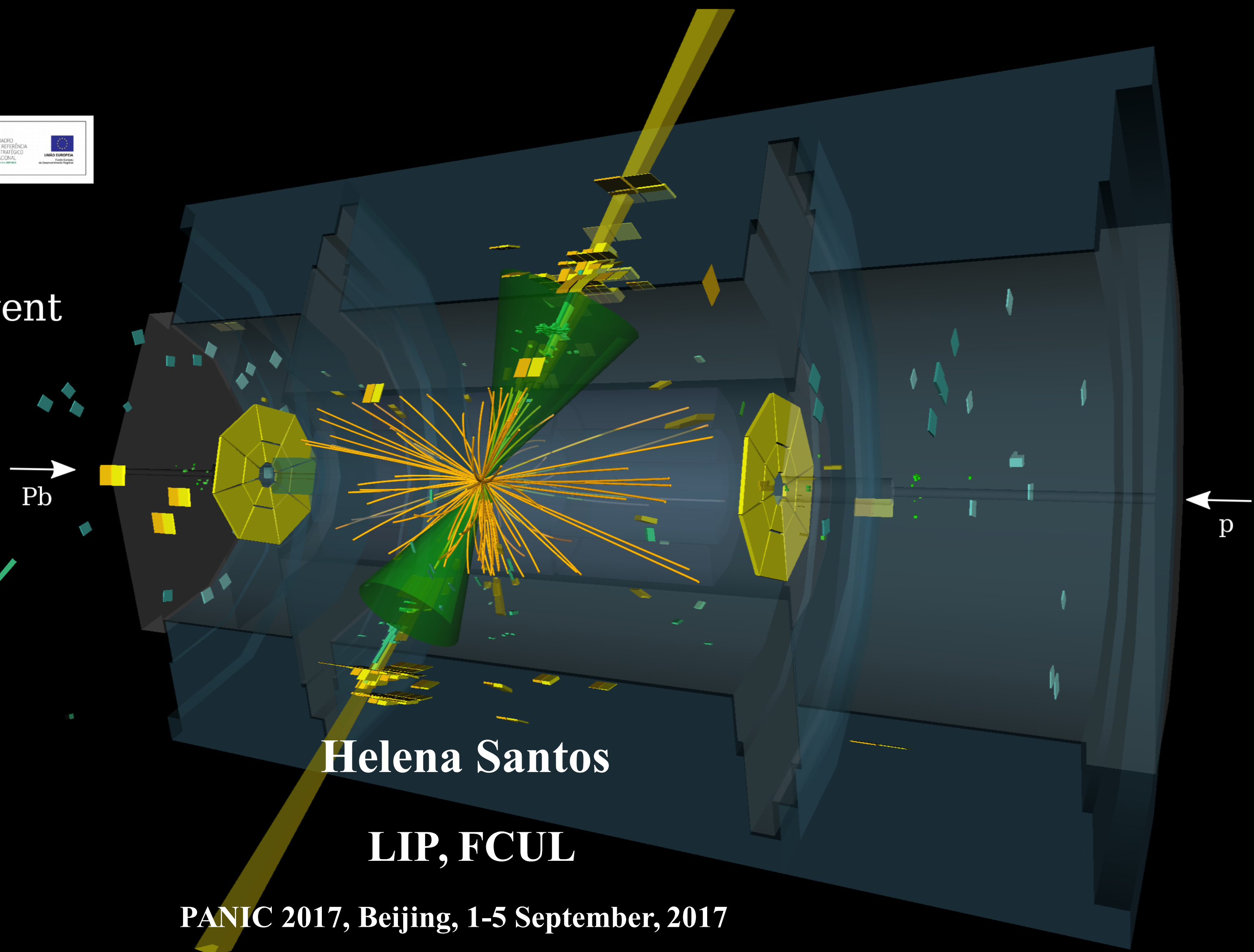
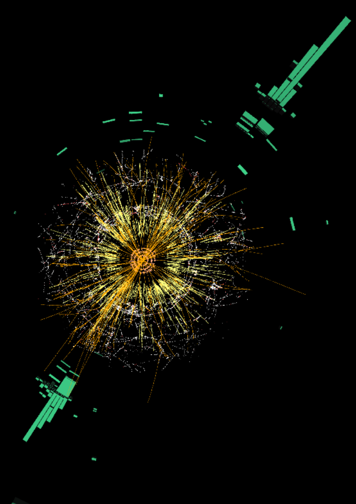
Jets in heavy ion collisions with the ATLAS detector

Dijet p+Pb event

Run: 217946
Event: 13617174
Date: 2013-01-20





Helena Santos

LIP, FCUL

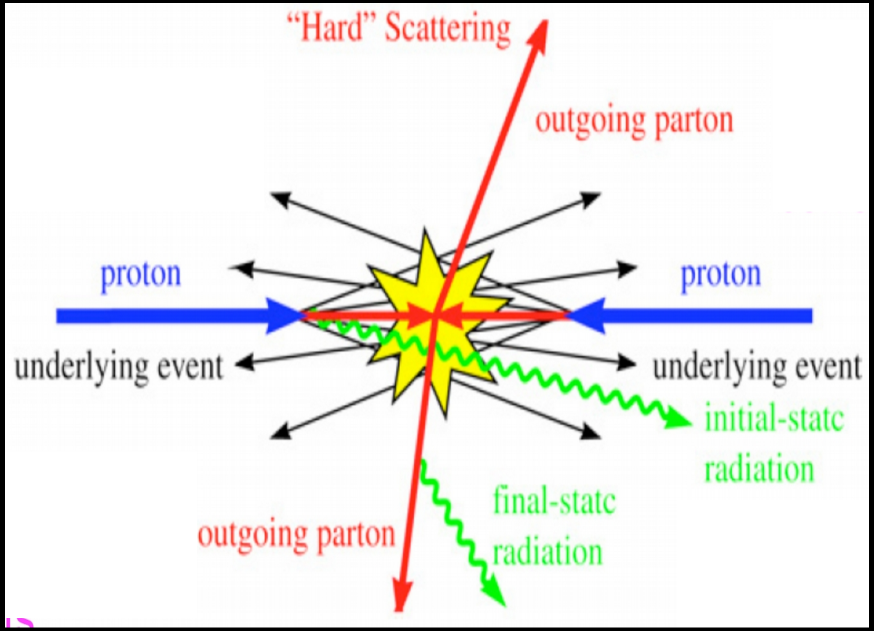
PANIC 2017, Beijing, 1-5 September, 2017

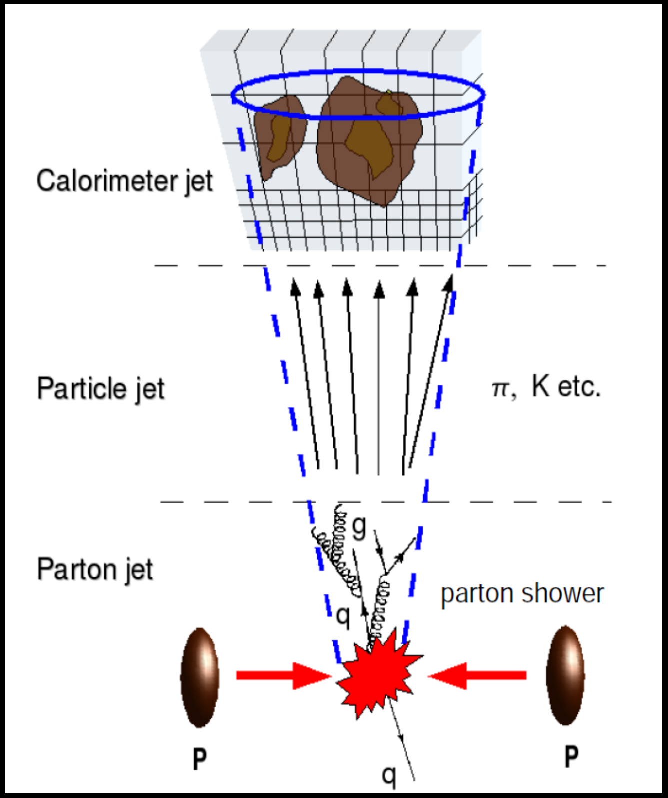
Outline

- Motivation
- Inclusive jet production
- Fragmentation functions
- Dijet and photon-jet asymmetry
- Summary

Jets in p+p – a baseline for Pb+Pb

The common picture (p+p):

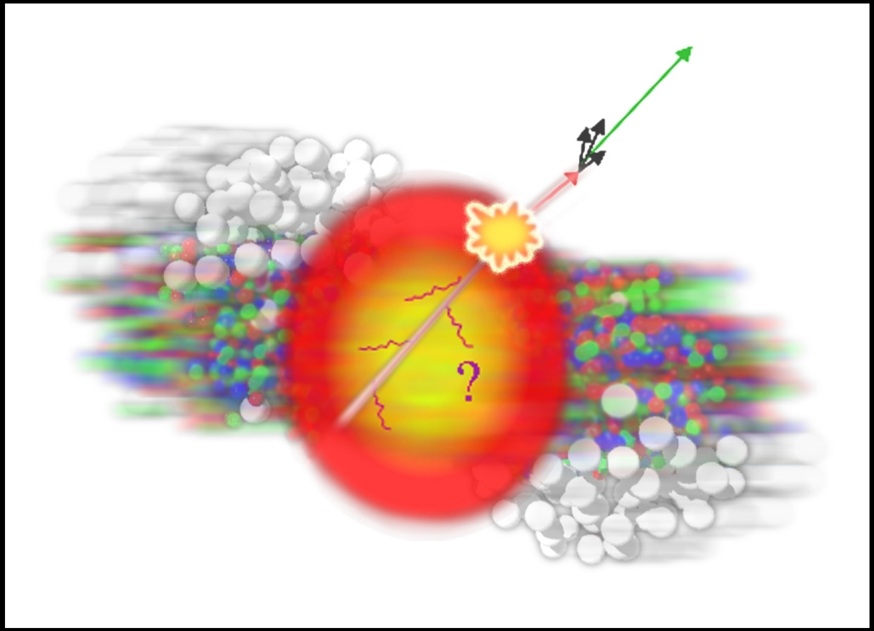


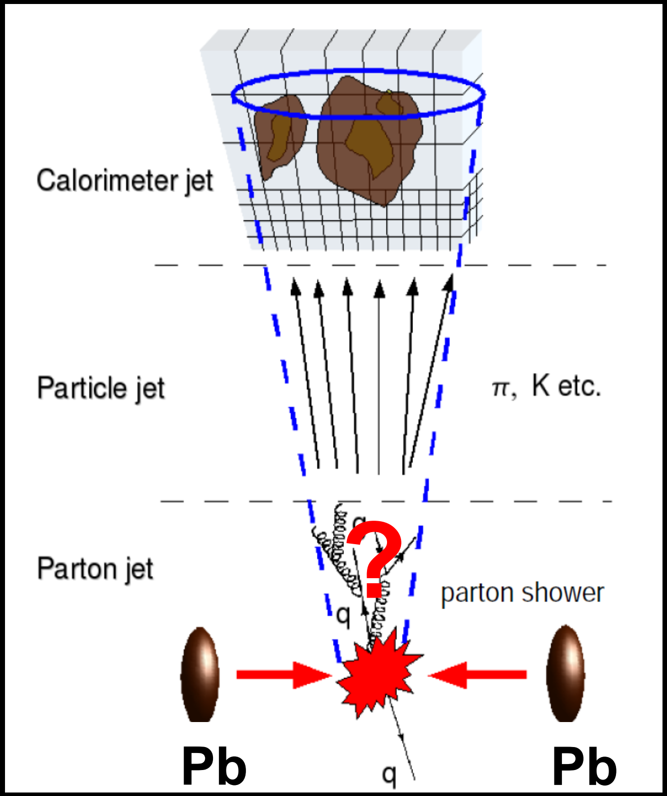


Jets produced in vacuum are well understood and constitute a reliable baseline to study medium-dependence effects.

Jets as probes of hot matter

Quark Gluon Plasma is opaque to coloured partons.
How do parton showers in the hot and dense medium differ from those in vacuum?



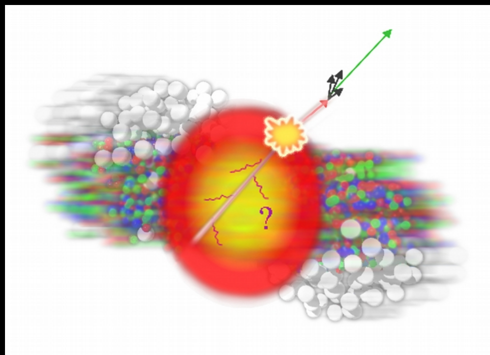


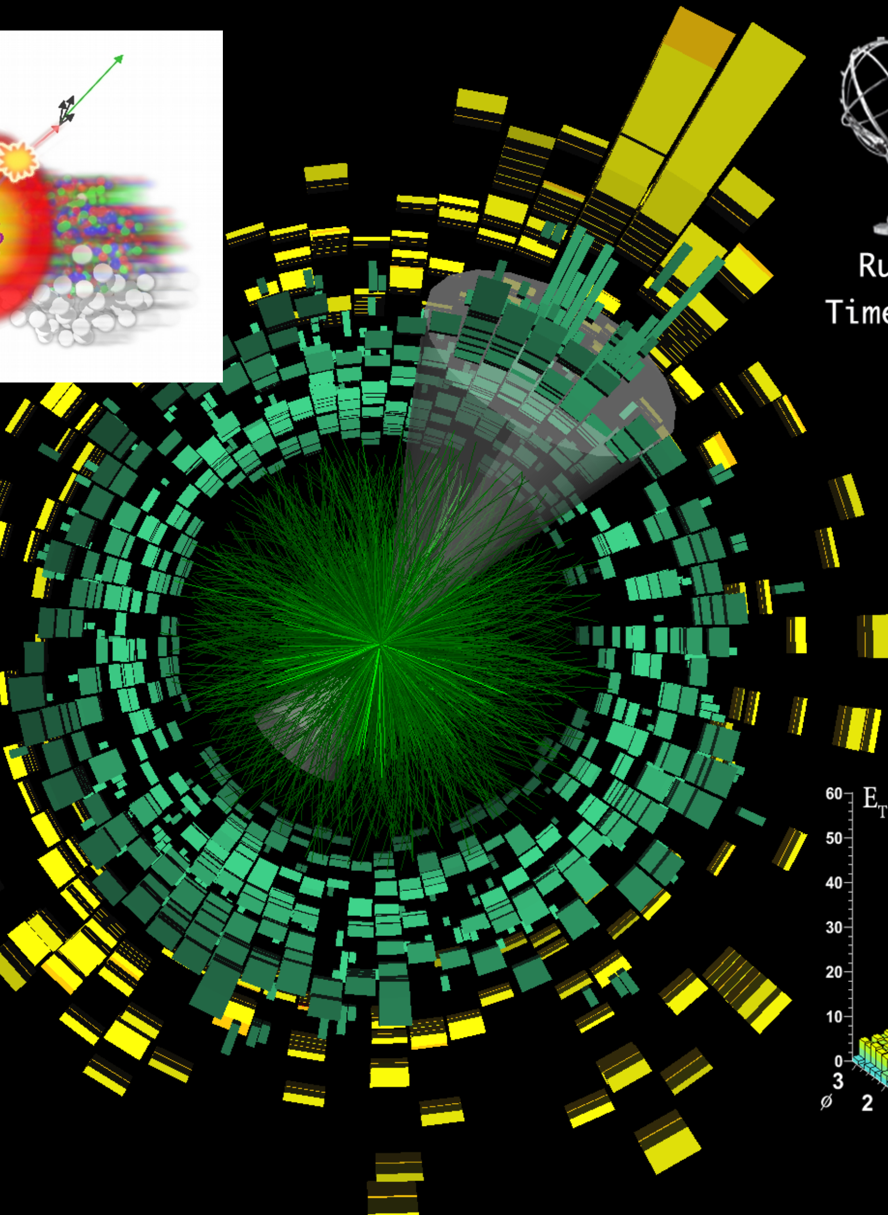
What is expected:

Partons lose energy, resulting in jet “quenching”.

Jets probe the very first phase of the collision → they carry relevant information about the QGP .

Observed "jet quenching"



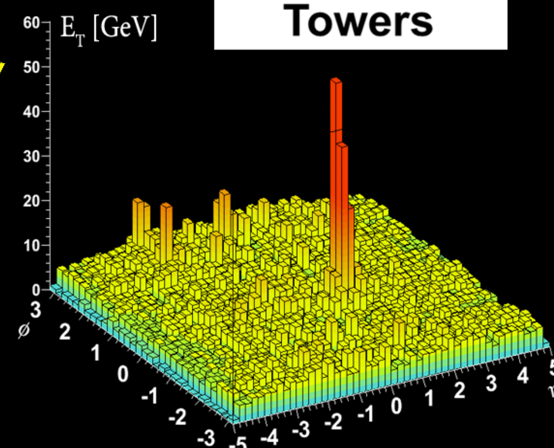


ATLAS EXPERIMENT

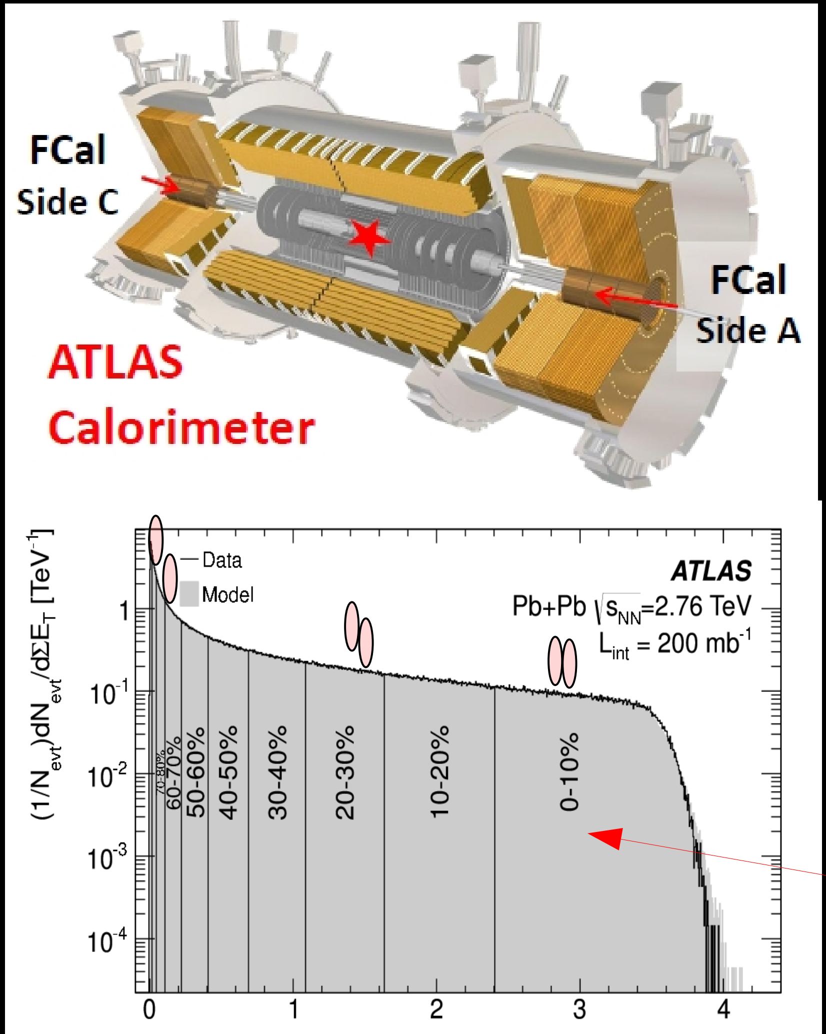
Run 168795, Event 7578342

Time 2010-11-09 08:55:48 CET

Calorimeter Towers

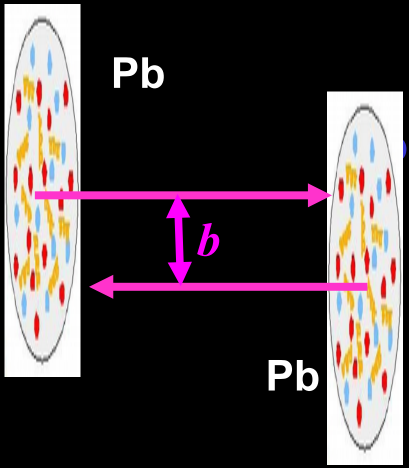


Collisions' "Centrality"



PLB 707 (2012) 330

HI collision's dynamics controlled by impact parameter "*b*"



Transverse energy, E_T, deposited in Forward Calorimeter compared to Glauber model of nucleon-nucleon collisions.

The nuclear thickness function, T_{AA}, and number of participants in a collision, N_{part}, for each centrality interval is estimated with the same Glauber model.

Nuclear Modification Factor - R_{AA}

$$R_{AA} = \frac{\boxed{\frac{1}{N_{\mathrm{evnt}}} \frac{\mathrm{d}^2 N^{PbPb}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\Big|_{\mathrm{cent}}}}{\boxed{\langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}}} \times \boxed{\frac{\mathrm{d}^2\sigma^{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}}$$

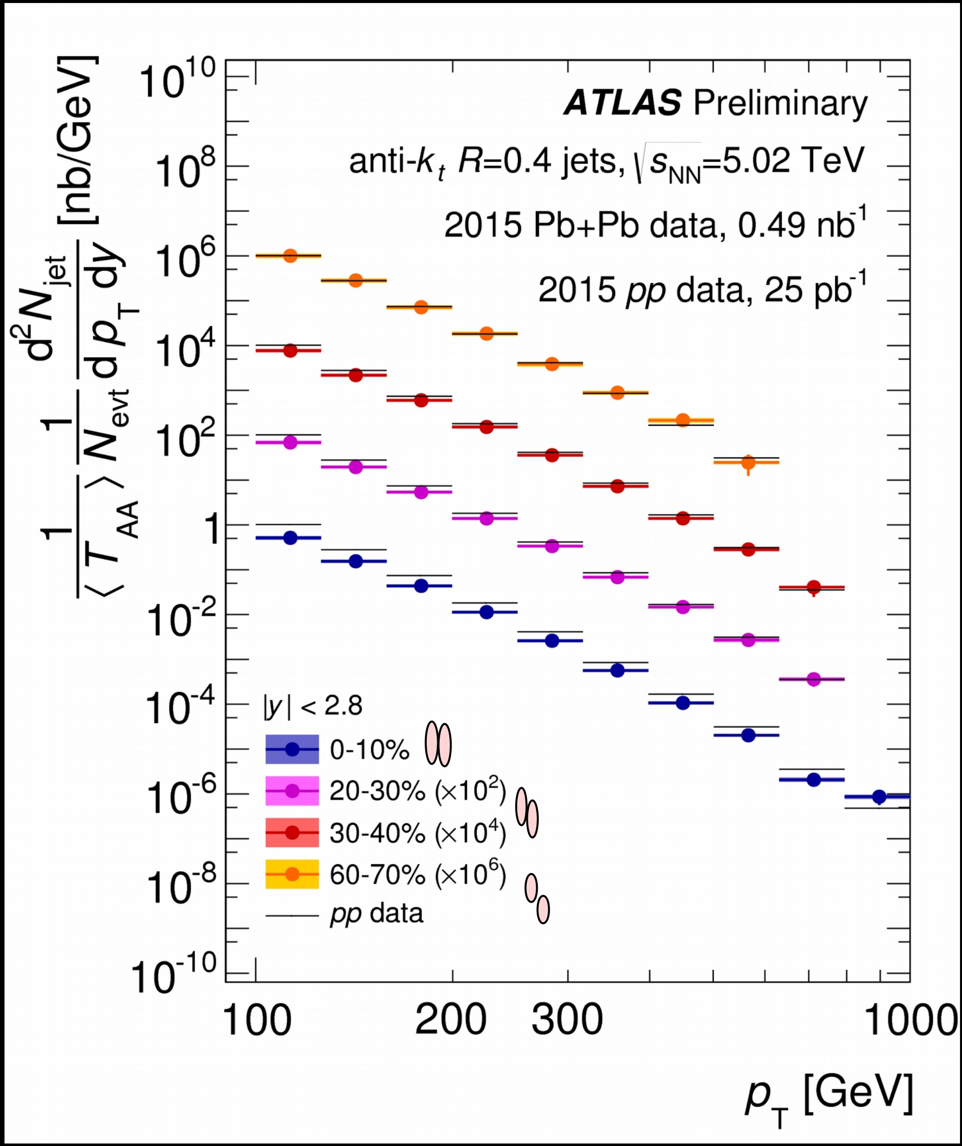
Yield in Pb+Pb collisions, (in medium)

Nuclear thickness function **$\langle N_{coll} \rangle / \sigma_{NN}$**

Cross section in pp collisions (in vacuum)

- Nuclear modification factor quantifies the magnitude of the suppression of an observable, which is dominantly due to final state interactions with constituents of the medium (QGP).
- Any deviation from **unity** points to suppression or enhancement of jet observables.

Inclusive Jet Yields



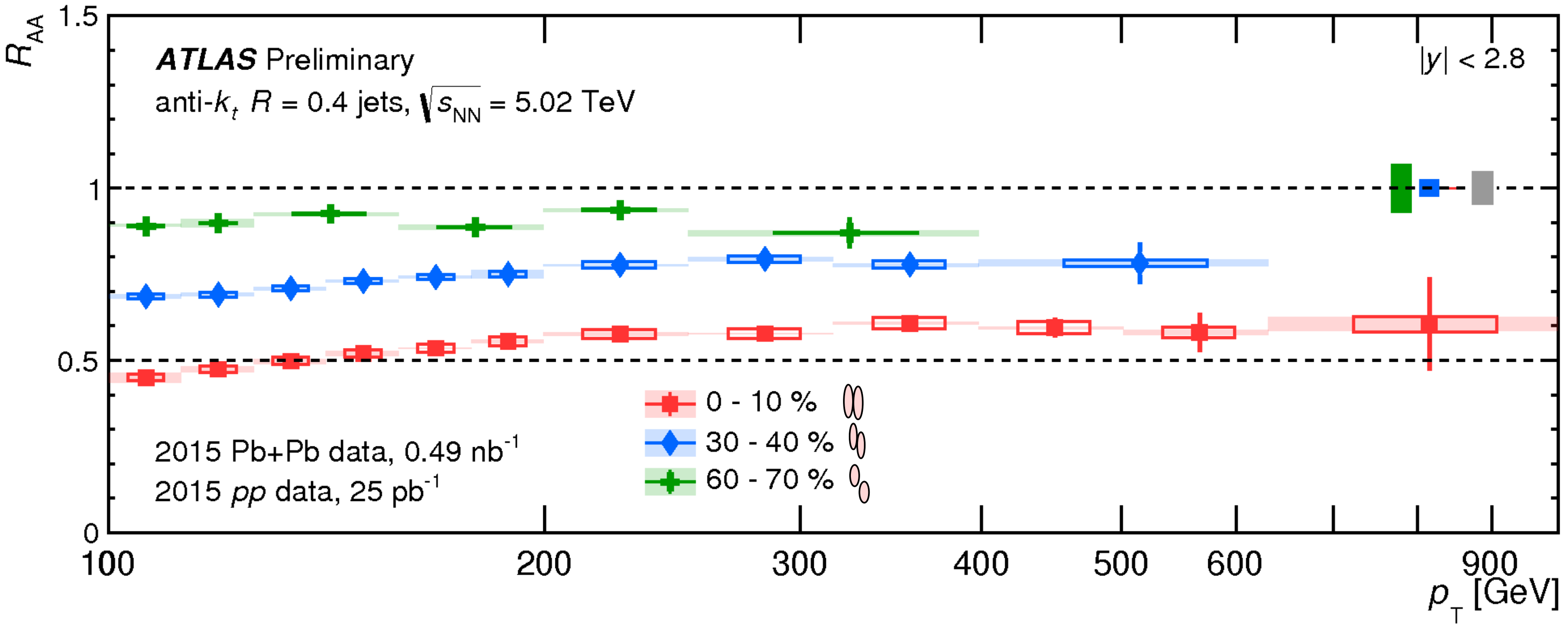
Per event jet yields in Pb+Pb collisions, divided by <T_{AA}>, as a function of jet p_T for different centrality intervals .

pp data is represented by a line above the closed circles.

ATLAS-CONF-2017-009

Jet R_{AA}

Nuclear modification factor, R_{AA}, as a function of jet p_T for three centrality intervals.



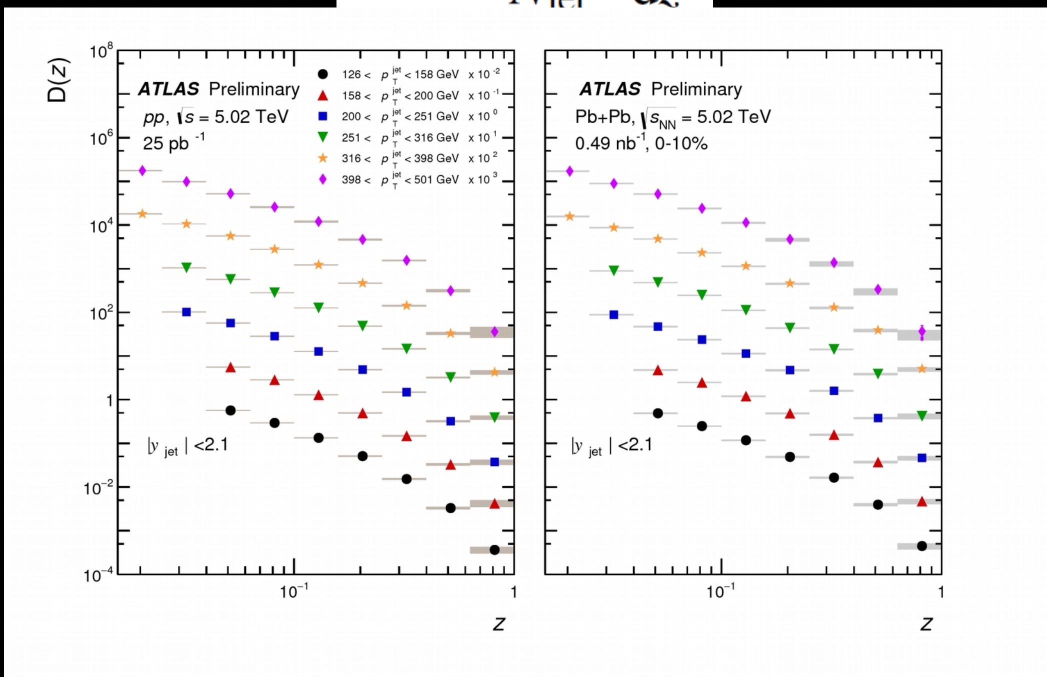
★ Jets are suppressed by a factor of two in central Pb+Pb collisions with slight dependence on transverse momentum, p_T.

ATLAS-CONF-2017-009

Jet fragmentation functions

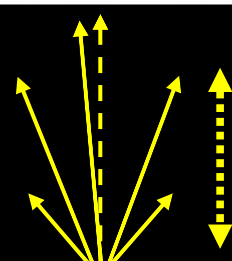
Jet internal structure is crucial to understand energy loss

$$D(z) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}z}$$



- N_{ch} is the number of charged particles associated to a jet.
- Jet structure measured in different p_T^{jet} ranges (126−501 GeV), using charged tracks with $p_T > 4$ GeV.
- FF are background subtracted, corrected for reconstruction inefficiency and unfolded with 2D Bayesian method.

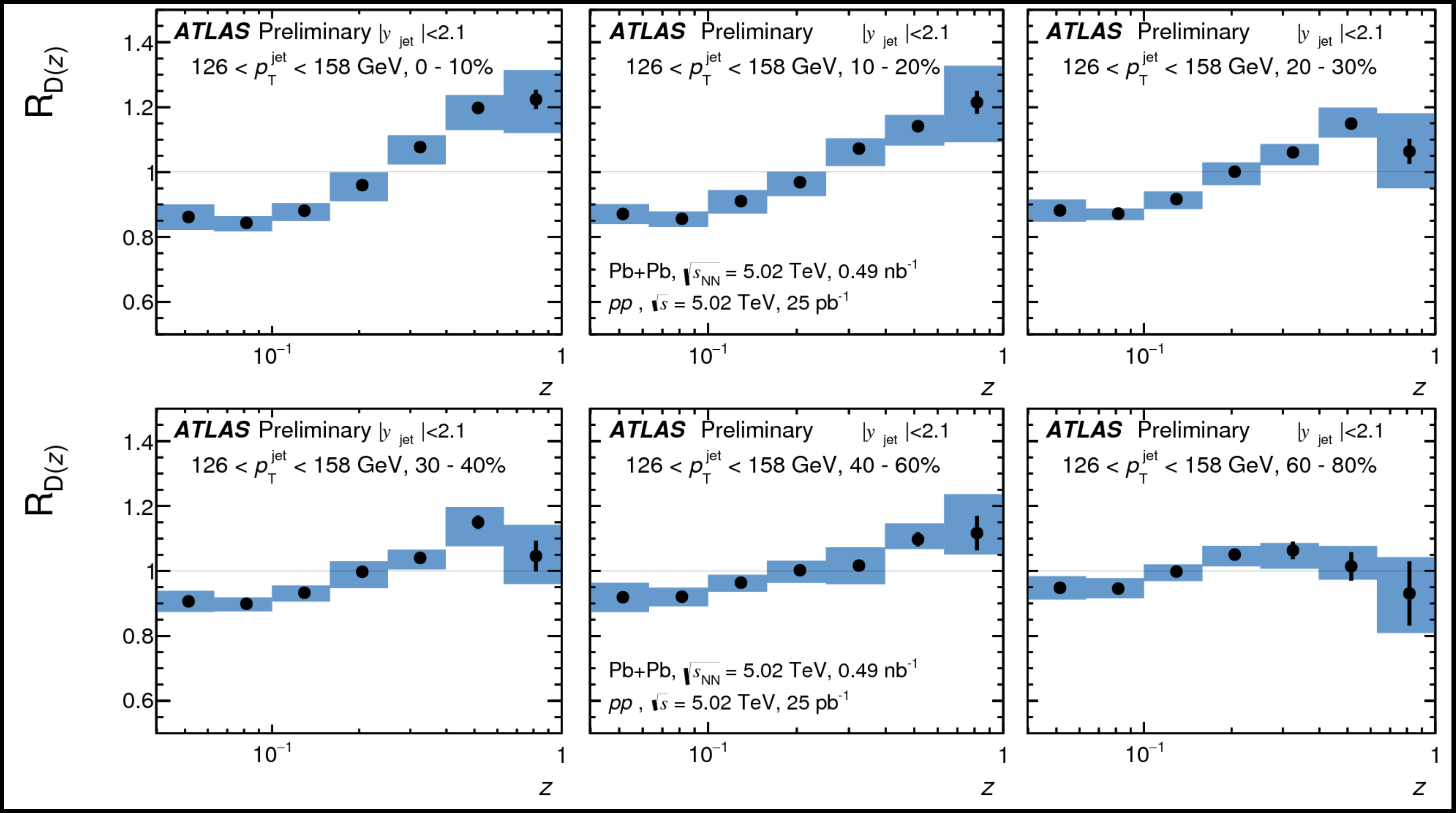
The FF decrease with z, independent of p_T^{jet}.



$$z \equiv \frac{p_{\mathrm{T}}}{p_{\mathrm{T}}^{\mathrm{jet}}} \cos \Delta R$$

ATLAS-CONF-2017-005

$R_{D(z)} = D(z)_{cent} / D(z)_{p+p}$

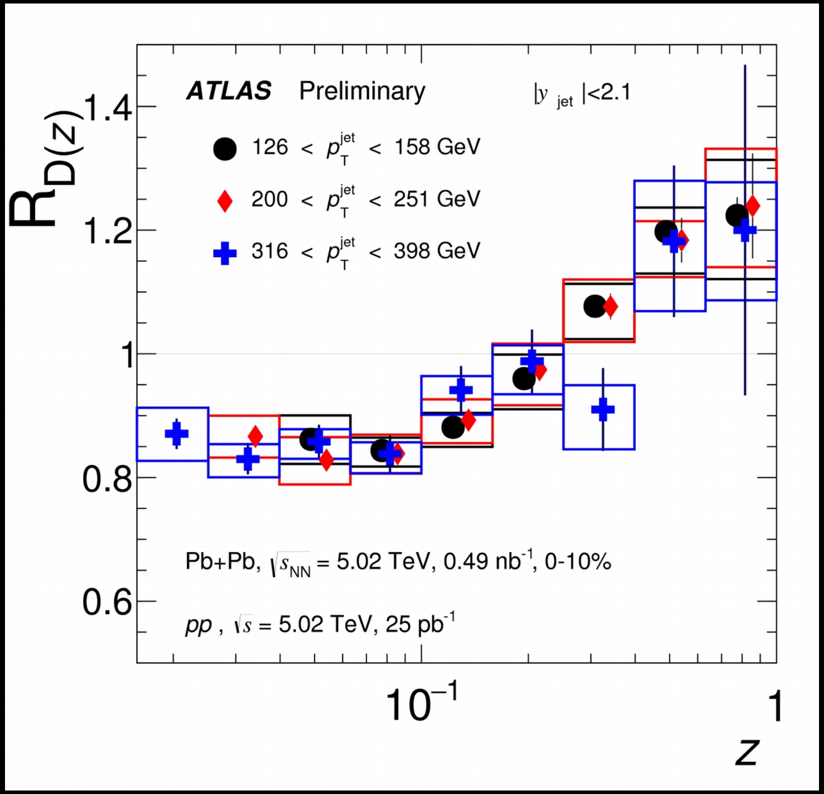


- Increasing modification of D(z) as centrality increases.
- Suppression of the charged particle yield for $z < 0.2$ and enhancement at high z in central collisions.

ATLAS-CONF-2017-005

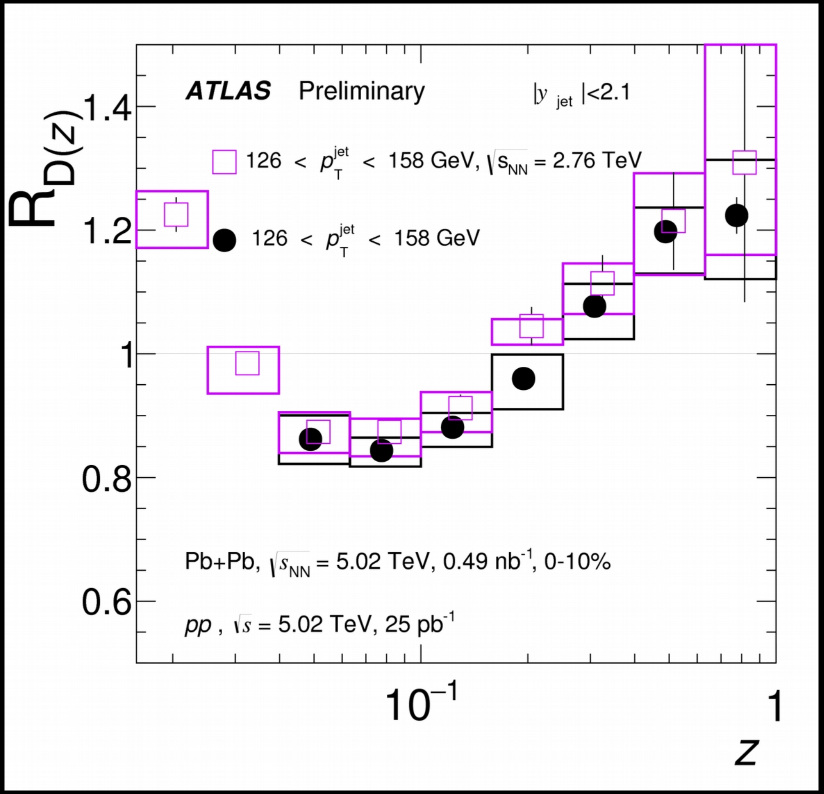
$R_{D(z)}$ in central collisions

Comparison between different p_T^{jet} ranges



$R_{D(z)}$ for $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV

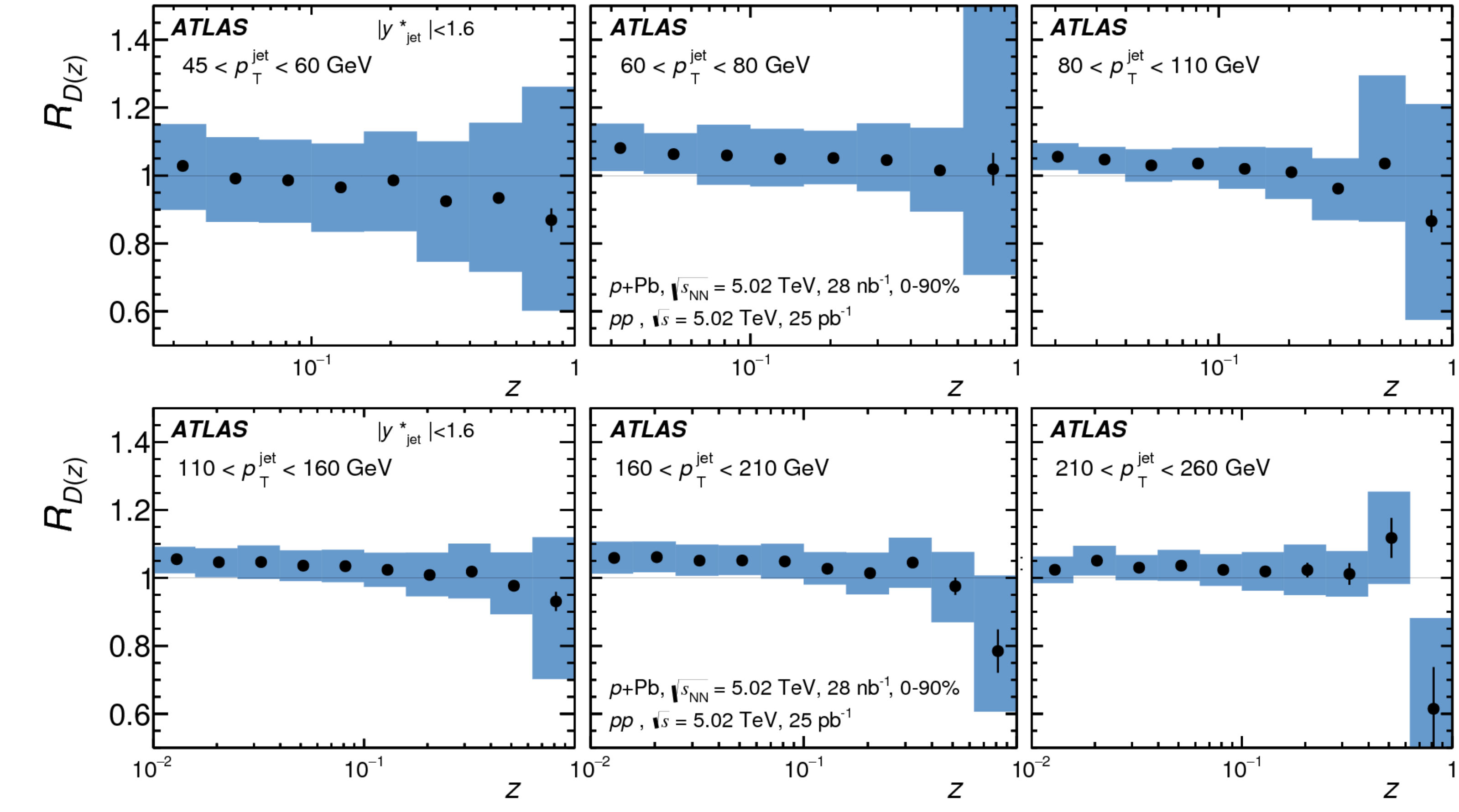
(5.02 TeV results do not include z < 0.04)



No dependence on jet p_T and collision's energy within uncertainties is observed.

ATLAS-CONF-2017-005

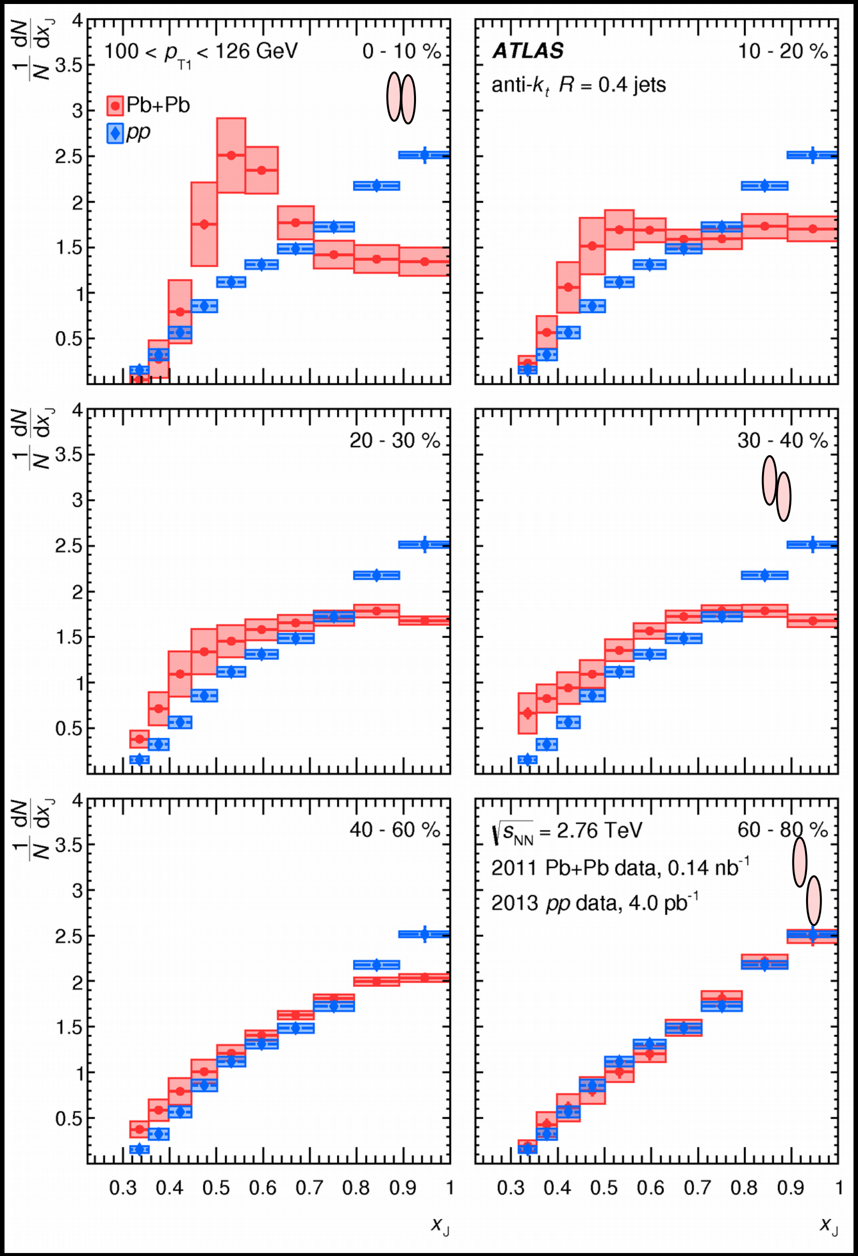
$R_{D(z)}$ in p+Pb collisions



$R_{D(z)}$ in p+Pb collisions is consistent with unity within systematic uncertainties, independently on the studied jet p_T range.

arXiv:1708.02859

$x_J = p_{T2} / p_{T1}$



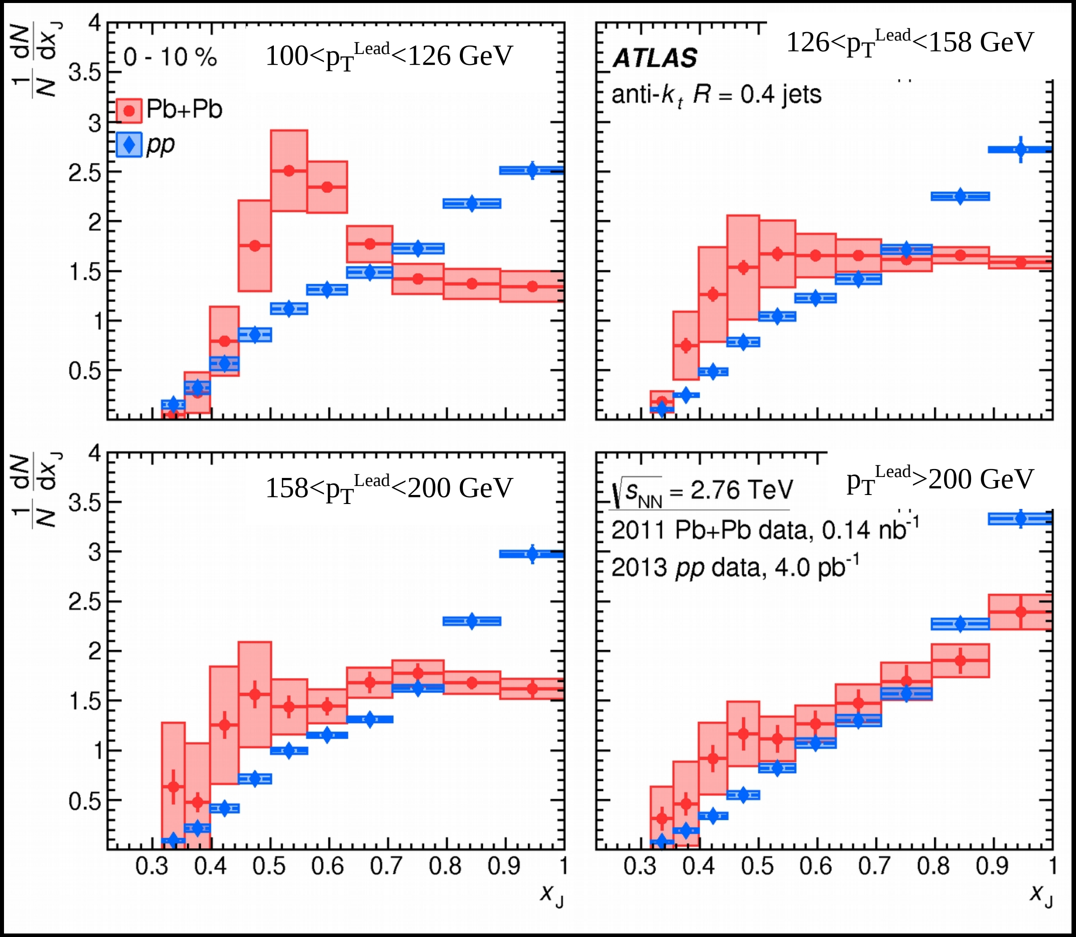
Dijet asymmetry probes differences in quenching between the two parton showers.

- The asymmetry in peripheral collisions is well compatible with pp collisions (no QGP formation)
- The asymmetry increases with collision centrality

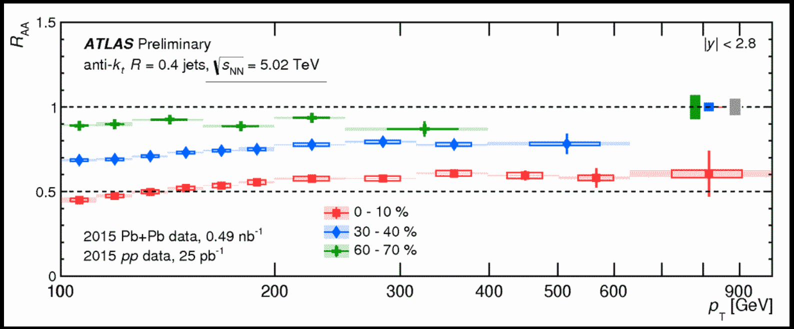
arXiv:1706.09363 [hep-ex]

Dijet asymmetry in central collisions

p_T^{Lead} dependence in 0-10% centrality



Clear dependence with p_T of the leading jet, in contrast to single jets. R_{AA} (@ 5.02 TeV) shows very weak p_T dependence.

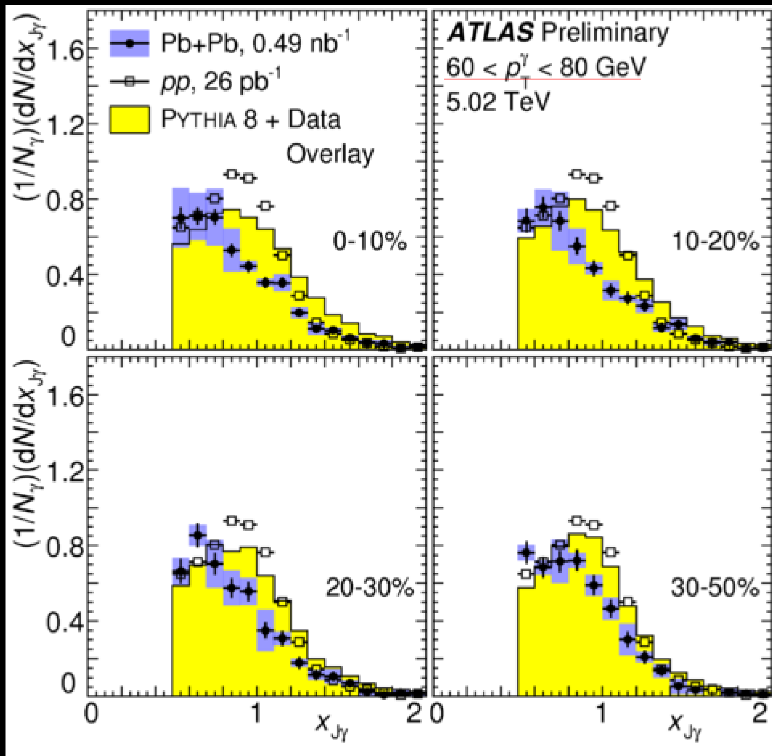


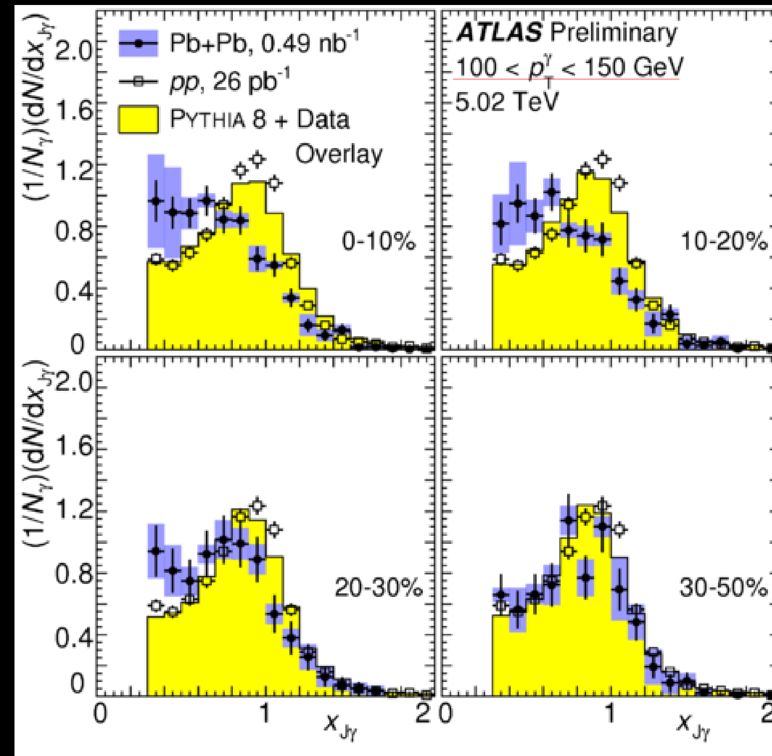
Much smaller modification at high p_T^{Lead}.

arXiv:1706.09363 [hep-ex]

Photon-jet asymmetry

anti-k_t R=0.4 jets; p_T^{jet} > 30 GeV; $|y^{jet}|$ < 2.1; $\Delta\varphi^{J\gamma}$ > 7π/8



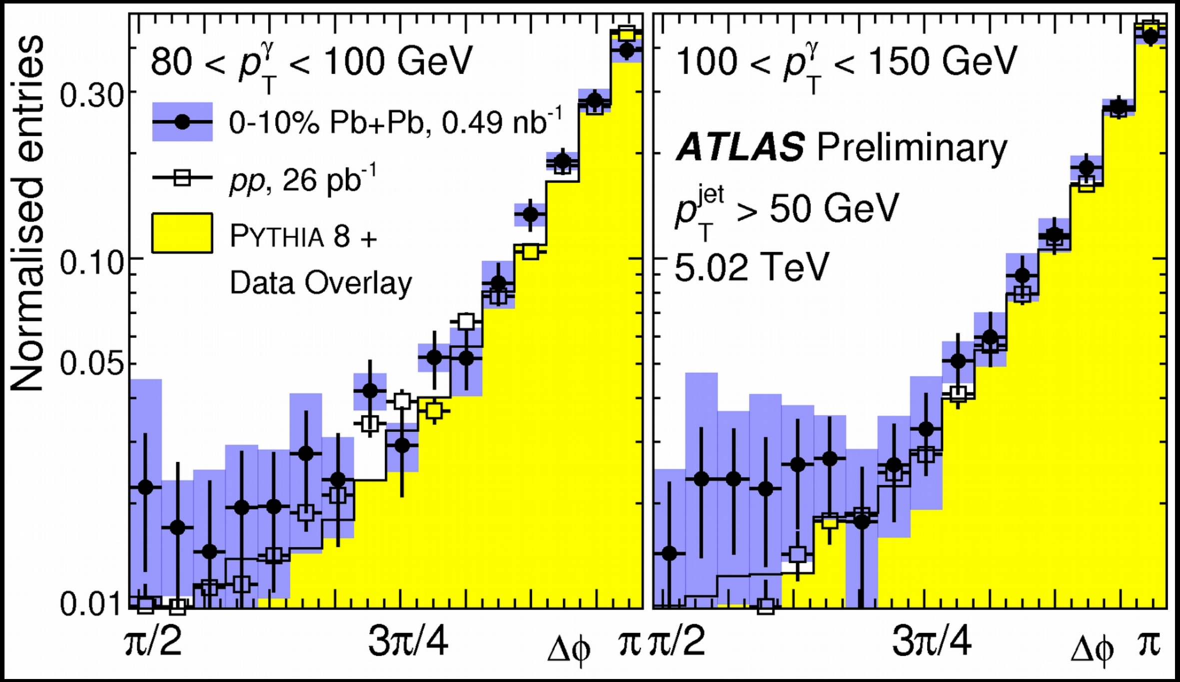


- **The photon-jet $x_{J\gamma} = p_T^J / p_T^\gamma$ is increasingly modified with increasing centrality, relative to pp collisions and MC.**
- **Less modified in 30-50% for larger photon momentum suggesting lower fraction of energy loss with increasing parton p_T.**

Photon-jet Δφ

anti-k_t R=0.4 jets; $p_T^{jet} > 30$ GeV; $|y^{jet}| < 2.1$; normalized to the integral in $\Delta\varphi^{J\gamma} > 7\pi/8$

ATLAS-CONF-2016-010



- **Similar behaviour in pp and Pb+Pb collisions within uncertainties.**

Messages from Jets

Inclusive jets in Pb+Pb are suppressed relatively to p+p up to a factor of 2.

Internal jet structure shows suppression of particle yields at low z and enhancement at high z in Pb+Pb central collisions; no dependence on jet p_T and collision energy.

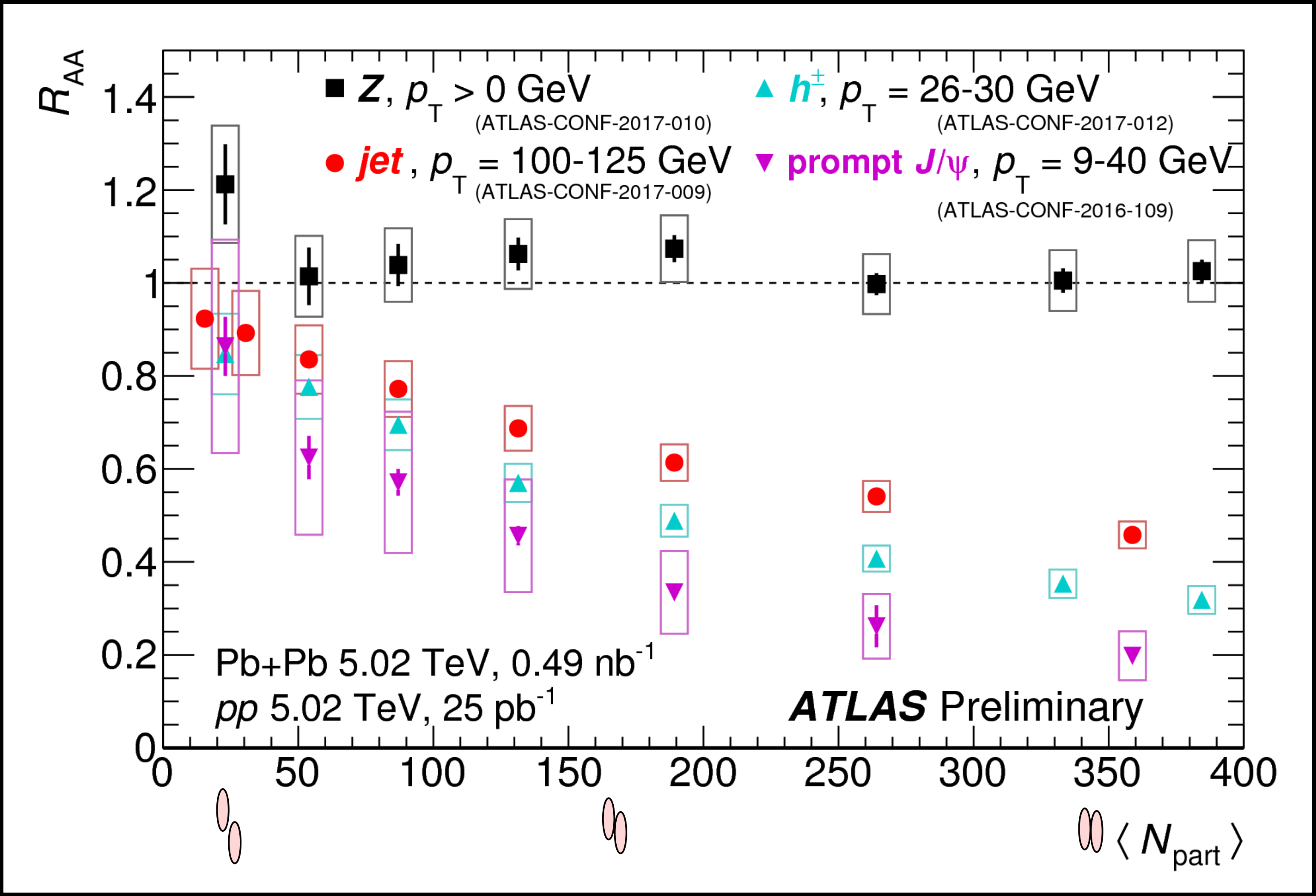
$R_{D(z)}$ compatible with unity in p+Pb collisions.

Enhancement of asymmetric dijets in Pb+Pb, w.r.t to p+p, as the centrality increases. Clear dependence with the p_T of the leading jet, in contrast to inclusive jets.

Increasingly asymmetric photon-jet balance with increasing centrality. Less pronounced with increasing photon p_T. Photons and jets remain back-to-back.

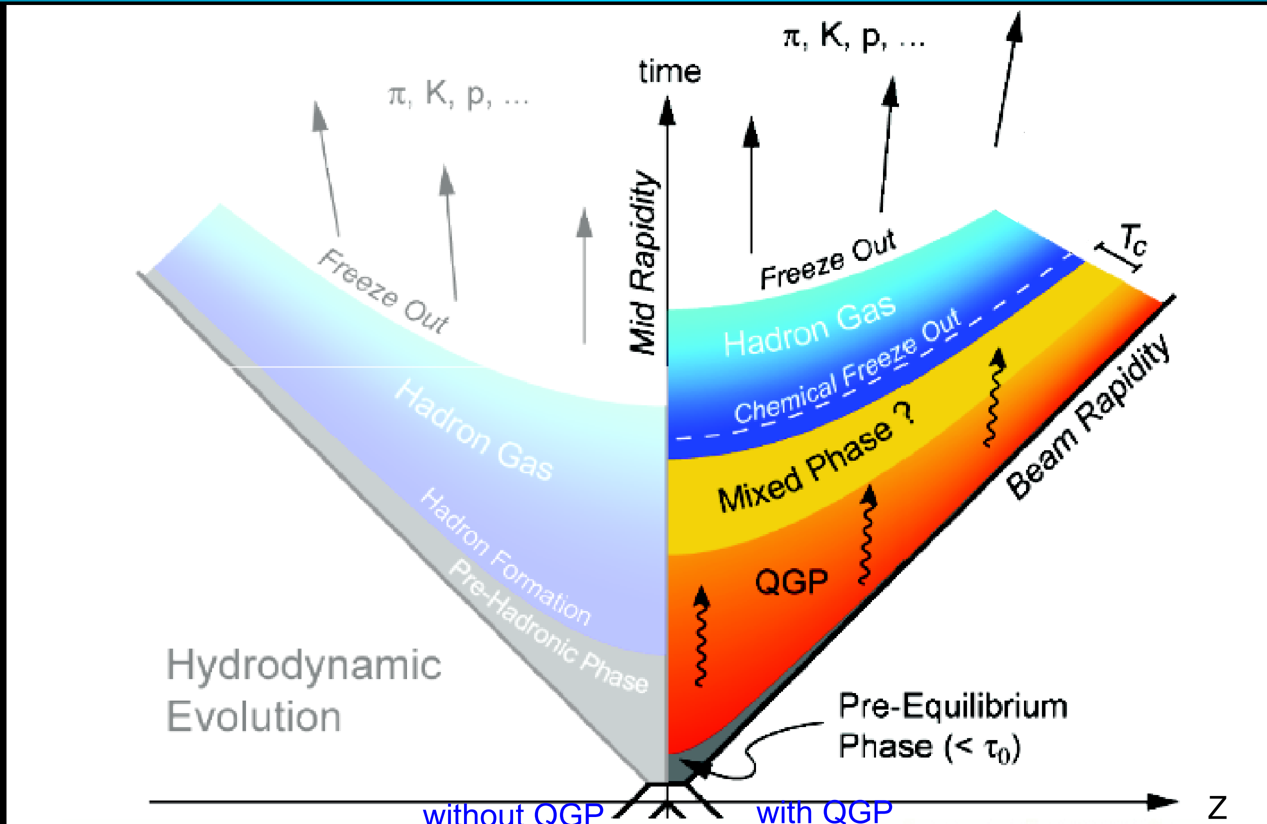
Backup

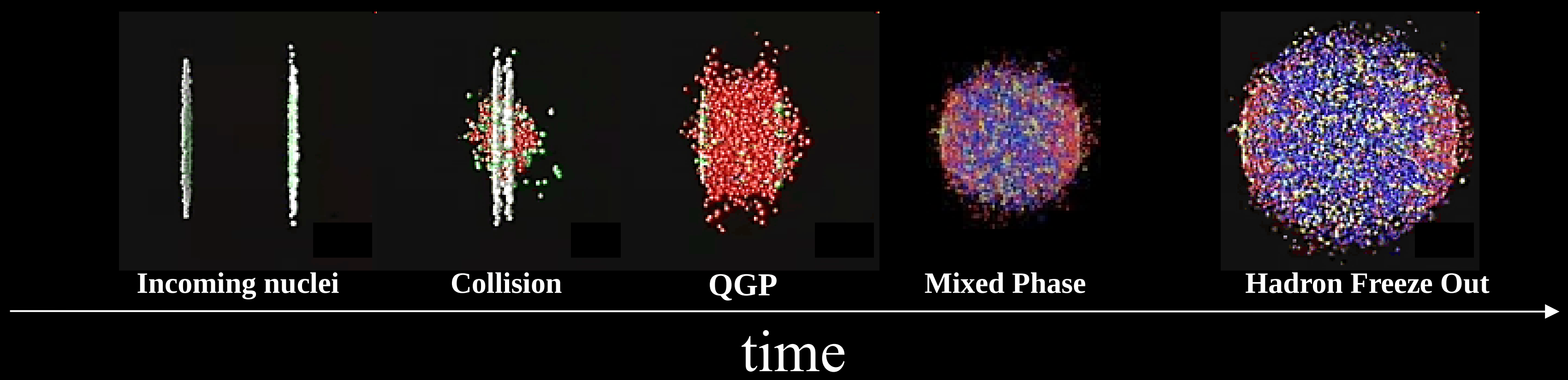
Summary Plot



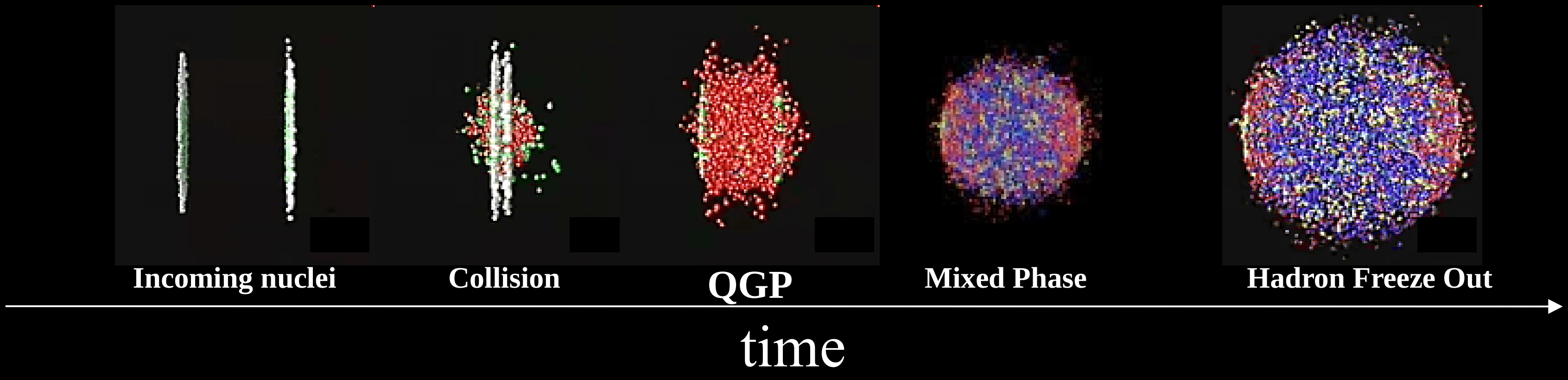
Compilation of results for the nuclear modification factor R_{AA} vs. number of participating nucleons, N_{part}, in different channels from Pb+Pb and pp data.

Heavy Ion collisions





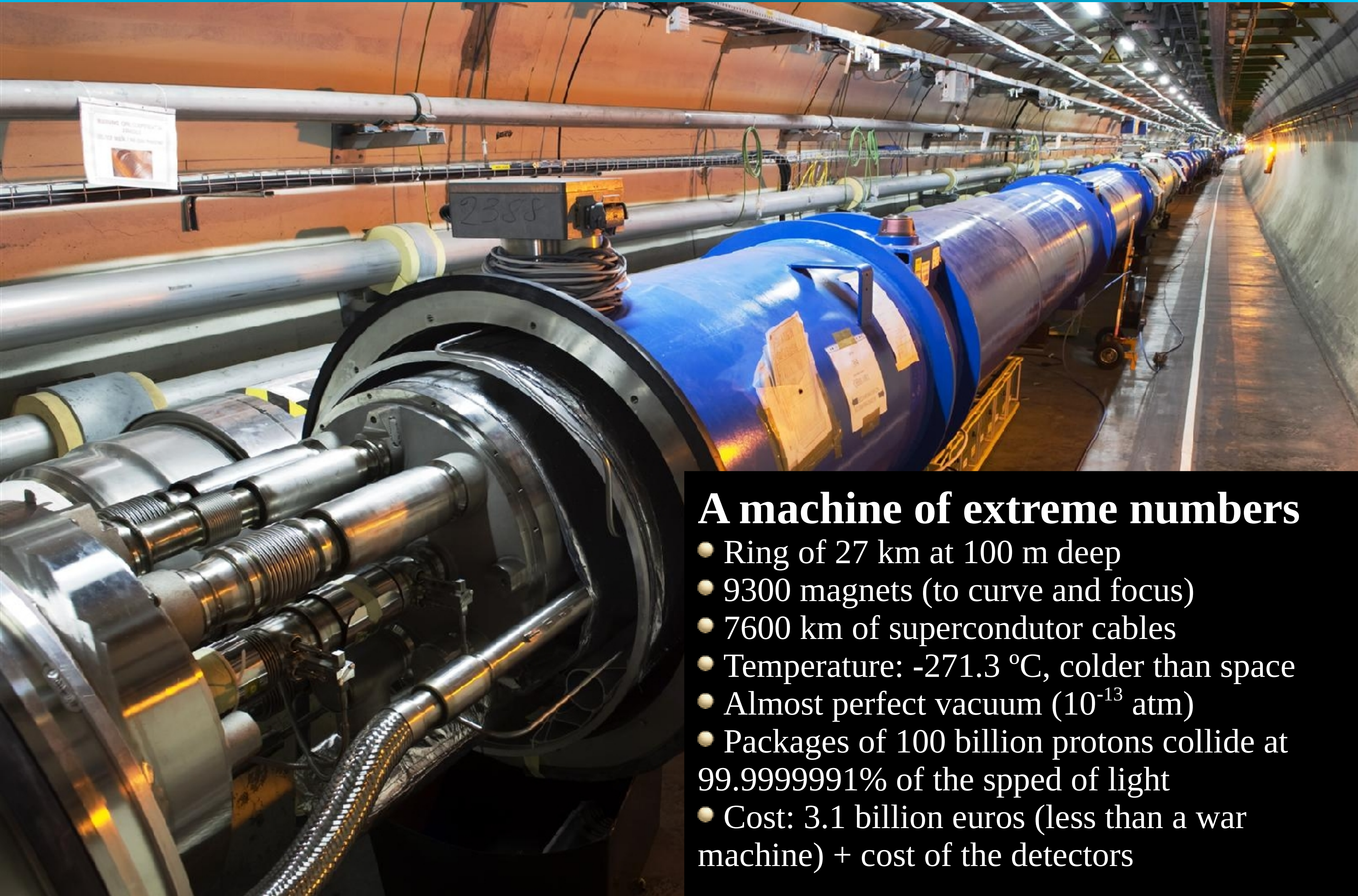
QGP Formation at the LHC



Which signatures of the QGP formation can we observe at the LHC ?

- Particle distributions; correlation between particles; collective motion.
- Suppression of resonances.
- "Jet quenching": modification of particle showers. The direction of the showers, their composition and how do they transfer energy to the hot and dense medium reveal the properties of the QGP.

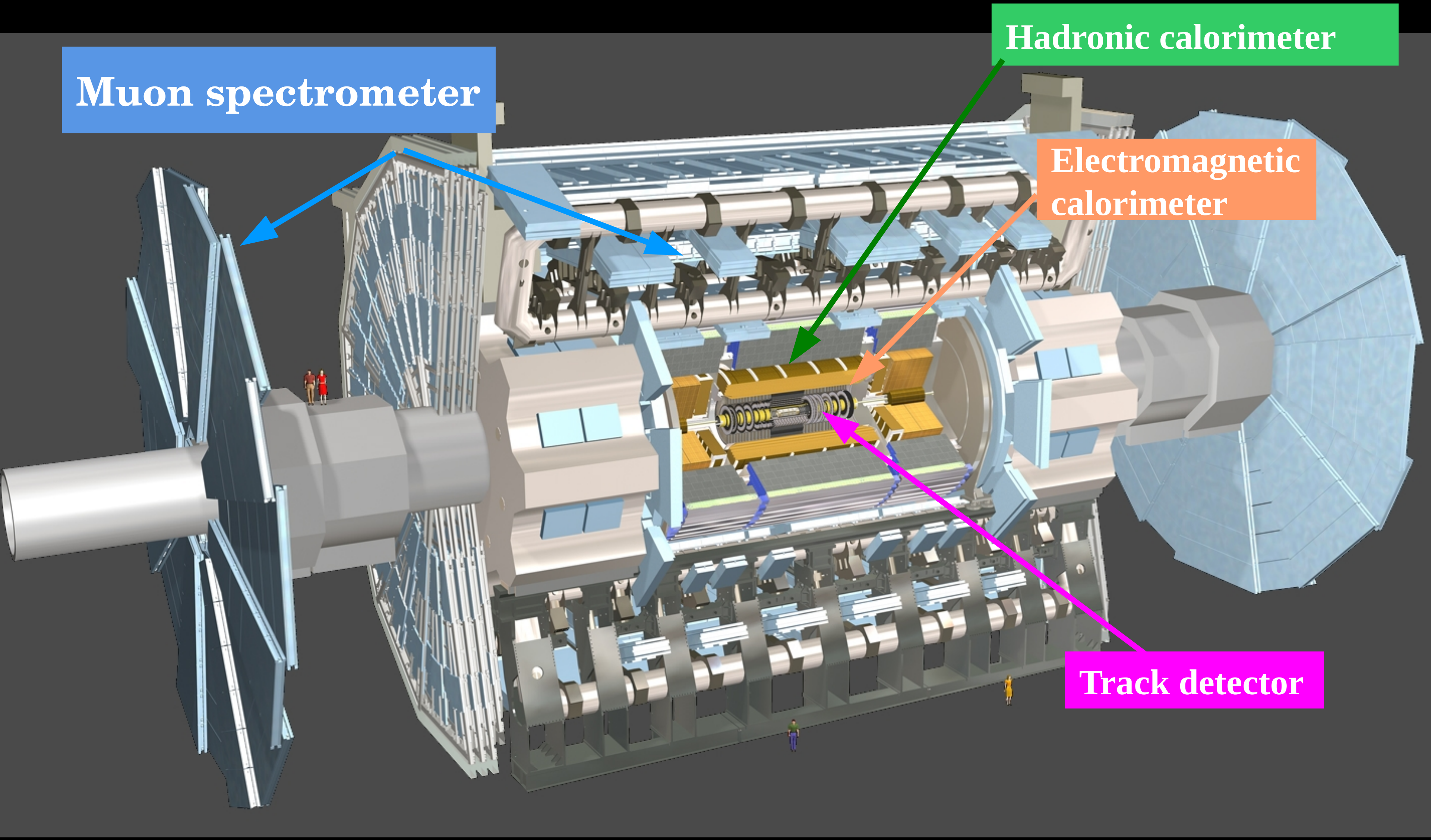
Large Hadron Collider



A machine of extreme numbers

- Ring of 27 km at 100 m deep
- 9300 magnets (to curve and focus)
- 7600 km of supercondutor cables
- Temperature: -271.3 ºC, colder than space
- Almost perfect vacuum (10^{-13} atm)
- Packages of 100 billion protons collide at 99.9999991% of the spped of light
- Cost: 3.1 billion euros (less than a war machine) + cost of the detectors

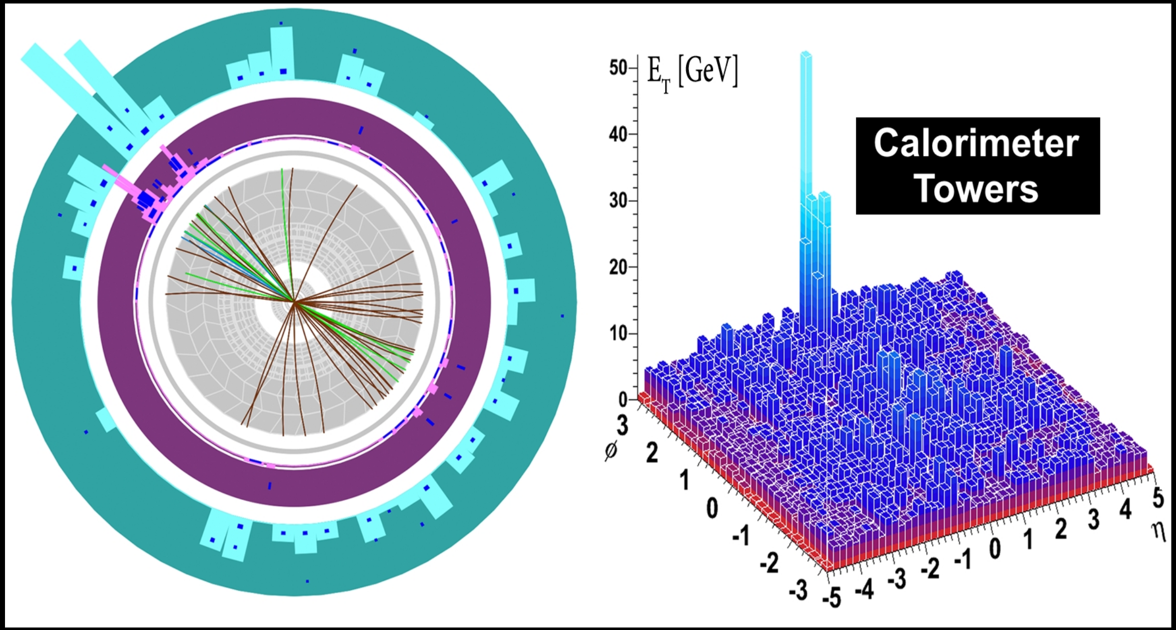
The ATLAS Experiment



Jet Reconstruction in the Detector

- Jets are reconstructed by computational algorithms that group "towers" of energy deposited in the calorimeters.

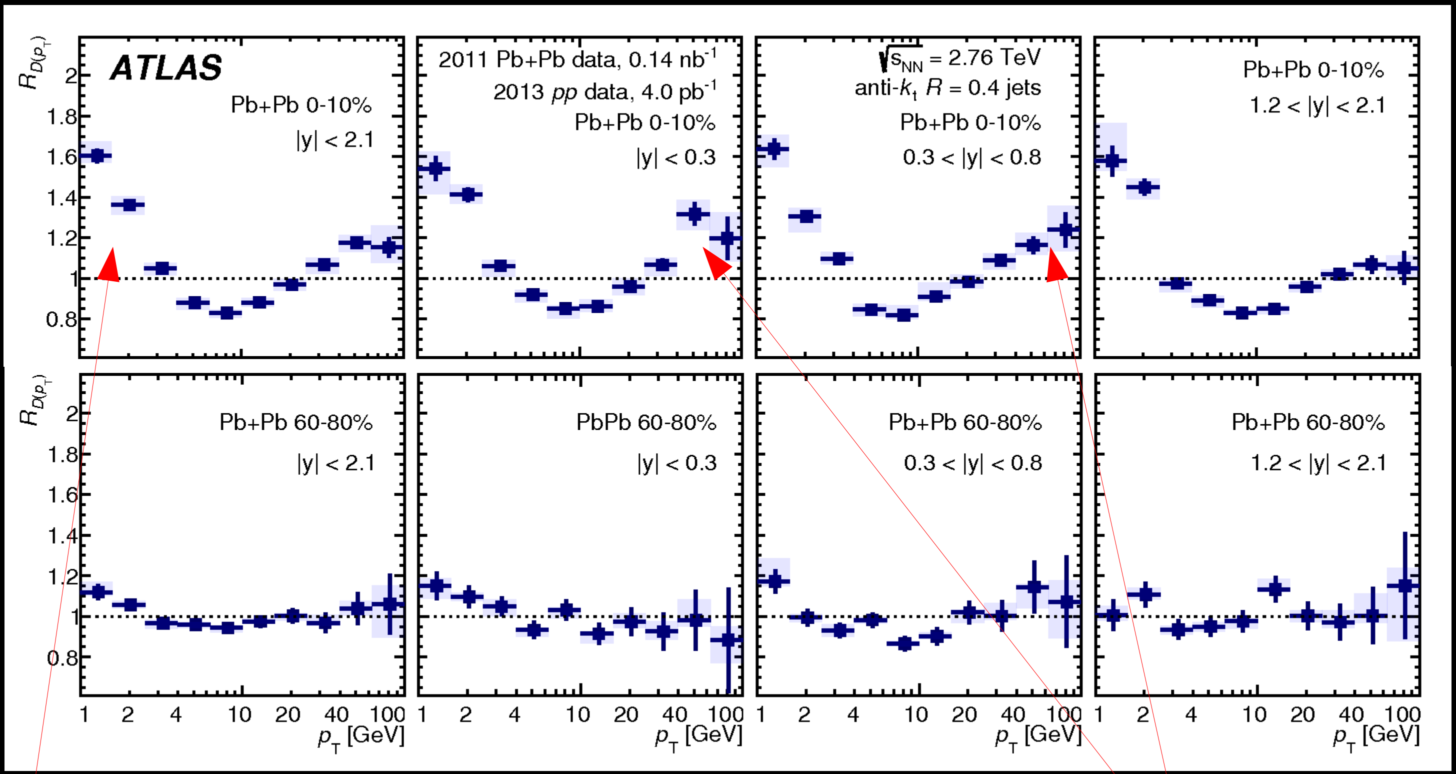
- The Underlying Event ("background") is estimated event-by-event, excluding the jet.



$R_{D(p\mathrm{T})} = \mathrm{D}(p_\mathrm{T})_{\mathrm{cent}} / \mathrm{D}(p_\mathrm{T})_{\mathrm{p+p}}$

Rapidity dependence of jet substructure modification

|η|<2.1 |η|<0.3 0.3<|η|<0.8 1.2<|η|<2.1



0-10%

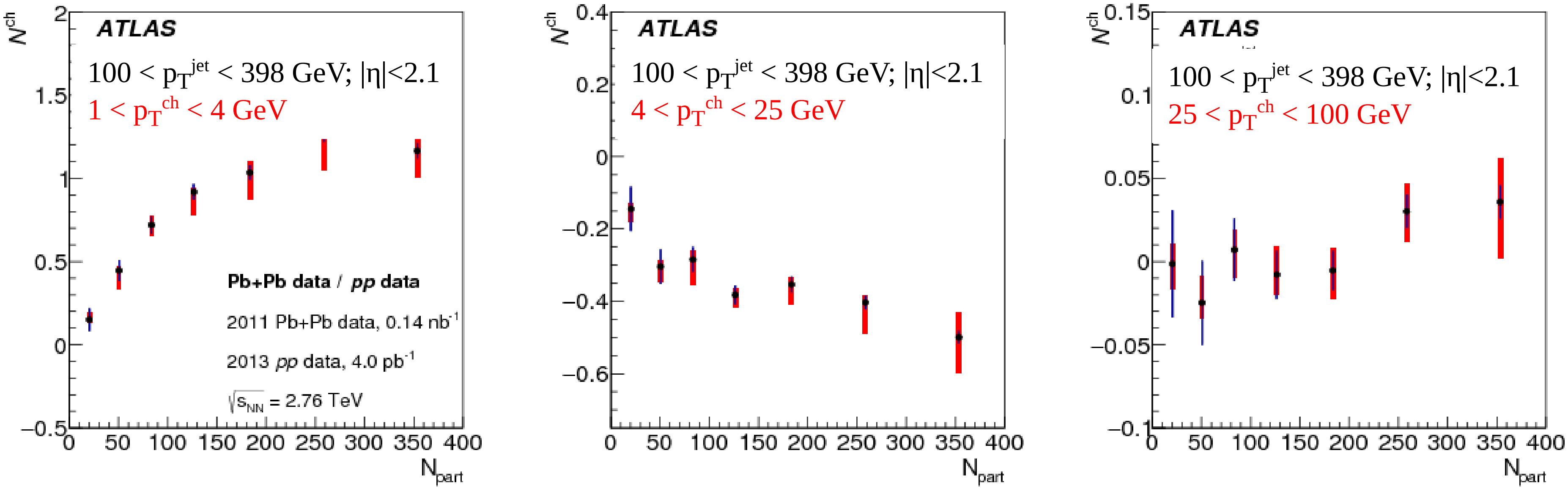
60-80%

In central collisions (0-10%):

- Enhancement of fragment yield for p_T^{ch} < 4 GeV; enhancement at p_T^{ch} > 25 GeV, mainly at mid-rapidity.
- Depletion at 4 < p_T^{ch} < 25 GeV.

EPJC (2017) 77, 379

extra/missing particles



$$N^{\mathrm{ch}} \equiv \int_{p_{\mathrm{T,min}}}^{p_{\mathrm{T,max}}} \left(D(p_{\mathrm{T}})|_{\mathrm{cent}} - D(p_{\mathrm{T}})|_{\mathrm{pp}} \right) \mathrm{d}p_{\mathrm{T}}$$

in a given centrality/N_{part} bin

Tells how many extra/missing particles is in charged particle p_T range

- **A clear increase of yields of particles with low transverse momentum ($1 < p_T^{ch} < 4$ GeV) as the collision's centrality increases is observed.**

- **Particles with p_T^{ch}>4 GeV do not exhibit noticeable variations with centrality.**

EPJC (2017) 77, 379