Opportunities for BSM physics in Cosmic Rays

Oliver Fischer



CORSIKA Cosmic Ray Simulation Workshop 22.06.2020

Beyond the Standard Model

Motivation as strong es ever:

- Dark Matter
- Baryon asymmetry of the Universe
- Neutrino oscillations
- Hierarchy problem

Popular explanations:

- WIMPs
- Dark sectors

 \Rightarrow Associated new dynamics

- Sterile neutrinos
- (SUSY)

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SUSY and others



No hint of weak-scale SUSY or other TeV-scale resonances ⇒ likely outside the LHC's energy reach.



- Indirect hints for BSM in LHCb flavor anomalies:
 - BSM contact operators,
 - E.g. leptoquarks with masses O(10) TeV.

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2 / 11

Discouraging for collider physics.

Anomalies in other experiments!

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3 / 11

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The ANITA excess

Observation of an Unusual Upward-going Cosmic-ray-like Event in the Third Flight of ANITA

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We report on an upward traveling, radio-detected cosmic-ray-like impulsive event with characteristics closely matching an extensive air shower. This event, observed in the third flight of the Antarctic Impulsive Transient Antenna (ANITA), a NASA-sponsored long-duration balloon payload, is consistent with a similar event reported in a previous flight. These events may be produced by the atmospheric decay of an upward-propagating r-lepton

Balloon-borne experiment, [1803.05088]

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4 / 11

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Opportunities in super-LHC energy collisions



- Explanations with TeV-scale resonances and Long-Lived Particles (LLP) cf. [1812.00919], [2002.12910], [2004.09464]
- IceCube makes compatible observations.
 D. B. Fox et al. [1809.09615]
- **b** BSM: resonances with $\sqrt{s} > 14$ TeV vs. small fluxes.
- Observable signatures in CR showers. Cf. [1906.09064]
- Visible signatures in large-scale experiments.

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5 / 11

Long lived particles



- "Natural" in many BSM models.
- Masses typically below the weak scale.
- Signatures: displaced vertices, kinked or disappearing tracks.
- Challenge the LHC and other experiments.
- Dedicated new experiments: FASER approved, many planned.
- Possible explanations for anomalies in neutrino experiments.

Cf. explanations of the MiniBooNE anomaly, e.g. OF et al [1909.09561]

The experimental landscape for LLP



On heavy neutral leptons, Gaia Lanfranchi for the ESPP in Granada, cf. [1901.09966] Similar for dark photons, scalars, axion-like particles.

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7 / 11

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LLP in CR showers



- LLP with masses ~ GeV can be produced in hadron decays.
- Possible in a CR shower even without TeV-scale mediator.
- LLP flux that has to be quantified for every model.
- CR at all energies and angles contribute.
- No new detectors necessary: Dedicated searches should be sensitive already.

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This is an upcoming topic!

- "Constraining strongly-coupled new physics from cosmic rays with machine learning techniques":
 - Physics: Sphaleron or strongly coupled dark sector.
 - Method: Herwig and HERBVI with the CORSIKA.

Spannowsky et al. [1906.09064]

- "Searches for Atmospheric Long-Lived Particles":
 - Physics: CR-produced LLP in IceCube or SuperKamiokande.
 - Method: Matrix Cascade Equation + SYBILL.

Coloma, Argüelles et al. [1910.12839]

- "Constraining New Physics with High Multiplicity : I. Ultra-High Energy Cosmic Rays on air-shower detector arrays":
 - Physics: Sphaleron, microscopic black holes.
 - Method: BlackMax + PYTHIA + CORSIKA

Jho & Park [1806.03063]

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Conclusions

• Cosmic rays constitute a source for BSM:

- Resonances at super-LHC energies;
- Long lived particles with masses \sim GeV;
- \Rightarrow Complementarity.
- A link between a CR simulation framework and BSM models is currently missing.
- ▶ Useful to study anomalies in IceCube, ANITA, and others.
- Signatures in Cosmic Ray showers.
- New Physics discovery potential!

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Thank you.

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11 / 11

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