# Application of Deep Learning methods to analysis of IACTs data

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Big Data Science in Astroparticle Physics
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# Contents

# The IACT technique

- Need to classify events (based on ellipticity) and reconstruct signal direction and energy
- Imaging => CNN based modelling

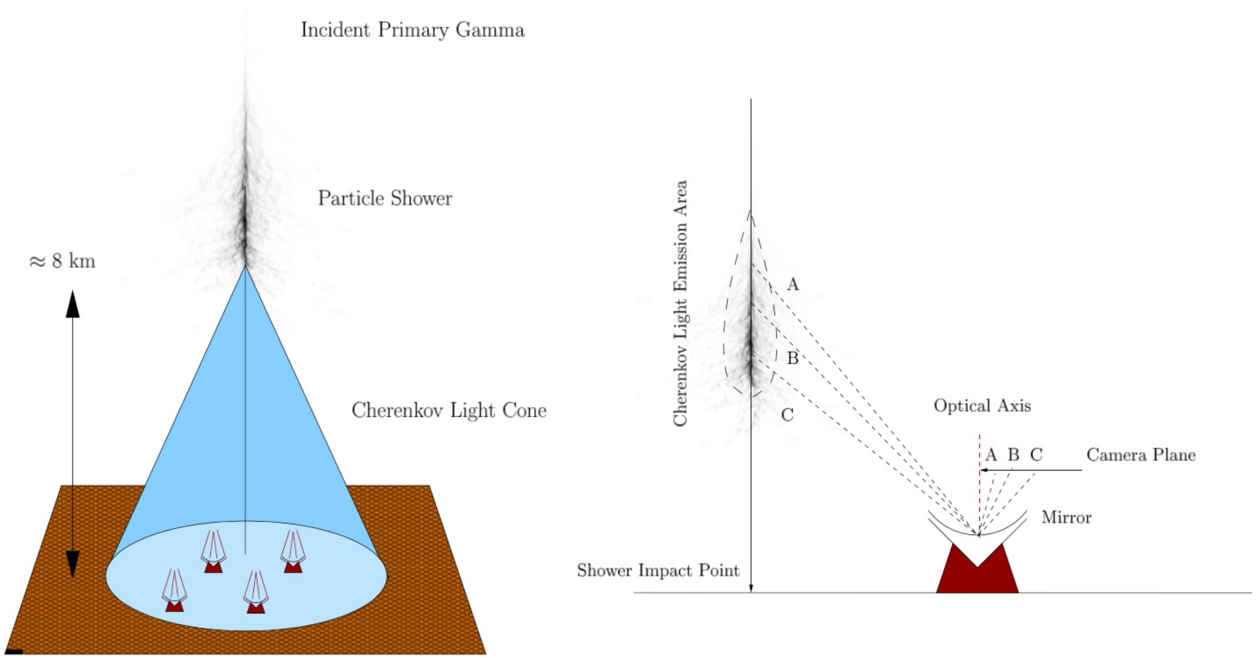


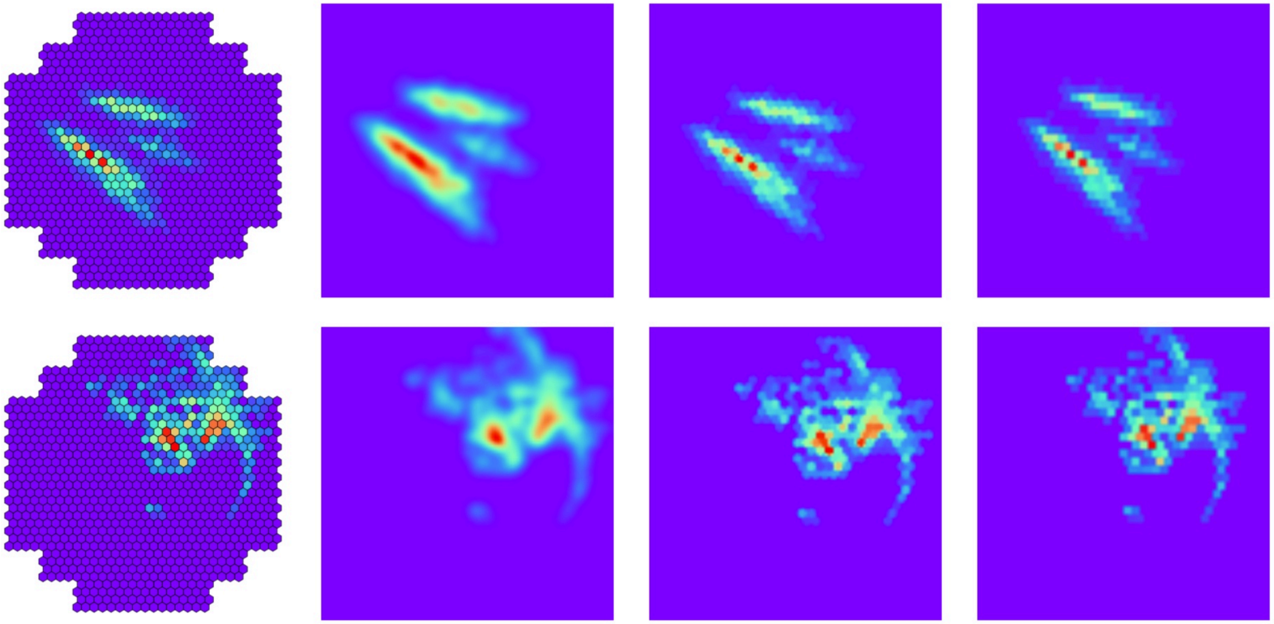

Image source: Funk, 2005

# Pipeline

1. H.E.S.S. DSTs (ROOT)
2. Convert MCDSTs to HDF5
3. Image preprocessing: transform hexagons to squares
4. Images (NumPy) to TFRecord binary files
5. DL framework: TensorFlow
6. Feed results back into ROOT (H.E.S.S analysis software)

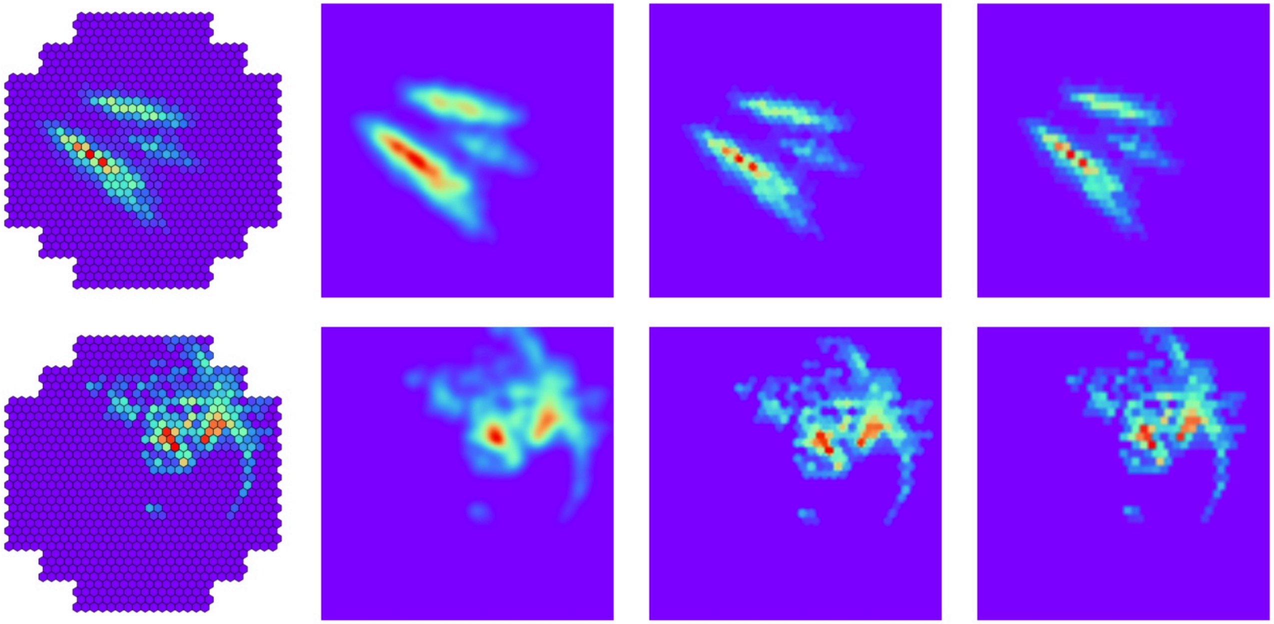
# Image preprocessing

- The H.E.S.S. cameras' pixels are arranged in a hexagonal grid
- Three conventional options: interpolation, rebinning, smoothing
- Standardize images => invariance to optical efficiency shifts
- Sequencing telescope images



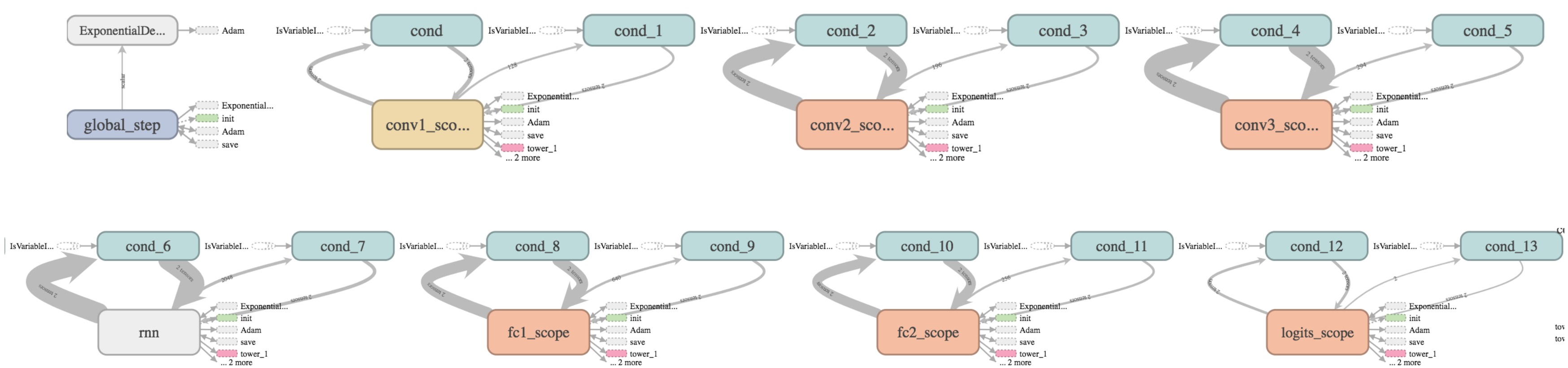
# Training and test datasets

- Training and validation sets are based on MC simulations (20 zenith)
- MC benchmark test sets - with and without preselection cuts
- MC/real-data discrepancy (see Stefan's talk in the afternoon)
- => MC test results can be used ***only*** to verify the learning process!



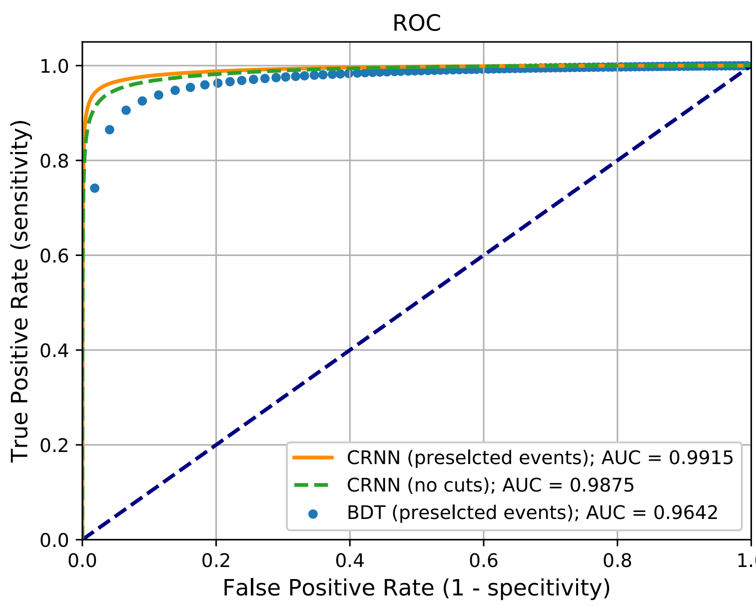
# Background rejection

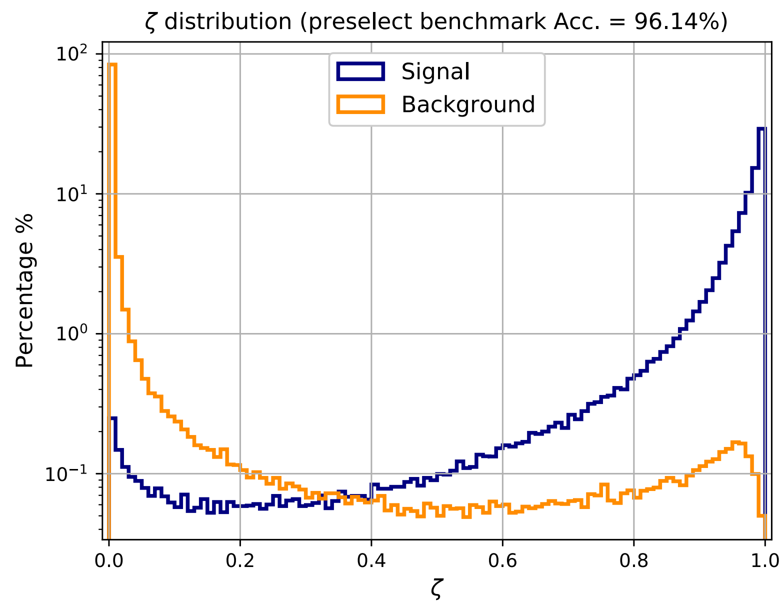
- The capability to reduce background is one of the key aspects that determine the sensitivity of an IACT
- AlexNet style CNN performs best on MCs - but not on real data
- A CNN combined with an RNN performs best on real data
- Weight decay + dropout
- Training for 6 epochs



# Background rejection - MC

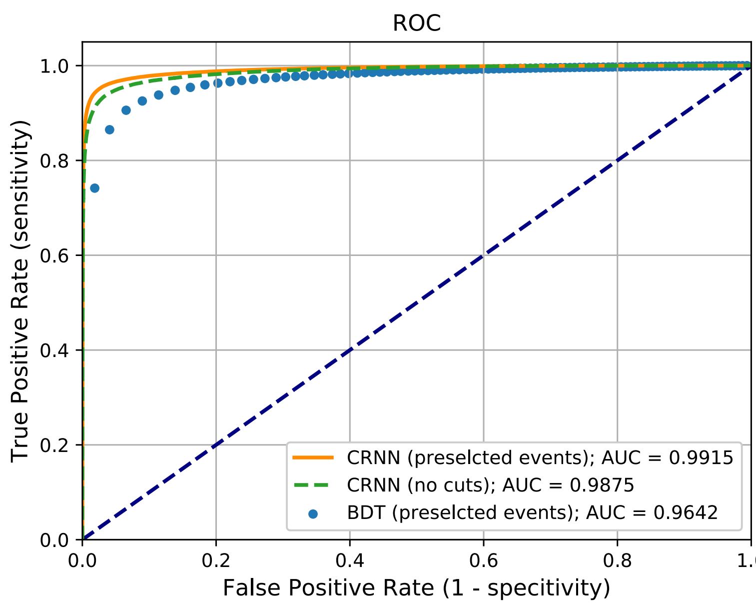
- Test on diffuse emissions (both gammas and protons)
- Preselected events (total amplitude and no truncation)
- CRNN exceeds current background rejection method performance

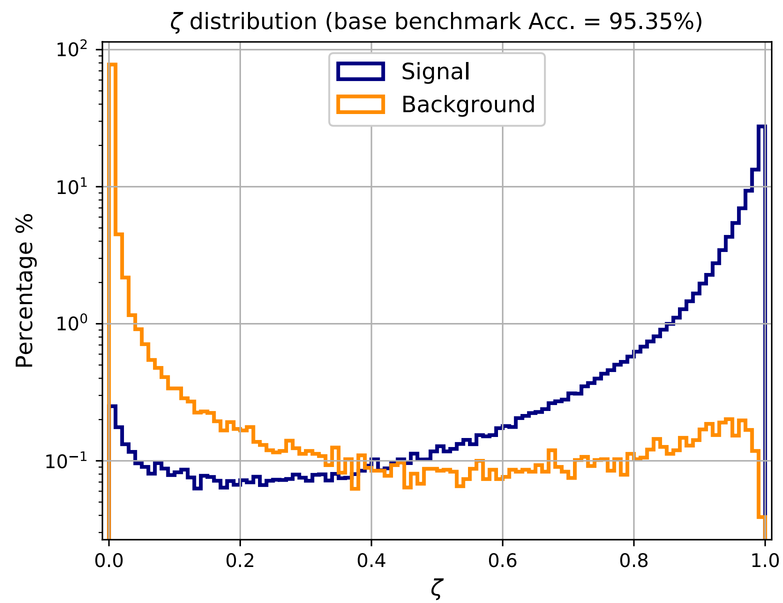


# Background rejection - MC

- Test on diffuse emissions (both gammas and protons)
- Events without preselection cuts
- Quite robust against defected data (truncation, broken pixels, etc.)



# Source analysis

- Old PKS 2155-304 (in non-flare state) H.E.S.S. runs from different optical efficiency phases were chosen to test our classifier on real data
- 14 runs with total live-time of 5.9 hours, taken between 2004-2010
- Need to overcome the CRNN classifier lack of knowledge about real data global distributions (width and length)

Width Length

Signal distribution
Bg distribution

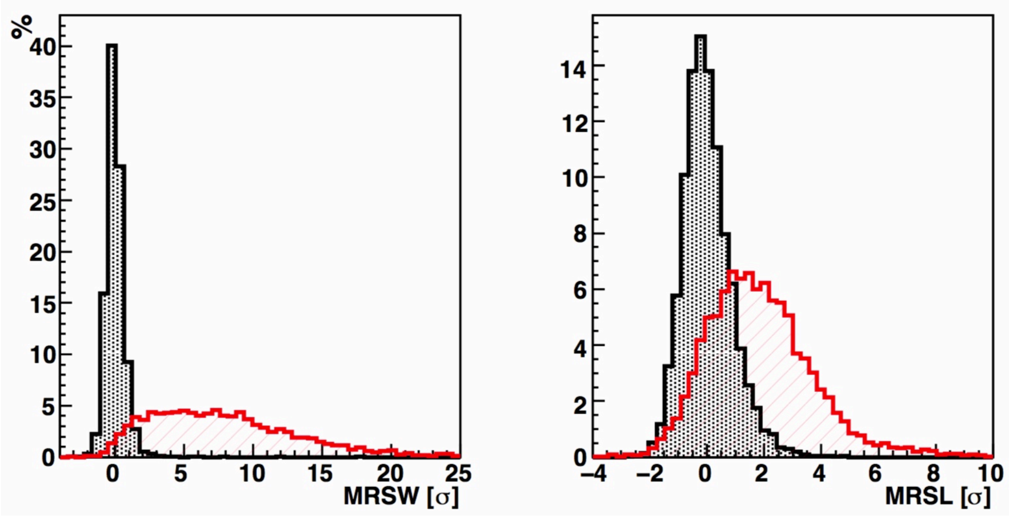
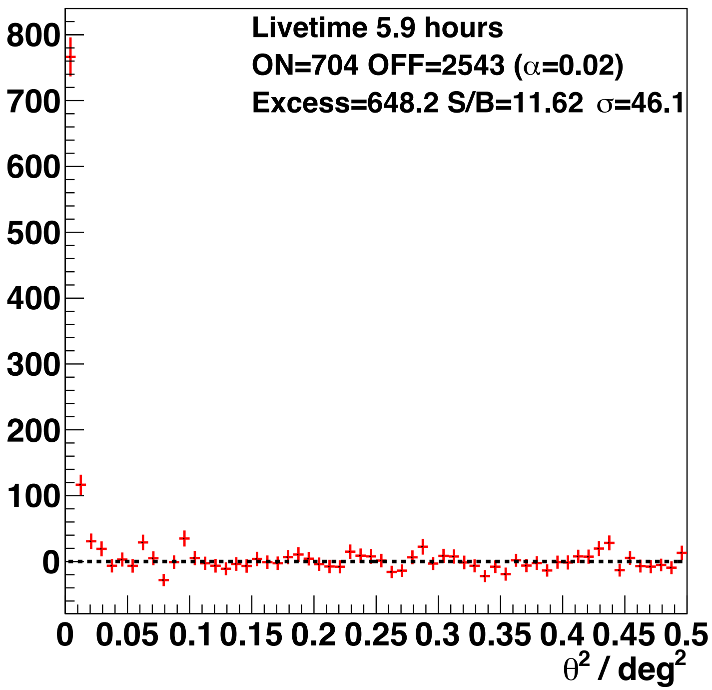



Image source : S. Ohm et al., Astroparticle Physics, 31 (2009) 383-391

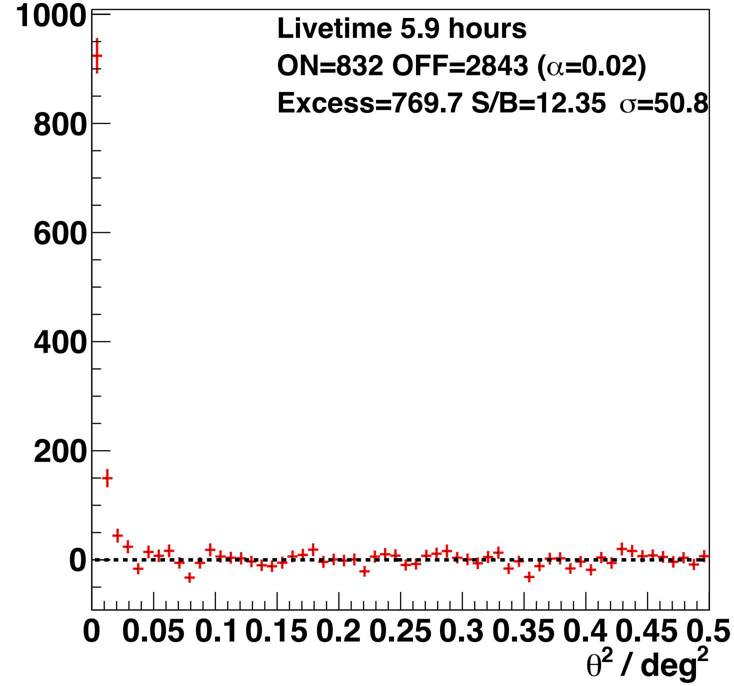
# Source analysis

- Classifier score cut is based on maximizing S/B in the observation runs. without loosing excess counts compared to the H.E.S.S. BDT classifier
- Chosen cut = 0.9

BDT




CRNN



# Source analysis

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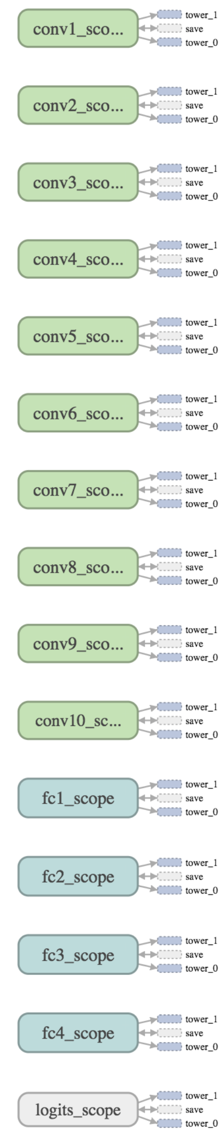
$$\alpha = 0.02193$$

| Config | $N_{on}$ | $\alpha N_{off}$ | $\sigma$ | $S/B$ |
|---|---|---|---|---|
| H.E.S.S. + BDT | 704 | 55.8 | 46.1 | 11.6 |
| H.E.S.S. + CRNN | 832 | 62.3 | 50.8 | 12.4 |

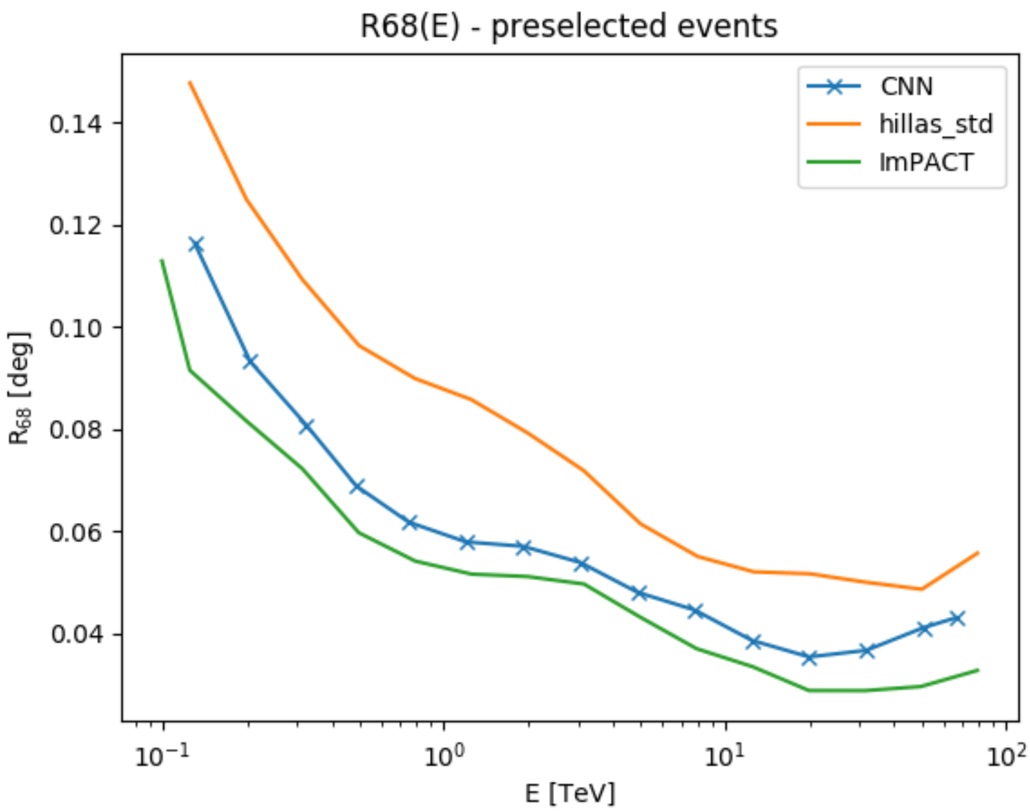
# Direction reconstruction

- Labels are given in $\Delta$-alt and $\Delta$-az, source relative to the pointing position
- Better to train separately for alt and az reconstruction
- This allows for different models per coordinate and achieving better test results than previous attempts
- But twice the time!
- No persistency needed
- 2-1 convolutional layers
- L1 loss
- Train for 14 epochs



# Direction reconstruction - MC

- To estimate the regressor performance we plot the angular resolution, (68% containment radius) of the reconstructed event positions from a point-like source



# Outlook

- We have demonstrated the improved background rejection performance of a CRNN on a real world bright source
- Direction reconstruction is constantly improving. Need to implement pointing correction to analyse real data
- Energy reconstruction - based on direction
- Study MC/real-data discrepancy
- Challenges with CTA
- Adding zenith bins to analyse more runs and more sources

*We thank the H.E.S.S. Collaboration for supporting this study and for granting us access to MC simulation and real observation data.*

*Thank you!*

H.E.S.S.

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# The H.E.S.S. array