Jets and high P_T probes

observables and concepts

Thorsten Renk

The context
Some QCD in vacuum
- virtuality-ordered shower evolution
- mass effects
Jets in medium
- what is seen, and what else might be there
Jets in experiment
- biases, biases, biases
Summary

UNIVERSITY OF JYVÄSKYLÄ
Suomen Akatemia
HELSINKI INSTITUTE OF PHYSICS

Context

Bigger picture: Why are you listening?

We want to understand **collectivity**, **thermodynamics** and the associated phenomena in QCD.

• What is the phase diagram of QCD matter?
→ can we see a phase transition from hadronic to partonic matter?

• What are the properties of QCD matter?
→ can we measure e.g. transport coefficients?

• What is QCD matter made of?
→ can we observe in what degrees of freedom such matter arranges itself?

This talk: How do we get there by looking at hard (high-P_T) probes

Two themes:
→ What is the parton-medium interaction, i.e. what are the medium DOFs?
→ What can we infer about the global medium evolution (tomography)?

Factorized pQCD

Context: Why is high P_T interesting to solve this?

$$\mathcal{L}_{QCD} = \mathcal{L}_q + \mathcal{L}_{\mathcal{G}} = \overline{\Psi}(i\gamma_\mu D^\mu - \mathbf{m})\Psi - \frac{1}{4}\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu}$$

$$\mathcal{G}_{\mu\nu} = (\partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f^{abc} A_{\mu,b} A_{\nu,c}) t_a \quad \text{and} \quad D_\mu = \partial_\mu - i g t_a A^a_\mu$$

Because then we actually know what we're doing. The connection of QCD to fluid dynamics is tenuous, but with a large momentum p_T in the problem, we know that $\alpha_s(p_T) \ll 1$ and so we know how to start from $\mathcal{L}_{QCD}$ using a perturbative expansion.

- not all aspects of heavy-ion collisions are perturbative, the initial state is not!

$\Rightarrow$ factorized QCD - separate short-distance physics from long distance physics

$$d\sigma^{NN\rightarrow h+X} = \sum_{fijk} f_{i/N}(x_1, Q^2) \otimes f_{j/N}(x_2, Q^2) \otimes \hat{\sigma}_{ij\rightarrow f+k} \otimes D^{vac}_{f\rightarrow h}(z, \mu_f^2)$$

(parton distribution functions (PDFs) $f_{i/N}(x_1, Q^2)$ and fragmentation functions (FFs) $D^{vac}_{f\rightarrow h}(z, \mu_f^2)$)

Question: What part of this can be modified by the fluid medium?

Time ordering and the Heisenberg principle

Initial state: exists before the medium is formed and cannot be medium-modified
$\rightarrow$ but nuclear PDFs (nPDFs) describe the change from free to bound nucleon
$\rightarrow$ nPDFs can be determined in eA collisions

Hard process:

- pQCD interactions involve intermediate, highly virtual partons at scale p_T
  $\rightarrow$ these have lifetimes $1/p_T$
- some real numbers
  $\rightarrow$ 100 GeV jet has $\tau \sim 0.002$ fm
  $\rightarrow$ medium has $\tau \sim 1/T \sim 0.6$ fm

$\Rightarrow$ hard processes also take place long before the medium forms

Fragmentation function:

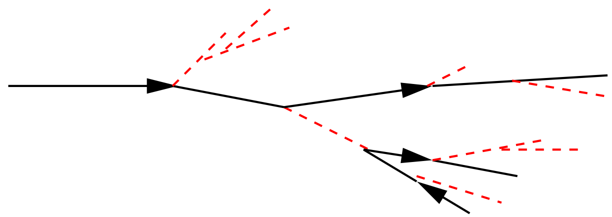
$\rightarrow$ must be the place where the medium acts, **medium-modified FF (MMFF)**

Fragmentation function physics

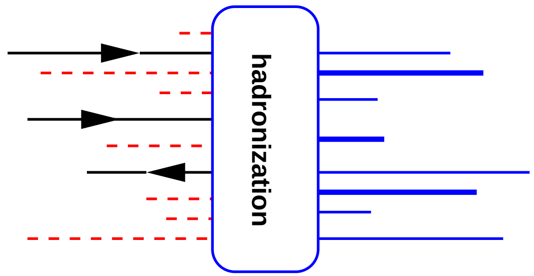
$D^{vac}_{f\to h}(z,\mu_f^2)$: yield of hadrons h at fraction z of momentum of parton f at scale μ^2

encodes the following physics:

- radiation from the highly virtual initial parton via $q\to qg$, $g\to gg$ and $g\to q\overline{q}$ (perturbatively calculable for $Q\simeq 1$ GeV)



- hadronization (non-perturbative)



Question: (to Heisenberg) At what timescales do we expect these phenomena to take place?

Fragmentation function timescales

Perturbative evolution:

• takes place at $1/Q$ where 1 GeV $< Q < p_T$ — but that's in its own restframe!
$\longrightarrow$ in lab frame, the hard parton has a time dilatation factor E/Q

$\Rightarrow$ so any pQCD radiation takes place at $\tau \sim E/Q^2$

Hadronization:

• takes place at $1/m_h$, but with the same time dilatation factor

$\Rightarrow$ hadronization into a hadron with mass m_h occurs at $\tau \sim E/m_h^2$

Examples:

• 5 GeV π^0 forms after ~ 57 fm
$\longrightarrow$ πs, the majority of produced particles, almost always hadronize free of medium

• 40 GeV proton forms after ~ 11 fm
$\longrightarrow$ for heavier hadrons, one needs to go to higher P_T to factorize hadronization

• 100 GeV B^+-meson forms after ~ 0.73 fm
$\longrightarrow$ the formalism shown in the following isn't applicable for b-quarks

Fragmentation function timescales

• for the majority of hadrons from jets, hadronization outside the medium works
$\longrightarrow$ the pQCD evolution of the FF is modified by the medium
$\longrightarrow$ but keep the limitations in mind!

$\Rightarrow$ we need to understand how Q^2 evolves as pQCD shower and medium evolve

> In the following, we're using the PYSHOW algorithm to illustrate the pQCD evolution of the FF. PYSHOW isn't the only way, but the most commonly used baseline for the MMFF in heavy-ion physics.

• the high Q^2 part of the evolution may still occur **before** a medium forms
• the low Q^2 part, for large jet energy, may still occur **outside** of the medium
$\Rightarrow$ only parts of the FF are touched by the medium!

QCD SHOWER EVOLUTION THE PYTHIA WAY (I)

Basic idea: Evolution as an iterated series of $1 \to 2$ splittings (parent/daughters)

• splitting phase space given by virtuality, (almost) collinear splitting:
$\to$ use $t = \ln(Q^2/\Lambda^2_{QCD})$ and z

• differential splitting probability is

$$dP_a = \sum_{b,c} \frac{\alpha_s(t)}{2\pi} P_{a\to bc}(z) dt dz$$

• splitting kernels from perturbative QCD

$$P_{q\to qg}(z) = \frac{4}{3}\frac{1+z^2}{1-z} \quad P_{g\to gg}(z) = 3\frac{(1-z(1-z))^2}{z(1-z)} \quad P_{g\to q\bar{q}}(z) = \frac{N_F}{2}(z^2+(1-z)^2)$$

• evolution proceeds in decreasing virtuality t and leads to a series of splittings $a \to bc$ where the daughter partons take the energies $E_b = zE_a$ and $E_c = (1-z)E_a$.

• $Q \sim P_T$ is the hard scale which makes the process perturbative for $Q^2 > 1$ GeV^2

QCD shower evolution the PYTHIA way (II)

- differential branching probability at scale t:

$$I_{a\to bc}(t) = \int_{z_-(t)}^{z_+(t)} dz \frac{\alpha_s}{2\pi} P_{a\to bc}(z).$$

- kinematic limits $z_\pm$ dependent on parent and daughter virtualities and masses $M_{abc} = \sqrt{m_{abc}^2 + Q_{abc}^2}$

$$z_\pm = \frac{1}{2}\left(1 + \frac{M_b^2 - M_c^2}{M_a^2} \pm \frac{|\mathbf{p}_a|}{E_a}\frac{\sqrt{(M_a^2 - M_b^2 - M_c^2)^2 - 4M_b^2 M_c^2}}{M_a^2}\right)$$

- probability density for branching of a occuring at t_m when coming down from t_{in}:

$$\frac{dP_a}{dt_m} = \left[\sum_{b,c} I_{a\to bc}(t_m)\right] \exp\left[-\int_{t_{in}}^{t_m} dt' \sum_{b,c} I_{a\to bc}(t')\right].$$

(probability for branching, times probability that parton has not branched before)

QCD shower evolution the PYTHIA way (III)

• 0th order: Q provides transverse phase space for radiation, E/Q boosts the system along original parton direction
$\longrightarrow$ a collimated spray of partons, i.e. a jet is generated

• 1st order: QCD leaves characteristic signatures (branching kernels)
$\longrightarrow$ preference for soft gluon emission, angular ordering due to interference

• a large quark mass such as m_c or m_b restricts radiation phase space
$\longrightarrow$ heavy quarks fragment harder, 'dead cone effect'

• medium interactions are parametrically small, since $Q \sim p_T$, but $\Delta Q \sim T \ll p_T$
$\longrightarrow$ expect a medium shower to be a perturbation around the vacuum shower
$\longrightarrow$ 3rd order: some extra medium-induced radiation phase space

• formation times are E/Q_i^2, hence high Q^2 vacuum radiation happens *early*
$\longrightarrow$ hard branchings occur even before a medium can be formed

Jet evolution essentials are simple physics principles

The role of the medium — basic expectations

Assume all this happens in a thermal QCD medium, and jet and medium interact

• in the limit $t \to \infty$, the jet will thermalize and isotropize
$\longrightarrow$ broadening and softening of jet constituents proportional to interaction time

Corollary: Broadening of jets isn't a specific signature of anything in particular.

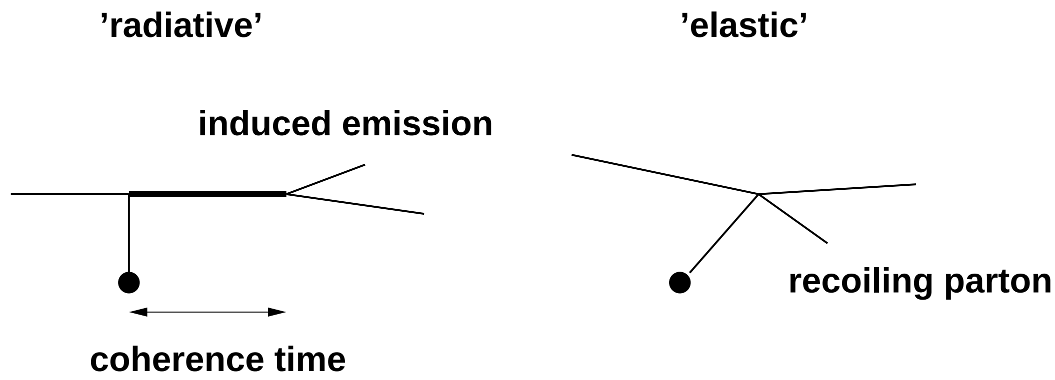
• jet P_T at LHC are $O(100)$ GeV, medium temperature is $O(0.5)$ GeV
$\longrightarrow$ scale separation, the medium can not kinematically deflect a jet
(if you calculate it, the angle is about 0.17 deg)

Corollary: Jet axis, subjet structure etc. are set by hard physics even in medium.

• this means the jet partons have to lose energy on average
$\longrightarrow$ jet partons with $p_T \sim T$ get soaked up by the medium

The role of the medium — what we know

Two basic mechanisms (cartoon warning!):



• radiative: interaction with the medium increases radiation phase space
$\longrightarrow$ s-channel, involves coherence time E/Q^2
$\Rightarrow$ lost energy in radiated gluons, non-linear pathlength dependence

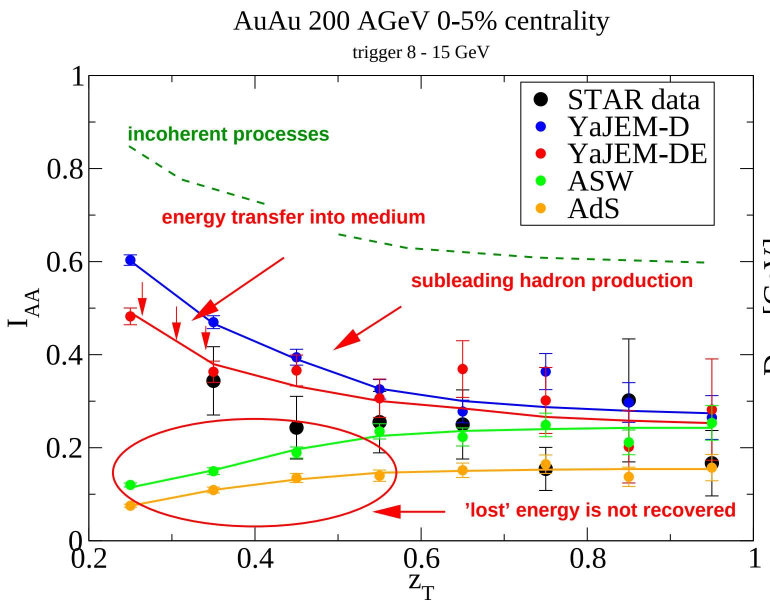
• elastic: jet parton gives a kick to medium parton and transfers energy in the process
$\longrightarrow$ t-channel, no coherence time
$\Rightarrow$ lost energy largely in medium dof, linear pathlength dependence

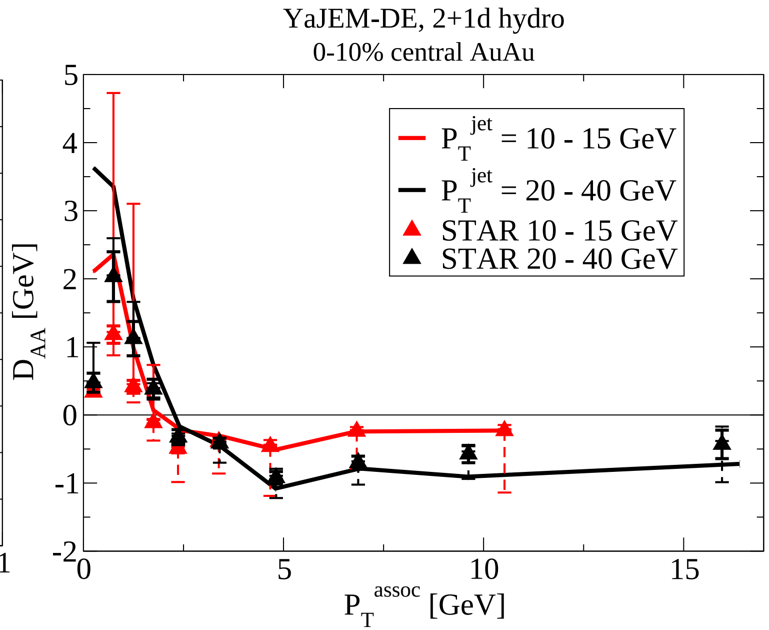
Remember: In reality, the incoming parton is **not** on-shell but highly virtual!

$\longrightarrow$ Impossible to separate medium-induced and vacuum emission, same phase space
$\longrightarrow$ The jet parton is kinematically 'heavy'

The role of the medium — why we know

Idea: In correlation measurements, hadronization of radiation is observed





- as expected, depletion at high P_T — 'energy loss'
- induced radiation is **observed** and its magnitude **calculable**

$\longrightarrow$ even its transverse broadening is observed and calculable

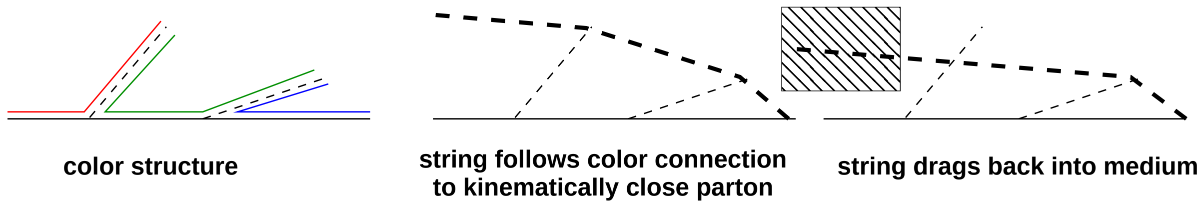
- also evidence for dissipation into the medium

$\longrightarrow$ surprisingly small, perhaps 10%

$\Rightarrow$ radiative energy loss $\gg$ elastic energy loss

The role of the medium — what we suspect

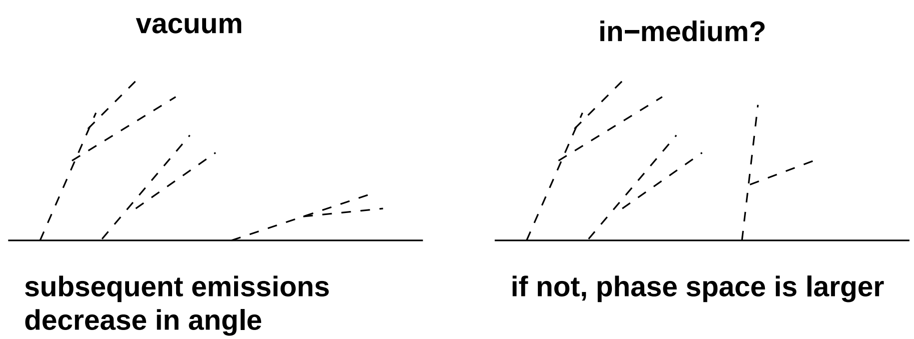
Idea: The medium might chance the way color is connected in the shower



⇒ this would soften fragmentation at the hadronization stage

• no clear signal proposed, no experimental evidence so far
→ can string stretch through deconfined medium?

A. Beraudo, J. G. Milhano and U. A. Wiedemann, Phys. Rev. C **85** (2012) 031901



• subsequent emissions are angular-ordered in vacuum
→ this can break down due to medium effects, increased radiation phase space

• only unspecific broadening predicted, no experimental evidence so far

Y. Mehtar-Tani, C. A. Salgado and K. Tywoniuk, Phys. Rev. Lett. **106** (2011) 122002

The role of the medium — what theorists implement

What is the microscopical model of the medium?

• A **free** or **perturbatively tractable** gas of quarks and gluons
→ allows to treat interaction with medium in pQCD as well, i.e. 'easy' to compute
→ in **striking disagreement** with fluid picture of bulk medium
→ large (50%) energy transfer into medium by elastic reactions and recoil
(cf. JEWEL, AMY, MARTINI, opacity expansions like GLV or WHDG, . . .)

• A **strongly coupled** system described by the AdS/CFT duality
→ cannot be decomposed into quasiparticles, but drag forces
→ rather than with density T^3, effects scale with T^4

• **Static** color dipole scattering centers
→ simplifies kinematics in pQCD interactions with medium, no recoil
→ has no elastic energy loss
→ **no physics motivation**, just an *ad hoc* assumption
(cf. ASW, Q-PYTHIA,. . .)

• No idea
→ medium appears via transport cofficients $\hat{q}$ and $\hat{e}$
→ parametrize the non-perturbative interaction in terms of exchanged momenta
(cf. YaJEM, HT, . . .)

The role of the medium — what theorists implement

What part of the evolution equations gets modified?

• The splitting kernels $P_{i\to jk}(z)$
$\rightarrow$ underlying assumption: asymptotic kinematics, no scale in the problem
$\rightarrow$ okay for *vacuum QCD*, but the medium has a scale T
$\Rightarrow$ leads to **fractional energy loss** models where radiation scales $\sim zE_{jet}$
(Q-PYTHIA, . . .)

• The kinematics entering the evolution equations
$\rightarrow$ parton may pick up virtuality providing additional radiation phase space, $\hat{q}$
$\rightarrow$ parton may loose energy to medium degrees of freedom, $\hat{e}$
$\rightarrow$ both change the phase space limits branching by branching
$\Rightarrow$ breaks energy momentum conservation in shower, only recovered with medium
(YaJEM, JEWEL, . . .)

• None - combine energy loss of on-shell partons with vacuum fragmentation
$\rightarrow$ **energy loss approximation**, not applicable for all observables
$\rightarrow$ **hybrid models** where part of the evolution before the medium is done
$\Rightarrow$ probabilistic **energy shift** of parton before fragmentation
(MARTINI, PYQUEN, ASW, WHDG, GLV, . . .)

Flow chart

model of medium DOF ⇒ **elementary modification of splitting**

⇓

$P'_{i\to jk}(z)$, ΔQ^2, ΔE

correlation of emissions ⇒ **iterated splitting, MMFF**

⇓

$D_{f\to h}(z, Q^2|\hat{q}(\zeta), \hat{e}(\zeta), \ldots)$

model of medium geometry ⇒ **space-time averaging**

⇓

$\langle D_{f\to h}(z, Q^2|\hat{q}(\zeta), \hat{e}(\zeta), \ldots)\rangle$

folding with primary pQCD spectrum

⇓

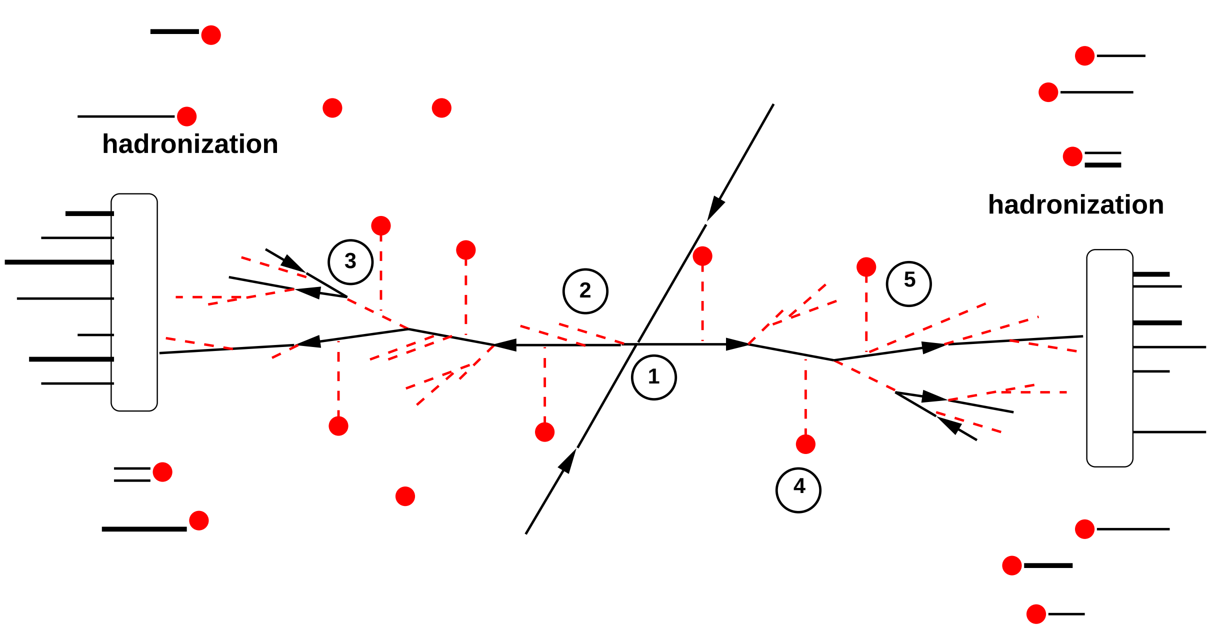
hadron yields

PID cuts, clustering, binning,. . . ⇒ **getting biases right**

⇓

observables

Medium-modified jets in the eye of a theorist



1) hard process 2) vacuum shower 3) medium-induced radiation 4) medium evolution 5) medium correlated with jet by interaction

- series of splittings $a \to bc$ with decreasing t

$$dP_a = \sum_{b,c} \frac{\alpha_s(t)}{2\pi} P_{a\to bc}(z) dt dz \quad \text{with} \quad t = \ln Q^2/\Lambda_{QCD} \quad \text{and} \quad z = E_d/E_p$$

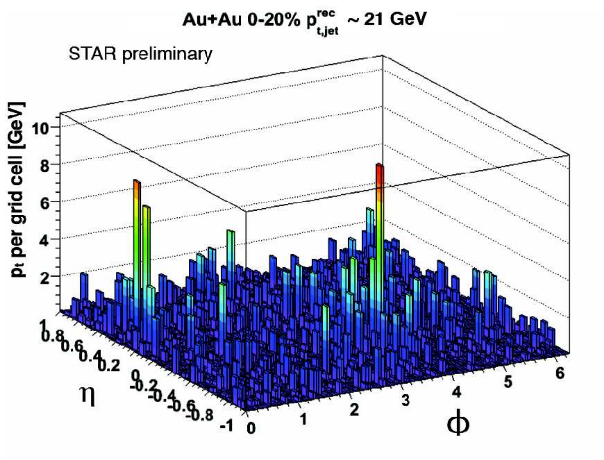
$$P_{q\to qg}(z) = \frac{4}{3}\frac{1+z^2}{1-z} \quad P_{g\to gg}(z) = 3\frac{(1-z(1-z))^2}{z(1-z)} \quad P_{g\to q\overline{q}}(z) = \frac{N_F}{2}(z^2+(1-z)^2)$$

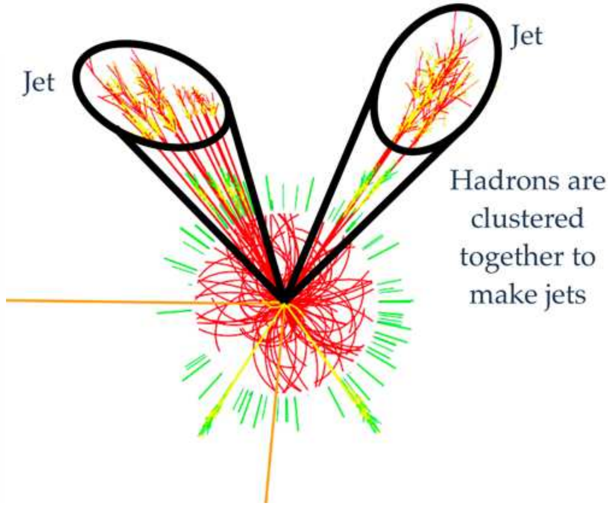
- add medium perturbations, terminate at a soft virtuality scale t_0 or Q_0 and hadronize

$\Rightarrow$ compute the fate of the hard parton *forward* in time to get the final hadron shower

Medium-modified jets in the eye of an experimentalist

• experiment doesn't know about initial partons and the evolution, just about hadrons
⇒ clustering (prescriptions to combine hadrons to 'jets', anti-k_T, SISCone,. . .)





Idea: Undo soft physics, define objects which are comparable to 'partons' of pQCD
⇒ problem: $\Lambda_{QCD} \sim T \sim 300$ MeV — the medium effect is soft physics

Complications: In A-A collisions, the jet is embedded into a background
⇒ small radii, P_T cut, background subtraction, unfolding,. . .

Corollary: Jets in A-A collisions are almost never good proxies for partons!

⇒ conclude from the observed jet *backward* in time what the hard process and the modification might have been

Theory vs. experiment

In other words: Upon hearing the words **100 GeV jet**

Theorist thinks: about a 100 GeV high virtuality parton from a hard process and its subsequent evolution, might even be in terms of an MLLA-type formula where jets appear as analytical relations rather than particles

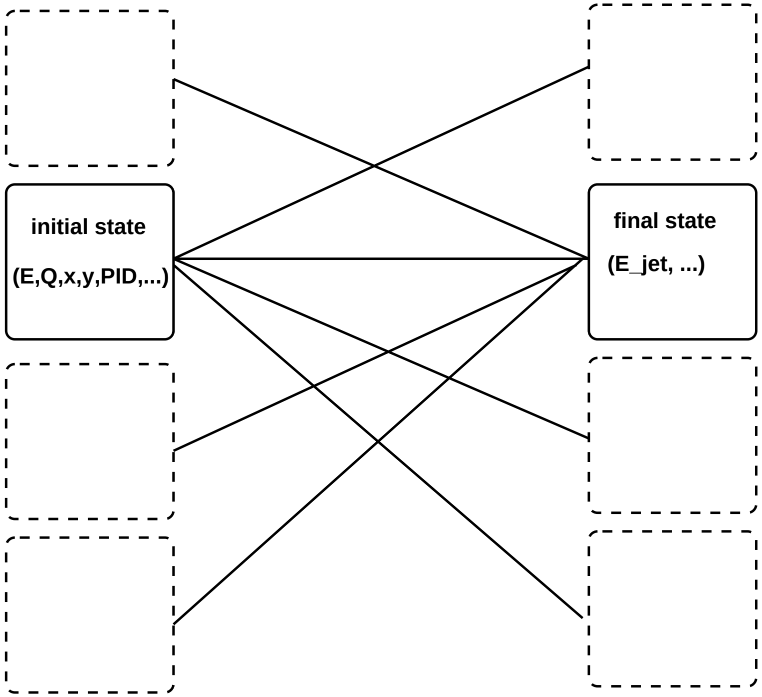
$\rightarrow$ doesn't usually think about background fluctuations, unfolding, out of cone vacuum radiation, PID issues

Experimentalist thinks: what anti-k_T found in my event after background subtraction and correction for any detector-specific effects

$\rightarrow$ doesn't usually think about QCD evolution, parton kinematics, angular ordering and color coherence . . .

Reality might be: The remnants of a 165 GeV gluon fragmentation process, where due to a hard splitting 70 GeV go out of cone as a subjet, 5 GeV are missed by the detector which doesn't see K_0^s and 10 GeV are dissipated into the medium, but due to an upward fluctuation of the background the jet energy still reaches 100 GeV

Does this matter?



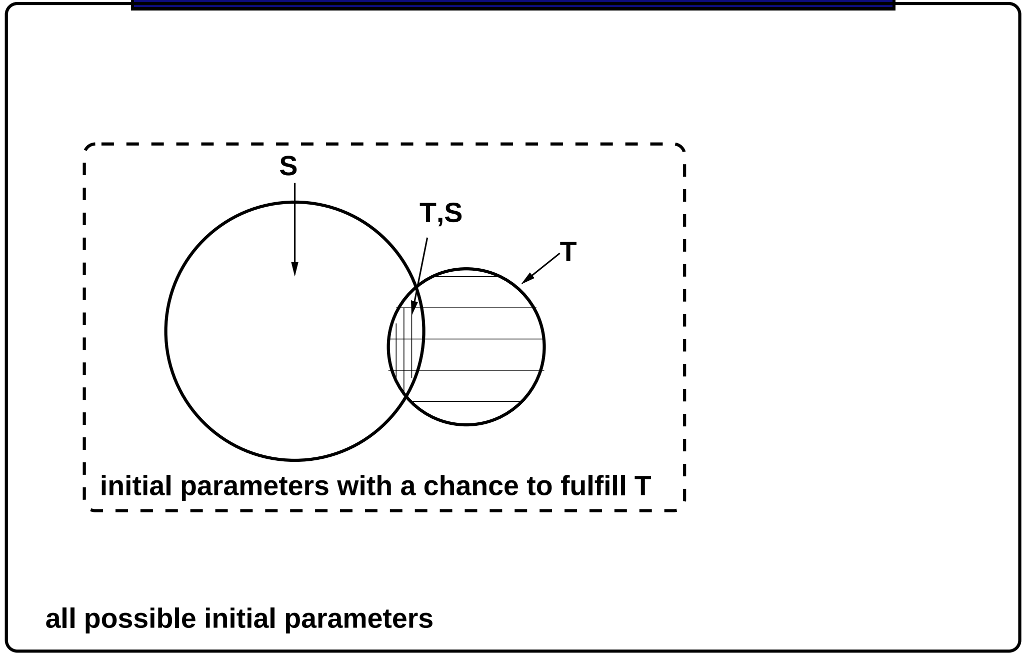
• initial state assumed by the theorist can lead to final states which are not triggered (and remain unobserved)

• experimental final state can come from initial states theory did not consider (background fluctuations, 'fake jets',. . .)

⇒ a correct comparison requires to compute for *all* initial states, taking the *biases* by the experimental observation into account

T. R., Phys. Rev. C **88** (2013) 054902

Biases in a nutshell



• triggered observation of observable $S \leftrightarrow$ subset of all initial states A evolved which
$\rightarrow$ have property S and fulfill trigger T (conditional probability)
(e.g. T: particles cluster to a 100 GeV jet S: particle has momentum between 20 and 25 GeV)

• if T is a small subset of all possible events, this subset is usually not typical
$\rightarrow$ thus $T \cap S$ is different from S, it is *biased* (unless T and S are correlated)
(e.g. yield of 20-25 GeV particles is different if a jet is in the event)

• size(T)/size(A) is the normalized rate at which triggered events occur
$\rightarrow$ related to *disappearance observables* such as $R_{AA} = \text{size(T)}_{med}/\text{size(T)}_{vac}$

Types of biases

In dicussing high P_T reactions in heavy-ion collisions, 4 types of biases are relevant:

• **kinematic bias** — shift in the relation between hadron and parton kinematics
$\rightarrow$ occurs because the medium induces some extra radiation from partons

• **parton type bias** — shift in the mixture of quark to gluon jets
$\rightarrow$ occurs because gluons couple with a factor $C_F = 9/4$ more strongly to the medium

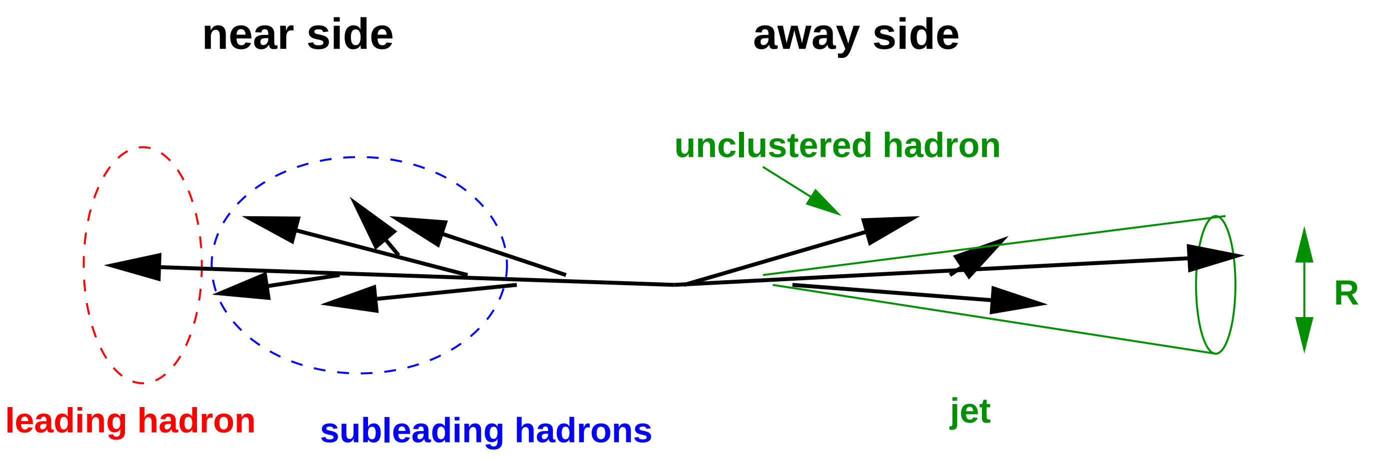
• **geometry bias** — observed hard reactions do not come from all vertices equally
$\rightarrow$ occurs because medium effect grows with medium density and pathlength

• **shower bias** — a trigger condition makes some shower structures unobserved
$\rightarrow$ occurs because of a direct selection effect

In discussing almost any high P_T observable, we need to make sure we understand these biases and and account for their effect in interpretaing the data!

T. R., Phys. Rev. C **88** (2013) 054902

High P_T observables



- basic structure: back to back hard QCD event
- trigger object: leading hadron, γ, Z^0, clustered jet

$\longrightarrow$ yield of QCD objects reduced in medium, R_{AA} observables

- trigger object defines near and away side

$\longrightarrow$ correlation observables, near and away side I_{AA}, correlation angular width

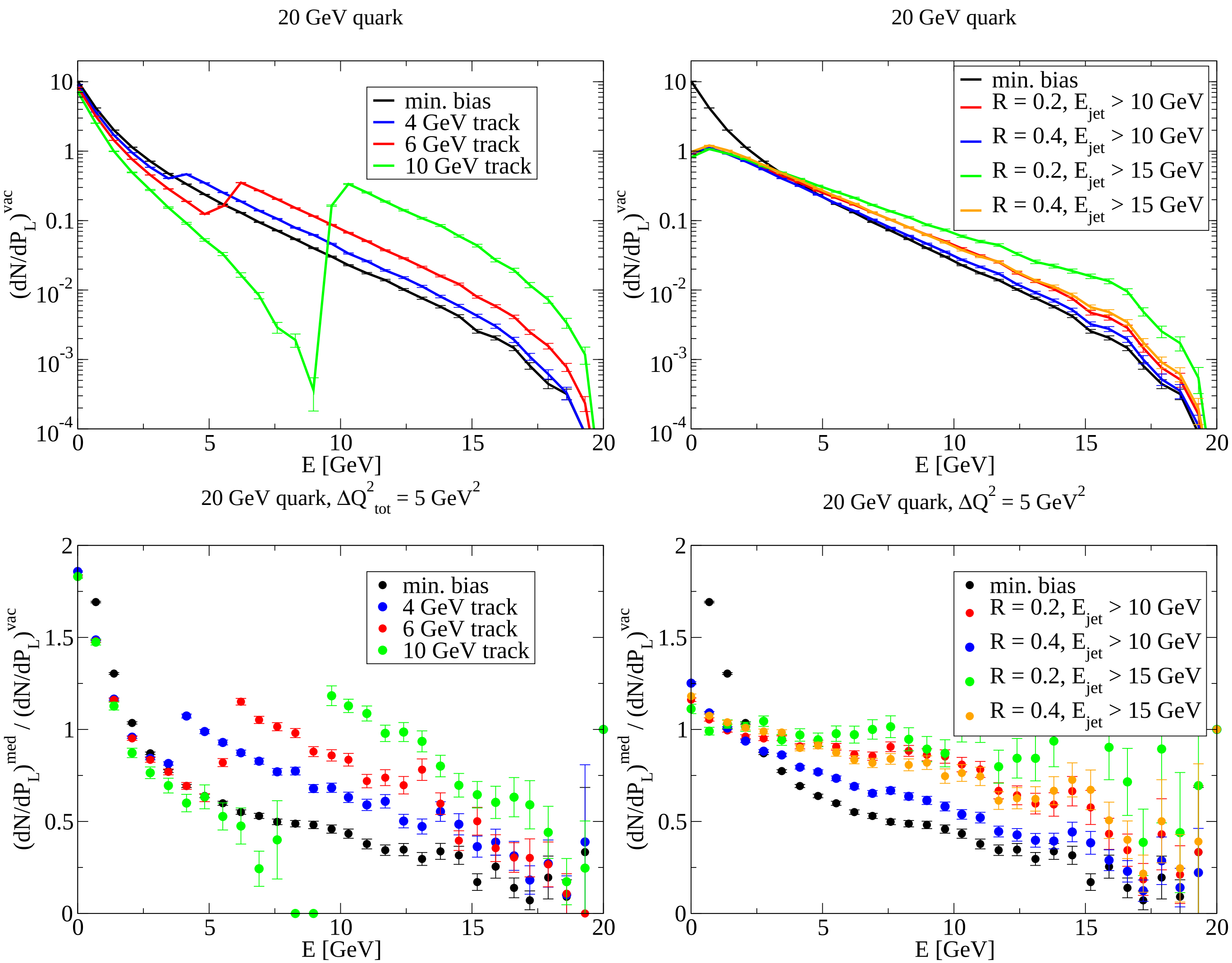
- hadron analysis inside a found jet

$\longrightarrow$ jet observables, jet shape and fragmentation function

- can all be done dependent on orientation with v_n event plane

Example: the shower bias

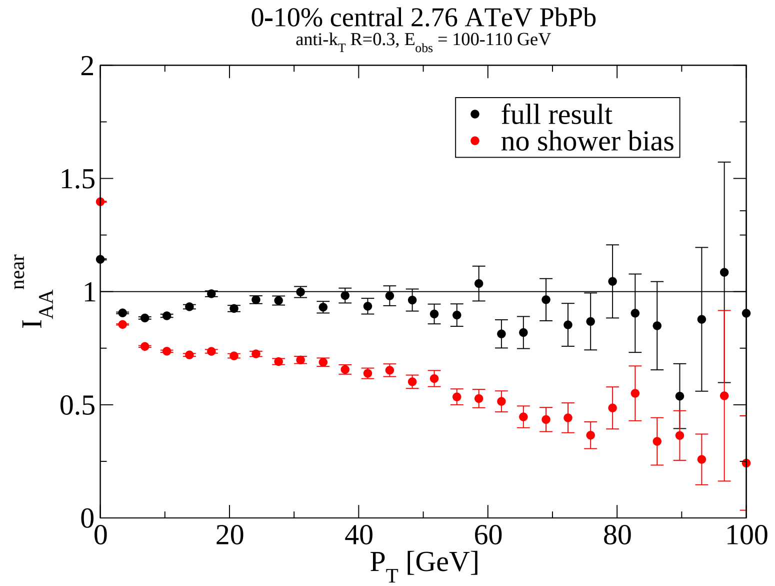
- a trigger condition biases the shower in which the trigger is created



- suppresses medium-modifications — highly modified showers don't trigger

Example: the shower bias

- longitudinal momentum distributions of hadrons in 100-110 GeV jets

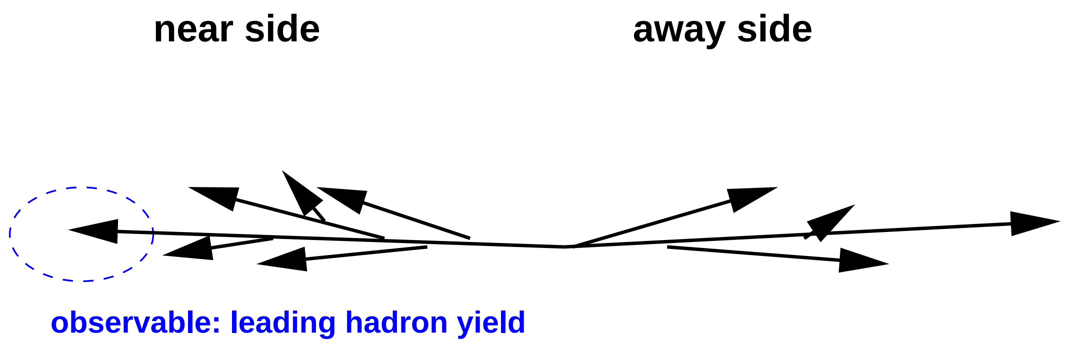


- without shower bias: strong depletion at high z, enhancement below 3 GeV
  (real kinematics, but assuming all showers were analyzed, not only triggered ones)
- with shower bias, completely different picture

$\Rightarrow$ the bias alters the apparent message of the observation drastically

Corollary: If a calculation does not simulate experimental trigger conditions, don't take it seriously with data.

Leading hadron R_{AA}



• only look at the leading hadron yield, discard rest of the event
→ medium over vacuum yield gives nuclear suppression factor R_{AA}

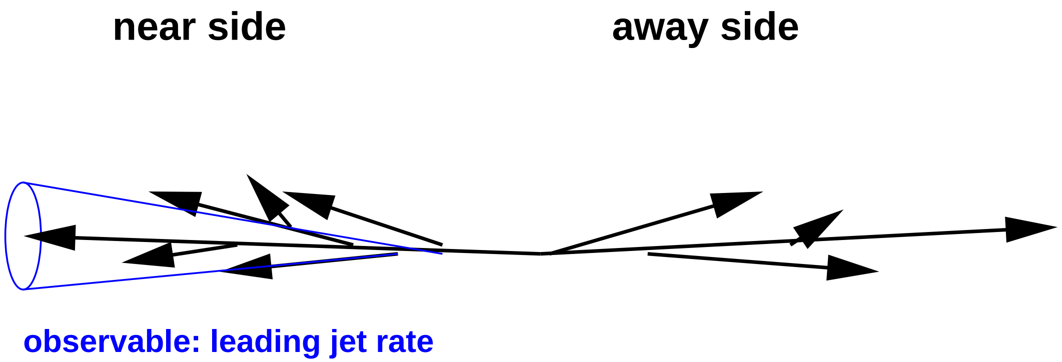
• theorists often use **energy loss approximation** for this:

$$D_{i\to h}(z, E, Q_0^2|T_i(\zeta)) \approx P(\Delta E, E|T_i(\zeta)) \otimes D_{i\to h}(z, Q_0^2)$$

∗ take an on-shell parton in the medium, compute medium-induced radiation
→ (it won't have vacuum radiation since it's on-shell and has no phase space)
∗ subtract the energy it radiated before exiting the medium
∗ then put it off-shell to the hard scale and let it evolve in vacuum

Remember: This is an approximation **only** good for leading hadron observables.
→ limited information and constraints

Leading jet R_{AA}



- cluster the near side shower, discard the rest

$\longrightarrow$ if you analyze the jet structure, it is shower-biased

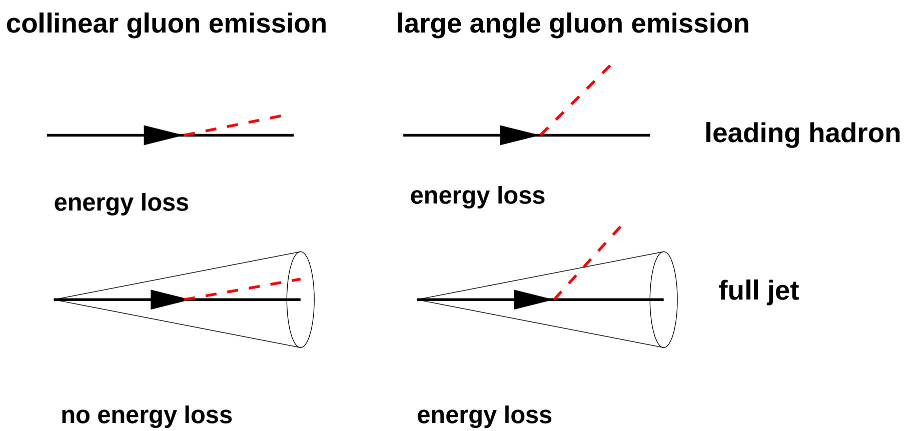
$\longrightarrow$ if you do not, clustering suppresses physics at scale T

- can not be done using energy loss approximation

Remember: Even finding and defining jets in a HI environment is complicated!

$\longrightarrow$ if someone suggests 'jet = parton', don't take this seriously

- jets are harder to quench:

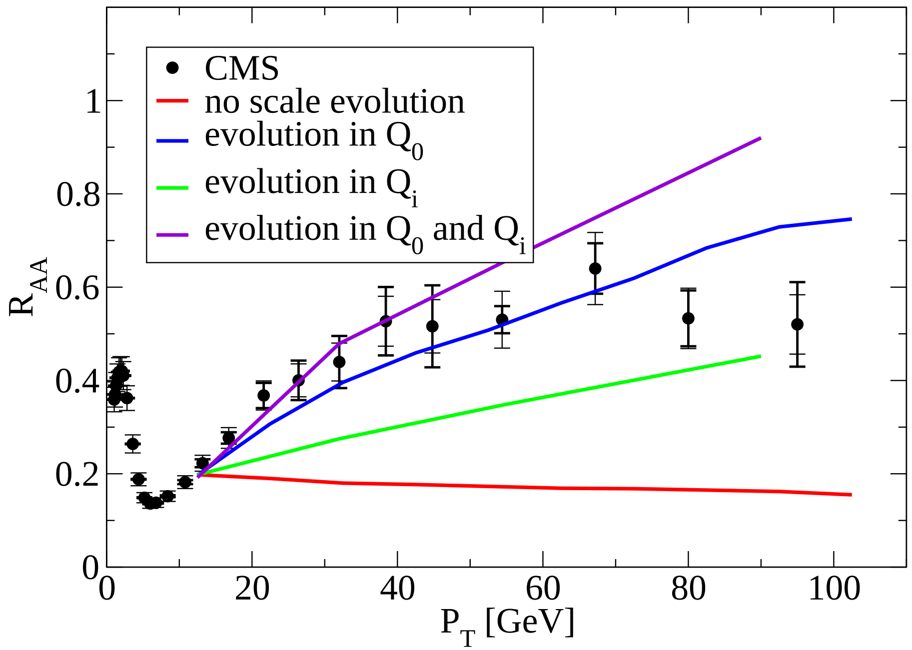


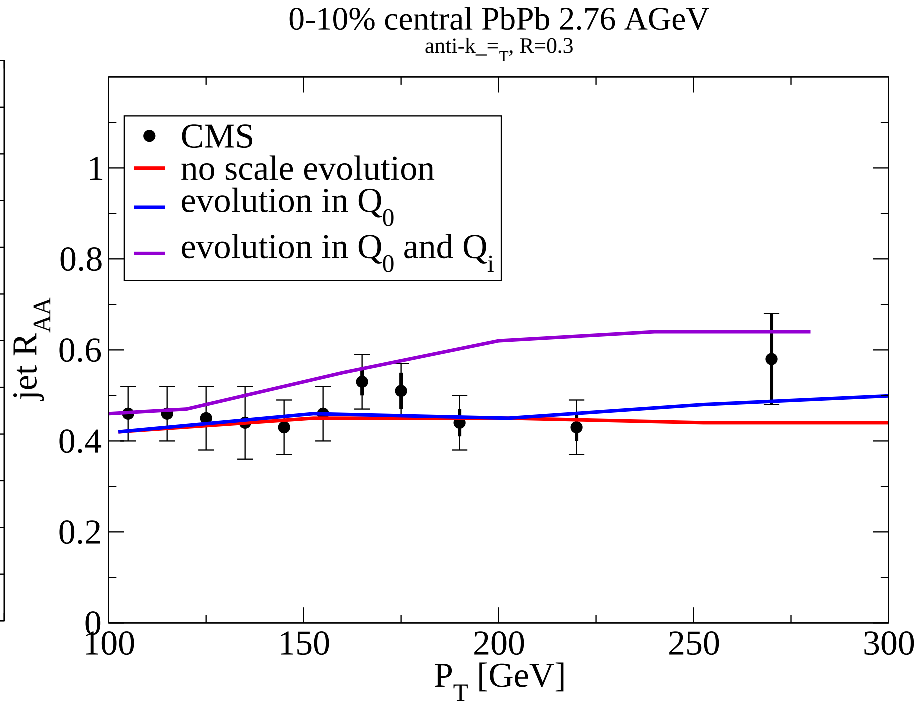
Hadron vs. Jet R_{AA}

- generally: R_{AA} shows a yield suppression, explained in terms of energy loss

$\longrightarrow$ non-trivial P_T evolution, constraints for models

- compare the effect of QCD scale evolution and out of medium evolution





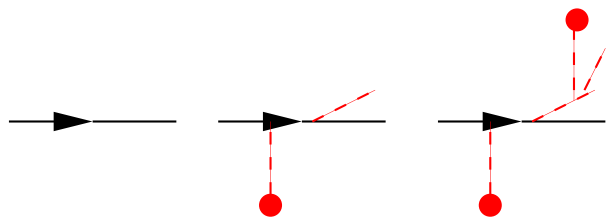
$\Rightarrow$ clustering removes the sensitivity to medium physics and scale evolution (as it should)

TR, Phys. Rev. C **88** (2013) 014905

How to suppress jets

• If collinear radiation is clustered back, how are jets quenched?

→ medium alters hard parton kinematics slightly
→ medium-induced soft gluon emission
→ medium alters soft gluon kinematics a lot, soft gluon thermalizes



Universal mechanism: gluons with $p_T \sim T$ are effectively out of cone

• energy flow to large angles $R \gg 0.6$, hydro degrees of freedom relevant
→ not picked up by jet finders

• probes medium physics, not jet physics
→ largely **independent** of specific shower-medium interaction assumptions

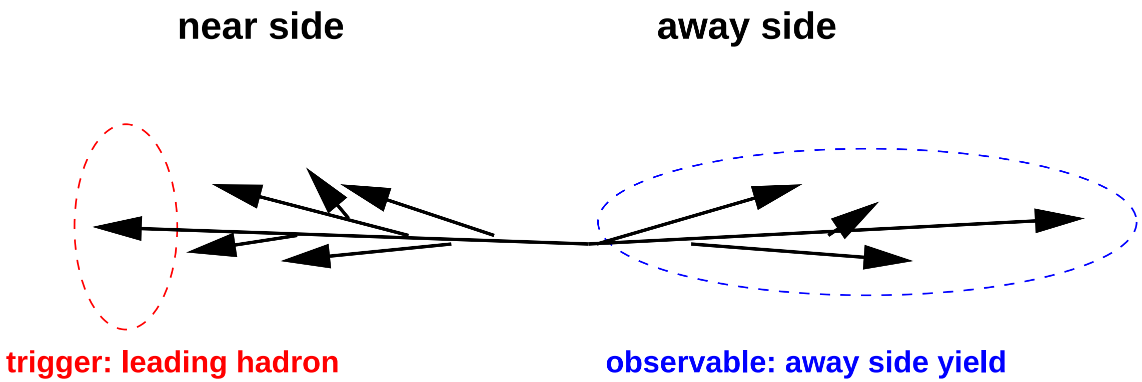
• not an issue for gluons with $p_T \sim$ few T
→ more difficult to change their kinematics

T. R., Phys. Rev. C **80** (2009) 044904, J. Casalderrey-Solana *et al.*, J. Phys. G G **38** (2011) 035006

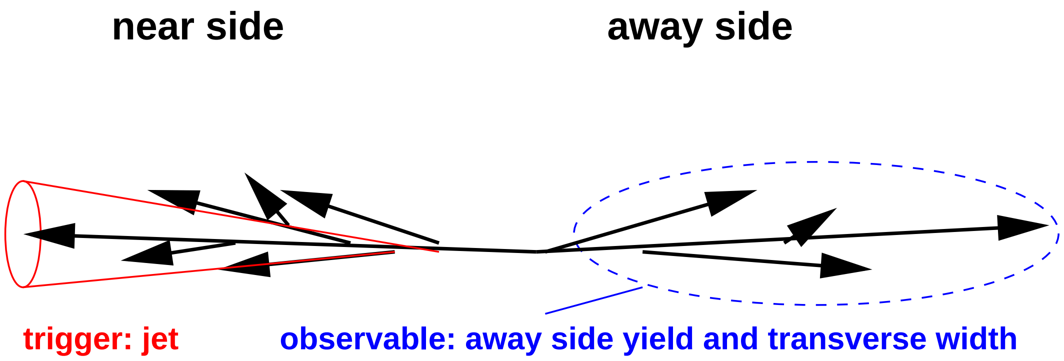
Correlation observables

Idea: Analyze the away side shower without shower bias

• h-h correlations: significant kinematic and parton type bias, low statistics



• jet-h: reduced bias, higher statistics

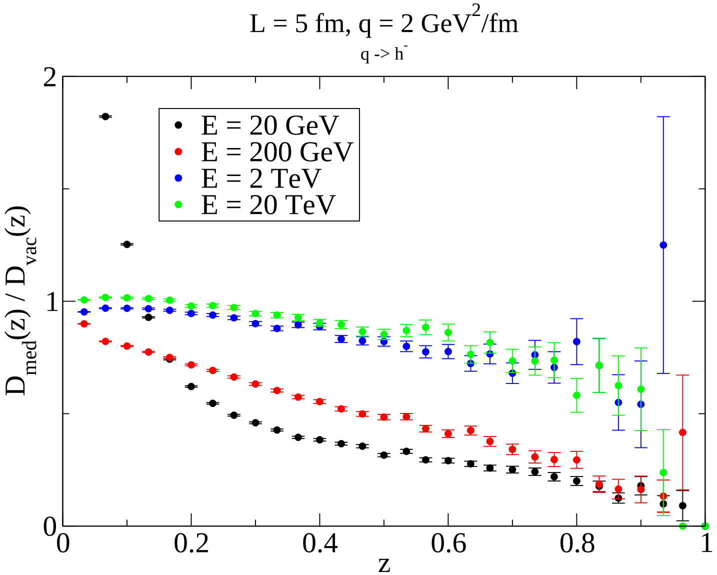


Observation: Same physics, different bias.

Bias as a filter

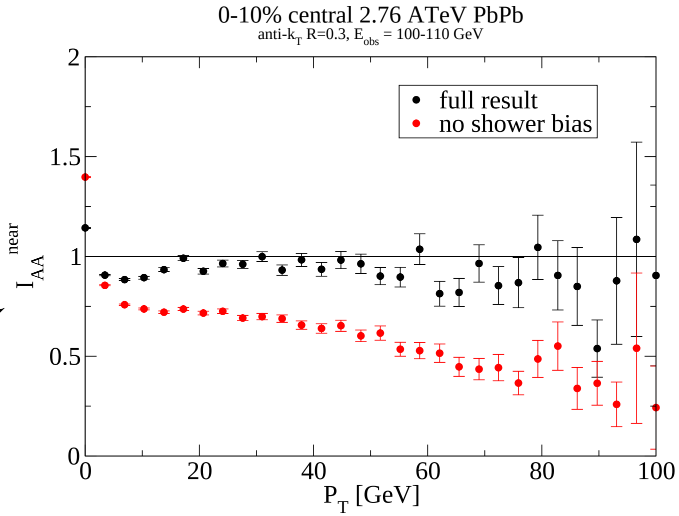
unfiltered distribution

(theoretical object)

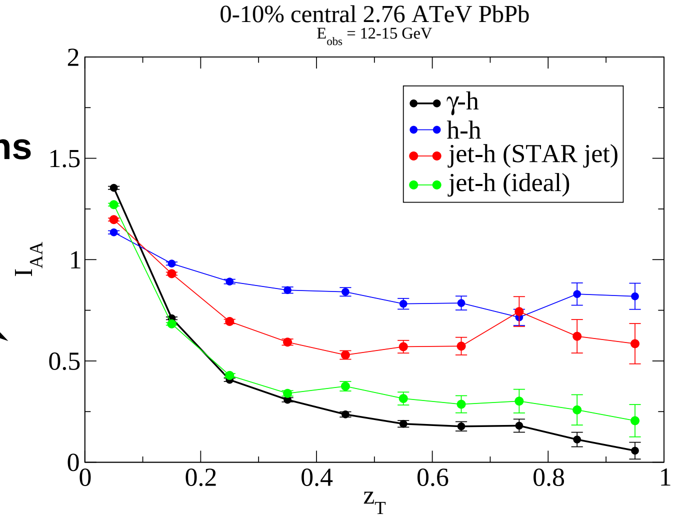


seen through

clustering



jet correlations



- different averaging process — filter set for different physics
- differently 'blurred' filter — γ-h is a cleaner trigger than h-h

A summary of some results

We know how medium-modified jets look like.

• they've been observed through a number of different filters with consistent results
$\longrightarrow$ above ~ 3 GeV, structure resembles vacuum jets, but distributions are depleted
$\longrightarrow$ below ~ 3 GeV, broad and soft pedestal by hadronizing induced radiation
$\longrightarrow$ very broad structure from energy dissipated into hydro medium
• this structure can be measured and plotted in many different ways
$\longrightarrow$ efforts should perhaps move towards detailed quantitative understanding

We know what does not work.

• AdS/CFT (for realistic virtuality evolution) misses $\sqrt{s}$ and P_T dependence of R_{AA}
$\longrightarrow$ jet evolution is not strong coupling dynamics (there is a hard scale Q)

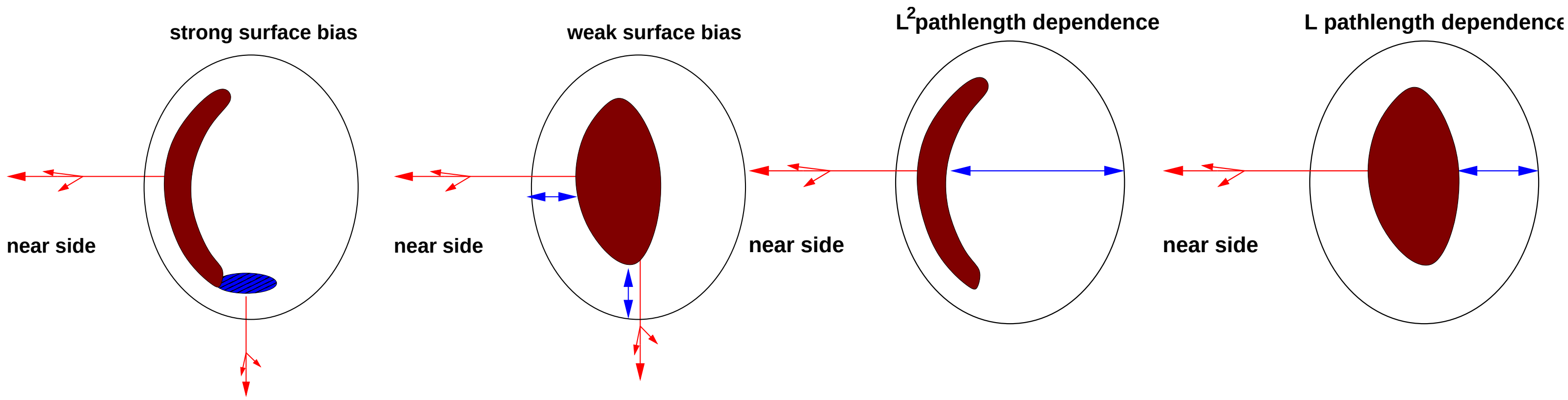
• fractional energy loss misses approx. P_T independent modification scale of 3 GeV
$\longrightarrow$ models need explicit kinematics, not asymptotic kinematics

• large fraction of elastic energy loss fails correlations by huge margin
$\longrightarrow$ the medium DOF are not weakly interacting quasiparticles

Tomography

Proposal: distinguish **key** observables from **tomographic** observables
→ key: probing parton-medium interaction, tomographic: probing medium evolution

Example: I_{AA} vs. $R_{AA}(\phi)$



- both are sensitive to the pathlength dependence of parton-medium interaction

→ but $R_{AA}(\phi)$ changes $\sim 100\%$ for different fluid dynamics, $I_{AA} < 20\%$

⇒ Use I_{AA} to constrain pahtlength dependence, then R_{AA} to constrain medium

Summary

Take-home messages from this talk:

• the medium acts as a perturbation to the vacuum virtuality evolution of a jet
→ all else (energy loss, separate medium radiation . . .) is an approximation

• defining jets in an A-A environment is **not** simple
→ leading partons, analytic expressions etc. are not good proxies for jets in A-A

• theoretical jets are evolved partons, experimental jets result from a jet-finder
→ this difference and the resulting biases need to be taken very seriously

• many observables probe the **same physics** through a **different filter**
→ (and to make things interesting collaborations also plot different quantities)
→ this is needlessly confusing, it's not nearly as bad as it looks on first glance

• the key observable phase is basically over, jet-medium interaction is constrained
→ though not all models are tested against a large enough data set

Thank you and enjoy QM 2014!