MESON 2000 CONFERENCE SUMMARY *lite**

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This short contribution is a *lite* MESON2000 conference summary. As appropriate for the 600th anniversary of the Jagellonian University, it begins with a brief summary of the last 600 years of European history and its place in hadron physics. Next a "physicist chirality" order parameter $\mathcal{PC}$ is introduced. When applied to MESON2000 plenary speakers this order parameter illustrates the separation of hadron physicists into disjoint communities. The individual plenary talks in MESON2000 are next sorted according to the subconference associated with each of the 36 plenary speakers. Finally, I conclude with a previously unreported Feynman story regarding the use of models in hadron physics.

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1. Hadrons and the last 600 years of European history

I was very happy to accept an invitation from H. Machner to give the summary talk for MESON 2000. However I was quickly surprised and somewhat dismayed by many of the plenary talks, which discussed meson physics from viewpoints with which I was only vaguely familiar. A second theme of this meeting, beginning with Prof. Jarczyk's welcoming talk, was the 600th anniversary of the refounding of the Jagellonian University, and its place in Polish and European history. Late one night, while puzzling over how to reduce this rather broad meeting to a few remarks, the random thought

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occurred to me that it would be easier to summarize the last 600 years of European history than to summarize this conference. And, like many wild ideas, this one would not go away. So, please bear with me through Fig. 1.

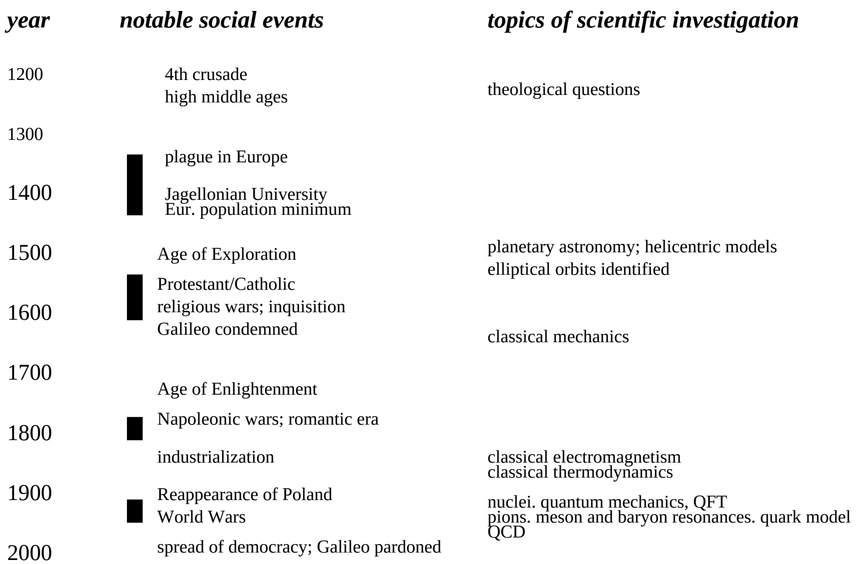

Fig. 1. Hadrons and the last 600 years of European history.

One can learn several interesting things from Fig. 1. The first is that, in physics at least, we have made considerable progress. At the beginning of this timeline scholars were mainly concerned with theological considerations that were not amenable to experimental confirmation. With the reestablishment of European universities and recovery of classical texts, physicists again turned to the study of astronomy, which led to a precise formulation of classical mechanics in the 17th century. The copy of *De Revolutionibus Orbium Coelestium* (Copernicus) which many of us have seen here in Cracow is a stirring reminder of the work of our antecedents in this field. To my mind European culture peaked in the 18th century Age of Enlightenment, both in the development of scientific attitudes and socially, in fields as disparate as government (Jefferson), history (Gibbon), literature (Goethe) and music (Mozart). With the emergence of the romantic movement in the 19th century, a general decline was evident; theories of government became more radical, nationalism became fashionable in Europe, and music and literature increasingly reflected the social problems of the age. To quote Wittgenstein regarding music, as early as Brahms 'I can begin to hear the sound of machinery.' [1]. Physics nonetheless continued dramatic advances, due in part to developments in this machinery and in mathematics, and the 19th century saw major achievements in the establishment of the theories of electromagnetism and classical thermodynamics. Finally, in the 20th century Europe entered very troubled times indeed, from which we are only now emerging. One should note that good things can arise even in times of adversity, such as the reappearance of an independent Poland in 1919. Physics also went through crises at the beginning of the 20th century, but we must all agree that the resulting quantum physics and relativity are two of the most exciting and fascinating developments in the field.

Against this 600 year historical background the development of hadron physics has been strikingly rapid. The identification of the compact atomic nucleus, the home of most terrestrial hadrons, was due to Rutherford in 1911. The identification of the positively charged proton, the first known hadron, can also be dated to about 1911. The first meson to be identified was the pion, found by Lattes *et al.* in 1947 (in cosmic rays), and it had been anticipated by Yukawa as the carrier of the strong nuclear force. The familiar light mesons K, ρ, ω *etc.* were found in the late 1950s to early 1960s, and the identification of these and the light baryons suggested the quark model to Zweig, Gell–Mann and Ne'emann in about 1963. The identification of QCD as the theory of the strong interaction, in 1973, was due mainly to its property of asymptotic freedom, which had been observed at SLAC in the late 1960s. The crucial confining property of QCD was at the time regarded as an unproven conjecture, and is still poorly understood. The mid to late 1970s saw the experimental establishment of the charm and beauty families of hadrons, the first searches for glueballs, and the development of new theoretical techniques such as LGT. The remarkable QCD predictions of glueballs and exotic mesons have taken longer to test experimentally, and the more widely accepted experimental candidates for these states were identified in the middle 1990s. This short time scale is most reassuring; in Fig. 1 we can see that almost all the progress in strong interaction physics has been made in the last 10% of the timeline, and the study of QCD itself occupies only the final 5%.

And finally, as if to close the circle, at the end of the millennium many theoreticians have again turned to theological speculations which are not amenable to experimental confirmation.

2. The many phases of the meson community

After the first few plenary talks I was confirmed in my suspicion that hadron physics, even meson physics, is a very broad field with clearly identifiable communities that have little overlap. Since much of the work in contributing to a new field involves learning the field's terminology or "jargon", one can identify the different communities by the rate of recurrence of characteristic words or expressions in research papers or presentations at conferences.

Two obvious communities in nonperturbative QCD are the effective Lagrangian/chiral symmetry specialists (to whom the pion is the most interesting meson) and the hadron spectroscopists (to whom it is not). As a test of the idea of separating these groups by their use of language, I invented an order parameter which I call "physicist chirality" ($\mathcal{PC}$) to distinguish them. $\mathcal{PC}$ is defined by the number of times a plenary speaker used the word "chiral" compared to the exotica words "glueball", "hybrid" or "exotic",

$$\mathcal{PC} = \frac{N_{\rm chiral} - N_{\rm exotica}}{N_{\rm chiral} + N_{\rm exotica}} \,. \tag{1}$$

This quantity is -1 for a purely exotic physicist and $+1$ for a purely chiral physicist. I had expected to find an interesting distribution of $\mathcal{PC}$ in this meeting, so I applied it to the first 18 plenary speakers. The result, shown in Fig. 2, is rather disturbing. One sees clear evidence of "phase separation" in the presence of two almost completely disjoint communities in meson physics!

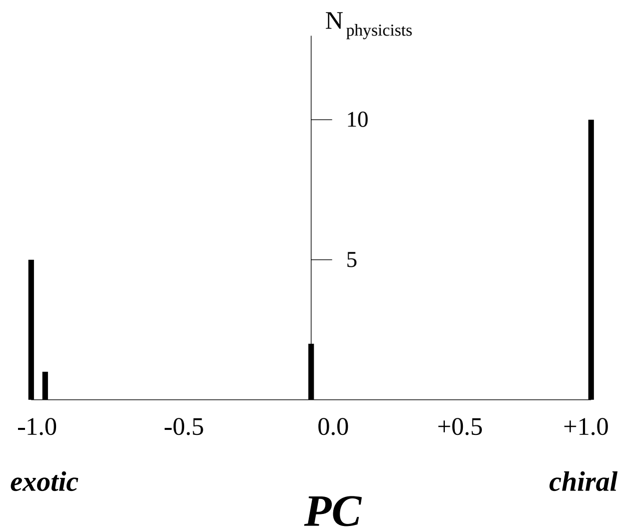

Fig. 2. Phase separation in the hadron physics community.

For those who are keeping score, the two extreme cases on an absolute scale were W. Weise (39 uses of chiral) and A. Szczepaniak (over 29 uses of exotic). There were also 0/0 scores (recorded at 0), which suggested additional phases; eventually I identified five subconferences at MESON 2000, which are summarized in the following section.

3. The index of plenary speakers and their conferences

3.1. The condensed matter hadron conference

This subdiscipline of meson physics considers the pion to be the most interesting of mesons because it is the lowest-lying excitation, in condensed matter jargon the "gap mode". In this field one discusses hadrons in terms of the $\langle q\bar{q}\rangle$ "order parameter", writes effective Lagrangians for pions and nucleons, and derives the resulting low-energy scattering amplitudes and in-medium properties. Apparently part of the game is to borrow as much of the condensed matter viewpoint and jargon as possible, and use it in a hadronic context. (I am not being entirely frivolous about what appears to me to be an exercise in borrowing jargon, since I actually work in condensed matter physics [2].)

Our first plenary speakers Weise, Thomas and (rather surprisingly for an impartial experimentalist) Nefkens identified themselves as belonging to this community through their frequent references to chiral symmetry and order parameters. Mosel, Senger, Grioni, Cassing and Oset also participated in this subconference, which was largely concerned with prospects for seeing mass shifts *e.g.* of kaons, nucleons and vector mesons in medium, and in-medium corrections to other processes, such as $\pi\pi$ scattering. In these talks one could often hear loan words from condensed matter, extending in extreme cases to "spectral functions" and even "good quasiparticle", which is a rather imprecise notion even in quantum magnetism.

Throughout I confess to having a feeling that we need one very clear, unambiguous experimental observation of a hadronic in-medium mass shift in a relatively narrow state, such as the ω, before this work on mass shifts can be regarded as supported by experiment; the inclusive distribution of dilepton mass pairs, composed of many hypothetical broad contributions, seems less than convincing. Cassing noted in particular that there are several interesting prospects for observing ω mass shifts.

Experiment has not contributed much to this field "in-vacuum" recently, largely because the favored topics of low energy $\pi\pi$ and πN scattering were studied long ago, *albeit* not with especially good statistics in $\pi\pi$. At this meeting however we heard plans for two new relevant measurements. One is a determination of the a_2–a_0 $\pi\pi$ scattering length difference using $\pi^+\pi^-$ atoms, discussed by Gianotti. There are dispersion relations known as the Roy equations that purportedly constrain these quantities accurately, so this will be a useful measurement. The second (at DAPHNE, discussed here by Lauss) is a measurement of $\bar{K}N$ a_0 and a_1 scattering lengths, similarly using radiative transitions in the hadronic atom.

3.2. The good auld hadrons conference

This second subconference was concerned with "good auld hadrons", by which I mean low energy reactions and the spectroscopy of reasonably well established quark model states. There was a large experimental component from the various few-GeV facilities that are studying these processes. Meson production near threshold, especially as accessible at COSY, was discussed by Speth. The interesting topics here are the various possible mechanisms for π and η production and the recurring question of the physical size of the qqq "quark core" in a baryon. Haberzettl gave a clear review of the complications of electroproduction amplitudes, in particular in the production of associated strangeness at CEBAF. Filippi told us about OZI violation in $P\bar{P}$ annihilation, especially in the final state $\phi\pi$, and discussed ways of distinguishing between intrinsic strangeness and rescattering effects such as $K^*\bar{K} \to \phi\pi$. Moskal discussed $PP \to PPf$ at COSY-11, where $f = \pi, \eta, \eta'$ and K^+K^-, and noted the importance of ISI and the possibility of measuring the $P\eta'$ scattering length. Salabura discussed $PP \to PPf$ at DISTO, where one can also study $f = \rho, \omega, \phi$. He noted that one may test hidden-$s\bar{s}$ components using polarized $PP \to PP\phi$, and also that the $PP \to PK^+\Lambda$ data supports a simple K-exchange picture. Ströher discussed baryon resonance production and decays, and noted that such a programme at COSY using P beams would be a useful complement to the various photon facilities now planned or in operation. Niskanen discussed the origin of isospin violation effects in nucleon-nucleon scattering and suggested channels in which these effects may be largest. Klimala considered meson production in PD collisions and discussed how one might test models such as intermediate Δ production. Eyrich discussed prospects for strangeness production at COSY using TOF, including $K\Lambda$ (current), N^*s (possible in future), and the very interesting but long neglected Z^* exotic flavor channels (in particular the sector $uud\bar{d}\bar{s}$). Kupść summarized future plans for CELSIUS/WASA, which include rare π^o and η decays, including the processes $\eta \to \pi^o\pi^+\pi^-$ (I violating, of interest in χPT) and $\eta \to \gamma\pi^+\pi^-$ (for which VMD and χPT give rather different predictions). Finally, Braccini reviewed the very interesting results on $\gamma\gamma$ couplings of $n\bar{n}$, $s\bar{s}$ and $c\bar{c}$ resonances which have come from LEP and Cornell recently. These results include observations of the possible radial excitations $\eta(1440)$ and $a_2'(1752)$, and in $\gamma\gamma^*$ evidence for the light axials $f_1(1285)$ and $f_1(1440)$ and the η_c, which is apparently produced through J/ψ vector dominance.

3.3. The exotica conference

The subject of non-$q\bar{q}$ mesons, the so-called "exotica", has seen exciting developments of late, with the announcement of glueball and spin-parity exotic candidates. This, I admit, was the conference I attended.

Barnes first gave a review of exotic mesons (exotic meaning having quantum numbers forbidden to conventional $q\bar{q}$ states). We now have two light exotic candidates, the $\pi_1(1400)$ (BNL, Crystal Barrel, VES) and $\pi_1(1600)$ (BNL, VES). Unfortunately it may be too soon to celebrate, since LGT predicts that the 1^{-+} exotic level should lie at about 2.0 GeV, much higher than reported. Klempt discussed glueballs, in particular the various states in the 0^{++} sector. These include the Crystal Barrel candidate $f_0(1500)$, the possibility of a single very broad scalar "der Rote Drache", and various models of scalar mixing and decays. Szczepaniak summarized the CEBAF Hall D project, which is a proposed high-statistics meson photoproduction experiment for the study of light exotic and $s\bar{s}$ meson spectroscopy. Willutski reviewed results from BNL E852, including evidence for the $\pi_1(1590)$, and in $\omega\eta$ for a 1^{+-} $h_1(1590)$ and a 1^{--} $\omega(1650)$. Note that the $h_1(1590)$ is considerably lighter than expected by Godfrey and Isgur for a $2P$ state. Close reviewed his very interesting work on the exchanged angular quantum numbers and Q_i^2 dependences in diffractive meson production, which can be used as a "discriminator" between $q\bar{q}$ and G candidates. Clearly something very important about diffraction has been discovered here, although just what is as yet unclear. Peters restricted himself to the "past, present and future" of meson spectroscopy, including the 10th anniversary of the Crystal Ball $3\pi^o$ Dalitz plot, developments in exotics, the importance of high statistics, complications in analyses, scalars, D decays, ... and future facilities. Finally, Stefanski reviewed results from the charm photoproduction experiment E791 at Fermilab, and noted that the 3π Dalitz plots from D^+ and D_s^+ show evidence for strong isobar contributions, including $\rho\pi$, $f_0\pi$ $f_2\pi$ and $\sigma\pi$. The interesting evidence of FSI effects in the complex relative phases of these states was also noted.

3.4. The HEP conference

Subconference 4 (on HEP) was the shortest, with just two plenary contributions. These contributions could be identified by the fact that the hadrons were clearly considered non-essential complications to the interesting physics. The first HEP contribution was by Sciaba, who summarized the status of the search for $B_s^o \leftrightarrow \bar{B}_s^o$ mixing. This has not yet been observed, but the limits are now rather close to theoretical expectations, "watch this spot". Next, Fleischer reviewed the general subject of CP violation in B decays in impressive detail, and suggested several final states which may be of interest in future experimental studies.

3.5. The photon–hadron conference

The final subconference I identified, with six plenary contributions, was on photon-hadron interactions. (Braccini's two-photon talk might also be listed here as a seventh contribution.) The first contribution was by Levi Sandri, who reviewed the baryon resonance program at GRAAL, and noted some interesting results, such as the fact that the $D_{13}(1520)$ $A_{3/2}/A_{1/2}$ ratio does not agree well with Capstick and Isgur's quark model predictions. Bruncko reviewed DESY results on vector photoproduction of ρ, ω, ϕ, ψ, ψ' and Υ. A remarkable "universal curve" of electroproduction cross sections versus Q^2 was shown for these states. Steffens reviewed polarized deep inelastic scattering at HERMES, especially the "semi-inclusive" processes $\gamma^* P \to \rho, \omega, \phi, \psi, \Upsilon + X$, tests of SCHC, production mechanisms and parton distributions. Arends reviewed the status of the DHG sum rule and concluded that there is no indication of disagreement with experiment. Nikolaev discussed diffractive electroproduction of vector mesons and the interesting possibility of distinguishing $2S$ from D states through their different Q^2 dependences. And finally, Muccifora discussed charged and neutral π electroproduction at HERMES, which can be used to test the Q^2 evolution of fragmentation functions. These results included surprising evidence of possible isospin symmetry violation above $z = 0.7$.

4. Personal favorites

Although there were many interesting results presented at the meeting, I would like to take advantage of my rôle as summary speaker to cite what seemed to me personally to be the single most remarkable new experimental and theoretical results.

In experiment: The "universal curve" for the Q^2 dependence of vector meson electroproduction appears to be a very suggestive observation, and presumably tells us something very general about hadron electromagnetic couplings. Does this establish a vector dominance picture over direct photon-quark pQCD amplitudes? If so, most quark model calculations of resonance photoproduction and electroproduction amplitudes may be inaccurate! The question of just what this result teaches us should clearly be pursued.

In theory: Close has found remarkably simple and accurate results for diffractive scattering amplitudes, using an almost conserved vector coupling model; this is telling us *something* profound about the long standing issue of just what the "pomeron" is at the quark–gluon level. As with many interesting discoveries, it is not yet clear what these results mean, but they suggest that progress in this long-standing question may now be possible.

5. Feynman story

At this conference, the question of the limits of usefulness of various models must have occurred to many of the attendees. This story gives some indication as to Feynman's attitude to the use of models in hadron physics.

In about 1974 as a new Caltech graduate student I was looking for an interesting thesis topic. This was an exciting period with many new developments in physics, such as supersymmetry, string theory, the parton model, non-Abelian gauge theories, compact objects in astrophysics and so forth. Although I was initially interested in rather formal problems in quantum gravity, the very practical and skeptical research atmosphere at Caltech strongly encouraged graduate students to study topics that led to direct comparison with experiment. Since QCD had just been proposed, and a group at MIT had just published their first paper on the "bag model" which showed that one could derive many experimentally observable properties of light hadrons quite simply using quark and gluon "cavity resonator" modes, I began work on this model and suggested it as a thesis topic to my advisor Jon Mathews. Since Mathews was a rather pure mathematical physicist, he was unenthusiastic. He suggested however that I talk to Feynman about this work, since Feynman had heard about the model at a meeting and had since worked out many of its predictions for hadrons himself. I found that Feynman, unlike Mathews, was very interested in and excited by what could be derived in this simple model; so much so that I rather courageously asked him if he would tell Mathews that the study of this model was a suitable thesis topic. The resulting transition from initial to final states is shown in Fig. 3 below (this is a Feynman diagram in which Feynman actually appears).

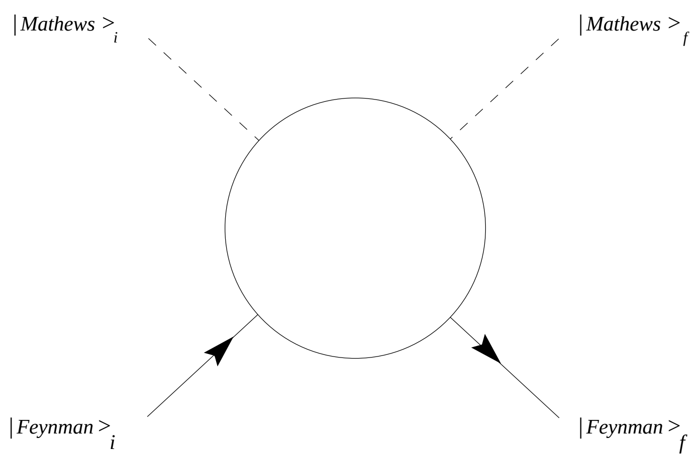

Fig. 3. A Mathews–Feynman scattering diagram.

As usual, precisely what took place within the circle is unknown, but much can be inferred from the initial and final states. In this case, in the initial state $|Mathews\rangle_i$ the MIT bag model was *not* a suitable Ph.D. thesis topic, and in the final state $|Mathews\rangle_f$ it *was* a suitable topic. Although the details of the interaction were not observed, $|Mathews\rangle_f$ made statements to the effect that *the study of models is useful in hadron physics because one can abstract model-independent features.* I presume that this is the justification Feynman gave to Mathews. This has indeed proven to be the case for the bag model, since it was the first to predict a light $J^{PC} = 1^{-+}$ exotic meson; this exotic has been found by all subsequent approaches, including LGT. We now have two experimental exotic meson candidates with these quantum numbers, which were discussed in detail at this meeting, and the general topic of "exotica" is now widely considered the most interesting subject in light hadron spectroscopy.

In summary, each model is wrong in detail, but they may nonetheless contain some common physical truth.

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REFERENCES

[1] R. Monk, Ludwig Wittgenstein, *The Duty of Genius*, Penguin, 1990, p.13.

[2] For a recent reference on magnon–magnon bound states, which have nothing to do with QCD spectroscopy, see `cond-mat/0005222`.

[3] All contributions cited after the historical introduction are implicitly Plenary Contribution, MESON 2000 (these proceedings).