Jet quenching phenomenology

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Outline

What is jet quenching phenomenology. . .

. . . as opposed to jet quenching theory?

My attempt at a definition

In phenomenology, people are trying to

- quantitatively describe data,
- arrive at a comprehensive physical picture encompassing all aspects.

What is jet quenching phenomenology...

...as opposed to jet quenching theory?

My attempt at a definition

In phenomenology, people are trying to

- quantitatively describe data,
- arrive at a comprehensive physical picture encompassing all aspects.

Consequences of having to deal with all relevant aspects

- often cannot treat effects with same theoretical rigour as when concentrating on one aspect
- have to rely more on (phenomenological) models
- suitable tools: Monte Carlo event generators

Thoughts on jet quenching models

We have a variety of – partly very different – models.

AMPT, BAMPS, HybridModel, HYDJET++, JEWEL, LBT, MARTINI, MATTER, Q-HERWIG, Q-PYTHIA, ...

Why I think this is a good thing:

1. it is always good to have several independent approaches

   even for a well-defined task like PDF fitting

   - even formally sub-leading choices can be numerically relevant
   - independent checks help avoid bugs and problems
2. we are dealing with complex multi-scale problem
   $\rightarrow$ have to test ideas, approximations and hypotheses
3. models are developed for different purposes, for example
   - a minimal model to test a well-defined physical picture
   - a flexible multi-component model to describe large variety of data

   plus everything in between and others

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Thoughts on jet quenching models

- different approaches are needed

  for falsifying theoretical ideas,
  testing approximations,
  modeling of data for unfolding etc.,
  ...

- when comparing models, keep in mind that they may be very different
- as a user one has to
  - keep in mind models are designed to do different things
  - choose one fit for the purpose
  - interpret results accordingly
- standards like Rivet can save a lot of our time

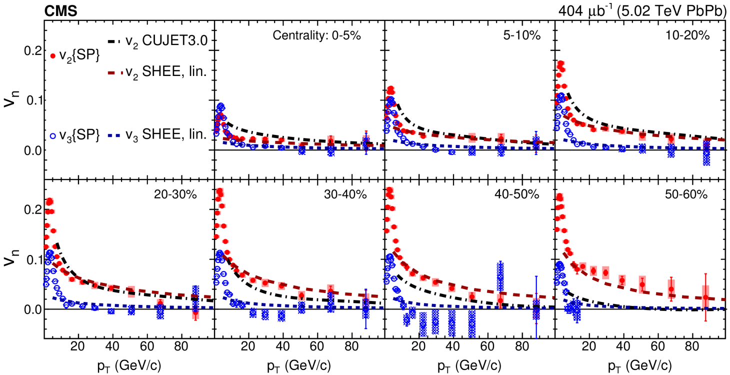
What we want to know

A subset of the questions we are trying to answer:

- What are the most relevant mechanisms leading to jet energy loss?
- Are the jet and the medium strongly coupled?
- Does the jet resolve quasi-particles in the medium?
- How does the medium react to the energy and momentum deposition?
- How does this in turn affect the jet?

Energy loss mechanism

Idea: distinguish radiative and collisional e-loss via path length dependence



CMS, Phys. Lett. B **776** (2018) 195 [arXiv:1702.00630]

Betz at al, Phys. Rev. C **95** (2017) no.4, 044901 [arXiv:1609.05171]

Energy loss mechanism – problem solved?

Well, not really...

- energy loss model a simple parameterisation
- coherent radiative energy no $\Delta E \propto L^2$ under realistic conditions

Zapp, Wiedemann, Eur. Phys. J. C 72 (2012) 2028, [arXiv:1202.1192]

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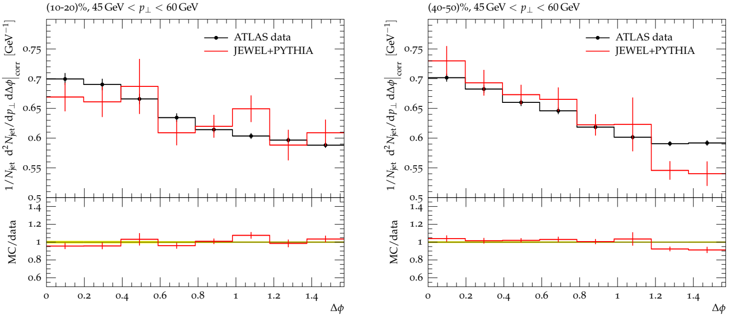
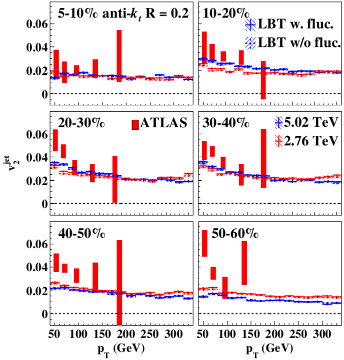
So what do dynamical energy loss models have to say?



ATLAS, Phys. Rev. Lett. 111 (2013) 152301
Zapp, Phys. Lett. B 735 (2014) 157

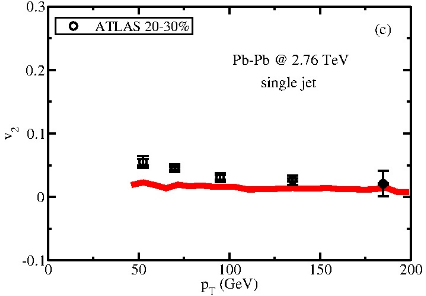
Energy loss mechanism – problem solved?

LBT



He, PoS HardProbes 2018 (2019) 100

MATTER



Cao, Majumder, arXiv:1712.10055 [nucl-th]

- radiative & collisional energy loss
- only radiative energy loss

Energy loss mechanism – why is this so difficult?

Observations

- jet evolution gets convoluted with space-time dependent density
- background fluctuations are large and have to be taken into account

  dilutes path length dependence

  Betz at al, Phys. Rev. C 95 (2017) no.4, 044901 [arXiv:1609.05171]

- energy loss fluctuations are also important — dilutes path length dependence

  Milhano, Zapp, Eur. Phys. J. C 76 (2016) no.5, 288
  Escobedo, Iancu, JHEP 1605 (2016) 008 & JHEP 1612 (2016) 104

- "observation bias": energy loss + jet $p_\perp$ cut favour narrow jets

  narrow jets have smaller-than-average energy loss

  Milhano, Zapp, Eur. Phys. J. C 76 (2016) no.5, 288
  Rajagopal, Sadofyev, van der Schee, Phys. Rev. Lett. 116 (2016) no.21, 211603 [arXiv:1602.04187]
  Casalderrey-Solana, Gulhan, Milhano, Pablos, Rajagopal, JHEP 1703 (2017) 135 [arXiv:1609.05842]

- surface bias — observed jets may have smaller-than-average path length

  amount of surface bias varies widely from model to model

Energy loss mechanism – why is this so difficult?

Conclusions

- requires detailed and dynamical modeling
- so far we didn't learn what we wanted to know. . .
- . . . but we did learn other interesting things

Jet-medium interactions: weak or strong coupling?

- Are the jet and the medium strongly coupled?
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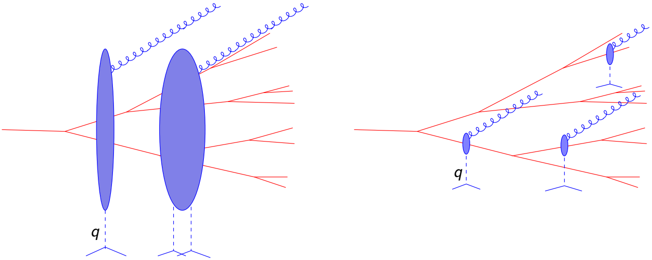
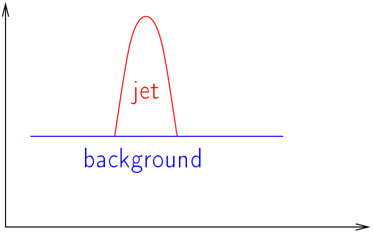


- momentum transfer q from medium defines resolution
- jets resolve medium & medium resolves jets
  - low q: jet sub-structure not resolved $\rightarrow$ unmodified jet core
  - high q: jet structure resolved $\rightarrow$ can modify jet core
- jet sub-structure observables should be able to distinguish them

Medium response



- ideal situation: flat background – can be subtracted

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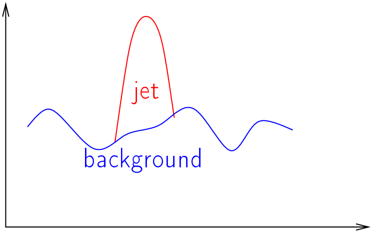

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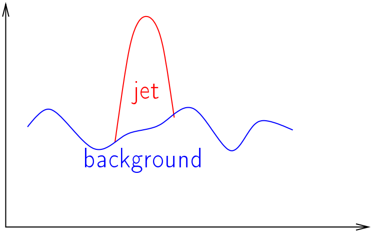

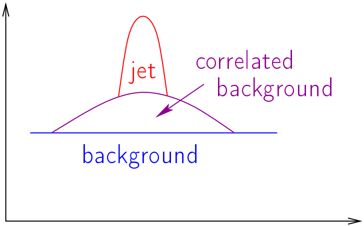

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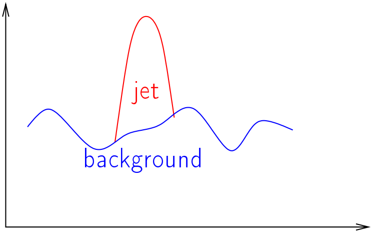

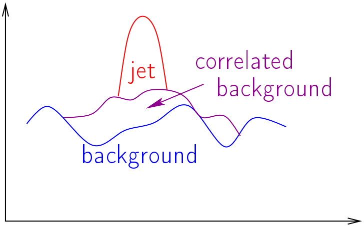

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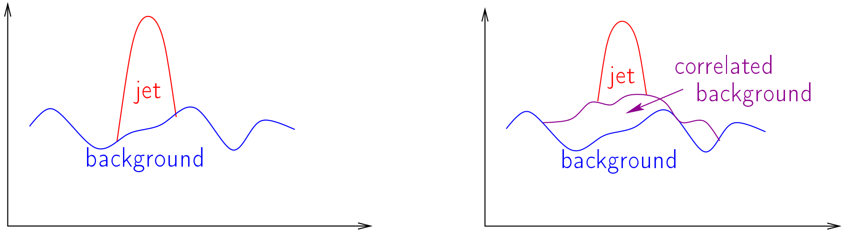

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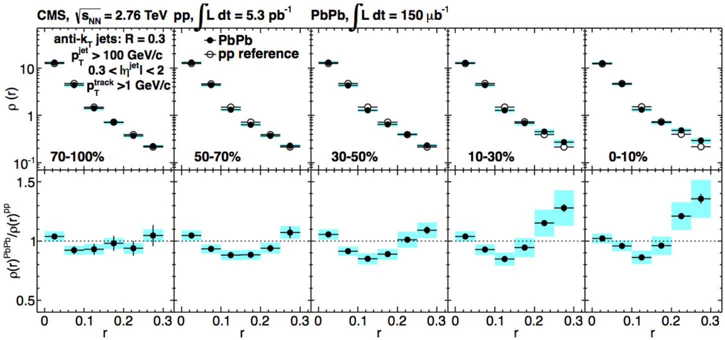
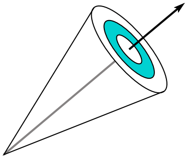
- finally: also fluctuations in correlated part of background matter
- affects reconstructed jets, particularly jet sub-structure

Intra-jet energy distribution: Jet profile

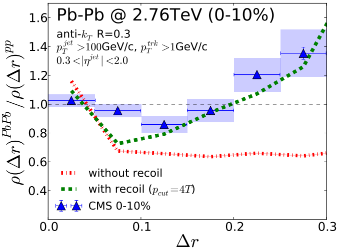




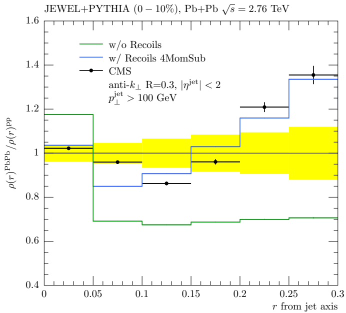
CMS, Phys. Lett. B 730 (2014) 243

- suppression of activity at intermediate r
- increase near the edge of the jet
- is this medium response?

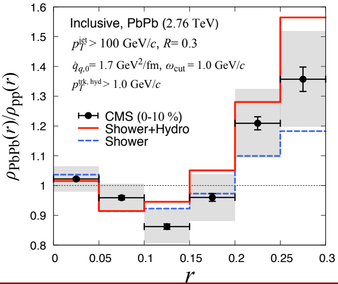
Jet profile: results



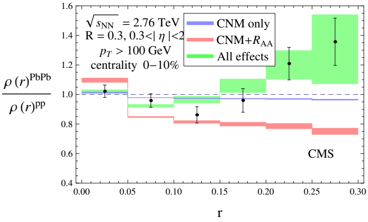
Park, Jeon, Gale, arXiv:1807.06550



Kunnawalkam Elayavalli, Zapp, JHEP 1707 (2017) 141



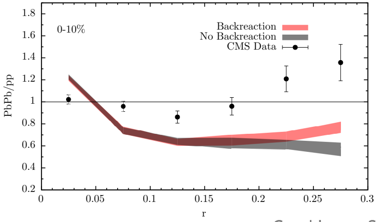
Tachibana, Chang, Qin, Phys. Rev. C 95 (2017) no.4, 044909



Chien, Vitev, JHEP 1605 (2016) 023

Jet profile: conclusion

One more result

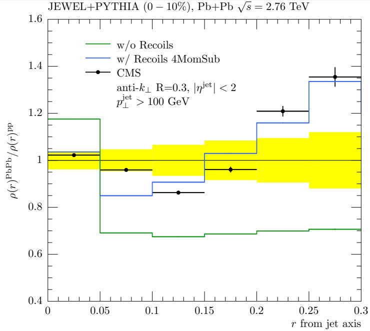


Casalderrey-Solana *et al*, JHEP 1703 (2017) 135

A sobering conclusion

- looked like a promising observable to see medium response
- models don't agree
- will require further work

Consistency of jet mass and profile?



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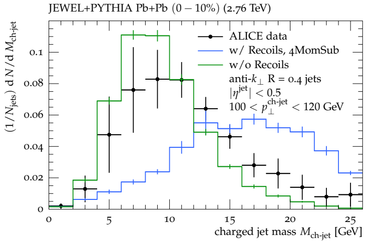

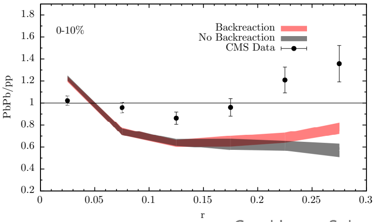

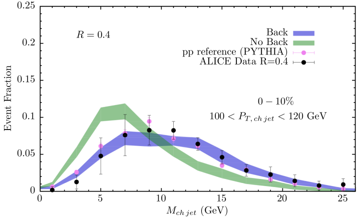

Casalderrey-Solana *et al*, JHEP 1703 (2017) 135, talk by D. Pablos at Hard Probes 2018

This is intriguing...

- HybridModel and JEWEL are very different models
  - HybridModel: AdS/CFT energy loss
  - JEWEL: pQCD based re-scattering
- overall performance very similar
- orthogonal assumptions about recoil particles/energy:
  - HybridModel: fully thermalised
  - JEWEL: free streaming recoils
- can this discrepancy teach us something about medium response?

Warning!

Comparisons to ALICE's jet mass should be taken with a grain of salt

- jet mass receives large non-perturbative corrections

  not the most solid part of the model

- hadronisation not retuned with JEWEL parton shower

  usually fine, as JEWEL parton shower similar to PYTHIA's

- ALICE measures charged jet mass – cannot be calculated in JEWEL

  requires ad-hoc rescaling

- ALICE's area based subtraction for jet mass cannot be paralleled in JEWEL

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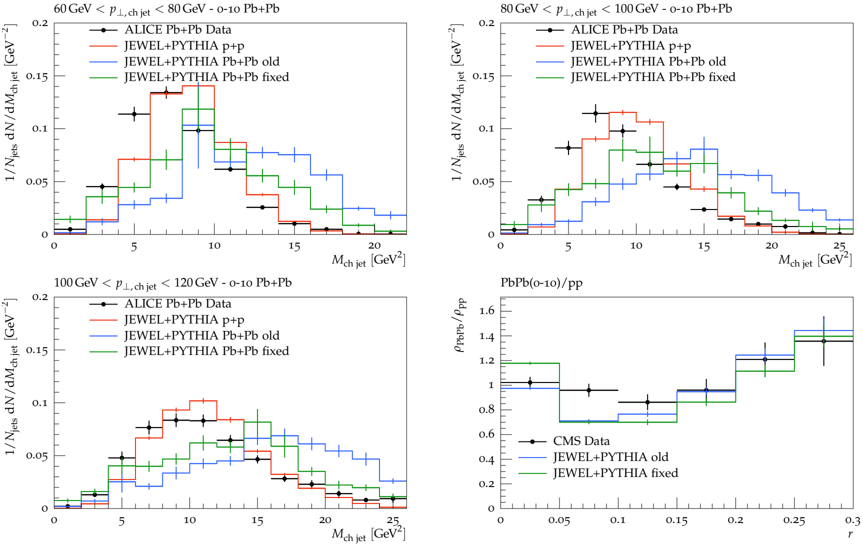
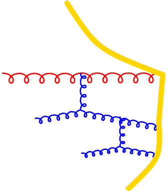
Fixing a problem in subtraction for JEWEL helps



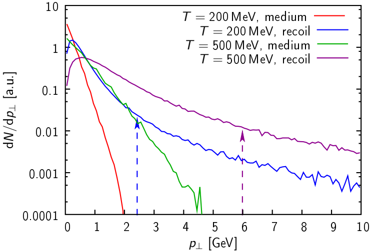
Re-scattering of recoils in JEWEL



- new option: allow for re-scattering of recoils
- can afford only re-scattering of hard recoils

internal event record too small

- preliminary results for recoils with $p > 4 \times 3T$



Zapp, Ingelman, Rathsman, Stachel and Wiedemann, Eur. Phys. J. C **60** (2009) 617

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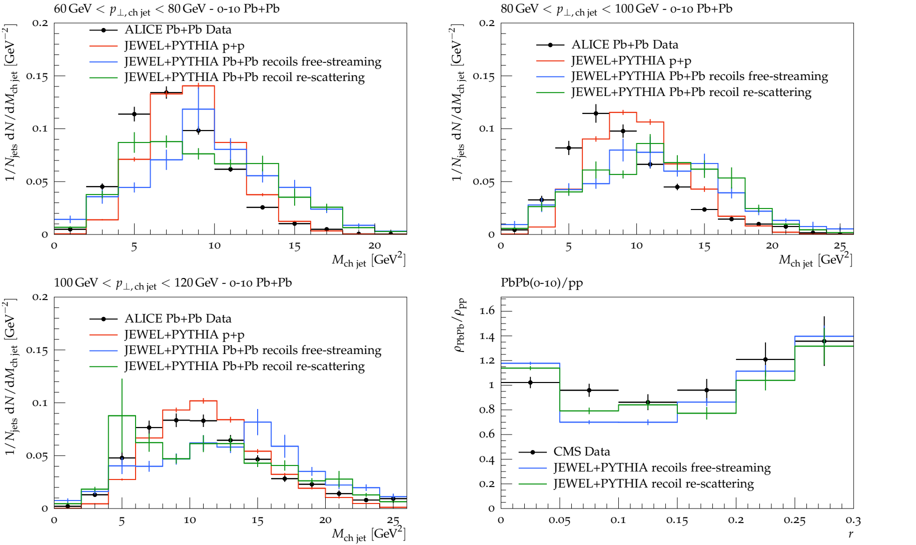

Summary

- phenomenology relies on models
- tries to construct a coherent model of jet-medium interactions
- what we haven't learned so far:
  - how much of the energy loss is radiative and collisional?
  - are jets and medium weakly or strongly coupled?
  - is the jet profile modification due to medium response?
  - what can jet mass and jet profile teach us about medium response?
- what we have learned instead:
  - fluctuations matter
    - background fluctuations
    - energy loss fluctuations
    - fluctuations in hard (vacuum-like) fragmentation pattern

    $\rightarrow$ "observation bias"
  - theory - data comparisons have to be apples-to-apples
- we are close to constraining medium response with jet sub-structure

. . . my humble opinion. . .