# Reconstruction of open charm in STAR with KF Particle Finder

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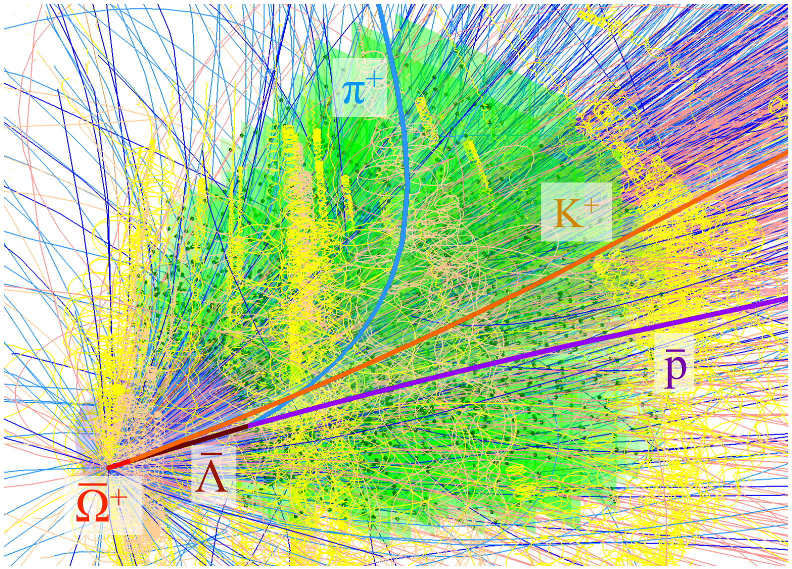
# Concept of KF Particle




$\bar{\Omega}^{+} \rightarrow \bar{\Lambda} K^{+}$

$\quad \hookrightarrow \bar{p}\, \pi^{+}$

```
KFParticle Lambda(P, Pi);                    // construct anti Lambda
Lambda.SetMassConstraint(1.1157);            // improve momentum and mass
KFParticle Omega(K, Lambda);                 // construct anti Omega
PV -= (P; Pi; K);                            // clean the primary vertex
PV += Omega;                                 // add Omega to the primary vertex
Omega.SetProductionVertex(PV);               // Omega is fully fitted
(K; Lambda).SetProductionVertex(Omega);      // K, Lambda are fully fitted
(P; Pi).SetProductionVertex(Lambda);         // p, pi are fully fitted
```

**State vector**

Position, momentum and energy

$$\mathbf{r} = \{\, x, y, z, p_x, p_y, p_z, E \,\}$$

$$\mathbf{C} = \langle \mathbf{r}\mathbf{r}^T \rangle$$

**Covariance matrix**

**Concept:**

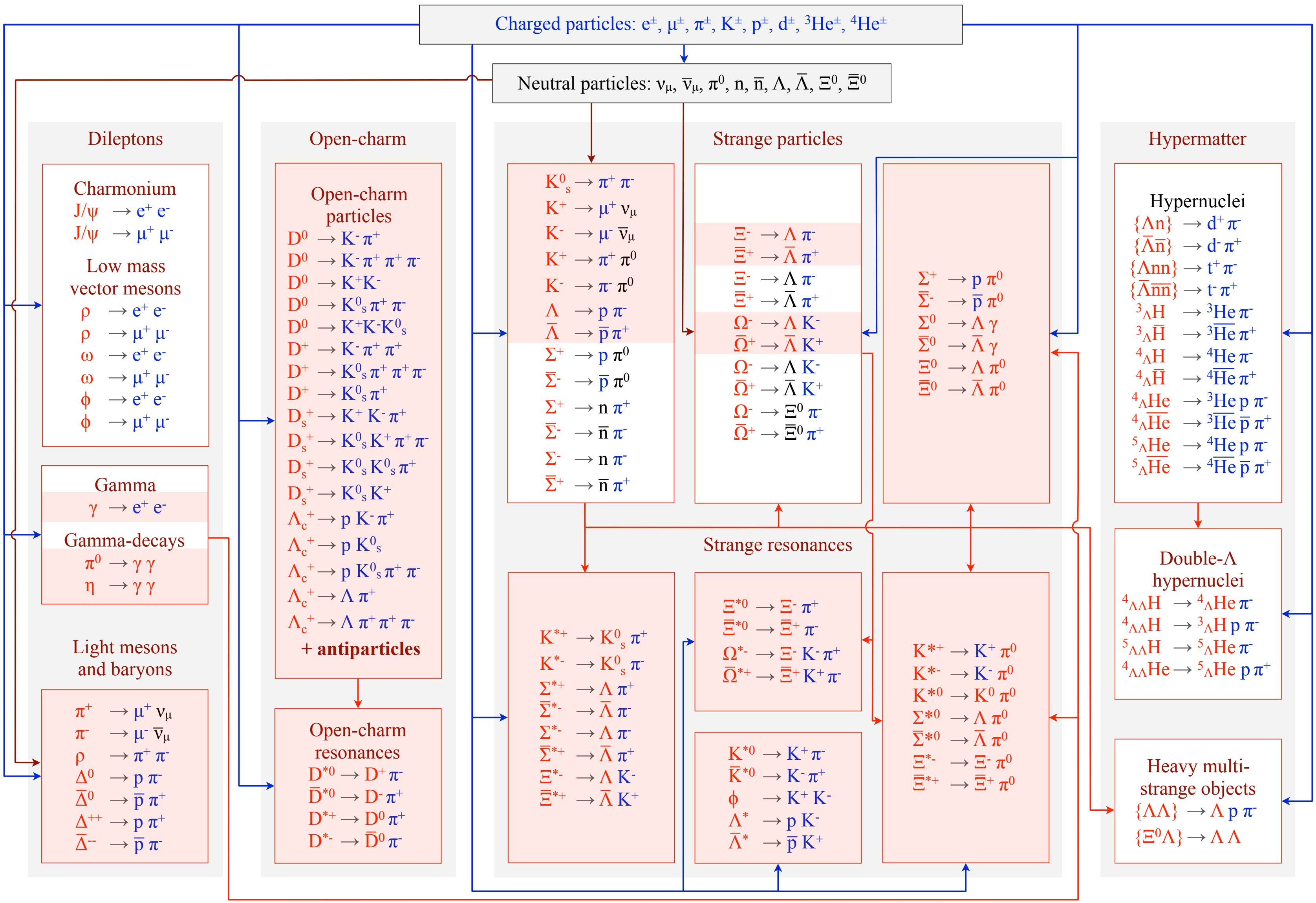
- Mother and daughter particles have the same state vector and are treated in the same way
- Geometry independent
- Reconstruction of all physics parameters together with their errors
- Kalman filter based
- Easy reconstruction of decay trees
- Fast and fully vectorised

# Functionality of KF Particle

| Functions | CBM | STAR | ALICE | PANDA |
|---|---|---|---|---|
| Construction of mother particles | + | + | + | + |
| Addition and subtraction of the daughter particle to (from) the mother particle | + | + | + | + |
| += and -= operators | + | + | + | + |
| Accessors to the physical parameters (mass, momentum, decay length, lifetime, rapidity, etc) | + | + | + | + |
| Transport: to an arbitrary point, to the decay and production points, to another particle, to a vertex, on the certain distance | + | + | + | + |
| Calculation of a distance: to a point, to a particle, to a vertex | + | + | + | + |
| Calculation of a deviation: from a point, from a particle, from a vertex | + | + | + | + |
| Calculation of the angle between particles | + | + | + | + |
| Constraints: on mass, on a production point, on a decay length | + | + | + | + |
| KF Particle Finder | + | + | + | + |

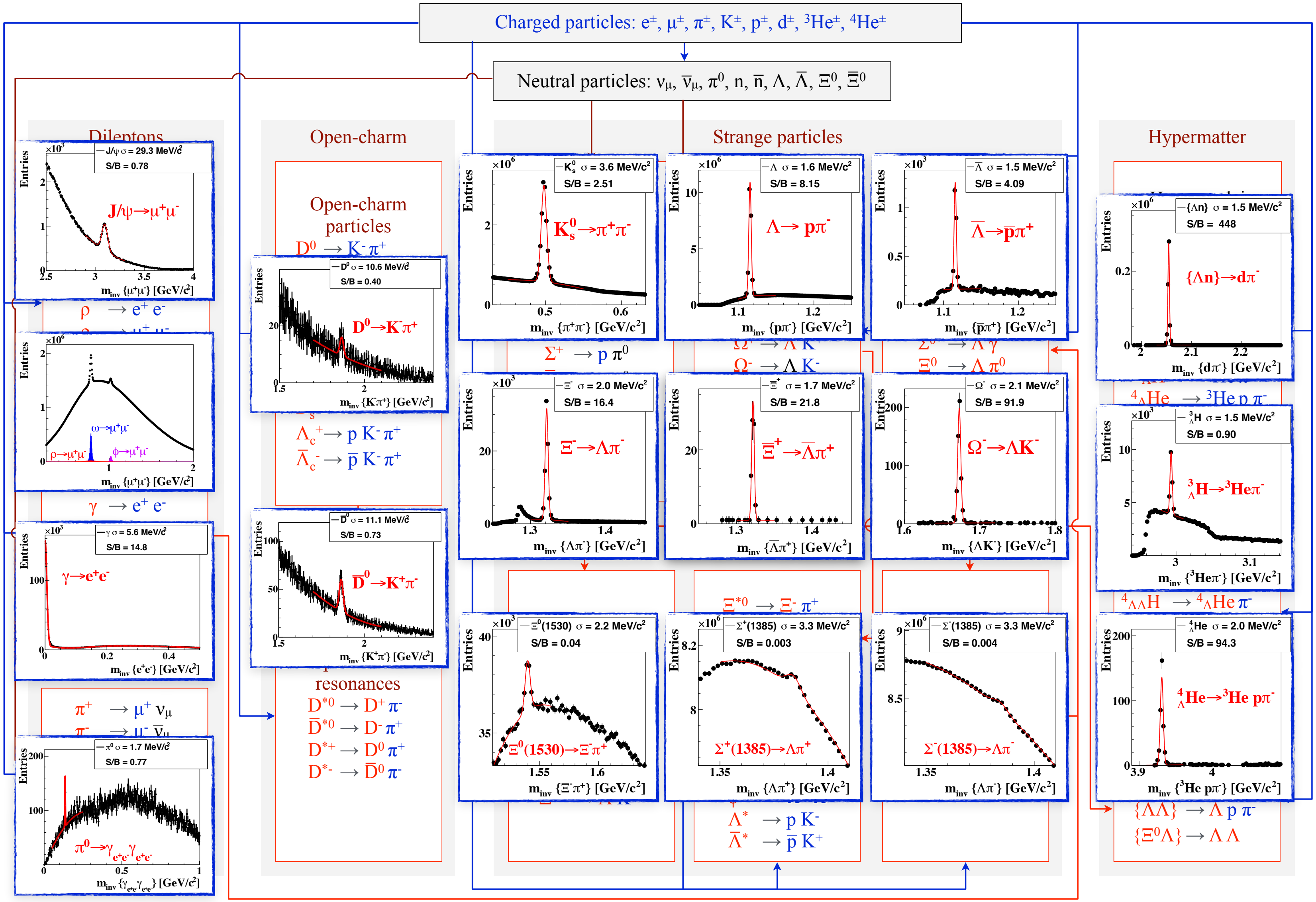
Exactly the same package in all four experiments: CBM, ALICE, PANDA and STAR.
Added to the .DEV2 git repository, continuously updated from the KF Particle svn repository.

# KF Particle Finder




Marked decay channels are currently being tuned in STAR

# Physics coverage

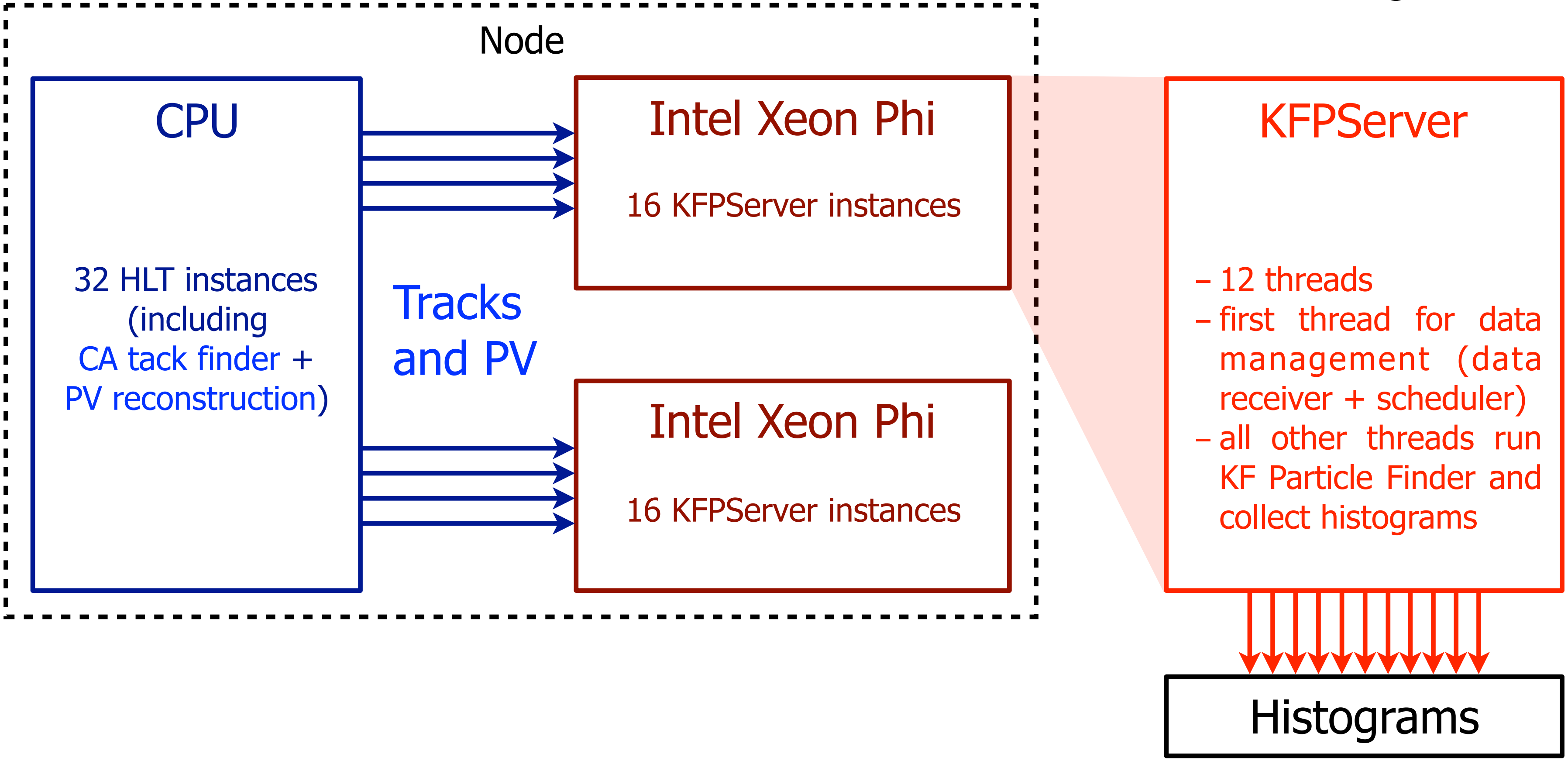



All main decay channels are covered in the CBM experiment

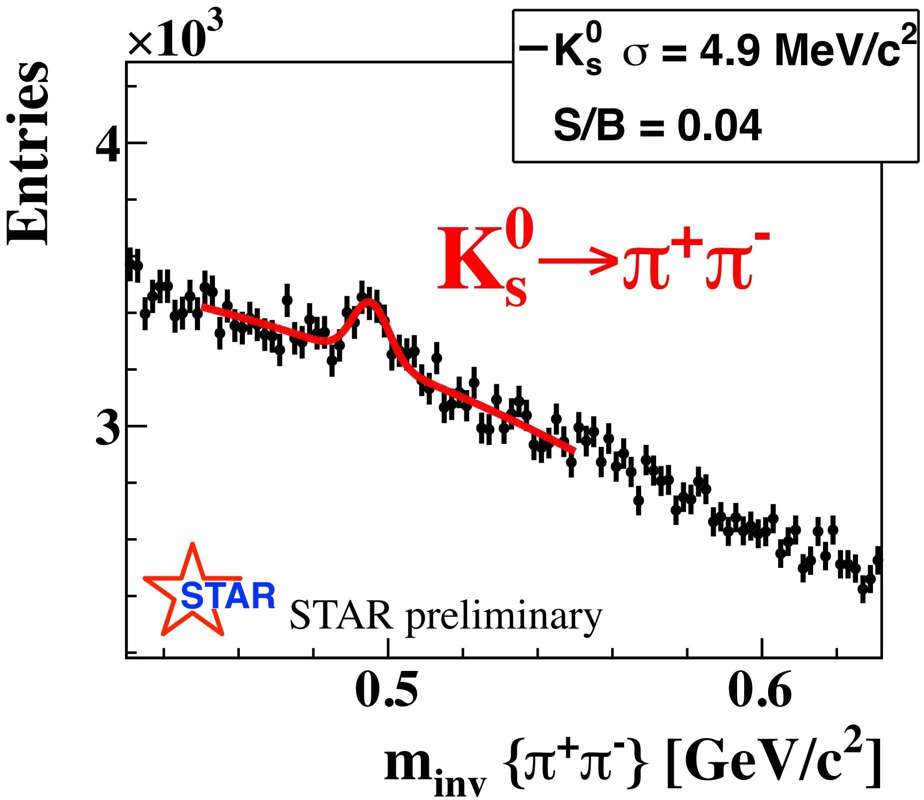
# Operation scenario in HLT during the run 2016

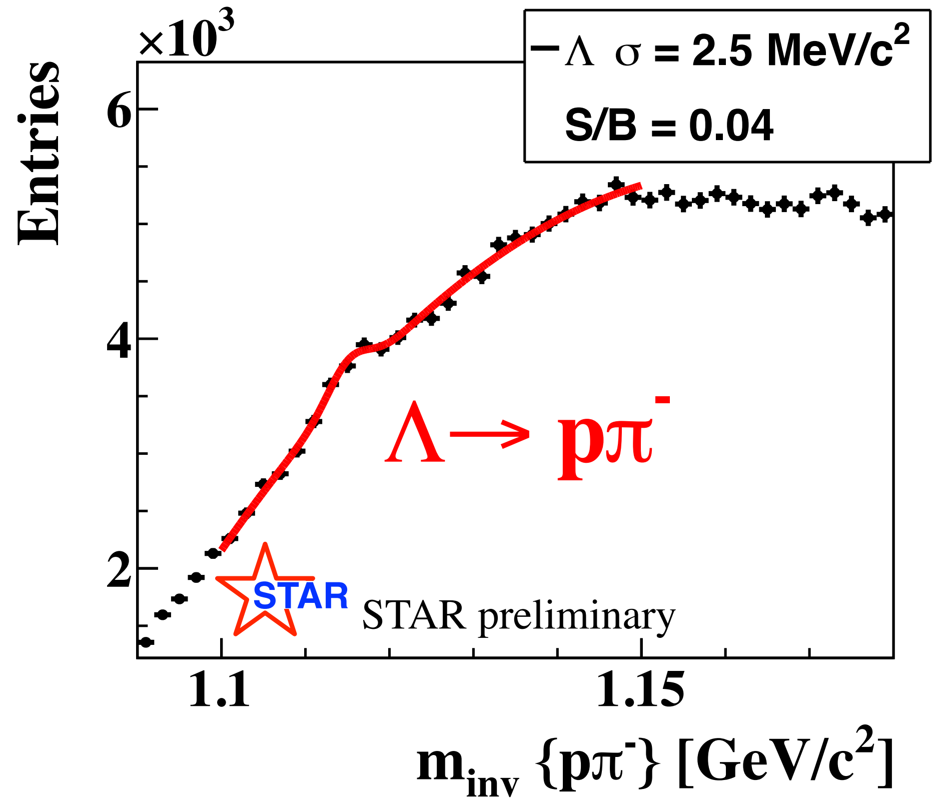
- 22 nodes:
  - 40/48 CPU cores per node
  - 2 Xeon Phi 7120P (244 threads, 16GB RAM)
- The connection is established using SCIF API.
- The first scheme of online short-lived particles reconstruction is implemented and successfully tested during the 2016 run:

**With Hongwei Ke**



# Online spectra by KF Particle Finder on Intel Xeon Phi in run 2016



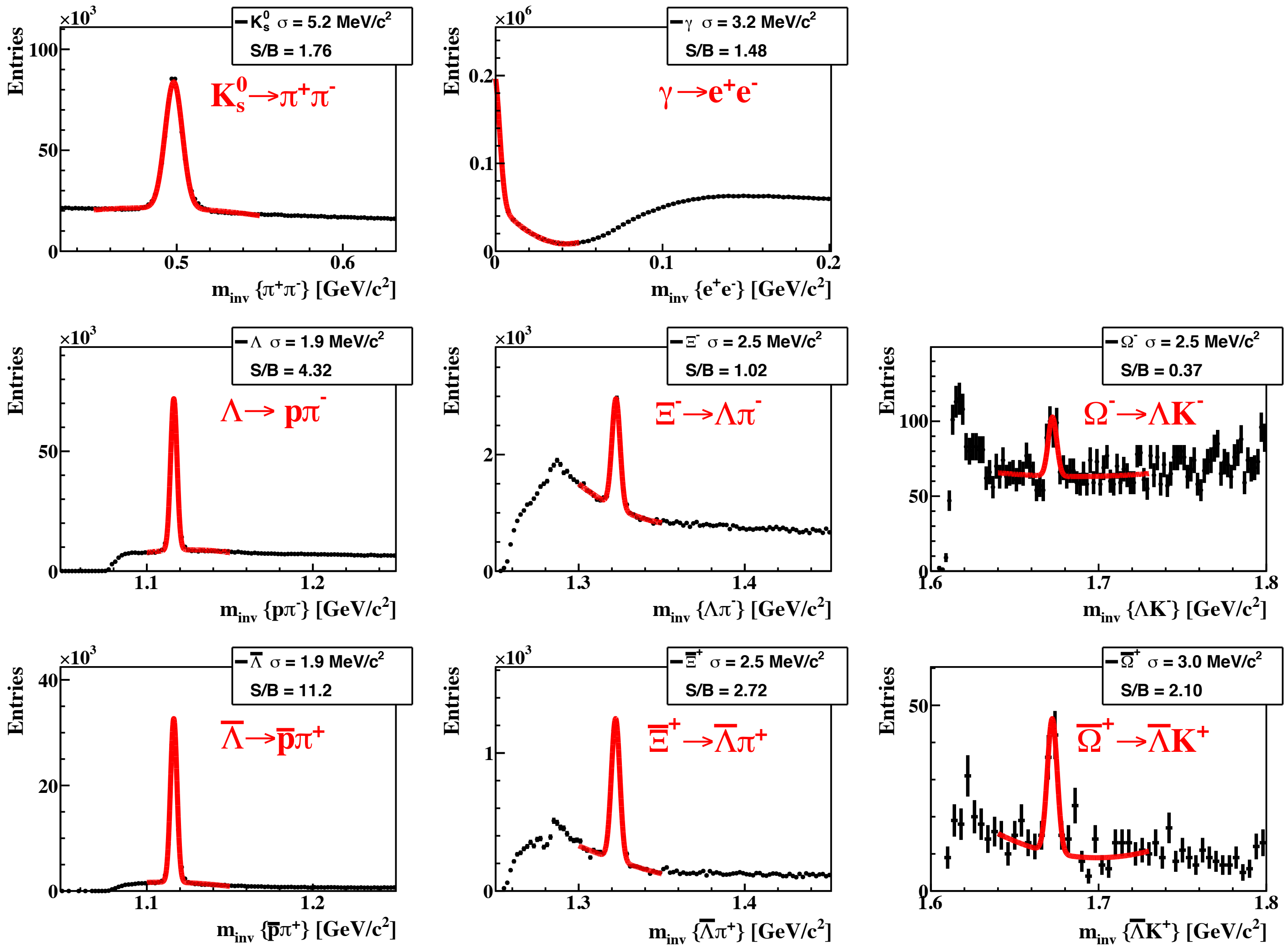

**With Hongwei Ke**

- Offline alignment from the runs of the previous years.
- Total spectra of primary and secondary particles are collected - high background.
- No PID information  for tracks, only TPC tracks are used.
- Peaks from $K^0_s$ and Λ are clearly seen within the current statistics with nice width.

5k mbias AuAu events at 200 AGeV, 2016 year

# Offline reconstruction of strange particles in run 2016

- As the first step KF Particle Finder was adapted for strange particle reconstruction.
- Reconstructed strange particles are used as decay products for charm.




630k mbias AuAu events at 200 AGeV, 2016 year

# New charm channels

- New channels provide a tool for the crosscheck of the main channels.
- They can give better understanding of the systematic errors.
- Better understanding of the detector and PID efficiency.
- Possible decays to be studied:

Standard channels:

| | | | |
|---|---|---|---|
| $D^0 \to K^- \pi^+$ | $D^+ \to K^- \pi^+ \pi^+$ | $D_s^+ \to K^+ K^- \pi^+$ | $\Lambda_c^+ \to p K^- \pi^+$ |

New channels:

| | | | |
|---|---|---|---|
| $D^0 \to K^- \pi^+ \pi^+ \pi^-$ | $D^+ \to K^0_s \pi^+ \pi^+ \pi^-$ | $D_s^+ \to K^0_s K^+ \pi^+ \pi^-$ | $\Lambda_c^+ \to \Lambda \pi^+ \pi^+ \pi^-$ |
| $D^0 \to K^+ K^-$ | $D^+ \to K^0_s \pi^+$ | $D_s^+ \to K^0_s K^0_s \pi^+$ | $\Lambda_c^+ \to p K^0_s \pi^+ \pi^-$ |
| $D^0 \to K^0_s \pi^+ \pi^-$ | | $D_s^+ \to K^0_s K^+$ | $\Lambda_c^+ \to \Lambda \pi^+$ |
| $D^0 \to K^+ K^- K^0_s$ | | | $\Lambda_c^+ \to p K^0_s$ |

# Embedding as a tool to study new channels

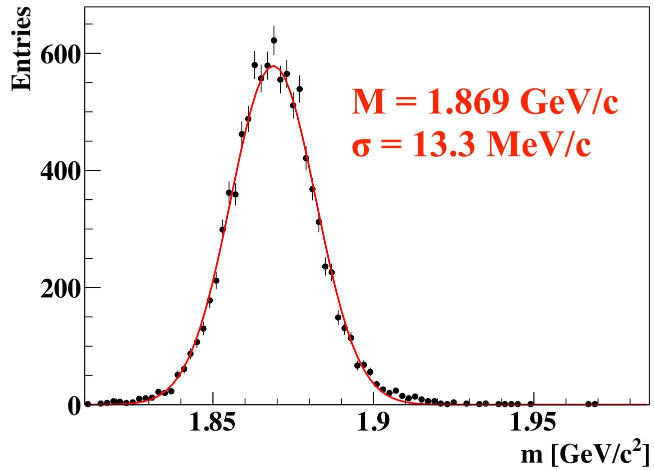
1. Why do we need embedding?
   - To understand efficiencies of charm reconstruction with HFT.
   - To optimize cuts.
   - To estimate and to reduce systematical errors in cross section measurements with new channels.
2. How can we account effect of geometrical alignment and detector response on the efficiency estimation?
   - We propose to use ROOT VMC approach, which provide tools to account detector misalignment in simulation.
   - The misalignment parameters are taken from the Database and are applied to the geometry used for VMC simulation.
   - Ist slow simulator is almost ready to be used. The work on Pixel and Sst slow simulators is in progress.
   - Monte Carlo "MC raw data" is merged with data and reconstructed with a standard chain — we can estimate efficiency of the signal and check the background.
3. To understand and to prioritize the set of decay channels that should be used for embedding:
   - Pure signal events were generated with $p_T$ distribution $dN/dm_T^2 \sim exp(-m_T /T)$ for each decay channel.
   - The obtained sets are used:
     - to extract signal;
     - to optimize cuts;
     - to apply the cuts to the real data.
4. The most promising decay channels from the signal simulation are used for the embedding. As the first step, the reference channels are simulated and being studied.

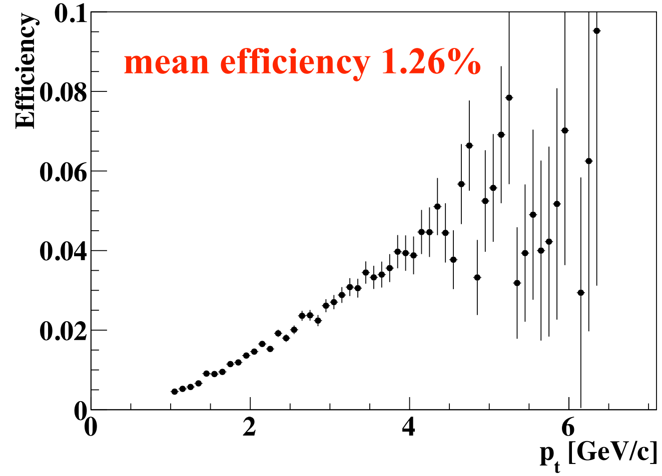
# STAR acceptance for different channels of charm

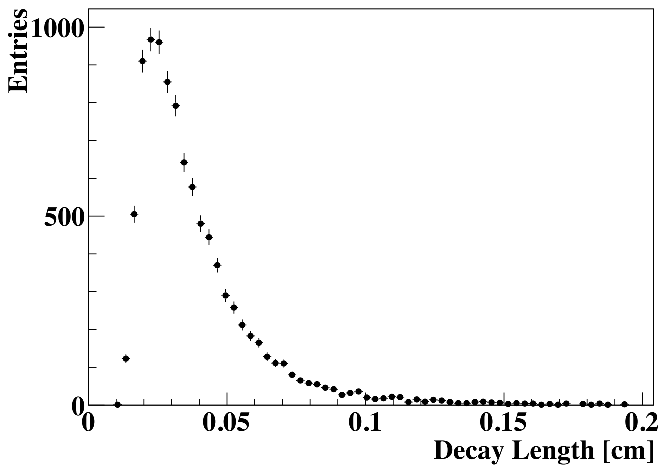
| mode | Branching Ratio (%) | Ideal geometry | | Real geometry | |
|---|---|---|---|---|---|
| | | Efficiency $4\pi$ (%) | $BR*Eff_{4\pi}$ | Efficiency $4\pi$ (%) | $BR*Eff_{4\pi}$ |
| $D^0 \to K^-\pi^+$ | 3.93 | 28 | $1.1*10^{-2}$ | 21.7 | $8.5*10^{-3}$ |
| $D^0 \to K^+K^-$ | 0.4 | 25.6 | $1.0*10^{-3}$ | 17.8 | $7.0*10^{-4}$ |
| $D^0 \to K^0\pi^+\pi^-$ | 2.85*0.692 | 16.7 | $3.3*10^{-3}$ | 13.0 | $2.5*10^{-3}$ |
| $D^0 \to K^-\pi^+\pi^+\pi^-$ | 8.06 | 7.7 | $6.2*10^{-3}$ | 6.6 | $5.7*10^{-3}$ |
| $D^+ \to K^-\pi^+\pi^+$ | 9.46 | 14.4 | $1.2*10^{-2}$ | 12.7 | $1.2*10^{-2}$ |
| $D^+ \to K^0\pi^+$ | 1.47*0.692 | 33.8 | $3.4*10^{-3}$ | 28.6 | $2.9*10^{-3}$ |
| $D^+ \to K^0\pi^+\pi^+\pi^-$ | 3.05*0.692 | 8.5 | $1.8*10^{-3}$ | 7.2 | $1.5*10^{-3}$ |
| $D_s^+ \to K^+K^-\pi^+$ | 5.39 | 13.2 | $7.1*10^{-3}$ | 8.3 | $4.5*10^{-3}$ |
| $D_s^+ \to K^0K^+$ | 1.49*0.692 | 30.8 | $3.2*10^{-3}$ | 23.8 | $2.5*10^{-3}$ |
| $\Lambda_c^+ \to pK^-\pi^+$ | 5.0 | 21.2 | $1.1*10^{-2}$ | 13.9 | $7.0*10^{-3}$ |
| $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ | 2.6*0.639 | 20.5 | $3.4*10^{-3}$ | 15.5 | $2.6*10^{-3}$ |

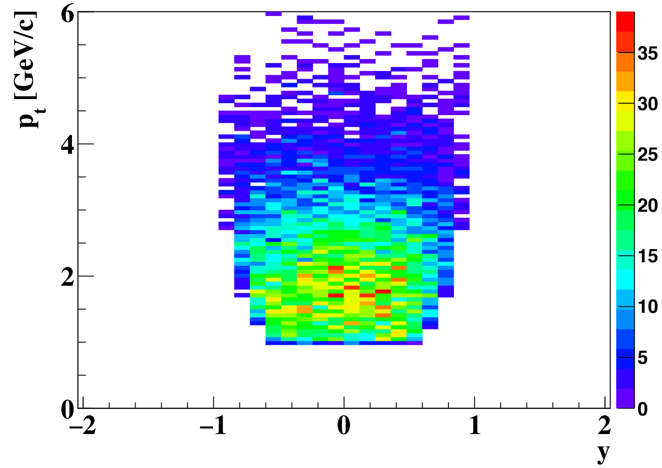
- Ideal geometry assumes ideal response, real geometry introduces missalignment and dead channels.
- Spectra with $p_t$ > 2 GeV/c for $\Lambda_c$ and $p_t$ > 1 GeV/c for D mesons were generated.
- Acceptance is similar for ideal and real geometries. Track in acceptance should have at least 3 HFT and 10 TPC hits.
- Proposed open charm channels have comparable acceptance with the standard decays and are worth to be studied.

# Reconstruction of embedded $D^0 \to K^- \pi^+$



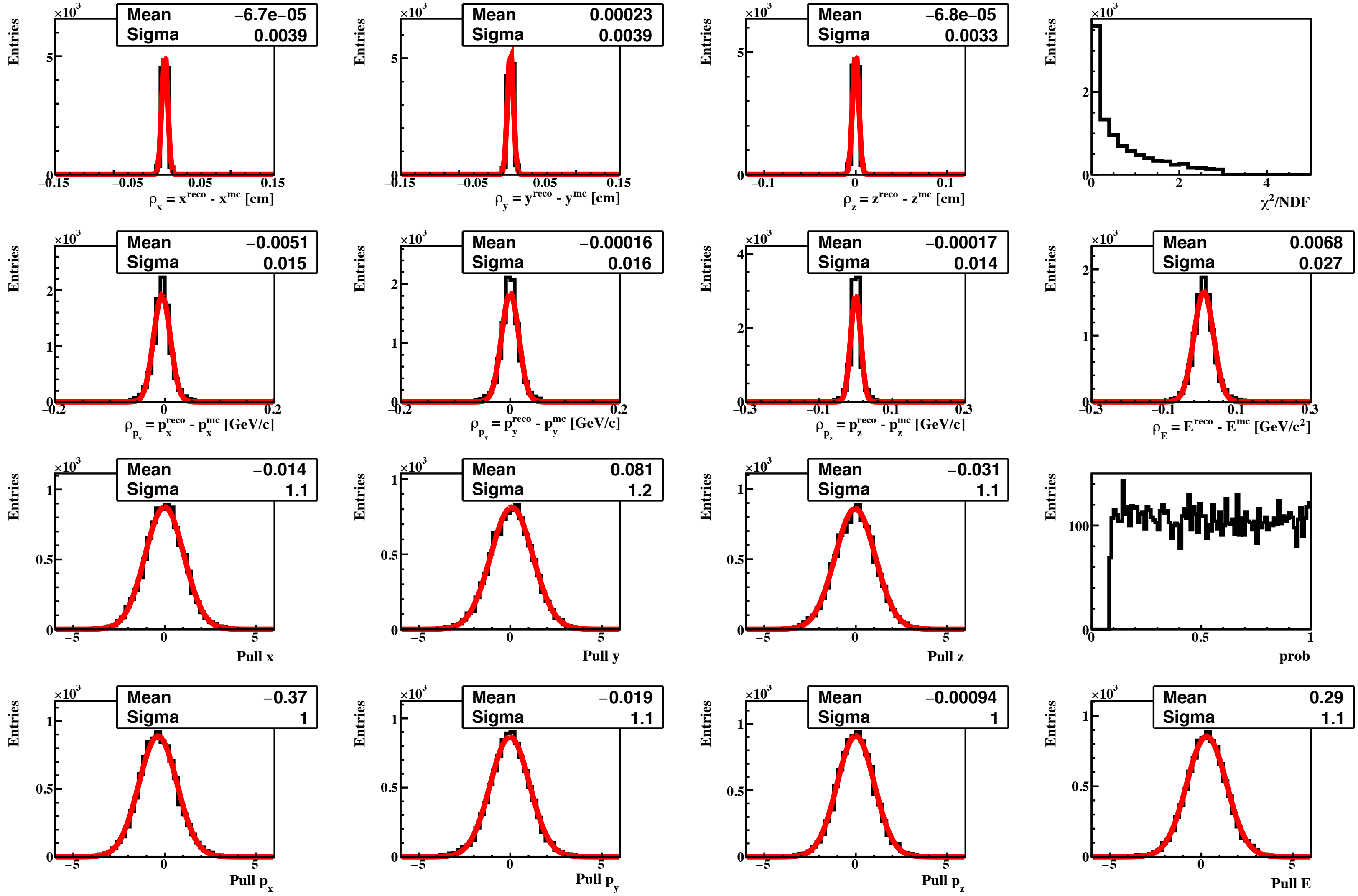




775k mbias embedded AuAu events at 200 AGeV, 2016 year

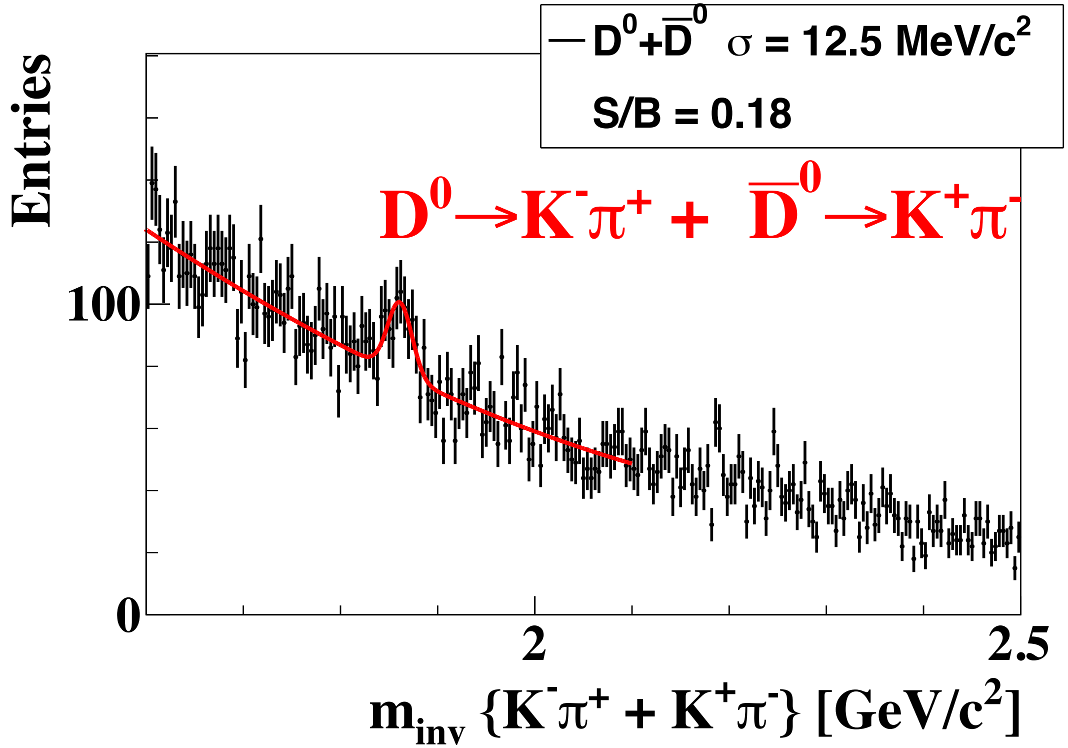
- 775k embedded events were generated with $p_t$ distribution $dN/dm_T^2 \sim \exp(-m_T/T)$, $p_t > 1$ GeV/c.
- For embedding the data from 2016 run were used.
- Efficiency of 1.26% was achieved with a simple cut tuning.
- Reconstructed parameters are in a good agreement with the simulated values.

# Fit quality, $D^0 \to K^- \pi^+$




- Fit of $D^0 \to K^- \pi^+$ demonstrates high quality of the obtained parameters.
- Pulls of width 1 and flat prob distribution shows the correctness of errors.

# Reconstruction of $D^0 \to K^- \pi^+$ in Run 2016 real data




985k mbias AuAu events at 200 AGeV, 2016 year

- 174 $D^0$ and $\overline{D}^0$ particles were found in 985k mbias AuAu events at 200 AGeV of run 2016.
- Investigation of other channels requires significantly higher statistics.
- For higher statistics we will move from micro DST to pico DST.
- Cuts will be further optimised (using TMVA).

# Summary and plans

## Summary

- The KF Particle Finder package, initially developed and tuned in CBM, provides a rich functionality for reconstruction of a wide range of short-lived particle decays, that significantly increases the set of available decay modes for the physics analysis.
- Use of the Kalman filter mathematics provides accurate and mathematically correct procedures for reconstruction of particles with high precision and efficiency.
- KF Particle Finder is successfully tested in the online operation at the Xeon Phi.
- KF Particle Finder is being tuned with the embedded data.
- As the first step $D^0$ particles are found.

## Plans

- Increase the statistics for analysis of all possible open charm channels.
- Tune the cuts with TMVA.
- Apply and run the CBM algorithms on the real data in online and offline mode, and on the many-core architectures of the HLT farm.
- Share the knowledge, experience and tools between CBM and STAR in reconstruction and physics analysis.