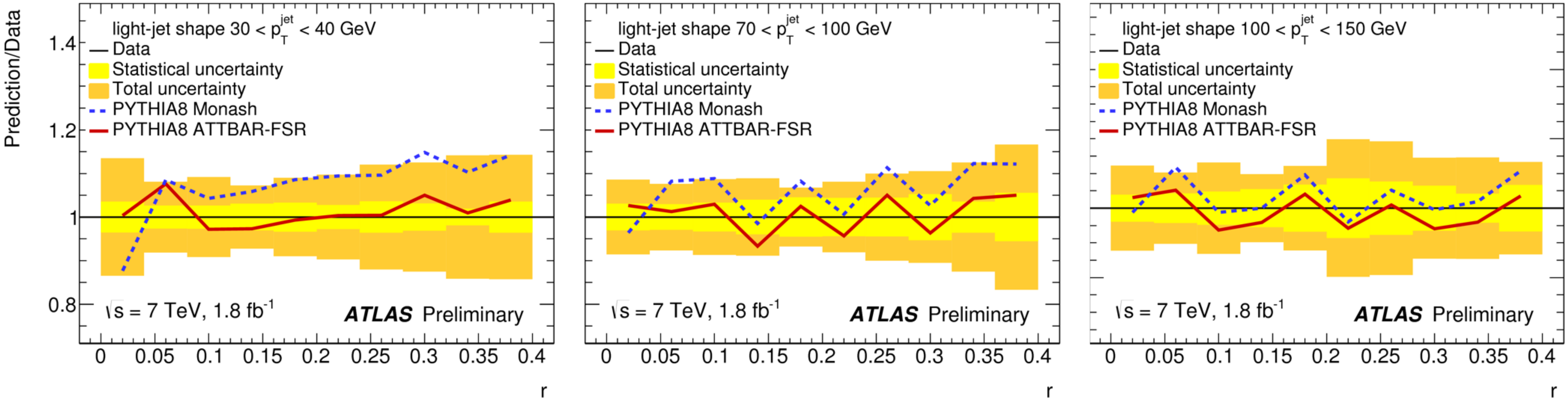
- Because of this tension we discard the b-jet shape in the FSR tune







FSR TUNE



- We also include an additional parameter to which the data shows sensitivity, the IR cutoff of the FSR shower: $p_{T,min}^{FSR}$

Parameter	light-jet shapes	Monash
$\alpha_s^{FSR}(m_Z)$	0.135 ± 0.003	0.1365
$p_{T,min}^{FSR}$	$1.31^{+0.18}_{-0.20}$	0.5
χ^2_{min}/dof	57/49	

Including $p_{T,min}^{FSR}$ improves the chi2 and brings α_s^{FSR} the back to the values of the baseline tunes

The quite large value of $p_{T,min}^{FSR}$ leaves however a large gap between the shower cut-off scale and hadronisation

ATTBAR

- A combined tune of the four parameters is performed using the three measurements combined
- The tuned parameter values are compatible with the separate tunes
- Including correlations allows to obtain a χ^2/dof close to unity and to reduce the uncertainty on the parameters by up to 50%

Parameter	ATTBAR-Monash	Monash
$\alpha_s^{\mathrm{ISR}}(m_Z)$	0.121 ± 0.004	0.1365
$p_{T,\mathrm{damp}}^{\mathrm{ISR}}$	$1.18^{+0.08}_{-0.07}$	-
$\alpha_s^{\mathrm{FSR}}(m_Z)$	0.137 ± 0.003	0.1365
$p_{T,\mathrm{min}}^{\mathrm{FSR}}$	1.26 ± 0.17	0.5
$\chi^2_{\mathrm{min}}/\mathrm{dof}$	92/85	

- The MPI cut-off is retuned to the ATLAS measurement of UE in Drell-Yan events. (no measurement of UE in ttbar is available yet). The tuned value of the cut-off, ***pT0Ref*** is of 2.16 GeV, compared to 2.28 GeV in Monash

Matched NLO+PS tunes

- The ATTBAR tune is then applied to two NLO+PS generators and additional parameters related to the scale of the process are tuned to data
- *hdamp* is tuned in **Powheg v2-r2915**
  - Using the main31 routine and **$p_T$def=2** (wimpy shower)
- *frac_upp/low* are tuned in **MadGraph5_aMC@NLO-v2.2.2**
  - Using both the global recoil option as recommended by the authors and the local recoil setting

	Powheg setting	Variation range	default
Sudakov region	hdamp $= h \cdot m_t$	$0.5 \cdot m_t - 4.0 \cdot m_t$	∞
	aMC@NLO setting		
MC subtraction term	frac_low = frac_upp = f	$0.2 - 1.0$	frac_low = 0.1 frac_upp = 1.0

In principle two different numbers, but best modelling obtained if taken the same

NLO+PS results

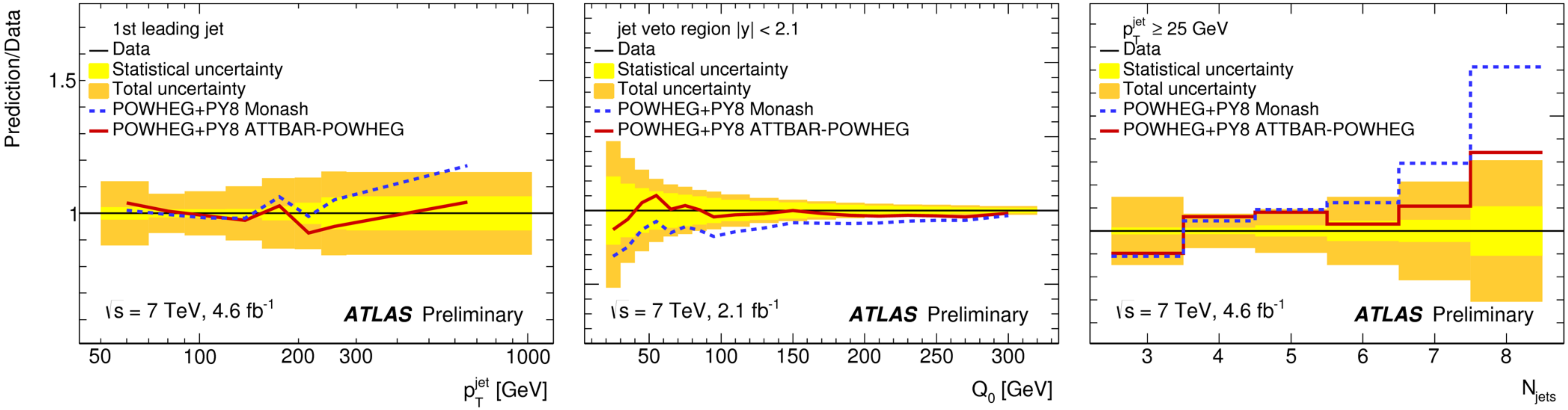


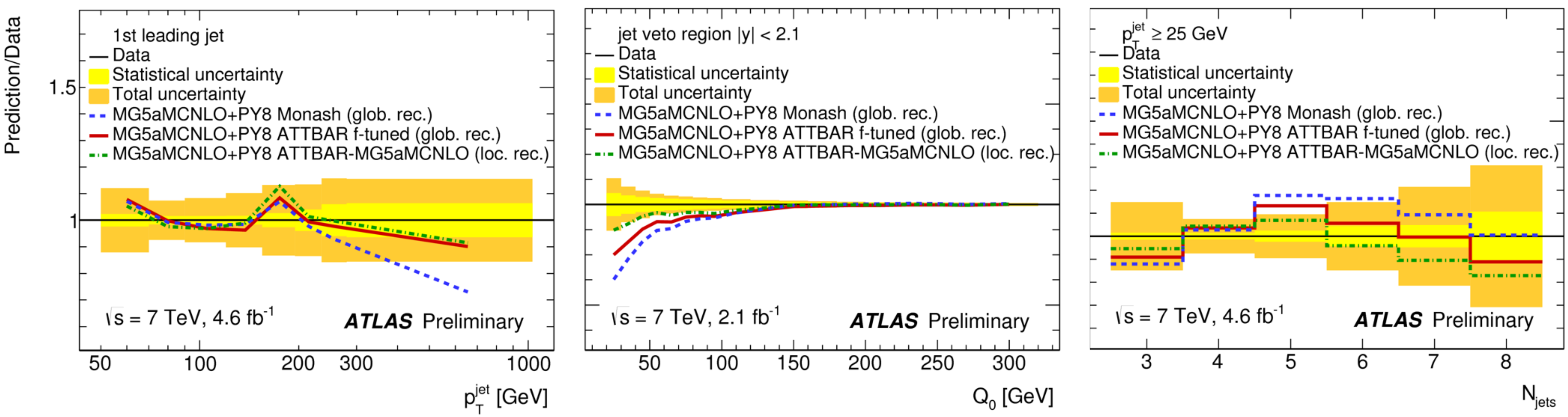
Table 14: Tuning results of the `hdamp` POWHEG parameter to the differential $t\bar{t}$ cross sections as functions of jet multiplicity and jet transverse momentum ($t\bar{t}$+jets), and to the gap fraction as a function of Q_0 ($t\bar{t}$ gap fraction), using the ATTBAR-Monash tune.

Parameter	$t\bar{t}$+jets	$t\bar{t}$ gap fraction	$t\bar{t}$+jets and $t\bar{t}$ gap fraction
`hdamp`	$1.7^{+0.5}_{-0.3} \cdot m_t$	$2.2^{+2.9}_{-0.7} \cdot m_t$	$1.8^{+0.4}_{-0.3} \cdot m_t$
$\chi^2_{\text{min}}/\text{dof}$	$40/20$	$11.9/17$	$52.1/38$

NLO+PS results

Table 12: Tuning results of `frac_upp` = `frac_low` = f to the differential $t\bar{t}$ cross sections as functions of jet multiplicity and jet transverse momentum ($t\bar{t}$+jets), and to the gap fraction as a function of Q_0 ($t\bar{t}$ gap fraction), using the ATTBAR-Monash tune.

Parameter	$t\bar{t}$+jets	$t\bar{t}$ gap fraction	$t\bar{t}$+jets and $t\bar{t}$ gap fraction
f	0.58 ± 0.03	$0.53^{+0.09}_{-0.08}$	0.57 ± 0.03
$\chi^2_{\mathrm{min}}/\mathrm{dof}$	42.5/20	14.3/17	57.1/38



The global recoil configuration is theoretically more consistent, but the local recoil option is in better agreement with data

Summary

- Presented results of the **Pythia8** ATTBAR tune to ATLAS measurements of ttbar production at high-p_T
- The standalone **Pythia8** can describe extra radiation in ttbar data by adding a damping factor to the ISR emission probability
  - The tuned value of α_S^{ISR} is compatible with the Z p_T determinations
  - The tuned value of α_S^{FSR} to light-jet shapes is compatible with LEP data
  - The high value of $p_{T,min}^{FSR}$ is in tension with the values preferred by LEP, but it still provides a much better modelling of data than the A14 tune with it's low value of α_S^{FSR}
- The ATTBAR tune has been applied to NLO+PS generators **Powheg** and **MadGraph5_aMC@NLO** and additional parameters hdamp and frac_upp/low have been tuned to data
  - Not obvious if the difference between local and global recoil is due to the fixed-order or showering part

Backup

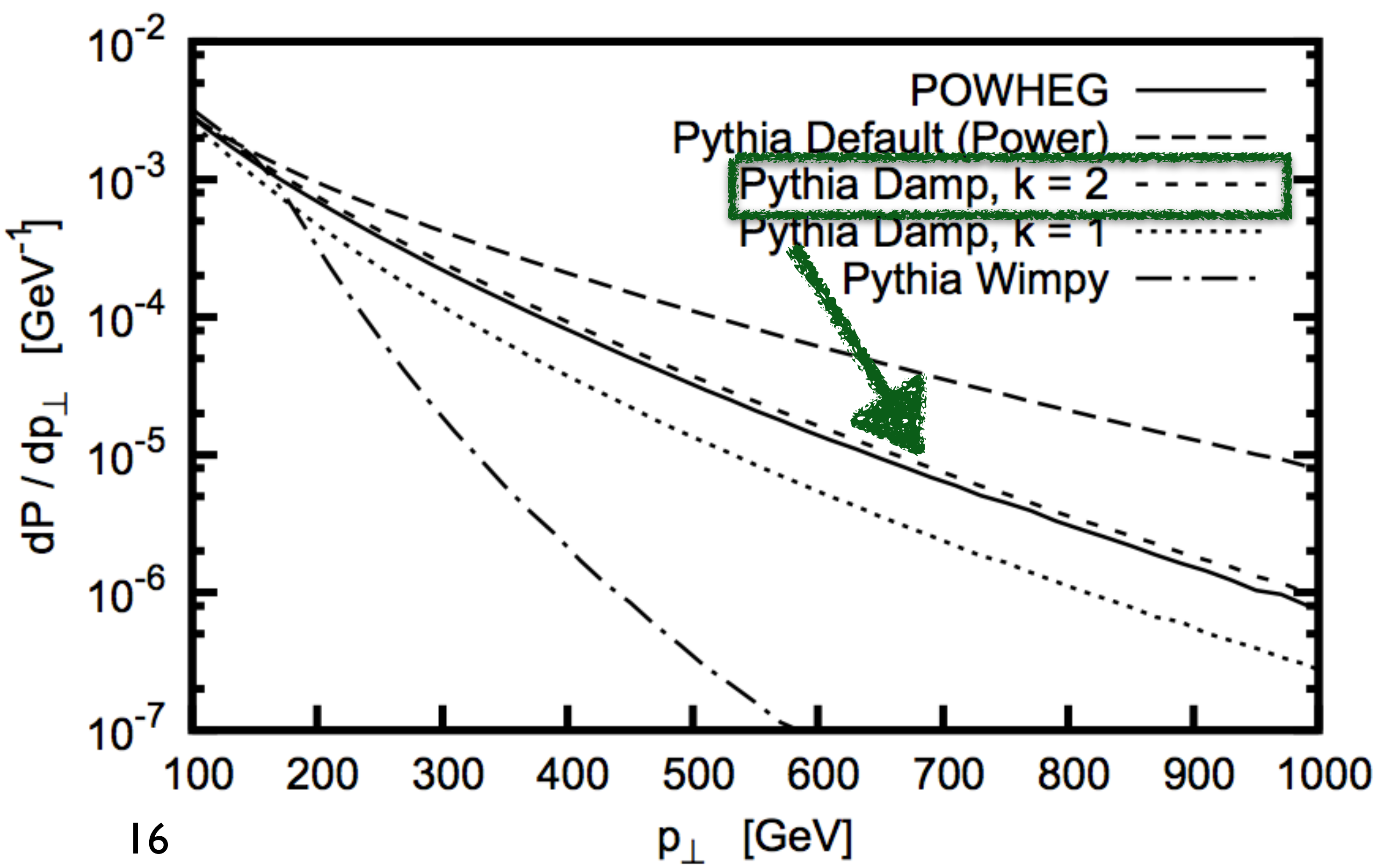
Motivation

- Inspired by (hep-ph:1003.2384):
  "Improved parton showers at large transverse momenta"
  - Neither power or wimpy showers are found to describe the high-p_T tail of ttbar events:
    - **Wimpy shower** ($1/p_T^2$ up to fac. scale, 0 after) underestimate data
    - **Power shower** ($1/p_T^2$ over all p_T range)
  - A new correction is introduced to get the first emission right
    - $1/p_T^2$ up to fac. scale, then gradually shifting to $1/p_T^4$

ren. or fac. scale (only coloured states play a role)

$$\frac{d\mathcal{P}_{ISR}}{dp_\perp^2} \propto \frac{1}{p_\perp^2} \frac{k^2 M^2}{k^2 M^2 + p_\perp^2}$$

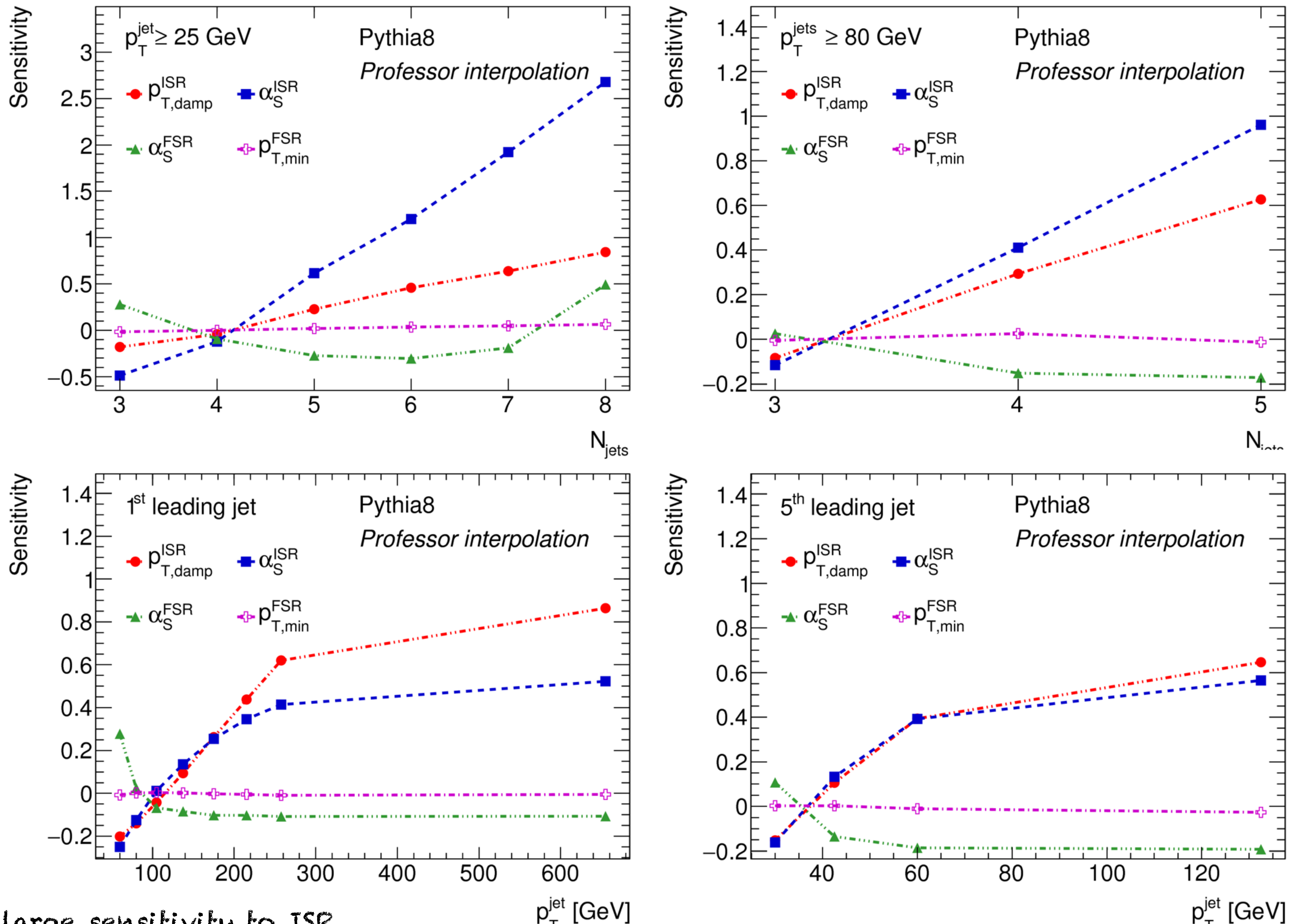
fudge factor of order unity



Observables Selection

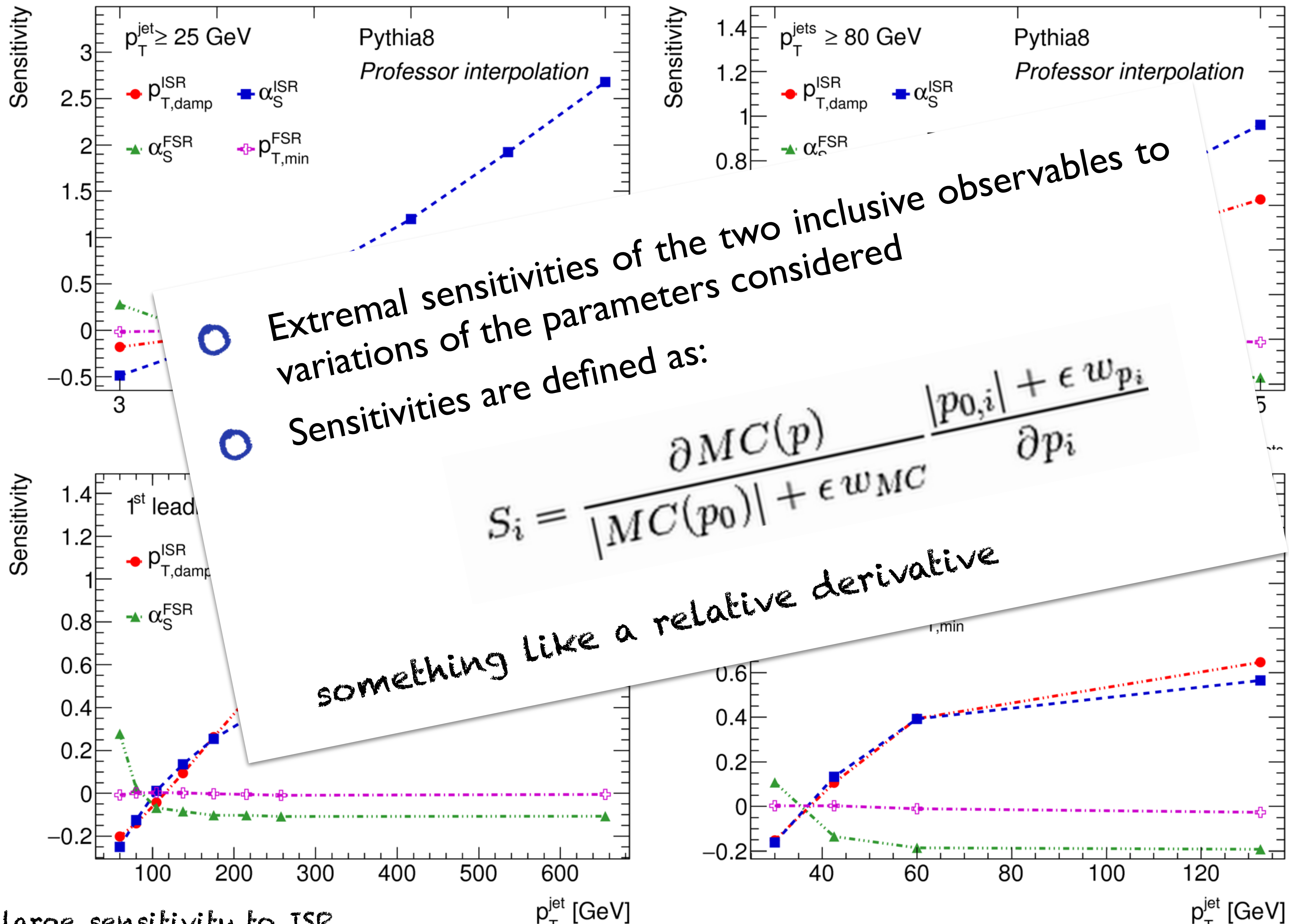
- *We have considered all available (in Rivet) ATLAS measurements of top pair production, discarding observables that are considered correlated or could not be modelled by the MC*
- **"Measurement of ttbar production with a veto on additional central jet activity in pp collisions at sqrt(s) = 7 TeV using the ATLAS detector"**
  - Considered the inclusive gap fraction as function of the leading jet p_T threshold, Q_0
  - The inclusive gap fraction as function of the sum of jets above
  - Observables in bins of rapidity have been discarded as the gap fraction rapidity dependence could not be reproduced with any of the generator setups
- **"Measurement of the ttbar production cross-section as a function of jet multiplicity and jet transverse momentum in 7 TeV proton-proton collisions with the ATLAS detector"**
  - Considered the distribution of leading and 5th jet p_T and the number of jets for jets with p_T>25 and p_T>80 GeV
  - All the other distributions are considered correlated with the ones considered and thus discarded
- **Measurement of jet shapes in top-quark pair events at √s = 7 TeV using the ATLAS detector**
  - Considered the distributions of differential jet shapes for jet with 30<p_T<150 GeV (5 observables) for light- and b-jets. The b-jet shapes have however been taken out of the tune as in
  - The integrated jet shapes have not been used as correlated to the differential

Sensitivities - ttjets



large sensitivity to ISR

Sensitivities - ttjets



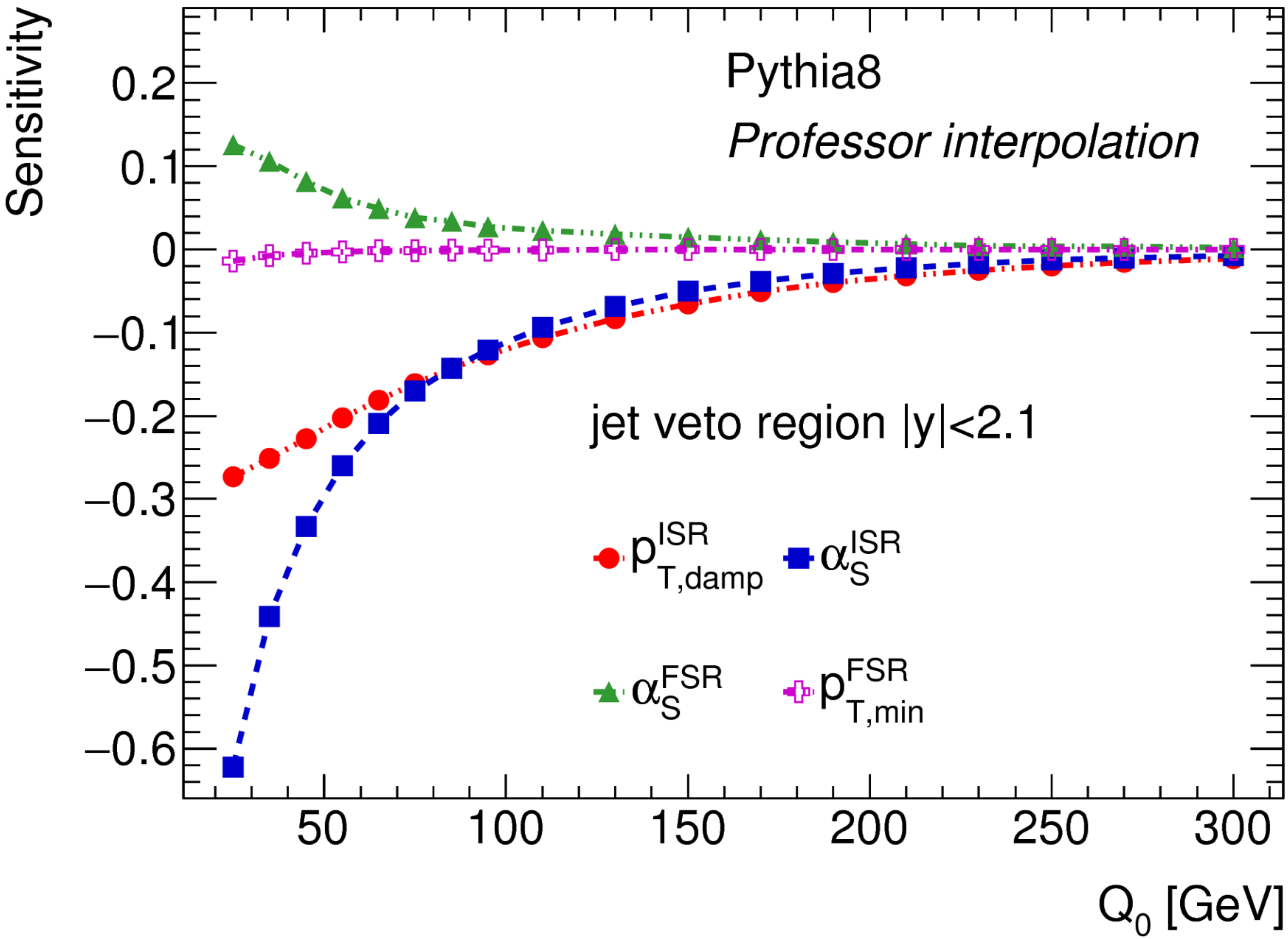
- Extremal sensitivities of the two inclusive observables to variations of the parameters considered
- Sensitivities are defined as:

$$S_i = \frac{\partial MC(p)}{|MC(p_0)| + \epsilon\, w_{MC}} \frac{|p_{0,i}| + \epsilon\, w_{p_i}}{\partial p_i}$$

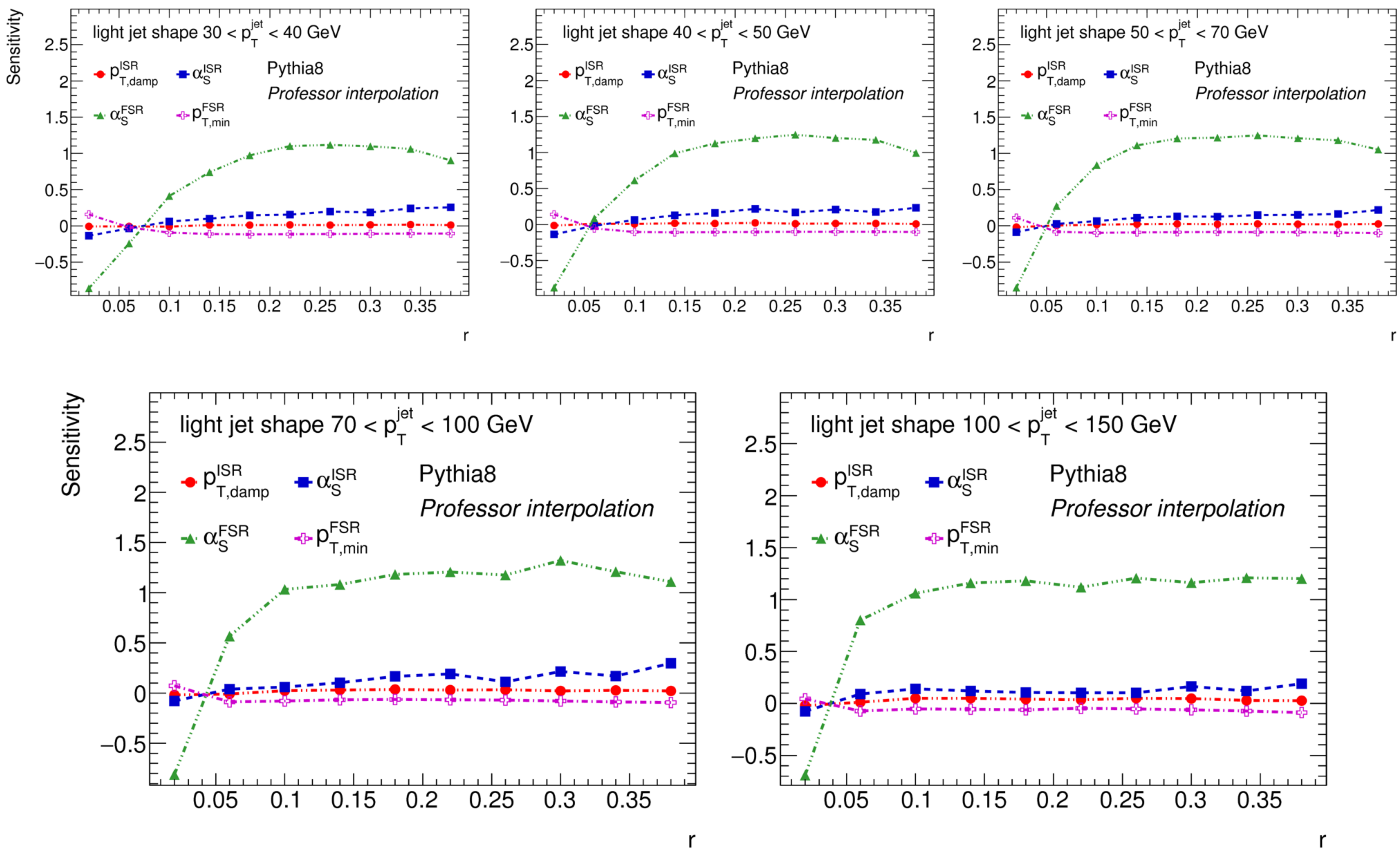
something like a relative derivative

large sensitivity to ISR

Sensitivities - ttgap



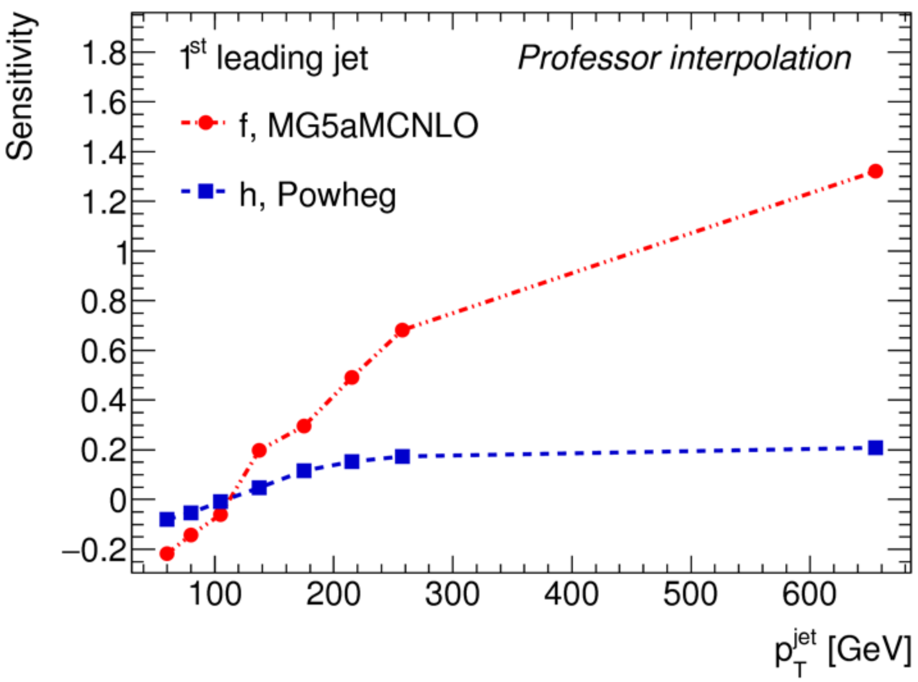
Sensitivities - jet shapes

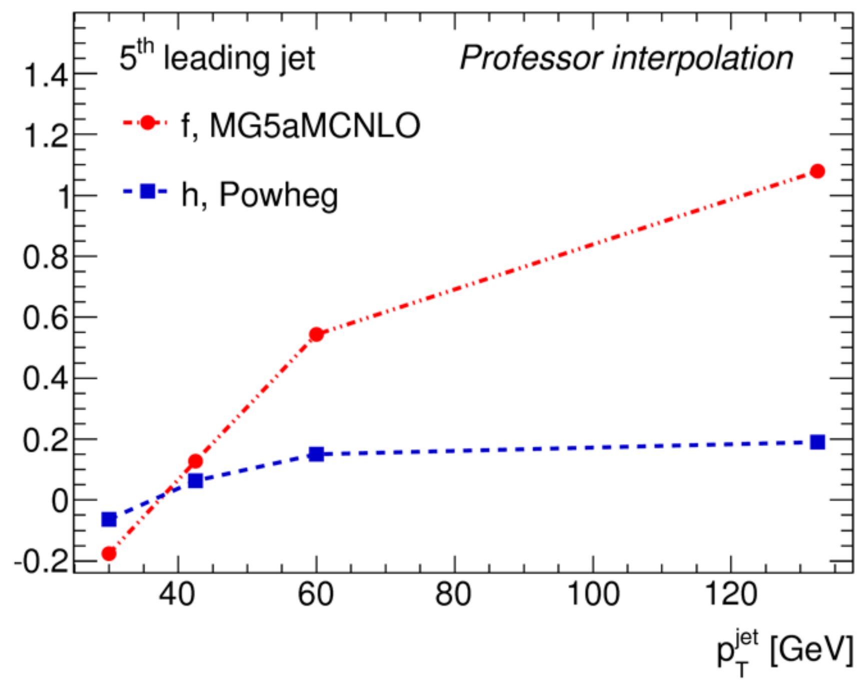


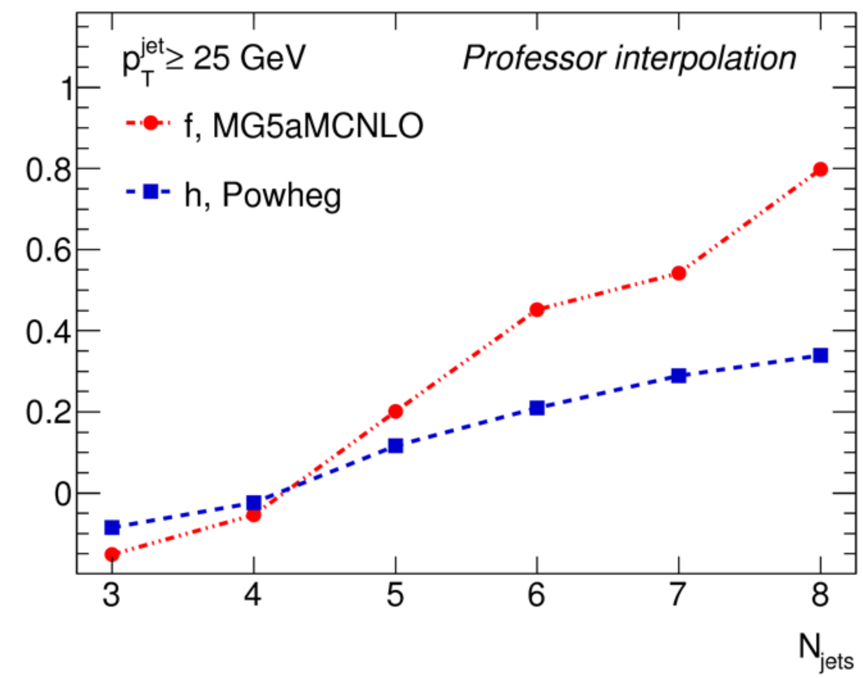
mostly sensitive to FSR,

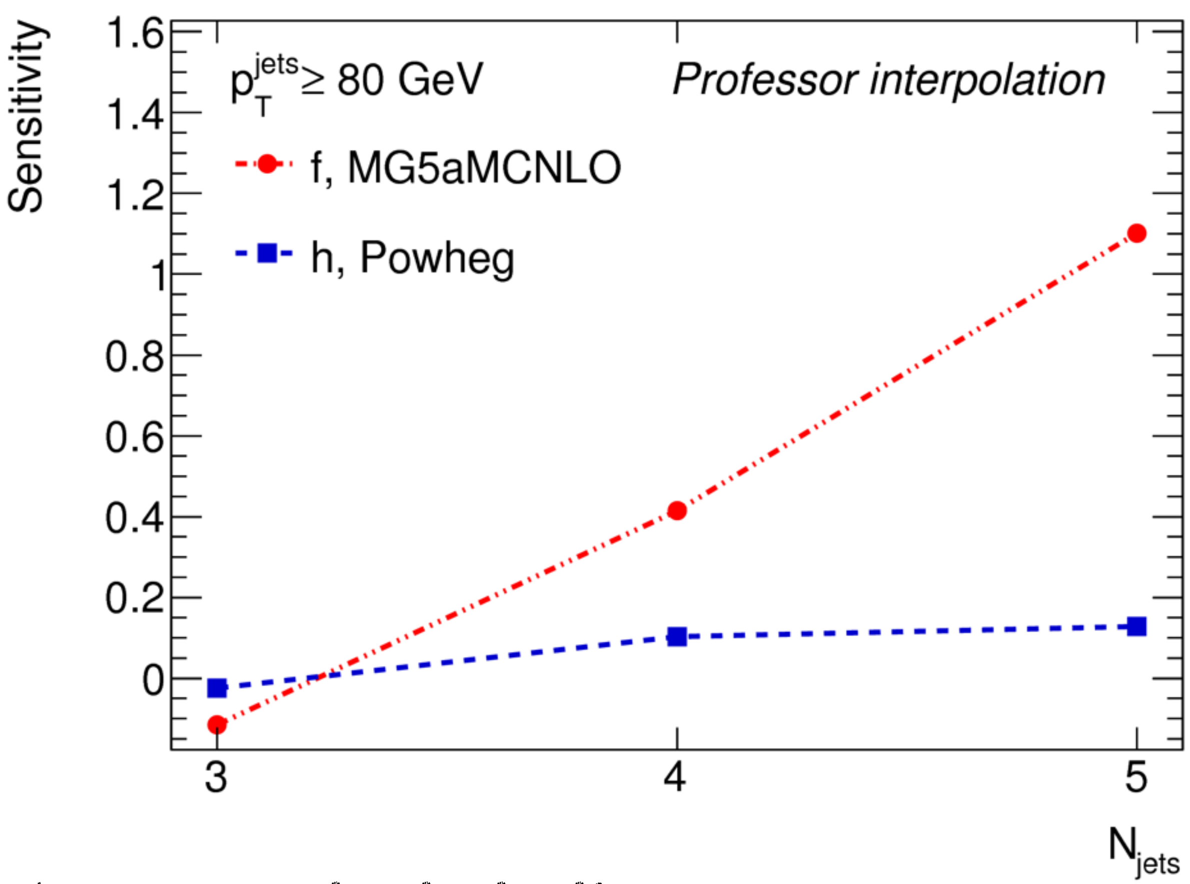
b-jet shapes have similar behaviour

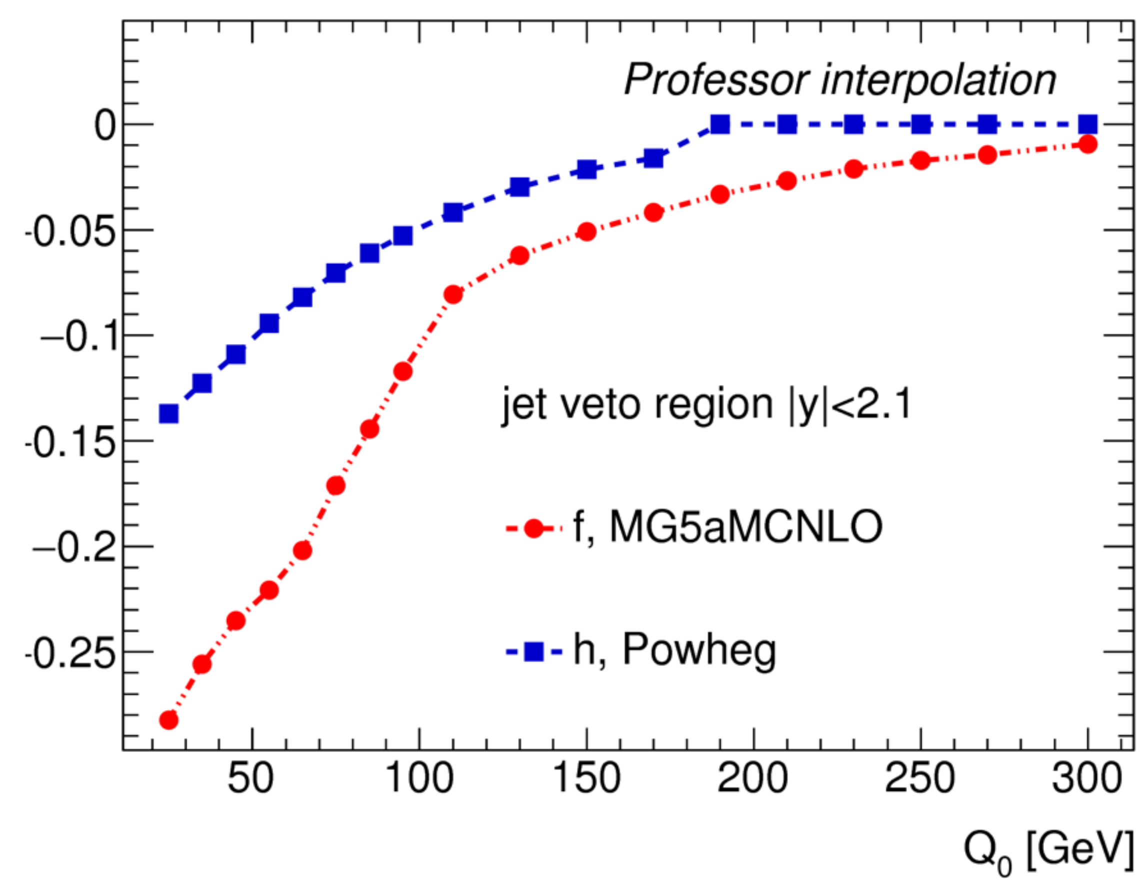
Sensitivities - NLO+PS





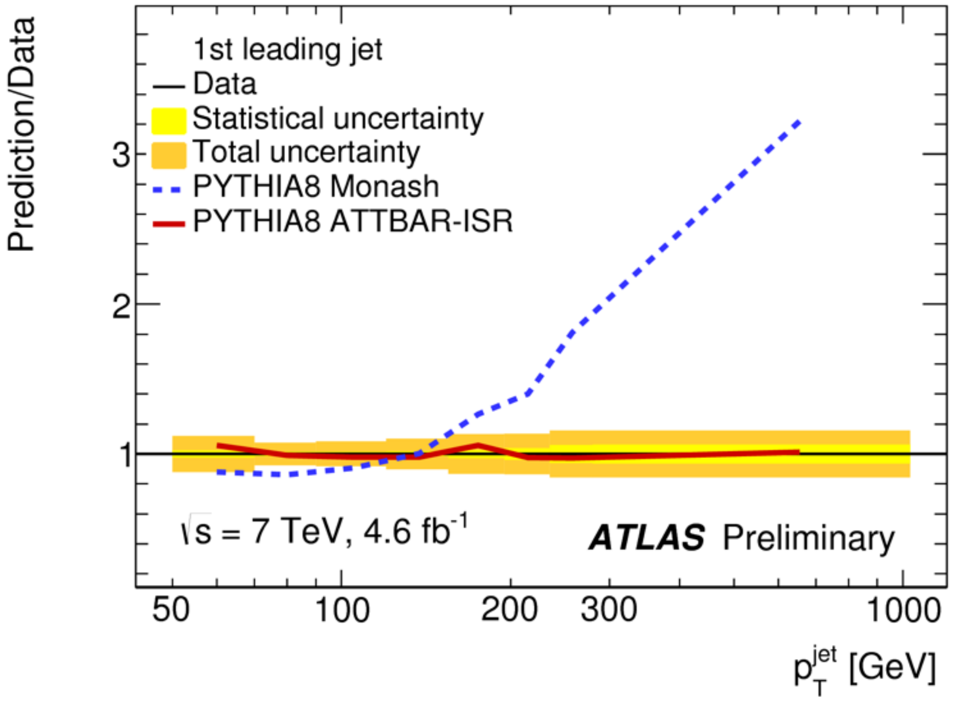




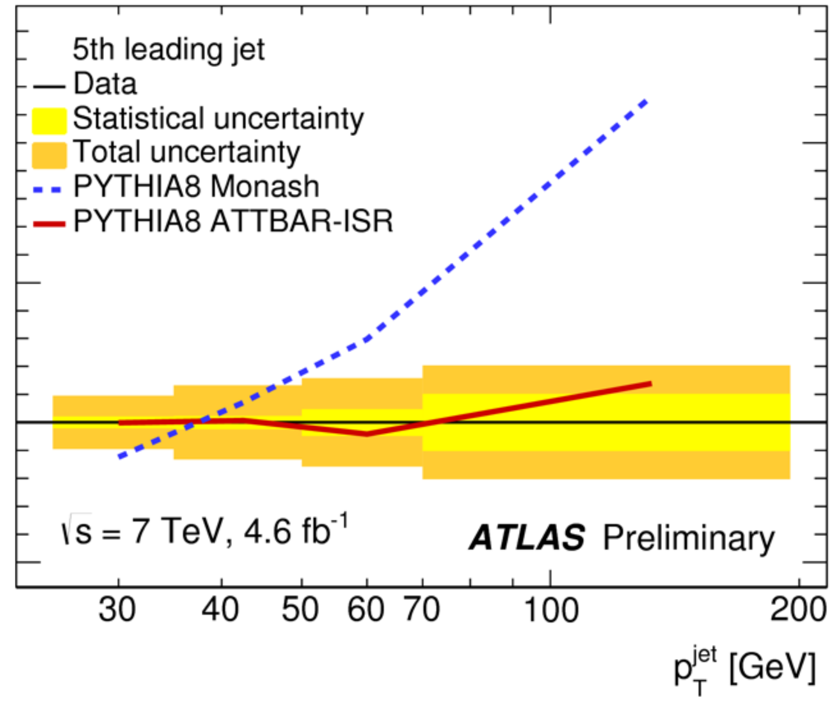


Very large sensitivity to the
f parameter in aMC@NLO

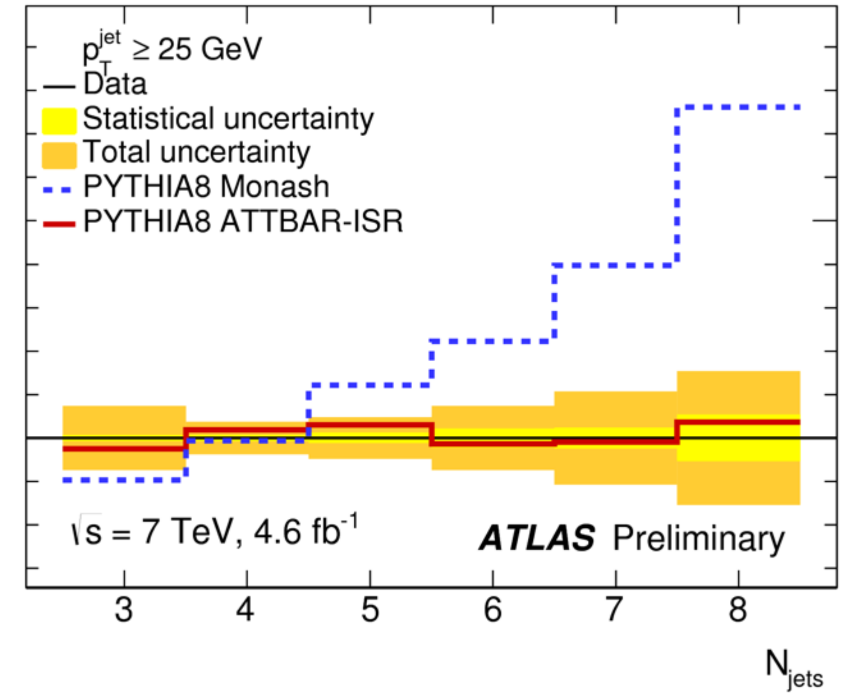
ATTBAR-ISR



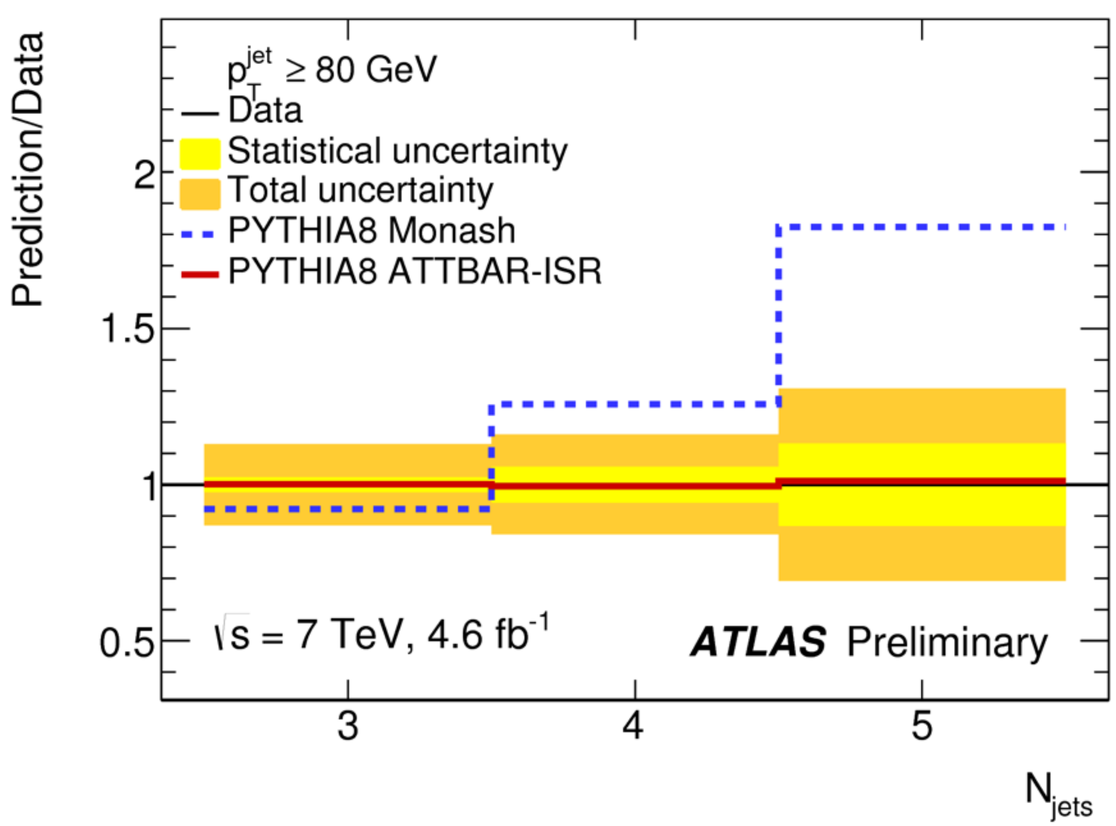
Prediction/Data
1st leading jet
Data
Statistical uncertainty
Total uncertainty
PYTHIA8 Monash
PYTHIA8 ATTBAR-ISR
√s = 7 TeV, 4.6 fb-1
ATLAS Preliminary
p_T^jet [GeV]



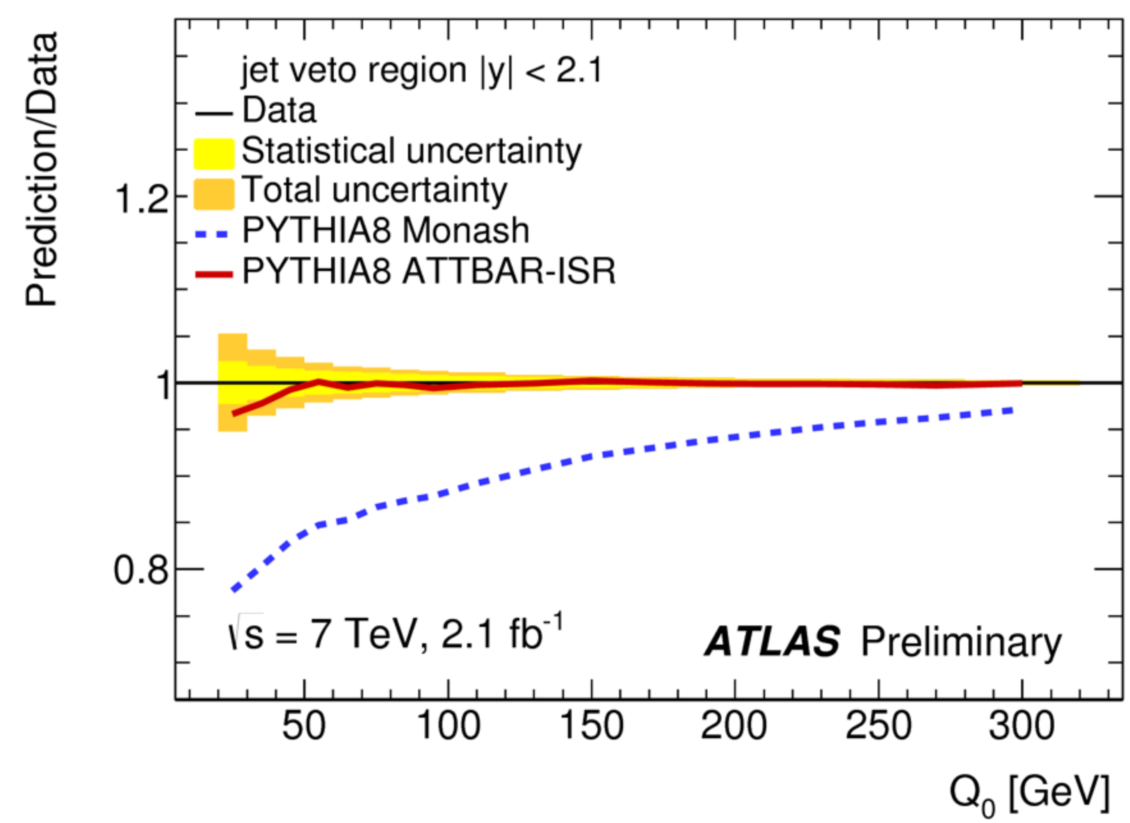
5th leading jet
Data
Statistical uncertainty
Total uncertainty
PYTHIA8 Monash
PYTHIA8 ATTBAR-ISR
√s = 7 TeV, 4.6 fb-1
ATLAS Preliminary
p_T^jet [GeV]



p_T^jet ≥ 25 GeV
Data
Statistical uncertainty
Total uncertainty
PYTHIA8 Monash
PYTHIA8 ATTBAR-ISR
√s = 7 TeV, 4.6 fb-1
ATLAS Preliminary
N_jets

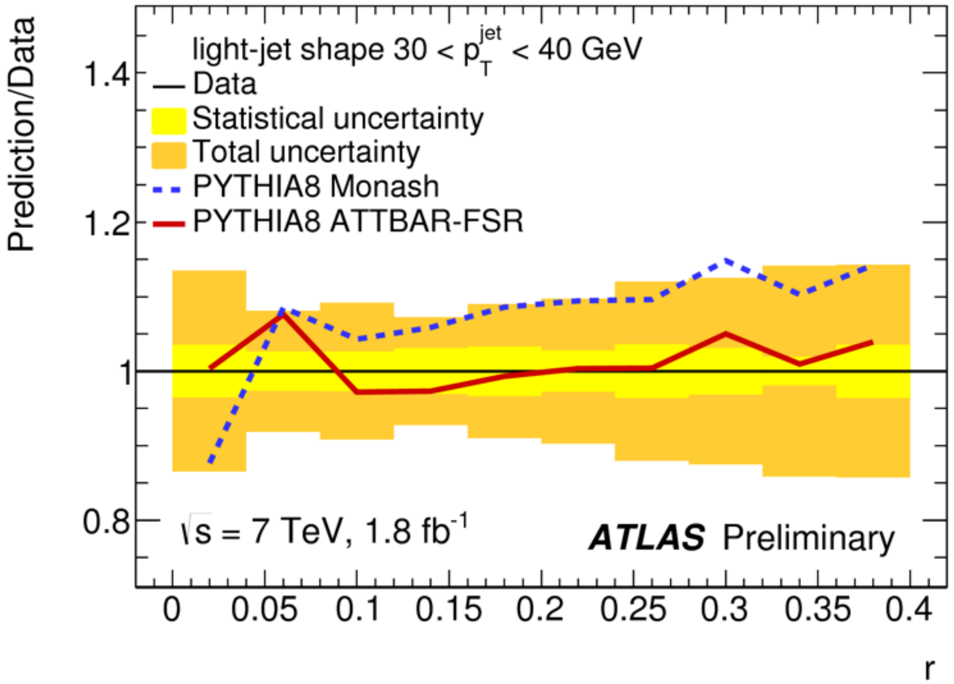


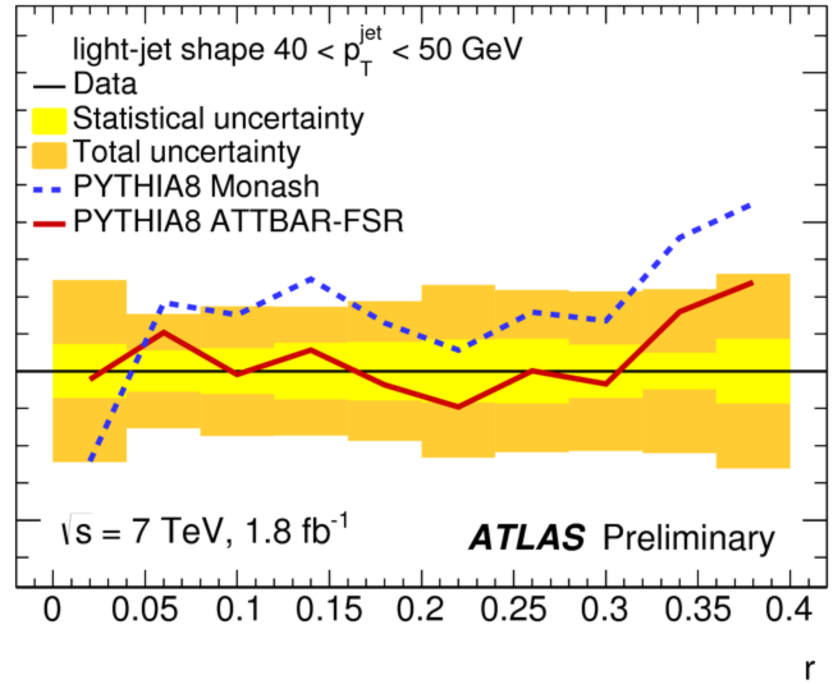
Prediction/Data
p_T^jet ≥ 80 GeV
Data
Statistical uncertainty
Total uncertainty
PYTHIA8 Monash
PYTHIA8 ATTBAR-ISR
√s = 7 TeV, 4.6 fb-1
ATLAS Preliminary
N_jets

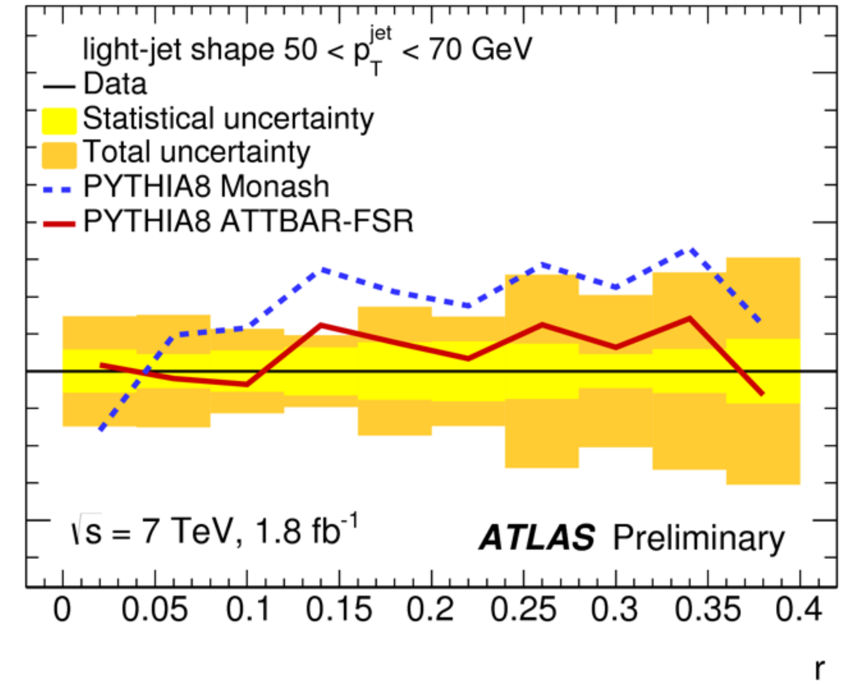


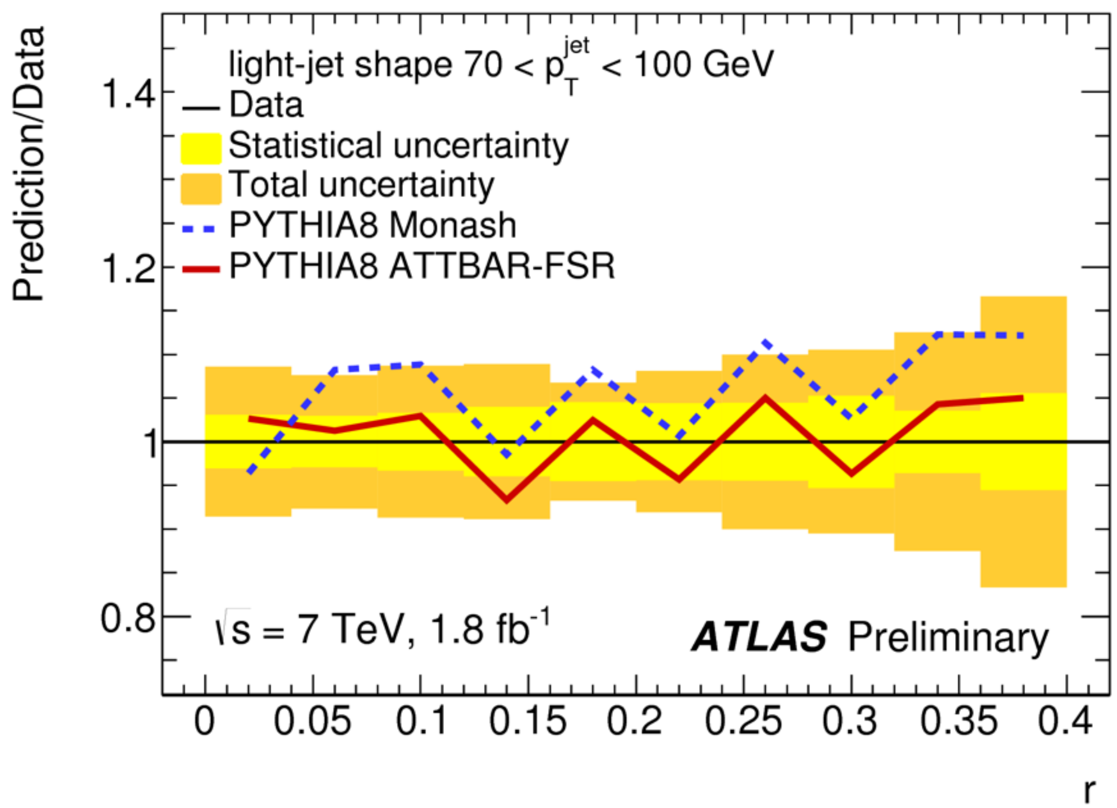
Prediction/Data
jet veto region |y| < 2.1
Data
Statistical uncertainty
Total uncertainty
PYTHIA8 Monash
PYTHIA8 ATTBAR-ISR
√s = 7 TeV, 2.1 fb-1
ATLAS Preliminary
Q_0 [GeV]

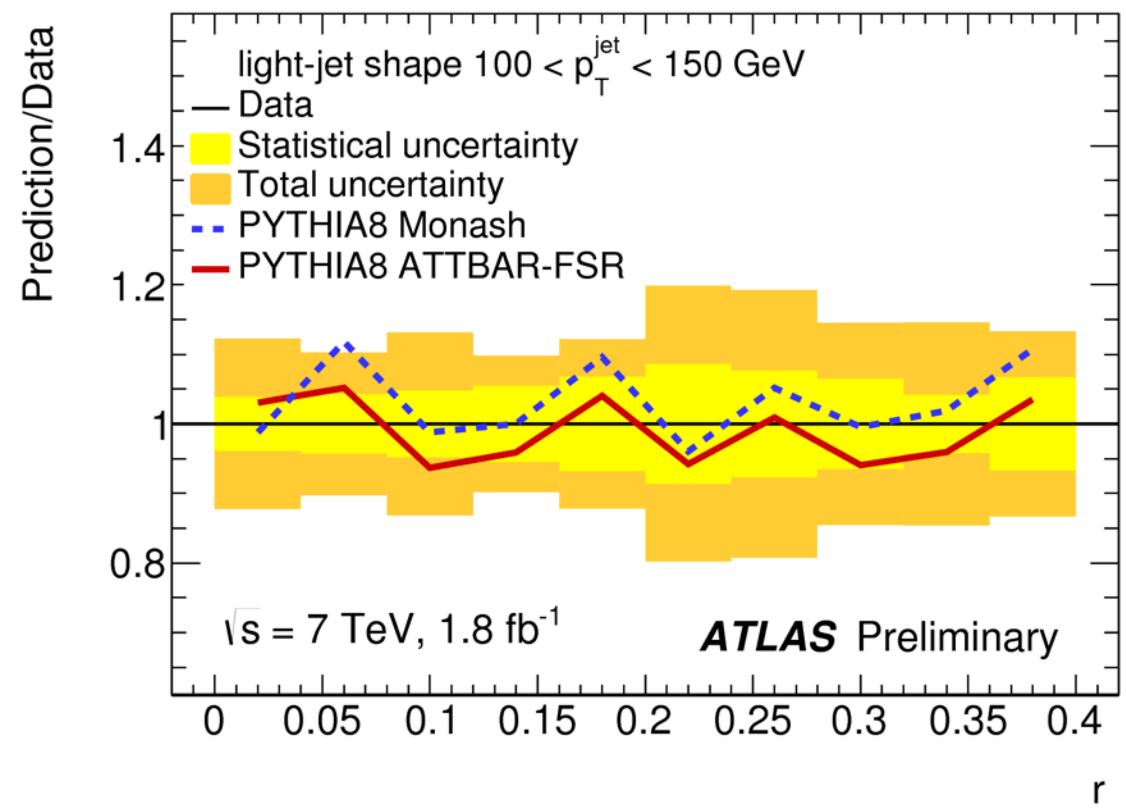
ATTBAR-FSR light jet shapes



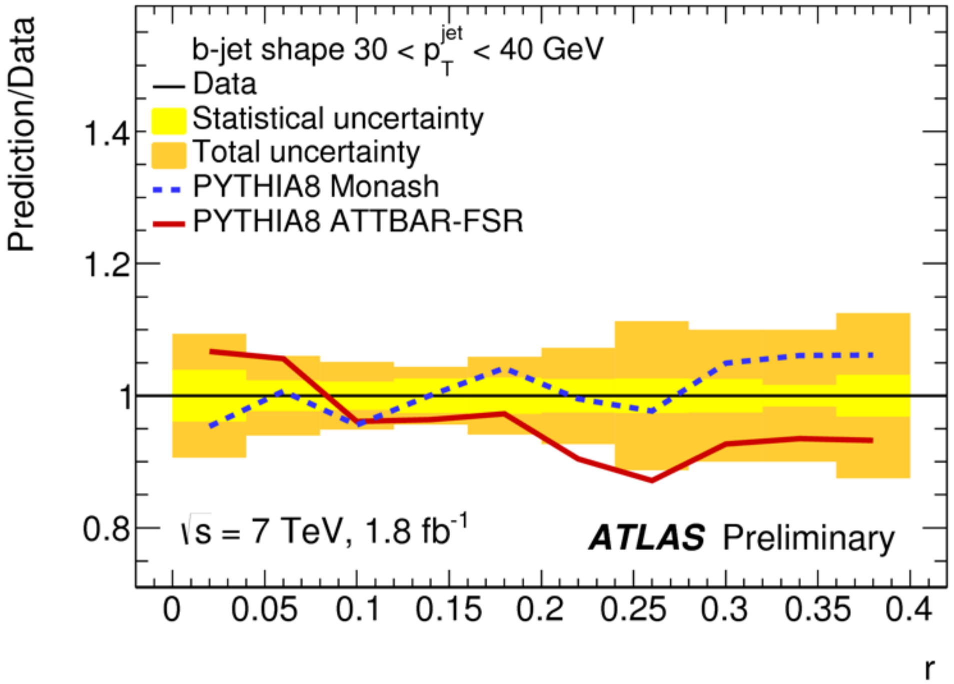


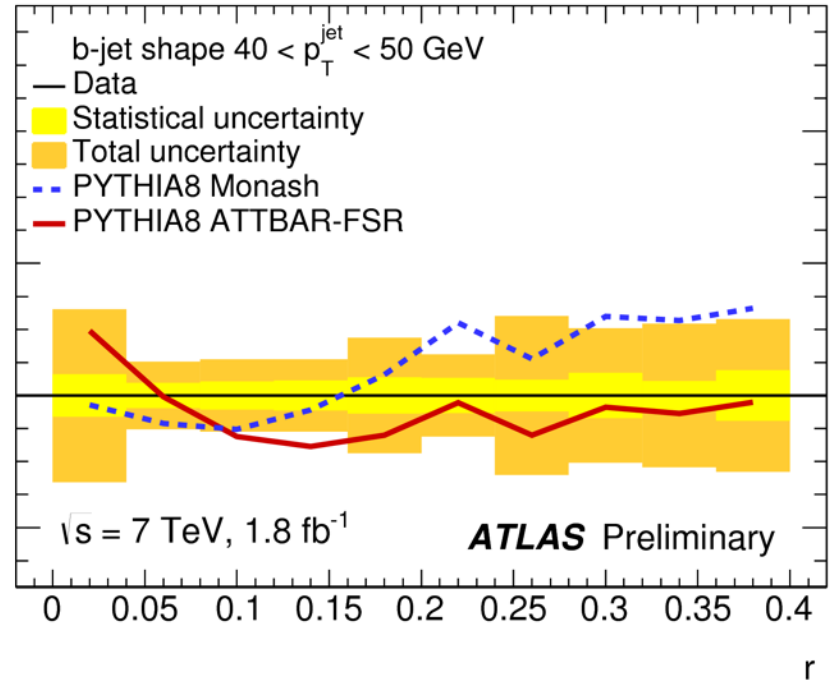


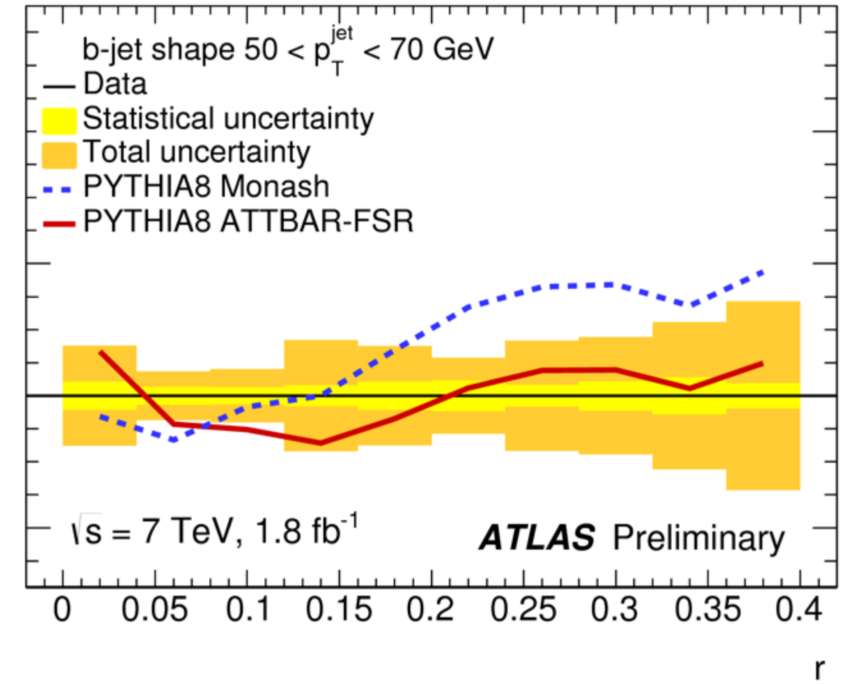


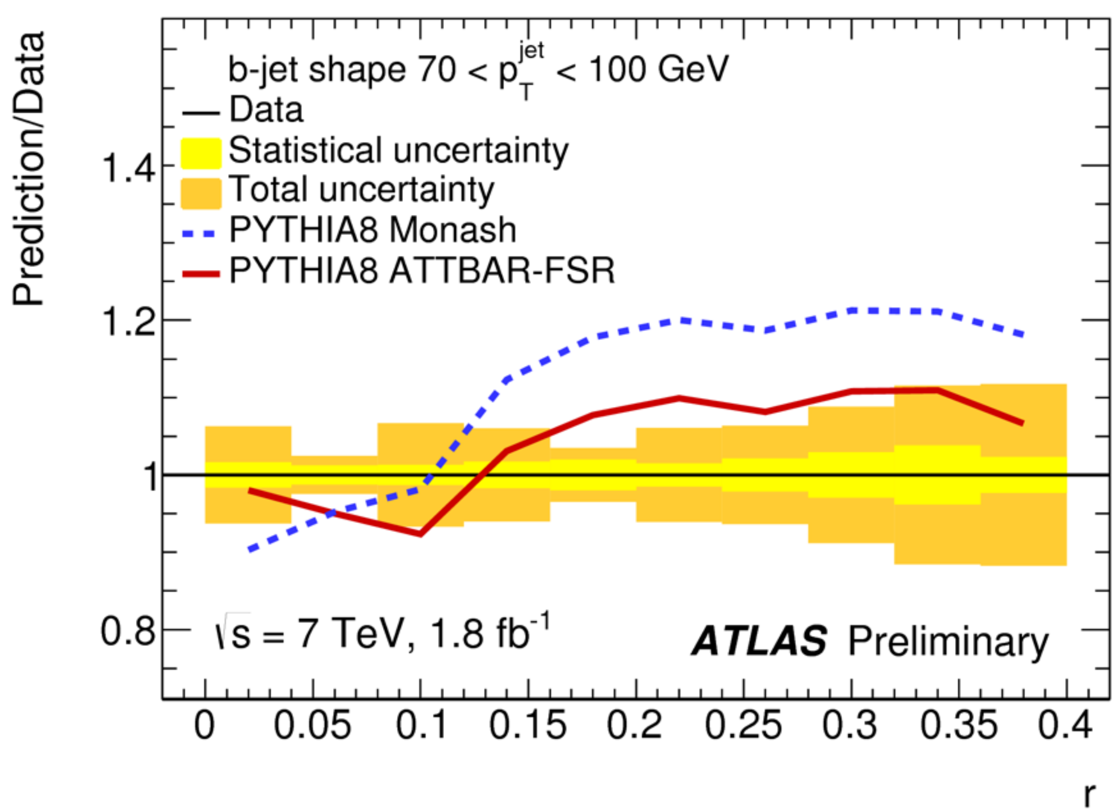


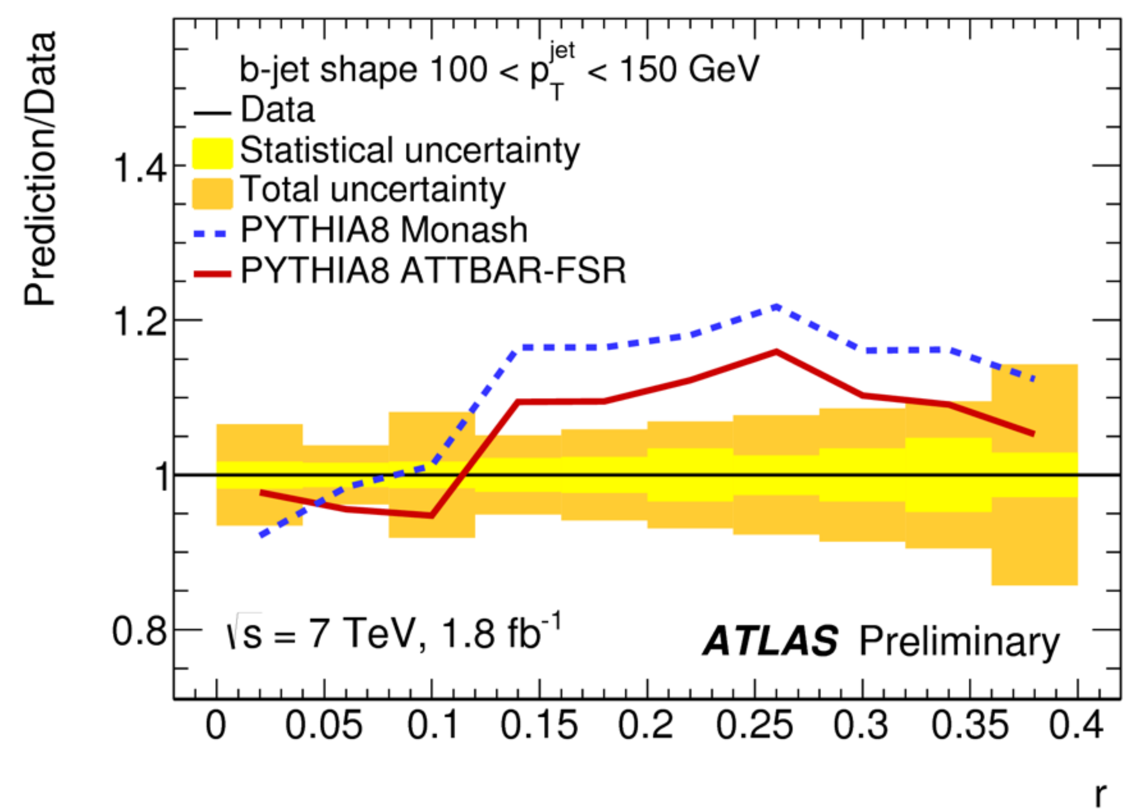
ATTBAR-FSR b-jet shapes



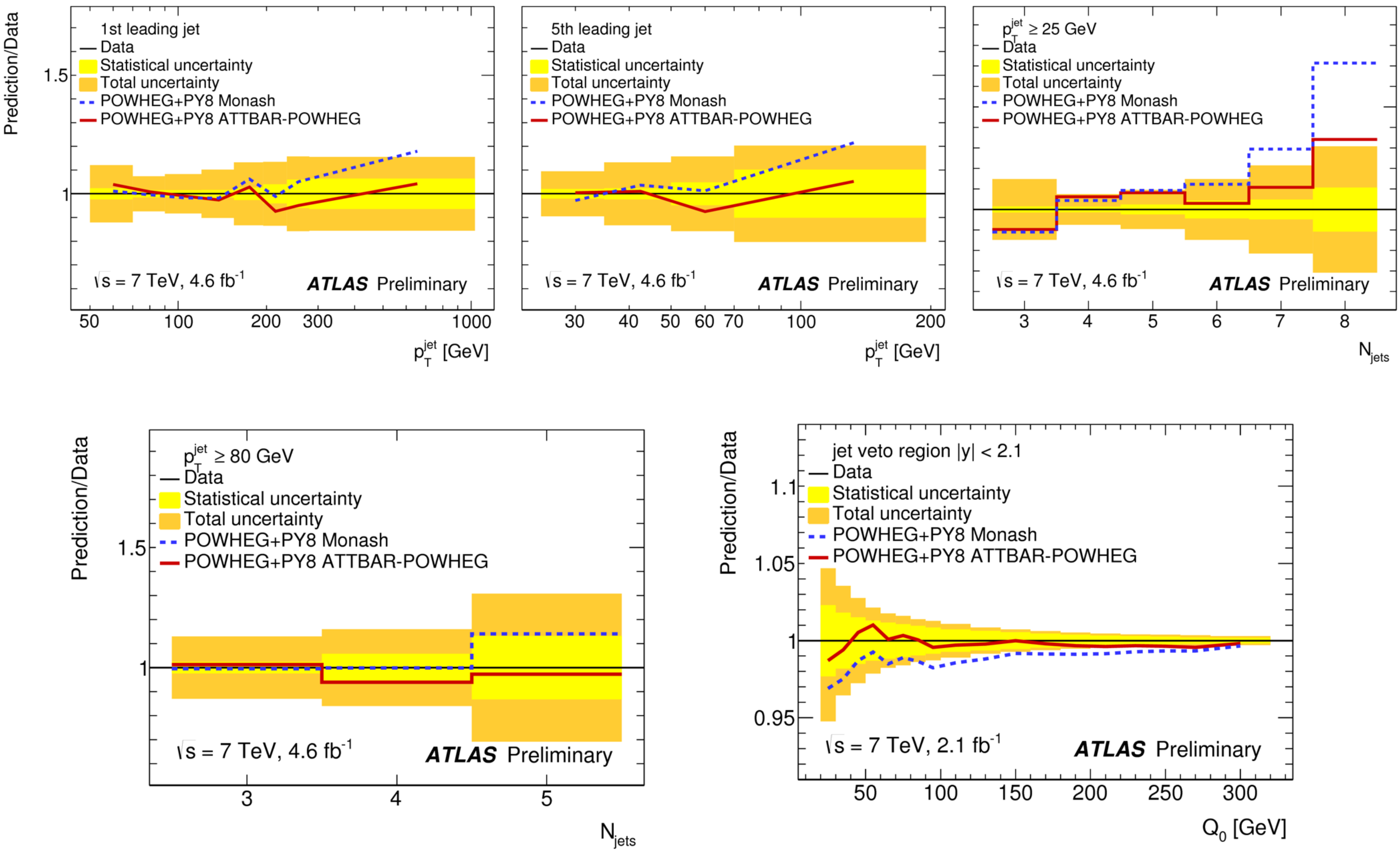




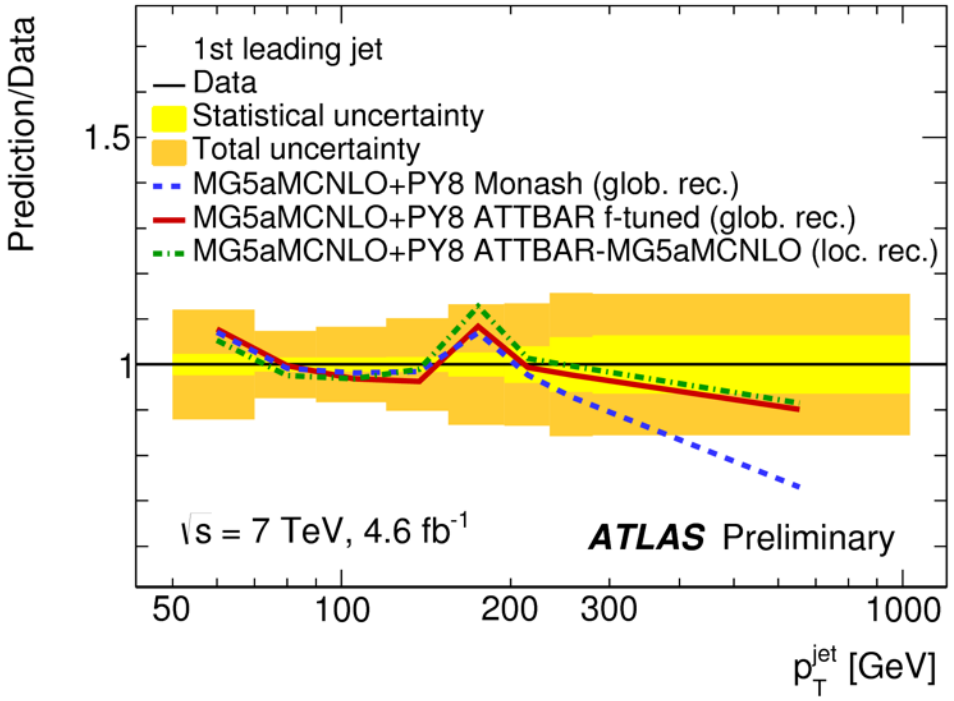


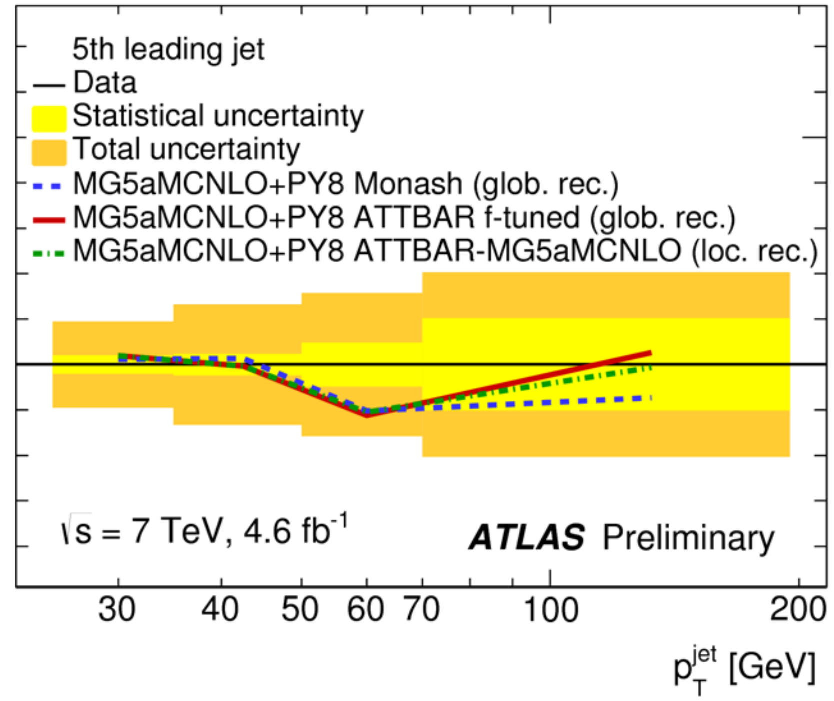


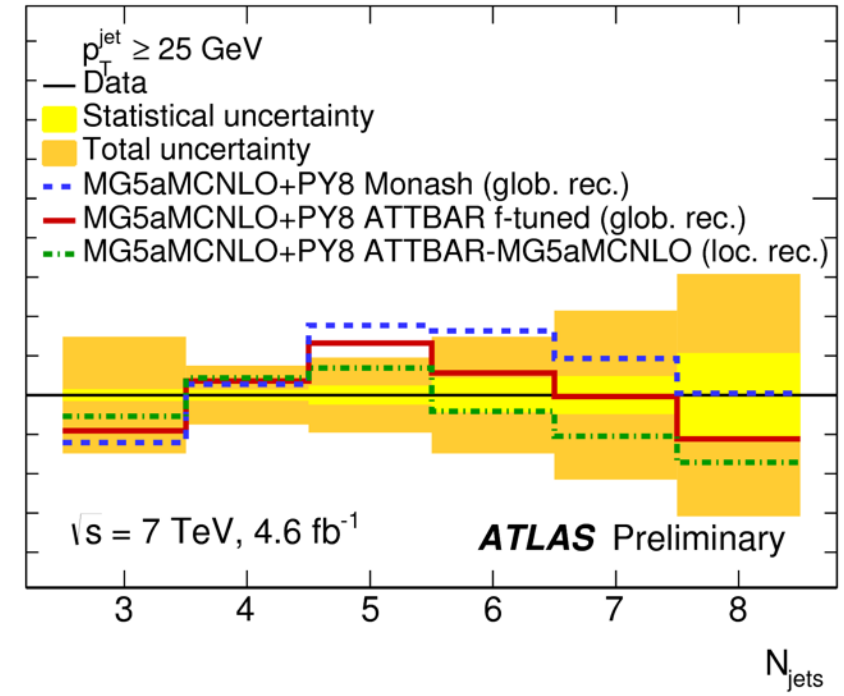
POWHEG TUNE

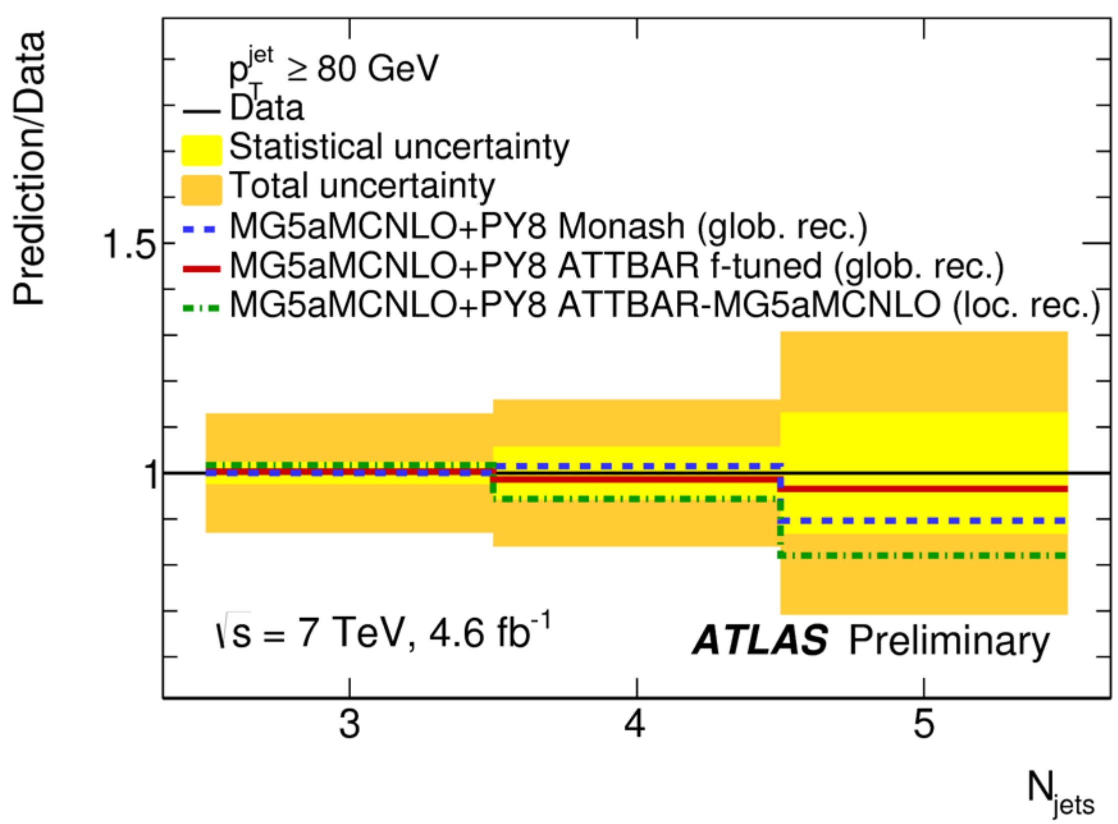

Prediction/Data
1st leading jet
Data
Statistical uncertainty
Total uncertainty
POWHEG+PY8 Monash
POWHEG+PY8 ATTBAR-POWHEG
√s = 7 TeV, 4.6 fb-1
ATLAS Preliminary
p_T^jet [GeV]
5th leading jet
p_T^jet ≥ 25 GeV
N_jets
p_T^jet ≥ 80 GeV
jet veto region |y| < 2.1
√s = 7 TeV, 2.1 fb-1
Q_0 [GeV]

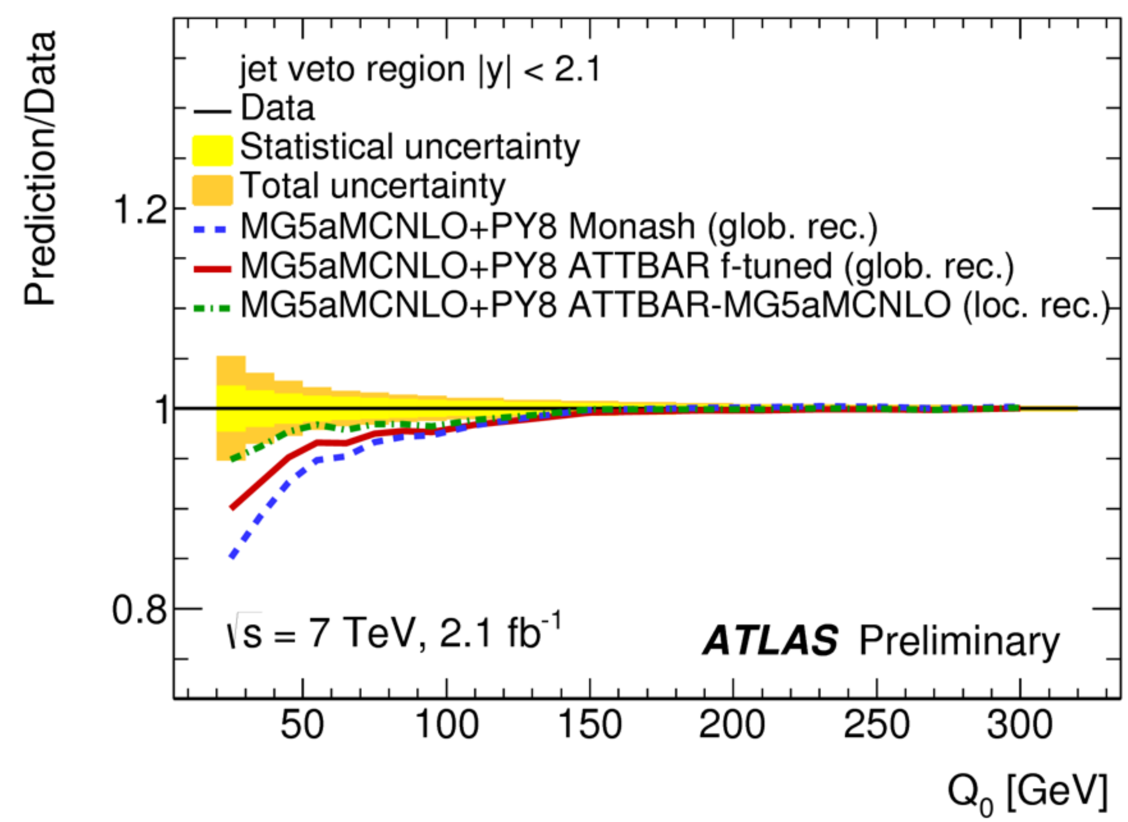
aMC@NLO tune











A better agreement is found using the local recoil option

Parameter correlations

- Correlation in the output parameters as returned from the tune
  - ISR and FSR parameters are decoupled

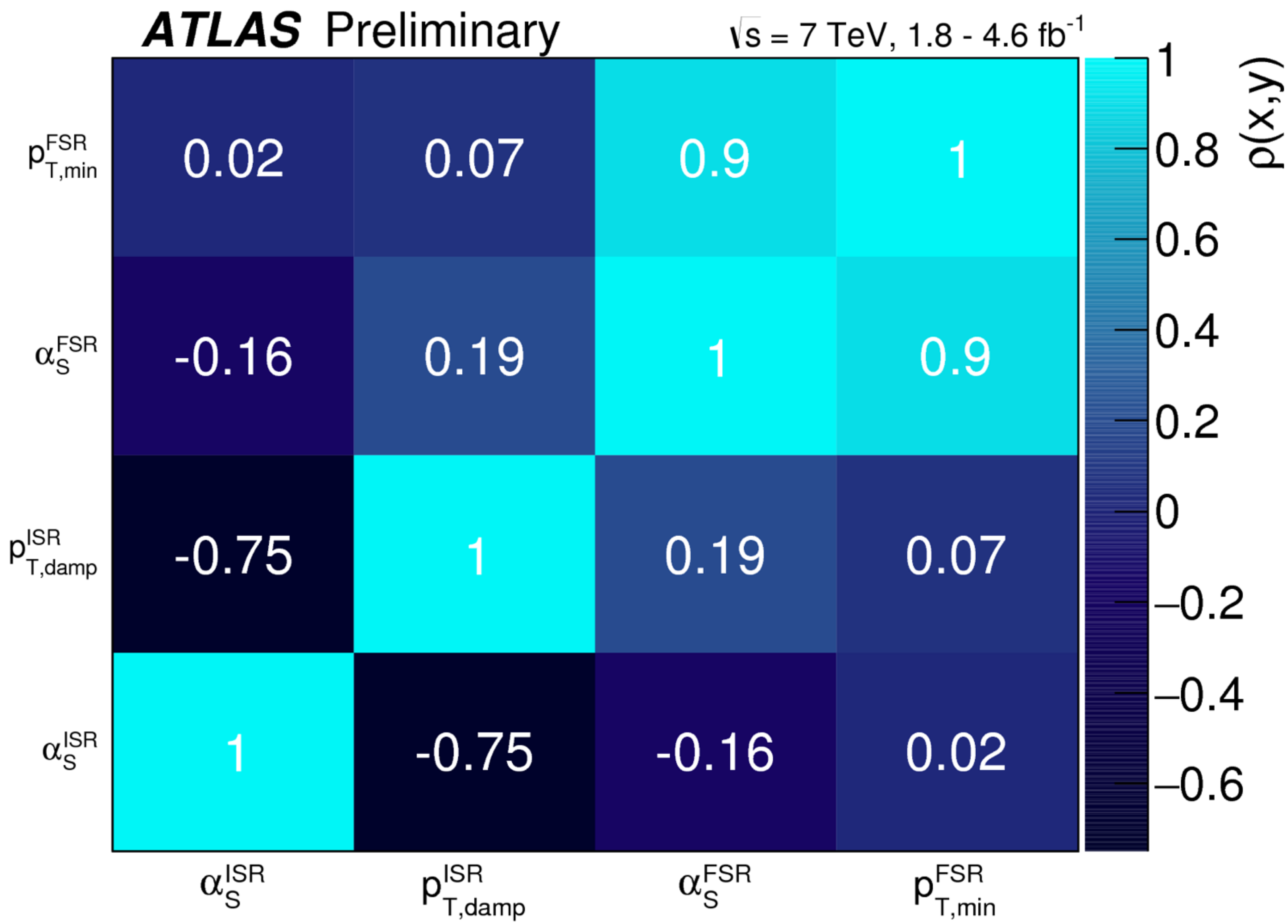


Table 11: The optimal parameters and their uncertainties as determined in the ATTBAR tune and in a tune performed without uncertainties correlations.

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

Global/Local recoil settings

Table 12: Global-recoil and local-recoil settings of Pythia8 for the MadGraph5_aMC@NLO+Pythia8 generator. The '-' symbol is used in case the setting is not applicable.

Pythia8 setting	Global recoil	Local recoil
`SpaceShower:pTmaxMatch`	1	1
`SpaceShower:MEcorrections`	off	off
`TimeShower:MEcorrections`	off	off
`TimeShower:globalRecoil`	on	off
`TimeShower:globalRecoilMode`	2	-
`TimeShower:nMaxGlobalBranch`	1	-
`TimeShower:nPartonsInBorn`	2	-
`TimeShower:limitPTmaxGlobal`	on	-

Tune settings

Pythia8 settings	ATTBAR	ATTBAR-MG5aMCNLO	ATTBAR-POWHEG
SpaceShower:alphaSvalue	0.121	0.121	0.121
SpaceShower:pTdampMatch	1	0	0
SpaceShower:pTdampFudge	1.18	-	-
TimeShower:alphaSvalue	0.137	0.137	0.137
TimeShower:pTmin	1.26	1.26	1.26
MultipartonInteractions:pT0Ref	2.16	2.16	2.16
TimeShower:globalRecoil	-	off	-
SpaceShower:pTmaxMatch	0	1	2
SpaceShower:MEcorrections	on	off	on
TimeShower:MEcorrections	on	off	on
POWHEG:veto	-	-	1
POWHEG:vetoCount	-	-	3
POWHEG:pThard	-	-	0
POWHEG:pTemt	-	-	0
POWHEG:emitted	-	-	0
POWHEG:pTdef	-	-	2
POWHEG:MPIveto	-	-	0
MadGraph5_aMC@NLO settings			
frac_upp	-	0.54	-
frac_low	-	0.54	-
scaleMCdelta	-	0	-
Powheg settings			
hdamp	-	-	$1.8 \cdot m_t$