EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE/98-45
3 November 1998

A study of Double Pomeron Exchange in ALICE

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hep-ph/9811230 3 Nov 1998

Abstract

The non-Abelian nature of QCD suggests that particles that have a gluon constituent, such as glueballs or hybrids, should exist. Experiments WA76, WA91 and WA102 have performed a dedicated search for these states in central production using the CERN Omega Spectrometer. New results from central production show that there is a kinematical filter which can select out glueball candidates from known $q\overline{q}$ states. A further study of this at high energies is essential in order to get information on the $M(X^0) > 2$ GeV region. This paper describes how this could be done using the the ALICE detector at the LHC.

1 Introduction

Recent developments in the study of hadronic interactions show that central production is a mechanism which can be used to great advantage in the study of hadronic spectra. The current studies have been performed in fixed target experiment at $\sqrt{s} \sim 20$ GeV. It would be of great interest to extend these studies to higher energies, where it should be much easier to disentangle the production mechanism. This paper is organized as follows. In section 2 the spectrum of non-$q\overline{q}$ mesons is discussed, in section 3 the results from the Omega Central Production experiments are reviewed, and in section 4 a possible extension of these studies using the ALICE detector in pp mode is presented.

2 The Glueball Spectrum

The present understanding of strong interactions is that they are described by Quantum ChromoDynamics (QCD). This non-Abelian field theory not only describes how quarks and antiquarks interact, but also predicts that the gluons which are the quanta of the field will themselves interact to form mesons. If the object formed is composed entirely of valence gluons the meson is called a glueball, however if it is composed of a mixture of valence quarks, antiquarks and gluons (i.e. $q\overline{q}g$) it is called a hybrid. In addition, $q\overline{q}q\overline{q}$ states are also predicted.

The best estimate for the masses of glueballs comes from lattice gauge theory calculations [1] which show that the lightest glueball has $J^{PC} = 0^{++}$ and that

$$m(2^{++})/m(0^{++}) = 1.5$$

and depending on the extrapolation used from the lattice parameters to mass scale that

$$m(0^{++}) = (1500 - 1750)\text{MeV}.$$

The mass of the 0^{-+} glueball is predicted to be similar to that of the 2^{++} glueball whilst glueballs with other quantum numbers are predicted to be higher in mass.

The flux tube model has been used to calculate the masses of the lowest lying hybrid states and recent predictions [2] are that

$$m(1^{--}, 0^{-+}, 1^{-+}, 2^{-+}) \approx 1900 \text{ MeV}.$$

Hence, these non-$q\overline{q}$ states are predicted to be in the same mass range as the normal $q\overline{q}$ nonet members and hence we need a method of identifying them.

The following have been suggested as possible ways to identify gluonic states.

- To look for "oddballs": States with J^{PC} quantum numbers not allowed for normal $q\overline{q}$ states. For example $J^{PC} = 1^{-+}$.

- However the lightest non-$q\overline{q}$ states are predicted to have the same quantum numbers as $q\overline{q}$ states. Therefore we need to look for extra states, that is states that have quantum numbers of already completed nonets and that have masses which are sufficiently low that they are unlikely to be members of the radially excited nonets and hence they can not be described as being pure $q\overline{q}$ states.
- If extra states are found then in order to isolate which state is the likely non-$q\overline{q}$ state we can

  a) Look for states with unusual branching ratios.

  b) Look for states preferentially produced in gluon rich processes. These processes are described below.

Fig. 1 summarises several dynamical configurations which have been suggested as possible sources of gluonium and where experiments have been performed.

1. Pomeron-Pomeron scattering is shown in fig. 1a). The Pomeron is an object which can be described as a multi-gluon state, and is thought to be responsible for the large cross sections of diffractive reactions. Consequently Double Pomeron Exchange (DPE) is considered to be a possible source of glueballs.
2. The J/ψ decay is believed to be a highly glue rich channel either via the hadronic decay shown in fig. 1b), or via the radiative decay shown in fig. 1c).
3. Figure 1d) shows proton-antiproton annihilation; the annihilation region of quarks and antiquarks is a source of gluons where glueballs and hybrids could be produced.
4. Special hadronic reactions, an example of which is shown in fig. 1e) where the $\phi\phi$ system is thought to be produced via an intermediate state containing gluons. Reactions of this kind which have disconnected quark lines are said to be OZI violating [3].

The first reaction is the one studied by experiments WA76, WA91 and WA102 at the Omega spectrometer. In the following section the status of these experiments is reviewed and the possibility of a glueball-$q\overline{q}$ filter in central production is discussed.

3 The Omega Central production experiments

3.1 Introduction

The Omega central production experiments (WA76, WA91 and WA102) are designed to study exclusive final states formed in the reaction

$$\mathrm{pp} \longrightarrow \mathrm{p}_f X^0 \mathrm{p}_s,$$

where the subscripts f and s refer to the fastest and slowest particles in the laboratory frame respectively and X^0 represents the central system. Such reactions are expected to be mediated by double exchange processes where both Pomeron and Reggeon exchange can occur.

The trigger was designed to enhance double exchange processes with respect to single exchange and elastic processes. Details of the trigger conditions, the data processing and event selection have been given in previous publications [5].

3.2 The possibility of a Glueball-$q\overline{q}$ filter in central production

The experiments have been performed at incident beam momenta of 85, 300 and 450 GeV/c, corresponding to centre-of-mass energies of $\sqrt{s}$ = 12.7, 23.8 and 28 GeV. Theoretical predictions [6] of the evolution of the different exchange mechanisms with centre of mass energy, $\sqrt{s}$, suggest the following behaviour for the cross sections:

$$\sigma(\mathrm{RR}) \sim s^{-1},$$
$$\sigma(\mathrm{RP}) \sim s^{-0.5},$$
$$\sigma(\mathrm{PP}) \sim \text{constant},$$

where RR, RP and PP refer to Reggeon-Reggeon, Reggeon-Pomeron and Pomeron-Pomeron exchange respectively. Hence we expect Double Pomeron Exchange (DPE) to be more significant at high energies, whereas the Reggeon-Reggeon and Reggeon-Pomeron mechanisms will be of decreasing importance. The decrease of the non-DPE cross section with energy can be inferred from data taken by the WA76 collaboration using pp interactions at $\sqrt{s}$ of 12.7 GeV and 23.8 GeV [7]. The $\pi^+\pi^-$ mass spectra for the two cases show that the signal-to-background ratio for the $\rho^0(770)$ is much lower at high energy, and the WA76 collaboration report that the ratio of the $\rho^0(770)$ cross sections at 23.8 GeV and 12.7 GeV is 0.44 $\pm$ 0.07. Since isospin 1 states such as the $\rho^0(770)$ cannot be produced by DPE, the decrease of the $\rho^0(770)$ signal at high $\sqrt{s}$ is consistent with DPE becoming relatively more important with increasing energy with respect to other exchange processes.

However, even in the case of pure DPE the exchanged particles still have to couple to a final state meson. The coupling of the two exchanged particles can either be by gluon exchange or quark exchange. Assuming the Pomeron is a colour singlet gluonic system if a gluon is exchanged then a gluonic state is produced, whereas if a quark is exchanged then a $q\overline{q}$ state is produced (see figures 2a) and b) respectively). It has been suggested recently [8] that for small differences in transverse momentum between the two exchanged particles an enhancement in the production of glueballs relative to $q\overline{q}$ states may occur. The difference in the transverse momentum vectors (dP_T) is defined to be

$$dP_T = \sqrt{(P_{y1} - P_{y2})^2 + (P_{z1} - P_{z2})^2}$$

where Py_i, Pz_i are the y and z components of the momentum of the ith exchanged particle in the pp centre of mass system.

Figures 3a), b) and c) show the effect of the dP_T cut on the K^+K^- mass spectrum where structures can be observed in the 1.5 and 1.7 GeV mass region which have been previously

identified as the $f_2'(1525)$ and the $f_J(1710)$ [10]. As can be seen, the $f_2'(1525)$ is produced dominantly at high dP_T, whereas the $f_J(1710)$ is produced dominantly at low dP_T.

In the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum a dramatic effect is observed, see figures 3d), e) and f). The $f_1(1285)$ signal has virtually disappeared at low dP_T whereas the $f_0(1500)$ and $f_2(1900)$ signals remain. Similar effects are observed in all the other channels analysed to date [16, 17]. In fact it has been observed that all the undisputed $q\overline{q}$ states (i.e. $\rho^0(770)$, η', $f_2(1270)$, $f_1(1285)$, $f_2'(1525)$ etc.) are suppressed as dP_T goes to zero, whereas the glueball candidates $f_J(1710)$, $f_0(1500)$ and $f_2(1900)$ survive. It is also interesting to note that the enigmatic $f_0(980)$, a possible non-$q\overline{q}$ meson or $K\overline{K}$ molecule, does not behave as a normal $q\overline{q}$ state.

A Monte Carlo simulation of the trigger, detector acceptances and reconstruction program shows that there is very little difference in the acceptance as a function of dP_T in the different mass intervals considered within a given channel and hence the observed differences in resonance production can not be explained as acceptance effects.

3.3 Summary of the effects of the dP_T filter

The contribution of each resonance as a function of dP_T has been calculated. Figure 4 shows the ratio of the number of events for $dP_T < 0.2$ GeV (the glue rich exchange region) to the number of events for $dP_T > 0.5$ GeV (the quark rich exchange region) for each resonance considered. It can be observed that all the undisputed $q\overline{q}$ states which can be produced in DPE, namely those with positive G parity and $I = 0$, have a very small value for this ratio (≤ 0.1). Some of the states with $I = 1$ or G parity negative, which can not be produced by DPE, have a slightly higher value (≈ 0.25). However, all of these states are suppressed relative to the interesting states, i.e. those which could have a gluonic component, which have a large value for this ratio.

3.4 Conclusions

The results observed in central production to date indicate the possibility of a glueball-$q\overline{q}$ filter mechanism in central production. All the undisputed $q\overline{q}$ states are observed to be suppressed at small dP_T, but the glueball candidates $f_0(1500)$, $f_J(1710)$, and $f_2(1900)$, together with the enigmatic $f_0(980)$, survive.

4 Possible studies in ALICE

4.1 Introduction

A new effect has been observed in pp collisions and deserves to be studied more fully. Performing these studies at LHC energies has two very useful consequences. Firstly the mass range of the centrally produced system is given by

$$M^2 = s(1 - x_{F1})(1 - x_{F2})$$

hence by increasing s the mass range (M) is increased. The second feature is that the exchange will be effectively 100 % double Pomeron i.e. there will no contamination from Reggeon exchange. This second feature should help greatly in understanding the underlying dynamics.

4.2 What can be done in ALICE

Due to the limited γ detection in ALICE only all charged decays of the centrally produced system can be studied namely: $\pi^+\pi^-$, K^+K^-, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, $K^+K^-K^+K^-$ and e^+e^-. Although this is a limited number of channels it is interesting to note that all the glueball candidates observed to date have been seen in one or more of these decay modes.

One of the major requirements of this study is that we are able to reconstruct exclusive events i.e we can exclude decays that have π^0s in their final state by using momentum balance. This of course requires that we observe all the charged tracks including the outgoing protons.

In order to exclude decays that involve a π^0 we need to require that the missing $P_T \leq 200$ MeV. In order to do this we need

- the spread in the transverse momentum of the incident beam momentum be small and
- small measurement errors on the outgoing protons.

4.2.1 Incident Beam

The spread in the momentum of the incident beam is determined by the β^* of the final focus. For a β^* of 0.5 m the spread in the transverse momentum (δP_T) of the incident beam is δP_T =225 MeV. Hence a β^* of 0.5 m would be unacceptable. For a β^* of 250 m the δP_T is 10 MeV which would be acceptable. This is in agreement with the plans to run ALICE with the maximum possible β^* during pp running in order to reduce the luminosity.

4.2.2 Outgoing protons

The two outgoing protons could be measured using two stations of Roman pots. The exact position of these stations need to be determined. Initial simulations show that we can accept protons that are scattered between 30 and 180 μrad. Where the inner limit is defined by the 10σ profile limit of the beam and the outer limit by the beam pipe. Assuming that each station was composed of several planes of 10μm pitch microstrip detectors then the outgoing proton could be measured with a precision of

$$\delta P_T = 50 \text{ MeV and } \delta P_L = 7 \text{ GeV}.$$

These values would be sufficient for our requirements.

4.3 Machine optics

The requirements of the machine optics have been studied by the TOTEM collaboration [18, 19, 20] who have a similar requirement of measuring the scattered protons. A schematic layout for the Roman Pot detectors is shown in fig. 5. The detectors are placed in a long straight section of the accelerator on both sides of the intersection point. On each beam there will be a telescope of two Roman Pots placed 130 meters apart and therefore able to measure both the position and direction of the scattered protons. Between the detectors and the crossing point there will be magnetic elements of the machine which are used to make the machine collide. In order to get the best measurement of the scattered protons the best configuration of these magnetic elements is the so called "parallel-to-point" focusing configuration.

The minimum distance of approach of the inner edge of the detectors to the beam axis, z_d, is proportional to the r.m.s. beam size at the detector position, σ_{z_d} i.e. $z_d = k\sigma_{z_d}$. At the SPS collider it was found empirically by the UA4 experiment that $k \approx 15 - 20$.

For protons which hit the detector on the inner edge, the scattering angle will be

$$\theta_{z_d} = k\sqrt{\frac{\epsilon_z}{\beta_z^*}} \tag{1}$$

where ϵ_z is the emittance which has a nominal value of 5.0×10^{-10} m rad [21]. The useful minimum angle is given by $\theta_{z_{min}} = \sqrt{2}\theta_{z_d}$. For a $\beta_z^* = 250m$, $\theta_{z_{min}} = 30\mu$rad.

An additional requirement comes from the fact that the actual distance z_d of the inner edge of the detector from the machine axis should not be too small, in order to avoid problems from possible beam instabilities. Assuming a minimum acceptable value for z_d of 1.5 mm [18] then

$$L_{z_{eff}}\theta_{z_d} \geq z_{d_{min}} = 1.5\text{mm} \tag{2}$$

which fixes the effective distance of the detectors to be $L_{z_{eff}} \geq 50$m.

The layout of the right hand side of intersection point 2 is shown in fig. 6. There are in principle two possible locations for the detectors, one just before dipole D2 and the second between Q5 and Q6. The position at D2 has the advantage that the tracking of the scattered protons is easier because they transverse only four magnets. The advantage of the Q5-Q6 setup is a larger lever arm between the two detectors in the Roman pot telescope.

4.4 Simulations

The reaction

$$\text{pp} \longrightarrow \text{p}X^0\text{p},$$

at $\sqrt{s} = 14$ TeV, has been generated using a modified version of the WA102 event generator. The x_F distribution of the exchange particles has been assumed to scale as $1/\sqrt{s}$ and the t slope of the proton vertex, which is parameterised as e^{-bt}, with $b = b_0 ln(s/s_0)$ where $b_0 = 6$ GeV^{-2}

and $s_0 = 784$ GeV^2. The four momentum transfer distribution from the proton vertex then has a distribution of the form e^{-24t}.

The outgoing protons are required to be detected in Roman pot detectors and the centrally produced system, X^0, is decayed into 2 or 4 particles which are required to be within the acceptance of the central tracking detectors.

4.5 Detector and trigger requirements

The cross section for DPE at $\sqrt{s} = 30$ GeV is $\sigma(PP) = 140$ μb. Assuming the cross section scales as $s^{0.08}$ then the cross section at $\sqrt{s} = 14$ TeV is $\sigma(PP) = 370$ μb. In order to trigger on the centrally produced events we would need a low multiplicity trigger in the central region to allow us to detect events composed of two or four tracks. An additional trigger would require two outgoing protons that had scattered into the Roman pot detectors.

Fig. 7a) shows the distribution of the azimuthal angle of the protons scattered in DPE collisions together with the acceptance region of the Roman Pots. Fig. 7b) shows the distribution of the centrally produced charged particle together with the acceptance of the central trackers. This results in an acceptance for centrally produced events in the 2 GeV mass region of ≈ 12.5 %.

Assuming a luminosity of 10^{30} cm^{-2}s^{-1} we would have a trigger rate of 8 Hz from DPE events. This would give us an integrated annual data sample (10^7 s) of 80 million events.

4.6 The Central multiplicity trigger

A capability to trigger on one of the central detectors, for example the pixel layers, seems advisable in order to select minimum bias p-p events. We know that the mean multiplicity will be low. At present triggering is done using the FMD detectors only. These may have trouble rejecting background if used alone. Furthermore, a realistic assessment of the noise requires a very detailed Monte Carlo study, which has not yet been done and would be very time consuming.

A central trigger, particularly one looking for spatial correlations between adjacent layers, complements the information from the FMD (time correlations between different disks) very well, and should lead to efficient background rejection.

The practical problems concerning the implementation of such a trigger have been discussed with the ITS group (Fabio Formenti). The pixel chips can have a trigger output, giving a response in 50ns, and there are no overwhelming obstacles to having such a trigger. However, having one clearly makes the job of setting up the pixel layers considerably more difficult, particularly from the point of view of accommodating the large numbers of trigger cables coming out of the ITS area. This is because the trigger signals are not suitable for multiplexing. For this reason, a solution in which several pixel chips within a ladder are grouped to make a logical unit with a larger area is the recommended solution. A moderate amount of Monte Carlo work

should suffice to optimize the size of the logical units. A consequence of this is that if this study implies that the pixel trigger output is required, the ITS group should be requested to include it in their TDR.

The requirements for a Double Pomeron trigger would also be very well served by such a pixel trigger. Here one would require no activity in the FMD, but expect to find the correlated hits in the forward particle stations at level 2.

4.7 Roman Pots for proton detection

Contact has been made with the TOTEM group who have a similar Roman pot requirement. They are well advanced with their design and currently in favour of using the CMS detector. They have performed simulations of where to put the Roman pots for all four intersection regions [20, 21]. In particular they have found that a modification to the beam optics is required. In the present design the quadrapoles nearest to ALICE are composed of 4 linked magnets working from one power supply. In the modified design only the middle two magnets are linked and hence three power supplies are needed. This greatly helps in measuring deflected protons. Of course such changes need to be notified to the machine group as soon as possible.

If TOTEM does go to CMS then we could profit from their developments of the Roman pots and detectors. A very preliminary costing for the Roman pots plus microstrip detectors would be 500 kChf.

4.8 Additional advantage of having Roman Pot detectors

The addition of Roman Pot detectors to the ALICE setup would allow an accurate measurement of the luminosity during p-p running in ALICE which would enable better comparisons to be made with the ion-ion running.

4.9 Summary

New results from central production show that there is a kinematical filter which can select out glueball candidates from known $q\overline{q}$ states. A further study of this at high energies is essential in order to get information on the $M(X^0) > 2$ GeV region. This could be done using the ALICE detector by studying all charged decay modes. It should be recalled that all the known glueball candidates have been observed in these decay modes.

To perform this study we would require the addition of a low multiplicity central particle trigger, which is also needed to select minimum bias pp events. We also need the addition of Roman Pots which could also be used to give an accurate measure of the luminosity in the ALICE detector. It would allow a new area of physics to be explored during proton-proton data taking.

Acknowledgements

We would like to thank A. Faus-Golfe, W. Kienzle and M. Haguenauer for useful discussions.

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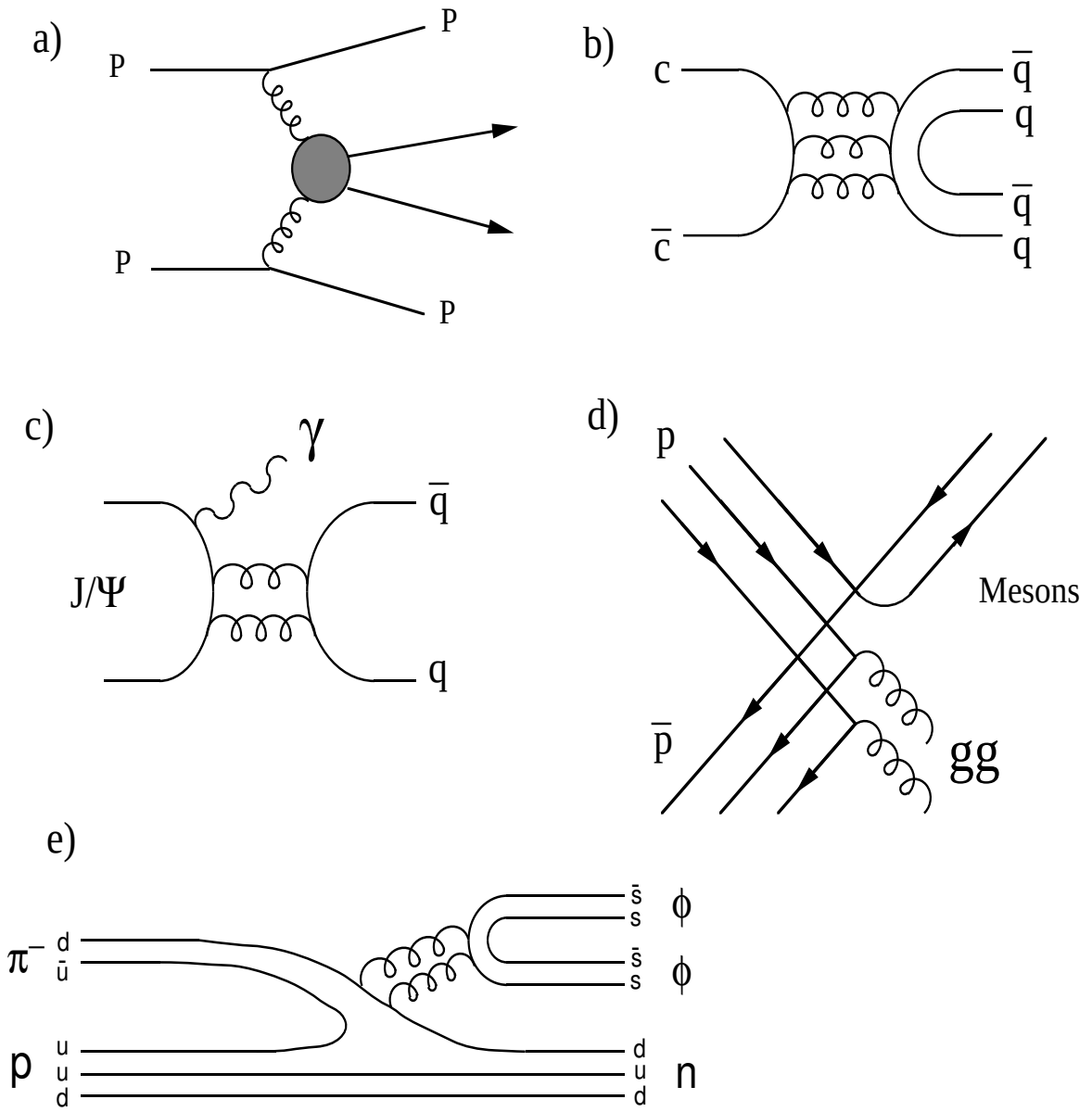

Figure 1: Gluon rich channels. Dynamical configurations that have been used to study light hadron spectroscopy in a search for glueball states.

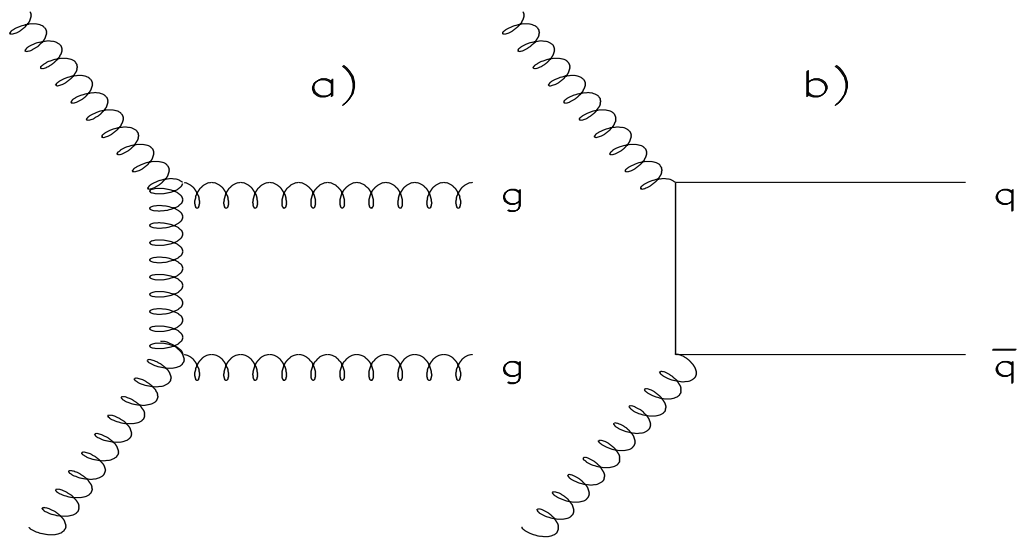

Figure 2: Schematic diagrams of the coupling of the exchange particles into the final state meson for a) gluon exchange and b) quark exchange.

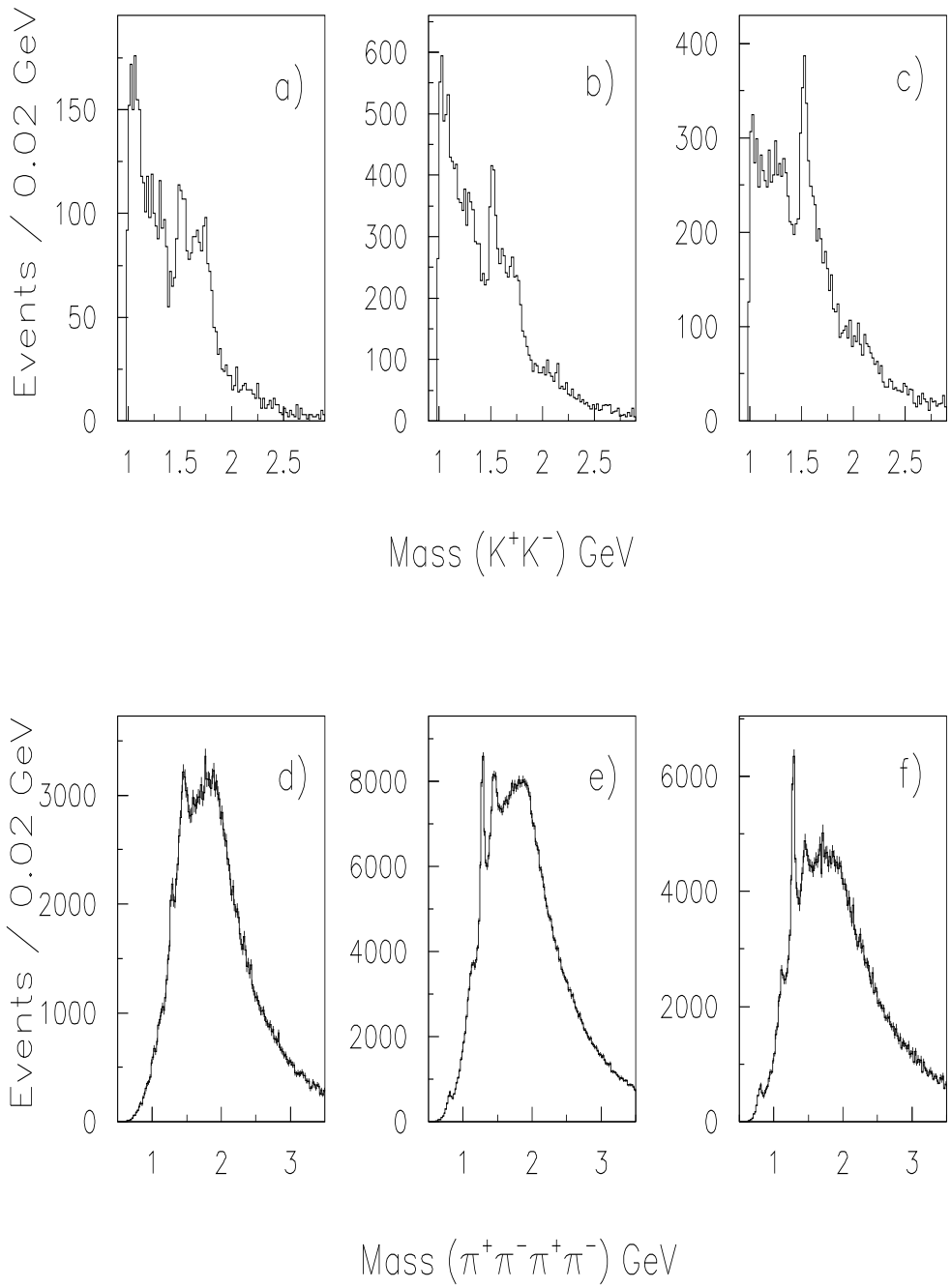

Figure 3: K^+K^- mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV and the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for d) $dP_T < 0.2$ GeV, e) $0.2 < dP_T < 0.5$ GeV and f) $dP_T > 0.5$ GeV.

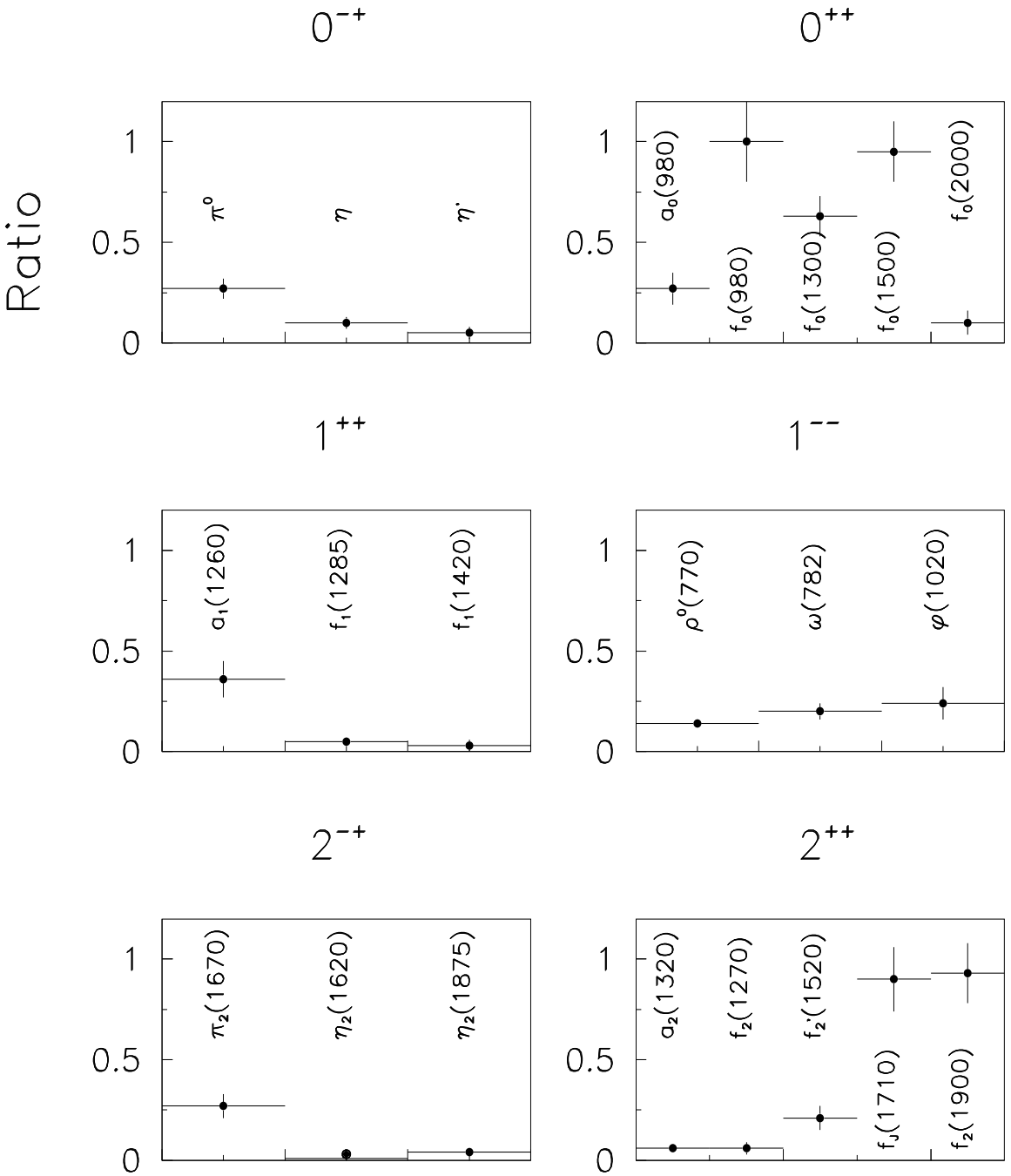

Figure 4: The ratio of the amount of resonance with $dP_T \leq 0.2$ to the amount with $dP_T \geq 0.5$ GeV.

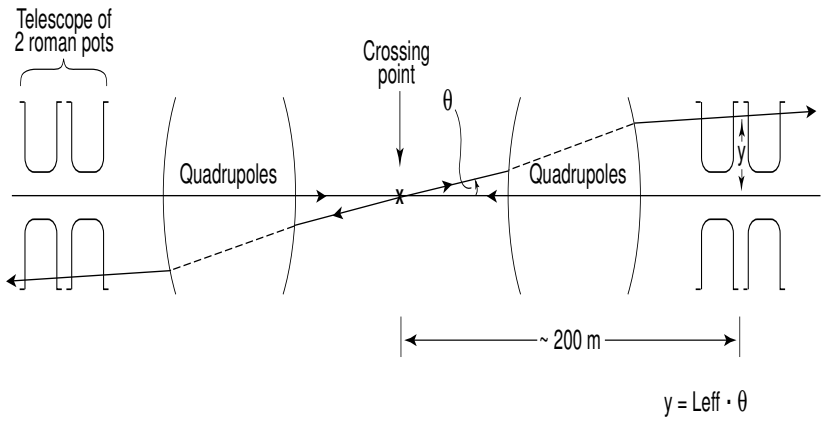

Figure 5: Schematic layout of the Roman pots.

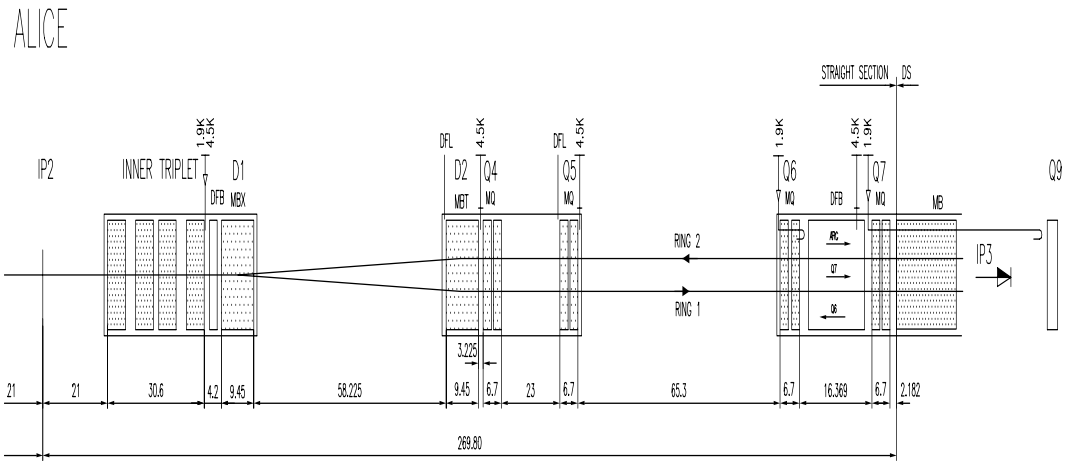

Figure 6: Layout of the right part of intersection region 2.

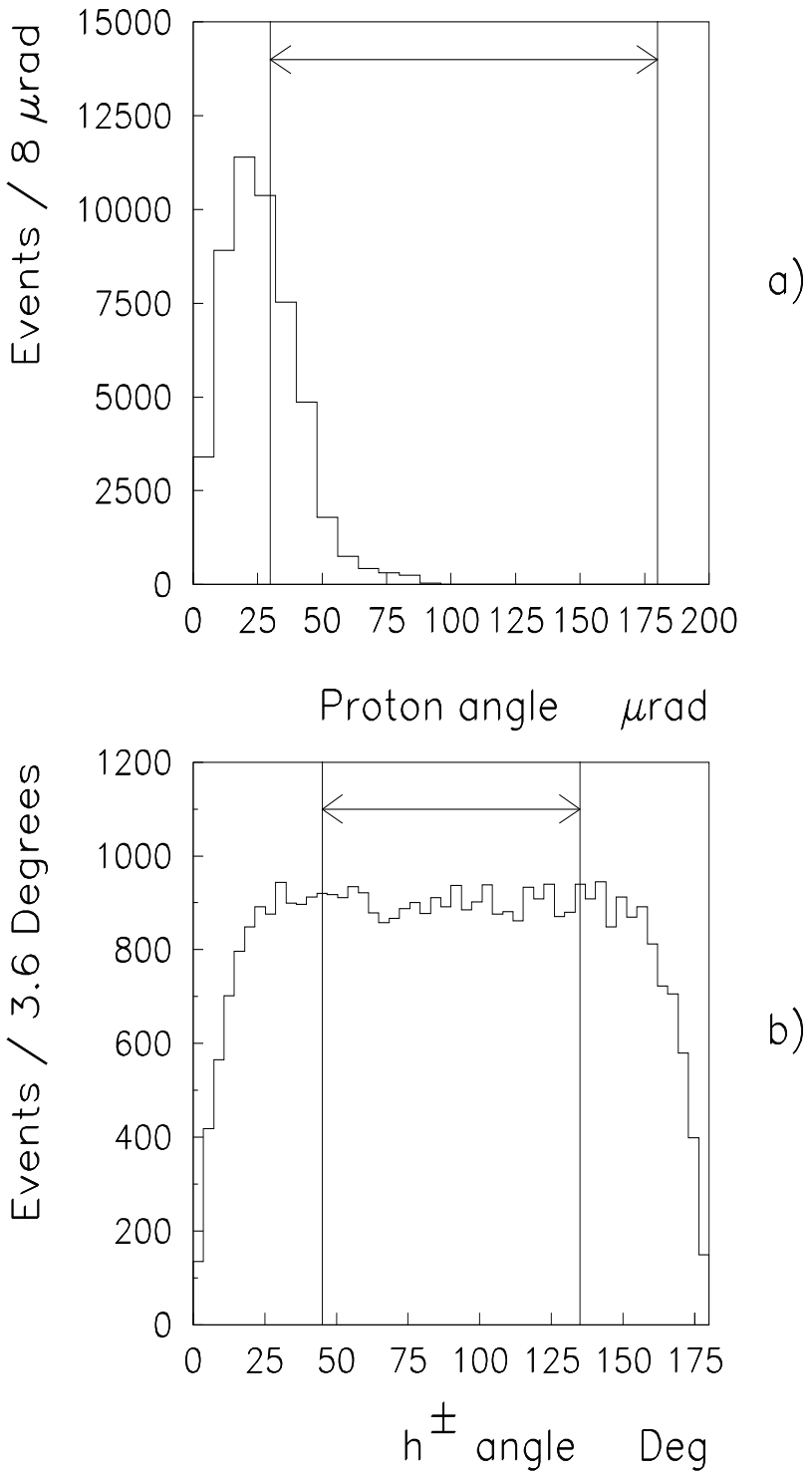

Figure 7: Results of the simulation. a) The scattered angle of the protons and b) the central system.