

# The Future of A+A at RHIC: Beyond the Plasma

How our discoveries at RHIC will now enable  
us to investigate all-new regimes of QCD

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~~Hardware~~

# What have we learned at RHIC so far? (warning: greatly compressed)

Strong modification of jets

↳ High Density

Medium “senses” its initial (transverse) geometry

↳ Fast local equilibration

Evolution preserves transverse anisotropy

↳ Low dissipation (ie shear viscosity)

⇒ Strong self-interaction: the **sQGP**

## Physics Question

What is the 3+1D evolution of the collision?

What are the transport/ non-equilibrium properties of the QGP?

How are conserved quantum numbers transported?

How does the QGP decay? I.e. hadronization

What happens at higher baryon density (incl. phase plane)?

What is the parton-medium interaction?

How/when is initial equilibration/ entropy generation achieved?

Are there nuclear effects at very high  $Q^2$ ?

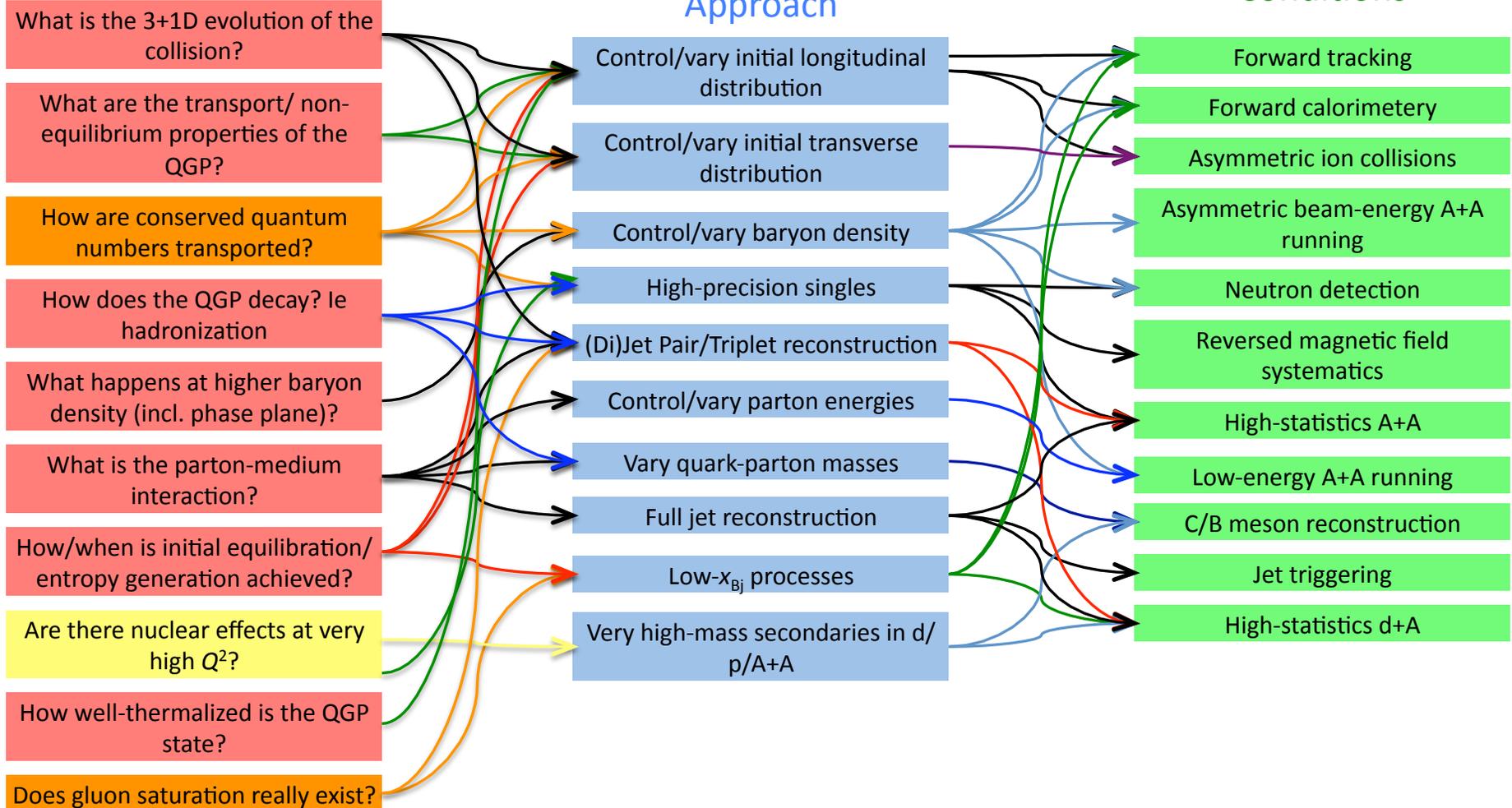
How well-thermalized is the QGP state?

Does gluon saturation really exist?

## Physics Question

## Measurement Approach

## Detector & Running Conditions



# Three Eras of QCD

## **Era I: Perturbative QCD**

Great successes include running of  $\alpha_s$  and evolution of hadron structure functions

## **Era II: Thermal QCD**

The QGP state of matter: state  $\rightarrow$  static  $\rightarrow$  equilibrium, but near-equilibrium (transport) properties are very interesting

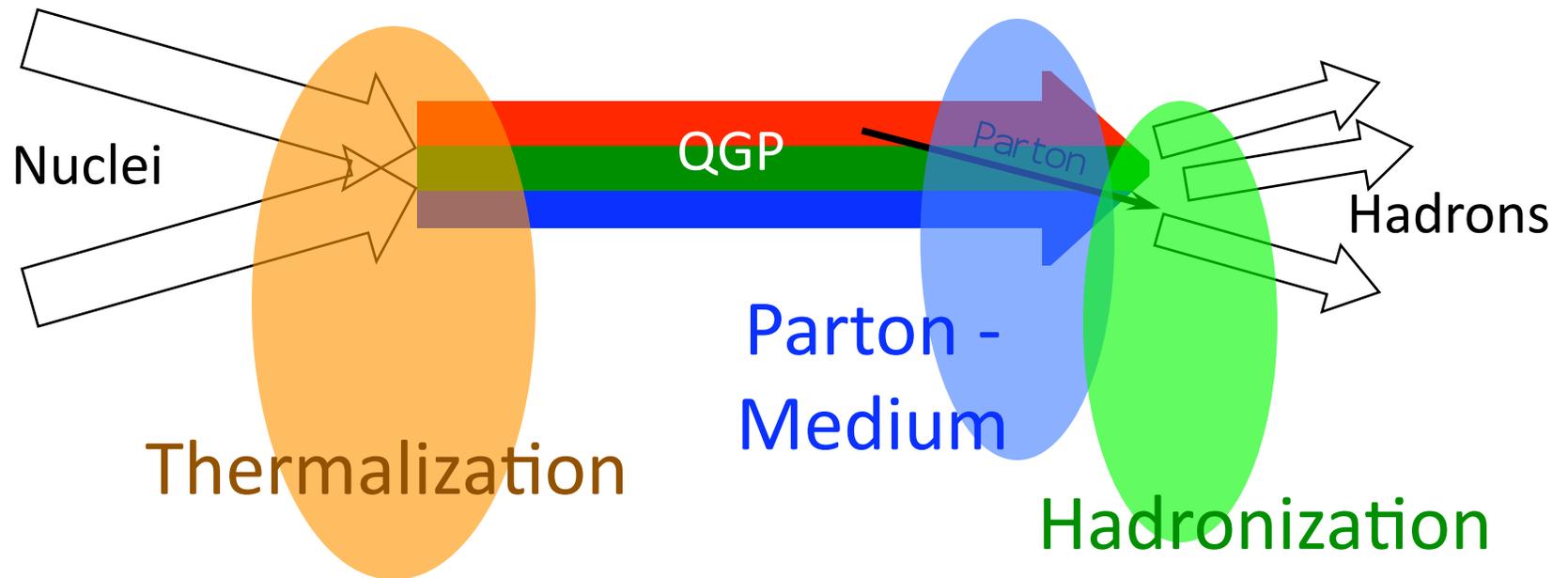
## **Era III: Non-perturbative, Non-thermal QCD**

A big tent! that previous successes now enable us to investigate within A+A collisions at RHIC

*“Our discoveries at RHIC, in addition to being intriguing in their own right, will now enable us to systematically and quantitatively investigate all-new non-perturbative, non-thermal regimes of QCD.”*

sQGP: Locally equilibrated, nearly ideal hydrodynamics; but with interesting transport properties

→ Textbook?



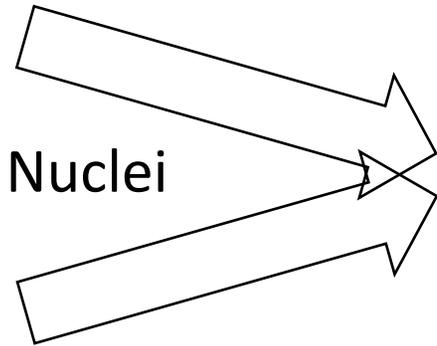
*New, fundamental QCD physics questions lie beyond the plasma!*

Are there nuclear effects at very high  $Q^2$ ?

Does gluon saturation really exist?



### Era I: Perturbative



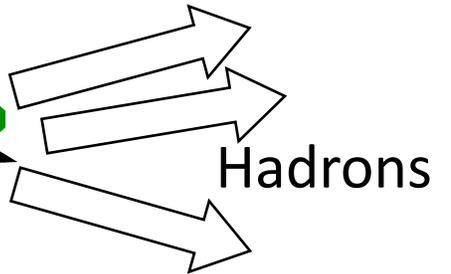
How well-thermalized is the QGP state?

What happens at higher baryon density?

What is the 3+1D evolution of the collision?



### Era II: Thermal



What are the transport/non-equilibrium properties of the QGP?

How does the QGP decay? i.e. hadronization

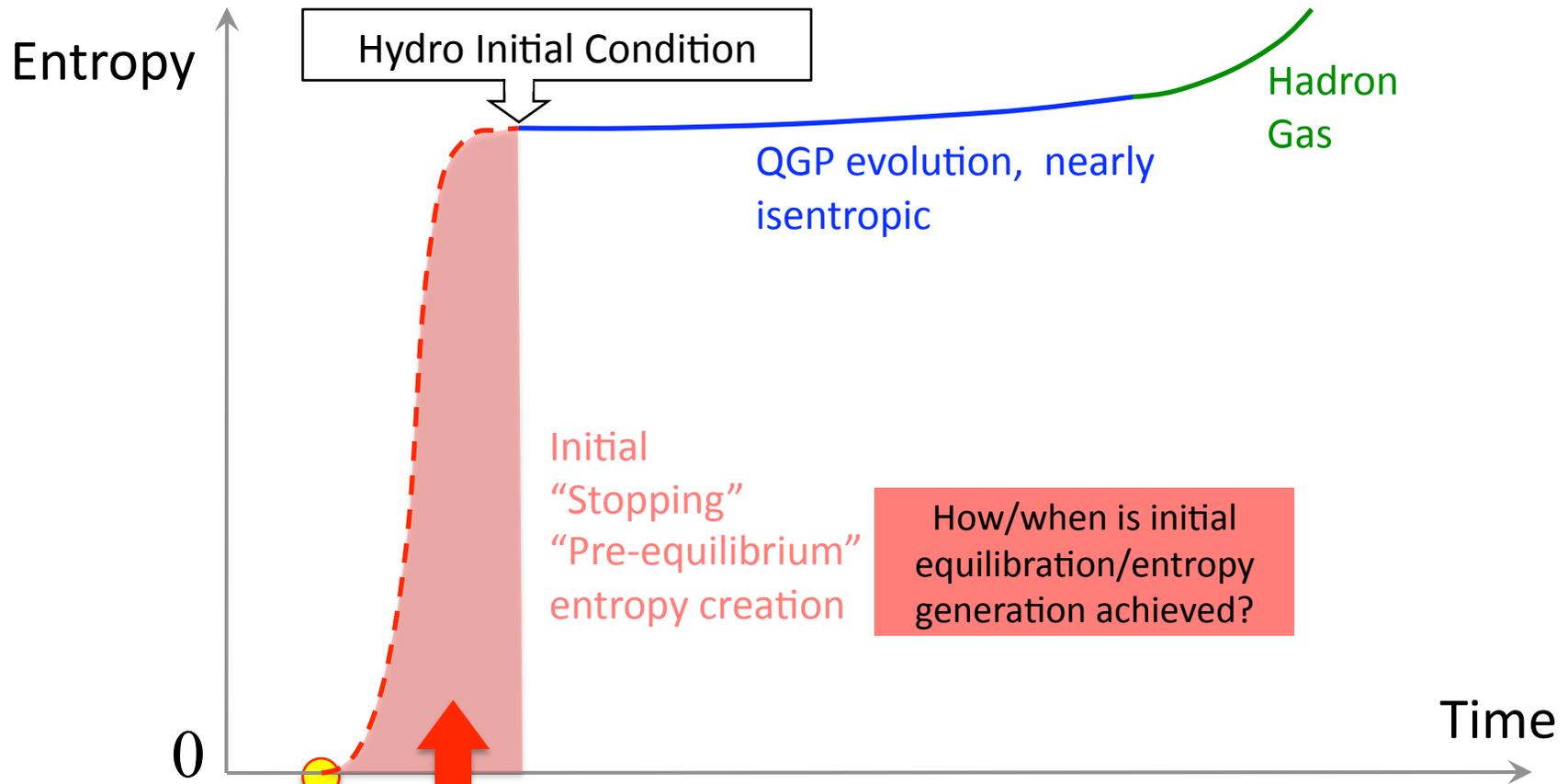
How/when is initial equilibration/entropy generation achieved?

How are conserved quantum numbers transported?

What is the parton-medium interaction?



### Era III: Non-Perturbative and Non-Thermal



Non-Perturbative  
Non-Equilibrium  
QCD

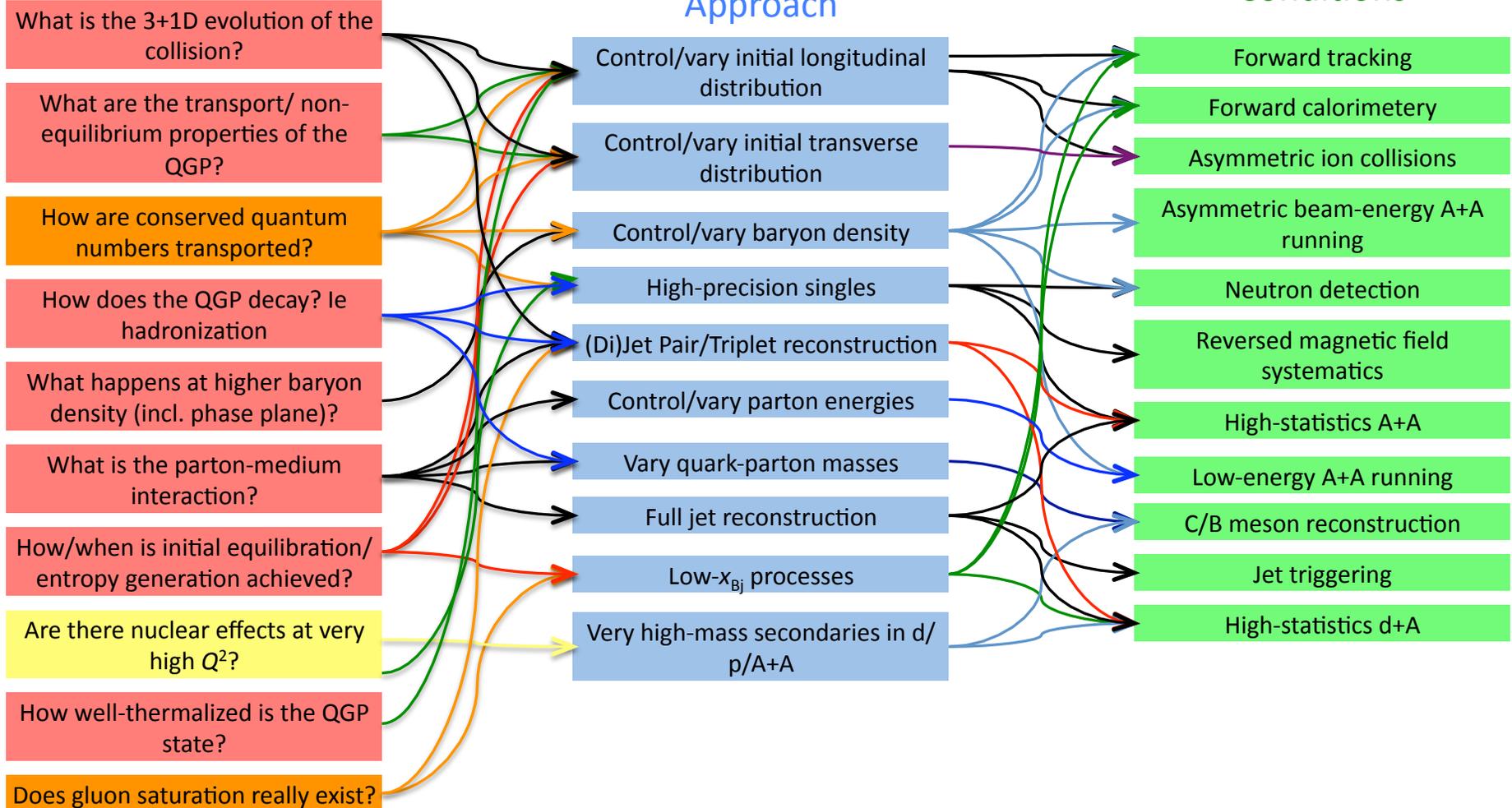


The  
Big  
Fish

## Physics Question

## Measurement Approach

## Detector & Running Conditions



## Physics Question

What is the 3+1D evolution of the collision?

How/when is initial equilibration/  
entropy generation achieved?

## Measurement Approach

Control/vary initial longitudinal distribution

Control/vary initial transverse distribution

(Di)Jet Pair/Triplet reconstruction

Low- $x_{Bj}$  processes

## Detector & Running Conditions

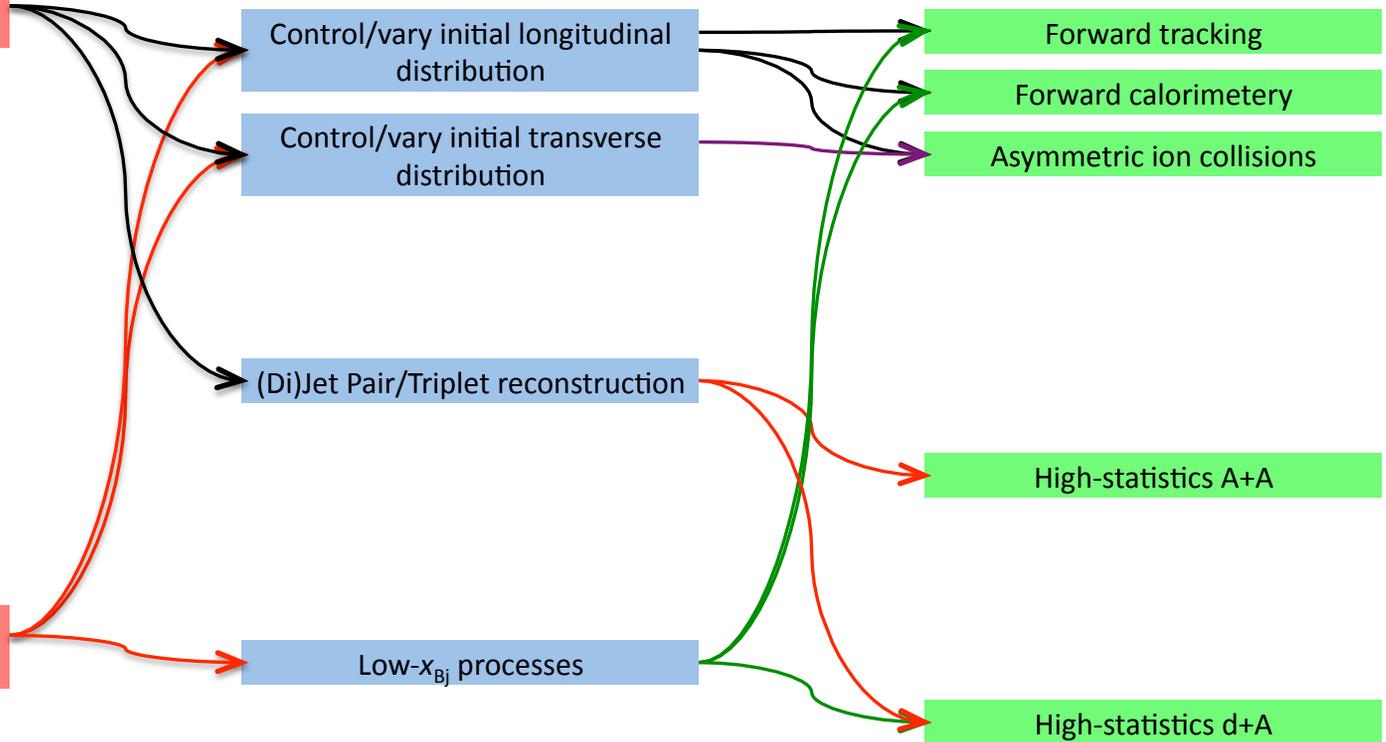
Forward tracking

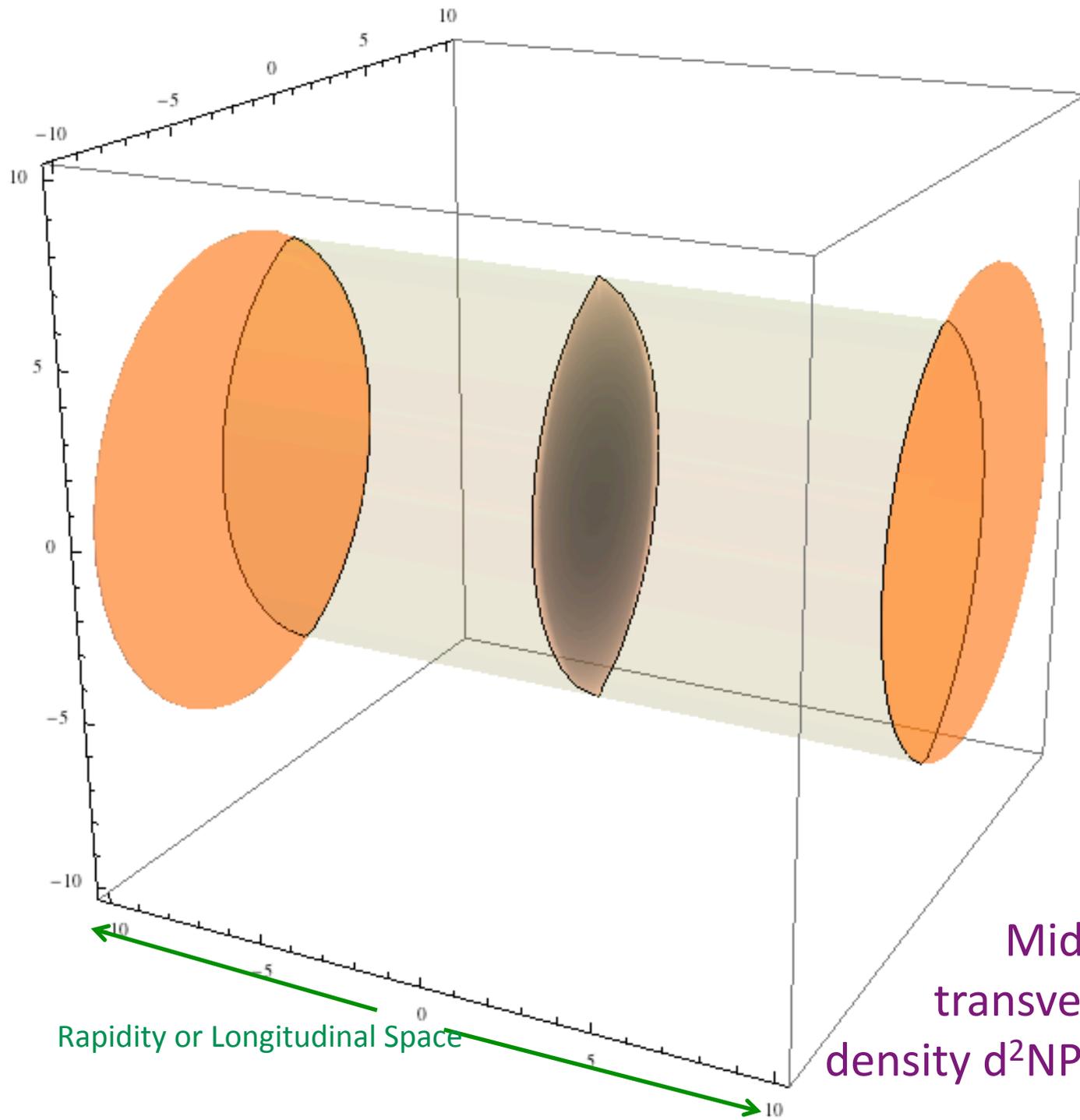
Forward calorimetry

Asymmetric ion collisions

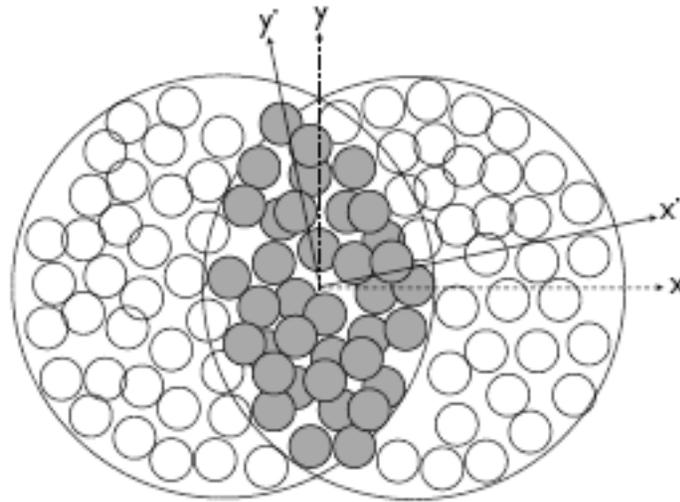
High-statistics A+A

High-statistics d+A





Mid-rapidity  
transverse slice,  
density  $d^2N_{Part}/dx dy$

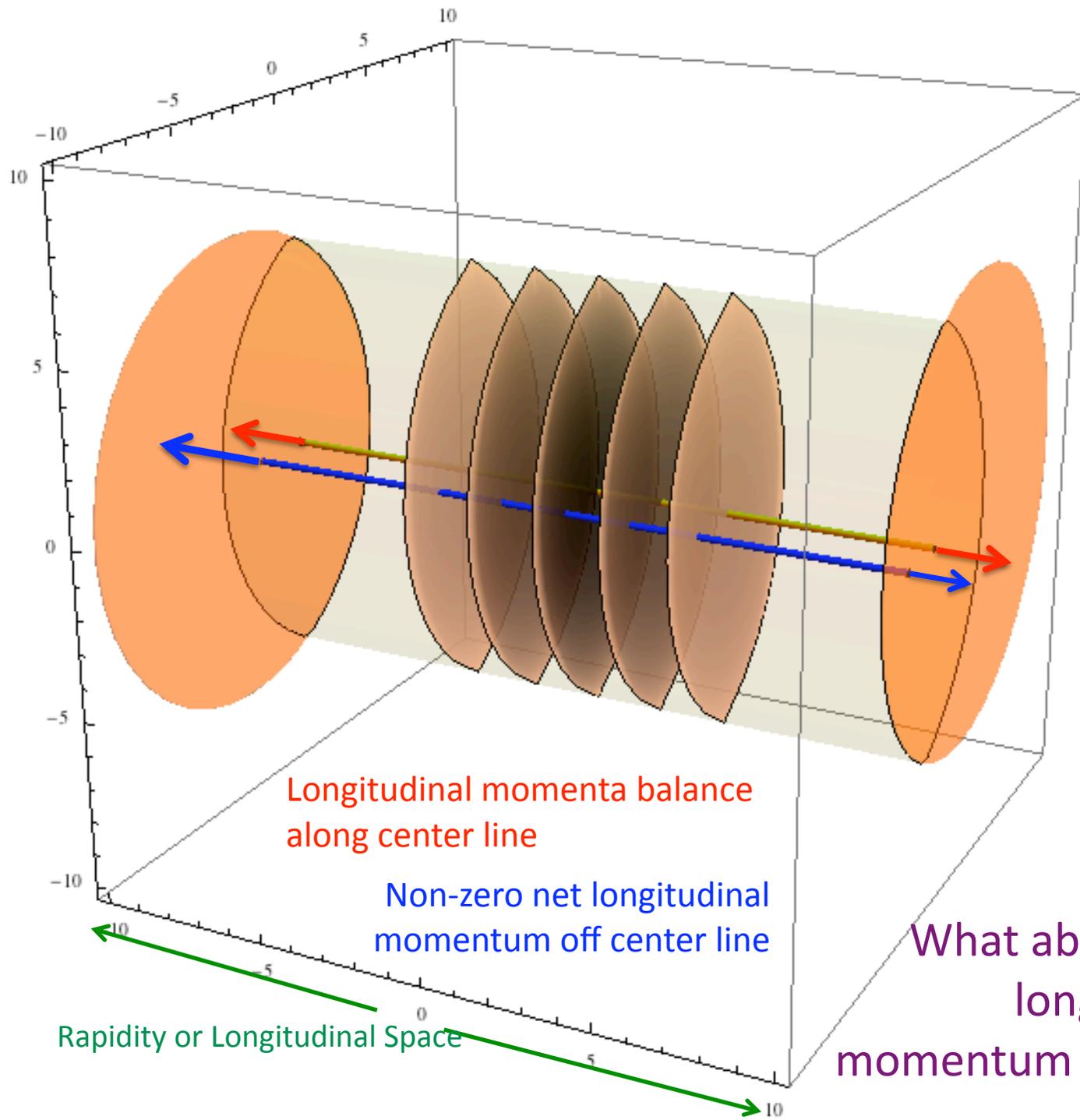


Typical participant  
energy deposit  
initial condition

FIG. 1: Schematic picture of a nucleus-nucleus collision depicted in the transverse plane (from [9]). The principal axes ( $x'$  and  $y'$ ) of the area formed by the participants are tilted with respect to the reaction plane given by the axes ( $x$  and  $y$ ) of the transverse plane.

“His pattern indicates two-dimensional thinking.”





Longitudinal momenta balance  
along center line

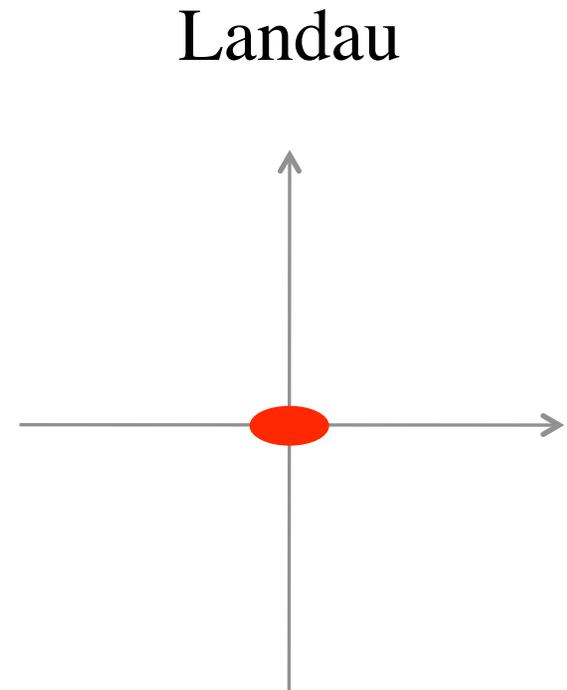
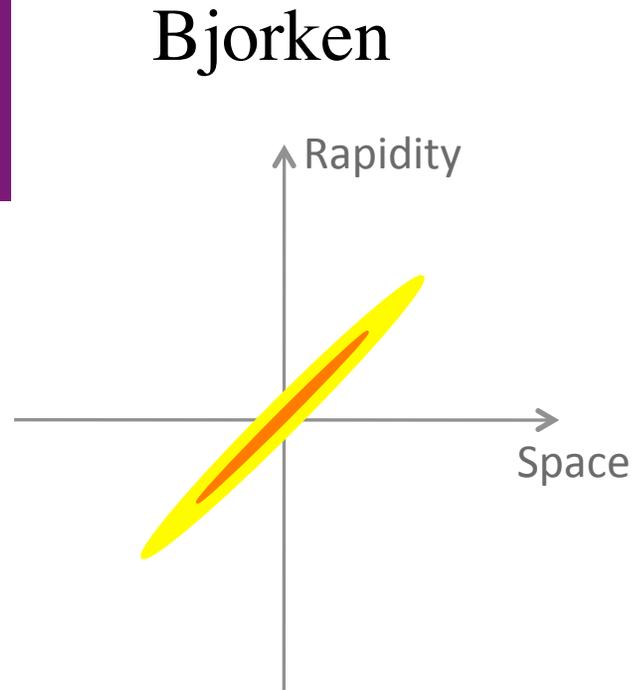
Non-zero net longitudinal  
momentum off center line

What about local  
longitudinal  
momentum density?

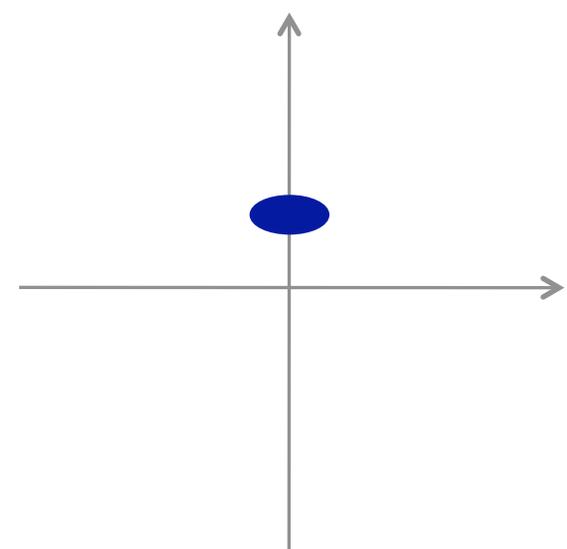
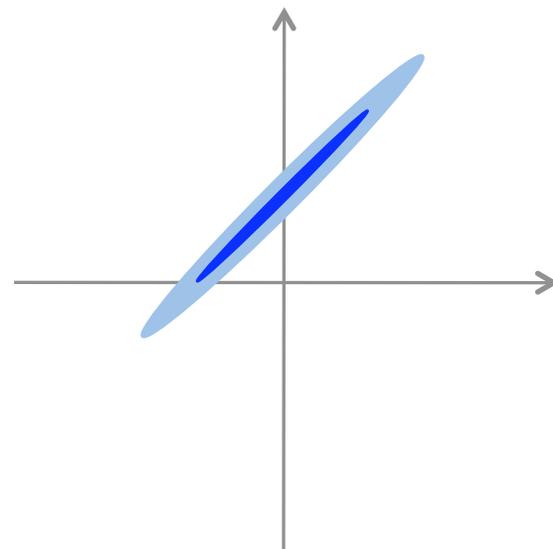
# Fundamental Questions

Initial distributions along one longitudinal line

On Axis

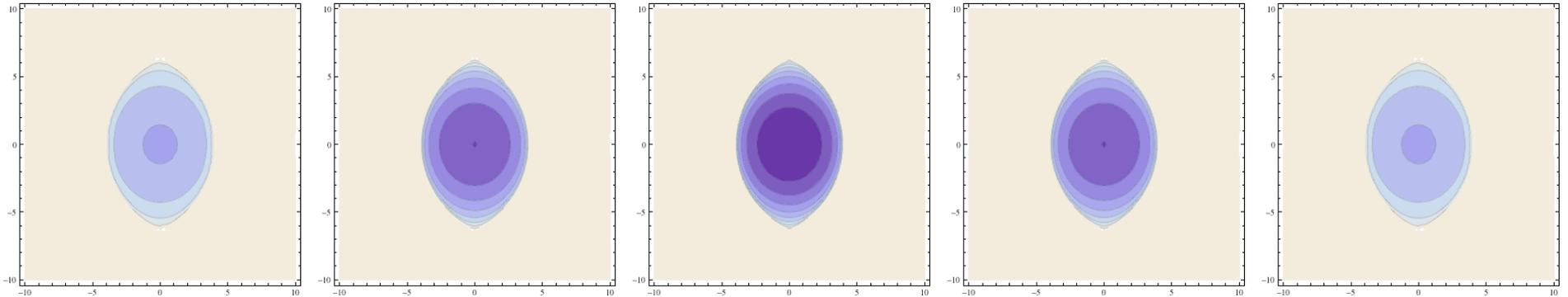


Off Axis

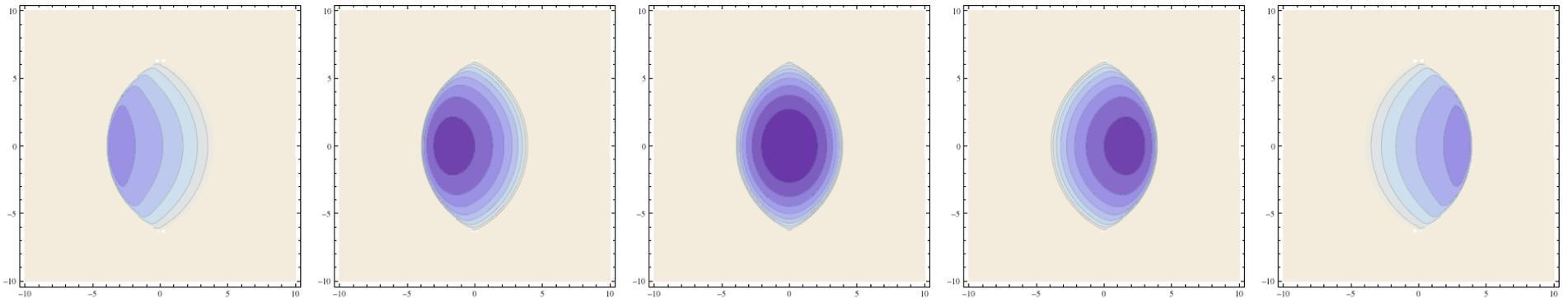


# Transverse profiles of initially-deposited energy density

← Rapidity or Longitudinal Space →



Assuming no rapidity dependence of transverse profile



With rapidity dependence based on local longitudinal momentum density *and* a particular choice for the initial spread along  $z/Y$

Detailed measurements of a 3-D final state

Trace back through 3+1D hydrodynamics, including the effects of jet quenching.

Constrain the 3-D hydro initial state

Investigate the initial thermalization mechanism directly and quantitatively

How/when is initial equilibration/  
entropy generation achieved?

*Just one example of using the QGP as a tool to access other fundamental physics within the laboratory of an  $A+A$  collision*

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**Era III: Non-Perturbative and Non-Thermal**

# Conclusions

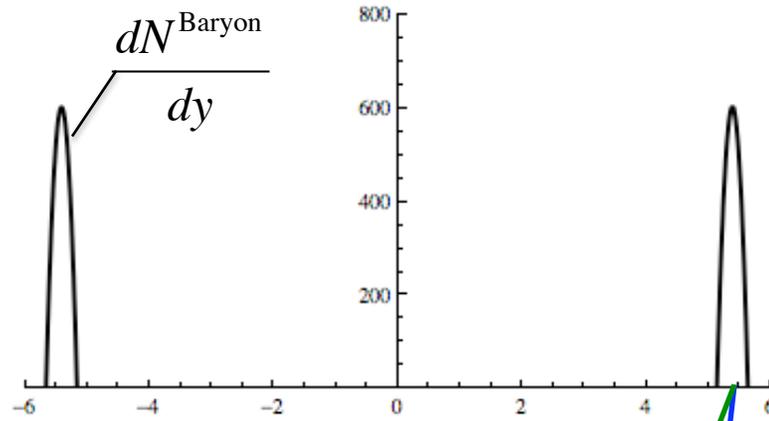
RHIC has been a great success! in creating and observing thermalized QCD, the sQGP.

Thermal and near-thermal QCD have many interesting properties which we are now comprehensively characterizing.

Our successes to date now enable us to investigate *whole new regimes of QCD* within the laboratory of A+A collisions at RHIC.

Backup

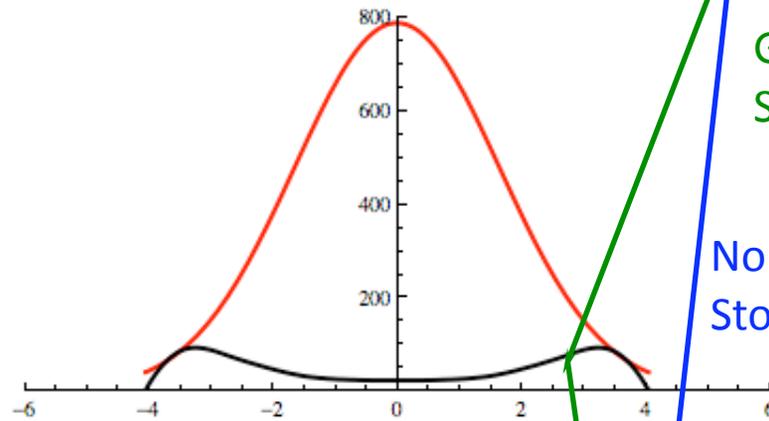
Initial



How/when is initial equilibration/entropy generation achieved?

How are conserved quantum numbers transported?

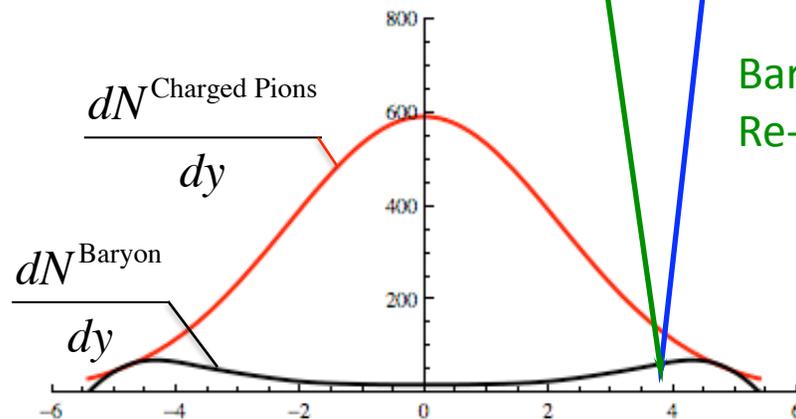
Early Hydro



Greater Baryon Stopping

Nominal Baryon Stopping

Late Hydro



Baryon Re-Acceleration!