AIR SHOWER RECONSTRUCTION USING A GRAPH NEURAL NETWORK FOR THE ICEACT TELESCOPES

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Workshop on Machine Learning for Cosmic-Ray Air Showers 2022

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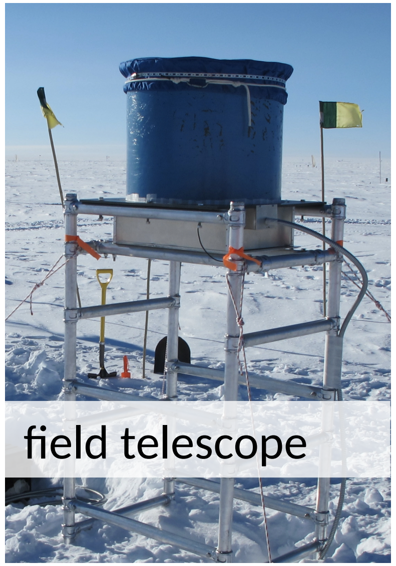
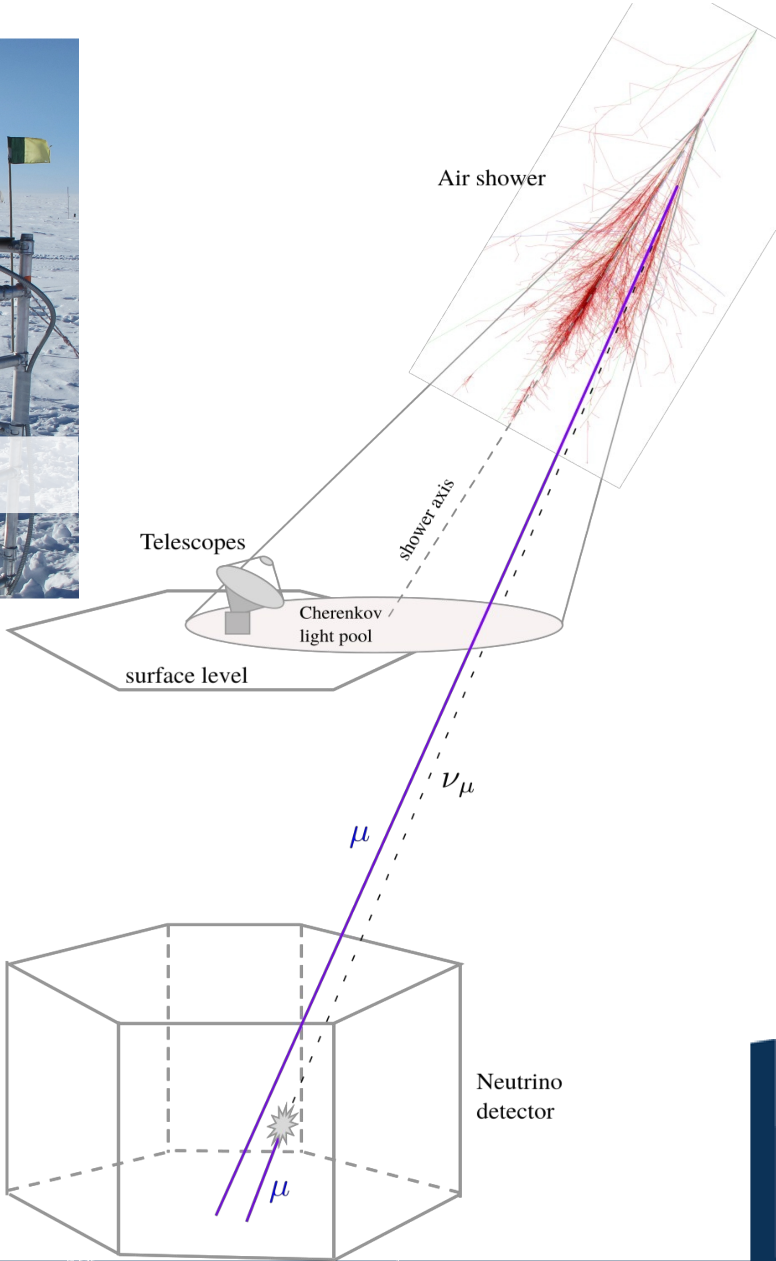
Outline:

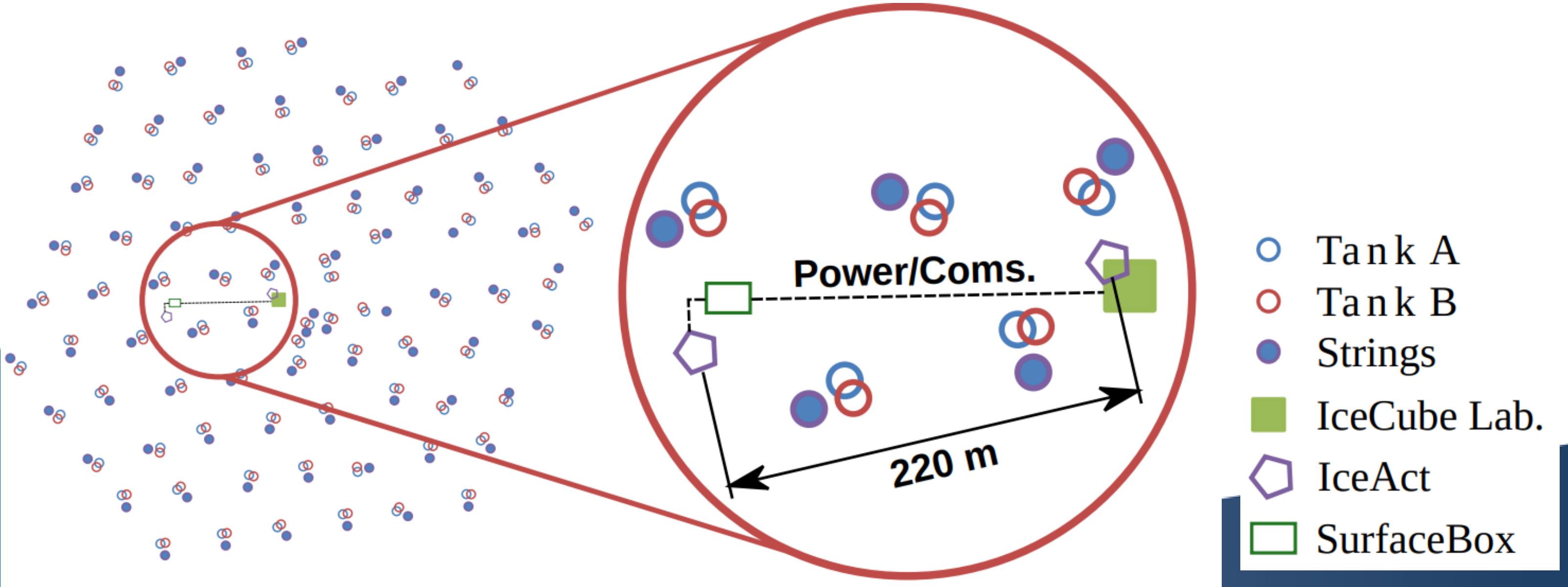
- Introduction into IceCube and IceAct
- Description of the used data set
- Introduction into Graph Neural Networks
- Event reconstruction graph neural network
- Summary and outlook

The IceAct telescopes:

- Cherenkov telescope with 61 pixel SiPM camera, small and robust
- 2 IceAct telescopes taking data since 2019
- combine with particle footprint on ground level and in-ice muon reconstruction:
  - cross-checks of geometry and energy reconstruction for the different detector components
  - hybrid composition studies







MC simulation data set:

At each position 7 telescope are simulated in a station configuration: 1 pointing straight up, the 6 surrounding telescopes are tilted 13 degree.

Standard simulation data set:

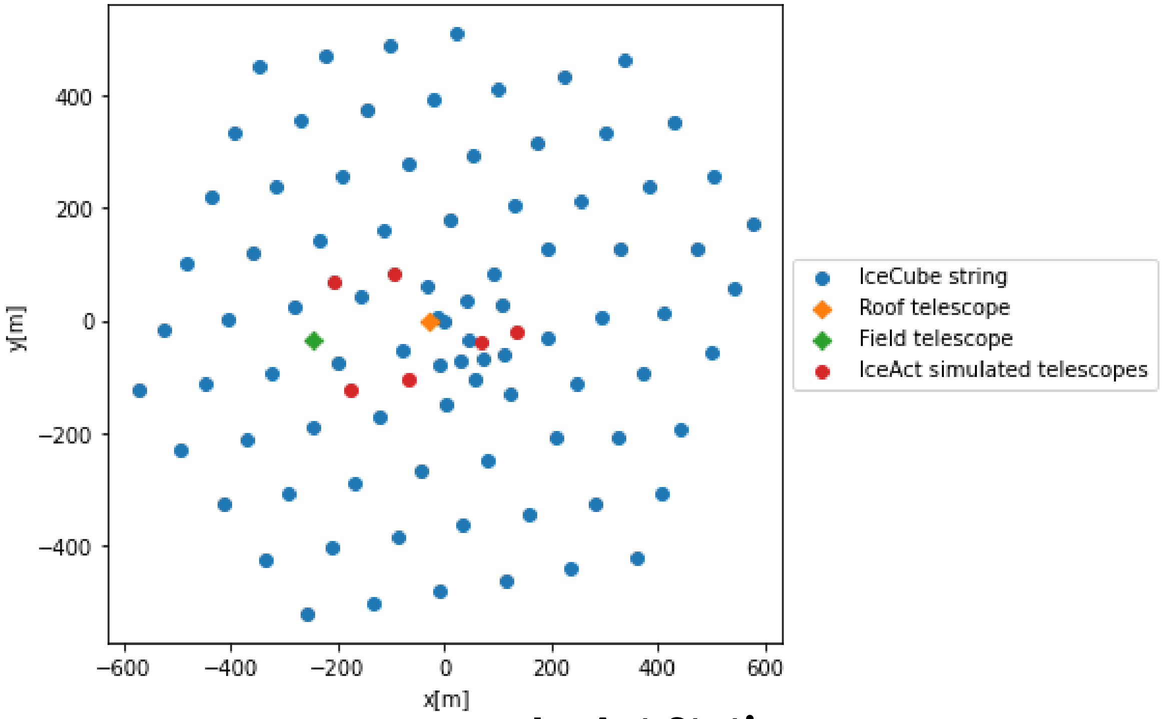
- E**-1, 3TeV-1PeV, 0-20 zenith,
- round array with increasing radius:
  - $3.5 \leq \log10(E) \leq 4$ => r = 250m;
  - log10(E) > 4 => dlog10(E)=0.25 => dr = 50m
- 110k events for proton and iron
- 100k events for photon, helium, aluminum, oxygen
- 20k events for neon

Smaller lower energy simulation data set:

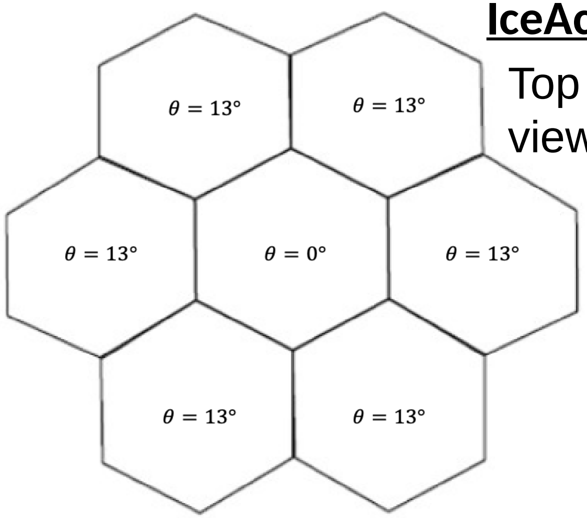
- E**-1, 3-100TeV, 0-20 zenith,
- round array increasing radius (see above)
- 50k events for proton, iron, photon, helium, aluminum oxygen

=> For the further analysis both data sets have been merged and each telescope event is treated as single event.

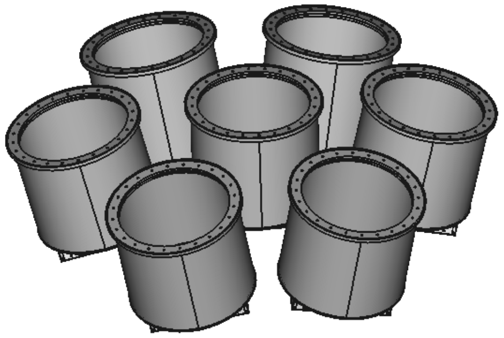
IceAct simulated array



IceAct Station

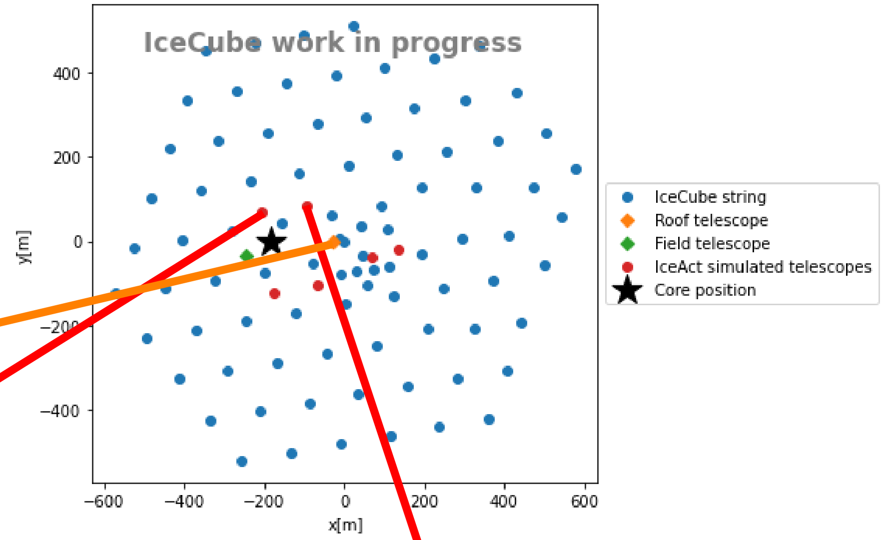


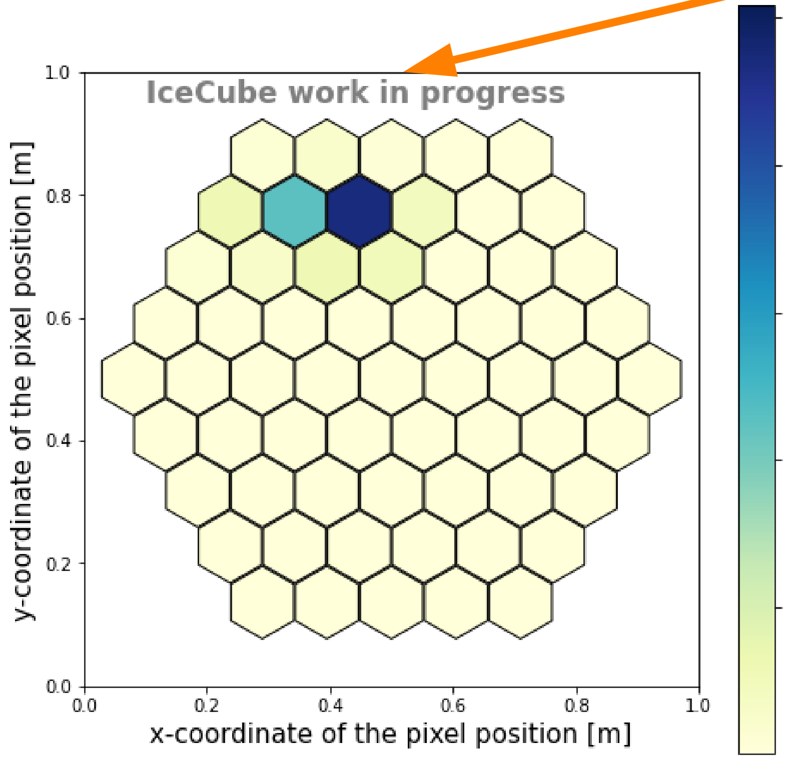
Top view

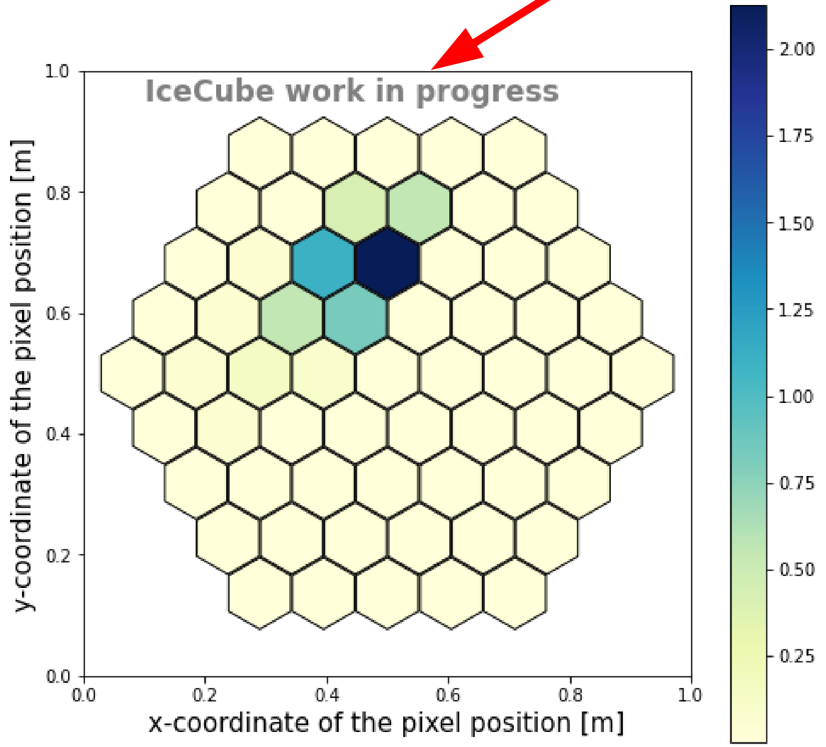


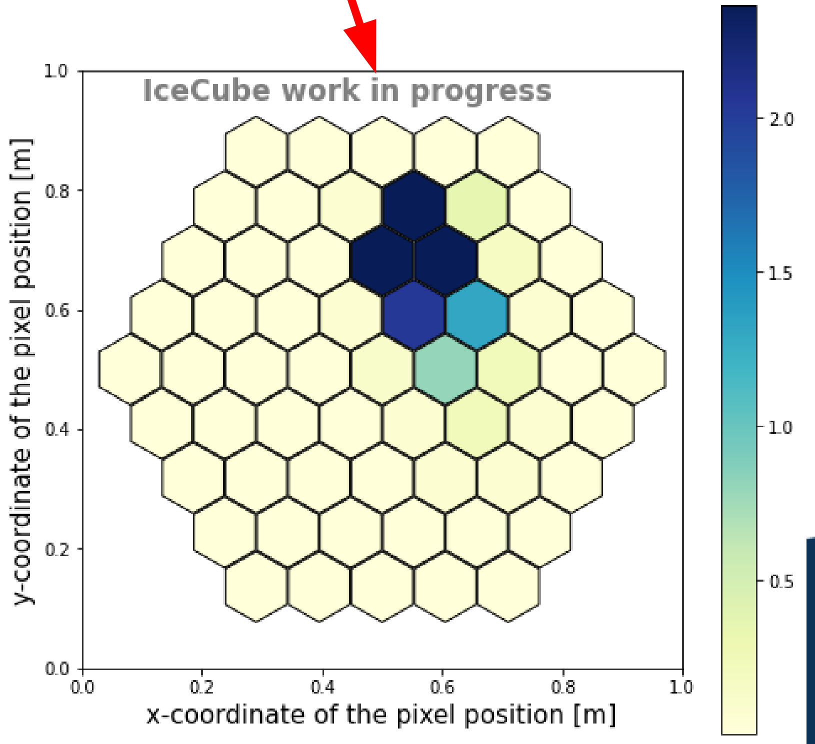
Example of a simulated event:

- Simulated proton event seen in multiple telescopes
- Energy : 656TeV; Zenith: 4° ; Azimuth: 79° ;
- X: -181.747m; Y: -1.2746m





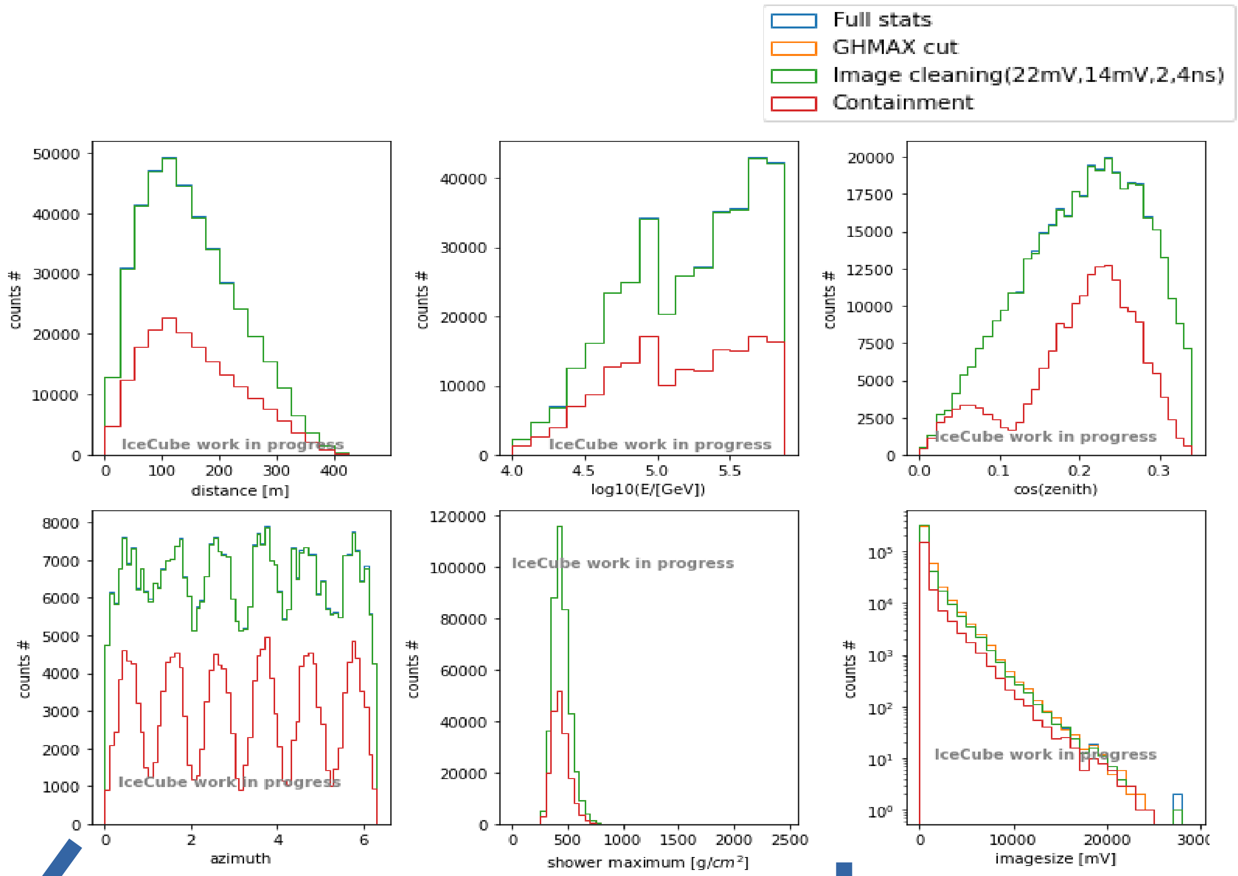




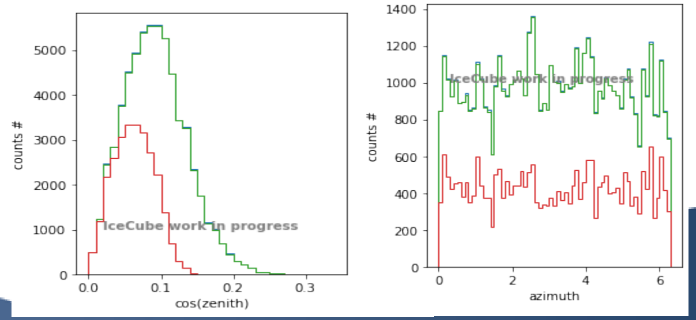
MC simulation data set:

- GHMAX cuts events with nonphysical shower maximum values in the CORSIKA file
- Image cleaning keeps pulse if they are:
  - Above 22mV
  - Between 14mV-22mV if they are next to two pixel with pulses above 22mV
- Containment keeps events if the sum of the inner pixels heights is 4 times larger than the sum of the outer pixel heights

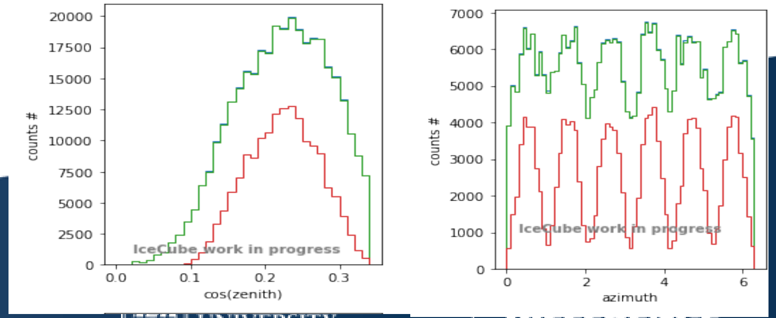
=> Input and Output parameters are normalized before they are used in the gnn



Up pointing telescopes: (used in this talk)

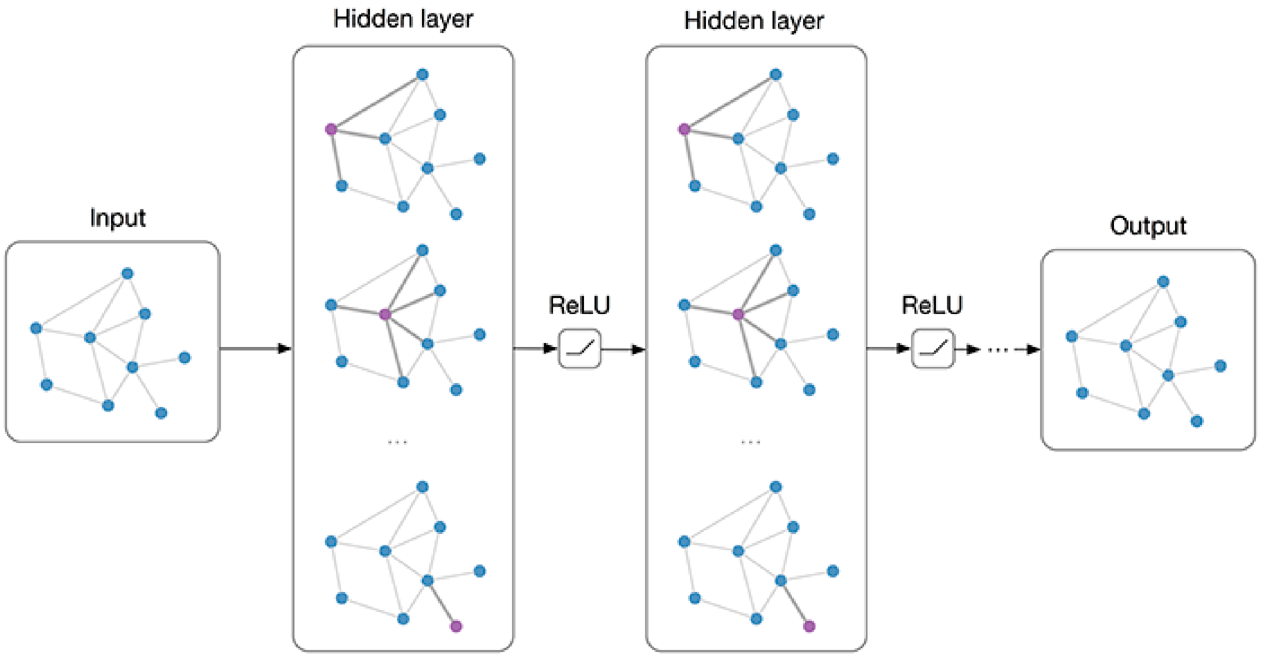


Tilted telescopes (used for the RFT talk):



Introduction into graph neural network (gnn)

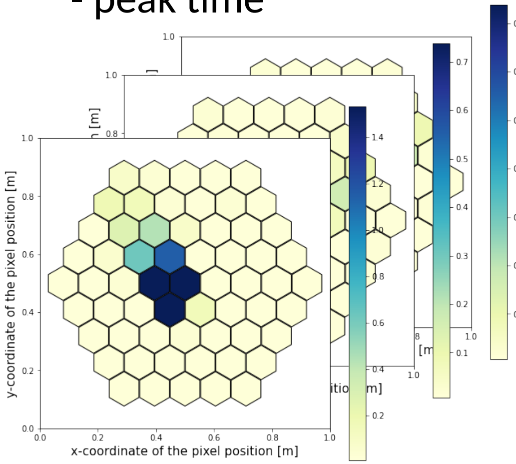
- Simple Graph Neural Network using Spektral package
- A Graph consists of nodes, each node has features and connections to other nodes
- For each event the number of nodes can be different
- The connection between nodes is defined in an adjacency matrix
- Hidden layers are matrix convolutions of the graphs and the adjacency matrix
- The normalization of the matrix differs depending on the chosen convolutional layer



https://tkipf.github.io/graph-convolutional-networks/

event reconstruction: graph neural network (gnn)

Graphs features:
- 61 nodes = 61 pixel
- each node has 4 layers:
  - pixel x position
  - pixel y position
  - peak height
  - peak time



Adjacency matrix :
each pixels knows itself and its neighbors

Edges between nodes:
same connection between all pixels

Output variables:
8 parameters
- E = energy primary
- D = distance between shower core and the telescope
- Sine and cosine angle on the x-y plane between
  x-axis and vector to shower core
- Zenith
- Sine and cosine of the azimuth angle
- shower maximum

Shower core position

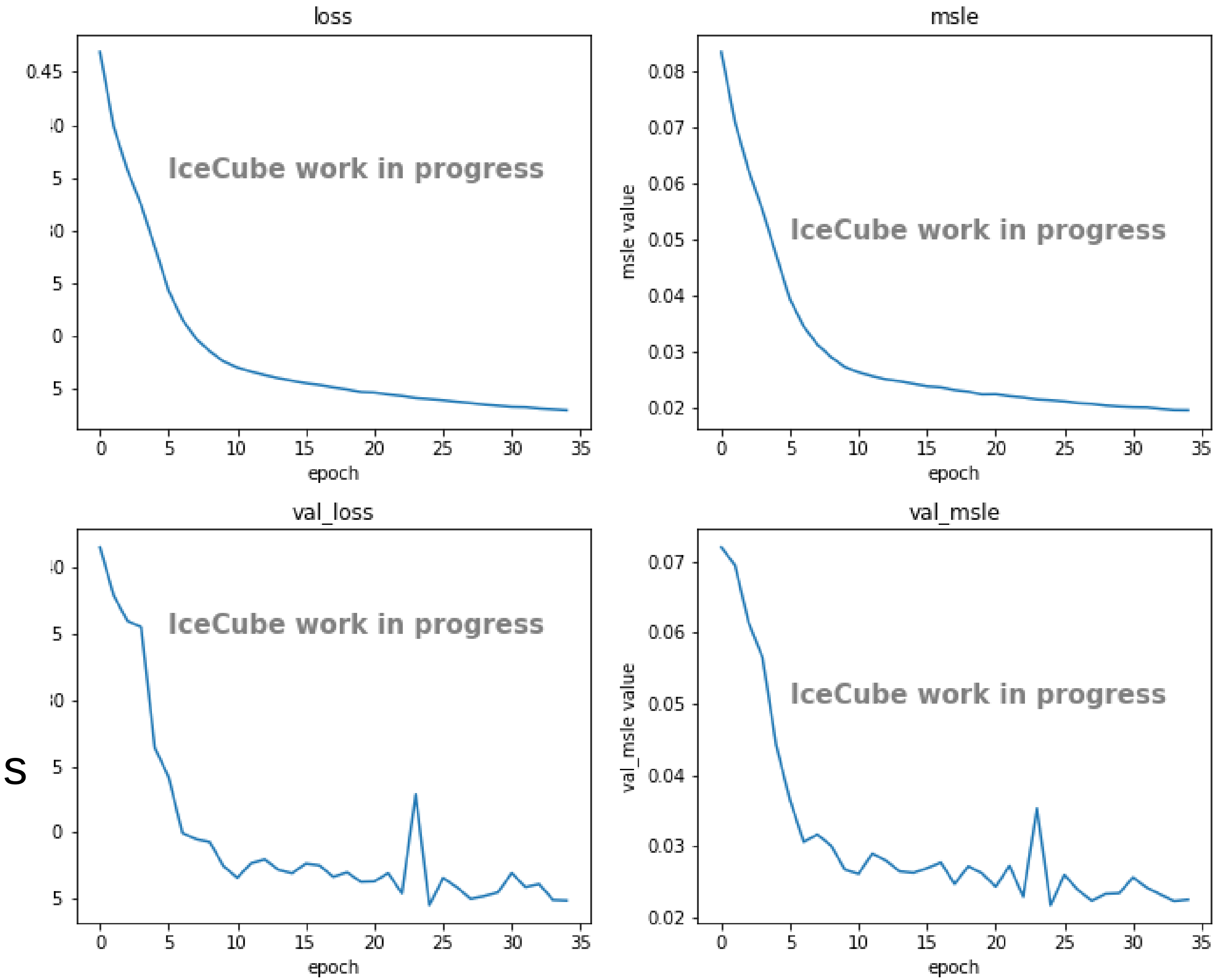
Shower direction

Model:
2 GatedGraphConv. Layer
1 GlobalSumPool Layer
3 Dense Layer

event reconstruction: graph neural network (gnn)

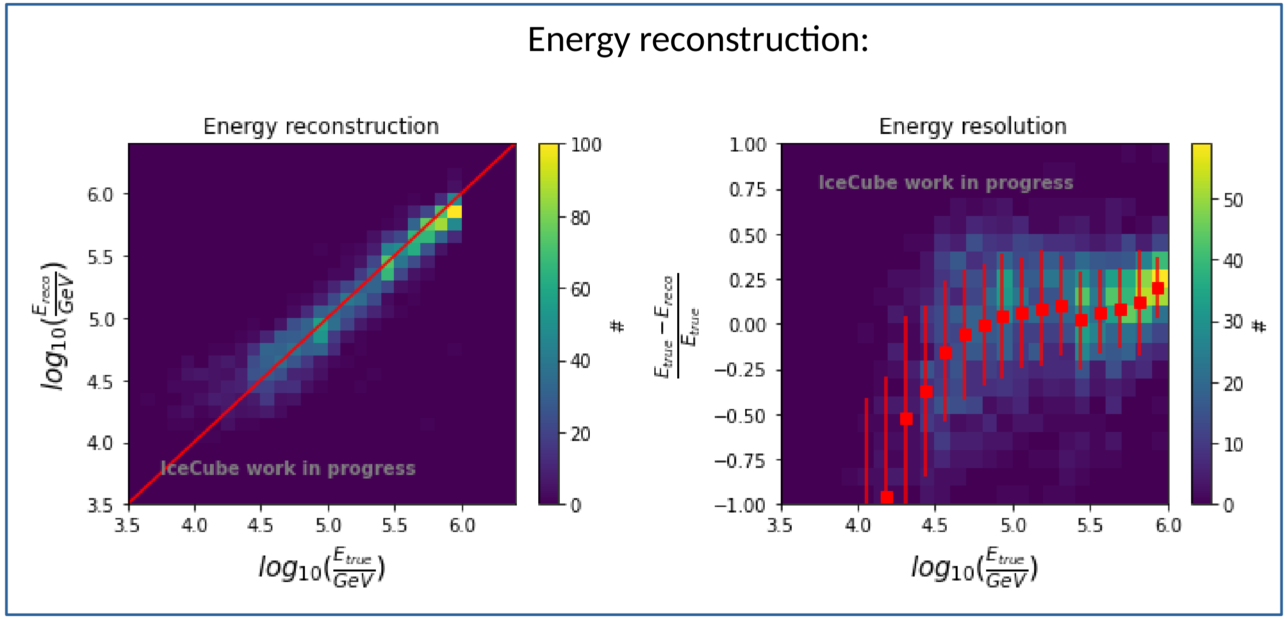
Loss function and validation loss of the used graph neural network

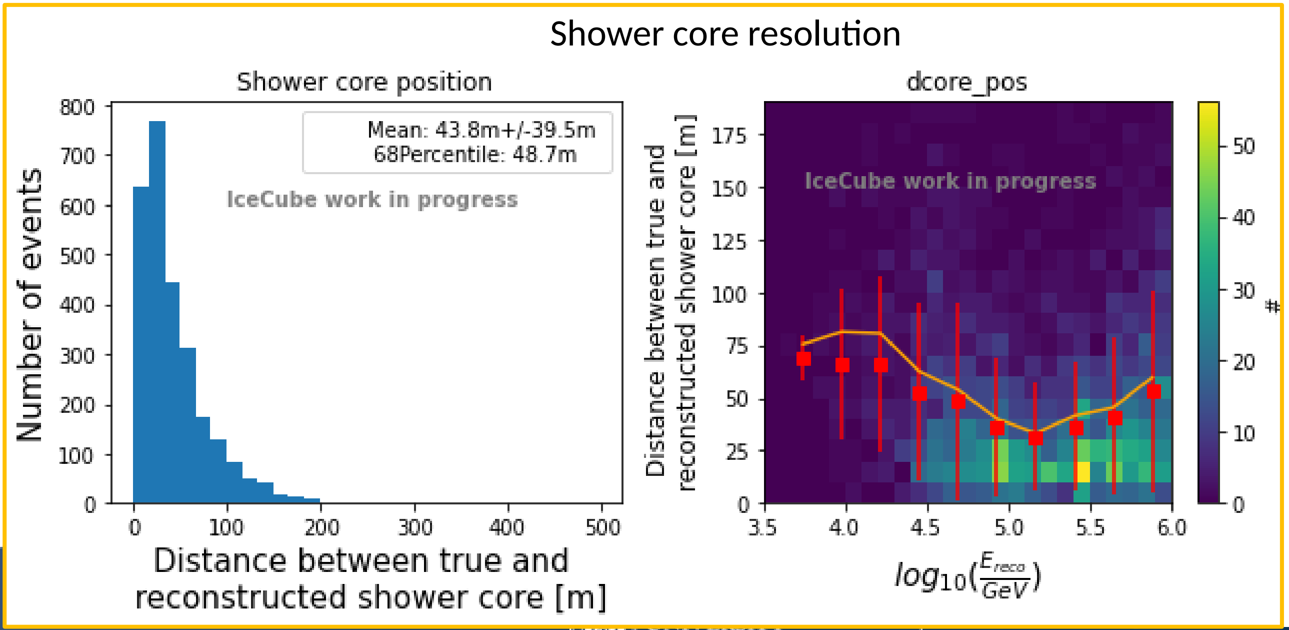
- Loss functions are used to evaluate the performance of the network
- Used for optimizing this network is the mean square error (mse) function
- In addition to that the mean square logarithmic error (msle) is also used as metric to evaluate the network
- In contrast to the loss function the metric is not used during the training of the loss function



Reconstruction results:

- For Cherenkov telescopes there is an ambiguity between nearby low energetic air showers and more distant higher energetic air showers
- Therefore this first results look very promising for a single telescope reconstruction
- Adding further information of the other detector components and simultaneous detection of several telescope should improve these results





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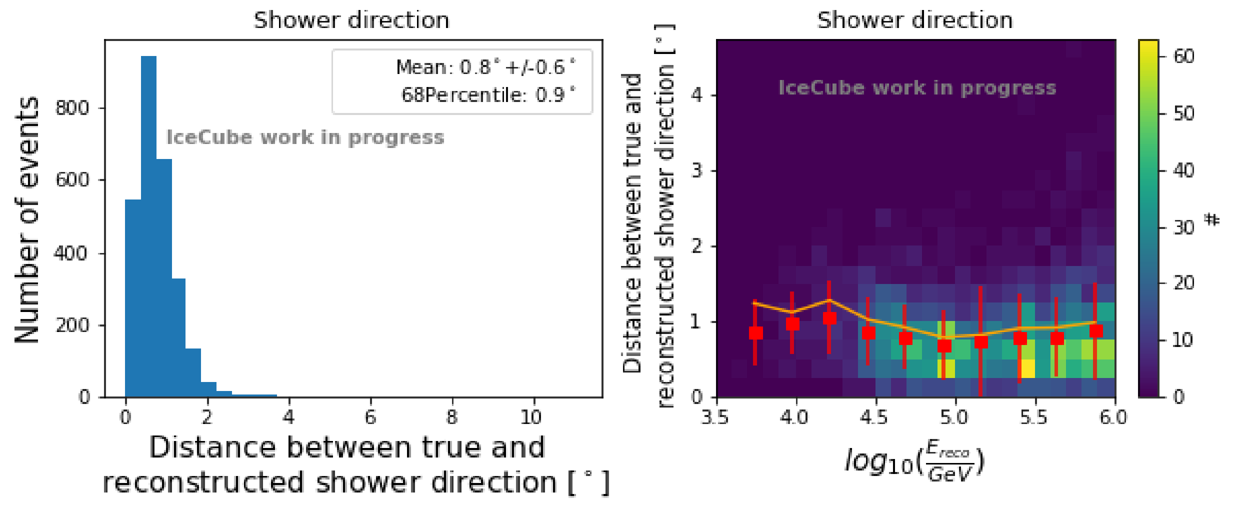
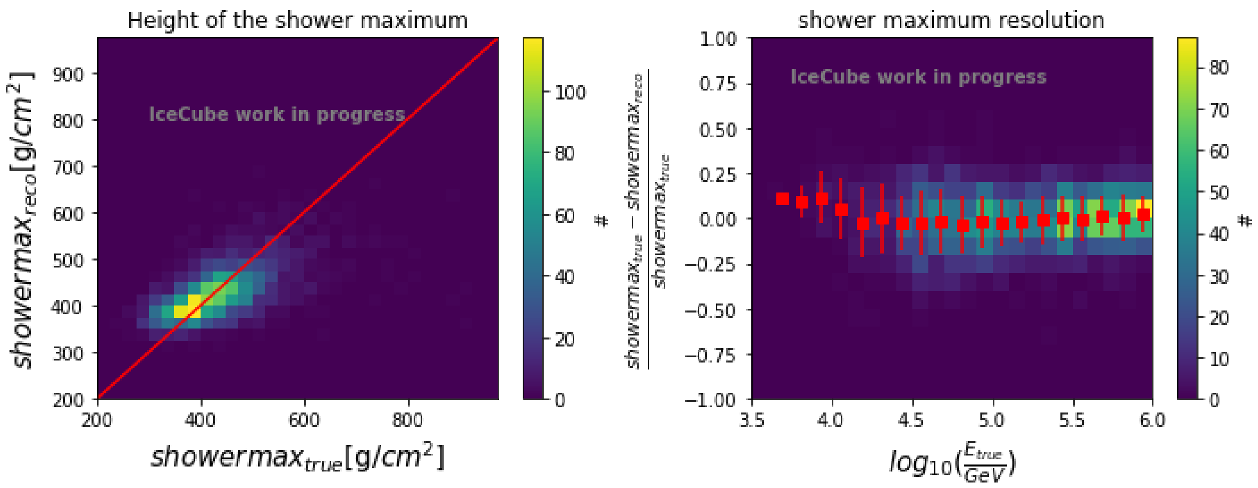
angle between true and reconstructed shower direction



Reconstruction of the shower maximum:



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Summary and outlook

- IceAct telescope measure the el.mag. air shower component independently
- With just a few simple cuts a gnn was successfully implemented
- Station trigger needs to be implemented to make use of the full station and to reconstruct events seen in more than one telescope.
- Further improvement in reconstructions anticipated by implementing:
  - Test different normalizations of the input or/and output parameters
  - Simultaneous reconstruction of events seen in more than one station
  - Including additional parameter like reconstruction results from IceTop and IceCube
- Increase the MC statistic and the energy range of the MC