DIRAC events generator

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Abstract

In this note we describe a fast generator program to produce the physics events of interest for the DIRAC experiment. This generator has been used to perform the break-up probability calculation and as the source of the Monte Carlo events for the analysis of experimental data. This note describes the last version of the code prepared for an easy use with the DIRAC-GEANT Monte Carlo. A major upgrade is made in the break-up distributions of pionium thanks to the input provided by T.Heim.

1 Introduction

DIRAC measurement is based in the analysis of the low relative momentum spectrum of $\pi^+\pi^-$ pairs. In this region there are four ingredients contributing to the data samples:

- Coulomb correlated pairs. Both pions yield in the same proton-target interaction from the fragmentation of the nucleus or the decay of a long-lived resonance.

- Non-Coulomb pairs. Both pairs produced in the same interaction, at least one coming from the decay of a short-lived resonance.

- Accidentals. Each pion originated in a different proton-target interaction. For the accidentals we will distinguish between accidentals in the prompt region ($t \sim 0ns$) and outside the prompt region ($t \in [0, 20]ns$).

- Atomic Pairs. Pairs from atoms break-ups after passing through an atomic bound state.

This note presents a physics events generator code which produces all these four types of events and that is ready to produce input files for the *geant-dirac* Monte Carlo simulation of DIRAC spectrometer [1]. Furthermore, it is planned its integration into the *geant-dirac* program to simplify even more the user interface. When this happens this note will remain as a reference document or as a manual for those who wish to make studies on the generator events directly.

Many of the basics of the generator have been already reported in previous works [2, 3] however, the latest improvements, namely the inclusion of highly excited discrete states break-up spectra, and the new easy user interface needed to be explained. We will start by explaining a correction in the extraction of the laboratory momentum spectra the $\pi^+\pi^-$ pairs and the Coulomb, non-Coulomb background generators, as well as

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the accidentals. Finally we will shortly comment on the atoms from break-up generator and the latest improvement of including many discrete states break-up spectra.

The code can be found in the author public directory in the lxplus:

/afs/cern.ch/user/c/cibran/public/gener.tar.gz

or directly in DIRAC web page as a tarball file.

2   Background Generation

The main characteristic of the pion pairs we study is that the cross sections can be split into two parts, one depending on the center of mass momentum of the pair in the laboratory system ($\vec{P}$) and the other on the relative momentum in the center of mass system ($\vec{Q}$).

In particular the prompt events background, formed by Coulomb Correlated CC and Non Coulomb NC pairs, follows the equation:

$$\frac{dN}{d\vec{P}d\vec{Q}} = A_C(Q)\frac{dN^{CC}}{d\vec{P}d\vec{Q}}\Bigg|_{\vec{Q}=0} + \frac{dN^{NC}}{d\vec{P}d\vec{Q}}\Bigg|_{\vec{Q}=0}, \tag{1}$$

where $A_C(Q)$ is the Coulomb enhancement function. The percentage of pion pairs produced from short-lived sources, yielding non-Coulomb pairs, $\omega_s(P)$ depends on the laboratory momentum only [4] and can be obtained using the FRITIOF6 Monte Carlo as explained in [3]. Taking this into account we can relate the laboratory momentum spectrum as:

$$\frac{dN}{d\vec{P}} = \left(\int_{\vec{Q}\in\Omega} A_C(Q)d\vec{Q}\right)\frac{dN^{CC}}{d\vec{P}d\vec{Q}}\Bigg|_{\vec{Q}=0} + \left(\int_{\vec{Q}\in\Omega} d\vec{Q}\right)\frac{1-\omega_s(P)}{\omega_s(P)}\frac{dN^{CC}}{d\vec{P}d\vec{Q}}\Bigg|_{\vec{Q}=0}, \tag{2}$$

being Ω a certain region in the $\vec{Q}$ space.

We have chosen Ω to be the $5MeV/c < Q < 10MeV/c$ region which, in the experimental data is free from atomic pairs. Moreover, in this region, the experimental Coulomb enhancement function (after multiple scattering and setup reconstruction) coincides with the shape at production [5]. For this selection:

$$\frac{\int A_C(Q)d\vec{Q}}{\int d\vec{Q}} = 1.48. \tag{3}$$

On the other hand, we can change the symbol of the CC spectra on $\vec{P}$ at $\vec{Q}=0$ by:

$$\frac{dN^{CC}}{d\vec{P}d\vec{Q}}\Bigg|_{\vec{Q}=0} \rightarrow \frac{dN^{CC}}{d\vec{P}}$$

since there is not dependence on $\vec{Q}$. All this transforms (2) into:

$$\frac{dN}{d\vec{P}} \propto \left(1.48 + \frac{1-\omega_s(P)}{\omega_s(P)}\right)\frac{dN^{CC}}{d\vec{P}} \rightarrow \frac{dN^{CC}}{d\vec{P}} \propto \frac{\omega_s(P)}{1+0.48\omega_s(P)}\frac{dN}{d\vec{P}}. \tag{4}$$

Of course, obtaining the Non Coulomb laboratory spectrum is straightforward:

$$\frac{dN^{NC}}{d\vec{P}} \propto \frac{1-\omega_s(P)}{1+0.48\omega_s(P)}\frac{dN}{d\vec{P}}. \tag{5}$$

Equations (4) and (5) have been explicitly shown because they correct the corresponding one in [3] which were wrongly based in a value of 1 of (3).

The $\vec{P}$ vector is a three components system. In our case we have used spherical variables taking the beam direction as the Z axis. As the proton-target nucleus interaction has axial symmetry there is not correlation between the polar (ϕ) angle with any of the two other variables (P,θ). The polar angle distribution is completely ruled by the spectrometer geometry and almost uniform around 90 degrees in an interval of ± 1 degree with some edge effects. The other two components of $\vec{P}$ are stored in a two dimensional look-up table. This method is equivalent to the storage in a histogram which was previously used [3] but more portable to other systems since it does not need the compilation of the code with the hbook libraries.

The laboratory momentum spectra are corrected for detector efficiency in such a way that the input distributions of the generator produce the correct output distributions after the full *geant-dirac* [1] and the *ariane* [6] reconstruction of the events [1].

The laboratory momentum generation process is the same for the Coulomb correlated, the Non Coulomb and the accidental events changing the (P,θ) look-up table only.

The position of the pions in the generation is uniform in the target thickness and follows a two-dimensional gaussian distribution according to the beam profile ($\sigma_x = 0.8\ mm$ and $\sigma_y = 1.6\ mm$) [7]. For the accidental events two independent vertexes are generated. However for the prompt accidentals both time values are set to zero.

Finally, the relative momentum in the center of mass system is generated according to:

$$\frac{dN^{CC}}{dQ d\theta d\phi} \propto A_C(Q)Q^2 \sin\theta \qquad (6)$$

where θ and ϕ are azimuth and polar angle using the $\vec{P}$ direction as the z axis. The explicit expression for the $A_C(Q)$ Coulomb enhancement function is given by:

$$A_C(Q) = \frac{2\pi M_\pi \alpha/Q}{1 - e^{-2\pi M_\pi \alpha/Q}}. \qquad (7)$$

The accidental and non Coulomb pairs relative momentum is generated following:

$$\frac{dN^{NC}}{dQ d\theta d\phi} \sim \frac{dN^{Acc}}{dQ d\theta d\phi} \propto Q^2 \sin\theta \qquad (8)$$

which corresponds to the pure phase space uniform three dimensional distribution.

In addition, the Prague group of prof. R. Lednicky has proposed that the Coulomb enhancement function should be modified accounting for finite size effects of the source [8]. The use of (7) as the Coulomb enhancement function assumes that the two pions of the pair are created at zero distance. Of course this is an approximation which has to be corrected for nuclear size effects and decay paths of resonances. The proposed correction changes the Coulomb enhancement function to be:

$$A_C^*(Q) = \left\{ 1.0017 - 0.0285 \left(\left[1. + \left(\frac{0.278Q}{(MeV/c)} \right)^2 \right]^{-0.421} - 1. \right) \right\} A_C(Q) \qquad (9)$$

and is also included as an option in the background generator.

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[1]Essentially this means that the input events are all except those with zero efficiency, mainly because of geometrical reasons.

ITYPE	Background type
0	Coulomb Pairs.
1	Coulomb Pairs with finite size correction (9).
2	Non Coulomb Pairs.
3	Accidentals.
4	Prompt ($t = 0$) Accidentals.

Table 1: Different possible values of the ITYPE flag and the corresponding event type.

2.1 Background Code Use

In the practice, the physics of the generated events can be skipped by the user. The use of the FORTRAN routines in any program can be easily performed by following the next instructions.

The background main routine, which will provide the position in the target and momenta of the corresponding $\pi^+\pi^-$ pair, needs a prior call to an initializing routine:

CALL INITBCKGRND(TG,ISEED,ITYPE,IBEM,NTAR,WTAR,QTCUT,QLCUT)

- The target material TG, is a CHARACTER*2 variable. Only 'Ni' is supported for the moment but other materials could be easily added.

- The random number generator seed ISEED. It has to be inputed with an integer value which produces an unique random event series.

- Finally ITYPE stands for the different background types according to table 1.

- The beam energy IBEM. IBEM=0 means 24 GeV/c and IBEM=1 stands for 20 GeV/c.

- The target geometry is introduced with two variables. NTAR is the number of target layers and WTAR the thickness of every layer in micrometers. For practical purposes NTAR=1 and NTAR=12 are the natural choices for out single and multi layer targets. WTAR would be 94. or 98. μm for the single target or the 7.94, 7.94, 7.98, 7.94, 7.98, 7.96, 7.97, 7.97, 7.96, 7.99, 8.00, 8.00 μm sequence for the multi-layer target [9].

- The background parameterizations of (6) and (8) are accurate up to $Q \sim 100 MeV/c$. However, these functions are quickly increasing with Q and it would not be efficient to generate events with too large values because they would be certainly suppressed by the setup geometry and the trigger system. In order to select a reasonable region for the generated pairs two cuts in QT and QL have to be defined in MeV/c. Studies made by C. Schuetz show that save choices for QLCUT and QTCUT are 20 and 8 MeV/c respectively.

There is a single routine for any type (Coulomb, Non-Coulomb, Accidentals, Prompt Accidentals and Coulomb modified by (9)) of background. The routine is used by a single call:

CALL BCKGRND(XYZ1,PXYZ1,TIME1,XYZ2,PXYZ2,TIME2)

where we obtain the position in the target (XYZ1(3) and XYZ2(3)) in cm, momentum (PXYZ1(3) and PXYZ2(3)) in GeV/c and time (TIME1 and TIME2) in ns for the two pions. In the case that both pions are generated in the same vertex (real events) XYZ1=XYZ2 and TIME1=TIME2=0. Moreover, for Prompt Accidentals TIME1=TIME2=0.

3   Atomic Pairs Generator

The atomic events generator is a completely different routine since the physics of this system is more complicated. The atoms are created in a certain point of the target (uniformly distributed in the target thickness) and suffer in its evolution several collisions with subsequent target atoms. In these collisions the atom might undergo a transition between two discrete states or break-up. The topic is deeply treated in [2]. A last major change in this last version of the generator is that the different break-up spectra of pionium have been considered up to the discrete state with $n = 7$. For higher excited states an approximation has been followed. The spectra have been brilliantly calculated by T.Heim [10].

As we did for the Coulomb correlated background events a correction due to the Check group to the original yield of $1/n^3$ in the S states is included as an option in the code. This deviation is mathematically expressed as [8]:

$$P_n = (1 + 0.003/n)/n^3 \tag{10}$$

To use the generator of atomic pairs we need to call the initializing routine:

CALL INITGENE(TG,ISEED,IATOM,IBEM,NTAR,WTAR)

where the variables are the same as for the initialization of the background generator except IATOM which stands for whether we are using the standard $1/n^3$ law (IATOM=0) or the modified (10) one (IATOM=1).

The atomic pairs are generated after a single call to this routine by subsequent calls to:

CALL GENE(XYZ,PXYZ1,PXYZ2)

where XYZ(3) is the break-up position of the atom and PXYZ1(3) and PXYZ2(3) the momenta of the two pions from the break-up. The units are, of course, the same as for the case of background.

4   A useful main program

In the routines set a useful main program (called main) can be found. The executable will be produced by typing $make$ and is prepared to produce input files for the $geant-dirac$ [1] program by making the appropriate selection in the cards file.

In general the output will be compatible with the one single vertex format of $geant-dirac$ program which can be chosen by selecting SWIT(3)=3 in the jobcrds.dat file. This is true for atomic, Coulomb and Non-Coulomb pairs, with or without finite-size corrections. The only exceptions are Accidentals and Prompt Accidentals which are produced in a format that must be read with the SWIT(3)=4 option.

5   Ionization spectra corrections

The major new feature of this generator version from previous ones is that we have used the calculated dipole spectrum at break-up of pionic atoms up to states with n=7. This work was made by T.Heim et al [10] and now included in the evolution Monte Carlo [2]. The spectra for states with large l value has also been obtained by overcoming a problem with the numerical precision of the form factor evaluation. In figure 1 the Q and θ distributions are shown for several father bound states. Remember that θ is the angle between the laboratory momentum and the center of mass relative momentum $\vec{Q}$. In the previous version of the generator the spectra of the 1S and 2S states calculated by L. Afanasyev and A. Tarasov [11] were considered for the n=1 and n=2 states while for higher excited states an approximation based on the 1S state was used. However, this improvement is not really important in the final shape of the spectrum after reconstruction due to the multiple scattering in the target.

References

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[2] C. Santamarina, PhD thesis: Detection and lifetime measurement of Pionium in the DIRAC experiment (2001); C. Santamarina et al., J. Phys. B **36** 4273 (2003).

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[4] Afanasyev L G *et al*. Phys. At. Nucl. 60 938 (1997).

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[9] A. Kuptsov and V. Kruglov, private communication.

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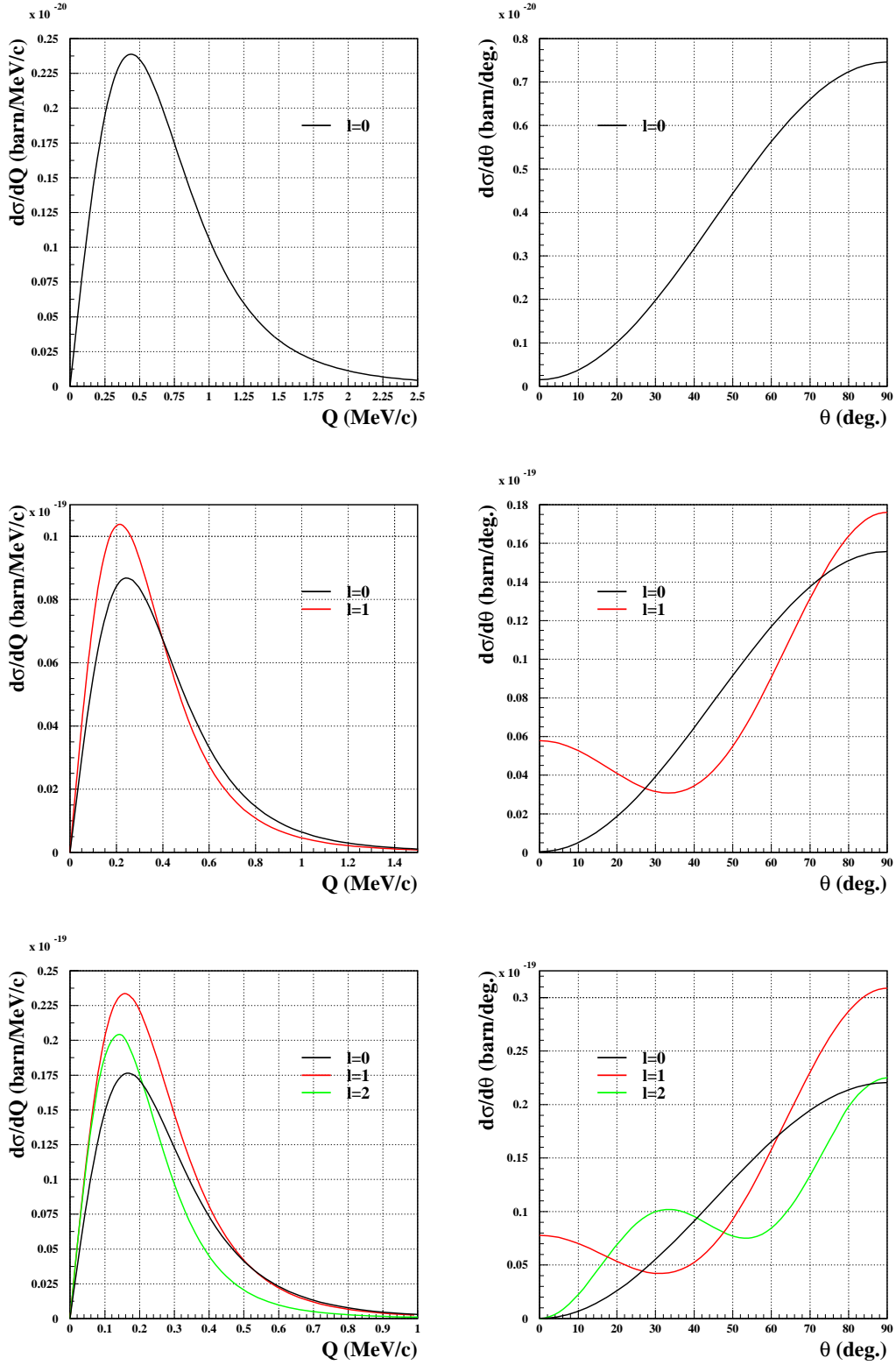[11] L. Afanasyev, Observation of $\pi^+\pi^-$ atoms, PhD thesis, JINR, Dubna (1997)

Figure 1: Relative momentum magnitude spectra of the S states with $n = 1$, $n = 2$ and $n = 3$. On the right hand side the angular distribution, with respect to the laboratory momentum is shown. The spectra are averaged over the even z parity ($l - m$ even) states of the corresponding subshell.
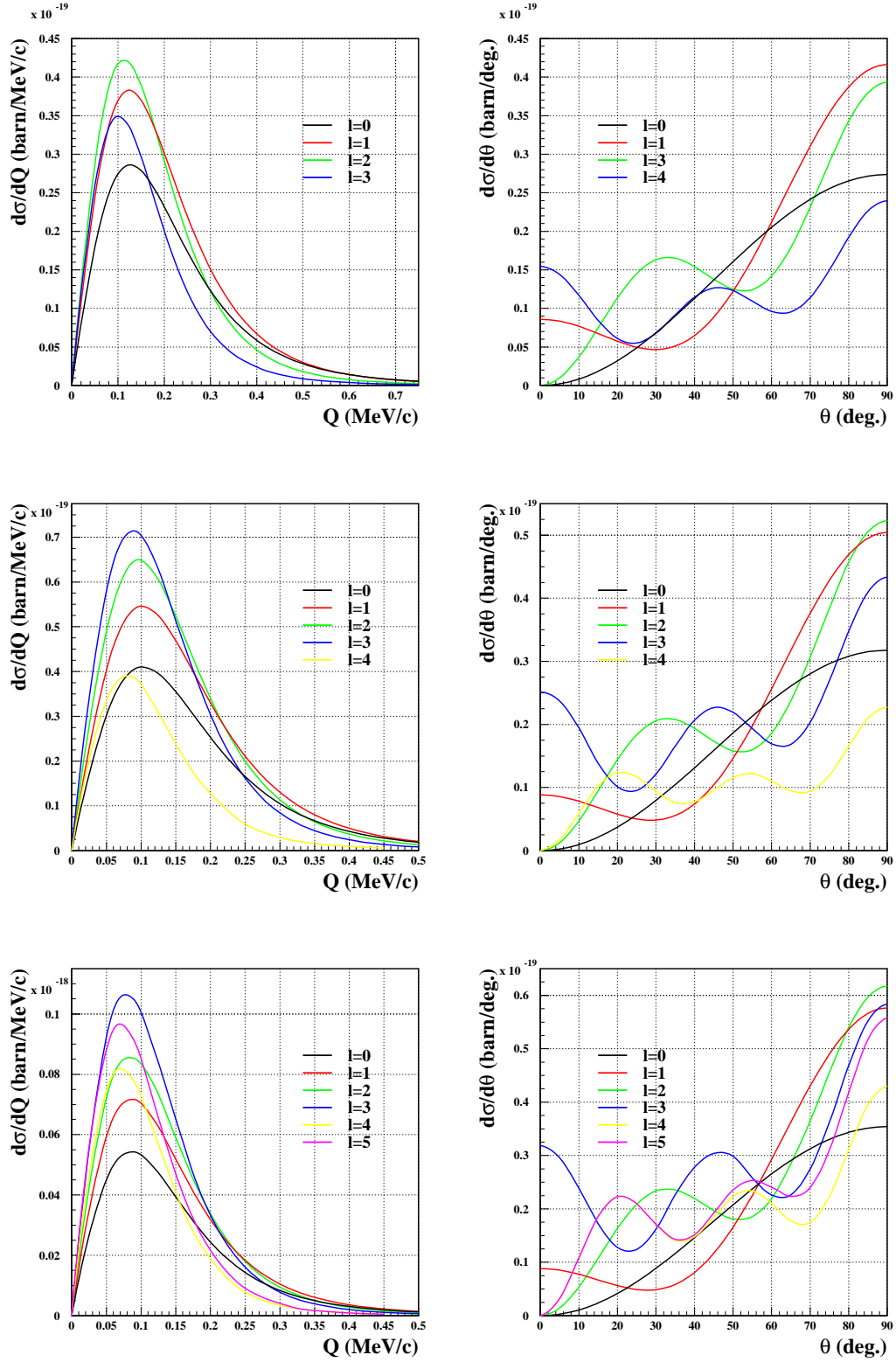
Figure 2: Relative momentum magnitude spectra of the S states with $n = 4$, $n = 5$ and $n = 6$. On the right hand side the angular distribution, with respect to the laboratory momentum is shown. The spectra are averaged over the even z parity ($l - m$ even) states of the corresponding subshell.