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# Deep learning methods for gamma event selection in TAIGA-IACT image analysis in stereo-mode

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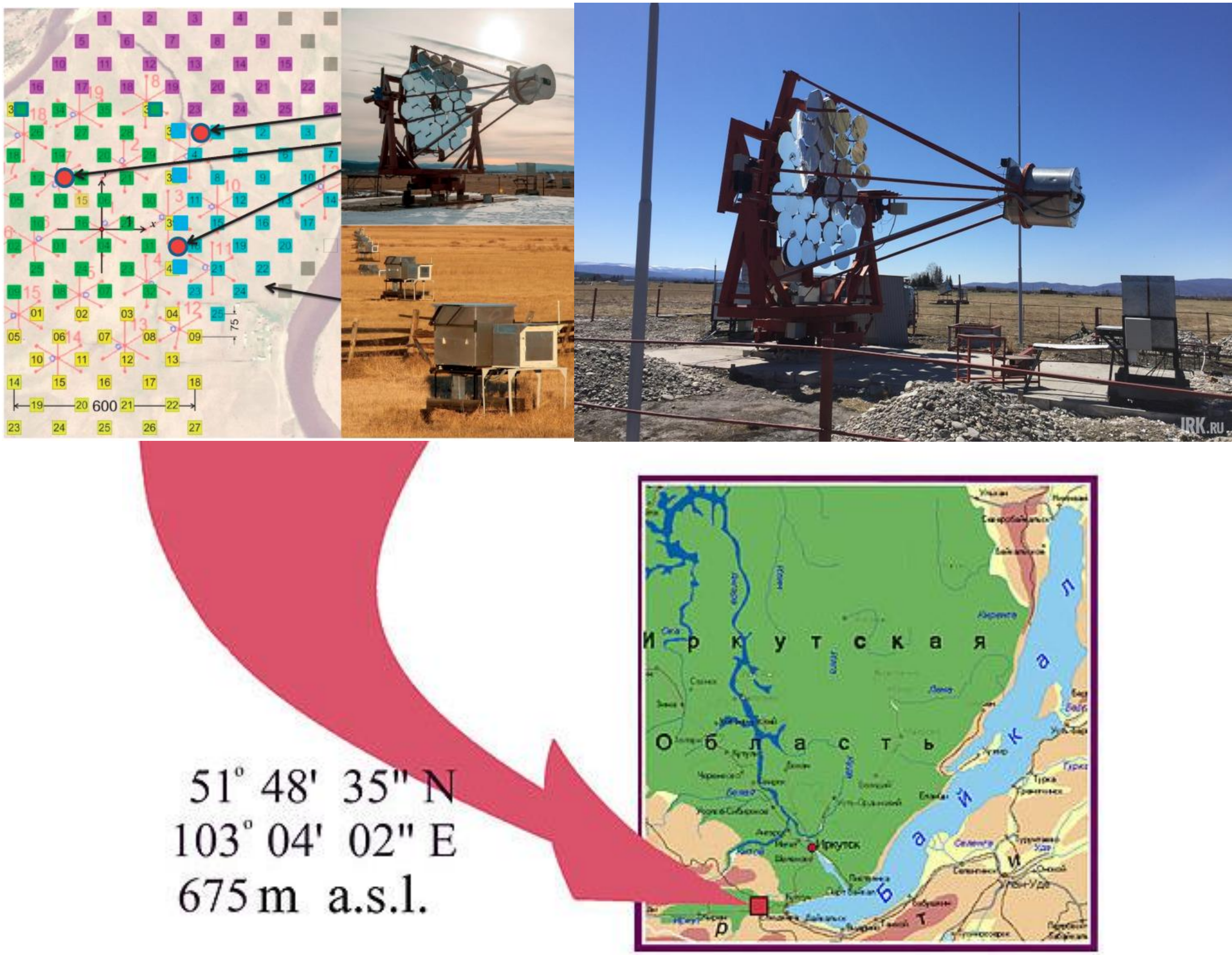
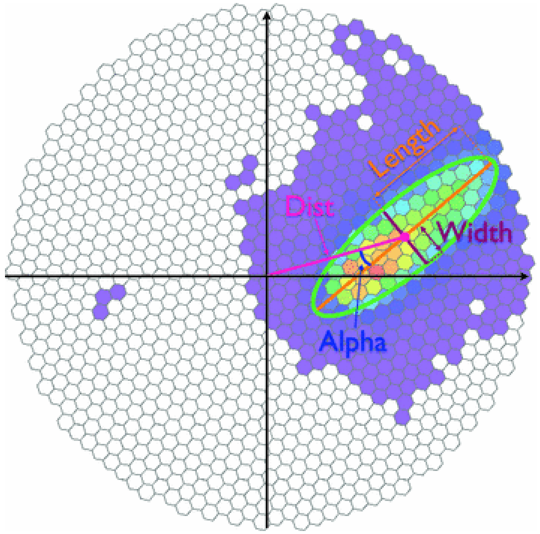
# TAIGA-IACT

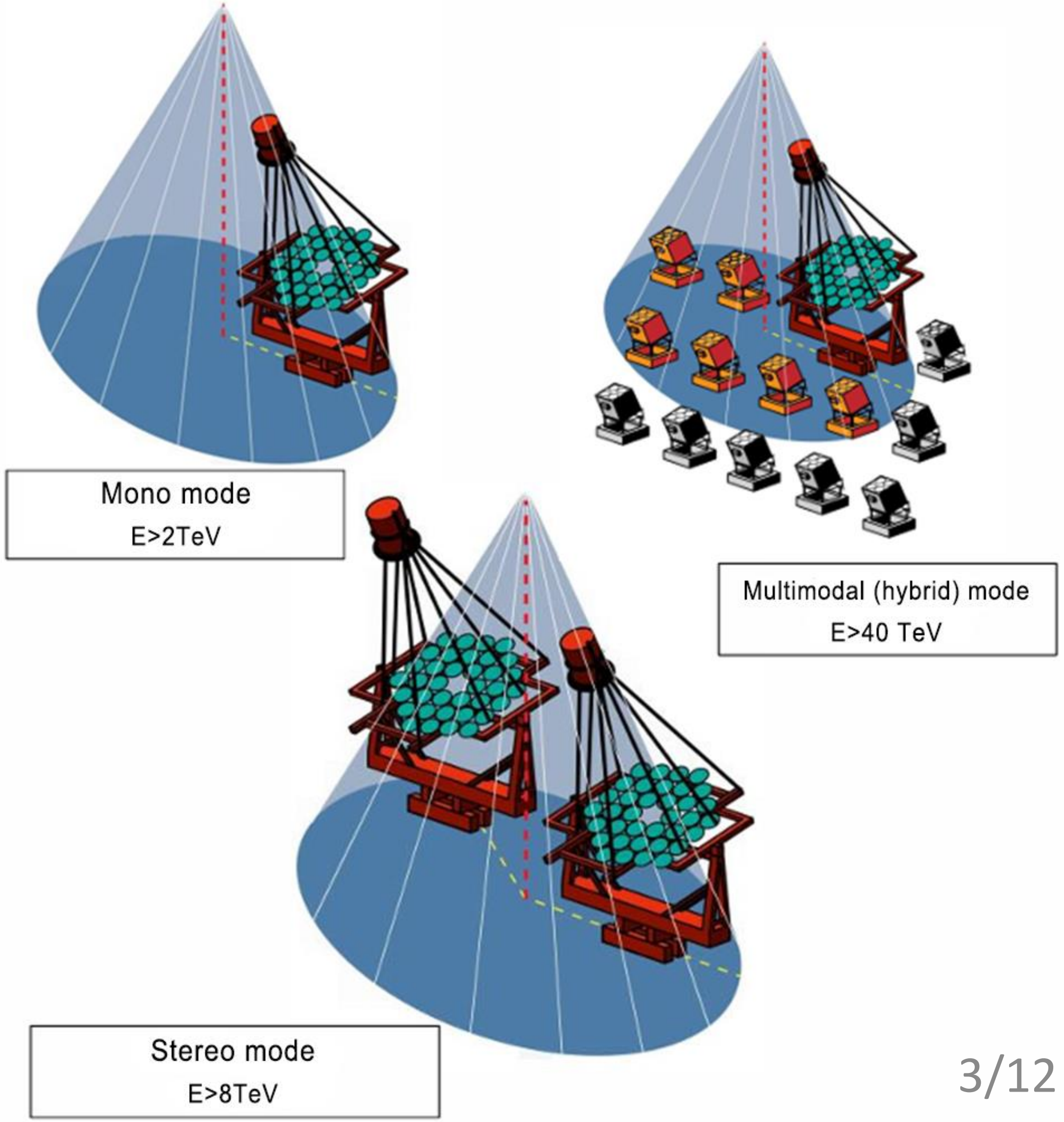
- Imaging Air Cherenkov Telescopes (IACT) are located in Tunka Valley, Republic of Buryatia, at the astrophysical gamma observatory TAIGA of the API ISU.
- Mirror diameter: 4.3m
- FoV: 9.6°
- Camera: 600 PMT XP1911, grouped into 22 clusters.
- Four TAIGA-IACTs are in operation mode.



# Stereo mode

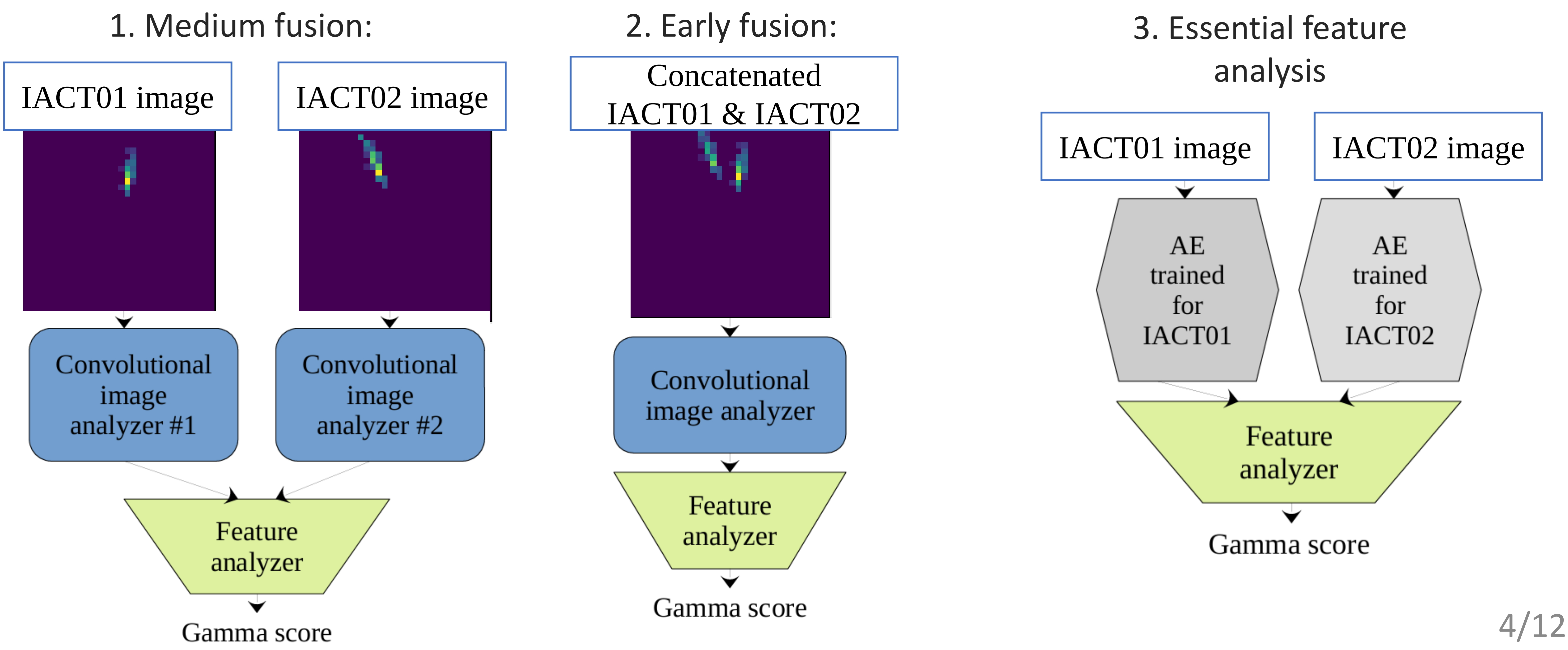
- Every telescope detects the Cherenkov light from EAS.
- Since telescopes is located near each other (250-350 m), Cherenkov light cone can trigger multiple telescopes.
- Classical approach is based on the analysis of normalized Hillas parameters extracted from the images.



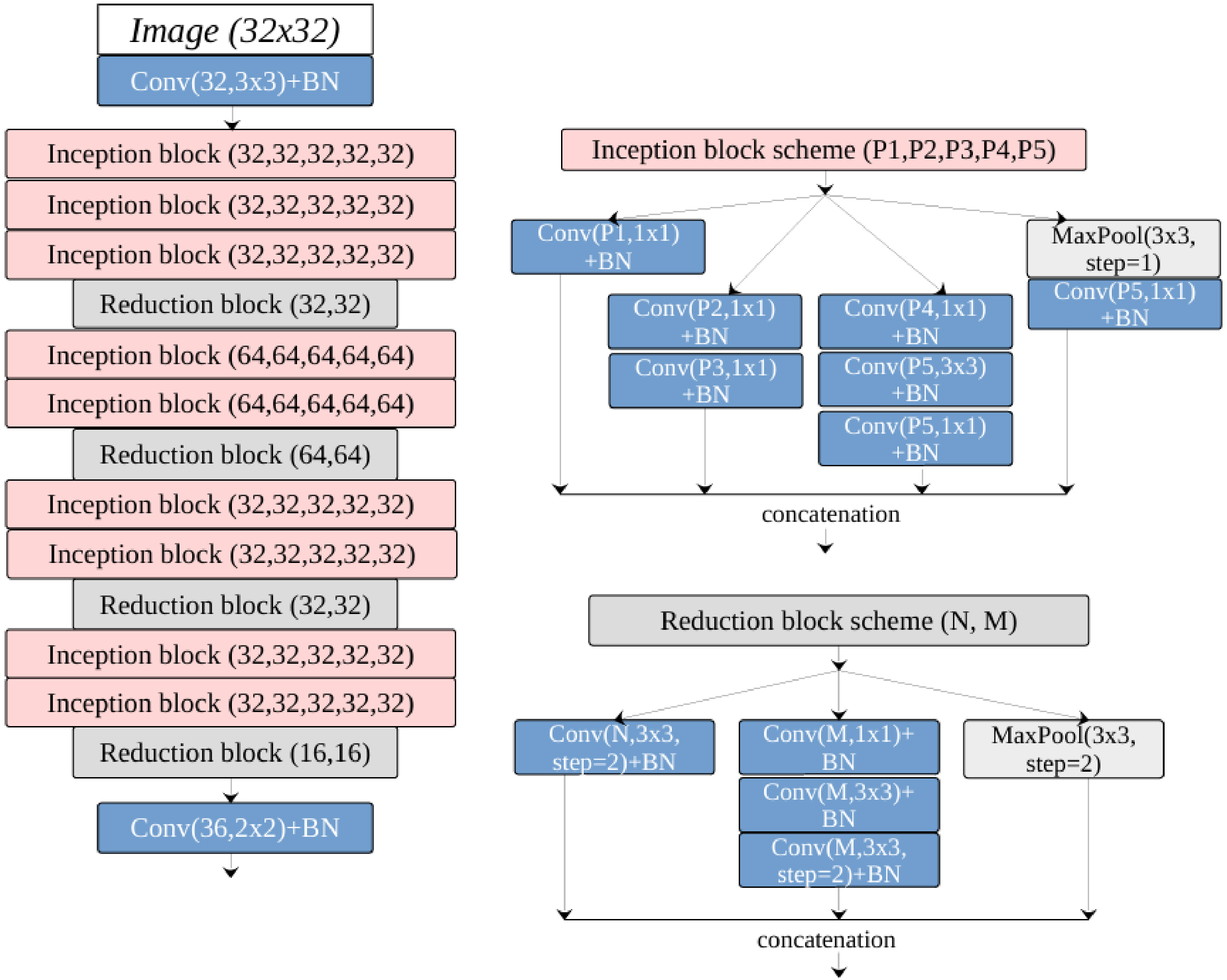



# Proposed deep learning approaches for IACT stereo-mode

- The aim of the research: develop neural network methods for gamma selection with TAIGA-IACTs in stereoscopic observations

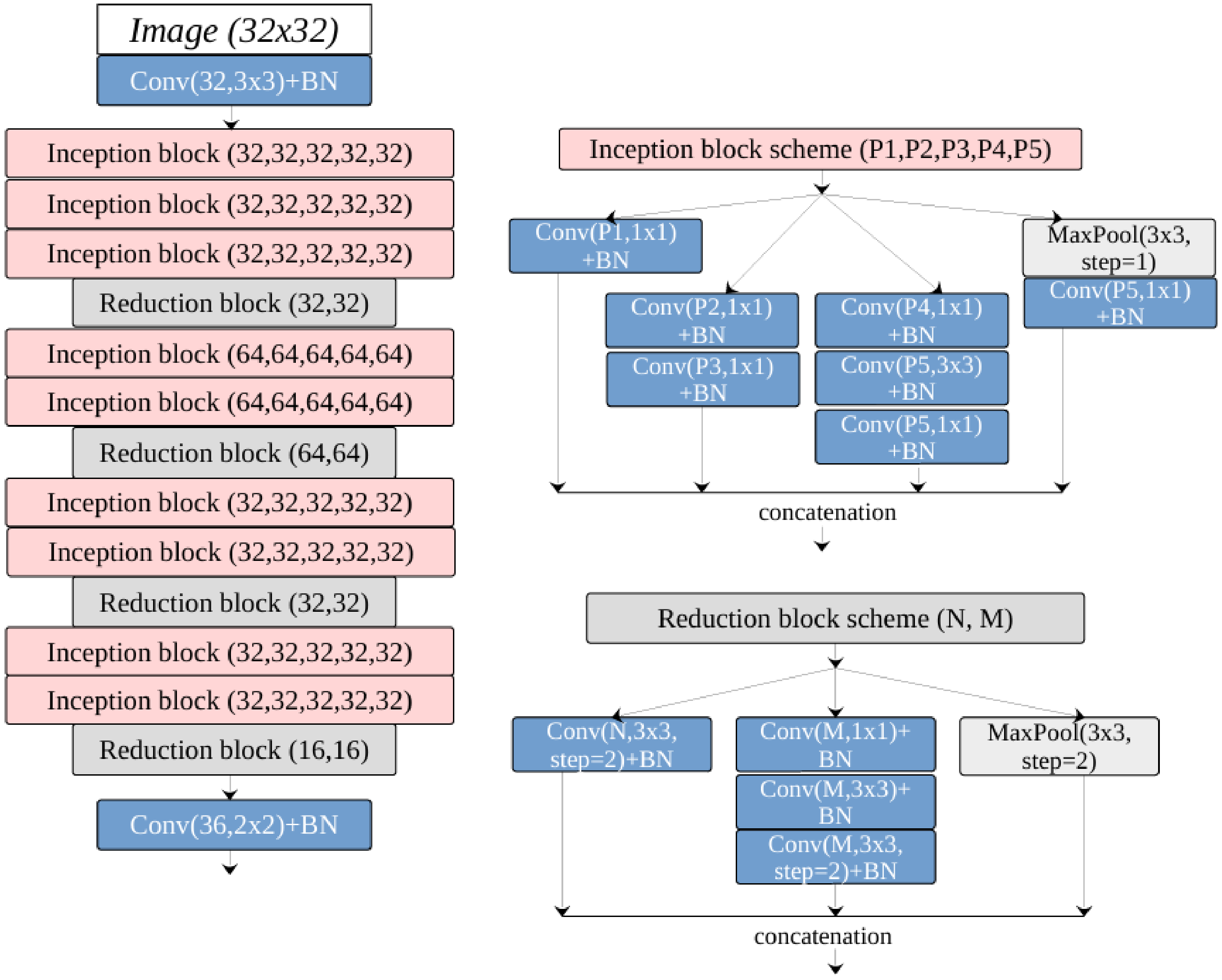


# Proposed deep learning approaches for IACT stereo-mode




- Simplified Inceptionv4 CNN
- Total trained weights: ~1.1 million
- In case of medium and early image fusion, 1 dense layer is feature analyzer
- For AE latent space analysis feature analyzer structure:
- Input(36) -> dense(2048) -> reshape(8,8,32)-> conv2d(2x2,128, s=2) -> conv2d(2x2,256 , s=2) -> conv2d(2x2,512 , s=2) -> dense(512) -> dense(1)

# Proposed deep learning approaches for IACT stereo-mode

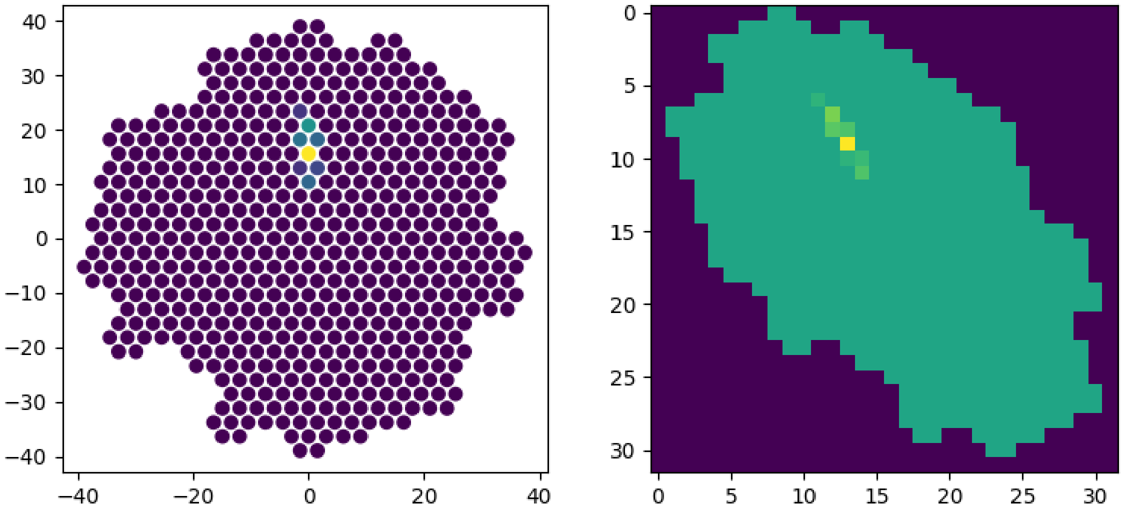



- Classification loss function: binary crossentropy, *focal loss*.
- Image reconstruction loss function: MSE.
- Activation function: silu
- Epoches (classifier): ~10
- Epoches (AE): ~100
- Learning rate: 0.0001, with step decay

# Training and Validation

- MC data was generated with CORSIKA. Simulation includes relative PMT sensitivity, PMT’s Winston cone, background noise, etc.
  - Gamma and proton events spectrum slope: -1
  - Energy range: 40-400 TeV.
- <u>Gamma training events:</u> 29 900
- <u>Proton training events:</u> 157 000
  - AE was trained on proton events.
  - Augmentation for stereo-mode CNN: class weights, input channel switch.

- <u>Image preprocesing</u>:
  - Image cleaning;
  - Image transformation to square form;
  - Logarithmic amplitude scaling.

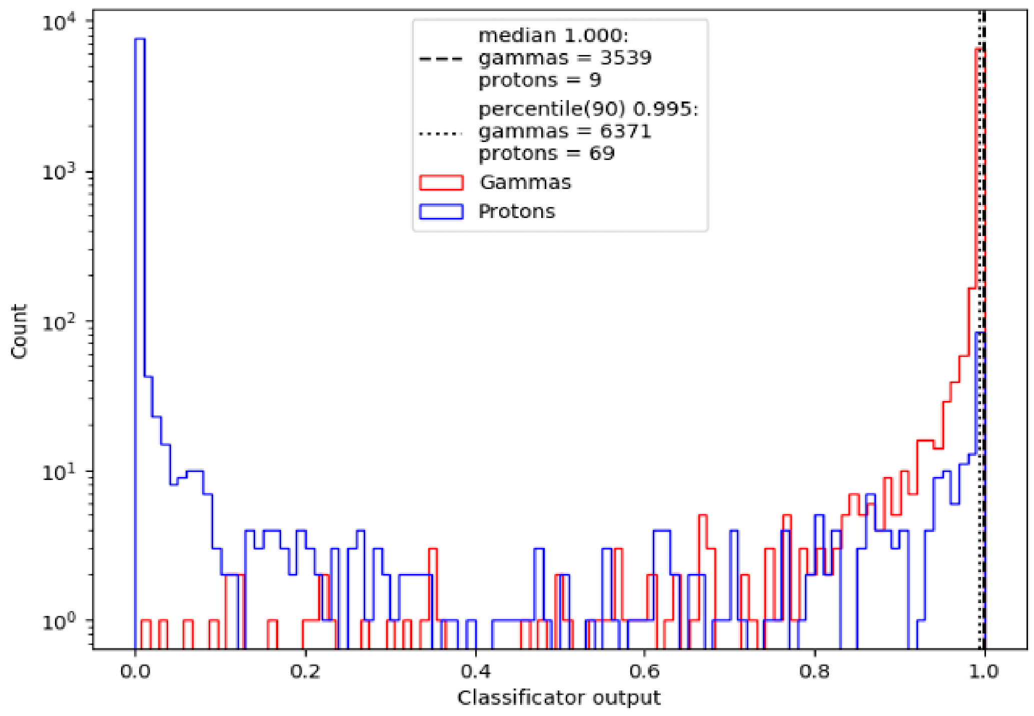



Example of image transformation

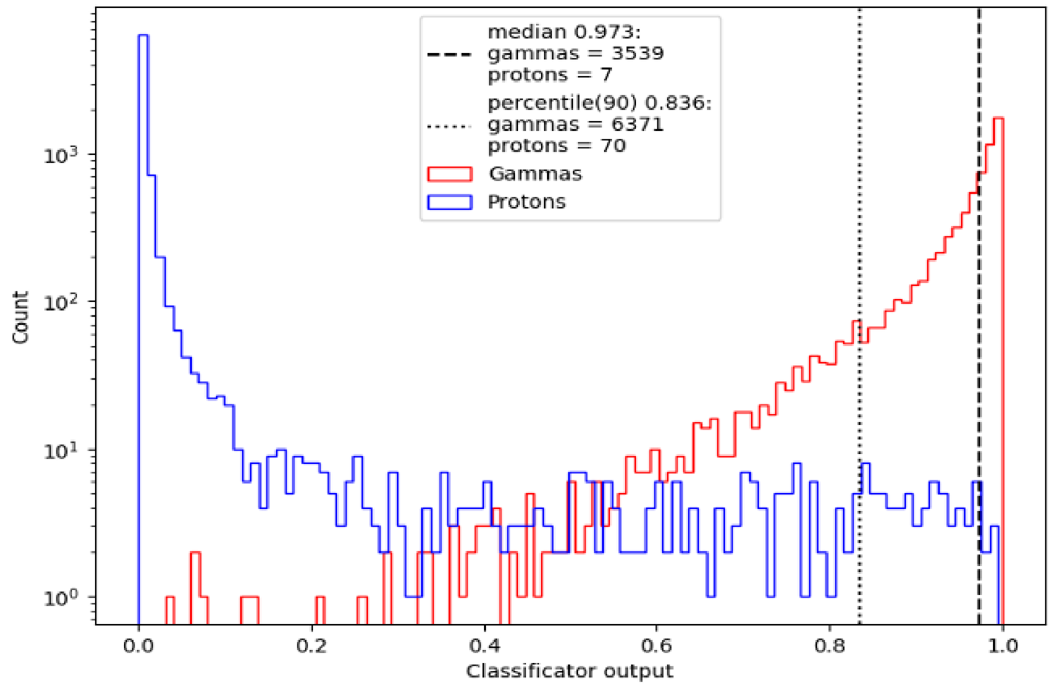
# Training and Validation

- Validation gamma events: 7 100
- Validation protons events: 7 600
- Class threshold: 50% gamma remaining

Binary crossentropy (0.99994)




Focal loss (0.973)

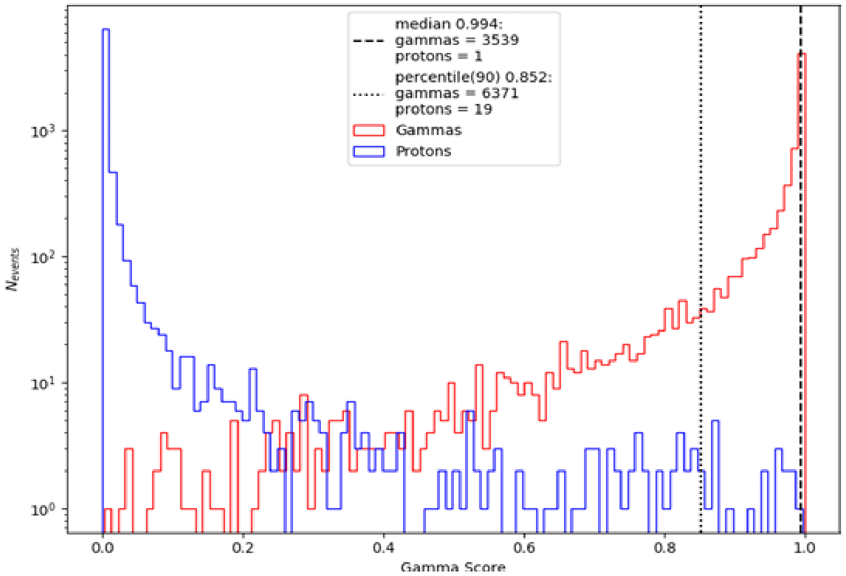


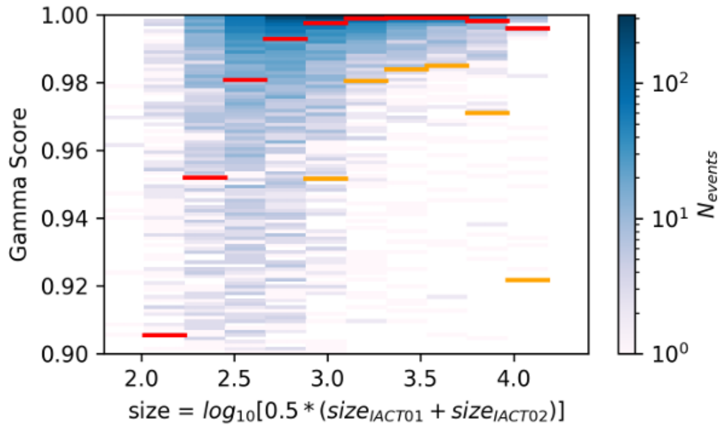
# Training and Validation

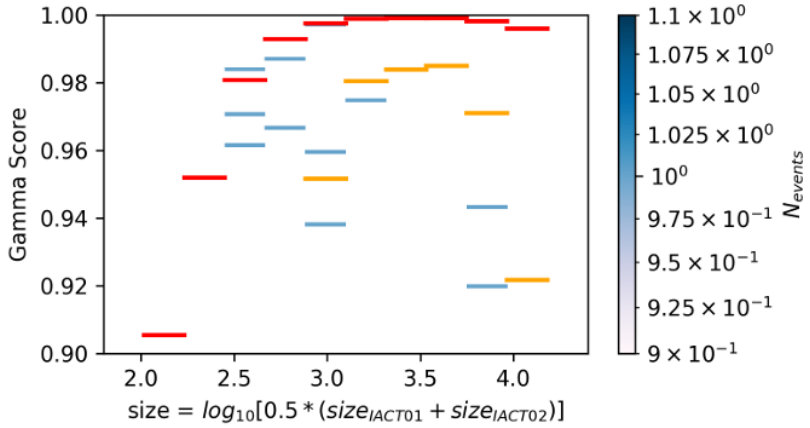
Gamma

Protons

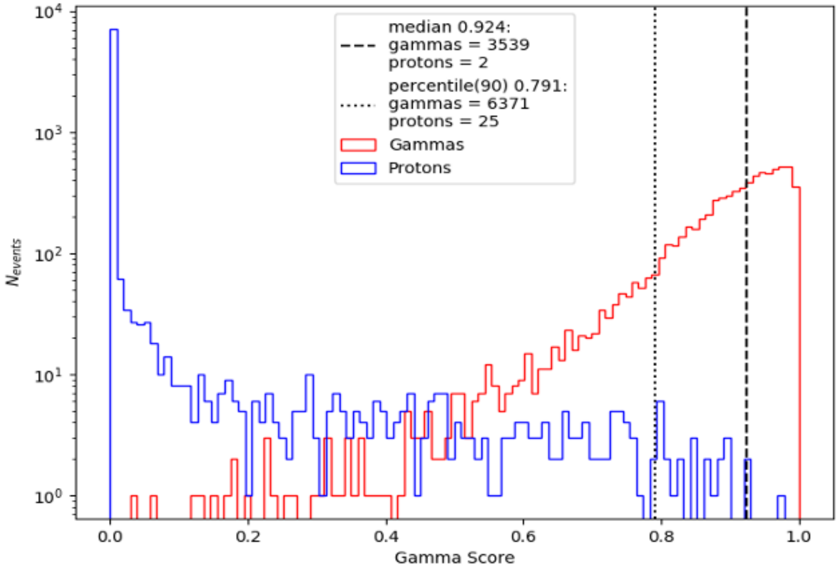
Medium fusion

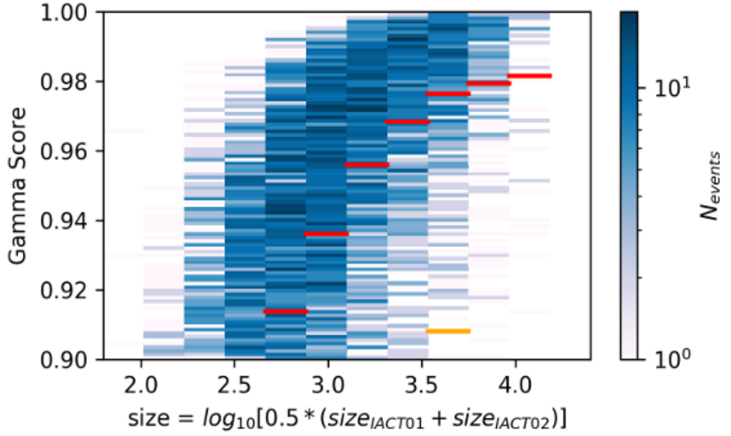


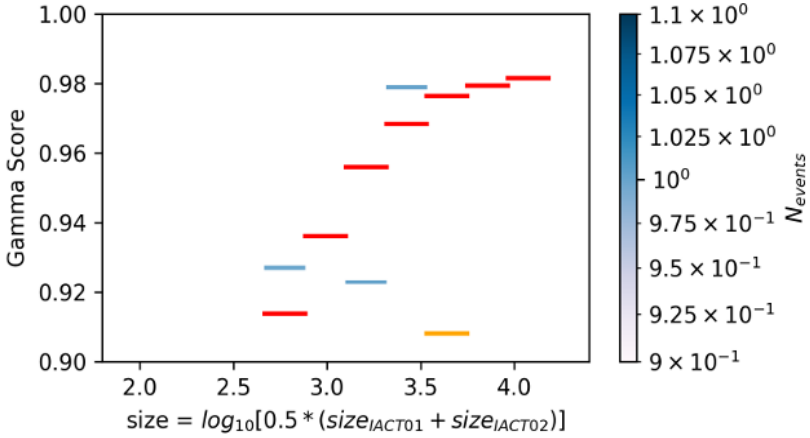




Latent space analysis




On pictures above: red – 50% gamma threshold, yellow – 90% gamma

# Selection in case of class imbalance

- For the most gamma sources, significant gamma/hadron imbalance (1/10000) are observed in TeV energy range.
- Thus, test imbalance was around 1/100 to investigate the CNN capibilities. Also, test results for mono-mode are presented. Class thresholds obtained from CNN validations.

| | DL methods | Total gamma | Total hadrons | selected gamma | selected protons | Gamma remained | Hadron suppression |
|---|---|---|---|---|---|---|---|
| **Size-independent class threshold** | CNN (mono-mode) | 320 | 35000 | 147 | 41 | 45.9% | 854 |
| | CNN (medium fusion) | 400 | 39600 | 188 | 9 | 47.0% | 4400 |
| | CNN (early fusion) | 400 | 39600 | 206 | 3 | 51.5% | 13200 |
| | AE essential feature analysis | 400 | 39600 | 199 | 16 | 49.8% | 2475 |
| **Size-dependent class threshold** | CNN (mono-mode) | 320 | 35000 | 151 | 119 | 47.2% | 294 |
| | CNN (medium fusion) | 400 | 39600 | 188 | 26 | 47.0% | 1523 |
| | CNN (early fusion) | 400 | 39600 | 203 | 18 | 50.8% | 2200 |
| | AE essential feature analysis | 400 | 39600 | 217 | 40 | 54.3% | 990 |

# Conclusion

- Multiple deep learning methods was proposed and studied in the gamma/hadron classification task: medium fusion (separate IACTs images analysis in CNN before concatenation), early fusion (concatenated IACTs images are fed to CNN) and autoencoder-derived essential feature analysis.
- Test results demonstrated that for highly imbalanced classes early fusion is the most promising method. Analysis of essential feature hadn’t met the expectations.
- Stereo-mode classification results demonstrated significant improvement in comparison to neural network mono observations with background noise suppression close to the gamma/hadron imbalance observed in the experiment.

Thank you for your attention!