

UiO : **Department of Physics**
University of Oslo

Application of Supervised Machine Learning to the Search for New Physics in ATLAS data

A Study of Ordinary Dense, Parameterized
and Ensemble Networks and their Application
to High Energy Physics

William Hirst

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1 Introduction

2 The Implementation

3 Methods & Results

4 Conclusion & Outlook

1 Introduction

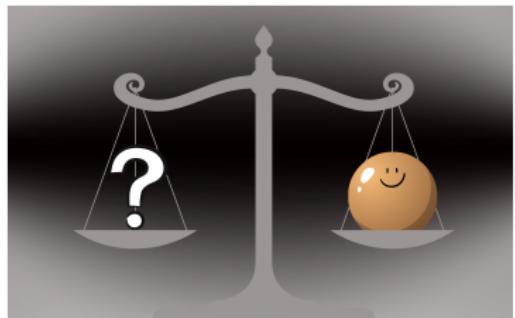
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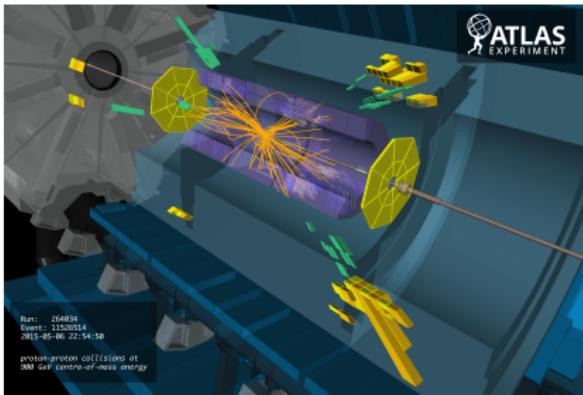
Why apply machine learning to HEP problems?

- The standard model (SM) is successful, but not enough
- Large amount of data
- Machine learning (ML)



How do we search for new physics?

- Compare theory with experiment
 - Experiment: Measured
 - Theory: Simulated
- Search regions
- Expected significance
 - $Z_{\text{exp}} \approx \frac{\text{signal}}{\sqrt{\text{background}}}$
- Difficult to separate → ML



Aim

- 1 Signal → background
- 2 Use ML to separate signal from background
- 3 Measure performance in Z_{exp}
- 4 Study and compare

The Implementation

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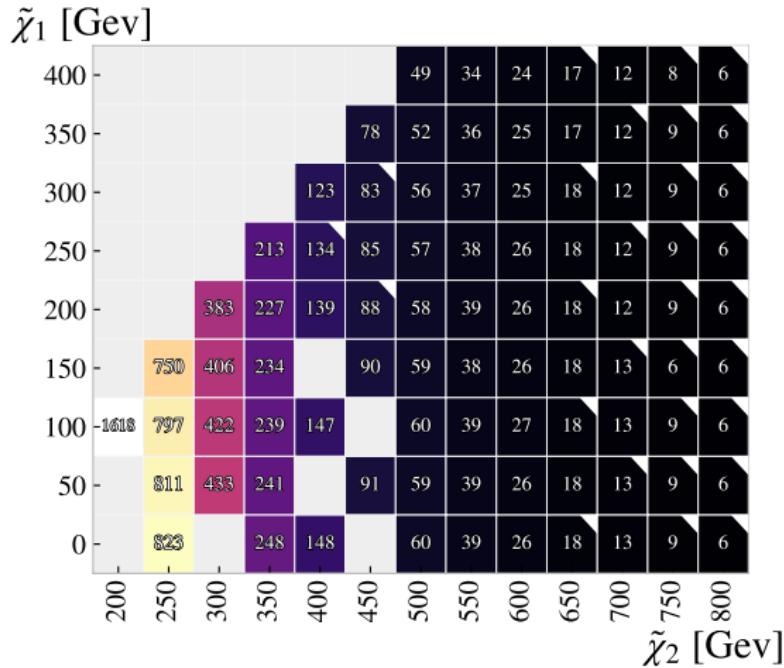
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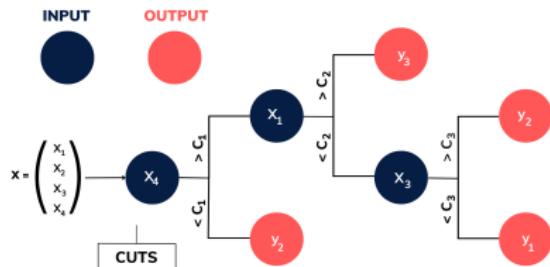
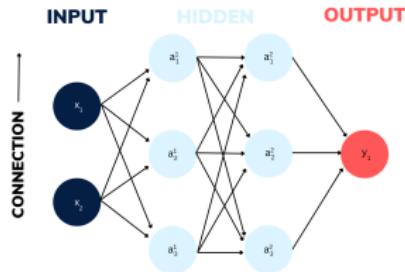
The Supersymmetry signal

- Chargino-neutralino production
- Free parameters → masses
- Nr-of-Events(Mass)



A summary of the applied methods

- Three neural network variants
 - Ordinary dense neural network
 - Ensemble networks/Local-Winner-Takes-All (LWTA)
 - Parameterized neural networks (PNN)
- One boosted decision tree method



Training strategy

- Classification
 - Background → 0
 - Signal → 1
- 80% training and 20% validation
- Early stopping criteria
 - Performance on validation set

Methods & Results

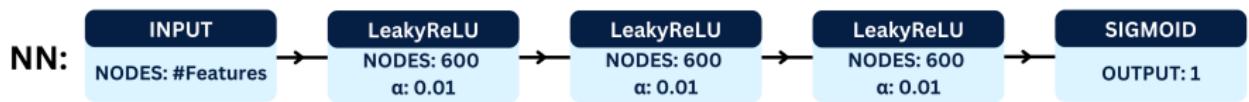
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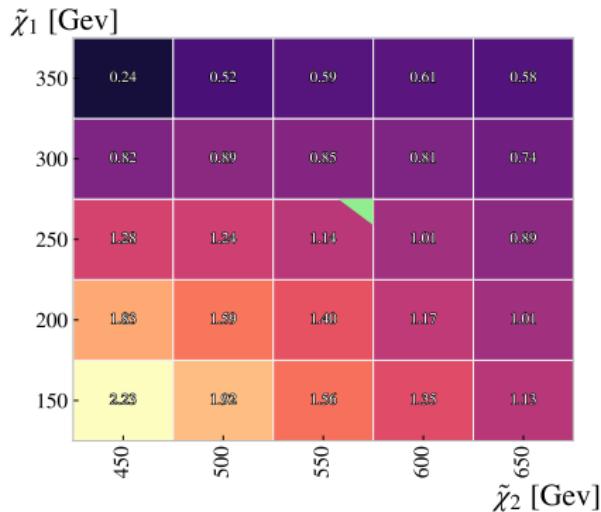
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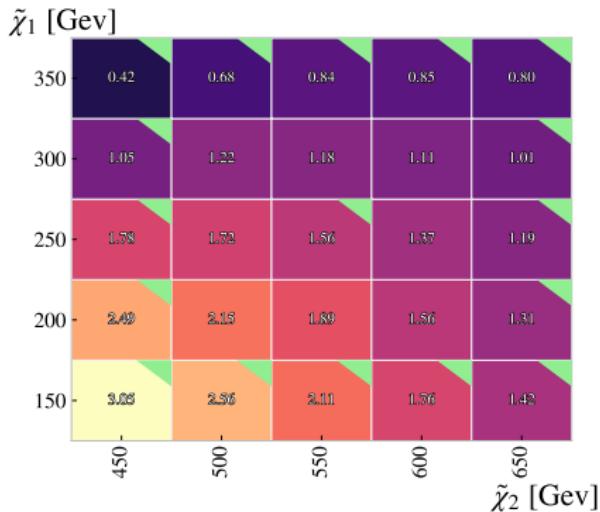
“Ordinary” dense neural network



Compare one-mass approach to several-masses approach



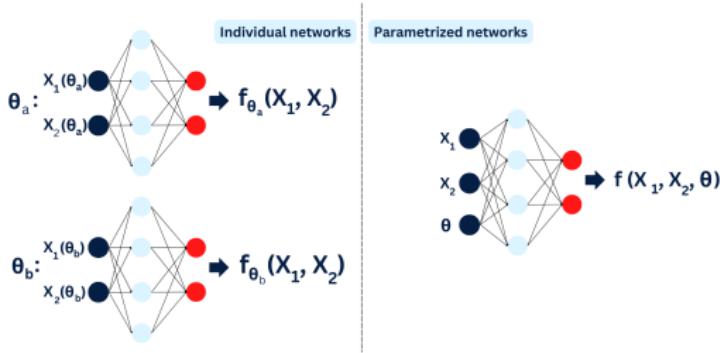
One-mass-model (OMM)



Several-mass-model (SMM)

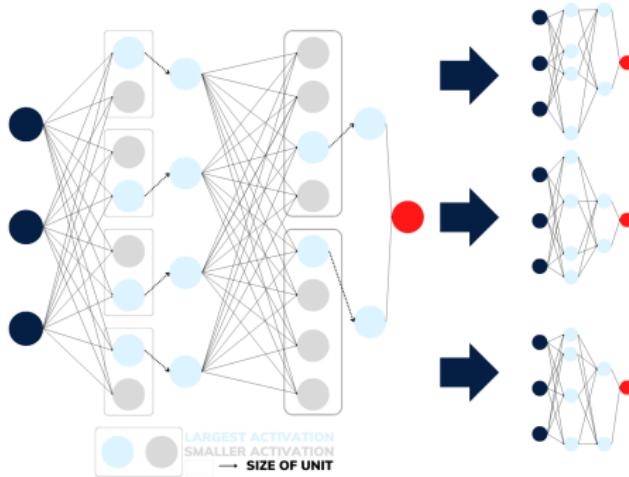
Parameterized neural network

- Long-term memory
- PNN → signal includes mass parameter in feature set
- Background assigned parameters randomly

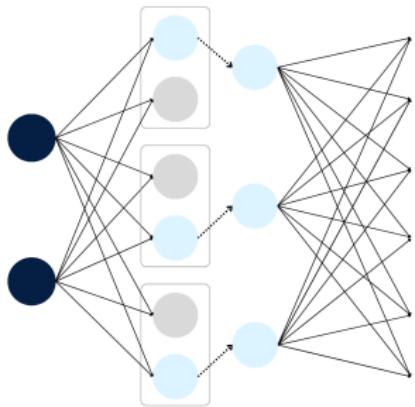


Ensemble methods - Local-Winner-Takes-All (LWTA)

- Dropout
- Competing nodes - Units
- Encode information in pattern specific pathways



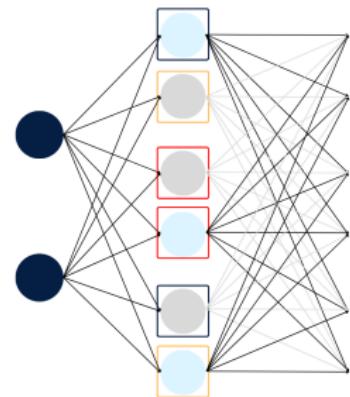
Maxout, Channel-Out and Stochastic-Channel-Out (SCO)



MAXOUT

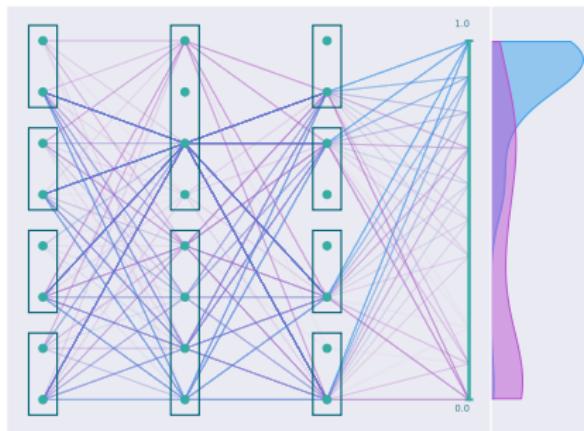


CHANNEL-OUT

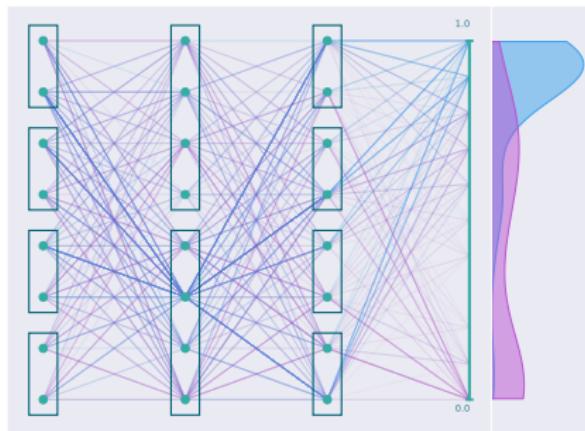


SCO

Visualization and study of sparse pathways

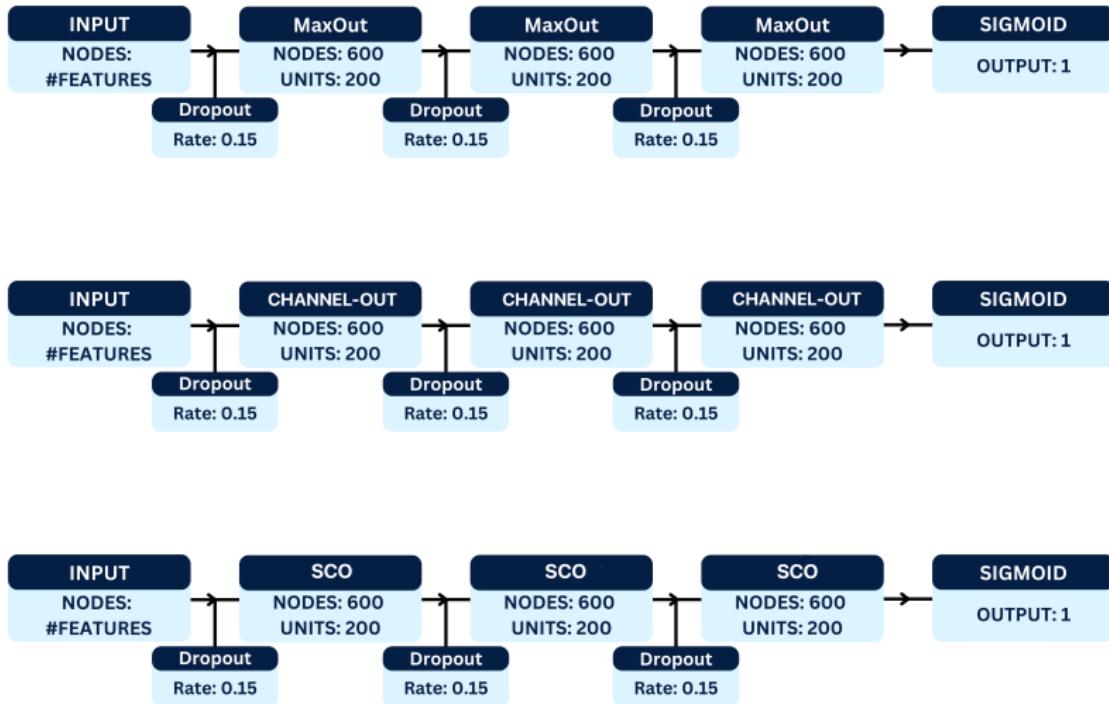


Maxout

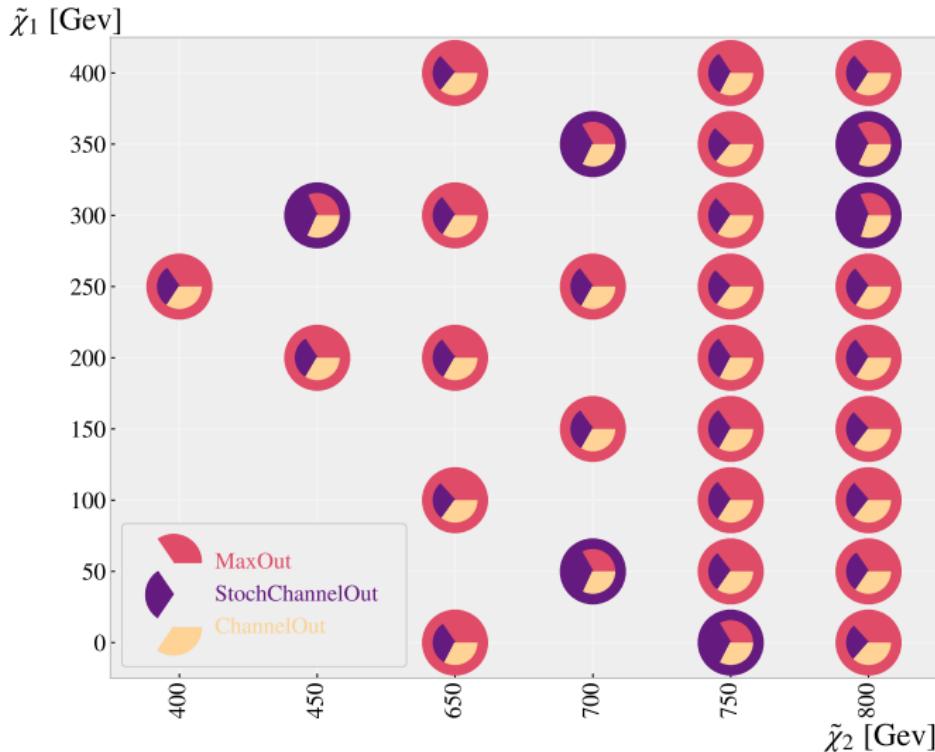


SCO

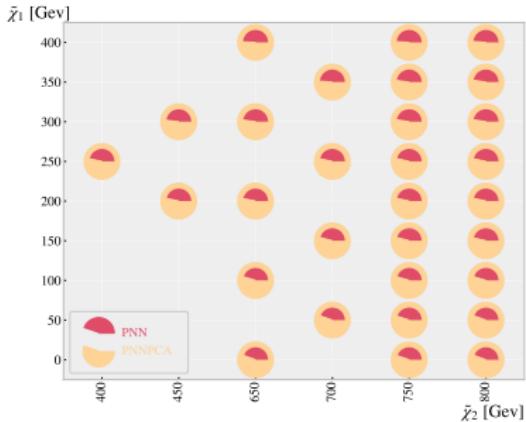
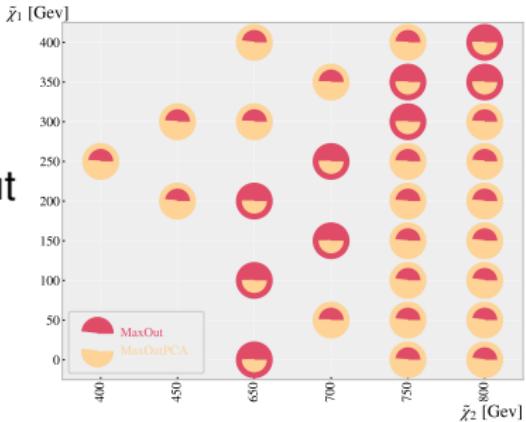
Ensemble network architecture



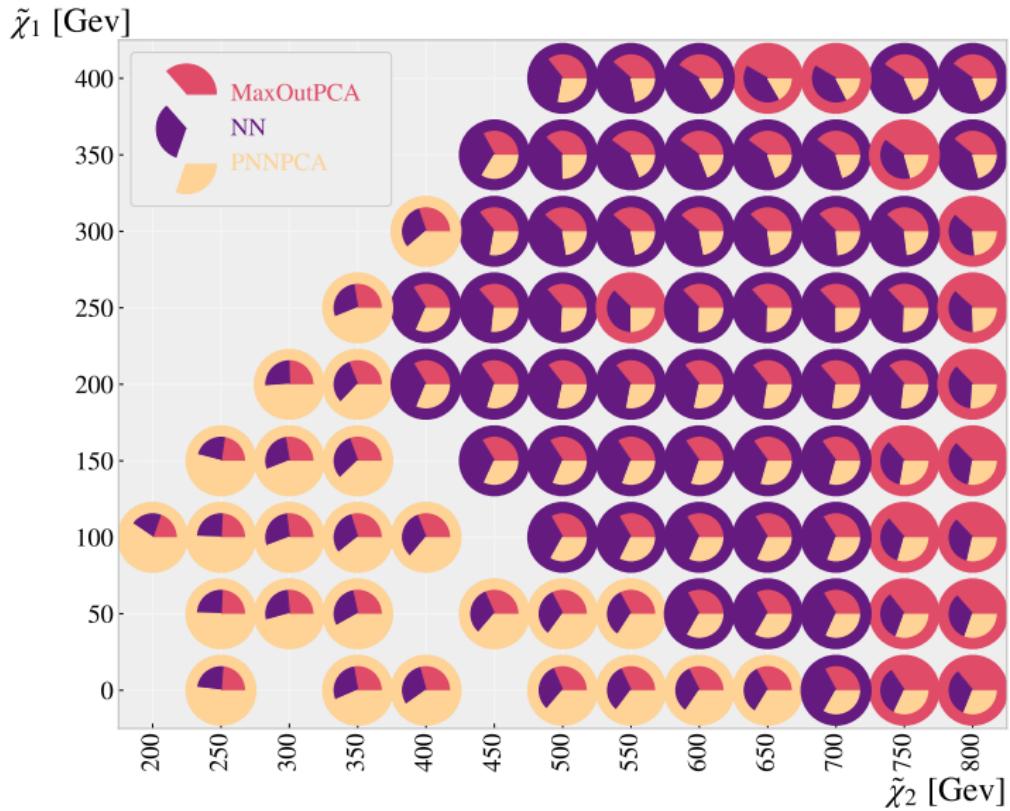
Comparing sensitivity of channel-out, SCO and maxout



Increasing sensitivity using principal component analysis

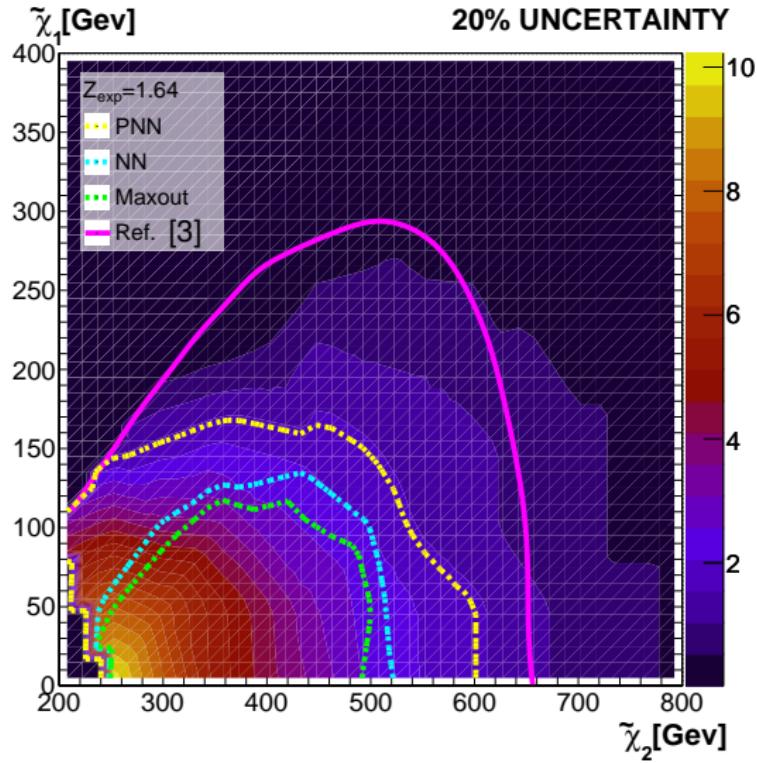


Comparing methods on full signal grid



Comparing the methods to previous analysis

- Compare the expected limits to analysis made by ATLAS in 2021 [3]



Conclusion & Outlook

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Key findings

- 1 Diverse signal → improve performance
- 2 SCO
- 3 PNN bias towards smaller masses
- 4 Maxout achieved balanced performance

The way forwards

- 1 More advanced analysis of ML output
- 2 LWTA promising (SCO)
- 3 Combine PNN and LWTA



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References

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Figure on front page
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‘ATLAS event at 900 GeV - 6 May 2015 - Run 264034 lb 659 event 11526514’.
<https://cds.cern.ch/record/2015238>
Figure on slide 4
-  ATLAS Collaboration [3].
‘Search for chargino–neutralino pair production in final states with three leptons and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector’.
<http://arxiv.org/abs/2106.01676>