Universal Monte Carlo Event Generator

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CHEP19, Adelaide

Supported by Jefferson Lab Laboratory
research and development (LDRD19-13)

Partnership with computer scientists

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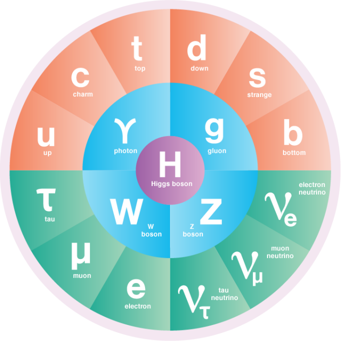
- T. Liu (JLab)
- R. E. McClellan (JLab)
- W. Melnitchouk (PI) (JLab)
- E. Pritchard (Davidson College)
- R. Ramanujan (Davidson College)
- M. Robertson (Davidson College)
- NS (co-PI) (JLab)
- R. R. Strauss (Davidson College)
- L. Velasco (Dallas)

The big picture

hadrons as emergent phenomena of QCD



quarks and gluons

The big picture

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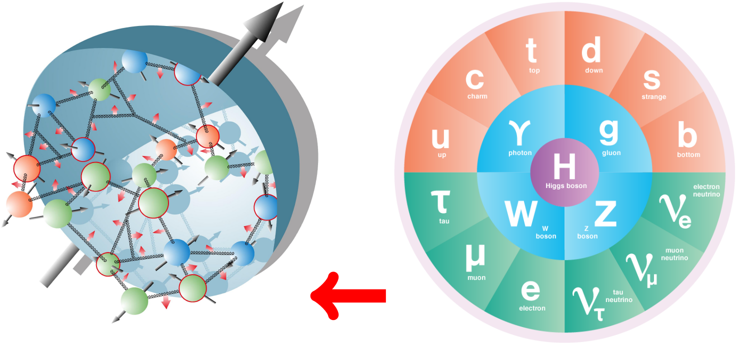
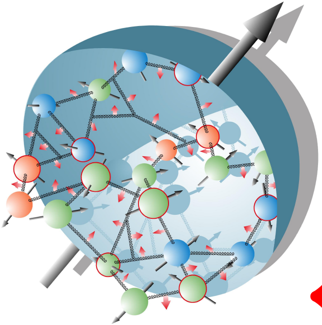


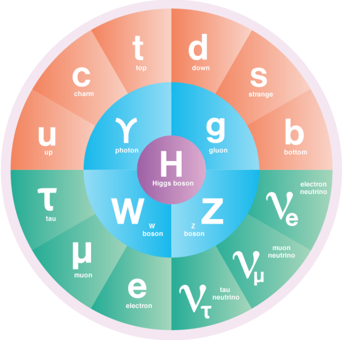
nucleon structure **quarks and gluons**

The big picture

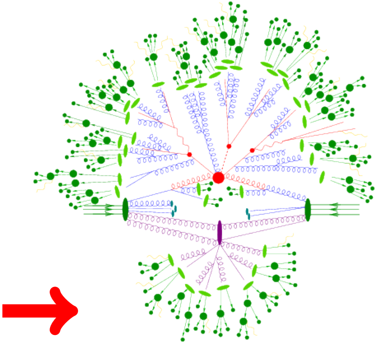
hadrons as emergent phenomena of QCD



nucleon structure



quarks and gluons



hadronization

Motivations

- A **new era** of nuclear physics has started with the JLab 12 GeV program

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- New tools based on Machine Learning (ML) **to boost the discovery potential** are needed

The goals

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- Build a **theory-free** MCEG

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- Map out particles correlations without biases from **approximated theory**

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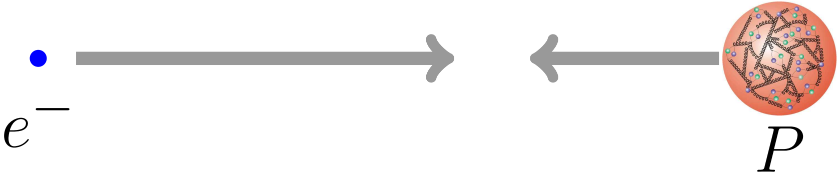
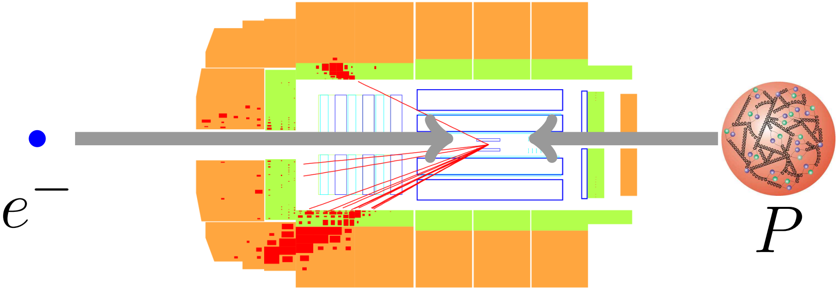
- MCEG as a **data storage utility**

Nature

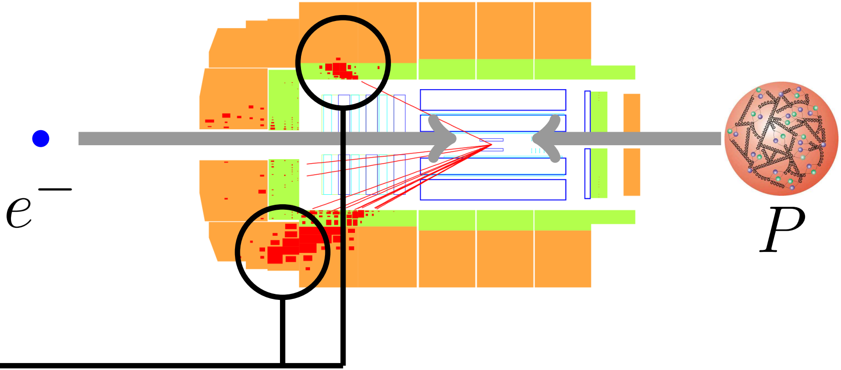


Nature



experimental detector

Nature



experimental detector

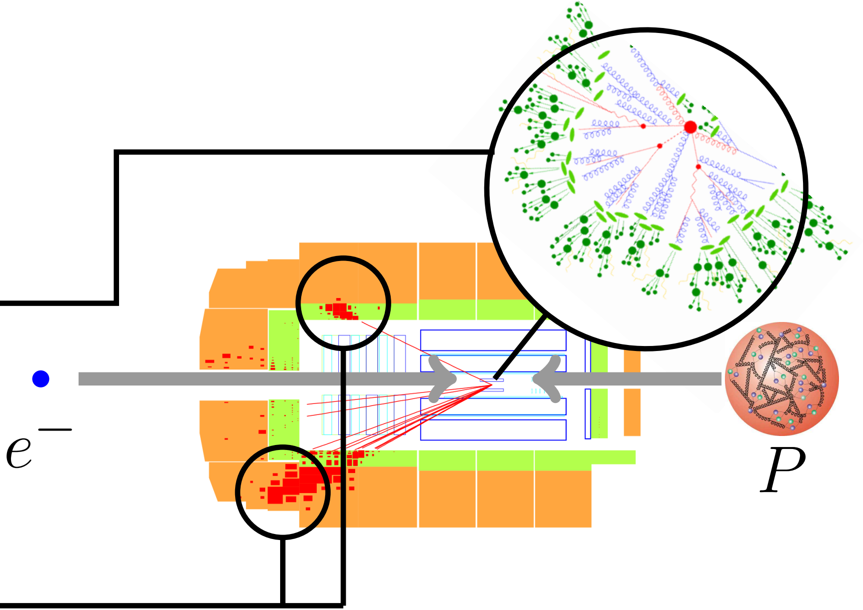
detector level events

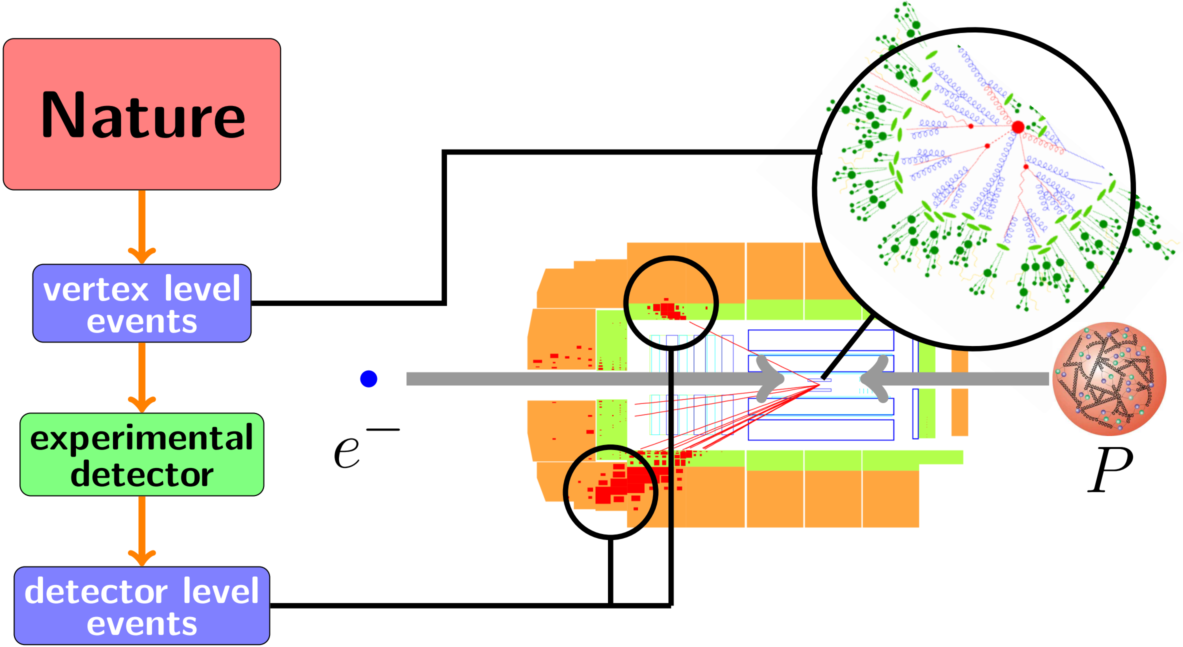
Nature

vertex level events

experimental detector

detector level events





Nature

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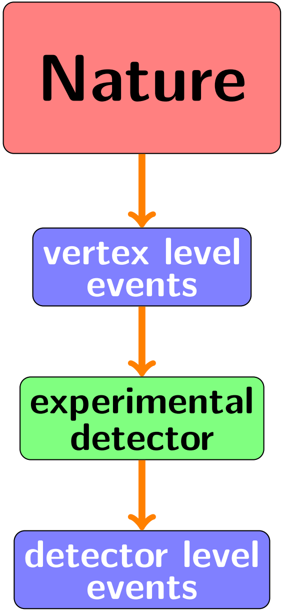

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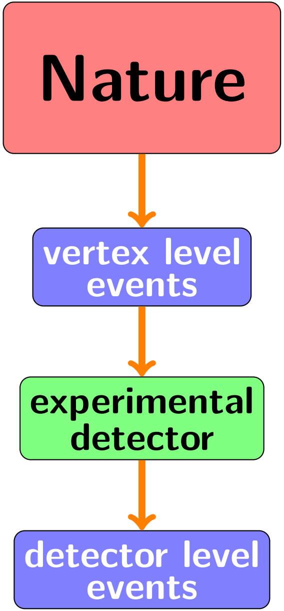
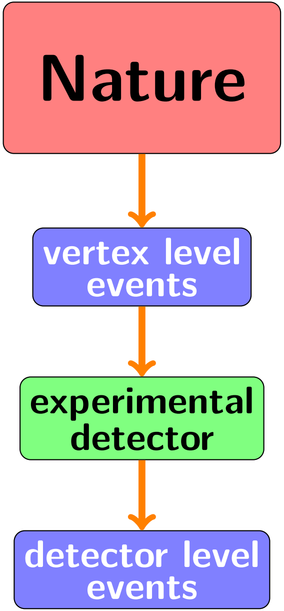
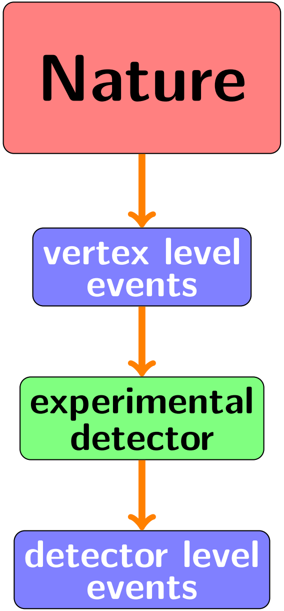


Can we use ML to:



Can we use ML to:

- simulate vertex level events?



Nature

vertex level events

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Can we use ML to:

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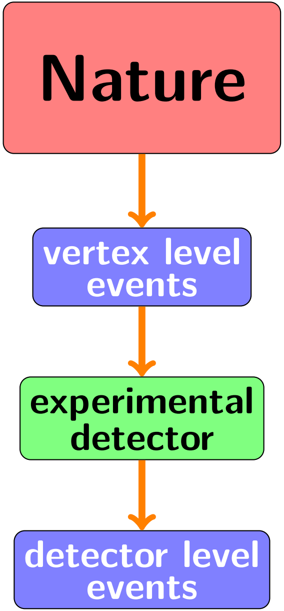
- simulate detector level events?



Nature

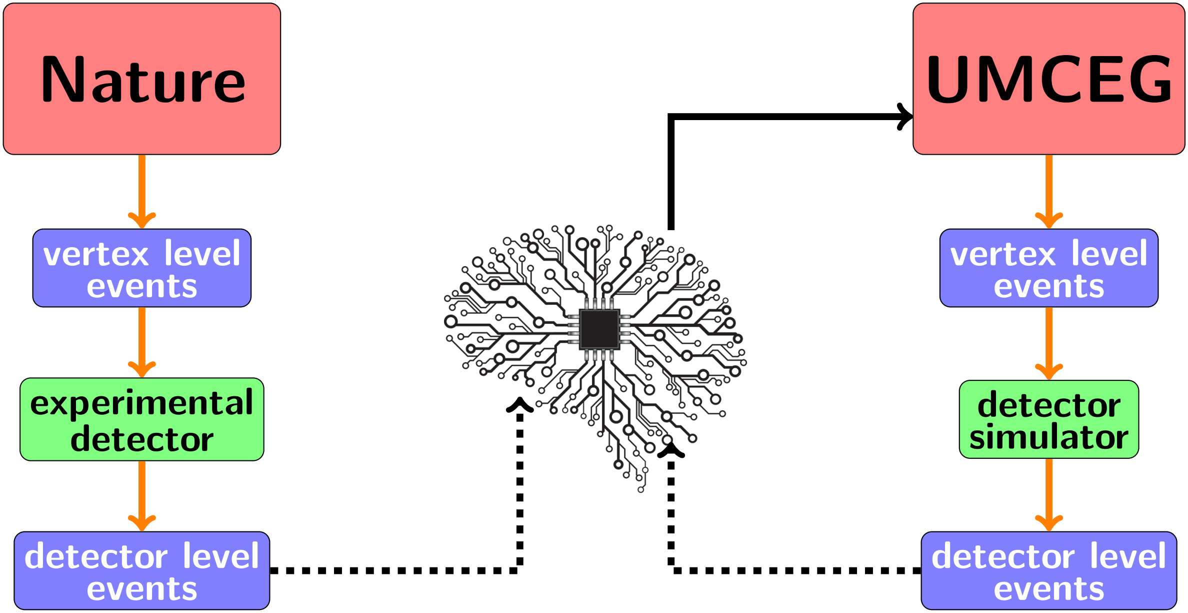
vertex level events

experimental detector

detector level events

Can we use ML to:

- simulate vertex level events?
- simulate detector level events?
- simulate **nature**?



Nature

vertex level events

experimental detector

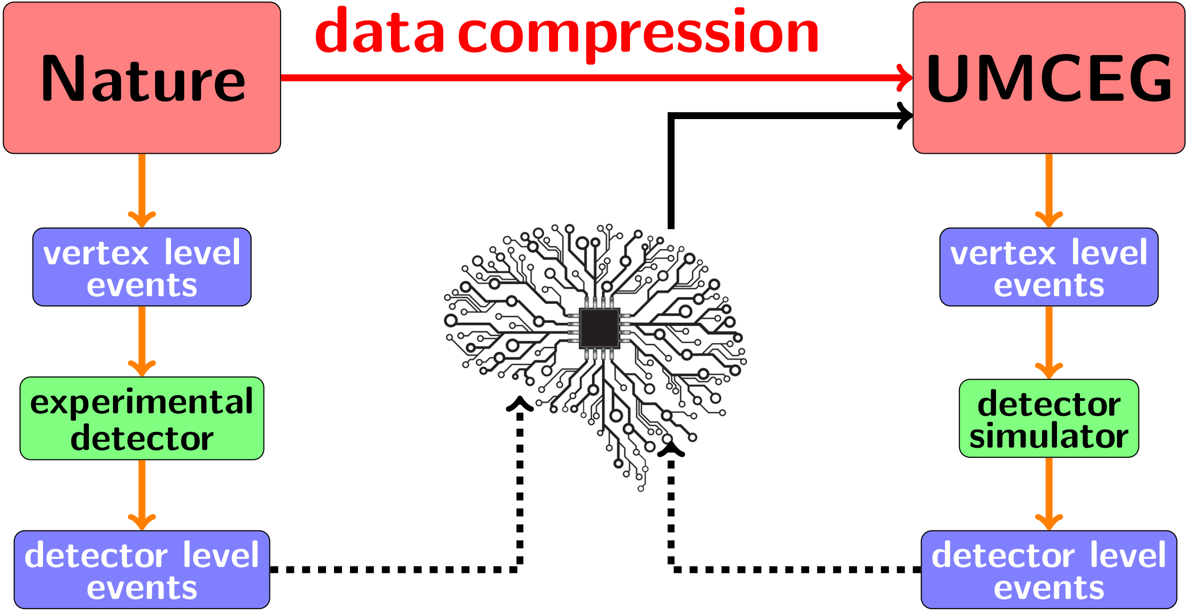
detector level events

UMCEG

vertex level events

detector simulator

detector level events



Nature

data compression

UMCEG

vertex level events

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detector simulator

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Our strategy

- Event level ML training → **GAN**

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- Use a dual GAN as the event generator

$$\underbrace{\rho(\text{particles}|\text{multiplicity})}_{\text{vectors generator}} \times \underbrace{\rho(\text{multiplicity})}_{\text{multiplicity generator}}$$

Challenges

- Find optimal data representation
  → what is the **image of an event**?

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- How to escalate from low to higher multiplicities?

Our current work in progress

- Use Pythia as a training and validation tool

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- Ignore detector effects

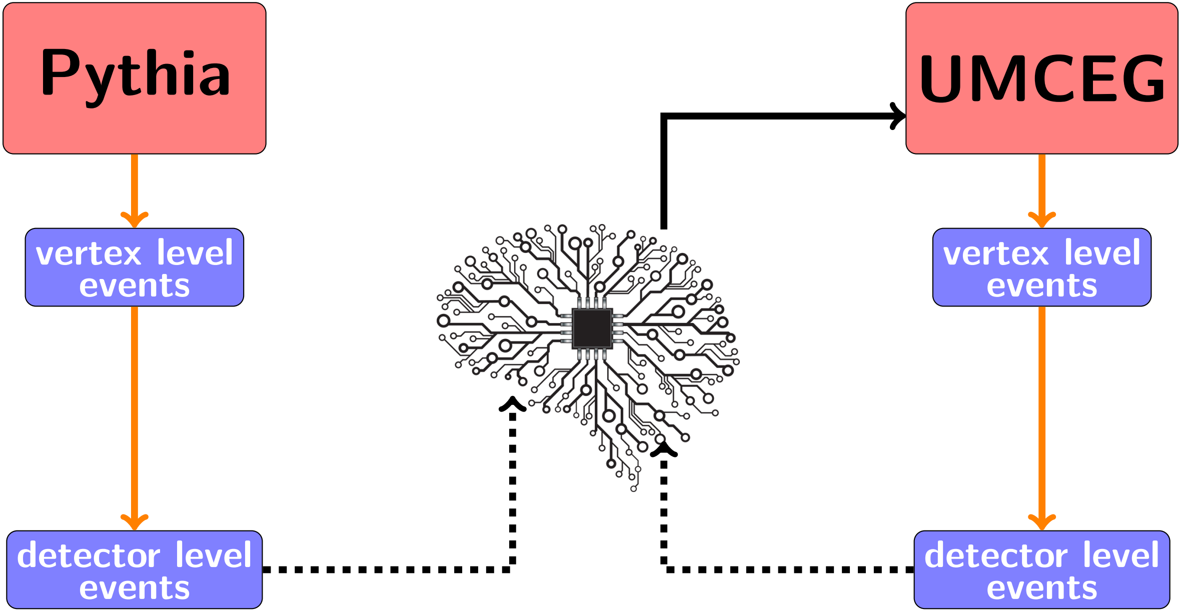
Our current work in progress

- Use Pythia as a training and validation tool

- Ignore detector effects

- Start with inclusive particle generator

$$\rho(\mathrm{particles}|\mathrm{multiplicity}) \to \rho(\mathrm{particles} + \mathrm{X})$$



Pythia

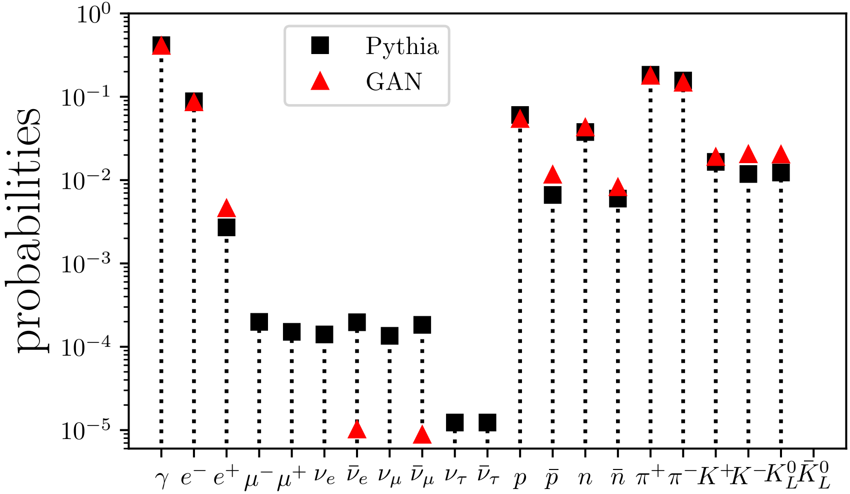
vertex level events

detector level events

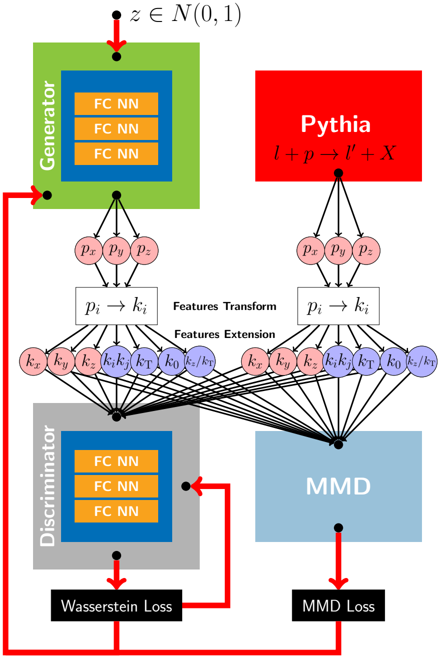
UMCEG

vertex level events

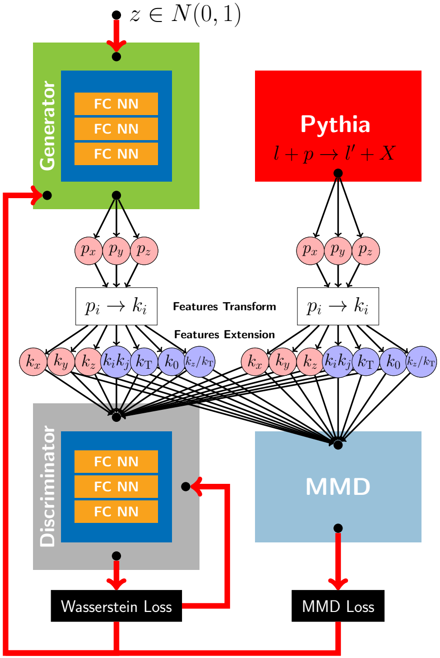
detector level events



Multiplicity generator

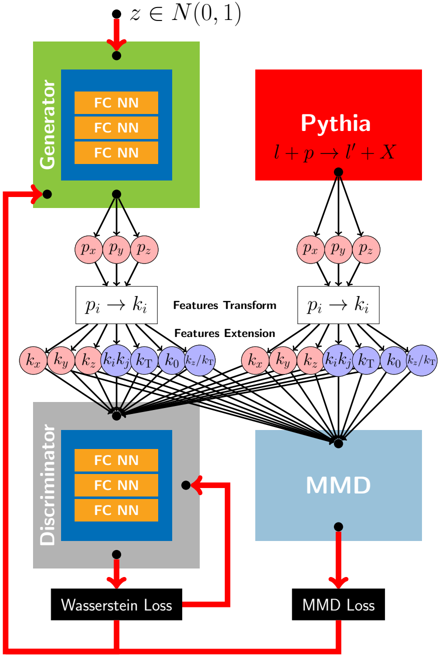


Vectors generator



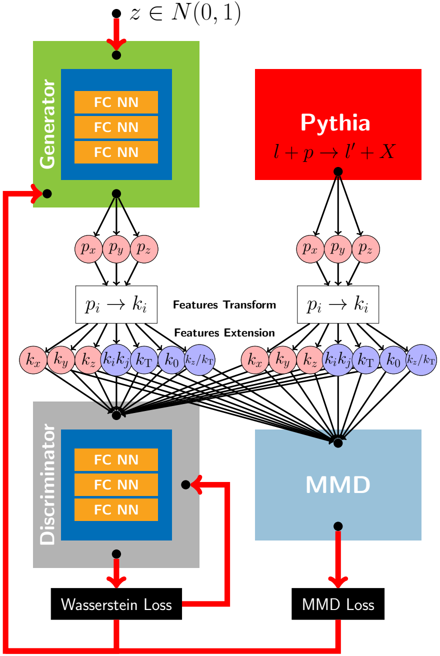
- Event image $= l'_{x,y,z}$

Vectors generator



- Event image $= l'_{x,y,z}$
- Feature extension:
  $l'_i \cdot l'_j, \quad l'_0, \quad l'_z/l'_\mathrm{T}$

Vectors generator



- Event image $= l'_{x,y,z}$
- Feature extension: $l'_i \cdot l'_j, \quad l'_0, \quad l'_z/l'_{\mathrm{T}}$
- WGAN+MMD Butter, Plehn, Winterhalder ('19)

Vectors generator

Validation

Validation

- Relevant observables for inclusive DIS

$$Q^2 = -(l - l')^2 \qquad x_{\mathrm{bj}} = \frac{Q^2}{2P\cdot(l-l')}$$

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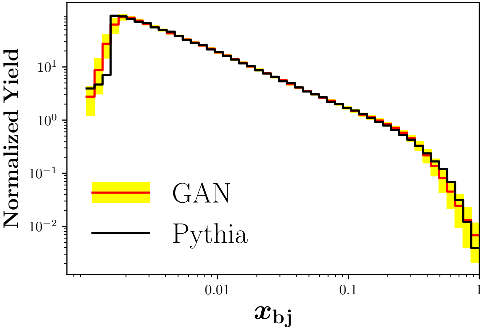
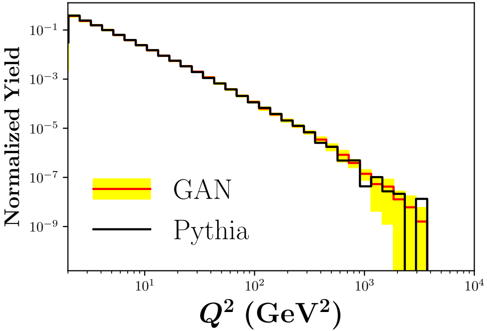
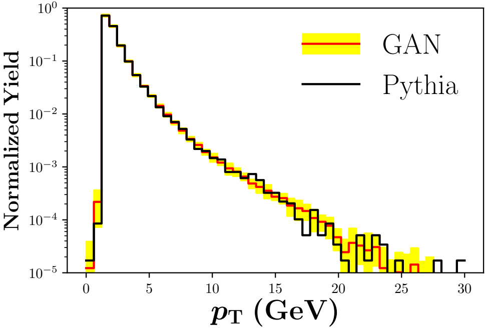
$$Q^2 = -(l - l')^2 \qquad x_{\mathrm{bj}} = \frac{Q^2}{2P\cdot(l-l')}$$

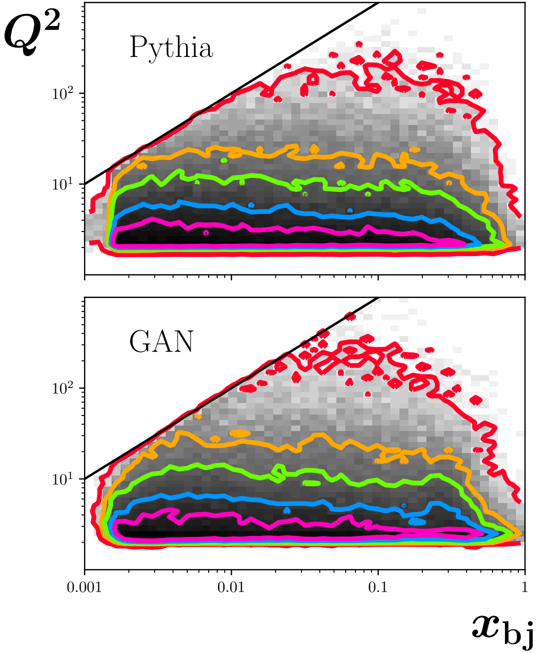
- x_{bj}, Q^2 **not included** as features







Error bands generated with bootstrapped samples



- Isocontours are in agreement
- x_{bj}, Q^2 correlation is learned without adding $x_{\mathrm{bj}} \cdot Q^2$ feature

Summary and outook

- It is possible to train a GAN at the **event level** to build a MCEG

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- The current design provides **a blueprint** for a generator with higher multiplicity

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- A fully trained UMCEG will be a **complementary tool** to theory-based MCEGs such as Pythia