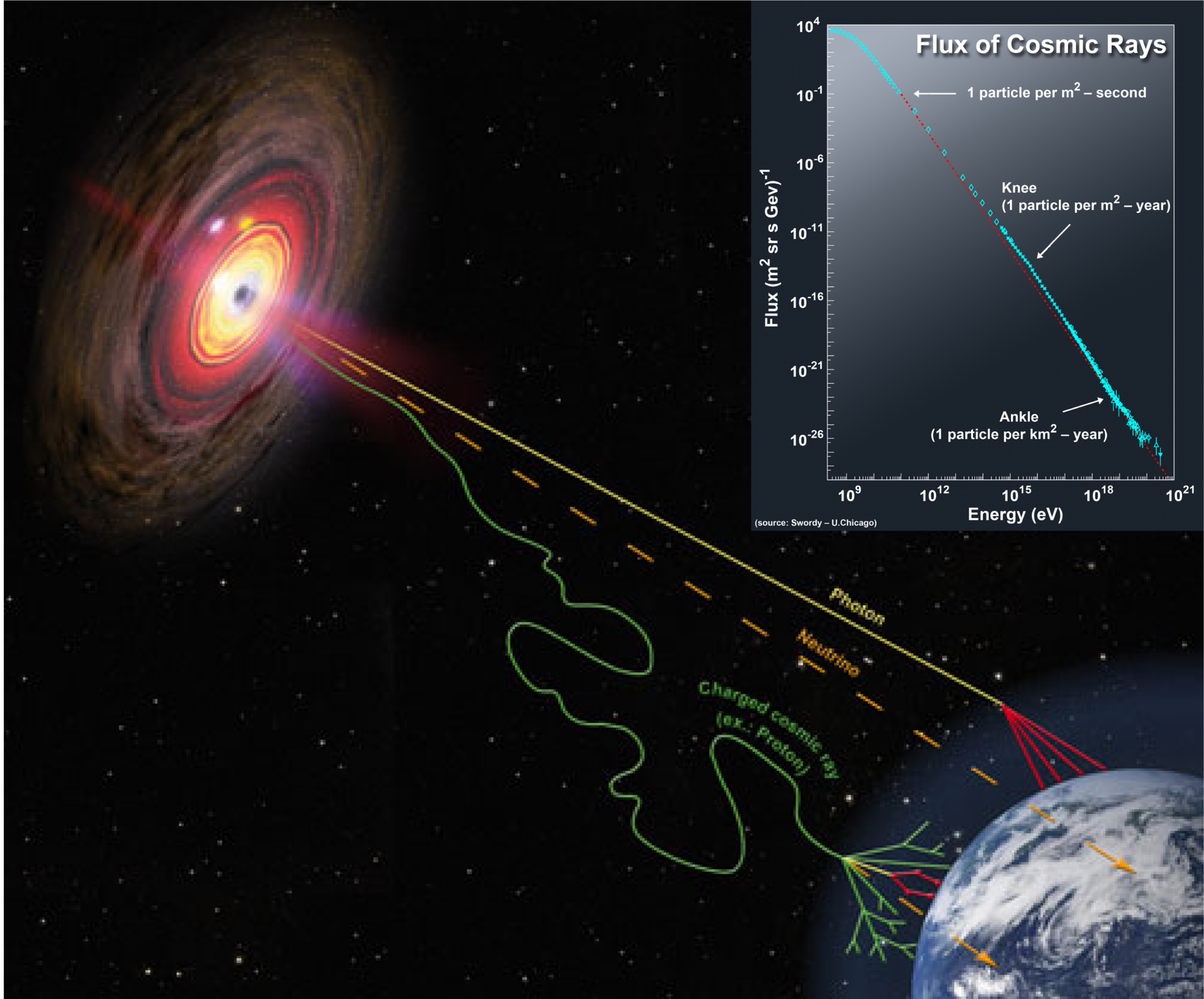
# Can LHCf help to improve searches for Galactic Pevatrons?





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# Current work horse for Pevatron searches

**Parametrization of gamma-ray production cross-sections for $pp$ interactions in a broad proton energy range from the kinematic threshold to PeV energies**

Ervin Kafexhiu,[1] Felix Aharonian,[2] Andrew M. Taylor,[3] and Gabriela S. Vila[3]

- The differential gamma-ray flux is what we measure.
- It is our expertise to derive a statistical and systematic error on the flux.

Astrophysics, hadron spectrum: This is what we try to constrain

$$\Phi_\gamma(E_\gamma) = 4\pi n_{\mathrm{H}} \int \frac{d\sigma}{dE_\gamma}(T_p, E_\gamma) J(T_p) dT_p, \qquad (25)$$

The smaller the uncertainty in particle physics, the better our ability to constrain the astrophysics.

# Problem

$$\Phi_\gamma(E_\gamma) = 4\pi n_{\rm H} \int \frac{d\sigma}{dE_\gamma}(T_p, E_\gamma) J(T_p) dT_p, \qquad (25)$$

- No useful error estimate available to me for the particle physics factor (differential cross section for p + X -> gamma + Y)

- Need to constrain the astrophysics very well in order to derive really useful conclusions regarding CR acceleration up to the “knee” of the CR spectrum
  - Good constraints of astrophysics are only possible if uncertainties in particle physics are small and quantified.
  - The absolute cross-section is irrelevant; only energy dependence is important.
  - The propagation of the particle physics uncertainty into our Pevatron results is non-trivial: Need simulations.

# Current particle physics modeling error

- The Kafexhiu et al. best fit (in red below) is compared to different models (SIBYLL 2.1 below, others: QGSJET-I, Pythia 8.18 in the paper)
- They quote a typical error of 20%
- Looking at the plots, the error is sometimes even larger than 20%

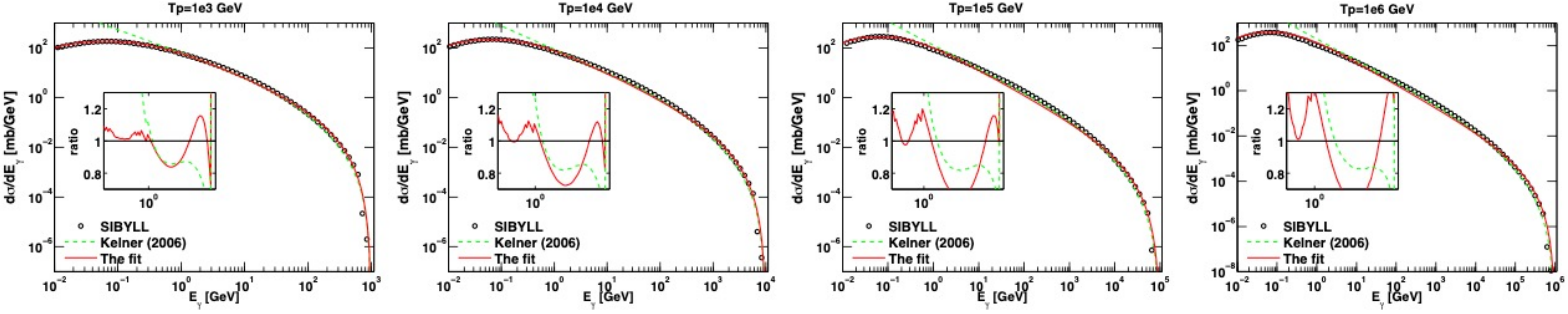



FIG. 12. SIBYLL 2.1 $\gamma$-ray production differential cross section for some specific proton kinetic energies. The open circles are SIBYLL 2.1 calculations, the full red line is the fit formula shown in eq. (11) with the corresponding $\alpha(T_p)$, $\beta(T_p)$ and $\gamma(T_p)$ listed in table V and the dash green line is the fit given in [44]. The ratio between the fit and the calculations shows that the accuracy of the fit is of the order 20 %.

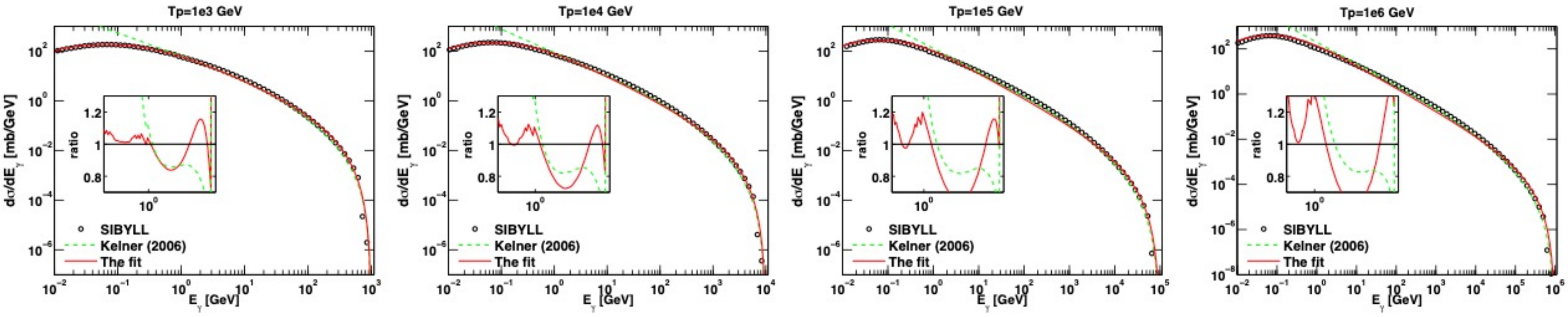
# Summary of my problems with the Kafexhiu et al. paper

- The Kafexhiu et al. paper is undoubtedly clear progress over previous studies (e.g., Kelner, Aharonian, Bugayov (2006)), and a lot of excellent work went into that paper. But we need to go further.

- I miss a clear and, in practice, helpful treatment of errors: This is of high relevance for Pevatron searches

# Possible concrete step to start with

- Can we repeat the study below from Kafexhiu et al. and derive a machine-readable energy-dependent error of the parametric model fit wrt to the MC generators (2d: error as a function of proton energy and gamma energy)?
- This would be the input needed to propagate an error within our analyses.

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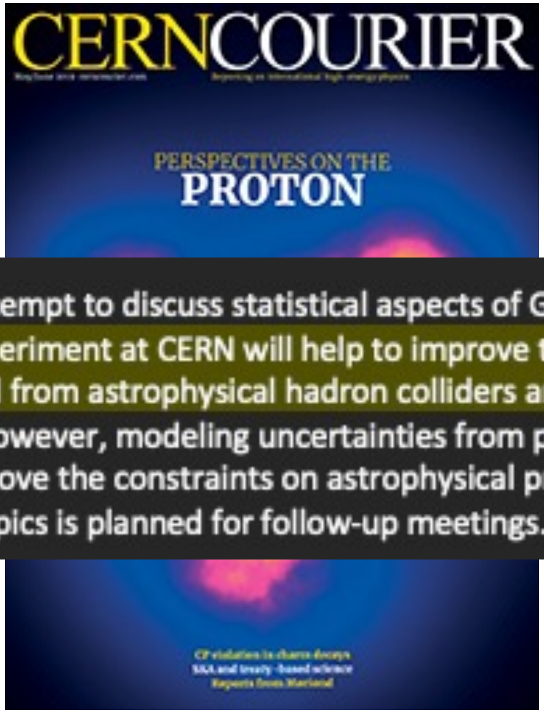
# Paper (?)

- I think at least a paper in ‘Astroparticle Physics’ is possible: E.g., ‘Estimating particle physics uncertainties for Pevatron searches with Gamma-Ray observatories’. Probably, it’s also fine for Astronomy & Astrophysics.
- Content (just a first idea):
  1. Repeat the parametric model fit from Kafexhiu et al. to the current MC generator outputs (PYTHIA, …) and derive a machine-readable error band (see the last slide)
  2. Discuss whether statistical errors from the parametric model fit discussed in Kafexhiu et al. or systematic errors among the MC generators dominate. Discuss whether uncertainties could be reduced with LHCf measurements.
  3. Implement the result of (1) in the open-source Naima package. Estimate the error in our typical Pevatron analyses, which gets propagated from the derived particle physics uncertainties.
  4. Derive an uncertainty on the gamma-ray production in more general collisions than pp: E.g. He-H2, or p-CO.

# Summary

- Helping with Pevatron searches could be an excellent additional motivation for LHCf
  - Note: Pevatrons are one of the key topics in AP.
  - Large community …
- I even mention this briefly in a CERN courier article planned for the November issue.
- It would be a great collaboration between PP and AP …

Excerpt of a conf report planned for the CERN courier Nov 2022 issue:




PHYSTAT-gamma was only the first attempt to discuss statistical aspects of Gamma-Ray astronomy. For example, the LHCf experiment at CERN will help to improve the prediction of the gamma-ray flux, which is expected from astrophysical hadron colliders and measured by Gamma-Ray observatories like CTA. However, modeling uncertainties from particle physics must be treated appropriately to improve the constraints on astrophysical processes. The discussion of this and many further topics is planned for follow-up meetings.

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