PHYSICS Working Group Plan for 2018-2019

PHYS-WG

JETSCAPE
Collaboration Meeting
Berkeley

29th May 2018

Where are we going?

- Each new module, each new framework capability opens the window to exciting new possibilities, whose actual potential we cannot fully anticipate.

- The flexibility and usability of the JETSCAPE framework, and the degree of sophistication of its different modules, will empower, and encourage the end users to produce highly relevant scientific work in our field.

→ It's not only "don't reinvent the wheel", but rather "Grab all those nice wheels and build yourself a fancy racing car".

Overall Goal - Comprehensive Jet Studies

- Key Objectives

1. Test of our current scale-by-scale approach w/ or w/o the planned improvements.

2. Subjects to study:

- Jet quenching (leading hadrons & jets)
- High p_T v_n's
- Hadron-Jet correlations
- Photon-Jet correlations
- Z^0-jet & W-jet correlations
- Jet shape modifications (different R spectra ratio, transverse energy, girth, p_T^D…)
- Longitudinal fragments distribution modification
- Groomed observables (splitting function z_g, number of Soft Drop splittings, Lund Map)
- Jet super-structure: large angle correlations, overall momentum balance
- Flavor dependence
- Color charge dependence

………..

Highly constrained physics

↓

$\#$ unique info observables $\gg$ $\#$ modelling parameters

Hydrodynamic background is **crucial** in all of these studies!

OSU & DUKE

PHYS-WG To-Do List

- Incorporation of SMASH generator: First priority. **New Module Class.**
  SMASH is about to be released.
  Hadron Resonance Gas (HRG) Phase physics.

- Dealing with *Heavy Quark E-loss*.
  New Dedicated Energy Loss Module.
  Some modules (LBT, MATTER) can add heavy quark functionality as well.

- *Concurrent* running and feedback between *Jet & Fluid* dynamical evolution.
  “Awakening” of an already present **Framework Capability.**
  Indispensable physics for jet quenching under fluid QGP paradigm.

- Implementing the Next-to-Leading-Order (NLO) kernel.
  Hard Scattering Matrix Elements Improvement.
  LO adequate for hadron observables, but not enough for *Gamma-Jet Observables*.

- Inclusion of multi-parton *Coherence* (a.k.a. *Finite Resolution Effects*).
  Cross-talk with theory experts to include such physics in the E-loss Modules.
  Many jet properties are modified as color coherence effects are considered.

Incorporation of SMASH

Taken from H. Petersen's talk at QM '18

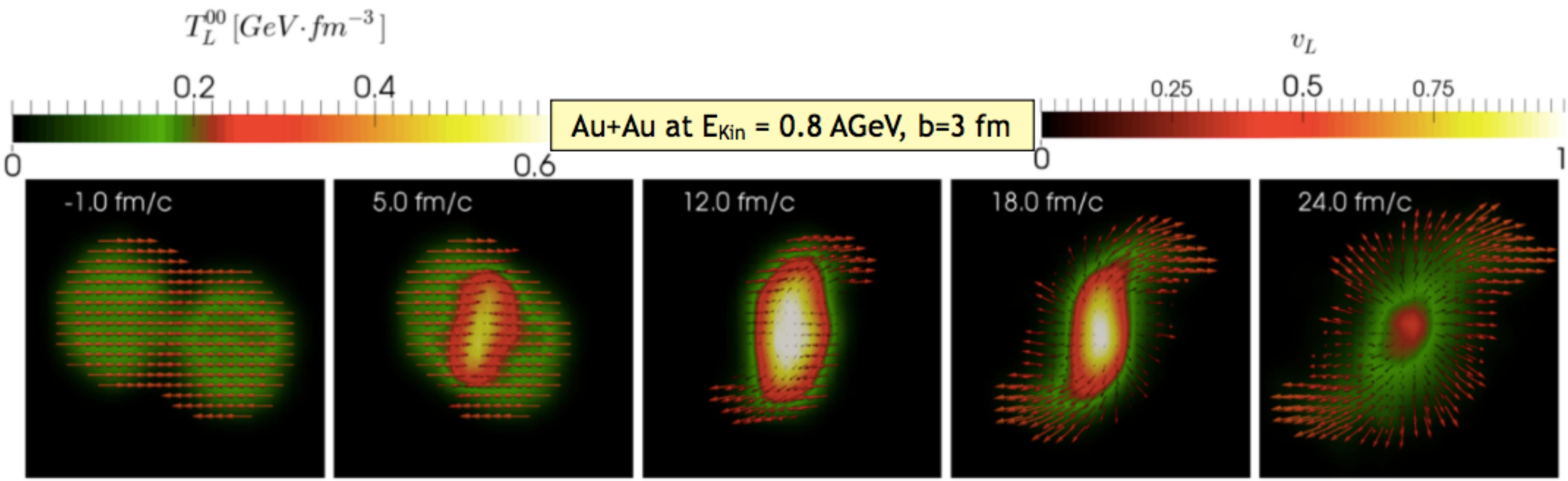
- Physical Importance

→ Hadronic **non-equilibrium** dynamics is crucial for:

- Full/partial evolution at **low**/intermediate **beam energies**
- Late stage **re-scattering** at high beam energies (RHIC/LHC)

Effective solution of relativistic Boltzmann equation

$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C^i_{\mathrm{coll}}$$



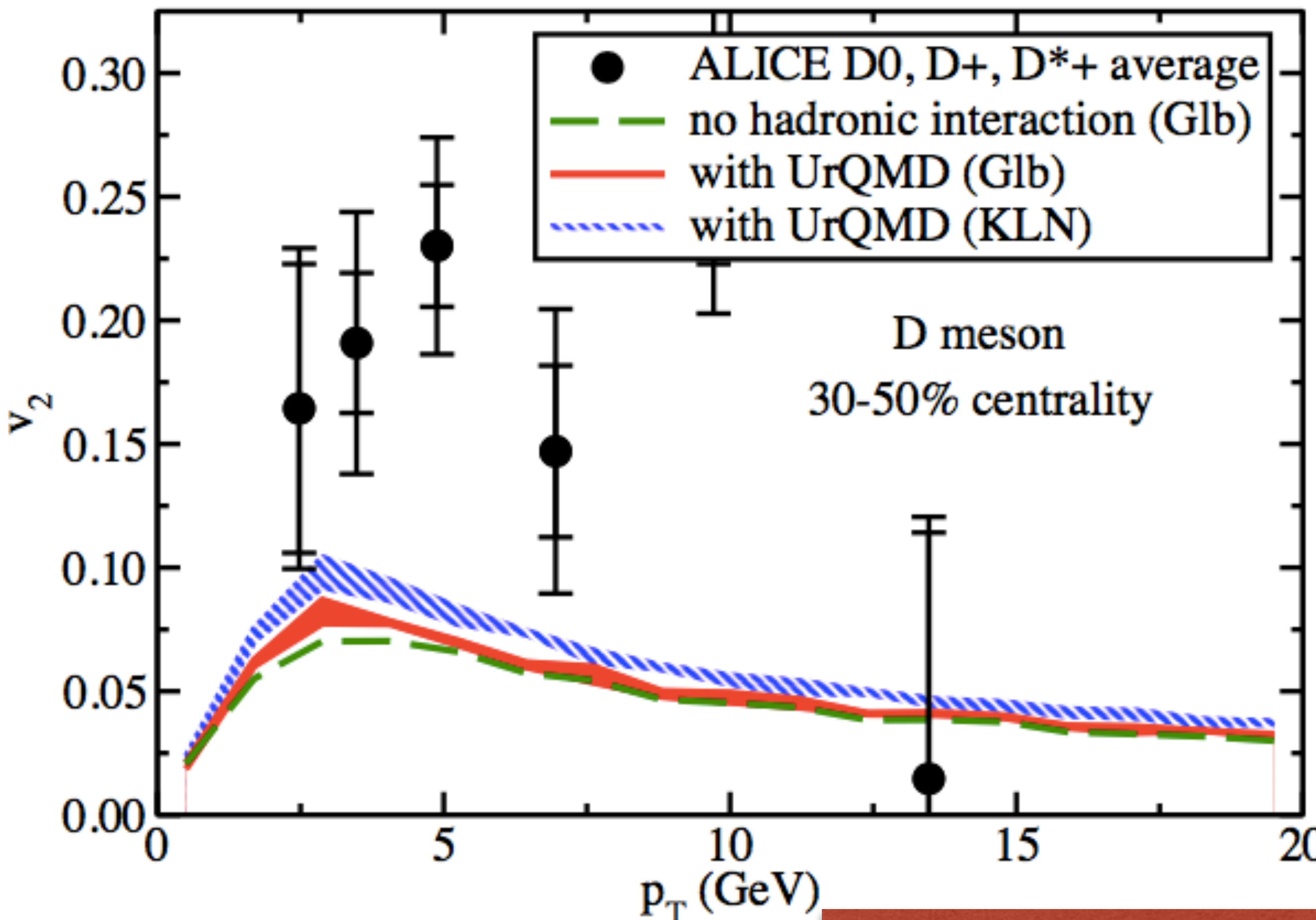
* Simulating Many Accelerated Strongly-Interacting Hadrons

Incorporation of SMASH

- Physical Importance

→ Additional jet energy loss and medium response in hadronic phase.

Ex: Heavy meson re-scattering in HRG (using UrQMD) produces sizeable effect in azimuthal anisotropy.



S. Cao et al. - 1505.01413

Which are the re-scattering effects for soft (& semi-hard) hadrons contained in high p_T jets?
Does it modify the substructure?

needs further study!

? Can we devise an unambiguous way to extract $\hat{q}$ for HRG phase?

→ From local entropy density?

→ Purely from microscopic dynamics?

→ …

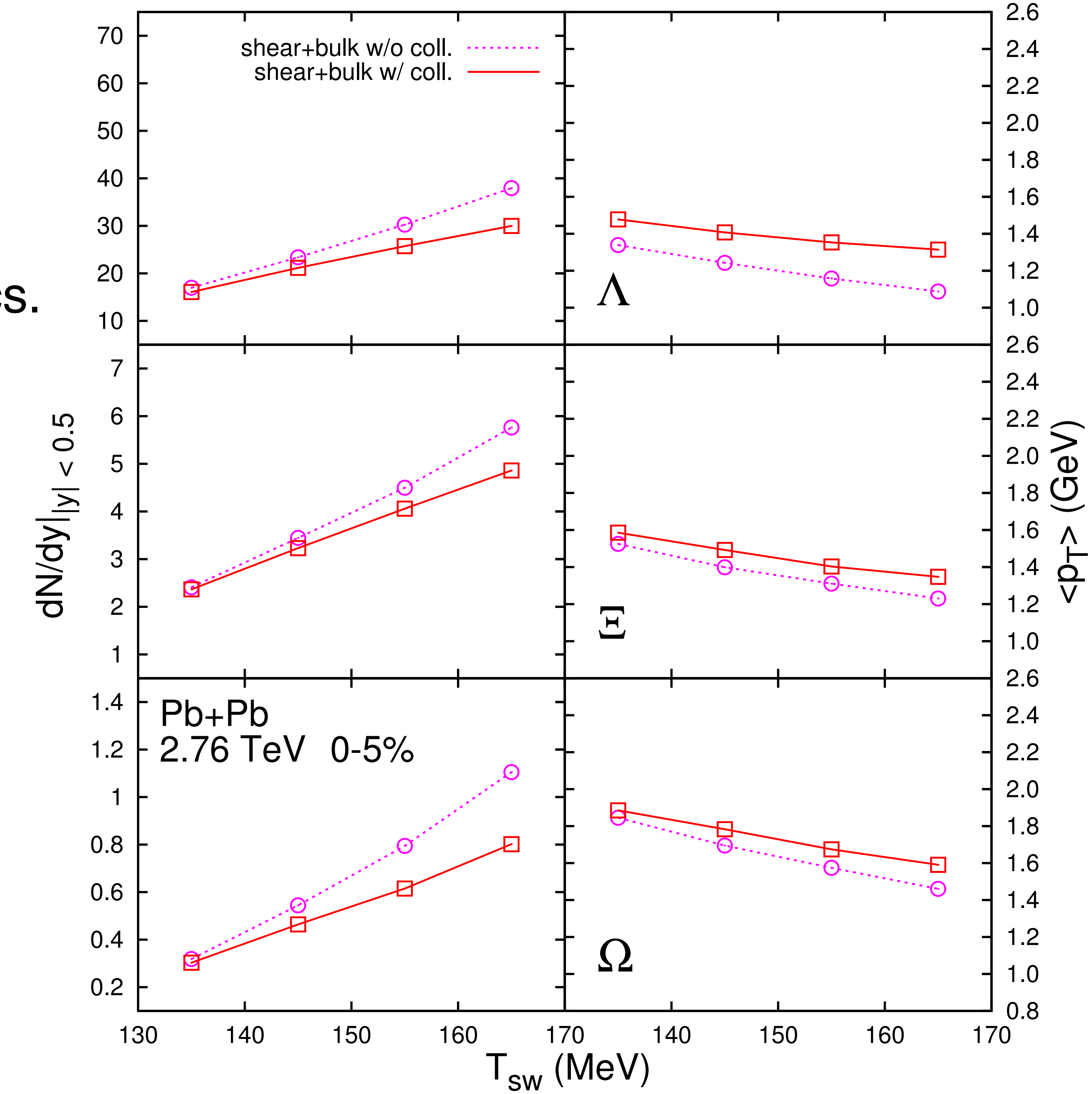
Incorporation of SMASH

- Physical Importance

  → Better incorporation of finite mean free path effects – Important for baryon dynamics.

  Switching temperature dependence of baryon and meson yields.

  → Hadronic decays are taken care of.



S. Ryu et al. - 1704.04216

Incorporation of SMASH

- Implementation
  - Responsible: Dmytro Oliinychenko
  - Support: LongGang Pang
  - External Contact: Hannah Petersen

- Timeline
  - Implementation: ~ 2 months
  - Tests/Data generation: > 2 months

Heavy Quark Energy Loss

- Physical Importance

→ Independent validation of thermal QCD (inspired) jet quenching models.

Ex: Higher Twist gluon radiation

LBT, MATTER

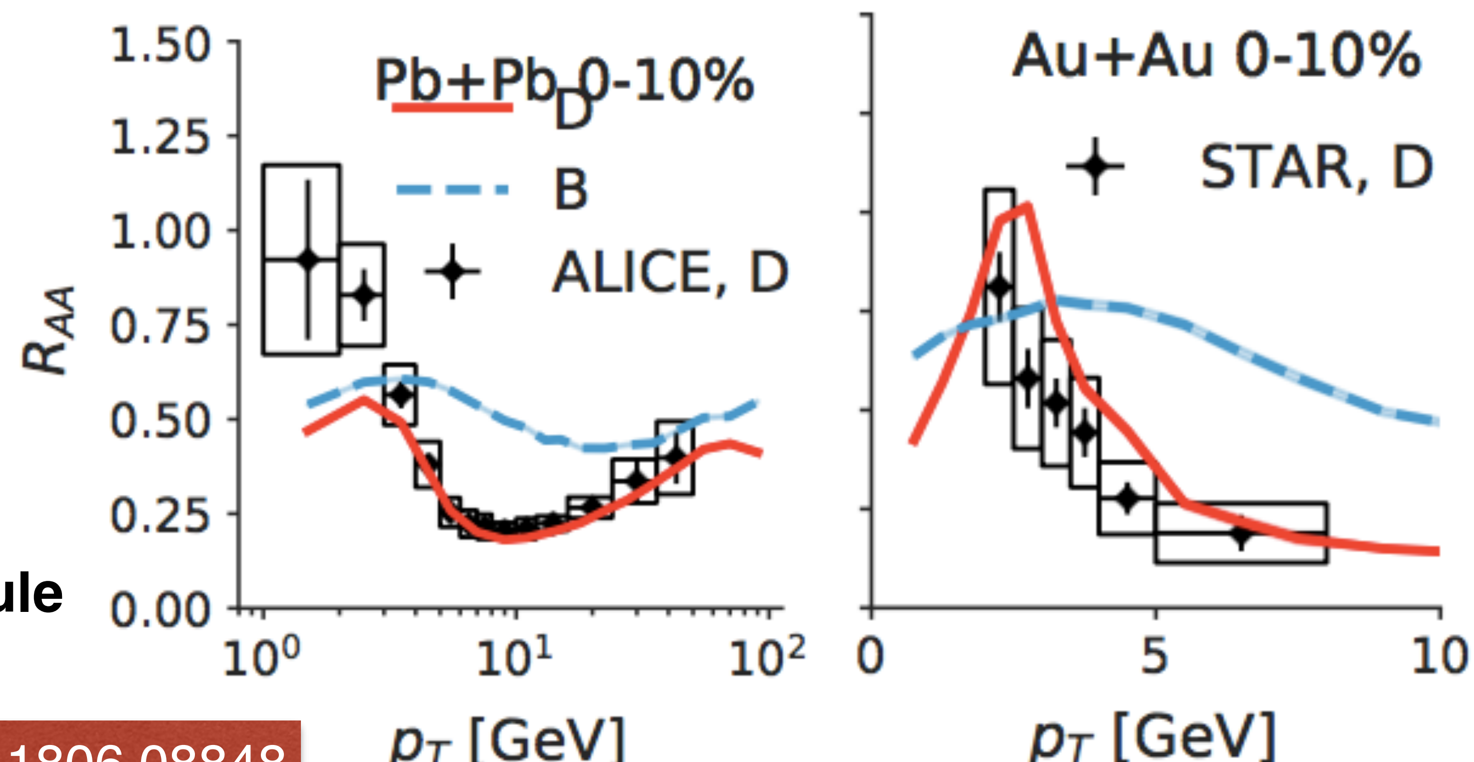
$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s P(x)\hat{q}}{\pi k_\perp^4} \sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2 + x^2 M^2}\right)^4$$

quenching parameter — quark mass

Independent probe of QGP properties and the possibility of heavy quark flow.

→ Power counting, LPM effect, dead-cone effect, etc; all behave differently when $\sqrt{s} \gg m_Q \gg T$

DUKE, New Heavy Quark E-loss Module



W. Ke et al. - 1806.08848

Heavy Quark Energy Loss

- Implementation
  - Responsible: Wenkai Fan, Weiyao Ke, Steffen Bass (for New Dedicated Module)
  - Support: Shanshan Cao, Abhijit Majumder, Tan Luo
- Timeline
  - Implementation: ~ 3 months
  - Tests/Data generation: > 3 months

Concurrent evolution of jets and hydro

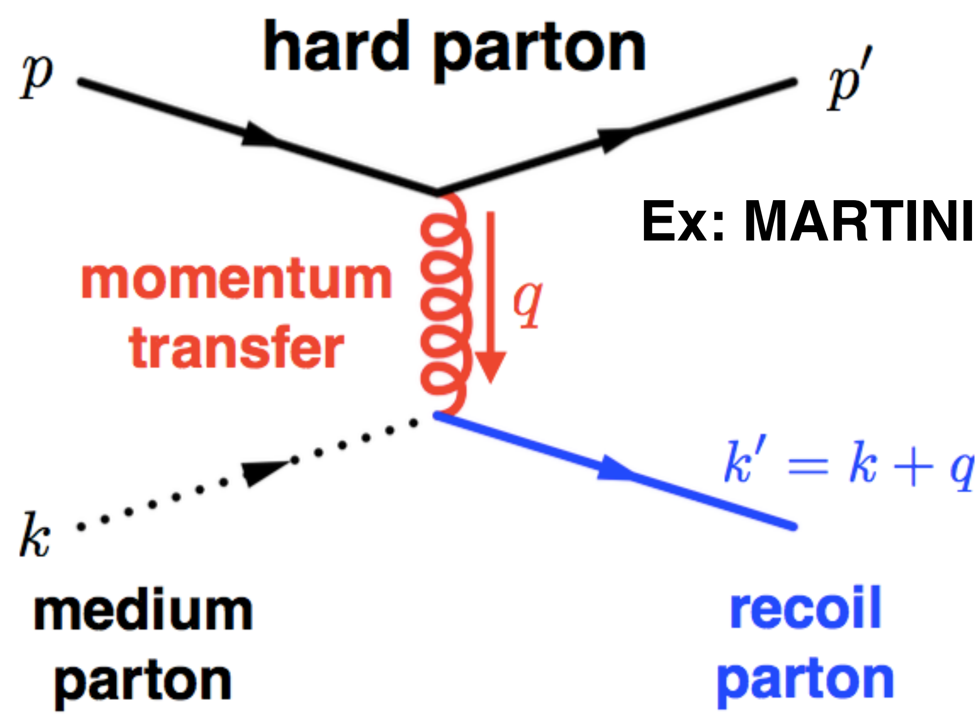
- Physical Importance

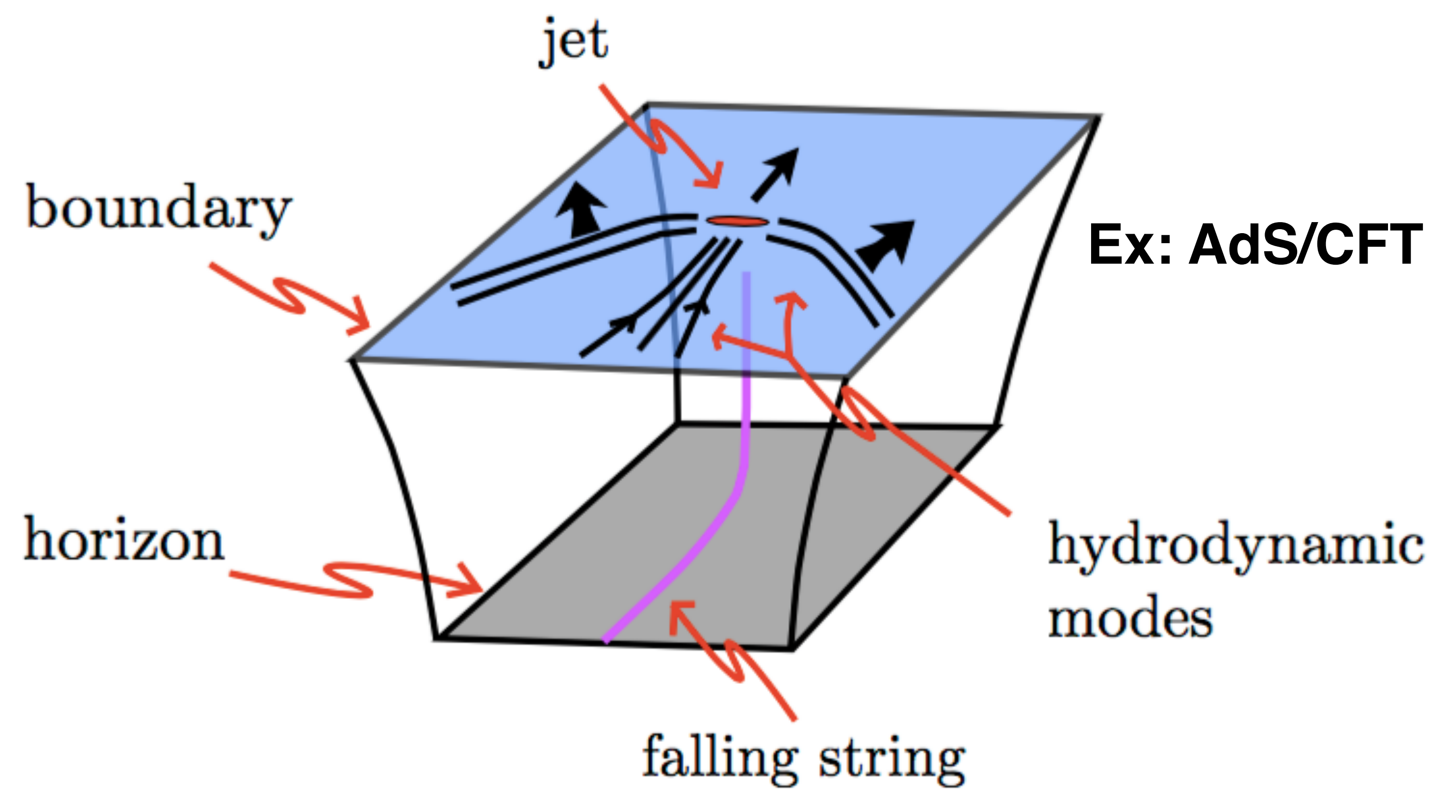
→ Consistency: Overall 4-momentum conservation.

momentum exchange with QGP constituents

and/or

soft quanta/modes absorption by QGP liquid





modifies the hydro {
- jet partons perceive the new jet-modified hydro (hotter, boosted).
- deposited energy & momentum will decay into “extra” soft hadrons.

No approximations or assumptions taken, *captures full non-linearity* of the problem.

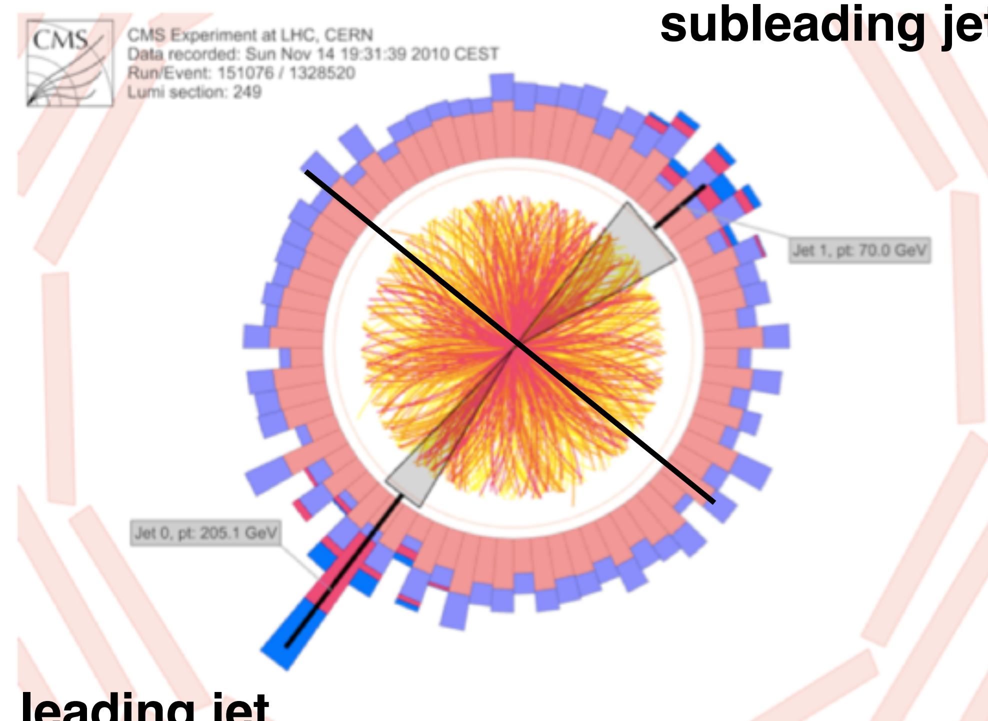
Concurrent evolution of jets and hydro

- Physical Importance

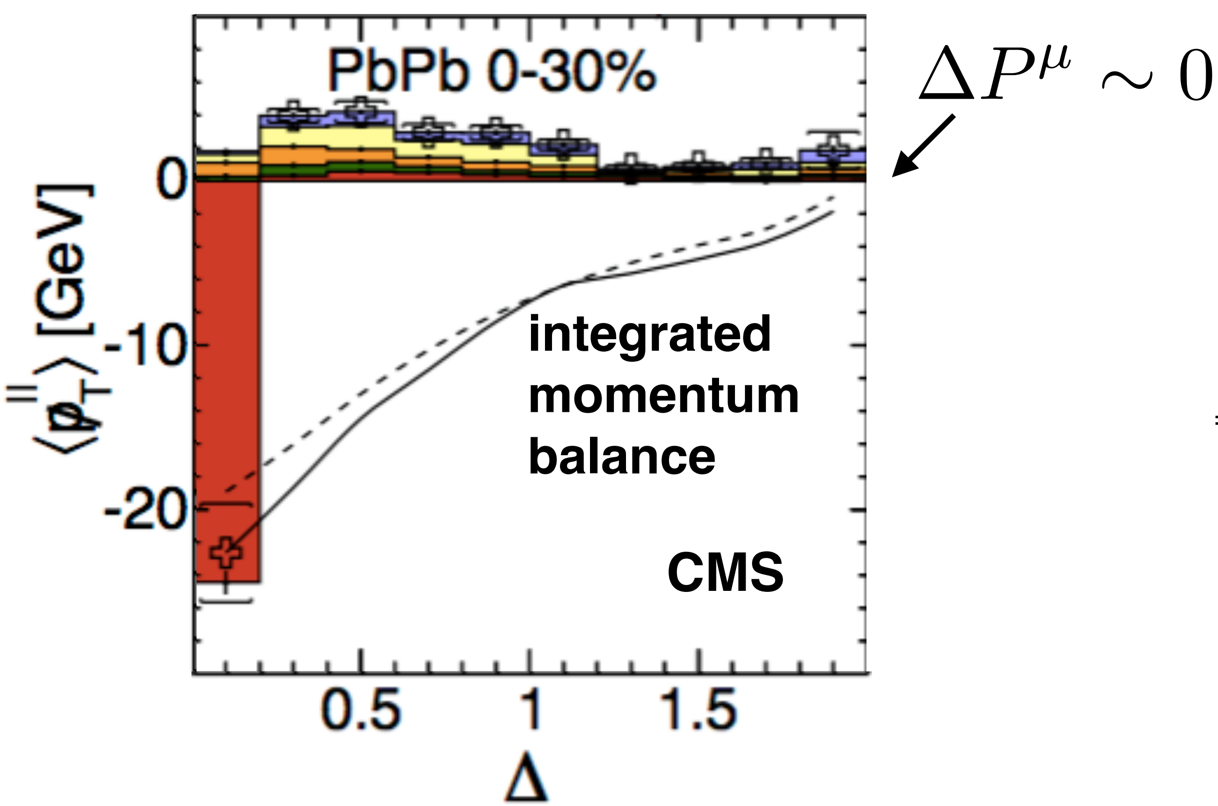
→ Phenomenology: Jet super-structure

Ex: correlate *all* particles in the event with di-jet axis: “missing-p_T” observables.

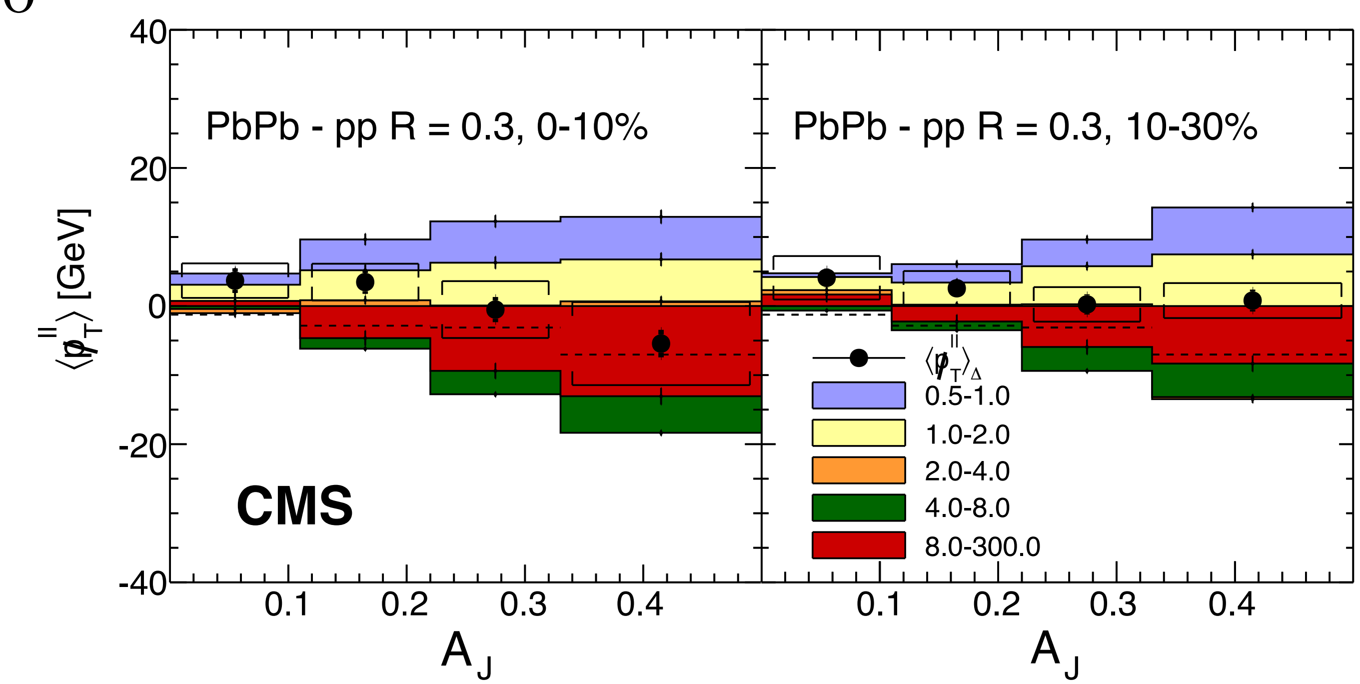
$$\not{p}_T^{||} \equiv -p_T \cos\left(\phi_{\rm dijet} - \phi\right)$$



large angle tracks



soft tracks



p_T balance vs angle w.r.t. axis.

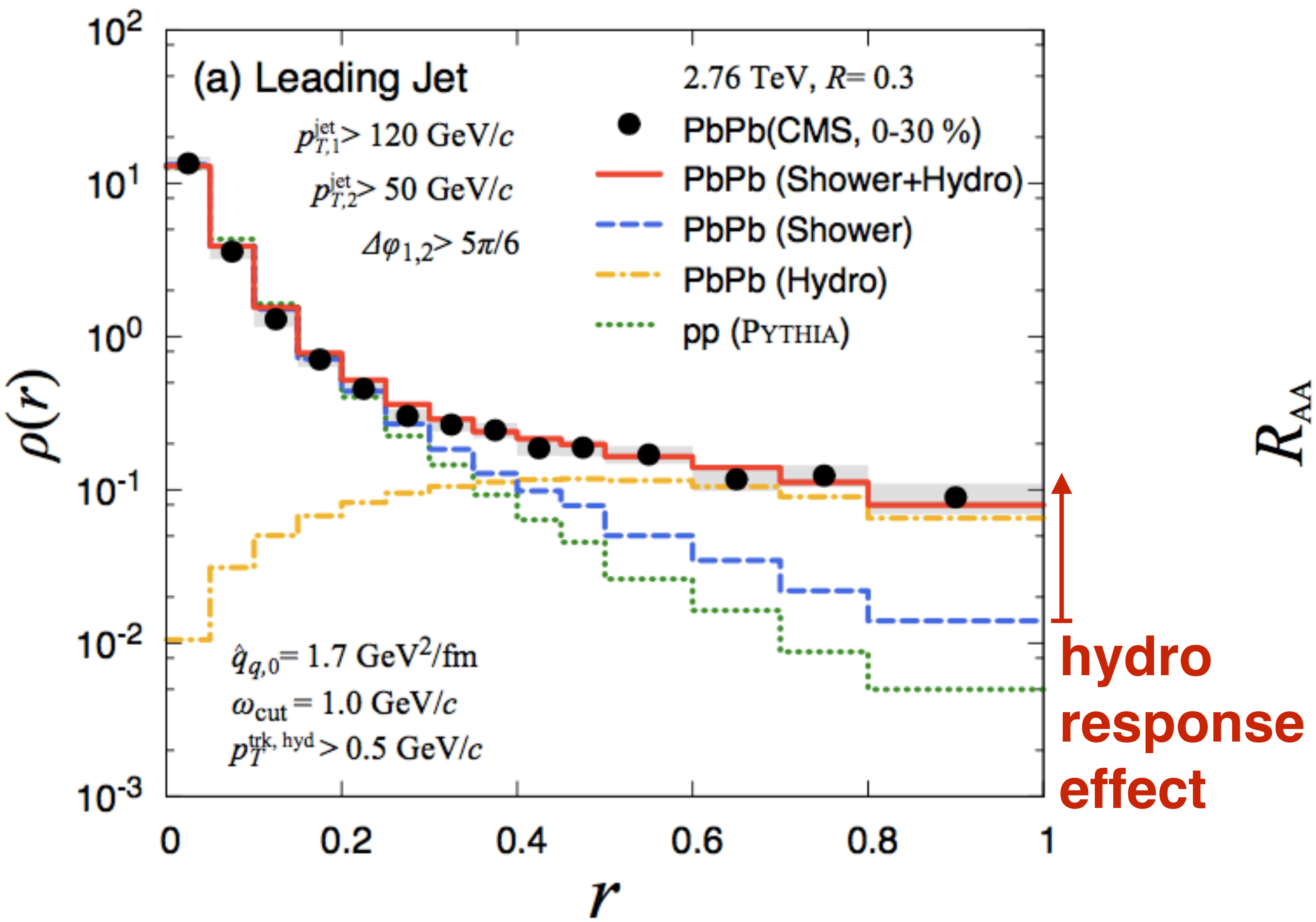
p_T balance vs amount of asymmetry A_J.

Concurrent evolution of jets and hydro

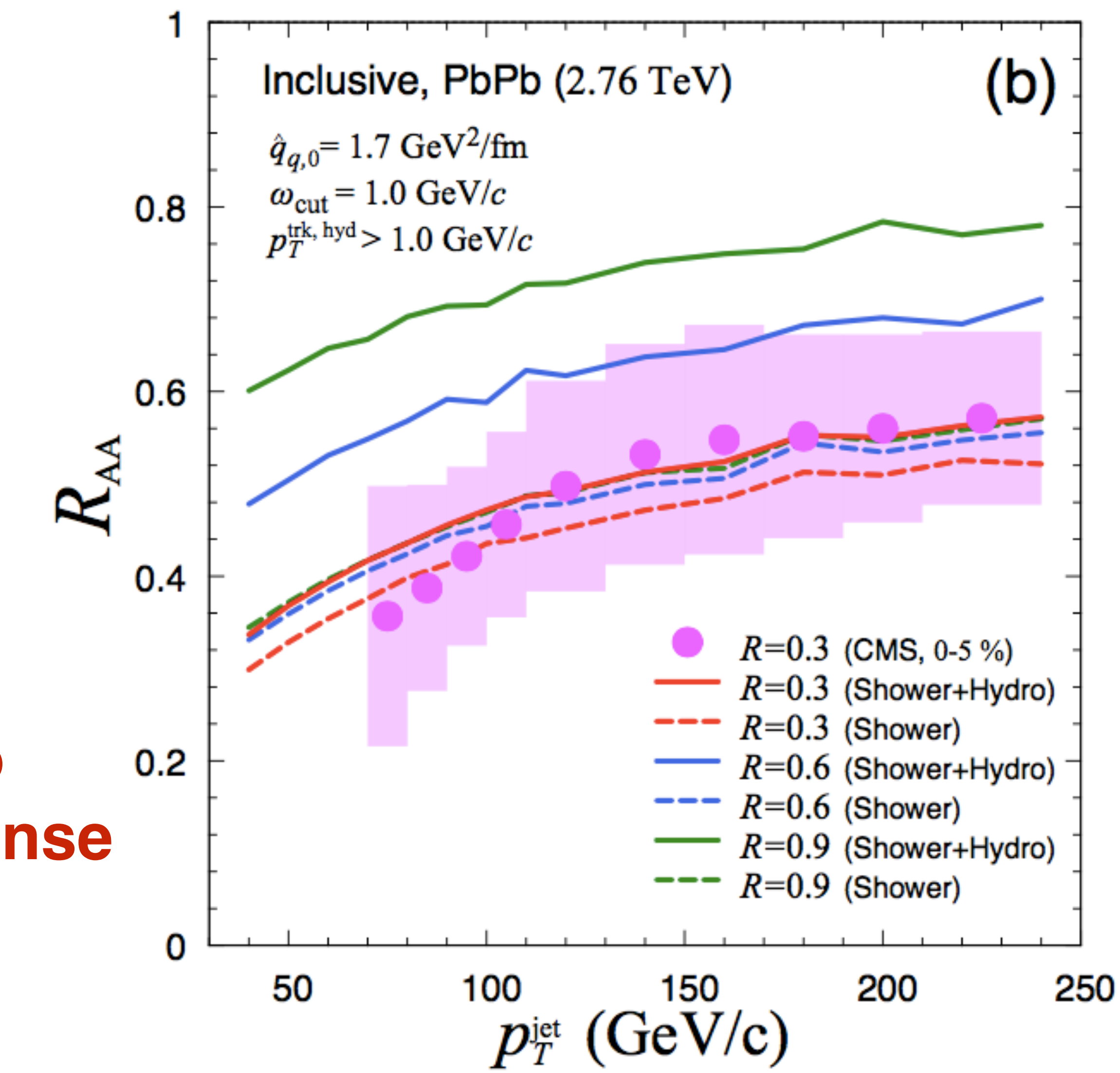
- Physical Importance

→ Phenomenology: Jet super-structure

Opening the jet cone allows for partial recovery of “lost” energy.



Transverse energy distribution w.r.t. jet axis.



Jet suppression as a function of jet opening angle R.

Y. Tachibana et al. - 1701.07951

Concurrent evolution of jets and hydro

- Physical Importance

→ Phenomenology: Jet sub-structure

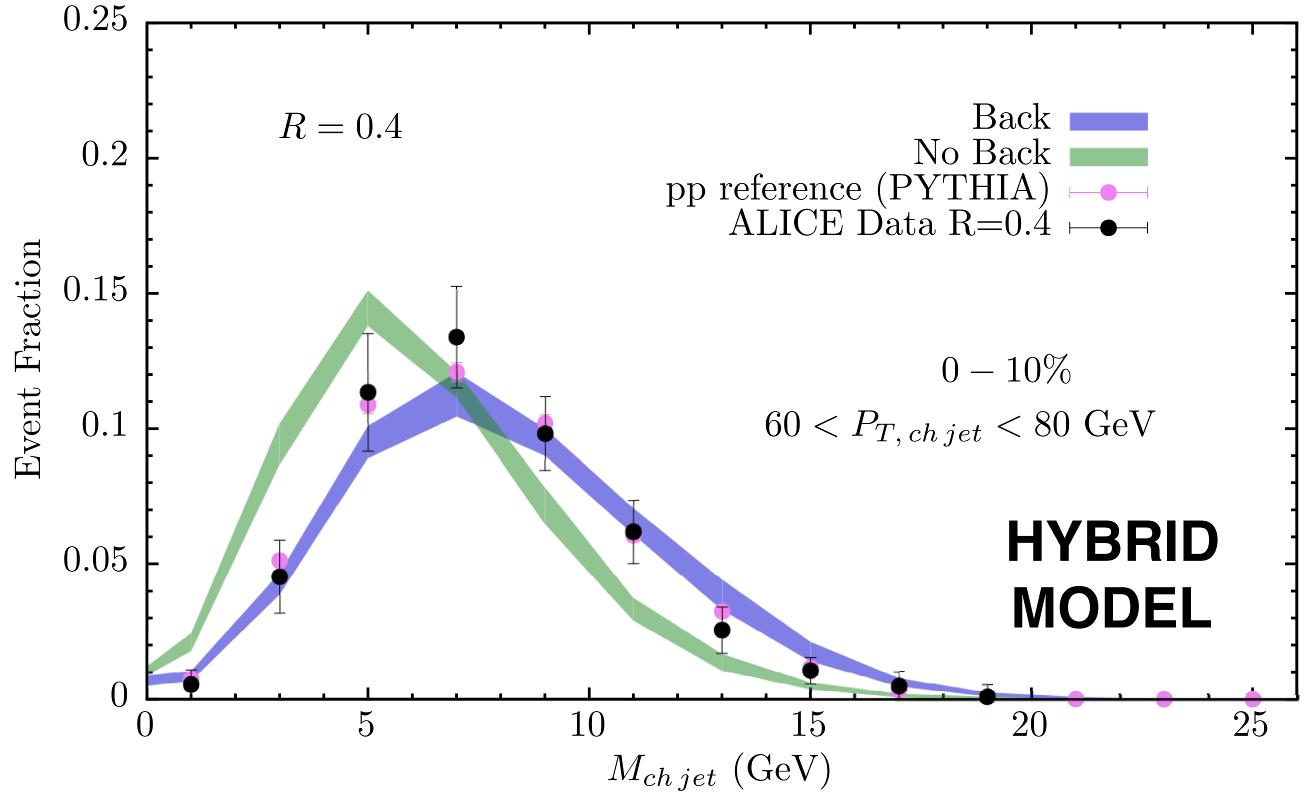
quenching | back-reaction

consistent pattern among different jet quenching models: **jet/QGP cross-talk is crucial**

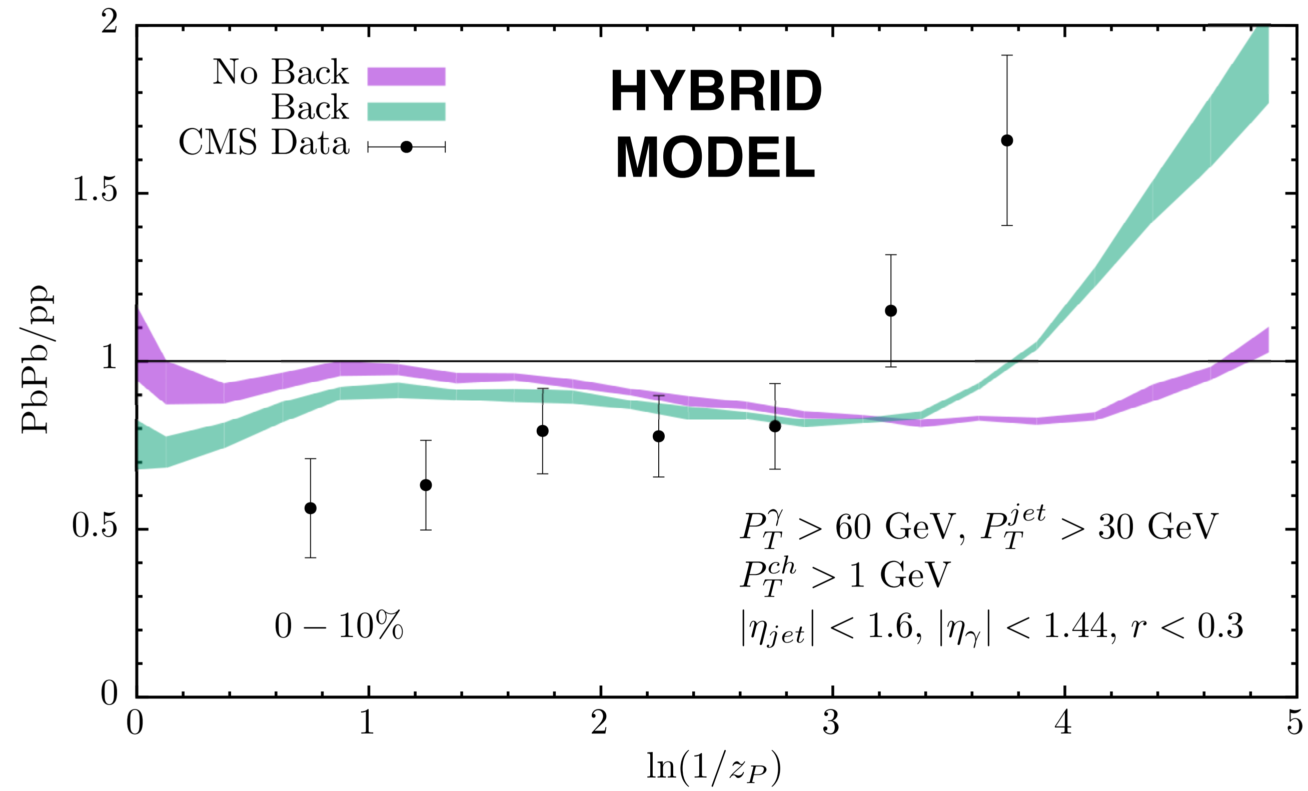
jet narrowing reduces jet mass

soft particles at edges rapidly increase mass

soft fragment enhancement due to medium response



Charged jet mass distribution



recoiling fragment p_T distribution w.r.t. trigger photon

Concurrent evolution of jets and hydro

- Physical Importance

→ Potential Studies:

Is jet sub/super-structure sensitive to the value of η/s ?

- Independent validation of jet-medium interactions and QGP properties such as the soft particle mean free path:

  Can we constrain QGP transport coefficients by confronting to data the effect of medium response to the presence of the jet?

  (or, inversely, can we constrain e-loss models based on their consistency with extracted transport coefficients from minimum bias soft physics?)

……………………………………

- *Only* concurrent jet+hydro evolution allows a dynamical initialisation of hydro:

From mini-jet quenching: M. Okai et al. - 1702.07541

From stopping strings: C. Shen & B. Shenke - 1710.00881

Concurrent evolution of jets and hydro

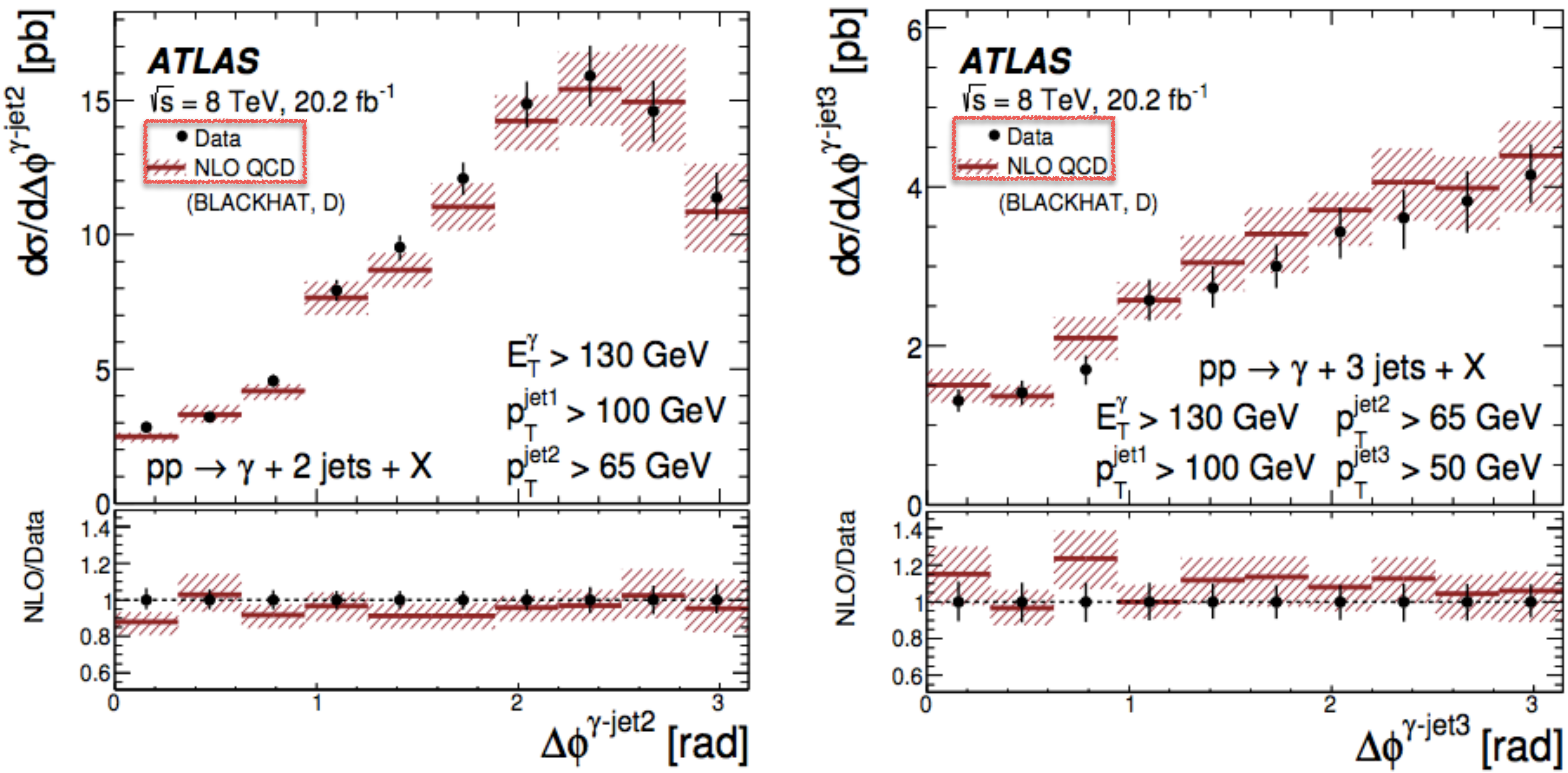
- Implementation (mostly done)
  - Responsible: Ebrahim Khalaj, Kolja Kauder
  - Support: Mayank Singh, LongGang Pang, Yasuki Tachibana, Wei Chen
- Timeline
  - Implementation: ~ 5 months
  - Tests/Data generation: ~ 6 months

NLO Kernel

Taken from D. Perepelitsa's talk at QM '18

- Physical Importance

→ LO simulations adequate for hadronic observables, but NLO needed for gamma related observables, e.g. gamma-multi-jet observables.

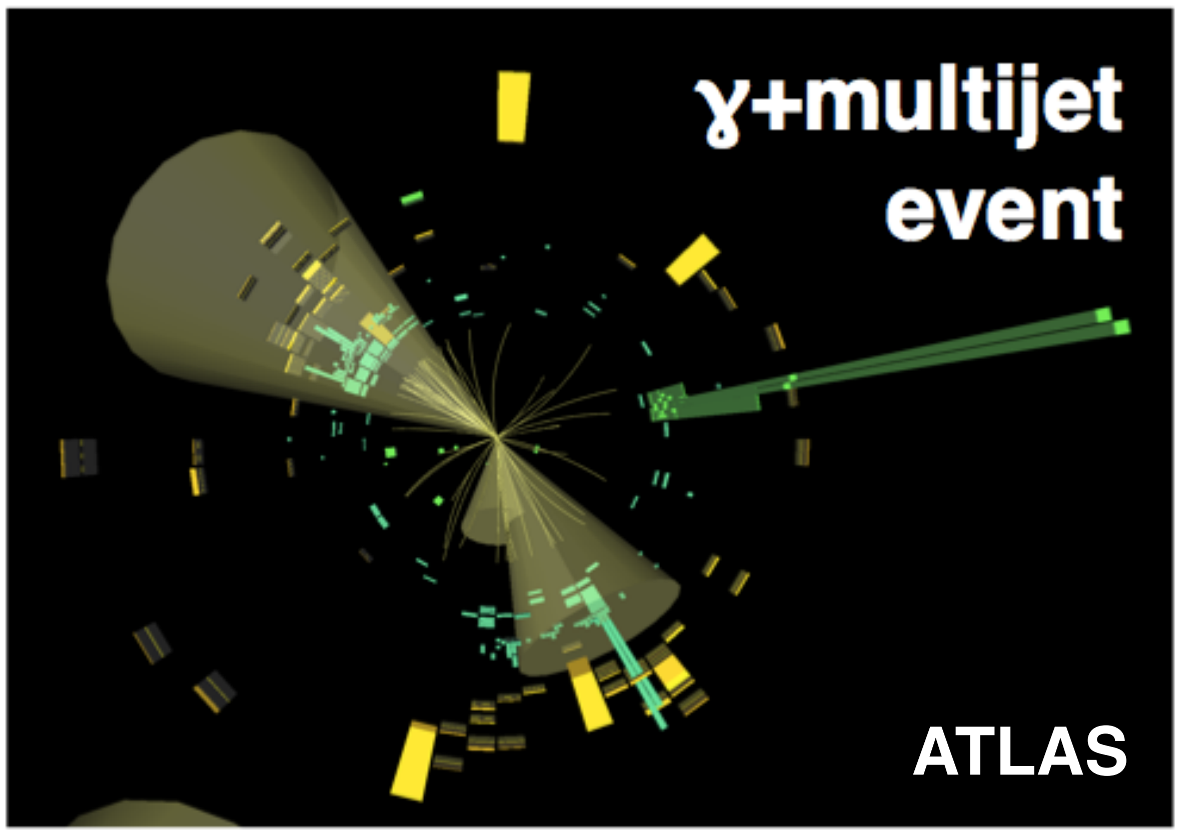


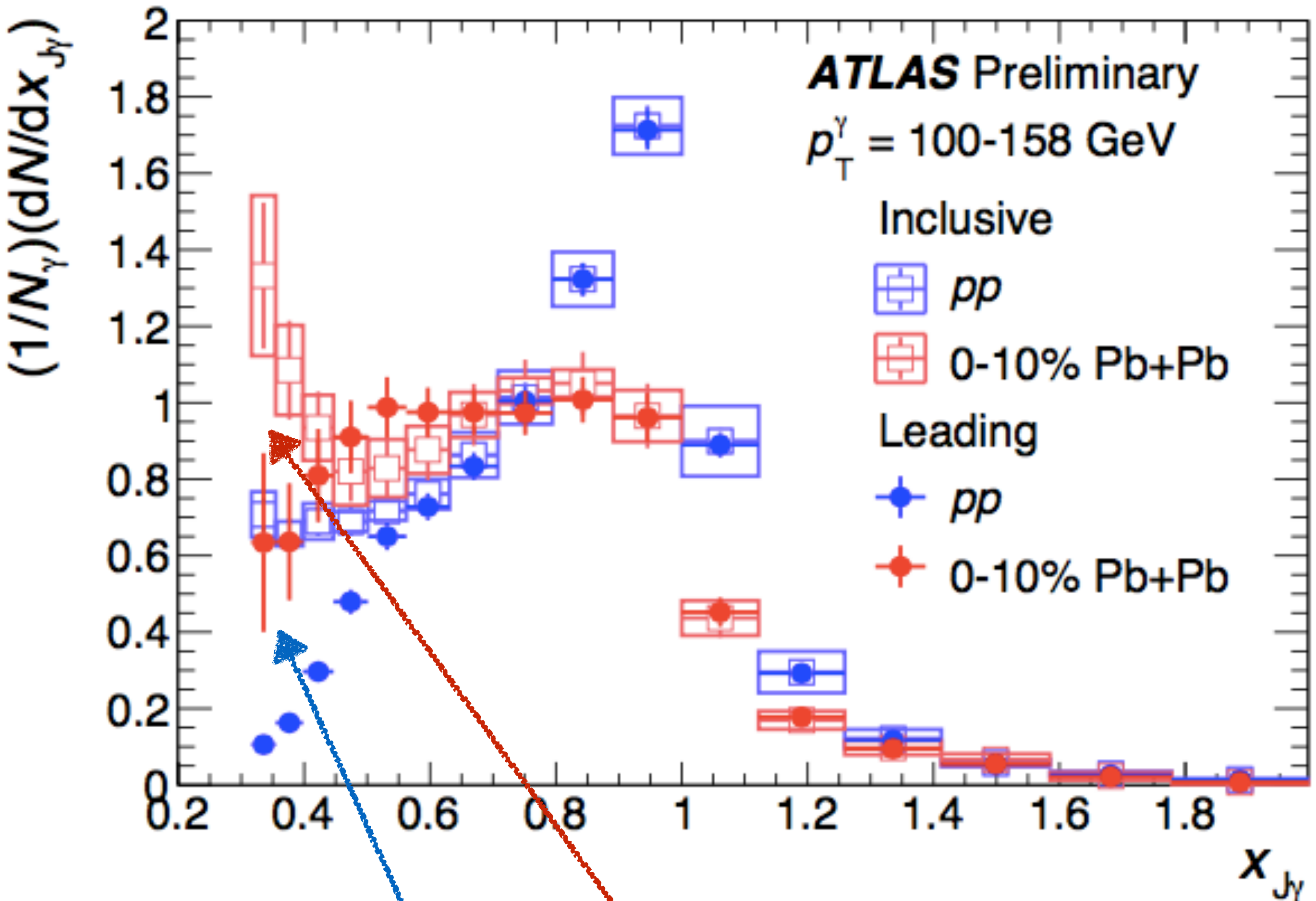
Measured in detail by HE community.

NLO Kernel

- Physical Importance

  → Large differences in photon-jet asymmetry depending on inclusive vs leading associated jet selection.





Specially important al low $x_{J\gamma}$, both for pp and PbPb.

Taken from D. Perepelitsa's talk at QM '18

NLO Kernel

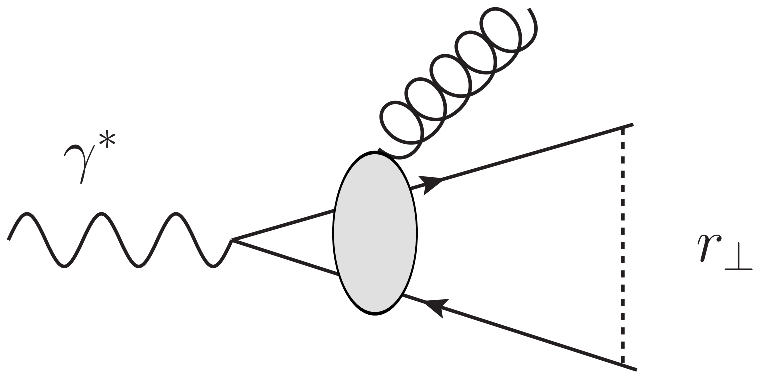
- Implementation
  - Responsible: Abhijit Majumder
  - Support: Daniel Pablos, Kolja Kauder, Ebrahim Khalaj

- Timeline
  - Implementation: ~ 3 months
  - Tests/Data generation: ~ 3 month

Coherence Effects

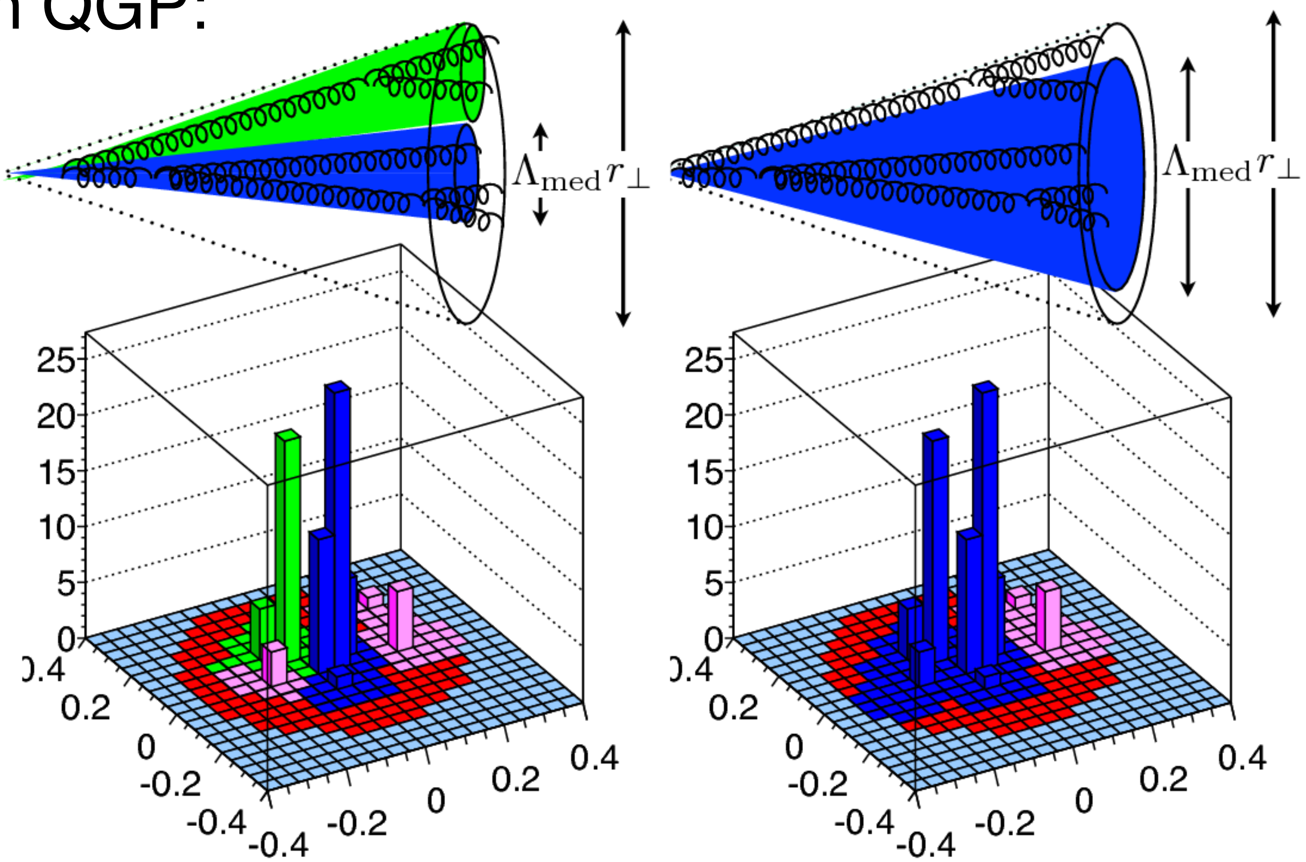
- Physical Importance

→ It's quantum mechanics!



If wavelength of an emission cannot resolve size of the dipole, radiation effectively occurs from global charge.

In QGP:



$r_\perp$ dipole size

$$1/\Lambda_{med}^2 \equiv \hat{q}L$$ medium scale

Their interplay determines whether medium induced emissions resolve the jet internal structure.

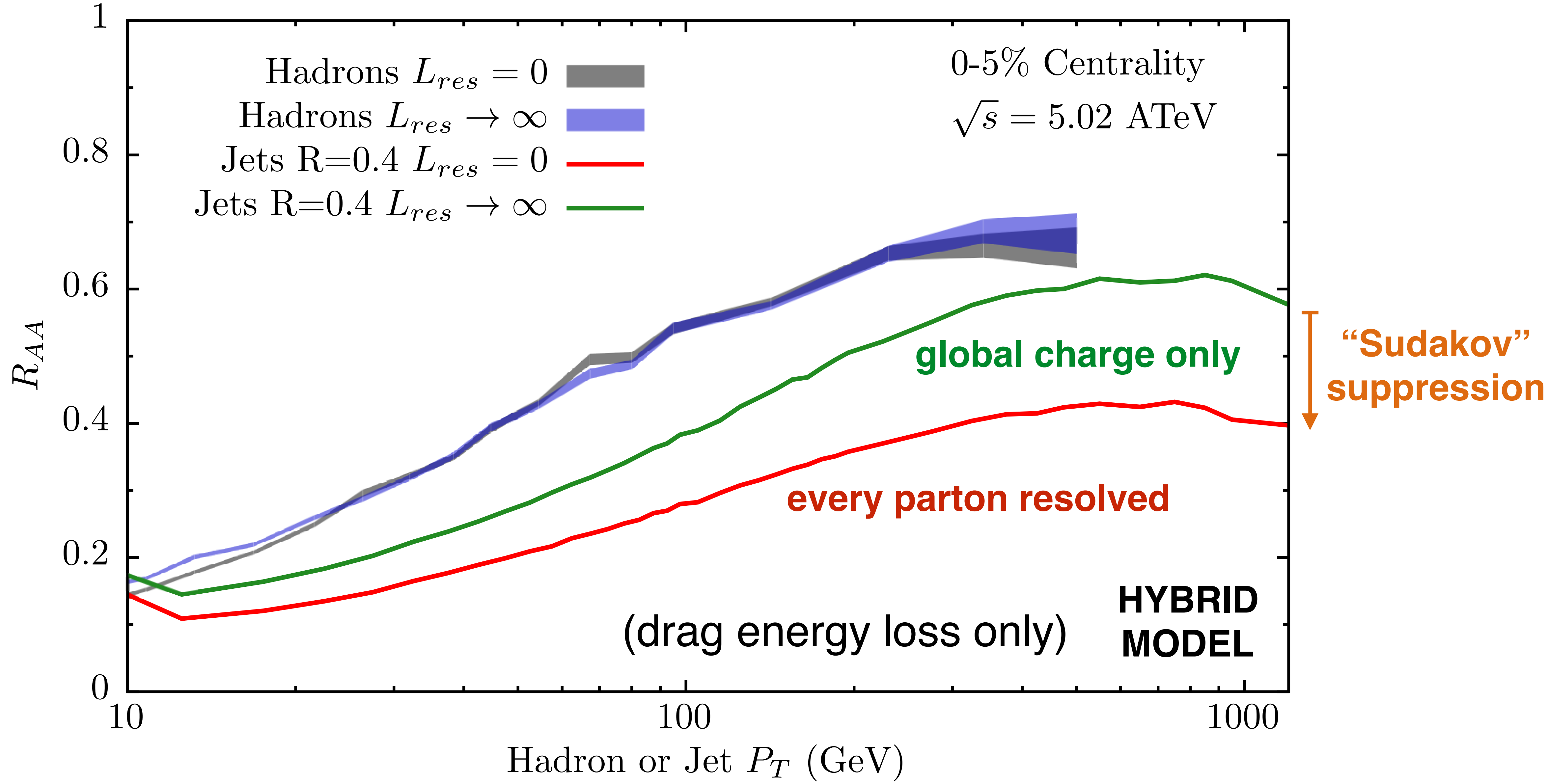
Affects jet e-loss & substructure.

J. Casalderrey et al. - 1210.7765

Coherence Effects

- Physical Importance

→ Ex: Relation between jet & hadron suppression is modified by resolution effects .



Jet is collection of partons, therefore more total energy loss than single parton…
unless they are not resolved at all (extreme case!).

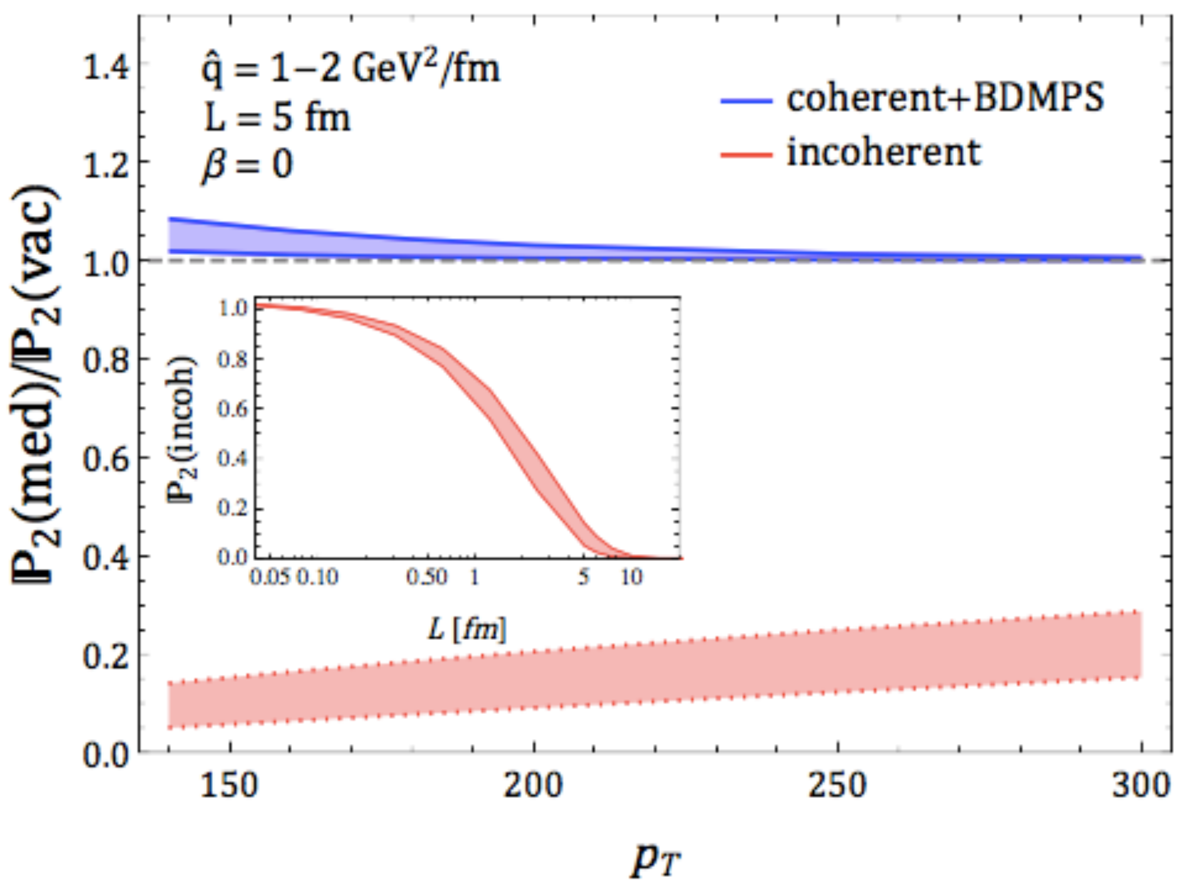
Coherence Effects

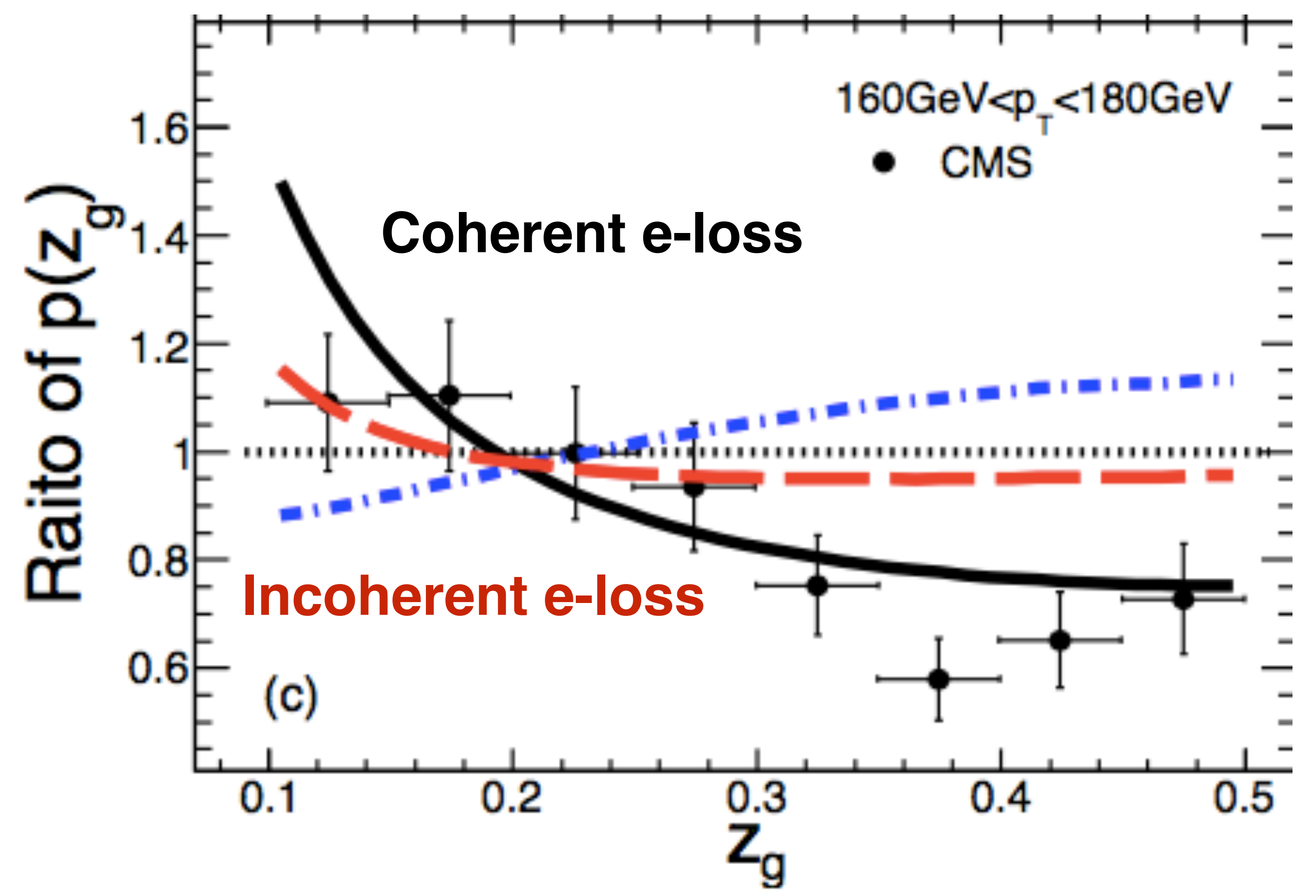
- Physical Importance

→ Ex: New generation groomed observables affected by coherence.

Probability of finding two sub-jets with energy balance of at least 10% w.r.t. vacuum.

Modification of the momentum balance distribution w.r.t. vacuum.





Y. Mehtar-Tani & K. Tywoniuk - 1610.08930

N. Chang et al. - 1707.03767

Coherence Effects

- Implementation in JETSCAPE

  → Different possible alternatives depending on the logic and assumptions of each e-loss module.

In Hybrid Model:

- So far, assume that splittings are dominated by initial high virtuality, *but* neglects role of virtuality injected by the medium at latest stages.

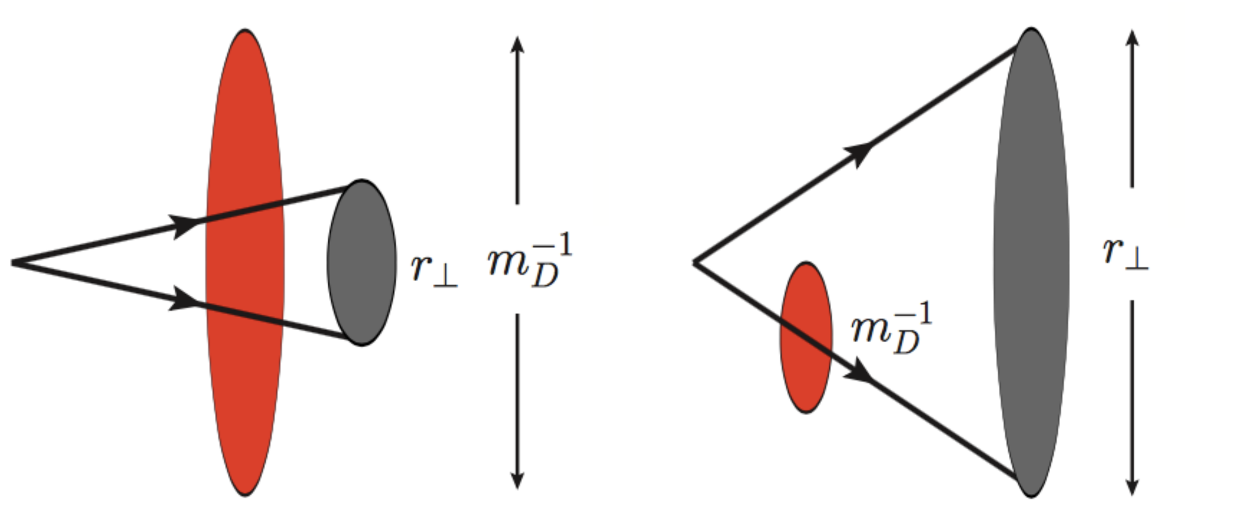
  → Introduce new splittings according to well-known antenna spectrum.

$$\omega\frac{dN^{\rm med}}{d^3k} = \frac{8\,\alpha_s C_F\,\hat{q}}{\pi}\int_{\mathcal{V}(\boldsymbol{q})}\int_0^{L^+} dx^+$$
$$\left\{\left[1-\cos\left(\frac{\boldsymbol{\kappa}+\bar{\boldsymbol{\kappa}}-2\boldsymbol{q}}{2}\cdot\delta\boldsymbol{n}\,x^+\right)\right]\boldsymbol{L}\cdot\bar{\boldsymbol{L}}\right.$$
$$+\left[1-\cos\left(\frac{(\boldsymbol{\kappa}-\boldsymbol{q})^2}{2k^+}x^+\right)\right]\boldsymbol{C}(\boldsymbol{k}-\boldsymbol{q})\cdot\boldsymbol{L}$$
$$\left.-\left[1-\cos\left(\frac{(\bar{\boldsymbol{\kappa}}-\boldsymbol{q})^2}{2k^+}x^+\right)\right]\boldsymbol{C}(\boldsymbol{k}-\boldsymbol{q})\cdot\bar{\boldsymbol{L}}\right\}$$

Mehtar-Tani et al. - 1112.5031

Limiting cases:

“dipole” regime — “saturated” regime



Coherence Effects

- Implementation
  - Responsible: Daniel Pablos, Joern Putschke
  - Support: E-loss Modules contact persons

- Timeline
  - Implementation: ~ 6 months
  - Tests/Data generation: ~ 4 months

Outcomes

- JETSCAPE v 2.X with full set of physics modules.

- Papers

AA papers:

- Leading hadron / Full jet R_{AA} study w/ high p_T v_n.
- Correlation study (hadron-jet, photon-jet).
- Jet angular sub- and super-structure study.
- Medium modified fragment distribution & splitting study.

pA papers:

- Same as the above.
- Resolve the $R^{jet}_{pA} = 1$ puzzle?

Members

- BNL
- CCNU
- Duke
- FIAS
- LLNL
- McGill
- MIT
- OSU
- TAMU
- UCBerkeley
- UoT
- WSU