

CTAO

LST
COLLABORATION

anr[®]

LAPP



Evaluating the scientific potential and performance of Gammalearn on LST-1 observations

39th International Cosmic Ray Conference (ICRC 2025)

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J. Talpaert, S. Caroff and T. Vuillaume on behalf of the CTAO-LST
Project

Preamble

I - Introduction

II - Differences between MC and real data

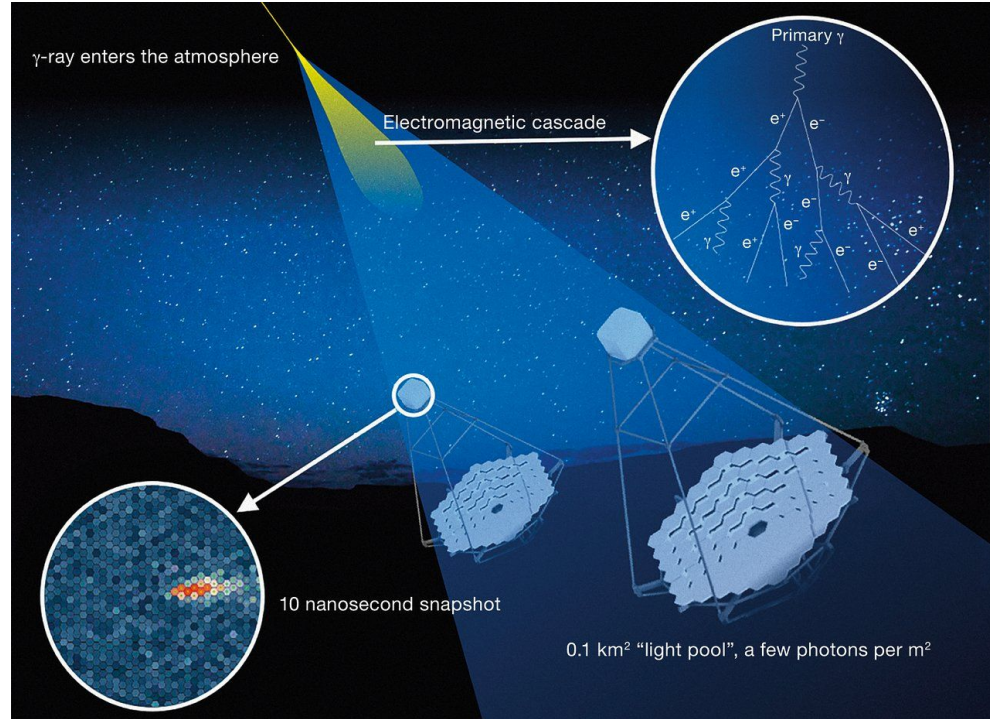
III - Exploring domain adaptation techniques

IV - Evaluating the effects of cleaning on CNN

I - Introduction: Cherenkov astronomy with the first Large-Sized Telescope (LST-1) of CTAO




LST-1, Credit : Cyann Plard (pink hair)

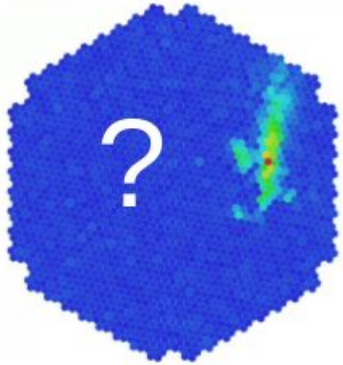


Credit : ESO

I - Introduction: From camera images to science products



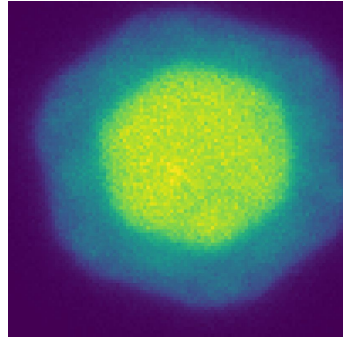
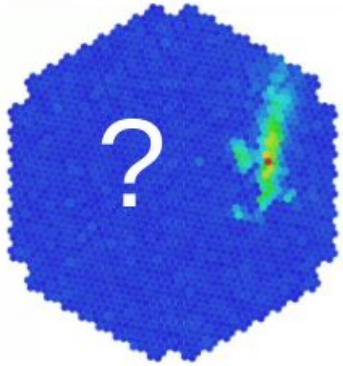
gamma/hadron ?
Energy ?
Direction ?



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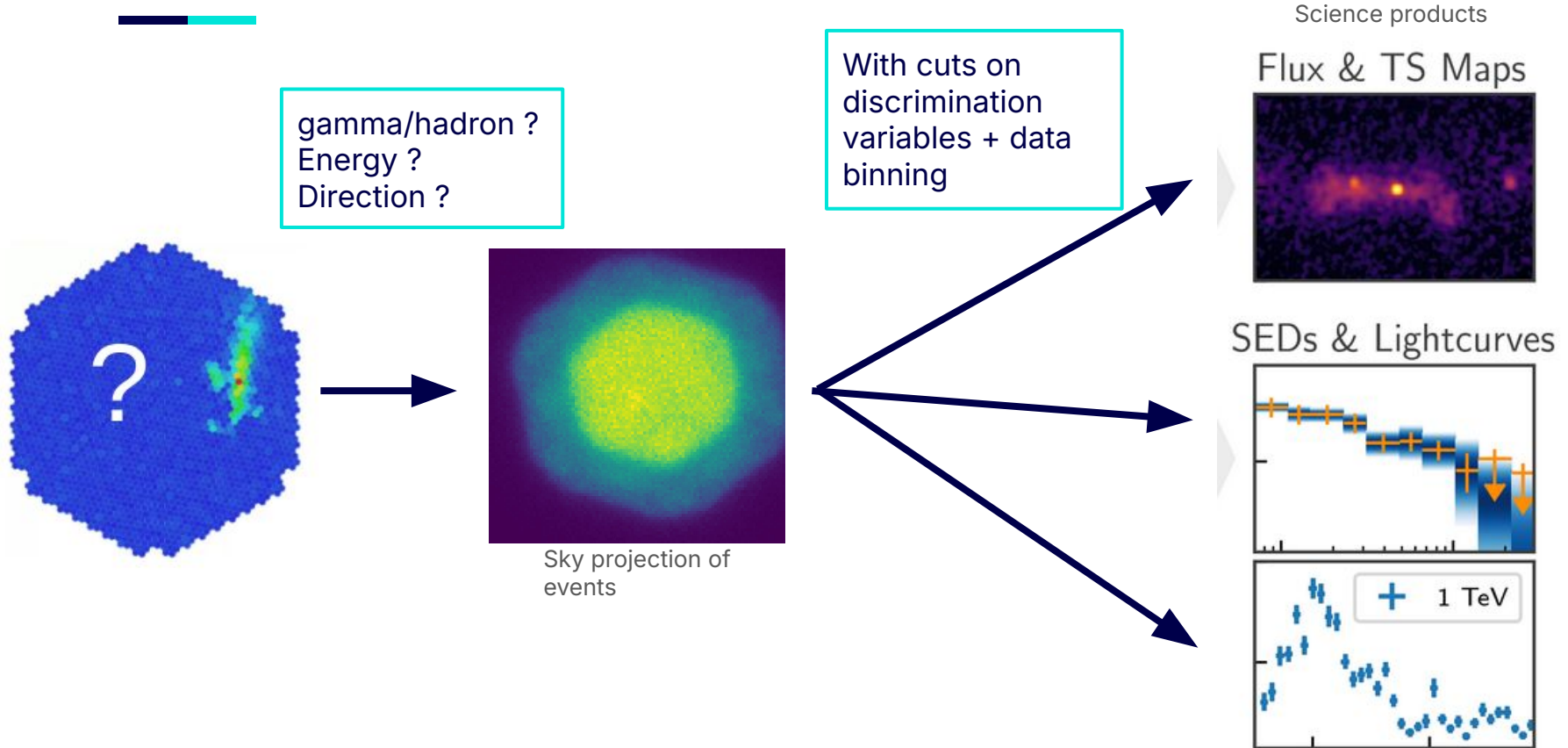


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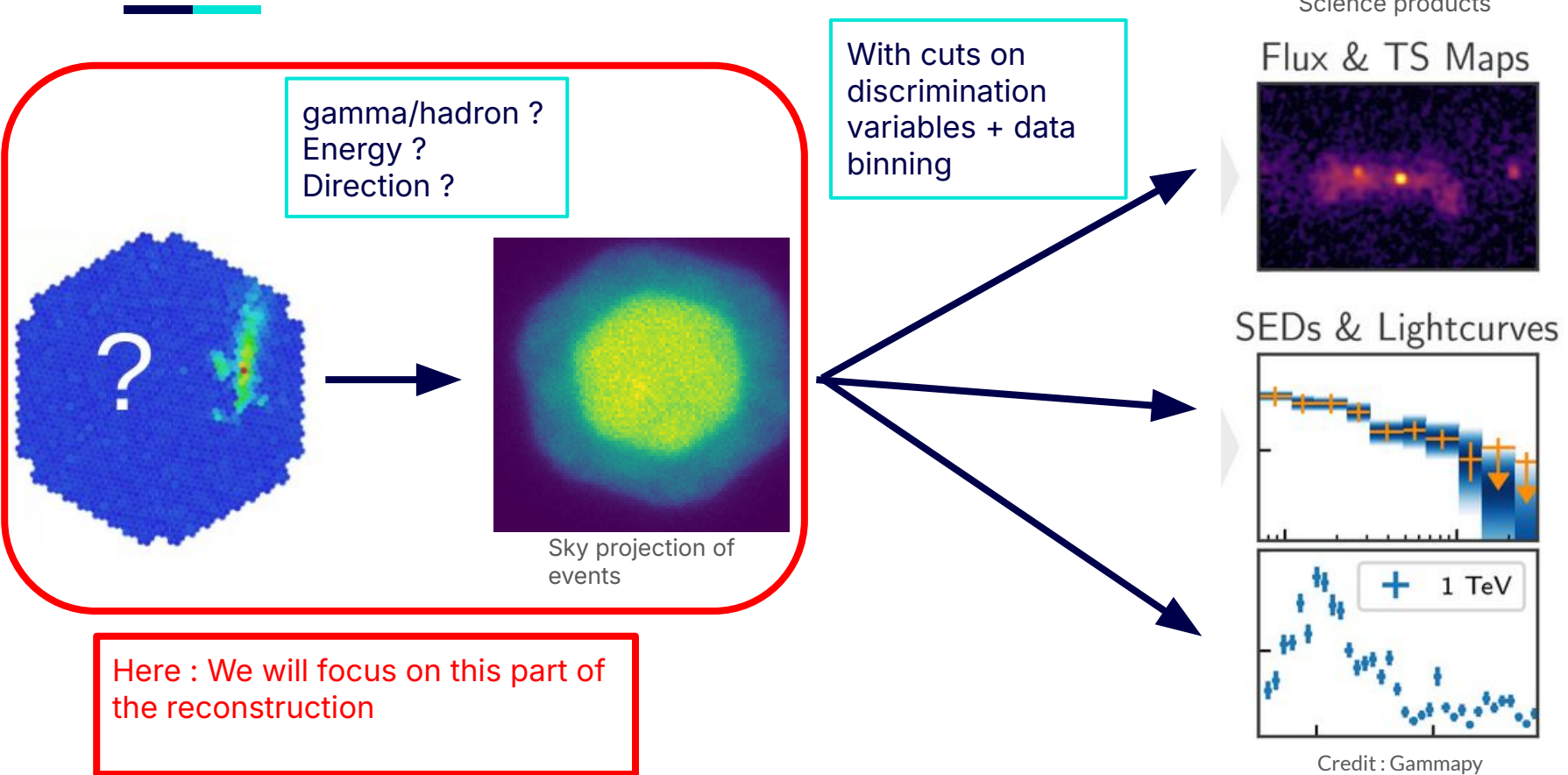


Sky projection of events

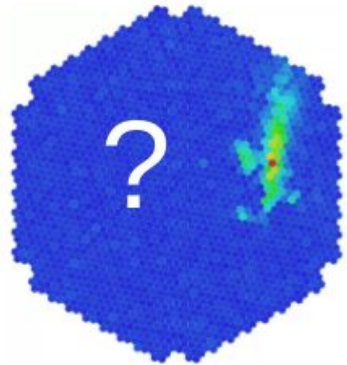
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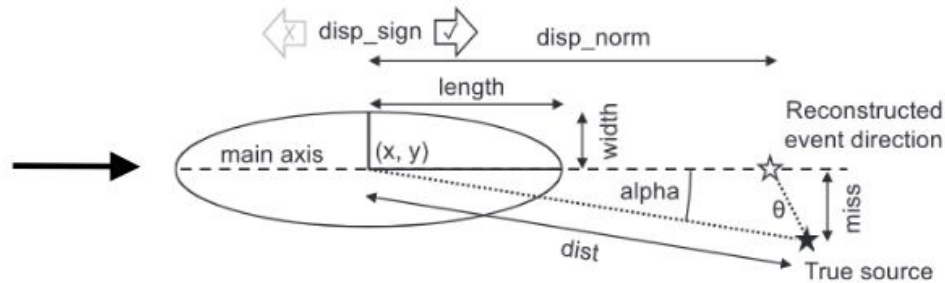


I - Introduction: Random forest (RF) reconstruction



Credit : Cyann Plard (pink hair)

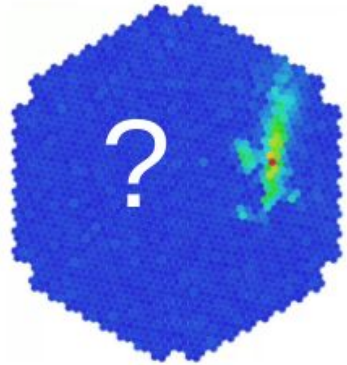
CTA-1stchain



[Abe et. al. 2023]

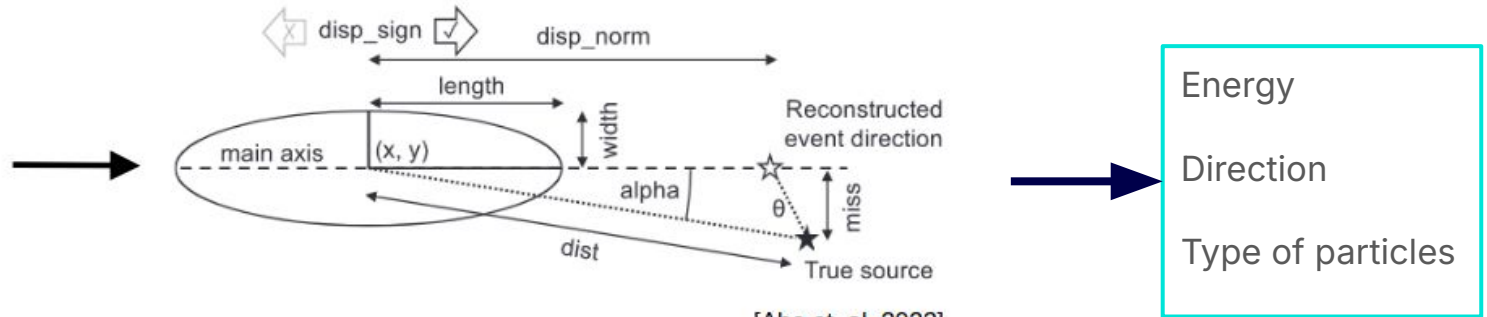
RF are trained with Monte-Carlo (MC) simulations of images

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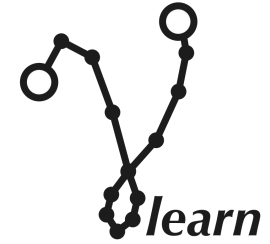
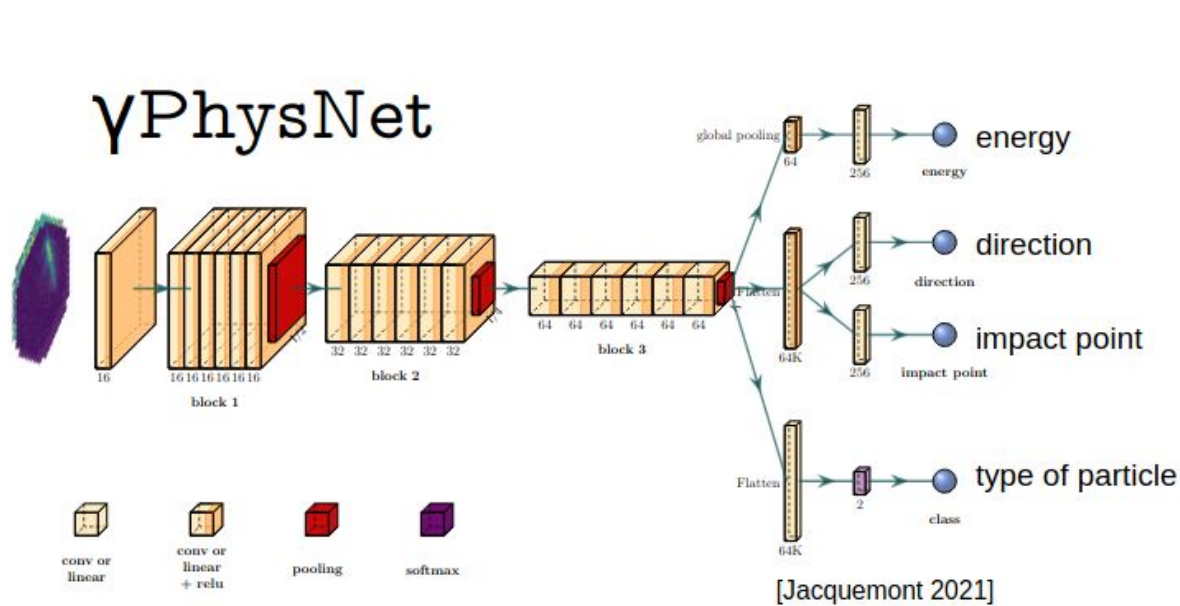
CTA-1stchain



- Energy
- Direction
- Type of particles

RF are trained with Monte-Carlo (MC) simulations of images

I - Introduction: Deep learning: GammaLearn

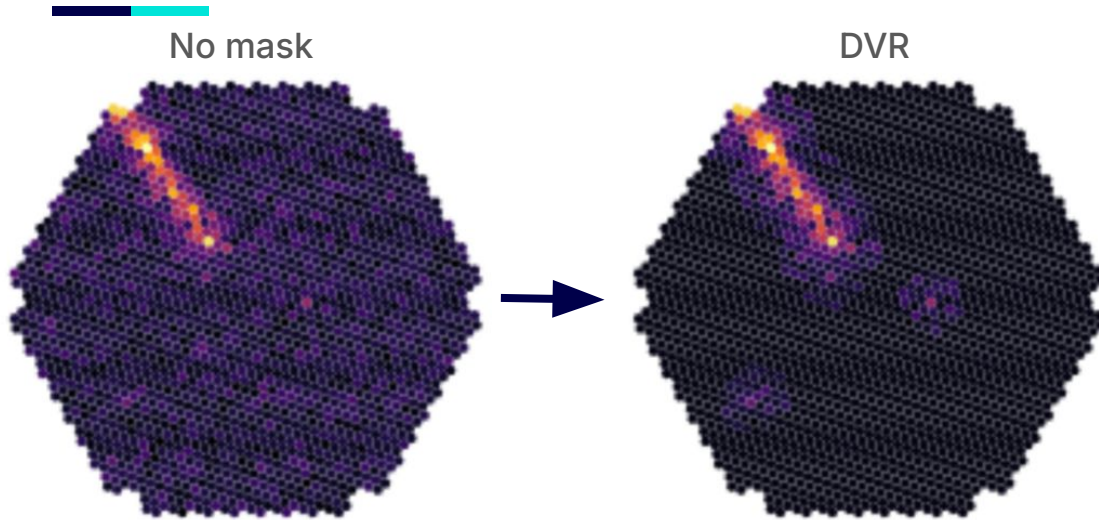


Jacquemont et. al. 2021 – arXiv:2105.14927:

Credit : Cyann Plard (pink hair)

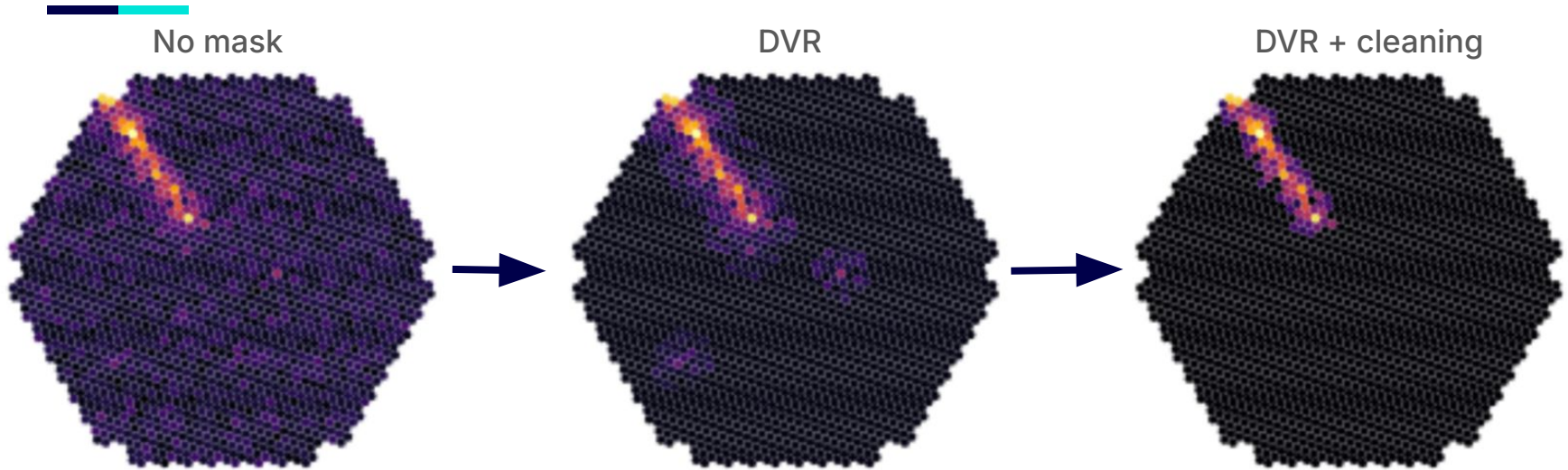
<https://gammalearn.pages.in2p3.fr/pages/>

I - Introduction: Data reduction of images



- In order to **reduce the amount of data**, an efficient **data volume reduction (DVR)** is asked by CTAO ([2411.14852](#))

I - Introduction: Data reduction of images

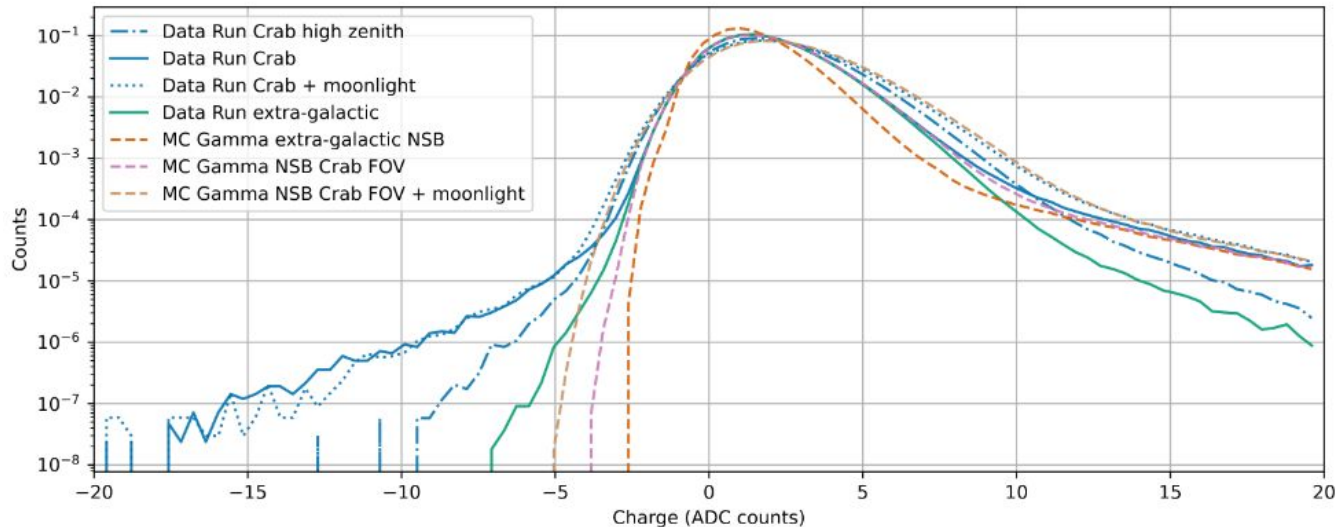


- In order to **reduce the amount of data**, an efficient **data volume reduction (DVR)** is asked by CTAO ([2411.14852](#))
- Moreover, to **improve the signal-to-noise ratio** and reduce the negative impact of NSB effects, RF is usually coupled with **image cleaning** (tailcuts) ([2306.12960](#))

II - Differences between MC and real data

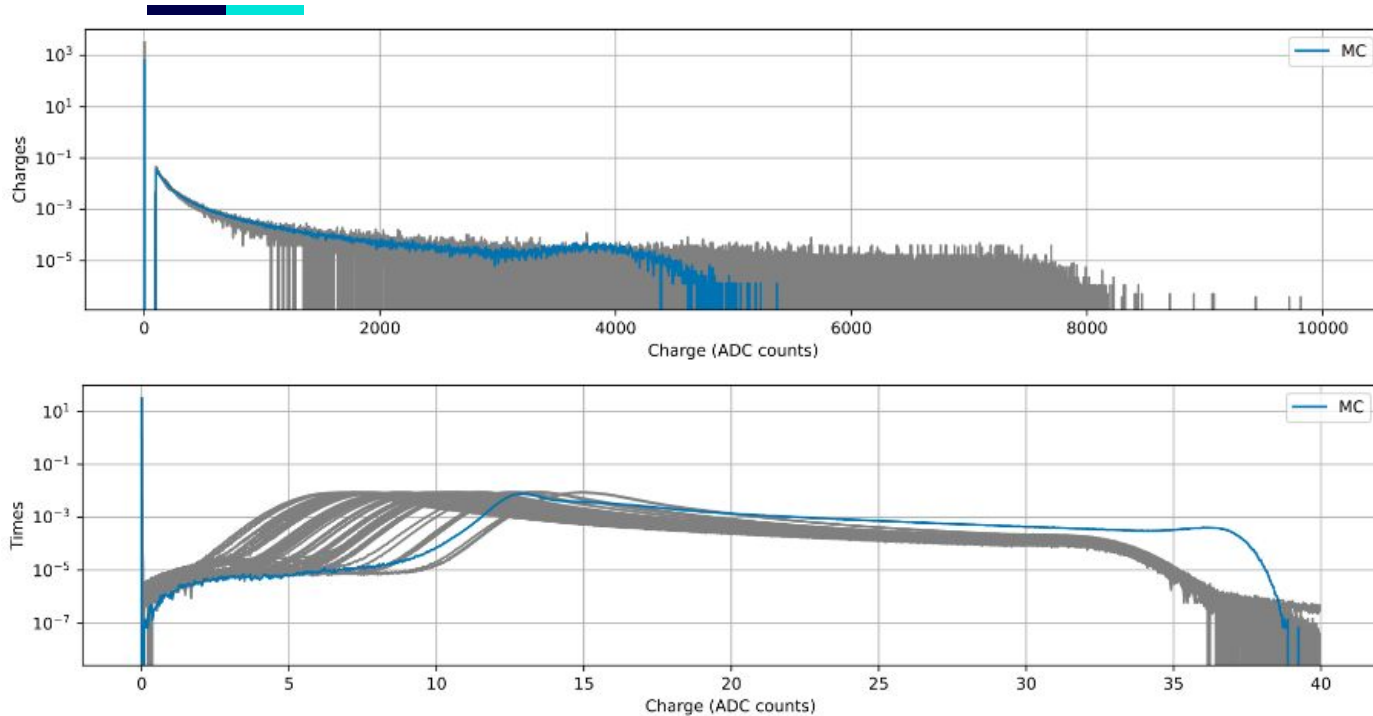
- The **night sky background (NSB)** affect real data, its impact **depends on**:
 - the **field of view (FOV)**, stars
 - the **atmospheric** conditions
 - the **pointing**
 - the **moonlight**

- Several effects **can be simulated in Monte-Carlo (MC)**, such as:
 - the **NSB rate in the FOV**
 - the **pointing**
 - the **moonlight**
- Others, are **challenging** or too much **time consuming**:
 - **Fog** on the camera / the **atmospheric** transmission



Distribution of charges in pixels dominated by the noise

II - Differences between MC and real data

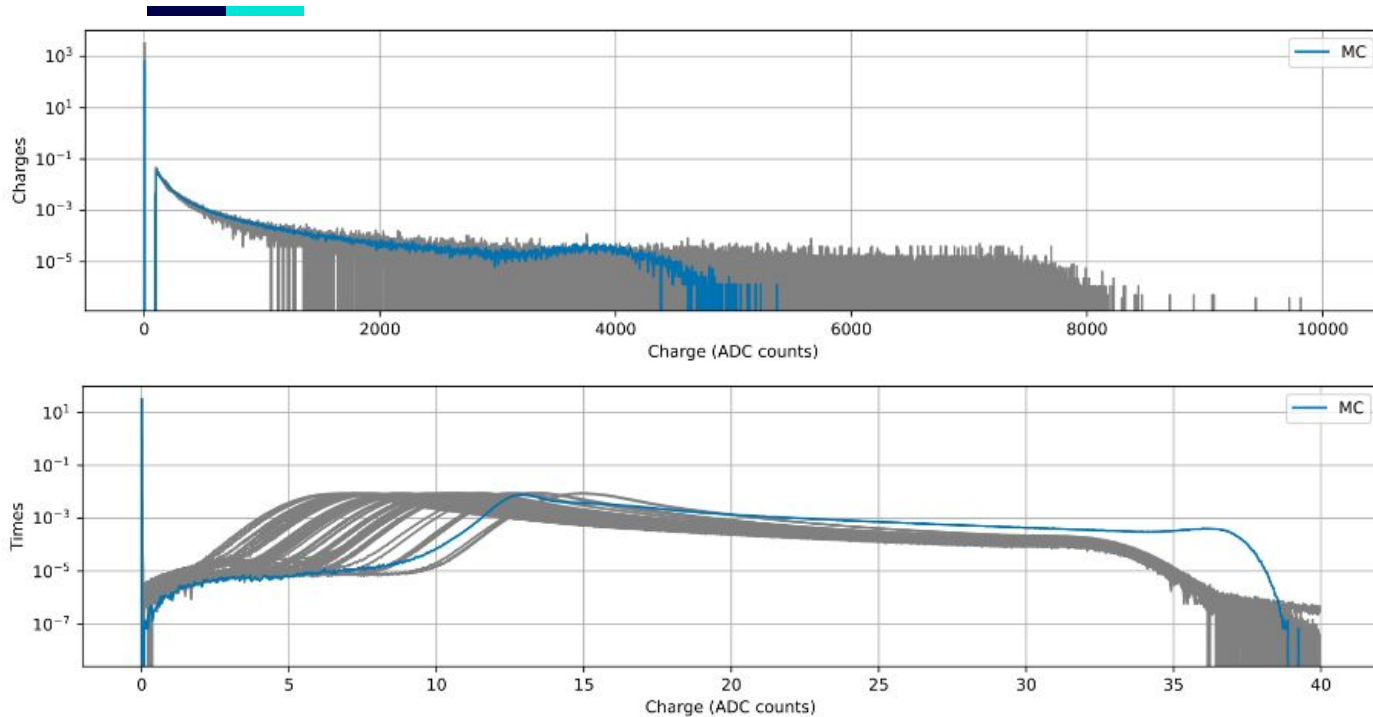


For images **with cleaning**:

- **Good agreement** between **MC** and **real data** for the **charge** per pixel distribution
- **Clear differences** for the **maximum peak time** distributions, depending on:
 - the NSB
 - the **camera configuration** which can be changed

Distribution of charges (up) per pixels in ADC counts and position of the peak time in waveforms (down). The blue line is computed from MC simulations tuned on the Crab Nebula FOV, produced with south pointing with a zenith of 20 degrees. Each gray line is computed for a single observation of the Crab

II - Differences between MC and real data



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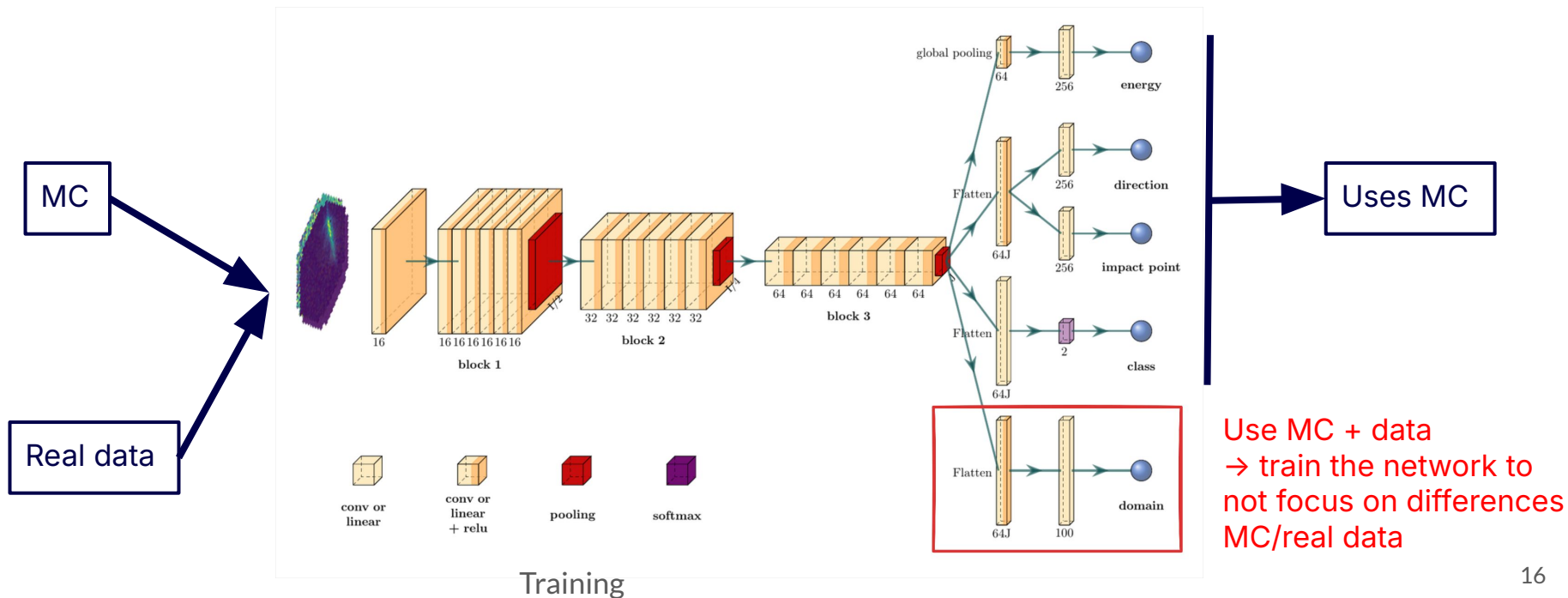
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→ **This effect is more visible on cleaned images**

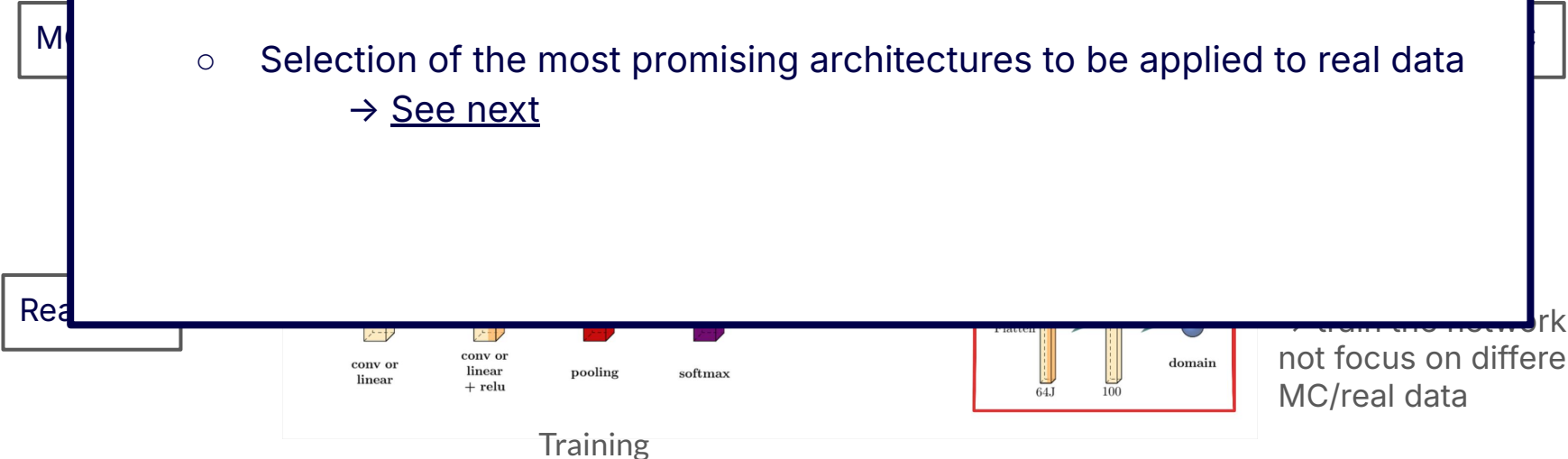
III - Exploring domain adaptation techniques with gammaLearn

- Development and comparison of **domain adaptation techniques** merged into our multi-task architecture ([2403.13633](#)).
- goal: **train** the model **with real data** to learn to **automatically adapt to the differences between MC and real data** (e.g. NSB, stars, planes, fog...)



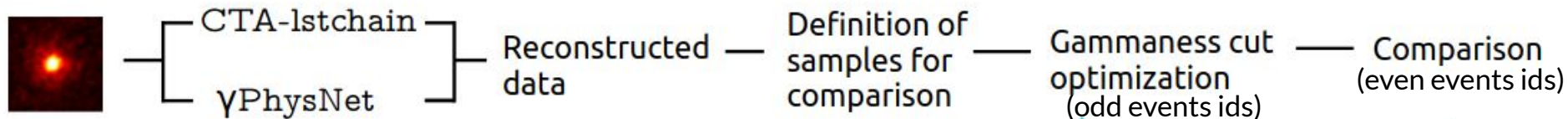
III - Exploring domain adaptation techniques with gammaLearn

- Results on MC (2308.12732):
 - Integration of **several domain adaptation architectures** (DANN, DeepCORAL, DeepJDOT...) in a **multi-task framework**
 - **Validated on simulated data with added NSB**
 - Selection of the most promising architectures to be applied to real data
→ See next



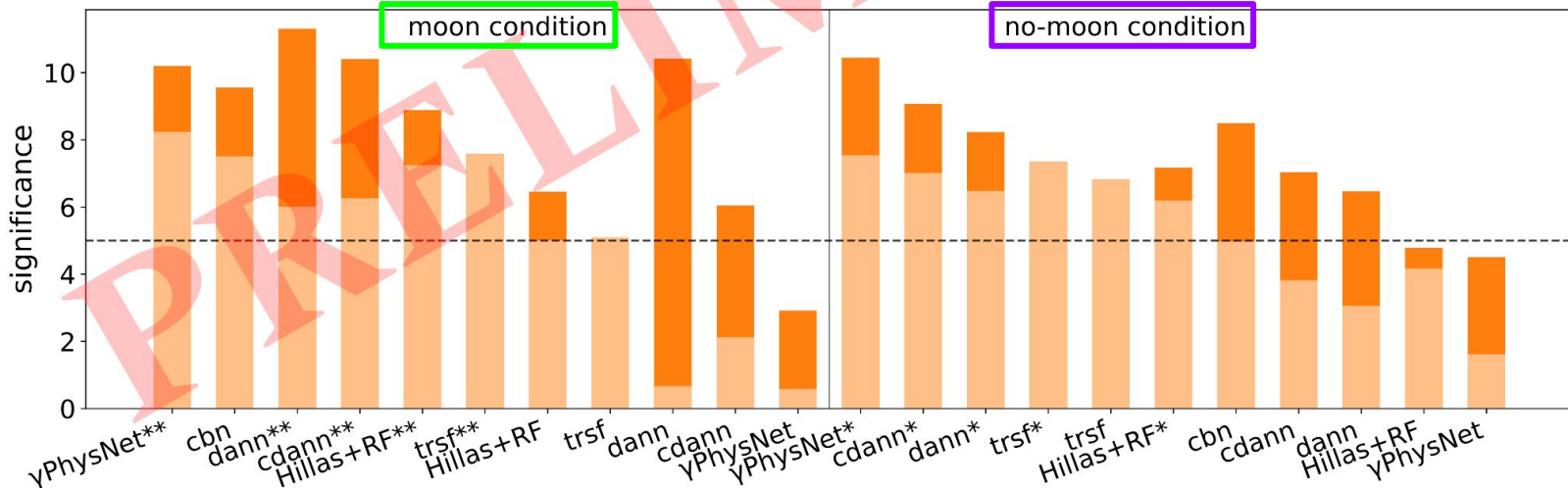
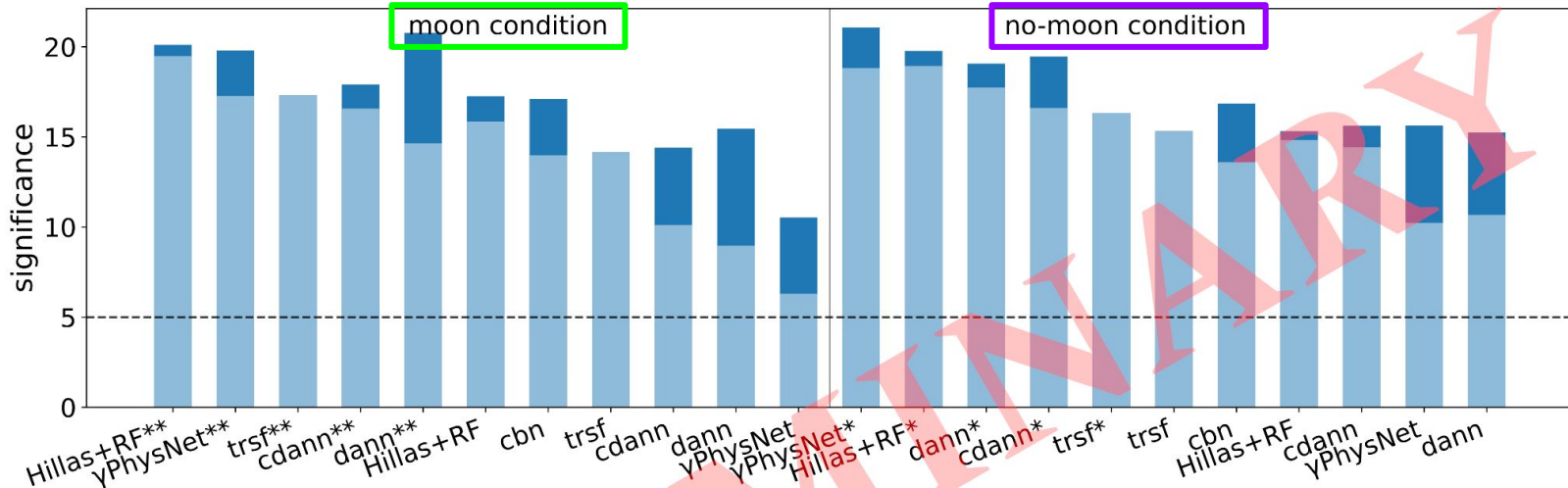
III - Exploring domain adaptation techniques with gammaLearn

Credit : Cyann Plard (pink hair)



- Comparison **on 4 runs of real data** of the **Crab Nebula**
- Study the **effect of the moon**
- **Any DVR or cleaning**

Test sample	2022-02-05 runs 6892, 6893	2022-02-05 runs 6894, 6895
Observation condition (avg. intensity (pe))	moonlight (2.46, 2.35)	no moonlight (2.07, 2.07)
Zenith angle (deg)	14, 18	25, 30
Total livetime (min)	38	38

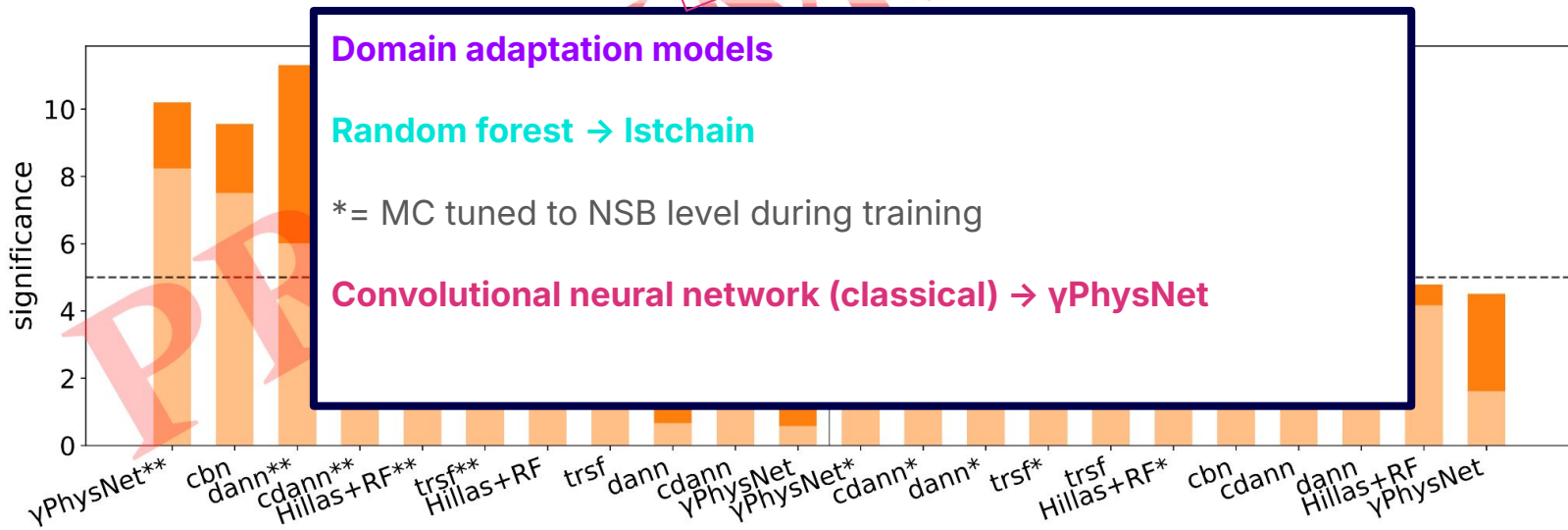
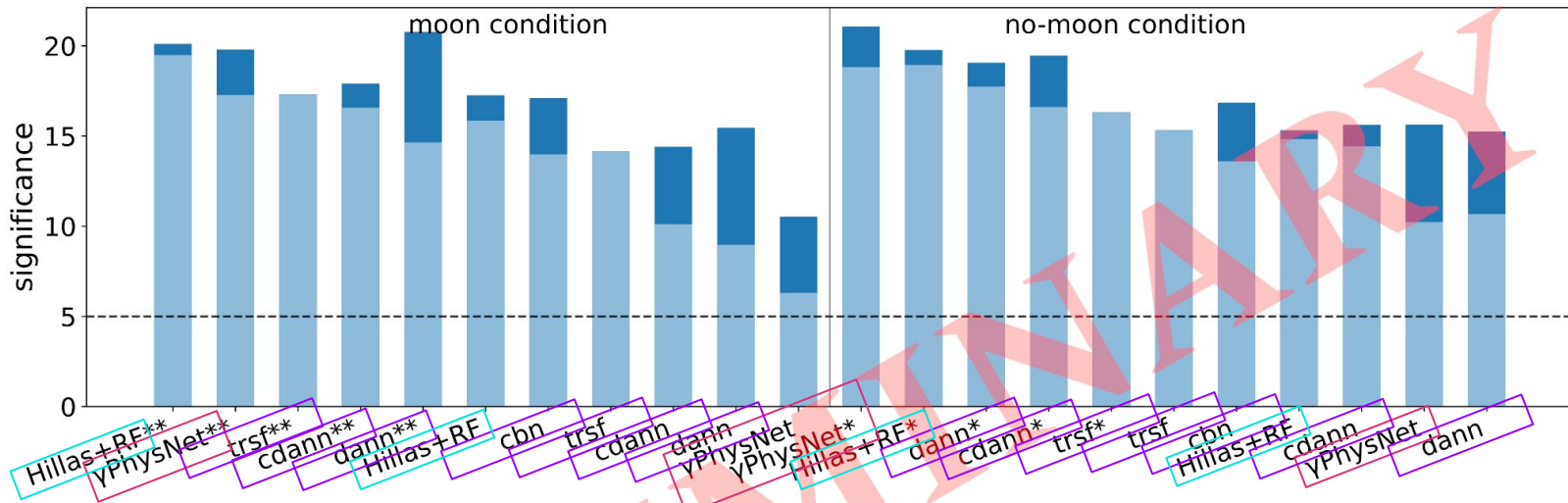


no star:
extragalactic
NSB

one star:
NSB = 1.76
p.e.
→ Average
Crab FOV NSB

2 stars:
NSB = 2.34
p.e.
→ Crab FOV
with moonlight

Credit : Cyann
Plard (pink hair)

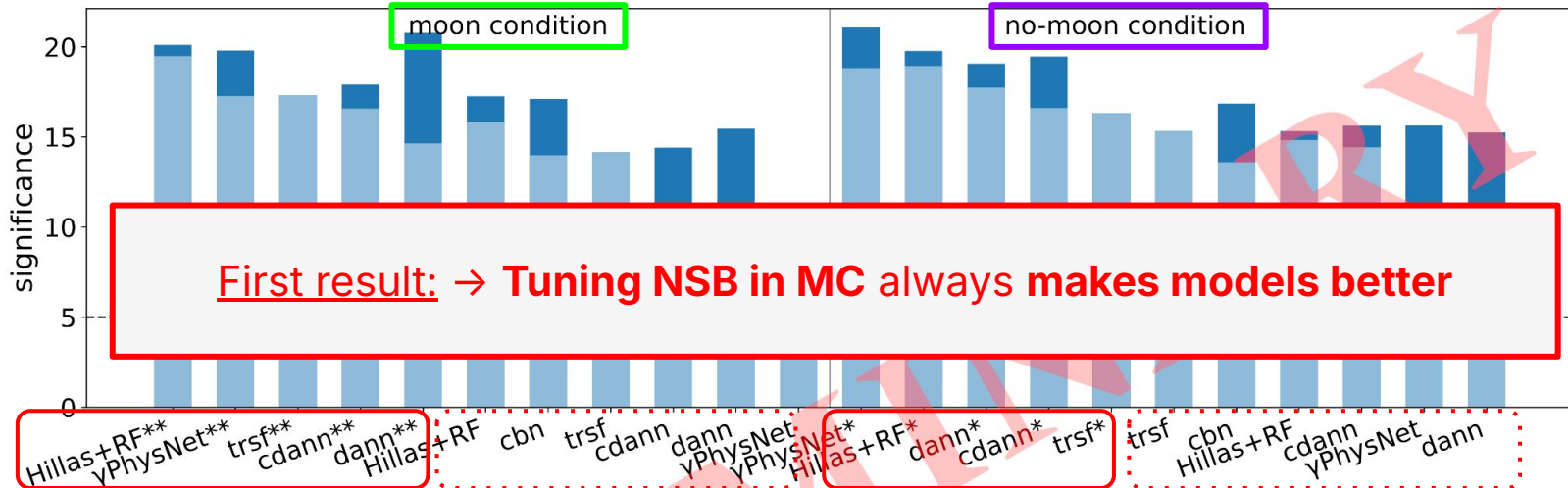


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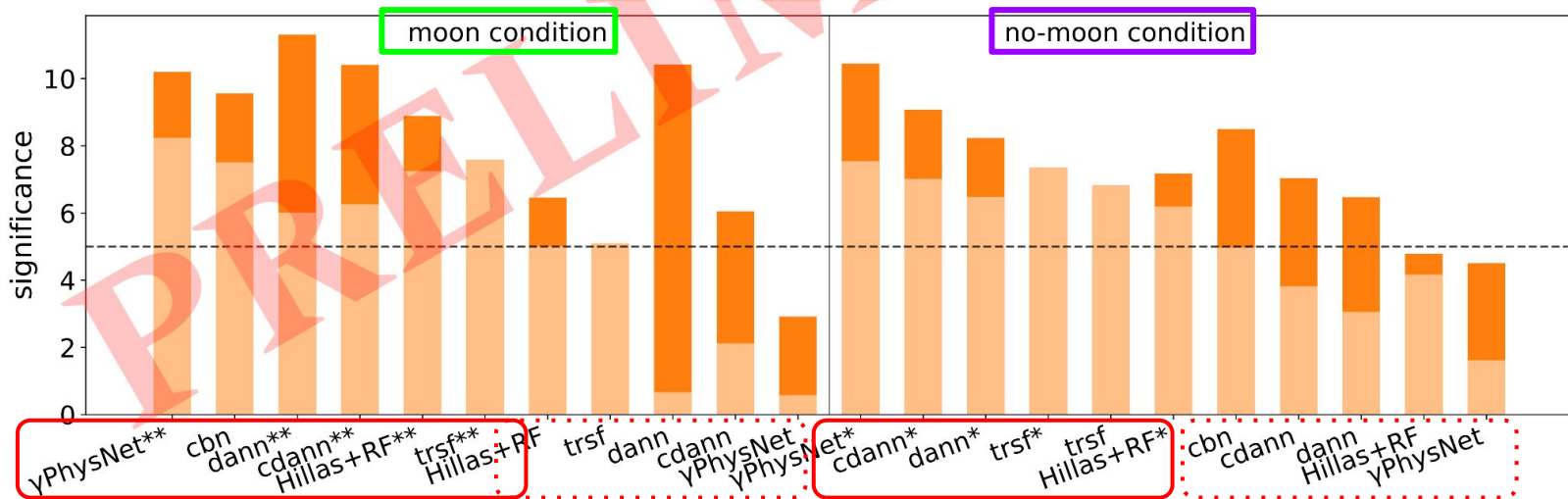
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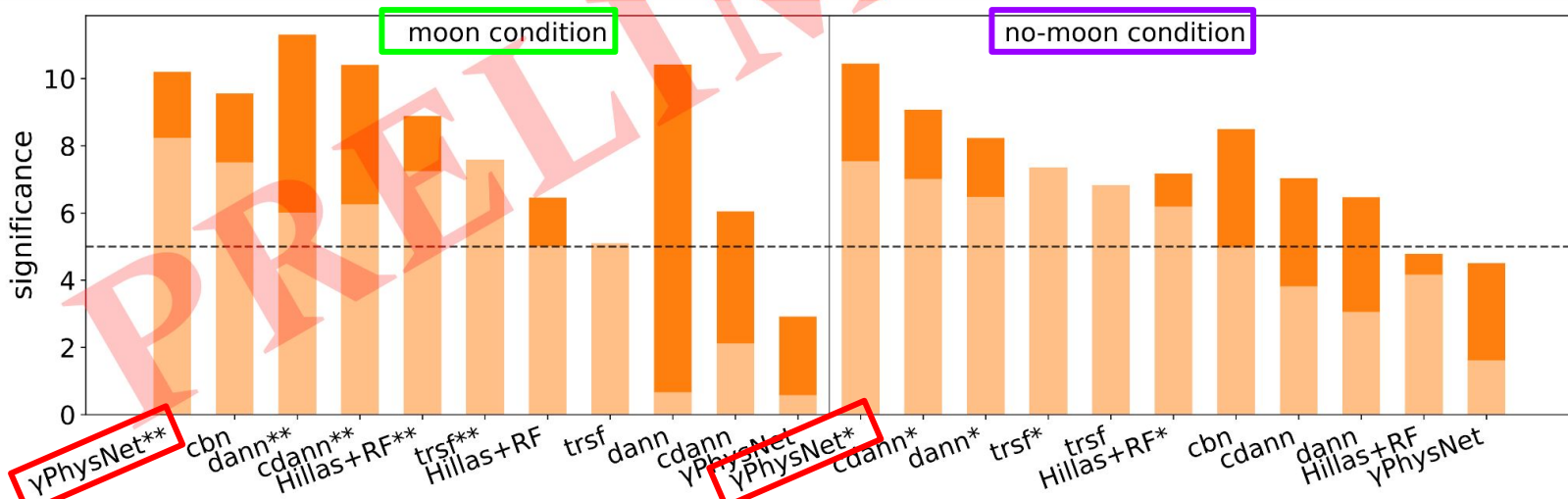
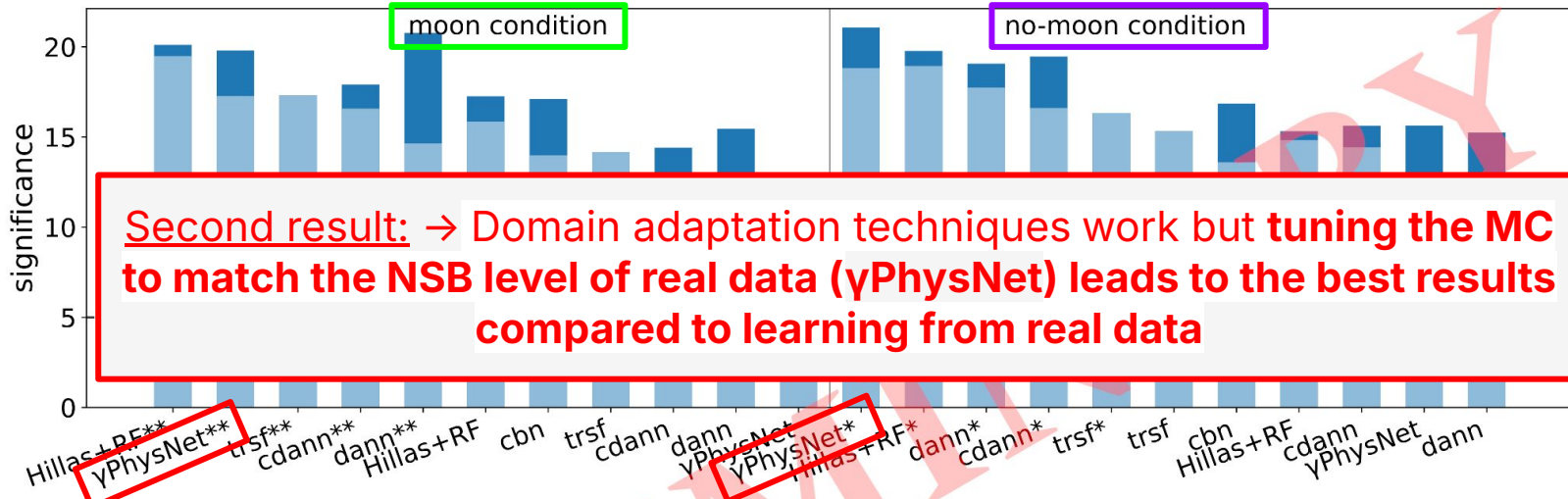
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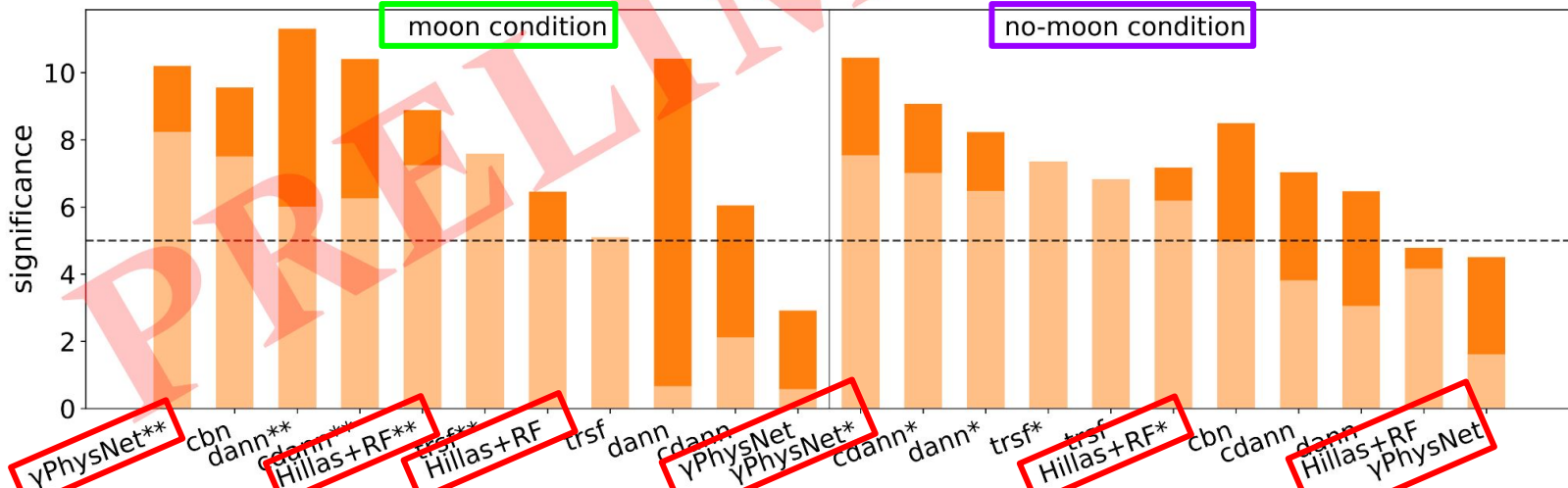
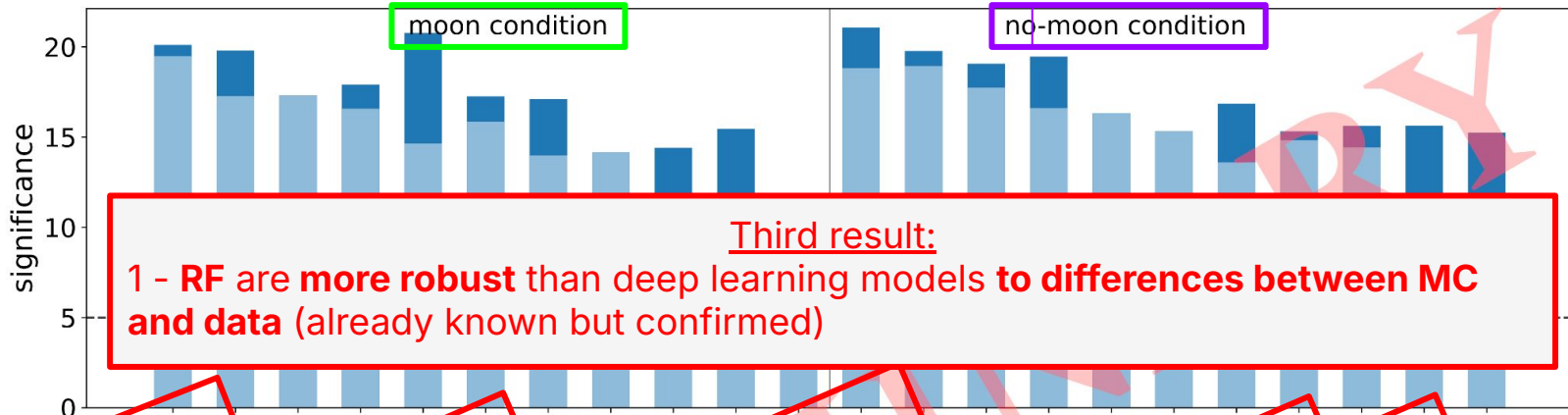


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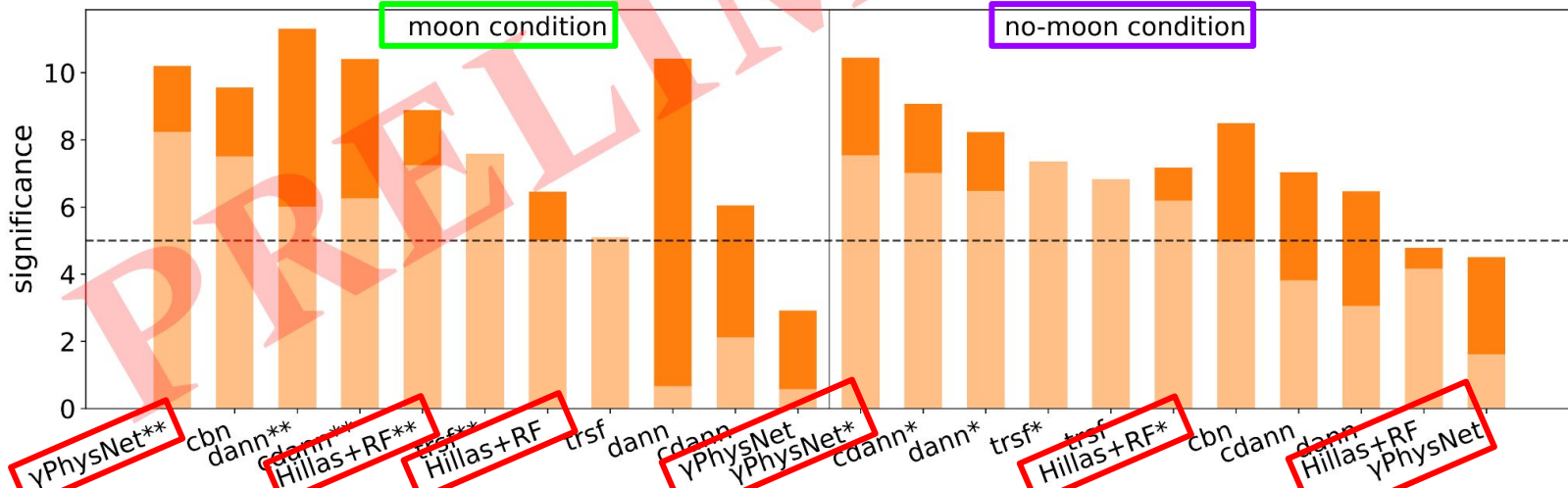
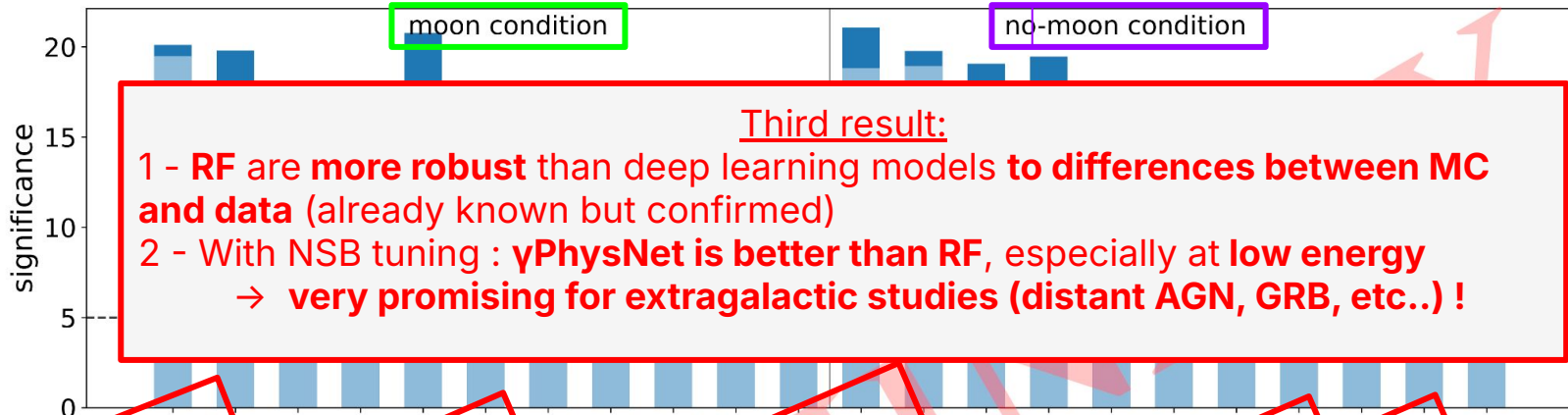


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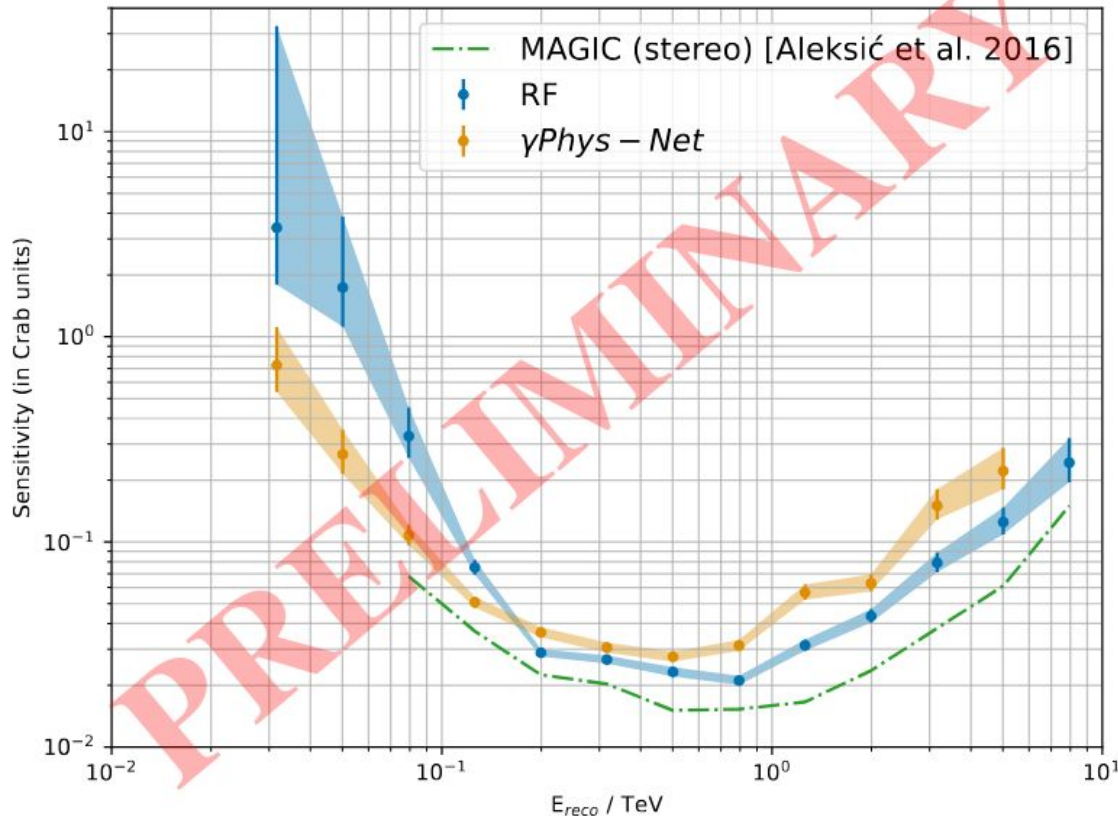
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Credit : Cyann Plard (pink hair)

IV - Evaluating the effects of cleaning on CNN (γ PhysNet)

- Extension of the comparison between **γ PhysNet and RF** with :
 - **with cleaning applied on images**
 - a sample of about **5h of Crab Nebula observations**, from the end of 2021 to the end of 2023
 - **zenith angle between 18 and 22 degrees** → avoid any effects of the zenith
 - here again, cuts are optimized on odd events
- First point: **with cleaning, we needed to correct the maximum peak time in MC** to match with the data to get a reliable reconstruction
- To compare both reconstruction method, **sensitivity curves** have been computed, with the **same algorithm** than the one used for the **LST-1 performance paper** ([2306.12960](#))

IV - Evaluating the effects of cleaning on CNN (γ PhysNet)



- Better performance of CNN at energies **below 160 GeV**, by a **factor of about 3**
- Here, **cleaning is applied**, considering reduction of performance seen with MC, **we can expect a even better sensitivity with only DVR**
- We will optimize the way to match the maximum peak time between data and MC

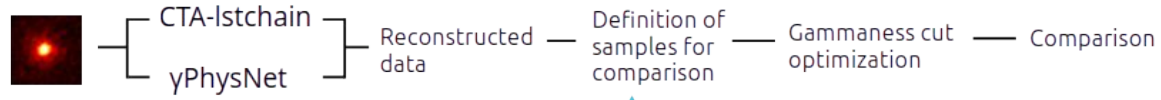
Conclusion

- **Crab Nebula** have been used to assert **the performance** offered by **deep learning**, compared to the **one** of **RF**
- **Domain adaptation** based models, although efficient in automatically bridging the gap between MC and real data, **are not as efficient as carefully tuning the MC** simulations to match closely the test data.
- **Applying the cleaning** to images **reduces the performance offered by our CNN**. A looser (or no) image cleaning would probably improve the reconstruction performances. Further work is needed **in** this **matter**.
- **γ PhysNet(CNN)** already **shows higher sensitivity to low energy gamma-rays than standard RF**, offering an **unprecedented view of extra-galactic sources**, where the performances below a few GeV are crucial.

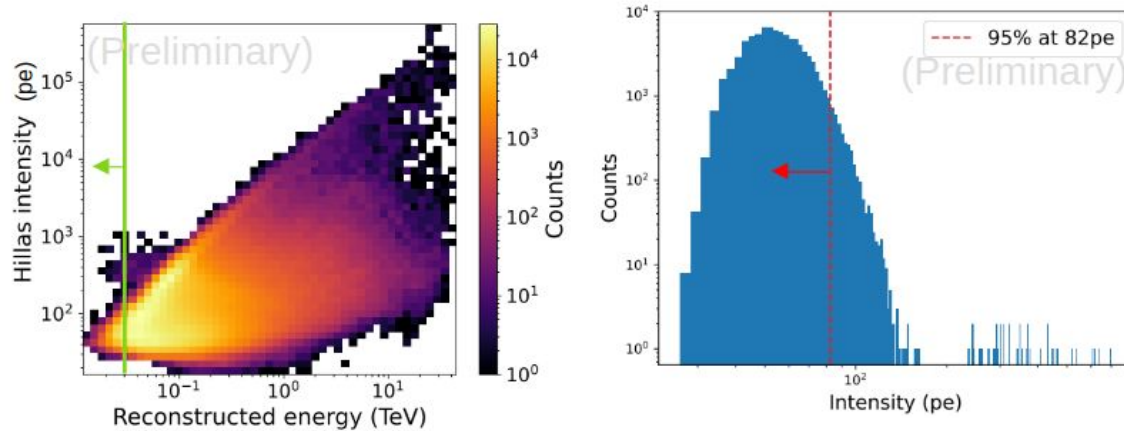


BACKUP

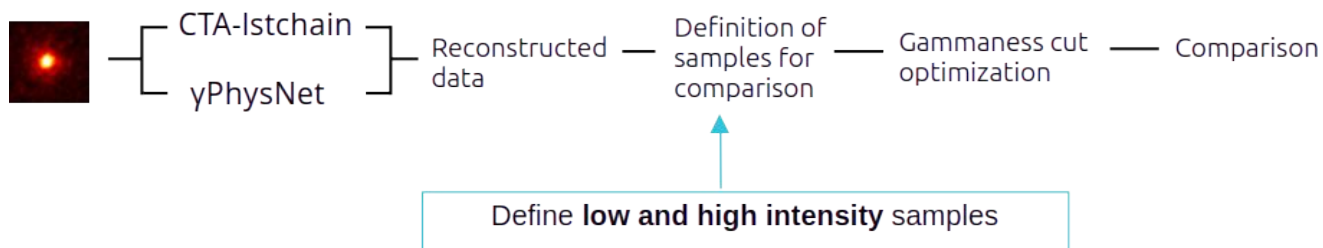
Comparison with the benchmark gammascan



On CTA-Istchain data:
Use as minimal value the **intensity** corresponding to
95% of counts with **energy < 30 GeV**

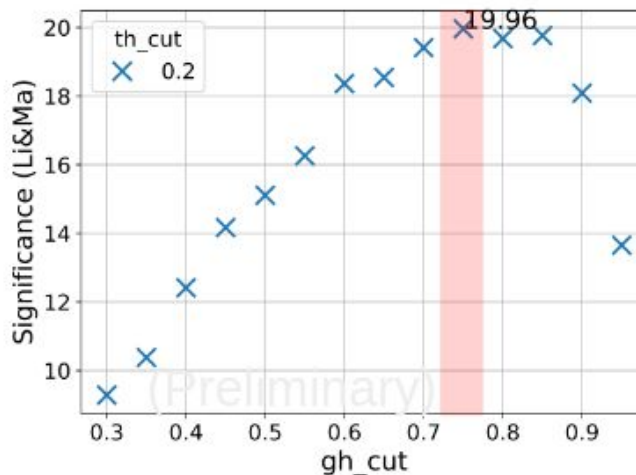
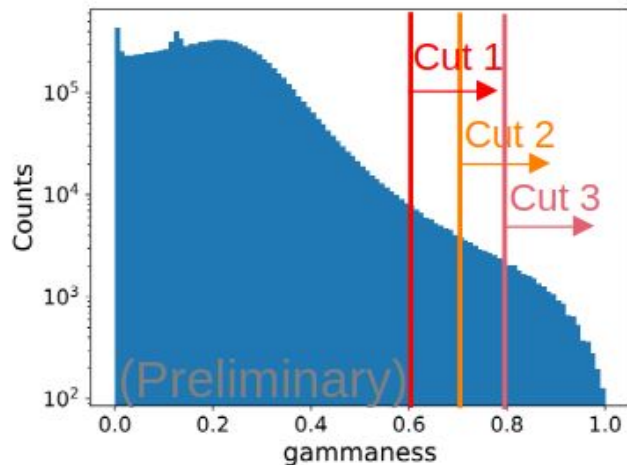
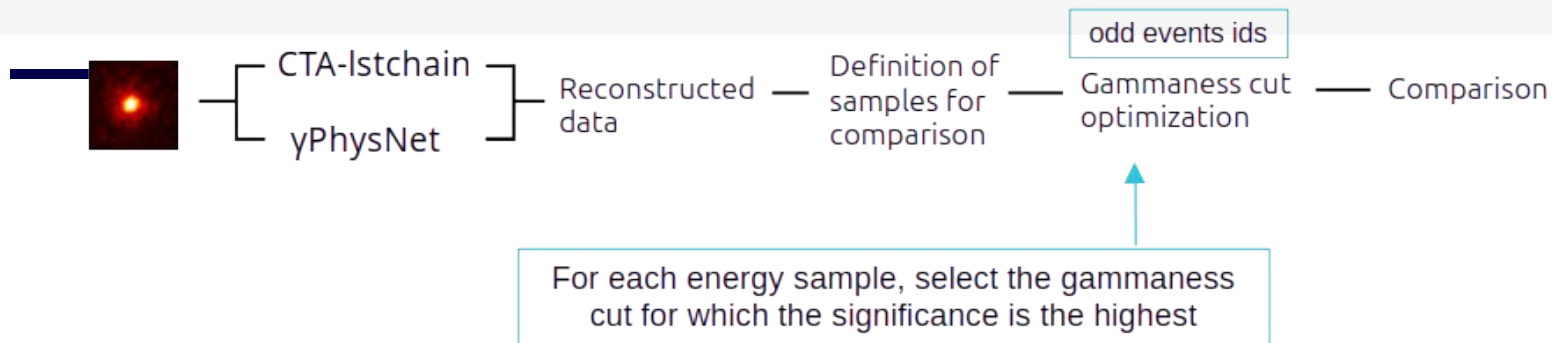


Comparison with the benchmark gammascan



(Preliminary)	All energies	Low energies	High energies
Intensity range (pe)	[80 ; inf[[80 ; 500[[500 ; inf[
Equivalent energy range for cta-Istchain	30 GeV < E	30 GeV < E < 2 TeV	2 TeV < E

Comparison with the benchmark gammascan



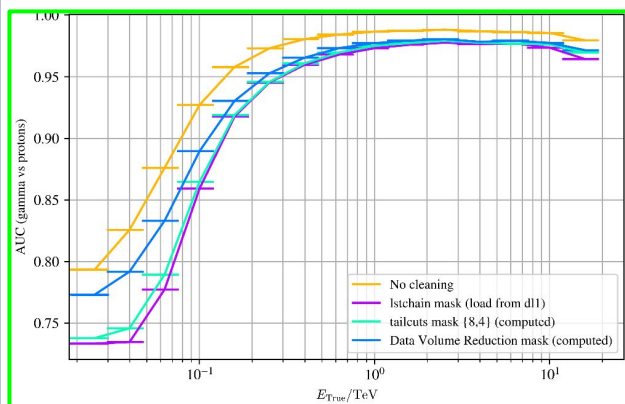
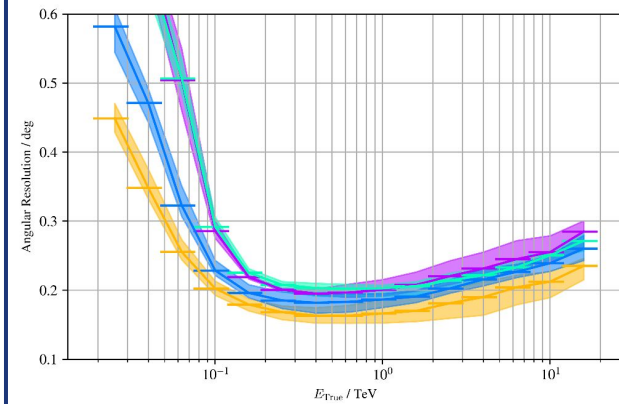
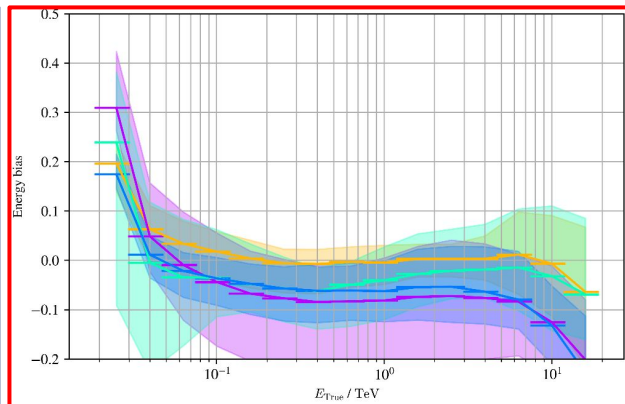
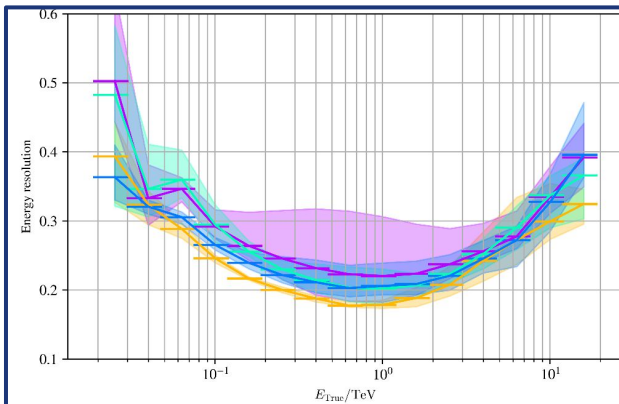
Effect of DVR and Cleaning on MC

[arXiv:2502.07643](https://arxiv.org/abs/2502.07643)

NO MASK

DVR

DVR +
CLEANING



Performances with DVR are worse than without mask -> in particular for **energy bias**

With cleaning :
-> **big bias for energy**
-> Worse energy/angular resolution

-> Worse **discrimination** at low energy