ATLAS MPI tunes with various PDFs

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The latest development in ATLAS MC generator tunings using LHC data will be discussed. Pythia 6 generator have been tuned with a variety of PDFs. Pythia 8 tunes have been constructed for six different PDFs, and are primarily aimed at an optimal description of minimum bias, for use in pile-up simulation. Also tunes of Herwig+JIMMY were performed for the final time inside ATLAS. Interesting effects were observed in MPI simulation when using MC-adapted PDFs.

1 Introduction

This article describes the effort within ATLAS to provide Monte Carlo (MC) generator parameter sets – "tunes" – which provide an optimal description of this ATLAS data for use in future LHC physics studies. These tunes have been constructed for the Pythia 6 [1], Pythia 8 [2] and Herwig/Jimmy [3, 4] event generators, making maximal use of the available published data from ATLAS as well as the Tevatron and LEP experiments, for a variety of parton density functions (PDFs).

The effect of PDFs on MC tunes has gained a lot of attention recently. LHC experiments are more and more using NLO parton shower Monte-Carlos for many of the processes, but historically LO PDFs has been used for the LO parton shower Monte Carlo generation. MC-adapted PDFs [5–7] are a relatively new concept which provide PDFs especially designed for LO generators. The idea is to obtain the behavior of a LO PDF – in particular the LO gluon distribution – in the phase space relevant for the soft QCD models, while at the same time modifying the high-x PDFs such that the predictions of the LO MC generator for hard processes closely resemble the full NLO predictions, i.e. using NLO PDFs in NLO MC calculations. ATLAS was the first experiment to use these "mLO" PDFs in MC production campaigns. It has been shown by comparison to Tevatron data [8] that there is no final answer yet as to which PDFs give the best results. PDF effects on MC model predictions are difficult to obtain unless the PDF-dependent model parameters are tuned to the data. This note presents comparisons of full tunes to a variety of MC-adapted, NLO and LO PDFs to LHC data to further check this approach to PDF construction.

The tuning strategy [9–11] employed was to tune only to published ATLAS $\sqrt{s} = 7$ TeV and $\sqrt{s} = 900$ GeV minimum bias (MB) [12] and leading track and cluster underlying event (UE) [13, 14] data, and also to CDF leading jet and Drell-Yan UE [15] and MB [16] data at $\sqrt{s} = 1.96$ TeV. Since it was seen that tuning to LHC and Tevatron data with three different center-of-mass energies is very challenging, more weight was put on ATLAS 7 TeV distributions, and for Pythia 8 CDF data was not included in the tuning. For Herwig/Jimmy, due to the limitation of the energy extrapolation model, the tuning input came from 7 TeV and ~ 2 TeV

PDF type	PDF set	Used in tuning
Leading order (LO)	CTEQ6L1 [20]	Herwig/Jimmy, Pythia 6, Pythia 8
	MSTW08LO [21]	Herwig/Jimmy, Pythia 6, Pythia 8
Modified leading order (mLO)	MRSTMCal (LO**) [6]	Herwig/Jimmy, Pythia 6, Pythia 8
	CT09MC2 [22]	Herwig/Jimmy, Pythia 6
	MRST2007 (LO*) [5]	Pythia 6, Pythia 8
Next-to leading order (NLO)	CTEQ6.6 [23]	Herwig/Jimmy, Pythia 6, Pythia 8
	CT10 [24]	Herwig/Jimmy, Pythia 6, Pythia 8
	MSTW08NLO [21]	Herwig/Jimmy
	HERAPDF1.0 [25]	Herwig/Jimmy
	HERAdis [26]	Herwig/Jimmy
	NNPDF2.1 [27]	Herwig/Jimmy, Pythia 6

Table 1: PDF sets used for tuning with corresponding MC generator

data only. The set of Herwig/Jimmy and Pythia 6 tunes were named AMBT2 and AUET2 depending on whether minimum bias or underlying event data was used in the MPI stage of the tuning. The tunes were performed using the stand-alone AGILe event generator interface [17] (except for C++ Pythia 8) to steer parameters and switches and to feed events to the Rivet [18] analysis package. The parameter optimization was done using the Professor [19] tool.

PDFs from different PDF groups such as CTEQ, MSTW and, for the first time, also HERA and NNPDF2.1 were used and shown in Table 1, along with which generator-tunes used which set.

2 Herwig/Jimmy

The Herwig event generator is a general-purpose shower and hadronisation generator similar to Pythia 6 but with an angular-ordered (rather than $p_\perp$-ordered) parton showers, and a cluster-based rather than string-based hadronisation model. Notably, Herwig itself does not have an MPI model: this feature is added by the Jimmy add-on generator, and this combination in this article is referred to as Herwig/Jimmy. The MPI parameters are tuned [9].

Since the Jimmy MPI model is by design not valid for multiple scattering where the signal process is itself a soft scatter, minimum bias data cannot be used for tuning of this generator. As the underlying event data from ATLAS and CDF represent a smooth transition from minimum bias to UE-type processes, the softest parts of these observables must also be excluded from fits. In the ATLAS UE data, and that from the CDF 2001 UE study, the events are considered to be closer to minimum bias than hard QCD, and so Jimmy is instructed to generate the softest possible scatters by setting its UE mode to 0, via `JMUEO` = 0 and setting the lower phase space cut in p_T in hadronic jet production, `PTMIN`, to the value of the MPI cut-off, `PTJIM`. The cut-off for multiple parton interactions modeled with Jimmy is a single parameter, `PTJIM`, without any dependence on $\sqrt{s}$. In order to make the model fit to data for various collider energies, we apply the following energy dependence of `PTJIM` which is inspired by the "pomeron" energy evolution of the similar cut-off in the Pythia 6 model:

$$\mathtt{PTJIM}(\sqrt{s}) = \mathtt{PTJIM}_0 \cdot \left(\frac{\sqrt{s}}{1800\ \mathrm{GeV}} \right)^{\mathtt{EXP}}, \quad (1)$$

where the tuning parameter $\texttt{PTJIM}_0$ is the value for $\texttt{PTJIM}$ $(\sqrt{s})$ at the reference energy 1800 GeV. The energy exponent tuning parameter, `EXP`, was manually set at 0.274 in the MC08 JIMMY tune, and was kept fixed at this value for all PDFs). The final MPI parameter for tuning is the hadronic form factor radius: although JIMMY allows the proton and anti-proton radius to be set separately (`JMRAD(73)`, `JMRAD(93)`), we use the same variable, `PRRAD`, for both.

Equivalently-weighted tunes were performed for a total of ten PDFs. We found that the data distributions can be described to a similar degree for all PDFs. The Figures 1. show these tunes, compared with ATLAS 7 TeV UE data. Left-hand plot shows the comparison of data to the AUET2 tunes for the LO and mLO PDFs, as well as the AUET1 tune for the mLO LO$*$ PDF; the right-hand plot is a comparison of data with all the AUET2 tunes for NLO PDFs.

The JIMMY/HERWIG model does not have as many parameters as in PYTHIA 6, where a "color reconnection" mechanism can be used to level out the differences between the two classes of observable, and so one will always be described better than the other. This is particularly obvious in the observables featuring $\langle p_\perp \rangle$. The regions governed by soft physics are not described due to the missing soft physics in JIMMY/HERWIG. It can generally be said that the PDF effect can be "tuned away" with the available parameters, meaning that very similar agreement can be reached for all PDFs studied. However some differences are visible, e.g. the $\langle p_\perp \rangle$ vs. $N_{\rm ch}$ observables are a bit better described by the mLO PDFs than by the LO and NLO PDFs.

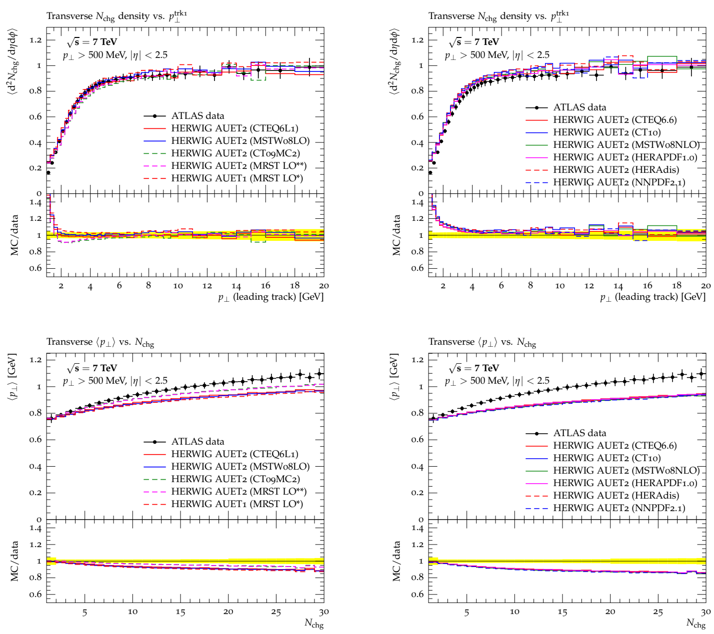

Figure 1: Comparison plots of the new HERWIG/JIMMY AUET2 tunes to 7 TeV ATLAS track-based UE data. Left column: LO and mLO PDFs. Right column: NLO PDFs. The track $p_\perp$ cut for all observables is 500 MeV.

3 Pythia 6

The Pythia 6 MC generator is used as the main general-purpose event generator in ATLAS, including in connection with the higher-order matrix element generators. It is based, as are all general-purpose showering/hadronisation generators, on (leading-order) partonic matrix elements augmented with QCD radiation resummation via initial- and final-state parton showers, a non-perturbative model for the combination of the resultant partons into physical hadrons, a standard treatment of the decays of these hadrons, and – importantly for this note – a phenomenological modeling of the bulk interactions of the colliding protons via the formalism of multiple partonic interactions (MPI). We will focus on the MPI tuning part in this article, for the details of hadronisation and final state shower setup, and shower tune, one can refer to [10, 11]. We use a five-parameter tuning space and numerically optimize the description of MPI-sensitive data from ATLAS and CDF, with weighted emphasis on the ATLAS observables. We just list briefly the parameters used in this tuning:

- The $p_\perp$ cut-off/regularize value used to avoid soft divergences in the model, set for a reference scale of $\sqrt{s} = 1800$ GeV, and the exponent used in its energy evolution to other beam energies are given by `PARP(82)` and `PARP(90)` respectively.
- The hadronic matter distribution is modeled by a double-Gaussian distribution, parameterized by `PARP(83)` and `PARP(84)`: as these parameters are strongly correlated, we fixed `PARP(83)` to its AMBT1 value of 0.356 and only tuned `PARP(84)`.
- The final parameters are `PARP(77)` and `PARP(78)`, which control the probabilities of color reconnection occurring for fast-moving (high-$p_\perp$) and general color strings.

The tunes were constructed with equal fitting weights for several PDFs. As there is neither theoretical nor practical motivation for use of NLO PDFs in description of minimum bias observables, and mLO PDFs were observed in the previous tuning to introduce strong and untuneable deviations from data in minimum bias, we only attempt to describe underlying event (UE) observables here: in other words we extend the PDF coverage of the AUET2B tune series, but not the AMBT2B one. The behaviors of the resulting tunes in ATLAS underlying event observables are shown in Figures 2.

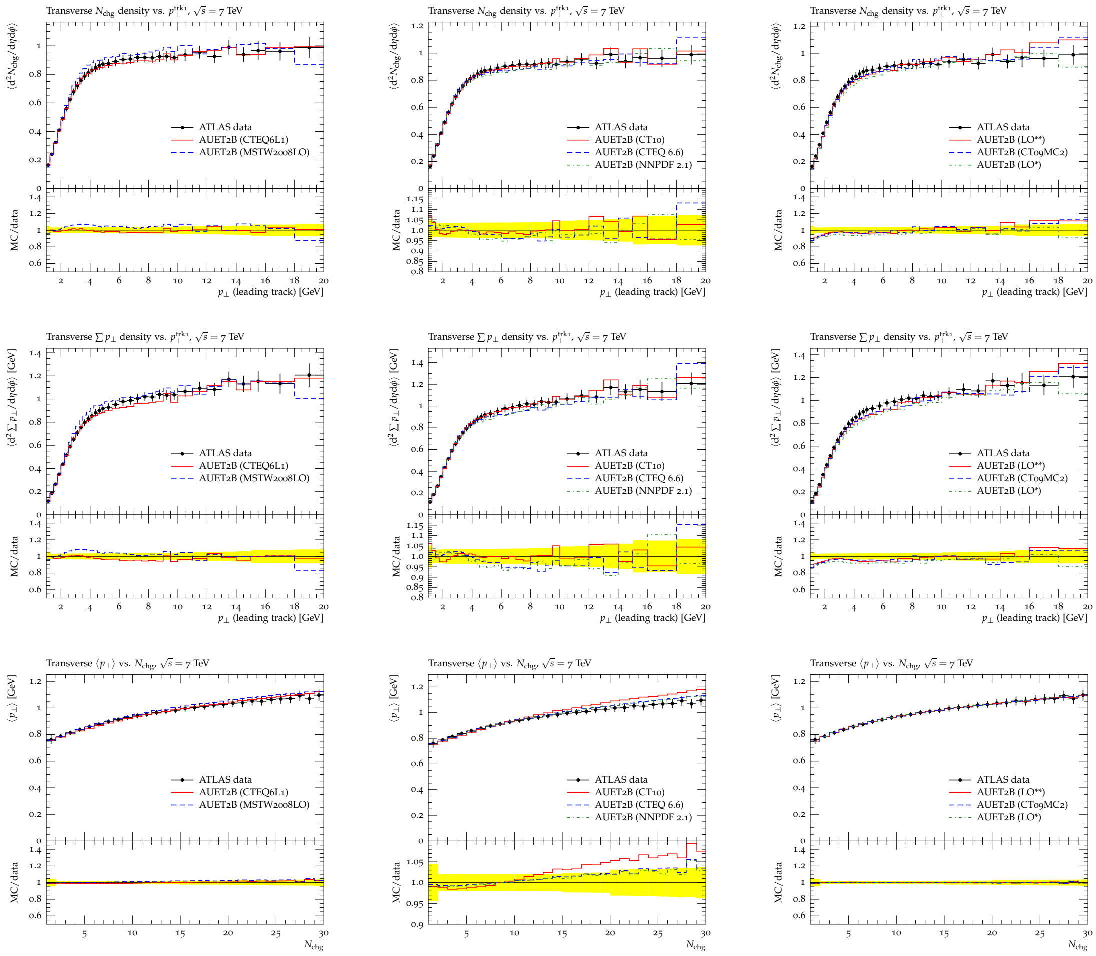

Figure 2: Comparison plots of the new PYTHIA 6 tunes to ATLAS underlying event data at 7 TeV [13, 14]. The tunes corresponding to LO, NLO and mLO PDFs are shown respectively in the left, center and right columns. The yellow shaded areas represent data uncertainty.

4 Pythia 8

The use of the C++ Pythia 8 generator is gaining more popularity, partly because this is the version being supported and developed by the authors, and partly because it has better diffractive modeling than PYTHIA 6. Pythia 8 tunes have been performed using a newly introduced feature in version 8.153, where the width of the transverse matter distribution varies depending on the momentum fraction of the interacting partons. The parameters tuned are MultipleInteractions:ecmPow (subsequently referred to as ecmPow), MultipleInteractions:pT0Ref (subsequently refereed to as pT0Ref), BeamRemnants:reconnectRange (subsequently referred to as reconnectRange) and MultipleInteractions:a1 (subsequently referred to as a1). The MultipleInteractions:a1 parameter represents the constant in the Gaussian matter distribution width and the rest are described with the corresponding Pythia 6 parameters for easy reference in Table 2. The other parameters are same from tune 4C [28], except that SpaceShower:rapidityOrder is turned off, as there are some indications from multi-jet matching results that the shower gets closer to the matrix-element results when it is switched off.

MPI parameter	Equivalent Pythia 6 parameter
MultipleInteractions:pT0Ref	`PARP(82)`
MultipleInteractions:ecmPow	`PARP(90)`
BeamRemnants:reconnectRange	`PARP(77)`, `PARP(78)`
MultipleInteractions:bProfile	`MSTP(82)`
If MultipleInteractions:bProfile = 2 (double-Gaussian matter dbn.)	
MultipleInteractions:coreFraction	`PARP(83)`
MultipleInteractions:coreRadius	`PARP(84)`
If MultipleInteractions:bProfile = 3 (exp/Gaussian overlap dbn.)	
MultipleInteractions:expPow	`PARP(83)`

Table 2: Pythia 8 MPI parameters

The tuning was done separately for six different PDFs. It was found that with the LO PDFs, a common tune (named A2) for minimum bias and underlying event could be obtained. However, for higher order PDFs, this was not the case, and underlying event (AU2) tunes were performed. Figure 3 shows the new LO MB tunes (and tune 4C and 4Cx [29]), compared with ATLAS minimum bias data at $\sqrt{s} = 7$ TeV. Figure 4 shows the tunes for all PDFs compared with ATLAS underlying event data at $\sqrt{s} = 7$ TeV.

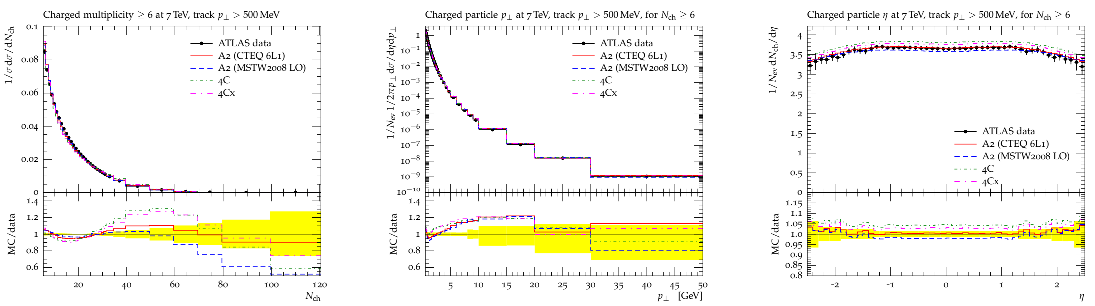

Figure 3: Comparison plots of the new Pythia 8 tunes to ATLAS minimum-bias event data [12] at 7 TeV. The yellow shaded areas represent data uncertainty.

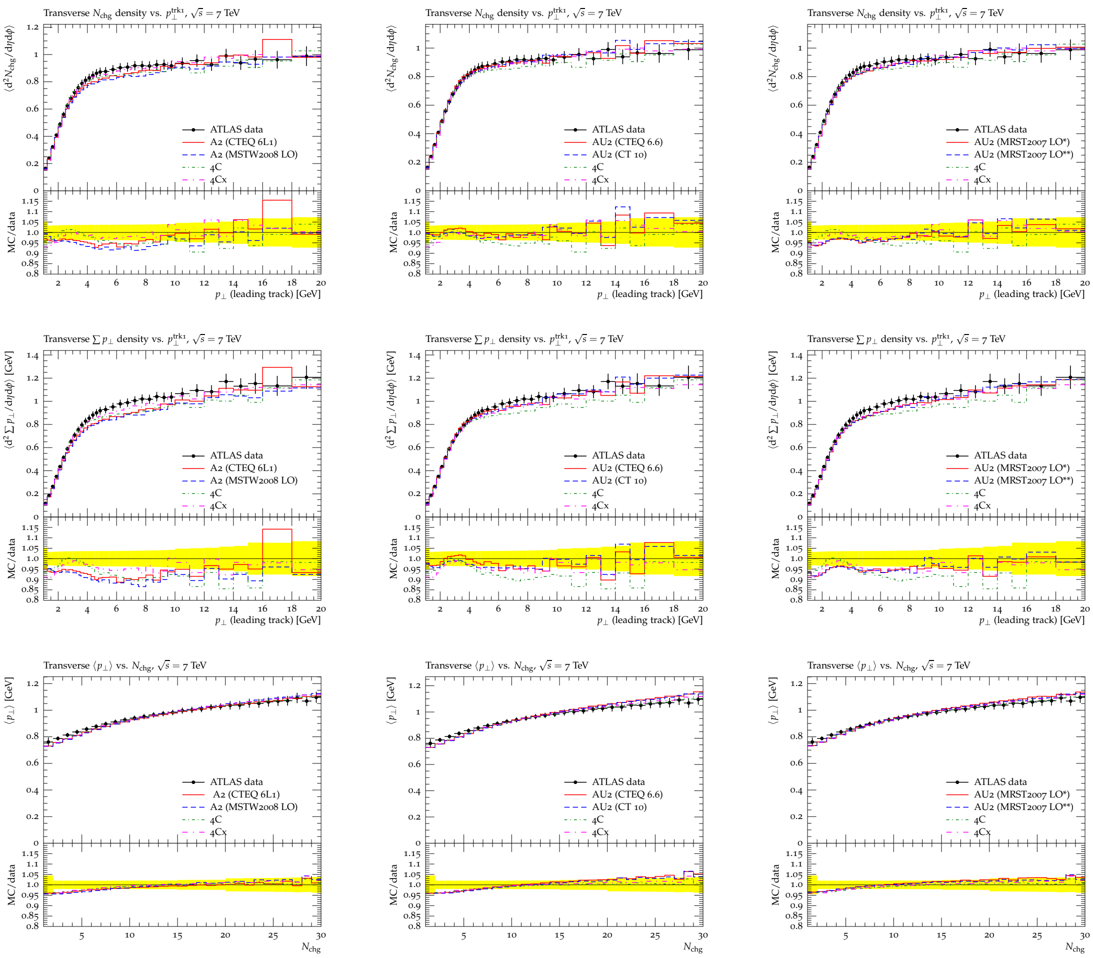

Figure 4: Comparison plots of the new Pythia 8 tunes to ATLAS underlying event data at 7 TeV [13, 14]. The tunes corresponding to LO, NLO and mLO PDFs are shown respectively in the left, center and right columns. The yellow shaded areas represent data uncertainty.

5 Effect of PDFs

We observed that for HERWIG/JIMMY tunes the cut-off parameter PTJIM group according to the PDF type with the mLO PDFs yielding the highest values, followed by the LO and the NLO PDFs, seen in Figure 5. Since a high cut-off values means that less activity is required by the parton shower to match the data this result is in agreement with the expectation that the mLO PDFs create more activity from the beginning.

The tunings presented in this note, for both the PYTHIA 6 and Pythia 8 generators, have indicated a significant connection between the PDF being used and both the parameter values obtained and some qualitative features of MPI-influenced observables. For PYTHIA 6 results show a strong differentiation between the tunes to LO and mLO PDFs. The LO** PDF arguably

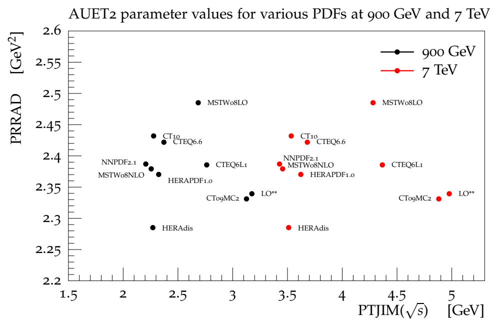

Figure 5: Observed grouping of tuning results of PTJIM by PDF type.

has the worst behavior for minimum bias observables, with a very substantial overshoot in the description of charged multiplicity from $N_{\mathrm{ch}} \gtrsim 40$ for a track $p_\perp$ cut of 500 MeV. All the mLO PDFs display a factor-of-2 overshoot in the minimum bias $p_\perp$ spectra for much of the available range, an observable well described for both LO PDFs. The underlying event observables are also in general described better by the LO PDFs, with the two MRST mLO PDFS (LO$*$ and LO$**$) undershooting the turn-over region. NLO PDFs seem to prefer lower values of the `PARP(82)` and `PARP(90)` MPI parameters that are typically favored by LO and mLO PDFs. Similarly for Pythia 8, we saw that the different PDFs prefer particular values of the tuning parameters. The tunes corresponding to two LO PDFs need very different set of tune values, although they behave very similarly in MB and UE plots. The behavior of tunes corresponding to mLO PDFs (LO$*$ and LO$**$) are very similar, however they almost reduce back to the single Gaussian matter distribution. This is in fact a common feature for all the tunes, with very low a1 values. The tunes corresponding to NLO PDFs seem to demand a stronger color reconnection strength than the others, but somewhat lower MPI p_{T} cut-off and energy exponent. Respectively these parameter shifts mean that NLO PDF tunes have less MPI cross-section screening (i.e. more activity) at Tevatron energies than LO/MLO equivalents, and the increase in screening scale with center-of-mass energy is slower than for lo/mLO PDF tunes.

6 Conclusions

In this article we have presented latest tunes of the Herwig/Jimmy, Pythia 6 and Pythia 8 event generators, with different PDFs. The effect of PDFs on the tunes has been studied, and this represents an ongoing effort to decide which PDF and tune combinations will give the best description of the available data.

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