Preparation of KF Particle Finder for the real time express physics analysis during BES II

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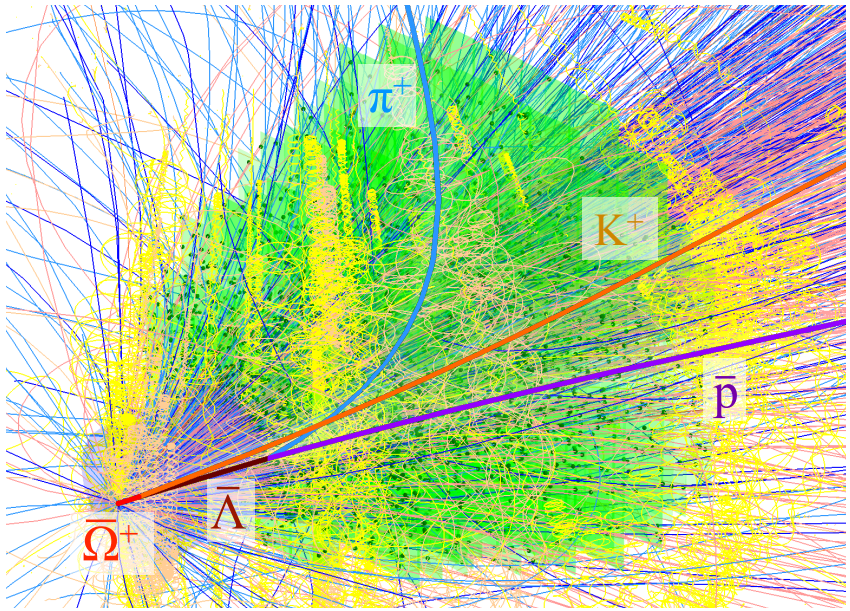
Concept of KF Particle in CBM



$$\bar{\Omega}^+ \leftarrow \bar{\Lambda}\, K^+$$
$$\quad\ \ \bar{p}\, \pi^+$$

```
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
```

1. KFParticle class describes particles by:

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

State vector

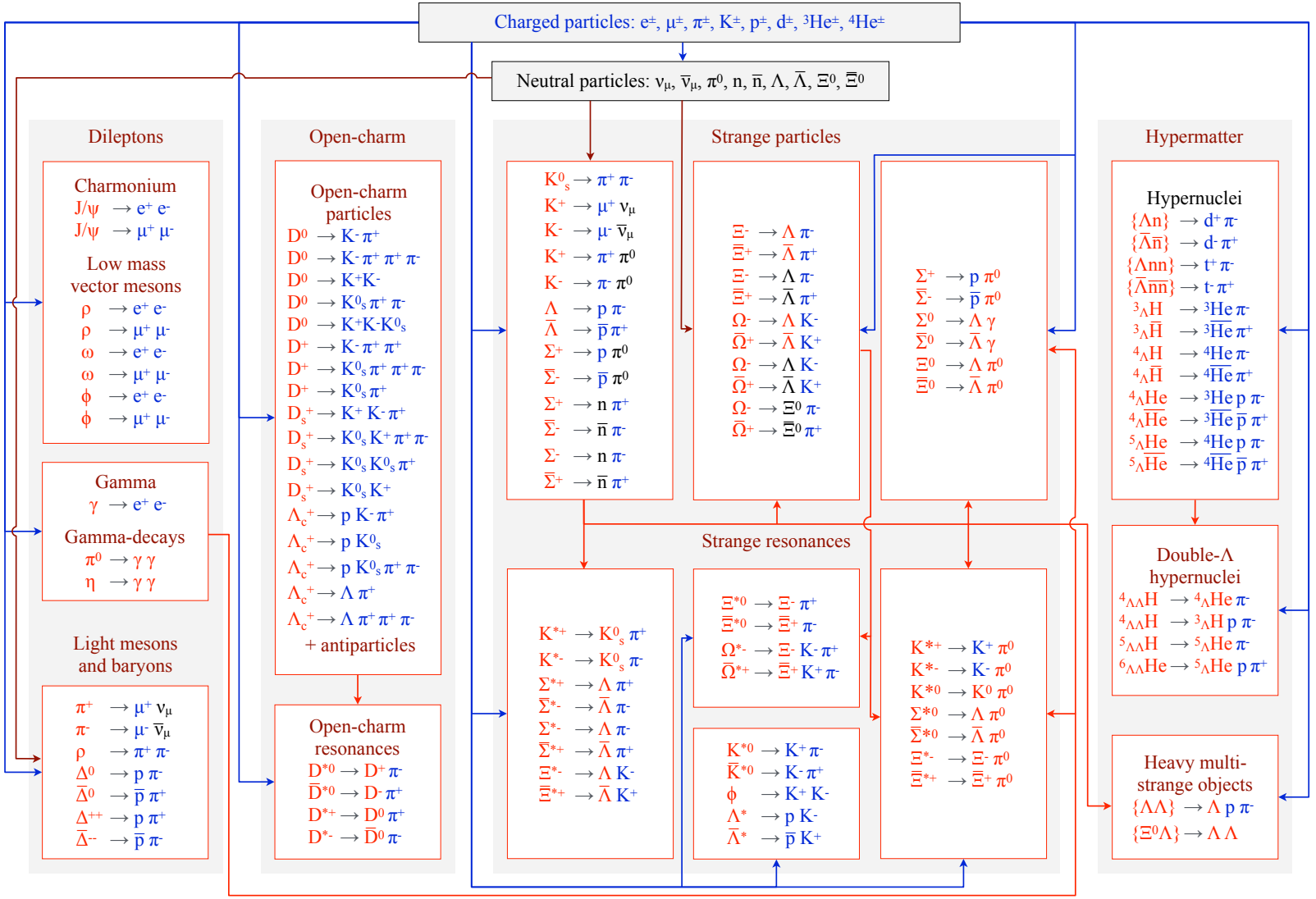
$$C = \langle \mathbf{r}\mathbf{r}^T \rangle = \begin{bmatrix} \sigma_x^2 & C_{xy} & C_{xz} & C_{xp_x} & C_{xp_y} & C_{xp_z} & C_{xE} \\ C_{xy} & \sigma_y^2 & C_{yz} & C_{yp_x} & C_{yp_y} & C_{yp_z} & C_{yE} \\ C_{xz} & C_{yz} & \sigma_z^2 & C_{zp_x} & C_{zp_y} & C_{zp_z} & C_{zE} \\ C_{xp_x} & C_{yp_x} & C_{zp_x} & \sigma_{p_x}^2 & C_{p_xp_y} & C_{p_xp_z} & C_{p_xE} \\ C_{xp_y} & C_{yp_y} & C_{zp_y} & C_{p_xp_y} & \sigma_{p_y}^2 & C_{p_yp_z} & C_{p_yE} \\ C_{xp_z} & C_{yp_z} & C_{zp_z} & C_{p_xp_z} & C_{p_yp_z} & \sigma_{p_z}^2 & C_{p_yE} \\ C_{xE} & C_{yE} & C_{zE} & C_{p_xE} & C_{p_yE} & C_{p_zE} & \sigma_E^2 \end{bmatrix}$$

Covariance matrix

2. Covariance matrix contains essential information about tracking and detector performance.
3. The method for mathematically correct usage of covariance matrices is provided by the KF Particle package based on the Kalman filter (KF) developed by FIAS group[1,2] primarily for CBM and ALICE.
4. Heavy mathematics requires fast and vectorised algorithms.
5. Mother and daughter particles are KFParticle and are treated in the same way.
6. The natural and simple interface allows to reconstruct easily rather complicated decay chains.
7. The package is geometry independent and can be easily adapted to different experiments.

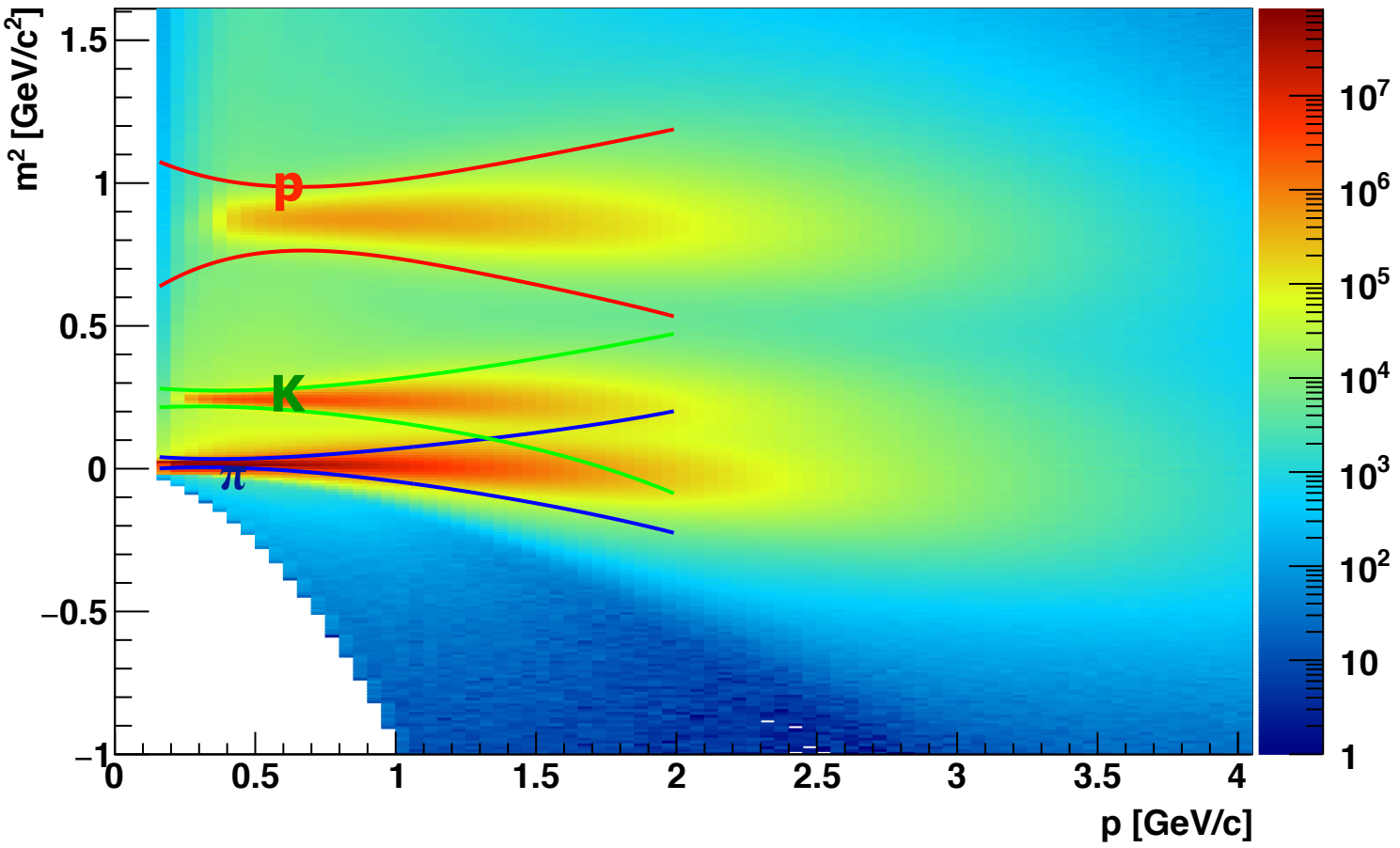
1. KF Particle — S. Gorbunov, "On-line reconstruction algorithms for the CBM and ALICE experiments," Dissertation thesis, Goethe University of Frankfurt, 2012, http://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/29538
2. KF Particle Finder — M. Zyzak, "Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR," Dissertation thesis, Goethe University of Frankfurt, 2016, http://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/41428

KF Particle Finder in CBM and STAR



- Full online event reconstruction and physics analysis in CBM at 10^7 interaction rate.
- Plan to use in STAR for physics analysis as well as in HLT for monitoring at 10^3 collisions/s.
- About 30 decays are added.

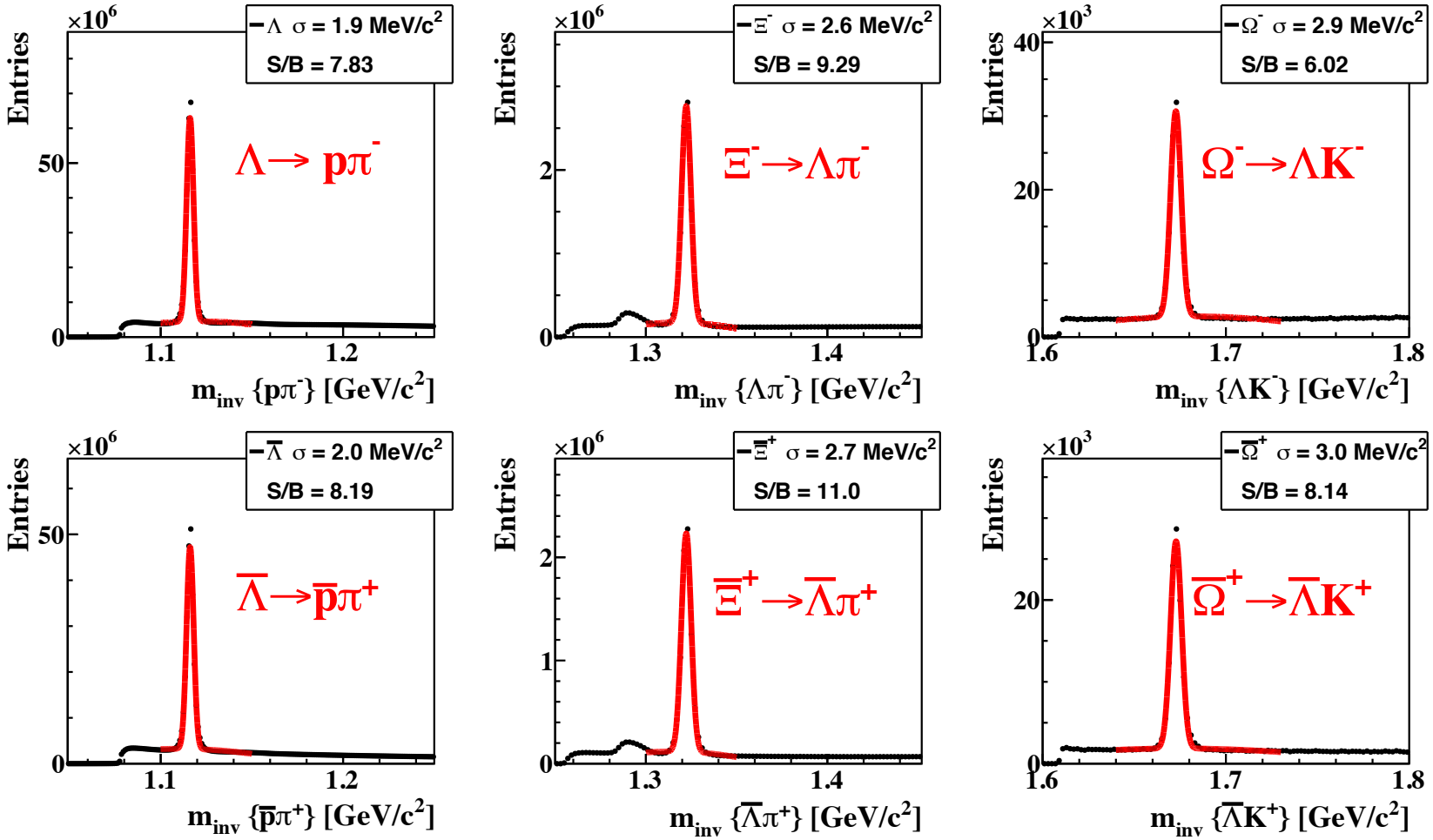
Optimisation of ToF PID



- Cuts on ToF are set taking into account the shape of the distribution for each specie providing better PID.
- In each p-bin each distribution is fitted with a Gaussian, mean and sigma are fitted with polynomials.
- Is ready to be used with eTOF.

Check with hyperon reconstruction

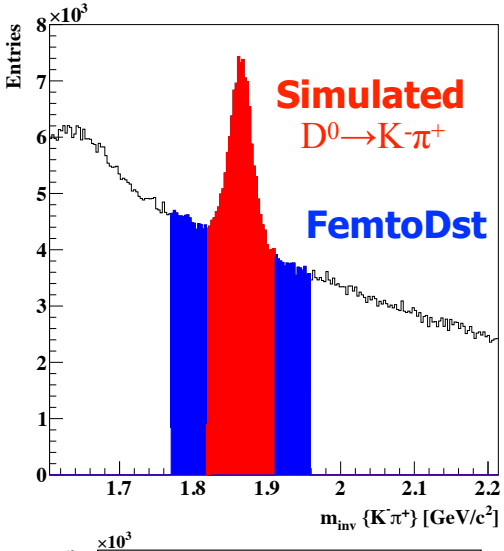
1 B AuAu events at 200 GeV, year 2016

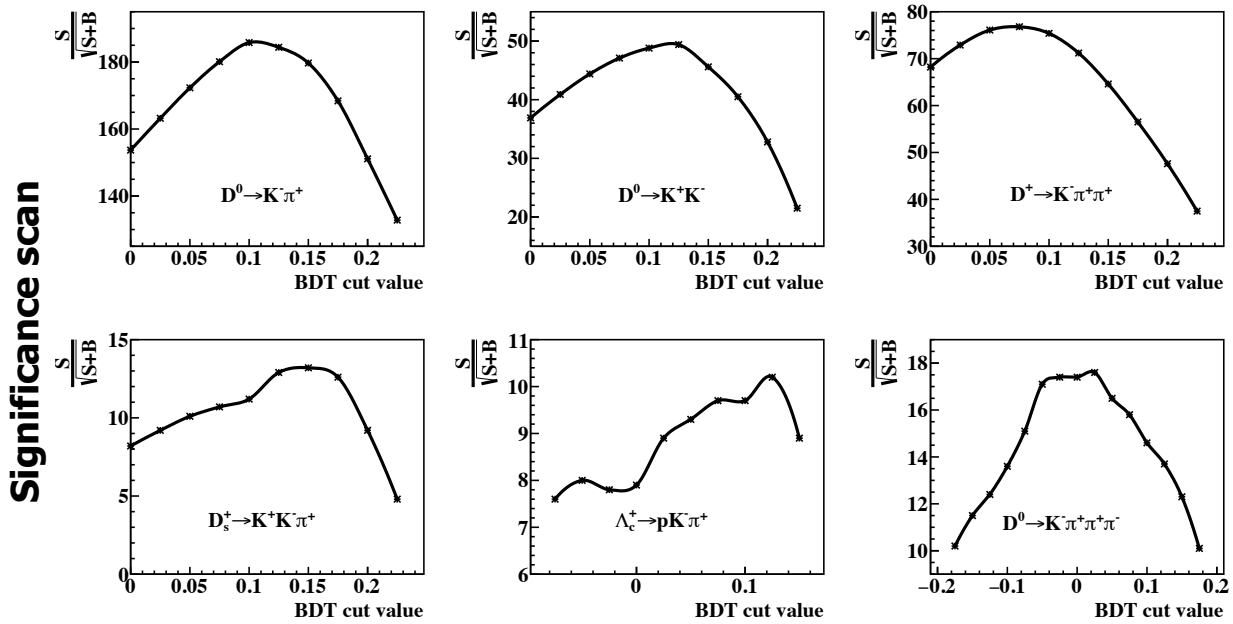


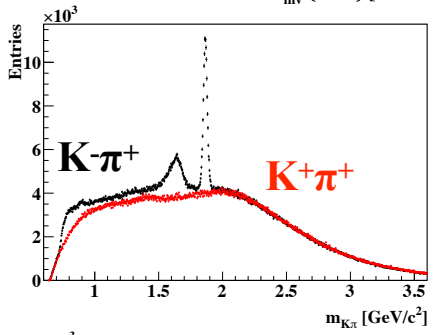
- Hyperons are used to monitor PID and selection criteria.
- K^0_S and Λ are used for reconstruction of open charm.
- KF Particle Finder provides clean spectra of hyperons.

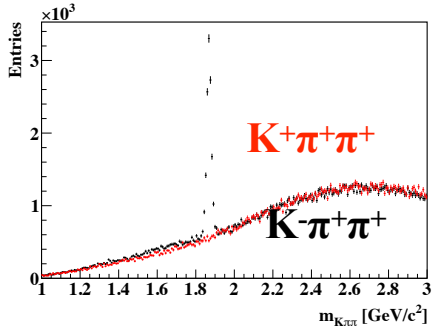
TMVA optimisation

- A framework for production of NTuples for TMVA (Toolkit for Multivariate Data Analysis in Root) optimisation is written within KF Particle Analysis interface.
- We use χ^2 and covariance matrices — more information for TMVA.
- BDT (Boosted Decision Tree) method is used for cut optimisation.
- To find the optimal BDT cut a scan over significance near the estimated value was performed.
- Wrong-sign combination were constructed with the same cuts. No peak-like structure is observed — no bias.



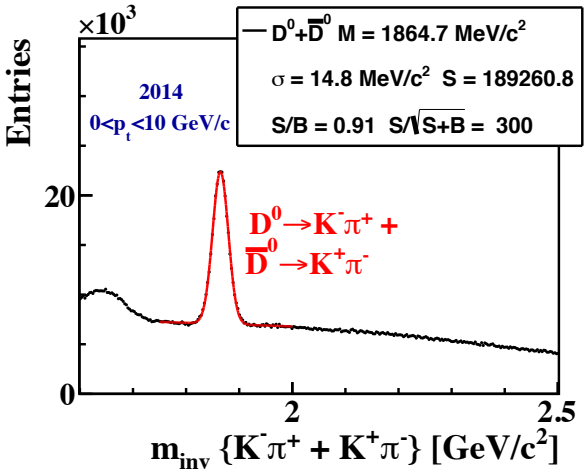


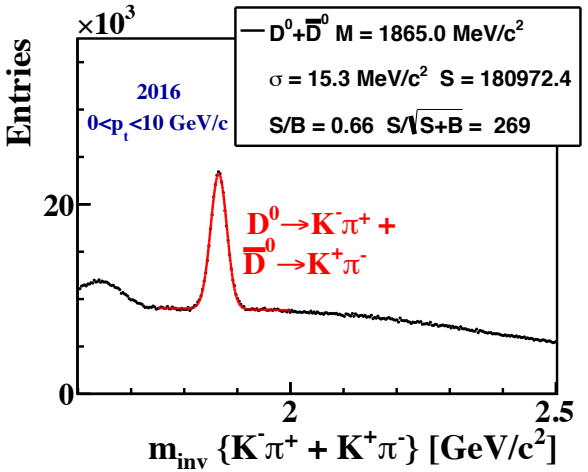


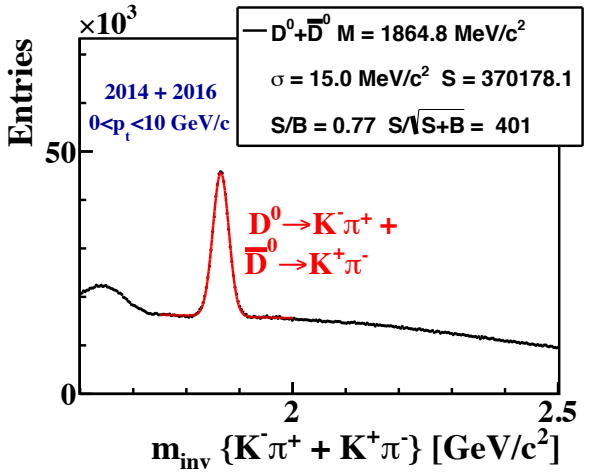


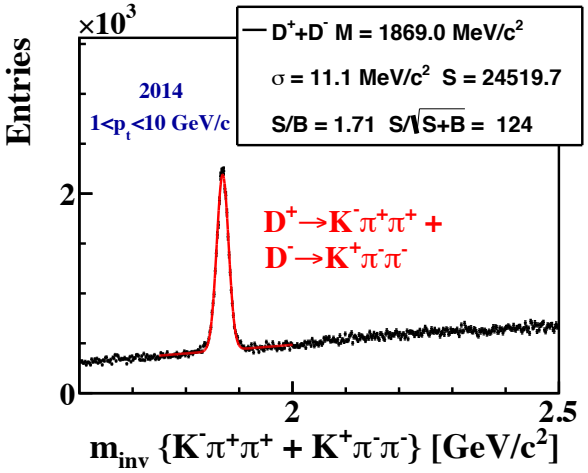
Michal's talk

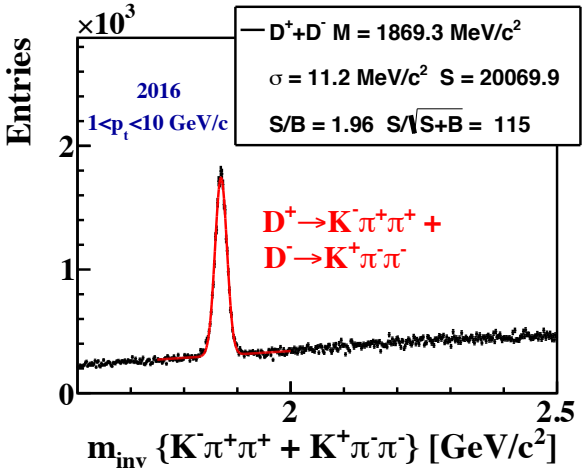
Standard channels D^0 and D^+

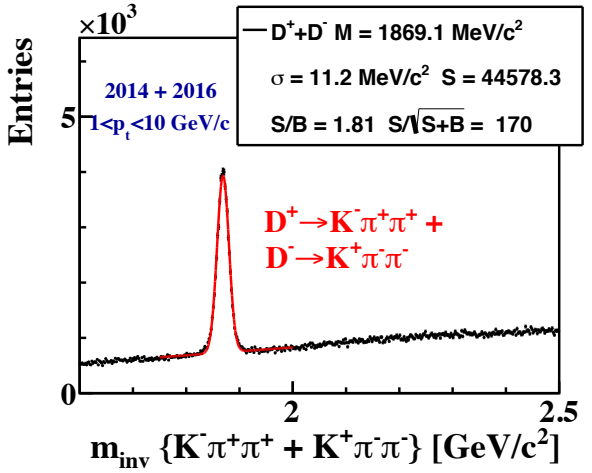








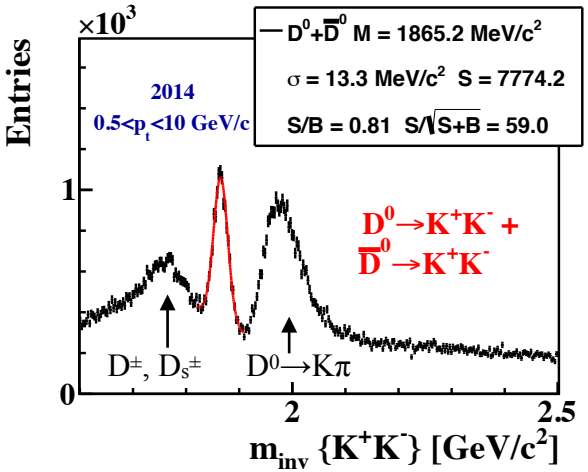


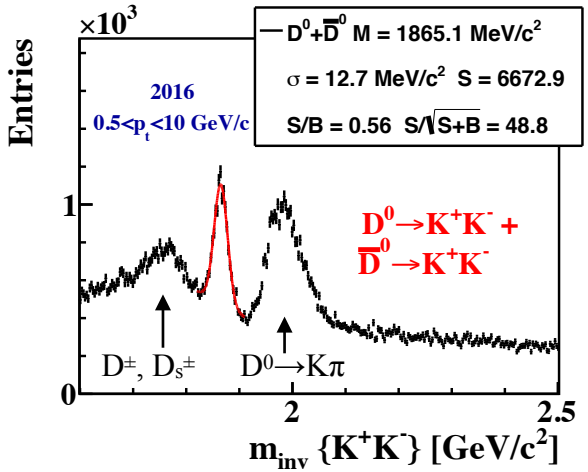


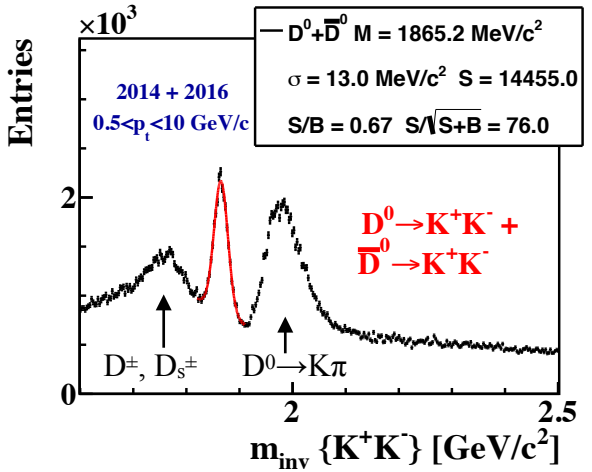
- 2014 and 2016 are consistent.
- KF Particle Finder provide clean signal with high significance.

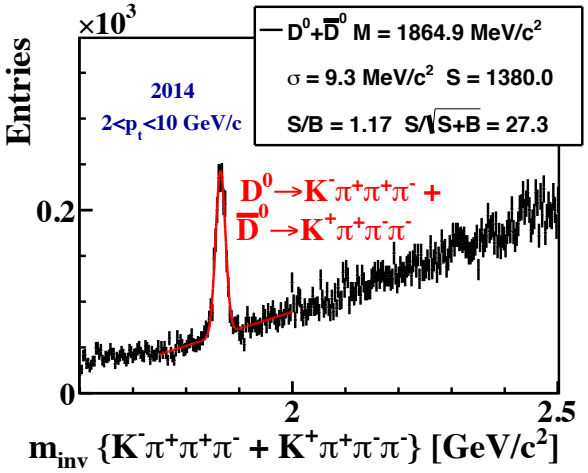
Decay	Signal	Significance	S/B	σ, MeV/c²
$D^0 \to K\pi$	370 k	401	0.77	15.0
$D^{\pm} \to K\pi\pi$	44.6 k	170	1.81	11.2

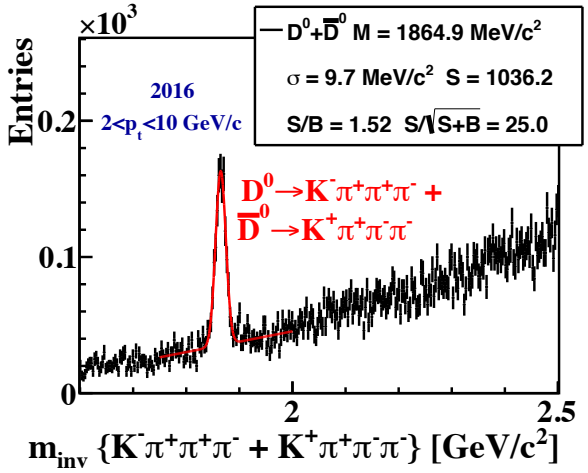
New D⁰ channels

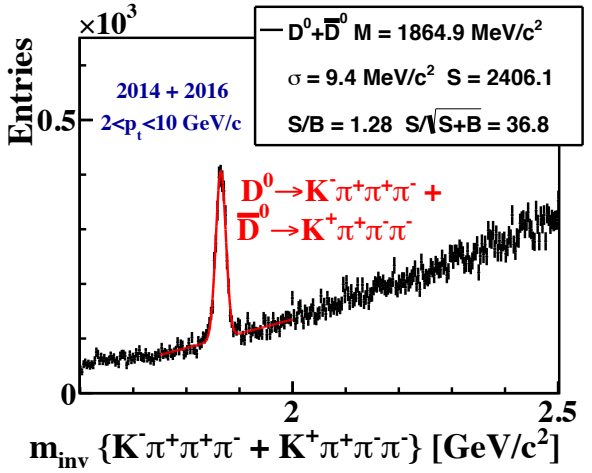








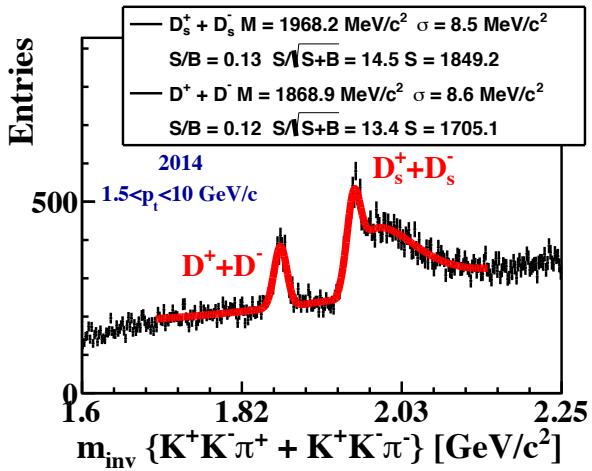


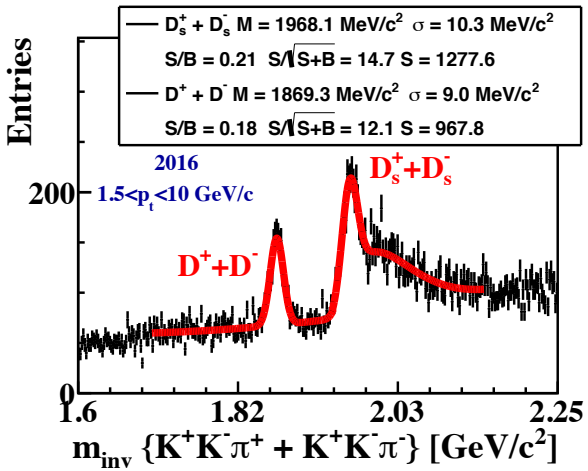


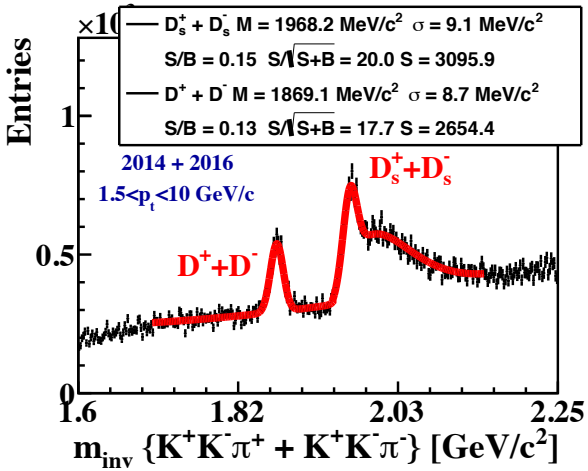
- D^0 is seen in new channels: K^+K^- and $K\pi\pi\pi$.
- Kinematical reflections are due to particle misidentification in K^+K^- spectra.
- Statistics is enough to extract spectra and study systematics.

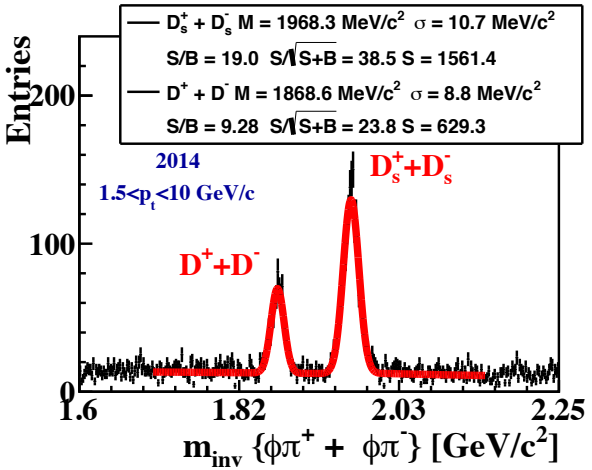
Decay	Signal	Significance	S/B	σ, MeV/c²
$D^0 \to K^+K^-$	14.5 k	76	0.67	13.0
$D^0 \to K\pi\pi\pi$	2.4 k	37	1.28	9.4

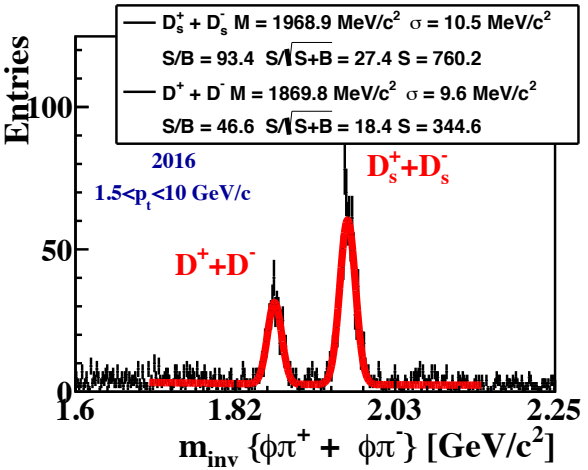
D_s results

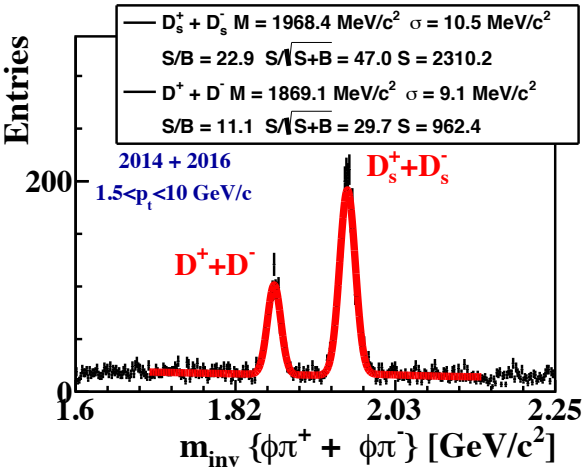








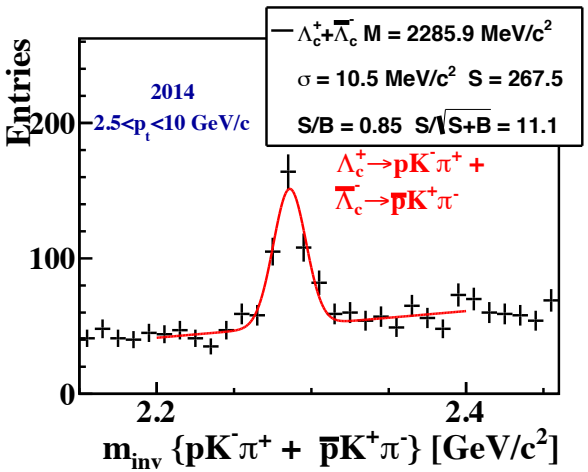


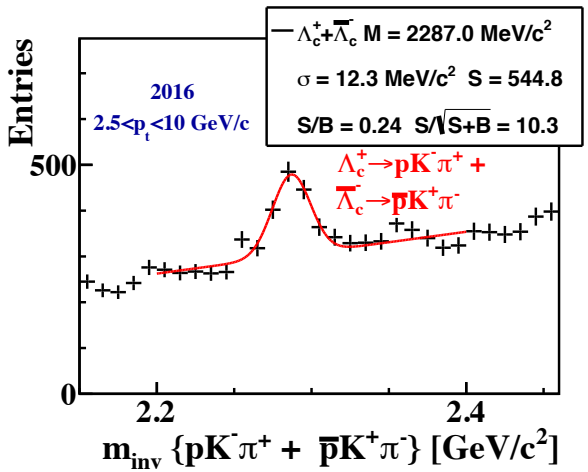


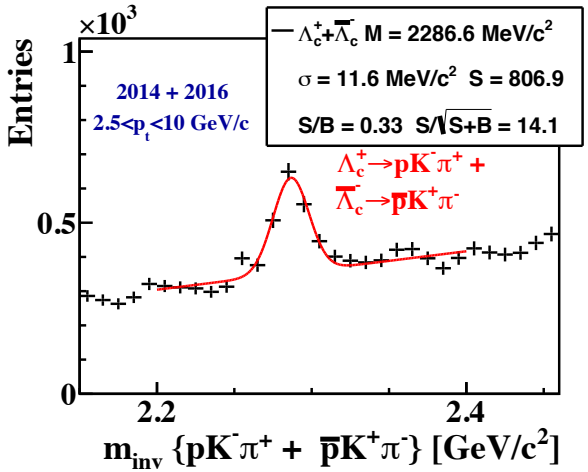
- $D^{\pm}$ and $D_s^{\pm}$ are reconstructed in $KK\pi$ and $\phi(\rightarrow KK)\pi$ with exactly the same cuts.
- In $KK\pi$ kinematical reflection is due to misidentified $D^{\pm}$ (no cut on ϕ).
- Direct measurement of branching ratios.

Decay	Signal	Significance	S/B	σ, MeV/c²
$D_s^{\pm} \rightarrow KK\pi$	3.1 k	20	0.15	9.1
$D_s^{\pm} \rightarrow \phi\pi$	2.3 k	47	22.9	10.5
$D^{\pm} \rightarrow KK\pi$	2.7 k	18	0.13	8.7
$D^{\pm} \rightarrow \phi\pi$	1.0 k	30	11.1	9.1

Λ_c results







- In total about 800 particles are reconstructed with significance of 14.1.
- The achieved reconstruction results are suited for studies of Λ_c spectra.
- KF Particle Finder allows studies of Λ_c^+ and $\bar{\Lambda}_c^-$ separately.
- The full data set of PicoDst with covariance matrix will allow to go down in p_t.

Decay	Signal	Significance	S/B	σ, MeV/c²
$\Lambda_c^{\pm} \to pK\pi$	0.8 k	14	0.33	11.6

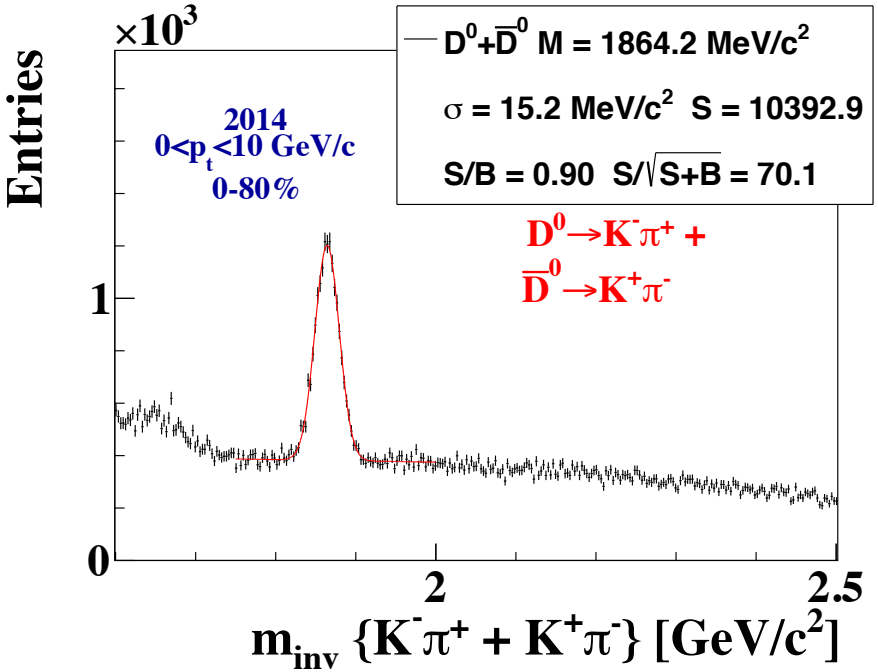
Open charm reconstruction using FemtoDst

Decay	Signal	Significance	S/B	σ, MeV/c^2
$D^0 \to K\pi$	370 k	401	0.77	15.0
$D^0 \to K^+K^-$	14.5 k	76	0.67	13.0
$D^0 \to K\pi\pi\pi$	2.4 k	37	1.28	9.4
$D^\pm \to K\pi\pi$	44.6 k	170	1.81	11.2
$D^\pm \to KK\pi$	2.7 k	18	0.13	8.7
$D^\pm \to \phi\pi$	1.0 k	30	11.1	9.1
$D_s^\pm \to KK\pi$	3.1 k	20	0.15	9.1
$D_s^\pm \to \phi\pi$	2.3 k	47	22.9	10.5
$\Lambda_c^\pm \to pK\pi$	0.8 k	14	0.33	11.6

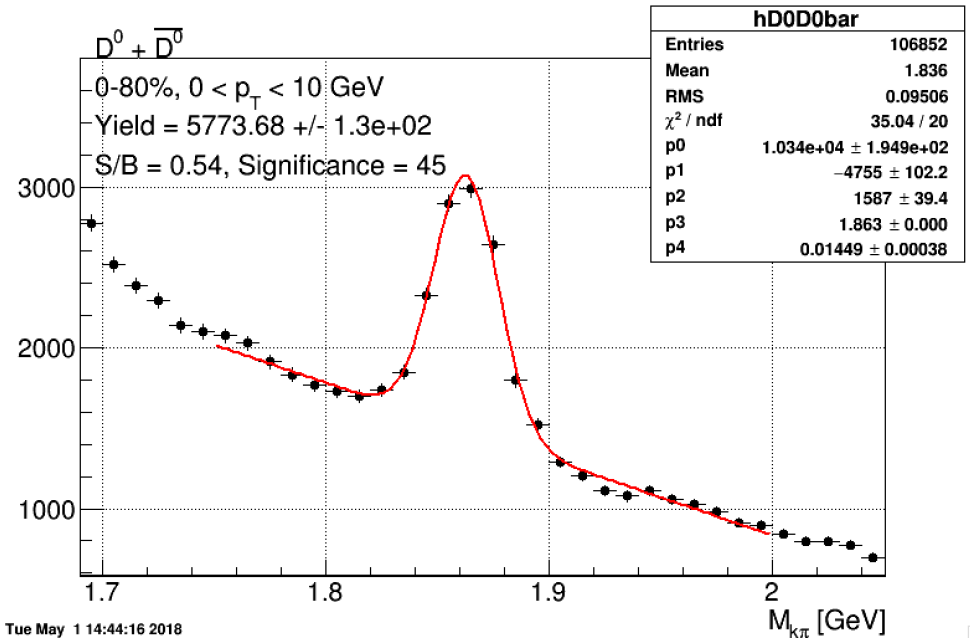
- 1.3 B events of 2014 run and 1.4 B events of 2016 run were analysed using data in FemtoDst format.
- All open charm channels under investigation have enough significance for their studies including extraction of spectra.
- KF Particle Finder provides **additional channels** for independent studies.

Comparison of D^0 results

KF Particle Finder

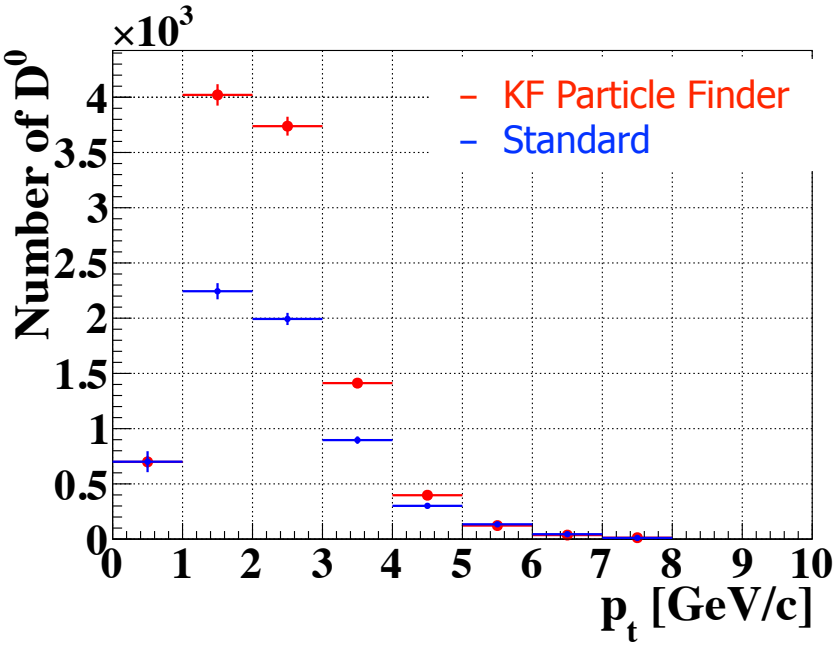


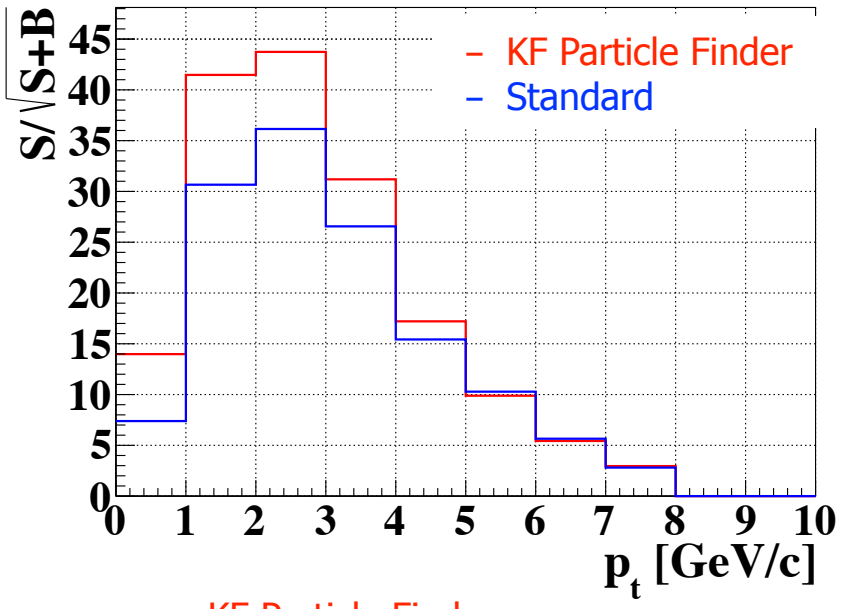
Standard reconstruction

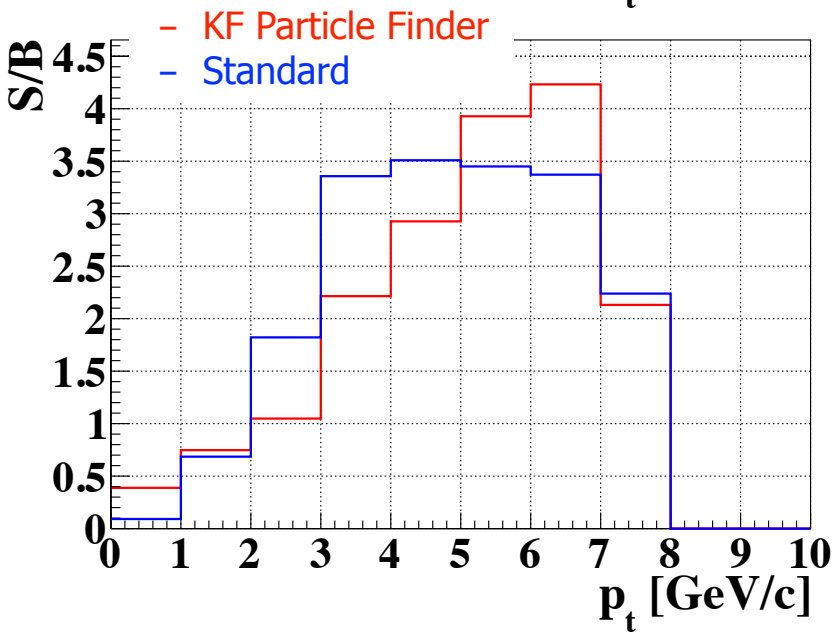


- Results obtained with **KF Particle Finder** are compared with the **standard reconstruction by Sooraj** and **Xinyue**.
- Performance comparison was done on the same data sample of year 2014.
- The comparison was done using the same cuts on events, same regions of centrality and p_t are used.
- TMVA was used for cut optimisation in both procedures.
- Optimisation of the cuts did not take into account centrality dependence for both.

Performance of D^0 reconstruction in different p_t

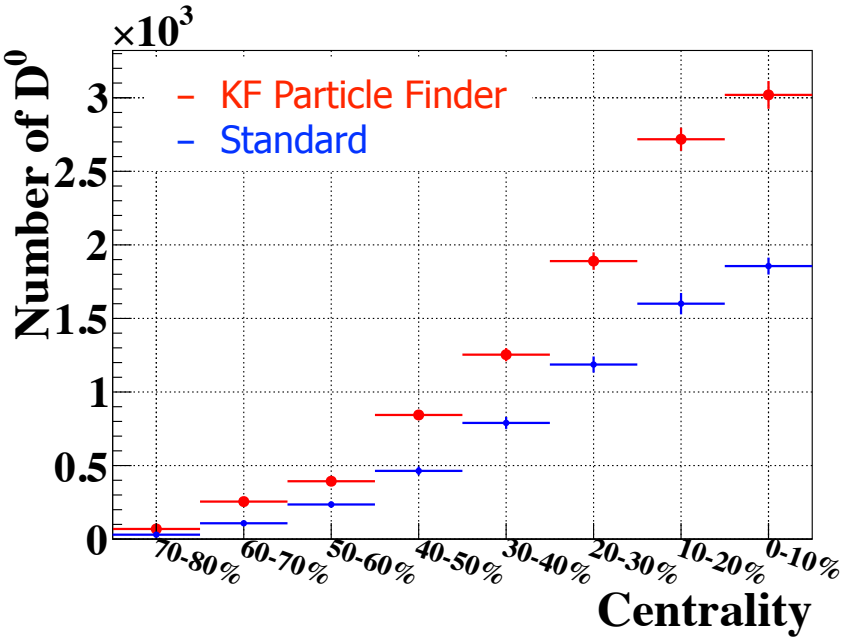


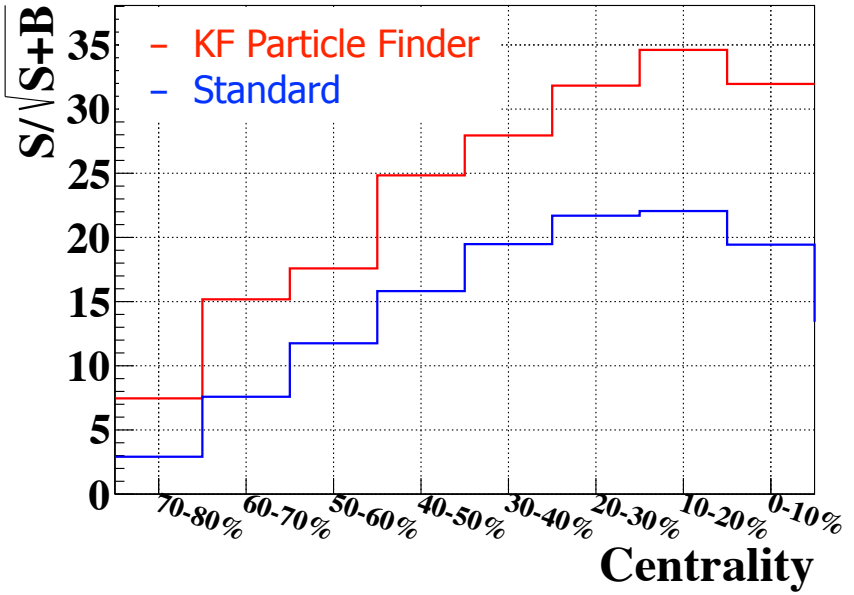


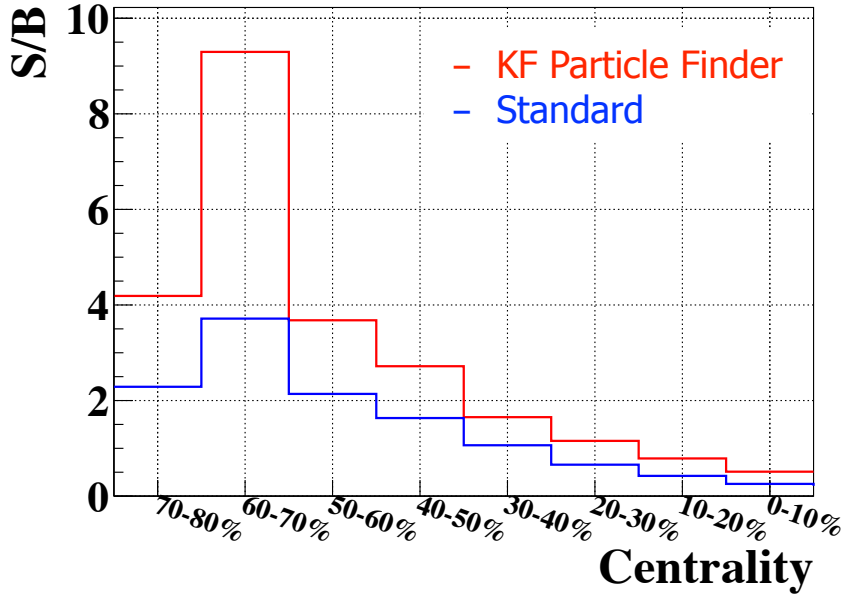


- Particle yields, significance, and signal to background ratios were studied as a function of p_t.
- KF Particle Finder allows to get improvement in significance in the low and intermediate p_t regions.

Performance of D^0 reconstruction in different centralities







- Particle yields, significance, and signal to background ratios were studied as a function of centrality.
- KF Particle Finder allows to get improvement in all centrality regions.

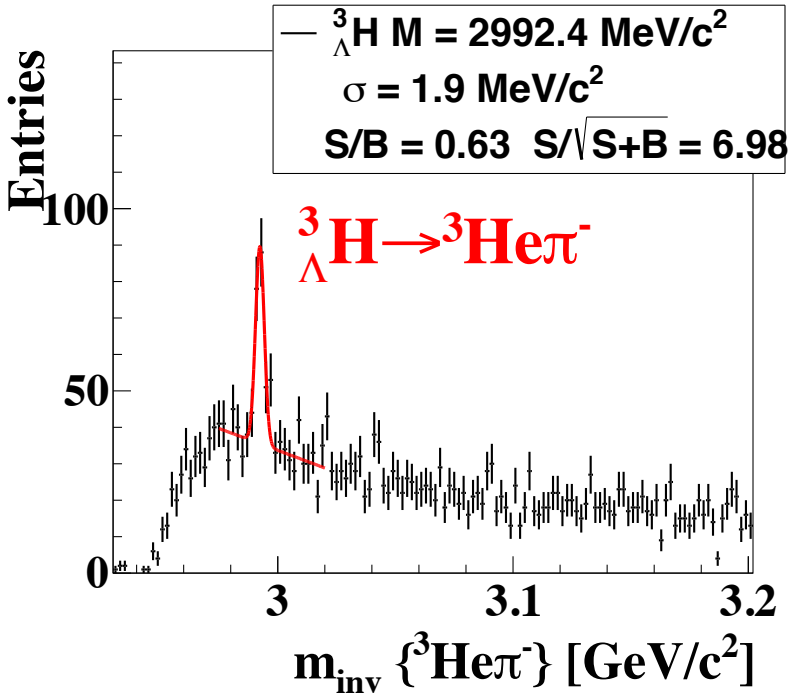
Comparison summary

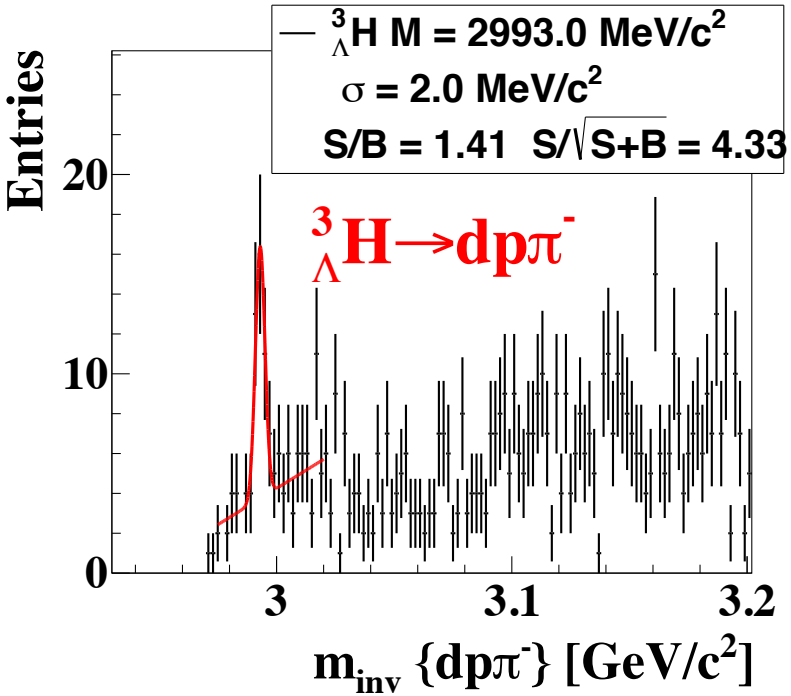
Decay	year	Signal	Significance	p_t
$D^0 \rightarrow K\pi$	2014	10393	70	0-10 GeV/c
		5774	45	
$D^{\pm} \rightarrow K\pi\pi$	2014	1357	30	1-10 GeV/c
		774	25	
$\Lambda_c^{\pm} \rightarrow pK\pi$	2014	261	11.0	3-10 GeV/c
		122	8.3	
	2016	459	9.6	
		337	7.6	

- Results obtained with KF Particle Finder are compared with the standard reconstruction approach by **Sooraj** and **Xinyue**.
- KF Particle Finder allows to get 1.5-2 times more signal with 1.2-1.5 times better significance reconstructed in all compared channels due to better utilisation of the data.

1. Performance comparison of D^0 and $D^{\pm}$ was done on the same data sample of year 2014. For $\Lambda_c^{\pm}$ the full statistics was used.
2. The standard method for $D^{\pm}$ gain of using low cut on p_t>0.3 GeV/c of the daughter particles. However, FemtoDst format does not allow to use low-pt tracks for KF Particle Finder, comparison is shown for p_t>0.5 GeV/c.

Feasibility studies of $^{3}_{\Lambda}H$ using BES I data with $\sqrt{s_{NN}}$ = 7.7-39 GeV



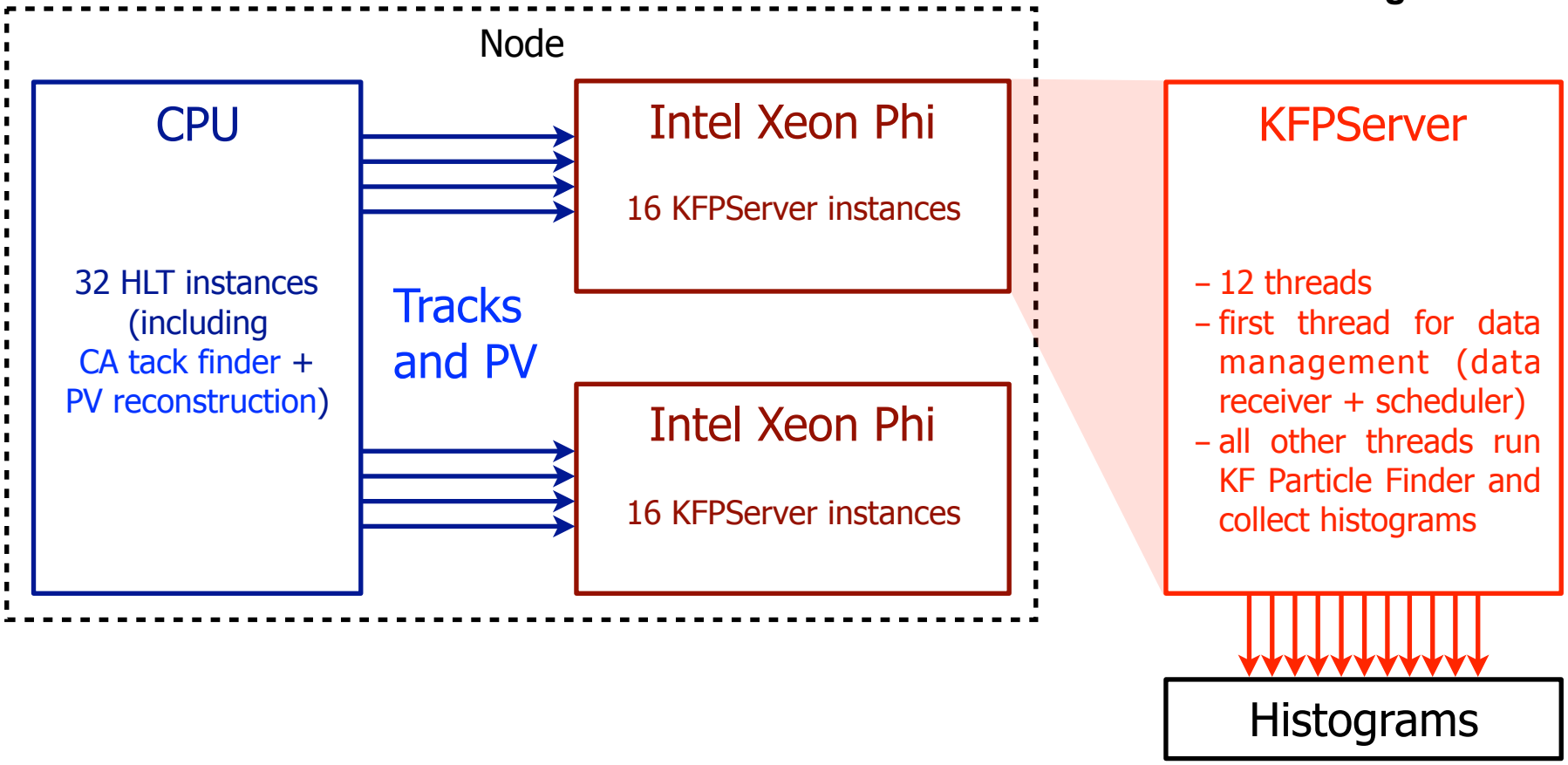


- Feasibility studies of $^{3}_{\Lambda}H$ were performed using BES I data with beam energies 7.7 — 39 GeV, total spectra are shown.
- Cuts are yet to be tuned, very preliminary spectra are obtained.
- The signal is clearly seen in two independent decay channels, the results are consistent.
- STAR data will provide reference points for the CBM physics analysis.
- They are extremely important for understanding and tuning of the current theoretical models.

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.
- CA Track Finder — CPU, physics analysis — Intel Xeon Phi.
- The first scheme of online short-lived particles reconstruction is implemented and successfully tested during the 2016 run:

With Hongwei Ke



Summary and plans

Summary:

- KF Particle Finder package originally developed for CBM is being successfully applied in STAR.
- STAR data are excellent to investigate and further develop KF Particle Finder:
  - the detector behaviour, material budget, errors of the hit input data are well understood;
  - all procedures up to track finding and PID are well established;
  - high quality of the input data allow to tune CBM algorithms without fixing the problems of the experimental setup.
- Approbation of CBM algorithms with the real data showed:
  - the KF Particle mathematics correctly operate with the real tracks and their errors;
  - we obtained a high quality signal for open charm including extremely rare particles like Λ_c;
  - KF Particle Finder allows to get 1.5-2 times more signal with 1.2-1.5 times better significance.

Plans:

- Application of KF Particle Finder to BES I, BES II, and fixed target data will provide reference points for physics analysis in CBM Day 1.
- During BES II data taking STAR HLT will operate with Intel Xeon Phi accelerators for the real time express physics analysis. Adaptation of KF Particle Finder for this computing platforms is an intermediate step towards use of GPUs for CBM Day 1.
- STAR proposed to organise a KFParticle workshop on December 11th before the STAR physics analysis meeting, a strong interest is expressed by groups studying Lambda/exotics, Lambda polarisation, heavy flavour etc.