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The Synergy Between Astroparticle and Collider Physics

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Abstract: There is a tripartite synergy between astropraticle and collider physics. The first synergy is between ATLAS QCD and forward physics and the study of high energy cosmic rays. The second synergy involves high transverse momentum production of realtivley rare processes at the LHC and the search for and study of new phenomena in the cosmos, such as dark matter. The final synergy is expressed by the use of collider detectors as shallow undeground cosmic ray muon detectors. We will briefly discuss each of these cases concentrating on the search for dark matter.

Keywords: Cosmic rays, LHC, extended air showers, hadronic physics, cosmic muons, dark matter

1 Direct, InDirect and Collider Searches for Dark Matter

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2 LHC Results on Hadron Physics in the Study of High Energy Cosmic Rays

The status of hadronic generators for air-shower physics with respect to LHC data is beocming clear. But, while a large part of the available LHC results have been used for data to MC comparisons, the model tuning is not finalized. A collbaoration of various cosmic-ray physicists (both from experiment and theory) and also physicists engaged at the LHC, to complete the understanding of hadronic air shower generators in view of the LHC run 1 data. Another goal of this collaboration is to identify what studies be necessary to improve the modeling of hadronic processes in air showers.

Any comparison of current LHC data to Monte Carlo generators modeling the first and the subsequent high-energy interactions of cosmic rays and air in the Earths atmosphere requires, at the moment, extrapolations from proton-proton, proton-lead, lead-lead initial states to particle combinations relevant for interactions in air showers (protons, pions, kaons and nuclei up to iron colliding with oxygen, carbon or nitrogen nuclei). Such extrapolations introduce uncertainties, as they require the use of models, for example the so-called Glauber model, to convert observables of proton-proton collisions to quantities applicable to proton-nuclei collisions. A clear wish was formulated by cosmic-ray physicists to mitigate these uncertainties from extrapolations by recording data with light ion LHC running (primarily proton interactions with light nuclei such as carbon, oxygen or nitrogen, but also other c ombinations such as carbon-carbon or iron-carbon interactions would be very interesting), thereby allowing for more direct data to Monte Carlo comparisons. An informal presentation by an LHC accelerator physicist suggested that: a) Oxygen or nitrogen running is technically feasible and would require at most some 8 to 12 weeks of parasitic commissioning; b) The scheduling is the big challenge given the large and diverse LHC physics program. c) Given the scheduling issue, light-ion running is unlikely to happen on short timescales (before the next long shutdown in 2018) unless such a running mode is strongly supported by all the LHC experiments themselves. Discussions between the cosmic-ray and heavy-ion communities of the LHC experiments about such light-ion runs are not only desirable but essential to outline a possible running plan that can be considered by the CERN scientific committees and management

2.1 Direct Detection of Dark Matter

Some of the recent dark matter (DM) direct detec- tion experiments such as DAMA [?],[?], [?], CoGeNT [?], [?] and CRESST-II [?] have reported events which cannot be explained by conventional backgrounds. The excesses, if interpreted in terms of DM particle elastic scattering on target nuclei, may imply light DM particles with mass around 8-10 GeV and scattering cross-section around 10^{-40} cm^2. The latest direct search for weakly interacting massive particle (WIMP) dark matter (DM) carried out by the CDMS Collaboration has come up with a tantalizing possible hint of its collisions with ordinary matter [?]. Their analysis of data collected using the CDMS II silicon detectors has turned up three events in the signal region with confidence level of about 3 sigmas. If interpreted to be due to spin-independent WIMP-nucleon scattering, the new data favor a WIMP mass of 8.6GeV [?] and scattering cross-section of 1.9×10^{41} cm^2. Other experiments such as XENON100 [9, 10], and SIMPLE [11] etc., have reported null results in the same DM mass range.

The WIMP-nucleon cross-section σ_{el}^{N} limits - where the WIMP is a scalar dark matter particle called the darkon [?] compared to 90XENON100, CDMS Ge, CDMS Si (blue solid curve), Stage 2 of SIMPLE, , EDELWEISS and TEXONO are shown in Fig . Also plotted are two 2σ confidence areas representing the CRESST-II, DAMA, , the 90effect of residual surface event contamination), and an area for a possible signal at 68

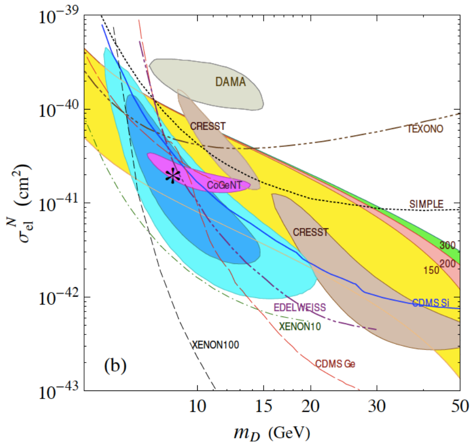

Figure 1: The darkon-nucleon cross-section σ_{el}^N compared to 90%CL upper limits for current direct dark matter searches

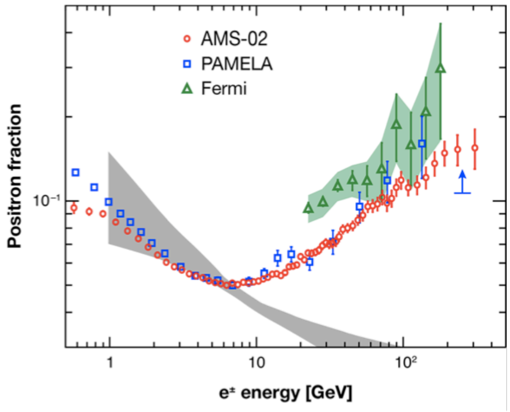

Figure 2: The positron fraction measured by AMS-02, FERMI and PAMELA. The gery band shows the astrophysical expectation for the ratio as expressed by GALPROP.

2.2 Indirect Dark Matter Searches

The indirect search for Dark Matter is based on the detection the signatures of the annihilation or decays of DM particles in the fluxes of Cosmic Rays (CRs). The three detection modes involve: charged particles (electrons and positrons, protons and antiprotons, deuterium and antideuterium), photons (gamma rays, X-rays, synchrotron radiation) and neutrinos. A key point of all these searches is to look for channels and ranges of energy where it is possible to beat the background from ordinary astrophysical processes. This is for instance the basic reason why searches for charged particles focus on fluxes of antiparticles (positrons, antiprotons, antideuterons), much less abundant in the Universe than the corresponding particles, and searches for photons or neutrinos have to look at areas where the DM-signal to astro-noise ratio can be maximized.

2.2.1 Status of the Search for Charged Cosmic rays Signatures of Dark Matter

Data from the PAMELA satellite [?] show a steep increase in the energy spectrum of the positron fraction $(e^+/(e^+ + e^-)$ above 10 GeV up to 100 GeV. These findings were confirmed with an independent measurement by the FERMI satellite [14], and extended to about 200 GeV. Data from PAMELA [?] also showed no excess in the $p\overline{p}$ energy spectrum compared with the predicted background. Recently, the AMS collaboration published its measurement of the cosmic ray positron fraction over the range of 0.5 to 350 GeV [?]. Their findings confirm with unprecedented precision earlier measurements from the PAMELA and Fermi collaborations. The situation is summed up in Figure .

2.3 Collider Searches

ATLAS and CMS use searches in the mono-jet + E_T^{miss} and mono-photon + E_T^{miss} final states to set limits on the couplings of dark matter to quarks and gluons. For certain types of operators, in particular spin-independent dark matter - gluon couplings and spin-dependent dark matter - quark couplings, LHC constraints from the mono-jet channel are competitive with, or superior to, limits from direct searches up to dark matter masses of order 1 TeV. Mono-photon limits are somewhat weaker than mono-jet bounds, but still provide an important cross check in the case of a discovery in mono-jets. In the event that dark matter - SM interactions cannot be described by effective operators, the constraints can become either significantly stronger, or considerably weaker, depending on the mass and width of the intermediate particle. In the special case of dark matter coupling to the Higgs boson, the searches for invisible Higgs decays would provide superior sensitivity, particularly for a light Higgs mass and light dark matter.

3 Underground Cosmic-ray Measurements by LHC Detectors

Underground measurements, made by Collider detectors, of multiplicities or charge ratios of muons produced by cosmic rays in the atmosphere were first made by the LEP detectors ALPHA, DELPHI and L3. At the LHC ALICE has already reported similar measurements using their ACORDE sub-detector. In particular events with very large muon multiplicities measured underground are not easily reproducible with MC generators. It was clearly recognized that such measurements increase the physics output of LHC detectors and provide very valuable cosmic-ray measurements that probe Monte Carlo generators. Support of or collaboration with the astroparticle physics community is needed to carry out and to analyse such measurements in future. Dedicated cosmic-ray campaigns could be performed during LHC running and during shutdown periods and should ideally be combined with surface detector arrays (e.g. scintillators) to measure air shower parameters (core location etc.) that are crucial for the interpretation of high-multiplicity events. A group in the ATLAS collaboration is preparing a LoI to deploy a surface array in conjunction with the ATLAS muon system. The advantage of the proposed ATLAS program is that it takes advantage of a unprecedented horizontal area of ~1000 m^2 of precision muon detection.

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