Prospects of Charm Meson Measurements at the SPD

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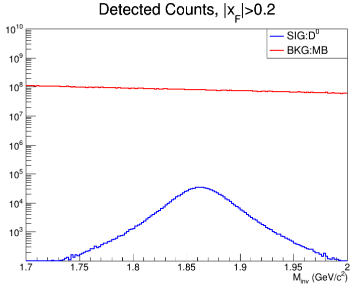
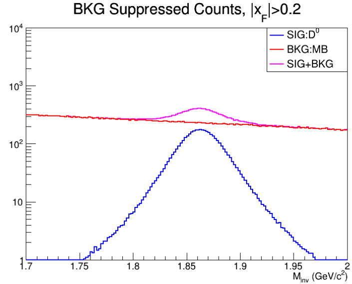
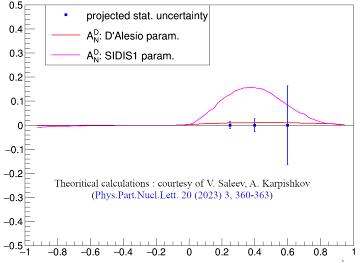
From the Last Collaboration Meeting







(1) d-type contributions to A_N^D of inclusive D mesons shown

(2) statistical uncertainties for D^0 in ideal case simulation

Now extending to more realistic simulation and charged D mesons

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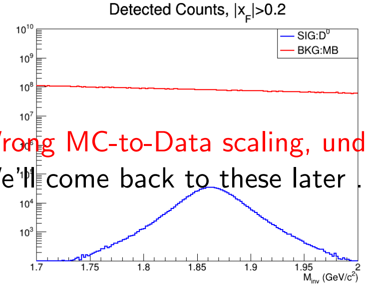
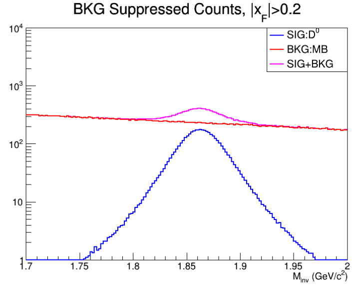
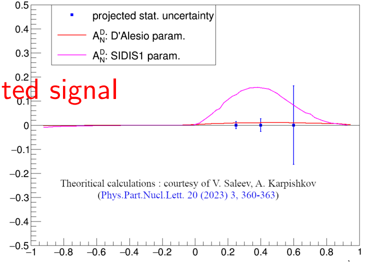


Wrong MC-to-Data scaling, underestimated signal

We'll come back to these later ...





(1) d-type contributions to A_N^D of inclusive D mesons shown

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Now extending to more realistic simulation and charged D mesons

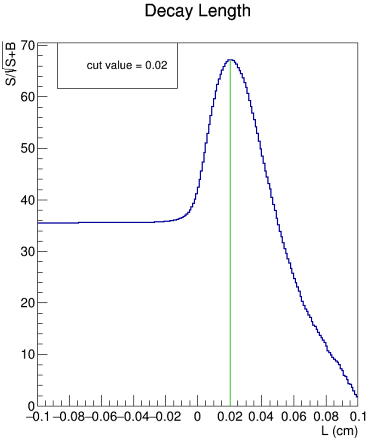
Continuing the Saga ...

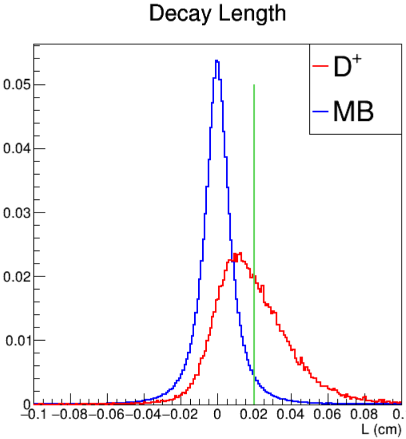
- So far neutral D meson simulation with ideal case (no vertex smearing and perfect PID) shown
- Extended study to realistic simulation with vertex smearing in generator and use of TOF (up to $p = 1.5$ GeV/c) and AeroGel (up to $p = 2.5$ GeV/c) for particle identification
- Also studied charged (D^+) meson
- Some details of the D^+ simulation with realistic simulation will be shown
- One year projected statistic before and after selection criteria and resulting statistical uncertainties will be shown
- Caution : these plots assume ALL data recorded, so these uncertainties are more of a guideline than proper expected values

Simulation (Pythia8+SpdRoot) Details

- Subsystems : Beam-pipe, Inner Tracker, Straw Tracker, Magnet
- Silicon Inner Tracker : MAPS, 4 layers with end-caps
- Event vertex (0,0,0), 30 cm Gaussian z-smearing
- TOF and AeroGel likelihoods used for PID
- MinBias for background study and open-charm for signal
- $D^+ \to \pi^+\pi^+K^-$ forced (branching ratio 9.22%)
- V0 reconstruction with KFParticle package, constrained to primary vertex
- Require at least 3 SVD hits for daughter (π, K) track candidates
- SpdVertexCombiFinder to reconstruct all combinations of $(\pi, \pi$,K)
- Mass window cut (1.7 - 2.0 GeV/c^2) for all

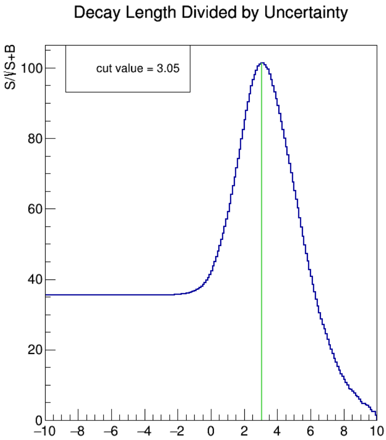
Figure Of Merit and Cuts : Decay Length

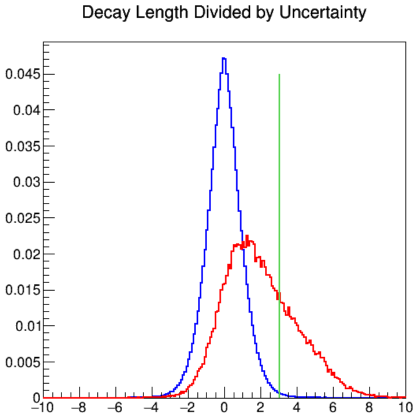




Acceped above 200 μm

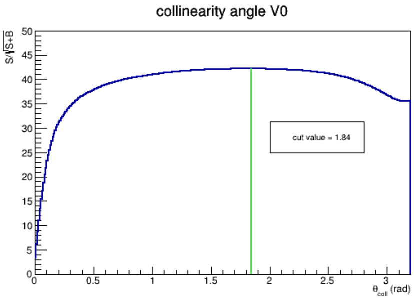
FOM and Cuts : Decay Length Divided by Uncertainty

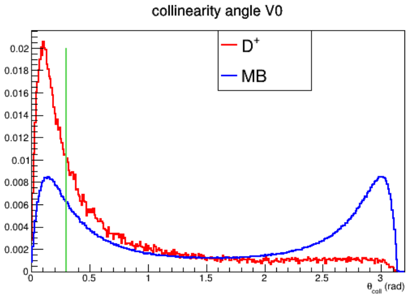




Accepted above $\frac{L}{\delta_L} = 3$

Other Considerations



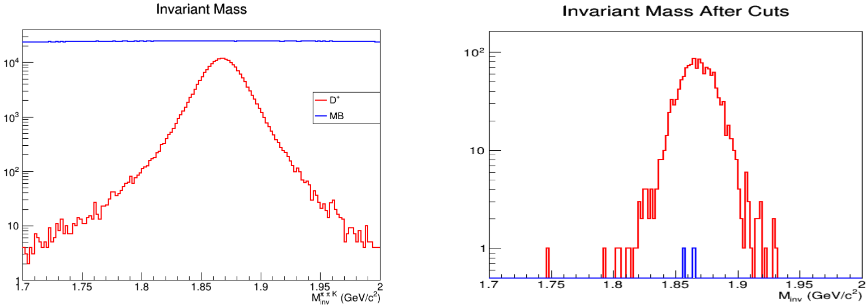


Accepted below $\theta_{coll} = 0.3$ rad although FOM suggests $\theta_{coll} = 1.84$ rad
collinearity angle = angle between invariant momentum (of daughter tracks) and vector from primary vertex to reconstructed decay position - supposed to be small angles

Cuts to Suppress MB Background

- Decay length : $L > 0.02$ cm, $L/dL > 3.05$
- Collinearity angle : $Acol < 0.3$ rad
- V0 properties : $\chi^2_{V0-PV} > 0.5$, $DCA_{V0-PV} > 0.005$ cm
- Daughter track properties :
- $DCA_{\pi-K} < 0.012$ cm, opening angle $OA < 1.5$ rad
- Daughter to PV : $\chi^2_{d-PV} > 2.5$, $DCA_{d-PV} > 0.012$ cm
- Daughter to V0 : $DCA_{d-V0} < 0.01$ cm
- Invariant mass window 1.7-2.0 GeV$/c^2$
- $|x_F| > 0.2$ for asymmetry measurements

D^+ Study : MC Before and After Selection



Realistic MC study of D^+ reconstruction and background :

20 Million open-charm and 80 Million minbias events generated

Left : reconstructed invariant mass spectra, 215964 D^+, 3.657×10^6 random bkg

Right : selected invariant mass spectra, 1420 D^+, 2 random bkg

After $|x_F| > 0.2$ cut, 138 D^+ and no background survive

Some Relevant Numbers

- Following CDR estimates for projected statistics :
- $D^0 \to \pi^+ K^-$: 360 M in 1 year
- $D^+ \to \pi^+ \pi^+ K^-$: 520 M in 1 year
- D^0 decay channel branching ratio = 3.89%
- D^+ decay channel branching ratio = 9.22%
- In the open-charm events generated with Pythia8, 54.4% events have D^0's and 20% events have D^+'s
- All these are taken into account when scaling MC to data for one year

Example of MC to Data Scaling

- D^+ in MC : 20 M $\times$ 0.2 $\times$ 0.0922 = 368800
- D^+ in data : 520 M (CDR : in one year)
- Signal scale : 1410 (for projected total reconstructed counts)
- MinBias in MC : 80 M
- MinBias in data : 32800 B (32.8 mb cross-section and 1 fb^{-1} integrated luminosity for one year)
- Background scale : 410000 (for projected total reconstructed counts)
- Scale for selection criteria : 0.66% for D^+, 5.47×10^{-7} for MB
- Scale for $|x_F| > 0.2$ cut : 10% for D^+, 37% for MB
- Final scale factors : 0.93 for D^+, 0.08 for MB (after all selections)

Prescription for SSA (and uncertainty) Calculation

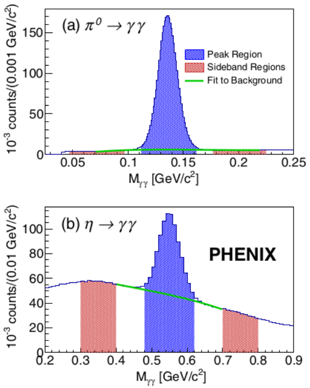


Figure 1: Illustrative plot from PHENIX : π^0 (above) and η (below) from di-photon invariant mass spectra

- Following the standard practice at STAR, PHENIX and COMPASS:
- From invariant mass spectra in azimuthal (ϕ) slices, define signal region (often 2σ around the peak), count total, calculate raw asymmetry (and uncertainty)
- Far from signal peak, count pure background, calculate background asymmetry (and uncertainty)
- Correct 'raw' asymmetry with background asymmetry (and relative contribution) to extract 'signal' asymmetry (and uncertainty)

Now Some Explicit Equations

Transverse Single Spin Asymmetry :

$$A_N(\phi) = \frac{1}{P\langle|cos(\phi)|\rangle}\frac{N(\phi) - \mathcal{R}.N(\phi+\pi)}{N(\phi) + \mathcal{R}.N(\phi+\pi)}$$

where P is beam polarization, $\langle|cos(\phi)|\rangle = \frac{\int_{\phi_1}^{\phi_2} cos(\phi)d\phi}{\phi_2 - \phi_1}$ is the average of the cosine of azimuth in the ϕ bin, $\mathcal{R}$ is relative luminosity for opp. pol. dir. of beam, N's are counts in ϕ bins. One can use $N(\phi) = N_L$ and $N(\phi+\pi) = N_R$ for left and right as simplified notation

Statistical Uncertainty of SSA (propagation of error assuming two independent variables $N(\phi)$ and $N(\phi+\pi)$) :

$$\sigma_{A_N}(\phi) = \frac{1}{P\langle|cos(\phi)|\rangle}\frac{2\mathcal{R}.N(\phi).N(\phi+\pi)}{(N(\phi)+\mathcal{R}N(\phi+\pi))^2}\sqrt{(\frac{\sigma_{N(\phi)}}{N(\phi)})^2 + (\frac{\sigma_{N(\phi+\pi)}}{N(\phi+\pi)})^2}$$

Simplifications

Assume $\mathcal{R} \sim 1$, $N(\phi) \sim N(\phi + \pi) = N$ where N is the count of candidates in a ϕ bin ($N = N_{detected}/n$ if you have n bins in azimuth) and assume Poisson distribution of counts (so that $\sigma_N = \sqrt{N}$)

Simplified version of statistical uncertainty of SSA :

$$\sigma_{A_N}(\phi) = \frac{1}{P\langle|cos(\phi)|\rangle}\frac{1}{\sqrt{2N}}$$

Finally : The Signal

Corrected signal SSA :

$$A_N^{Sig}(\phi) = \frac{A_N^{Raw}(\phi) - r.A_N^{Bkg}(\phi)}{1 - r}$$

where $r = \frac{N_{Bkg}}{N_{raw}}$ is background contribution to raw/total count under the signal peak

Corrected signal statistical uncertainty of SSA :

$$\sigma_{A_N^{Sig}}(\phi) = \frac{\sqrt{\sigma^2_{A_N^{Raw}}(\phi) + r^2\sigma^2_{A_N^{Bkg}}(\phi)}}{1 - r}$$

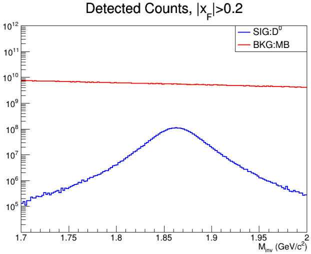
Procedure

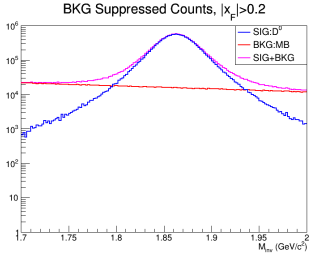
- After background suppression cuts, scale MC counts of signals in x_F bins to get counts in 1 year of data
- Using S/B ratio from analysis, estimate raw/total and background counts - done because we lack enough bkg MC to get bkg count directly
- For each x_F bin, distribute N_t and N_b in 12 ϕ bins, estimate raw and background uncertainties in each ϕ bin
- For each pair of $(\phi, \phi + \pi)$ bins, extract corrected signal uncertainty $\sigma_{A_N}(\phi)$
- For x_F bin, combine uncertainties for independent measurements in 6 (pairs of left-right) ϕ bins

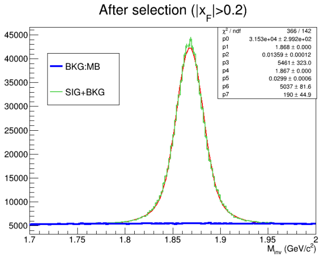
$$\sigma_{A_N}(x_F) = \frac{1}{\sqrt{\sum_{i=1}^{6} \frac{1}{\sigma^2_{A_N}(\phi_i)}}}$$

- Next : scaled spectra and projected statistical uncertainties for 4 cases : D^0 ideal and realistic MC, D^+ ideal and realistic MC

Efficiency of Selection Criteria : Projected for 1 Year of Data : D^0 Ideal Case

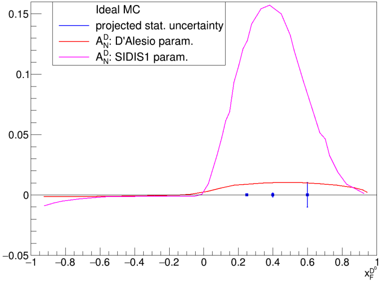


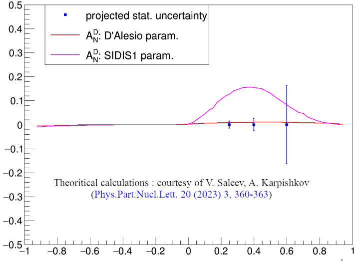




- Properly scaled this time ...
- Fitted with two Gaussians for signal + linear function for background
- S/B for entire mass range = 0.12
- S/B for 2σ mass window = 20

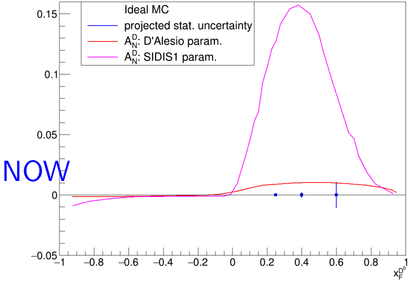
Projected Statistical Uncertainties : D^0 Ideal Case

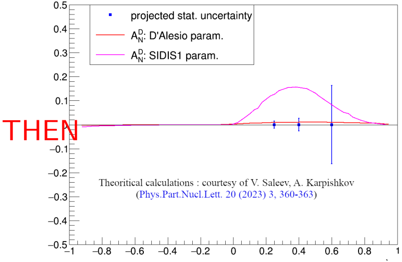




- Two changes/corrections form the plot shown before (bottom left):
- Wrong scaling in the last calculation (BR and x_F cut applied twice)
- Major difference : S/B ratio, used 1/8 before, now using 20 (affects uncertaincy directly through $r = B/(S + B)$)

Projected Statistical Uncertainties : D^0 Ideal Case





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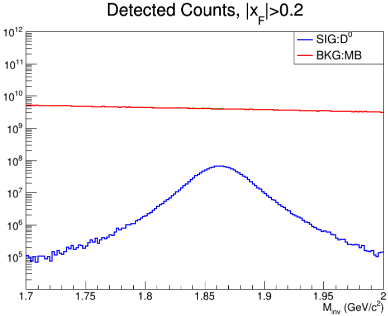
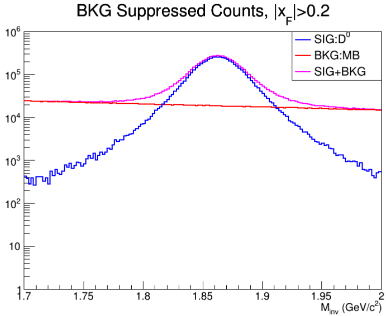
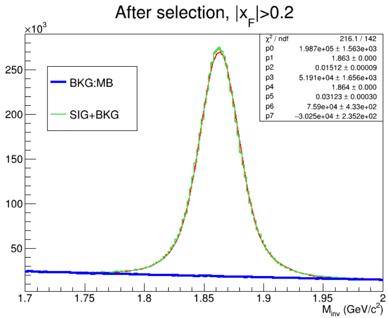
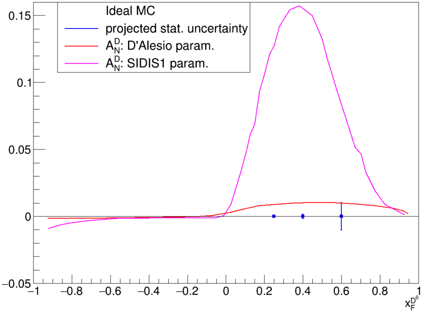
Efficiency of Selection Criteria : Projected for 1 Year of Data : D^0 Realistic Case





Projected Statistical Uncertainties : D^0 Realistic Case

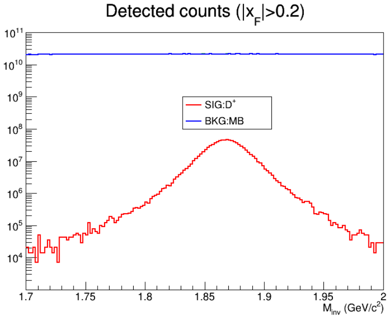


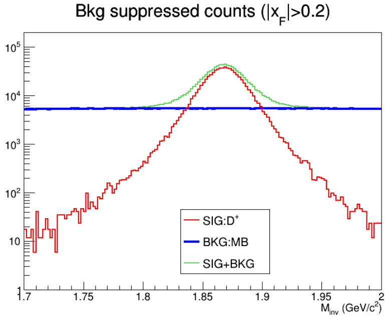


S/B for entire mass range $= 0.044$

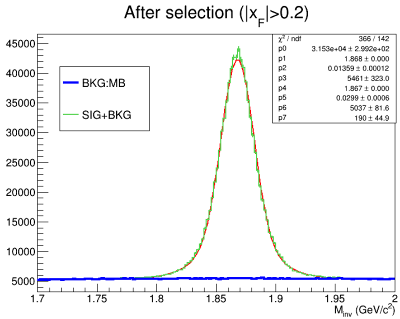
S/B for 2σ mass window $= 8.4$

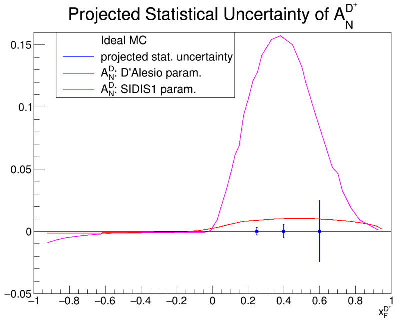
Efficiency of Selection Criteria : Projected for 1 Year of Data : D^+ Ideal Case





Projected Statistical Uncertainties : D^+ Ideal Case

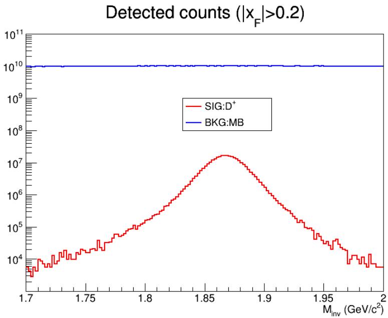


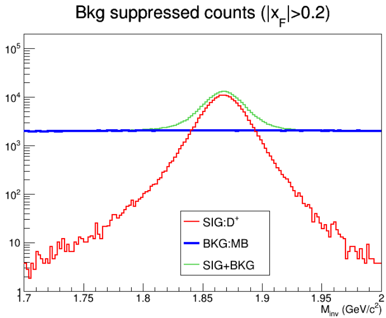


$$S/B \text{ for entire mass range} = 0.054$$

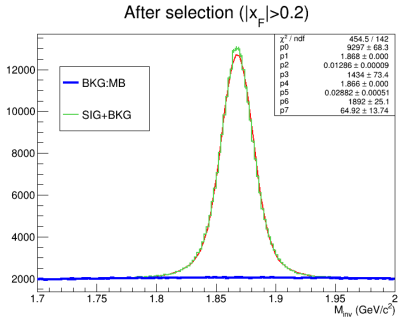
$$S/B \text{ for } 2\sigma \text{ mass window} = 4.4$$

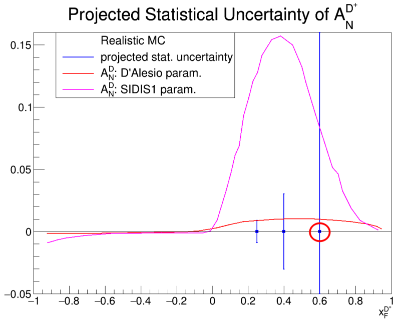
Efficiency of Selection Criteria : Projected for 1 Year of Data : D^+ Realistic Case





Projected Statistical Uncertainties : D^+ Realistic Case





S/B for entire mass range = 0.054

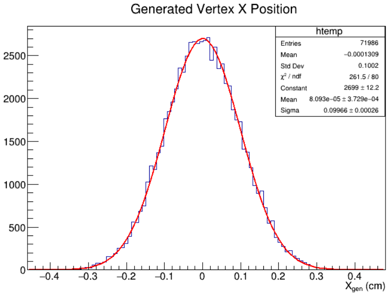
S/B for 2σ mass window = 4.4

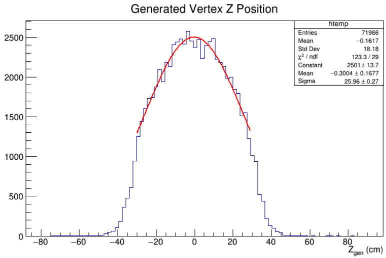
Summary

- Background suppression seems on the right tracks
- Uncertainties shown here assume perfect data recording, therefore DAQ performance (and software event selection) needs to be taken into account
- Counts after cuts are not statistically meaningful yet
- Trying tighter cuts is impossible with zero counts after selections from limited MC sample
- For all 4 sets of studies, produced more than 250 Million events
- Fine tuning of cuts have to wait till large MC samples are available from software/production team
- Plan to look into the effects of track reconstruction efficiency and TOF performance into D meson reconstruction

Backup

Generated Event Vertex Smearing





$$\sigma_x = \sigma_y = 1 \text{ mm}$$

$$\sigma_z = 30 \text{ cm}$$

Vertex Z distribution probably distorted because the distribution shown here are only for events with reconstructed $\pi^+\pi^+K^-$ invariant mass within $1.7 - 2.0$ GeV$/c^2$