Measuring D^0 at SPD Via Hadronic Channel

Amaresh Datta
(amaresh@jinr.ru)

DLNP
Dubna, Russia

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D Mesons At SPD

- At SPD energies gluon fusion process dominates charmed meson production, making asymmetries sensitive to gluon spin distributions : third probe of particular interest besides direct photon and charmonia
- Among different possible decay modes of charmed mesons, SPD detectors can best measure in handronic decay channel. For example
- $D^0 \rightarrow \pi^+ + K^-$, Branching Ratio 3.89%
- $\bar{D}^0 \rightarrow \pi^- + K^+$
- $D^+ \rightarrow \pi^+ + \pi^+ + K^-$, Branching Ratio 9.22%
- $D^- \rightarrow \pi^- + \pi^- + K^+$
- Today, we shall focus on D^0 measurements in particular using MC simulations

Since Last Collaboration Meeting

- A thorough cross-check was performed by parallel independent analyses done by Vladimir Andreev and myself
- Results were presented in monthly Physics and MC meetings
- We looked at primary vertex reconstruction, secondary veretx reconstruction with KFParticle package
- Compared all relevant kinematic and fit variable distributions
- We fixed some bugs and standardized the analysis technique for the ideal case of perfect PID and fixed event vertex
- We are now confident in the reconstruction performance and trust the variable distributions

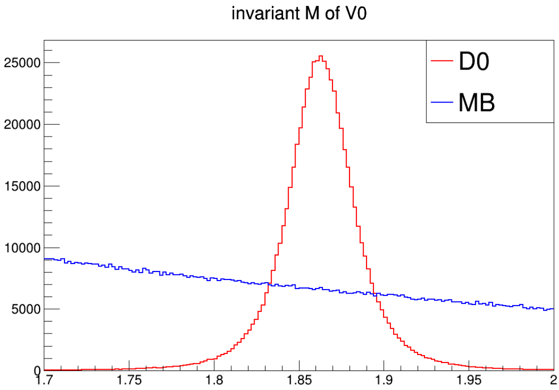
Simulation Details : Ideal Scenario

- Pythia8 + SpdRoot
- Subsystems Used : Beam-pipe, Inner Tracker, Straw Tracker, Magnet
- Magnetic field : Bz = 1 Tesla
- Silicon Inner Tracker config : MAPS, 4 layers, no end-cap
- Event vertex at (0,0,0)
- Ideal PID from MC
- Minimum bias (except elastic) for background study and opencharm channels for signal (D^0) study
- $D^0 \to \pi^+ K^-$ channel forced to enhance statistics in simulation (original branching ratio 3.89%)

Analysis Details

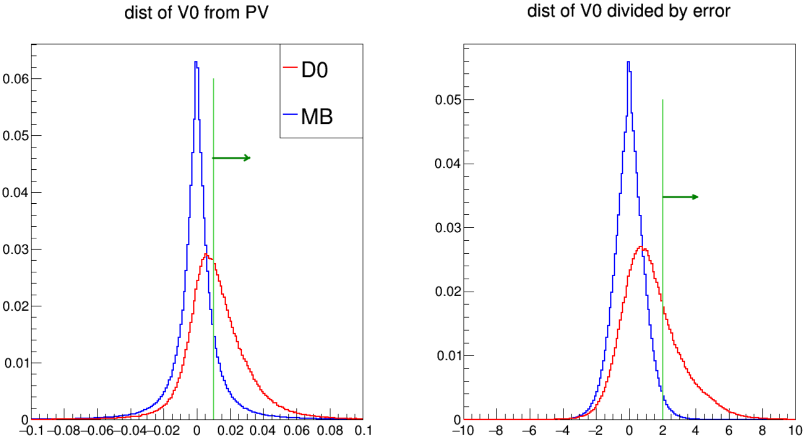
- V0 reconstuction with KFParticle package
- Good quality tracks and at least 3 SVD hits for daughter (π, K) track candidates
- SpdVertexCombiFinder used to reconstruct all possible combinations of (π,K) in minbias event
- Mass window cut (1.7 - 2.0 GeV/c^2) applied for all cases for both signal D0 and random background from MB
- 4 M open-charm events generated, $D^0 \rightarrow \pi^+ K^-$ forced
- 40 M MB (except elastic) events generated

Starting Point



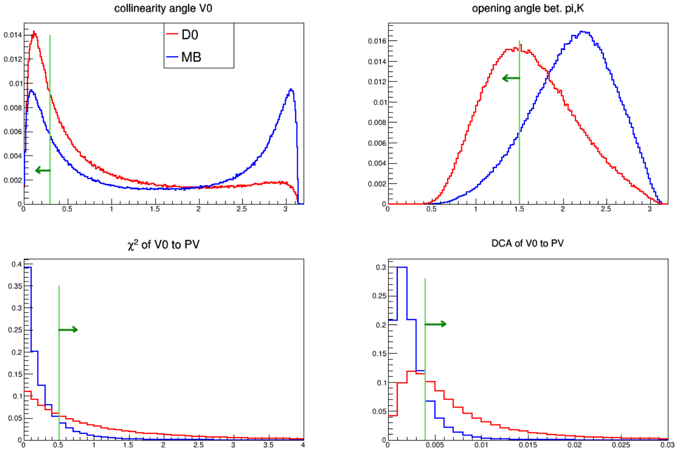
Generated : 4 M open-charm events, 40 M MinBias events
Detected : 633533 D0, 1.02634×10^6 MB

V0 Decay Length and Uncertainty



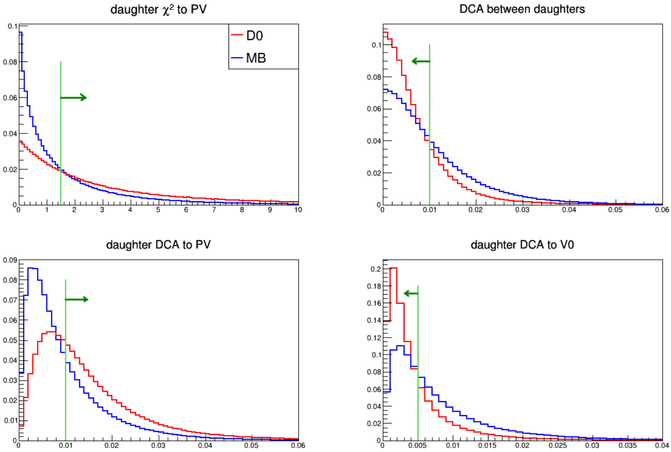
Accept V0 above the cuts

V0 Reconstruction Variables



Accept V0 below angle cuts and above χ^2,DCA cuts

Daughter Track Reconstruction Variables

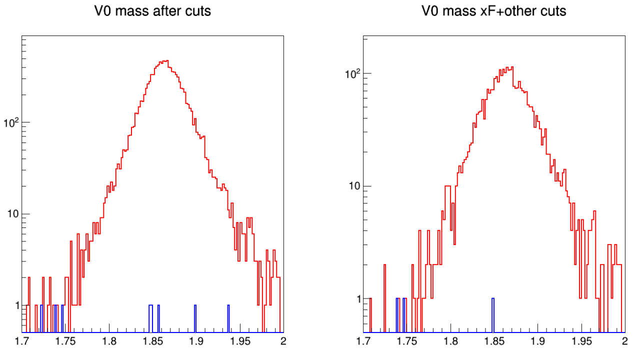


Accept V0 above the cuts related to PV and below DCA-to-V0 cut and DCA-between-daughters cut

Cuts to Suppress MB Background

- Decay length : $L > 0.008$ cm, $L/\delta L > 2$.
- Collinearity angle : $\theta_{col} < 0.3$ rad
- V0 properties : $\chi^2_{V0-PV} > 0.5$, $DCA_{V0-PV} > 0.004$ cm
- Daughter track properties :
- $DCA_{\pi-K} < 0.01$ cm, opening angle $\theta_{OA} < 1.5$ rad
- Daughter to PV : $\chi^2_{d-PV} > 1.5$, $DCA_{d-PV} > 0.01$ cm
- Daughter to V0 : $DCA_{d-V0} < 0.005$ cm
- Invariant mass window 1.7-2.0 GeV/c^2
- $|x_F| > 0.2$ for asymmetry measurements

After Cuts



Started with : 633533 D^0, 1.02634×10^6 MinBias

Before x_F cut : 11456 D0, 8 MB

After x_F cut : 3279 D0, 3 MB

Cut Effect

- S/B = 1093 (from *generated* MC event ratio $N_S/N_B = 1/10$)
- Accounting for proper D0 branching ratio, S/B = 42.5
- Assuming 32.8 mb for MB and 9.4 μb for open-charm, real data *produced* event ratio $N_S/N_B = \sigma_S/\sigma_B = 1/3489$
- Expected from data, S/B $\sim 1/8$
- Independent study by Vladimir Andreev obtained same S/B ratio for the 'ideal scenario'
- There is room for experimentation with cuts
- Background counts after cut statisticlaly not reliable yet. Requires a much larger sample ($\sim$billion or $\sim$10 billon events)

Ideal Scenario : Vladimir Andreev

Final results

1. add some additional kinematic cuts on generator level

2. were generated 125000 MB events => ~ 32 M effective MB events

3. were generated 38000 D0 events => ~250000 effective D0 events

4. add next cuts:

   a) apply Δm and xF cuts
   b) cosine of V0, K^- and pi+ should be $|\cos\theta| < 0.95$
   c) open angle between K^- and pi+ => $0.6 < \Omega < 1.5$
   d) momentum of K^- => p > 0.5 GeV/c
   e) DCA of V0 to PV => DCA > 0.003 cm

5. all these cuts give the next suppression factor:

   MB => 640 (K- pi+) pairs => $\sim 2.0*10^{-5}$
   D0 => 2221 (K- pi+) pairs => $\sim 1.2*10^{-2}$

6. $\sim 6.4*10^{4}$ MB events and only 1 D^0 event with taking into account BR (3.9 %)

   ~107 MB and only 1 D0 events

7. add new cut => decay length > 0.01 cm, DCA K- and pi+ > 0.01 cm:

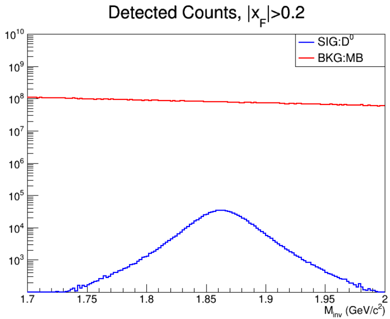
   MB => 26 (K- pi+) pairs => $\sim 8.2*10^{-7}$
   D0 => 1075 (K- pi+) pairs => $\sim 4.3*10^{-3}$

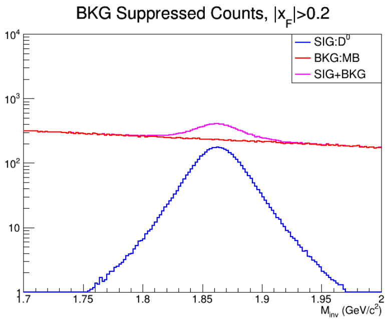
8. $\sim 6.4*10^{4}$ MB events and only 1 D^0 event with taking into account BR (3.9 %)

   ~ 12 MB and only 1 D0 events or with another cuts configuration => ~8 MB and 1 D0 events

V. Andreev, 17

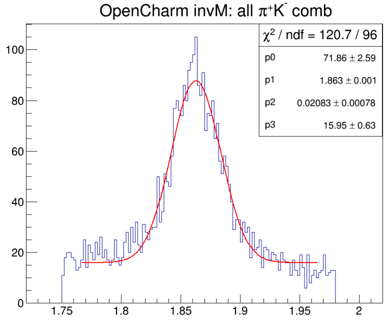
Cut Effect : Scaled For One Year Integrated Luminosity





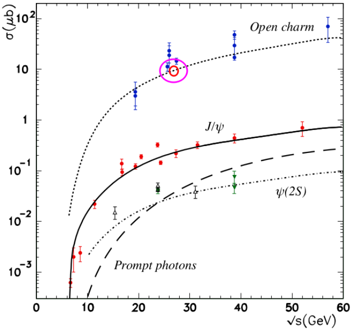
IFF all data from one year were recorded, this is how it would look : before (left) and after (right) cuts to reduce background

Clarification 1) Background From Open-Charm Events



- Even in open-charm/signal events, there can be multiple π, K combinations
- These combinations also can add to the background
- Plot shows it is a small contribution, especially compared to orders of magnitude higher background form MinBias events
- We neglect this for now

Clarification 2) Process Cross-section

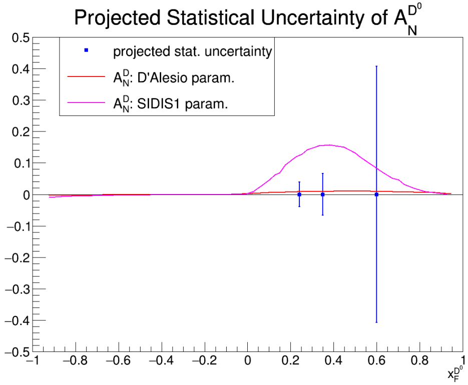


- CDR plot gives open-charm cross-section $\sim 9.4\ \mu b$ (PYTHIA open-charm cross-section $\sim 1.5\ \mu b$ at $\hat{p_T}_{min} = 1$ GeV)
- D^0 is produced in ~ 49% open-charm events with channel BR 3.89%, process cross-section $\sim 180\ nb$
- CDR suggests twice this (360 nb)
- One year data (int. lum. 1 fb^{-1}), events produced with $D^0 \to \pi^+ K^-$ process : 180-360 Million. Let's take the golden mean : 240 M

Estimated Statistical Uncertainty of Asymmetry

- 4M of open-charm events ($\sim$ 2M events with D0 forced decay) produces counts :
  1. xF: 0.2-0.3 : 2416
  2. xF: 0.3-0.5 : 841
  3. xF: 0.5-1.0 : 22
- Statistical uncertainty of A_N will crucially depend on software event selection - how many D0 events will be retained?
- One year data : 240 M process events produced (factor of 120 gain over simulated counts here)
- Accounting for proper branching ratio, statistical uncertainty of D^0 single transverse spin asymmetry ($\sigma^{stat}_{A_N^{D^0}}$) in xF bins :
  1. xF: 0.2-0.3 : 0.039
  2. xF: 0.3-0.5 : 0.066
  3. xF: 0.5-1.0 : 0.407

Projected Asymmetry of $A_N^{D^0}$

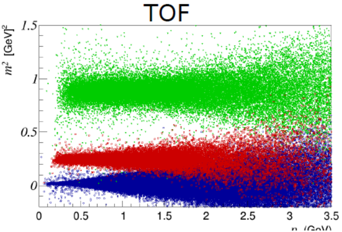


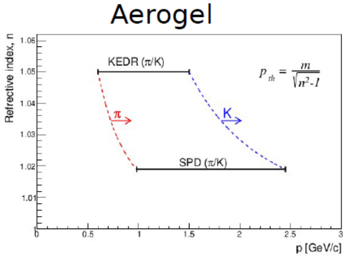
Best case scenario : SPD results can conclusively help reduce model dependence

$$\sigma_{A_N^S} = \frac{\sqrt{\sigma^2_{A_N^T} + r^2\sigma^2_{A_N^B}}}{1 - r}$$

- where S is signal, B is background, T is total = signal+background and ratio $r = \frac{B}{B+S}$
- $\sigma_{A_N^T}$ and $\sigma_{A_N^B}$ are Poissonian uncertainties of total and background counts in the x_F bins in this case

SPD PID Capabilities





- Upto momentum 1.5 GeV/c use TOF for realistic PID
- Above 1.5 GeV/c, Aerogel is of limited use : protons and kaons can be misidentified
- Negative tracks are assumed as K^-
- Positive tracks are assumed as π^+

Simulation Details : Realistic Scenario

- Subsystems Used : Beam-pipe, Inner Tracker, Straw Tracker, Time-of-Flight, Aerogel, Magnet
- Magnetic field : Bz = 1 Tesla
- Silicon Inner Tracker config : MAPS, 4 layers, no end-cap
- Event vertex position smeared with $\sigma_{x/y} = 1\ mm, \sigma_z = 30\ cm$
- For $|P| \leq 1.5$ GeV/c, pid from TOF used
- For $|P| \geq 1.5$ GeV/c, Aerogel information was used

Effects of Realistic PID and Vertex Smearing

- Ideal case :
  1. Signal suppression : 5×10^{-3}
  2. Background suppression : 2.9×10^{-6}
  3. $S/B \sim 8$
- TOF only for PID :
  1. Signal suppression : 3×10^{-3}
  2. Background suppression : 9.7×10^{-6}
  3. $S/B \sim 57$
- TOF+Aeg for PID :
  1. Signal suppression : 3.9×10^{-3}
  2. Background suppression : 4.7×10^{-6}
  3. $S/B \sim 22$

Effects of Realistic PID and Vertex Smearing

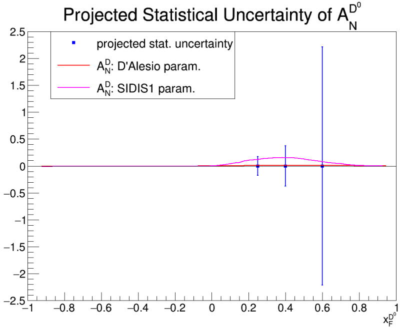


Figure 1: TOF PID

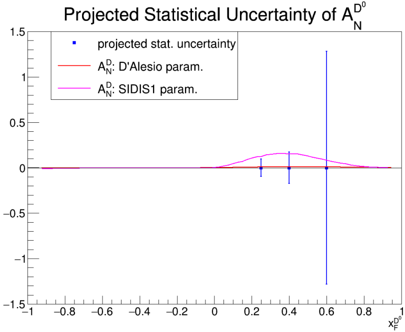


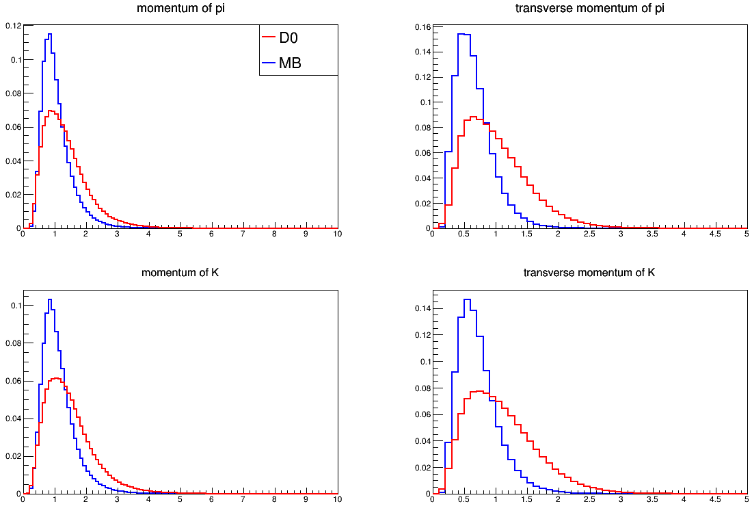
Figure 2: TOF+Aeg PID

Summary

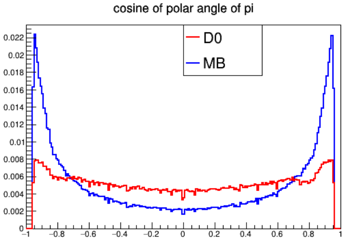
- D0 analysis technique on the right track, can improve S/B further
- Variables are correlated - possibly multi-variate analysis may help achieve better S/B
- Study of background after suppression requires a large MC data set - SPD software team may make such MC data set available soon
- Online event selection criteria may record data with some background already suppressed, analysis here assumes simple MinBias data
- PID capability is a crucial part of the secondary vertex reconstruction. Aerogel is of limited use. Cherenkov detector with low threshold might be a better solution - this is being considered.
- In future we shall investigate $D^{\pm}$ measurements via hadronic decay

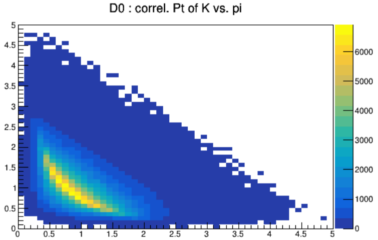
Backup

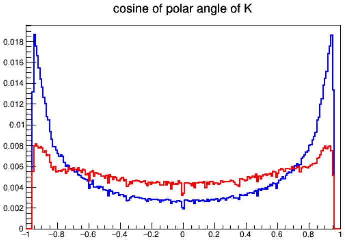
Daughter Track Kinematic Variables : Set 1

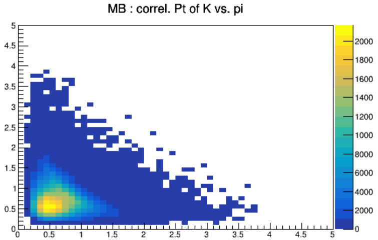


Daughter Track Kinematic Variables : Set 2

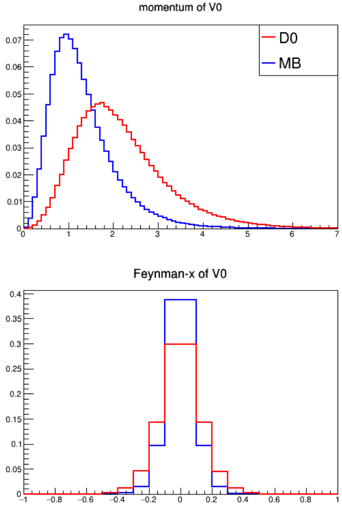








V0 Kinematic Variables



D Meson SSA Prediction at SPD

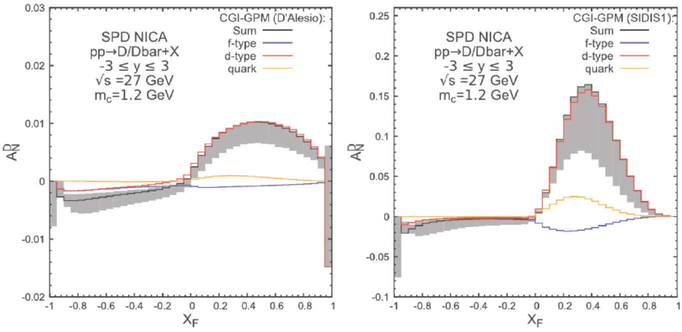


Figure 3: A_N estimations for D mesons (not just D^0)

Inclusive charmed meson uncertainties form our Samara colleagues for two different hadronization parameters