Experimental Summary Moriond QCD 2008

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2008 was a vintage year for the QCD Moriond meeting. Plenty of new data from Tevatron, HERA, B-Factories and other experiments have been reported. Some brand new results became public just before or even during the conference. A few new hints for New Physics came up in Winter 2008, but these await further scrutiny. This paper is the write-up of the experimental summary talk given at the Moriond QCD March meeting.

1 Introduction

In this paper I will discuss the progress in the different areas as reported at Moriond QCD 2008. This year's Moriond meeting is very special indeed: it is the last Moriond before the switch on of the long awaited LHC – if all goes as planned. Next year's Moriond meetings are very likely to contain presentations of real LHC data.

This year is also the first Moriond meeting after the switch off of the HERA accelerator at DESY, Hamburg. HERA has been a very faithful contributer to Moriond QCD conferences in the last 15 years. At Moriond QCD 1993, only a mere 8 months after the first timid collisions, the HERA experiments started to show their first QCD results. In fact, the first F_2 measurements at low x were shown at Moriond QCD 1993 [1], and simultaneously at first DIS meeting in Durham [2]. After 15 years of producing outstanding QCD results, HERA has now been terminated just before midnight on the 30th of June 2007. Many results will still be completed in the next few years and presented at future Moriond QCD meetings (and elsewhere).

One of the excitements at this Moriond meeting was caused by the possible hints for New Physics, like the one from the B_s decays. Some of the discussion of these new effects will be developed further in the theoretical summary of Chris Quigg [3].

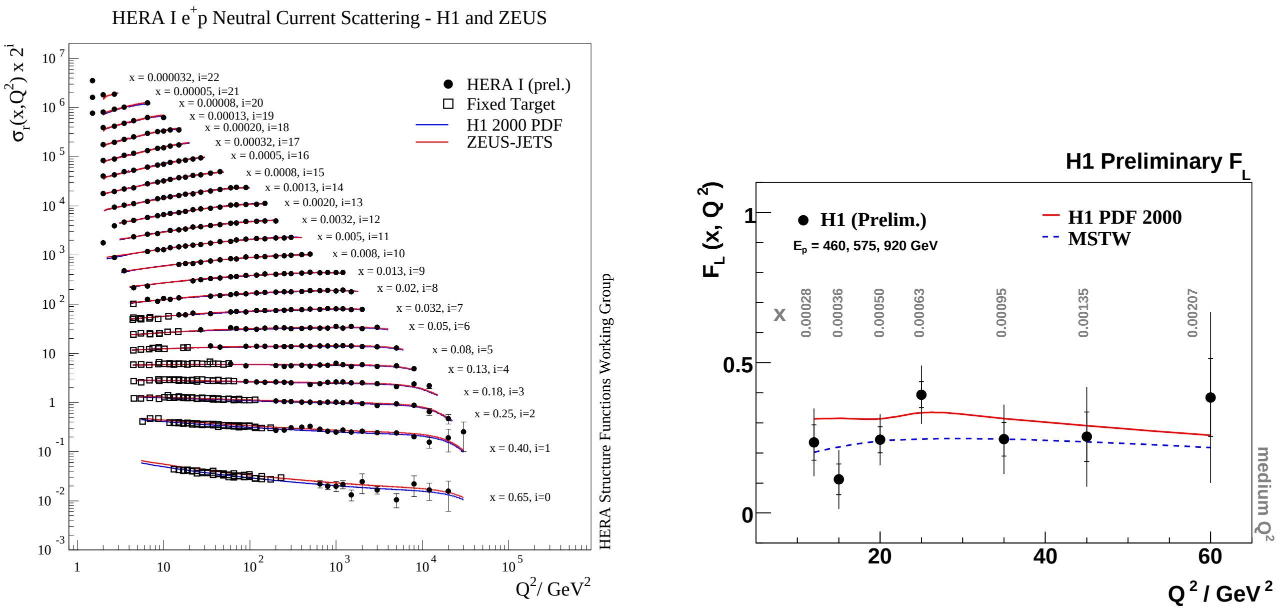

Figure 1: Overview of the HERA structure function F_2 data (left), and first preliminary measurement of the longitudinal structure function F_L

2 QCD

The first topics discussed in this summary are the ones probably most consistent with the title and spirit of this conference, namely on QCD.

Important input for the LHC will be the understanding of the parton distributions of the proton. Key input to these parton distribution determinations are the F_2 structure function measurements of HERA. The precision of the HERA F_2 data is now 1–3% in the bulk region, but still statistics limited for the largest x and Q^2 values, see Fig. 1. At this Moriond meeting a direct measurement of the second structure function F_L was released for the first time[4], see Fig. 1. During the last 3 months of operation HERA ran at reduced proton energy (at two different energies, namely 460 and 575 GeV) and combining these data with the data at 920 GeV allows to extract F_L. Another recent development is the combined structure function data set from the two HERA experiments[5], ie combining the ZEUS and H1 F_2 data and using clever techniques to cross calibrate the systematics. These combined measurements have reached a truly fantastic precision, and during the HERA-LHC workshop[6] on May 2008 the power of these combined structure functions F_2 in PDF extractions was shown, reducing the parton uncertainties by a factor of two or so in a large region. Getting the best PDFs for the LHC is one of the ongoing challenges and has recently condensed in a forum to stimulate that work, called PDF4LHC [7].

Jets are another set of classical QCD measurements, and several new jet measurements were shown [8] at this meeting; an example are the mini-jet measurements for jets with $p_T > 3$ GeV. These measurements are likely to be important for helping to understand the dynamics of the underlying event data at the LHC. Inclusive jet measurements are now also being included in PDF analyses. This particularly helps to additionally constrain the gluon at high and medium x. It also allows to extract precise values at α_s as discussed in the theory summary talk.

A third strong leg of HERA QCD measurements is provided by the diffractive data. The diffractive structure function F_2^D is measured precisely [9], as shown in Fig. 2. Several different methods are used by the experiments for extracting F_2^D. Some notable differences between the

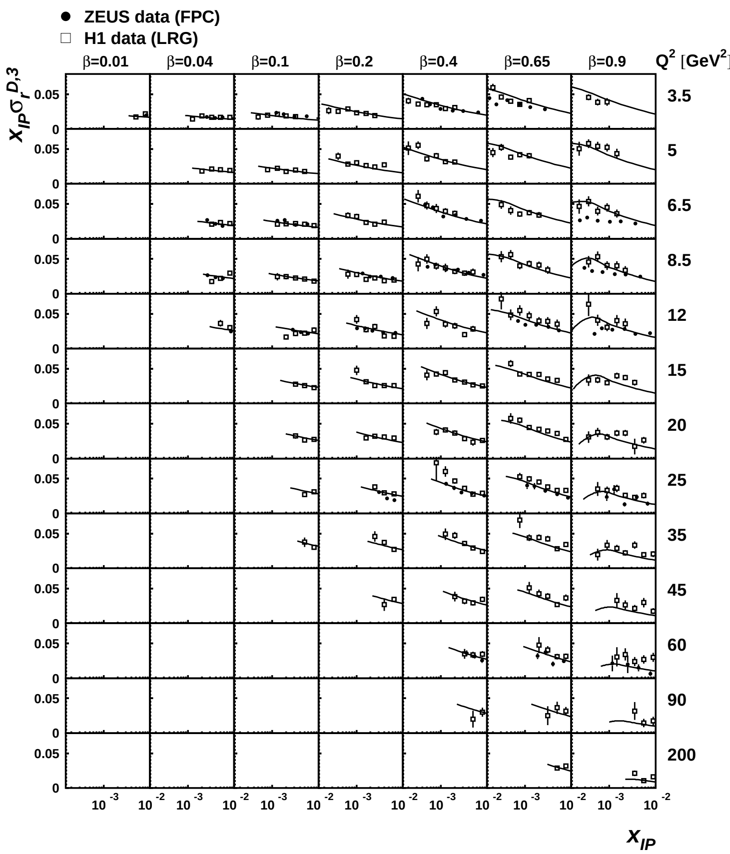

Figure 2: Measurement of the di ractive structure function by H1 and ZEUS and the theoretical prediction from [10]

H1 and ZEUS data, eg at high and Q^2 of about 5–10 GeV^2, are present. A phenomenological analysis carried out in [10] o ers a parameter free prediction of the di ractive cross sections, and {amusingly{ does seem to referee between the "o bins" in the data sets. However there is no over-all winner, in some bins (high) the H1 data are preferred, but at 0:4 the model seems to prefer the ZEUS data. The di ractive structure function data is also used to extract parton distributions of di ractive exchange, as shown in Fig.3.

The Tevatron has been delivering impressive data on jet measurements in the last years. CDF and D0 showed recent precision jet measurements for jet p_T values up to 600 GeV [11]. Some of these recent measurements are shown in Fig.4. Again these measurement will help to constrain the gluon at high x in PDF studies, and are now being incorporated in the global ts. These measurements add value for the PDFs studies on top of the HERA jet measurements, since they are generally at a higher scale (several hundreds of GeV^2) than the HERA ones.

A particularly important measurement for LHC studies is the reported result on exclusive di-jet production in events with rapidity gaps (aka di ractive events). CDF discussed the ratio of the distribution of the invariant mass of the di-jets over the invariant mass of all objects observed in the central detector. The amount of events at values above 0.6 of this ratio can only be understood if exclusive dijet events, i.e. events with only two jets in the central detector, are added to signals in the Monte Carlo. Hence this demonstrates (together with other channels such as exclusive di-photon production) that exclusive processes exist at high energies. Moreover the observed amount of exclusive events is close to the prediction of the Durham group [12]. The main interest in this channel for the LHC is the exclusive production of the Higgs boson, as will be discussed later.

Results on jet+ photon data have been discussed at the meeting. These measurements have a

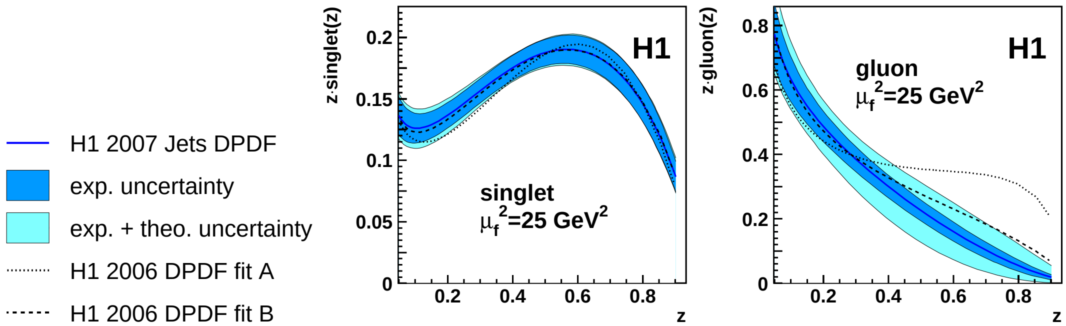

Figure 3: The diffractive quark density (left) and the diffractive gluon density (right) versus z, the momentum fraction of the parton, for the squared factorisation scale $\mu_f^2 = 25$ GeV^2.

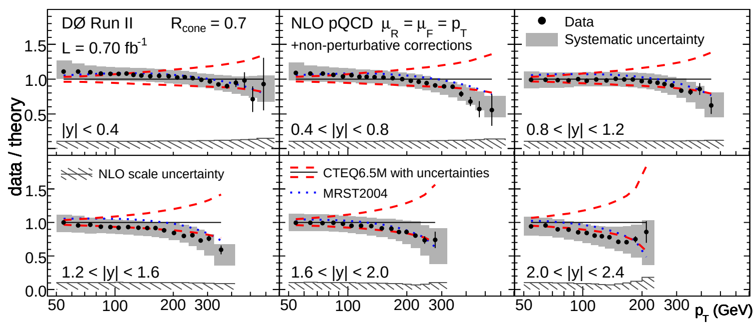

Figure 4: Measured data divided by theory for the inclusive jet cross section as function of p_T in several y bins.

long history of "avoiding agreement with theory" and this still seems to be the case for the latest measurements[13]. The recent D0 data show a $\approx$ 20% lower cross section than the theoretical expectation for photon p_T values larger than 100 GeV. This may well be bad news for the LHC, where one counts on this process for PDF and other QCD studies. Originally this process was expected to be more reliable at high p_T values. However, CDF data seems to be more in accord with the theory in this region. Remarkably the photon+ b-quark jet seems to agree already with the LO calculations. Just luck? More precise data will show.

New heavy flavour data, in the QCD context, were presented by both HERA and the Tevatron. The latest results on F_2^b shows that the b-content of the proton is about 1%. This measurement is important for the determination the Higgs production cross sections at the LHC, especially in extensions of the Standard Model (SM).

A few years ago at the Tevatron there were discrepancies between the measured b-quark spectra and the theoretical predictions. Meanwhile these differences have been ironed out but the question remained whether the modifications applied would also work at other energies (say LHC) or other processes (say ep scattering). The HERA p_T spectra of the b-quark jets[14] shed light on this issue: indeed the calculations work reasonably well for HERA, "from the first shot". Some discrepancies at low p_T values are observed. More precise data will be the referee here, but it is likely that some additional theoretical work may be needed for the low p_T region.

New Tevatron data resolve the outstanding puzzle on the di-muon cross section: the CDF run-I measurement was significantly higher than the expectation but the new CDF Run-II measurements are in agreement with the NLO calculation. The J/ψ polarization data are found not to be described by NRQCD calculations[15] (In the discussion it was claimed that the Durham calculations can however describe these data[16]). In all: how well do we really understand heavy quark production at the Tevatron and HERA? Can we safely extrapolate to the LHC? There clearly are some areas where more insight is needed.

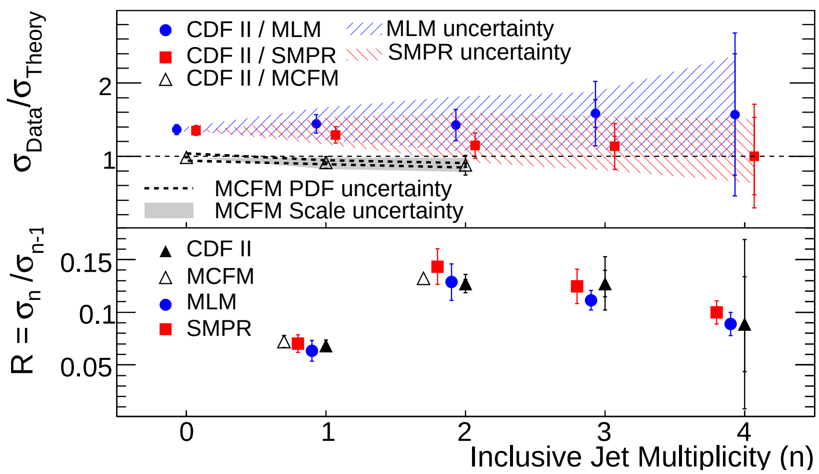

Figure 5: The ratio of data to theory for the total cross sections as a function of the jet multiplicity n. Bottom: σ_n/σ_{n-1} for data, MLM, SMPR and MCFM calculations. Inner (outer) error bars denote the statistical (total) uncertainties on the measured cross sections.

Of particular relevance for the LHC is the understanding of vector boson production (+ jets) at the Tevatron. Processes with vector bosons will constitute an important background to many searches for new physics, notably for supersymmetry. CDF reported a first observation of the ZZ process at the Tevatron: a signal is seen with 4.4σ significance, based on 3 clear events with basically zero background[17]. Remarkable are the results on W + jets, Z+ jets, W + c jets and Z+ b jets measurements. The W + jet measurements are now made for up to 4 jets, as shown in Fig. 5. The measured cross sections are in excellent agreement with the NLO MCFM predictions, essentially straight out of the box, for up to two jets. This is excellent news for the LHC and leaves us to hope that we will understand the W + jets background at the LHC fast. However there is a caveat: the MCFM predications are at the parton level and the data are corrected to the hadron level only, so the agreement may not be as impressive as it looks at first sight[18], but still it is still very close.

Time for a few electroweak measurements from HERA. During Run-II the electrons and positrons beams of HERA could be polarized to roughly 60%. This can be used to search for right-handed currents or make measurements on the axial and vector couplings of the u and d quarks. It can also be used to set limits on the quark radius; and the limit is now $R_q < 0.74 \times 10^{18}$ m at 95% CL.

Beam polarization in QCD can further be used to make measurements of the proton spin structure. The study of the longitudinal spin decomposition of the proton is still an active field, and new results from the proton-proton collider RHIC, with polarized beams, were reported at this meeting. Using combined measurements from STAR and PHENIX, for jets and π^0s, the A_{LL} asymmetry constrains the polarized gluon ΔG to be $-0.8 < \Delta G < 0.2$ with 90% CL in the range of $0.02 < x < 0.3$[19]. This is a good constraint for the various models and predictions.

One of the mysterious observations in QCD are the large transverse single spin asymmetries. These have been established at low center of mass (cms) energy collisions over 10 years ago, and recently got confirmed at the RHIC collider at the highest cms energies[20] for polarised collisions: $\sqrt{s} = 200$ GeV. The asymmetries of the process $p^{\uparrow}p \to \pi X$ are studied at different Feynman-x values with a single transversely polarized proton beam. The asymmetries increase with x_F and reach values as large as 0.1. The results are compatible with zero at small and negative x_F. It was noted[21] that there is a stringent prediction from QCD that can be checked namely Sivers(DIS) = $-$Sivers(DY). Hence, one should go out and confirm this prediction!

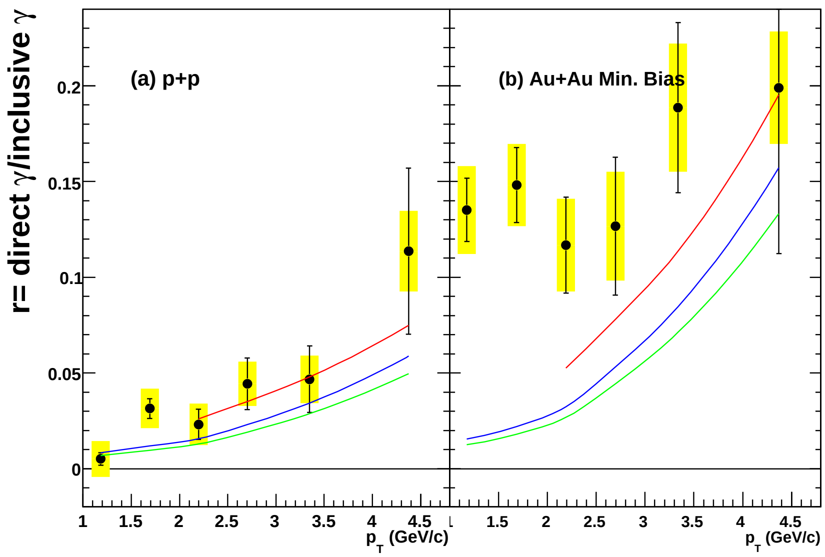

Figure 6: The obtained fractions of the virtual direct photon component as a function of p_T in p+p (left) and Au+Au (right) collisions.

3 Heavy-Ion Collisions

The RHIC heavy ion collider was conceived in order to establish a new state of matter in heavy ion collisions (aka the quark gluon plasma). Recent years have provided a wealth of data and measurements in e.g. gold-gold collisions. Results on thermal dilepton pairs were discussed in [22;23]. As shown in Fig.6 the pp data seem to be consistent with NLO calculations, while AuAu data are systematically above the predictions. For the resonance measurements, the gets wider and there is an excess in the region M which is not due to charm production. Inspecting the T_{eff} shows a rise at small invariant mass, consistent with the radial ow of a hadronic source, while the drop at large invariant mass indicates a partonic source.

Jet quenching has been observed since a number of years and is further studied in detail. Taking one jet as the trigger jet (near side) one can eg. study the cone angle of the second jet (away side). The result disfavours Cerenkov radiation as the main e ect of the quenching. It is still unclear what the dynamics of the "ridge" at the near side is. It behaves as the inclusive part but more correlation studies are ongoing [24].

Three particle correlations are studied with jet variables [25]. Presently the correlations are found to be consistent with conical emission but the presence of other jet topologies cannot be ruled out yet. Finally, hard probes are being studied, such as heavy avours and the colour charge e ect [26]. Correlations are studied e.g. looking at the nuclear enhancement of N_{part} for a certain photon E_T trigger, where a suppression is seen for high N_{part} [27]. A puzzling part in the J= suppression data at RHIC is the PHENIX data that show that the more central part of the production is LESS suppressed than the more forward part, by almost a factor of 2! The data are shown in Fig. 7. This is a priori counter intuitive and brings up the fear that perhaps the J= may be NOT a good probe for the study of the new state of matter. An approximate formulae for $dP=dx_E$ was discussed in [28]

Clearly a lot of progress was made over the last years in understanding the state of matter that is created in high dense systems. This new state seems to act as a perfect liquid. But the data show that we cannot yet be fully satis ed with our understanding, and more detailed and sophisticated correlation studies are expected to shed more light on the dynamics. In other

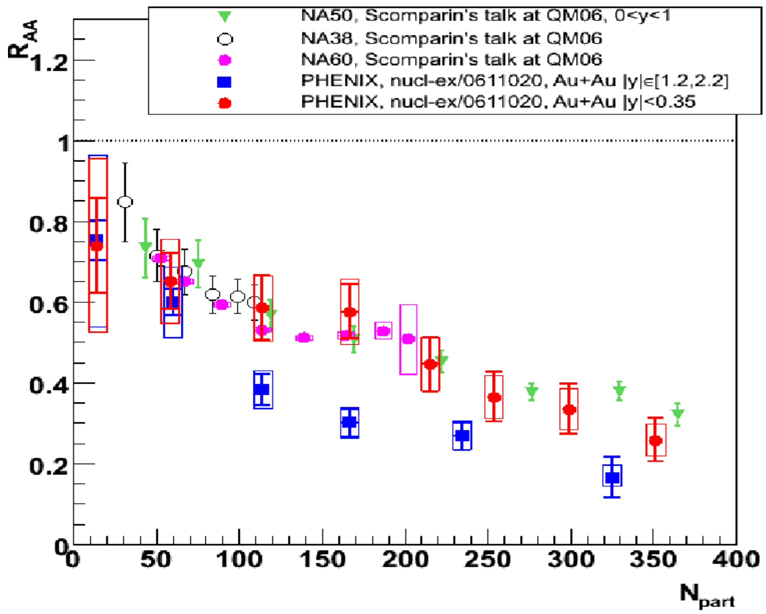

Figure 7: J/ψ R_{AA} vs. N_{part} at SPS compared to RHIC.

words, we are well en route, but not quite there yet.

4 Heavy Flavours

The harvest of heavy flavour physics from BaBar, Belle, CLEO, Tevatron is very rich. The B-factories collected now about 1.3 ab^{-1} together. Samples of in total of about 10^{12} $B_{u,d}$ decays, 10^{6} B_s decays and a few times 10^{7} ψ(2s) decays[29] are available now. Heavy flavours are a way to probe new physics through appearance of the new particles in the loops. To discover new physics this way luminosity is crucial. I will be relatively brief in this section since much of that is picked up in[3].

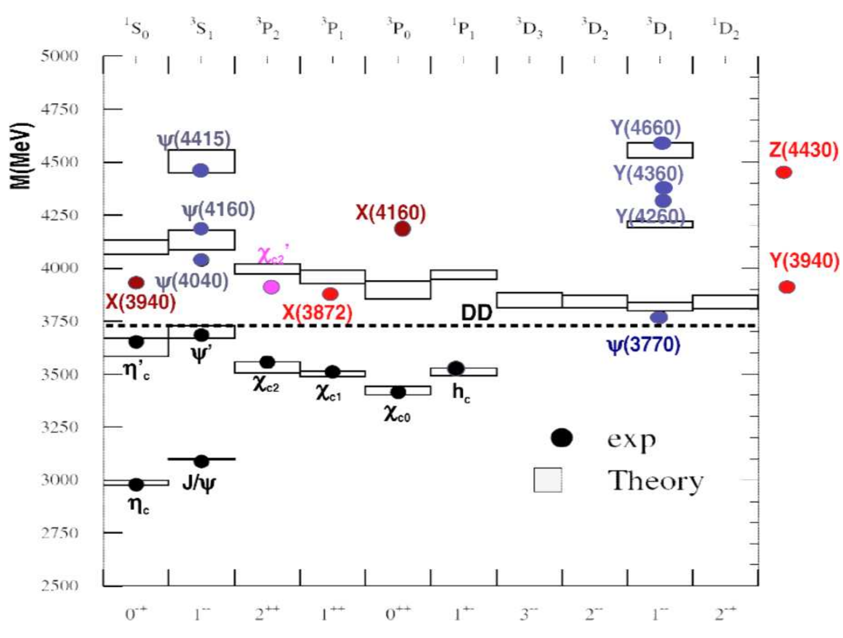

Figure 8: Spectrum of new states studied at Belle an BaBar (from [30])

Belle and BaBar reported on the new charmonia that have been observed [30,31,32], several

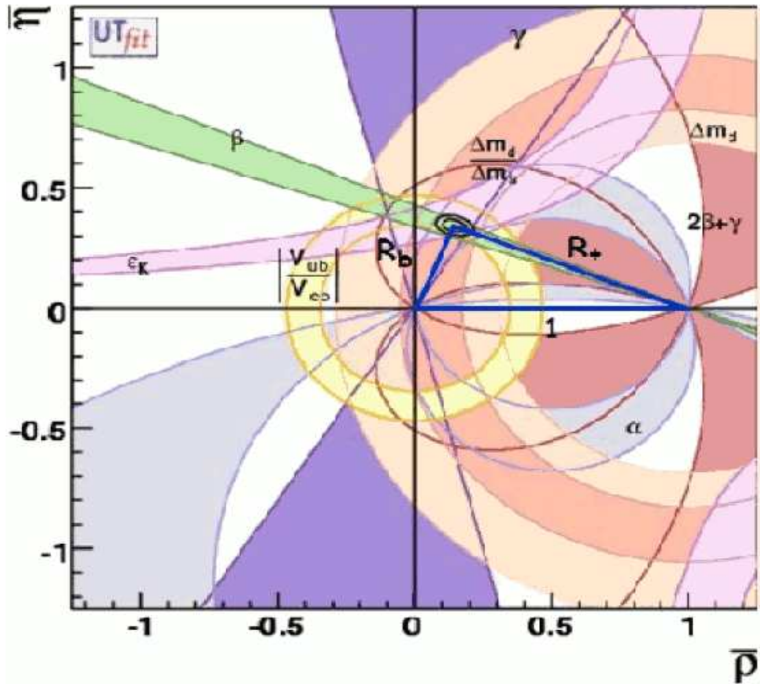

Figure 9: Update of the unitarity triangle constraints[2]

of which are candidates for new states. An overview picture is given in Fig. 8. The τ and charm decay studies have been reported[33]. There is evidence for new Σ_c states with masses of 3055 and 3122 MeV respectively. The earlier discovered states at 2980 and 3077 MeV have been confirmed. New quarkonium results from BaBar include a measurement of the B meson mass difference: $m(B^0) - m(B^+) = 0.33 \pm 0.05 \pm 0.03$ MeV which is compatible with the world average but the error is a factor 4 reduced w.r.t. previous measurements. The significance for a non zero mass difference is now larger than 5σ[34]. The hadronic B decays from BaBar and Belle showed evidence for direct CP violation from a Dalitz plot analysis of $B^{\pm} \to K^{\pm}\pi\pi$ at the level of 3σ[35]. An update of the unitarity triangle is shown in Fig. 9, which includes improvements due to results from the B-factories and the Tevatron[29]. The precision on the angles is now roughly $\pm 8^0$; $\pm 1^0$ and $\pm 13^0$.

The Tevatron showed recent measurements on masses and lifetimes of hadrons containing b-quarks. Σ_b mesons are now well established and CDF made the measurement of the mass to be $5792.9 \pm 2.5(stat.) \pm 1.7(sys.)$ MeV. The B_s lifetime measured in $B_s \to J/\psi\phi$ is now 1.52 ps with an error of a few % as measured in CDF and D0[36].

Charm mixing was reported exactly a year ago for the first time from BaBar and Belle, and has now also been observed at the Tevatron in CDF, with a 3.8σ significance disfavoring the no-mixing scenario. The elongated error ellipses are large for the different experiments and do not have the same central points in the so called $x^0; y^0$ space, but are claimed to be all compatible.

About two years ago, reported at the Moriond meetings for the first time, the first measurement of the B_s oscillation was shown to the world by D0. Meanwhile both CDF and D0 have shown more evidence and improved the results. The experiments now report[37]

$$\text{CDF:} \quad \Delta m_s = (17.77 \pm 0.10 \pm 0.07)\,ps^{-1}$$

$$\text{D0:} \quad \Delta m_s = (18.53 \pm 0.93 \pm 0.30)\,ps^{-1}$$

Also measurements on $|V_{td}|/|V_{ts}|$ where reported which are now dominated by theoretical uncertainties. The personal world average calculated by the rapporteur is $\Delta m_s = (17.78 \pm 0.12)\,ps^{-1}$ and $|V_{td}|/|V_{ts}| = 0.2059 \pm 0.0007(exp)^{+0.0081}_{-0.0060}(theor)$.

New results on rare B and charmed meson decays were reported in [38]. In particular the decay $B_s \to \mu\mu$ generates considerable interest. The limits of D0 and CDF are now respectively 7.5 and 4.7×10^{-8}, derived with 2 fb^{-1} of data. The SM expected value is 3.4×10^{-9}, and if e.g. SUSY exists one should see the decay well before that, hence the Tevatron experiments are closing in on it! For the decay $B \to \mu\mu$ the present Tevatron and B-factory limits are still more than 2 orders of magnitude away from the SM limit. Finally, a first direct CP violation measurement of hadronic charmless b baryon decays was reported by CDF.

In connection with the interpretation of the g-2 experiment at BNL (for further discussion see [3]), it is very important to measure the e^+e^- cross section at low $\sqrt{s}$. Such measurements can be made but they are very tricky. It was shown that measurements are under way [31] in BaBar, using radiative events, but it may take some time before all final states in the 1-2 GeV energy region are analysed. The hope is that when it all comes together one could have the total cross section determined with a precision of about 1%.

CLEO showed an analysis of the 2007 data in the cms energy range of 7-10 GeV. The data below 8 GeV showed a large discrepancy between the different experiments (Mark-I, Crystal Ball and MD1)[39]. The very precise CLEO data referees that region and shows that the Mark-I data may well suffer from a systematic effect since the R value is about 20-25% larger compared to the new precise measurements.

Staying with the CLEO data, we hit the first serious hint for New Physics at this Moriond meeting. CLEO [40] has made a precise measurement of the leptonic decay constant for D_s mesons: f_{D_s} equal to $274 \pm 10 \pm 5$ MeV. This constant can be calculated on the lattice and in fact a precision determination exists, which shows that there is a 3.8σ discrepancy between the calculation and the data [41,42]. Can one take this discrepancy seriously? A discussion on the theory part is given in [3]. If indeed this is a real effect then a natural explanation could be given by leptoquarks in the mass range of 700-800 GeV. Other possible scenarios include new W primes or charged Higgses.

In the week before the conference, the UTFIT collaboration reported on first evidence for new physics in the b to s transitions[43]: an analysis of $B_s \to J/\psi\phi$ decays measured at the Tevatron experiments has found a disagreement between the observed mixing amplitude ϕ_s and the SM prediction at the 3.7σ level. This lead to a discussion at the conference both in and outside the sessions. All agree that there is indeed tension in the present data. Not everybody agrees on the claimed significance. At this point it is perhaps more a hint than evidence, and the jury is still out for the final verdict. CKM fitters await more input on the data from CDF/D0, and both experiments themselves are engaged in making their own fits. So watch that space!

An important next player in this field will be LHCb[44]. LHCb can measure ϕ_s with a precision of about 0.02 with 2 fb^{-1} and can clear up the status of the discrepancy. Note that LHCb can also measure the $B_s \to \mu\mu$ of the level of the SM with 0.5 fb^{-1}, hence it should be a referee on both issues already within the first 1-2 years of physics data (ie 2009-2010). The expectations for LHCb are shown in Fig. 10.

Finally a third hint of new physics was discussed, the so called ΔA_K puzzle, and discussed in the theoretical summary of this meeting[3].

5 Top Quark Physics

The Tevatron is still the only place in the world where the top quark is produced in the laboratory. Not for much longer, however! The 3.5 fb^{-1} delivered luminosity/experiment at the Tevatron is good for 22K produced top pairs. The analyses presently use between 0.9 an 2.3 fb^{-1}.

The top analyses at the Tevatron are truly impressive! At this conference a new value of the top mass was presented. The reported value is [45]: $m_{top} = 172.6 \pm 1.4$ GeV, hence $\Delta m_{top}/m_{top} =$

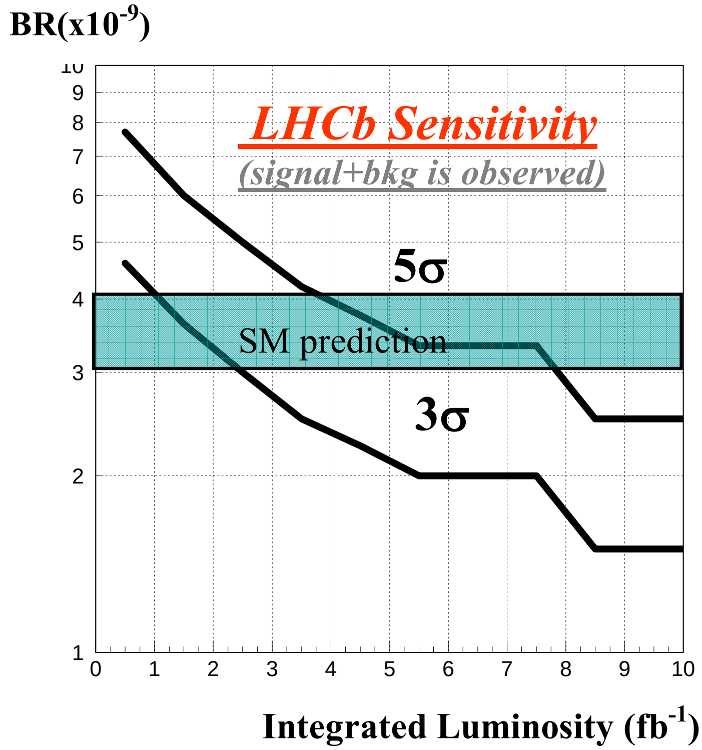

Figure 10: Observation (3) and Discovery (5) limits for B_s ! $^+$ as a function of integrated luminosity in case where both signal and background are observed.

0.8% . It looks like the Tevatron experiments will succeed to reach a m_{top} of 1 GeV by 2009 or so. Hence the LHC will have a hard time competing with these results. But the large statistics at the LHC (factor 100 more per fb ^{1}) will pay o at the end by allowing for more stringent selections and leaving room for more ingenious methods, yet to be developed. A summary of the top mass measurements at the Tevatron, and the new summary of the t of the electroweak data [46] are given in Fig. 11.

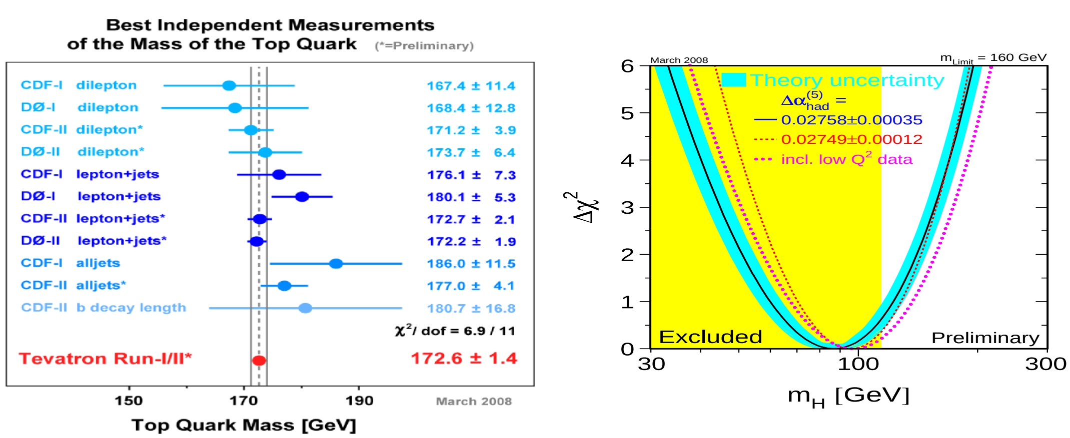

Figure 11: (left) Summary of the top quark mass measurements at the Tevatron; (right) summary of the t of the electroweak data with the new top mass[46].

A check was presented of the precision on the mass that could be reached from the cross section of the top quark production. Presently that looks like a factor of 5 worse[47] than achieved with the methods above. The new top mass measurement was included in the electroweak ts[46] and the following t results were obtained (Table1).

$\Delta\alpha_{had}$	=	0.02767 ± 0.00034
α_s	=	0.1185 ± 0.0027
M_Z	=	91.1874 ± 0.0021 GeV
m_{top}	=	172.8 ± 1.4 GeV
m_{Higgs}	=	87^{+36}_{-27} GeV

Table 1: Current values of the parameters of the fit of the electroweak data with the new top mass

Further top quark properties have been studied [48] and reported. The decay branching ratio of top to Wb is larger than 79% at 95% CL, and the branching ratio to the decay $B(t \to Zq)$ is less than 3.7% at 95% CL. The lower mass limit on a 4th generation t' is now 284 GeV at 95% CL. Top charge is consistent with the Standard Model and exotic models are excluded with 87% CL. Helicity measurements are consistent with SM expectations but have still 30-50% uncertainties and leave room for a surprise. In any case, as far as we can see, the top behaves pretty much as expected "for a top quark".

Top pair production comes dominantly from $q\bar{q}$ production at the Tevatron, with only a fraction of about $0.07^{+0.15}_{-0.07}$ coming from gluon-gluon processes. This is well known to be quite different at the LHC. The total cross section from a combination of all the channels is quoted by CDF to be $7.3 \pm 0.5 \pm 0.6 \pm 0.4$ pb where the errors are statistical, systematical and lumi respectively. This is consistent with the theory prediction, which is between 6 and 7.5 pb for a top mass of 175 GeV. A search for charged Higgs production in top decays ($t \to H^+ b \to c\bar{s}b$) with a charged Higgs mass of 80 GeV shows that $B(t \to H^+ b) < 0.35$ at 95% CL [49].

Last year the first evidence of single top production was reported. It has turned out to be very difficult to extract the signal in the environment of high SM background processes, but the Tevatron experiments have succeeded to do so. Many special statistical techniques have been deployed to find the signal (matrix elements, decision trees, Bayesian NN, likelihood functions etc.) and the interconsistency of the results of the different methods has generated confidence in the initial result. By now more data has been included in these studies (eg CDF updated with 2.2 pb^{-1}) and the analysis techniques got better tuned. The single top signal seems well established now in both CDF and D0 with a significance larger that 3σ [50]. The cross section is about 2 pb measured in CDF and about 4.7 pb in D0. Due to the large uncertainties (30-50%) the measurements are both still consistent with the theoretically expected value of about 3 pb.

6 Higgs Searches

The whole world is waiting for the turn on of the LHC, to start the ultimate and decisive hunt for the so far elusive Higgs particle. This "God particle", coined like that by L. Lederman because it created diversity in what would otherwise be a dull Universe, is often thought of as the last missing piece of the Standard Model. It is responsible for the electroweak symmetry breaking in the SM, telling us why e.g. Z and W bosons are so heavy. The whole world is waiting? Not quite: in a region in Batavia, IL, USA, there is brave "gaulois" resistance to the upcoming reign of the LHC over this region, and all possible efforts are made to get to the Higgs before the LHC turns into routine physics operation. Many channels are studied at the Tevatron [51], e.g.: $W/H \to e/\mu\nu + b\bar{b}$; $Z/H \to ee/\mu\mu + b\bar{b}$; $Z/H \to \nu\nu + b\bar{b}$; $W/H \to \tau\tau$; $H \to \tau\tau$; $H \to \gamma\gamma$; $H \to WW \to l\nu l\nu$ and new results were reported at this meeting on most channels. A new Tevatron combination was made for QCD Moriond 2008, which is presented in Fig. 12 for a 95% CL exclusion limit compared to the SM expectation. The remarkable thing to note is that, perhaps due to a lucky downward fluctuation, the observed limit at 160 GeV starts to get close the the SM expectation, i.e. if this continues the Tevatron could exclude that region –or discover the Higgs!– before the search at the LHC starts in earnest. The region around 160 GeV is the one where the LHC could make a discovery with a few 100 pb^{-1}, i.e. very early on. Theorists at the conference made a plea to look also at signals down to 100 GeV masses or lower, despite the LEP limit of 114 GeV, and give the combination plot also with signal and error.

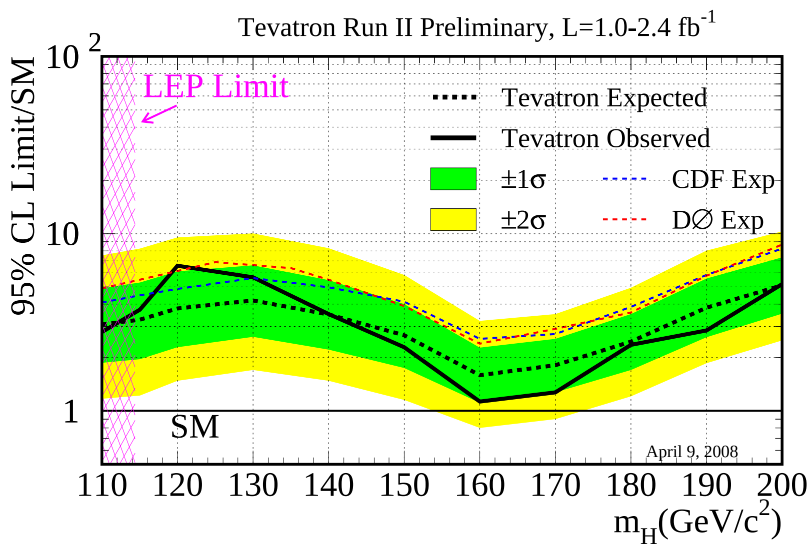

Figure 12: The combined exclusion plot for the Higgs from the Tevatron data.

The Higgs to decays was looked at with special attention, generated since last year's upward uctuation in the visible mass spectrum of the two 's in CDF, which could be consistent with an M_A of 160 GeV. Later that year D0 reported no excess in that channel (in fact if anything, a de cit), and adding new statistics also now in CDF the spectrum is "back to normal"[52]. Updates on the 3b channel, which shows a slight deviation as well, are coming soon.

Various other channels such as H ! ; H^{++}H ! $^{+}$ $^{+}$; H ! aa ! have been looked at, but no smoking gun was found[53]. Also a fourth generation seems to be excluded for a Higgs in the mass range of 130 to 195 GeV at 95% CL.

Bring in the LHC[54]! Clearly, the ATLAS and CMS experiments have been tailored for the discovery of the Higgs. The expected discovery plot for the combination of the two experiments is shown in Fig. 13, and shows that about 1 fb^{-1} of well understood CMS plus ATLAS combined data can be su cient to discover the Higgs except when the mass is 130 GeV or below, or above 500 GeV, which will need more data. A review of the LHC capabilities for Higgs discovery is reported in[56]. In all, the prospects for the LHC are excellent to answer the by now over 40 years old question: does the Higgs particle (and eld) exist or not? But there are always killjoys: in [57] it is argued that it may well be that Higgs particle may not be detectable at the LHC at all because it will be too broad a state ... More on that is discussed in[3].

7 Searches for New Physics

The Tevatron continues to push for searches for new particles and new phenomena[58;59]. So far these searches are negative (otherwise the content of this summary would have been quite di erent). Table 2 gives the present approximate limits on the masses for SUSY particles.

Jet or photon plus missing transverse momentum signatures have been used to search for large extra dimensions; the new limits on the scale M_D now range from 1420/1160/1060/990/950

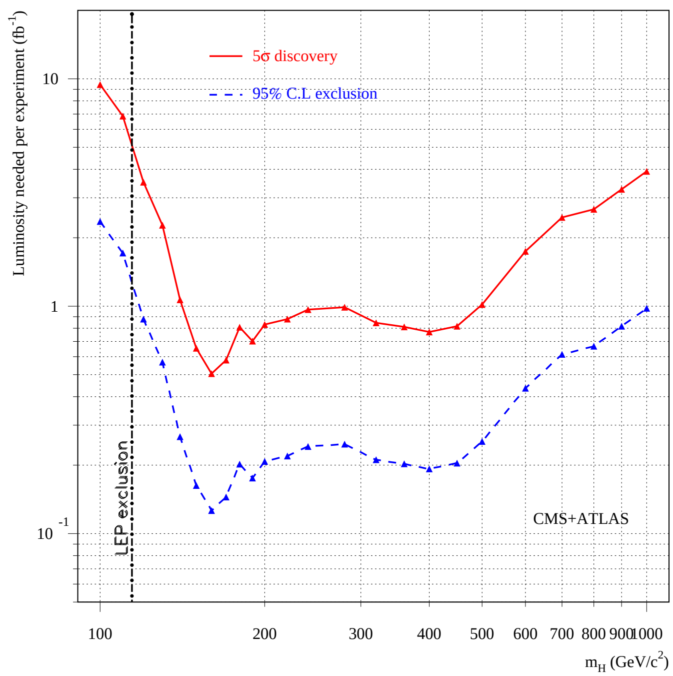

Figure 13: The prospects for discovering a Standard Model Higgs boson in initial LHC running, as a function of its mass, combining the capabilities of ATLAS and CMS. From [55].

GeV for 2/3/4/5/6 extra dimensions, according to the CDF measurements. For RS gravitons the range 850 (350) GeV is excluded for $k/M_{Pl} = 0.1 (0.01)$, see Fig. 14. New Gauge bosons a la Z' are excluded in the range below 750 GeV to 1 TeV, depending on the model.

With the advent of the LHC and the plethora of possible new physics scenarios, one can wonder if it is possible that we will miss a prominent signal simply because we didn't think if looking in a specific, perhaps weird, channel. Do we need automatic tools for "discovering new physics"? Several attempt have been made in that direction since a number of years, with so called generic searches. At this meeting a detailed exposure on a package of tools for tackling new, basically unknown, data was reported' [60], namely the VISTA package, complemented with SLEUTH and Bump Hunter. The tool has been used recently on CDF data and after considerable effort to understand all features in data (including non-collision background etc),

Chargino mass (mSUGRA)	140 – 150 GeV
NL neutralino mass (mSUGRA)	140 – 150 GeV
Chargino mass (GMSB)	230 GeV
LSP Neutralino mass (GMSB)	125 GeV
Chargino mass (mSUGRA) RPV	200 GeV
Neutralino mass (mSUGRA) RPV	100 GeV
Squark mass	400 GeV
Gluino mass	300 GeV
Light stop or RPV stop mass	150 GeV
Stop as CHAMP	250 GeV

Table 2: Approximate limits on the masses for SUSY particles from the Tevatron searches

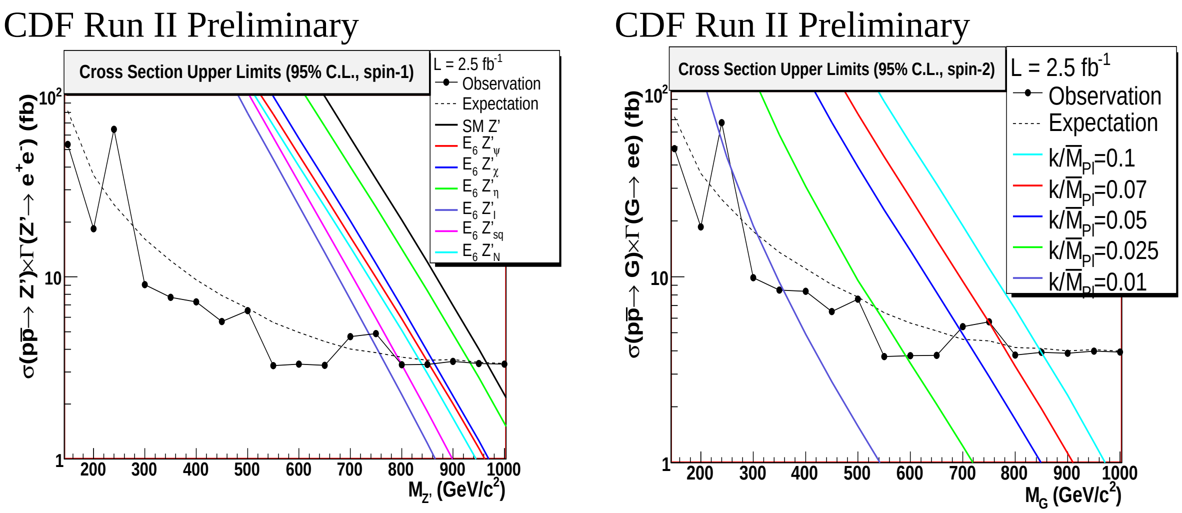

Figure 14: 95% CL limit from the CDF dielectron resonance search for various Z^0 bosons (left) and RS gravitons (right).

applied to search for new physics. At the end a number of discrepancies with the data {not related to e.g. insufficient QCD modeling{ have been identified. An example is shown in Fig.15 showing the summed transverse momentum of like sign leptons, clearly overshooting the data. So far no discovery has been claimed for this excess, however ...

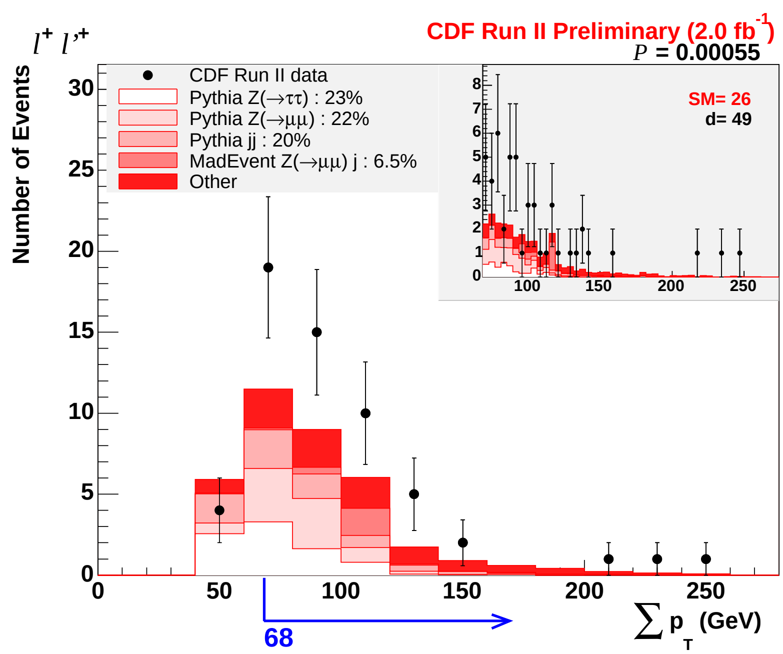

Figure 15: Sum p_T for like sing leptons in the CDF data for 2.0 fb^{-1} as found by Sleuth in The region with the most significant excess of data over SM expectation is indicated by the blue line and displayed in the inset. The significance of the excess is shown by P.

Once the discoveries are made, it will be important to disentangle the signatures and map these to theory space to extract the underlying theory. This is sometimes also called the inverse problem. In the last few years several attempts are made to test this mapping [61], look for footprints[62], set up dictionaries [63], providing tools to tackle such questions from data [64] and more. I believe such exercises have been useful and such tools will be needed once new signatures, less trivial than e.g. a Z', will show up in the early LHC running.

The LHC is probably the most complex and challenging scientific instrument ever made by mankind. After a long wait, it finally will turn into operation in 2008, and its start-up is highly anticipated by the particle physics community. Next year's Moriond meeting should contain LHC data!

It is unlikely {but not entirely excluded{ that the data of 2008 will reveal exciting discoveries, more so since this year we expect that the top energy of the machine will be 10 TeV instead of 14 TeV, due to some magnets that will need retraining during shutdown after the pilot run. The expected luminosity delivered to the experiments is about 40 pb^{-1} for 2008, with a large margin of uncertainty of course.

At this conference, many presentations were made on the expectations with first data of the LHC and on strategies for searches [65,66,69,67,68,70,71,72,73,74,75]. These have been presented at many conferences in the past, but in recent years the attention of the experiments has turned to more data driven techniques for estimating backgrounds and efficiencies, and full simulation of the different channels.

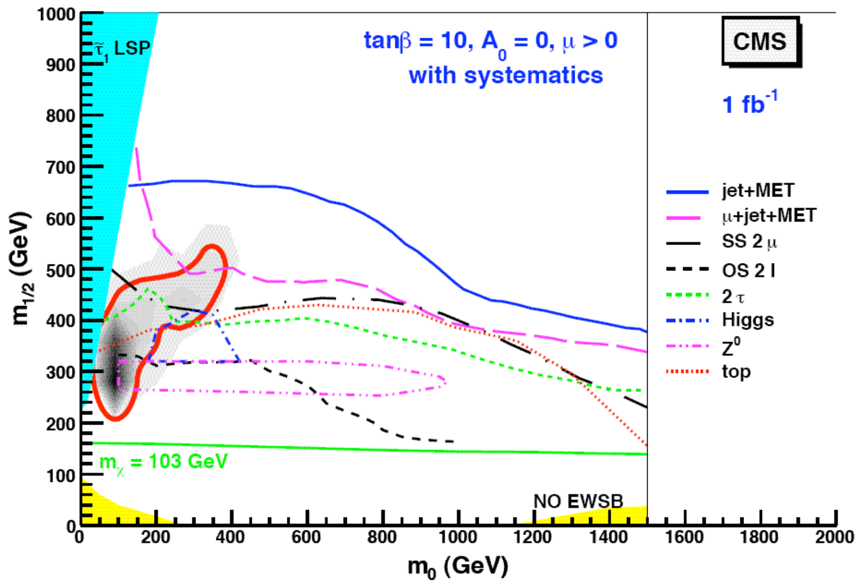

Figure 16: Regions of the m_0 – $m_{1/2}$ plane showing the CMS reach with 1 fb^{-1}. The dark region represents the most favoured fit to precision data (see text).

Early discoveries are possible at the LHC; take e.g. supersymmetry. The reach in SUSY parameter space that can be covered by the early measurements is typically studied for bench-mark scenarios. Fig. 16 shows that reach for different final state signatures, as function of two mSUGRA model parameters, namely the Universal scalar and gaugino masses: m_0 and $m_{1/2}$. The early reach of the LHC will be large, as already anticipated from the cross sections given above. The dark region at low m_0 shows the "preferred" region based on a fit of present precision data and heavy flavour variables within the constrained MSSM [78]. Clearly this region will be probed already with the first data.

As it got announced that the startup energy of the machine will be 10 TeV the prospects of these predictions will change. The global effect can be anticipated from Fig.17, which shows the ratio of the cross sections for 10 TeV to 14 TeV for quark-quark and gluon-gluon processes. In the area for discoveries, say above a TeV, the cross sections typically go down by a factor two or more.

Let me end by giving one example of additions that are proposed already now to the baseline

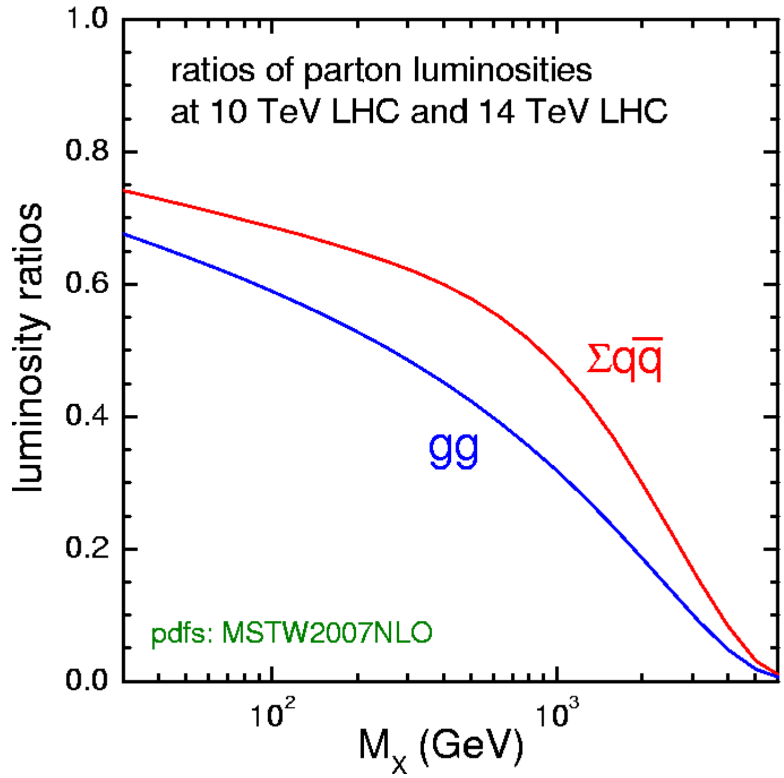

Figure 17: The ratio of the cross sections for 10 TeV to 14 TeV for quark quark and gluon gluon processes in pp collisions at the LHC, from [79]

detectors. My completely unbiased choice fell on the FP420 project as discussed in [76]. This project proposes and extension of the ATLAS and/or CMS baseline detectors by putting detectors at 420m away from the interaction point for protons that have lost less that 1% of their energy in the interaction but otherwise remain intact. A full R&D report on how to do this in practice is now available[77]. From the physics side it will not only allow CMS and ATLAS to make a number of uncanny QCD, two-photon and diffractive measurements due to the extra coverage, but will possibly also open a window to study properties of the Higgs, such as spin quantum numbers or –thanks to selections rules– the $b\bar{b}$ decay mode and coupling, otherwise difficult or impossible to access with the baseline LHC detectors[77,12]. The key process here is $pp \to p + H + p$, i.e. exclusive central Higgs production.

9 Conclusions

It has been a very lively Moriond QCD 2008, with lots of good data and discussions to remember, including a first showing of the F_L from HERA, the new top mass determination and corresponding EW t results, and a new Higgs search limit, starting to scratch the area of sensitivity to the SM Higgs. Some signatures of BSM physics, a bit larger than 3σ, have surfaced but we have to see if these is will survive further scrutiny and more data.

But one thing is clear: the LHC is coming this fall! Hence Moriond 2009 promises to be yet again a very interesting meeting.

Acknowledgments

I would like to thank the organizers for the invitation and for organizing at times real bad weather, so I did not feel alone, not skiing. I do wish to congratulate them for organizing a perfect conference.

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