JEWEL – A Monte Carlo Model for Jet Quenching

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Outline

Reminder: JEWEL

Brick Problem in JEWEL

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Introduction

JEWEL characteristics:

- parton shower interleaved dynamically with elastic and inelastic scattering in a medium
- includes LPM-interference
- consistent with all known limiting cases
  - vacuum parton shower
  - elastic energy loss
  - inelastic energy loss in the absence of vacuum radiation
  - inelastic energy loss with of vacuum radiation
- minimal in the modelling
- work in progress: combination of medium induced radiation and vacuum splittings not fully tested yet (no results today)

Vacuum Baseline

Heart of the parton shower simulation

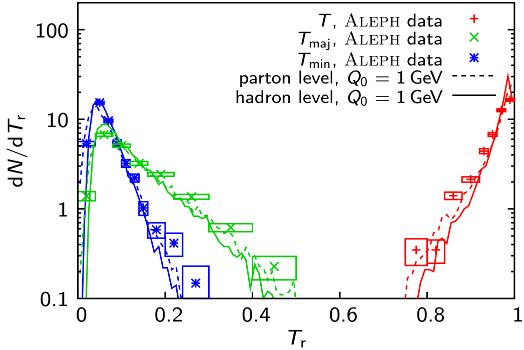
no-splitting probability (Sudakov form factor)

$$\mathcal{S}_\mathrm{a}(Q_\mathrm{i}^2, Q_\mathrm{f}^2) = \exp\left[- \int\limits_{Q_\mathrm{f}^2}^{Q_\mathrm{i}^2} \frac{\mathrm{d}Q'^2}{Q'^2} \int\limits_{z_-(Q'^2,E)}^{z_+(Q'^2,E)} \mathrm{d}z \, \frac{\alpha_\mathrm{s}}{2\pi} \sum_{\mathrm{b},c} \hat{P}_{\mathrm{a}\to\mathrm{b}c}(z) \right]$$

Hadronisation

- variant of Lund string fragmentation
- replace knowledge of colour flow by assumption of maximal colour correlation of partons close in phase space

Vacuum Baseline



$$T \equiv \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|} \qquad T_{maj} \equiv \max_{\vec{n}_T \cdot \vec{n}=0} \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|} \qquad T_{min} \equiv \frac{\sum_i |\vec{p}_{ix}|}{\sum_i |\vec{p}_i|}$$

- not very sensitive to hadronisation

A. Heister *et al.* [ALEPH Coll.] Eur. Phys. J. C **35** (2004) 457

Elastic Energy Loss Baseline

- scattering cross section:

$$\sigma^{\mathrm{I}}_{\mathrm{elas}} = \int_0^{|t_{\mathrm{max}}|} \mathrm{d}|t| \, \frac{\pi \, \alpha_s^2(|t| + \mu_{\mathrm{D}}^2)}{s^2} C_R \, \frac{s^2 + u^2}{(|t| + \mu_{\mathrm{D}}^2)^2}$$

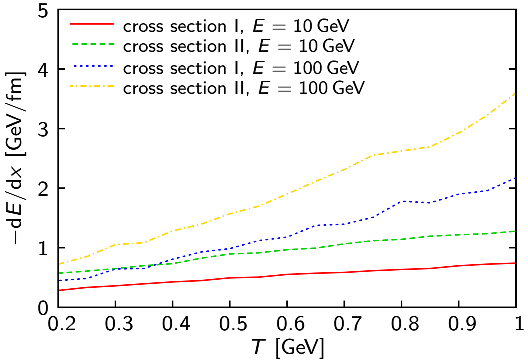
or

$$\sigma^{\mathrm{II}}_{\mathrm{elas}} = \int_{\mu_{\mathrm{D}}^2}^{|t_{\mathrm{max}}|} \mathrm{d}|t| \, \frac{\pi \, \alpha_s^2(|t|)}{s^2} C_R \, \frac{s^2 + u^2}{|t|^2}$$

- no-scattering probability: $\exp(-n\sigma_{\mathrm{elas}}\tau)$
- possibility to let the recoil scatter (not explored here)
- medium: collection of scattering centres (here: constant temperature, ideal quark-gluon gas EOS)

Elastic Energy Loss Baseline

mean collisional energy loss without Q^2-evolution



- reproduces analytical calculations (with their dependence on regularisation schemes)

Radiative Energy Loss Baseline

was covered by Urs Wiedemann this morning...

Medium Modifications to the Shower

Underlying Assumption

- assume that elastic scattering does not affect Q^2-evolution (no significant transverse phase space opened)

$\longrightarrow$ parton shower and elastic scattering decoupled

Spatio-temporal structure of shower

- lifetime of parton in shower (estimate from uncertainty principle):

$$\tau = \frac{E}{Q_f^2} - \frac{E}{Q_i^2}$$

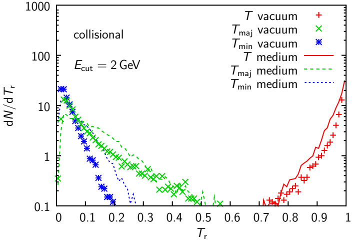
To compare with: simple model for induced radiation

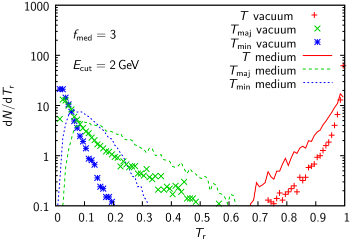
- increase probability for perturbative splitting by factor $1 + f_{med}$ inside the medium

Borghini, Wiedemann, hep-ph/0506218

Medium Modifications to the Shower

100 GeV quark jet, only hadrons with $E_h > 2$ GeV included

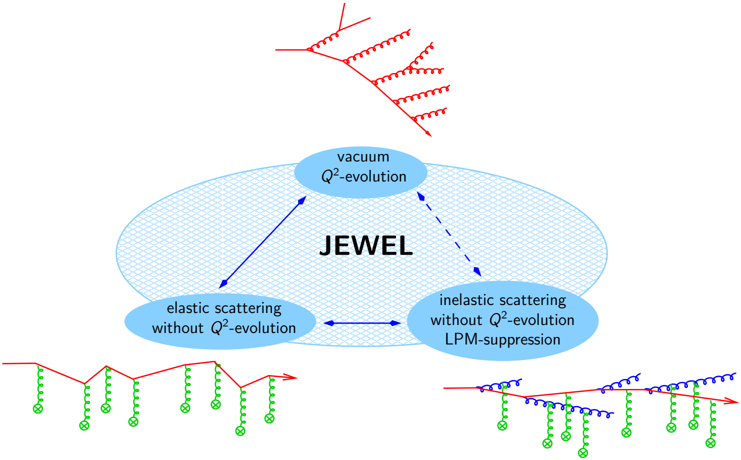




$$T = 500\,\text{MeV},\ L = 5\,\text{fm}$$

- might allow to distinguish between elastic and radiative energy loss

Summary


vacuum
Q^2-evolution
JEWEL
elastic scattering
without Q^2-evolution
inelastic scattering
without Q^2-evolution
LPM-suppression

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Brick Problem in JEWEL

JEWEL and the Brick

- brick problem considers only elastic and inelastic energy loss, but no vacuum radiation
- naturally included in JEWEL, but uses/tests only part of JEWEL functionality
- qualitative differences between medium induced radiation in the presence/absence of vacuum radiation
- interesting variation of brick problem: determine energy loss based on leading parton instead of outgoing projectile
- remark: our BDMPS-ASW reference is a Monte Carlo reproduction of the analytical calculation

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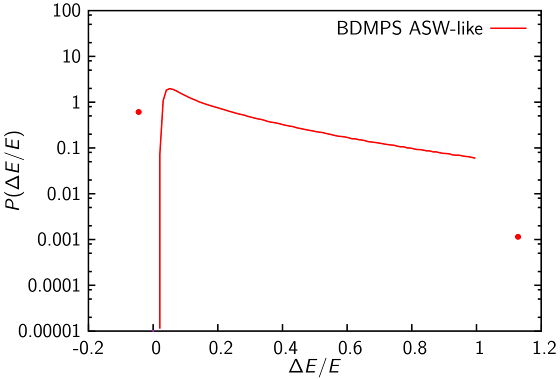
JEWEL-Answer to Brick Problem



$$L = 2\,\text{fm}$$

$$E_q = 10\,\text{GeV}$$

$$\langle \frac{\Delta E}{E_q} \rangle = 0.1$$

JEWEL radiative: energy carried by radiated gluons

JEWEL recoil: energy carried away by recoil in elastic or inelastic scattering

$\Rightarrow$ distinct differences between BDMPS ASW and JEWEL scenario

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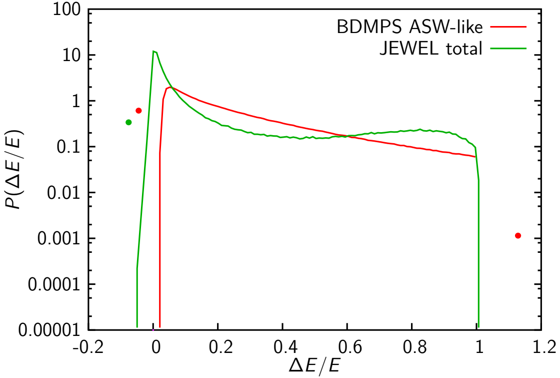

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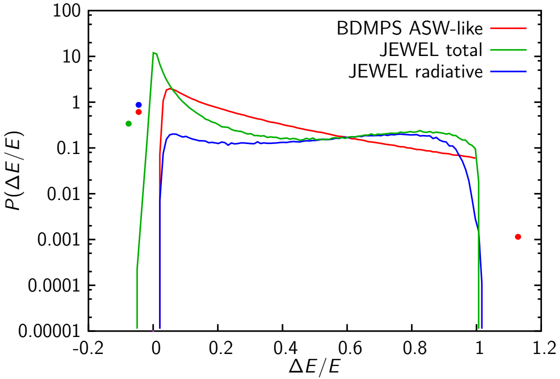

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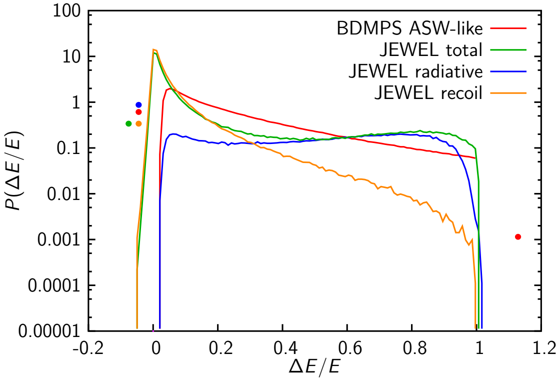

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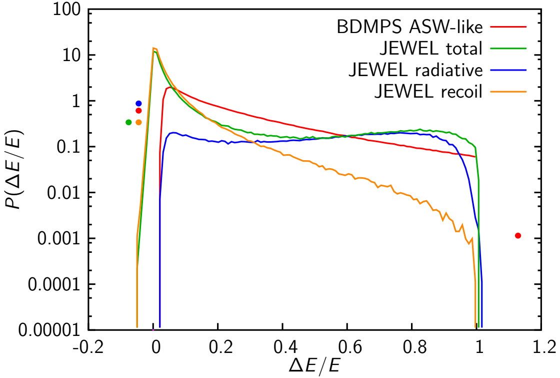

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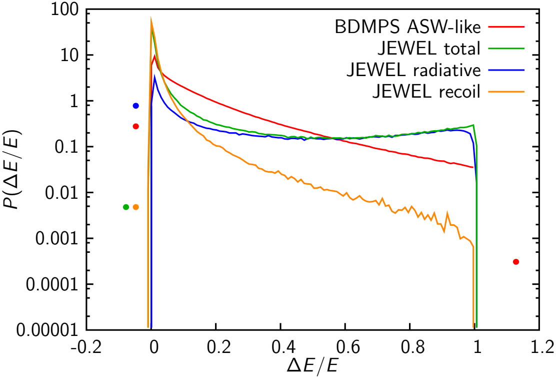

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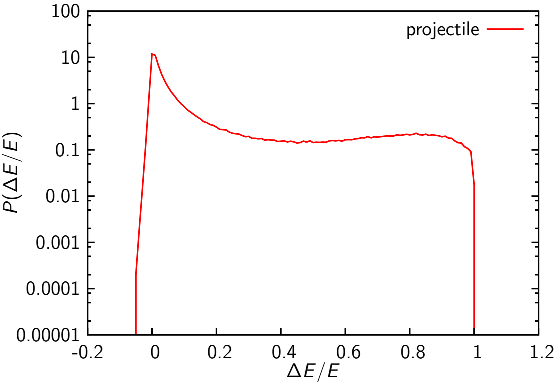
Brick Based on Leading Parton



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- no rescattering of formed gluons and scattering centres

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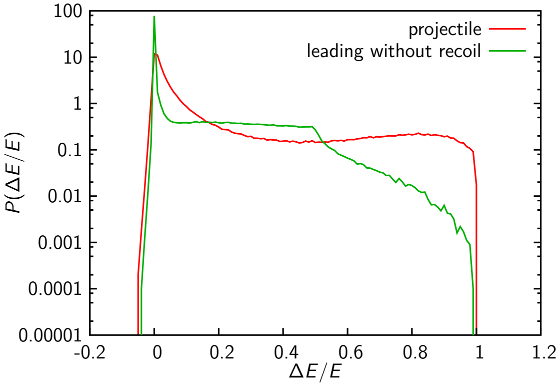

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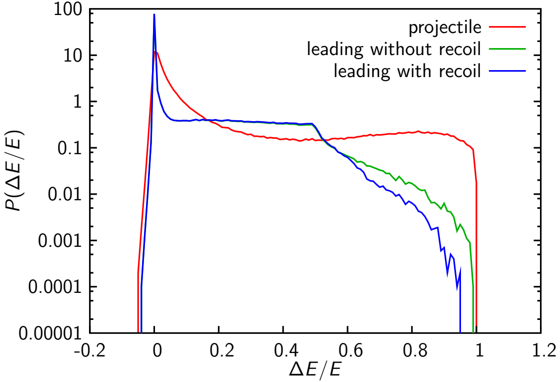

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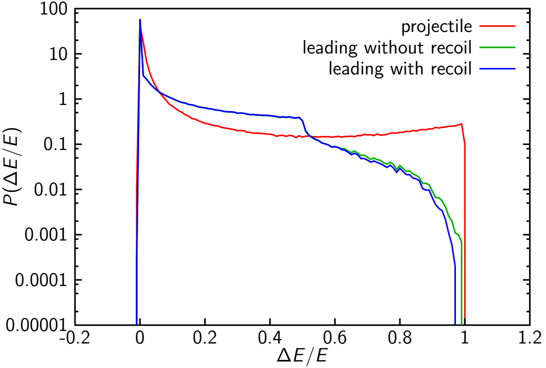

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Conclusions

- these are exploratory studies

$\Rightarrow$ there is more to follow, so stay tuned

Backup Slides

LPM in MC

BDMPS ASW opacity expansion:

$$\omega \frac{\mathrm{d}I(N=1)}{\mathrm{d}\omega\,\mathrm{d}\mathbf{k}_\perp\,\mathrm{d}\mathbf{q}_\perp} =$$
$$\frac{\alpha_s}{\pi^2}\frac{C_R}{2\omega^2}\frac{1}{(2\pi)^2}|A(\mathbf{q}_\perp)|^2(\mathbf{k}_\perp\cdot\mathbf{q}_\perp)n_0\tau\tau_1^2\left[\frac{L}{\tau_1}-\sin\left(\frac{L}{\tau_1}\right)\right]$$

explicit field theoretic manifestation of the formation time

$$\tau_1 = \frac{2\omega}{(\mathbf{k}_\perp-\mathbf{q}_\perp)^2}$$

interpolates between limiting cases

$\tau_1 \gg L$: totally coherent

$\tau_1 \ll L$: totally incoherent

MC procedure:

1. create gluon in inelastic process
2. check if scattering during t_f

no: gluon is formed, back to 1

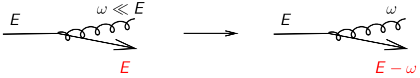
yes: scattering after time $\Delta t < t_f$, re-evaluate formation time, back to 2

Going Beyond BDMPS ASW

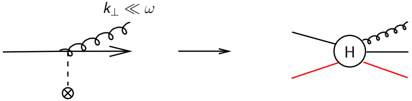
1. relaxing soft scattering approximation of BDMPS ASW

$$\frac{d\sigma}{dq_\perp^2} \propto \frac{1}{(q_\perp^2+\mu^2)^2}\,\theta(q_\perp^2-4\mu^2) \to \frac{1}{(q_\perp^2+\mu^2)^2}$$

2. going beyond BDMPS soft gluon approximation



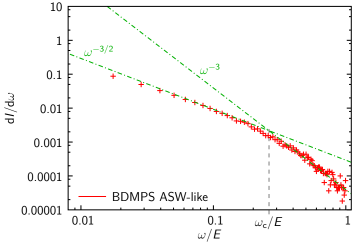
3. exploring realistic kinematics of inelastic process



here: extreme limit $\frac{d^2\sigma^{qQ\to qQg}}{d\omega\, dk_\perp^2} = \sigma^{qQ\to qQ}\frac{C_F 4\alpha_s}{\pi}\frac{1}{\omega}\frac{1}{k_\perp^2}$

4. this includes recoil effects in elastic and inelastic processes

Radiative Energy Loss Baseline



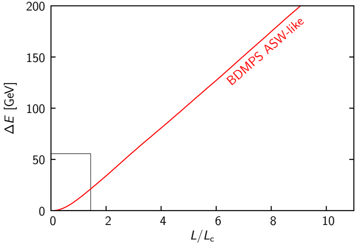
BDMPS ASW results:

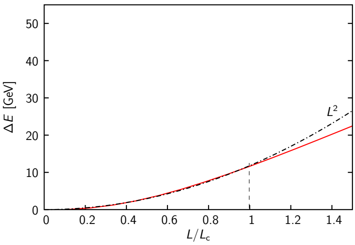
$$\frac{dI}{d\omega} \propto \omega^{-3/2} \quad \text{for} \quad \omega < \omega_c$$

$$\frac{dI}{d\omega} \propto \omega^{-3} \quad \text{for} \quad \omega > \omega_c$$

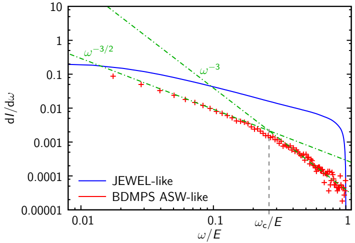
$$\Delta E \propto L^2 \quad \text{for} \quad L < L_c$$

$$\Delta E \propto L \quad \text{for} \quad L > L_c$$





Improving Radiative Energy Loss



going beyond BDMPS ASW:

all improvements lead to

- loss of coherence
- enhanced energy loss