Fitting B/C cosmic-ray data in the AMS-02 era: a cookbook

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Motivation

→ High quality AMS-02 data (systematics > statistical errors)

→ Need to re-evaluate how analyses are carried out

PHENOD meeting
05/07/2019

χ^2 with covariance and nuisance

How to compare model to data?

$$\mathcal{D}_{\text{no-cov}} = \sum_{k=1}^{n_E} \frac{(\text{data}_k - \text{model}_k)^2}{\sigma_k^2}$$

→ Standard χ^2

$$\mathcal{D}_{\text{cov}} = \sum_{i,j=1}^{n_E,n_E} (\text{data}_i - \text{model}_i)\,(\mathcal{C}^{-1})_{ij}\,(\text{data}_j - \text{model}_j)$$

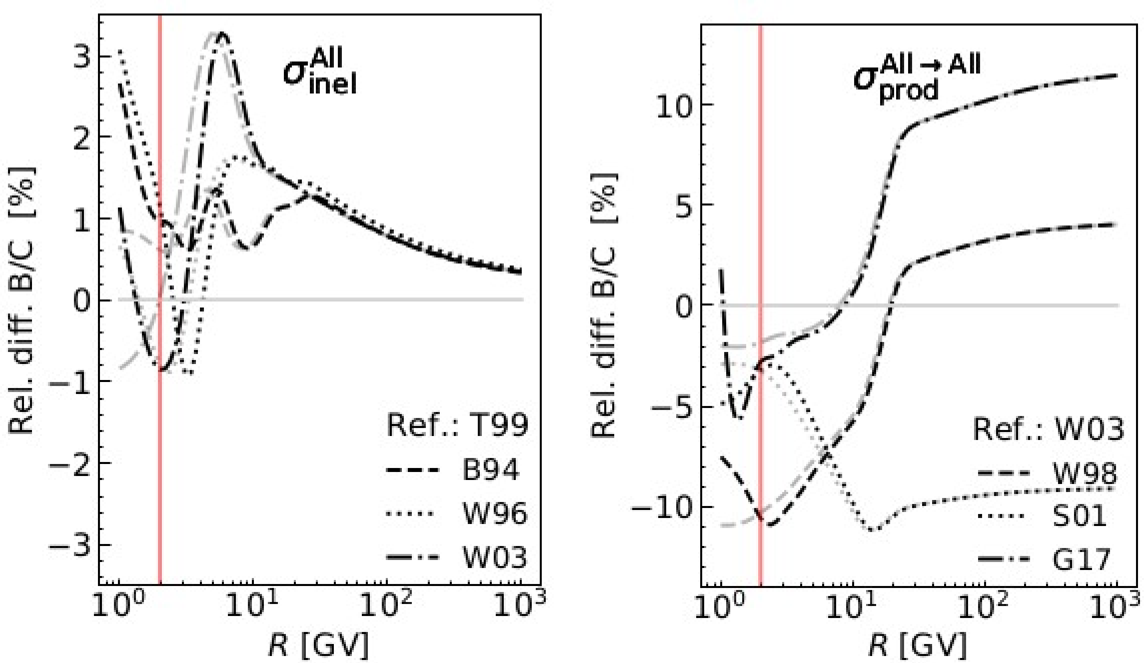
→ Include possible correlations in adjacent data bins via covariance matrix of data errors

$$\chi^2 = \underbrace{\sum_t}_{\text{time periods}} \left(\underbrace{\sum_q}_{\text{qties}} \left(\mathcal{D}_{\text{cov}}^{t,q} + \mathcal{N}^{t,q} \right) + \mathcal{N}^t \right) + \underbrace{\mathcal{N}}_{\text{generic}},$$

→ Account for possible nuisance parameters: penalty if parameter value several σ away from its expected value (from `external' experiment)

- 't': depends on data taking periods (e.g., modulaton level per given CR dataset)
- 'q': depends on specific quantities considered
- Time- and quantity-independent (e.g., cross section values)

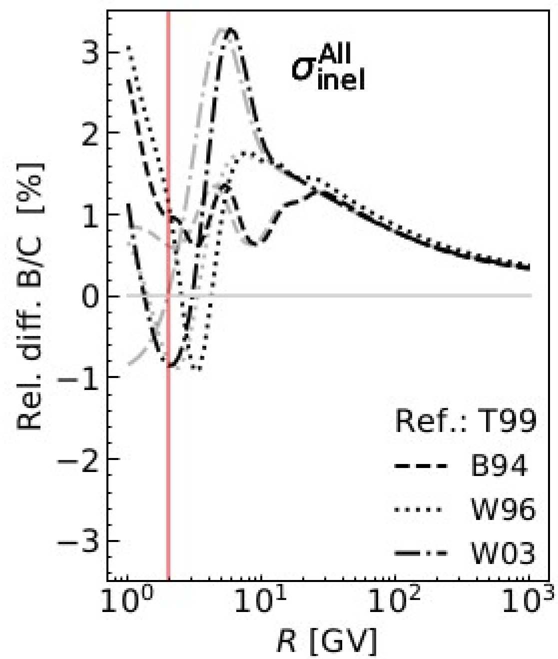
Impact of different XS datasets on B/C

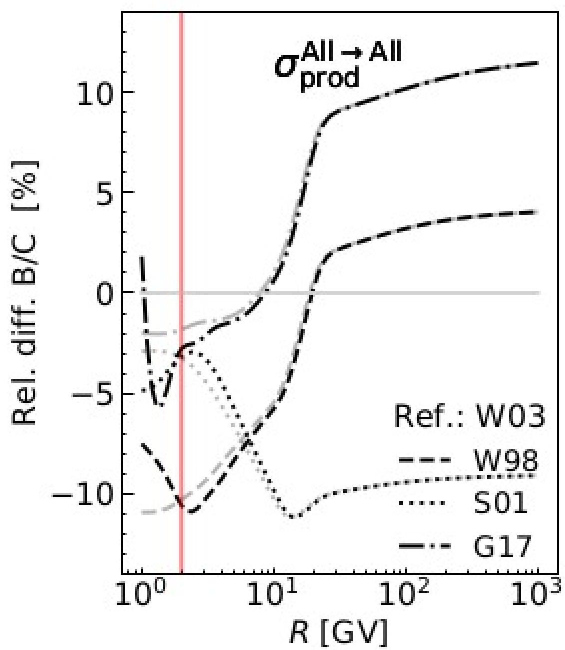


→ Enable 'continuous deformations' of XS to encompass XS uncertainties

Handling cross-section uncertainties (2)

Impact of different XS datasets on B/C + **Dominant reactions**





+

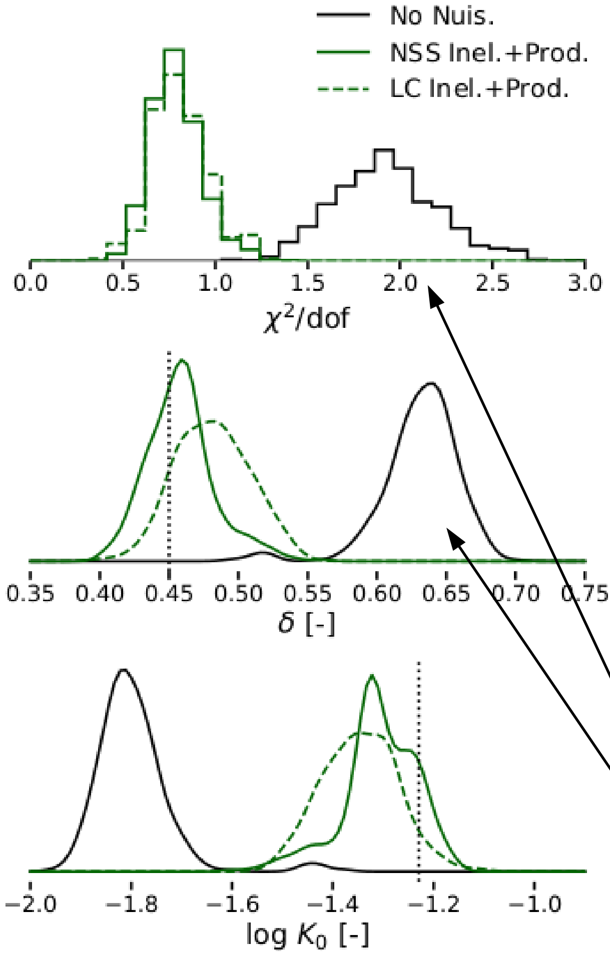
Reaction (max. impact on B/C)
^{16}O+H (1%)
^{12}C+H (3%)
^{11}B+H (2%)
^{16}O+H→^{11}B (15%)
^{16}O+H→^{10}B (9%)
^{12}C+H→^{11}B (12%)
^{12}C+H→^{10}B (14%)

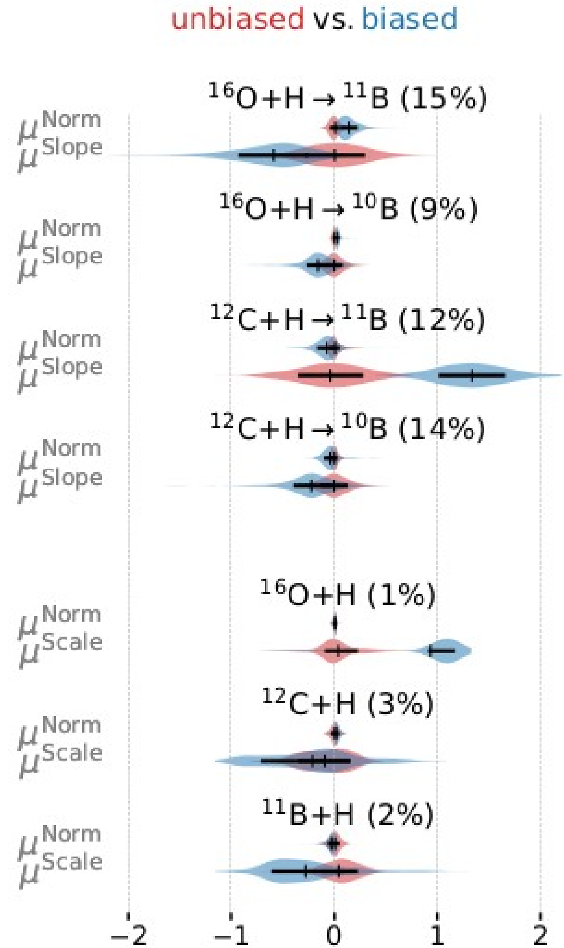
→ Enable ‘continuous deformations’ of XS to encompass XS uncertainties

→ Nuisance on `deformation’ parameters of most impacting reactions (stop when impact < data uncertainties)

Handling cross-section uncertainties (3)

Vaidation on mock data + **nuisance NSS (Norm, Slope, Scale)**

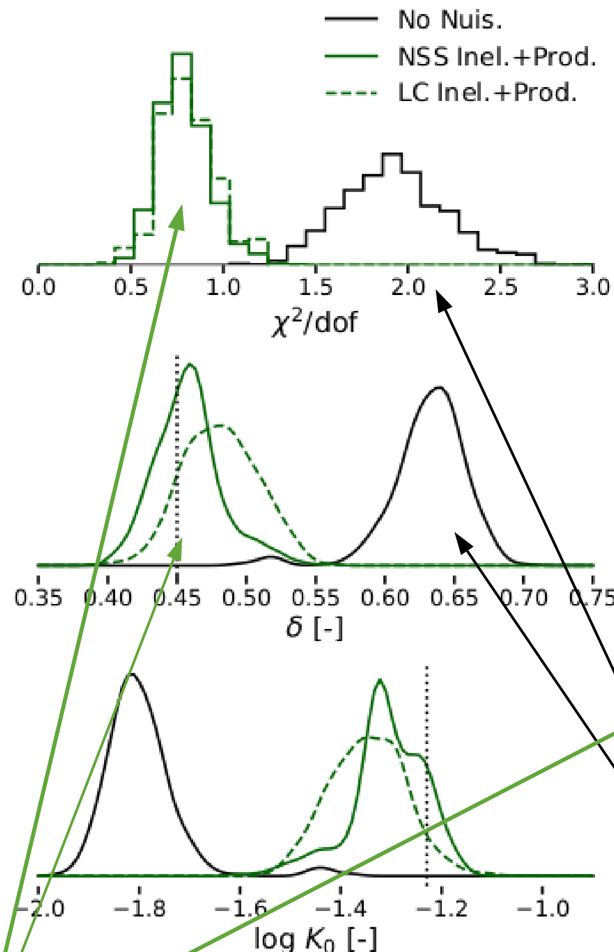


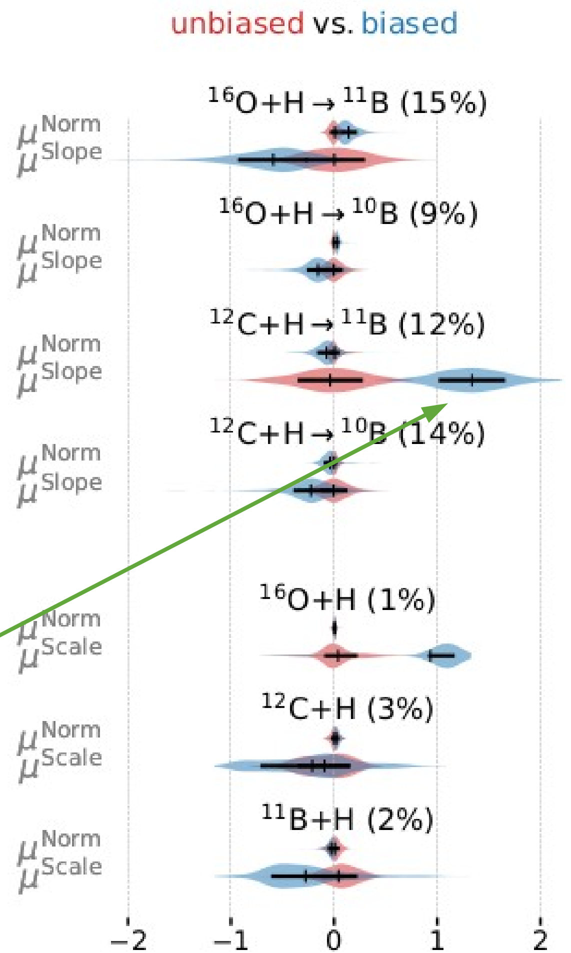


→ If wrong XS, biased statistical interpretation (model excuded)

Handling cross-section uncertainties (4)

Vaidation on mock data + **nuisance NSS (Norm, Slope, Scale)**



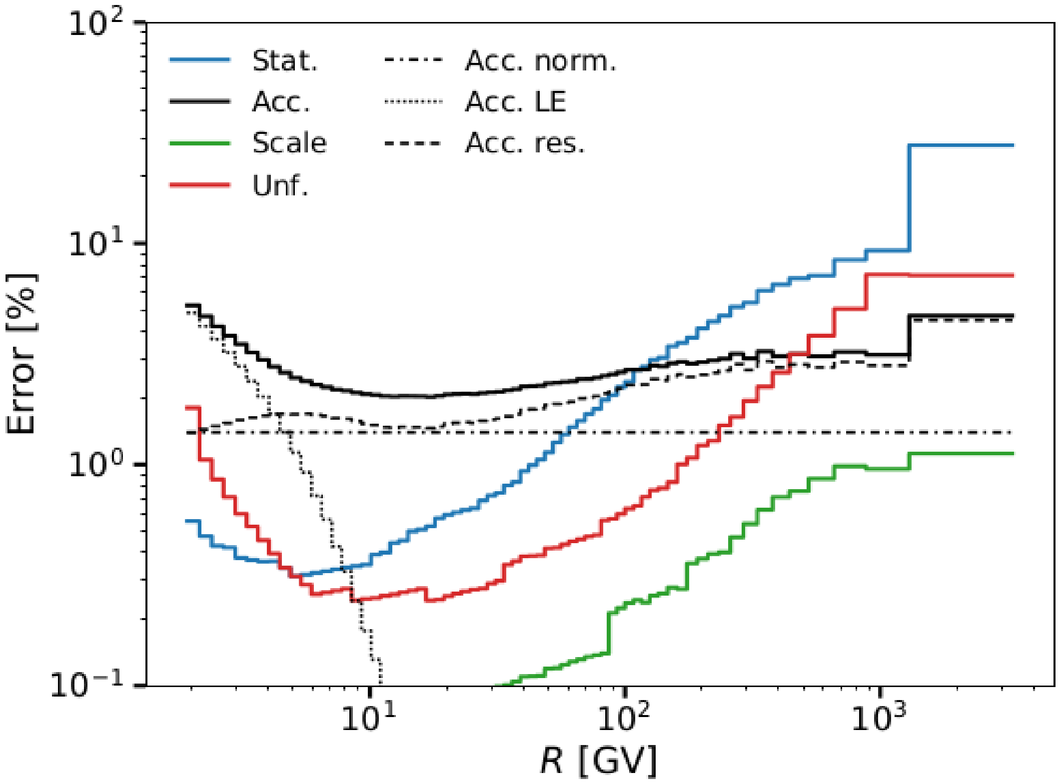


→ If wrong XS, biased statistical interpretation (model excuded)

→ Nuisance parameters ‘NSS’ allow to recover true values and meaningful χ^2

Handling systematic from experimental data (1)

AMS-02 level of systematics + **`model' for correlation length**



$$(C^{\alpha}_{\rm rel})_{ij} = \sigma^{\alpha}_i \sigma^{\alpha}_j \exp\left(-\frac{1}{2}\frac{(\log(R_i/R_j))^2}{(l^{\alpha}_{\rho})^2}\right)$$

l = 0 → no correl. (e.g. stat. errors)

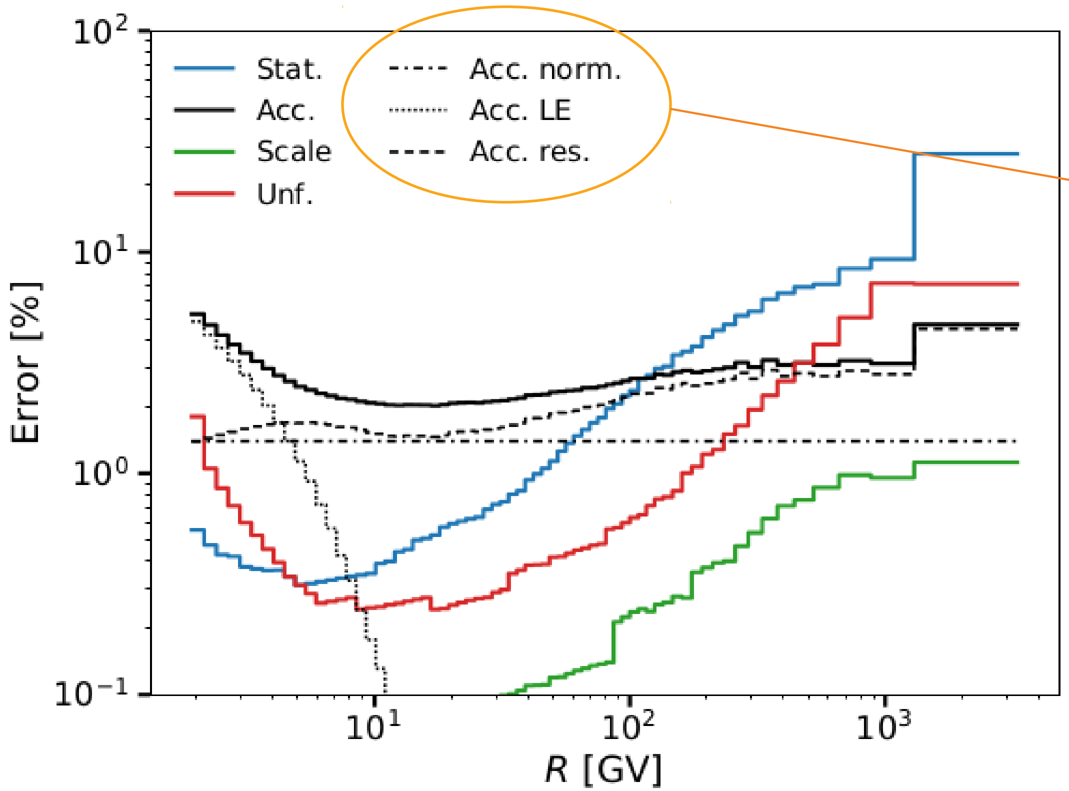
l = ∞ → full correl. = norm. (e.g. scale)

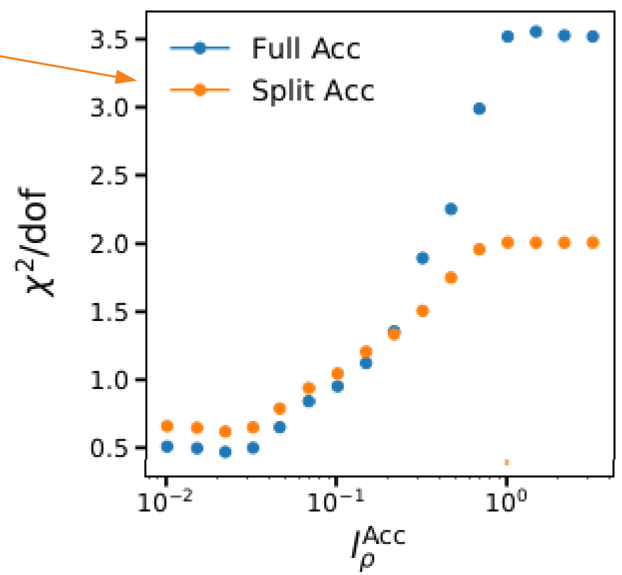
→ Correlation lengths built from detector and analysis characteristics

Handling systematic from experimental data (2)

AMS-02 level of systematics + **`model' for correlation length**

$$(C^{\alpha}_{\rm rel})_{ij} = \sigma^{\alpha}_i \sigma^{\alpha}_j \exp\left(-\frac{1}{2}\frac{(\log(R_i/R_j))^2}{(l^{\alpha}_{\rho})^2}\right)$$





→ Acceptance is one of the most complicated systematics (includes several effects)

→ Choice of its correlation length crucial for sound statistical interpretation of data

Conclusions (1)

Cross sections

→ 10-15% uncertainties from XS: using wrong XS bias transport parameters

→ nuisance parameters propagate ‘uncertainties’ and remove biases

AMS-02 data systematics

→ 3-6% uncertainties, correlation matrix and lengths built from ‘detector’

→ Fix l_{acc} to get meaningful χ^2

N.B.: to do better would require lot of work from AMS-02 collaboration

Model precision, numerical convergence, etc.

→ Ensure that model calculation much better than data uncertainties

→ Ensure qty calculated with model is same as in data (# events in bin)

→ Sound and flexible framework to carry out AMS-02 data analyses, accounting for all dominant uncertainties

Conclusions (2)

→ All analyses performed with USINE [https://lpsc.in2p3.fr/usine]

https://arxiv.org/abs/1807.02968

USINE

version 3.5

Search docs

1. General information
2. Installation and tests
3. Models and equations
4. Inside USINE (c++)
5. USINE input files
6. Parameter value syntax (init. file)
7. Tutorial: `./bin/usine`
8. Licenses

Doxygen (for developers)

Home » USINE documentation

Edit on GitLab

USINE documentation

Welcome to USINE, a library with several semi-analytical Galactic cosmic-ray (GCR) propagation models (PDF version of documentation here).

We hope you will enjoy using USINE whether you want to:

- **learn and know more about CR propagation phenomenology**, taking advantage of the simple command-line interface and graphical pop-ups to quickly see and compare the importance of various ingredients on the resulting fluxes;
- **perform state-of-the art analyses of new CR data**, taking advantage of the very flexible ASCII parameter file to select your model, configuration, etc., to fit your data with any number of free parameter (transport, source, geometry...) and nuisance parameters (cross sections, data systematic uncertainties...);
- **develop and use you own semi-analytical model** without having to spend years setting all inputs and outputs right, taking advantage of the modularity and flexibility of the USINE C++ library.

If you use USINE, please cite Maurin (2018)

For any question, contact D. Maurin (LPSC).