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Hard diffraction at the LHC

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We present a short review about hard diffraction at the LHC. We start by describing the interest of exclusive diffractive event production, and we discuss the search for these events both at the Tevatron and the LHC. We discuss in particular the exclusive diffractive production of Higgs bosons, W and top events. We finish by discussing the uncertainties on the gluon distribution in the pomeron at large β and some new methods to measure the survival probability.

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1. Diffractive exclusive event production

1.1 Interest of exclusive events

A schematic view of non diffractive, inclusive double pomeron exchange, exclusive diffractive events at the Tevatron or the LHC [1, 2, 3] is displayed in Fig. 1. The upper left plot shows the “standard" non diffractive events where the Higgs boson, the dijet or diphotons are produced directly by a coupling to the proton and shows proton remnants. The bottom plot displays the standard diffractive double pomeron exchange where the protons remain intact after interaction and the total available energy is used to produce the heavy object (Higgs boson, dijets, diphotons...) and the pomeron remnants. These events can be described using the parton densities in the pomeron measured at HERA. There may be a third class of processes displayed in the upper right figure, namely the exclusive diffractive production. In this kind of events, the full energy is used to produce the heavy object (Higgs boson, dijets, diphotons...) and no energy is lost in pomeron remnants. There is an important kinematical consequence: the mass of the produced object can be computed using roman pot detectors and tagged protons:

$$M = \sqrt{\xi_1 \xi_2 S}. \tag{1.1}$$

We see immediately the advantage of those processes: we can benefit from the good roman pot resolution on ξ to get a good resolution on mass. It is then possible to measure the mass and the kinematical properties of the produced object and use this information to increase the signal over background ratio by reducing the mass window of measurement. It is thus important to know if this kind of events exist or not.

1.2 Search for exclusive events at the Tevatron

The CDF collaboration measured the so-called dijet mass fraction in dijet events - the ratio of the mass carried by the two jets divided by the total diffractive mass - when the antiproton is tagged in the roman pot detectors and when there is a rapidity gap on the proton side to ensure that the event corresponds to a double pomeron exchange. The results are shown in Fig. 2 and are compared with the POMWIG [4] expectation using the gluon and quark densities measured by the H1 collaboration in dashed line [5]. We see a clear deficit of events towards high values of the dijet mass fraction, where exclusive events are supposed to occur (for exclusive events, the dijet mass fraction is 1 by definition at generator level and can be smeared out towards lower values taking into account the detector resolutions). Fig. 2 shows also the comparison between data and the predictions from the POMWIG and DPEMC generators, DPEMC being used to generate exclusive events [2]. There is a good agreement between data and MC. However, this does not prove the existence of exclusive events since the POMWIG prediction shows large uncertainties (the gluon in the pomeron used in POMWIG is not the latest one obtained by the H1 collaboration [6, 2] and the uncertainty at high β is quite large [7]). The results (and the conclusions) might change using the newest gluon density and will be of particular interest. In addition, it is not obvious one can use the gluon density measured at HERA at the Tevatron since factorisation does not hold, or in other words, this assumes that the survival probability is a constant, not depending on the kinematics of the interaction.

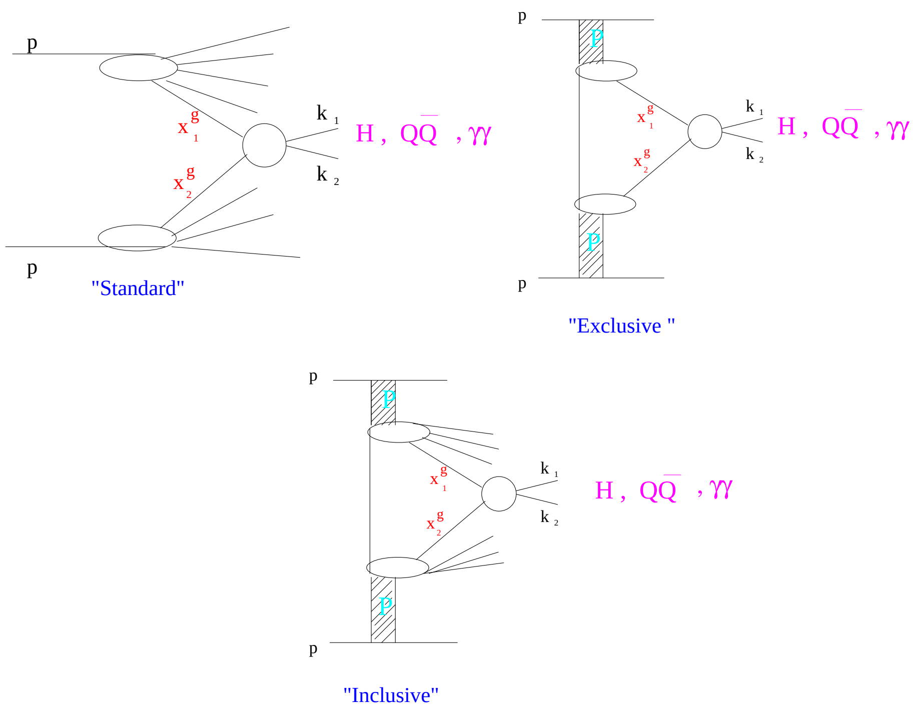

Figure 1: Scheme of non diffractive, inclusive double pomeron exchange, exclusive diffractive events at the Tevatron or the LHC.

A direct precise measurement of the gluon density in the pomeron through the measurement of the diffractive dijet cross section at the Tevatron and the LHC will be necessary if one wants to prove the existence of exclusive events in the dijet channel. However, this measurement is not easy and requires a full QCD analysis. We expect that exclusive events would appear as a bump in the gluon distribution at high β, which will be difficult to interprete. To show that this bump is not due to tail of the inclusive distribution but real exclusive events, it would be necessary to show that those tails are not compatible with a standard DGLAP evolution of the gluon density in the pomeron as a function of jet transverse momentum. However, it does not seem to be easy to distinguish those effects from higher twist ones. It is thus important to look for different methods to show the existence of exclusive events.

The CDF collaboration also looked for the exclusive production of dilepton and diphoton. Contrary to diphotons, dileptons cannot be produced exclusively via pomeron exchanges since $gg \rightarrow \gamma\gamma$ is possible, but $gg \rightarrow l^+ l^-$ directly is impossible. However, dileptons can be produced via QED processes, and the cross section is perfectly known. The CDF measurement is $\sigma = 1.6^{+0.5}_{-0.3}(stat) \pm 0.3(syst)$ pb which is found to be in good agreement with QED predictions and shows that the acceptance, efficiencies of the detector are well understood. Three exclusive diphoton events have been observed by the CDF collaboration leading to a cross section of $\sigma = 0.14^{+0.14}_{-0.04}$ $(stat) \pm 0.03(syst)$ pb compatible with the expectations for exclusive diphoton production at the Tevatron.

Other searches like χ_C production and the ratio of diffractive b jets to the non diffractive ones as a function of the dijet mass fraction show further indications that exclusive events might exist

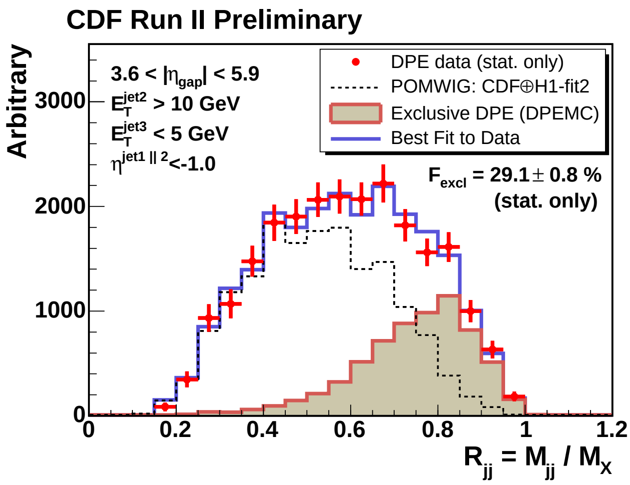

Figure 2: Search for exclusive diffractive events at CDF.

but there is no definite proof until now.

1.3 Search for exclusive events at the LHC

The search for exclusive events at the LHC can be performed in the same channels as the ones used at the Tevatron. In addition, some other possibilities benefitting from the high luminosity of the LHC appear. One of the cleanest way to show the existence of exclusive events would be to measure the dilepton and diphoton cross section ratios as a function of the dilepton/diphoton mass. If exclusive events exist, this distribution should show a bump towards high values of the dilepton/diphoton mass since it is possible to produce exclusively diphotons but not dileptons at leading order.

The search for exclusive events at the LHC will also require a precise analysis and measurement of inclusive diffractive cross sections and in particular the tails at high β since it is a direct background to exclusive event production.

2. Results on exclusive diffractive Higgs production

One special interest of diffractive events at the LHC is related to the existence of exclusive events. So far, two projects are being discussed at the LHC: the installation of roman pot detectors at 220 m in ATLAS [8], and at 420 m for the ATLAS and CMS collaborations [9].

The results discussed in this section rely on the DPEMC Monte Carlo to produce Higgs bosons exclusively [1, 2, 3] and a fast simulation of a typical LHC detector (ATLAS or CMS). Results are given in Fig. 3 for a Higgs mass of 120 GeV, in terms of the signal to background ratio S/B, as a function of the Higgs boson mass resolution. Let us notice that the background is mainly due the exclusive $b\bar{b}$ production. However the tail of the inclusive $b\bar{b}$ production can also be a relevant contribution and this is related to the high β gluon density which is badly known at present. In order to obtain a S/B of 3 (resp. 1, 0.5), a mass resolution of about 0.3 GeV (resp. 1.2, 2.3 GeV) is needed. A mass resolution of the order of 1 GeV seems to be technically feasible.

M_{Higgs}	cross section	signal	backg.	S/B	σ
120	3.9	27.1	28.5	0.95	5.1
130	3.1	20.6	18.8	1.10	4.8
140	2.0	12.6	11.7	1.08	3.7

Table 1: Exclusive Higgs production cross section for different Higgs masses, number of signal and background events for 100 fb^{-1}, ratio, and number of standard deviations (σ).

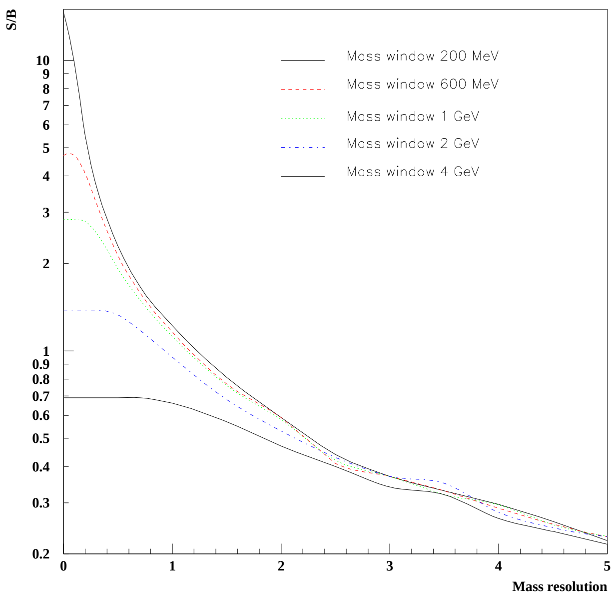

Figure 3: Standard Model Higgs boson signal to background ratio as a function of the resolution on the missing mass, in GeV. This figure assumes a Higgs boson mass of 120 GeV.

The diffractive SUSY Higgs boson production cross section is noticeably enhanced at high values of $\tan\beta$ and since we look for Higgs decaying into $b\bar{b}$, it is possible to benefit directly from the enhancement of the cross section contrary to the non diffractive case. A signal-over-background up to a factor 50 can be reached for 100 fb^{-1} for $\tan\beta \sim 50$ [10] (see Fig. 4).

3. Threshold scan method: W, top and stop mass measurements

In the same way that Higgs bosons can be produced exclusively, it is possible to produce W, top and stops quark pairs. WW bosons are produced via QED processes which means that their cross section is perfectly known. On the contrary, top and stop pair production are obtained via double pomeron exchanges and the production cross section is still uncertain.

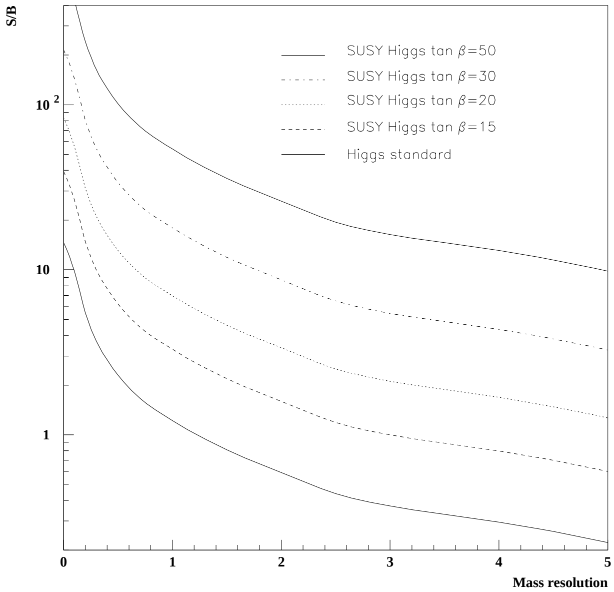

Figure 4: SUSY Higgs boson signal to background ratio as a function of the resolution on the missing mass, in GeV. This figure assumes a Higgs boson mass of 120 GeV.

The method to reconstruct the mass of heavy objects double diffractively produced at the LHC is based on a fit to the turn-on point of the missing mass distribution at threshold [11].

One proposed method (the "histogram" method) corresponds to the comparison of the mass distribution in data with some reference distributions following a Monte Carlo simulation of the detector with different input masses corresponding to the data luminosity. As an example, we can produce a data sample for 100 fb^{-1} with a top mass of 174 GeV, and a few MC samples corresponding to different top masses between 150 and 200 GeV. For each Monte Carlo sample, a χ^2 value corresponding to the population difference in each bin between data and MC is computed. The mass point where the χ^2 is minimum corresponds to the mass of the produced object in data. This method has the advantage of being easy but requires a good simulation of the detector.

The other proposed method (the "turn-on fit" method) is less sensitive to the MC simulation of the detectors. As mentioned earlier, the threshold scan is directly sensitive to the mass of the diffractively produced object (in the WW case for instance, it is sensitive to twice the WW mass). The idea is thus to fit the turn-on point of the missing mass distribution which leads directly to the mass of the produced object, the WW boson. Due to its robustness, this method is considered as the "default" one.

The precision of the WW mass measurement (0.3 GeV for 300 fb^{-1}) is not competitive with other methods, but provides a very precise check of the calibration of the roman pot detectors. WW events will also allow to assess directly the sensitivity to the photon anomalous coupling since it would reveal itself by a modification of the well-known QED WW production cross section. We can notice that the WW production cross section is proportional to the fourth power of the

γW coupling which ensures a very good sensitivity of that process [12]. The precision of the top mass measurement is however competitive, with an expected precision better than 1 GeV at high luminosity provided that the cross section is high enough. The other application is to use the so-called “threshold-scan method" to measure the stop mass [10]. After taking into account the stop width, we obtain a resolution on the stop mass of 0.4, 0.7 and 4.3 GeV for a stop mass of 174.3, 210 and 393 GeV for a luminosity (divided by the signal efficiency) of 100 fb^{-1}.

The caveat is of course that the production via diffractive exclusive processes is model dependent, and definitely needs the Tevatron and LHC data to test the models. It will allow us to determine more precisely the production cross section by testing and measuring at the Tevatron the jet and photon production for high masses and high dijet or diphoton mass fraction.

4. Hard inclusive diffraction at the LHC

In this section, we would like to discuss how we can measure the gluon density in the pomeron, especially at high β since the gluon in this kinematical domain shows large uncertainties [7] and this is where the exclusive contributions should show up if they exist. To take into account the high-β uncertainties of the gluon distribution, we chose to multiply the gluon density in the pomeron measured at HERA by a factor $(1-\beta)^{\nu}$ where ν varies between -1.0 and 1.0. If ν is negative, we enhance the gluon density at high β by definition, especially at low Q^2.

A possible measurement at the LHC is described in Fig. 5. The dijet mass fraction is shown in dijet diffractive production for different jet transverse momenta ($P_T > 100$ (upper left), 200 (upper right), 300 (lower left) and 400 GeV (lower right)), and for the different values if ν. We notice that the variation of this distribution as a function of jet p_T can assess directly the high β behaviour of the gluon density. In the same kind of ideas, it is also possible to use $t\bar{t}$ event production to test the high-β gluon. Of course, this kind of measurement will not replace a direct QCD analysis of the diffractive dijet cross section measurement.

Other measurements already mentionned such as the diphoton, dilepton cross section ratio as a function of the dijet mass, the b jet, χ_C, W and Z cross section measurements will be also quite important at the LHC.

5. Possibility of survival probablity measurements at DØ

A new measurement to be performed at the Tevatron, in the DØ experiment has been proposed [13], which can be decisive to test directly the concept of survival probability at the Tevatron, by looking at the azimuthal distributions of the outgoing proton and antiproton with respect to the beam direction.

In Fig. 6, we display the survival probability for three different values of t as a function of the difference in azimuthal angle between the scattered p and $\bar{p}$. The upper black curve represents the case where the t of the p and $\bar{p}$ are similar and close to 0. In that case, only a weak dependence on $\Delta\Phi$ is observed. The conclusion is different for asymmetric cases or cases when t is different from 0: Fig. 6 also shows the result in full red line for the asymmetric case ($t_1 = 0.2$, $t_2 = 0.7$ GeV^2), and in full and dashed blue lines for $t_1 = t_2 = 0.7$ GeV^2 for two different models of survival

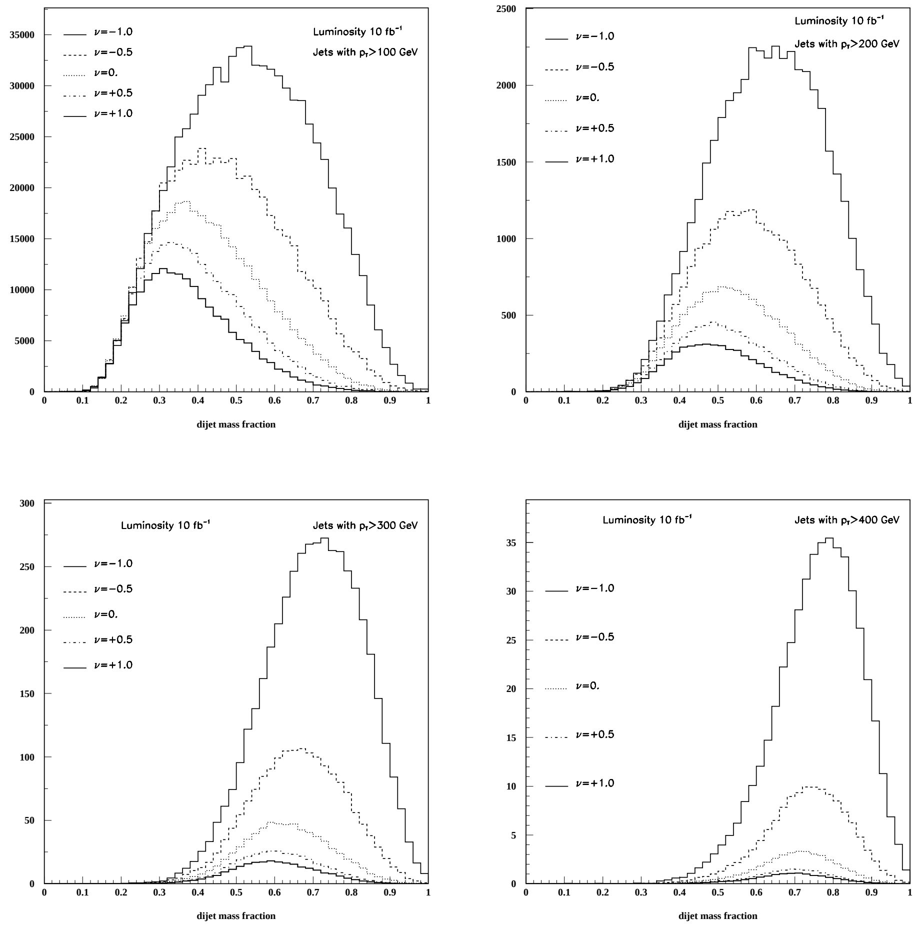

Figure 5: Dijet mass fraction for jet $P_T > 100$ (upper left), 200 (upper right), 300 (lower left) and 400 GeV (lower right) for different gluon assumptions at high β (the gluon is multiplied by $(1-\beta)^{\nu}$).

probabilities. We notice that we get a very strong $\Delta\Phi$ dependence of more than one order of magnitude.

The Φ dependence can be tested directly using the roman pot detectors at DØ (dipole and quadrupole detectors) and their possibility to measure the azimuthal angles of the p and $\bar{p}$. For this purpose, we define the following configurations for dipole-quadrupole tags: same side (corresponding to $\Delta\Phi < 45$ degrees), opposite side (corresponding to $\Delta\Phi > 135$ degrees), and middle side (corresponding to $45 < \Delta\Phi < 135$ degrees). In Table 2, we give the ratios $middle/(2 \times same)$ and $opposite/same$ (note that we divide *middle* by 2 to get the same domain size in Φ) for the different models. In order to obtain these predictions, we used the full acceptance in t and ξ of the FPD detector. Moreover the ratios for two different tagging configurations, namely for $\bar{p}$ tagged in dipole detectors, and p in quadrupoles, or for both p and $\bar{p}$ tagged in quadrupole detectors [13] were computed.

The results are also compared to expectations using another kind of model to describe diffrac-

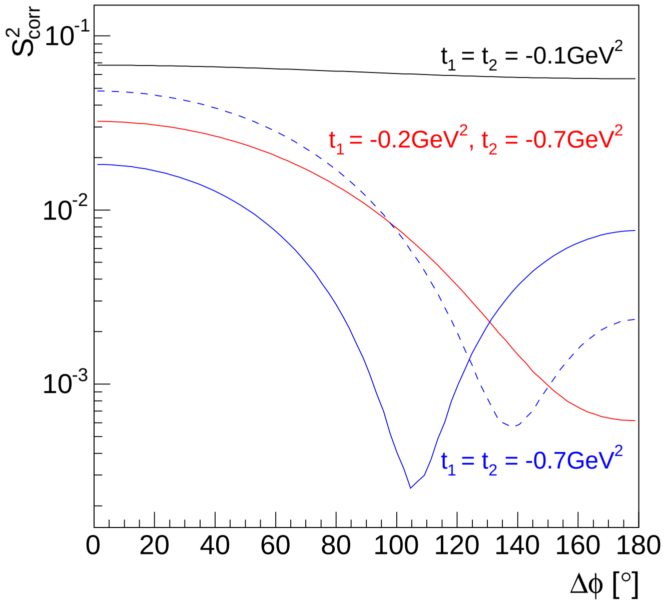

Figure 6: $\Delta\Phi$ dependence of the survival probability for two different models of survival probability where $\Delta\Phi$ is the difference in azimuthal angle between the scattered p and $\bar{p}$ in the final state, and for three different values of t (see text).

tive events, namely soft colour interaction [14]. This model assumes that diffraction is not due to a colourless exchange at the hard vertex (called pomeron) but rather to string rearrangement in the final state during hadronisation. In this kind of model, there is a probability (to be determined by the experiment) that there is no string connection, and so no colour exchange, between the partons in the proton and the scattered quark produced during the hard interaction. Since this model does not imply the existence of pomeron, there is no need of a concept like survival probability, and no dependence on $\Delta\Phi$ of diffractive cross sections. The proposed measurement would allow to distinguish between these two dramatically different models of diffraction.

6. Conclusion

In this short review about hard diffraction at the LHC, we started by describing the interest of exclusive diffractive event production, and we discussed the search for these events both at the Tevatron and the LHC. We discussed in particular the exclusive diffractive production of Higgs bosons, W and top events. We finished by discussing the uncertainties on the gluon distribution in the pomeron at large β and some new methods to measure the survival probability.

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Config.	model	midd./ same	opp./ same
Quad. + Dipole	SCI	1.3	1.1
	Pom. 1	0.36	0.18
	Pom. 2	0.47	0.20
Quad. + Quad.	SCI	1.4	1.2
	Pom. 1	0.14	0.31
	Pom. 2	0.20	0.049

Table 2: Predictions for a proposed measurement of diffractive cross section ratios in different regions of $\Delta\Phi$ at the Tevatron (see text for the definition of middle, same and opposite). The first (resp. second) measurement involves the quadrupole and dipole detectors (resp. quadrupole detectors only) leading to asymmetric (resp. symmetric) cuts on t.

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