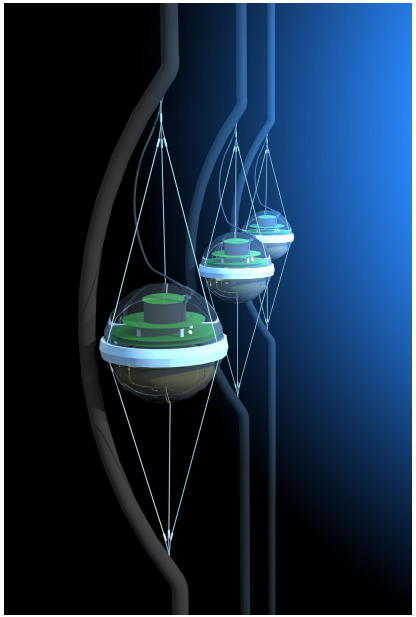
Bundesministerium
für Bildung
und Forschung

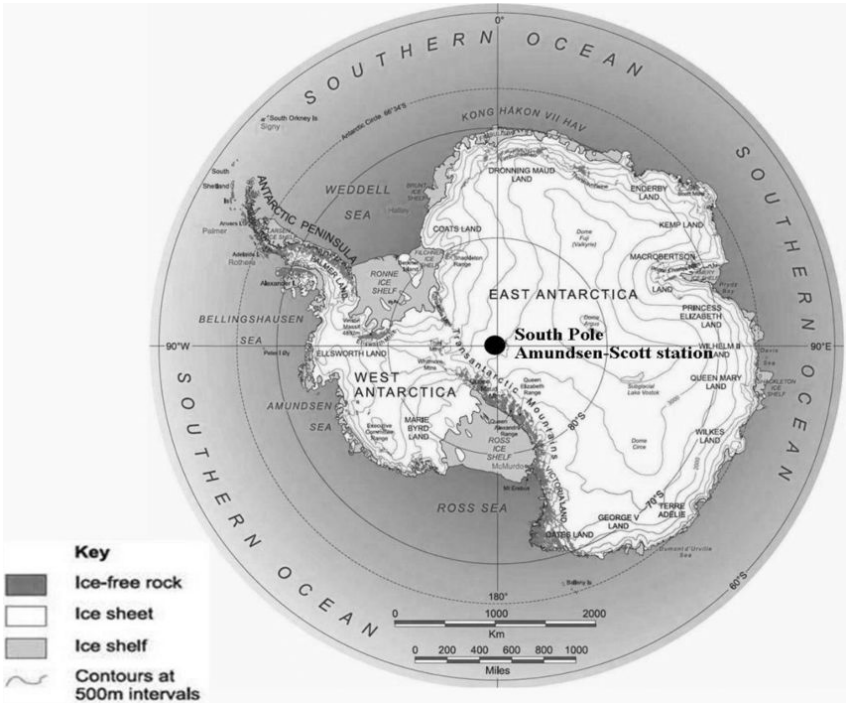
IceCube

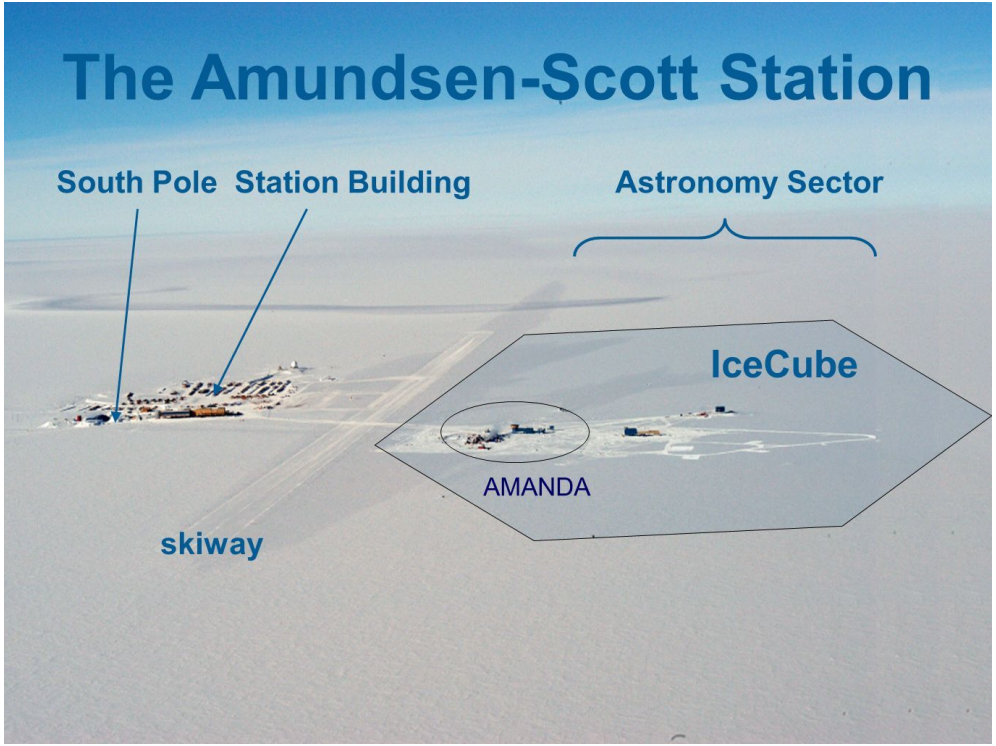
IceCube
-
deep learning developments



Thorsten Glüsenkamp, FRANCI seminar, 1.8. 2022

IceCube - the detector





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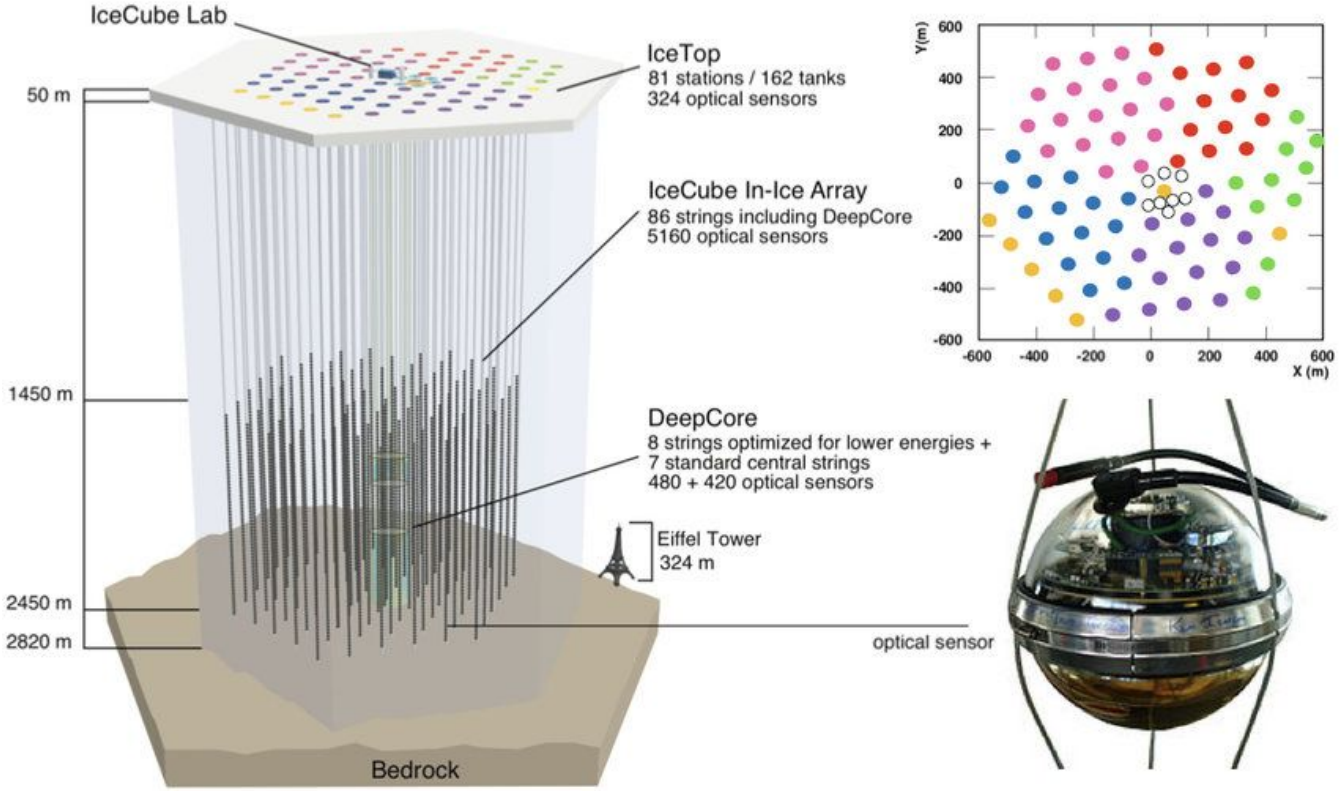
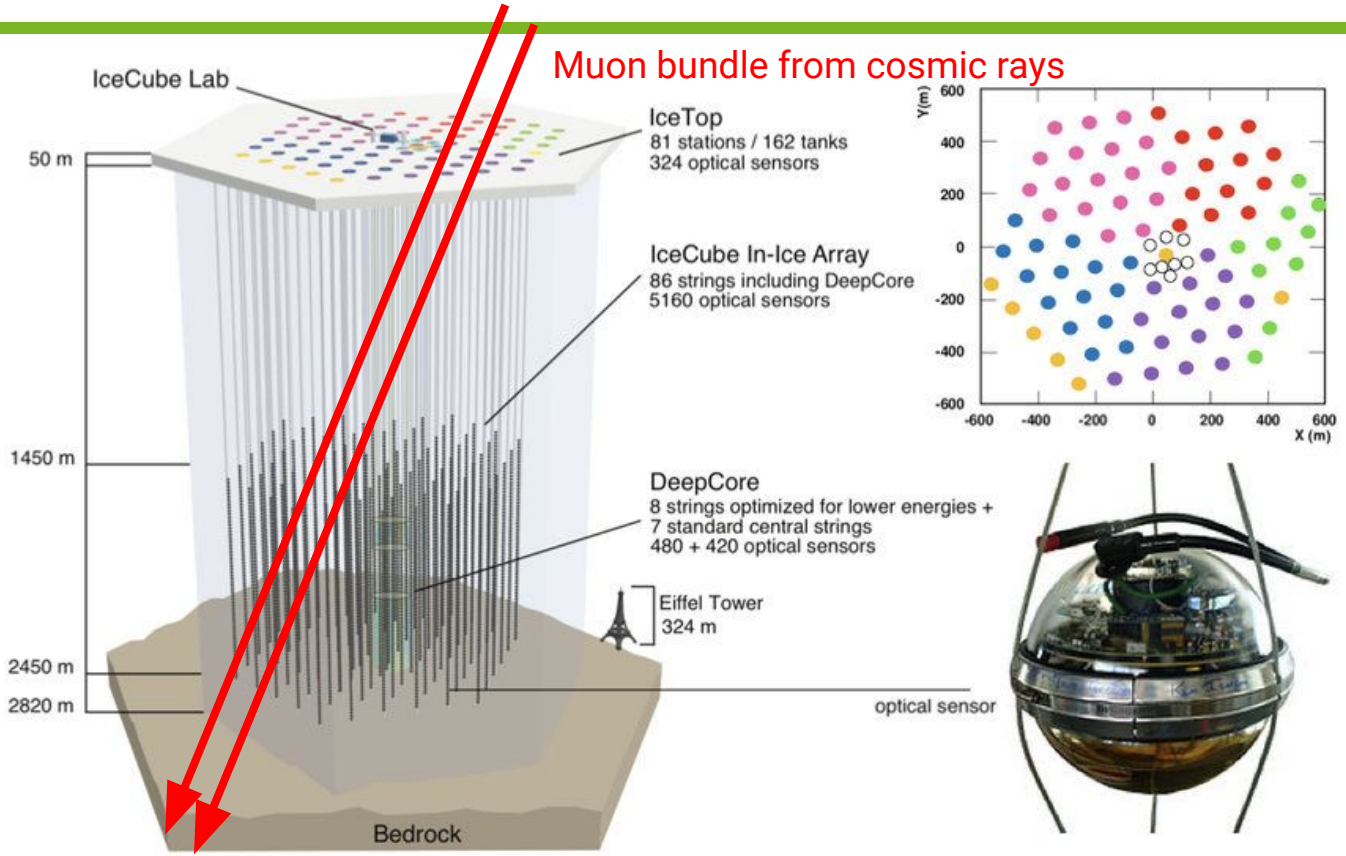


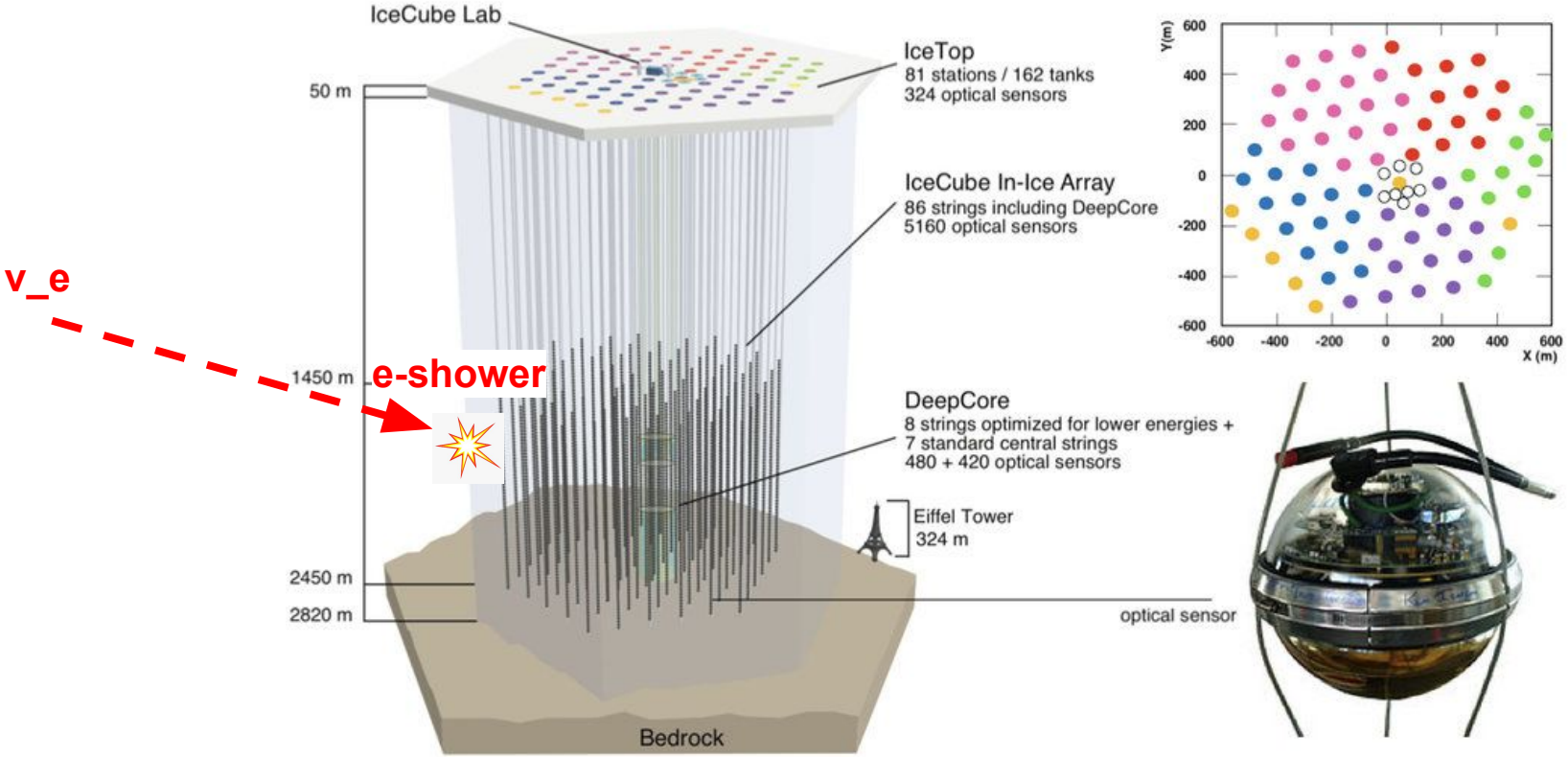
Digital Optical Module

IceCube - the detector



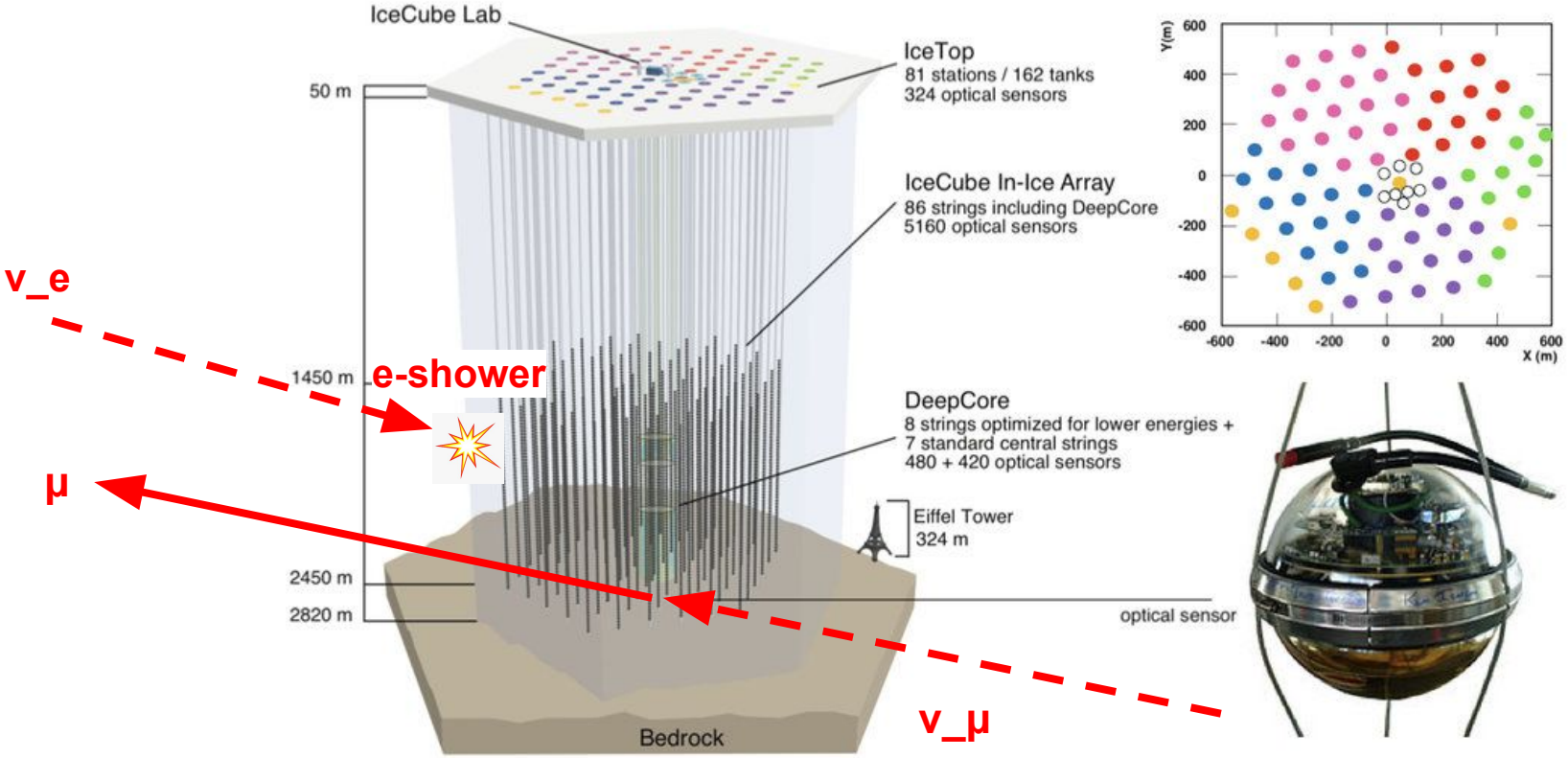
Digital Optical Module

IceCube - the detector



Digital Optical Module

IceCube - the detector



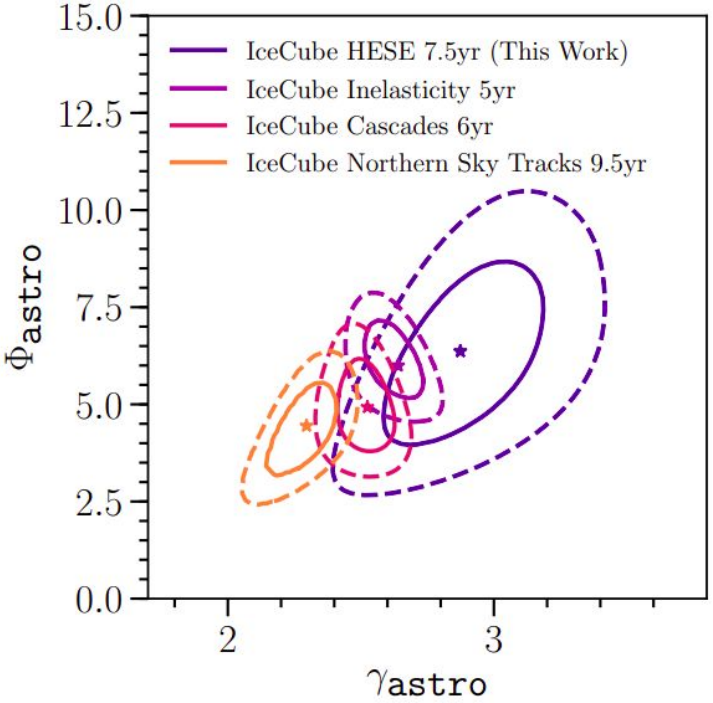
Digital Optical Module

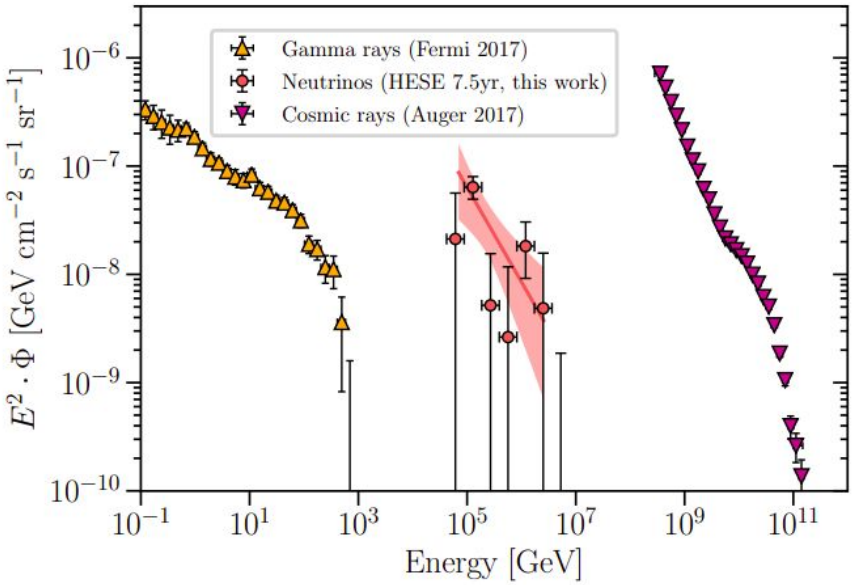
IceCube - the detector

Digital Optical Module

velocity of charged particle larger than speed of light in ice (~0.75 * c) -> emission of Cherenkov light

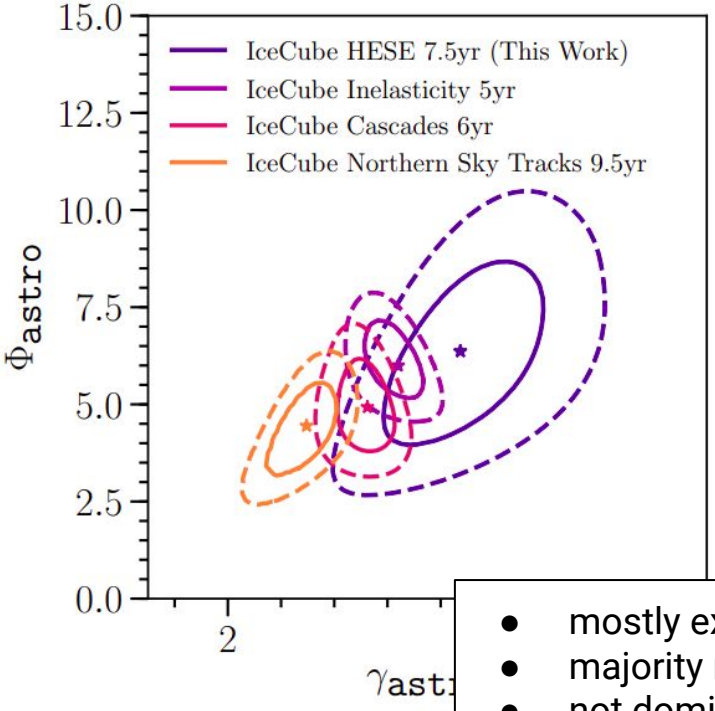
Some recent physics results (7.5 years starting event data)

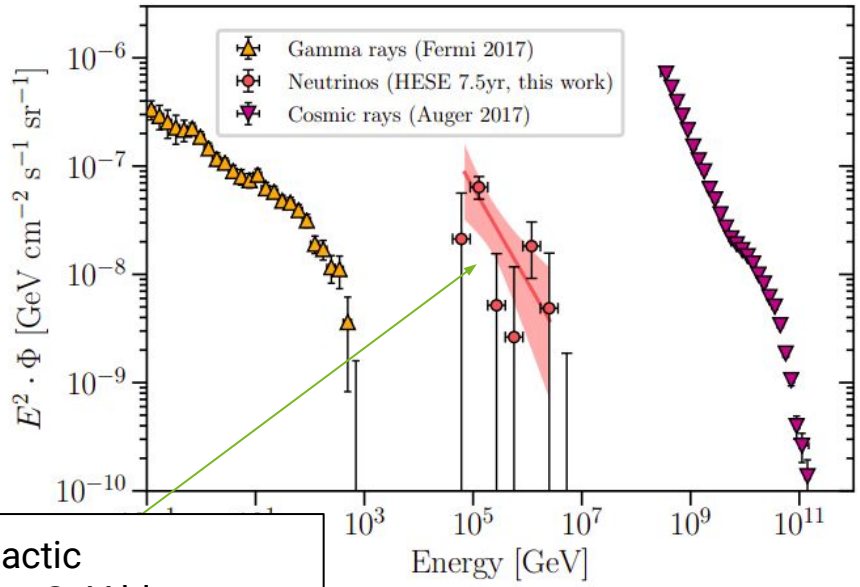




Phys. Rev. D 104, 022002 (2021)

Some recent physics results (7.5 years starting event data)





- mostly extragalactic
- majority not from GeV-blazars
- not dominated by GRBs

Phys. Rev. D 104, 022002 (2021)

Some recent physics results (TXS 0506+056 - the first point source)

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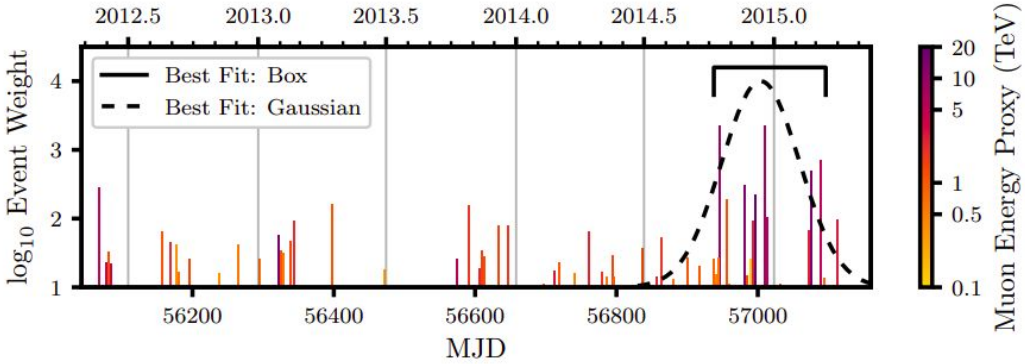
Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
*on **28 Sep 2017; 10:10 UT***
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

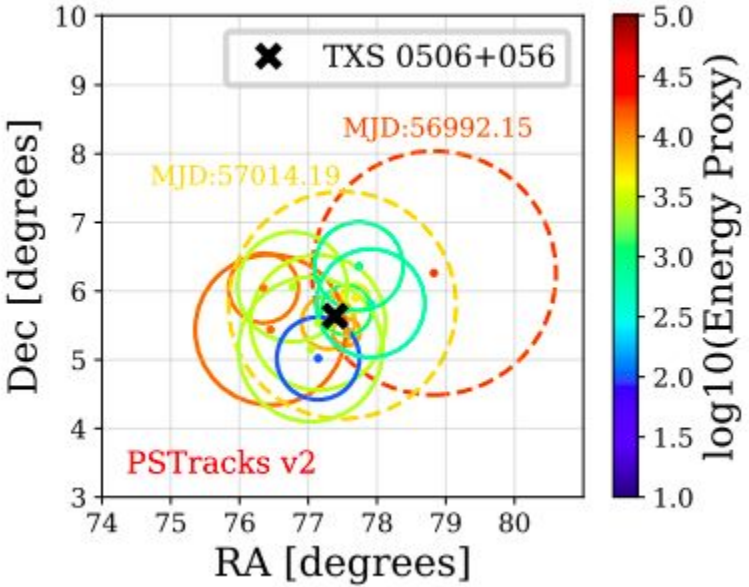
Subjects: Gamma Ray, Neutrinos, AGN

Follow up of ATEL
Gave independent > 3 sigma
Evidence for time dependent neutrino
Emission in historic data

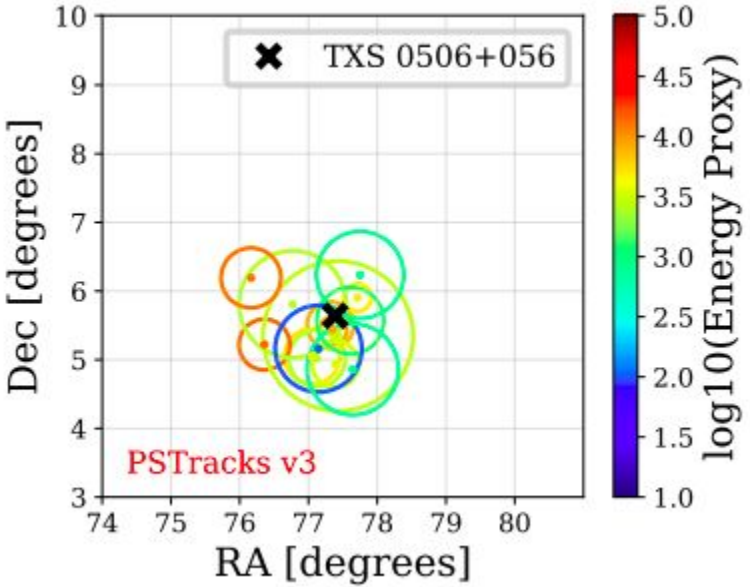


Some recent physics results (Revisiting of the time dependent TXS analysis)

Old processing (> 3 sigma)



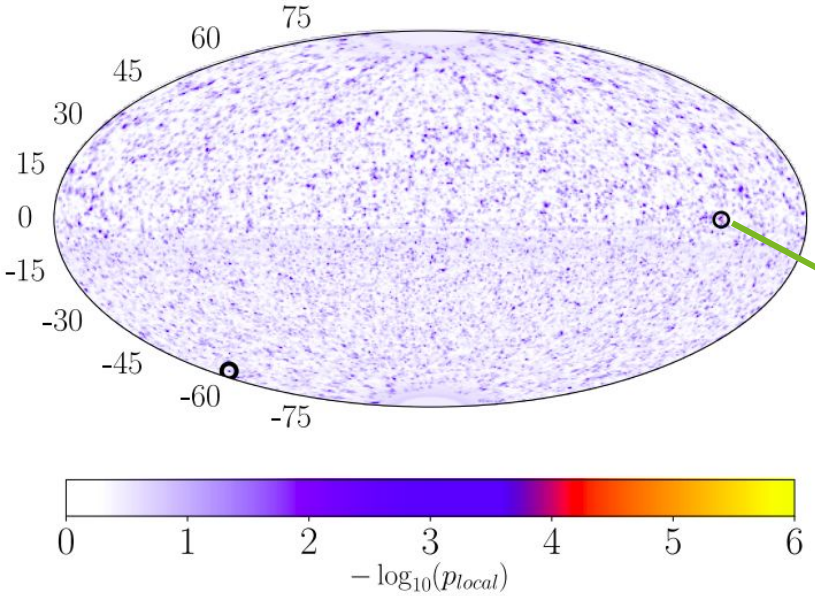
new processing (< 3 sigma)



But: combination with ATEL still very non-trivial

arXiv:2101.09836

Some recent physics results (Another interesting source candidate - NGC 1068)



TXS 0518+211	BLL	80.44	21.21	15.7	3.8	0.92	6.6
TXS 0506+056	**BLL**	**77.35**	**5.70**	**12.3**	**2.1**	**3.72**	**10.1**
PKS 0502+049	FSRQ	76.34	5.00	11.2	3.0	0.66	4.1
S3 0458-02	FSRQ	75.30	-1.97	5.5	4.0	0.33	2.7
PKS 0440-00	FSRQ	70.66	-0.29	7.6	3.9	0.46	3.1
MG2 J043337+2905	BLL	68.41	29.10	0.0	2.7	0.28	4.5
PKS 0422+00	BLL	66.19	0.60	0.0	2.9	0.27	2.3
PKS 0420-01	FSRQ	65.83	-1.33	9.3	4.0	0.52	3.4
PKS 0336-01	FSRQ	54.88	-1.77	15.5	4.0	0.99	4.4
NGC 1275	AGN	49.96	41.51	3.6	3.1	0.41	5.5
NGC 1068	**SBG**	**40.67**	**-0.01**	**50.4**	**3.2**	**4.74**	**10.5**
PKS 0235+164	BLL	39.67	16.62	0.0	3.0	0.28	3.1

https://doi.org/10.1103/PhysRevLett.124.051103

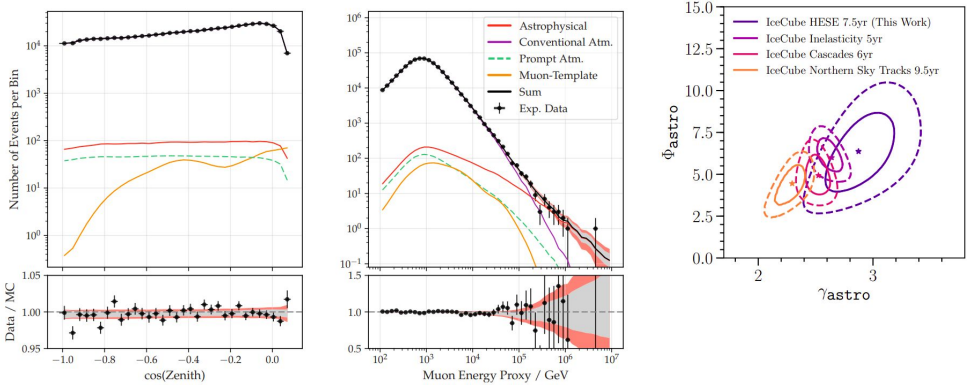
"prototypical Seyfert AGN"

10 year time independent analysis
With updated source list (based on gamma emission) finds new hot spot in northern sky: NGC 1068 … TXS is second hot spot

Post-trial p-value: 2.9 sigma

Reconstruction have crucial impact

Reconstructions impact variables in analyses …
could we do this better?



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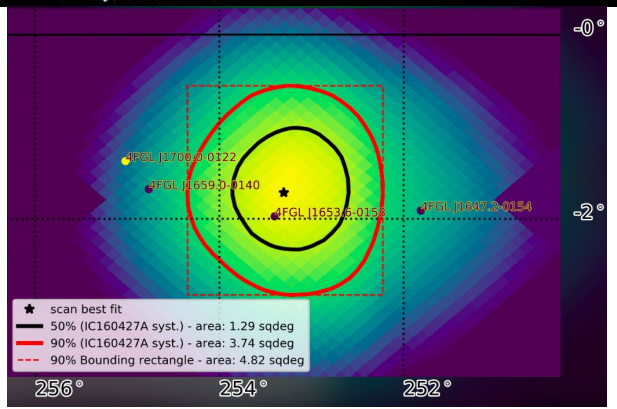
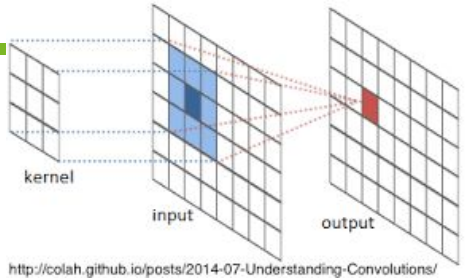


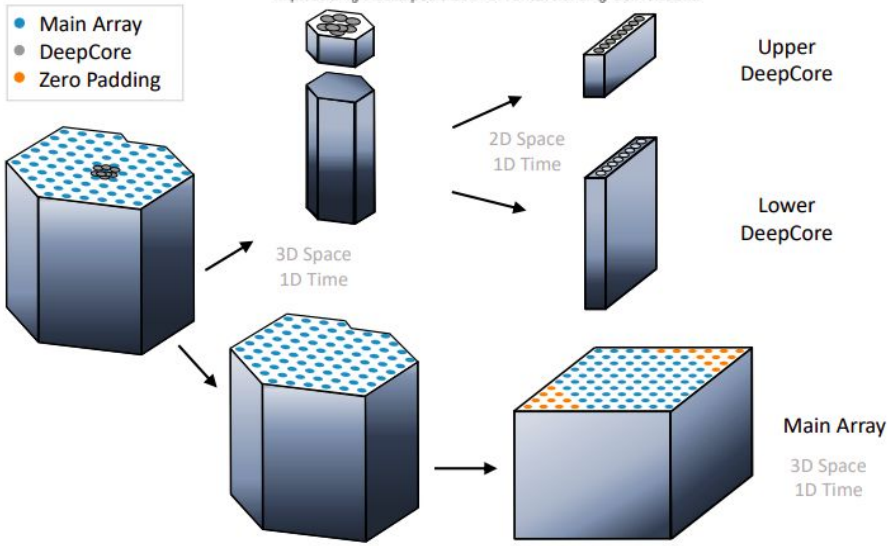
For certain online alerts, we perform
Time consuming likelihood scans (~ 12 hours +)

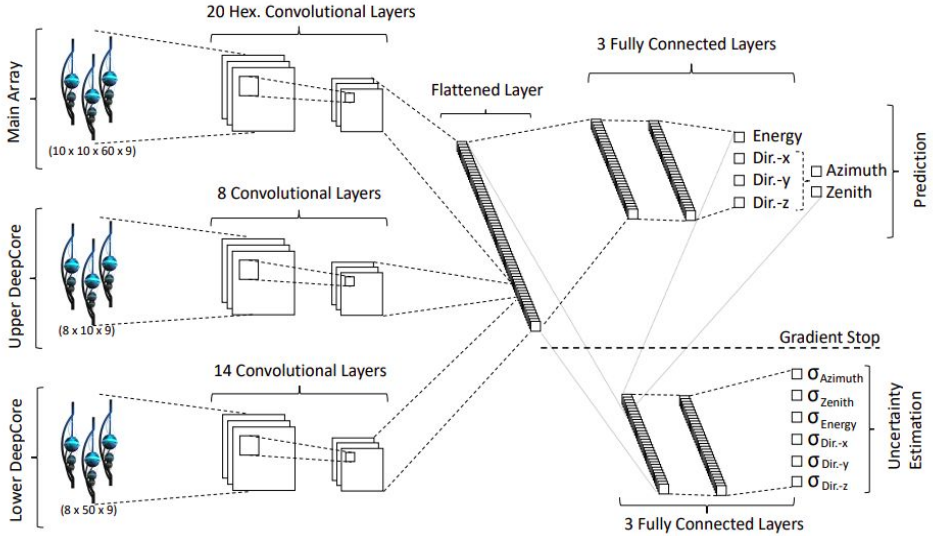
Issue: we know they include certain biases, and do not include certain systematics (ice optical properties)

-> convervative over correction

Deep learning for showers

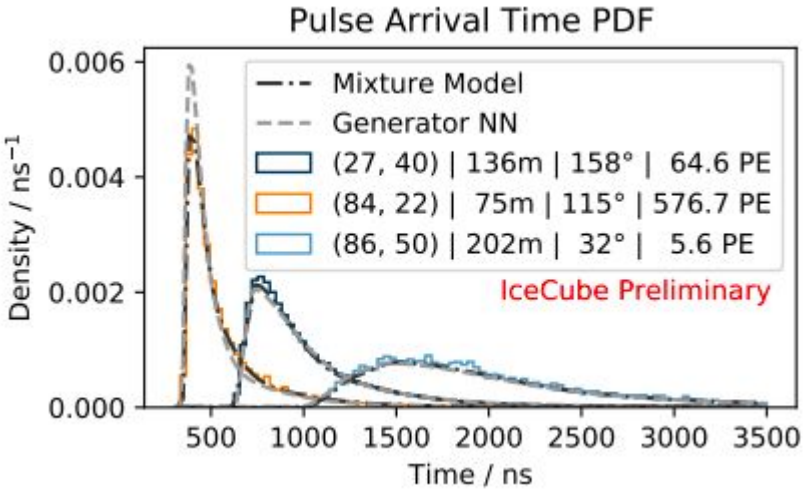


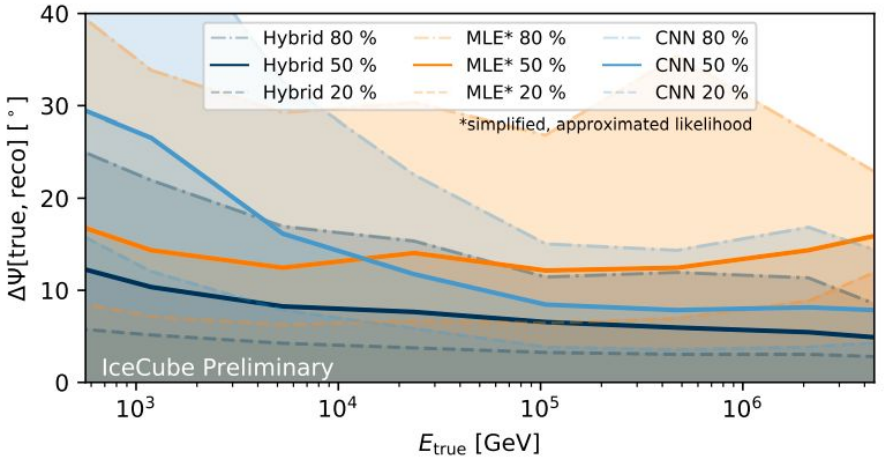




arXiv:2101.11589

Deep learning for showers

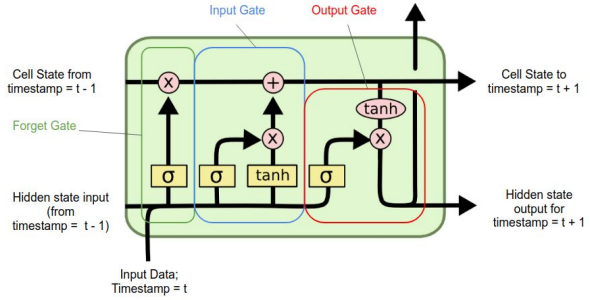


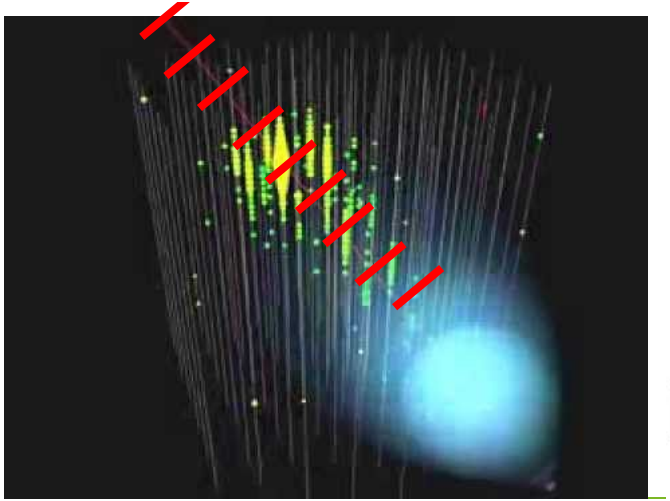


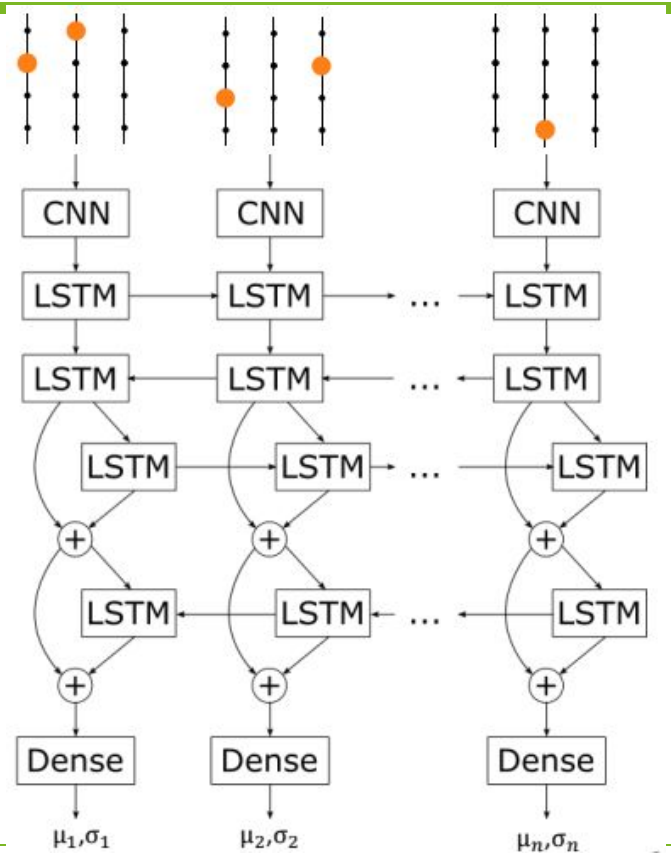
$$\mathcal{L}_{\text{event}}\left(\vec{x}=\{\vec{c},\vec{t}\}\,|\,\vec{\xi}\right)=\prod_{d}^{D}\text{Poisson}\left(\sum_{i}^{N_d}c_{d,i}\,|\,\lambda_d\left(\vec{\xi}\right)\right)\cdot\prod_{i}^{N_d}P_d(t_{d,i}\,|\,\vec{\xi})^{c_{d,i}}$$

PoS-ICRC2021-1065

CNN / RNN mixture - high energy muons (G. Wrede, ECAP)



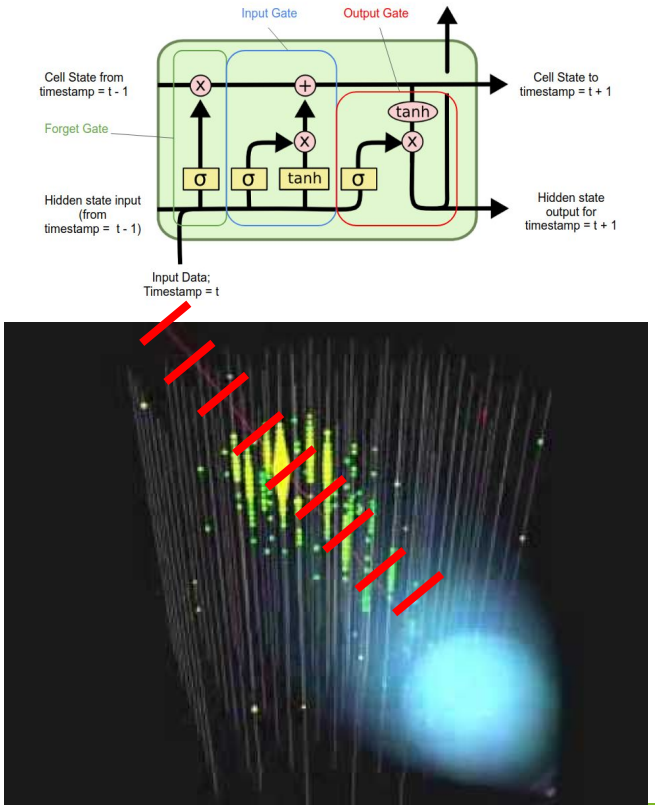


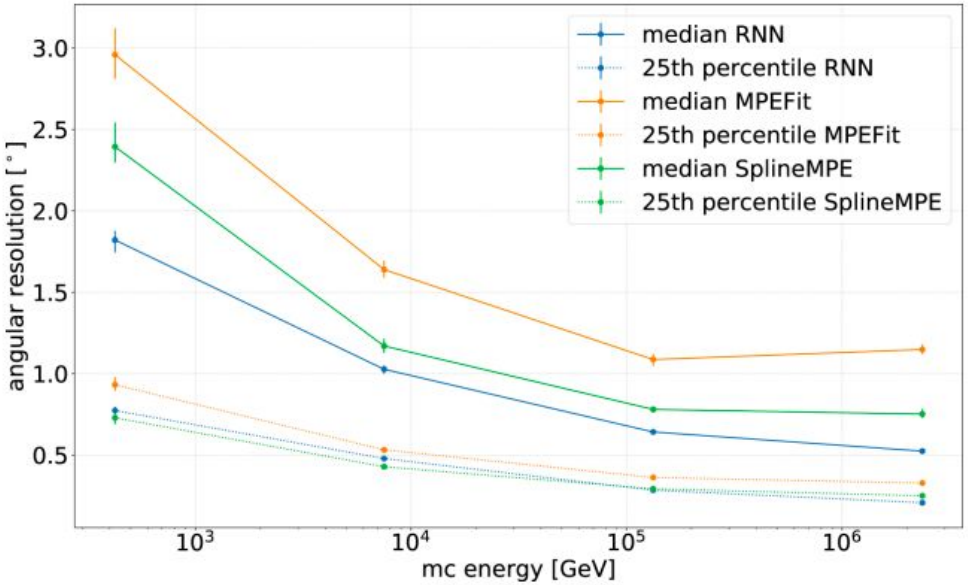


\+ Second Network that Takes as input The predicted Positions from The LSTM

Direction + Uncertainty

CNN / RNN mixture - high energy muons (G. Wrede, ECAP)

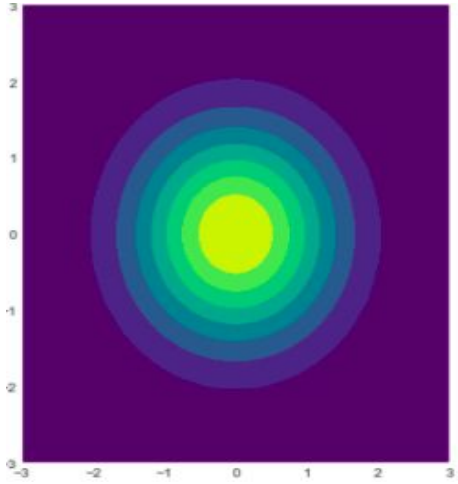




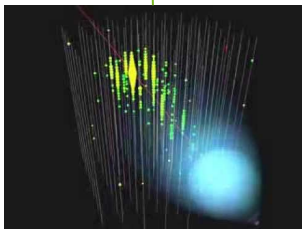
Normalizing flows for Posterior prediction (T. Glüsenkamp, ECAP)

$$\ln(q(z_o)) = \ln(p_b(\rho^{-1}(z_o)) - \ln(\det(J_{\hat{z}}^{\rho_\phi}))$$

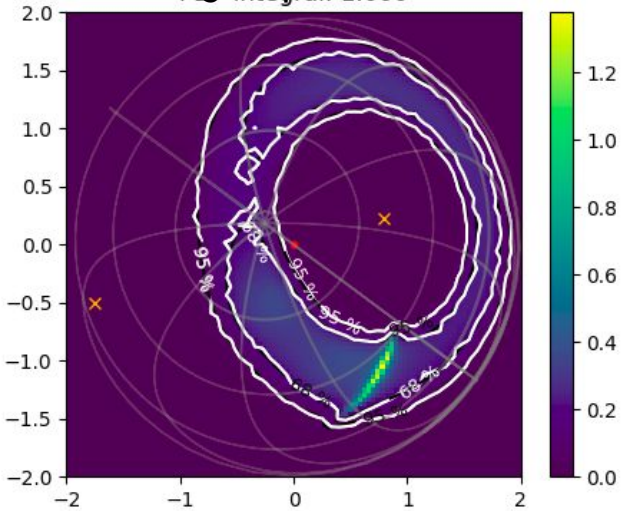
base space



$$z_o = \rho_{\phi(x)}(z)$$



target space



1) Systematics
2) Coverage control
3) Goodness-of-Fit
(2008.05825)

Advantages of deep learning

1) Fast

2) Easier to include systematics

3) Better performance
   Performance ML vs standard likelihood?

Showers 

Throughgoing tracks (direction) 

Starting Tracks 

Energy estimation 

Low energy events (<200 GeV) 

Summary

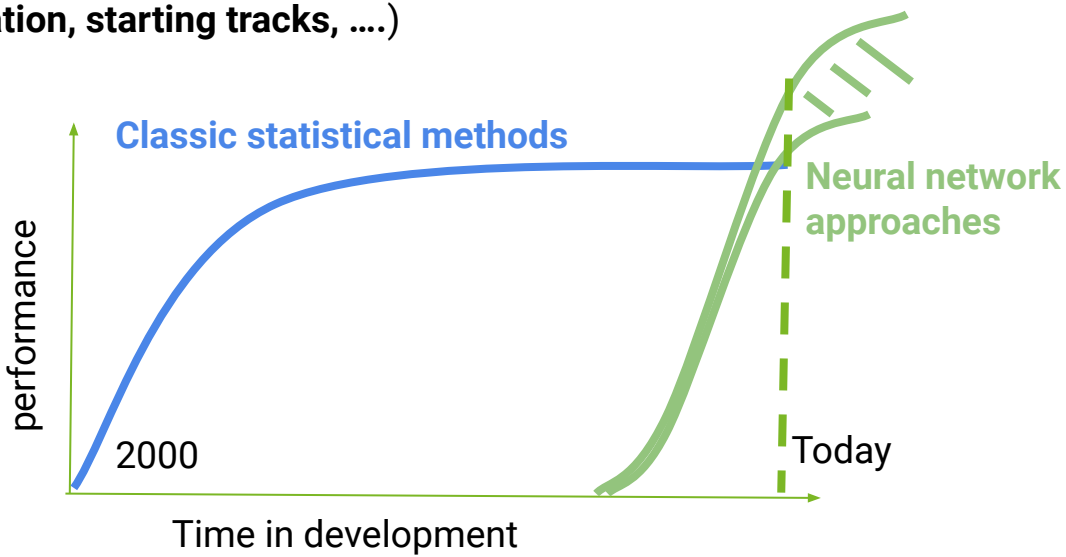
- Determining origin of neutrino flux ongoing effort in IceCube
- Deep-Learning based reconstructions are taking over (including ECAP activities)
- Already offer faster and more precise reconstructions for a large number of use cases (**shower-type topologies, energy estimation, starting tracks, ….**)

Summary

- Determining origin of neutrino flux ongoing effort in IceCube
- Deep-Learning based reconstructions are taking over (including ECAP activities)
- Already offer faster and more precise reconstructions for a large number of use cases (**shower-type topologies, energy estimation, starting tracks, ….**)

Classical llh approaches run into bottleneck
(20+ years of history in IceCube/Amanda)

New Machine learning methods
(only ~2-3 years of investigation)
already better in many areas



New physics results and improvements of existing results guaranteed in the next years !