Imaging subnuclear systems:
Concepts, objectives, applications

C. Weiss (JLab), CNF Imaging Workshop, Jefferson Lab, Aug.19-20, 2019
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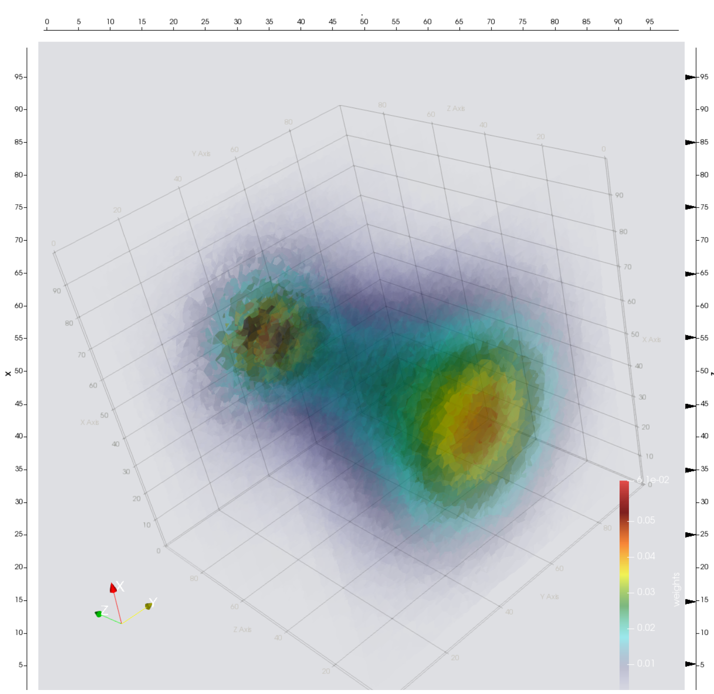


Subnuclear systems

- Scales, properties ⟷ bio/med systems
- Scattering experiments ⟷ microscope

Workflow in measurements

- Model - data comparison

Using imaging techniques - tessellation

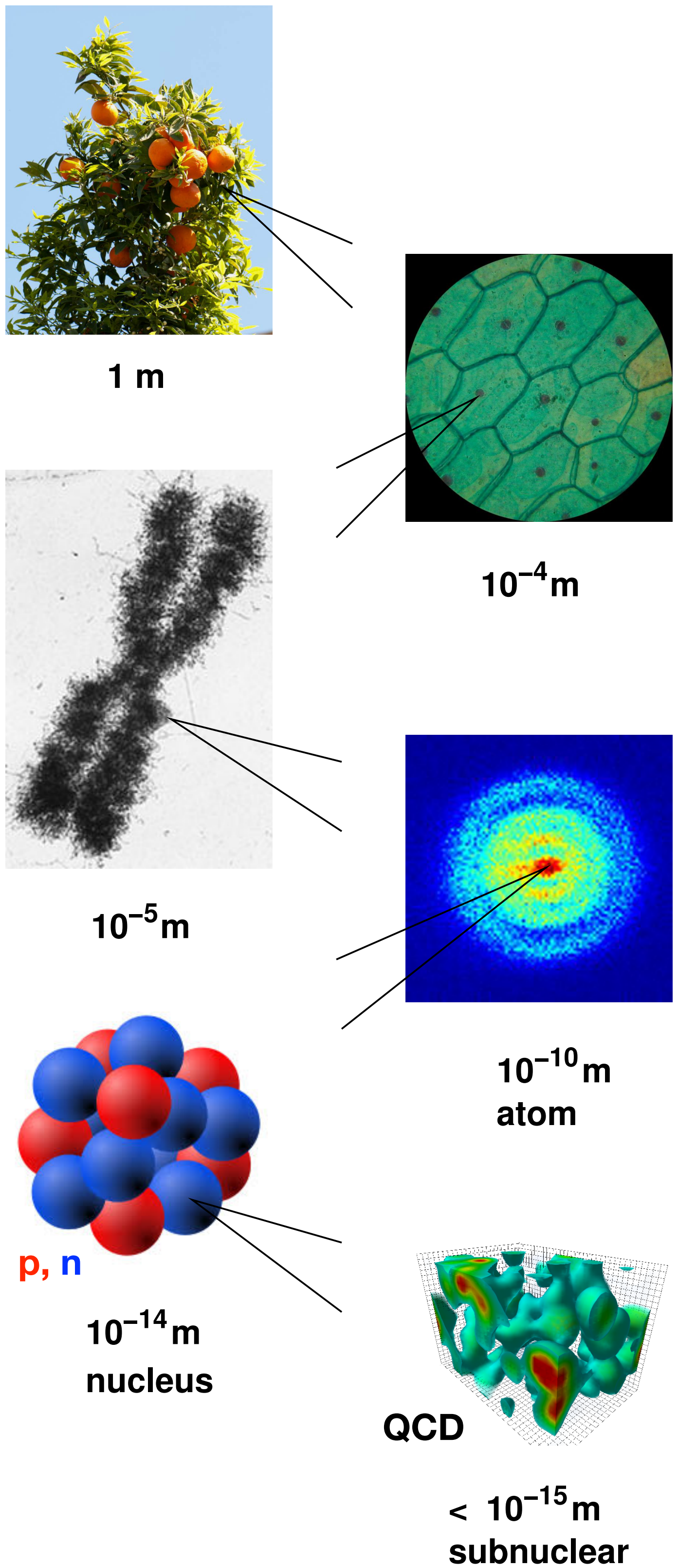
- Analysis of phase space distributions
- Visualization of proton structure

Old Dominion University 1930

Jefferson Lab

CNF Project "Next-generation imaging filters and mesh-based data representation for phase-space calculations in nuclear femtography"

Subnuclear systems: Scales



Emergent phenomena

- Interacting large systems develop complex structure that is not present in “parts”
- Common paradigm in life sciences and physics

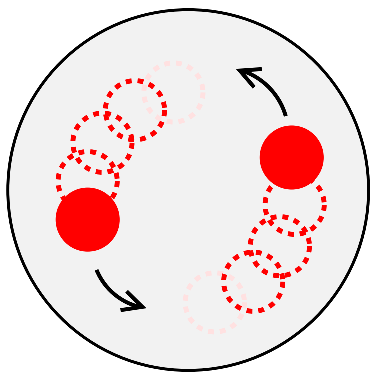
Explore subnuclear systems

- Fundamental theory of strong interaction: Quantum Chromodynamics - quarks, gluons
- Understand proton/neutron as emergent phenomena: Structure, interactions

Interest

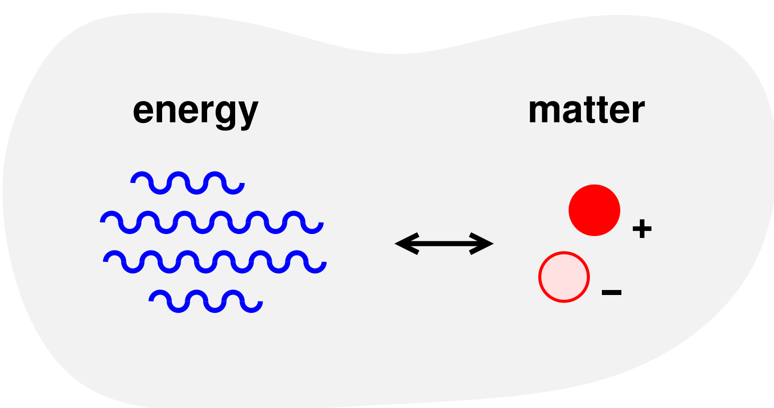
- Intellectual: Basic building blocks of “matter,” 99% of mass in visible Universe
- Applications: Nuclear structure and reactions, nuclear energy, astrophysics

Subnuclear systems: Properties



“Unusual” dynamical system

- Quantum mechanics: Constituents in proton are in “perpetual motion”

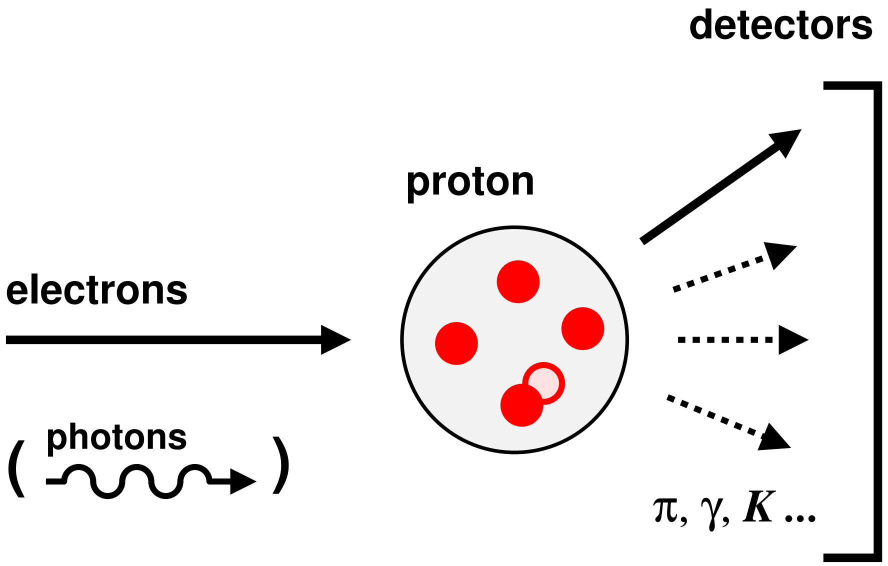


- Relativity: Energy = mass, conversion processes. Proton is “cauldron” filled with radiation energy and matter/antimatter

Implications for measurements and visualization

- Only average properties are measurable: Densities, correlations
- Formulation/visualization of spatial structure possible with appropriate concepts

Subnuclear systems: Scattering experiments



Electron scattering as microscope

- Incident energy determines spatial resolution
- Multi-GeV energies needed for resolving proton's internal structure. 10^5 x hard x-ray energy!
- Use particle accelerators and detectors: Large-scale facilities, world-wide effort
  JLab 12 GeV: Energy x intensity frontier

Information recorded

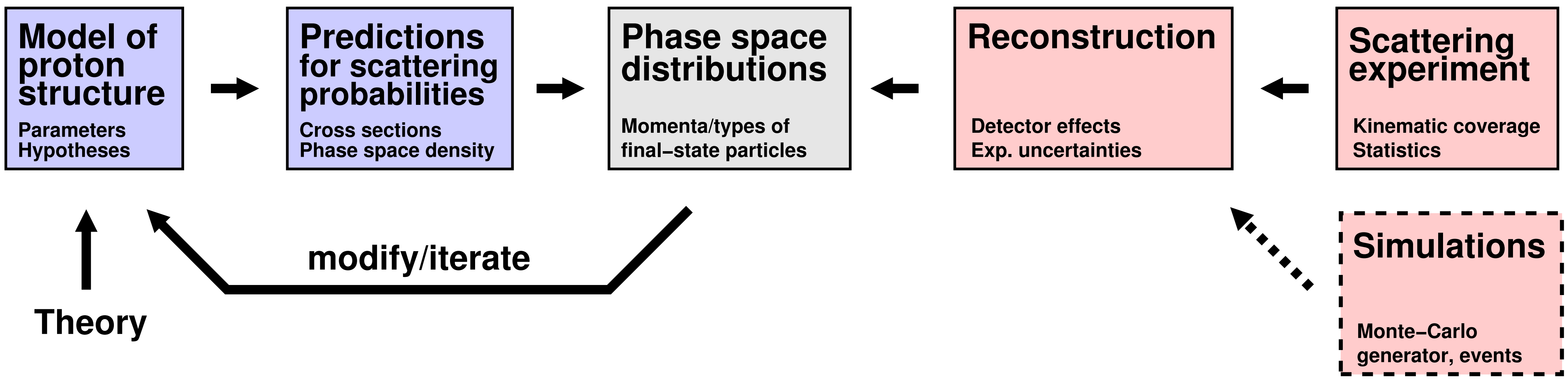
type	p_x	p_y	p_z
π	X	X	X
π	X	X	X
K	X	X	X
⋮	⋮		

+

[for each scattering event]

- Phase space distribution of particles produced in scattering events: types, momenta
- "Expression" of proton's internal structure (in average sense)
- Large number of scattering events: 10^6-10^9 in typical JLab experiments

Workflow: Measurements



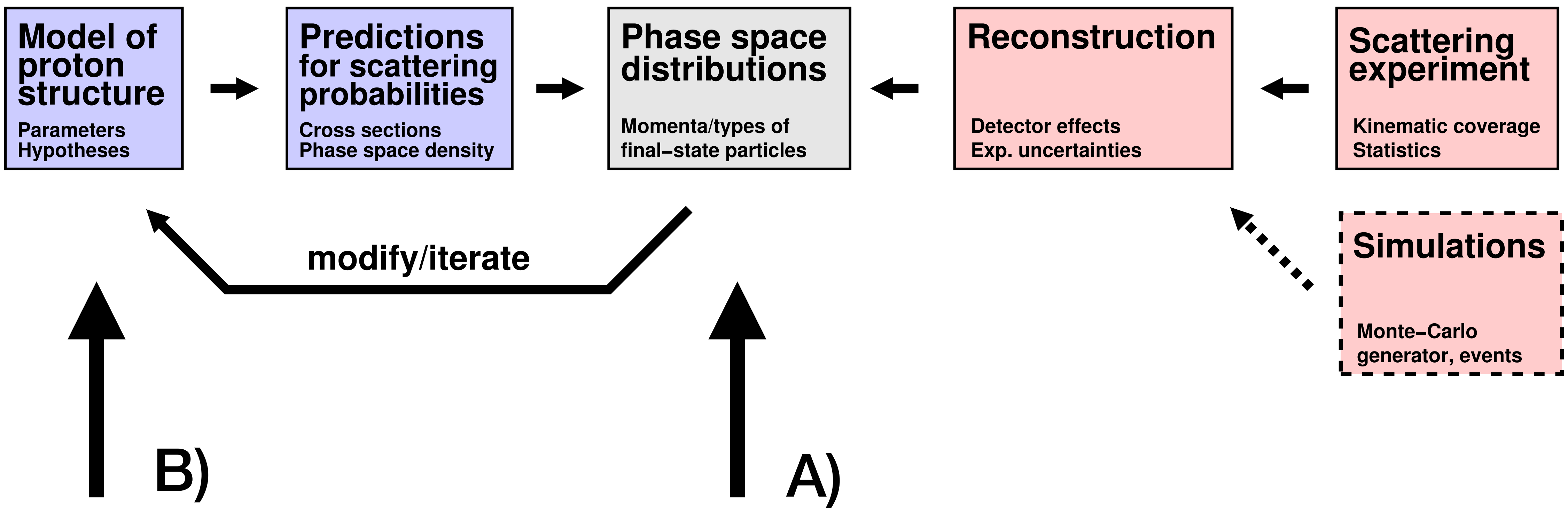
- Phase space distributions as “meeting ground” between theoretical models and experimental data/simulations

- Uncertainty quantification essential - theoretical, experimental

- Operated with actual experimental data or Monte-Carlo simulations

- “Final” picture of proton from synthesis of multiple experiments and theoretical models

Workflow: Using imaging techniques



A) Phase space distributions: Use imaging techniques (tesselation, slicing, viewing, …) for representation and analysis of phase space data

B) Proton structure: Use imaging techniques for visualization of subnuclear system and synthesis of information

Imaging: Phase space distributions

- Phase space distributions = types + momenta of particles produced in scattering events. Multidimensional distribution with attributes.

- Large data volume: ~ 10^6-10^9 events in typical experiments

Operations needed in analysis

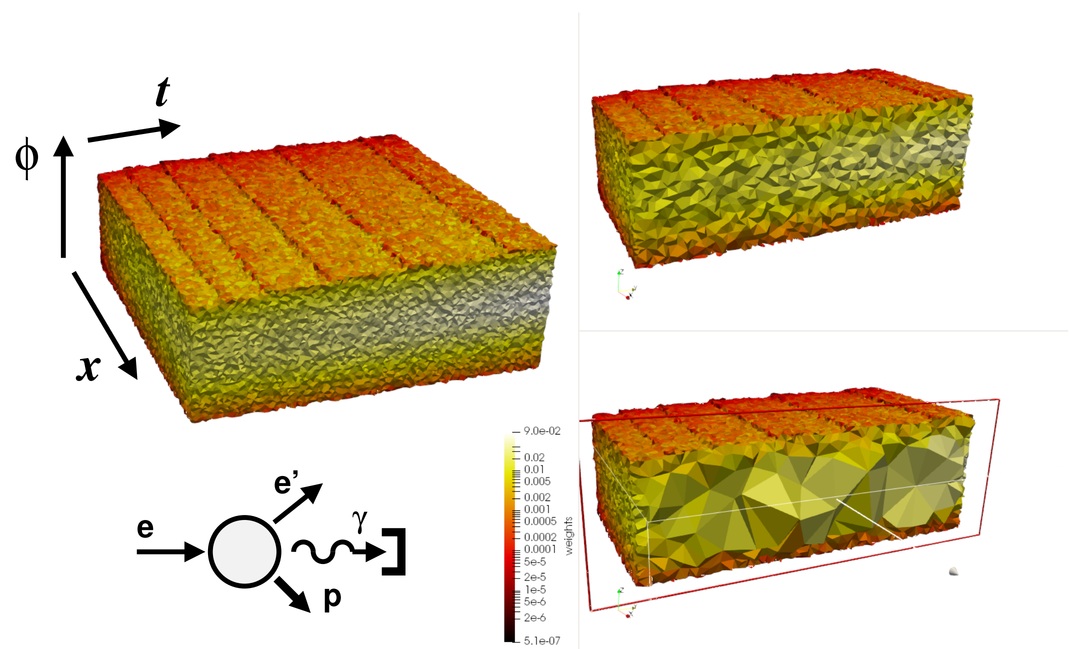
- View distributions - projections, cuts, features
- Compare distributions from different physics models
- Interpolate/refine distributions for simulations

Used so far

- Dedicated tools FORTRAN/C++
- Uniform cells/bins

New: Use tesselated representation

→ Presentation by G. Gavalian



- 3-dim phase space divided in tetrahedral cells, generalizable to N-dim

- Compact, memory-efficient representation

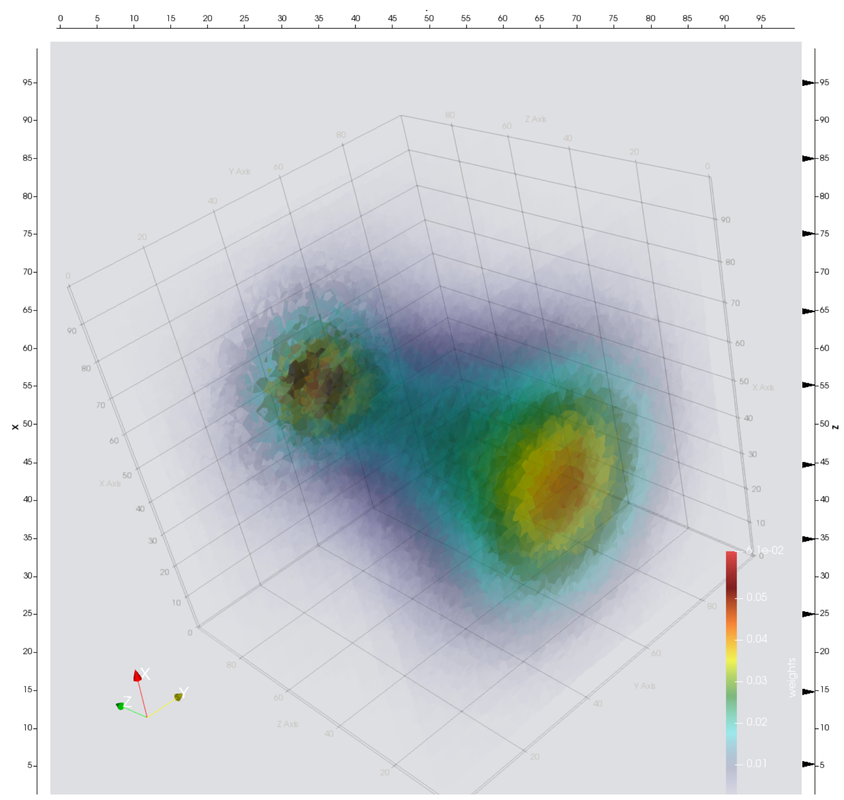
- Adaptive mesh generation for accuracy

- Viewing/Slicing with ParaView

- Efficient interpolation/refinement for MC simulations

Imaging: Visualization of proton

Tomographic image of u-quark density in proton
[theoretical model, not actual experimental data]



- Tomographic image (set of projections) of quark density in proton along axis of high-energy scattering process
- Image concept appropriate for relativistic quantum system
- Synthetic image, constructed with information from theory and multiple experiments
- Fundamental physics interest: Spatial size, internal motion of quarks, …

New: Tesselated representation

- Viewing/Slicing with ParaView
- Next-generation visualization?

→ Presentation by G. Gavalian

Summary

- Subnuclear systems have a composite internal structure with unique properties: internal motion, interactions

- The internal structure is expressed in the phase space distributions of particles produced in high-energy scattering experiments

- Novel applications of imaging methods using tessellated representation

  A) Analysis of phase space distributions

  B) Visualization of proton structure

- Looking forward to discussions!