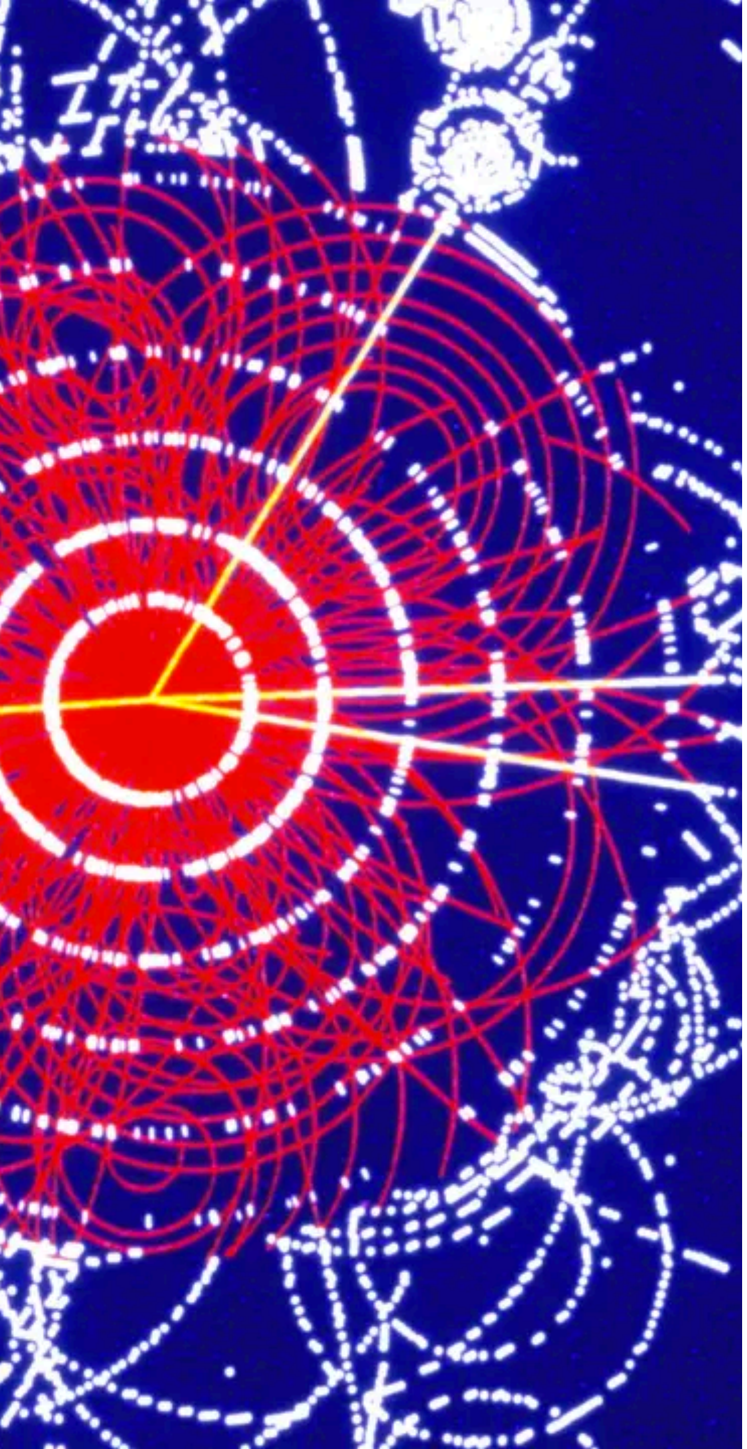


Enhancing DM searches in LHC with ML

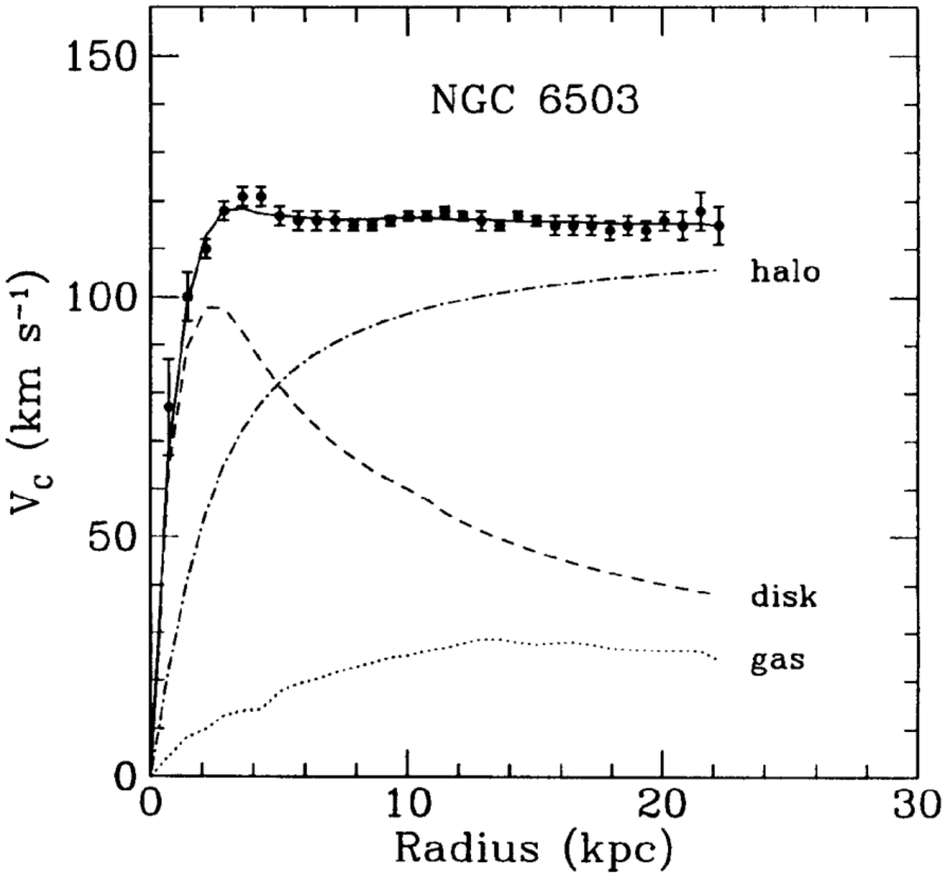
Rafał Masełek

in collaboration with
M. Nojiri (KEK, Japan) & K. Sakurai (University of Warsaw, Poland)

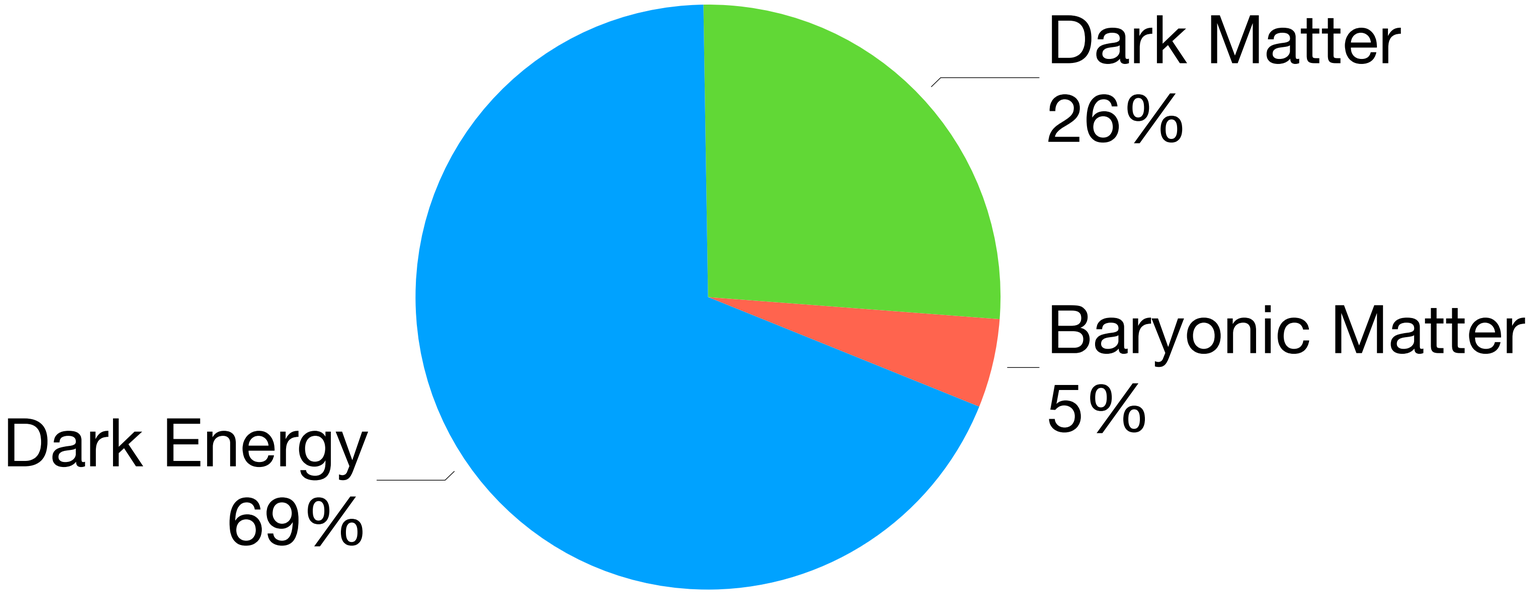
IRN Terascale
Marseille, 25-10-2023

Research founded by Polish National Science Centre grants:
PRELUDIUM 20 2021/41/N/ST2/00972
GRIEG 2019/34/H/ST2/00707
and Polish National Agency for Academic Exchange grant:
BEKKER 2022 BPN/BEK/2022/1/00253/DEC/1

Dark Matter (DM)



img source: arXiv:0812.4005 [astro-ph]



- long-lived over the age of the Universe
- feebly-interacting with photons and baryons
- not too hot

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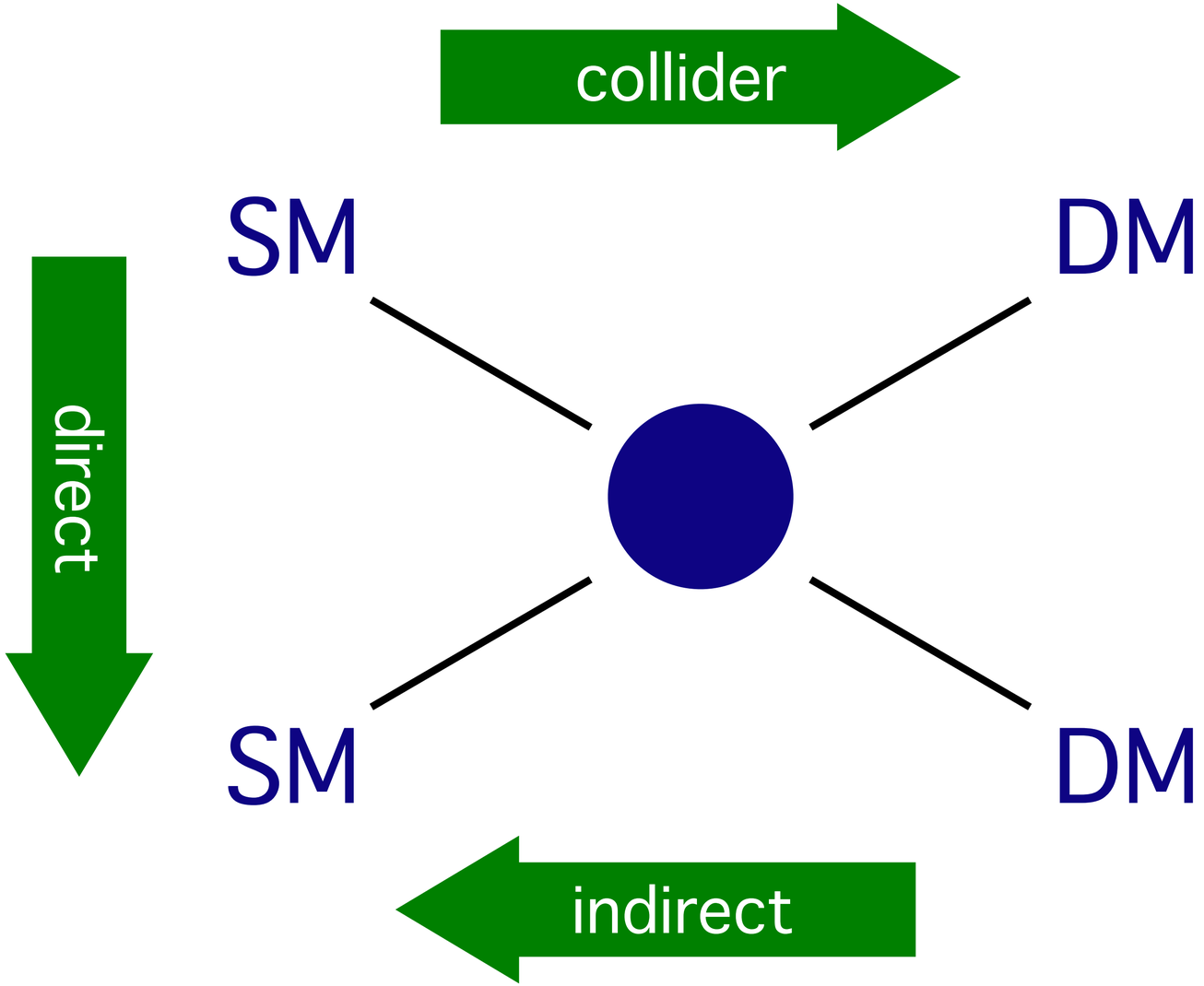
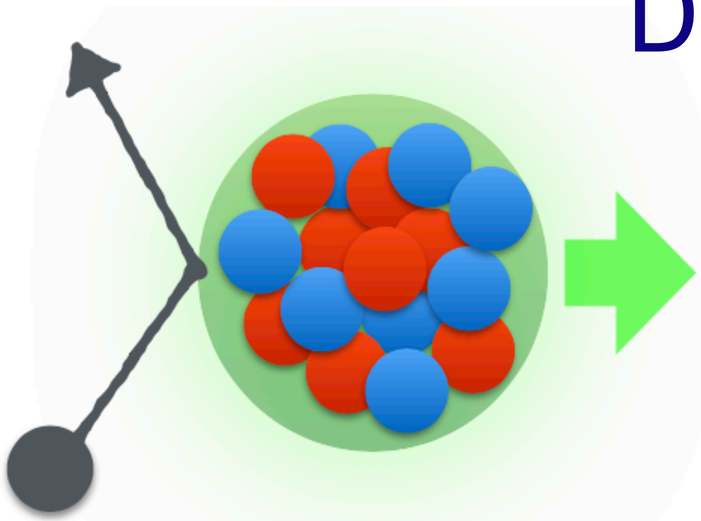
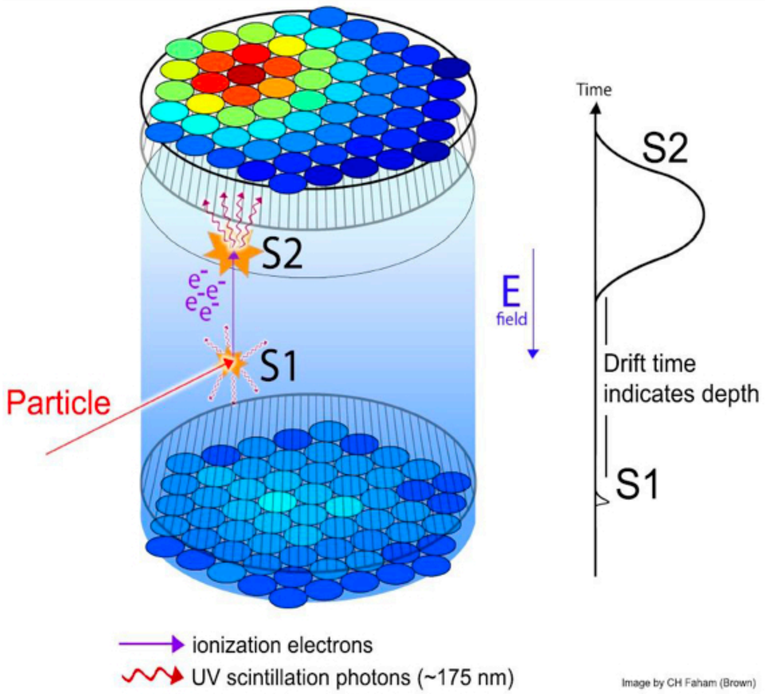
searches for Dark Matter particles



Direct DM searches





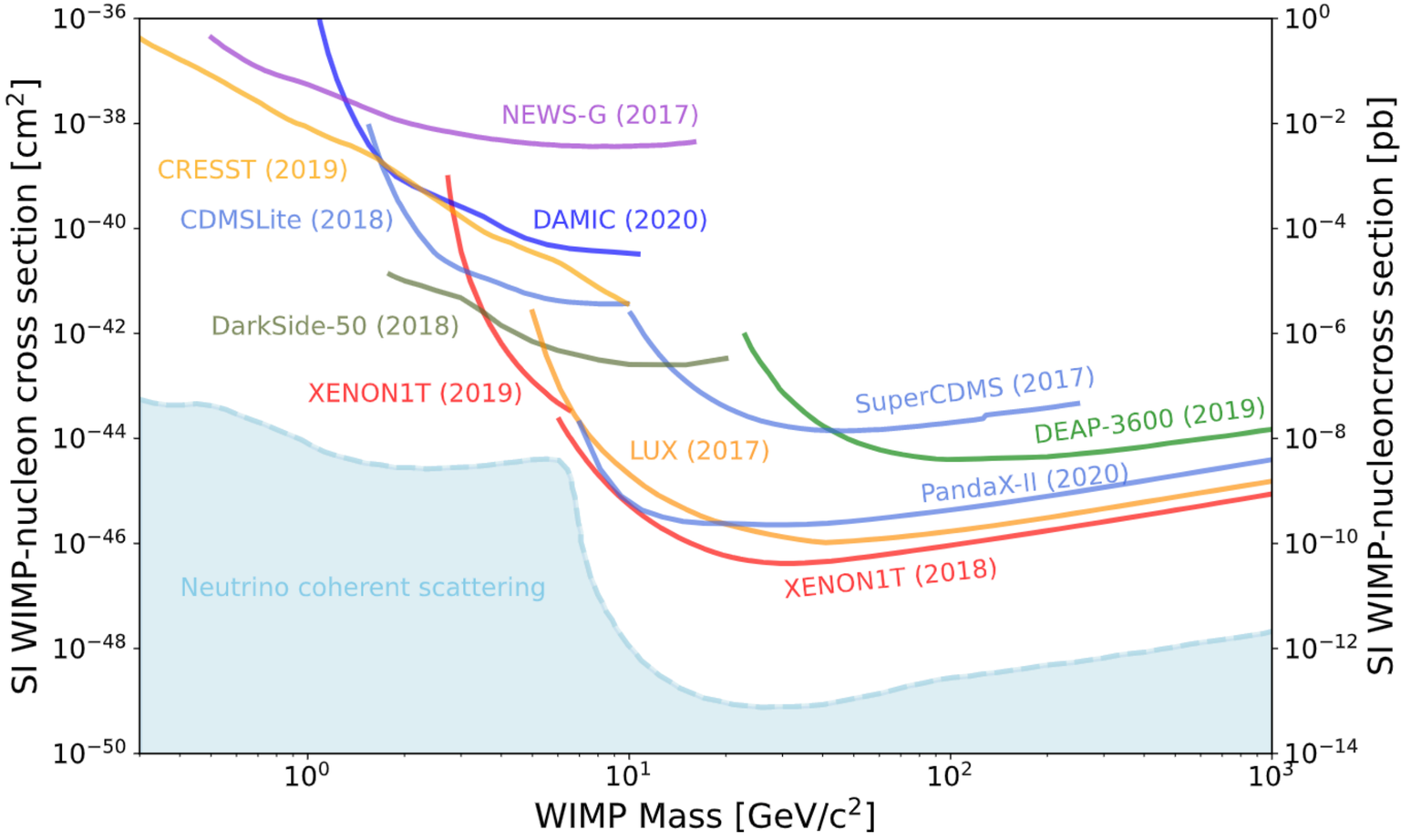


Figure 27.1: Upper limits on the SI DM-nucleon cross section as a function of DM mas

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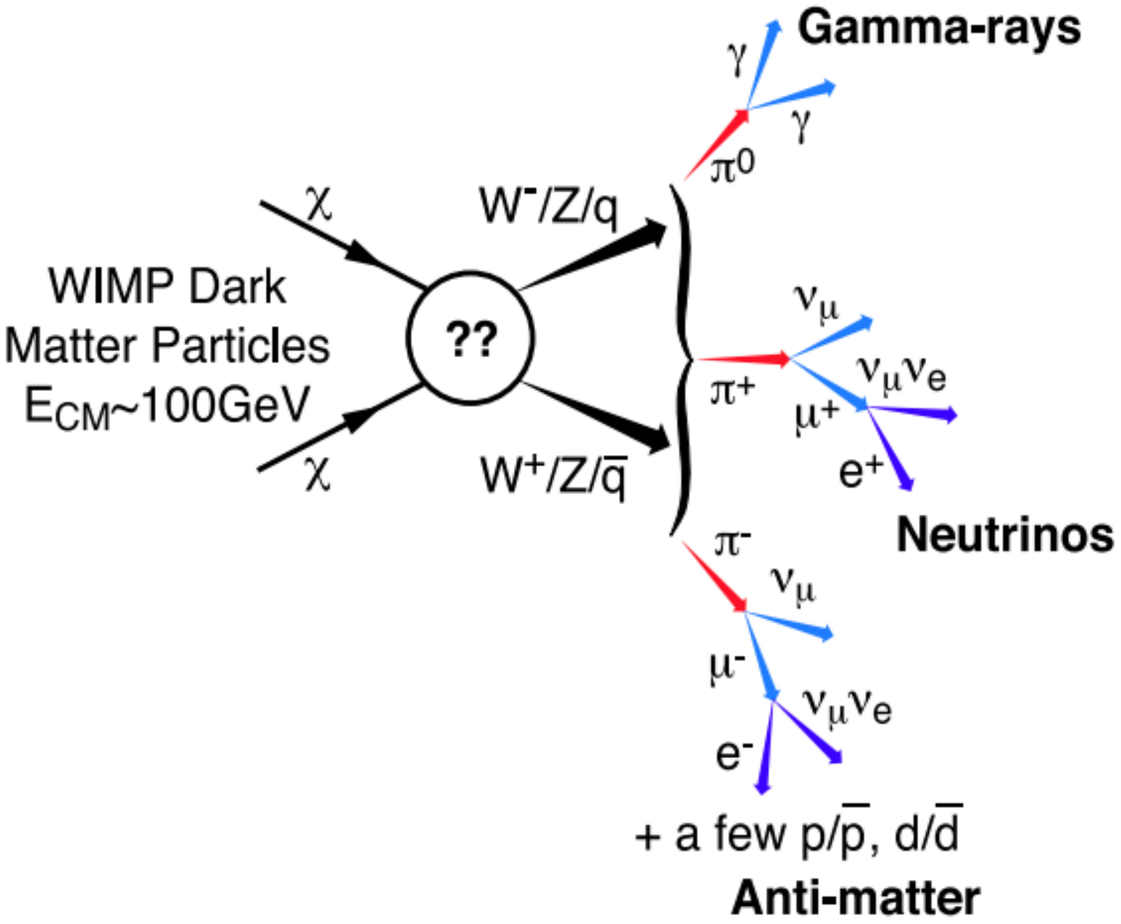
img source: PDG Review 2022; chapter 27 (Dark matter)

img source: A. Kmada lecture notes on Astrophysics

img source: http://nirmalraj.wikidot.com/physics

Indirect DM searches



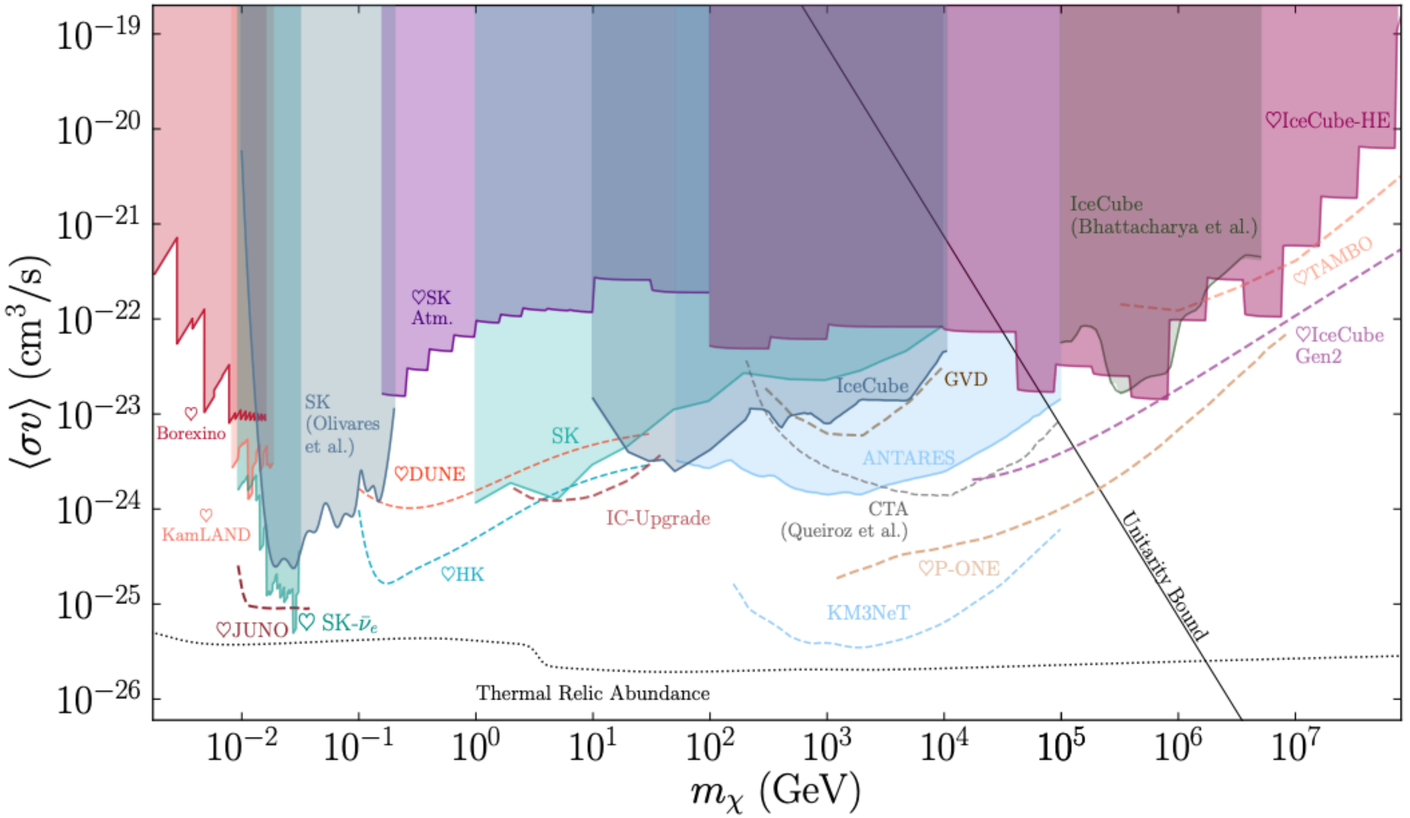
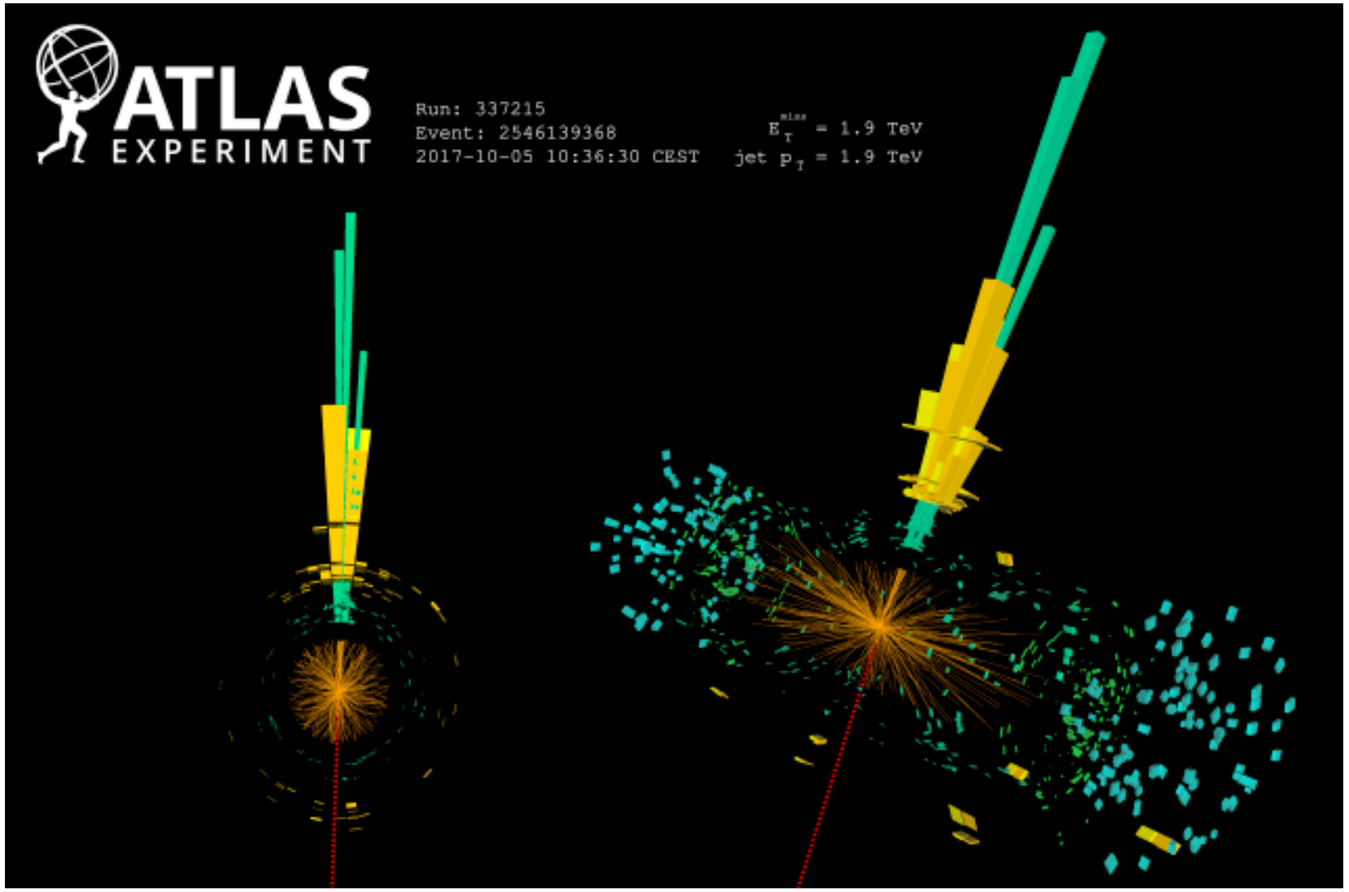
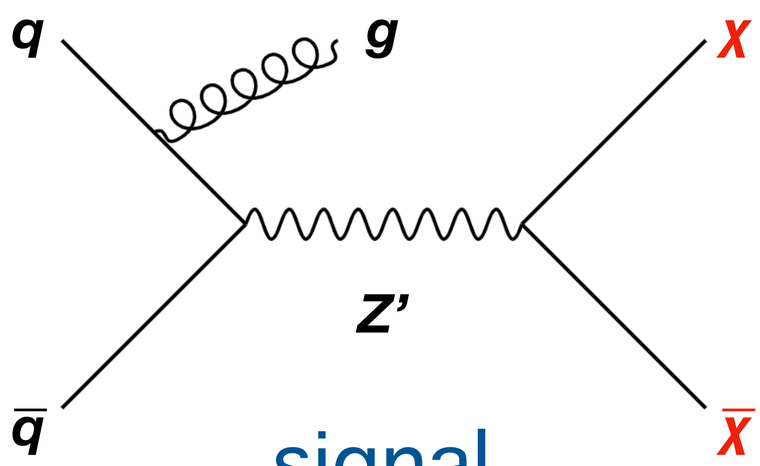


Fig. 6 Summary of results on the velocity weighted dark matter annihilation cross section from different experiments. Solid lines show limits, dashed lines sensitivities of future facilities assuming five years data taking (100 h of observation for the CTA sensitivity). The heart symbols represent analyses performed by the authors of [156] with public data, and not by the collaborations. Figure from [156]

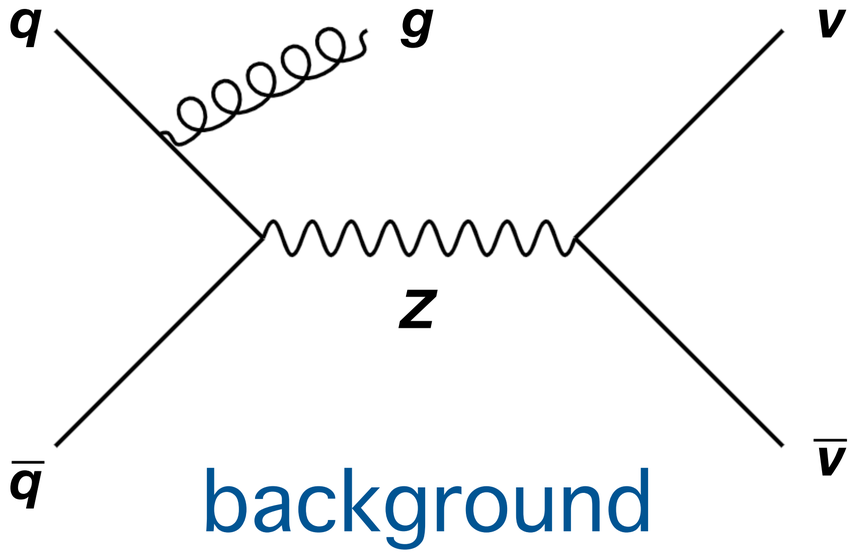
DM searches @ LHC — Monojet

Monojet channel = 1 or more hard jets
recoiling against a missing transverse momentum
and no isolated leptons





signal



background

img source: https://cds.cern.ch/record/2725235

The idea

- One of the challenges for the Monojet searches is that we observe very similar jets for both signal and background
- Analysis of jet substructure is needed
- With Machine Learning we can analyse low-level data
- ML can learn both local and global correlations
- GOAL: Design new analysis using ML

Data

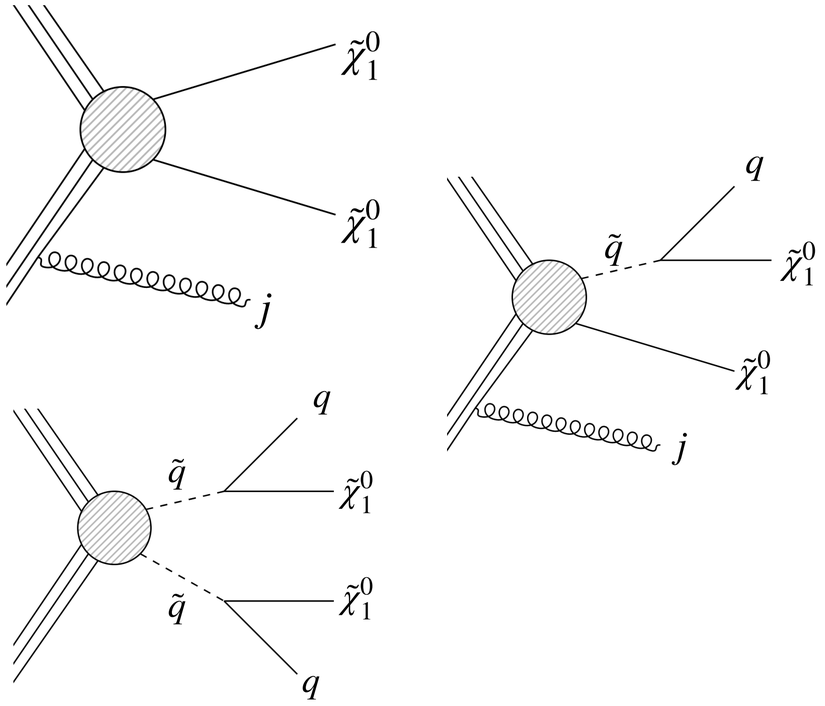
SM

$pp \to Z + \text{jets};\ (Z \to \nu\bar{\nu})$

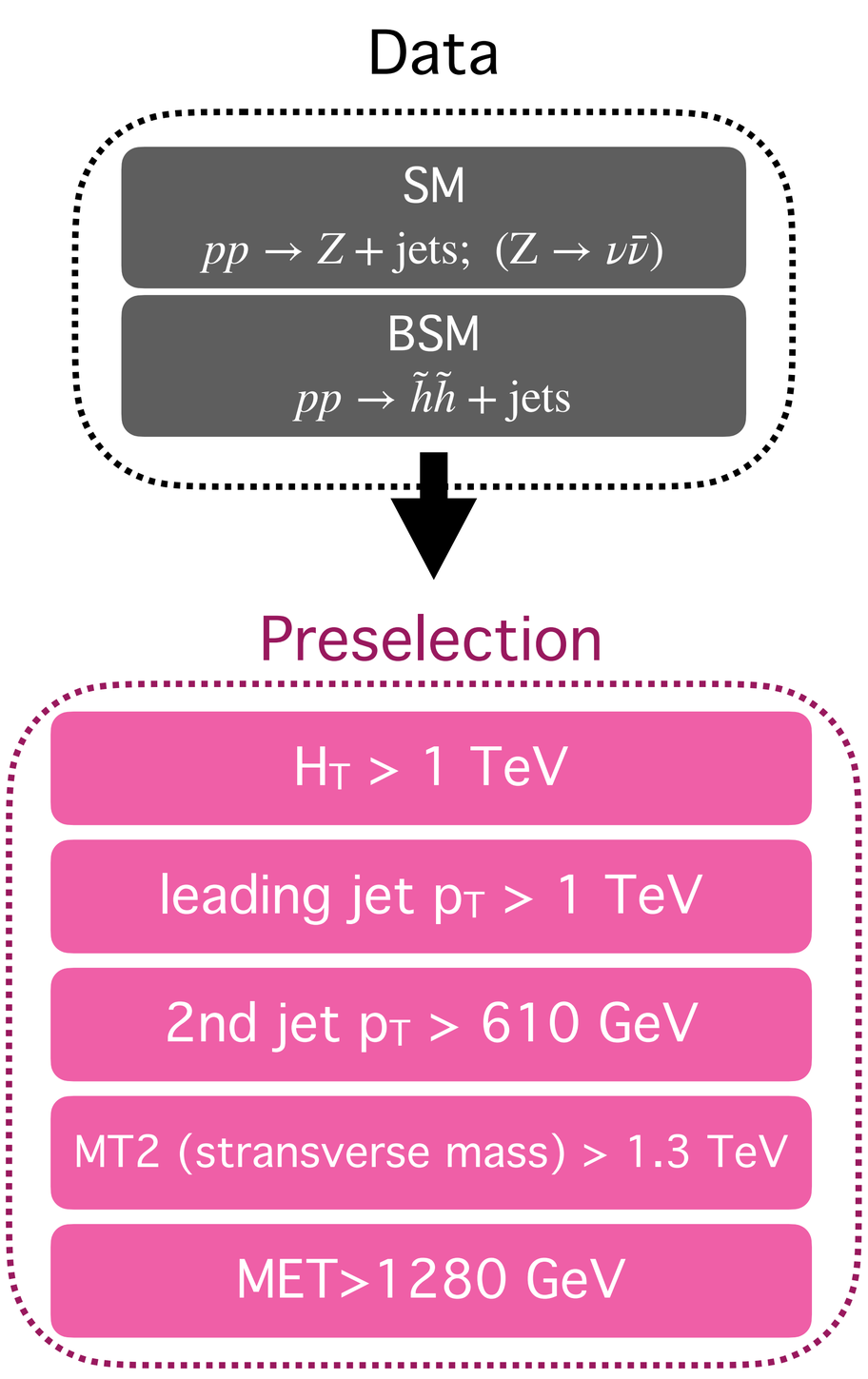
BSM

$pp \to \tilde{h}\tilde{h} + \text{jets}$

Benchmark model SUSY



neutralino flavour	neutralino mass [GeV]	squark mass [TeV]
higgsino	200	2.00
higgsino	300	2.00
higgsino	400	2.00
higgsino	500	2.00
higgsino	600	2.00
higgsino	300	2.25
higgsino	300	2.50
higgsino	300	2.75
higgsino	300	3.00
wino	200	2.00
wino	500	2.00



First start with the preselection

Data

SM

$pp \to Z + \text{jets};\ (Z \to \nu\bar{\nu})$

BSM

$pp \to \tilde{h}\tilde{h} + \text{jets}$

Then apply NN to hard-to-distinguish events

Preselection

- H_T > 1 TeV
- leading jet p_T > 1 TeV
- 2nd jet p_T > 610 GeV
- MT2 (stransverse mass) > 1.3 TeV
- MET>1280 GeV

Neural Network

- particle information
- global variables

Final result — event-by-event classifier

Data

SM

$pp \to Z + \text{jets};\ (Z \to \nu\bar{\nu})$

BSM

$pp \to \tilde{h}\tilde{h} + \text{jets}$

Preselection

- H_T > 1 TeV
- leading jet p_T > 1 TeV
- 2nd jet p_T > 610 GeV
- MT2 (stransverse mass) > 1.3 TeV
- MET>1280 GeV

Neural Network

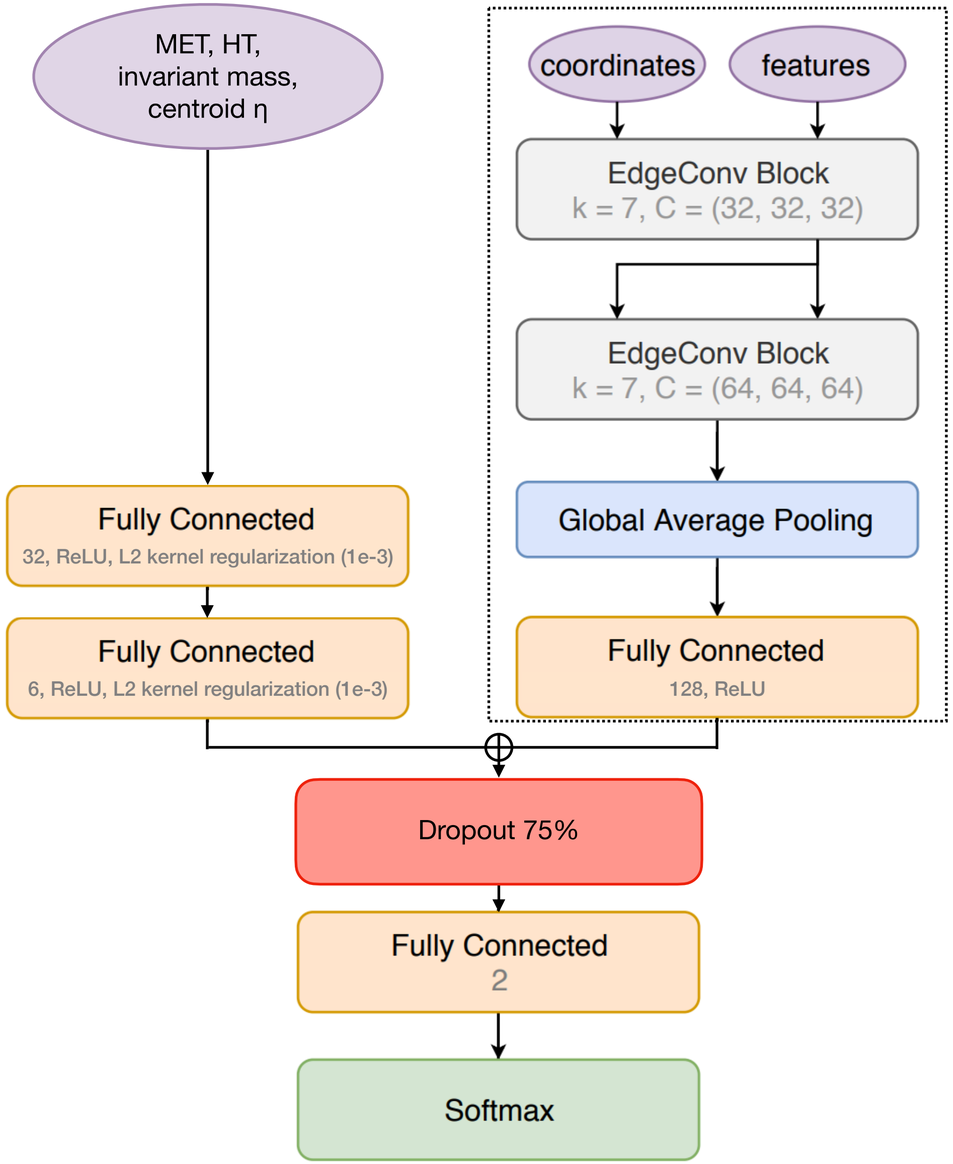
- particle information
- global variables

Classifier

- signal
- background

Neural Network architecture

Global variables

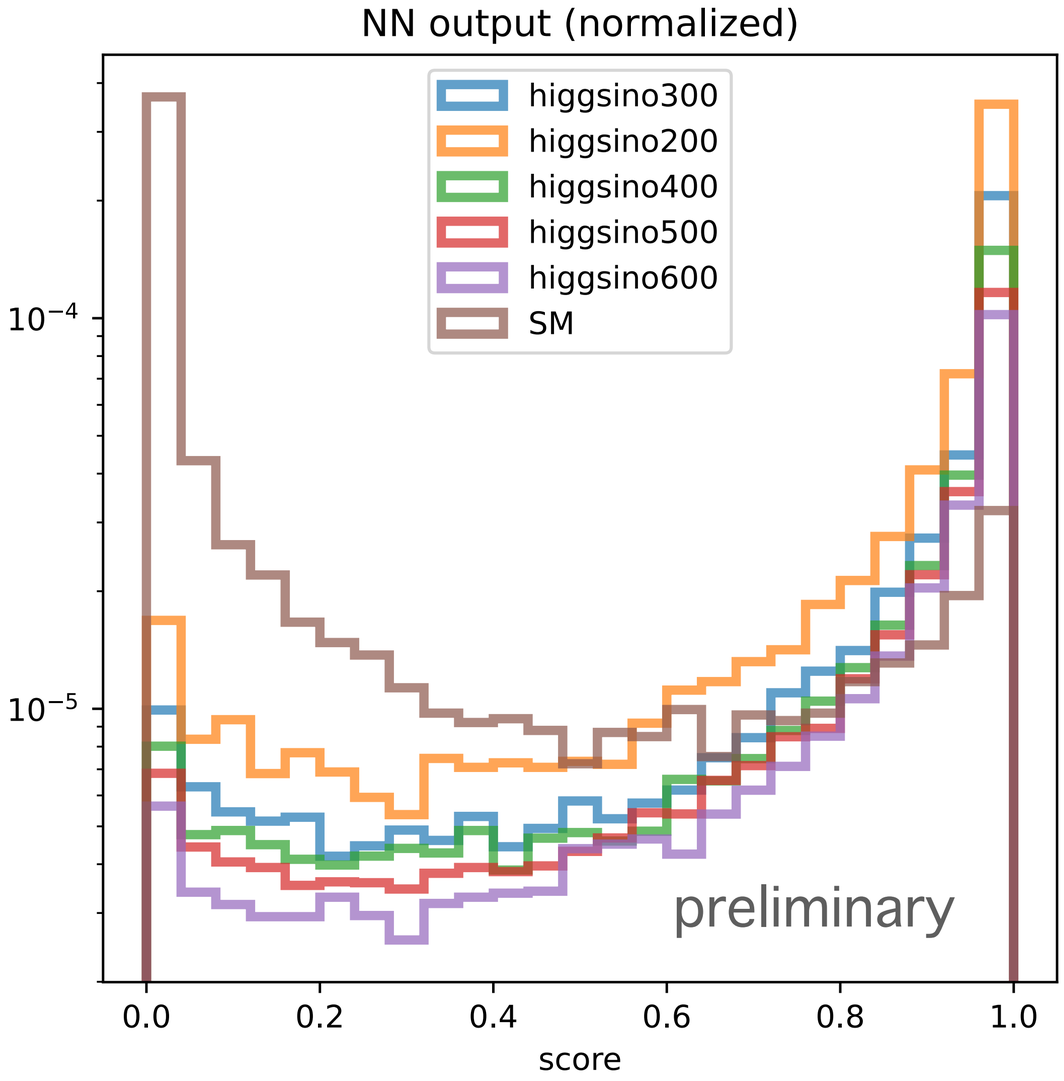


Local variables
Based on ParticleNet Lite

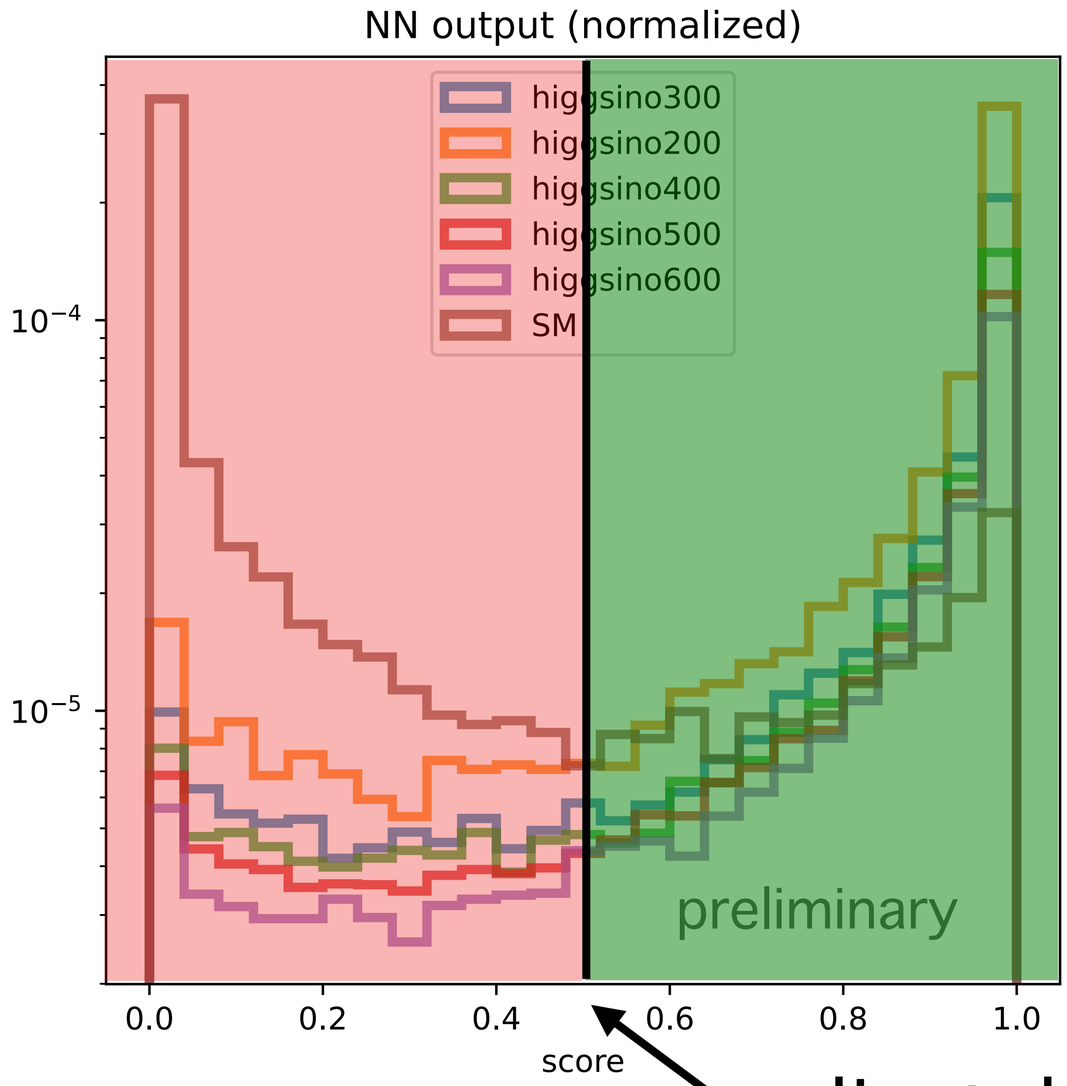
Evaluation

Malbork Castle, Poland
photo from museum's FB page

Evaluation — varying Higgsino mass



Evaluation — varying Higgsino mass

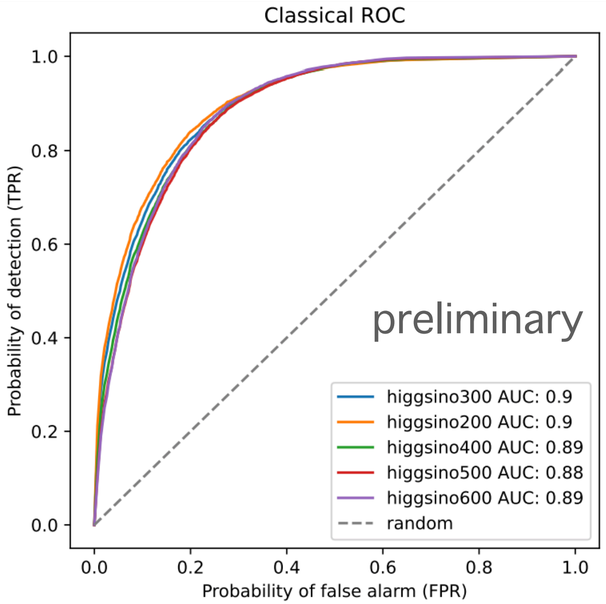


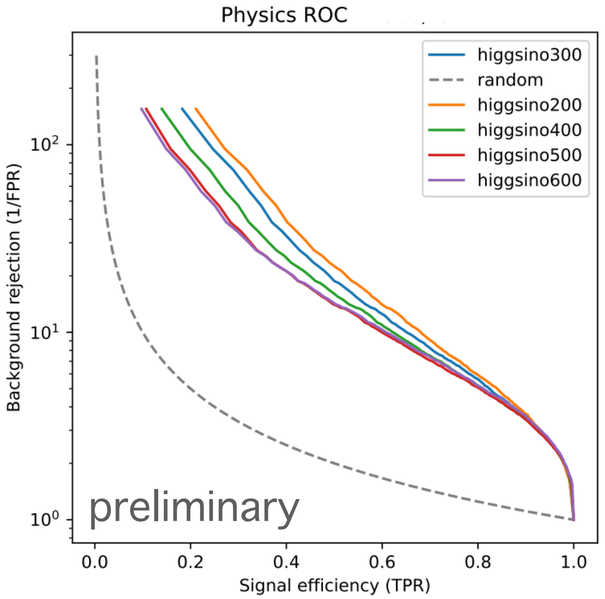
background

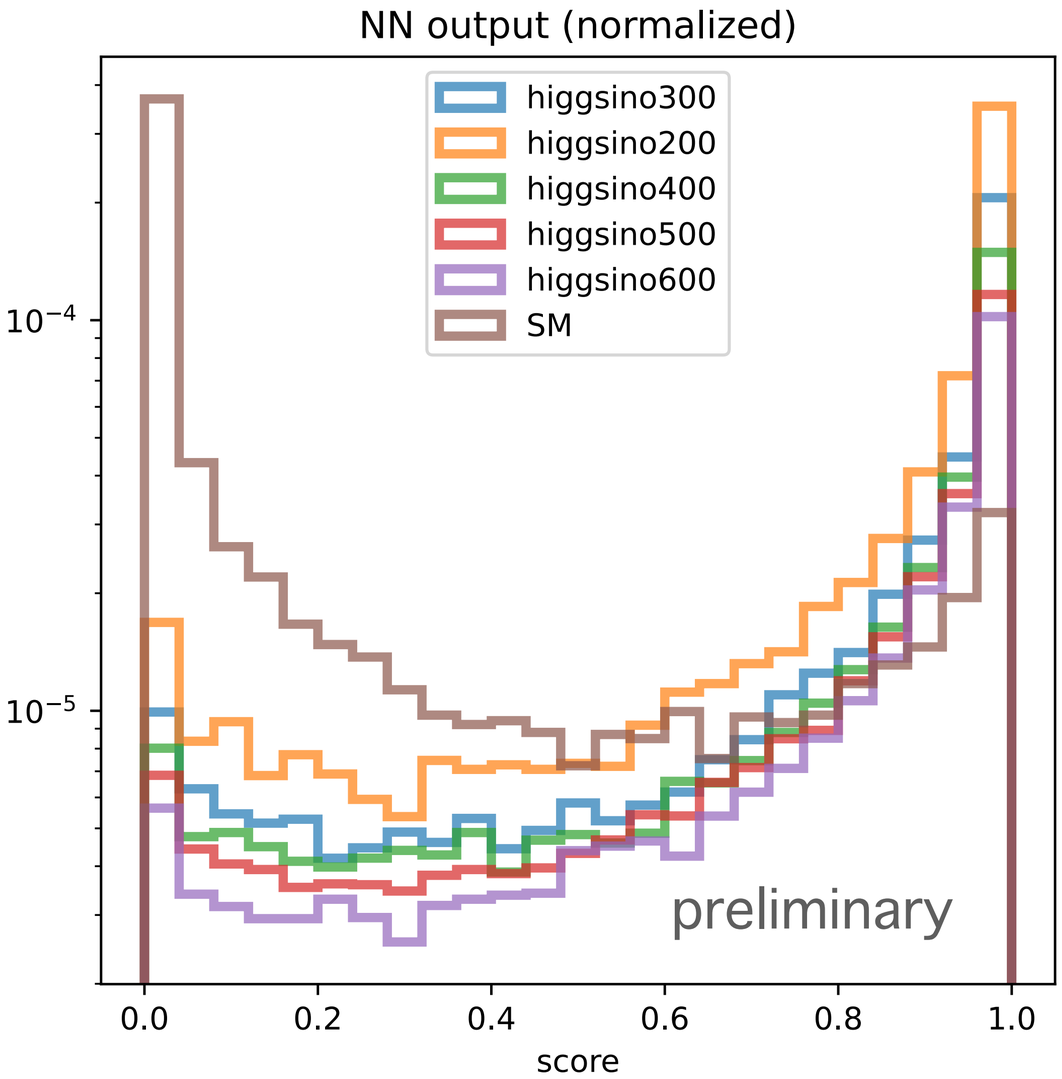
signal

adjustable threshold

Evaluation — varying Higgsino mass







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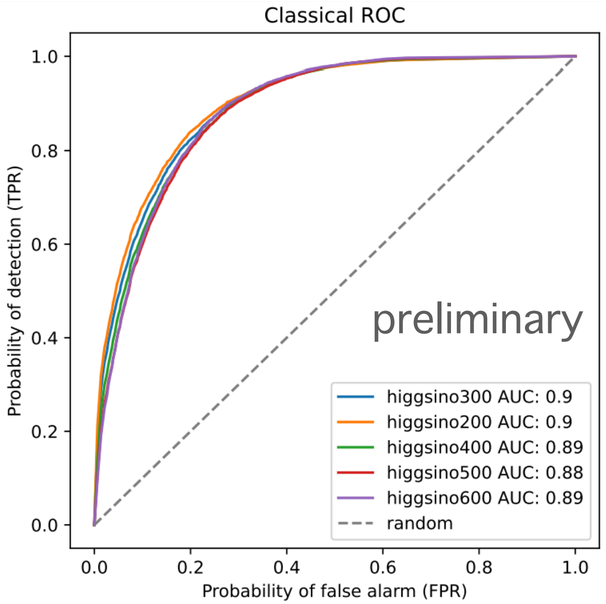
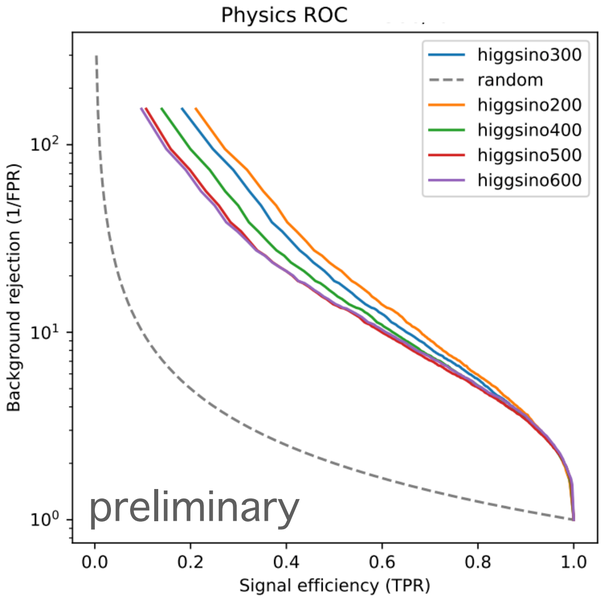
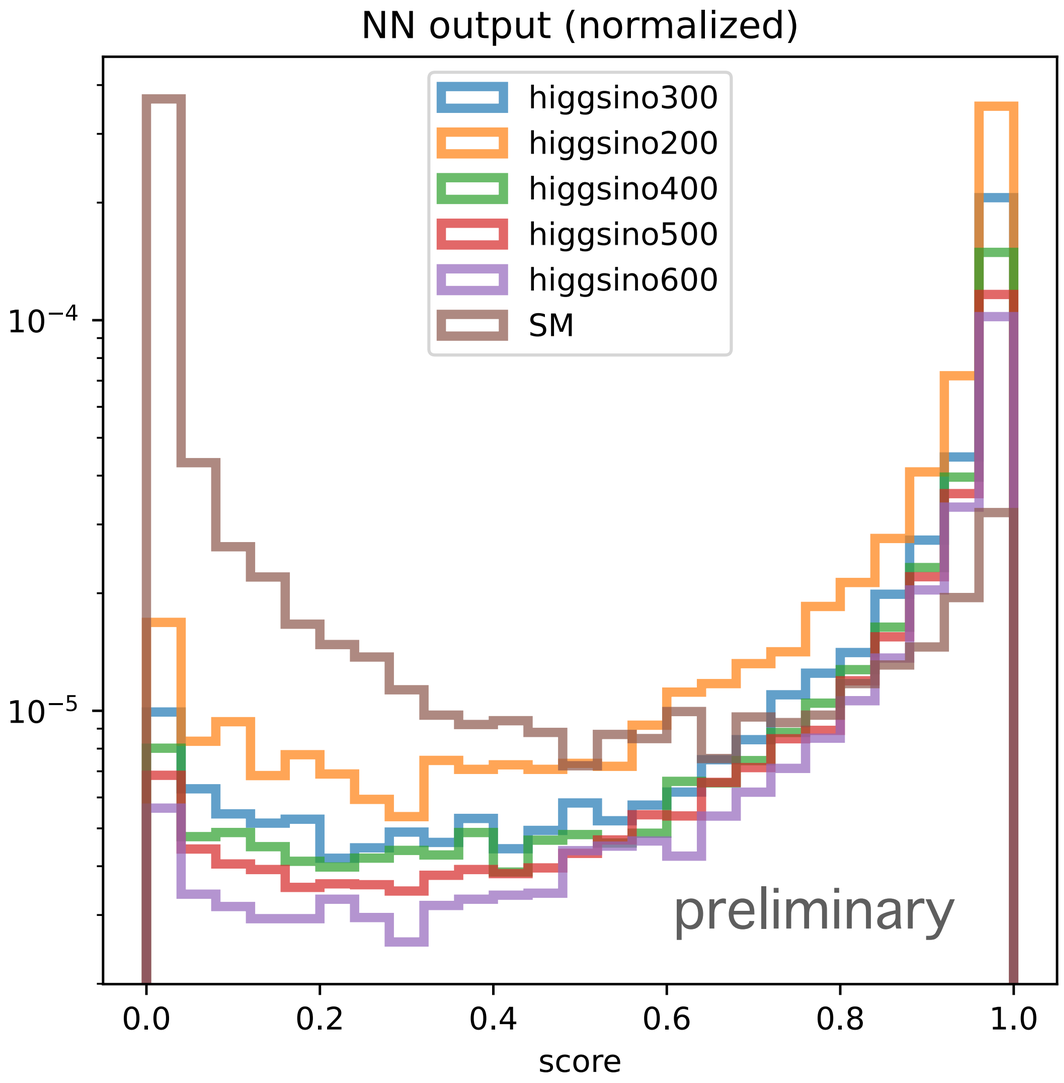
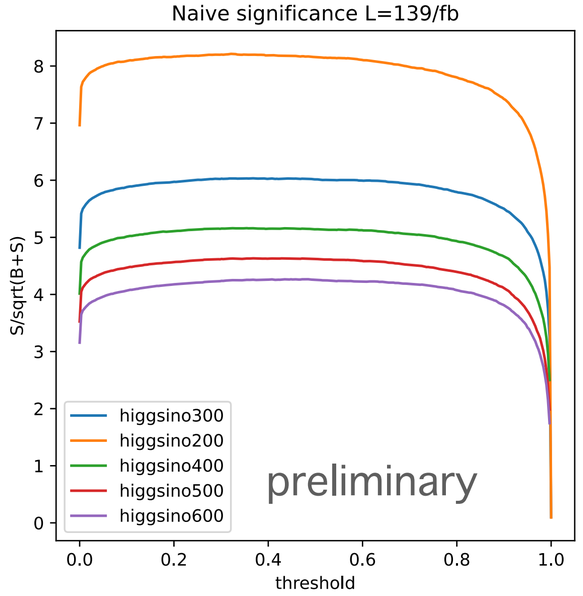
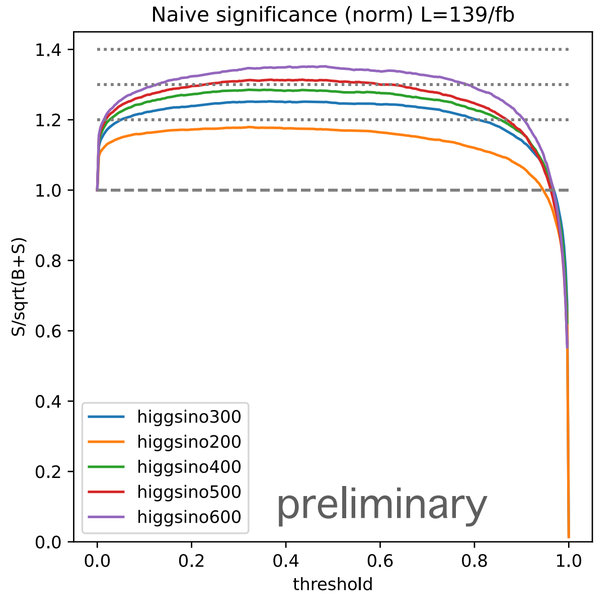
Evaluation — varying Higgsino mass











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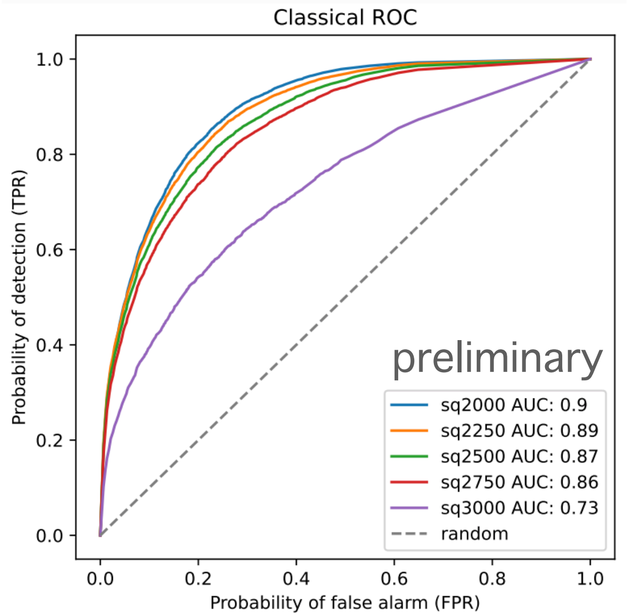
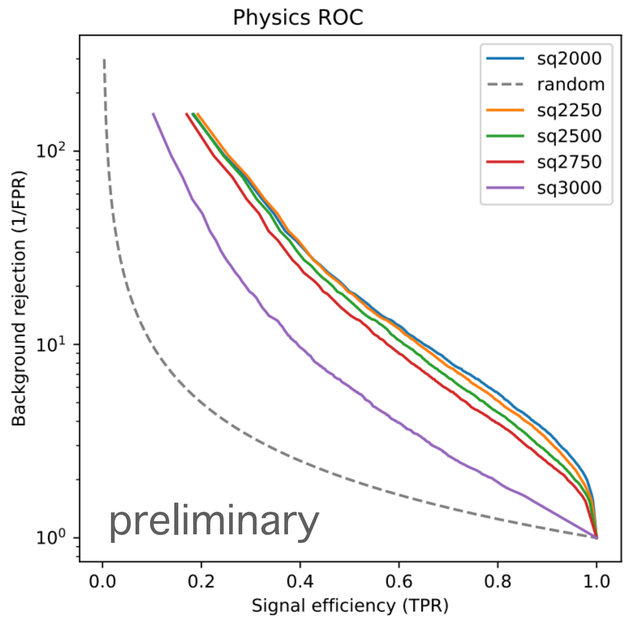
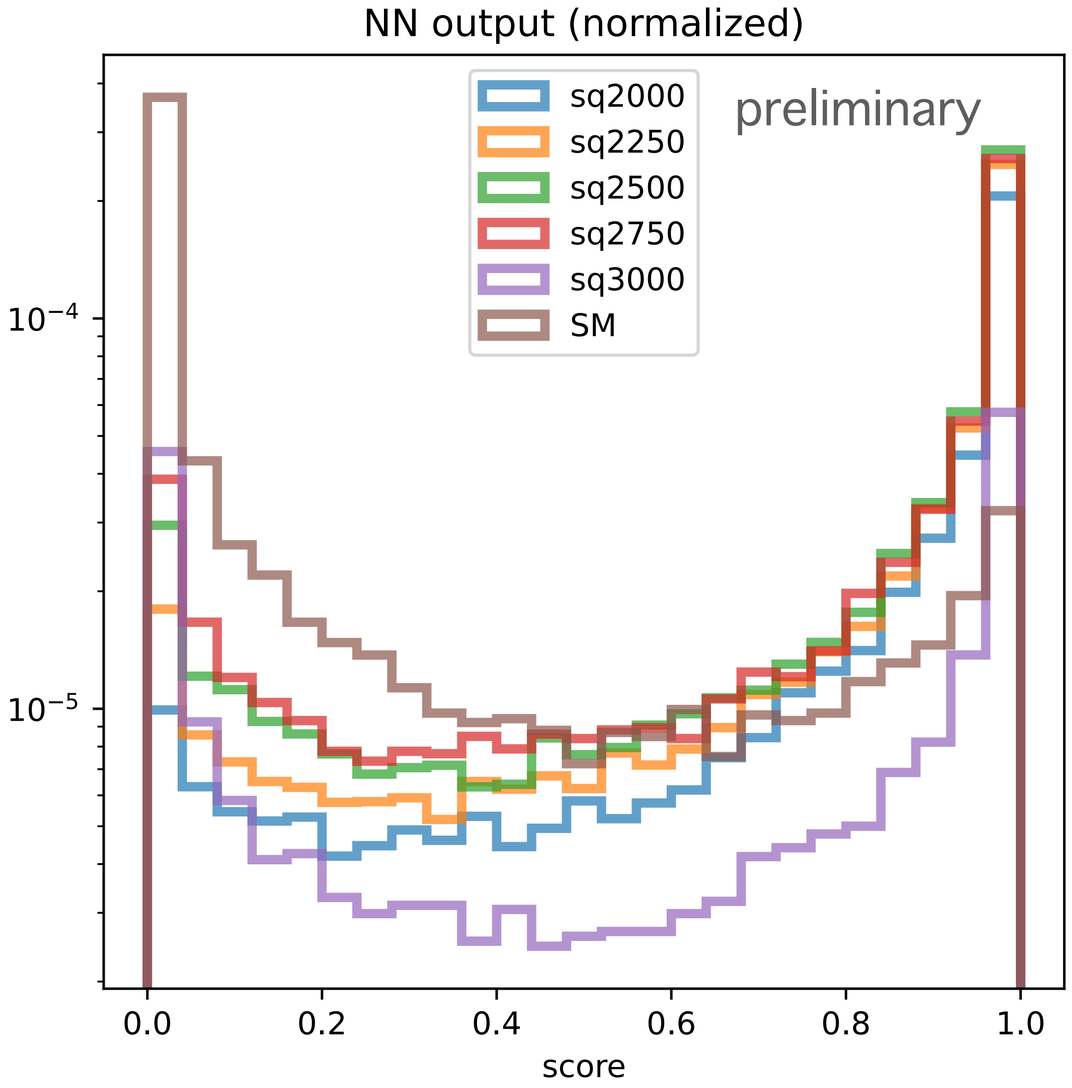
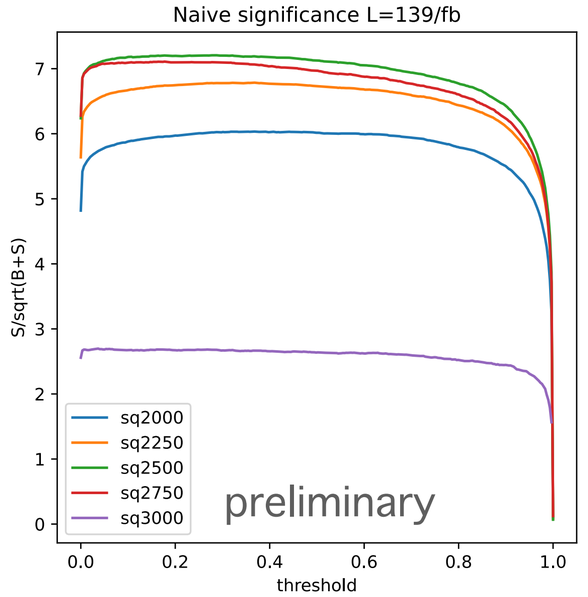
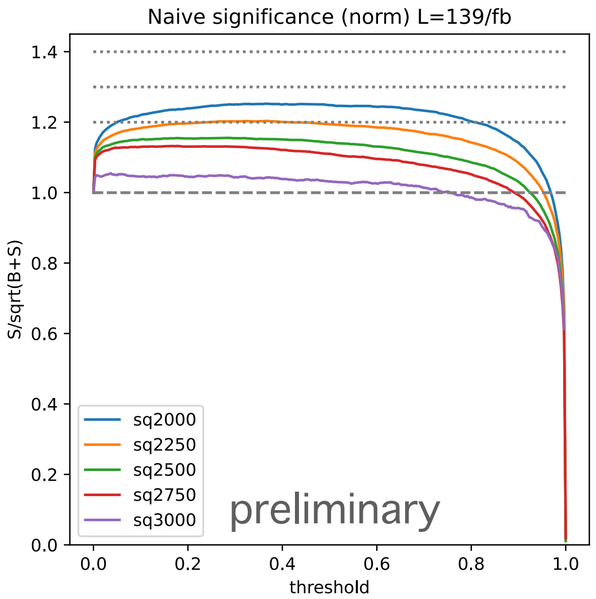
Evaluation — varying squark mass











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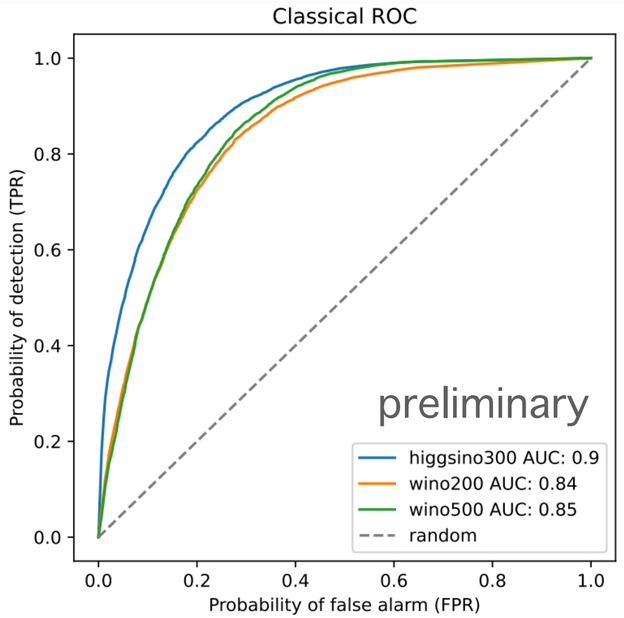
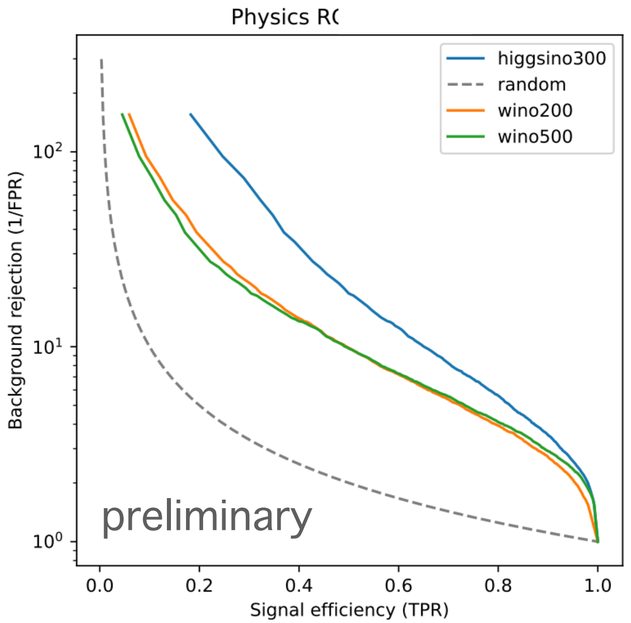
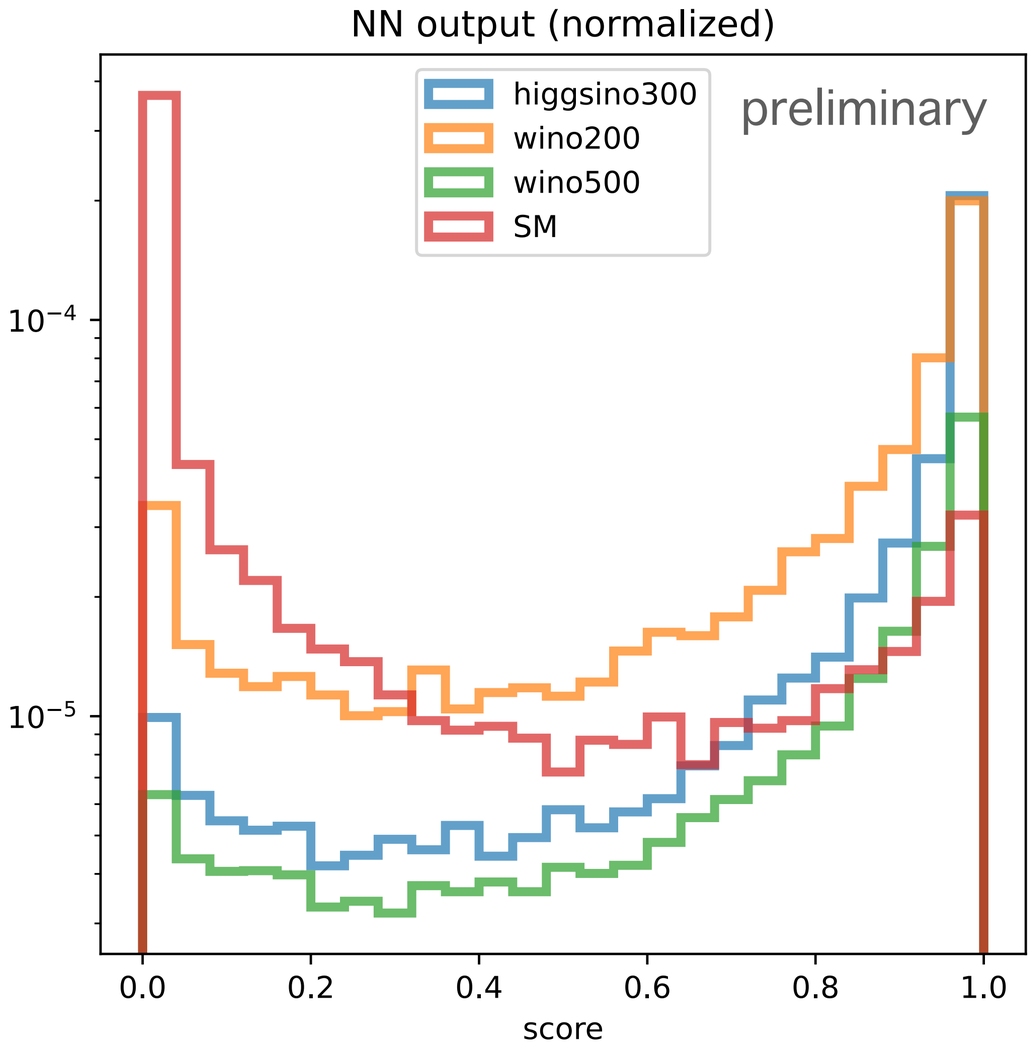
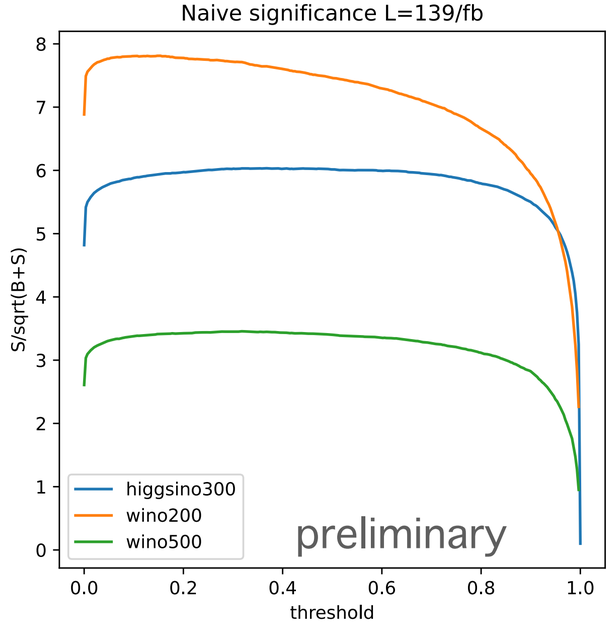
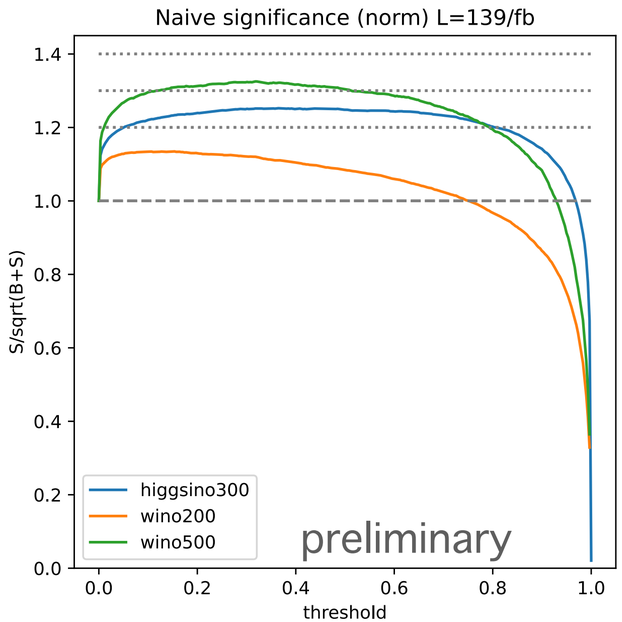
Evaluation — winos











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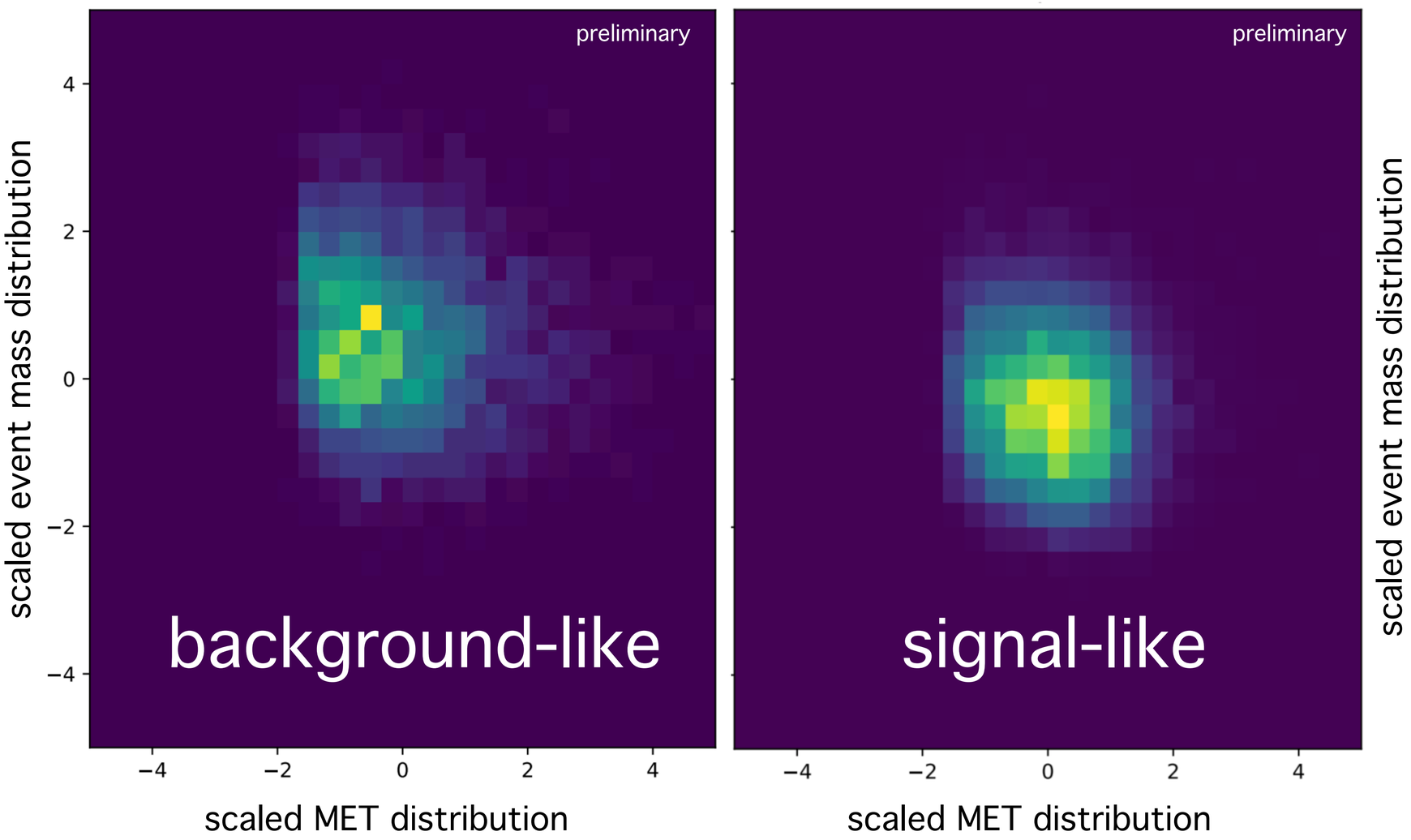
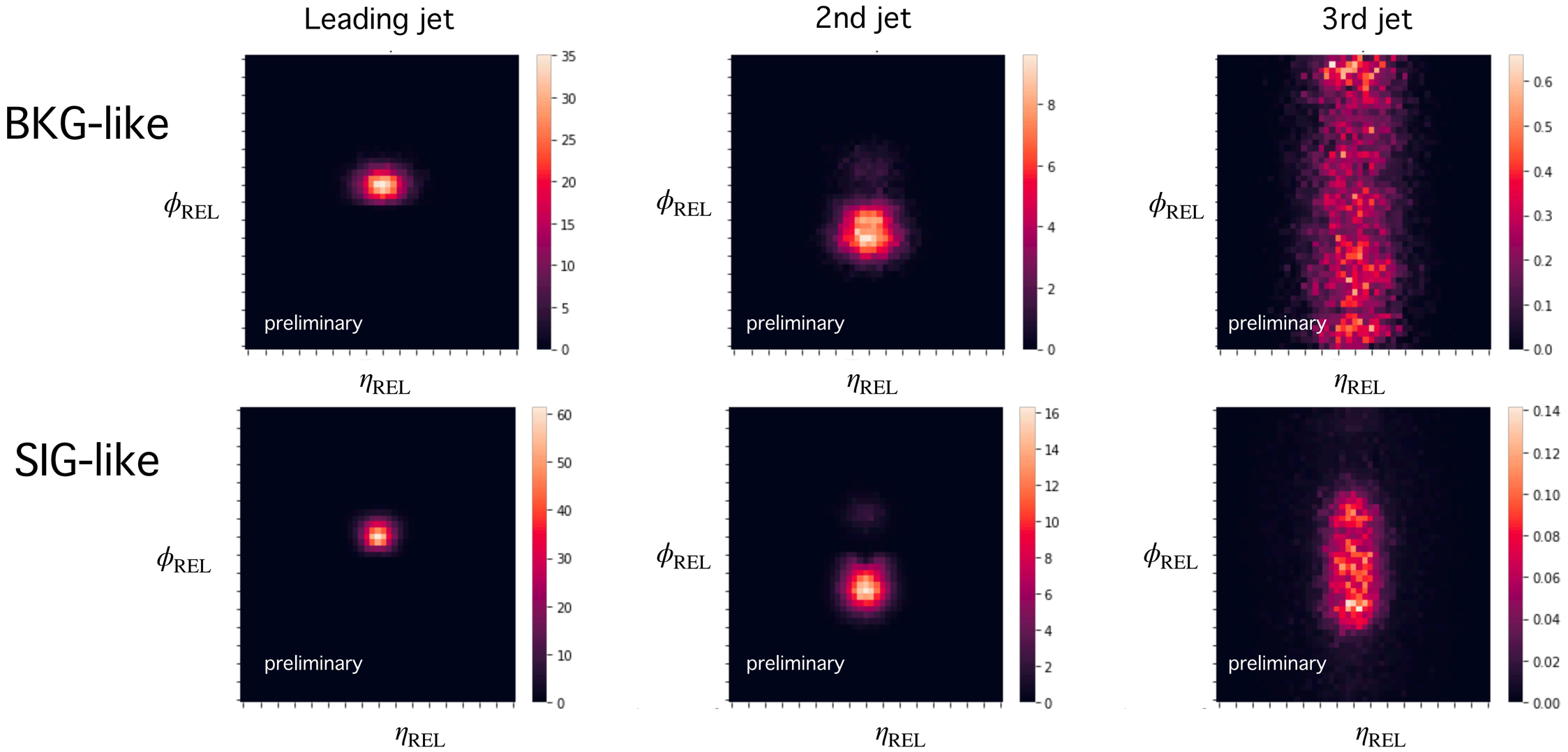
Interpretation

Morskie Oko, Tatra, Poland

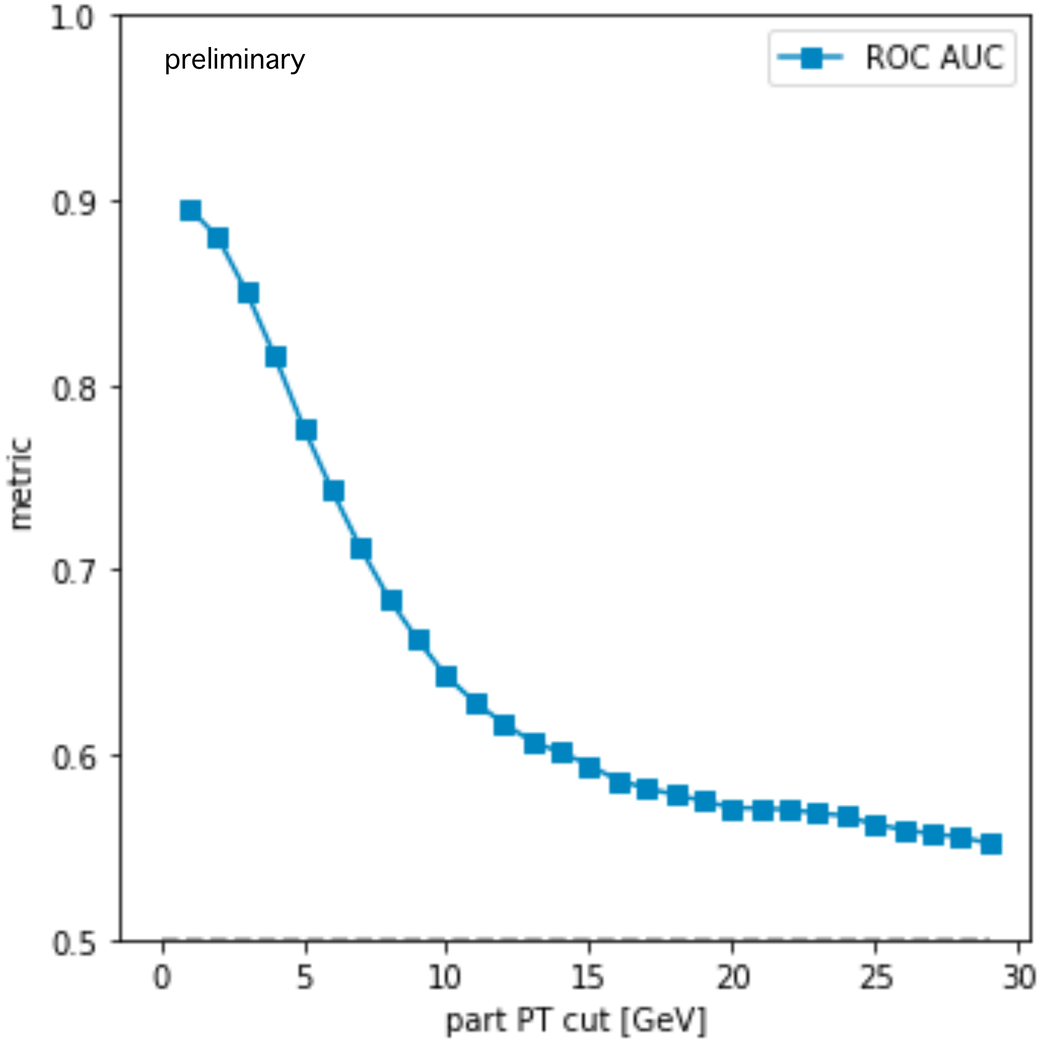
Interpretation — event-level distributions



Interpretation — calorimeter image



Interpretation — sensitivity to soft particles



Outlook

- Understand better what allows the network to distinguish between the signal and the background.
- Generate samples for heavier sparticles.
- Estimate how much the current limits on sparticles can be improved.
- Compare with BDT method

Summary

⚛Dark Matter can be searched at colliders, e.g. in the monojet channel.

⚛One of the DM candidates is neutralino in SUSY.

⚛Searches in the monojet channel can be improved if ML techniques are used.

⚛We used preselection and Neural Network based on ParticleNet applied to whole-event information.

⚛We are able to get 10-35% improvement over just preselection in terms of $S/\sqrt{(S+B)}$, depending on the sample.

⚛We are trying to interpret the model:
Network learns distributions of global variables; correlations between jets and jets' constituents; it uses information about soft particles

⚛Final goal is to estimate how the limits on sparticles' masses will improve.

⚛The method can be used also for other models contributing to the monojet channel

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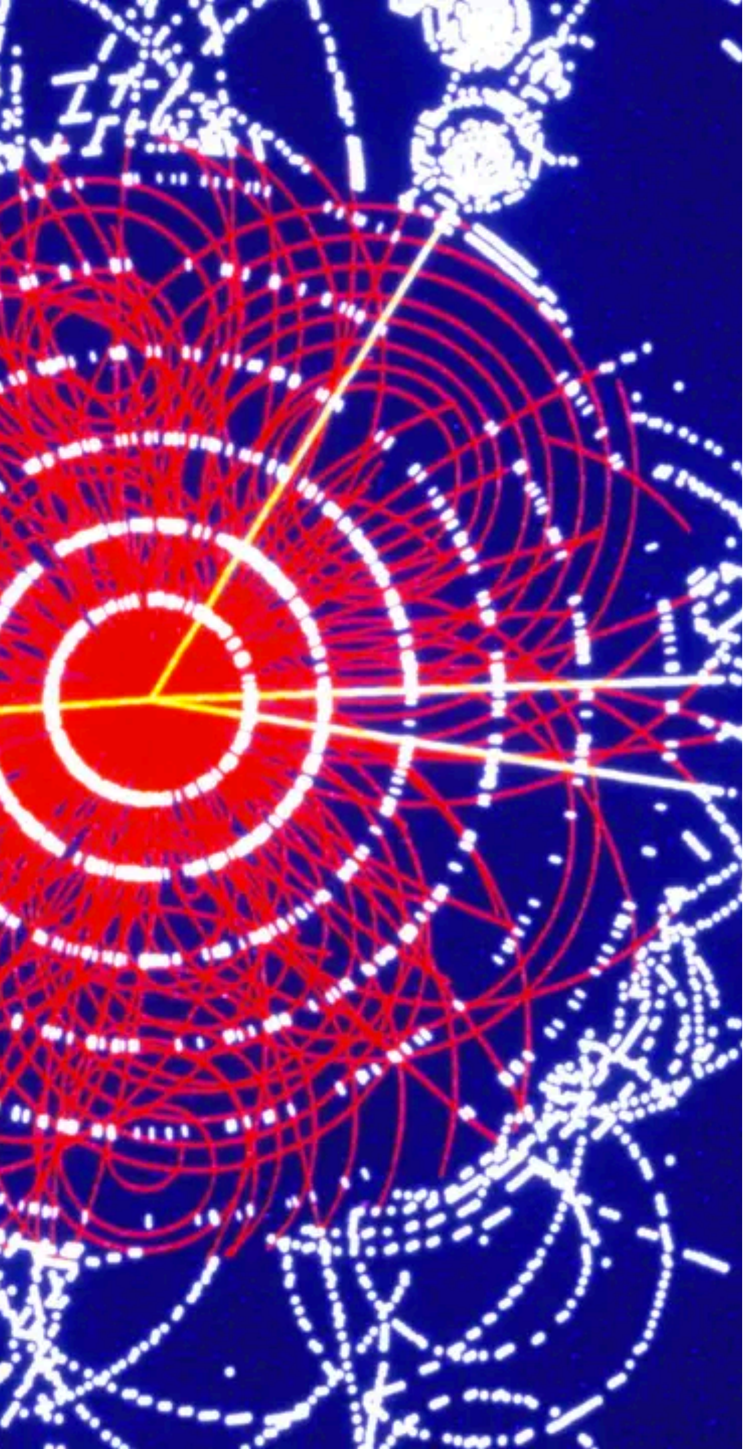
Thank you for attention!

r.maselek@uw.edu.pl

Dolina Chochołowska, Poland
photo by Piotr Kałuża



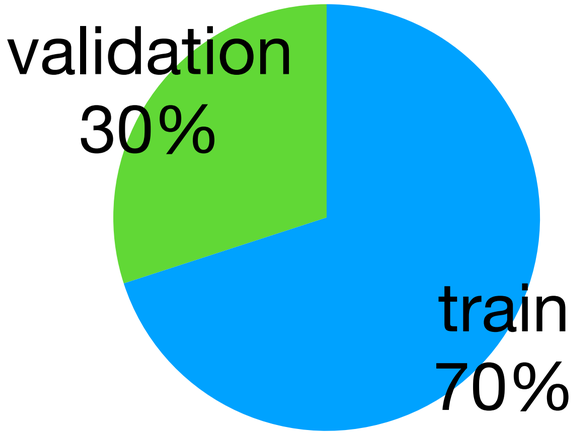
FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

Backup slides

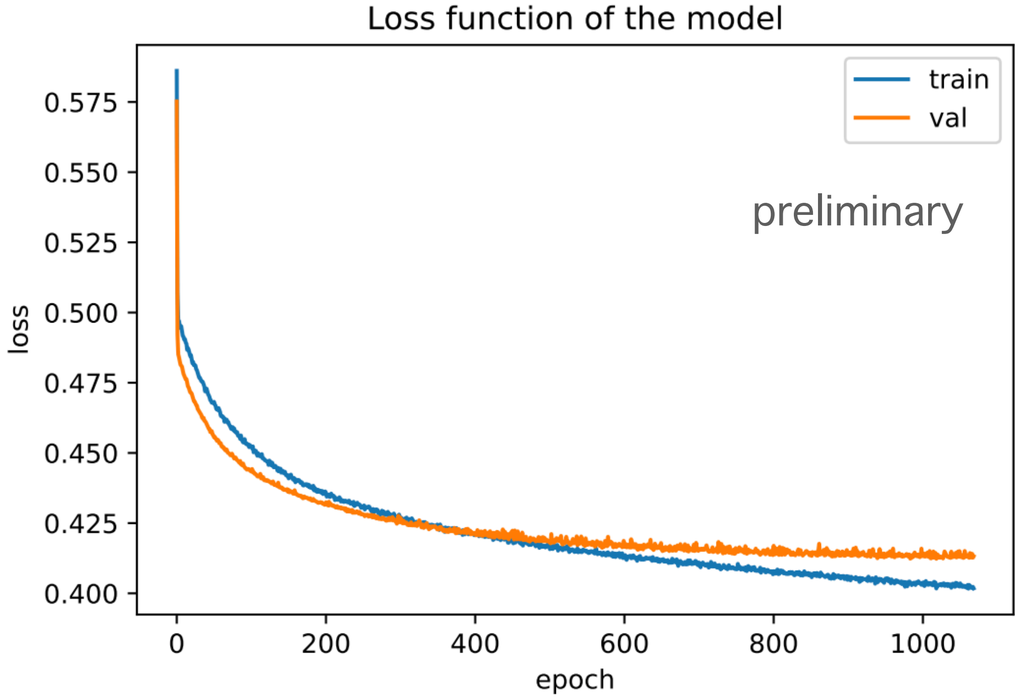
Rafał Masełek

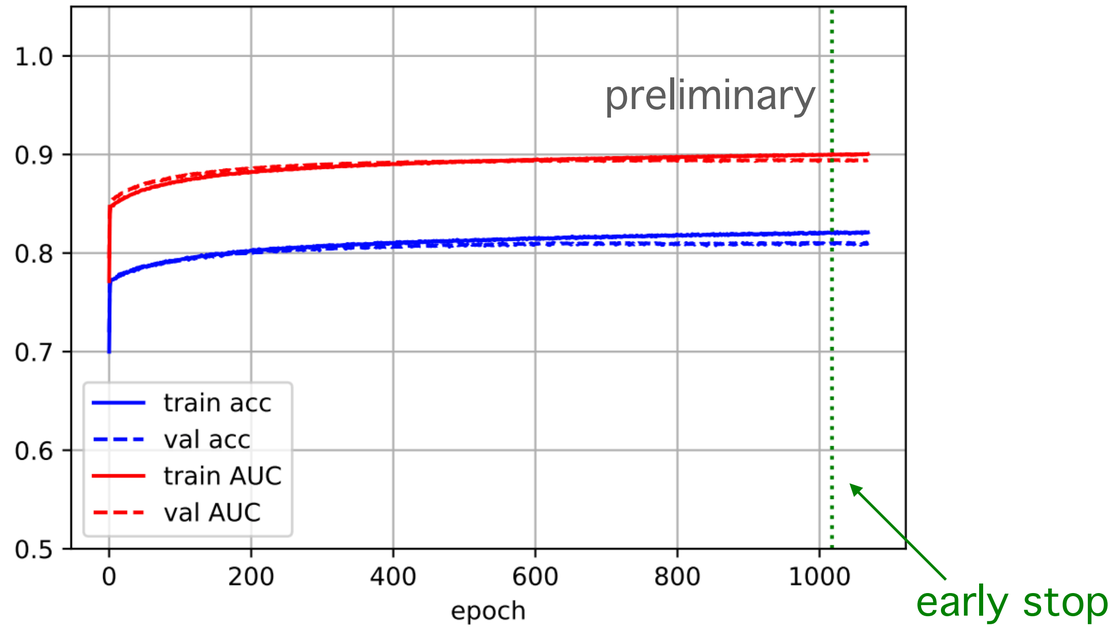
Marseille, 25-10-2023

Training



- particle p_T > 1 GeV cut on eflow objects
- fully supervised training for up to 1500 epochs
- early stopping after 50 epochs of validation loss not changing
- cosine decay learning scheduler (initial_learning_rate=0.001)





MC generation & Preselection

Training Samples

- signal:
  $pp \to \tilde{h}\tilde{h} + \text{jets},\ \mathrm{m}_{\tilde{\mathrm{h}}} = 300\ \text{GeV},\ \mathrm{m}_{\tilde{\mathrm{q}}} = 2\ \text{TeV}$
- background: $pp \to Z(\to \nu\bar{\nu}) + \text{jets}$

Testing Samples

- $m_{\tilde{q}} = 2\ \text{TeV};\ m_{\tilde{h}} \in \{200, 300, 400, 500, 600\}\ \text{GeV}$
- $m_{\tilde{h}} = 300\ \text{GeV};\ m_{\tilde{q}} \in \{2, 2.25, 2.50, 2.75, 3\}\ \text{TeV}$
- $m_{\tilde{q}} = 2\ \text{TeV};\ m_{\widetilde{W}} \in \{200, 500\}\ \text{GeV}$

Generator cuts (MG5)

- PT for at least one heavy final state > 800 GeV (SM)
- minimum jet (parton) PT > 500 GeV

Preselection

- HT > 1 TeV
- PT of the leading jet > 1 TeV
- PT of the second jet > 610 GeV
- MT2 (stransverse mass) > 1300 GeV [arXiv:hep-ph/9906349]
- MET>1280 GeV

neutralino flavour	neutralino mass [GeV]	squark mass [TeV]
higgsino	200	2.00
higgsino	300	2.00
higgsino	400	2.00
higgsino	500	2.00
higgsino	600	2.00
higgsino	300	2.25
higgsino	300	2.50
higgsino	300	2.75
higgsino	300	3.00
wino	200	2.00
wino	500	2.00

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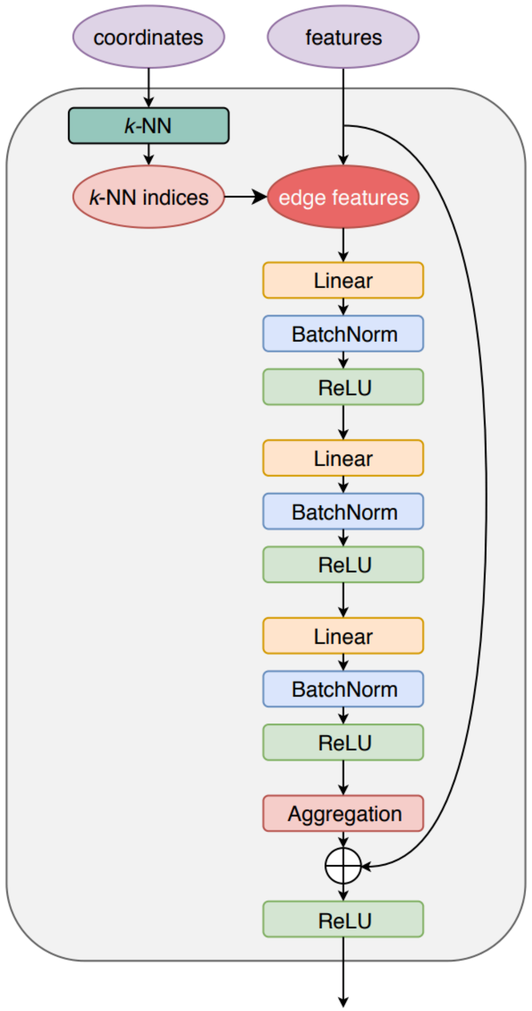
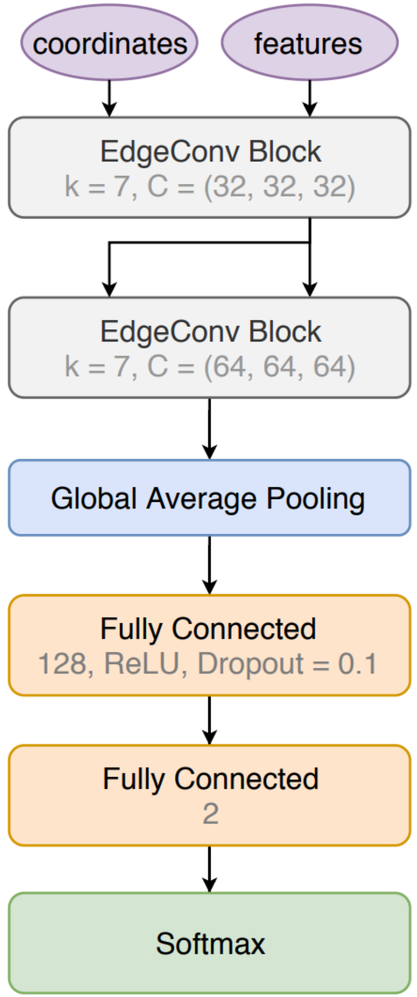
ParticleNet (lite)





(b) ParticleNet-Lite

FIG. 1: The structure of the EdgeConv block.