White box AI for parton shower development

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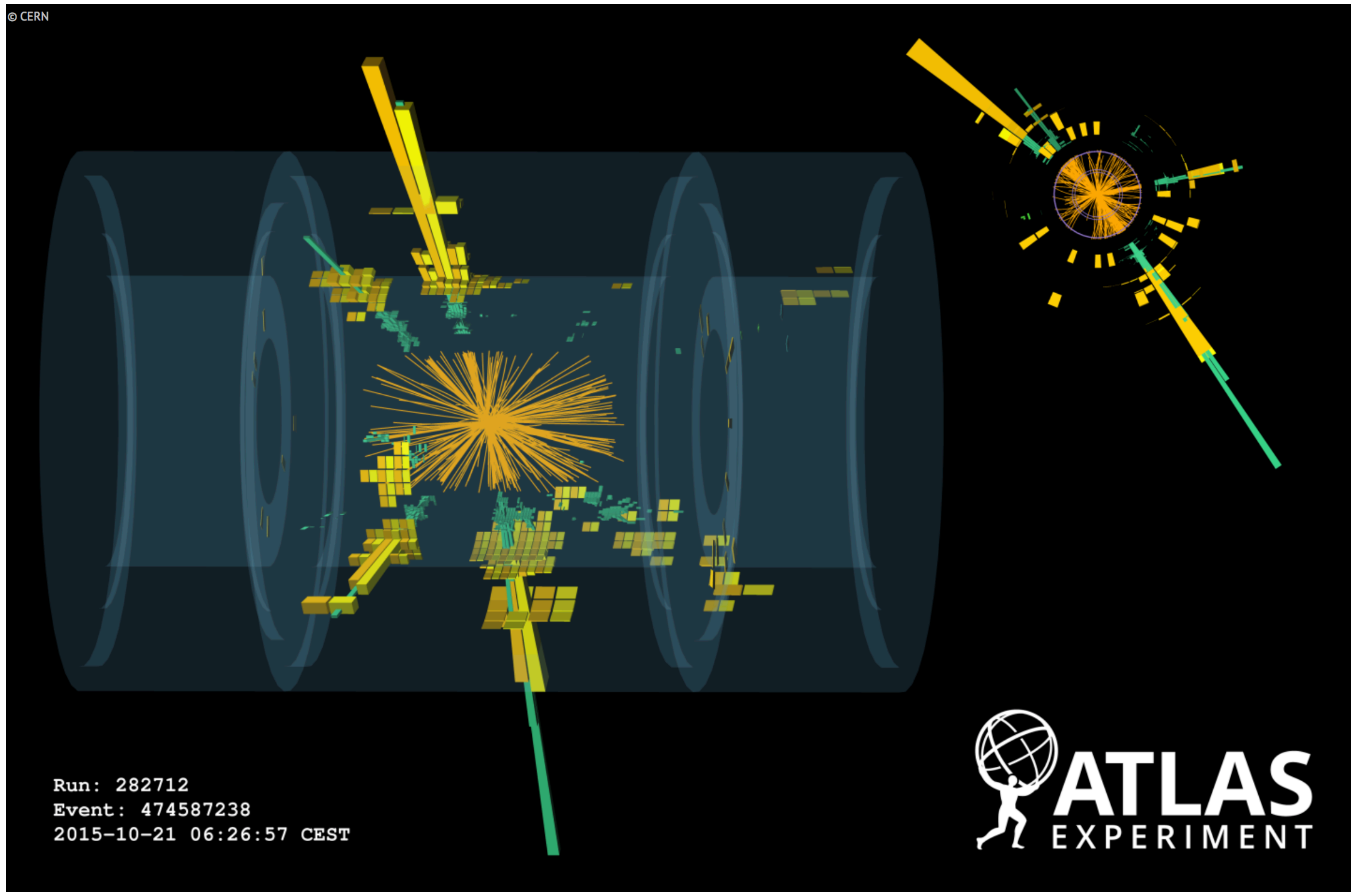
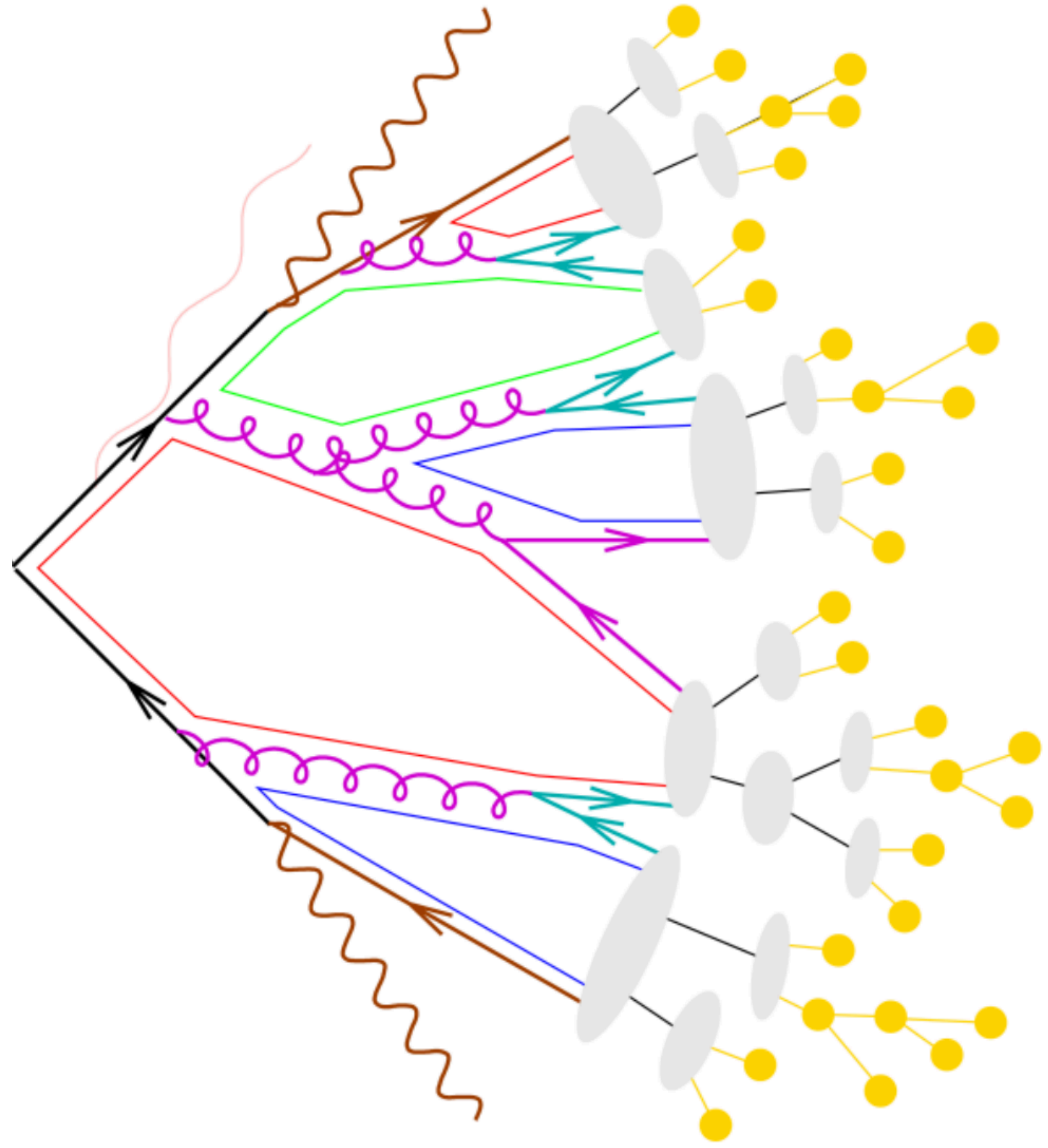
arXiv:2012.06582

ML4Jets workshop, 07/07/21

QCD and collider physics



Production of high-energy hadrons and jets



Parton shower

Parton shower development

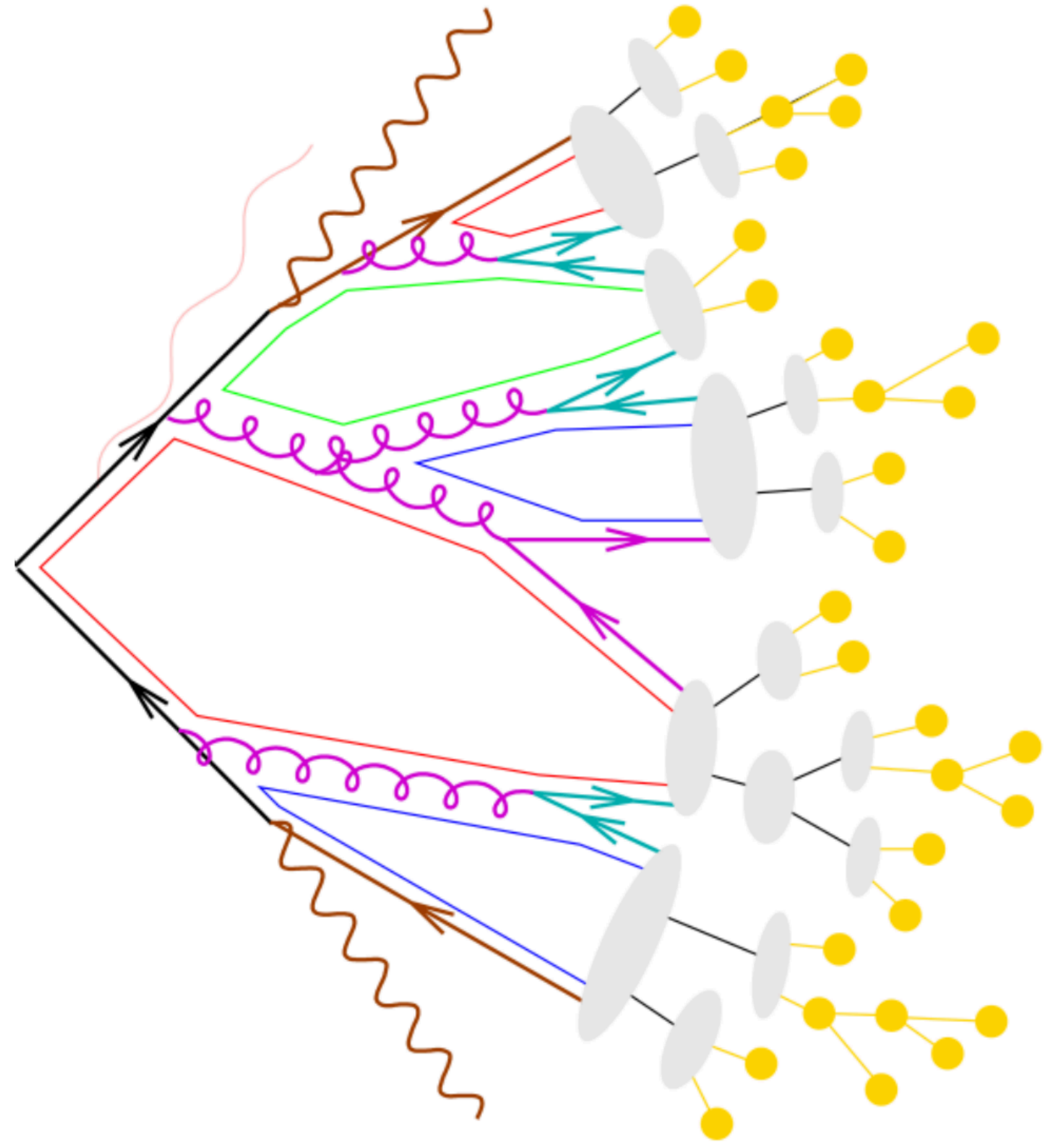
- Multi-purpose event generators

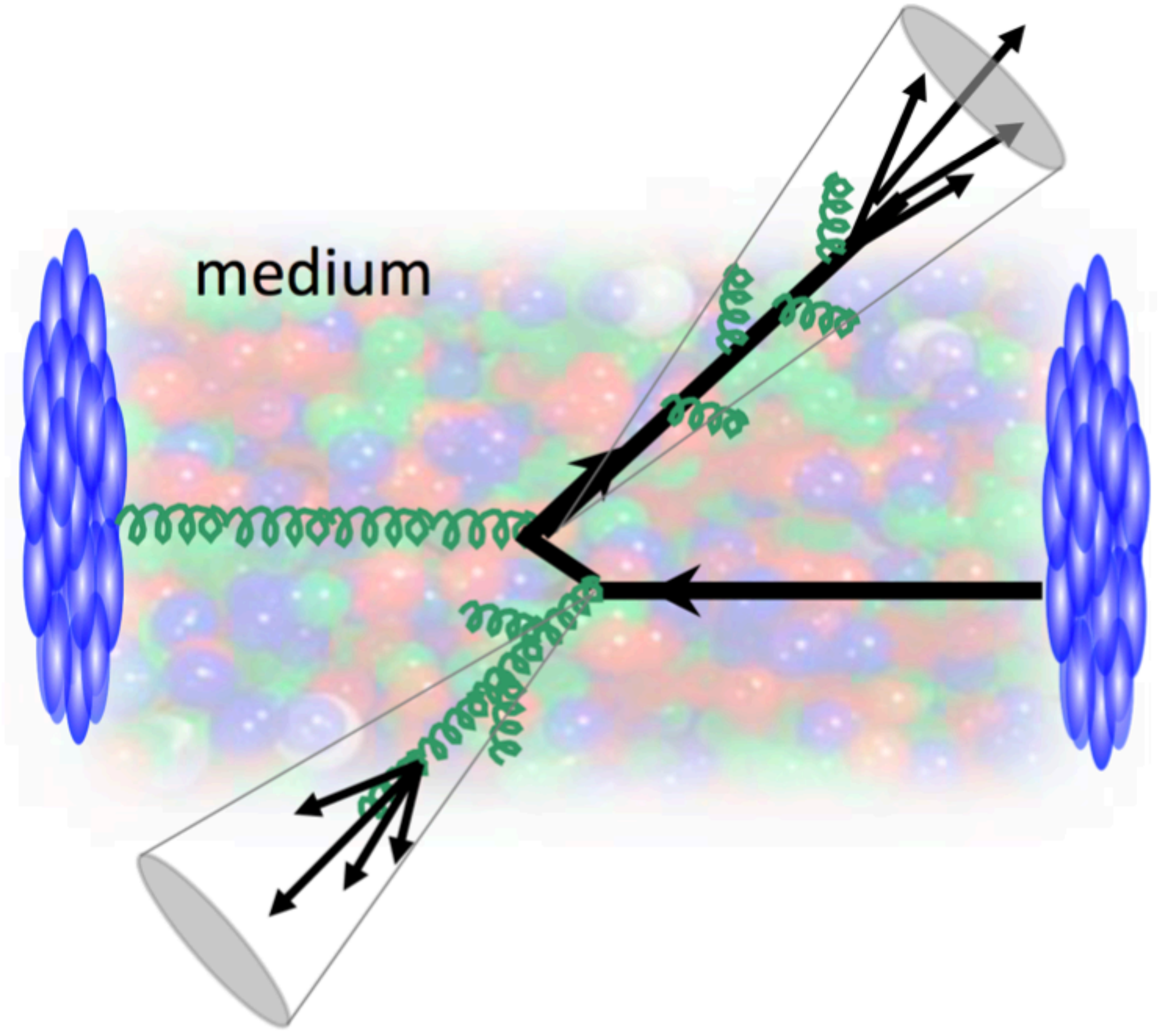
  Pythia, Herwig, Sherpa

- Recent theory efforts

  Bauer et al.; Höche, Prestel; Salam et al.
  Nagy, Soper; Neill, FR, Sato `21, …

- Angular ordered, dipole showers, jet functions





- Different hadronization models, collective effects, factorization breaking

- The modification in heavy-ion collisions *Jetscape, Jewel, LBT …*

Parton shower development

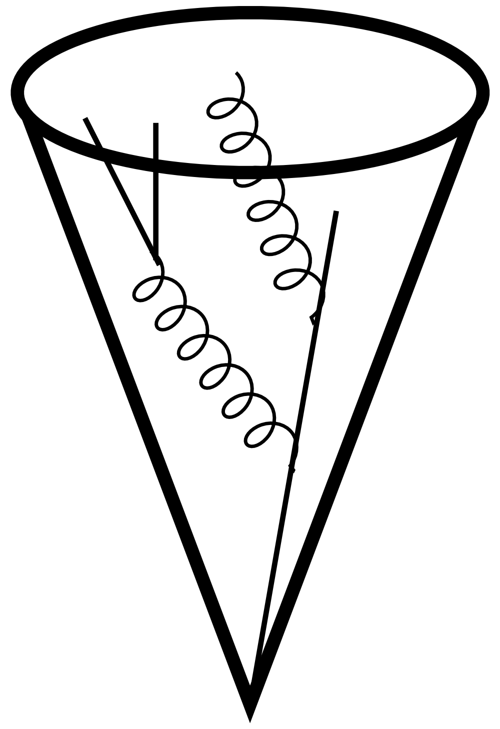
- Effective Field Theory perspective of jets and fragmentation
- Parton showers solve renormalization group equations

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

  - Systematically match precision calculations e.g. jet functions and threshold resummation *Neill, Ringer, Sato `21*

  - Include well-defined nonperturbative components e.g. shape functions, rapidity anomalous dimension

Dokshitzer, Webber `95, Dasgupta, Magnea, Salam `08
Shanahan, Wagman, Zhao `20

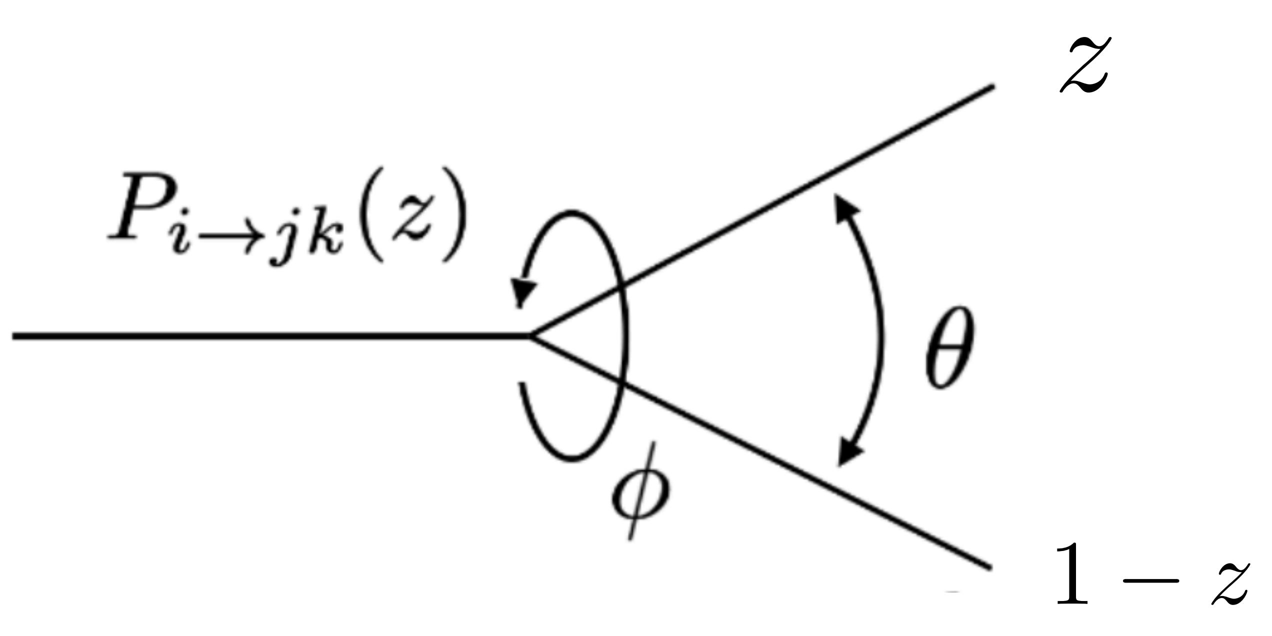


⟶ Set up a White Box AI framework which learns the underlying physics of parton showers using full event information

Gluon DGLAP shower

Lai, Ploskon, Neill, FR `20

Iterate a single parton splitting



Energy fraction z

Relative opening angle/
Ordering variable θ

Azimuthal angle ϕ

$$\exp\left[-\Delta t \sum_{i=q,\bar{q},g} \int_{\epsilon}^{1-\epsilon} \mathrm{d}z\, P_i(z)\right] \xrightarrow{t+\Delta t} \quad t(Q,\theta) = \int_{Q\tan(\pi/2)}^{Q\tan(\theta/2)} \frac{\mathrm{d}t'}{t'} \frac{\alpha_s(t')}{\pi}$$

Gluon DGLAP shower

Lai, Ploskon, Neill, FR `20

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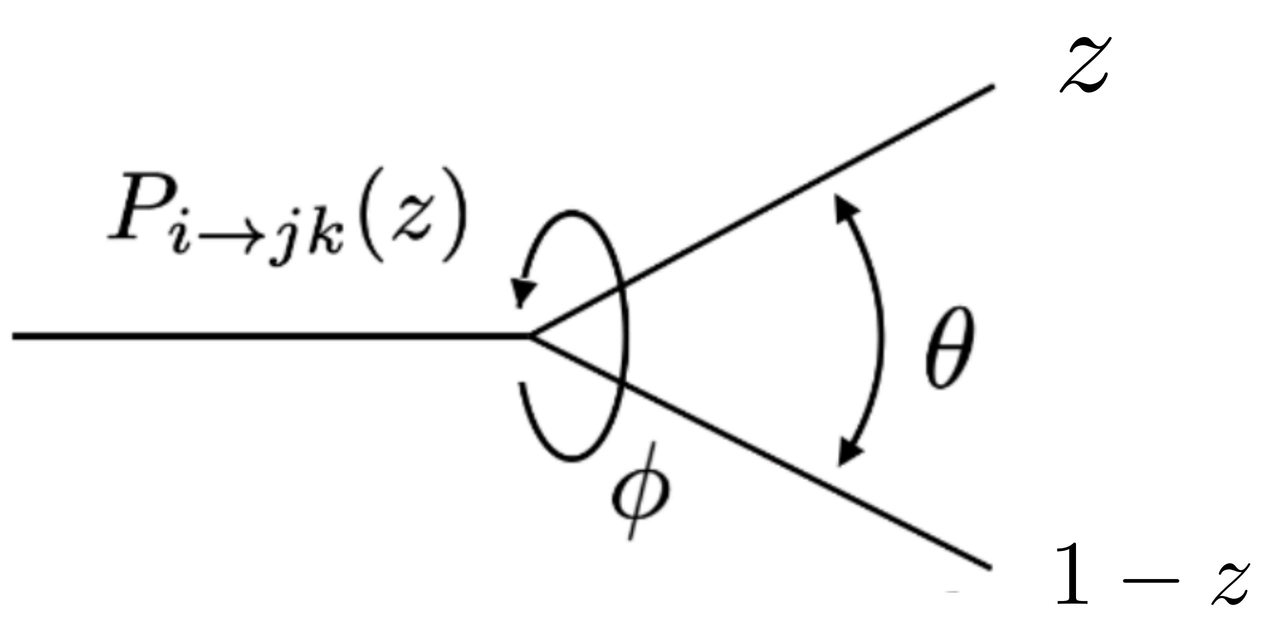
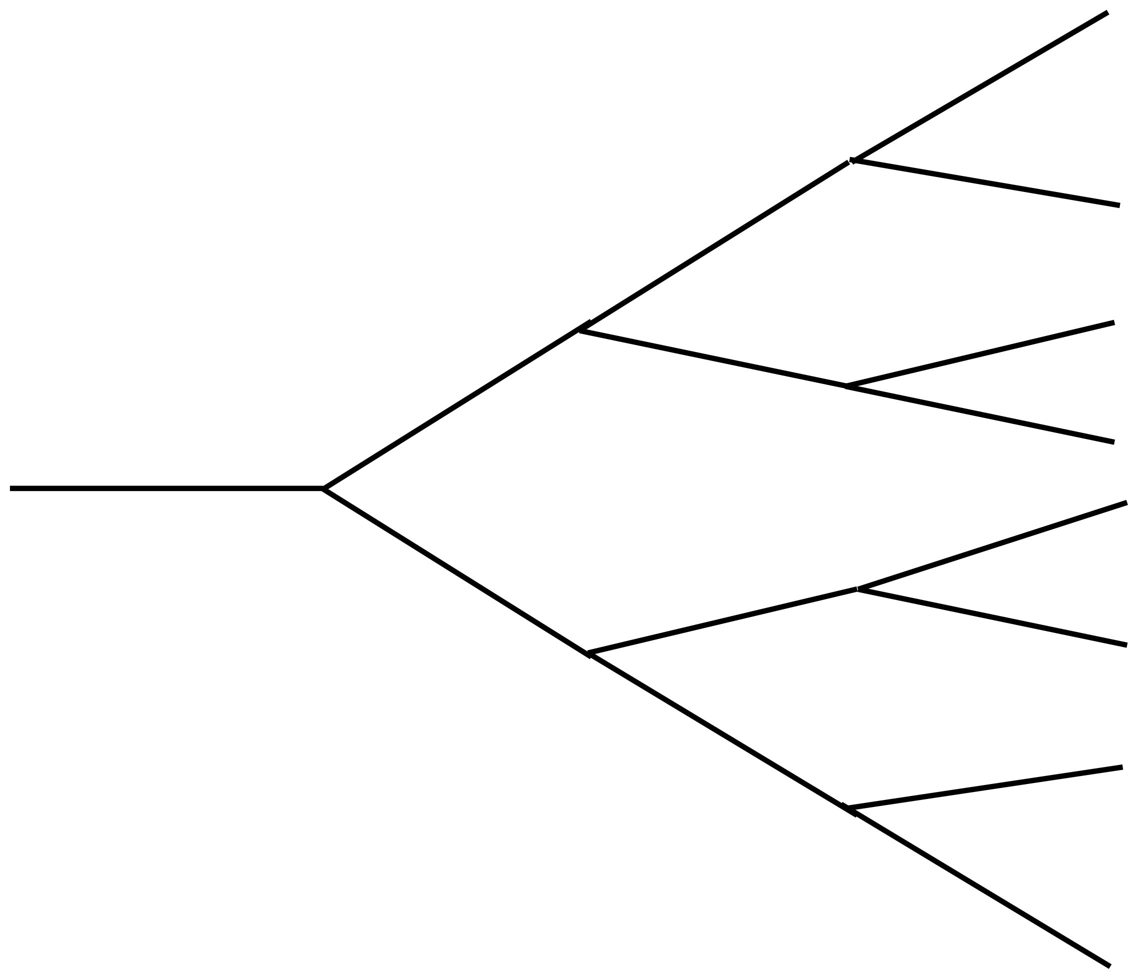
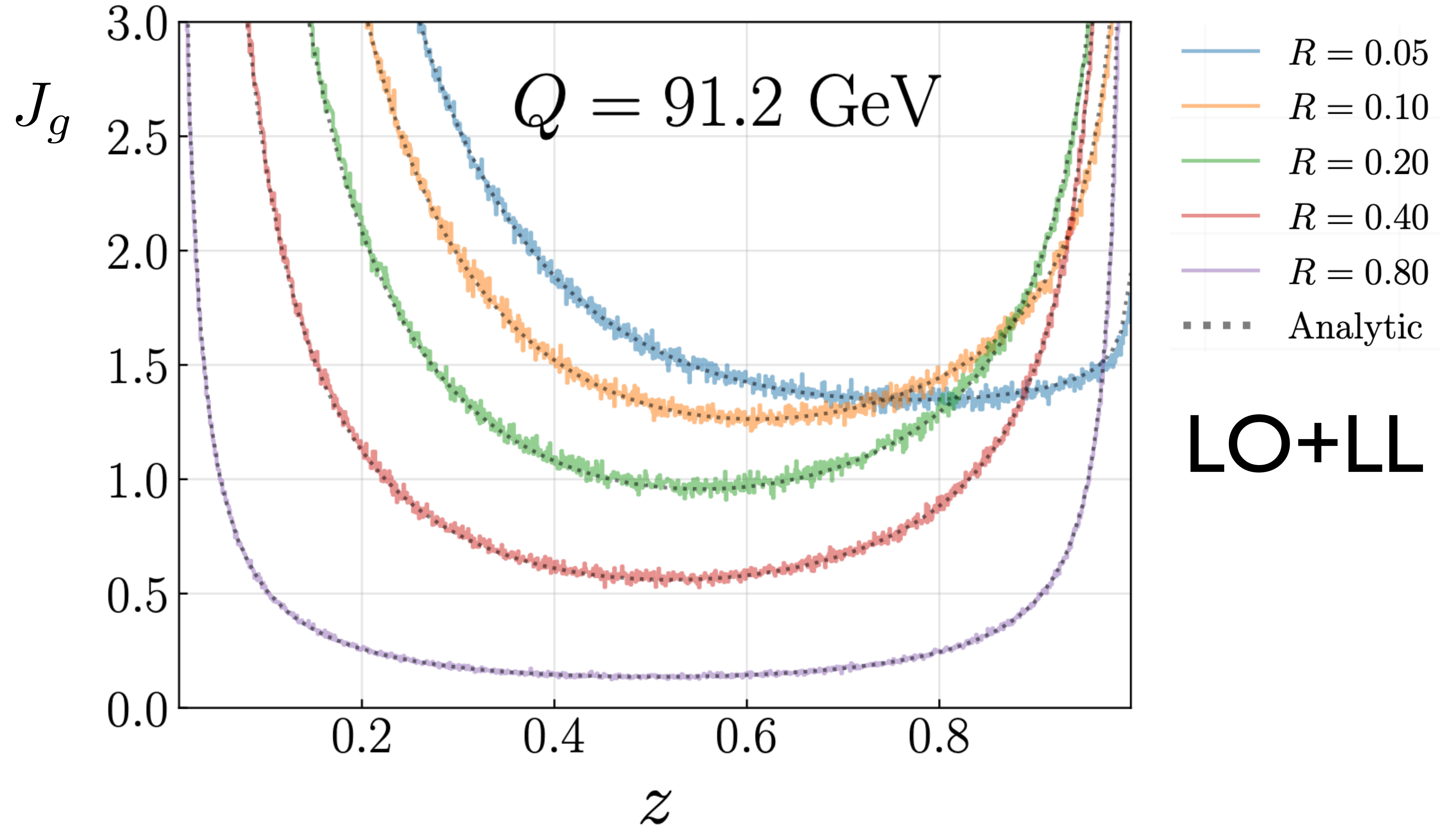




Shower cutoff



LO+LL

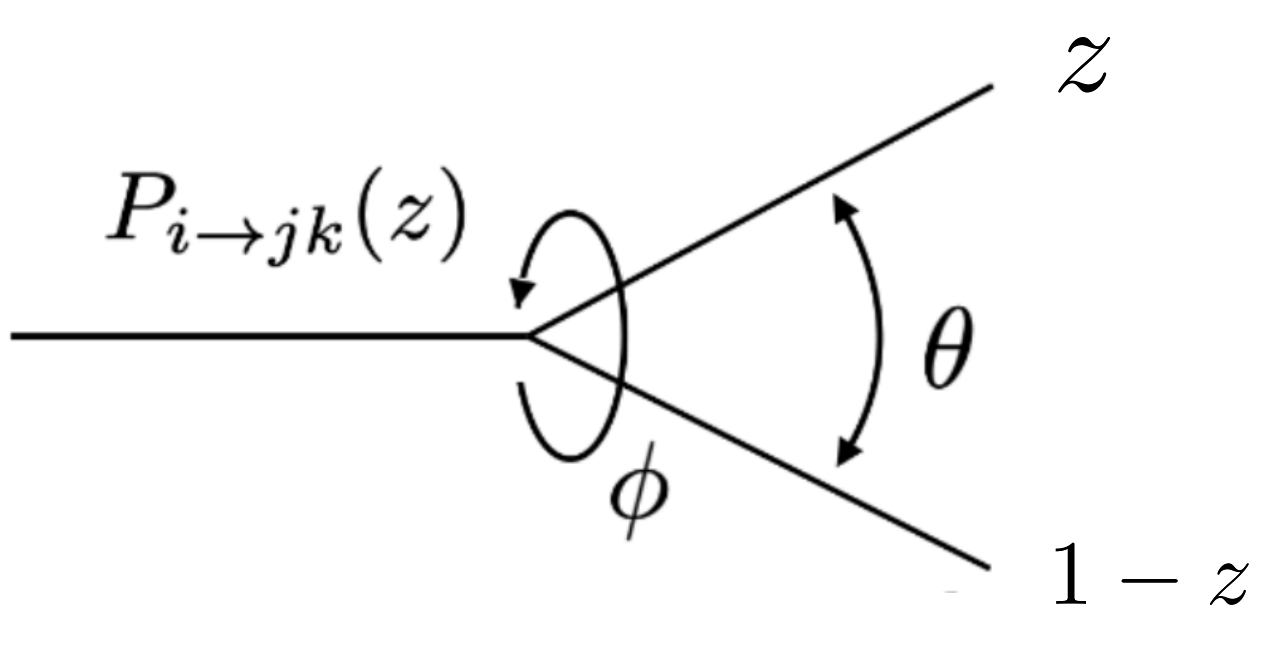
Agrees with analytical calculation and can be extended systematically

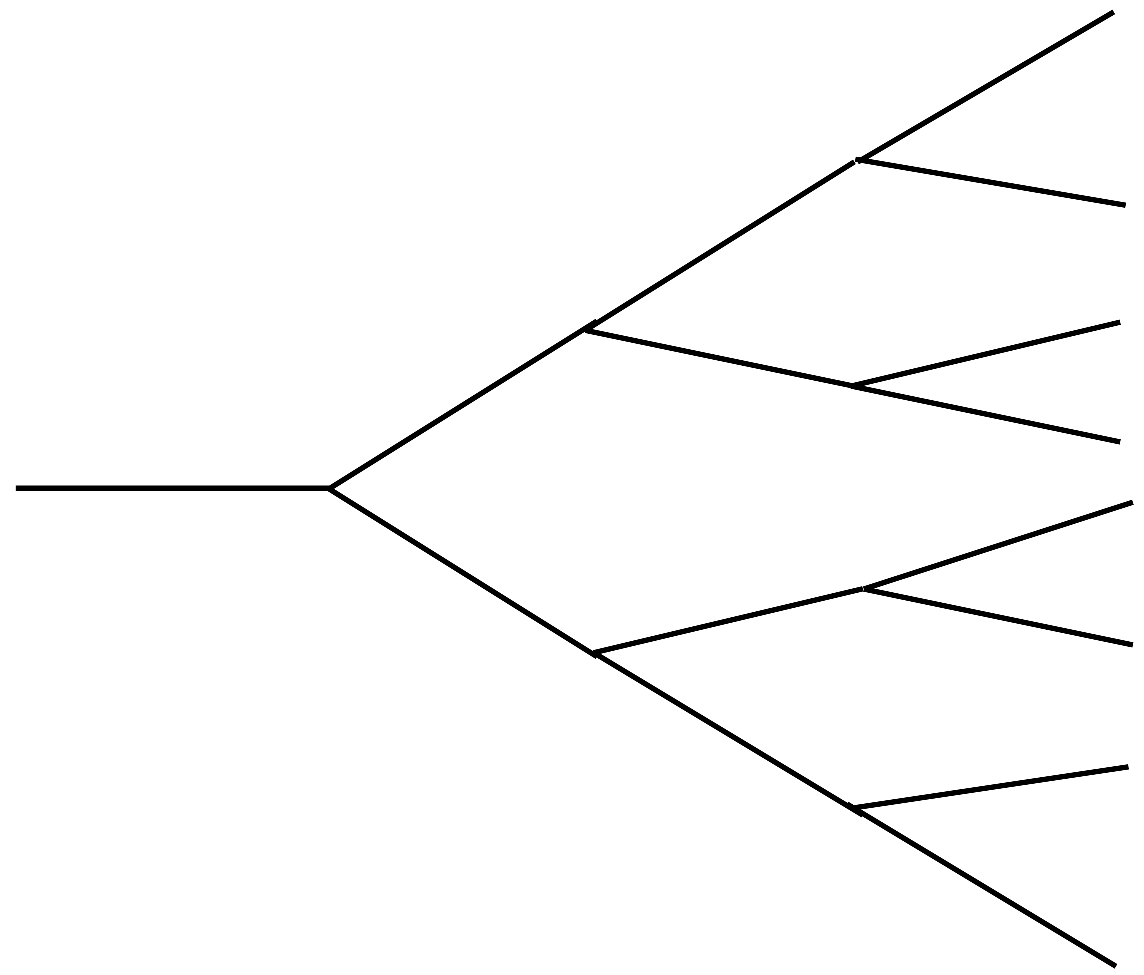
Neill, FR, Sato `21

Gluon DGLAP shower

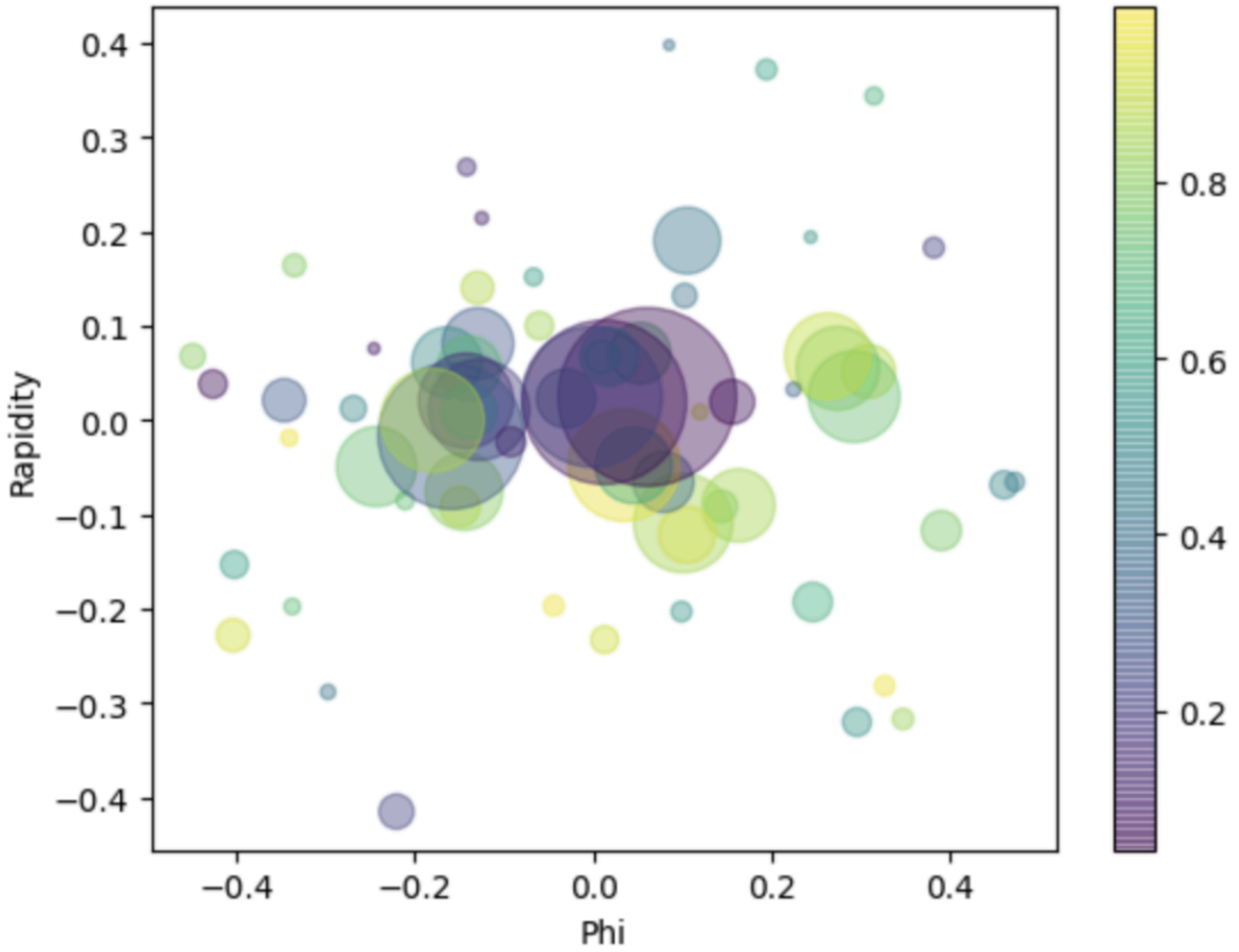
Lai, Ploskon, Neill, FR `20

Iterate a single parton splitting



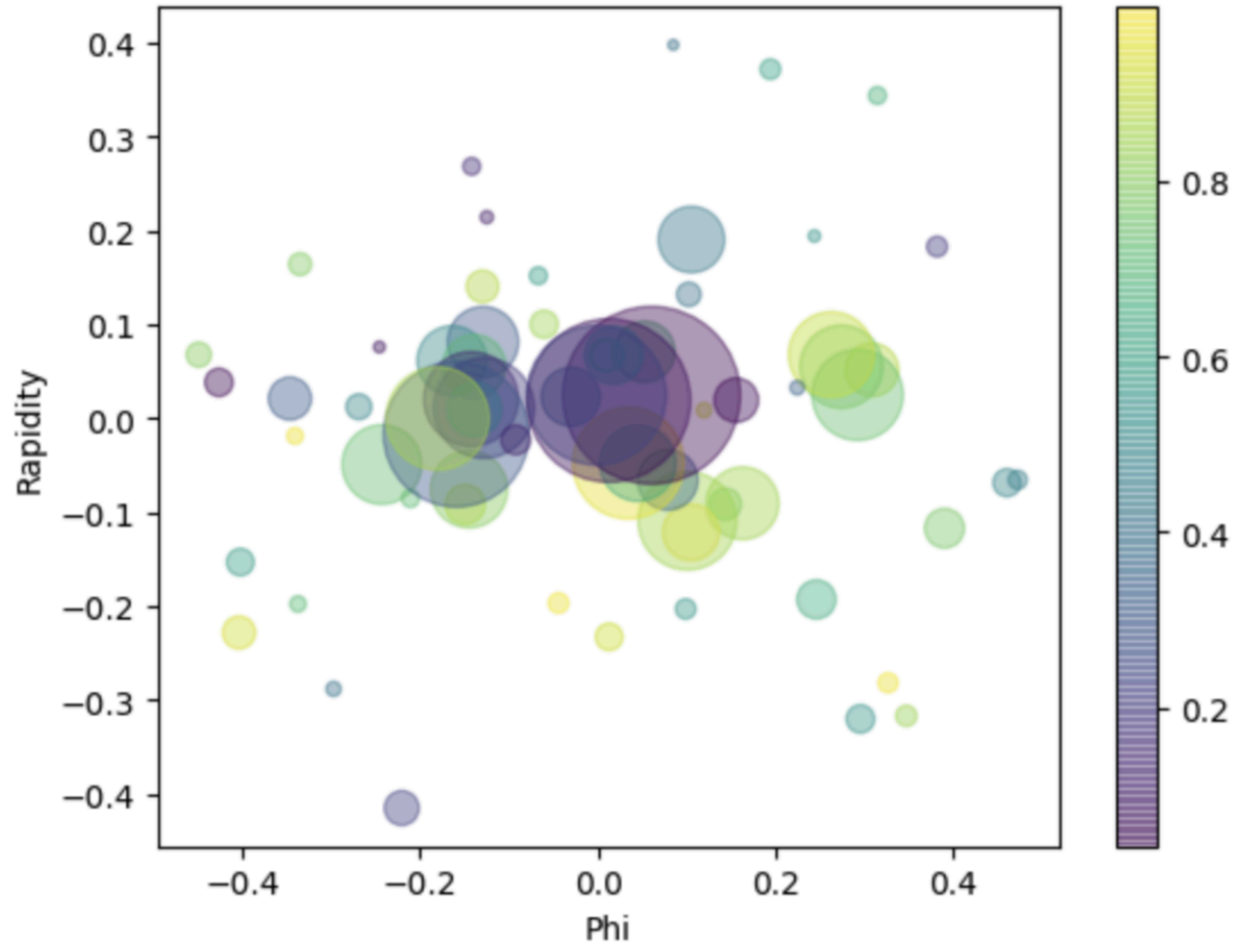


Shower cutoff



Parton showers and GANs

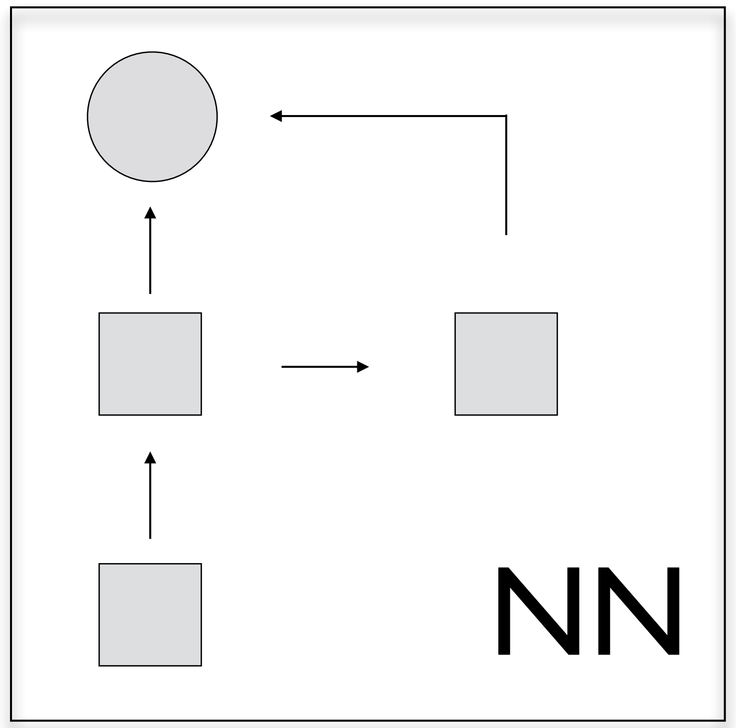
Train GAN on the final output of the shower



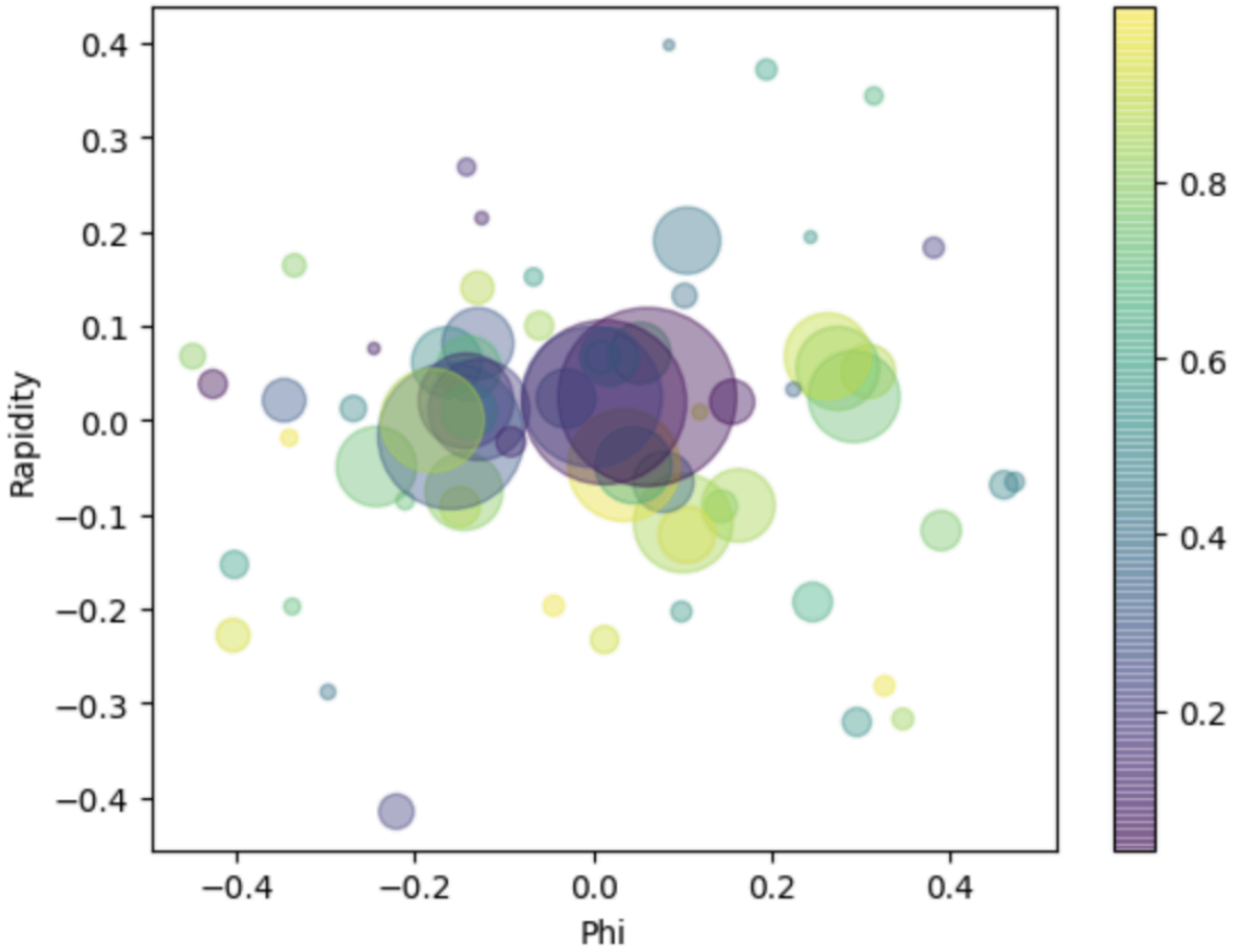
Black box ML for fast generative modeling

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

Parton showers and GANs



Train GAN on the final output of the shower



White box/Explainable ML *Lai, Neill, Ploskon, Ringer `20*

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

Parton showers and GANs

- Deep sets/Particle Flow Networks (PFNs) used for training

  Permutation invariant data representation, variable length

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

Komiske, Metodiev, Thaler `18

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

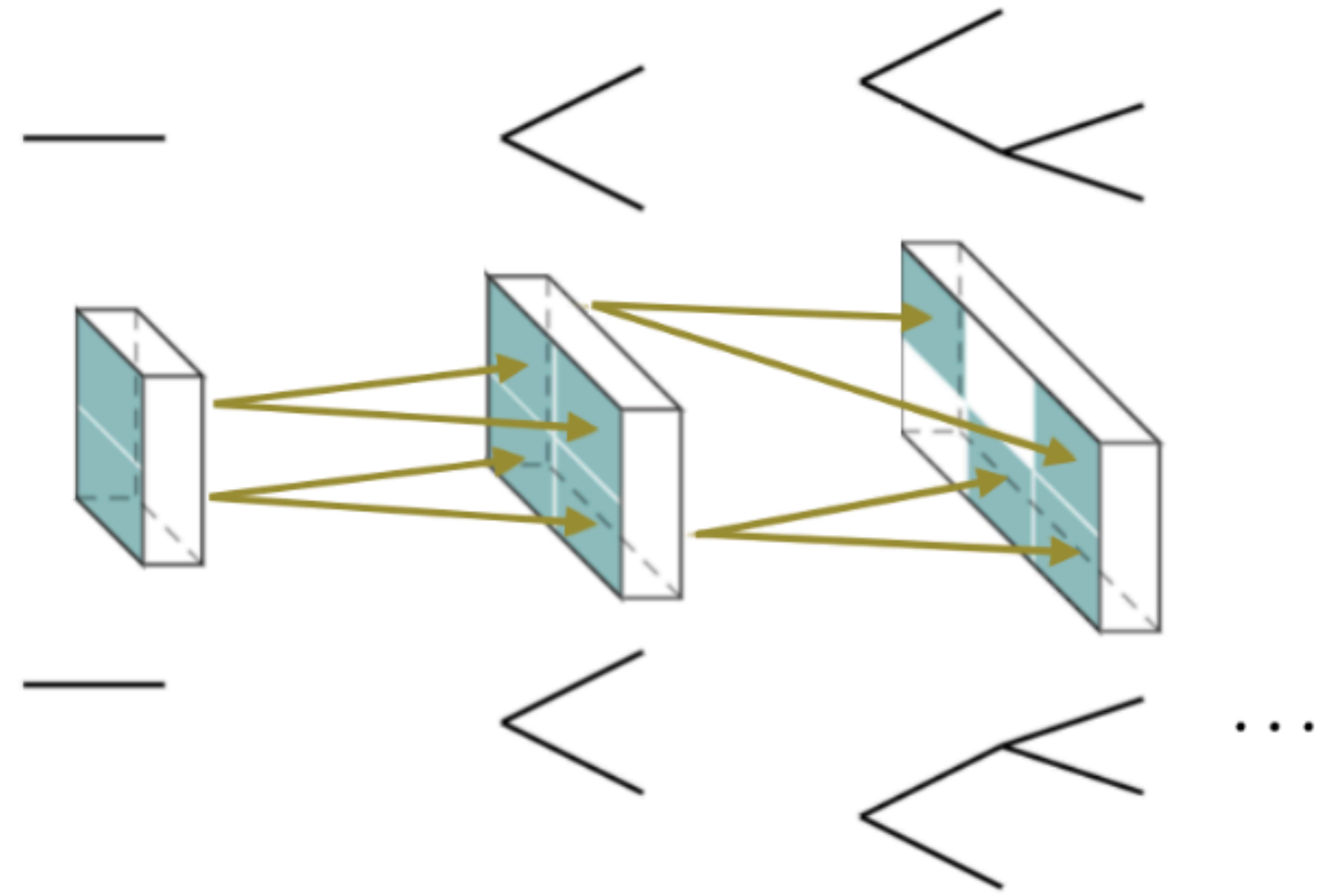
$$f\left(p_1,\ldots,p_M\right)=F\left(\sum_{i=1}^{M}\Phi\left(p_i\right)\right)$$

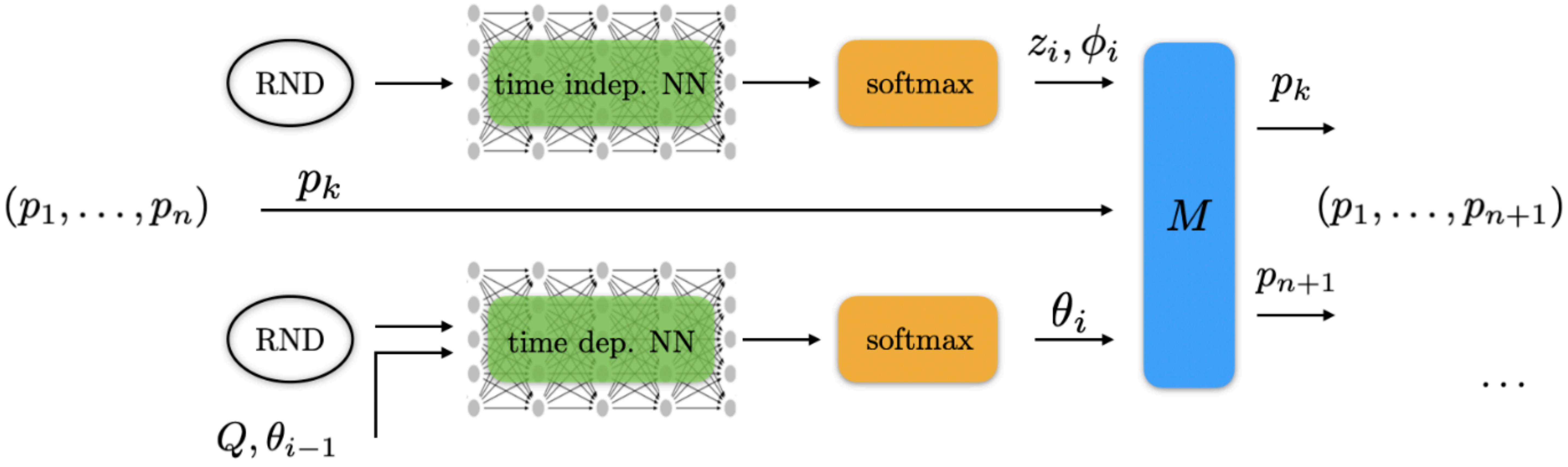
- Future exploration of IRC Safe Energy Flow Networks (EFNs)

Parton showers and GANs

Lai, Ploskon, Neill, FR `20

- The generator sequentially generates partons $n \to n+1$
- Analogy to a Recurrent Neural Network (RNN)
- Pick a parton and determine splitting kinematics

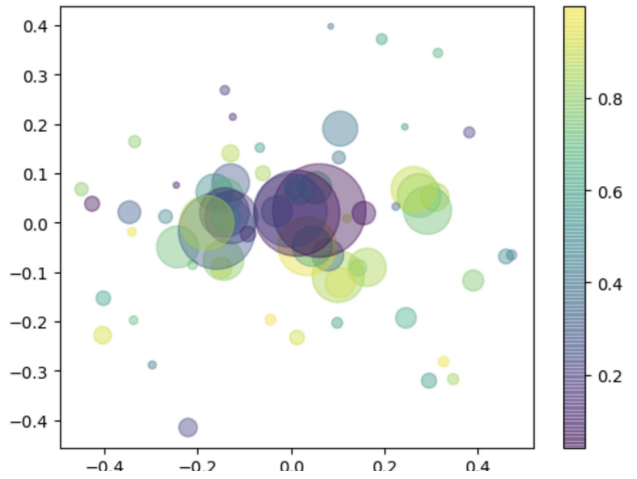




Shower history

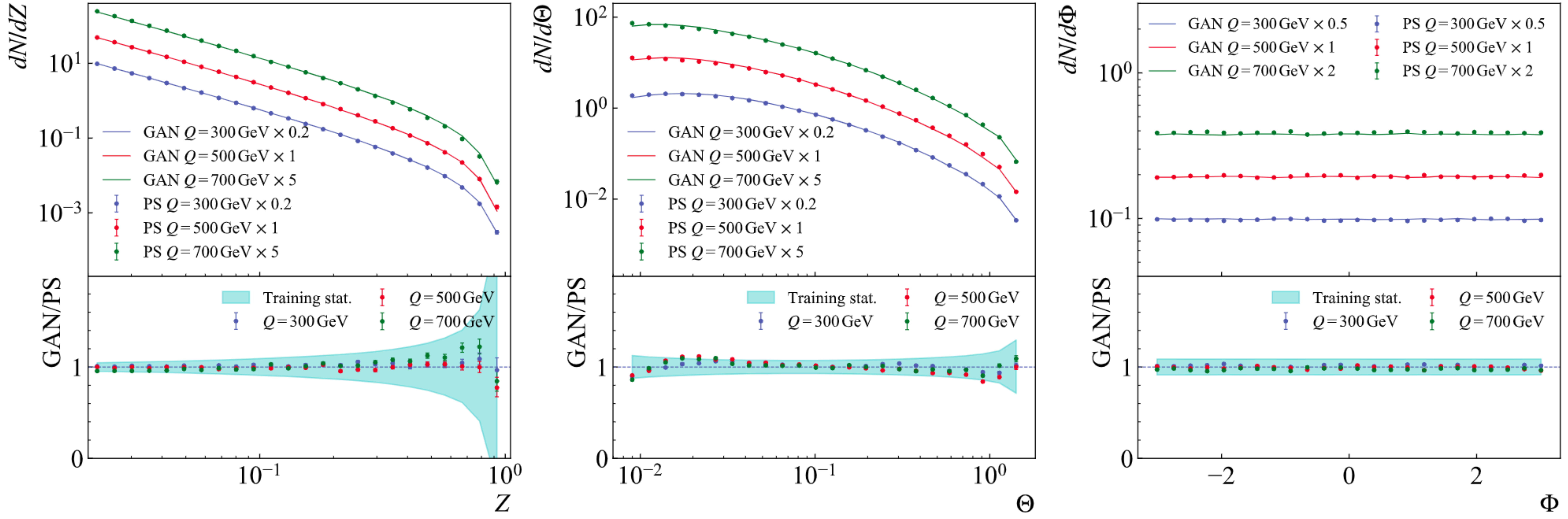
Individual splitting

- Shower cutoff currently not trainable



Numerical results

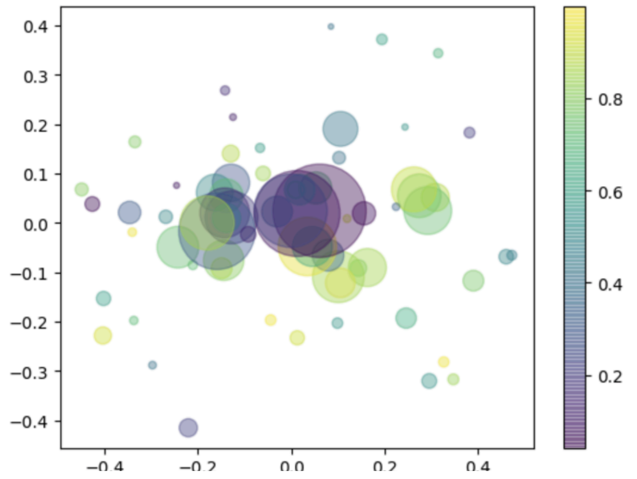
Lai, Ploskon, Neill, FR `20



Energy fraction

Polar angle

Azimuthal angle



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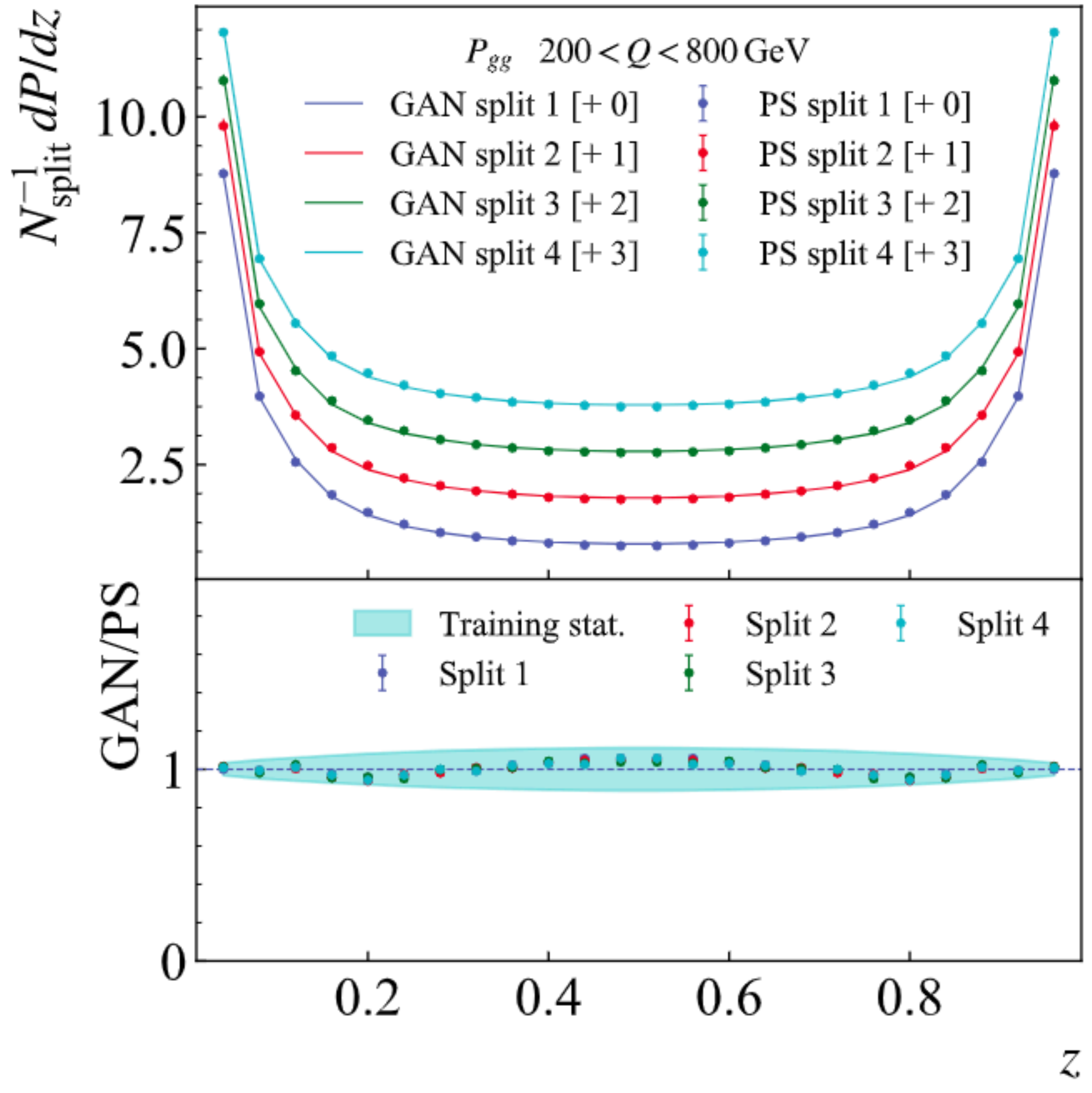
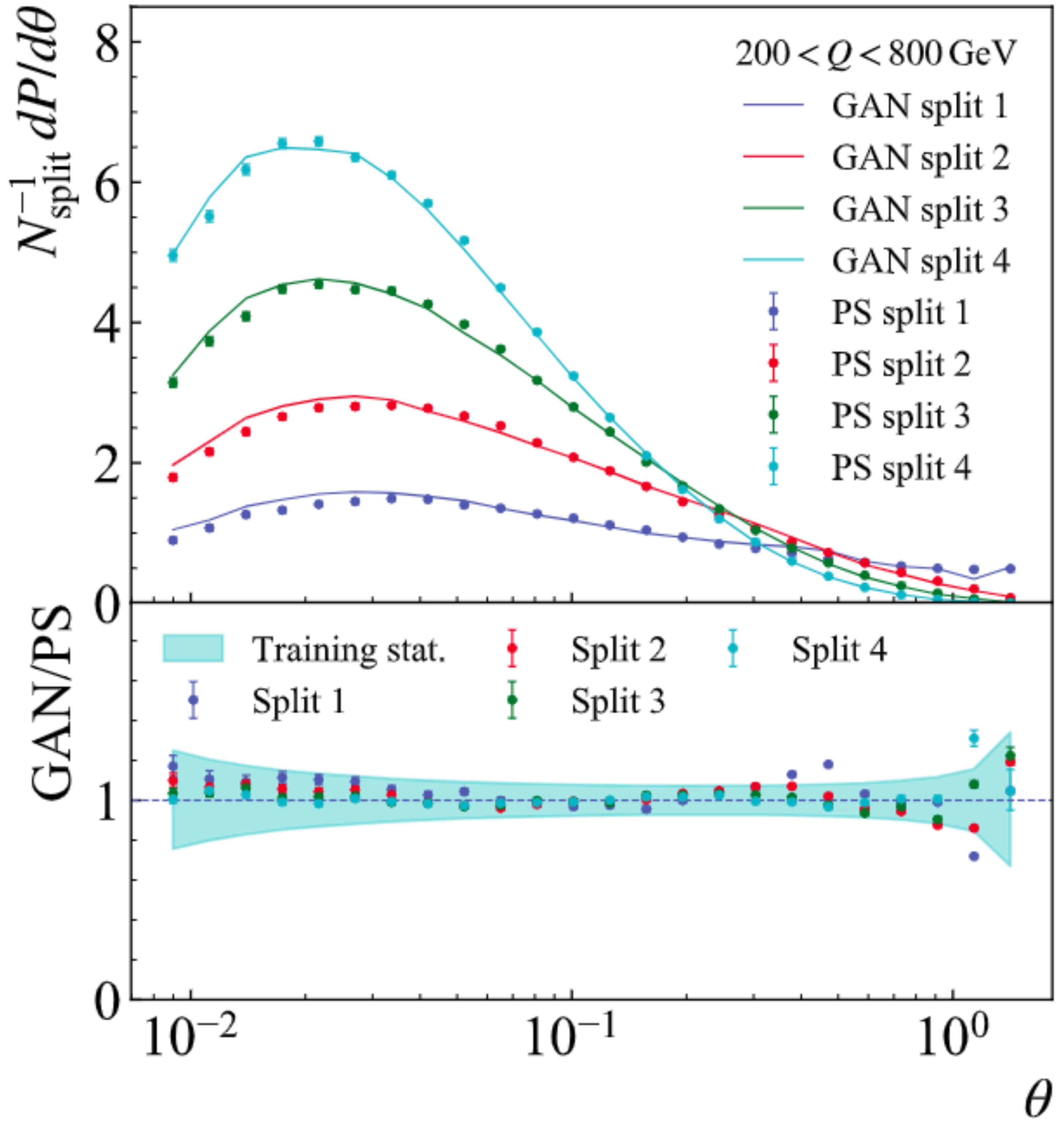
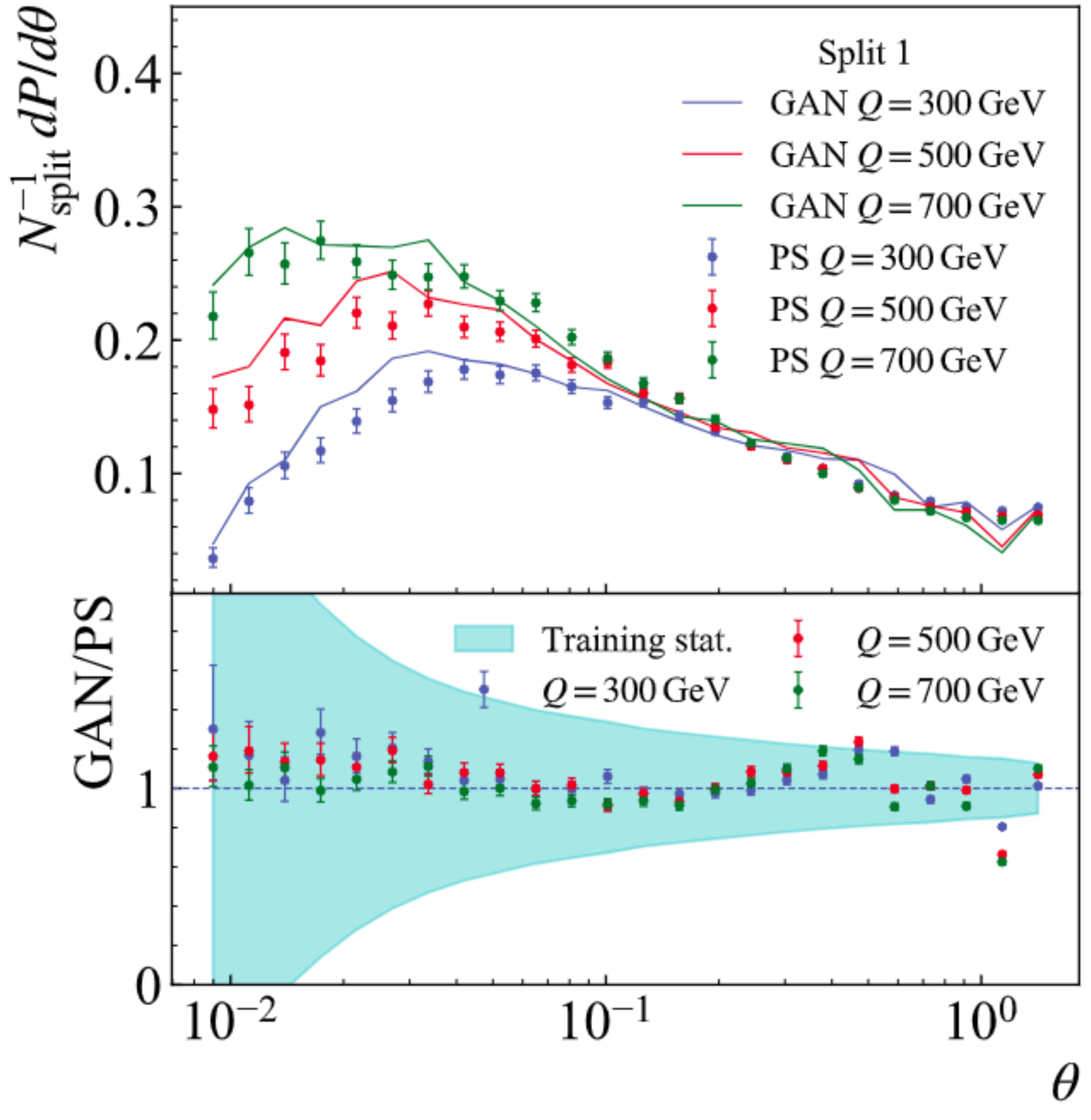


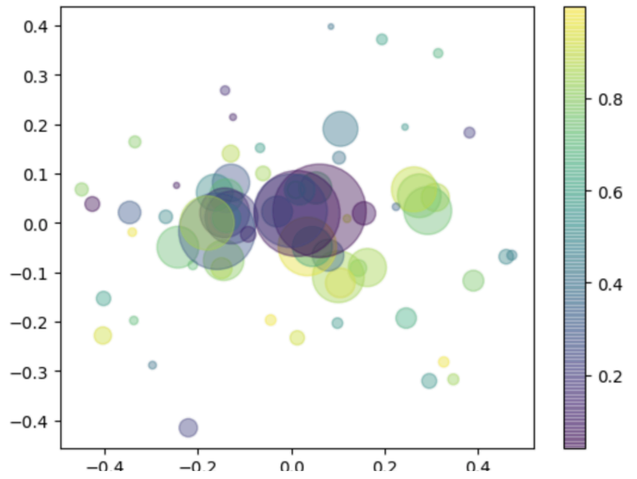
Energy fraction, split 1-4



Ordering variable, split1-4

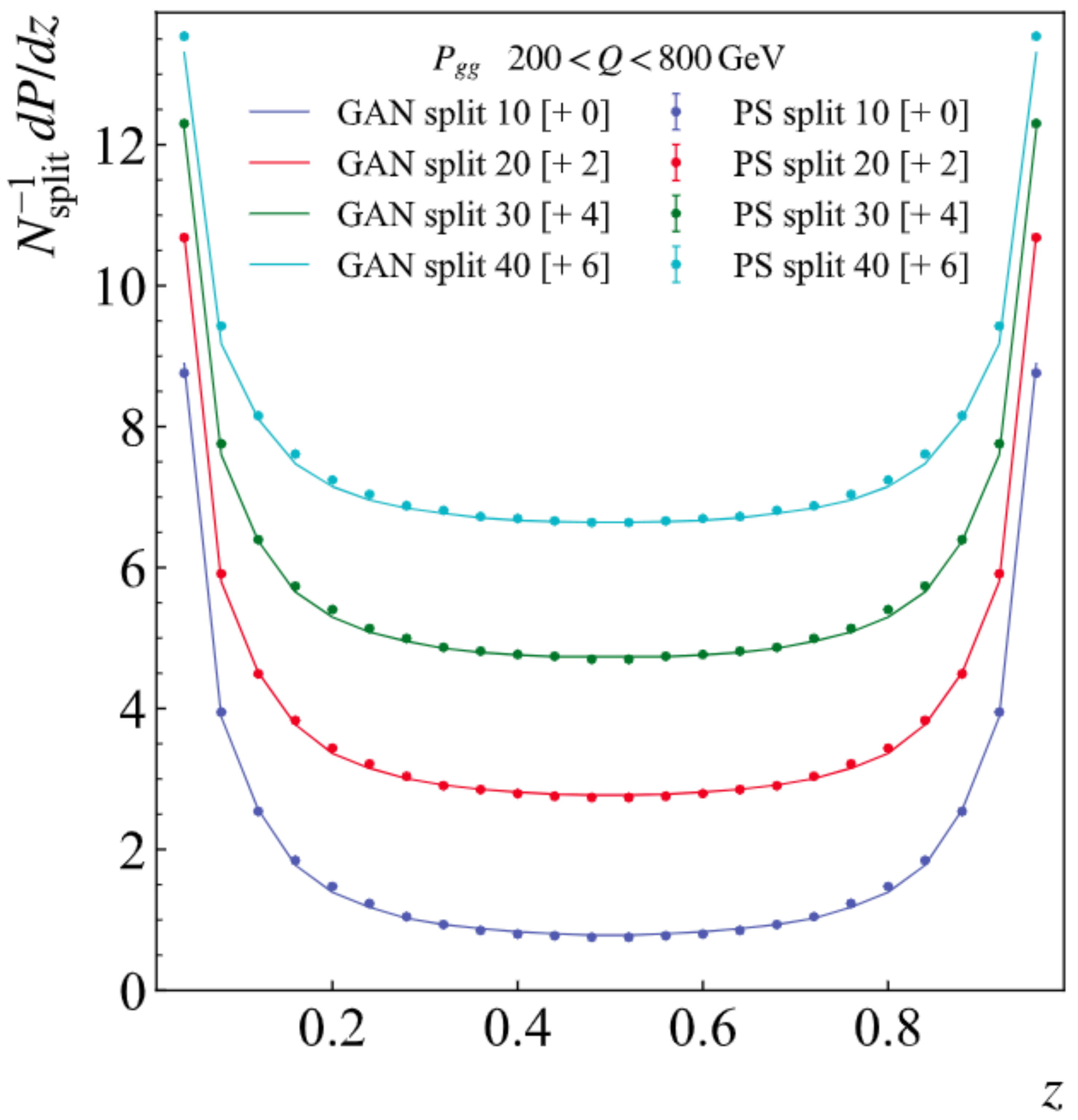


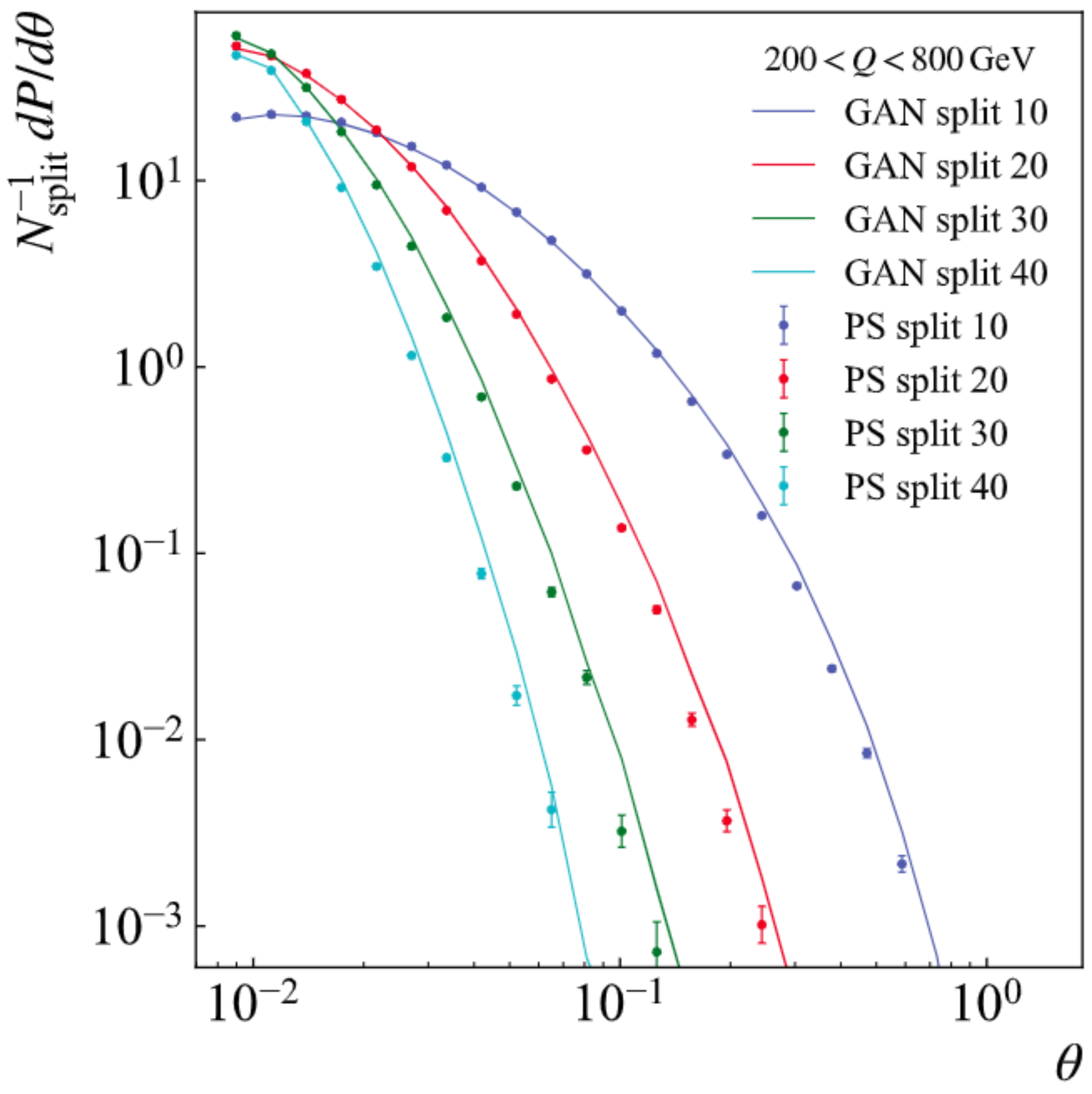
Ordering variable, different Q



Numerical results

Lai, Ploskon, Neill, FR `20





Energy fraction, split 10-40

Ordering variable, split10-40

For the chosen kinematics average number of splittings is 65, max 200

Conclusions

- White box AI
- Parton shower development
- Extract the underlying physics using low-level data
- Particularly relevant for physics that is difficult to describe from first principles