GANs for parton shower development

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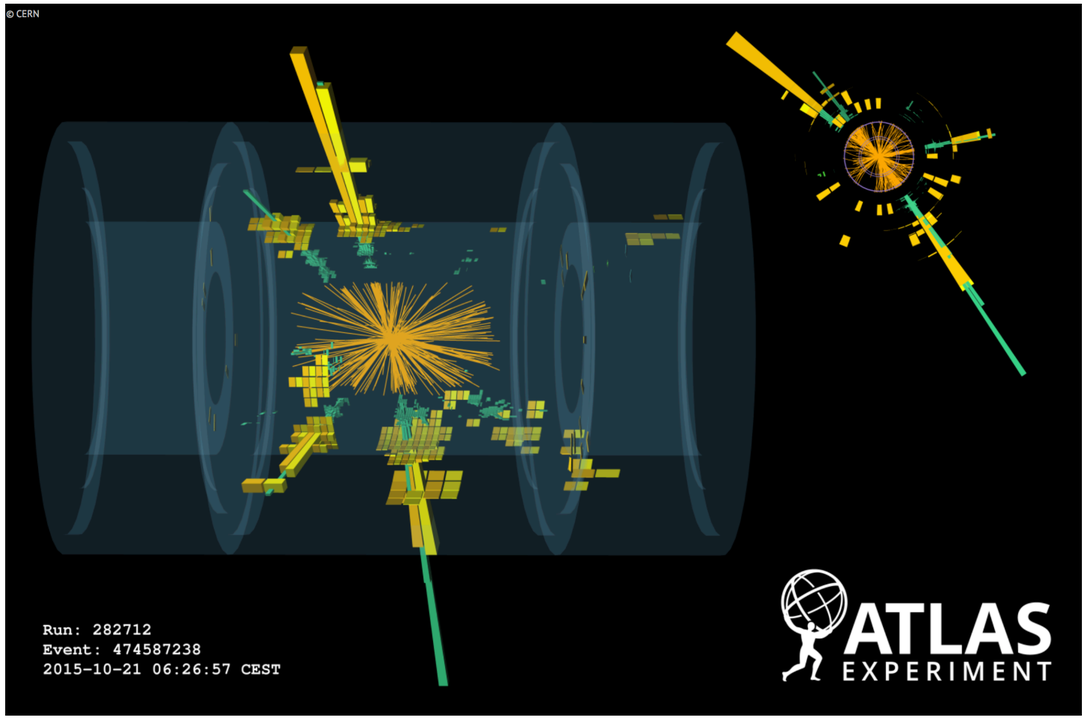
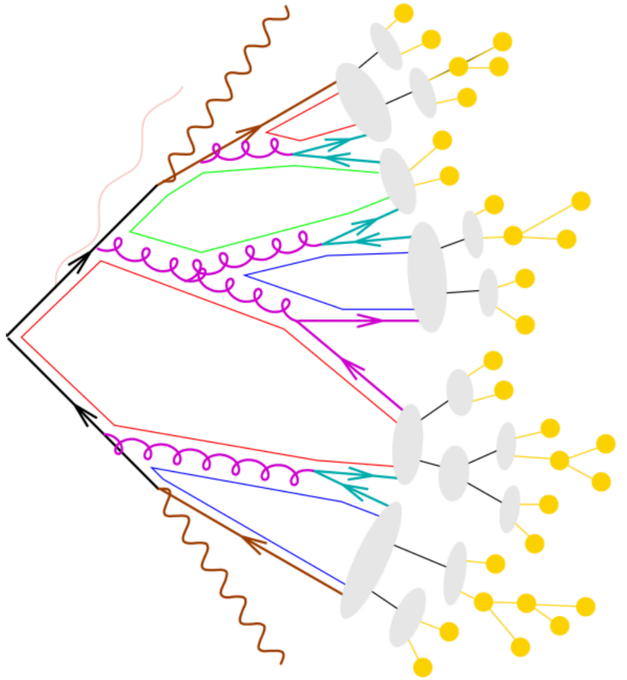
QCD and collider physics





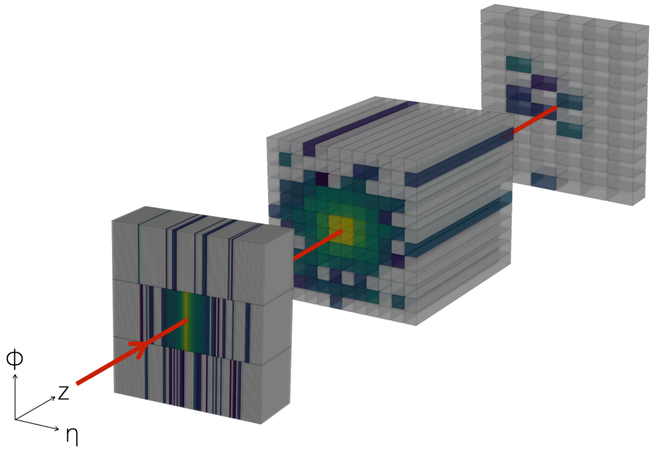
Production of high-energy hadrons and jets

Parton shower

GANs for QCD and collider physics

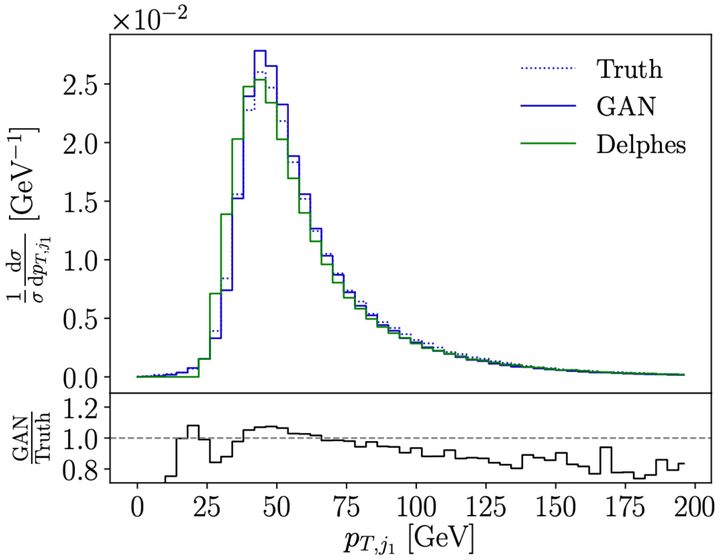
- Fast detector simulation

  e.g. Paganini, Oliveira, Nachman `17



- Unfolding techniques

  e.g. Bellagente, Butter, Kasieczka, Plehn, Winterhalder `19,
  Andreassen, Komiske, Methodiev, Nachman, Thaler `19



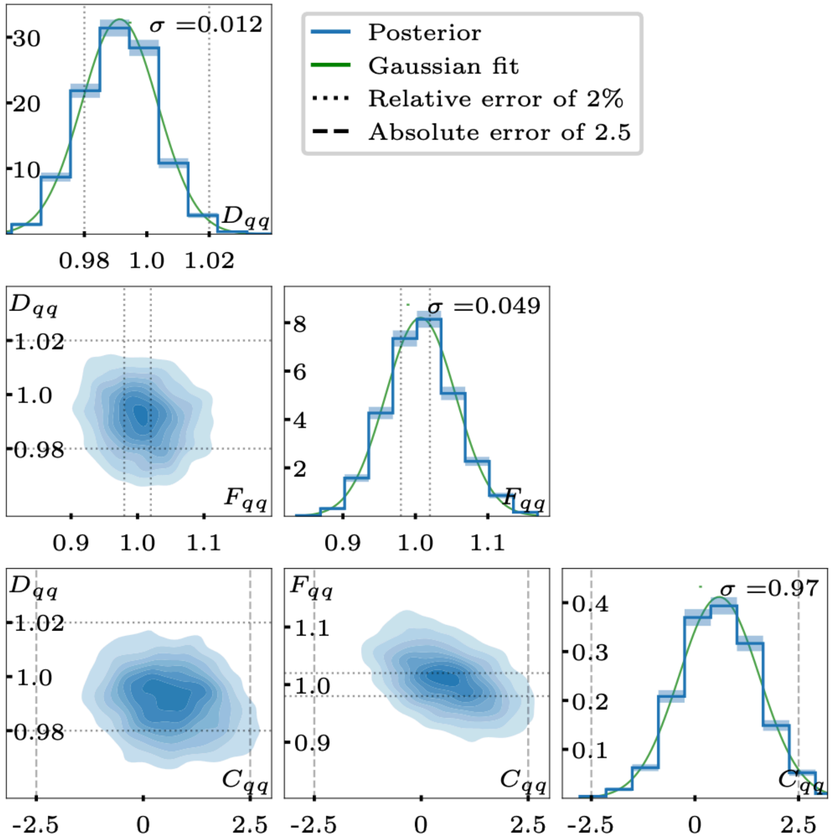
GANs for QCD and collider physics

- Event simulation

  e.g. Butter, Plehn, Winterhalder `19, Sipio, Giannelli et al. `19, Alanazi, Sato, Liu et al. `20

- Extract information about the parton shower

  e.g. Monk `18, Nachman, Thaler `20, Bieringer, Butter, Höche et al. `20



- Other work: https://github.com/iml-wg/HEPML-LivingReview *Feickert, Nachman, `21*

Parton shower development

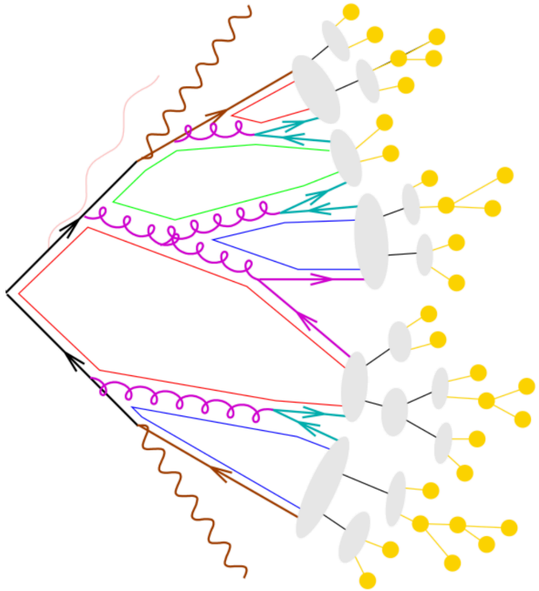
- Multi-purpose event generators

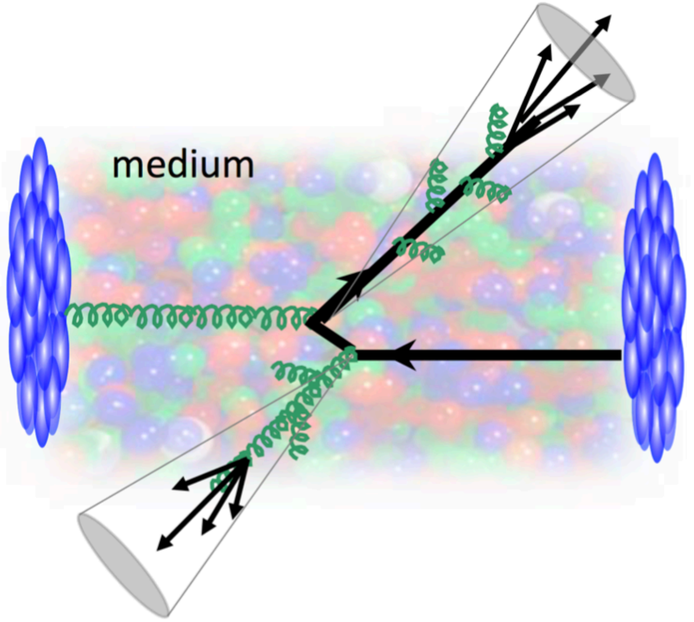
  Pythia, Herwig, Sherpa

- Recent theory efforts

  Bauer et al.; Höche, Prestel; Salam et al.

- Angular ordered and dipole showers





- Different hadronization models

- The modification in heavy-ion collisions is an open question *Jetscape, Jewel, LBT …*

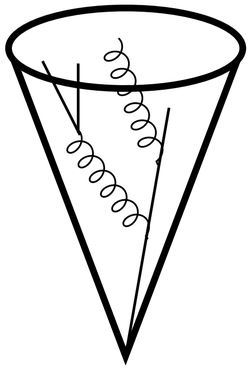
Parton shower development

- Effective Field Theory perspective of jets and fragmentation
- Parton showers solve renormalization group equations

$$\mu \frac{\mathrm{d}}{\mathrm{d}\mu} J_i = \frac{\alpha_s}{2\pi} \sum_j P_{ji} \otimes J_j$$

  - Systematically match precision calculations
  - Include well-defined nonperturbative components

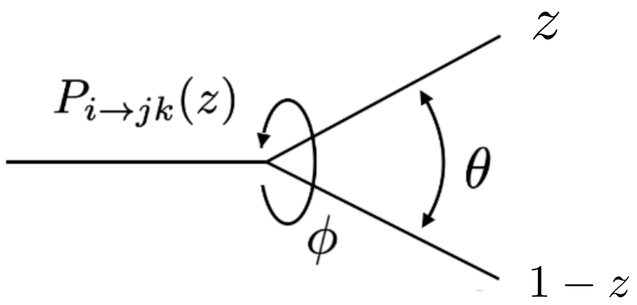
Neill, Ringer, Sato - in preparation



Gluon DGLAP shower

Lai, Ploskon, Neill, Ringer `20

Iterate a single parton splitting



Energy fraction z

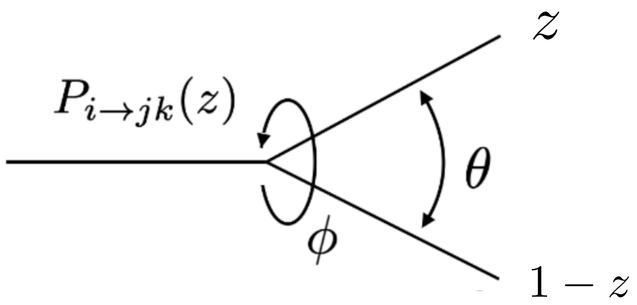
Relative opening angle/
Ordering variable θ

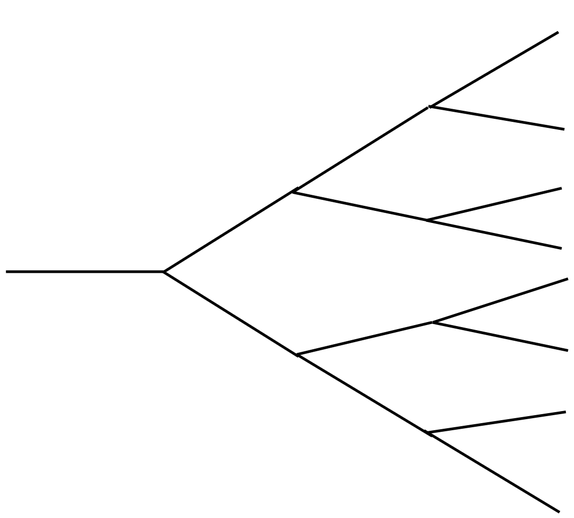
Azimuthal angle ϕ

Gluon DGLAP shower

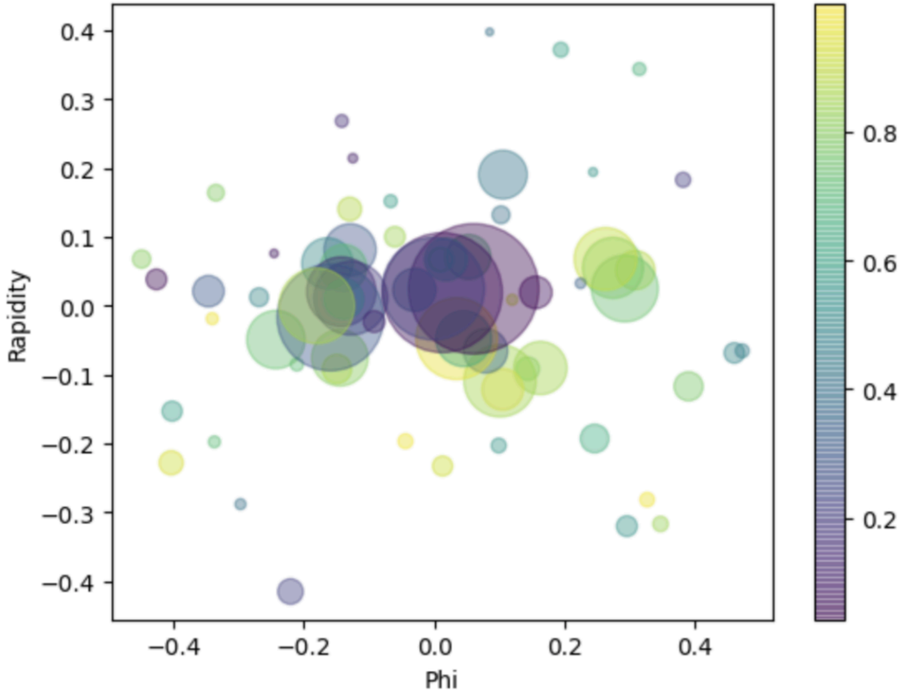
Lai, Ploskon, Neill, Ringer `20

Iterate a single parton splitting



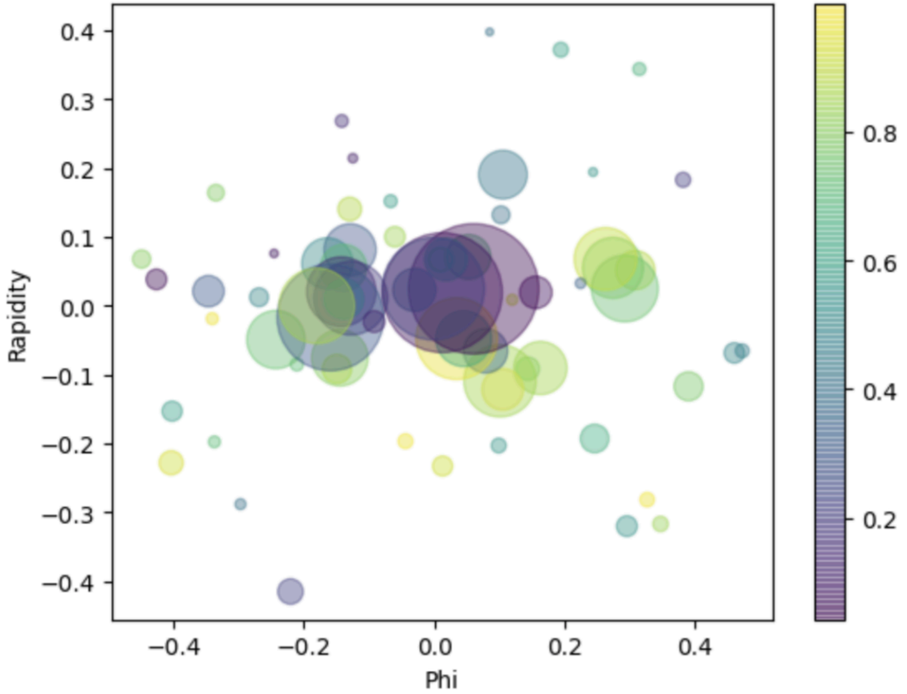


Shower cutoff



Parton showers and GANs

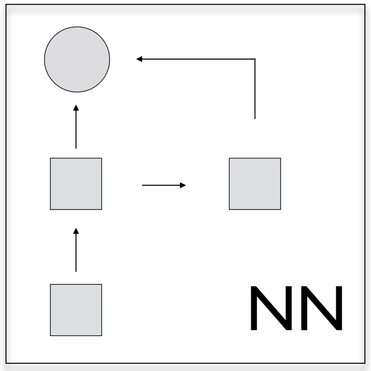
Train GAN on the final output of the shower



Black box ML

Butter, Plehn, Winterhalder `19
Alanazi, Sato, Liu et al. `20

Parton showers and GANs



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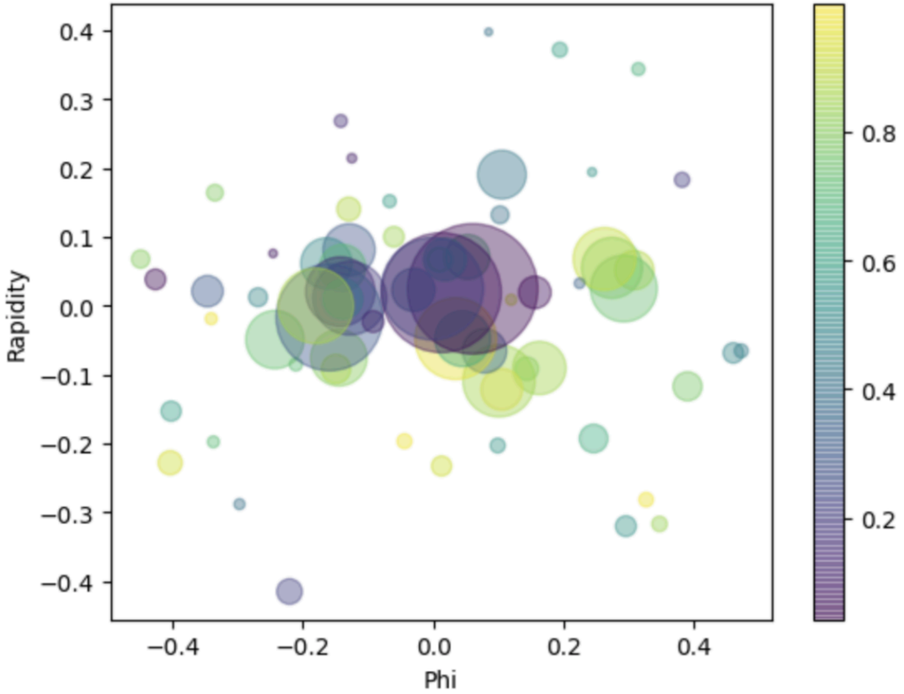


White box/
Explainable ML

Lai, Neill, Ploskon, Ringer `20

Parton showers and GANs

Lai, Ploskon, Neill, Ringer `20

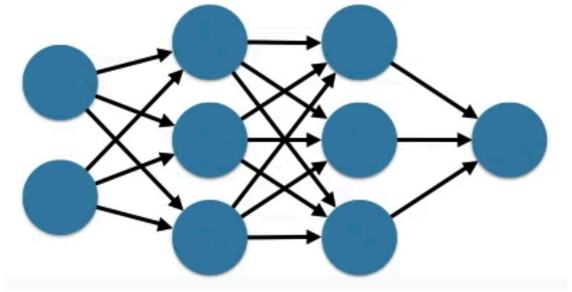
- Deep sets used for training

  Permutation invariant data representation, variable length

Zaheer et al. `18
Wagstaff et al. `19
Bloem-Reddy et al. `19

$$f\left(p_1, \ldots, p_M\right) = f\left(p_{\pi(1)}, \ldots, p_{\pi(M)}\right)$$

$$f\left(p_1, \ldots, p_M\right) = F\left(\sum_{i=1}^{M} \Phi\left(p_i\right)\right)$$

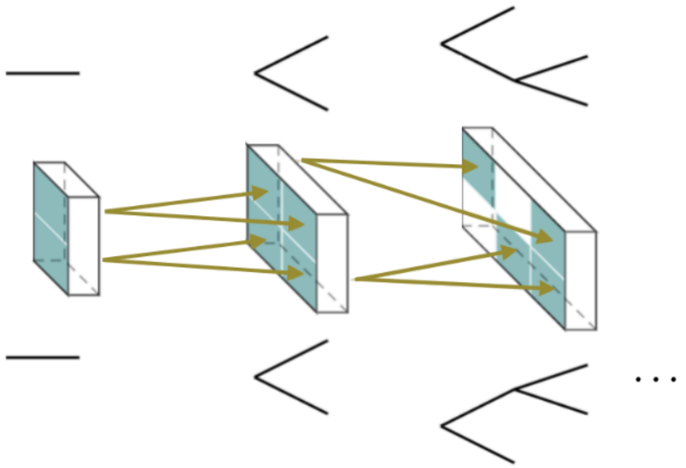


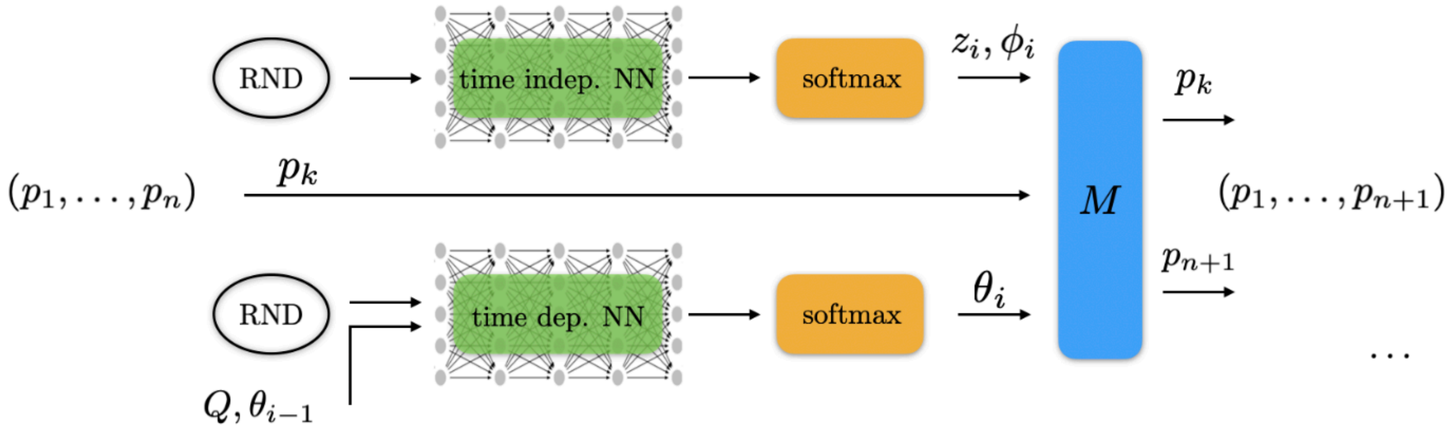
- Infrared-Collinear Safe version see *Komiske, Metodiev, Thaler `18*

Parton showers and GANs

Lai, Ploskon, Neill, Ringer `20

- The generator sequentially generates partons $n \to n+1$

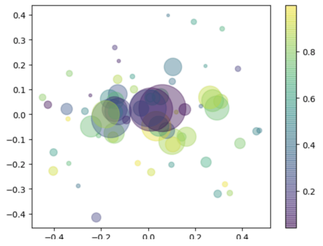




Shower history

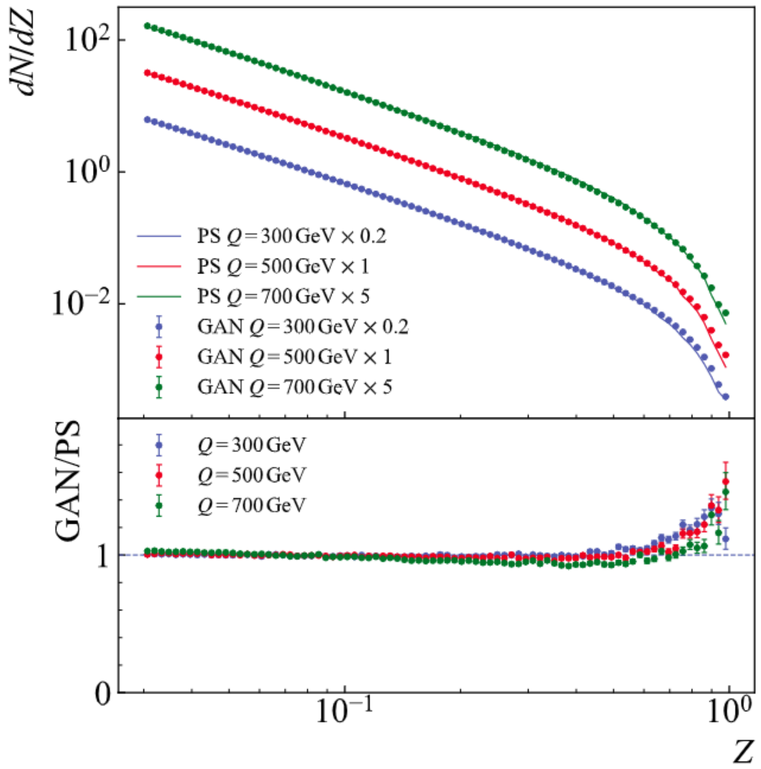
Individual splitting

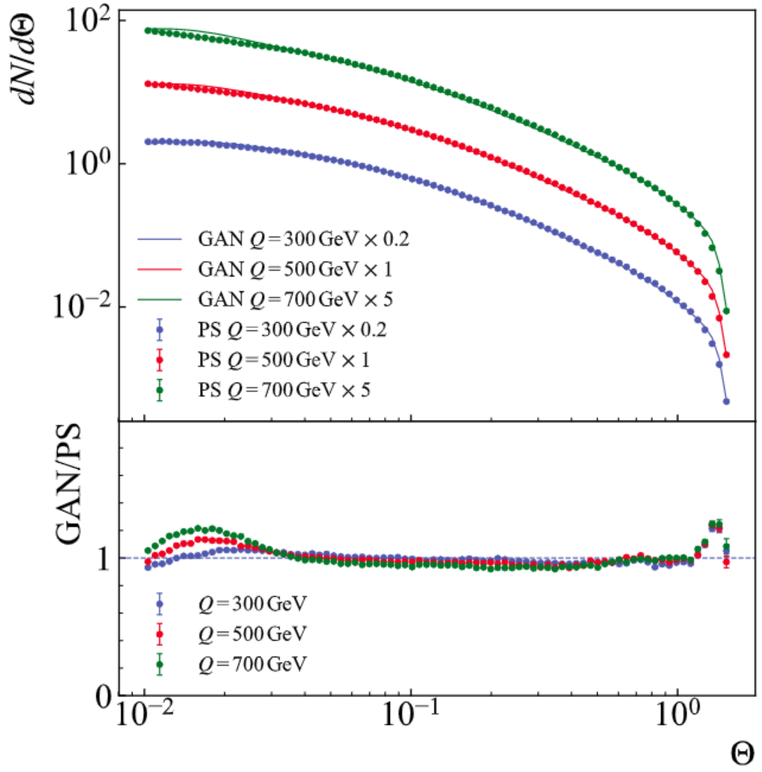
- Shower cutoff currently not trainable

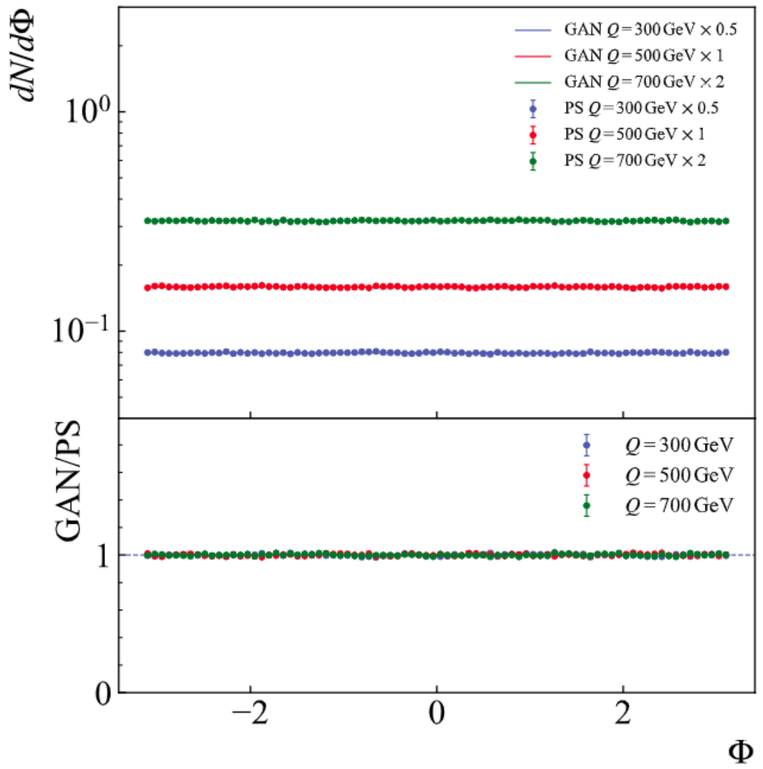


Numerical results

Lai, Ploskon, Neill, Ringer `20



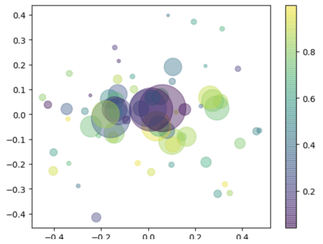




Energy fraction

Polar angle

Azimuthal angle



Numerical results

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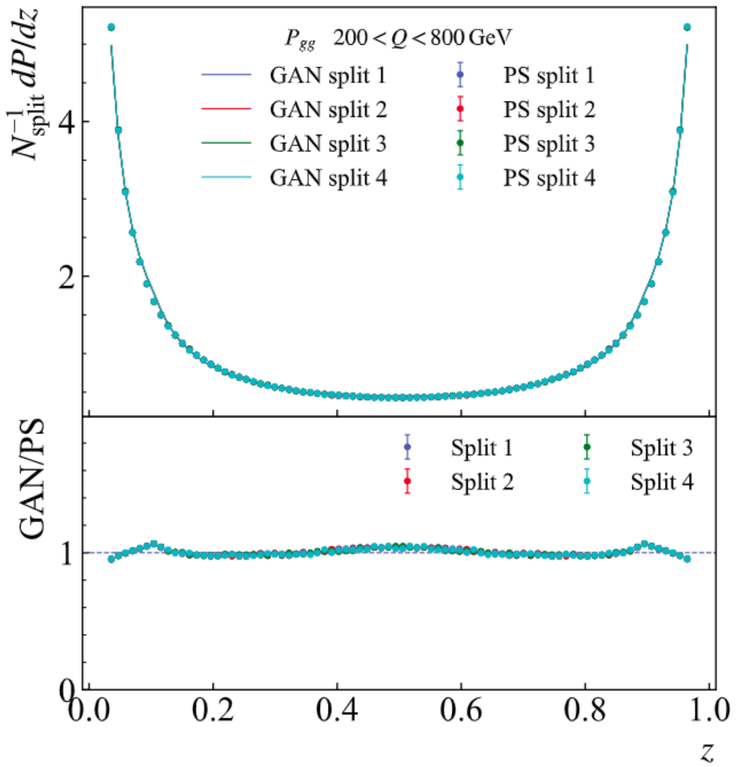
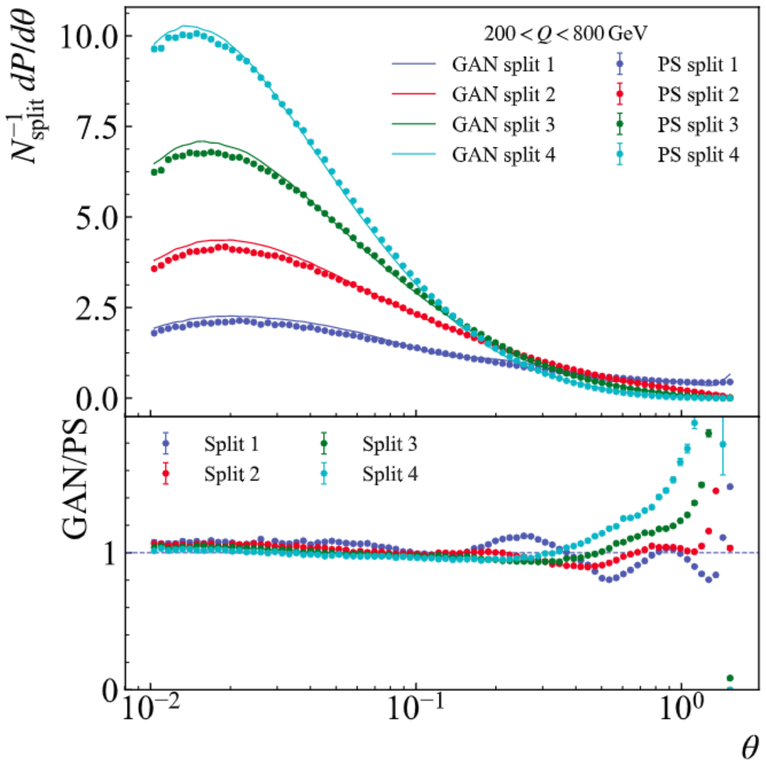
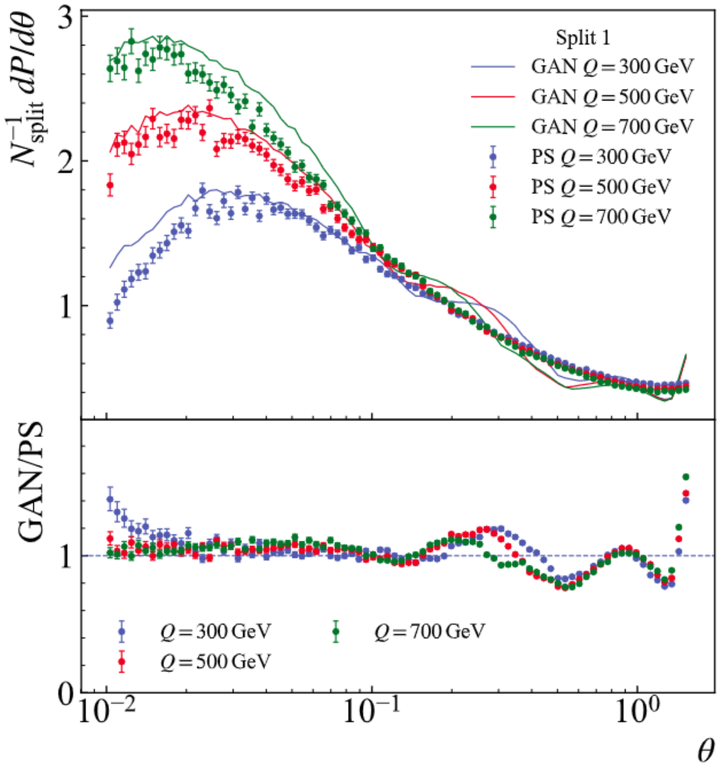






Energy fraction

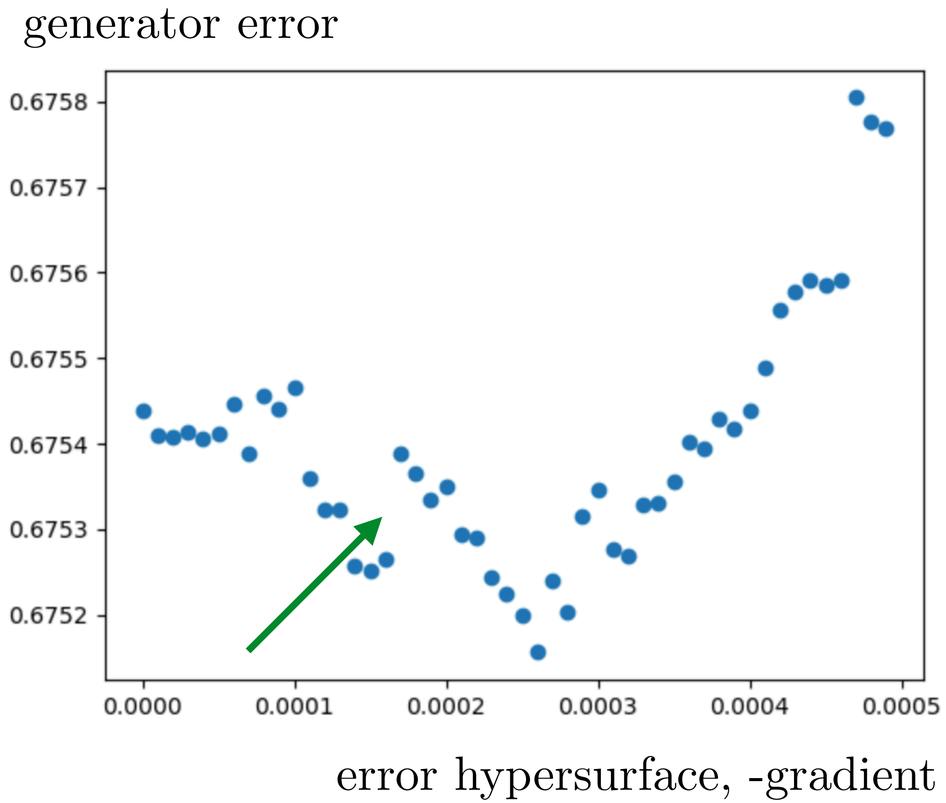
Ordering variable, split1-4

Ordering variable, different Q

GAN training

Lai, Ploskon, Neill, Ringer `20

- Error surface has steps
- Likely due to deep sets with variable length
- Initialization of weights
- Hope to increase the training performance



Conclusions

- Various applications of GANs in high-energy nuclear & particle physics
- Parton shower development
- Physics analyses using low-level data
- Particularly relevant for physics that is difficult to describe from first principles