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 the following areas:

- Flavour physics, precision tests and physics beyond the Standard Model (F. Mescia, G. Isidori, M. Nicolaci),
- Light flavour spectroscopy and τ-physics (O. Leitner)
- Hadronic Form Factors and meson spectroscopy (S. Pacetti)
- Hadronic cross-sections (A. Achilli, G. Pancheri and O. Shekhovtsova)
- QCD and the Higgs boson at the LHC (V. Del Duca)

The activity of the phenomenology group at Frascati can be seen in detail at the site

`http://www.lnf.infn.it/theory/pheno2.html`

In the following we shall briefly describe all the different projects undertaken by the above participants.

2 Flavour physics, precision tests, and physics beyond the Standard Model

One of the strategies to obtain additional clues about the nature of New Physics (NP) is by means of precision tests of the Standard Model (SM) at low energies. These are particularly interesting in: i) electroweak processes calculable with high precision, where even tiny deviations from the SM can be detected; ii) processes which are not mediated by tree-level SM amplitudes, where the relative effect of NP contributions can be enhanced. Up to now there is no clear evidence for deviations from the SM in both type of processes, and this leads to significant constraints in building realistic extensions of the SM. For instance, realistic models must possesses a highly non-generic flavour structure. These constraints are particularly severe for NP models with new degrees of freedom around the TeV scale, as required by a natural stabilisation the $SU(2)_L \times U(1)_Y \to U(1)_Q$ spontaneous symmetry breaking. The attempt to clarify this problem, 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.

A closely related subject –which is also one of the primary research objectives of our group– is a better understanding of the SM itself, fixing his fundamental couplings (quark masses, CKM angles, non-perturbative condensates, ...) by means of precise calculations within the framework of effective field theories and Lattice QCD.

Within this general scenario, last year we have performed a series of works on:

Supersymmetry and Higgs-boson mass.

Motivated by recent progress in consistently and rigorously calculating electroweak precision observables and flavour related observables, we have performed a global analysis of

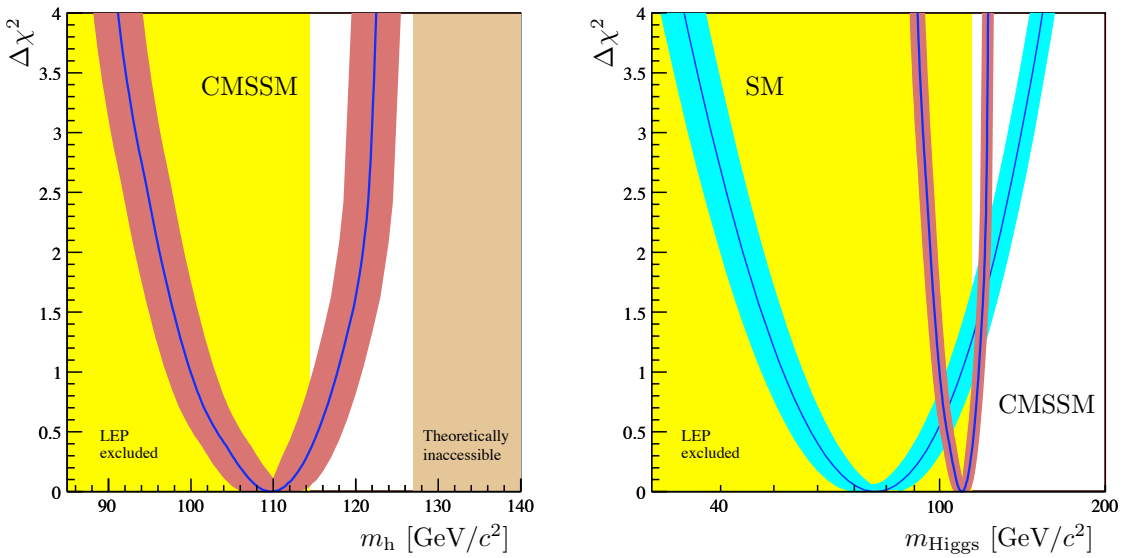

Figure 1: Left: Scan of the lightest Higgs boson mass versus $\Delta\chi^2 = \chi^2 - \chi^2_{\rm min}$. The curve is the result of a CMSSM fit using all of the available constraints, except the limit on $m_{\rm h}$. The red (dark gray) band represents the total theoretical uncertainty. Right: Scan of the Higgs boson mass versus $\Delta\chi^2$ for the SM (blue/light gray), as determined by the LEP Electroweak WG using all available electroweak constraints, and for comparison, with the CMSSM scan superimposed (red/dark gray). The blue band represents the total theoretical uncertainty.

the Constrained Minimal Supersymmetric Standard Model (CMSSM), taking into account electroweak precision data, flavour physics observables and the abundance of Cold Dark Matter. [1] The model is found to be consistent with data and the lightest Higgs boson mass in predicted to be $m_h^{\rm CMSSM} = 110^{+8}_{-10}({\rm exp.}) \pm 3({\rm theo.}){\rm GeV}/c^2$ (see Fig. 1).

Heavier values of the Higgs mass are found in a different version of the MSSM, namely the MFV-large tan β sscenario, which is also well motivated and consistent with present data. [2]

We have also refined and updated the metastability constraints on the Higgs boson mass which hold within the SM, [3] assuming a scale of new physics very high (around the Planck mass). Interestingly, we find that present best-fit ranges of the top and Higgs masses mostly lie in the narrow metastable region.

Leptogenesis in models with MFV.

Minimal Flavor Violation (MFV) is an attractive approach to solve the flavour problem assuming that the Yukawa couplings are the only irreducible sources of flavour symmetry breaking also beyond the SM. We have investigated the viability of leptogenesis in models respecting the MFV hypothesis in the lepton sector (i.e. models with three heavy right-handed neutrinos, where the charged-lepton and the neutrino Yukawa couplings are the only irreducible sources of lepton-flavour symmetry breaking). We have shown that in this framework a specific type of resonant leptogenesis can generate the observed matter-antimatter asymmetry. [4]

Kaon physics.

We have extended our previous studies of rare K decays and precision tests of the SM in

the K system. [5, 6, 7, 8] Most notably, the matrix elements relevant to rare K decays have been related to those measured in K_{l3} using Chiral Perturbation Theory, beyond the lowest order. [5] As a result, the non-parametric errors for $B(K \to \pi\nu\bar{\nu})$ and for the direct CP-violating contributions to $B(K_L \to \pi^0\ell^+\ell^-)$ are now completely dominated by those on the short-distance physics. We have also derived analytical expressions for the electromagnetic correction factors relevant to the distortion of Dalitz-plot distributions of $K \to 3\pi$ decays. [8]

Lattice QCD.

We have explored different strategies to extract the D-meson semileptonic decay form factors from the Green functions computed in QCD numerically on the lattice. [9] We have found that strategies based on the use of double ratios of 3-point correlation functions, lead to an appreciable reduction of systematic uncertainties. This is an important step in reducing the overall uncertainty in the lattice QCD results for the D-decay form factors which are needed to determine the CKM entries $|V_{cd}|$ and $|V_{cs}|$.

3 Light flavour spectroscopy and τ-physics

This part of the project is aimed at analysing three open-questions, mainly inlight flavour physics: the search for T-observable, the prediction of τ-decay and the understanding of the quark structure in scalar mesons. Within the Standard Model framework, one has obtained promissing results as shortly described below:

Time Reversal effect

Calculations of the angular distributions, which represent real physical observables, as well as branching ratios of the process $\Lambda_b \to \Lambda V$ with $\Lambda \to P\pi$ and V into lepton lepton or V into hadron hadron have been performed by using the helicity formalism and stressing on the correlations which arise among the final decay products. A first computation of the asymmetry parameter, α_{As}, in Λ_b decays into Λ V has been performed as well as the longitudinal polarization of the vector meson, which is shown to be dominant [10].

Tau decay

In order to study the phenomenology of light flavor mesons below 1 GeV, one needs a framework which includes in a well defined manner the lowest nonets of pseudo scalar and vector mesons: the hidden local symmetry model, HLS. In our approach, we proposed to have a framework giving simultaneously an account of the partial decay width of light meson decays of the pion form factor in e+e- data and in tau decay. In our approach, we made a prediction of the tau decay 2 pion spectrum which can be compared with the existing measurements.

Scalar mesons

A phenomenological analysis of the scalar meson $f_0(980)$ was performed, which makes use of experimental D branching ratios. With a relativistic quark model formalism, in which the transition form factors are calculated for time like momenta, and electroweak D decay amplitudes calculated in QCD factorization, one can extract informations on the structure of the meson $f_0(980)$ in terms of the quark-antiquark pairs as well as on the mixing angle theta between strange and non strange components. The electroweak transition form factors are computed using triangle diagrams within the constituent quark model in CLFD [11, 12, 13].

4 Hadronic form factors- S. Pacetti

5 Hadronic cross-sections

Hadronic cross-sections were studied in two different type of processes and different energy ranges, namely at DAPHNE, within a study for future prospects [14] and final state radiation effects in $e^+e^- \to \pi^+\pi-$ near threshold, and at high energy colliders in $A + B \to X$ where A, B could be a proton or an antiproton or a photon, where the emphasis lies on the role played by soft gluons on the saturation of the Froissart bound

Final State Radiation effects at DAPHNE

Final state radiation in the process e+e- into two charged pions is being studied as a possibility to test a pion-photon interaction model near two-pion threshold. A Monte Carlo event generator FEVA that simulates the process $e^+e^- \to \pi^+\pi^-\gamma$ and $e^+e^- \to \pi^0\pi^0\gamma$ for the DAΦNE accelerator setup has been developed. The applied formalism is quite general and consistent with all symmetries of the strong and EM interactions [15, 16, 17].

Total cross-sections and the Froissart bound

A model for total cross-sections based on the complementarity between QCD mini-jets contributions and soft gluon resommation has been applied to study minimum bias effects in high energy hadronic collisions. This model, labelled after Bloch-Nordsieck (BN) resummation type effects in QCD, puts central emphasis on the infrared behaviour of the strong coupling constant for which the following ansätz has been formulated:

$$\alpha_s(Q^2) \to \frac{1}{Q^{2p}} \qquad as \quad Q^2 \to 0 \tag{1}$$

with $1/2 < p < 1$ for convergence of the infrared integral and analyticity requirements. It has been shown that such a model, whose results are shown in Fig.2, allows for compliance with the Froissart bound on total cross-sections [20]. Application of the model to photon processes has been presented at Photon 2007 Workshop in Paris, in july 2007, and is under progress.

6 QCD and the Higgs boson at the LHC-V. Del Duca

This project is focused on Higgs studies and the strong interactions in the Standard Model (SM). Its research goals are:

i) to evaluate accurately signals and backgrounds for Higgs boson production at the LHC;

ii) to develop advanced techniques to improve the precision of the calculation of scattering cross sections at high momentum transfer Q^2.

Higgs Boson Production in Hadronic Collisions

At the LHC, the Higgs boson will be produced mostly via gluon fusion, with the Higgs boson interacting with the gluons via a top-quark loop. This production mode is known at next-to-leading-order (NLO) accuracy in the strong coupling constant α_S for finite values of the top-quark mass m_t, and at next-to-next-to-leading-order (NNLO) accuracy in the limit $m_t \to \infty$. The latter, though, generates spurious logarithms $\ln(\hat{s}/m_H^2)$, which are not present when the full m_t dependence is taken into account. Higgs production via gluon fusion has been considered for finite values of m_t in the limit of high parton centre-of-mass energy $\hat{s}$ [19], which allows us to improve upon the NNLO calculation mentioned above.

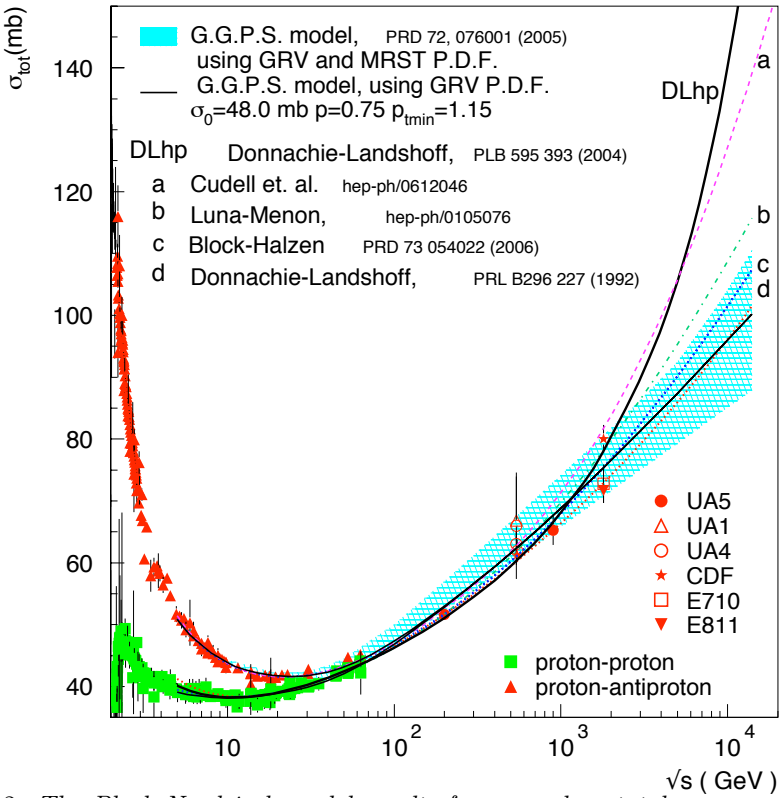

Figure 2: *The Bloch-Nordsieck model results for pp and $p\bar{p}$ total cross-sections are compared with data and other model predictions.*

The second largest Higgs production mode is via vector boson fusion (VBF). Besides providing a clean discovery channel, this allows for the study of the coupling of the Higgs boson to the electro-weak gauge sector. To enhance Higgs production via VBF over the one via gluon fusion, it is convenient to produce the Higgs boson in association with two jets far apart in rapidity. In a realistic simulation, the final-state partons shower and hadronise. Thus more than two jets usually appear in the final state. Such a final state has been considered through a matrix-element Monte Carlo generator in Ref. [20].

Higher-Order Corrections to Scattering Cross Sections at high Q^2

In the quest to discover New Physics signals, typically covered by the huge SM backgrounds, the precise experimental measurements at the Tevatron and at the LHC require theoretical calculations which are at least as precise. In some instances, like in the inclusive production of the Higgs boson via gluon fusion mentioned above, the desired accuracy is achieved only at NNLO in α_S. Thus, a general algorithm to compute jet cross sections at NNLO is being implemented.

7 List of Conference Talks by LF21 Participants in Year 2007

1. V. Del Duca, Higgs the missing link of the Standard Model, Workshop "Physics for Large and Small Scale", Nha Trang, Vietnam, 2007.

2. V. Del Duca, Higgs production in association with jets at the LHC, 3^{rd} Hera and LHC

Workshop, DESY, Hamburg, Germany, 2007.

3. V. Del Duca, Higgs production in association with jets at the LHC, XLII Rencontres de Moriond, La Thuile, Italy 2007.

4. G. Isidori, Flavour Physics: Now and in the LHC era, 23rd International Symposium on Lepton-Photon Interactions (LP07), Daegu, Korea, 13-18 Aug 2007.

5. G. Isidori, Large tan(beta) effects in flavour physics, 15th International Conference on Supersymmetry (SUSY2007), Karlsruhe, Germany, July 26 - August 1, 2007.

6. G. Isidori, Conference summary, Kaon International Conference (KAON'07), Frascati, Italy, 21-25 May 2007.

7. G. Isidori, Supersymmetric effects in favour physics, Supersymmetry at LHC: Theoretical and Experimental Perspectives, Cairo, Egypt, 11-14 March 2007.

8. G. Isidori, Rare Kaon decays within and beyond the SM, 6th KEK Topical Conference: Frontiers in Particle Physics, KEK, Japan, 6-8 Fb 2007.

9. G. Pancheri, LHC Predictions for total cross-sections from the eikonal mini-jet model and the Froissart Bound, XLII Rencontres de Moriond, La Thuile, Italy, 17-24 March 2007.

10. G. Pancheri, QCD predictions for total cross-sections and the Froissart bound, IX Workshop on Perturbative QCD, Paris, France, June 4-8, 2007.

11. G. Pancheri, Minijets, soft gluon resummation and photon cross-sections, Photon 2007, Paris, France, 9-13 July 2007.

12. G. Pancheri, Large rapidity gaps survival probabilities LHC, International Symposium on Multiple Dynamics (ISMD07), Berkeley, California, 4-9 August 2007.

13. G. Pancheri, QCD Contributions to the Froissart bound for the total cross-section, Hadron Structure (HS07), Modra-Harmonia, Slovak Republik, september 3-9 2007.

14. G. Pancheri, Total cross-sections and rapidity gaps survival probability at LHC, XII Conference on Hadron Spectroscopy, Frascati, 4-10 september 2007

15. G. Pancheri, QCD issues in photon-photon total cross-section : why we need a photon collider, International Workshop on Laser-Electron Interactions, Hiroshima, Japan, 10-14 december 2007

8 Publications of the year 2007

References

1. O. Buchmueller *et al.*, *Prediction for the Lightest Higgs Boson Mass in the CMSSM using Indirect Experimental Constraints,* Phys. Lett. B **657** (2007) 87 [arXiv:0707.3447 [hep-ph]].

2. G. Isidori, F. Mescia, P. Paradisi and D. Temes, *Flavour physics at large* $\tan\beta$ *with a Bino-like LSP,* Phys. Rev. D **75** (2007) 115019 [arXiv:hep-ph/0703035].

3. G. Isidori, V. S. Rychkov, A. Strumia and N. Tetradis, *Gravitational corrections to Standard Model vacuum decay,* Phys. Rev. D **77** (2008) 025034 [arXiv:0712.0242 [hep-ph]].

4. V. Cirigliano, A. De Simone, G. Isidori, I. Masina and A. Riotto, *Quantum Resonant Leptogenesis and Minimal Lepton Flavour Violation,* JCAP **0801** (2008) 004 [arXiv:0711.0778 [hep-ph]].

5. F. Mescia and C. Smith, *Improved estimates of rare K decay matrix-elements from K_{l3} decays,* Phys. Rev. D **76** (2007) 034017 [arXiv:0705.2025 [hep-ph]].

6. F. Mescia, *Precision tests with Kl3 and Kl2 decays,* arXiv:0710.5620 [hep-ph].

7. G. Isidori, *Soft-photon corrections in multi-body meson decays,* Eur. Phys. J. C **53** (2008) 567 [arXiv:0709.2439 [hep-ph]].

8. G. Isidori, *KAON 2007: Conference Summary,* arXiv:0709.2438 [hep-ph].

9. D. Becirevic, B. Haas and F. Mescia, *Semileptonic D-decays and Lattice QCD,* PoS(LATTICE 2007)355. arXiv:0710.1741 [hep-lat].

10. O. Leitner, B. Loiseau, B. El-Bennich, J.P. Dedonder, *Form factors in B to f0(980) and D to f0(980) transitions from dispersion relations*, Int. J. Mod. Phys. **A22**, 641, 2007.

11. O. Leitner, B. Loiseau, B. El-Bennich, J.P. Dedonder, *Scalar meson properties from D-meson decays*, Nucl. Phys. **A790**, 510, (2007).

12. O. Leitner, B. Loiseau, B. El-Bennich, J.P. Dedonder, *Resonances and weak interactions in $D^+ \to \pi^+\pi^-\pi^+$ decays*, Int. J. Mod. Phys. **E16**, 2876, 2007.

13. O. Leitner, B. Loiseau, B. El-Bennich, J.P. Dedonder, *Pseudoscalar-scalar transition form-factors in covariant light front dynamics*, World Scientific, vol II, 984, 2007.

14. F. Ambrosino *et al.*, *Prospects for e^+e^- physics at Frascati between the ϕ and the Ψ*, Eur.Phys.J. **C50**, 729.

15. G. Pancheri, O. Shekhovtsova, G. Venanzoni, *Tests of the final-state radiation model at DAPHNE near π^+pi^- threshold*, Eur.Phys.J. **A31**, 458 (2007).

16. G. Pancheri, O. Shekhovtsova, G. Venanzoni, Acta Pol. Phys. **38** (2007) 2999.

17. G. Pancheri, O. Shekhovtsova, G. Venanzoni, JETP **133** (2008) 544, [arXiv: 0706.3027].

18. A. Achilli, R.M. Godbole, I. Grau, G. Pancheri and Y.N. Srivastava, LHC predictions for total cross-sections from the eikonal mini-jet model and the Froissart bound, in: 2007 QCD and High Energy Hadronic Interactions, Proc. XLII Rencontres de Moriond, (eds. E. Auge', B. Pietrzyk and J. Tran Than Van, La Thuile, March 2007), pag. 321 (World Scientific, Singapore, 2008).

19. S. Marzani, R. D. Ball, V. Del Duca, S. Forte and A. Vicini, "Higgs production via gluon-gluon fusion with finite top mass beyond next-to-leading order," arXiv:0801.2544 [hep-ph].

20. V. Del Duca, "Monte Carlo studies of jet activities in Higgs production in association with 2 jets at the LHC", Proc. 42nd Rencontres de Moriond, La Thuile 2007.