JET QUENCHING ENDGAME

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Wayne State University

GHP-2019, APS spring meeting Denver CO, April 2019

Outline

Intro, pQCD and scale dependence

From one theory to multiple theories,

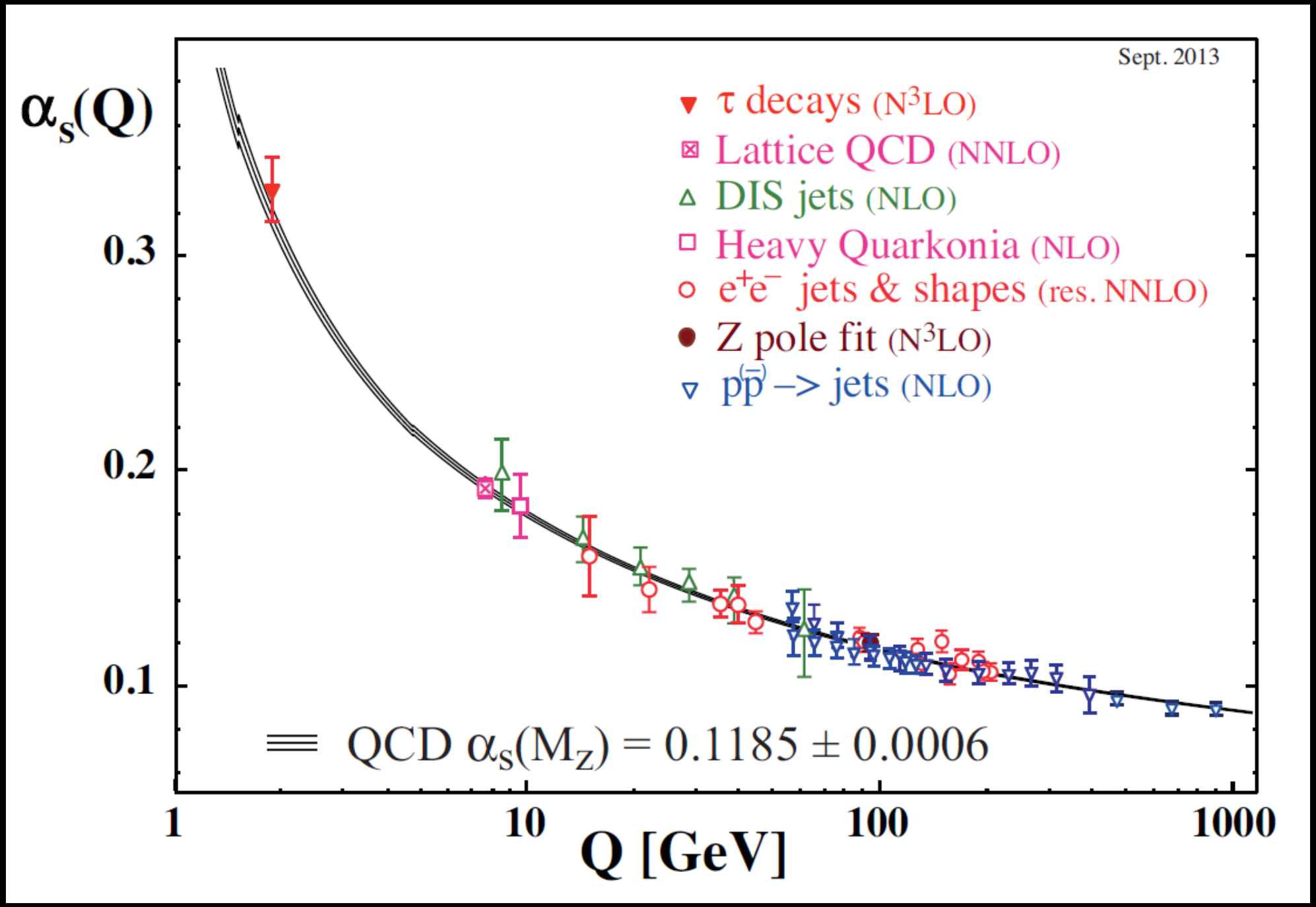
Role of scale in jets and jet observables,

Analytic calculations and Monte Carlo simulations

Results of simulations, and extracted information

Outlook!

QCD is all about scale!



Well known from DIS

What the electron sees, depends on E, Q^2

Increasing energy Q^2 = getting closer to proton

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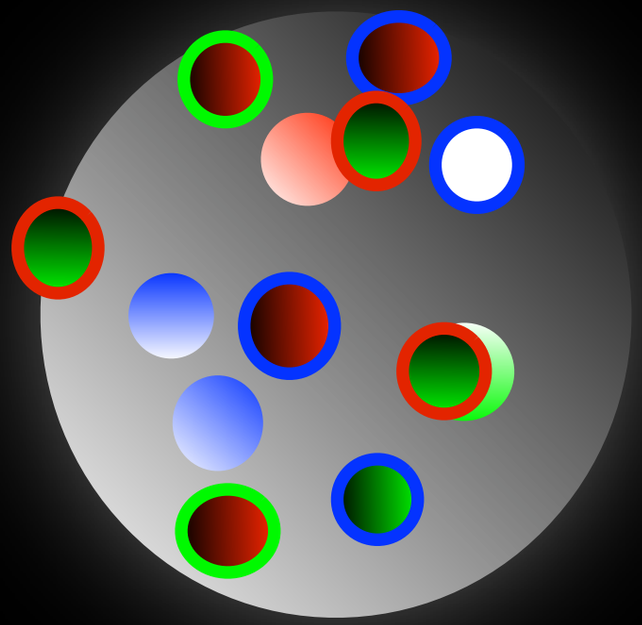

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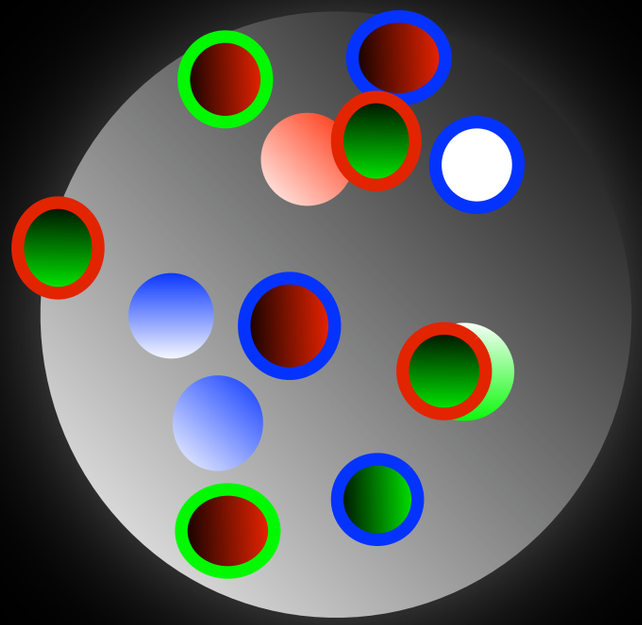

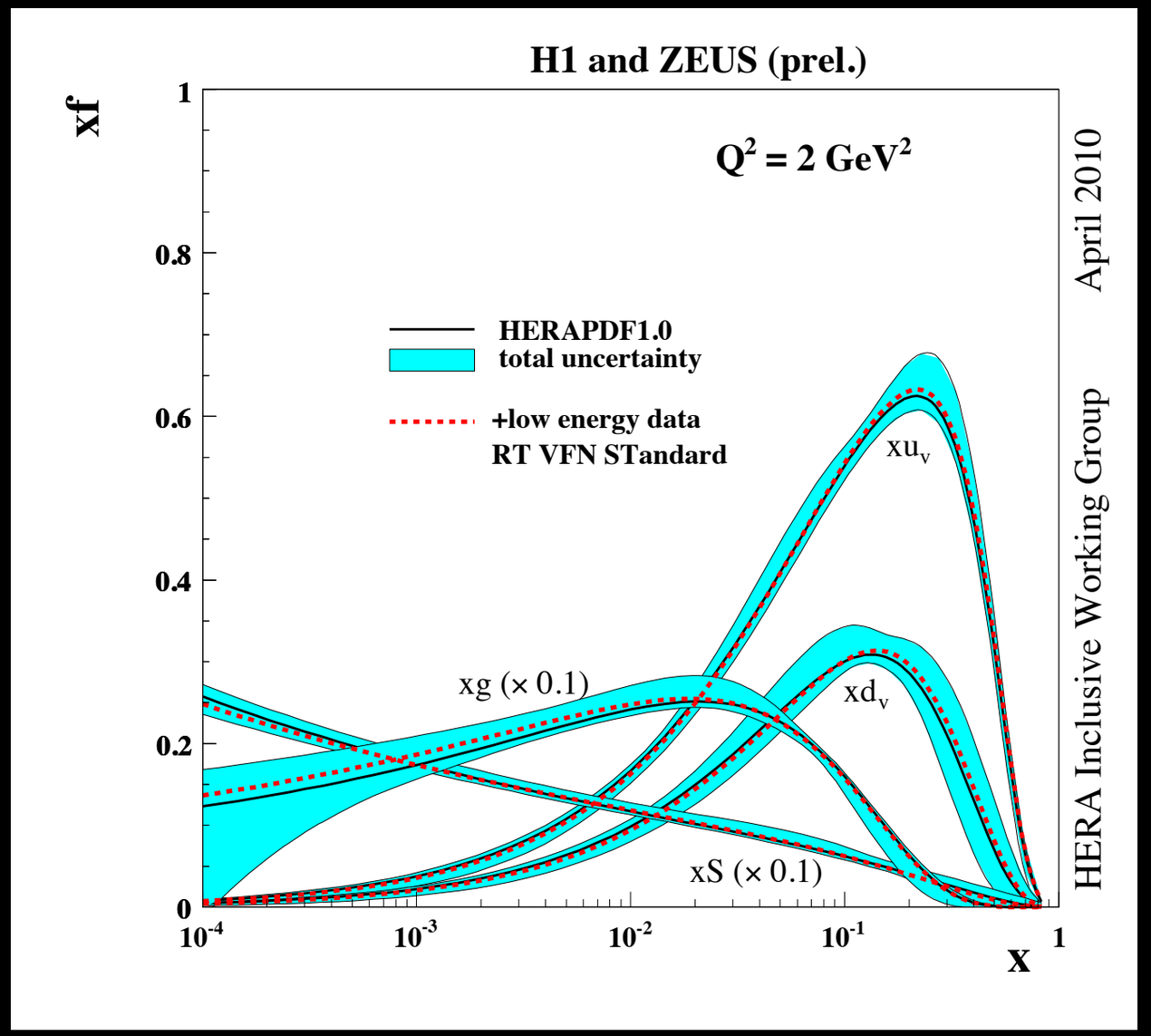

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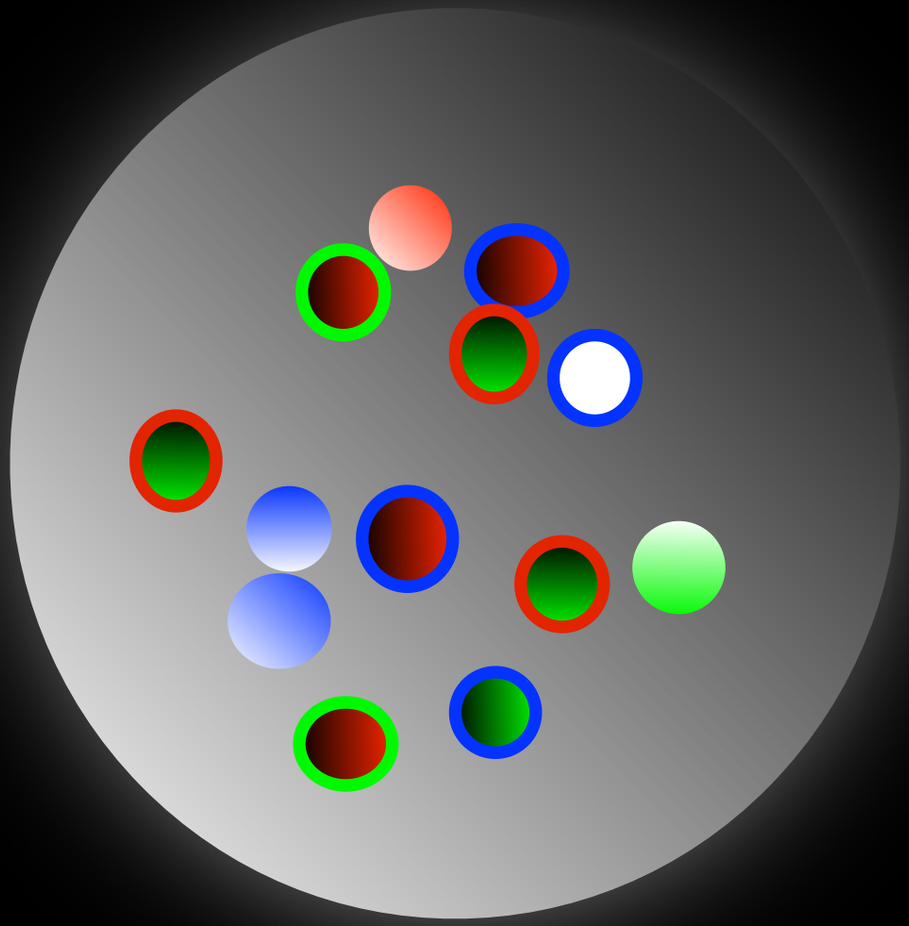

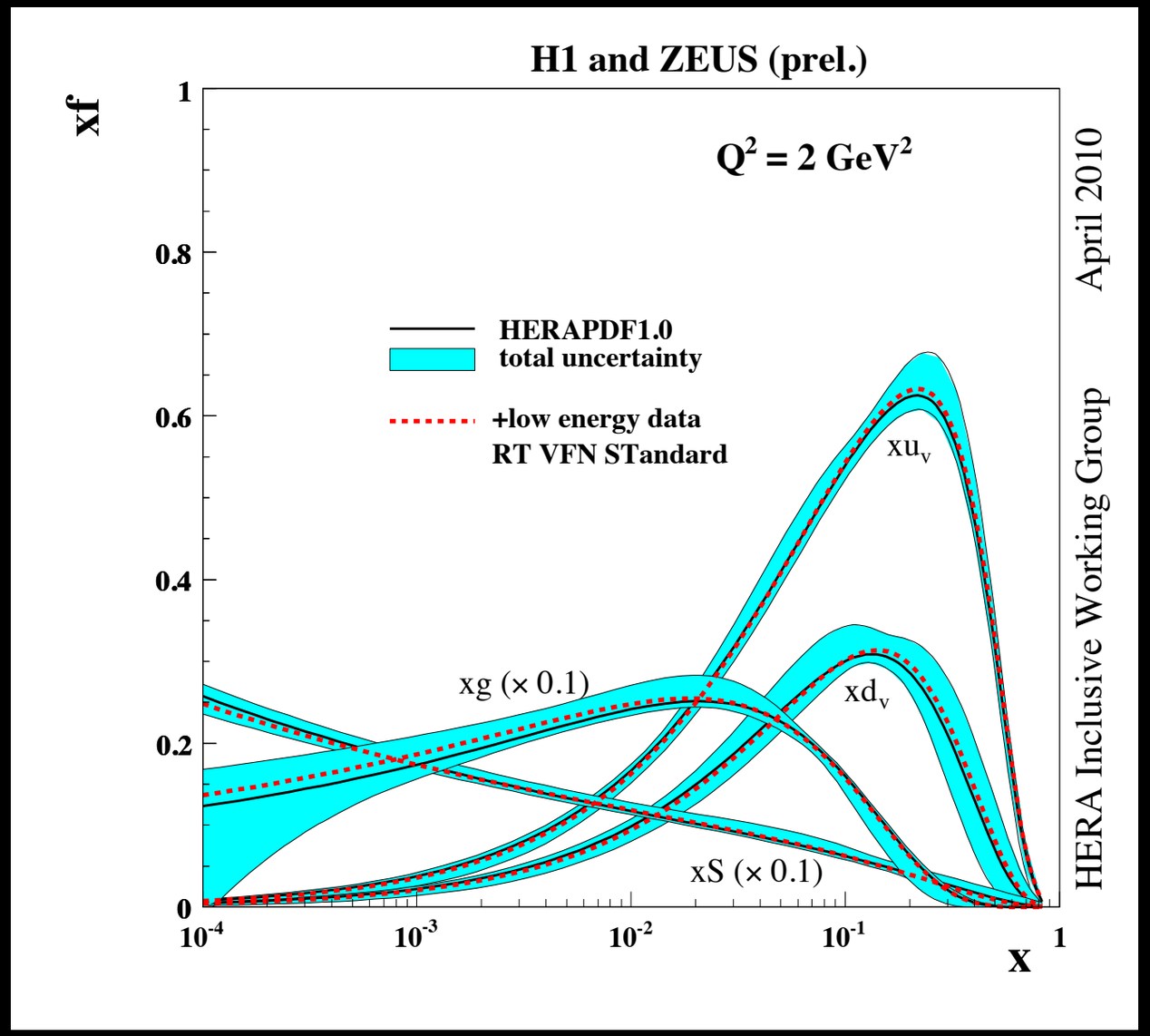

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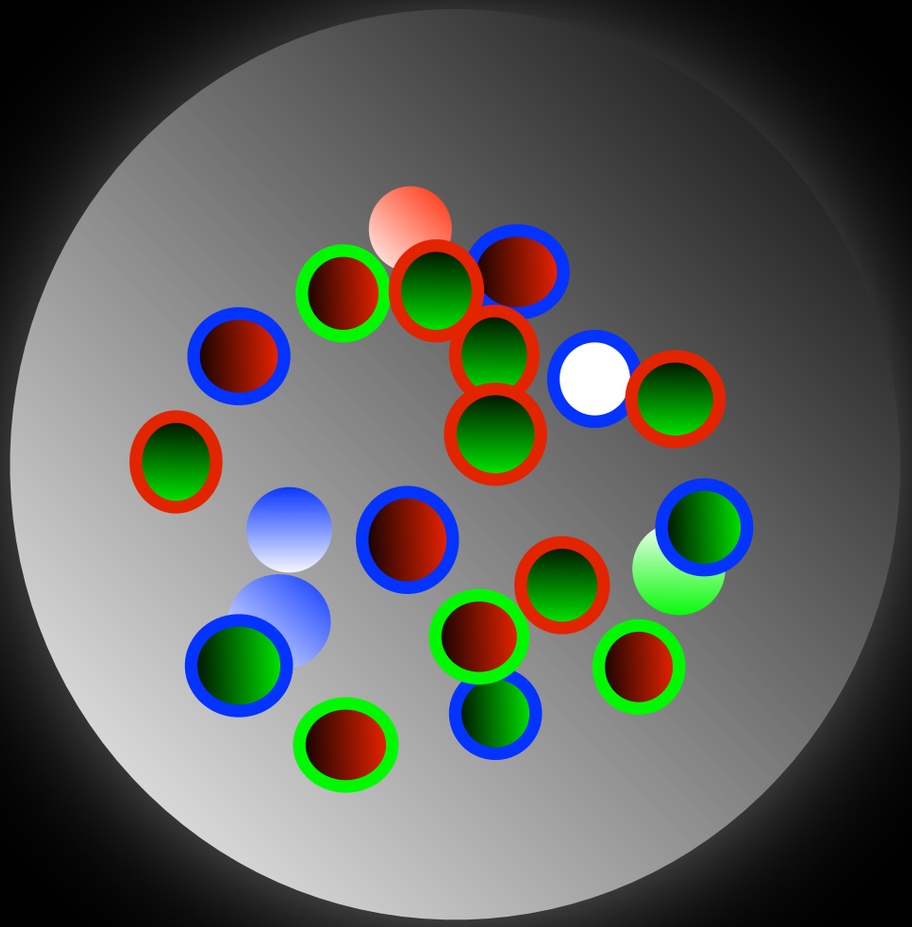

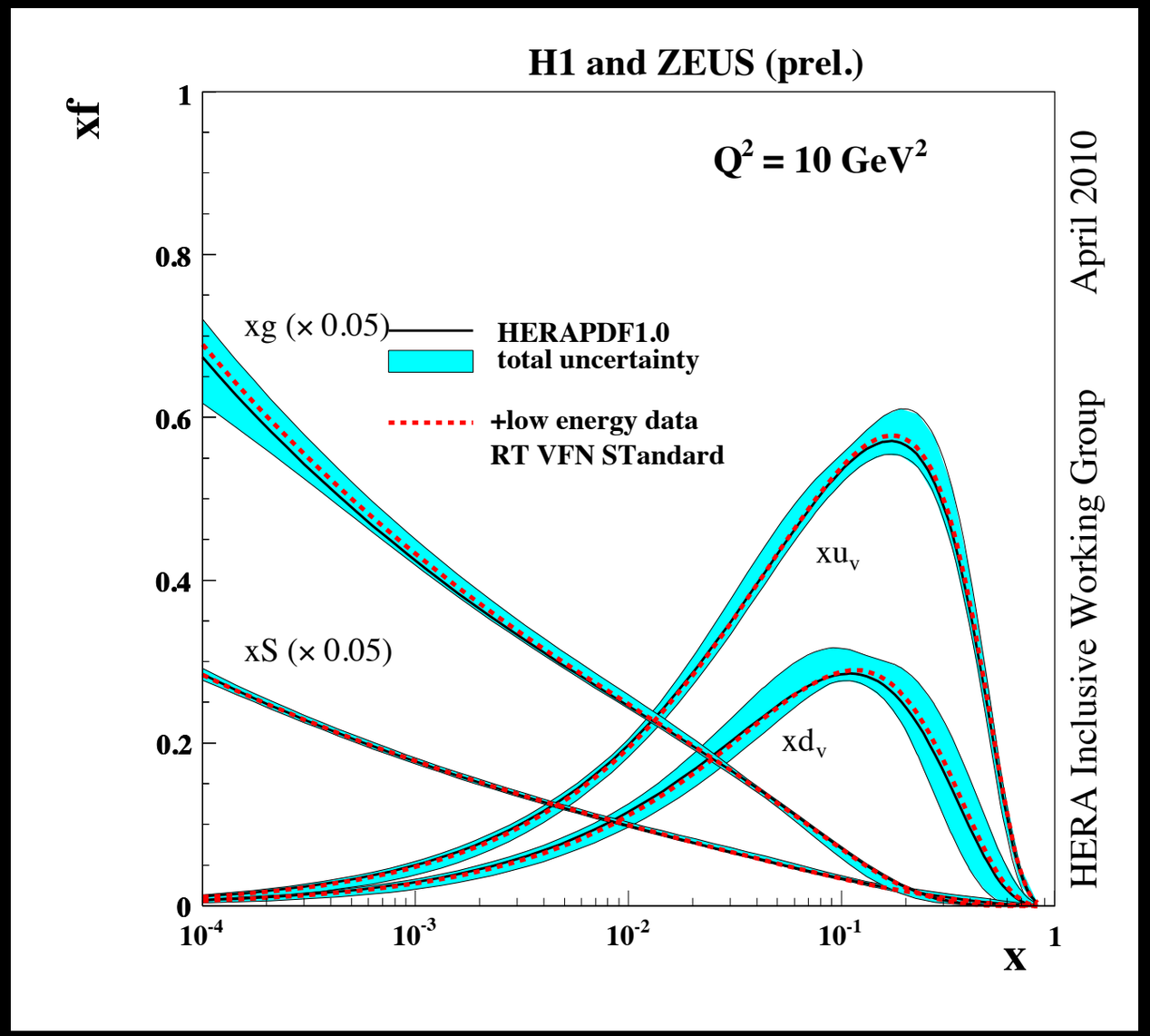

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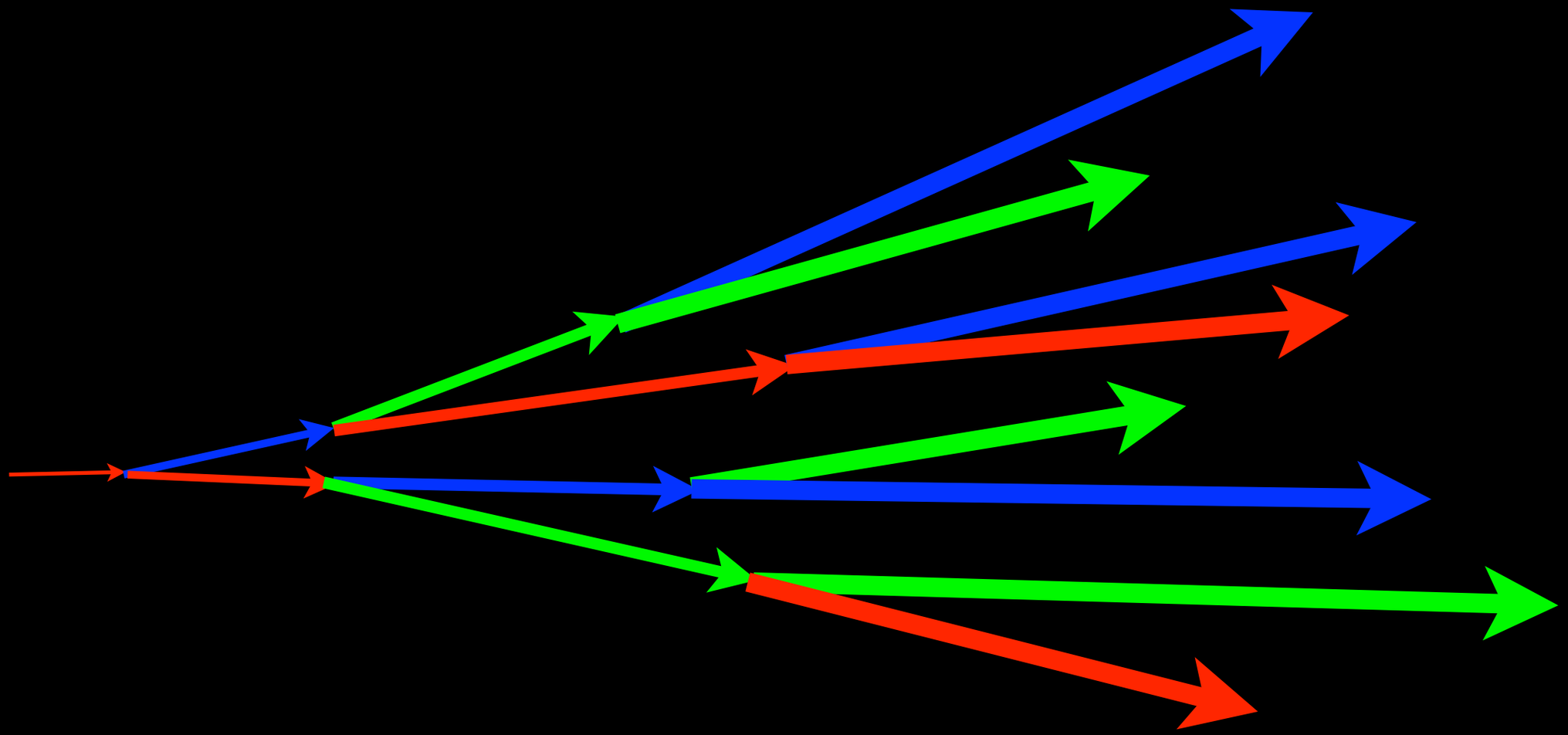

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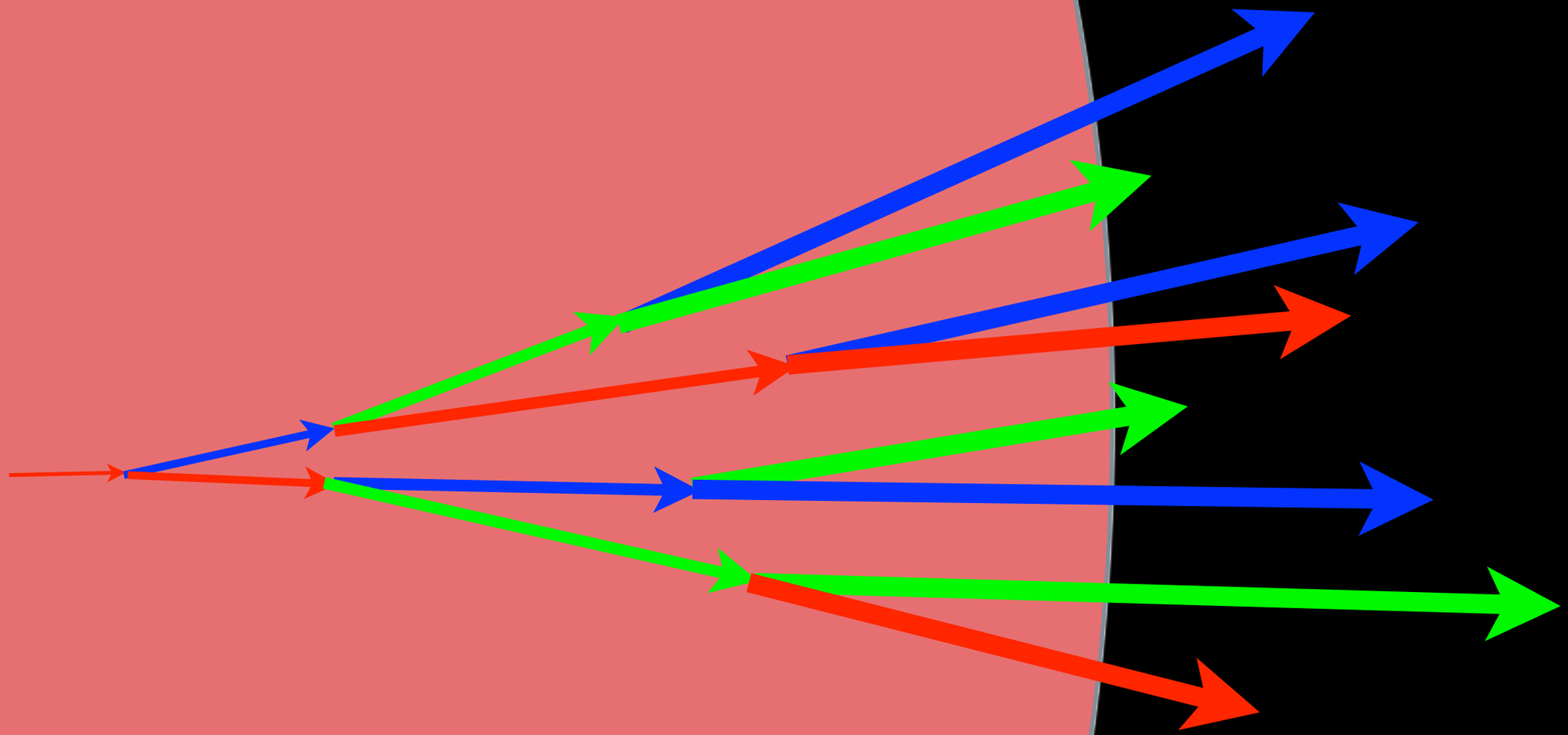

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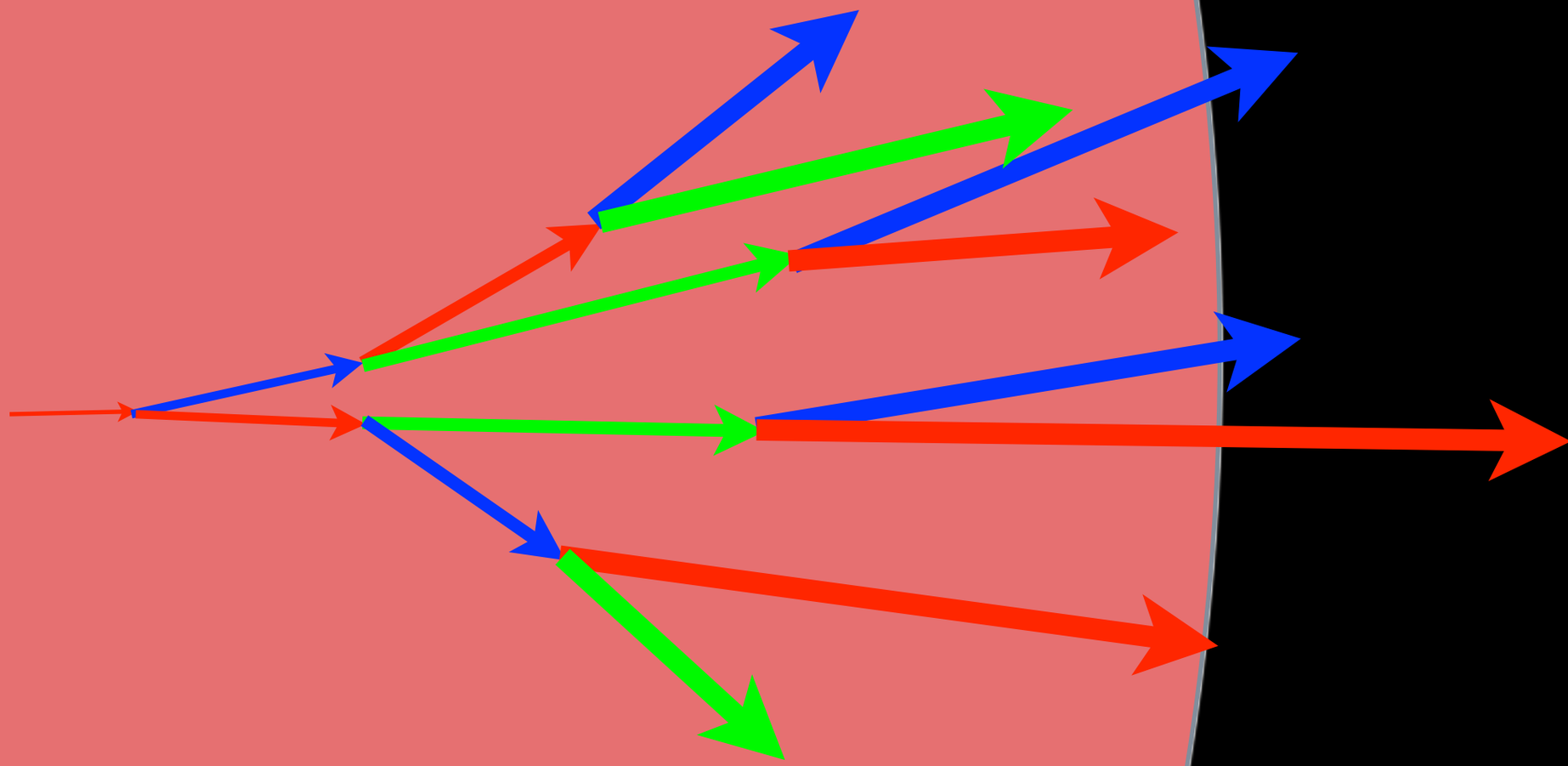

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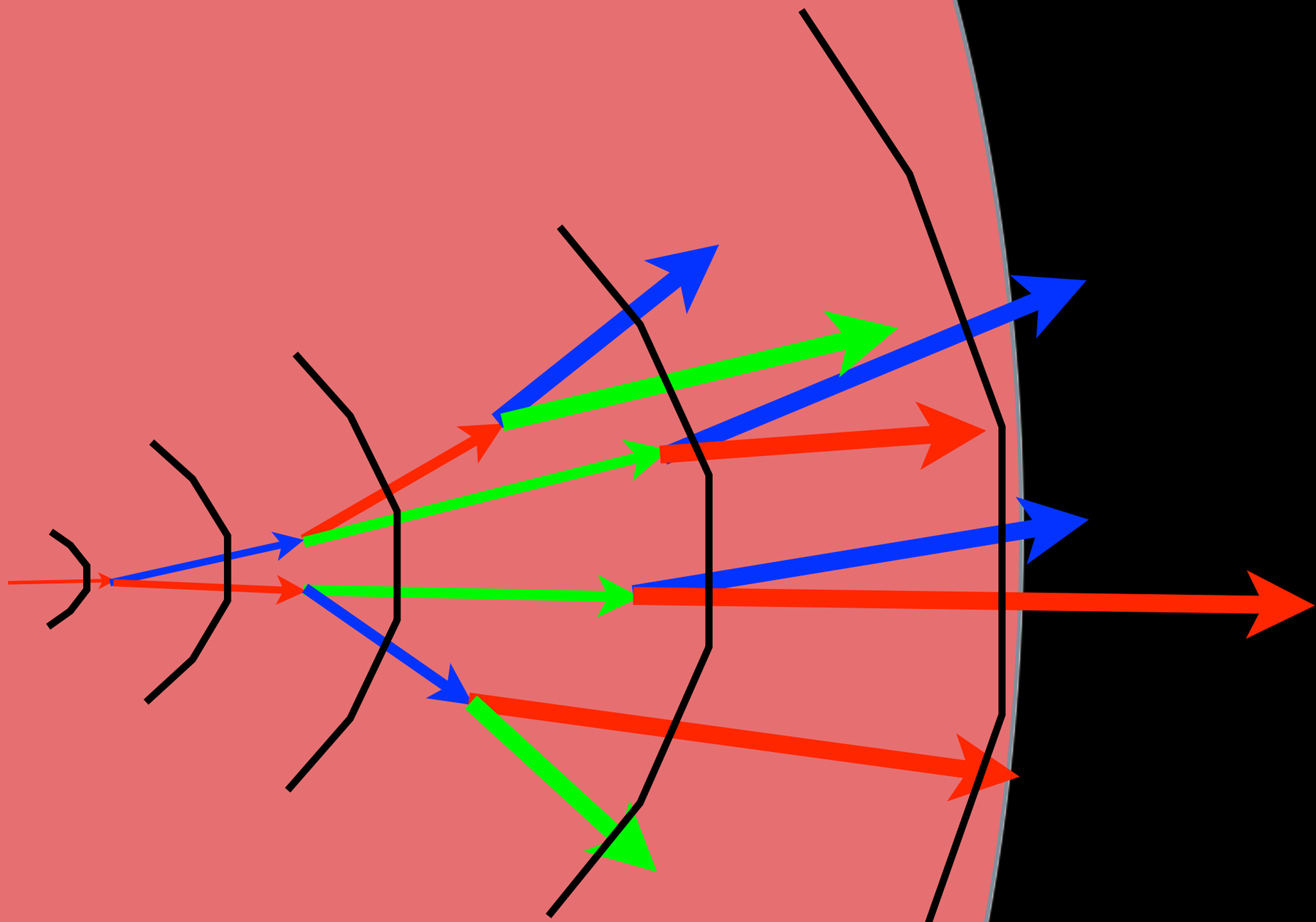

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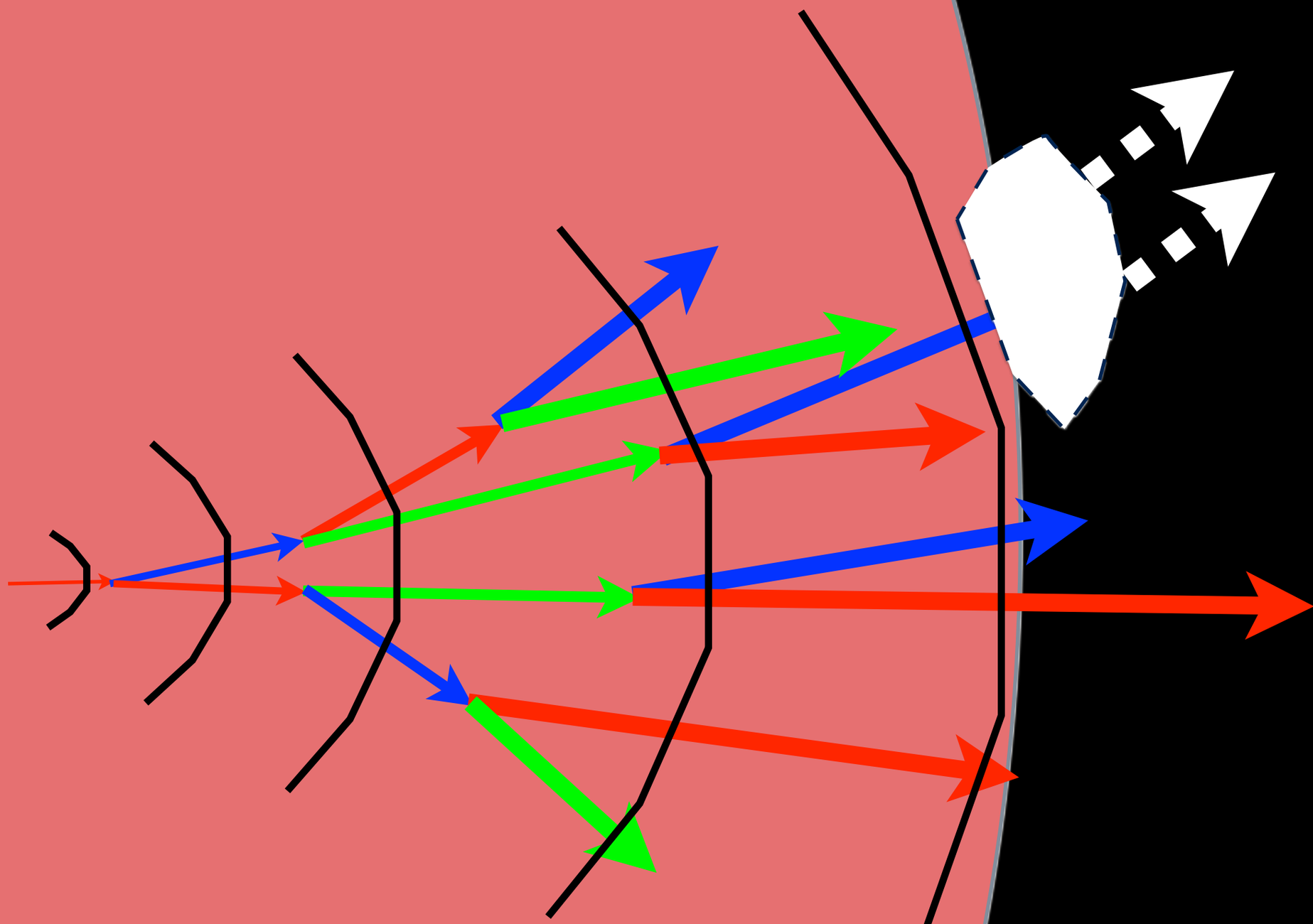

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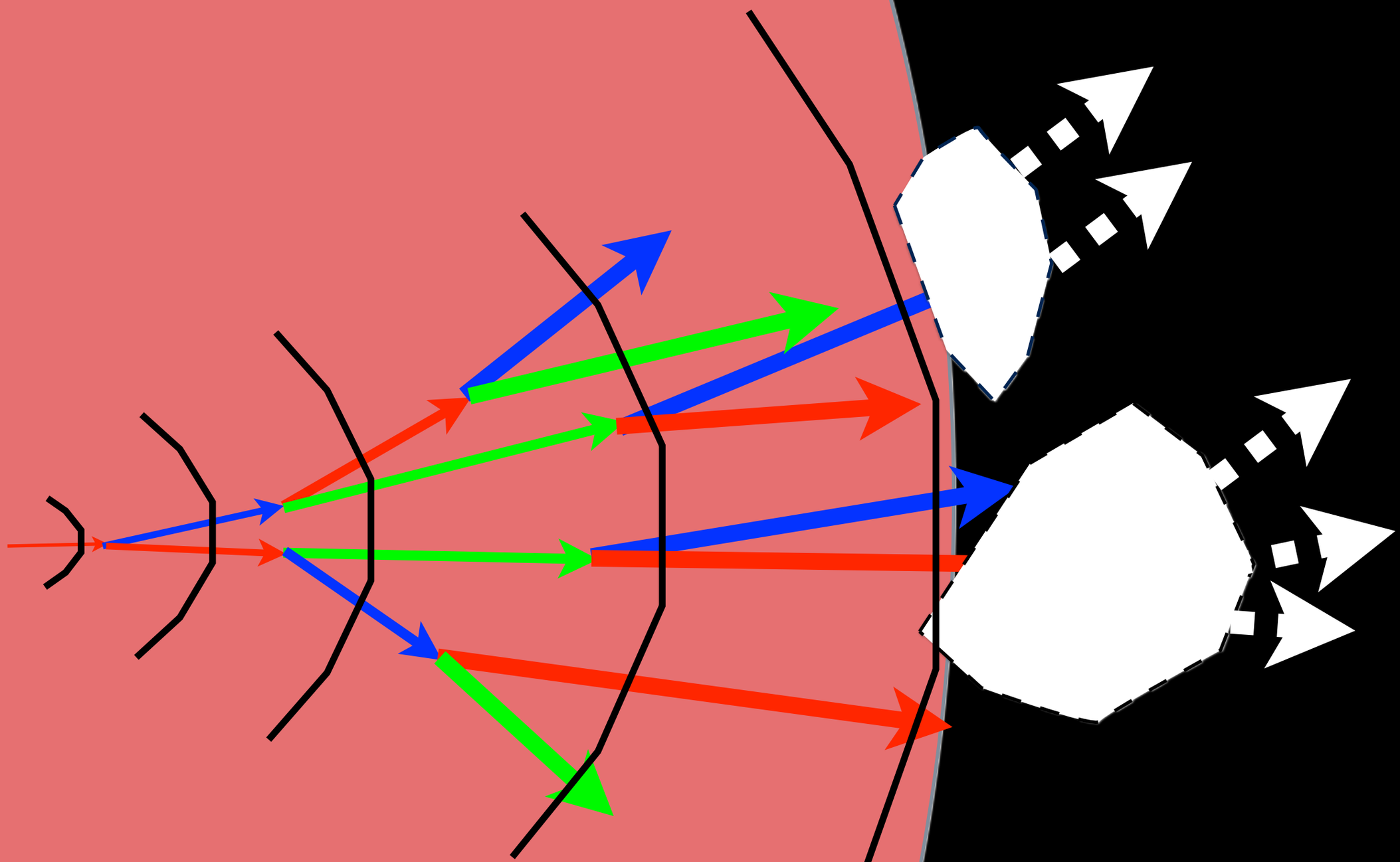

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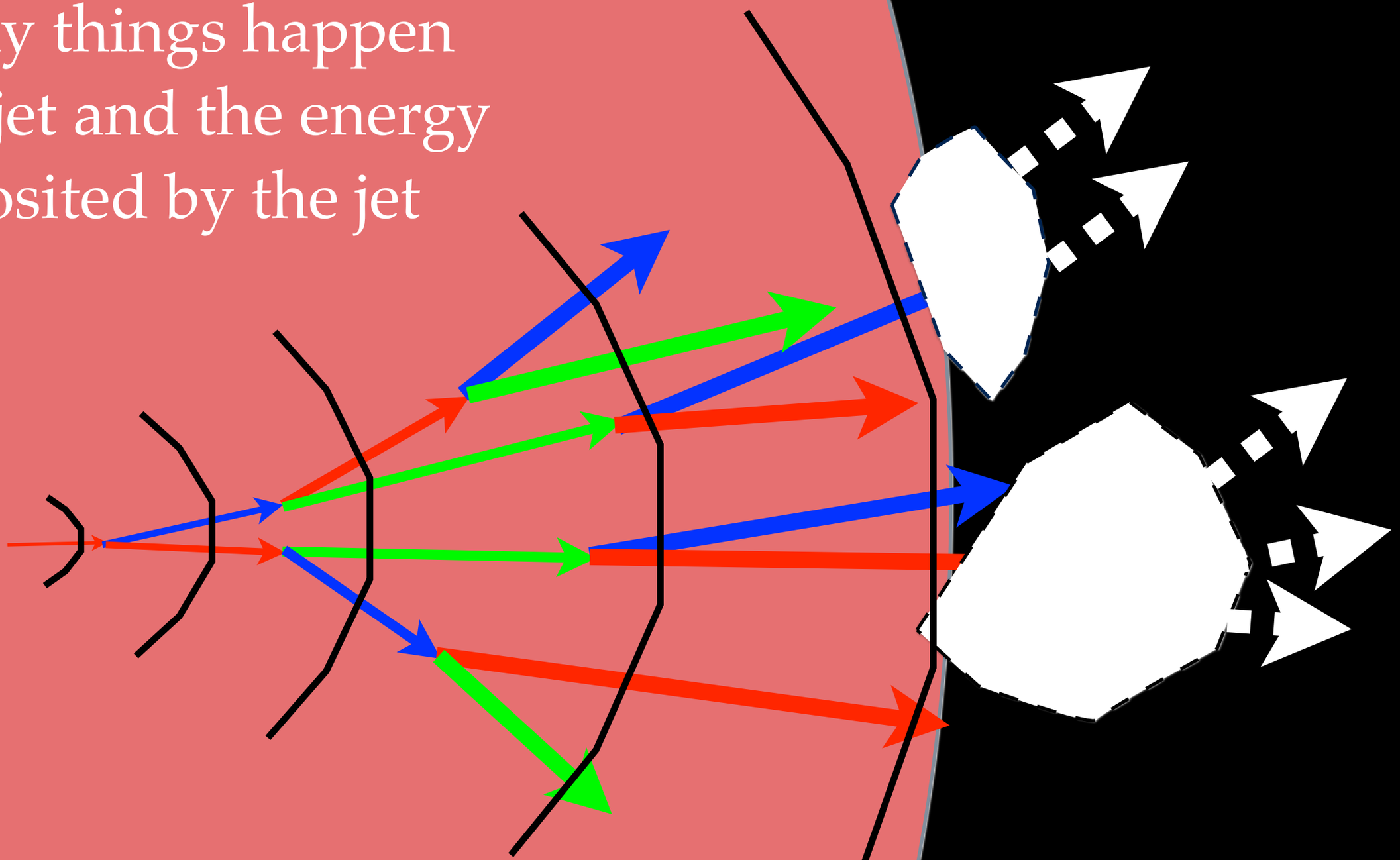

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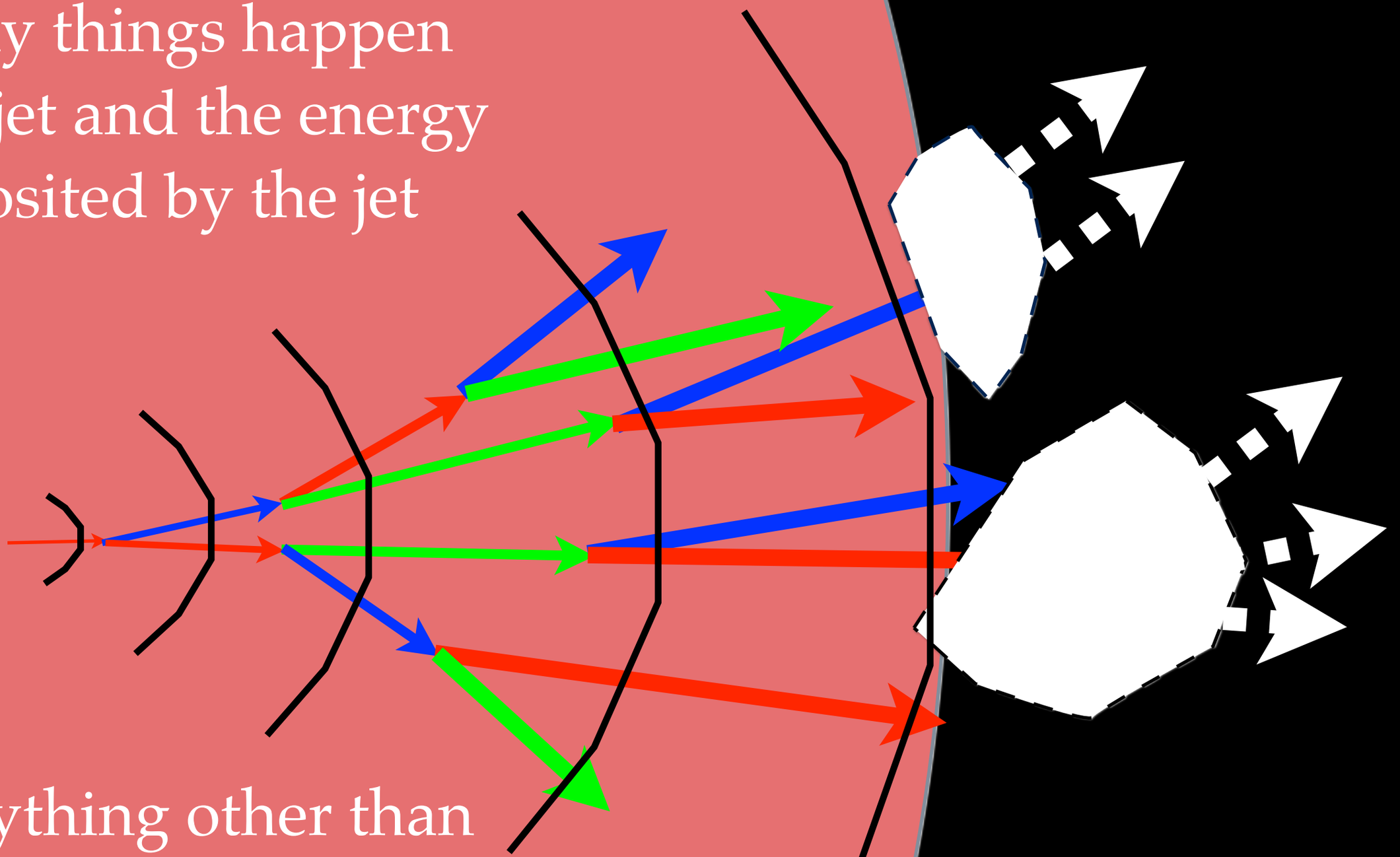
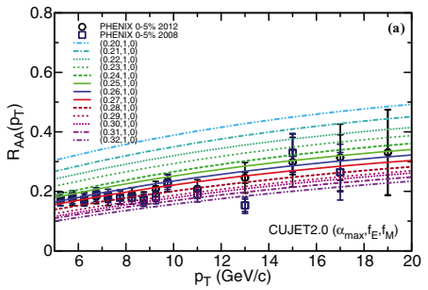
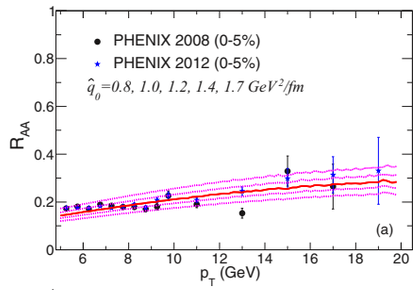
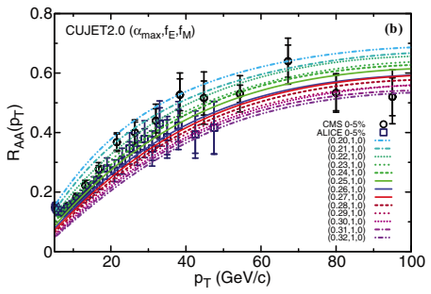


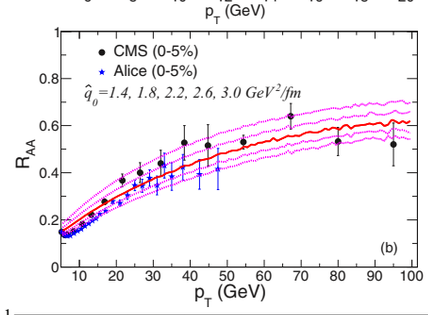
Everything other than
leading hadrons is strongly
affected by the medium

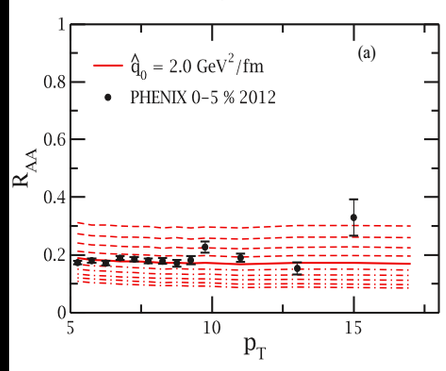
This is not how things were done traditionally

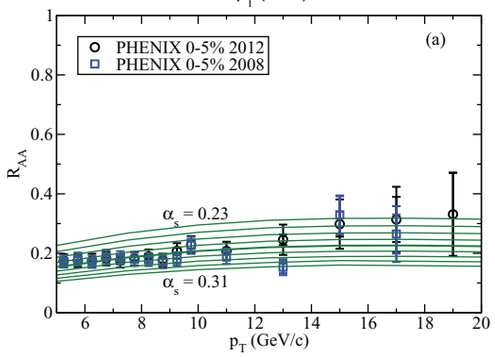


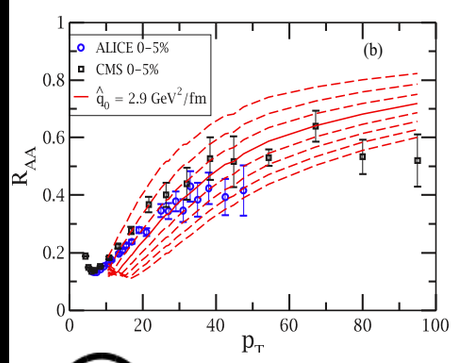


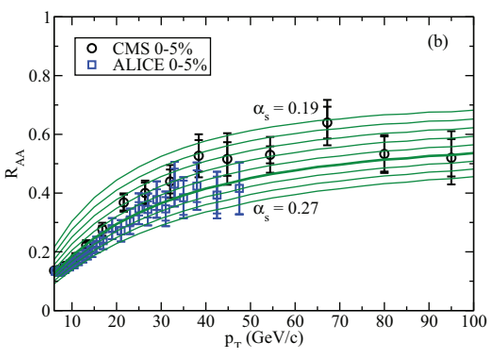


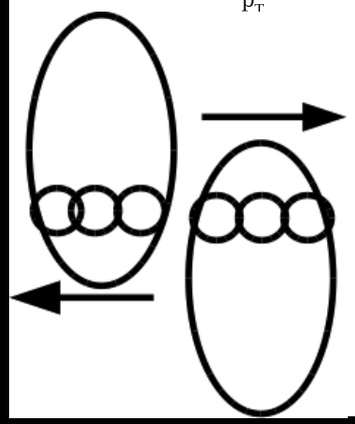












$$R_{AA} \sim \frac{\frac{dN_{AA}}{dp_T dy}}{N_{bin}\frac{dN_{pp}}{dp_T dy}}$$

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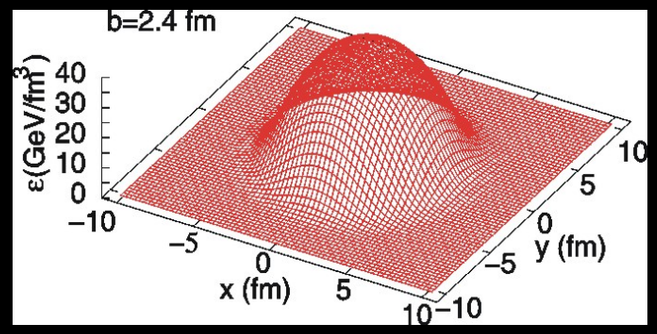
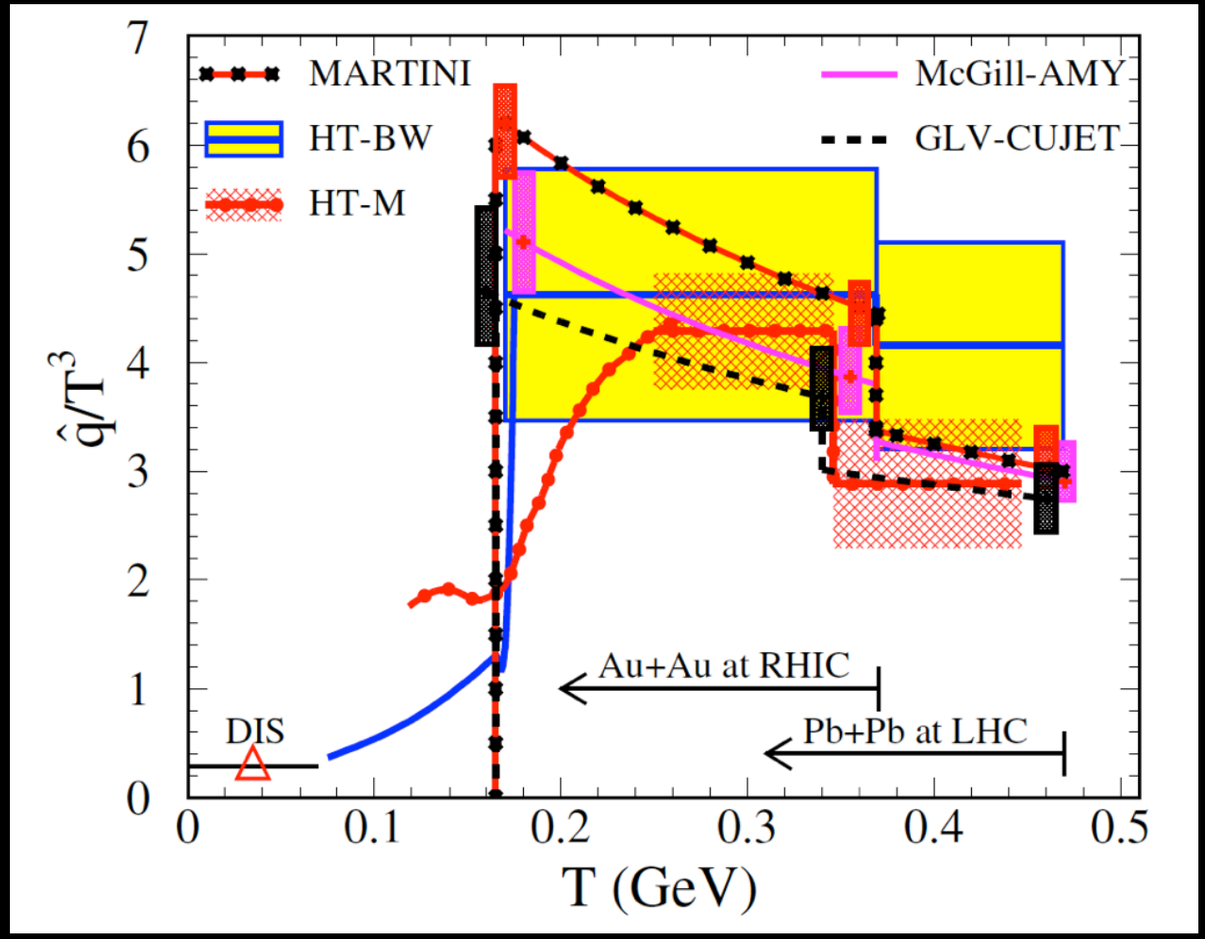


Applied different formalism to the entire history of the jet.



A complete change of paradigm!

How jets interact with the medium and evolve depends on

- Temperature of the medium
- Energy of the jet
- scale of the parton in the jet (E,μ^2)
- other scale of the medium ($\hat{q}\ \tau$)

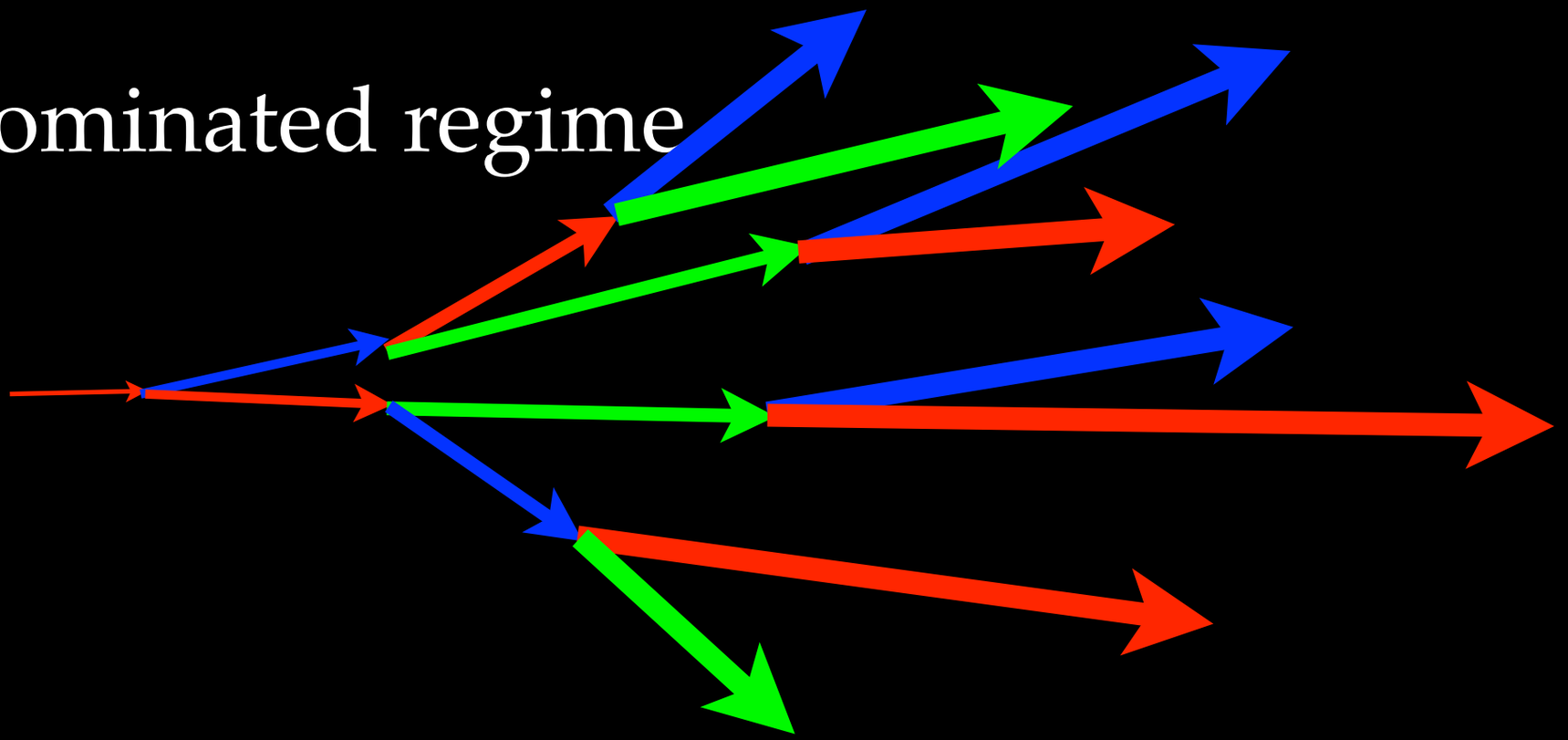
Different approaches to E-loss are valid in different epochs of the jet

A complete description requires all of these approaches

Discussion moves to boundaries between approaches

High energy and high virtuality part of shower

- Radiation dominated regime



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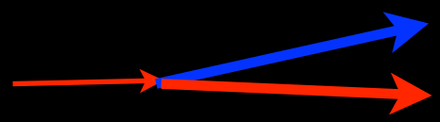

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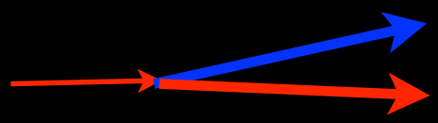

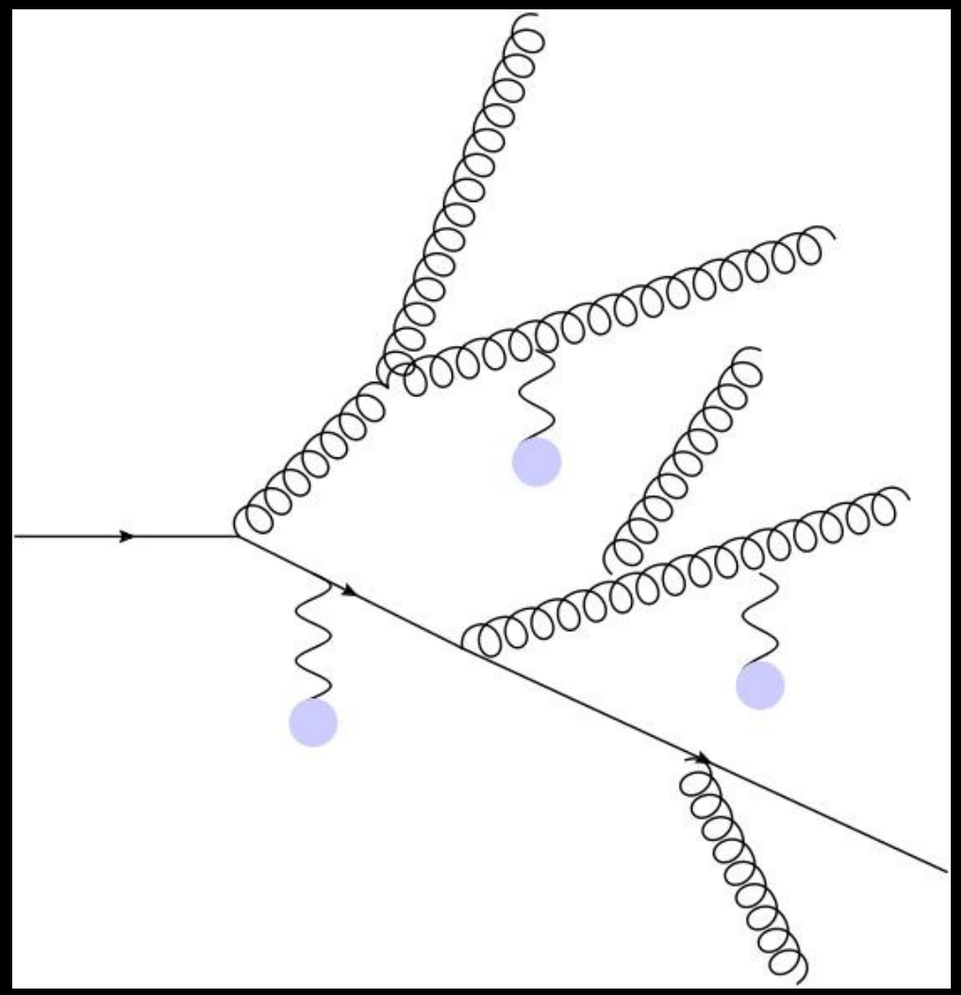

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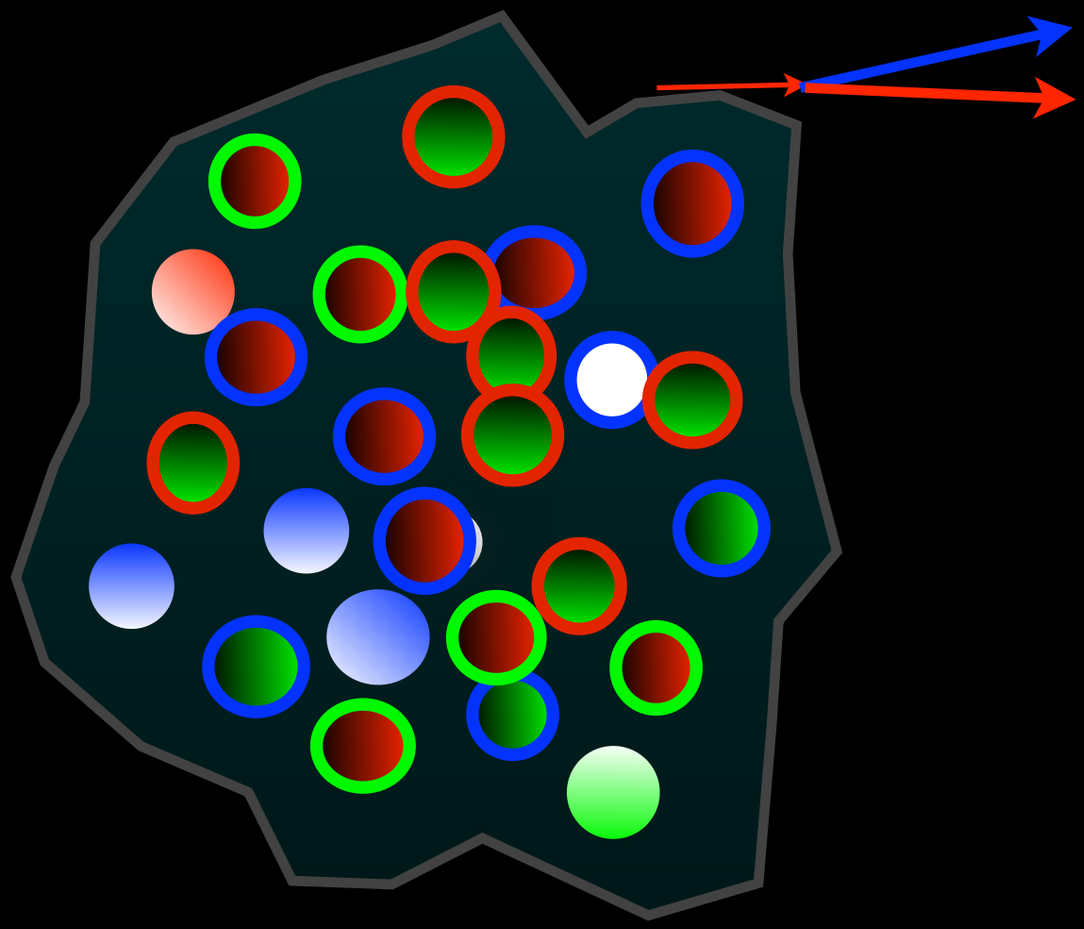

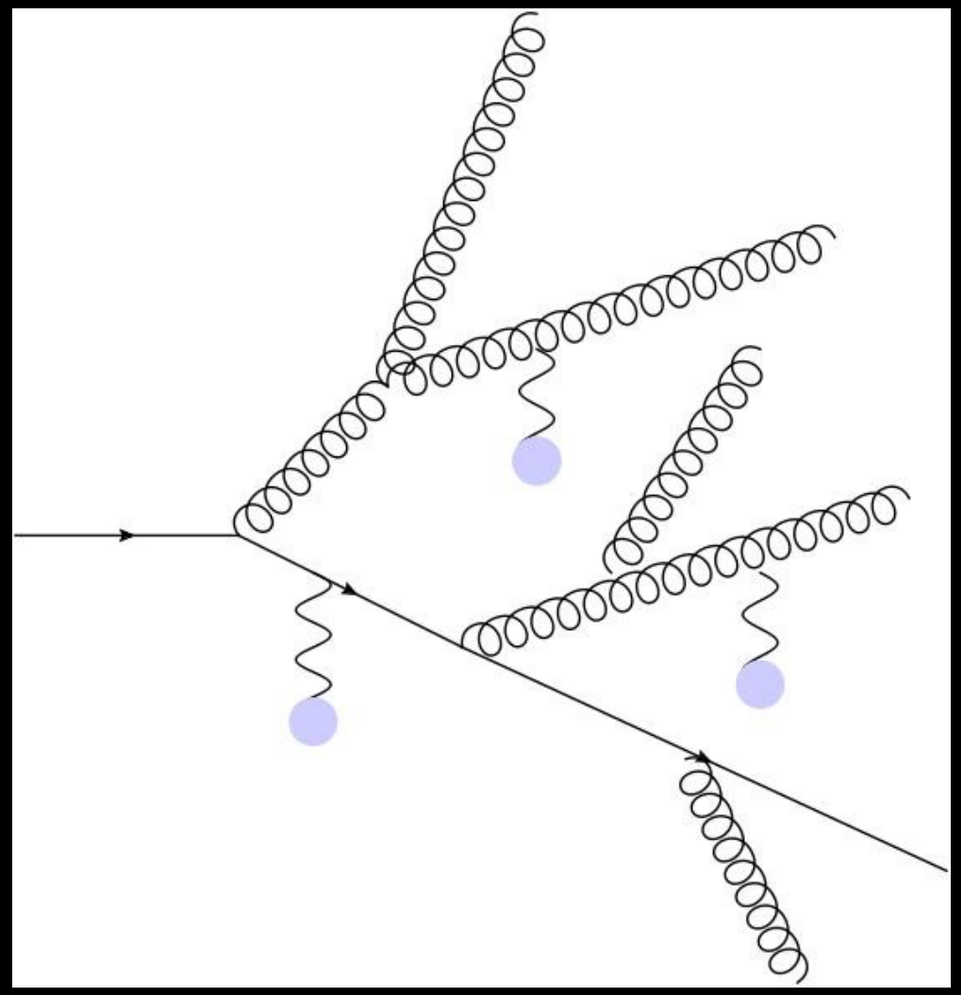

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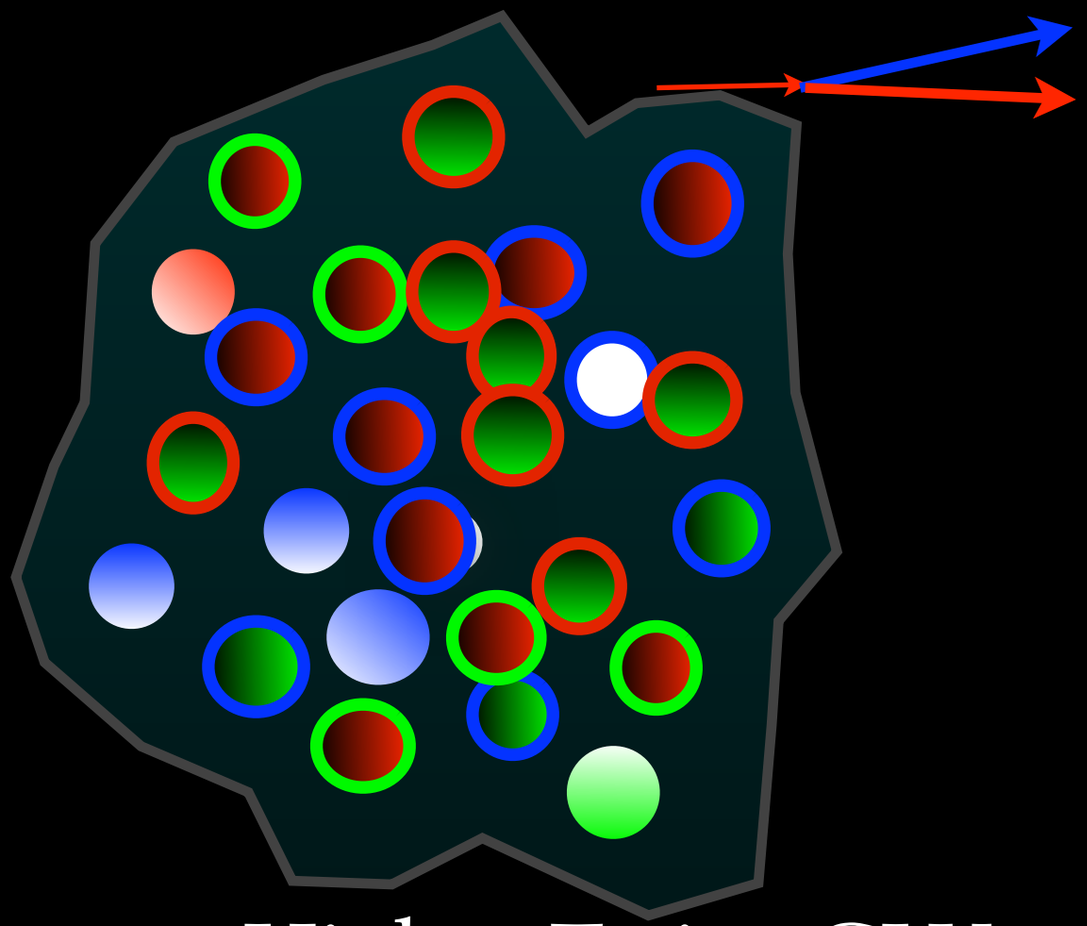
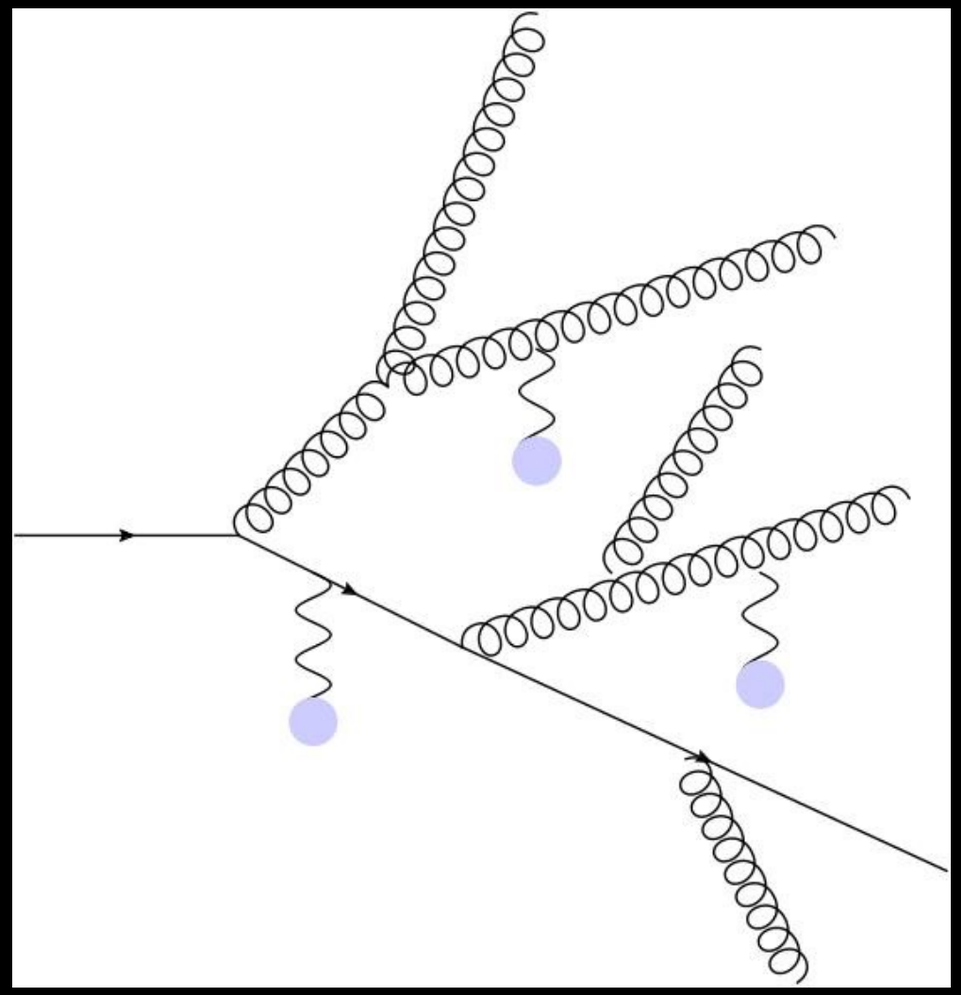


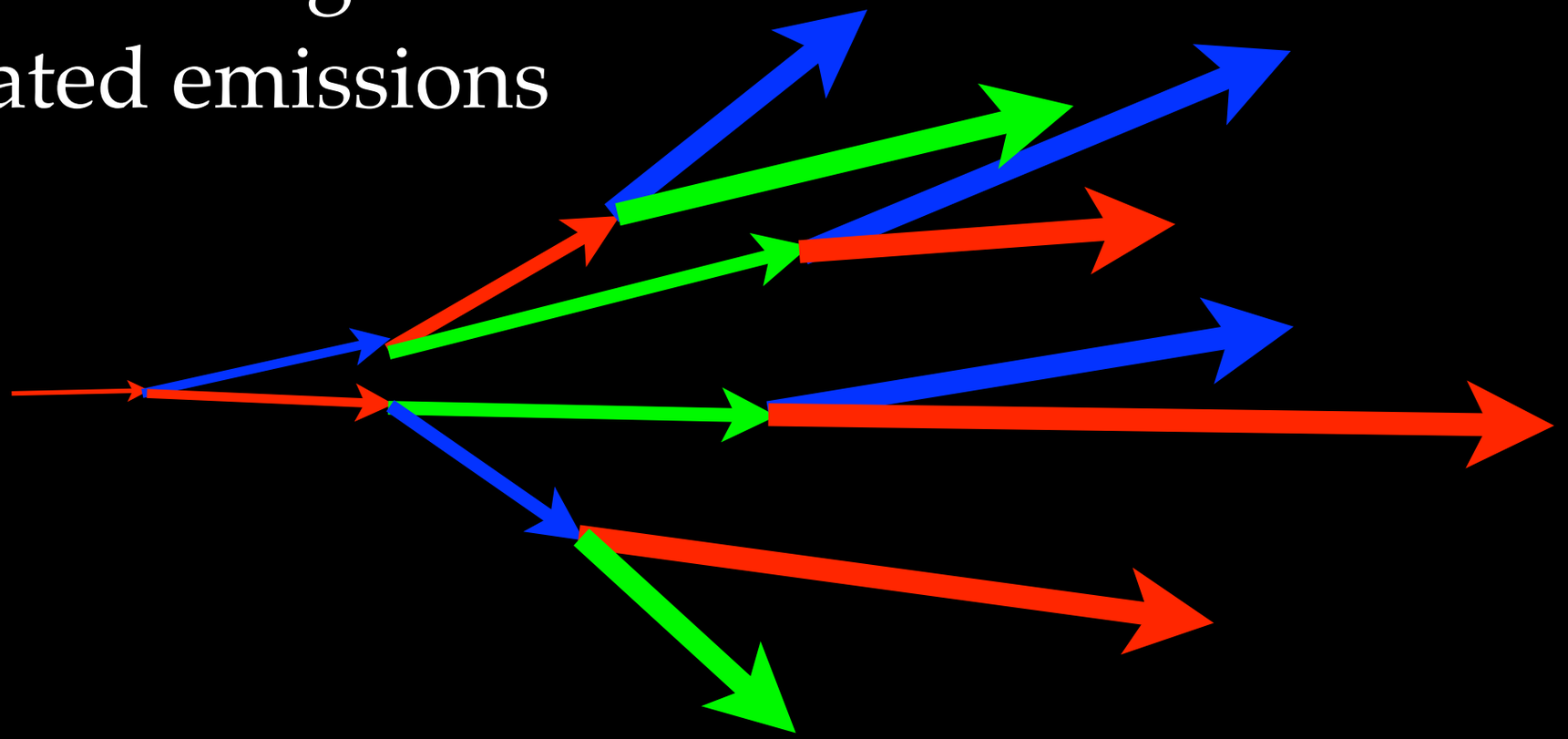


Theory: Higher Twist, GLV

MC: MATTER, YaJEM

Low virtuality, high energy part

Scattering dominated regime
Few, time separated emissions



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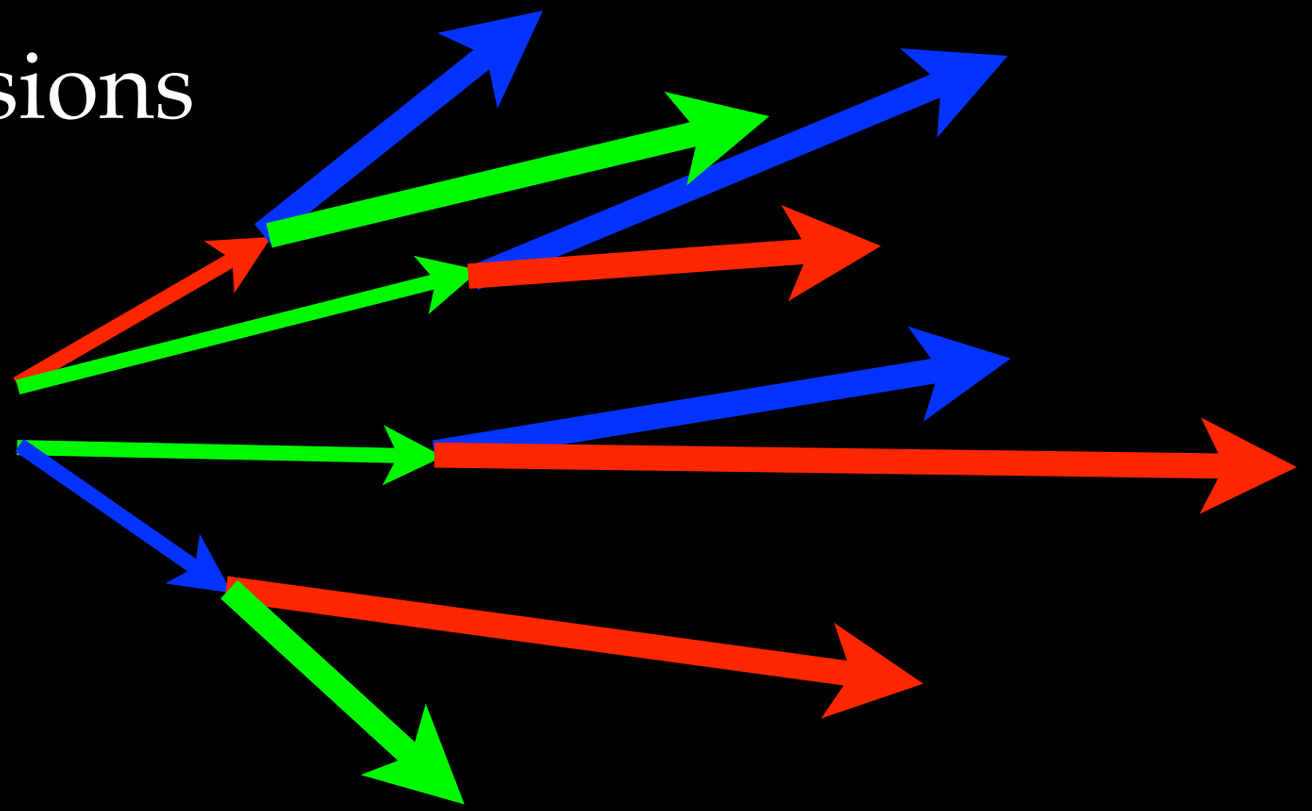

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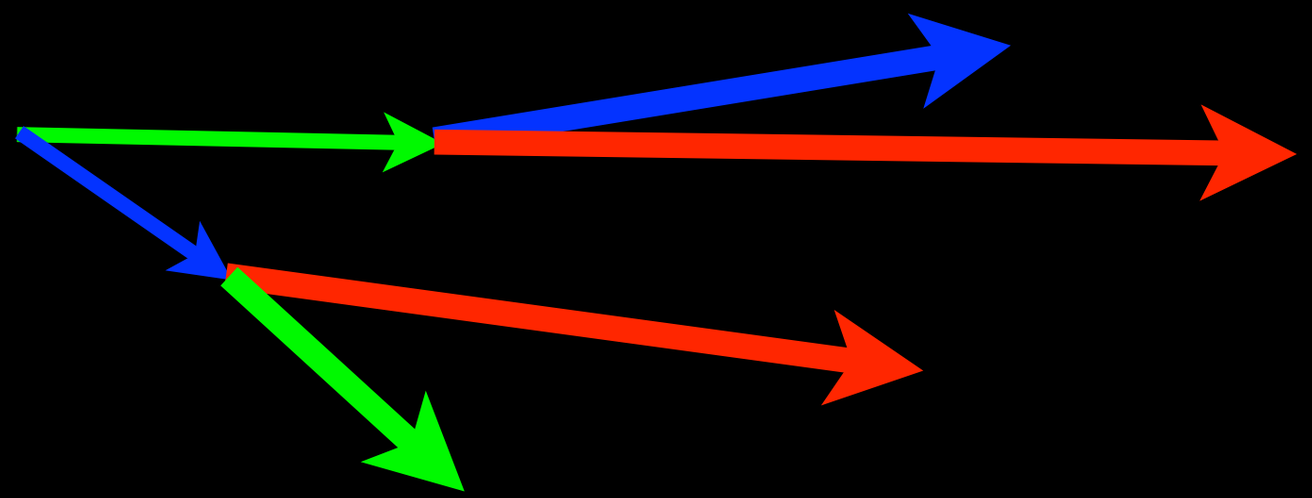

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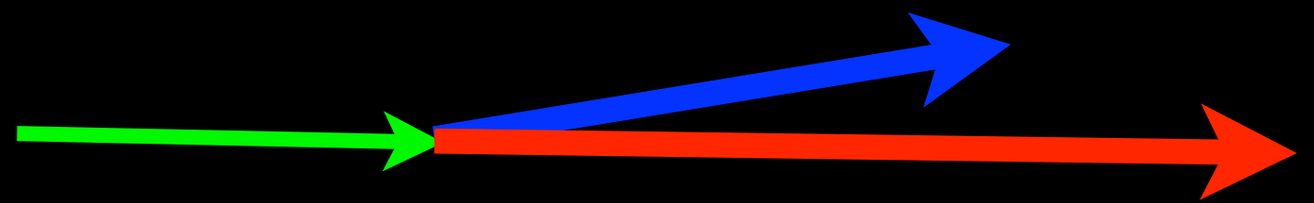

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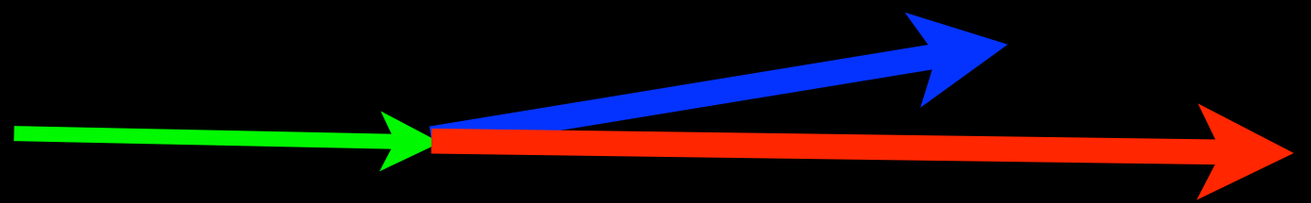

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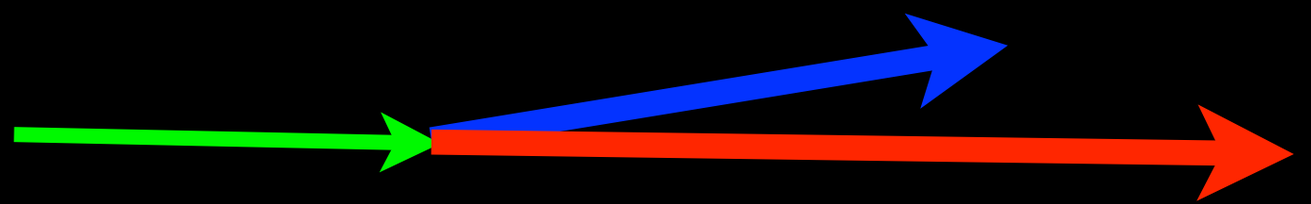

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MC: LBT*, MARTINI, JEWEL*

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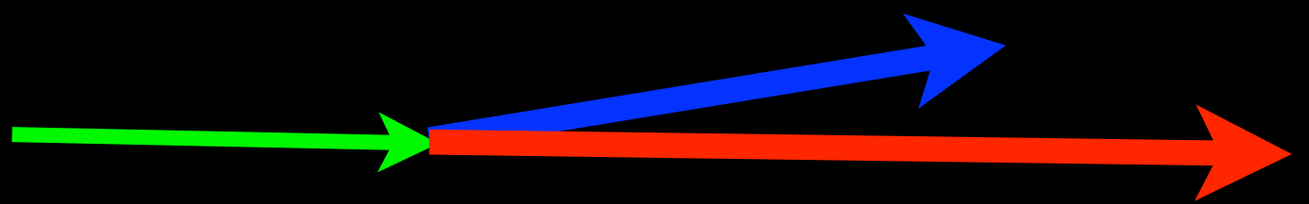

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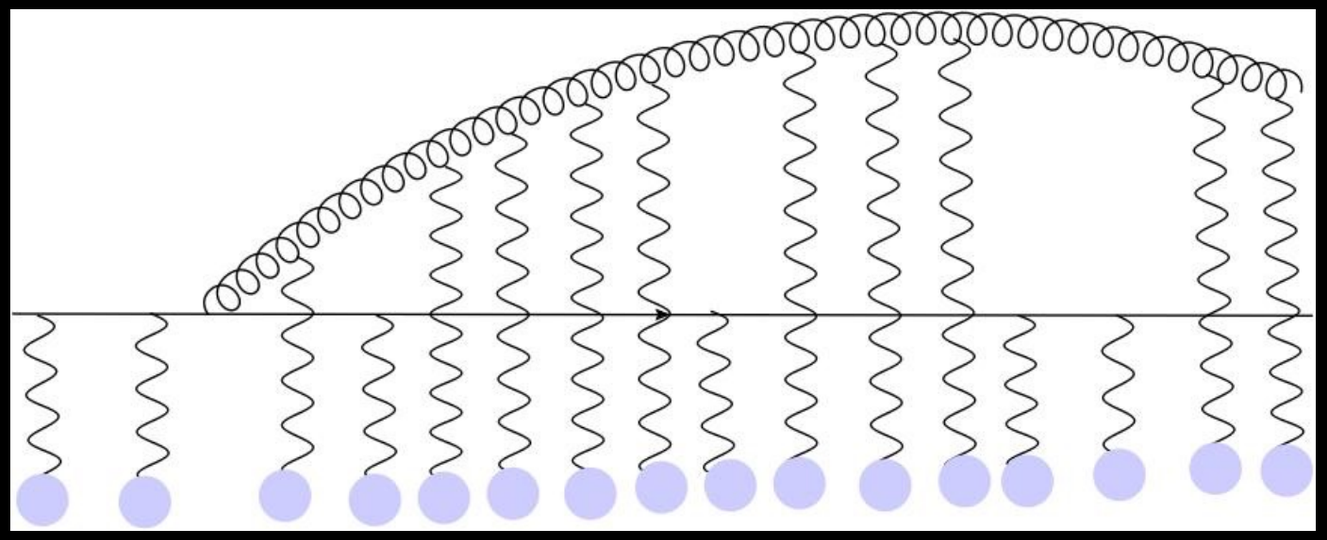

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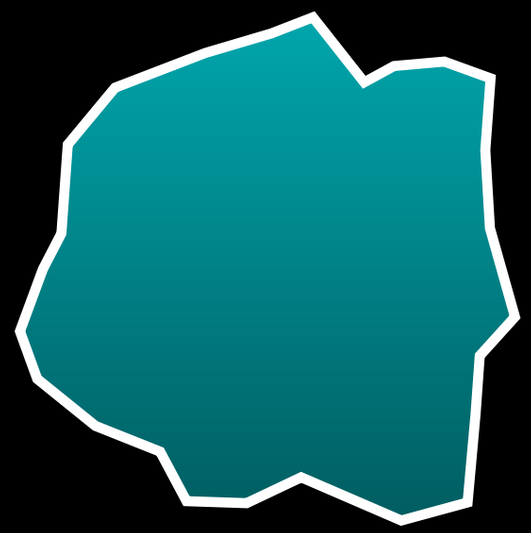

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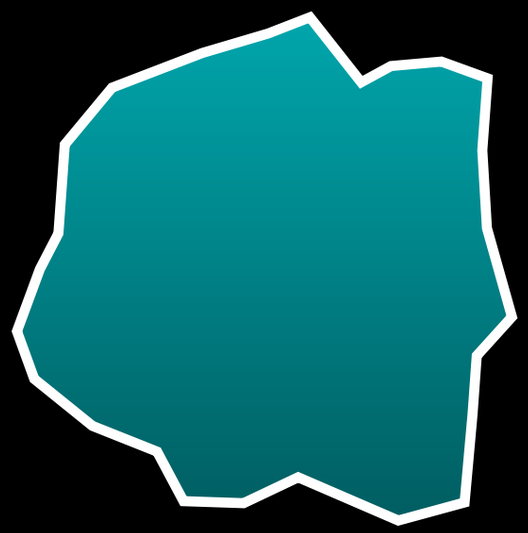

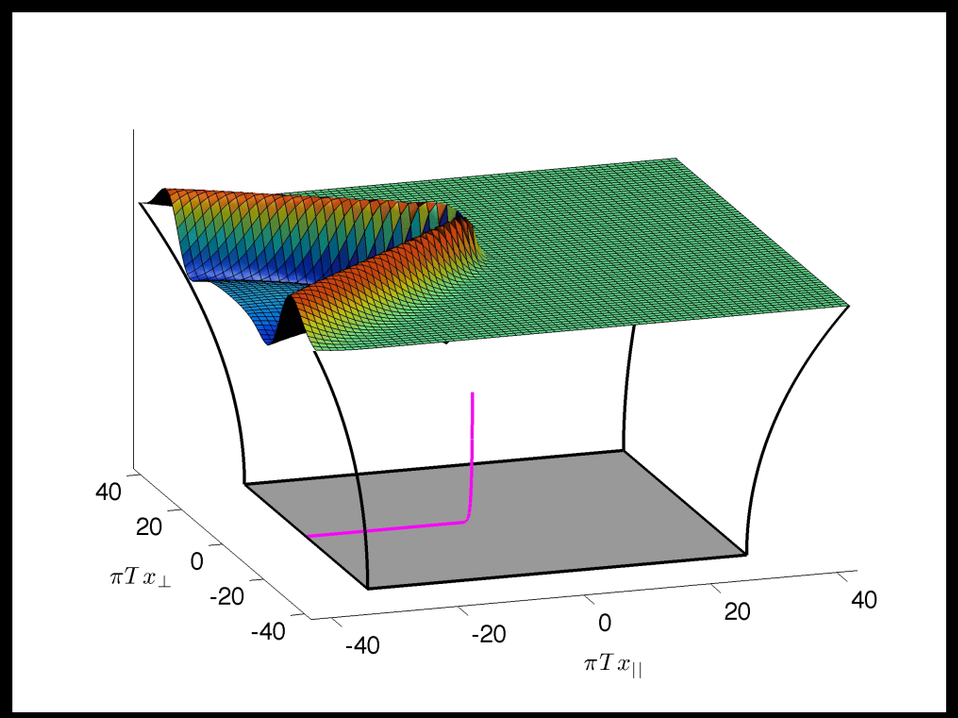

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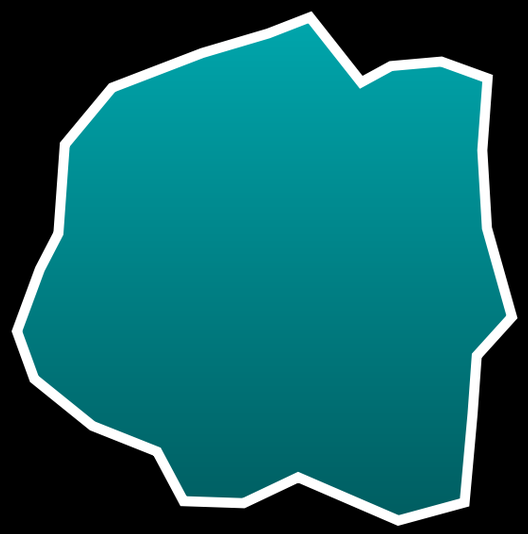
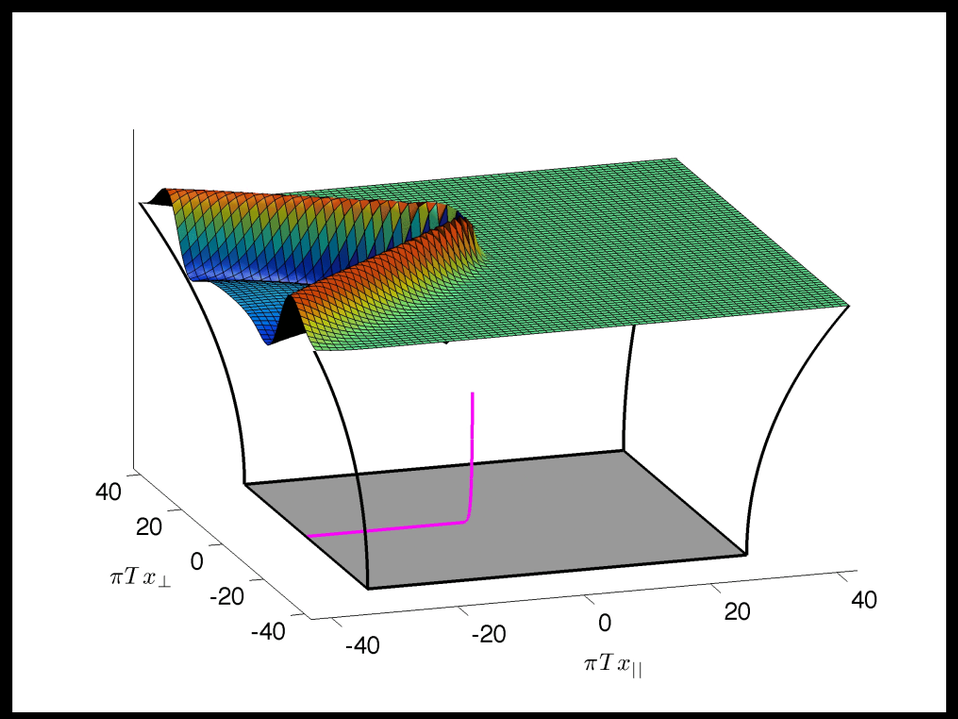
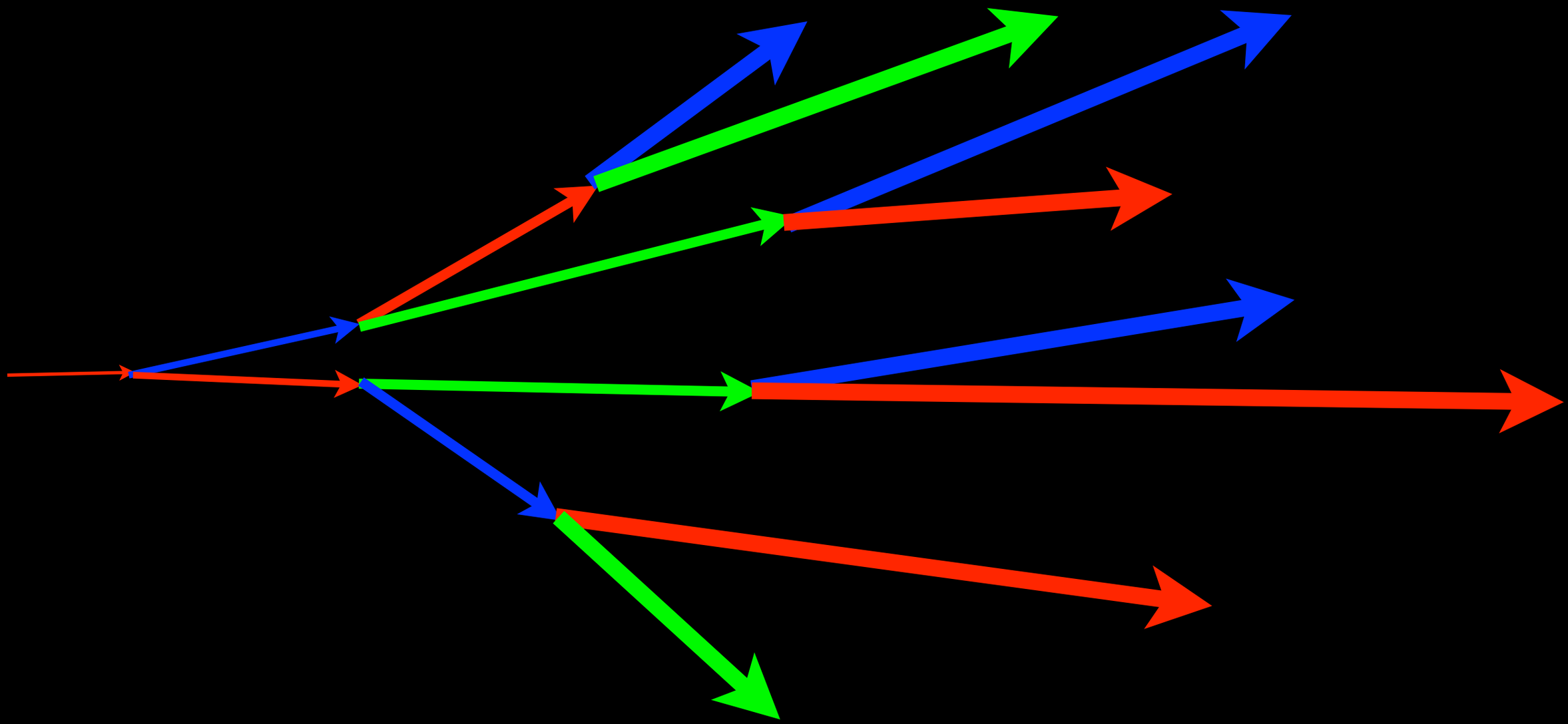




P. Chesler, W. Horowitz J. Casalderrey-Solana,
G. Milhano, D. Pablos, K. Rajagopal

Grand picture (leading hadrons)



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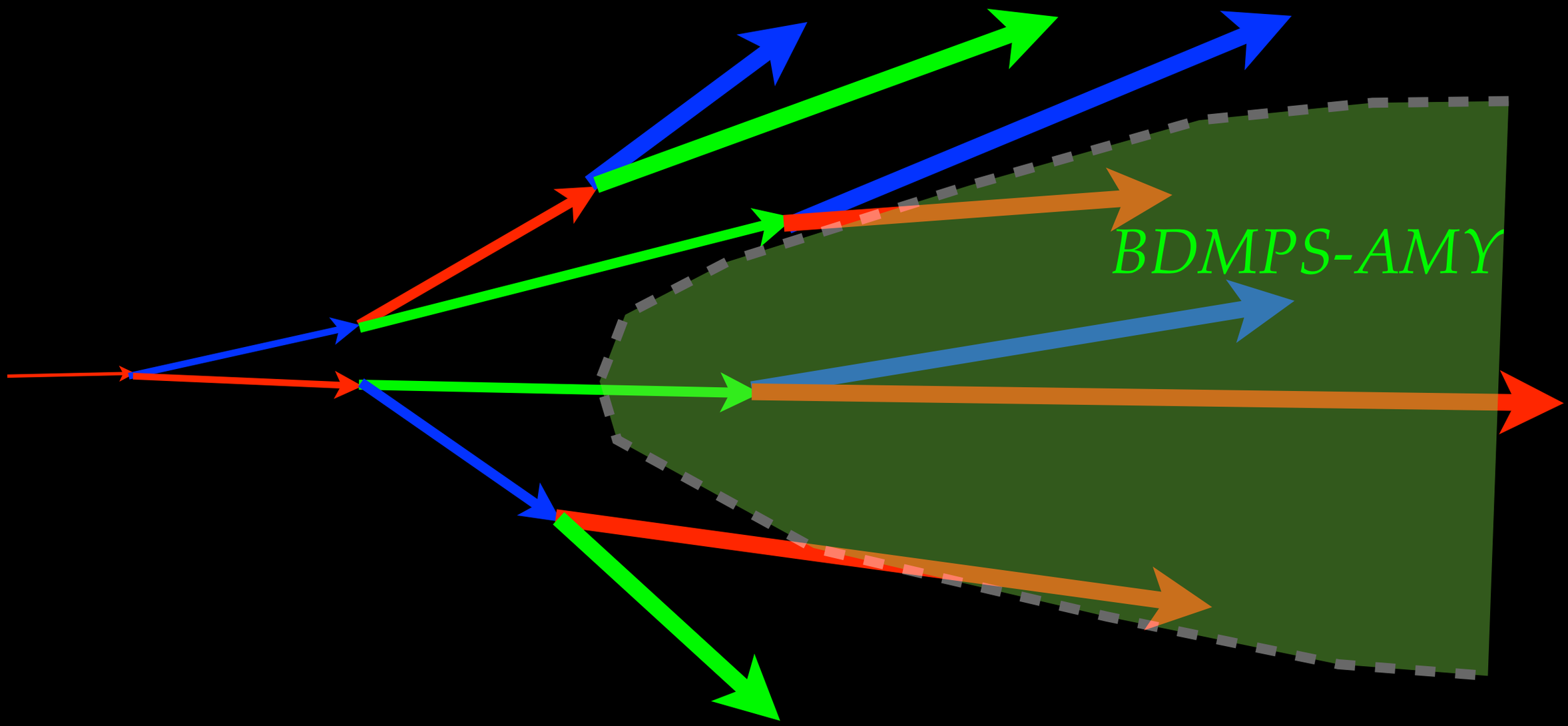

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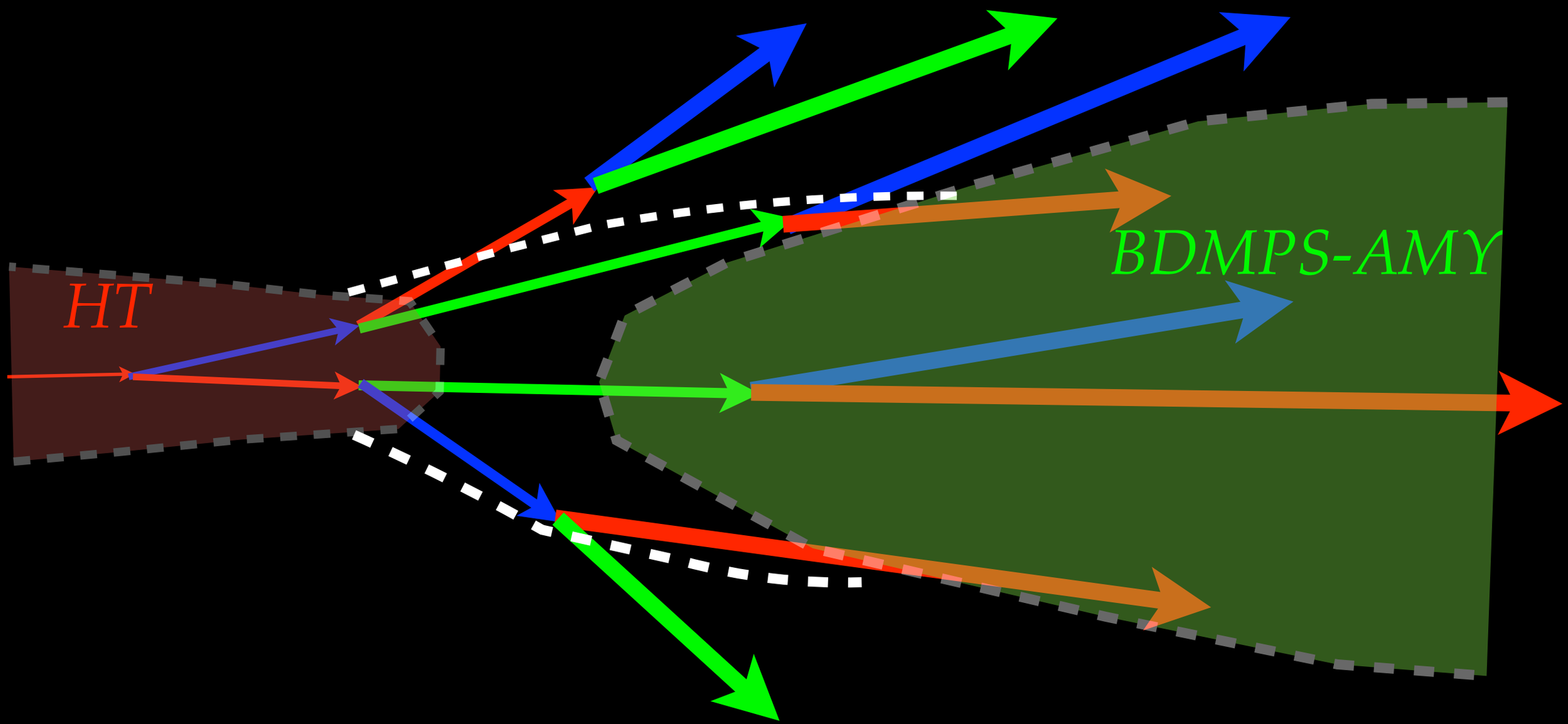

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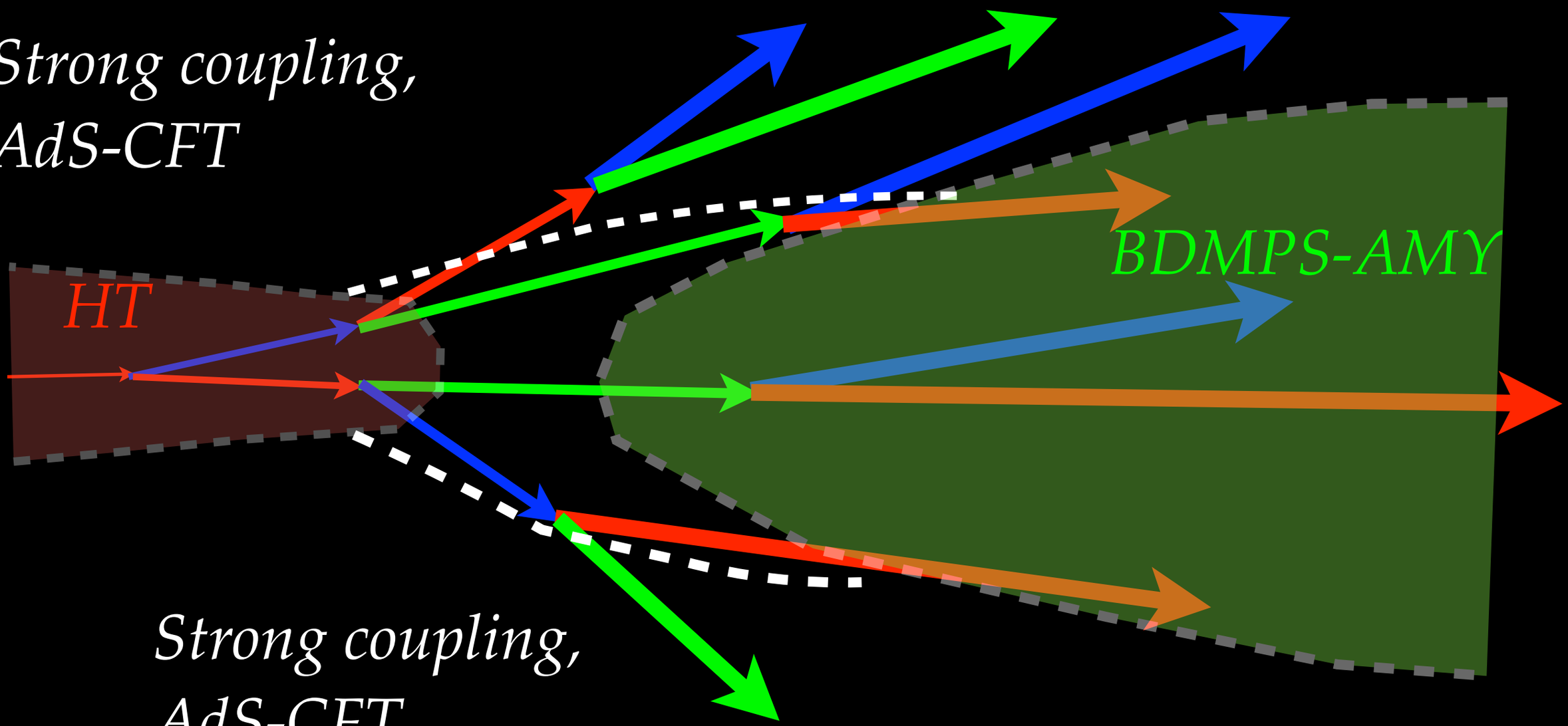

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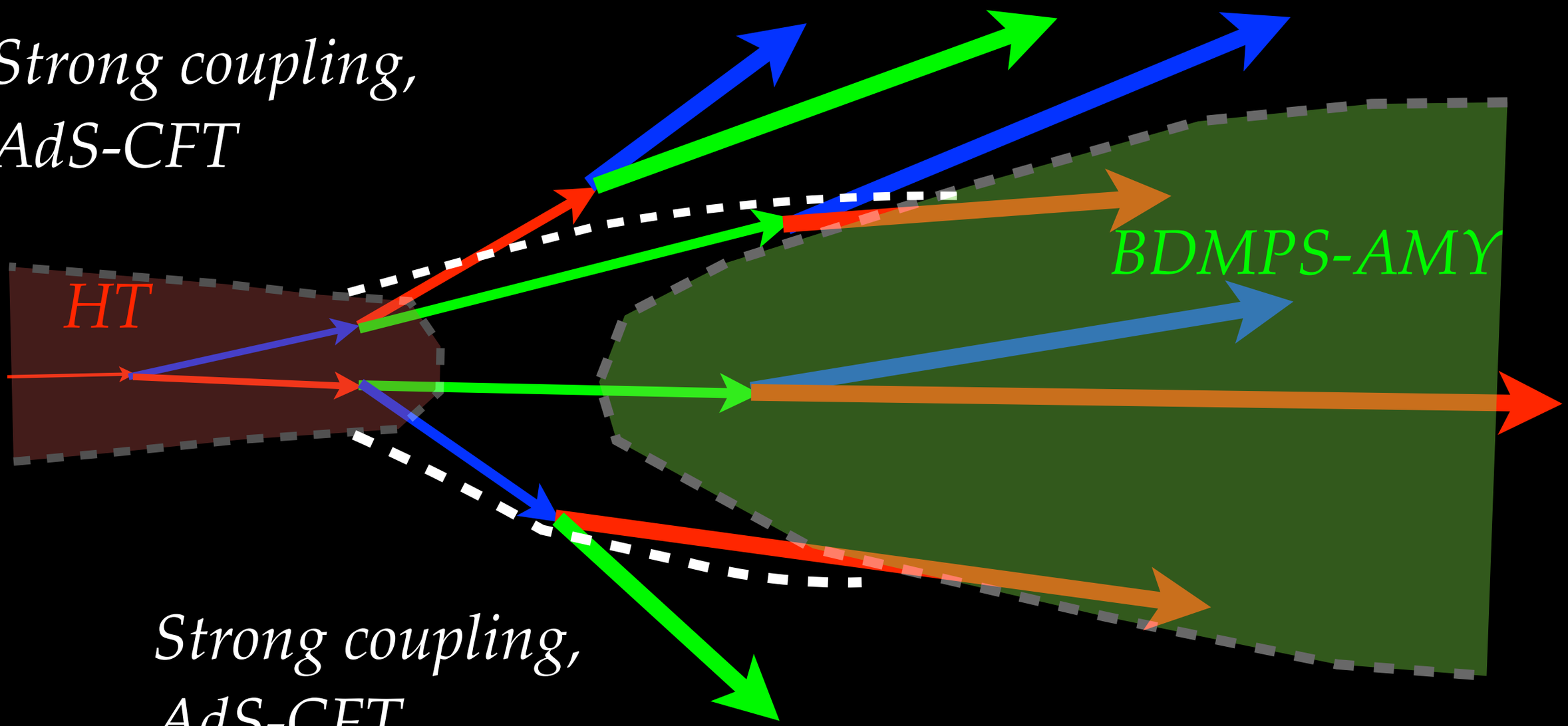

In an expanding QGP

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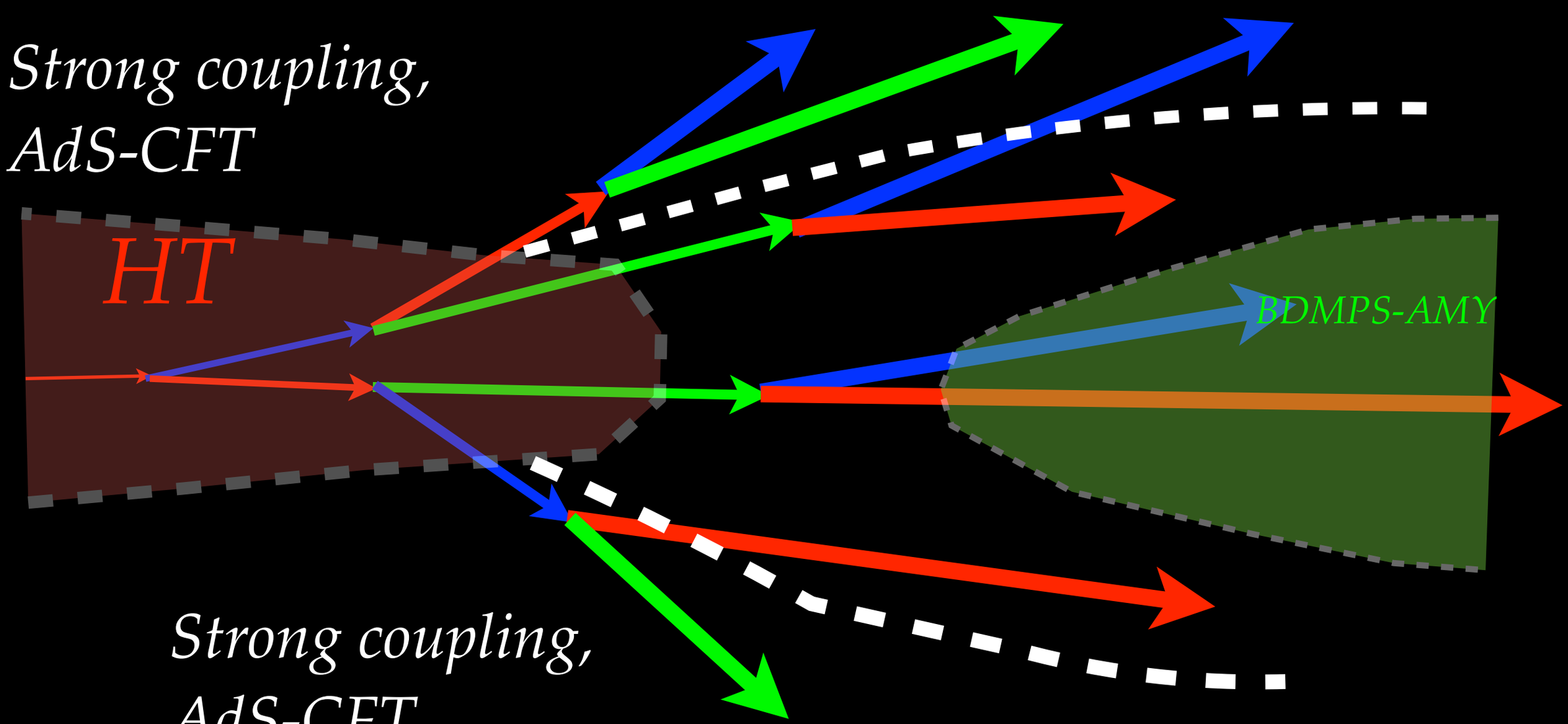
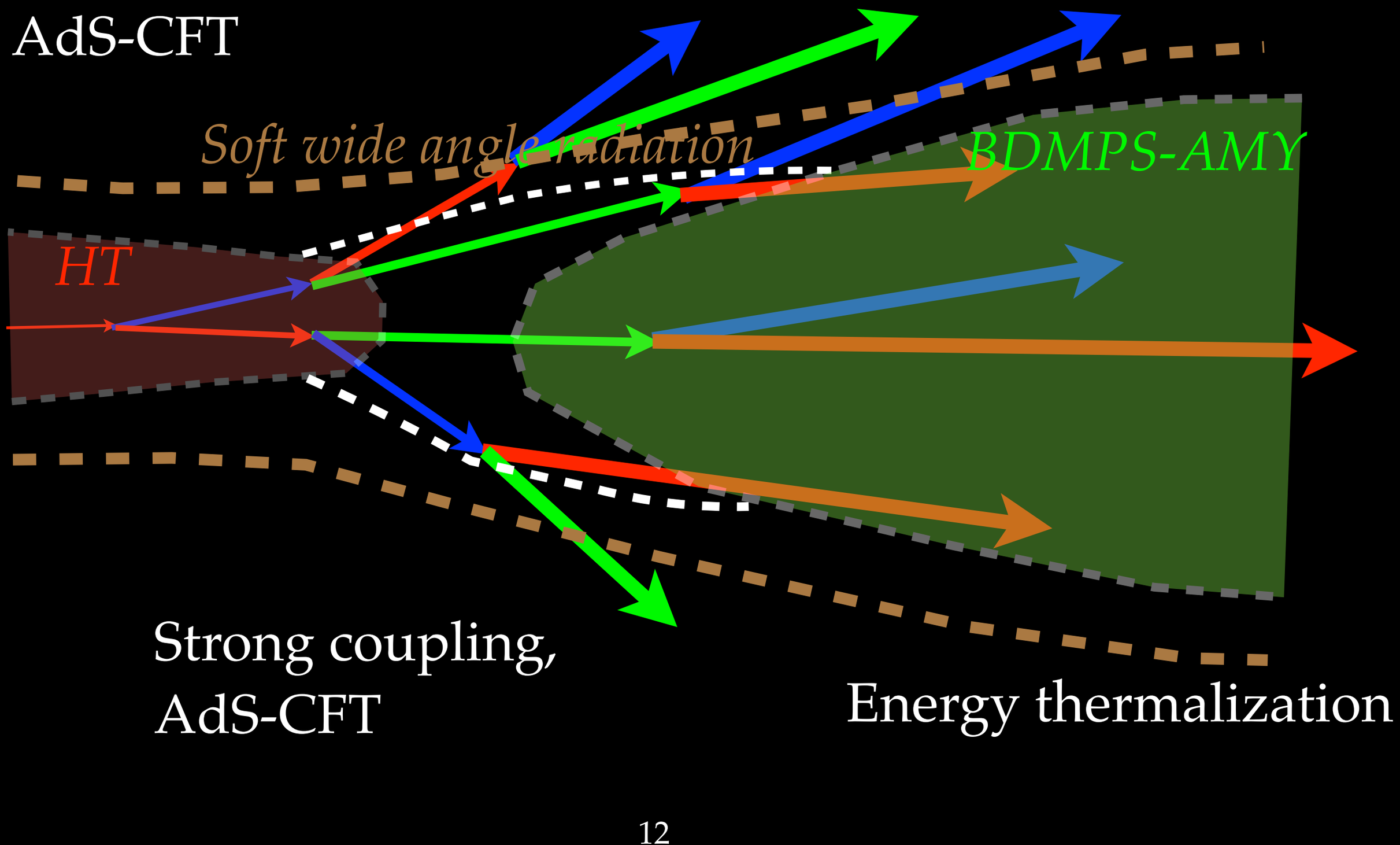


In an expanding QGP

Energy deposition-thermalization

Strong coupling,
AdS-CFT

Energy thermalization



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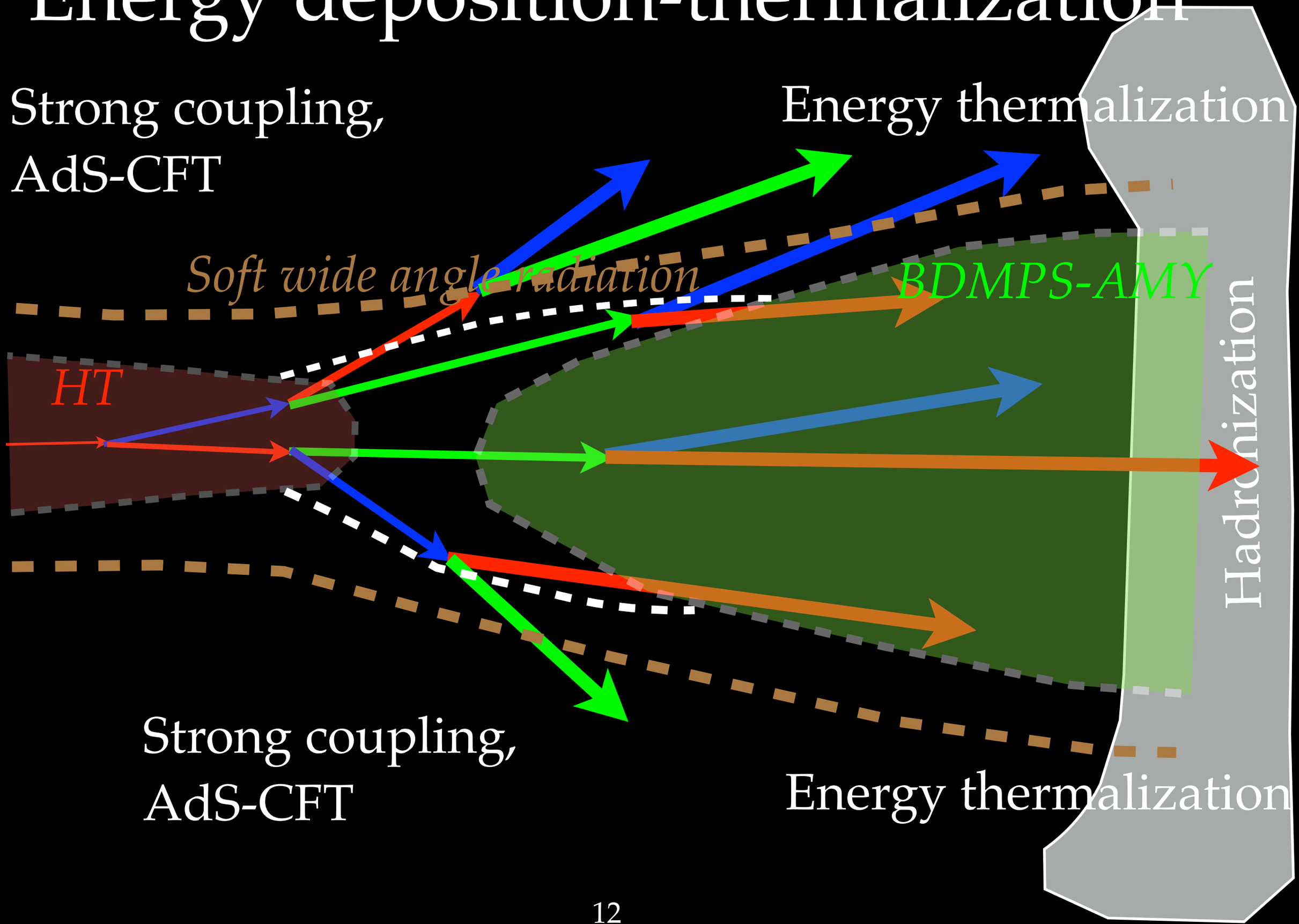
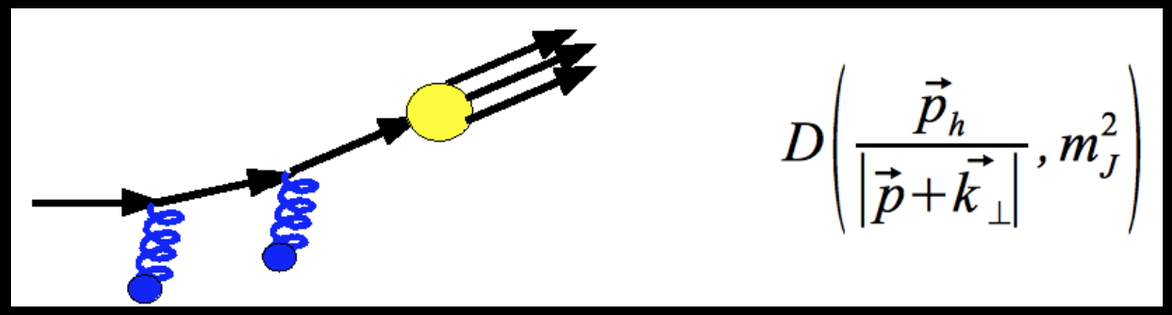


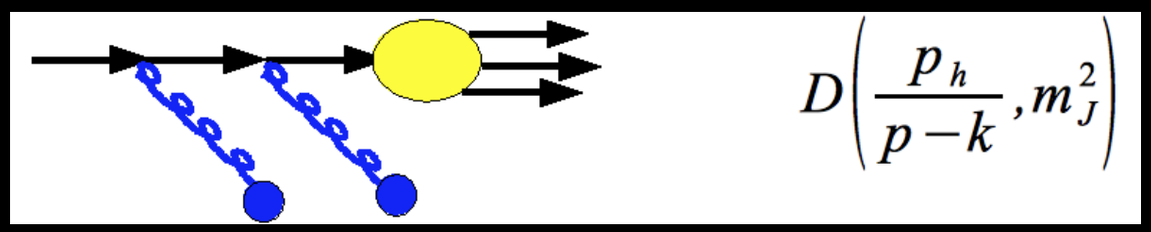
Transport coefficients for partons in a dense medium

$$p_z^2 \simeq E^2 - p_\perp^2 \qquad p^+ \simeq p_\perp^2 / 2p^-$$



$$\hat{q} = \frac{\langle p_\perp^2 \rangle_L}{L}$$

Transverse momentum diffusion rate



$$\hat{e} = \frac{\langle \Delta E \rangle_L}{L}$$

Elastic energy loss rate
also diffusion rate e_2

By definition, describe how the medium modifies the jet parton!

In general, 2 kinds of transport coefficients

Type 1: which quantify how the medium changes the jet

$$\hat{q}(E, Q^2) \qquad \hat{q}_4(E, Q^2) = \frac{\langle p_T^4 \rangle - \langle p_T^2 \rangle^2}{L} \dots$$

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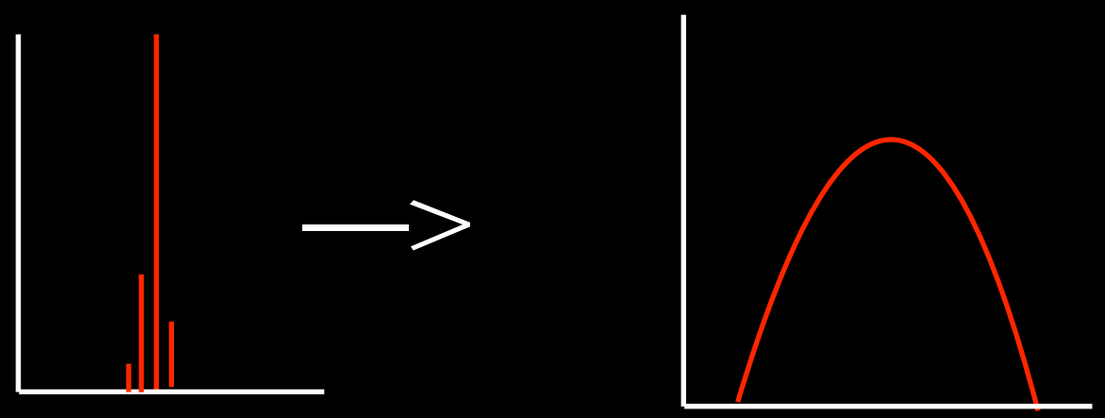
Type 2: which quantify the space-time structure of the deposited energy momentum at the hydro scale

$$\delta T^{\mu\nu}$$



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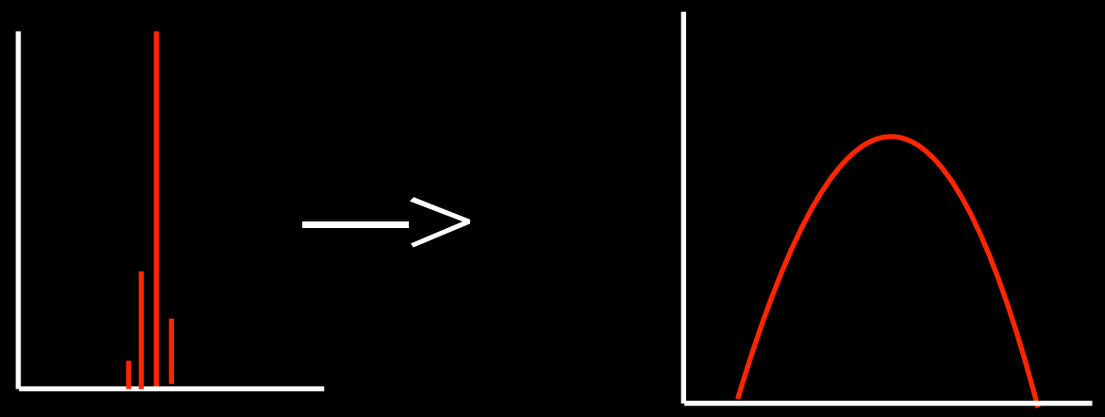

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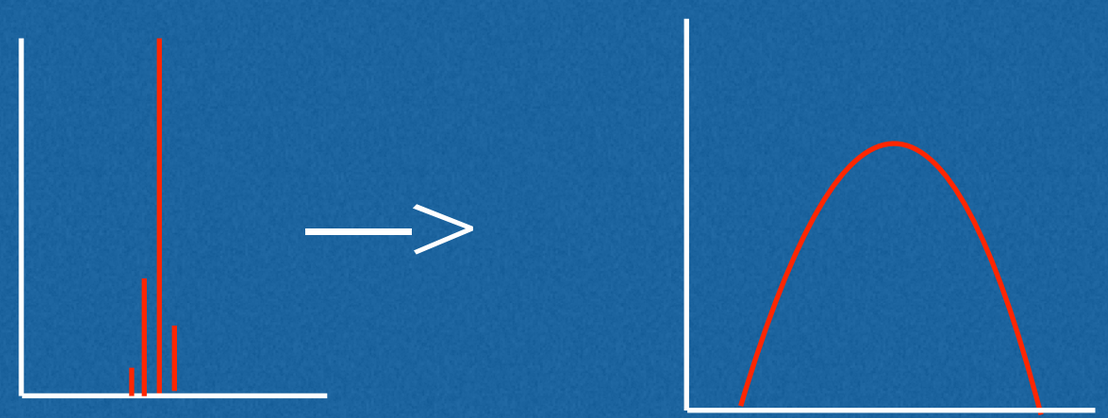
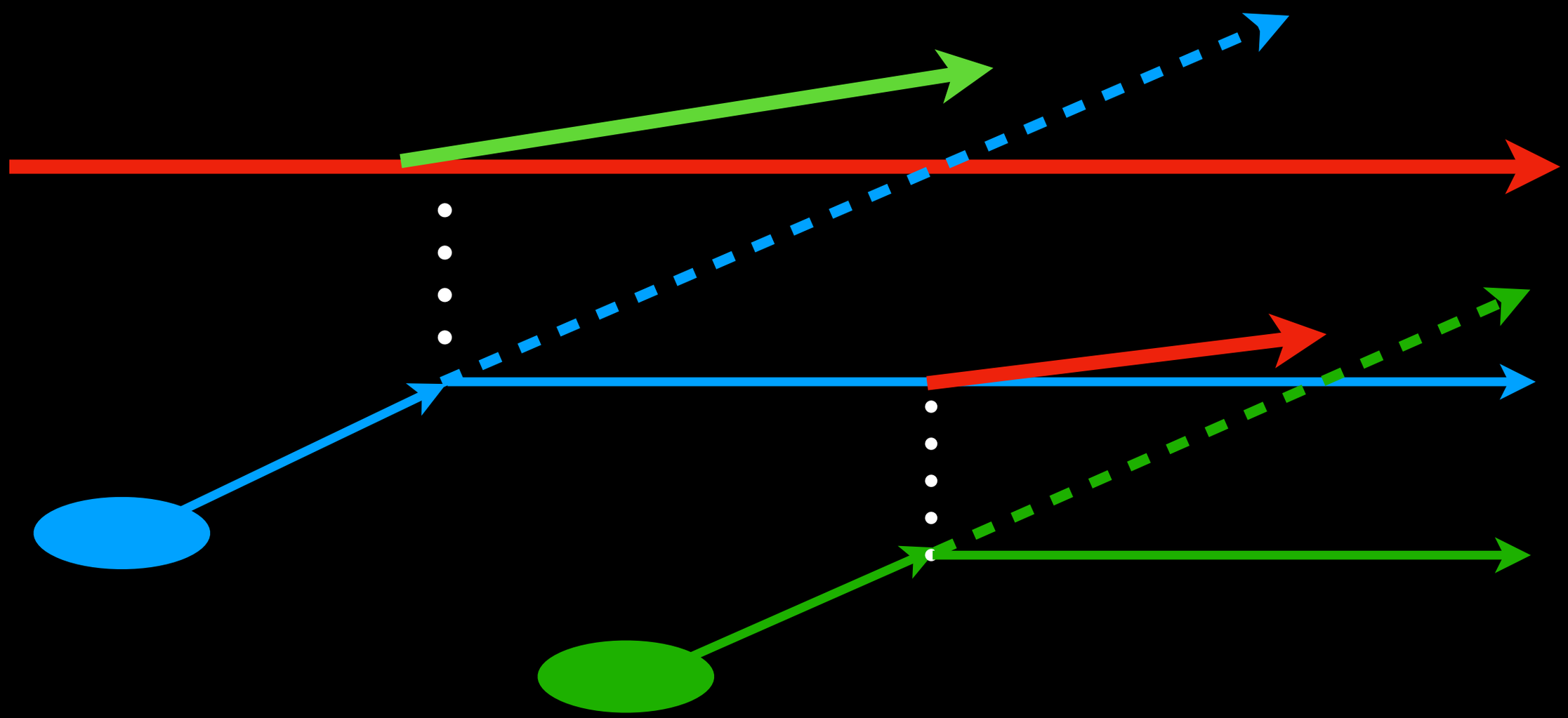


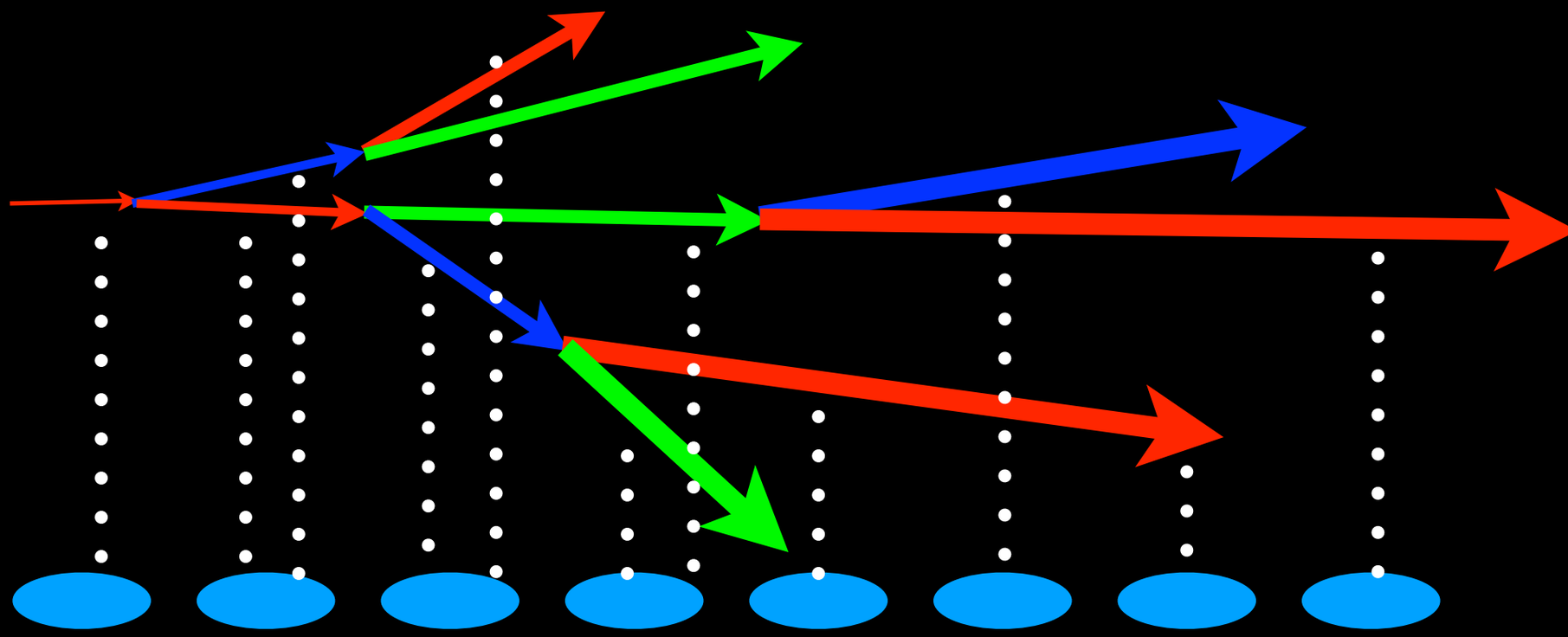
How this done currently



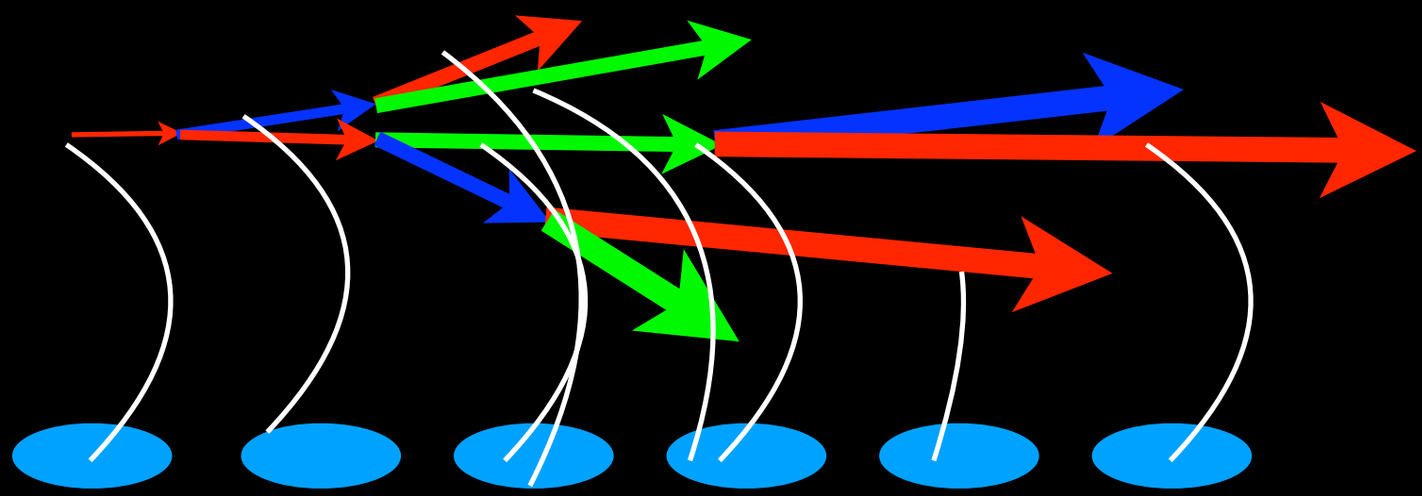
Full jet carries recoil particles
sampled from a Boltzmann distribution.
as regular jet partons, and negative parsons or holes

Other methods

Constant
Broadening



AdS/CFT drag



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- Which can allow you to model medium response, and entire range of transport coefficients

- Can address all observables simultaneously

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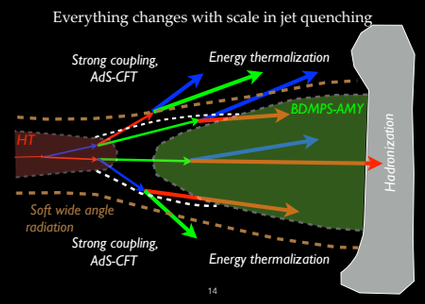

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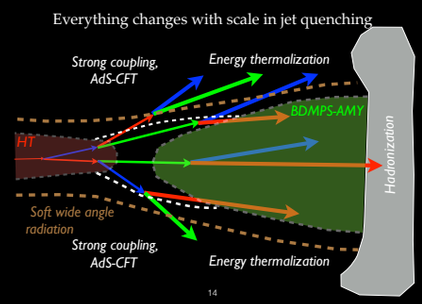

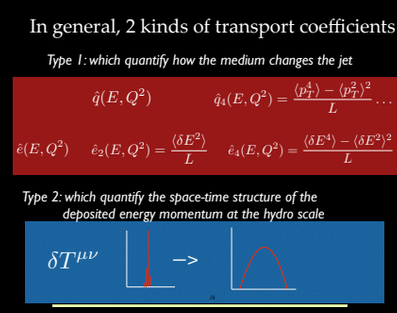

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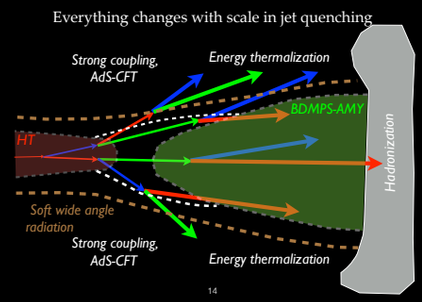

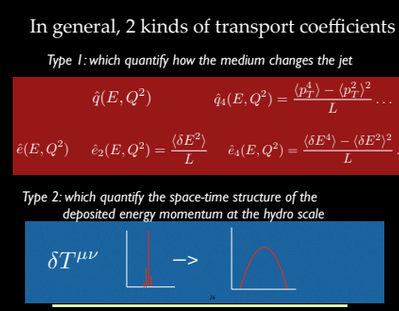

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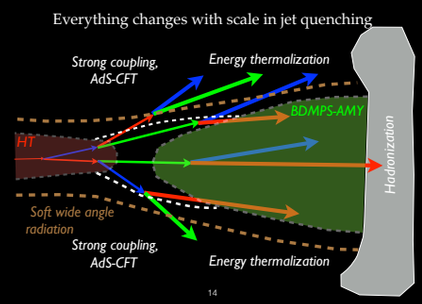
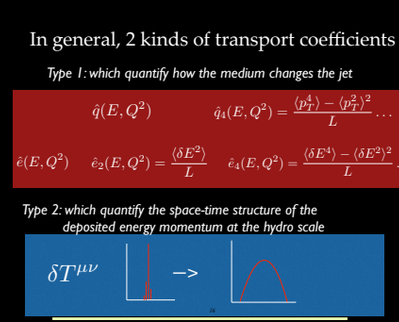
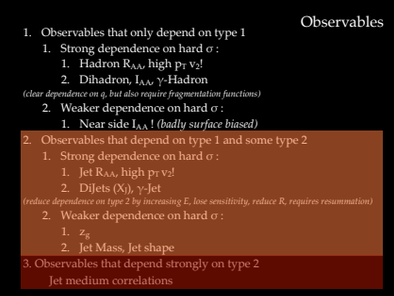




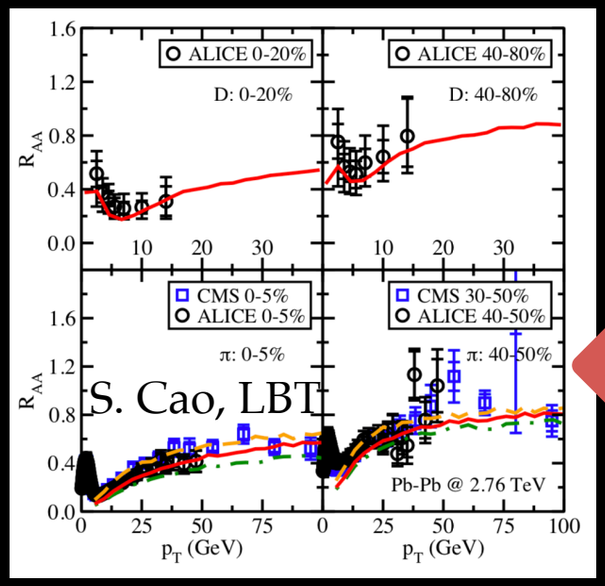


Such a framework now exists: JETSCAPE
https://github.com/JETSCAPE

Applying Multi-scale models

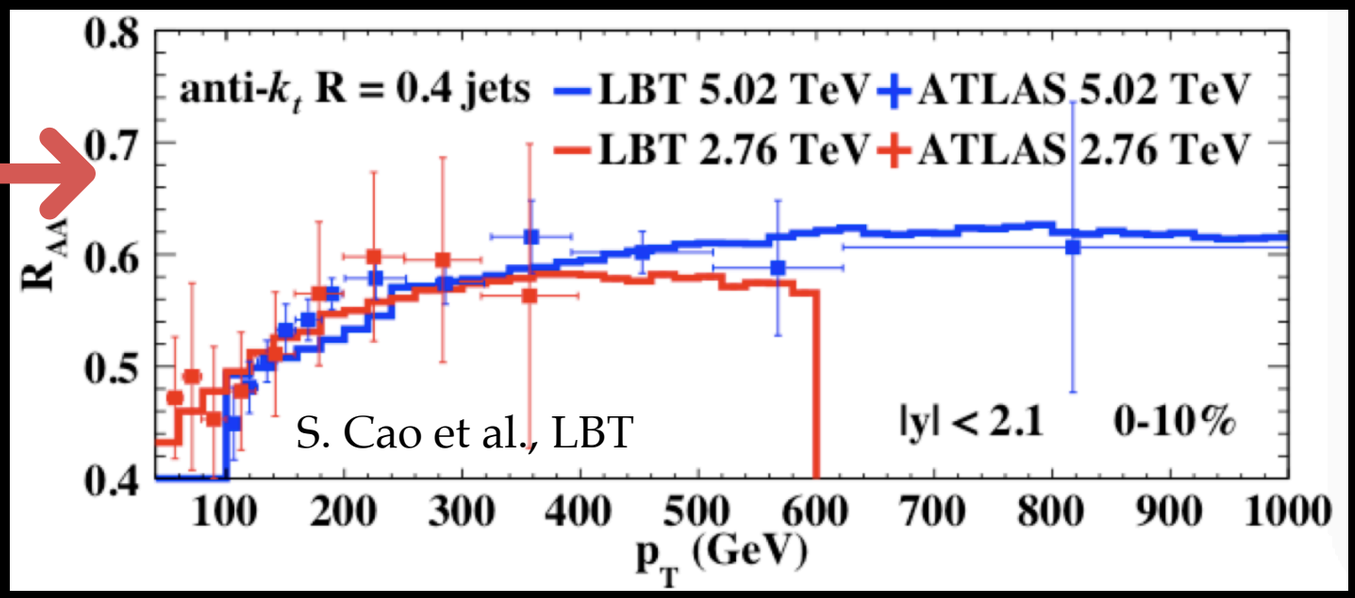
Its the right thing to do.

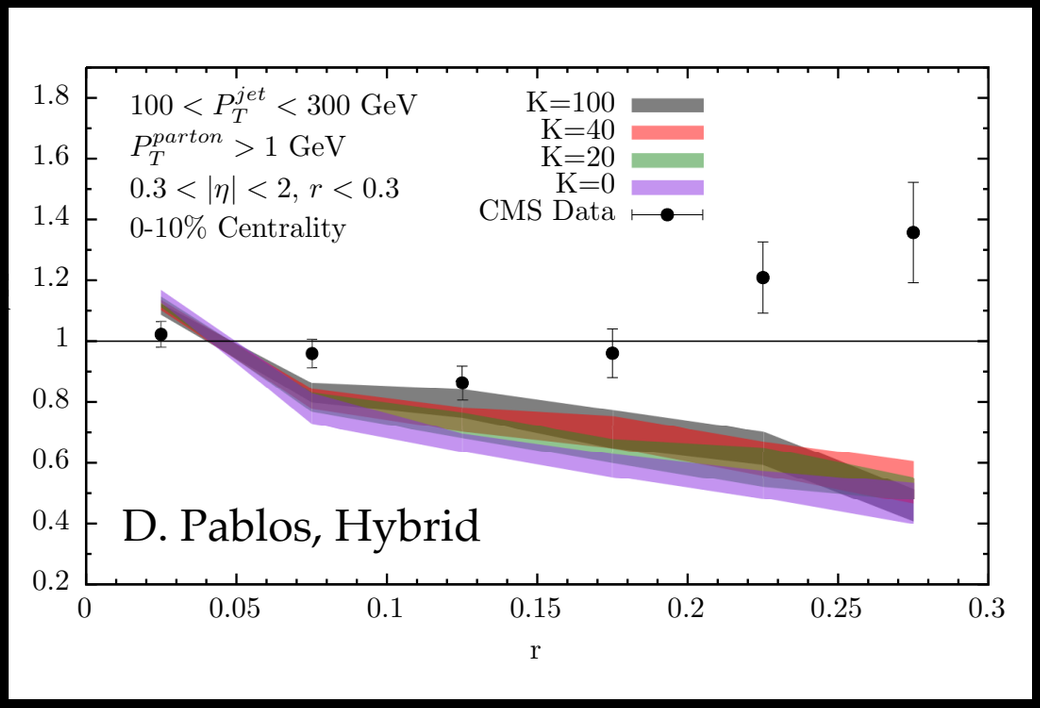
Pushing limited approaches past limits creates tension!

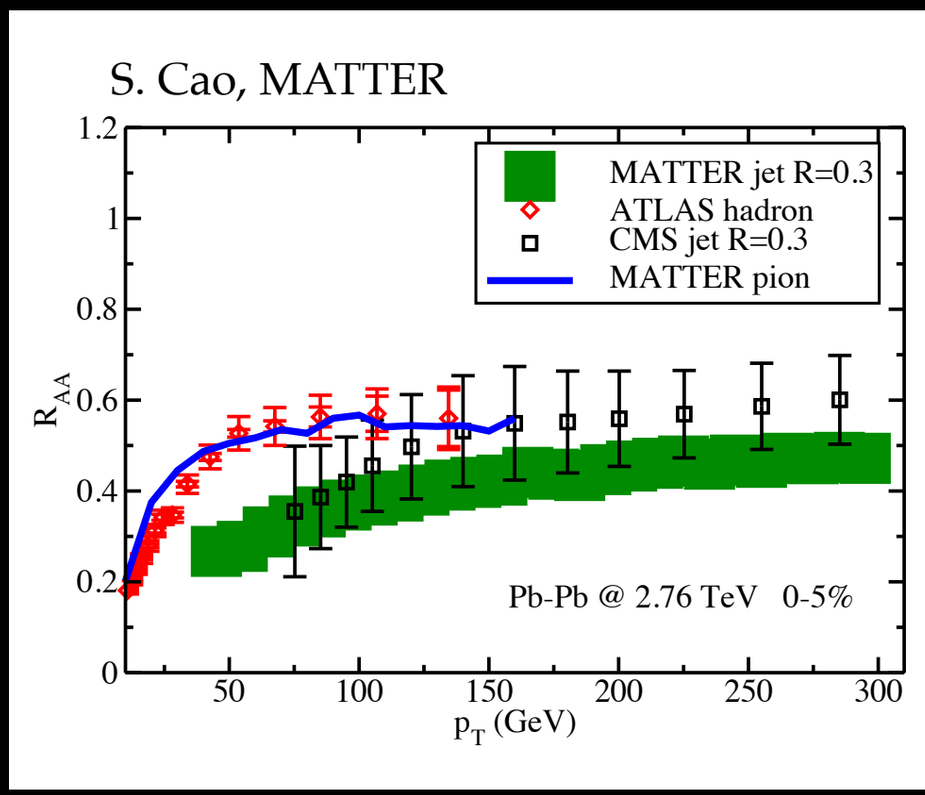


LBT
fixed α_S=0.15

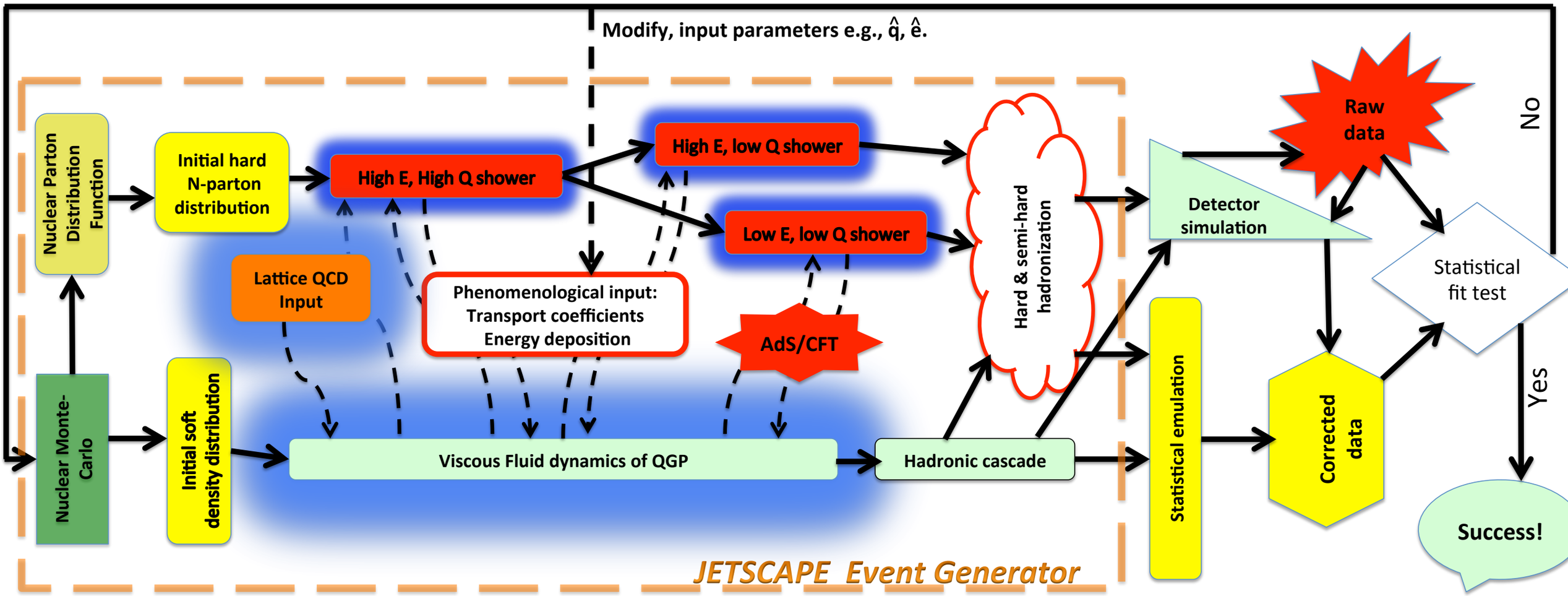
mean α_S=0.2







How would this work?



JETSCAPE Manual e-Print: arXiv:1903.07706 [nucl-th]

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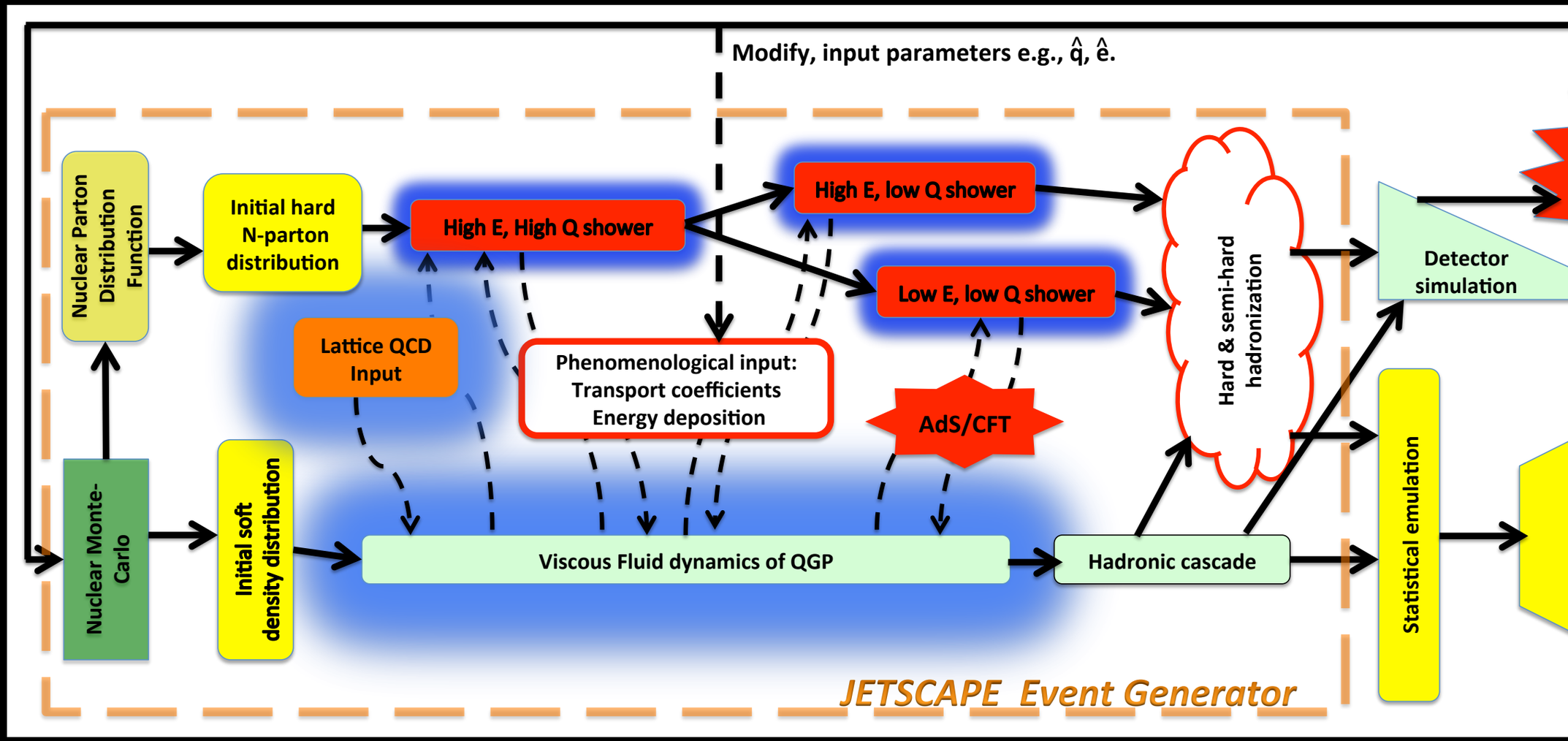

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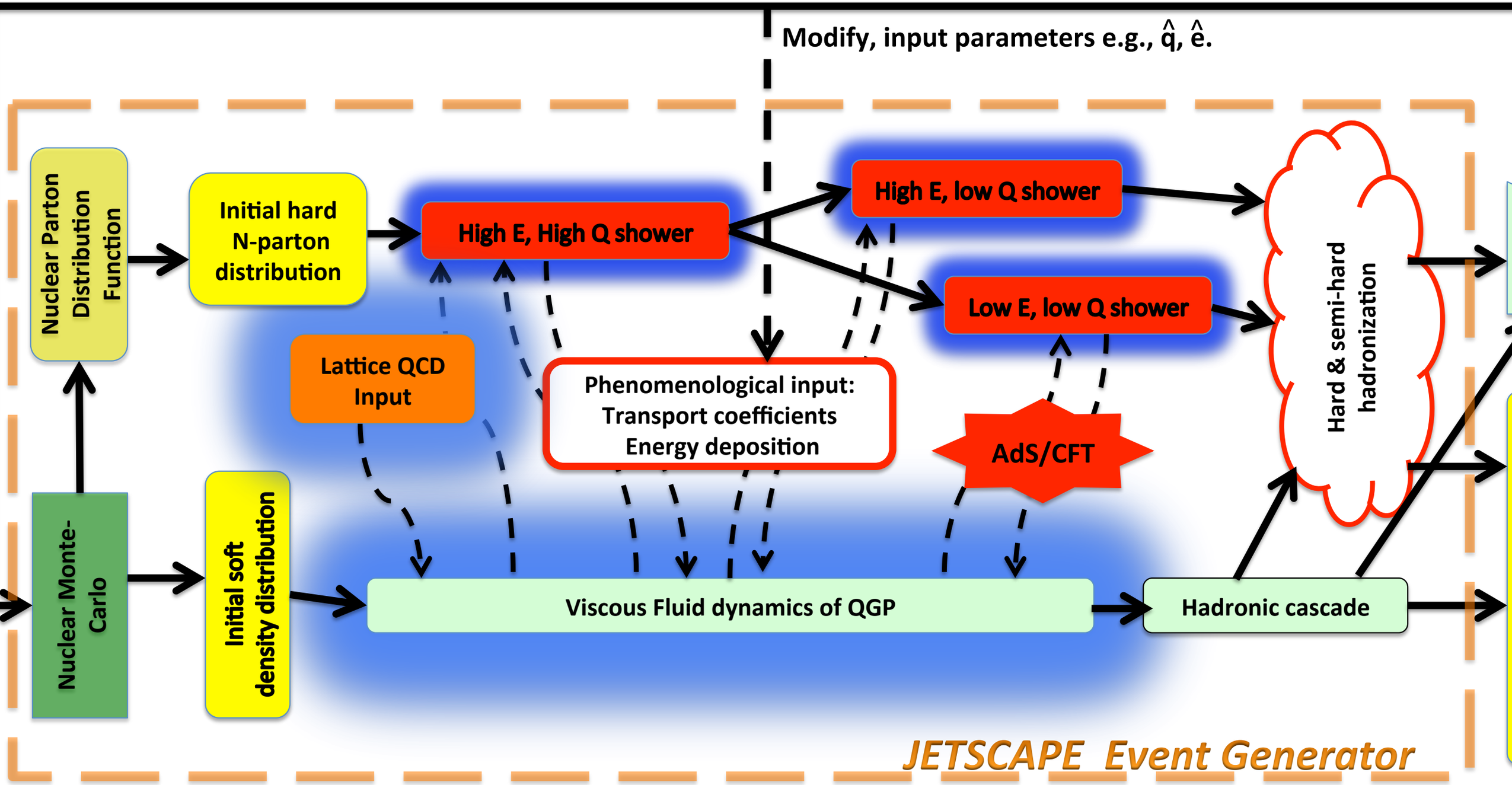

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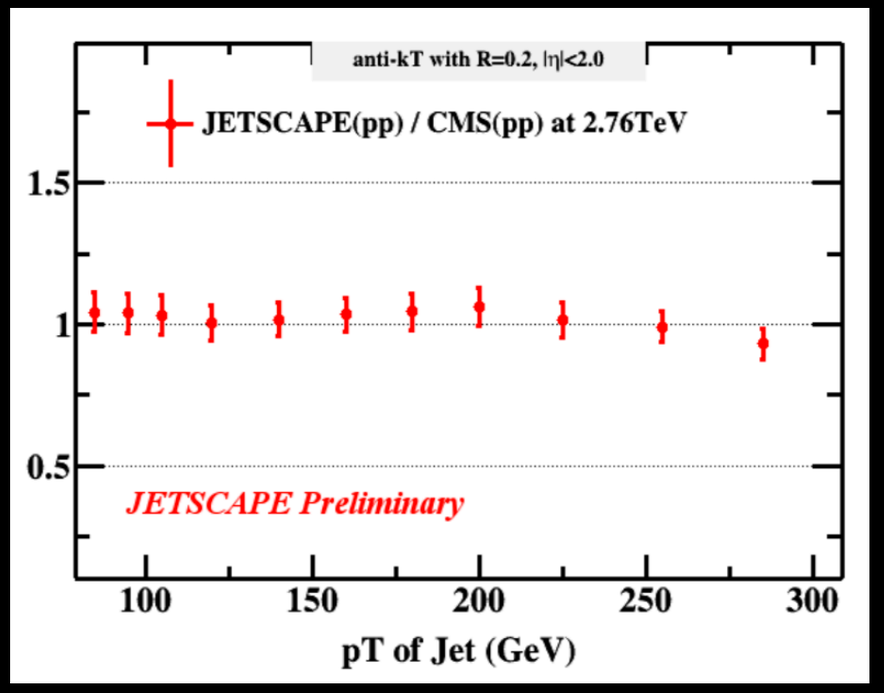
Using the full event generator

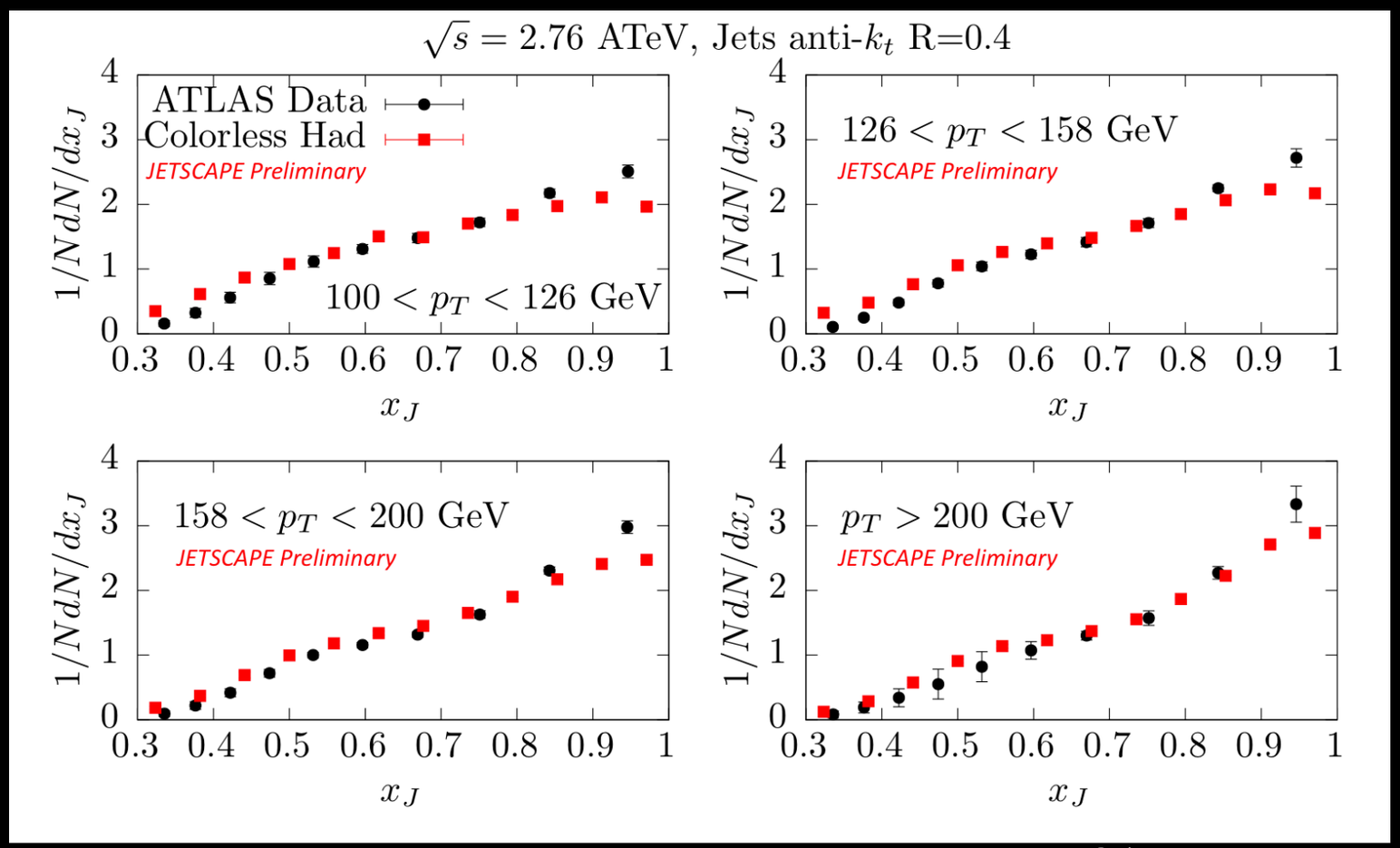
- Any good event generator needs a good p-p baseline

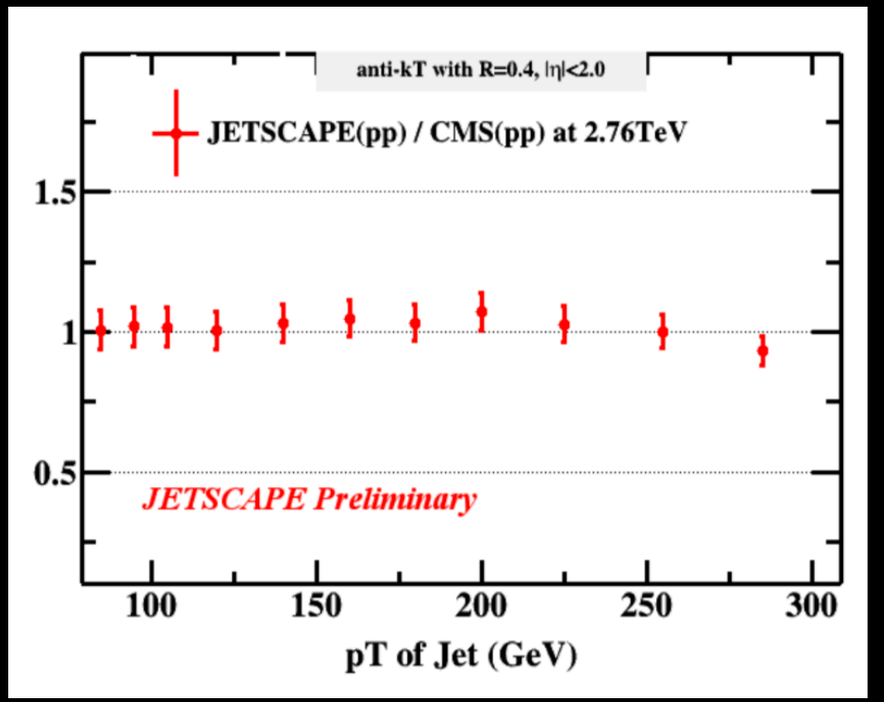
PYTHIA for initial state

MATTER for all final state partons > 1GeV

PYTHIA based hadronization of final partons







Preliminary results from JETSCAPE

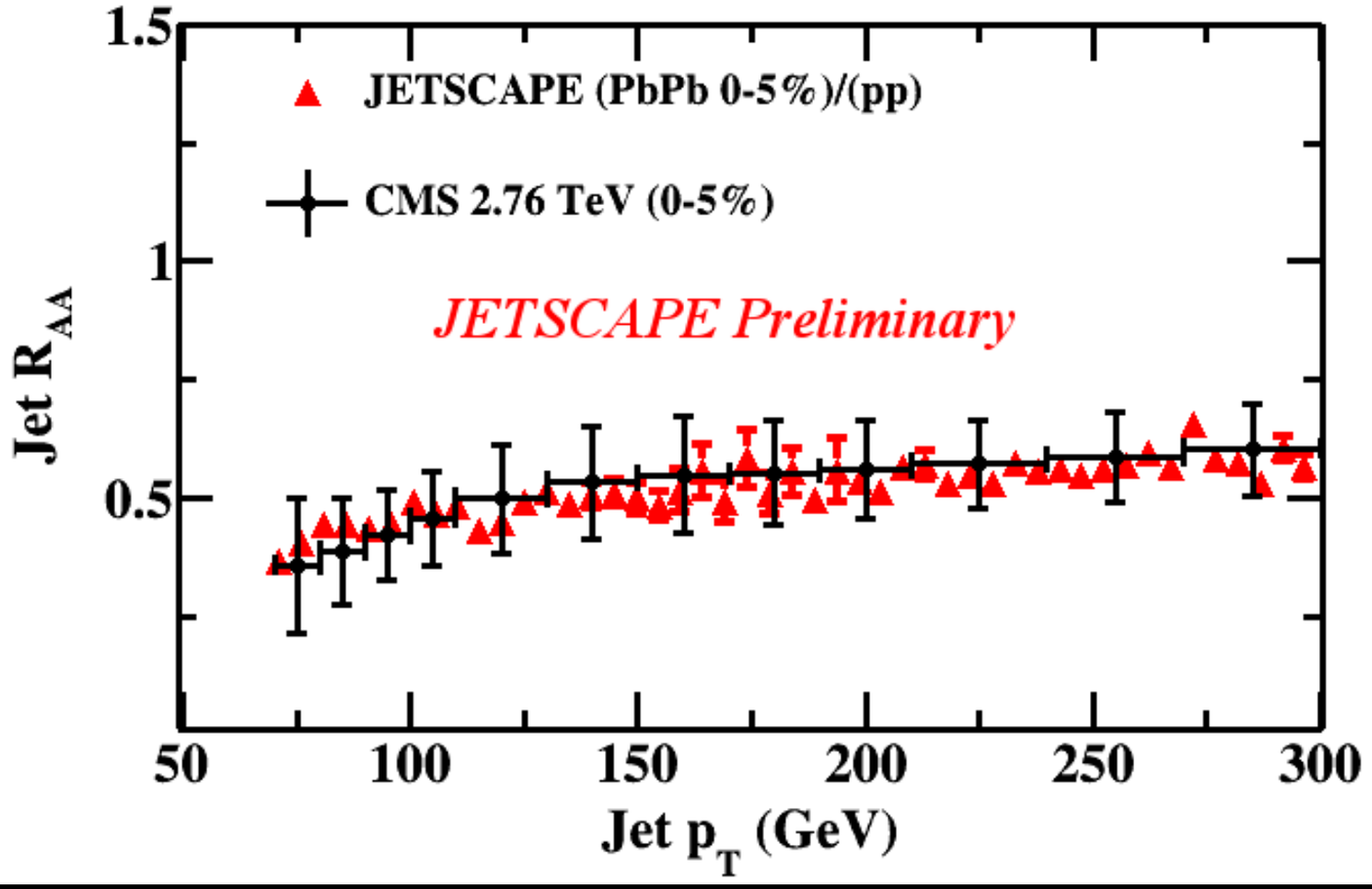
Initial state with TRENTO for both hydro and jets

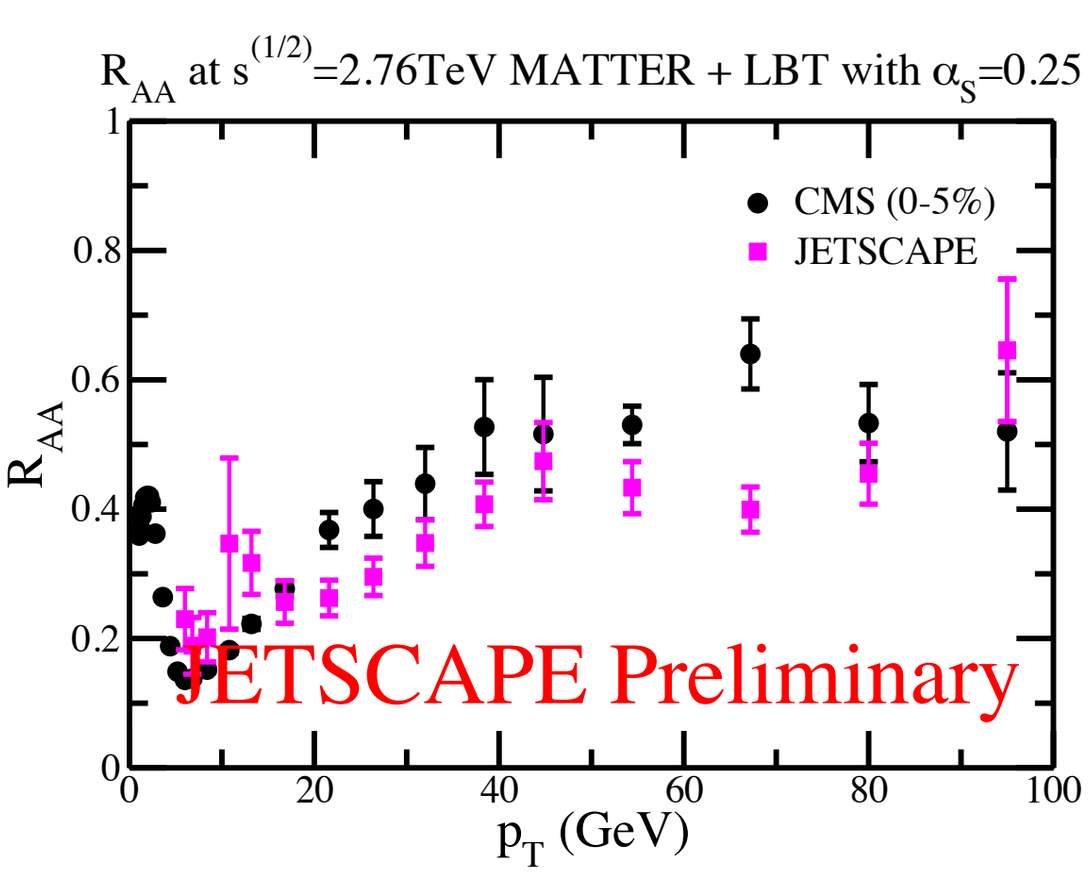
TRENTO —> PreEquib—> MUSIC —> Soft Hadronization

TRENTO —> PYTHIA init

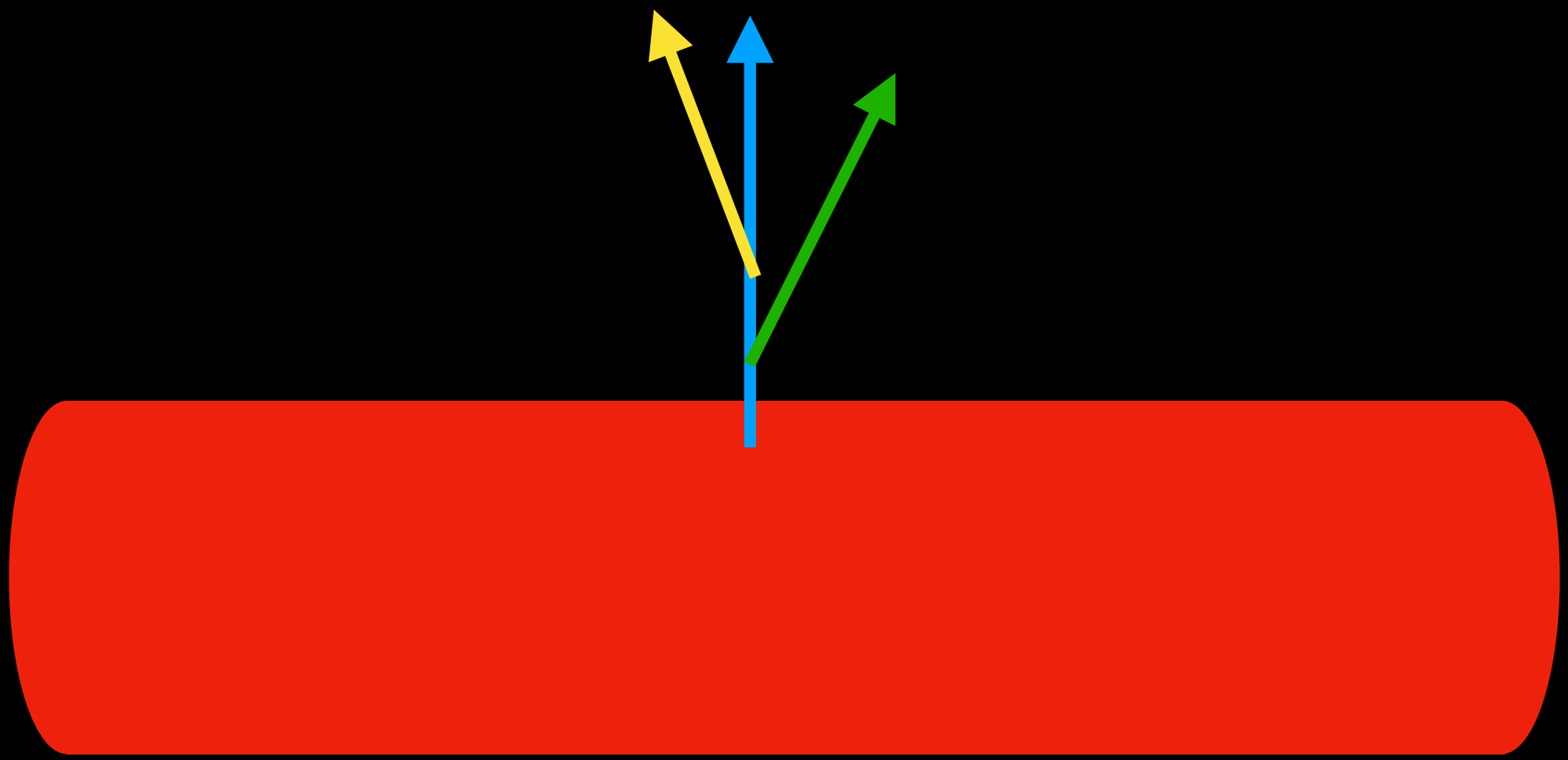
—> (MATTER/LBT/MARTINI/AdS) + MUSIC profile

—> PYTHIA based hadronization





A jet hadronization mechanism that generalizes from p-p to A-A



1) Have separate strings for each shower initiating parton (colored)
2) Connect all the showers with one string to one fake (colorless)

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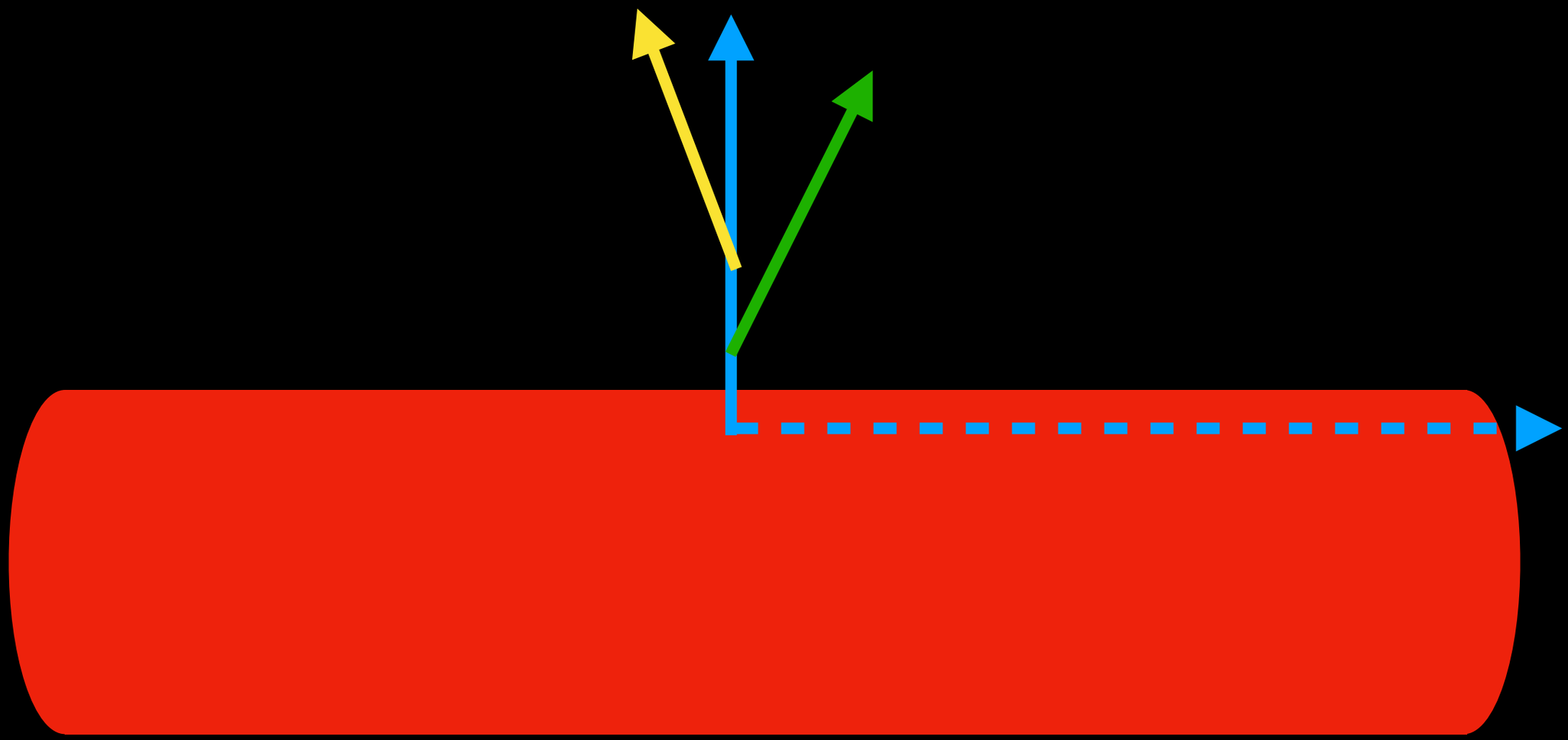

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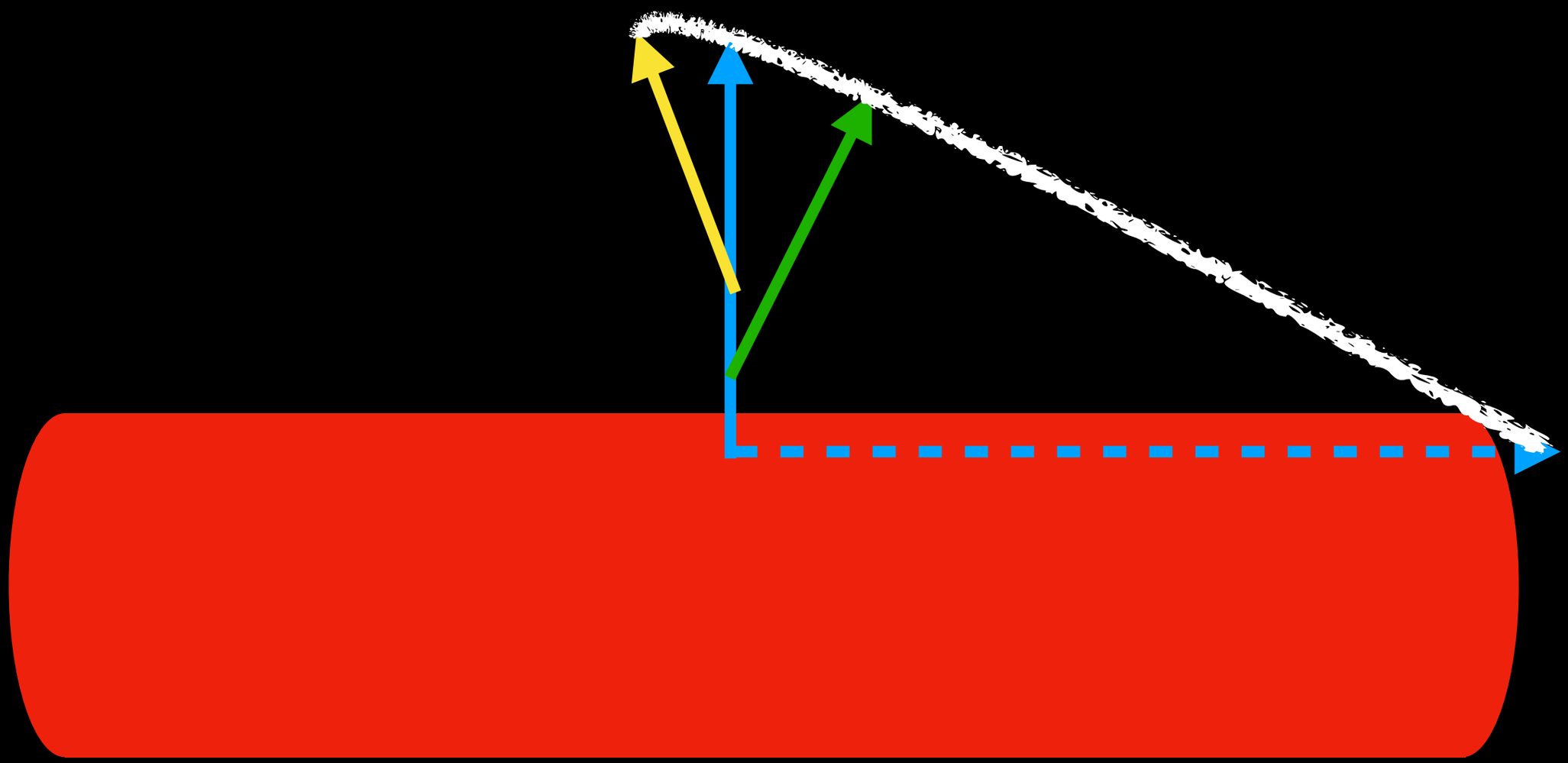

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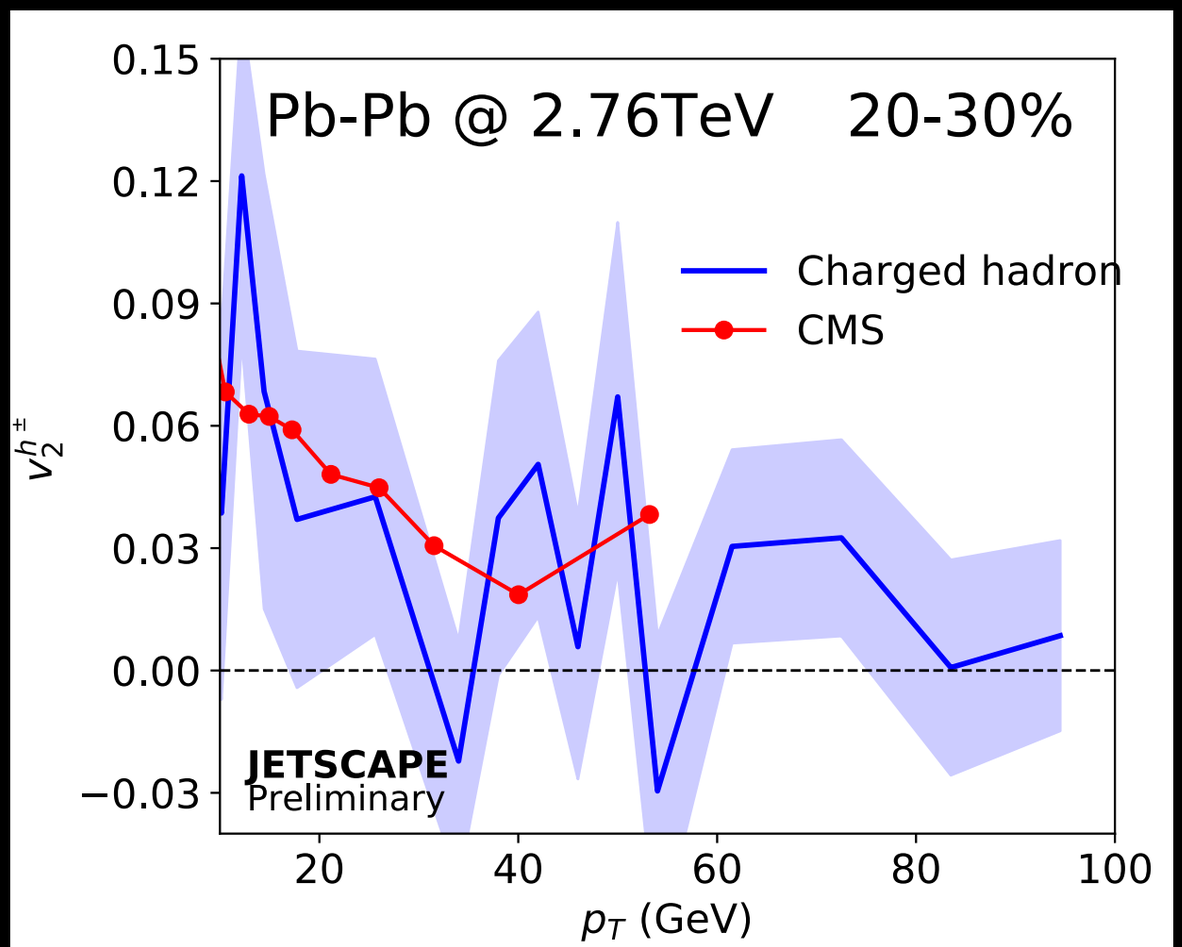
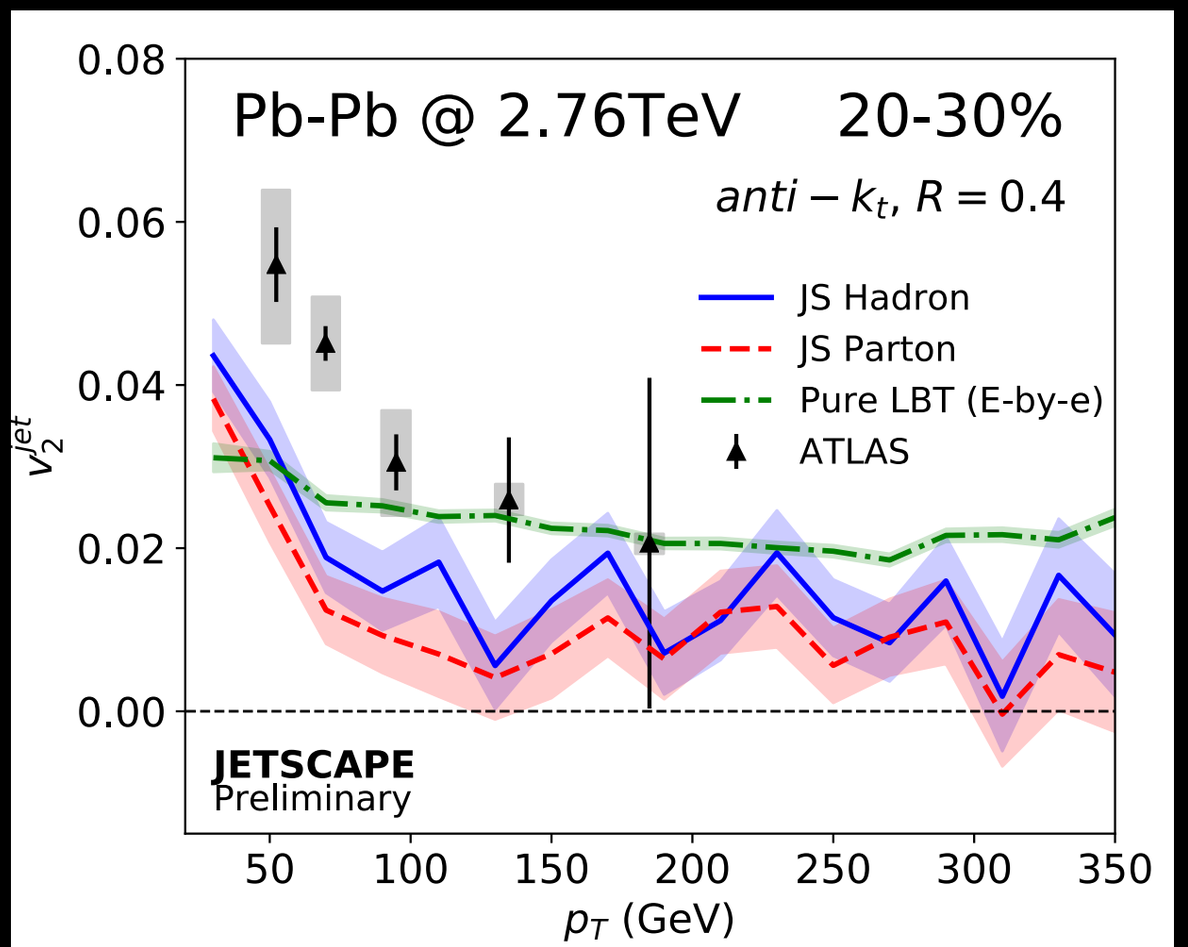
Jet and leading hadron v_2

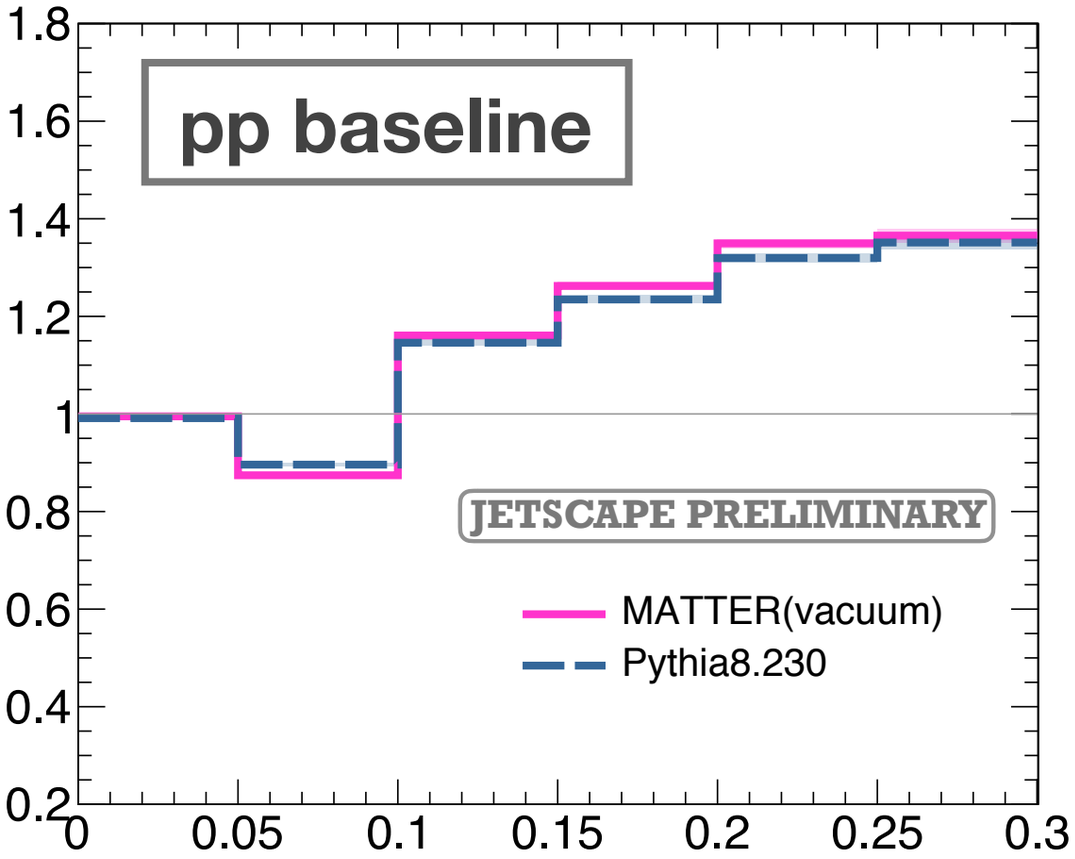


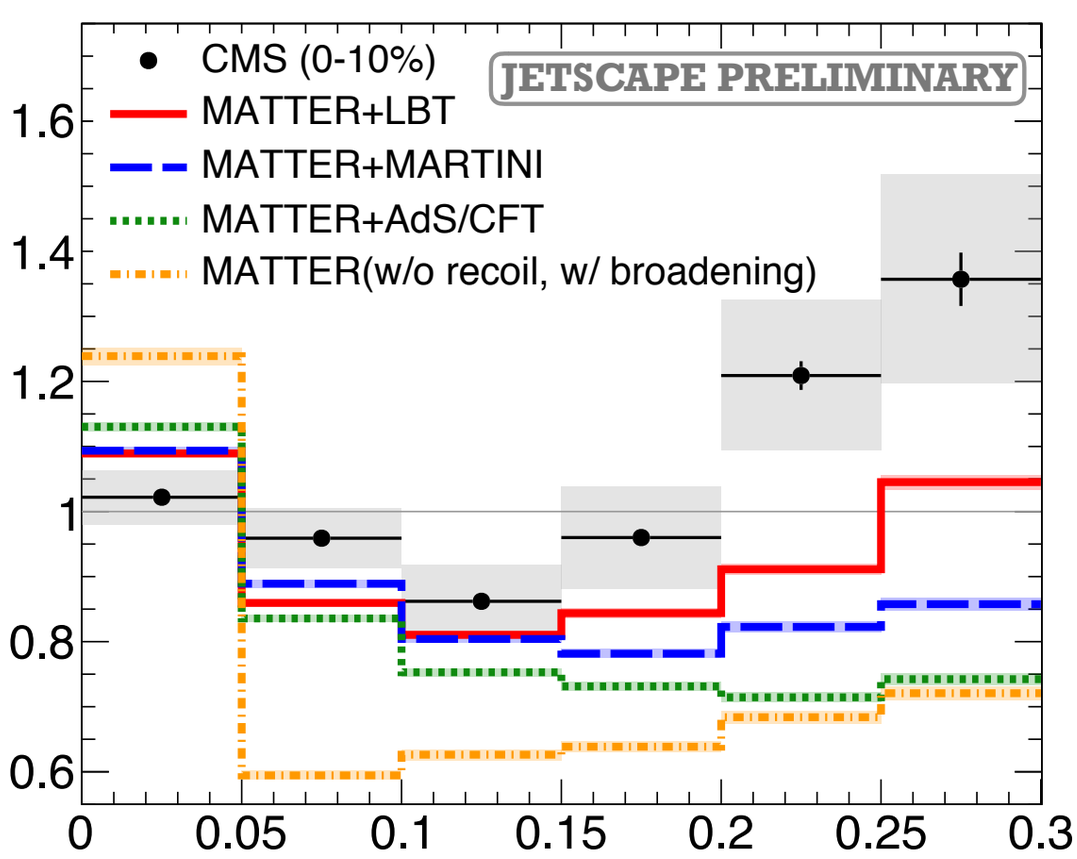


Need event-by-event hydro and initial state to hydro adjustments

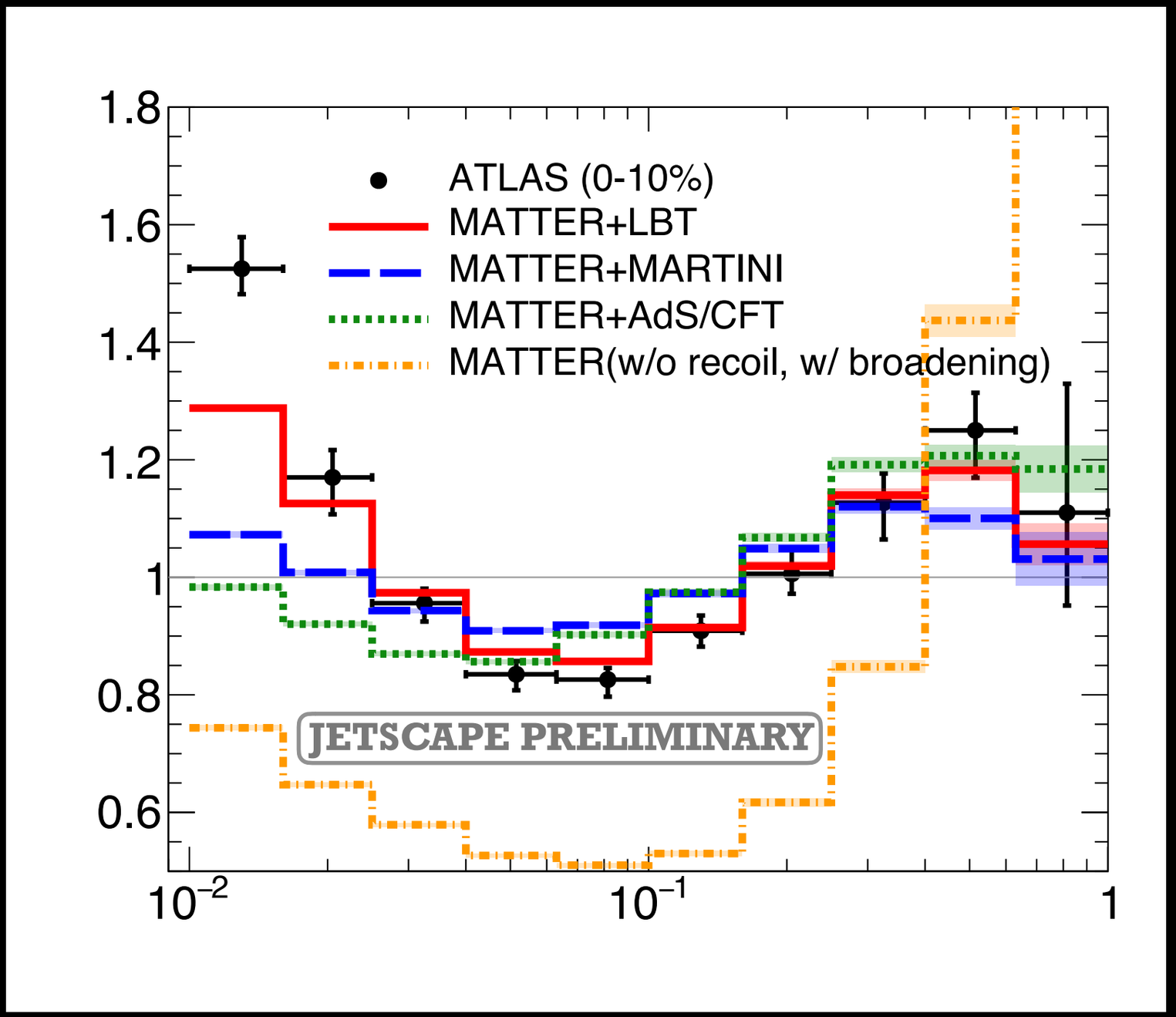
Jet shape

Energy in angle away from jet axis





Fragmentation function



fraction of energy carried by hadrons in jet

What did we learn from all this?

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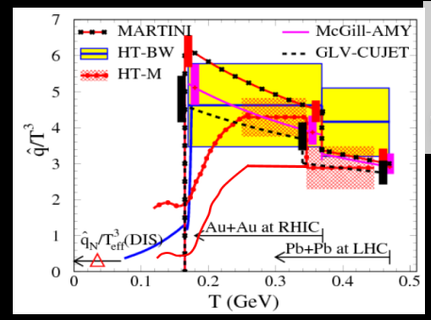
$\hat{q}/T^3 \sim 4$ at 0.2TeV, ~ 3 at 2.76TeV



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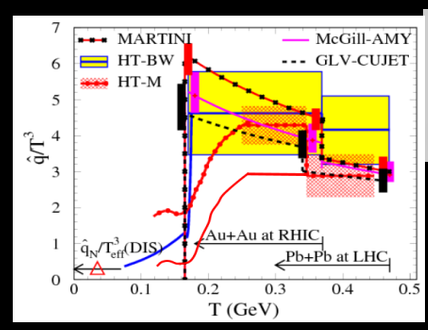
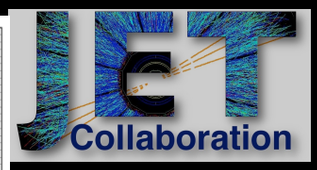
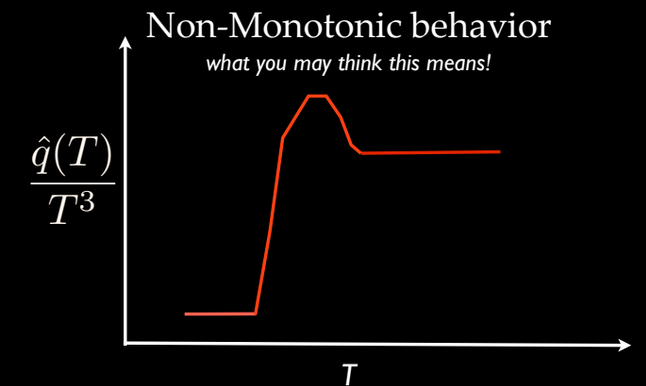




Personal opinion: its not this —> rather an energy or scale dependence in $\hat{q}$



If this is true, must effect the centrality dependence of R_{AA}, v_2, and its centrality dependence at a given collision energy

30

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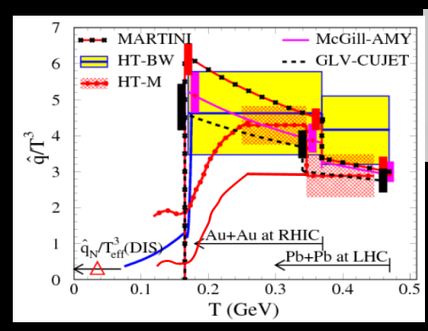

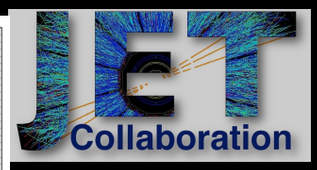

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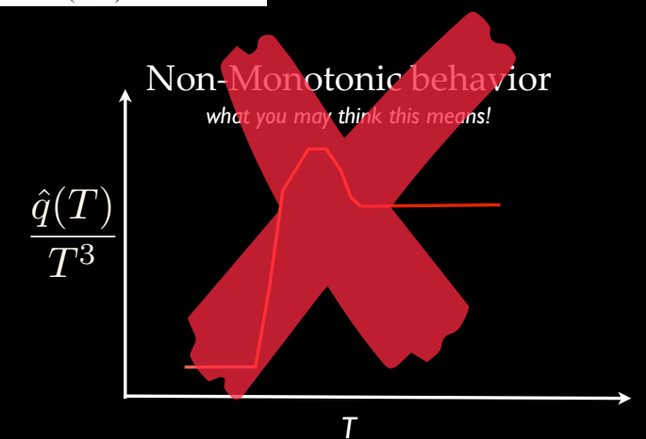

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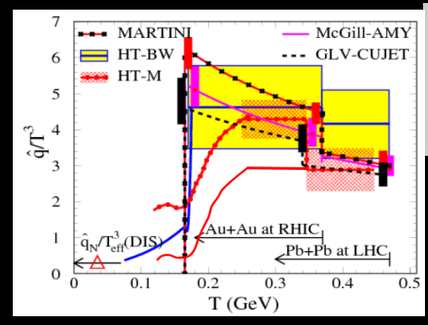

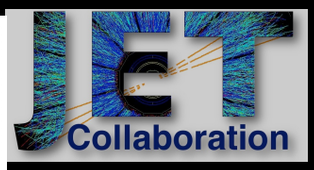

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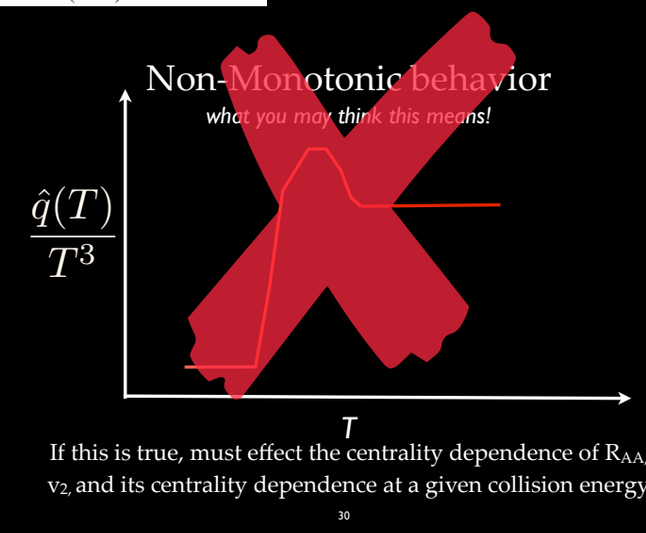

Jets have multiple scales, with different interactions with medium

Qualitatively similar but quantitatively different picture for heavy Q

Limits on $\hat{e}$ from jets and leading hadrons

Medium recoil needed to get jet physics

What do you want to learn

What do you want to learn

How does the parton in the jet see the medium?

What do you want to learn

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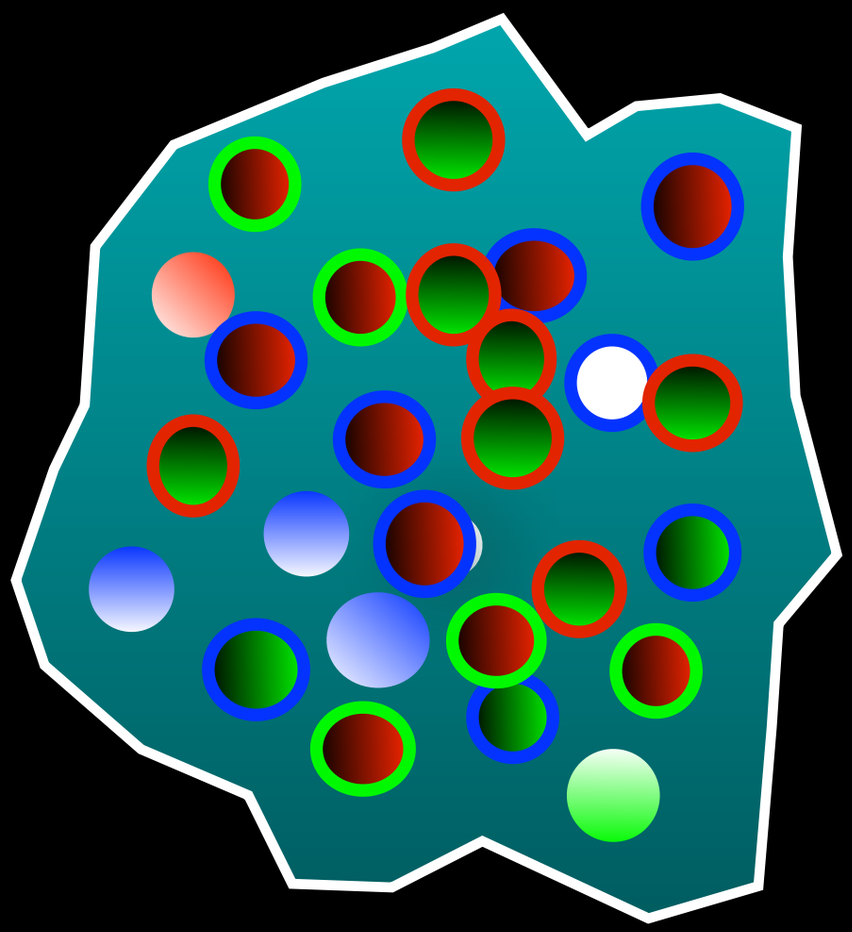

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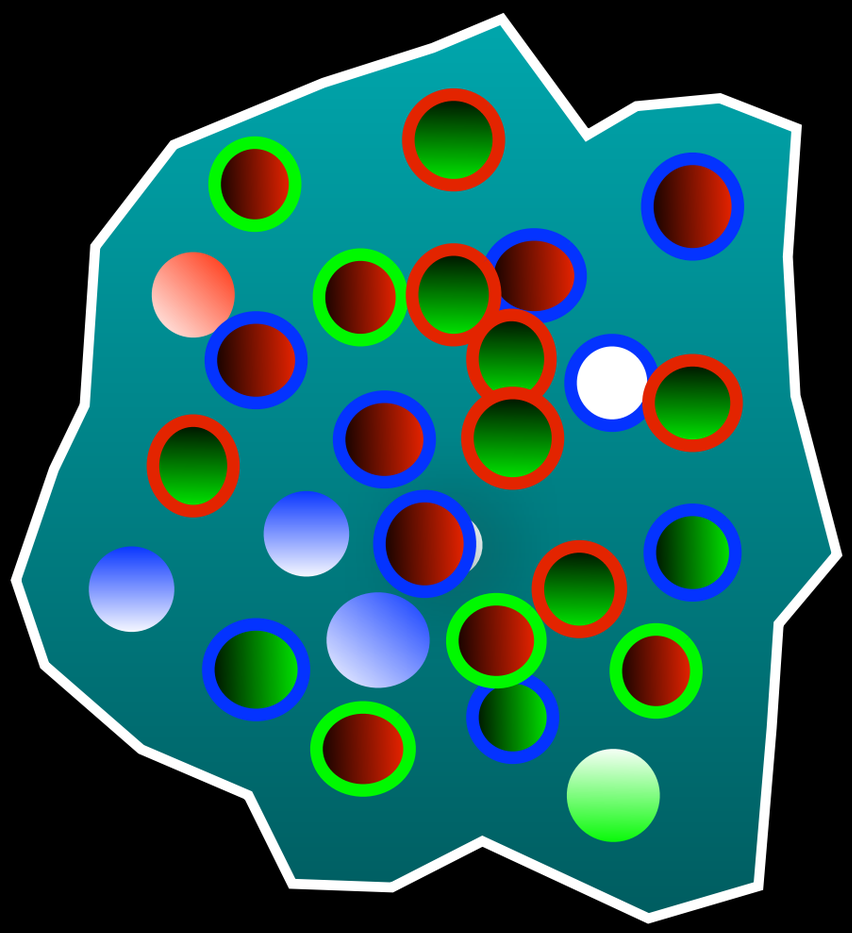
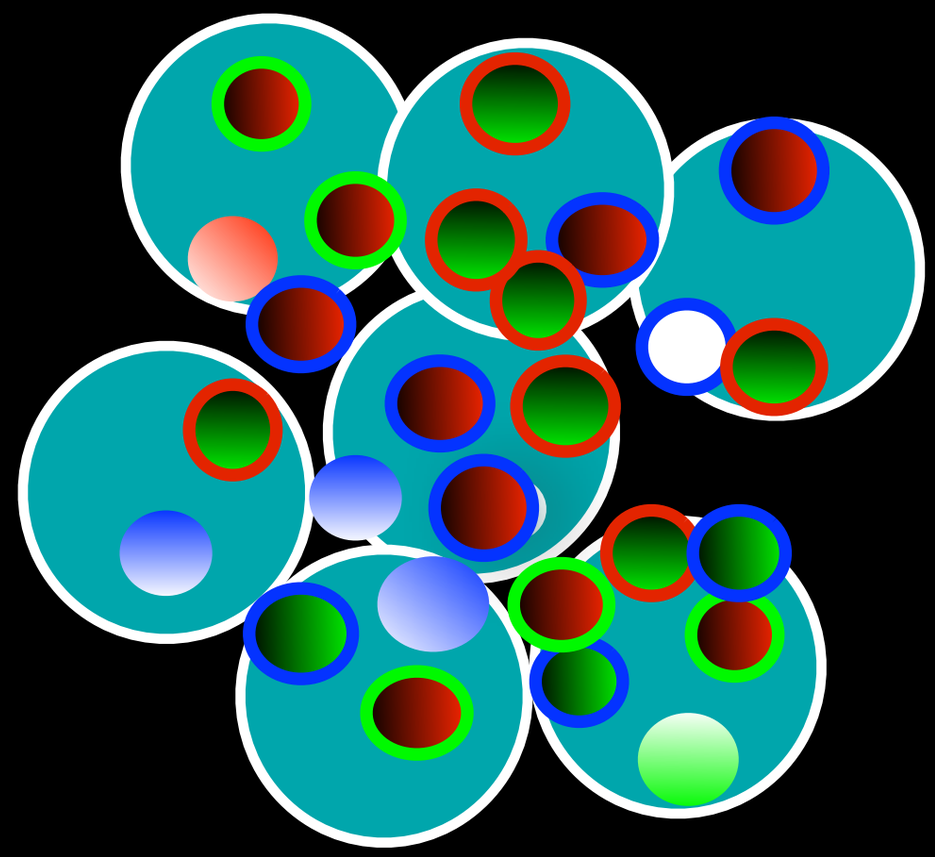
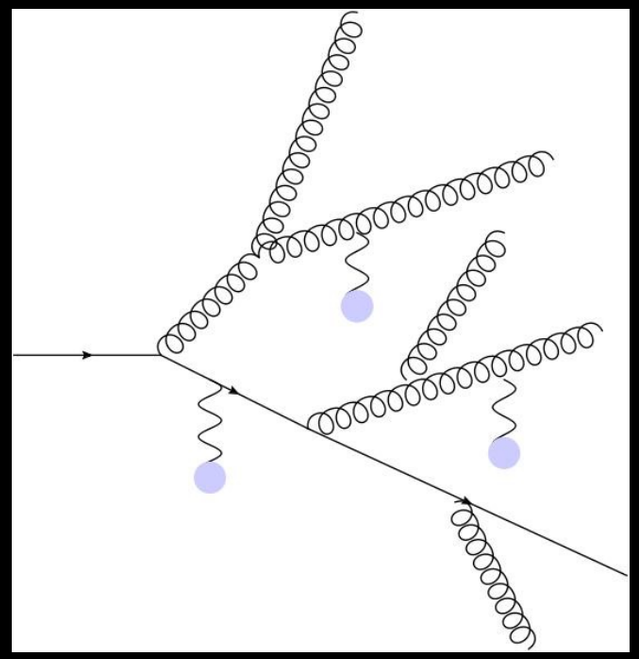
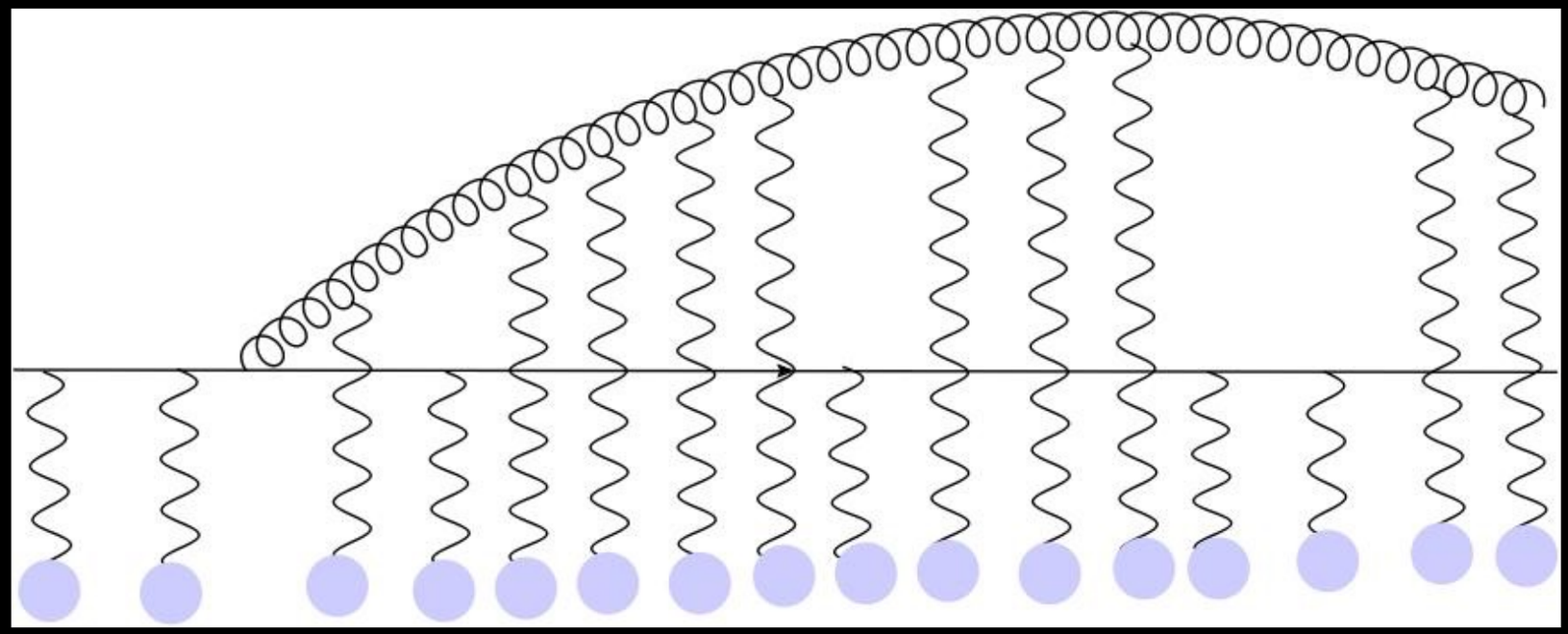
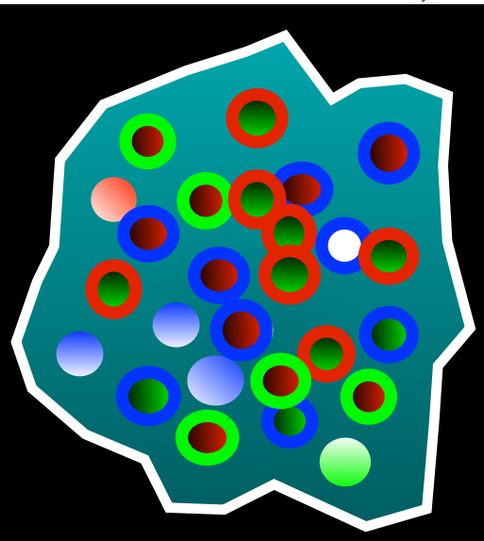




Does the interaction with medium change with scale







This not only affects E-loss but also how E distributed

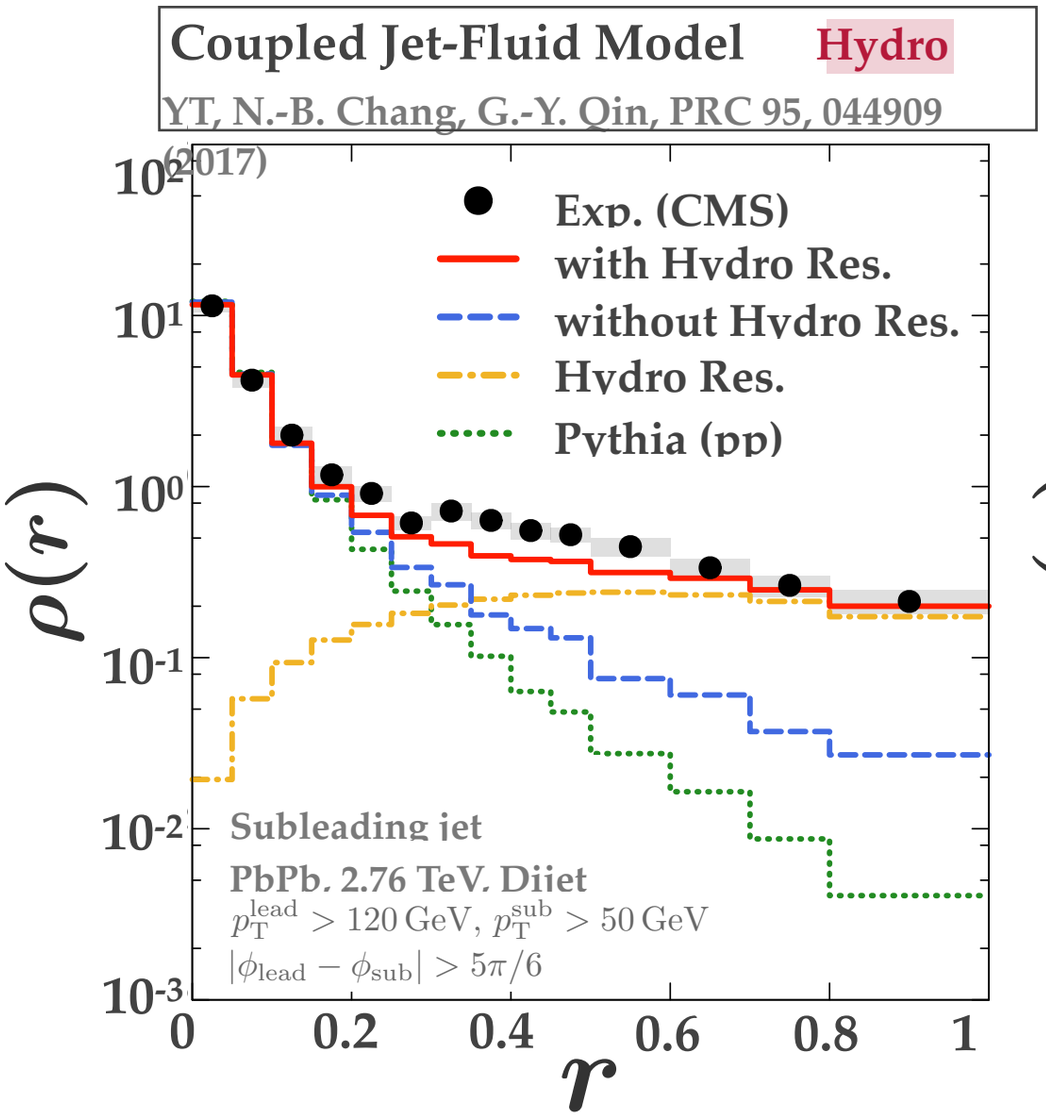
Consistent with the the idea of Coherence!

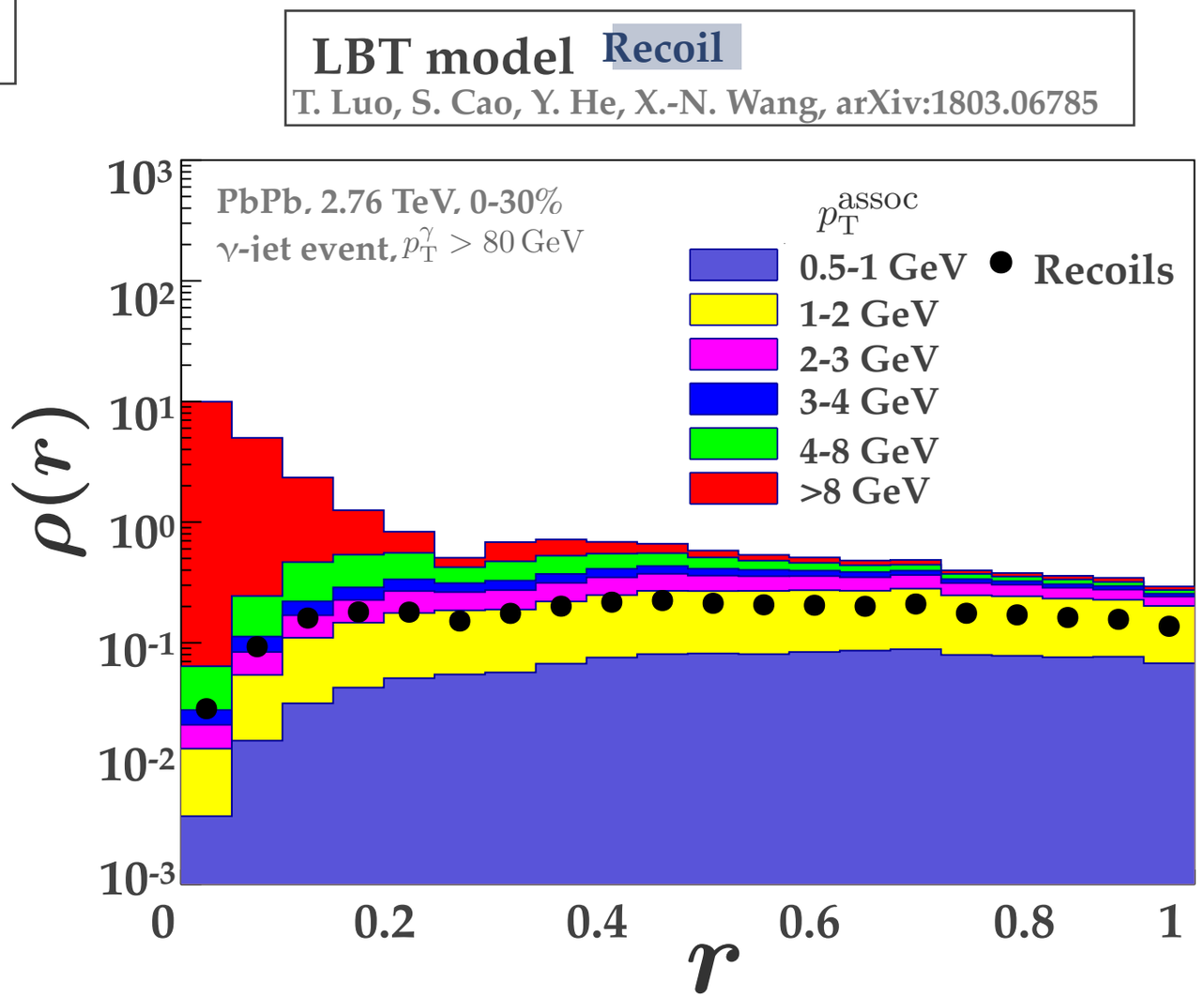
Casalderrey-Solana et al. PLB 725 (2013) 357

Jet medium correlations !

Jet medium interactions, allow for a needle like probe of the hydro medium

Allow us to shatter quasi-particles and see them reconstitute





Outlook

Jets provide multi-scale probes of the evolving QGP

Multi-scale dynamics, growing number of T.Cs, and observables

Requires a modular, modifiable, event generator —> JETSCAPE

Established values of $\hat{q}$, $\hat{e}$,

(Heavy-quarks provide a slightly shifted view of this)

Need for medium response for jets studies.

Jet medium correlations provide a possible window into degrees of freedom of the QGP, next stage of JETSCAPE.

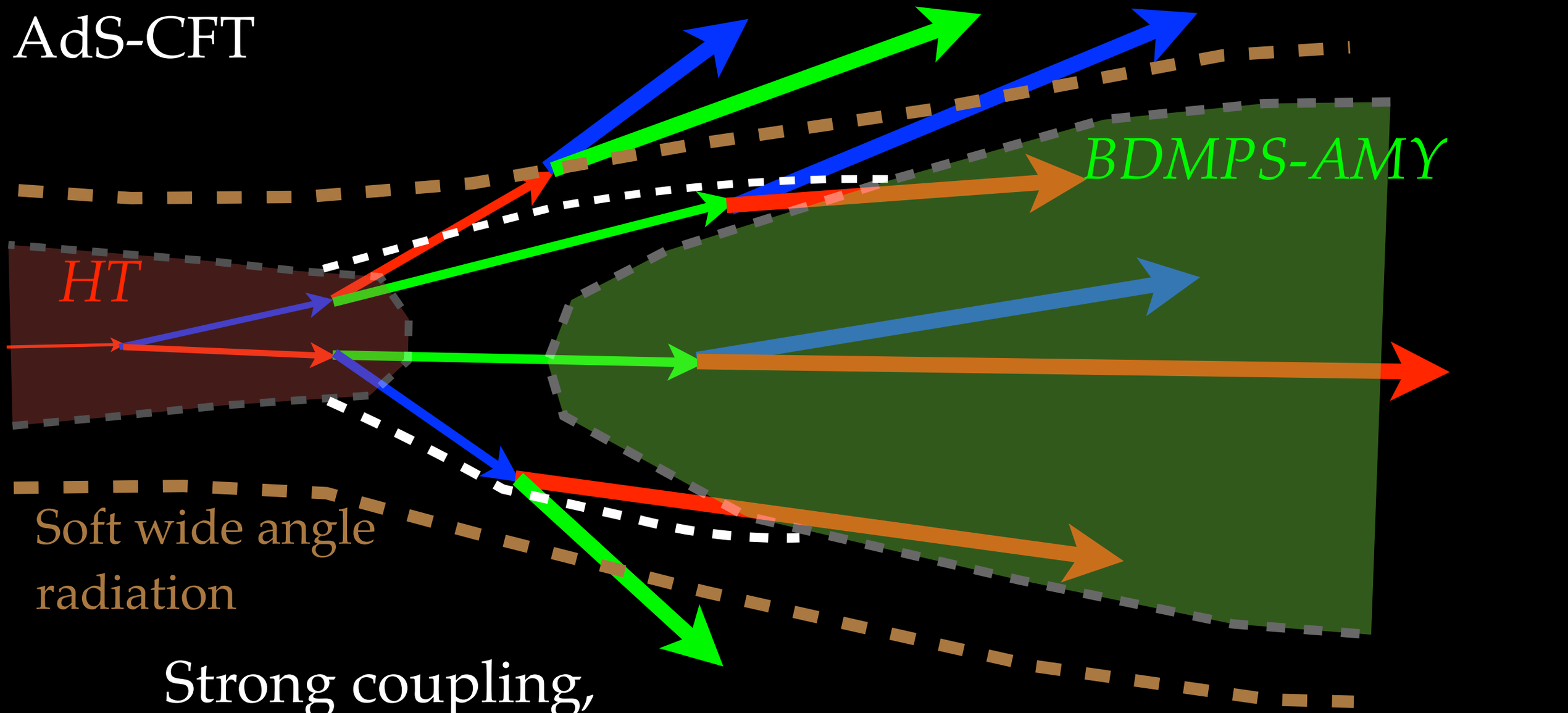
Back Up

Everything changes with scale in jet quenching

Everything changes with scale in jet quenching

Strong coupling,
AdS-CFT

Energy thermalization



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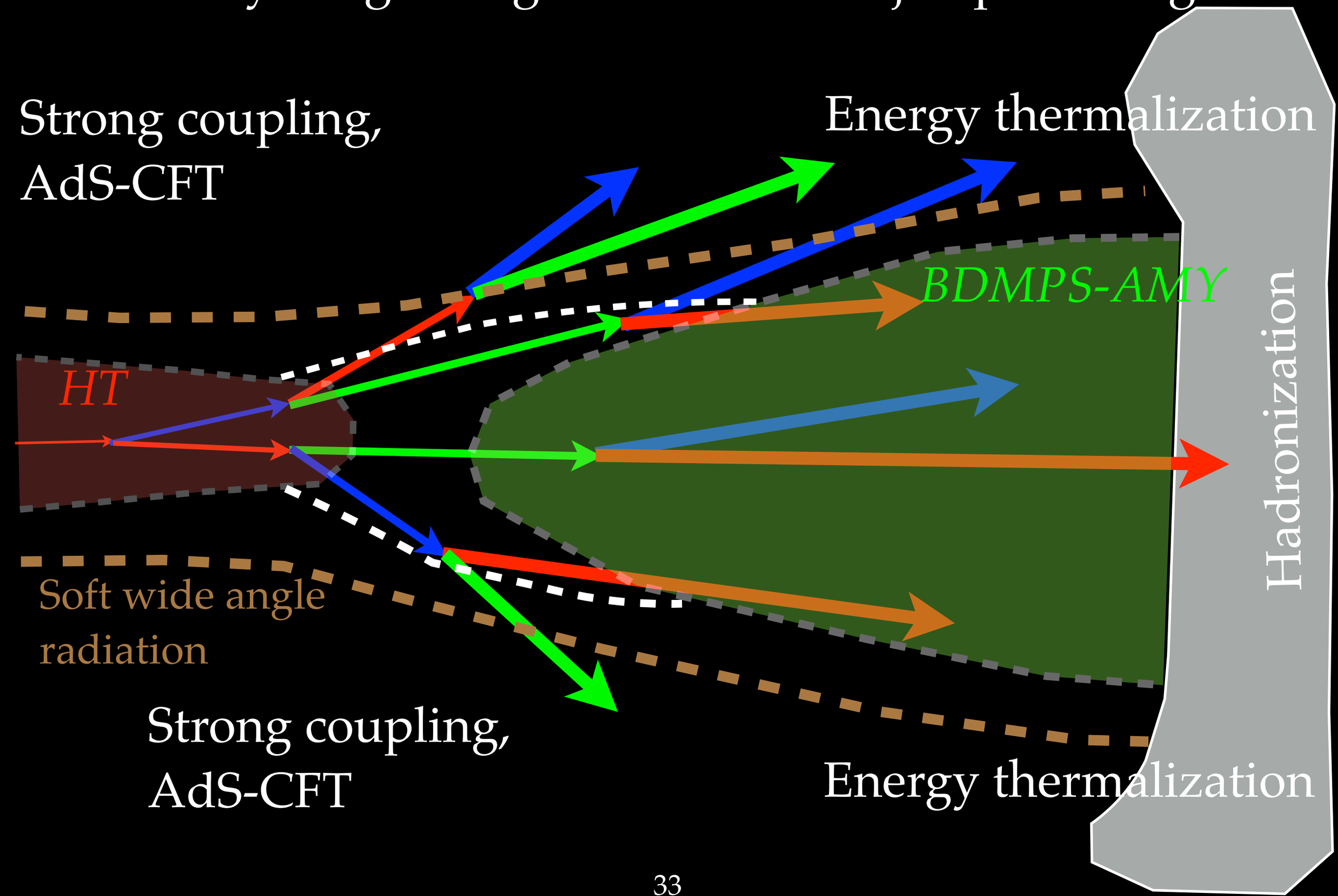
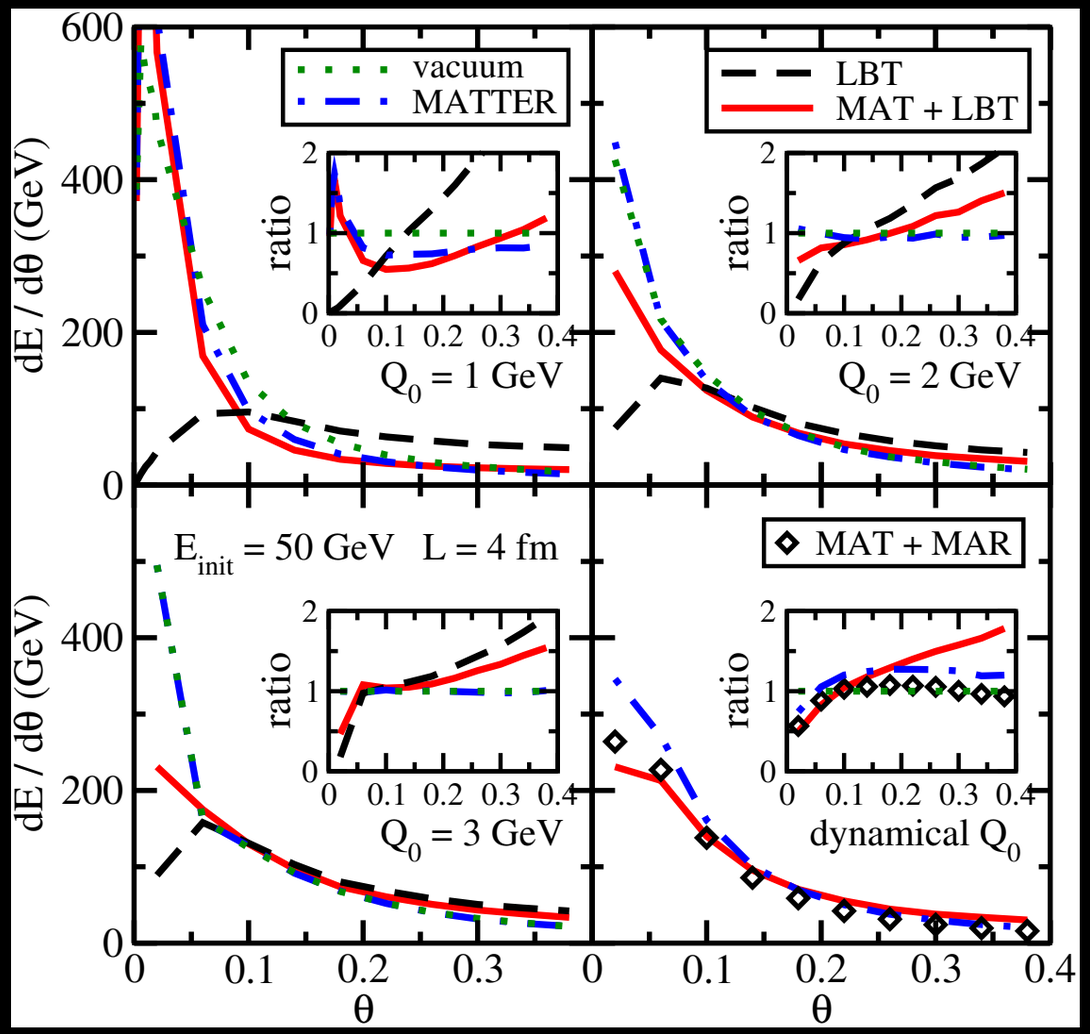
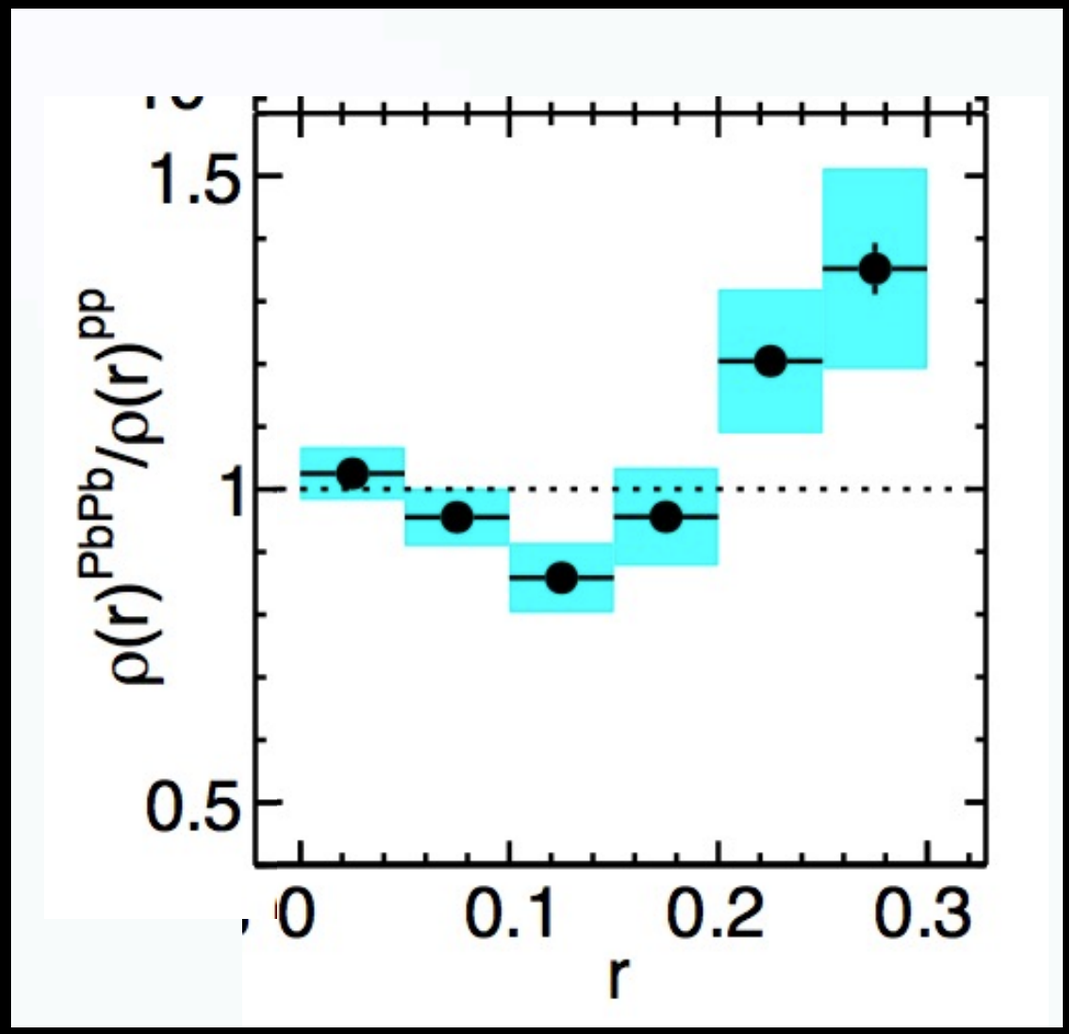


Evidence of multiple scales from multiple-stage Monte Carlos

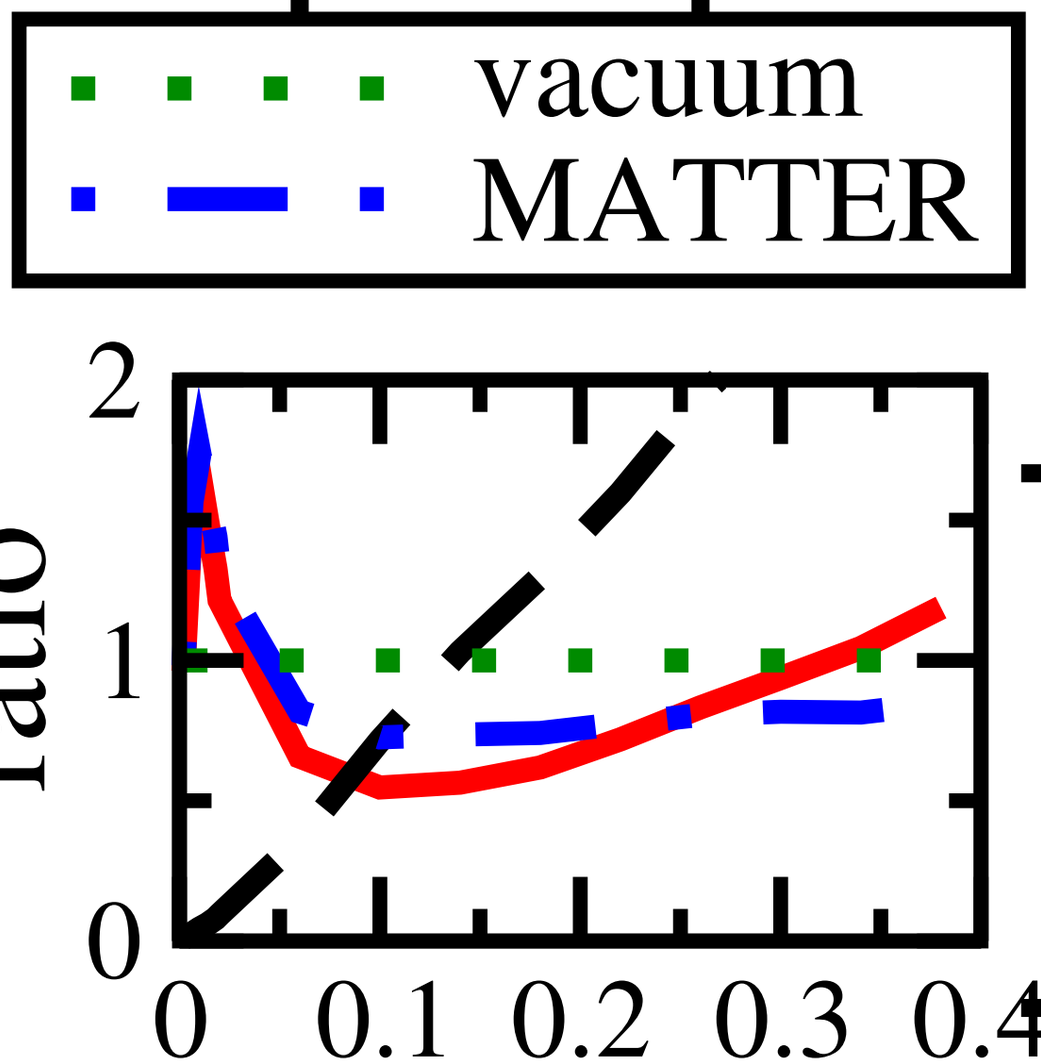


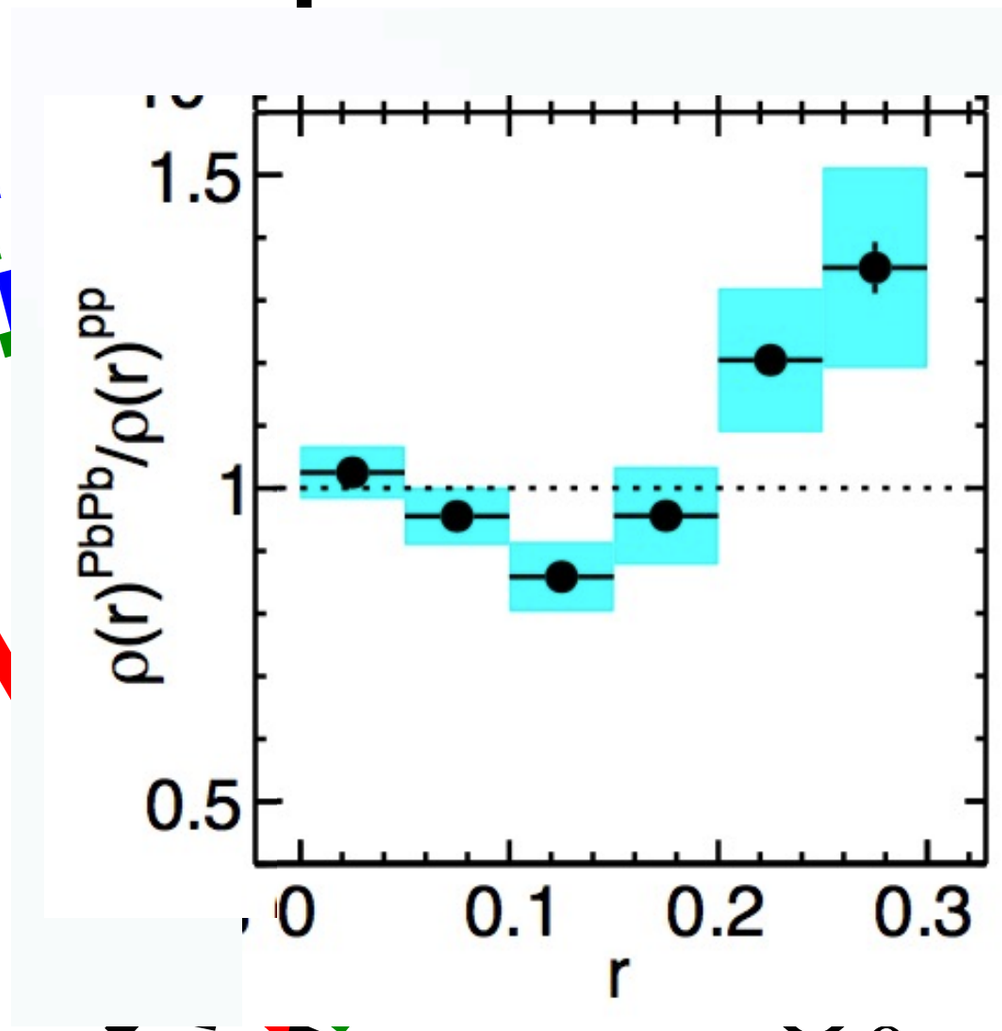


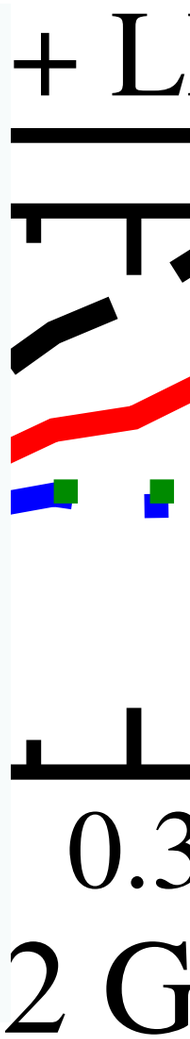
Switching between one event-generator and the next in a brick @JETSCAPE Phys.Rev. C96 (2017) no.2, 024909

Repeat with hadronization and fluid medium being calculated

Evidence of multiple scales from

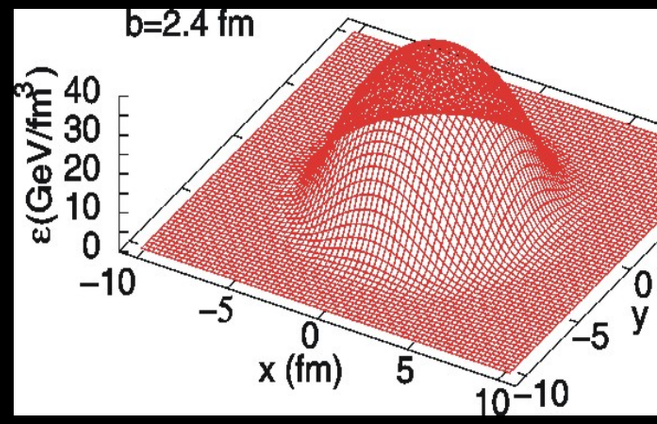






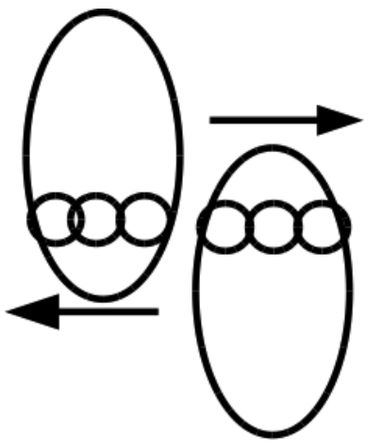
In all calculations presented bulk medium described by viscous fluid dynamics

Medium evolves hydro-dynamically as the jet moves through it
Fit the q for the initial T in the hydro in central coll.

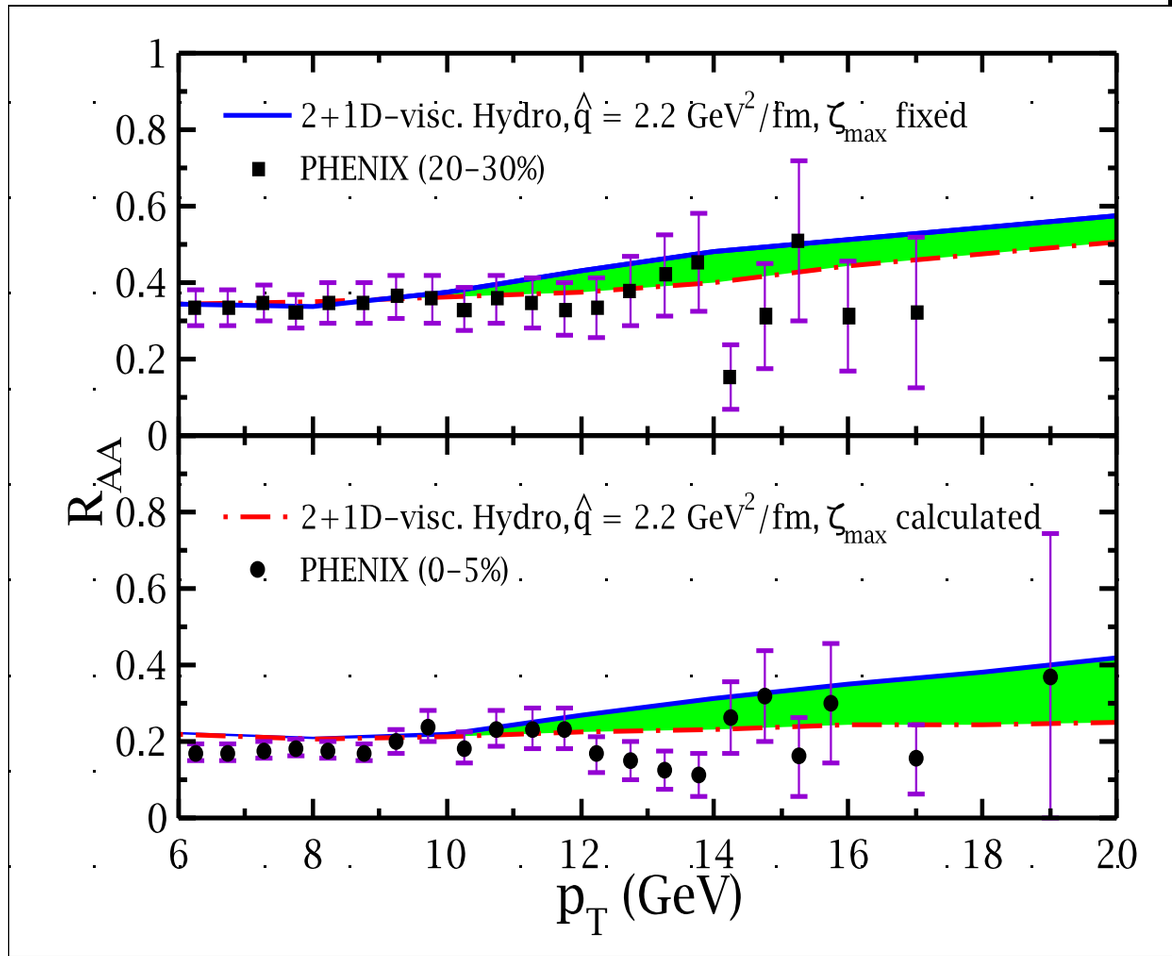


$$\hat{q}(\vec{r},t) = \hat{q}_0 \frac{s(\vec{r},t)}{s_0}$$

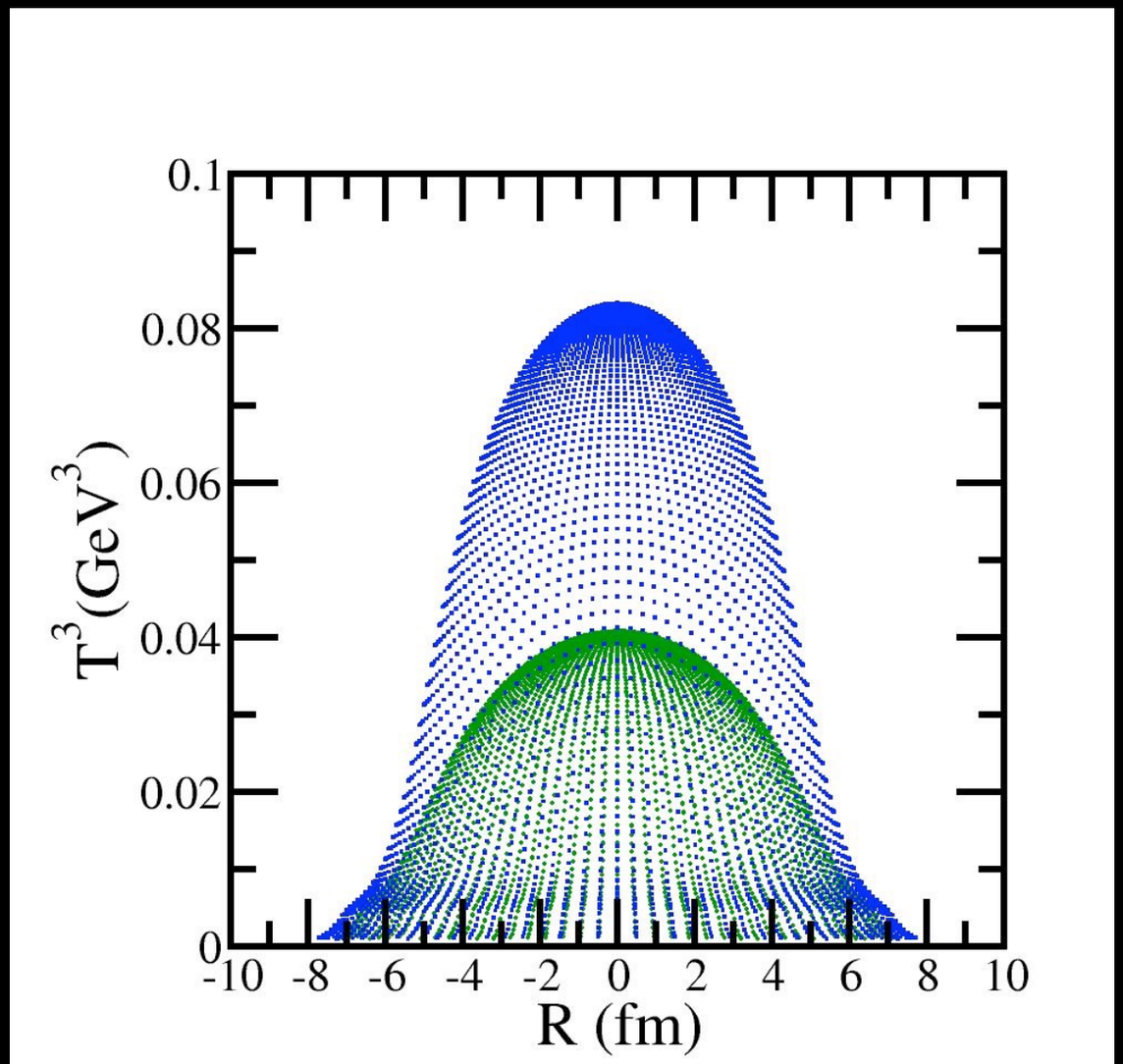
$$s_0 = s(T_0)$$

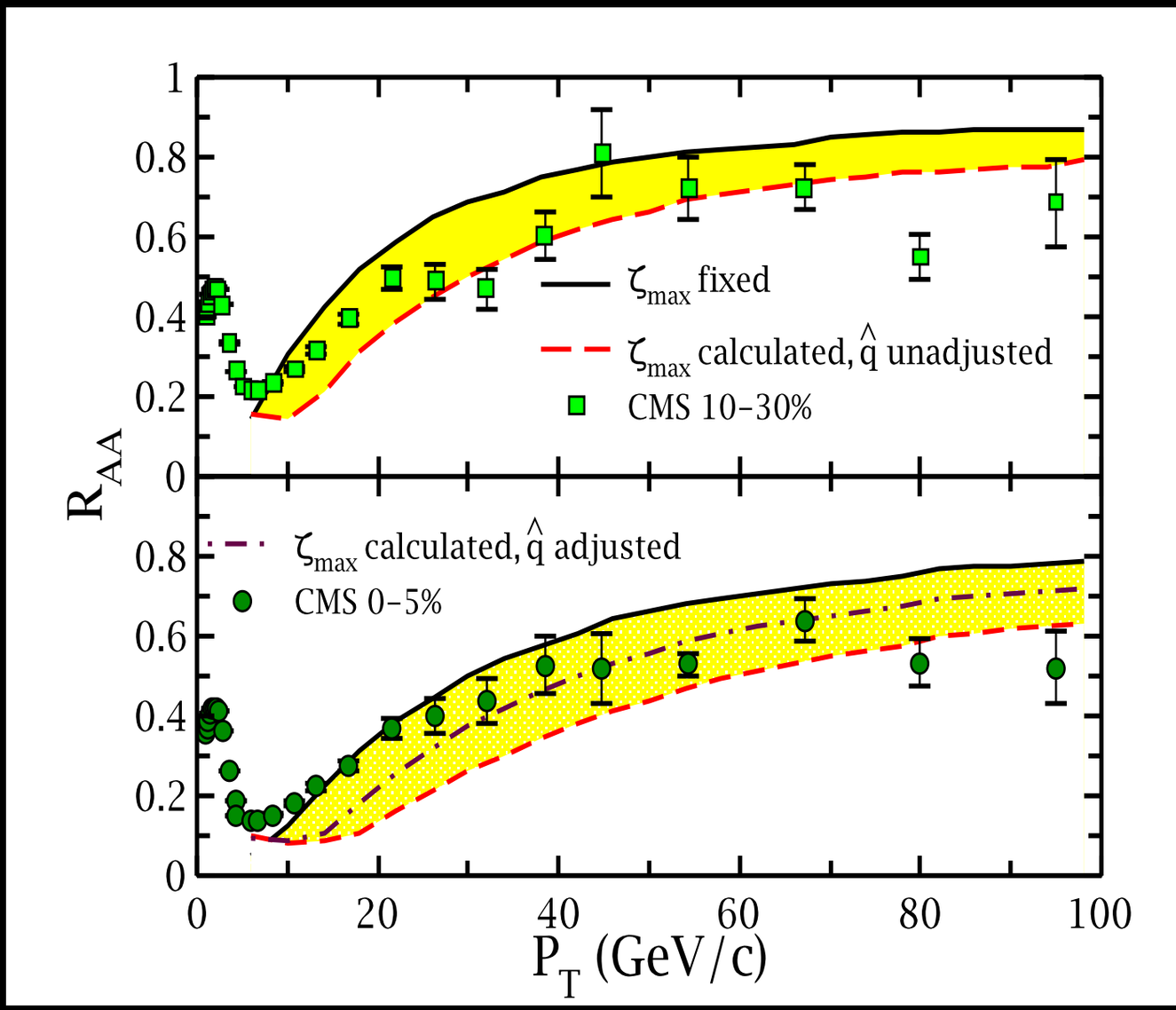


$$R_{AA} \sim \frac{\frac{dN_{AA}}{dp_T dy}}{N_{bin}\frac{dN_{pp}}{dp_T dy}}$$



From RHIC to LHC circa 2012





Reasonable agreement with data,
no separate normalization at LHC
W/O any non-trivial x-dependence (E dependence)