Universiteit Utrecht

Radiative energy loss in a hot QCD medium: from RHIC to LHC

Marta Verweij
Utrecht University
ALICE mini meeting @ Frascati

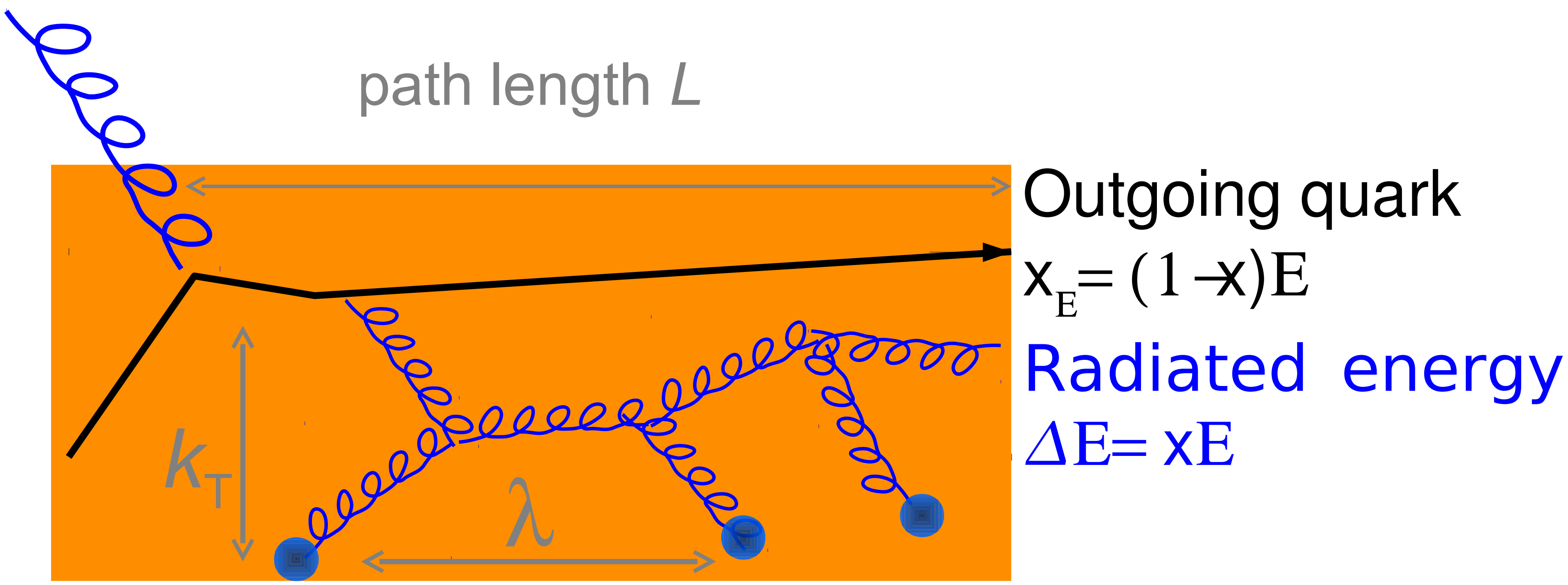
Introduction / Outlook

- Energy loss due to gluon bremsstrahlung in a hot dense medium.
- What can we learn from measuring R_{AA} & comparison to models?
- Formalisms give a different estimation of medium properties when fitting to RHIC R_{AA} data (factor ~5 difference in density).
- Estimates for LHC energies.

- In this talk:
  Apple-to-apple comparison of:
  - Multiple soft scattering approximation (ASW-MS, BDMPS-Z, …)
    *Phys.Rev.**D68** 014008*
  - Opacity Expansions (ASW-SH and DGLV/WHDG rad N=1)
    *Phys.Rev.**D68** 014008, Nucl.Phys.**A784** 426*

Schematic picture of energy loss mechanism

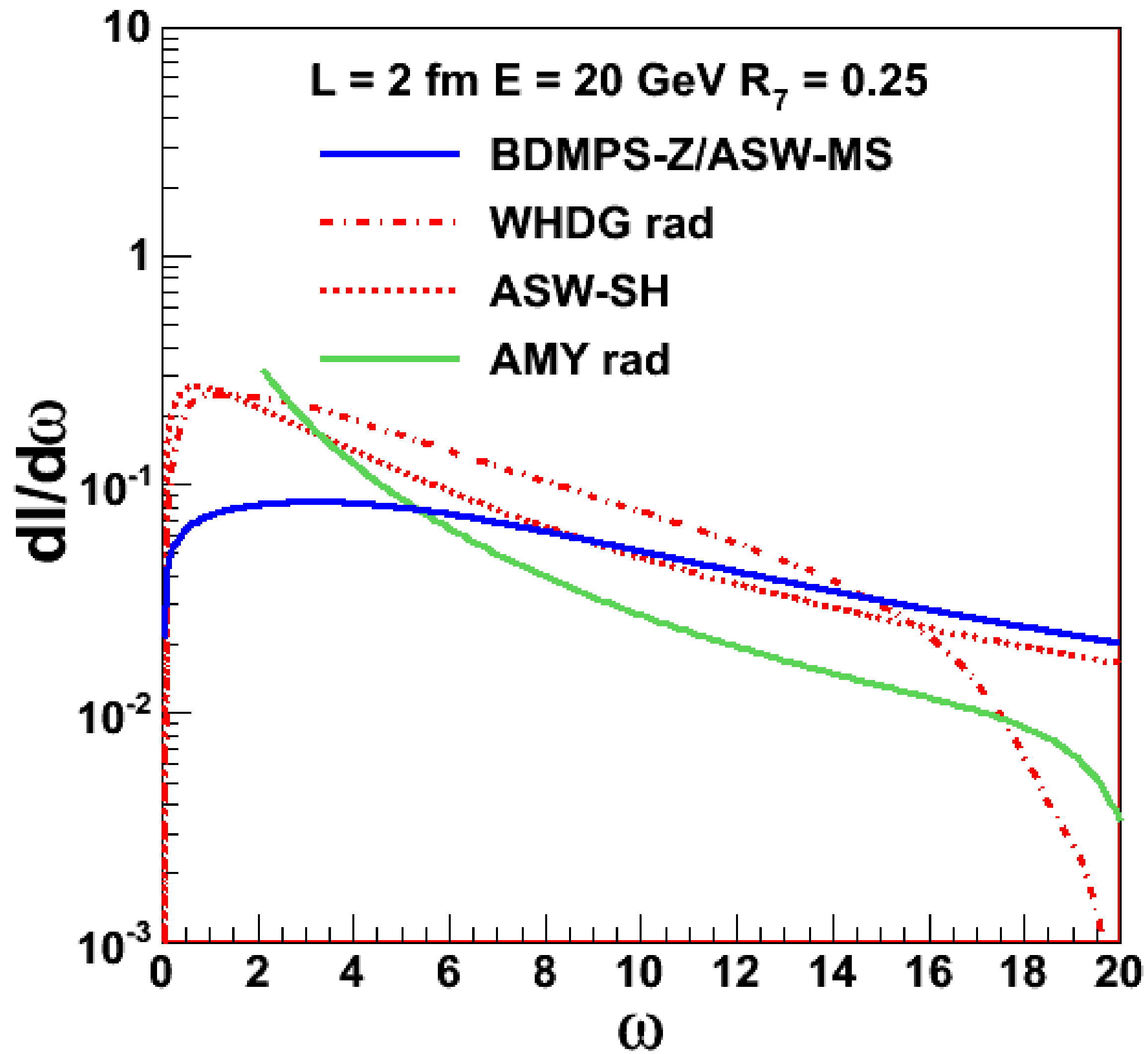
in hot dense matter



Gluon radiation

- Parton loses energy due to gluon radiation
  - Also in vacuum
  - More in medium
- Gluon spectrum is model dependent
- Results in a different jet structure

Gluon radiation spectrum for different energy loss models



Energy loss probability

- P(ΔE) is generated by a Poisson convolution of the single gluon radiation spectrum:

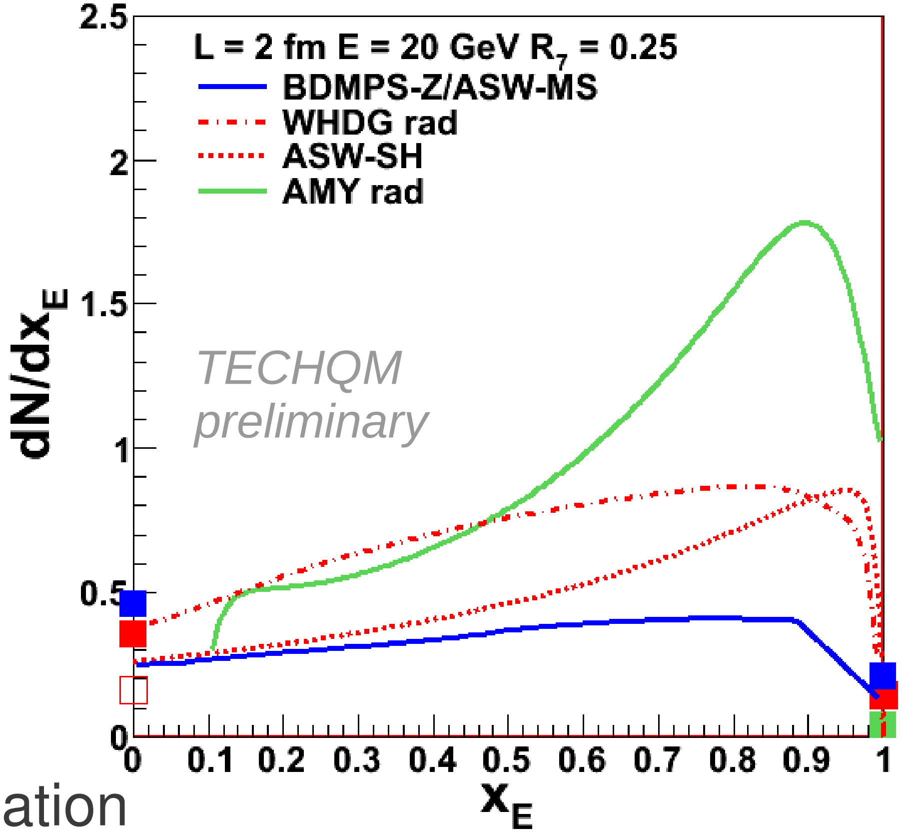
$$P(\Delta E) = p_0 \delta(\Delta E) + p(\Delta E)$$

- 3 distinct contributions:
  - p_0 = discrete weight = probability to not lose any energy = $e^{-\langle Ngluons \rangle}$
  - p(ΔE) = continuous energy loss = parton loses ΔE
  - If ΔE > E parton is absorbed by the medium

Energy loss probability

$$P(\Delta E) = p_0\delta(\Delta E) + p(\Delta E)$$

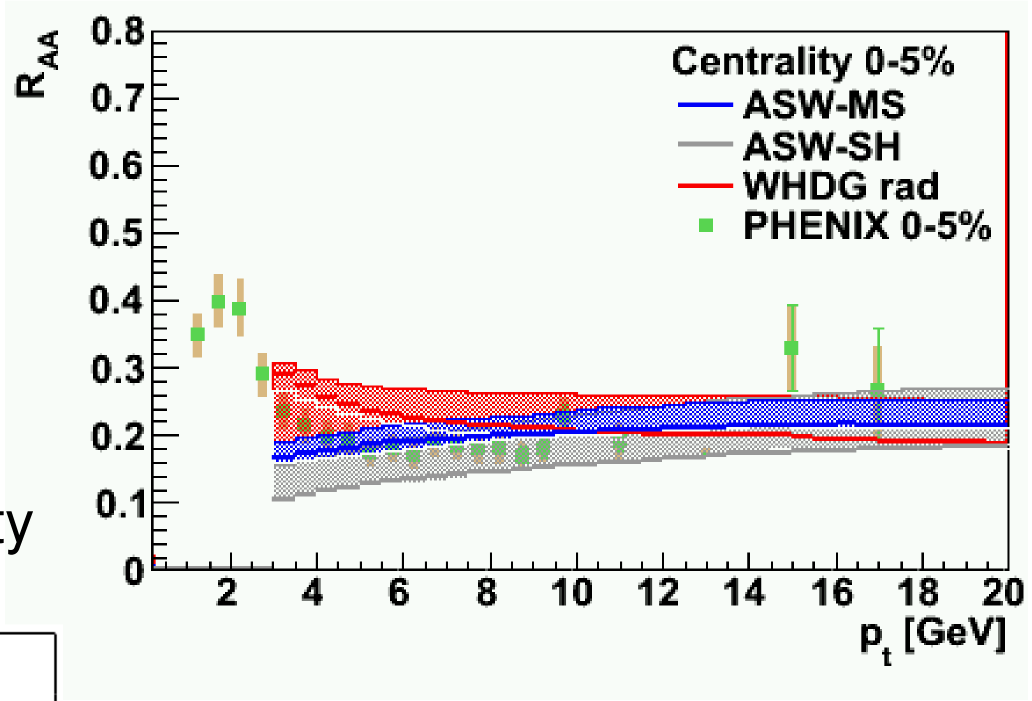
- This results in a outgoing quark spectrum:
  - $x_E = 1 - \Delta E/E$
  - $x_E = 0$: Absorbed quarks
  - $x_E = 1$: No energy loss



- Suppression factor R_7 dominated by:
  - ASW-MS: absorption of partons in the medium
  - OE'S: absorption and soft gluon radiation
- Continuous part of energy loss distribution more relevant for OE's.
- **Can we measure this?**

R_{AA} at RHIC

- Common input parameter for all models: Temperature
- All models can be fitted to R_{AA}.
- Best fit is estimated by modified χ^2 analysis.
- Each best fit is has a 1σ uncertainty band (shaded area).



	If $\tau < \tau_0$ $\hat{q} = \hat{q}_0$	
	$\hat{q}_0$ (GeV/fm^2)	T_0 (MeV)
ASW-MS	$20.3^{+0.6}_{-5.1}$	973^{+6}_{-90}
WHDG rad	$5.7^{+0.3}_{-1.9}$	638^{+11}_{-81}
ASW-SH	$3.2^{+0.3}_{-0.3}$	524^{+17}_{-18}

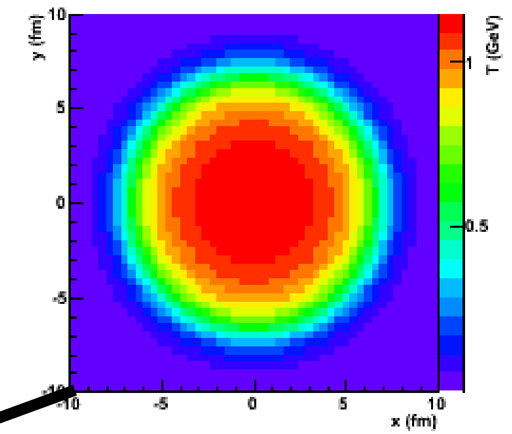
Factor 4-5 difference in density estimation between mulitple soft scattering approximation and opacity expansions.

*PHENIX data: Phys. Rev. **C77**, 064907 (2008)*

Geometry of HI collision

- Woods-Saxon profile
- Wounded Nucleon Scaling with optical Glauber
- Medium formation time: $\tau_0 = 0.6$ fm
- Longitudinal Bjorken Expansion $1/\tau$
- Freeze out temperature: 150 MeV

Temperature profile of central collision



$$\frac{dN}{dp_{t,hadr}} = \frac{dN}{dp_{t,parton}} \circ P(\Delta E) \circ D(p_{t,hadr}/p_{t,parton})$$

Measurement

Input parton spectrum Known LO pQCD

Energy loss

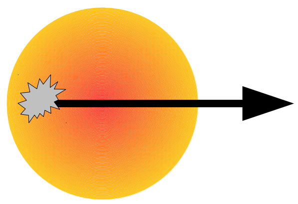
geometry

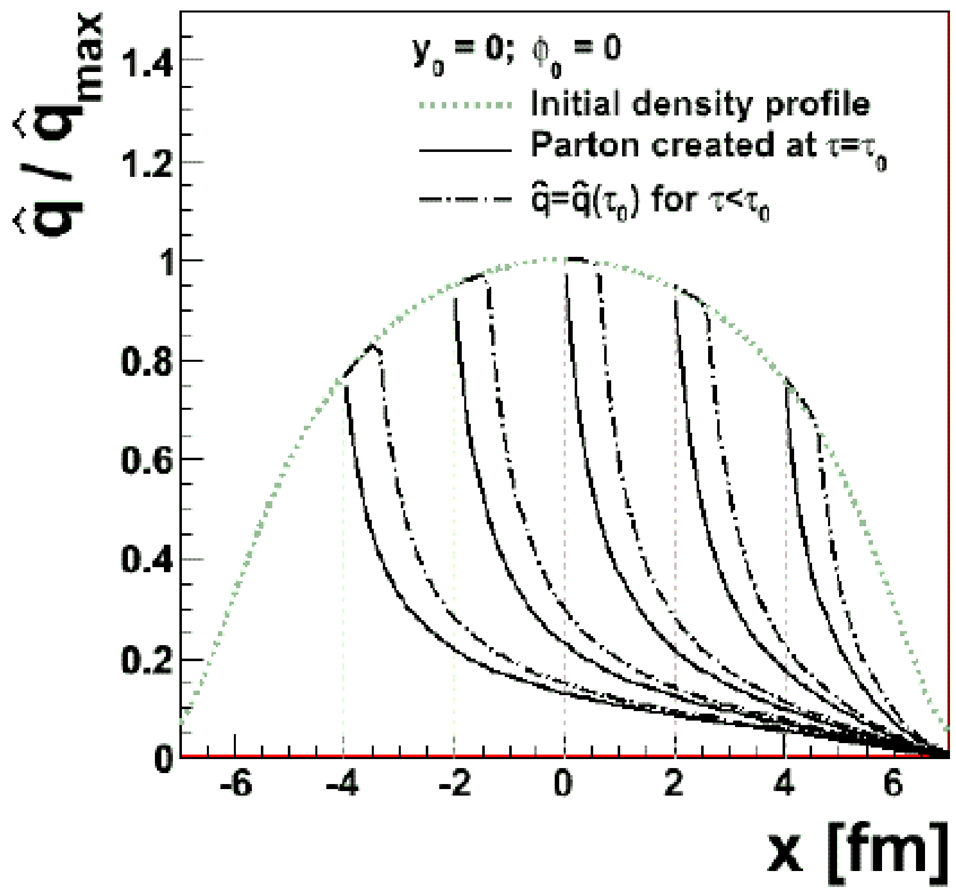
medium

Fragmentation Function Known from e+e-

Medium density profile

- Parton travels through evolving medium
- Parton *sees* different medium at each step in space and time
- Density of medium decreases as function of space and time





Local qhat as function of space-time coordinate x for different starting points

Model input parameters

- Multiple soft scattering approximation (ASW-MS):

$$N_{gluon} = \int d\omega \frac{dI}{d\omega}(\omega_c, R) = \int d\omega \frac{dI}{d\omega}(\hat{q}, L)$$

"Medium density"

- Opacity expansion (GLV, etc.):

$$N_{gluon} = \frac{L}{\lambda} \int d\omega \frac{dI}{d\omega}(\mu, L)$$

#scattering centers   Debye screening mass

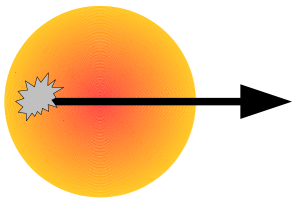
- No qhat for opacity expansions.

$$\hat{q} = \frac{\langle q_\perp^2 \rangle}{\lambda} \sim \frac{\mu^2}{\lambda}$$

- **How to determine input parameters in an evolving medium?**

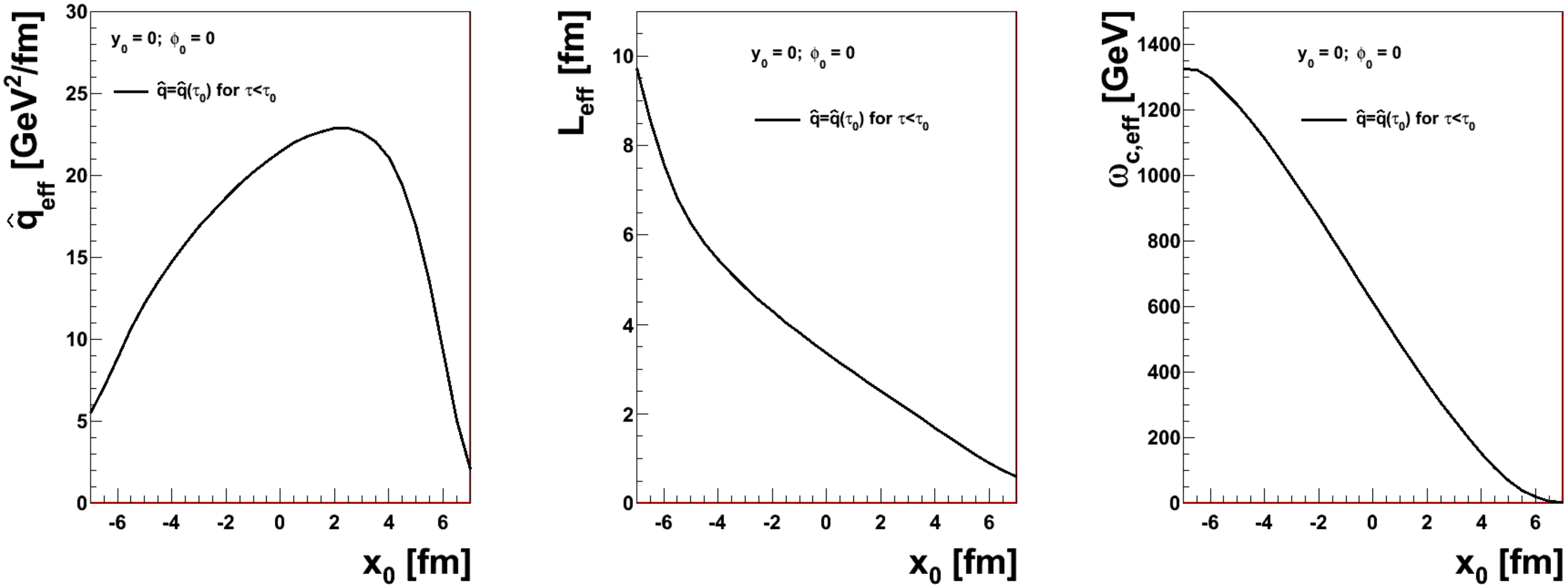
Medium as seen by parton

- Path average variables which characterize the energy loss.



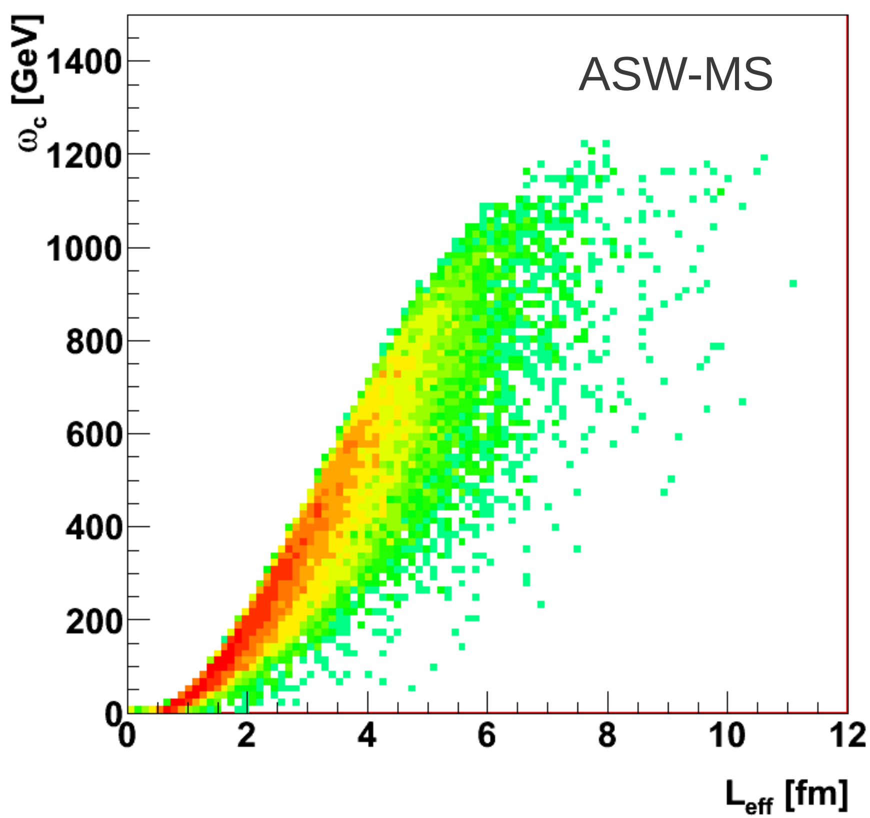
$$\langle \Delta E \rangle \propto \hat{q} L^2 \propto \omega_c$$

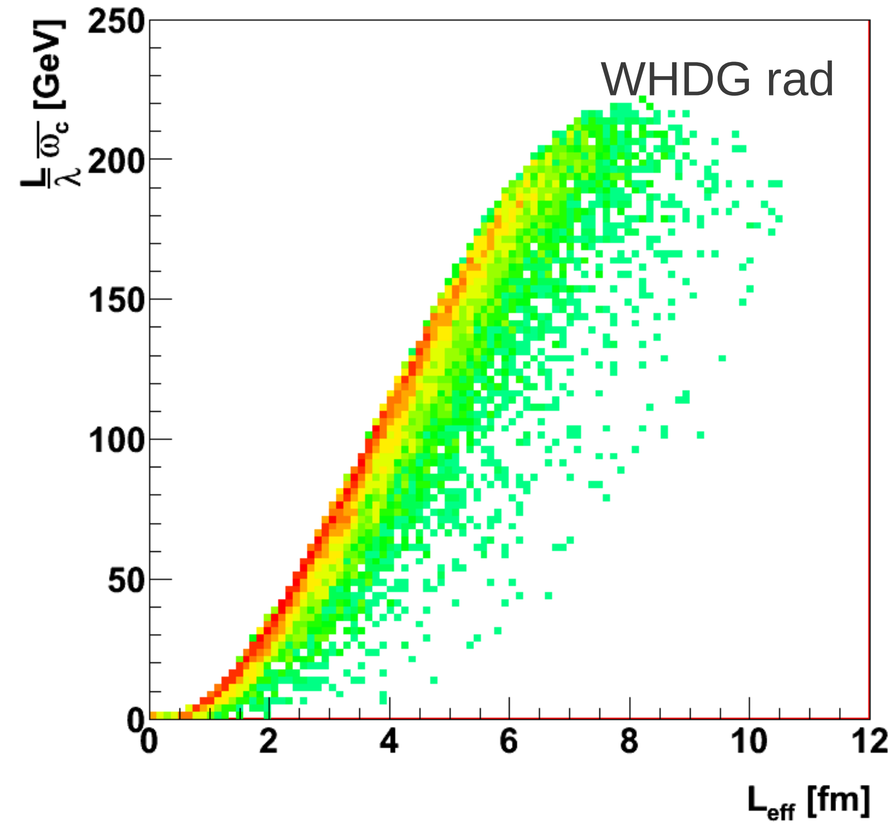
- Exercise:
  - Parton is created at x_0 and travels radially through the center of the medium until it leaves the medium or freeze out has taken place.



Medium as seen by parton

- Now: Partons in all directions from all positions
- Medium characterized by typical gluon energy ω_c and path length L



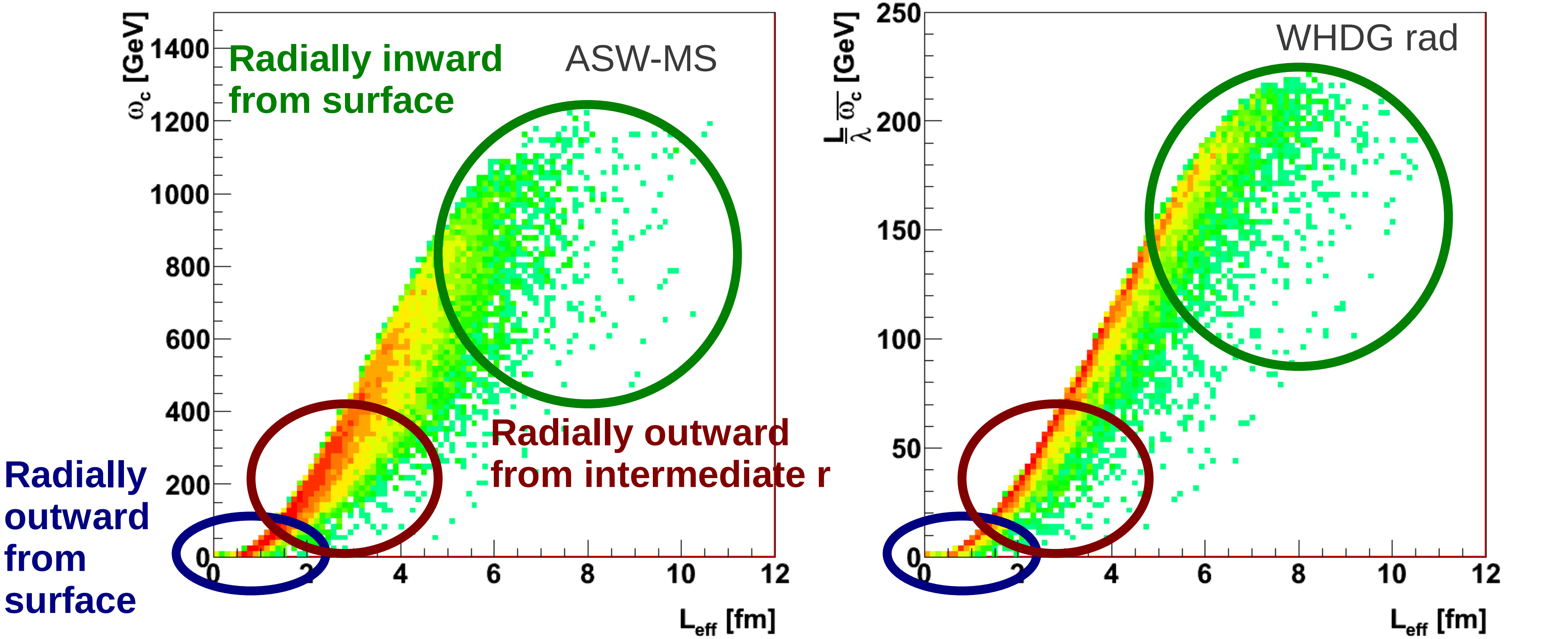


Different treatment of large angle radiation cut-off: qperp<E

Medium as seen by parton

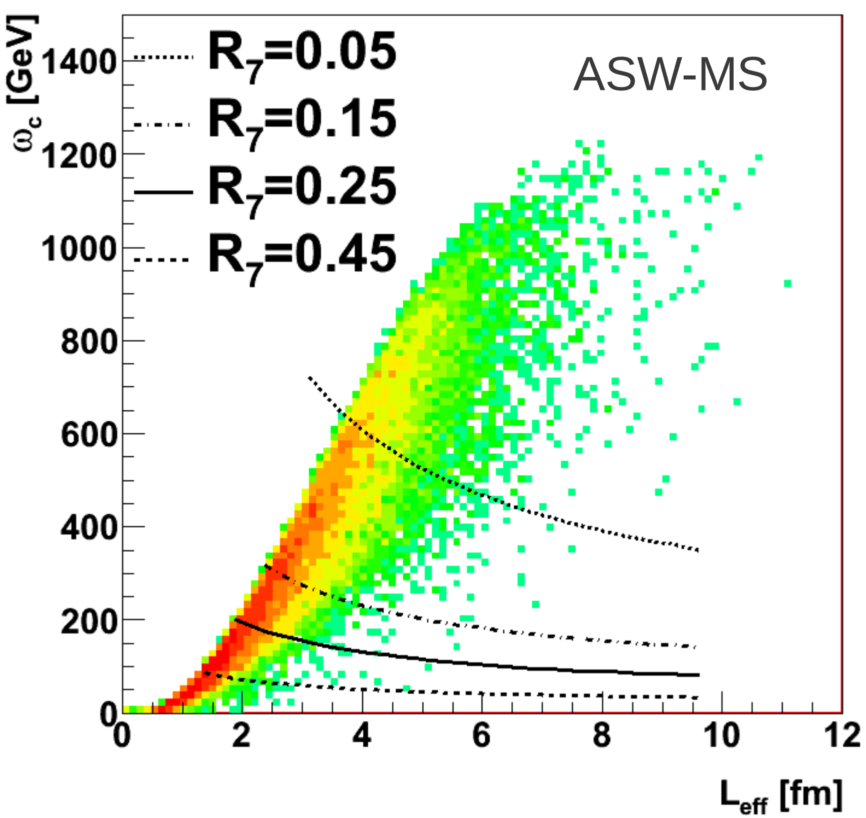
- Medium characterized by typical gluon energy ω_c and path length L

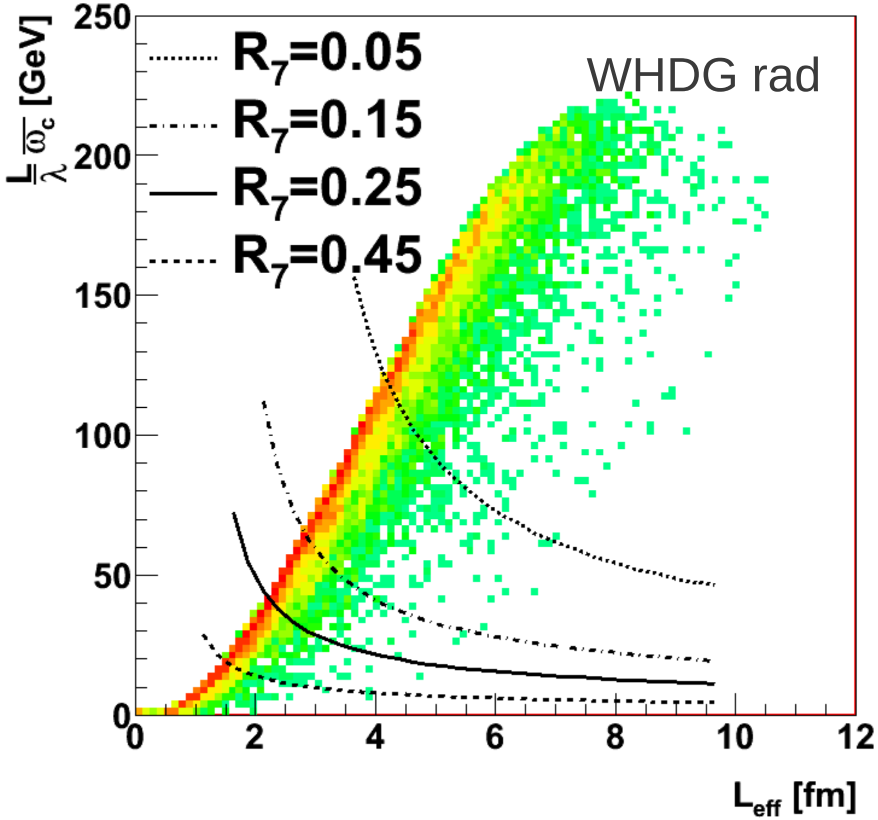
$$\langle \Delta E \rangle \propto \hat{q} L^2 \propto \omega_c$$



Medium as seen by parton

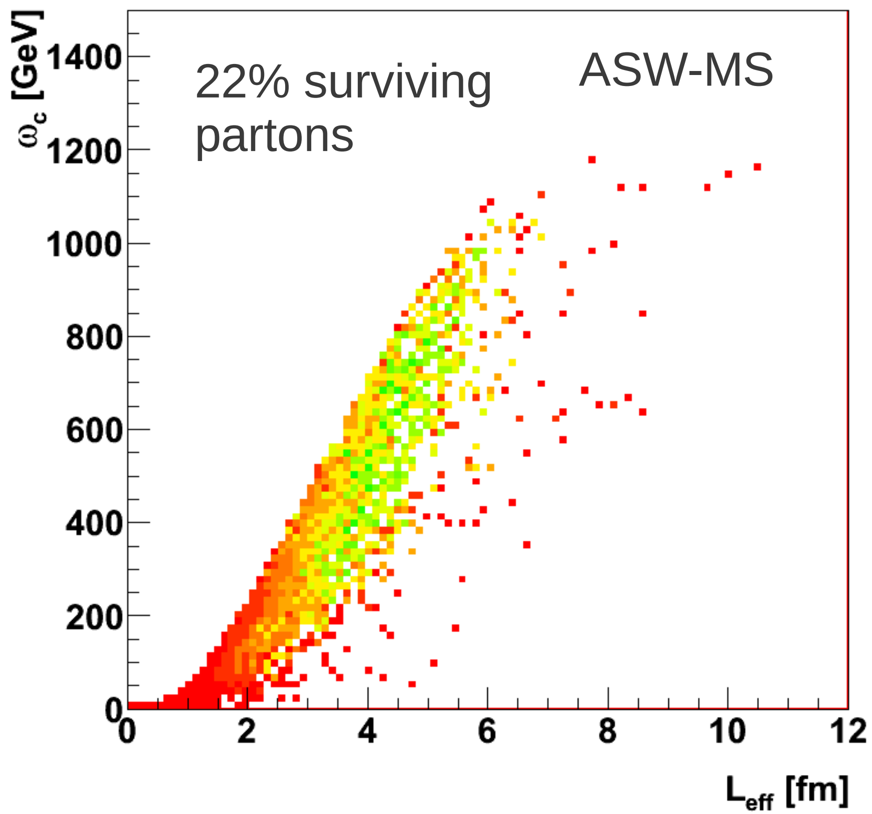
- Brick isolines for different values of typical suppression R_7
- R_{AA} is a superposition of a range of typical suppressions.

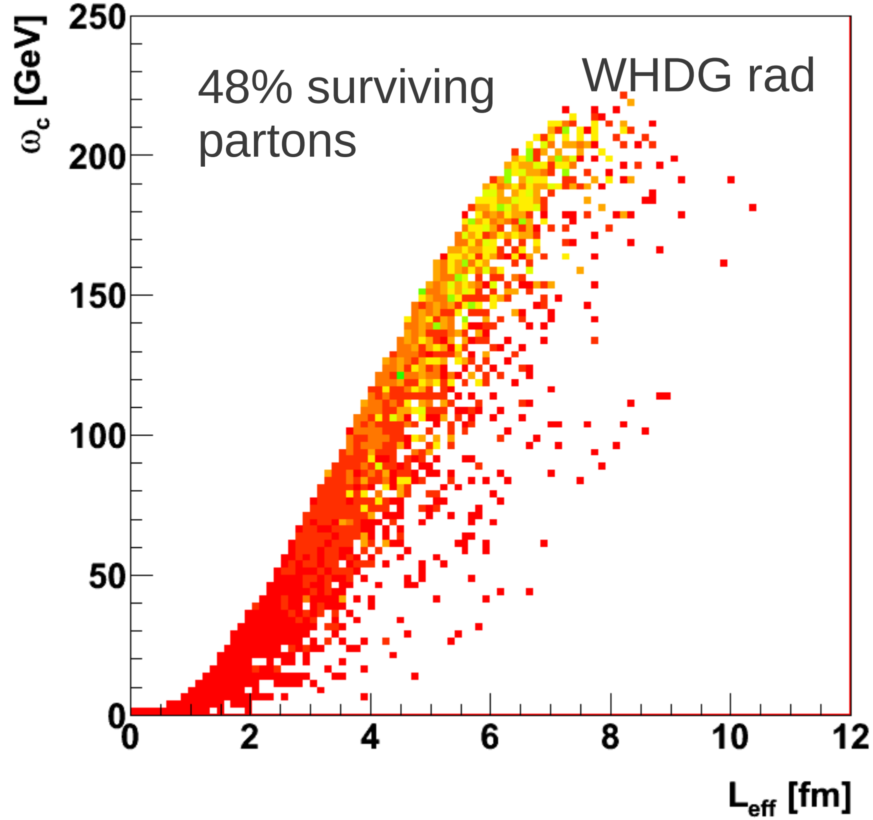




Surviving partons

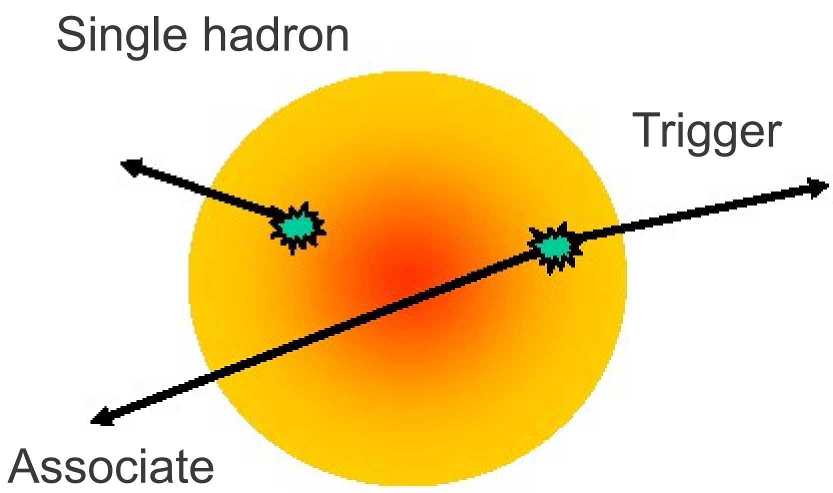
- WHDG probes deeper into medium.
- WHDG more surviving partons → more fractional energy loss.
- **Measure back-to-back hadrons could give a different picture.**





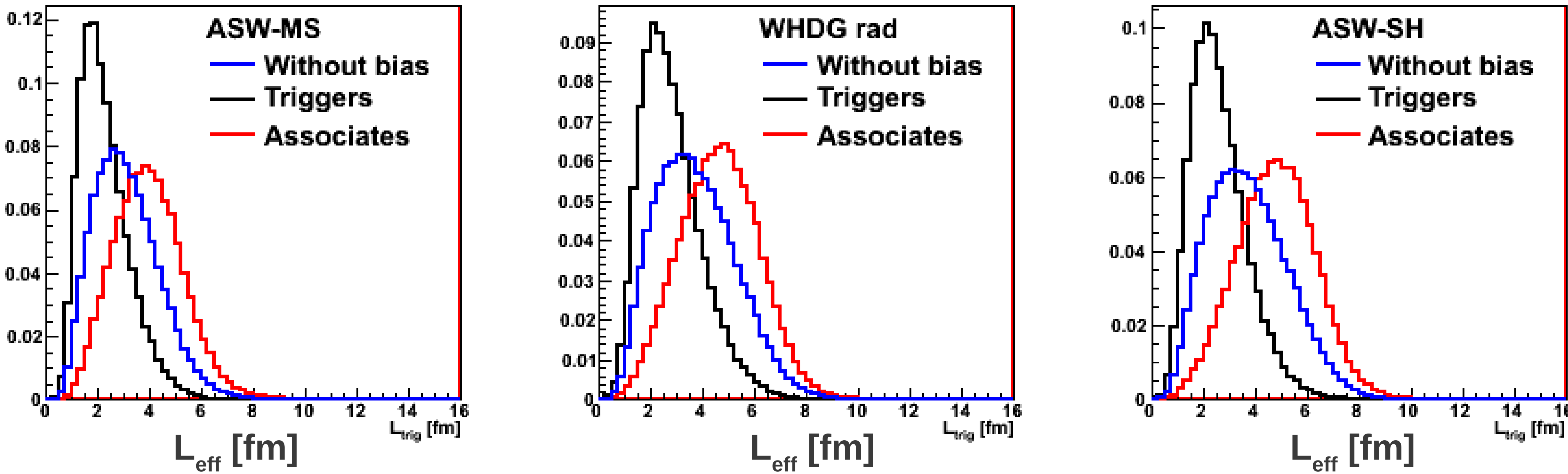
Why measure I_{AA}?

- Trigger to larger parton p_t
- Bias associated particle towards longer path length
- Probe different part of medium
- **Probe different energy loss probability distribution**



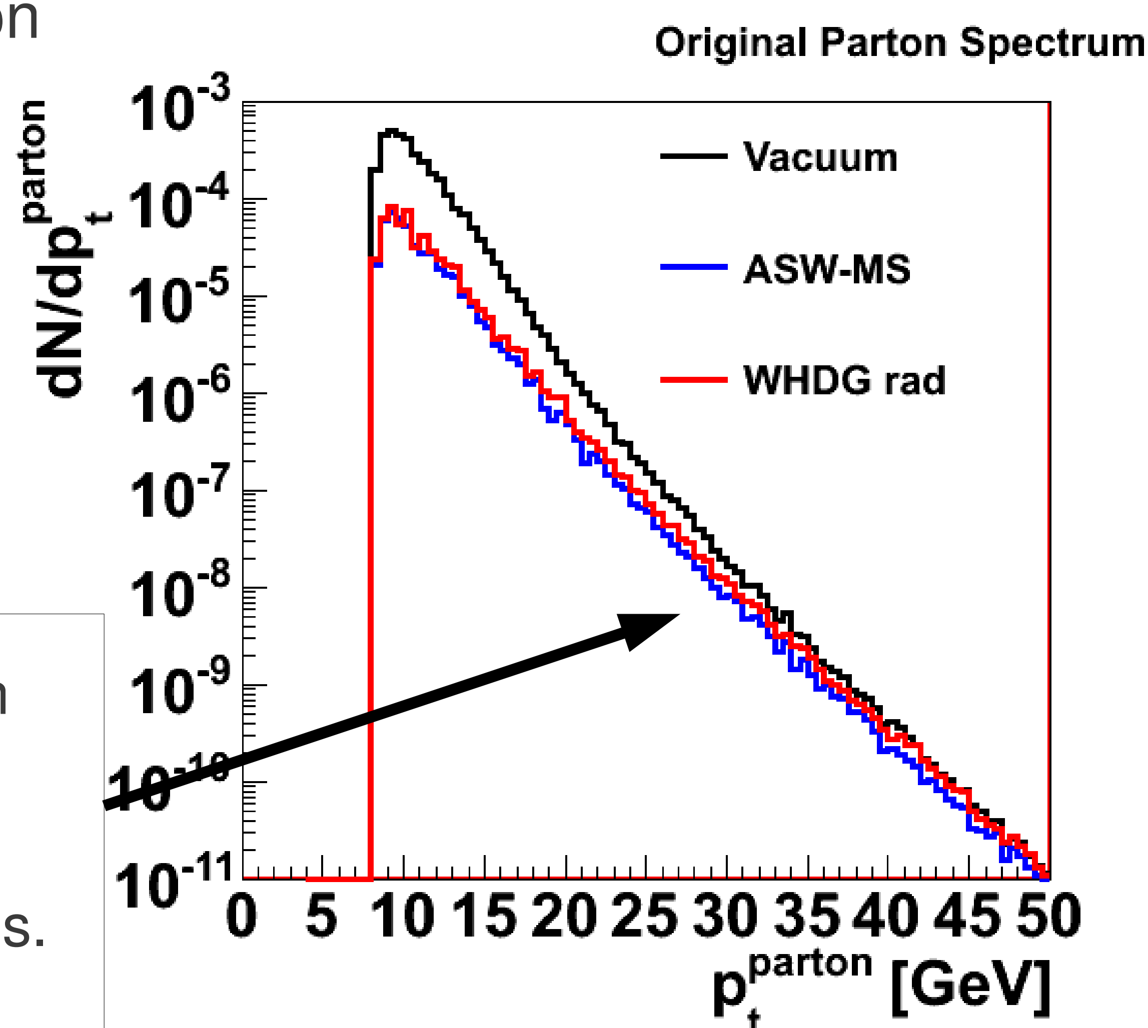
L_{trig} vs L_{assoc}

- For R_{AA} and I_{AA} different mean path length.
- P_t Trigger > P_t Assoc
- **Triggers** bias towards smaller L
- **Associates** bias towards longer L



R_{AA} vs I_{AA}

- What is the difference between R_{AA} and I_{AA}?
- Different part of the parton spectrum is probed.



Original parton spectra resulting in hadrons with $8<p_t^{hadron}<15$ GeV for without (vacuum) and with (ASW-MS/WHDG) energy loss.

R_{AA} and I_{AA} at RHIC

- All models can always be fitted to R_{AA}.
-

RHIC best fits	If $\tau < \tau_0$ $\hat{q} = \hat{q}_0$	
	$\hat{q}_0$ (GeV/fm^2)	T_0 (MeV)
ASW-MS	$20.3^{+0.6}_{-5.1}$	973^{+6}_{-90}
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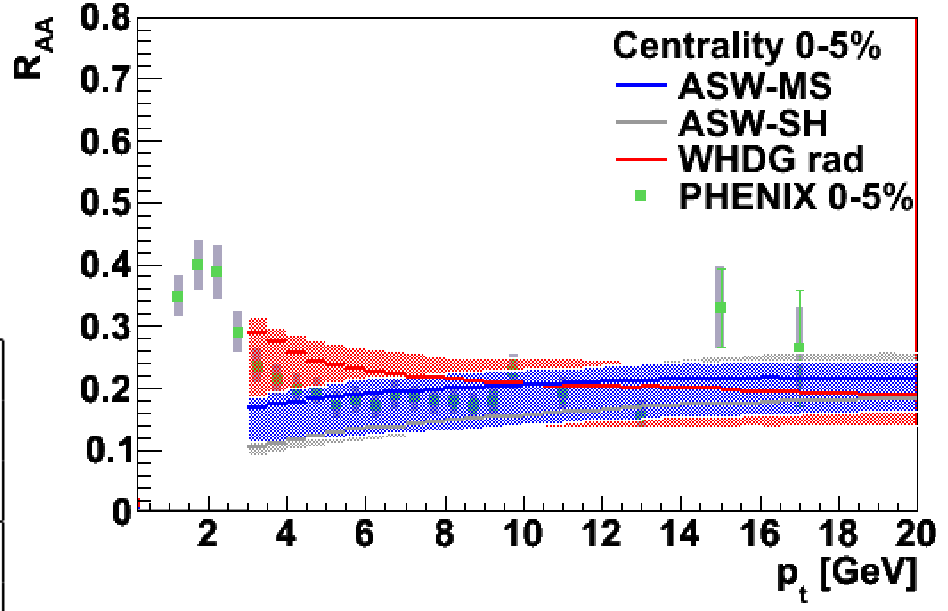
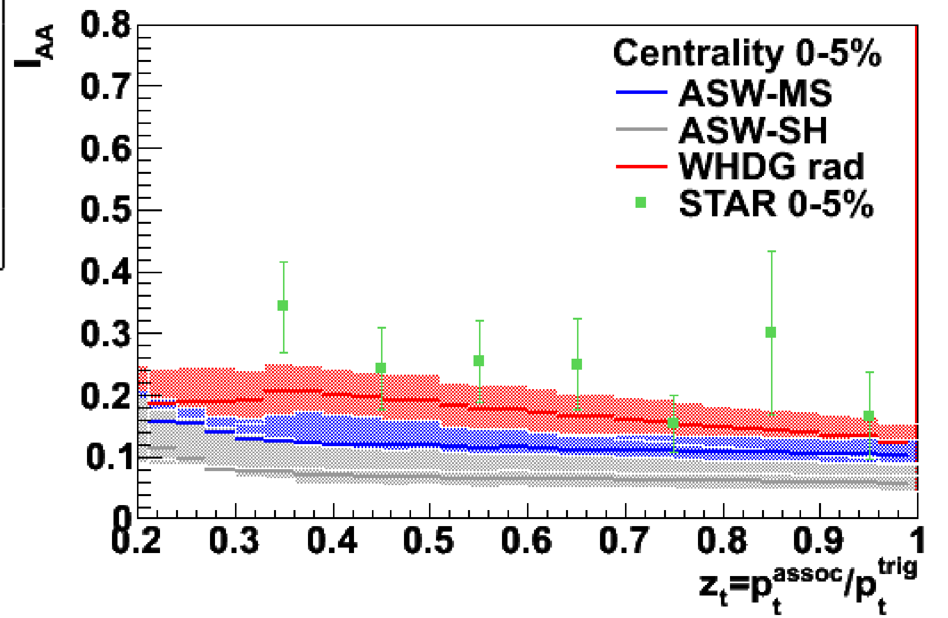
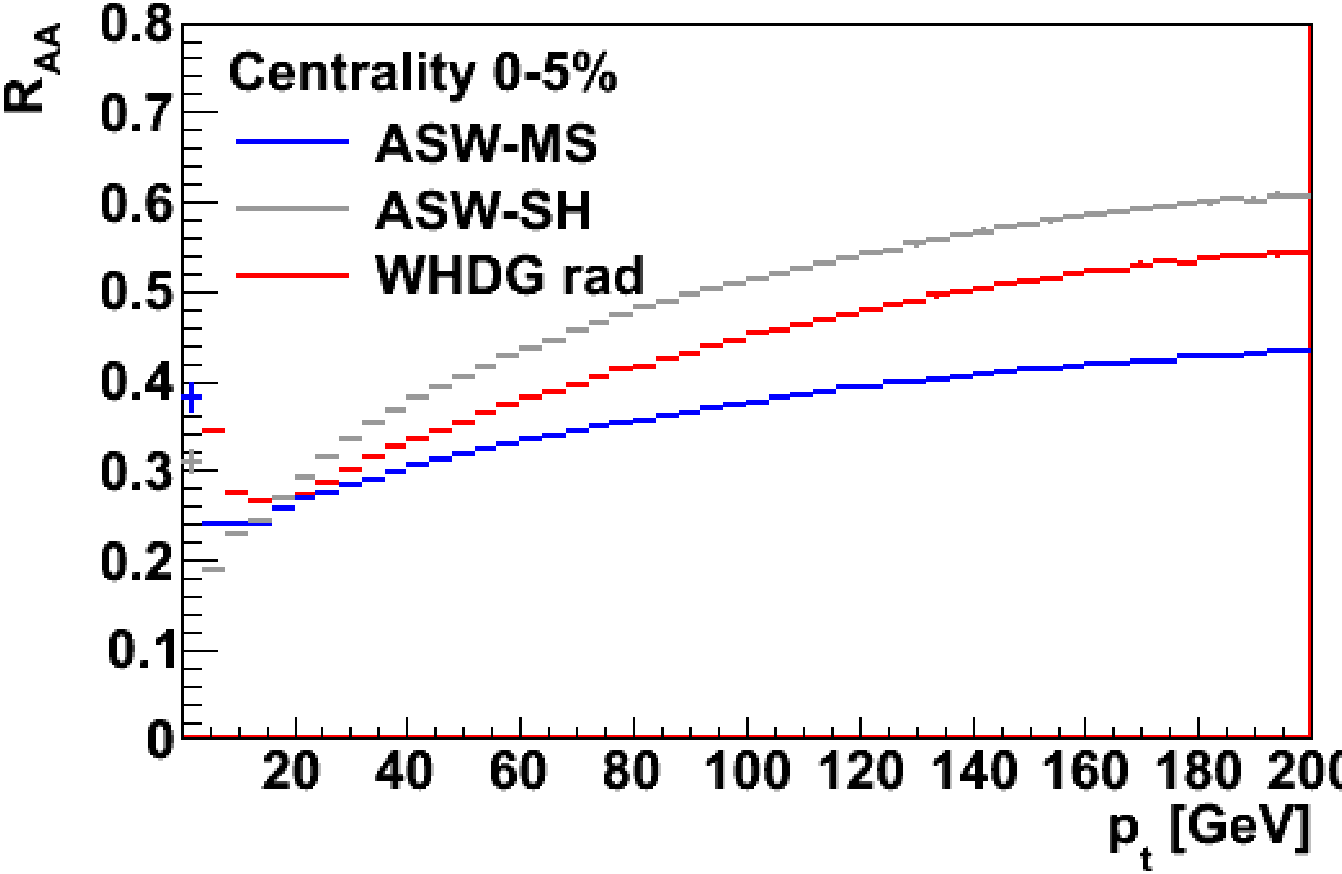
- Calibrate density using R_{AA} measurement,
  most models underestimate I_{AA}.



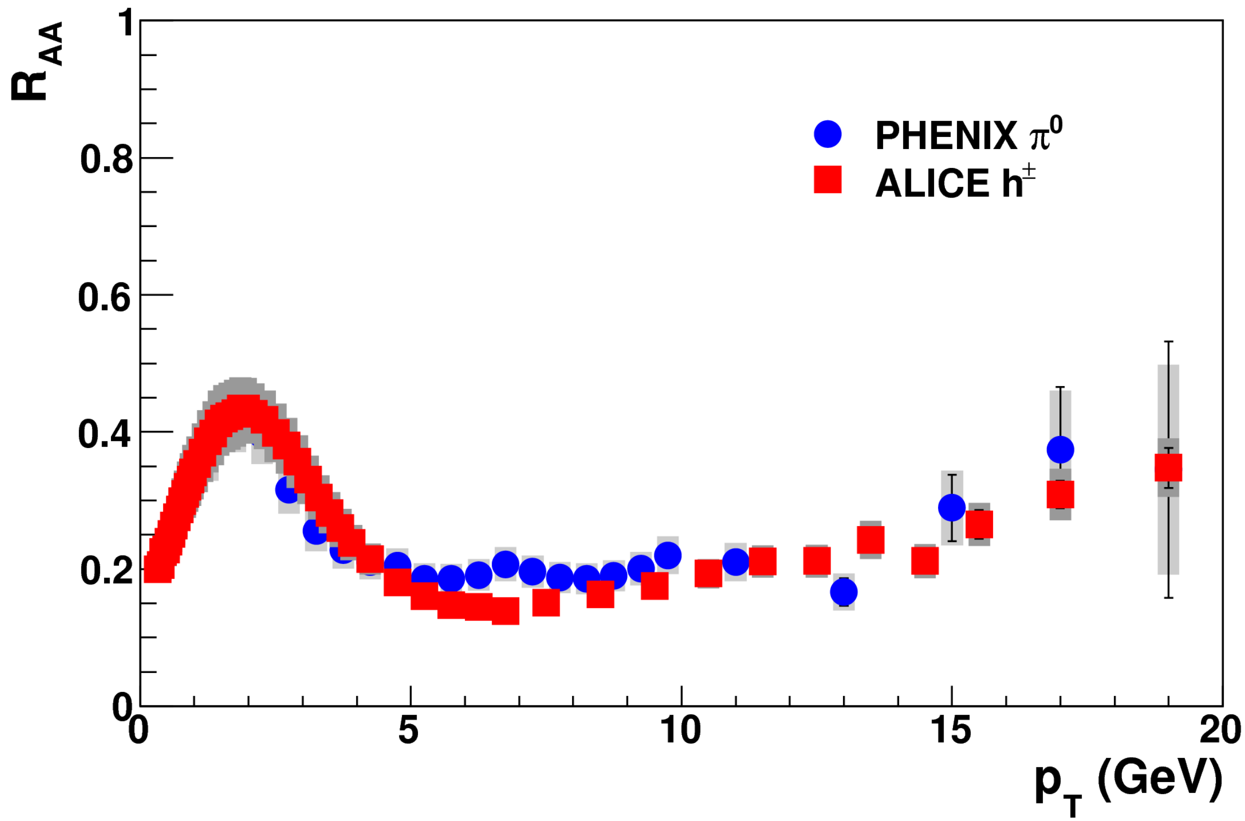


R_{AA} at LHC

- Assuming same medium density as at RHIC.
- Parton p_t spectrum for LHC flatter than at RHIC.
- Higher parton momenta than at RHIC.
- Different model dependence on p_t for R_{AA}



R_{AA} at ALICE

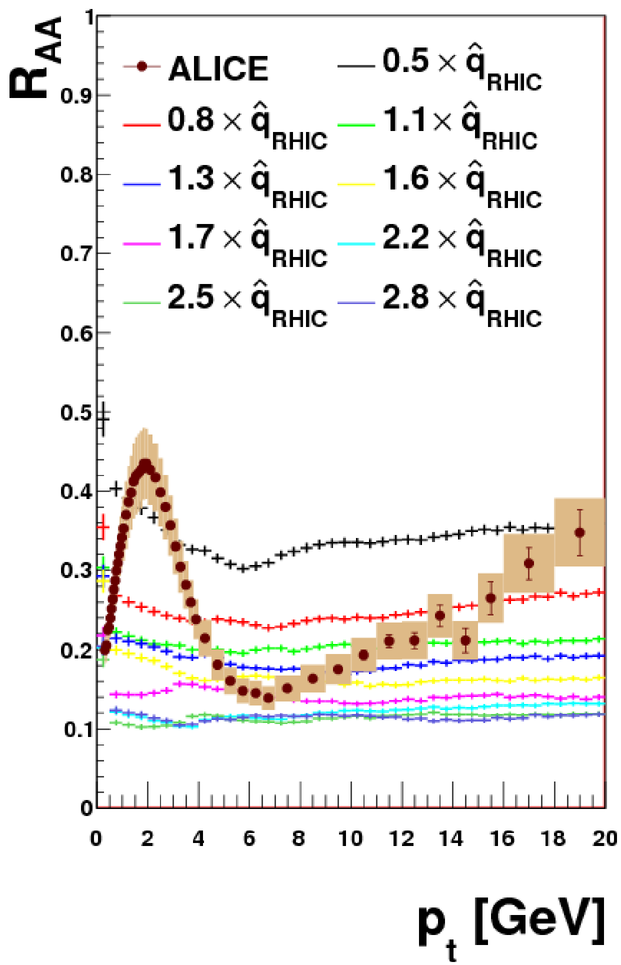


Plot compilation:
M. van Leeuwen

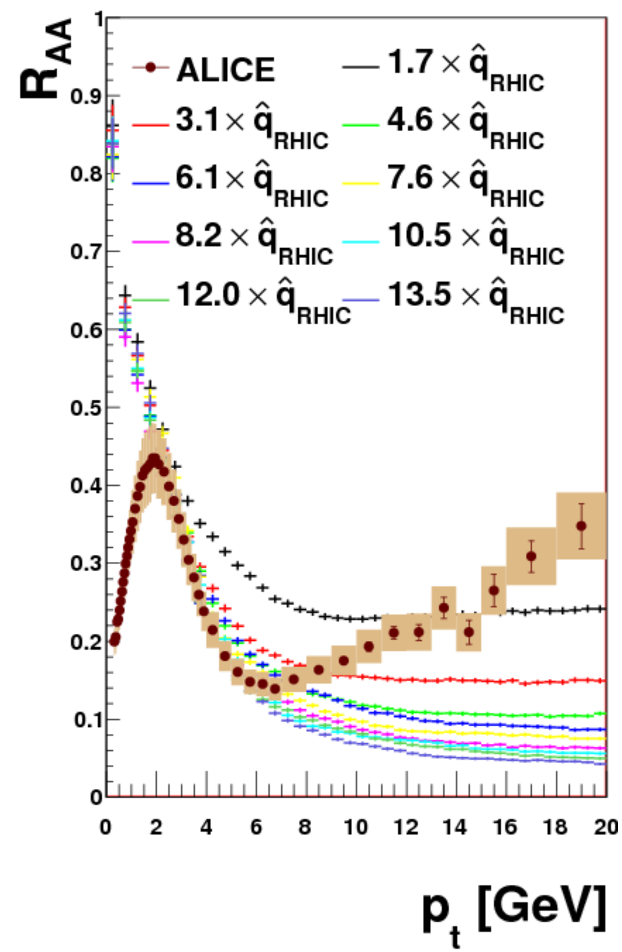
- R_{AA} PHENIX π^0 and ALICE h^{+-} not so different...

Models + ALICE R_{AA}

- Models *tuned* to PHENIX π^0 R_{AA} do not describe data very well.
- Roughly: 2-3 times larger qhat at LHC than at RHIC



Multiple soft scattering approximation



Opacity expansion

Summary

- Different energy loss models give different results in a brick and fitting to RHIC data.
- Opacity expansion probes deeper into the medium – different *surface bias*.
- P(ΔE) not trivial to recover from indirect measurement.
- If density of the medium is not too large, clear p_T dependence of radiative energy loss for LHC.
  - Done, steeper rise of R_{AA} with p_T than expected.