Modern jet physics with AI

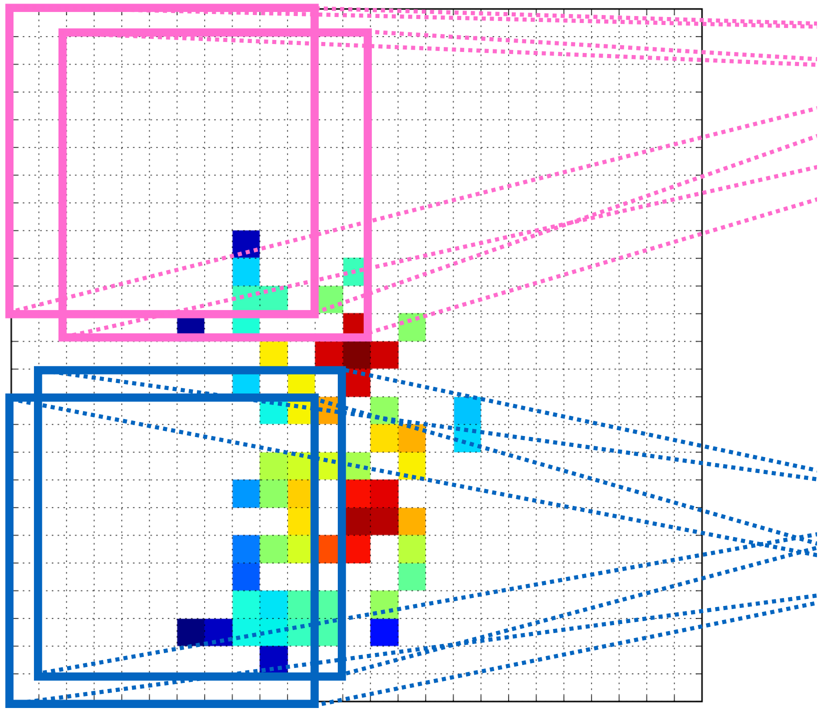
Benjamin Nachman

Lawrence Berkeley National Laboratory

bpnachman.com

bpnachman@lbl.gov

@bpnachman bnachman



BERKELEY LAB

BIDS
BERKELEY INSTITUTE
FOR DATA SCIENCE

Future *ep* workshop

Oct. 26, 2022

Data analysis in High Energy Physics

Theory of everything

↓

Physics simulators

↓

Detector-level observables

↓

Pattern recognition ↔

Nature

↓

Experiment

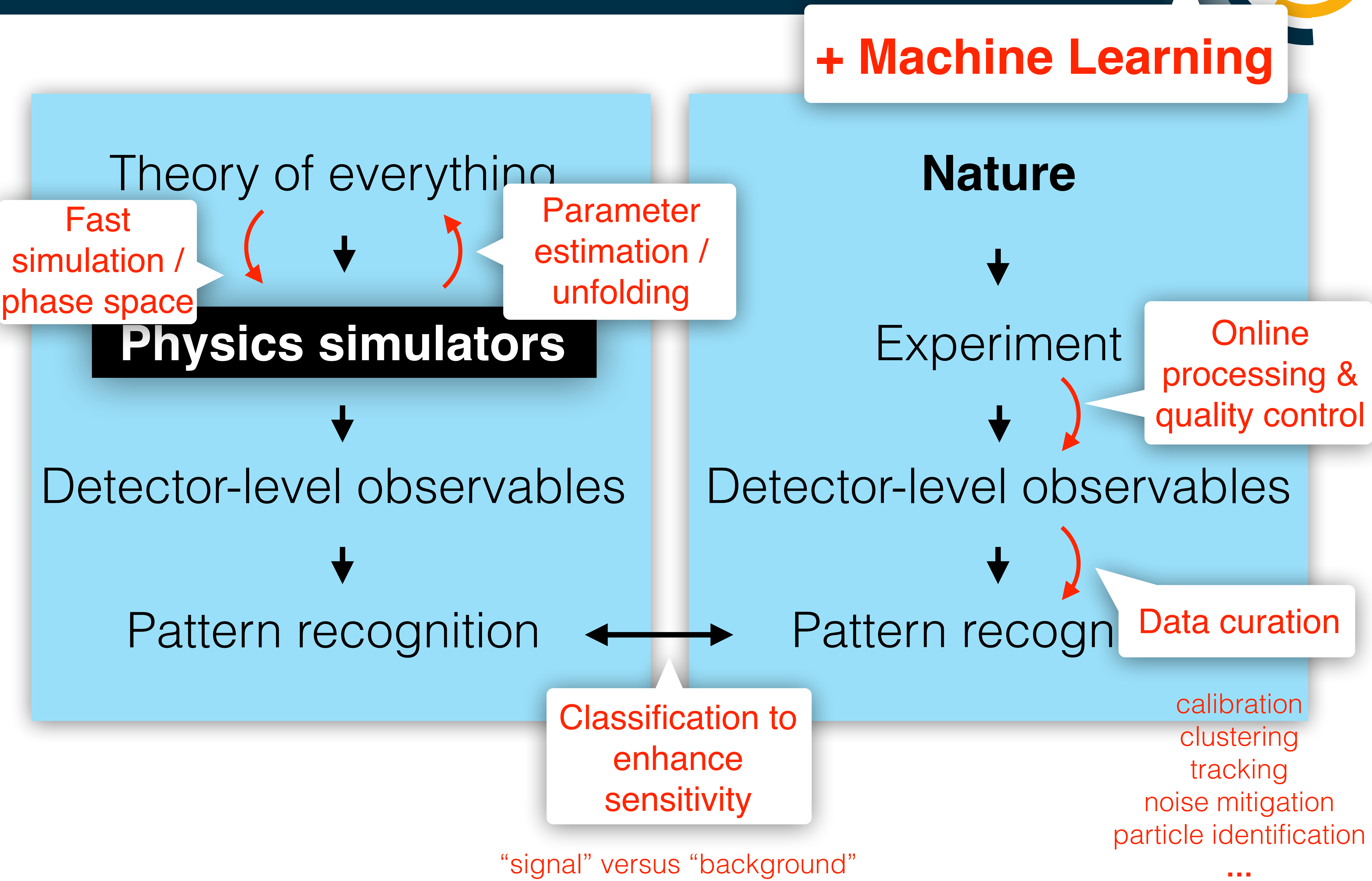
↓

Detector-level observables

↓

Pattern recognition

Data analysis in High Energy Physics



Data analysis in High Energy Physics

Today: I'll only have time to cover two topics:

Reconstruction and **Unfolding**

Part I: Reconstruction

5

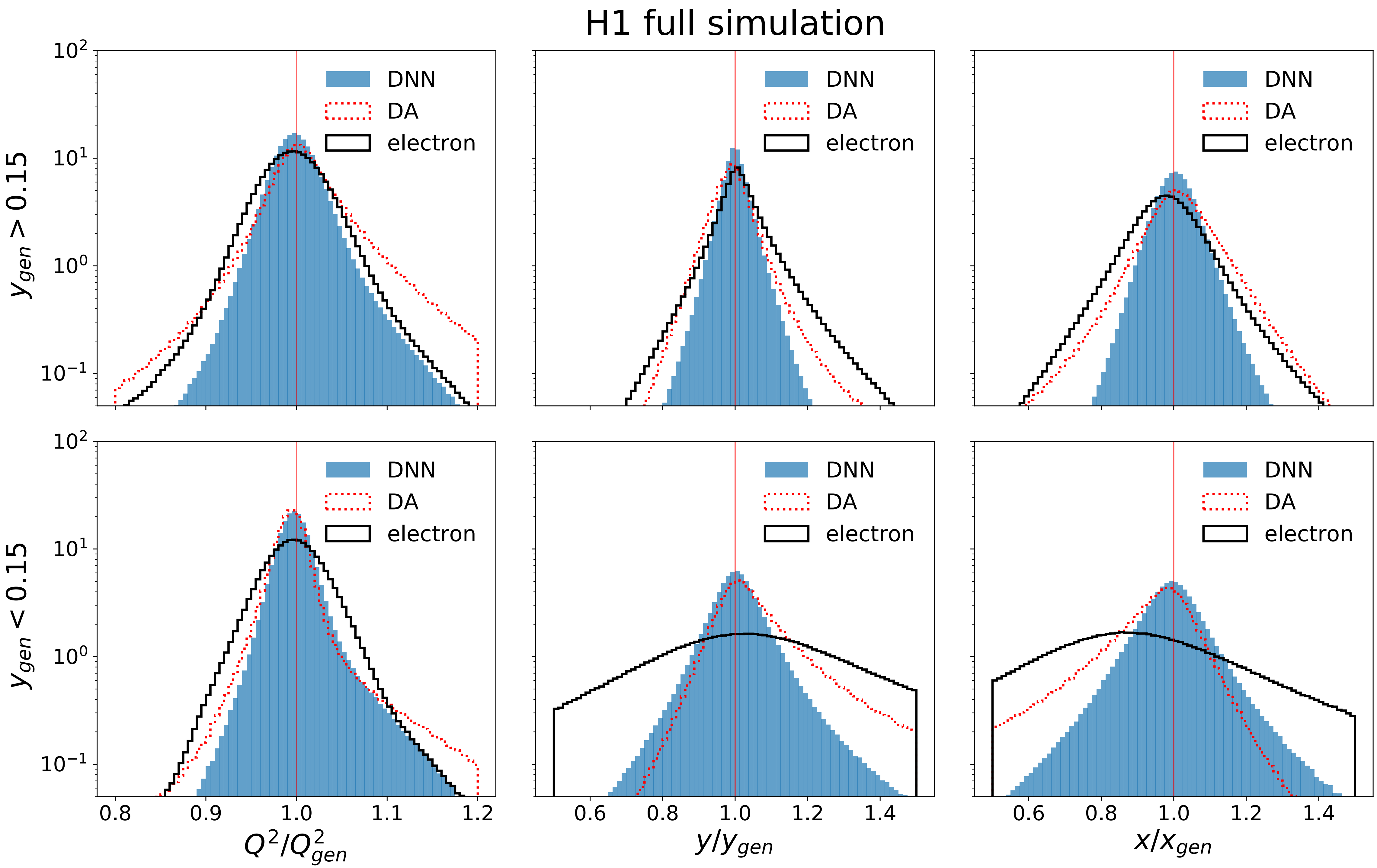
Reconstruction

Inclusive DIS; not jets per se, but critical for all jet studies

Method name	Observables	y	Q^2	$x \cdot E_p$
Electron (e)	$[E_0, E, \theta]$	$1 - \frac{\Sigma_e}{2E_0}$	$\frac{E^2 \sin^2\theta}{1-y}$	$\frac{E(1+\cos\theta)}{2y}$
Double angle (DA) [6, 7]	$[E_0, \theta, \gamma]$	$\frac{\tan\frac{\gamma}{2}}{\tan\frac{\gamma}{2}+\tan\frac{\theta}{2}}$	$4E_0^2 \cot^2\frac{\theta}{2}(1-y)$	$\frac{Q^2}{4E_0 y}$
Hadron (h, JB) [4]	$[E_0, \Sigma, \gamma]$	$\frac{\Sigma}{2E_0}$	$\frac{T^2}{1-y}$	$\frac{Q^2}{2\Sigma}$
ISigma (IΣ) [9]	$[E, \theta, \Sigma]$	$\frac{\Sigma}{\Sigma+\Sigma_e}$	$\frac{E^2 \sin^2\theta}{1-y}$	$\frac{E(1+\cos\theta)}{2y}$
IDA [7]	$[E, \theta, \gamma]$	y_{DA}	$\frac{E^2 \sin^2\theta}{1-y}$	$\frac{E(1+\cos\theta)}{2y}$
$E_0 E \Sigma$	$[E_0, E, \Sigma]$	y_h	$4E_0E - 4E_0^2(1-y)$	$\frac{Q^2}{2\Sigma}$
$E_0 \theta \Sigma$	$[E_0, \theta, \Sigma]$	y_h	$4E_0^2 \cot^2\frac{\theta}{2}(1-y)$	$\frac{Q^2}{2\Sigma}$
$\theta \Sigma \gamma$ [8]	$[\theta, \Sigma, \gamma]$	y_{DA}	$\frac{T^2}{1-y}$	$\frac{Q^2}{2\Sigma}$
Double energy (A4) [7]	$[E_0, E, E_h]$	$\frac{E-E_0}{(xE_p)-E_0}$	$4E_0 y (xE_p)$	$E + E_h - E_0$
$E \Sigma T$	$[E, \Sigma, T]$	$\frac{\Sigma}{\Sigma+E\pm\sqrt{E^2+T^2}}$	$\frac{T^2}{1-y}$	$\frac{Q^2}{2\Sigma}$
$E_0 E T$	$[E_0, E, T]$	$\frac{2E_0 - E \mp \sqrt{E^2-T^2}}{2E_0}$	$\frac{T^2}{1-y}$	$\frac{Q^2}{4E_0 y}$
Sigma (Σ) [9]	$[E_0, E, \Sigma, \theta]$	$y_{\mathrm{I}\Sigma}$	$Q^2_{\mathrm{I}\Sigma}$	$\frac{Q^2}{4E_0 y}$
eSigma ($e\Sigma$) [9]	$[E_0, E, \Sigma, \theta]$	$\frac{2E_0\Sigma}{(\Sigma+\Sigma_e)^2}$	$2E_0E(1+\cos\theta)$	$\frac{E(1+\cos\theta)(\Sigma+\Sigma_e)}{2\Sigma}$

2110.05505; see also 2108.11638

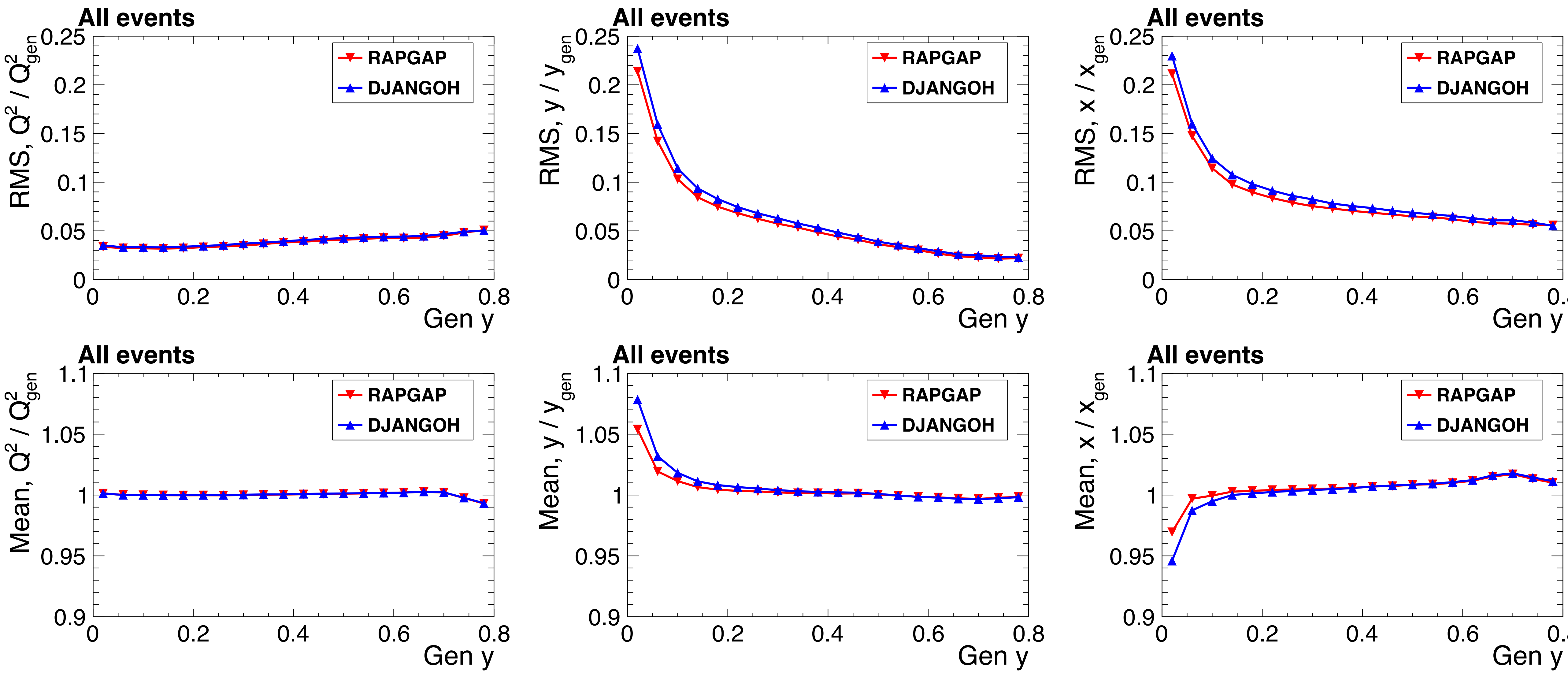
DIS Reco with simple NN



2110.05505; see also 2108.11638

DIS Reco with simple NN

H1 full simulation



Holds up to model variations!

2110.05505; see also 2108.11638

Reconstruction - word of caution!

All of the methods studied so far for DIS are of the form: predict true from measured via mean-squared error (or similar)

Claim: this is prior dependent !

What goes wrong?

Suppose you have some features x and you want to predict y.

detector energy *true energy*

One way to do this is to find an f that minimizes the mean squared error (MSE):

$$f = \text{argmin}_g \sum_i (g(x_i) - y_i)^2$$

Then, f(x) = E[y|x].

Why is this a problem?

What goes wrong?

Suppose you have some features x and you want to predict y.

detector energy *true energy*

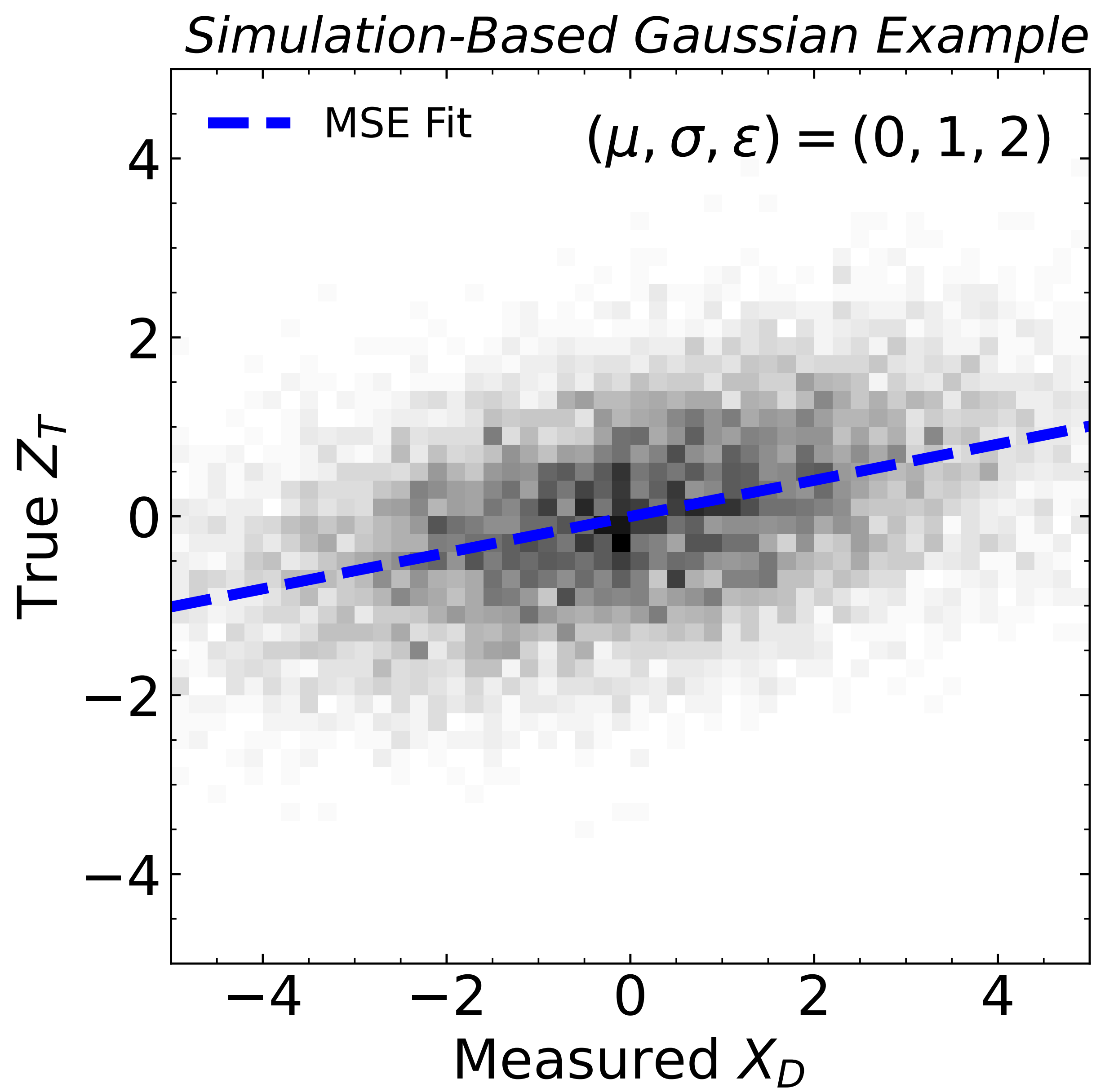
$$f(x) = E[y|x] = \int \mathrm{d}y\, y\, p(y|x)$$

$$E[f(x)|y] = \int \mathrm{d}x\, \mathrm{d}y'\, y'\, p_{\mathrm{train}}(y'|x)\, p_{\mathrm{test}}(x|y)$$

this need not be y even if $p_{train} = p_{test}$ (!)

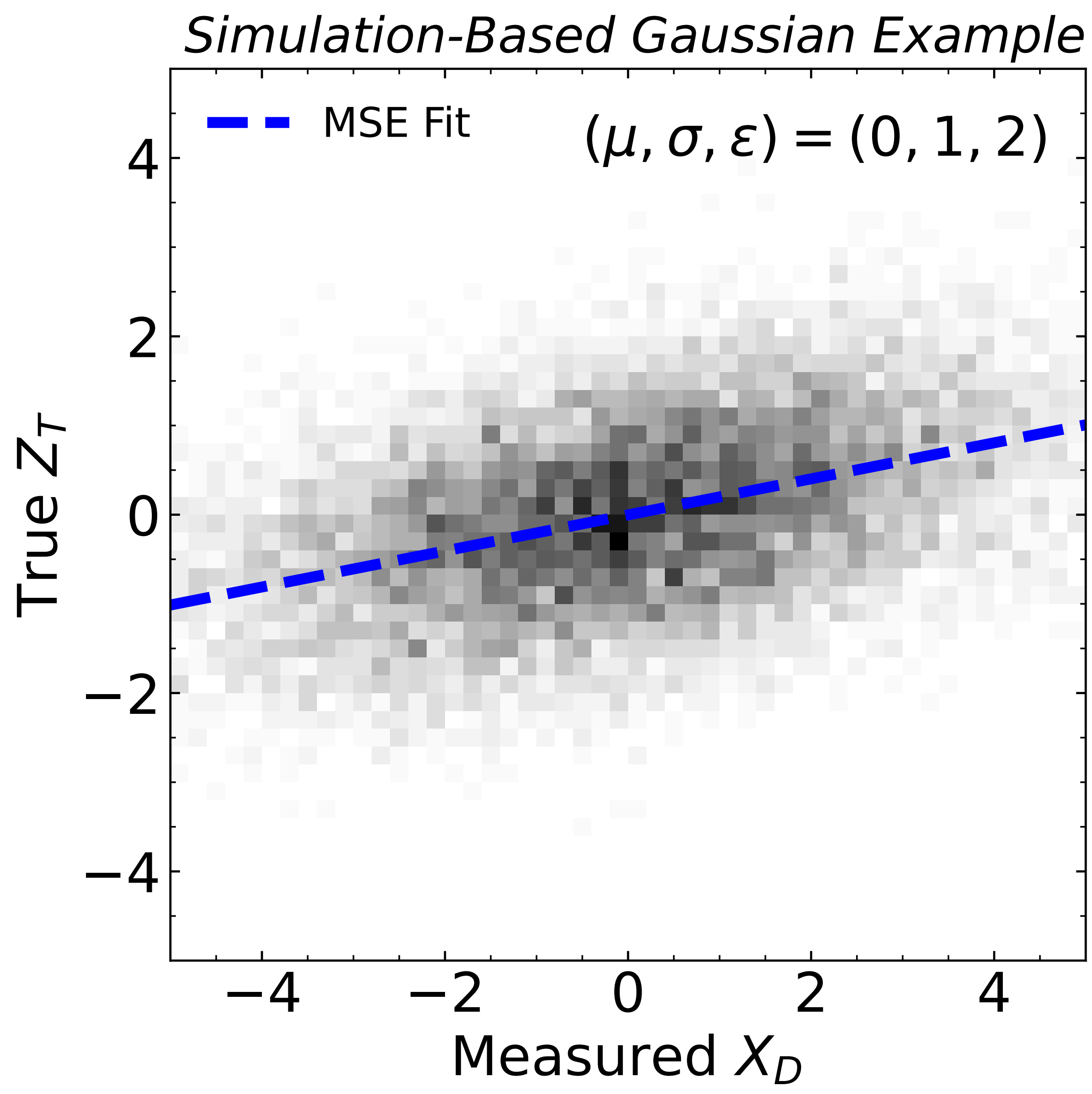
Why is this a problem?

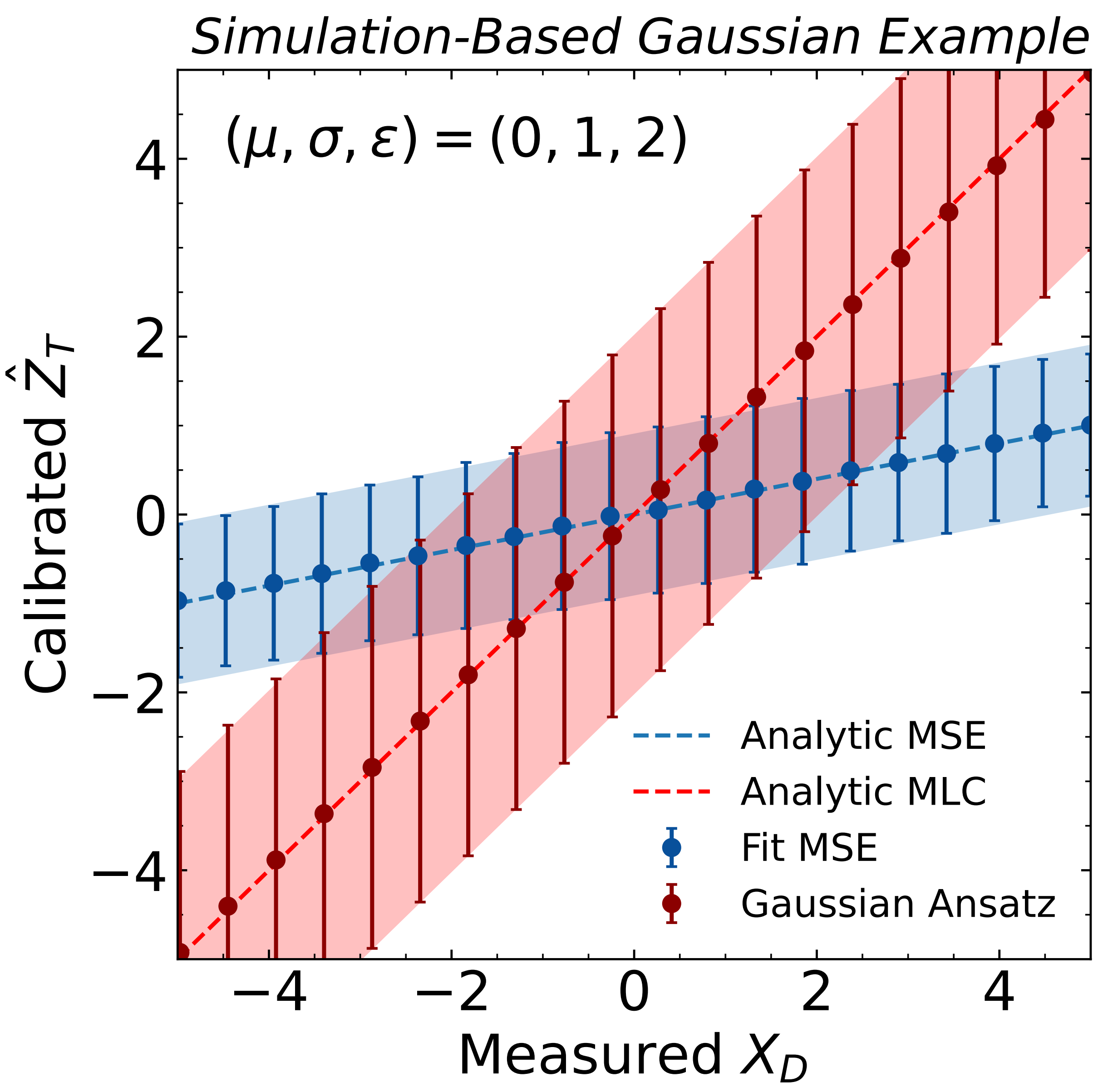
Gaussian Example



2205.05084

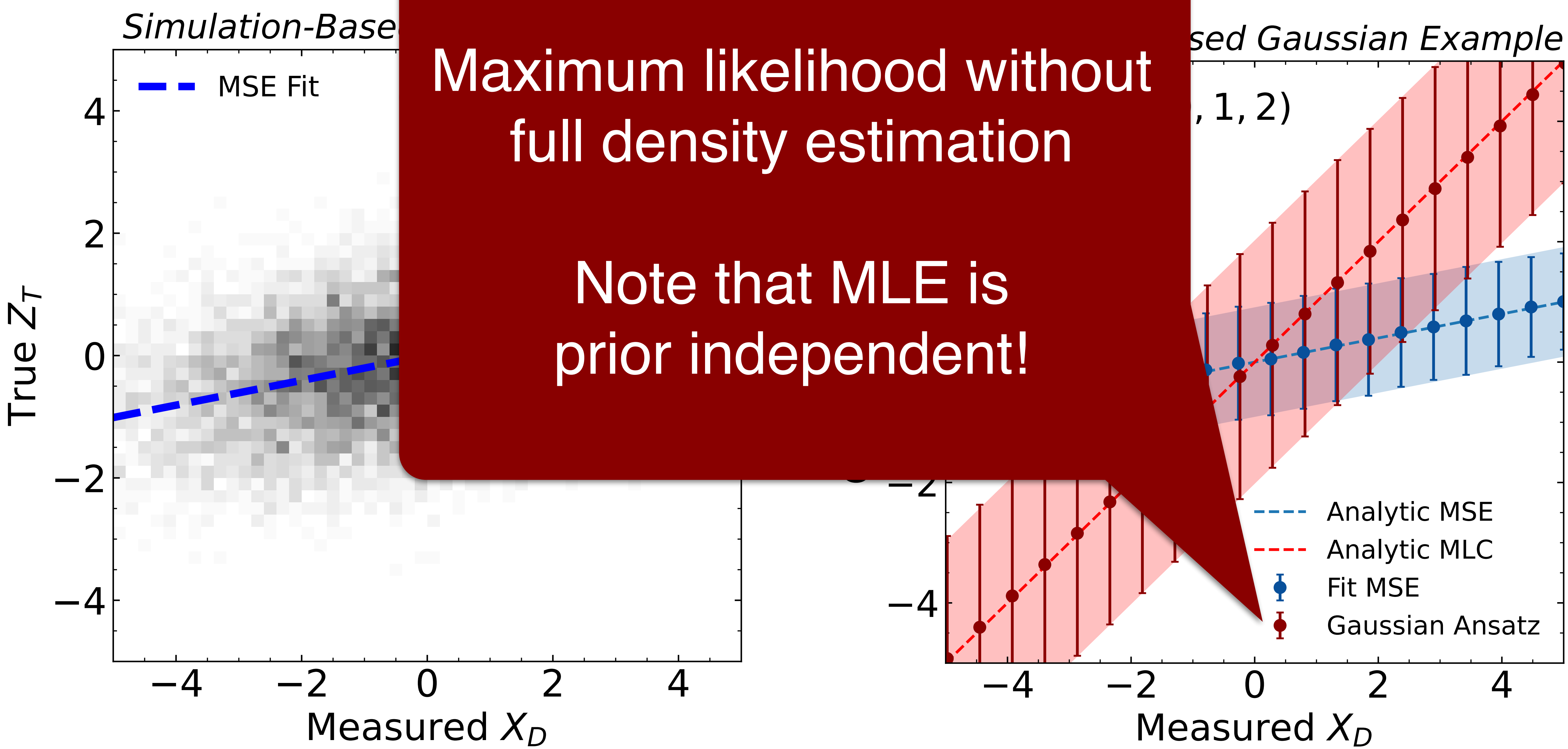
Gaussian Example





2205.05084

Gaussian Example

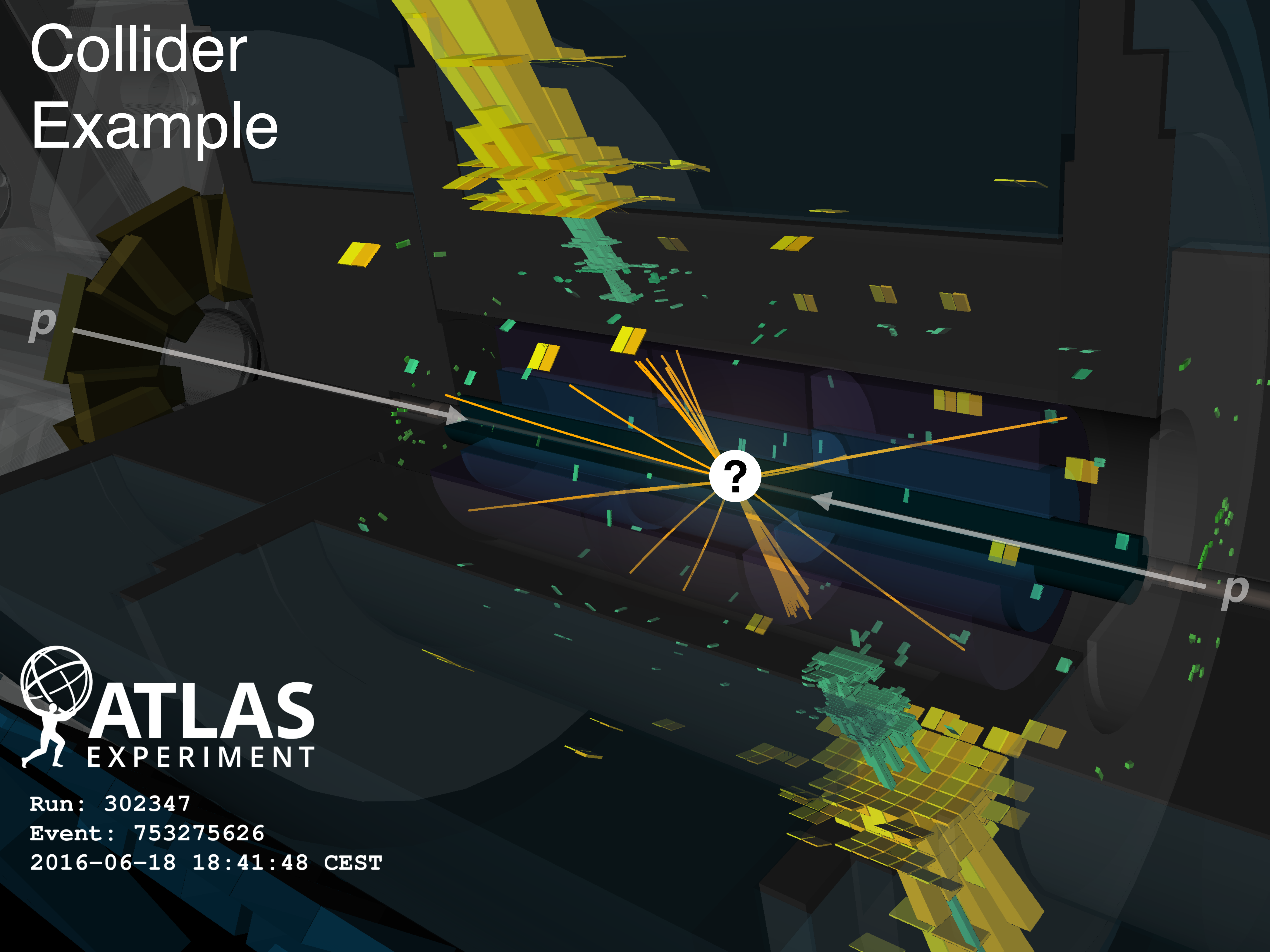


Maximum likelihood without full density estimation

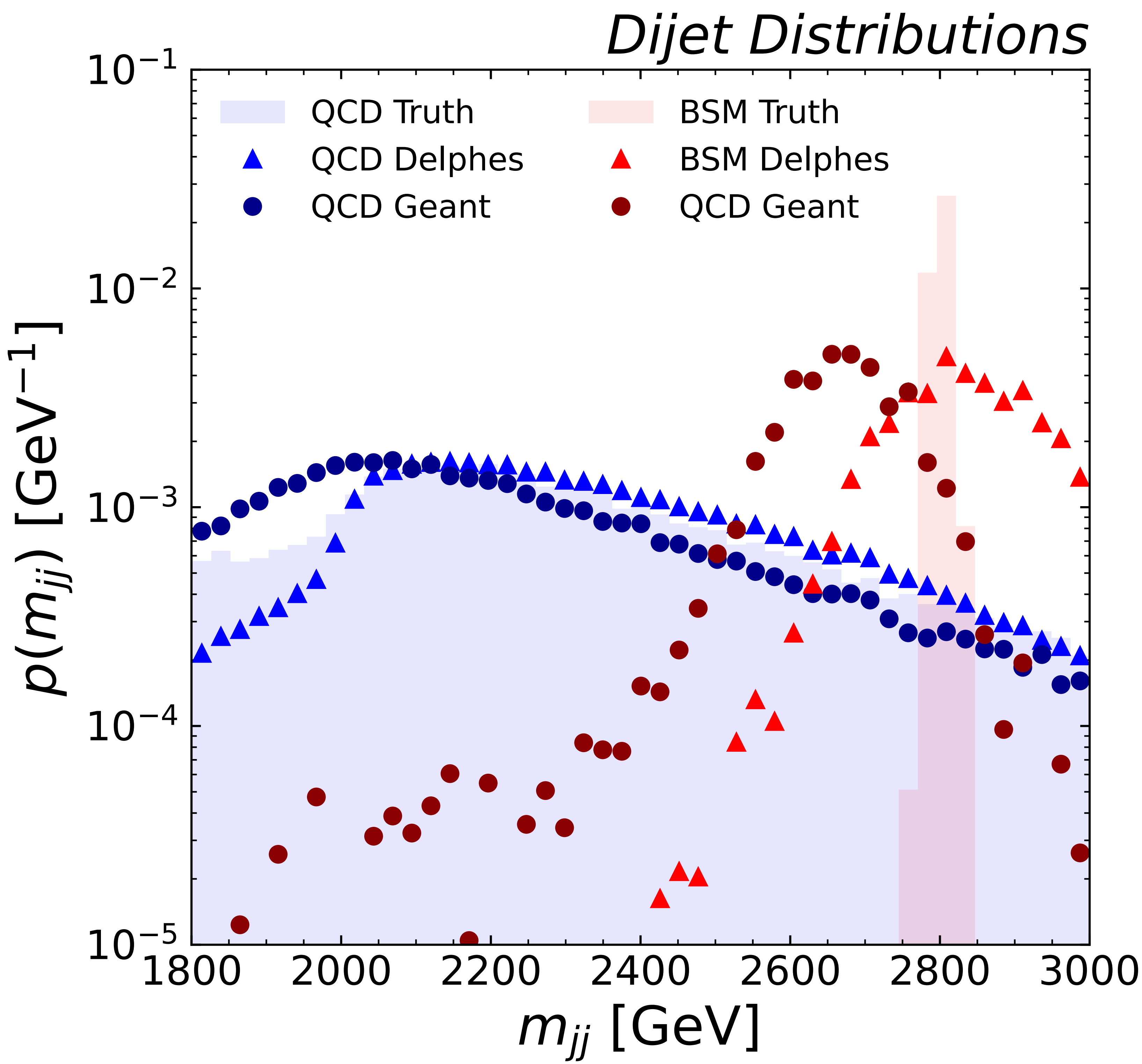
Note that MLE is prior independent!

2205.05084

Collider Example



Collider Example



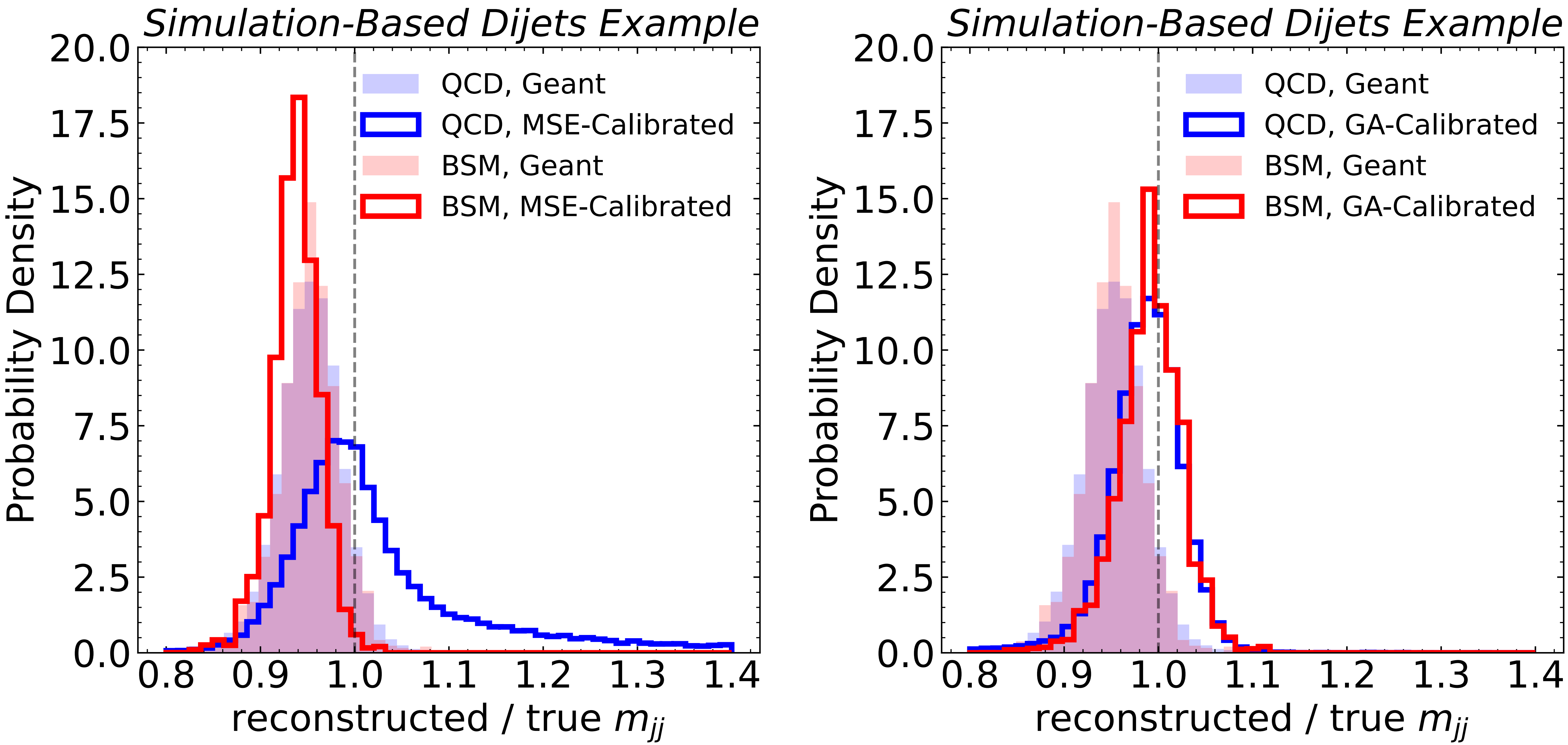
QCD = quarks and gluons

BSM = new physics

Looking for new massive particles that produce jets

2205.05084

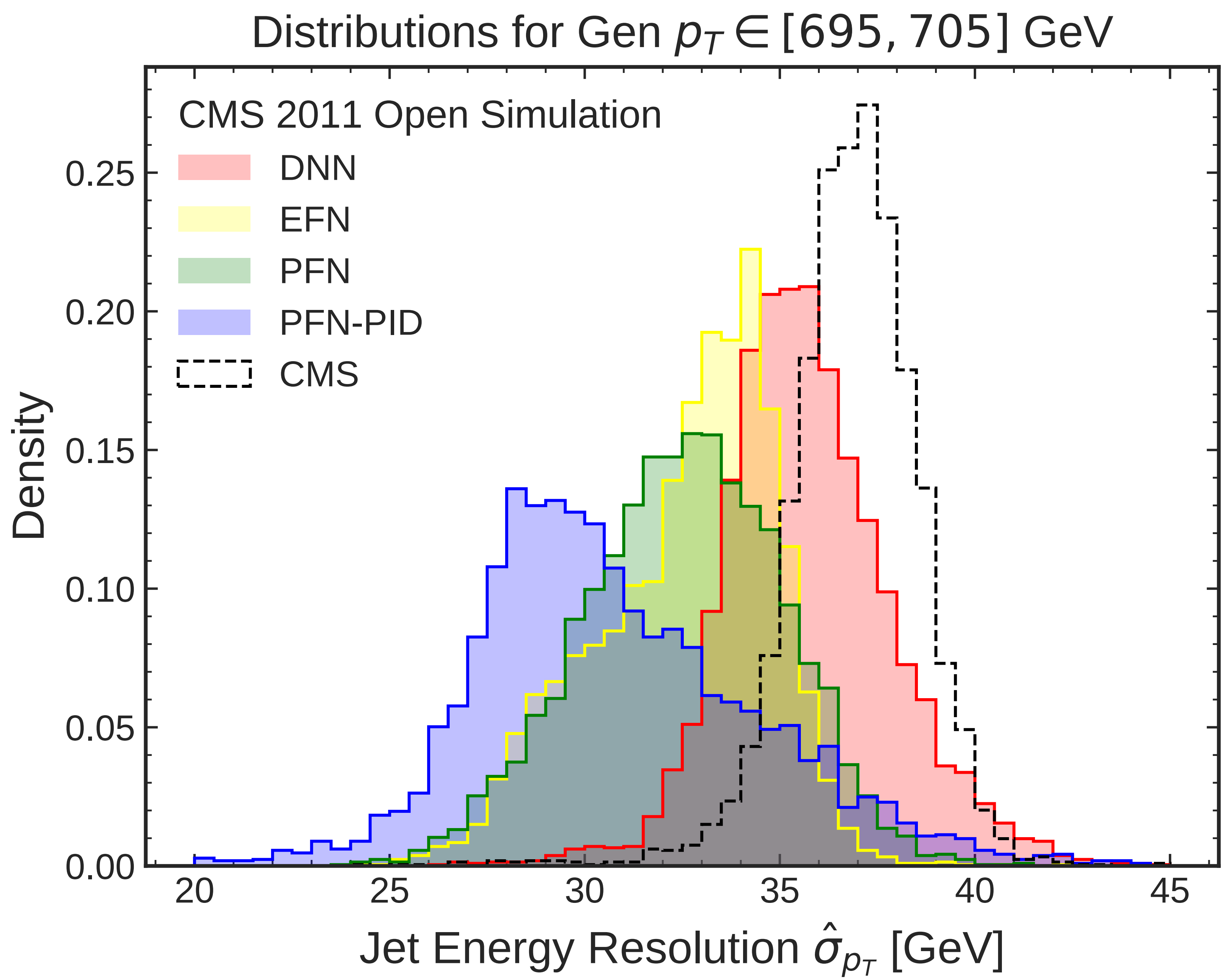
Collider Example



2205.05084

Collider Example

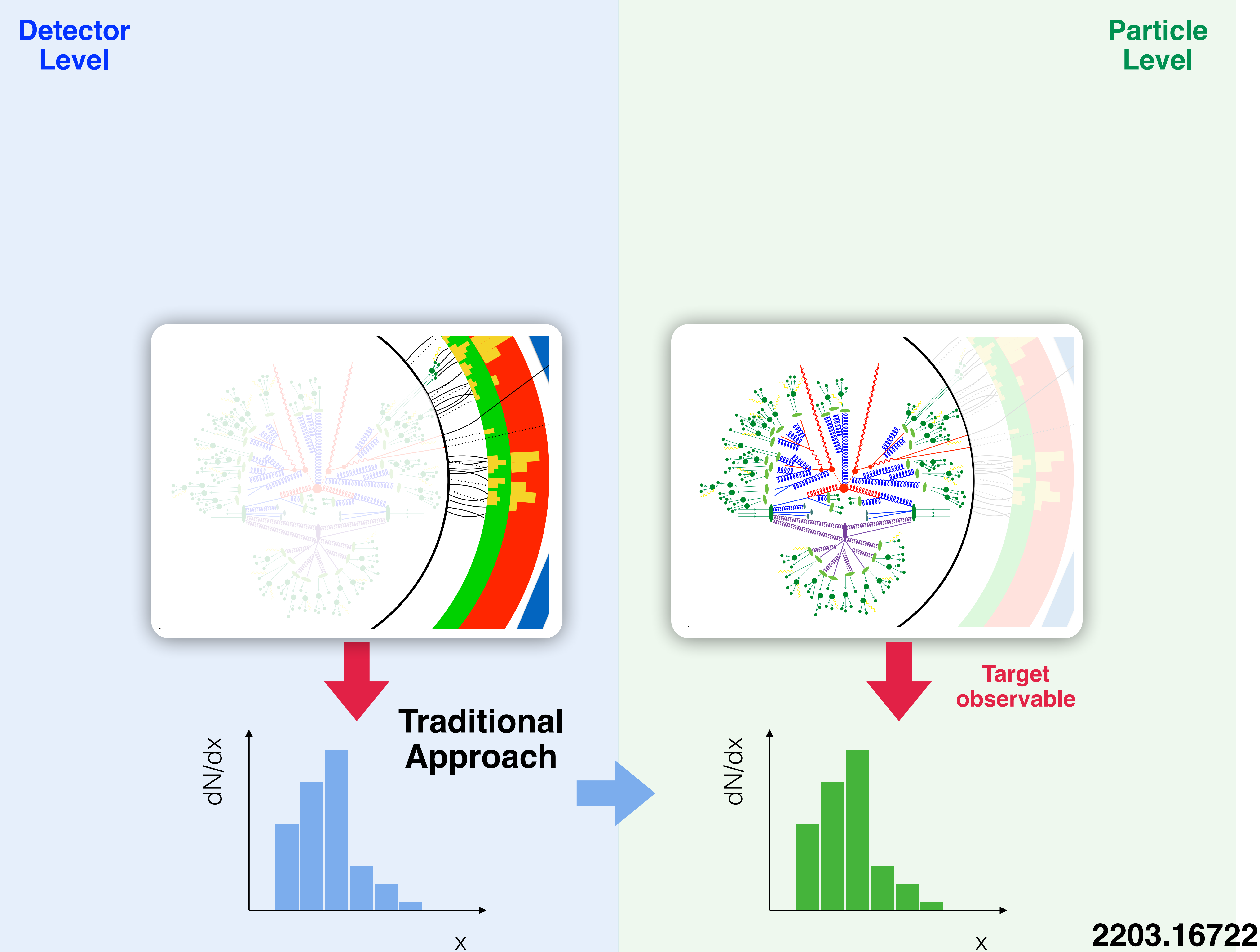
Can do high-dimensional regression in this framework

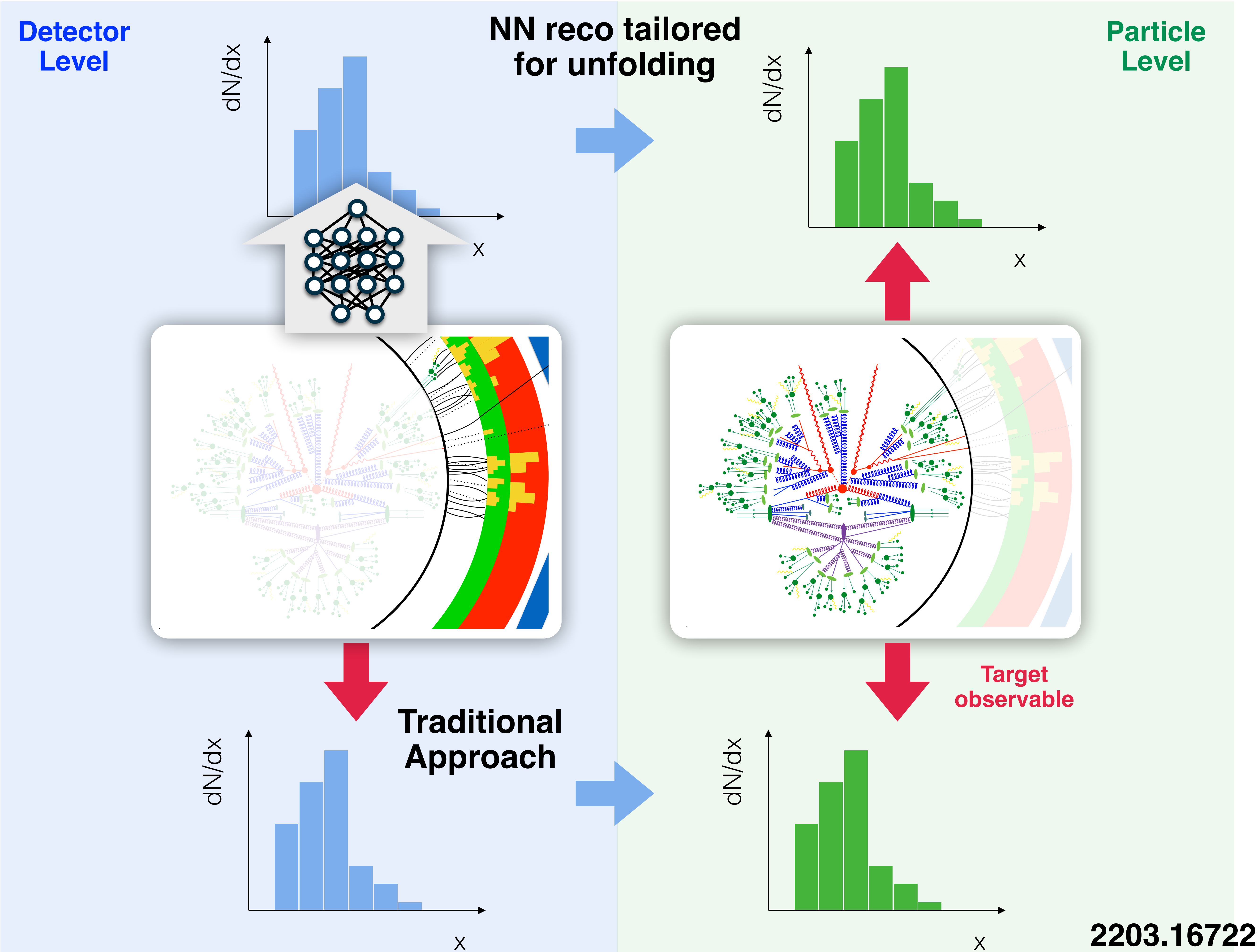


PFN-ID: process all particles inside jets

2205.03413

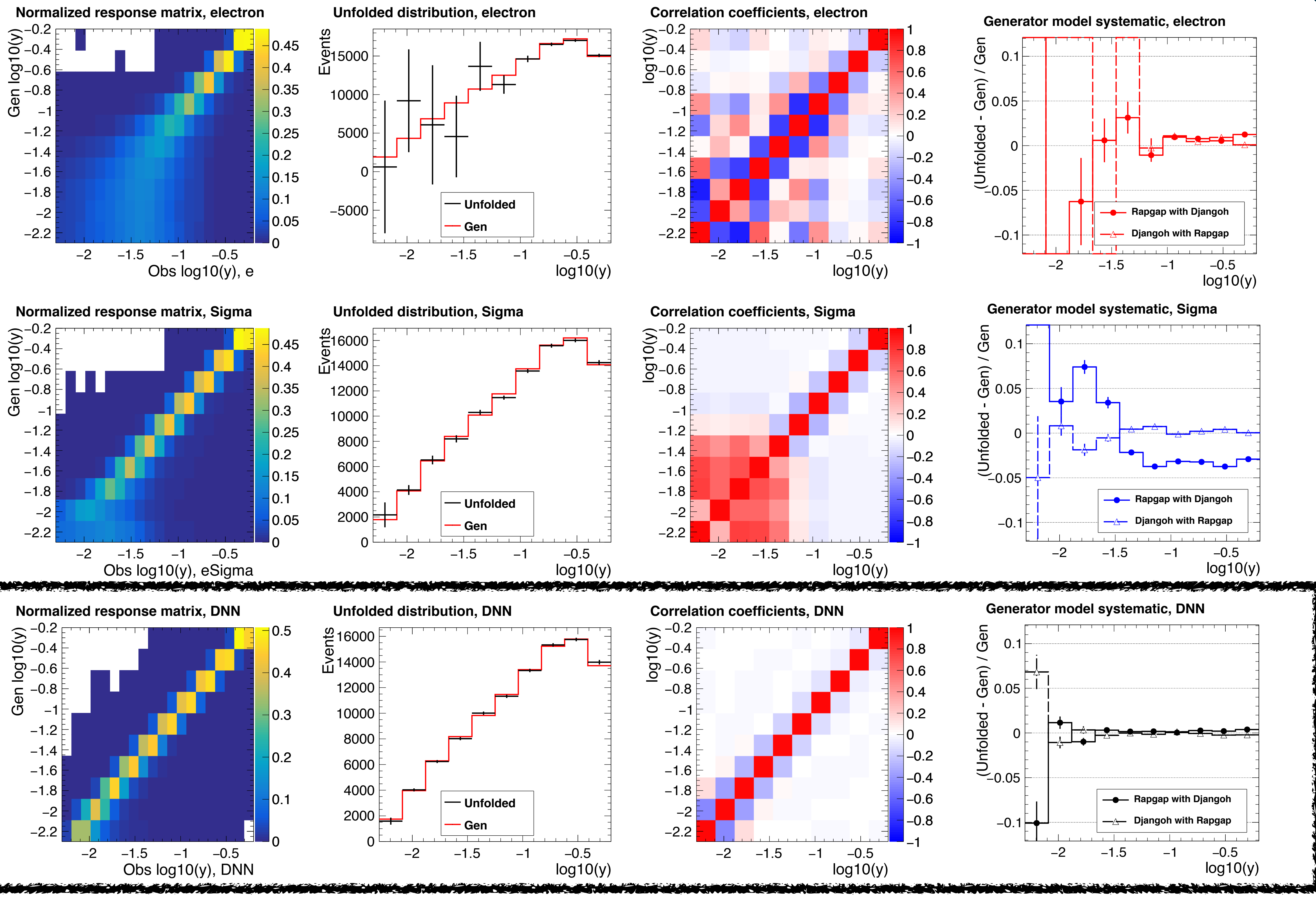
Part II: Unfolding


Detector Level
Particle Level
Traditional Approach
Target observable
dN/dx
x
dN/dx
x
2203.16722



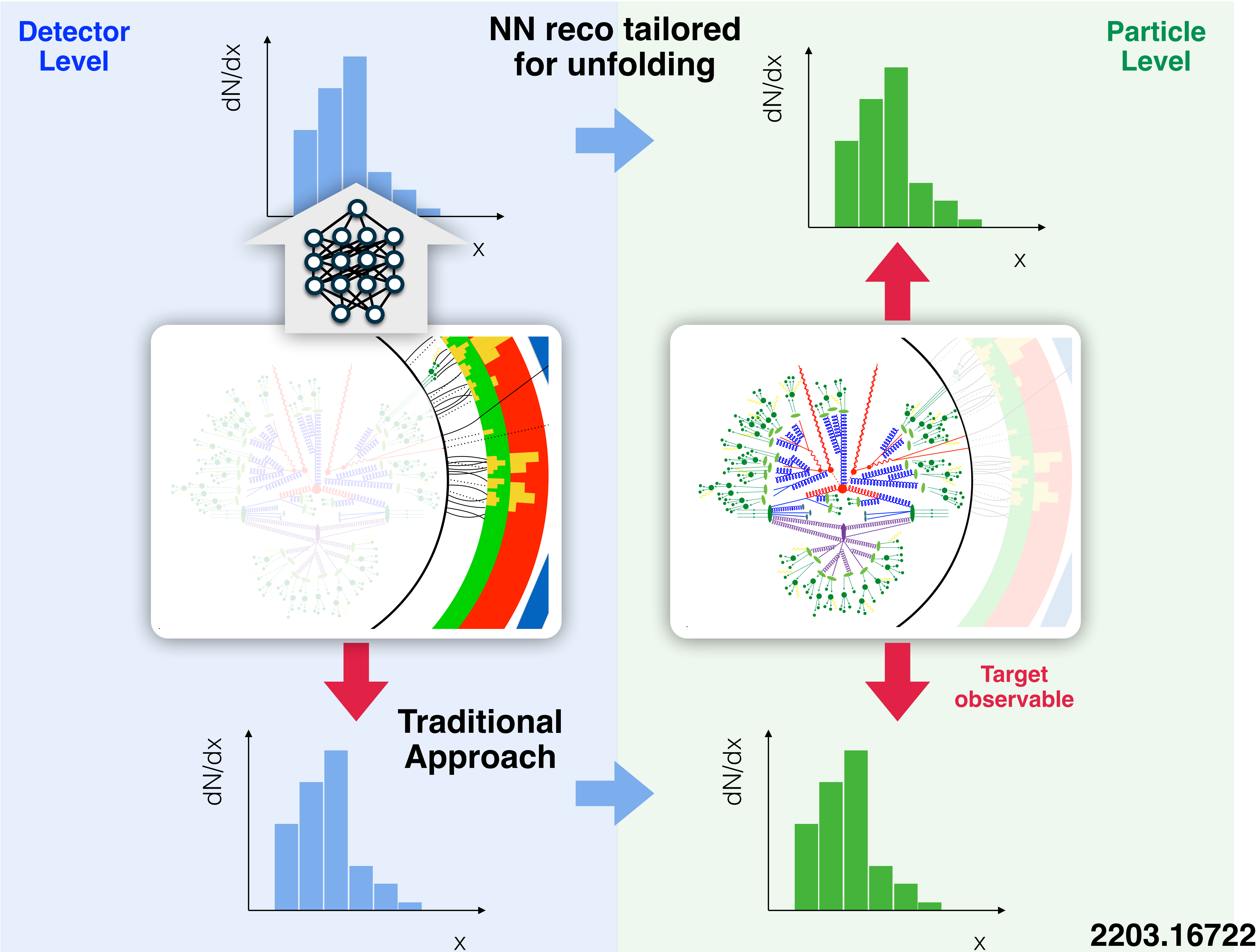
Detector Level
NN reco tailored for unfolding
Particle Level
dN/dx
x
Target observable
Traditional Approach
2203.16722

Tailored Reco for Unfolding

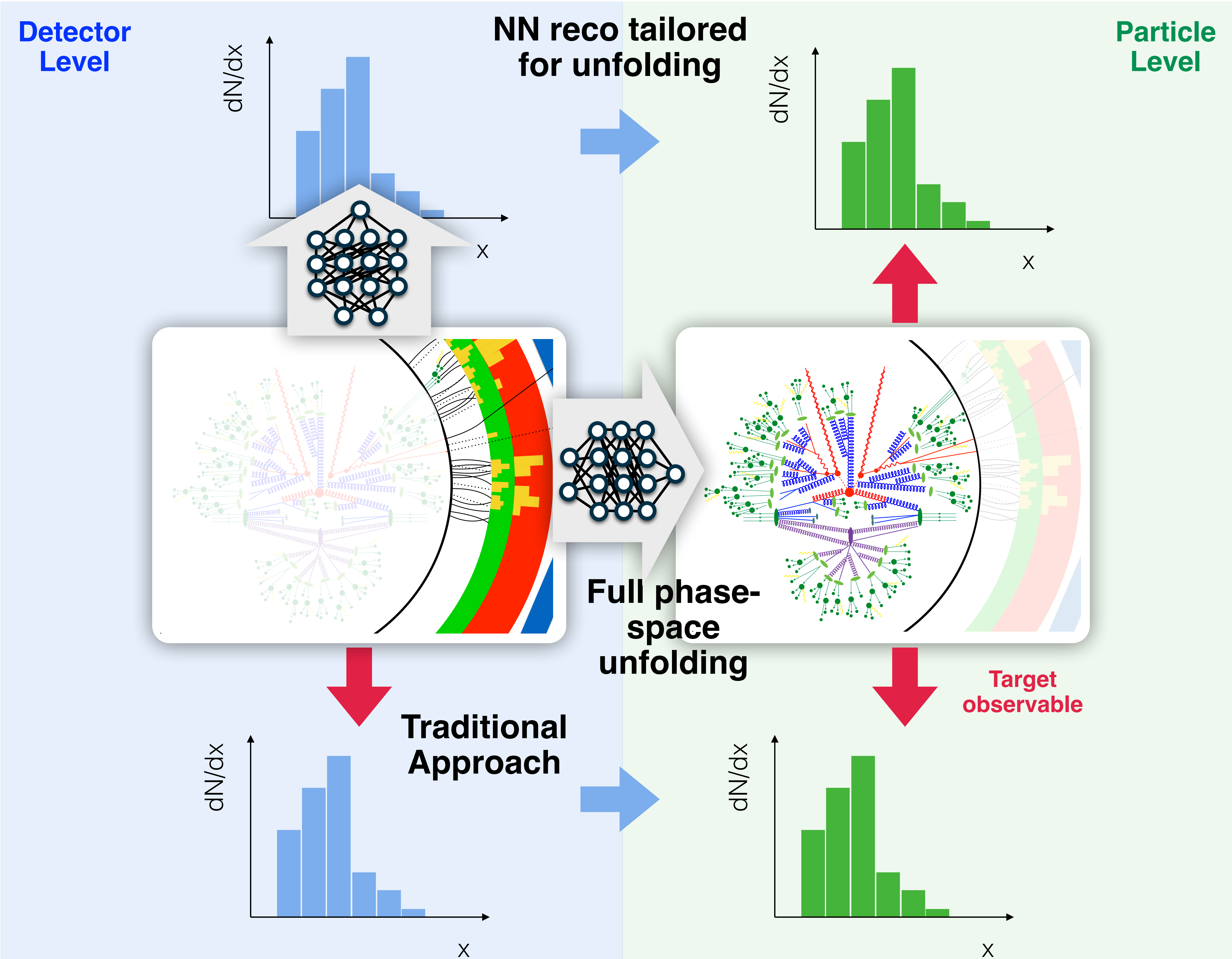


Impact on inclusive DIS: better stat + syst

2203.16722

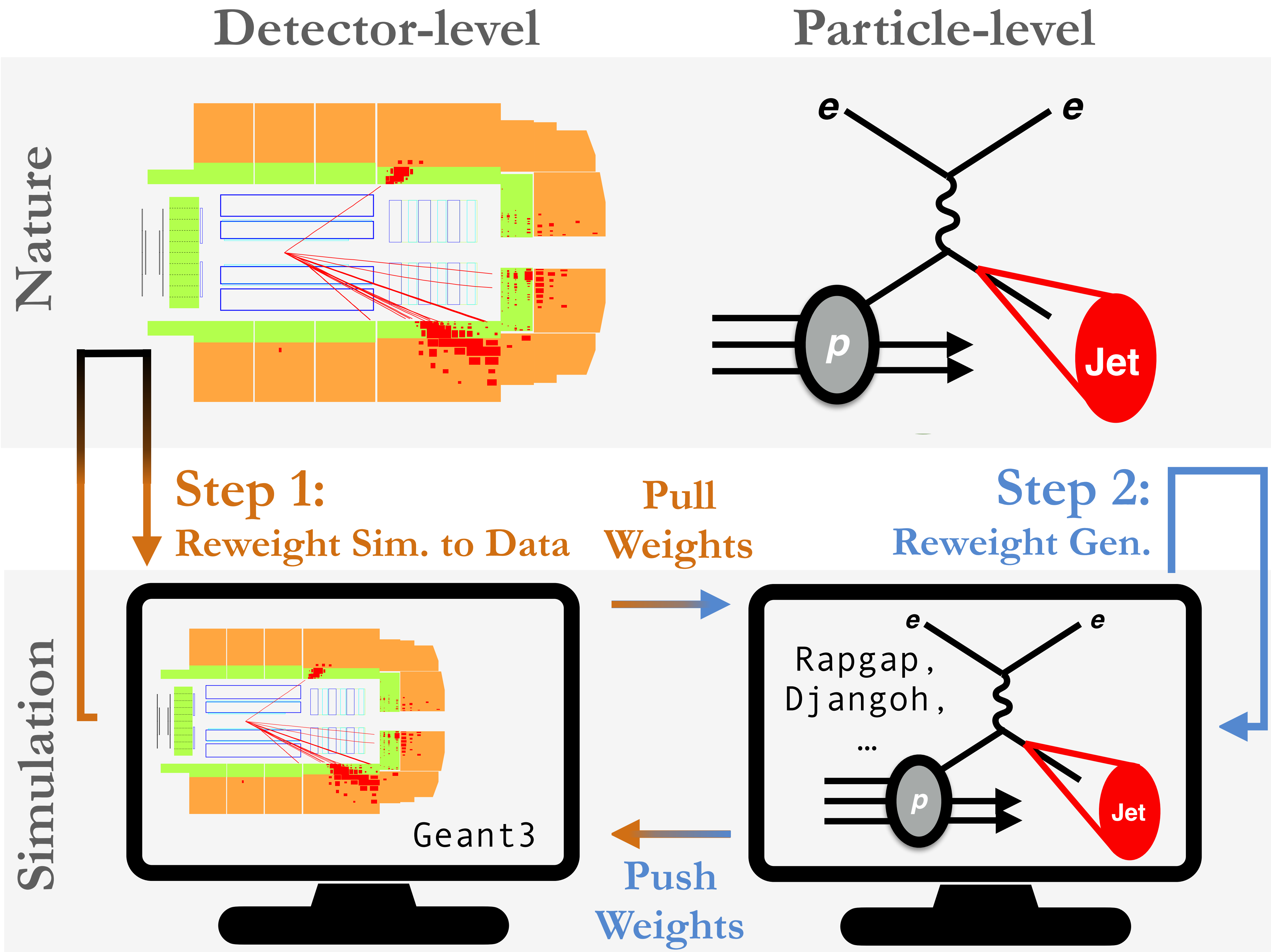


Detector Level
NN reco tailored for unfolding
Particle Level
dN/dx
x
dN/dx
x
Target observable
Traditional Approach
dN/dx
x
dN/dx
x
2203.16722



Detector Level
NN reco tailored for unfolding
Particle Level
dN/dx
x
dN/dx
x
Full phase-space unfolding
Target observable
Traditional Approach
dN/dx
x
dN/dx
x

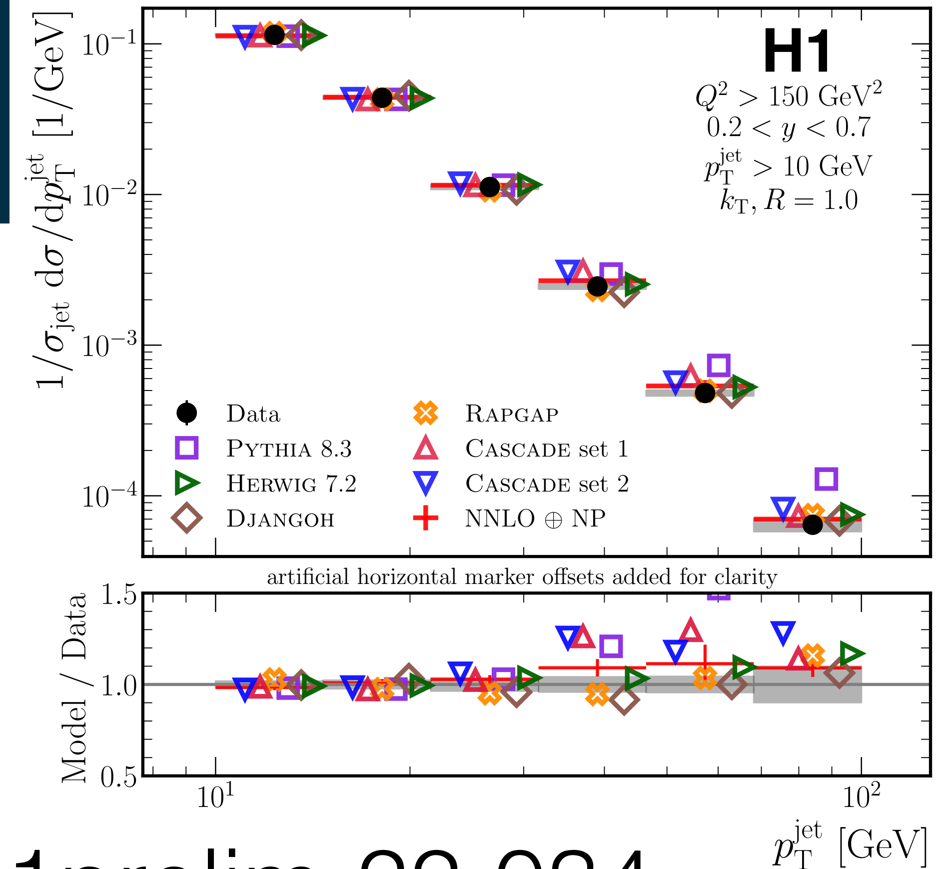
Full Phase via OmniFold



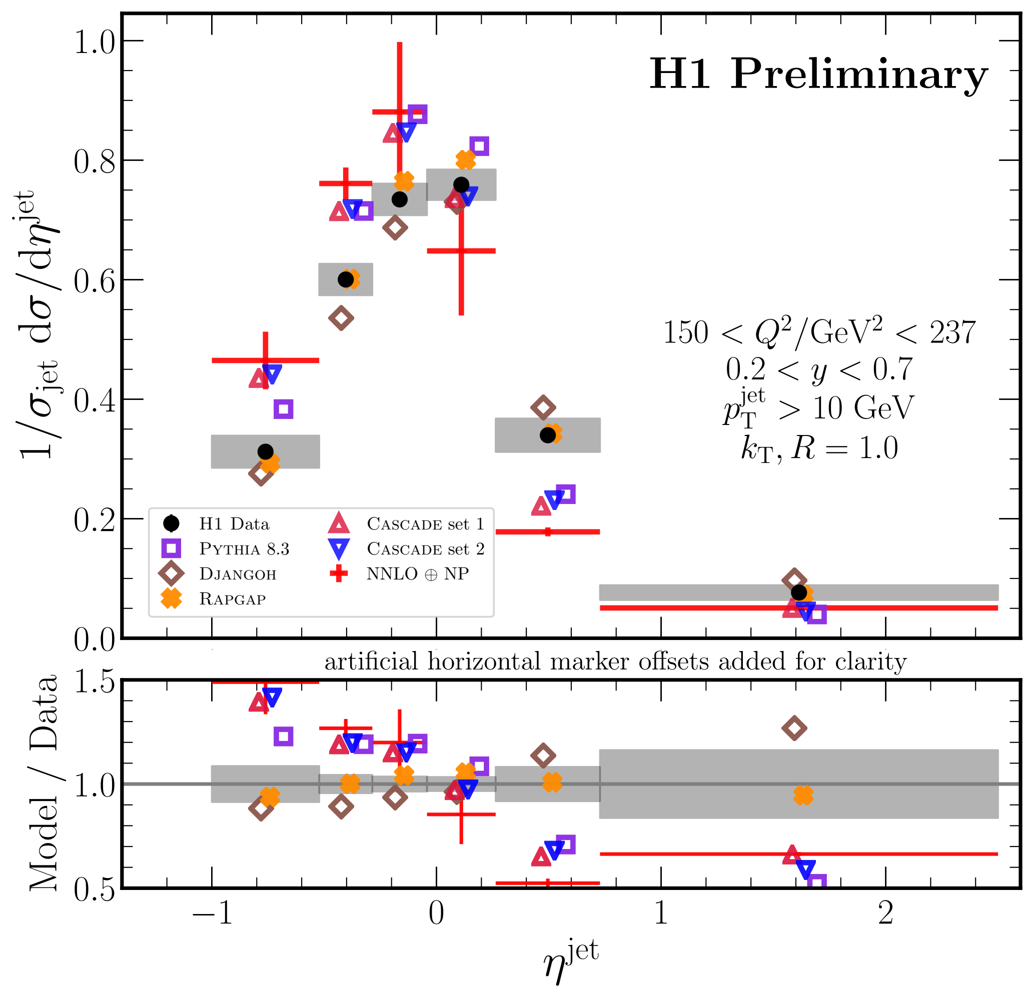
1911.09107; see other methods in 2109.13243

2108.12376

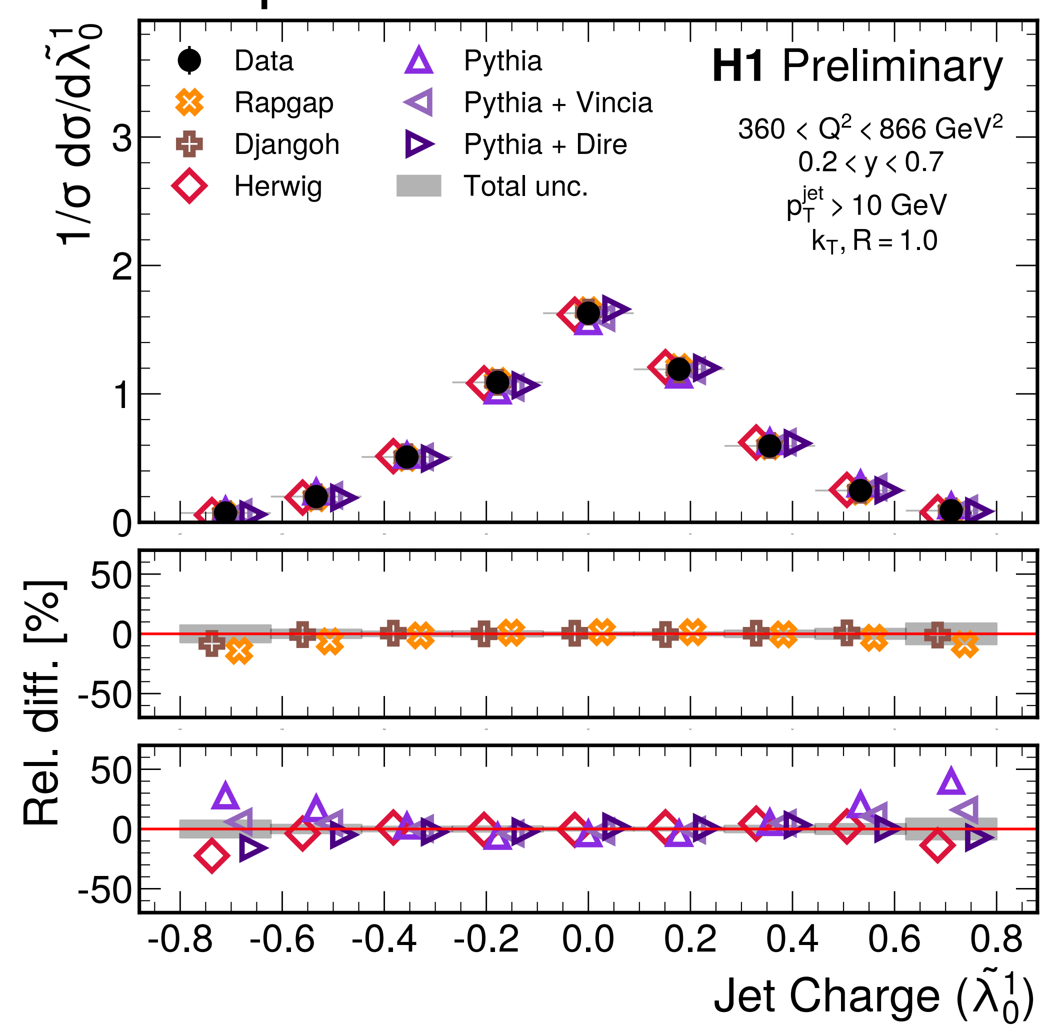
This is not a dream!



H1prelim-22-031

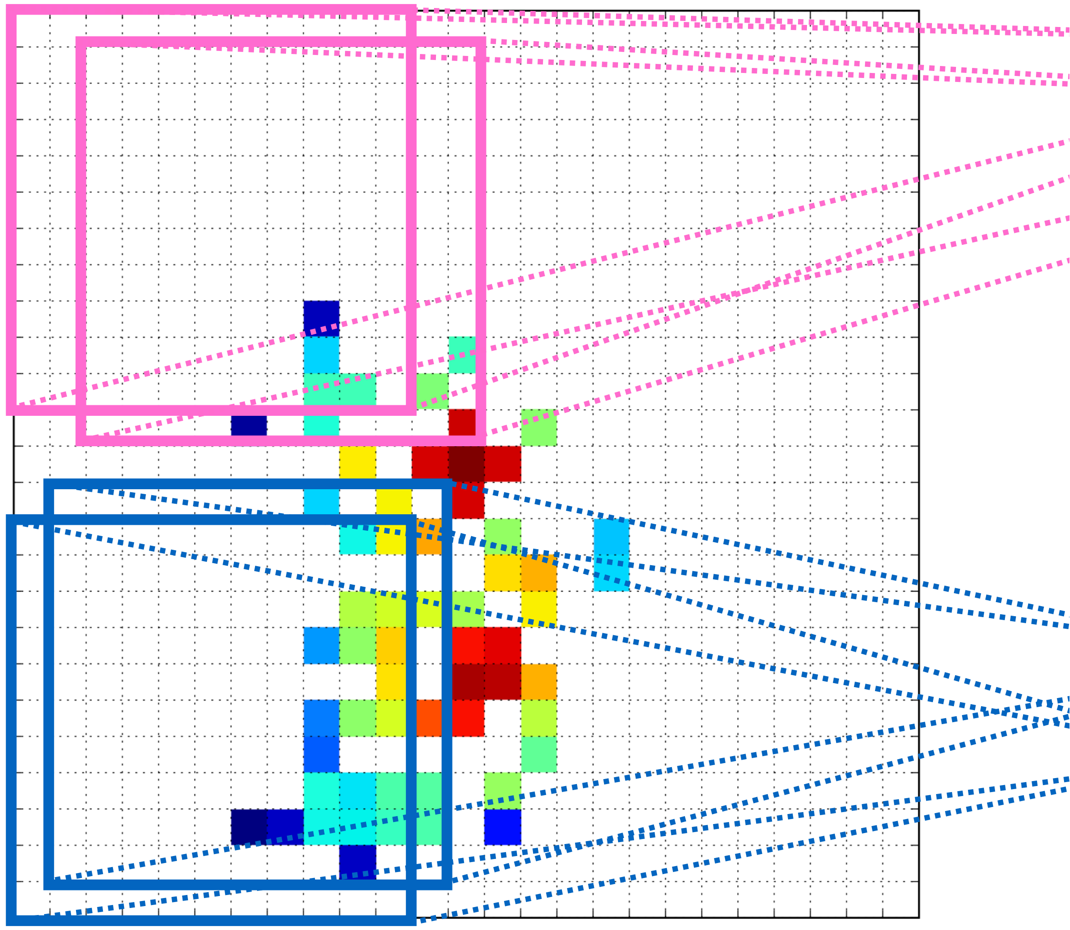


H1prelim-22-034

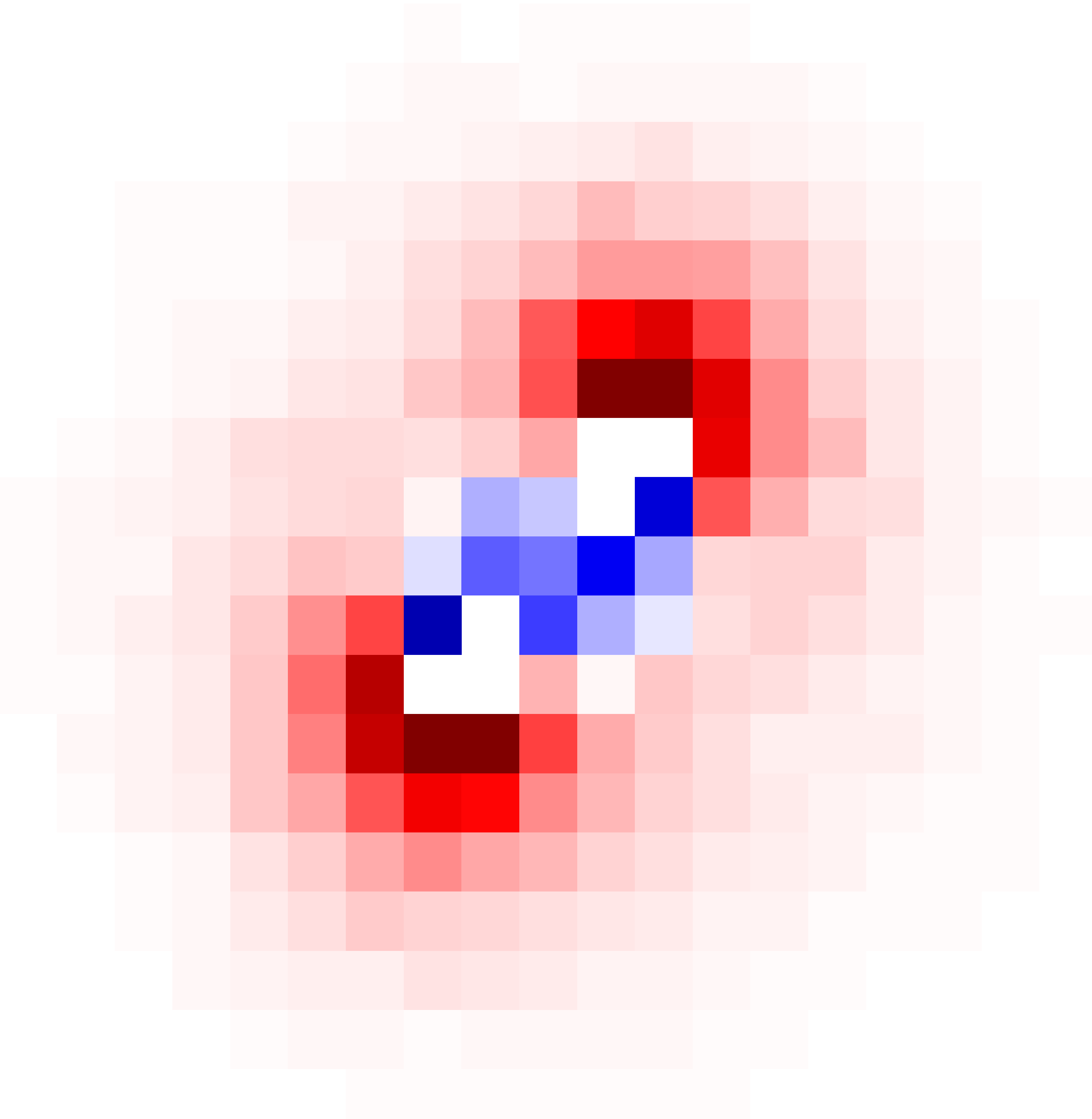


Conclusions and Outlook

AI/ML has a great potential to enhance reconstruction and analysis at a future *ep* collider



We can take advantage of developments from pp and already start exploring applications at HERA/EIC



Fin.