Collider searches for Dark Matter using Machine Learning

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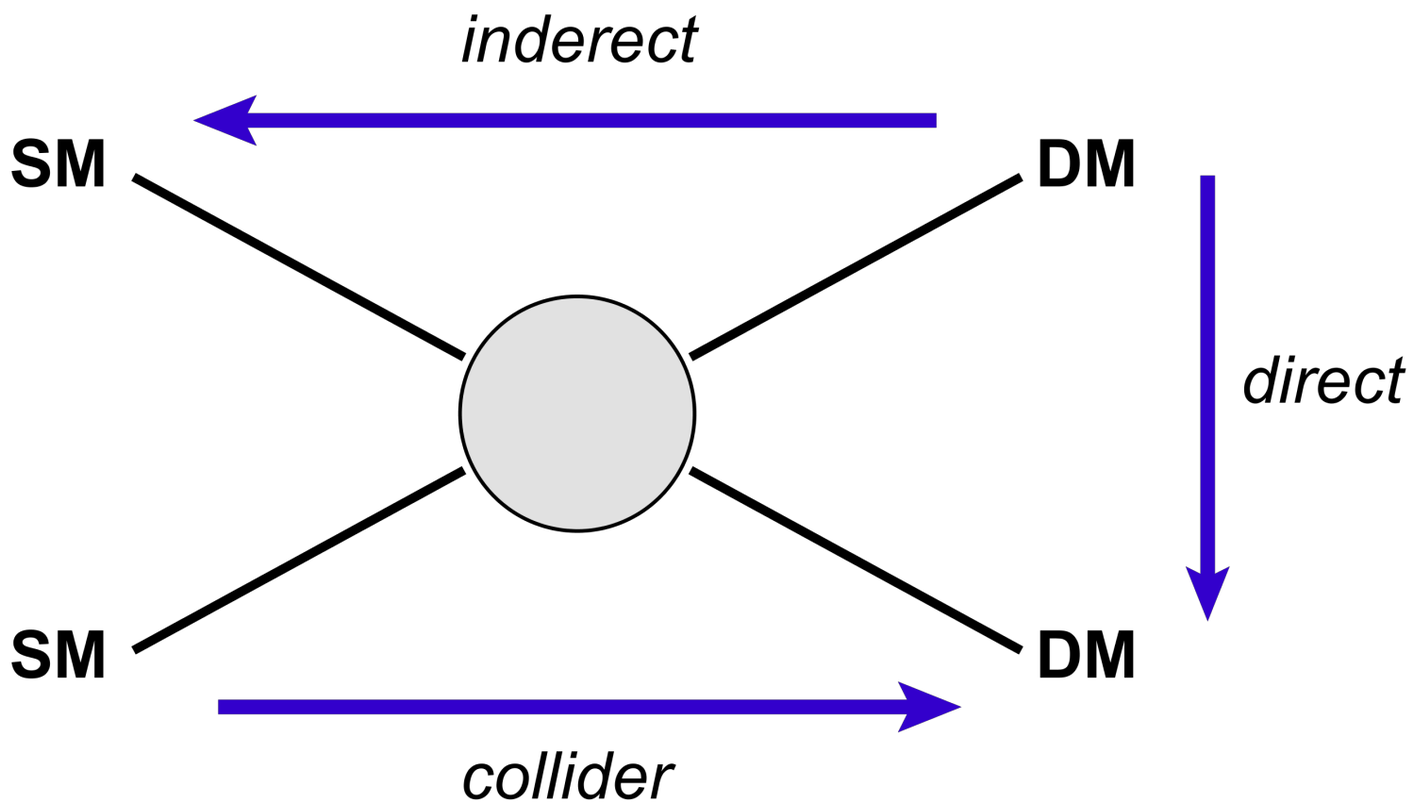
Work in progress

In collaboration with Veronica Sanz

Introduction



DM searches channels at collider : Mono jet/W/top/photon ← Caterina Doglioni's talk

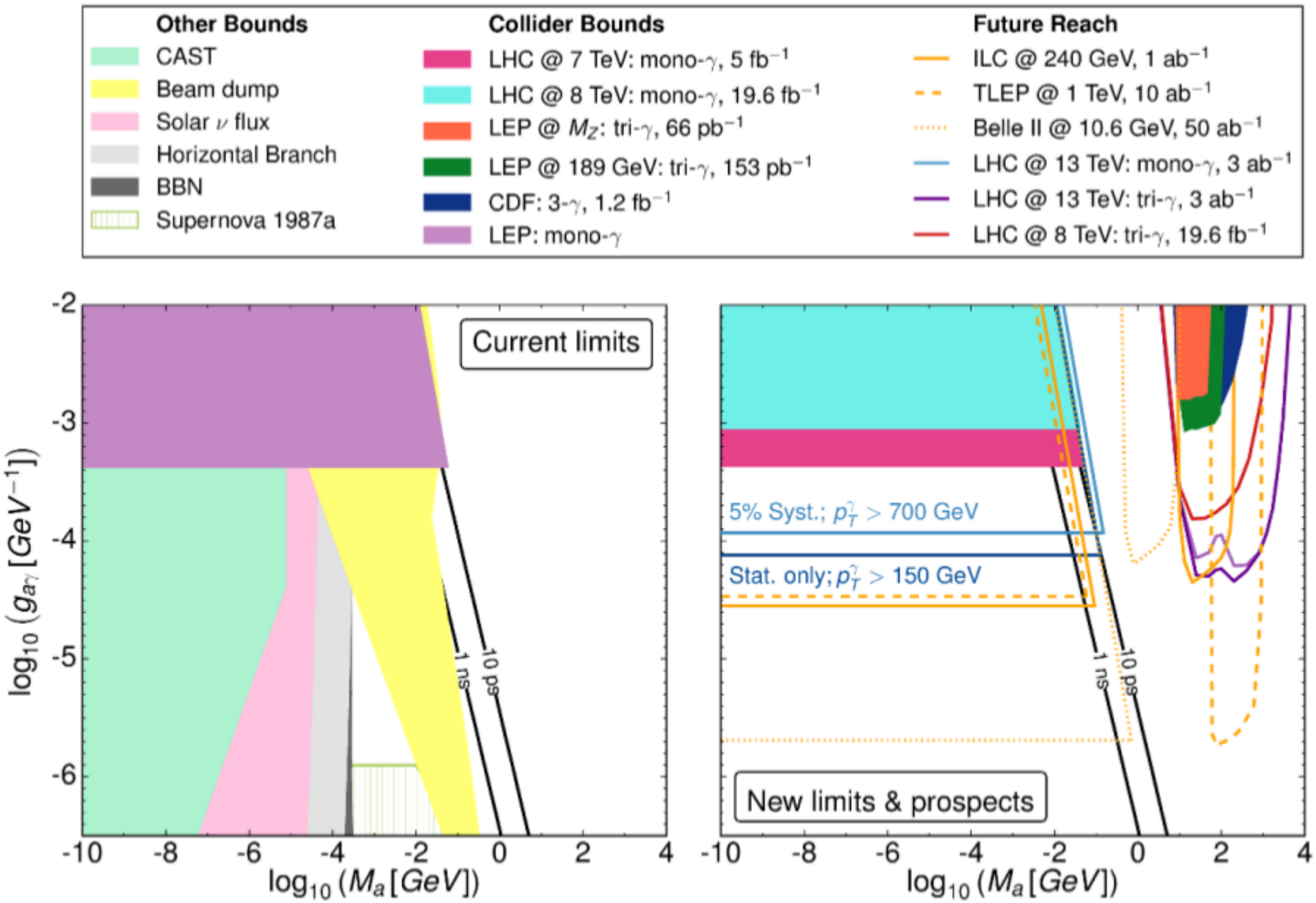
Signal : Monojet + MET **Model : Axion-like particles (ALPs)/WIMPs**

ALPs could look like MET if they decay outside the detector volume

Plan

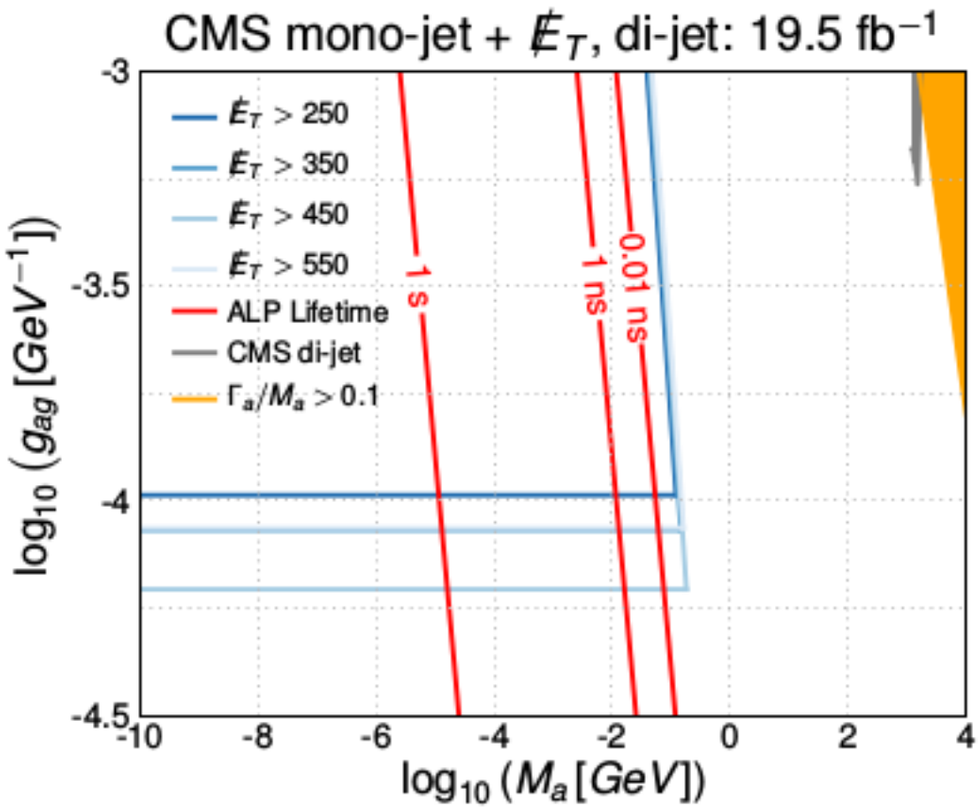
- Collider stable particles (Long lived particles)
- **First comparison:** Axions could be very light (collider stable) whereas typical DMs are not **(we expect distinction)**
- Multi-dimensional density information?
- Supervised to Unsupervised algorithms
- New physics?
- Anomaly detection

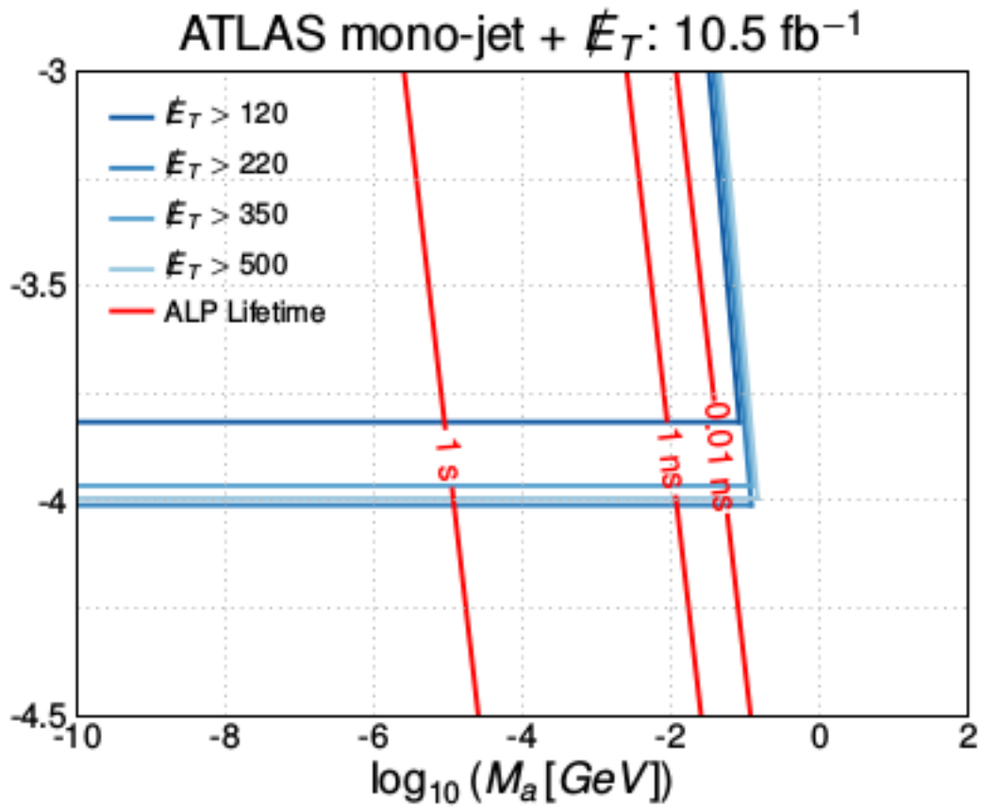
ALPs-Photon coupling



K. Mimasu and V. Sanz, JHEP06(2015)173

ALPs gluon coupling





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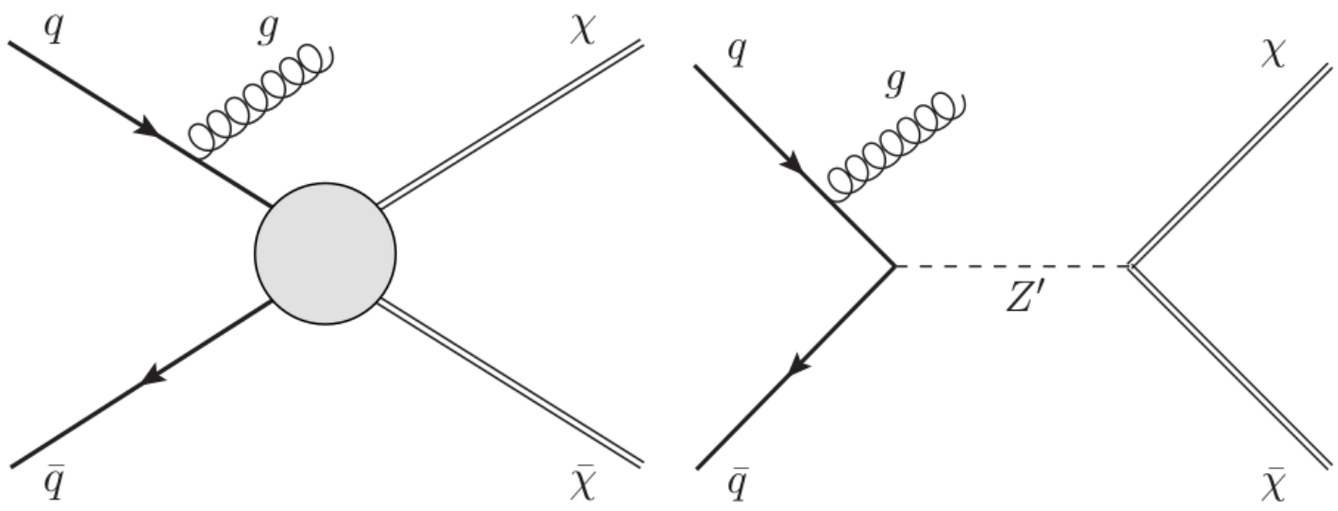
Effective interactions: WIMPs with SM



$$\frac{m_q}{M^2}\chi^\dagger\chi\bar{q}q$$

See, for example : ATLAS analysis, Eur.Phys.J. C75 (2015) 299

Analysis set-up : mono-jet

BP1: ALPs $pp \to aj$

Madgraph_amc@NLO, FeynRules Models

$$\mathscr{L}_a = \frac{1}{2}\partial_\mu a\,\partial^\mu a - \frac{1}{2}M_a^2 a^2 - \frac{g_{a\gamma}}{4} a\,F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{agg}}{2} a\,\mathbf{Tr}\left[G_{\mu\nu}\tilde{G}^{\mu\nu}\right] + \sum_\psi g_a^\psi\, m_\psi\, a\bar{\psi}\gamma^5\psi$$

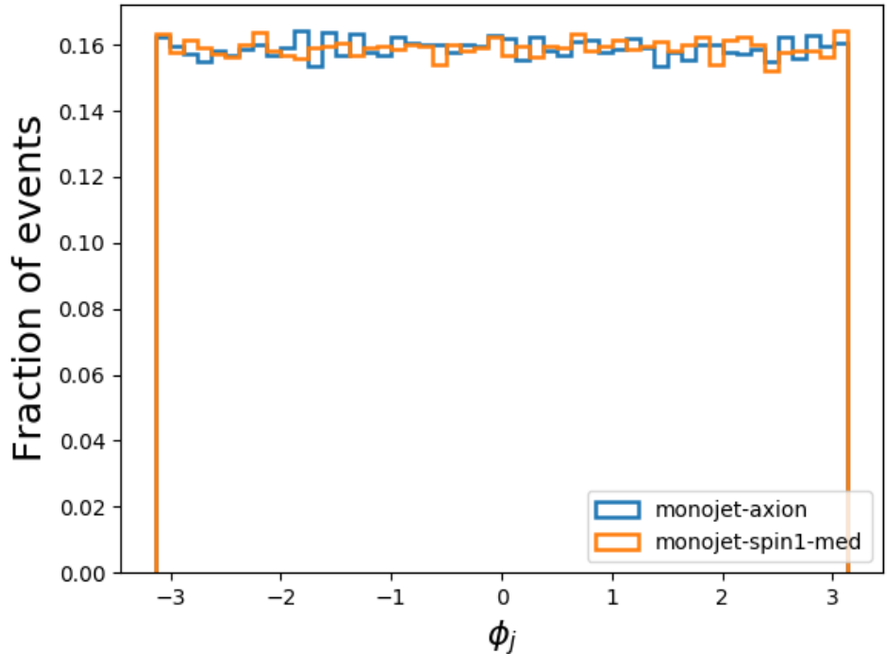
BP2 : Simplified dark matter models : heavy mediator decays to DM

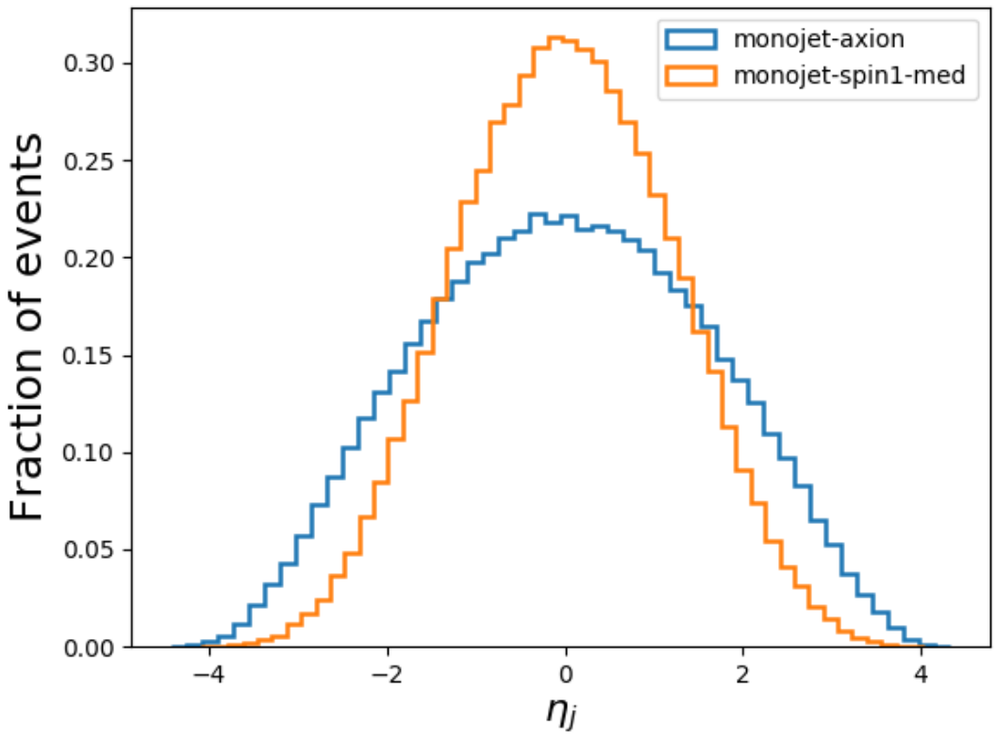
$pp \to \chi_d \chi_d j$ $\qquad$ $\frac{m_q}{M^2}\chi^\dagger\chi\bar{q}q$

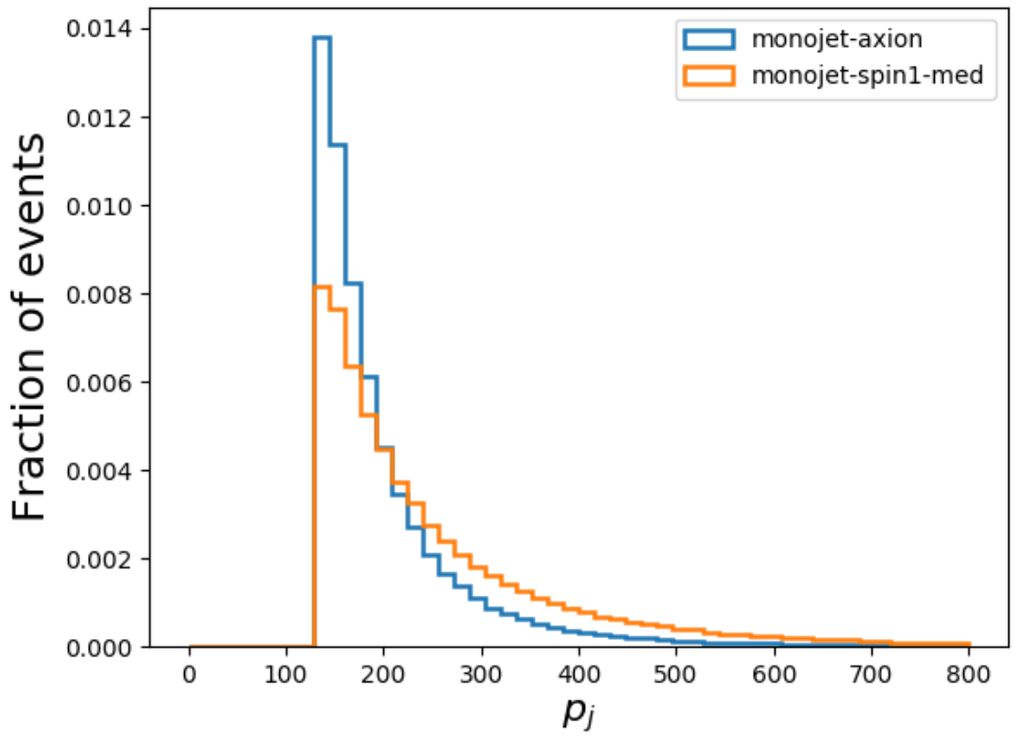
$p_T^j > 130\,GeV$

Assumption : very well understanding of the background $\qquad$ $p_T^j(MET), \eta_j, \phi_j$

1D distributions







Preliminary Results

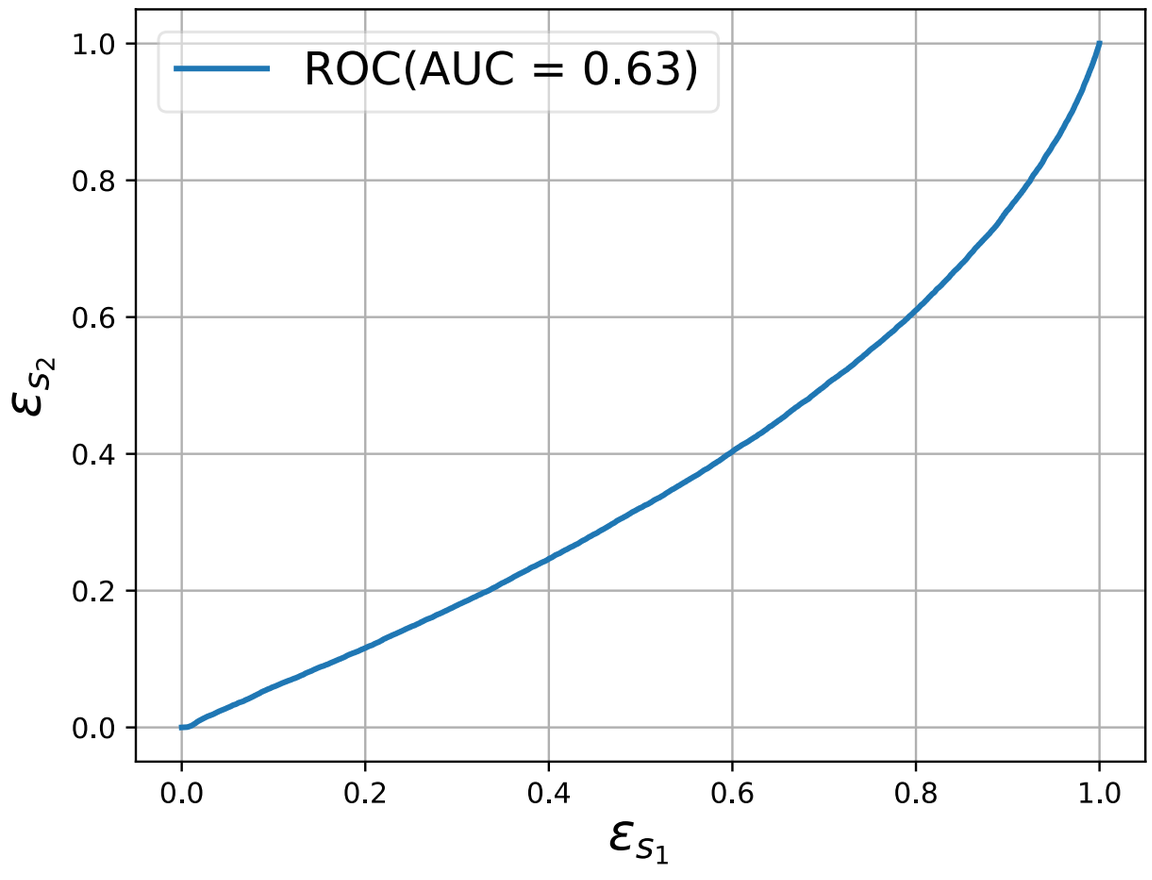
Supervised Learning (at the moment) before trying the semi-supervised/unsupervised algorithms

Logistic regression

Features : p_T^j, η_j, ϕ_j

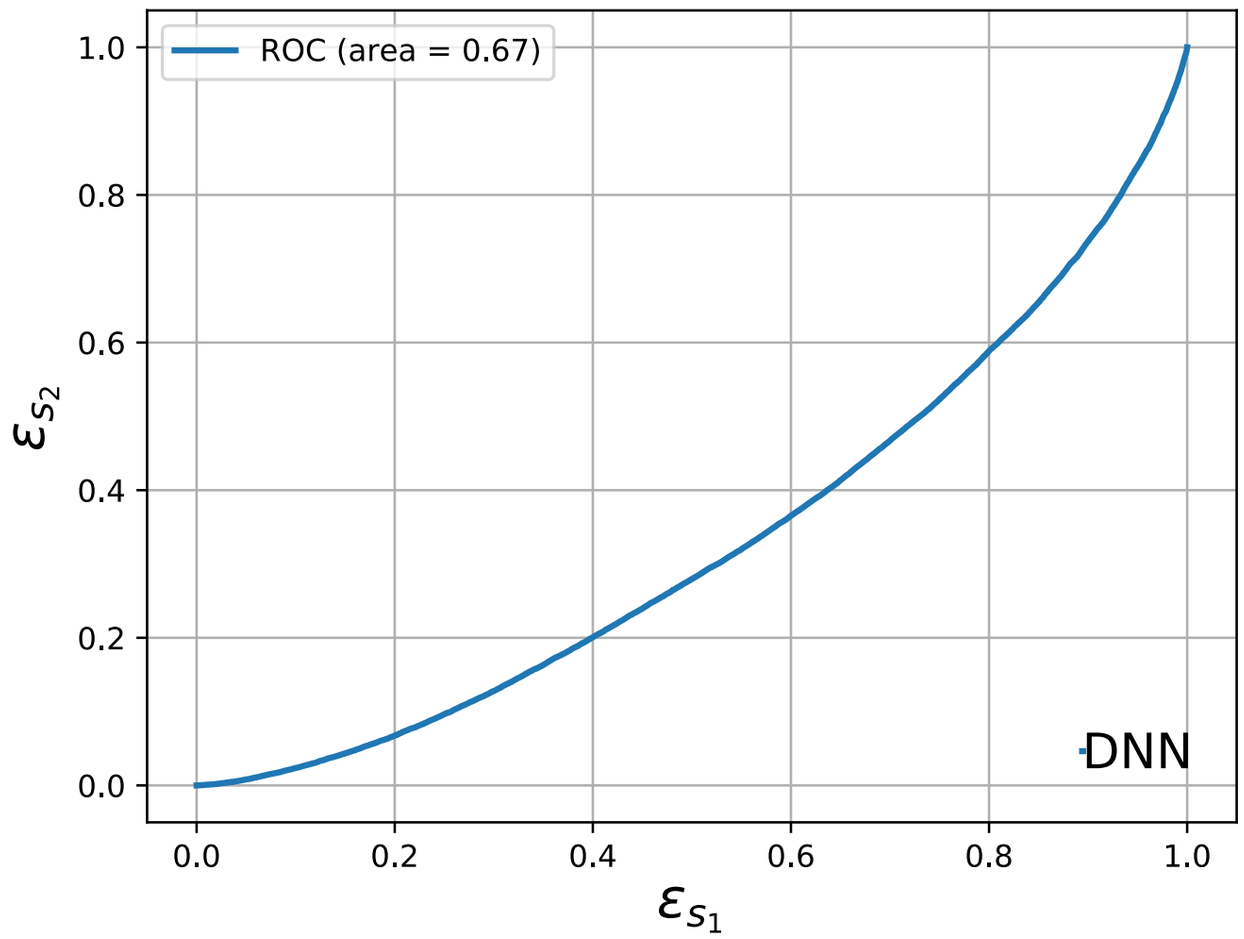
ϵ_{S_1} **: Correct identification of ALPs**

ϵ_{S_2} **: BP2 events labelled as ALPs**



DNN

- Hidden Layers:(after 5, same performance)
- Epochs : (>100, same)
- Activation function : ReLU
- Loss function : Binary cross-entropy



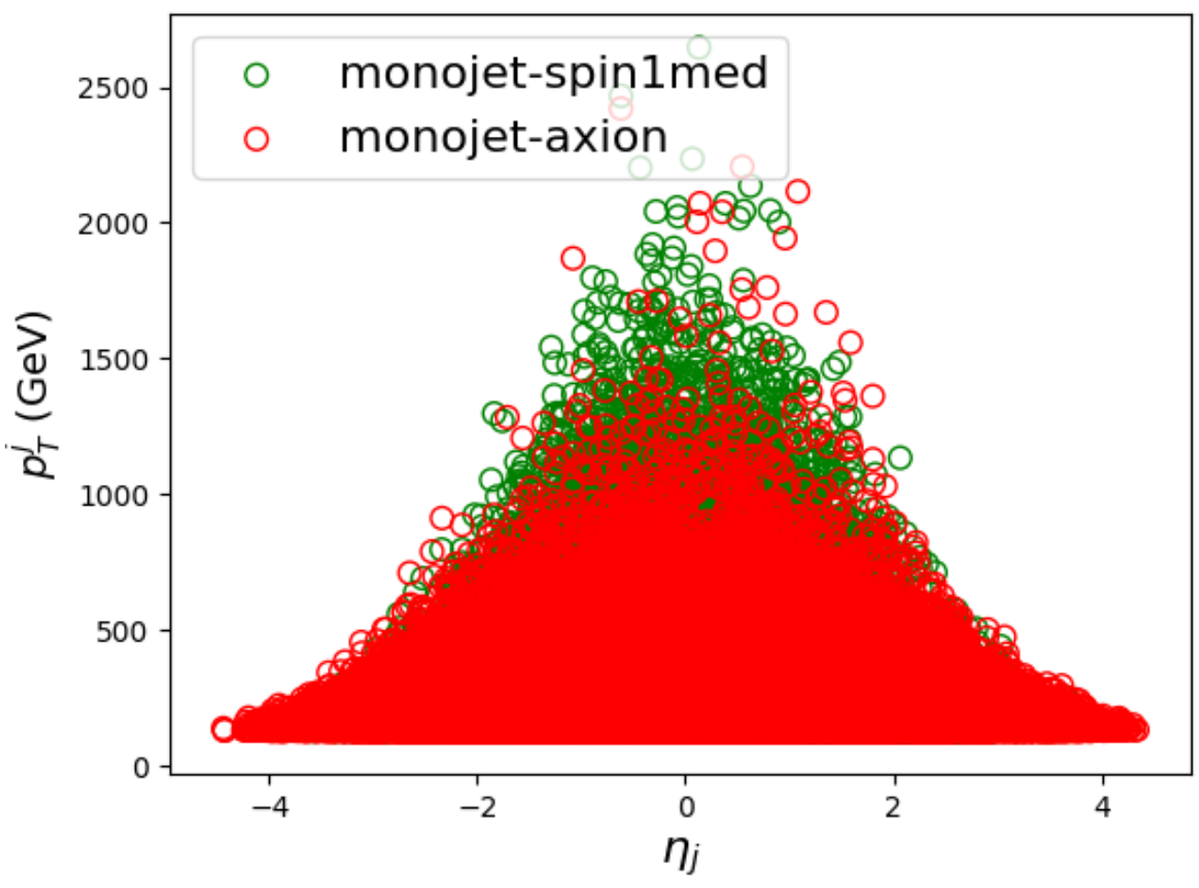
Multi-dimensional probability information

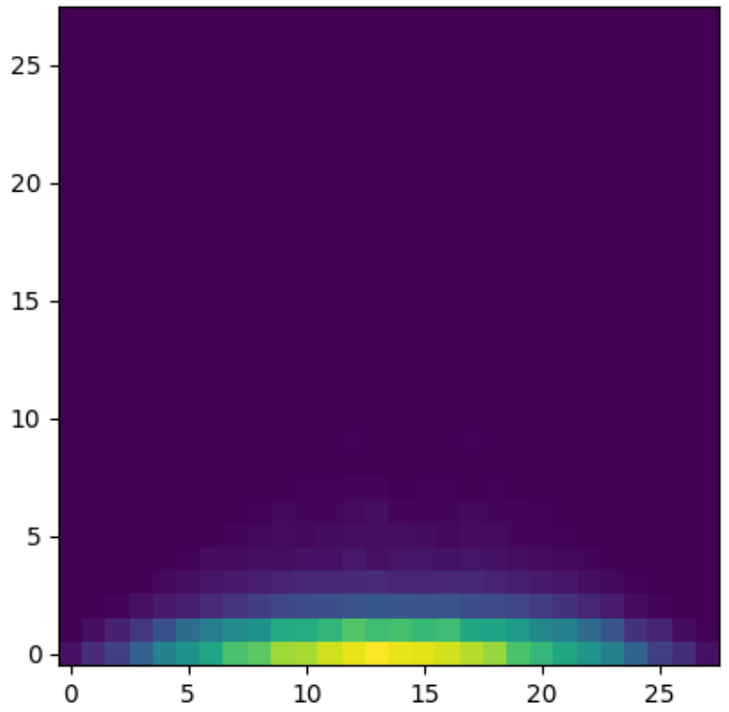
2D distributions : mono-jet

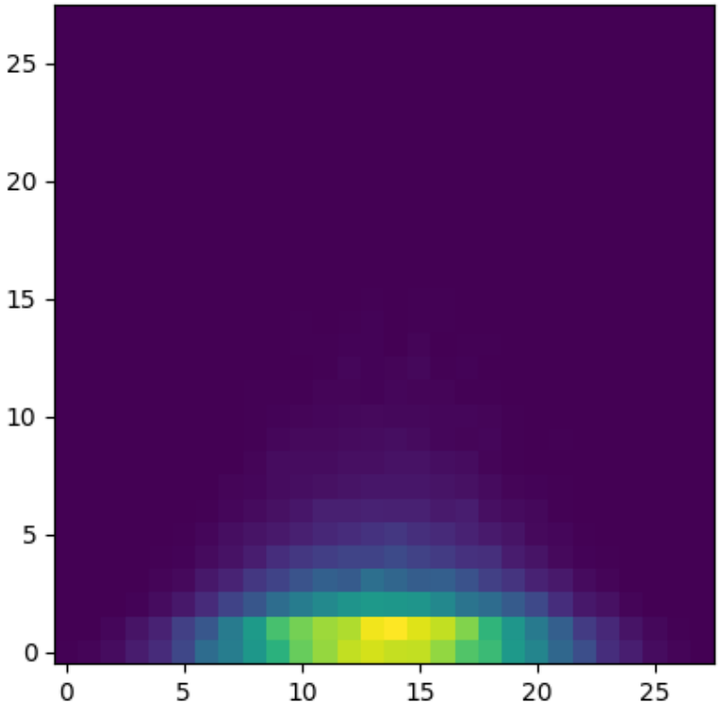
Binning: 29×29 (50K events per image)

$\eta_j : [-4,4]$

$p_T^j : [130,2000] GeV$







Data processing : events to images

- Information of correlation between variables exists in 2D histograms

- Little point (yet) in using 3D, 4D,..histograms

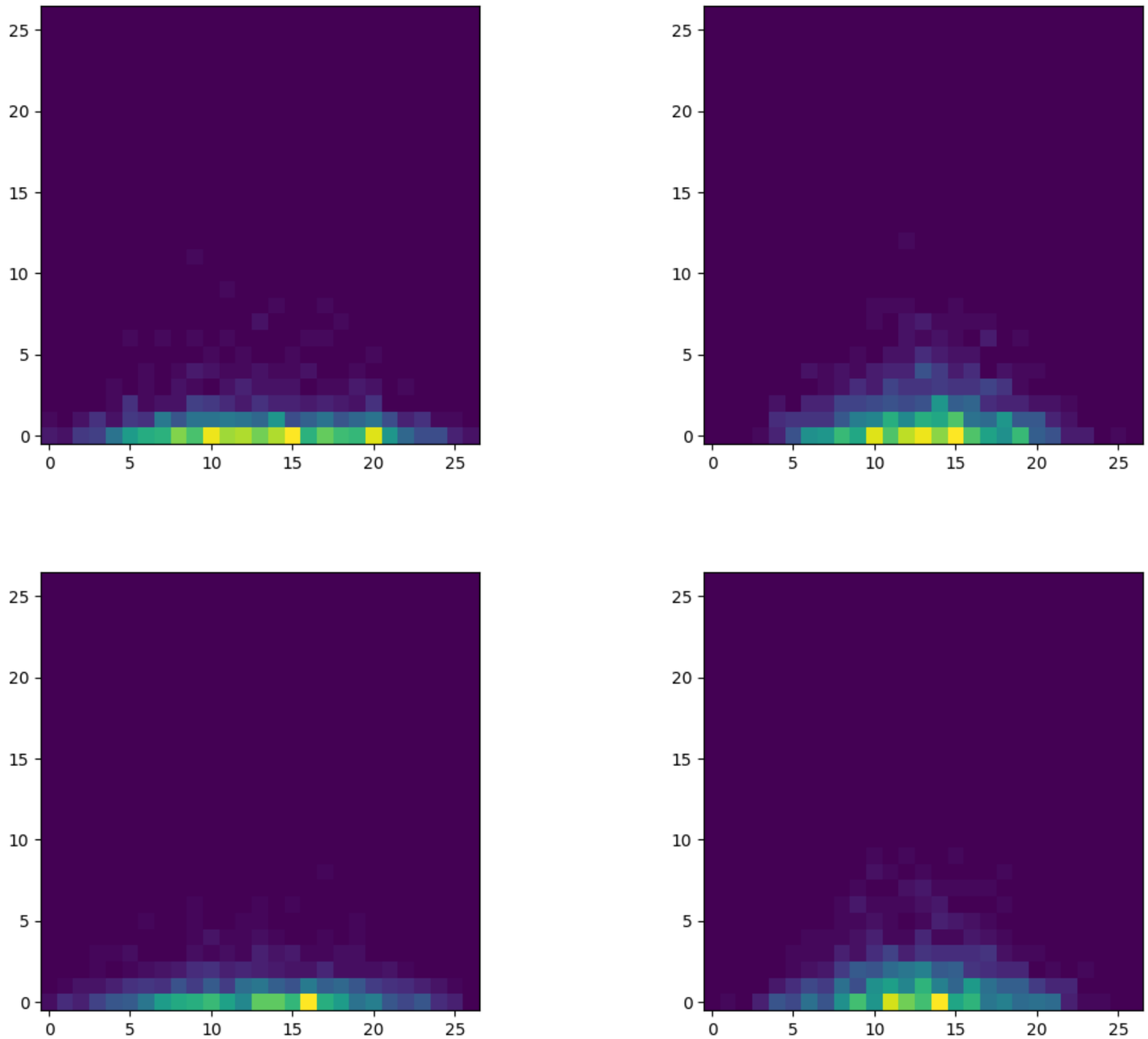
- Able to run CNN

- N=1000 no of events per image

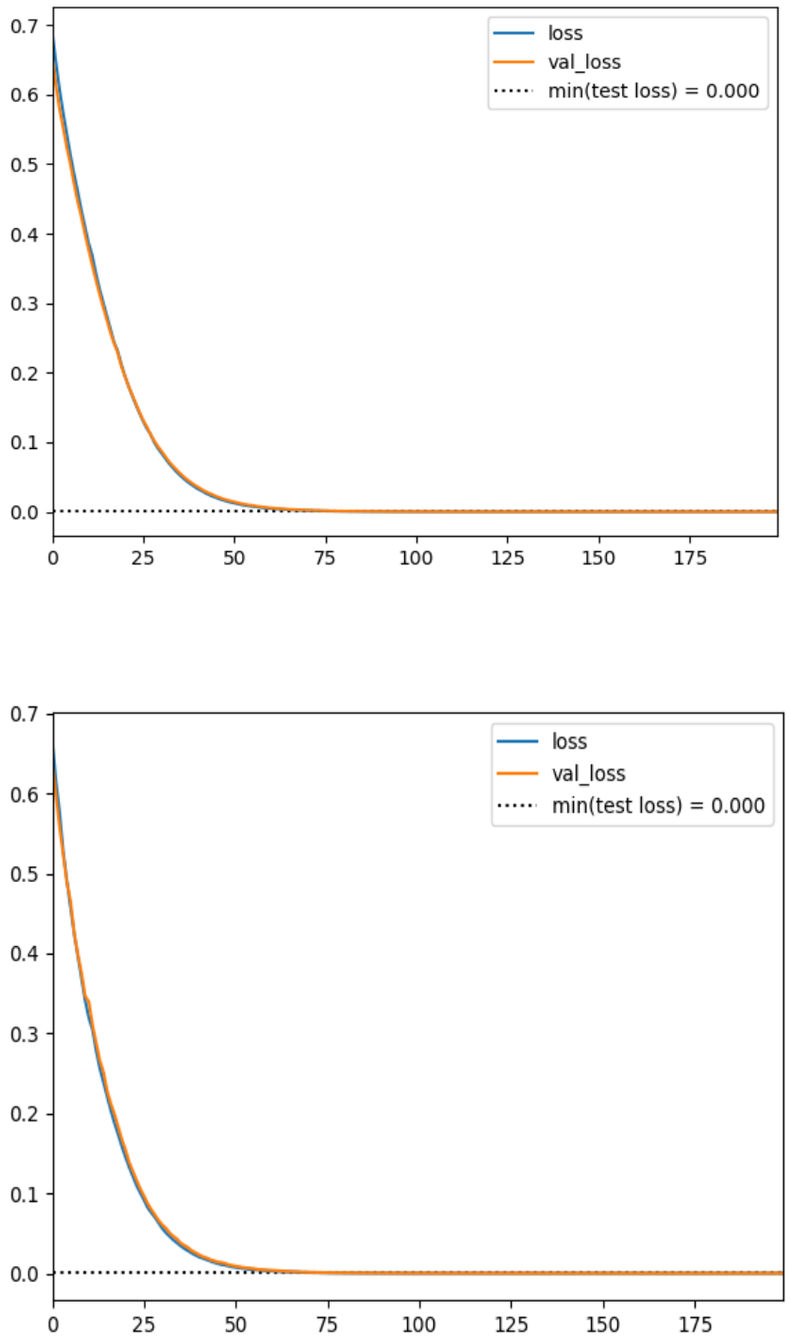
- Training : Validation : Test Sample = 320:40:40 images

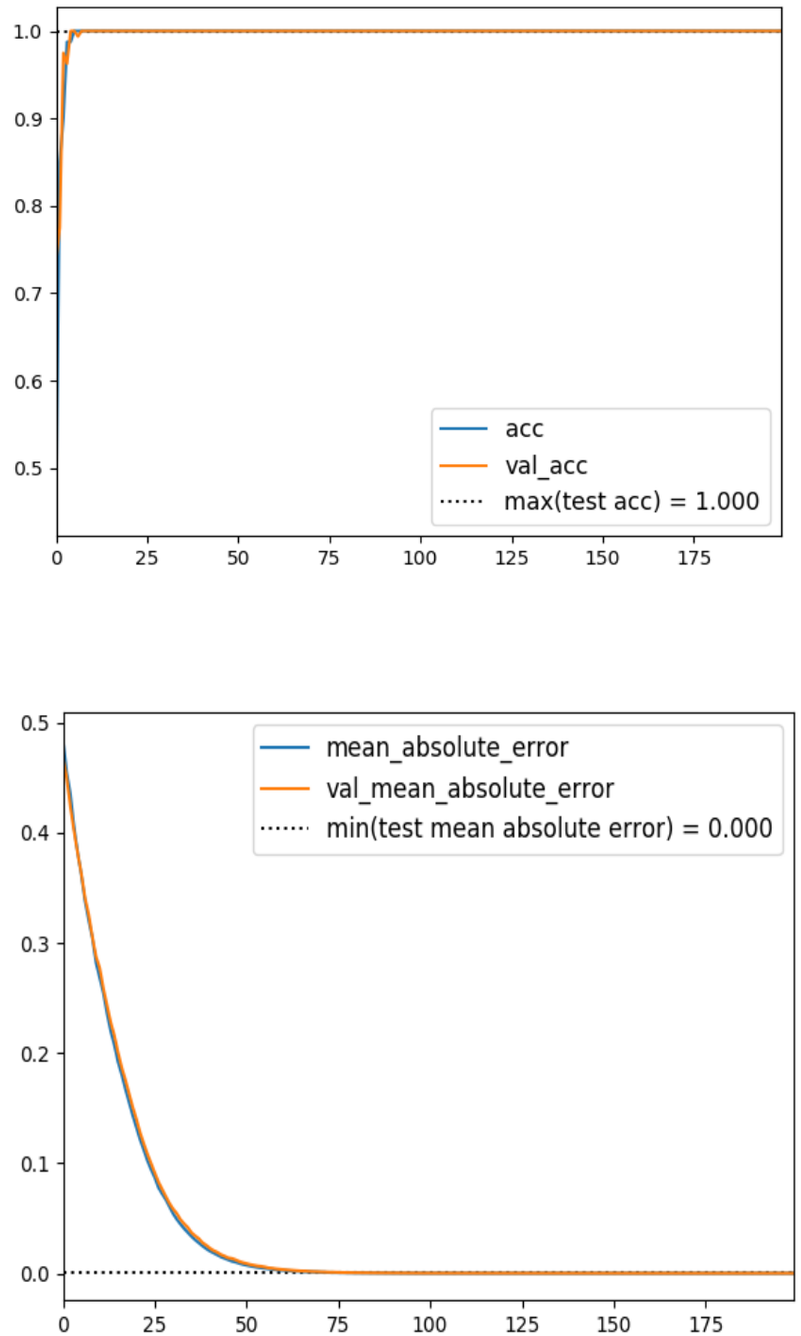
- Hidden layers: 2, Loss function: Binary cross-section, Activation functions : ReLU

Training the DNN (p_T:[130,1000]GeV)

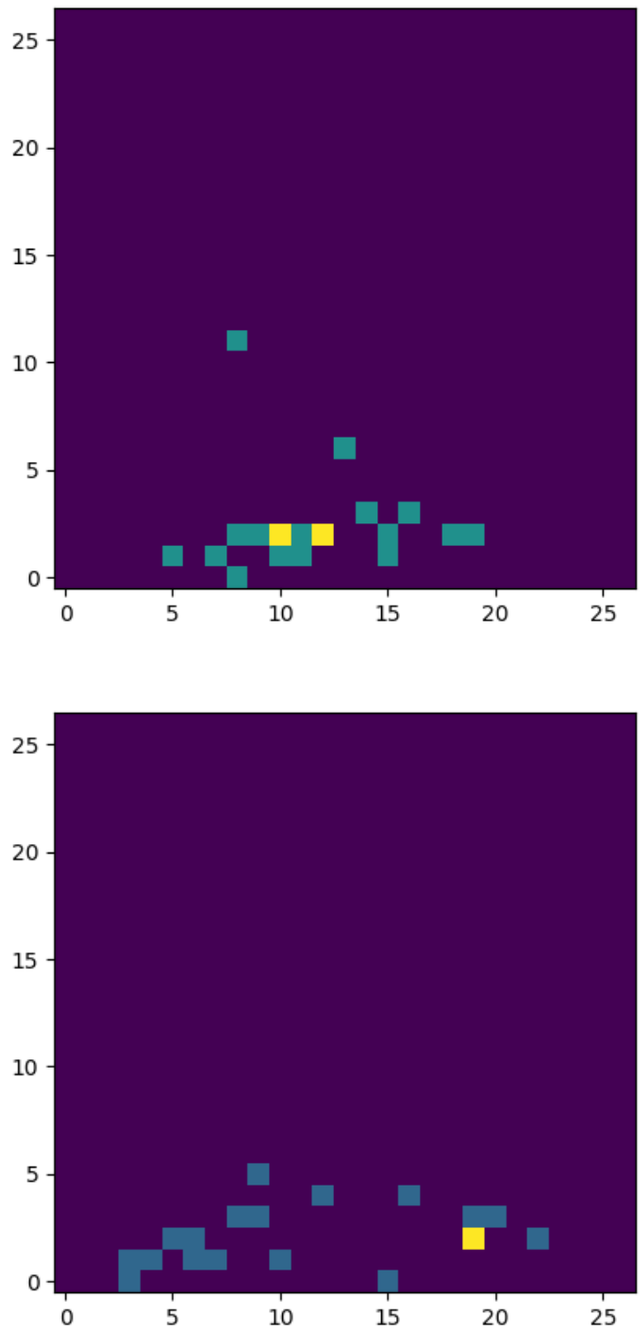
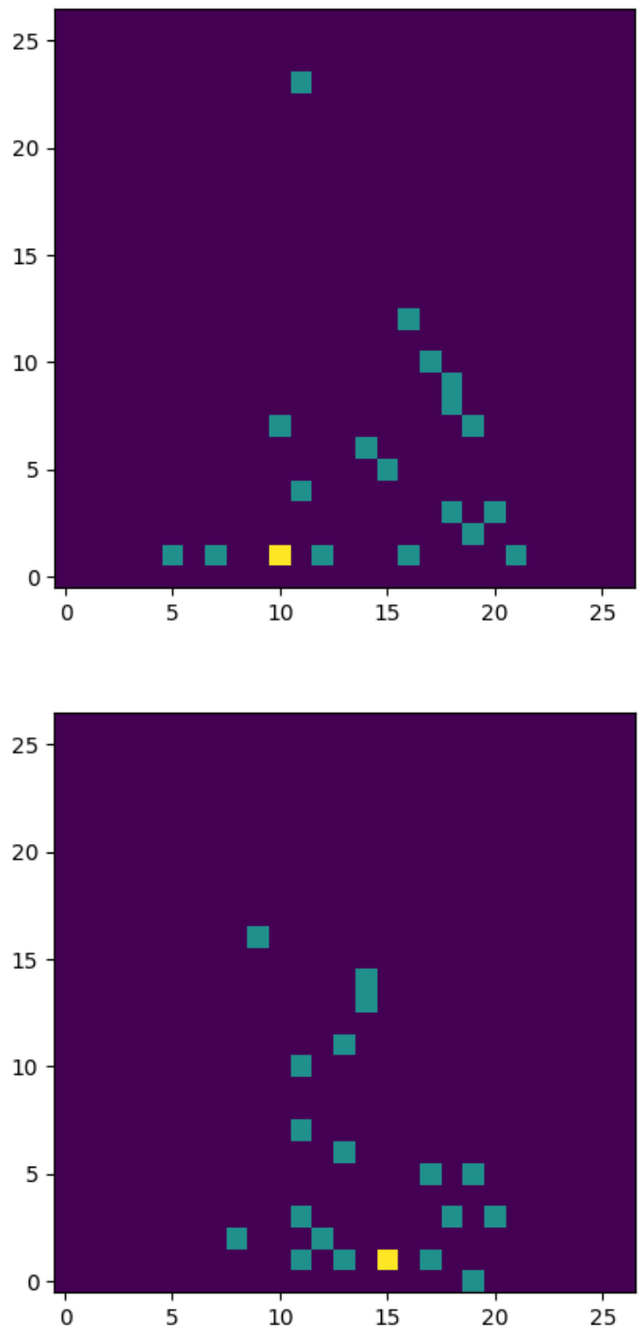


DNN training rates

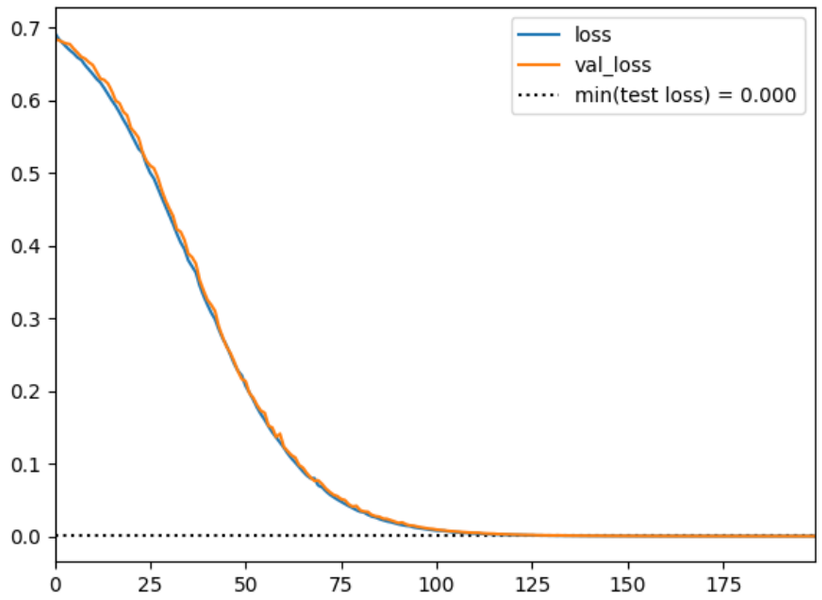


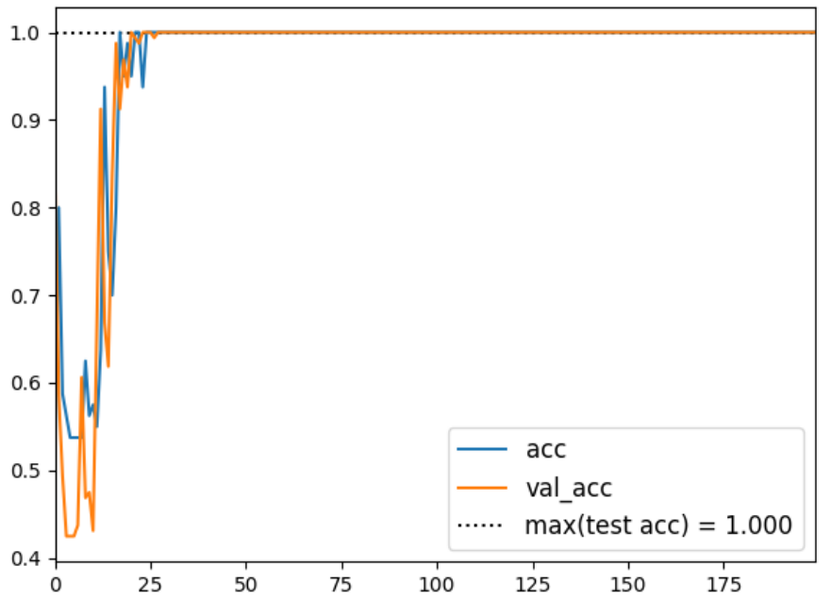


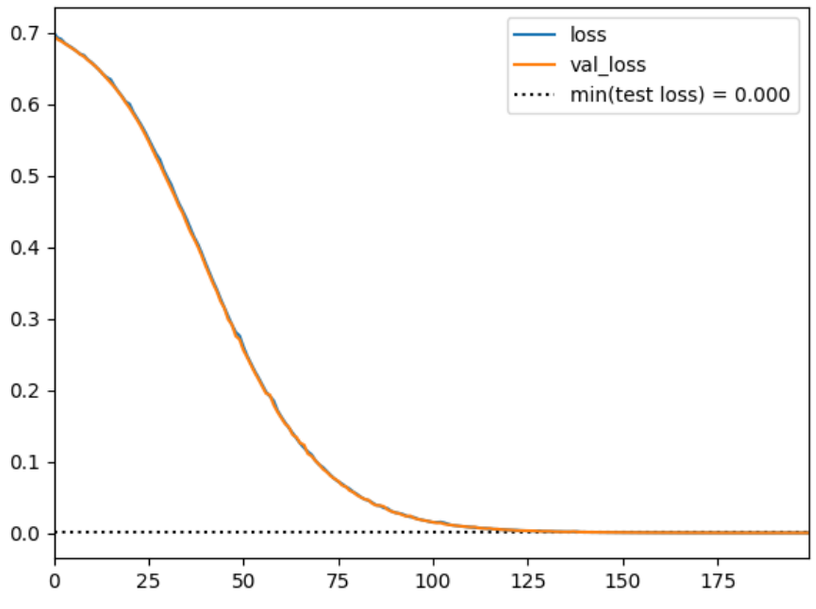
Testing against events with 20 events/image

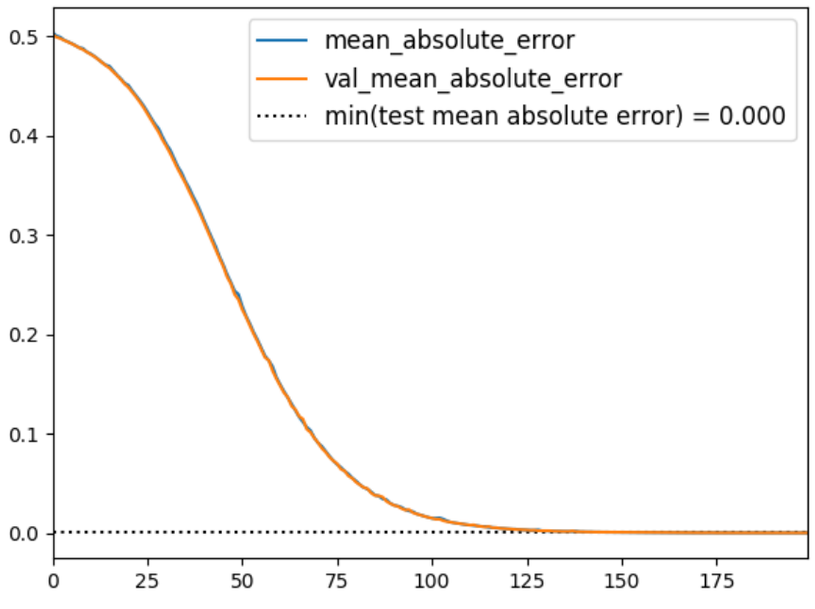



CNN training rates









Comparison of scores for density plots

- DNN accuracies:
  - Training: ~100%
  - Test: ~100%
  - Against data of 20 events/image: ~89.6%
- DNN mean absolute errors:
  - Training: ~2.11×10^{-5}
  - Test: ~1.36×10^{-5}
  - Against data of 20 events/image: ~0.165
- CNN accuracies:
  - Training: ~100%
  - Test: ~100%
  - Against data of 20 events/image: ~83.7%
- CNN mean absolute errors:
  - Training: ~2.14×10^{-5}
  - Test: ~3.29×10^{-5}
  - Against data of 20 events/image: ~0.332

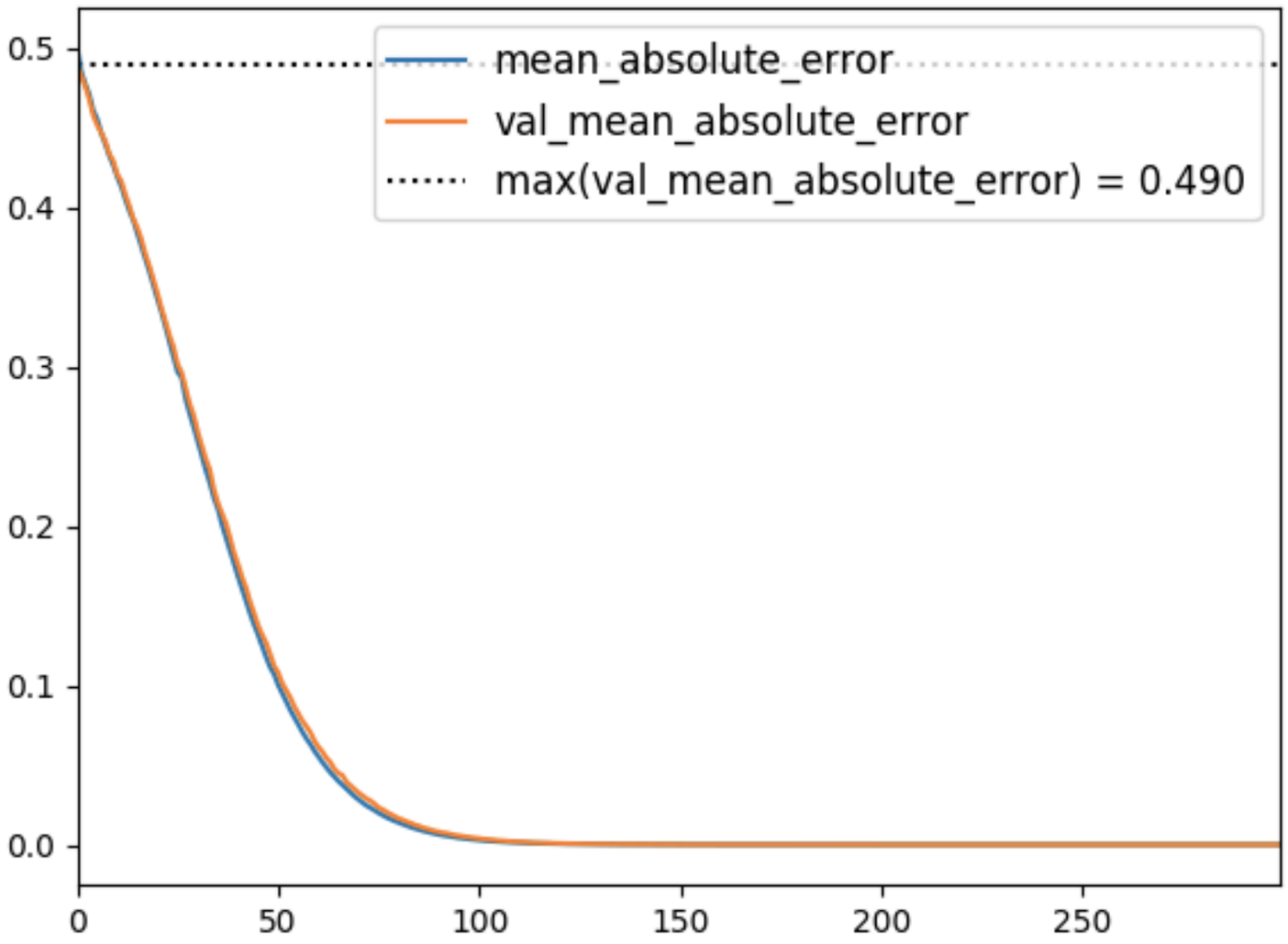
Summary and next steps

- **Parton level event generation for ALPs and simplified models**
- **Able to distinguish between signals when only a small number of events are present**
- **Looking to explore further the relations of events/image between datasets: is it a correct approach ?**
- **Compare to expected number of events/timeframe from LHC – requires knowledge of cross sections and model parameters**
- **Analysis with different DM/collider stable models and incorporate showering/hadronisation, detector effects, NLO effects & SM background.** $(p_T^{j_1}, p_T^{j_2}, \eta_{j_1}, \eta_{j_2}, MET, \Delta\phi_{jj}, \Delta\phi_{METj_1}, \Delta\phi_{METj_2})$
- **Move towards unsupervised learning algorithms**

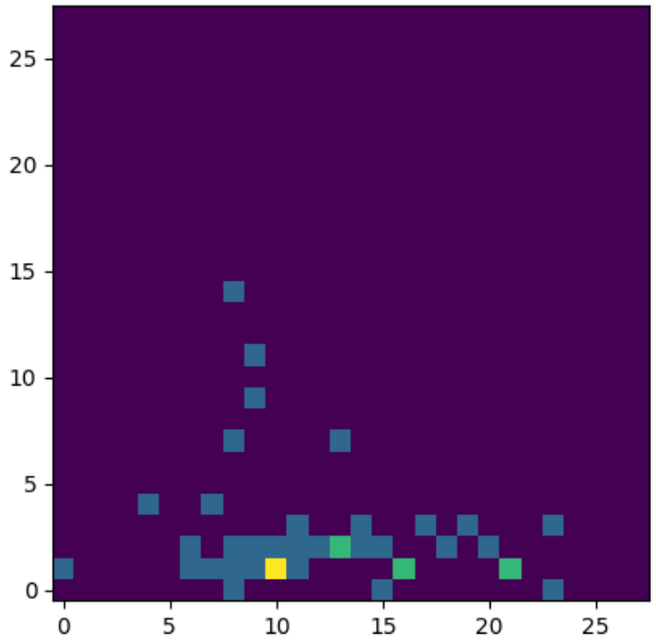
Thanks

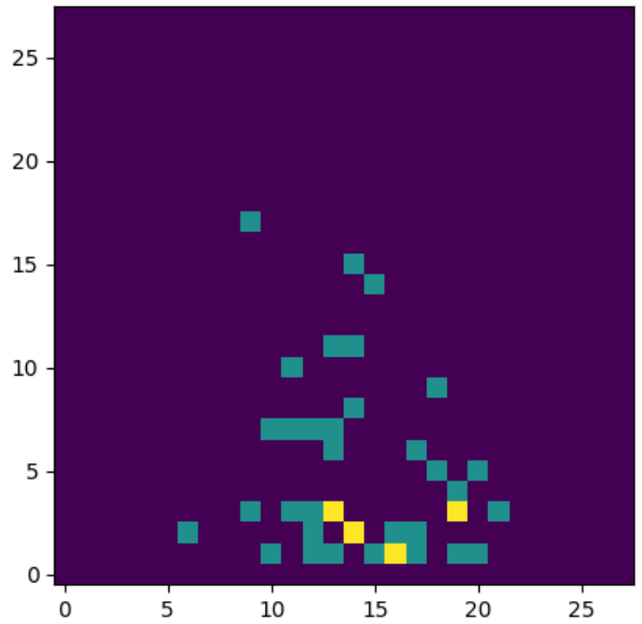
Suggestions/Questions ?

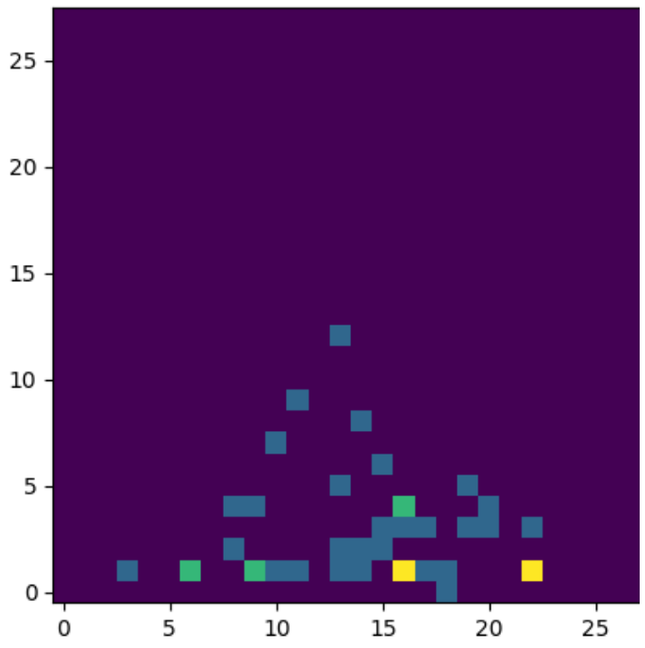
Small batch size

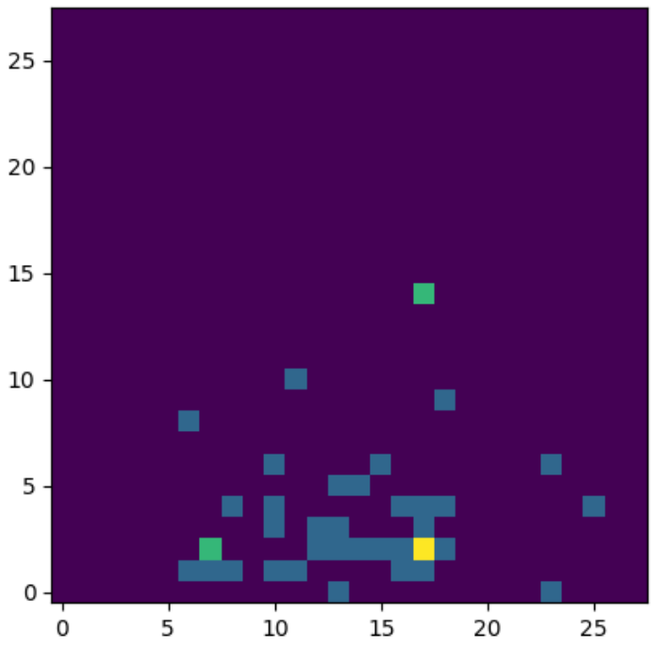


Data Sample 1 (p_T:[130,1000]GeV)





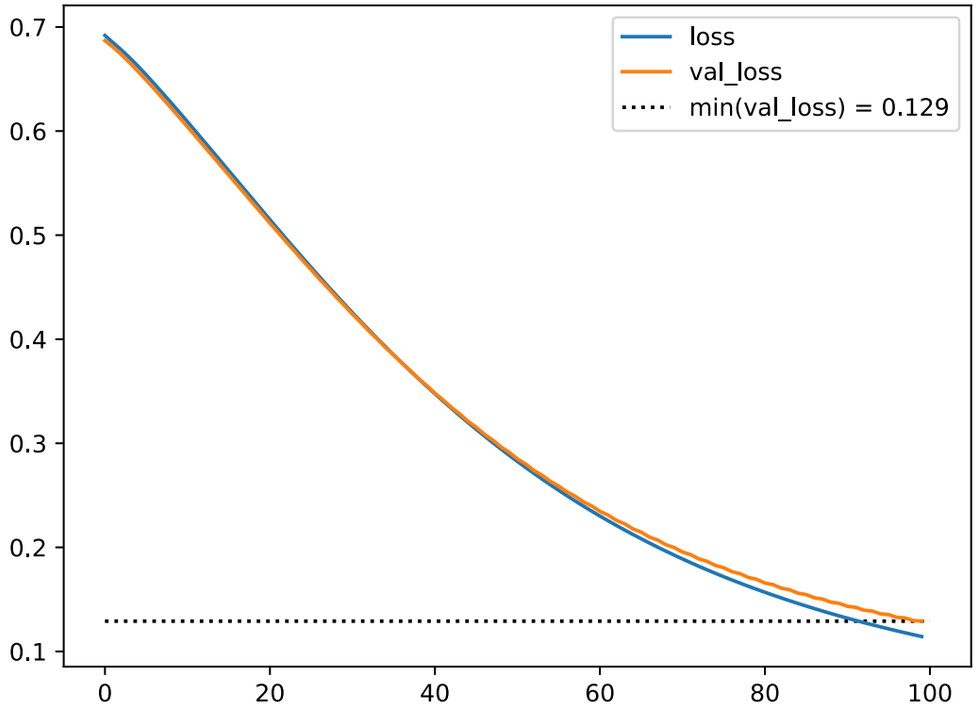


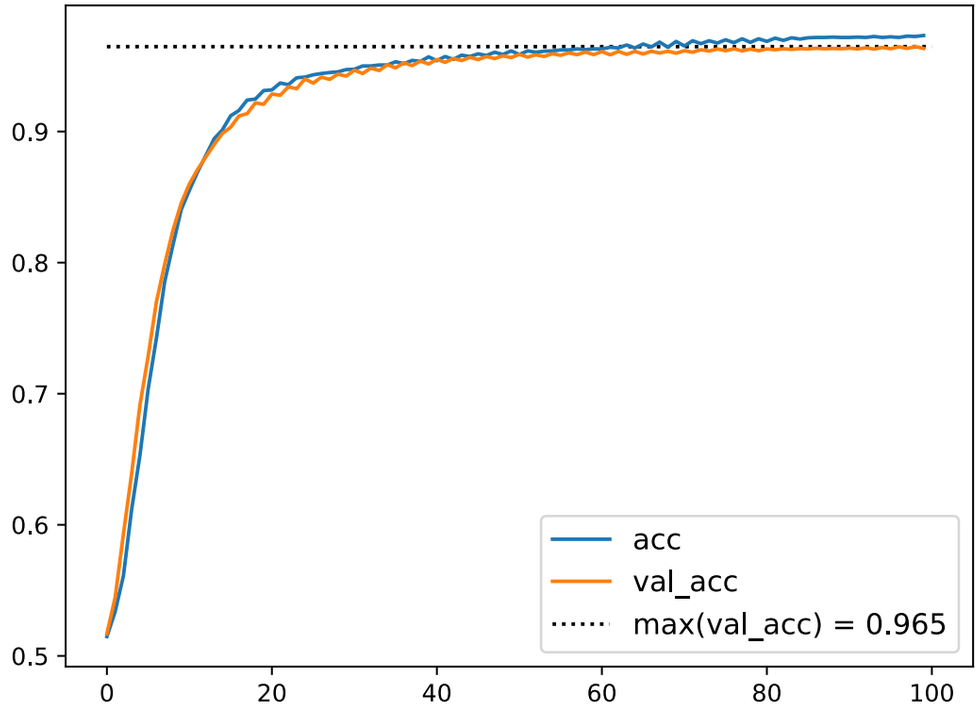


DNN (image recognition)

2D images : information of density is 1D array inout for NN

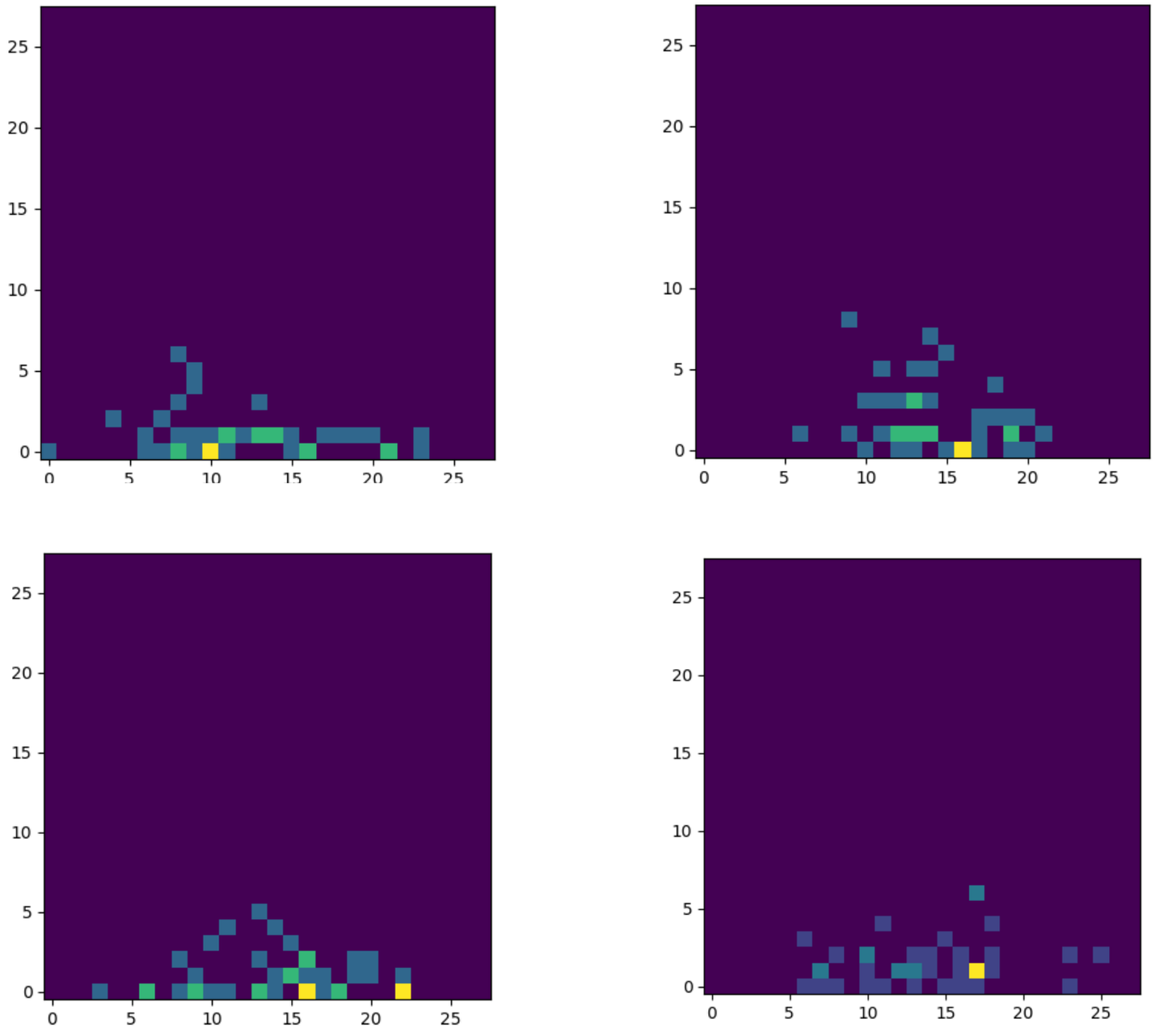
40 events per image





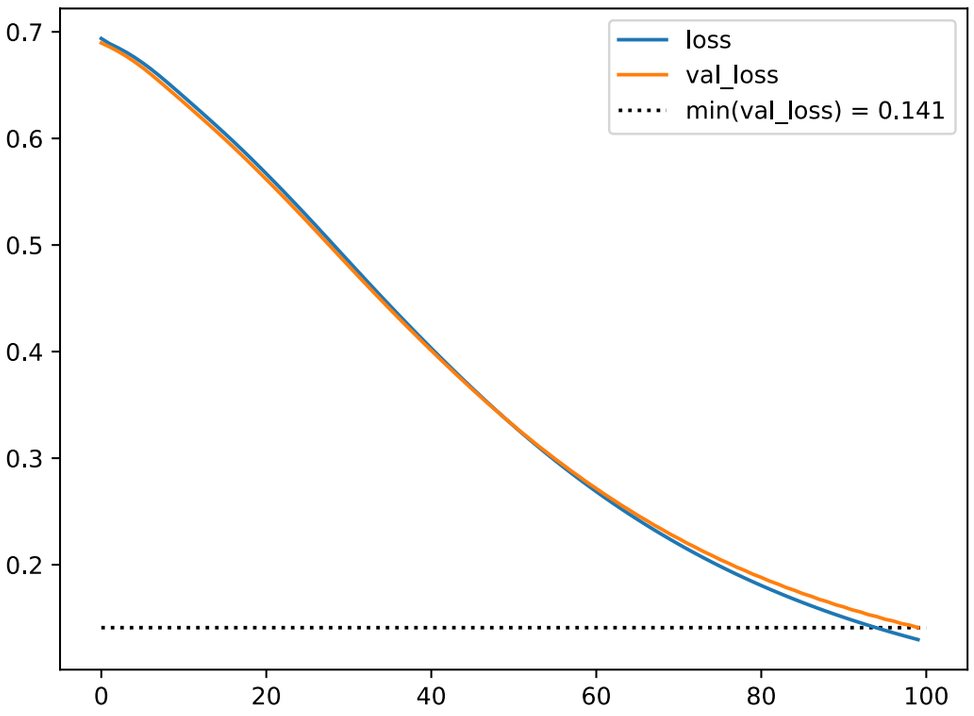
Hidden Layers : 2, Loss function : Binary cross-entropy, Activation function : ReLU

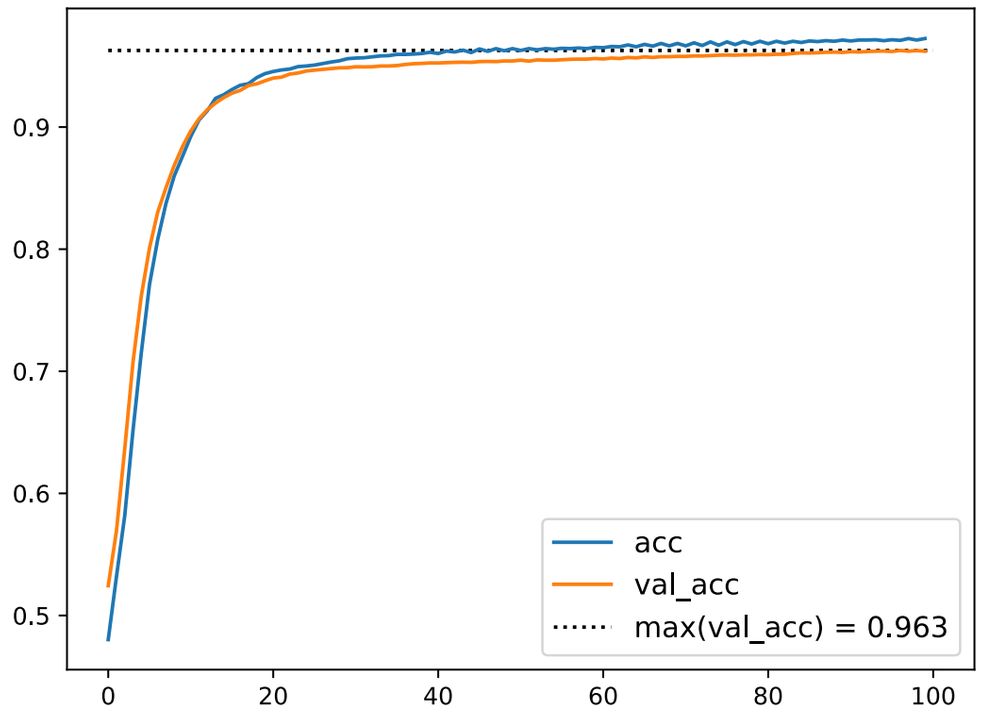
Data Sample 2 (P_T :[130,2000]GeV)



Algorithm has an information of rare events also

Same Performance ...





Dropouts ?