ENP: Exploring New Physics

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The research activity undertaken by the LNF research unit of the ENP project deals with the phenomenology of particle physics at present and future colliders, both within and beyond the Standard Model (BSM). In particular, we worked on top-quark physics and on BSM phenomenology from either model-independent perspectives or in scenarios like supersymmetry or the 331 model. We also gave an active contribution to the debate on the European strategy for particle physics and on the different collider options which have been discussed. Hereafter we highlight the main results achieved in 2024 by the ENP team.

- We explored light new physics in the top-quark sector, namely the invariant mass b-jet+lepton (m_{bl}) in $t\bar{t}$ events at LHC in the dilepton channel, i.e. both W's decay leptonically. We found that the low-mass tail of the spectrum is sensible to BSM effects and, as a working case, we considered some not-yet-excluded scenarios within the Minimal Supersymmetric Standard Model (MSSM), characterized by stops, charginos and neutralinos which are relatively light. In view of our findings, it would then be desirable recasting the present top-quark analyses, such as the one on the m_{bl} distribution [1].
- We acted as theory consultants for an ATLAS analysis on the top-quark mass measurement, namely the one which uses the $m_{l\mu}$ distribution, where l is a lepton from W in $t \to bW$ decay and μ is a muon from a B-hadron decay. The measured value of the top-quark mass, $m_t = 174.41 \pm 0.81$ GeV, represents the most precise single measurement at LHC up to date. Our contribution mostly dealt with the estimate of the theoretical uncertainty, taking particular care about bottom fragmentation in top decay [2].
- Beyond the Standard Model, we worked on possible signals of bileptons, i.e. heavy vectors with charge ± 2 and lepton number $L = \pm 2$, whose mass should be about 1.4 TeV, as dictated by renormalization group arguments. Such heavy bileptons are predicted in the so-called 331 model, based on a $SU(3)_L \times SU(3)_C \times U(1)_X$ symmetry and capable of explaining the number of families and the asymmetry of the third family with respect to the other two. This model also foresees the existence of exotic heavy quarks, with charge either 5/3 or 4/3 and mass in the TeV range. In the considered 331 scenario, the main bilepton decay mode is into lepton pairs, e.g. $Y^{++} \to l^+ l^+$; more recently, we investigated decays into TeV-scale quarks T, with charge 5/3, plus a Standard Model quark. We explored bilepton pair production, i.e. $pp \to Y^{++}Y^{--}$, followed by $Y^{++} \to T\bar{b}$ and $T \to l^+ l^+ b$, the latter occurring through a virtual Y^{++}. As a whole, we investigated final states with four b-jets and two same-sign lepton pairs and discovered that this is a signal which can possibly be detected at a 100 TeV FCC-hh, the LHC statistics being too low, even in the high-luminosity phase (HL-LHC) [3].
- We worked on models with anomaly-mediated supersymmetry breaking (AMSB) in two possible settings: extra-dimensional models where SUSY breaking occurs in a sequestered sector

and $4d$ models with dynamical breaking in a hidden sector. Although both models run into serious conflicts with LHC sparticle and Higgs mass constraints, as well as wino-like dark matter searches and bounds from naturalness, these drawbacks may be avoided by introducing minor changes to the underlying phenomenological model, namely a setting for natural anomaly mediation (nAMSB). In nAMSB, the wino is still the lightest gaugino, but the Higgsinos are expected to be the lightest electroweakinos in agreement with naturalness. We explored the LHC phenomenology of nAMSB models: for Higgsino-pair production, larger dilepton mass gaps arise from the soft dilepton-plus-jets signature than in models with gaugino-mass unification. For wino-pair production, a larger $m_{3/2}$ portion of nAMSB parameter space is excluded by recent LHC bounds. Nevertheless, the remaining parameter-space region, i.e. $m_{3/2} \simeq 90 - 200$ TeV, can be tested at HL-LHC through electroweakino-pair production [4].

- We extensively worked on the physics of future colliders, aiming at understanding the potential of an e^+e^- Higgs, top or electroweak factory. In fact, in the last update of the European Strategy for Particle Physics an e^+e^- collider serving as a Higgs factory was identified as the highest-priority next collider. The American P5 panel also recommends an off-shore Higgs factory, to improve the studies carried out at the LHC. In particular, we worked on the TwoF code, capable of precisely simulating two-fermion final states at the Z-mass peak and above. The cross section for fermion-pair production at the Z peak will be measured with a $\mathcal{O}(10^{-4})$ relative precision at future electron-positron colliders. To match the experimental precision, in principle, three-loop electroweak corrections, not available at present, would be necessary. Much work has nonetheless been carried out to calculate NNLO electroweak corrections to $e^+e^- \to q\bar{q}$ and, as an intermediate step, NNLO mixed strong-electroweak contributions. Possible deviations from the Standard Model can ultimately be interpreted not only in given BSM scenarios, but even in terms of higher-dimensional operators, i.e. in the Effective Field Theory framework. An interesting observable is expected to be the forward-backward asymmetry with bottom quarks, i.e. A^b_{FB}, since the third fermion family plays a special role in many BSM scenarios [5].

  Besides the work within the study group on electron-positron colliders, we were also members of the ECFA Early-Career Researchers Panel and contributed to the report for 2023 [6].

References

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