WORKSHOP ON MACHINE LEARNING FOR COSMIC-RAY AIR SHOWERS

SUMMARY & OUTLOOK

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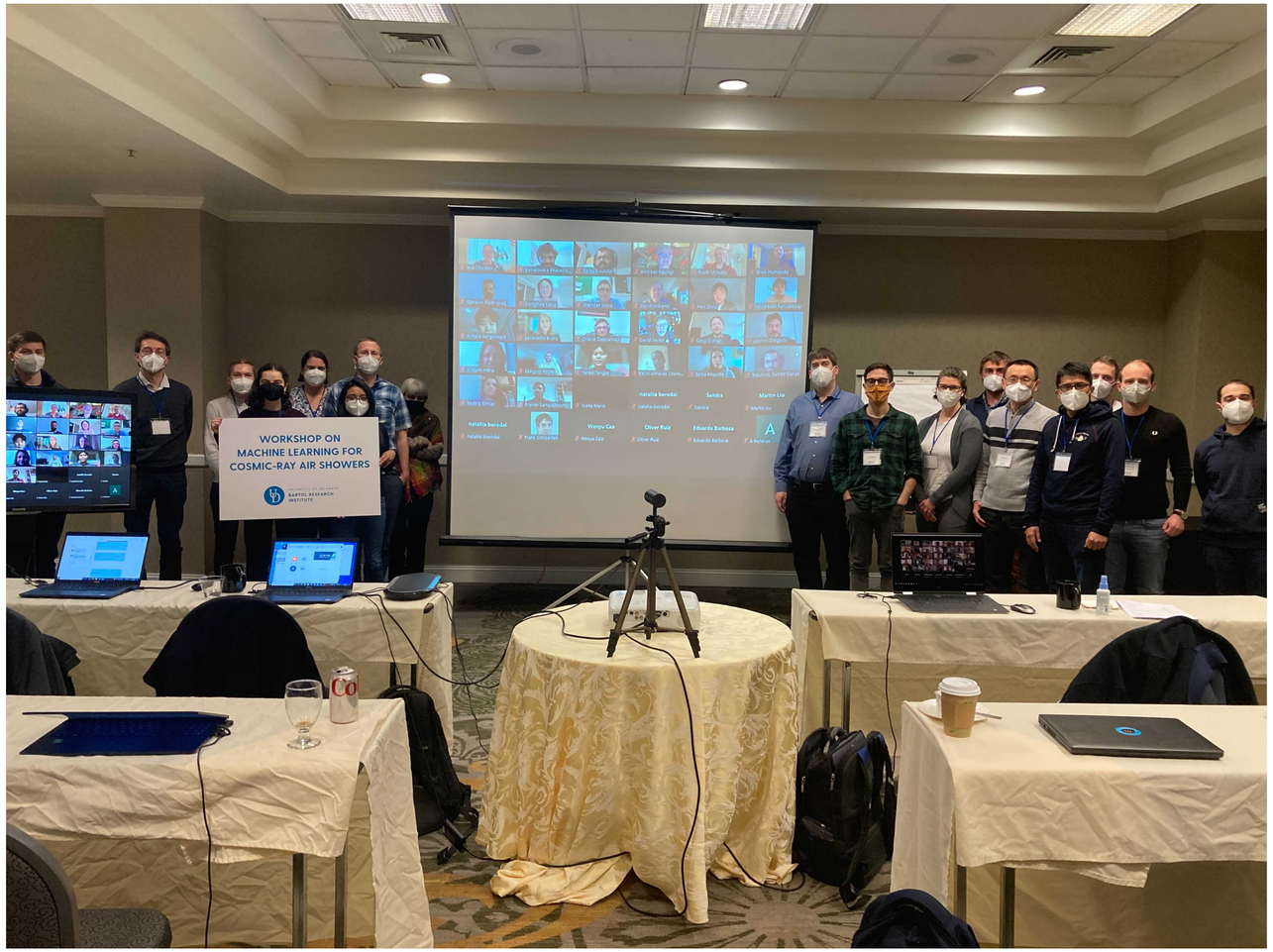
WORKSHOP STATS

- 111 registered international participants (28 on-site + 83 online)
- 3 days 30 talks



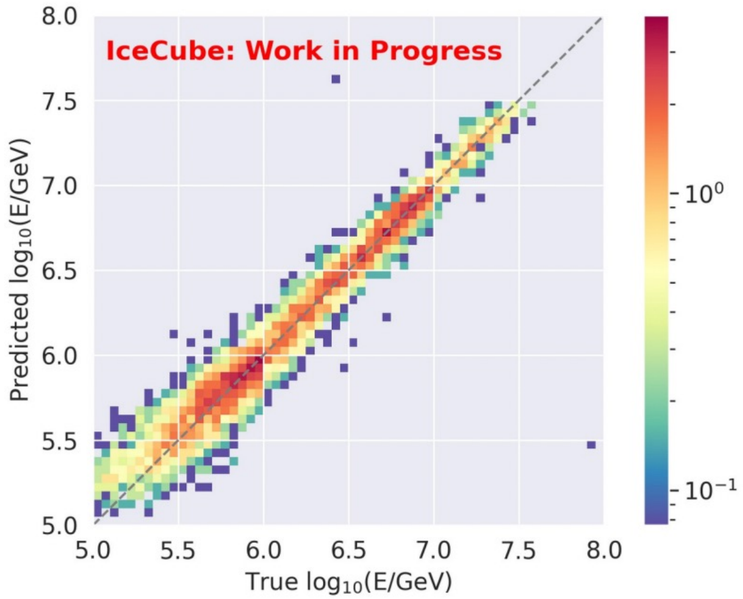
WORKSHOP TOPIC & EXPERIMENTS

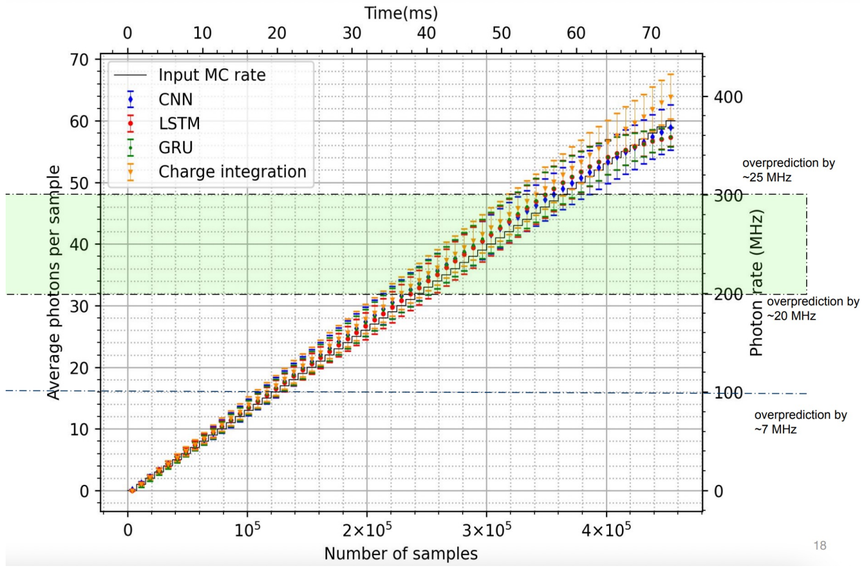
- Recent developments in high energy and astroparticle physics were shown
- Focus on technical approaches to CR analysis
- Machine learning takes on various forms, e.g.
  - Tree based algorithms
    - BDT
    - RF
  - Neural network algorithm
    - MLP
    - CNN, RNN and GNN
- Various application for classification, regression, denoising, background rejection …
- ML application on different detector components to
  - Surface, volume, IACTs, radio antennas
- Analysis techniques and results from LHC Auger, TA, IceCube/IceTop, KASCADE, Baikal, CTA, Neutron monitors were presented
- Excellent lecture on ‘Machine Learning and Artificial Intelligence in Physics’

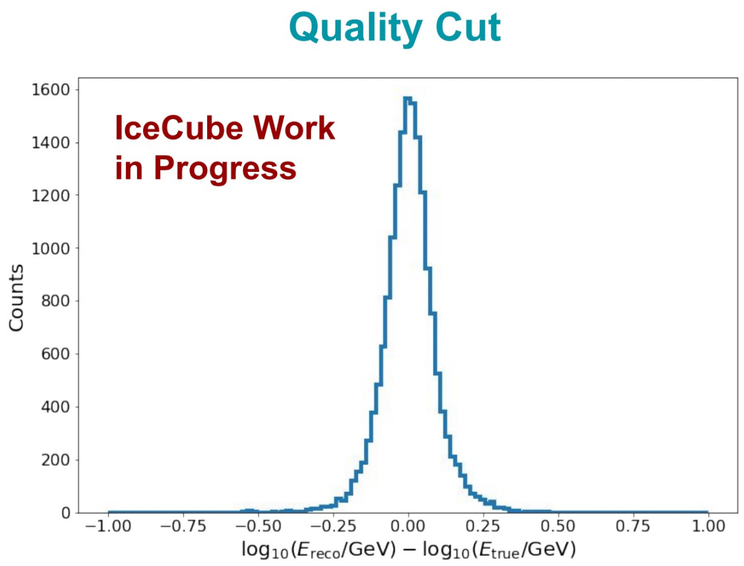
WORKSHOP TOPIC & EXPERIMENTS

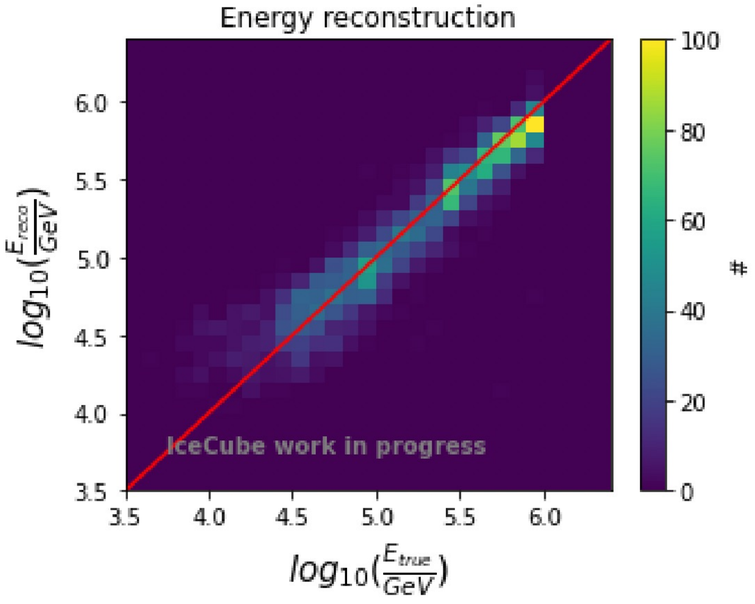
- Generative ML model
  - Application in MC generation
  - MC refinements using data
- Simulation
  - Corsika 7 & Corsika 8 are one of most essential tools
  - State-of-the-art detector simulation needed for proper ML analysis in all fields
    - Utilize domain knowledge and symmetries
- Open data/ Open source are slowly getting the standard approach in our field

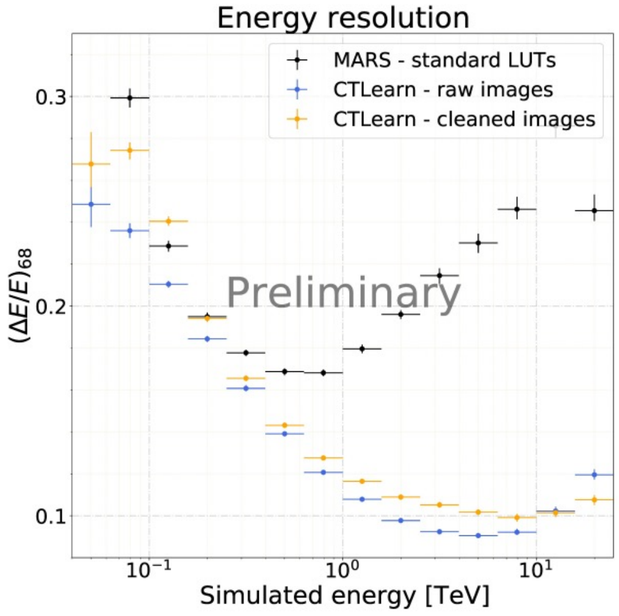
ENERGY ESTIMATION

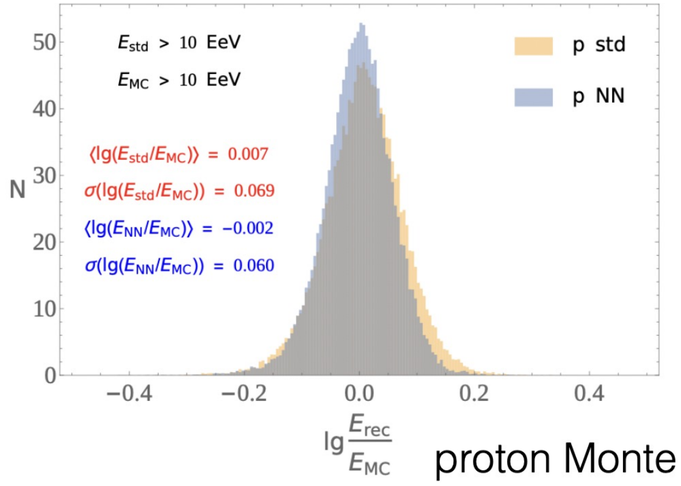






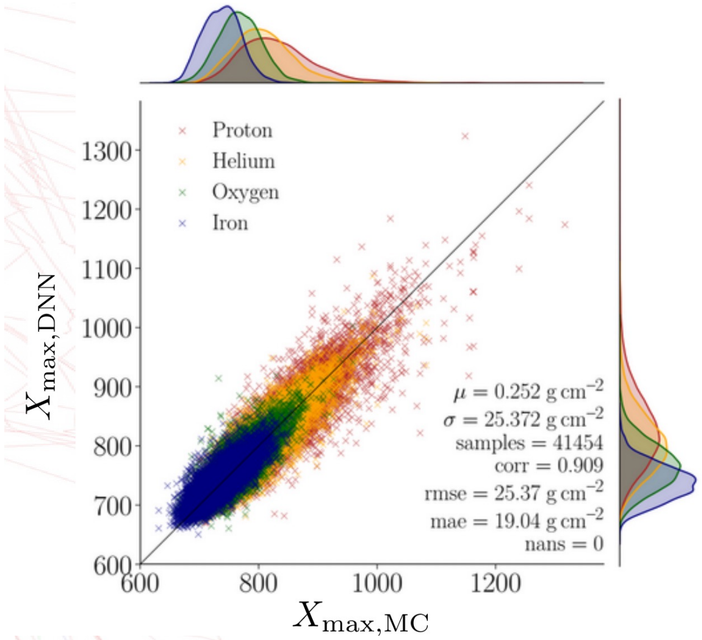




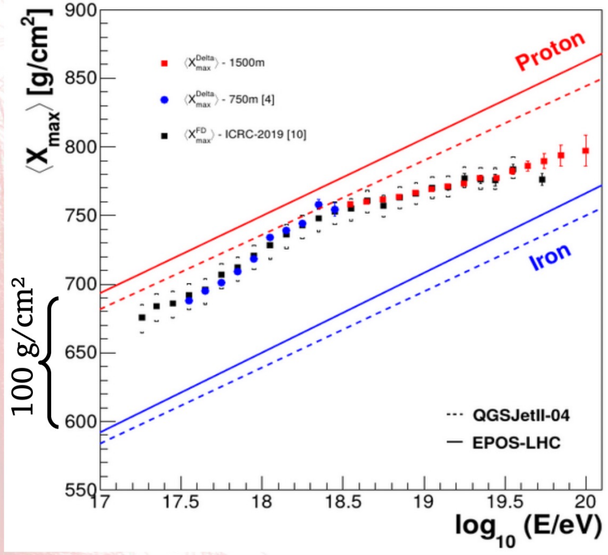


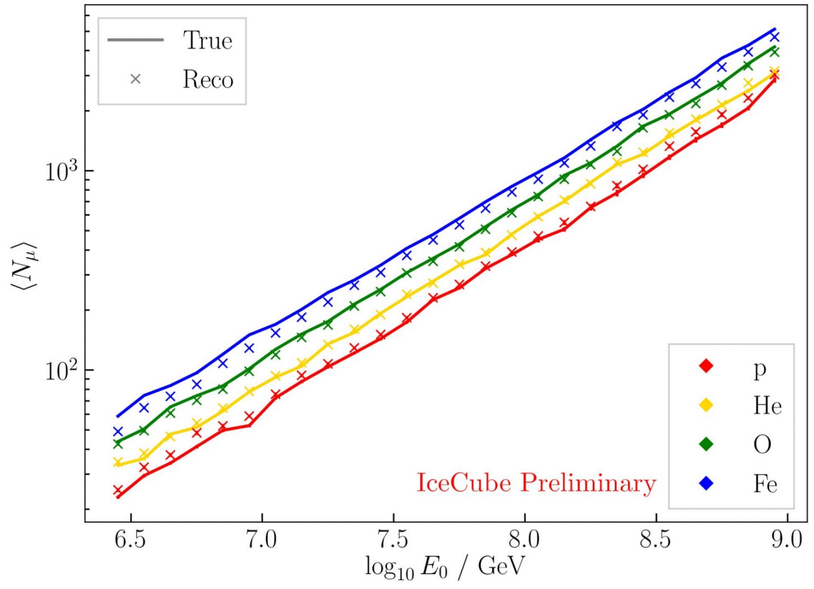
proton Monte

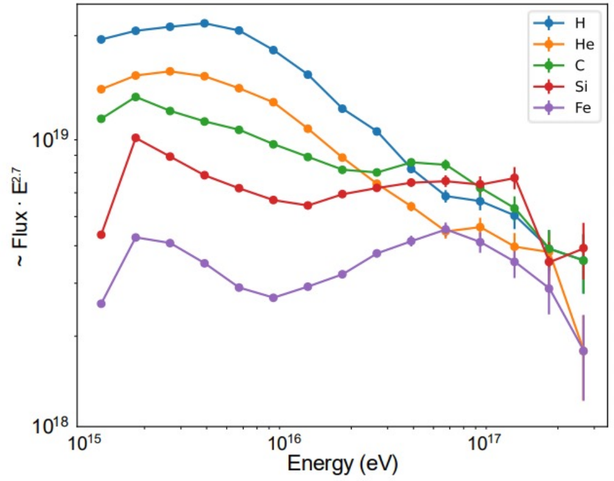
MASS COMPOSITION



1st moment $\langle X_{\mathrm{max}} \rangle$

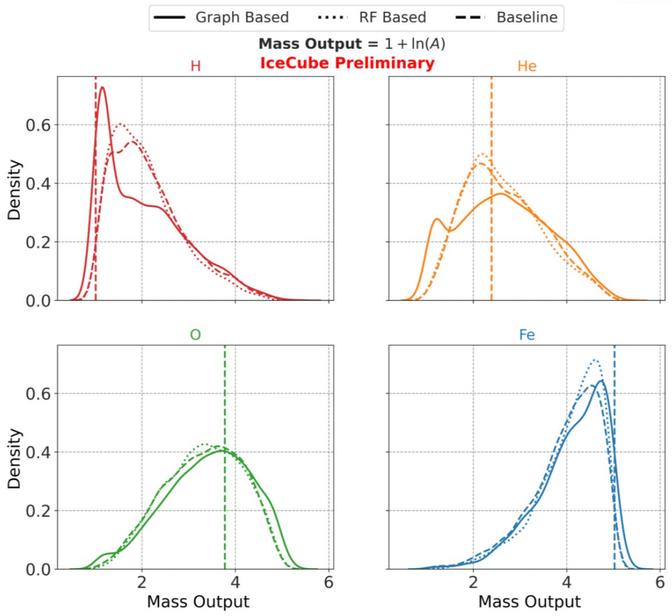


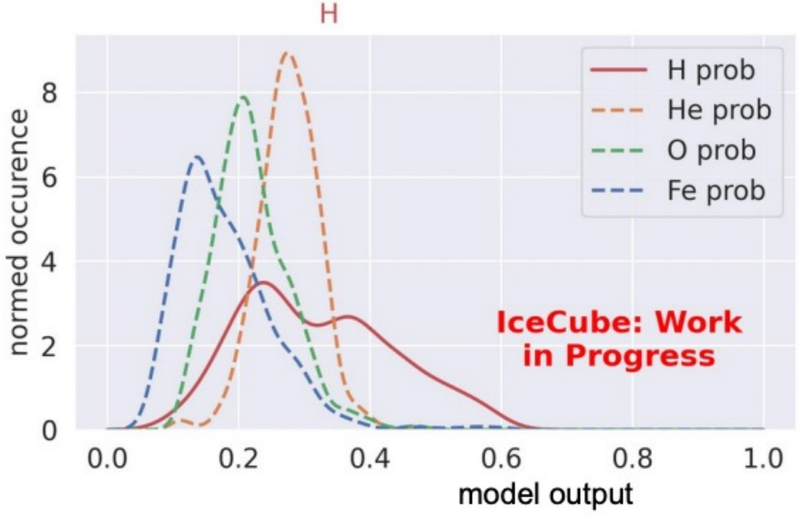




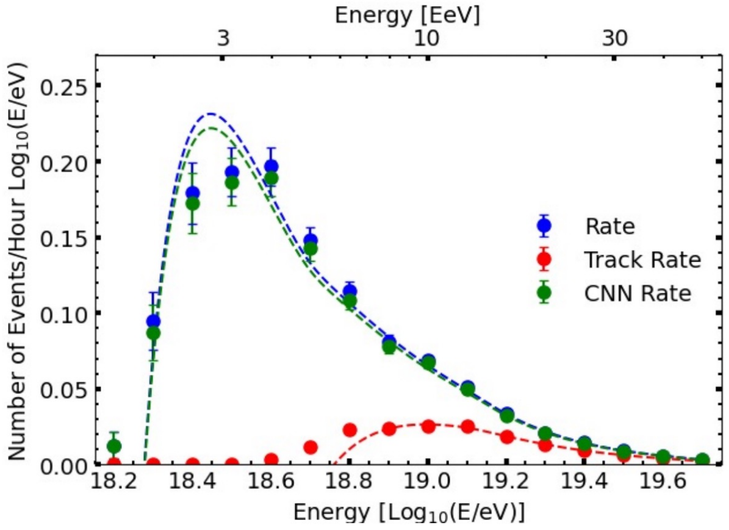
Spectra for CNN

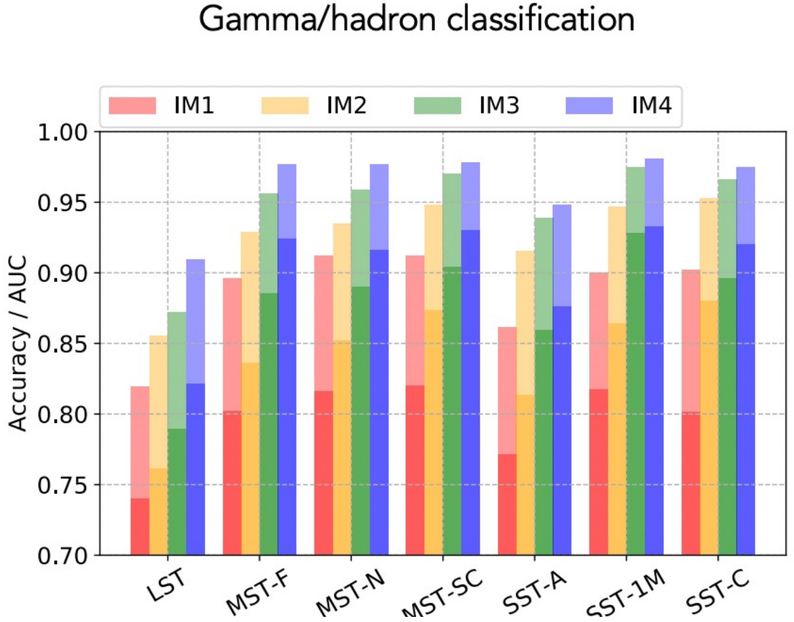
Full dataset

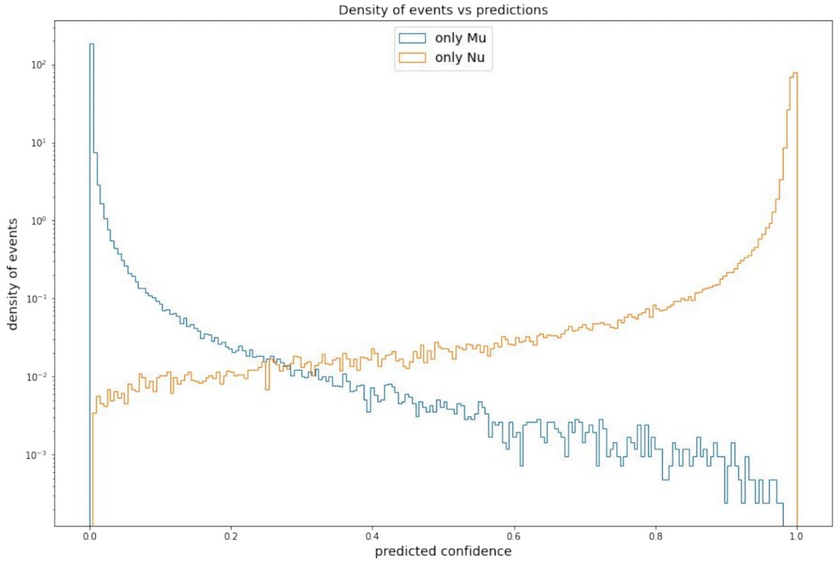


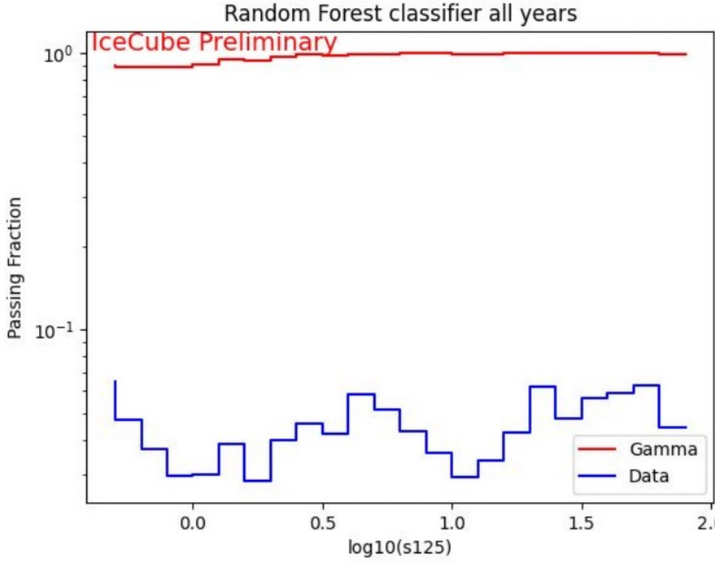


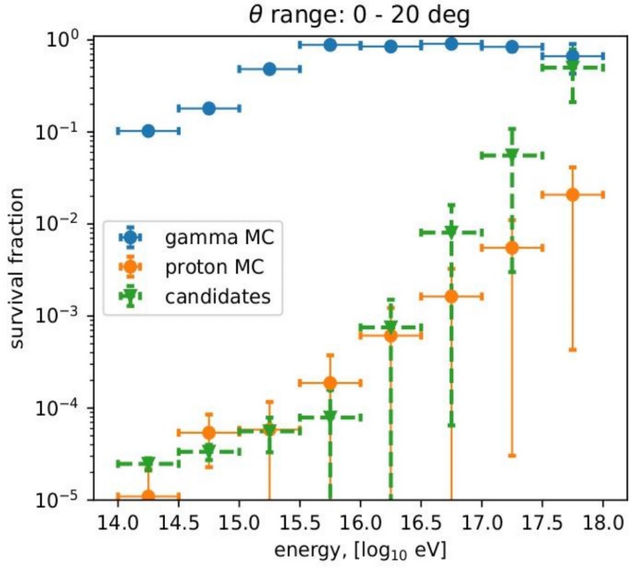
CLASSIFICATION



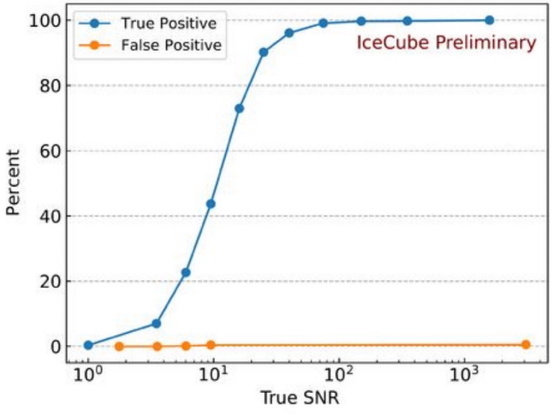


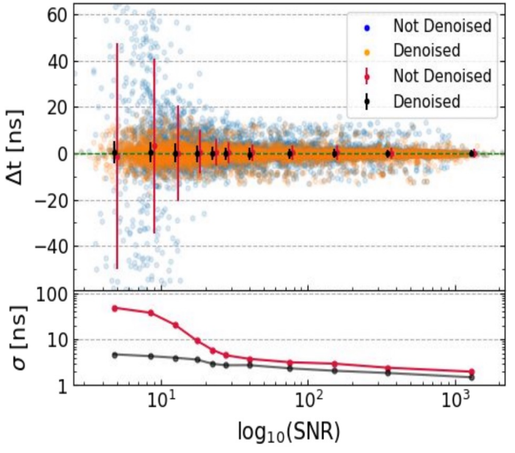




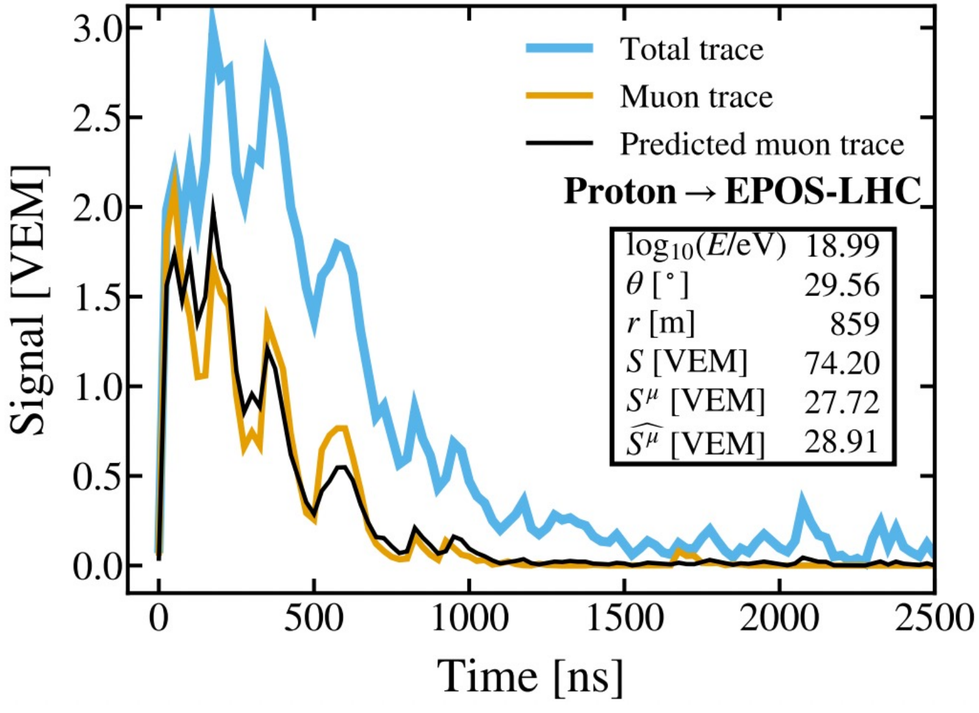


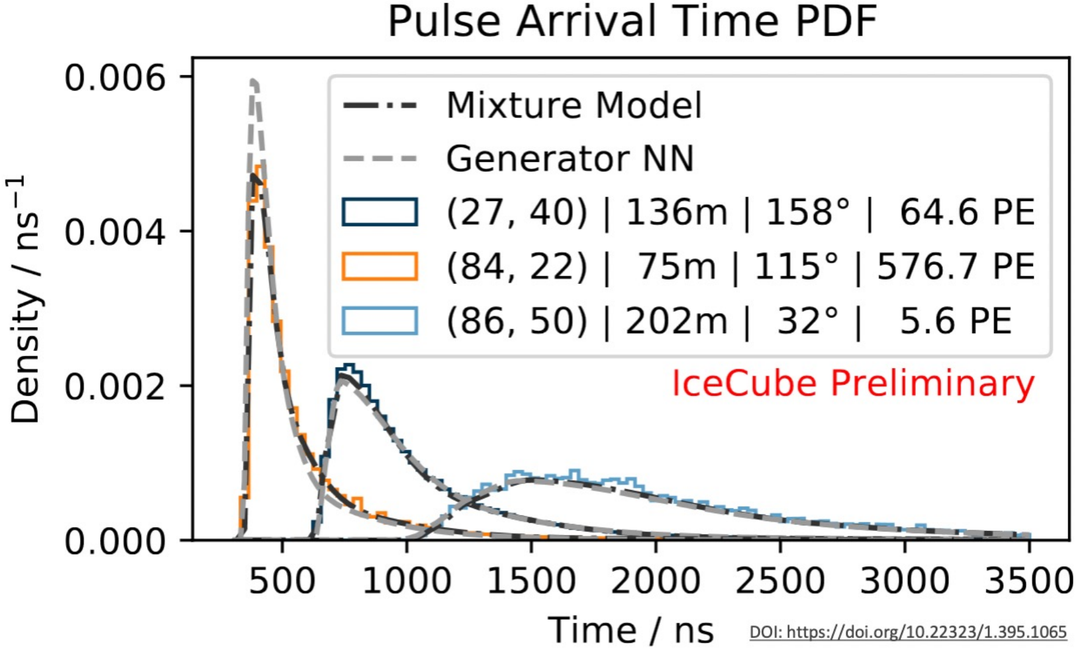
Denoiser

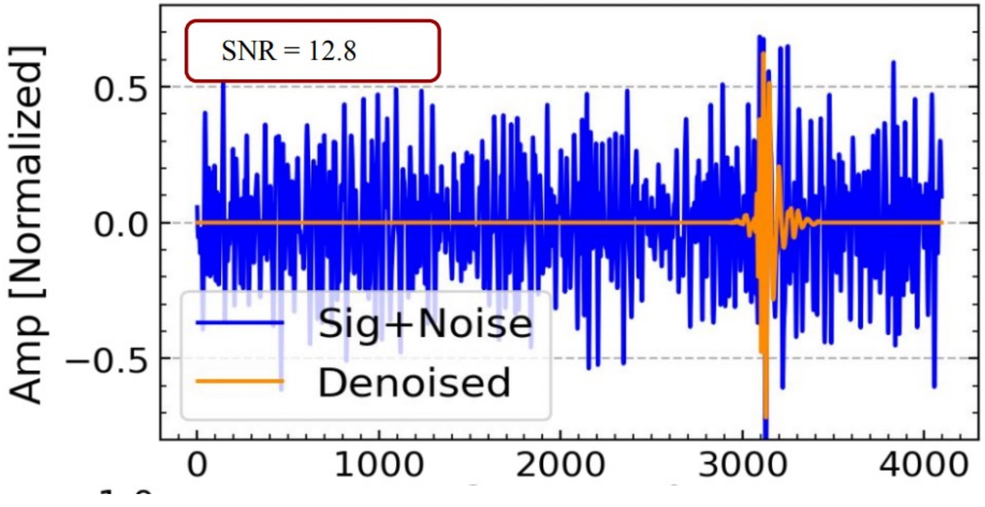


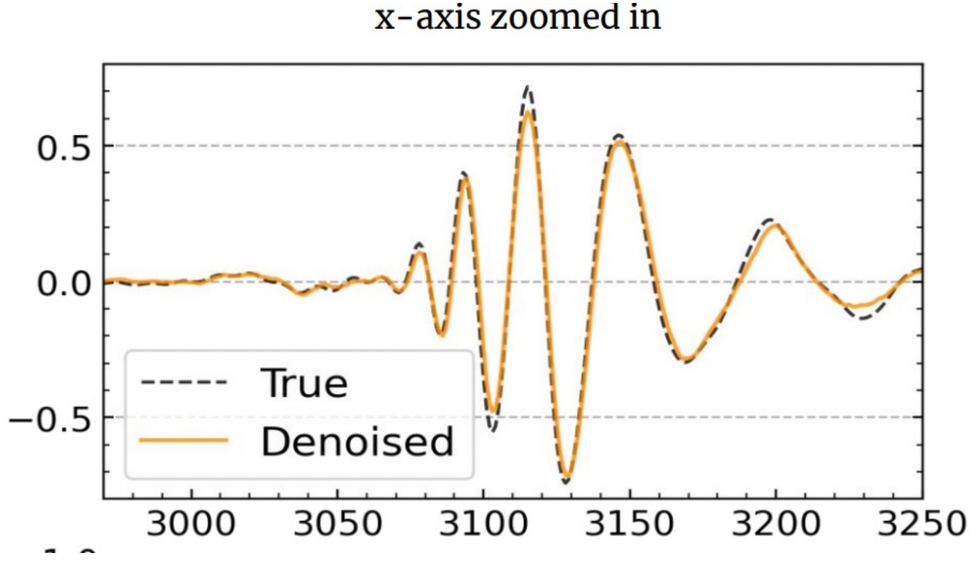


DATA PROCESSING WITH ML



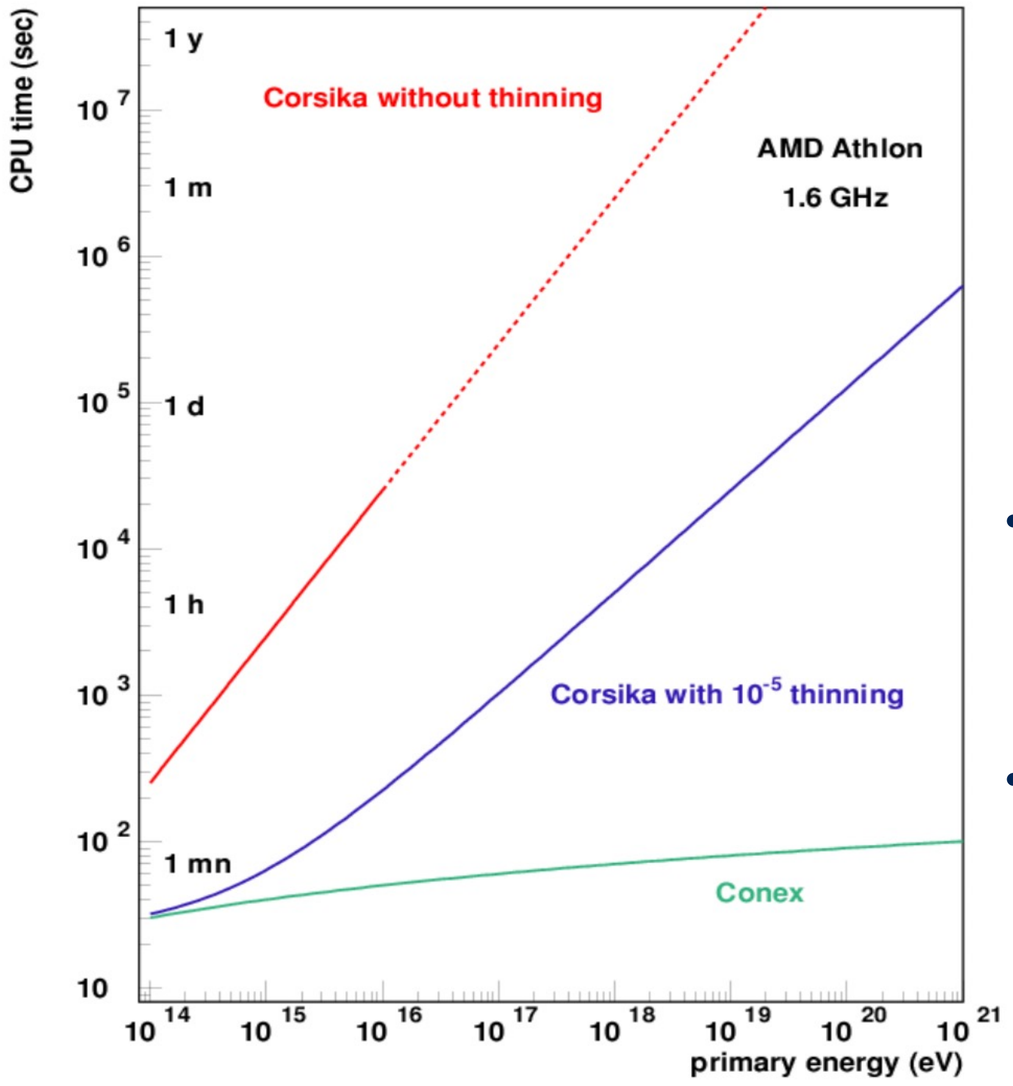


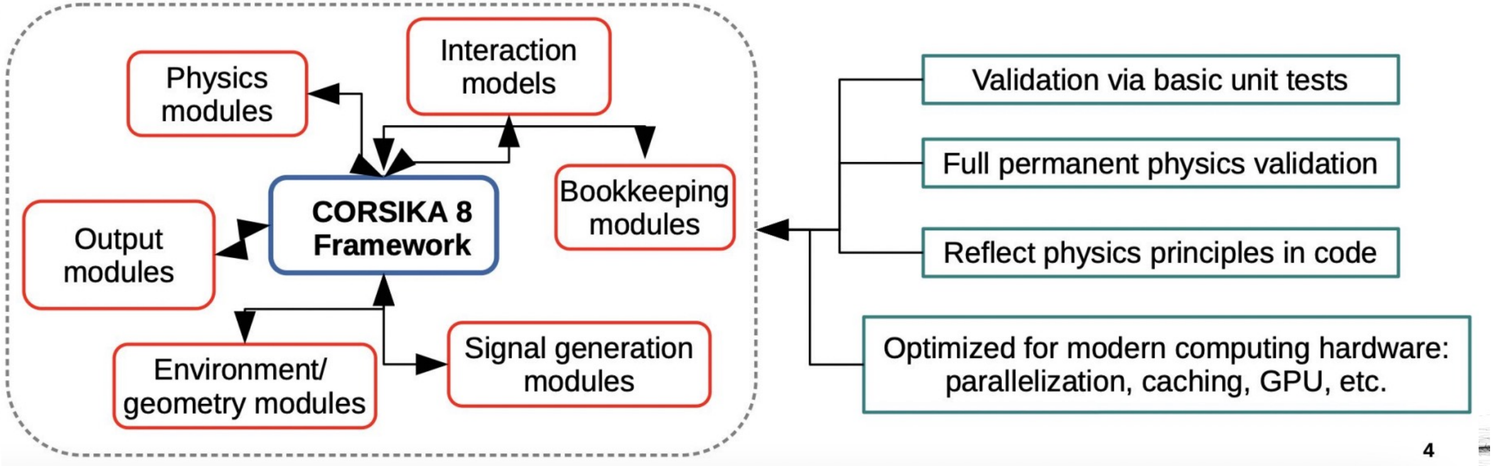




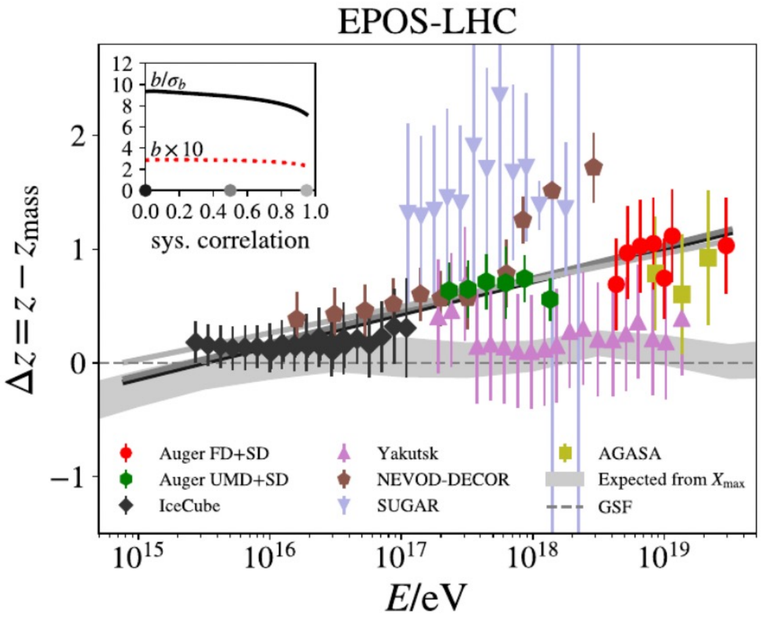
SIMULATION DEVELOPMENT

Corsika 7





- Significant improvements in simulation software Corsika 7 and Corsika 8
- However, we know current simulations and hadronic interaction model are not perfect



OUTLOOK IN THE FUTURE

- New CR experiments & extensions are been build or planned, e.g.
  - Auger Prime
  - TAx4
  - IceCube-Gen2
  - CTA
  - EUSO/POEMMA

- Machine learning will play an even bigger roll in the future observatories, by providing for example:
  - Better energy resolution
  - Better mass composition
  - Event-by-event classification over a broad energy range

- Keep up the great work! Take what you learned and try it with your experiment. Talk to your colleagues and form new collaborative efforts.

- Bright future is ahead in CR analysis using ML ☺

Thanks to the local organizer for creating this most interesting workshop and keeping it in-person in those unprecedent times!

Stay safe & healthy!

Hope to see everyone back in-person soon!