

Femtoscopic correlation study of D^0 meson and hadrons (π , k , p) within STAR experiment

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STAR Collaboration meeting



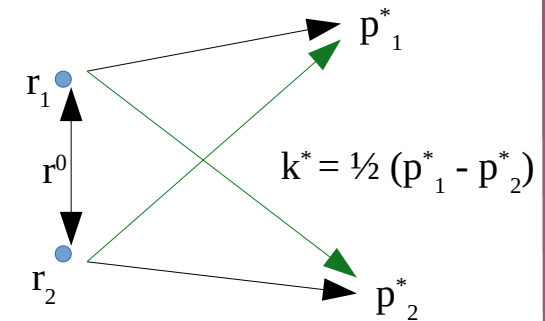
Femtoscopic correlation

- Femtoscopic correlations are observed between particles with low relative momentum.
- It is measured as a function of the reduced momentum difference (k^*) of the pair of two particles in rest frame.

$$C(\vec{k}^*) = \mathcal{N} \frac{A(\vec{k}^*)}{B(\vec{k}^*)}$$

where $k^* = 1/2(p_1^* - p_2^*)$ & N is normalization factor;

- Femtoscopic Correlation \longrightarrow QS + FSI
 - Quantum Statistics [QS]
 - Bose-Einstein quantum statistics
 - Fermi-Dirac quantum statistics
 - Final-State-Interaction [FSI]
 - Strong interaction & Coulomb interaction



r^0 is the radius of emitting source



Analysis

Data set 1

Energy \sqrt{s}_{NN}	Trigger name	Collision system	Year of data taken	Events produced	Events analyzed	Purpose of use
200 GeV	AuAu_20 0_producti on_mid_2 014	Au-Au	2014	900 M	D ⁰ events 3.7M (out of 604 M)	k* and C(k*) for D ⁰ -hadron (Pion, Proton, Kaon)

→ Analysis framework: PicoDSt



Analysis cuts (same for all data sets)

Event cuts

- $|V_z| < 6.0\text{cm}$.
- $|V_z - V_z V_{pd}| < 3.0\text{cm}$.
- $|V_x| > 1.0\text{e-}5\text{ cm}$.
- $|V_y| > 1.0\text{e-}5\text{ cm}$.
- $\sqrt{[(V_x)^2 + (V_y)^2]} \leq 2.0$
- Centrality = 0-80%

Track cuts

- $p_T > 0.5\text{ GeV}/c$
- $|dca_sign| > 0.0050\text{cm}$.
- $n\text{HitsFit} \geq 20$
- $|\text{pseudorapidity}| \leq 1.0$

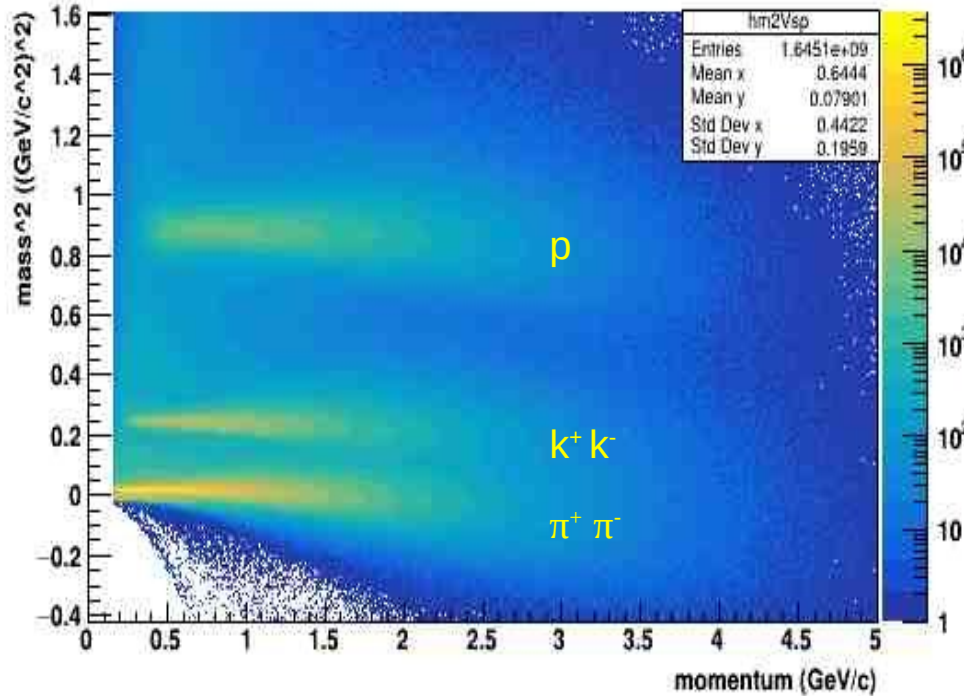
PID cuts for Pions, Kaons & Protons

- $|n\text{SigmaPion}| < 3.0$
- $|n\text{SigmaKaon}| < 2.0$ & $|n\text{SigmaProton}| < 2.0$
- $|(1/\beta) - (1/\beta_{\text{Pion}})| < 0.03$
- $|(1/\beta) - (1/\beta_{\text{Kaon}})| < 0.03$
- $|(1/\beta) - (1/\beta_{\text{Proton}})| < 0.03$



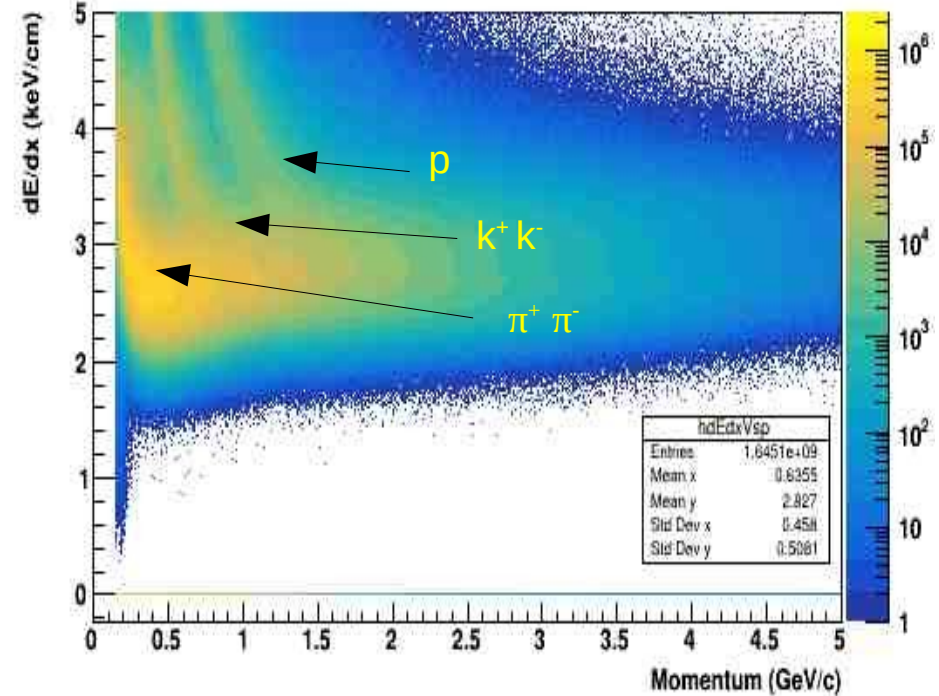
Hadron (π , p , k) identification

mass² vs momentum



Plot 1: Mass² vs. momentum for all particles

dE/dx vs momentum

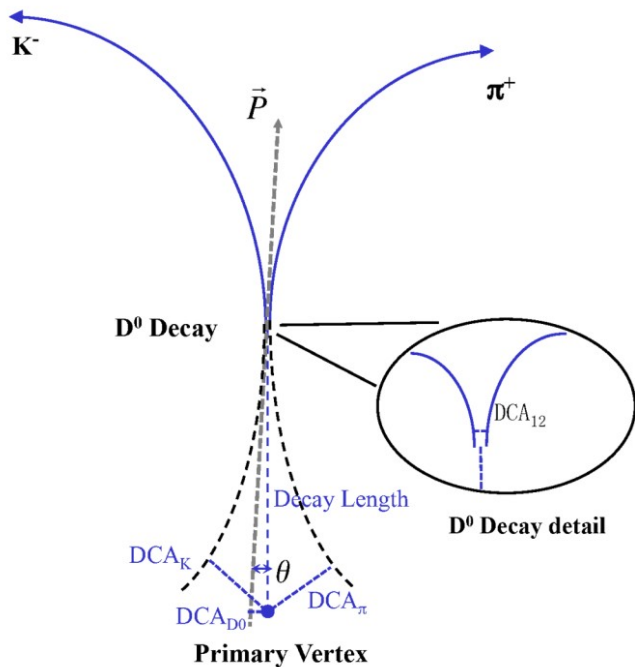


Plot 2: dE/dx vs. momentum for all particles



Reconstruction of D^0 meson

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DCA_{D^0} : DCA of reconstructed D^0 to PV

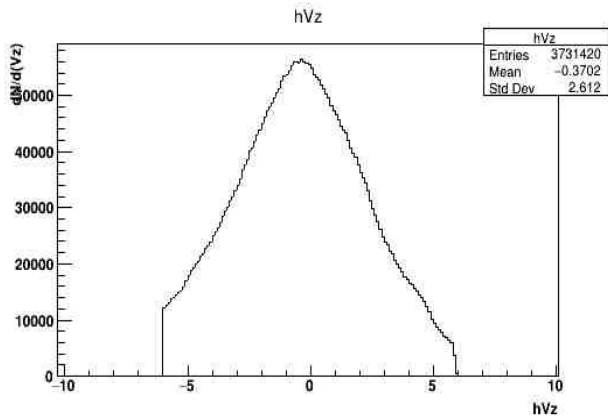
Topological cuts for 2014 data:

1. $1.6 < D^0 \text{ mass} < 2.2 \text{ GeV}/c^2$
2. $\cos(\text{pointing angle } \theta) > 0.95$
3. Decay length $> 0.025 \text{ cm}$.
4. $DCA_{12} < 0.02 \text{ cm}$.
5. $DCA_{\pi} > 0.008 \text{ cm}$.
6. $DCA_K > 0.008 \text{ cm}$.
7. Decay length $> [0.0145, 0.0181, 0.0212, 0.0247, 0.0259] \text{ cm}$; $[p_T: 0., 1., 2., 3., 5., 15] \text{ GeV}/c$
8. Decay length * $\sin(\text{pointing angle}) < [0.0061, 0.0049, 0.0038, 0.0038, 0.0040]$; $[p_T: 0., 1., 2., 3., 5., 15] \text{ GeV}/c$

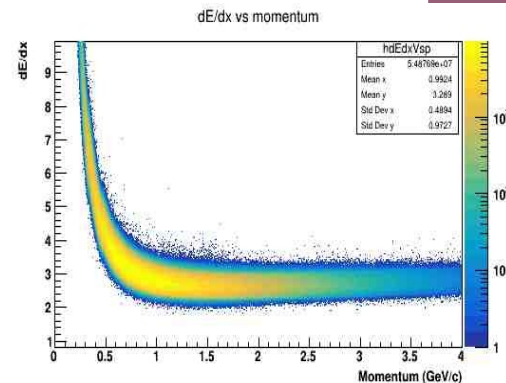
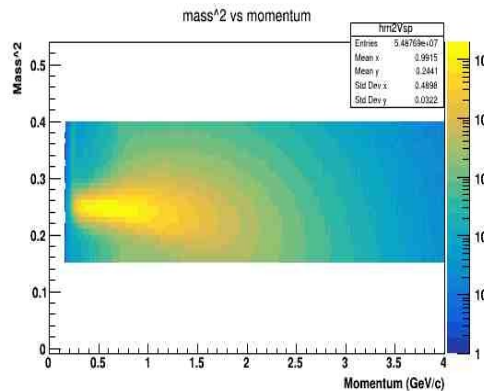
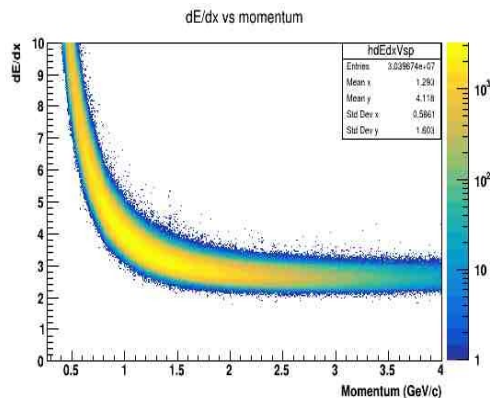
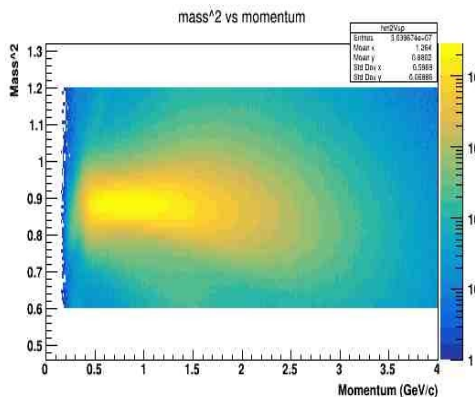
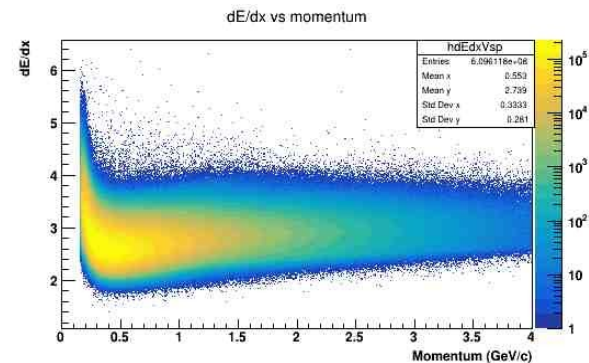
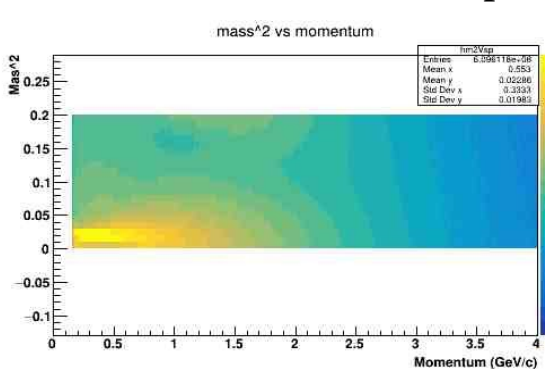


Hadron selection for D^0 - π , D^0 -p & D^0 -k pairs

- 3.7 million D^0 events reduced from 604 million events
- Chosen hadrons for pairing with D^0 : Pion, Proton, Kaon



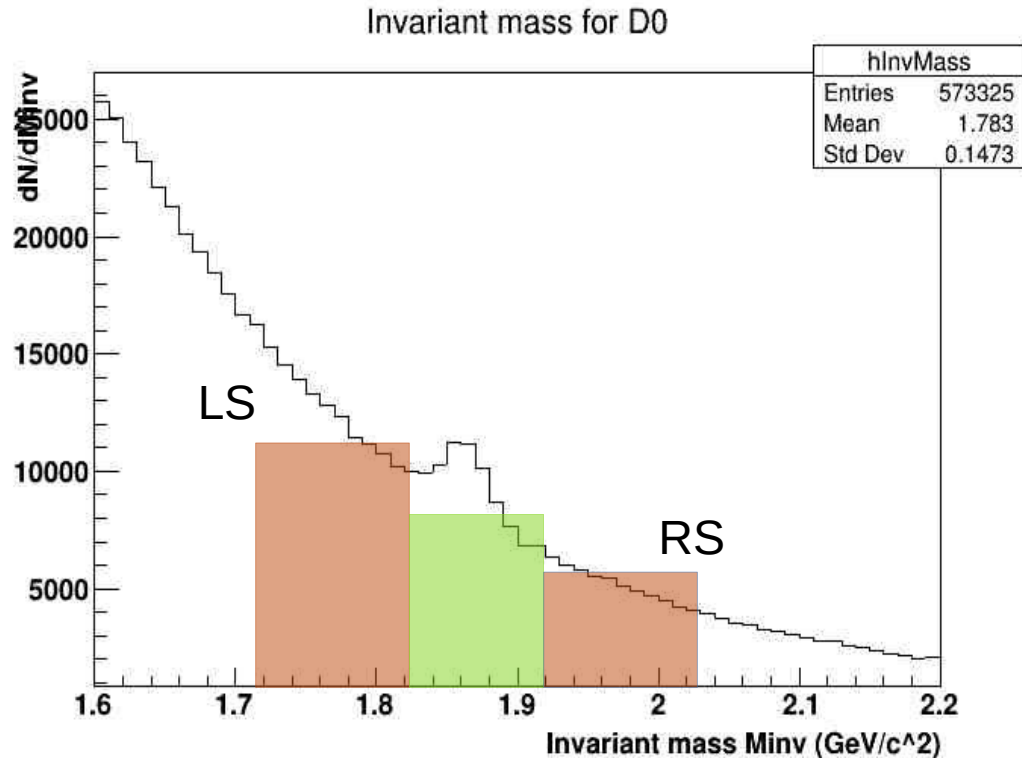
Plot 3: Vz for all events



Plot 4, 5, 6, 7, 8, 9: PID plots for pion, proton and kaons



Invariant mass distribution of D^0 mesons

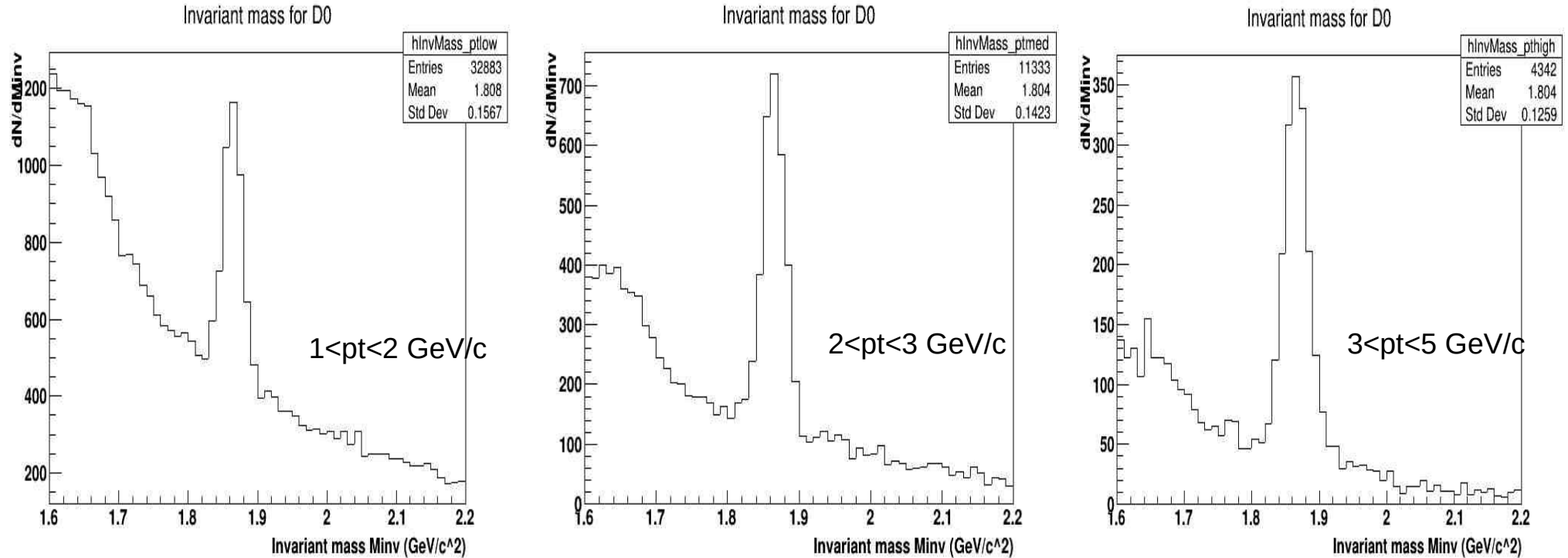


Plot 10: D^0 invariant mass distribution

- From mentioned topological & selection cuts D^0 candidates were selected
- No p_T cut applied here
- $1.82 < D^0 \text{ signal} < 1.91 \text{ GeV}/c^2$
- $1.72 < \text{LS band} < 1.81 \text{ GeV}/c^2$
- $1.91 < \text{RS band} < 2.0 \text{ GeV}/c^2$



D^0 invariant mass distribution with p_T cuts



Plot 11, 12, 13: D^0 signal in different p_T bins



k^* calculation

$$k^* = \frac{1}{2} (p_1^* - p_2^*)$$

p_1^* and p_2^* are momentum of two particles in the pair rest frame.

https://drupal.star.bnl.gov/STAR/system/files/HF%20PW%20Nov18_2021.pdf

https://drupal.star.bnl.gov/STAR/system/files/HF%20PWG%20Mar3_2022.pdf



Event Mixing technique for $C(k^*)$ calculation

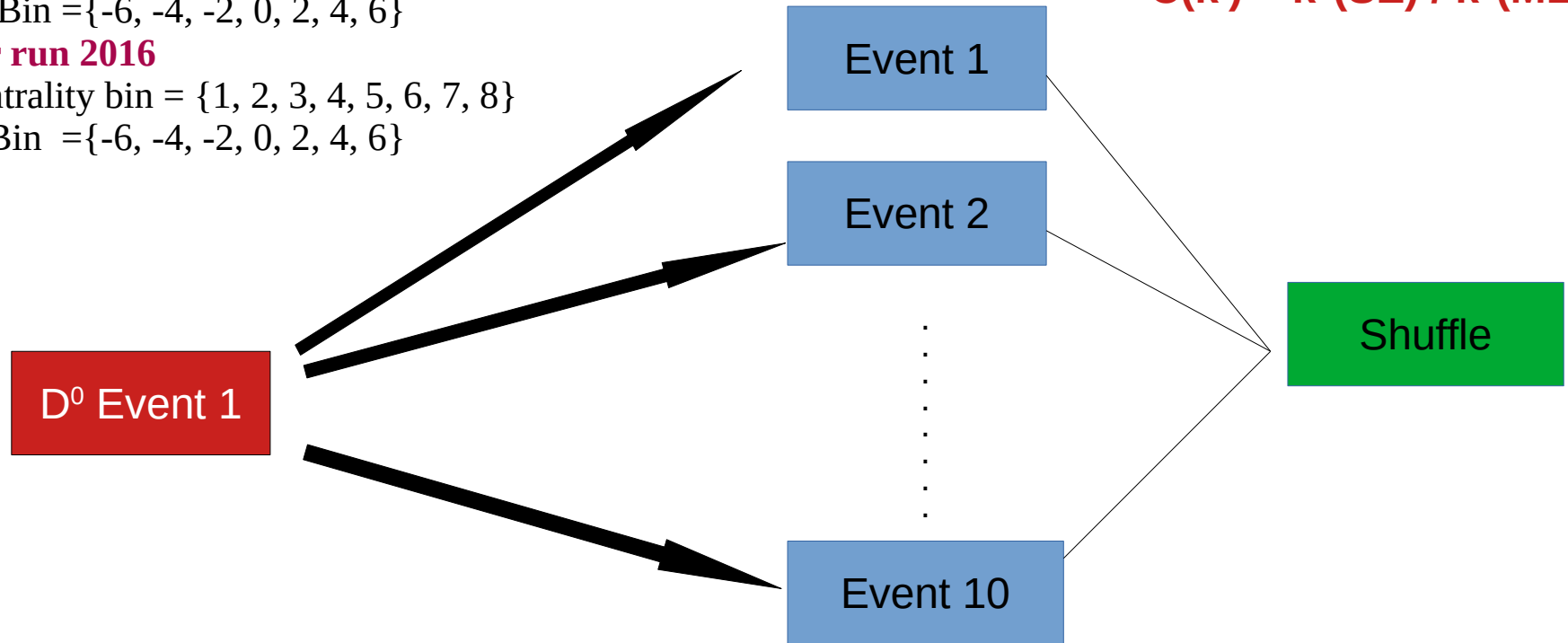
For run 2014

VzBin = {-6, -4, -2, 0, 2, 4, 6}

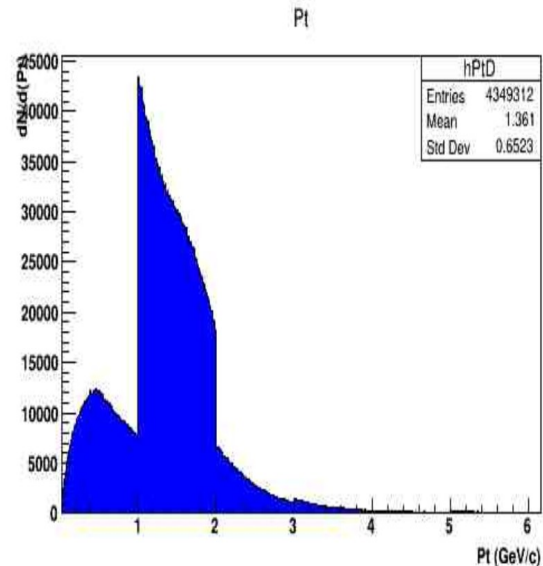
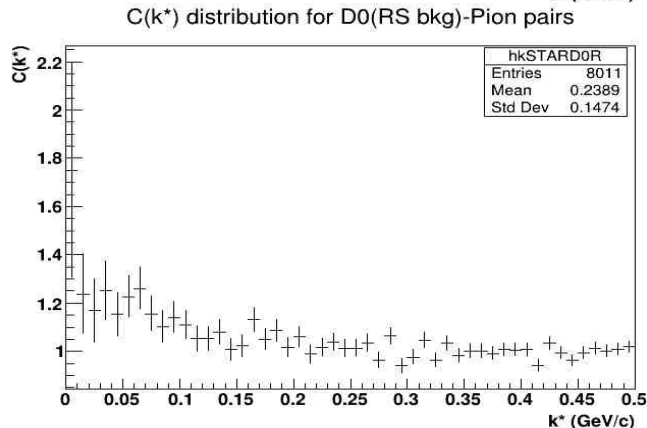
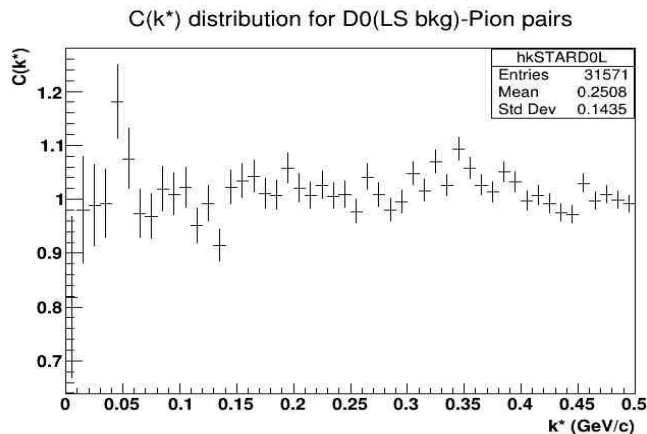
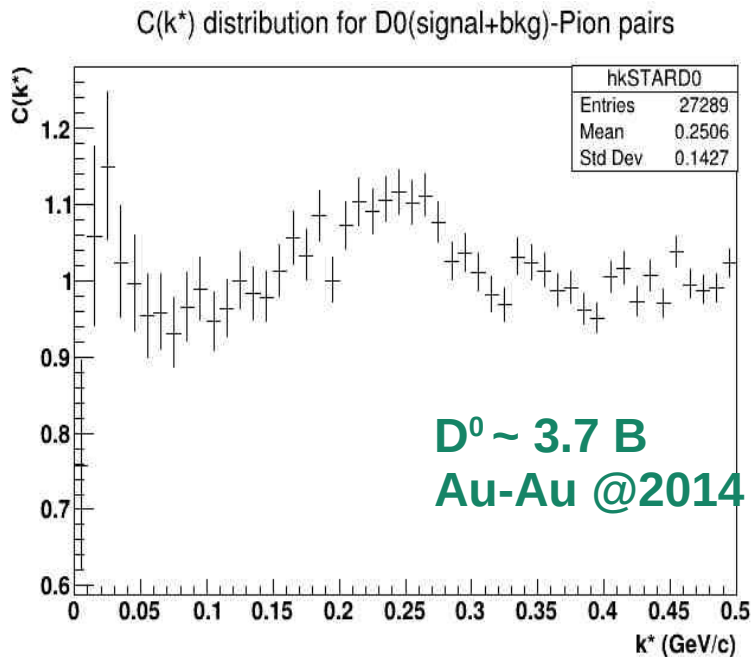
For run 2016

Centrality bin = {1, 2, 3, 4, 5, 6, 7, 8}

VzBin = {-6, -4, -2, 0, 2, 4, 6}



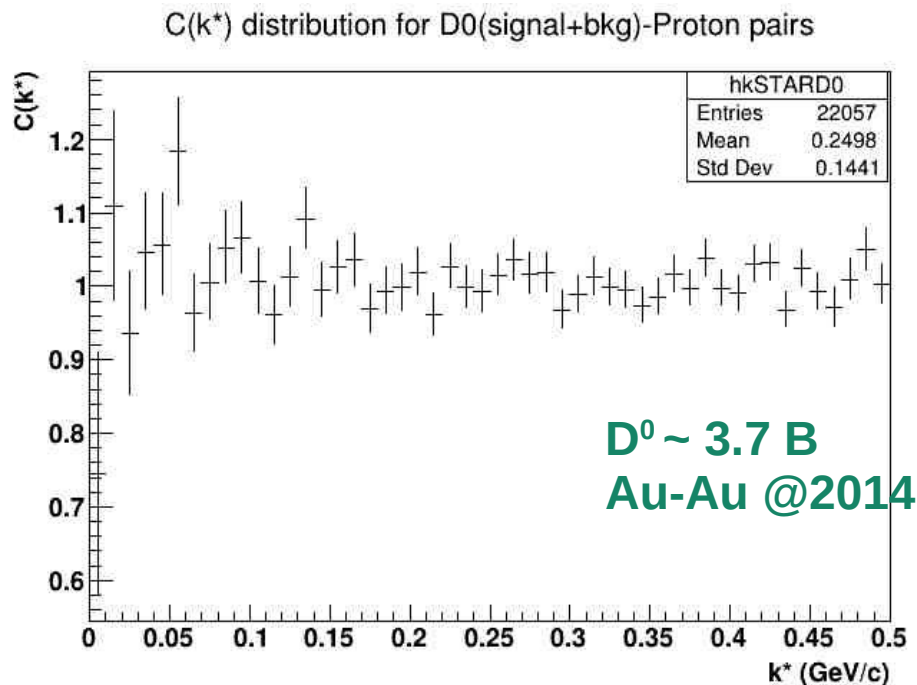
Correlation function $C(k^*)$ for D^0 - π pairs



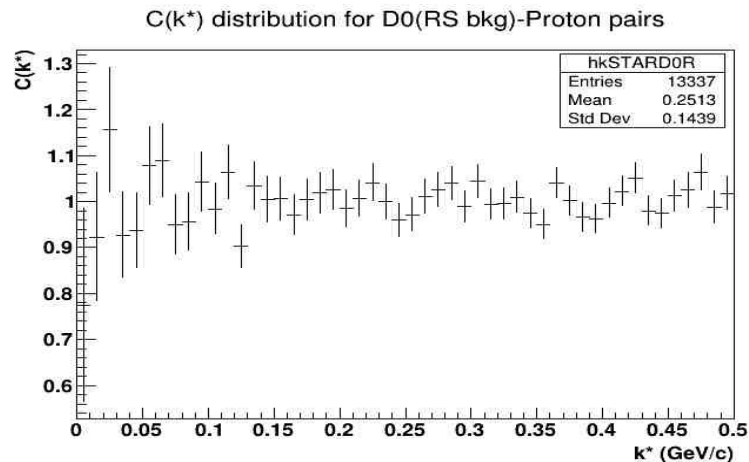
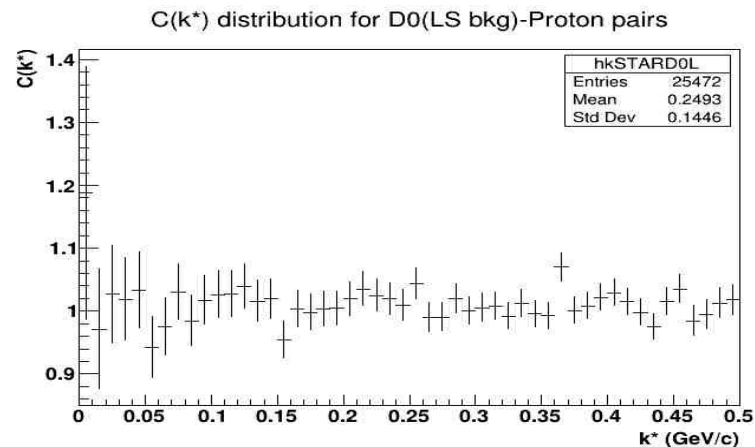
Plot 14, 15, 16: $C(k^*)$ distribution for D^0 -Pion pairs



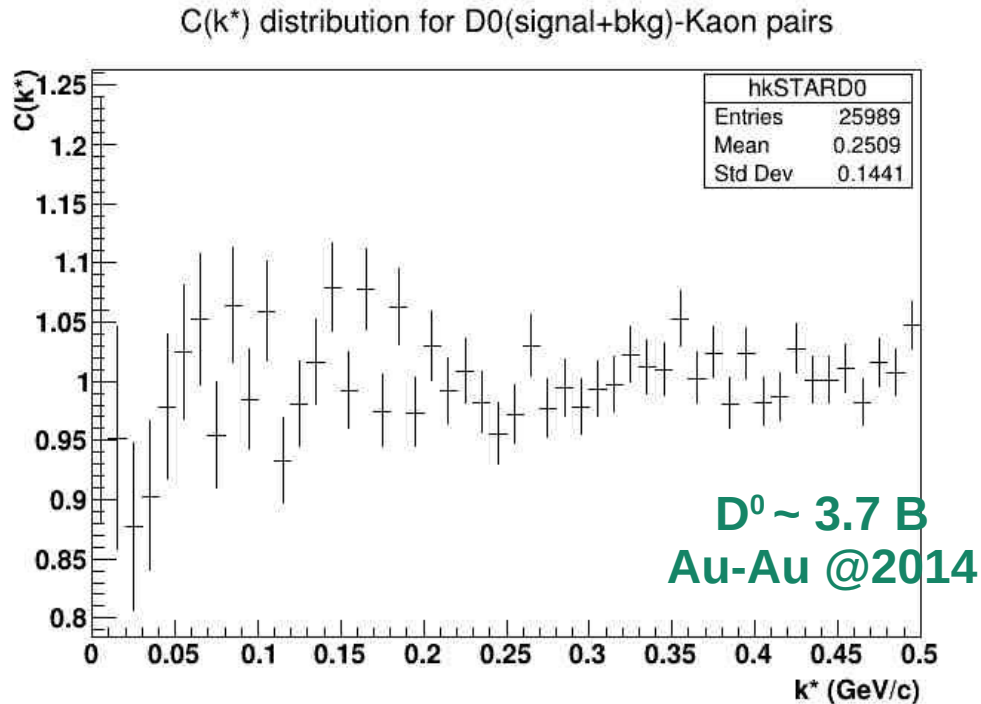
Correlation function $C(k^*)$ for D^0 -p pairs



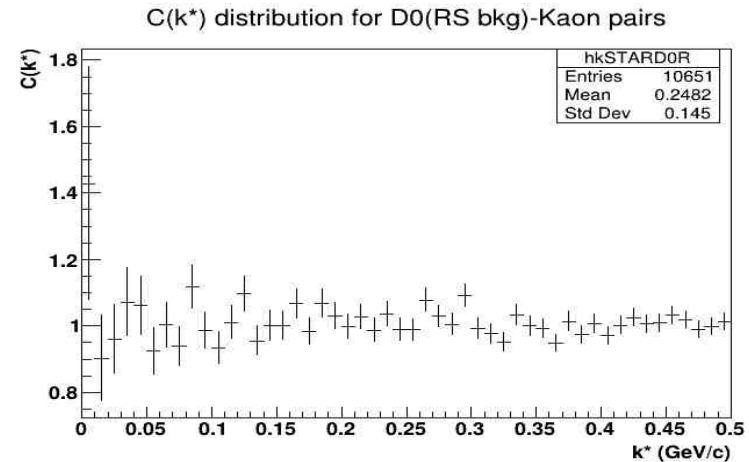
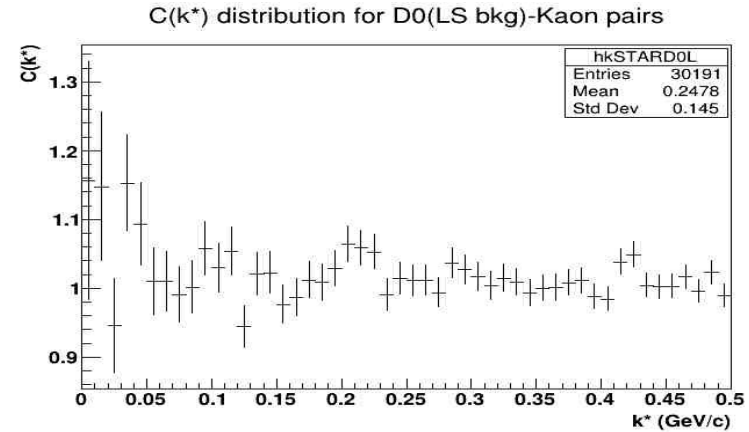
Plot 17, 18, 19: $C(k^*)$ distribution for D^0 -Proton pairs



Correlation function $C(k^*)$ for D^0 -k pairs



Plot 20, 21, 22: $C(k^*)$ distribution for D^0 -Kaon pairs



Analysis

Data set 2

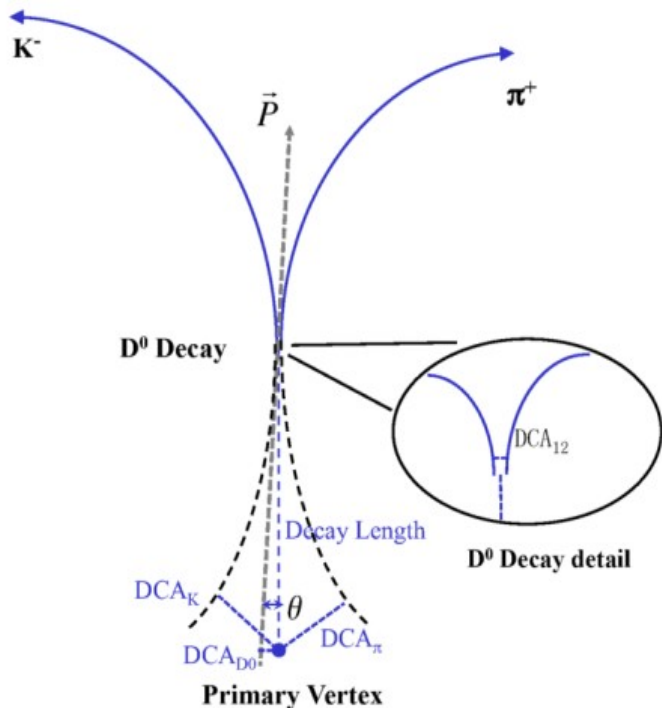
Energy \sqrt{s}_{NN}	Trigger name	Collision system	Year of data taken	Events produced	Events analyzed	Purpose of use
200 GeV	AuAu_200 _productio n_mid_201 6	Au-Au	2016	1.05 B	D ⁰ events ~ 8M	k* and C(k*) for D ⁰ - hadron (Pion, Proton, Kaon)

- Analysis framework: PicoDSt
- https://drupal.star.bnl.gov/STAR/system/files/HF%20PWG%20Apr21_2022.pdf



Reconstruction of D^0 meson

Source:
D0AnaNote_Feb
21_2019



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Fig 5: Schematic diagram of D^0 reconstruction

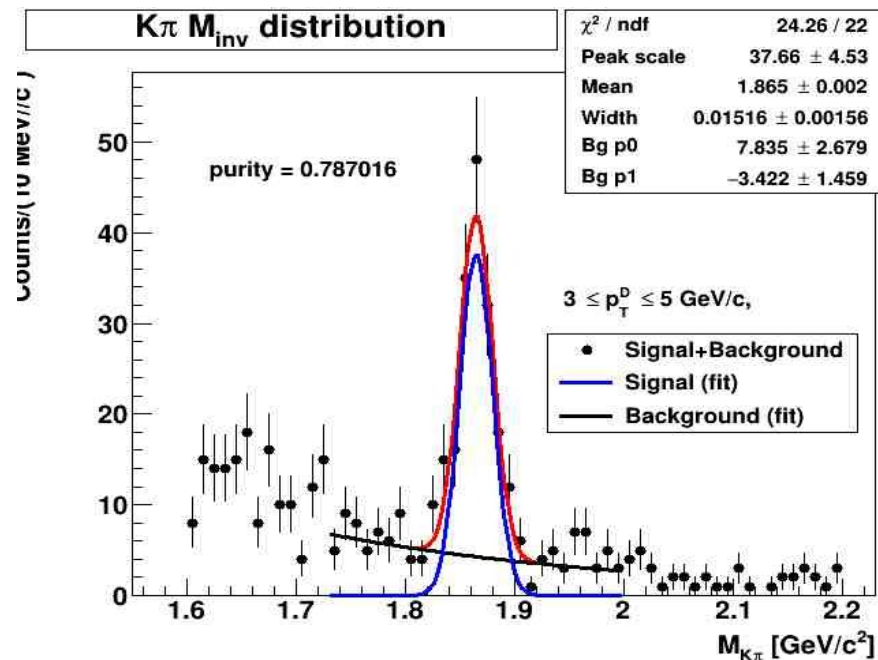
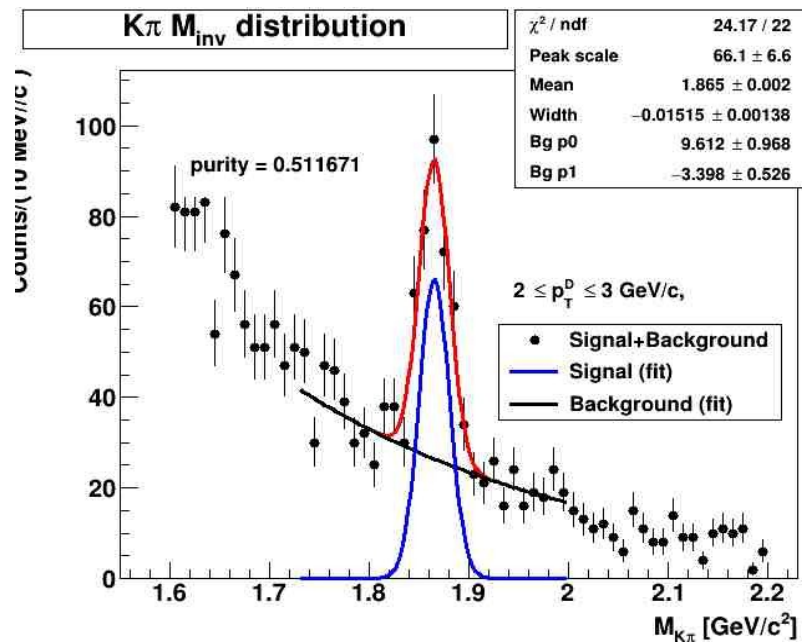
Standard topological cuts for $k^- - \pi^+$ pairs:

$D^0 p_T$ (GeV/c)	0 - 0.5	0.5-1	1-2	2-3	3-5	5-10
Centrality 60-80%						
decay length (μm) >	150	107	175	187	164	175
DCA between 2 daughters (μm) <	73	88	92	82	83	104
DCA between D^0 and PV (μm) <	75	66	64	50	58	38
DCA between π and PV (μm) >	100	96	93	94	59	50
DCA between K and PV (μm) >	113	103	81	66	46	38
pointing angle $\cos(\theta)$ >	0.95	0.95	0.95	0.95	0.95	0.95
Centrality 40-60%						
decay length (μm) >	140	133	190	201	215	219
DCA between 2 daughters (μm) <	76	87	90	82	101	93
DCA between D^0 and PV (μm) <	65	64	46	49	54	57
DCA between π and PV (μm) >	107	106	97	78	63	56
DCA between K and PV (μm) >	110	112	81	63	64	44
pointing angle $\cos(\theta)$ >	0.95	0.95	0.95	0.95	0.95	0.95
Centrality 20-40%						
decay length (μm) >	149	170	205	236	234	237
DCA between 2 daughters (μm) <	78	67	69	66	73	99
DCA between D^0 and PV (μm) <	45	48	42	43	52	55
DCA between π and PV (μm) >	117	106	97	66	64	56
DCA between K and PV (μm) >	98	89	74	85	63	49
pointing angle $\cos(\theta)$ >	0.95	0.95	0.95	0.95	0.95	0.95
Centrality 10-20%						
decay length (μm) >	151	173	204	240	237	231
DCA between 2 daughters (μm) <	70	70	62	67	76	85
DCA between D^0 and PV (μm) <	52	49	43	42	43	50
DCA between π and PV (μm) >	98	110	101	86	70	61
DCA between K and PV (μm) >	111	99	91	97	62	61
pointing angle $\cos(\theta)$ >	0.95	0.95	0.95	0.95	0.95	0.95
Centrality 0-10%						
decay length (μm) >	128	163	222	214	241	253
DCA between 2 daughters (μm) <	66	79	61	63	76	68
DCA between D^0 and PV (μm) <	61	46	42	41	37	48
DCA between π and PV (μm) >	109	106	81	92	80	57
DCA between K and PV (μm) >	104	99	73	86	67	56
pointing angle $\cos(\theta)$ >	0.95	0.95	0.95	0.95	0.95	0.95



Purity calculation & Correction

$$\text{Purity}_{D^0} = \text{signal} / (\text{signal} + \text{BG})$$

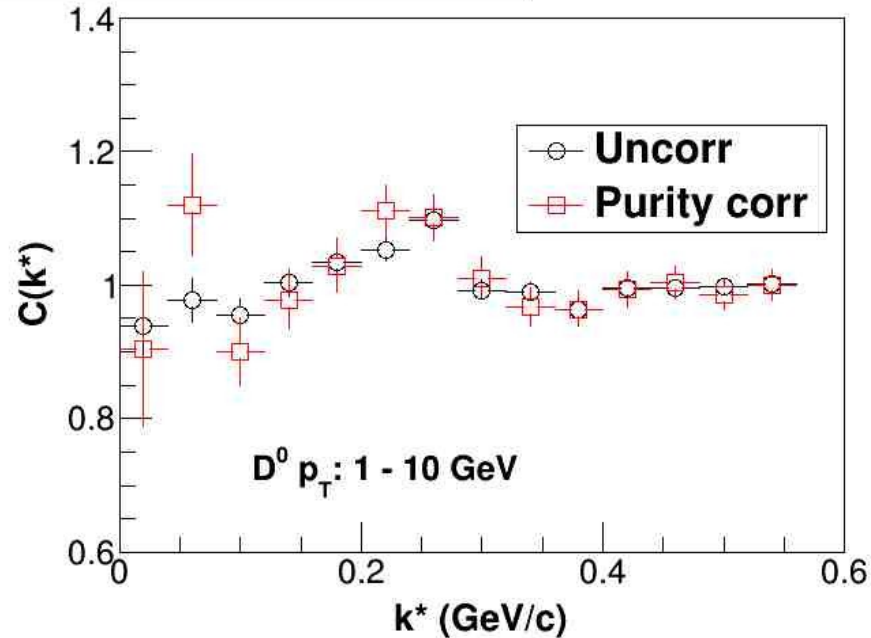


Plot 23, 24: Purity calculation of D⁰ signal

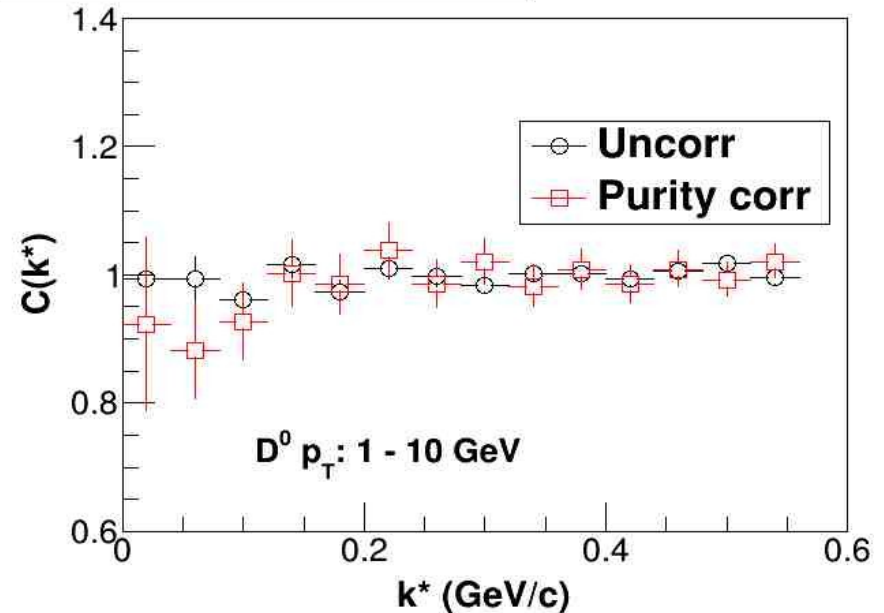
Purity correction

$$C_{\text{measured}}^{\text{corr}}(k^*) = \frac{C_{\text{measured}}(k^*) - 1}{\text{PairPurity}} + 1.$$

Without removal of merged tracks for D0-Pion pairs



Without removal of merged tracks for D0-kaon pairs



Plot 25, 26: Comparison of $C(k^*)$ with and without purity correction

Au-Au@2014



Summary of current & future studies

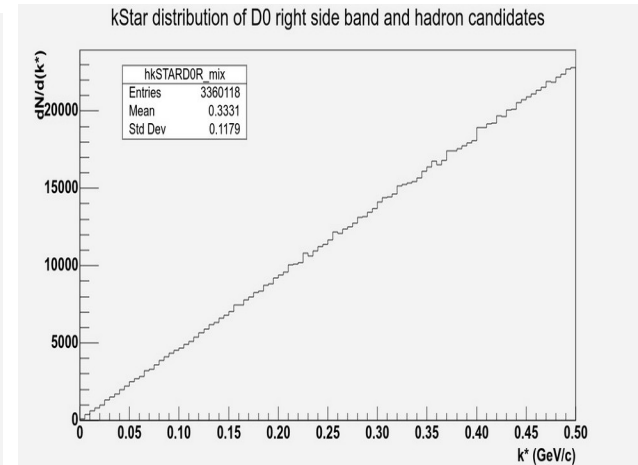
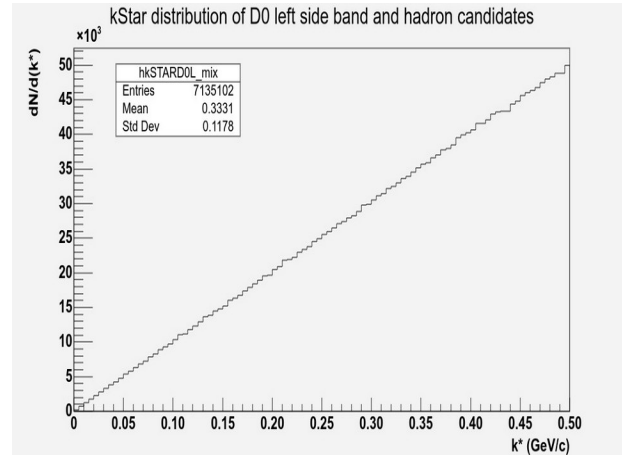
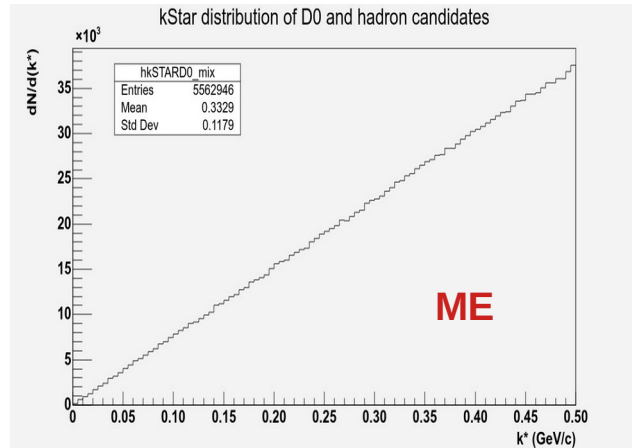
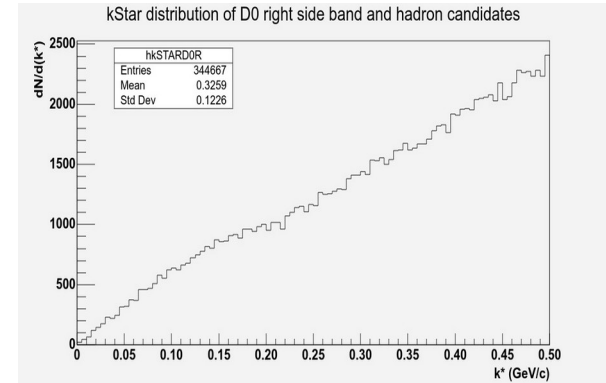
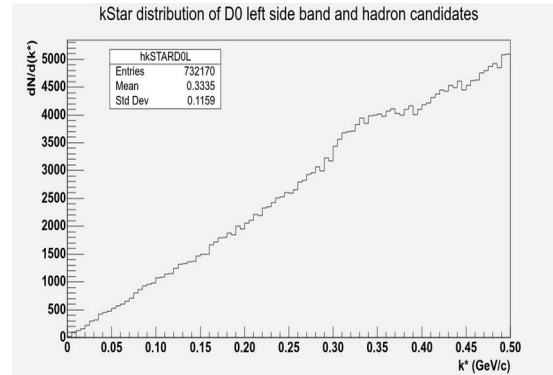
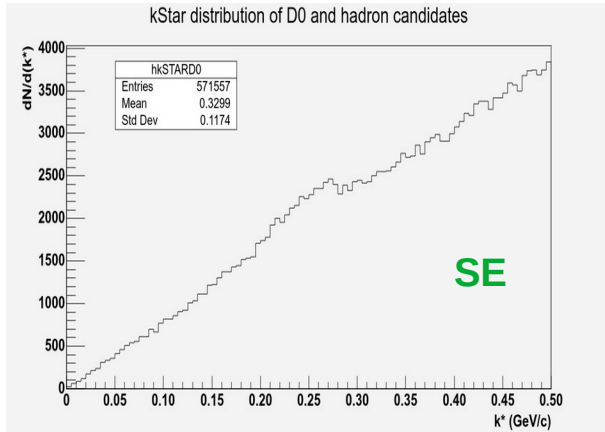
- Track merging effect removal, evaluation of systematic uncertainties and appeal for $C(k^*)$ STAR preliminary results.
- Fitting $C(k^*)$ with theoretical models (ex. Lednicky and Lyuboshitz analytical model) to extract parameters of interaction and the effective volume.
- Measurement of the size of the emission source, and a cross section for the interaction in the final state.
- Similar study for D^{+-} and hadron pairs.



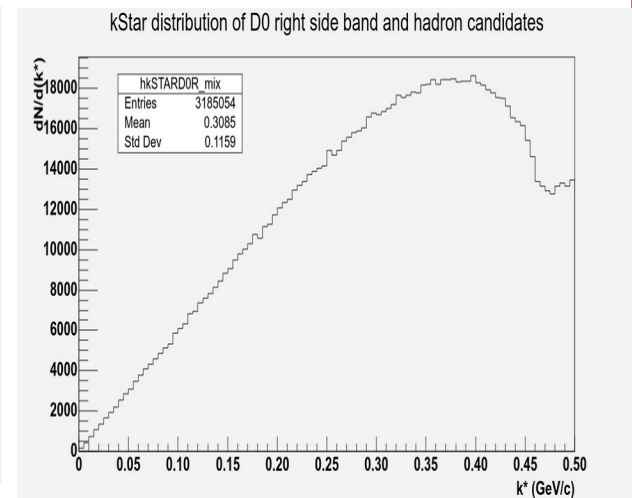
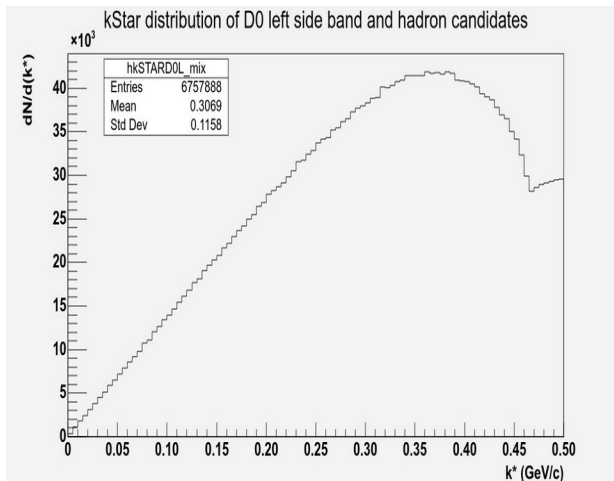
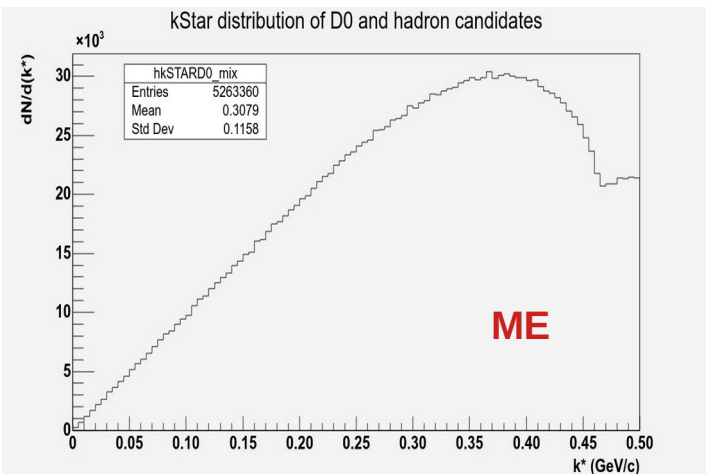
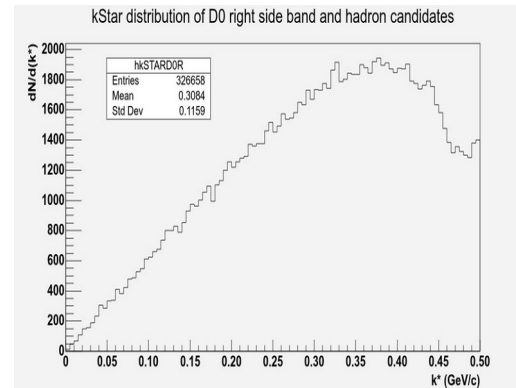
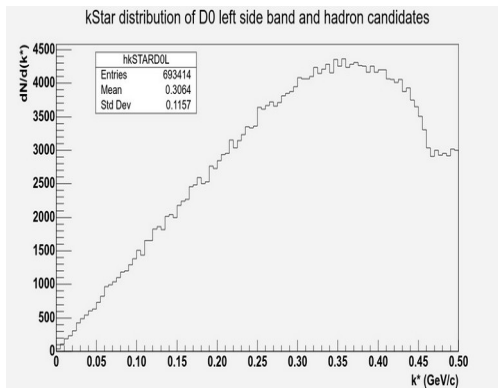
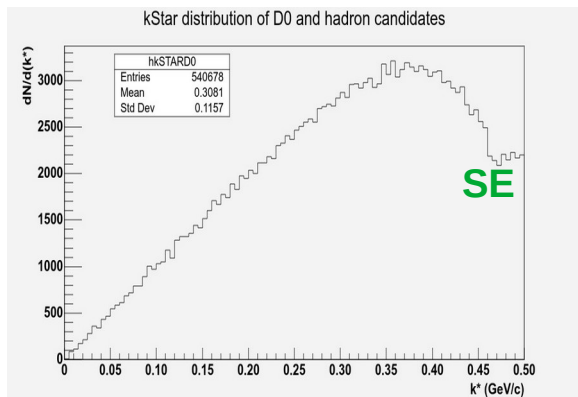
Back Ups



K^* distribution for $D^0\text{-}\pi^{+/-}$ [Au-Au @200 GeV (2016), 8M D^0]

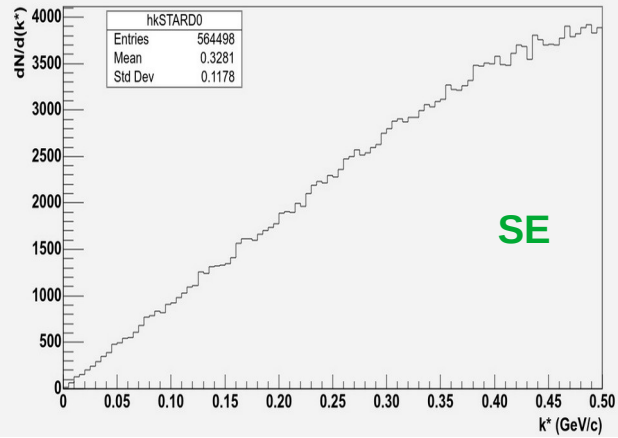


K* distribution for D⁰-p [Au-Au @200 GeV (2016), 8M D⁰]

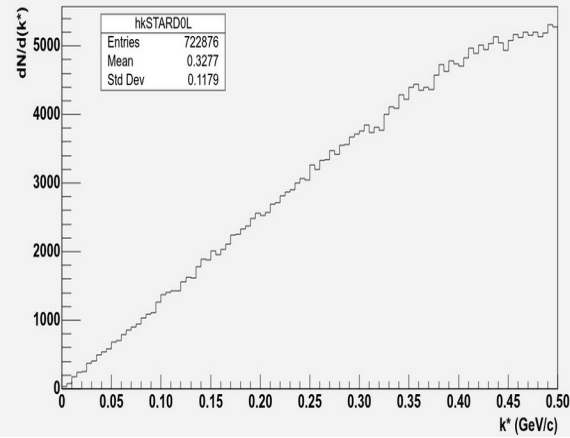


K^* distribution for D^0 - $K^{+/-}$ [Au-Au @200 GeV (2016), 8M D^0]

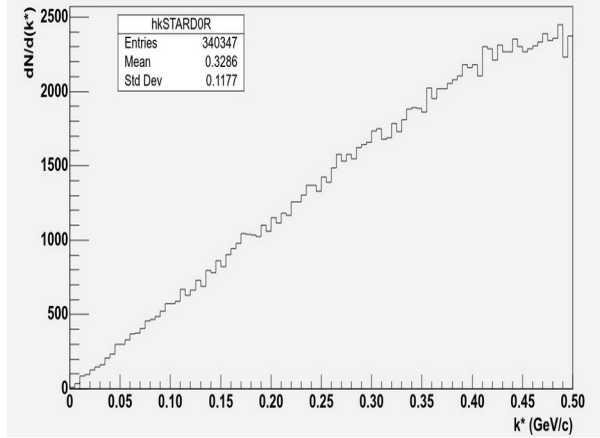
kStar distribution of D^0 and hadron candidates



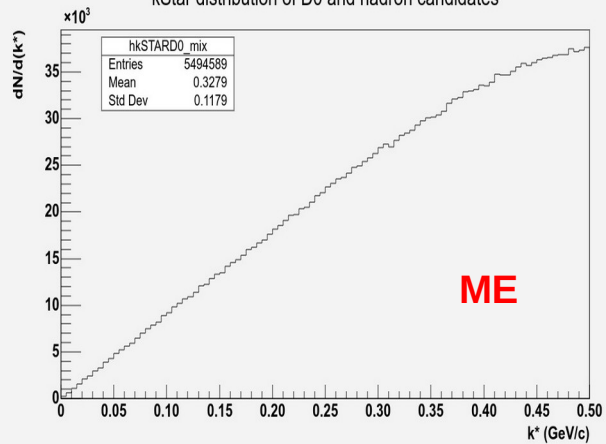
kStar distribution of D^0 left side band and hadron candidates



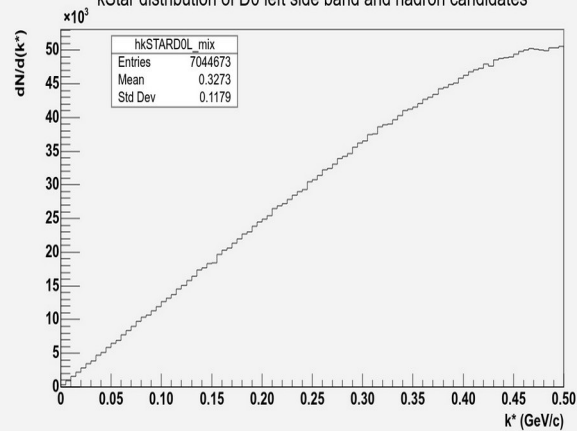
kStar distribution of D^0 right side band and hadron candidates



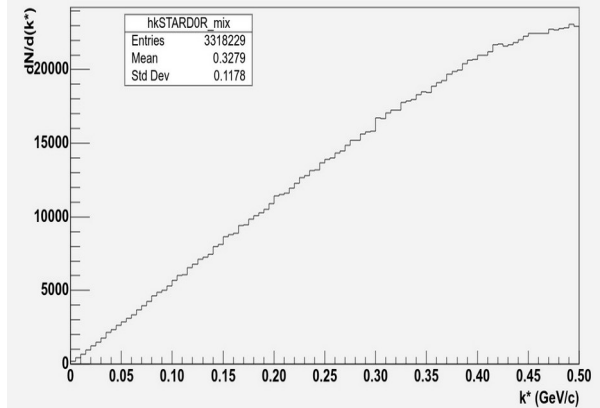
kStar distribution of D^0 and hadron candidates



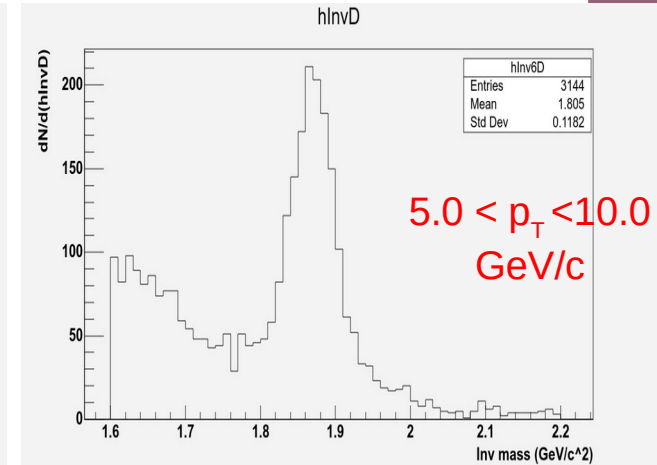
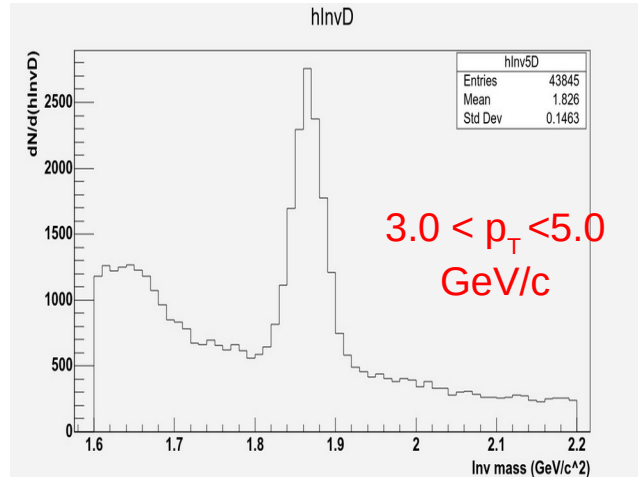
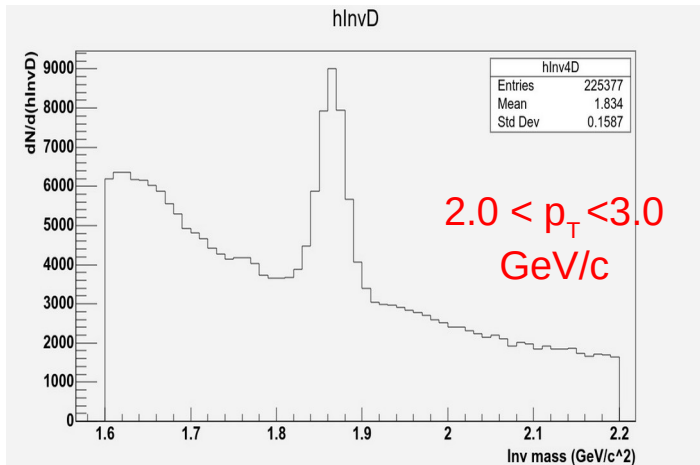
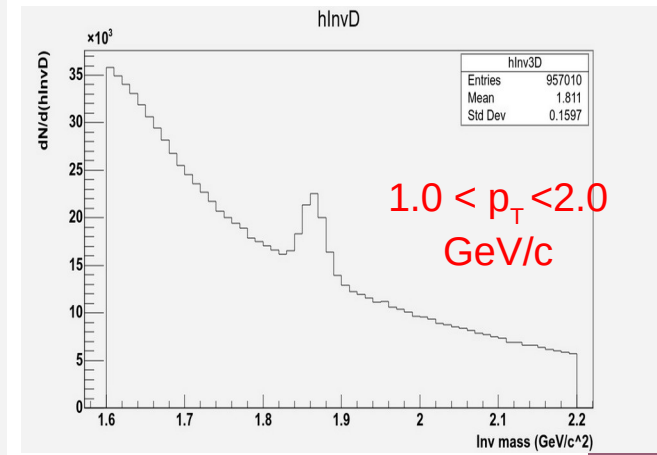
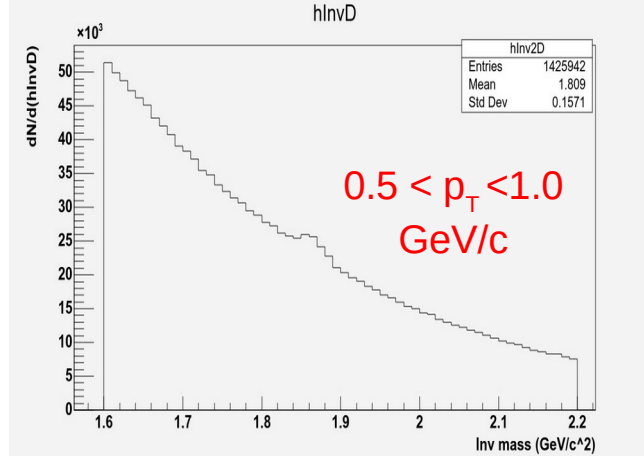
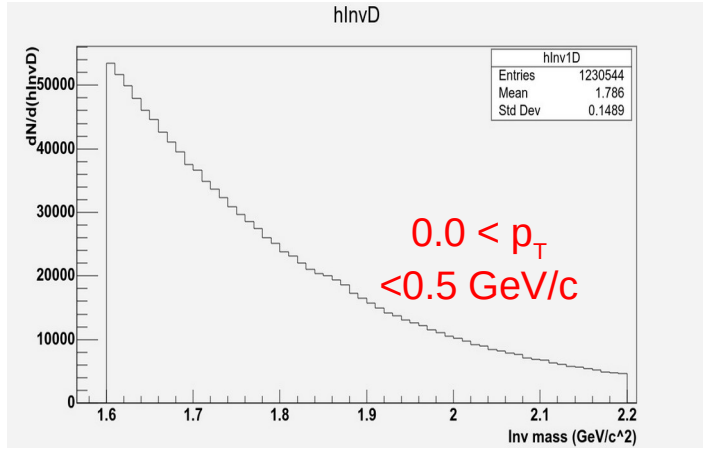
kStar distribution of D^0 left side band and hadron candidates



kStar distribution of D^0 right side band and hadron candidates

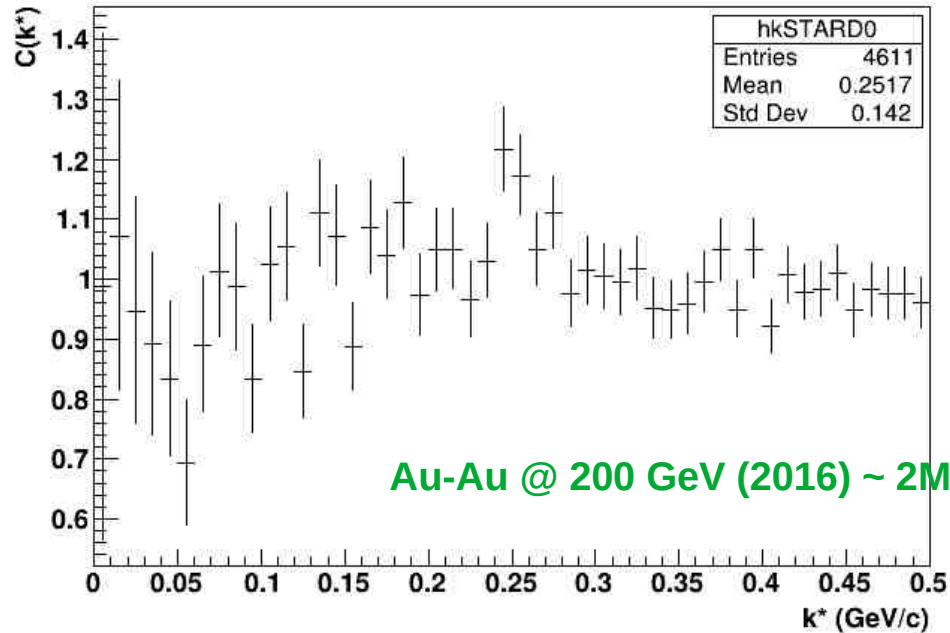


Inv. mass distribution of D^0 candidates in different p_T bins



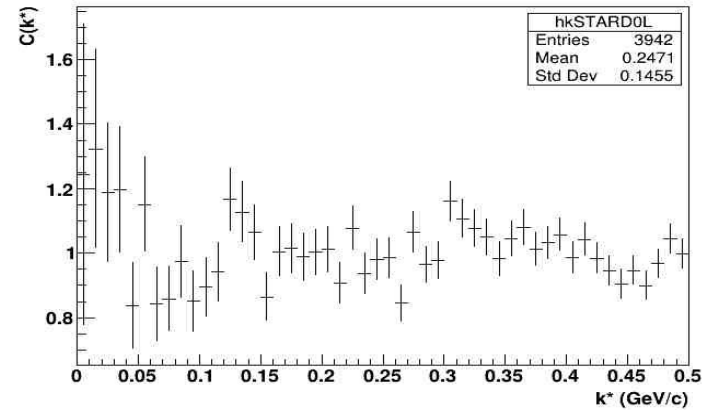
$C(k^*)$ for D^0 - π pairs using standard cuts

$C(k^*)$ distribution for $D^0(\text{signal+bkg})$ -Pion pairs

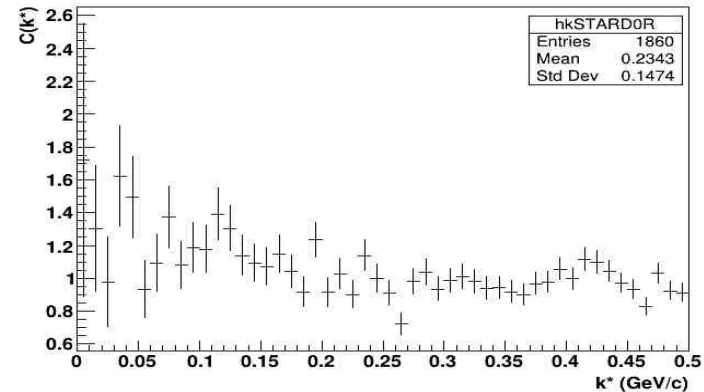


Plot 10, 11, 12: $C(k^*)$ distribution for D^0 -Pion pairs

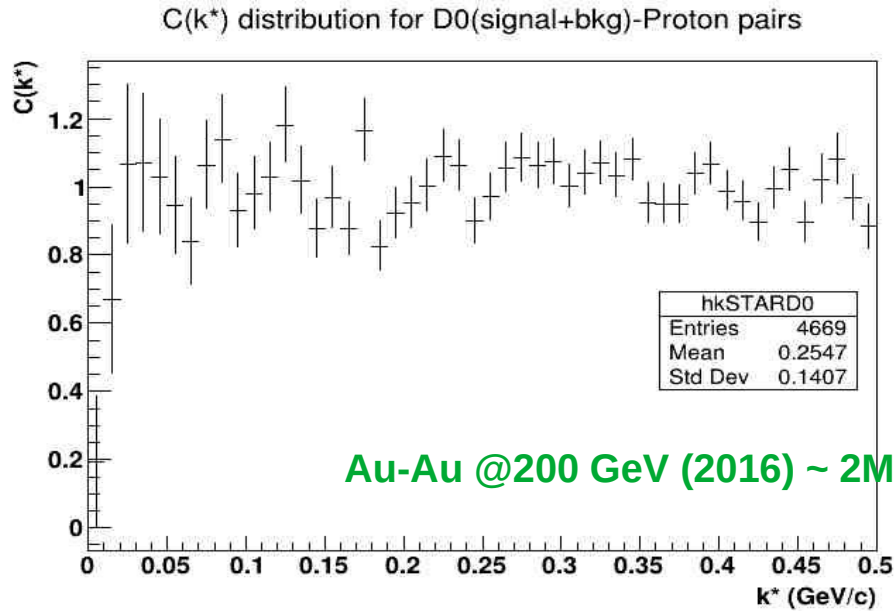
$C(k^*)$ distribution for $D^0(\text{LS bkg})$ -Pion pairs



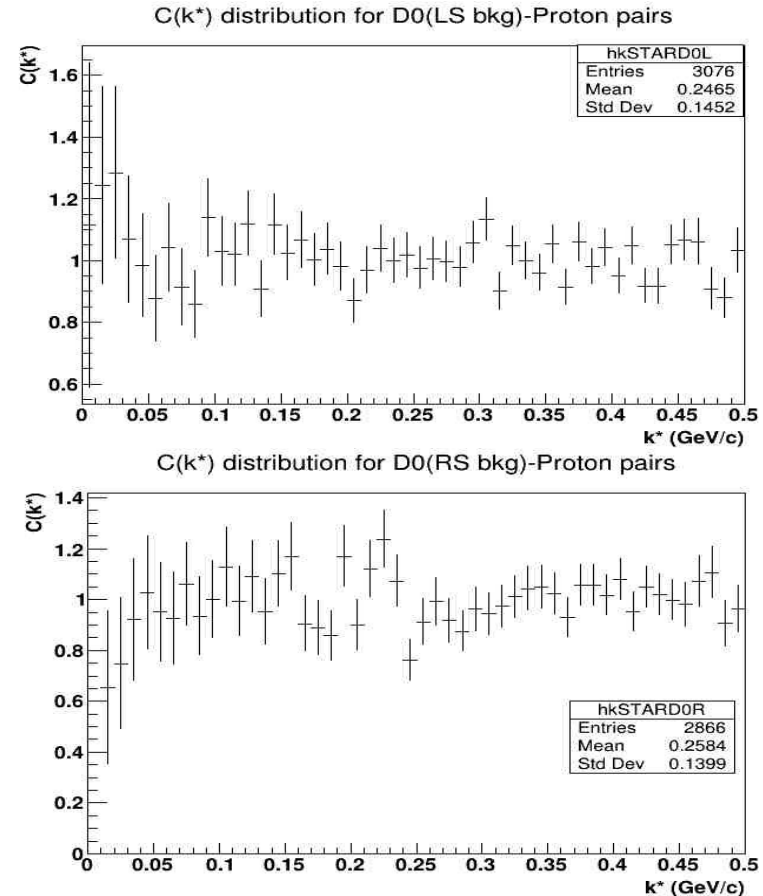
$C(k^*)$ distribution for $D^0(\text{RS bkg})$ -Pion pairs



$C(k^*)$ for D^0 -p pairs using standard cuts

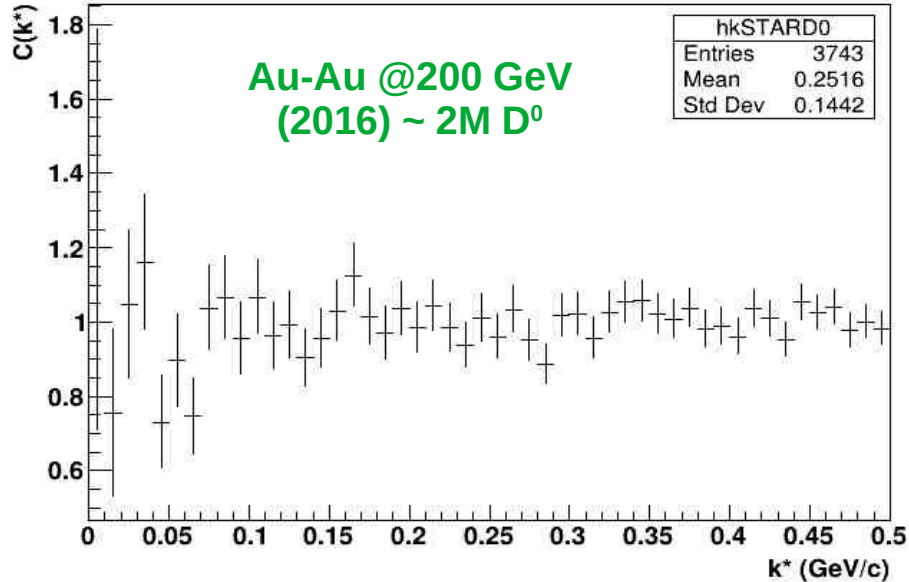


Plot 13, 14, 15: $C(k^*)$ distribution for D^0 -Proton pairs



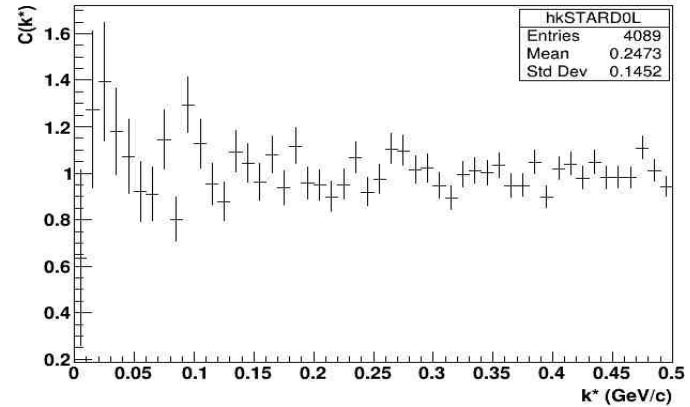
C(k*) for D⁰-k pairs using standard cuts

C(k*) distribution for D0(signal+bkg)-Kaon pairs

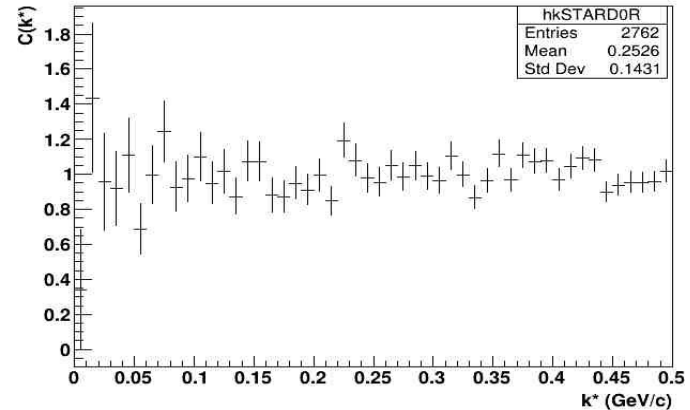


Plot 16, 17, 18: C(k*) distribution for D⁰-Kaon pairs

C(k*) distribution for D0(LS bkg)-Kaon pairs

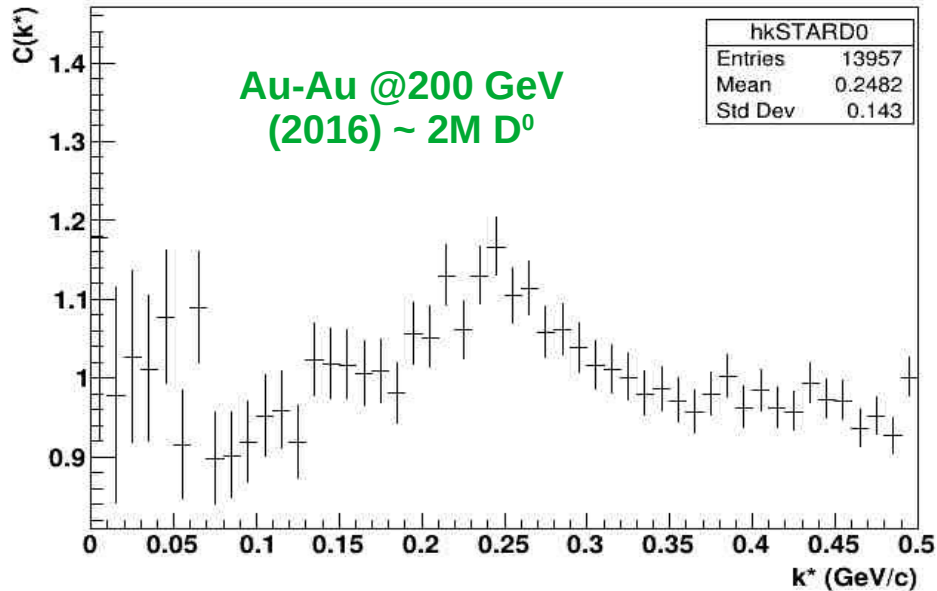


C(k*) distribution for D0(RS bkg)-Kaon pairs



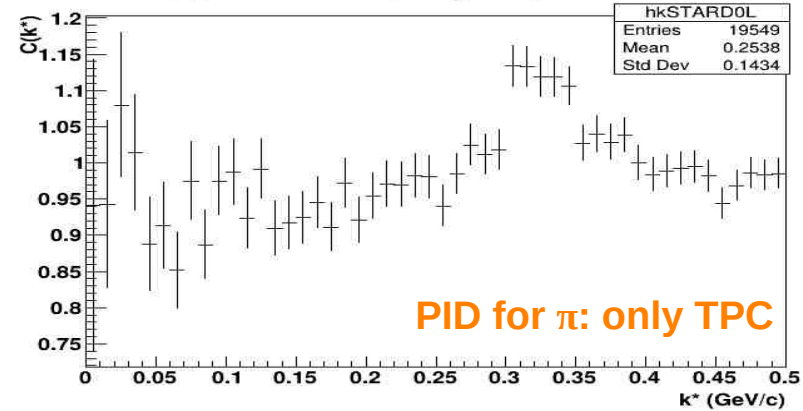
$C(k^*)$ for D^0 -Pion pairs using looser cuts

$C(k^*)$ distribution for $D^0(\text{sig}+\text{bkg})$ -Pion pairs for 2016 data

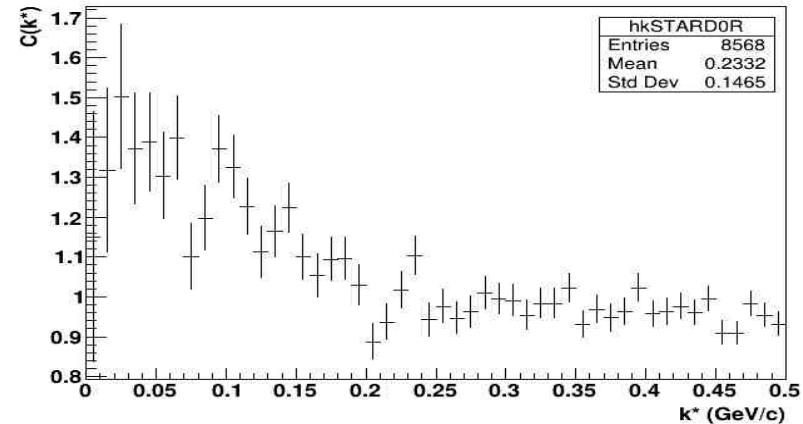


Plot 28, 29, 30: $C(k^*)$ distribution for D^0 -Pion pairs

$C(k^*)$ distribution for $D^0(\text{LS bkg})$ -Pion pairs for 2016 data

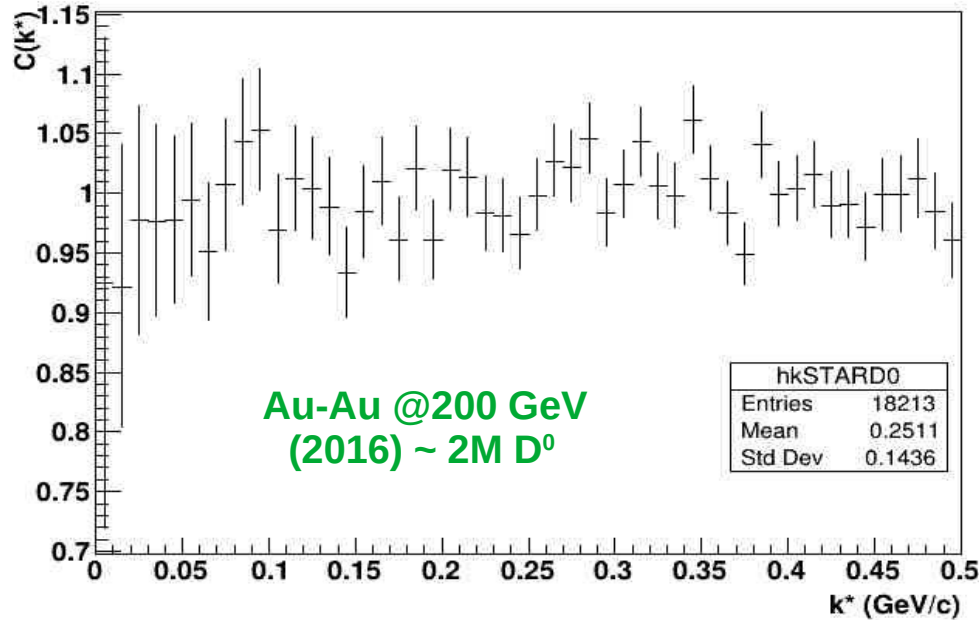


$C(k^*)$ distribution for $D^0(\text{RS bkg})$ -Pion pairs for 2016 data



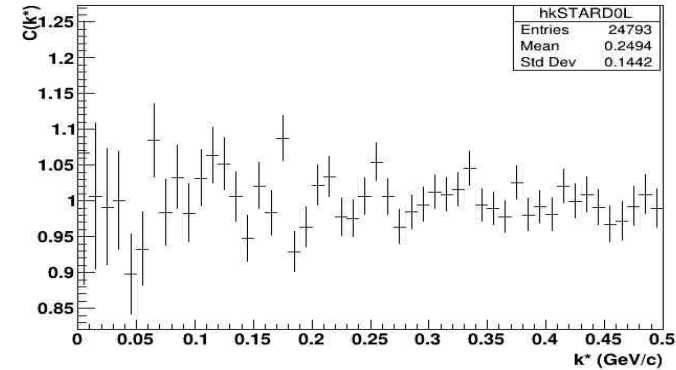
$C(k^*)$ for D^0 -Proton pairs using looser cuts

Combined $C(k^*)$ distribution for $D^0(\text{sig}+\text{bkg})$ -Proton pairs

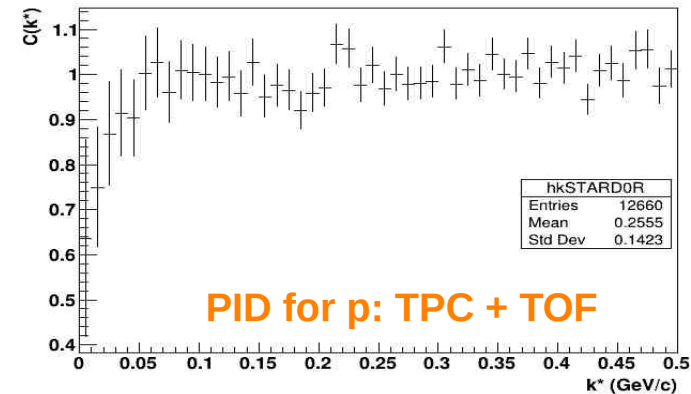


Plot 31, 32, 33: $C(k^*)$ distribution for D^0 -Proton pairs

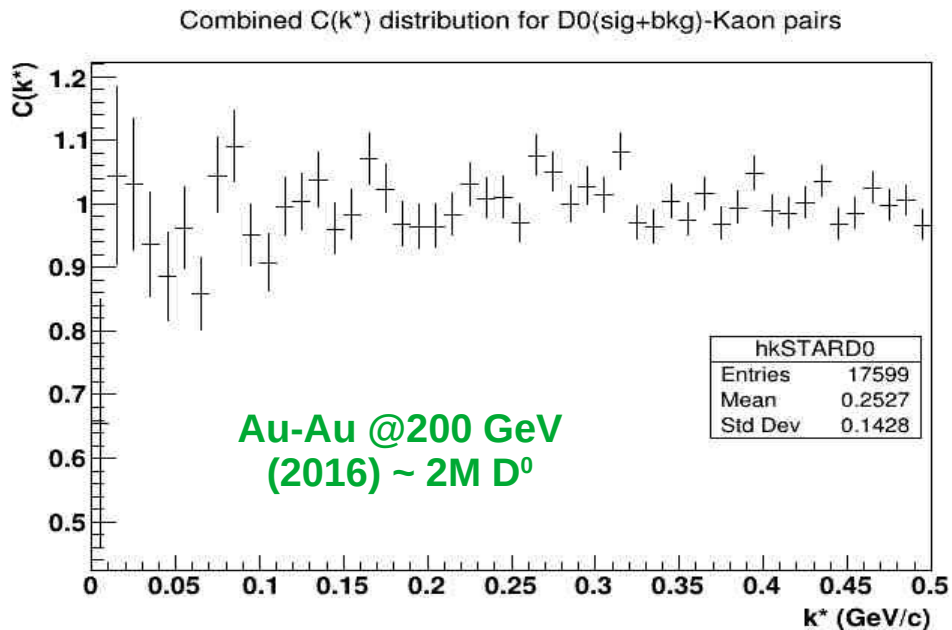
Combined $C(k^*)$ distribution for $D^0(\text{LS bkg})$ -Proton pairs



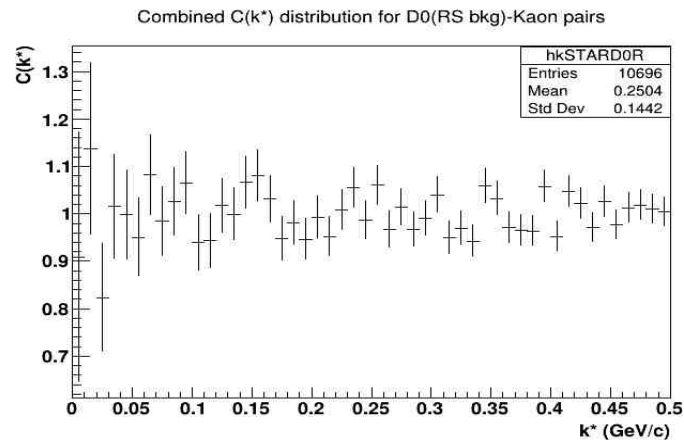
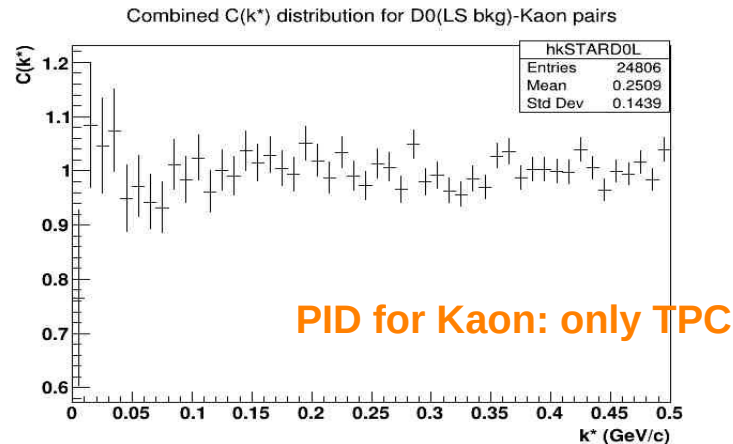
Combined $C(k^*)$ distribution for $D^0(\text{RS bkg})$ -Proton pairs



$C(k^*)$ for D^0 -Kaon pairs using looser cuts

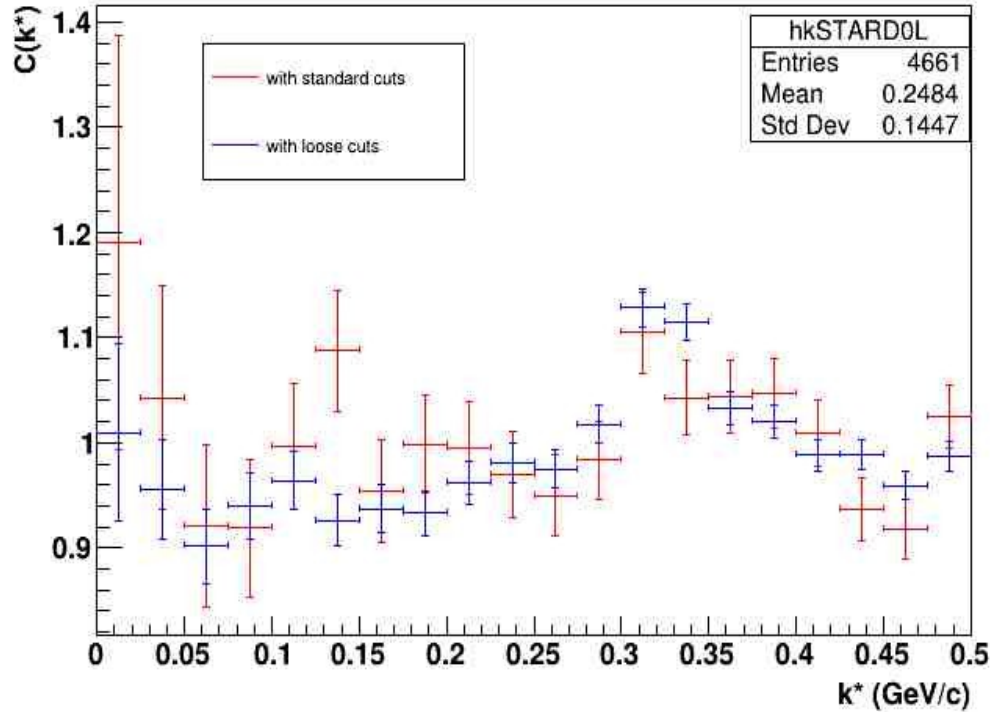


Plot 34, 35, 36: $C(k^*)$ distribution for D^0 -Kaon pairs

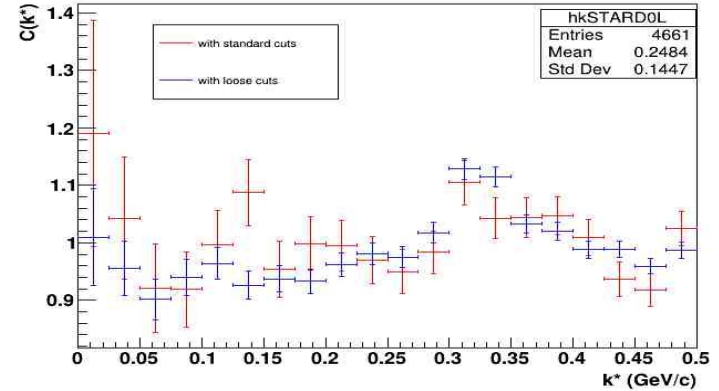


Comparison of $C(k^*)$ for D^0 -Pion pairs

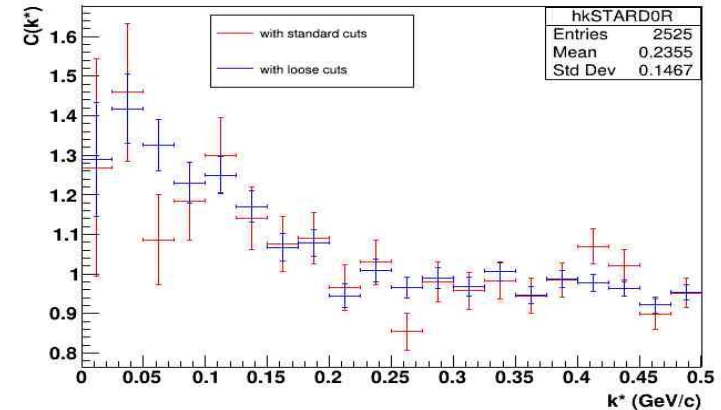
$C(k^*)$ for D^0 (LS bkg)-Pion pairs for 2016 data with standard and loose cuts



$C(k^*)$ for D^0 (LS bkg)-Pion pairs for 2016 data with standard and loose cuts



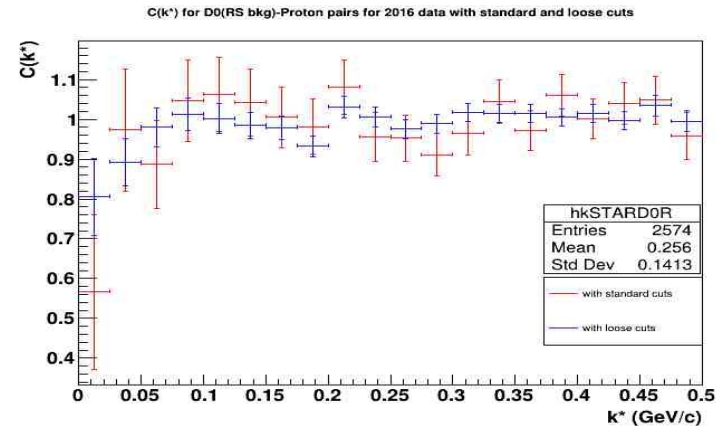
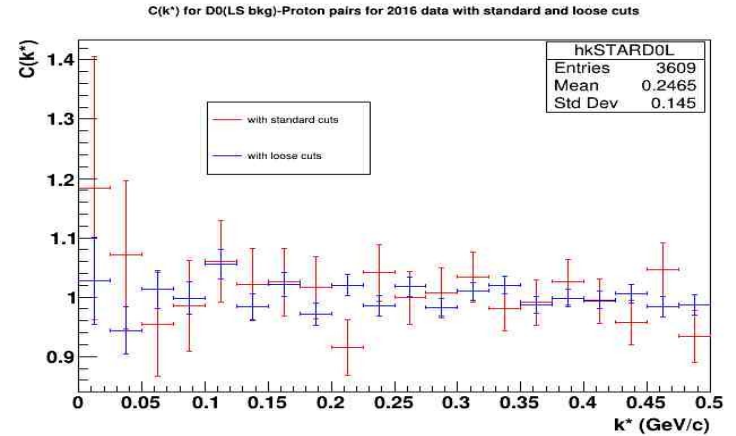
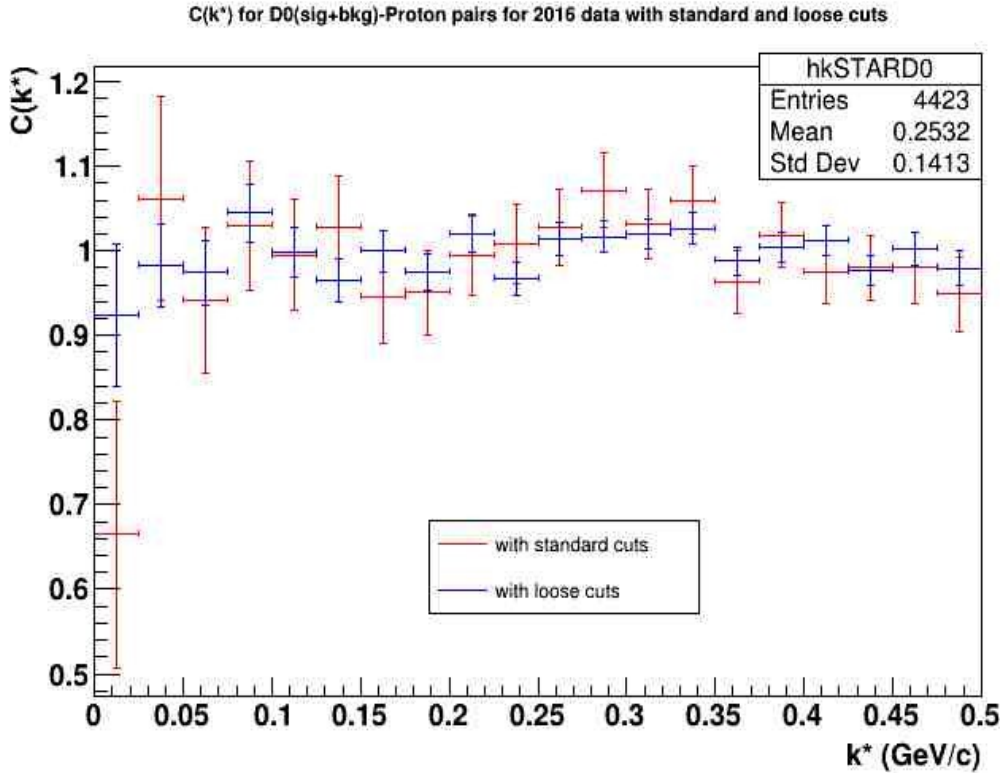
$C(k^*)$ for D^0 (RS bkg)-Pion pairs for 2016 data with standard and loose cuts



Plot 37, 38, 39: Comparison of $C(k^*)$ distribution for D^0 -Pion pairs



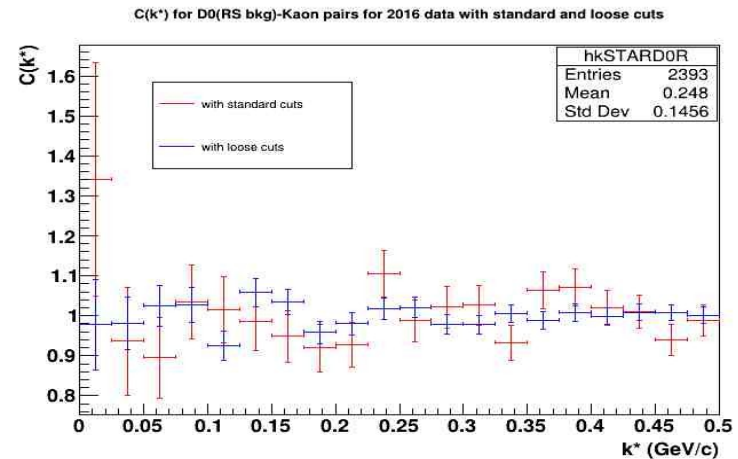
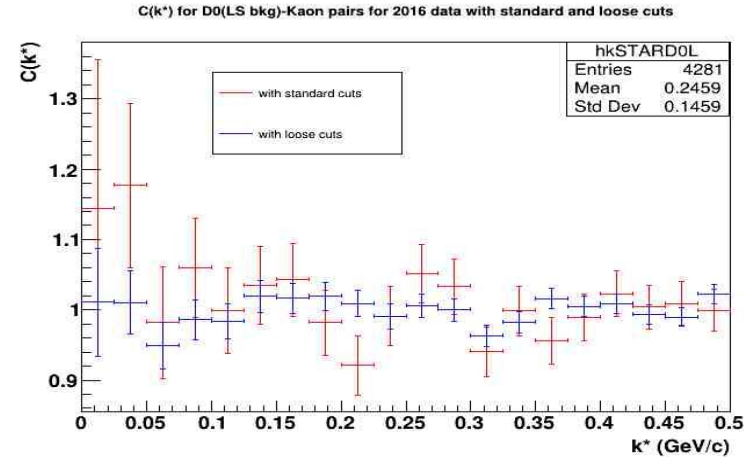
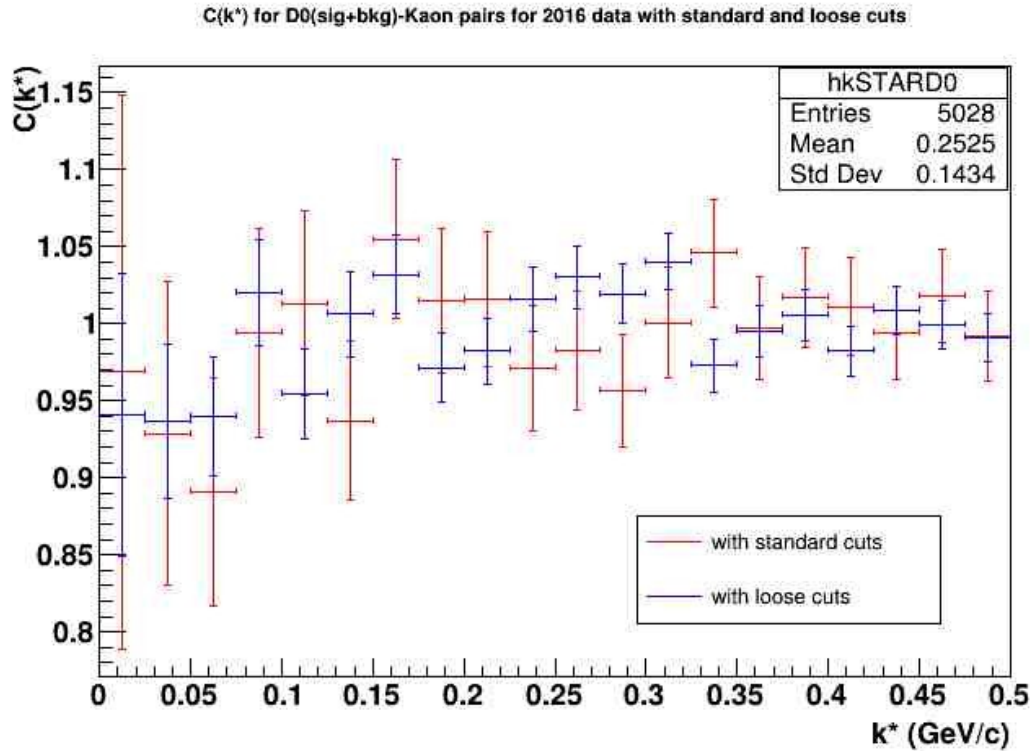
Comparison of $C(k^*)$ for D^0 -Proton pairs



Plot 40, 41, 42: Comparison of $C(k^*)$ distribution for D^0 -Proton pairs



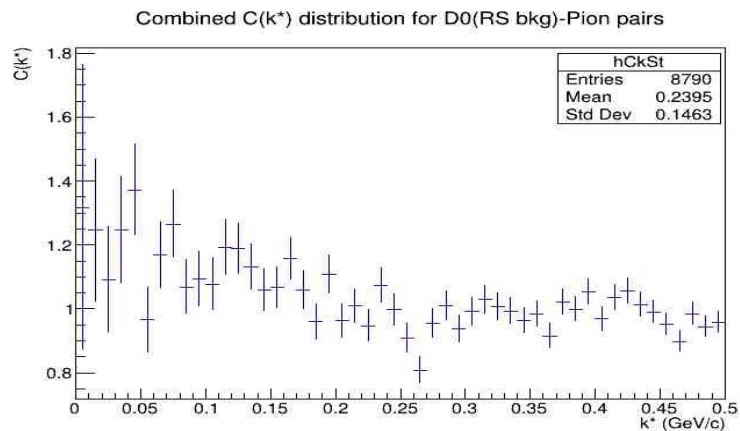
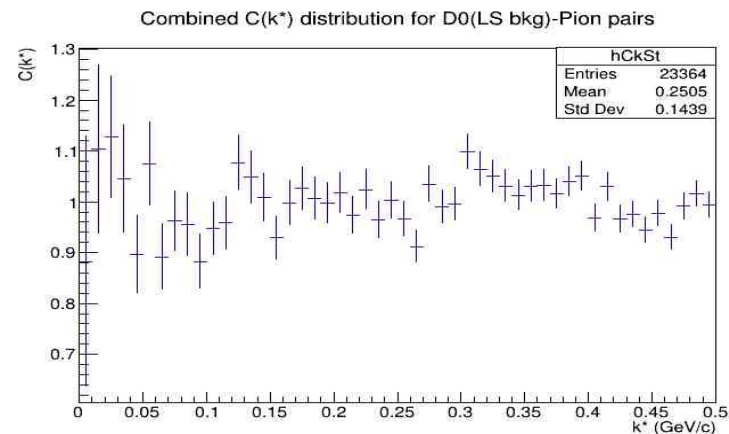
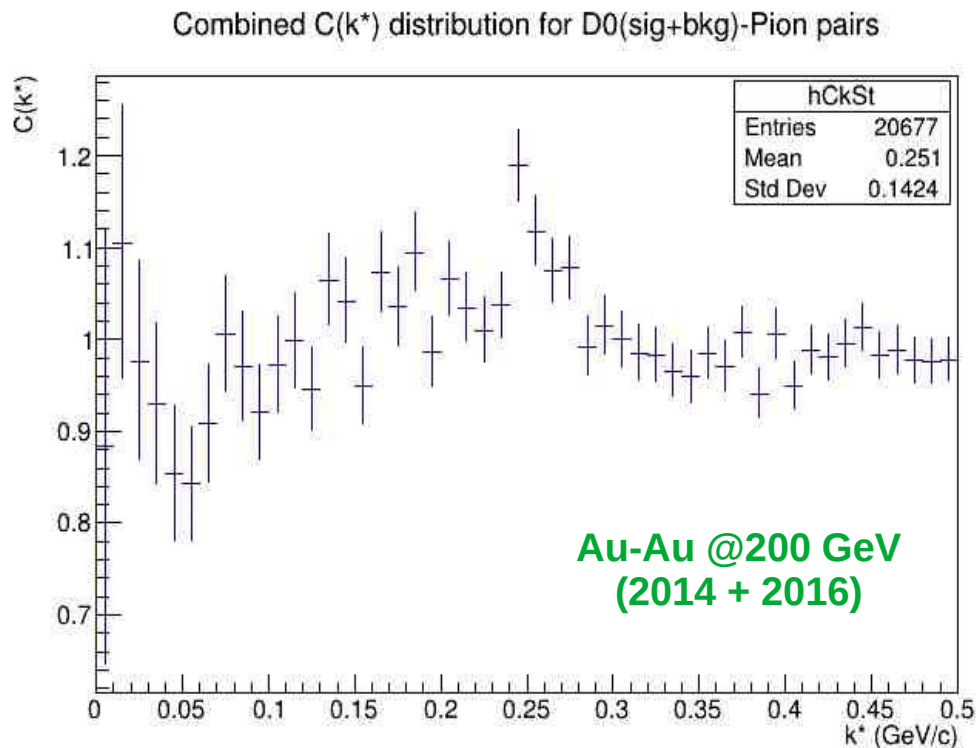
Comparison of $C(k^*)$ for D^0 -Kaon pairs



Plot 43, 44, 45: Comparison of $C(k^*)$ distribution for D^0 -Kaon pairs



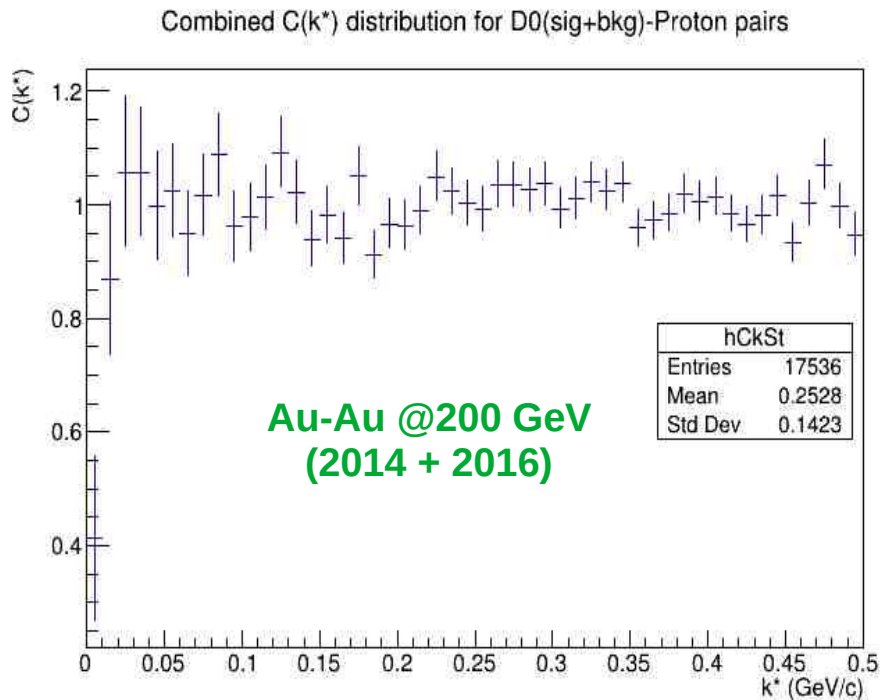
Combined $C(k^*)$ for D^0 - $\pi^{+/-}$ using standard cuts



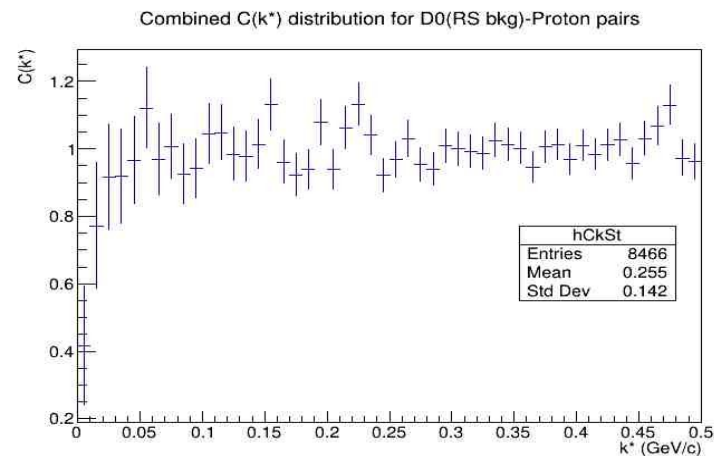
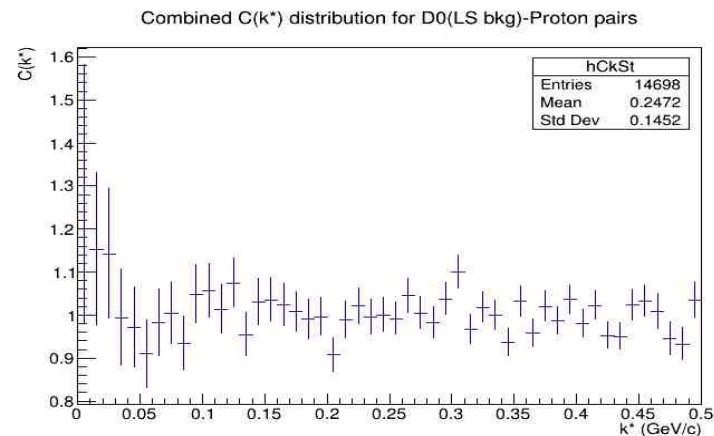
Plot 19, 20, 21: Combined $C(k^*)$ distribution for D^0 -Pion pairs



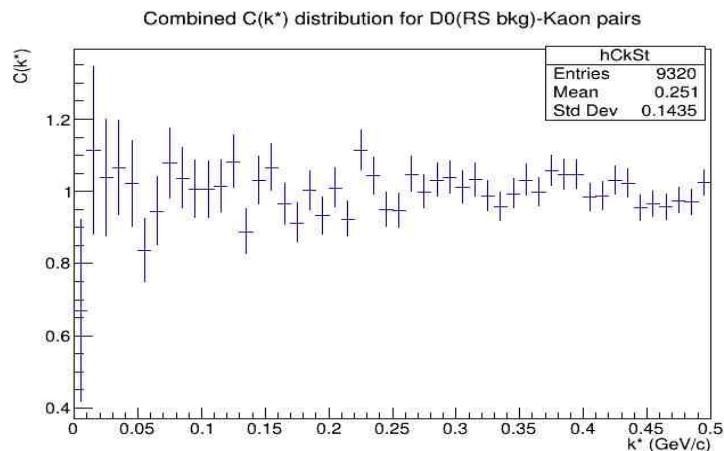
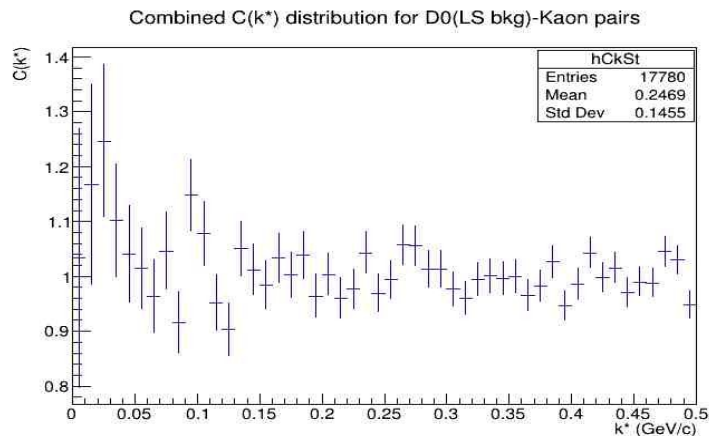
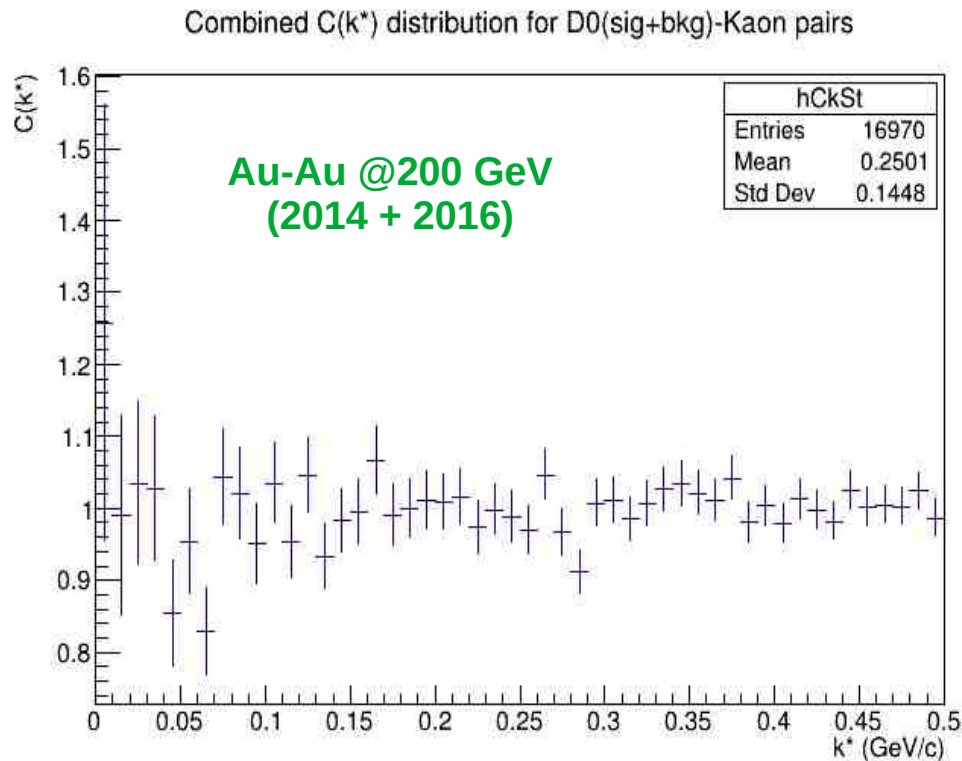
Combined $C(k^*)$ for D^0 - p^{\pm} using standard cuts



Plot 22, 23, 24: Combined $C(k^*)$ distribution for D^0 -Proton pairs



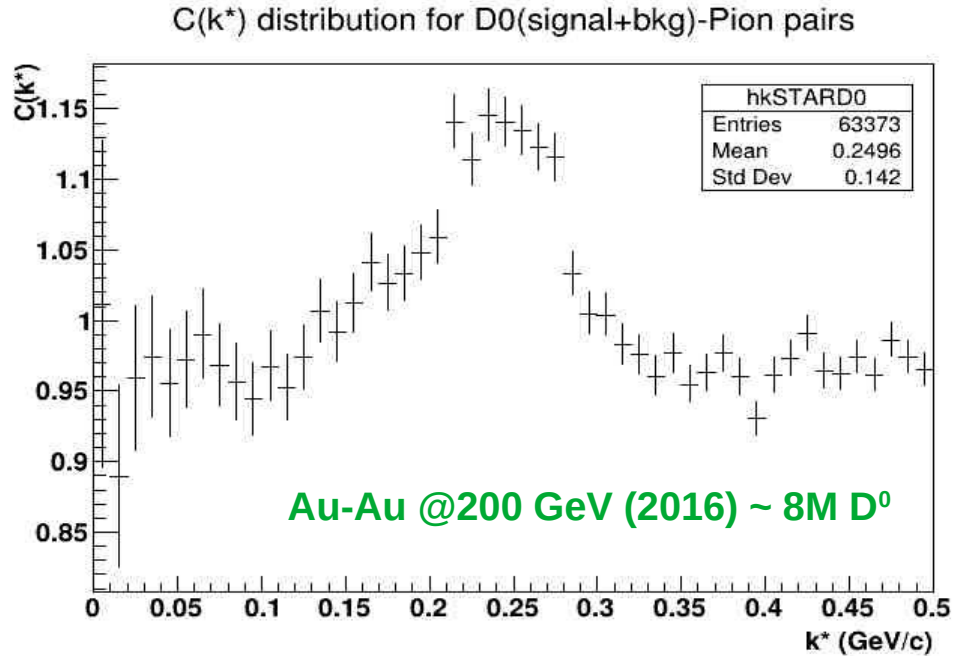
Combined $C(k^*)$ for D^0 - $K^{+/-}$ using standard cuts



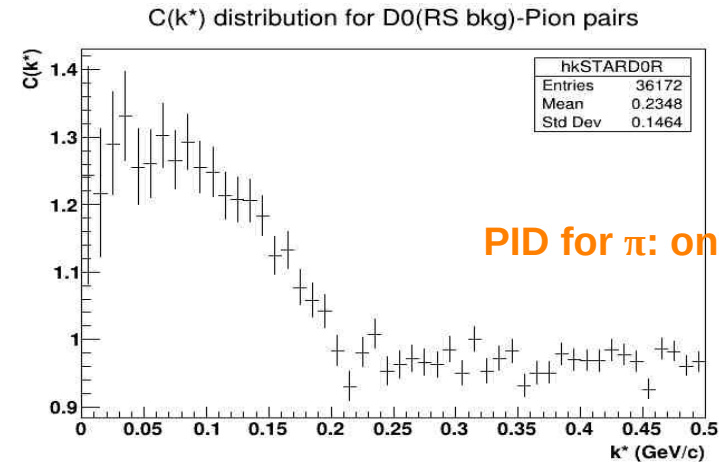
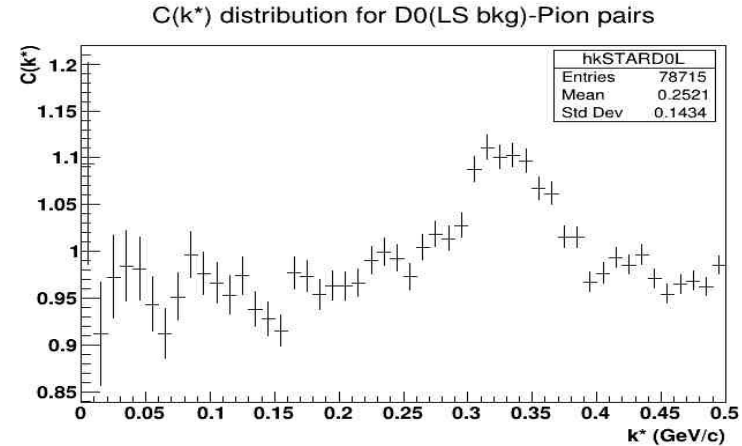
Plot 25, 26, 27: Combined $C(k^*)$ distribution for D^0 -Kaon pairs



C(k*) for D⁰-Pion pairs using looser cuts

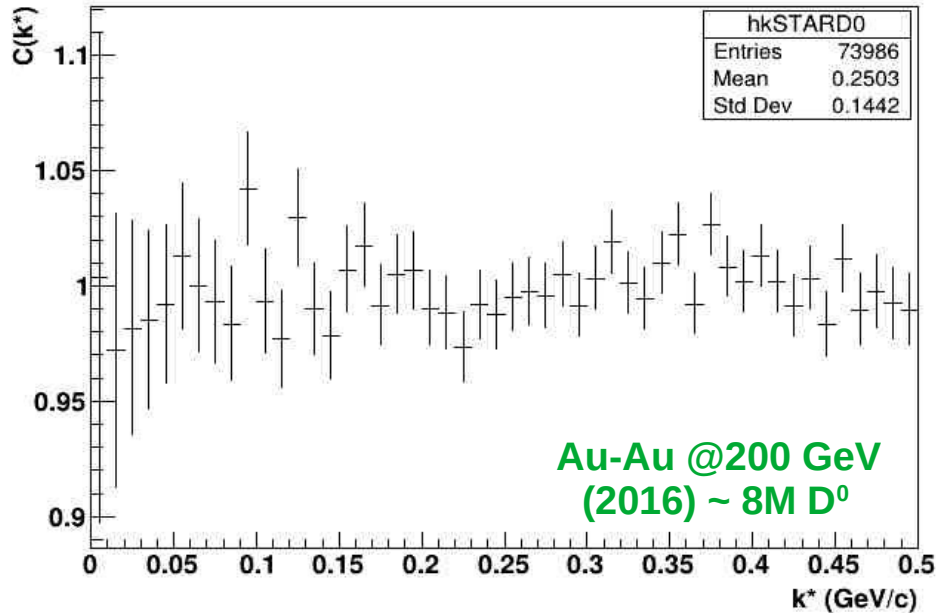


Plot 46, 47, 48: C(k*) distribution for D⁰-Pion pairs



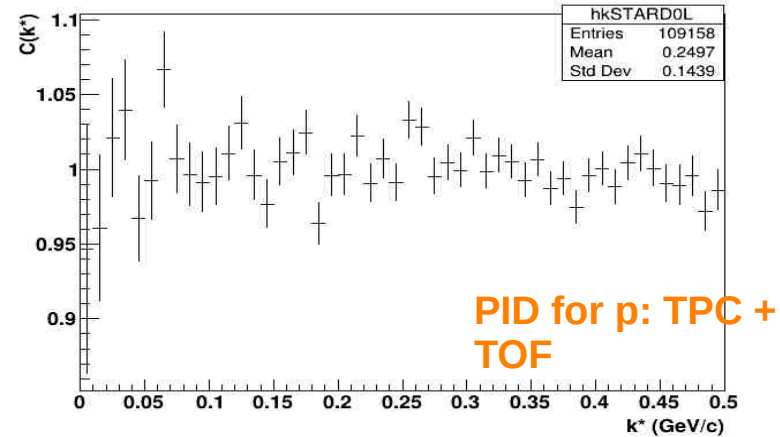
$C(k^*)$ for D^0 -Proton pairs using looser cuts

$C(k^*)$ distribution for $D^0(\text{signal+bkg})$ -Proton pairs

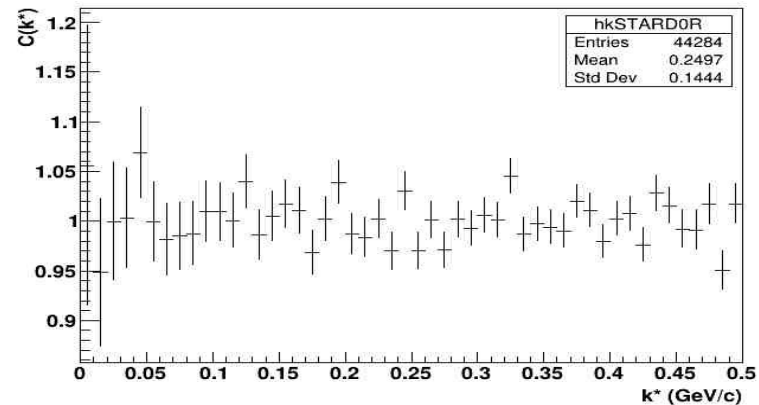


Plot 49, 50, 51: $C(k^*)$ distribution for D^0 -Proton pairs

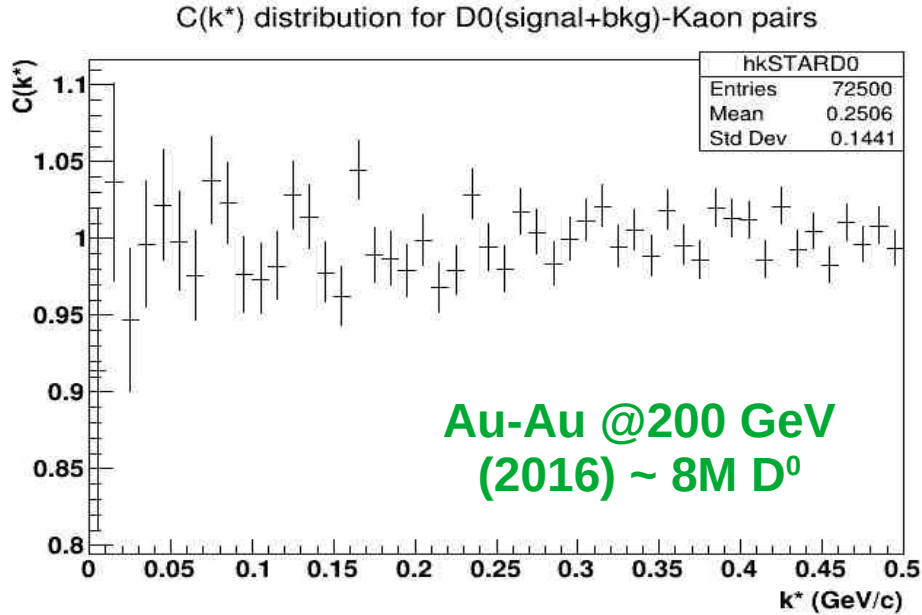
$C(k^*)$ distribution for $D^0(\text{LS bkg})$ -Proton pairs



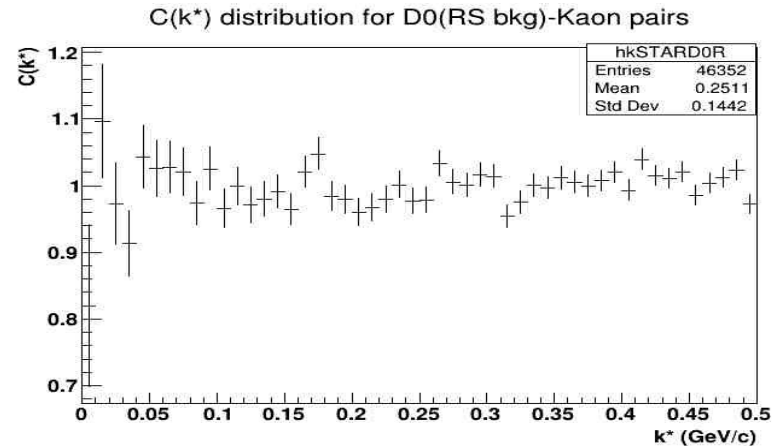
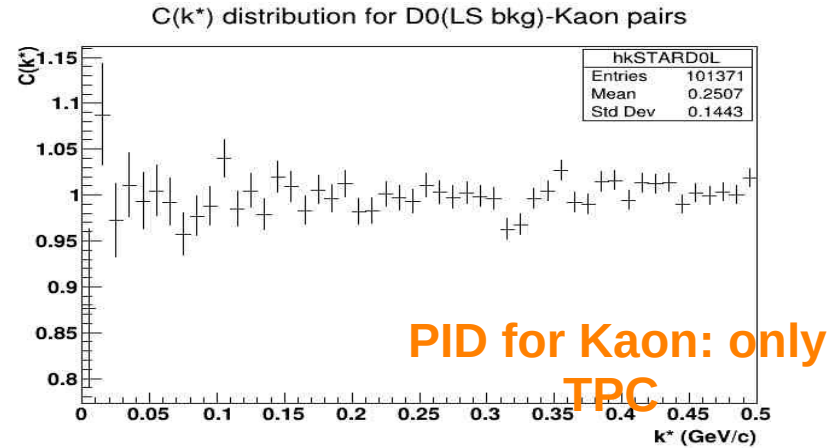
$C(k^*)$ distribution for $D^0(\text{RS bkg})$ -Proton pairs



$C(k^*)$ for D^0 -Kaon pairs using looser cuts

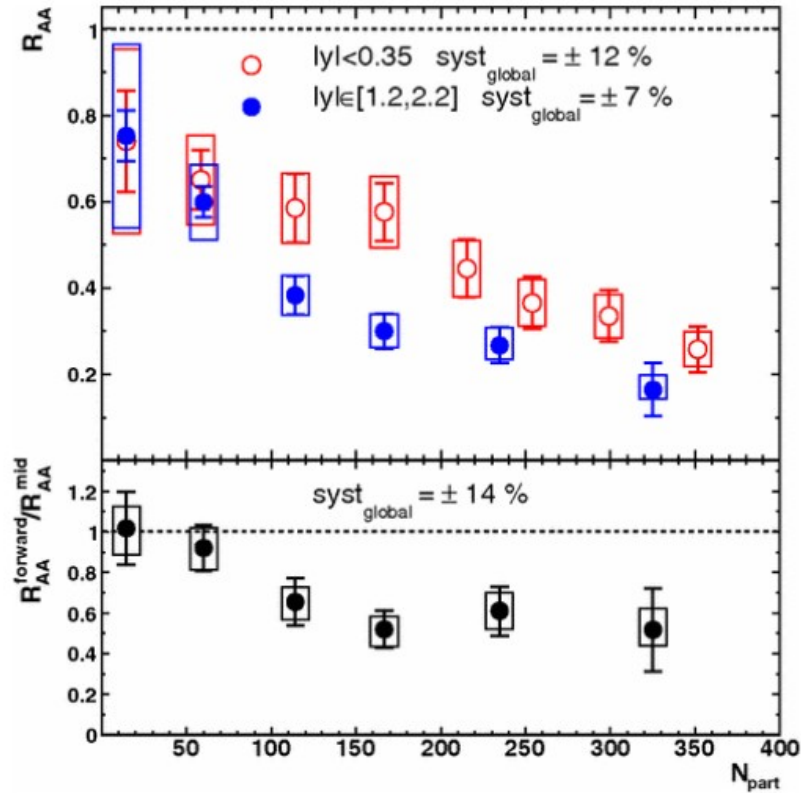


Plot 52, 53, 54: $C(k^*)$ distribution for D^0 -Kaon pairs



Motivation

Physical review letters 101, 232301 (2008)



Plot of R_{AA} (p_T integrated normalized J/ψ yield ratios for p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV) as a function of $\langle N_{part} \rangle$

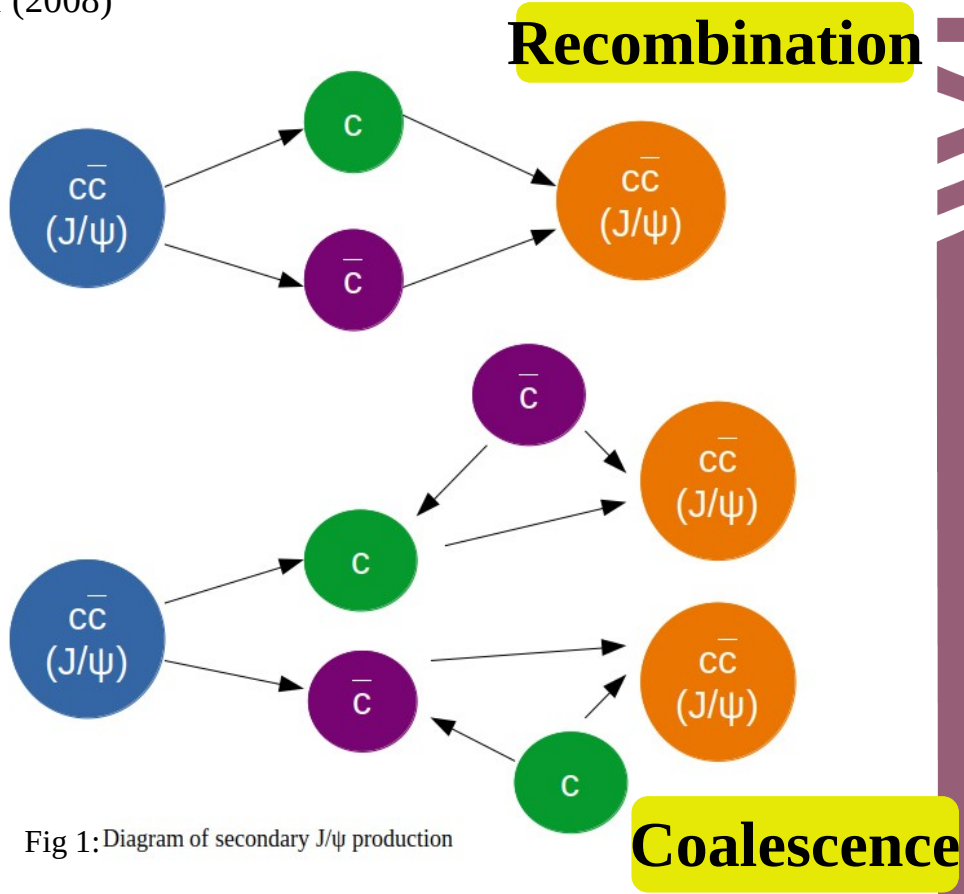


Fig 1: Diagram of secondary J/psi production



Methodology

- To measure \rightarrow Correlation function $C(k^*)$ for $D^0/D^{+/-}$ - (π, p, k) pairs
effective source size, $r^0 \rightarrow$ **Screening length of charm quarks in QGP**
effective volume of the source, V_{eff}
 - Strong correlation \rightarrow small r^0 & V_{eff} in compare to size of fireball
Weak correlation \rightarrow large r^0 & V_{eff} in compare to size of fireball
 - Small V_{eff} \rightarrow Recombination
Large V_{eff} \rightarrow Coalescence
- } **Conclusion about secondary J/Ψ production in QGP**
[On basis of Model studies]



Methodology

- **Lednický–Lyuboshitz** model study to fit analysis results using expt. Data

$$C(\vec{k}^*) = \int S(\vec{r}^*) |\Psi(\vec{k}^*, \vec{r}^*)|^2 d^3r^*,$$

where, $S(r^*)$ is the source emission function, $\psi(k^*, r^*)$ is the pair wave function, and r^* is the relative separation vector.

- Run Same analysis using $D^{+/-}$ instead of D^0

