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Abstract

We begin herewith the editing of physics notes taken in the course of Journal Club seminars at INFN-LNF in 1996. The activity consists of informal talks about work in progress and/or review of (more or less) recent physics results of interest to our laboratory. In the section titles the name of the speakers appear, together with the topics discussed in the seminars. We plan to publish these notes twice a year.

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1 S. Bellucci: In-medium $\bar{K}N$ scattering and chiral lagrangians, or the disappearance of $\Lambda(1405)$ in heavy kaonic atoms*

* Also presented at 2nd DEAR Collaboration Meeting, LNF, 1-2 April 1996.

My message here is twofold:

- there is a clean prediction of the chiral symmetry effective lagrangian, stating that the K^-p scattering length in a medium strongly depends on the nuclear density, so that its real part changes sign already at 1/8 of the normal nuclear density [1];
- a not negative kaon scattering length on an isolated proton (kaonic hydrogen) can be obtained only for values of the coupling constants among the 6 coupled meson-baryon channels, which are not compatible with SU(3) flavour symmetry. These constants are calculated in [2].

In what follows, I focus on the first point, which is a signal to the experimenters [3] of the importance of a measurement for atoms heavier than hydrogen and deuterium. For the second point, see also [4].

A recent study [1] obtains the following interesting results. Nuclear matter modifies very strongly the low-energy K^-p interaction. The attractive forces that produce the $\Lambda(1405)$ as a bound state are reduced by Pauli blocking. In medium the $\Lambda(1405)$ moves above the K^-p threshold at one-eighth the normal nuclear matter density. The K^-p scattering length depends strongly on the density. Its real part changes sign at one-eighth the normal nuclear matter density. Correspondingly the optical potential for kaonic atoms has an unconventional r -behaviour. The presence of the $\Lambda(1405)$ bound state just 27 MeV below the K^-p threshold invalidates the low-density theorem - stating that the optical potential goes linearly with the density - at unusually low density values.

The microscopic understanding of the above features is based on the low-energy QCD. A dynamical model of the $\Lambda(1405)$ structure as a bound state of \bar{K} and N in the I=0 channel (and a resonance in the $\Sigma\pi$ channel), based on the iteration of a pseudo-potential to infinite order in a Lippmann-Schwinger equation and describing successfully the data in the S=-1 strangeness sector, is modulated to respect the SU(3) chiral symmetry and have, in the Born approximation and up to terms of order $O(q^2)$ in the meson momentum, the same s-wave scattering length as the effective chiral lagrangian describing the low-energy meson-baryon interaction [2].

The successes of the theory in describing the s-wave coupled channel dynamics of the $\bar{K}N$ and π -hyperon systems (i.e. the Λ binding energy, its width, and all available low-energy data of $\bar{K}N$, $\Sigma\pi$, $\Lambda\pi$ systems), persist in describing how the nuclear matter affects the formation of the $\bar{K}N$ bound state. At a small density value, i.e. far out in the nuclear surface where the nuclear density distribution has some overlap with the atomic K^- wave function, the bound state disappears, as the Pauli exclusion principle yields enough repulsion energy to compensate the binding energy $E_\Lambda = -27$ MeV. The K^-p amplitude varies rapidly with the density near threshold, hence the effective scattering length in nuclear matter has a strong dependence on the density. The corrections to the K^-p amplitude due to the Fermi motion and the nucleon binding are also evaluated. They turn out to be much less important (and mutually opposing) effects, in comparison with the Pauli blocking of intermediate states [1].

2 M. Greco: QCD jets at high p_T

In a recent CDF paper [5] the comparison between the data - starting from a rather low p_T (≥ 15 GeV) and up to a maximum of 400 GeV - and the complete $O(\alpha_s^3)$ calculation [6, 7] of the inclusive jet cross-section

$$\frac{d\sigma^{jet}}{d^3p_T},$$

at large p_T with the rapidity ranging in the interval $0.1 \leq |\eta| \leq 0.7$, is carried out. The agreement is quite good for about ten orders of magnitude. However it appears that a small discrepancy is present at large p_T , i.e. the data suggest a departure from the $O(\alpha_s^3)$ prediction for $E_T \geq 200-250$ GeV. One must bear in mind that the D0 collaboration reported very recently new data showing no deviation effect in the same range. Due to the large errors in the high p_T region, the latter are in agreement with both the QCD calculation and the CDF data. The discrepancy has been indicated as a possible signal for quark compositeness. A composite scale $\Lambda = 1-2$ TeV has been estimated by means of an effective four-fermion interaction

$$\frac{1}{\Lambda^2}(\bar{q}\Gamma q)^2.$$

However, before drawing any definite conclusion, it is important to evaluate carefully the theoretical uncertainties in the QCD prediction, particularly at large E_T .

The data in the region of discrepancy are in the large x region ($x \geq 0.6$) where the structure functions, in particular the gluon one, are not very well measured. Indeed the CTEQ collaboration has tried to change the g structure functions and checked the corresponding effect [8]. Generally the theoretical uncertainties in the complete $O(\alpha_s^3)$ calculation due to the changes in the scales and the structure functions are of order 20-30%. In the estimate of the full theoretical prediction one needs however to take into account also the corrections coming from higher orders, which could become relevant near the boundary of the phase space ($p_T \simeq \sqrt{s}/2$). Indeed, in the large x region the QCD expansion parameter is $[\alpha_s \ln(1-x)]^n$, rather than α_s . Hence, when x is close to 1 and correspondingly $[\alpha_s \ln(1-x)] = O(1)$, one needs to resum all these terms, i.e. a finite order calculation is not enough. The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equation gets modified [9]. All those terms which diverge for $x \rightarrow 1$ are related to soft and collinear gluon radiation. In Drell-Yan processes this correction has been calculated and the effect of $x \rightarrow 1$ is important, but it has not been measured so far. The CDF data would eventually yield the first opportunity to measure this effect. The claim [10] is that the corrections increase the value of the inclusive jet cross-section at large p_T , i.e. they go in the right direction.

If the corrections turn out to be large, then one needs also to correct for $x \rightarrow 1$ the structure function code used in analyzing the DIS data. Of course before making any claim about possible evidence for the preonic structure of the quarks, one must include the effect of these higher order corrections.

3 G. Isidori: The problem of R_b : a phenomenological update

1. Electroweak precision tests performed at LEP and SLC have confirmed the Standard Model (SM) predictions with great accuracy. Among several observables which have been measured, only the ratio $R_b = \Gamma(Z \rightarrow b\bar{b})/\Gamma(Z \rightarrow \text{hadrons})$ shows a departure from the SM prediction larger than three standard deviations. In particular, the most recent determination of R_b obtained by combining the four LEP-experiments, $R_b^{\text{exp}} = 0.2219 \pm 0.0017$ [11], is 3.5σ far from the SM prediction: $R_b^{\text{SM}} = 0.2157 \pm 0.0001$.

2. Within the SM, due to non-decoupling effects induced by the top quark, the $Z \rightarrow b\bar{b}$ vertex receives non-universal corrections [12, 13]. The triangular diagrams $Z \rightarrow t\bar{t} \rightarrow q_d\bar{q}_d$ (W -exchange) and $Z \rightarrow W^+W^- \rightarrow q_d\bar{q}_d$ (t -exchange) are completely negligible for $q_d = d$ (due to small CKM matrix elements) whereas they are relevant for $q_d = b$. Interestingly, these effects are proportional to the Yukawa coupling of the top (this is the reason why they do not decouple as $m_t \rightarrow \infty$) i.e. they are related to the symmetry-breaking sector of the Model.

The leading correction induced by top loops can be written as a modification of the universal down-type coupling constants of the b quark with the Z boson: $g_V^b = g_V^d + \tau/2$ and $g_A^b = g_A^d + \tau/2$, where $\tau = (g_t/4\pi)^2$ and $g_t = m_t/(2\sqrt{2}G_F)^{-1} \simeq 1$ is the Yukawa coupling of the top. Since both g_V^d and g_A^d are negative the resulting effect is a *decrease* of $\Gamma(Z \rightarrow b\bar{b})$ with respect to $\Gamma(Z \rightarrow d\bar{d})$.

Besides the modification of $g_{V,A}^b$ induced by top exchanges, there are other non-universal corrections which affect $\Gamma(Z \rightarrow d\bar{d})$ [14]: phase space modifications due to $m_b \neq 0$, of order $O(m_b^2/M_Z^2)$; strong corrections calculated with $m_b \neq 0$, of order $O(\alpha_s m_b^2/M_Z^2)$; strong corrections to one-loop top-exchange diagrams $\sim O(\alpha_s g_t^2/16\pi^2)$. All the corrections have been calculated (up to two loop in many cases [13, 14]) and the corresponding uncertainties are negligible ($\delta R_b^{\text{SM}} \simeq 10^{-4}$ is a very conservative estimate).

3. Assuming that the discrepancy of R_b is generated by non-SM physics: $R_b^{\text{exp}} = R_b^{\text{SM}}(1 + \delta^{\text{non-SM}})$, then also the determination of $\alpha_s(M_Z)$ performed at LEP via the ratio $R_h = \Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow \mu^+\mu^-)$ has to be modified. The value of $\alpha_s(M_Z)$ extracted by R_h introducing $\delta^{\text{non-SM}}$ is lower than the uncorrected value and is in better agreement with the low energy determinations (from $\sim 2\sigma$ above the value shift to $\sim 1\sigma$ below [15]). Though not very significant from the statistical point of view, this result enforces the hypothesis of new physics in $\Gamma(Z \rightarrow b\bar{b})$. On the other hand, playing the same game with R_c , whose experimental value is about 2σ below the SM value, the resulting value of α_s is completely inconsistent with the low energy determinations.

4. New physics sources in the process $Z \rightarrow b\bar{b}$ can be generally divided in two classes: loop and tree-level effects. Let us start to analyze the former.

The contribution generated by a fermion (F), with the relative Yukawa scalar field (A), to the triangular diagram $Z \rightarrow b\bar{b}$ can be calculated in a model independent way (imposing only the conservation of charge and weak-isospin) [16]. The sign of the correction thus

obtained depends crucially from the weak-isospin assignment of F and can be applied to several interesting cases:

- **Two Higgs doublets.** In this case $F = t$ and $A = H^\pm$ (the new physical-charged-Higgs field). Like in the SM, the correction is negative and there is no possibility to improve the agreement with the data.
- **Fourth Generation.** In this case $F = t'$ (the new up-type quark) and $A = \phi^\pm$ (the SM unphysical-charged-Higgs field, which in the unitary gauge appears as the W longitudinal degree of freedom). Also in this case the correction is negative.
- **MSSM.** In this case there are three separate contributions: top and charged-Higgs, charginos and stop, neutralinos and sbottom. The first one has a negative sign (as in the Two Higgs doublet case) whereas the second and the third one can have a positive sign. For high (~ 1 TeV) and almost degenerate values of SUSY particle masses the three contribution cancel each other. Only for light stop and charginos (with small $\tan\beta$) or light sbottom and neutralinos (with very large $\tan\beta$) there is a chance to improve the agreement with the data. However, a recent correlated analysis of MSSM parameters (including new LEP data, $b \rightarrow s\gamma$ and Tevatron results) shows that is impossible to decrease to less than 2σ the discrepancy [17]. Furthermore, if this was the case, then light SUSY particles should be in the LEP200 range.

For what concerns tree-level effects, recently it has been shown that a leptophobic Z' [18], universally coupled to up-type and down-type quarks, not only can generate the right correction to R_b but can also improve the agreement with CDF data of the inclusive jet cross section at high p_T ($p_T \geq 200$ GeV) [5]. The mass of the Z' is estimated to be in the TeV range.

5. To conclude, we can say that there is no clear solution to the problem of R_b yet. The possibility of new heavy fermions with unconventional weak isospin assignment or the leptophobic- Z' hypothesis point in the right direction but are still *ad hoc* solutions. On the other hand, the possibility of a statistical fluctuation in the experimental data is far from being excluded.

4 D. Babusci: DHG sum rule and the nucleon spin polarizability at LEGS

Energy weighted integrals of the difference in helicity-dependent photoproduction cross sections ($\Delta\sigma = \sigma_{1/2} - \sigma_{3/2}$) provide information on [19]:

- the spin-dependent part of the asymptotic forward amplitude through the DHG sum rule

$$\int_{\bar{\nu}}^{\infty} \frac{d\nu}{\nu} \Delta\sigma(\nu) = -\frac{2\pi^2\alpha}{M^2} \kappa^2$$

- the nucleon spin-dependent polarizability γ

$$\int_{\bar{\nu}}^{\infty} \frac{d\nu}{\nu^3} \Delta\sigma(\nu) = 4\pi^2\gamma$$

There are no direct measurement of $\sigma_{1/2}$ and $\sigma_{3/2}$, for either the proton and the neutron. Estimates from current π -photoproduction multipole analyses [20], particularly for the *proton - neutron difference*, are in good agreement with the relativistic 1-loop (+ Δ -resonance) χ PT calculations [21] for γ but predict large deviations from the DHG sum rule.

Integral	Multipole Estimate	Theory
DHG _p - DHG _n (10 ⁻⁴ fm ²)	- 129	29.4
$\gamma_p - \gamma_n$ (10 ⁻⁶ fm ⁴)	- 96	- 104

The following two possible interpretations have been proposed:

1. *both* the higher order χ PT corrections to γ are large *and* the existing multipole are wrong
2. modifications to the DHG sum rule are required to fully describe the isospin structure of the nucleon

The helicity-dependent photoreaction amplitudes, for both the proton and the neutron, will be measured at LEGS from the pion-threshold to 470 MeV. Almost 90 % of the γ integral will be covered by this set of data, providing a reasonable comparison with the χ PT predictions. This data will also cover about 2/3 of the DHG integral.

In these double-polarization experiments, circularly polarized photons from LEGS will be used with SPHICE, a new frozen-spin target consisting of \vec{H} , \vec{D} in the solid phase. Reaction channels will be identified in SASY, a large detector array consisting of wire chambers, scintillators and Cerenkov counters with a global solid angle coverage of about 80 % of 4π .

5 C. Forti: Underground muons, a tool to study the cosmic ray composition and the properties of high energy interactions

We discuss the importance of the detection of underground muons for the study of the cosmic ray composition and spectra and of the properties of very high energy hadronic interactions. In particular, we show the application of the Monte Carlo HEMAS and HEMAS-DPM to the calculation of the muon multiplicity, topology and decorrelation, of the properties of multi-muon clusters and of the flux of muons from the decay of charmed mesons (prompt muons).

The study of the chemical composition of cosmic rays in the energy region around the knee of the spectrum is of fundamental importance for the understanding of cosmic ray acceleration and propagation processes. The properties of high energy (TeV) muons detected deep underground are strongly correlated with the mass and energy of the primary cosmic rays which originated the particle shower. The most important features of underground muon events are :

- the muon bundle multiplicity, that is the number of (almost parallel) muons originated by the same primary cosmic ray;
- the decoherence, that is the relative distances between all pairs of muons which can be formed within a muon bundle;
- the decorrelation curve, which is the relative angle between all muon pairs, as a function of their relative spatial separation;
- the number of muon clusters within the muon bundle.

We have shown that the distribution of the bundle multiplicity (called multiple muon rate) is clearly sensitive to the percentage of heavy nuclear species in cosmic rays. Composition models with more heavy nuclei predict more events with high bundle multiplicity, respect to lighter models. Also the decoherence curve is sensitive to the chemical composition, but its peculiar characteristic is to depend on the transverse momentum (P_t) distribution of hadrons (mainly pions) produced in the cascade. Then, the measurement of decoherence should allow to test the hypothesis about the P_t distribution adopted in the model for very high energy ($1 - 10^5$ TeV Lab) hadron-air interactions. The study of decorrelation and of muon clusters are new tools recently proposed to enhance the efficacy of underground measurements. In particular, the number of muon cluster within a muon bundle (with multiplicity larger than 8 at Gran Sasso Laboratory) is shown to be sensitive both to the primary composition and to the hadronic interaction properties. A great effort is being devoted to the comparison of different Monte Carlo simulations, adopting different hadronic interaction models. Actually, the evaluation of the systematical uncertainties in these complex calculations is one of the most difficult tasks to be accomplished. For example, a new Monte Carlo code (HEMAS-DPM [22]) has been realised : it is based on the Dual Parton Model (DPMJET-II [23]), interfaced to the HEMAS shower code (containing a phenomenological interaction model [24]). The HEMAS-DPM Monte Carlo allows to simulate the interaction of hadron and nuclei with the air target. Also, the production of charmed particles is accomplished. However,

calculations performed [25] indicate that the detection of high energy muons generated in the decay of charmed particles (the so-called prompt muons) could be a hard experimental task because the ratio signal (prompt muons) to noise (ordinary muons) is less than 1% for typical (> 1 TeV) underground experiments. A challenging control of systematics is thus required.

6 R. Baldini: Question marks in the nucleon time-like form factors

Question marks related to the measurements of the Nucleon Form Factors are reported (for a complete discussion see [26] and references therein), namely:

- the factor of 2 between "asymptotic" values of space-like and time-like of the proton magnetic form factor;
- the Nucleon Form Factor mainly imaginary at 9 GeV^2 , according to the FENICE results and a possible explanation within PQCD;
- baryonium rides again (according to the e^+e^- total multihadronic cross section near the $N\bar{N}$ threshold and according to the Proton Form Factor at threshold) and a short review of the old baryonium phenomenology;
- the Neutron time-like Form Factors: expectations and experimental results.

Dispersion Relations on the log of the modulus of the Form Factors are discussed, in order to achieve the Nucleon Form Factors in the unphysical region.

7 G. Pancheri: Eikonalized minijets cross-section in photon collisions*

* Work in collaboration with A. Grau and Y.N. Srivastava.

A model for the parton distributions of hadrons in impact parameter space has been constructed using soft gluon summation. This model incorporates the salient features of distributions obtained from the intrinsic transverse momentum behaviour of hadrons. Under the assumption that the intrinsic behaviour is dominated by soft gluon emission stimulated by the scattering process, the b-spectrum becomes softer and softer as the scattering energy increases. In minijet models for the inclusive cross-sections, this will counter the increase from σ_{jet} .

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