Quark Matter Review

Single hadron suppression and jet transport coefficient

Central China Normal University
Xie Man
2018/5/30

High frequency words

Critical temperature

J/ψ

Flow v2 v3

Cold nuclear effect

FFs

D0

Jet quenching

Pb+Pb collisions

R_{AA}

η/s

QGP

Jet

Energy loss

Heavy flavour

Ideal hydrodynamics

Jet transport

Au+Au collisions

Strangness particle

Medium response

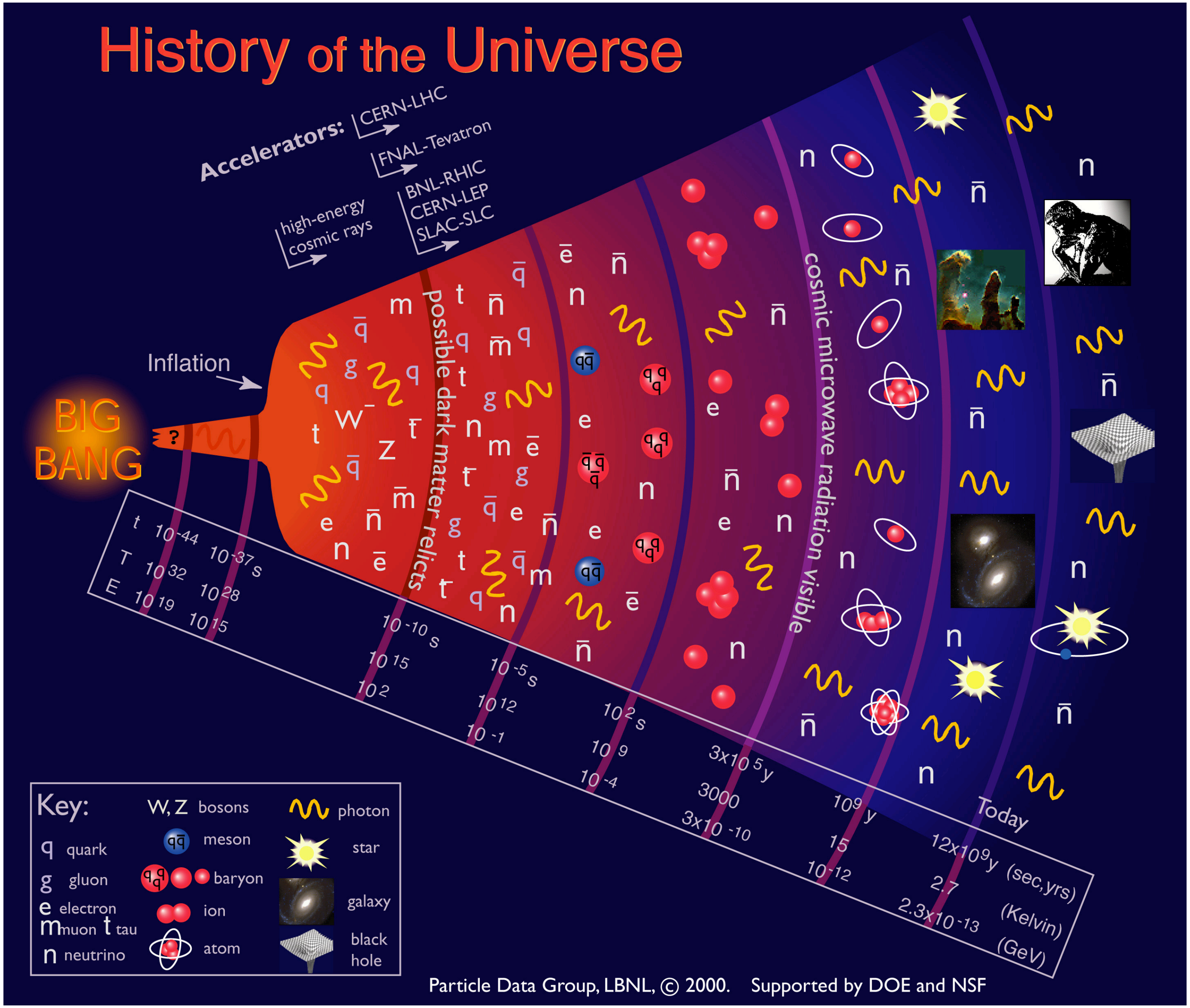
MC

Xe+Xe collisions

quarkonium

PDF

Electromagnetic probes


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
t 10^-44 10^-37 s
T 10^32 10^28
E 10^19 10^15
10^-10 s
10^15
10^2
10^-5 s
10^12
10^-1
10^2 s
10^9
10^-4
3x10^5 y
3000
3x10^-10
10^9 y
15
10^-12
Today
12x10^9 y (sec,yrs)
2.7 (Kelvin)
2.3x10^-13 (GeV)
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
e electron
ion
galaxy
m muon t tau
n neutrino
atom
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

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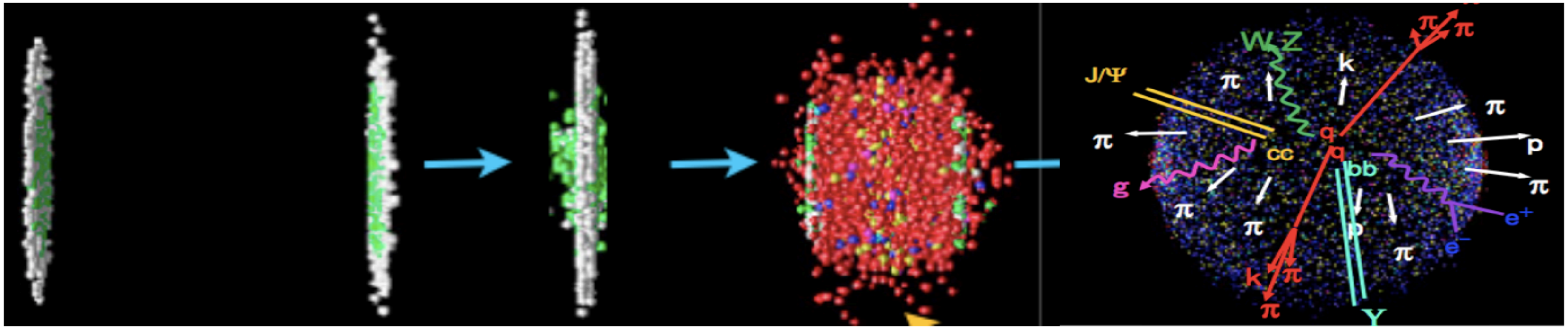
Outline

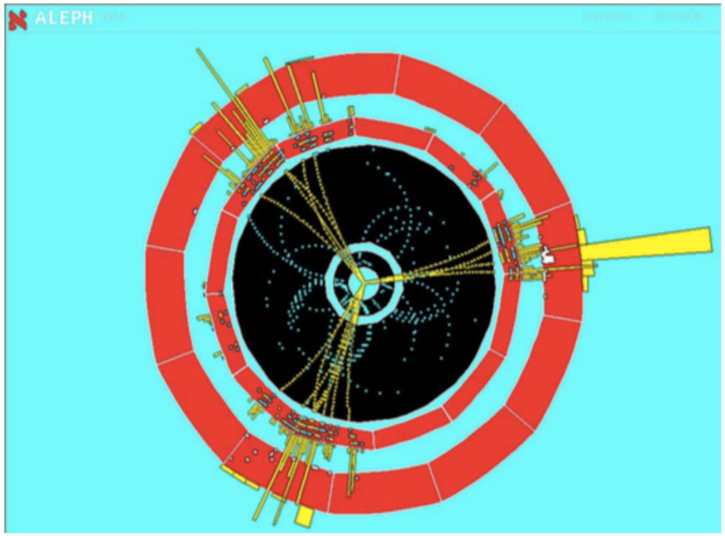
- Introduction
- Jet, jet quenching
- Extracted $\hat{q}_0$ via single hadron R_{AA}
- Xe+Xe collisions at 5.44TeV
- Summary

What is a jet?



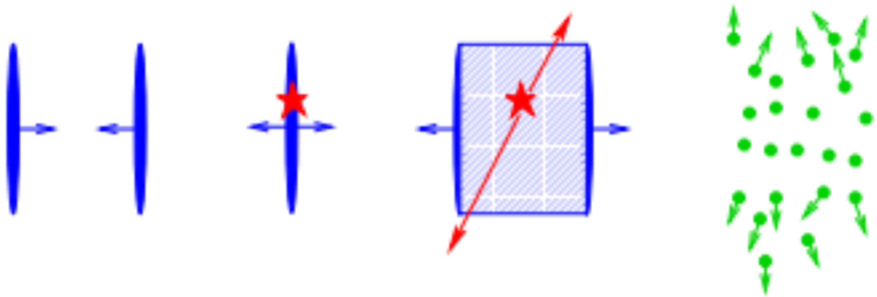
A jet is:

- ➢a collimated spray of hadrons
- ➢ result of fragmentation of an energetic quark or gluon



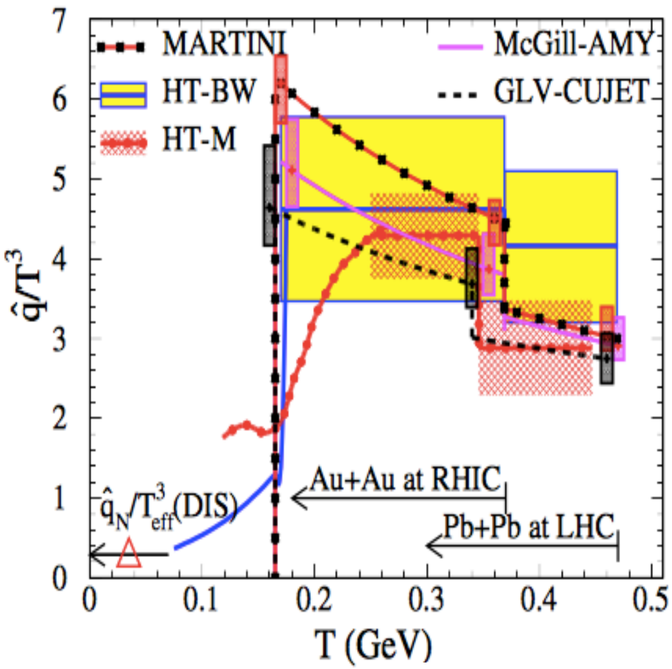
From QM 2018

Jet quenching



- The hard jet losses a large amount of its energy via radiating gluon induced by multiple scattering. [X.-N. Wang and M. Gyulassy, Phys. Rev. Lett. 68, 1480(1992)]
- Jet energy loss in the QGP medium: $\Delta E \propto \hat{q}$---jet transport coefficient.
- $\hat{q} \equiv \frac{d<q_T^2>}{dL}$:transverse momentum broadening squared per unit length. [BDMPS, NPB482(1997)291]

Extracting $\hat{q}$



In the initial time and in the center of the fireball

$$\hat{q} \approx \begin{cases} 1.2 \pm 0.3 \\ 1.9 \pm 0.7 \end{cases} \mathrm{GeV}^2/\mathrm{fm} \;\; \mathrm{at} \;\; \begin{matrix} \mathrm{T{=}370\ MeV,} \\ \mathrm{T{=}470\ MeV,} \end{matrix}$$

The JET collaboration.
arXiv:1312.5003,Dec 2013

$$\hat{q}_0(GeV^2/fm) \approx \begin{cases} 1.1 \pm 0.2 & at \;\; T = 373MeV \\ 1.7 \pm 0.3 & at \;\; T = 473MeV \end{cases}$$

$$\lambda_0(fm) \approx \begin{cases} 0.4 \pm 0.03 & at \;\; T = 373MeV \\ 0.5 \pm 0.05 & at \;\; T = 473MeV \end{cases}$$

[Z Liu, HZ Zhang, BW Zhang and E Wang, Eur. Phys. J. C (2016) 76: 20]

Extracting $\hat{q}$

- Modified fragmentation functions in QGP medium:

$$D_{h/c}(z_c,\mu^2,\Delta E_c) = (1-e^{-\langle N_g\rangle})\left[\frac{z_c{}'}{z_c}D^0_{h/c}(z_c{}',\mu^2) + \langle N_g\rangle\frac{z_g{}'}{z_c}D^0_{h/g}(z_g{}',\mu^2)\right]$$

$$+e^{-\langle N_g\rangle}D^0_{h/c}(z_c,\mu^2)$$

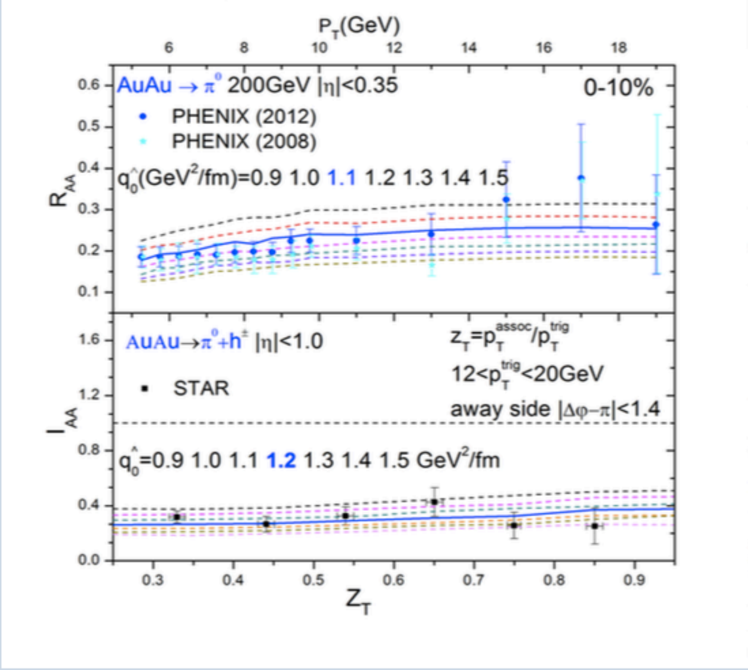
where $z_c{}' = p_T/(p_{Tc}-\Delta E_c)$, $z_g{}' = \langle N_g\rangle p_T/\Delta E_c$.
[X.-N. Wang, PRC70 (2004) 031901], [H. Z. Zhang, J.F. Owens, Phys. Rev. Lett. 98.212301 (2007)], and [H. Z. Zhang, J.F. Owens, Phys. Rev. Lett. 103, 032302 (2009)]

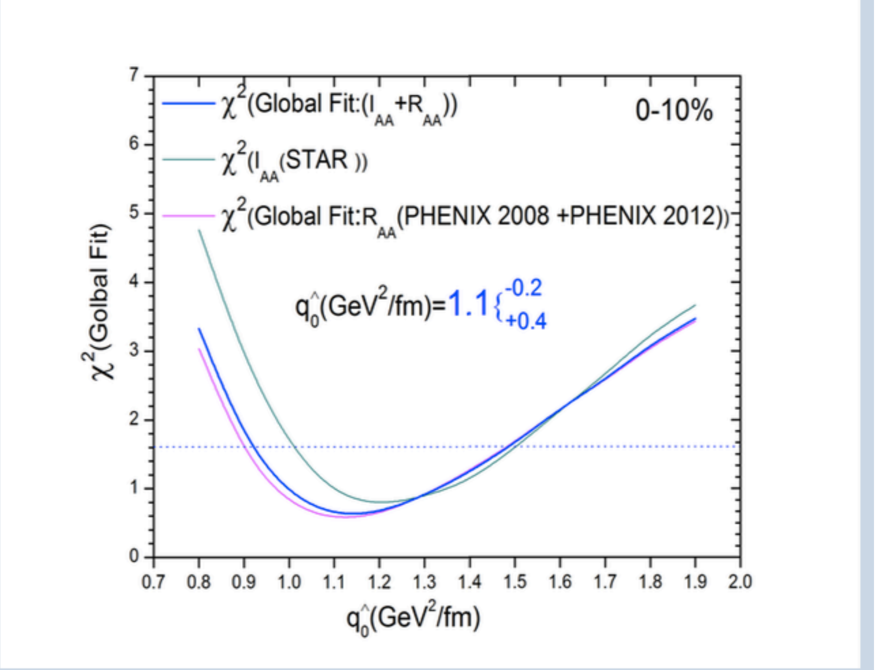
- Total energy loss of jet in high-twist method:

$$\frac{\Delta E}{E} = C_A\frac{\alpha_s}{2\pi}\int d\tau\int_0^{Q^2}\frac{dl_T^2}{l_T^4}\int_\epsilon^{1-\epsilon}dz\left[1+(1-z)^2\right]\times\hat{q}_F(y)4sin^2\left(\frac{l_T^2\tau}{4z(1-z)E}\right)$$

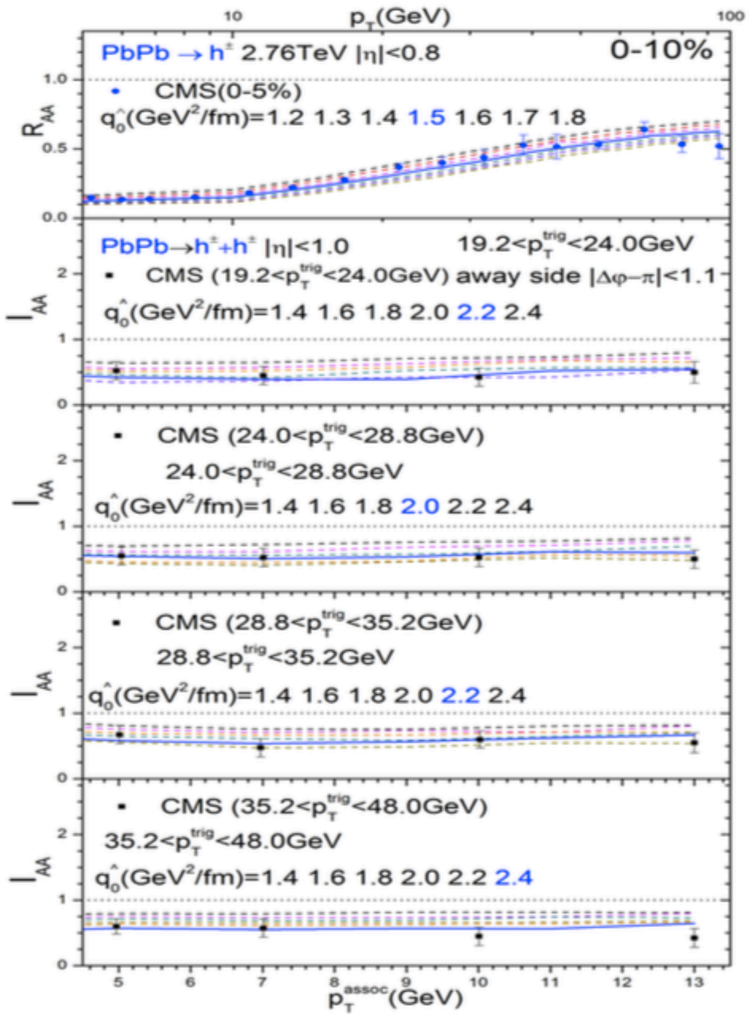
[W.T. Deng and X.-N. Wang, Phys. Rev. C81,024902(2010)], [E. Wang and X.-N. Wang, Phys. Rev. Lett. 87, 142301 (2001); 89, 162301 (2002)]

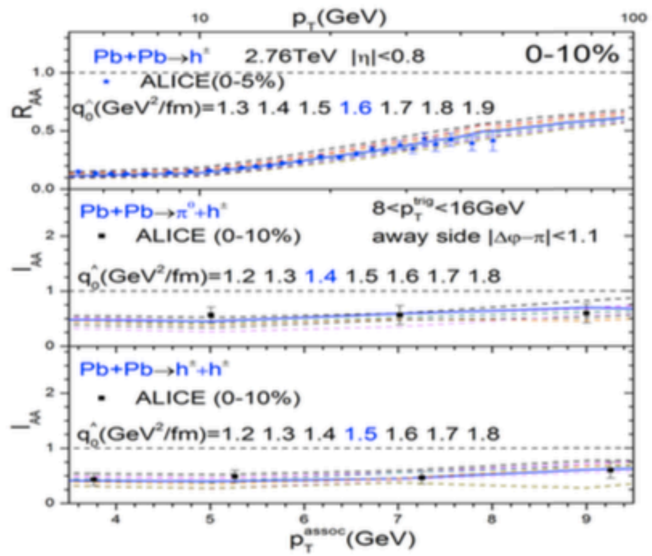
Extracting $\hat{q}$: Au+Au @200GeV

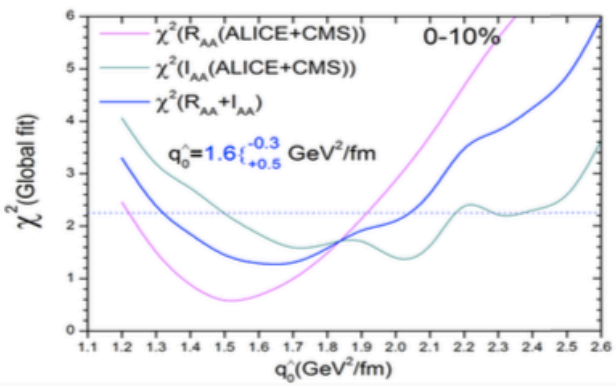




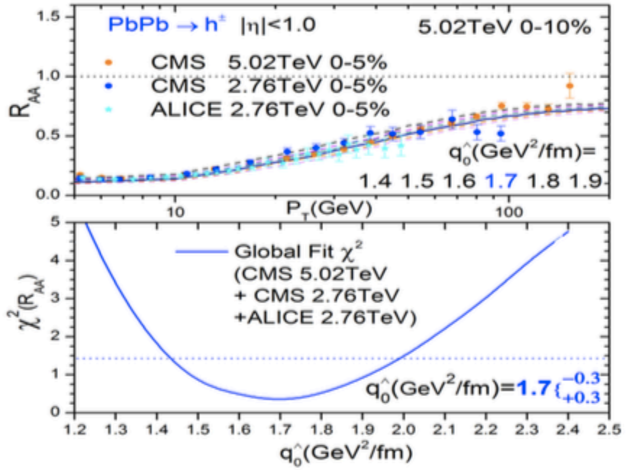
Extracting $\hat{q}$: Pb+Pb @ 2.76 TeV

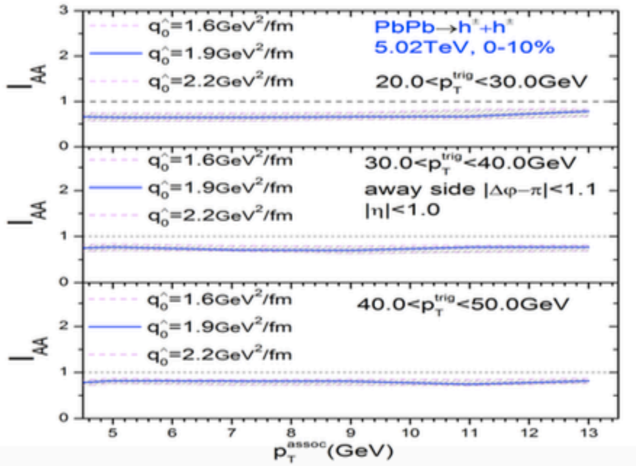






Extracting $\hat{q}$: Pb+Pb @ 5.02 TeV





Xe-Xe @ 5.44TeV

Xe-Xe collisions @ 5.44 TeV

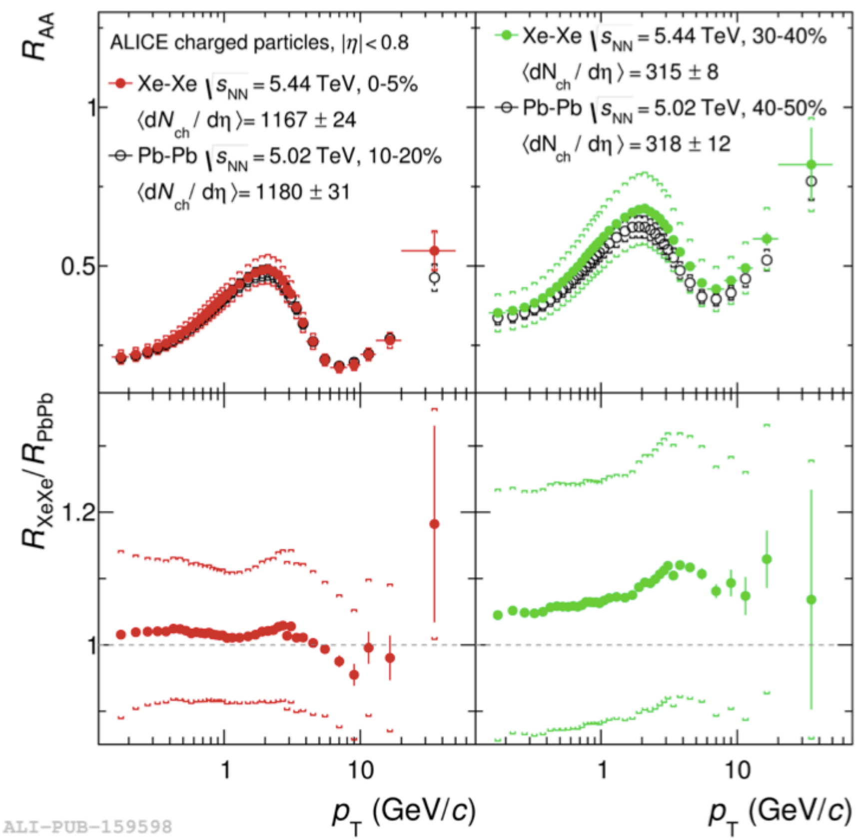
new

R_{AA} in Xe-Xe collisions

R_{AA} in central Xe-Xe collisions is similar to R_{AA} in Pb-Pb collisions at similar multiplicity.

→ Possibly the result of a non-trivial interplay of geometry and path length dependence.

D. Sekihata, Tue 09:00 [arXiv:1805.04399]

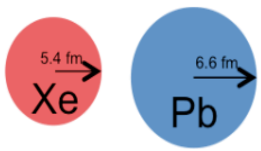


[QM 2018 ALICE]

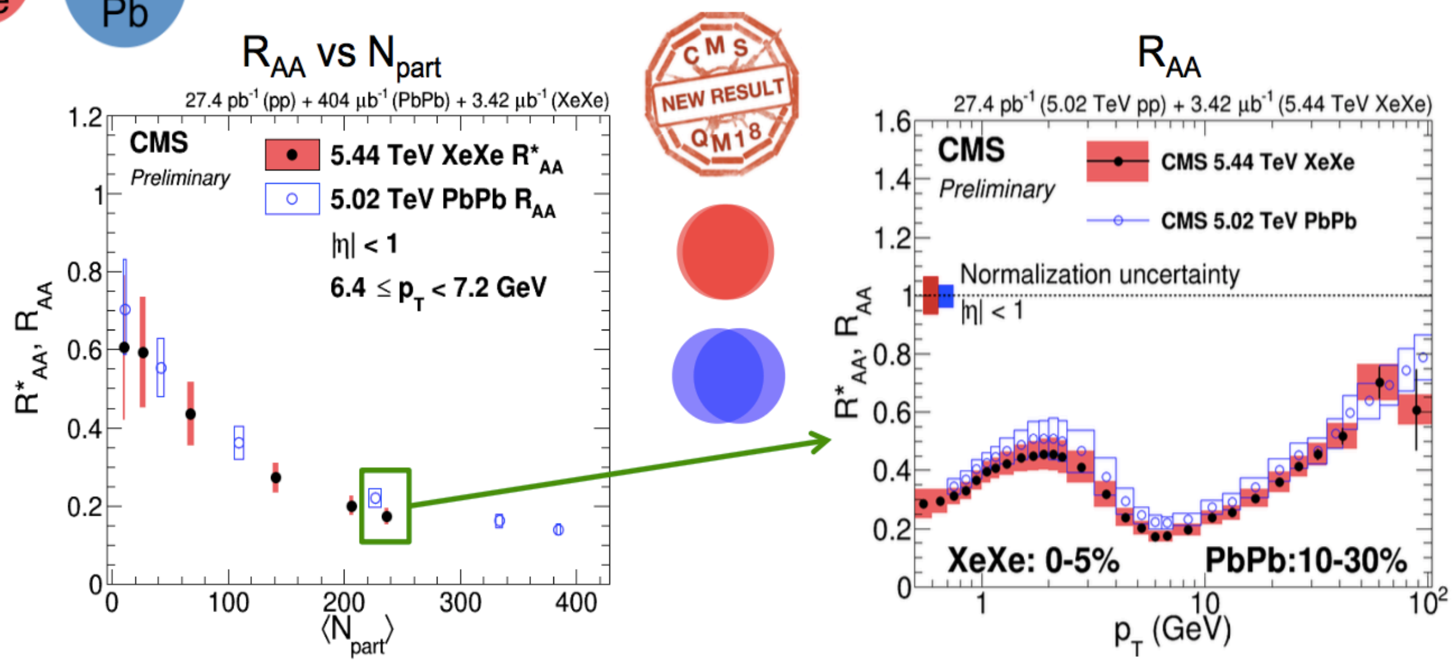
Xe-Xe collisions @ 5.44 TeV

new

CMS-PAS-HIN-18-004



XeXe: charged hadron R_{AA}



Similar scaling in XeXe and PbPb

Within uncertainties R_{AA} consistent

Talk, Jet modifications, Tue. 9:20, A. Baty

[QM 2018 CMS]

Xe-Xe collisions @ 5.44 TeV

new

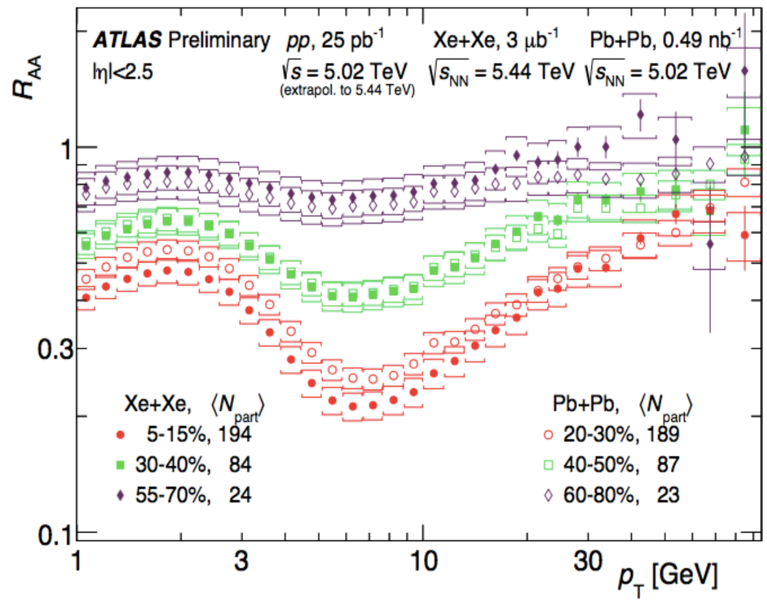
RAA FOR CHARGED HADRONS IN XE+XE

ATLAS-CONF-2018-007

NEW

16

- Measurement of charged-hadron spectra measured in Xe+Xe collisions at 5.44 TeV
  - Addresses a question about a role of geometry in HI collisions
- R_{AA} shows a centrality-dependent suppression with characteristics already observed in Pb+Pb
  - Increase to p_T=2 GeV (maximum), decrease to p_T~7 GeV (minimum), and again increase up to p_T~60 GeV
- R_{AA} in Xe compared to Pb in similar <N_{part}> intervals
  - In **central events**, hadron yields in **Xe more suppressed** to those in Pb, while in **peripheral events, milder suppression in Xe** than Pb
  - Also shapes of R_{AA} seem to be systematically different in two collision systems



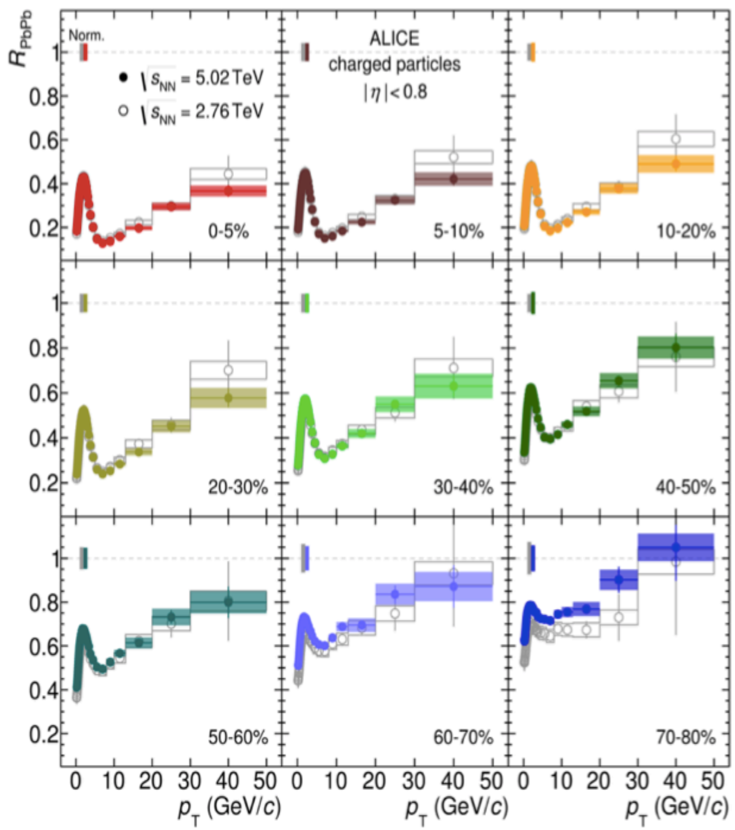
Talk by P.Balek on Tue 9:40

[QM 2018 ATLAS]

Charged hadron R_{AA} Pb+Pb @ 5.02 TeV vs. 2.76 TeV

R_{AA} of charged particles at 2.76 and 5.02 TeV

ALICE collaboration : arXiv:1802.09145



- Strong centrality dependence.
- Similar R_{AA} for the two collision energies, but harder p_T slope at higher collision energy.

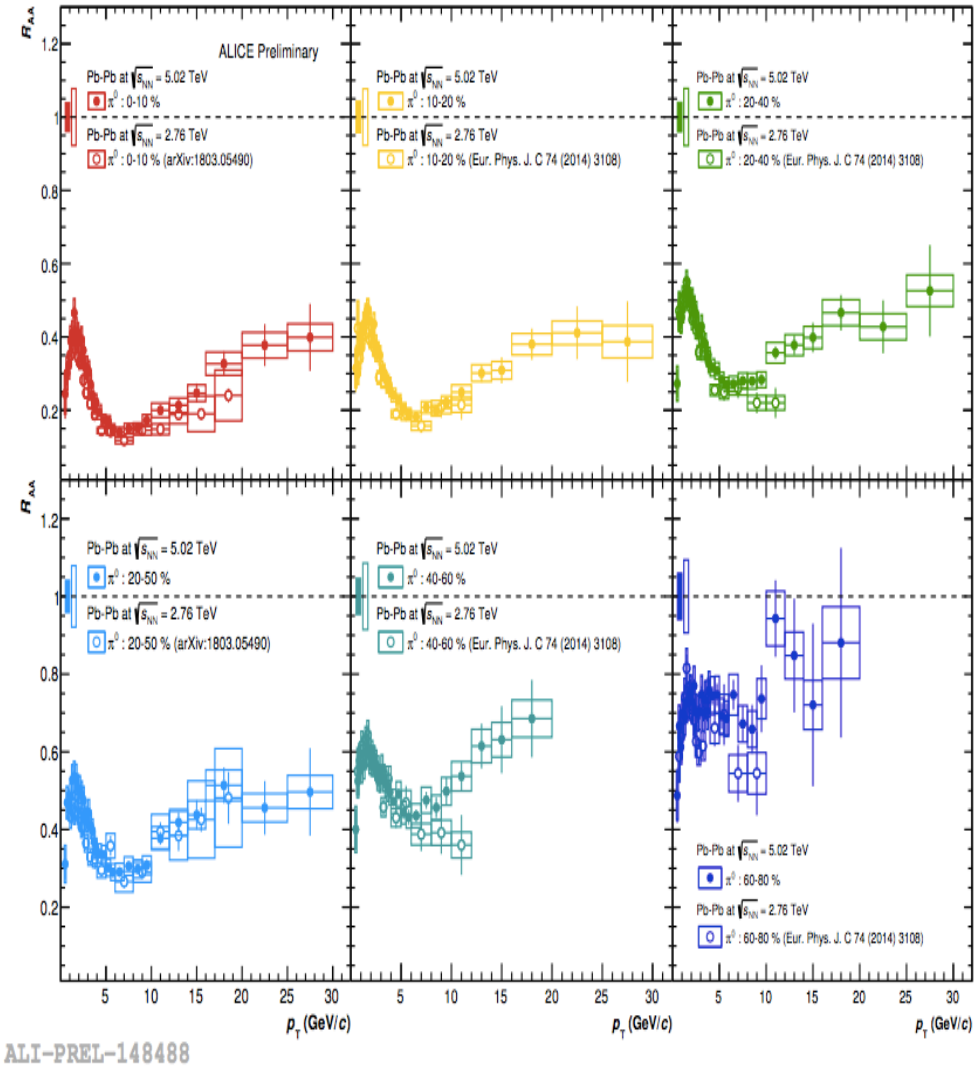
→ Larger energy loss at higher collision energy.

- Strongest suppression by a factor of about 8 at p_T = 6-7 GeV/c in the most central collisions (0-5%).
- The suppression is about 30% for the intermediate p_T and reaches unity for the highest p_T bin in peripheral collisions (70-80%).

[QM 2018 ALICE]

Comparison of π^0 R_{AA} at 2.76 and 5.02 TeV

NEW



- Well defined fragmentation function for an identified hadron, compared to inclusive charged particles.
- Strong centrality dependence.
- Similar R_{AA} for the two collision energies.

2010 data
ALICE collaboration :
Eur. Phys. J. C (2014) 74:3108

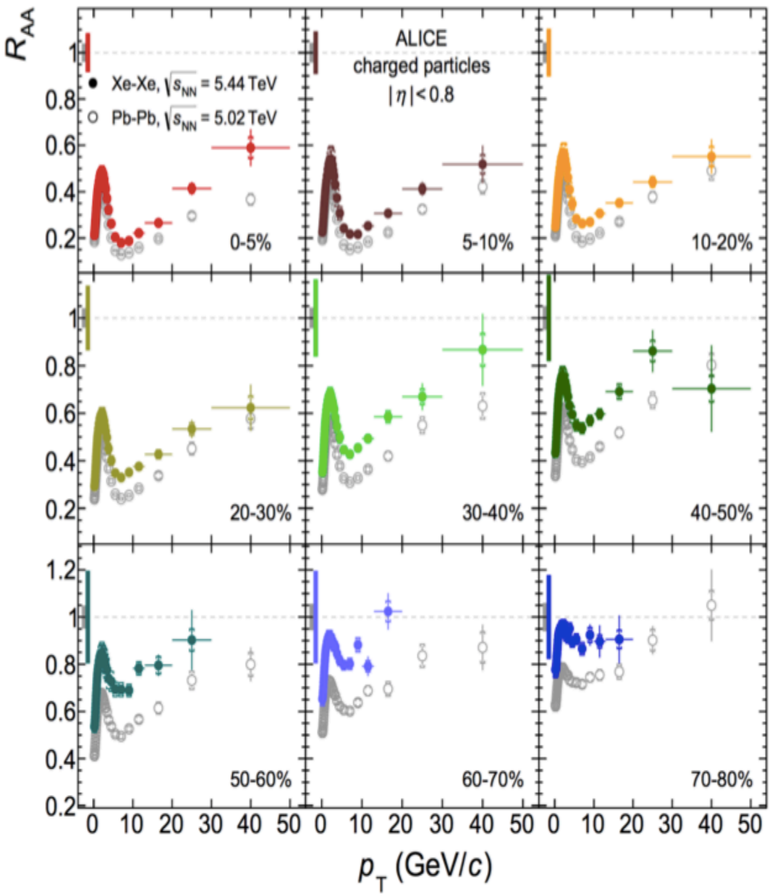
2011 data
ALICE collaboration :
arXiv:1803.05490

R_{AA}: Xe-Xe @ 5.44 TeV & Pb-Pb @ 5.02 TeV

R_{AA} in Xe-Xe at 5.44 TeV

NEW

arXiv:1805.04399 ALICE



- Strong centrality dependence.
- A minimum around p_T = 6-7 GeV/c and an almost linear rise at higher p_T.
- The strongest suppression by a factor of about 6 at the minimum in the most central collisions (0-5%).
- R_{AA} = 0.6 at the highest p_T bin (30-50 GeV/c) in the most central collisions.

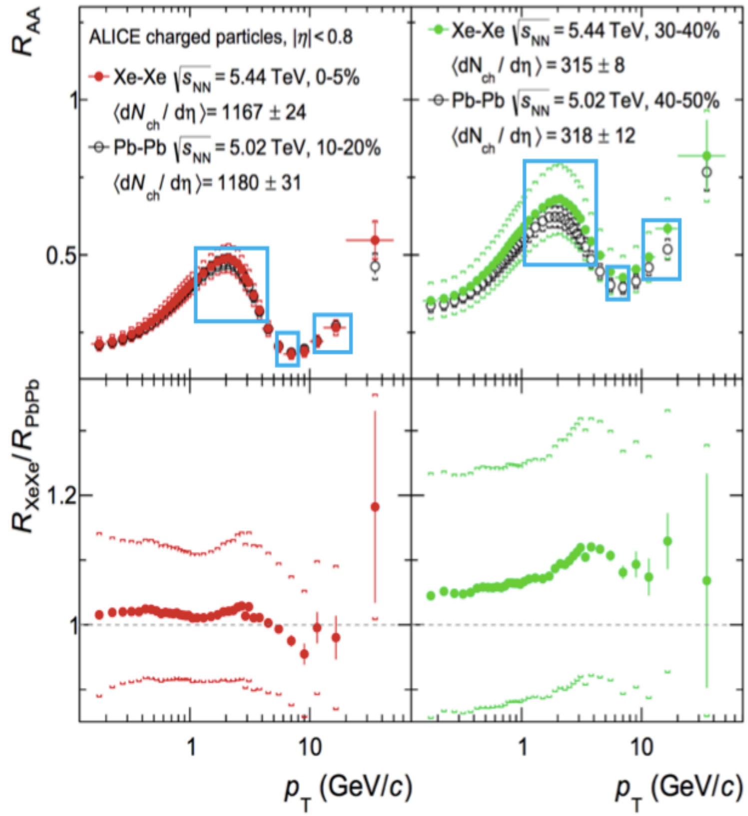
[QM 2018 ALICE]

Xe-Xe collisions @ 5.44 TeV

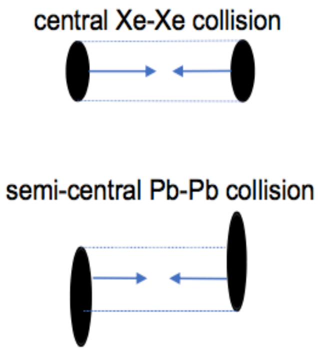
R_{AA} in Xe-Xe and Pb-Pb vs. p_T at similar $dN_{ch}/d\eta$

NEW

arXiv:1805.04399 ALICE



- Similar R_{AA} in the most central Xe-Xe collisions to that in 10-20% Pb-Pb collisions over the entire p_T range.
- Agreement of R_{AA} between 30-40% Xe-Xe and 40-50% Pb-Pb collisions within uncertainties.



centrality	N_{part}
0-5% Xe-Xe	236 ± 2
10-20% Pb-Pb	263 ± 4
30-40% Xe-Xe	82.2 ± 3.9
40-50% Pb-Pb	86.3 ± 1.7

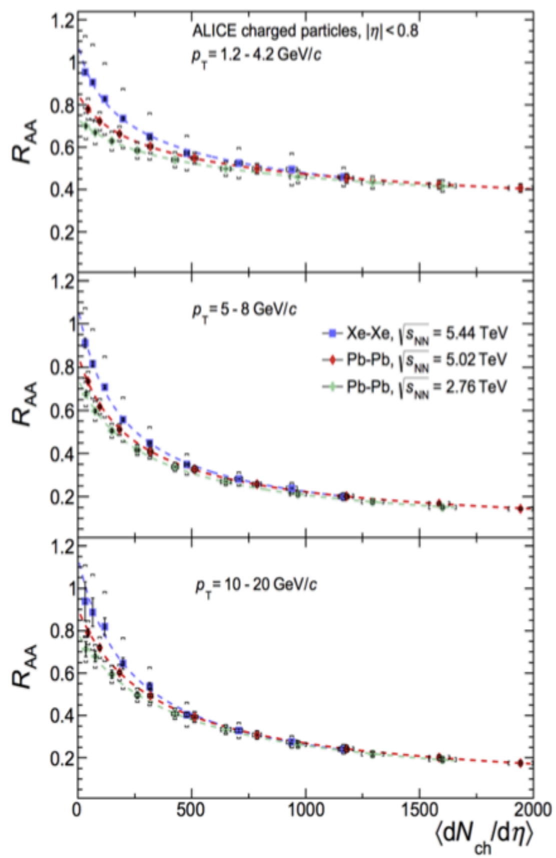
[QM 2018 ALICE]

Xe-Xe collisions @ 5.44 TeV

R_{AA} in Xe-Xe and Pb-Pb vs. $dN_{ch}/d\eta$

NEW

arXiv:1805.04399 ALICE



- A remarkable similarity in R_{AA} is observed between Xe-Xe collision at $\sqrt{s_{NN}}$ = 5.44 TeV and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 and 2.76 TeV for $dN_{ch}/d\eta > 400$.

$\langle \Delta E \rangle \propto \varepsilon \times L^2 \propto \langle dN_{ch}/d\eta \rangle / A_T \times L^2$

ΔE : radiative energy loss

ε : energy density

L : path length (related to the radius of the nucleus)

A_T : initial transverse area = $\pi \times r^2$ (r : radius of the colliding nuclei)

Phys. Rev. C 97, 034904
arXiv:0902.2011

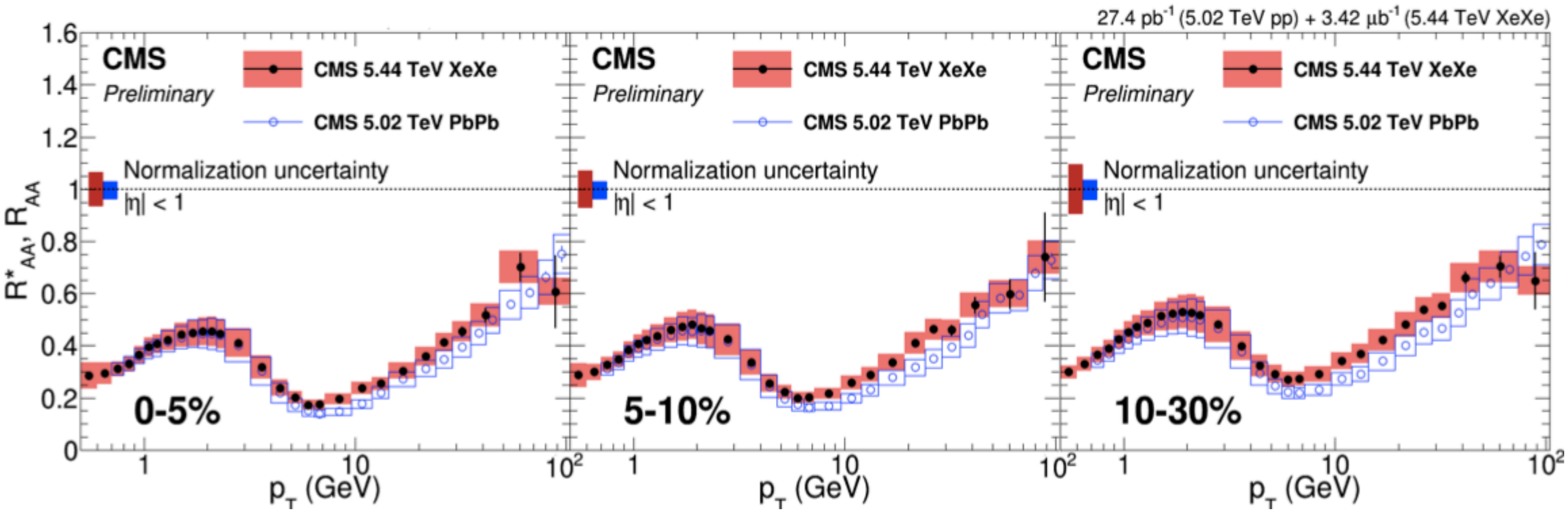
→This result can provide insight on the path length dependence of medium induced parton energy loss.

[QM 2018 ALICE]

CMS

- R^*_{AA} – asterisk denotes use of extrapolated reference
- XeXe R^*_{AA} compared with PbPb R_{AA}
- Strong suppression in XeXe
  - Similar oscillatory shape as PbPb
- XeXe and PbPb agree well for p_T< 3 GeV
- Indication of less suppression at higher p_T

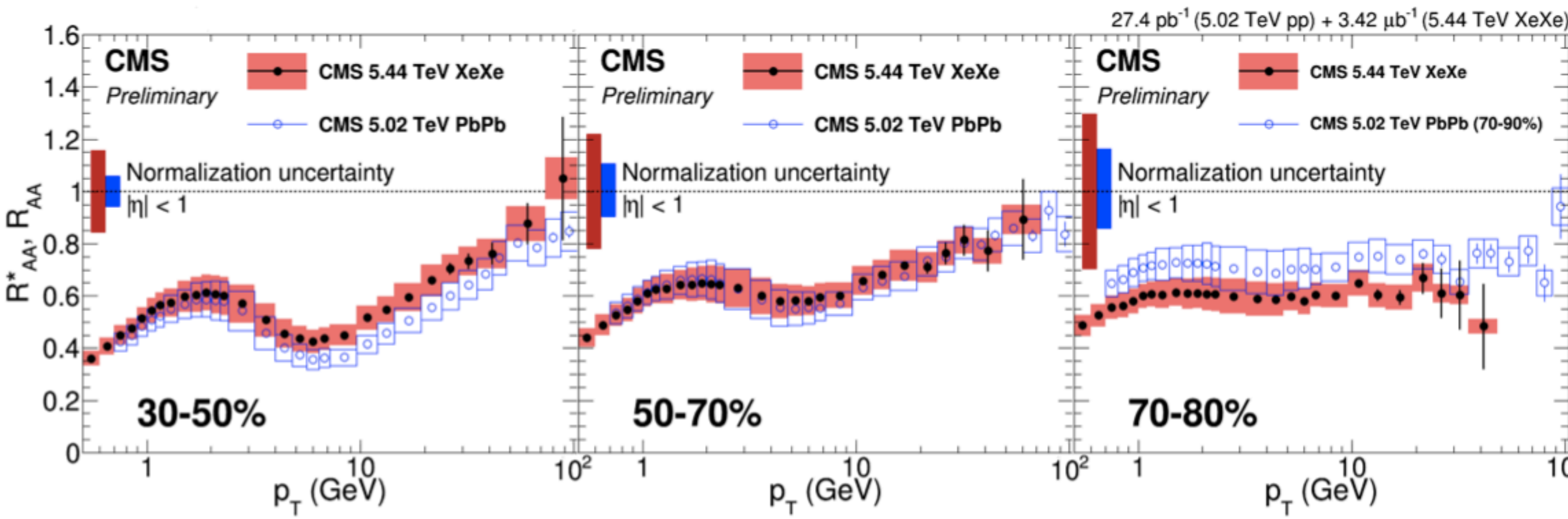
CMS-PAS-HIN-18-004



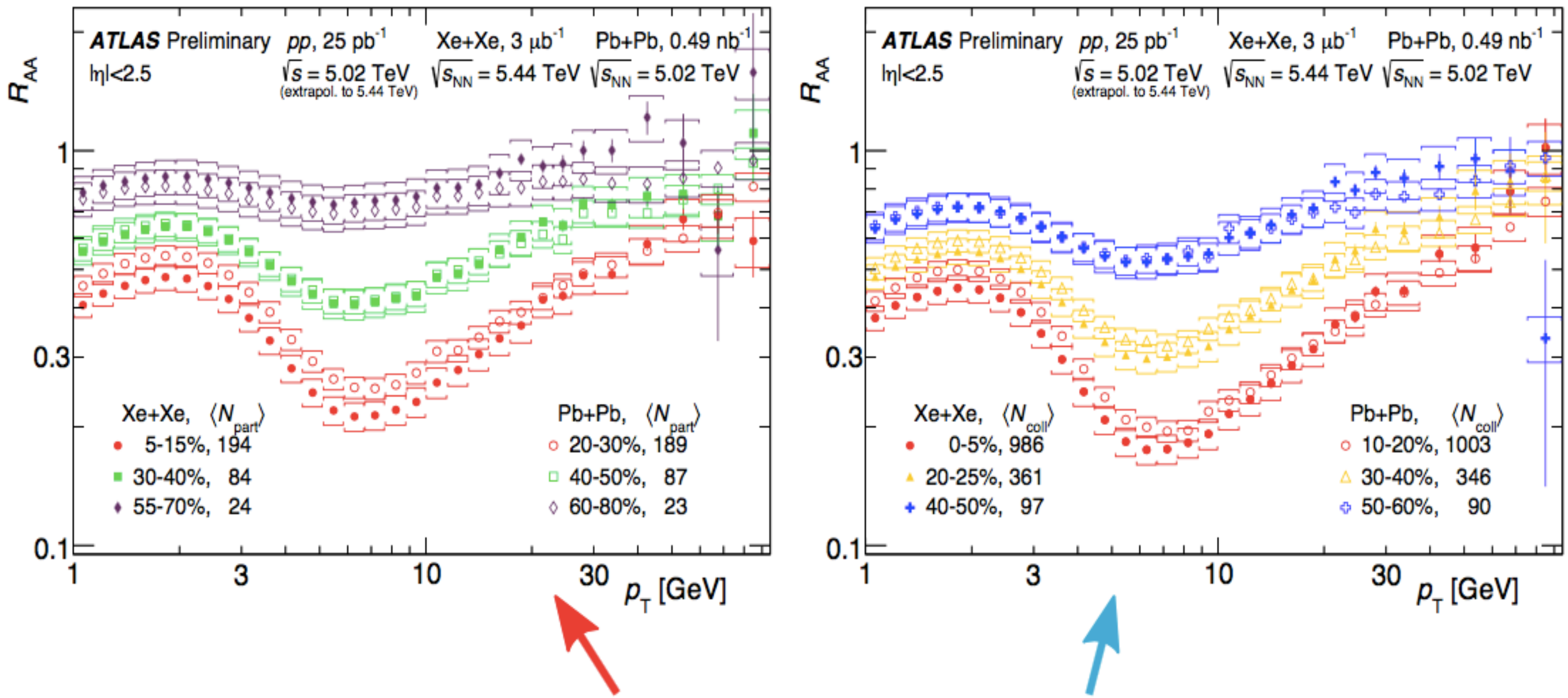
CMS

- XeXe R^*_{AA} increases in more peripheral events until last centrality bin
- Flat trend in 70-80% XeXe
  - Larger suppression than 70-90% PbPb events
  - 30% normalization uncertainty (T_{AA} + event selection efficiency)
- Strong quenching not expected in peripheral events
  - Could also be affected by p_T-dependent event selection biases

CMS-PAS-HIN-18-004



charged hadron R_{AA} in Xe+Xe and Pb+Pb

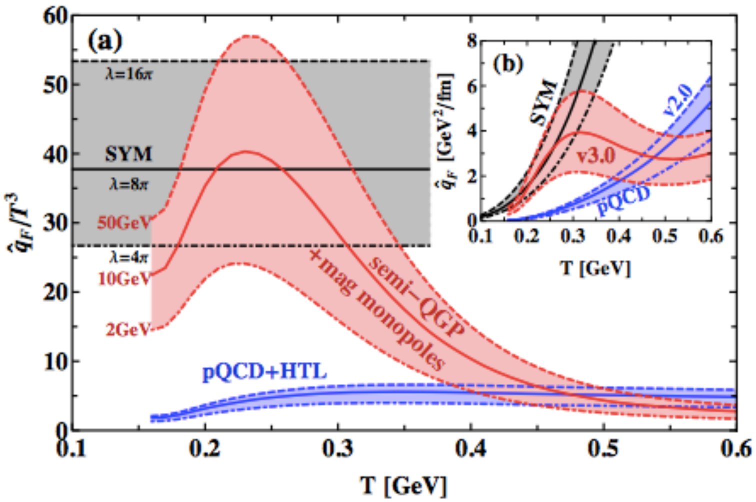


- same colors have similar $\langle N_{\mathrm{part}} \rangle$ and similar $\langle N_{\mathrm{coll}} \rangle$
- very similar p_T dependency in Xe+Xe as in Pb+Pb
- although the shape is not exactly the same

Summary and Outlook

- Large p_T hadrons are studied in a NLO pQCD parton model in heavy-ion collisions with mFFs due to jet quenching.
- We obtain $\hat{q}_0 \approx 1.1\{^{-0.2}_{+0.4}\ GeV^2/fm$ for central Au+Au collisions at 200GeV, and $\hat{q}_0 \approx 1.6\{^{-0.3}_{+0.5}\ GeV^2/fm$ for Pb+Pb central collisions at 2.76 TeV. We also have predicted the dihadron suppression factors for Pb+Pb collisions at 5.02TeV.
- Next we will use the latest data of Xe+Xe collisions to extract $\hat{q}_0$, and predict dihadron suppression factors for it.
- And, to study the temperature dependence of $\hat{q}\ /T^3$.

Back up: R_{AA} & v_2

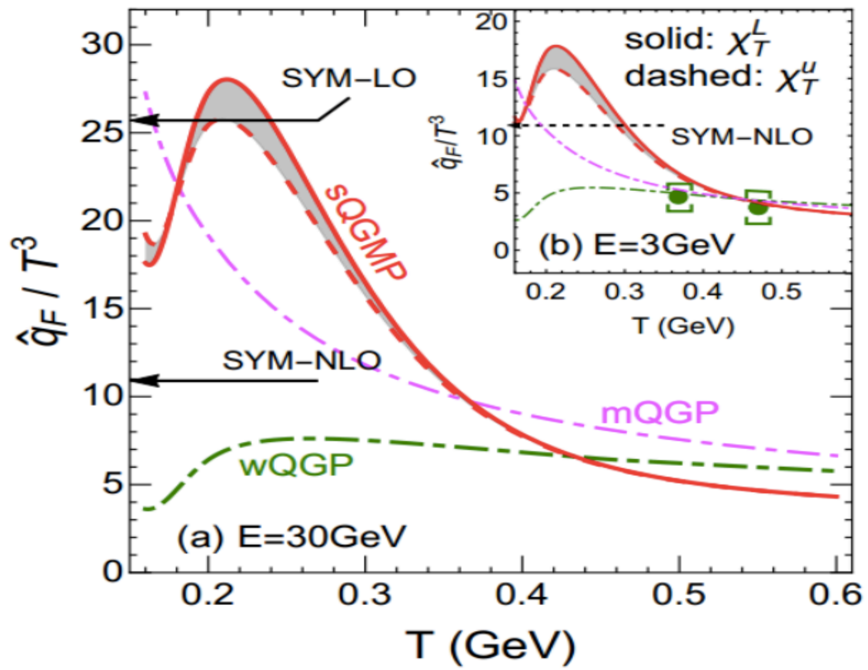


Assume $\hat{q}/T^3$ is linear dependent on T

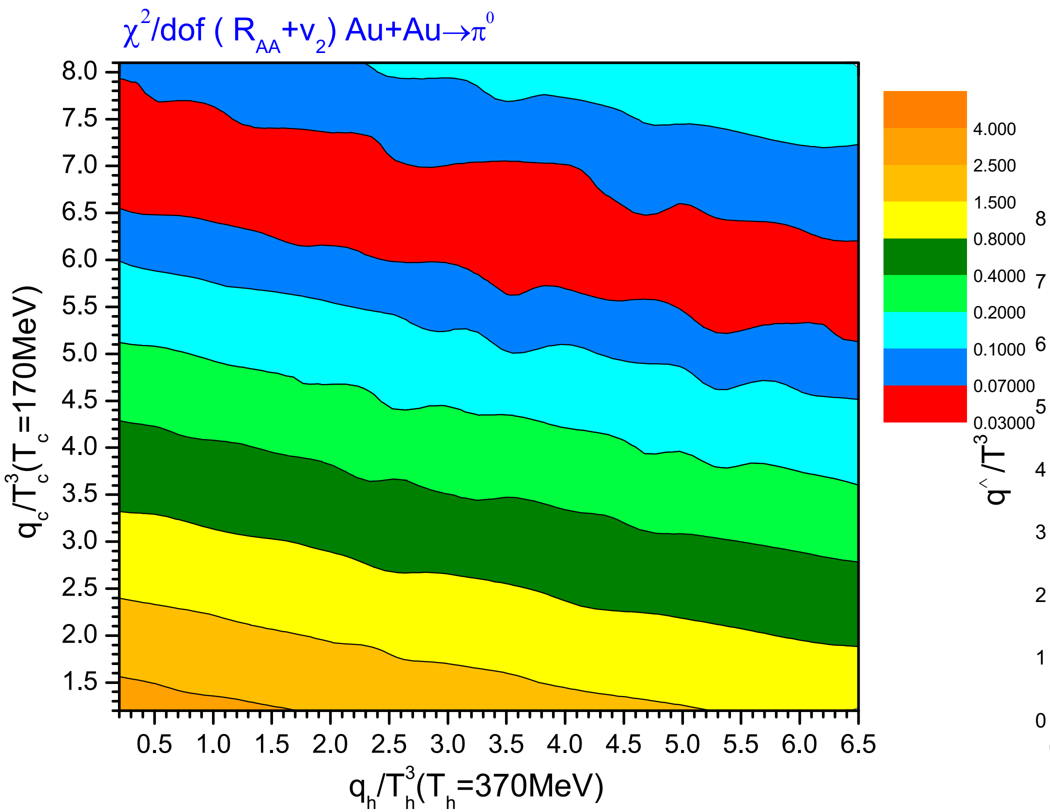
$$\frac{\hat{q}/T^3 - \hat{q}_c/T_c^3}{T - T_c} = \frac{\hat{q}_h/T_h^3 - \hat{q}_c/T_c^3}{T_h - T_c}$$

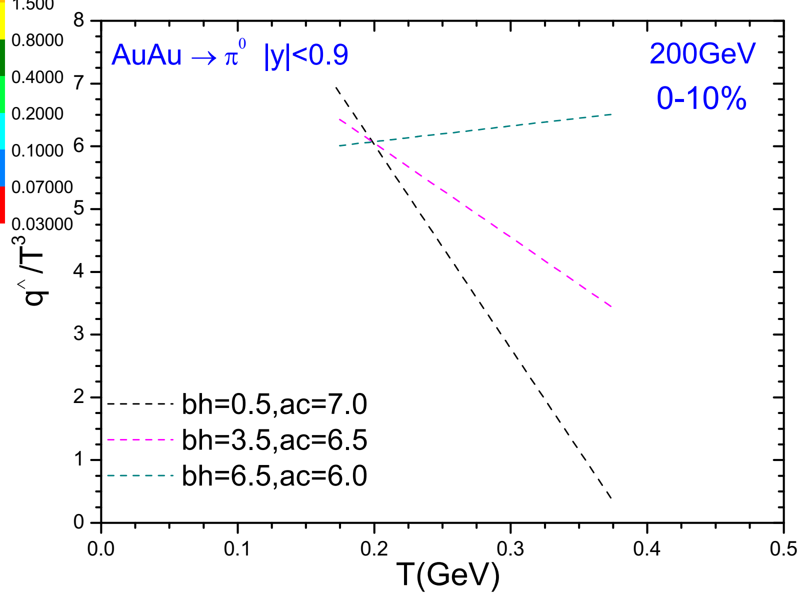
Two inputs: $\hat{q}_c/T_c^3$ $\quad T_c = 170 MeV$

$\hat{q}_h/T_h^3$ $\quad T_h = 370 MeV$

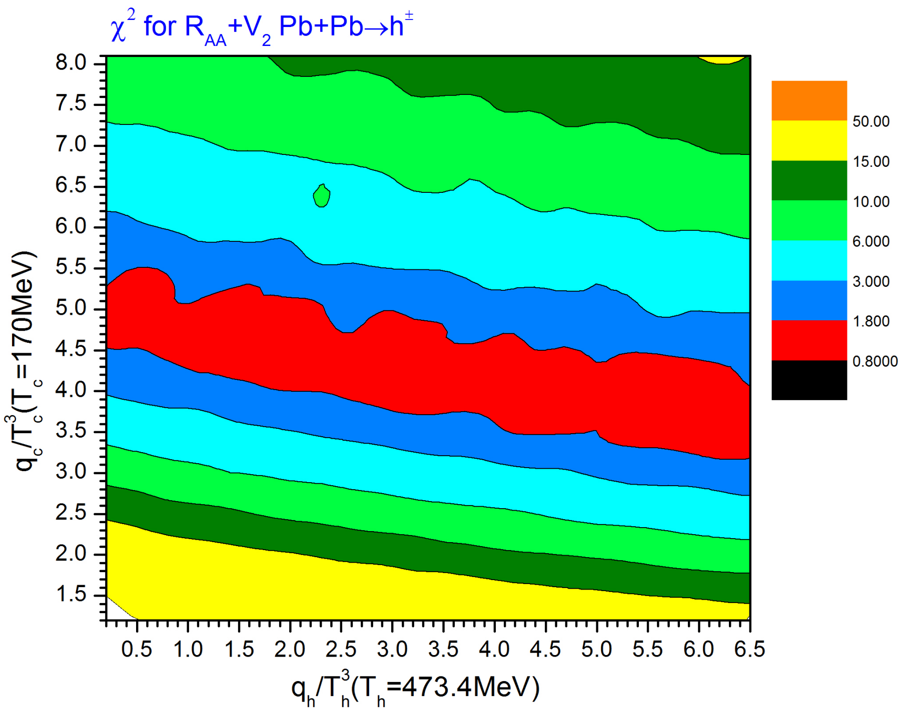


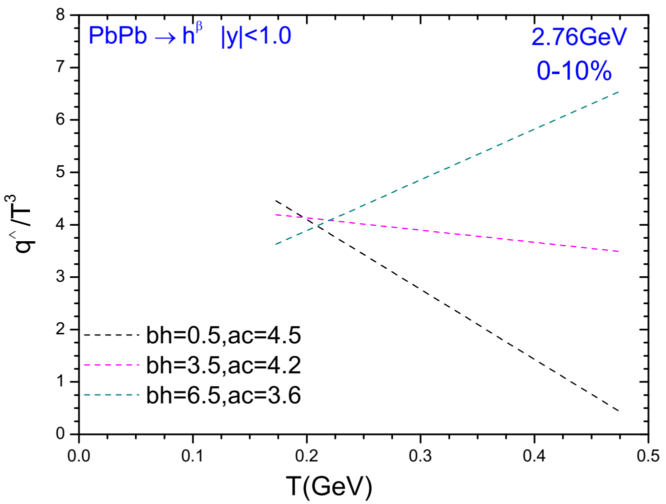
Back up: RHIC R_{AA}&v_2





Back up: LHC R_{AA}&v_2





- Partons originating from initial hard scatterings lose their energy in the hot and dense medium, which results in suppression of high pT hadrons.
- NEW: utilise **Xe collisions** to shed light on a role of geometry in HI collisions

Jet transport coefficient

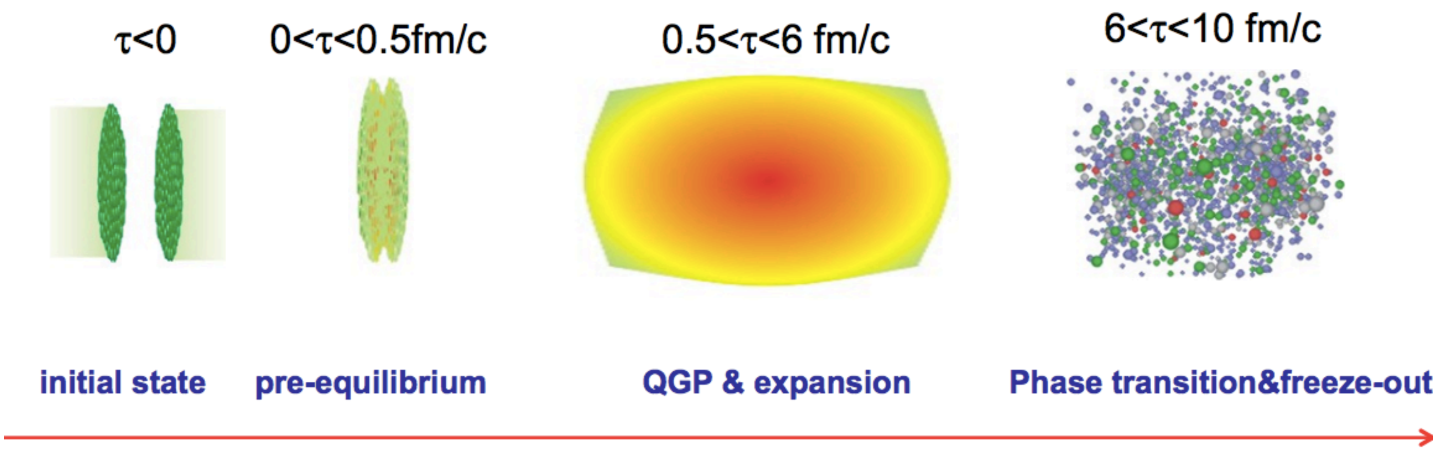
QCD transport coefficient $\hat{q}$

The effect of the QGP medium on a fast primordial parton:

$$\hat{q} = \rho\sigma \langle q^2_T \rangle = \lambda^{-1} \langle q^2_T \rangle$$

QCD Plasma Properties

Square momentum transfer with plasma


τ<0
0<τ<0.5fm/c
0.5<τ<6 fm/c
6<τ<10 fm/c
initial state
pre-equilibrium
QGP & expansion
Phase transition&freeze-out