STAR analysis on open charm reconstruction with KF Particle Finder

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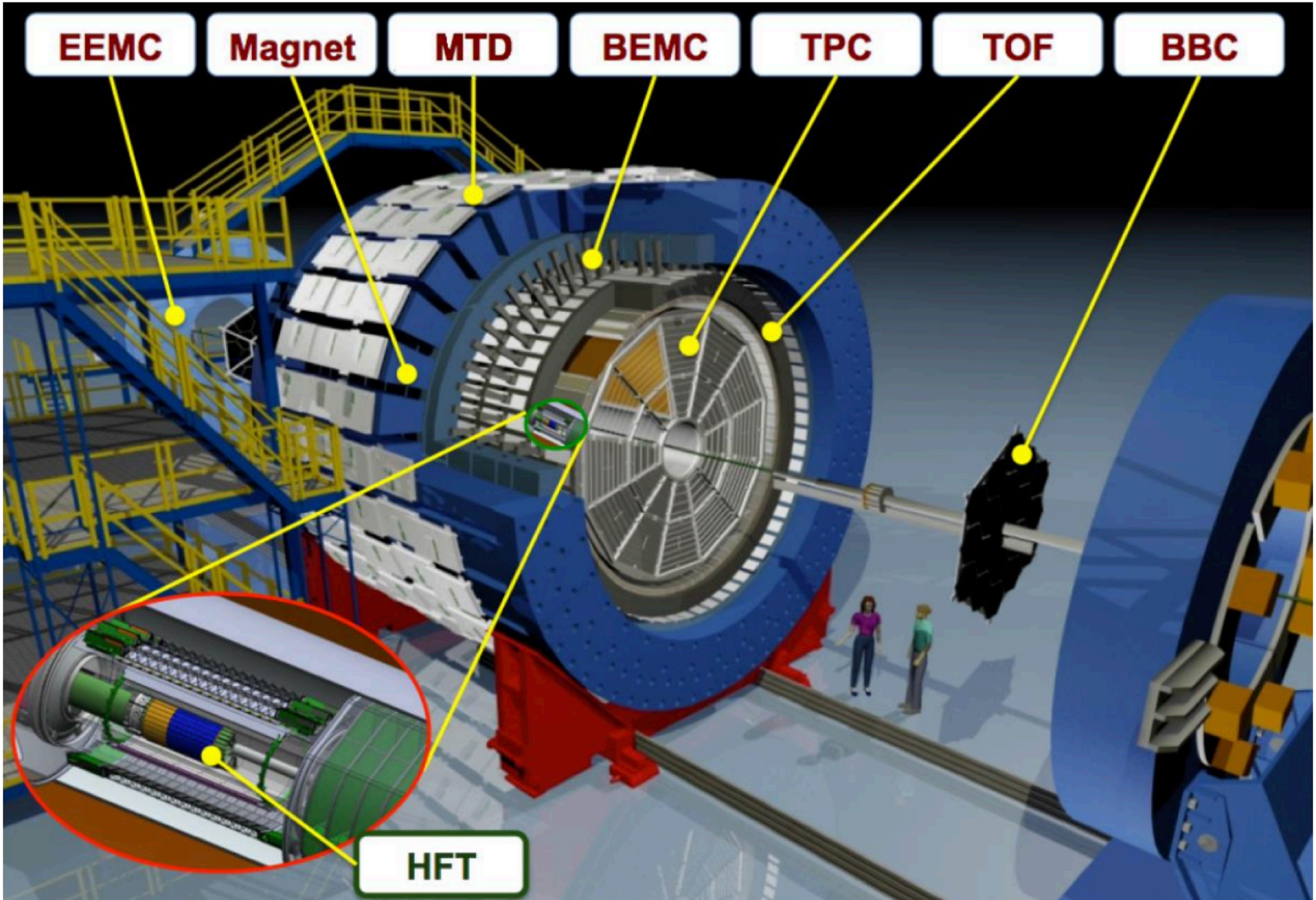
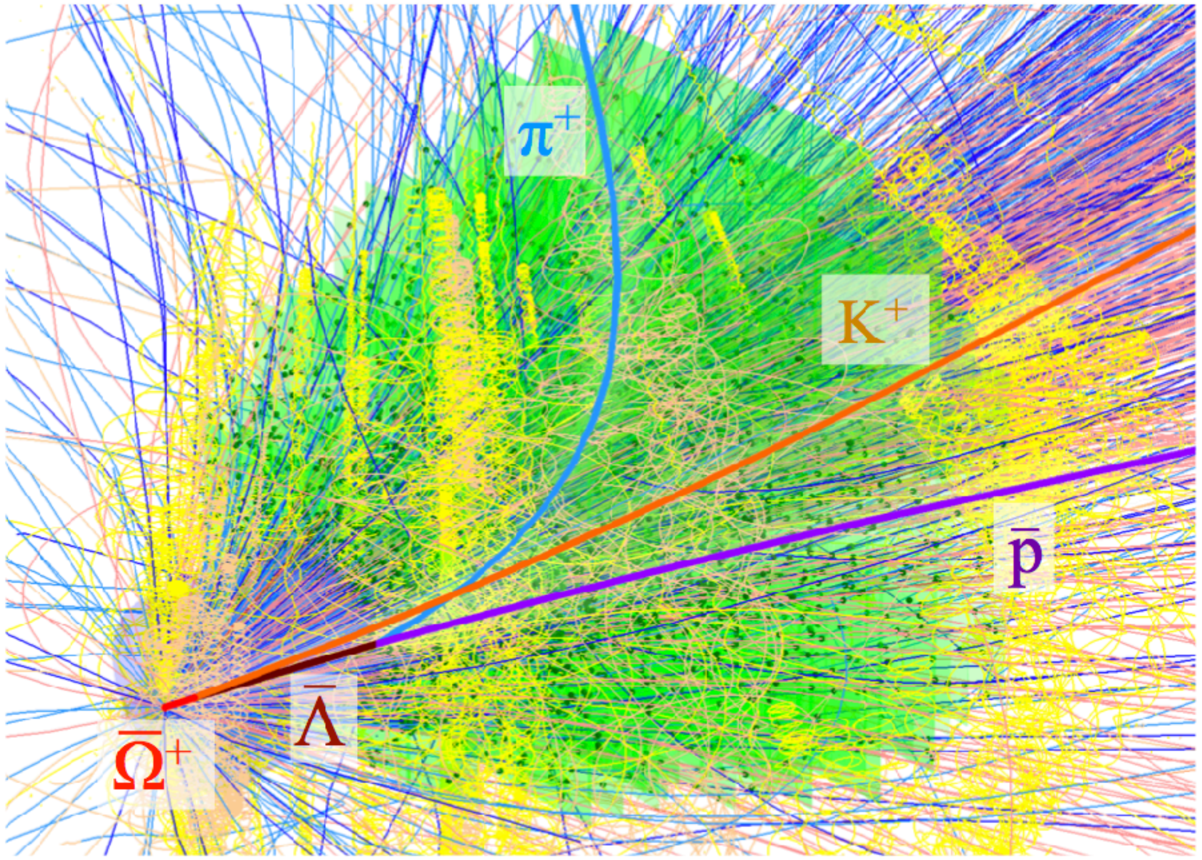
Outline

- STAR and KF Particle Finder
- TMVA optimization
- Results
- Comparison with standard method
- Summary

STAR



Concept of KF Particle



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

```
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
```

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

State vector

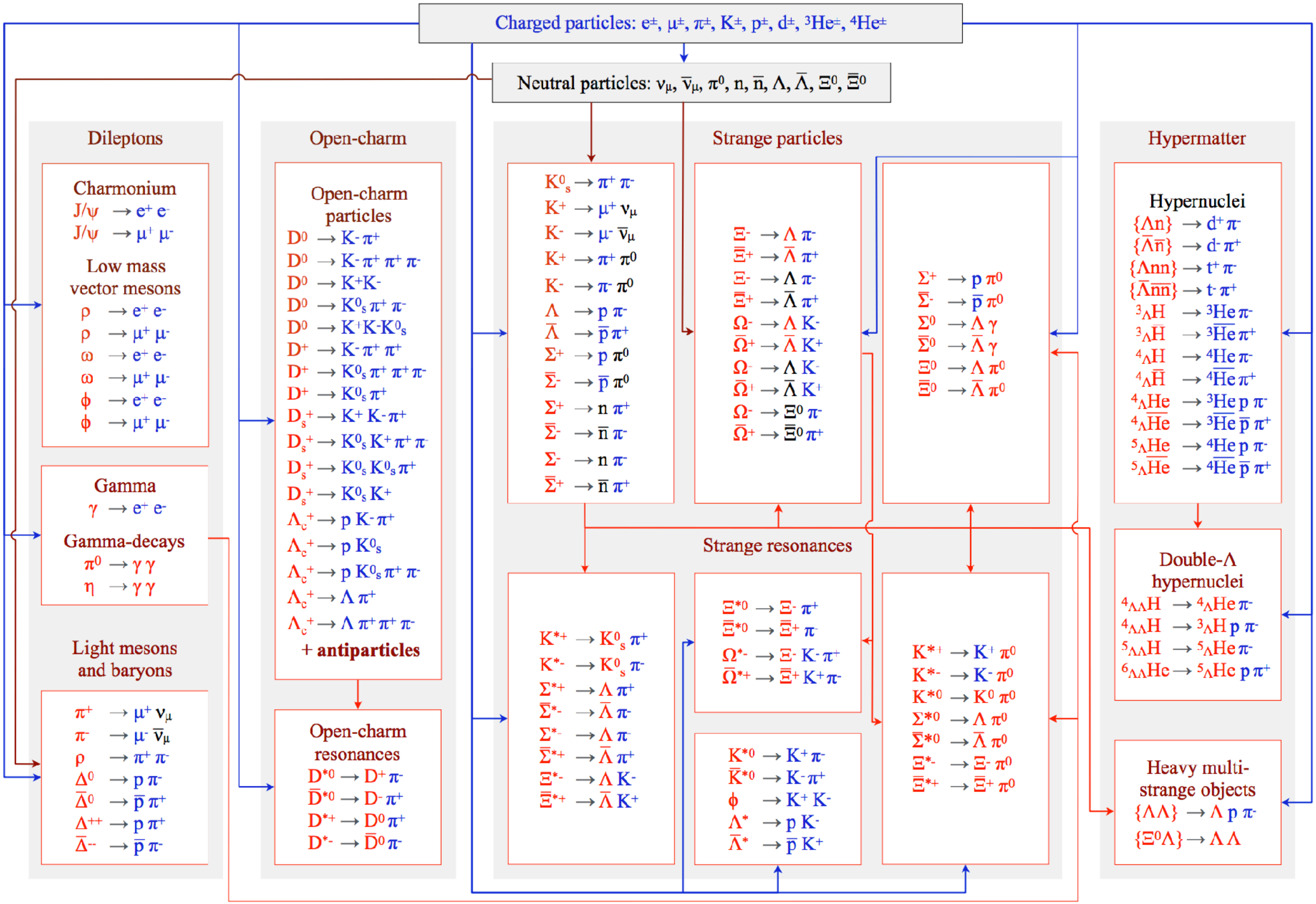
$$C = \langle \mathbf{r}\mathbf{r}^T \rangle = \begin{bmatrix} \sigma_x^2 & C_{xy} & C_{xz} & C_{xp_x} & C_{xp_y} & C_{xp_z} & C_{xE} \\ C_{xy} & \sigma_y^2 & C_{yz} & C_{yp_x} & C_{yp_y} & C_{yp_z} & C_{yE} \\ C_{xz} & C_{yz} & \sigma_z^2 & C_{zp_x} & C_{zp_y} & C_{zp_z} & C_{zE} \\ C_{xp_x} & C_{yp_x}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

Covariance matrix

1. Covariance matrix contains essential information about tracking and detector performance.
2. 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.
3. Heavy mathematics requires fast and vectorised algorithms.
4. Mother and daughter particles have the same state vector and are treated in the same way.
5. The natural and simple interface allows to reconstruct easily rather complicated decay chains.
6. 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



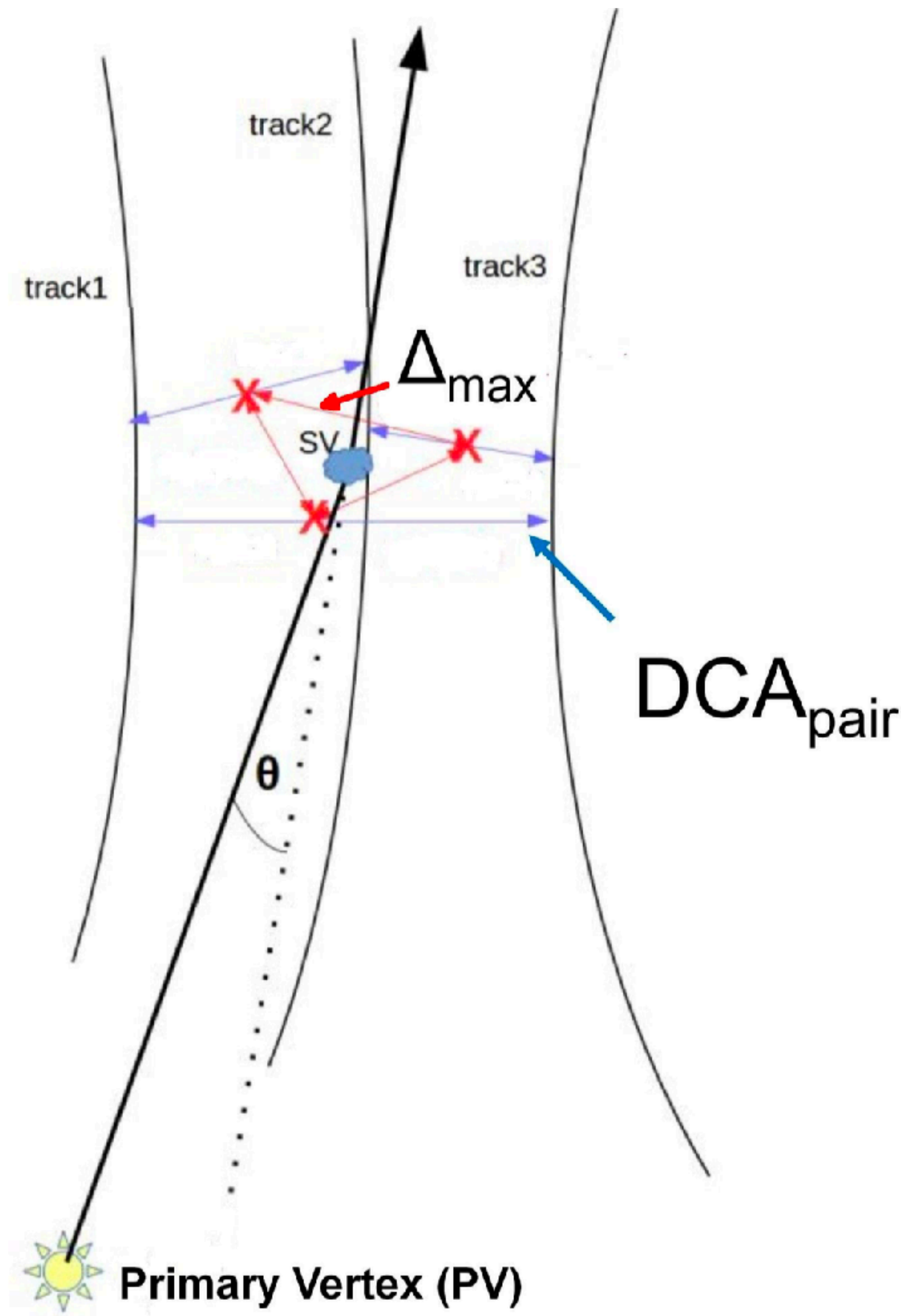
Full online event reconstruction and physics analysis in CBM at 10^7 interaction rate.

Plan to use in STAR for physics analysis as well as in HLT for monitoring at 10^3 collisions/s.

Cuts on event and tracks

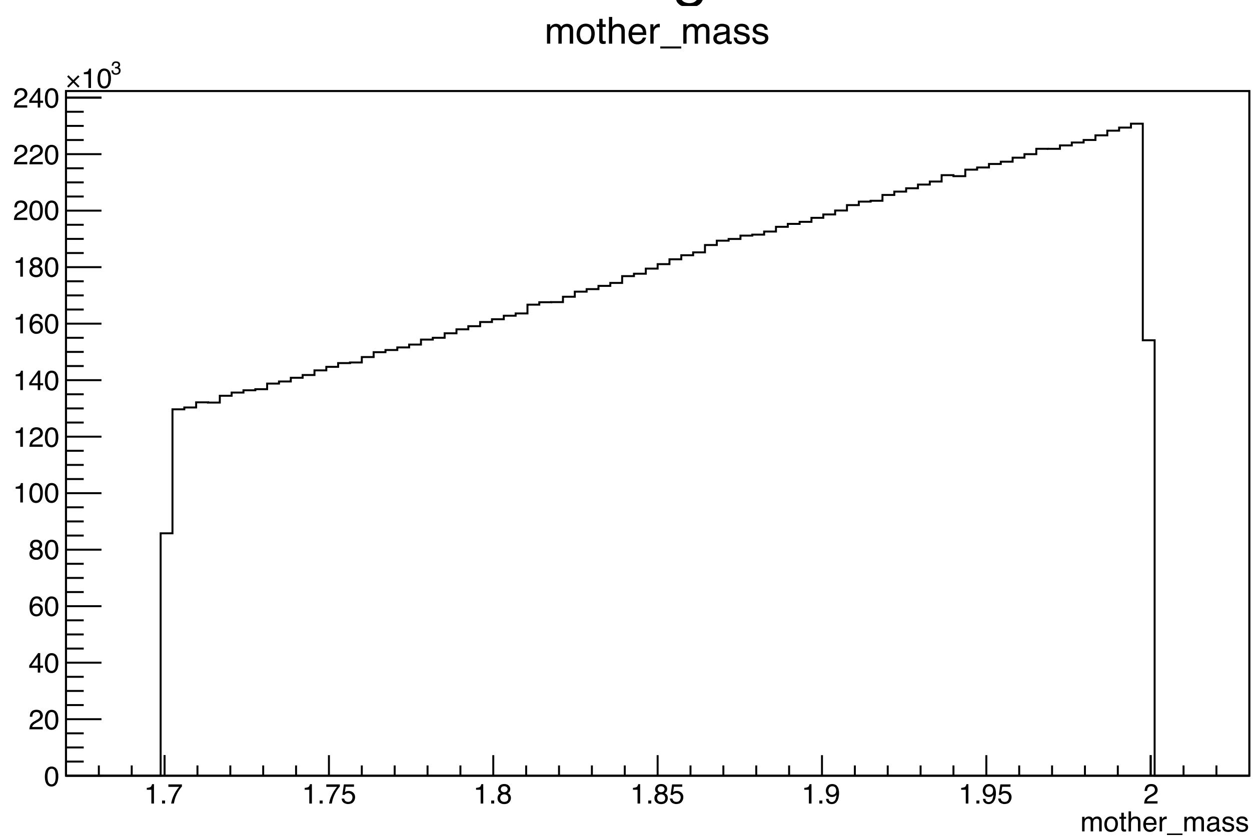
  - vertex position in beam direction $|V_z| < 6$ cm
  - correlation of primary vertices reconstructed using TPC and VPD $|V_{z,VPD} - V_{z,TPC}| < 3$ cm
  - tracks have hits in both PIXEL layers and at least one of the IST or SSD layer
  - 15 space points in the TPC
  - track pseudorapidity $|\eta| < 1$
- PID:
  - pt > 0.5 GeV/c (it will be changed in a future)
  - TPC: $|n\sigma\pi| < 3$, $|n\sigma K| < 2$, $|n\sigma p| < 3$
  - TOF: $|n\sigma\pi| < 3$, $|n\sigma K| < 2$, $|n\sigma p| < 3$

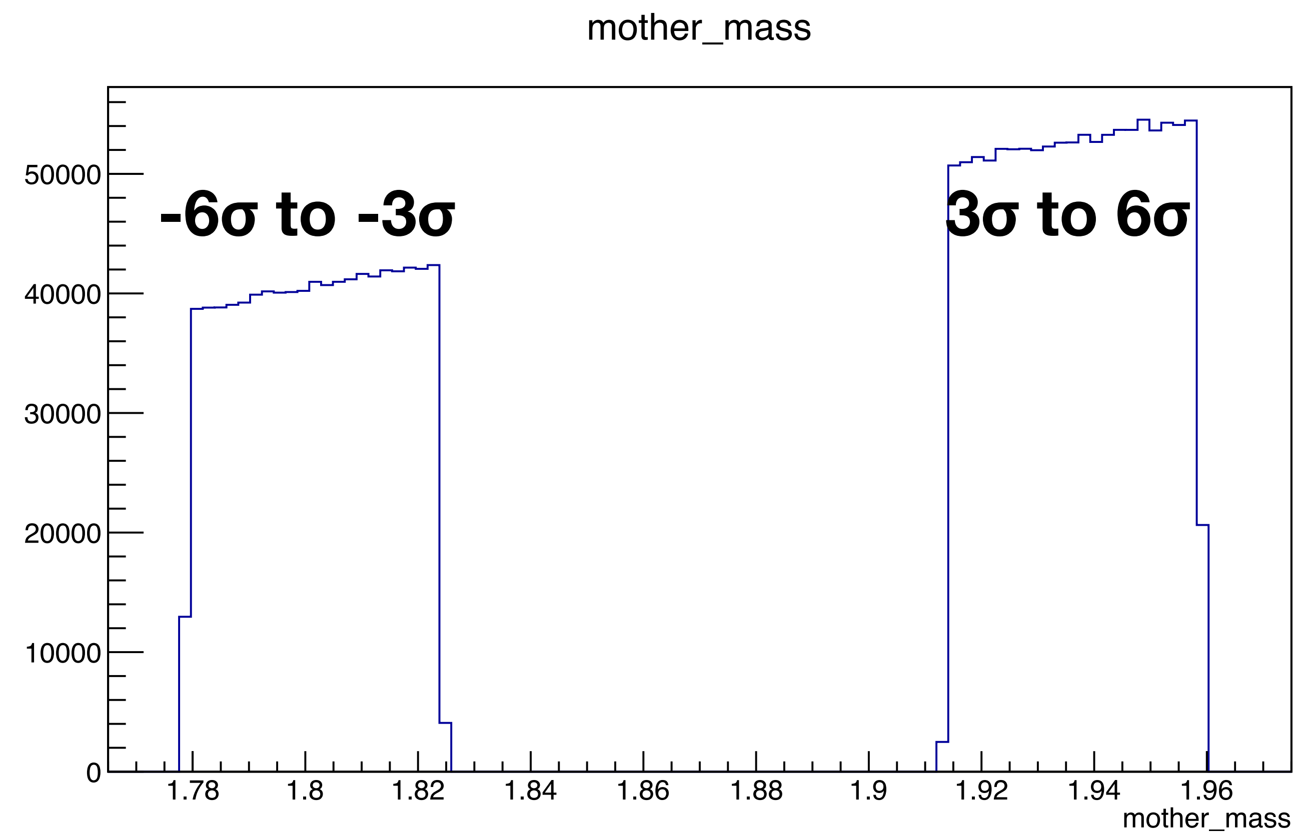
- Instead of using DCA and pointing angle θ, KF Particle is using Chi-square
  - Chi-square primary - criterion for distinguish between primary and secondary tracks
  - Chi-square fit - criterion calculated by KF Particle mathematics in the candidate fit, if trajectories of daughter particles intersect within their errors
  - Chi-square topo - criterion characterizes whether the particle is produced in the primary vertex region
  - distance from the decay point of the candidate to the primary vertex normalized on the error l/Δl



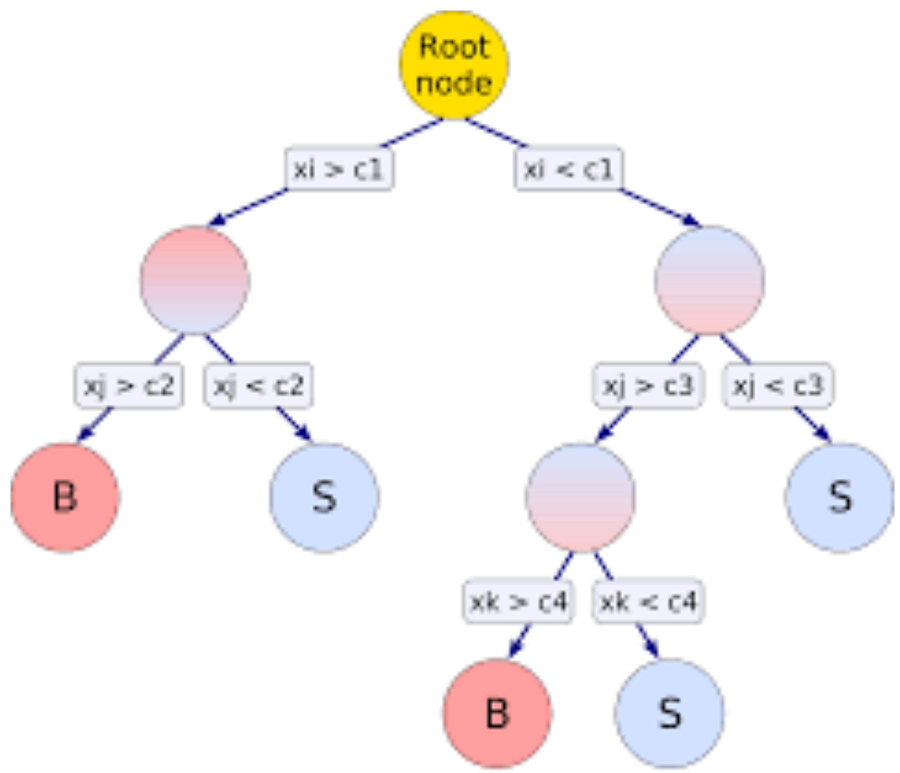
TMVA optimization

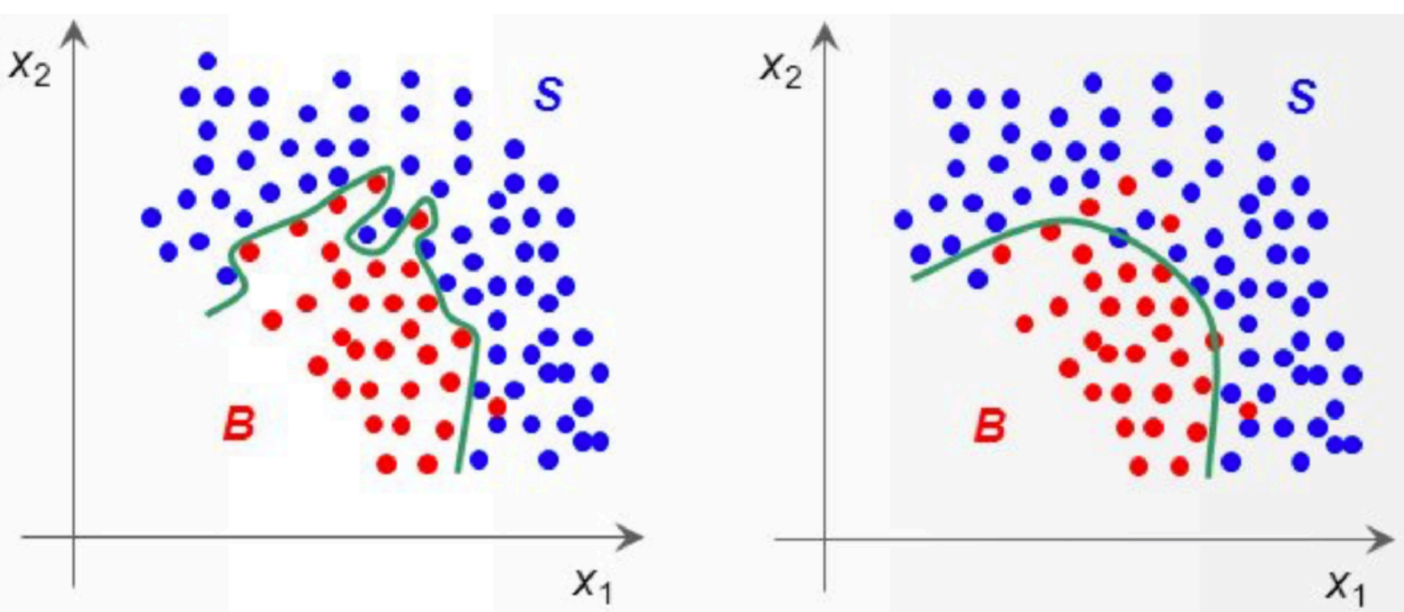
- trained for: D0, D0KK, D04, D+, Ds, DsPhi and Lc and applied also on antiparticles
- We are using open cuts for reconstruction candidate
- BDT method is used for cut optimization
- As the background - the side band method is used (not all candidates are used)
- As the signal - pure signal was simulated (from 50k to 8k for different particles)
- the default settings for BDT was used

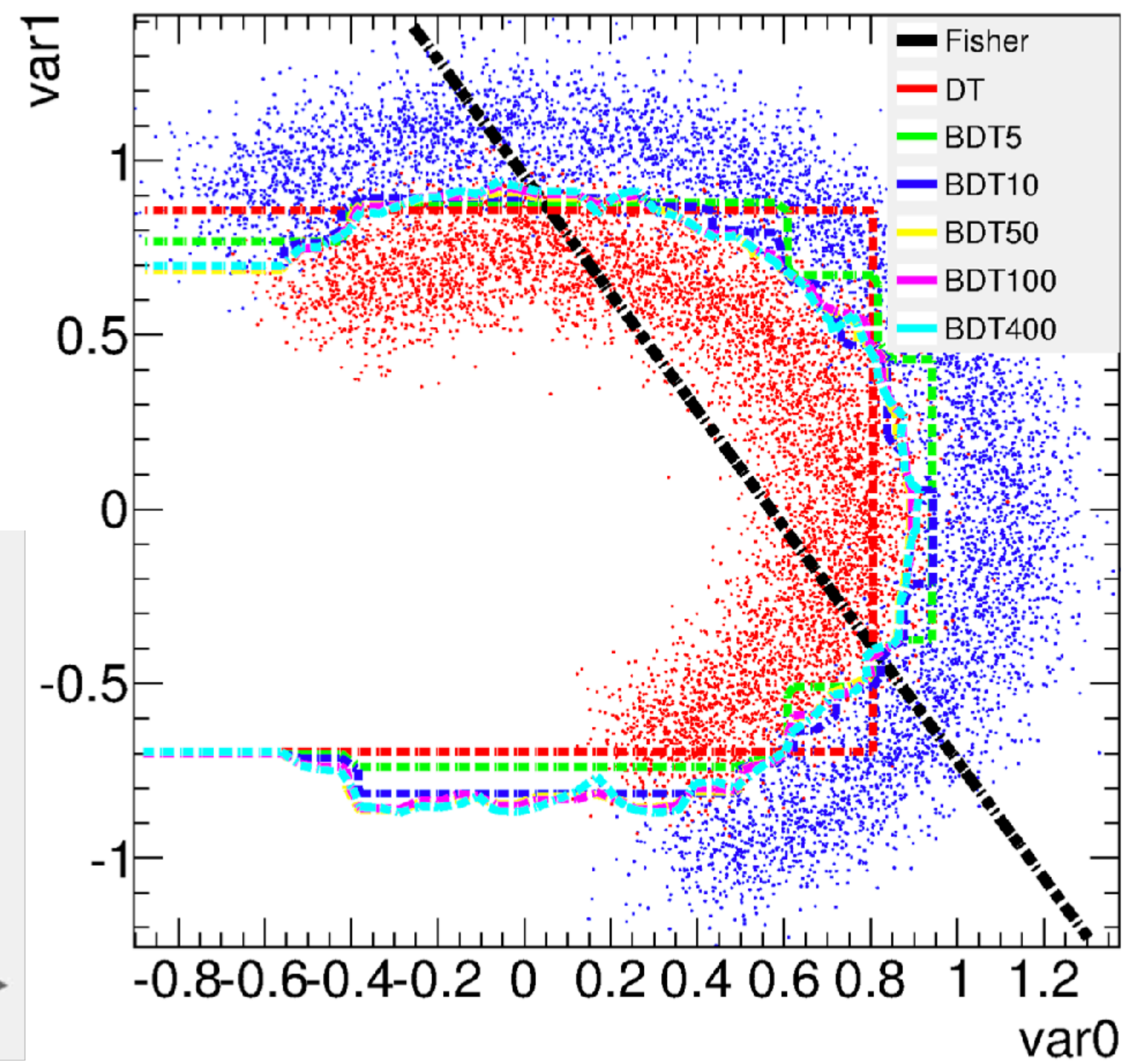




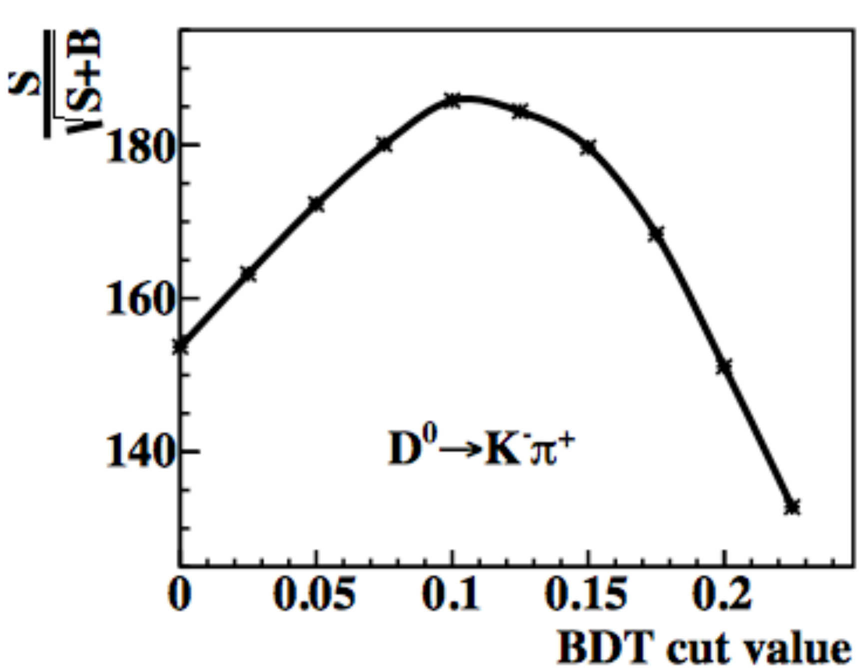
Boost Decision Tree

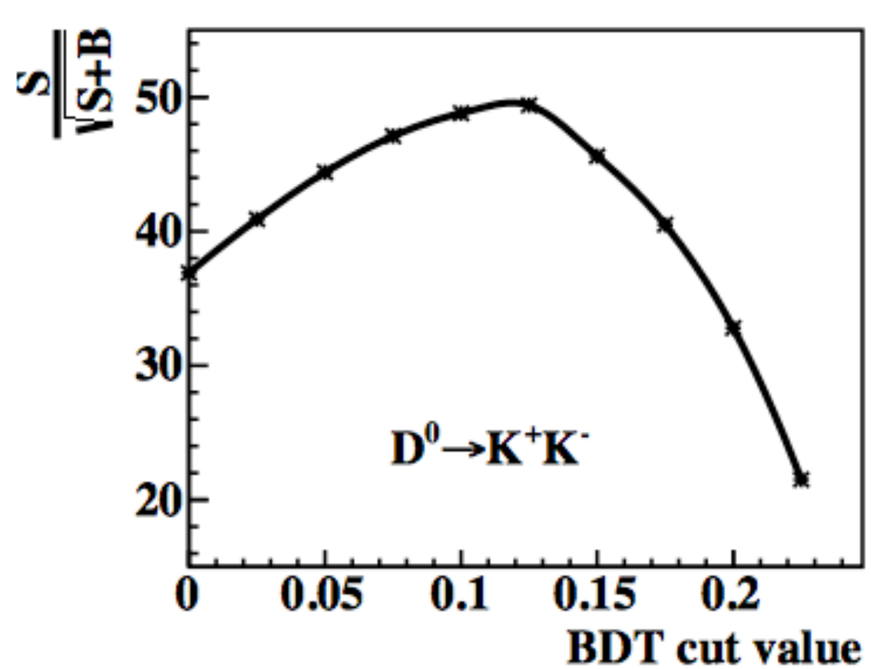


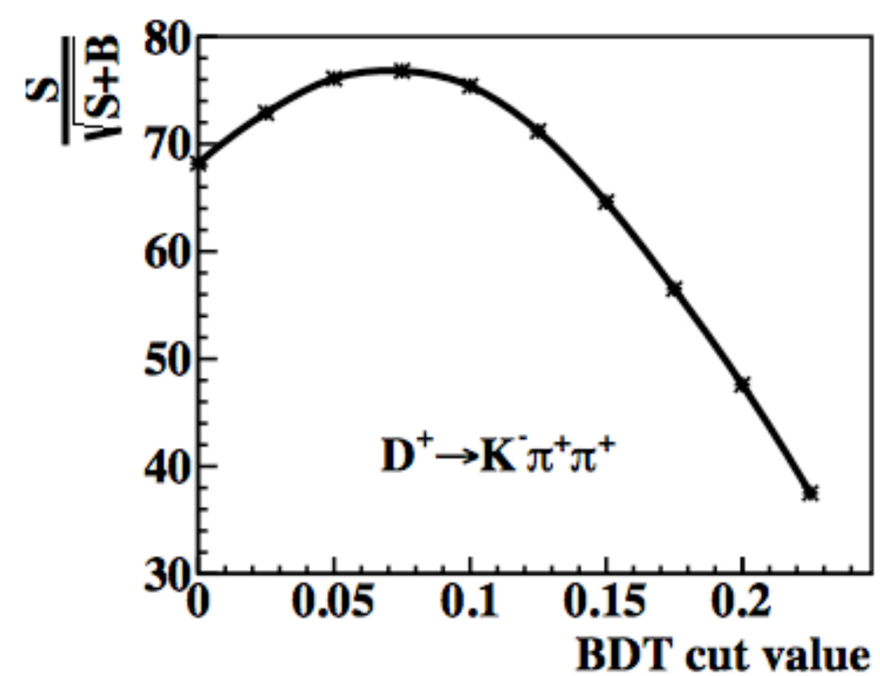


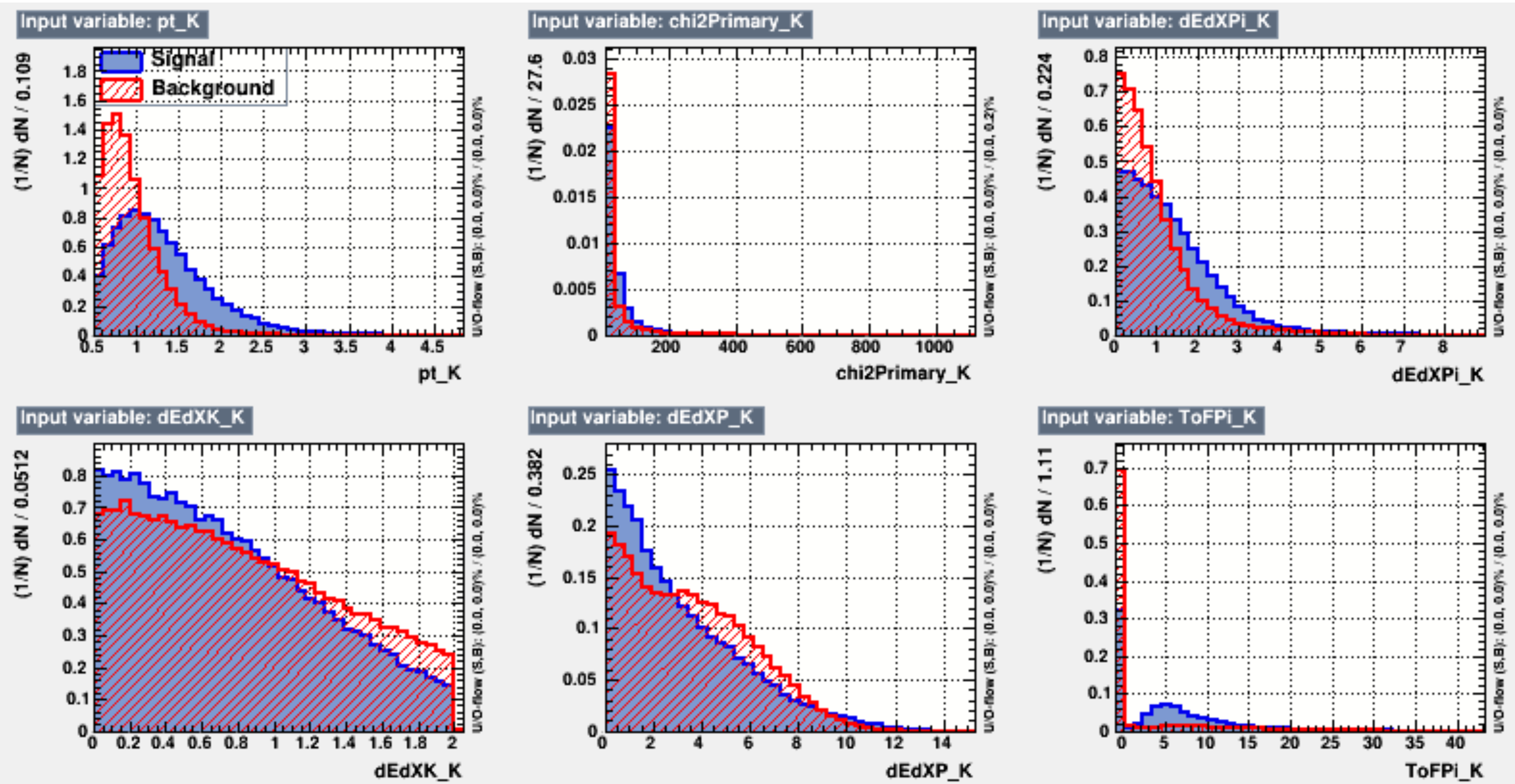


- For each track we used 8 parameters: p_t, 6 PID parameters, Chi-square primary
- For mother particle: l/Δl, Chi-square topo, Chi-square fit
- -> from 19 to 35 parameters is used
- For D0, D0KK and D+ TMVA is now optimized for each centrality bin
- Lc, Ds and D04 are optimized in regions: 0-10, 10-40, 40-80
- BDT cut is chosen based on significance scan on real data

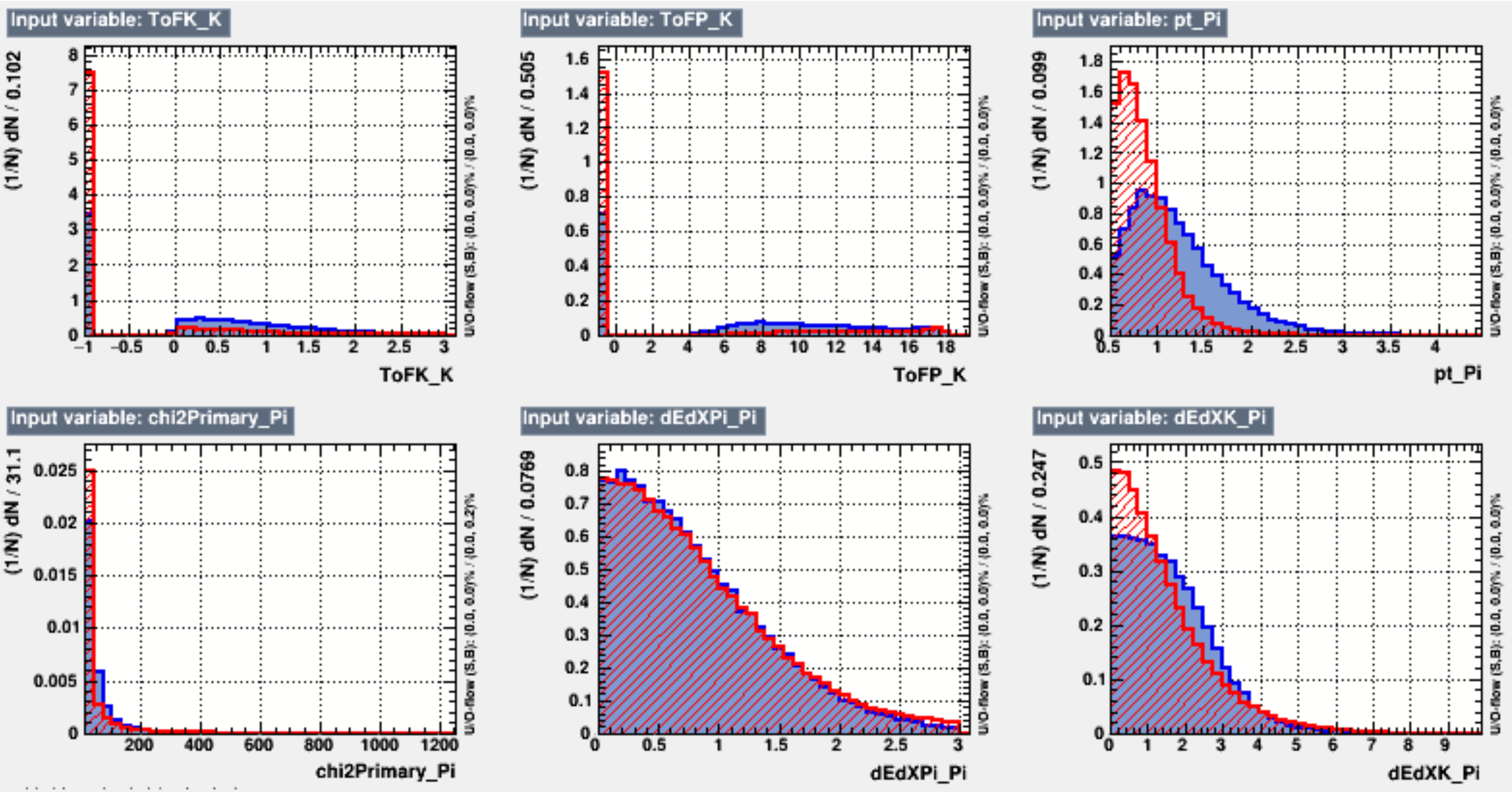




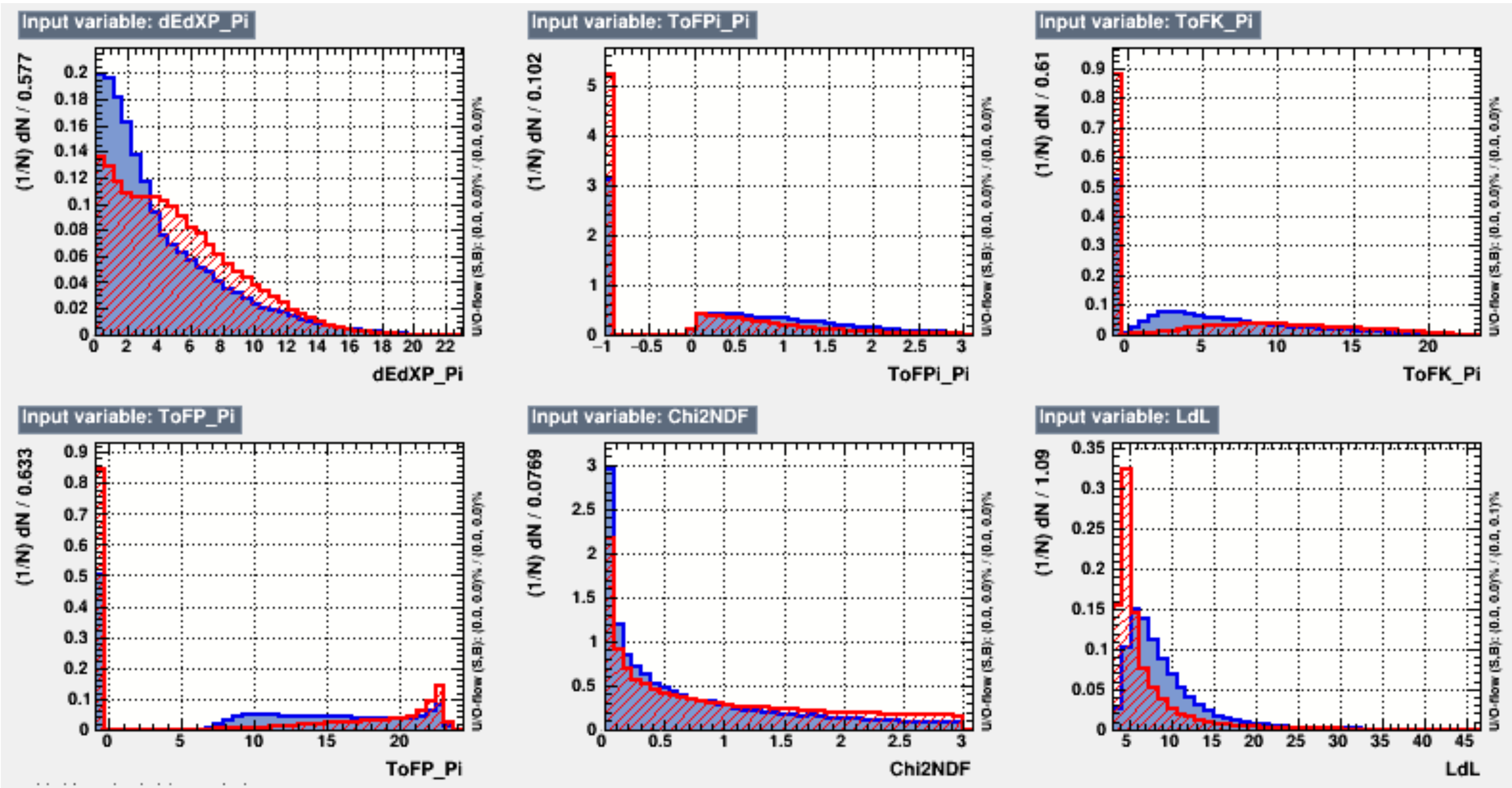


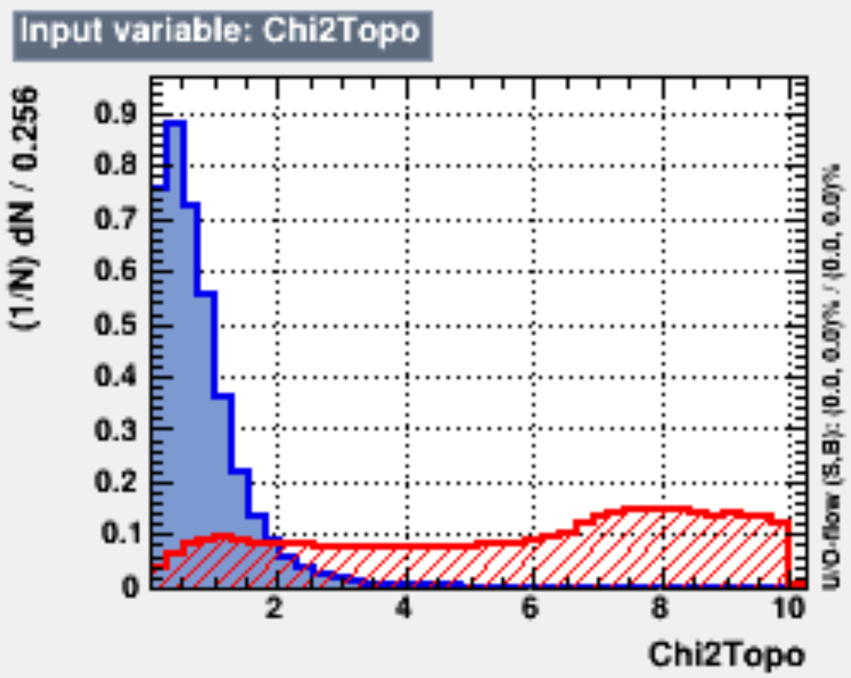


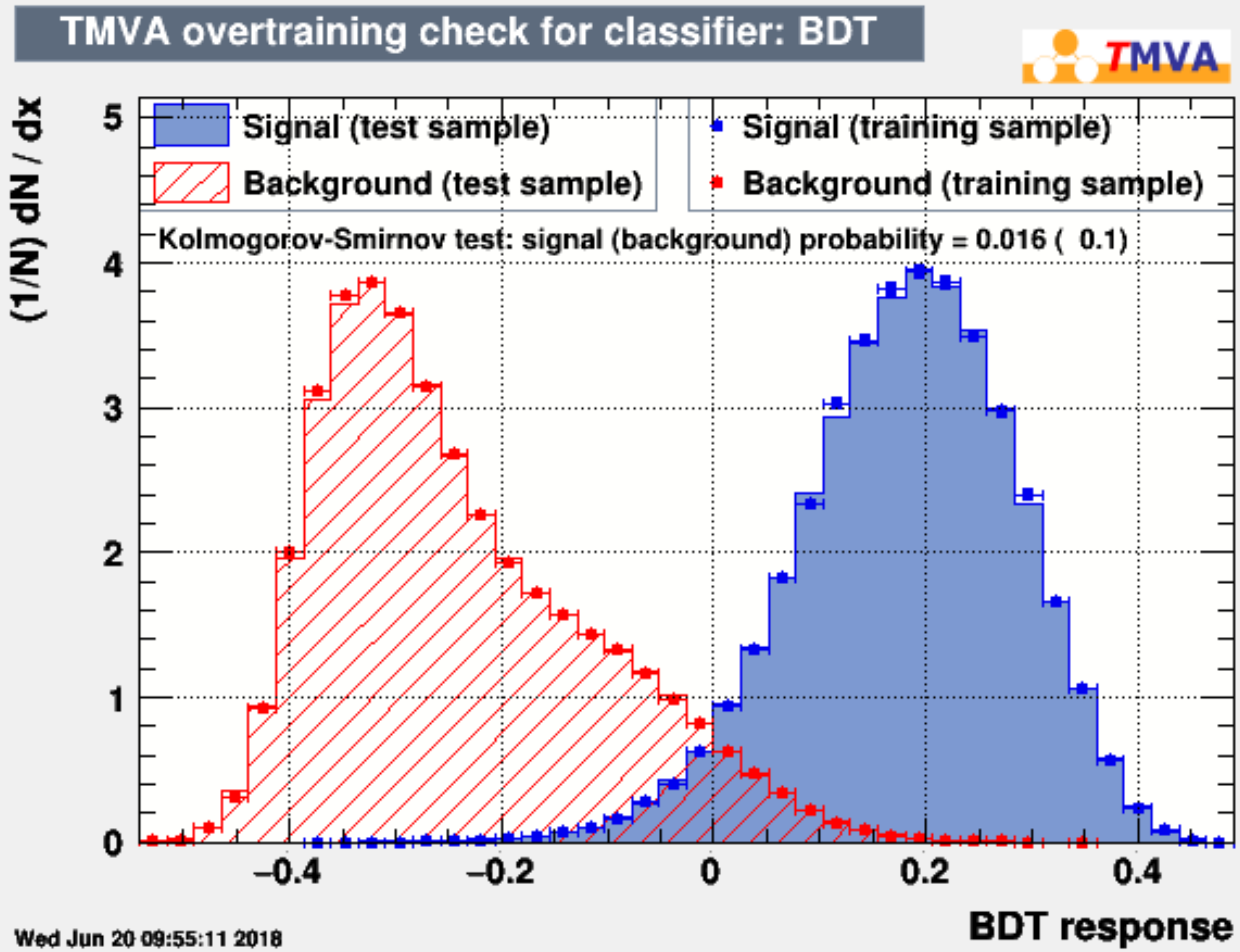
Input variable: pt_K
Signal
Background
(1/N) dN / 0.109
pt_K
Input variable: chi2Primary_K
(1/N) dN / 27.6
chi2Primary_K
Input variable: dEdXPi_K
(1/N) dN / 0.224
dEdXPi_K
Input variable: dEdXK_K
(1/N) dN / 0.0512
dEdXK_K
Input variable: dEdXP_K
(1/N) dN / 0.382
dEdXP_K
Input variable: ToFPi_K
(1/N) dN / 1.11
ToFPi_K



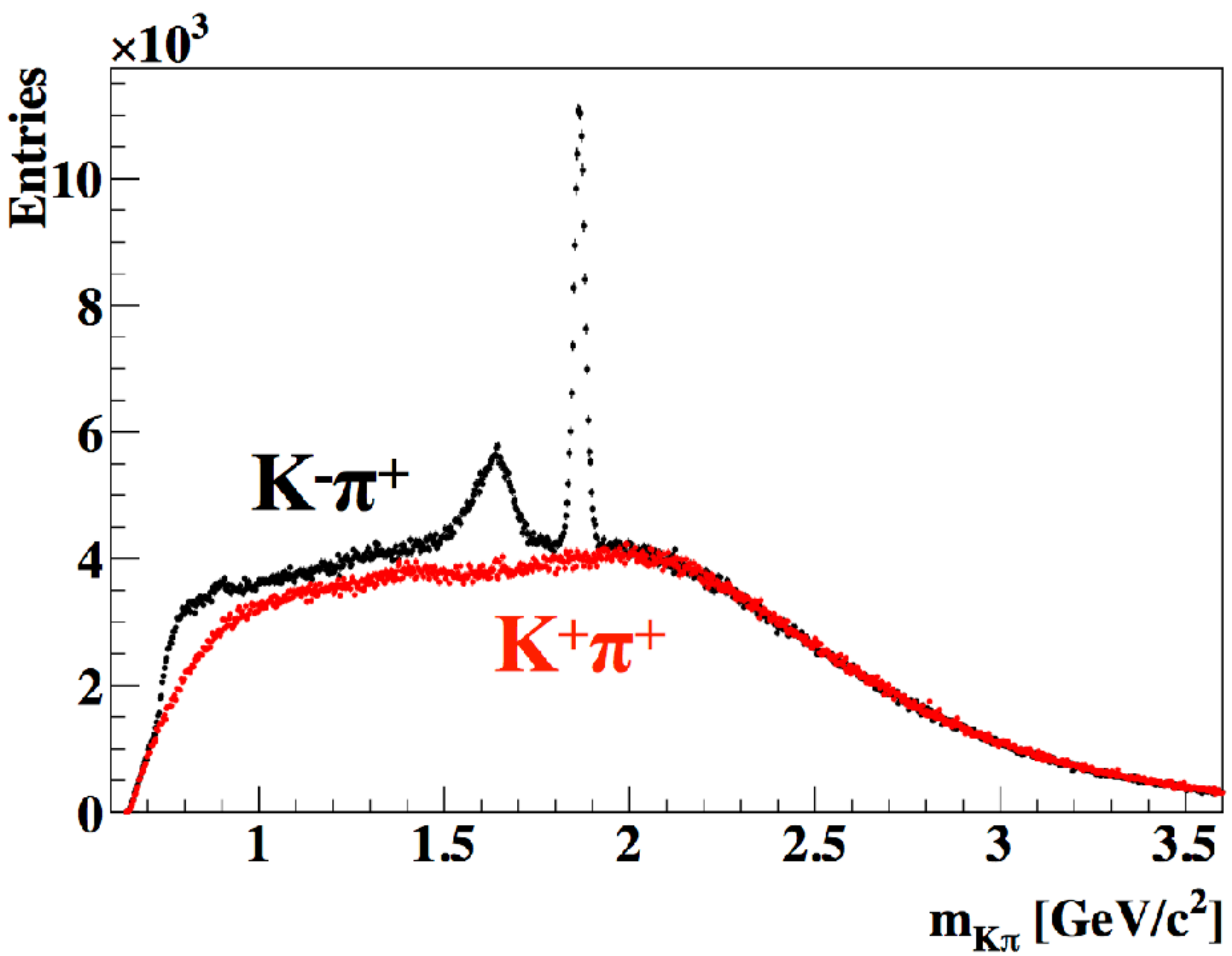
Input variable: ToFK_K
(1/N) dN / 0.102
ToFK_K
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: ToFP_K
(1/N) dN / 0.505
ToFP_K
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: pt_Pi
(1/N) dN / 0.099
pt_Pi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: chi2Primary_Pi
(1/N) dN / 31.1
chi2Primary_Pi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.2)%
Input variable: dEdXPi_Pi
(1/N) dN / 0.0769
dEdXPi_Pi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: dEdXK_Pi
(1/N) dN / 0.247
dEdXK_Pi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

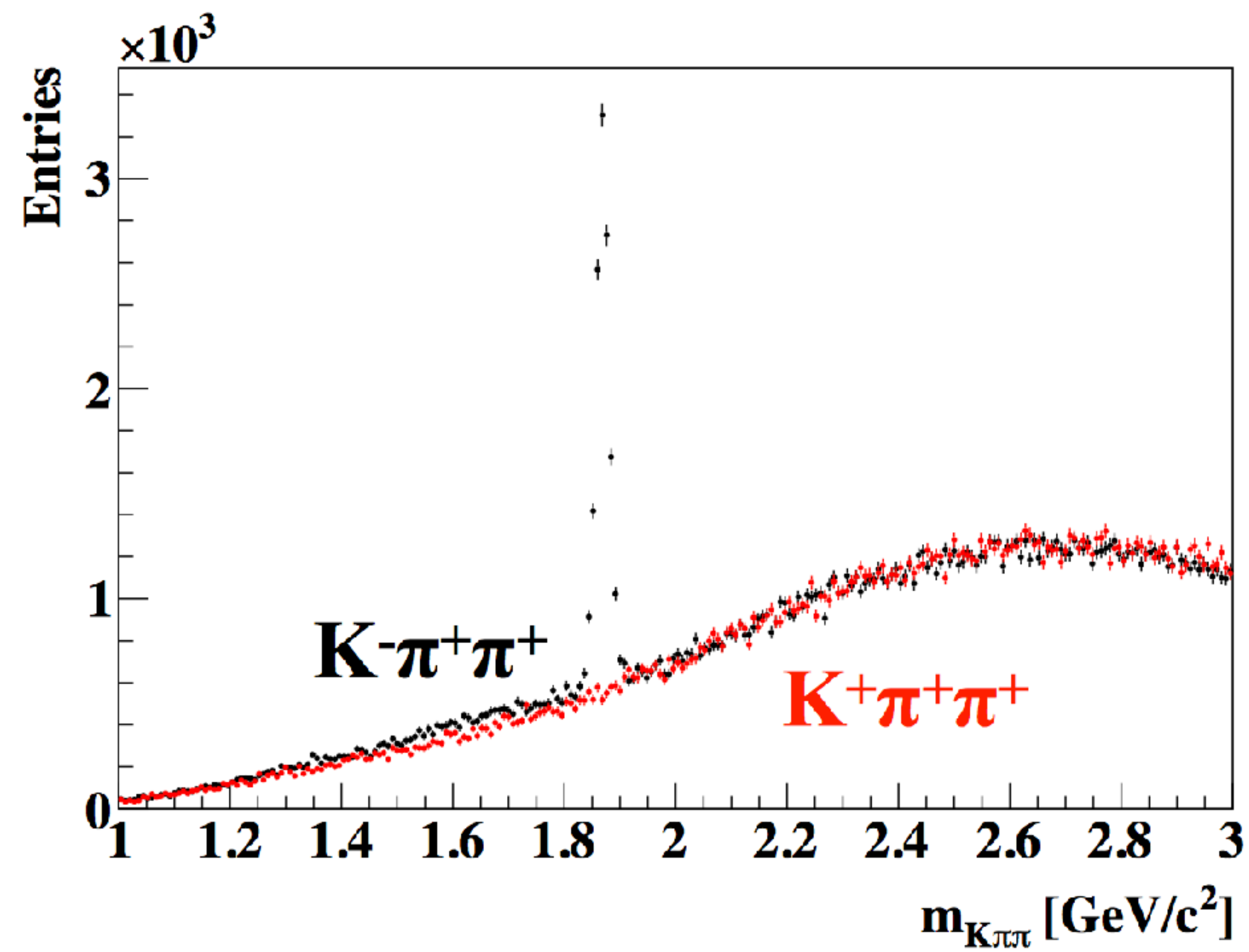

Input variable: dEdXP_Pi
(1/N) dN / 0.577
dEdXP_Pi
Input variable: ToFPi_Pi
(1/N) dN / 0.102
ToFPi_Pi
Input variable: ToFK_Pi
(1/N) dN / 0.61
ToFK_Pi
Input variable: ToFP_Pi
(1/N) dN / 0.633
ToFP_Pi
Input variable: Chi2NDF
(1/N) dN / 0.0769
Chi2NDF
Input variable: LdL
(1/N) dN / 1.09
LdL


Input variable: Chi2Topo
(1/N) dN / 0.256
Chi2Topo
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


TMVA overtraining check for classifier: BDT
TMVA
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.016 (0.1)
(1/N) dN / dx
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Wed Jun 20 09:55:11 2018

Test on wrong sign combination

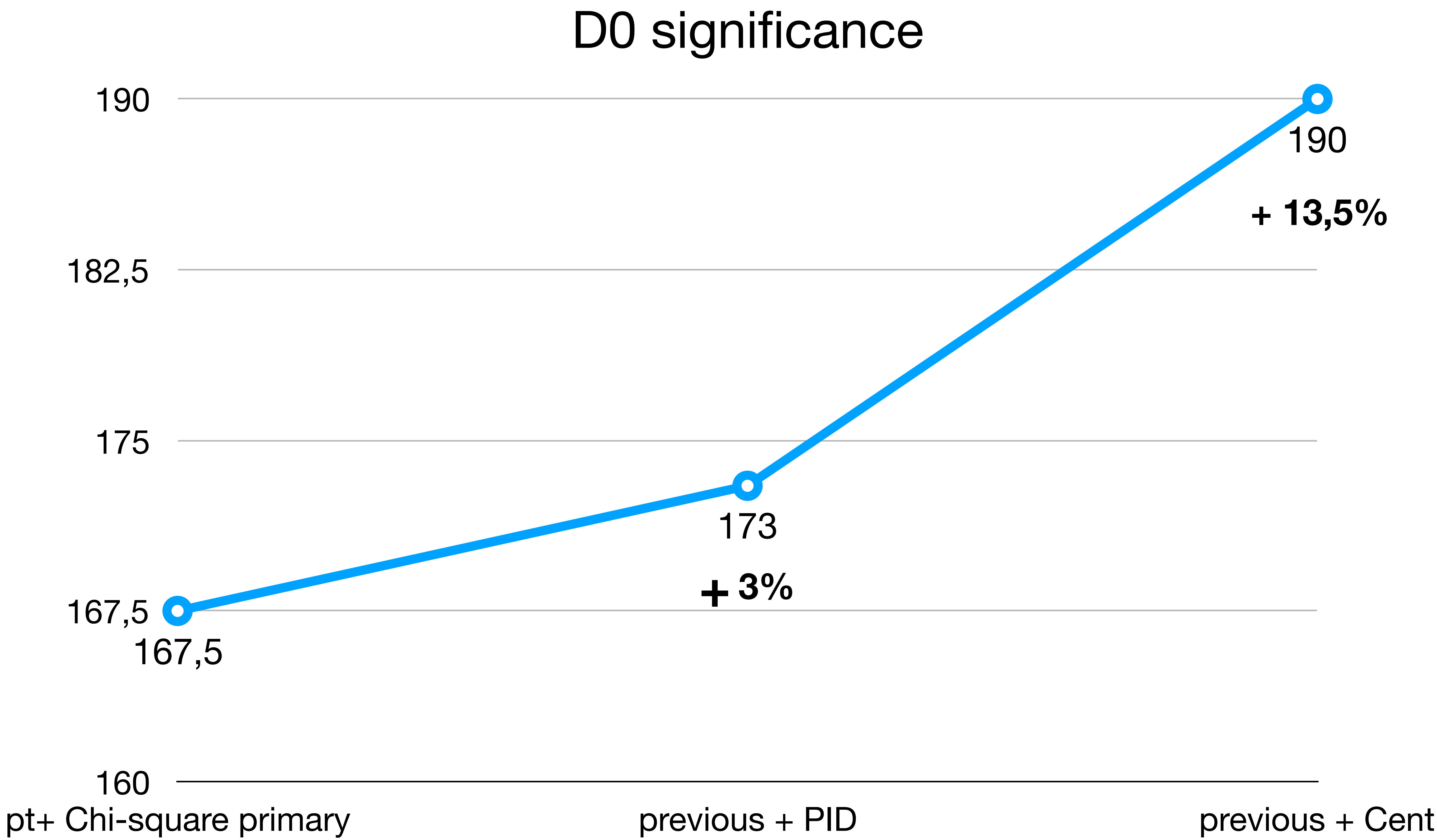


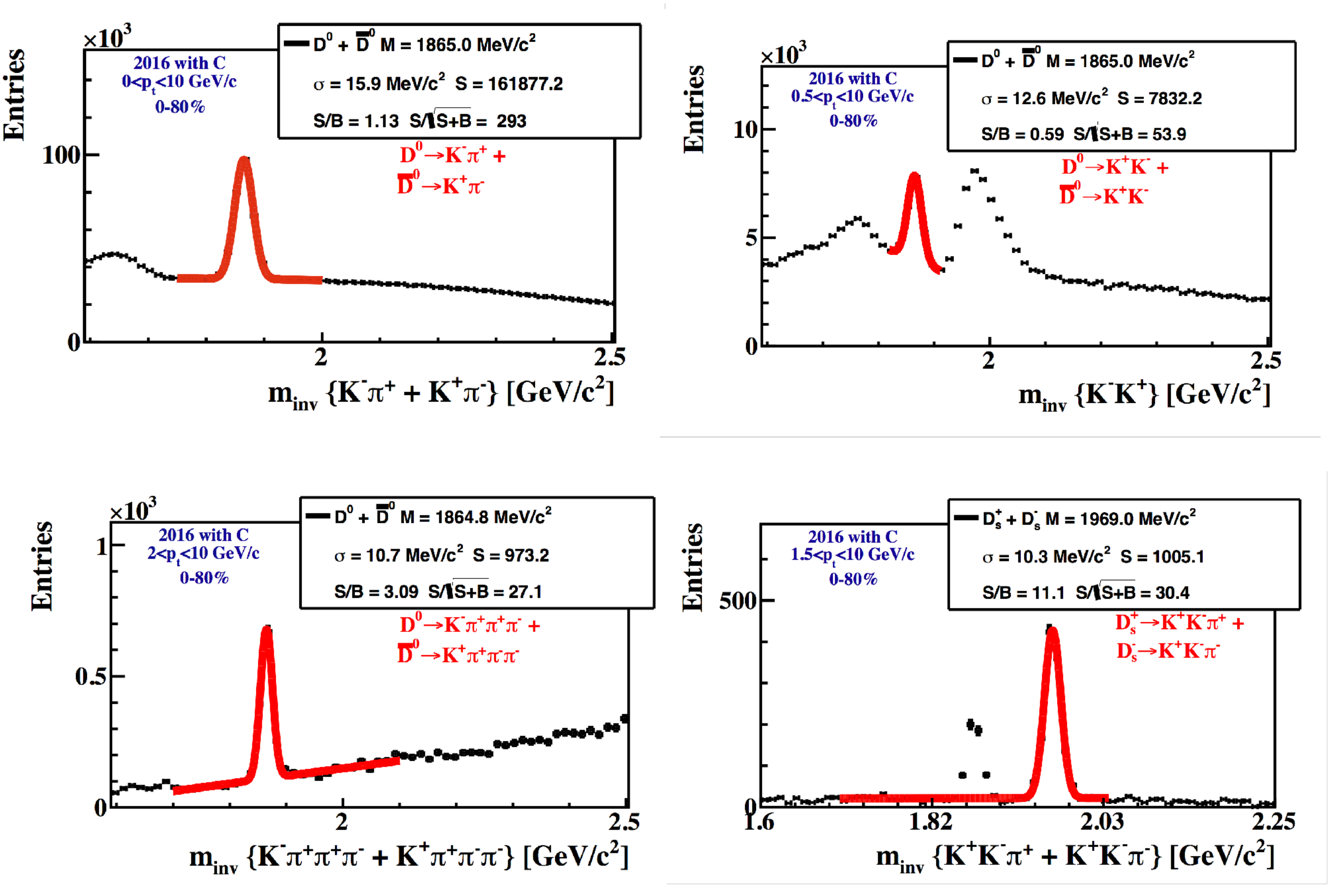


- wrong sign combination were constructed with the same TMVA weights files and same cuts

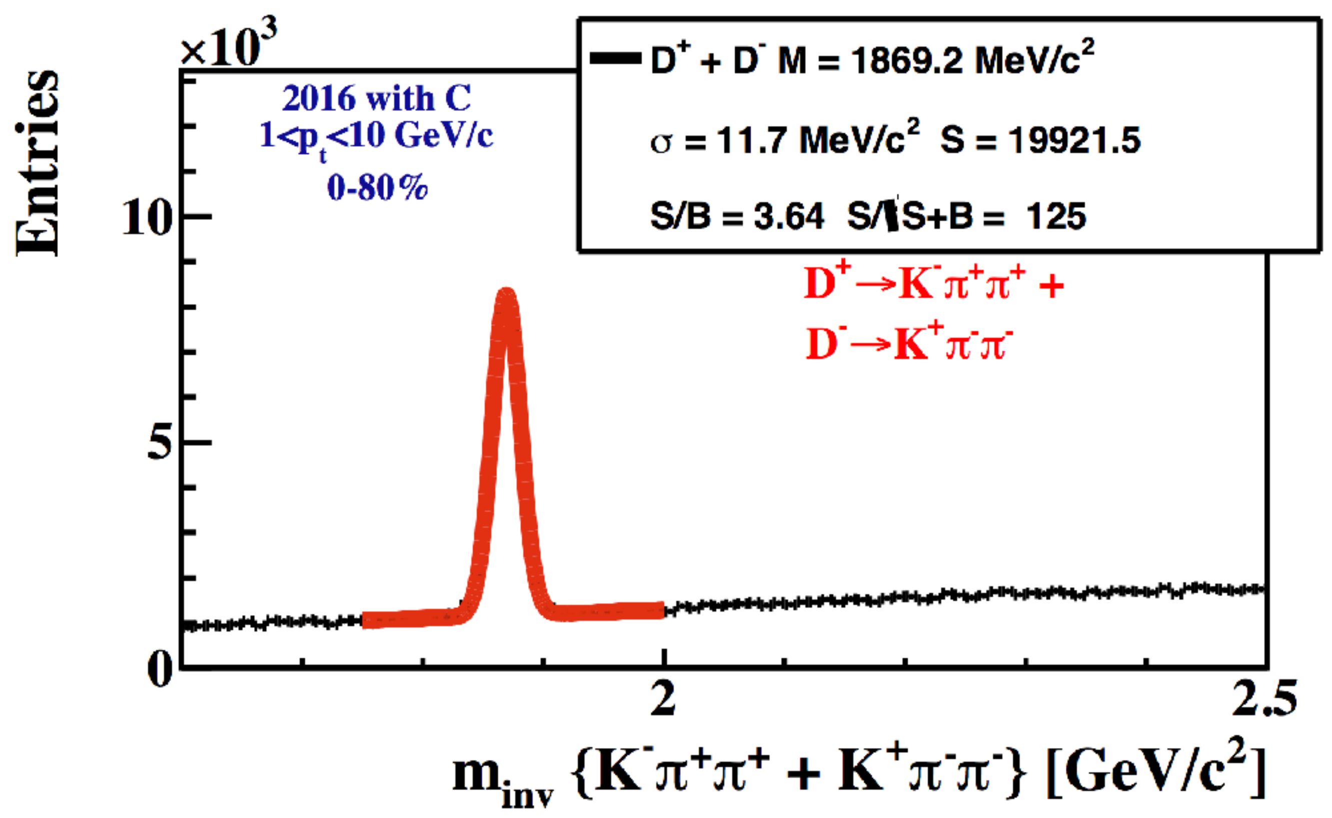
- no peak-like structure is observed -> no bias

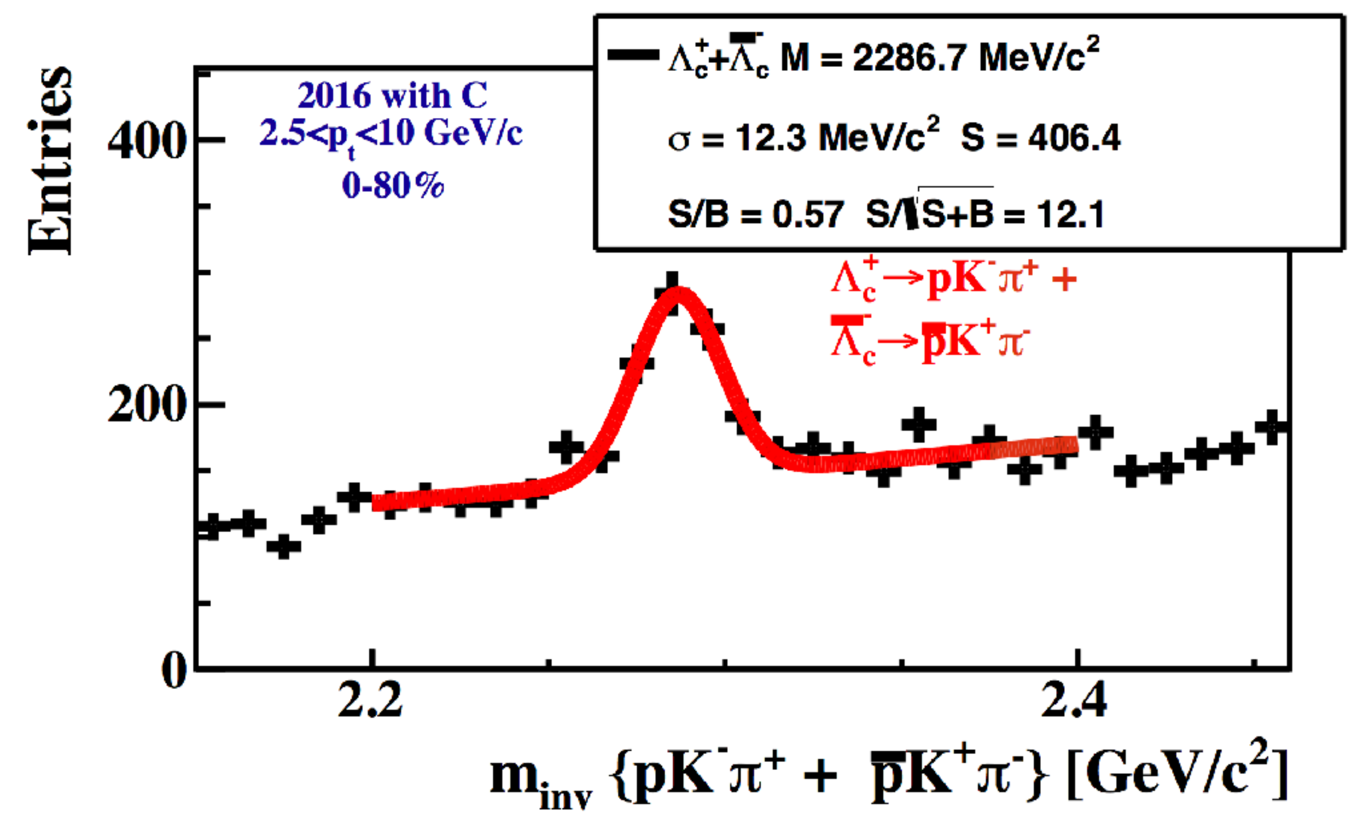
Significance based on daughters training parameters





×10^3
Entries
2016 with C
0<p_t<10 GeV/c
0-80%
D^0 + D̄^0 M = 1865.0 MeV/c^2
σ = 15.9 MeV/c^2 S = 161877.2
S/B = 1.13 S/√S+B = 293
D^0→K^-π^+ +
D̄^0→K^+π^-
100
0
2
2.5
m_inv {K^-π^+ + K^+π^-} [GeV/c^2]
×10^3
Entries
2016 with C
0.5<p_t<10 GeV/c
0-80%
D^0 + D̄^0 M = 1865.0 MeV/c^2
σ = 12.6 MeV/c^2 S = 7832.2
S/B = 0.59 S/√S+B = 53.9
D^0→K^+K^- +
D̄^0→K^+K^-
10
5
0
2
2.5
m_inv {K^-K^+} [GeV/c^2]
×10^3
Entries
2016 with C
2<p_t<10 GeV/c
0-80%
D^0 + D̄^0 M = 1864.8 MeV/c^2
σ = 10.7 MeV/c^2 S = 973.2
S/B = 3.09 S/√S+B = 27.1
D^0→K^-π^+π^+π^- +
D̄^0→K^+π^+π^-π^-
1
0.5
0
2
2.5
m_inv {K^-π^+π^+π^- + K^+π^+π^-π^-} [GeV/c^2]
Entries
2016 with C
1.5<p_t<10 GeV/c
0-80%
D_s^+ + D_s^- M = 1969.0 MeV/c^2
σ = 10.3 MeV/c^2 S = 1005.1
S/B = 11.1 S/√S+B = 30.4
D_s^+→K^+K^-π^+ +
D_s^-→K^+K^-π^-
500
0
1.6
1.82
2.03
2.25
m_inv {K^+K^-π^+ + K^+K^-π^-} [GeV/c^2]



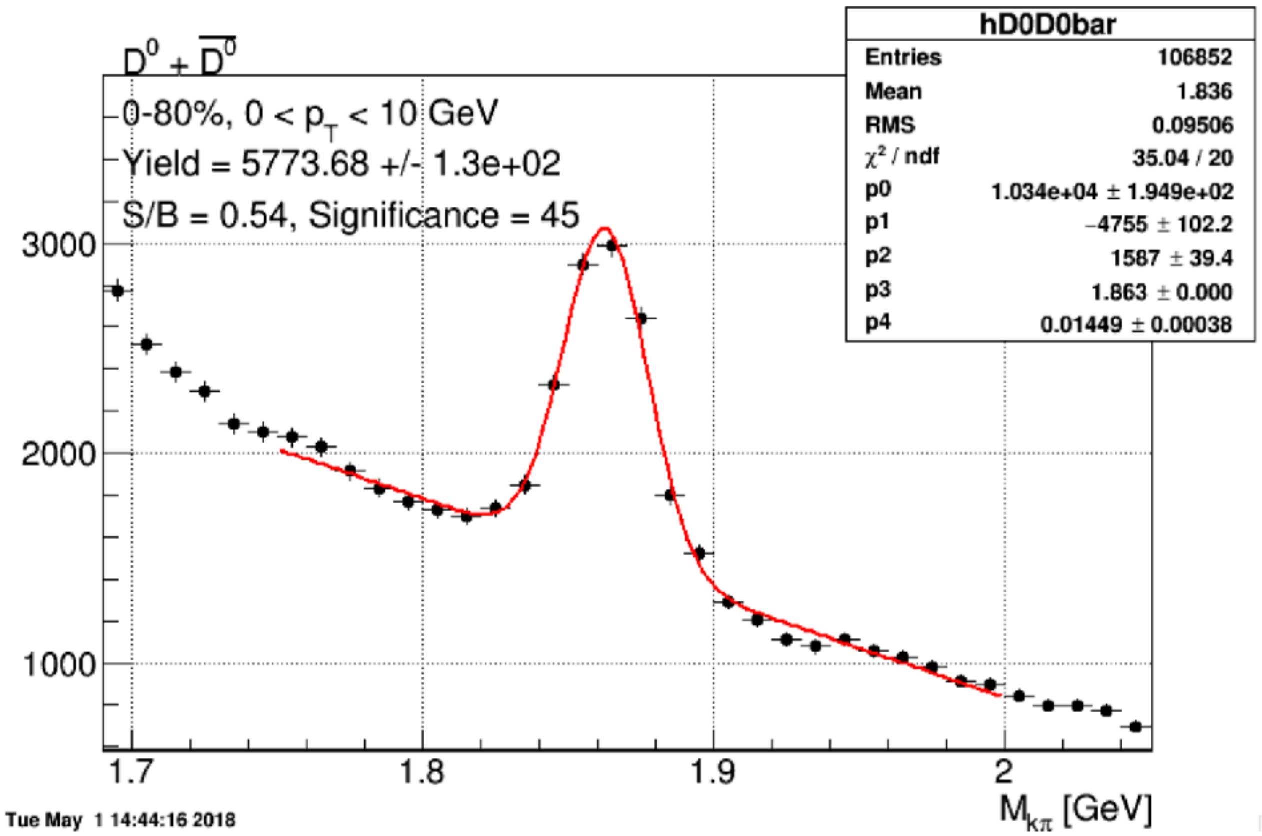


	S/B	Significance
D0 –> KPi	1.13	293
D0 -> KK	0.59	53.9
D0 -> KPiPiPi	3.09	27.1
DPlus -> KPiPi	3.64	125
Ds -> PhiPi -> KKPi	11.1	30
Lc -> PKPi	0.57	12.1

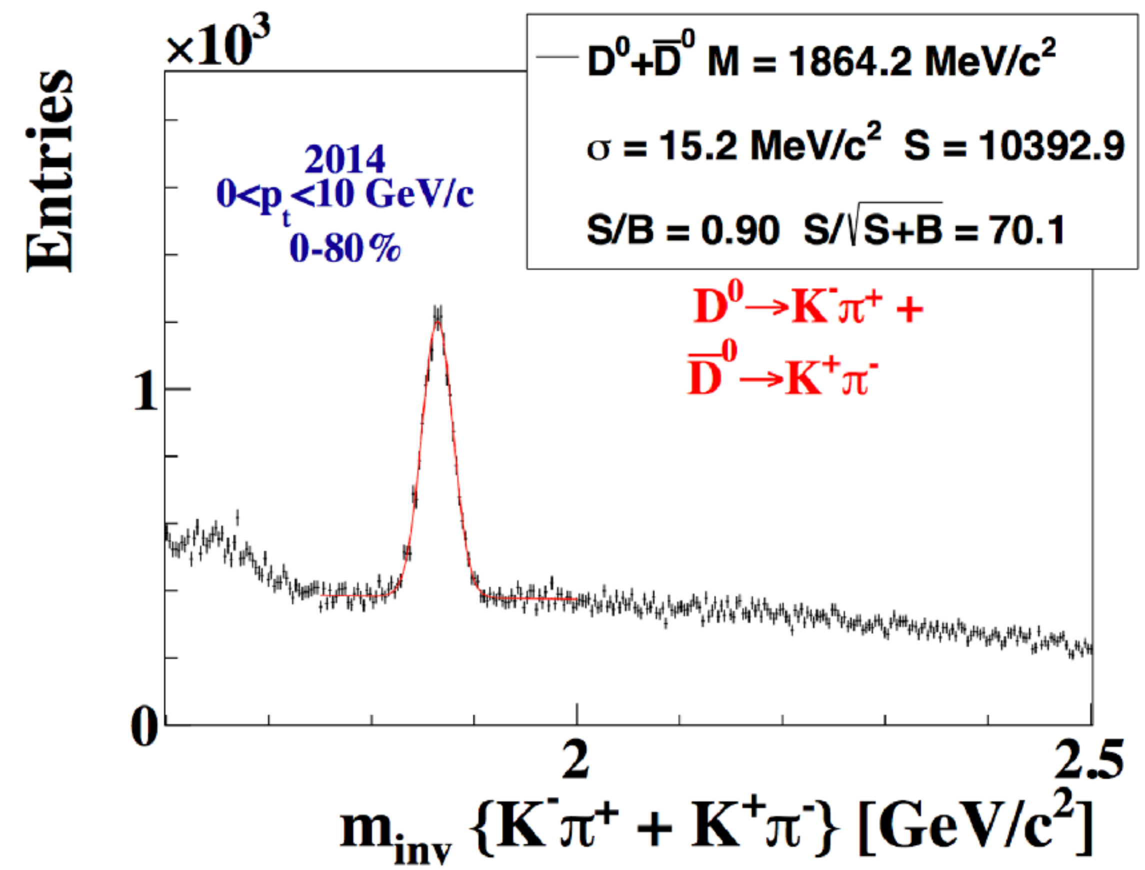
Comparison of standard method with KF Particle Finder

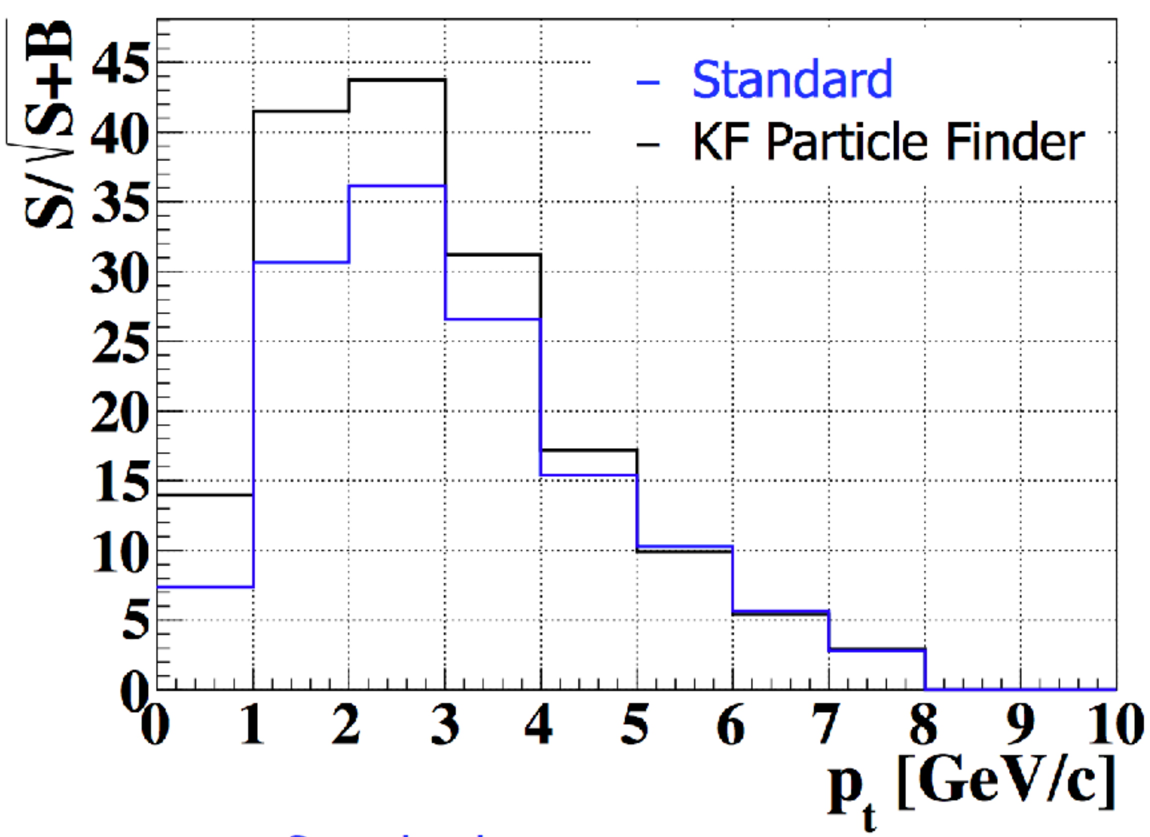
- for D^0, D^+ and L_c
- Analysis on the same data
- both trained with TMVA
- on HFT Analysis Meeting in April (Maksym, Sooraj, Guannan)

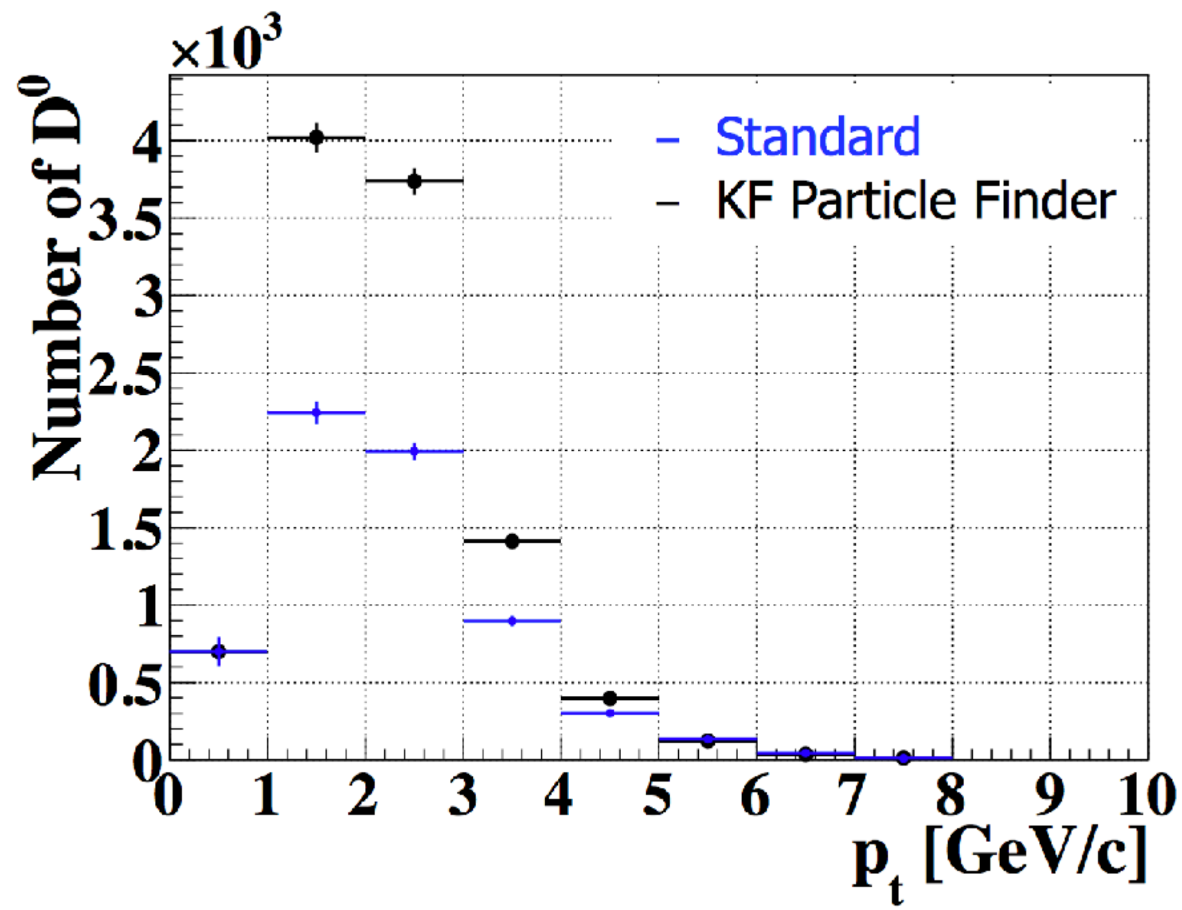
Standard reconstruction

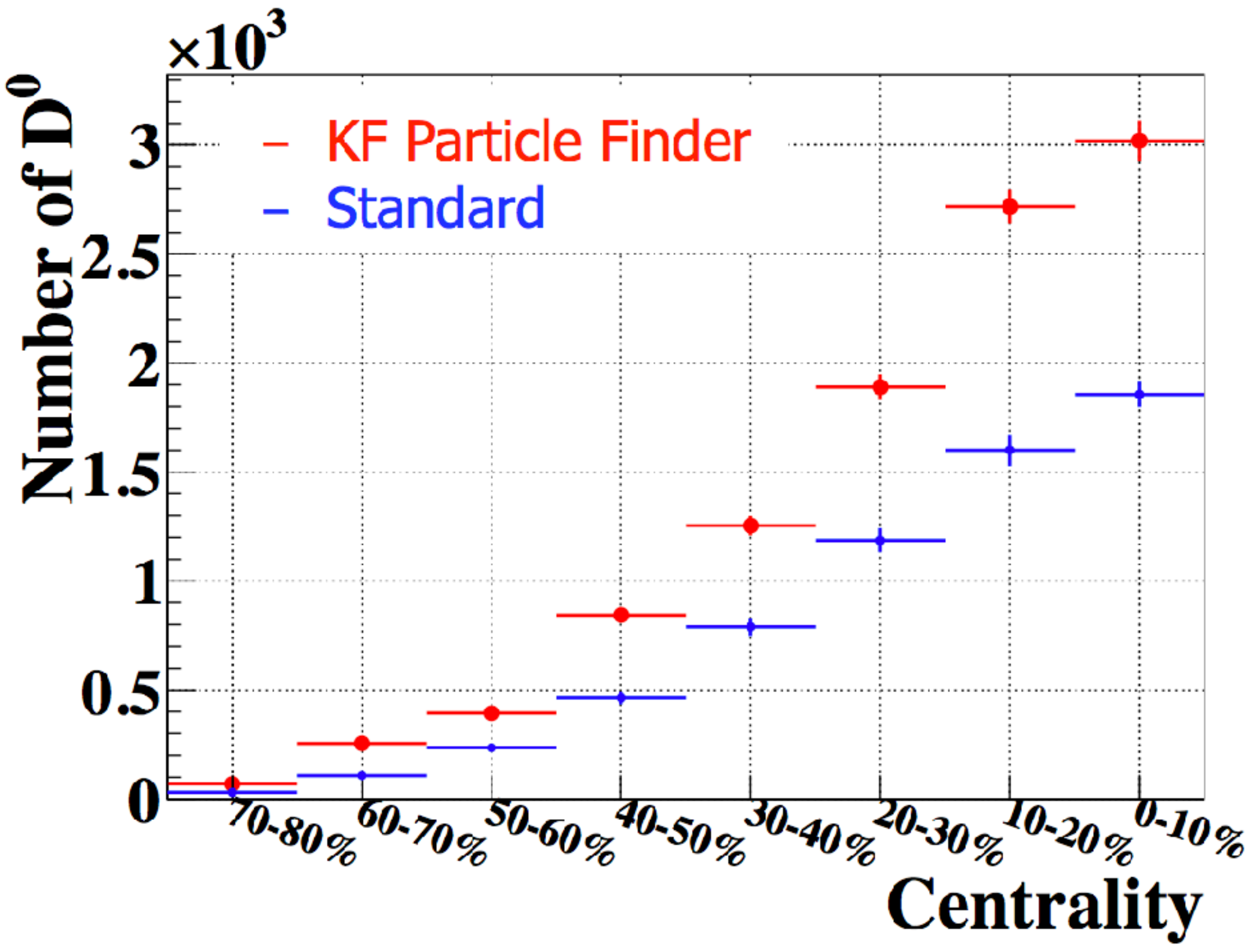


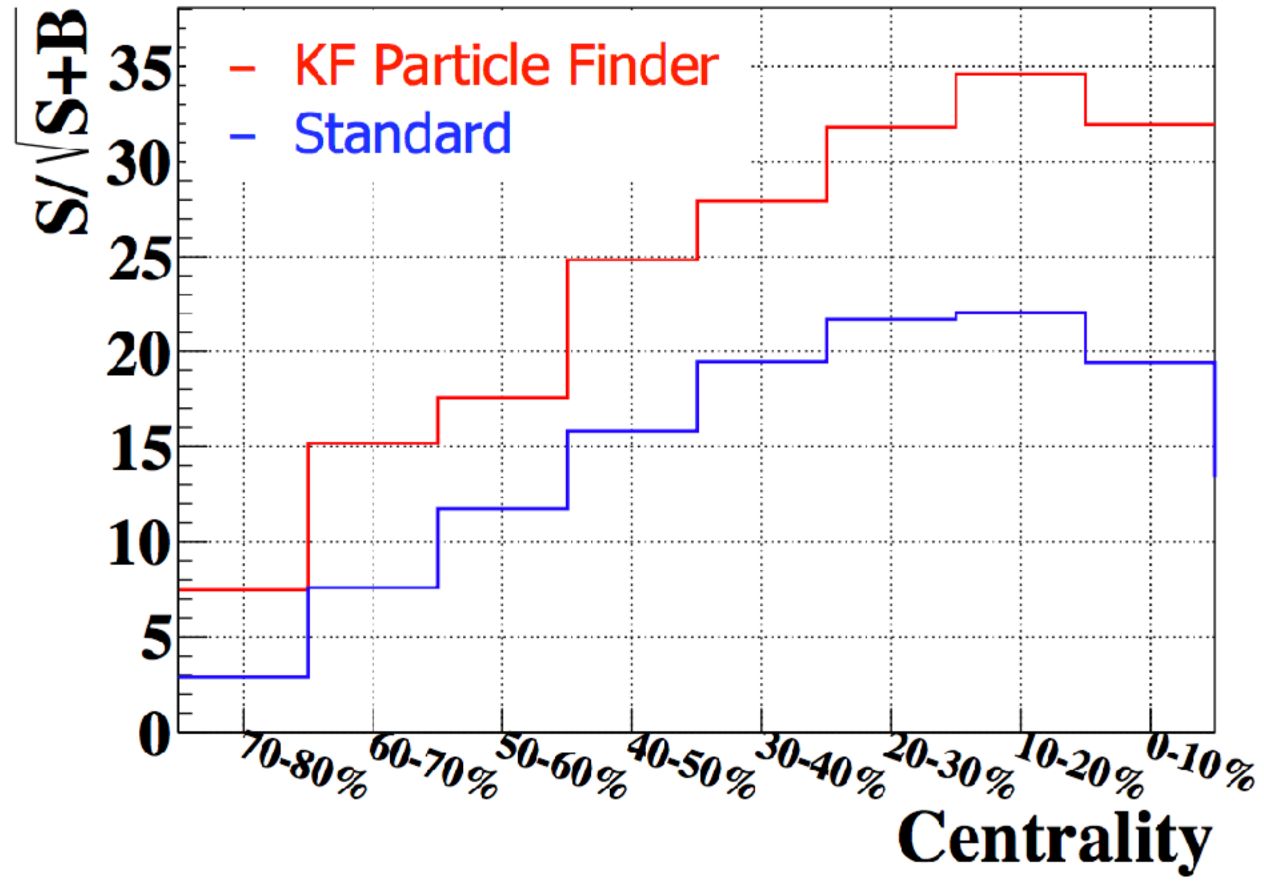
KF Particle Finder

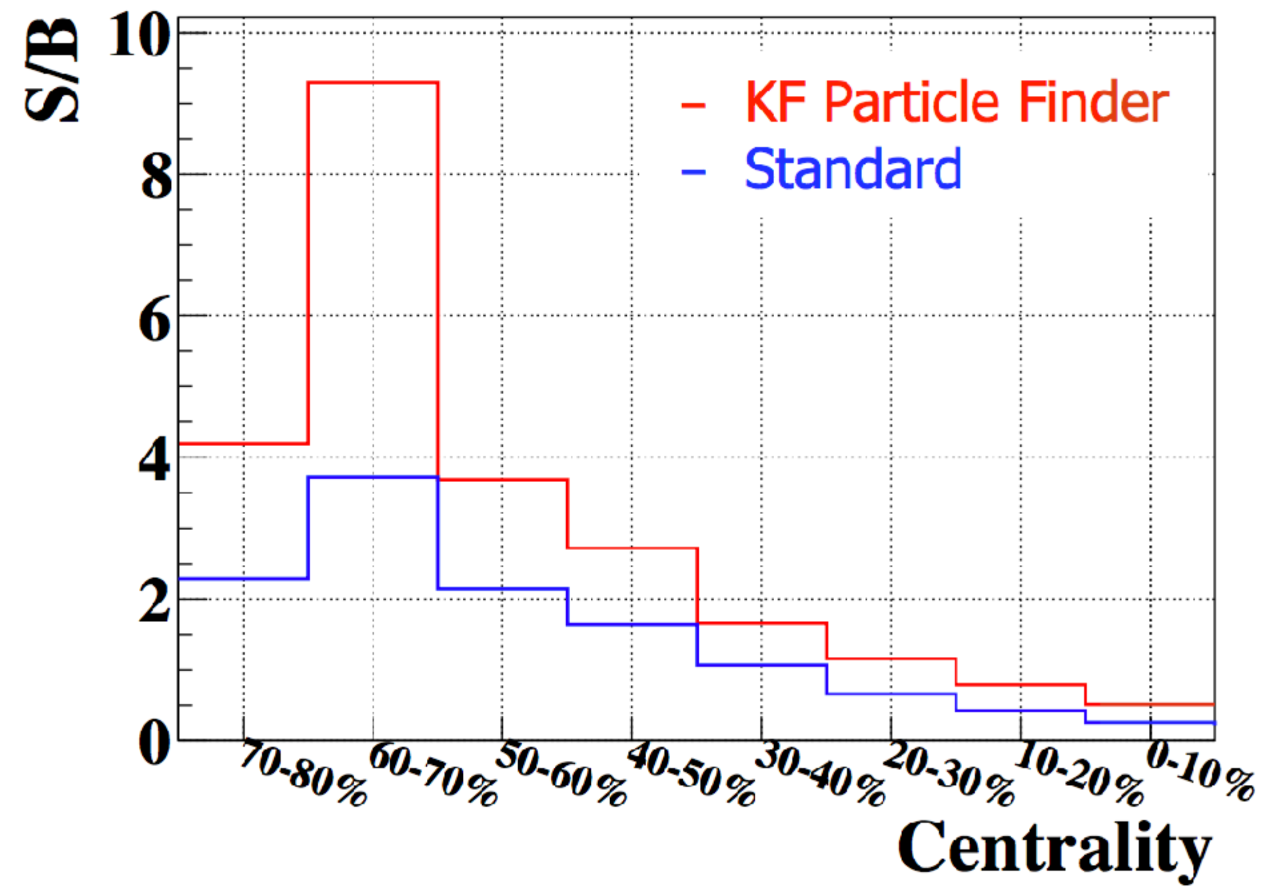












- Particle yields, significance, and signal to background ratios were studied as a function of centrality.
- KF Particle Finder allows to get improvement in all centrality regions.

Decay	year	Signal	Significance	p_t
$D^0 \to K\pi$	2014	10393	70	0-10 GeV/c
		5774	45	
$D^\pm \to K\pi\pi$	2014	1357	30	1-10 GeV/c
		774	25	
$\Lambda_c^\pm \to pK\pi$	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.

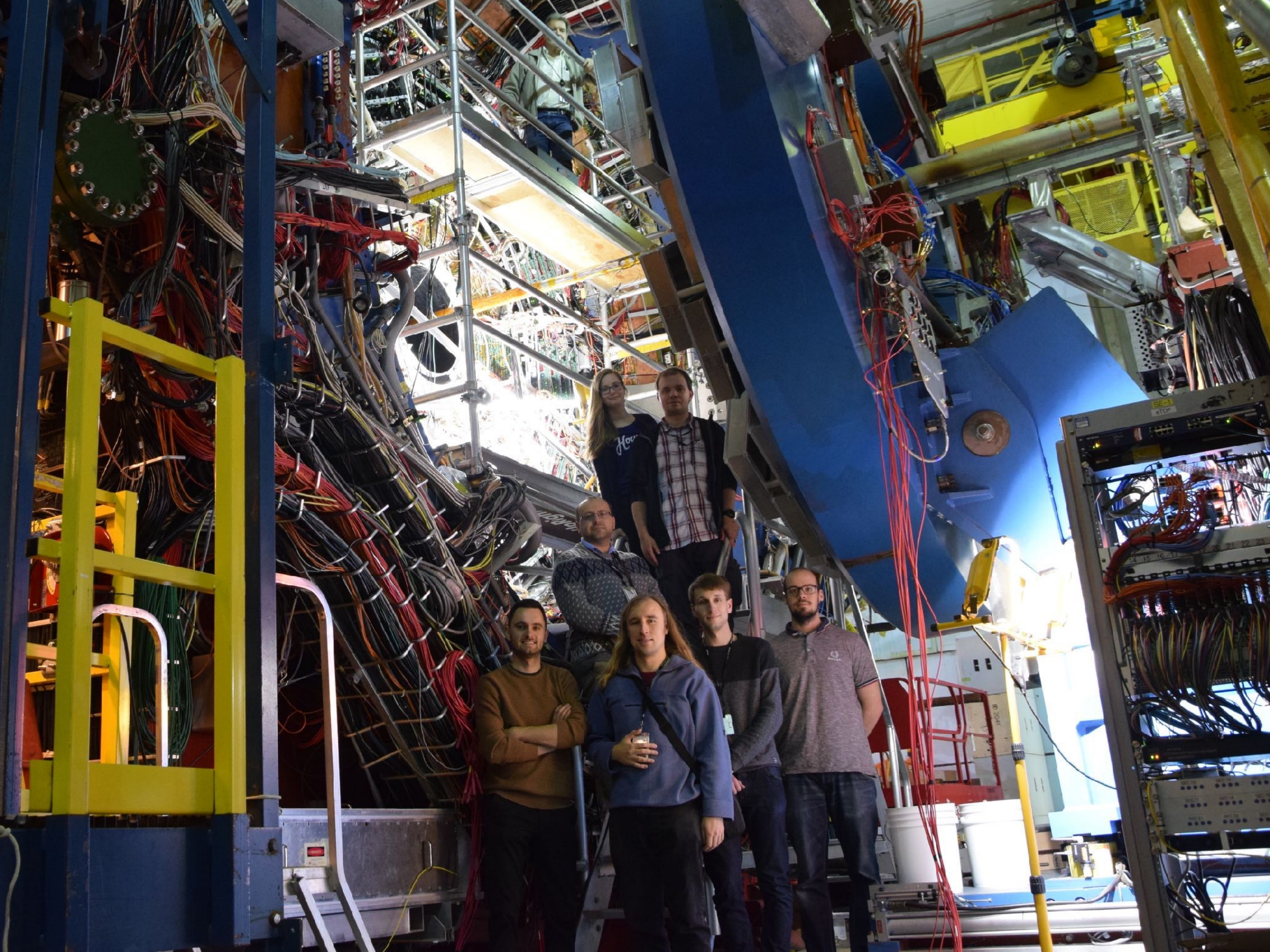
1. Performance comparison of D^0 and $D^\pm$ was done on selected same runs of year 2014. For $\Lambda_c^\pm$ the full statistics was used.
2. The standard method for $D^\pm$ gain of using low cut on p_t>0.3 GeV/c of the daughter particles. However, FemtoDst format does not allow to use low-pt tracks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

Summary

- TMVA procedure and results with KF Particle Finder were presented
- KF Particle Finder with TMVA optimization shows big improvements in significance
- KF Particle Finder vs Standard reconstruction methods was discussed


One more thing...

EJČF, rok nástupu 2012



The STARs

Thank You for EVERYTHING

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Miro Šimko

Miro Šaur

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