Armenian Journal of Physics, vol. 1, issue 4, 2008, pp. 270-279

Studying parton structure of the Pomeron in DPE processes with $\mu^+\mu^-$ pairs production on the CMS(LHC)

S. Chatrchyan, G. Hmayakyan, V. Khachatryan, and A. Sirunyan

Received January 12, 2009

Alikhanian Yerevan Physics Institute, Yerevan, Armenia

Abstract

Process of $\mu^+\mu^-$ pair production in hard Double Pomeron Exchange (DPE) is studied on the CMS (LHC) at energy $\sqrt{s}$ = 14 TeV. In the zero order of a_s this process is sensitive only to quark distributions. Using H1(DESY) data for quark-antiquark parton distributions in the Pomeron, calculations were performed to predict the quark-antiquark component of the parton distribution and the estimate is that quark-antiquark does not exceed 5%. Using CMSSW package, the events of the process were reconstructed. The method for estimation of valent quark(antiquark) contribution in the parton structure of the Pomeron is developed. This method could be used at the experimental data performance obtained on the CMS detector.

1. Introduction

Over the last decade, interest in studying diffractive processes has increased. The pronounced features of diffractive (nonperturbative) interactions were observed in the events registered in the experiments carried out at CERN [1], on HERA [2, 3] and Tevatron [4, 5]. First, secondary beams with a large longitudinal momentum ($x_F \sim 0.9$), i.e. with the ejection of a main energy of initial hadrons in a narrow phase space volume (diffraction cone), were registered. Second, an interval in the pseudorapidity space (between these beams), not filled with secondary hadrons ("rapidity gap"), was observed. (As shown, the existence of rapidity gaps (RG) is due to the exchange by a colourless object: a photon, *W-, Z*-bosons, etc. and, in particular, a Pomeron IP [6]). Thus, the energy characteristics of the particles involved in the process of scattering were such that these processes fell within the area of QCD applicability. The fraction of such events was: ~6-7% for *ep* interactions [2, 3] and ~ 1% for *pp* interactions [4, 5] of the total number of events of deep inelastic scattering. (The theoretical estimates predict a growth of this value for LHC energies up to ~ 10–15%, see [7, 8]). A detailed analysis of the experimental data has shown that they are well described by the Pomeron exchange.

The hypothesis of Pomerons, first suggested by I.Ya.Pomeranchuk in 1958, was used to explain the behavior of the total cross-section of hadron-hadron interactions at the limits of high energies

[9]. In the Regge theory, the Pomeron is a colourless object having vacuum quantum numbers. The Regge trajectory corresponds to it: $\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha t$, where $\alpha_{IP}(0) \sim 1$, $\alpha' \sim 0.25$ GeV^{-2} and t is the invariant momentum transfer to the Pomeron [10]. In 1985, G.Ingelman and P.Schlein put forward the idea of the parton structure of Pomeron [11]. It was then verified by the experiments on diffractive structure function $F_2^D\left(\xi,t,z,Q^2\right)$ [1–3].

Today there is no unambiguously defined picture of Pomeron‘s parton structure, such as for example, for protons or mesons. The assumption that Pomeron consists of soft (sea) and valent partons, i.e. quarks (antiquarks) and gluons, requires further qualitative and quantitative improvements. It is obvious that depending on Pomeron’s structure also the cross-sections of Pomeron mediated processes will be various.

In this work we consider a possibility to investigate parton structure of Pomeron, mainly quark-antiquark contribution in parton structure, on the CMS. With this purpose, the $\mu^+\mu^-$ pair production in hard Double Pomeron Exchange (DPE) process is considered:

$$\mathrm{p}+\mathrm{p}\rightarrow\mathrm{p}+\left(\gamma/\mathrm{Z}\right)\rightarrow\mu^{+}+\mu^{-}+\mathrm{X}+\mathrm{p} \qquad (1)$$

In the zero order of α_s this process proceeds exclusively from the quark-antiquark interaction (see Fig. 1).

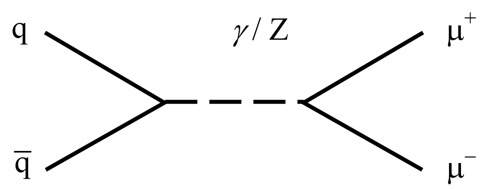

Fig 1: Feynman diagram describing $\mu^+\mu^-$ pair production from the interaction of quark-antiquark in the zero order of α_s.

At the present time, it is assumed that the Pomeron structure function $F_2^D(\xi, t, z, Q^2)$ can be represented as a product of the parton distribution function of Pomeron $P_{g/\mathbb{P}}(z, Q^2)$ and the factor of flow $F_{\mathbb{P}/p}(\xi,t)$ - the hypothesis of factorization[1] [12, 13]:

$$F_2^D\left(\xi,t,z,Q^2\right)=F_{\mathbb{P}/p}\left(\xi,t\right)\otimes P_{g/\mathbb{P}}\left(z,Q^2\right) \qquad (2)$$

In the presented work we will concentrate only on the parton distribution function $P_{g/\mathbb{P}}\left(z,Q^2\right)$.

[1]There is a number of papers, in which the hypothesis of factorization is called in question (see, for example, [14]), but even if factorization is violated for diffractive hard scattering, the effect may be weak at high energies [15].

2. Muon-antimuon pair production in DPE

Any parton distribution function in general can be consider as superposition of two so-called "seed" functions - "hard" and "soft". The definitions of seed functions are rather tentatively, so we define them from the general conditions. Typical a "hard"(i.e. describing valence parton distribution) parton function has the form $z\,P_{hard}(z) \simeq z*(1-z)$. This form describes the distribution that approaches zero at $z \rightarrow 1$, and also absence of the parton contribution with small *z,* i.e. the contribution of "sea" partons. Contrary to it, "soft" (describing sea distributions) function of parton distributions traditionally is presented in the form of $z\,P_{soft}(z) \simeq 1/\ z*(1-z)$. This form provides growth of partons contribution with small *z* and their absence at $z \rightarrow 1$.

Proceeding from it to investigate parton distributions in Pomeron we have chosen for such functions:

$$z\,P_{hard}(z\,,\,Q_0^2) \simeq N_h*\ \ z*(1-z). \tag{3}$$

–hard one, and

$$z\,P_{soft}(z\,,\,Q_0^2) \simeq N_s\,/\,z^{\,0.01}*(1-z)^{10}*(1-2*z^{\,0.5})^2. \tag{4}$$

- soft (sea) one. Here $Q_0^2 = 2$ GeV^2, where N_h and N_s are normalized constants. Figure 2 shows these functions in a graphical form.

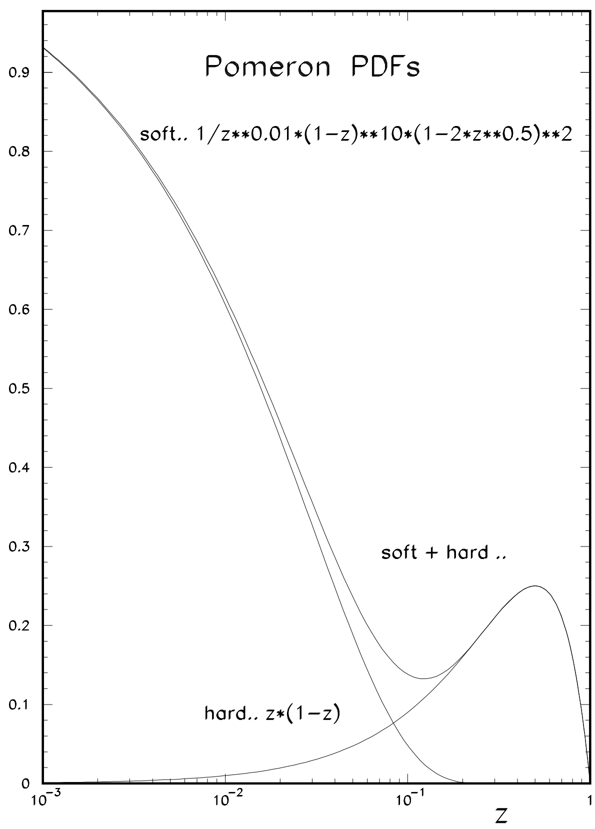

Fig. 2. Pomeron parton distribution functions $z\,P(z,\ Q_0^2)$,

where $Q^2{}_0 = 2$ GeV^2. Assuming, $N_{h,s} = 1$

Normalized constants are defined from restriction on the total contribution of quark-antiquark components in Pomeron's momentum:

$$N_d \int_0^1 zP_d\left(z, Q_0^2\right) = A_d, \tag{5}$$

where $d = s$, h for soft and hard distributions, correspondingly (for A_d see further)

The choice of such distributions is not unique and first of all is defined by need to separate in z-area the soft and hard components. In our case the border(separation) between them lies at $z \sim 0.1$. Of course, one can select other, more realistic seed distribution functions (3) and (4) in dependence on the specific tasks and express reconstructing distributions in terms of those.

Now, we define different sets of parton distribution functions on the base of these "seed" ones (see Table 1).

Table 1. Sets of parton distribution functions zP(z,Q2).
Here P=G,S,C,B,T depict quark flavours. It is assumed that quark and antiquark distributions coincide.

Partons	Set 1	Set 2	Set 3
$zU(z, Q_0^2)$	P_{soft}	P_{hard}	$P_{hard} + P_{soft}$
$zD(z, Q_0^2)$	P_{soft}	P_{hard}	$P_{hard} + P_{soft}$
$zP(z, Q_0^2)$	0	0	0

In Table 1 U, D depict appropriate quark flavours. Distributions for antiquarks coincide with quark ones. Also P depicts G,S,C,B,T partons.

The sets 1-3 of parton functions of Pomeron are used for simulation of 50000 events of $\mu+\mu-$ production in DPE process (1) at $\sqrt{s}$ = 14 TeV. The couple of Monte-Carlo generators POMWIG 2.0 beta [16] and HERWIG 6.510 [17] is used with that propose. Also, the parton distribution, obtained by H1 Collaboration (" H1 fit 2006 A " [18]), which is incorporated in the generator POMWIG have been used. The last one is used as an imitation of experimental (real) data.

Total cross-sections of process (1) calculated by parameterization of parton functions SET 1-3 and "H1 fit 2006 A" are given in Table 2

Table 2: Total cross-sections of process (1) obtained by parameterization
of parton functions SET 1-3 (normalizing constants are N_d = 1) and "H1 fit 2006 A" for $\sqrt{s}$ = 14 TeV.

Parameterization	$\sigma \pm \Delta\sigma$ (pb), N_d=1
Set 1 (soft)	163.7 ± 0.43
Set 2 (hard)	393.9 ± 0.8
Set 3 (full)	1779 ± 3.7
H1 fit 2006 A	31.9 ± 0.05

In calculations we used $N_d = 1$ (N_d are normalizing constants in (3), (4)). Distributions of momentum transfer and pseudorapidity for muon-antimuon pairs in process (1) for chosen sets of parton distribution functions are shown in Fig.3.

Comparison of curves shows that only distributions containing valence and sea quarks and antiquarks agree with experimentally measured distributions. Let's note that muon pairs production on mass surface of Z-boson is most sensitive to valence distributions and the main contribution to Z-boson production goes from the range $1 > z > z_{min} = M_Z/\sqrt{s} \approx 0.065$. Thus it is possible to affirm that in Pomeron there are both "hard" valence and "soft" (sea) quark (antiquark) components of parton distributions, i.e. the Pomeron has similar for meson parton structure.

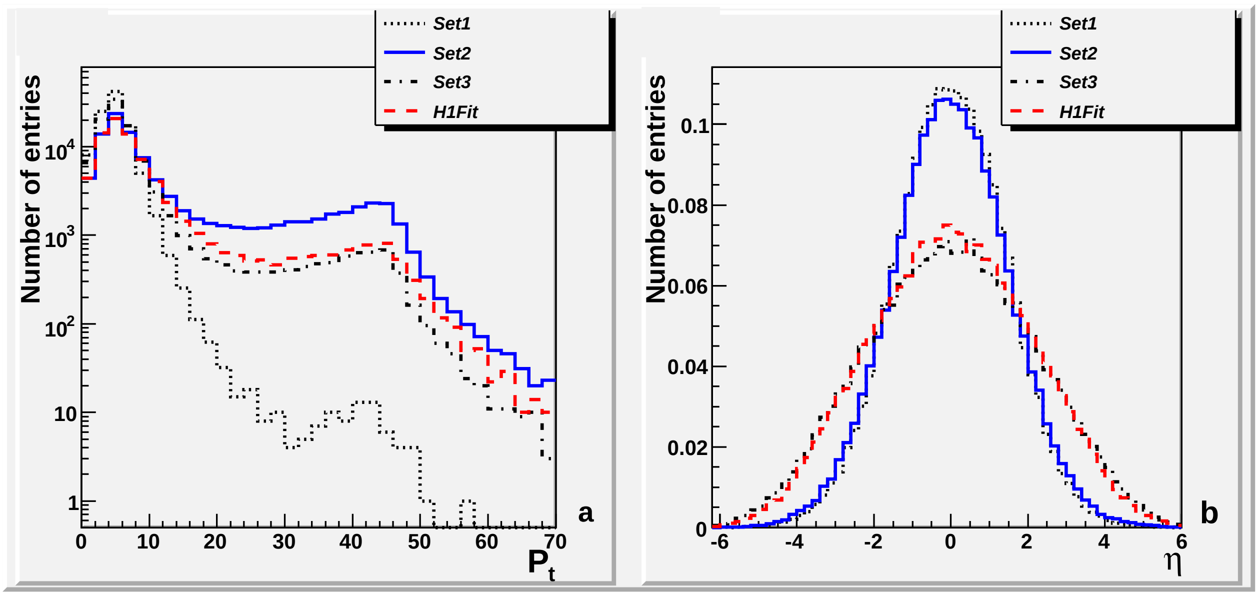

Figure 3: Distributions of momentum transfer (a) and pseudorapidity (b) for muon-antimuon pairs in reaction (1) using parameterization of parton functions SET 1-3 and "H1 fit 2006 A" at $\sqrt{s}$ = 14 TeV

Let's define the normalized constants $N_{h,s}$ in (5). For this purpose we shall equate to each other total cross-sections of process (1) for "H1 fit 2006 A" and sets "SET 1-3" (see Table 2). In view of the fact that we consider process DPE, i.e. the total cross-section will be proportional to the square of normalized constants $N_{h,s}$, we have:

$$N_i^2 \sigma_{Set\,i} = \sigma_{H1\,fit\,2006\,A}, \tag{6}$$

where $i = 1,2,3$. From condition (6) we find values of normalized constants $N_{d,i}$. Then integrating function (5) we get the value A_d that defines the contribution of parton component in Pomeron. SET 3 parametrization agrees best with H1 data and predicts quark-antiquark contribution of ~ 5% [19]. Next the gluon component is to be studied in parton distribution.

3. Event reconstruction with the CMSSW

To simulation and study of CMS detector the CMSSW software package was developed [20]. It includes programs to simulate events in the CMS as well as some general reconstruction and analyzing tools. So, let us consider a possibility of the quark(antiquark) parton distribution analysis in the CMS experiment.

For generation of process (1), simulation of the detector geometry, materials, particle propagation inside the detector, reconstruction of simulated events and finally, data analyzing the CMSSW 1.6.12 version of the package is used.

The ”global” muons(antimuons) which are originated in process (1) and reconstructed with the CMSSW are used in the analysis. The ”global” muon reconstruction consists in extending the muon trajectories to include hits in the tracker. Starting from reconstructed muons in muon stations, the muon trajectory is extrapolated from the innermost muon station to the outer tracker surface, taking into account the muon energy losses in the material and the effects of multiple scattering. Due to limited area of pseudorapidity covered by tracker and muon stations, only muons with $|\eta| < 2.5$ are accepted.

In Fig.4 η-distributions of any detected muons (antimuons) are shown. Also, the η-reconstruction efficiency is given. Easy to see that the efficiency of reconstructed muons is 0.8 in average, which coincides with the estimations of the detector performance [21].

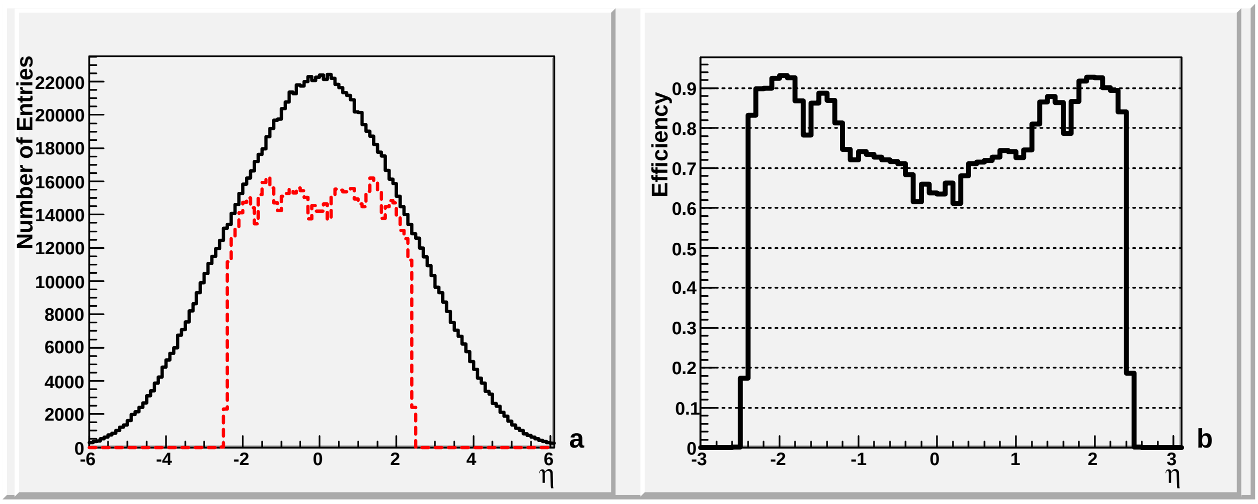

Fig. 4. Distributions of pseudorapidity (a) and its efficiency (b) for muon-antimuon pairs in process (1) obtained with parameterization ”SET 3”. Single muon reconstruction algorithm with CMSSW is applied.

The invariant mass of muon-antimuon pair is reconstructed on the base of events where both particles (μ^+ and μ^-) are reconstructed with an additional requirement that the vertexes of μ^+ μ^- coincide.

In Fig.5 the invariant mass distribution of generated and reconstructed $\mu^+\mu^-$ pairs is shown for area of masses > 10 GeV (a,c,e,g) and in area of Z-boson mass (b,d,f,h) for considered sets of parton distributions (see Table 1).

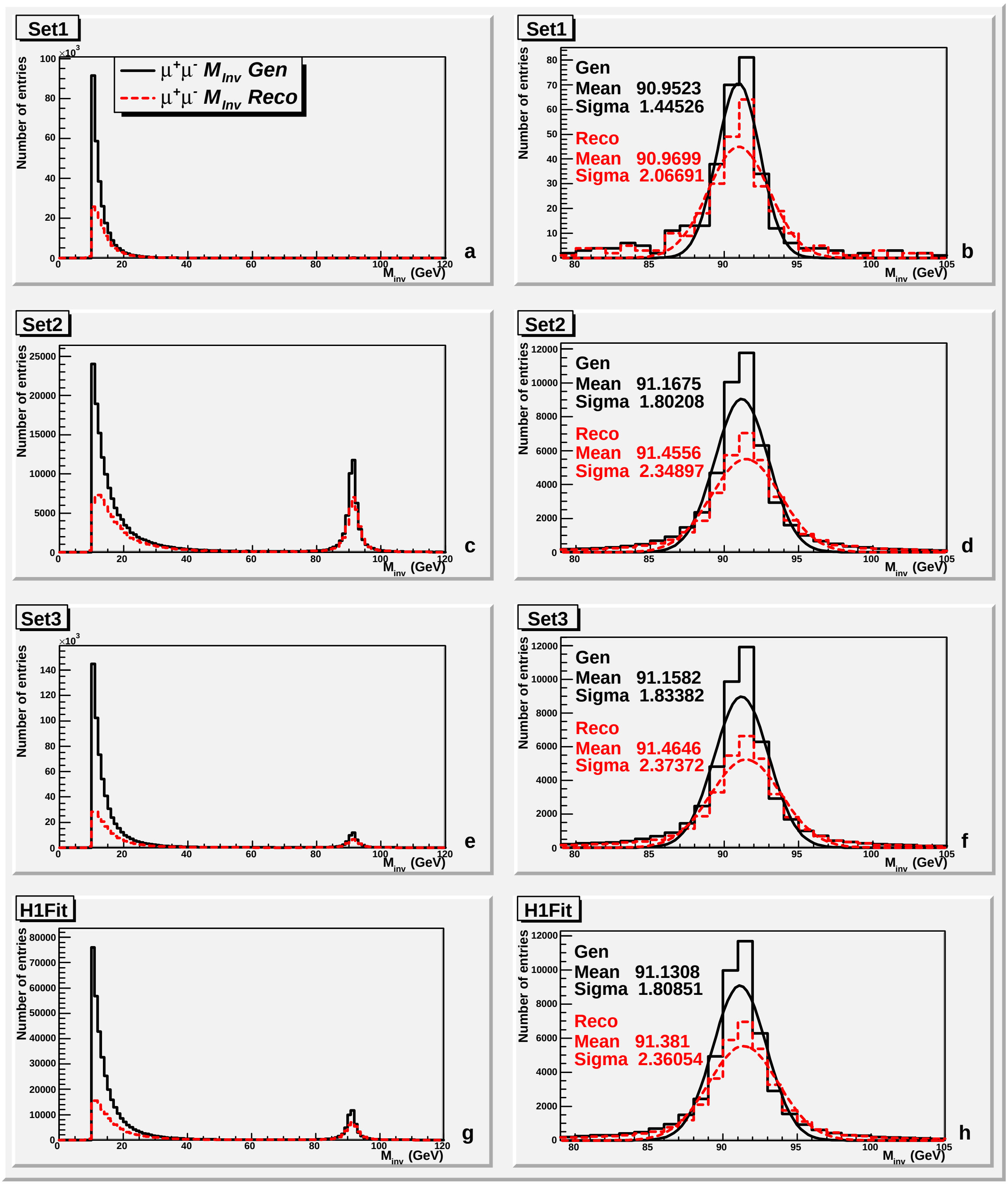

Fig. 5. Distribution by an invariant mass of muon-antimuon pairs and Invariant mass reconstruction efficiency. Muon-antimuon pair reconstruction algorithm with CMSSW is applied.

We estimate ratio of events in two areas of masses from 70 to 120 GeV *(M_Z)* and from 10 to 120 GeV *(M_{inv})*

$$R = M_z / M_{inv} \qquad (7)$$

In fact, the ratio *R* shows the contribution of hard quarks (antiauarks) into parton distribution function of the Pomeron. The values for all sets are given in Table 3.

Table 3: Invariant mass ratio in two different areas of masses defined in (7) for chosen sets of Pomeron parton distributions SET 1-3 and "H1 fit 2006 A".

Parameterization	*Rgen*	*Rreco*
Set 1 (soft)	0.12%	0.23%
Set 2 (hard)	26.0%	32.75%
Set 3 (full)	7.92%	14.90%
H1 fit 2006 A	12.38%	22.45%

One can see that the ratio for Set 3 is closer to the "real" one than it is for pure hard or soft sets. The same result we obtain after reconstruction (compare columns *gen* and *reco* in the Table 3). This means that reconstruction does not violate real distributions noticeably. Need to say that during reconstruction a huge part of events with "soft" production is omitted.

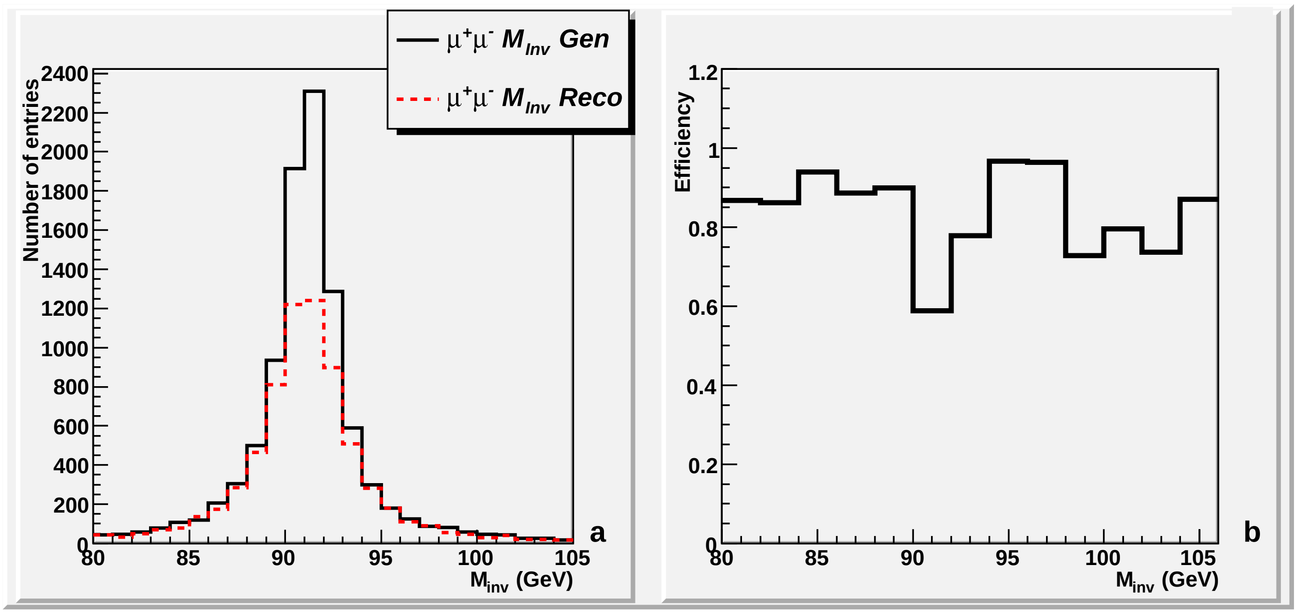

Fig. 6. Muon-antimuon pairs Invariant mass in the area of *Z*-boson mass and *Z*-boson mass reconstruction efficiency (by reconstruction with CMSSW 2.1.9).

Finally, we show the efficiency of *Z*-boson mass reconstruction. In Fig. 6 we show the invariant mass distribution of $\mu^+\mu^-$ system in area of *Z*-boson mass. Also, the *Z*-boson mass reconstruction efficiency is shown. The average value of the efficiency is approximately 75% [22].

4 Conclusion

Process of muon-antimuon pairs production in double Pomeron scattering of protons (1) has been considered at energy $\sqrt{s}$ = 14 TeV. Such process in the zero order of α_s is sensitive exclusively to quark-antiquark parton distributions in Pomeron. Using the parton distributions from H1 collaboration [18], it is shown that in the Pomeron there is ”hard” (valence) quark-antiquark component. Pomeron has a similar structure with mesons. The method to estimate a contribution of valent (sea) quark (antiquarks) in the parton structure of the Pomeron is considered. This method could be used at the experimental data performance obtained on the CMS detector.

References

[1] UA8 Collab., R.Bonio et al., Phys. Lett. **B211**, (1988), 239; UA8 Collab., A.Brandt et al., Phys. Lett. **B297**, (1992), 417.

[2] H1 Collab., T.Ahmed et al., Phys. Lett. **B348**, (1995), 681; Nucl. Phys. **B429**, (1995), 477; Nucl. Phys. **B439**, (1995), 471.

[3] ZEUS Collab., M.Derrick et al., Phys. Lett. **B315**, (1993), 481; Phys. Lett. **B332**, (1994), 228; Phys. Lett. **B338**, (1994), 483; Phys. Lett. **B369**, (1996), 55; Z. Phys. **C65**, (1995), 379; Z. Phys. **C68**, (1995), 569.

[4] CDF Collaboration, Phys. Rev. D 50, 5535, (1994); Phys. Rev. Lett. 69, 3704, (1992); **74**, 855,(1995).
CDF Collaboration, Phys. Rev. Lett. **78**, 2698, (1997). CDF Collaboration, Phys. Rev. Lett. **79**, 2636, (1997).

[5] D0 Collaboration, Phys. Rev. Lett **72**, 2332, (1994); **76**, 734, (1996).

[6] Y.Dokshitzer, V.Khoze, S.Troyan, in *Physics in Collision VI, Proceedings, Chicago, Illinois, 1986*, edited by M.Derrick (World Scientific, Singapore, 1987), 365; Yad. Fiz. **46**, 1220, (1987).

[7] J.D.Bjorken, Int. Jour. Mod. Phys. A **7**, 4189, (1992).

[8] A.Donnachie, P.Landshoff, Nucl. Phys. B **303**, 634, (1988).

[9] I.Y.Pomeranchuk, Sov. Phys. JETP **7**, 499, (1958).

[10] P.D.B.Collins, *Introduction to Regge Theory and High Energy Physics* (Cambridge University Press, 1977).

[11] G.Ingelman, P.Schlein, Phys. Lett. **B152**, (1985), 256.

[12] A.Donnachie, P.V.Landshoff, Phys. Lett. **B191**, (1987), 309; Phys. Lett. **B198**, (1987), 590; Phys. Lett. **B296**, (1992), 227; Nucl. Phys. **B244**, (1984), 322; Nucl. Phys. **B267**, (1986), 690.

[13] G.Ingelman K.Janson-Pritz, in Proc. of the ”Physics at HERA Workshop”, ed. W.Buchmuller and G.Ingelman, Hamburg, 1992, 239; Z. Phys. **C58**, (1993), 285.

[14] A.Berera, D.E.Soper, *”Behavior of diffractive parton distribution function”*, 1996, Preprint Pennsylvania State University, PSU/TH/163;

A.Berera, *"Jet production cross section with double Pomeron exchange."*, 1997, HEP-PH/9705283.

[15] Z.Kunszt, W.J.Stirling, *"The Parton Interpretation of Hard Diffractive Scattering"*, presented at the Workshop on HERA Physics, Durham, 1995; *"Hard Diffractive Scattering: Partons and QCD"*, Preprint DTP/96/71; ETH-TH/96-27; HEP-PH/9609245.

[16] B.E. Cox and J.R. Forshaw, Comput. Phys. Commun. **144**, 104, (2002); hep-ph/0312273v1; (see http://www.pomwig.com/).

[17] G. Marchesini, B.R. Webber, G. Abbiendi, I.G. Knowles, M.H. Seymour, and L. Stanco, Computer Phys. Commun. **67**, 465, (1992); G.Corcella, I.G.Knowles, G.Marchesini, S. Moretti, K.Odagiri, P,Richardson, M.H.Seymour and B.R.Webber, "HERWIG 6: An event generator for hadron emission reactions with interfering gluons," JHEP **0101**, 010, (2001); hep-ph/0011363; hep-ph/0210213; (see http://hepwww.rl.ac.uk/theory/seymour/herwig/herwig65.html).

[18] H1 Collaboration, A. Aktas et al., "Measurement and QCD Analysis of the Diffractive Deep-Inelastic Scattering Cross Section at HERA", DESY06-049; hep-ex/0606004; subm. to Eur. Phys. J.

[19] S.Chatrchyan, G.Hmayakyan, V.Khachatryan, A.Sirunyan, "Studying quark-antiquark parton distributions in Double Pomeron Exchange." - CMS AN-2008/067, CERN, Geneva, 2008.

[20] https://twiki.cern.ch/twiki/bin/view/CMS/WebHome.

[21] E.James, Y.Maravin, M.Mulders, N.Nenmeister, "Muon identification in CMS." -CMS NOTE-2006/010, CERN, Geneva, 2006.

[22] CMS Collaboration, "Detector performance and software. Physics Technical Design Report. v.1" - CERN/LHCC 2006-001; CMS TDR 008-1, CERN, Geneva, 2006.