What are initial state correlations and how do we see them?

a synopsis+'poster'

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3rd International þing on QCD Challenges from pp to AA

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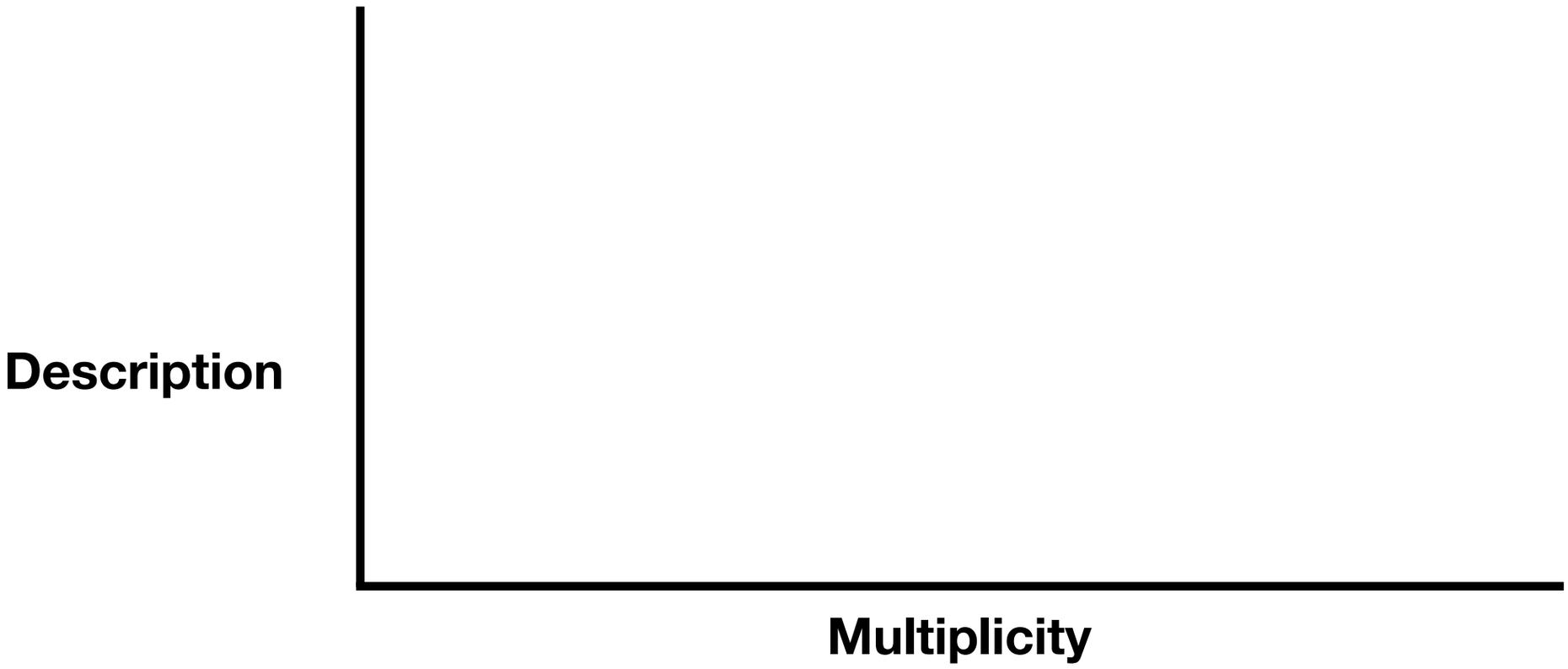
The landscape of calculations

How to understand particle production in high energy collisions



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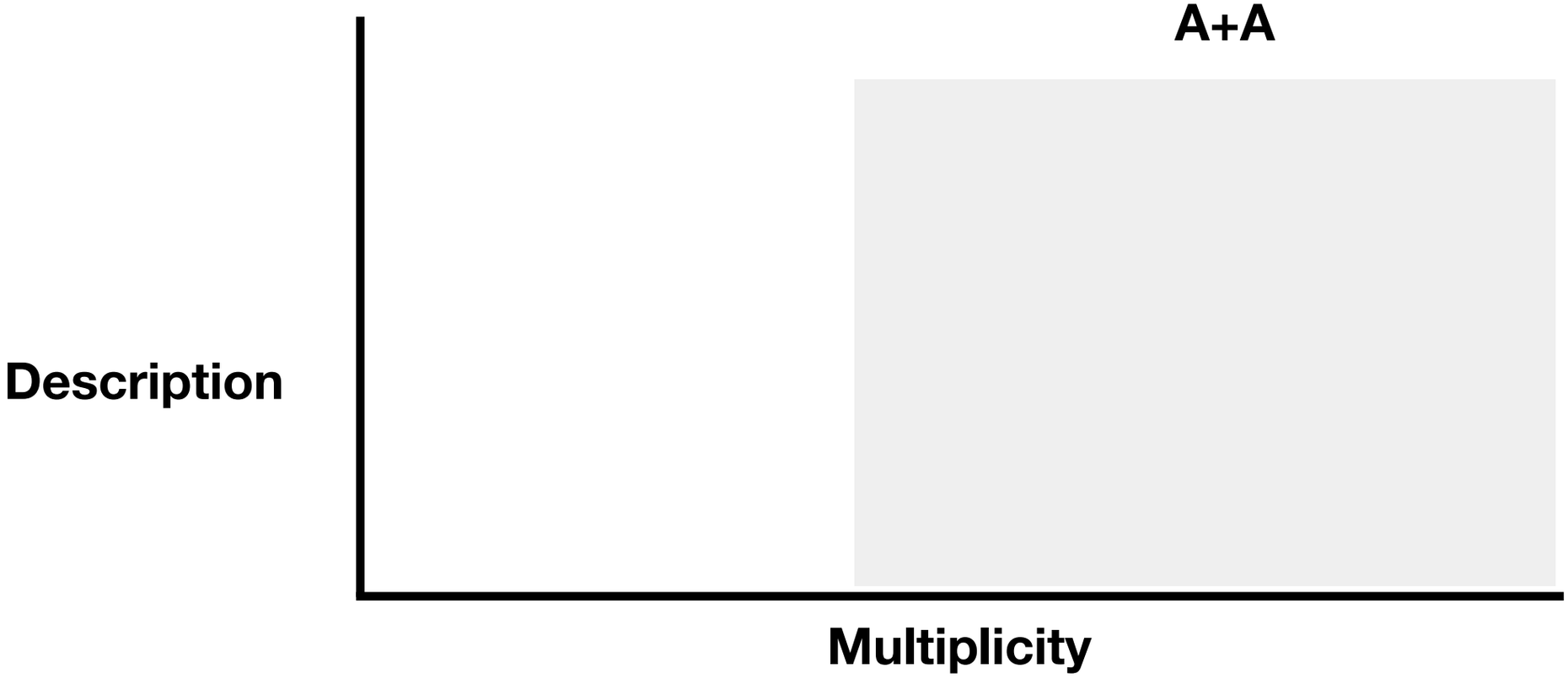

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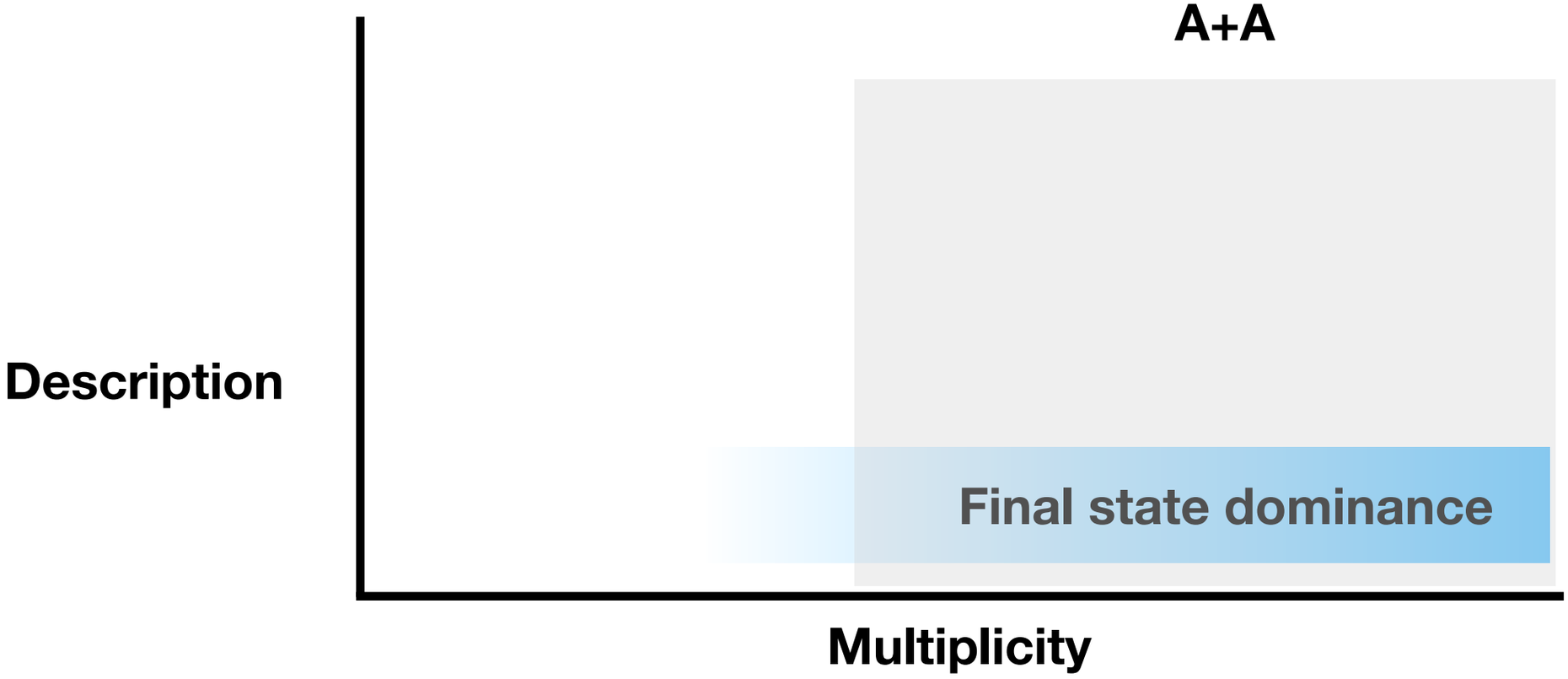

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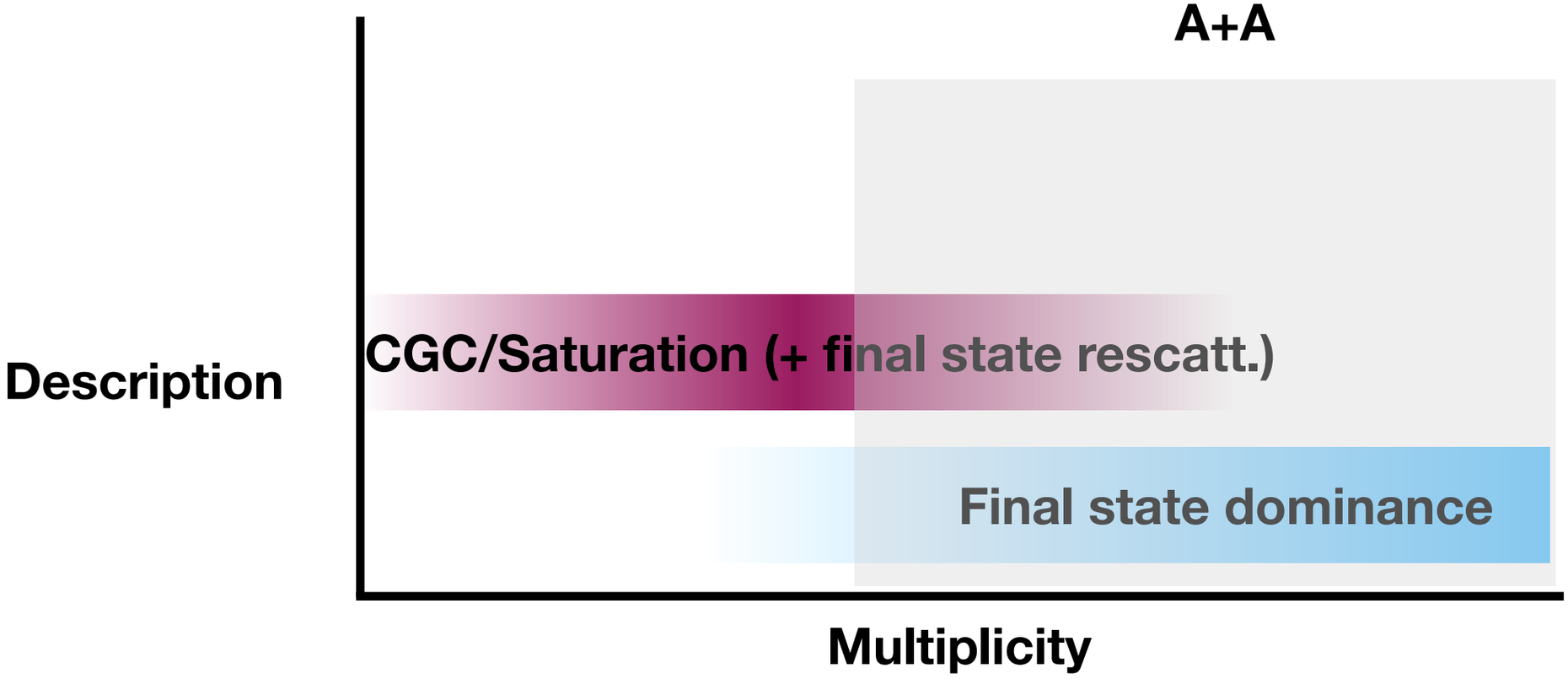

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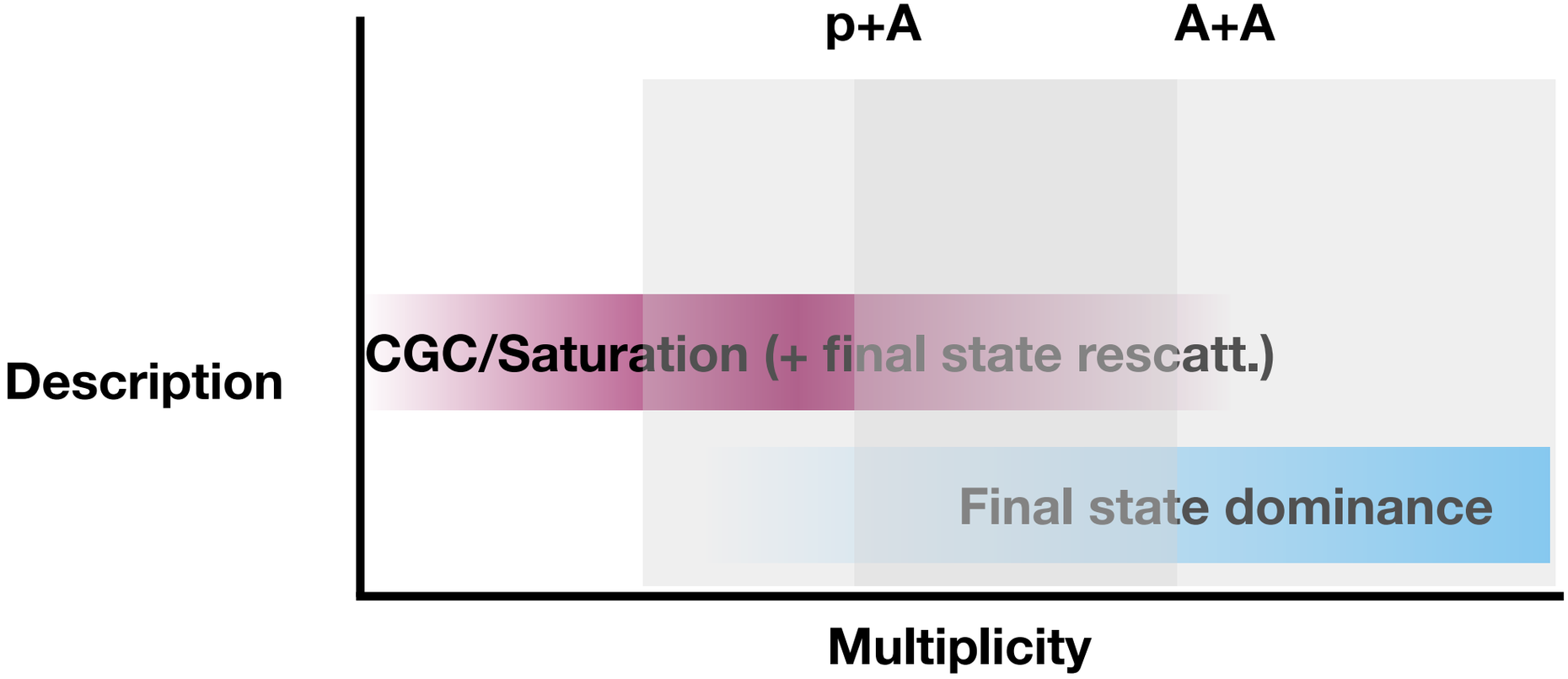

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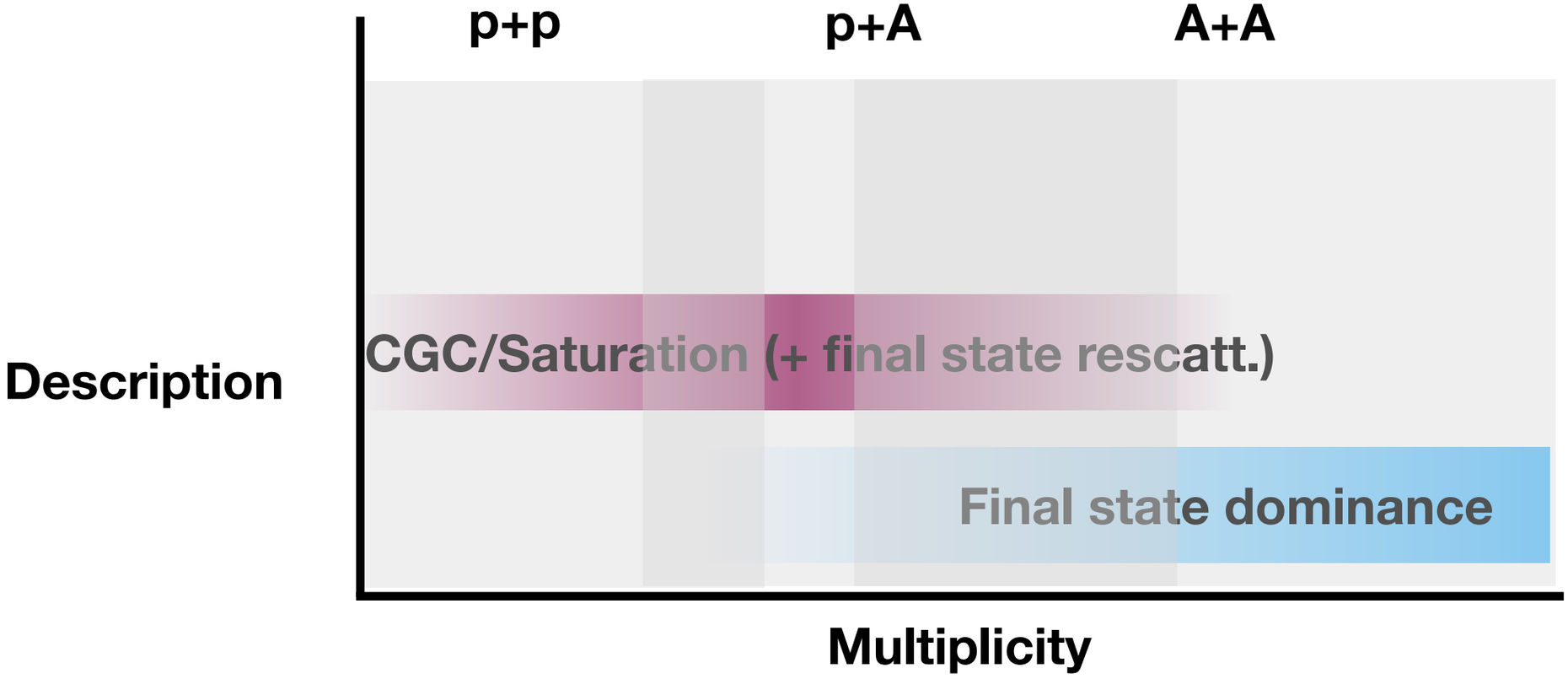

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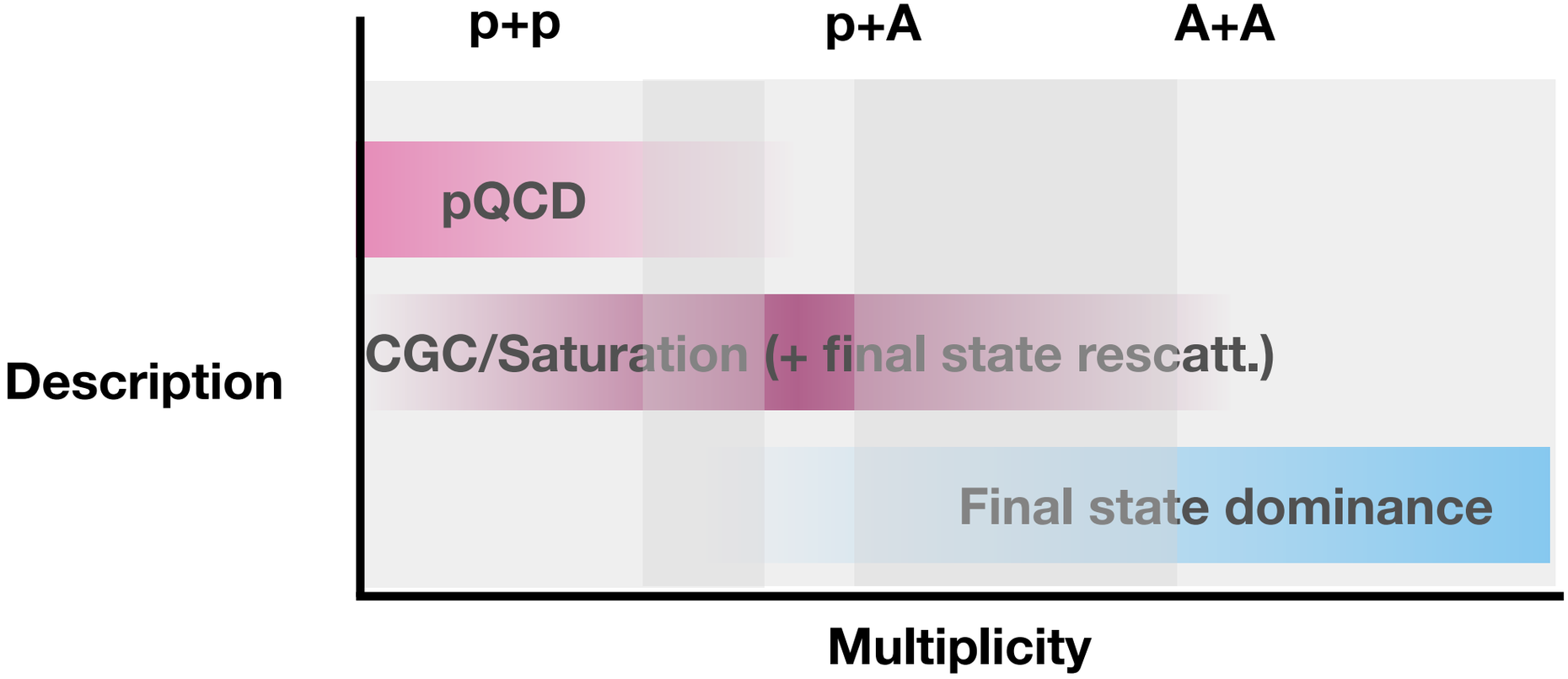

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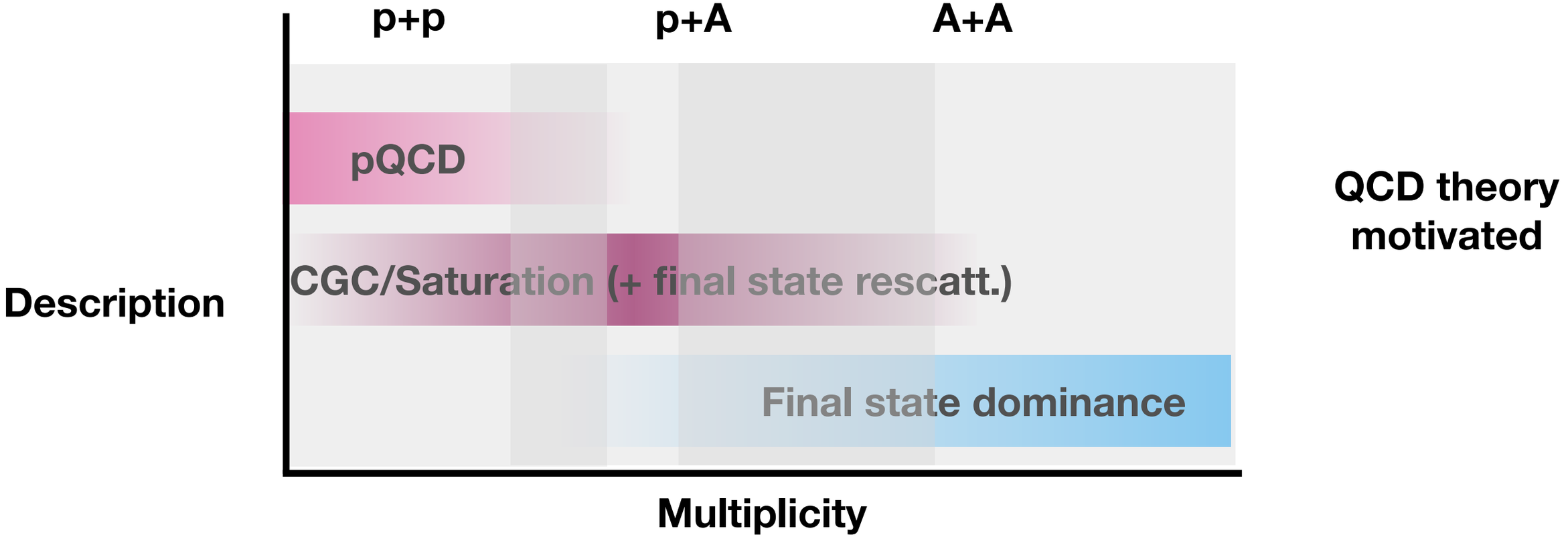

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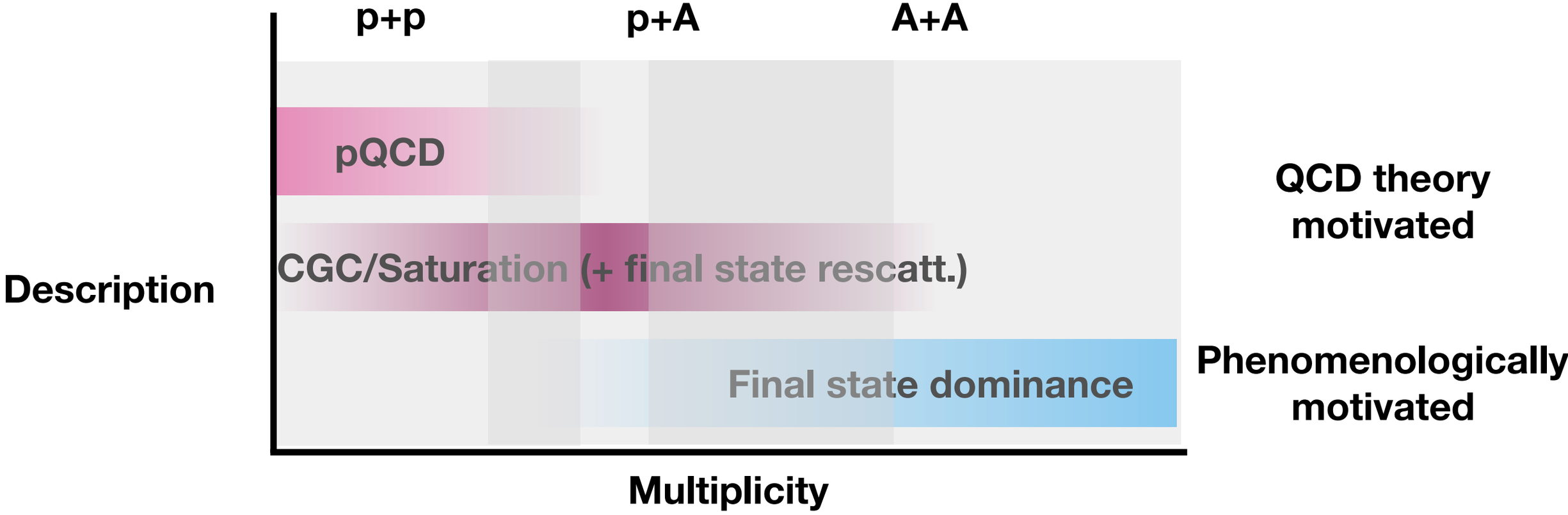

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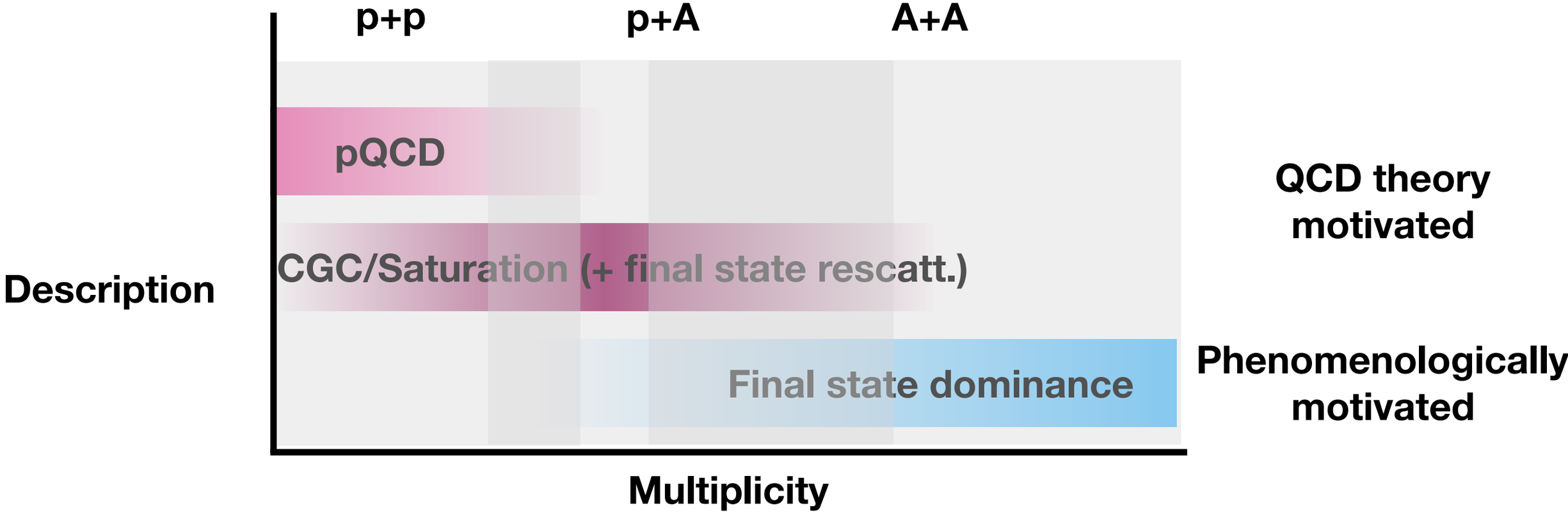


How to bridge the gap between QCD and phenomenological models?

Correlation production mechanisms

two extremes

Initial state (e.g. CGC)

Produced by initial momentum correlations which pre-exist in nuclei before collisions and/or develop at quickly after collision

Contains classical correlations (domains, as well as density gradients)

Contains quantum effects: Bose enhancement in incoming wavefunction, as well as gluon HBT

Final state/hydrodynamics

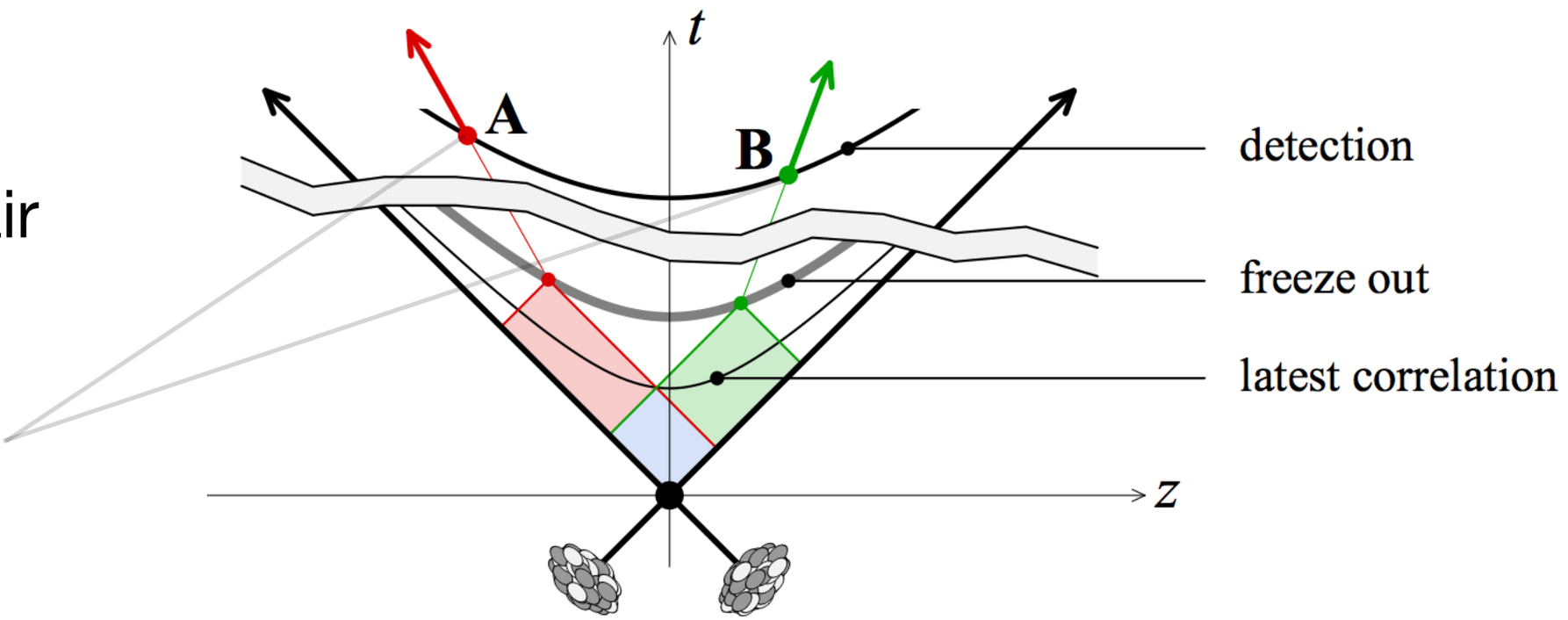
Produced by conversion of initial spatial (geometry) correlations are converted to final momentum correlations

Develops throughout evolution of the system

Well motivated from A+A, theory questions linger for smaller systems

Long range rapidity correlations as a chronometer

Consider pair of particles correlated rapidity Δy



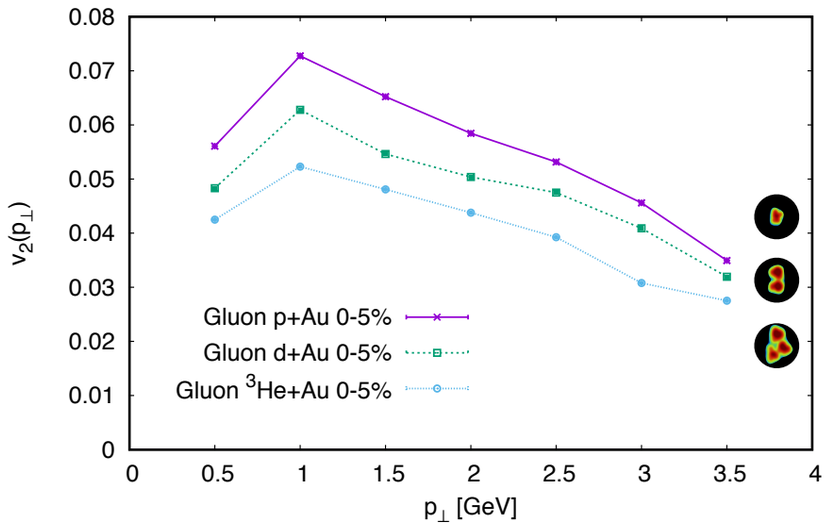
Dumitru, Gelis, McLerran, Venugopalan
NPA 810 (2008) 91-108

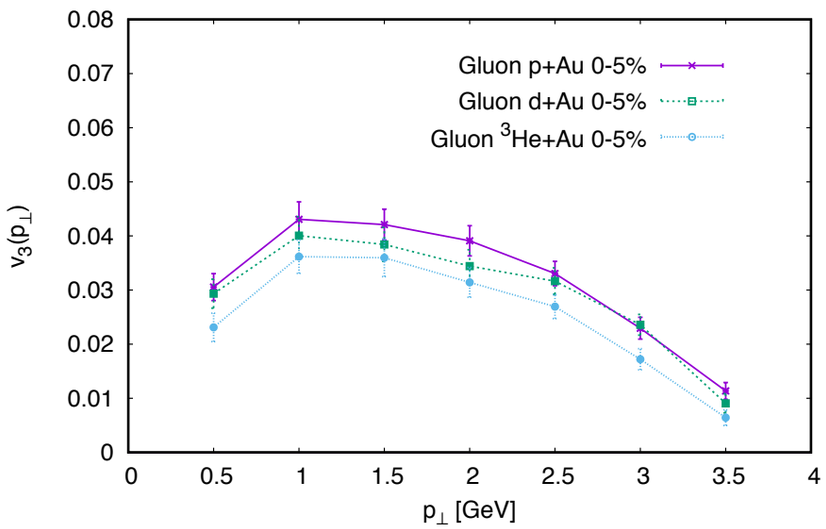
By causality, long-range rapidity correlations sensitive to early time dynamics, $\tau < \tau_{f.o.} e^{-\Delta y/2}$,in collision

Dilute-dense CGC solver publicly available: https://github.com/markfmace/DiluteDenseGluons

CGC gluons

Purely initial state correlations from CGC gets opposite hierarchy of *p*/*d*/^{3}He+Au seen by PHENIX



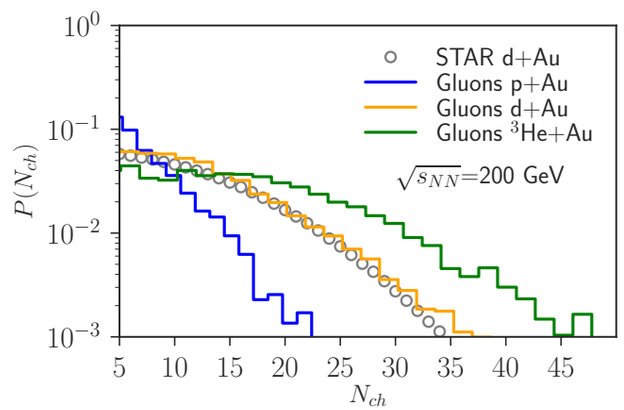


MM, Skokov, Tribedy, Venugopalan, PRL+Erratum

Qualitatively similar results from IP-Glasma (dense-dense) calculations

Other observables where initial state may be more transparent e.g. photons, DIS, UPCs,…

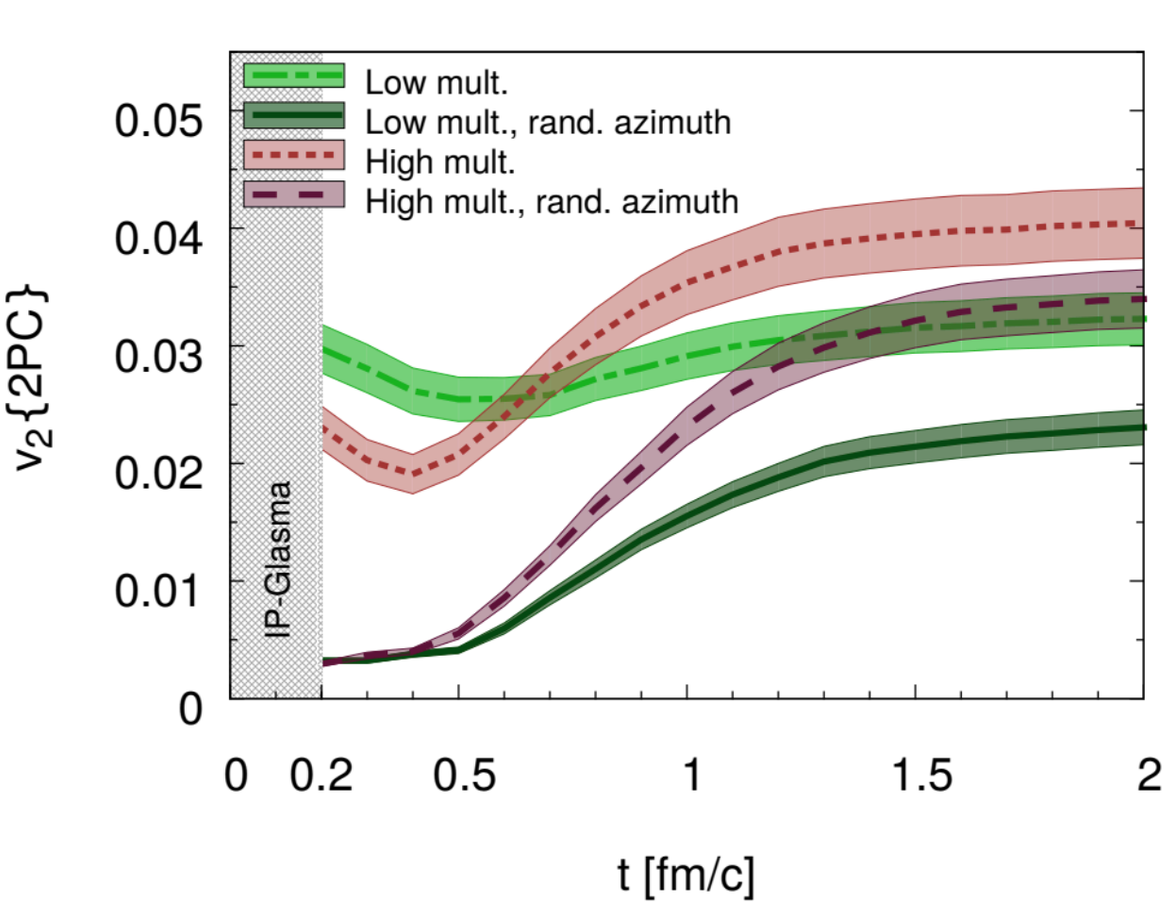
Multiplicity and v_2 anti-correlated in pure CGC calculations

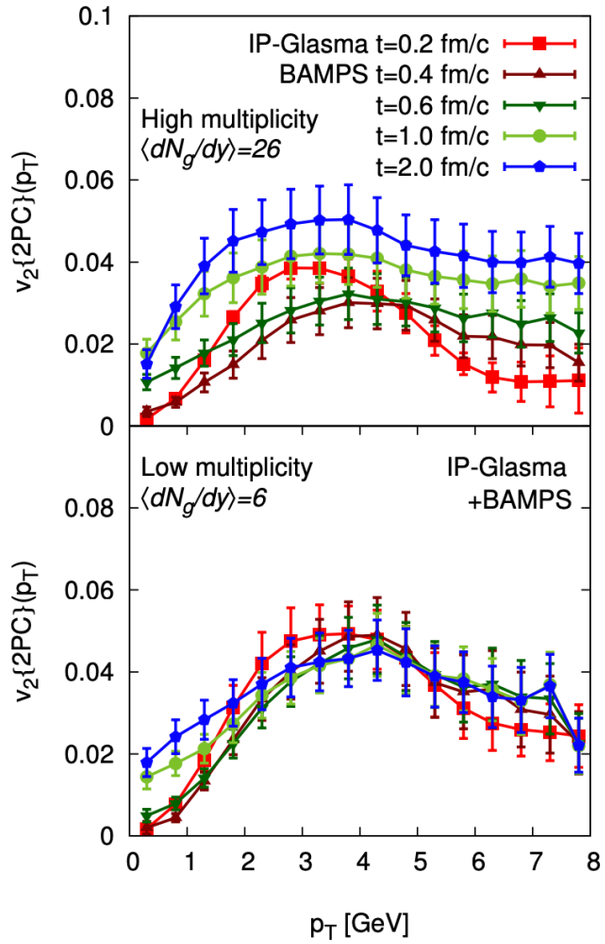


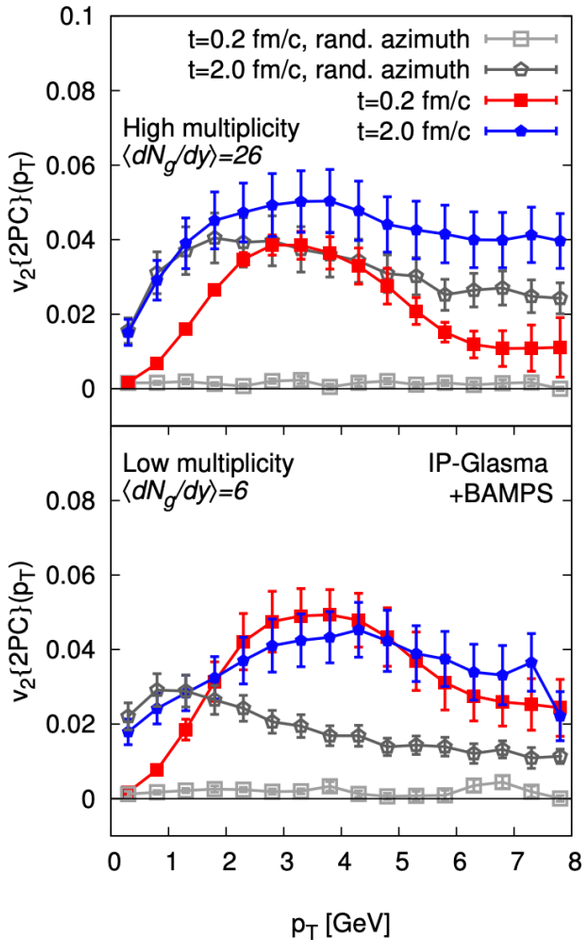
Purely initial state CGC approach seems unlikely to be able to describe the hadronic v_n *alone*

A few more kicks

IP-Glasma+BAMPS(kinetic theory)





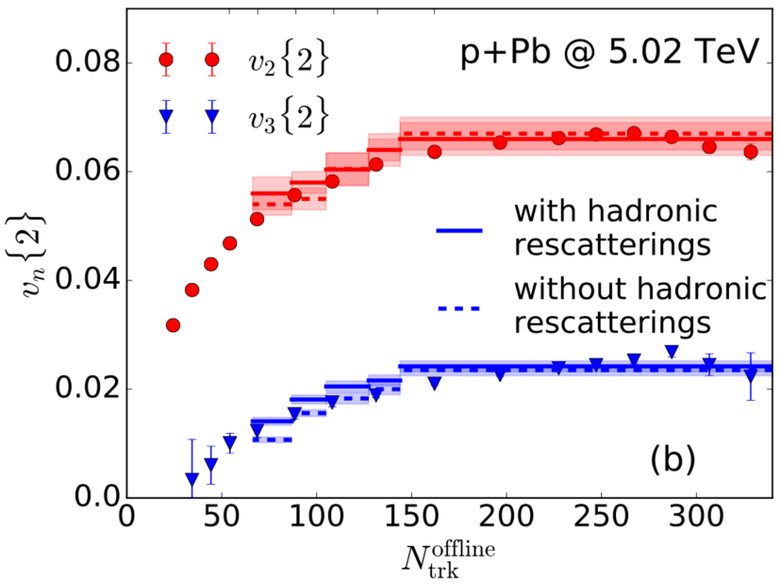


Initial CGC gives smaller v_2 for larger multiplicity system, but quickly reverse by kinetic theory

Greif, Greiner, Schenke, Schlichting, Xu PRD 96 (2017)

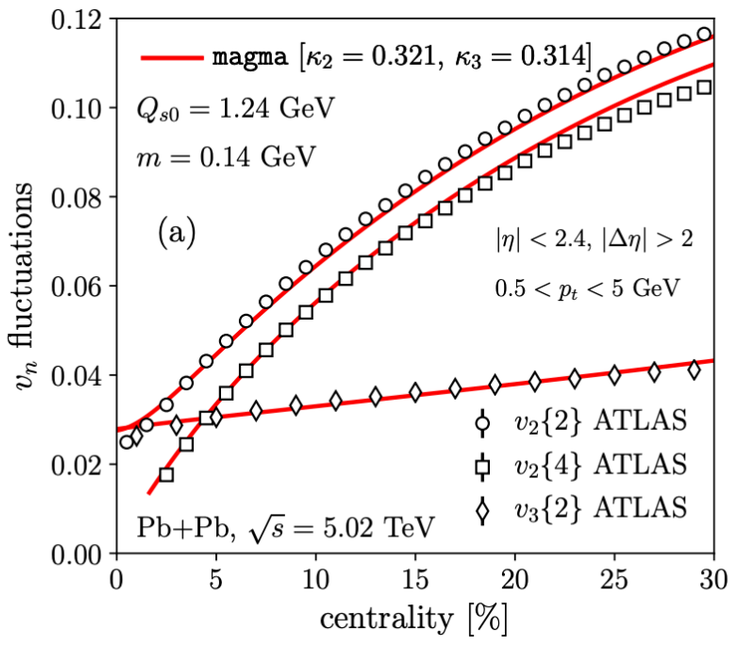
CGC+hydrodynamics

IP-Glasma (Glauber+IP-Sat) + MUSIC + UrQMD



Shen, Paquet, Denicol, Jeon, Gale, PRC95 (2017)

CGC energy-momentum correlations + linear response



Gelis, Giacalone, Guerrero-Rodríguez, Marquet, Ollitrault arXiv:1907.10948

Is there an over-counting of fluctuations in models like MSTV (and IP-Glasma) by also including Glauber modeling?

Need to disentangle theory (QCD-based) and modeling (not)

So now what?

Three (somewhat) different initial states coupled to hydro

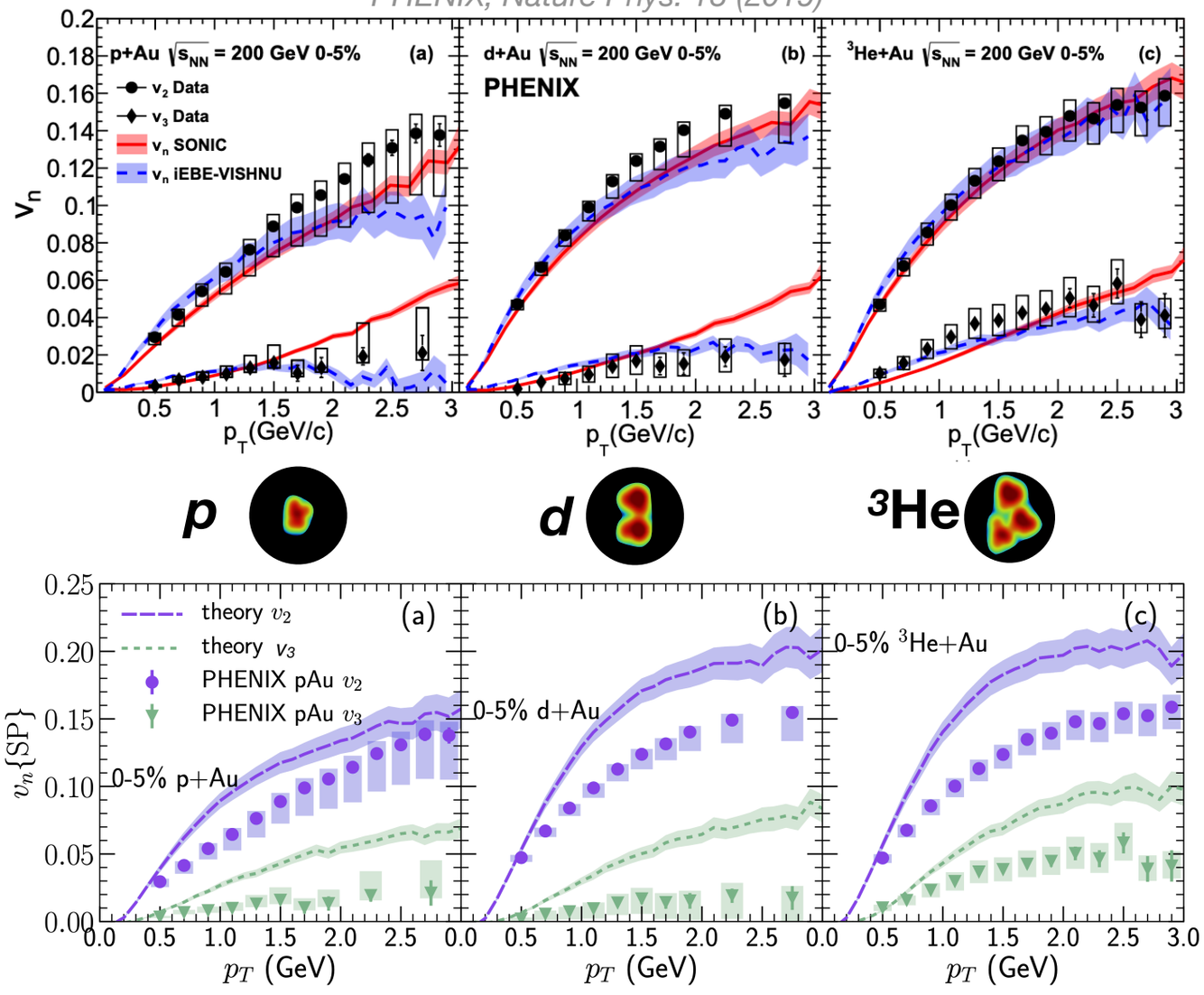
MC-Glauber
+ VISH2+1
+ UrQMD

Shen, Paquet, Denicol, Jeon, Gale PRC 95 (2017)

IP-Glasma
+ MUSIC
+ UrQMD

PRELIMINARY
Schenke, Shen, Tribedy, in preparation

PHENIX, Nature Phys. 15 (2019)



B. Schenke, RHIC-AGS Users Meeting June 4,2019

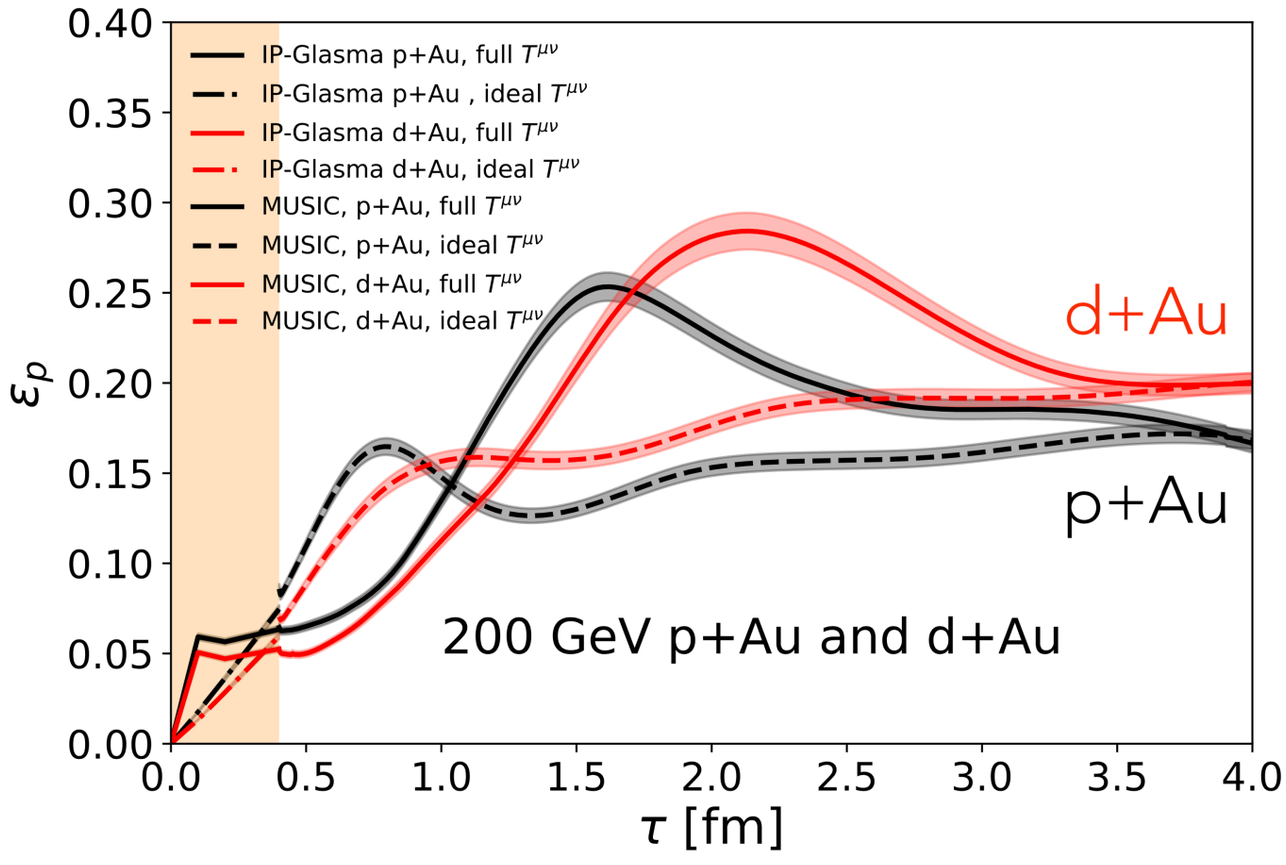
MC-Glauber+AdS
+UVH2+1
+B3D

Habich, Nagle, Romatschke EPJC 75 (2015)

Important differences — need to begin dissecting initial state

Anisotropy evolution

IP-Glasma+MUSIC+UrQMD



Measure momentum anisotropy

$$\epsilon_p = \sqrt{\frac{\langle T^{xx} - T^{yy} \rangle^2 + \langle 2T^{xy} \rangle^2}{\langle T^{xx} + T^{yy} \rangle^2}}$$

Not a Fourier harmonic

Dashed: ideal part of $T^{\mu\nu}$ only

Solid: full $T^{\mu\nu}$

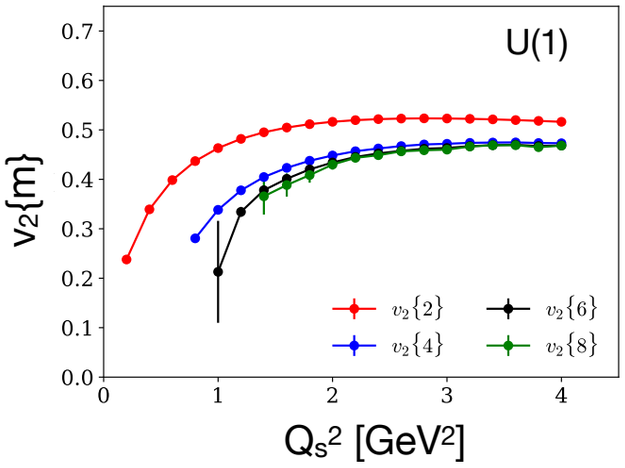
PRELMINARY *Schenke, Shen, Tribedy, in preparation*

B. Schenke, RHIC-AGS Users Meeting June 4,2019

Collectivity

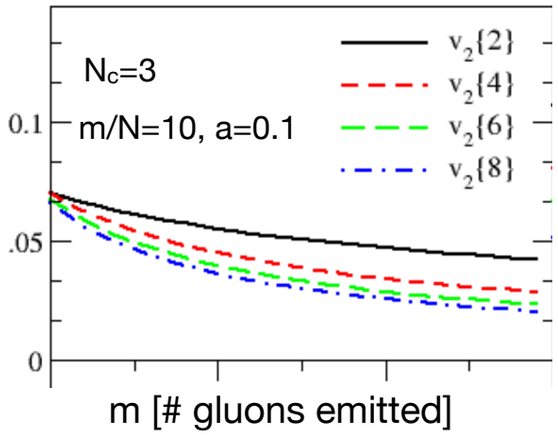
Roughly defined by $v_2\{2\} \gtrsim v_2\{4\} \simeq v_2\{6\} \simeq v_2\{8\}$

Parton-CGC model



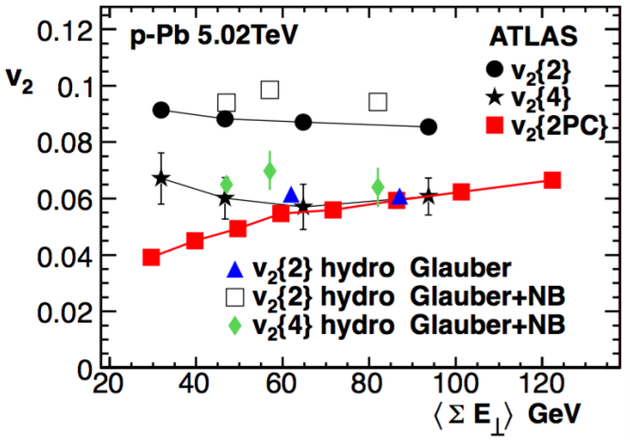
Dusling, MM, Venugopalan PRL 120 (2018)

QCD interference diagrams

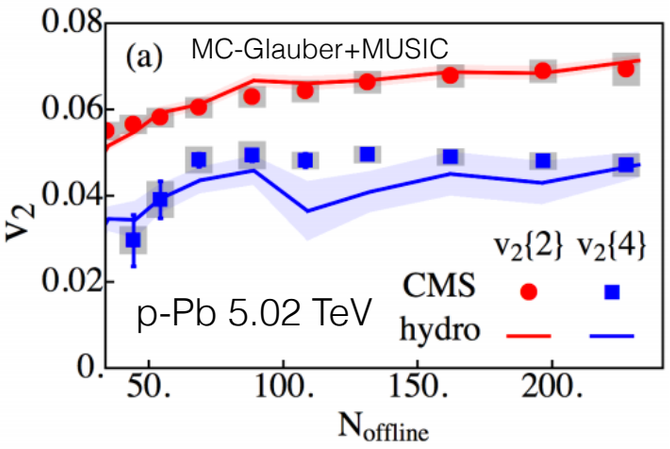


Blok, Wiedemann arXiv:1812.04113

Hydrodynamical models

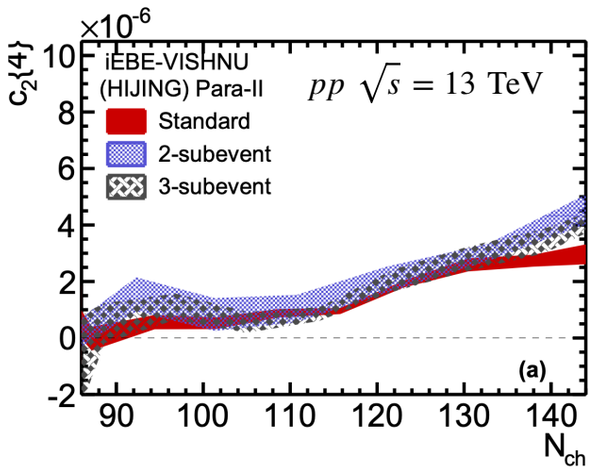


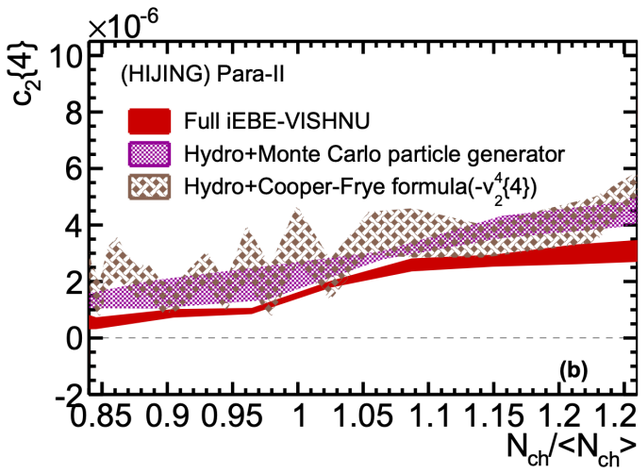
Bozek, Broniowski, PRC88 (2013)



Kozlov, Denicol, Luzum, Jeon, Gale NPA 931 (2014)

Absence of four-particle v_2 from hydro in *pp*





$c_2\{4\} > 0 \rightarrow v_2\{4\} \in \mathbb{C}$

Zhao, Zhou, Xu, Deng, Song PLB 780 (2018)

Outstanding challenges

(as I see them)

- Would like to know how a nuclei transforms into a fluid using QCD (and back!)
- Bottom-up: Starting from pQCD, when do we need more? (could be gluon saturation, kinetics, fluid)
    - Focus on observables like UPCs, DIS, EIC to directly constrain initial state?
    - Look at non-flow?
- Top-down: use final-state-dominant models to constrain models
    - Greater understanding coming by looking into initial conditions *as a function of time*
    - Further tests, such as larger particle number flow, very important
    - Understand what we are comparing to e.g. how does flow/non-flow subtraction effect results?
        - Particularly important for $c_2\{4,6,\ldots\}$ in small systems, etc