Understanding the path length dependence of jet quenching in Heavy Ion Collisions from RHIC to LHC

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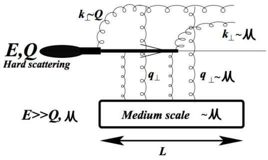
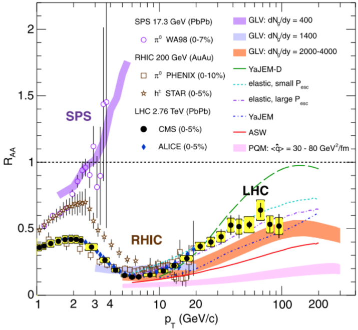
Outline

1. Physics motivation & basic concept
   - Nuclear modification factor R_{AA}
   - Anisotropic particle distribtuon flow v_2
2. Analysis
   - Convert R_{AA} as function of p_T and ϕ
   - Estimating path-length
3. Result
4. Summary

R_{AA} from RHIC to LHC



A schematic picture of the various scales involved in the modification of jets in dense matter.

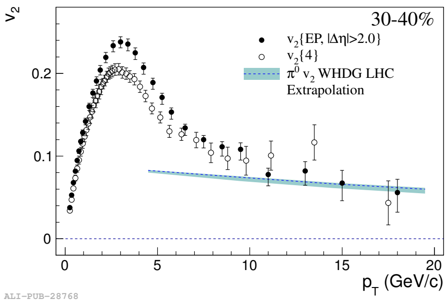


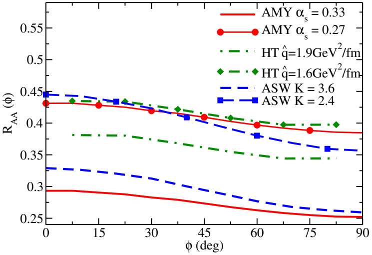
- Energy loss mechanism of jet in QGP medium is predicited by number of theoritical models, but still some controversies for the path-length dependence of energy loss. (T. Renk, PRC76, 064905, J. Auvinen et al, PRC82, 051901)
  - Elastics energy loss scheme $\Delta E \propto L$ (dominated by collisional - recoil energy loss)
  - Radiative energy loss scheme $\Delta E \propto L^2$ (medium induced gluon radiate LPM region)
  - AdS/QCD energy loss scheme $\Delta E \propto L^3$ (strongly coupled)

High p_T flow and suppression of jet particles

Flow, anisotropic particle distribtuion in transverse angle

- low p_T : Hydrodynamic evolution of almond shape system
- high p_T : Jet quenching along to in(out) plane of induced medium

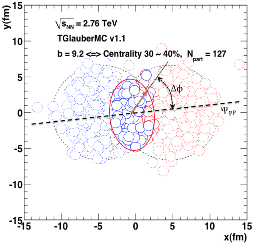




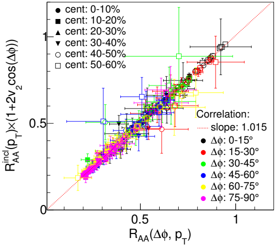
RHIC (Phys.Rev.C79.024901), R_{AA} vs. reaction plane in the 20-30% centrality event at $p_T = 6$ GeV/c. pQCD based models.

Combining R_{AA} and Flow I

$$
\begin{aligned}
R_{AA}(p_T, \Delta\phi) &= \frac{(1/N^{evt}_{AA}) d^2 N^{AA} / dp_T d\Delta\phi}{\langle N_{coll} \rangle (1/N^{evt}_{pp}) dN^{pp}/dp_T} \\
&= R_{AA}(p_T) \frac{dN^{AA}}{d\Delta\phi} \\
&= R_{AA}(p_T)(1 + \sum_{n=1} (2 v_n \cos n(\phi - \psi_n)) \\
&\sim R_{AA}(p_T)(1 + 2 v_2 \cos 2\Delta\phi)
\end{aligned}
$$

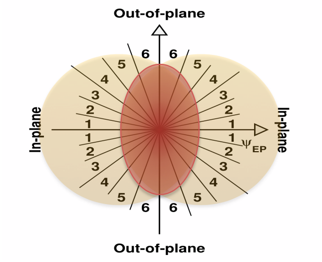


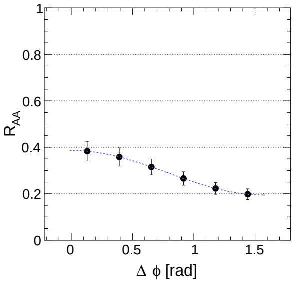
- higher order terms are neglected
- Above equation is verified with PHENIX data



Combining R_{AA} and Flow II

R_{AA} can be expressed as a function of 6 (x4) $\Delta\ \phi$ bins as shown figure below(left)



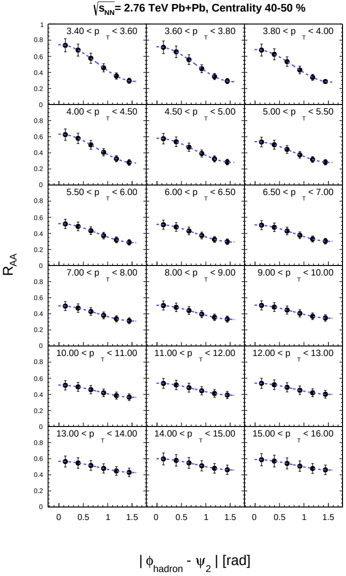


R_{AA} values for Centrality 10% $\sim$ 20%, $5.0 < p_T < 5.5$

- R_{AA} ALICE [Phys.Lett., B720, 52 - 62]
- v_2 CMS[Eur. Phys. J. C (2012) 72:1945]

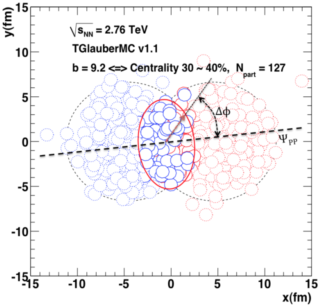
- The distribution is fitted with $N(1 + 2v_2\cos(2\Delta\phi))$ and v2 extracted from the fit (blue dotted lines) is consistent with the v2 results.

R_{AA} as a function of emssision angle for various p_T bins



Estimating path-length : Convert $\Delta\phi$ to Path-length

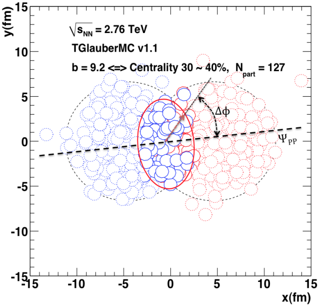
- Case I : length from center to edge of boarder
- Case II : Average length from scattering point to edge of boarder

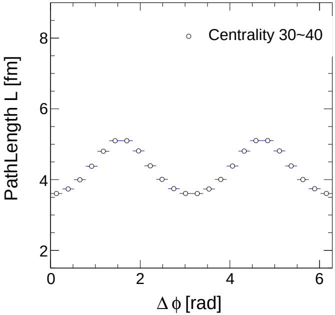


Glauber Model : Monte Calro approaches, which calculate "geometric" quantities to describe AA collisions.
The PHOBOS Glauber Monte Carlo - Alver, B. et al. arXiv:0805.4411

Path-length Case I : center to edge

- Assume that all particles produced at center of collision region. i.e. (0, 0) in figure
- then the path-length is from center to edge of the elliptical overlap zone of A-A collision
- Path-Length is radius of ellips

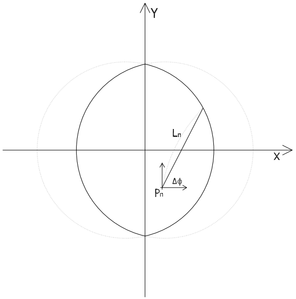


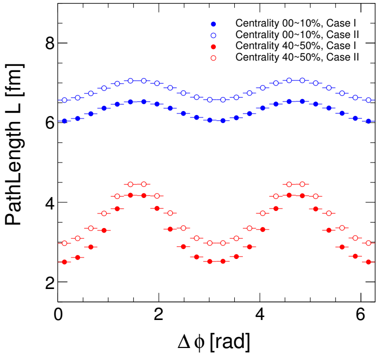


Path-length Case II: average length

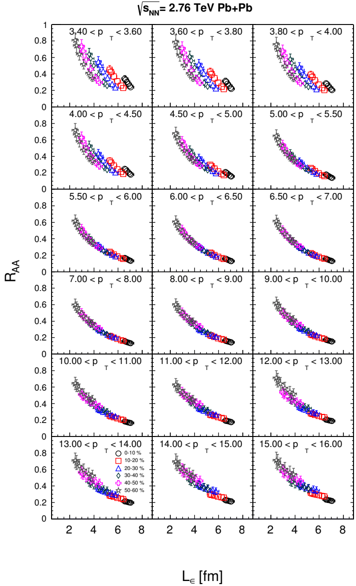
- But, in realistic situation, if the collision happens, the scattering point and the direction of scattered parton is random
- in this case Path-length can be written as

$$L(\Delta\phi) = \frac{\sum_{n=1}^{N} Ln(\Delta\phi)}{N} \qquad (1)$$





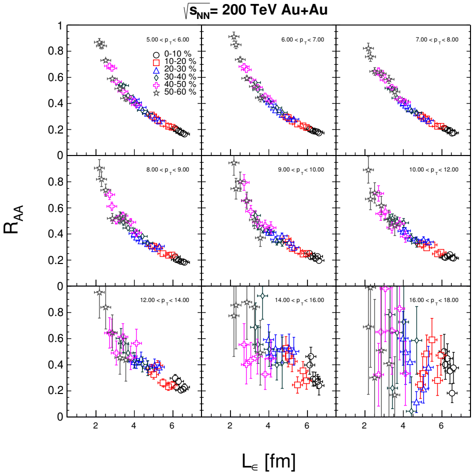
Results of R_{AA} as function of path-length(with Case II)



Result with LHC data

- R_{AA} starts to scale as a function of L for higher transverse momentum above 5 GeV/c which suggests that R_{AA} does depend on the L regardless of the centrality

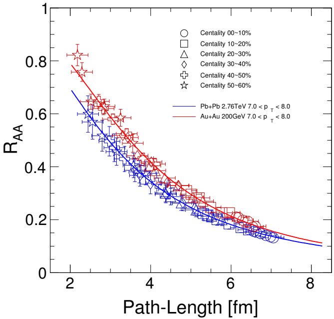
Results of R_{AA} as function of path-length(with Case II)

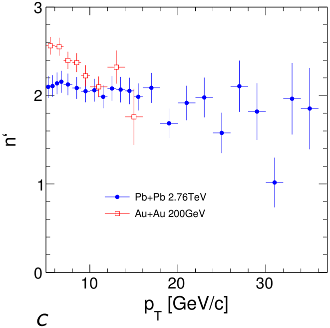


Result with RHIC data

- R_{AA} starts to scale as a function of L for higher transverse momentum above 5 GeV/c which suggests that R_{AA} does depend on the L regardless of the centrality

Understanding path-length dependence of R_{AA}





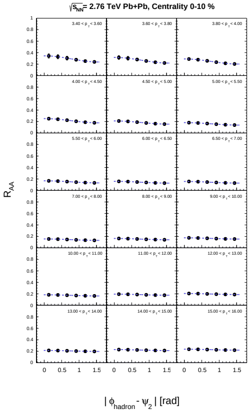
$$R_{AA}(L) = \frac{c}{c + L^{n'}} \quad (2)$$

- The result was fitted by given function and fit gives very nice descreption of distribution of R_{AA}(L)
- below 10GeV/c, n‘ at RHIC is bigger than the one in LHC by 20%, some p_T dependence in RHIC
- above 10GeV/c, n‘ around 2 both for RHIC and LHC

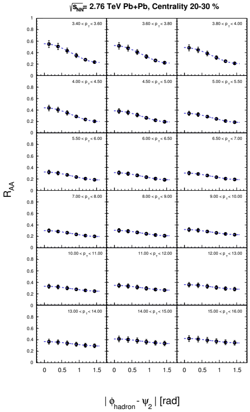
Summary

- Inclusive R_{AA} and v_2 have been measured with RHIC and LHC with good precision
  - Energy loss mechanism of jet in QGP medium is predicited by number of theoritical models, but still some controversies for the path-length dependence of energy loss.
- We tried to attempt to express jet-quenching as function of path-length by utilizing meausred R_{AA} and v_2
  - Path-length are estimated with Glauber simulation as averaged length from scattering point to the edge of collision zone
  - R_{AA} starts to scale as a function of L for higher transverse momentum above 5 GeV/c which suggests that R_{AA} does depend on the L regardless of the centrality
  - Below 10GeV/c, the n' at RHIC is bigger then the one in LHC and seems to be conversed around 2 from above 10GeV/c both for RHIC and LHC

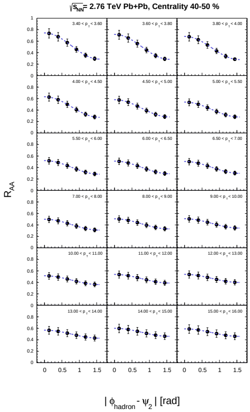
Back up



√s_NN = 2.76 TeV Pb+Pb, Centrality 0-10 %
R_AA
3.40 < p_T < 3.60
3.60 < p_T < 3.80
3.80 < p_T < 4.00
4.00 < p_T < 4.50
4.50 < p_T < 5.00
5.00 < p_T < 5.50
5.50 < p_T < 6.00
6.00 < p_T < 6.50
6.50 < p_T < 7.00
7.00 < p_T < 8.00
8.00 < p_T < 9.00
9.00 < p_T < 10.00
10.00 < p_T < 11.00
11.00 < p_T < 12.00
12.00 < p_T < 13.00
13.00 < p_T < 14.00
14.00 < p_T < 15.00
15.00 < p_T < 16.00
| φ_hadron - ψ_2 | [rad]



√s_NN = 2.76 TeV Pb+Pb, Centrality 20-30 %
R_AA
3.40 < p_T < 3.60
3.60 < p_T < 3.80
3.80 < p_T < 4.00
4.00 < p_T < 4.50
4.50 < p_T < 5.00
5.00 < p_T < 5.50
5.50 < p_T < 6.00
6.00 < p_T < 6.50
6.50 < p_T < 7.00
7.00 < p_T < 8.00
8.00 < p_T < 9.00
9.00 < p_T < 10.00
10.00 < p_T < 11.00
11.00 < p_T < 12.00
12.00 < p_T < 13.00
13.00 < p_T < 14.00
14.00 < p_T < 15.00
15.00 < p_T < 16.00
| φ_hadron - ψ_2 | [rad]



√s_NN = 2.76 TeV Pb+Pb, Centrality 40-50 %
R_AA
3.40 < p_T < 3.60
3.60 < p_T < 3.80
3.80 < p_T < 4.00
4.00 < p_T < 4.50
4.50 < p_T < 5.00
5.00 < p_T < 5.50
5.50 < p_T < 6.00
6.00 < p_T < 6.50
6.50 < p_T < 7.00
7.00 < p_T < 8.00
8.00 < p_T < 9.00
9.00 < p_T < 10.00
10.00 < p_T < 11.00
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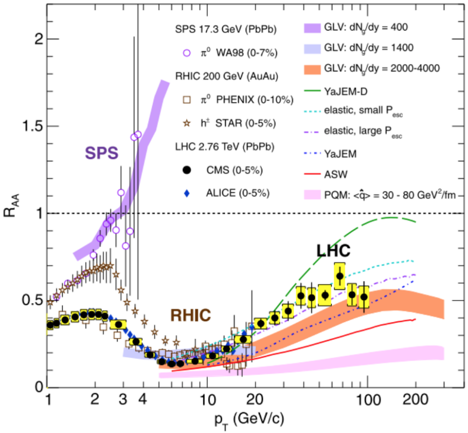
14.00 < p_T < 15.00
15.00 < p_T < 16.00
| φ_hadron - ψ_2 | [rad]

R_{AA} from RHIC to LHC



Eur. Phys. J. C (2012) 72:1945

$$R_{AA}(p_T) = \frac{(1/N_{AA}^{evt})dN^{AA}/dp_T}{\langle N_{coll}\rangle(1/N_{pp}^{evt})dN^{pp}/dp_T} \quad (3)$$

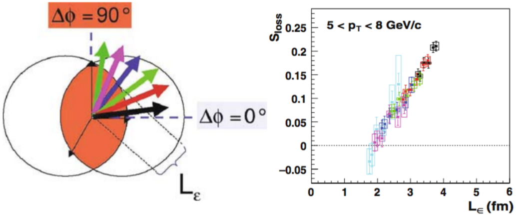
- From R_{AA} one can approximately obtain the fraction of energy lost, $E_{loss} = \Delta p_T/p_T$, via

$$E_{loss} \sim 1 - R_{AA}^{1/(n-2)}$$

where n is power laws in invariant spectra

- Suppression of high pT RAA can be related to path-length dependent energy loss

- Suppression of high p_T particles can be related with path-length using the centrality dependent R_{AA} and the azimuthal angle determined by elliptic flow
- Many models were developed to explain the high p_T suppression as result of energy loss of Jet, but still challenging for models to explain R_{AA} and flow simultaneously
- By combining R_{AA} and flow, we can estimate the partonic energy loss as a function of path-length travsed by the parton in the medium



S.S. Adler et al. [PHENIX Collaboration]: Phys. Rev. C 76, 034904 (2007) 310, 316, 317