JEWEL – past, present & future

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COST Workshop on Interplay of hard and soft QCD probes for collectivity in heavy-ion collisions
Lund 25. 02.–01. 03. 2019

Outline

1. The past
2. The present
3. The future

JEWEL: Basic idea and assumptions

Basic idea

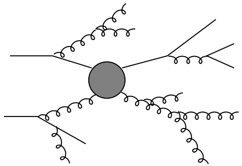
- complexity of problem asks for Monte Carlo event generator
- consistent dynamical model of jet evolution in medium
- anchored in analytical understanding of pQCD

Assumptions

1. medium as seen by jet: collection of quasi-free partons
2. use infra-red continued perturbation theory to describe all jet-medium interactions
3. formation times govern the interplay of different sources of radiation
4. use results from eikonal limit to include LPM-effect

Zapp, Krauss & Wiedemann, JHEP 1303 (2013) 080

JEWEL in a nutshell



- jet production in initial N+N collisions: ME+PS

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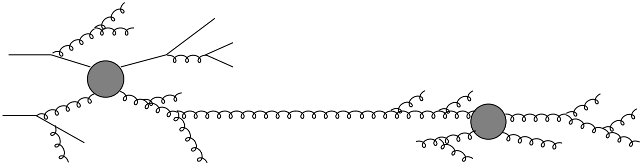

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- re-scattering: ME+PS
  - generates elastic & inelastic processes
  - with leading log correct relative rates
  - general kinematics

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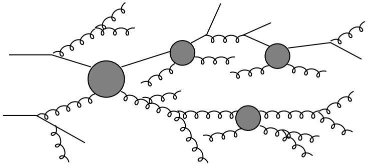

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  - all emissions (vacuum & medium induced) treated equally
  - hard structures remain unperturbed

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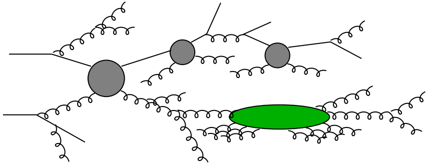

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- emission with shortest formation time is realised
  - all emissions (vacuum & medium induced) treated equally
  - hard structures remain unperturbed
- LPM interference

Zapp, Stachel, Wiedemann, JHEP **1107** (2011) 118

  - also governed by formation times
  - without kinematic restrictions

Outline

1 The past

2 The present

3 The future

Jet shape and jet sub-structure observables

- observables built from jet constituents

  particles, partons, calorimeter cells, ...
- characterise distribution of momentum & find structures inside jet

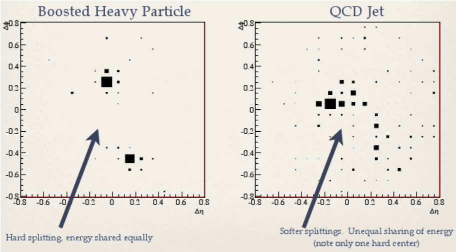
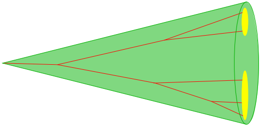


image from David Krohn

- various grooming techniques studied in p+p to separate hard structure from soft contaminations filtering, trimming, pruning, ...
- shapes/sub-structure of quenched jets sensitive to medium's reaction to energy & momentum deposited by jets

Soft Drop: measuring the splitting function?



Dasgupta, Fregoso, Marzani, Salam, JHEP 1309 (2013) 029
Larkoski, Marzani, Soyez, Thaler, JHEP 1405 (2014) 146

- Soft Drop procedure: identifies hardest 2-prong structure in a jet
- groomed shared momentum fraction $z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}}$
- calculation: $p(z_g) = \frac{P(z_g) + P(1 - z_g)}{\int_{z_{\rm cut}}^{1/2} \mathrm{d}z\, P(z) + P(1-z)} \Theta(z_g - z_{\rm cut})$

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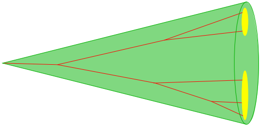

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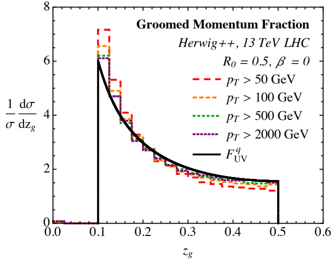

Larkoski, Marzani, Thaler, Phys. Rev. D 91 (2015) no.11, 111501

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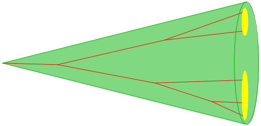

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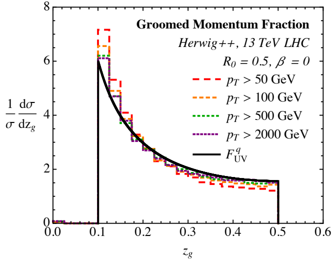
- Can this be used to measure the effective splitting function in medium?



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For experts: The Soft Drop algorithm

Soft Drop/modified Mass Drop Tagger algorithm:

1. cluster jet with anti-$k_\perp$
2. re-cluster with Cambridge/Aachen (based on angles)
3. undo last clustering step and compute z_g and ΔR_{12}
4. if $z_g > z_{\mathrm{cut}}(\Delta R_{12}/R)^\beta$ stop
   else reject softer prong and go back to 3

Larkoski, Marzani, Soyez, Thaler, JHEP **1405** (2014) 146

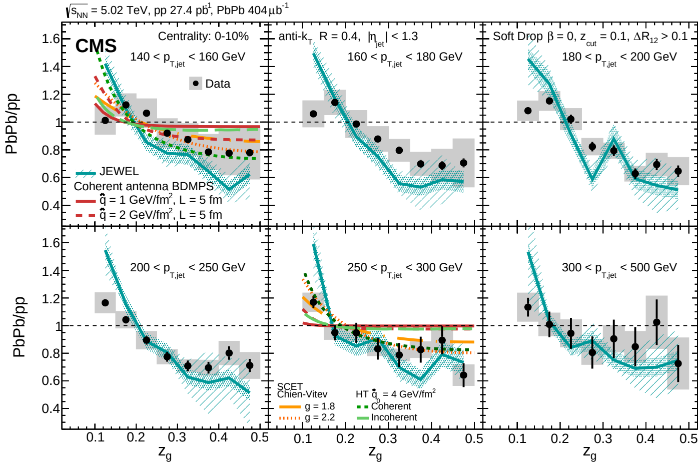
The CMS measurement:

- $z_{\mathrm{cut}} = 0.1$, $\beta = 0$
- $R = 0.4$
- CMS analysis requires also $\Delta R_{12} > 0.1$

removes large fraction of jet sample

CMS-HIN-16-006

z_g distribution in A+A



CMS, Phys. Rev. Lett. 120 (2018) no.14, 142302

Medium's response to energy deposited by jets

- common assumption: immediate thermalisation
- JEWEL: three options

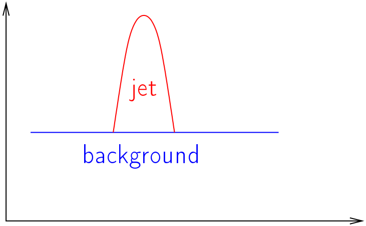
1. ignore recoiling thermal partons
2. extract source term for hydrodynamic description of medium

Flörchinger, Zapp, EPJC **74** (2014) no. 12, 3189

3. include recoiling partons
   - recoiling partons becomes colour neighbour of hard parton
   - recoiling partons do not re-interact other limiting case
   - have so subtract thermal component of recoil momentum

Kunnawalkam Elayavalli, Zapp, JHEP **1707** (2017) 141

Medium response: practical considerations



- ideal situation: flat background – can be subtracted

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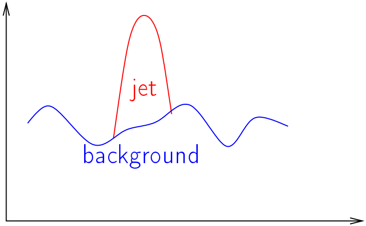

- ideal situation: flat background – can be subtracted
- more realistic: fluctuating background – can be subtracted on average, have to unfold

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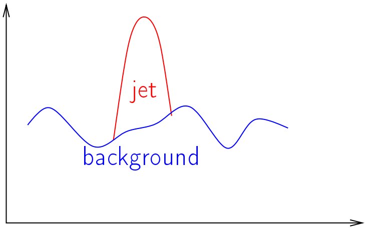

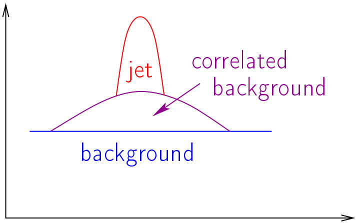

- ideal situation: flat background – can be subtracted
- more realistic: fluctuating background – can be subtracted on average, have to unfold
- adding medium response: correlated background
  - part of the background is correlated with jet $\rightarrow$ medium response
  - activity above uncorrelated background
  - correlated background cannot and should not be subtracted

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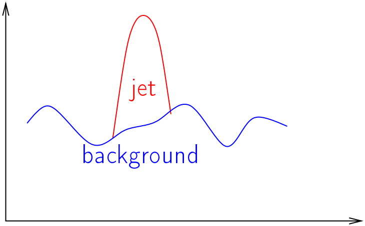

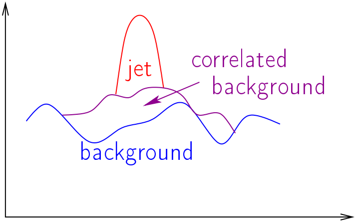

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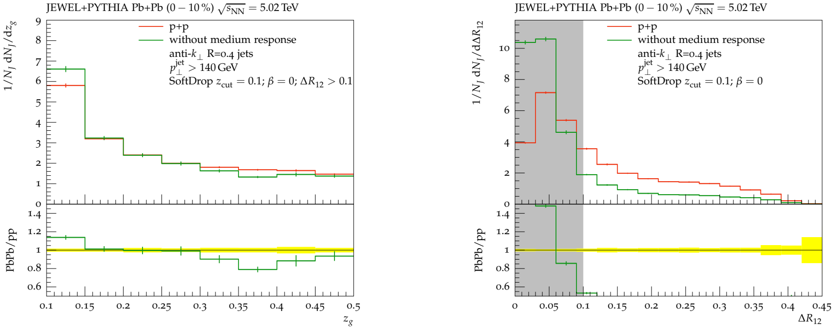
- more realistic: fluctuating background – can be subtracted on average, have to unfold
- adding medium response: correlated background
  - part of the background is correlated with jet → medium response
  - activity above uncorrelated background
  - correlated background cannot and should not be subtracted
- finally: also fluctuations in correlated part of background matter

z_g distribution in A+A

Milhano, Wiedemann, Zapp, Phys. Lett. B 779 (2018) 409



- w/o medium response: jets get narrower

→ broad jets more effected by medium → more likely to fail $p_\perp$ cuts

also seen in other observables

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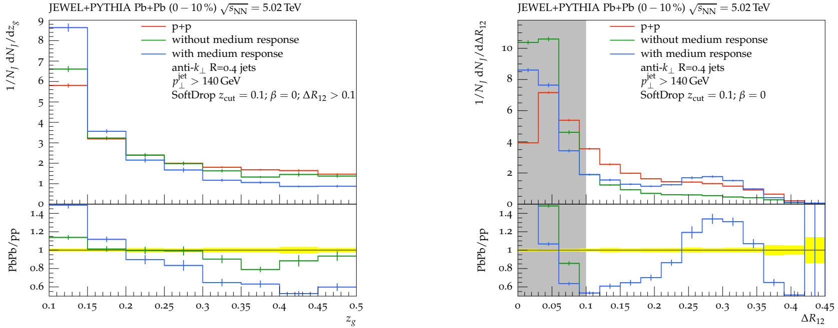
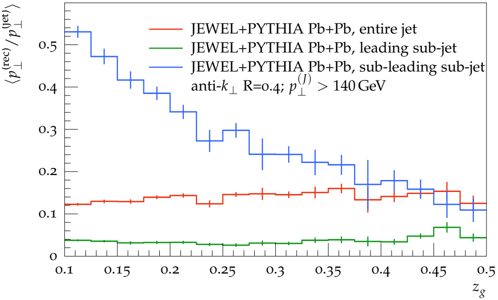
Milhano, Wiedemann, Zapp, Phys. Lett. B 779 (2018) 409



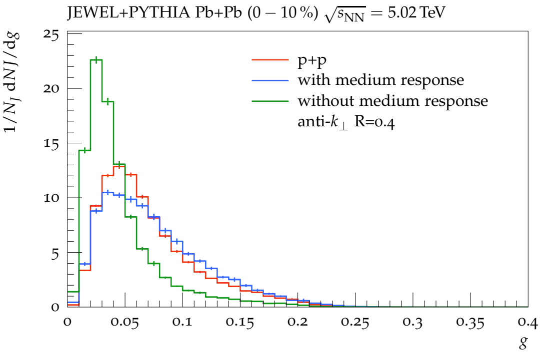
- w/o medium response: jets get narrower
- w/ medium response: additional component with large ΔR_{12} & small z_g
- additional $p_\perp$ from medium response promotes very asymmetric configurations above z_{cut}

Quantising contribution from medium response



- this is parton level
- average fraction of sub-jet $p_\perp$ coming from medium response
- much more important for softer prong
- more important at low z_g

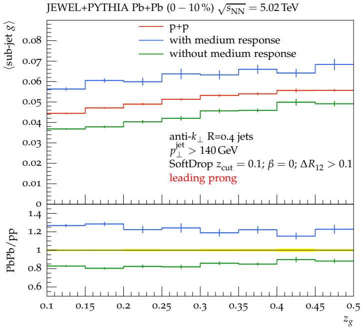
Relating this to an observable

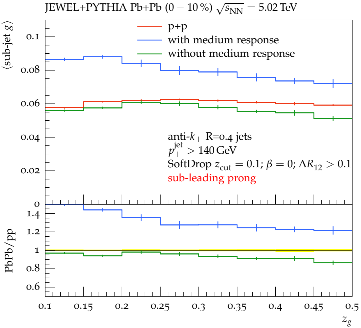


$$g = \frac{\sum_i p_{\perp,i} \Delta R_{iJ}}{p_\perp^{(J)}}$$

- first radial moment of $p_\perp$ distribution in jet
- w/o medium response g decreases – jets get narrower
- w/ medium response g increases again – contribution from recoils mostly at large ΔR

Sub-jet girth





- w/o medium response sub-jet girth decreases

everything gets narrower

- w/ medium response sub-jets get broader
- largest increase in softer prong at low z_g
- this is an observable

and maybe it can be measured...

Outline

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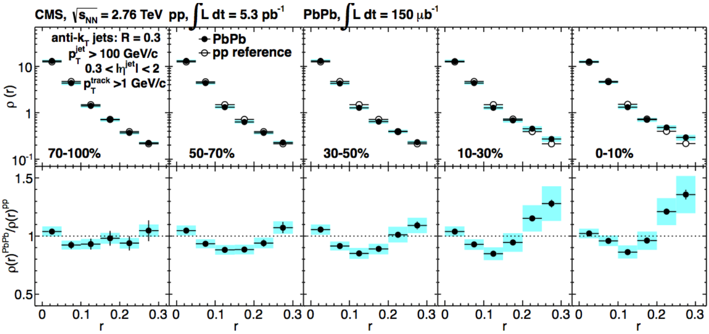
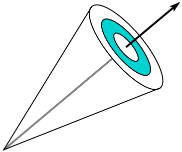
Intra-jet energy distribution: Jet profile

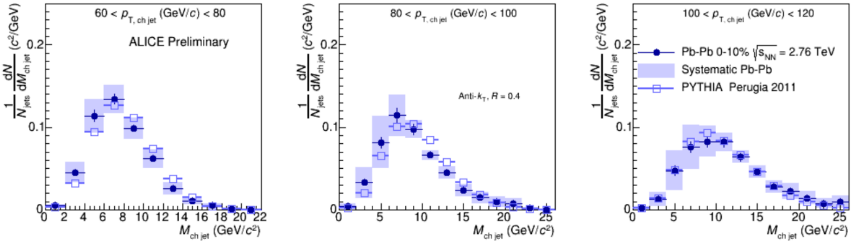




CMS, Phys. Lett. B 730 (2014) 243

- suppression of activity at intermediate r
- increase near the edge of the jet
- sensitive to soft particles at large r

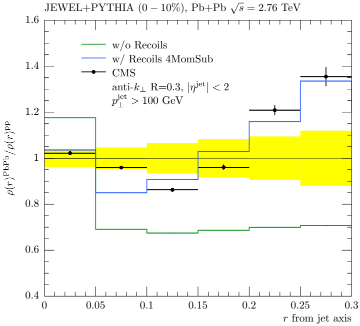
Jet mass



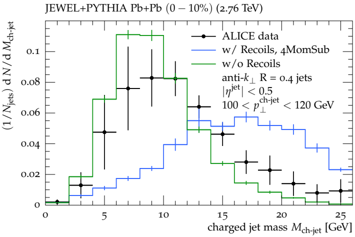
ALICE, Phys. Lett. B **776** (2018) 249

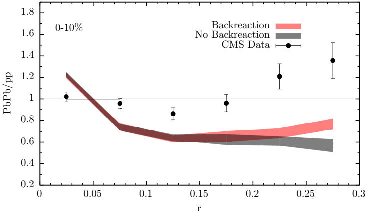
- looks like small shift towards smaller masses in Pb+Pb
- very sensitive to soft particles as large r
- How can this be reconciled with modification of jet profile?

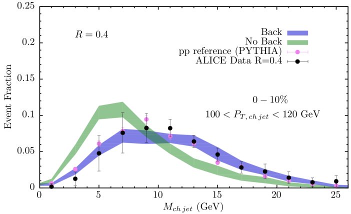
Consistency of jet mass and profile?



Kunnawalkam Elayavalli, Zapp, JHEP **1707** (2017) 141







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

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

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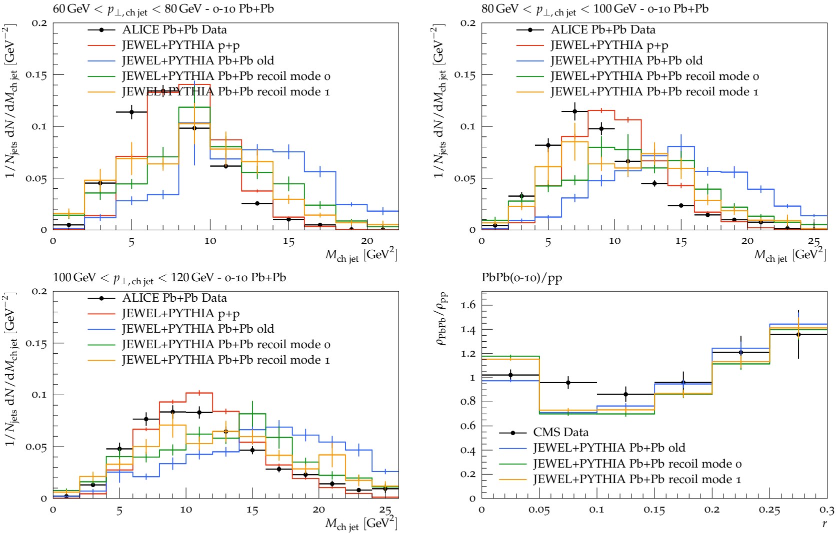
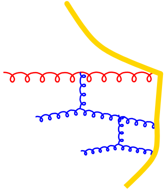
Improving subtraction method in JEWEL

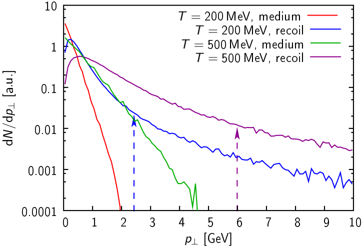


Re-scattering of recoils in JEWEL



- 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 $p > 4 \times 3T$
- a thing to worry about: very kinky strings



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

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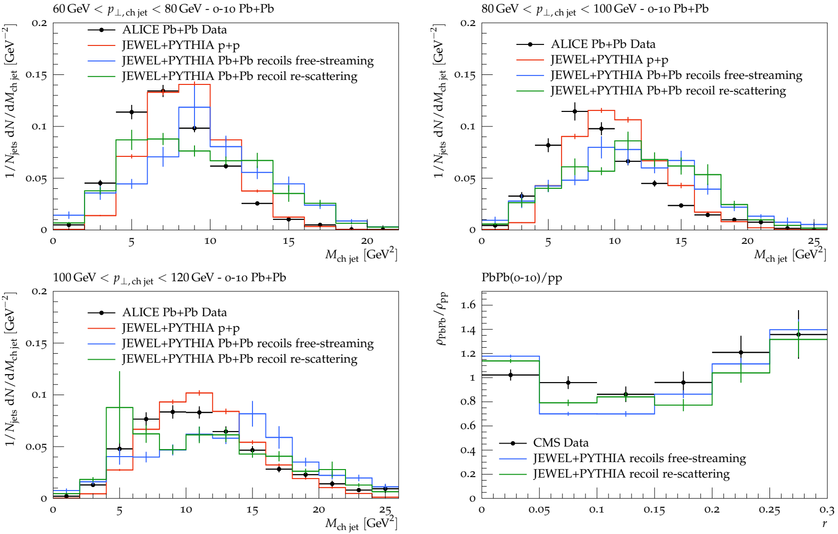

Outlook

In terms of physics

- consistency of jet mass and profile?

  current understanding: yes
- implications for jet quenching mechanisms?

  current understanding: not much

In practical terms

- explore different options for recoil treatment in JEWEL
- look at hadronisation with recoils
- release JEWEL 2.3