Separating Electron, Proton and Gamma-ray induced Air Showers

with Imaging Atmospheric Cherenkov Telescopes

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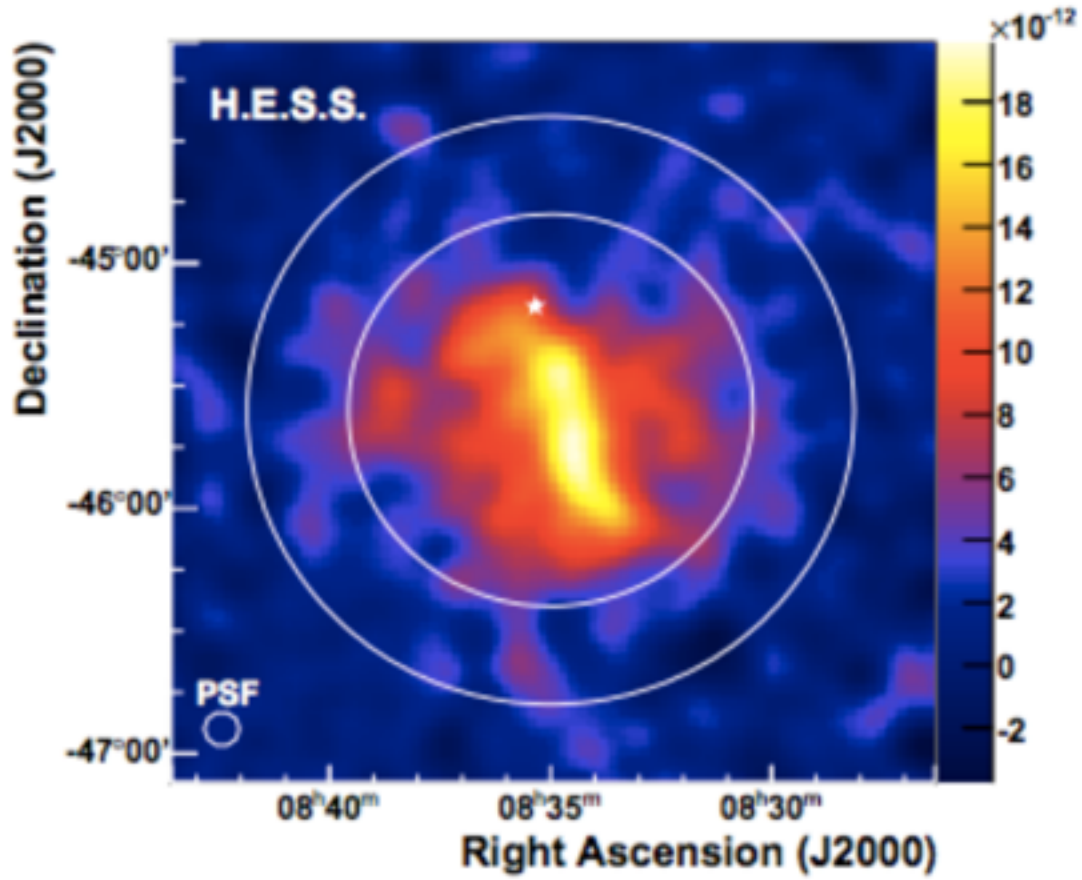
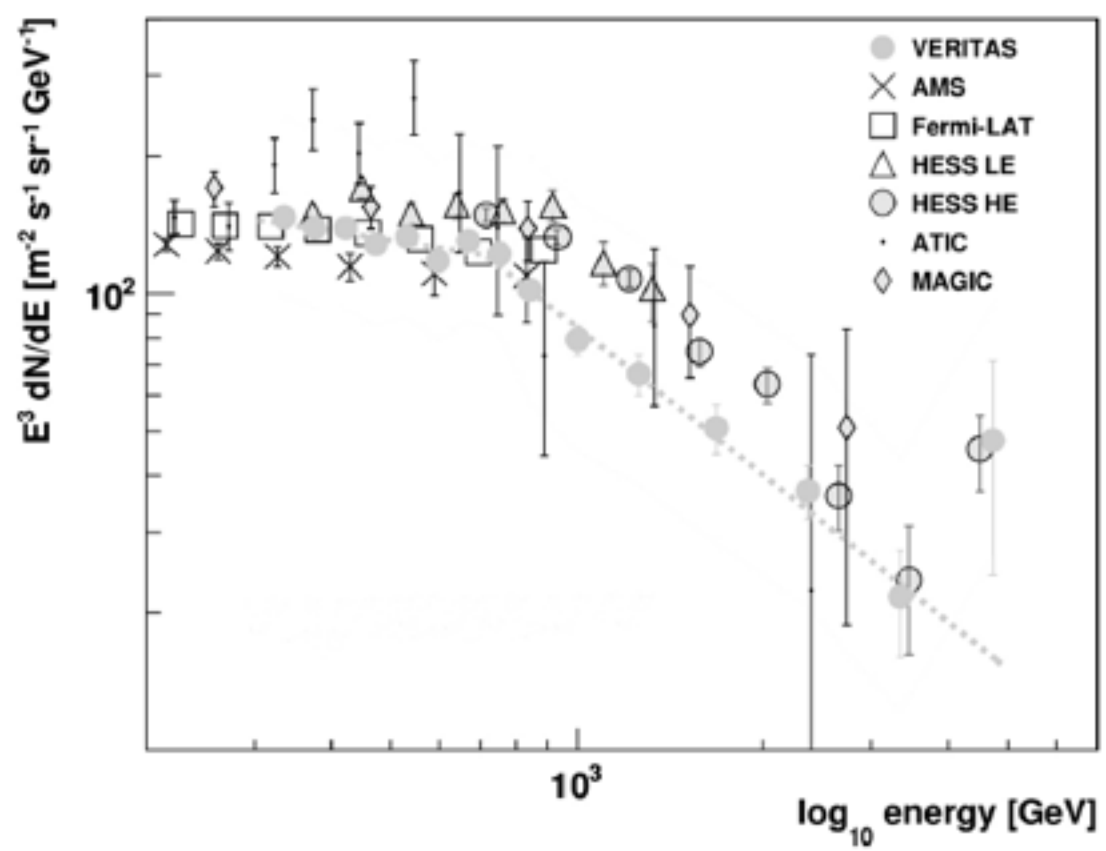
Motivation

> Increased Sensitivity of Imaging Atmospheric Cherenkov Telescopes

> Extended sources and diffuse emission studies



Aharonian et al, 2012



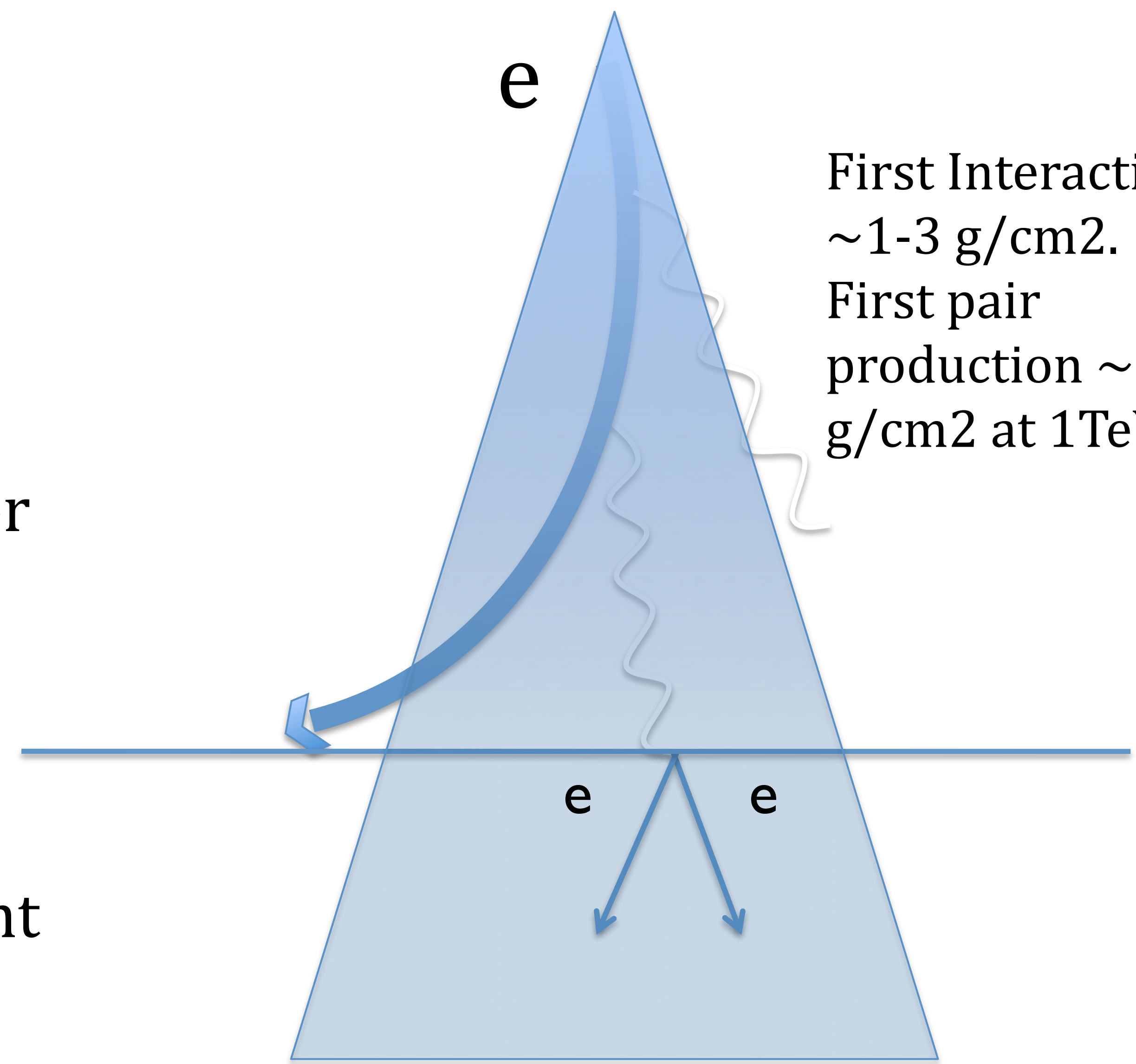
David Kolitzus

Shower Development

First Interaction at 47 g/cm2

> earlier shower development for e → image moves closer to source position

> Extra intensity at head of shower due to 'Direct' Cherenkov light

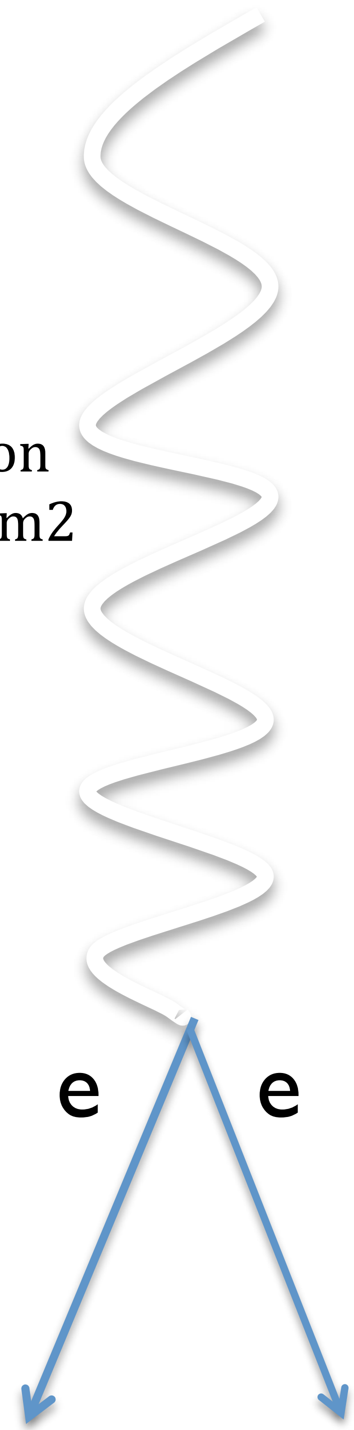


First Interaction ~1-3 g/cm2. First pair production ~16 g/cm2 at 1TeV.

> 'Direct' Cherenkov light defined here as light given off above the first pair production

Shower Development

First Interaction at 47 g/cm2



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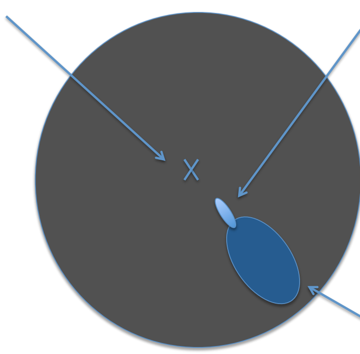

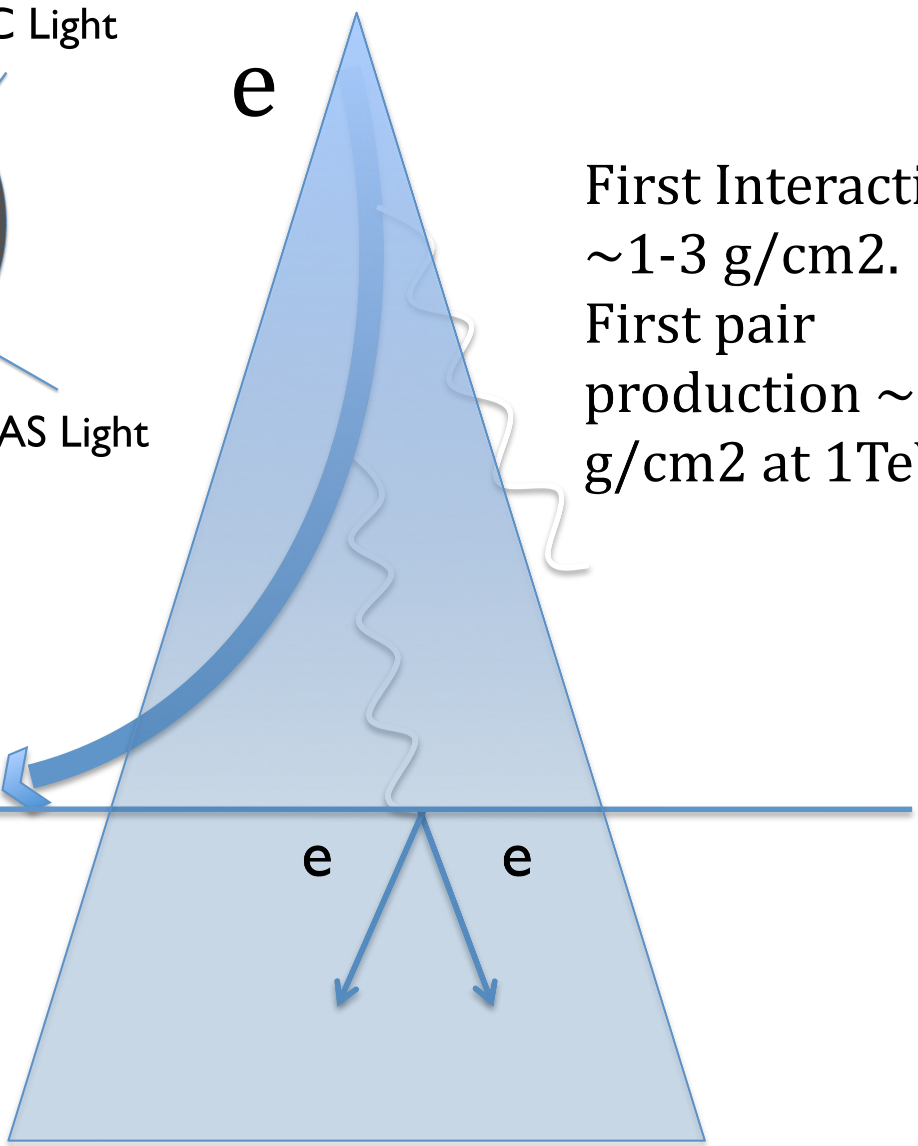

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> Extra intensity at head of shower due to 'Direct' Cherenkov light

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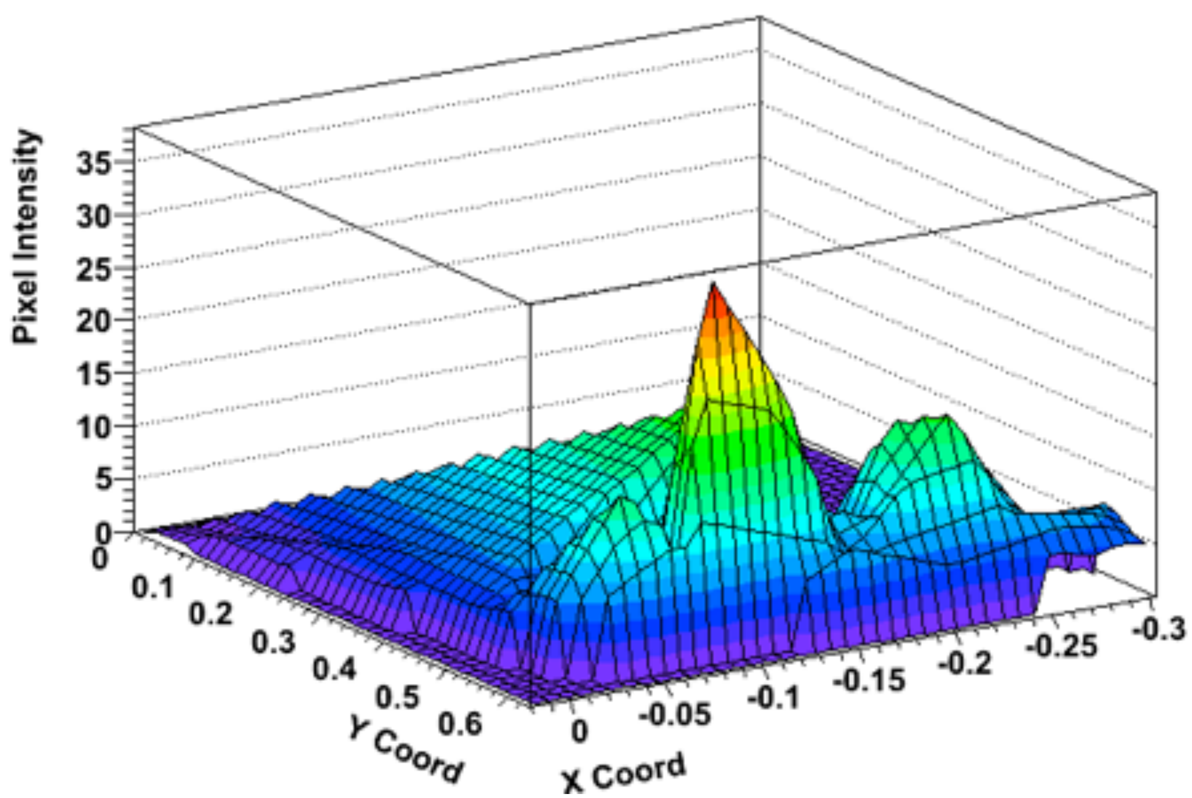
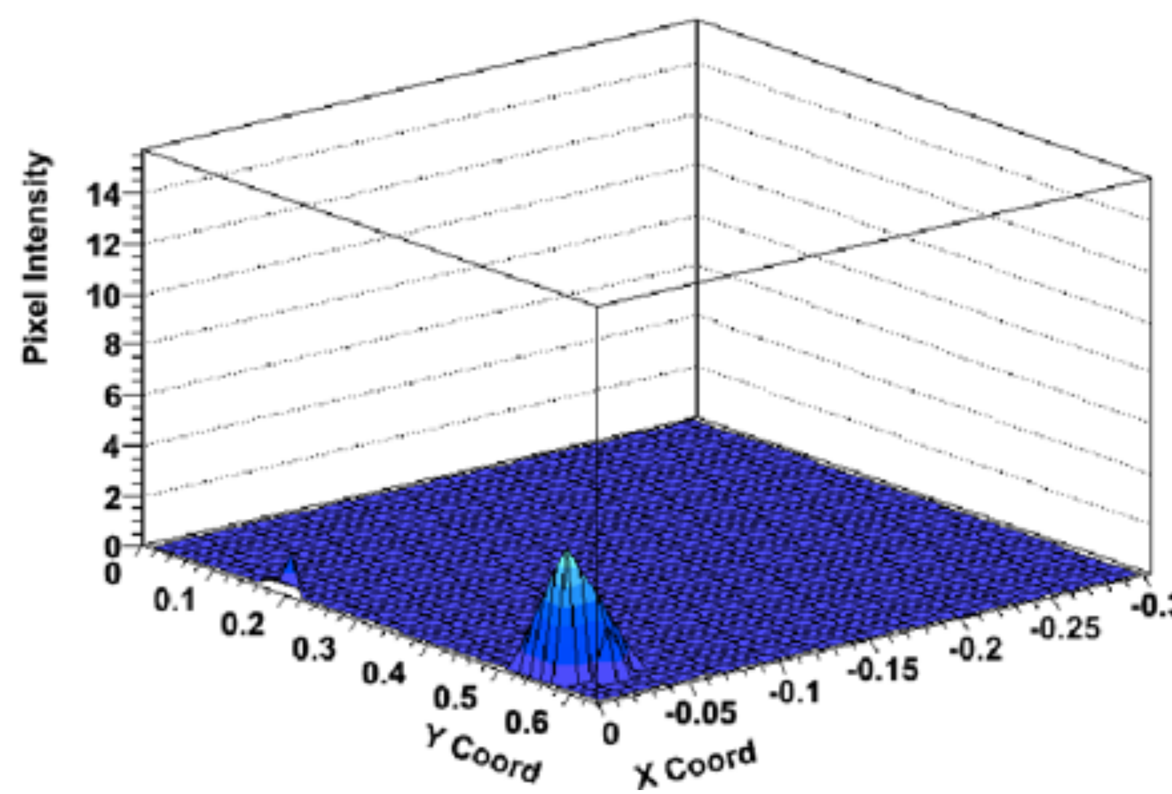
Direct Cherenkov

Simulated electron shower image at 100 GeV

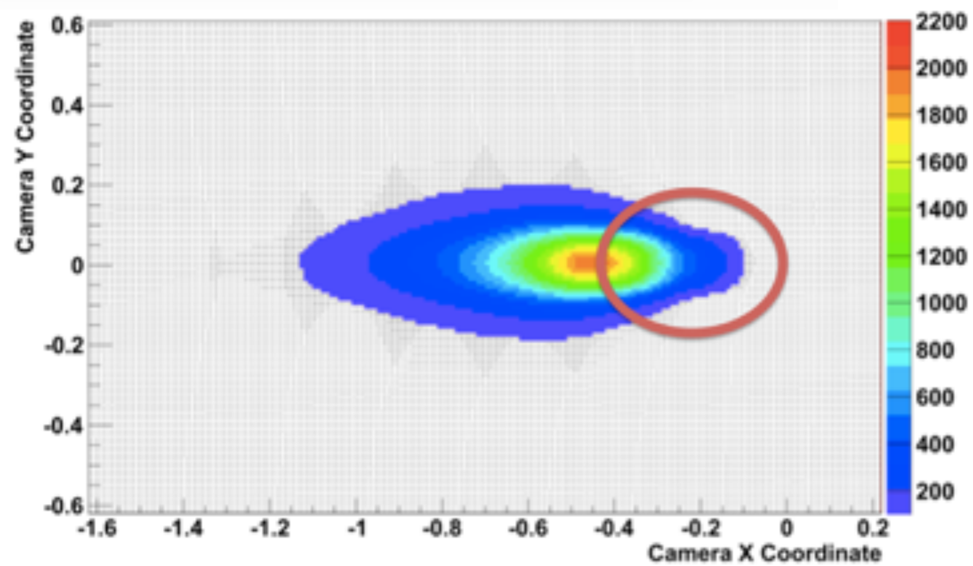


Direct Cherenkov component detected at the head of the simulated shower

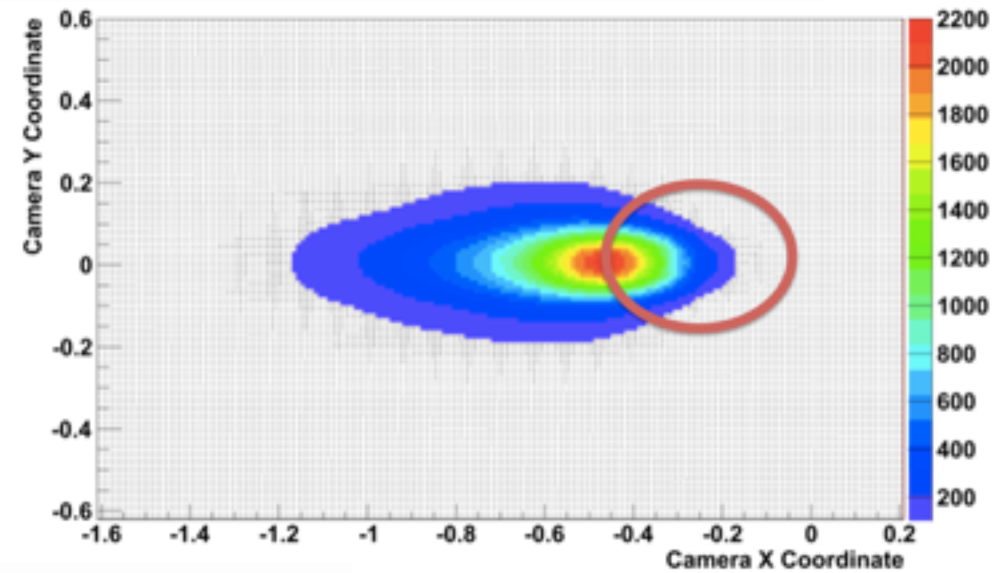


Electrons vs Gamma rays

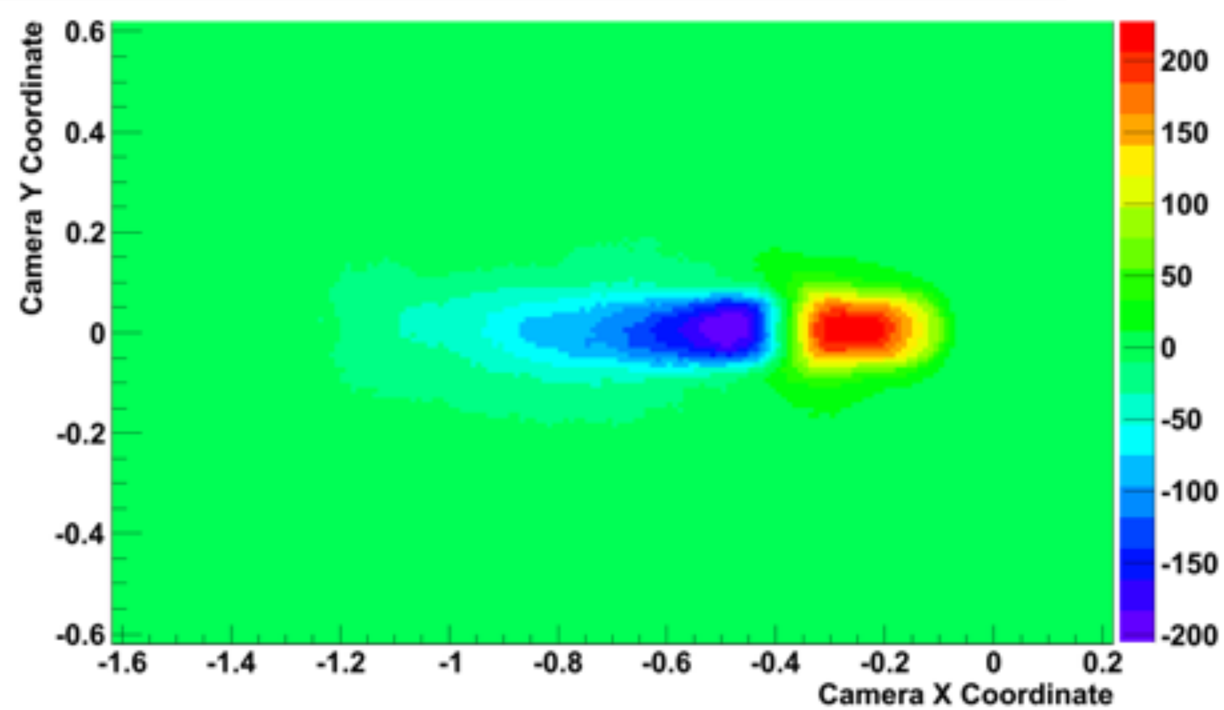
Averaged Electron Shower (10 000 events)



Averaged Gamma ray Shower (10 000 events)

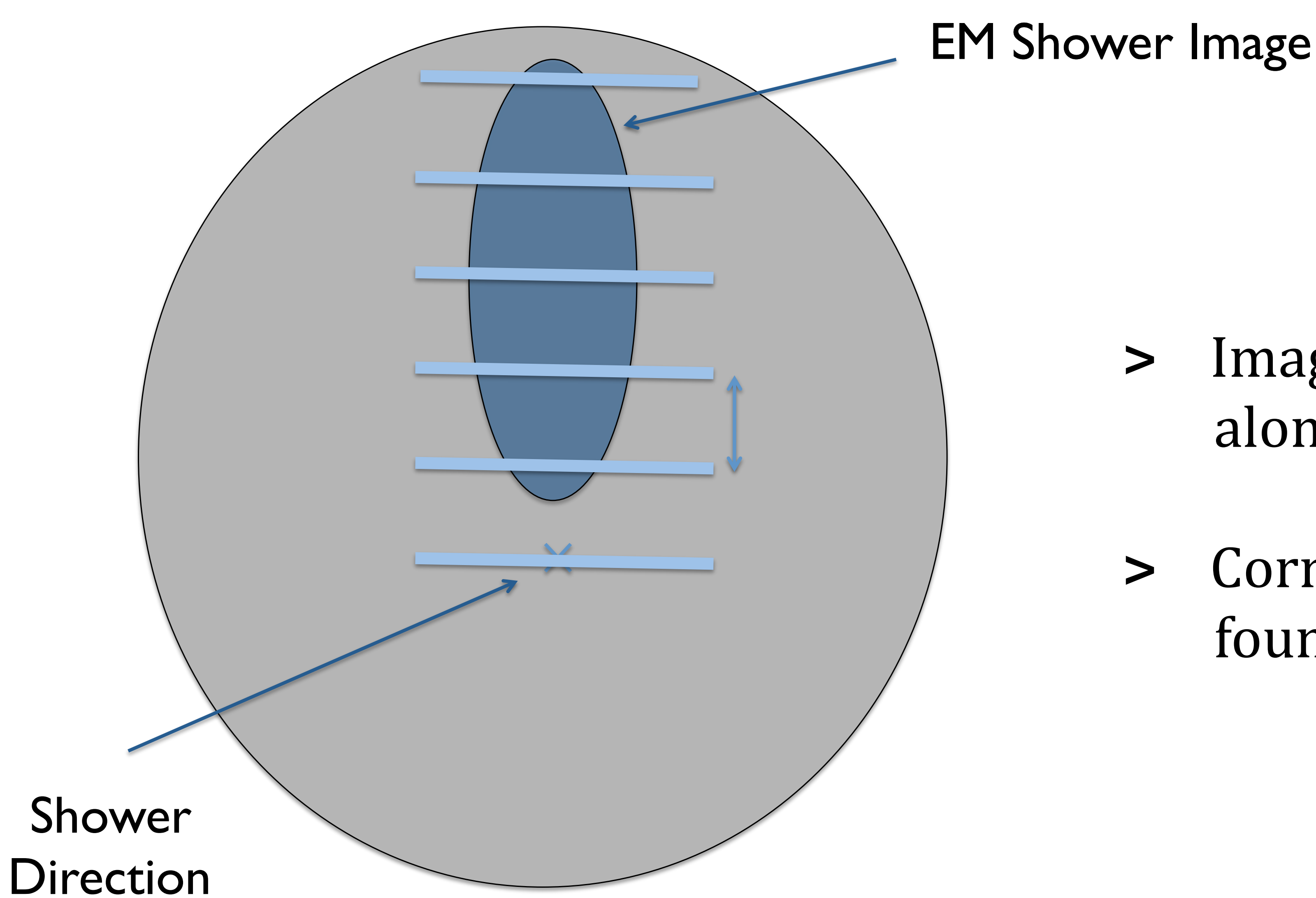


Difference



Discriminating Variable 1

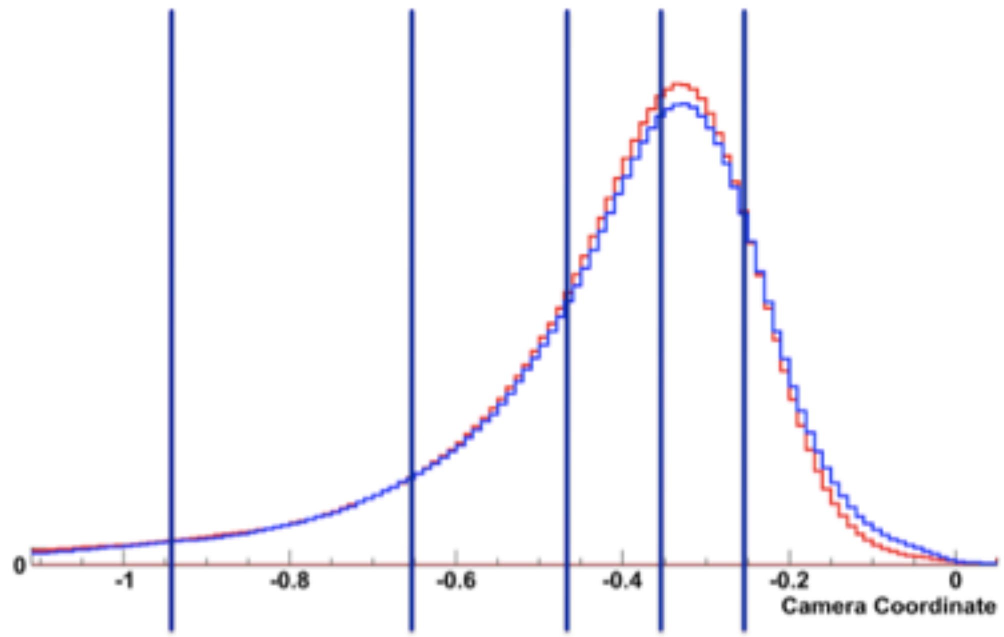
Intensity Image Slices

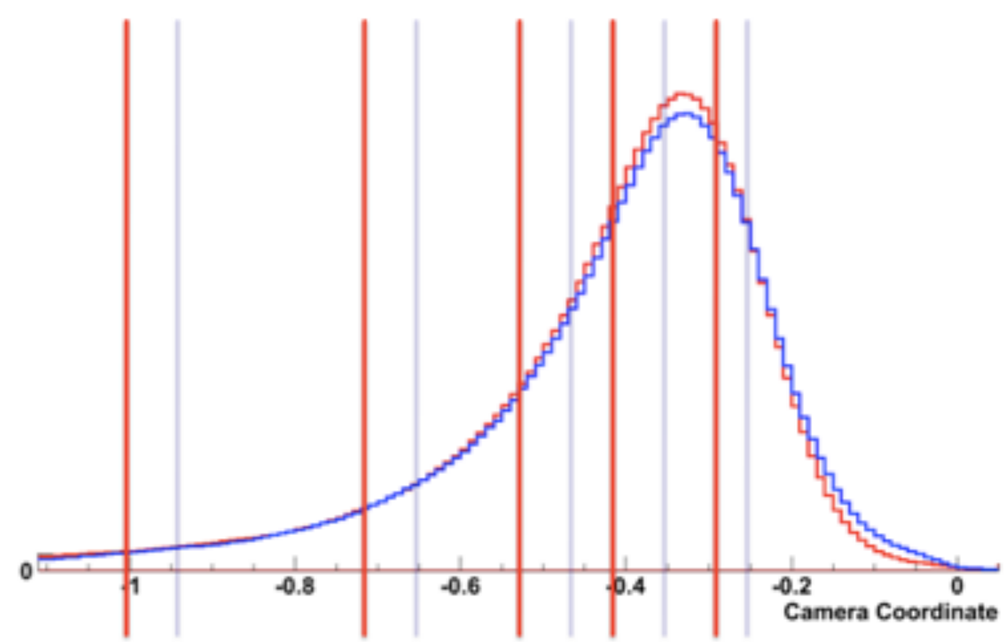


- Image is separated into slices along the shower axis
- Corresponding intensity is found

Discriminating Variable II

Intensity Lengths





Length along the camera where a certain percentage of the integrated intensity lies

electrons lie closest to the source position due to image shift and DC light

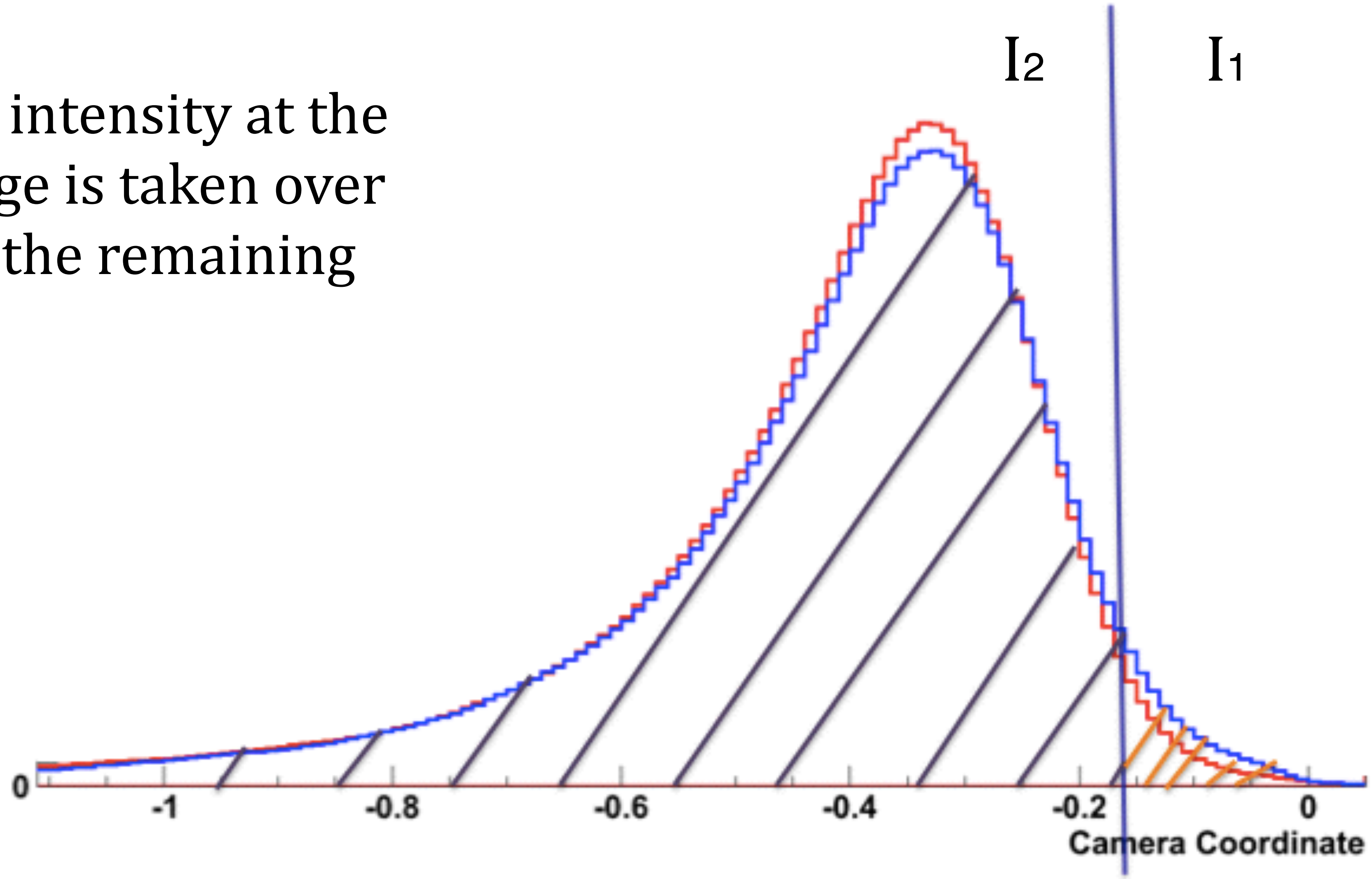
Protons are furthest due to the inaccurate source position reconstruction

Discriminating Variable III

Intensity Ratios

The ratio of the intensity at the start of the image is taken over the intensity of the remaining image.

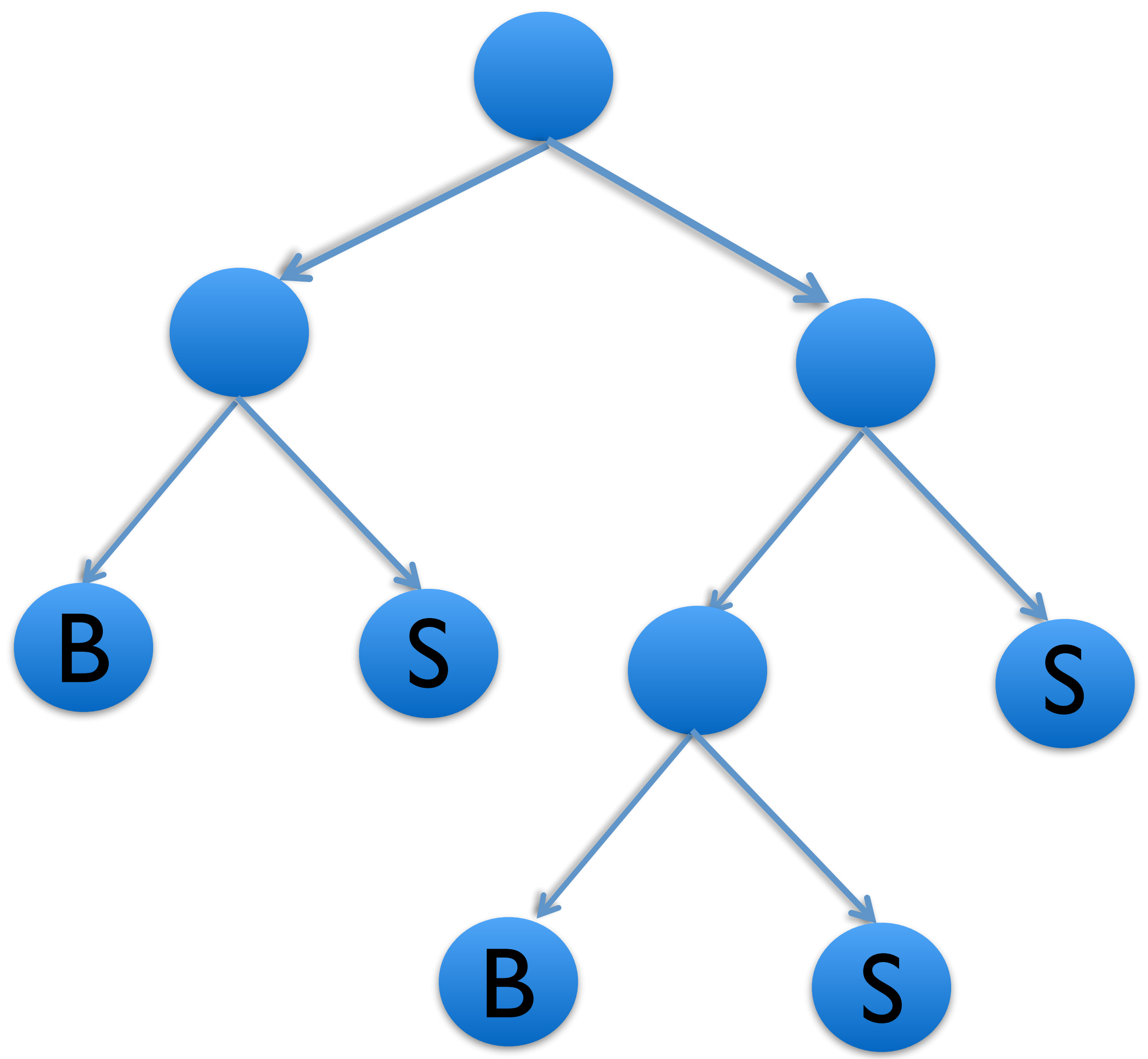
$$R = I_1/I_2$$



Variables Boosted with MVA

Multi Variate Analysis using Monte Carlo events

Boosted Decision Trees trained

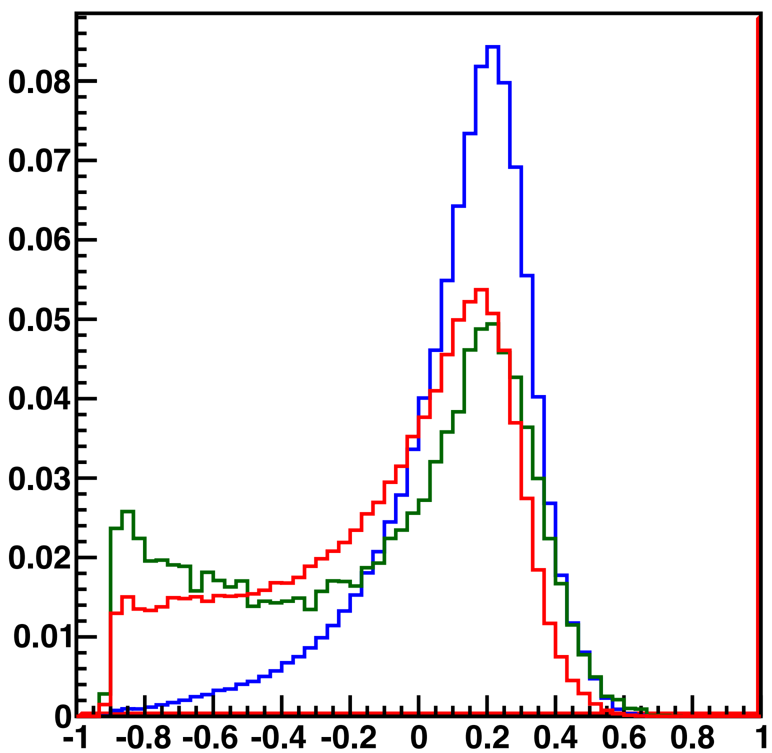


Variables Trained with MVA

Electron, gamma ray and proton Monte Carlo events

Electrons
Protons
Diffuse Gamma-rays

Electron vs Gamma ray



eg BDT Classifier

Variables Trained with MVA

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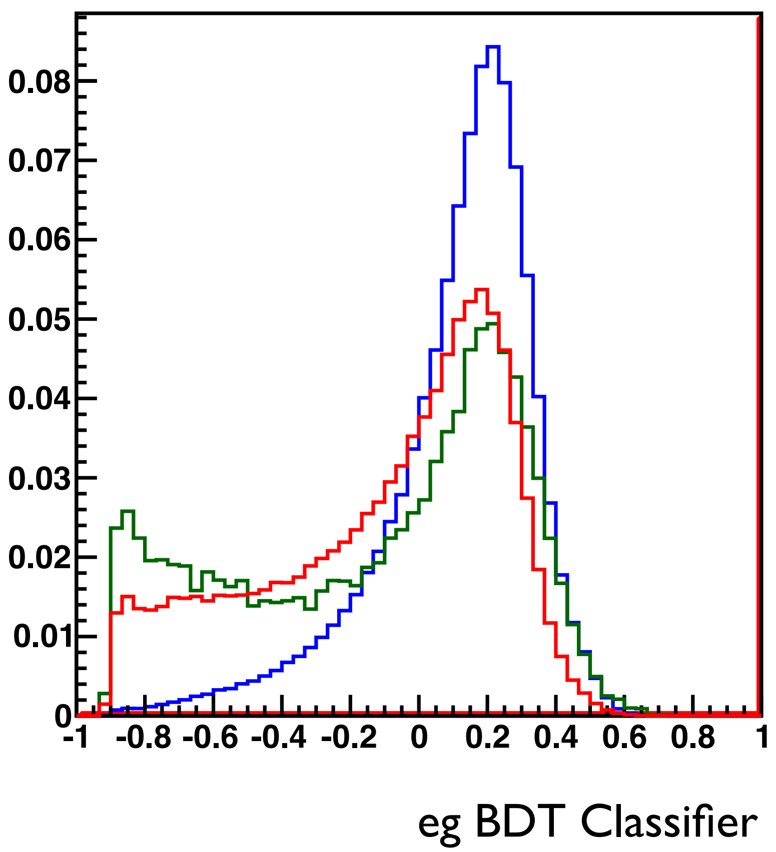
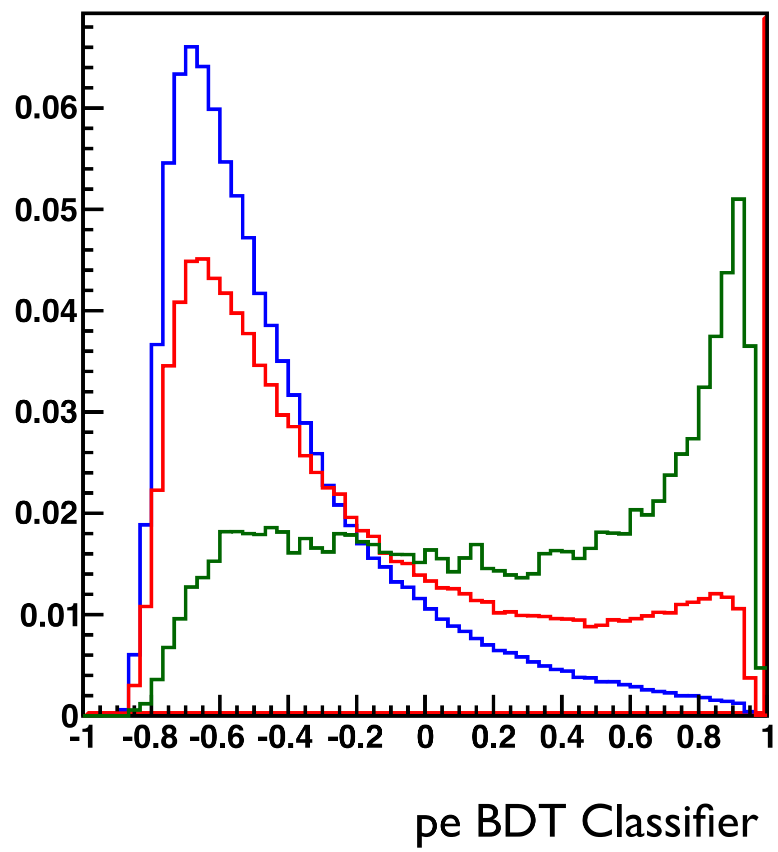


Proton vs Electron



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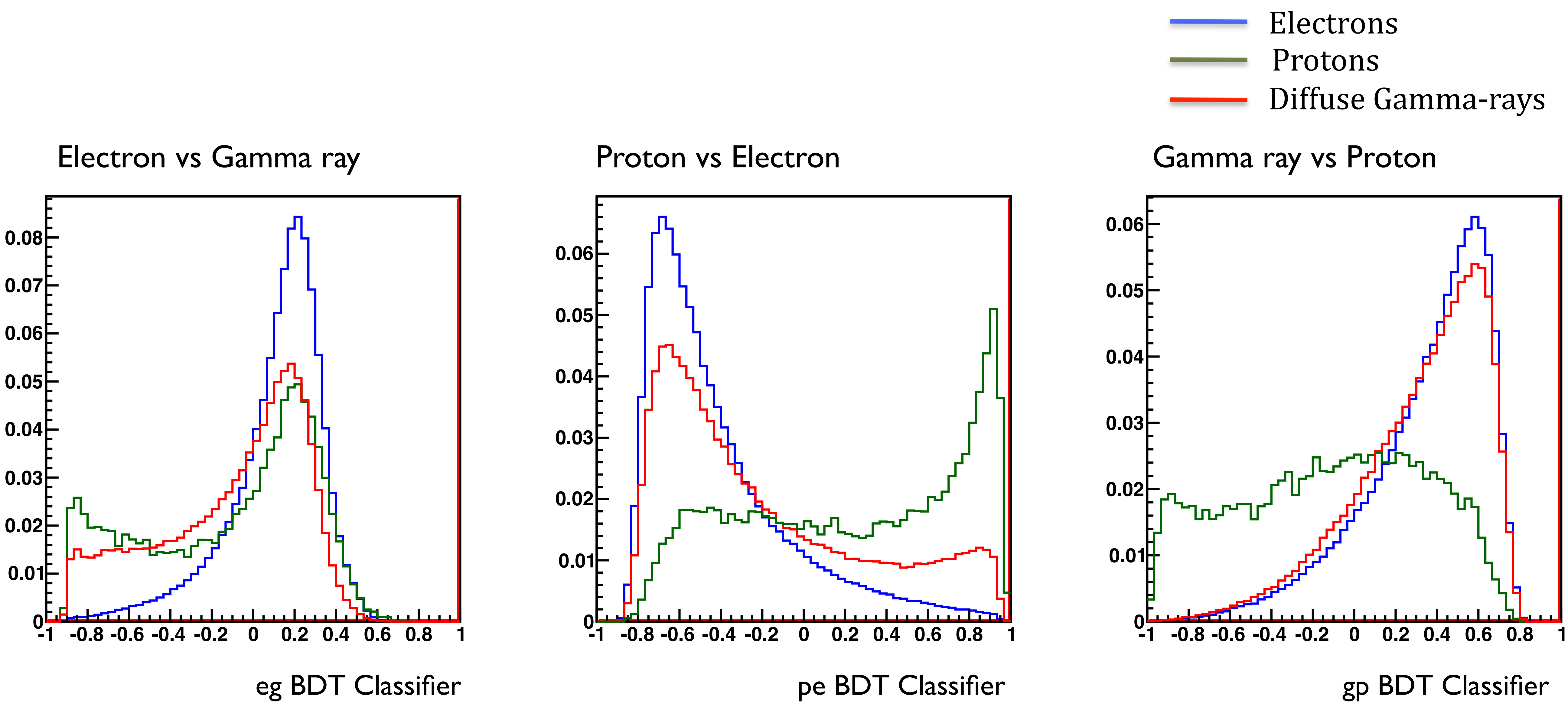
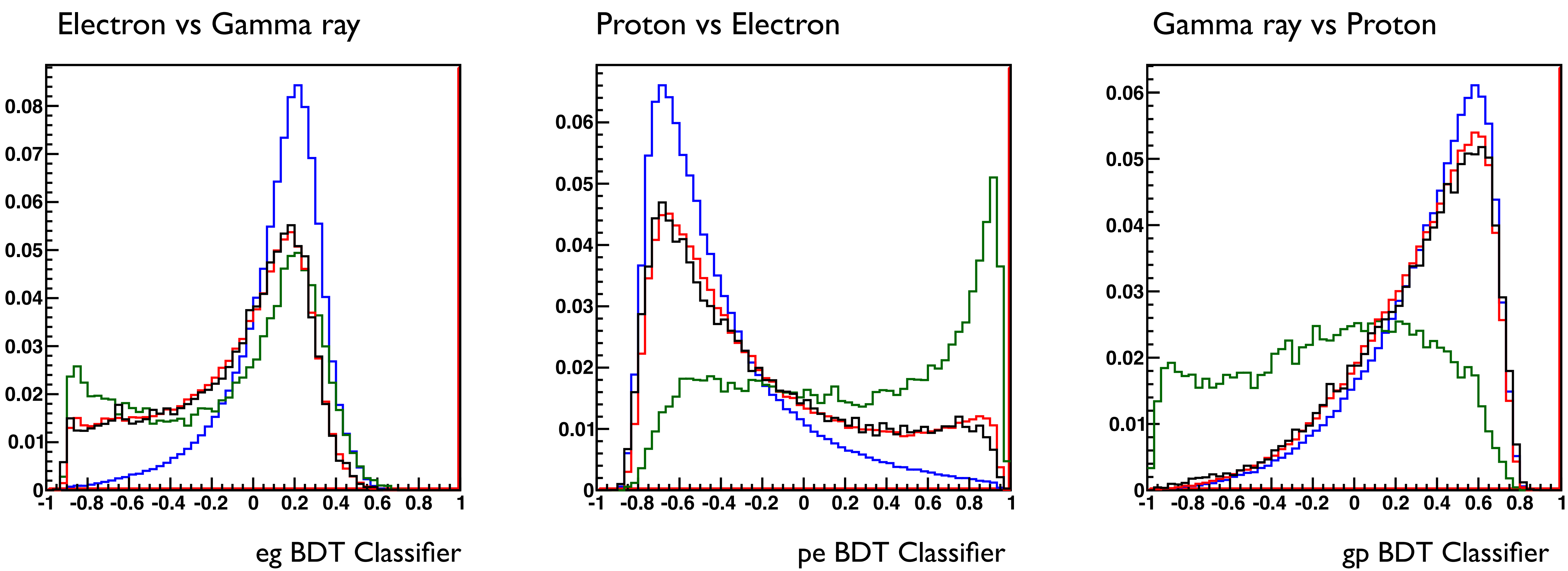


Comparison to Data

PKS 2155-304 excess events

- Excess Events
- Electrons
- Protons
- Diffuse Gamma-rays

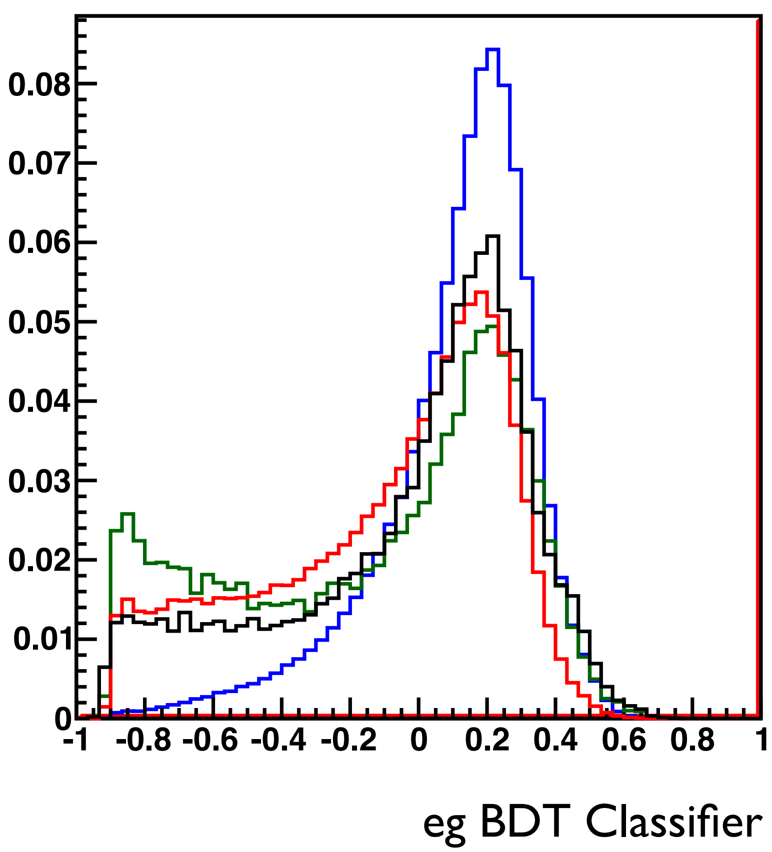


Comparison to Data

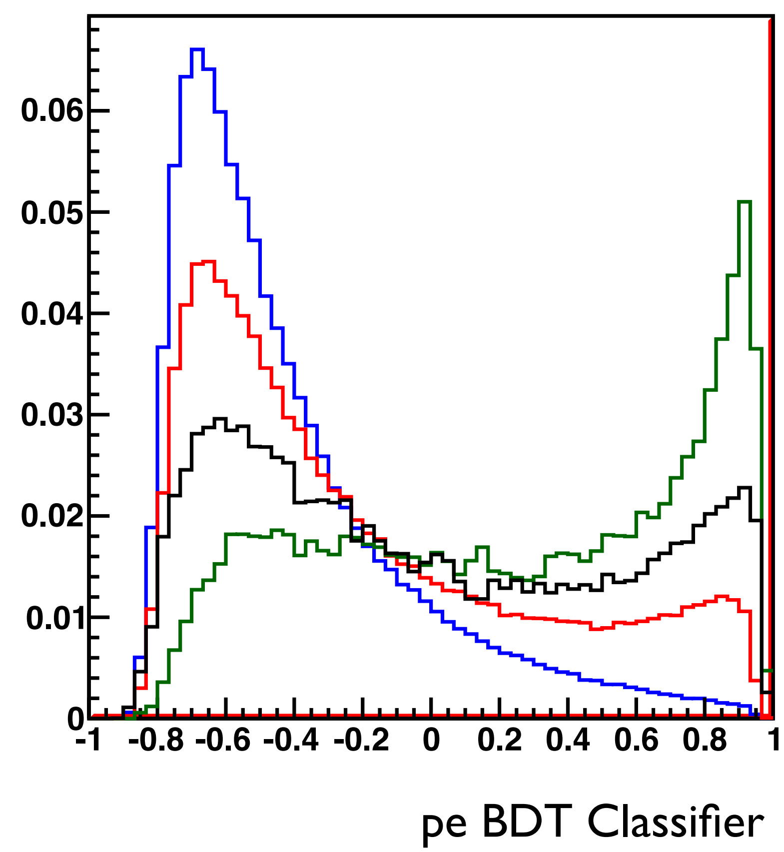
Background events

Background Events
Electrons
Protons
Diffuse Gamma-rays

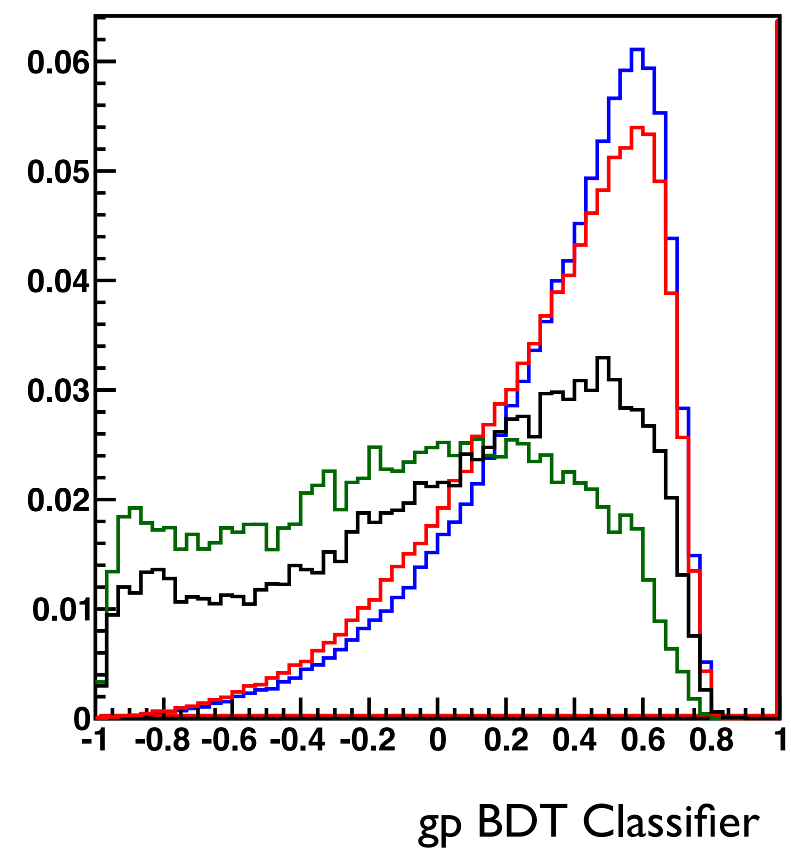
Electron vs Gamma ray



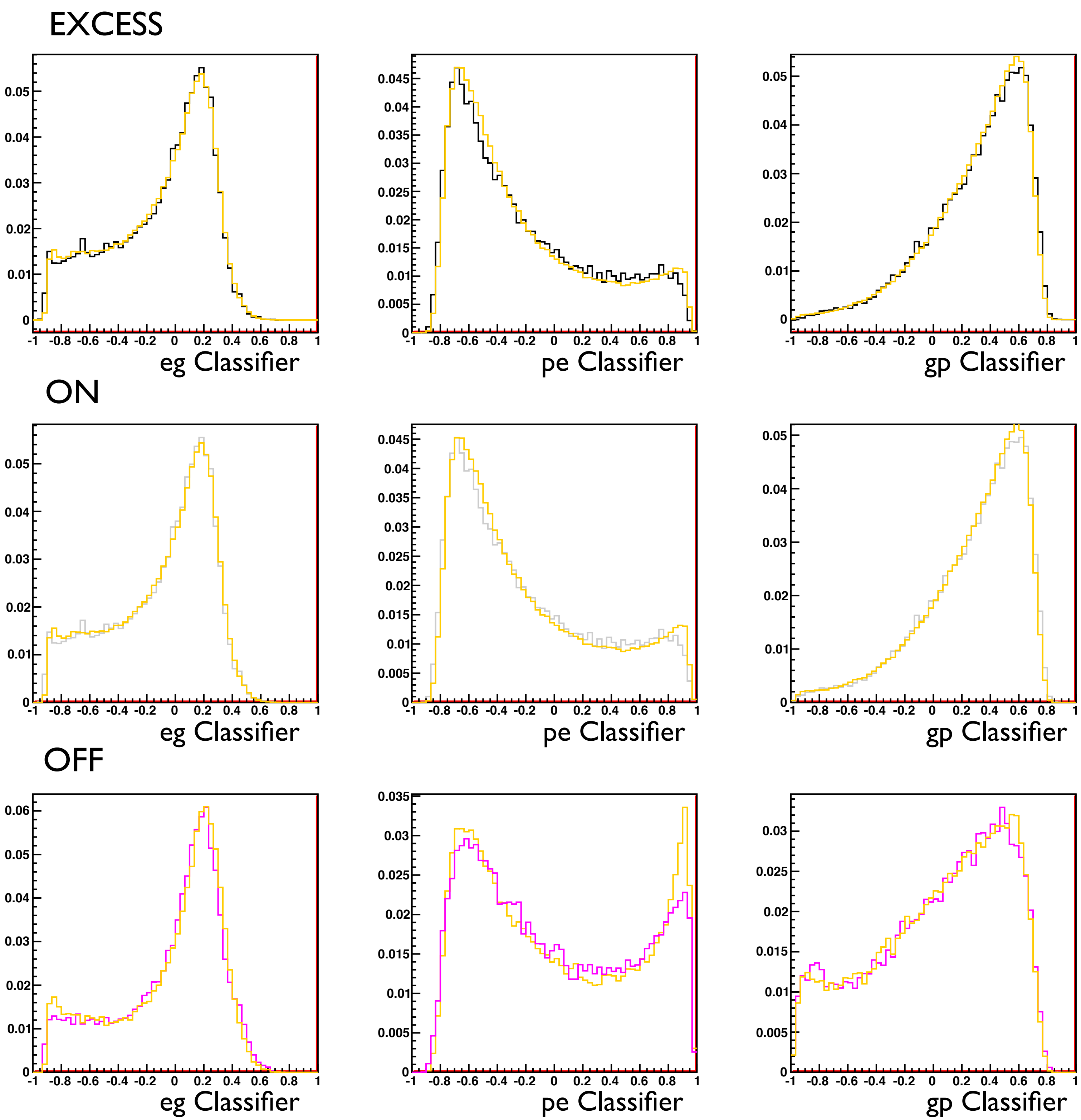
Proton vs Electron



Gamma ray vs Proton



Best Fit Model



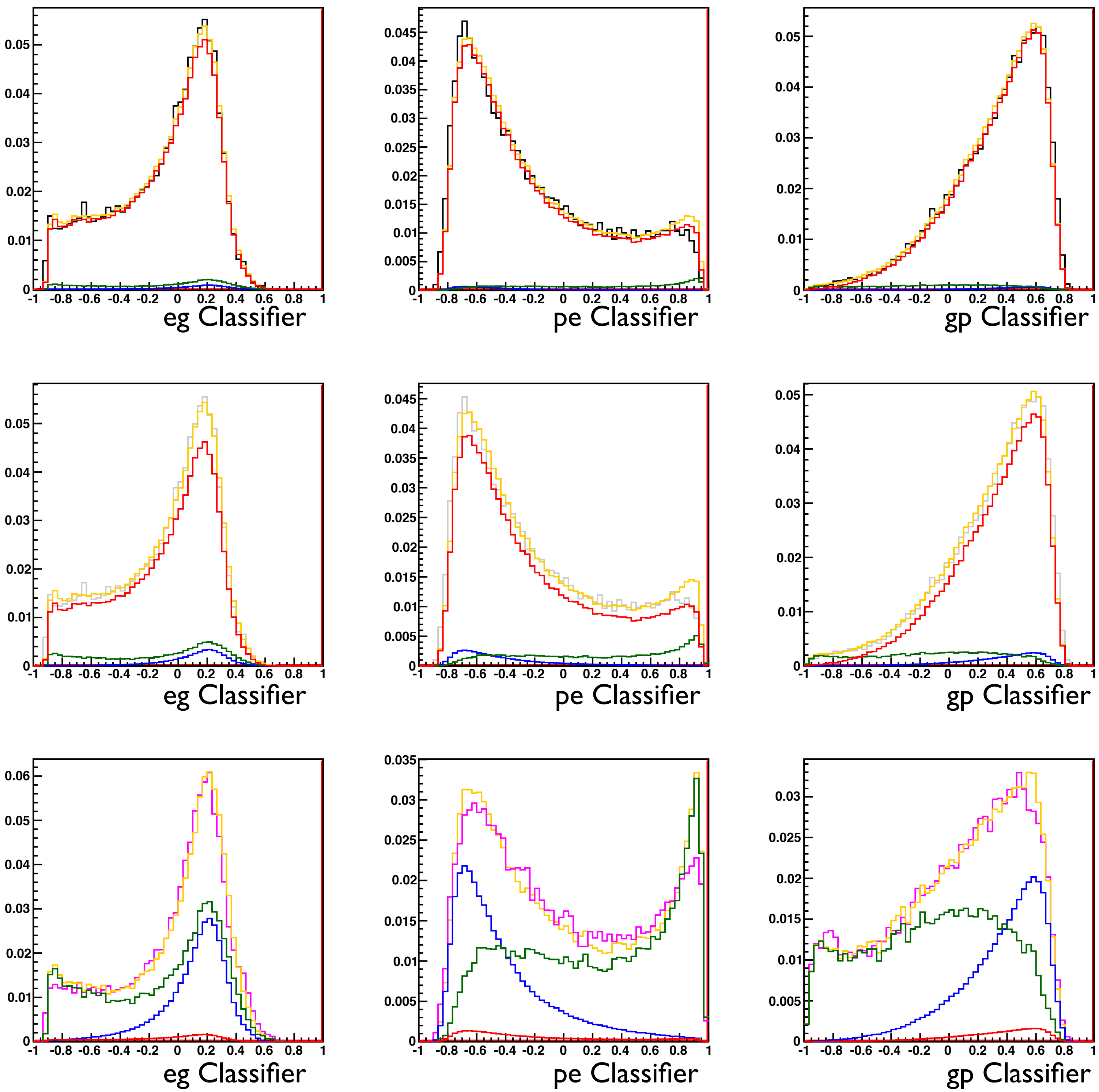
Three step fitting procedure

1) Fit proton and electromagnetic components

2) Fix proton component, fit electron and gamma ray contributions

3) Data affected by telescope optical efficiency
⟶ correction factor

Best Fit Model Individual Components



EXCESS Events

95% Gamma-rays
1% Electrons
4% Protons

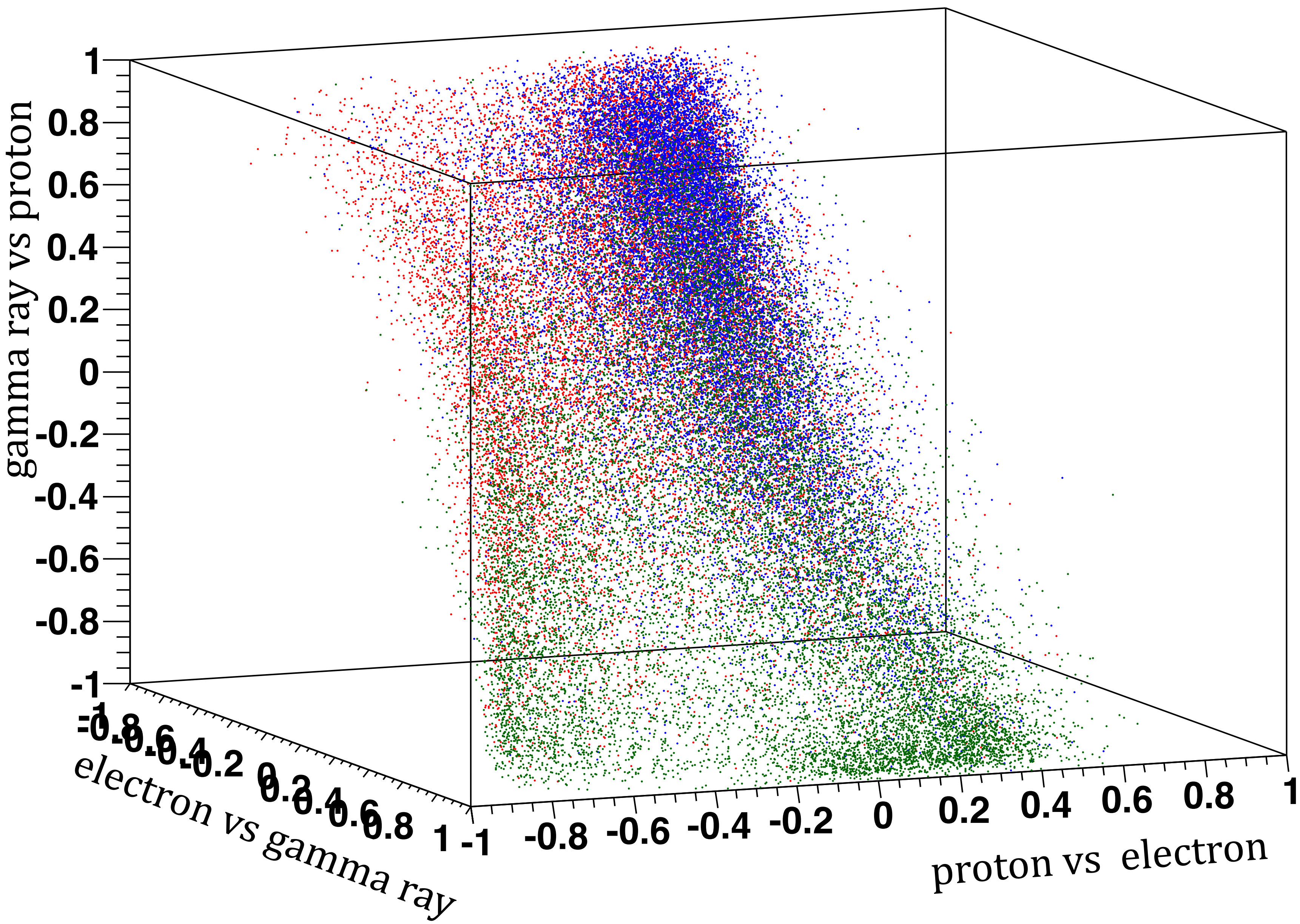
Source (ON) Region

86% Gamma-rays
4% Electrons
10% Protons

Background (OFF) Region

3% Gamma-rays
33% Electrons
64% Protons

Using All Classifiers



- 3D profile combines all three classifying distributions
- All events currently accepted as gamma rays with HESS are shown
- Making a cut allows 57% of remaining protons to be rejected while keeping 86% of gamma rays

Summary and Conclusion

> Separation of electron, proton and gamma-ray events is possible on a statistical basis

> Analysis fits data well with comparable ratio of protons to electrons in observation regions

> Cuts can be made to reduce background, with 57% of gamma-like protons rejected at 86% signal efficiency

> Next steps are to apply analysis to scientific studies