Transverse momentum spectra and nuclear modification factors of charged particles at $\sqrt{s_{NN}} = 5.02$ TeV measured by ALICE at the LHC

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

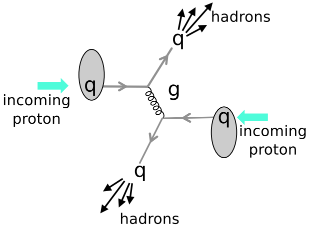
IKF Institut für Kernphysik Frankfurt

BMBF Forschungsschwerpunkt ALICE Experiment 202 ALICE

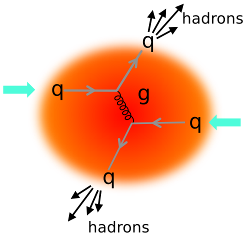
Comparing pp and AA collisions

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

- Initial hard collisions of partons
- Production cross section: pQCD
- Hadronisation



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



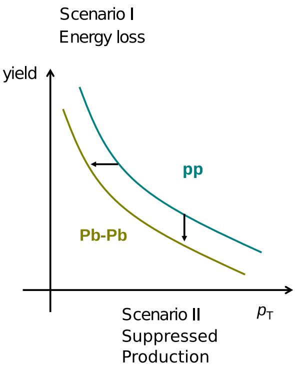
- Interaction with medium (QGP)
  Parton energy loss / jet quenching
- Idea suggested by Bjorken in 1982

J. D. Bjorken, FERMILAB-PUB-82-059-THY, FERMILAB-PUB-82-059-T.

The Nuclear Modification Factor: R_{AA}

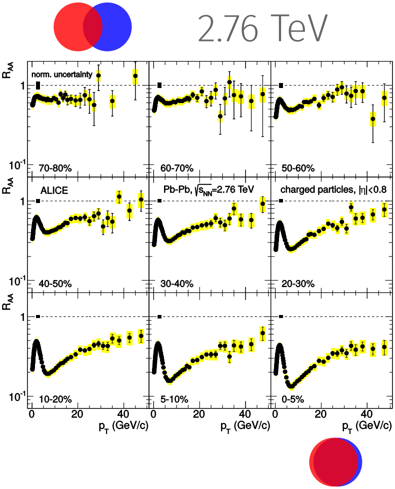
$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- R_{AA} is a comparison of nucleus nucleus (AA) collisions to proton proton (pp) collisions
- Scaling factor determined by Glauber Monte-Carlo calculations
  $\langle T_{AA} \rangle = \langle N_{coll} \rangle / \sigma_{inel}^{NN}$
- $\langle N_{coll} \rangle$ depends strongly on centrality
- If $R_{AA} < 1$, two scenarios possible:
  suppressed production or parton energy loss



The Nuclear Modification Factor: R_{AA}

2.76 TeV

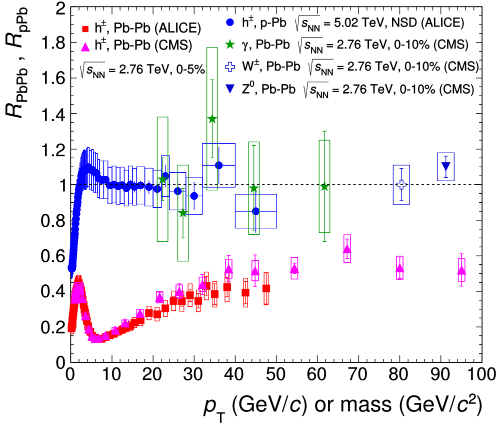


Phys.Lett.**B720**(2013) 52-62 — arXiv: 1208.2711

Charged Particles

- R_{AA} shows a clear centrality dependence:
  Central collisions:
  Strong suppression
  Peripheral collisions:
  Less suppression
- Suppression also observed for identified hadrons (e.g. strange or charm)
- $\langle N_{coll} \rangle$ scaling feasible?

The Nuclear Modification Factors: R_{AA} and R_{pPb}

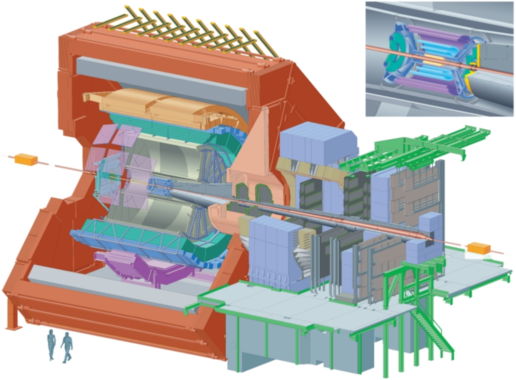


Int. J. Mod. Phys. A **29** (2014) 1430047

- $\langle N_{coll} \rangle$ scaling reliable
- High p_T : $R_{pPb} \sim 1$
  $\rightarrow$ no modification
- No modification for $\gamma, W^{\pm}, Z^0$
- Energy increase in Pb–Pb to $\sqrt{s_{NN}} = 5.02$ TeV :
  Larger / hotter medium?
  $\frac{dN_{ch}}{d\eta}(5.02\text{ TeV}) = 1.2\frac{dN_{ch}}{d\eta}(2.76\text{ TeV})$

Phys.Rev.Lett. 116 (2016) — arXiv: 1512.06104

ALICE



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:

$$\eta = -ln\left[tan\left(\frac{\theta}{2}\right)\right]$$

$$|\eta| < 0.8$$

$$p_T > 0.15\,\text{GeV}/c$$

$$|z_{vtx}| \leq 10\,\text{cm}$$

Analysis

	pp	Pb–Pb
Events	$25 \cdot 10^6$	$3.3 \cdot 10^6$
	(25% of tot. stat.)	(3% of tot. stat.)
Rate	11.5 - 13.5 kHz	25 - 480 Hz
MC	PYTHIA8 & GEANT3	HIJING & GEANT3

Complete data sets are reconstructed and beeing analysed

Analysis

Primary particles:
All prompt particles including decay products of short lived strong and electromagnetic decays, but excluding decay products of weakly decaying particles ($c\tau > 1$ mm).

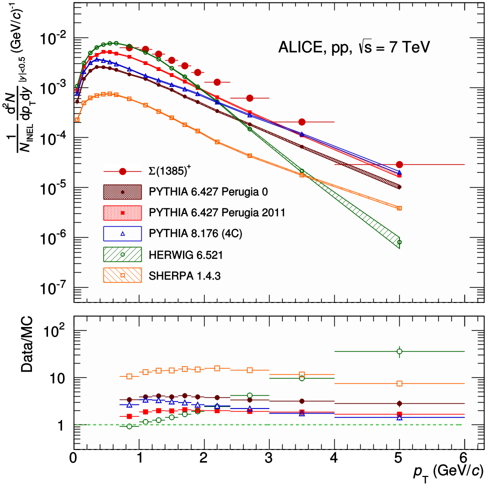
Track selection:
optimized to select primary charged particles particles at high p_{T}

Corrections:

Tracking efficiency: (data driven MC tuning performed)	$\sim 70\%$
Contamination with secondaries: (material & weak decays)	$\sim 10\%$ at $p_{\mathrm{T}} < 0.2$ GeV/c, $< 2\%$ at $p_{\mathrm{T}} > 1$ GeV/c (important at low p_{T})
p_{T} - resolution:	$\sim 2\%$ at $p_{\mathrm{T}} < 0.3$ GeV/c and $p_{\mathrm{T}} > 15$ GeV/c (important at high p_{T})

Particle Composition Correction

- Monte Carlo generators have different particle compositions than measured in data
- Particle species dependent efficiencies reweighed based on relative abundances measured in pp@7 TeV , Pb–Pb@2.76 TeV
- Largest effect for production of strange hyperons



$\Sigma(1385)^{+}$

ALICE Collaboration, Eur. Phys. J. C **75** (2015)

Systematic Uncertainties

Source of Uncertainty (%)	**pp**	**Pb–Pb** 0-5%	**Pb–Pb** 60-80%
Event selection (Z_v)	0.5	0.2	0.19
Track cuts	1.8 - 6.5	1 - 2.9	0.5 - 1
Secondary particles	1.8 - 1.2	5 - negl.	2 - negl.
Particle composition	0.1 - 0.4	0.5 - 5.9	0.5 - 3
Matching efficiency	1.4 - negl.	2.5 - negl.	2 - 3.5
Trigger and vertex biases	1.2 - negl.	-	-
p_T resolution	0 - 1.4	negl.	0.3
Material budget	1.5 - 0.2	1.5 - 0.2	1.5 - 0.2
Anchor point (centrality det.)	-	negl.	3
Total p_T dependent:	3.3 - 7	2 - 6	4 - 5.5
Run I uncertainties:	6.4 - 8	8.2 - 13.4	10.3 - 13.4

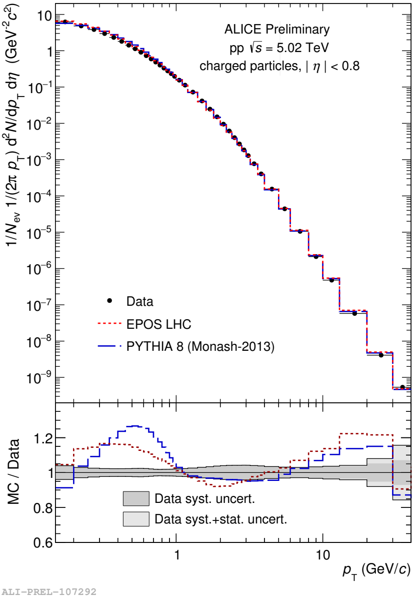
Improved systematic uncertainties compared to previous analyses

Spectrum in pp Collisions

- Spectra measured for $0.15\,\mathrm{GeV}/c < p_\mathrm{T} < 40\,\mathrm{GeV}/c$
- Discrepancy between models and measurement up to 20 %

(**EPOS LHC**: CRMC package version 1.5.3
Phys. Rev. C **92** (2015) no.3, 034906)

(**PYTHIA 8**: Version 8.210
Comput. Phys. Commun. **191** (2015) 159)



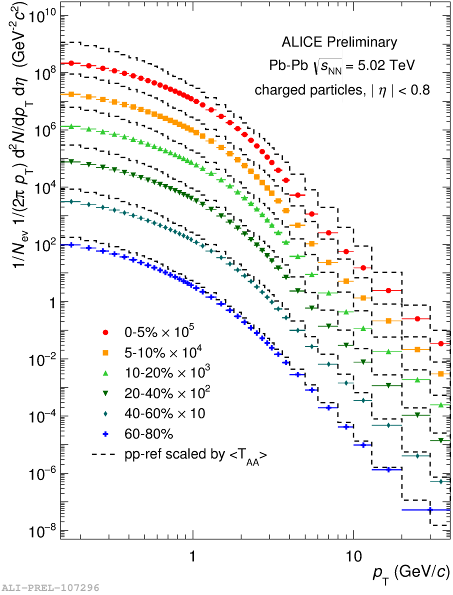
Spectra in Pb–Pb Collisions

- Spectra measured for $0.15\,\mathrm{GeV}/c < p_\mathrm{T} < 40\,\mathrm{GeV}/c$

Centrality	$\langle \mathbf{T_{AA}} \rangle$ (1/mb)
0-5%	26.27 ± 0.93
5-10%	20.48 ± 0.74
10-20%	14.30 ± 0.46
20-40%	6.76 ± 0.27
40-60%	1.95 ± 0.1
60-80%	0.40 ± 0.032

$$\langle \mathrm{T_{AA}} \rangle = \langle \mathrm{N_{coll}} \rangle / \sigma^{NN}_{inel}$$

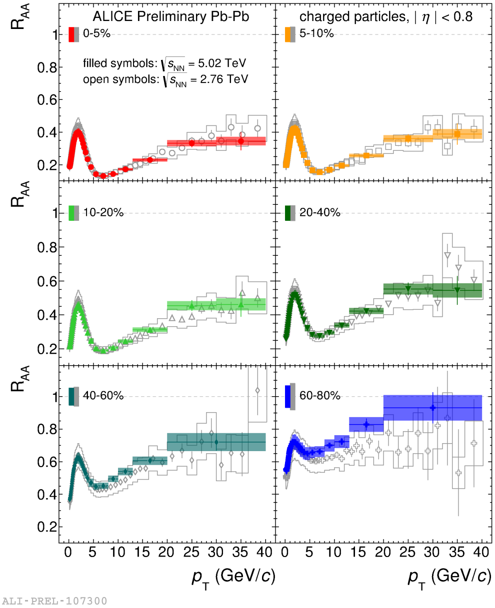
$$\sigma^{NN}_{inel} = (70 \pm 5)\ \mathrm{mb}$$



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} at 5.02 TeV similar to 2.76 TeV
- Parton production harder at higher energy
- Enhanced parton energy loss in hotter / denser medium?
- So far no cancellation of systematic uncertainties



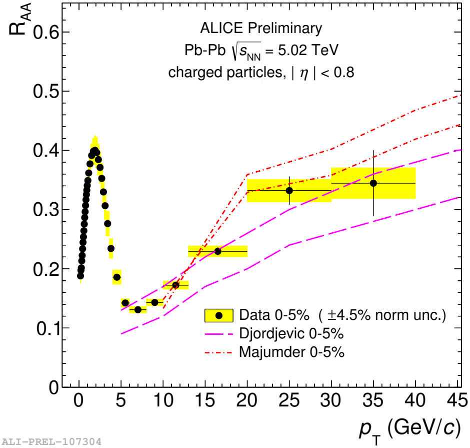
The Nuclear Modification Factor

- Models describe R_{AA}

  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

- Further constraint on medium properties ($\hat{q}$) possible

  e.g.: **JET Collaboration**: Phys. Rev. C **90**, 014909 arXiv: 1312.5003v2



The Nuclear Modification Factor

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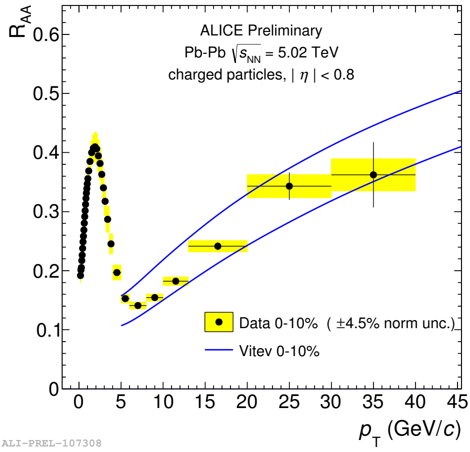


Preliminary measurement of transverse momentum spectra shown for **pp** and **Pb–Pb** at 5.02 TeV .

Reduced systematic uncertainties.

Reconstruction and track selection improved wrt. Run 1.

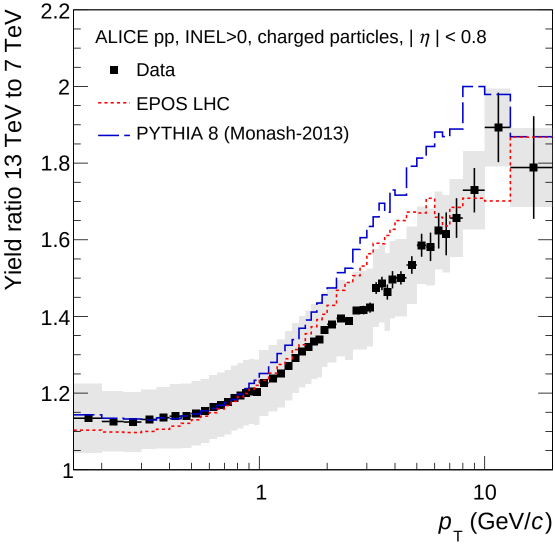
Nuclear modification factor: **Comparable** to 2.76 TeV .

Model predictions agree with measurement.

Larger statistics recorded for Pb–Pb and pp. - **analysis ongoing**.

Backup

Hardening of pp Spectrum



ALICE Collaboration, "Pseudorapidity and transverse-momentum distributions of charged particles in proton–proton collisions at $\sqrt{s} = 13$ TeV", Phys. Lett. B 753 (2016) 319, arXiv:1509.08734.