QuantOm Collaboration

QUAntum chromodynamics Nuclear TOMography Collaboration

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Argonne NATIONAL LABORATORY

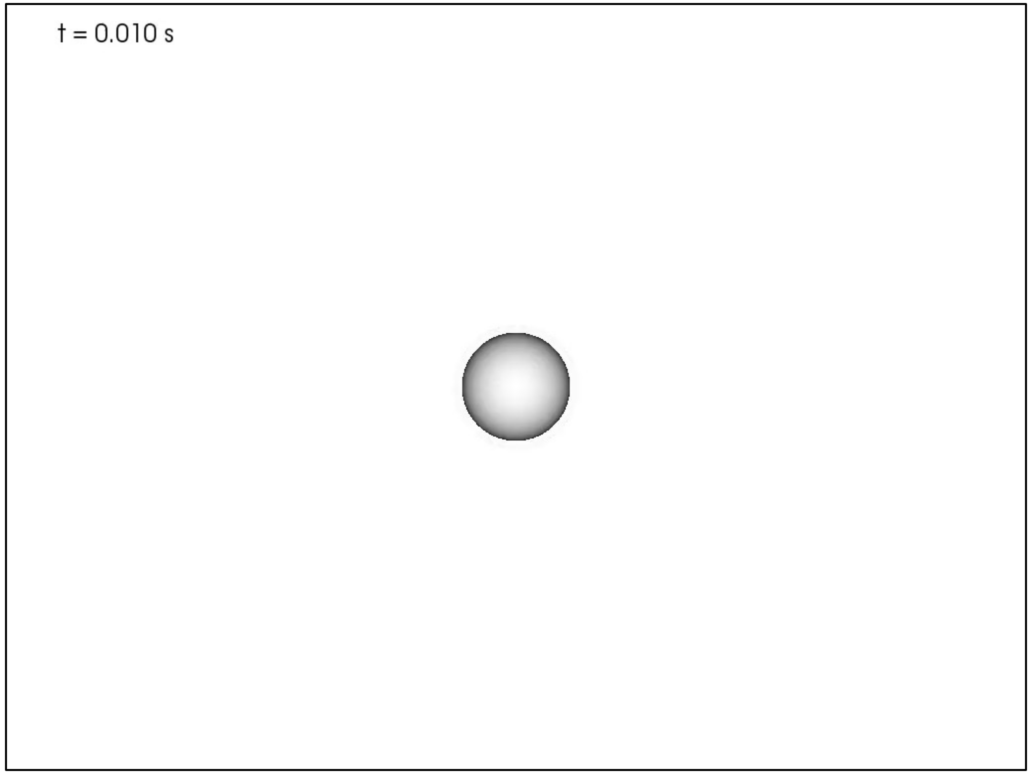
SciDAC overview

- Scientific Discovery Through Advanced Computing
- Initiated in 2001 to develop the Scientific Computing Software and Hardware Infrastructure needed to advance scientific discovery using supercomputers
- Partnership involving all US DOE’s 6 Office of Science (SC) programs
- Every 5 years, calls for new projects and renewals
- 3 current nuclear physics projects
  - **Femtoscale Imaging of Nuclei using Exascale Platforms (this one)**
  - Fundamental nuclear physics at the exascale and beyond
  - Nuclear Computational Low Energy Initiative (NUCLEI)

SciDAC

- Example of a feature from SciDAC

Three-Dimensional Simulations of Core-Collapse Supernova Explosions



QuantOm: https://www.anl.gov/phy/quantom

AIM

- To deliver: Femtoscale imaging of nuclei using exascale platforms

How?

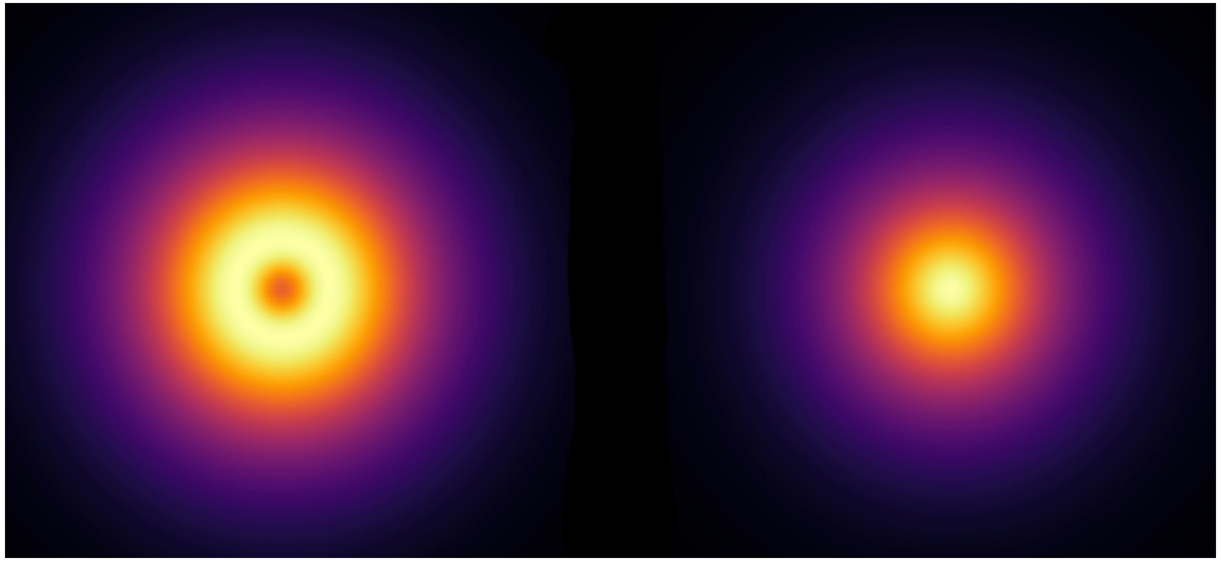
- Convene domain scientists, applied mathematicians, and computational scientists to address the challenge of 3D imaging of quarks and gluons in nucleons and nuclei
- Develop a unique event-level inference framework using high-energy scattering data

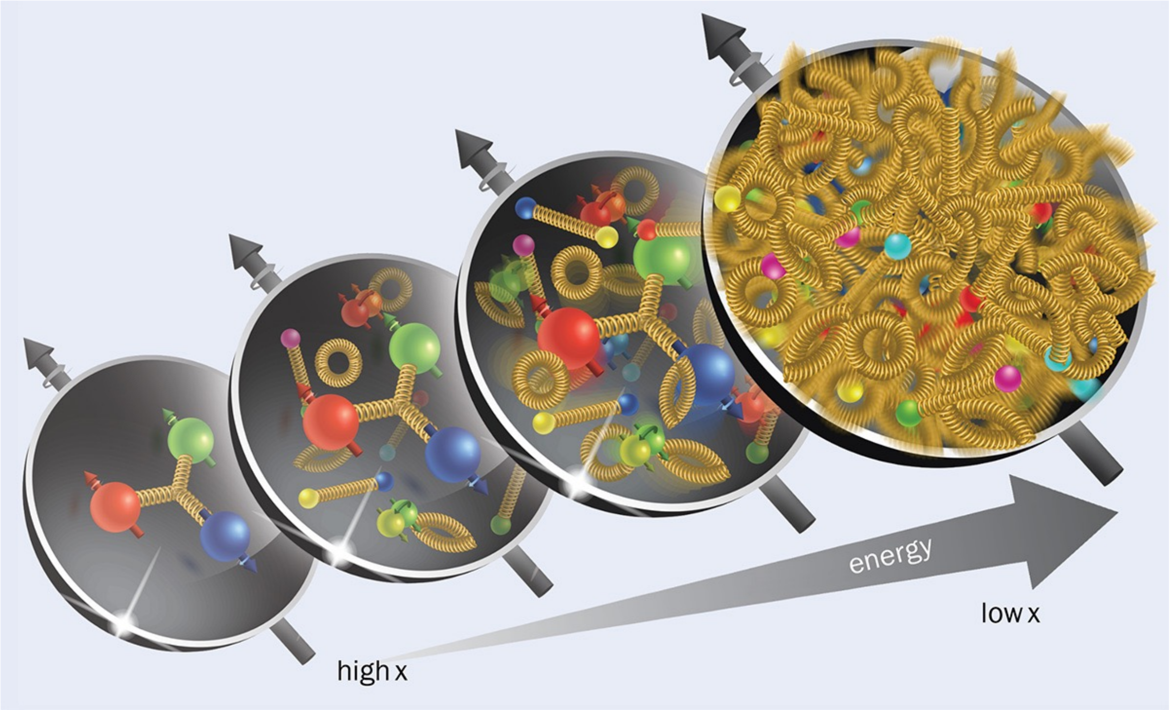
Science questions

- What is the 3d confined motion and spatial distribution of quarks and gluons in nucleons and nuclei?
- How do parton dynamics contribute to emergent phenomena such as mass?

Femtoscale imaging

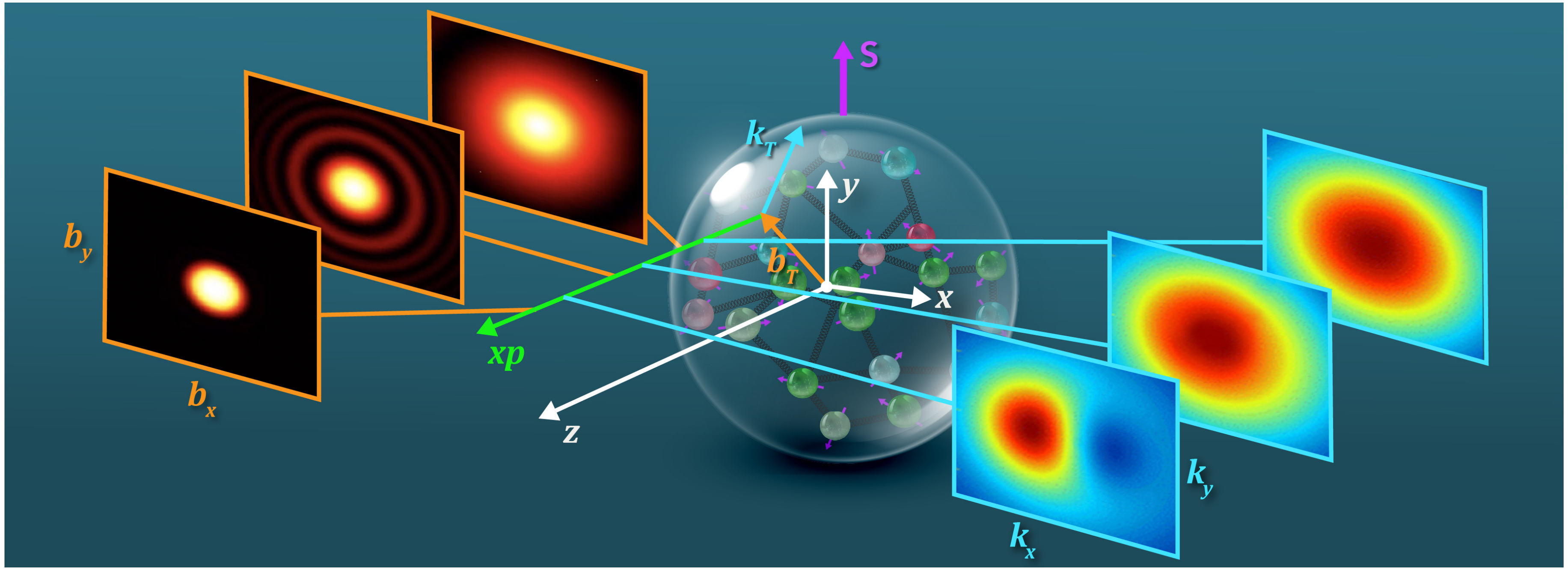
- Taking “pictures” of the proton as a function of scale





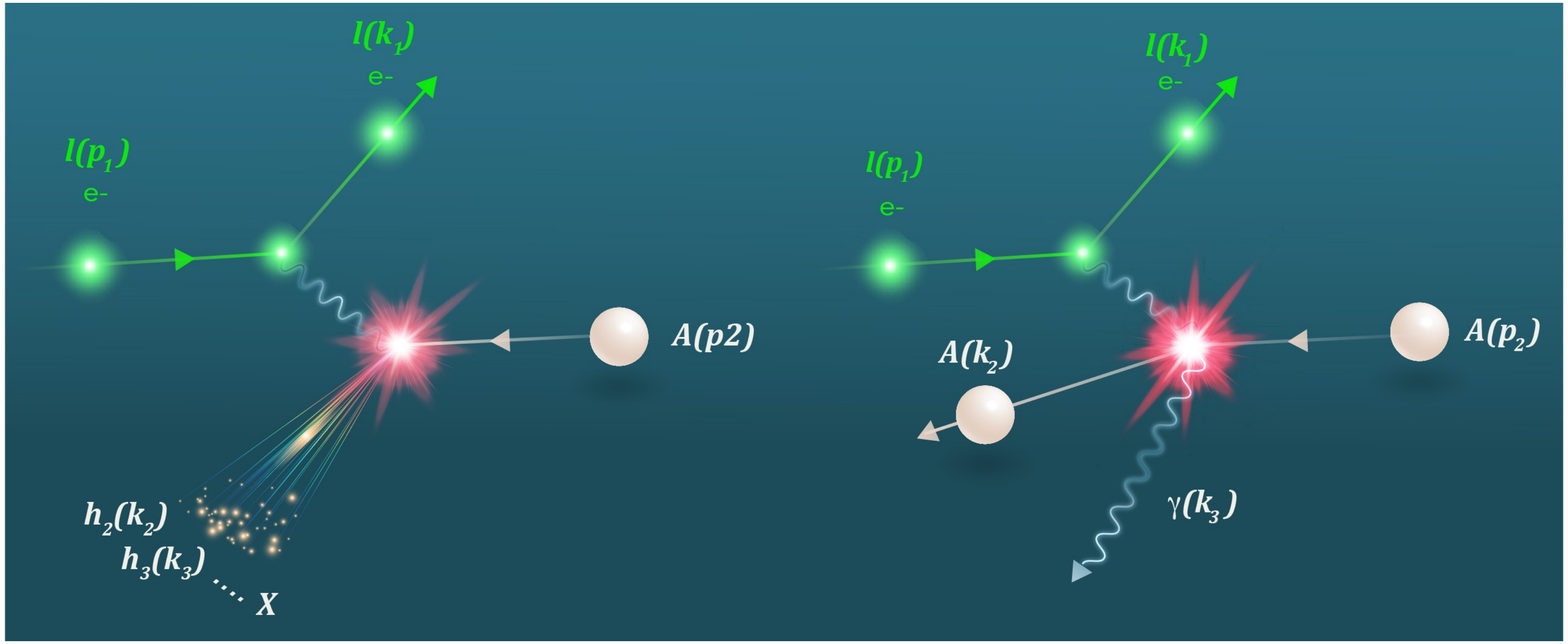
What are we looking for?

- Images of protons in coordinate and momentum space



How do we do it?

- Through experimental data in factorizable processes
- Focus on electron-induced reactions that can be realized at EIC and JLab



SIDIS -- TMDs

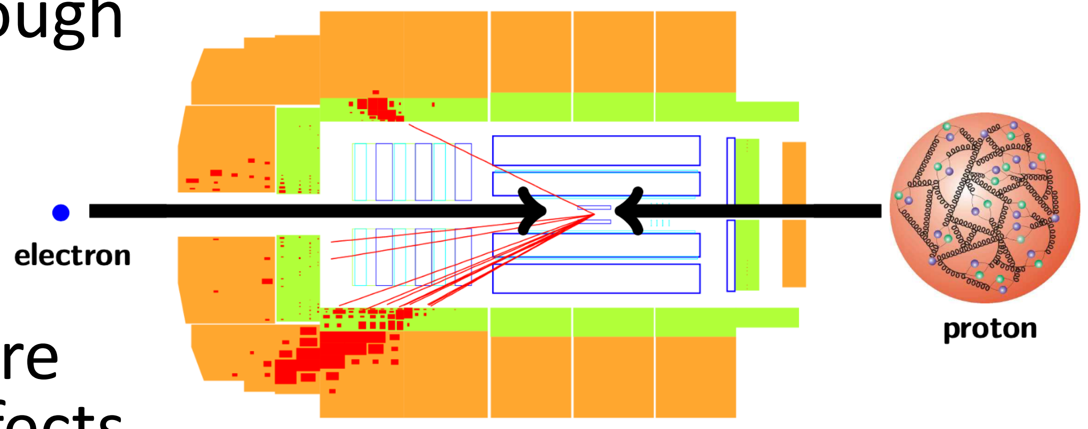
DVCS -- GPDs

Histogram Analysis

- Generally, all data are represented through histograms with each event binned by kinematatics

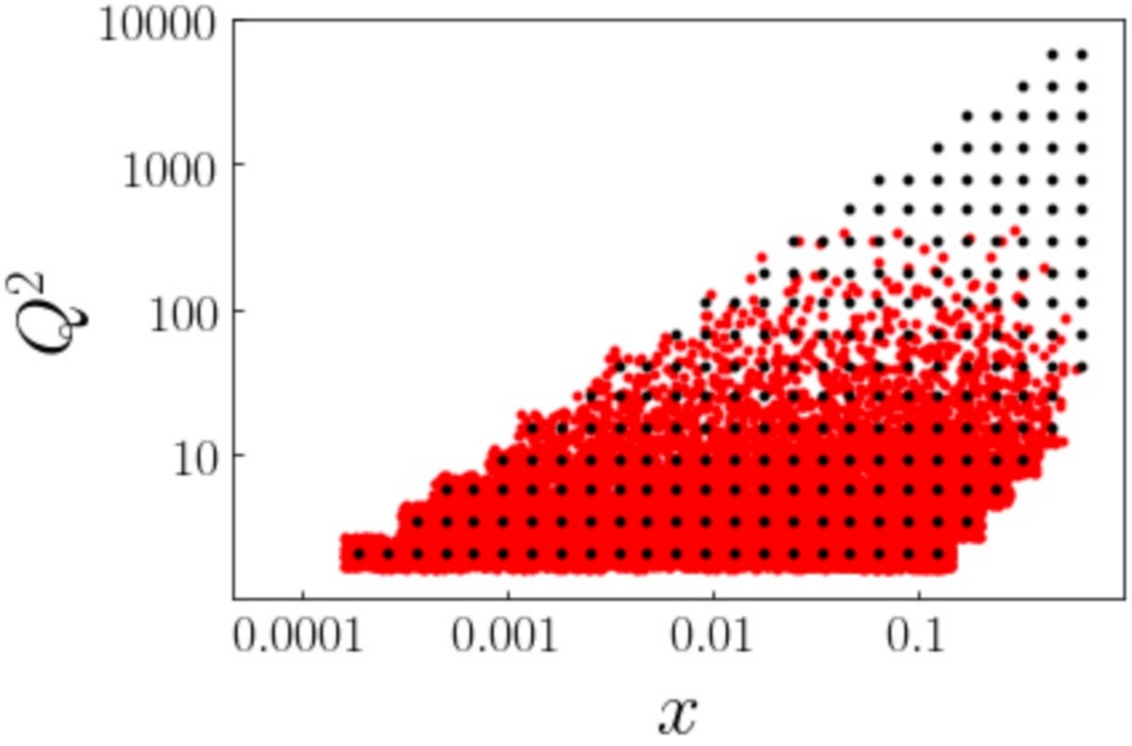
<u>**Disadvantages:**</u>

- Detector effects must be unfolded; more difficult than folding in the detector effects
- **Information lost**
  - Less granularity within bin
  - 3D pictures require events in 5 or more dimensions – need every bit of information gathered!



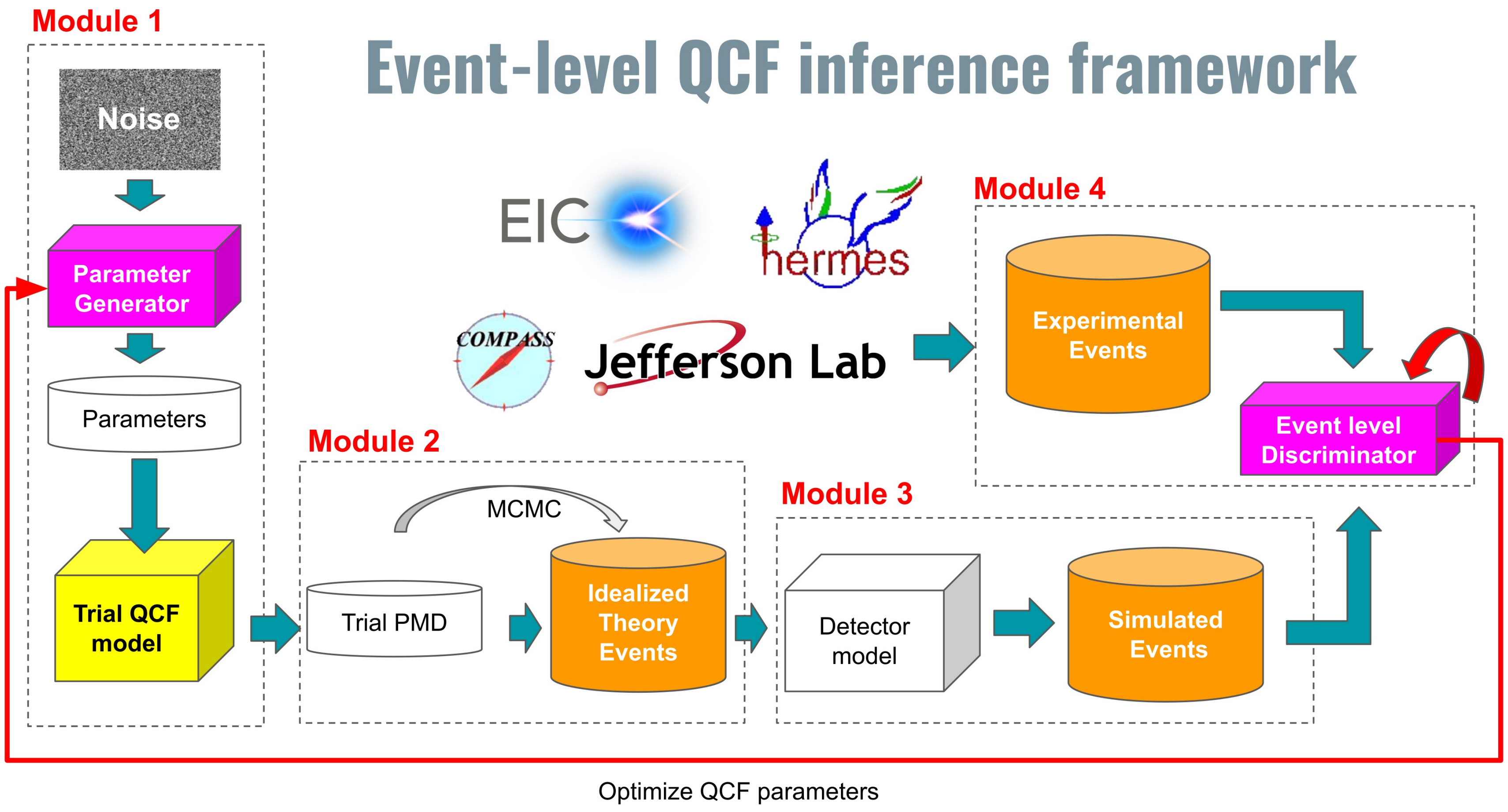
Event-level Analysis

- Not necessary to bin each event into histograms
- Need use of high-performance computing



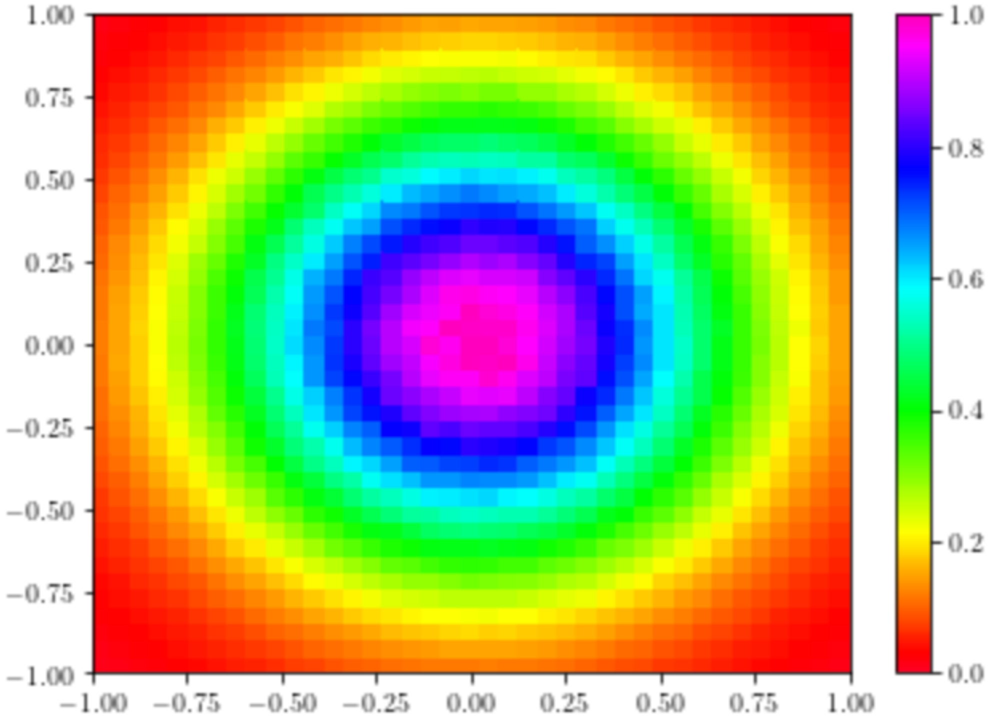
Framework

- Example of generative adversarial network (GAN)
- Feed in noise, through theory and data comparison, update parameter generator
- Need machine learning (ML) and artificial intelligence (AI) techniques

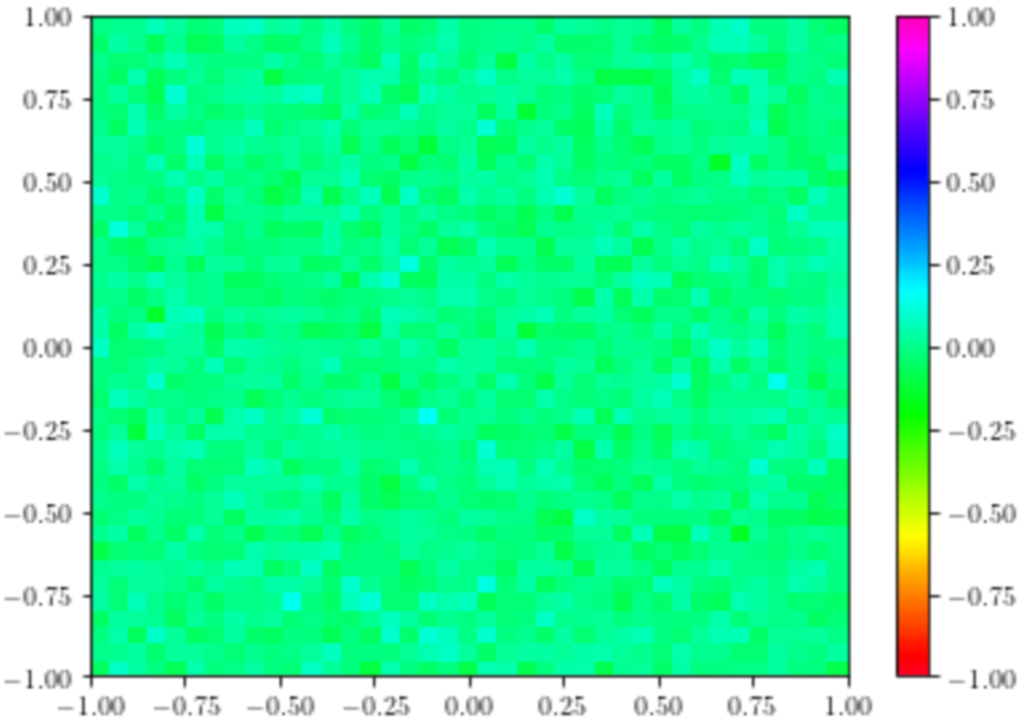


Example of training a GAN - initialize

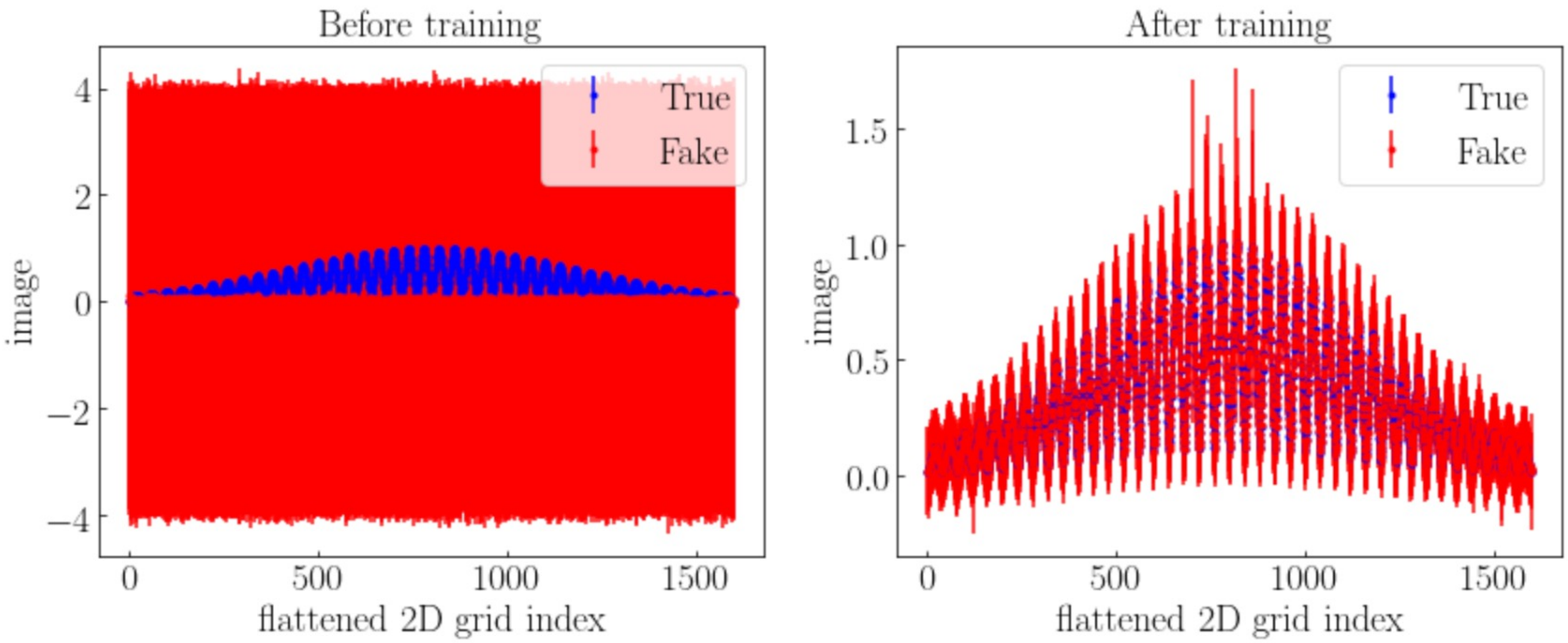
"True" image



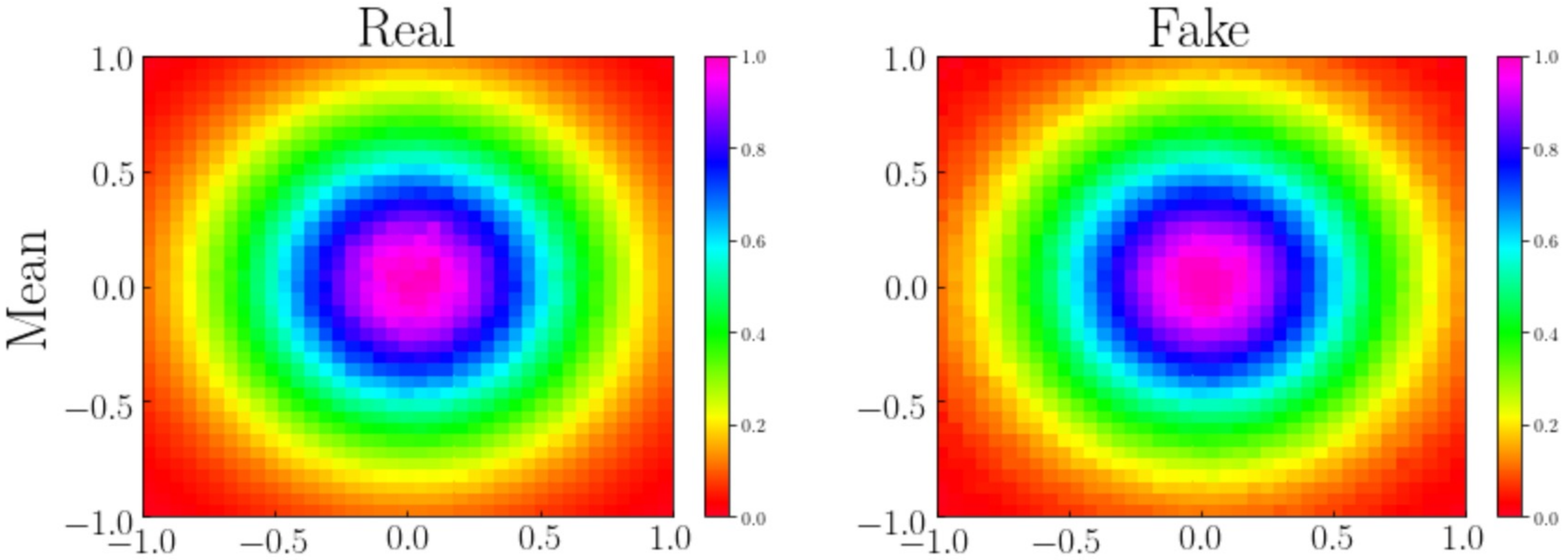
"Fake" image – just noise to start!



Flattened image and training



After training

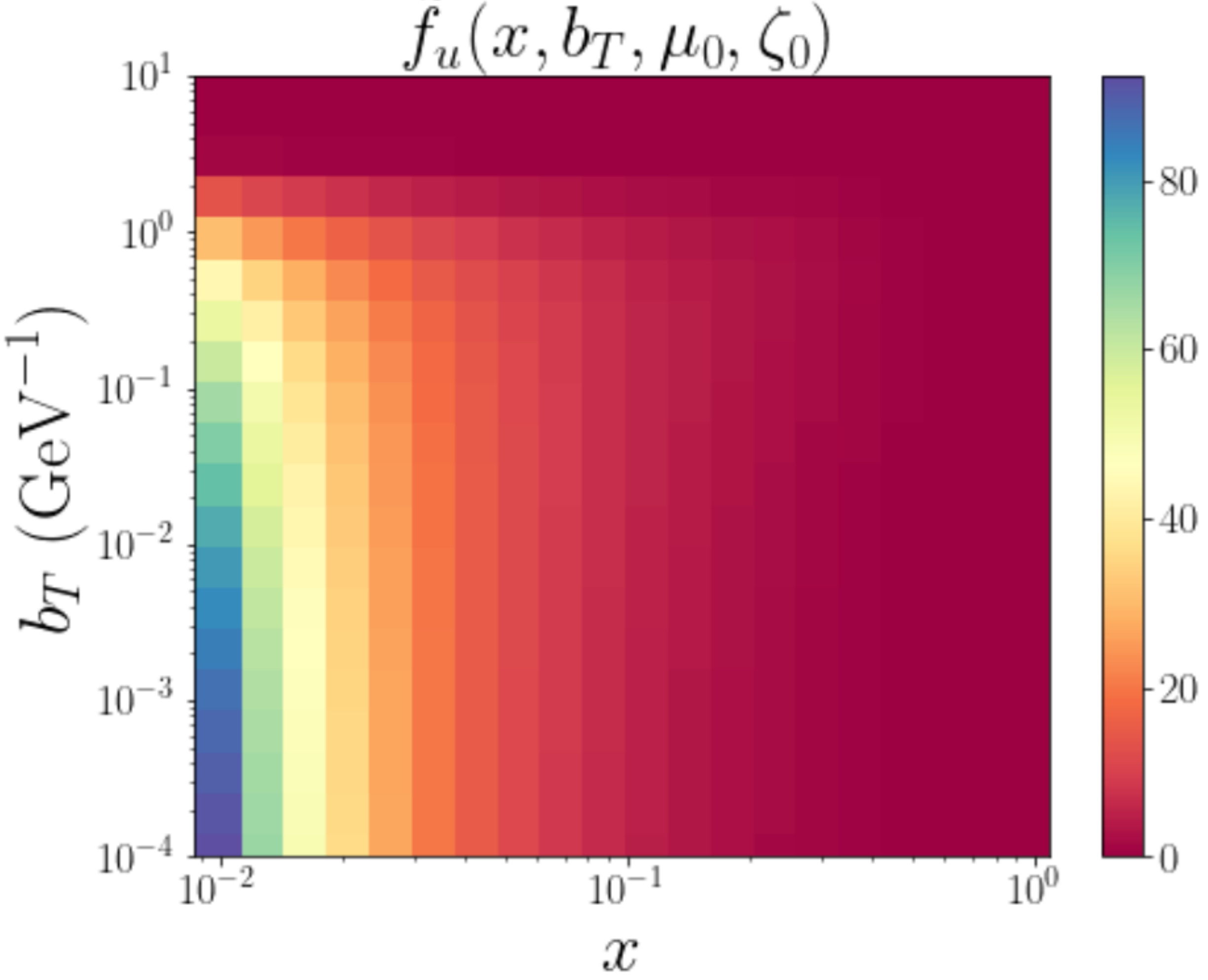


Outlook

- Want to perform on realistic cases
- Start in 1D - train theory events (PDF image-dependent) to match experimental events
- Move to 2D (my focus) – TMDs as a function of x and $k_T = |\boldsymbol{k_T}|$
  - Events are more differential – need a transverse momentum observable
  - Framework needs to be built for this – more challenging than 1d case
  - Create images of TMDs in x and b_T space

Teaser

- Show the initial-scale TMD in (x, b_T)
- Highly peaked at small x and small b_T



And eventually…

- Produce an image of the proton like another popular image