Charged-particle spectra and nuclear modification factors in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

2nd International Workshop QCD Challenges from pp to AA

Julius Gronefeld for the ALICE Collaboration

31.10.2017

GSI Darmstadt

ALICE

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

GSI

BMBF Forschungsschwerpunkt
ALICE Experiment 202
ALICE

Introduction

Pb–Pb vs pp collisions

partonic energy loss

Run 1

spectra & nuclear modification

mean transverse momentum

Run 2

challenges & improvements

spectra & nuclear modification

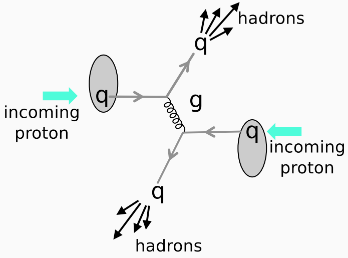
Comparing pp and AA collisions

$$\sigma(h) = \mathrm{PDF}(x_1, Q^2) \otimes \mathrm{PDF}(x_2, Q^2) \otimes \sigma(x_1, x_2, Q^2) \otimes \mathrm{FF}(z_h, Q^2)$$

- Initial hard collisions of partons
- Production cross section pQCD
- Hadronization

Parton Distribution Functions

Fragmentation Function



Comparing pp and AA collisions

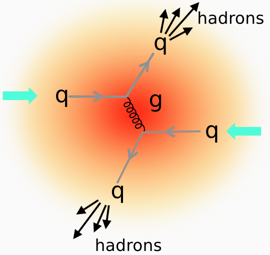
$$\sigma(h) = \mathrm{PDF}_A(x_1, Q^2) \otimes \mathrm{PDF}_A(x_2, Q^2) \otimes \sigma(x_1, x_2, Q^2) \otimes \mathrm{P}(\Delta E, Q^2) \otimes \mathrm{FF}(z_h, Q^2)$$

- Initial hard collisions of partons
- Production cross section pQCD
- Interaction with medium

  Parton energy loss & jet quenching

  Idea suggested by Bjorken in 1982

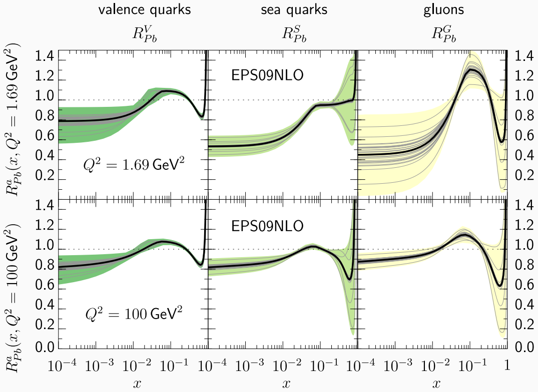
  J. D. Bjorken, FERMILAB-PUB-82-059-THY.
- Hadronization
- Investigate PDFs in p–Pb collisions



Medium modifies the distribution of partons created in the initial hard collision

Parton Distribution functions in nuclei

$$\sigma(h) = \mathrm{PDF}_A(x_1, Q^2) \otimes \mathrm{PDF}_A(x_2, Q^2) \otimes \sigma(x_1, x_2, Q^2) \otimes \mathrm{P}(\Delta E, Q^2) \otimes \mathrm{FF}(z_h, Q^2)$$



- PDFs differ in protons and nuclei but only small difference for high energy
- To probe and constrain the effect: Investigation of p–Pb collisions

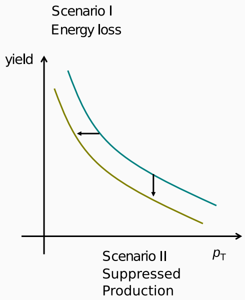
Nucl. Phys. A 855 (2011)

The nuclear modification factor: R_{AA}

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN^{AA}_{ch}/dp_T}{d\sigma^{pp}_{ch}/dp_T}$$

- R_{AA} is a comparison of nucleus nucleus (AA) collisions to proton proton (pp) collisions
- If a suppression occurs: $R_{AA} < 1$
- Scaling factor determined by Glauber Monte-Carlo calculation $\langle T_{AA} \rangle = \langle N_{coll} \rangle / \sigma^{NN}_{inel}$.

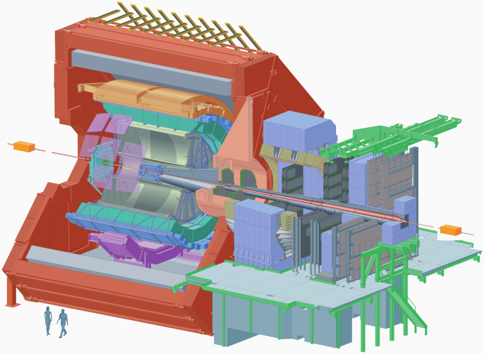
$\langle N_{coll} \rangle$: Mean number of binary nucleon-nucleon collisions per centrality interval



$$\langle N_{coll} \rangle_{60-80\%} = 28$$
$$\langle N_{coll} \rangle_{20-40\%} = 473$$
$$\langle N_{coll} \rangle_{0-5\%} = 1838$$

Run 1

ALICE



$$\eta = -\ln[\tan(\theta/2)]$$

Tracking:

ITS *Inner Tracking System*

TPC *Time Projection Chamber*

TRD *Transition Radiation Detector*

Centrality & trigger:

V0A $(2.8 < \eta < 5.1)$

V0C $(-3.7 < \eta < -1.7)$

p_{T} - spectra measurement:

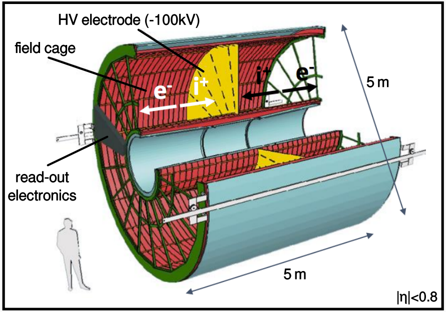
$|\eta| < 0.8$

$p_{\mathrm{T}} > 0.15\ \mathrm{GeV}/c$

$|z_{vtx}| \leq 10\ \mathrm{cm}$

The ALICE TPC

- Large time projection chamber
- Gas:
  90% Ne, 10%CO_2 (Run1)
  90% Ar, 10%CO_2 (Run2)
- Read-out with multi-wire proportional chambers
- Track reconstruction and p_T determination (including ITS)

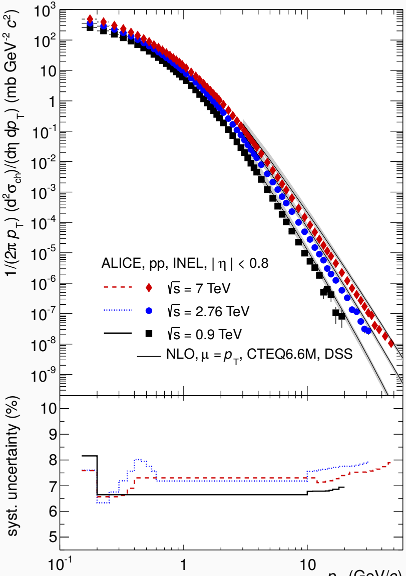


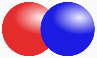
Transverse momentum distributions pp

- Measurement of transverse momentum distributions up to 50 GeV/c
- Observation of a harder spectra for higher energies

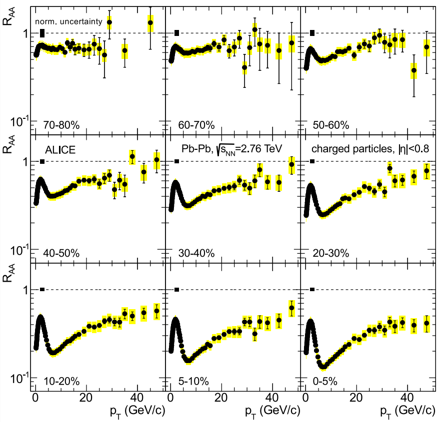
  Less steeply falling, more high p_{T} particles

Eur. Phys. J. C 73, 2662 (2013)

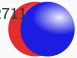




2.76 TeV



Phys.Lett. **B720** (2013) 52-62 — arXiv: 1208.2711



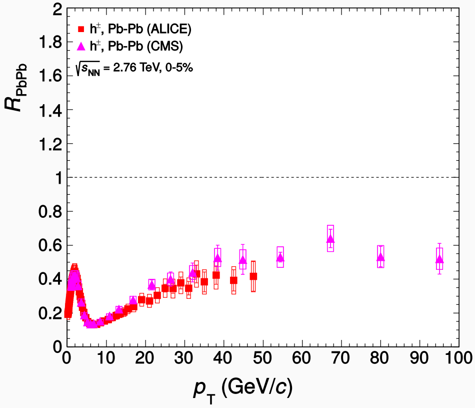
- R_{AA} shows a clear centrality dependence:

  Central collision:
  Strong suppression
  Peripheral collision:
  Less suppression

- Strongest suppression at $p_T \sim 6\,\mathrm{GeV}/c$
- Less suppression towards high p_T
  Still $R_{AA} \sim 0.5$

The nuclear modification factor: R_{pPb} (and R_{AA})

- ALICE and CMS agree
  $R_{AA} < 1$ for all p_T



Int.J.Mod.Phys. A29 (2014) 1430047 (arXiv: 1407.5003)

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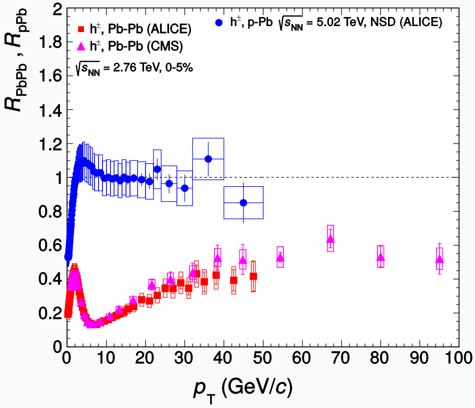

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ALICE

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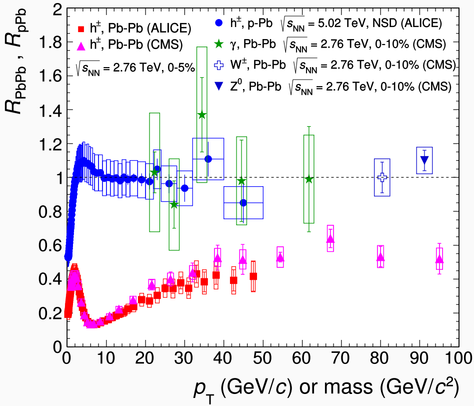
- Electroweak bosons $(\gamma, W^{\pm}, Z^0)$ show no suppression



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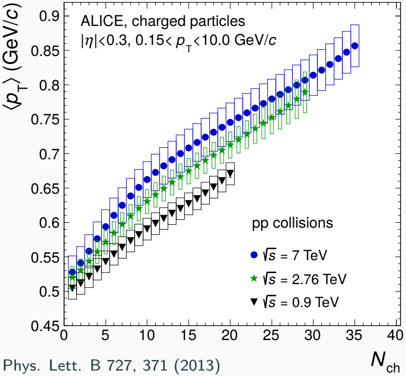
Measurement of $\langle p_T \rangle$

- pp: $\langle p_T \rangle$ for different $\sqrt{s}$
  - $\langle p_T \rangle$ increases with N_{ch}
  - Only small impact of $\sqrt{s}$



Phys. Lett. B 727, 371 (2013)

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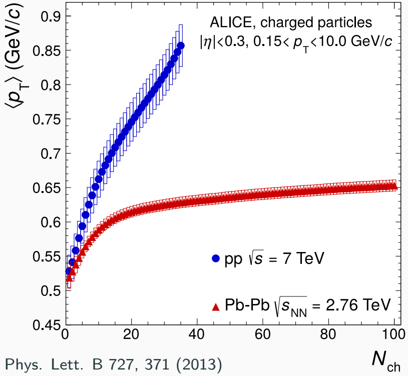
- Pb–Pb
  - Significantly lower $\langle p_T \rangle$, flat up to high N_{ch}



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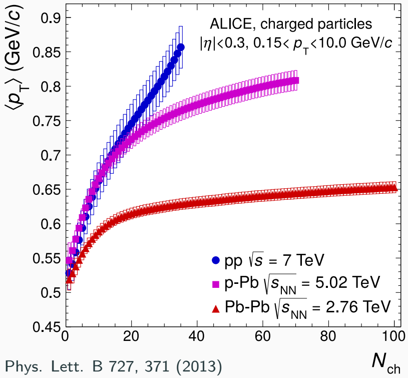
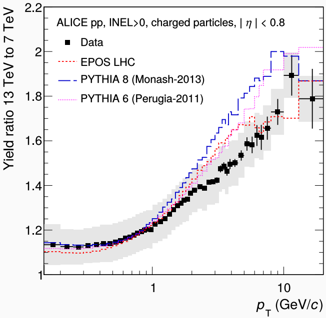
- Pb–Pb
  - Significantly lower $\langle p_T \rangle$, flat up to high N_{ch}
- p–Pb
  - $\langle p_T \rangle$ lower than in pp, but significantly higher than in Pb–Pb
- Departure from linear behaviour at $N_{ch} \approx 10$

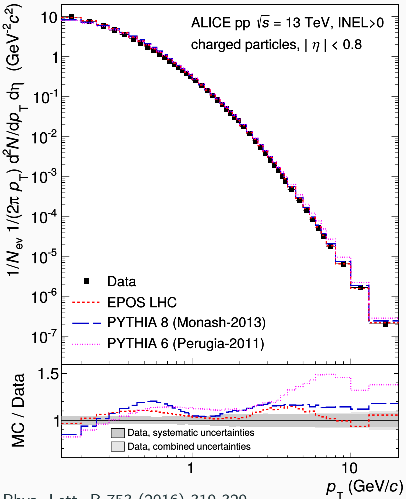


Phys. Lett. B 727, 371 (2013)

Run2

- Charged particle distribution
  $0.15\ \mathrm{GeV}/c < p_T < 20\ \mathrm{GeV}/c$
  Normalization to INEL > 0
- Comparison to 7 TeV publication
  Spectra significantly harder



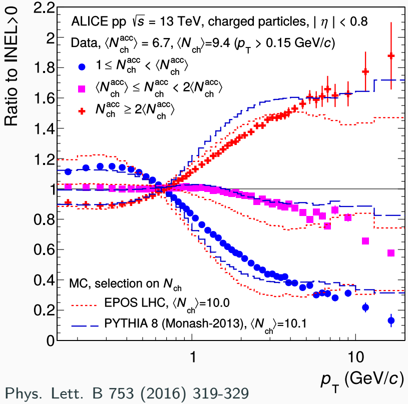


Phys. Lett. B 753 (2016) 319-329

- Spectra in bins of multiplicity

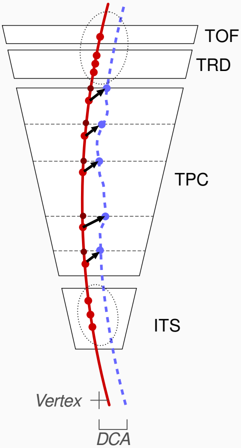
  Number of accepted charged tracks: $\langle N_{ch}^{acc} \rangle$.

- Ratio to MB spectra
- Harder for higher multiplicity
- Trend described by QCD inspired event generators



Phys. Lett. B 753 (2016) 319-329

Space charge distortions



- **Space charge** builds up at high interaction rates ($\sim 1\,\text{kHz}$ Pb–Pb) Enhanced by Argon as detector gas
- Path of **drifting electrons** is distorted on their way to the read-out
- TRD and ITS are used as reference detectors to correct for the distortion

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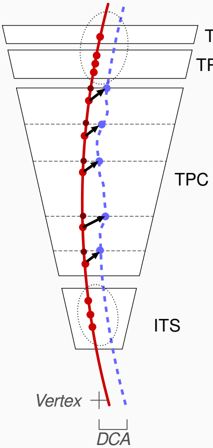

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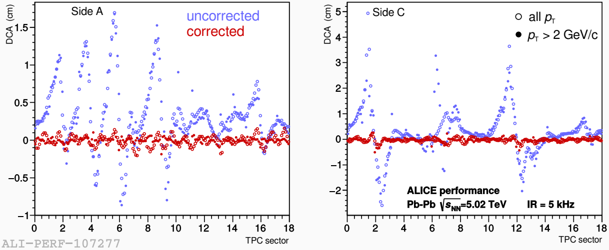


Corrections — Particle composition correction

- Abundances of primary particles not correctly reproduced in MC

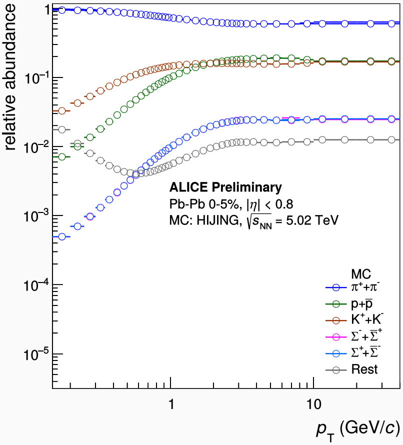
  (open symbols)

- Use measurements of identified particle spectra to recalculate fractions

  (full symbols)

- Largest deviation seen in strange baryons

  Using Λ as proxy for Σ^{+} & Σ^{-}



ALI-PREL-117658

Primary particles: Produced directly in the collision, including decay products from strong decays.

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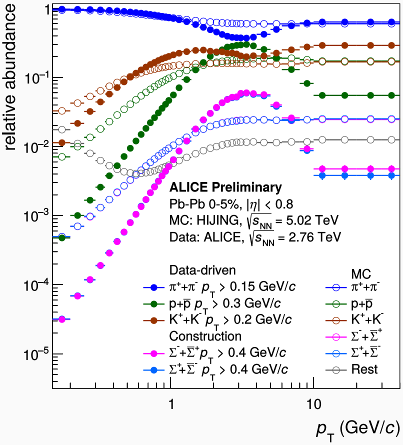

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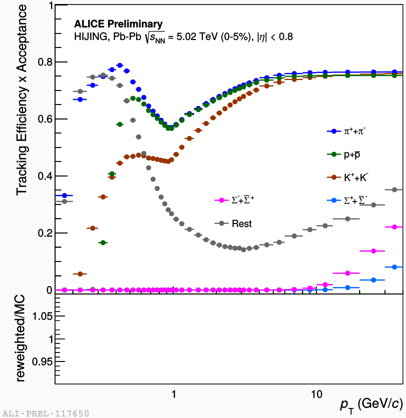
- Tracking efficiency differs for particle species.
- Largest influence at $\sim 3 - 4\,\mathrm{GeV}/c$
- Ratio taken as correction factor

This procedure eliminates the influence of different MC generators on the corrected spectra



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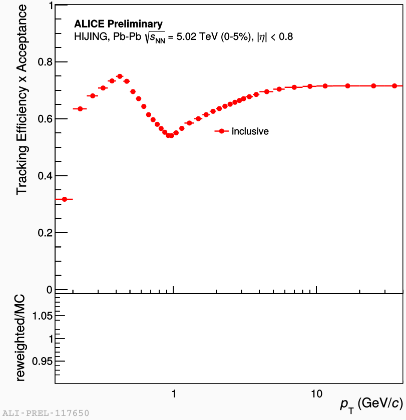

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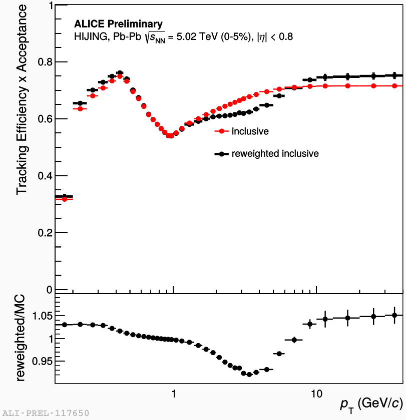


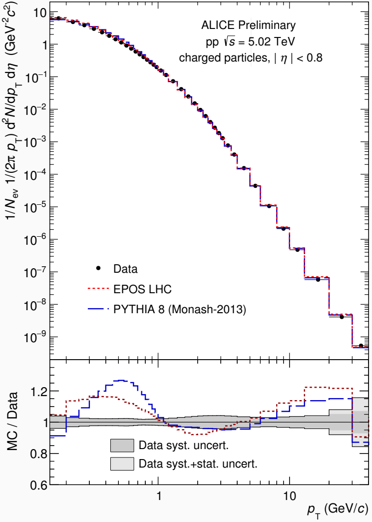
Spectrum in pp collisions

ALICE

- Spectra measured for $0.15\,\mathrm{GeV}/c < p_\mathrm{T} \leq 40\,\mathrm{GeV}/c$
- Models reproduce measurement with in 20-30% with better agreement at intermediate & high p_T

(**EPOS LHC**: CRMC package version 1.5.3)

(**PYTHIA 8)**: Version 8.210)



Spectra in Pb–Pb collisions

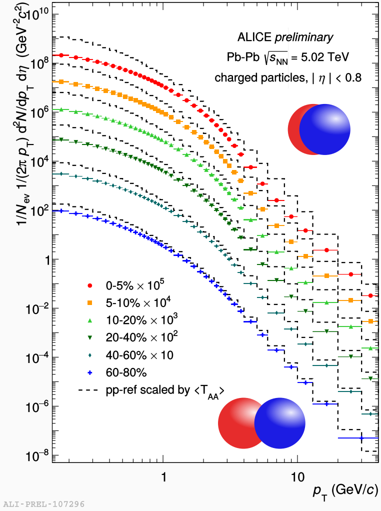
- Spectra measured for $0.15\,\text{GeV}/c < p_T \leq 40\,\text{GeV}/c$

Peripheral collisions:

- Spectra from Pb–Pb similar to pp reference

Central collisions:

- Pb-Pb spectrum differs from scaled pp reference

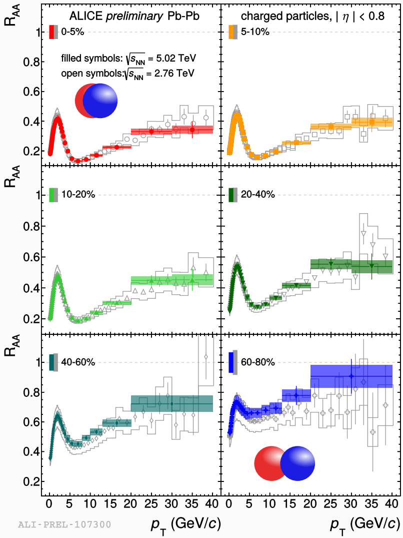


The nuclear modification factor

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{ch}^{AA}/dp_T}{d\sigma_{ch}^{pp}/dp_T}$$

- R_{AA} in 5.02 TeV similar to 2.76 TeV
- Despite harder input spectrum at higher collision energy

⟶ Results suggest a hotter / denser medium



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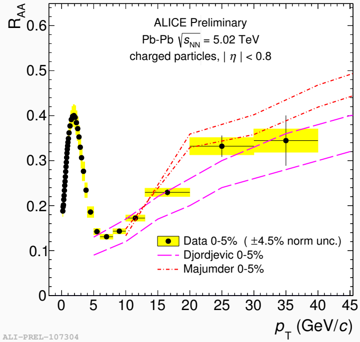
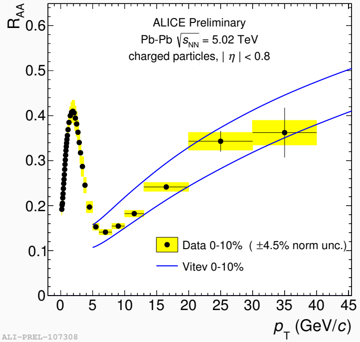




Vitev et al.,
Phys. Rev. D **93** (2016) no.7
arXiv:1509.02936
Djordjevic et al.,
arXiv:1601.07852
Majumder et al.,
Phys. Rev. Lett. **109** (2012)
arXiv:1103.0809

	Djordjevic	Majumder	Vitev
Elastic energy loss	✓		✓
Radiative energy loss	✓	✓	
Coherent multiple gluon emission		✓	
In-medium splitting function		✓	
Running α_s	✓		✓

Summary:

Charged particles offer insides into fundamental processes

New methods for **high precision** measurements

Nuclear modification factor: **Similar to 2.76 TeV**

suggesting a hotter and denser medium

More statistics is analysed

New methods are being applied to the analysis at 2.76 TeV

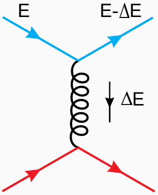
ALICE recorded $\sim$ 1.5 Million events of Xe–Xe at 5.44 TeV

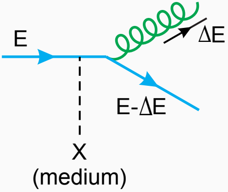
Forms of energy loss

$$\sigma(h) = \mathrm{PDF}_A(x_1, Q^2) \otimes \mathrm{PDF}_A(x_2, Q^2)$$
$$\otimes\sigma(x_1, x_2, Q^2) \otimes \mathrm{P}(\Delta E, Q^2) \otimes \mathrm{FF}(z_h, Q^2)$$

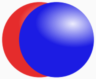
- Collisional energy loss:
  Energy loss through elastic collisions.
  Dominant at low p_T
  $\Delta E_{scatt} \sim L$
- Radiative energy loss:
  Dominant at high p_T
  $\Delta E_{rad} \sim L^2$

$$\Delta E_{tot} = \Delta E_{coll} + \Delta E_{rad}$$



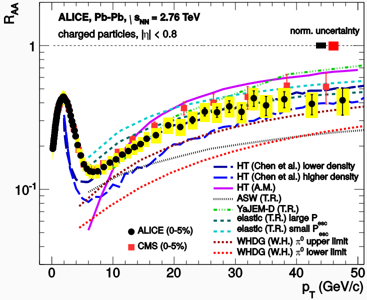


David d'Enterria
arxiv: 0902.2011



- Increase of R_{AA} due to a decrease of the relative energy loss towards high p_T

- Models connect the measured R_{AA} to energy loss in the medium $\Delta E_{rad} \cong \alpha_s \hat{q} L^2$

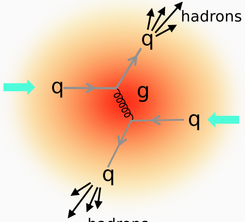


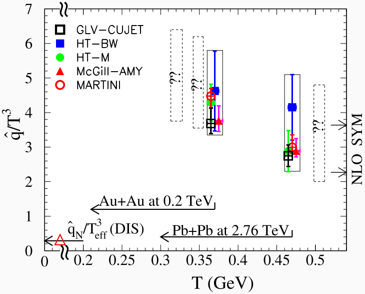
Phys.Lett. **B720** (2013) 52-62 — arXiv:1208.2711

Determination of the transport parameter $\hat{q}$

- Measurements are used to estimate medium quantities.
- Models can extract $\hat{q}$ from measurements
  $\Delta E_{rad} \cong \alpha_s \hat{q} L^2$

Extracted value of $\hat{q}$:
RHIC: $1.2 \pm 0.3 \mathrm{GeV}^2/\mathrm{fm}$
LHC: $1.9 \pm 0.7 \mathrm{GeV}^2/\mathrm{fm}$
Different T and α_s





Jet Collaboration
Phys. Rev. C 90, 014909 arXiv: 1312.5003v2