Femtoscopic correlation between D^0-K in Au+Au collisions @ $\sqrt{s_{NN}}$ = 200 GeV at STAR

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WPCF – Resonance workshop

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Femtoscopic correlation

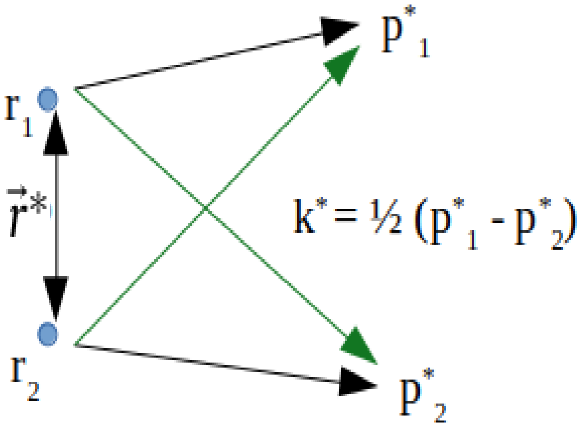
- Femtoscopic correlations are observed between pair of particles with low relative momentum
- It is measured as a function of the reduced momentum difference (k^*) of the pair of particles in rest frame

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

where, $S(\vec{r}^*)$ → source emission function

$\vec{r}^*$ → relative separation vector

$\Psi(\vec{k}^*, \vec{r}^*)$ → pair wave function



Femtoscopic correlation & k^*

- Femtoscopic Correlation ⟶ QS + FSI
  - Quantum Statistics [QS]: Bose-Einstein QS + Fermi-Dirac QS
  - Final-State-Interaction [FSI]: **Strong** & Coulomb interaction

(absent for our system)

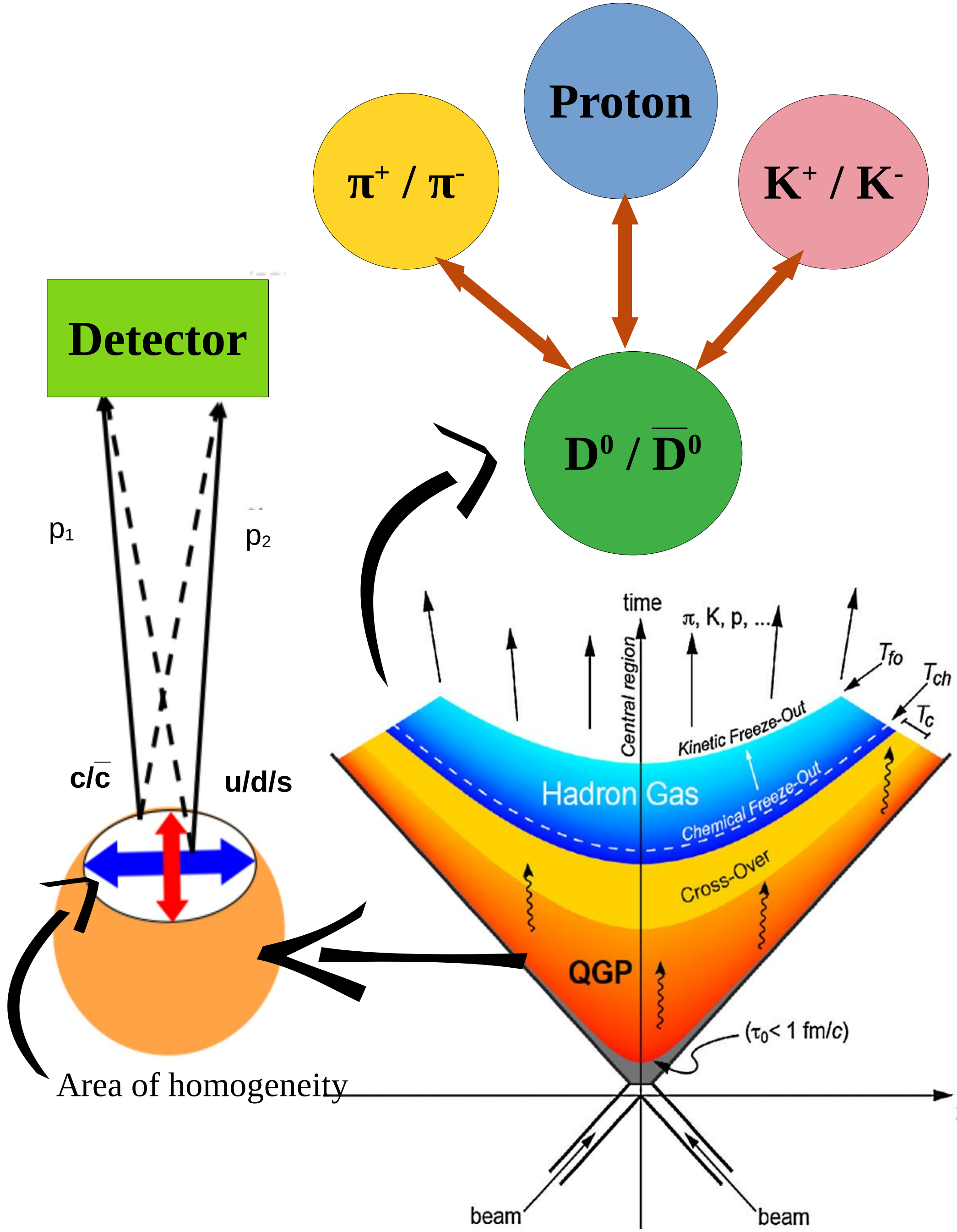
Motivation - QGP

- Femtoscopic correlation is sensitive to the interactions in the final state as well as to the extent of the region from which correlated particles are emitted

- D^0-hadron femtoscopy provides information about interaction between of charm and light quarks within QGP medium

- Average distance between emission points of correlated pairs is known as '*Length of homogeneity*'

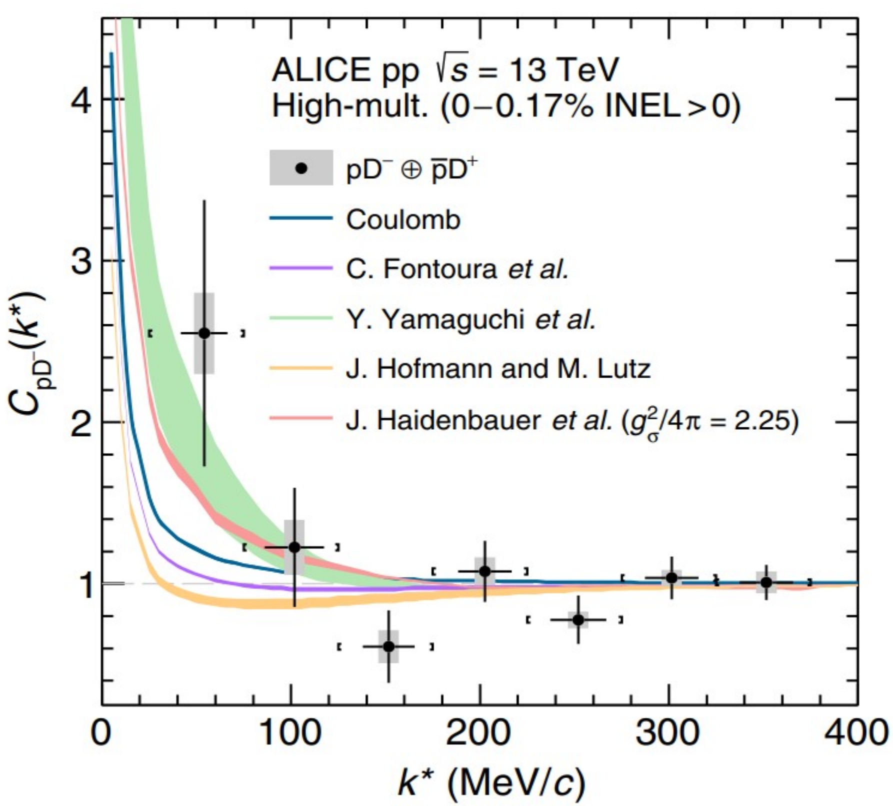
- This length could be interpreted as a measure of how far the interaction between charm quarks and light quarks extends in a medium



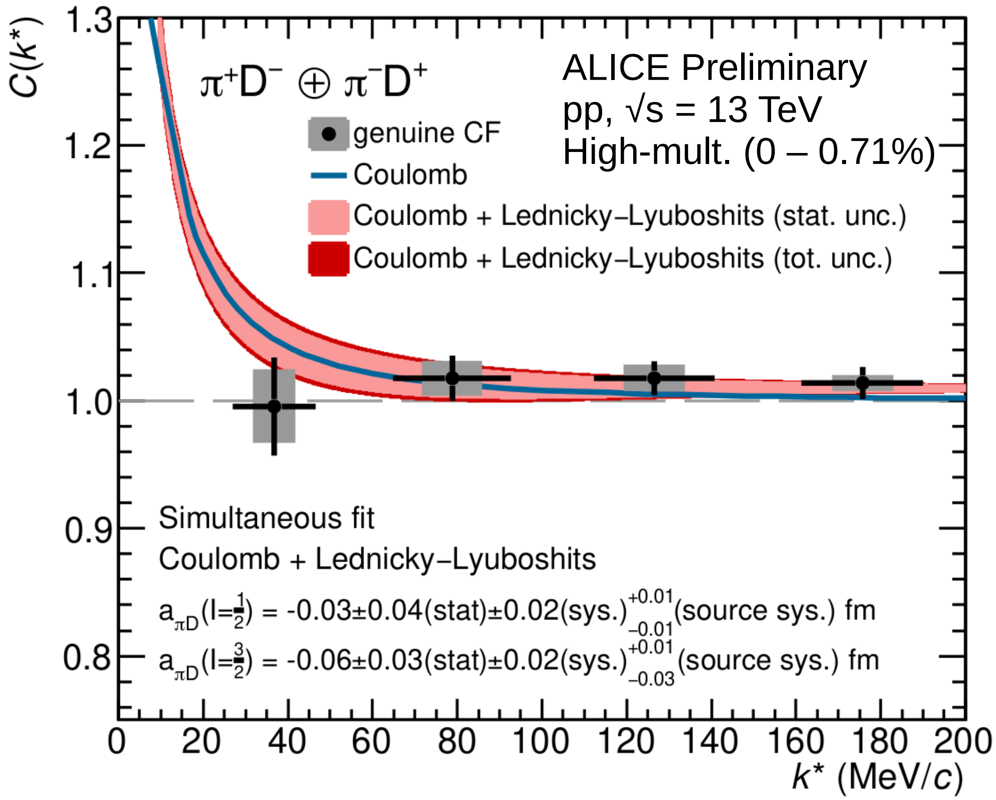
Motivation – pp collisions

- First studies of D-hadron interactions in pp at √s = 13 TeV by the ALICE experiment

Phys. Rev. D 106, 052010



QM 2022: https://indico.cern.ch/event/895086/contributions/4715876/

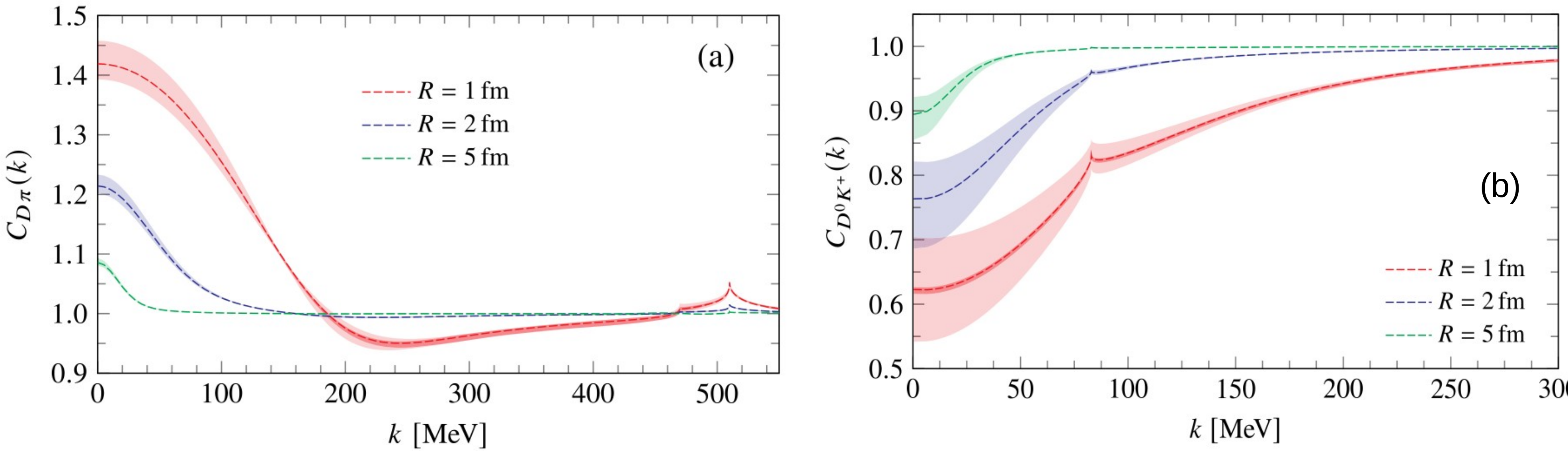


- CF data for pD^- and $\bar{p}D^+$ pairs are compatible within (1.1 – 1.5)σ with theory predictions obtained from the hypothesis of Coulomb only interaction

- Small values of $a_{\pi D}$ (scattering length) → small role of D meson re-scattering in the hadronic phase of heavy-ion collisions

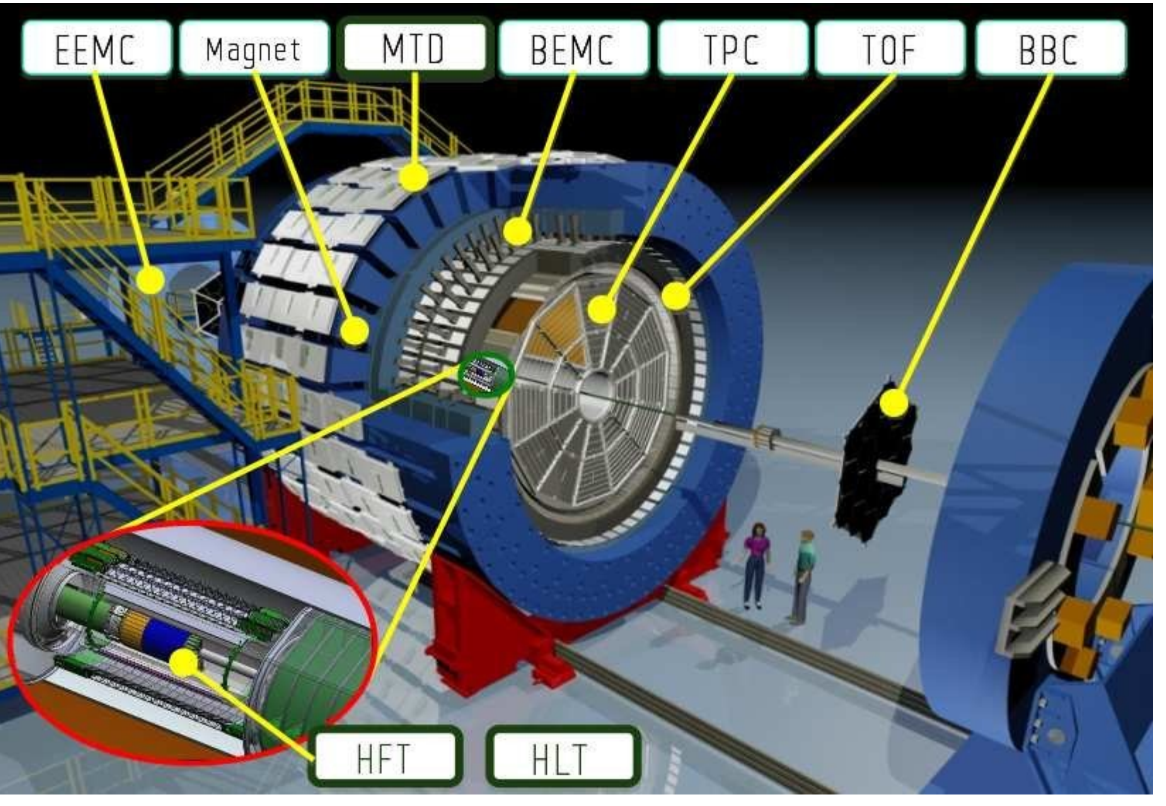
Motivation - theory

Phys. Rev. D 108, 014020



- Source size dependence of correlation functions for $D^0\pi^+$ and $D^+\pi^0$ mixed states (left) and D^0K^+ pairs (right)
- Smaller emission source size → Stronger correlation
- CF is sensitive to the resonance effects (D_0^* for $C_{D\pi}$ and $D_{S0}^*(2317)^{\pm}$ for $C_{D^0K^+}$)
- Resonance effect dilutes with increasing source size

***STAR** (Solenoidal Tracker At RHIC)*



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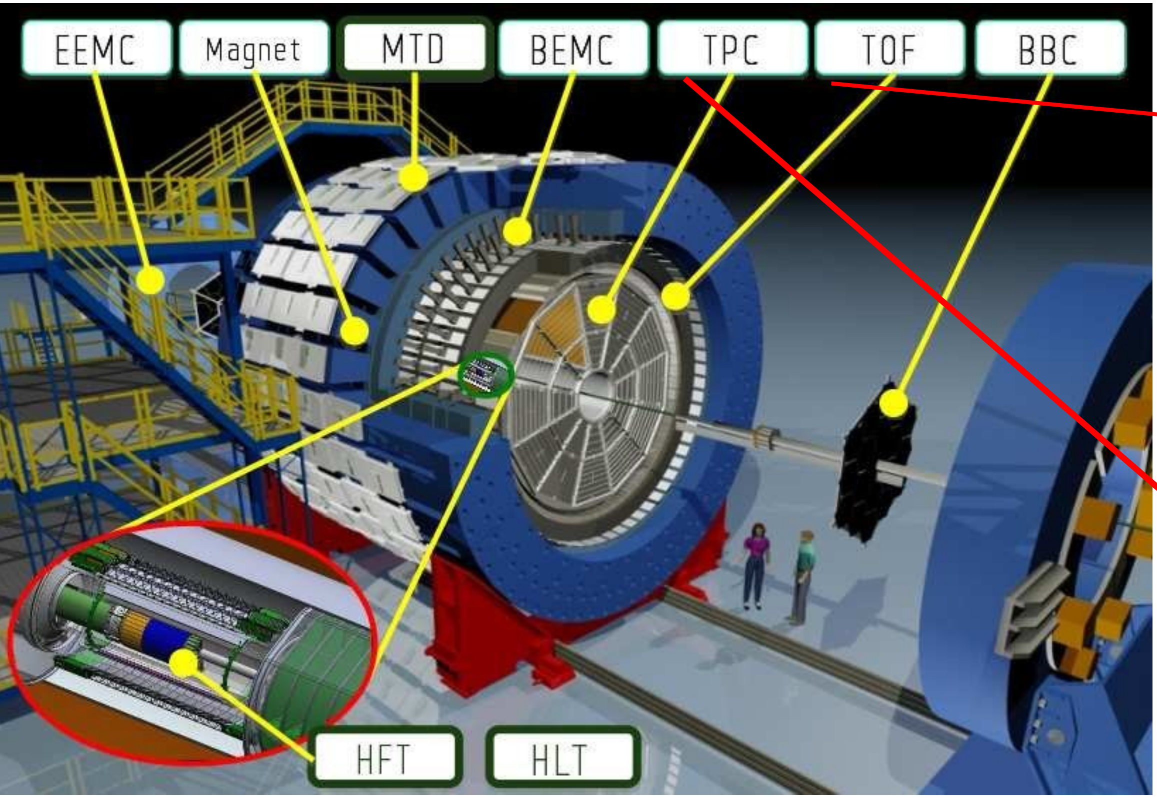
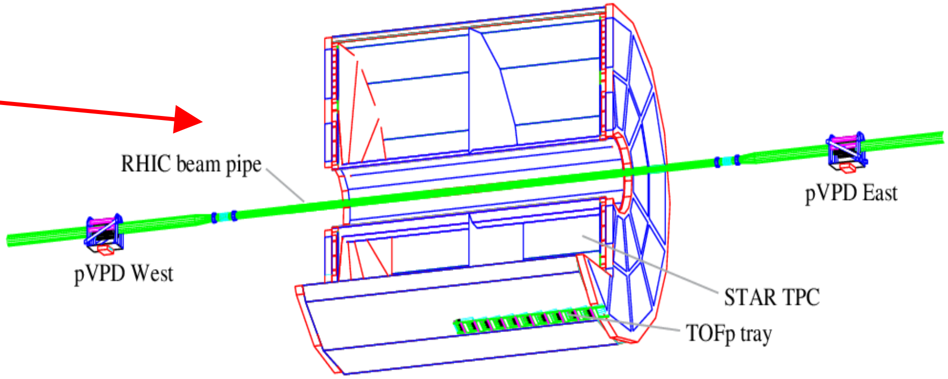
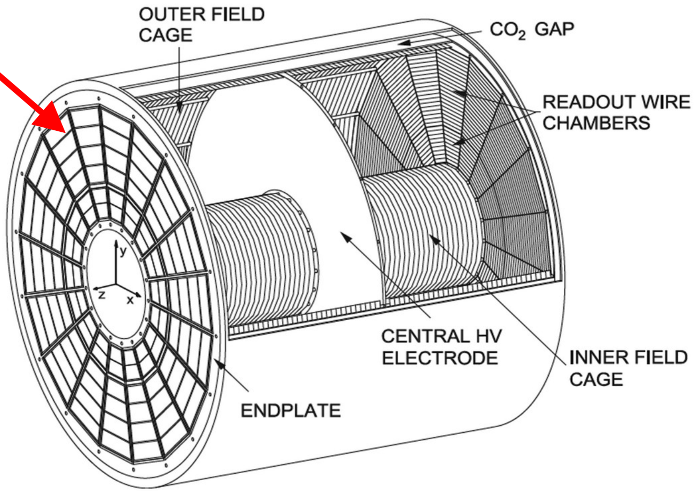




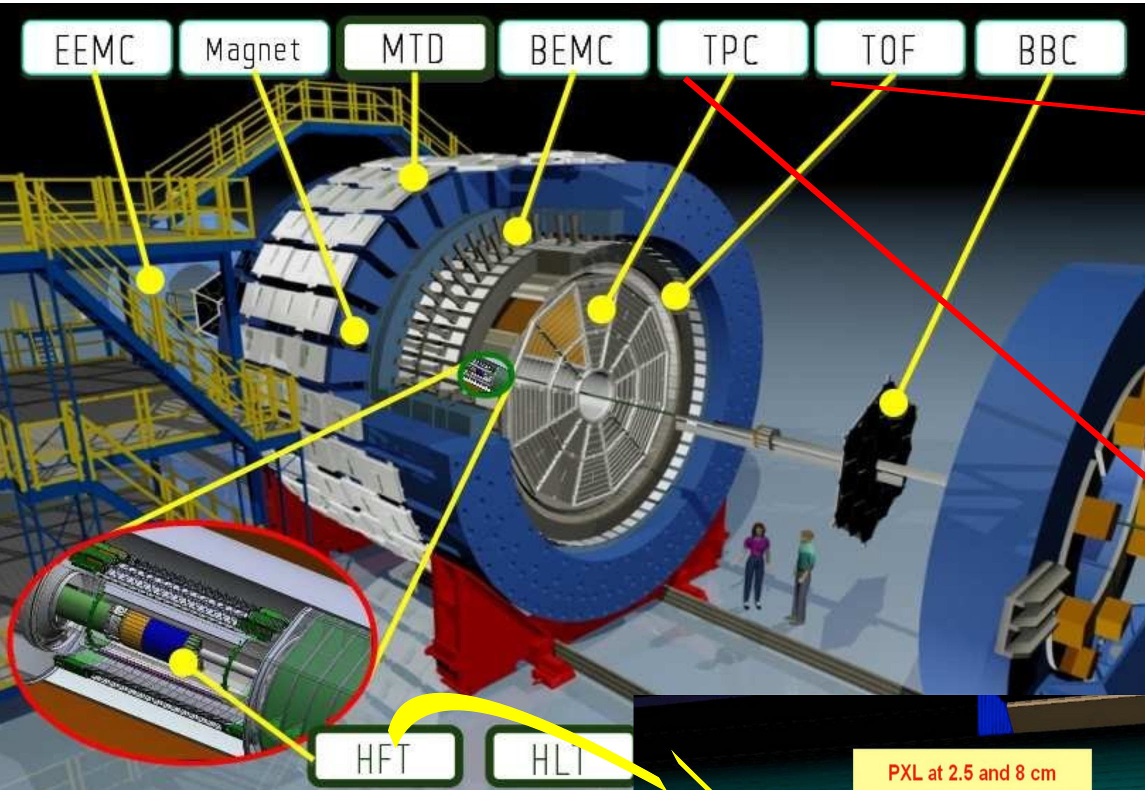
TOF (Time of Flight)

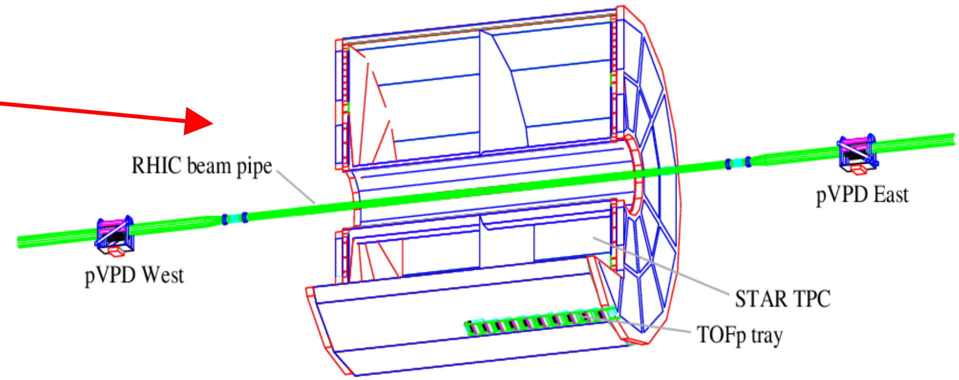


TPC (Time Projection Chamber)

- TOF & TPC used for PID

STAR *(Solenoidal Tracker At RHIC)*





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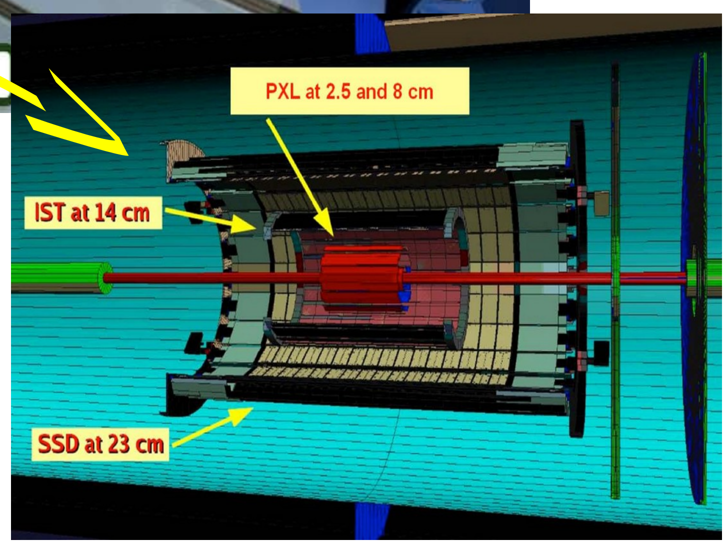
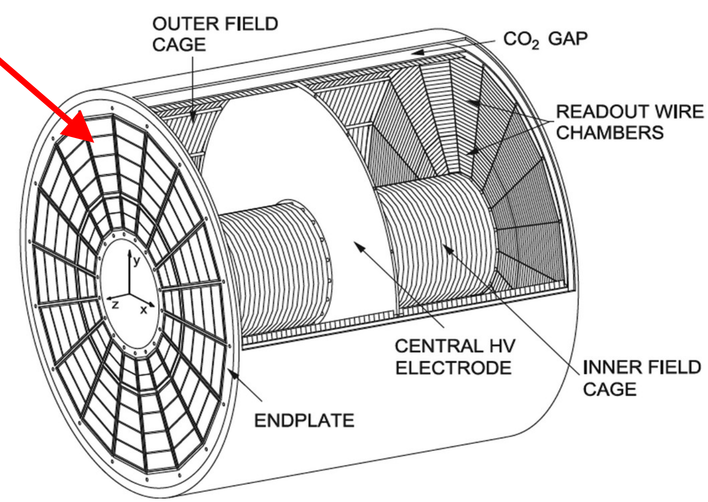


HFT (Heavy Flavour Tracker)

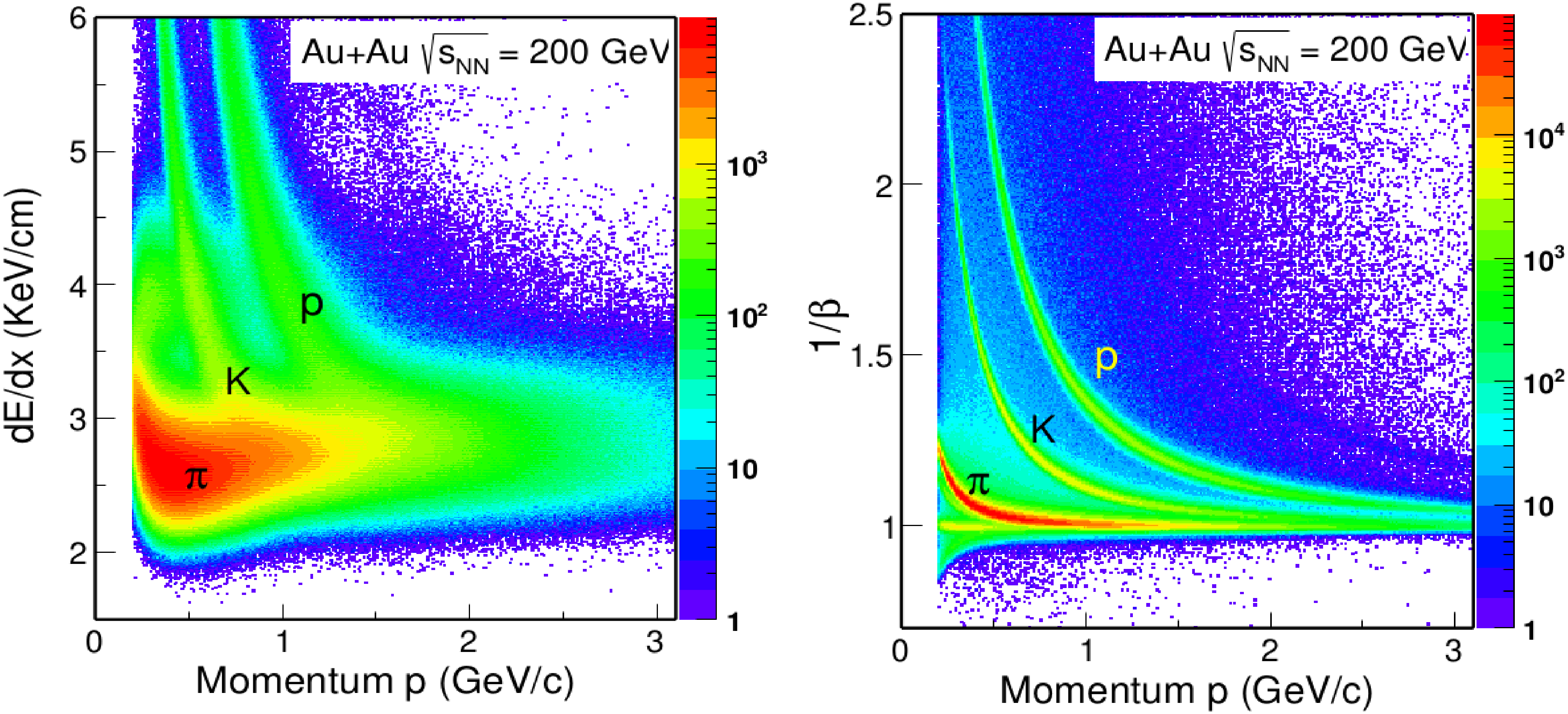


TPC (Time Projection Chamber)

- TOF & TPC used for PID
- HFT used for D^0 reconstruction

Particle Identification (PID)

Ref. - STAR: Phys. Rev. C 99, 034908 (2019)

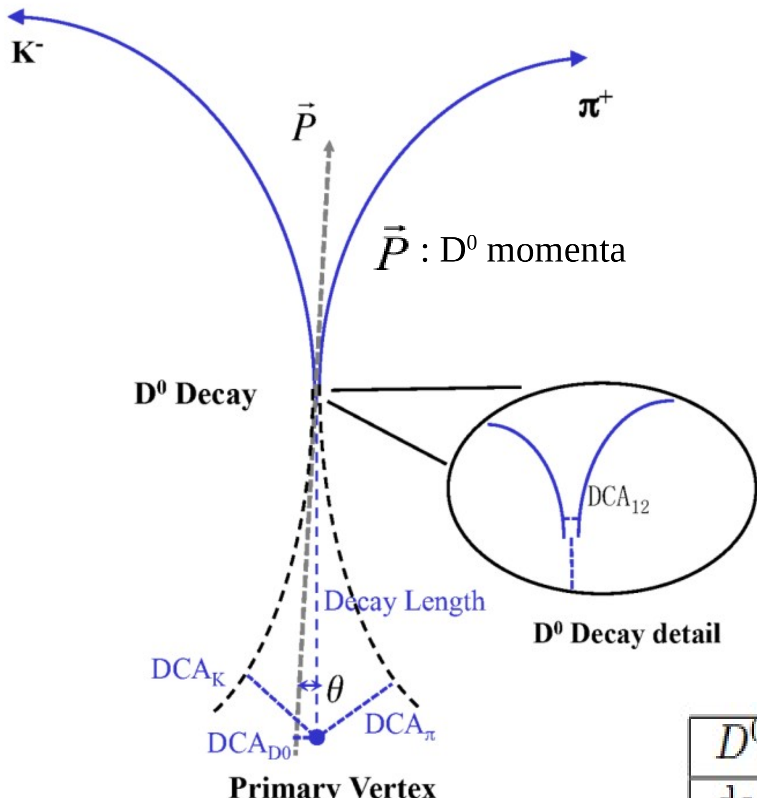


Particle identification using TPC (left) and TOF (right)

- dE/dx bands for π and K overlap around 0.7 GeV/c
- To distinguish between π and K at lower momenta (< 1 GeV/c), TOF info was required

Reconstruction of D^0 meson

Ref. - STAR: Phys. Rev. C 99, 034908 (2019)



$c\tau \approx 123\ \mu m$

$1.6 <$ D^0 mass < 2.2 GeV/c^2

- Decay length - distance between decay vertex and primary vertex (PV)
- Distance of Closest Approach (DCA) between:

  a) K^- & π^+ - DCA_{12}

  b) π^+ & PV - DCA_π

  c) K^- & PV - DCA_K

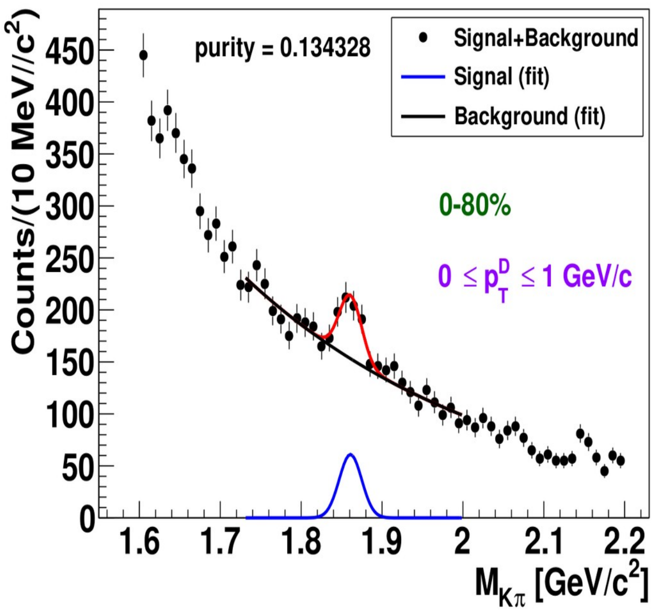
  d) D^0 & PV - DCA_{D0}

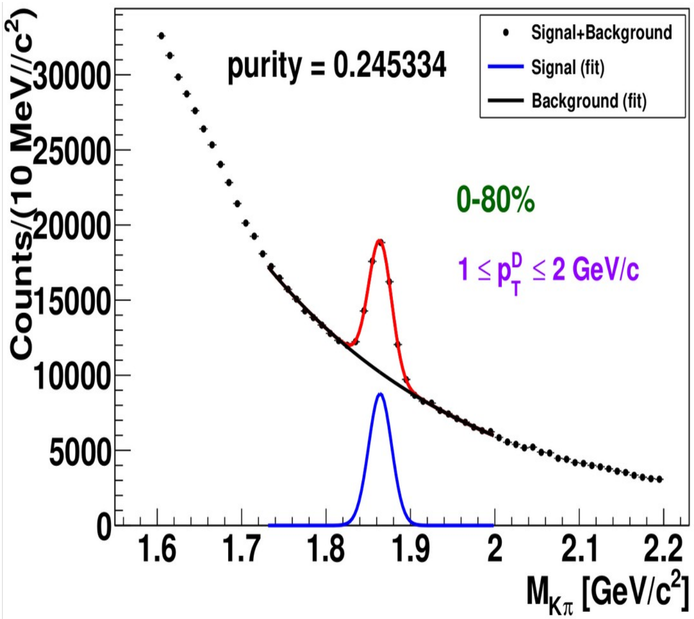
- θ - angle between $\vec{P}$ & decay length
- Here $D^0 \rightarrow$ ***mixture of D^0 ($K^-\pi^+$) and $\overline{D}^0$ ($K^+\pi^-$)***

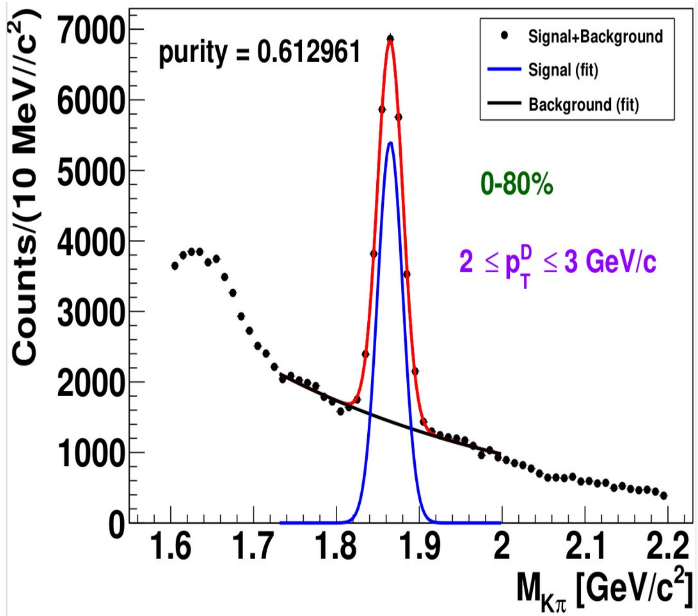
Topological selection criteria:

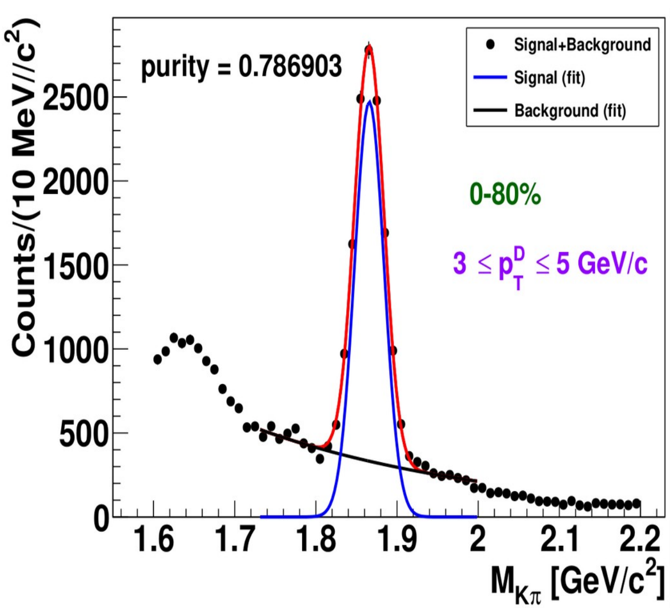
D^0 p_T (GeV/c)	$0-1$	1-2	2-3	3-5	5-10
decay length (μm) >	145	181	212	247	259
DCA between 2 daughters (μm) <	84	66	57	50	60
DCA between D^0 and PV (μm) <	61	49	38	38	40
DCA between π and PV (μm) >	110	111	86	81	62
DCA between K and PV (μm) >	103	91	95	79	58
pointing angle cos (θ) >	0.99	0.99	0.99	0.99	0.99

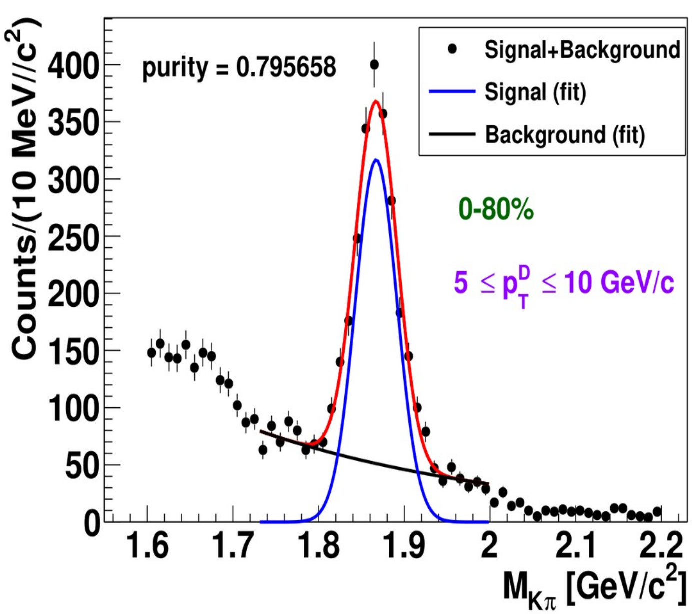
D^0 Invariant Mass











- D^0 invariant mass range: 1.82 – 1.91 GeV/c^2
- D^0 purity:

$$\frac{signal}{(signal + background)}$$

- Good S/B ratio for D^0 signal $p_T > 1$ GeV/c

Analysis

- Data set: Au+Au, Run 2014
- Energy: 200 GeV
- Trigger: Minimum bias
- Centrality: 0 – 80%
- Analyzed events: 604 M

➔ Applied formula to measure correlation function $C(k^*)$ for $D^0/\overline{D}^0$ - $K^{+/-}$ pairs

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

where, $A(\vec{k}^*)$ and $B(\vec{k}^*)$ $\rightarrow k^*$ distribution for correlated and uncorrelated pairs

$\mathcal{N} \rightarrow$ normalization factor

➔ To calculate k^* for uncorrelated pairs, event mixing technique was applied

Systematic uncertainty

1. Variation of topological cuts for D^0 reconstruction
2. Inclusion of uncertainty from D^0-K pair-purity correction

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

where PairPurity = **D^0 purity** * **hadron purity**

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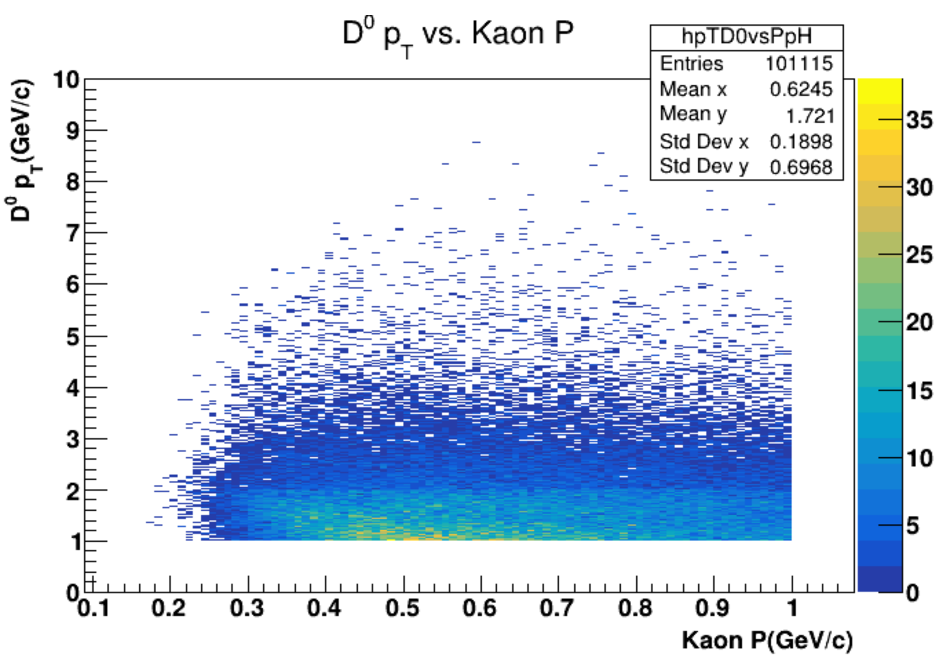

Momentum distribution of D^0 & K

- Mean kaon momentum: <p> ≈ 0.62 GeV/c
- Due to overlap with other hadrons, kaon with p < 1 GeV/c has been considered only
- Kaon purity ~ 97% ± 3%

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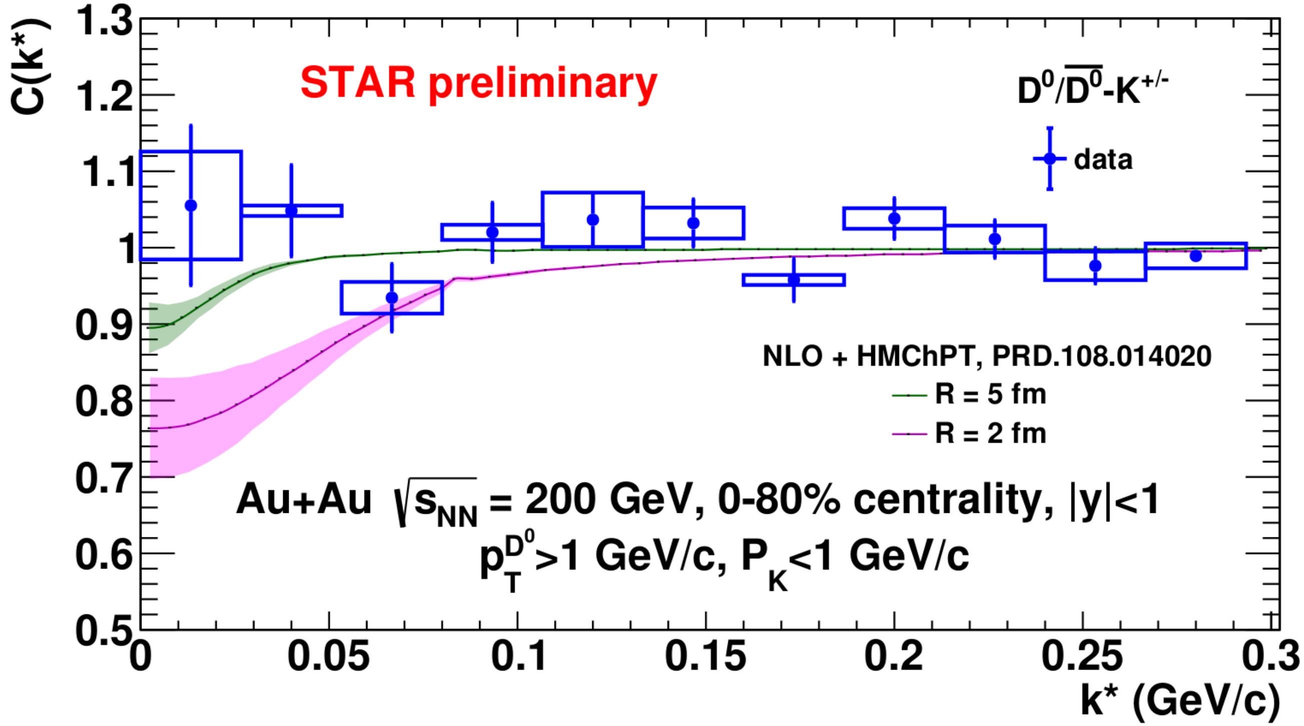
where PairPurity = **D^0 purity** * **hadron purity**

➔ Overall uncertainty on D^0-K pair purity ~ **10%** which covers all possible systematic uncertainties

Result: $D^0/\overline{D}^0$-$K^{+/-}$ correlation

NLO + HMChPT, Phys. Rev. D 108, 014020



- C(k*) contains D^0-K^+, D^0-K^-, $\overline{D}^0$-K^+ and $\overline{D}^0$-K^- with kaon momentum < 1 GeV/c and D^0 p_T > 1 GeV/c
- Ref. CF estimated for D^0-K^+ using next-to-leading order (NLO) - Heavy Meson Chiral Perturbation Theory (HMChPT) scheme

- STAR data shows **no correlations**, but the data also consistent with theoretical model predictions with **emission source size of 5 fm or larger**
- Resonance effect of $D_{s0}^*(2317)^{\pm}$ state is NOT visible due to large source size or large experimental uncertainties

Summary & Future Plans

- D-meson femtoscopy is useful to probe its interaction behavior and the phase space geometry of emission source
- Adding more statistics (Run 2016) to achieve more precise results
- Model study (ex. Lednický–Lyuboshitz) is on the plan to extract interaction parameters, like emission source size
- This study can lead us to get an insight of screening length of charm quarks within QGP medium
- Theoretical inputs are needed to explore the nature of interaction between charm and light quarks within QGP medium
- Analysis of D^0-π/p femtoscopy in Au+Au collisions at STAR are ongoing


WPCF - Resonance Workshop 2023
Thank you!
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2023
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Selection criteria

Event cuts

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

Track cuts

- $p_T > 0.5$ GeV/c
- |dca_sign| >0.0050cm.
- nHitsFit >= 20
- |pseudorapidity| <=1.0

PID cuts for Pions, Kaons & Protons

- |nSigmaPion| < 3.0
- |nSigmaKaon| < 2.0 & |nSigmaProton| < 2.0
- |(1/beta) - (1/beta_{Pion})| < 0.03
- |(1/beta) - (1/beta_{Kaon})| < 0.03
- |(1/beta) - (1/beta_{Proton})| < 0.03

Correction of detector effects

1. Self correlation: Possible correlation between D^0 candidates and their daughters were removed

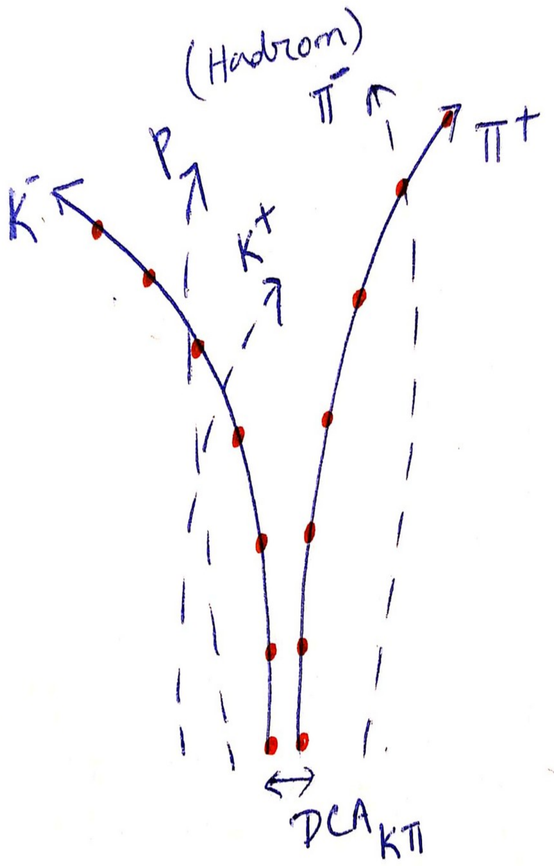
Hadron (chosen for pairing with D^0) track id ≠ Track id of D^0 (π^+K^-)

2. Track splitting: Track splitting causes an enhancement of pairs at low relative pair momentum k^*. This enhancement is created by a single track reconstructed as two tracks, with similar momenta. Track splitting mostly affects identical particle combinations (here, $\pi_D{}^0 - \pi$ and $K_D{}^0 - K$), as one track may leave a hit in a single pad-row. Due to shifts of pad-rows, it can be registered twice. In order to remove split tracks, we applied following condition.

No. of hit points / Max no. of hit points > 0.51

Correction of detector effects

3. Track merging:



Merging of tracks inside TPC

Approach 1:

- **δr(i) < mean TPC distance separation → 'merged' hits**
- δr(i) - distance between TPC hits of two tracks
- Pair of tracks with fraction of merged hits > 5% were removed as 'merged tracks'
- The technique was adopted from HBT maker

Approach 2:

- **δr(i) < threshold → 'merged' hits**

Approach 3:

- **SE/ME of Δη vs Δϕ distribution** → no dip around 0 → negligible effect of merged tracks