Harnessing Anomaly Detection Tools as Novel Analysis Resources for High Energy Physics

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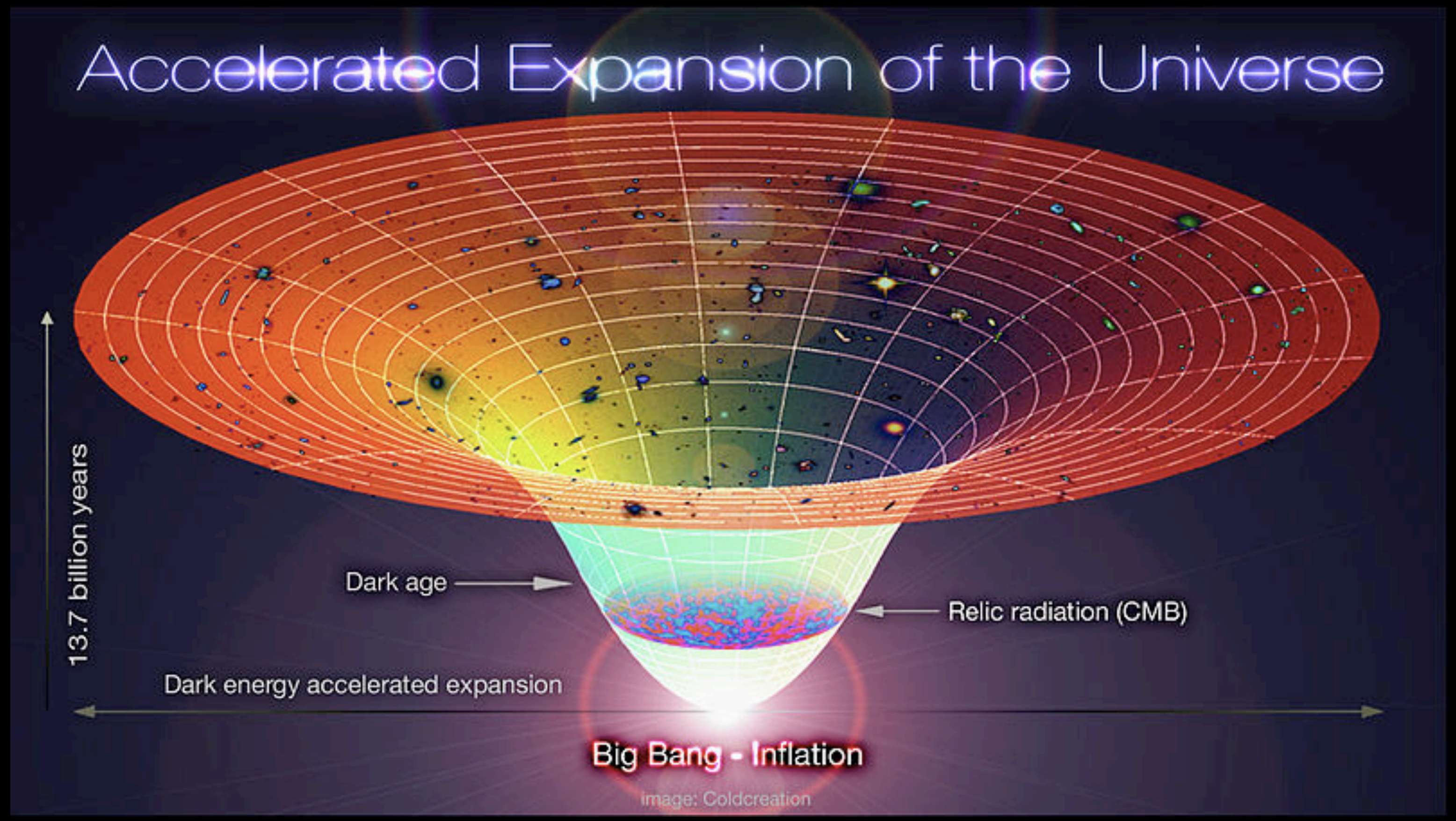
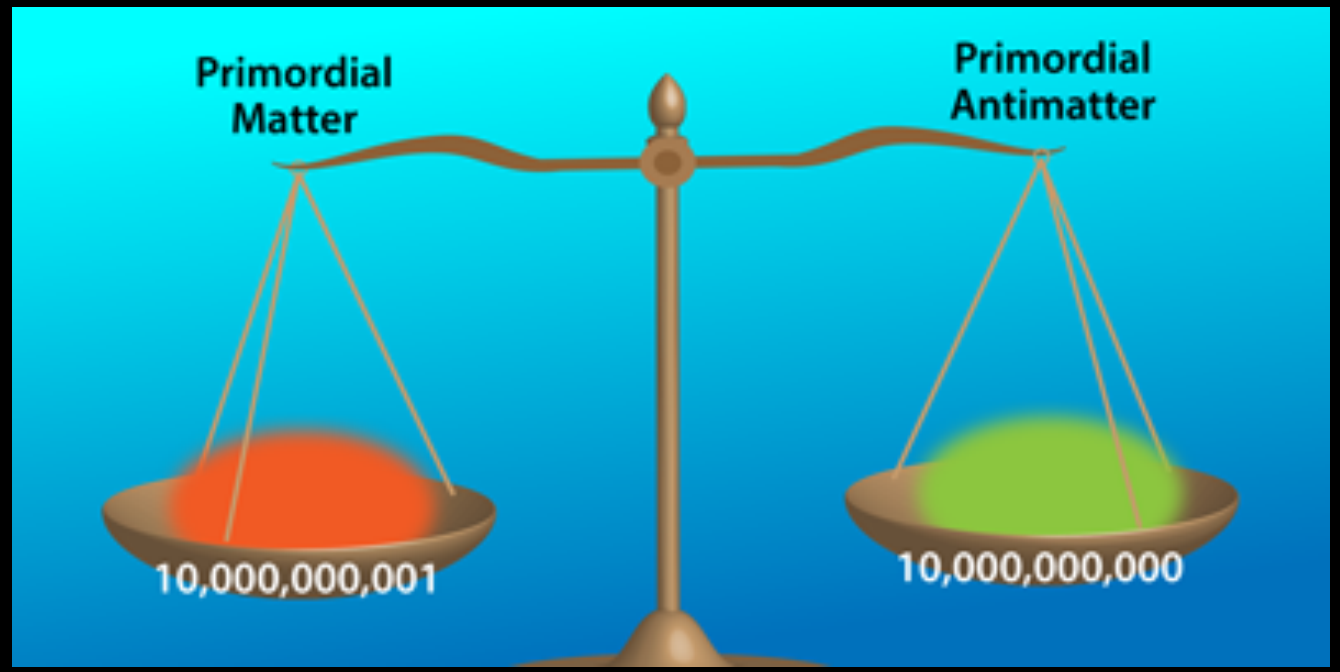
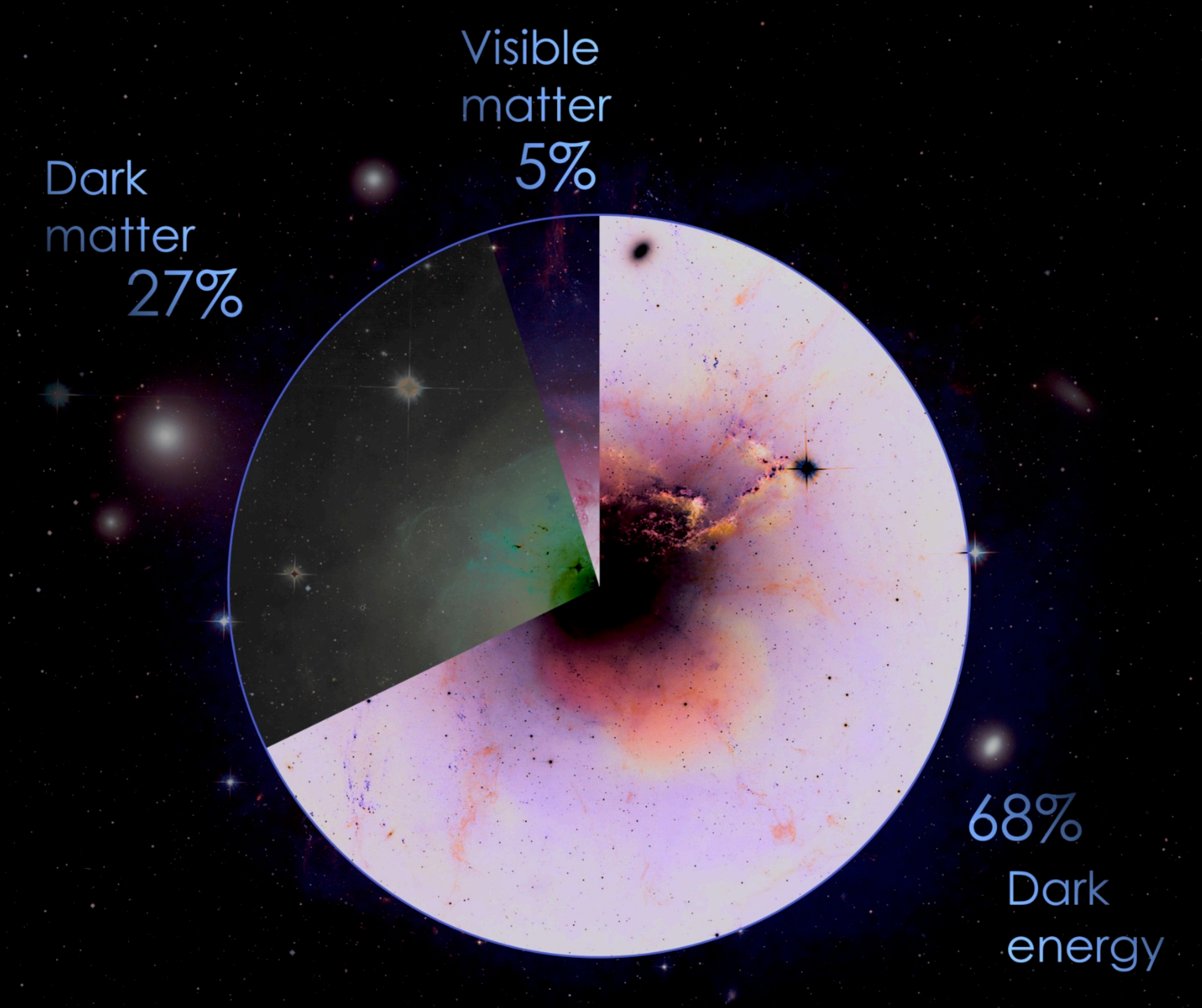
ATLAS EXPERIMENT

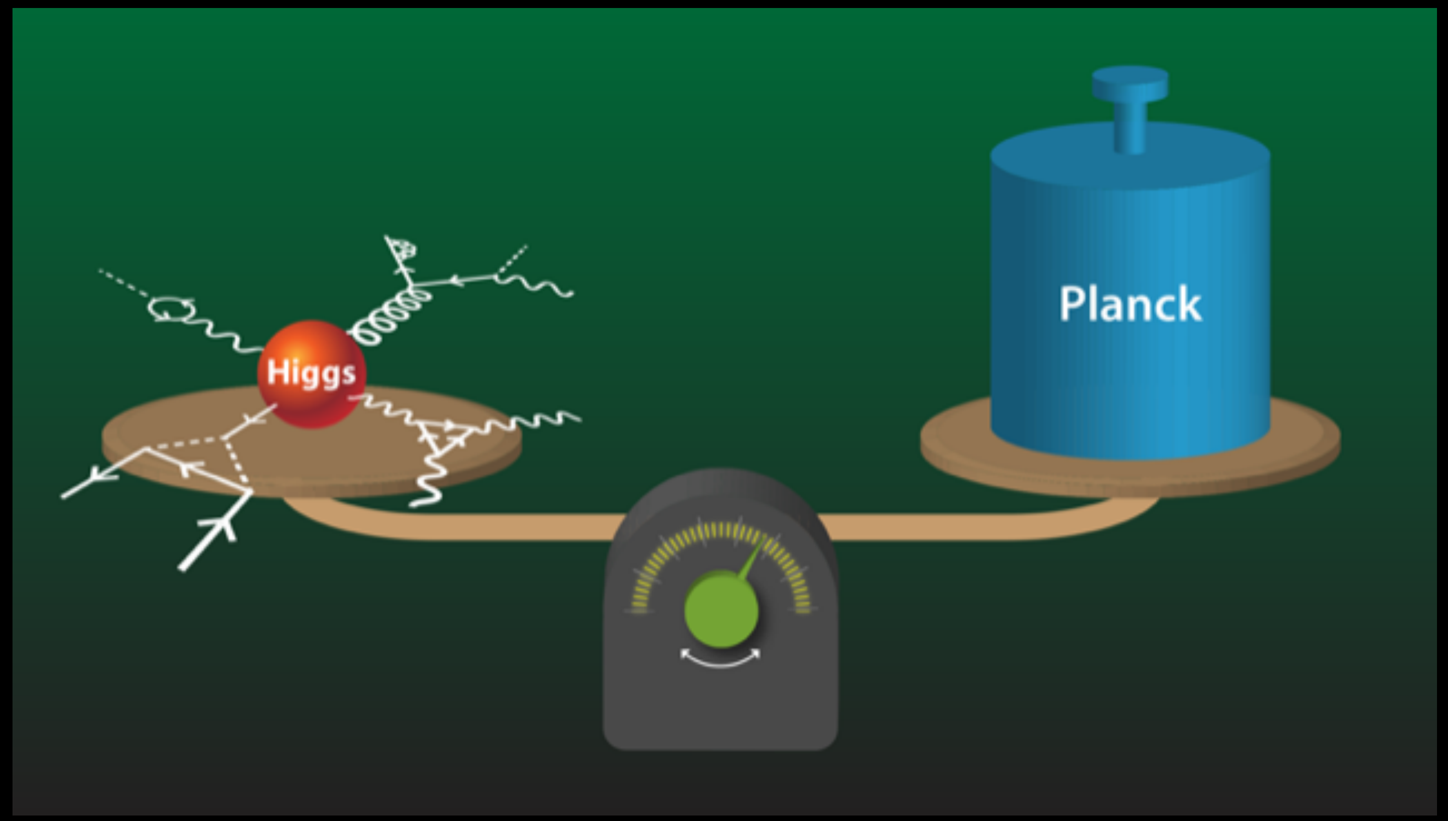
Many open questions in HEP and Cosmology

- Dark matter
- Accelerated expansion of universe → Dark Energy?
- Matter-antimatter asymmetry
- Hierarchy problem
- ……..



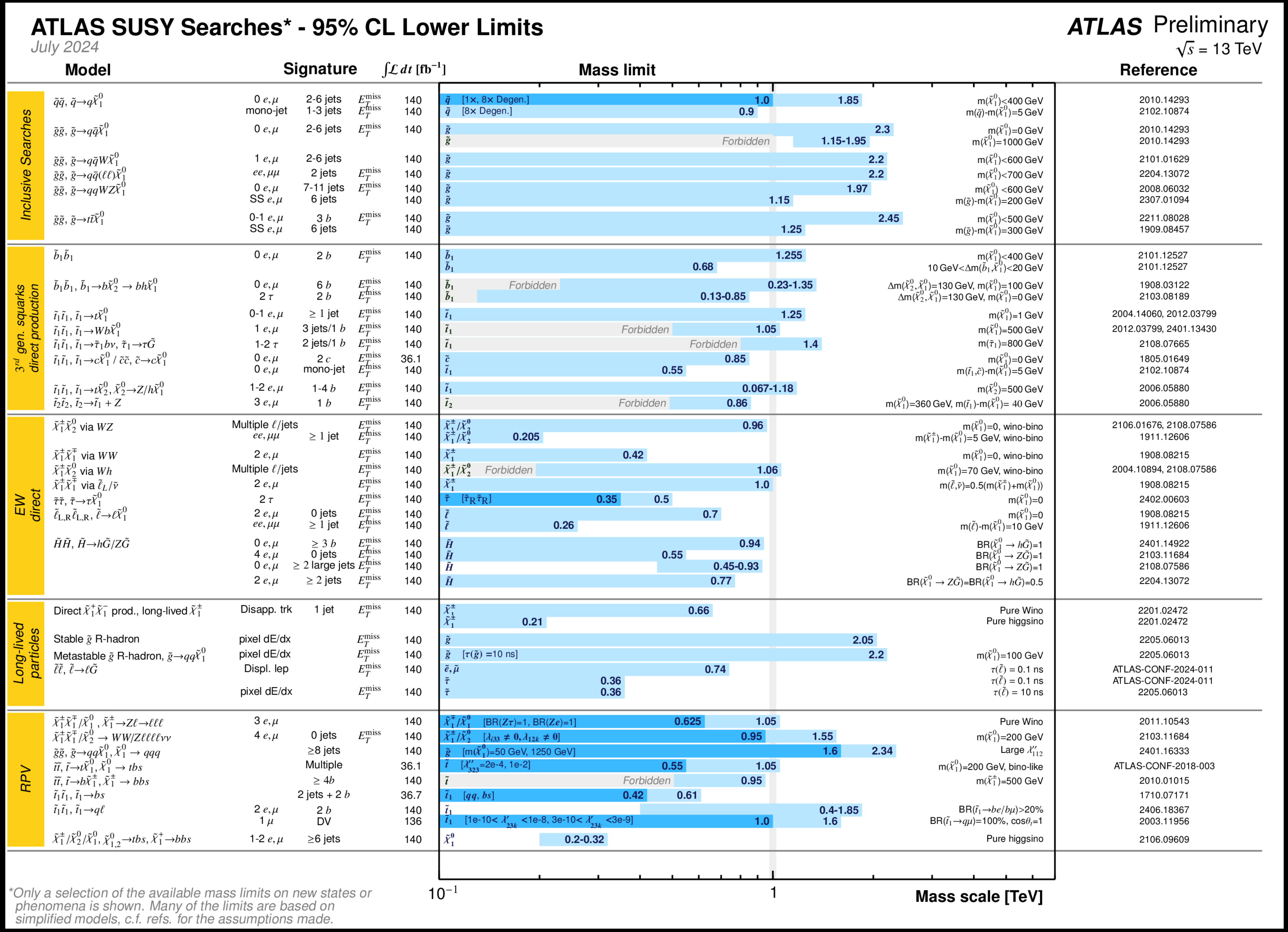


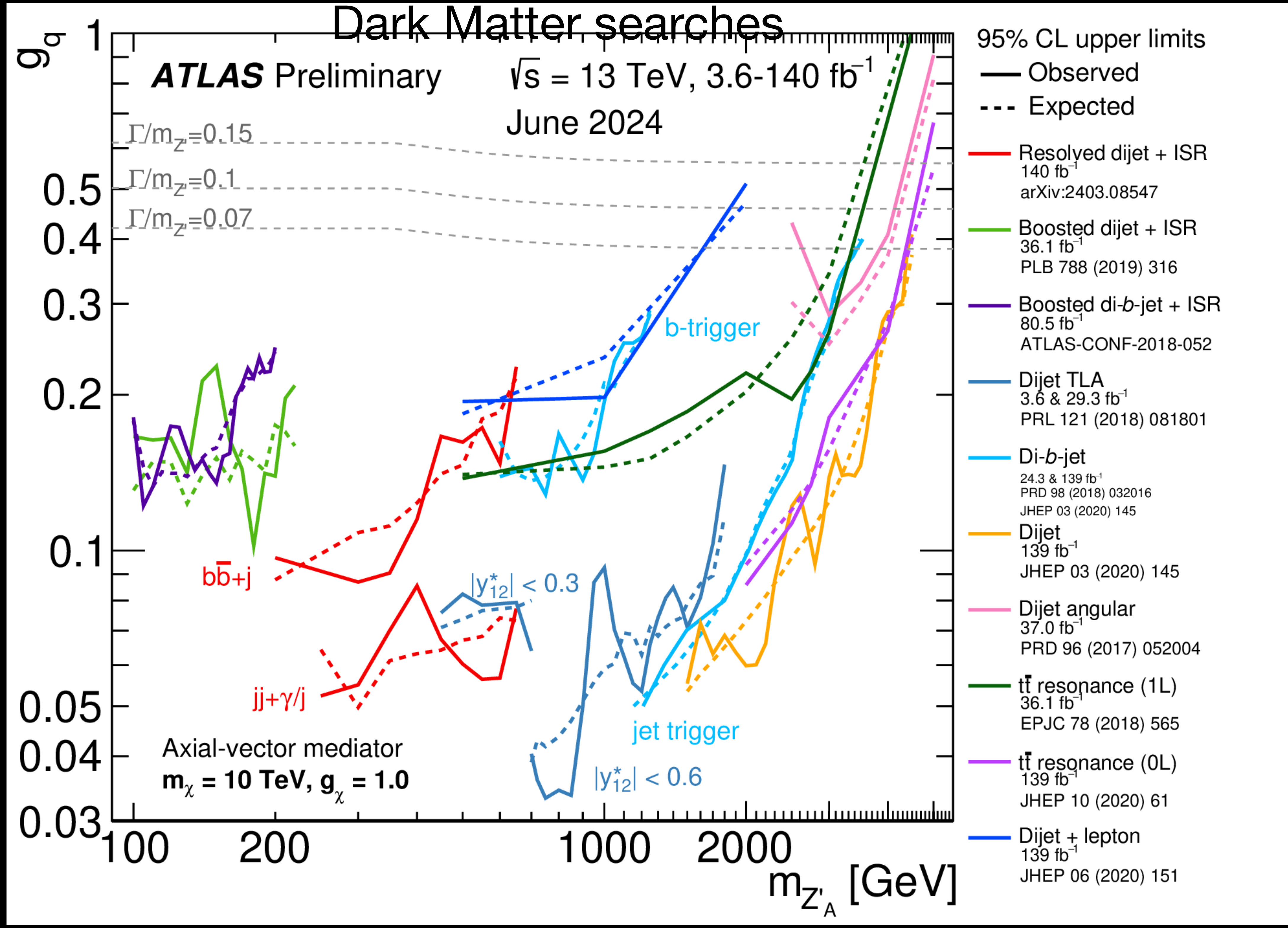




ATLAS experiment has an established Physics Program

Looking into various directions
→ No signs of new physics yet





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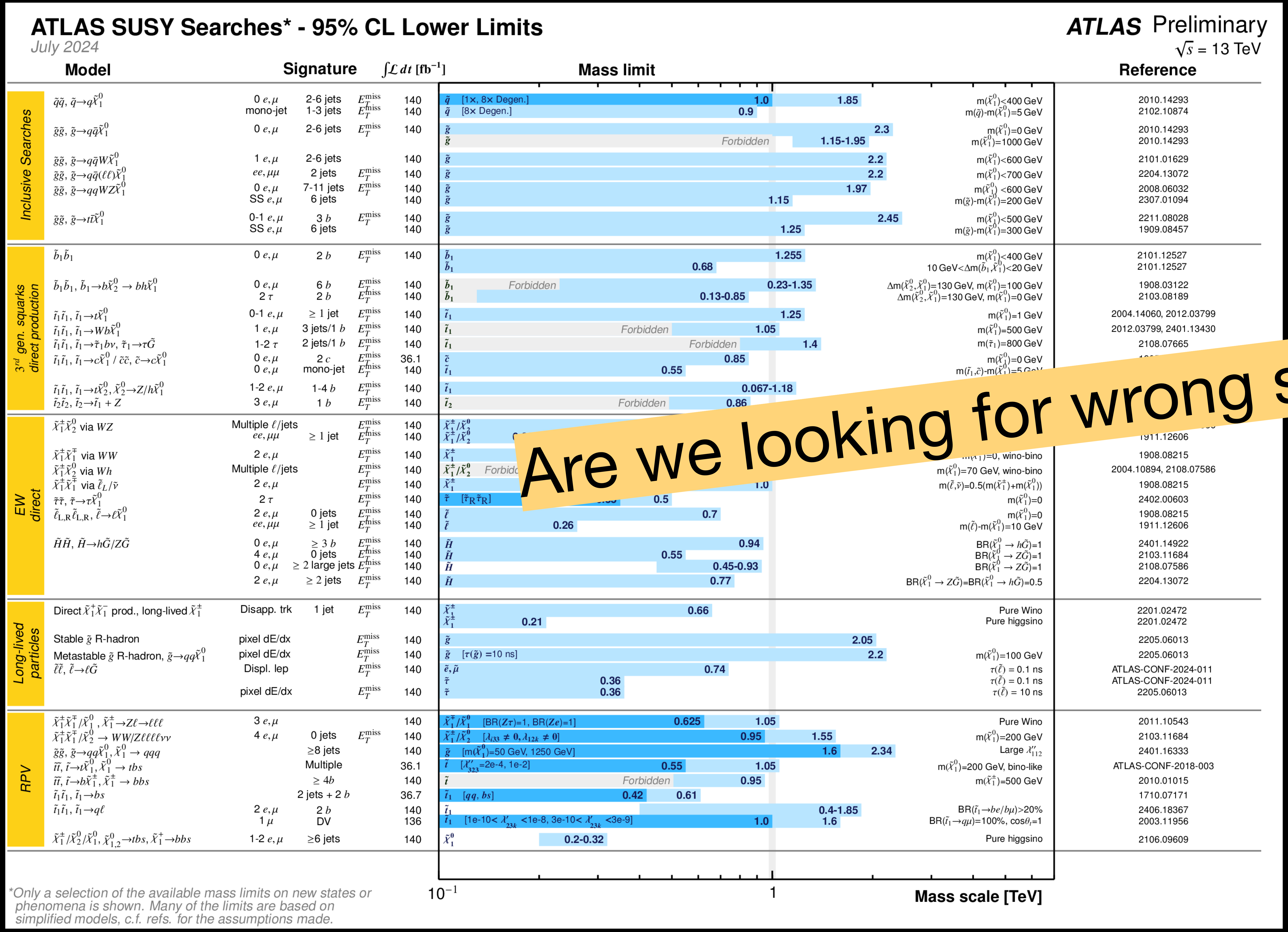
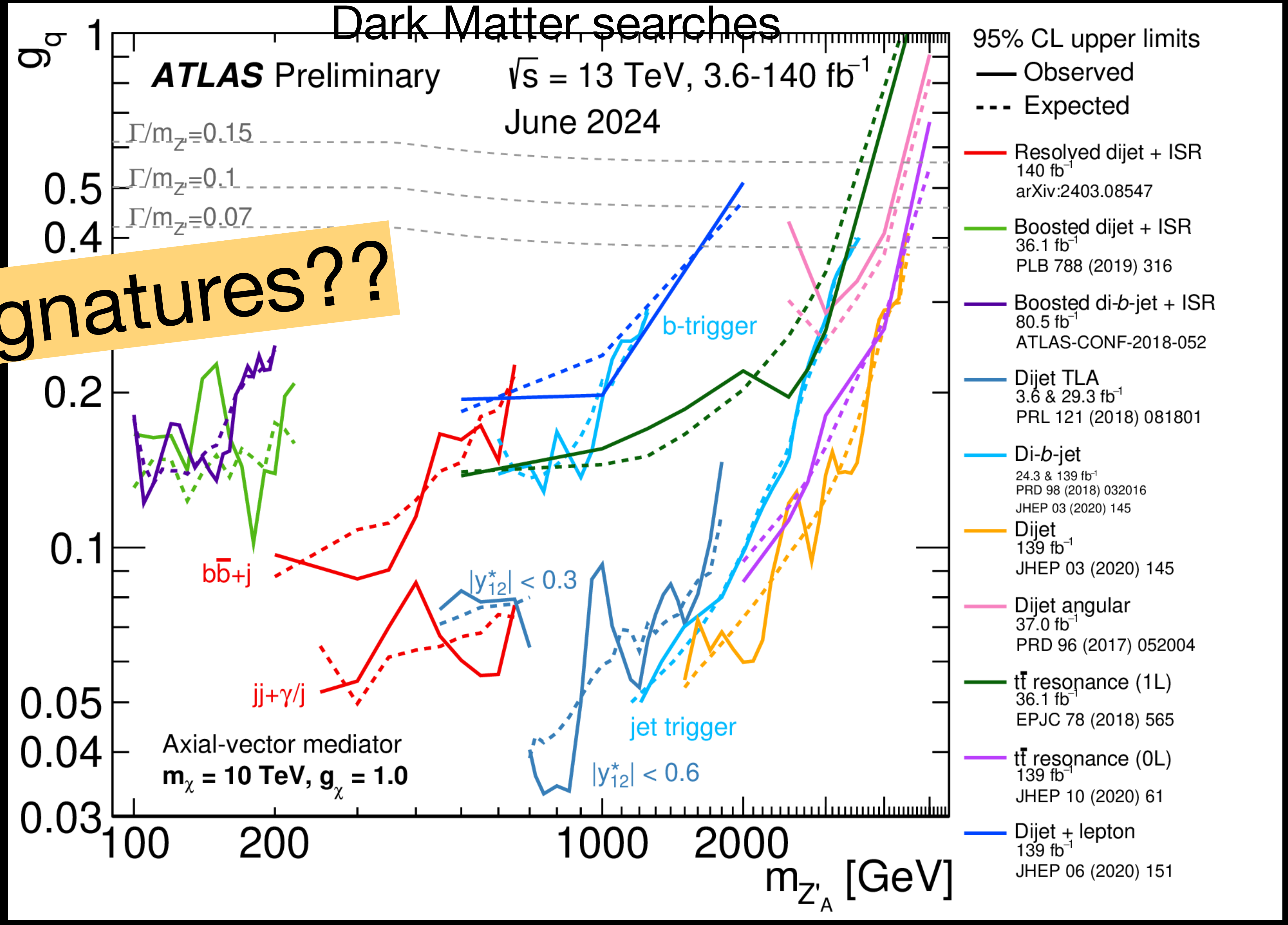




Are we looking for wrong signatures??

An alternative approach

- Instead of looking for a specific signal model, look for anomalies in data

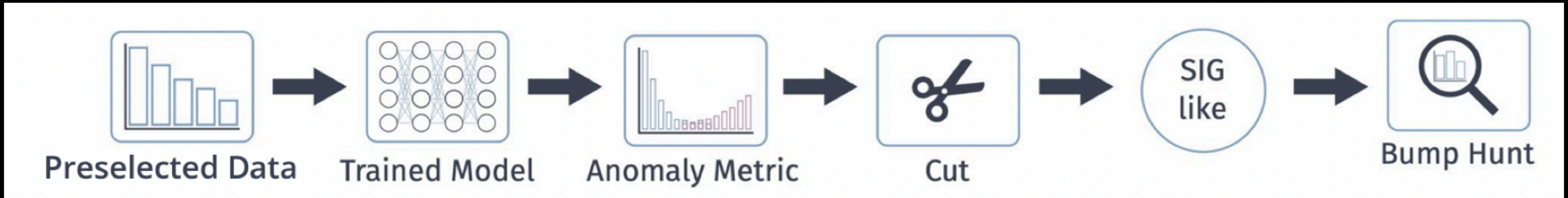
Does this event look like BSM theory ABC?

↓

Does this event look like Standard Model?

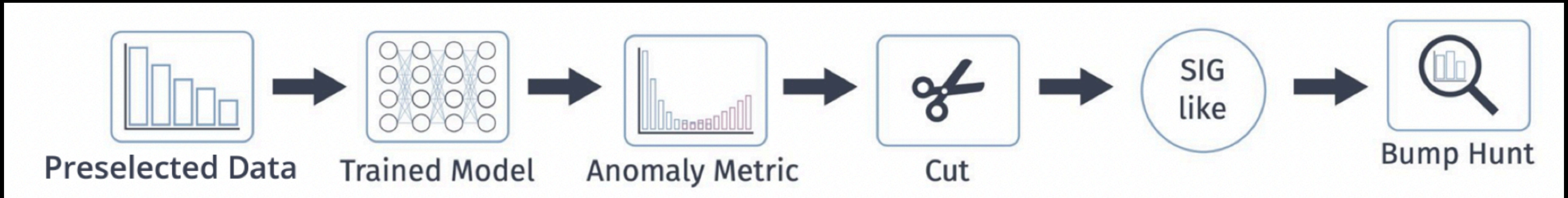
Anomaly detection in data

Analysis Strategy

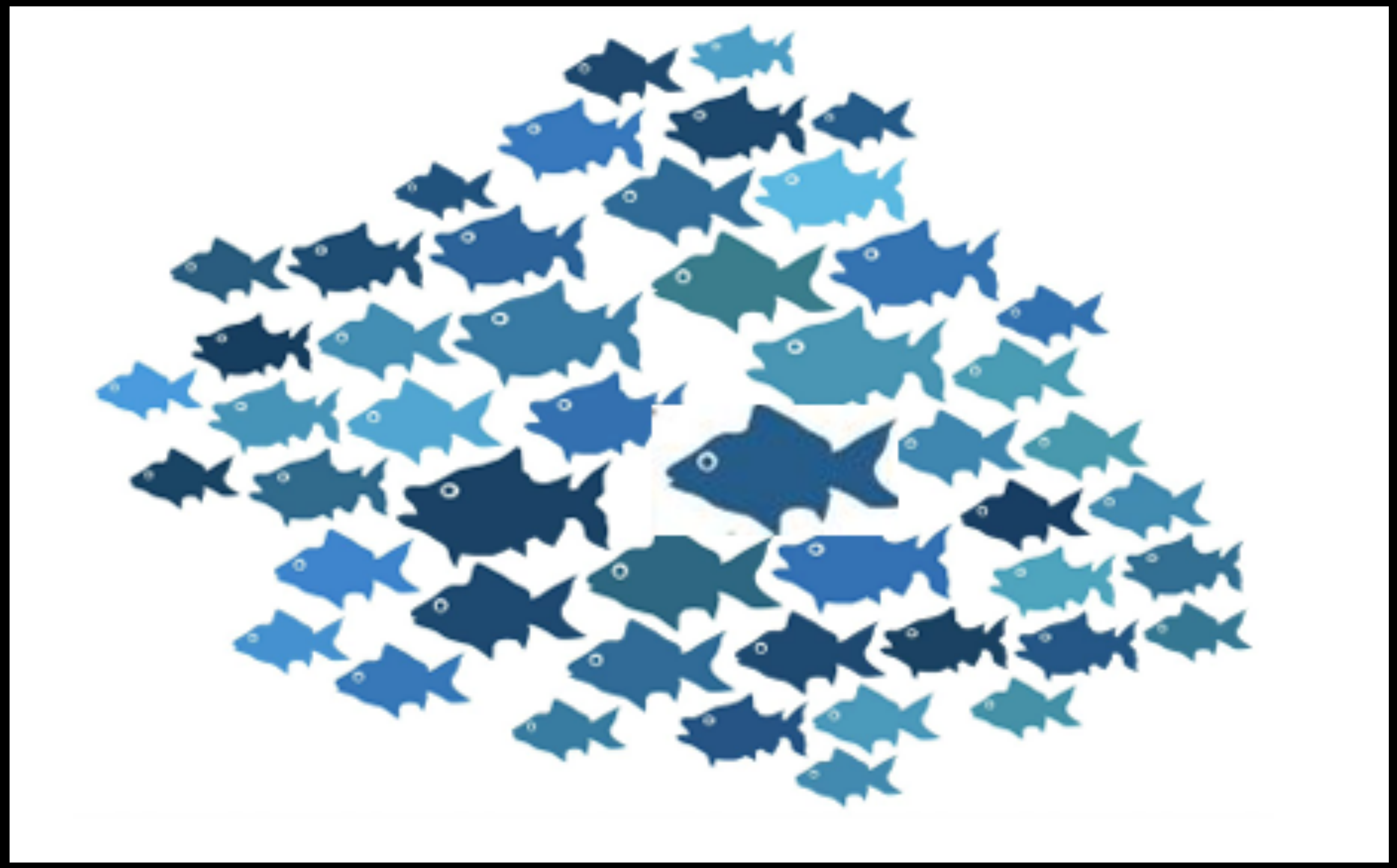


Anomaly detection in data

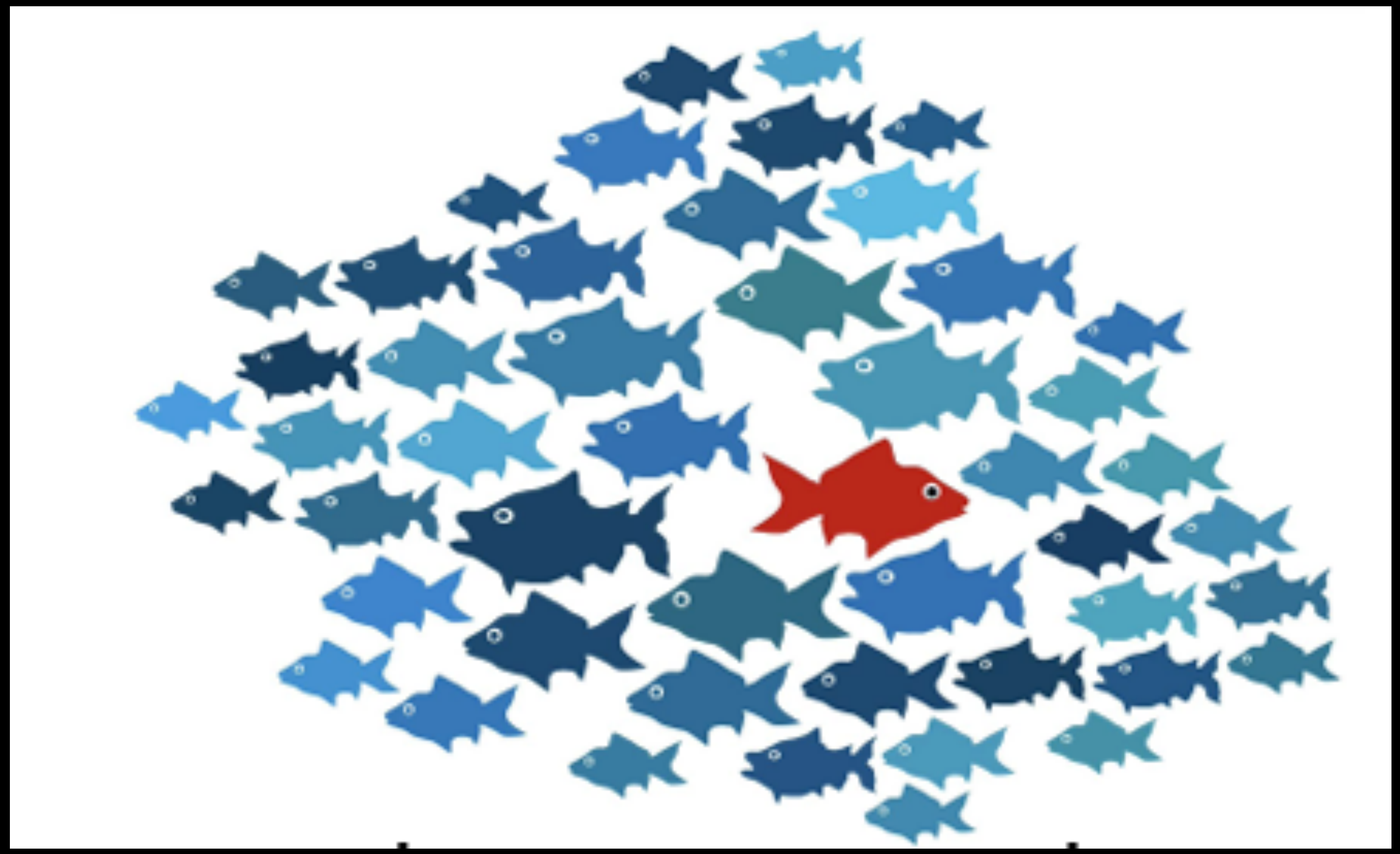
Analysis Strategy



Known training Sample (SM Physics)



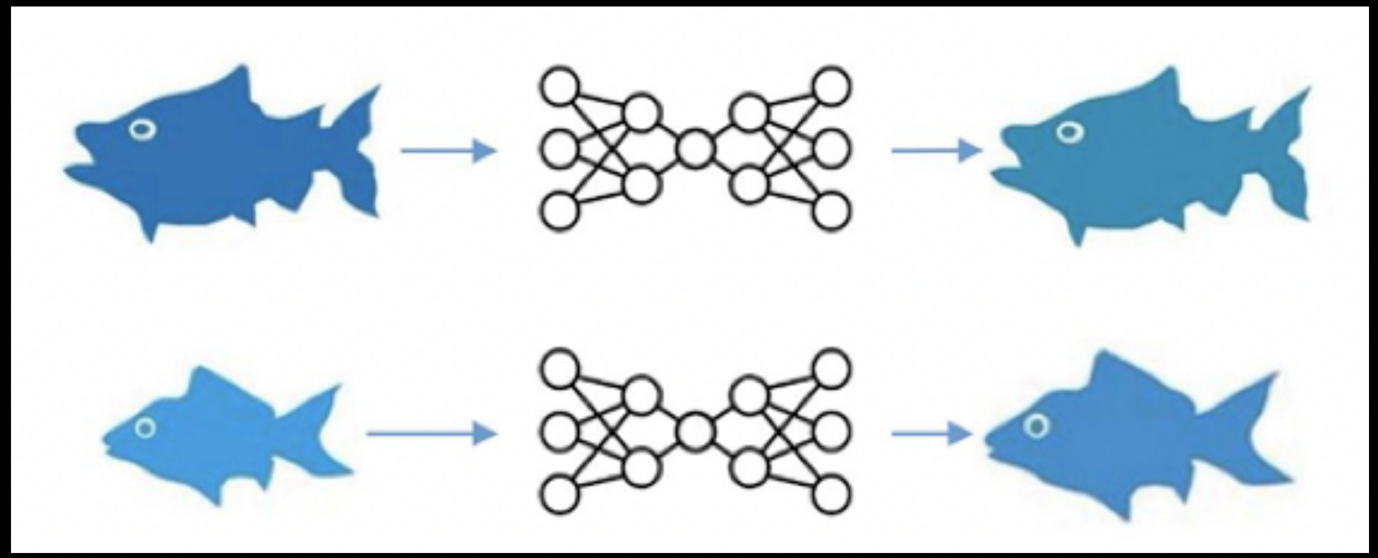
Unknown testing Sample (BSM Physics)



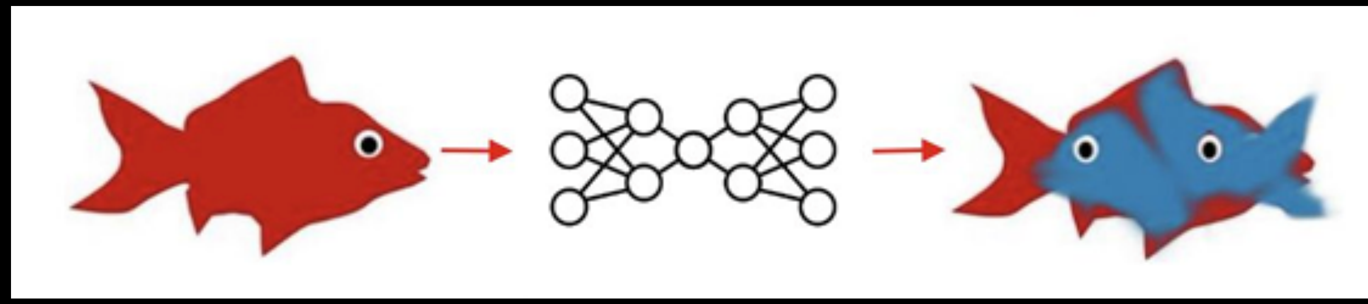
Illustrations by A. Kahn

Anomaly detection in data

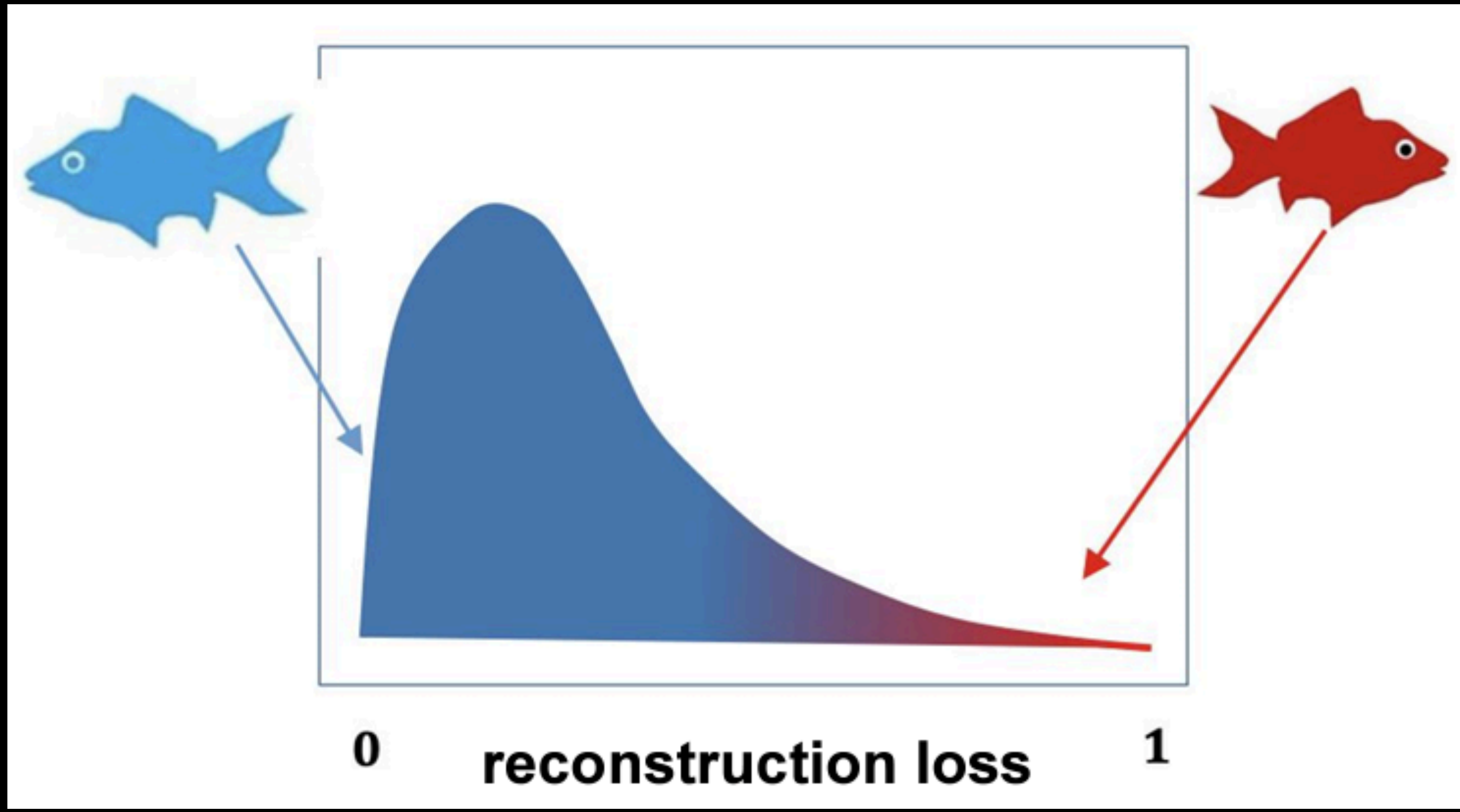
Train the model over non-anomalous samples
(known SM Background processes)



Test the model over real data to look for any anomalies



Anomaly Score

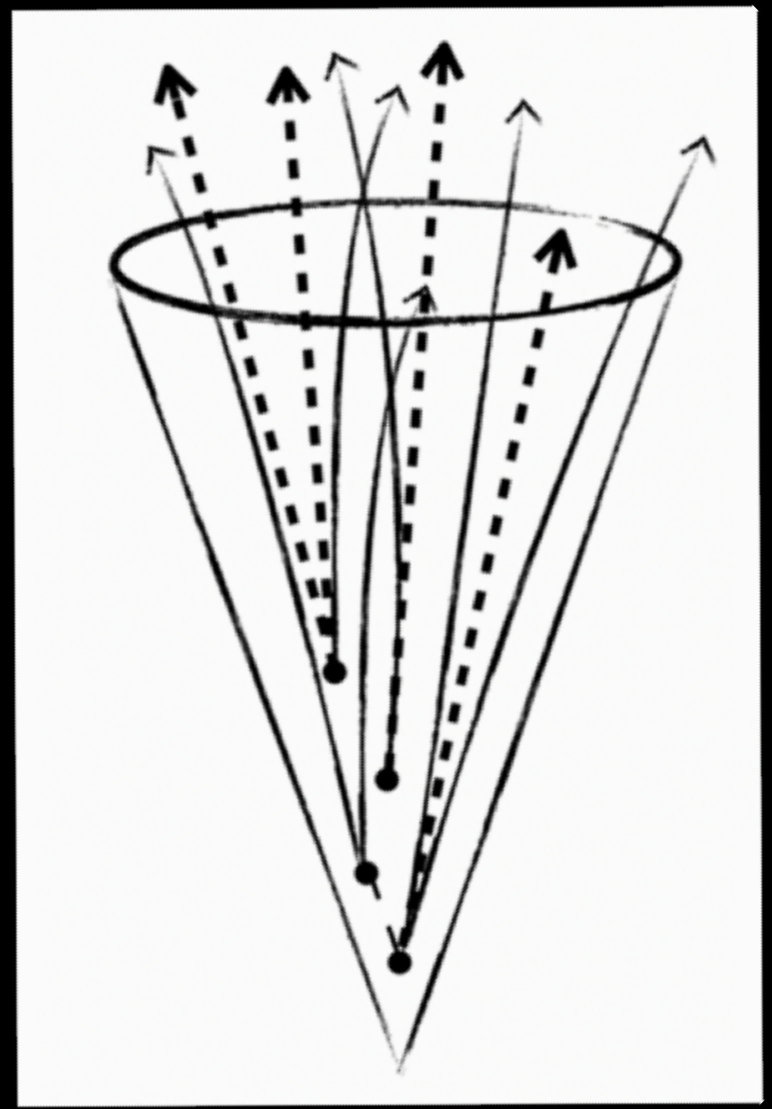


Illustrations by A. Kahn

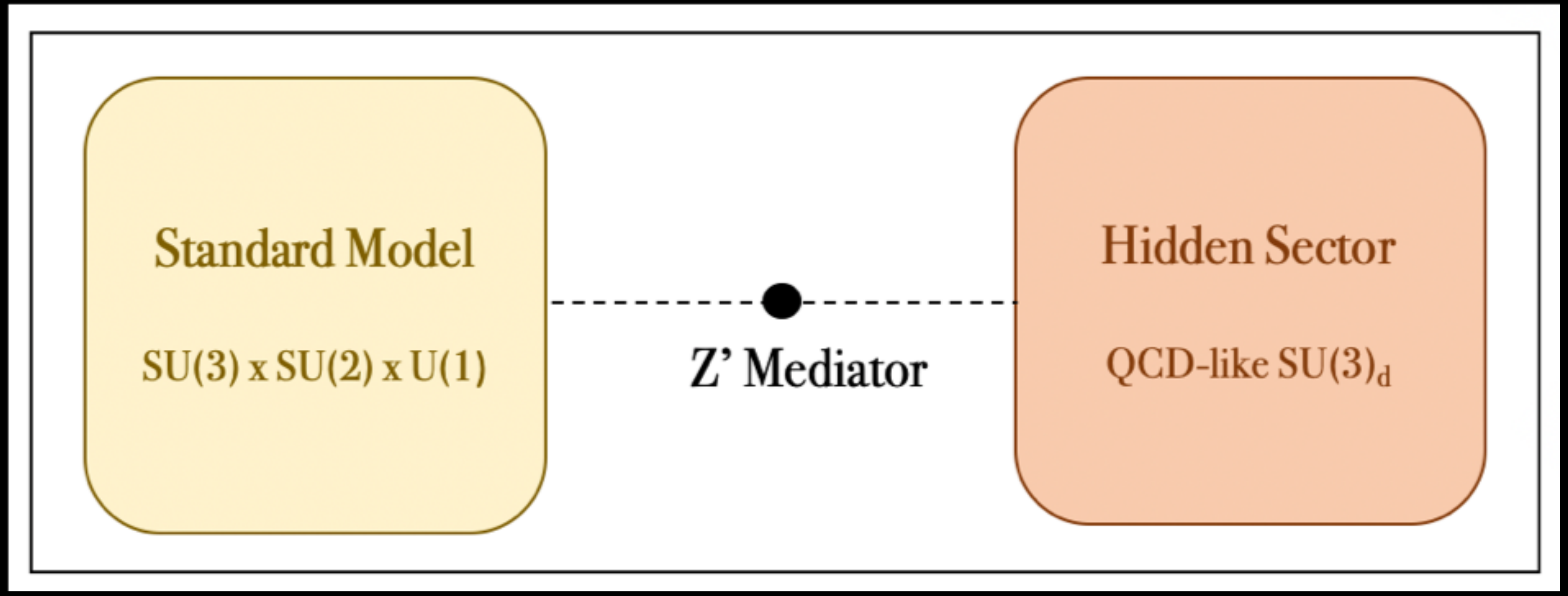
A case study: Semi-Visible Jets

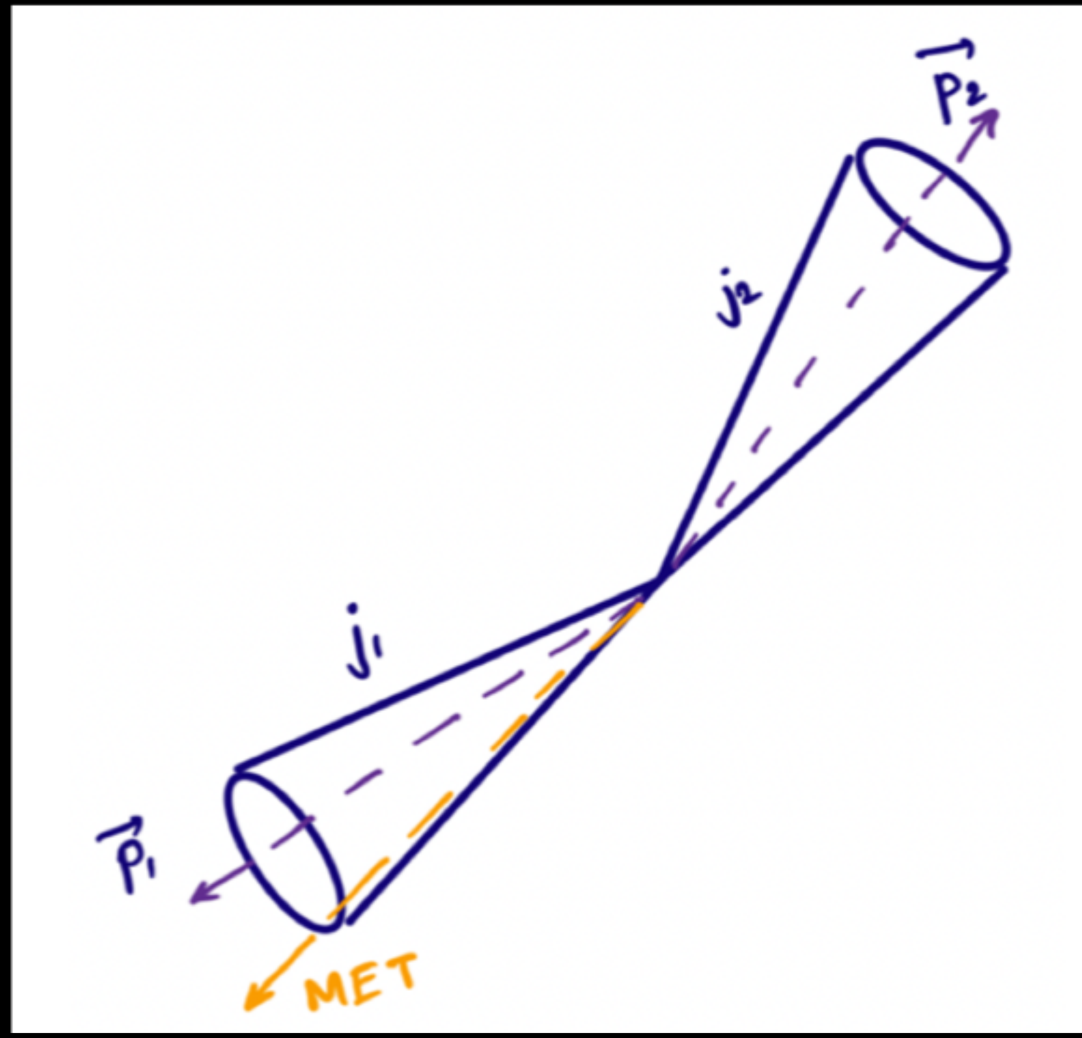
- Inspired by Hidden Valley Models: Dark Matter with rich internal structure/interactions

- Unusual signature → Two back-to-back jets with E_T^{miss} aligning with one of the jets



$\mathrm{SM}_{\mathrm{QCD}} \rightarrow \mathrm{Dark}_{\mathrm{QCD}}? \rightarrow$ Dark Jets?



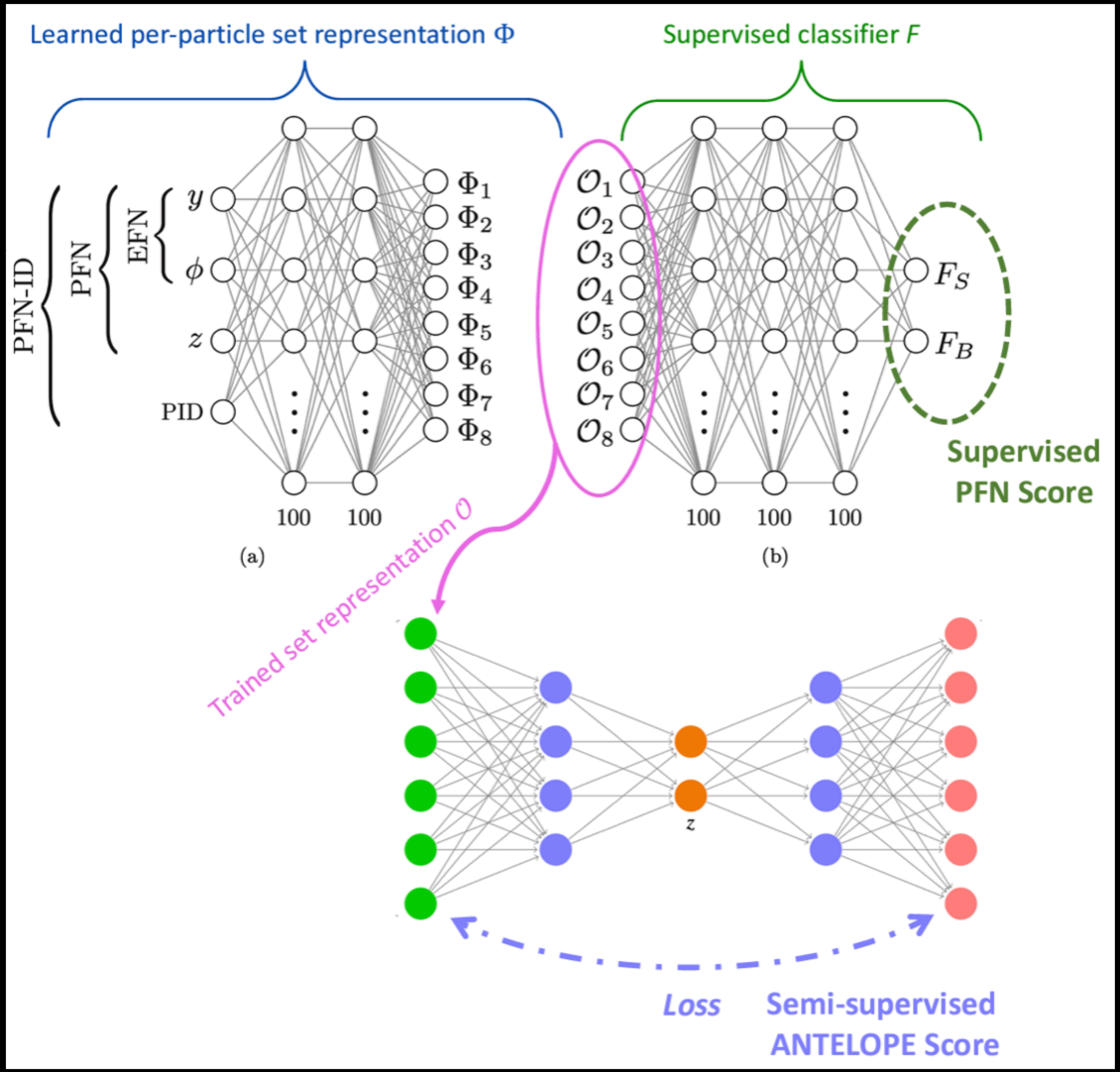


Link: Glance, Int. Note Theory paper

A case study: Semi-Visible Jets

- Semi-Visible jets differ from QCD jets at sub-structure level → information of tracks associated to jets: $p_T, \eta, \phi, E, d_0, z_0, q/p$

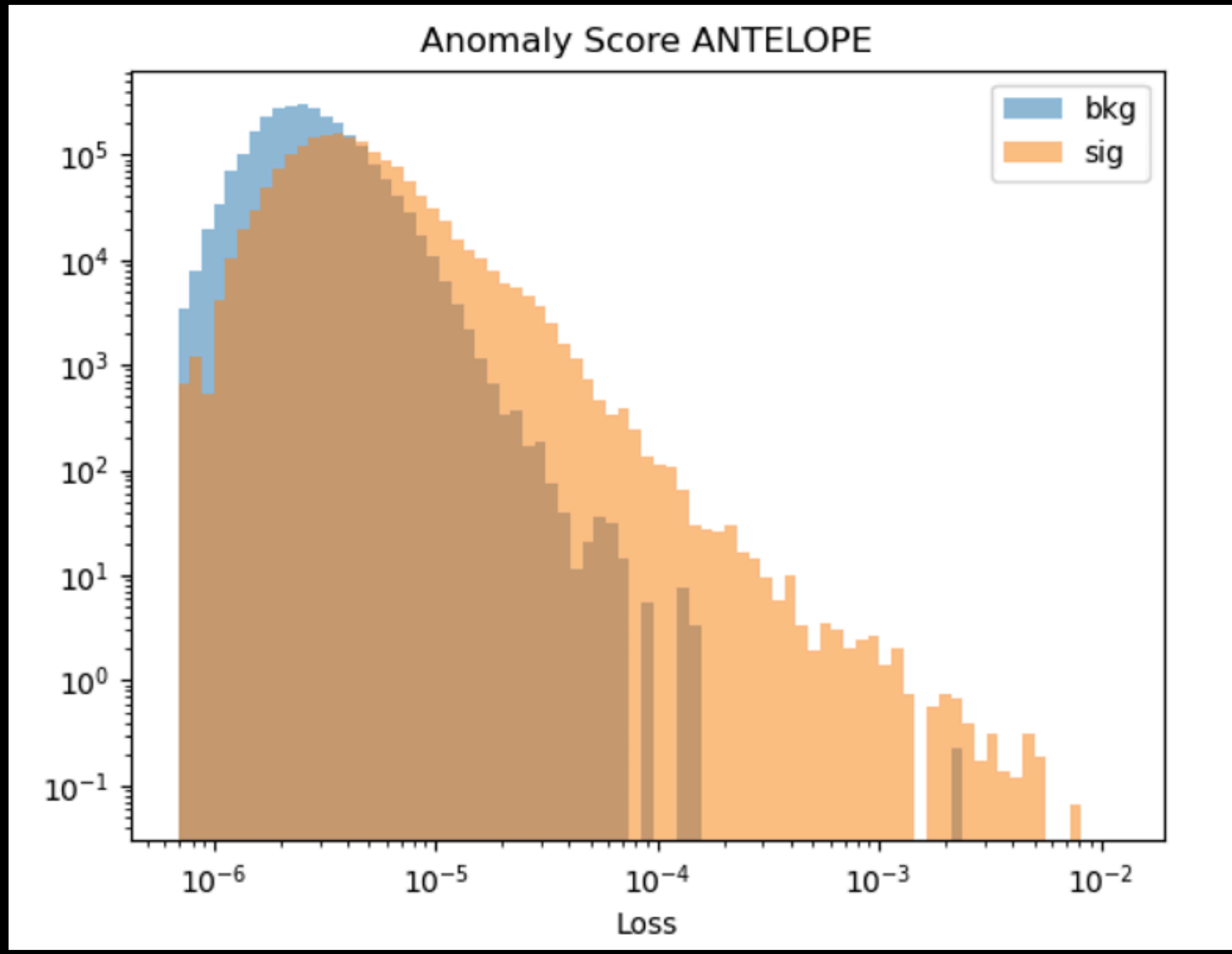
ANomaly deTEction on particle fLOw latent sPacE



A case study: Semi-Visible Jets

- Semi-Visible jets differ from QCD jets at sub-structure level → information of tracks associated to jets: $p_T, \eta, \phi, E, d_0, z_0, q/p$

Anomaly score for signal and background



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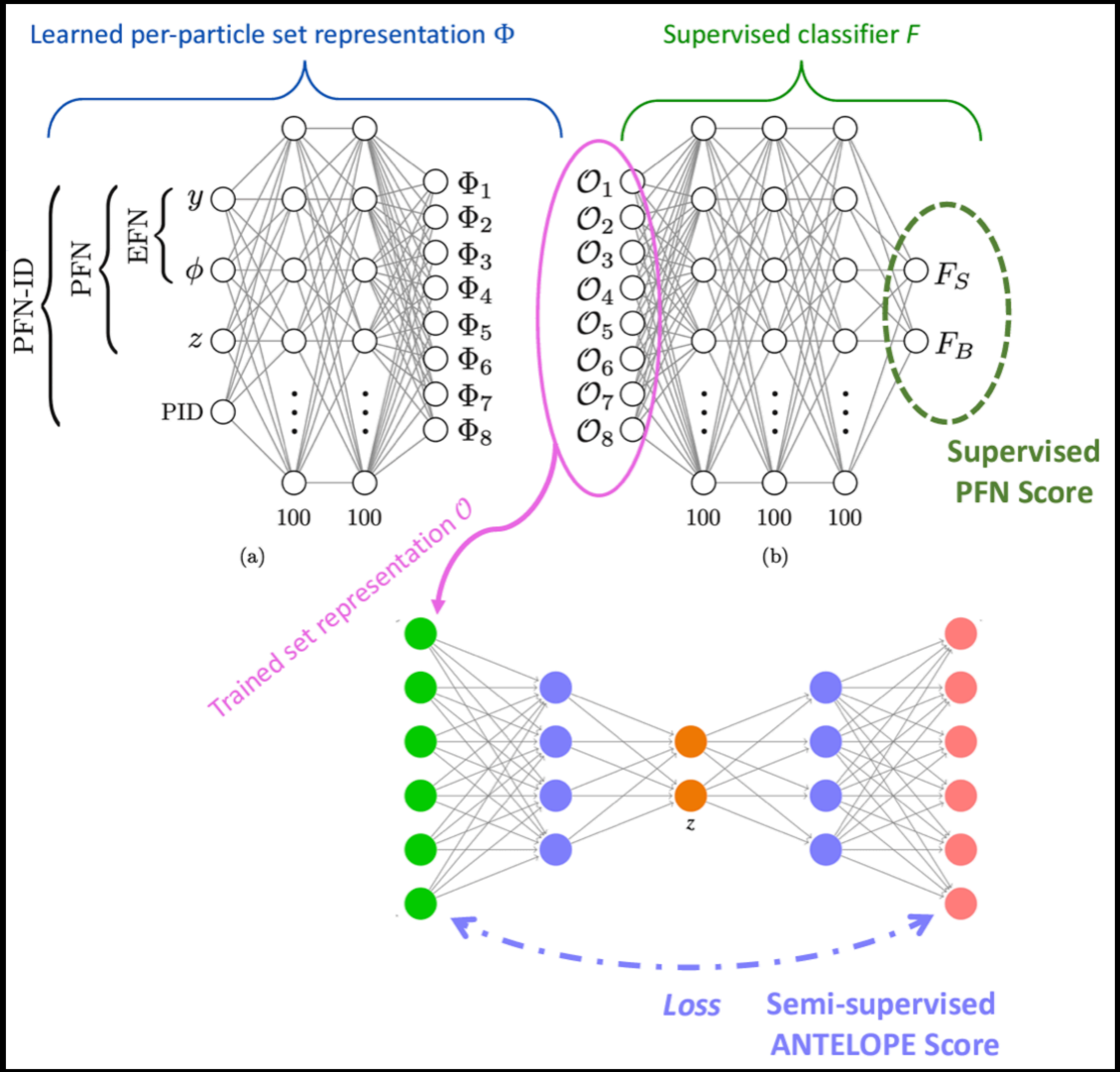
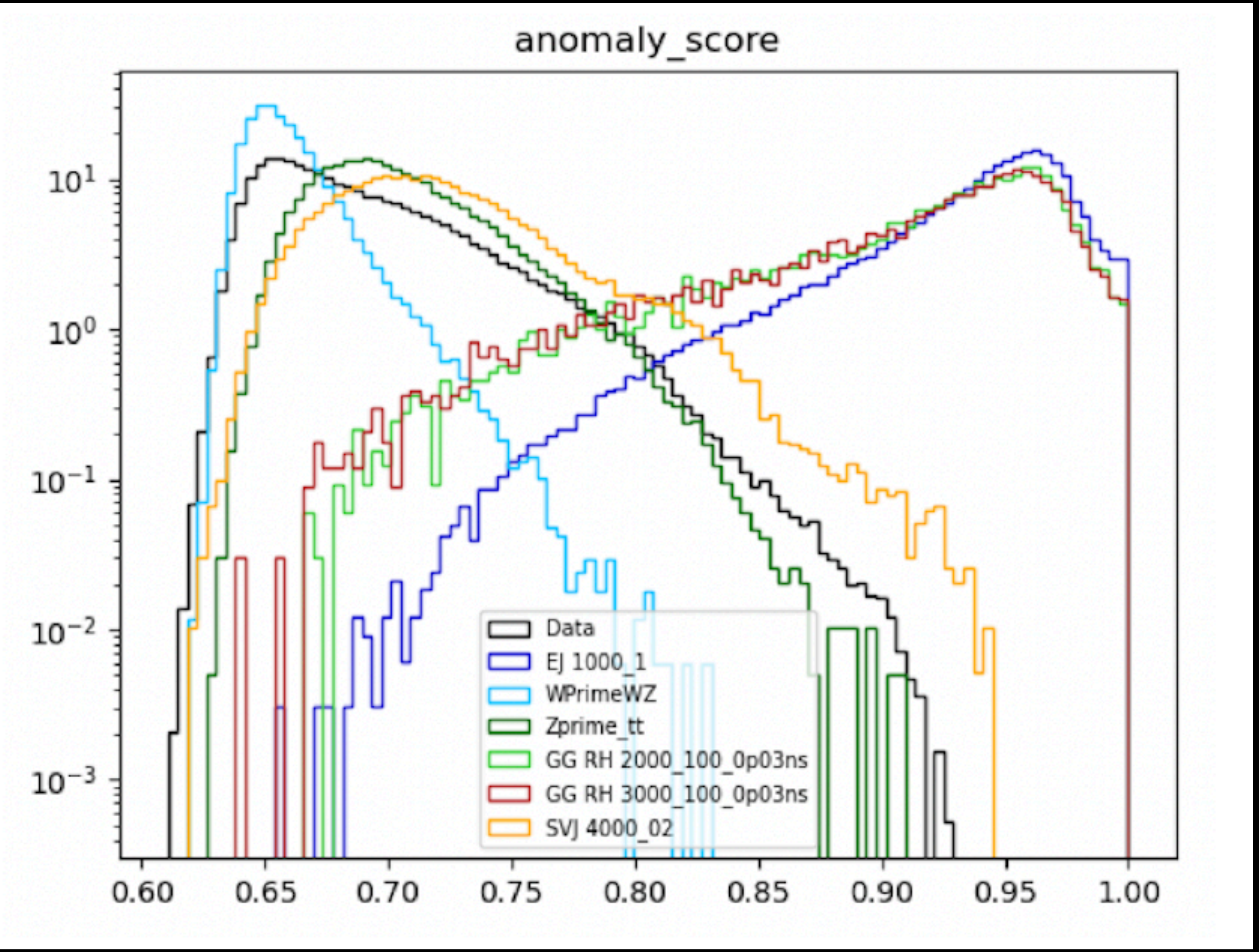


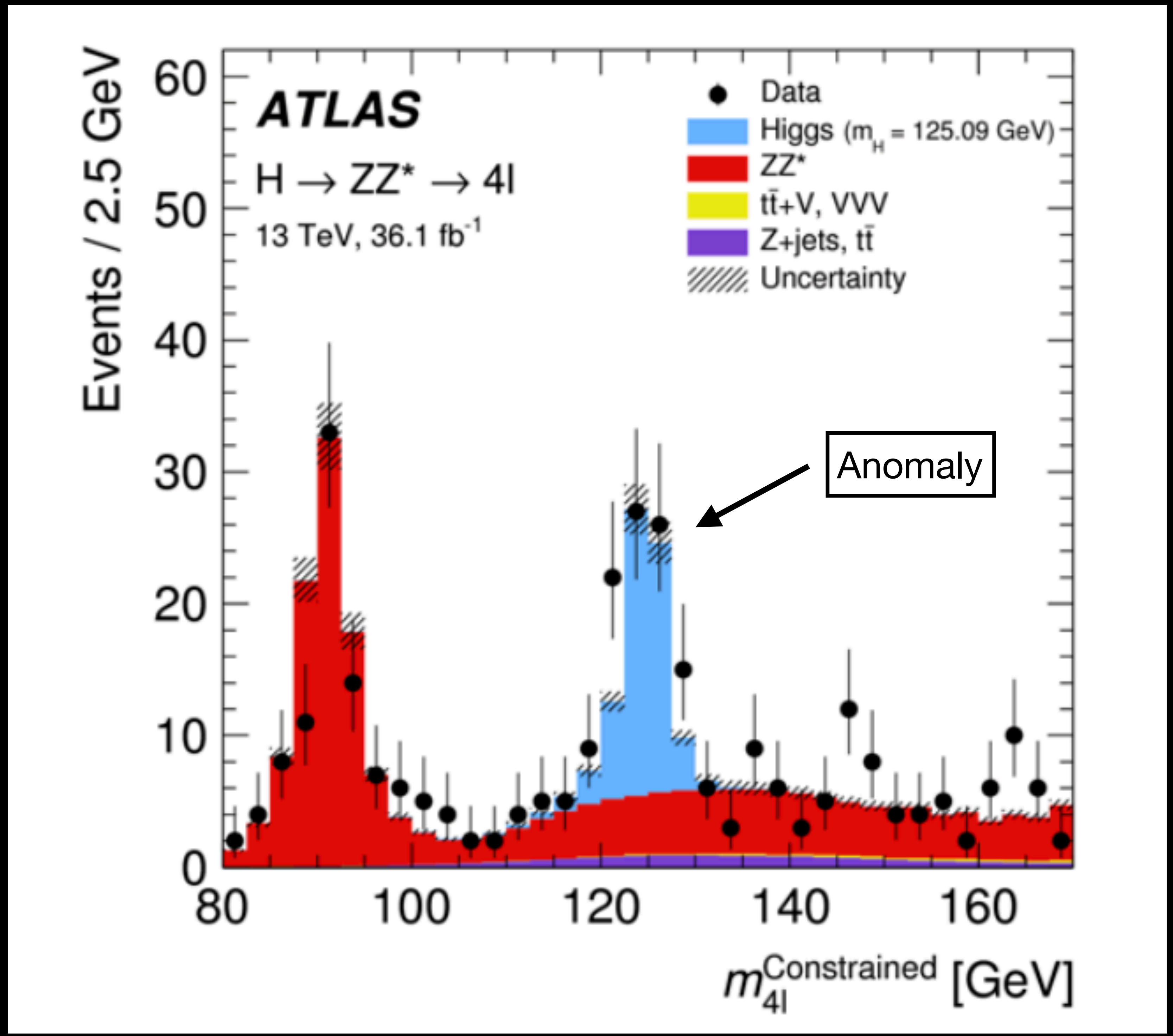
A case study: Semi-Visible Jets

- Antelope has learned model independence



Summary

- Anomaly detection has been a fundamental aspect in the field of High Energy Physics
  - z-significance, p-value estimation in statistical methods
- ML based techniques can provide new dimensions for searching anomalies
- These techniques are still in their infancy within HEP, but an increasing number of analyses are experimenting with them
- Exciting times ahead!!!!!



Back-up

Theoretical motivation behind these models

- DM may be composed of Strongly Coupled Dark Matter (SCDM) particles resembling SM QCD

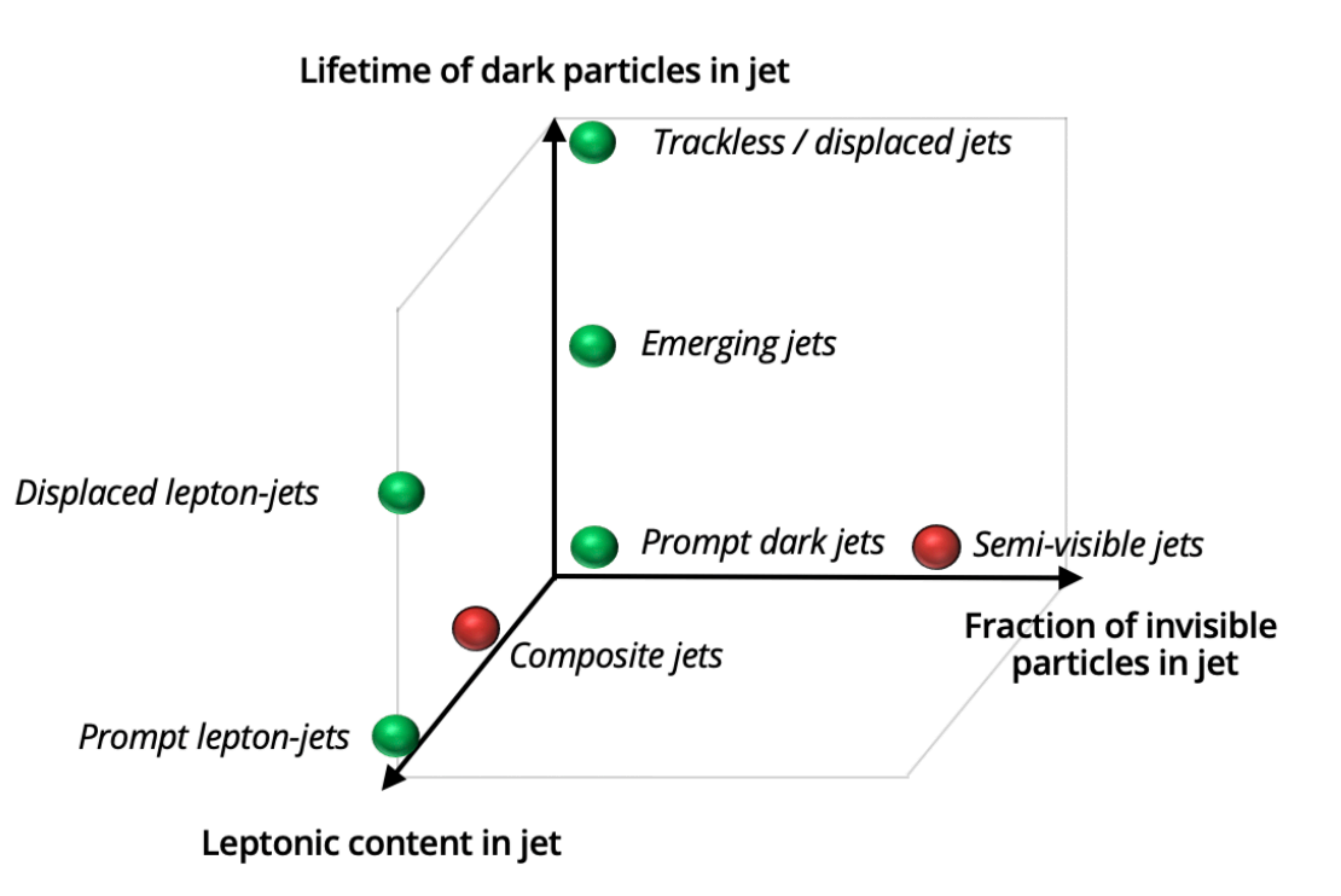
- These SCDM particles can undergo QCD-like showers, generating various stable and unstable DM states

- Various possible topologies; depending upon the couplings in the dark sector

  - Dark Jets: Dark hadrons decaying **promptly and fully** in QCD-like fashion

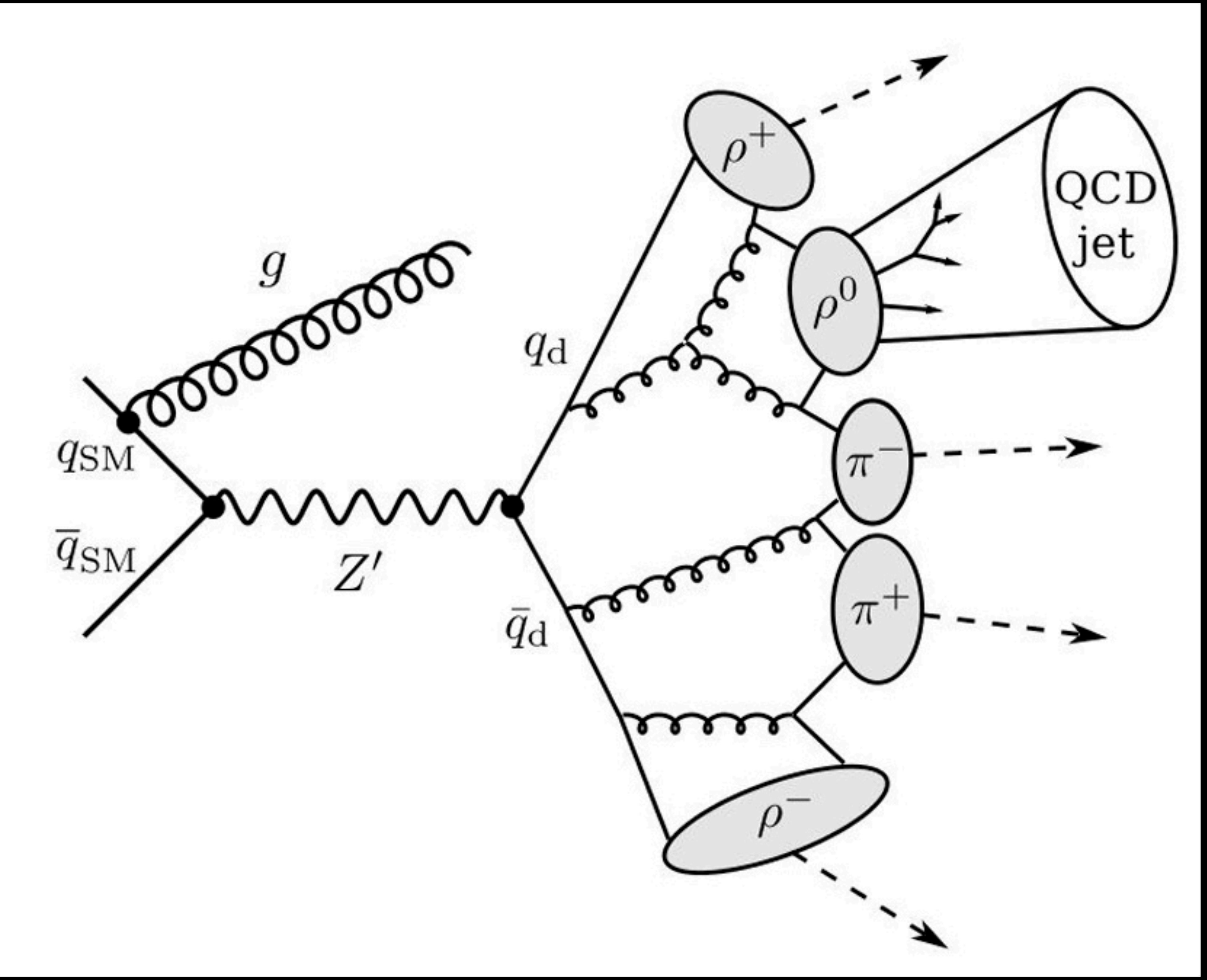
  - Semi-visible jets: Dark hadrons decaying **promptly and partially** in QCD-like fashion

  - Emerging Jets: Dark hadrons undergoing **displaced decays** in QCD-like fashion



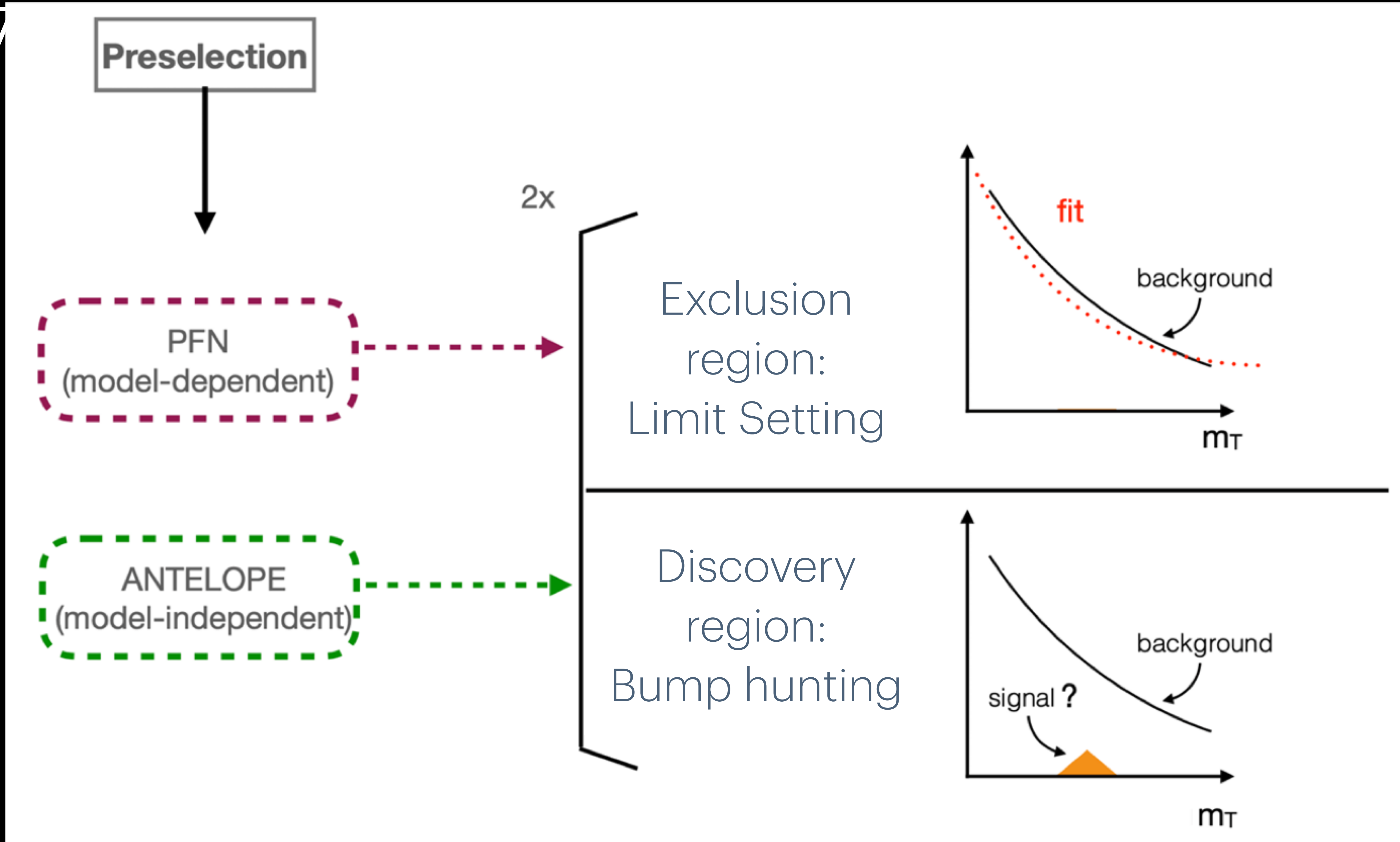
Semi-Visible Jets (SVJ) s-channel resonant production via Z' mediator

- Unusual signature → Two back-to-back jets with E_T^{miss} aligning with one of the jets
- Wide jet with high track multiplicity and significant E_T^{miss}



Full Run-2 dataset: 140 fb^{-1}

Analysis Strategy

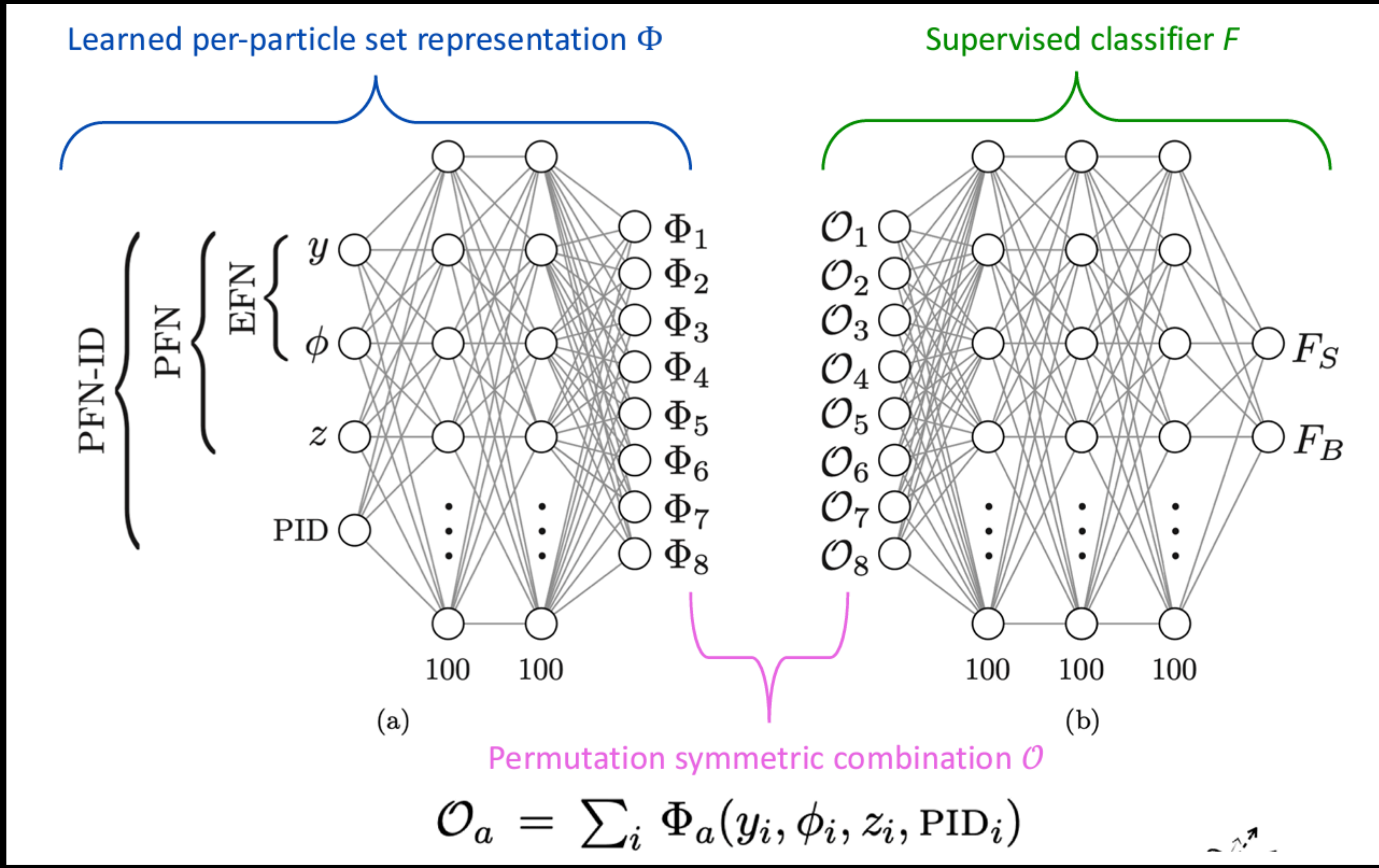


- Two back-to-back jets and E_T^{miss} in the final state
- Trigger and pre-selection
- Machine Learning Models
  - Particle Flow Network : Limit Setting
  - ANTELOPE : Bump hunting
- Construction of Control and validation regions
- Data-driven background estimation using multi-parameter function
- Systematics uncertainties and estimation of signal significance
- In the absence of significant deviation, set limits

ML tools

Particle flow networks (PFN)

- Semi-visible jets differ from QCD jets at substructure level, this property is utilized by providing low-level information of associated tracks to leading and sub-leading jets to PFN
    - Track info: $p_T, \eta, \phi, E, d_0, z_0, q/p$
- Supervised and model dependent approach: to enhance signal sensitivity



ML tools

Particle flow networks (PFN)

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  - Track info: $p_T, \eta, \phi, E, d_0, z_0, q/p$
- Supervised and model dependent approach: to enhance signal sensitivity
- Trained over QCD MC and SVJ signals
- PFN is found to be performant over the complete signal grid