Deep Learning Applications
RWTH Aachen

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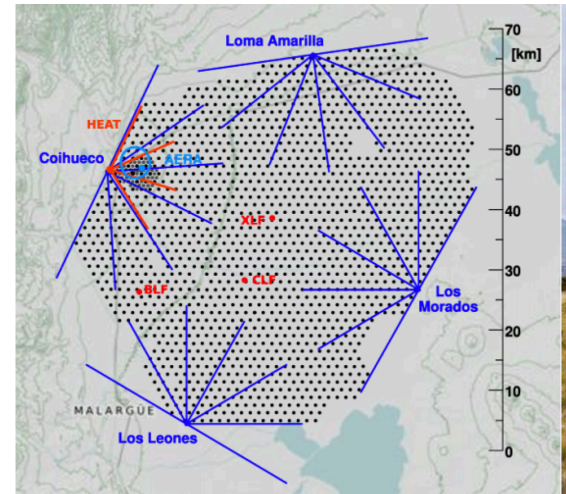
ErUM-Data @KIT

01.10.19

Research Projects: CMS and Auger

- Top-quark coupling measurements to Higgs boson
- Di-Higgs production measurement
- Event categorization into physics processes using Deep Learning
- Simulation of electromagnetic showers using generative models



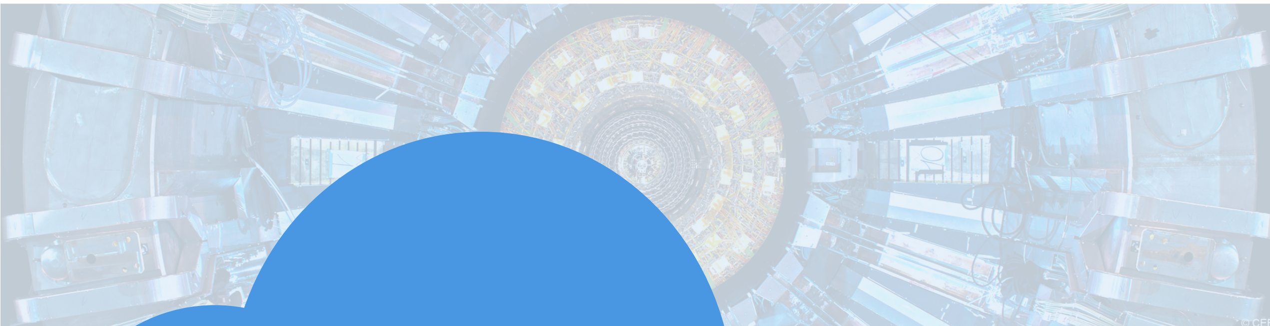
- Total energy calibration using radio emission of air showers
- Air-shower reconstruction using Deep Learning
- Search for arrival directions of cosmic rays including galactic magnetic fields

Both groups work on the VISPA Project:

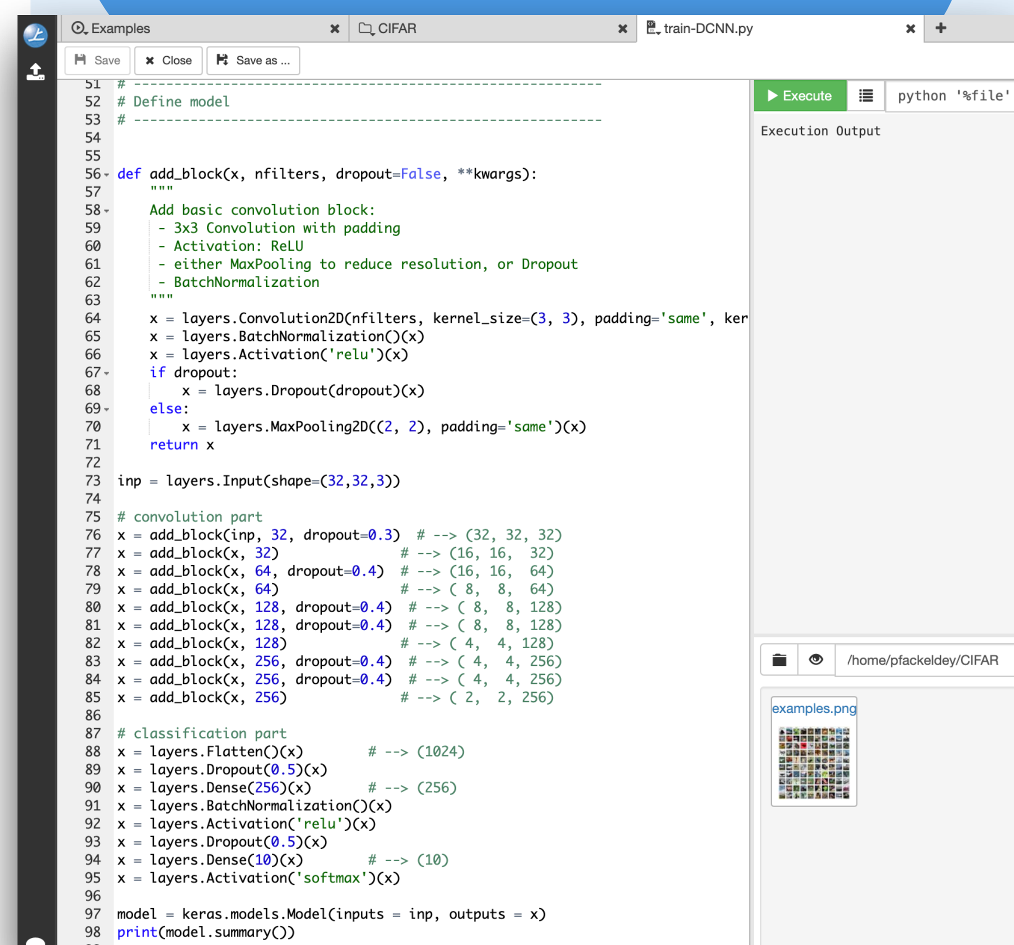
https://vispa.physik.rwth-aachen.de/

Research Projects: VISPA

RWTH AACHEN UNIVERSITY
Peter F. - 01.10.19



Use via webbrowser



- 20 NVIDIA GTX 1080
- Storage, NFS, Network
- ~200 CPU cores

Upcoming upgrade: +9 GPU RTX5000/6000

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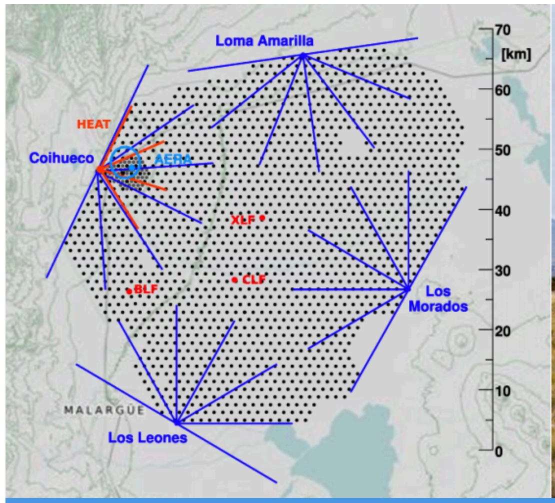

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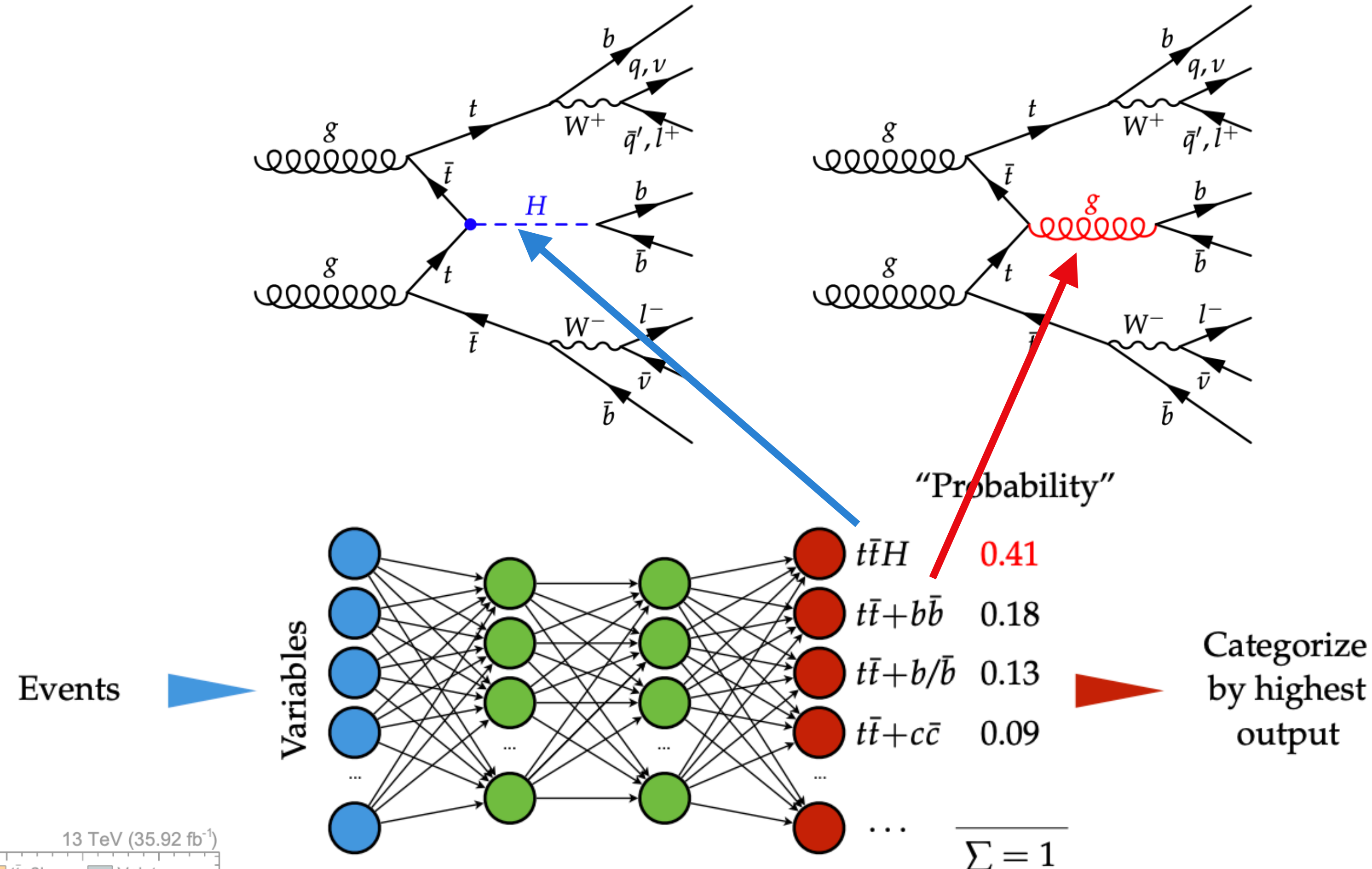
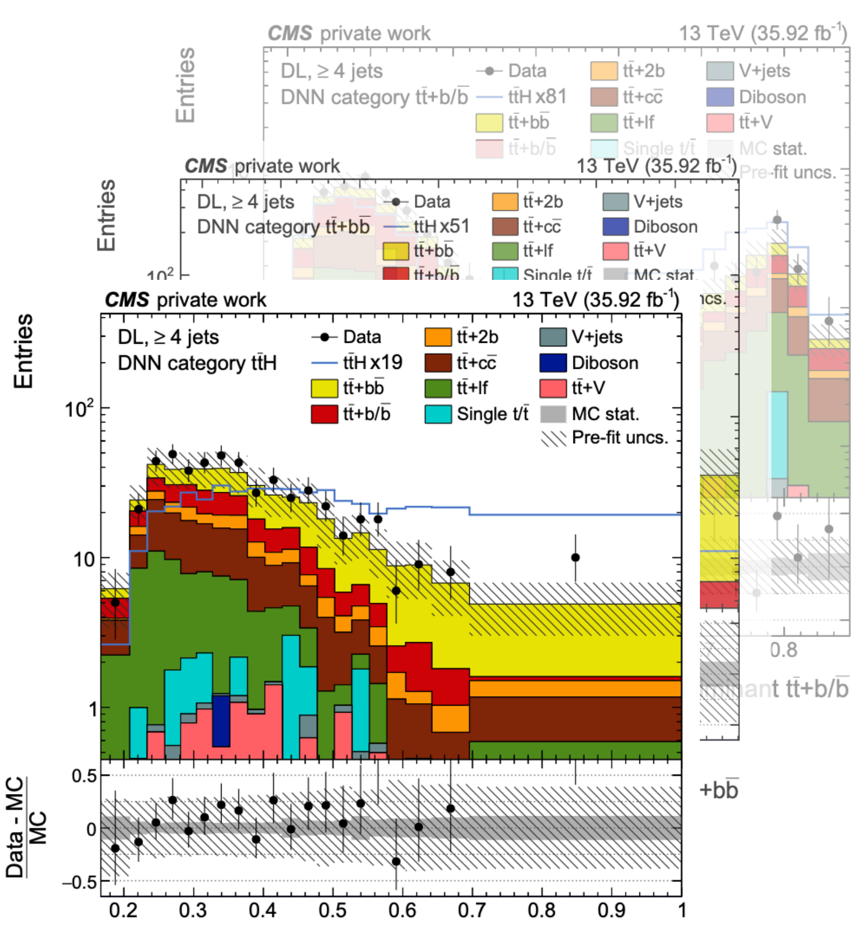
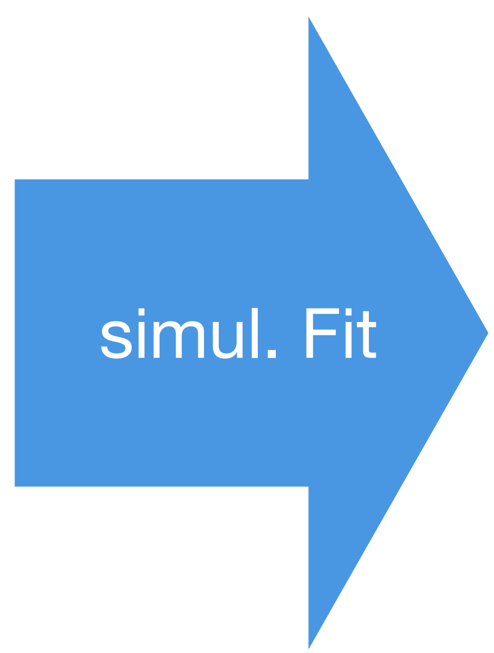
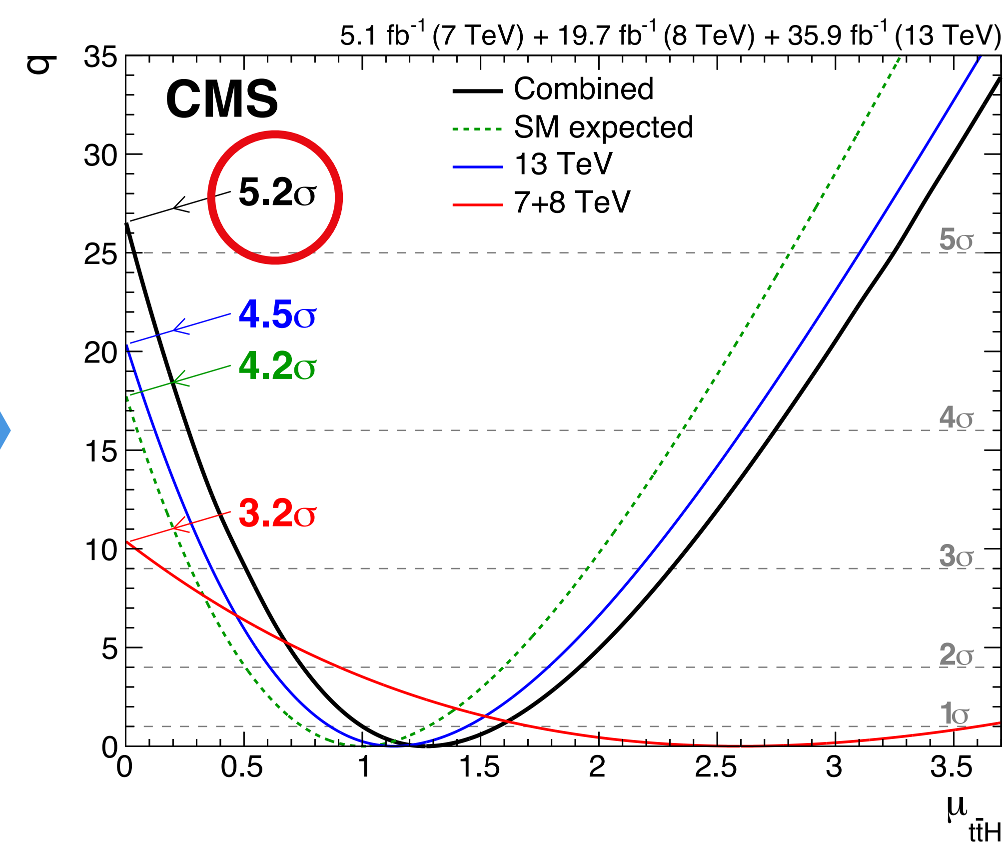
CMS: Event Categorisation

Rath master thesis





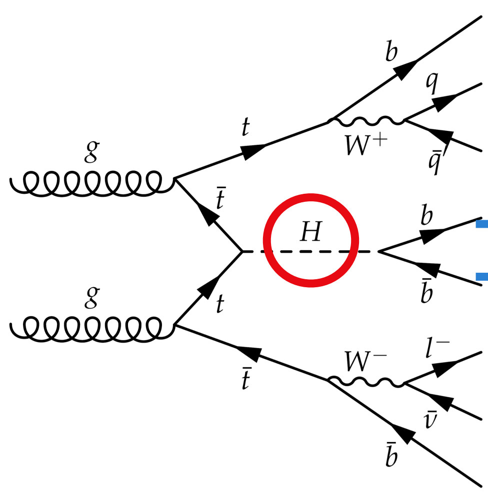




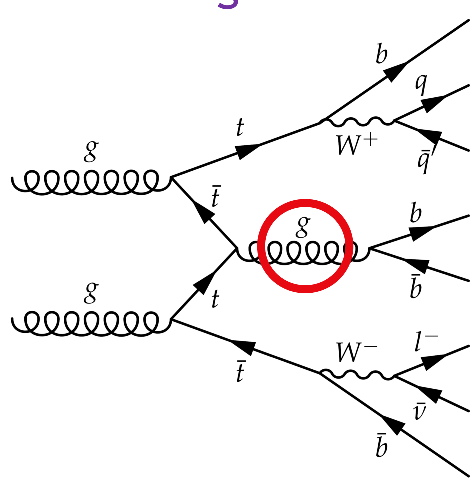
CMS: Autonomous Lorentz Boosts (LBN)

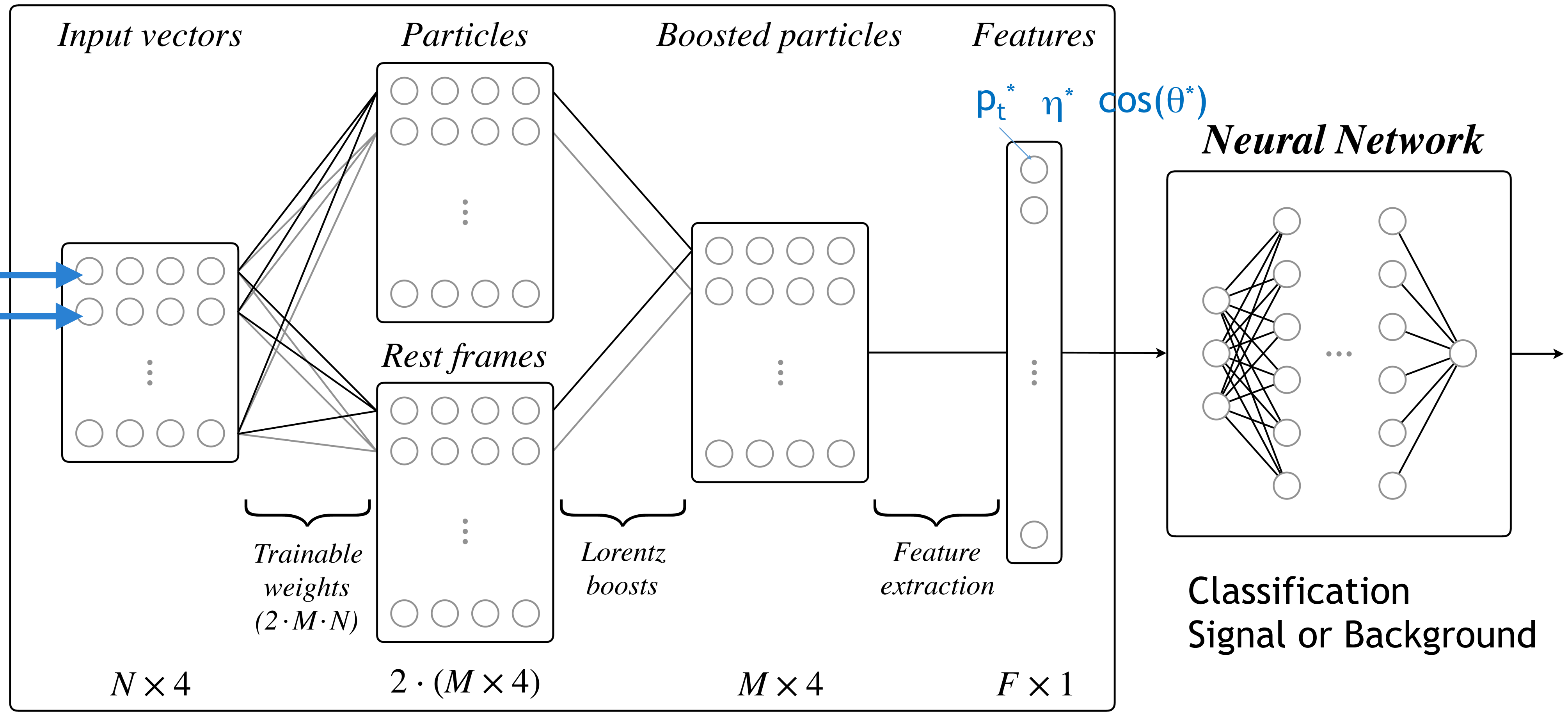
JINST 14 (2019) P06006

Higgs

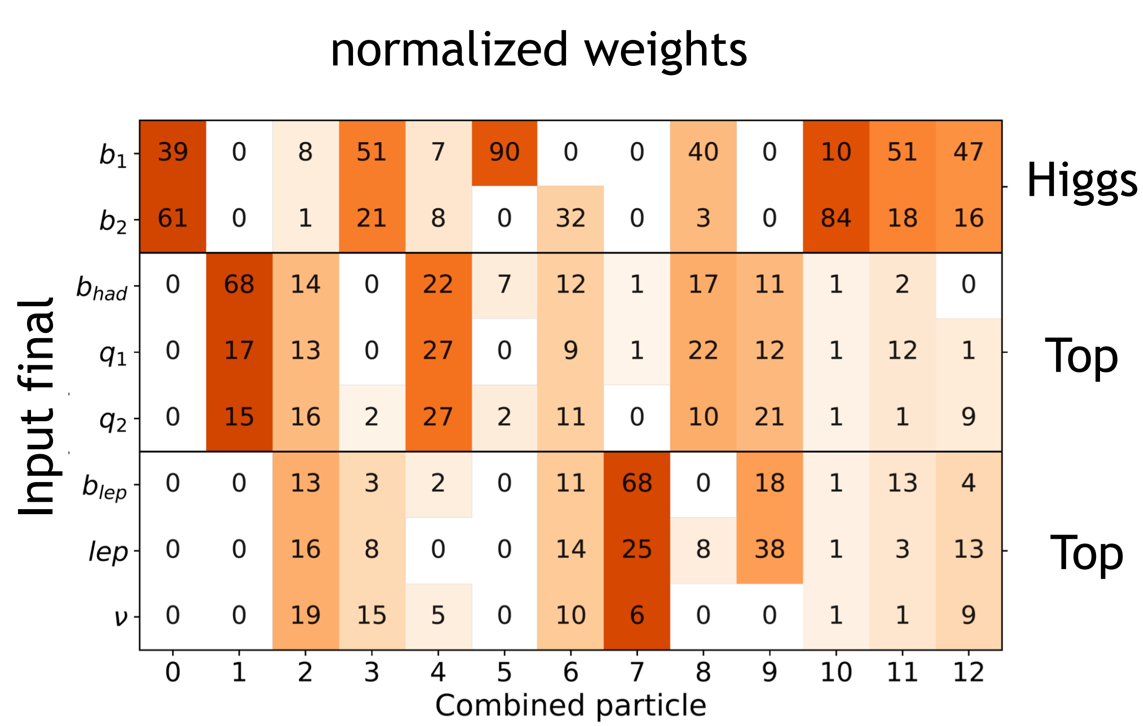


Background





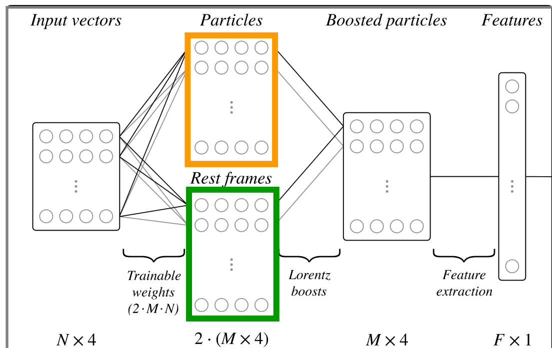
Classification
Signal or Background



- *generates meaningful particle combinations*

CMS: Autonomous Lorentz Boosts (LBN)

[JINST 14 (2019) P06006](#)



p_t^*
η^*
$\cos(\theta^*)$
...

combined particles in b-quark rest frame

b-quark in combined particles rest frame

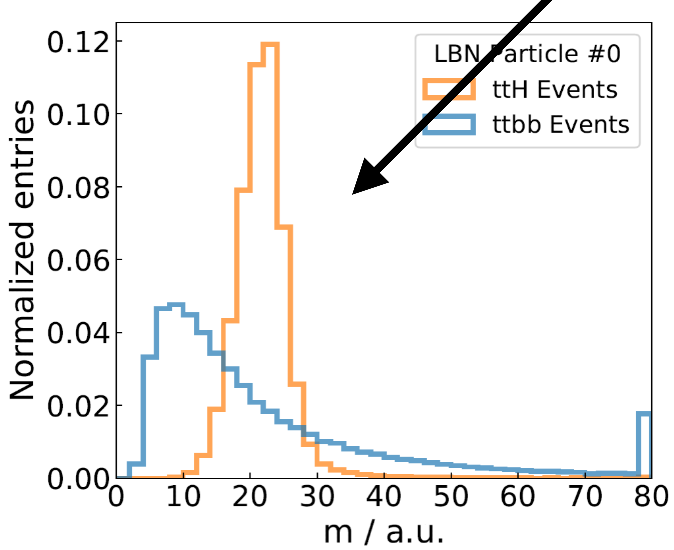
Input particle	0	1	2	3	4	5	6	7	8	9	10	11	12	
b_1	39	0	8	51	7	90	0	0	40	0	10	51	47	H
b_2	61	0	1	21	8	0	32	0	3	0	84	18	16	
b_{had}	0	68	14	0	22	7	12	1	17	11	1	2	0	
q_1	0	17	13	0	27	0	9	1	22	12	1	12	1	t_{had}
q_2	0	15	16	2	27	2	11	0	10	21	1	1	9	
b_{lep}	0	0	13	3	2	0	11	68	0	18	1	13	4	
lep	0	0	16	8	0	0	14	25	8	38	1	3	13	t_{lep}
ν	0	0	19	15	5	0	10	6	0	0	1	1	9	

Combined particle

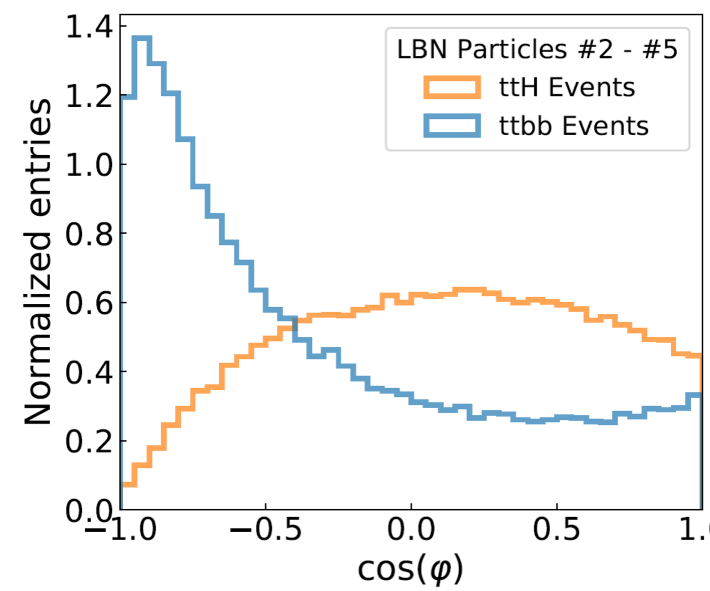
Input particle	0	1	2	3	4	5	6	7	8	9	10	11	12	
b_1	7	5	0	7	11	15	99	5	14	25	47	17	5	H
b_2	6	33	100	5	8	32	0	56	45	0	8	58	41	
b_{had}	11	30	0	0	7	15	0	4	10	3	8	2	5	
q_1	36	15	0	0	10	8	0	3	11	5	6	12	5	t_{had}
q_2	24	13	0	3	9	6	0	2	5	9	8	1	17	
b_{lep}	2	1	0	30	19	7	0	7	2	11	8	9	6	
lep	4	1	0	29	21	12	0	13	8	11	9	1	7	t_{lep}
ν	9	3	0	26	16	4	0	9	3	35	8	0	14	

Combined rest frame

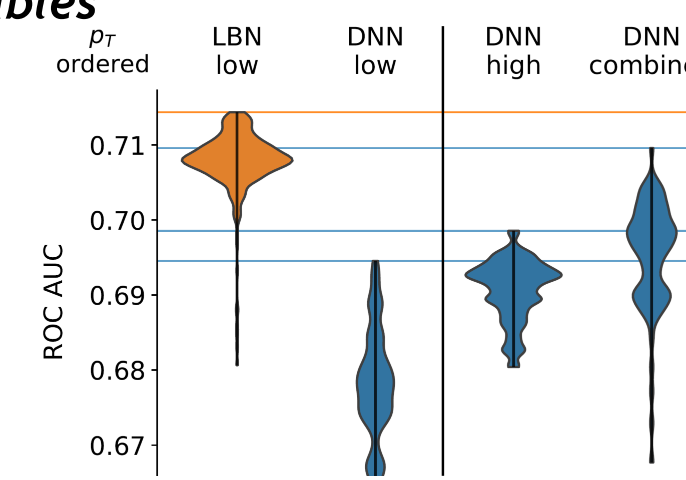
Mass distributions



Angular distributions

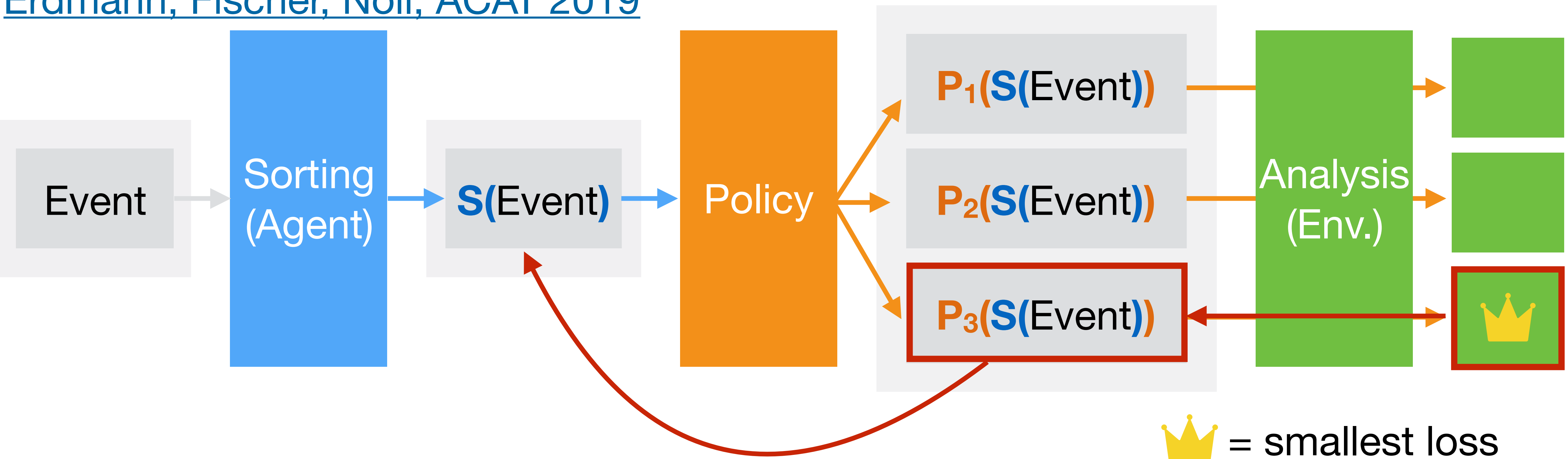


Even for pt-ordered jets: best result by autonomous variables

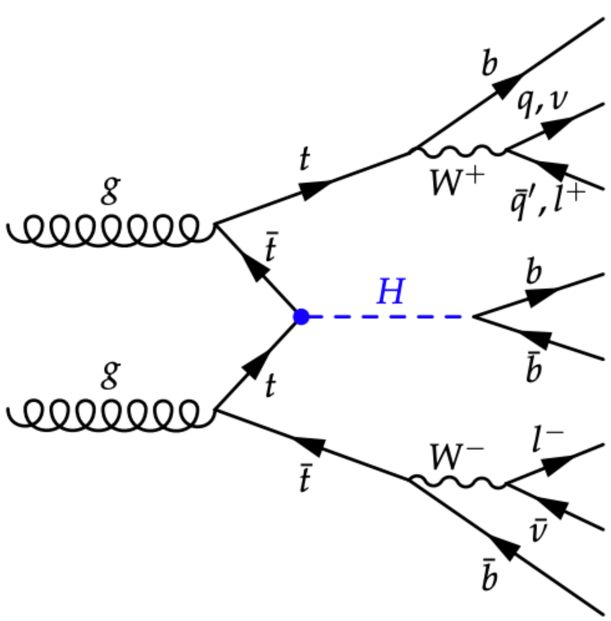


CMS: Reinforced Particle Sorting

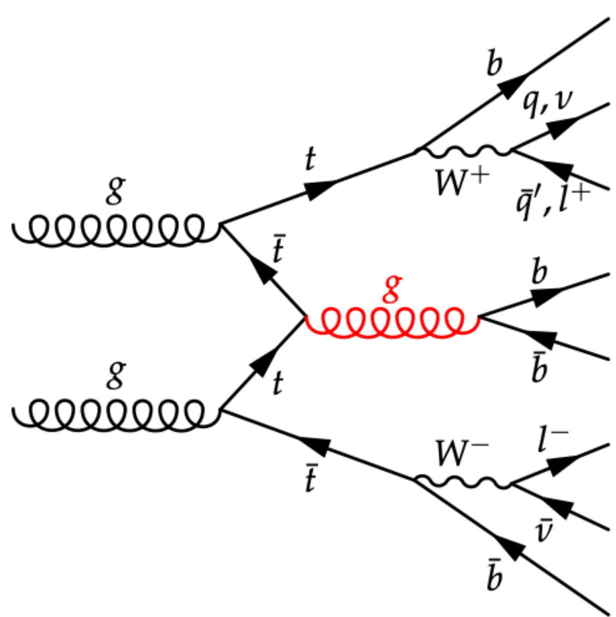
Erdmann, Fischer, Noll, ACAT 2019



= smallest loss

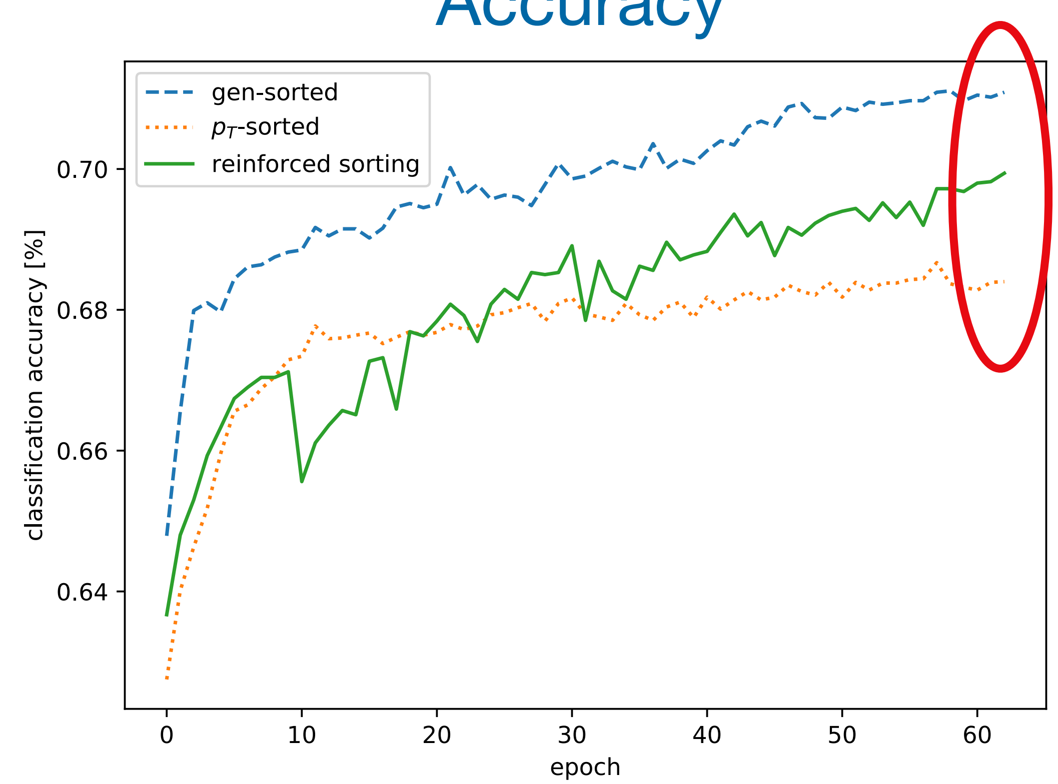


vs.



Classification performance improves
with proper particle sorting!

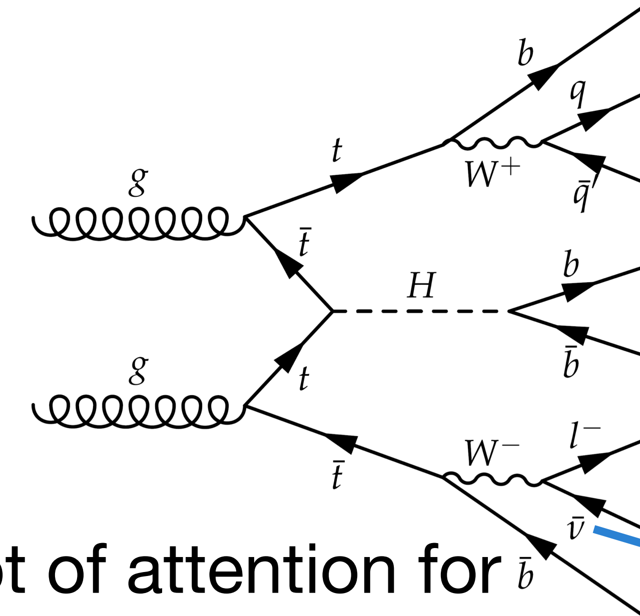
Accuracy



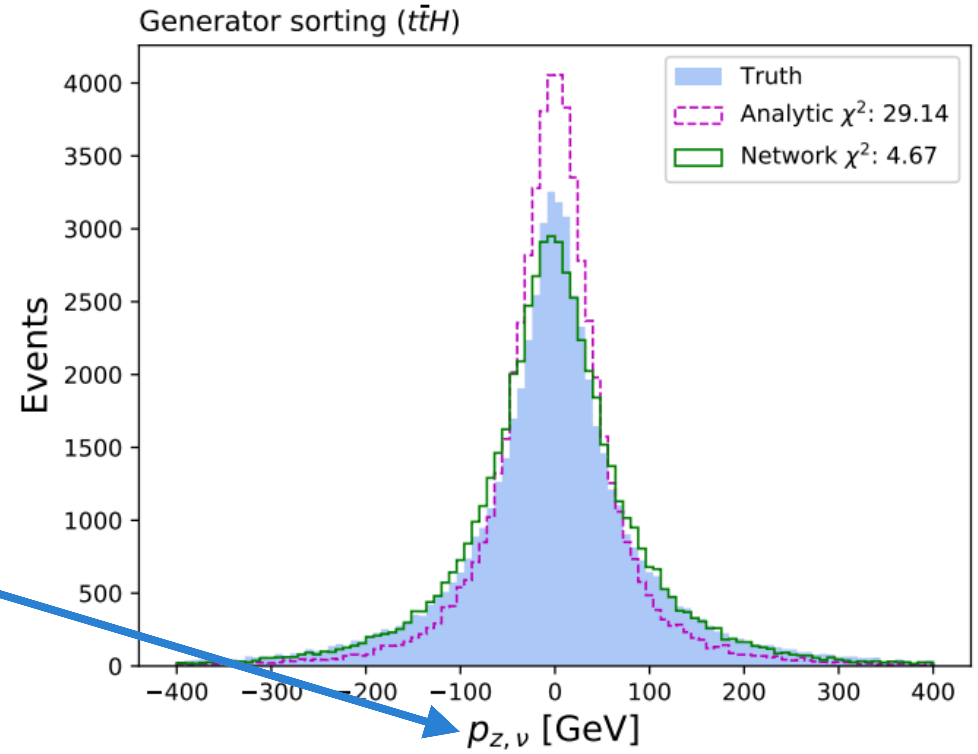
CMS: Neutrino Reconstruction (LBN)

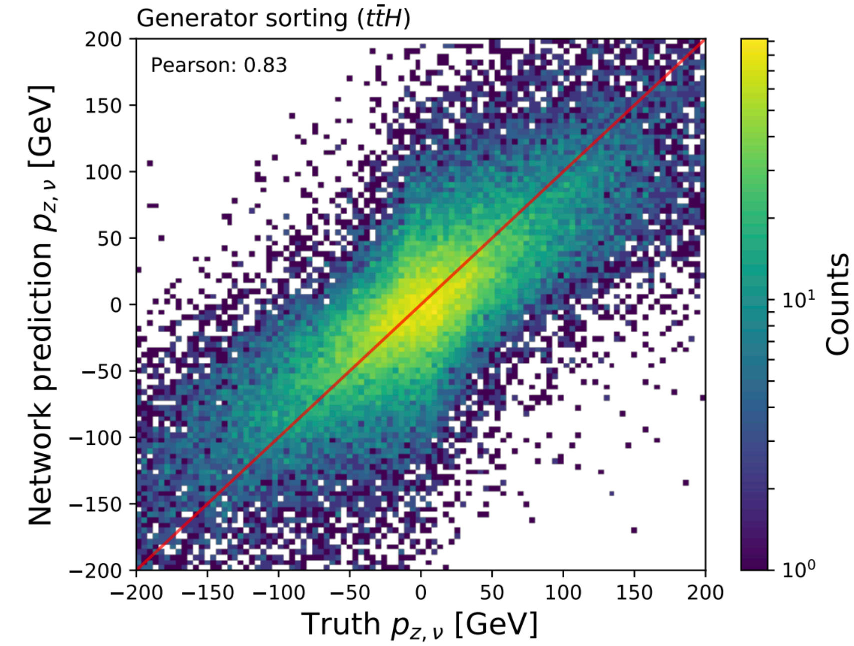
[Idaszek bachelor thesis, Fackeldey]()

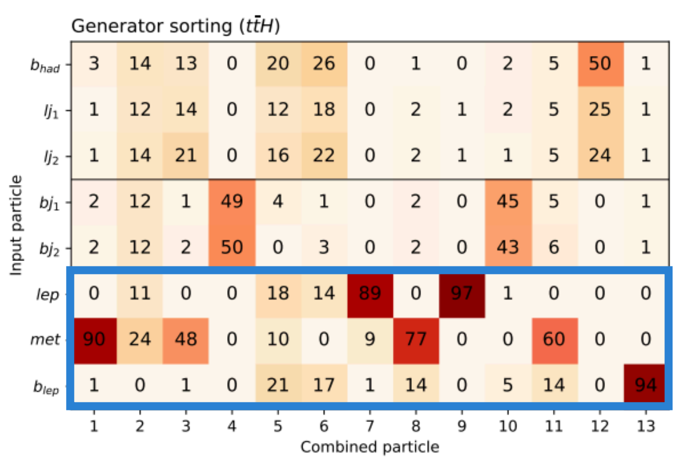
Full neutrino momentum unknown (only MET)

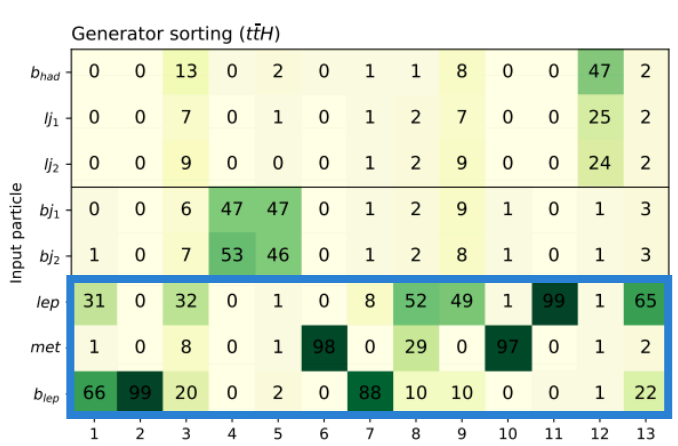


A lot of attention for lepton & neutrino!

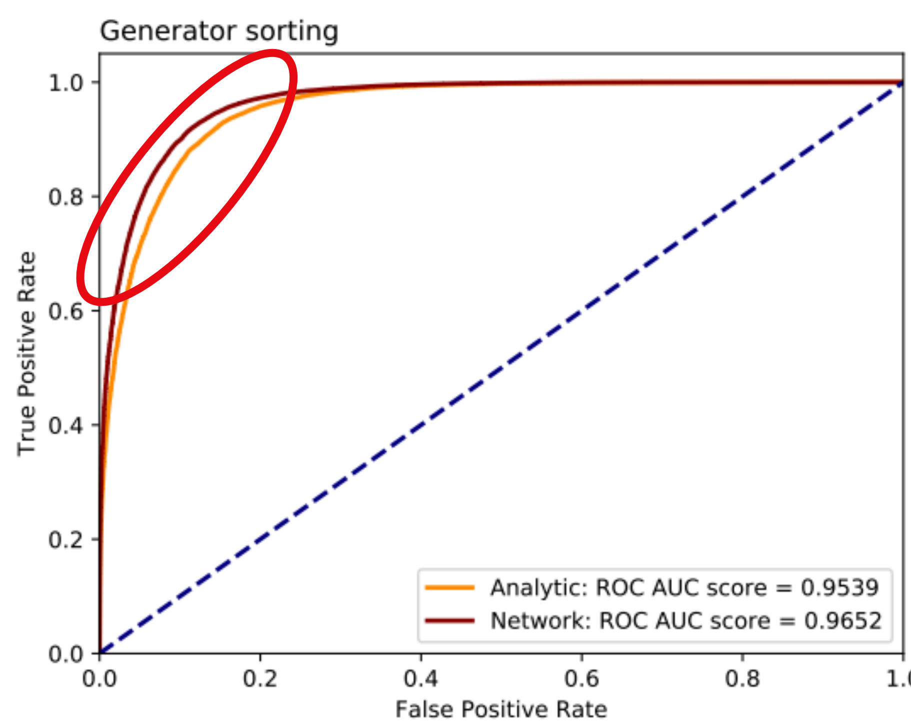


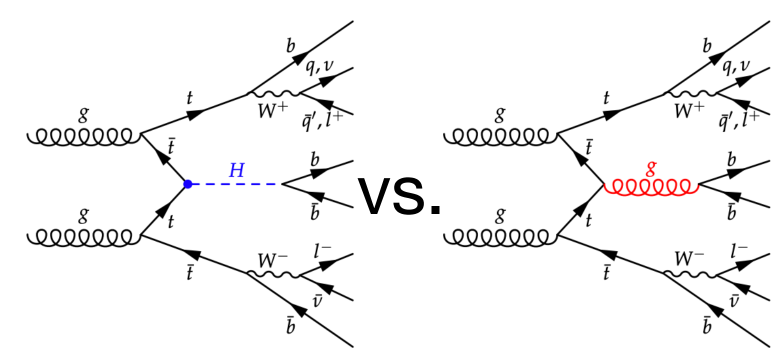






Improved classification with LBN-reconstructed neutrino momentum

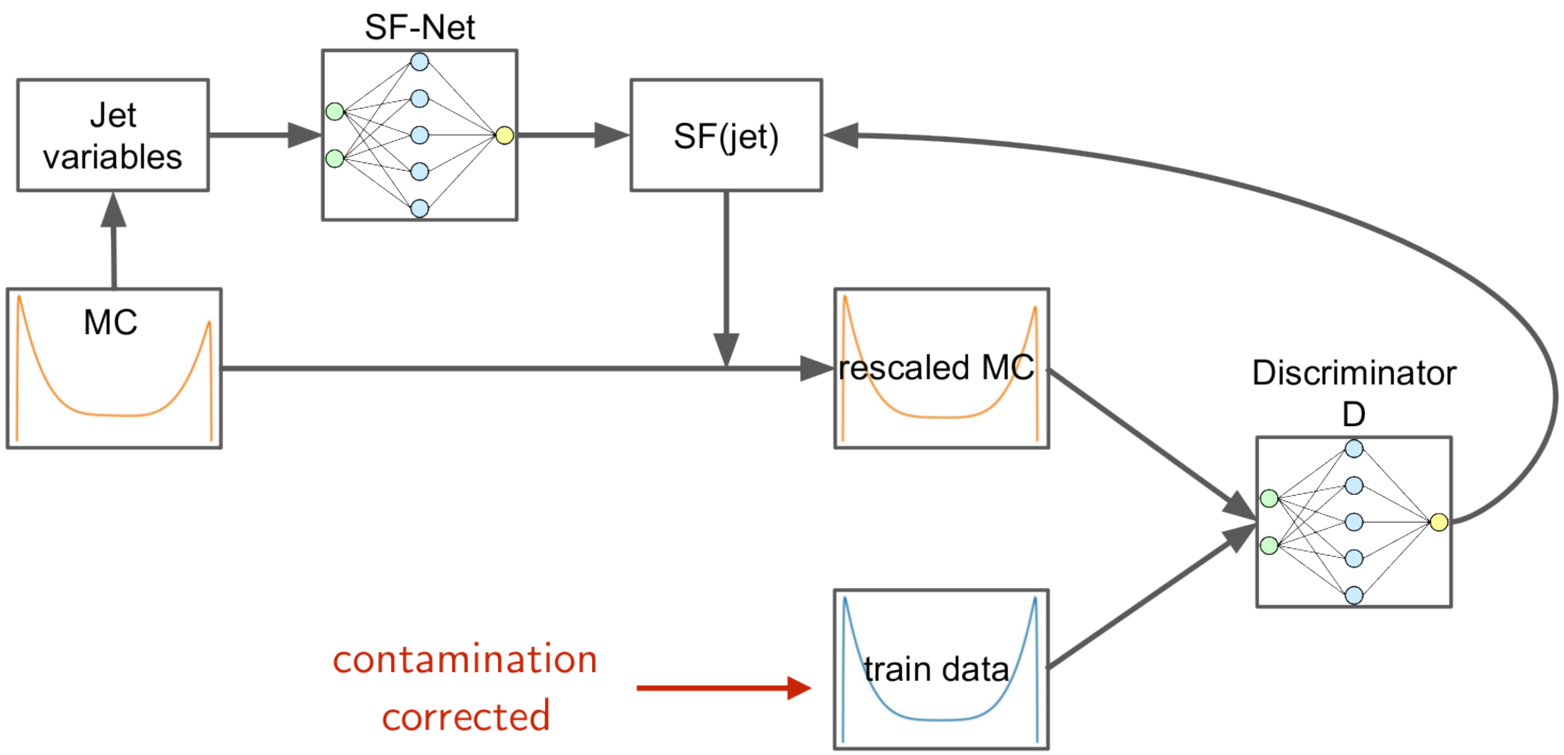




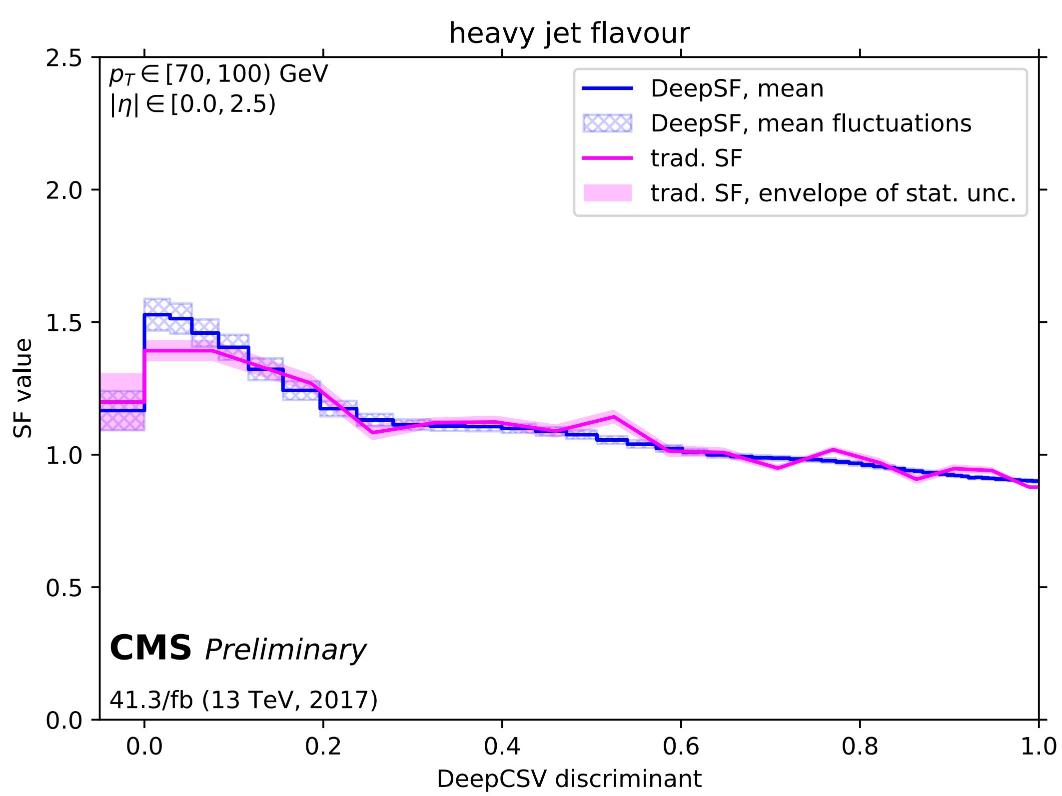
CMS: Deep Scale Factors

Erdmann, Fischer, ACAT 2019

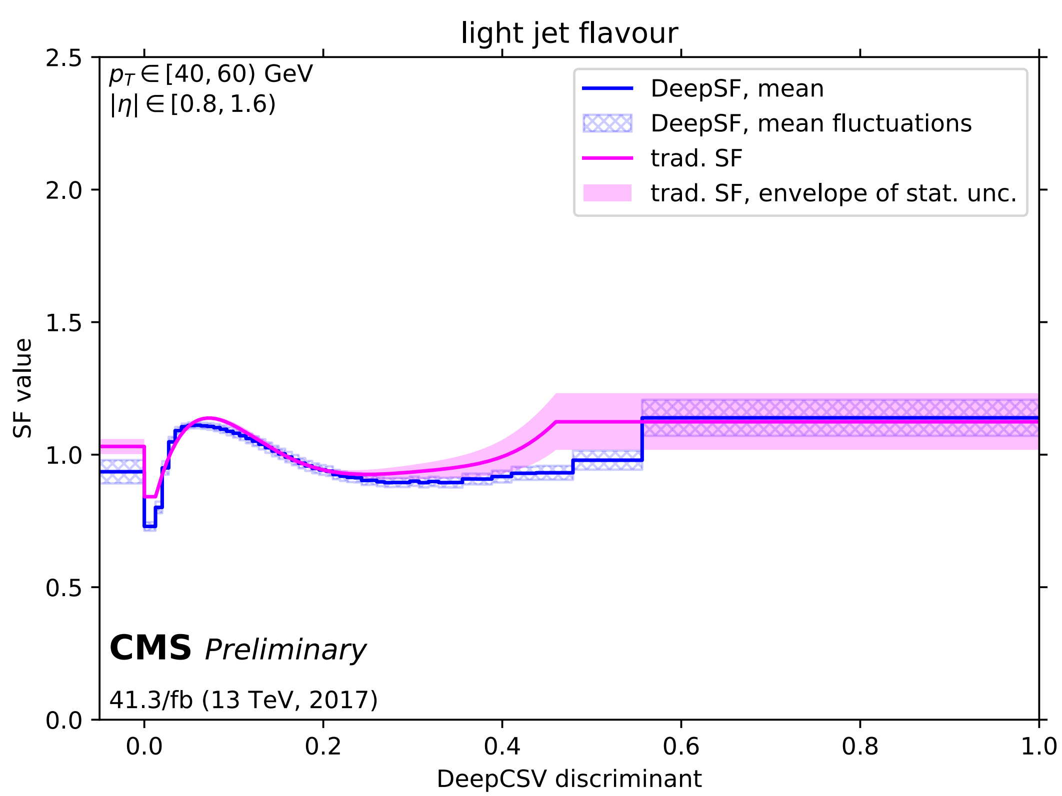
1. SF is calculated with jet variables from MC
2. MC is rescaled with SF
3. Discriminator (adversarial) discr. between data & rescaled MC
4. SF are recalculated with adversarial feedback



b jets



light jets



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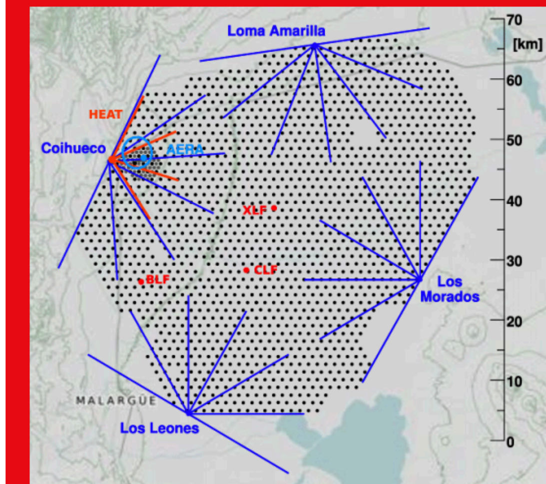

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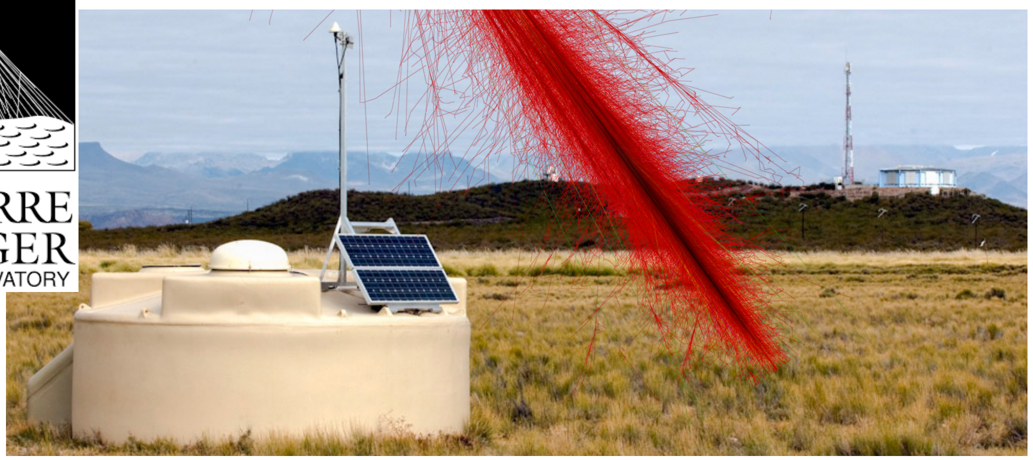
Auger: Air Shower Reconstruction

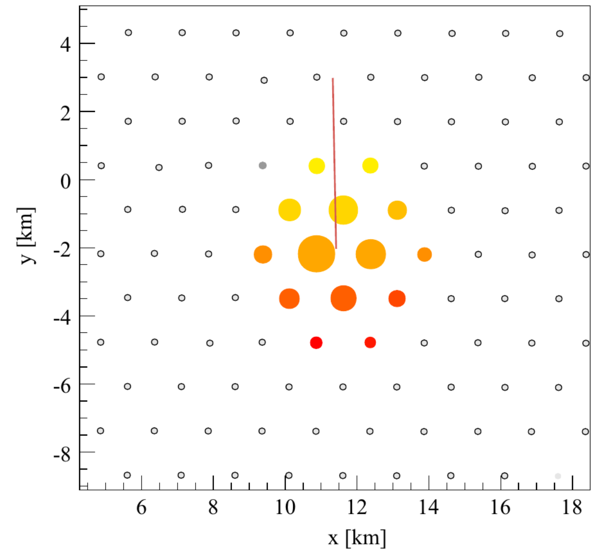
j.astropartphys.2017.10.006

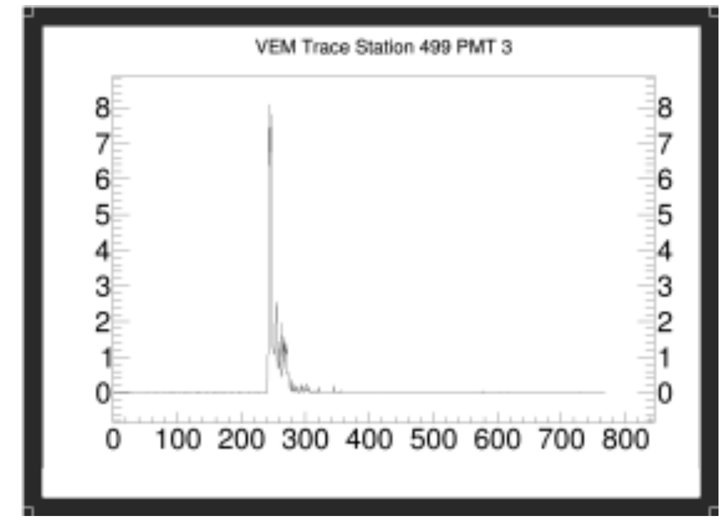
PIERRE AUGER OBSERVATORY



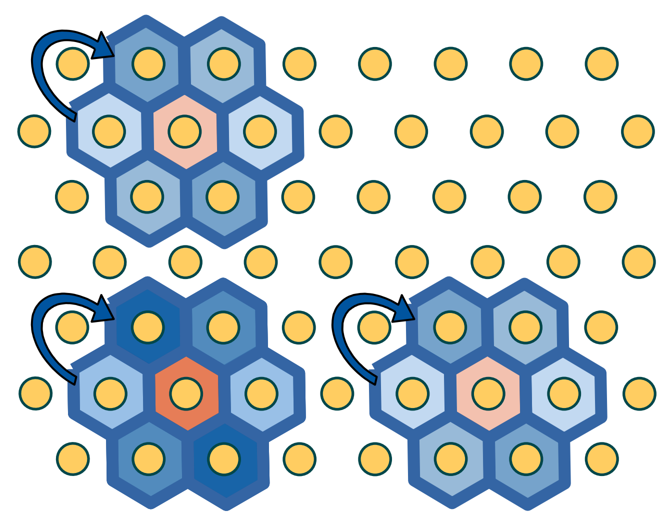
Pierre Auger Observatory

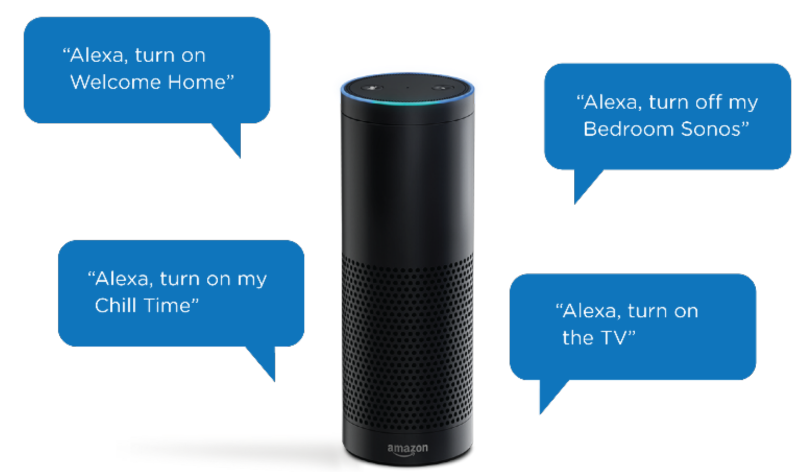
- Detection of cosmic-ray induced air showers
  - 1660 water-Cherenkov stations
  - 27 fluorescence telescopes
- Reconstruction of mass-sensitive information using deep learning
- Model relies on symmetries in data





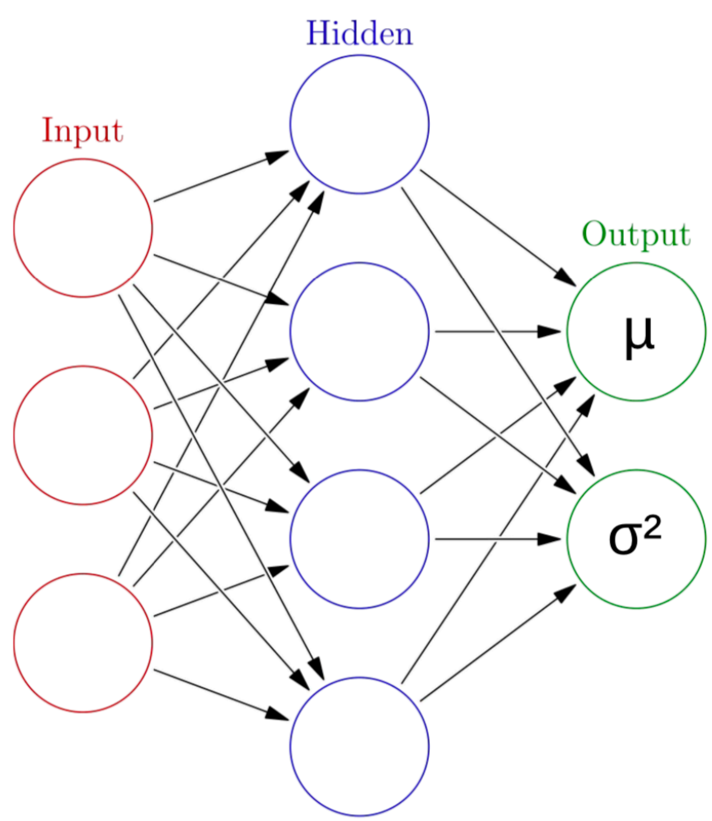
Hexagonal Convolutions + Recurrent Networks





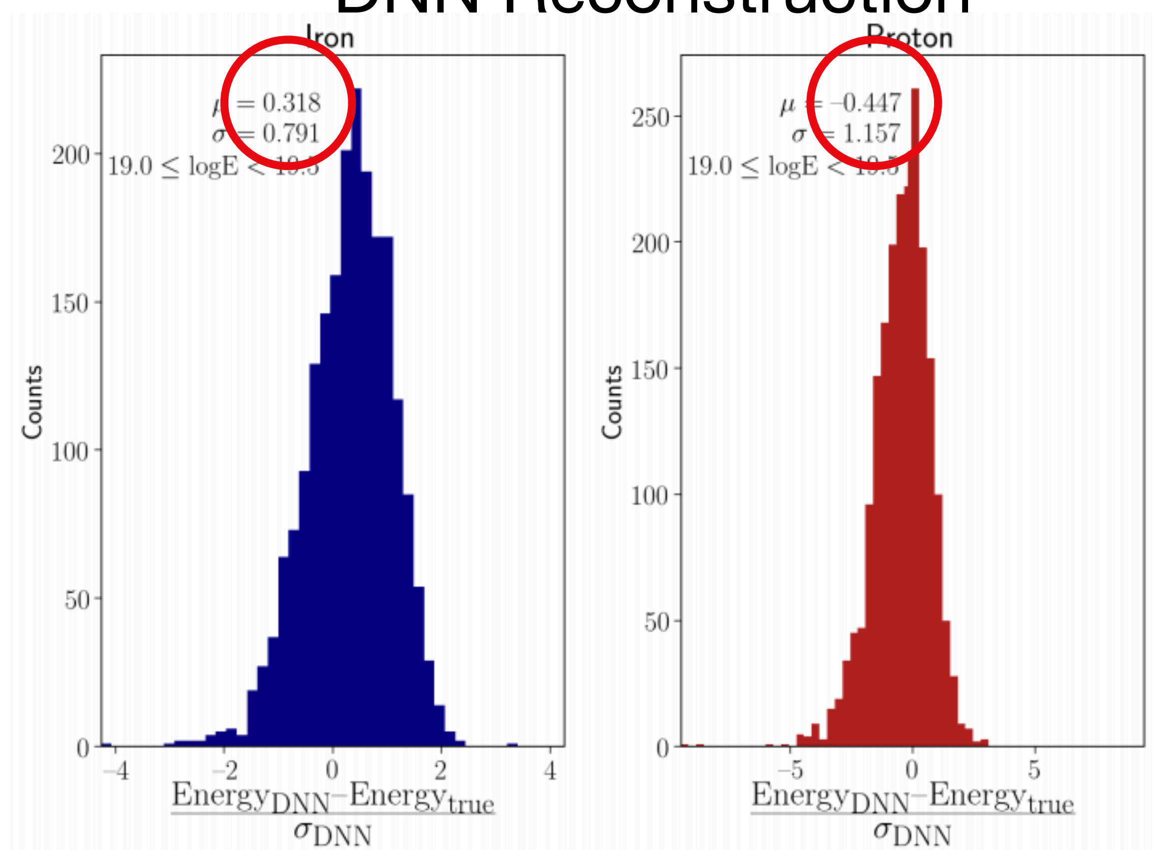
Straub bachelor thesis, Glombitza

- Allow for estimation of DNN uncertainties
- Assume normal distributed errors
  predict mean and variance
- Extend loss by taking variance into account
- Average over DNN ensemble using Gaussian Mixtures models



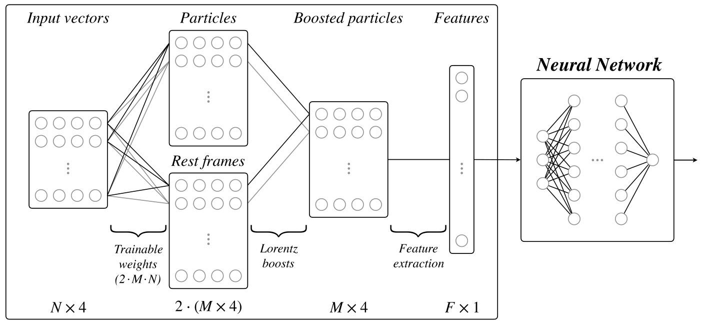
$$-\log p_\theta(y|x) = \frac{\log \sigma_\theta^2(\mathrm{x})}{2} + \frac{(y-\mu_\theta(x))^2}{2\sigma_\theta^2(x)}$$

DNN Reconstruction

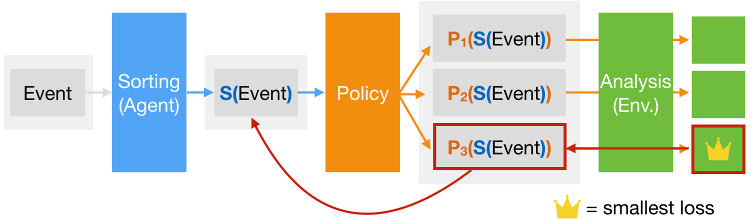


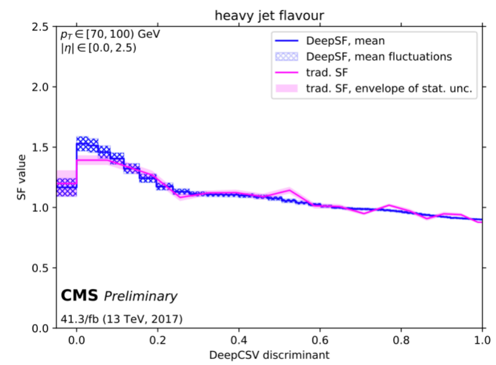
Summary

- Successful application of Deep Learning based algorithms at CMS and Auger
- Interpretable feature engineering with LBN:
  - Classification ttH vs ttbb
  - Neutrino reconstruction for e.g. ttH

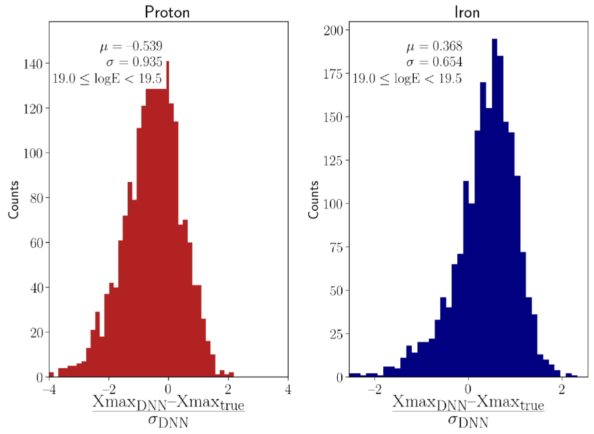


- Reinforced particle sorting
- DeepSF: General concept of SF calculation with adversarial training





- Air shower reconstruction:
  - convolution + recurrent
- Uncertainty Estimation for air shower reconstruction with Deep Learning



- VISPA project:
  - First efforts for *Marketplace*
  - Large software environment
  - Access via web browser
  - RWTH setup is backed up by extensive GPU/CPU resources
  - Soon: huge GPU upgrade!