

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**

**June 1, 2023**

## 1 Introduction

## 2 The Implementation

## 3 Methods & Results

## 4 Conclusion & Outlook

## 1 Introduction

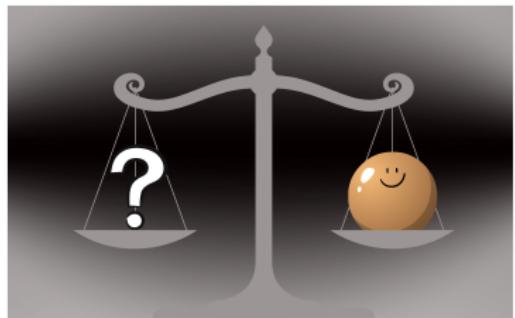
## 2 The Implementation

## 3 Methods & Results

## 4 Conclusion & Outlook

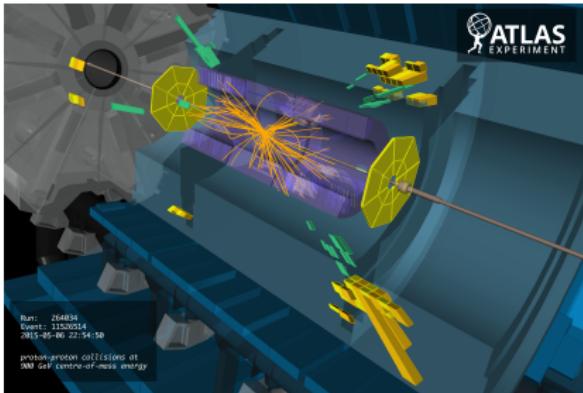
# Why apply machine learning to HEP problems?

- 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

## 1 Introduction

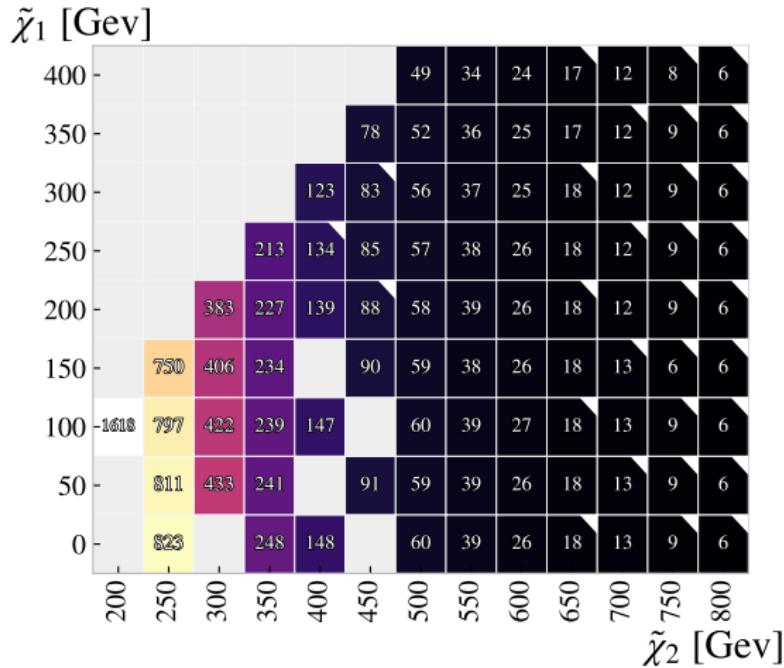
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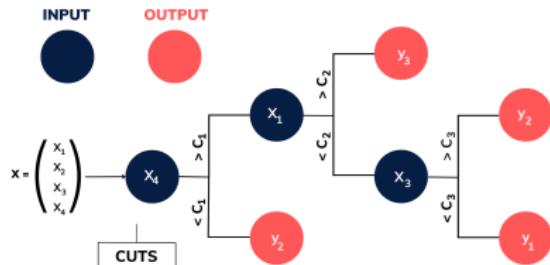
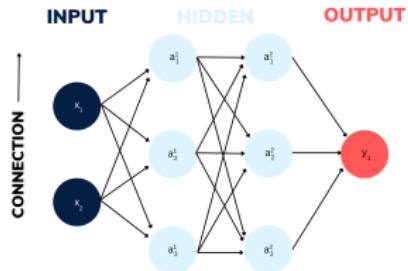
# The Supersymmetry signal

- 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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## 2 The Implementation

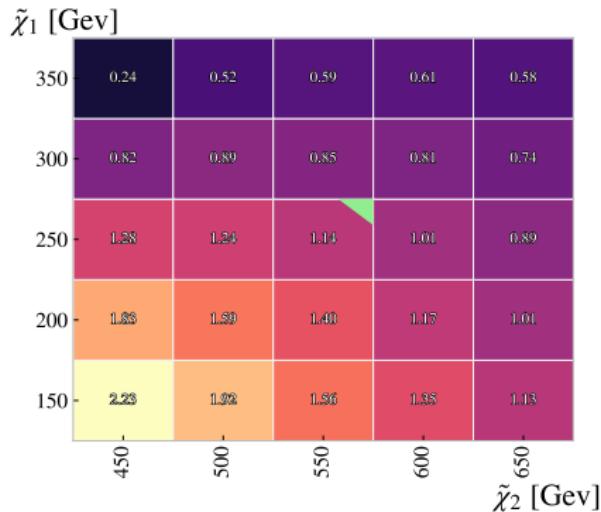
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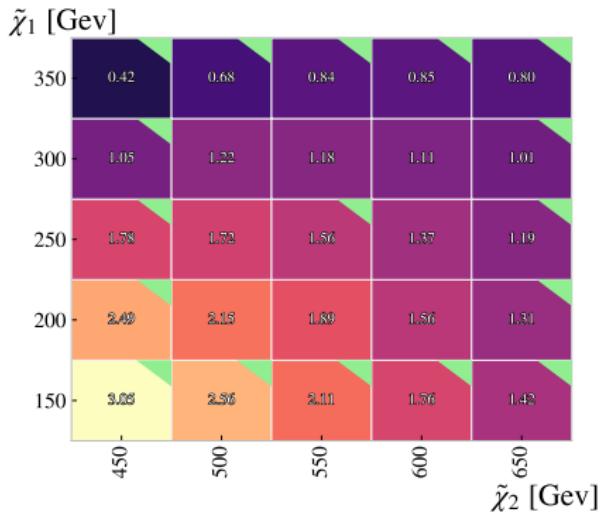
# “Ordinary” dense neural network



# Compare one-mass approach to several-masses approach



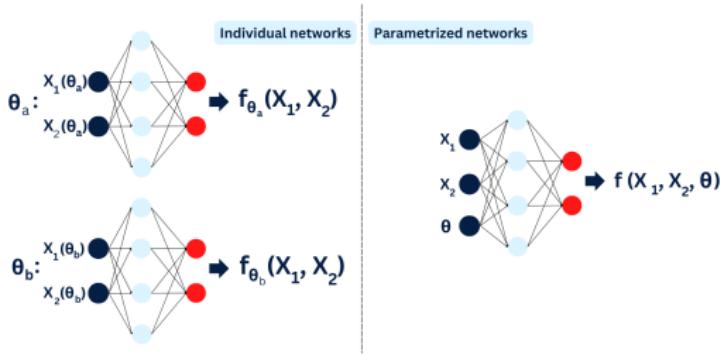
One-mass-model (OMM)



Several-mass-model (SMM)

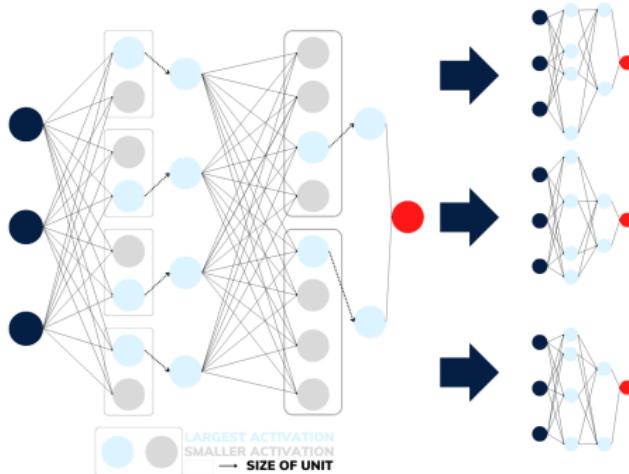
# Parameterized neural network

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

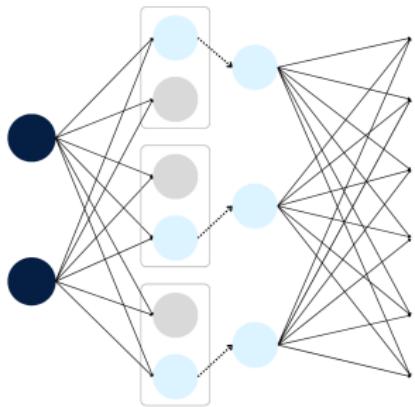


# Ensemble methods - Local-Winner-Takes-All (LWTA)

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



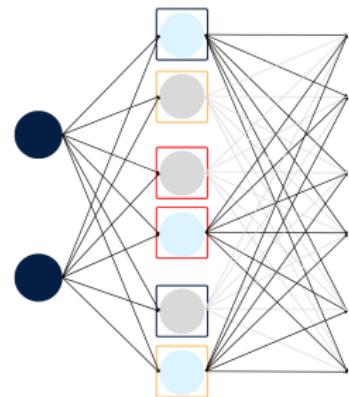
# Maxout, Channel-Out and Stochastic-Channel-Out (SCO)



MAXOUT

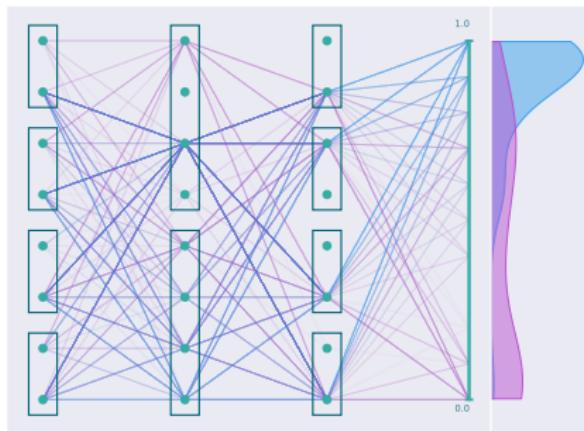


CHANNEL-OUT

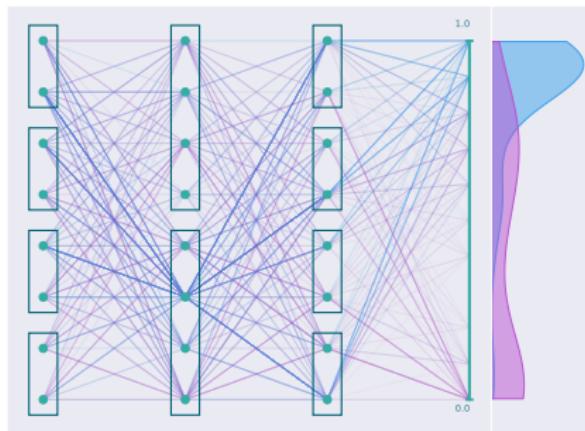


SCO

# Visualization and study of sparse pathways

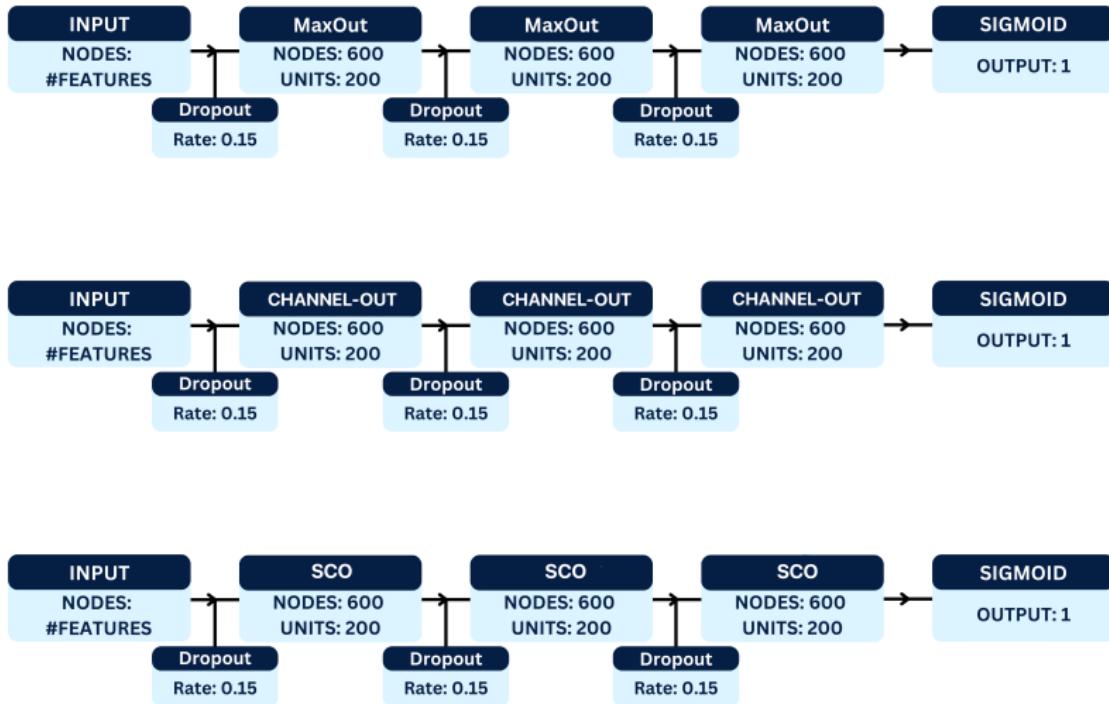


Maxout

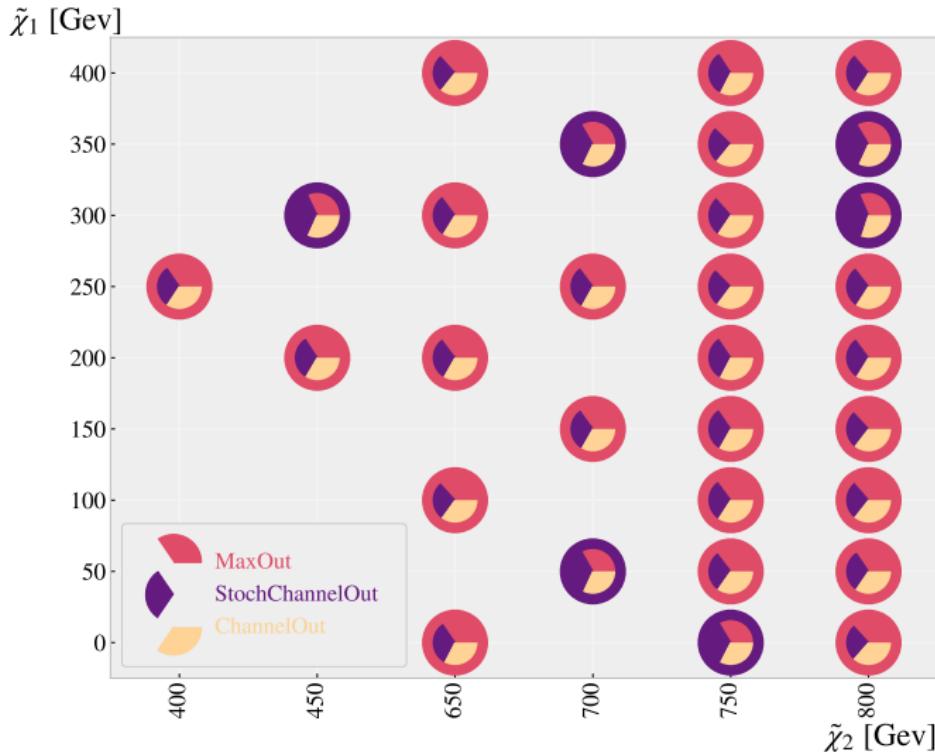


SCO

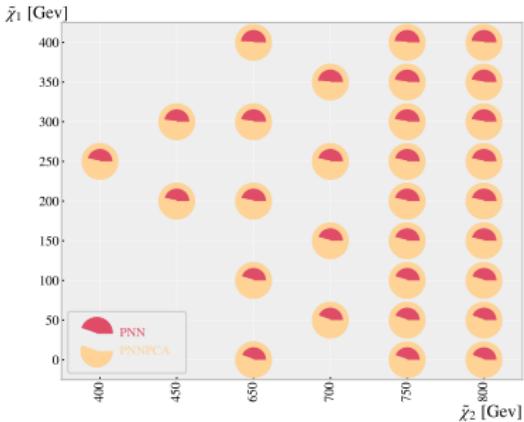
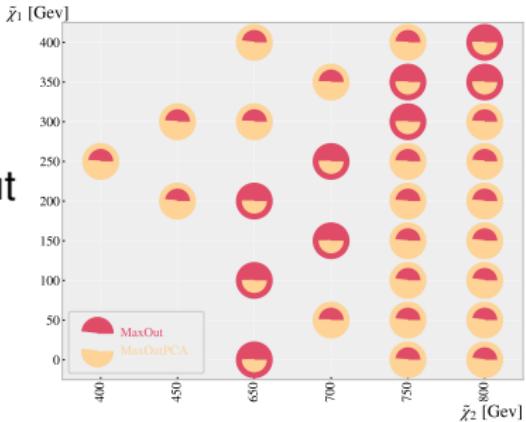
# Ensemble network architecture



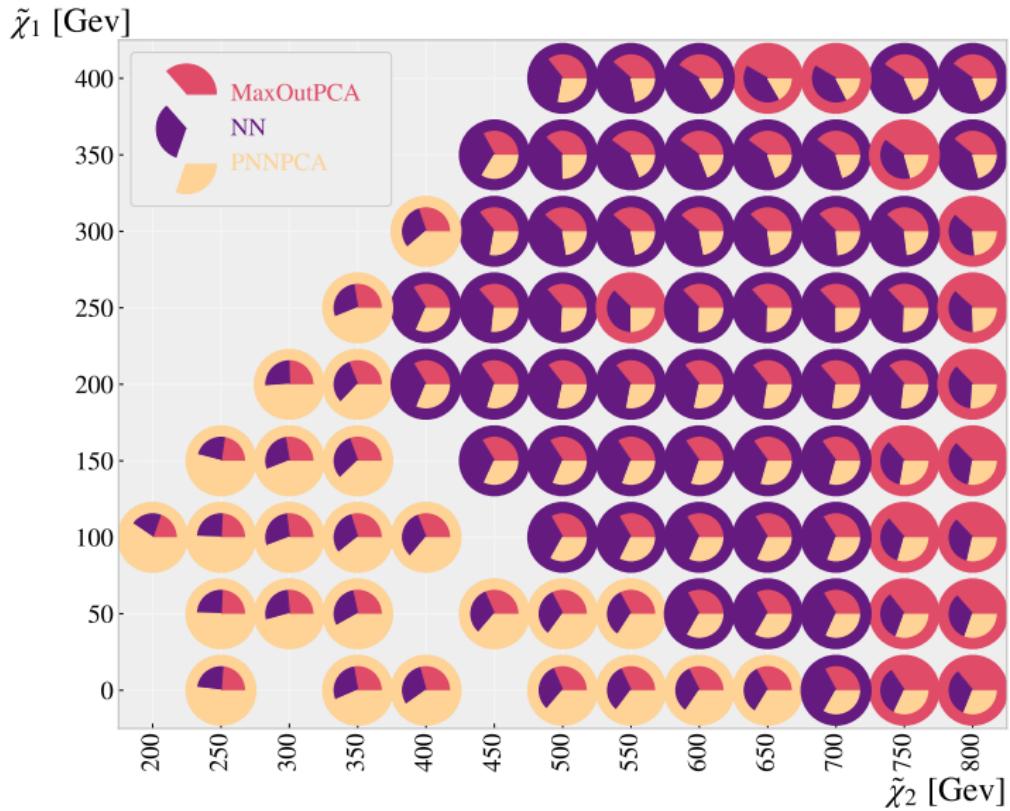
# Comparing sensitivity of channel-out, SCO and maxout



# Increasing sensitivity using principal component analysis

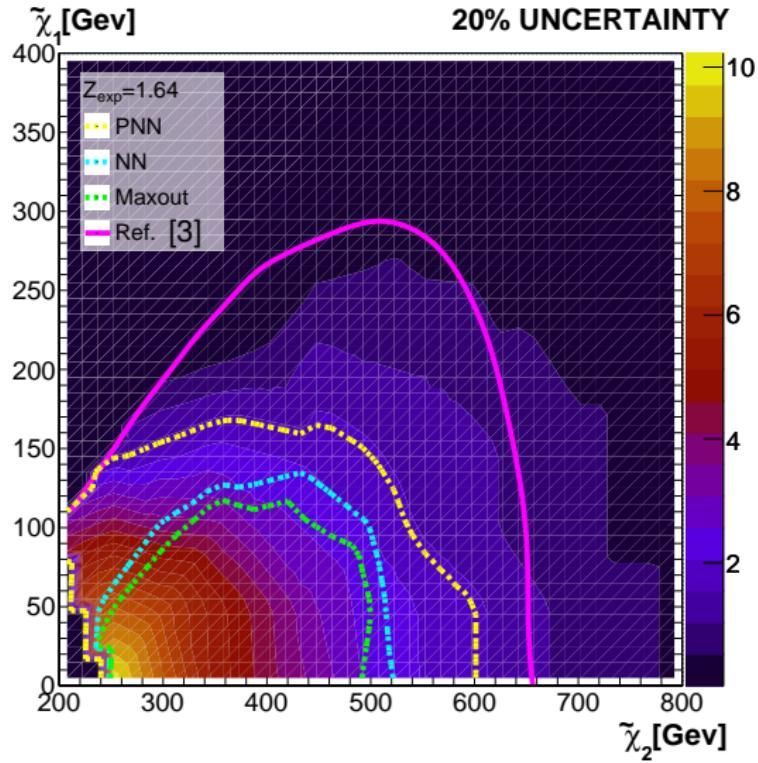


# Comparing methods on full signal grid



# 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

-  Maximilien Brice.  
‘Installing the ATLAS calorimeter. Vue centrale du détecteur ATLAS avec ses huit toroides entourant le calorimètre avant son déplacement au centre du détecteur’.  
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Figure on front page
-  ATLAS Collaboration.  
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<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>