Toward AI-based new physics searches at the EIC

Felix Ringer

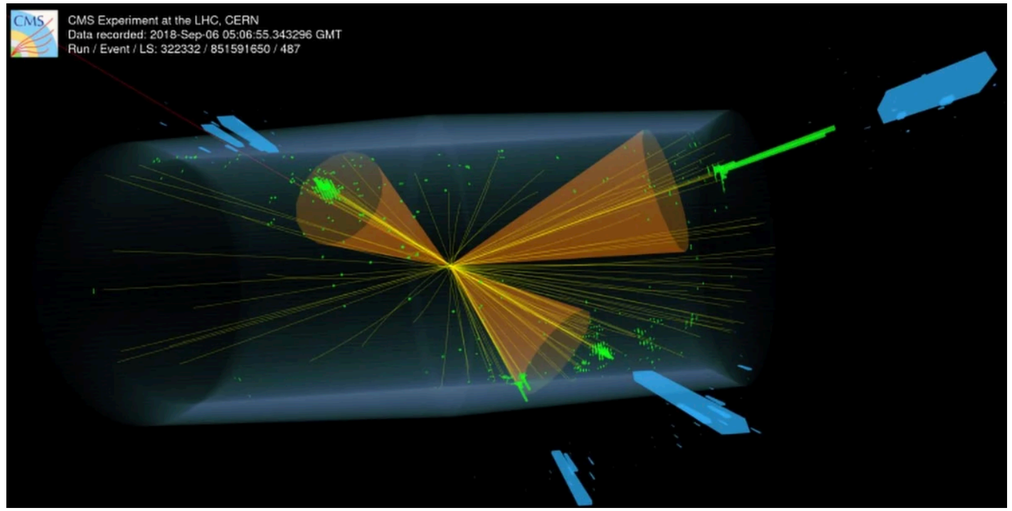
Loopfest `26, BNL

New physics searches

Dedicated searches for specific models

Constrain SMEFT operators

Anomaly detection



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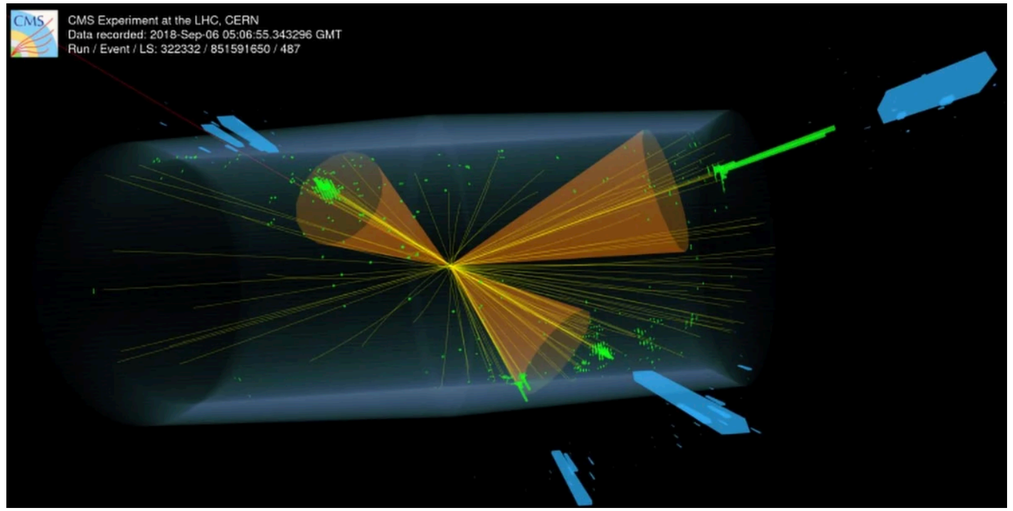
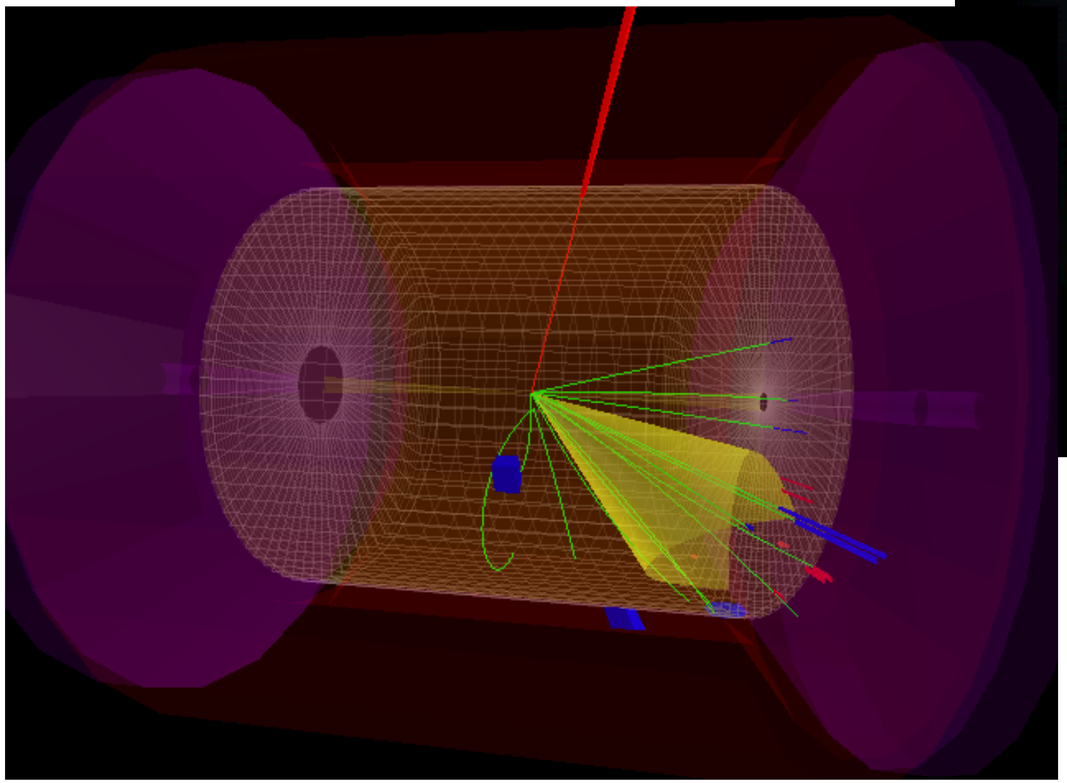


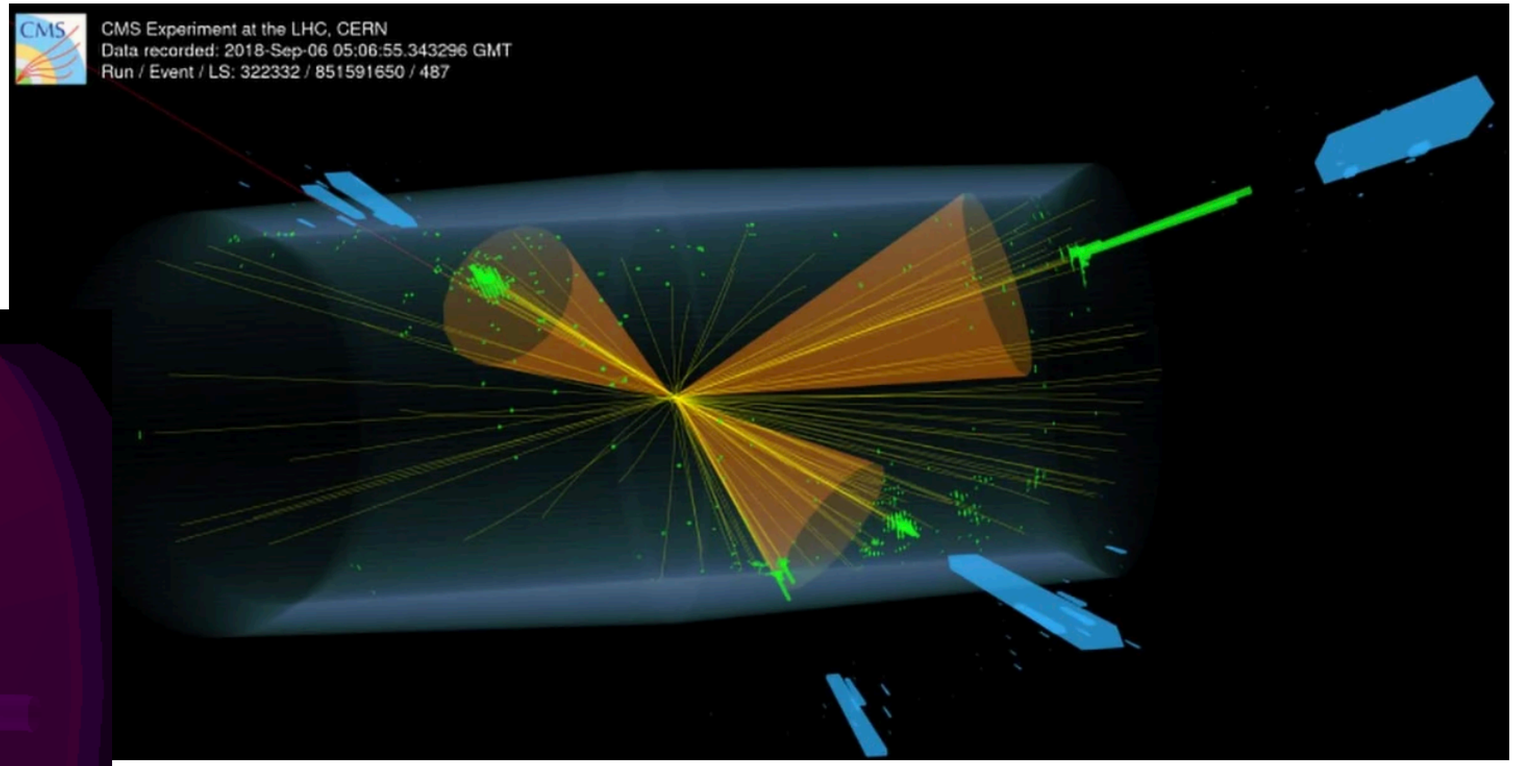
Model independent + use event-level information

+ various mixed techniques

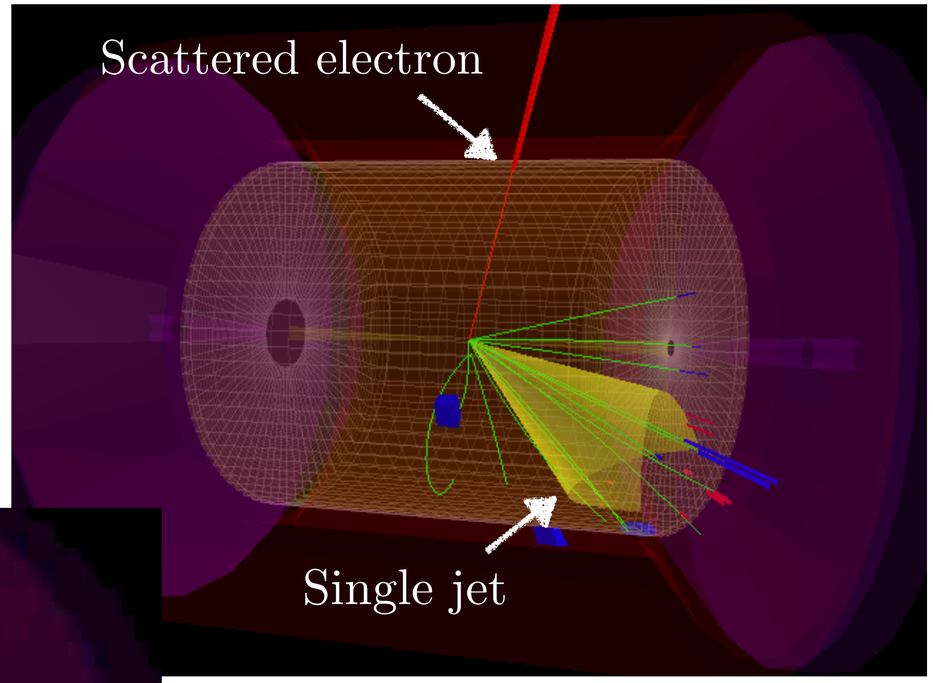
Jets at the LHC & EIC

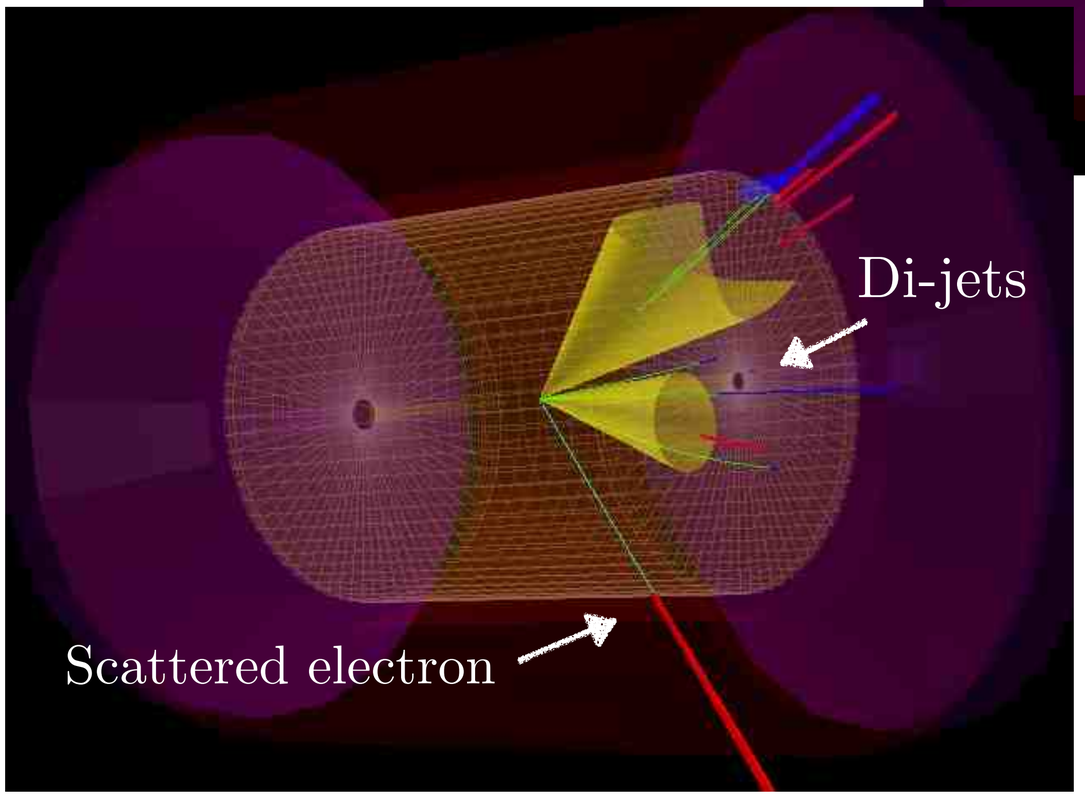
EIC simulation $\sqrt{s} = 140$ GeV





EIC simulation



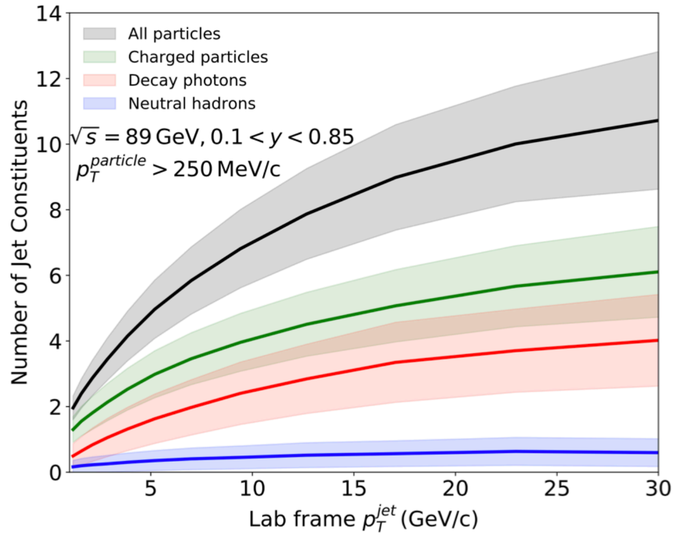


Single and dijet events

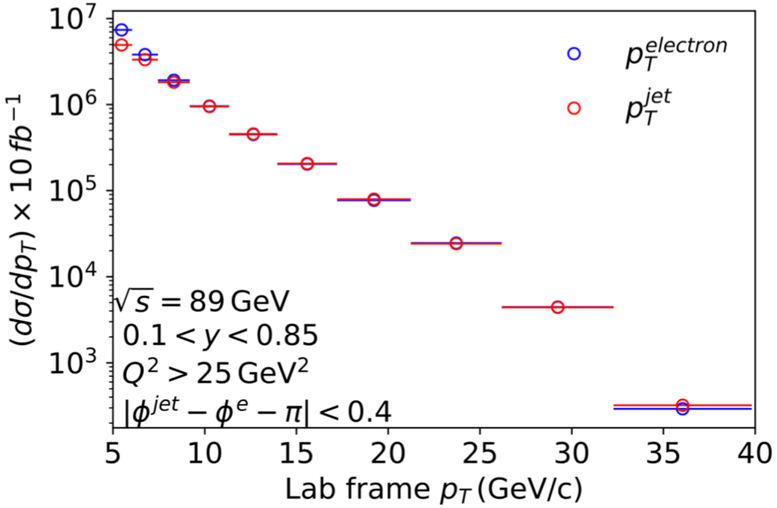
Nature of jets at the EIC

Particle #

Quark-like

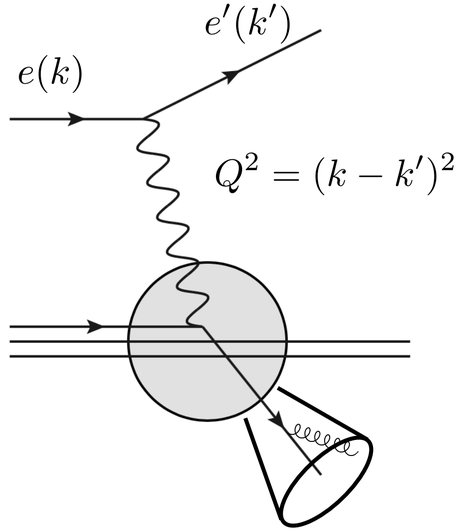


Transverse momentum



Two "natural" hard scales

- Jet transverse momentum p_T
- Photon virtuality Q^2



Arratia, Jacak, FR, Song `19
see also Aschenauer et al.

Anomaly detection at the LHC

Weakly supervised

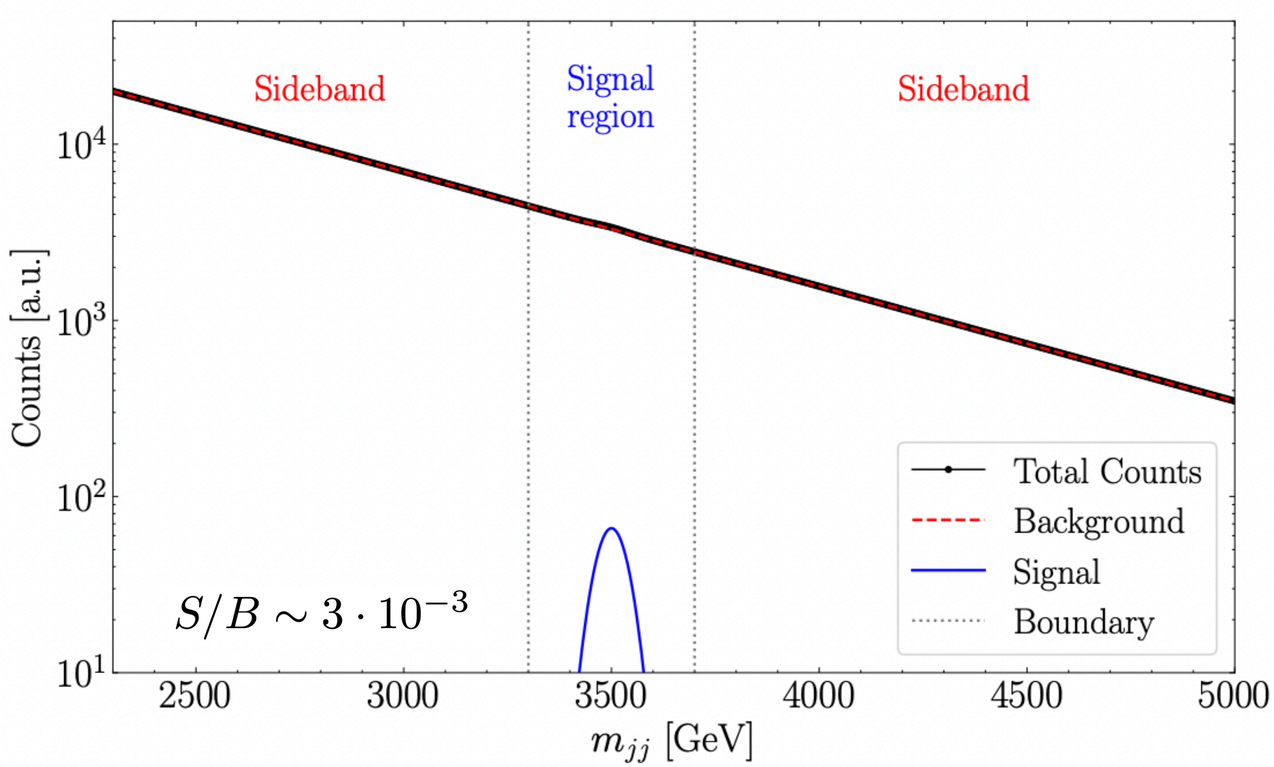
- Localized resonance
- Increase signal significance using full event information

- E.g. $Z' \to X(\to q\bar{q}), Y(\to q\bar{q})$ with $m_{Z'} = 3.5$ TeV

LHC Olympics data set

See e.g. Nachman, Thaler, Mikuni, Plehn, Spannowsky, Kasieczka, et al.

Dijet invariant mass spectrum



Anomaly detection at the LHC

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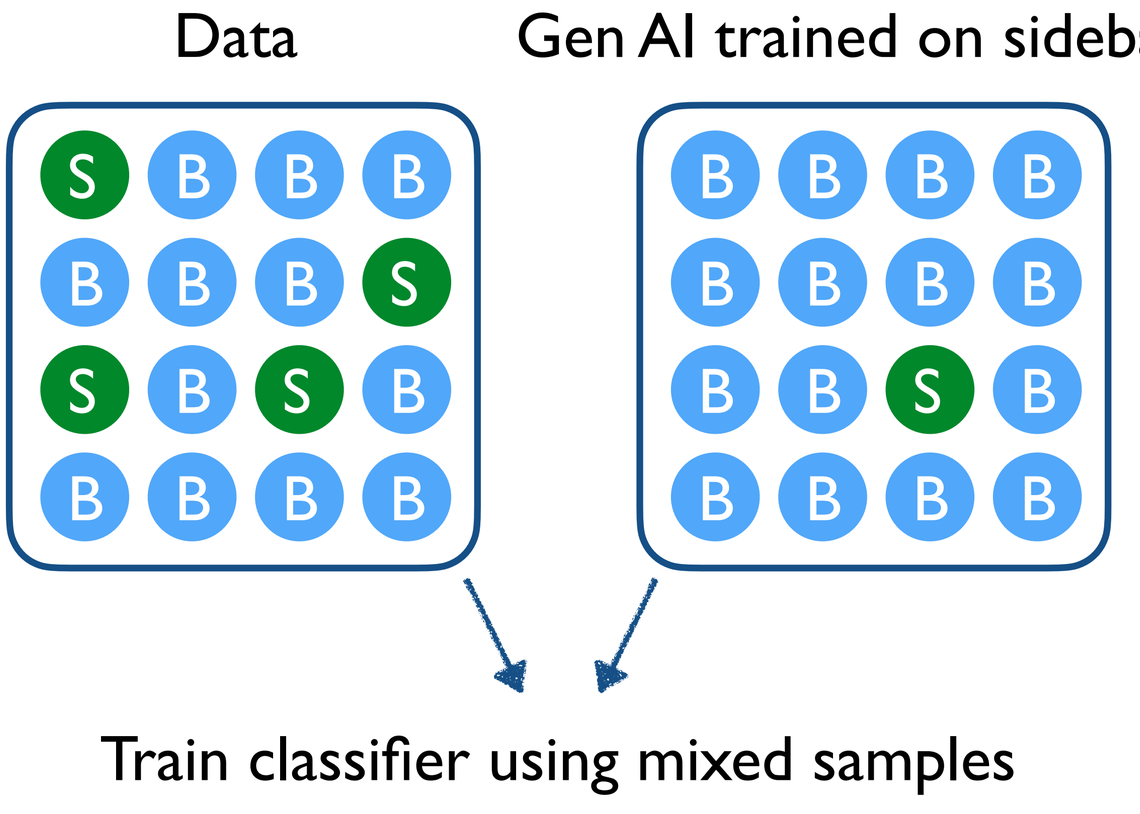
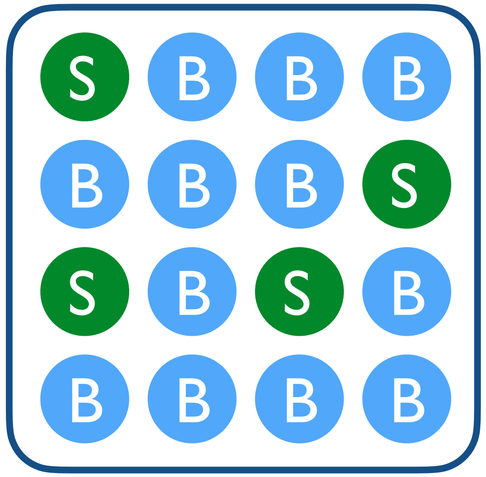


See e.g. Nachman, Thaler, Mikuni, Plehn, Spannowsky, Kasieczka, et al.

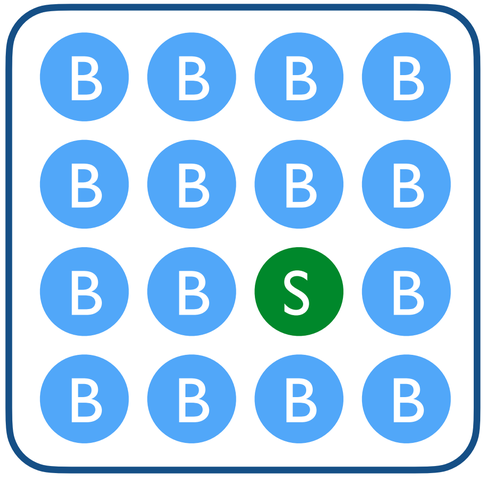
Anomaly detection at the LHC

Weakly supervised

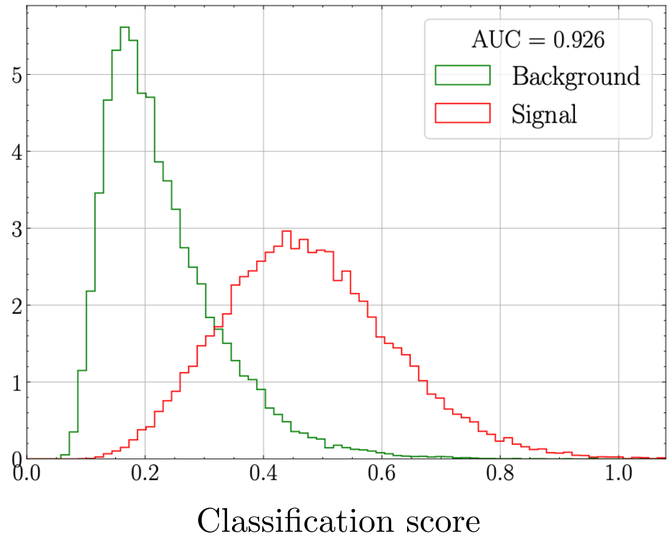
Data



Gen AI trained on sidebands



Train classifier using mixed samples

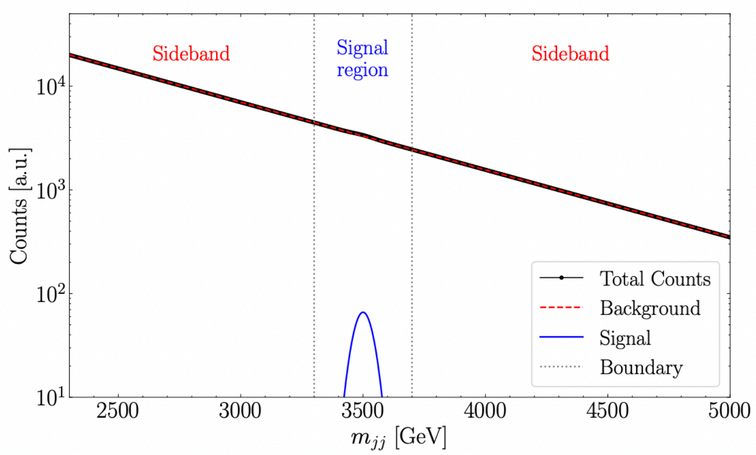


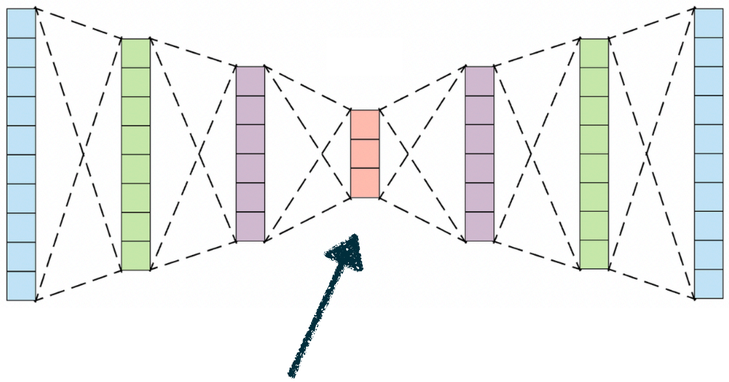
See e.g. Nachman, Thaler, Mikuni, Plehn, Spannowsky, Kasieczka, et al.

Anomaly detection at the LHC

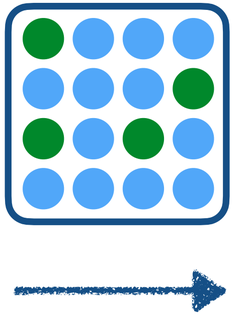
Fully unsupervised

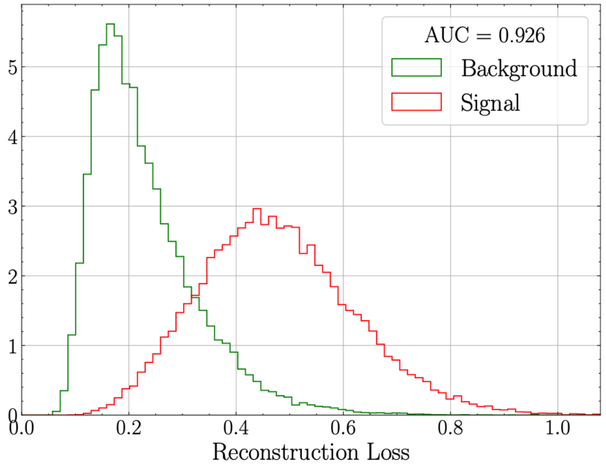
- Resonant and non-resonant
- Train autoencoder
- Complementary





Bottleneck



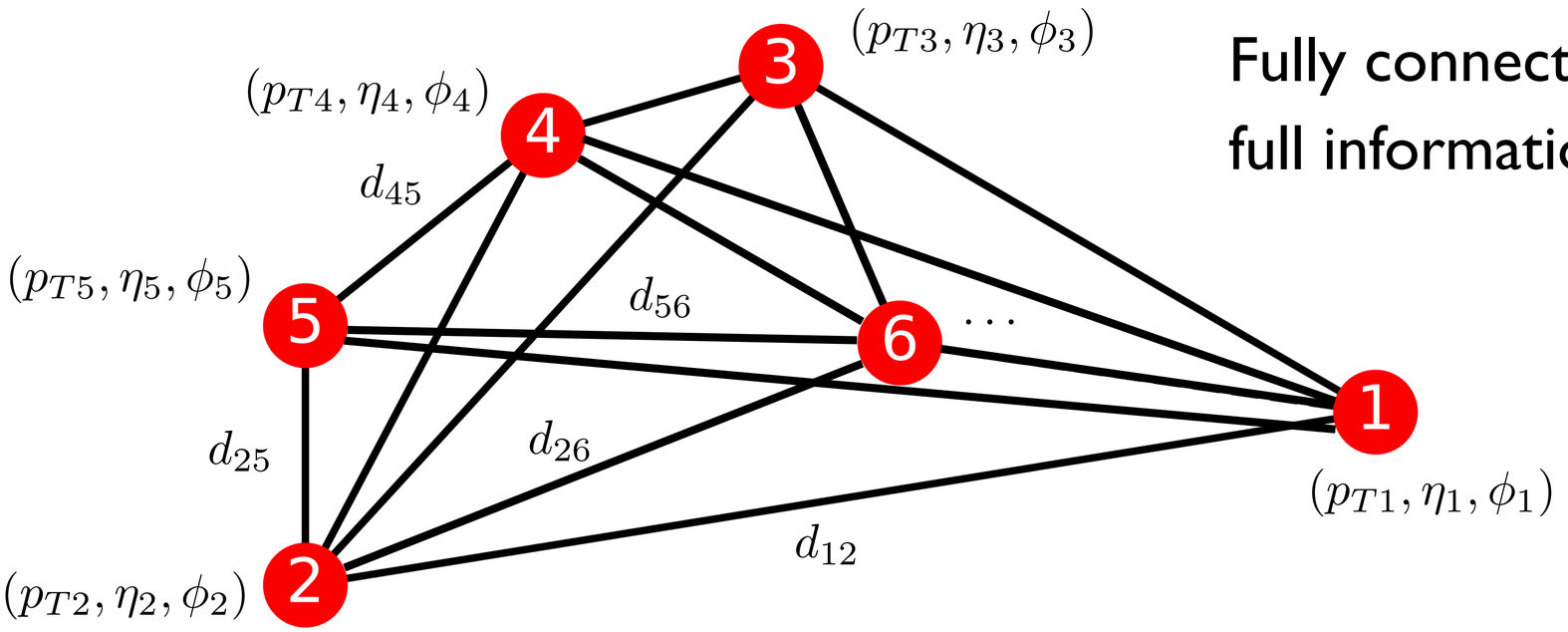


Reconstruction loss or anomaly score

Anomaly detection at the LHC

Araz, Athanasakos, Ploskon, FR `25
Selyak et al. `21

- Improve network architecture
- or change input features: Generally, more information $\neq$ better



Fully connected graph,
full information

- Alternatively, e.g. subjets, N-subjettiness basis or EFPs

Anomaly detection at the LHC

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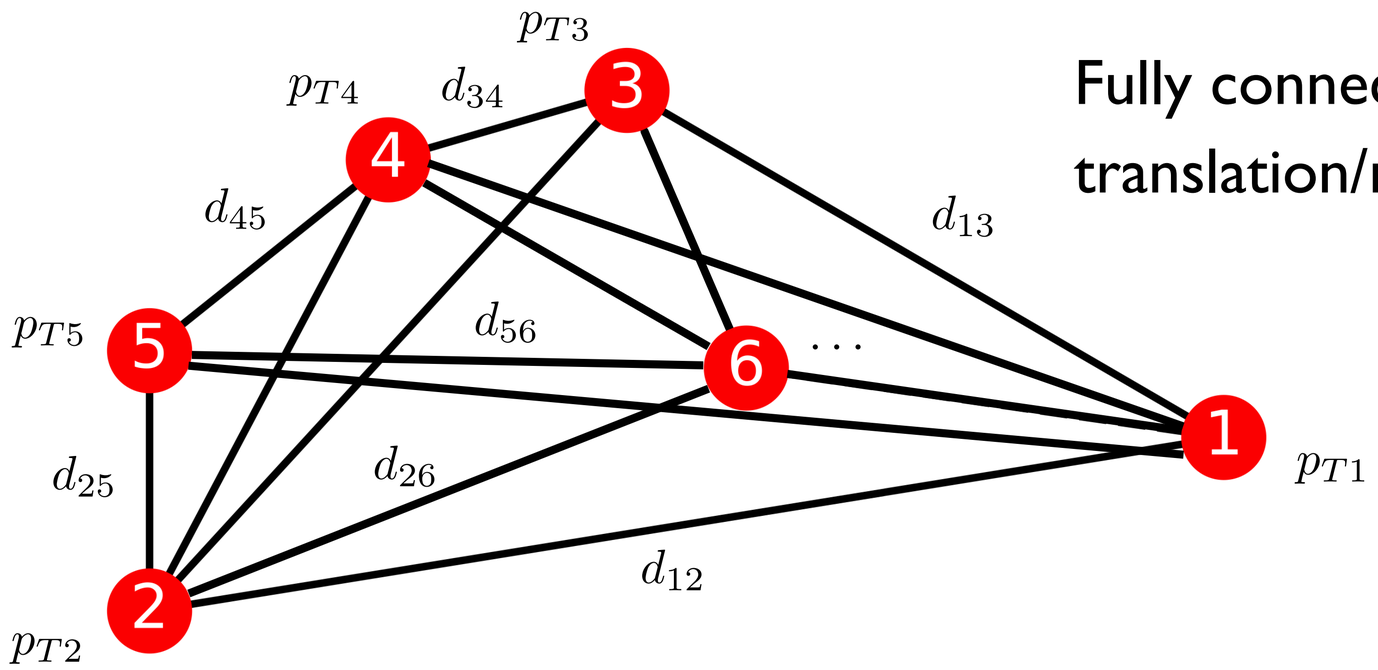

Fully connected graph, translation/rotation invariant

- Alternatively, e.g. subjets, N-subjettiness basis or EFPs

Anomaly detection at the LHC

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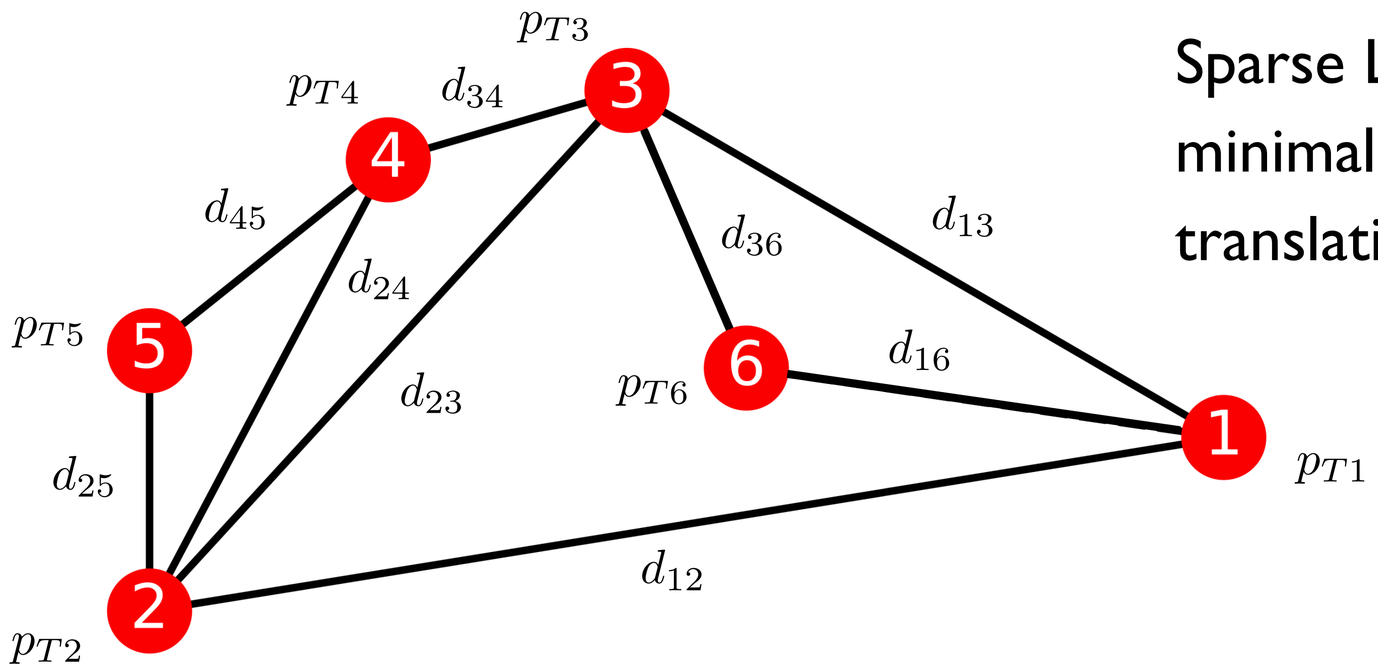


Sparse Laman graph,
minimal information,
translation/rotation invariant

- Alternatively, e.g. subjets, N-subjettiness basis or EFPs

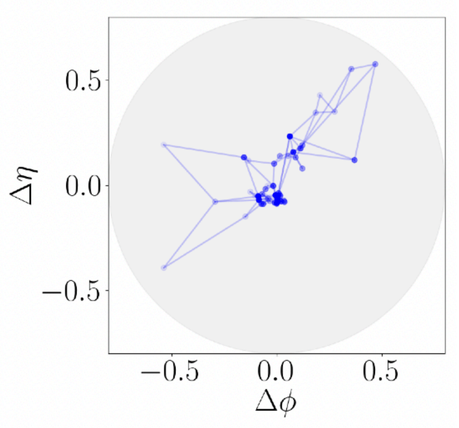
Anomaly detection at the LHC

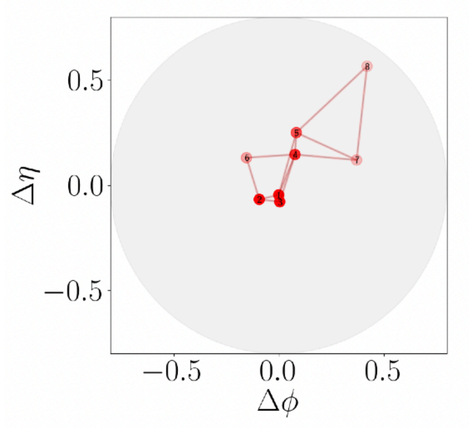
Araz, Athanasakos, Ploskon, FR `25

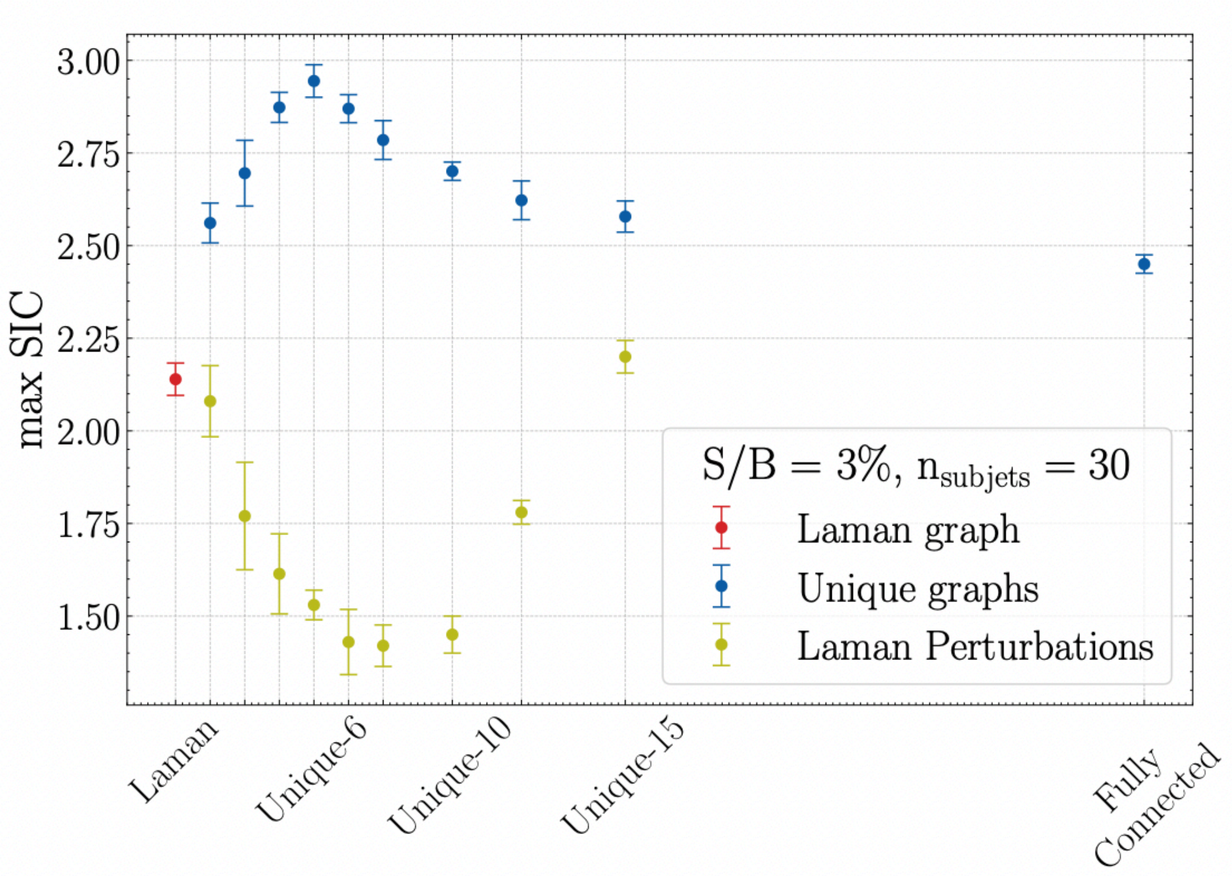
- Graph-based autoencoder

  LHC benchmark data set

  Certain sparse graphs perform best!

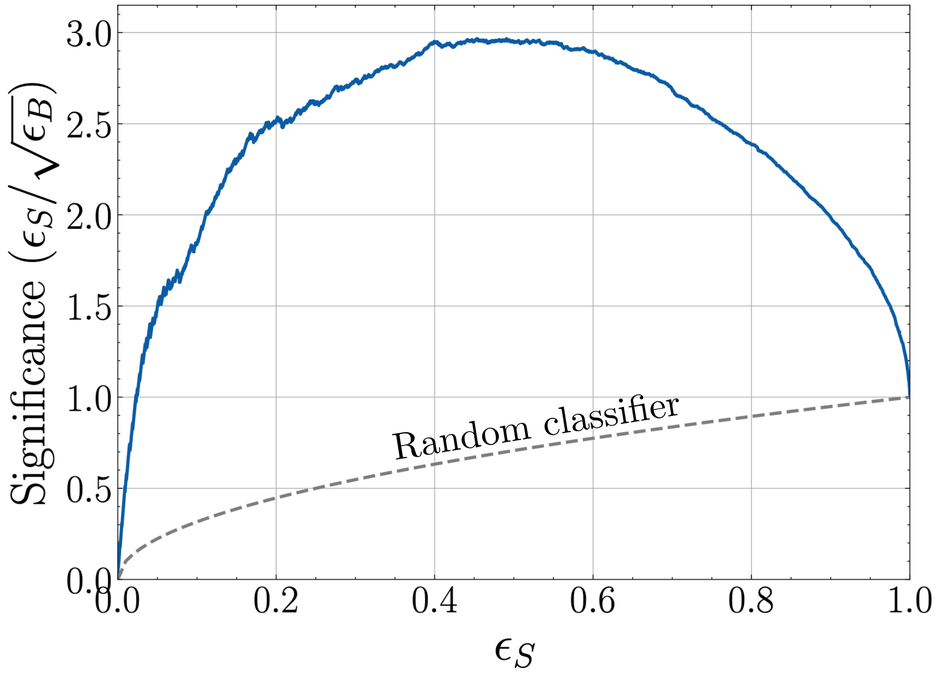


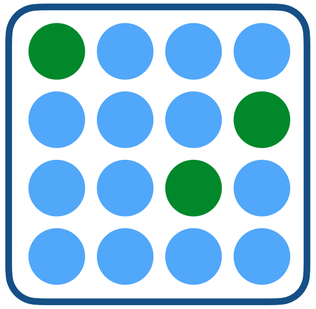




Autoencoder complexity bias

Araz, Athanasakos, Ploskon, FR `25



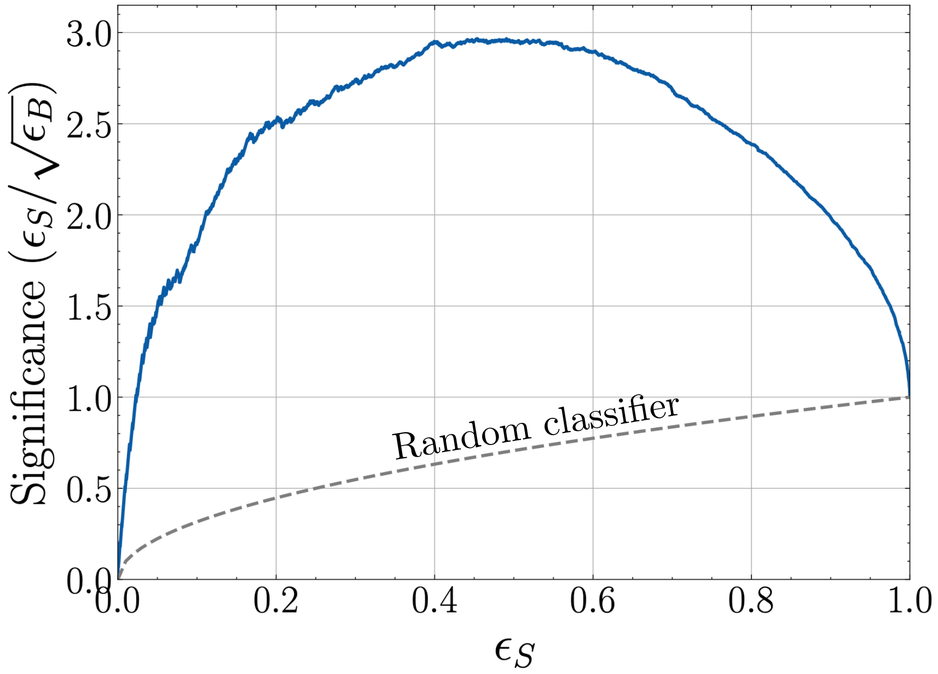


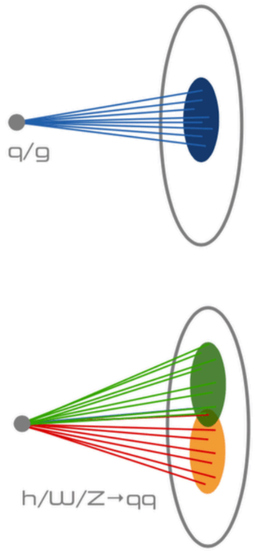
99% Background,

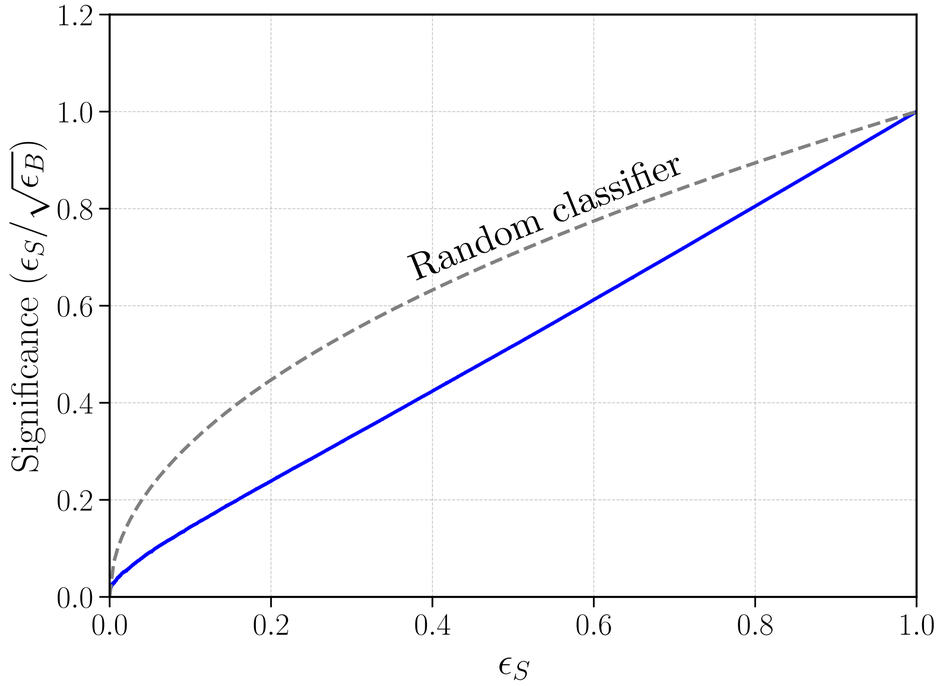
1% Signal

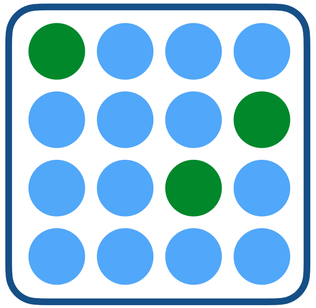
Autoencoder complexity bias

Araz, Athanasakos, Ploskon, FR `25





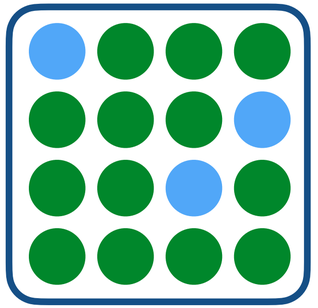




99% Background,
1% Signal

Exchange roles

99% Signal,
1% Background



Autoencoder complexity bias

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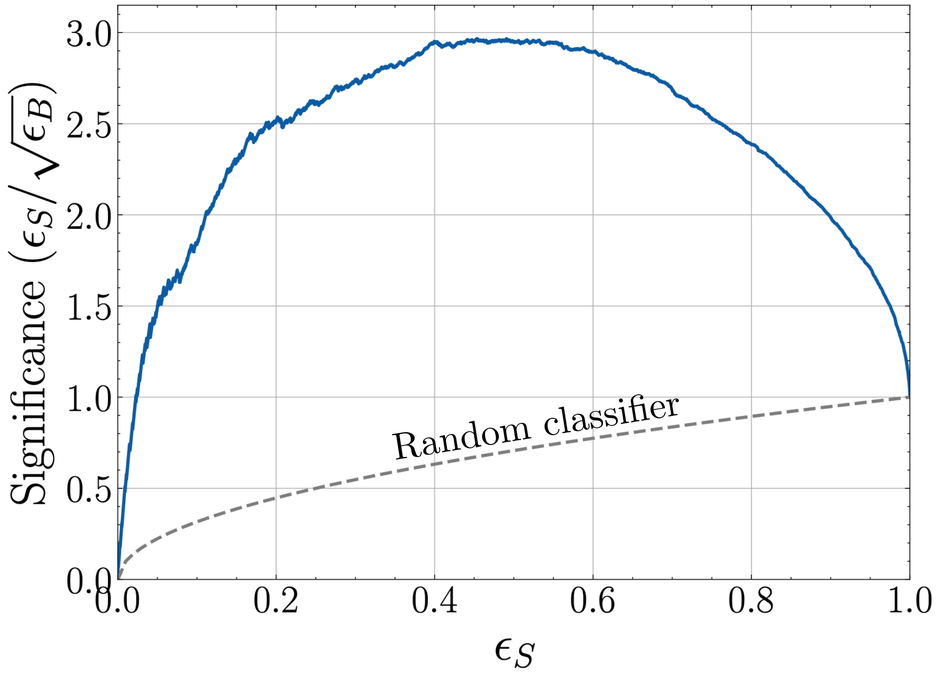
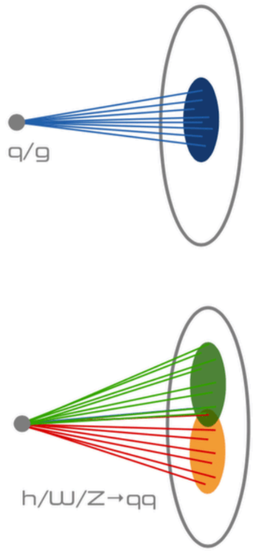
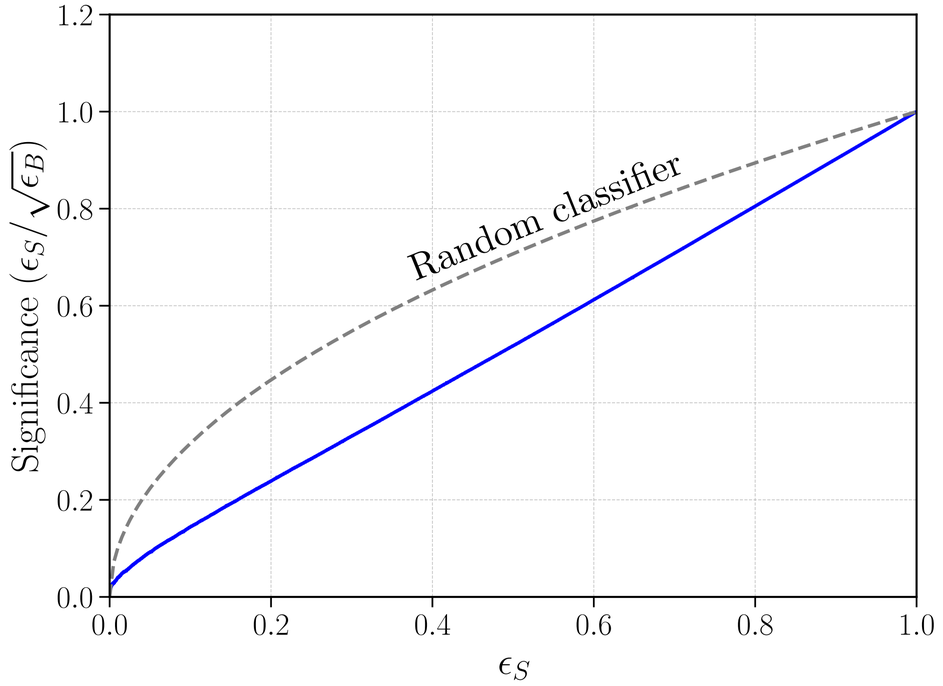
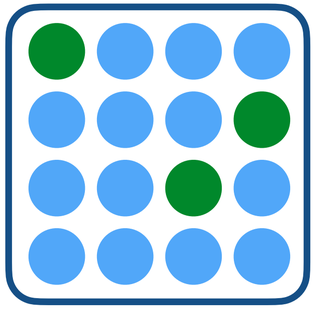






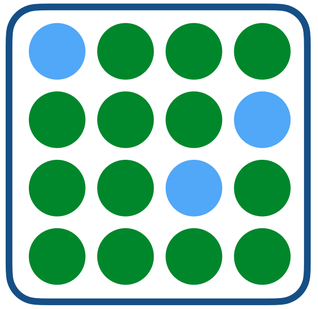


99% Background,
1% Signal

Exchange roles

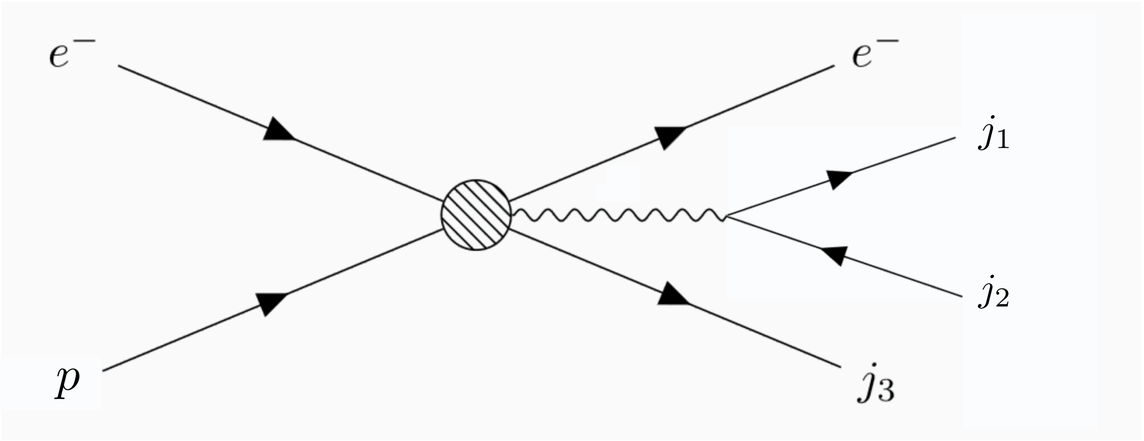
What about the EIC?

99% Signal,
1% Background



New physics searches at the EIC

- Consider an exemplary BSM signal
- B-L model, Z'_{B-L} from gauged $U(1)_{B-L}$
- Constraints in the low-mass region within reach of the EIC
- Electron + 3 jet signal (hadronic decay)

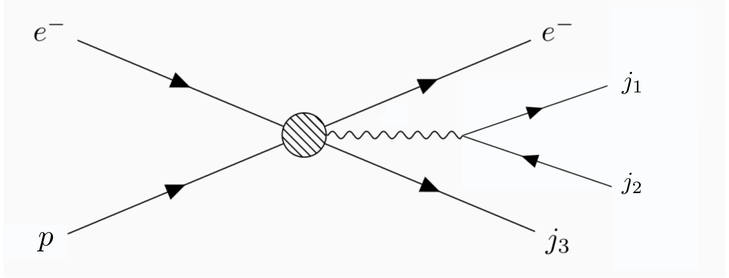


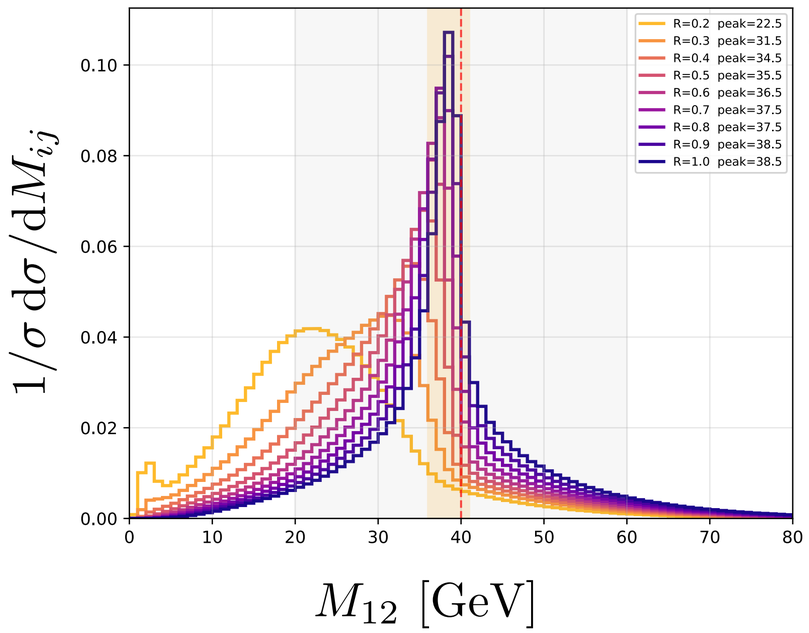
$$\mathcal{L}_{\text{int}} = g_{B-L} Z'_\mu J^\mu_{B-L} \quad \text{with} \quad J^\mu_{B-L} = \sum_f Q^f_{B-L} \bar{f} \gamma^\mu f$$

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

New physics searches at the EIC

- B-L model, Z'_{B-L} from gauged $U(1)_{B-L}$
- Signal cross section for $m_{Z'} = 40$ GeV





← Different jet radii R

← Only large-R jets align $M_{12} \sim m_{Z'}$

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New physics searches at the EIC

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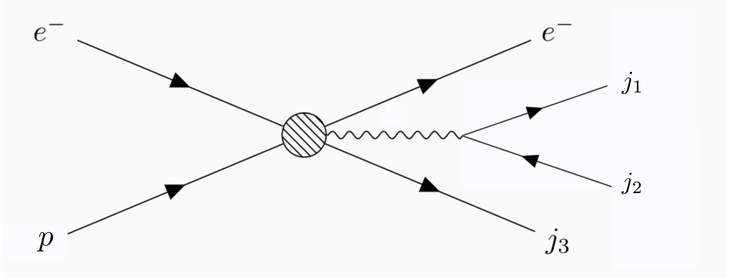
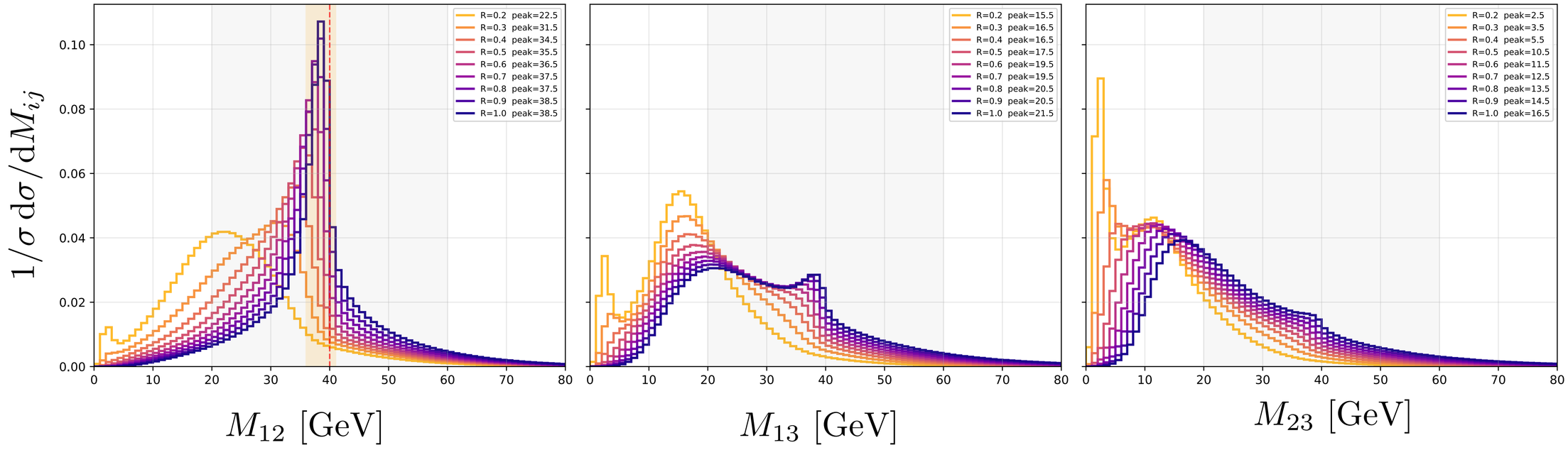




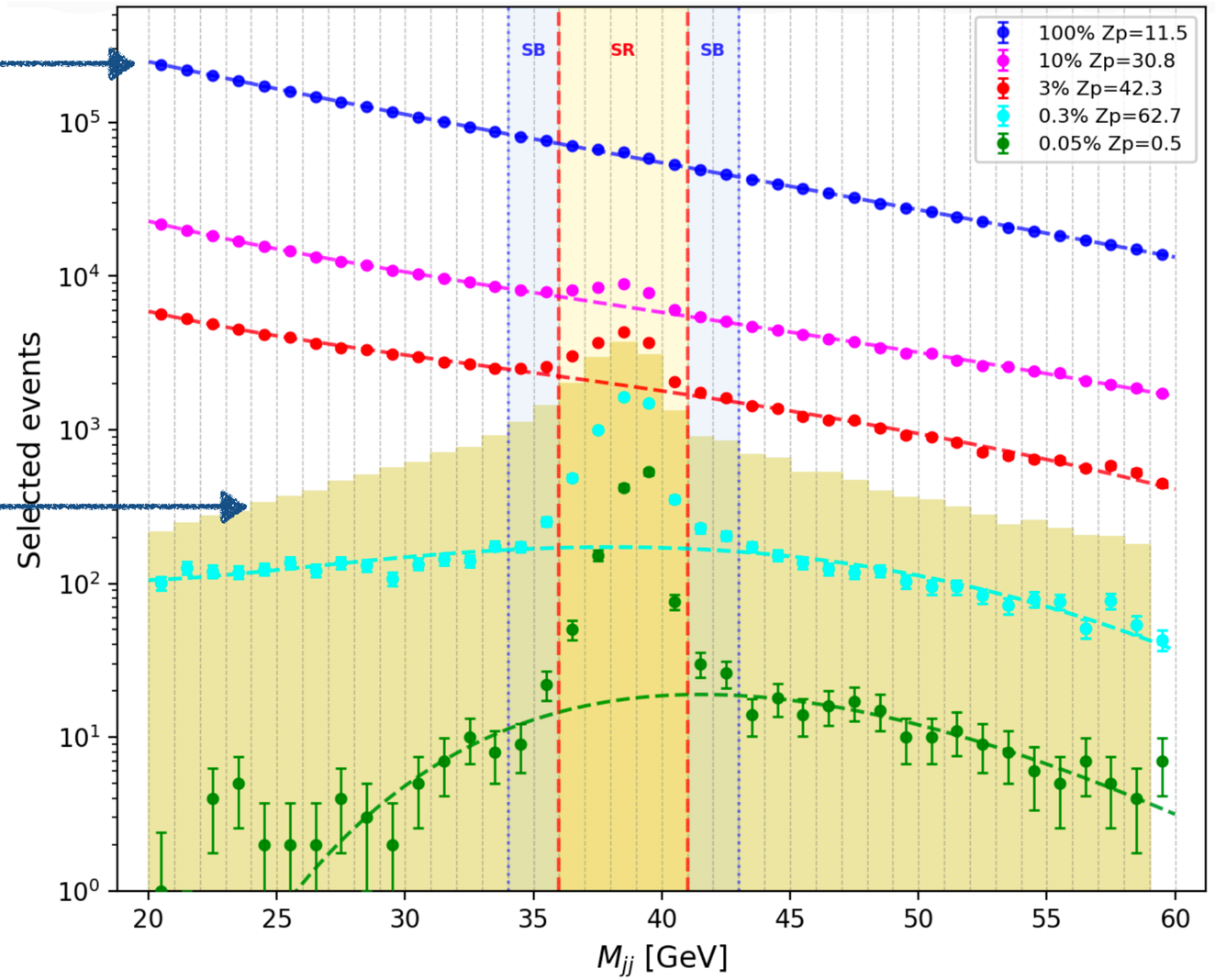
→ Use full event information!

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

New physics searches at the EIC

Signal + background

Signal



$S/B = 0.04$

Weakly supervised

Preliminary

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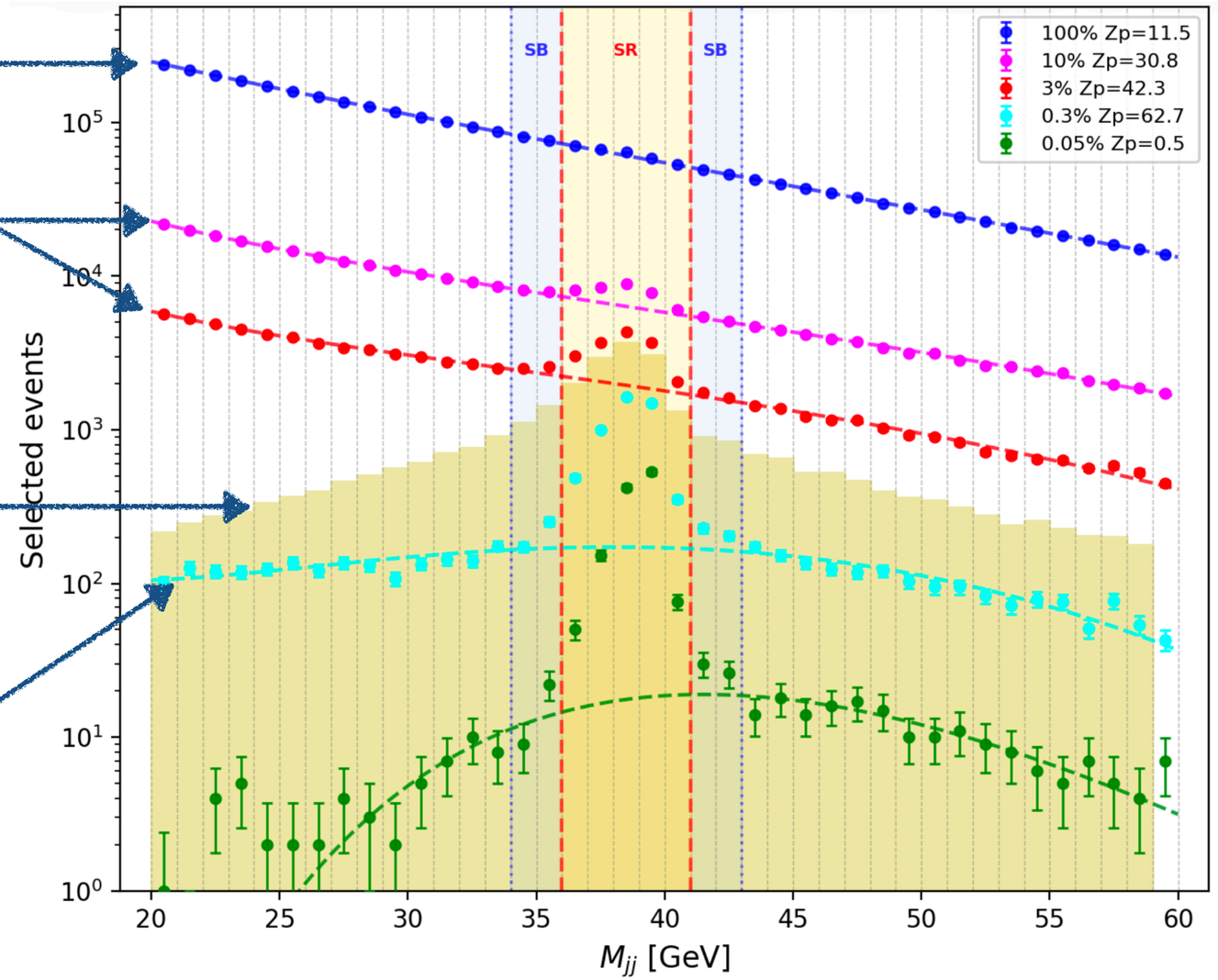
New physics searches at the EIC

Signal + background

Additional cut on classifier output

Signal

Dashed: Fits excluding the signal region



$S/B = 0.04$

Weakly supervised

Preliminary

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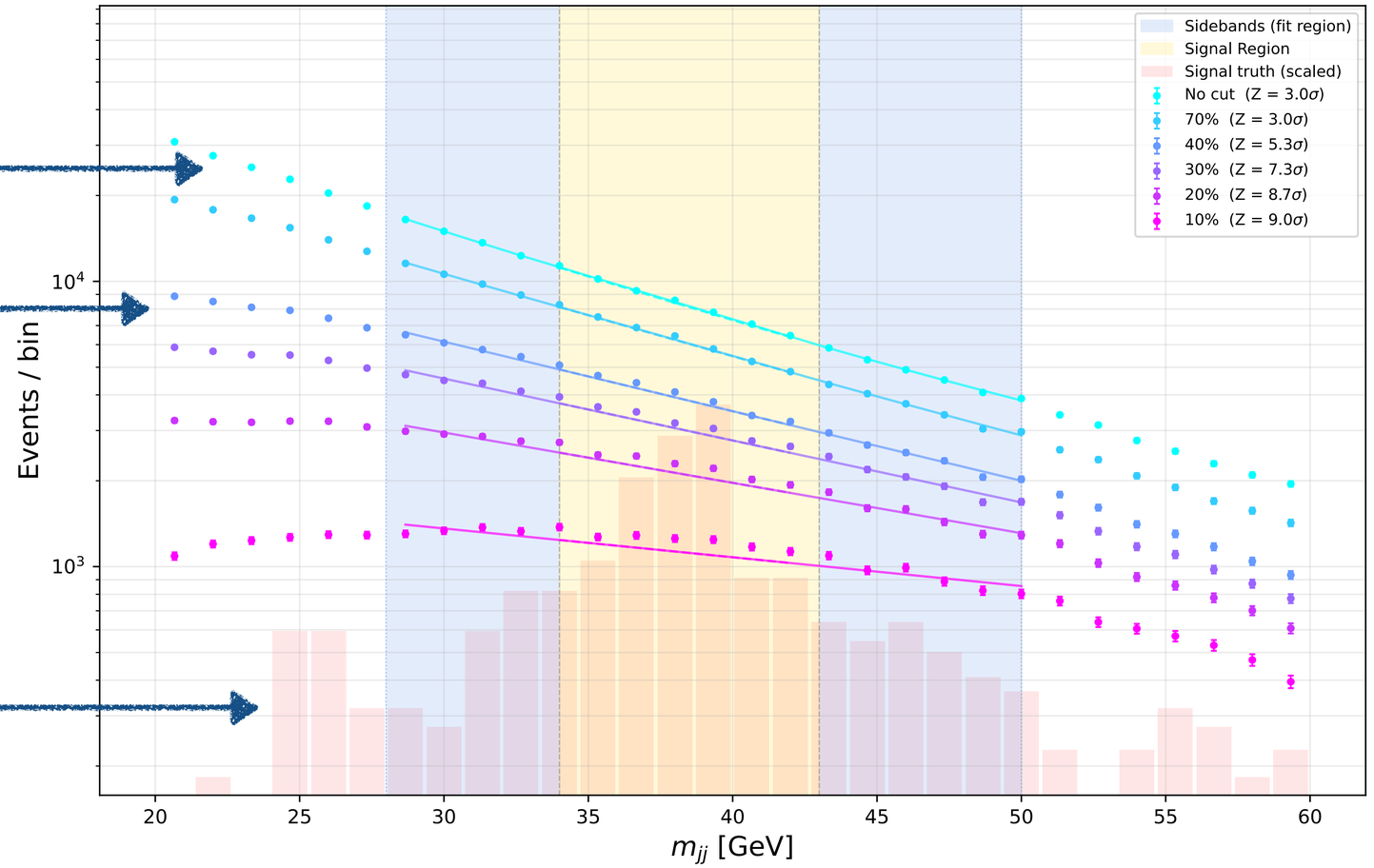
New physics searches at the EIC

Signal + background

Additional cut on reconstruction loss

Signal



Fully unsupervised

Preliminary

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

Summary

- Various search strategies of new physics at the LHC
- Exploration of AI-based techniques at the EIC
- Potential impact on design
- Non-resonant searches using theory simulations, etc.