New results on probing limitations of collinear QCD in lepton-jet correlations

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Low-x 2021

September 27, 2021

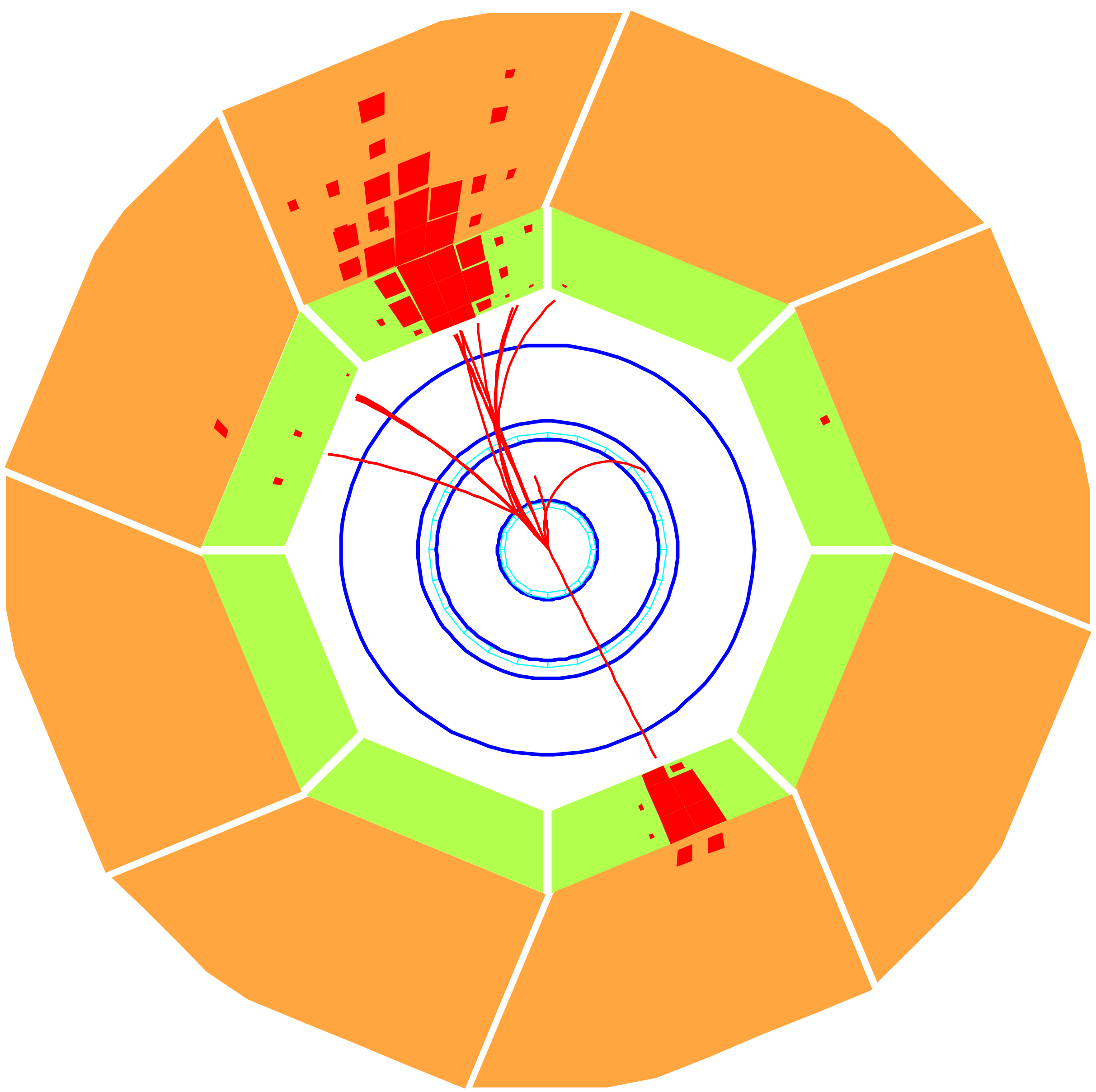
H1 and ZEUS @ HERA

Two multipurpose experiments at HERA.

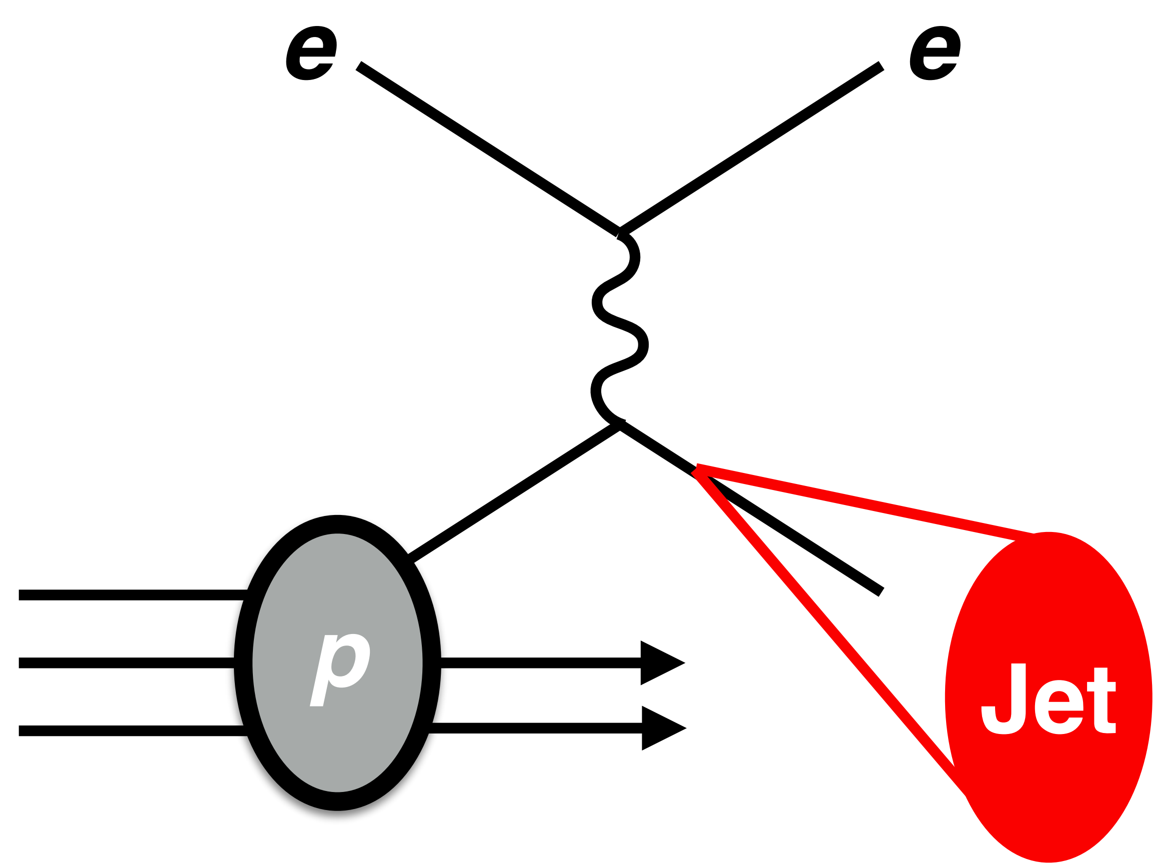
See also A. M. Cooper-Sakar's talk yesterday.

H1 and ZEUS @ HERA

For this talk: data from HERA II, O(100) pb^{-1}, ~320 GeV

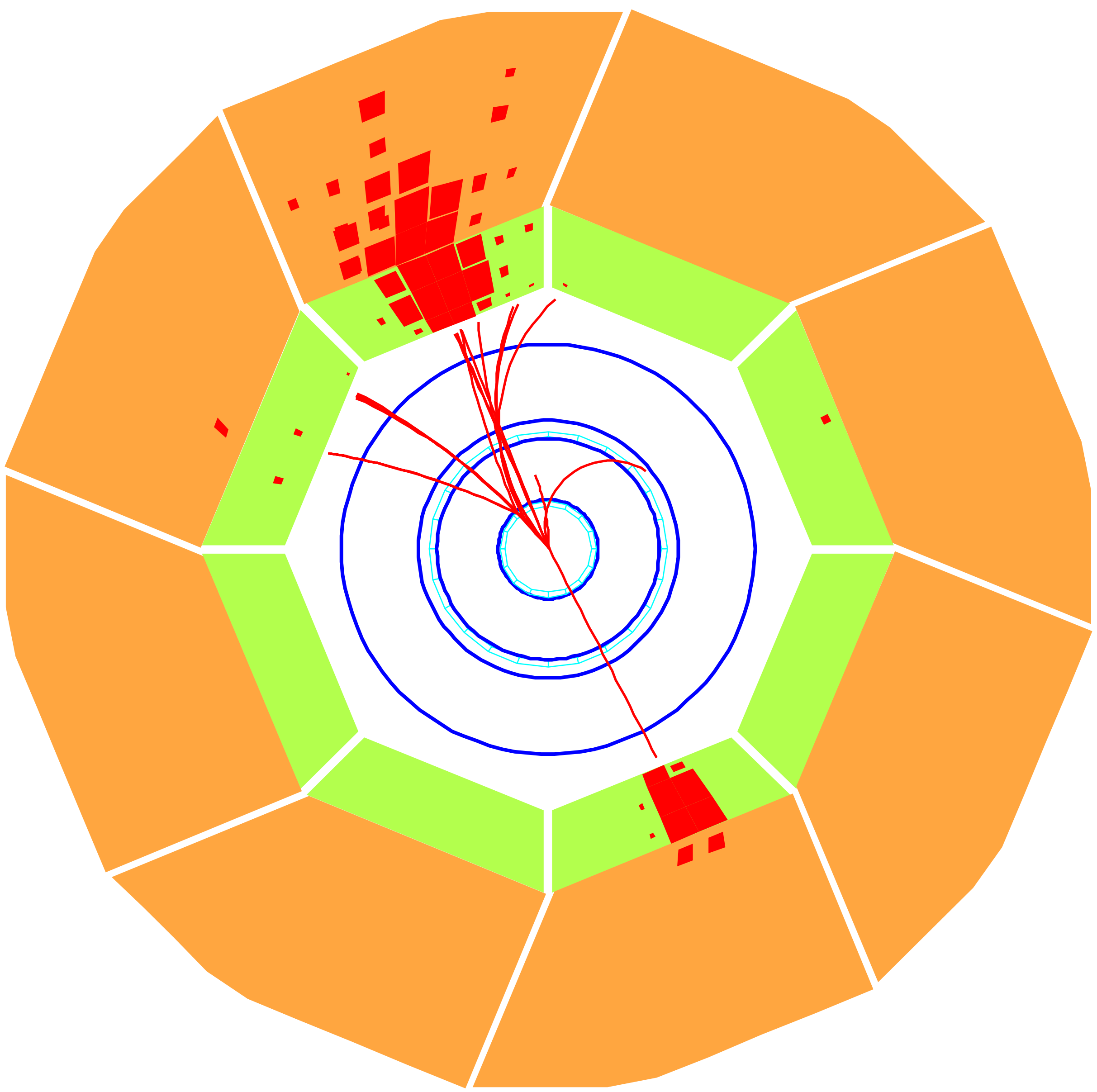


I'll present a measurement of the electron-jet inbalance



Why electron-jet imbalance?

Born-level configuration, electron and jet are back-to-back



Typically, jets are studied in the Breit frame, where the Born-level configuration is discarded

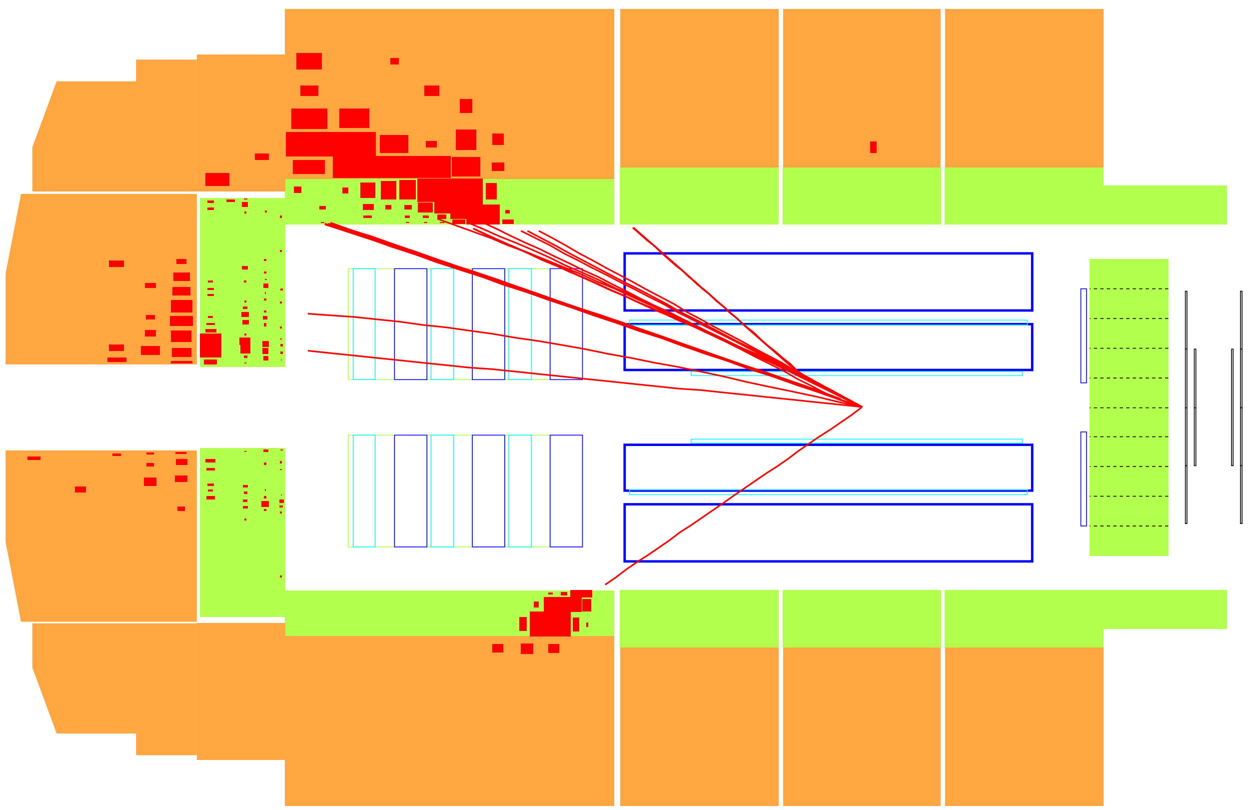
However, jet production in the lab frame can be useful for probing Transverse Momentum Dependent (TMD) Parton Distribution Functions (PDFs)

See e.g. Lieu et al. PRL (2019) 192003;
Gutierrez et al. PRL (2018) 162001

H1 measurement

5

Jets at H1

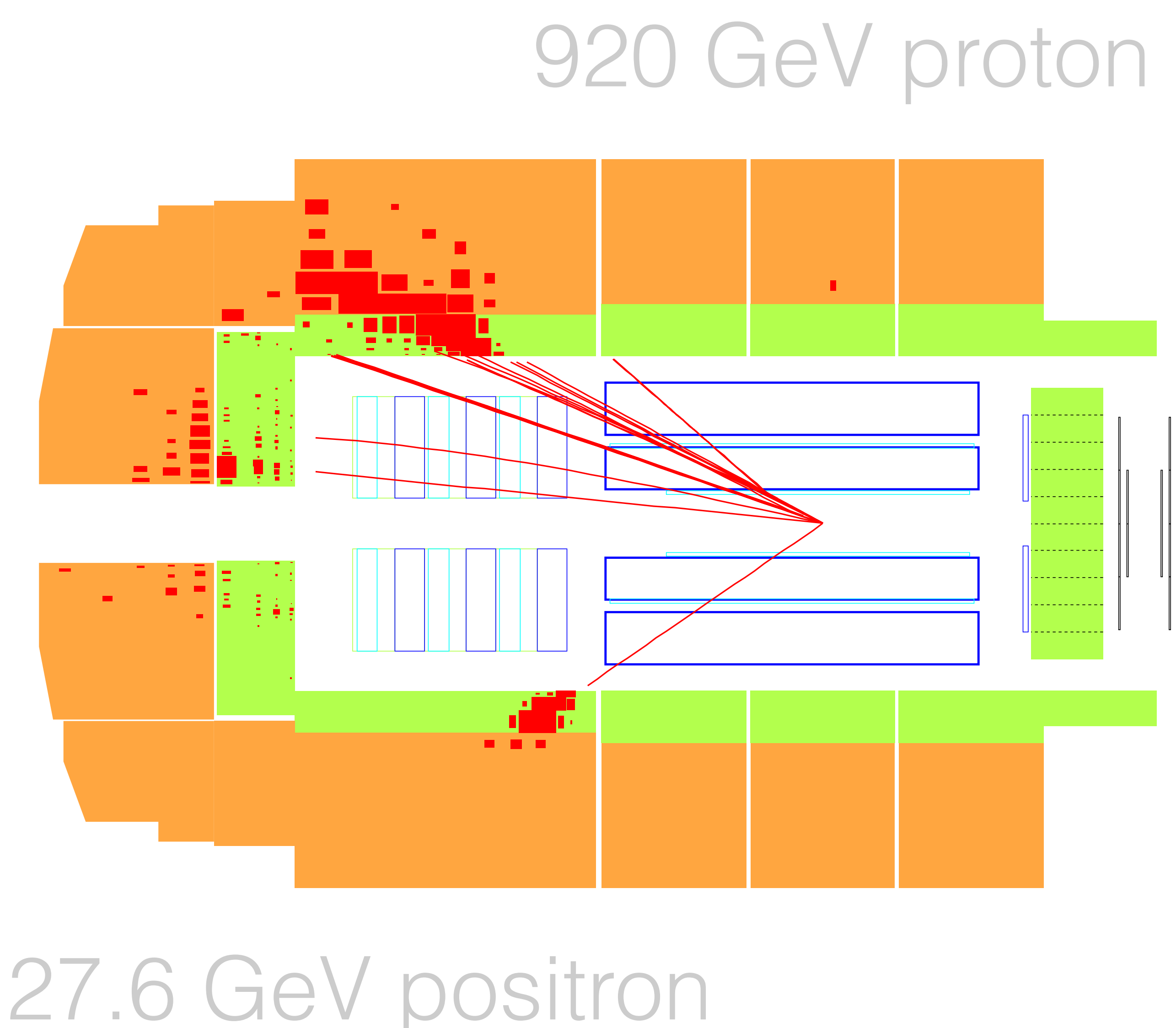


Energy flow algorithm (HFS) combines information from tracker and calorimeters

Neural network-based energy regression

1% jet energy scale uncertainty; 0.5-1% lepton energy scale uncertainty

Jets at H1



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Neural network-based energy regression

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Challenge: **unfold multidimensional phase space**

Jets at H1

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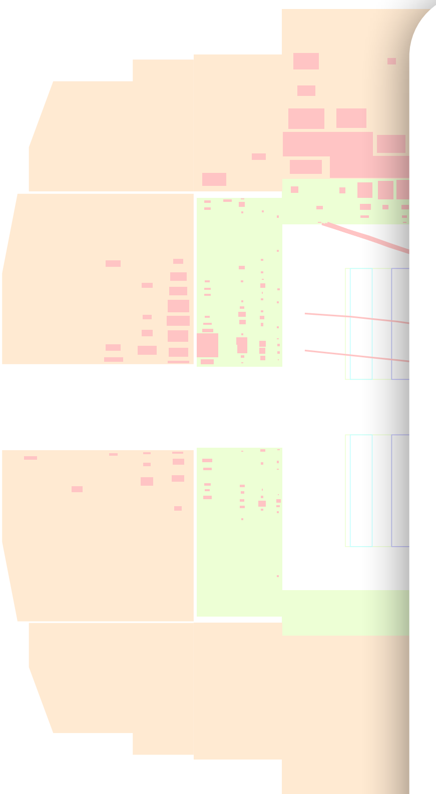
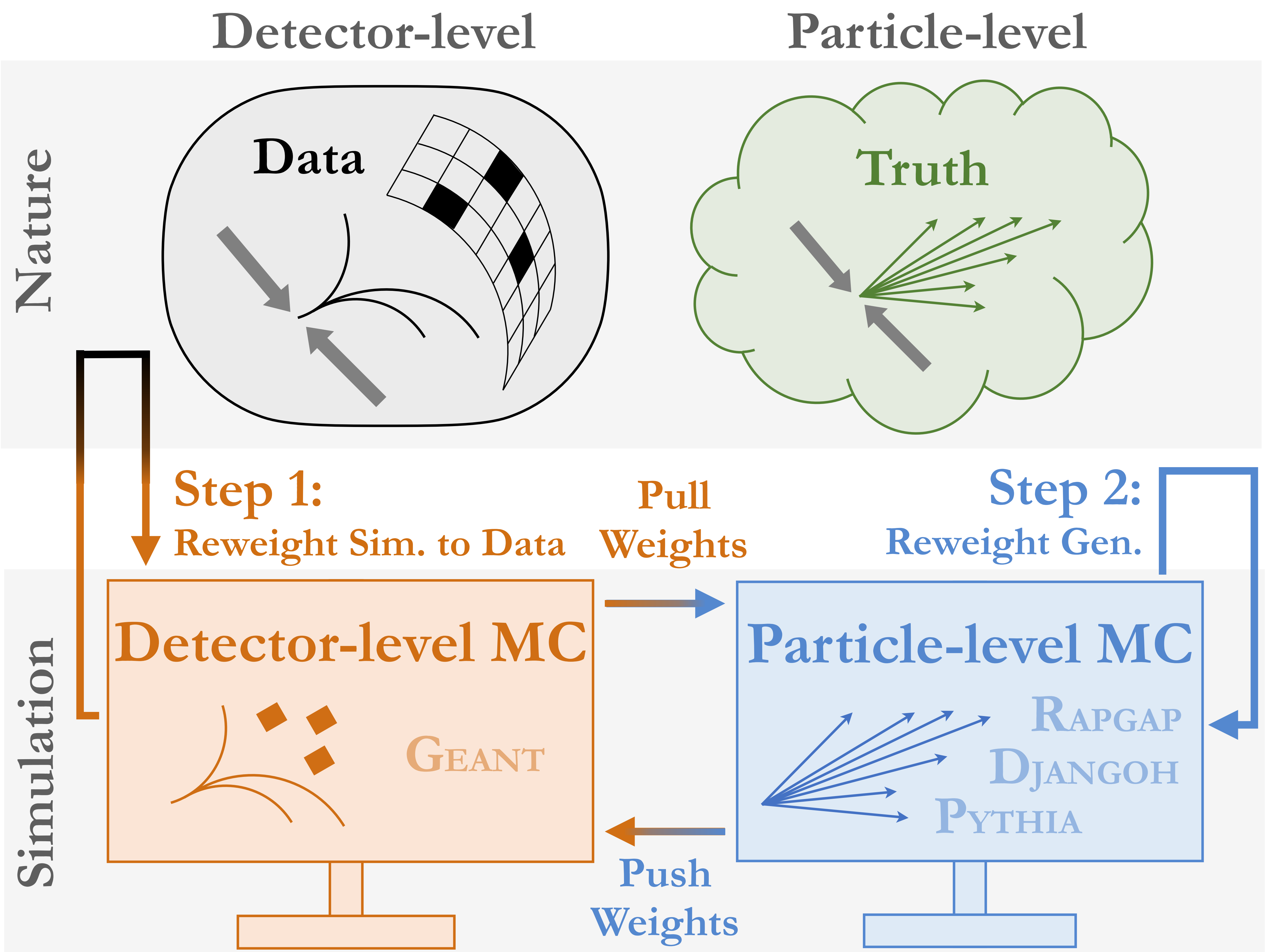


Solution: **use deep learning!**

…can do unbinned, high (and variable-)dimensional unfolding

Challenge: **unfold multidimensional phase space**

Unfold by iterating: OmniFold



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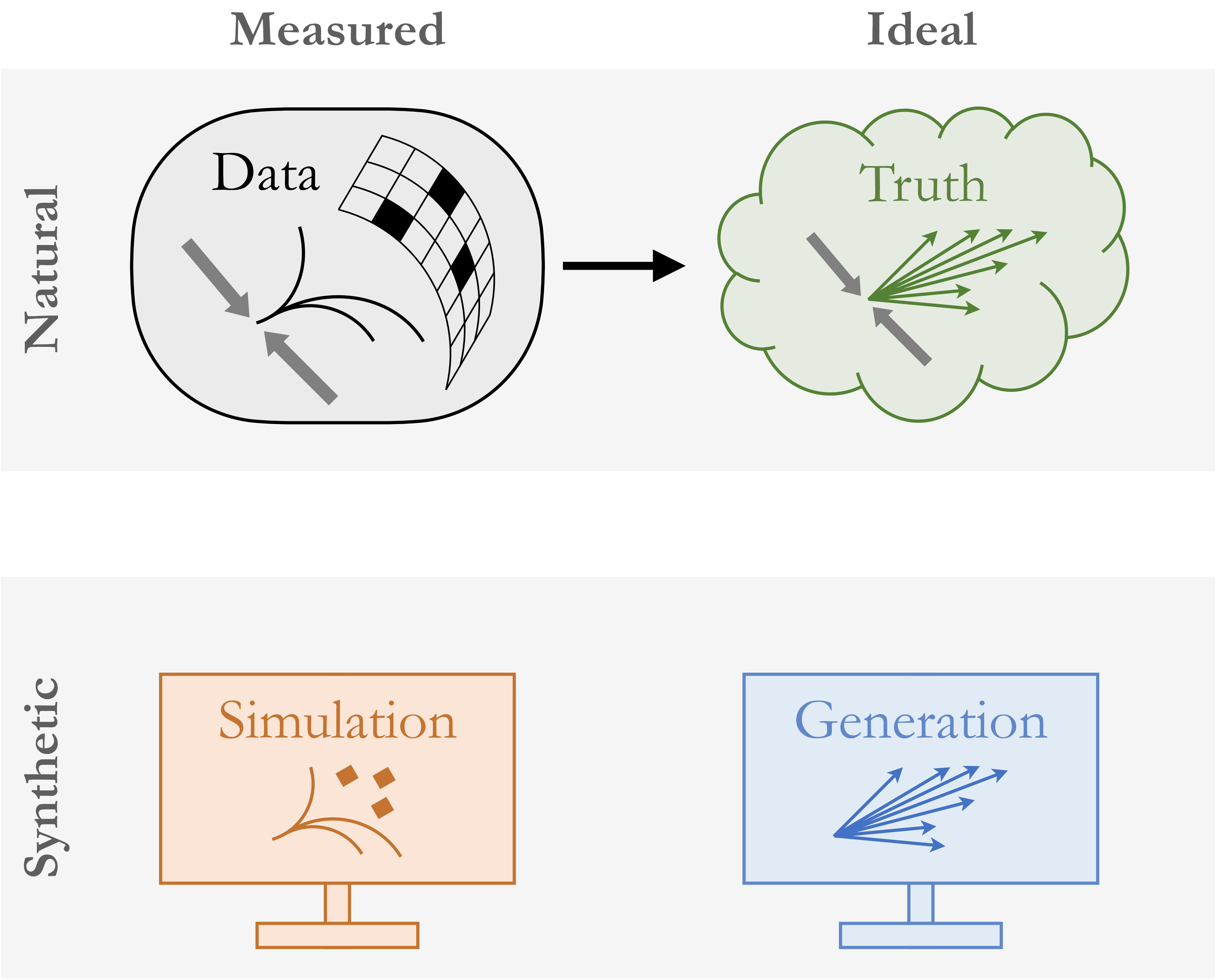

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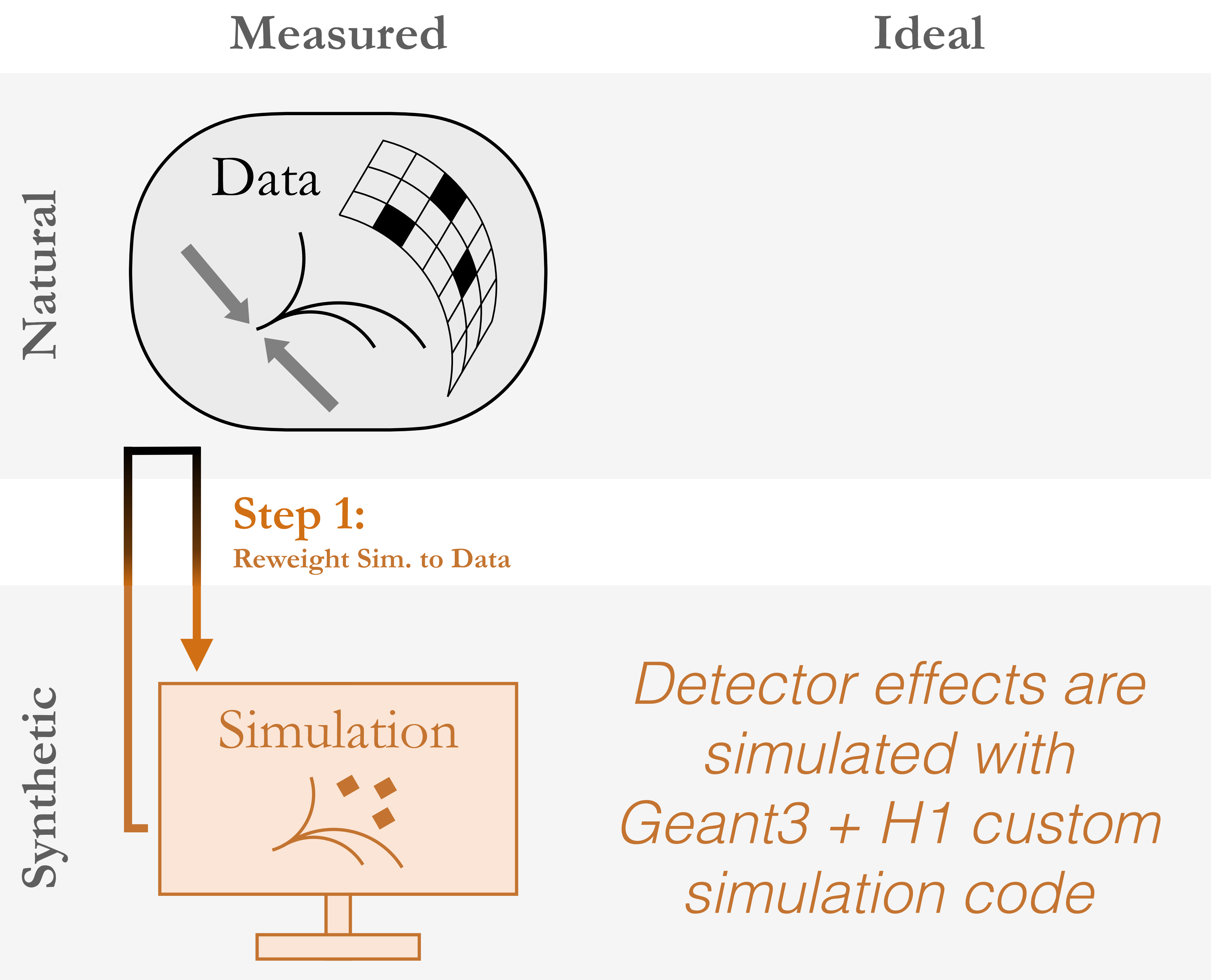

Detector effects are simulated with Geant3 + H1 custom simulation code

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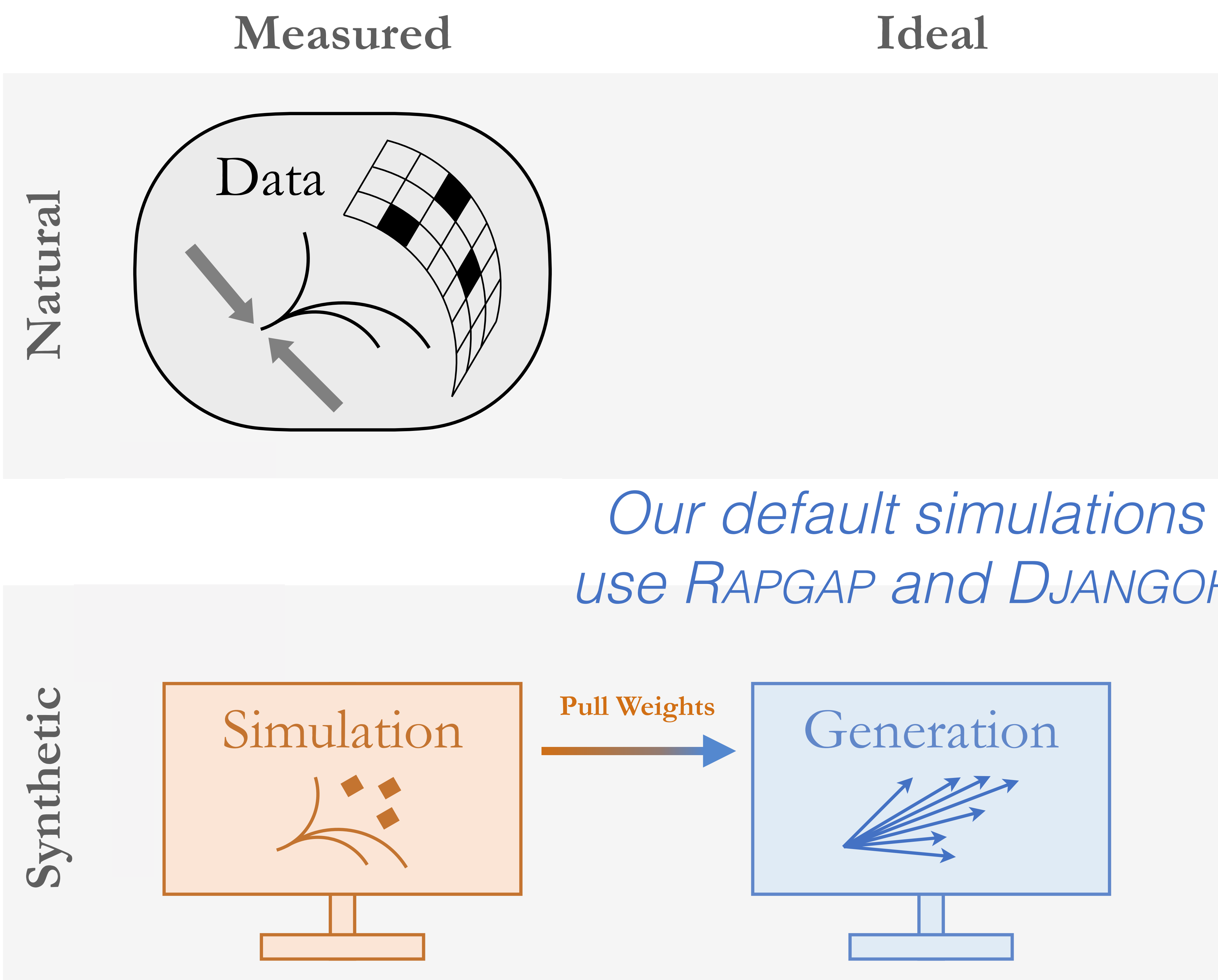

Our default simulations use RAPGAP and DJANGOH

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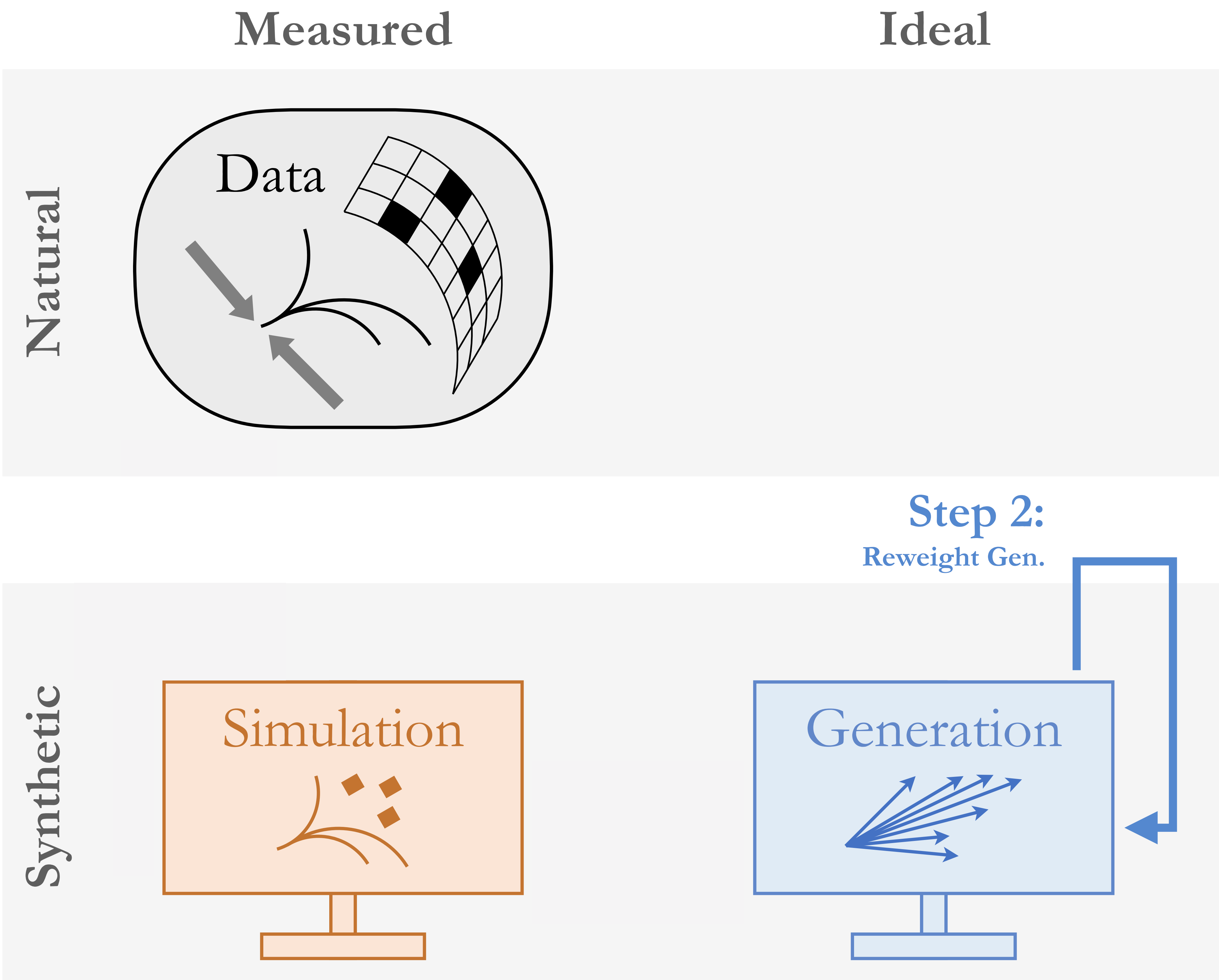

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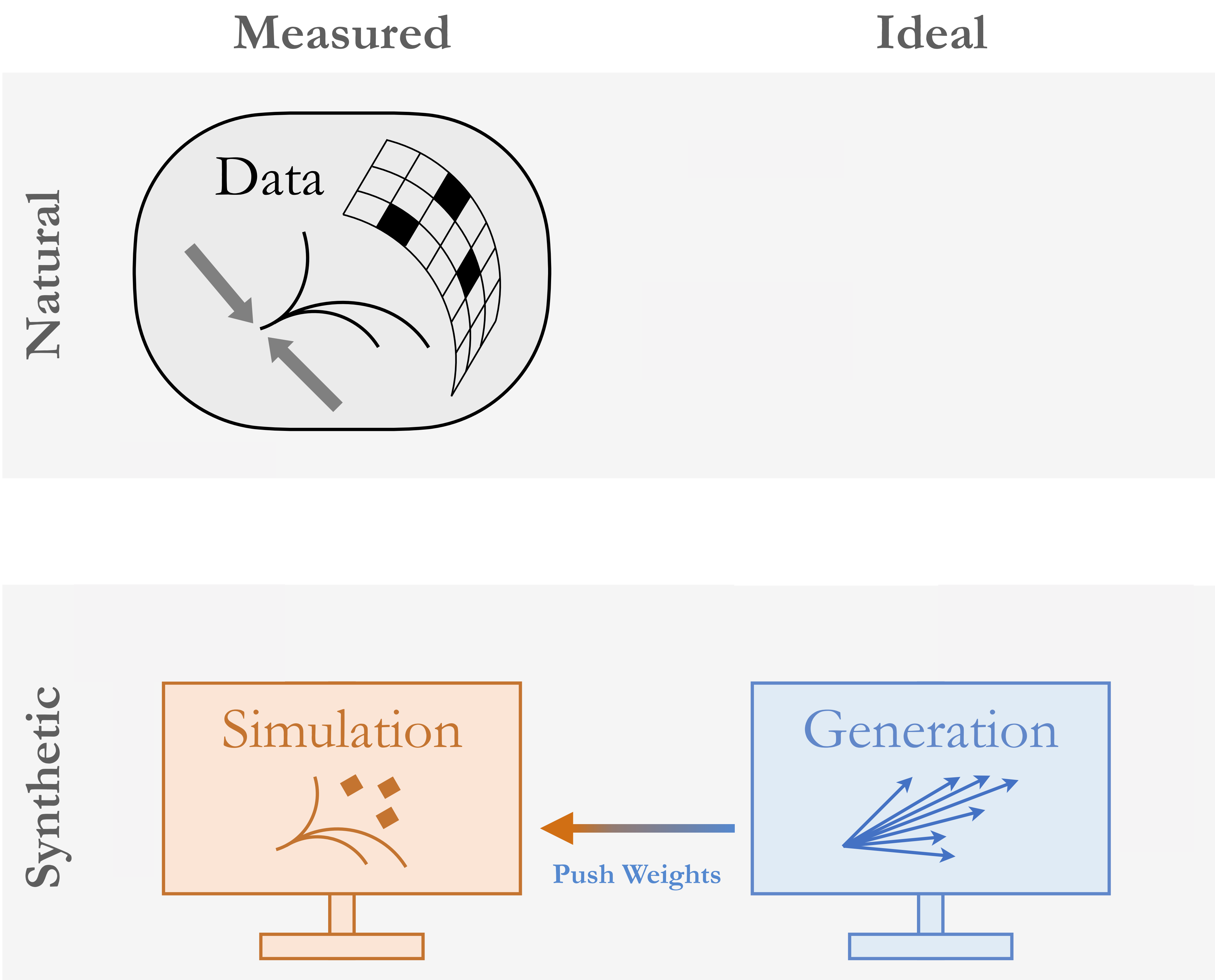

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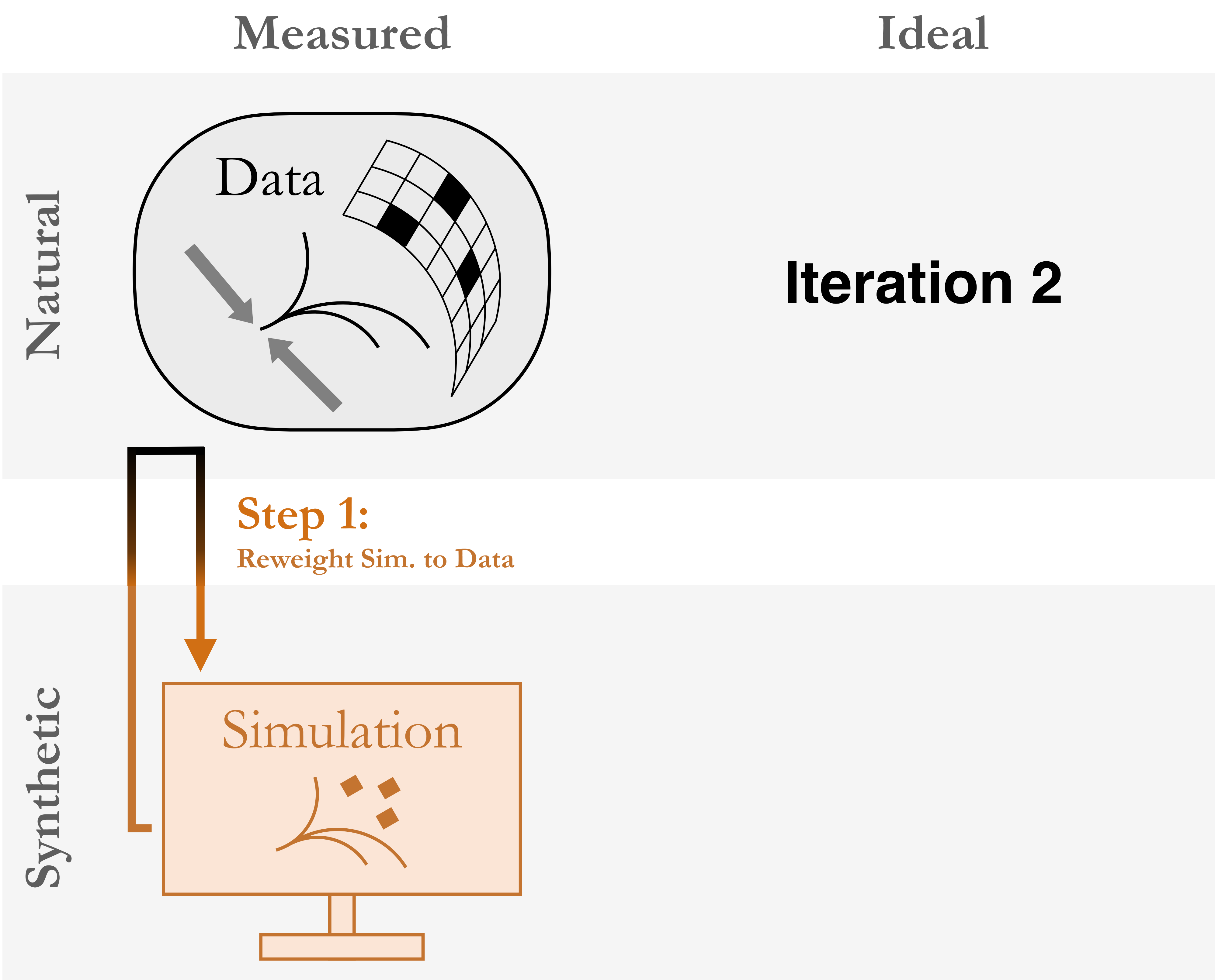

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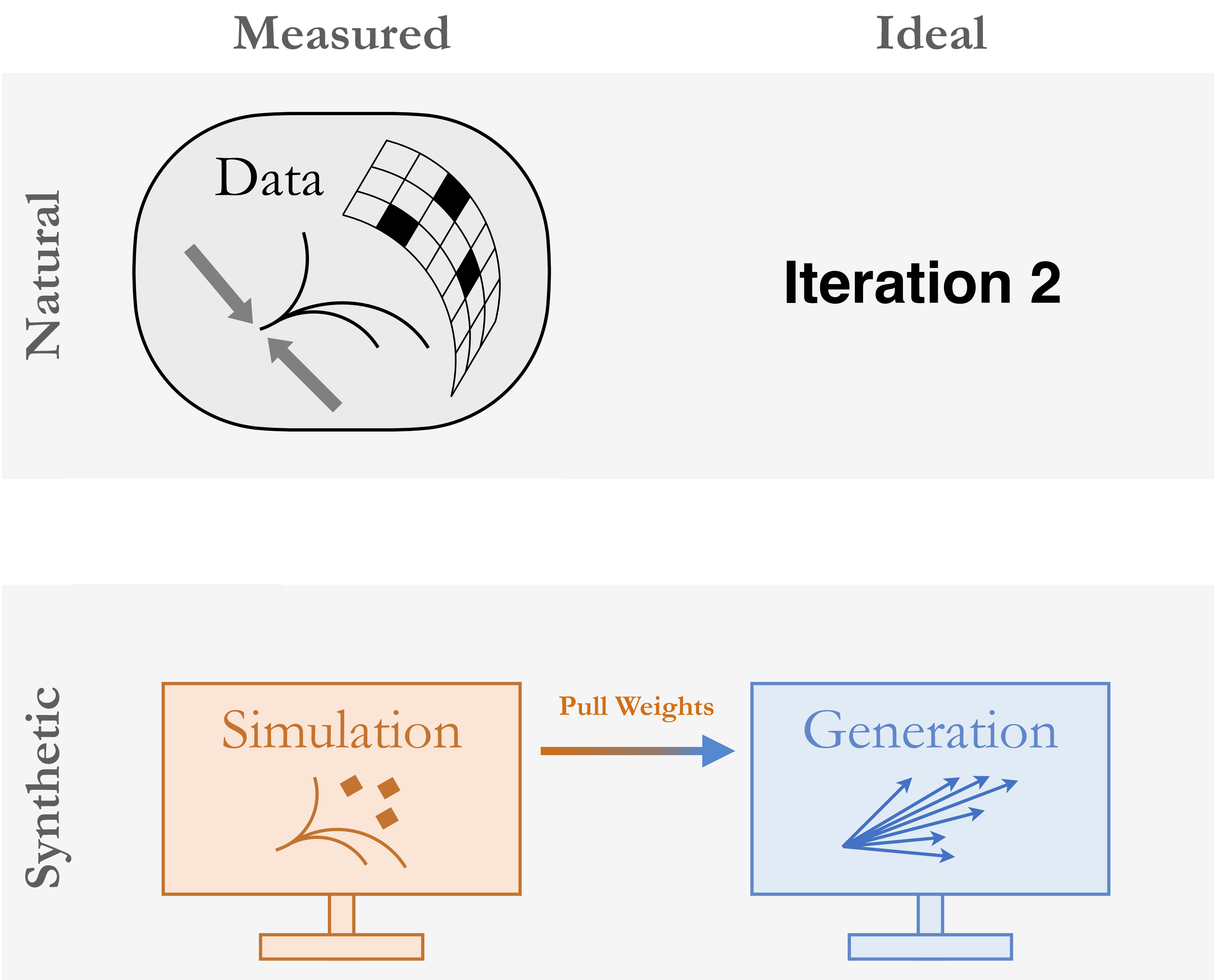

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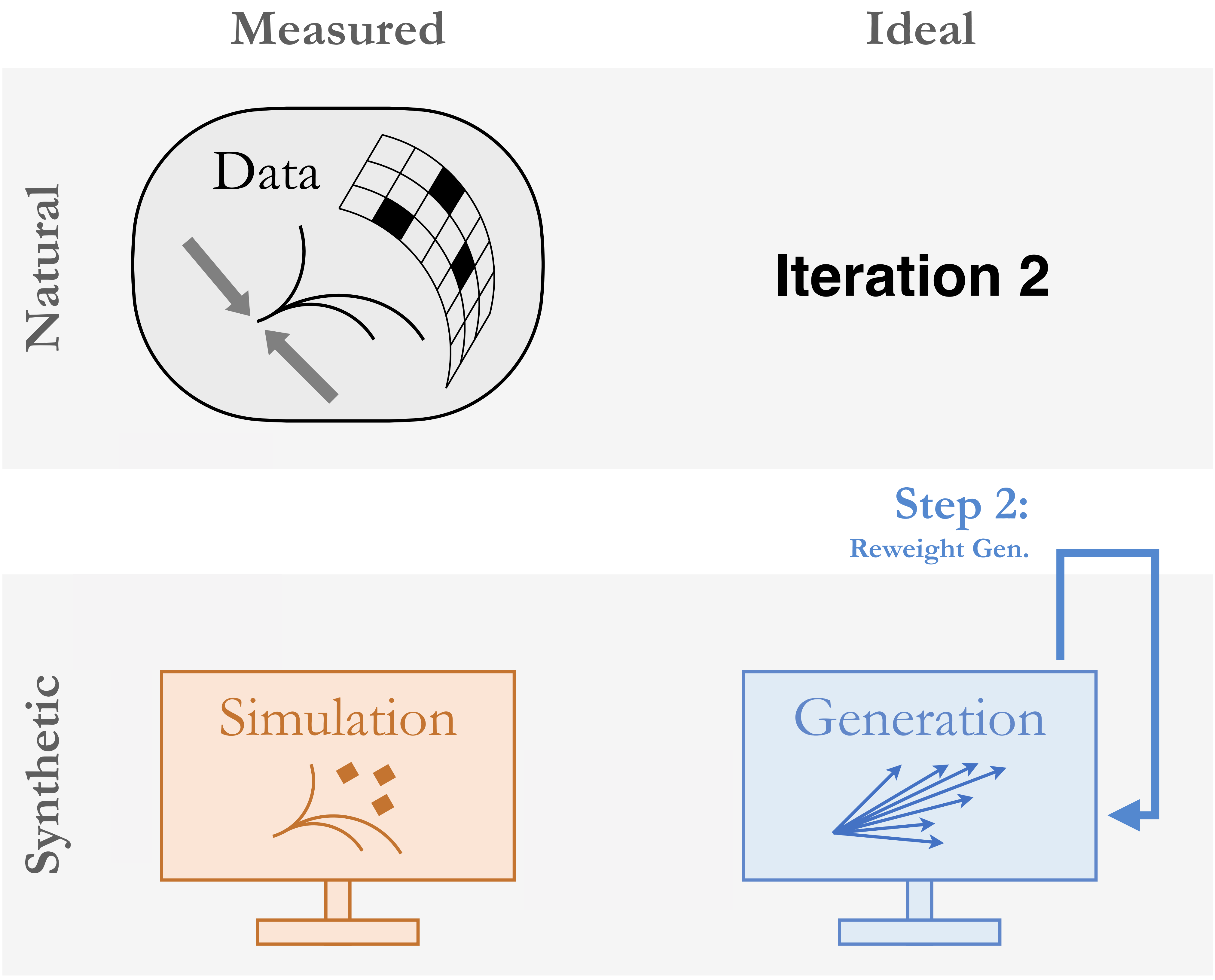

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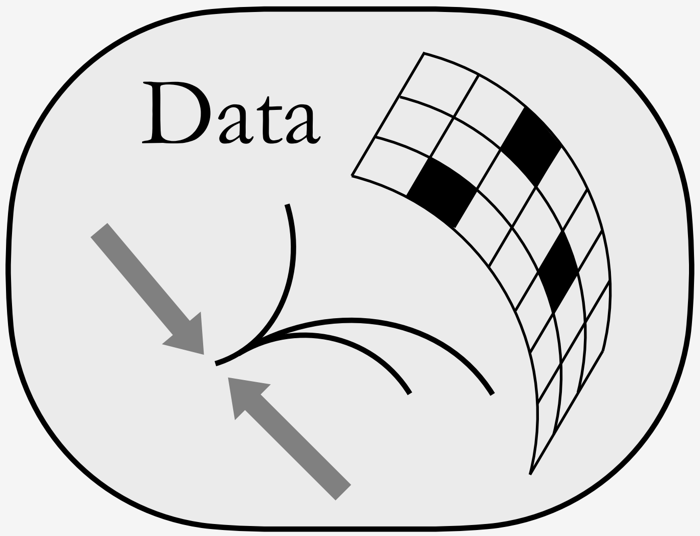
Unfold by iterating: OmniFold

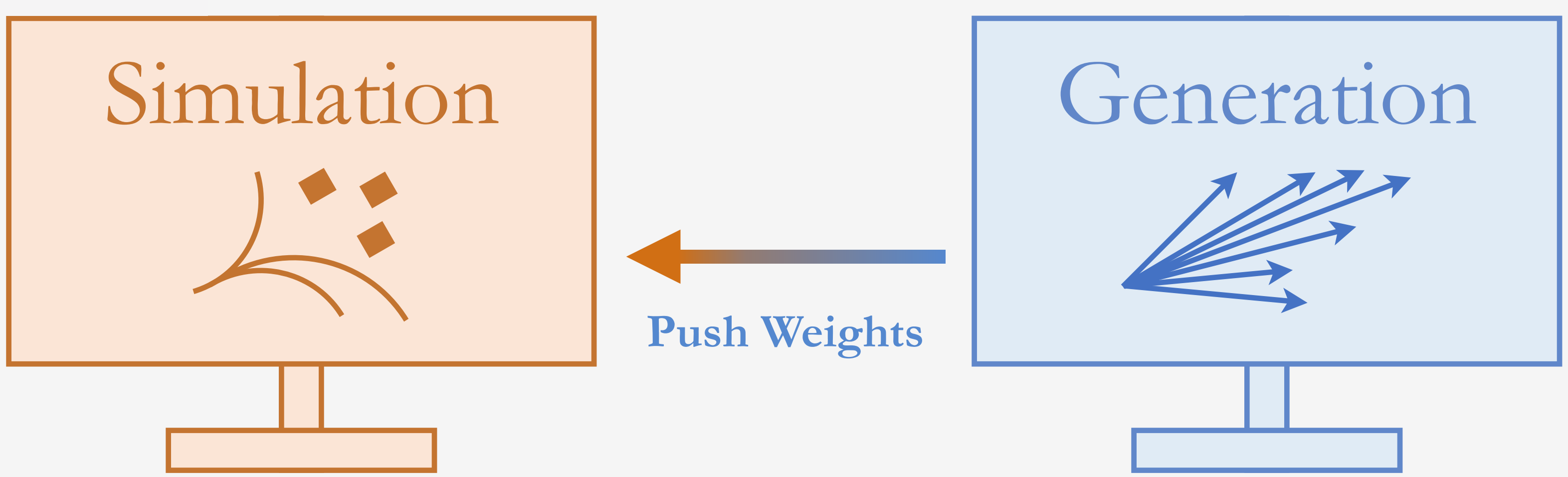
Measured | Ideal

Natural



Iteration 2

Synthetic



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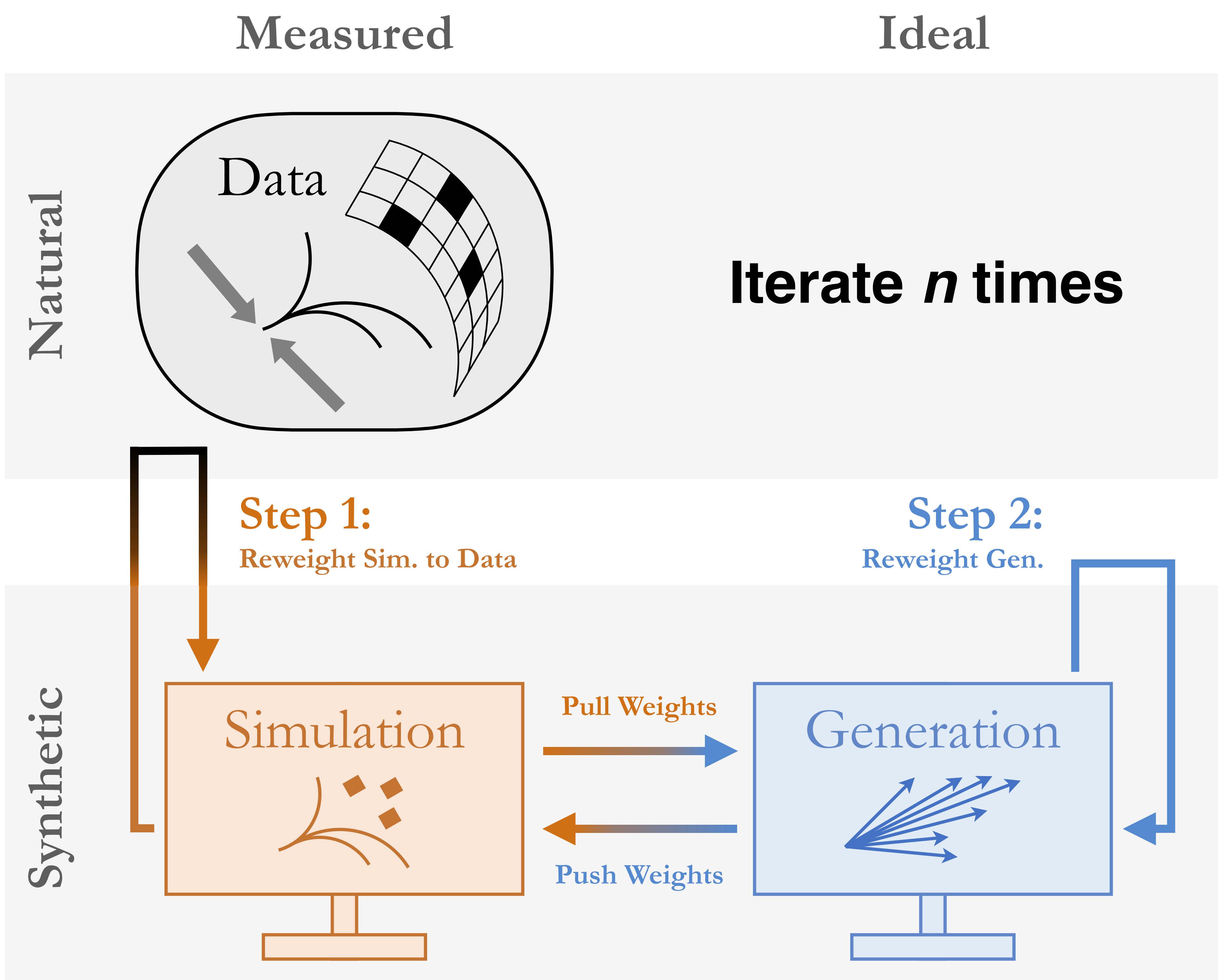

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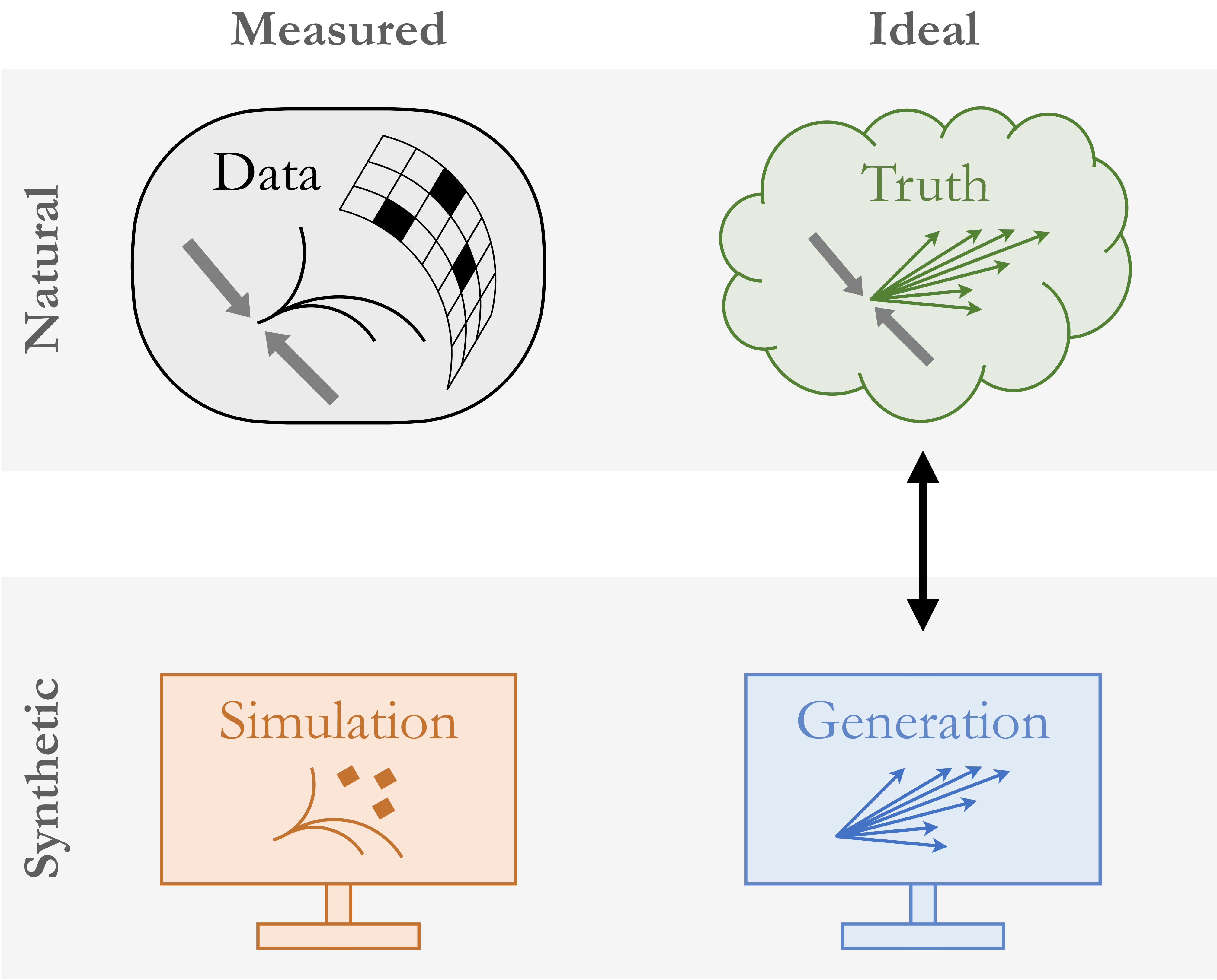

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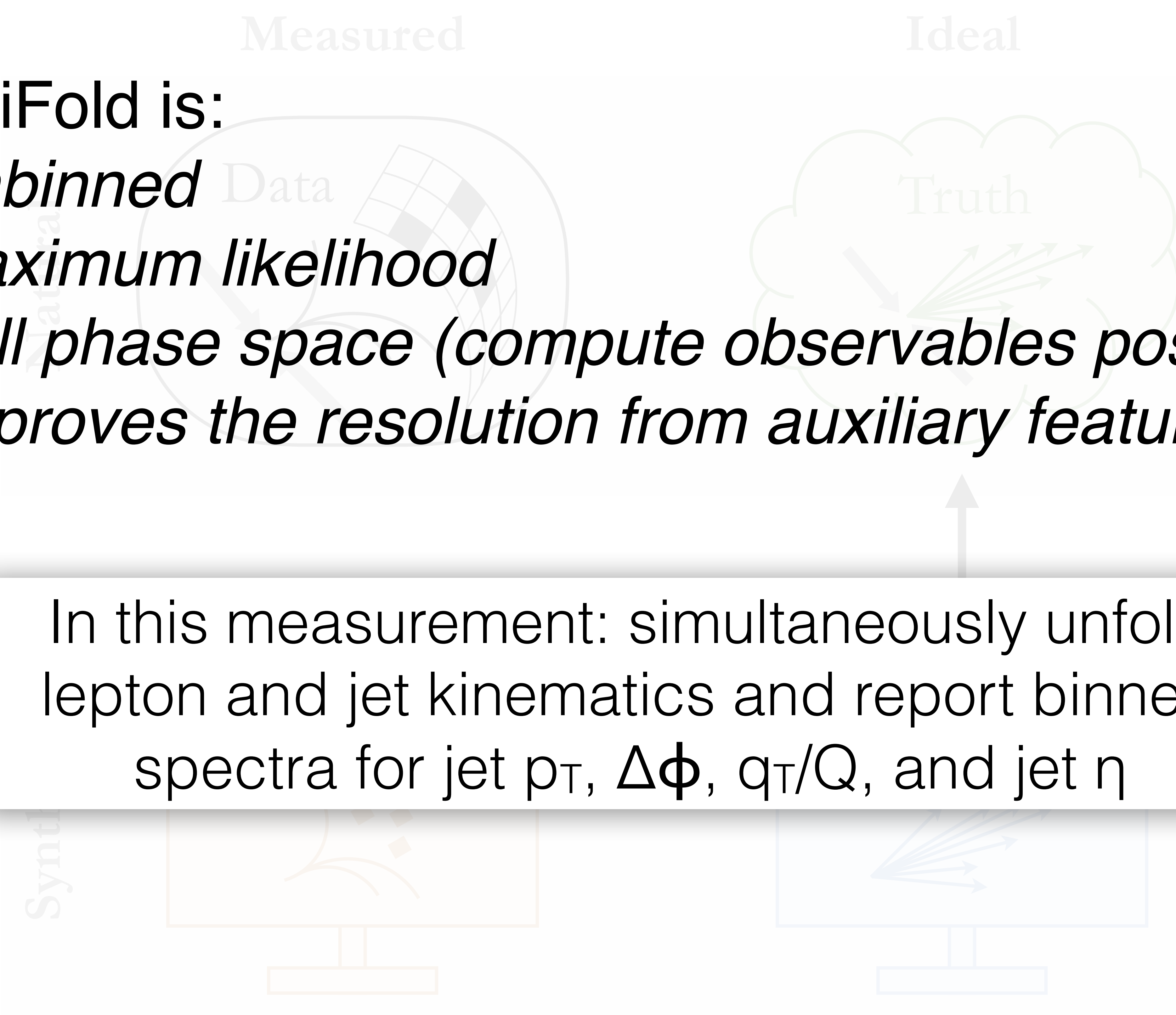
Unfold by iterating: OmniFold

OmniFold is:

- *Unbinned*
- *Maximum likelihood*
- *Full phase space (compute observables post-facto)*
- *Improves the resolution from auxiliary features*

Unfold by iterating: OmniFold



OmniFold is:
- *Unbinned*
- *Maximum likelihood*
- *Full phase space (compute observables post-facto)*
- *Improves the resolution from auxiliary features*

In this measurement: simultaneously unfold lepton and jet kinematics and report binned spectra for jet p_T, $\Delta\phi$, q_T/Q, and jet η

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Classification for reweighting

Neural networks are naturally unbinned and readily process high-dimensional data.

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$$\frac{p_1(x)}{p_0(x)} \approx \frac{\mathrm{NN}(x)}{1 - \mathrm{NN}(x)}$$

Classifier (NN) trained to distinguish data sampled from p_1 versus p_0.

Classification for reweighting

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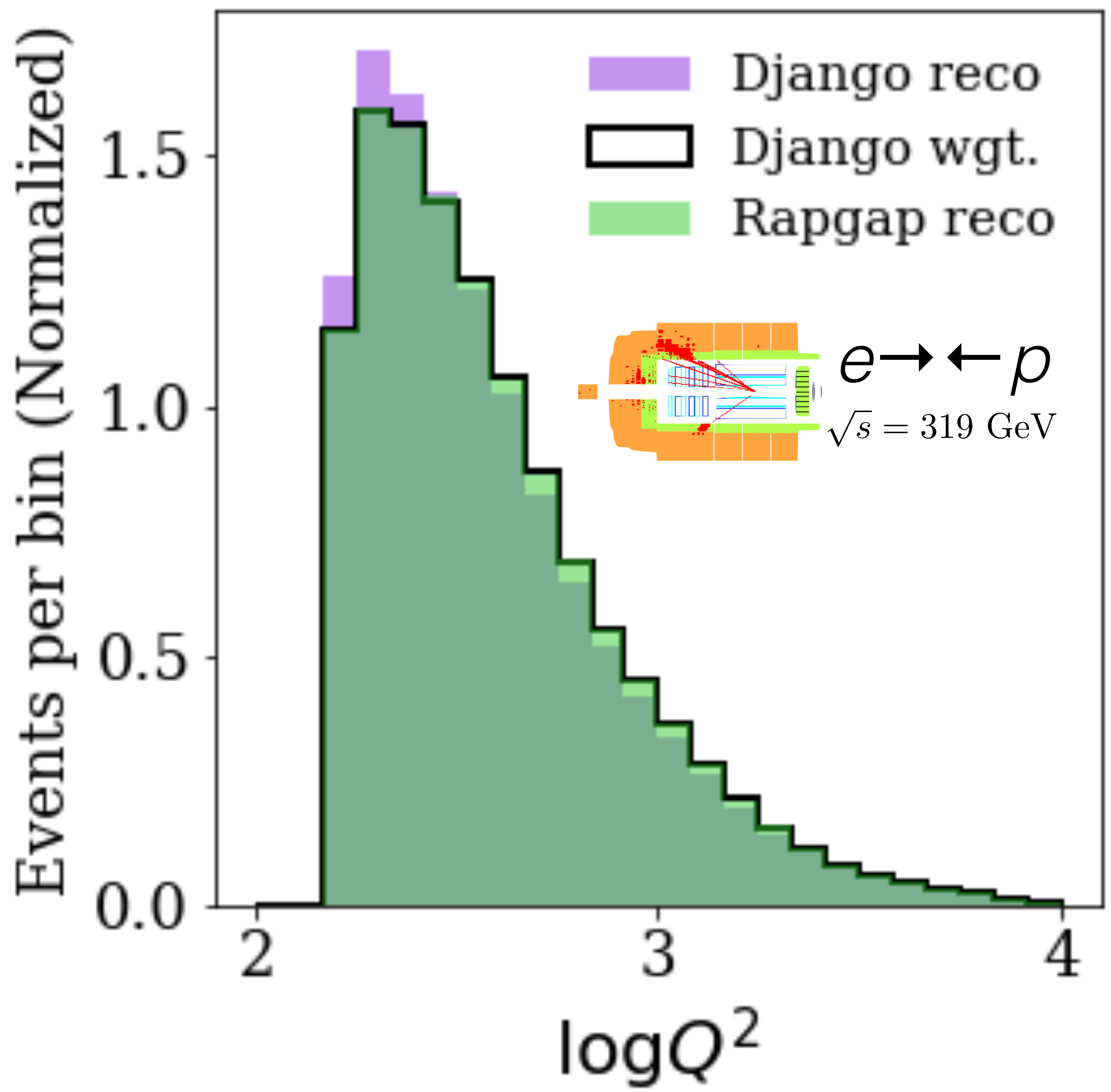
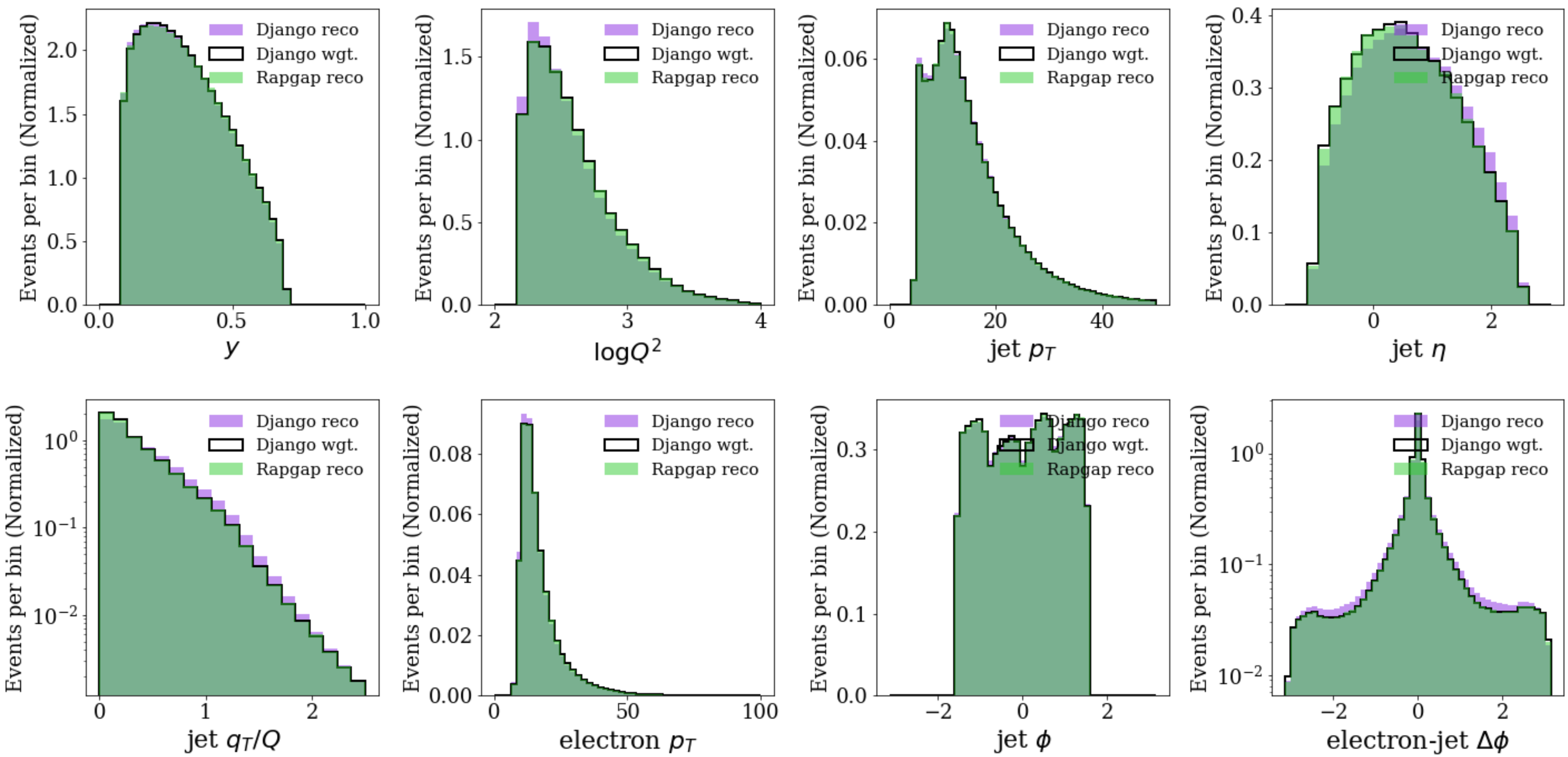
We use a trick whereby classifiers can be repurposed as reweighters

N.B. the distribution is binned for illustration, but the reweighting is unbinned.

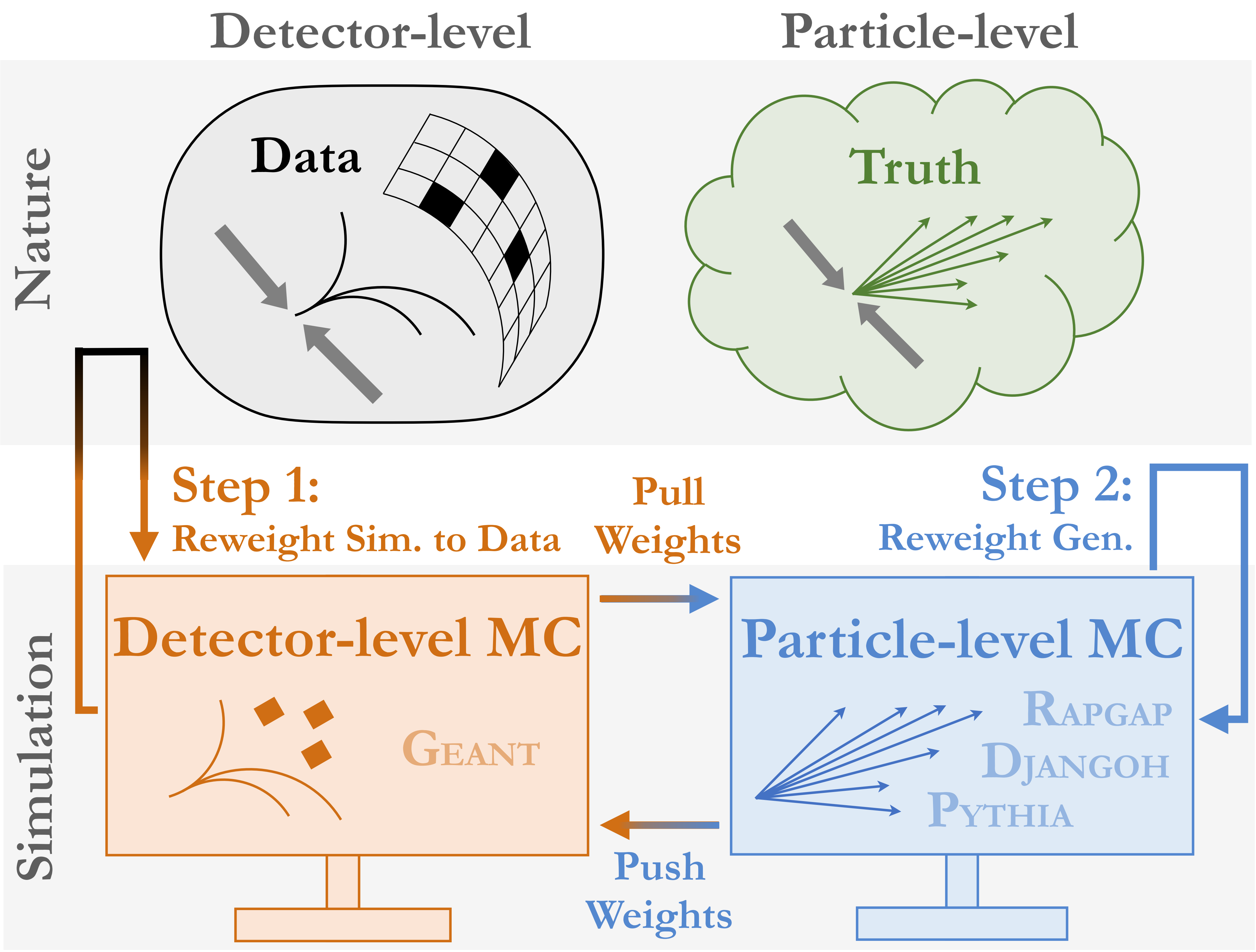


Classification for reweighting

All of these distributions are simultaneously reweighted!

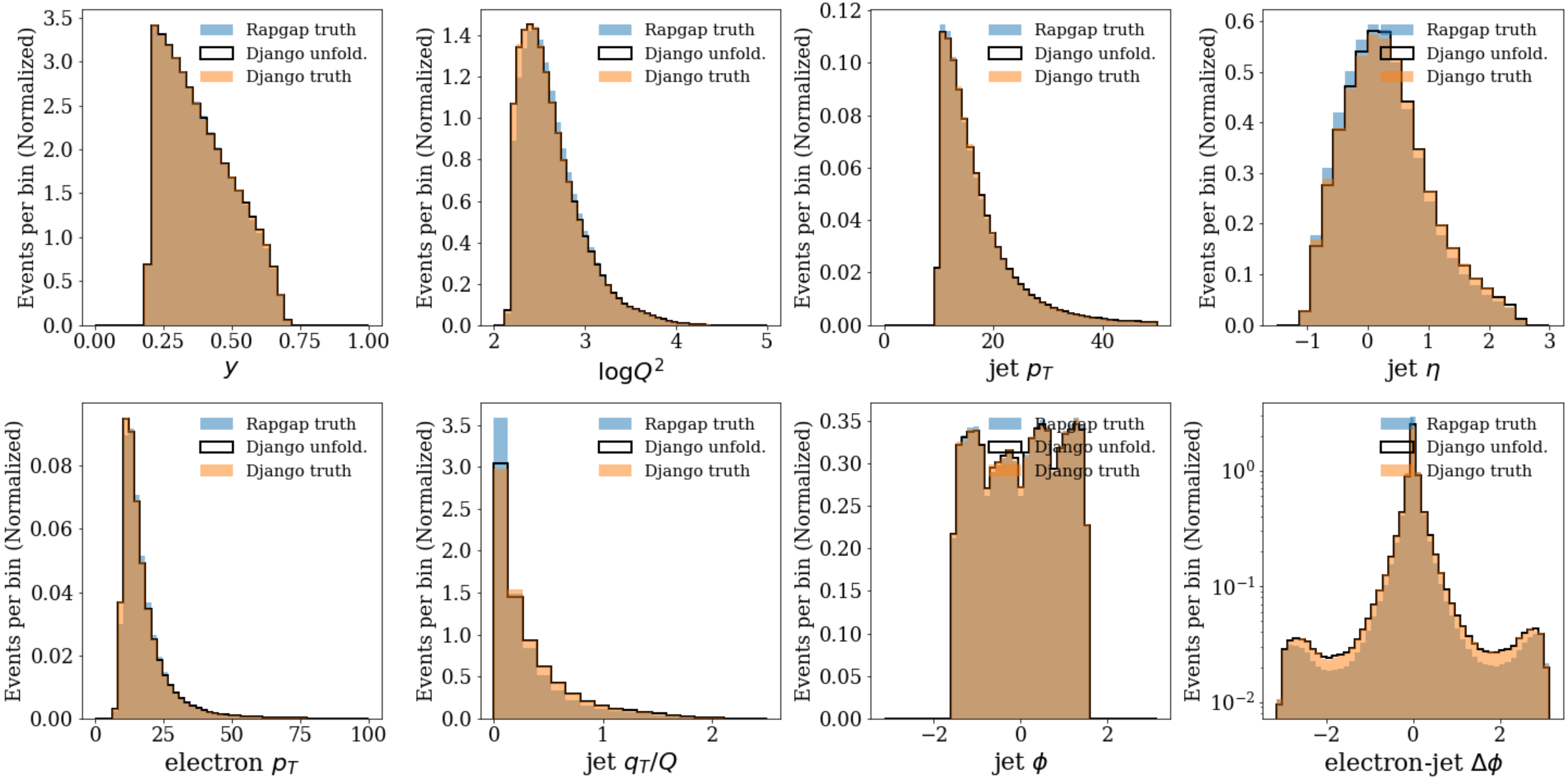


Unfold by iterating: OmniFold



OmniFolding *ep* simulations

We see excellent closure for the full phase space!



Results

2108.12376

DESY 21-130, ISSN 0418-9833

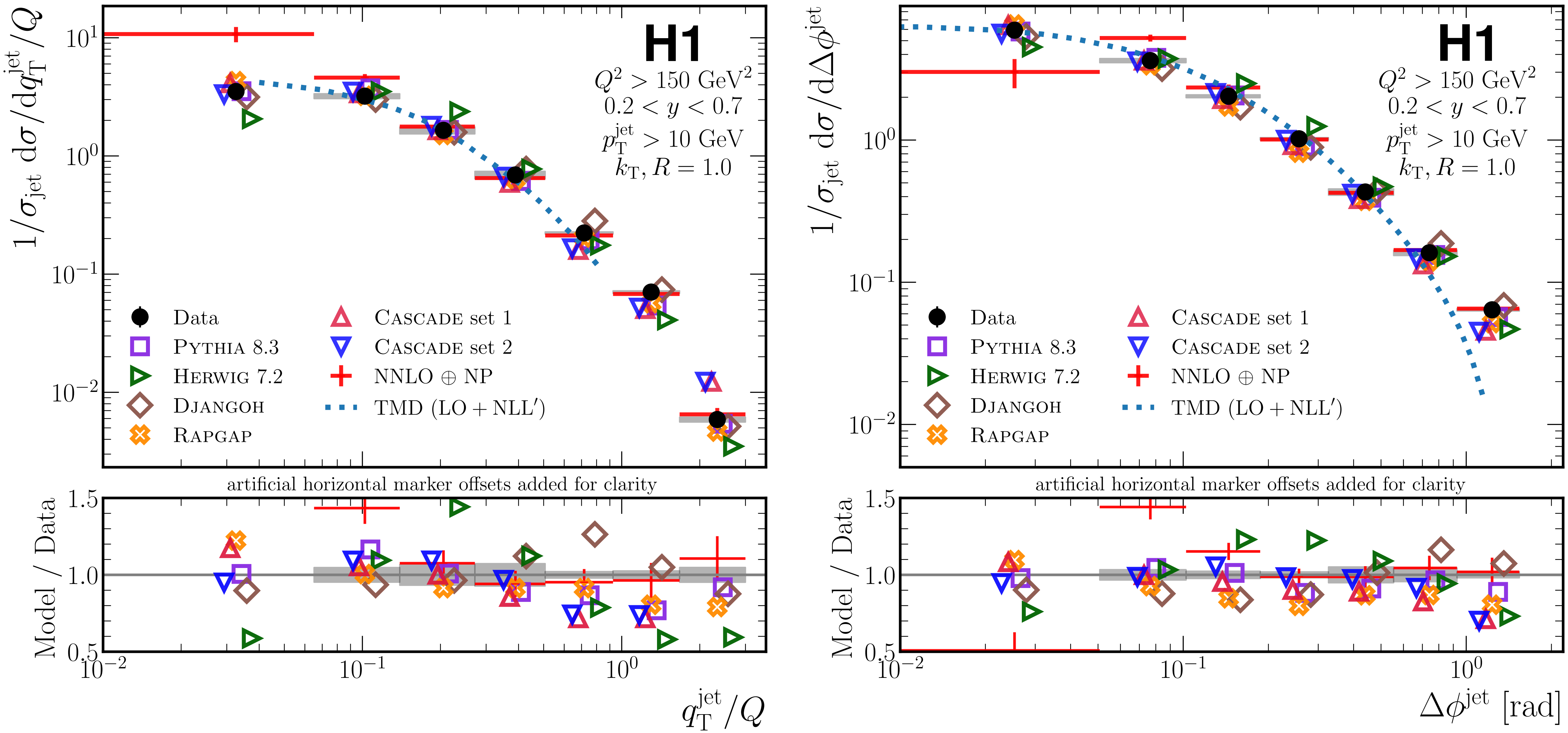
Measurement of lepton-jet correlation in deep-inelastic scattering with the H1 detector using machine learning for unfolding

H1 Collaboration*

(To be submitted to Physical Review Letters)
(Dated: August 30, 2021)

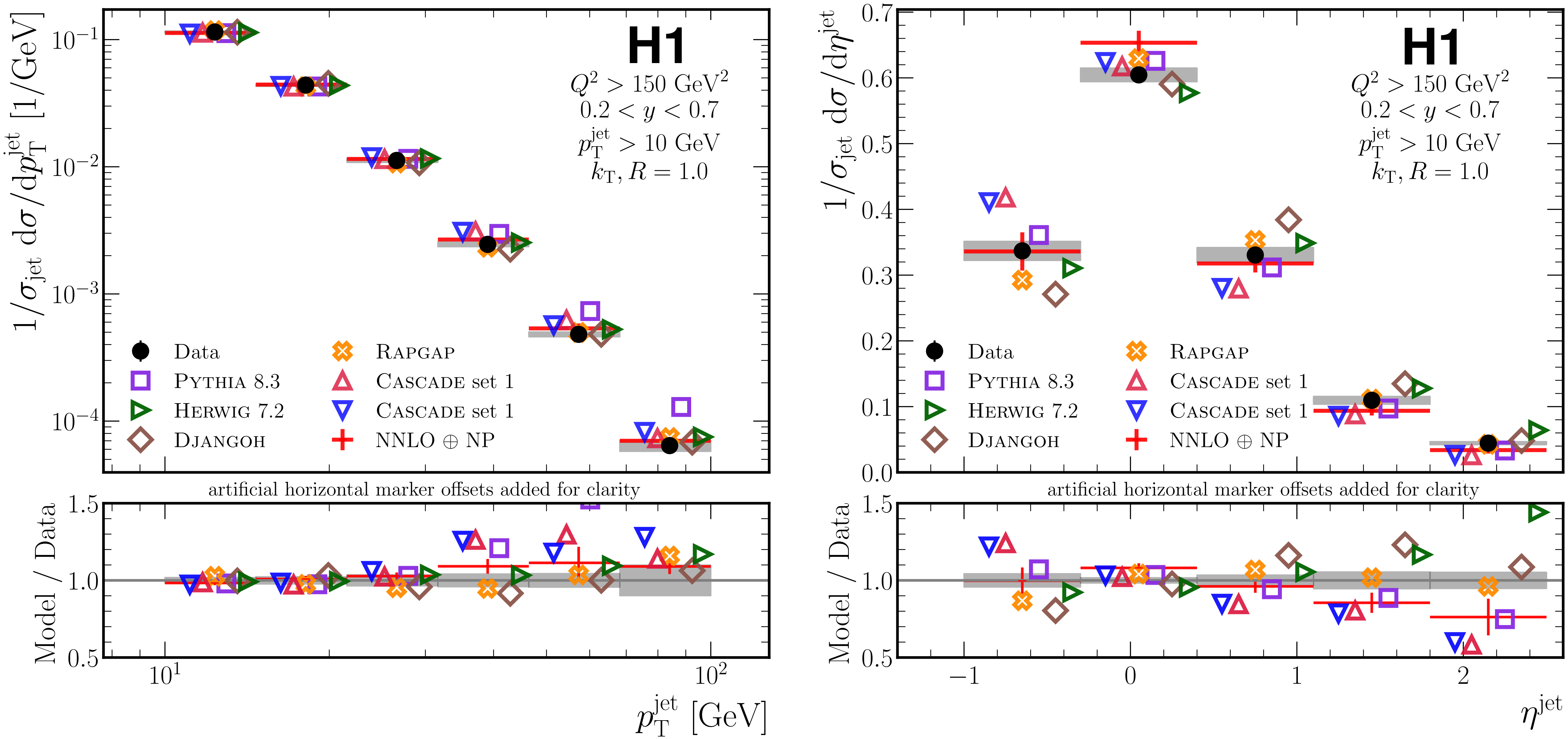
The first measurement of lepton-jet momentum imbalance and azimuthal correlation in lepton-proton scattering at high momentum transfer is presented. These data, taken with the H1 detector at HERA, are corrected for detector effects using an unbinned machine learning algorithm (OmniFold), which considers eight observables simultaneously in this first application. The unfolded cross sections are compared to calculations performed within the context of collinear or transverse-momentum-dependent (TMD) factorization in Quantum Chromodynamics (QCD) as well as Monte Carlo event generators. The measurement probes a wide range of QCD phenomena, including TMD parton distribution functions and their evolution with energy in so far unexplored kinematic regions.

Results



Excellent agreement with fixed order at high q_T,
excellent agreement with TMD prediction at low q_T.

Results



Parton shower Monte Carlo programs also provide excellent agreement with the data across the spectra.

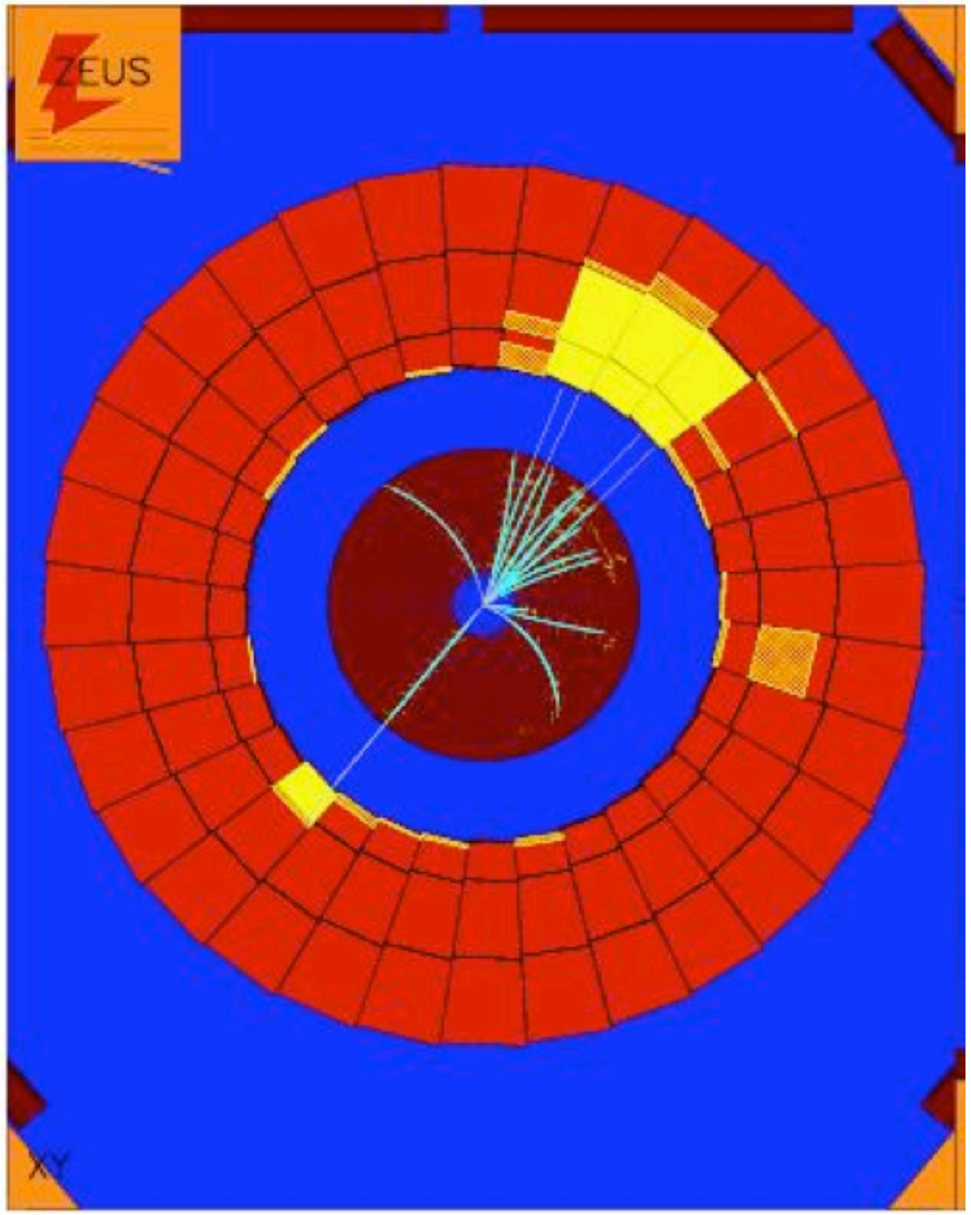
ZEUS measurement

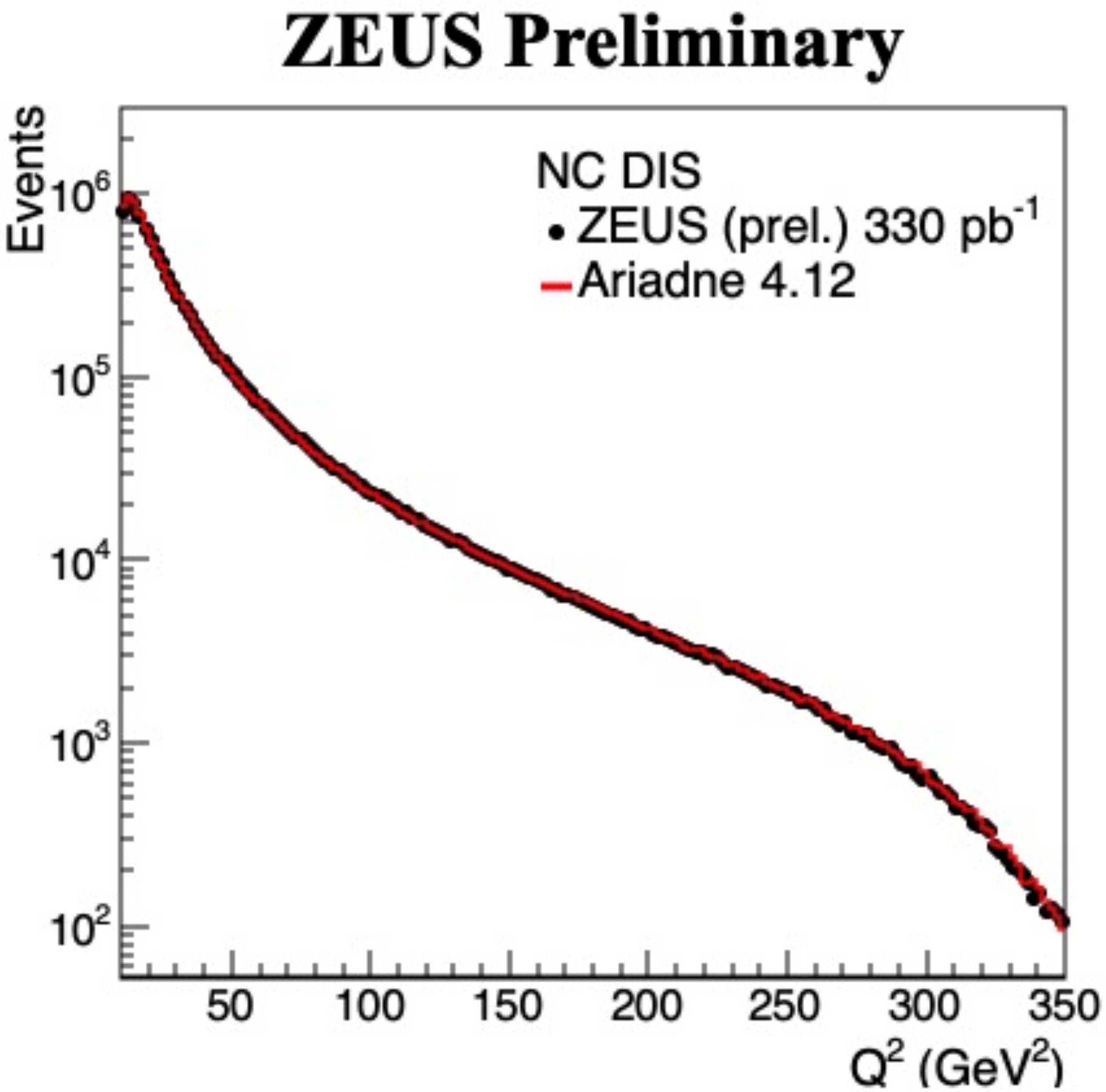
For further details, see this DIS talk.

Setup

Similar to H1, but with larger Q^2 and smaller $|\eta|$ acceptance.

TUnfold for 1D binned unfolding, to be done in bins of p_T, Q^2 and jet multiplicity.





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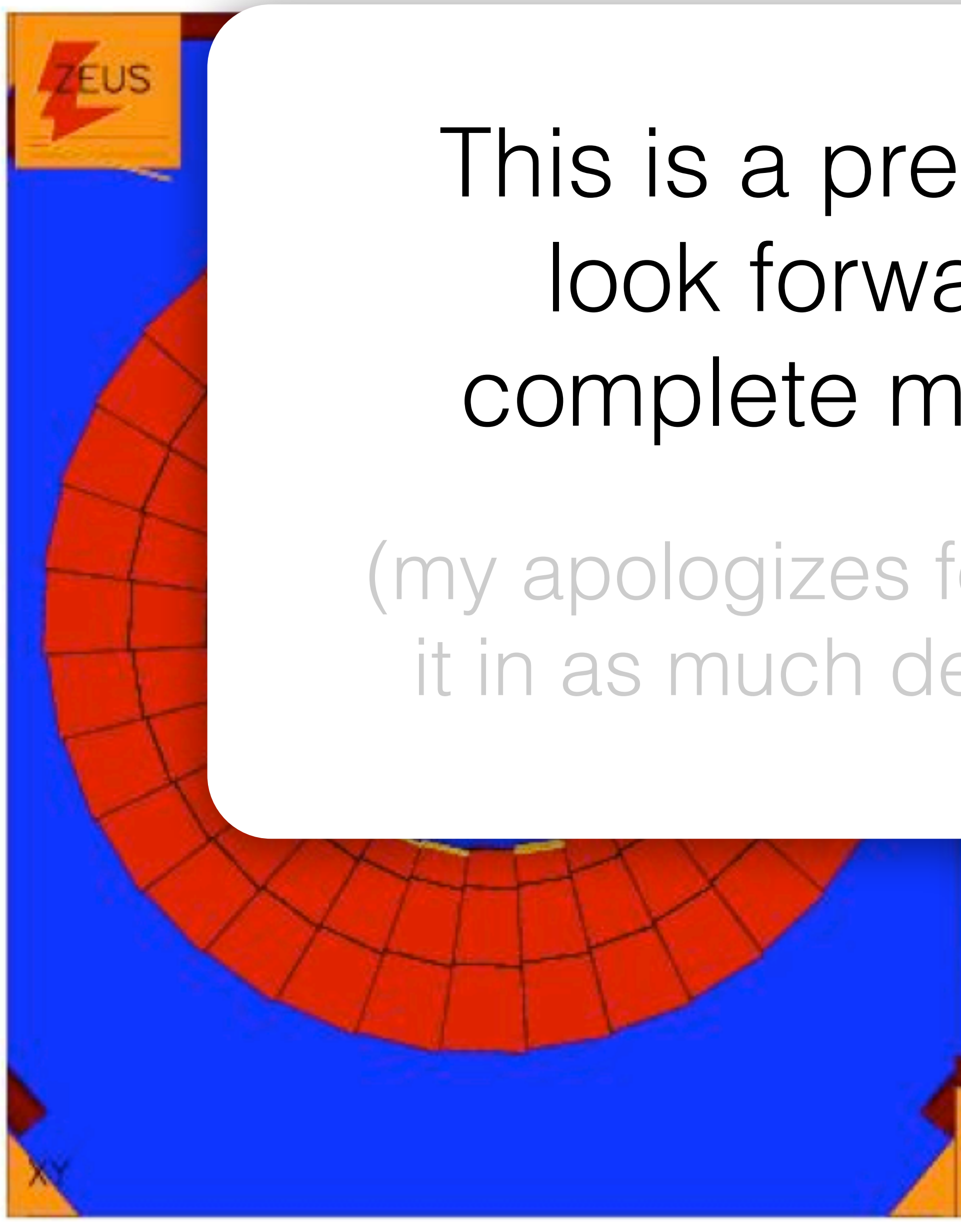
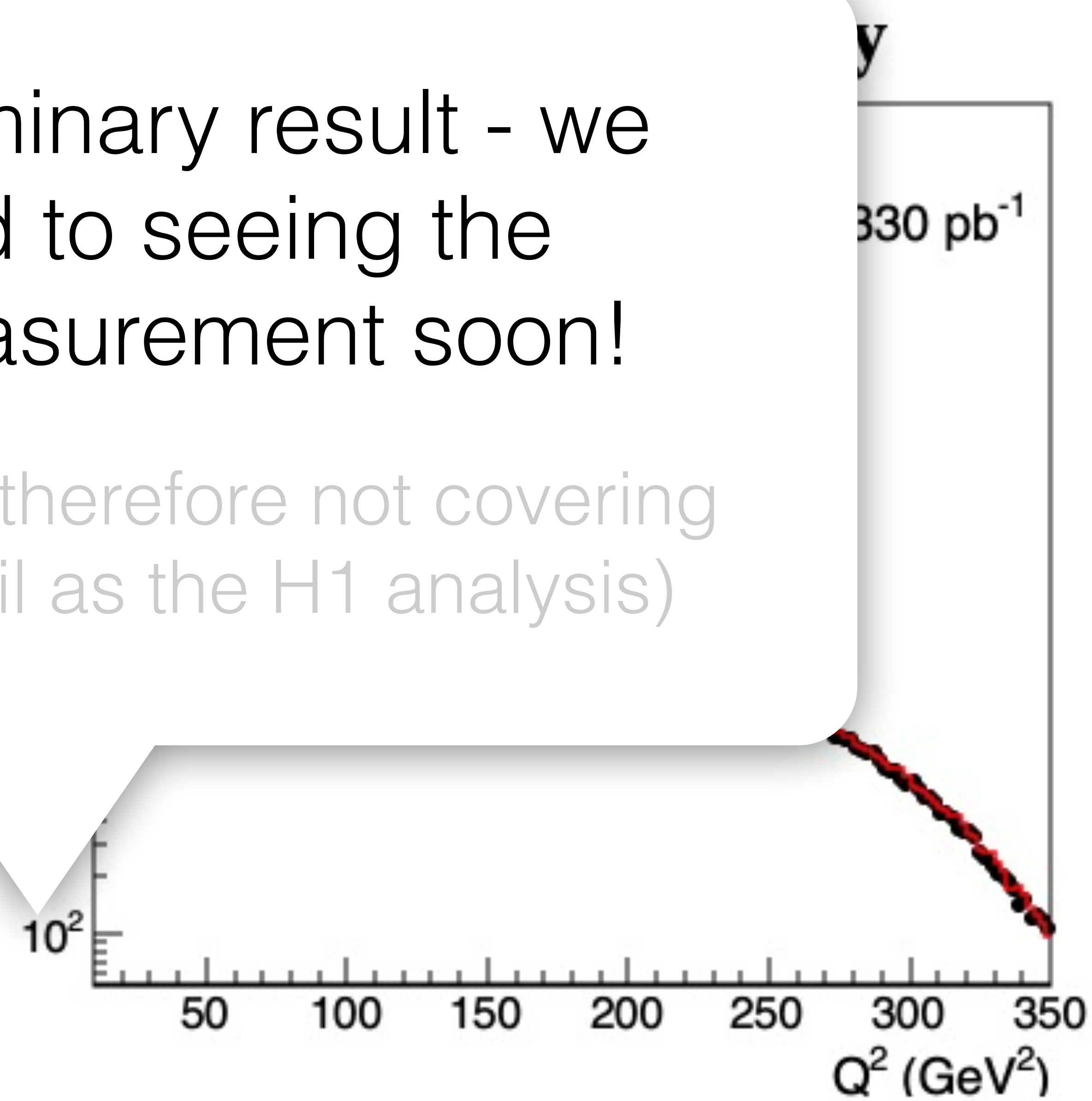
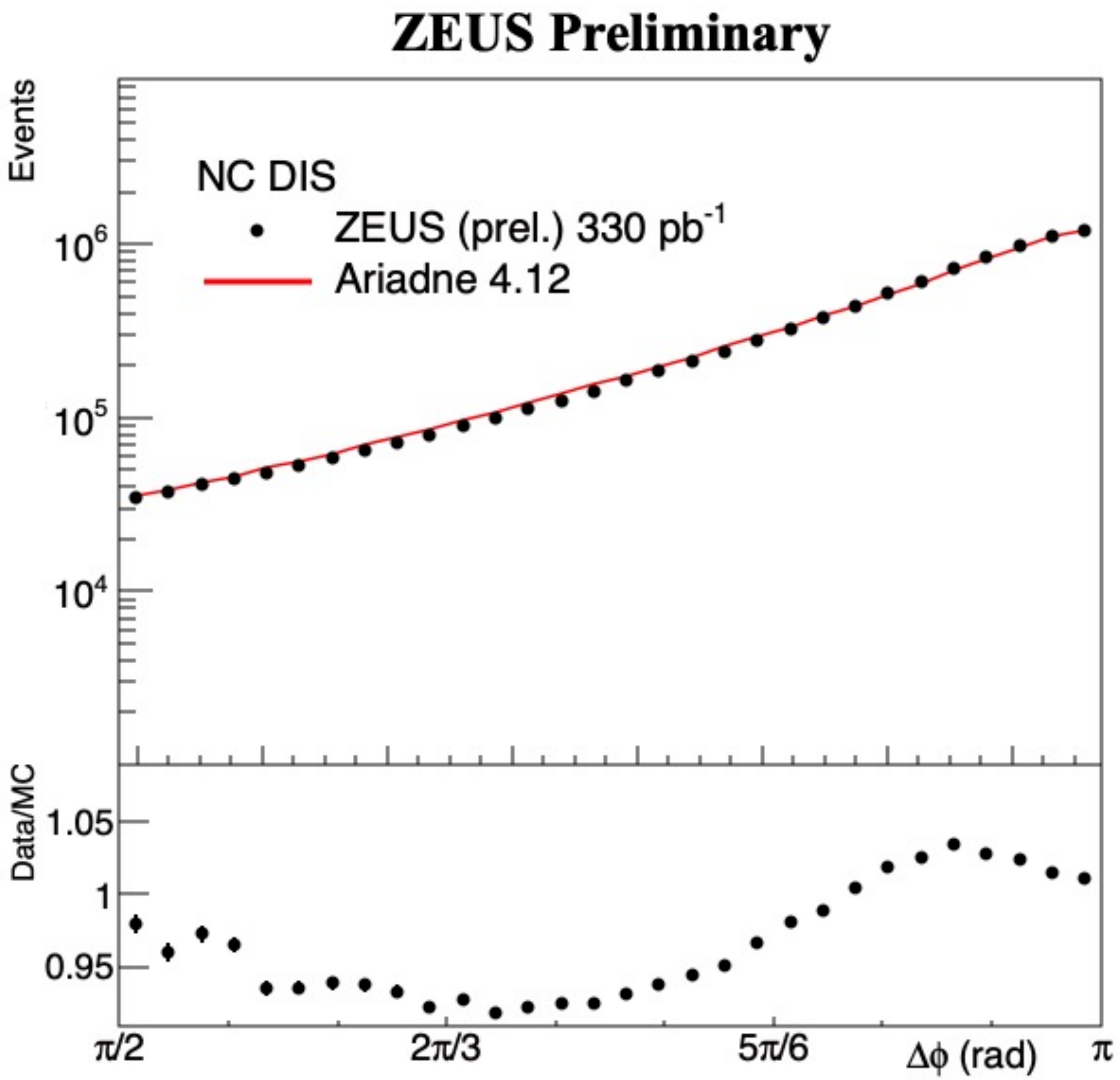


This is a preliminary result - we look forward to seeing the complete measurement soon!

(my apologizes for therefore not covering it in as much detail as the H1 analysis)

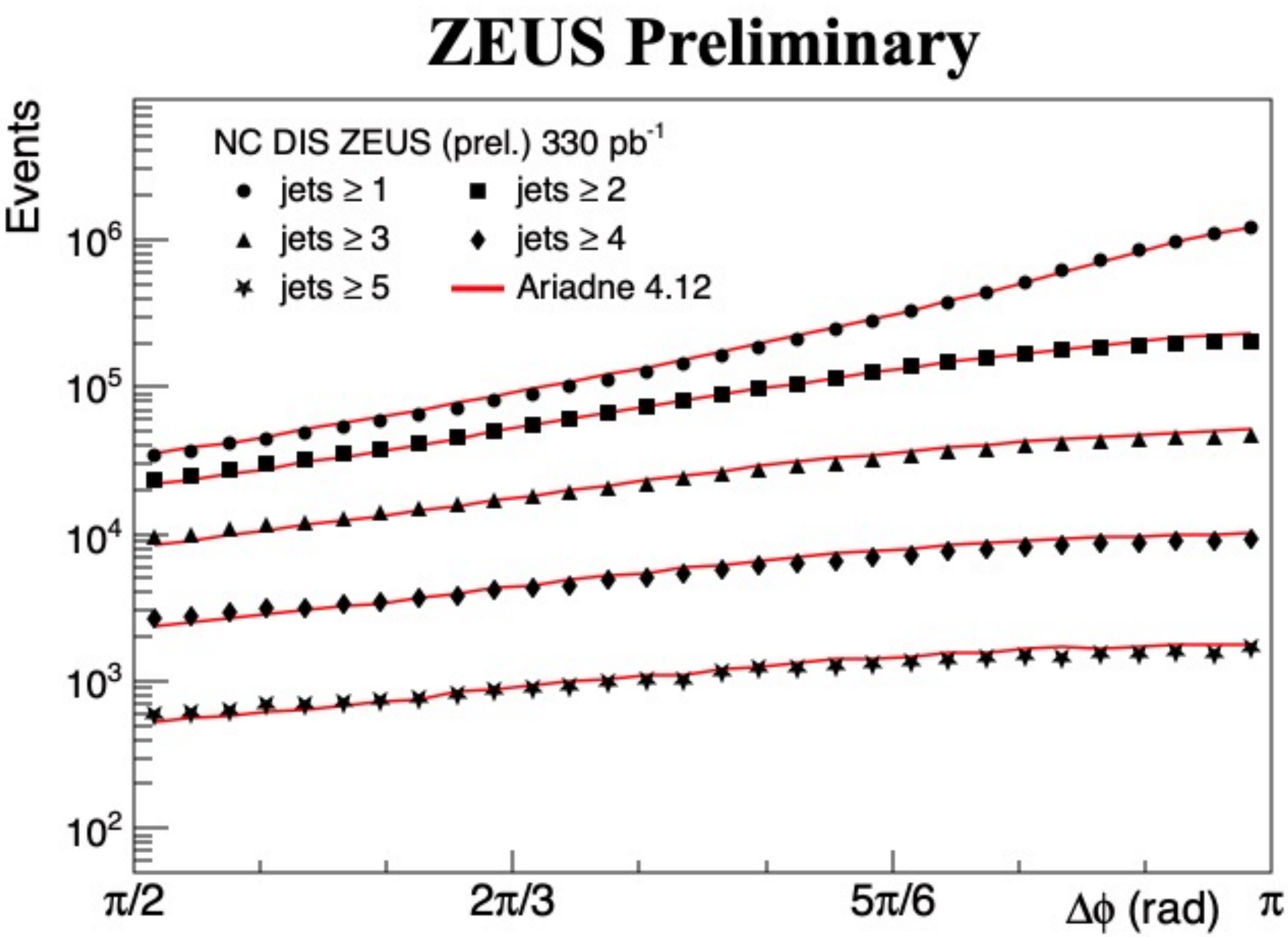


Preliminary Results



Agreement with Ariadne at the ~5% level

Preliminary Results

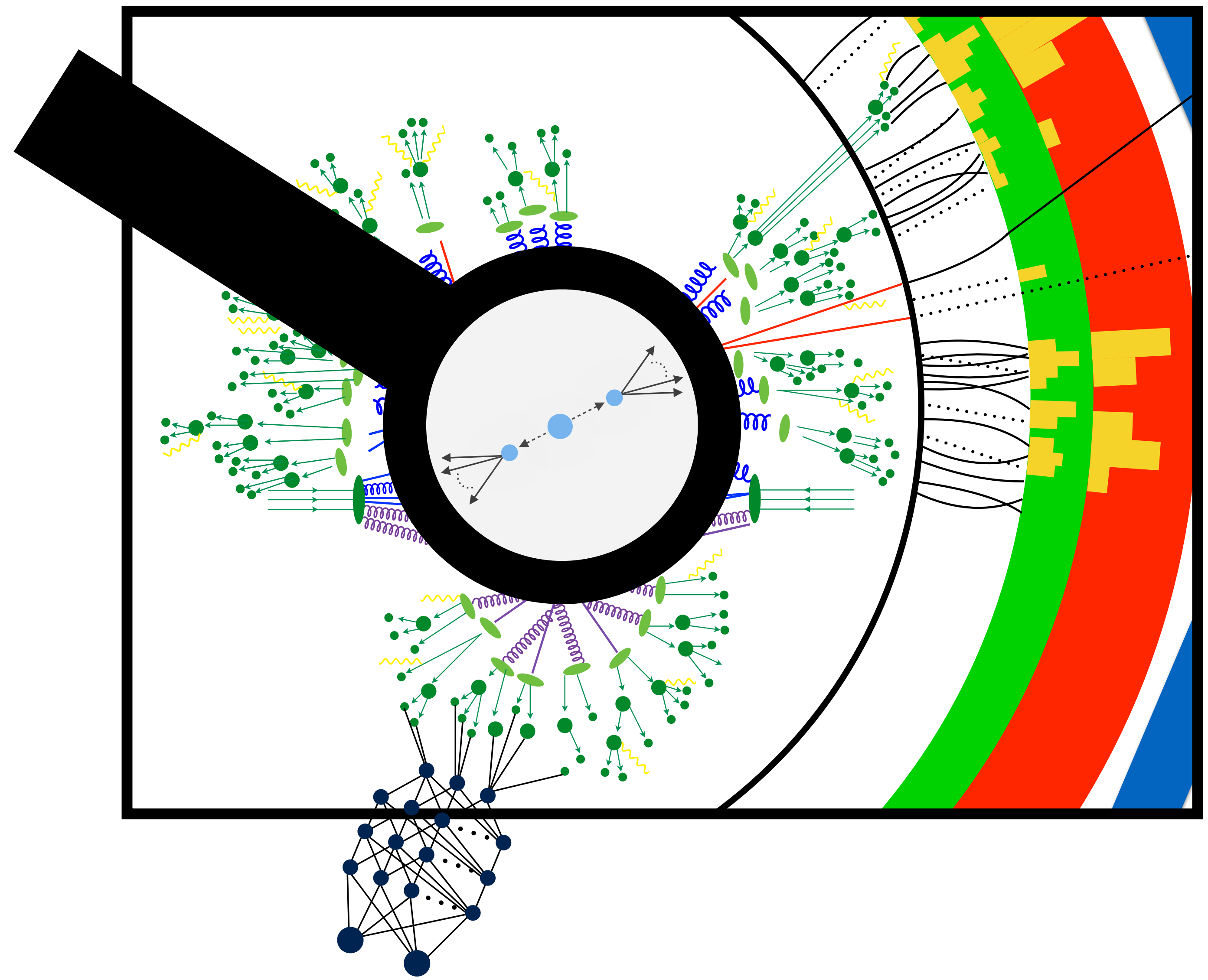


Agreement with Ariadne at the ~5% level

A bit worse at larger jet multiplicities

Conclusions and outlook

Today, I have presented results probing electron-jet correlations in the lab frame in neutral current DIS



These measurements have important constraining power for TMD PDFs and provide critical input to planning and design for the future EIC

Backup

Looking forward

Publishing unbinned measurements is tricky - we have started a conversation about this in a paper coming out tonight. Feedback is most welcome!

2109.tonight

Presenting Unbinned Differential Cross Section Results

Miguel Arratia,[a,b] Anja Butter,[c] Mario Campanelli,[d] Vincent Croft,[e] Dag Gillberg,[f] Kristin Lohwasser,[g] Bogdan Malaescu,[h] Vinicius Mikuni,[i] Benjamin Nachman,[j,k] Juan Rojo,[l,m] Jesse Thaler,[n,o] Ramon Winterhalder[p]

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[c] *Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany*
[d] *University College London, London WC1E 6BT, UK*
[e] *Department of Physics and Astronomy, Tufts University, Boston, MA 02155, USA*
[f] *Department of Physics, Carleton University, Ottawa ON K1S 5B6, Canada*
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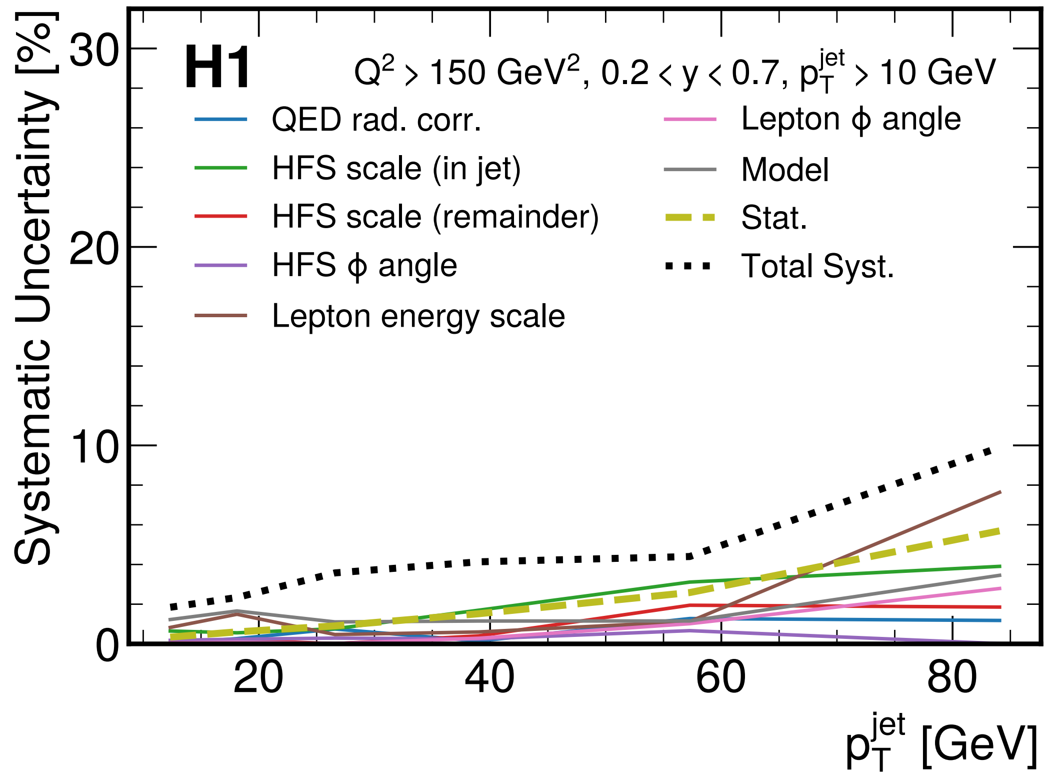
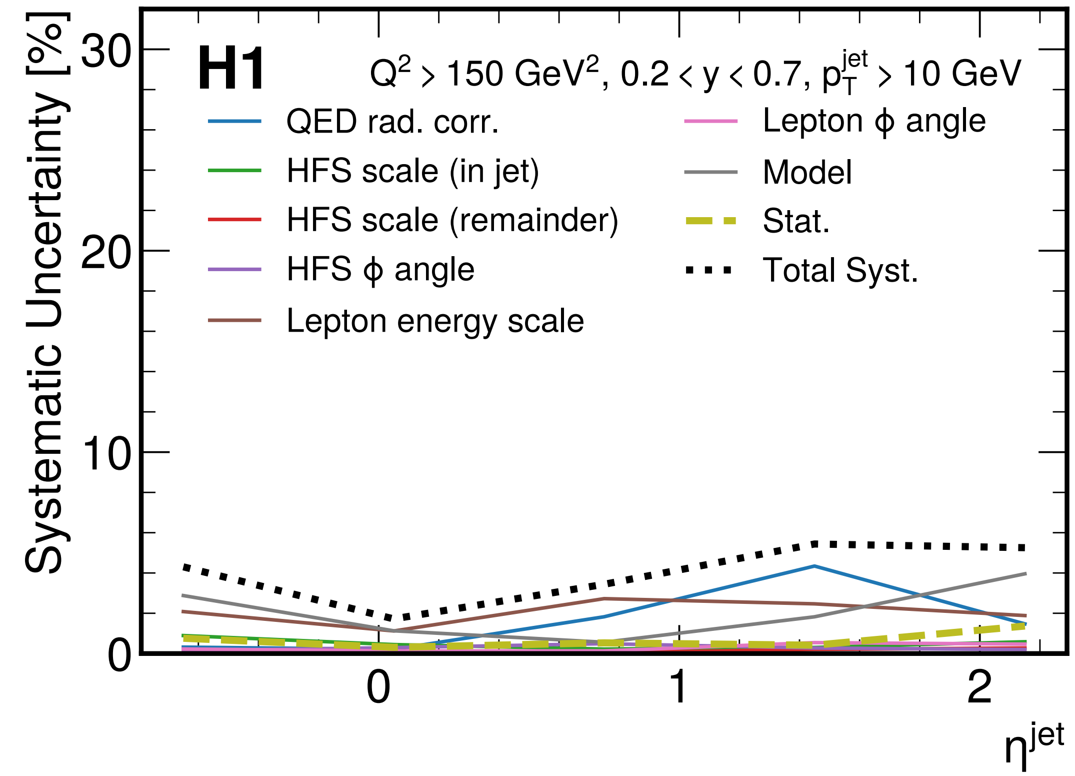
[h] *LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France*
[i] *National Energy Research Scientific Computing Center, Berkeley, CA 94720, USA*
[j] *Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[k] *Berkeley Institute for Data Science, University of California, Berkeley, CA 94720, USA*
[l] *Nikhef Theory Group, Science Park 105, 1098 XG Amsterdam, The Netherlands*
[m] *Department of Physics and Astronomy, Vrije Universiteit Amsterdam, NL-1081 HV Amsterdam, The Netherlands*
[n] *Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[o] *The NSF AI Institute for Artificial Intelligence and Fundamental Interactions*
[p] *Centre for Cosmology, Particle Physics and Phenomenology (CP3), Université catholique de Louvain, 1348 Louvain-la-Neuve, Belgium*

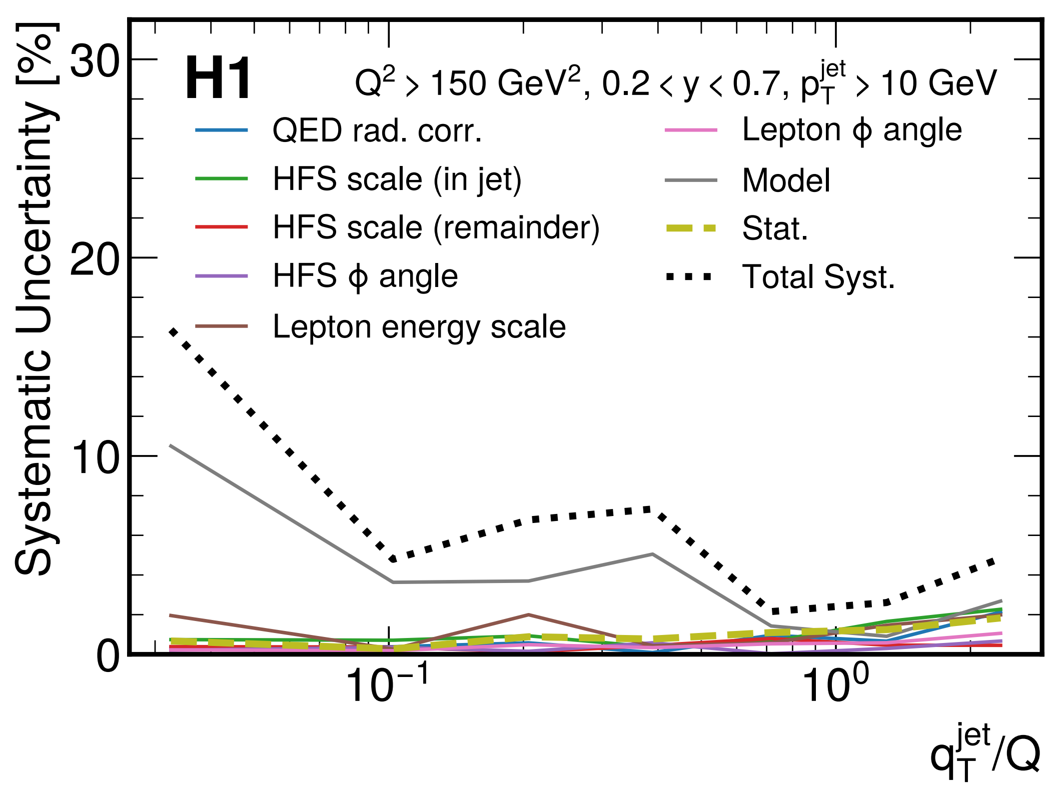
E-mail: bpnachman@lbl.gov

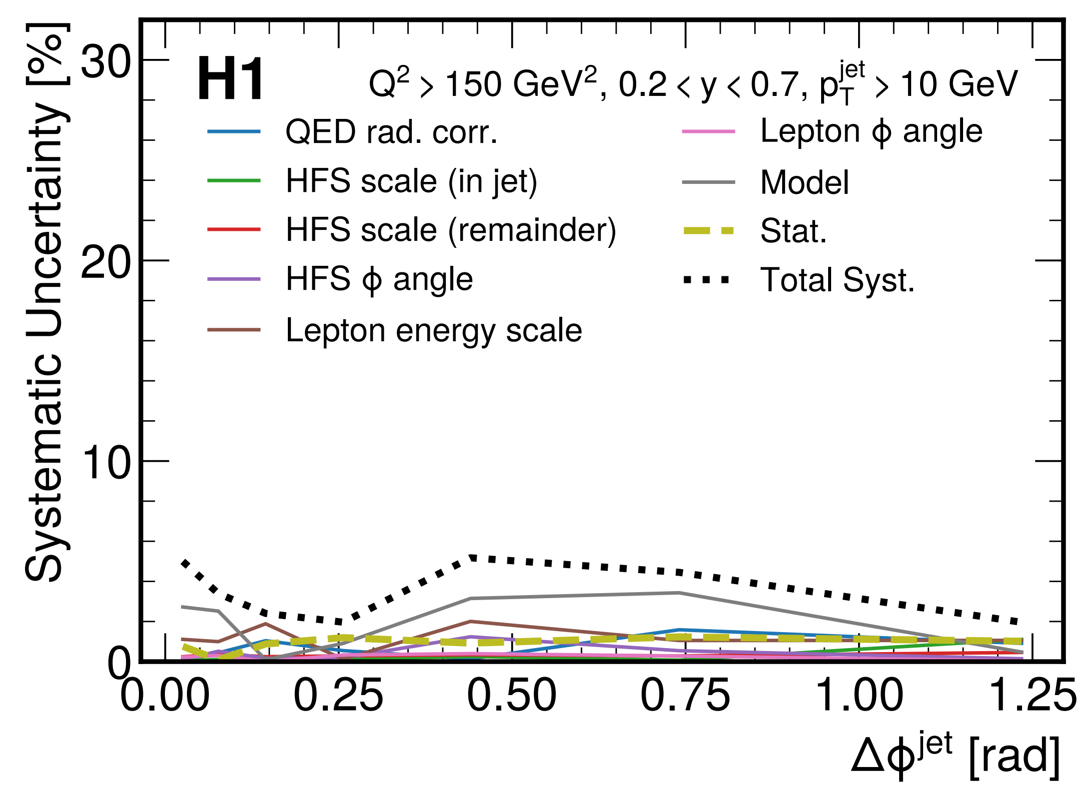
Abstract: Machine learning tools have empowered a qualitatively new way to perform differential cross section measurements whereby the data are unbinned, possibly in many dimensions. Unbinned measurements can enable, improve, or at least simplify comparisons between experiments and with theoretical predictions. Furthermore, many-dimensional measurements can be used to define observables after the measurement instead of before. There is currently no community standard for publishing unbinned data. While there are also essentially no measurements of this type public, unbinned measurements are expected in the near future given recent methodological advances. The purpose of this paper is to propose a scheme for presenting and using unbinned results, which can hopefully form the basis for a community standard to allow for integration into analysis workflows. This is foreseen to be the start of an evolving community dialogue, in order to accommodate future developments in this field that is rapidly evolving.

Preliminary Results



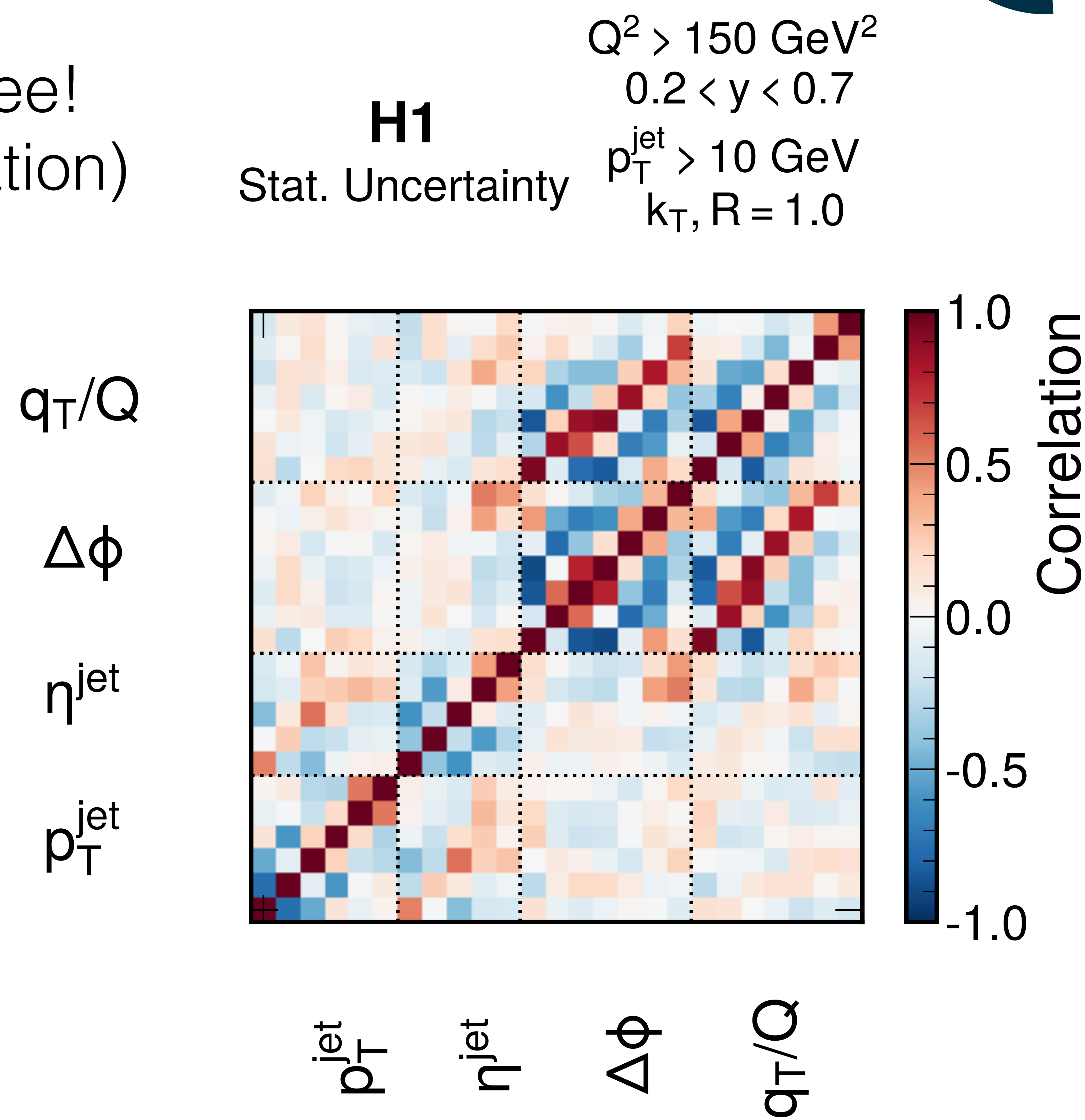




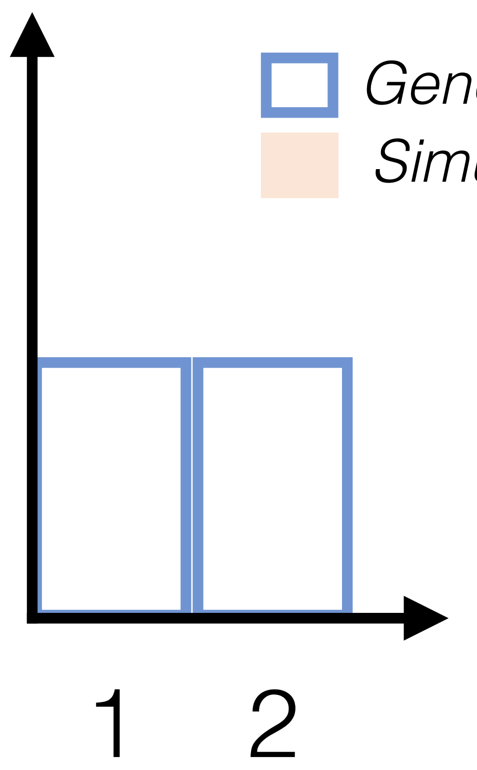


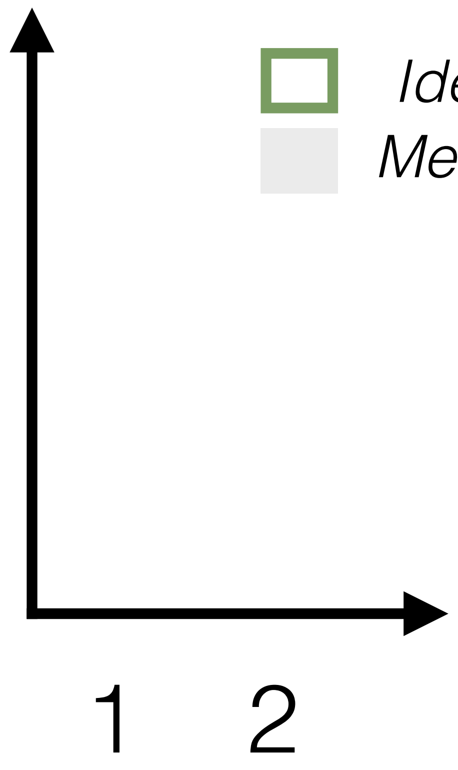
Preliminary Results

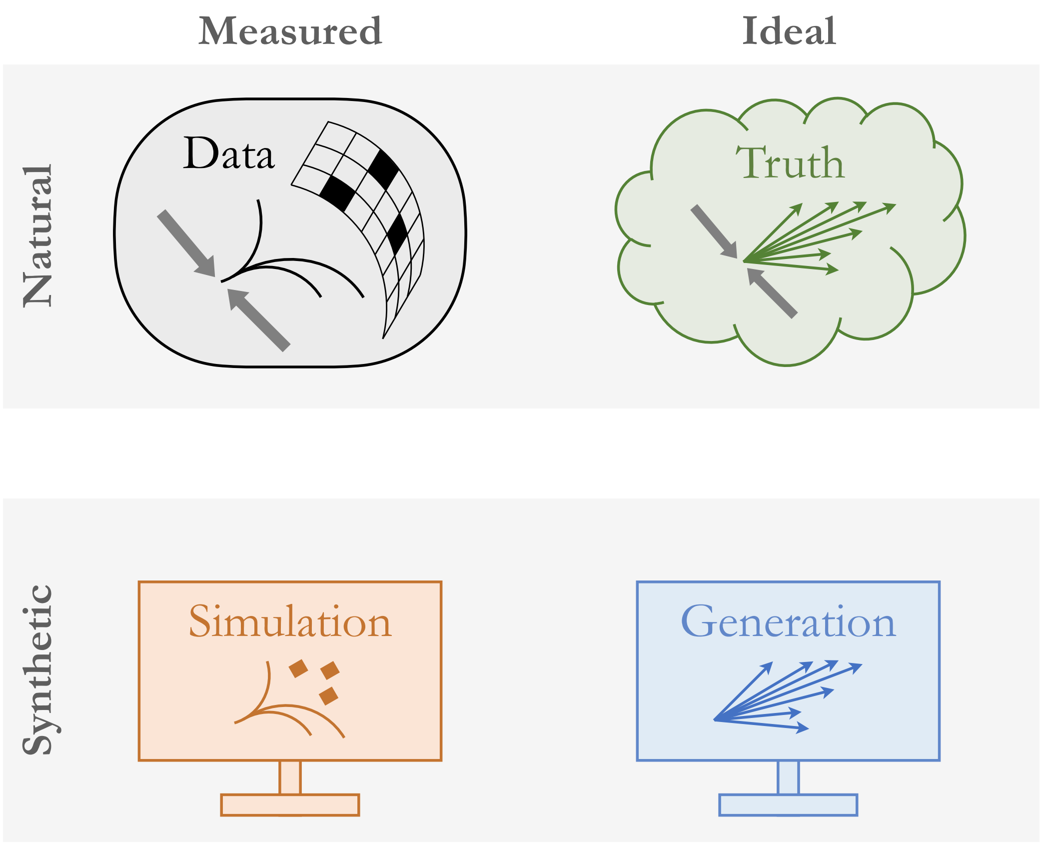
Simultaneous for free!
(binning is for illustration)



Unfold by iterating: OmniFold







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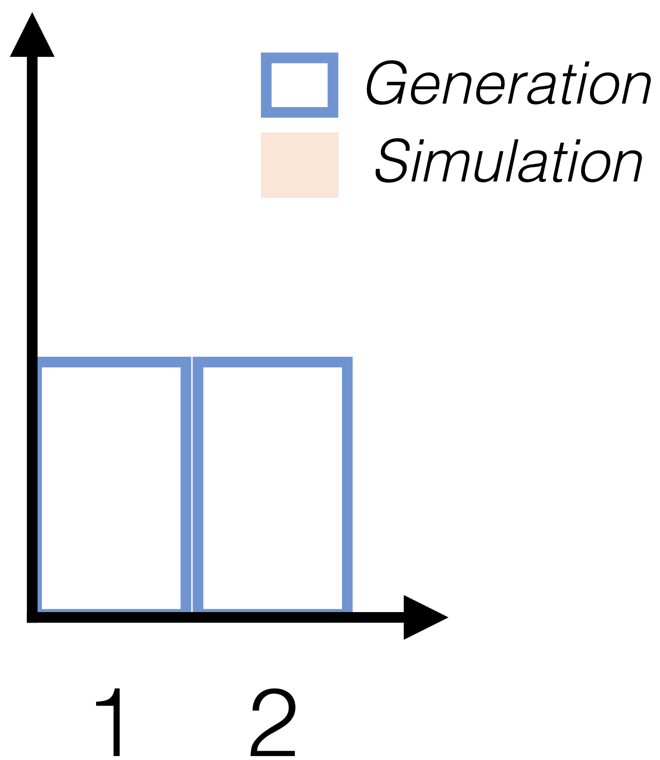
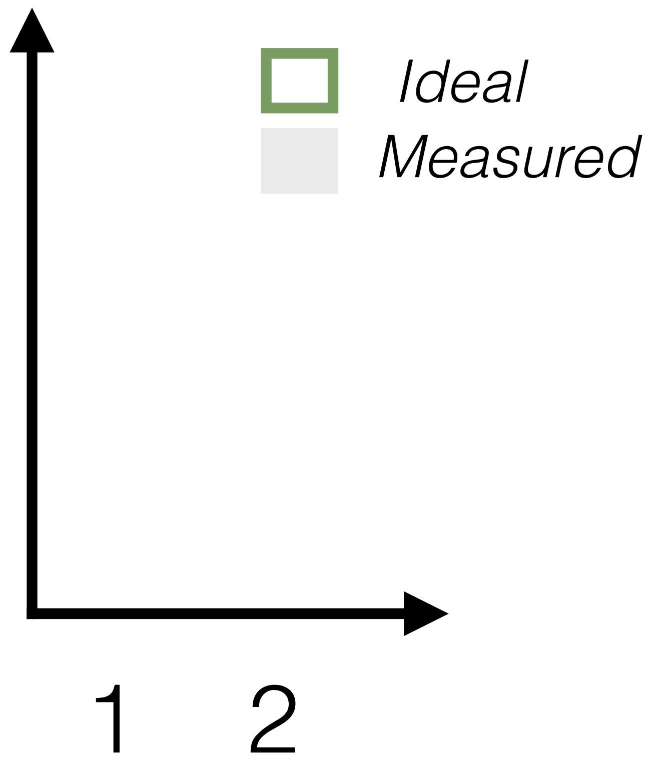
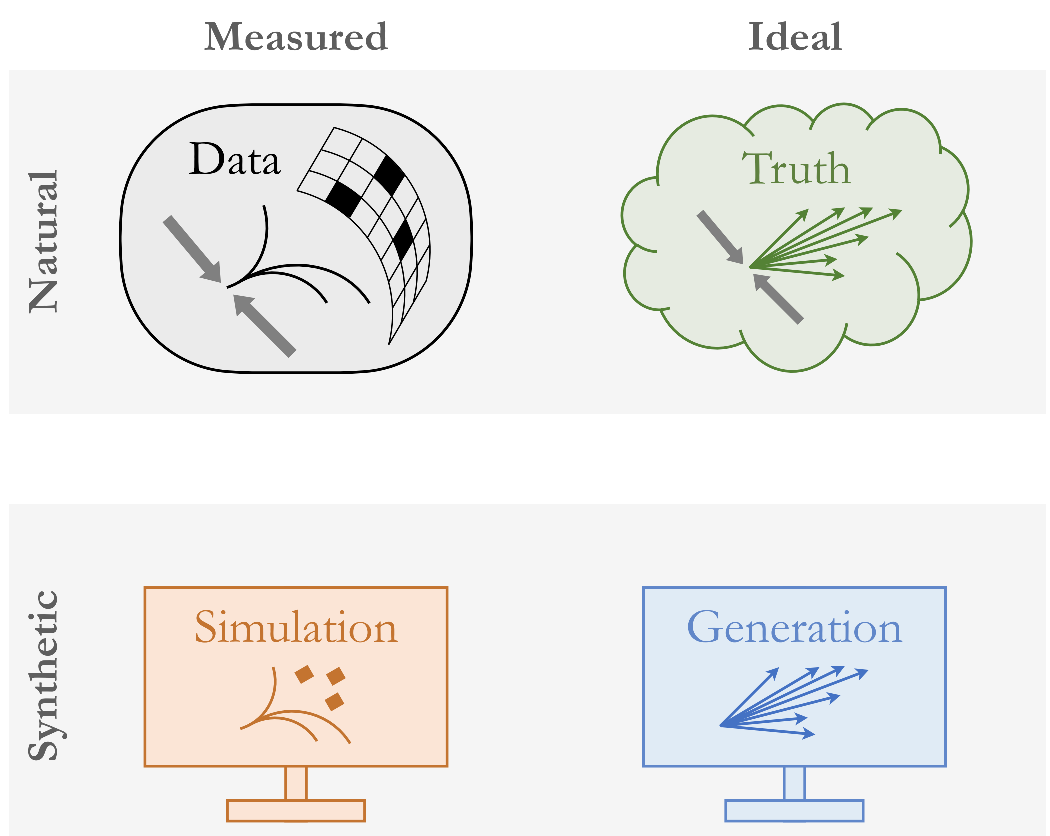




Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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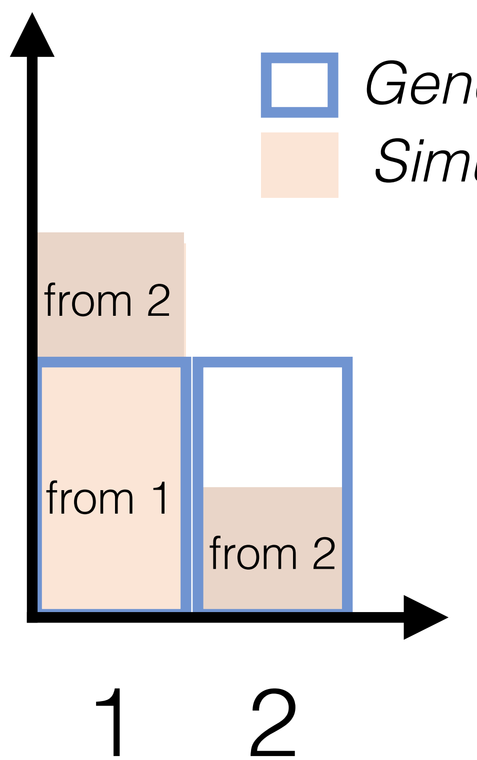

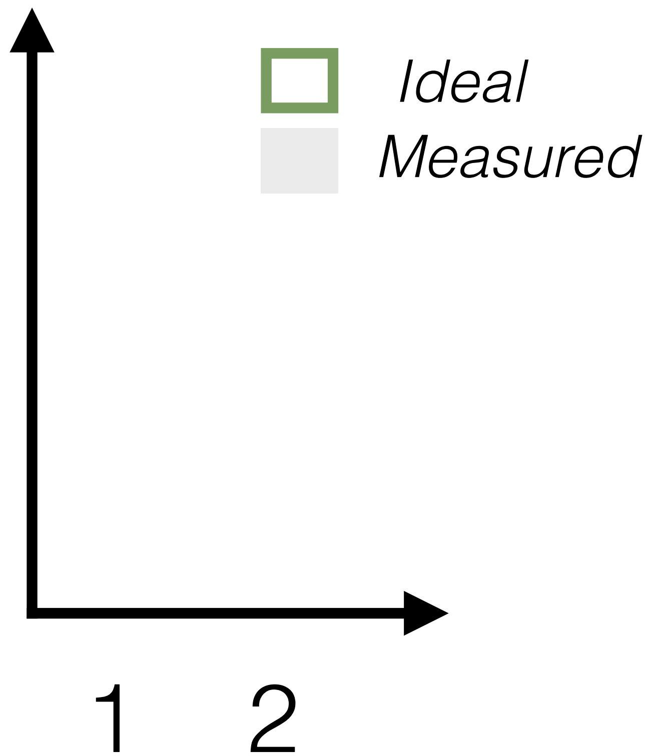

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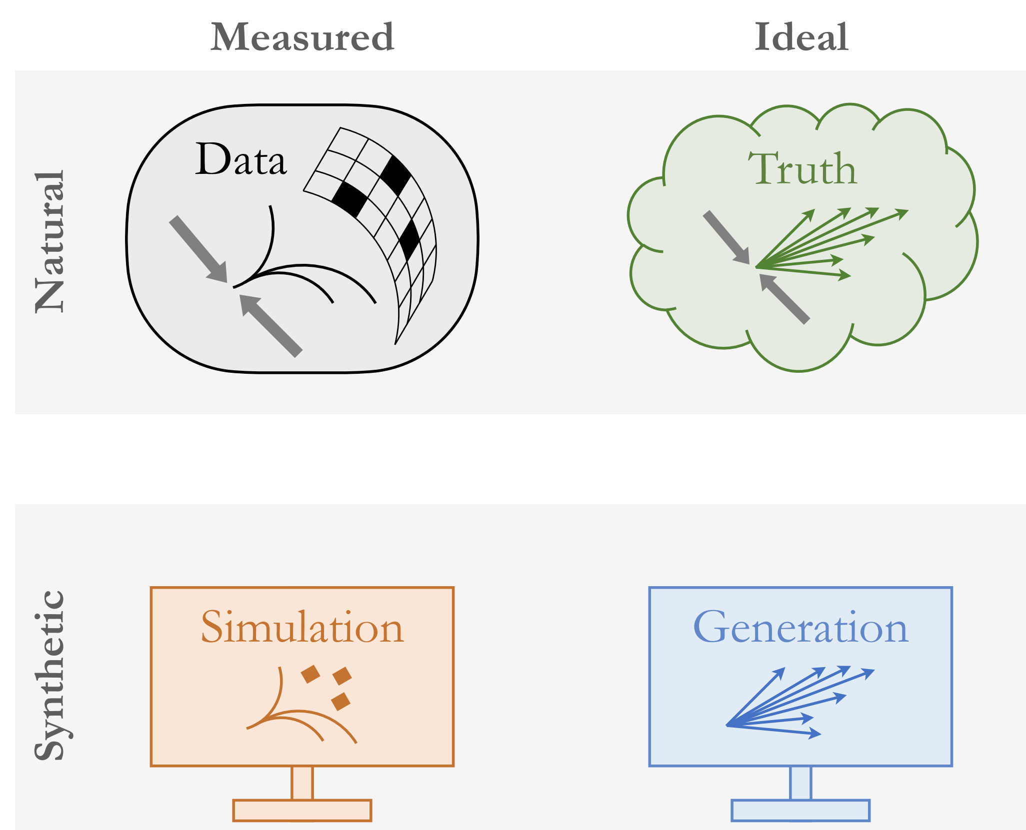

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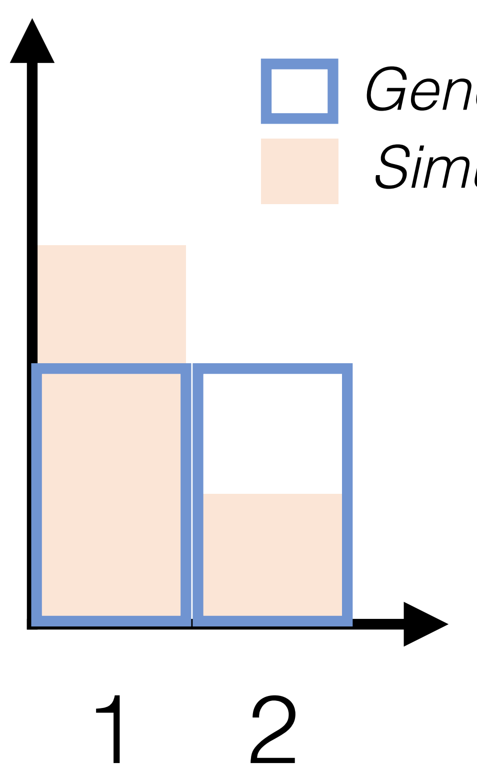

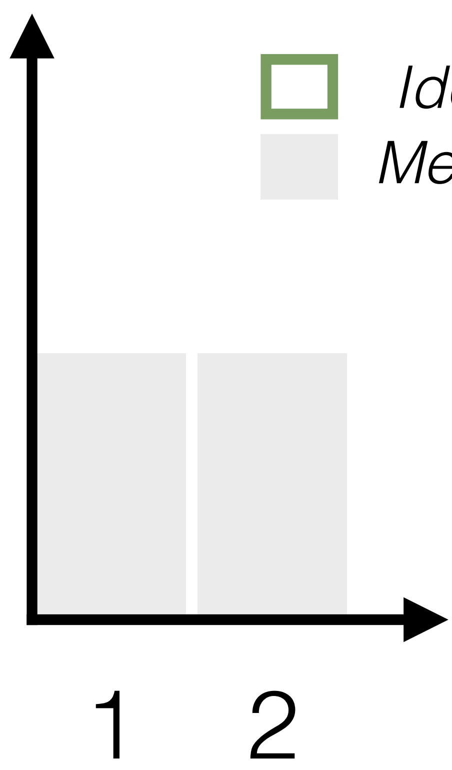

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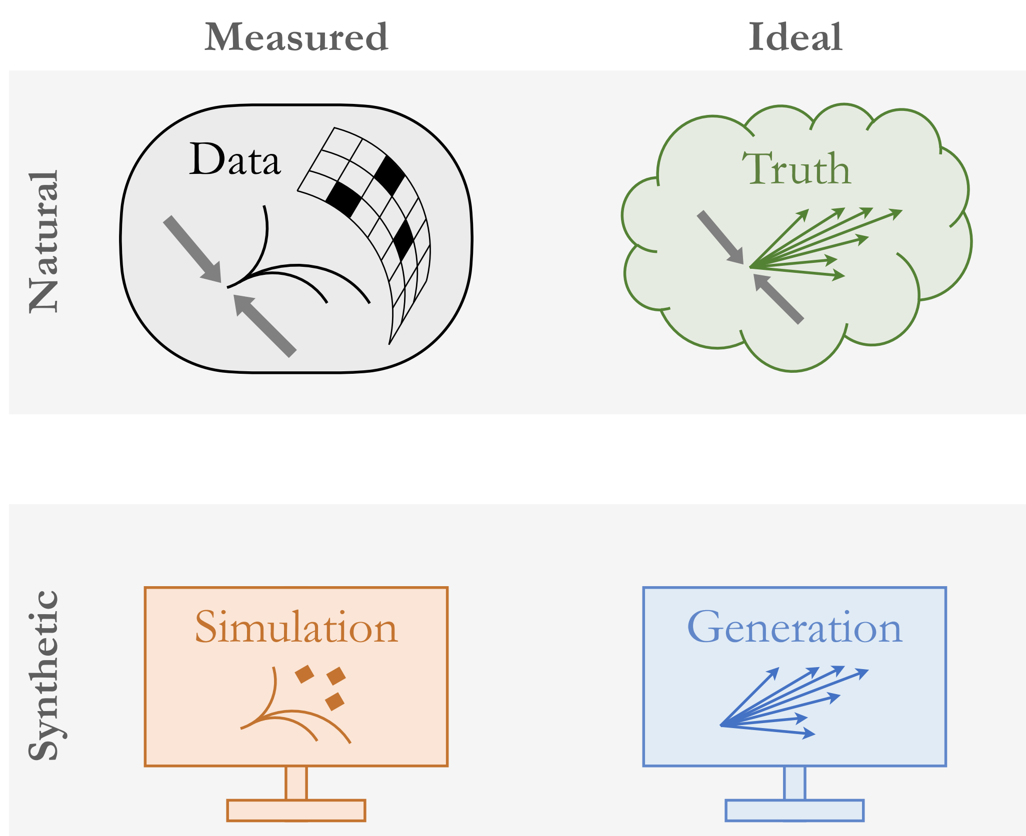

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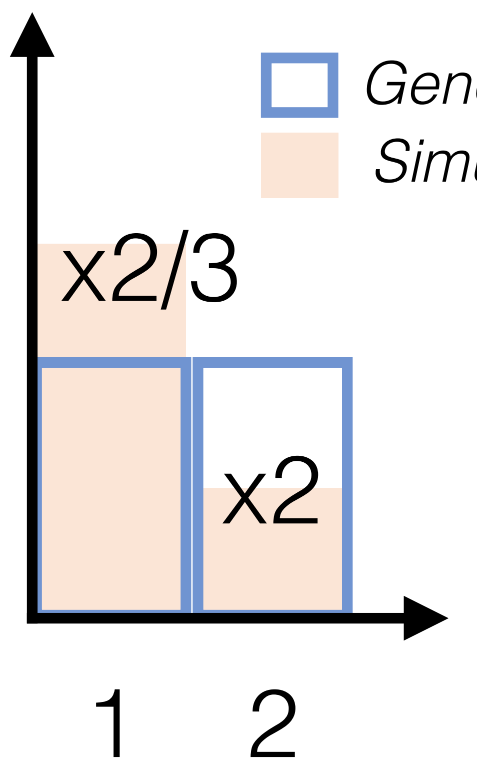
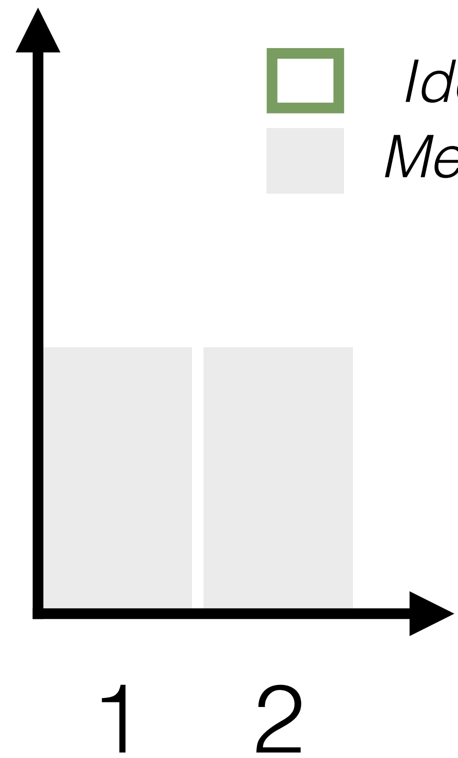
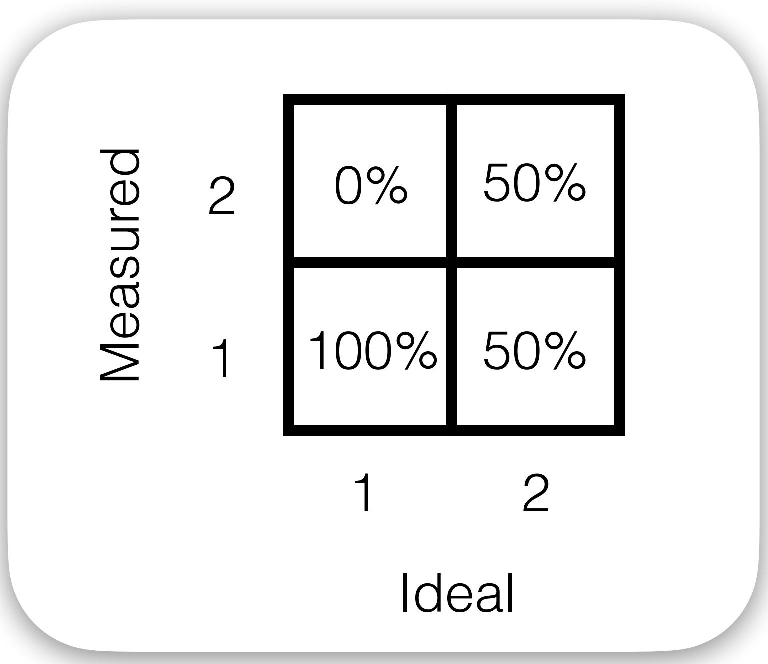
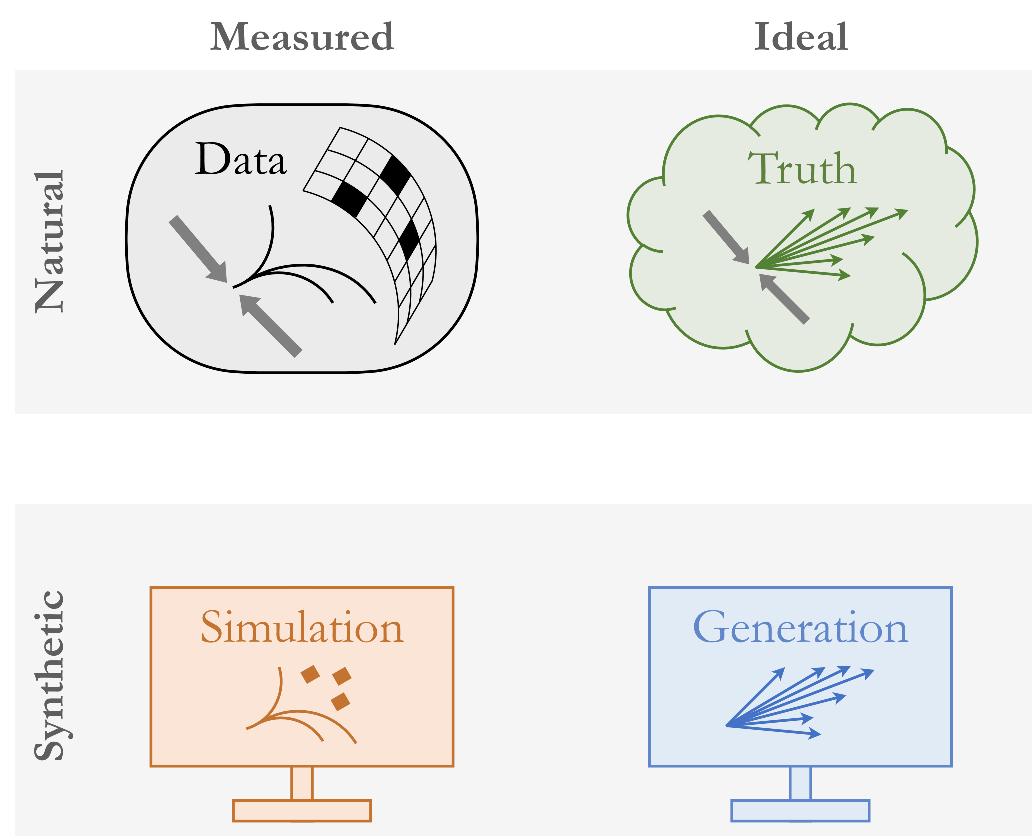
Unfold by iterating: OmniFold









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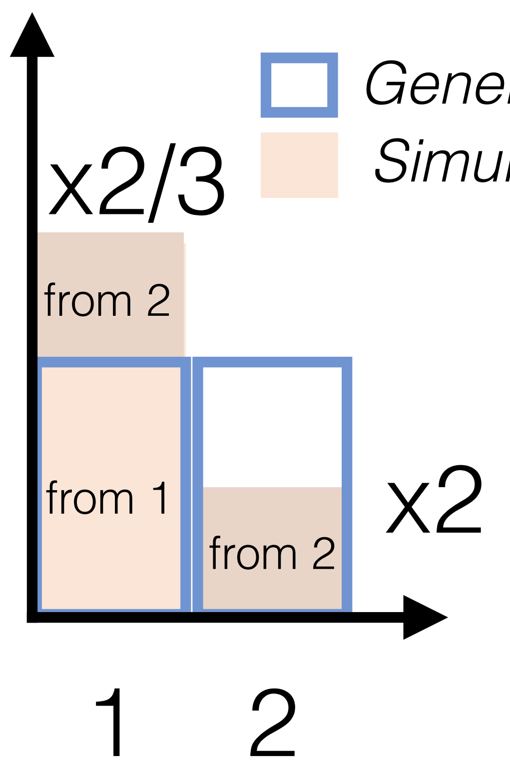
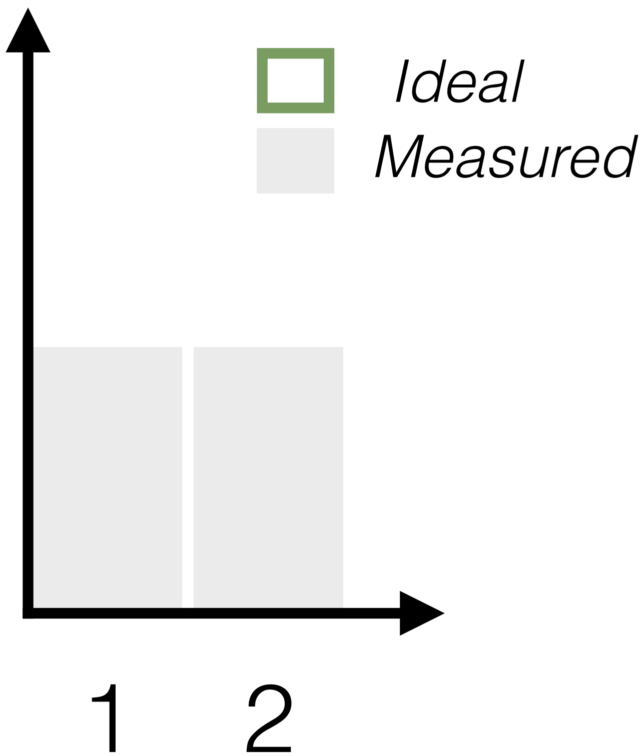
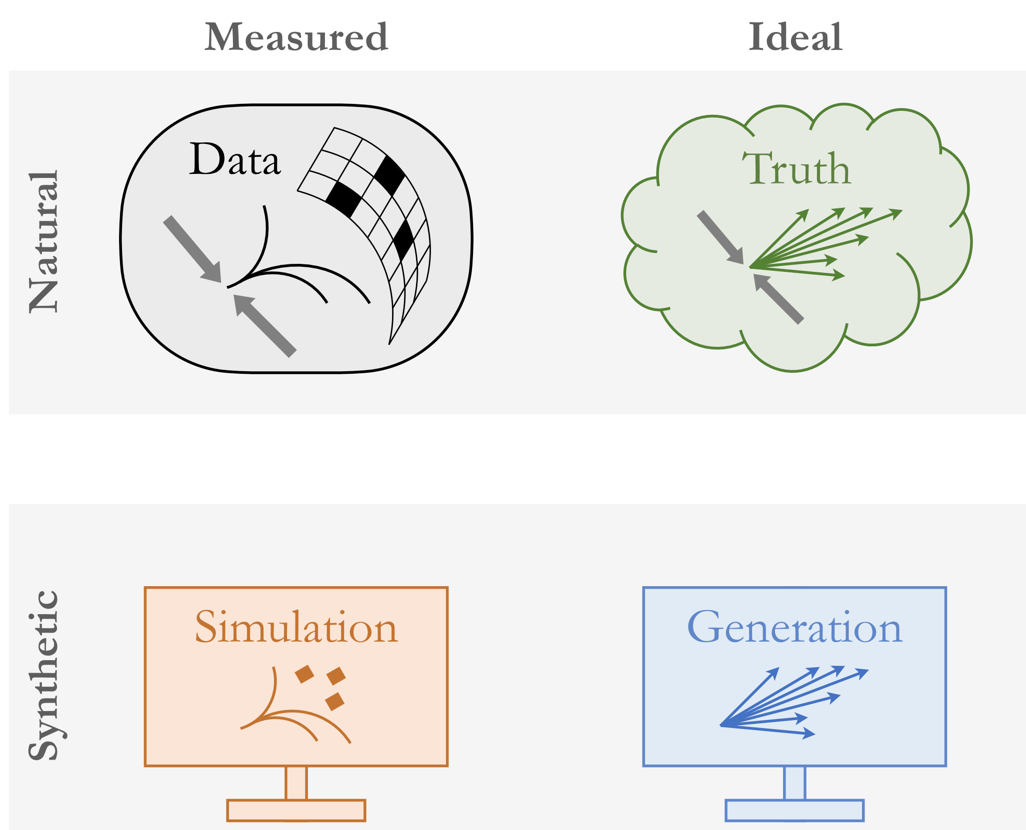
Unfold by iterating: OmniFold





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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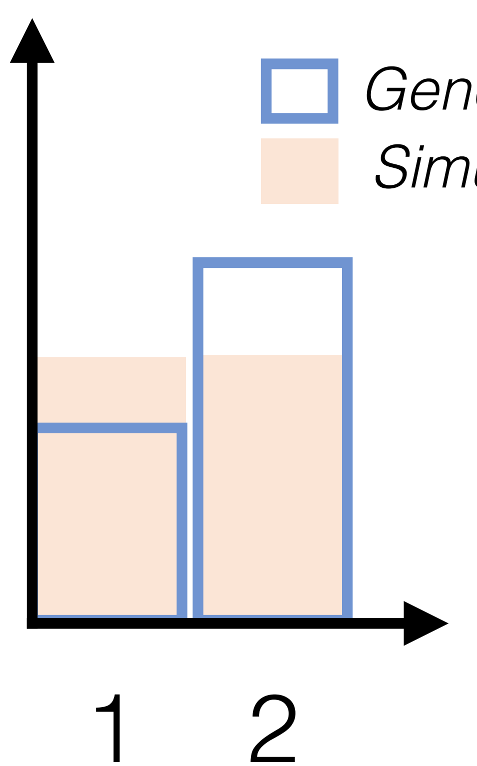
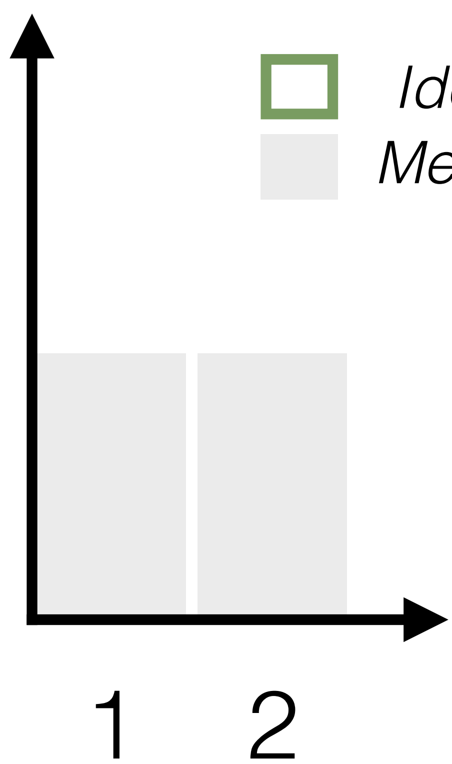
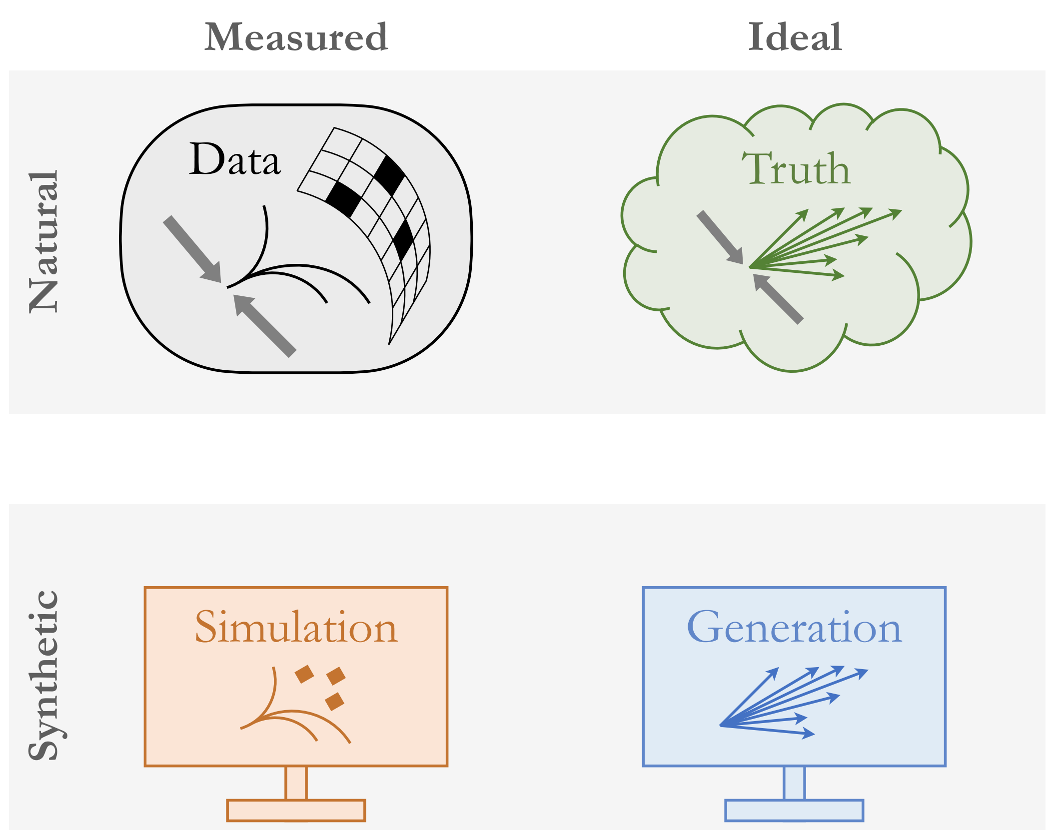
Unfold by iterating: OmniFold

After iteration 1





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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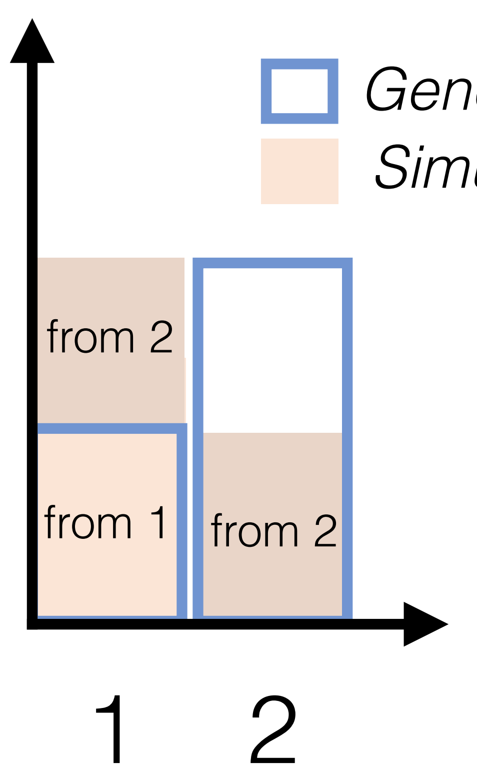
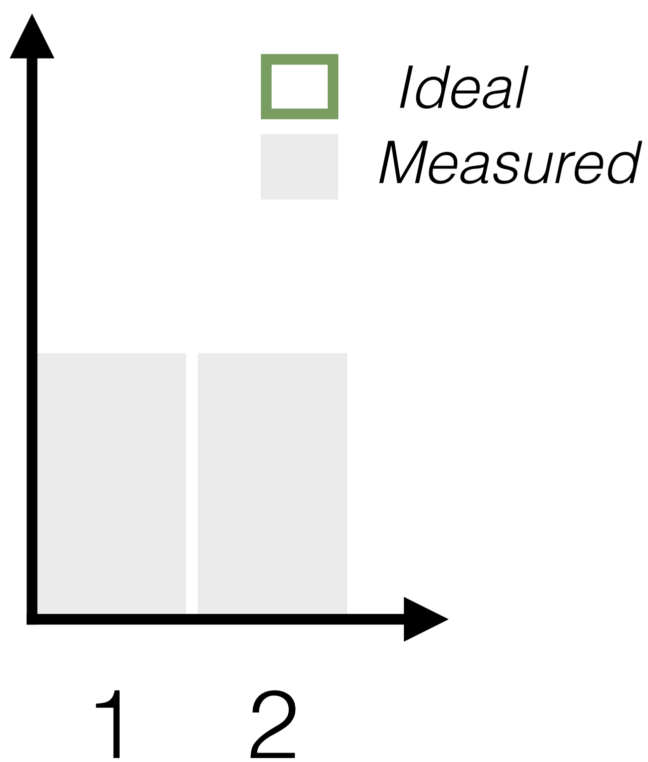
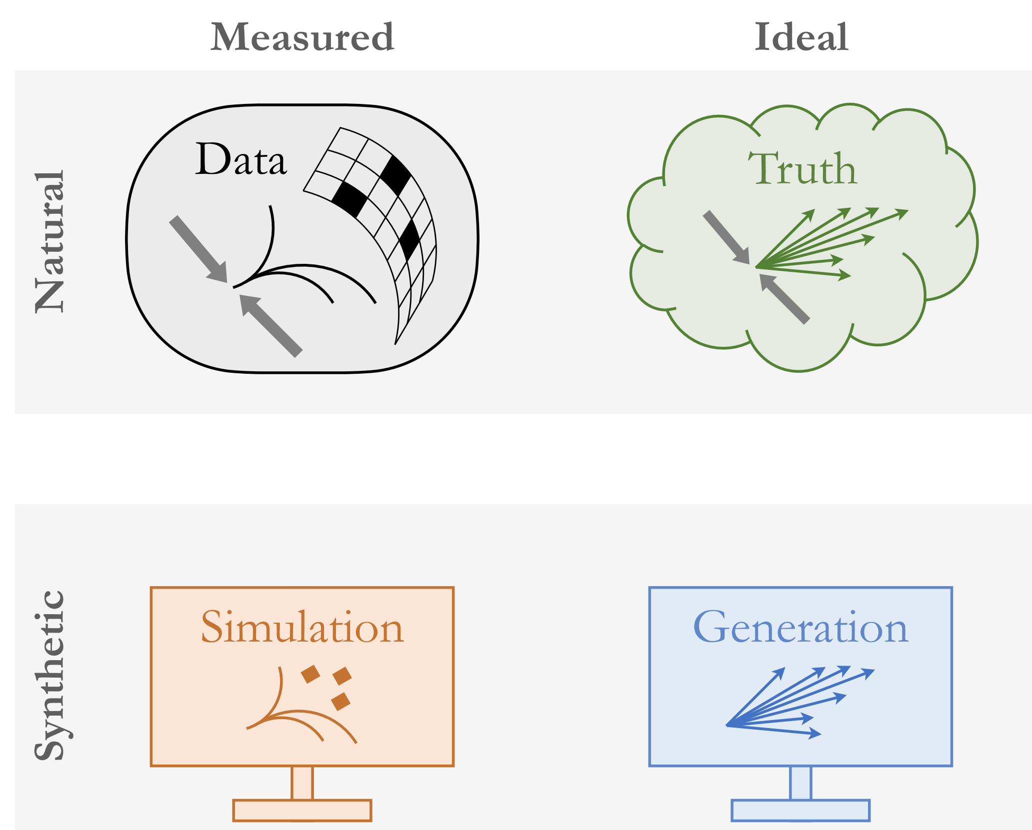
Unfold by iterating: OmniFold

After iteration 1





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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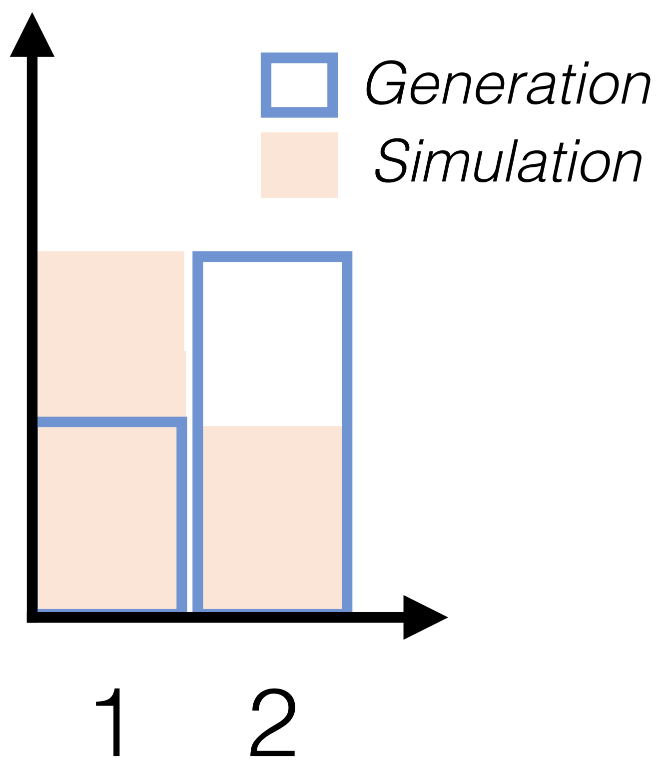
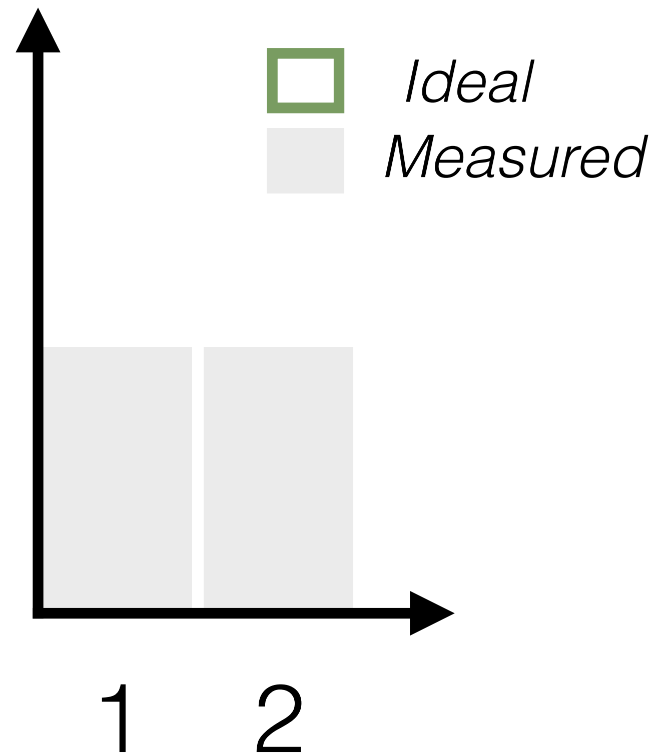
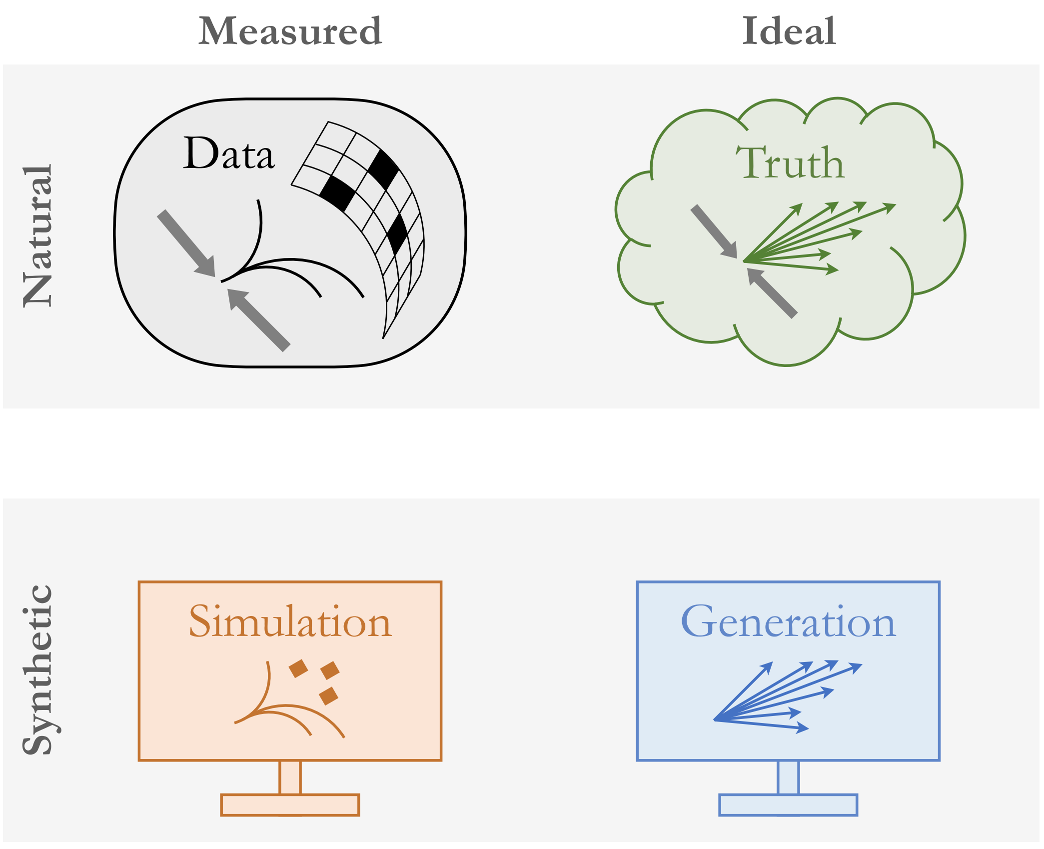
Unfold by iterating: OmniFold

After iteration 1





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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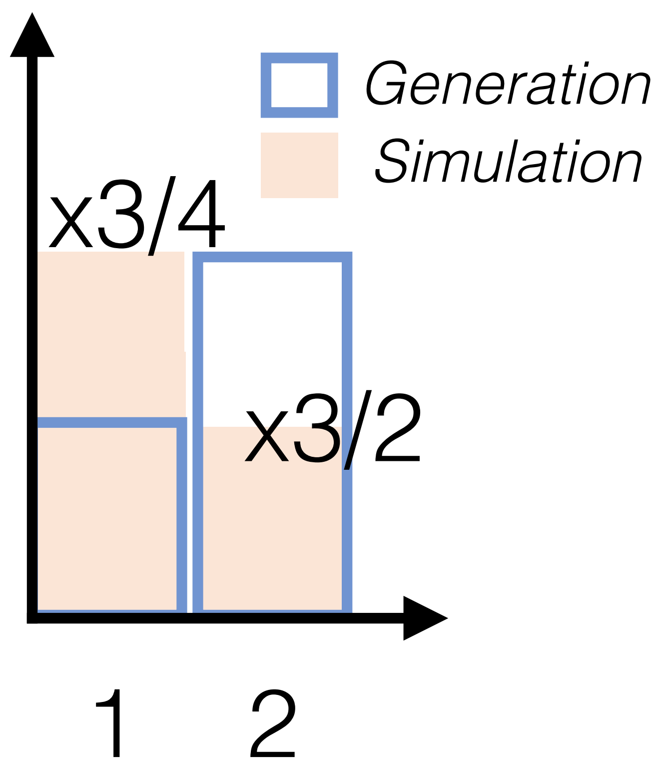
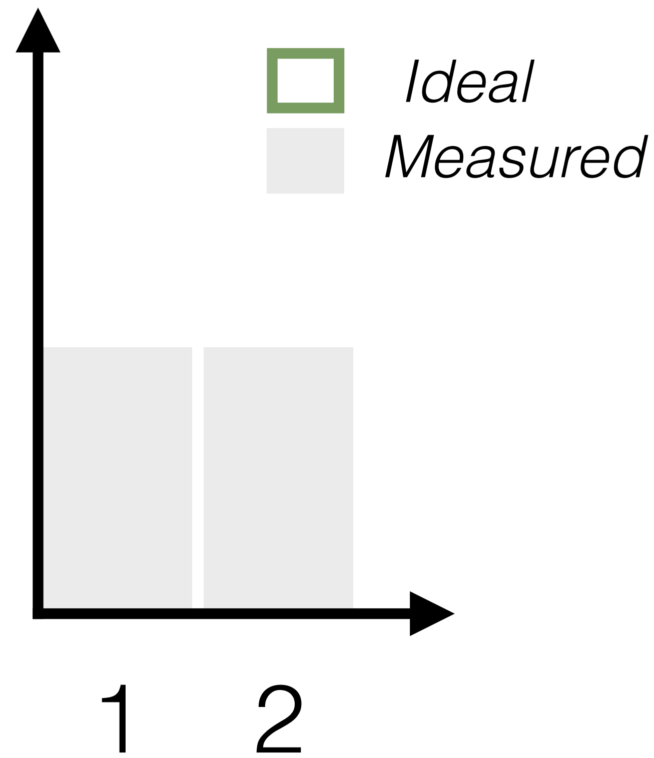
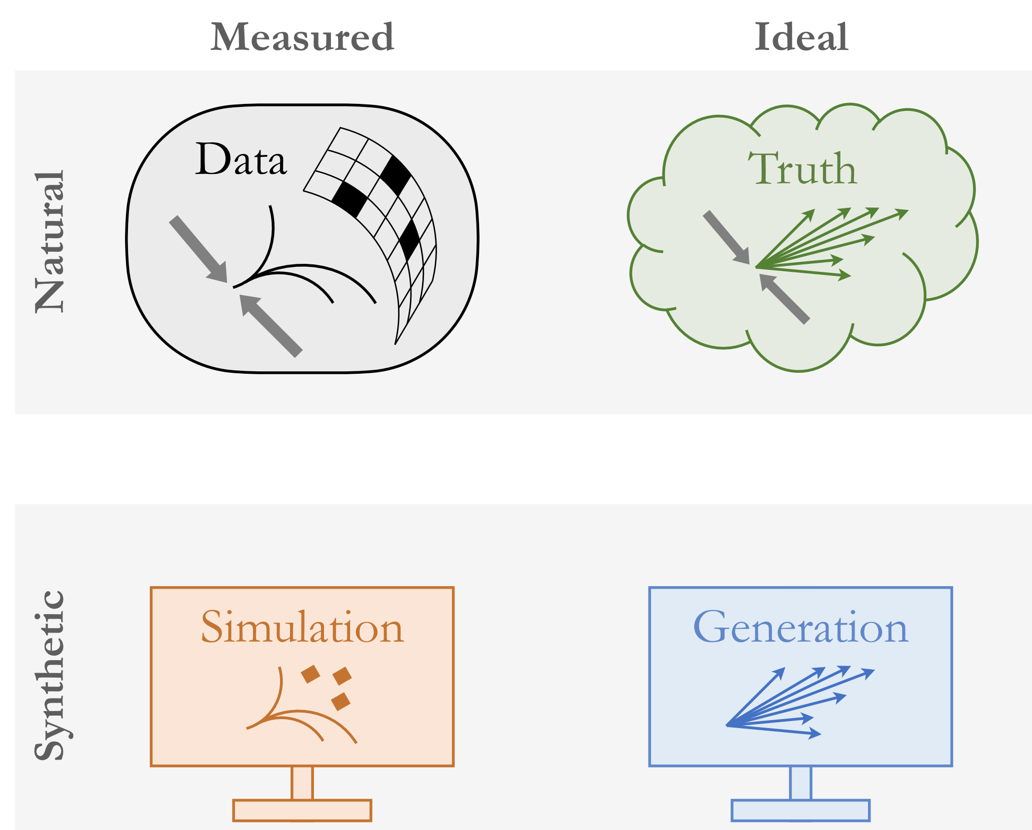
Unfold by iterating: OmniFold

After iteration 1





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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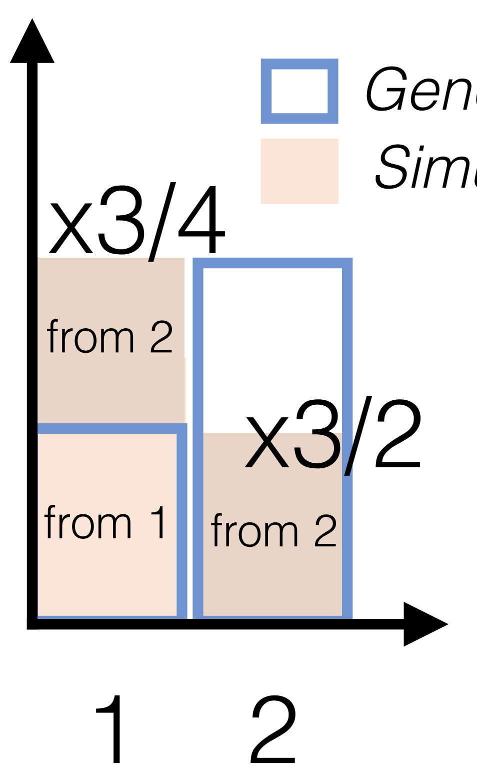
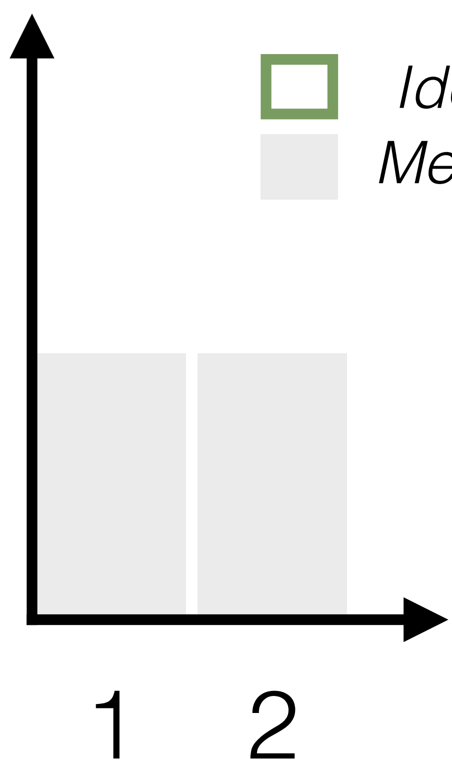
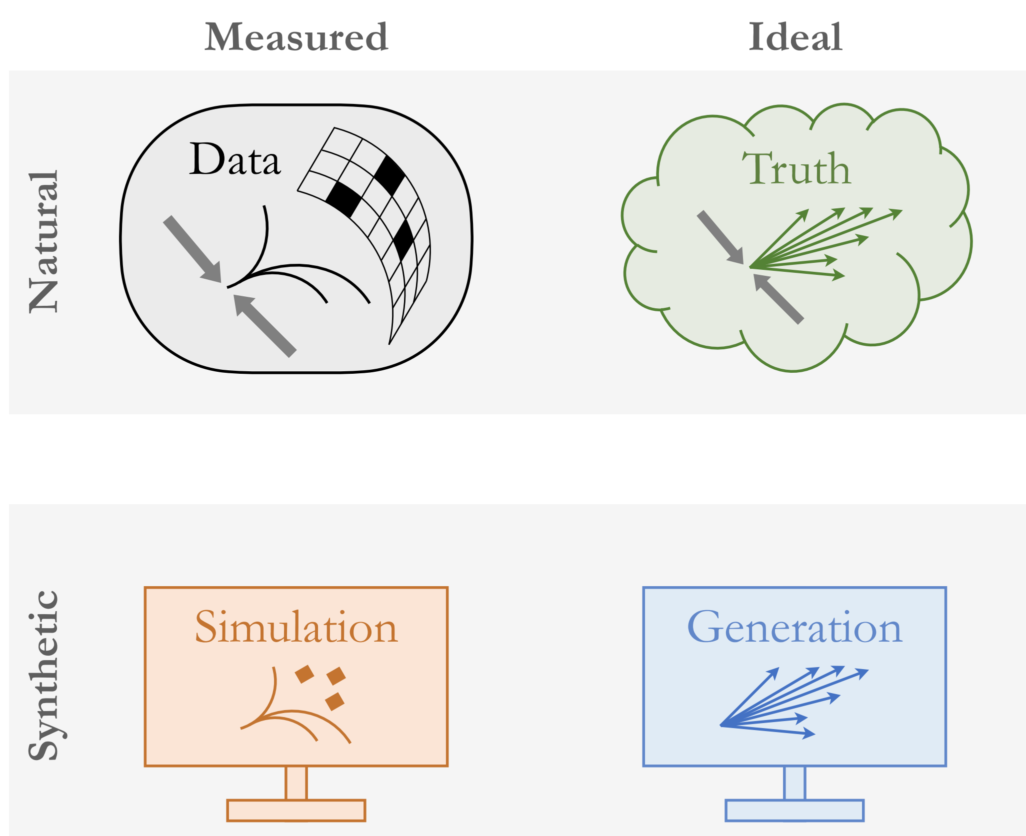
Unfold by iterating: OmniFold

After iteration 1





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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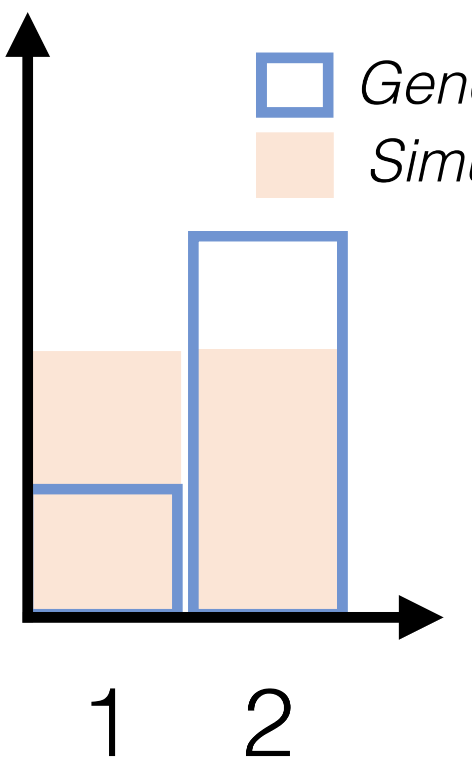
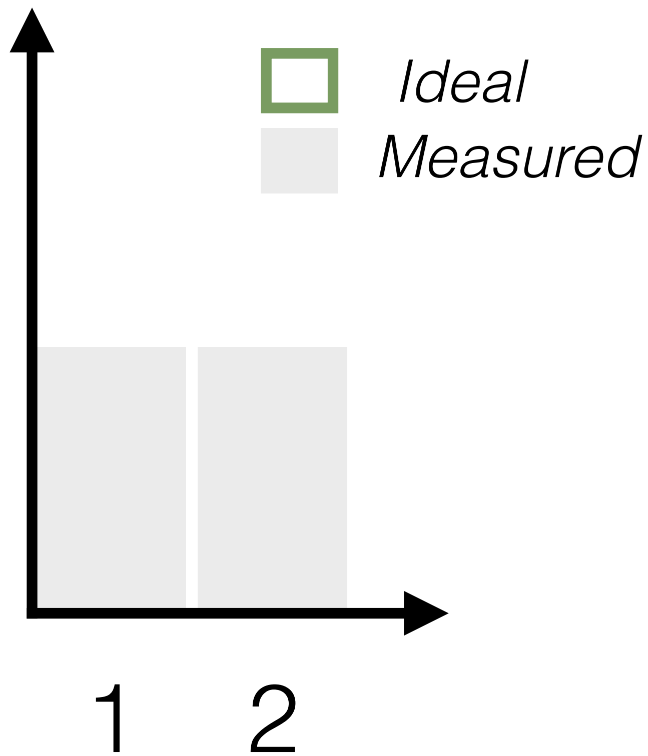
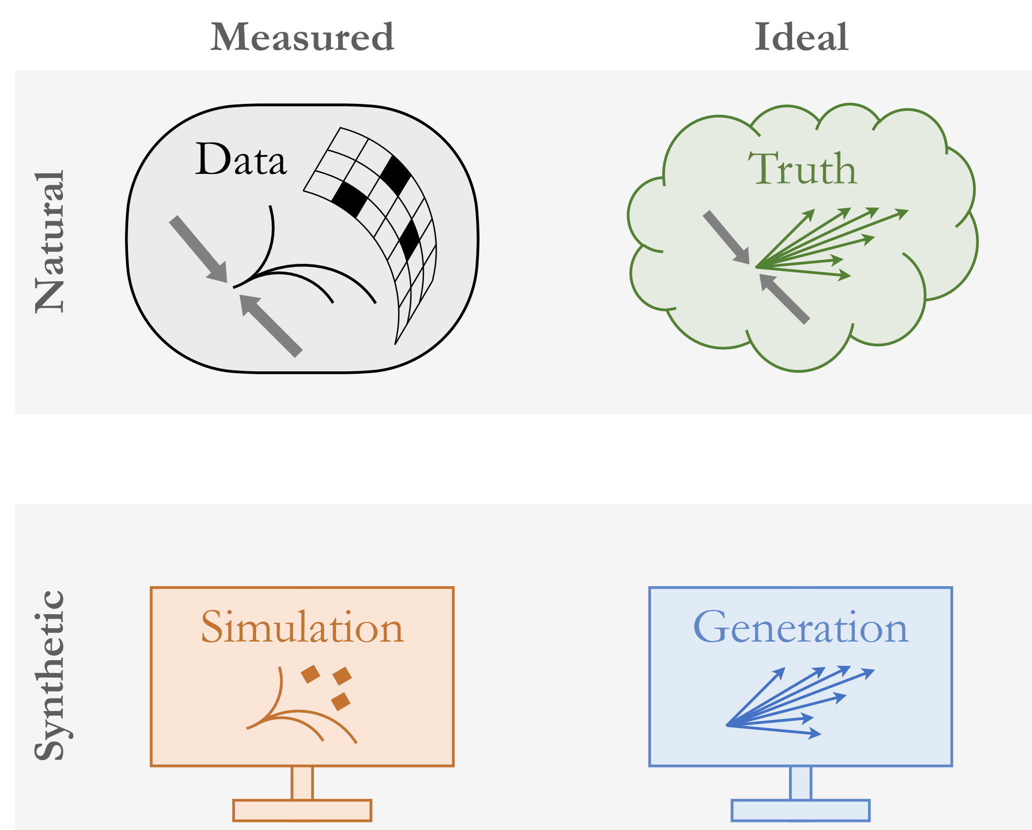
Unfold by iterating: OmniFold

After iteration 2





Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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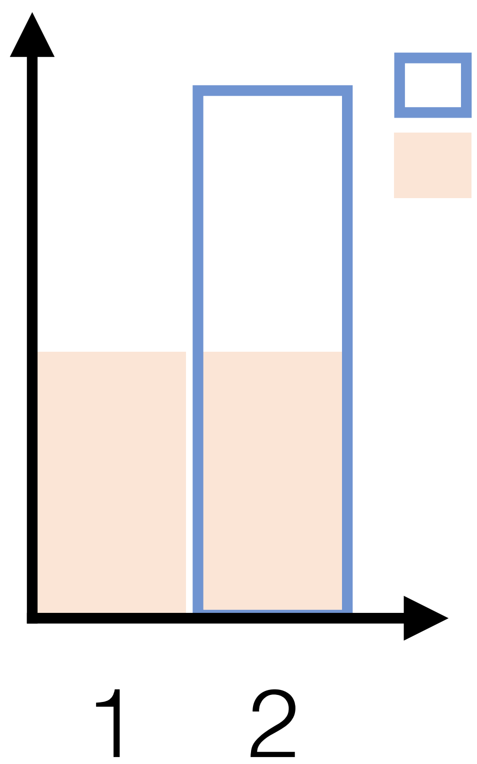
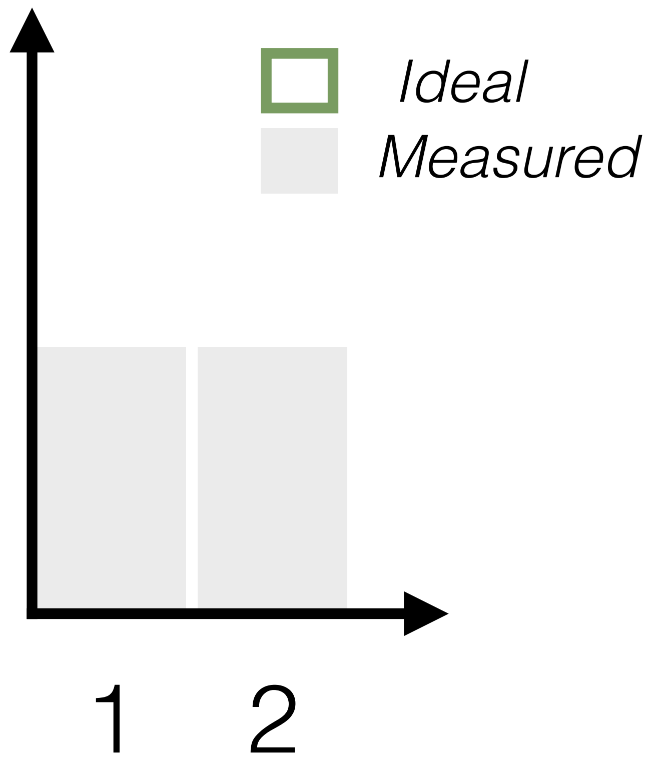
Unfold by iterating: OmniFold

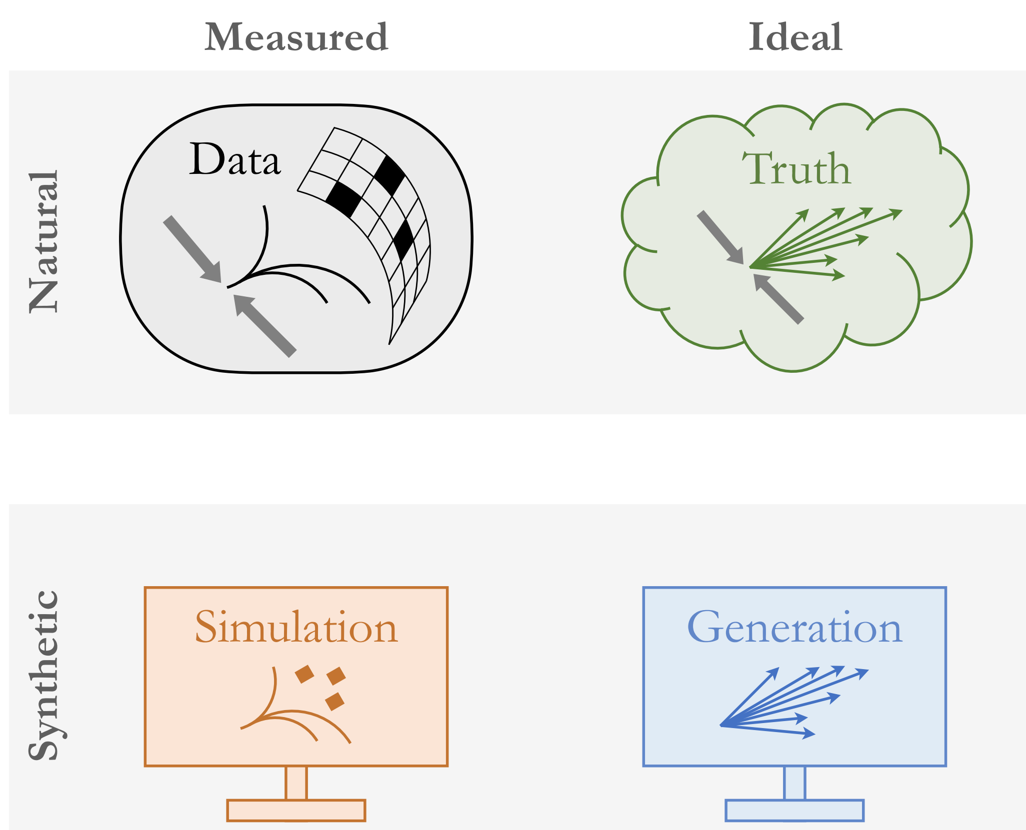
After iteration ∞





N.B. if you just apply p(ideal | measured), *you would have gotten the wrong answer!*

Measured \ Ideal	1	2
2	0%	50%
1	100%	50%



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