ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

NEW CROSS SECTION DETERMINATION FOR SECONDARY COSMIC RAY ELECTRONS AND POSITRONS IN THE LIGHT OF NEW DATA FROM COLLIDER EXPERIMENTS

Luca Orusa

UNIVERSITÀ DEGLI STUDI DI TORINO

INFN Istituto Nazionale di Fisica Nucleare

International Cosmic Ray Conference 2021

Berlin,12/07/2021

Work done with Dr. Michael Korsmeier(OKC), Prof. Fiorenza Donato(UNITO), Dr. Mattia Di Mauro(INFN)

Abstract

The cosmic-ray fluxes of electrons and positrons ($e^{\pm}$) are measured with high precision by the space-borne particle spectrometers AMS-02. To infer a precise interpretation of the dominant production process for $e^{\pm}$ in our Galaxy, it is necessary to have a correct description of the secondary component, produced by the interaction of cosmic-ray proton and helium with the interstellar medium. The goal of this work is to update the parametrization of the $e^{\pm}$ cross sections in order to obtain a new estimate of the lepton secondary component flux of the cosmic radiation. In the light of new cross section measurements performed at collider experiments of p+p→ $\pi^{\pm}$ + X we update the parametrization of the cross sections for these processes and then compute the $e^{\pm}$ ones from $\pi^{\pm}$ and $\mu^{\pm}$ decays. We use for the first time in this field the $e^{\pm}$ spectrum obtained from the $\mu^{\pm}$ decay computed till the next to leading order. The peculiarity of this work is the experiment based approach, that we adopt in order to obtain a better shape determination and a significant reduction of uncertainty of the current secondary cosmic ray $e^{\pm}$ flux predictions.

Introduction

During the last decades, space-based experiments like AMS-02 [1] have performed unprecedented precise measurements of the cosmic ray(CR) lepton fluxes. It is generally established that a large part of $e^{\pm}$ in our Galaxy is produced by the interaction of CRs with the interstellar medium (ISM), conventionally called secondary production. To infer correct conclusions on any modeling and interpretation of other possible primary sources, an accurate description of this contribution is necessary. The dominant contribution to the secondary flux comes from the proton-proton (pp) channel, namely CR proton on ISM hydrogen, and either the CR projectile or the ISM target replaced by helium (Hep, pHe, and HeHe). The energy-differential cross sections of $e^{\pm}$, that are mainly generated from the decay of pions ($\pi^{\pm}$) and kaons($K^{\pm}$), enter in the secondary source term calculation. In this work we search for an analytic description of the fully-differential and Lorentz invariant cross section of $\pi^{\pm}$ and $K^{\pm}$ through a fit to cross section data. Here we present only the formulae for the pp collisions. At energies below about 3 GeV, $e^{\pm}$ are mainly produced as the final output of the decay of $\pi^{\pm}$ and subsequent muons coming from the excitation of a Δ resonance. At higher energies the direct production of charged $\pi^{\pm}$ and $K^{\pm}$ dominates:

$$\mathrm{p}+\mathrm{H} \rightarrow X+\Delta \qquad \mathrm{p}+\mathrm{H} \rightarrow X+\pi^{\pm} \quad \mathrm{p}+\mathrm{H} \rightarrow X+K^{\pm}$$

The decay of $K^{\pm}$ produces muons (63.56%), pions (28.01%) and pions and leptons(8.42%) together, which then decay into $e^{\pm}$ as final products of their decay chain. Experiments do not directly measure the energy-differential cross section but rather the fully-differential cross section, usually expressed in a Lorentz invariant form. In the pion case we have:

$$\sigma_{\mathrm{inv}} = E_{\pi^{\pm}}\frac{d^3\sigma}{dp^3}(\sqrt{s}, x_R, p_T)$$

where $E_{\pi^{\pm}}$ is the total $e^{\pm}$ energy and p its momentum, $\sqrt{s}$, $x_R = E^{*}_{\pi^{\pm}}/E^{max*}_{\pi^{\pm}}$, p_T are the center of mass (CM) energy, the $\pi^{\pm}$ energy divided by the maximal $\pi^{\pm}$ energy in the CM frame, and the transverse $\pi^{\pm}$ momentum, respectively.

Materials

Now we review the principal steps in the computing of the $e^{\pm}$ spectrum from pion decay. For the first time in this field we consider the polarized muon decay computed till the next to leading order term(NLO) [2], adopting the Fermi theory. Cosmic ray muons origin from pion decay and are then polarized. The $e^{\pm}$ spectrum in the muon rest frame is described by:

$$F(\epsilon'_{e^{\pm}}, \cos\theta') = C[f(\epsilon'_{e^{\pm}}) \pm g(\epsilon'_{e^{\pm}})\cos\theta']$$

where $f(\epsilon'_{e^{\pm}})$ does not depend on the muon polarization, $g(\epsilon'_{e^{\pm}})$ is the term generated by the muon polarization, $\epsilon'_{e^{\pm}}$ is the energy of the $e^{\pm}$ and θ' is the angle between the direction of polarization of the muon and the direction of motion of the $e^{\pm}$.

As in [3], we perform two Lorentz transformations from the muon rest frame to the $\pi^{\pm}$ rest frame and from the pion rest frame to the laboratory(LAB) frame, to obtain the $e^{\pm}$ spectrum in the LAB frame.

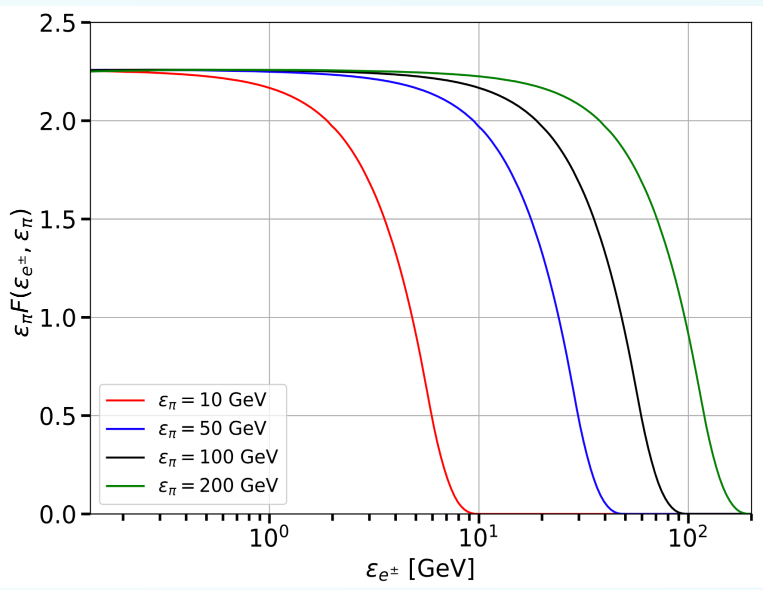

Fig. 1: $\epsilon_\pi F(\epsilon_{e^{\pm}}, \epsilon_\pi)$ for 4 pion different energies.

Results

In this section we report some preliminary results. We start our analysis from the data provided by the NA61/SHINE Collaboration [4] and collected at the CERN Super Proton Synchrotron (SPS), that performed recently precise measurements of $\pi^{\pm}$ and $K^{\pm}$ inclusive cross sections from p + p interaction, for different $\sqrt{s}$ values. The experiment kinematic setup is based on the collision between an incident beam and a fixed target, which is exactly the scenario that takes place in the Galaxy. We begin the analysis from the $\pi^{\pm}$ data, testing different possible parametrizations. In [5] a similar procedure was performed using the NA49 measurments [6], outlining how the currently available parametrizations for the inclusive $\pi^{\pm}$ cross-section do not provide an adequate description of the data.

At the moment we are searching for a new satisfying model able to take into account of the Δ resonance and of the direct production of $\pi^{\pm}$. In Fig. 2 we report some preliminary results, obtained from the fit to the NA61/SHINE $\pi^{\pm}$ data at $\sqrt{s} = 17.3$, grouped in different p_T values, using a tester parametrization. For clarity, the data and the theoretical curves at each p_T have been multiplied by a factor of $0.6^{n_{p_T}}$, where n_{p_T} is the integer(starting from 0) counting the p_T, from lower to higher (i.e. for p_T = 0.25 the rescaling is 0.6^2).

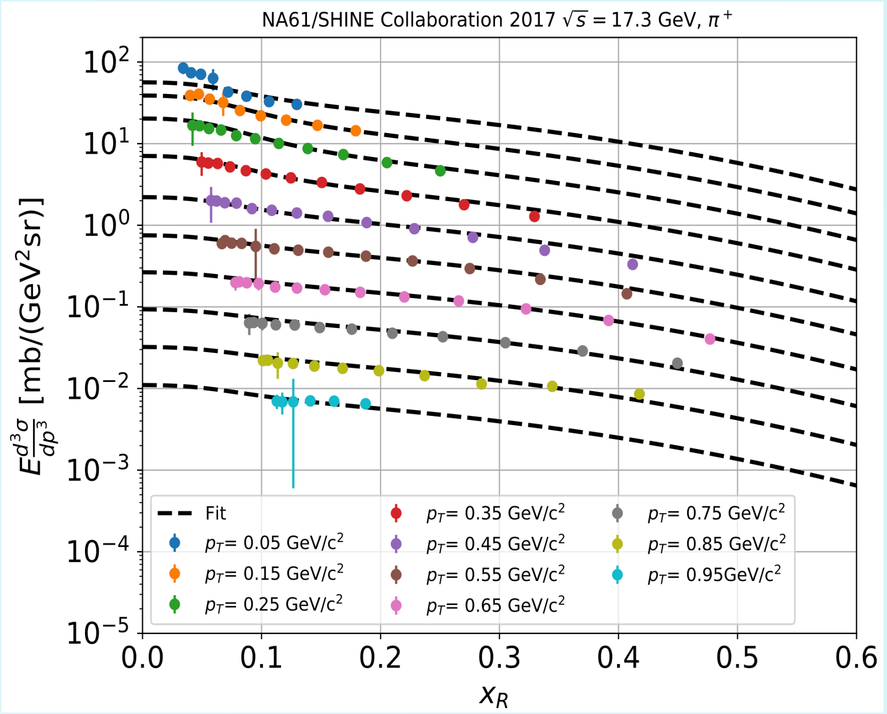

Fig. 2: Comparison between NA61/SHINE π^+ cross section data at $\sqrt{s}$=17.3 GeV, grouped in different p_T values, with a tester fitting function.

Future steps

We discussed a novel approach in the determination of the $e^{\pm}$ cross section from pp collisions. Our preliminary results show that the method can provide useful information in the computing of the secondary positron production.

The next step of our analysis will be the combination between different datasets, considering also measurements from NA49 [6], ALICE [7] and CMS [8]. The procedure will be repeated also for $K^{\pm}$ and for the other possible reactions (pHe, Hep, HeHe). Once obtained the parametrizations, we will perform the convolution with the decay spectrum of $e^{\pm}$ from pions and kaons in order to obtain the inclusive $e^{\pm}$ cross section in nuclear reactions that enters in the source term of the secondary flux.

Bibliography

1. **AMS** Collaboration, *PoS* **ICRC2019** (2020) 091.
2. A. Arbuzov, *Physics Letters B* **524** (Jan, 2002) 99–106.
3. J. H. Scanlon and S. N. Milford, *ApJ* **141** (Feb., 1965) 718.
4. **NA61/SHINE** Collaboration, A. Aduszkiewicz et al., *Eur. Phys. J. C* **77** (2017), no. 10 671, [arXiv:1705.0246].
5. J. W. Norbury and L. W. Townsend, *Physical Review D* **75** (Feb, 2007).
6. **NA49** Collaboration, C. Alt et al., *The European Physical Journal C* **45** (Dec, 2005) 343–381.
7. **ALICE** Collaboration, J. Adam et al., *Eur. Phys. J. C 75 (2015), no. 5 226*,
8. A. Sirunyan et al., *Physical Review D* **96** *(Dec, 2017)*.