LF21: PHENOMENOLOGY OF ELEMENTARY PARTICLE INTERACTIONS AT COLLIDERS

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1 Summary of the project

The research topics investigated by this project can be divided into three main areas:

- Flavour physics.
- Quantum Chromodynamics and the rise of total cross-sections.

The first area, discussed in Section 2, concerns the possibility to perform new low-energy precision tests about the mechanism of quark-flavor mixing, by means of K and B meson decays. The second area, discussed in Section 3, is the project related to the QCD description of hadronic and photonic total cross-section at high energies.

2 Flavour Physics

Despite the Standard Model (SM) provides a successful description of particle interactions, it is natural to consider it only as the low-energy limit of a more general theory, or as the renormalizable part of an effective field theory valid up to some still undetermined cut-off scale Λ. Since the SM is renormalizable, we have no direct indications about the value of Λ. However, theoretical arguments based on a natural solution of the hierarchy problem suggest that Λ should not exceed a few TeV.

One of the strategies to obtain additional clues about the value of Λ is to constrain (or find evidences) of the effective non-renormalizable interactions, suppressed by inverse powers of Λ, which encode the presence of new degrees of freedom at high energies. These operators should naturally induce large effects in processes which are not mediated by tree-level SM amplitudes, such as $\Delta F = 1$ and $\Delta F = 2$ flavour-changing neutral current (FCNC) transitions. Up to now there is no evidence of these effects and this implies severe bounds on the effective scale of dimension-six FCNC operators. For instance the good agreement between SM expectations and experimental determinations of K^0–$\bar{K}^0$ mixing leads to bounds above 10^3 TeV for the effective scale of $\Delta S = 2$ operators, i.e. well above the few TeV range suggested by the Higgs sector.

The apparent contradiction between these two determinations of Λ is a manifestation of what in many specific frameworks (supersymmetry, techincolour, etc.) goes under the name of *flavour problem*: if we insist with the theoretical prejudice that new physics has to emerge in the TeV region, we have to conclude that the new theory possesses a highly non-generic flavour structure. Interestingly enough, this structure has not been clearly identified yet, mainly because the SM, *i.e.* the low-energy limit of the new theory, doesn't possess an exact flavour symmetry. The attempt to clarify this structure, both at the phenomenological level (with the help of precision data on rare decays) and at a more fundamental level (with the help of new symmetry principles), is one of the main activity of our group. [1)]

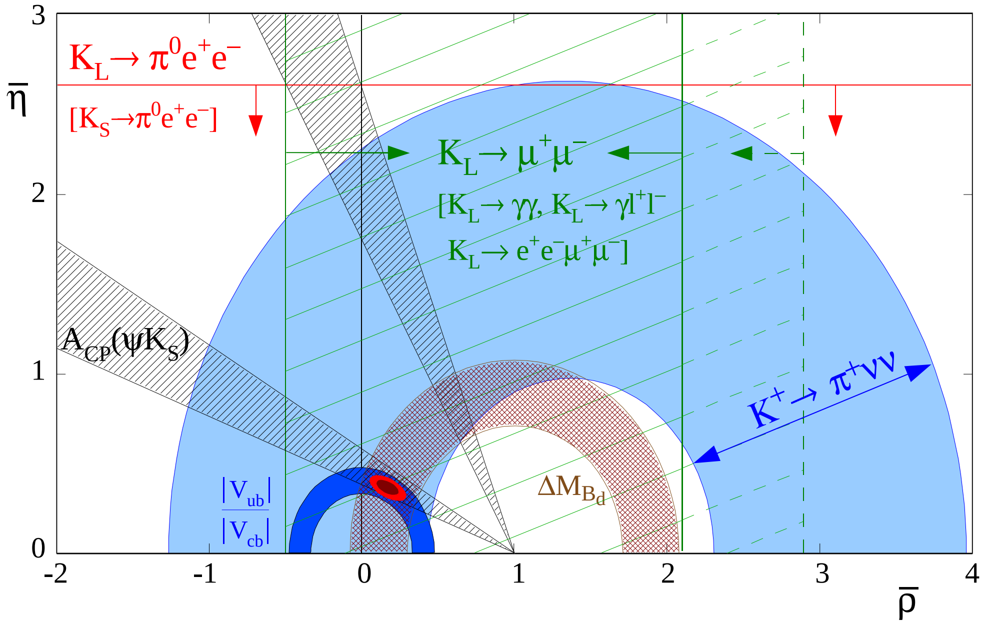

Figure 1: Summary of the present constraints in the $\bar{\rho}$–$\bar{\eta}$ plane from rare K decays: the $K_L \to \mu^+\mu^-$ bound on $\bar{\rho}$, [10], the $K_L \to \pi^0 e^+ e^-$ bound on $\bar{\eta}$, [9] and the $K^+ \to \pi^+ \nu\bar{\nu}$ ellipse. [7] The constraints on $|V_{ub}|$ and B–$\bar{B}$ mixing, from Ref. [11], are also shown for comparison.

In the last year we performed a series of studies on the rare decay $B \to X_s \ell^+ \ell^-$ [2, 3, 4] and other rare B decays; [5, 6] on the rare K decays $K_L \to \pi\nu\bar{\nu}$, [7, 8] $K_L \to \pi^0 e^+ e^-$, [9] and $K_L \to \mu^+\mu^-$; [10] on the precise determination of the Cabbibo angle from $K_{\ell 3}$ decays. [11, 12]

Concerning $K_L \to \mu^+\mu^-$, [10] our aim was the precise calculation of the long-distance two-photon amplitude, taking advantage of recent experimental results from KLOE, NA48 and KTeV. Our analysis allows to extract the conservative bounds on the Wolfenstein parameter shown in Fig. 1. Similarly, we performed a new analysis of the rare decay $K_L \to \pi^0 e^+ e^-$ taking into account important experimental progress that has recently been achieved in measuring $K_L \to \pi^0\gamma\gamma$ and $K_S \to \pi^0 e^+ e^-$. [9] As a result, we obtained the first reliable prediction of the total rate for this process: $B(K_L \to \pi^0 e^+ e^-) = (3.2^{+1.2}_{-0.8}) \times 10^{-11}$. The latter result turns out to be dominated by CP violation with a sizable contribution ($\sim 40\%$) from the direct-CP-violating amplitude (see Fig. 2).

3 Quantum Chromodynamics and the rise of total cross-sections

This project [13, 14, 15] is presently developed through collaborations between G. Pancheri and Rohini Godbole, for what concerns strictly the Eikonal Minijet Model, R. Godbole, A. Grau and Y.N. Srivastava for the studies of the effect of Soft Gluon Resummation on the taming of the rise of total cross-section, and with Albert de Roeck for the study of total cross-sections at Linear Colliders.

The goal of this project is to obtain a QCD description of the initial decrease and the final

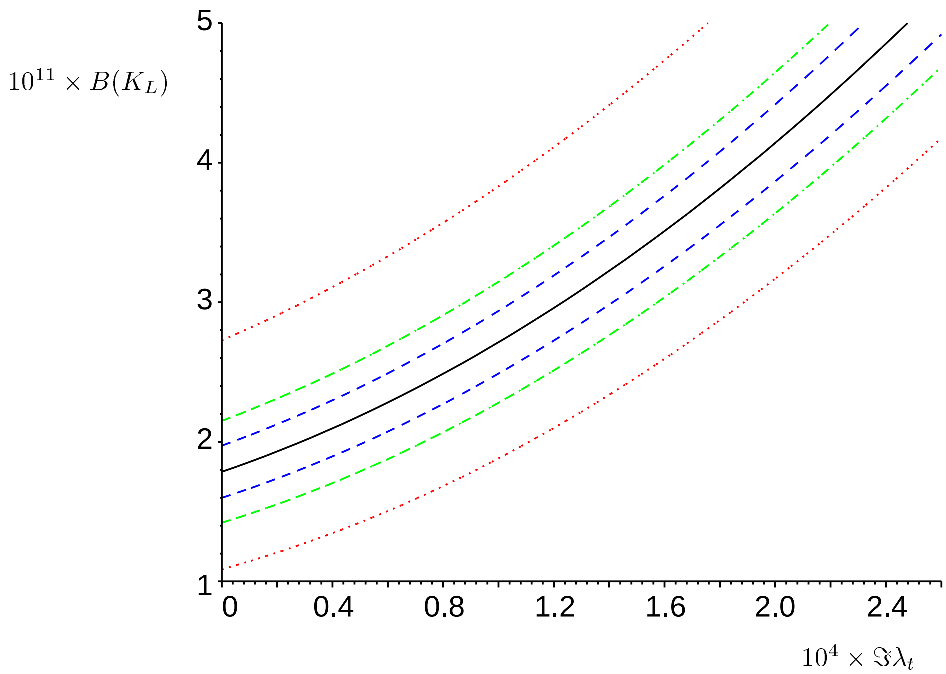

Figure 2: SM Prediction for $B(K_L \to \pi^0 e^+ e^-)$ as a function of $\Im\lambda_t = \Im(V_{ts}^* V_{td})$, assuming a positive interference between direct- and indirect-CP-violating components. [9] The three curves correspond to the central value of $B(K_S \to \pi^0 e^+ e^-)$ from NA48 and no error (central full line); 10% error (dashed blue lines); 20% error (dashed green lines); present error (red dotted lines).

increase of total cross-sections through soft gluon summation (via Bloch-Nordsieck Model) and QCD calculable jet x-sections, also known as mini-jets in this context. Thus, the physical picture includes multiple parton collisions and soft gluons dressing each collision.

3.1 *The Eikonal Minijet Model for protons and photons*

In the Eikonal Minijet Model (EMM) the rise can be obtained using the QCD calculable contribution from the parton-parton cross-section, whose total yield increases with energy. For a unitary description, the jet cross-sections are embedded into the eikonal formalism, where the eikonal function contains both the energy and the impact parameter distribution in b-space. The simplest formulation with minijets to drive the rise, and hadronic form factors for the impact parameter distribution, can be applied to all the available x-sections. One finds that proton-antiproton high energy data can be reproduced by this model. However it is not possible to describe both the early rise, which in proton-antiproton scattering takes place around $10 \div 50\, GeV$, and the Tevatron data, with a single set of parameters.

Photo-production data can be described through the same simple eikonal minijet model, with the relevant parton densities for the jet cross-sections, scaling the non perturbative part with VMD and quark counting factors. However, just like in the proton-proton case and in the

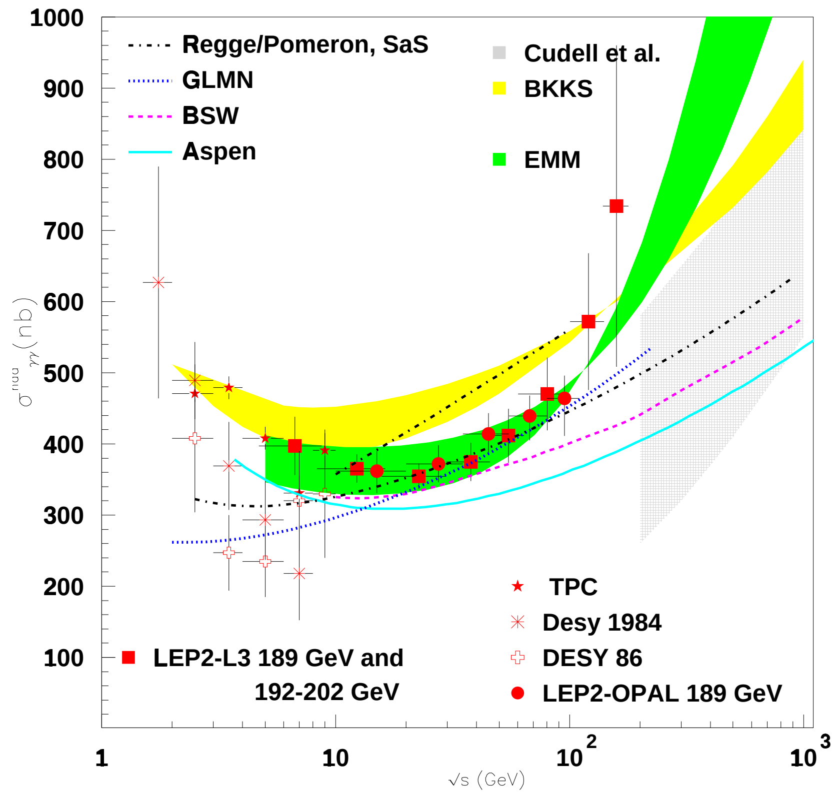

Figure 3: *The predictions from factorization (proton like) models, Regge-Pomeron exchange and a QCD structure function model together with those from the EMM are compared with the present data.*

gamma gamma case, the case for extrapolation of the EMM to higher energies is not convincing. A compilation of $\gamma\gamma$ data, including present LEP data, done for future Linear Collider indicated that the EMM describes quite well the rise at present energies, but the extrapolation to even higher energies appears unrealistic and may need to be modified, as found in the proton case. In the figure from [14] we show the predictions of this model for photon-photon collisions in comparison with predictions from different models and with the available data.

A possible way to decrease the uncertainty in the predictions is to refine the QCD analysis, through resummation of soft gluon emission from the initial state partons, a feature absent from most simple EMM.

3.2 *Soft Gluon Summation and the impact parameter distribution of partons*

A model for the impact parameter space distribution of parton in the hadrons has been developed and applied to the proton and photon cross-sections in order to obtain a better description of total cross-section. The physical picture underlying this model is that the fast rise due to mini-jets and the increasing number of gluon-gluon collisions as the energy increases, can be reduced if one takes into account that soft gluons, emitted mostly by the initial state valence quarks, determine an acollinearity between the partons which reduces the overall parton-parton luminosity. This model can describe very well all available data for proton collisions and appears very flexible when applied to photon processes. We show next a representative figure from [13].

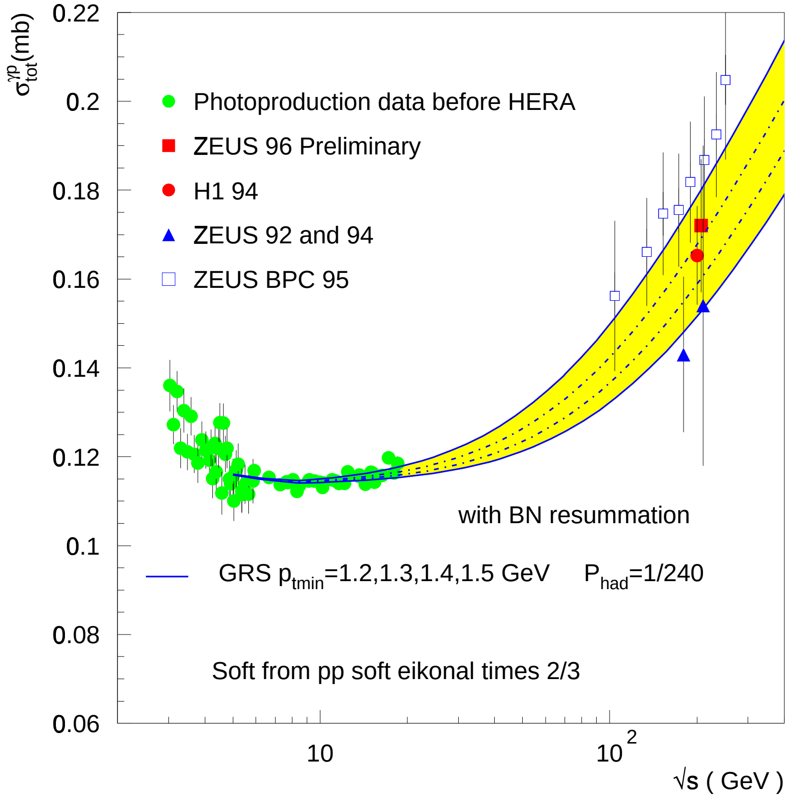

Figure 4: *Total γp cross-section, with soft gluon resummation (BN) and GRS densities in the mini-jet cross-section, for an indicative set of values for p_{tmin}.*

4 Work Program for the year 2004

Most of the activity previously described in hadronic physics will be continued into the year 2004. The work on QCD and total cross-sections, a long term project, will focus mainly on discussing the complementarity between the coming measurements at LHC and the prospects of measuring total cross-sections at the Lineaar Colliders.

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