NEW DETERMINATION OF THE PRODUCTION CROSS SECTION FOR SECONDARY POSITRONS AND ELECTRONS IN THE GALAXY

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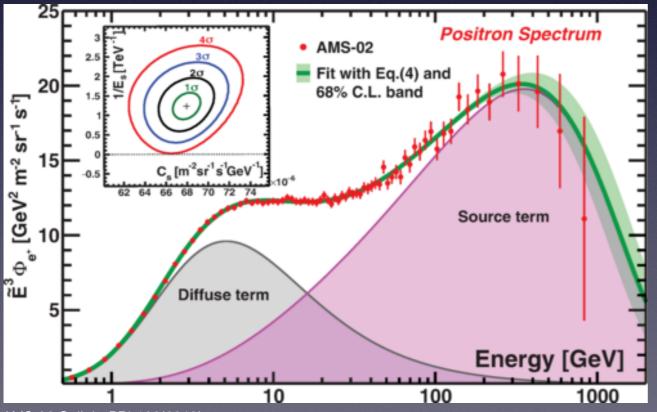
1. Secondary electrons and positrons

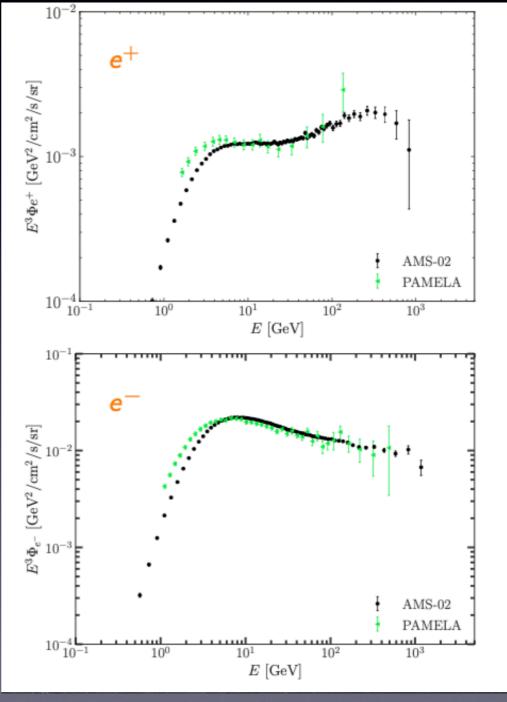
The journey started with the attempt, shared by many, to interpret the e^+ and e^- data.

•AMS-02 positron flux measures → secondary + primary contribution.

$$q(T_{e^{\pm}}) = \sum_{i,j} 4\pi \, n_{\text{ISM},j} \int dT_i \, \phi_i(T_i) \frac{d\sigma_{ij}}{dT_{e^{\pm}}} (T_i, T_{e^{\pm}})$$

•Previous $d\sigma(p+H\to e^{\pm}+X)$ predictions affected by factor 2 of uncertainty.





AMS-02 Collab, PRL122(2019)

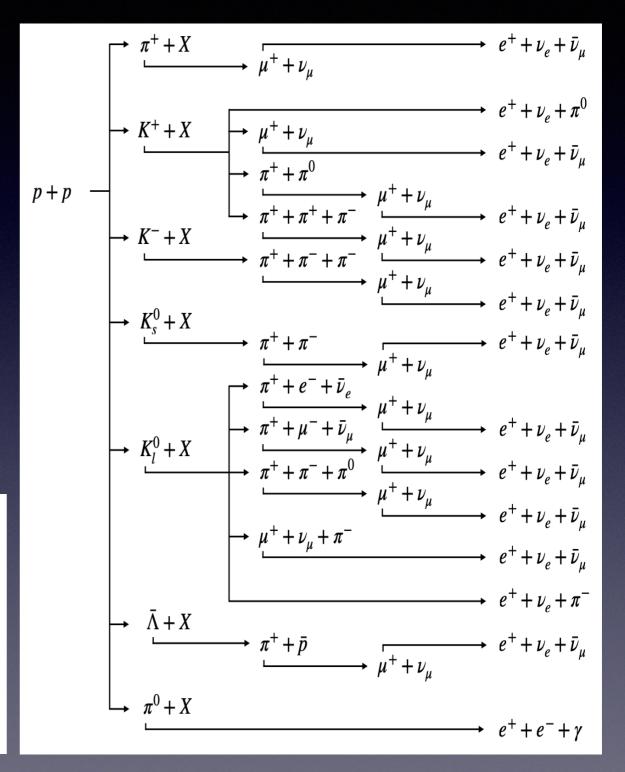
2. Production cross-sections of e^{\pm}

In this talk we concentrate on the hadronic production of e^+ . The source is the scattering site of a relativistic cosmic ray nucleus i colliding with an interstellar nucleus j at rest:

$$\bullet \sigma_{\text{inv}}^{(ij)} = E_{\pi^{\pm}} \frac{d^3 \sigma_{ij}}{dp_{\pi^{\pm}}^3}$$

We repeat the same analysis for e^- .

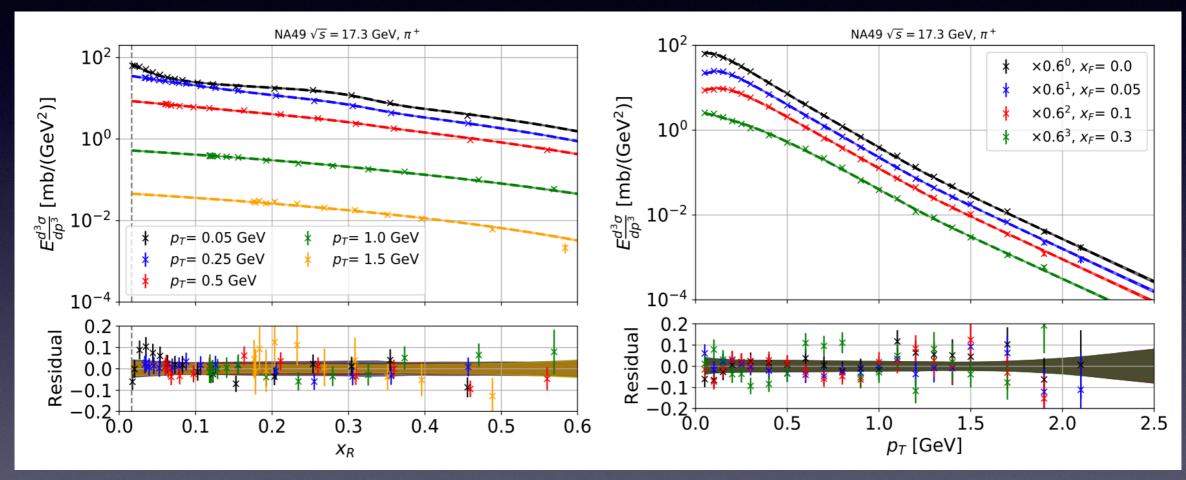
Experiment	$\sqrt{s} \; [\mathrm{GeV}]$		$\sigma_{ m inv}$	n	Ref.
NA49	17.3	(π^\pm,K^\pm)		-	[67, 76]
ALICE	900	(π^+,K^\pm)		-	[77]
CMS	900,2760,7000,13000	(π^\pm,K^\pm)		-	[78, 79]
Antinucci	3.0, 3.5, 4.9, 5.0, 6.1, 6.8	(π^\pm)	-		[80]
	$2.8,\ 3.0,3.2,\ 5.3,\ 6.1,\ 6.8$	(K^+)	-		[80]
	4.9, 5.0, 6.1, 6.8	(K^-)	-		[80]
NA61/SHINE	6.3, 7.7, 8.8, 12.3, 17.3	(π^{\pm}, K^{\pm})	-		[68]



3. Fit to NA49 π^+ data

The structure of our fit formula is:

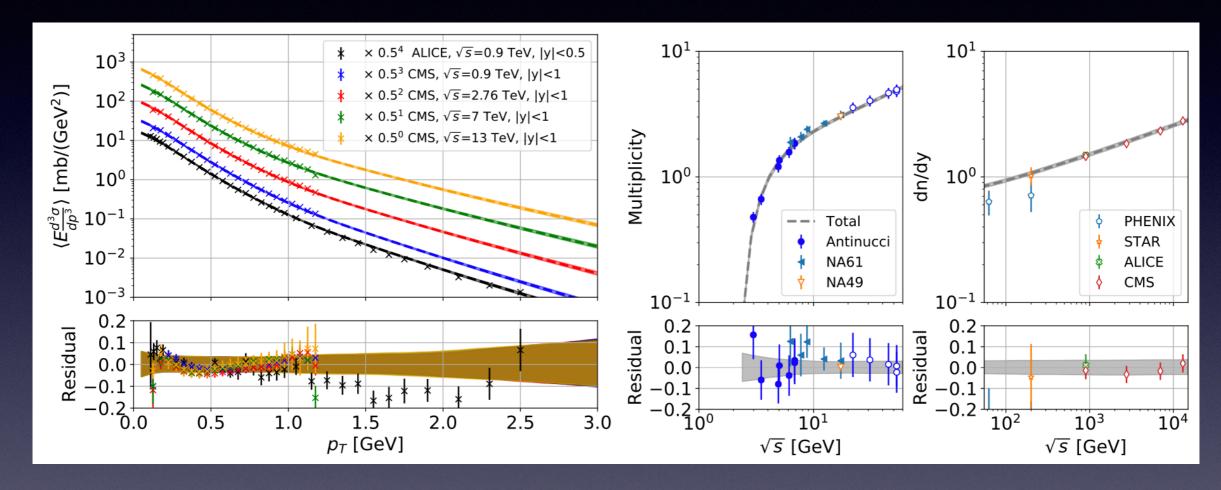
$$\sigma_{\text{inv}} = \sigma_0(s) c_1 \left[F_p(s, p_T, x_R) + F_r(p_T, x_R) \right] A(s)$$



We perform a χ^2 -fit using the Multinest package to minimize the χ^2 , with statistical and systematic uncertainties added in quadrature($\tilde{\chi}^2$ =1.29). The uncertainty band at the 68% confidence level of our model spans about 5% over all the kinematic range explored by the NA49 data.

4. The \sqrt{s} dependence

The \sqrt{s} dependence is determined with a second fit to σ_{inv} or multiplicities measurements provided by CMS and ALICE collaboration or reported in literature, ($\tilde{\chi}^2$ =1.46).



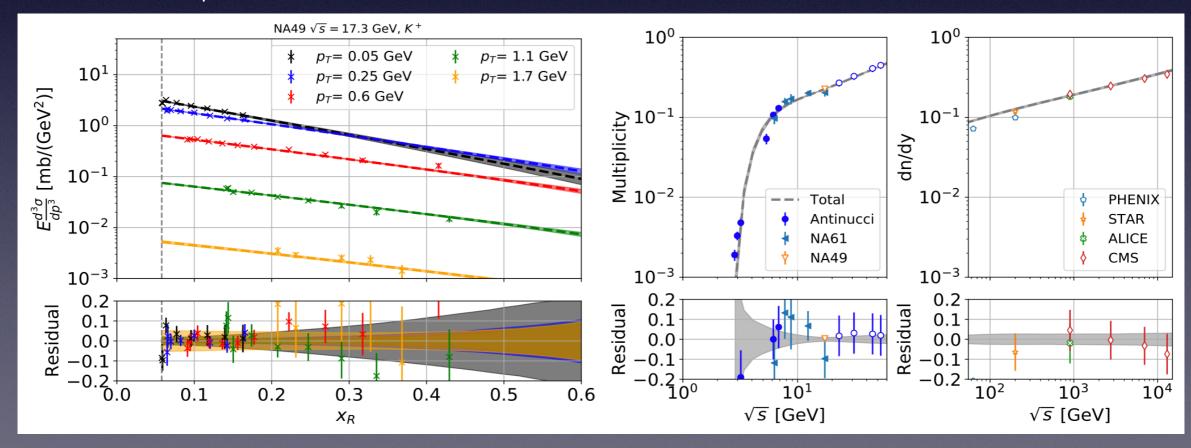
- Total uncertainties between 5 and 10%.
- Integrating the σ_{inv} over the solid angle and combining the result with the π^+ decay, we obtain the $\frac{d\sigma_{ij}}{dT_{e^+}}(T_i,T_{e^+})$ from π^+ .

5. Other channels: kaons

About 10% of the positrons produced in p+p collisions come from the decays of charged kaons. The main different decay channels considered in this work (branching fraction in brackets) are:

- $K^+ \to \mu^+ \nu_\mu$ (63.6 %),
- $K^+ \to \pi^+ \pi^0$ (20.7 %),
- $K^+ \to \pi^+ \pi^+ \pi^-$ (5.6 %),
- $K^+ \to \pi^0 e^+ \nu_e$ (5.1 %).

Adopting the same strategy used for π^+ , we fit in two steps our fit formulas, separating the general kinematic and \sqrt{s} dependence ($\tilde{\chi}^2$ =1.21).

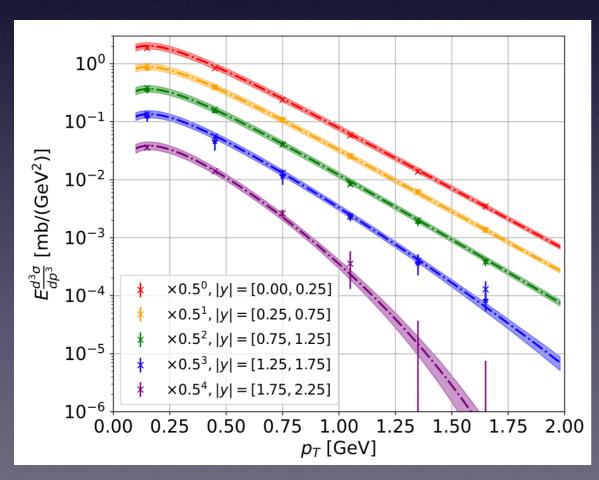


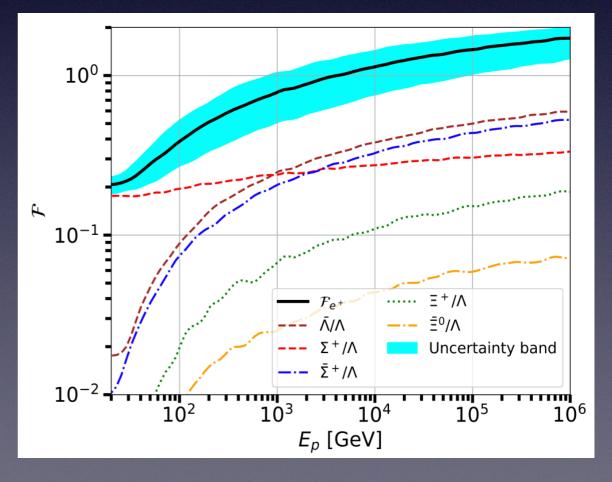
6. Other channels

We also have to consider the π^+ created from weak decays of strange particles and not included in π^+ dataset, that are:

- K_S^0 : fit on available data.
- K_L^0 : rescaled contribution from K_S^0 .
- $\bar{\Lambda}$, Σ and Ξ : rescaled contribution from the Λ .

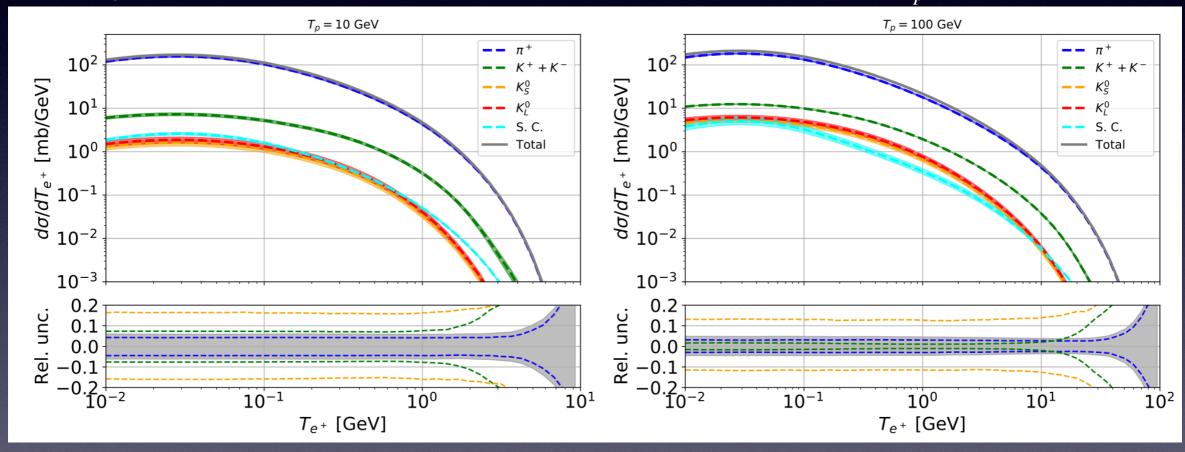
In the end we also consider the contribution from π^0 to the e^+ yield by multiplying the charged pions cross sections by a normalization factor connected to the multiplicity of π^+ , π^0 .





7. Results on the e^+ production cross section

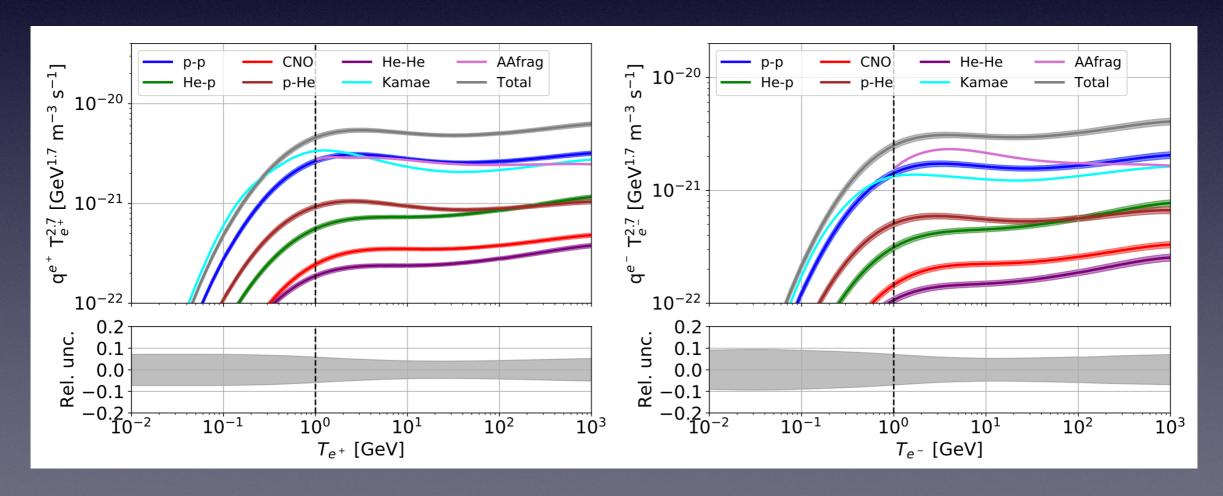
- The π^+ channel dominates the total cross section, being about 10 times higher than the K^+ channel.
- Positron production from K_S^0 , K_L^0 , and subdominant channels are all contributing at a few % level.
- The main comment to these results is the smallness of the uncertainty with which we determine $d\sigma/dT_{e^+}$. At 1σ the uncertainty band around the best fit is 5% to 8% at all T_p energies.



In the Galaxy, nuclei interactions (p + A, A + p, and A + A) give a significant contribution to the production of secondary particles. We use the data of NA49 for the production of π^+ in p+C collisions at \sqrt{s} =17.3 GeV and NA61 data at \sqrt{s} =7.7 GeV for the other channels.

8. Results on the e^+ production cross section

- The q(E) is predicted with a remarkably small uncertainty, ranging from 5% to 8% depending on the energy.
- The channels involving He, both projectile and target, constitute 30-40% of the total spectrum depending on the positron energy.
- The heavier primary CNO nuclei contribute a non negligible few percent at the AMS-02 energies.
- \bullet For e^- an analogous analysis has been performed.



9. Conclusions

- We determined through an analytical description or by referring to Monte-Carlo generators, the inclusive cross section of π^{\pm} , K^{\pm} , $K_0^S, K_0^L, \Lambda, \bar{\Lambda}, \pi^0, \Sigma$ and Ξ .
- •Including all the production and decay channels, the total $d\sigma/dT_{e^{\pm}}(i+j\to e^{\pm}+X)$ is predicted from 10 MeV up to tens of TeV of e^{\pm} energy (<u>https://github.com/lucaorusa/positron_electron_cross_section</u>).
- Future measurements of pion production in the p+He could help to improve the predictions for nuclei channels.
- Our major result resides in the precision with which this source term is predicted (5% 8% for e^+ and 7% and 10% for e^-).



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$$\sigma_{\text{inv}} = \sigma_0(s) c_1 \left[F_p(s, p_T, x_R) + F_r(p_T, x_R) \right] A(s)$$

$$F_p(s, p_T, x_R) = (1 - x_R)^{c_2} \exp(-c_3 x_R) p_T^{c_4} \times \exp\left[-c_5 \sqrt{s/s_0}^{c_6} \left(\sqrt{p_T^2 + m_\pi^2} - m_\pi\right)^{c_7 \sqrt{s/s_0}^{c_6}}\right]$$

$$F_r(p_T, x_R) = (1 - x_R)^{c_8} \times \exp\left[-c_9 p_T - \left(\frac{|p_T - c_{10}|}{c_{11}}\right)^{c_{12}}\right] \times \left[c_{13} \exp(-c_{14} p_T^{c_{15}} x_R) + c_{16} \exp\left(-\left(\frac{|x_R - c_{17}|}{c_{18}}\right)^{c_{19}}\right)\right]$$

$$A(s) = \frac{1 + \left(\sqrt{s/c_{20}}\right)^{c_{21} - c_{22}}}{1 + \left(\sqrt{s_0/c_{20}}\right)^{c_{21} - c_{22}}} \left(\sqrt{\frac{s}{s_0}}\right)^{c_{22}}$$

	π^+	π^-	K^+	K^-
$\chi^2_{ m NA49}/{ m d.o.f.}$	338/263	287/290.	146/151	197/151
$\chi_n^2/{\rm d.o.f.}$	189/129	169/96	160/102	135/100
$\chi^2_{ m ALICE}$	77(33)	-	42(27)	36(27)
$\chi^2_{ m CMS}$	100 (88)	154 (88)	77 (68)	54 (68)
$\chi^2_{ m NA61,Antinucci}$	10 (12)	15 (12)	39 (11)	44 (9)
$\chi^2_{ m tot}/{ m d.o.f.}$	527/392	456/386	306/253	332/251

- The uncertainties are about 5% for almost all T_{e^+}
- The relative uncertainty increases above 20% when approaching the maximum energy, that has a negligible impact on the final uncertainty.
- The results of this Section already hint at the final result. The by far dominant contribution of e^+ production in p+p collisions comes from π^+ .

