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Experimental Summary of HSQCD2005 *

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DESY

A summary of experimental contributions to HSQCD 2005 is given. This includes results from the four HERA experiments H1, ZEUS, HERMES and HERA-B, as well as results from the Tevatron (D0), the CERN hyperon beam (WA98), from RHIC (PHENIX), and IHEP (SVD). I present a short survey of the points appearing most relevant to me.

1 Introduction

This summary is the write-up of a quick and spontaneous tour through the experimental results presented at the conference [1], rather than a deep discussion of the experimental situation of QCD in general.

Among the accelerators, which presently provide results, HERA concentrates most on topics related to QCD, which is at the heart of interests of the HSQCD organisers at Gatchina. And, in spiritu loci, many analyses presented at this conference consider the limitations of DGLAP evolution, ask whether BFKL evolution might be more appropriate. But there is progress in many other respects as well, e.g. parton density analyses get more precise and more general, similarly, the data on charm and beauty production in ep interactions improve rapidly, the spin structure of the proton is studied in more and more detail, RHIC continues to provide interesting results on hadronic high density states. Although not all experiments, which produce relevant results in context of QCD were represented, a wide spectrum of interesting results was displayed.

QCD is generally discussed in the frame of the standard model. I will therefore begin with searches for physics beyond it.

*presented at HSQCD2005, 20 - 24th September, St. Petersburg.

[1] In fact the speaker was found by tossing a coin by Leonid Gladilin and myself during a coffee break.

2 Searches Beyond the Standard Model

D. South [1] reported on searches at HERA for physics beyond the standard model (SM) which was not really shaken yet, although in e^+p the H1 collaboration observes more events than expected with isolated leptons and large missing transverse momentum and large p_t^X (> 25 GeV), the transverse momentum of the summed hadronic final state. However in this kinematic range the statistics is still rather small, with 15 events with isolated electrons or muons for a SM expectation of 4.6 ± 0.8 events. This excess is not confirmed by the ZEUS collaboration and is not observed in e^-p data.

It is certainly very important to take as much data as possible, but it might be difficult to get full clarity in the remaining HERA running time. The same is true for the multi-lepton final states, where 6 multi-electron states with a di-electron invariant mass above 100 GeV were recorded by H1, 3 ee events and 3 eee events with SM expectations of 0.44 ± 0.10 and 0.29 ± 0.06 events, respectively.

3 Inclusive ep scattering

With increasing statistics, HERA enters a phase of mature electro-weak physics analyses. The available NC and CC data give the opportunity to demonstrate nicely the unification of electro-weak physics (see [2]). The absence of right handed weak currents could be demonstrated by the the dependence of the CC cross section on the polarisation of the incident $e^\pm$ beam (see Figs. in [2]). The propagator mass in CC reactions is measured with a precision of about 2 GeV and found to be consistent with the time like W mass determined in e^+e^- and $\bar{p}p$. Finally, first results are presented for light quark-Z^0 couplings [3] which supplement the LEP and Tevatron measurements.

Since its beginning, HERA is the world supplier for information on the proton structure at low x. After the discovery of the rise of F_2 towards small x [4], this rise is described with continuously increasing precision in terms of parton density functions (pdfs) (see [5]). Now the HERA collaborations provide pQCD analyses of their NC and CC data with the aim to include as little other data as possible, thereby avoiding additional systematic uncertainties. In particular, due to the sensitivity of the CC reaction $e^+p \to \bar{\nu}X$ to the valence d quark distribution, pdf fits without inclusion of ed scattering data are possible, thereby avoiding nuclear corrections. The ZEUS collaboration provided also a pdf fit [6] using jet data, in addition to the inclusive data, thereby exploiting their sensitivity to the gluon density via the boson-gluon fusion interaction. The pdf

fits recently provided by the HERA collaborations are consistent with the results of the global fitters [7].

Still increasing precision can be expected at small x from the final analysis of the full HERA I data including results at large y which are sensitive to the longitudinal structure function F_L and therefore to the gluon density. In addition new techniques are explored to improve the NC measurements at very high x [5]. Thus, further progress in the determination of parton densities can be expected in future.

4 Jets

Complementary to inclusive ep scattering (previous section), the convolution of proton pdfs with the hard interaction processes can be studied in detail by the observation of jets in deep inelastic scattering (DIS) and photoproduction [8]. The high precision HERA data at large Q^2 and large transverse momenta provide, besides detailed comparisons with pQCD calculations, results on the strong coupling constant α_s which turn out to be consistent and competitive with results from inclusive ep or e^+e^- data. As mentioned already above, the inclusion of γp and DIS jet data in pdf fits improves the determination of the gluon density in the proton at medium and large x, where the inclusive NC data have only little sensitivity. In most of the phase space, the experimental uncertainties of the available jet data are smaller than the theoretical ones.

Extra complications appear in the theoretical description of dijet production in DIS at low Q^2 and large E_T^2. Here a resolved virtual photon contribution is expected, where a partonic fraction of the virtual photon enters the hard interaction. This is supported by the data which are not described in this region by NLO calculations with only direct photon interactions.

Such a resolved component improves also the description of "forward jet" data [9]. By requiring $E_T^{jet} \sim Q^2$ and jet angles as close to the proton beam as possible with the H1 and ZEUS calorimeters, a phase space is selected, where the data might discriminate the calculations based on DGLAP evolution or CCFM or BFKL evolutions. Less jet production is obtained in the k_t ordered DGLAP evolution than in unordered emissions like in the CDM model, which might be close to BFKL expectations, or the CCFM approach (angular ordering). Indeed, the DGLAP based models produce too small cross sections at small $x_{Bjorken}$ compared to the measurements of H1 and ZEUS. However the best descriptions are obtained in conceptually quite different models like CDM with unordered emissions, and the DGLAP based RAPGAP model, where the strict k_t ordering

is broken by a resolved photon component. Interesting to note that for a more special event selection, requiring besides the forward jet two additional central jets, the resolved RAPGAP model also fails, in contrast to CDM [10].

Impressive data on inclusive single jet production in $p\bar{p}$ were presented by the D0 collaboration [11]. The p_t distributions agree beautifully with pQCD in NLO. Angular correlations demonstrate very well that there is no need for higher orders. However the large effect of the experimental uncertainty of the jet energy scale on the cross section measurement allows no conclusions on pdfs to be drawn.

5 Inclusive Diffraction

The observation of diffractive phenomena in DIS at HERA gives hope to reach, in terms of QCD, full understanding of the Regge exchange processes, which dominate the strong interactions processes at high energies.

So far, the efforts to describe the colour singlet exchange in diffractive interactions by pdfs are partially successful, as diffractive inclusive data, diffractive jet production and diffractive charm production can indeed be described in a common approach [12]. These pdfs, however, can not be naively applied to diffractive $p\bar{p}$ data, not even to diffractive photoproduction of jets. In the latter case, the predictions, which are based on the pdfs deduced from inclusive diffraction, are above the data by about a factor two. This may indicate that in photoproduction, as in $p\bar{p}$ interactions, the gap signature of the diffractive interaction is more often destroyed than in DIS by additional parton-parton interactions. More results are expected from HERA and the hadron colliders which may help to describe diffractive phenomena coherently.

6 Vector Mesons and DVCS

New results were presented on J/ψ photo- and electro production at low t, on J/ψ production in DIS at high t, as well as high t ρ^0 photoproduction, and on ϕ production in DIS [13].

Photo and electro-production of vector mesons (VM) is an interesting testing ground for QCD due to the interplay of soft processes described by Regge theory and hard interactions described by pQCD. For the latter different hard scales may be involved, Q^2, the VM mass, the momentum transfer t. The presented results show that whenever hard scales are involved, the data can not be described by soft pomeron exchange. Vector

mesons are particularly suited for detailed QCD calculations as the measured decay angular distributions provide information on the helicity structure of the interaction. Such an analysis was presented for $\gamma p \to \rho p$ at high t [13].

J/ψ production in 920 GeV proton-carbon interactions where presented by the HERA-B collaboration which extend the available $x_{Feynman}$ distributions far into the target region [14] (see also the discussion [15]).

Results on Deeply Virtual Compton Scattering (DVCS, $ep \to \gamma p$) were presented by the HERMES [16], H1 and ZEUS collaborations [13]. The reaction $ep \to \gamma p$, which, in contrast to VM production, does not require knowledge of a non-perturbative wave function, gives in principle access to generalised non collinear parton densities. HERMES obtains DVCS amplitudes by measuring asymmetries due to the interference of Bethe Heitler (BH) γ emissions from electrons with the DVCS process. There are already first results on e-beam-spin and on beam-charge asymmetries and on longitudinal and transverse target spin asymmetries, both on p and d targets. More data are expected with improved control of the elasticity of the final state with the new Recoil Detector of HERMES.

H1 and ZEUS have not yet exploited the BH-DVCS interference, which vanishes when integrated over the phase space of the measurements, but provide DVCS cross section measurements which are described by NLO pQCD calculations and various colour dipole models. The measured energy dependence of the cross section is characteristic of processes where a hard scale is involved. Precise measurements of the t dependence allow the theoretical predictions to be normalised. It remains to hope that the future data will distinguish better between the different theoretical approaches.

7 Charm and Beauty Production

Heavy flavour production in electro and photoproduction is expected to be well described by pQCD due to the large scale given by the heavy quark mass. It was therefore surprising, that in spite of this advantage, beauty (b) production cross sections were notoriously above the pQCD NLO predictions [17]. This is still the case, but it is interesting to note that the available more inclusive measurements with large acceptance, which use b identification by life time tags, are consistent with the predictions.

The contributions of charm and beauty to the inclusive proton structure function F_2 are substantial, about 20% to 30% for charm and about 0.3% to 3% for beauty, in the covered kinematic region [5, 17].

Fragmentation properties of c quarks were studied by H1 in DIS and with more statistics in γp by ZEUS [18]. By and large, the findings are consistent with e^+e^- results, supporting "universality" of c quark fragmentation.

Results on hadroproduction of open beauty near threshold were presented by HERA-B [14] which are reasonably consistent with Fermilab data and pQCD calculations which include NNLO soft gluon corrections [19].

8 Spin Physics

8.1 HERMES results

The HERMES experiment [16] produces a wealth of results on the many measurable effects of the proton spin in electron nucleon scattering when besides the scattered electron one hadron is detected. In particular the effects of the nucleon spin polarisation transverse to the electron beam direction ("transversity") lead to sophisticated analyses which distinguish between the effect of the quark polarisation on the p_t transverse to it in fragmentation (Collins effect), and the effect of the struck quarks p_t in the polarised nucleon on the p_t in fragmentation (Sivers effect), which gives access to the quark angular momentum.

For π^- the Collins moments are negative but larger in absolute than expected. The Sivers moments show a striking difference between π^+ and π^-, the latter being consistent with zero, the first definitely positive which points to the valence u content of the π^+.

The expected future data and further theoretical analyses might eventually lead to a clear understanding of the proton spin[2].

8.2 Hyperon polarisation

Many results exist on the polarisation of hyperons produced in hadron beams, without clear theoretical understanding [20]. In particular, the results obtained by WA98 in the 340 GeV Σ^- beam on the polarisation of inclusively produced Λ and Σ^- baryons originally came as a surprise with a large unexpected positive polarisation of the Λ 's (normal to the production plane). Meanwhile explanations exist in terms of recombination of a quark with a strange di-quark [21]. However no coherent theoretical approach to the observed detailed polarisation phenomena exists yet. "Food for theorists!" (W.H. Siebert [20])

[2] The HERMES results on DVCS are mentioned in section 6.

9 Elliptic Flow in Nucleus-Nucleus Collisions

RHIC data show a strong azimuthal anisotropy of the particle flow in Au Au collisions at $\sqrt{s_{NN}} = 200$ GeV [22]. The particle flow is increased in the direction transverse to the reaction plane. It is understood to be sensitive to the initial geometric overlap of the colliding nuclei as well as the later expansion driven by the initial pressure. The effect is seen for all final state hadrons and the results suggest [22] early formation of the anisotropy in a still partonic phase.

To clarify the mechanism, it is particularly interesting to measure the energy flow for direct photons. As not strongly interacting, direct photons penetrate through hadronic clouds and are known to be not suppressed in heavy ion collisions [23] in contrast to hadrons. With present statistics the data on prompt photons are not yet conclusive [24].

10 Pentaquarks

A new result of a pentaquark search was reported [25] from the SVD-2 detector using the 70 GeV proton beam at IHEP. In the reaction $pA \to pK_s^0 + X$ a bump is seen at the pK_s^0 mass $M = 1526 \pm 2(\text{stat.}) \pm 3$ (syst.) MeV with a width $\Gamma < 24$ MeV, which can be interpreted as the signal of $uudd\bar{s}$ pentaquark Θ^+. The estimated significance is 5.6 σ.

The many negative and positive evidences for pentaquarks were discussed in a review by V. Popov [26]. L. Gladilin [18] reported on the results from HERA which are not yet clear, with ZEUS seeing a Θ^+ signal in contrast to H1 and H1 seeing a candidate for a charmed pentaquark Θ_c at a mass of 3100 GeV which is not confirmed by ZEUS and other experiments. Negative results were reported for $\Xi^{--}_{3/2}$ [18, 20].

Also other non standard hadronic states were discussed, namely possible tensor glue balls with masses around 2000 MeV [27]

The great time of rapid pentaquark discoveries seems to be over, but there are still many interesting signals which need final confirmation or other explanations.

11 FAIR, a forthcoming facility for QCD physics

The approved **F**acility for **A**ntiproton and **I**on **R**esearch (FAIR) at GSI, Darmstadt (Germany) is expected to provide in 2013 very intensive beams (e.g. primary beams of $10^{10}/s$ $^{238}\text{U}^{73+}$ up to 35 GeV/u and $3 \times 10^{13}/s$ protons of 30 GeV) [28]. Besides various radioactive secondary beams, a $\bar{p}$ beam will be available for the planned experiment PANDA which foresees a rich program on hadron spectroscopy, in particular for searches

of glue balls or exotic hadrons and detailed studies of charmonia and production of open charm. It is seen as an advantage of $p\bar{p}$ compared to e^+e^- interactions that the formation of states is not restricted to the virtual photon quantum numbers 1^{--}.

Thus, FAIR will be after 2013 an interesting facility for hadron physics in the low and medium energy range.

12 Conclusion

There is still intensive experimental activity addressing QCD related questions.
HERA, the Tevatron, RHIC will provide important information before the LHC will produce results.
We experimentalists have not yet presented results which need BFKL beyond any doubt, however some final state analyses prefer non k_t ordered gluon emissions.
At next HSQCD we will know considerably more.

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