Charged-particle production in Pb+Pb and Xe+Xe collisions measured with the ATLAS detector

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introduction

- quark-gluon plasma is created in heavy-ion (HI) collisions
- partons traversing through this matter lose their energy
- charged-hadron spectra in heavy-ion collisions are driven by the mechanism of energy loss and also by other effects

- nuclear modification factor R_{AA} quantifies the difference between the HI and pp spectra:

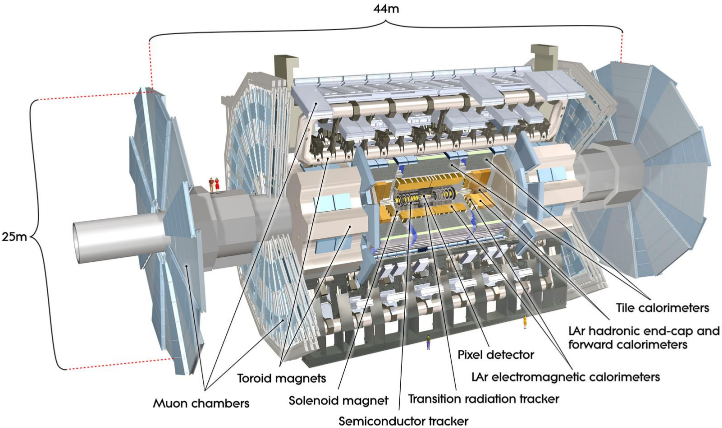
$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \frac{1/N_{\mathrm{evt}}\ \mathrm{d}^2 N_{\mathrm{A+A}}/\mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2 \sigma_{\mathrm{pp}}/\mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}$$

- both HI and pp collisions must be at the same center-of-mass energy

- what are differences between Pb+Pb and Xe+Xe collisions?

Xe+Xe: ATLAS-CONF-2018-007, Pb+Pb: ATLAS-CONF-2017-012

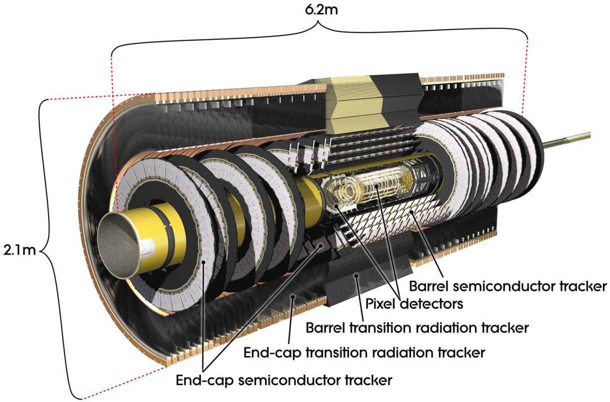
ATLAS detector



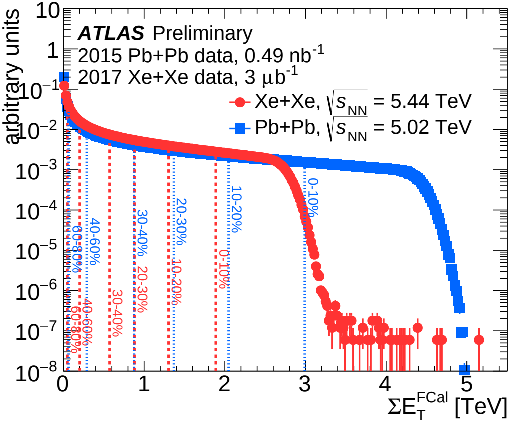
- Inner detector – 2 T magnetic field
- Forward calorimeter – used for determination of the centrality

ATLAS detector – Inner detector

- $|\eta| < 2.5$
- full ϕ coverage



- centrality based on energy deposited in both sides of the Forward Calorimeter ($3.1 < |\eta| < 4.9$)
- pile-up events are removed from the analysis
- geometric parameters estimated from the Glauber model



Xe+Xe	$\langle T_{AA} \rangle$ [mb^{-1}]
0–5%	13.89 ± 0.09
5–10%	10.87 ± 0.07
10–20%	7.54 ± 0.09
20–30%	4.50 ± 0.10
30–40%	2.55 ± 0.09
40–50%	1.37 ± 0.06
50–60%	0.69 ± 0.04
60–80%	0.23 ± 0.02

used data & collected luminosity

	Xe+Xe	Pb+Pb	*pp*
rejecting events with pile-up	✓		
rejecting fake and secondary tracks	✓		
bin-by-bin unfolding (correction for p_{T} resolution + track reconstruction efficiency)	✓		
bayesian unfolding			
track reconstruction efficiency			

- Xe+Xe data:
  - 2017, $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV
  - $3\,\mu\mathrm{b}^{-1}$

used data & collected luminosity

	Xe+Xe	Pb+Pb	*pp*
rejecting events with pile-up	✓	✓	
rejecting fake and secondary tracks	✓	✓	
bin-by-bin unfolding (correction for p_{T} resolution + track reconstruction efficiency)	✓		
bayesian unfolding		✓	
track reconstruction efficiency		✓	

- Pb+Pb data:
  - 2015, $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
  - $0.49\,\mathrm{nb}^{-1}$

used data & collected luminosity

	Xe+Xe	Pb+Pb	*pp*
rejecting events with pile-up	✓	✓	
rejecting fake and secondary tracks	✓	✓	✓
bin-by-bin unfolding (correction for p_{T} resolution + track reconstruction efficiency)	✓		
bayesian unfolding		✓	✓
track reconstruction efficiency		✓	✓

- *pp* data:
  - 2015, $\sqrt{s} = 5.02\,\mathrm{TeV}$
  - $25.0\,\mathrm{pb}^{-1}$

used data & collected luminosity

	Xe+Xe	Pb+Pb	*pp*
rejecting events with pile-up	✓	✓	
rejecting fake and secondary tracks	✓	✓	✓
bin-by-bin unfolding (correction for p_{T} resolution + track reconstruction efficiency)	✓		
bayesian unfolding		✓	✓
track reconstruction efficiency		✓	✓

pp baseline at $\sqrt{s} = 5.44\,\mathrm{TeV}$:

- *pp* at $\sqrt{s} = 5.02\,\mathrm{TeV}$ is extrapolated to $\sqrt{s} = 5.44\,\mathrm{TeV}$

$$\sigma^{\mathit{extrap.\ data}}_{5.44\,\mathit{TeV}}(p_{\mathrm{T}},\eta) = \sigma^{\mathit{data}}_{5.02\,\mathit{TeV}}(p_{\mathrm{T}},\eta) \times \frac{\sigma^{\textsc{Pythia}}_{5.44\,\mathit{TeV}}(p_{\mathrm{T}},\eta)}{\sigma^{\textsc{Pythia}}_{5.02\,\mathit{TeV}}(p_{\mathrm{T}},\eta)}$$

- increase by around 4% at 1 GeV; 11% at 10 GeV; 17–26% at 80 GeV

systematic uncertainties

source	highest uncertainty		
	pp	Xe+Xe	R_{AA}
track selection selection	6%	5%	11%
particle-to-track association	1%	1%	1%
fake and secondary tracks	1%	1%	1%
bin-by-bin unfolding	–	8%	8%
bayes unfolding	9%	–	9%
baseline extrapolation	13%	–	13%
momentum resolution	5%	–	5%
efficiency	1%	–	1%
material budget	6%	6%	–
luminosity	5%	–	5%
$\langle T_{\mathrm{AA}} \rangle$	–	8%	8%

systematic uncertainties

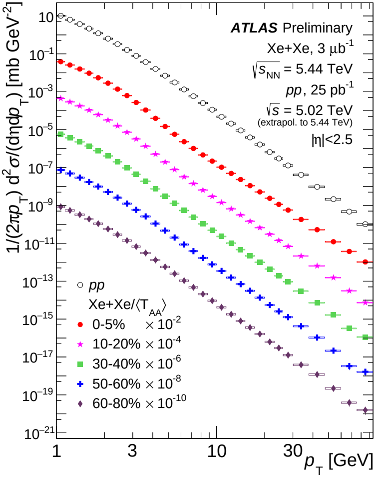
source	typical uncertainty		
	pp	Xe+Xe	R_{AA}
track selection selection	2%	2%	3%
particle-to-track association	1%	1%	1%
fake and secondary tracks	1%	1%	1%
bin-by-bin unfolding	–	4%	4%
bayes unfolding	3%	–	3%
baseline extrapolation	6%	–	6%
momentum resolution	1%	–	1%
efficiency	1%	–	1%
material budget	3%	3%	–
luminosity	5%	–	5%
$\langle T_{\mathrm{AA}} \rangle$	–	4%	4%

systematic uncertainties

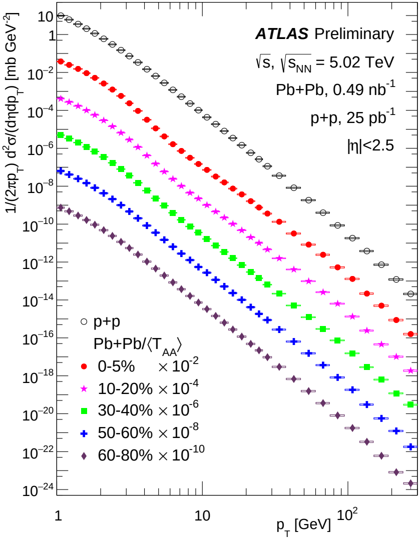
source	typical uncertainty		
	pp	Xe+Xe	R_{AA}
track selection selection	2%	2%	3%
particle-to-track association	1%	1%	1%
fake and secondary tracks	1%	1%	1%
bin-by-bin unfolding	–	**4%**	**4%**
bayes unfolding	3%	–	3%
baseline extrapolation	**6%**	–	**6%**
momentum resolution	1%	–	1%
efficiency	1%	–	1%
material budget	3%	3%	–
luminosity	**5%**	–	**5%**
$\langle \boldsymbol{T}_{\mathbf{AA}} \rangle$	–	**4%**	**4%**

Xe+Xe and Pb+Pb spectra

Xe+Xe



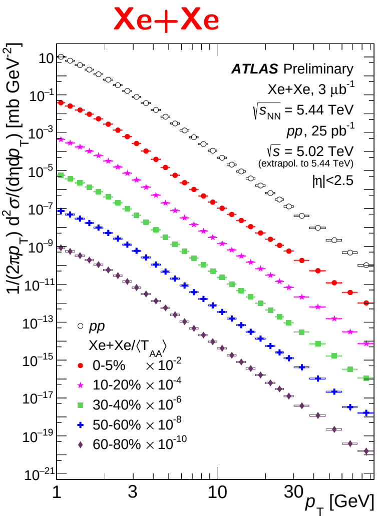
Pb+Pb

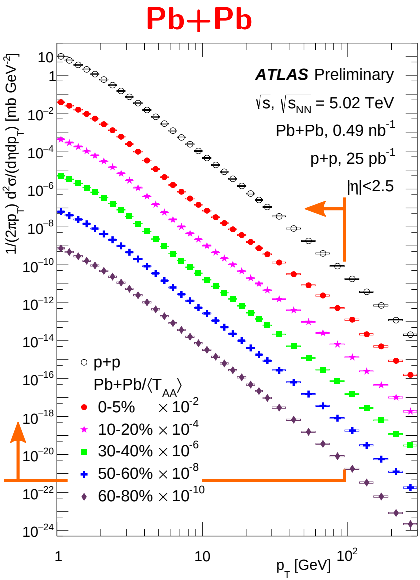


- note different x-axis

ATLAS-CONF-2018-007, ATLAS-CONF-2017-012

Xe+Xe and Pb+Pb spectra

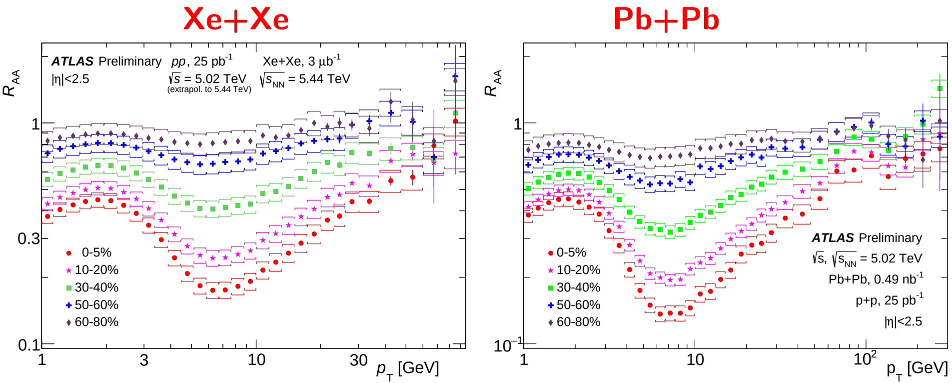




- note different x-axis

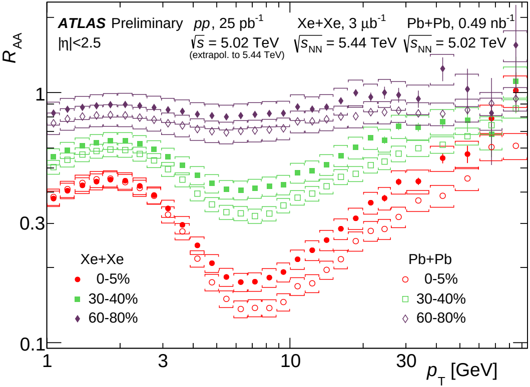
ATLAS-CONF-2018-007, ATLAS-CONF-2017-012

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



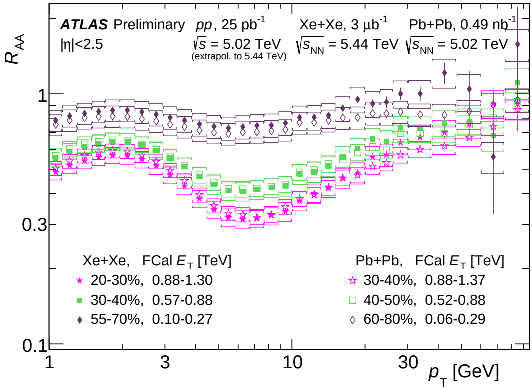
- note different x-axis
- qualitatively similar trends
- what is the variable which drives the overall suppression?

charged hadron $R_{\rm AA}$ in Xe+Xe and Pb+Pb



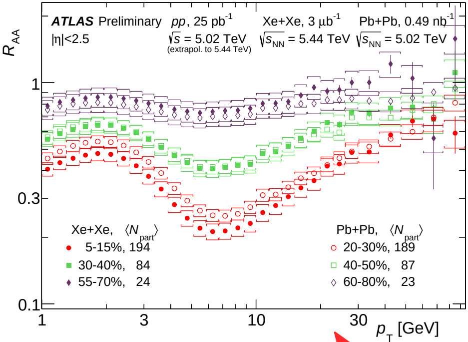
- same colors have the same centrality percentiles
- $R_{\rm AA}$ is very similar at low $p_{\rm T}$ in central collisions
- otherwise Xe+Xe less suppressed than Pb+Pb

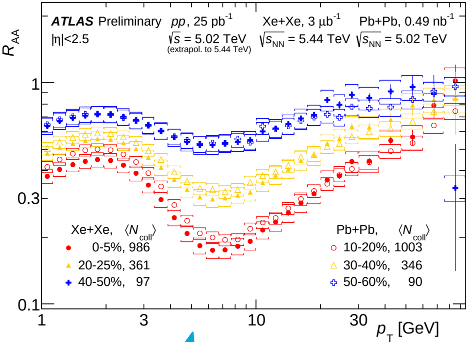
charged hadron R_{AA} in Xe+Xe and Pb+Pb



- same colors have similar FCal E_T, i.e. systems have similar size
- scaling with the system size?
- the most central intervals are not presented here

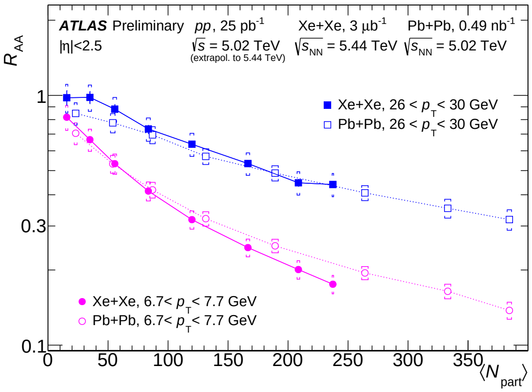
charged hadron R_{AA} in Xe+Xe and Pb+Pb





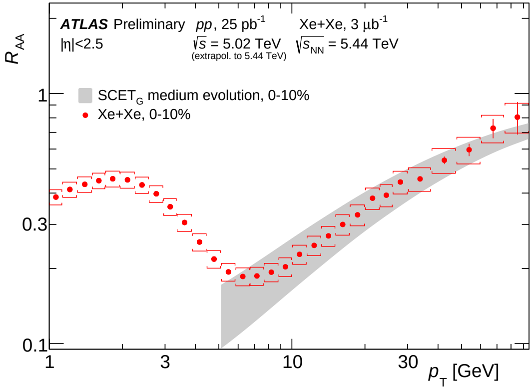
- same colors have similar $\langle N_{\mathrm{part}} \rangle$ and similar $\langle N_{\mathrm{coll}} \rangle$
- low-p_{T} particle production scales better with $\langle N_{\mathrm{part}} \rangle$
- high-p_{T} particle production scales better with $\langle N_{\mathrm{coll}} \rangle$

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



- same trend for Pb+Pb and Xe+Xe
- at higher p_{T} (26–30 GeV) the results are compatible
- same scaling for (possible) future colliding systems?
  - Ar+Ar (up to ∼80 participants)
  - Kr+Kr (up to ∼160 participants)

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



- prediction done in a similar way as in arXiv:1509.02936, however the modification of in-medium parton showers was evaluated as in arXiv:1801.00008 (I. Vitev et al.)
- very good agreement

conclusion

- measured spectra and nuclear modification factor in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ and Xe+Xe collisions at $\sqrt{s_{\mathrm{NN}}} = 5.44\,\mathrm{TeV}$
- baseline estimated from *pp* data with $\sqrt{s} = 5.02\,\mathrm{TeV}$; extrapolated to the center-of-mass energy of Xe+Xe collisions
- the suppression in Xe+Xe is similar to that measured in Pb+Pb
  - at low p_{T}, Xe+Xe is slightly more suppressed than Pb+Pb in central collisions but slightly less suppressed in peripheral collisions (at similar $\langle N_{\mathrm{part}} \rangle$)
  - at higher p_{T}, the suppression is comparable within uncertainties

jet and di-jet production in PbPb and XeXe?

$\rightarrow$ see talk by Radim Slovak, Thursday, 9:00

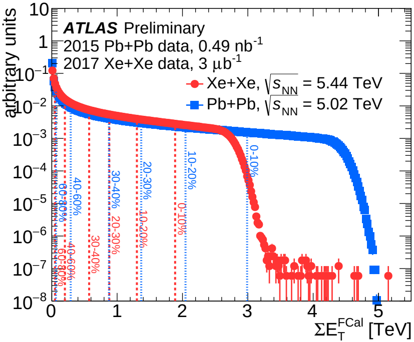
backup

Xe+Xe centrality calibration

[1] "Xes" in 2.4 of PHOBOS MC Glauber

[2] scaling from Xe-132 ("Xe"), reweighted, WS scaling in MC Glauber 3.0 ("Xerw")

[3] ATLAS&TOTEM measurements of σ_{tot}



- characterized with FCal E_{T}, $3.1 < |\eta| < 4.9$
- Xe-129 nuclear wavefunction from $A^{1/3}$ scaling of Sb-122 Woods–Saxon parameters [1]

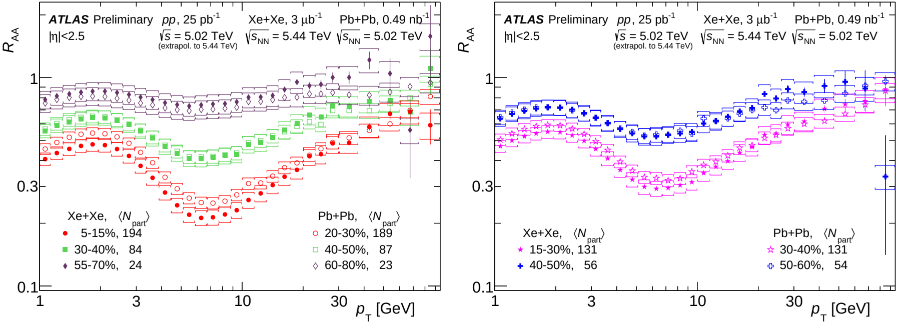
  $\rightarrow$ alternative description in systematics [2]

  $\rightarrow$ co-dominant T_{AA} uncertainty in 0–50%
- $\sigma_{pp} = (71 \pm 3)$ mb [3]
- central T_{AA} values from 2CM fit with $x = 0.09$ $\rightarrow$ same used for ATLAS Run 1 and Run 2 Pb+Pb
- 82.4% of distribution in range FCal $E_{\mathrm{T}} > 40$ GeV

  $\rightarrow$ conservatively free of "non-Glauber" backgrounds

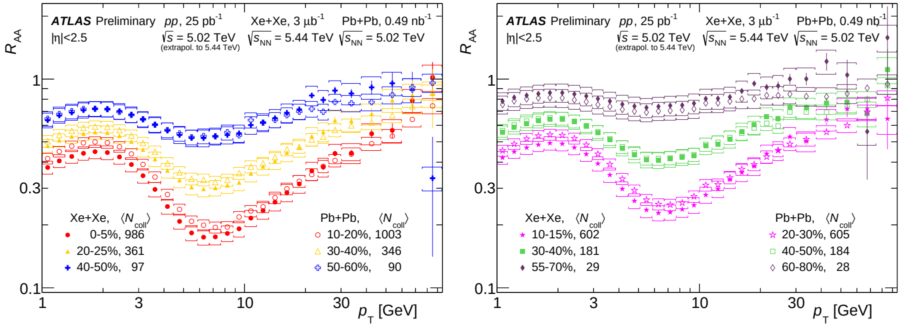
  $\rightarrow$ $\pm 1\%$ uncertainty, dominant systematics

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



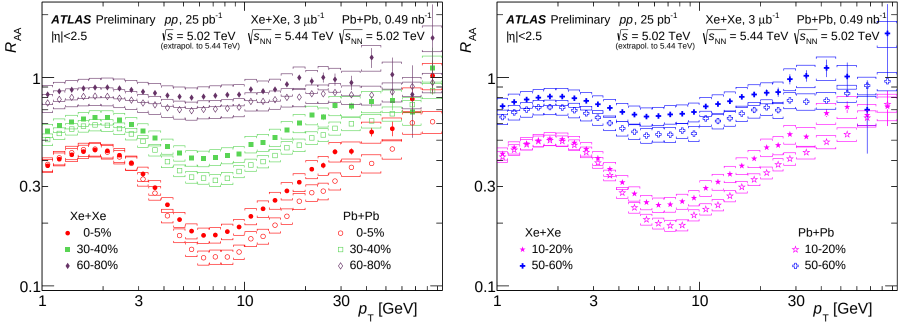
- same colors have similar $\langle N_{\mathrm{part}} \rangle$

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



- same colors have similar $\langle N_{\mathrm{coll}} \rangle$
- for R_{AA} in the same $\mathrm{d}N/\mathrm{d}\eta$, ALICE compares intervals in red (left) and green (right); they have comparable both $\langle N_{\mathrm{coll}} \rangle$ and $\mathrm{d}N/\mathrm{d}\eta$

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



- same colors have the same centrality percentiles