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Summary of the “Electroweak and QCD Physics” session

P. Di Nezza([1])(*) and C. Oleari([2])(**)

([1]) *INFN, LNF - via E. Fermi, 40 I-00044 Frascati, Italy*
([2]) *Università di Milano-Bicocca and INFN, Sezione di Milano-Bicocca Piazza della Scienza 3, 20126 Milano, Italy*

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Summary. — Summary of the “Electroweak and QCD Physics” session: theoretical and experimental talks.

PACS 12.38.-t – Quantum chromodynamics.
PACS 12.15.-y – Electroweak interactions.
PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy > 10 GeV).
PACS 13.87.-a – Jets in large-Q^2 scattering.

1. – Theory summary

Giuseppe Bozzi talked about VBFNLO, a fully flexible partonic Monte Carlo program for vector boson fusion, double and triple vector boson production processes at next-to-leading order (NLO) in the strong coupling constant. The simulation of $\mathcal{CP}$-even and $\mathcal{CP}$-odd Higgs boson production in gluon fusion, in association with two jets, is implemented at leading order (for this process, the leading order starts at one-loop level). Future improvements are directed along two main lines of development: further processes at NLO QCD accuracy will be included (*e.g.*, $pp \to WW\gamma$ and $pp \to W\gamma j$) and new features will be added to the already existing processes, such as anomalous triple and quartic gauge boson couplings and Kaluza-Klein excitations. Higgs production via gluon fusion within the generic two-Higgs-doublet model will be extended to a complete simulation within the Minimal Supersymmetric Standard Model, including full dependence on scalar top- and bottom-quark masses. Matching the NLO QCD processes to a parton shower at next-to-leading order accuracy is currently in progress.

Diogo Franzosi presented a study concerning the high-energy behavior of longitudinal vector boson scattering (LVBS). This process, in fact, carries information on the strength of the symmetry breaking (SB) sector. The Standard Model (SM) with a light Higgs boson predicts a suppression of longitudinal boson scattering and a weak-coupled SB sector. Without the Higgs boson, LVBS grows with the scattering energy and must

(*) E-mail: Pasquale.DiNezza@lnf.infn.it
(**) E-mail: carlo.oleari@mib.infn.it

be cut off by new strong dynamics from the SB sector at higher scales, in order not to violate unitarity. The SM without the Higgs (*No Higgs* scenario) represents a benchmark scenario for the study of strong SB dynamics. He presented a recent study on the possibility to discriminate the *No Higgs* scenario from the SM one, through vector boson scattering at the LHC. For this purpose, with his collaborators, he performed a complete partonic analysis, generating full six-parton final states for the following channels: $pp \to 4j\ell\nu$, $pp \to 4j\ell^+\ell^-$ and $pp \to 2j\ell^+\ell^-\ell'\nu$. They developed a strategy to suppress the main backgrounds, aiming at optimizing the discriminatory power in each channel, which was estimated in a precise probabilistic meaning. Furthermore, they generalized this estimate of the discriminatory power to the combination of many channels. As a final result they showed that the LHC has good chances to distinguish the *No Higgs* scenario from the SM.

Massimiliano Grazzini presented a work on the calculation of higher-order corrections to the production of vector bosons in hadron collisions. When the transverse momentum of the vector boson q_T is small, the perturbative series is affected by large logarithmic contributions that spoil the convergence of the standard fixed-order expansion. He presented a calculation at next-to-leading logarithmic (NLL) accuracy which is matched at high q_T to the standard fixed-order expansion at $\mathcal{O}(\alpha_S)$, NLL+LO. The calculation allows a consistent study of perturbative uncertainties. With his collaborators, he compared their results for Z boson production to the Tevatron data and found good agreement. The extension to NNLL+NLO is underway. In addition he discussed a computation of vector boson production up to NNLO in QCD perturbation theory. Higher-order contributions to hard scattering cross-sections are plagued by infrared divergences that affect the intermediate steps of the calculation and prevent the straightforward implementation of numerical techniques. The amplitudes needed to compute NNLO corrections to vector boson production have been known for more than 15 years, when the total cross-section was computed at this order. The first fully exclusive computation at NNLO was completed only in 2006. The calculation he presented is done with a completely independent method and is implemented in a parton level Monte Carlo program that allows the user to apply arbitrary cuts on the final-state leptons and the associated jet activity and to plot the required kinematic distributions in the form of bin histograms. He presented an illustrative selection of their results at the Tevatron and the LHC.

Stefano Nicotri gave a talk on the scalar-meson sector, a widely debated sector of QCD, that he examined through a phenomenological holographic approach, based on the Soft-Wall model of AdS/QCD. The model is based on the AdS/CFT correspondence and consists in representing the strongly coupled Yang-Mills theory through a higher-dimensional semiclassical theory, formulated in a curved space. Two- and three-point correlation functions of the QCD local operator, describing scalar mesons, have been analytically evaluated, and quantitative information on mass spectrum, decay constants and coupling with two pseudoscalar mesons were extracted. The results were compared to the current phenomenological measurements, finding a good agreement. This is interpreted as a confirmation of the fact that the holographic approach is promising for the non-perturbative sector of chromodynamics.

Carlo Oleari presented POWHEG, a novel method, proposed by P. Nason a few years ago, to merge a NLO calculation with a Parton Shower program. As the acronym says, POWHEG (Positive-Weight Hardest Emission Generator) generates (unweighted) events with positive weight, that can be further showered by any LO Monte Carlo program, such as HERWIG and PYTHIA. The generated events merge together the good features of typical NLO calculations (correct high-p_T behavior, milder dependence on renormalization and factorization scales, total cross-section exact at NLO) and of a LO Monte Carlo (correct Sudakov suppression in the low-p_T region, shower correct at leading logarithmic accuracy, hadronization models). Up to now, the available processes at a hadronic collider are: ZZ, $Q\bar{Q}$, W/Z, H, $H+W/Z$, single top and $Z+1$ jet production. In addition he presented the POWHEG-BOX, a completely automatized package that turns any NLO calculation into the POWHEG formalism almost with no effort. The user has only to provide the Born, real and virtual amplitudes, the Born phase space and the list of Born and real subprocesses.

Giovanni Ossola presented the Ossola, Papadopoulos and Pittau (OPP) method to reduce and compute arbitrary one-loop amplitudes, operating at *the integrand level*. In this approach, the coefficients of the different scalar integrals are numerically determined by solving a system of algebraic equations that are obtained by: i) the numerical evaluation of the numerator of the integrand at explicit values of the loop momentum; ii) the knowledge of the most general polynomial structure of the integrand itself. The solution of the system of equations becomes particularly simple if one exploits the set of kinematical equations corresponding to the so-called quadruple, triple and double cuts, used in the unitarity-cut method too. The OPP reduction was developed from the beginning to be suited for automatization. The recent progress in the automated generation of the numerators, or in the generation of dipole terms, is of crucial importance in this direction. It is likely that, in the near future, the combination of HELAC and OPP reduction will lead to a fully automatized tool for the calculation of any process, both in QCD and electroweak theory, without limitations on the masses of internal and external particles. At the same time, it will be important to continue to improve the efficiency and the stability of the method, to reach the same level of reliability of the traditional methods.

Marco Ruggieri gave a talk on one of the challenges in modern theoretical physics: the theoretical investigation on the QCD phase diagram. One of the aspects of the most relevant QCD phase transitions, namely the deconfinement of color and the chiral-symmetry restoration at finite temperature, is that they are smooth crossovers at zero baryon chemical potential. However, the picture might change as the baryon chemical potential, μ, is increased. As a matter of fact, it is commonly accepted that there exists a critical value μ above which the chiral crossover becomes a first-order transition. In QCD, this result was obtained for the first time on the lattice. The existence of a critical end point (CEP) is also observed in simple models like Nambu–Jona-Lasinio (NJL). With his collaborators, he performed a detailed study of the NJL model phase diagram, with a particular emphasis to the search for the CEP. They considered a model with $2+1$ flavors, meaning two light quarks (up and down) and one heavier (the strange quark). This model allows to keep into account the thermodynamics of the chiral condensates and of the Polyakov loop as well, which are usually referred to as pseudo-order parameters for chiral-symmetry restoration and confinement-deconfinement transition. They results are summarized in fig. 1, where they have neglected the vector interaction and considered only the scalar and pseudoscalar interactions together with the t'Hooft term. Their picture is in agreement with the latest lattice results, namely, a CEP is absent at relatively small values of the baryon chemical potential.

Francesco Tramontano presented a new next-to-leading order calculation for single-top production at hadron colliders. The approach is novel in the fact that the calculation has been performed starting from the $2 \to 3$ Born process, $qg \to q'tb$, keeping the b-quark massive. They compared the results for the total cross-section with the one

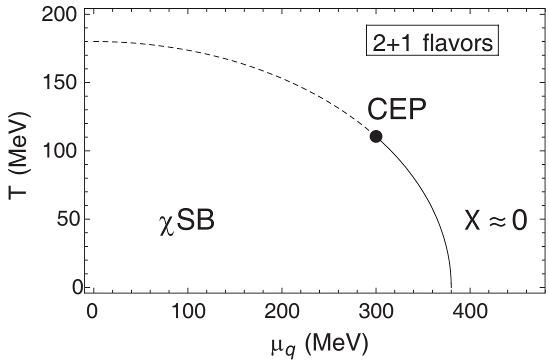

Fig. 1. – Sketch of the phase diagram of the PNJL model with 2+1 massive flavors. Here μ_q denotes the quark chemical potential, $\mu_q = 3\mu$, where μ corresponds to the baryon chemical potential. The dashed line denotes the chiral crossover; the solid line corresponds to a first-order transition. The region denoted symbolically by χ_{SB} denotes the zone of the phase diagram with quark condensate different from zero. In the region $\chi \approx 0$, one has $\langle \bar{u}u \rangle \approx 0$ but $\langle \bar{s}s \neq 0 \rangle$.

obtained with the standard approach, based on the b-parton distribution function (pdf) and found that the two calculations are compatible both at the Tevatron and at the LHC, showing that the effect of the resummation is small. This new calculation allows for a genuine NLO determination of the p_T spectrum of the spectator b. Furthermore, in fig. 2, he presented an estimation of the acceptance for the spectator b in single-top events, as a function of the factorization scale. The dependence of the $2 \to 3$ calculation, being the ratio of two genuine NLO quantities, turns out to be milder with respect to the standard prediction obtained with the b-pdf approach.

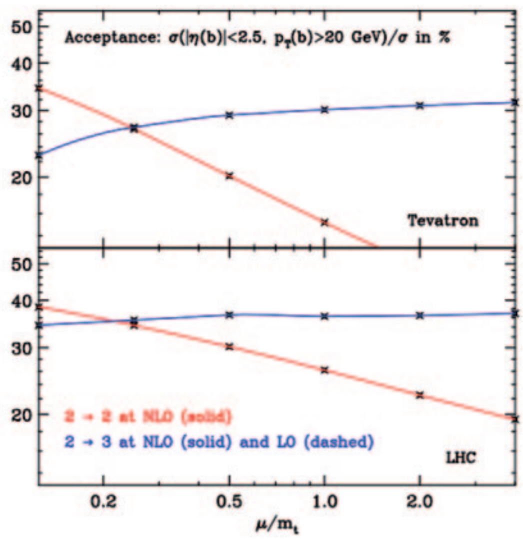

Fig. 2. – Signal acceptance for the second b quark with $|\eta| < 2.5$ and $p_T > 20\,\text{GeV}$ at the Tevatron, as a function of the factorization scale.

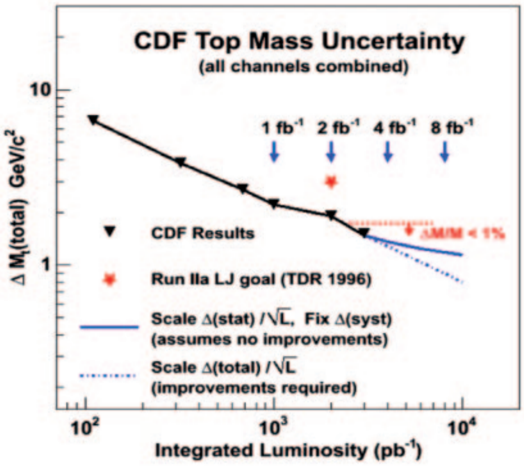

Fig. 3. – Future projection on CDF top mass measurement precision.

2. – Experiment summary

Maria D'Errico, on behalf of the CDF experiment, presented the single top quark production, one of the most important topics in the top physics at Fermilab. The expected cross-section for the electroweak production of single top quarks is $\sigma_{st} \sim 2.9\,\text{pb}$, much smaller than those of competitive background processes. Therefore, multivariate techniques have been developed to improve the discrimination between signal and background. CDF has observed this process with a combined single top s- and t-channel cross-section of $\sigma_{ts} = 2.3^{+0.6}_{-0.5}\,\text{pb}$. The observed signal has a significance of 5.0σ, which is sufficient for observation. The latest top mass measurements at CDF use a data sample with an integrated luminosity of up to $3.2\,\text{fb}^{-1}$, reaching a top mass knowledge with 0.8% of precision has been also presented. Combining results from Run-I (1992-1996) with the most recent Run-II (2001-present) measurements the CDF average mass of top quark is: $m_t = 172.6 \pm 0.9(\text{stat.})\ \pm 1.2\ (\text{syst.})\ \text{GeV}/c^2$. Projection about how precisely CDF can measure the top quark mass as a function of integrated luminosity upholds a precision below 1%, fig. 3.

Michele Pinamonti talked about the top-pair production cross-section, one of the first future observations at the ATLAS experiment. The relevance of this measure is manifold: it will allow to perform a direct comparison with a theoretical calculation, but it also will be a useful background measurement for many new physics phenomena, and, even more important from the experimental point of view, it will surely be useful to test and calibrate the whole detector, as the measurement method involves most of its parts to reconstruct electrons, muons, jets and missing energy. As the all-hadronic decay channel will be hard to trigger and reconstruct, the two main measurement channels are expected to be the one- and two-leptons ones, *i.e.* with one or two of the Ws coming from the tops decay going into an electron- or muon-neutrino pair. Using Monte Carlo samples, a number of selections have been studied to separate the chosen signal events from the background ones, both using and without using the b-tagging information. On the selected data samples, different measurement methods have been developed, including simple counting experiments and more sophisticated likelihood fits. For each method in each channel, the main systematics have been studied resulting in an expected total uncertainty of about 20% with $100\,\text{pb}^{-1}$ of 14 TeV pp collision data.

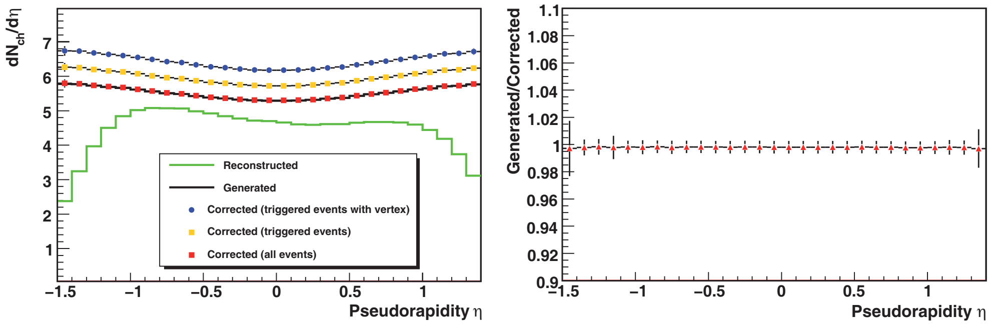

Fig. 4. – Pseudorapidity density distributions at different correction stages (left) and final ratio between the fully corrected and the Monte Carlo distributions (right).

Two important measurements from the ALICE Collaboration were presented. The first, described by Maria Nicassio, is the charged-particle pseudorapidity density distribution with the silicon pixels. This is the first measurement that will be carried out with the ALICE detector, both in *pp* and in PbPb collisions. The reconstruction of the $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distribution in the central η region can also be performed using only data provided by the two innermost layers of the inner tracking system, namely the Silicon Pixel Detector (SPD). Compared to the same measurement based on the fully reconstructed tracks, the $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ reconstructed with only the pixels has some basic advantages (larger acceptance coverage both in pseudorapidity and transverse momentum and much smaller reliance on alignment and calibration procedures) that would allow to extract results from the very first available data. The algorithm associates pairs of clusters in the two SPD layers ("tracklet") if they are aligned with the reconstructed primary vertex within fiducial windows. Several effects have to be taken into account in order to reconstruct the physical distribution from the measured one, both at tracklet and event level. These effects and the corresponding corrections have been studied and computed using dedicated Monte Carlo productions. The fully corrected distribution reproduces very well the generated Monte Carlo one and the overall systematic uncertainty has been estimated to be at a few per cent level, fig. 4. The other ALICE measurement was reported by Francesco Noferini. This was an example of first physics results in *pp* collisions concerning identified hadron spectra and ϕ resonance production using the TOF capabilities. Through a Monte Carlo simulation of the full detector response in *pp* collisions at 10 TeV it is shown how the ALICE Time Of Flight will be ready to contribute to the Collaboration physics program with a limited statistics, corresponding to some days of data acquisition, and with the current 130 ps TOF time resolution, calibrated with cosmic rays. Therefore the identified hadron spectra up to 2–3 GeV/c and the ϕ resonance can be measured at the startup of the LHC with good accuracy as can be seen in fig. 5.

Measurements about the production and decay of W and Z bosons in ATLAS and CMS were presented by Andrea Di Simone and Martina Malberti. Di Simone talked about this measurement as a way to access the performance of the detector, by means of data-driven techniques such as the tag and probe method. The event selections exploit the tracking and identification potential of the experiment, and will allow to select high-purity samples muonic decays of both W and Z bosons. The analyses of the electronic decays, on the other hand, suffer from uncertainties in the backgrounds (mainly the QCD jet) and will have to extensively use data itself to estimate the residual background contamination. The sistematic errors connected to the cross-section measurements of

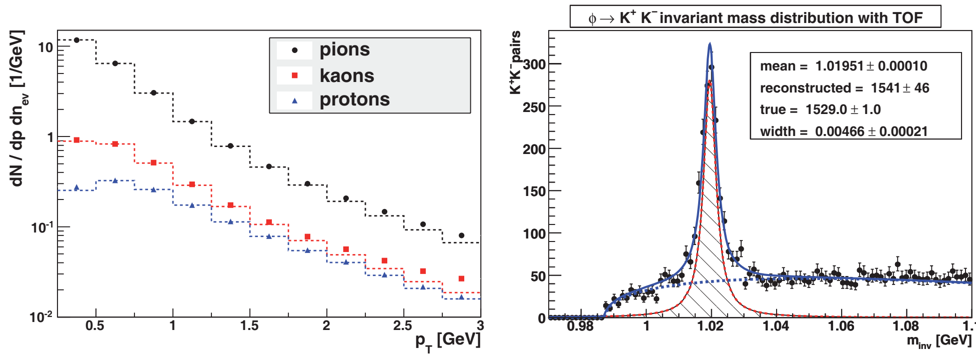

Fig. 5. – Hadron spectra reconstructed with the TOF current resolution, on the left. ϕ reconstructed invariant mass is shown for 1.8 M *pp* events generated with PYTHIA6, on the right.

the different channels must be carefully estimated, in order to provide reliable results. Indeed, even at the relatively low integrated luminosity of $50\,\mathrm{pb}^{-1}$, the statistical error is negligible when compared to the systematic one, which comes mainly from background uncertainties (in particular in the W decay channels) and reconstruction efficiency (in particular for Z decays). Another source of systematics is the acceptance, as computed using Monte Carlo generators. The different effects contributing to this error have been studied in detail, and the main one was found to be the PDF uncertainties. With increasing statistics, on the other hand, all the systematic contributions get smaller, and the dominant one remains the error on acceptance (*i.e.* mainly, the PDF uncertainties). Malberti reported about the importance and understanding of these processes that will be very important for all the LHC physics program. She discussed the ATLAS and CMS detectors potential for an early measurement of W and Z inclusive cross-sections and lepton asymmetries, the prospects for the precision measurement of the W boson mass and for the study of di-bosons production processes.

Another way to access measurement on W and Z bosons is when there are associated jets, as showed by Emanuele Di Marco for the CMS detector in the first LHC *pp* collisions at $\sqrt{s} = 10\,\mathrm{TeV}$.

Standard Model Higgs searches at CDF was presented by Michele Giunta. Fermilab Experiments CDF and D0 excluded in March, 2009 the existence of a Standard Model Higgs boson having a mass in the [160; 170] GeV/c^2 range at 95% CL. He resumed the analysis channels and techniques used by CDF to reach this result.

LHCb is a dedicated experiment for the study of b-hadrons, exploiting the copious production of beauty mesons and baryons in proton-proton collisions at the CERN LHC, as was showed by Francesco Dettori. The LHCb detector was already able to take data in September 2008 and now is being commissioned for the new LHC start-up in September 2009. Good use has been made of the cosmic rays data, despite the detector orientation, for time and space alignment and for the study of the detectors performances. Beam-induced events helped in tuning the small detectors. Improvements in each subdetector are being performed; moreover the last of the muon stations is being installed. Full experiment system tests, with Monte Carlo data injected in the processing framework, have shown the readiness of LHCb from data taking to data processing. Commissioning of LHCb will continue looking forward to the physics data taking run in 2009.

Maria Margherita Obertino presented the rich program of forward physics, including very low-x QCD dynamics, diffraction in the presence of a hard scale and photon-mediated processes, as studied by the CMS Collaboration by exploiting the forward

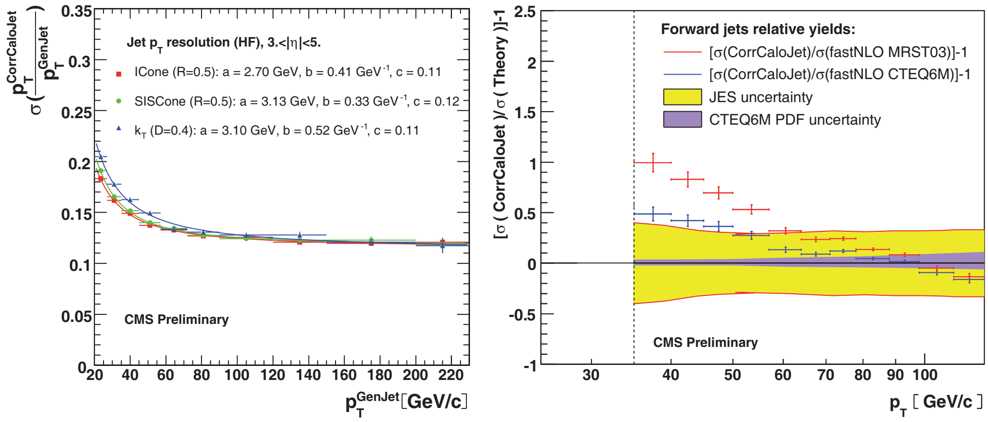

Fig. 6. – Left: p_T resolution *vs.* p_T in HF for different jet algorithms. Right: percentage differences between the reconstructed forward jet p_T spectrum and the fastNLO predictions for two PDFs. The error bars include the statistical and the energy resolution smearing error.

detector instrumentation around the interaction point. The partonic structure of the proton and the QCD part on evolution dynamics can be investigated in a Q^2-x region not covered by previous experiments by means of forward jet measurements. Diffractive pp reactions, characterized by the fact that at least one of the incoming protons emerges from the interaction intact with an energy loss within a few percent, can be considered an additional tool to study the structure of the proton under the condition that it does not dissociate in the collision. These processes are predominantly soft but can also occur in the presence of a hard scale, as observed at UA8, HERA and the Tevatron. CMS has detailed, quantitative plans to re-discover hard diffraction at LHC with the first 10–100 pb^{-1} collected, fig. 6. Three feasibility studies have been performed concerning single diffractive dijet and W production, as well as exclusive Υ photoproduction. Among the $\gamma\gamma$ processes exclusive dilepton production is particularly interesting because it allows an absolute luminosity measurement with a 4% precision with 100 pb^{-1} of data.

A different and very rich field of physics was touched by Tiziana Capussela. The KLOE experiment has successfully completed its data taking in March 2006 and it has collected an integrated luminosity of about 2.5 fb^{-1} and 250 fb^{-1}, on and off the ϕ meson peak, respectively. The KLOE dataset together with a precise simulation of the detector response and of a large number of several processes—ϕ meson and continuum $\mathrm{e}^+\mathrm{e}^-$ annihilations—allowed for an extensive study of hadron physics. In particular it was shown the most precise BR($\eta \to \pi^+\pi^-e^+e^-$) determination and the first measurement of the asymmetry between $\pi^+\pi^-$ and e^+e^- planes, found compatible with zero. The evidence of valence gluons in the η' wave function to three standard deviations. The good agreement between two $\eta\pi^0\gamma$ analyses with different systematics, where the combined fit of the two spectra points to a sizable strange quark content in the $a_0(980)$. The upper limit in the BR($\phi \to K\bar{K}$) at 90% CL with the whole KLOE statistics. Then the new precise measurement of the pion form factor and determination of $\pi\pi$ contribution to $a_\mu^{\pi\pi}$ in the interval $0.592 < M_{\pi\pi} < 0.975$ GeV, based on an integrated luminosity of 240 pb^{-1}. The result confirms the previous measurement and it is in agreement with SND and CMD-2 values.

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