LEPTON PRODUCTION IN HADRONIC REACTIONS

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Abstract : Recent results on the production of leptons and lepton pairs in hadronic reactions are reviewed.

Résumé : Nous présentons une revue de résultats récents sur la production de leptons et de paires de leptons dans les collisions de hadrons à haute energie.

1. INTRODUCTION

The status of the rapidly developing field of lepton production in hadronic reactions was described by several reviews in the summer of 1975 [1-3]. A summary of the information then available is shown in Table 1. The first observation of direct lepton production indicated a similarity in the transverse momentum dependence of leptons and pions produced in hadronic collisions (with the leptons being depressed by $\sim 10^{-4}$). This similarity persisted over the 5 orders of magnitude drop in cross-section between $0.8 < p_T < 5.4$ GeV/c, even exhibiting the s-dependence of the p_T behaviour

Table 1

Review of single lepton production

$\theta^* \simeq 90°$			
Experiment	$\sqrt{s}$ (GeV)	p_T range (GeV/c)	Results
Serpukhov	11.5	1.8-2.8	$\mu/\pi \simeq 2.5 \times 10^{-5}$
Chicago-Princeton (FNAL)	23.8	1.5-5.4	$\mu/\pi \simeq 10^{-4}$
Columbia-Fermilab	23.8	1.8-4.0	$e/\pi \simeq \mu/\pi \simeq 10^{-4}$
Chicago-Harvard-Penn.-Wisconsin	7.6-23.8	1.0-2.3	$\mu/\pi \simeq 10^{-4}$
CCR (ISR)	52.7	> 6.0	no $e^{\pm}$, $E\left(\frac{d^3\sigma}{dp^3}\right) < 2 \times 10^{-36}$ cm^2/GeV^2
CCRS (ISR)	23.5-62.4	1.3-3.5	$e/\pi \simeq 10^{-4}$
Penn.-SUNY (BNL)	4.5, 5.5, 6.8	0.8-1.5	$e^+/\pi^- \simeq 10^{-4}$
BNL-MIT	7.6		$e^-/\pi^- \simeq 10^{-4}$
$\theta^* \neq 90°$			
Experiment	$\sqrt{s}$ (GeV)	θ^*	Results
BNL-Yale	7.5	0°	$\mu/\pi \simeq 10^{-4}$-10^{-6}
CERN-Rome (ISR)	52.7	0°	$e^-/\pi^- < 3.4 \times 10^{-4}$
K. Winter	6.1	$\simeq 37°$	$e^+/\pi^+ < 0.3 \times 10^{-4}$
CHORMN (ISR)	52.7	30°	$e/\pi > 10^{-4}$

observed in large-p_T hadron production. A constant ratio of leptons to pions over a large range of the several variables s, p_T, θ^*, etc., would certainly be suggestive of a common mechanism for their production. The results of several of the experiments with $\theta^* \sim 90°$ are shown in Fig. 1 as a function of $\sqrt{s}$ (an exception is the data of Winter, which were taken at $\theta^* \sim 37°$). This figure was presented at the Palermo Conference[1]. The Fermilab and ISR experiments could be viewed as showing a slight $\sqrt{s}$ dependence over the range 23 GeV $\leq \sqrt{s} \leq$ 62.4 GeV, but are also consistent with the lepton/pion ratio being constant at $\sim 1 \times 10^{-4}$. Data at lower $\sqrt{s}$ values appeared to be contradictory and further experiments (or better isolation of the relevant variables) were obviously called for.

In the period since the Palermo and SLAC Conferences, new results have appeared, while several of the conference presentations have been conspicuous by their absence in published form. This review will concentrate on developments in this period and leave Refs. 1-3 for motivations, historical reviews, and descriptions of experimental technique.

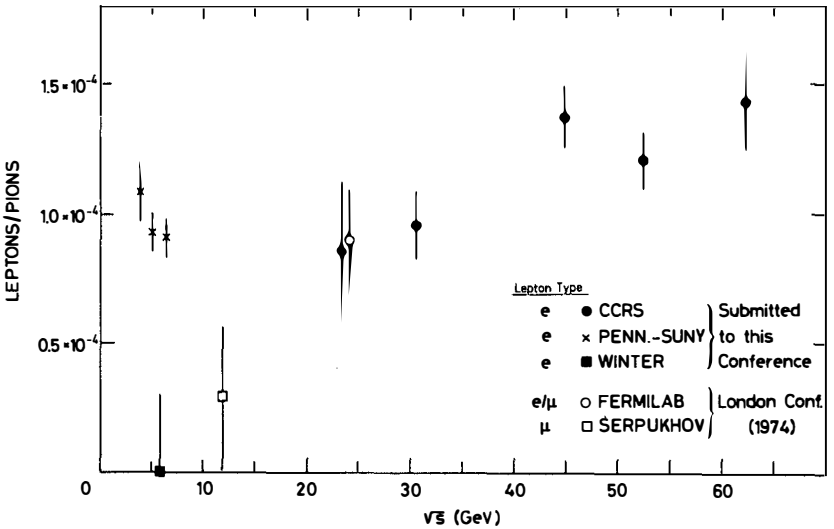

Fig. 1 The ratio of leptons to pions observed in several experiments integrated over transverse momentum and plotted as a function of centre-of-mass energy $\sqrt{s}$.

2. SINGLE LEPTONS

The data of the CERN-Columbia-Rockefeller-Saclay (CCRS) Collaboration presented at the Palermo Conference[1] were extended down to transverse momenta of ~ 0.6 GeV/c and presented at the SLAC Conference[3]. In the course of the re-analysis necessitated by the study of this low-p_T domain, it was real-

ized that the contributions to the signal from electrons from the Dalitz decay of π^0 and η mesons were larger than previously estimated. This effect is shown in Fig. 2 as a function of p_T. The complete results, after the subtraction of this effect, are still not available. However, preliminary results for the $p_T \geq 1.3$ GeV/c data have been calculated and indicate that the signal has been reduced by $\sim 30\%$ for $\sqrt{s} = 52.7$ GeV. The data at low p_T are expected to be even more affected.

The experiment of the CERN-Harvard-Orsay-Riverside-München-Northwestern (CHORMN) Collaboration, which is mentioned in Fig. 1, has, since last summer, produced a series of very interesting results in this field[4]. The apparatus which is installed at the ISR is shown in Fig. 3 and consists of an electron spectrometer at $\theta^* = 30°$ and a muon telescope at $\theta^* = 50°$ on the other side of the intersection region. An initial stage of the experiment involved studying the inclusive production of electrons. Results, together with background estimates, are shown in Figs. 4 and 5. As can be seen, the data appear to indicate a rise in the ratio of electron to pion production as the transverse momentum is reduced. This surprising result has been interpreted as evidence for the possible existence of a new charged vector boson of isospin = 0 and with a mass in the range 100-700 MeV[5]. The authors, however, note that such a "pile-up" of leptons at low-p_T would also

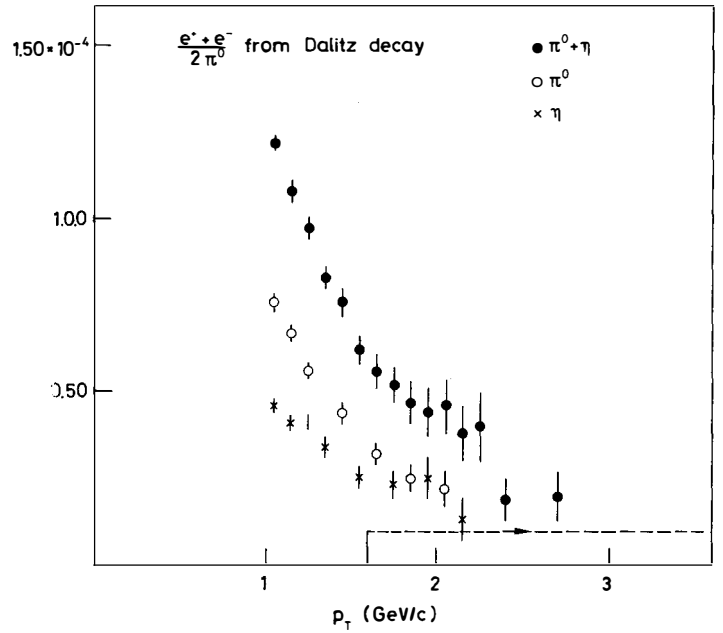

Fig. 2 The contribution of the Dalitz decays of π^0 and η mesons to the background of the CCRS Collaboration.

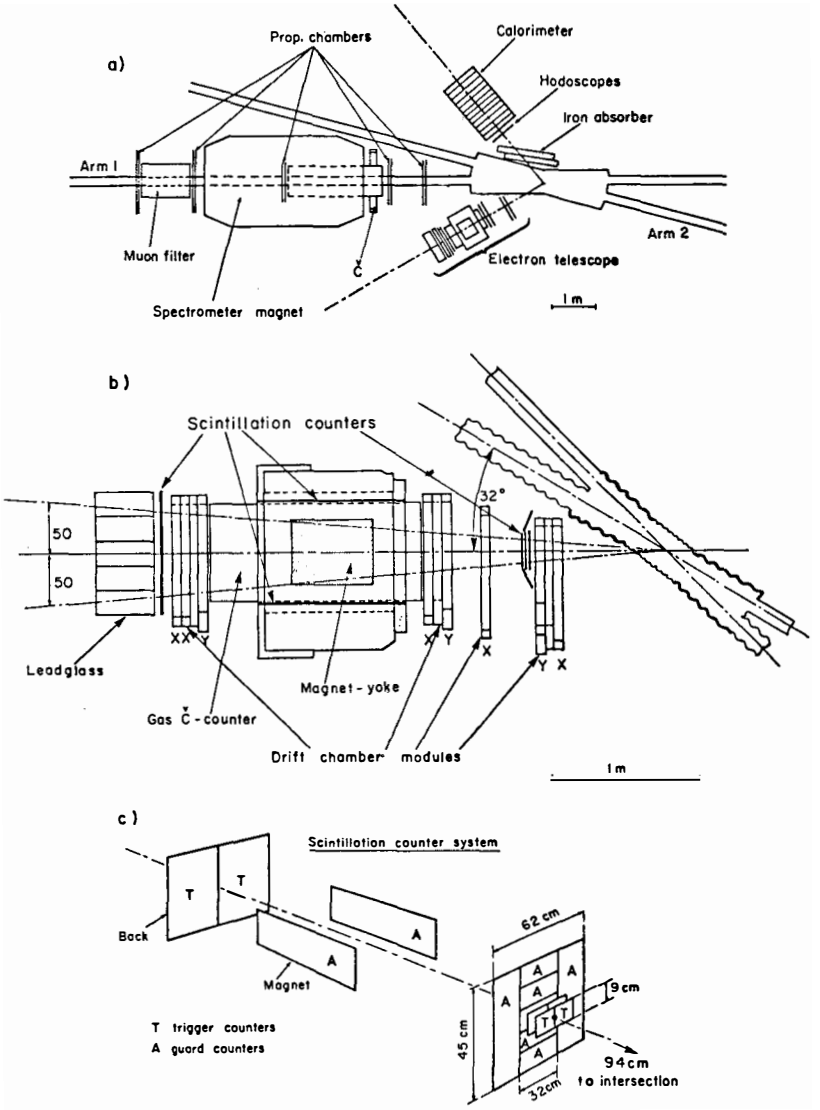

Fig. 3 The apparatus of the CHORMN Collaboration.

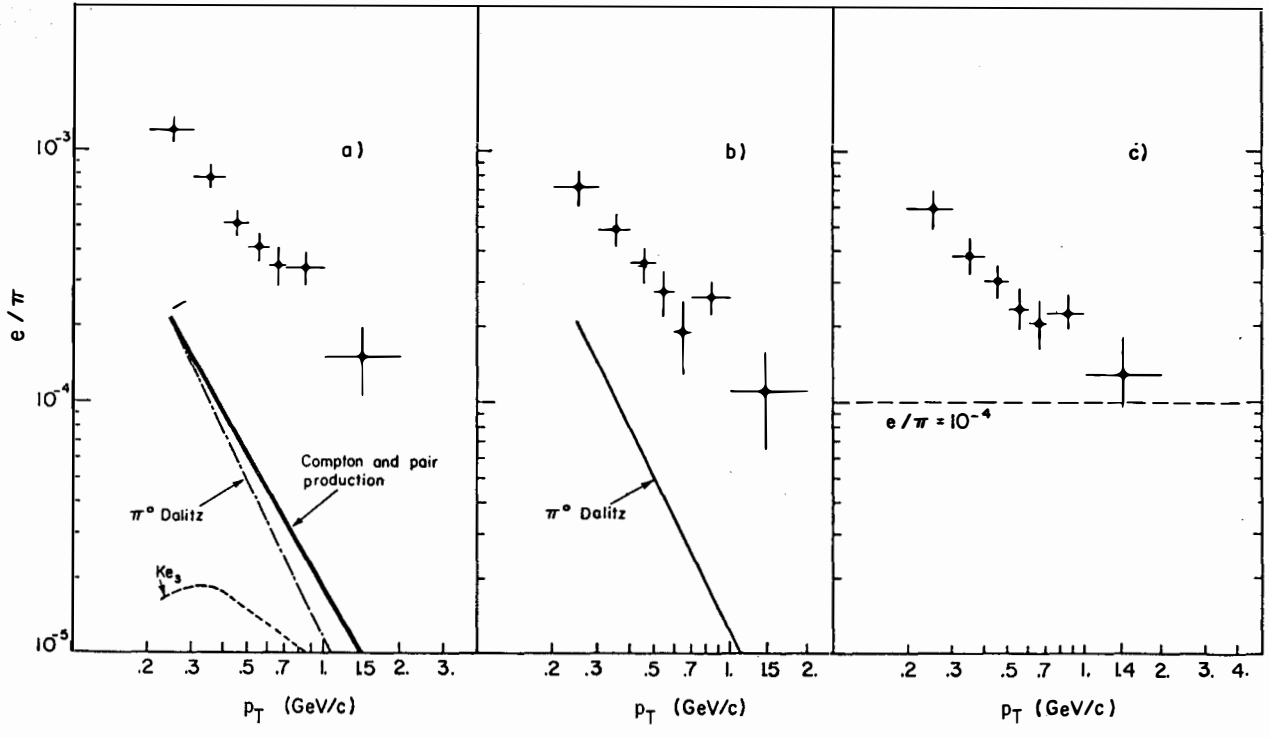

Fig. 4 The ratio of electrons to pions observed by the CHORMN Collaboration plotted as a function of transverse momentum. Contributions of various backgrounds are also shown.

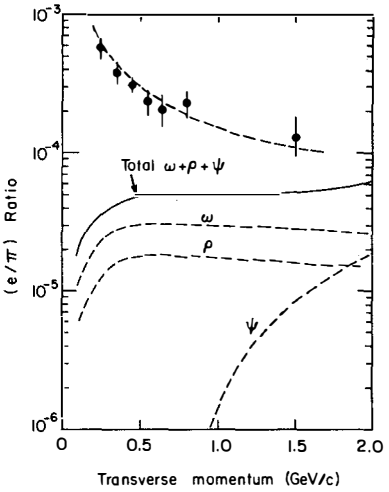

Fig. 5 The background-corrected value for the ratio of electrons to pions plotted as a function of transverse momentum. The contributions expected from the known vector mesons are also shown.

be expected from the associated production and subsequent decay of charmed particles. The production of a pair of particles of mass $\sim$ 1.8 GeV/c decaying into eνK would (with some model uncertainty) be expected to give a "good fit" to the data if the product of production cross-section and branching ratio (σB) was $\sim 6 \times 10^{-30}$ cm^2. It could be expected that the production of new charged hadrons might give rise to a charge asymmetry in the single lepton distributions. No such asymmetry has been found over and above that expected from the background of electrons from Compton scattering in the vacuum chamber wall.

The CHORMN Collaboration has searched for muons associated with an electron trigger. Muons could be identified by their passage through an iron absorber of 370 g/cm^2 and their subsequent penetration into a calorimeter consisting of 12 modules, each 67 g/cm^2 in thickness. The maximum range of the muon arm was 1160 g/cm^2, corresponding to a muon momentum of 1.8 GeV/c ($p_T \sim$ 1.38 GeV/c). It was not possible to determine the charge of the muon. Muons associated with an "electron" trigger were compared with muons associated with a "pion" trigger (Čerenkov counter and lead-glass not required in the electron spectrometer). Preliminary results indicate that an excess of muons did indeed occur for an electron trigger and that this excess increased as a function of the penetration of the muon through the calorimeter.

Two recent experiments, not reported at the conferences of last summer, have contributed new data on the production of leptons in the forward direc-

tion. A BNL-Yale Collaboration[6] has studied the production of direct muons in 400 GeV proton-copper interactions at Fermilab. The results are shown in Table 2. The ratio of direct negative muons to negative pions produced in the forward direction is seen to fall as a function of the energy (or x value) of the produced muon. The ratio of prompt positive muons to negative muons was about 1. Similar data have been obtained by a CalTech-Chicago-Fermilab-Princeton-Rockefeller Collaboration[7], which has observed direct muon production in the forward direction (p_T < 0.4 GeV/c) in 300 GeV proton-uranium collisions. These results are also shown in Table 2 and appear to be in essential qualitative agreement with the BNL-Yale data.

Table 2

Production of prompt muons in the forward direction

BNL-Yale results[a]			
E_μ (GeV)	x	μ^+/π^+ ($\times 10^5$)	μ^-/π^- ($\times 10^5$)
230	0.57	0.903 ± 0.13	1.93 ± 0.31
102	0.26	1.95 ± 0.23	3.05 ± 0.61
55	0.135	5.10 ± 0.88	5.77 ± 1.01
CalTech-Chicago-Fermilab-Princeton-Rockefeller results[b]			
E_μ (GeV)	x	μ^+/π^+ ($\times 10^5$)	μ^-/π^- ($\times 10^5$)
150	0.5		4.2 ± 2.3
90	0.3	6.4 ± 1.3	18.3 ± 4.3

a) Ref. 6
b) Ref. 7.

The BNL-Yale Collaboration has measured the polarization of 185 GeV prompt muons[8]. The value $\rho = 0.00 \pm 0.10$ suggests that the muons are produced through electromagnetic interactions. The same group has compared measurements of prompt single muons with the results of measurements of muon pairs produced under the same conditions[9]. It is concluded that the bulk of the inclusive muon flux can be derived from muon pair production where the mean invariant mass of the pairs is $\sim$ 900 MeV/c. At Fermilab energies it is estimated that the cross-section for producing muon pairs such that the momentum of the centre of mass of the pair ranges from $0.125 < x < 0.70$ is about 1.55 μb.

3. LEPTON PAIR PRODUCTION

3.1 Ψ production

For completeness a short summary of recent results on Ψ production is given in Table 3. Figure 6 shows the production of Ψ as a function of centre-of-mass energy $\sqrt{s}$.

Table 3

Recent results on Ψ production

Experiment	Reaction	$\sqrt{s}$ (GeV)	Comments
IISN (Belgium) -LAPP (Annecy)	$p + C \to e^+e^- + \ldots$	6.8	
Chicago-Princeton[a] (FNAL)	$\left.\begin{matrix} p \\ \pi \end{matrix}\right\} + Be \to \mu^+\mu^- + \ldots$	16.8	$(\sigma)_\pi/(\sigma)_p \sim 1.64 \pm 0.73$
Serpukhov[b]	$p + Be \to \mu^+\mu^- + \ldots$	11.5	φ peak seen
CHOV[c] (ISR)	$p + p \to \mu^+\mu^- + \ldots$	52.7	
Columbia-FNAL -Stony Brook	$p + Be \to e^+e^- + \ldots$	23.8	no Ψ′ seen

a) Ref. 13
b) Ref. 14
c) Ref. 15.

3.2 Ψ′ production

No conclusive evidence has been offered for the observation of the Ψ′(3.7) in hadronic reactions. Indeed the Columbia-Fermilab-Stony Brook Collaboration[10] claims that the production cross-section for the Ψ′ is less than 14% of that of the Ψ.

3.3 T production

The Columbia-Fermilab-Stony Brook Collaboration[11] has reported the observation of 11 e^+e^- events which cluster at masses between 5.8 and 6.1 GeV suggesting the existence of a new resonance at 5.97 GeV (see Fig. 7). These events would correspond to a σB of $(5.2 \pm 2.0) \times 10^{-36}$ cm^2 per nucleon.

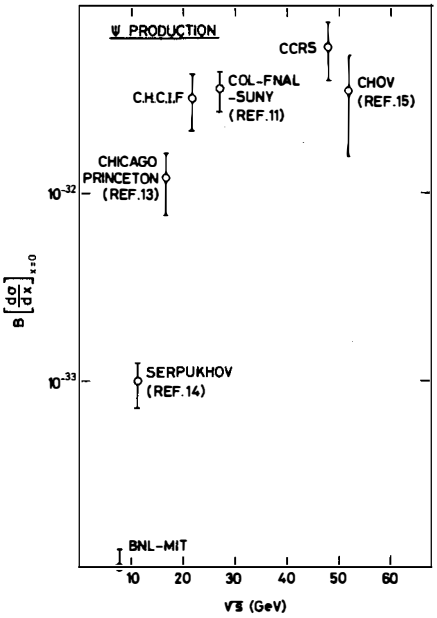

Fig. 6 The production of ψ plotted as a function of centre-of-mass energy $\sqrt{s}$.

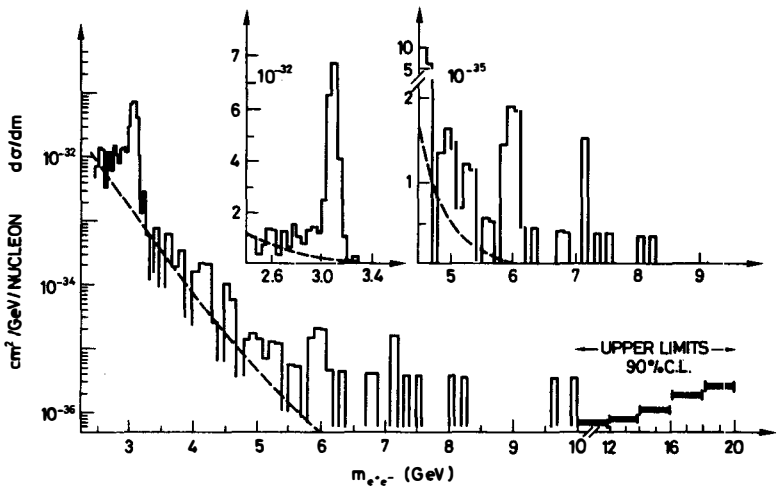

Fig. 7 Electron-positron mass spectrum $d\sigma/dm$ plotted as a function of the effective mass. Data of the Columbia-Fermilab-Stony Brook experiment.

3.4 Continuum production

The Columbia-Hawaii-Cornell-Illinois-Fermilab Collaboration[12] [having previously measured Ψ(3.1) production in neutron collisions] has reported the observation of a continuous distribution of muon pairs in the invariant mass range 1.0-3.0 GeV/c^2. Figure 8 shows this distribution compared with the group's estimate for the contribution of the Drell-Yan process (uncoloured). The agreement is thought to be good.

The Columbia-Fermilab-Stony Brook Collaboration[11] describes the cross-section for non-resonant electron pairs in the mass interval between 5 and 10 GeV by the distribution:

$$\frac{d\sigma}{dm} \sim \frac{4 \times 10^{-32}}{m^5} \text{ cm}^2/\text{GeV/nucleon} \quad .$$

This cross-section is approximately a factor of 5 lower than the group's prediction of recent versions of Drell-Yan models (without colour), but tends towards the model at higher mass.

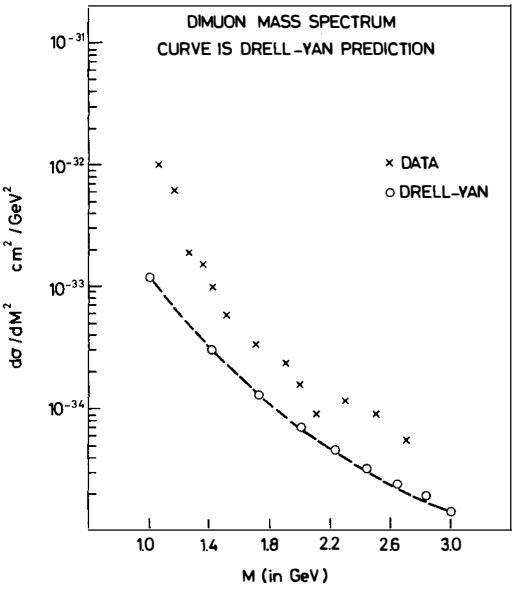

Fig. 8 Muon pair mass spectrum dσ/dm plotted as a function of the effective mass. Data of the Columbia-Hawaii-Cornell-Illinois-Fermilab Collaboration. The contribution from the Drell-Yan process is also shown.

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