V. L. Rykov
February 25, 2003

Plots for DCA-distributions, accounting large angle scattering

Please, find update for the *DCA* distribution for electrons from heavy charm, beauty and Dalitz decays at http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_electrons_geant.ps.gz . Compared to http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_electrons.ps.gz (see comments as of October 18, 2003 below), this time the *DCA*-distributions for the background Dalitz electrons have been simulated for PHENIX Central Arm with GEANT, accounting large angle scattering, energy losses and bremsstrahlung (please notice that plots for electrons from heavy flavors are the same as in the old "ca_electrons.ps.gz" file, because large angle scattering, etc. little affect these distributions). The VXD geometry used is: 1 layer of pixels with $50\times425\ \mu m^2$ pitch at $R = 2.5\ cm$, and 3 layers of strips with $80\times1000\ \mu m^2$ pitch at $R = 6, 8$ and $10\ cm$. The beam pipe is $0.5\ mm\ Be$ at $R = 2\ cm$.

The estimates for Dalitz electron cross sections for various *DCA* and P_T cuts, given in the tables 1 & 2 below, should be compared to the cross sections in the tables 3-6 as of 11/21/2002 for the electrons from heavy flavors (see page 2 of this note). This comparison can be used to get an idea about the Dalitz electron background to heavy flavors. Cross sections are given in *nb*. The various cross section ratios are shown in the last 3 pages of "ca_electrons_geant.ps.gz" file.

Table 1: Simulated Dalitz electron cross sections at various *DCA* and P_T cuts for VXD thickness $1\%X_0$ per VXD layer. The shown errors are statistical only.

P_T^{cut}, GeV/c / DCA_{xy}^{cut}, μm	0.5	1.0	1.5	2.0	2.5	3.0	3.5
0	7430	669	116.1	28.5	8.66	3.08	1.22
120	625±5	7.7±0.16	$(52\pm2)\cdot10^{-2}$	$(64\pm3)\cdot10^{-3}$	$(153\pm8)\cdot10^{-4}$	$(35\pm2)\cdot10^{-4}$	$(110\pm8)\cdot10^{-5}$
160	233±3	3.4±0.11	$(25\pm1)\cdot10^{-2}$	$(35\pm2)\cdot10^{-3}$	$(77\pm6)\cdot10^{-4}$	$(18\pm2)\cdot10^{-4}$	$(56\pm6)\cdot10^{-5}$
200	108±2	2.06±0.08	$(16\pm1)\cdot10^{-2}$	$(22\pm2)\cdot10^{-3}$	$(49\pm5)\cdot10^{-4}$	$(12\pm1)\cdot10^{-4}$	$(36\pm5)\cdot10^{-5}$
400	19±1	0.49±0.04	$(37\pm5)\cdot10^{-3}$	$(45\pm8)\cdot10^{-4}$	$(13\pm2)\cdot10^{-4}$	$(28\pm7)\cdot10^{-5}$	$(10\pm2)\cdot10^{-5}$

Table 2: Simulated Dalitz electron cross sections at various *DCA* and P_T cuts for VXD thickness $2\%X_0$ per VXD layer. The shown errors are statistical only.

P_T^{cut}, GeV/c / DCA_{xy}^{cut}, μm	0.5	1.0	1.5	2.0	2.5	3.0	3.5
0	7430	669	116.1	28.5	8.66	3.08	1.22
120	1370±9	21.1±0.3	$(112\pm3)\cdot10^{-2}$	$(132\pm5)\cdot10^{-3}$	$(26\pm3)\cdot10^{-3}$	$(67\pm4)\cdot10^{-4}$	$(17\pm1)\cdot10^{-4}$
160	651±6	7.6±0.2	$(49\pm2)\cdot10^{-2}$	$(68\pm4)\cdot10^{-3}$	$(14\pm1)\cdot10^{-3}$	$(34\pm3)\cdot10^{-4}$	$(9.7\pm1)\cdot10^{-4}$
200	307±4	4.0±0.14	$(31\pm1.6)\cdot10^{-2}$	$(40\pm3)\cdot10^{-3}$	$(89\pm8)\cdot10^{-4}$	$(21\pm2)\cdot10^{-4}$	$(63\pm8)\cdot10^{-5}$
400	37±1.4	0.85±0.1	$(73\pm8)\cdot10^{-3}$	$(14\pm2)\cdot10^{-3}$	$(26\pm4)\cdot10^{-4}$	$(7\pm1)\cdot10^{-4}$	$(20\pm4)\cdot10^{-5}$

V. L. Rykov
December 10, 2002

Kinematics of charm & beauty hadrons, decaying into electrons, which contribute to the inclusive e^+ & e^- detected in the PHENIX Central Arm

The P_T and y distributions for charm & beauty hadrons (mostly *D*- & *B*-mesons), decaying (directly or via the chains) into $e^{\pm}+X$ and contributing to the inclusive electron spectra detected in the PHENIX Central Arm, are shown in the 6-page file:
http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/eca_hf_hadr_kine.ps.gz .

The histogram colors in the right frames correspond to the *DCA* cuts of the three lego plots at left. One can observe that *DCA* cuts virtually do not affect the kinematics of the contributing heavy flavor parents, but just reduce statistics (and, hopefully, even more strongly reduce background). However, the higher P_T electrons are produced by the higher P_T and more central (i.e. more narrowly *y*-distributed) parents.

V. L. Rykov
November 21, 2002

Cross section estimates for the inclusive e^++e^- from charm & beauty in the PHENIX Central Arm with various P_T and DCA_{xy} cuts

Please, find below the simulated cross section estimates for the inclusive e^++e^- from charm and beauty in the PHENIX Central Arm with various P_T and DCA_{xy} cuts[1]. The assumptions used in simulation and the total cross sections correspond to those described in this note in the section dated 10/08/2002 (see below). The respective DCA_{xy} distributions are shown in:
http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_electrons.ps.gz .

Cross sections are given[2] in *nb*.

Table 3: Electrons from charm. Statistical errors of simulations: $\frac{\delta\sigma}{\sigma} \approx \sqrt{\frac{1.9\cdot 10^{-3}\, nb}{\sigma}}$.

VXD thickness is $0.01\times X_0$ per layer.

DCA_{xy}^{cut}, µm \ P_T^{cut}, GeV/c	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
0	11900	3250	536	99.0	22.7	6.36	2.18	0.853
120	5175	513	61.5	10.0	2.22	0.594	0.198	0.0711
160	4127	313	38.9	6.34	1.42	0.384	0.133	0.0423
200	3420	209	26.4	4.18	0.924	0.265	0.0903	0.0288
400	1864	50.4	5.87	0.893	0.198	0.0615	0.0115	0.00576

[1] I.e. $P_T^e > P_T^{cut}$ and $DCA_{xy}^e > DCA_{xy}^{cut}$. The DCA cuts have been applied to the "measured" DCA, i.e. after smearing with the DCA resolution for the VXD thickness of $0.01\times X_0$ or $0.02\times X_0$ per layer.
[2] 3-digit numbers for the cross sections are given just for uniformity and in no way mean that author always trust them to the last digit(s).

Table 4: Electrons from beauty. Statistical error of simulations: $\frac{\delta\sigma}{\sigma} \approx \sqrt{\frac{1.2\cdot 10^{-5}\,nb}{\sigma}}$. VXD thickness is $0.01\times X_0$ per layer.

DCA_{xy}^{cut}, μm \ P_T^{cut}, GeV/c	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
0	116	62.6	36.6	20.7	11.3	6.07	3.27	1.80
120	63.5	25.3	13.2	6.97	3.61	1.87	0.972	0.518
160	54.3	20.1	10.4	5.39	2.77	1.42	0.731	0.386
200	47.0	16.2	8.26	4.26	2.17	1.10	0.564	0.298
400	26.4	6.59	3.20	1.58	0.776	0.384	0.193	0.100

Table 5: Electrons from charm. Statistical errors of simulations: $\frac{\delta\sigma}{\sigma} \approx \sqrt{\frac{1.9\cdot 10^{-3}\,nb}{\sigma}}$. VXD thickness is $0.02\times X_0$ per layer.

DCA_{xy}^{cut}, μm \ P_T^{cut}, GeV/c	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
0	11900	3250	536	99.0	22.7	6.36	2.18	0.853
120	6053	667	67.1	10.6	2.30	0.615	0.196	0.0788
160	4951	392	40.9	6.50	1.42	0.398	0.140	0.0538
200	4159	246	27.3	4.24	0.934	0.259	0.0941	0.0346
400	2296	53.0	5.97	0.939	0.186	0.0634	0.0115	0.00576

Table 6: Electrons from beauty. Statistical error of simulations: $\frac{\delta\sigma}{\sigma} \approx \sqrt{\frac{1.2\cdot 10^{-5}\,nb}{\sigma}}$. VXD thickness is $0.02\times X_0$ per layer.

DCA_{xy}^{cut}, μm \ P_T^{cut}, GeV/c	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
0	116	62.6	36.6	20.7	11.3	6.07	3.27	1.80
120	66.5	26.1	13.4	7.03	3.63	1.87	0.975	0.518
160	57.3	20.6	10.5	5.42	2.78	1.42	0.735	0.387
200	50.1	16.6	8.33	4.29	2.17	1.10	0.567	0.297
400	29.2	6.66	3.21	1.59	0.778	0.384	0.192	0.100

V. L. Rykov
October 18, 2002

Comments to figures in the file "ca_electrons.ps.gz"
(Update as of 10/18/2002)

For this update, all figures are placed into the single 6-page long PS-file: http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_electrons.ps.gz . First 5 pages represent essentially the same figures as had been shown on 10/08/2002 (for the original comments as of 10/08/2002, see the respective pages of this document below), but with the larger number of events in the histograms. The 6th page is new. Currently, the number of event in all histograms corresponds to the integrated *pp* luminosities of $\sim 0.25\ pb^{-1}$ for *charm* and $\sim 40\ pb^{-1}$ for *beauty.*

In **page 1**, the simulated **inclusive** $e^{\pm}$ P_T-spectra for *pp*-collisions at $\sqrt{S} = 200$ GeV are shown. Besides the larger statistics, I also have done some limited correctness check of the results in frame of the used assumptions for these simulations, keeping in mind the discussion of the previous phone meeting on the relative contributions of *Dalitz-pairs* and *charm*. Last time, I used the "shortcut" to produce Dalitz-pair spectrum. Namely, I generated the PHENIX measured π^0s spectrum, but then "asked" PYTHIA to decay π^0s. It is known, however, that in most cases PYTHIA handles particle decay in simplified, i.e. rather incorrect ways. To make sure that the Dalitz-decay belongs to those few ones which are handled by PYTHIA correctly, I have done some necessary "arithmetic" and wrote my own code for the pseudo-scalar to $\gamma f\bar{f}$ -decay. Then I compared the results of this code and PYTHIA. I found them in the perfect agreement. So, the conclusion is that Dalitz-decay does belong to those few ones which PYTHIA 6.1 handles correctly. Obviously, I did not do the same for the PYTHIA's *charm* and *beauty* productions and decays, … because I have now clue on how to do this and, I suspect, this is exactly what we intend to do experimentally in PHENIX, don't we?

In **pages 2-5**, the transverse *DCA* distributions for **inclusive** $e^{\pm}$ in PHENIX Central Arm are shown at various P_T-*cuts.* This time I tried a bit more to quantify somehow the apparently different "slopes" of *charm* and *beauty DCA*-spectra and to answer the question on whether we will be able to separate *charm*- and *beauty*-originated inclusive electrons in the model independent way. The curves which are present in the plots of pages 2-5 are fits to the *DCA*-spectra in the interval *200-1000* μm with the function:

$$\frac{dN}{d(DCA)} = a \times (DCA)^{-b \cdot \log^3 (DCA)}$$

The results for such fits are shown in figures of **page 6**. Apparently, the "slopes" *b* for *charm* and *beauty* are well separated in the entire P_T-*cut* range from *0.5* to *3 GeV/c*. At low P_T, the "slope" b from the fits to the summary spectrum is closer to the *charm,* but then it moves to the *beauty's* range as P_T rises.

So, it looks like, using the *DCA*-spectra, the quantitative criterion could potentially be found to determine whether *charm* or *beauty* contributes to the detected *inclusive electrons* at various P_T. However, a lot more of simulations are needed to check the robustness of such "slopes"[3] against the variation of heavy flavor production and decay kinematics. And this is my short **conclusion** for now.

V. L. Rykov
October 8, 2002

Comments to figures in the file "ca_eptspec.ps" and "c_edca.ps"

The figures in these files represent a progress report toward understanding on how well we will be able to separate **inclusive** electrons (and positrons) from *charm*, *beauty* and background *prompt* electrons *from the primary vertex* in the PHENIX Central Arm (CA), using measurements of electron's transverse Distance of the Closest Approach (DCA) to the z-line through the primary vertex with the proposed 4-layer Si Vertex Detector (VXD). Dalitz-pair electrons have been used here as an example for the prompt $e^{\pm}$ background[4].

In the file http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_eptspec.ps , the simulated $e^{\pm}$ P_T-spectra for *pp*-collisions at $\sqrt{S} = 200$ GeV are shown. To simulate *charm*, PYTHIA parameters tuned and suggested in *K. Adcox et al (PHENIX), Phys. Rev. Lett **88** (2002) 192303* have been used. The parameters for *beauty* have been tuned by myself with the available experimental data, mainly from *CDF* and *D0.* As a result, for the *beauty* simulations, the following parameters have been changes from the PYTHIA 6.1 defaults:

- ✓ MSTP(51)=6; MSTP(52)=1 – *GRV94D(NLL,DIS)* structure functions.
- ✓ MSTP(33)=1; PARP(31)=2.6 – *k-factor=2.6.*
- ✓ MSTP(32)=4 – $Q^2 = \hat{s}$.

With these parameters, PYTHIA gives the total cross section of charm production in *pp* collisions at $\sqrt{S} = 200$ GeV at *~650 μb,* and for beauty it is *~2 μb.*

To simulate *Dalitz-pairs*, the measured π^0 production cross section from *PHENIX Analysis Note 143* has been used.

It is believed, that as P^e_T rises, the electrons from heavy flavors overtake all other significant electron sources. At P^e_T above a few *GeV, beauty* eventually becomes the main

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[3] … and/or something else. This study does not discourage in any way searches for other, more elaborate fitting functions to the *DCA*-spectra. However, trying functions with more parameters would require using the simulated spectra with much more statistics, particularly for *charm.*

[4] For this particular background, the other rejection criteria will also be used (on top of DCA measurements) like pair mass cut, double ionization in the VXD and/or TPC, etc. But these additional selection criteria may not always be applicable to other sources of prompt background electrons. For a time being, we also ignore here the background from "non-prompt" sources like K^0_S, Λ, etc. decays.

source of high-P_T electrons[5]. However, to understand in model independent way, *who* and *where contributes* and *how much,* the DCA distributions for electrons are exploited in many experiments along with other signatures.

The simulated DCA distributions at various P^e_T*–cuts* are shown in figures of the file http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/ca_edca.ps, assuming the DCA resolutions from page 6 of my August-2002 report[6]:
UpgradeWorkshopAugust2002.ppt at the same URL:
http://www.phenix.bnl.gov/phenix/WWW/publish/vrykov/.

In the left and right columns, it is assumed that the VXD thickness was *1%* and *2%* of X_0 per layer, respectively. One can observe that the noticeable difference between these two thicknesses is at the lowest P^e_T*–cut=0.5 GeV/c.* For $1\% X_0/layer$, the backround is above *charm* at $DCA \leq 150$ *mkm* (approximately), but with $2\% X_0/layer$, it is spread up to *~200 mkm*.

Up to P^e_T*–cut=1.5 GeV/c*, electrons from *charm* dominates at *100-200 mkm* $\leq$ *DCA* $\leq$ *1000 mkm* and then they are overtaken by electrons from *beauty.* "By eyes", the slopes of DCA distributions from *charm* and *beauty* are significantly different. However, since the distributions cannot be described by simple exponents, the numerical evaluation of the "slopes" need some work. In this simulations, I tried fitting the DCA distributions with the function: $dN/dDCA = a \times \exp(-bx^c)$. These fits are shown in figures. The fits to the simulated distributions yield *b* in the range of *0.5-1.5* for *charm* and in the range of *0.1-0.2* for *beauty* with $c \approx 0.3\text{-}0.5$ for the both, i.e. there is really significant numerical difference in parameter *b* for *charm* and *beauty*. However, at this point I am still not suggesting this particular function to be used, because I feel that parameters *b* and *c* are too correlated to each other which results in some kind of "instability" of the fits[7]. Anyway, I have almost no doubts that, after doing some more "arithmetic", the right function and parameters to clearly separate charm and beauty could be found. And this is, essentially, my short **conclusion** to the presented figures.

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[5] For these particular simulations, *beauty* overtakes other sources at about *3.5 GeV.*

[6] Purely Gaussian DCA smearing has been used, ignoring the large angle scattering, which, of course, will create some "tails" to the Gaussians.

[7] One option to get rid of this could be just to fix *c=0.4-0.5*, but I have not tried this yet.