Unsupervised tagging of semivisible jets with energy-based autoencoders in CMS

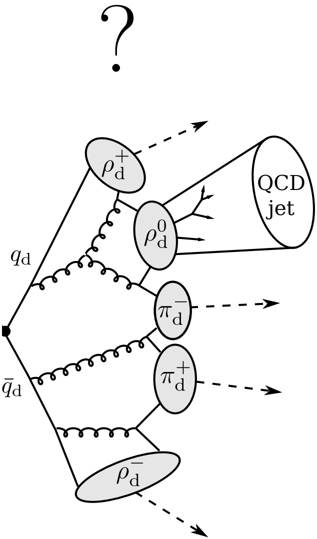
Florian Eble, on behalf of the CMS collaboration

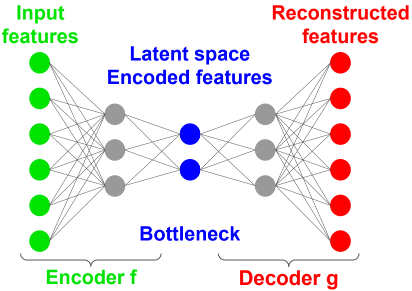
ETH zürich

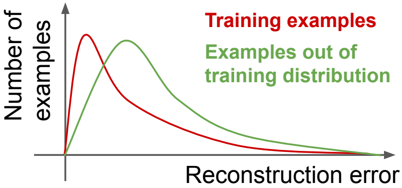
01/05/2024

EuCAIFCon 2024

Anomaly detection to search for semivisible jets (SVJs)



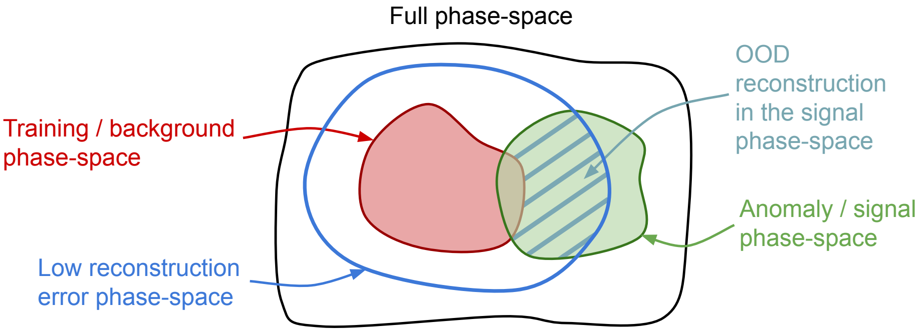




The problem of out-of-distribution (OOD) reconstruction

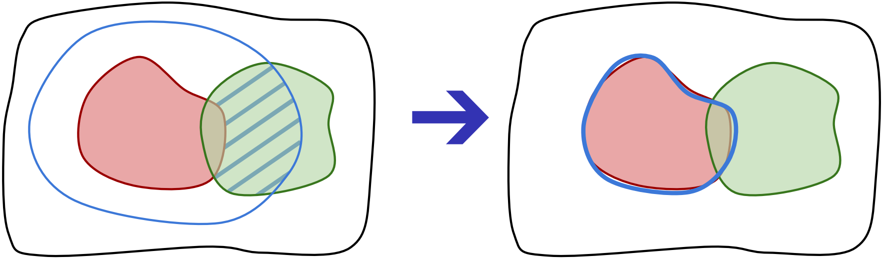
- **AEs are free to minimize reco error outside the background phase space!** including the unknown signal phase space...

➔ This is the problem of **OOD reconstruction**:



Normalized Autoencoders (NAE)

- NAE features a mechanism to suppress OOD reconstruction
- First introduced in arXiv:2105.05735 and used in HEP in arXiv:2206.14225



- NAE paradigm:
  - Define a probability distribution p_θ so that high probability regions have low reco error
  - Sample from p_θ via a MCMC
  - Minimize the distance between the background and p_θ probability distributions
- We propose a different metric to measure this distance, using the Earth Mover's Distance (a.k.a Wasserstein distance) and train NAEs in a fully signal-agnostic fashion

Multi-class classification of gamma-ray sources and the nature of excess of GeV gamma rays near the Galactic center

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Dmitry Malyshev

EuCAIFcon, Amsterdam, 30.04 – 03.05 2024
Poster session B, location 116

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Deutsche Forschungsgemeinschaft
German Research Foundation

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Dark matter in the Galactic center

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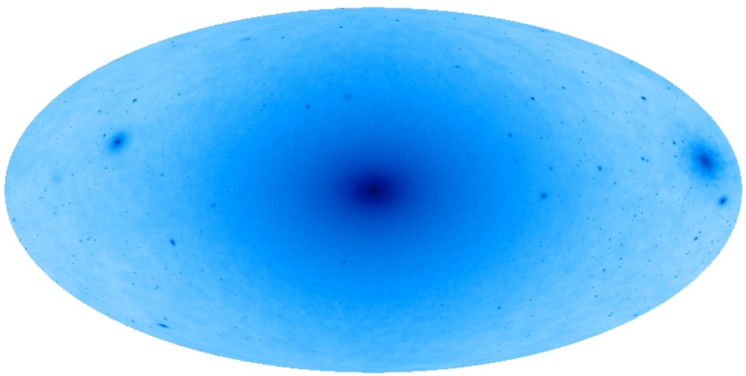
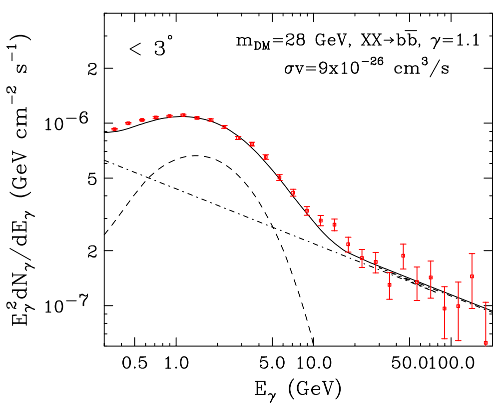
- Galactic center (GC) is the strongest possible source of dark matter (DM) annihilation signal



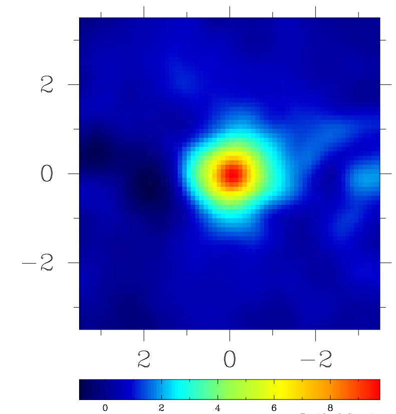
Via Lactea II simulation of a Milky-way-like galaxy. Kuhlen et al. (2009)

- Excess consistent with DM annihilation was detected in Fermi-LAT gamma-ray data two months after the data became public

Goodenough & Hooper (2009), Vitale & Morselli (2009), Hooper & Linden (2011), Abazajian & Kaplinghat (2012), Hooper & Slatyer (2013), Gordon & Macias (2013), Calore et al. (2015), Daylan et al. (2016), Ajello et al. (2016), Ackermann et al. (2017) etc



Goodenough & Hooper (2009)



Abazajian & Kaplinghat (2012)

Astrophysical explanation

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- A population of millisecond pulsars (MSPs) near the GC can explain the Galactic center excess (GCE)

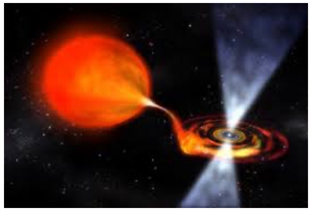
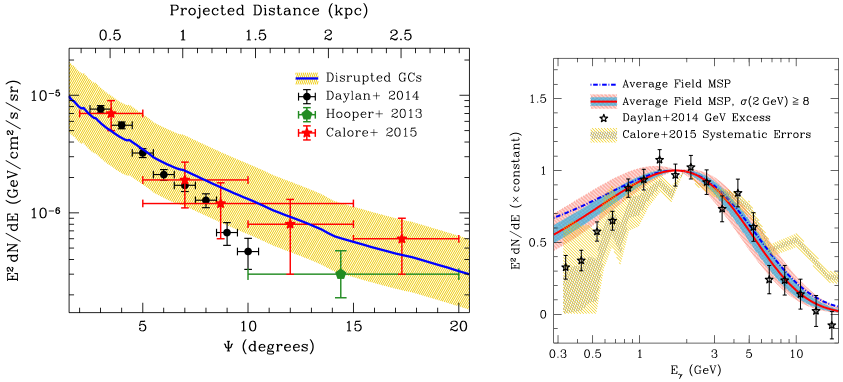
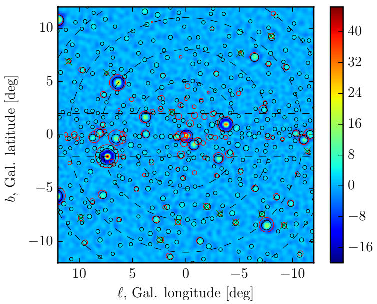


Image credit: NASA



Brandt & Kocsis (2015)



Bartels et al. (2016)

- Statistical studies

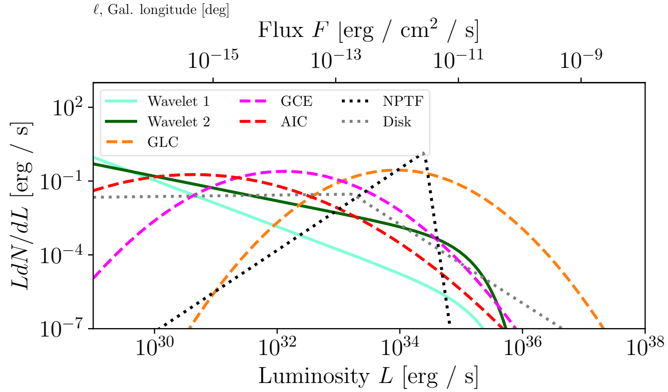
  Lee et al. (2015, 2016), Bartels et al. (2016), Leane & Slatyer (2019, 2020), Zhong et al. (2020), List et al. (2020), Calore et al. (2021), Mishra-Sharma & Cranmer (2022), Caron et al. (2023), Manconi et al. (2024) etc.

  - Based on statistical properties of the Gamma-ray data

- Population studies

  Brandt & Kocsis (2015), Hooper & Linden (2016), Bartels et al. (2018), Ploeg et al. (2020), Dinsmore & Slatyer (2022) etc.

  - Associated (bright) MSPs are used to constrain the models



Dinsmore & Slatyer (2022)

How can machine learning help?

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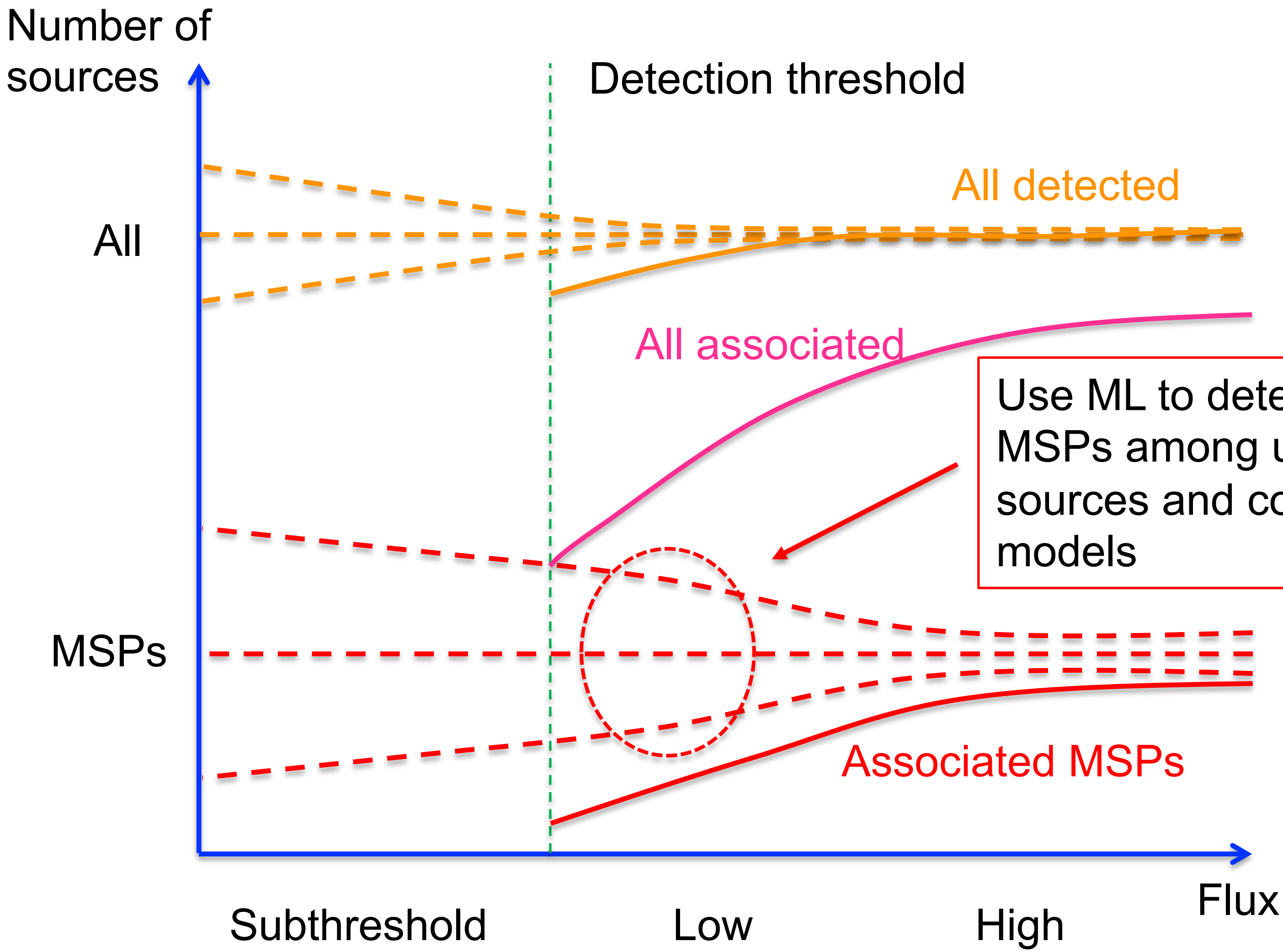
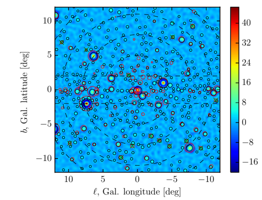


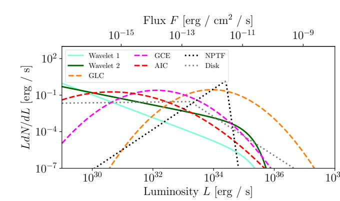


Bartels et al. (2016)

Statistical studies

Use ML to determine MSPs among unassociated sources and constrain MSP models

Population studies



Dinsmore & Slatyer (2022)

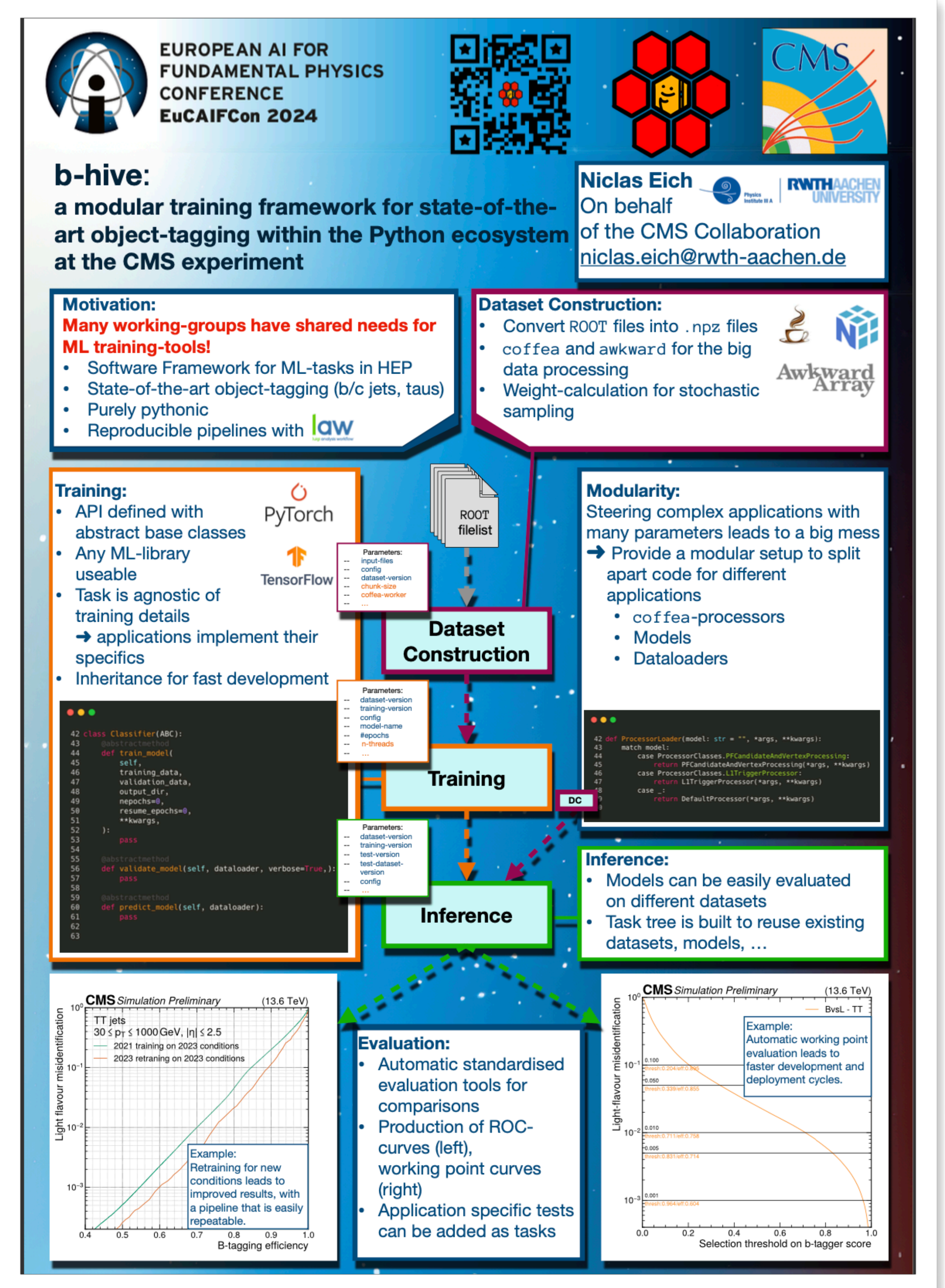
Details and results: poster session B, location 116 & arXiv:2401.04565

b-hive:
a modular training framework for state-of-the-art object-tagging within the Python ecosystem at the CMS experiment

Niclas Eich
On behalf of
the CMS Collaboration
III. Physikalisches Institut A
RWTH AACHEN UNIVERSITY

Motivation:

- Everybody wants to do Machine-Learning trainings
- Full end-to-end pipeline is way harder than an example Notebook
  - Big data processing (`ROOT` files)
  - Conversion into a ML-friendly format (`.npy`/`.npz`)
  - Deploy state-of-the-art models
    - ParticleNet (graph-convolutions)
    - Transformer models



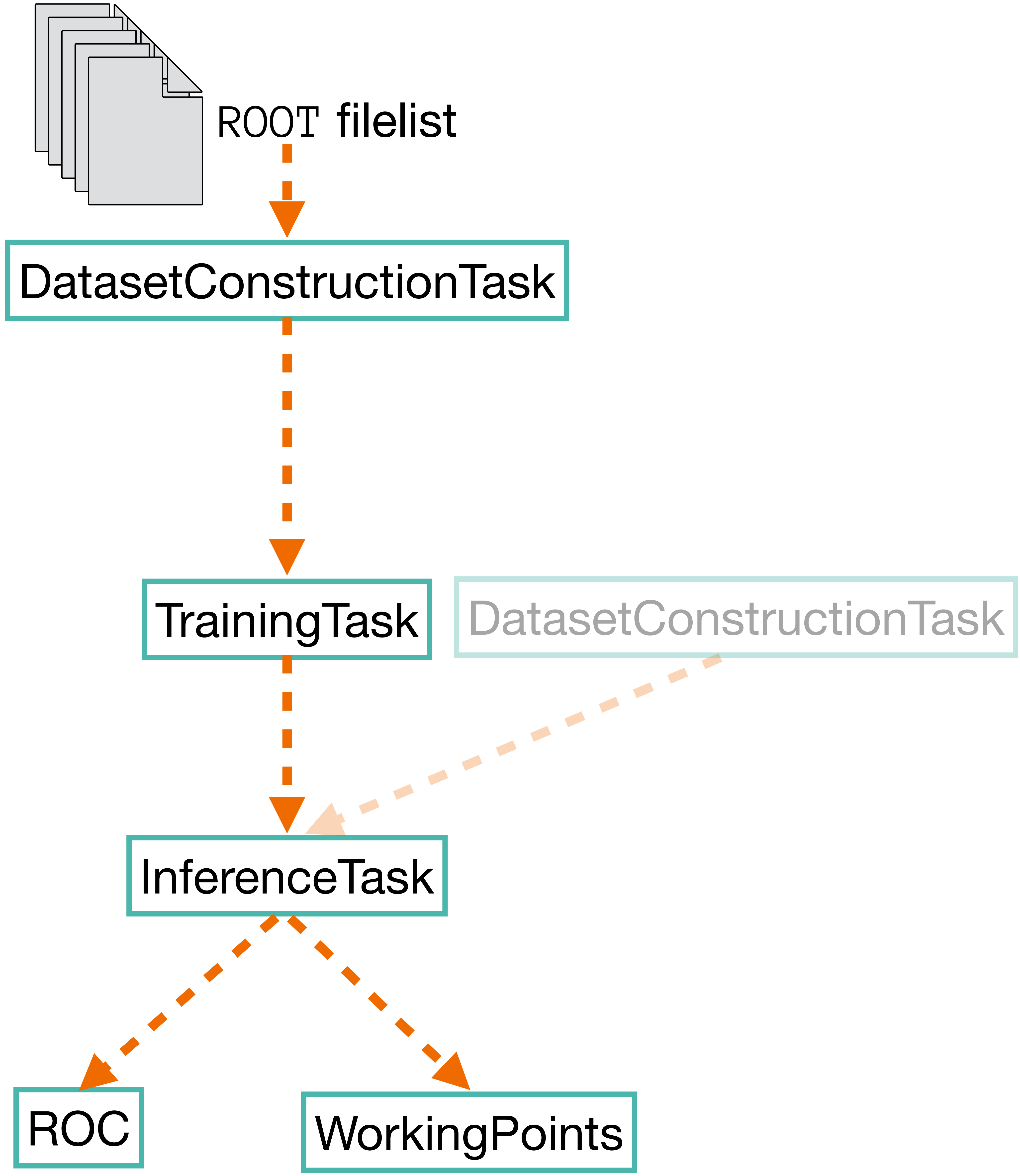
Also:

- Have clearly defined workflows (not your 7 bash scripts!)
- Make trainings repeatable
- Standardized evaluation tools

b-hive attacks these problems

- Pythonic training framework
- Workflow management with `law`
- `coffea`, `awkward`, `numpy` for the heavy data lifting
- No ML-framework lock in
  - `TensorFlow` and `PyTorch` can be used
  - ➜ Modular Setup

```yaml
bins_pt:
  - 30
  - 100
  - 500
  - 2000

bins_eta:
  - -2.5
  - -2.0
  - -0.5
  - 0.5
  - 2.0
  - 2.5

treename:
  "producer/custom_tree"

global_features:
  - "jet_pt"
  - "jet_eta"
  - "n_Cpfcand"
  - "n_Npfcand"
  - "nsv"
  - "npv"

pf_candidate_features:
  - "pfcand_pt"
  - "pfcand_eta"
  - "pfcand_trackPt"
  - "pfcand_trackEta"
  - "pfcand_trackDeltaR"

truths:
  - "isB"
  - "isUDS"
  - "isG"
```



- Easy configuration for different working-groups
- New applications are embedded in the pipeline

➜ Knowledge-sharing by code-sharing

Have a look: CERN-CMS-DP-2024-020

ENERGY-BASED GRAPH AUTOENCODERS FOR SEMIVISIBLE JET TAGGING IN THE LUND REPRESENTATION

Annapaola De Cosa, Roberto Seidita, Florian Eble, Christoph Ribbe[1]

[1]Did most of the work but could not join

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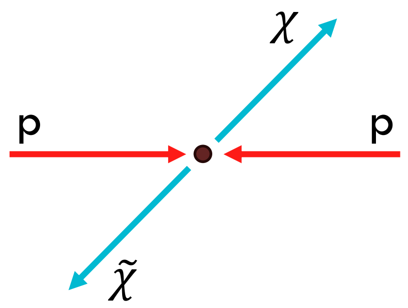
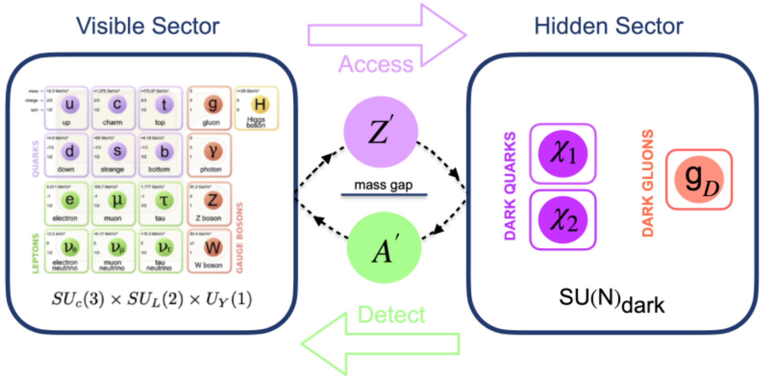
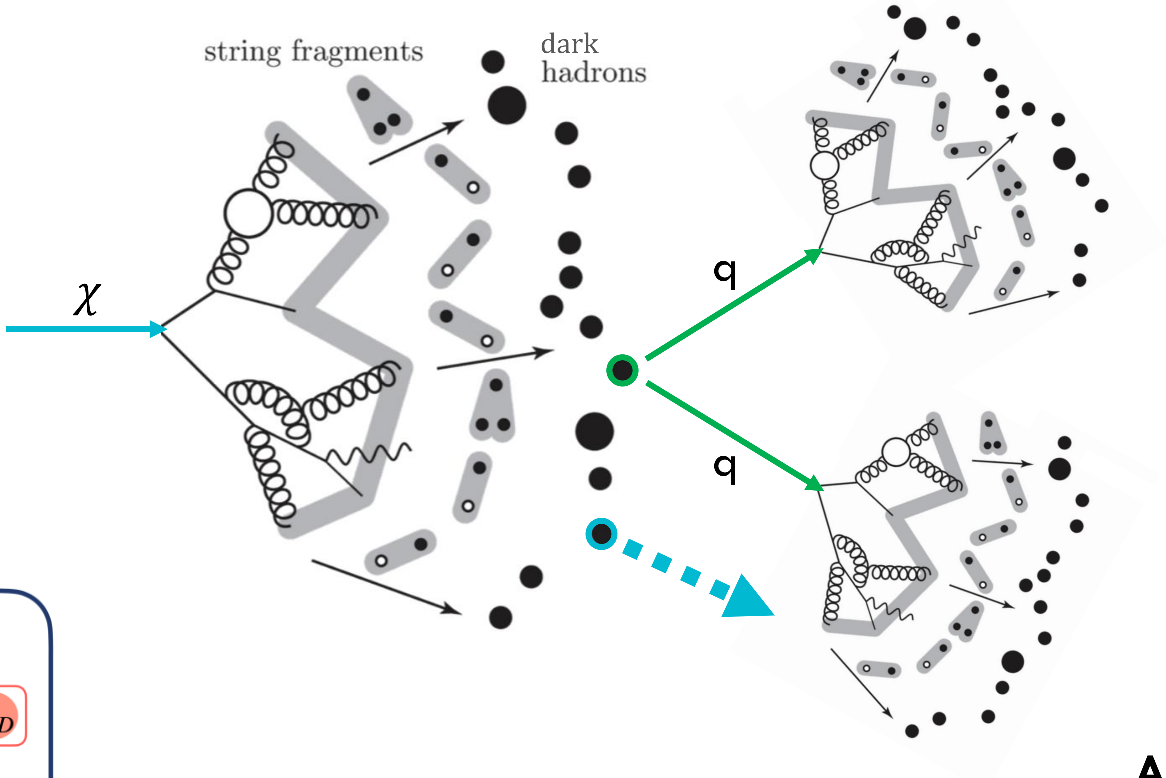
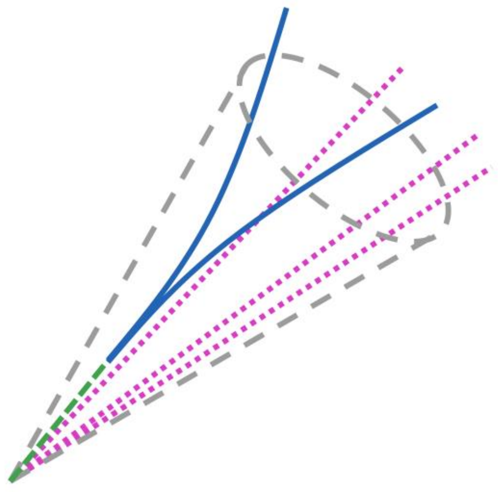


Dark quarks from a proton-proton collision





Shower of **stable (invisible)** and **unstable (visible)** dark particles



A semivisible jet (SVJ): a spray of particles with missing stuff between them

WHY UNSUPERVISED?

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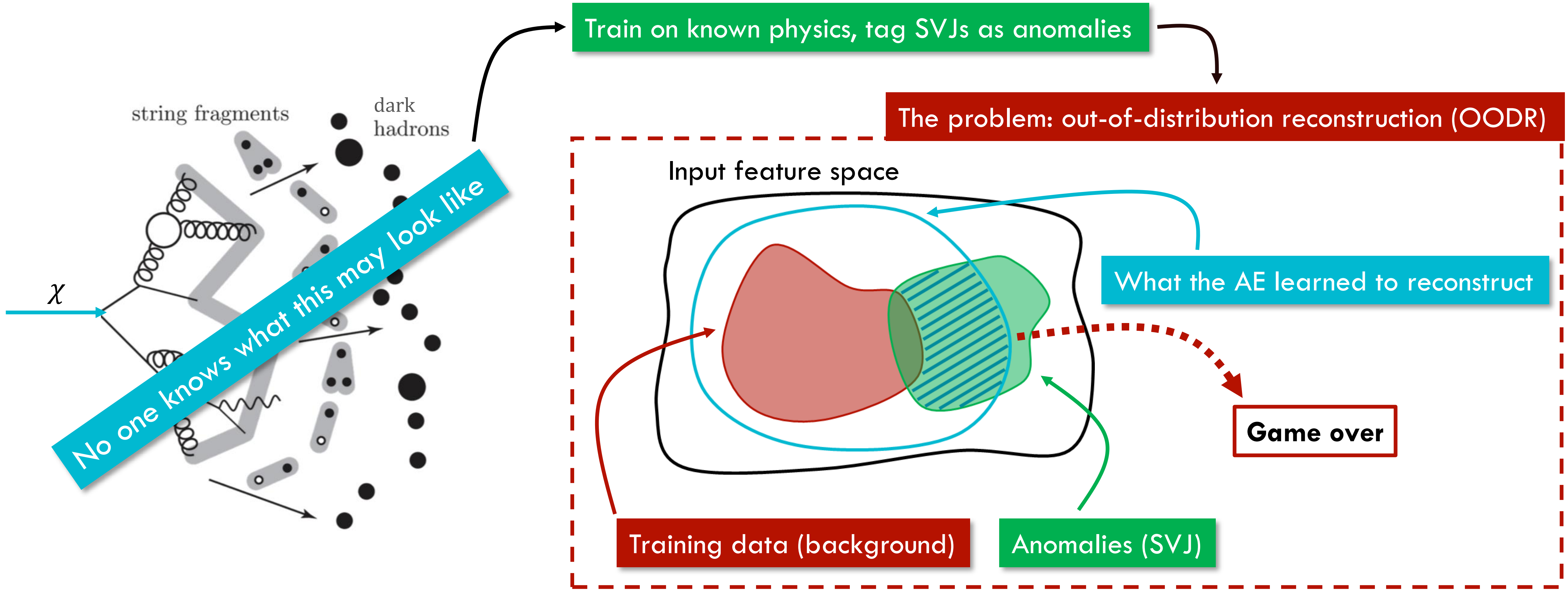
Annapaola De Cosa, Roberto Seidita,
Florian Eble, Christoph Ribbe



JETS AS LUND GRAPHS

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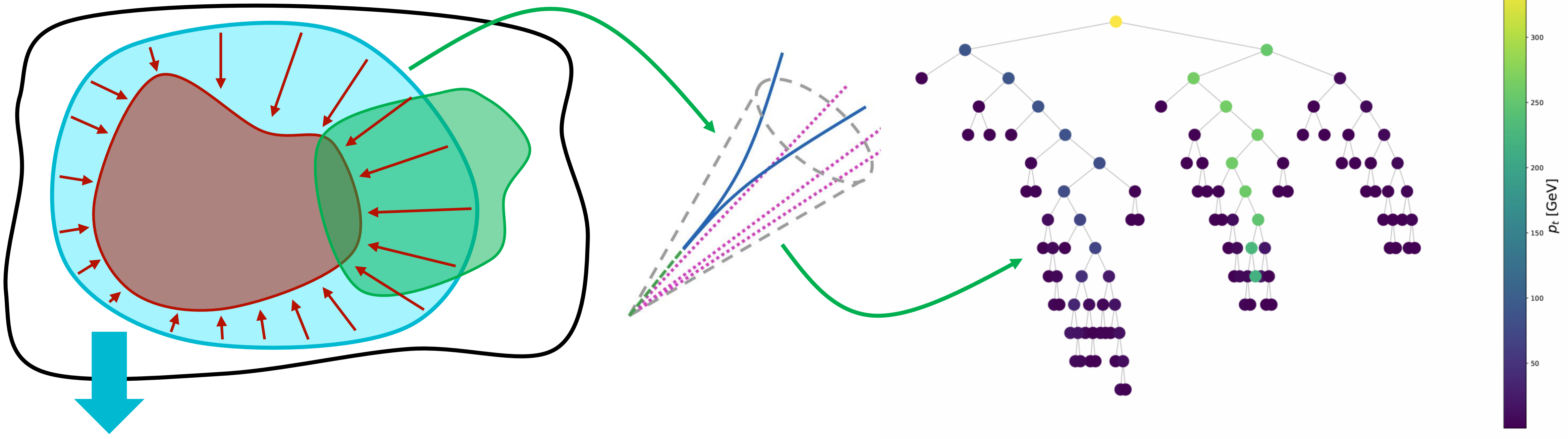
Florian Eble, Christoph Ribbe

Input feature space



Sample here and enforce $p_{model} = p_{data}$

Normalized autoencoder

How do you sample from graph space? Come to the session tomorrow!