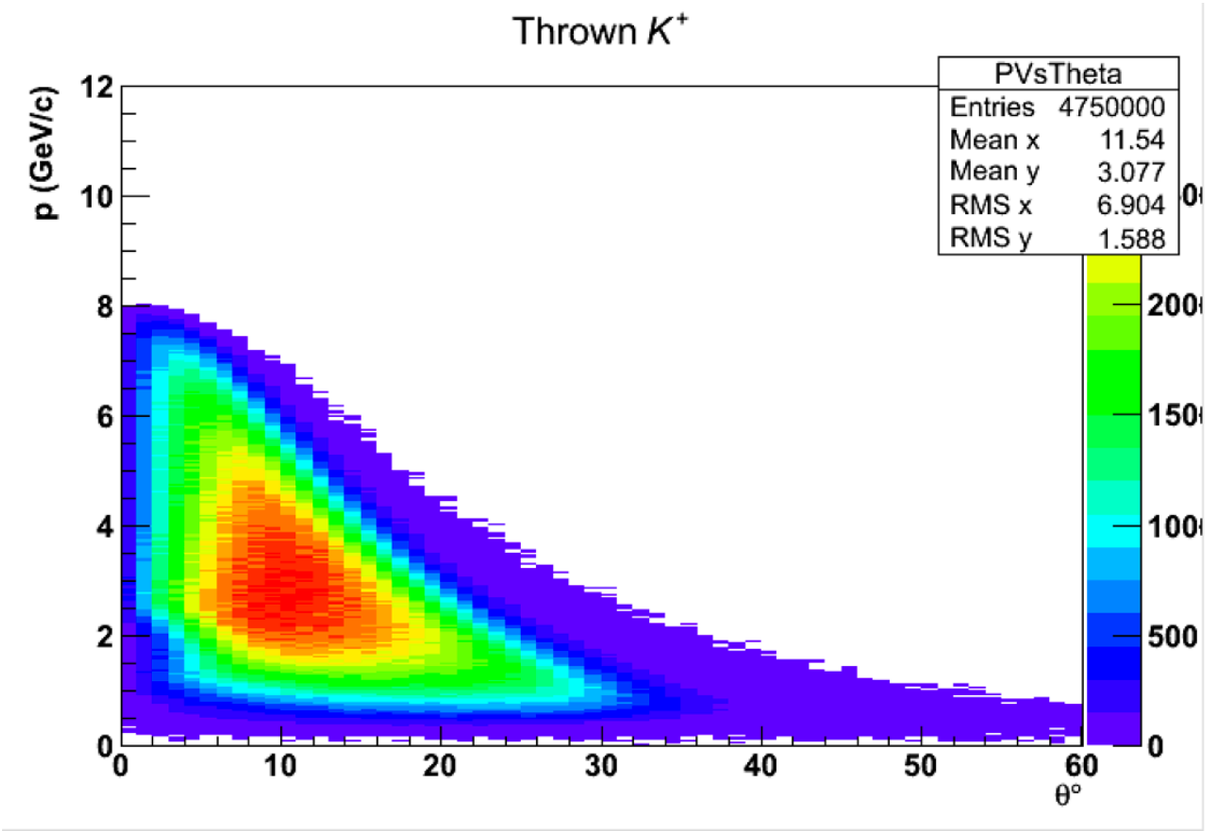
Adding recoil proton reconstruction

Justin Stevens

PID Upgrade Meeting: 3.8.13

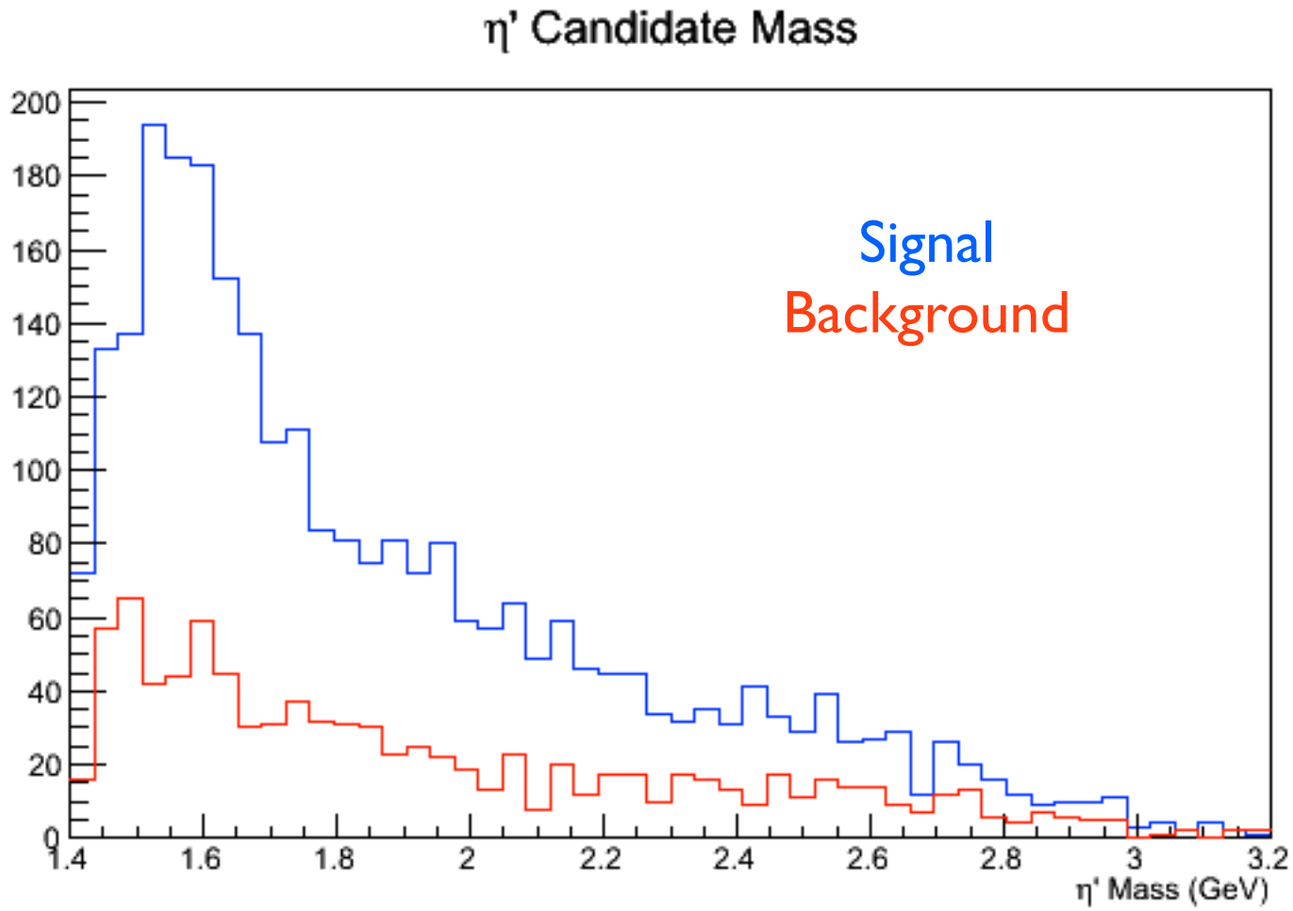
Example: η‘(2300)



$$\gamma p \to \eta_1'(2300) p$$
$$\eta_1'(2300) \to K^*(892)^0 K_s^0$$
$$K^*(892)^0 \to K^+ \pi^-$$
$$K_s^0 \to \pi^+ \pi^-$$

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

Missing proton reminder



BDT Cut and
±1.5 Γ cut on K* and η' masses

Improve S/B by a factor of ~10 with BDT!

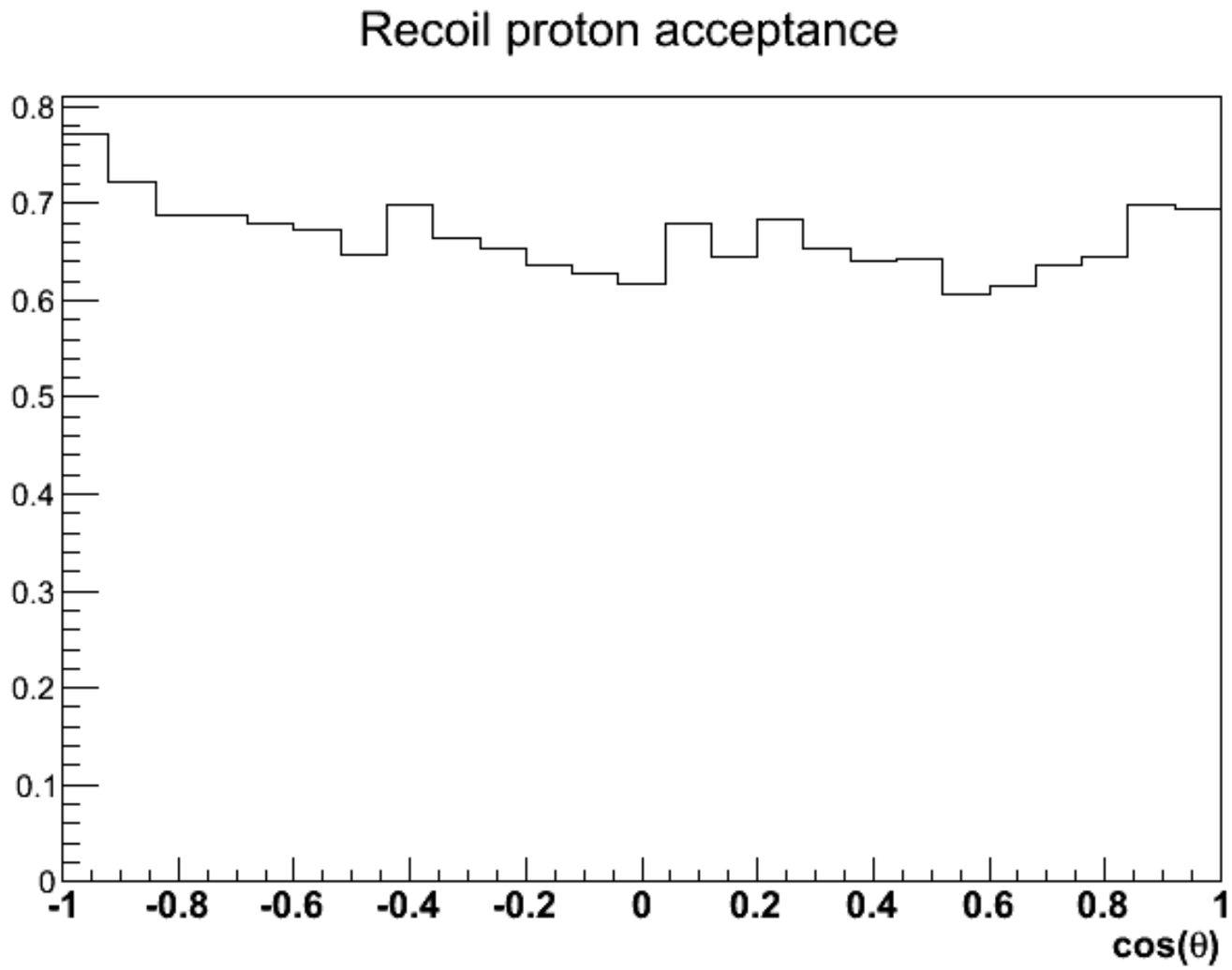
Analysis	Selection Efficiency	S/B
Cuts-based	0.10	0.24
BDT (compare cuts)	0.10	2.37

Reminder of variables included in the BDT

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

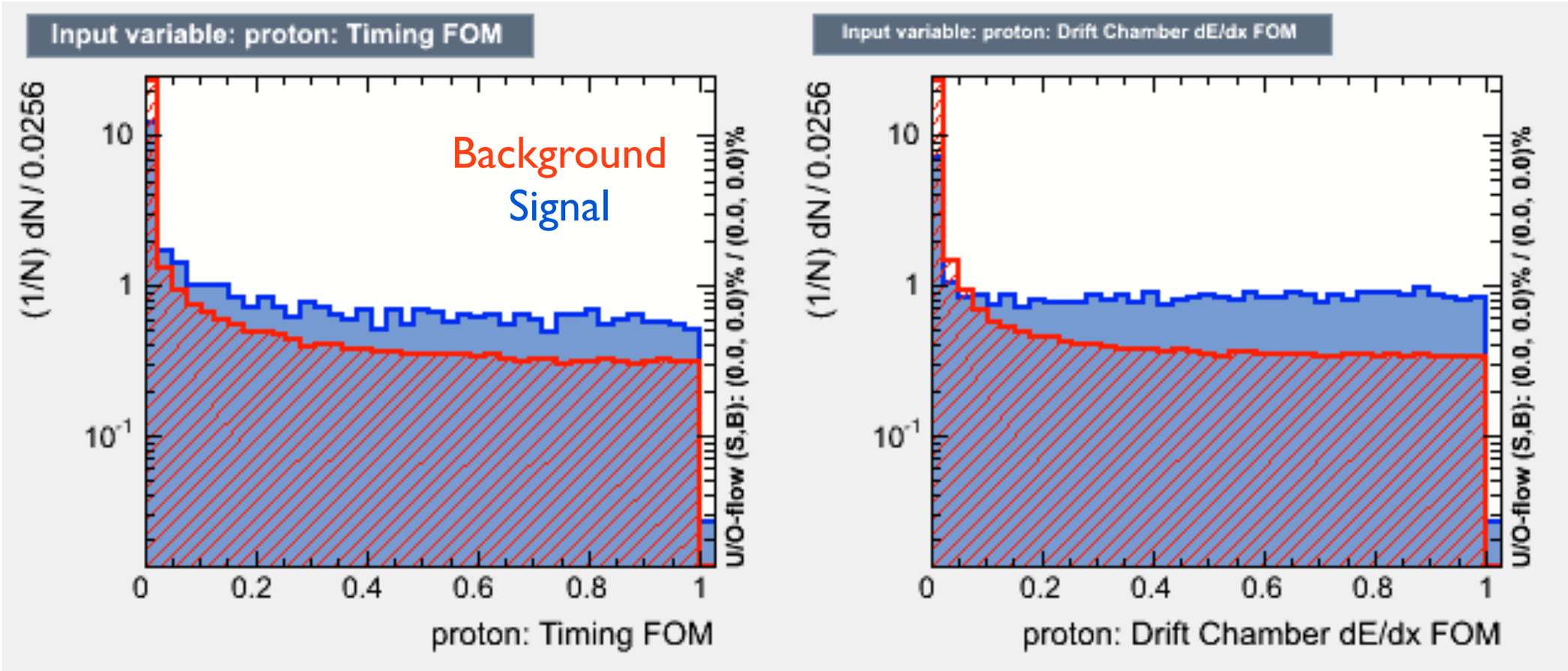
Same list as presented at collaboration meeting, but isolation cone definition changed to use track covariance matrix

Recoil proton acceptance



- Proton acceptance of ~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 η'(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 = π+ (Ks)

p2 = π- (Ks)

p3 = π- (K*)

p4 = K+ (K*)

p5 = proton

Highest ranked variables:

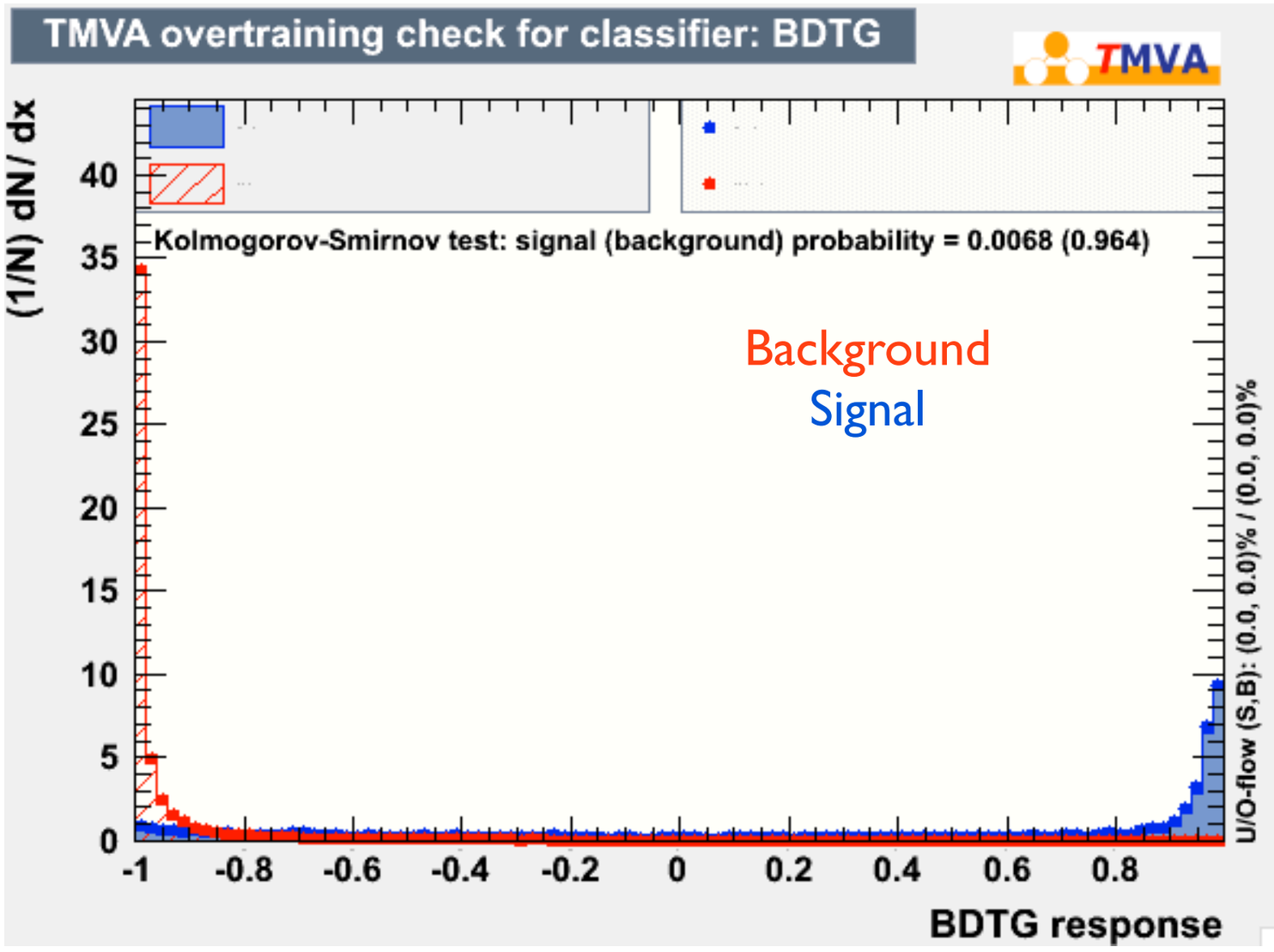
Kinematic Fit

Secondary vertex displacement

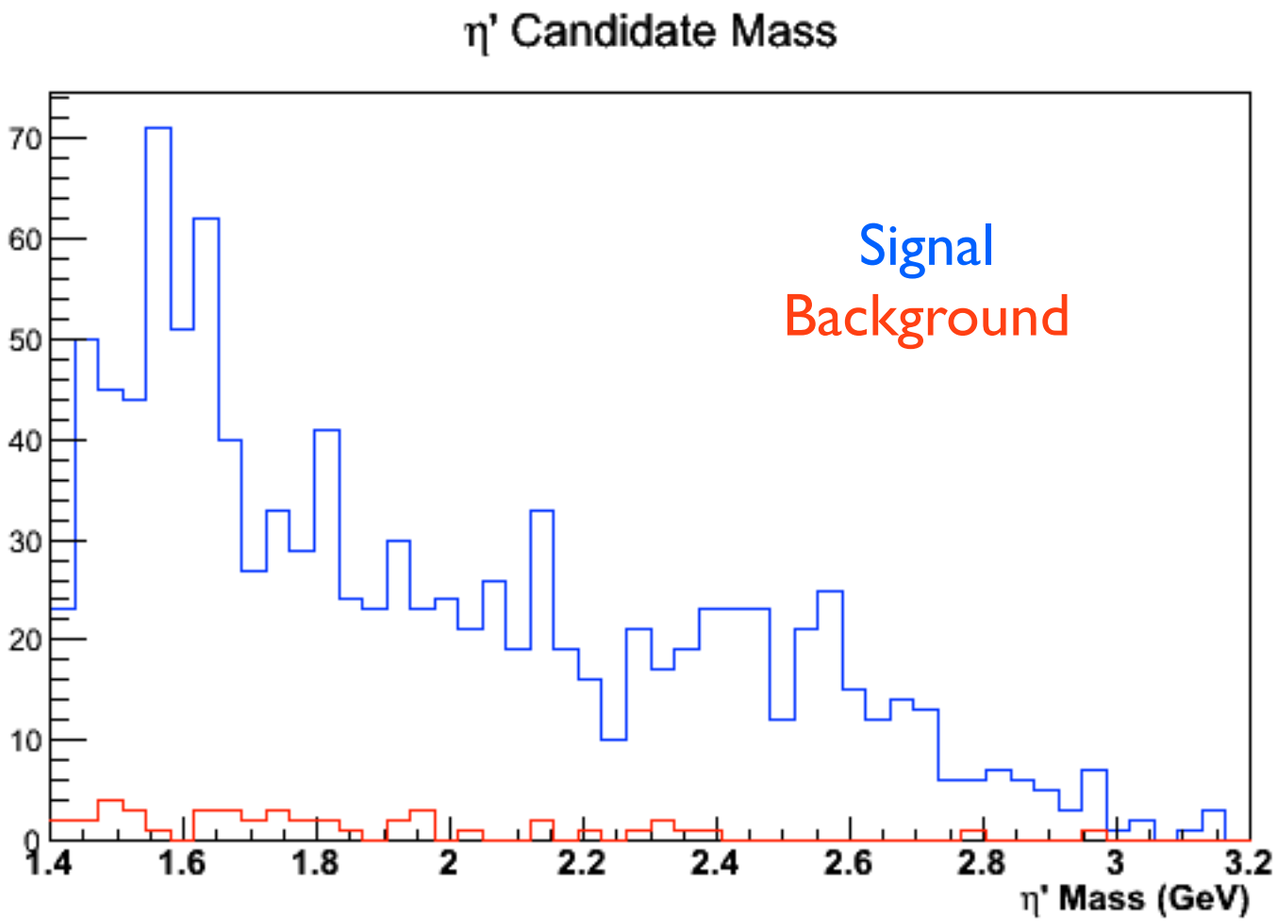
PID information

χ^2 variables

Reco proton η'(2300)



Reco proton η'(2300)



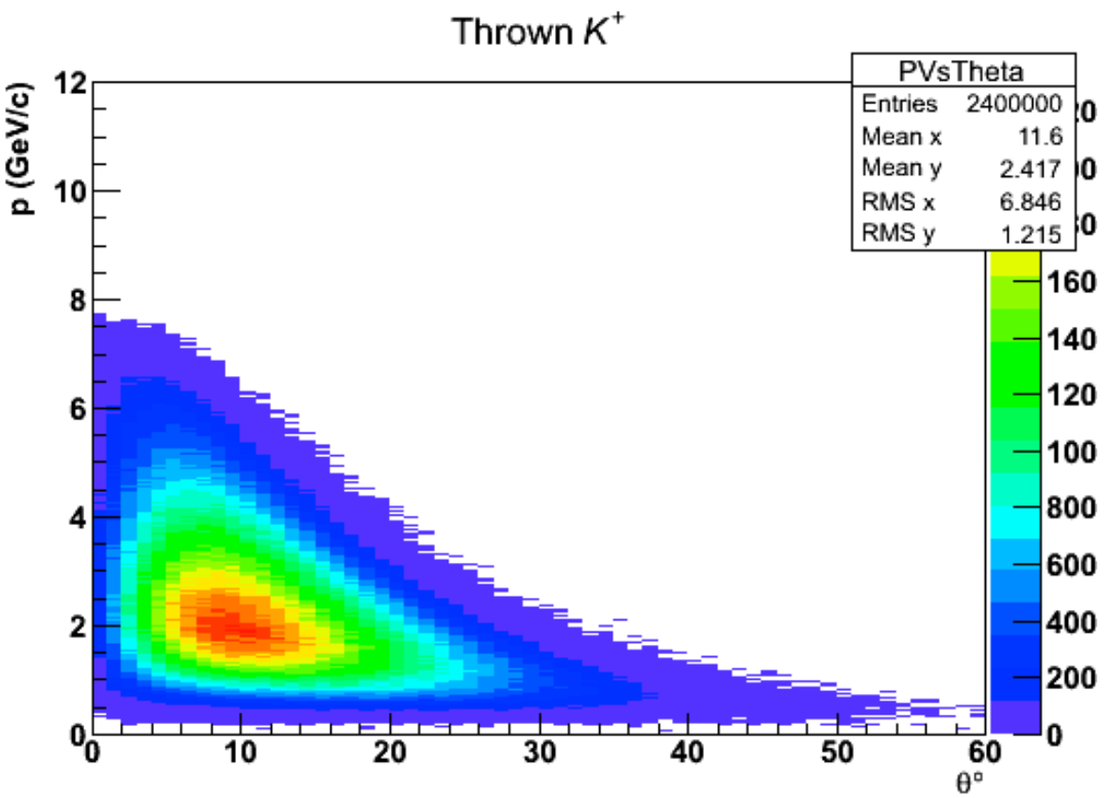
BDT Cut and
±1.5 Γ cut on K* and η' masses

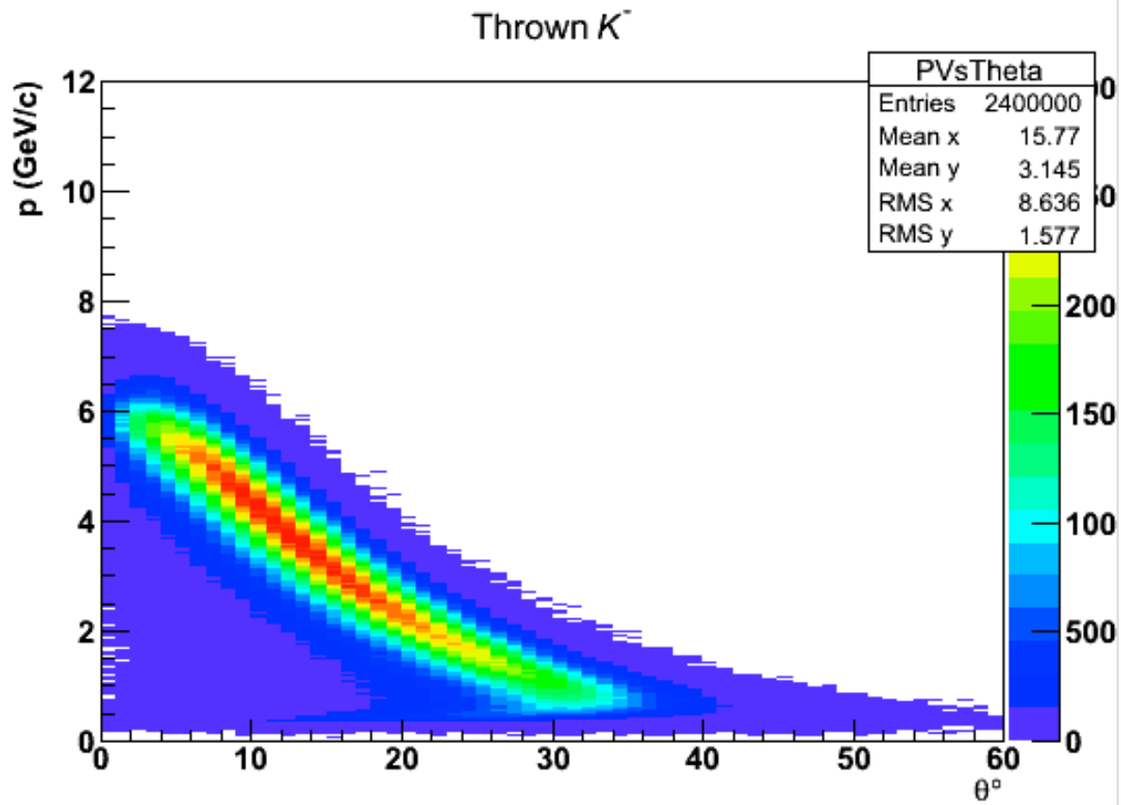
Improve S/B by a factor of ~6
with BDT!

Can still loosen BDT cut to
improve efficiency and still
maintain high purity

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

Example: h'(2600)



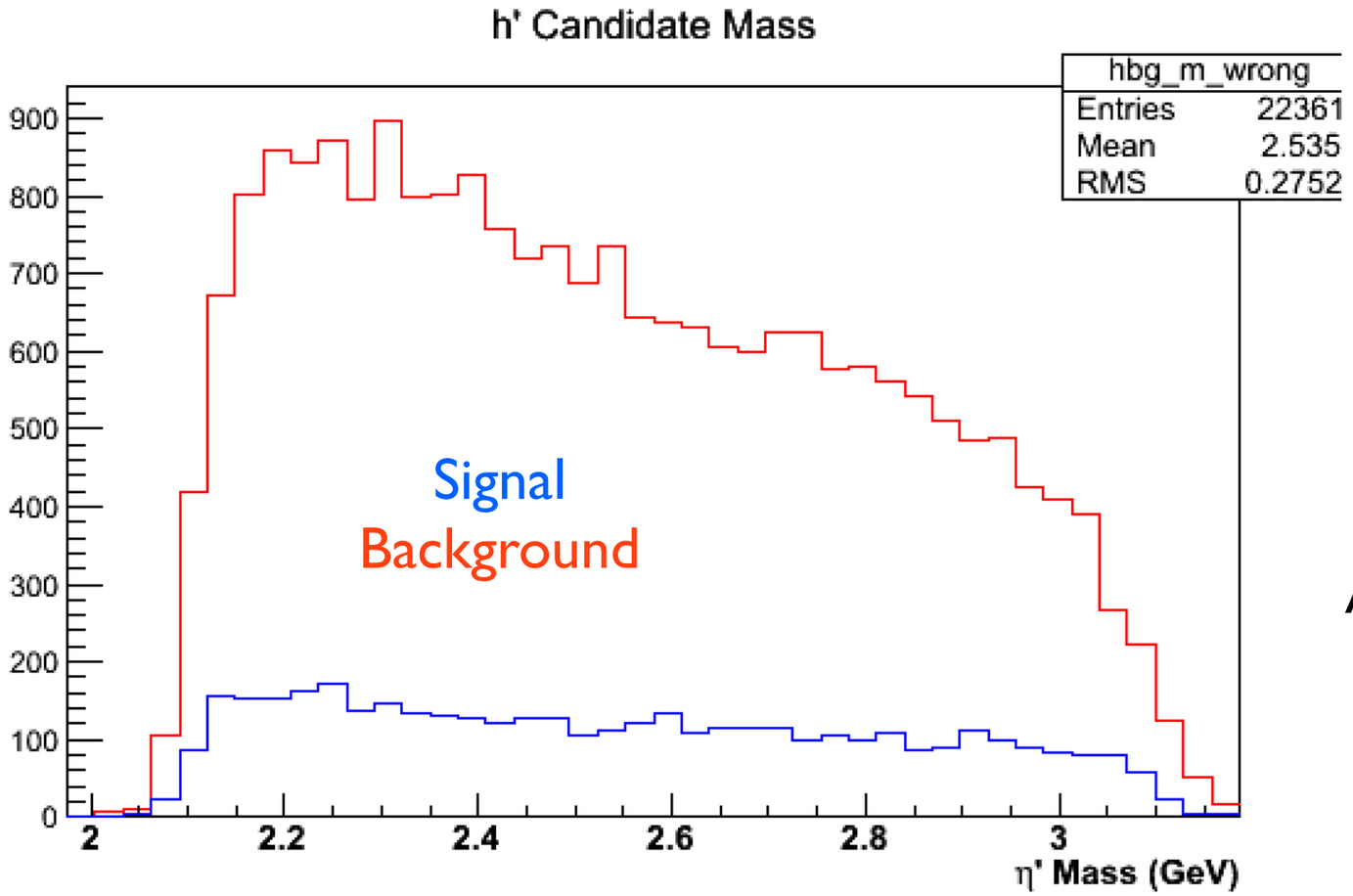


- Data samples (data challenge bggen with 8.4<E_γ<9 GeV):
  - Signal: Exclusive requirement on final state K+, K-, π+, π-
  - Background: All bggen not satisfying signal requirement
- All particle combinations are considered with **no cuts** applied before the decision tree

$$\gamma p \to h_2'(2600)p$$
$$h_2'(2600) \to K_1(1400)^+ K^-$$
$$K_1(1400)^+ \to K^*(892)^0 \pi^+$$
$$K^*(892)^0 \to K^+ \pi^-$$

Note: No displaced vertex!

Missing proton reminder



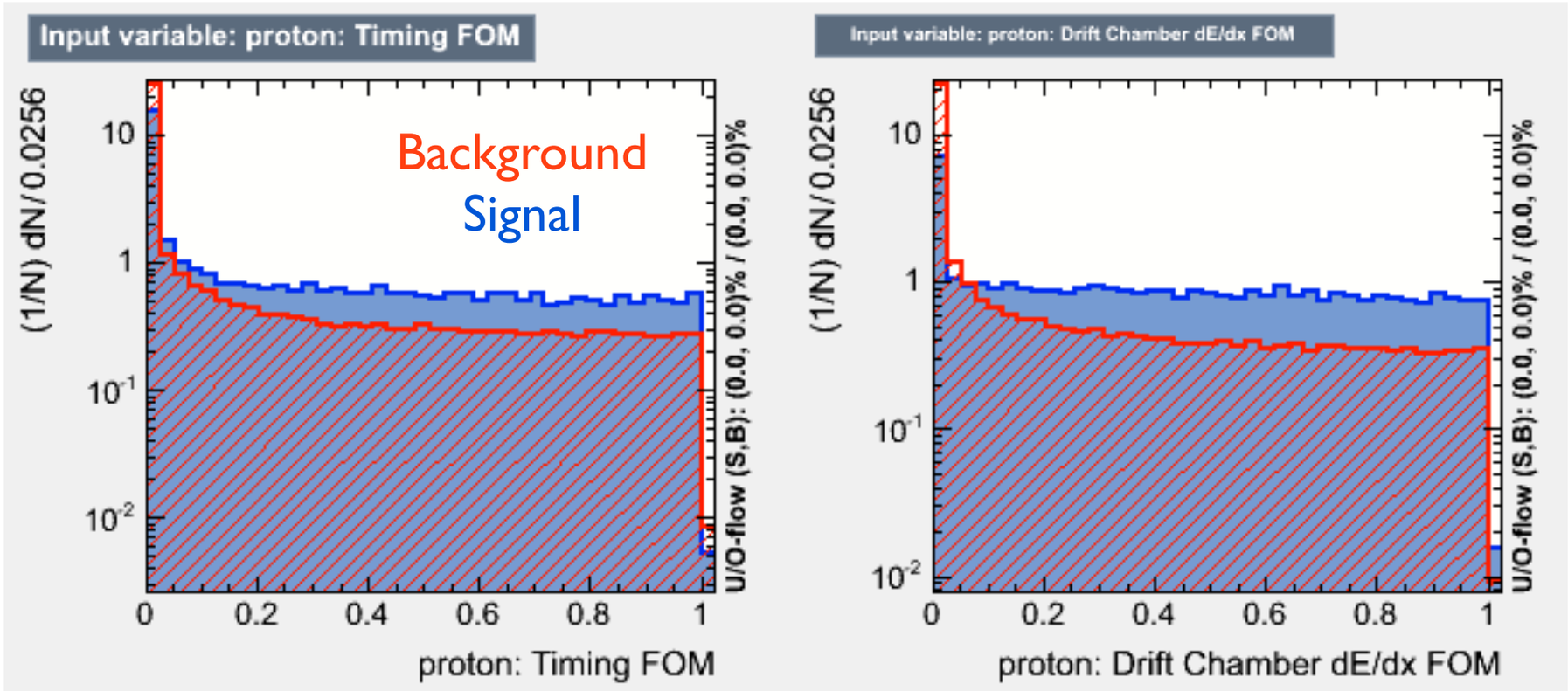
BDT Cut and
±1.5 Γ cut on K_1, K* and h' masses

Improve S/B by factor of ~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 = π+

p2 = π-

p3 = K+

p4 = K-

p5 = proton

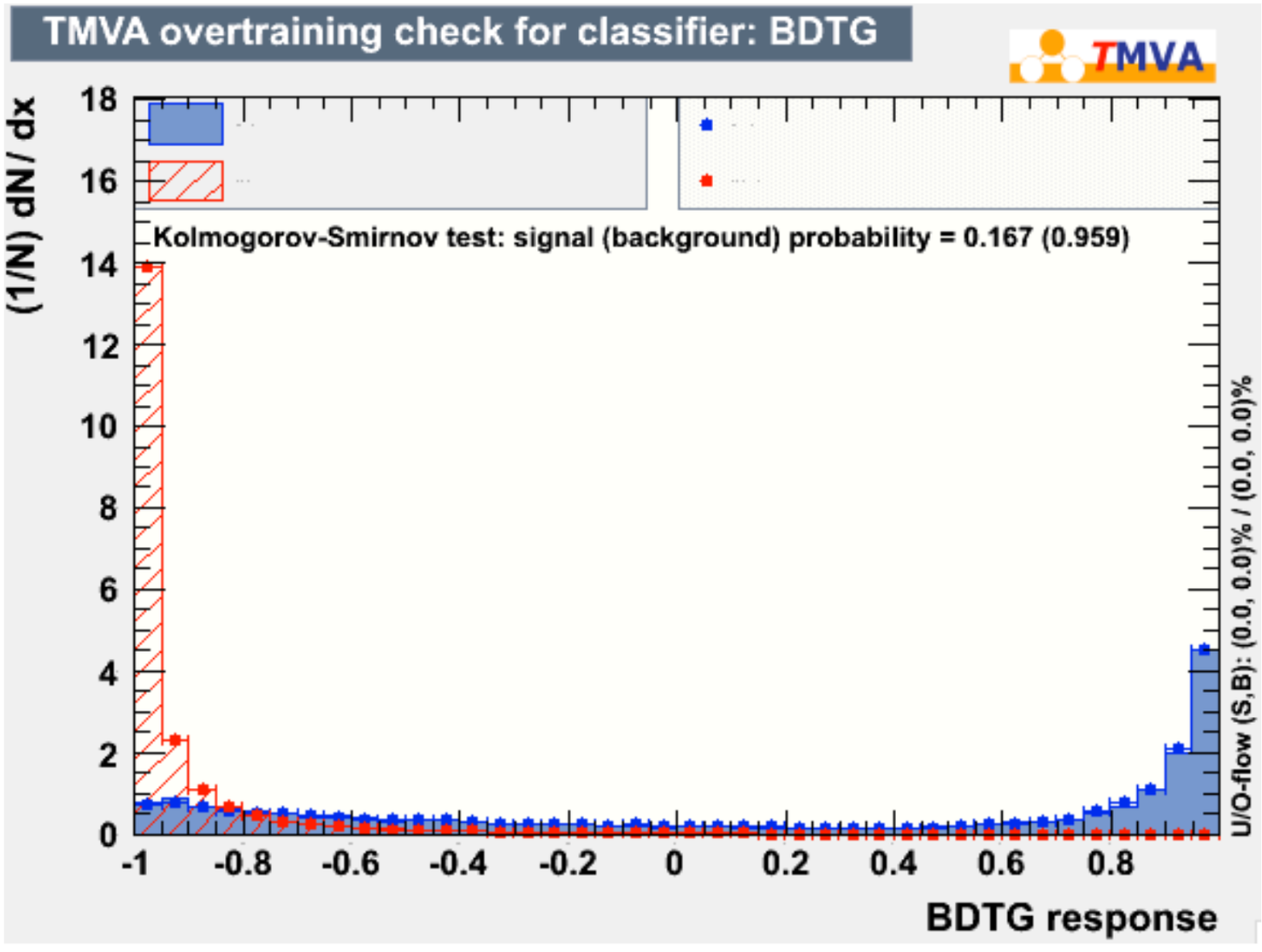
Highest ranked variables:

Kinematic Fit

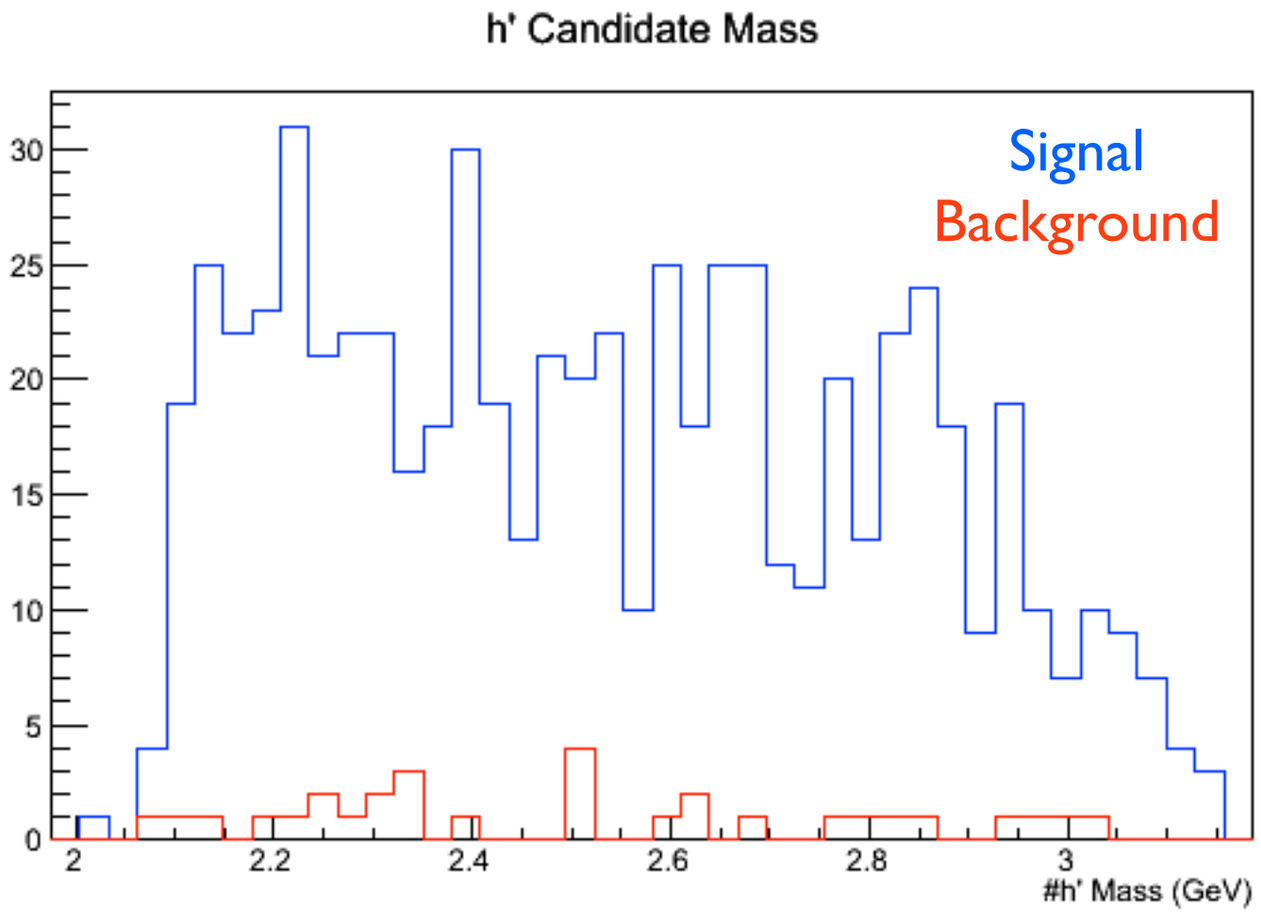
PID information

χ^2 variables

Reco proton h'(2600)



Reco Proton Results



BDT Cut and
±1.5 Γ cut on K_1, K* and h' masses

Improve S/B by factor of ~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
η'(2300)	~0.88 M	~0.36 M
h'(2600)	~1.75 M	~0.82 M

- Integrate signal yields in the expected hybrid mass ranges from the previous slides (for reco proton with BDT have S/B ~ 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?

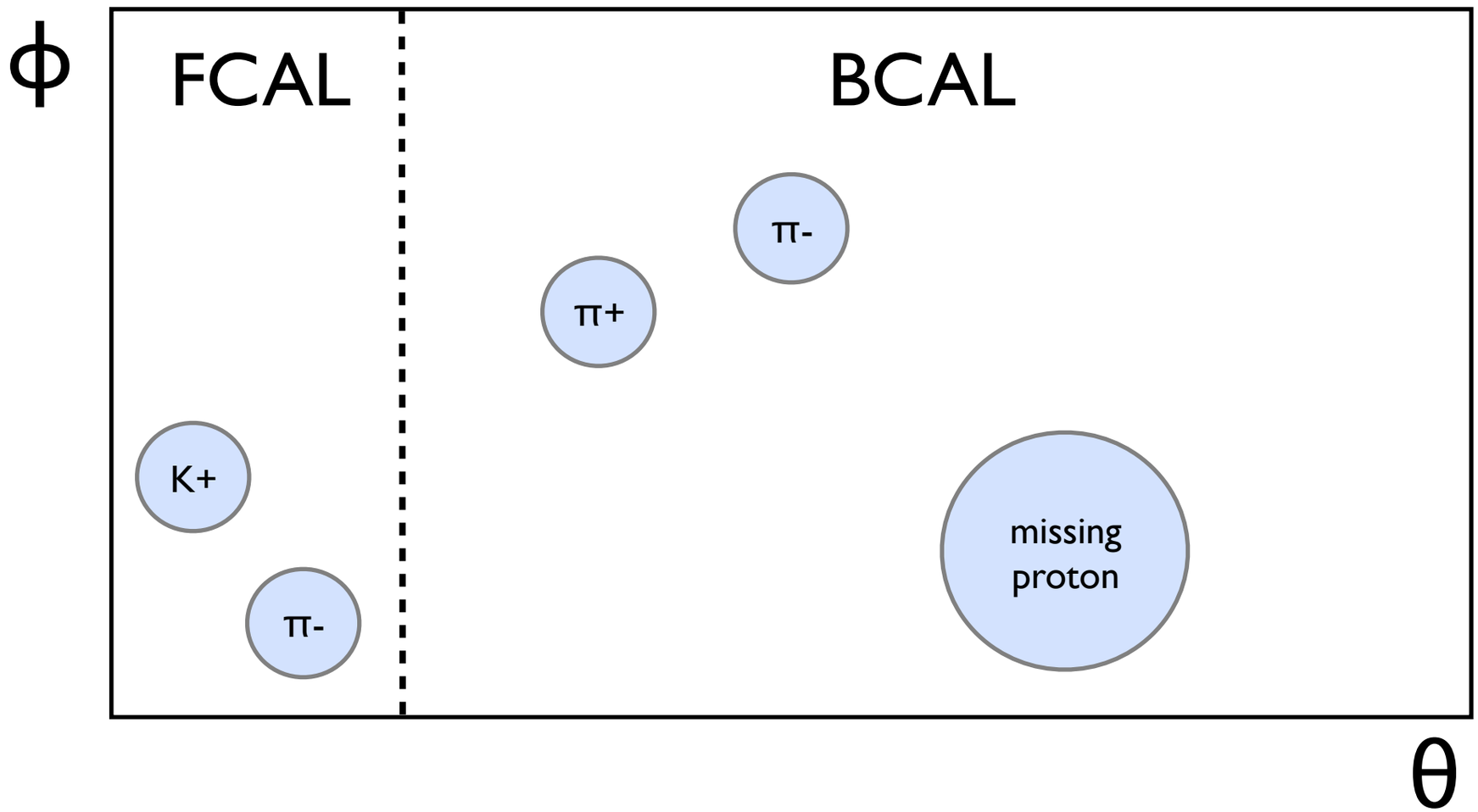
Backup

Variables included in the BDT

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

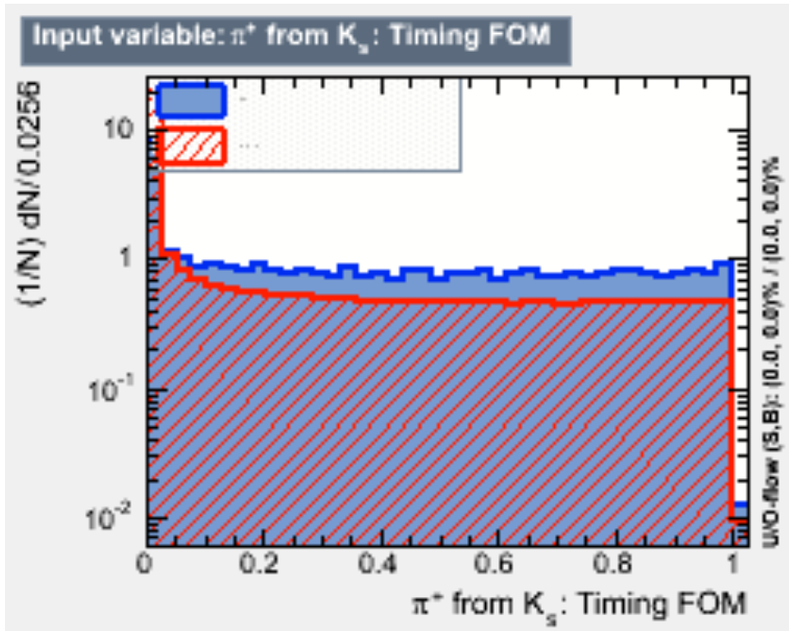
Notes:
- No Cherenkov detectors added at this point
- No problem with adding too many variables, less useful variables simply don't branch the decision tree

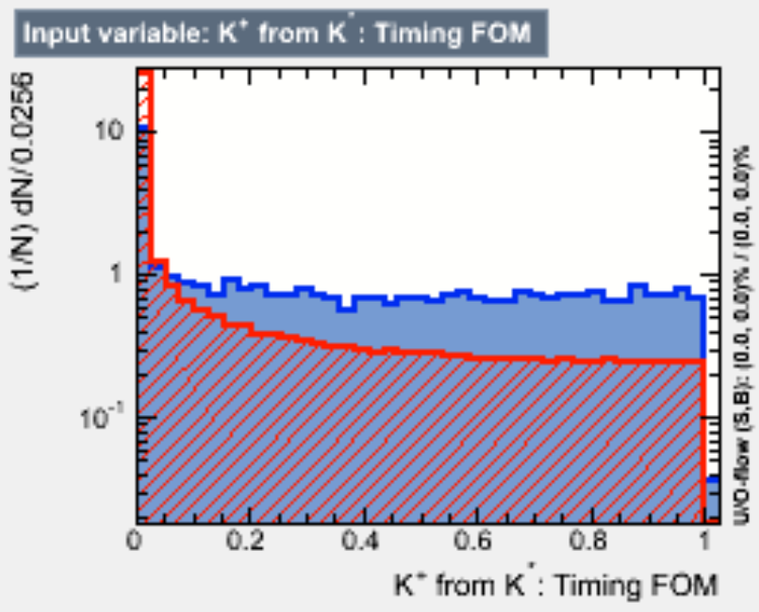
Isolation Variables

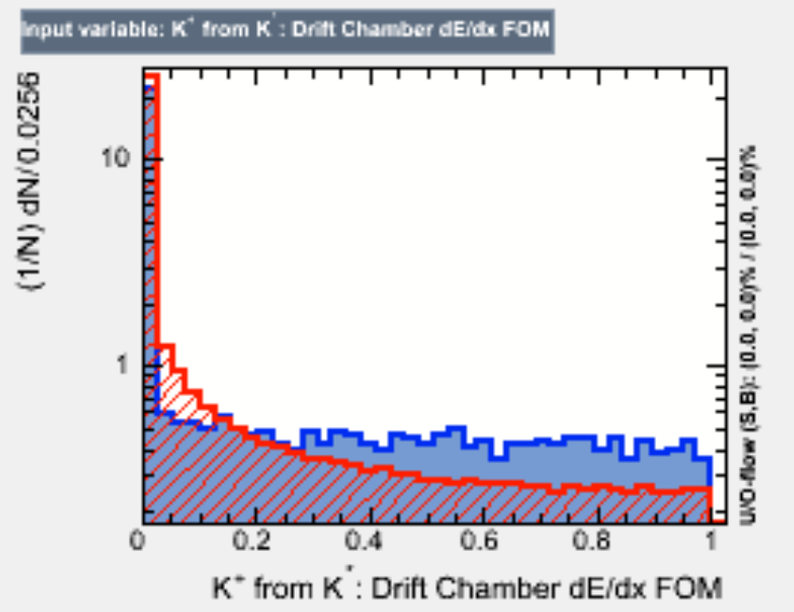


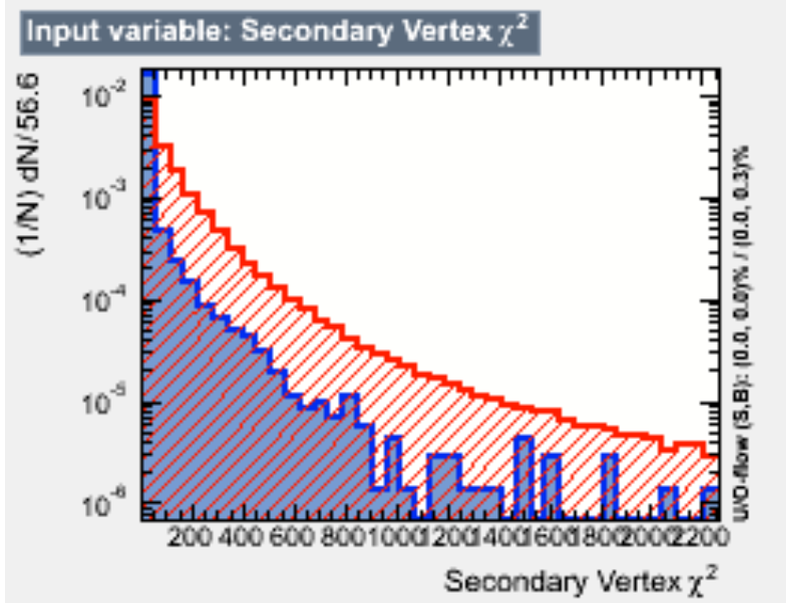
- Motivation: identify backgrounds with extra charged track or neutral outside of the desired topology
- Use covariance matrices for reconstructed tracks to identify a "cone" around each track which we exclude ECAL showers within

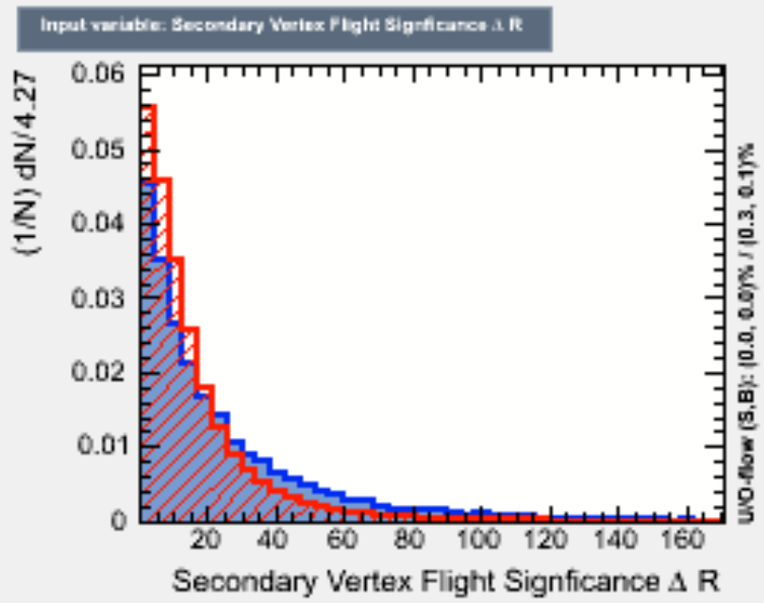
Input distributions

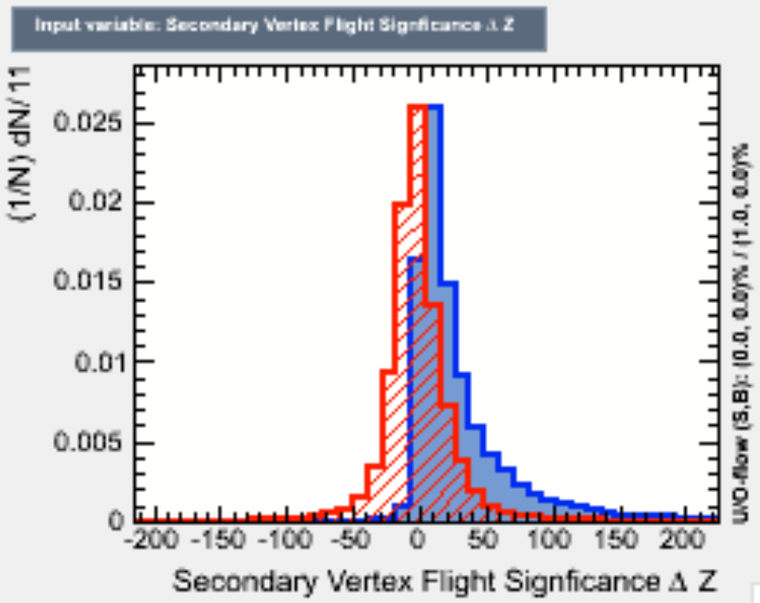




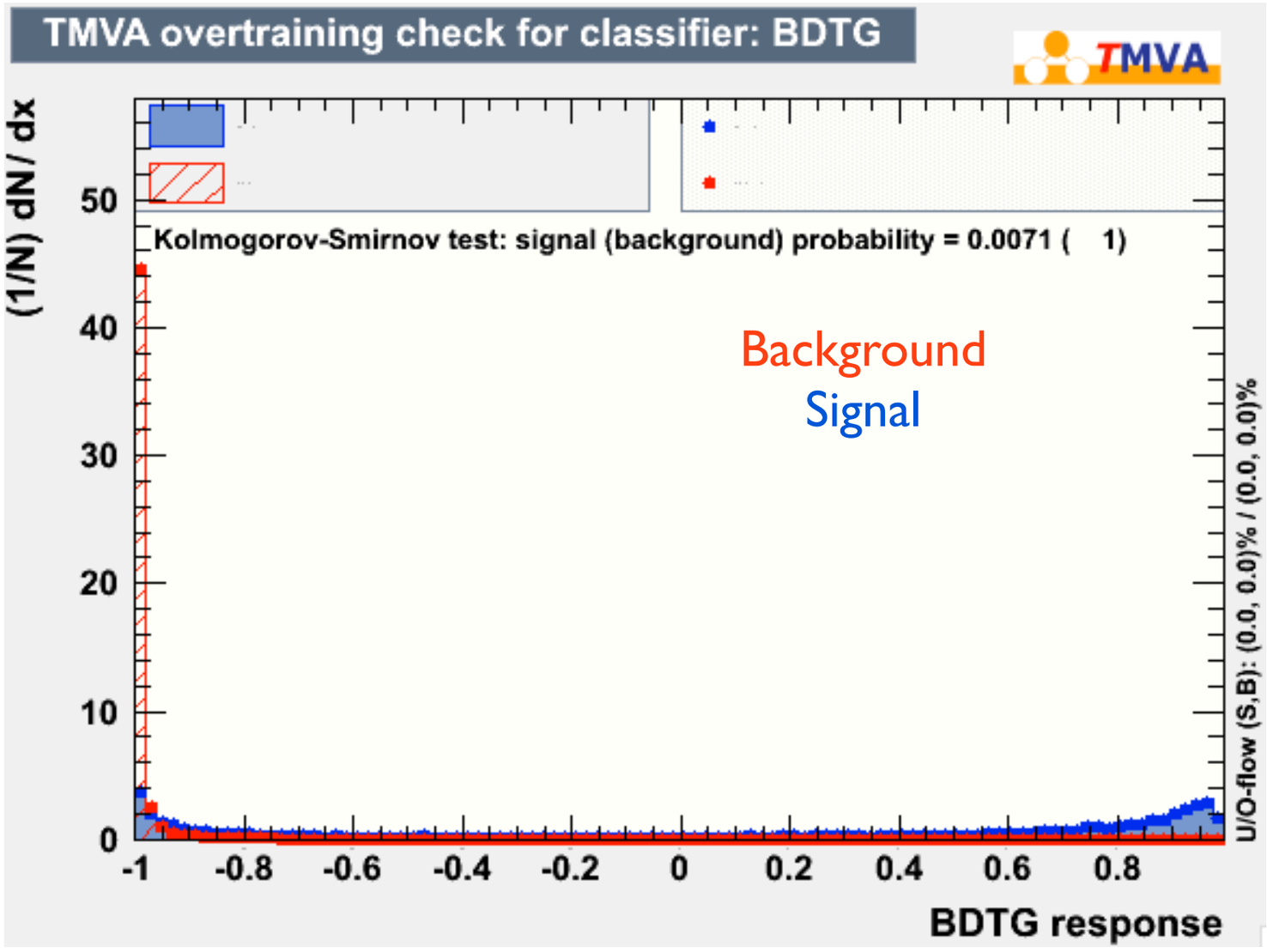




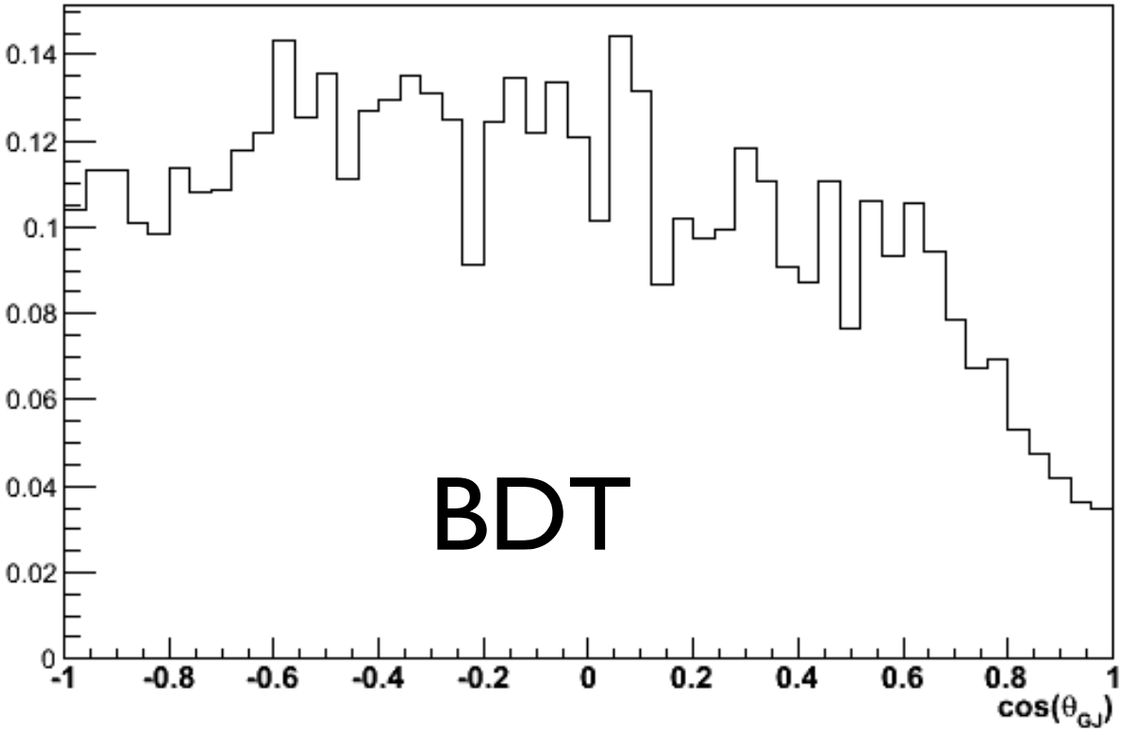


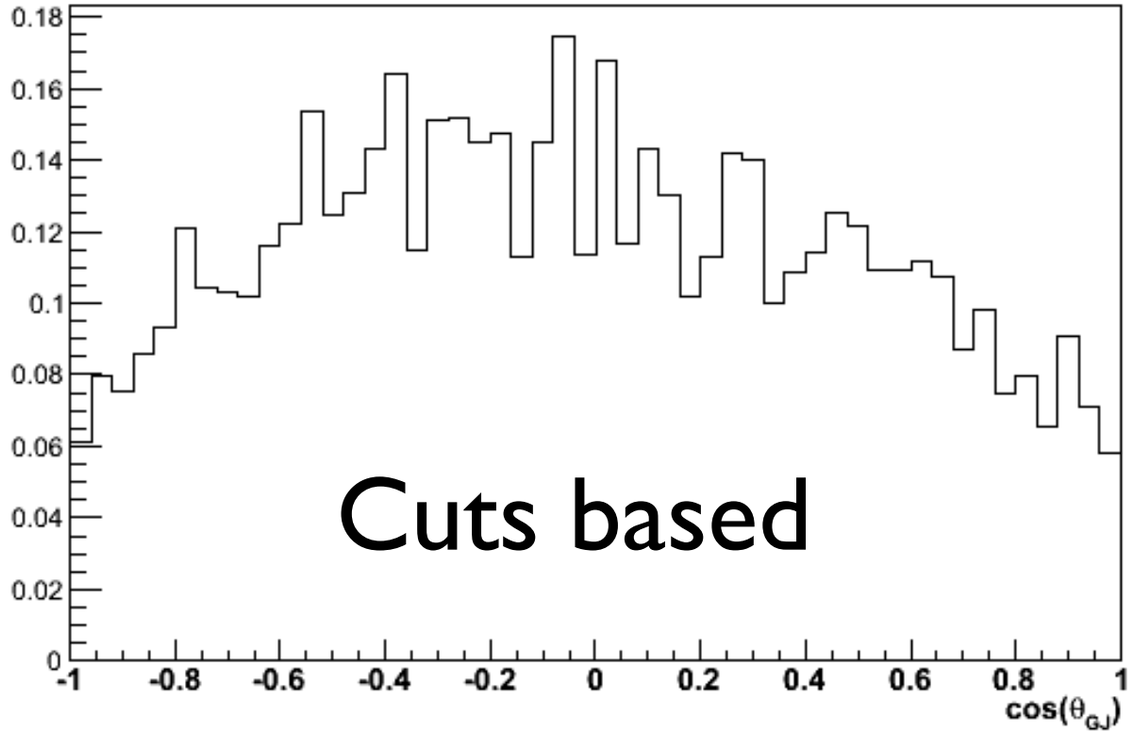


Missing proton η'(2300)



Angular Acceptance

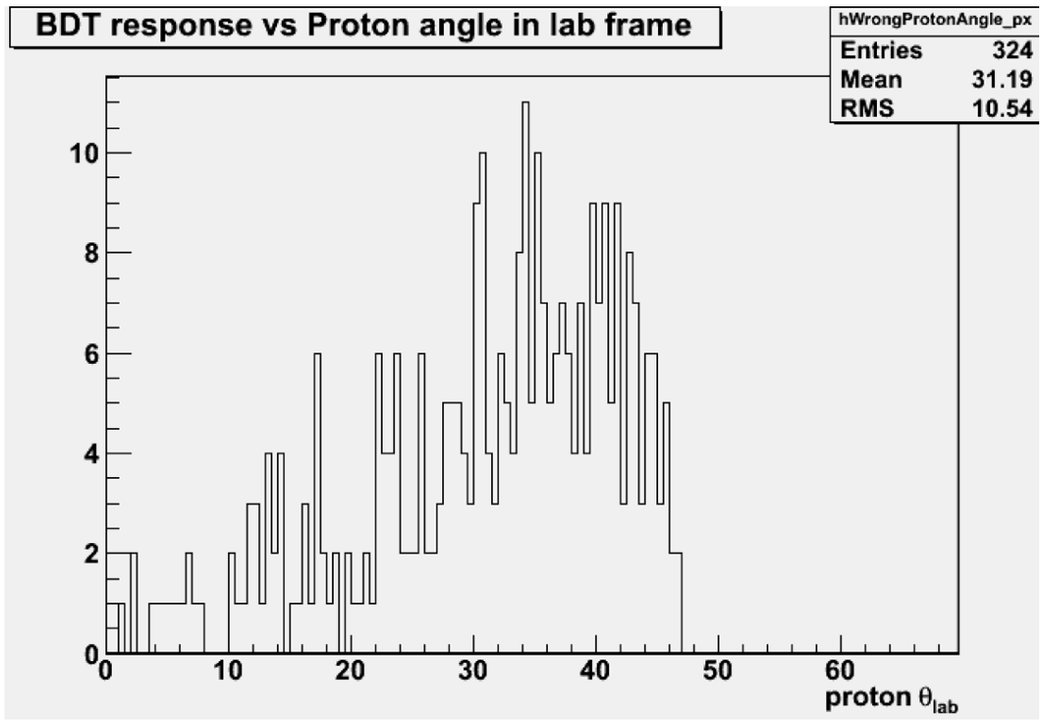




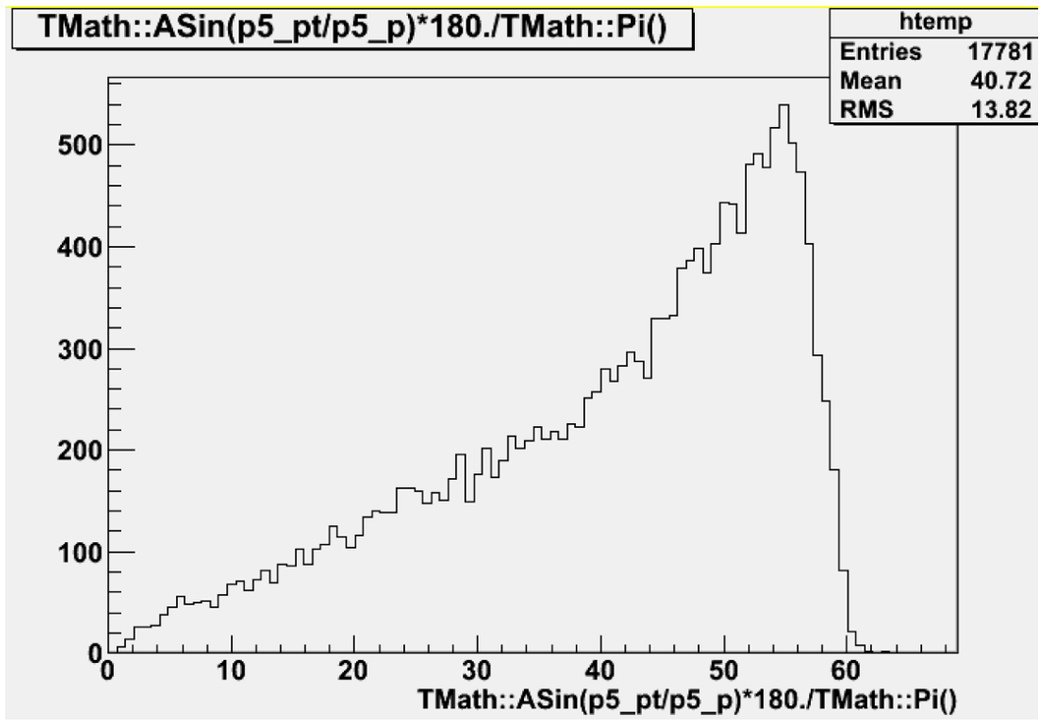
- In this case the "flatness" of the acceptance vs GJ angle is comparable to that of the cuts based, but may not be true for all BDT selection
- We've developed a procedure to include a "smooth" out the acceptance in the boosting procedure to maintain uniform acceptance

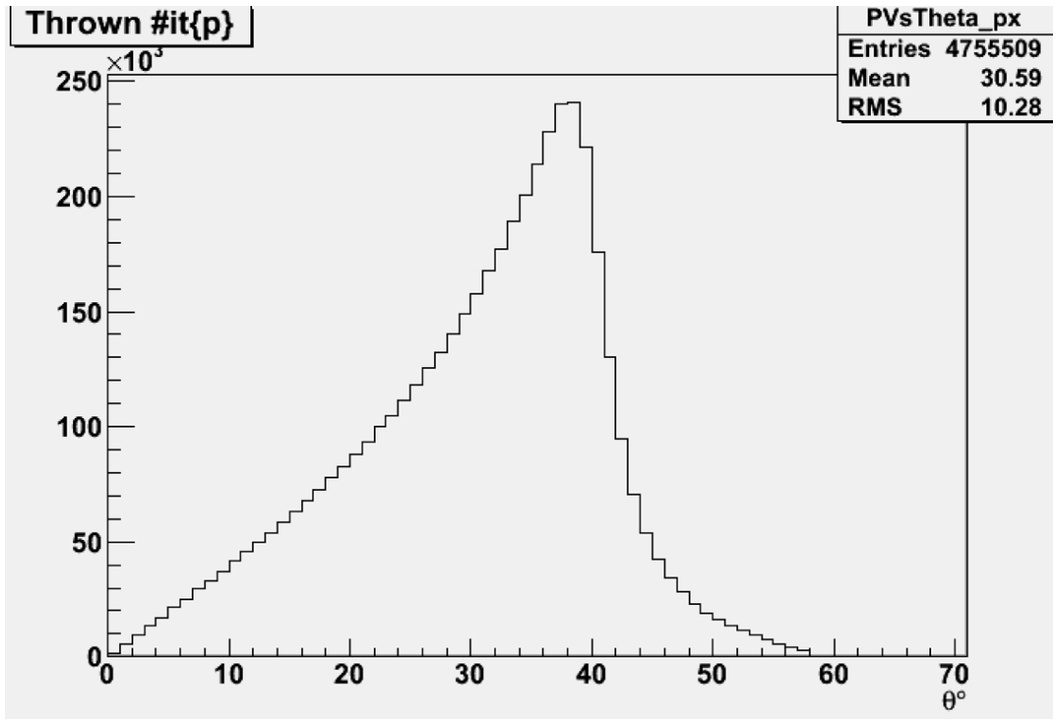
Proton angle

Missing proton θ for non-topology η' candidates which passed the BDT cut



Reconstructed proton θ for all true topology η' events





Thrown proton θ from η' hybrid MC generator