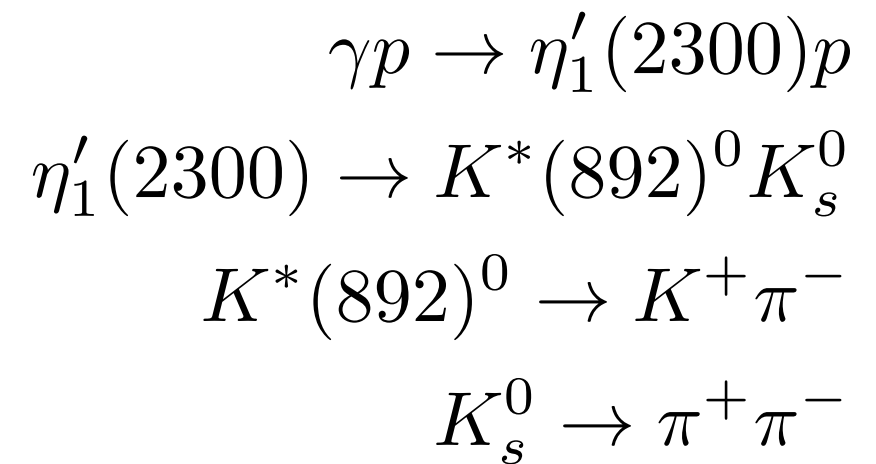
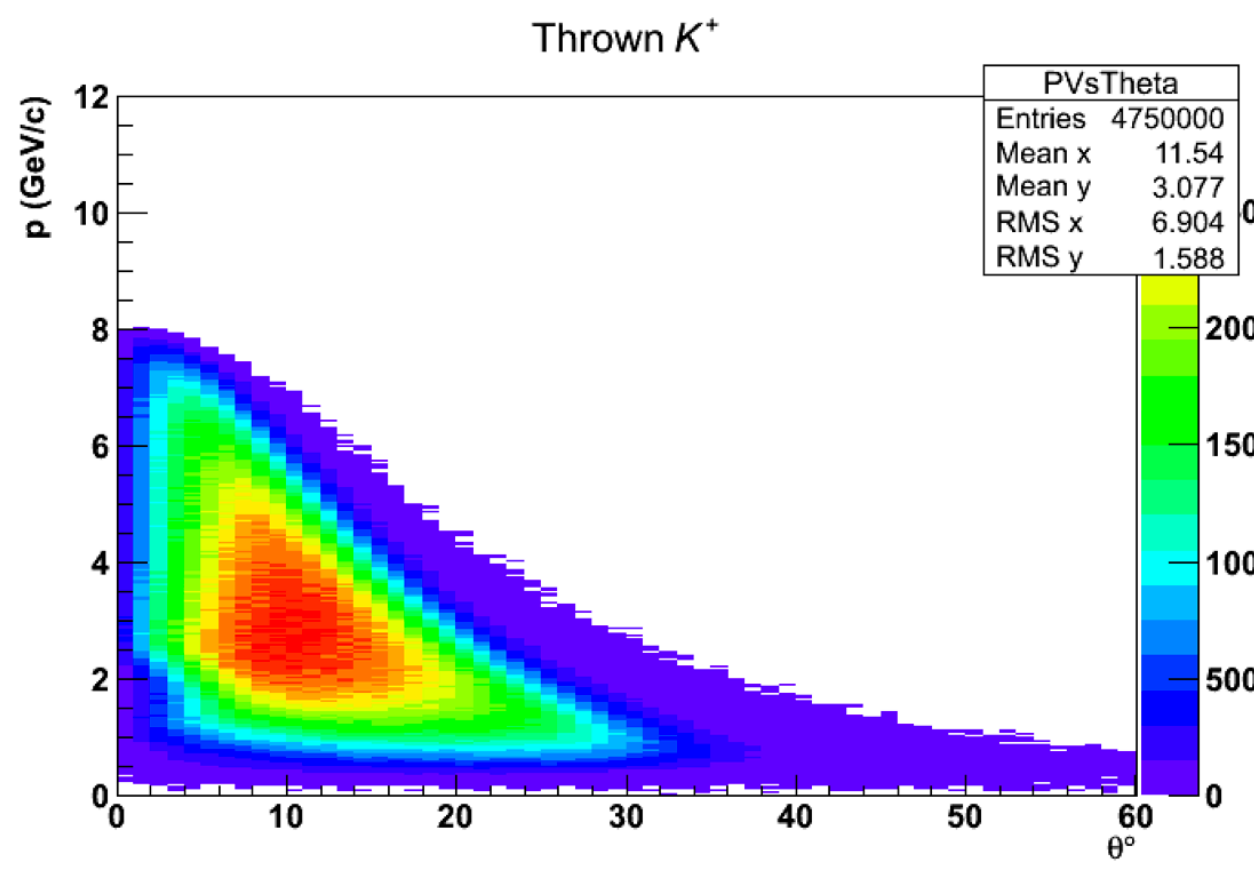


# Adding recoil proton reconstruction

Justin Stevens  
PID Upgrade Meeting: 3.8.13



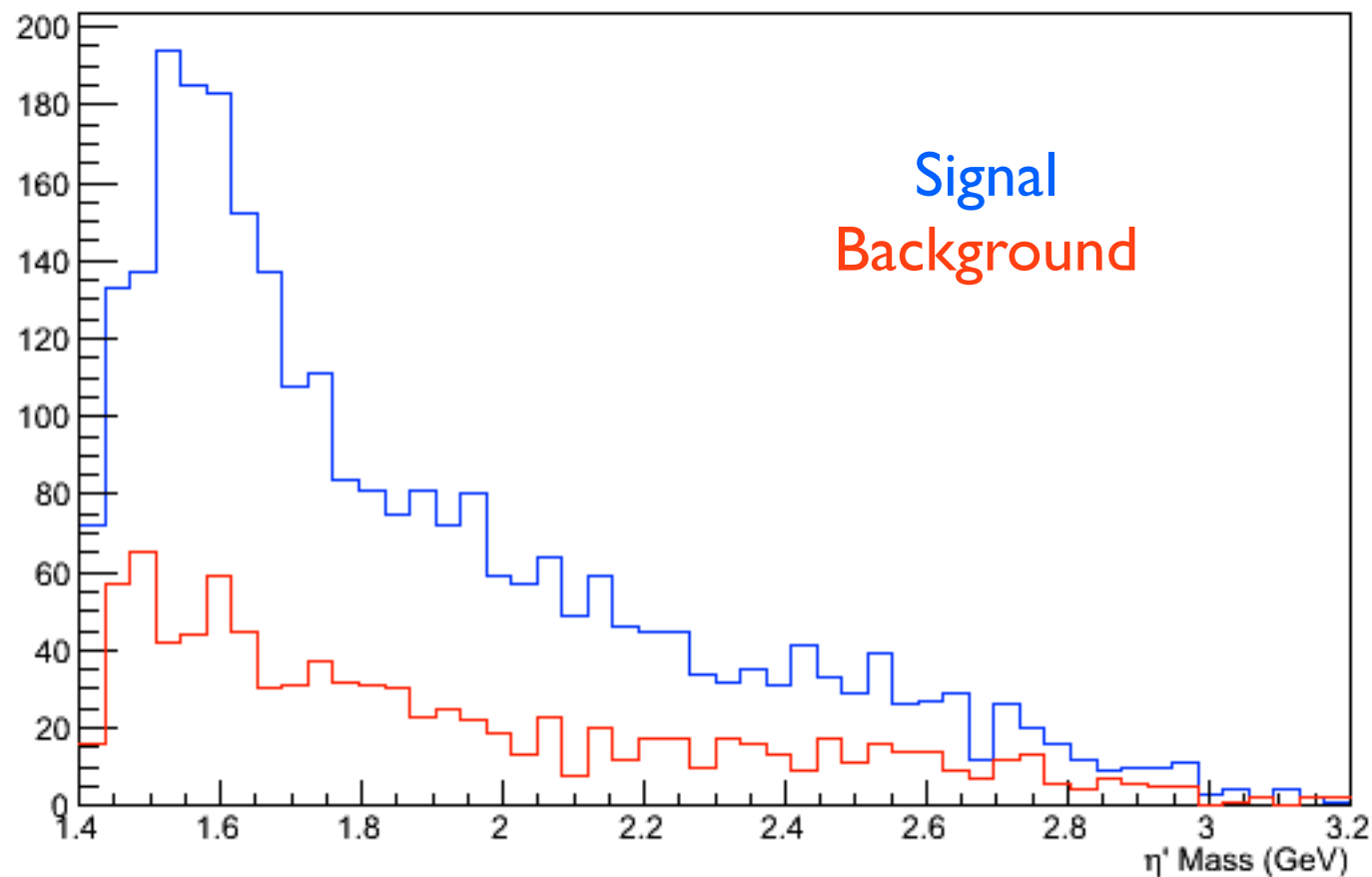
# Example: $\eta'(2300)$



- Data samples (data challenge bggen with  $8.4 < E_\gamma < 9$  GeV):
- Signal: Exclusive requirement on final state  $K^+, \pi^-, K_s \rightarrow \pi^+ \pi^-$
- Background: All bggen not satisfying signal requirement
- All particle combinations are considered with **no cuts** applied before the decision tree

# Missing proton reminder

$\eta'$  Candidate Mass



BDT Cut and  
 $\pm 1.5 \Gamma$  cut on  $K^*$  and  $\eta'$   
masses

Improve S/B by a factor  
of  $\sim 10$  with BDT!

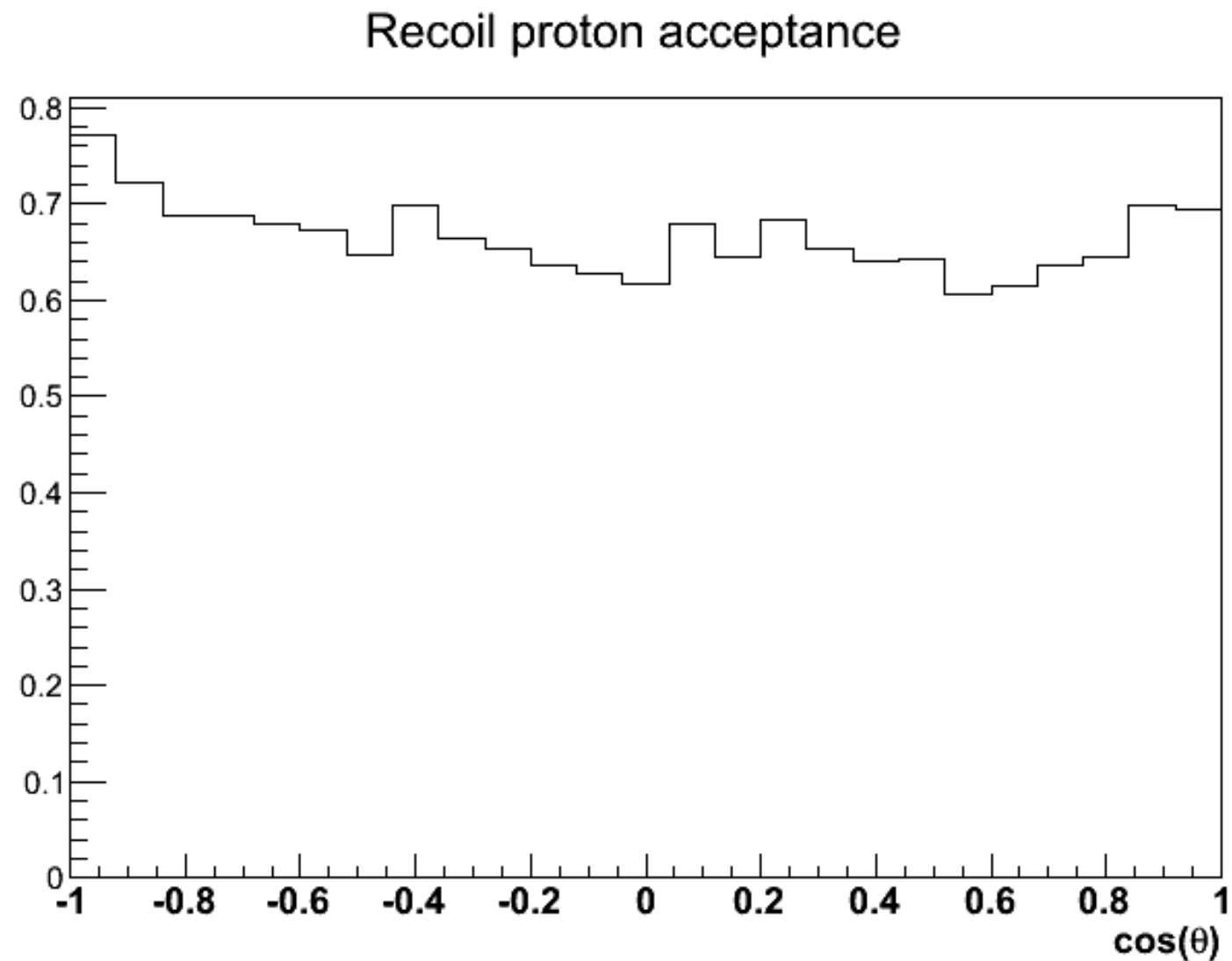
Analysis	Selection Efficiency	S/B
Cuts-based	0.10	0.24
BDT (compare cuts)	0.10	2.37

# Reminder of variables included in the BDT

- Kinematic Fit CL
- Primary vertex  $\chi^2$ : Quality of  $K_s K^+ \pi^-$  from a single point
- Secondary vertex  $\chi^2$ : Quality of  $\pi^+ \pi^-$  from a single point
- $K_s$  flight distance significance in R and Z (separately)
- $K_s$  impact parameter  $\chi^2$ : Change in PV  $\chi^2$  when particle removed from PV
- Isolation sums for track momenta, BCAL and FCAL energy
- For each track use:
  - $\chi^2$  from track fit
  - Time of flight CL
  - Track energy loss dE/dx CL
  - Impact parameter  $\chi^2$ : Change in PV  $\chi^2$  when particle removed from PV

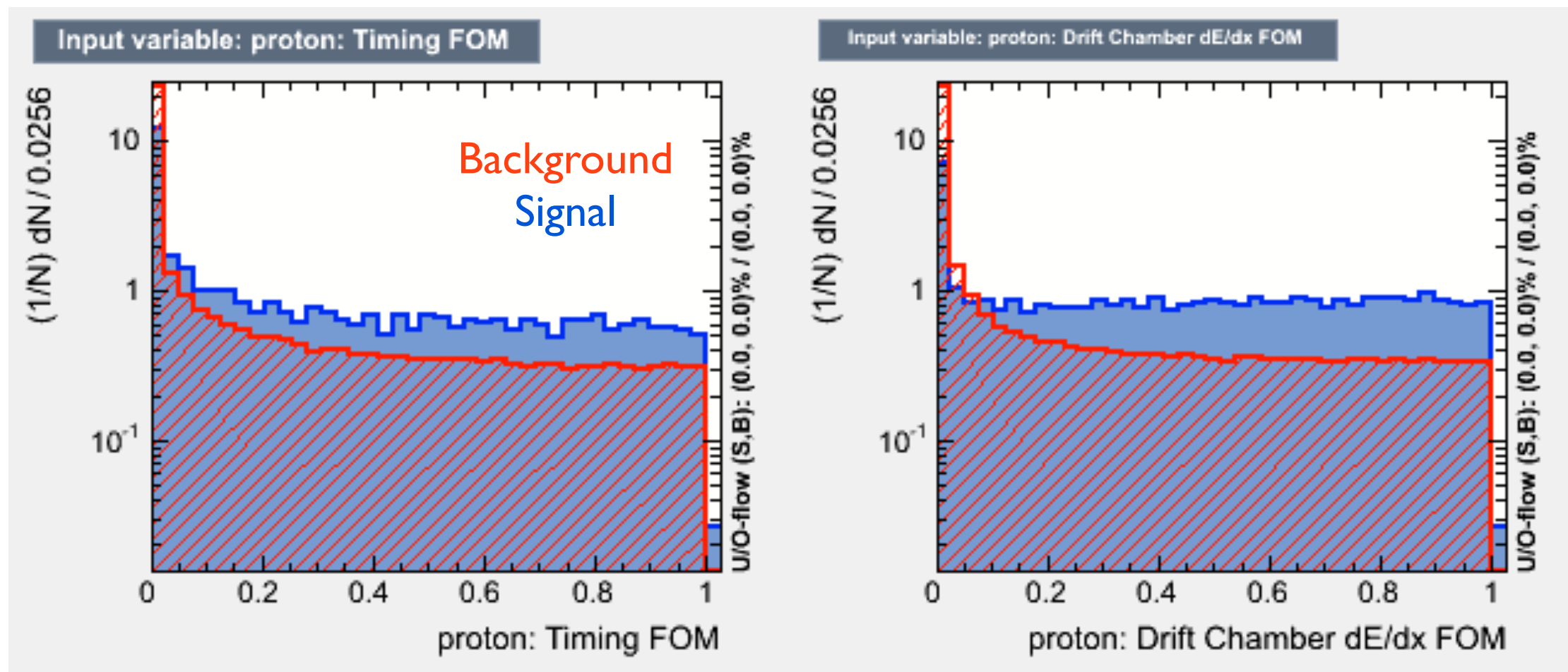
Same list as presented at collaboration meeting, but isolation cone definition changed to use track covariance matrix

# Recoil proton acceptance



- Proton acceptance of  $\sim 70\%$  (relative to missing proton analysis)
- No strong dependence for GJ angle

# Recoil Proton Input Distributions



Good discrimination from proton PID

# Variable ranking: Reco proton $\eta'$ (2300)

```

--- BDTG :-----
--- BDTG : Rank :Variable           :Variable Importance
--- BDTG :-----
--- BDTG : 1 : SV_flightSignificanceDelZ : 1.534e-01
--- BDTG : 2 : SV_flightSignificanceDelR : 1.273e-01
--- BDTG : 3 : p4_timeFOM                : 7.268e-02
--- BDTG : 4 : p5_dEdxFOM                : 5.785e-02
--- BDTG : 5 : p5_timeFOM                : 5.442e-02
--- BDTG : 6 : kinFitCL                  : 4.787e-02
--- BDTG : 7 : p1_timeFOM                : 4.701e-02
--- BDTG : 8 : p4_dEdxFOM                : 3.866e-02
--- BDTG : 9 : PV_r                      : 3.716e-02
--- BDTG : 10 : p1_dEdxFOM               : 3.504e-02
--- BDTG : 11 : p3_timeFOM               : 3.219e-02
--- BDTG : 12 : SV_ChiSq                 : 3.106e-02
--- BDTG : 13 : p2_timeFOM               : 2.971e-02
--- BDTG : 14 : p3_ChiSq                 : 2.335e-02
--- BDTG : 15 : chiSqKplusIP             : 2.137e-02
--- BDTG : 16 : p3_dEdxFOM               : 2.098e-02
--- BDTG : 17 : p2_ChiSq                 : 1.906e-02
--- BDTG : 18 : p5_ChiSq                 : 1.823e-02
--- BDTG : 19 : p2_dEdxFOM               : 1.753e-02
--- BDTG : 20 : chiSqPiMinusIP           : 1.745e-02
--- BDTG : 21 : isolatedTrackSumP        : 1.725e-02
--- BDTG : 22 : isolatedBCALSumE         : 1.648e-02
--- BDTG : 23 : PV_ChiSq                 : 1.572e-02
--- BDTG : 24 : p4_ChiSq                 : 1.476e-02
--- BDTG : 25 : p1_ChiSq                 : 1.451e-02
--- BDTG : 26 : chiSqKshortIP            : 1.090e-02
--- BDTG : 27 : isolatedFCALSumE         : 8.056e-03
--- BDTG :-----

```

Particle codes:

p1 =  $\pi^+$  (Ks)

p2 =  $\pi^-$  (Ks)

p3 =  $\pi^-$  (K\*)

p4 =  $K^+$  (K\*)

p5 = proton

Highest ranked variables:

Kinematic Fit

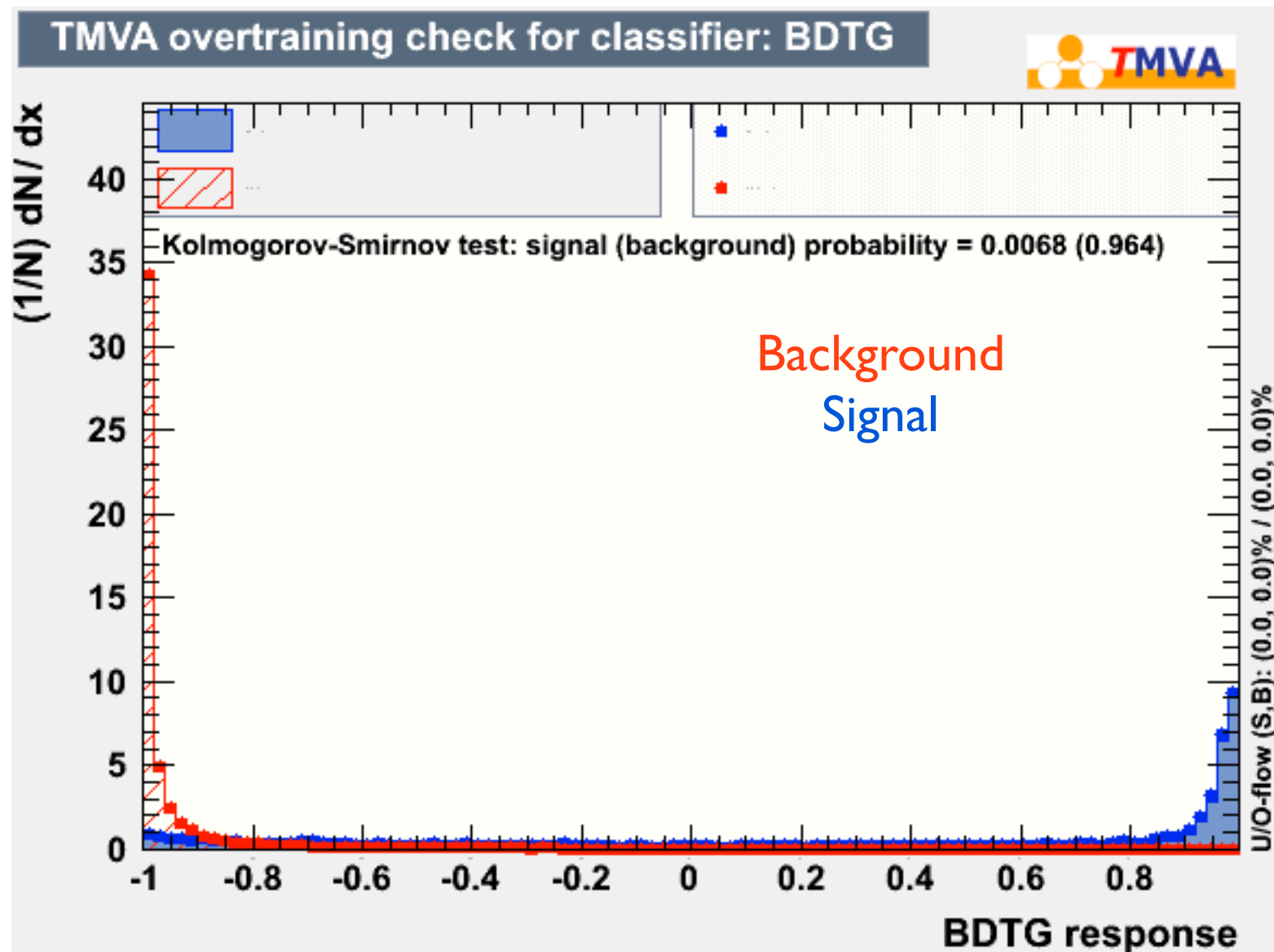
Secondary vertex

displacement

PID information

$\chi^2$  variables

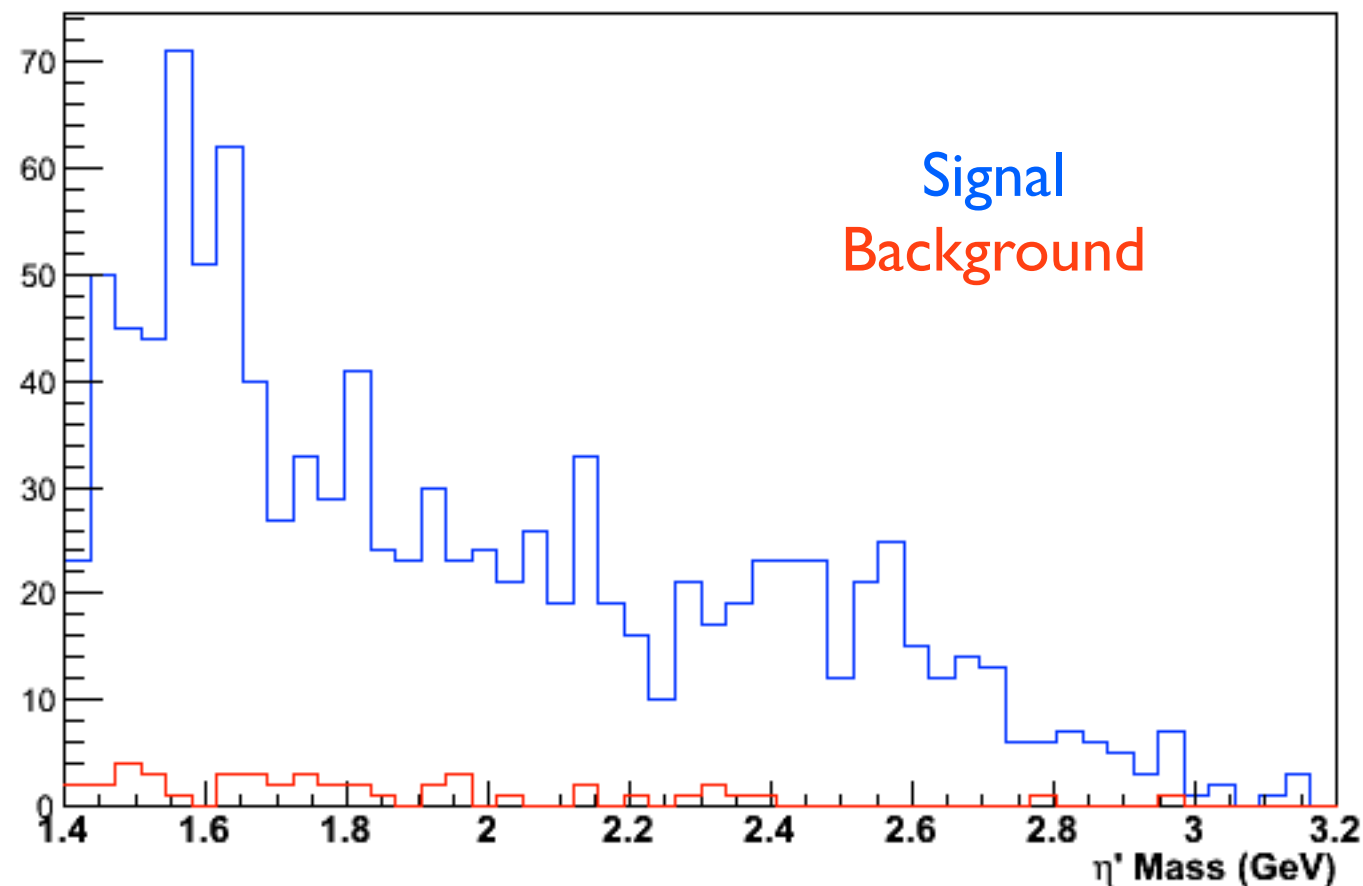
# Reco proton $\eta'$ (2300)





# Reco proton $\eta'$ (2300)

$\eta'$  Candidate Mass

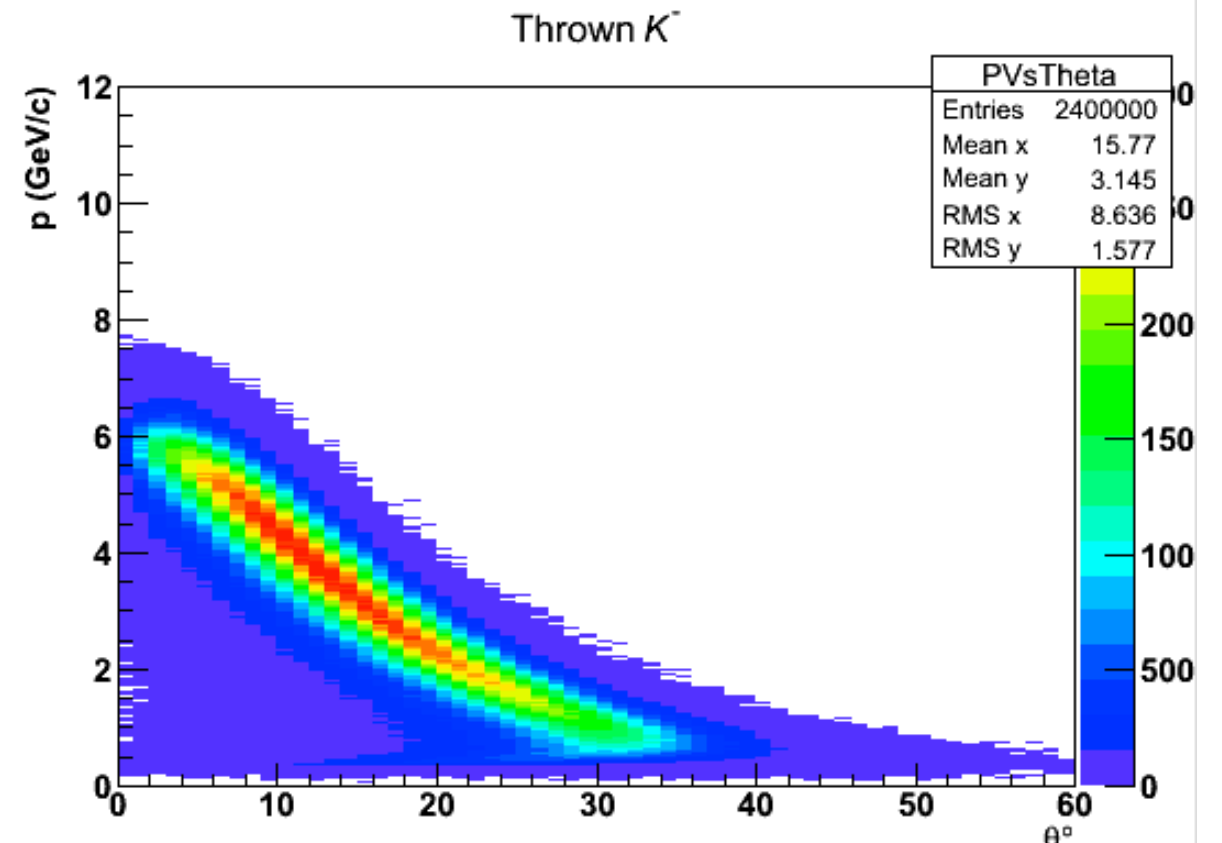
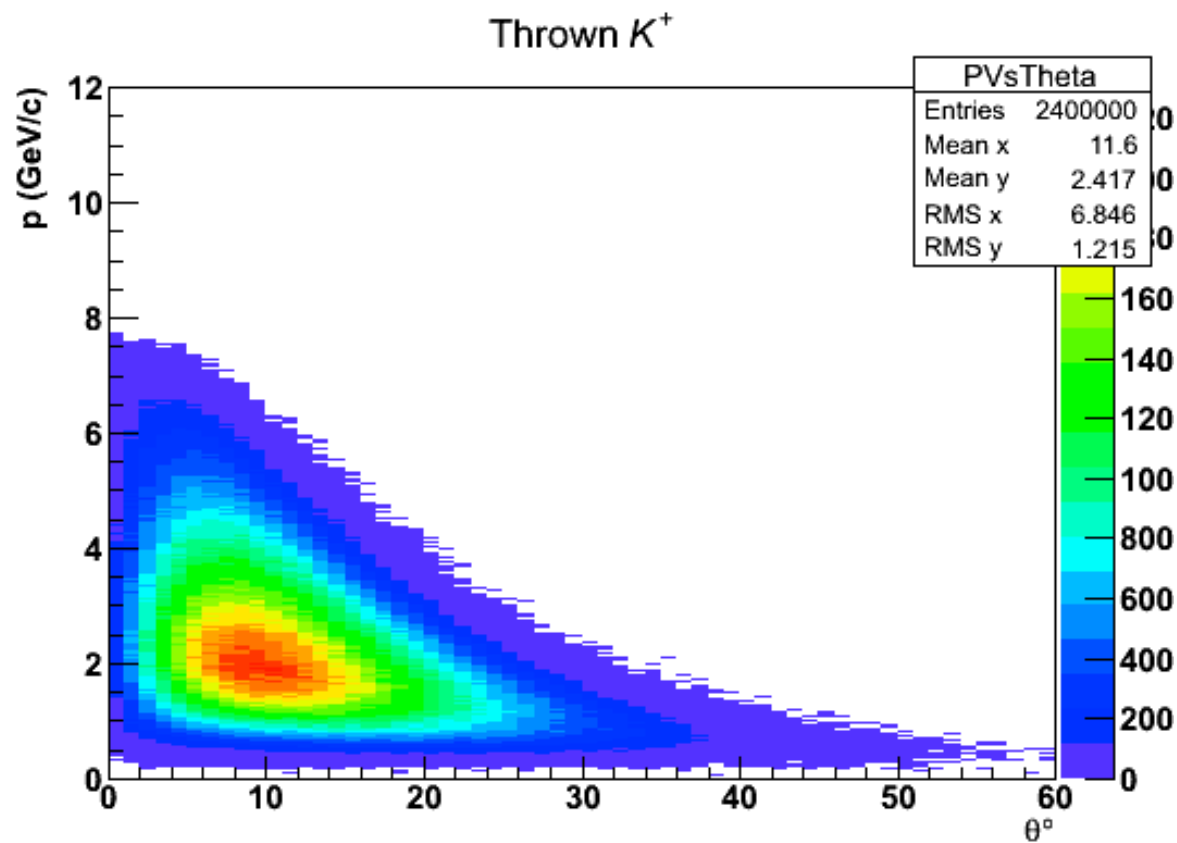


BDT Cut and  
 $\pm 1.5 \Gamma$  cut on  $K^*$  and  $\eta'$   
masses

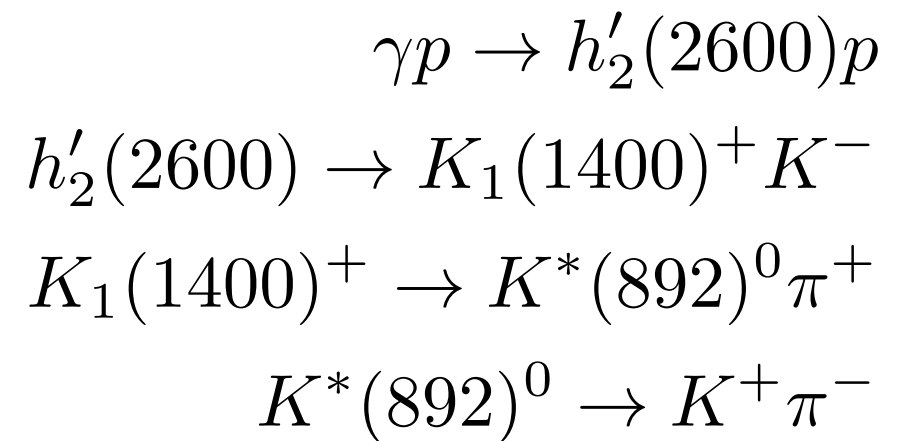
Improve S/B by a factor  
of  $\sim 6$  with BDT!

Analysis	Selection Efficiency	S/B
Cuts-based	0.05	5.51
BDT (compare cuts)	0.05	32.5

# Example: $h'(2600)$

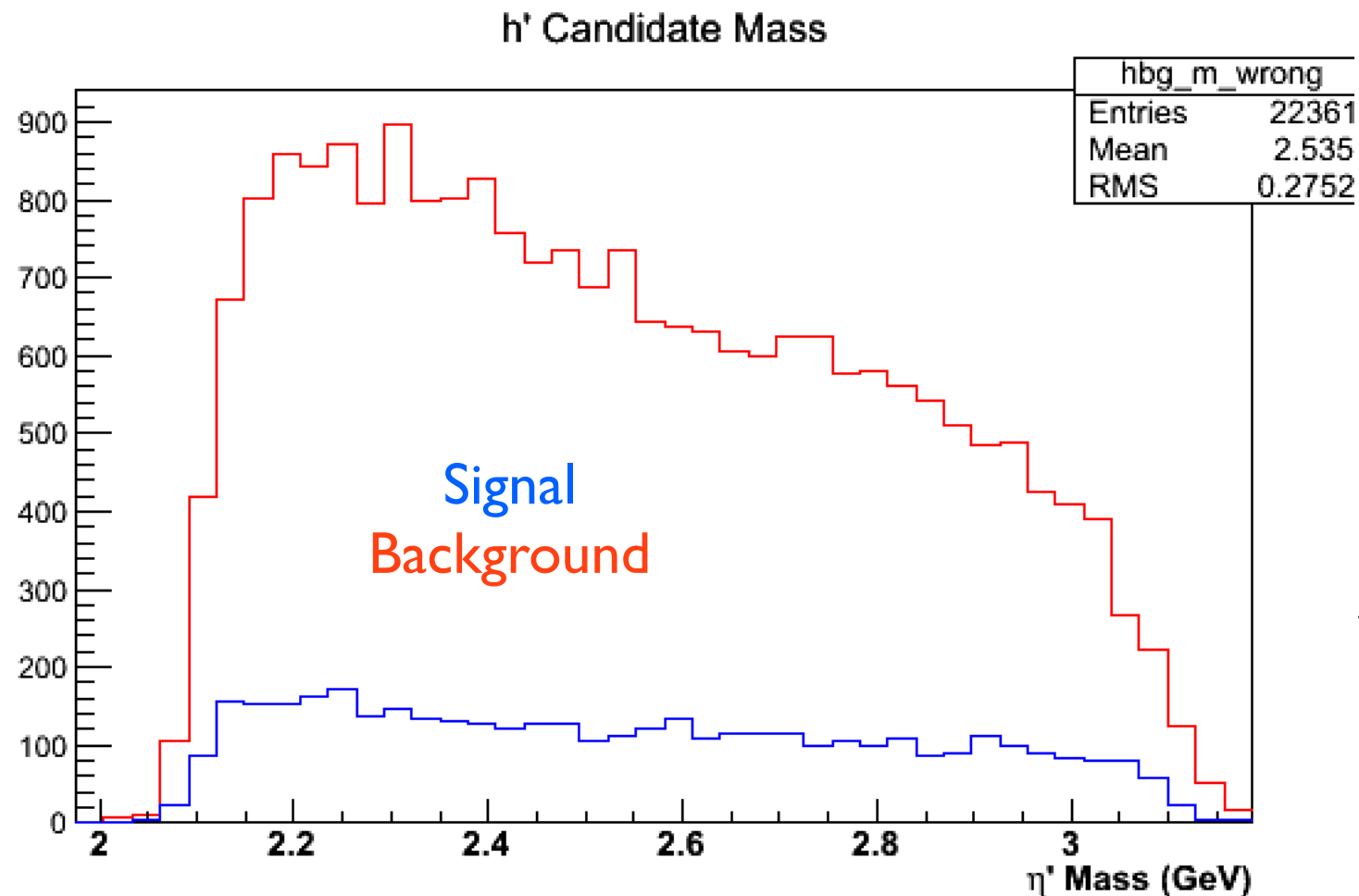


- Data samples (data challenge bggen with  $8.4 < E_\gamma < 9$  GeV):
- Signal: Exclusive requirement on final state  $K^+, K^-, \pi^+, \pi^-$
- Background: All bggen not satisfying signal requirement
- All particle combinations are considered with **no cuts** applied before the decision tree



**Note:** No displaced vertex!

# Missing proton reminder



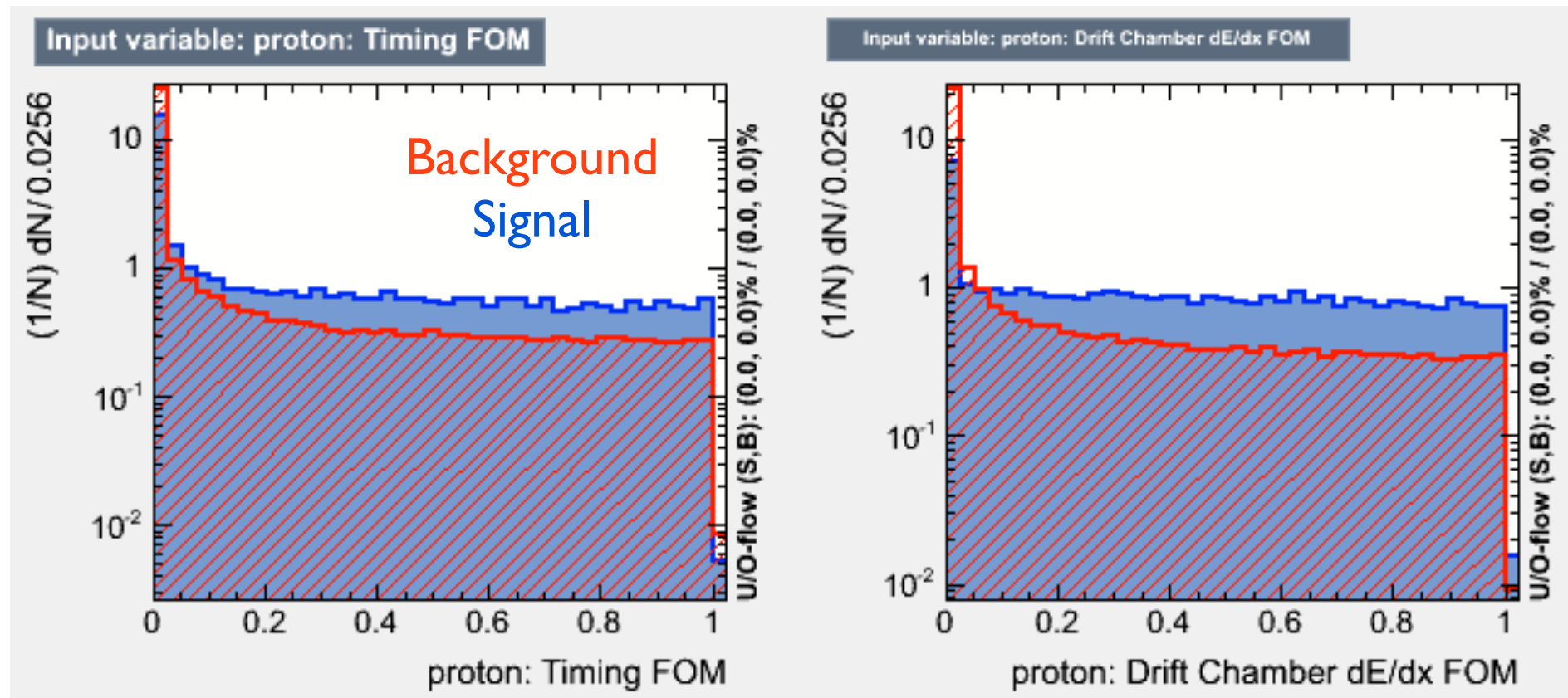
BDT Cut and  
 $\pm 1.5 \Gamma$  cut on  $K_L, K^*$  and  $h'$  masses

Improve S/B by factor of  $\sim 3$

Additional PID info needed to analyze this  
decay channel?

Analysis	Selection Efficiency	S/B
Cuts-based	0.04	0.06
BDT (compare cuts)	0.04	0.18

# Recoil Proton Input Distributions



Good discrimination from proton PID

# Variable ranking

## Reco proton h` (2600)

```

--- BDTG :-----
--- BDTG : Rank :Variable      :Variable Importance
--- BDTG :-----
--- BDTG : 1 : p3_timeFOM      :9.033e-02
--- BDTG : 2 : p5_dEdxFOM      :7.450e-02
--- BDTG : 3 : kinFitCL        :7.118e-02
--- BDTG : 4 : p5_timeFOM      :5.606e-02
--- BDTG : 5 : p4_timeFOM      :5.493e-02
--- BDTG : 6 : PV_r            :5.487e-02
--- BDTG : 7 : PV_ChiSq        :4.957e-02
--- BDTG : 8 : p1_dEdxFOM      :4.543e-02
--- BDTG : 9 : p4_dEdxFOM      :4.506e-02
--- BDTG :10 : p3_dEdxFOM      :4.450e-02
--- BDTG :11 : p1_timeFOM      :4.148e-02
--- BDTG :12 : chiSqPiPlusIP   :4.032e-02
--- BDTG :13 : chiSqPiMinusIP  :3.651e-02
--- BDTG :14 : p1_ChiSq        :3.468e-02
--- BDTG :15 : p2_ChiSq        :3.100e-02
--- BDTG :16 : p4_ChiSq        :2.941e-02
--- BDTG :17 : p5_ChiSq        :2.890e-02
--- BDTG :18 : p2_timeFOM      :2.600e-02
--- BDTG :19 : isolatedTrackSumP :2.549e-02
--- BDTG :20 : p2_dEdxFOM      :2.430e-02
--- BDTG :21 : chiSqKminusIP   :2.287e-02
--- BDTG :22 : p3_ChiSq        :2.183e-02
--- BDTG :23 : isolatedBCALSumE :2.013e-02
--- BDTG :24 : chiSqKplusIP    :1.861e-02
--- BDTG :25 : isolatedFCALSumE :1.203e-02
--- BDTG :-----

```

Particle codes:

p1 =  $\pi^+$

p2 =  $\pi^-$

p3 =  $K^+$

p4 =  $K^-$

p5 = proton

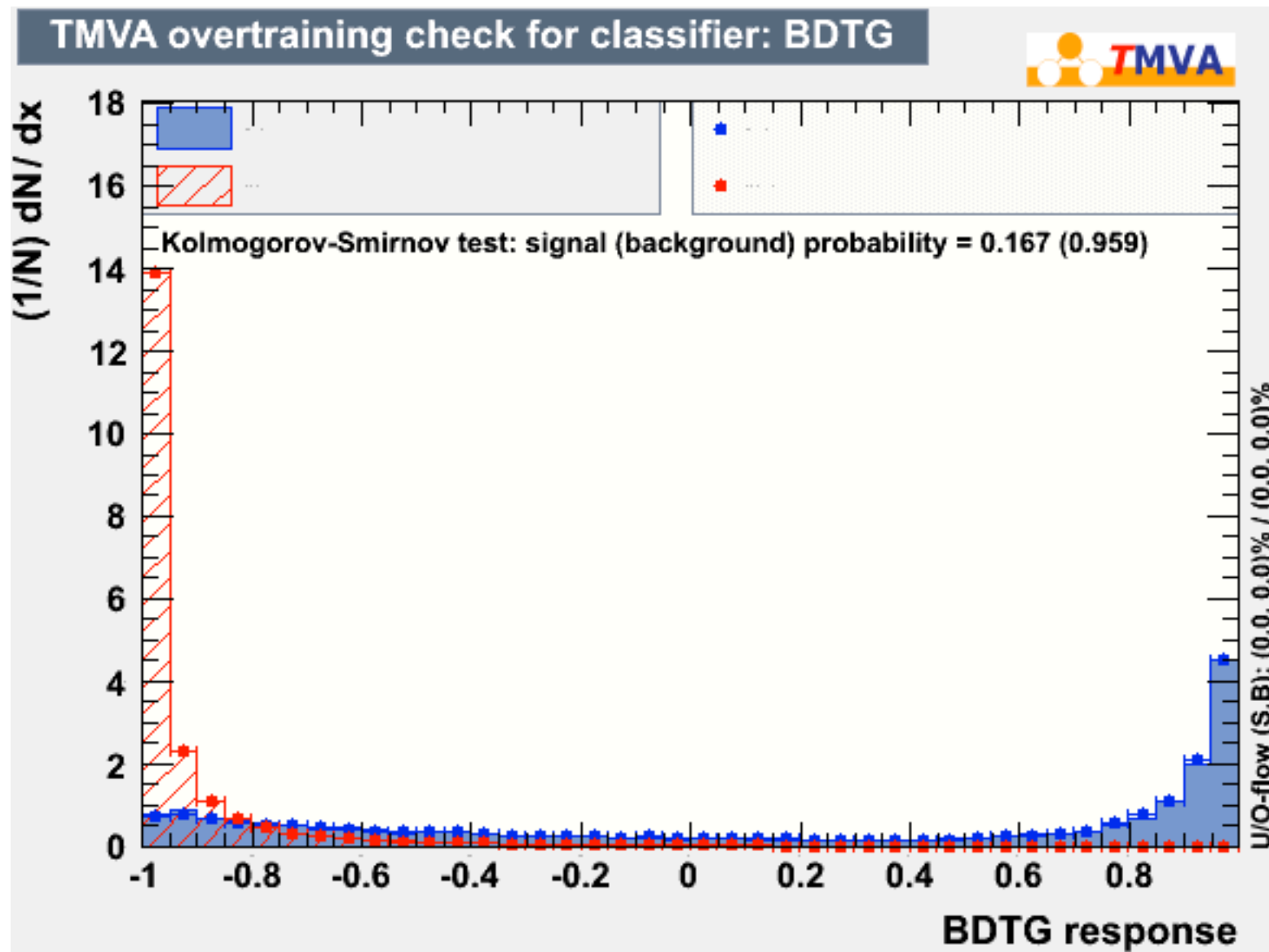
Highest ranked variables:

**Kinematic Fit**

**PID information**

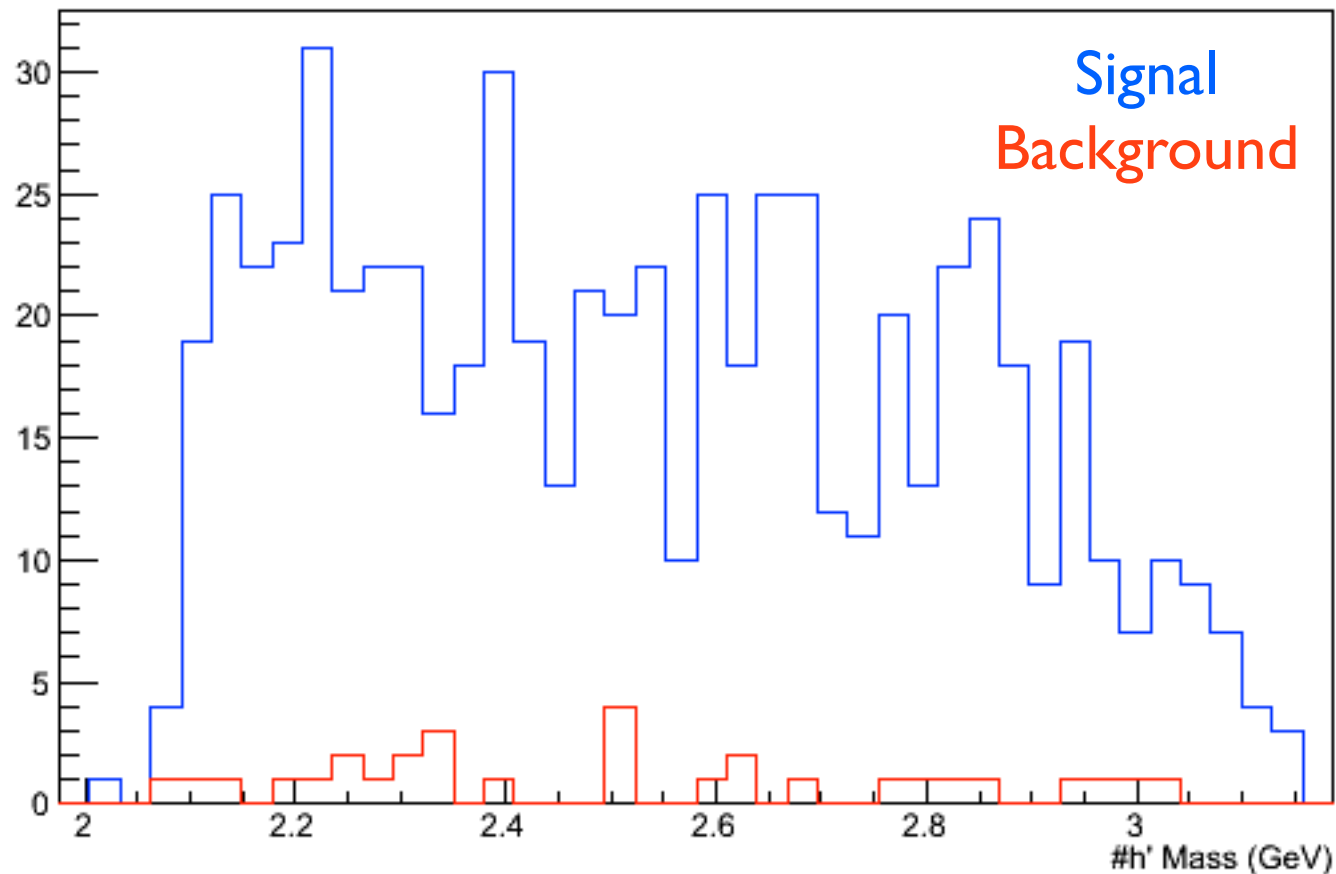
**$\chi^2$  variables**

# Reco proton $h'$ (2600)



# Reco Proton Results

h' Candidate Mass



BDT Cut and  
 $\pm 1.5 \Gamma$  cut on  $K_1, K^*$  and  $h'$  masses

Improve S/B by factor of  $\sim 3$  with BDT

Possibly accessible without additional PID!  
But is the efficiency too low?

Analysis	Selection Efficiency	S/B
Cuts-based	0.02	8.6
BDT (compare cuts)	0.02	26.8

# Some rough “topology” yield estimates

	missing proton	reco proton
$\eta'$ (2300)	$\sim 0.88$ M	$\sim 0.36$ M
$h'$ (2600)	$\sim 1.75$ M	$\sim 0.82$ K

- Integrate signal yields in the expected hybrid mass ranges from the previous slides (for reco proton with BDT have S/B  $\sim 30$ )
- Scale signal yields from this small sample to 220 PAC days with 70% uptime at  $10^8$  photons/s



# Summary

- Significant reduction in background when using reconstructed recoil proton
- Lower efficiency but possibly viable without additional PID
- Analyzing larger statistics to better quantify
- Next steps:
  - Add Cherenkov detector performance (John's study) to BDT
  - Other channels?

# Backup

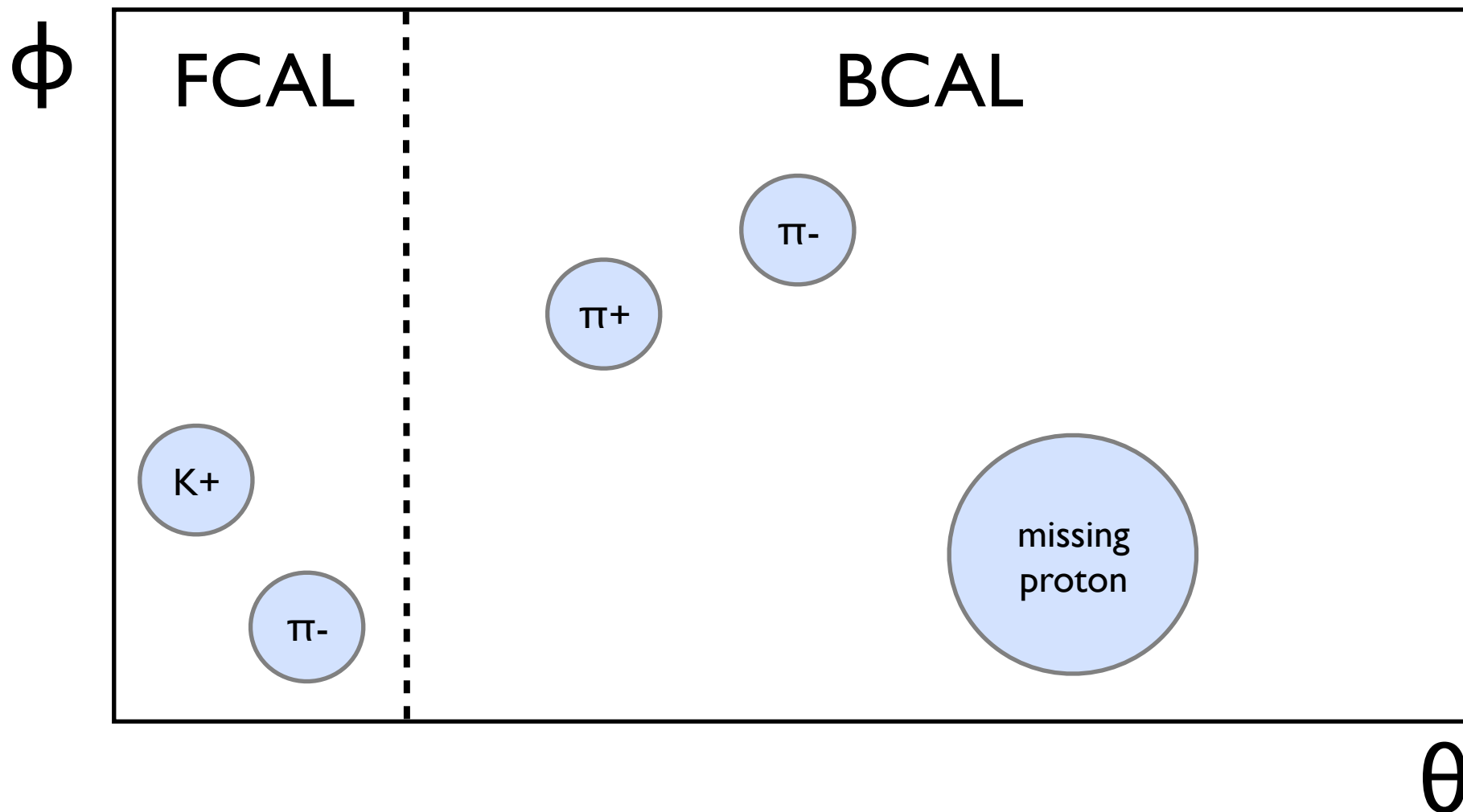
# Variables included in the BDT

- Kinematic Fit CL
- Primary vertex  $\chi^2$ : Quality of  $K_s K^+ \pi^-$  from a single point
- Secondary vertex  $\chi^2$ : Quality of  $\pi^+ \pi^-$  from a single point
- $K_s$  flight distance significance in R and Z (separately)
- $K_s$  impact parameter  $\chi^2$ : Change in PV  $\chi^2$  when particle removed from PV
- Isolation sums for track momenta, BCAL and FCAL energy (next slide)
- For each track use:
  - $\chi^2$  from track fit
  - Time of flight CL
  - Track energy loss  $dE/dx$  CL
  - Impact parameter  $\chi^2$ : Change in PV  $\chi^2$  when particle removed from PV

## Notes:

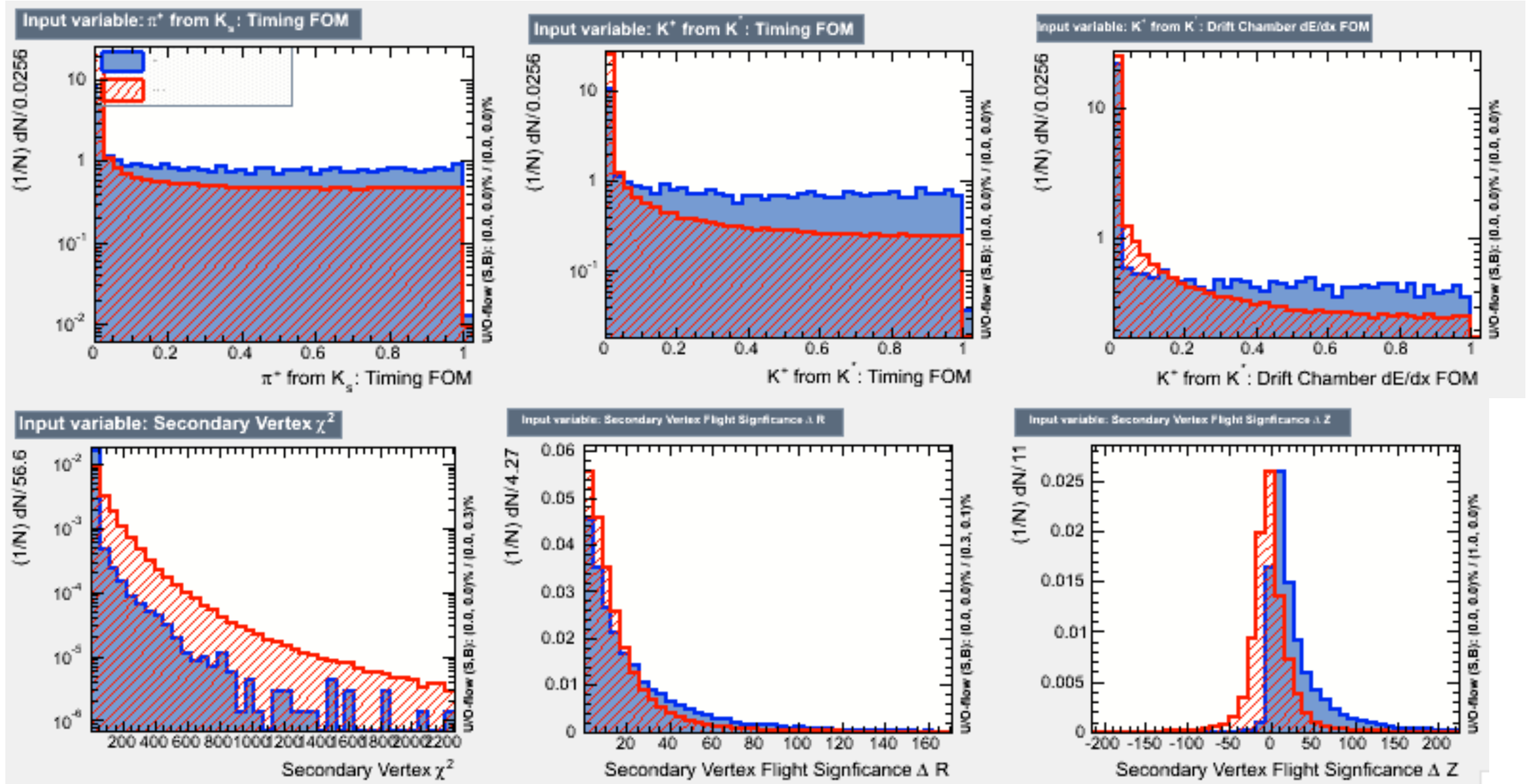
- No Cherenkov detectors added at this point
- No problem with adding too many variables, less useful variables simply don't branch the decision tree

# Isolation Variables

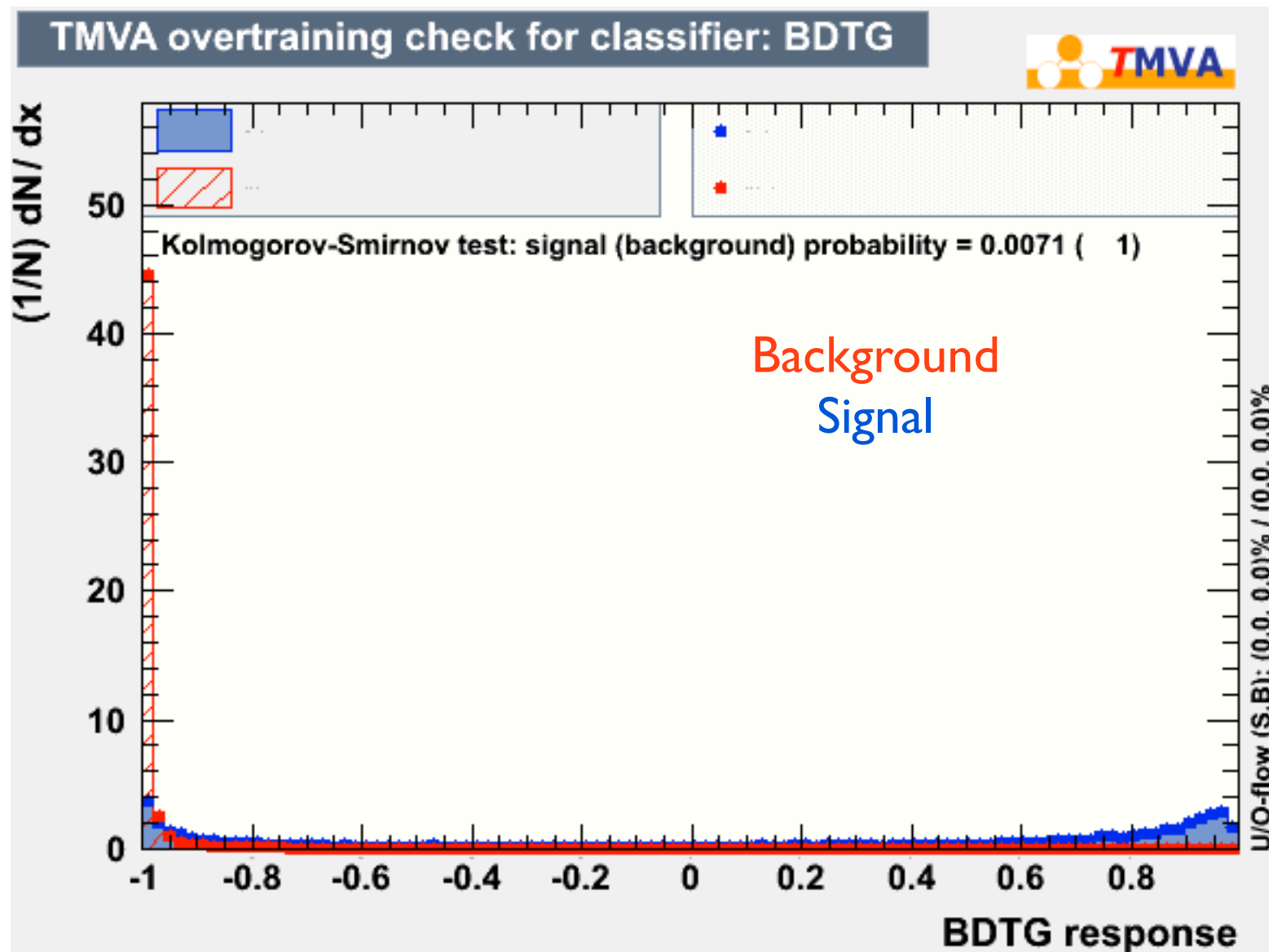


- Motivation: identify backgrounds with extra charged track or neutral outside of the desired topology
- Use covariance matrices for reconstructed tracks to identify a “cone” around each track which we exclude ECAL showers within

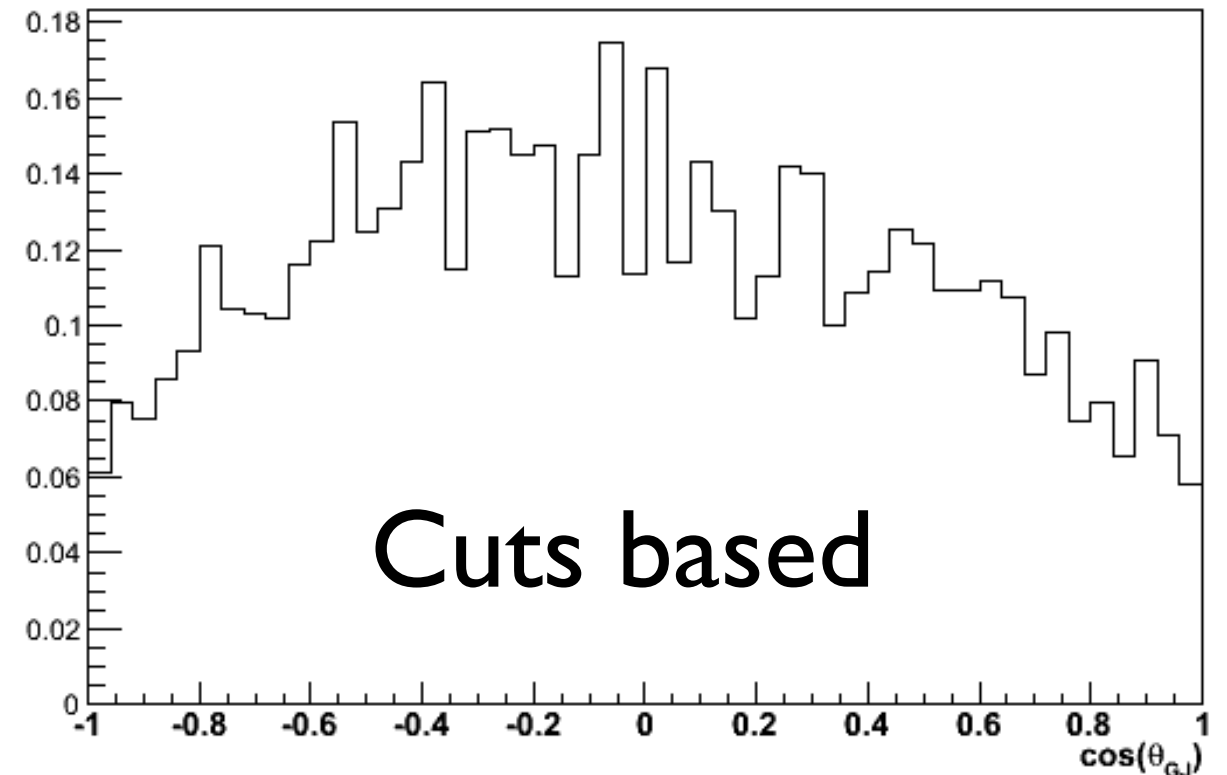
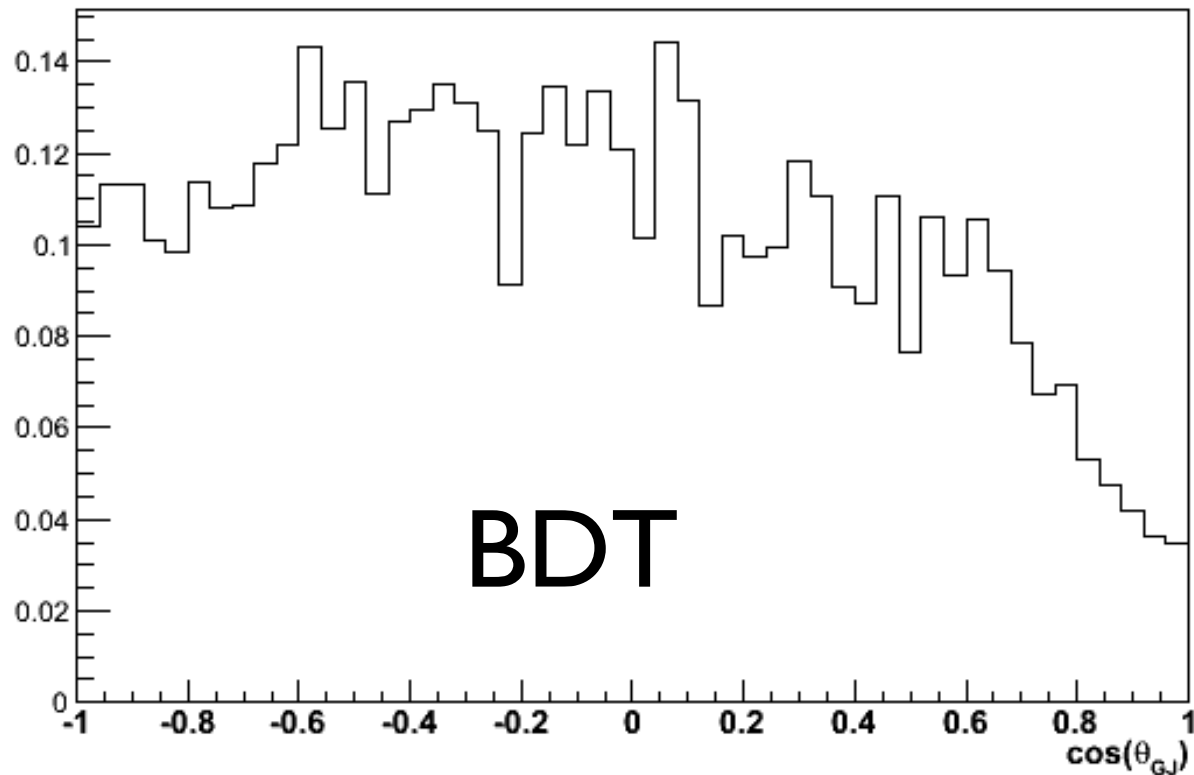
# Input distributions



# Missing proton $\eta'$ (2300)



# Angular Acceptance

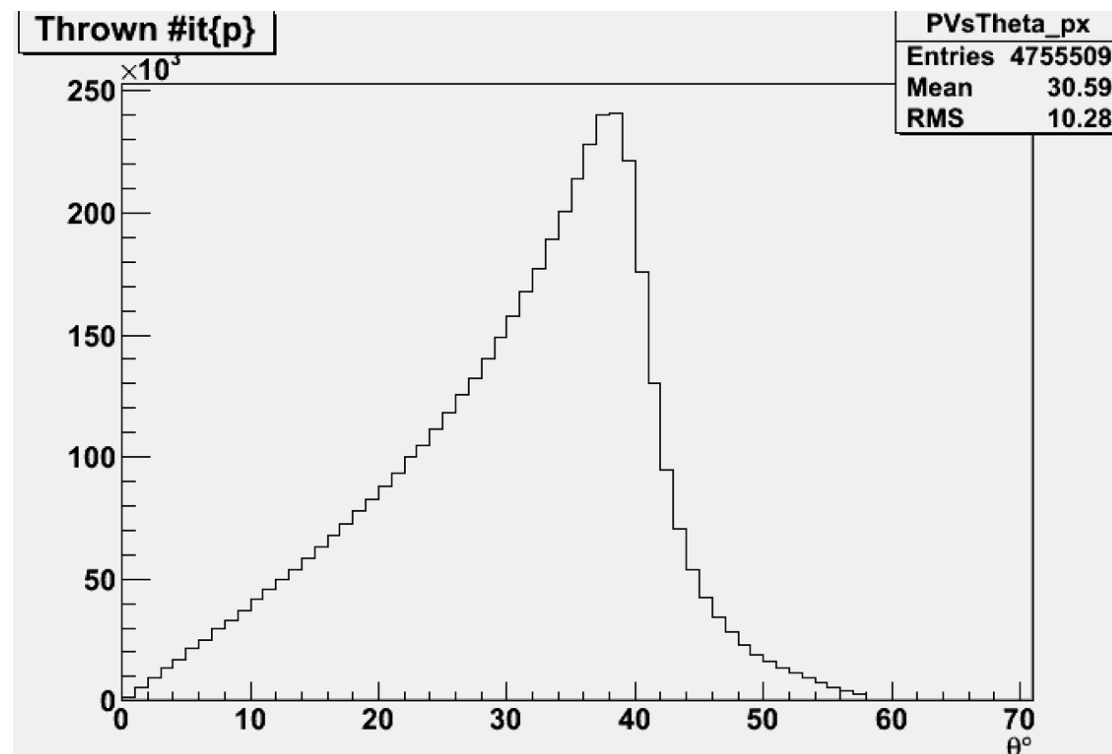
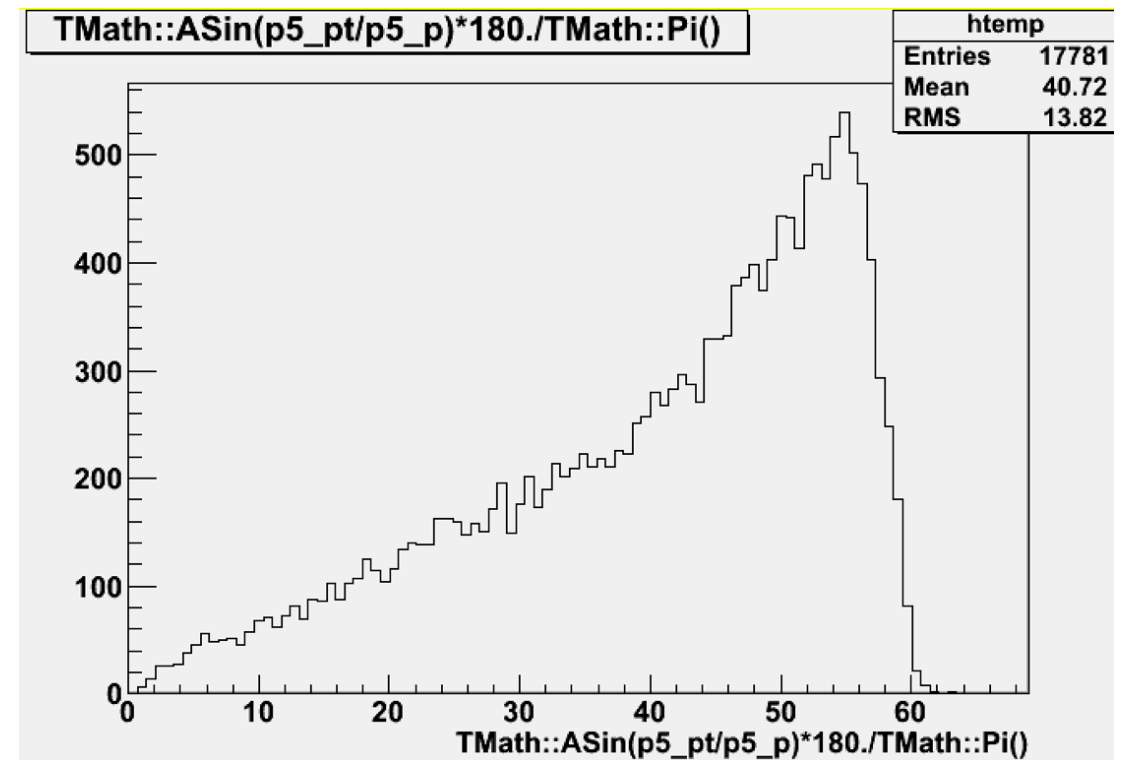
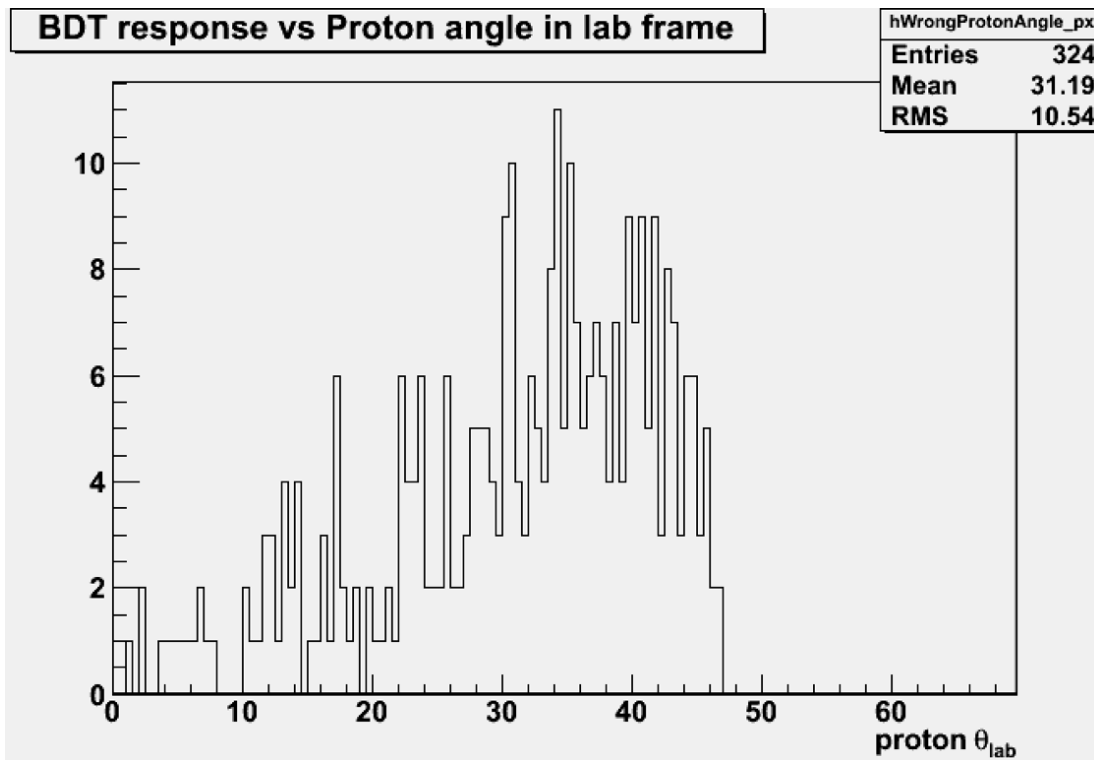


- In this case the “flatness” of the acceptance vs GJ angle is comparable to that of the cuts based, but may not be true for all BDT selection
- We’ve developed a procedure to include a “smooth” out the acceptance in the boosting procedure to maintain uniform acceptance

# Proton angle

Missing proton  $\theta$  for non-topology  $\eta'$  candidates which passed the BDT cut

Reconstructed proton  $\theta$  for all true topology  $\eta'$  events



Thrown proton  $\theta$  from  $\eta'$  hybrid MC generator