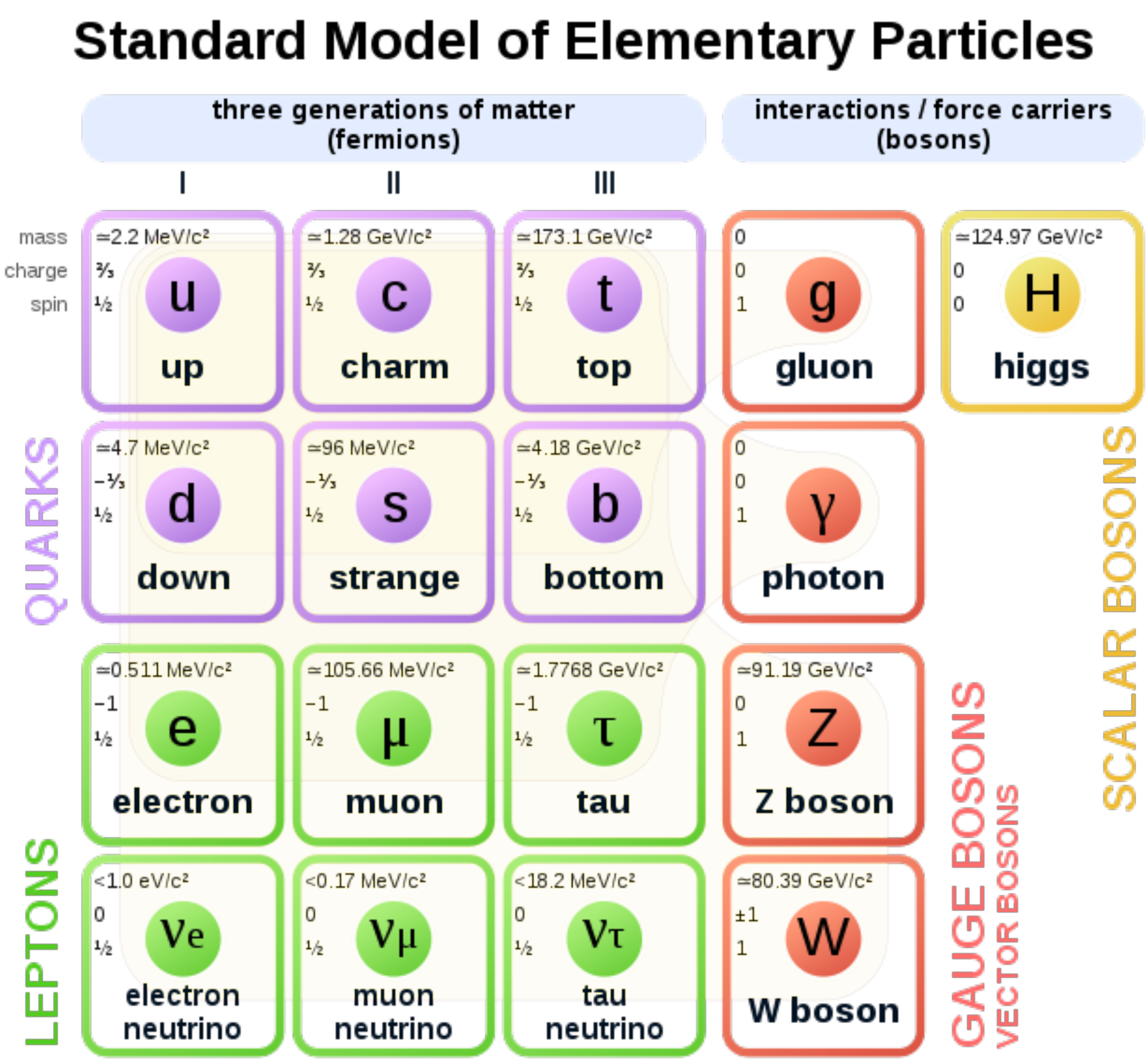
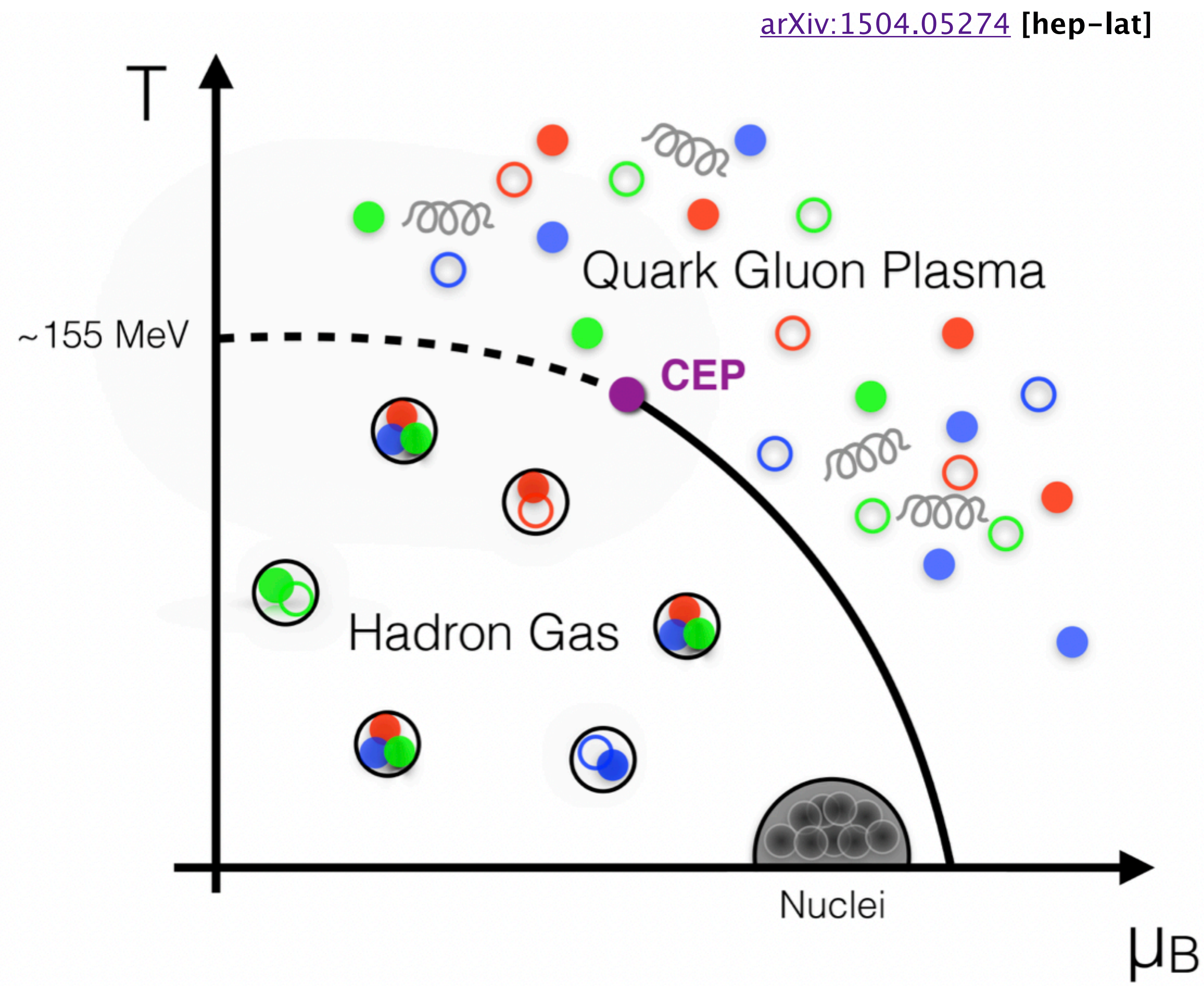
Overview of the ATLAS results on jet quenching

Dominik Derendarz
February 23, 2021

Heavy ion collisions - QCD laboratory

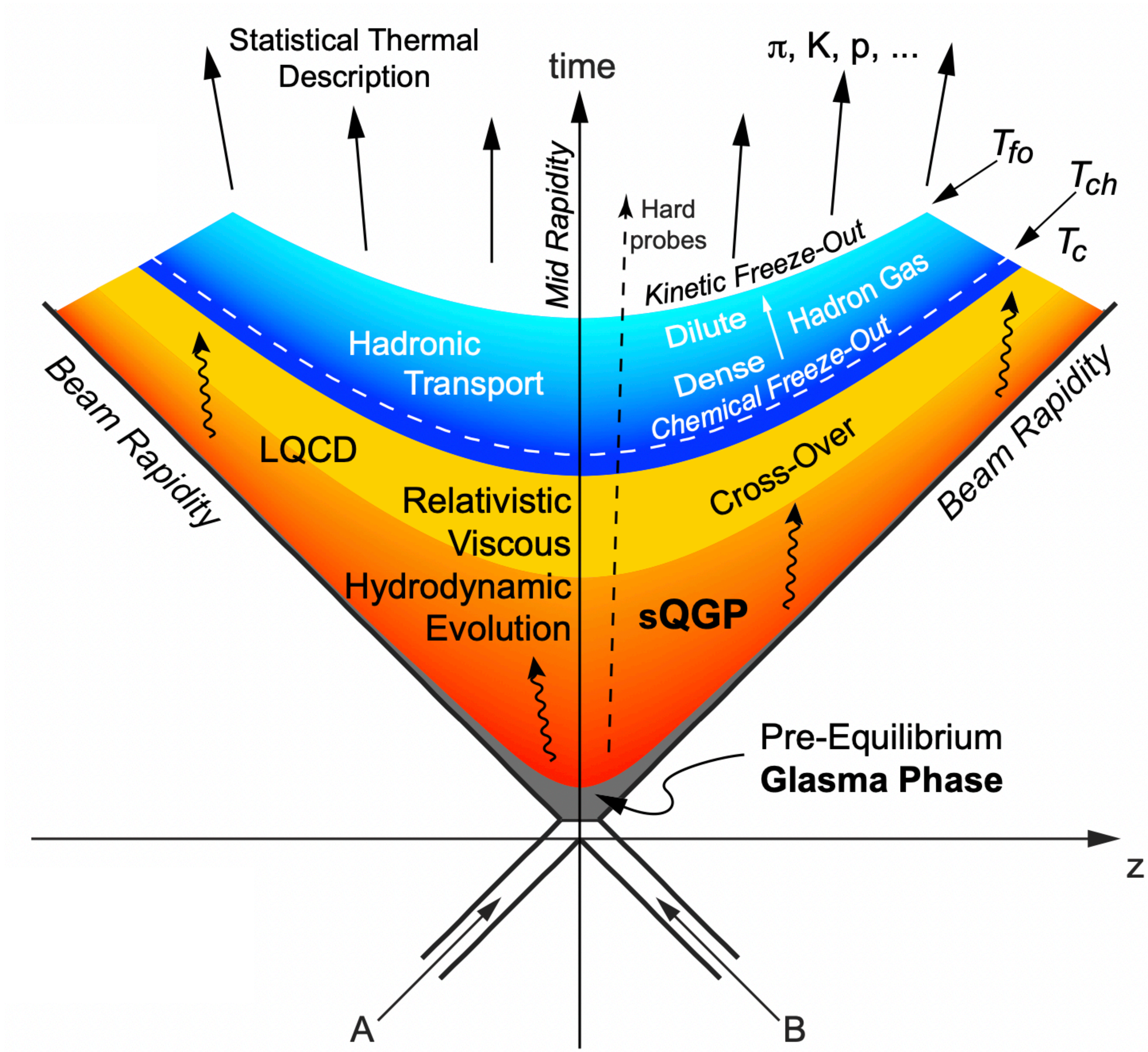


Schematic QCD phase diagram



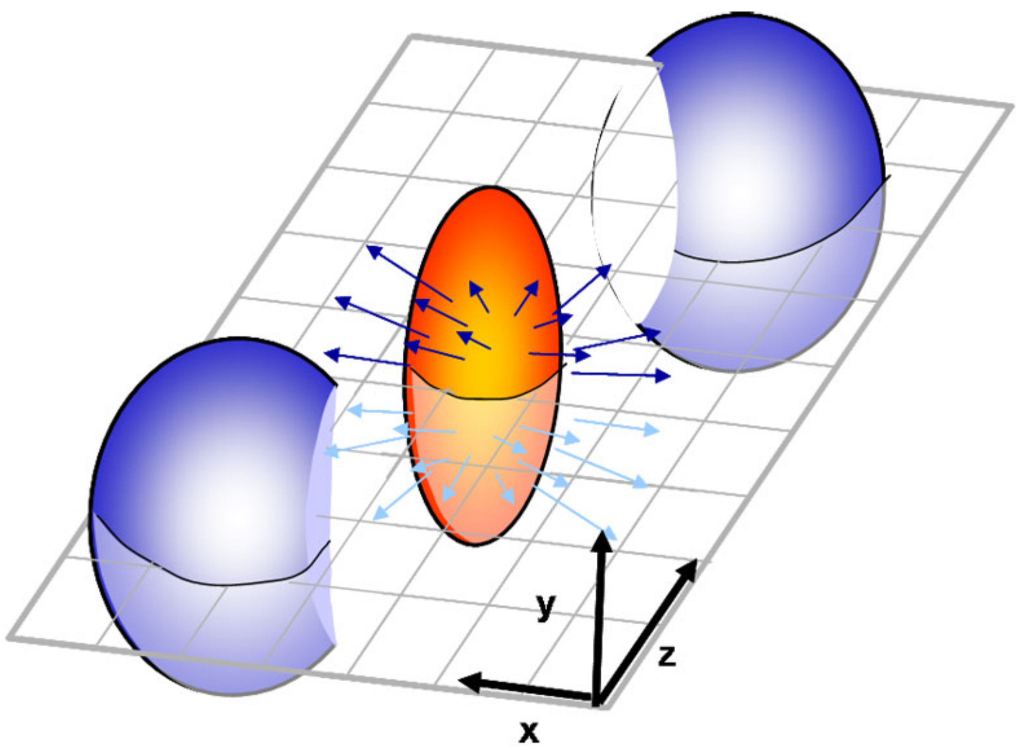
Phase transition at sufficiently high temperature

Heavy ion collisions - QCD laboratory



Heavy ion collisions allows to reach high enough temperature to trigger the phase transition to QGP (for about few fermi or few 10^{-23} s)

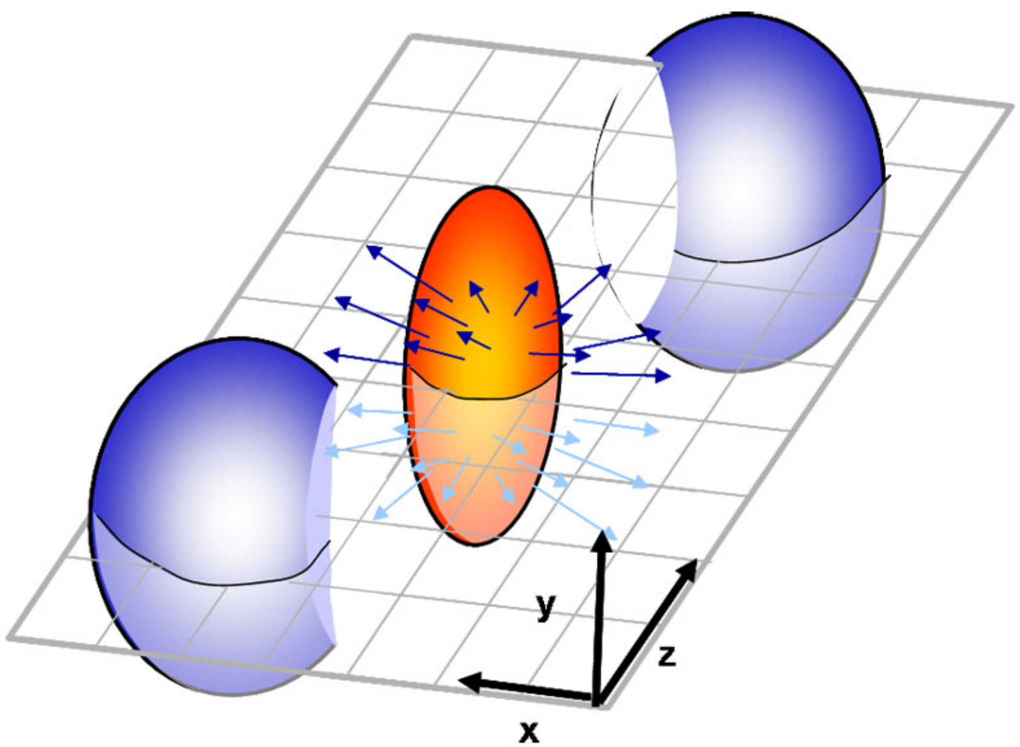
Collective phenomena



- Initial **spatial** anisotropy is converted to **momentum** anisotropy of final state particles

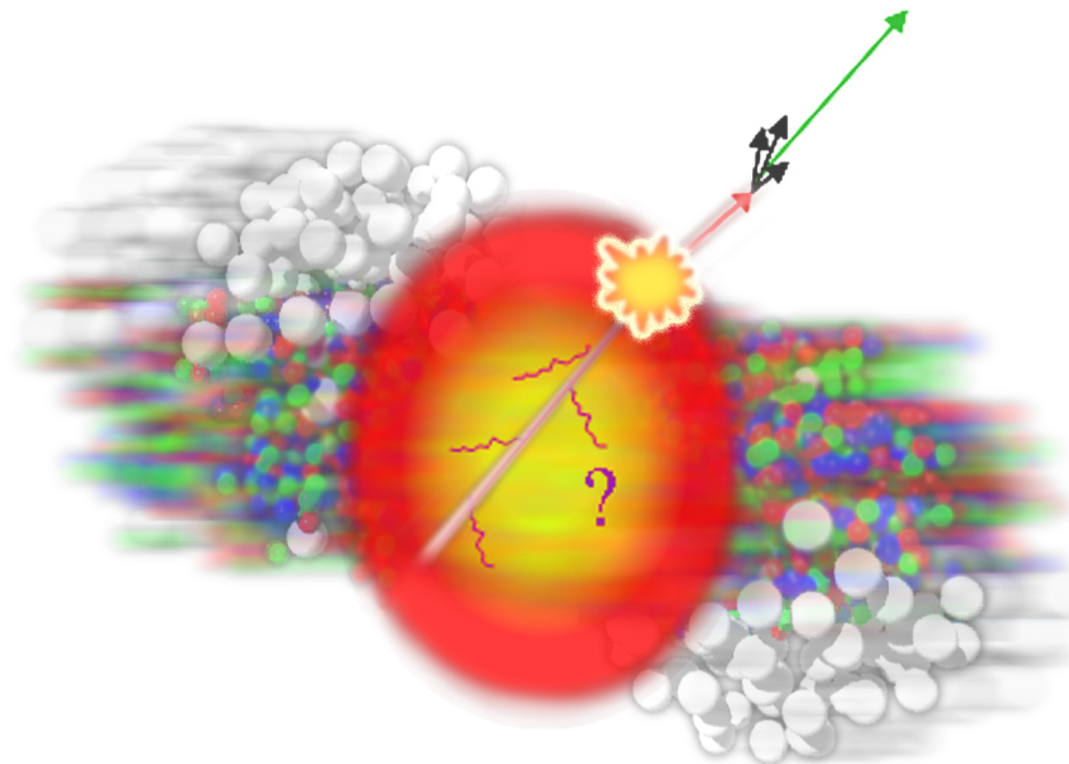
Signatures of QGP formation

Collective phenomena



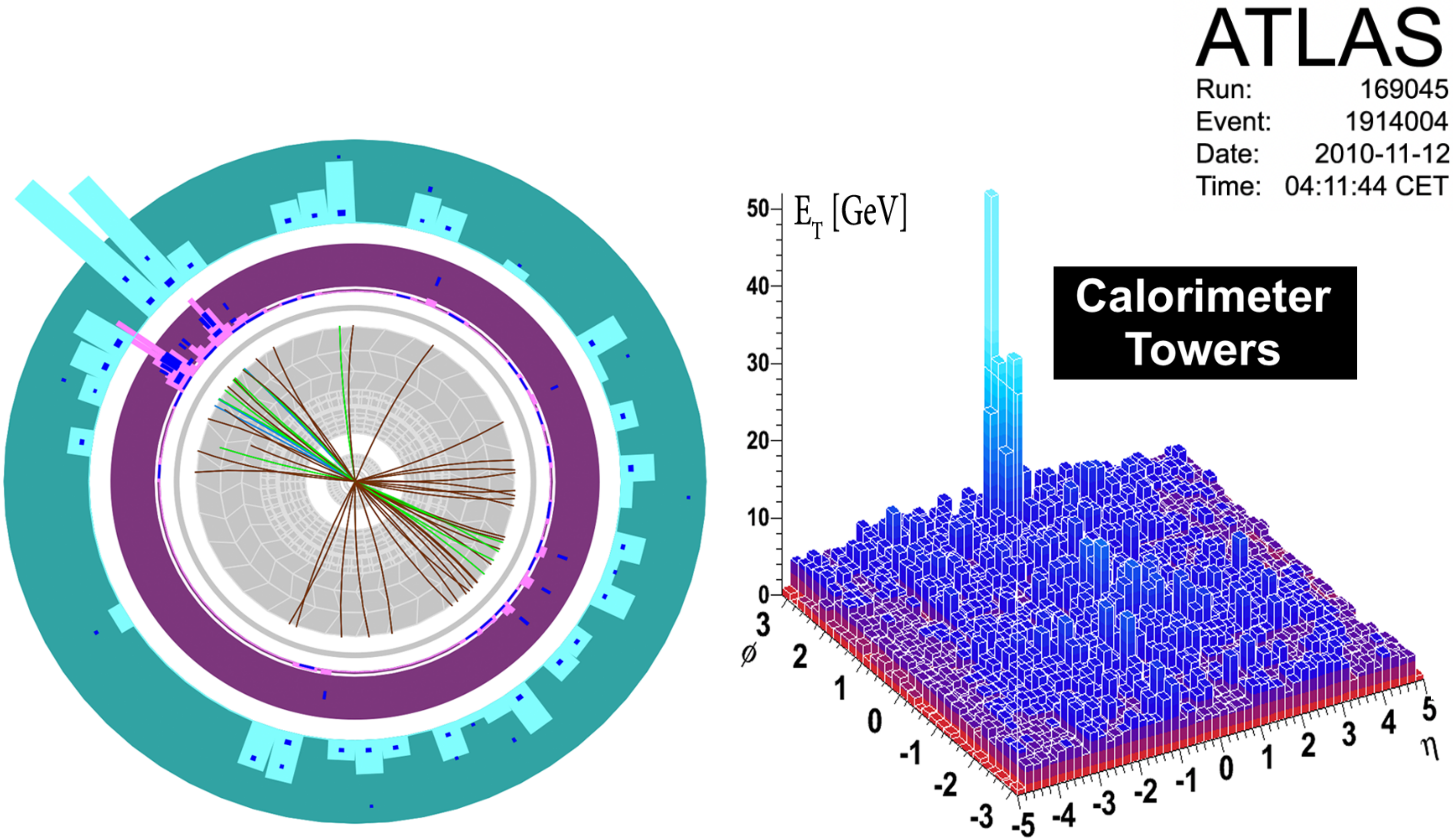
- Initial **spatial** anisotropy is converted to **momentum** anisotropy of final state particles

Jet quenching



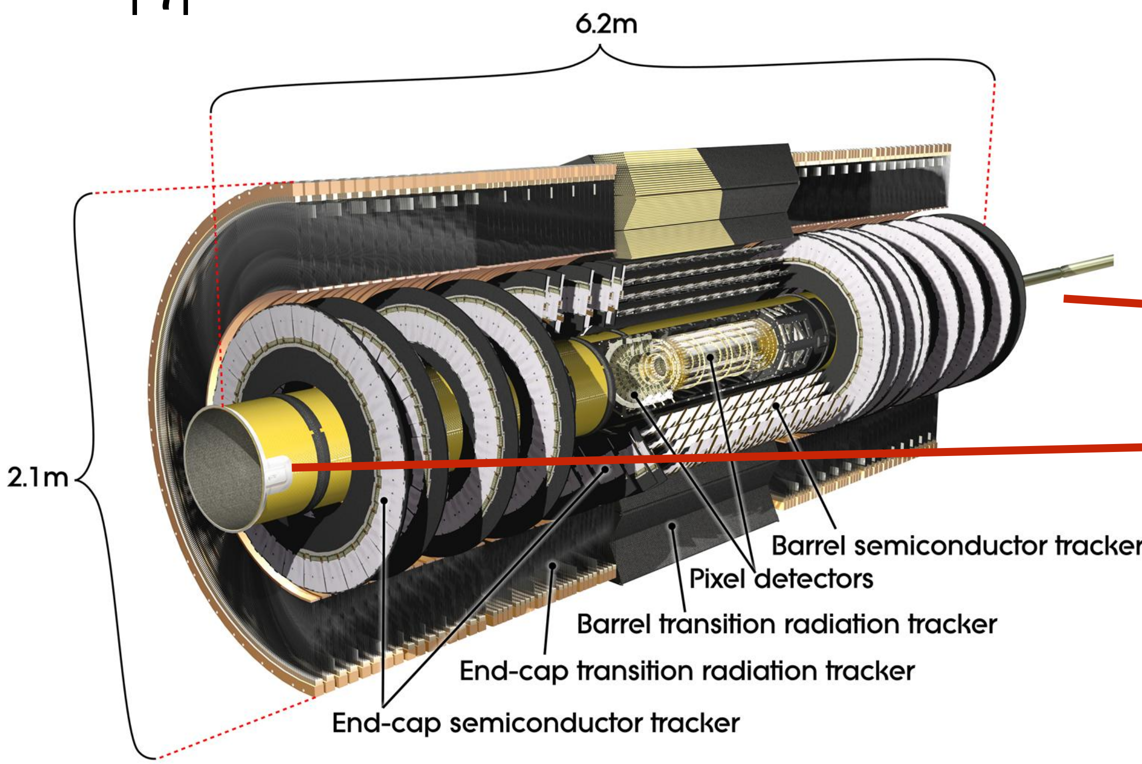
- Energy loss of high pT patron due to the interactions with the QGP medium

Bare eye jet quenching from 2010

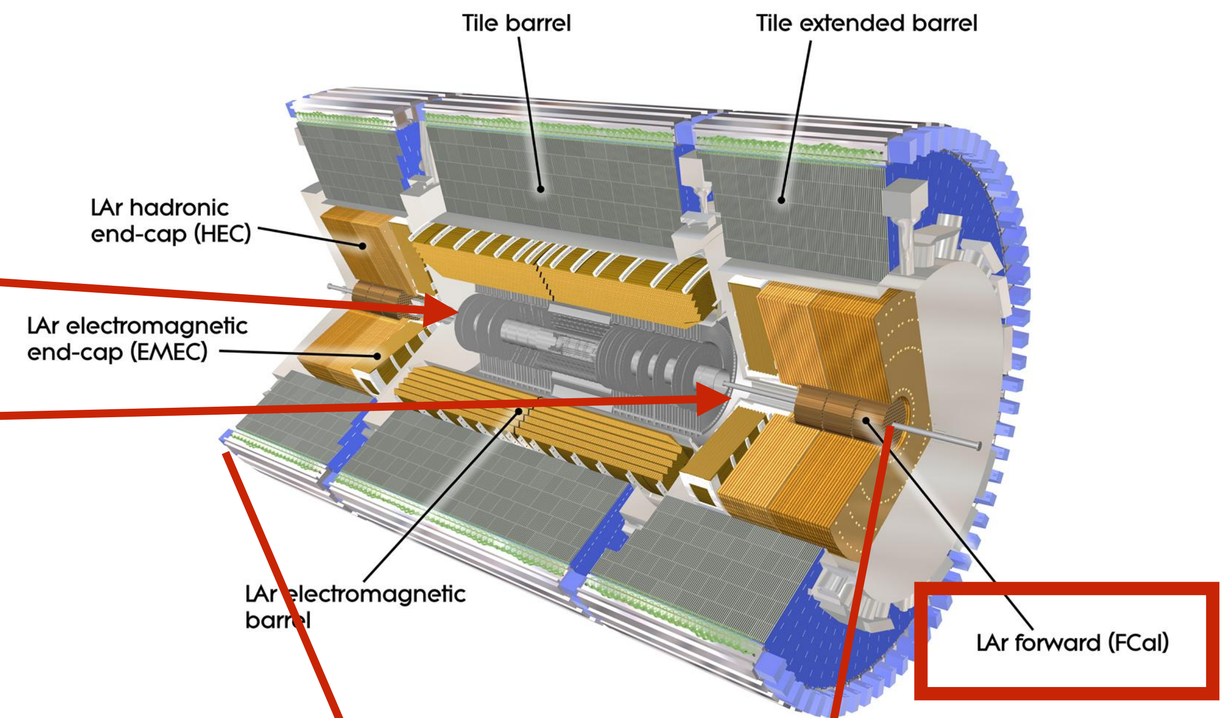


ATLAS detector

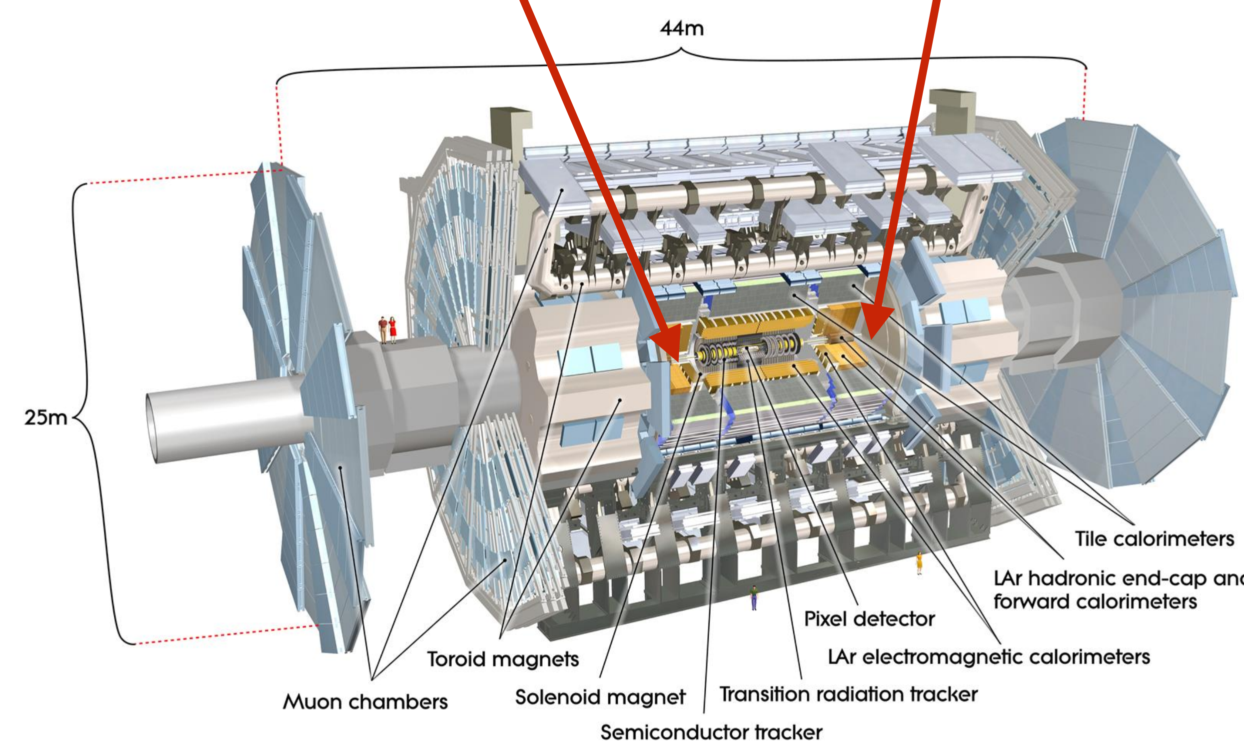
Tracker $|\eta| < 2.5$



Calorimeters $|\eta| < 4.9$



- And forward detectors located far far away from the interaction point ZDC (140m), AFP & ALFA (~240m)



Heavy ion datasets

	System	Year	sqrt(s_{NN}) [TeV]	L_{int}
Run1	Pb+Pb	2010	2.76	7 μb^{-1}
	Pb+Pb	2011	2.76	0.14 nb^{-1}
	pp	2012	8	19.4 fb^{-1}
	pp	2013	2.76	4 pb^{-1}
	p+Pb	2013	5.02	29 nb^{-1}
Run2	pp	2015	5.02	28 pb^{-1}
	Pb+Pb	2015	5.02	0.49 nb^{-1}
	p+Pb	2016	5.02	0.5 nb^{-1}
	p+Pb	2016	8.16	0.16 pb^{-1}
	Xe+Xe	2017	5.44	3 μb^{-1}
	pp	2017	5.02	270 pb^{-1}
	Pb+Pb	2018	5.02	1.76 nb^{-1}

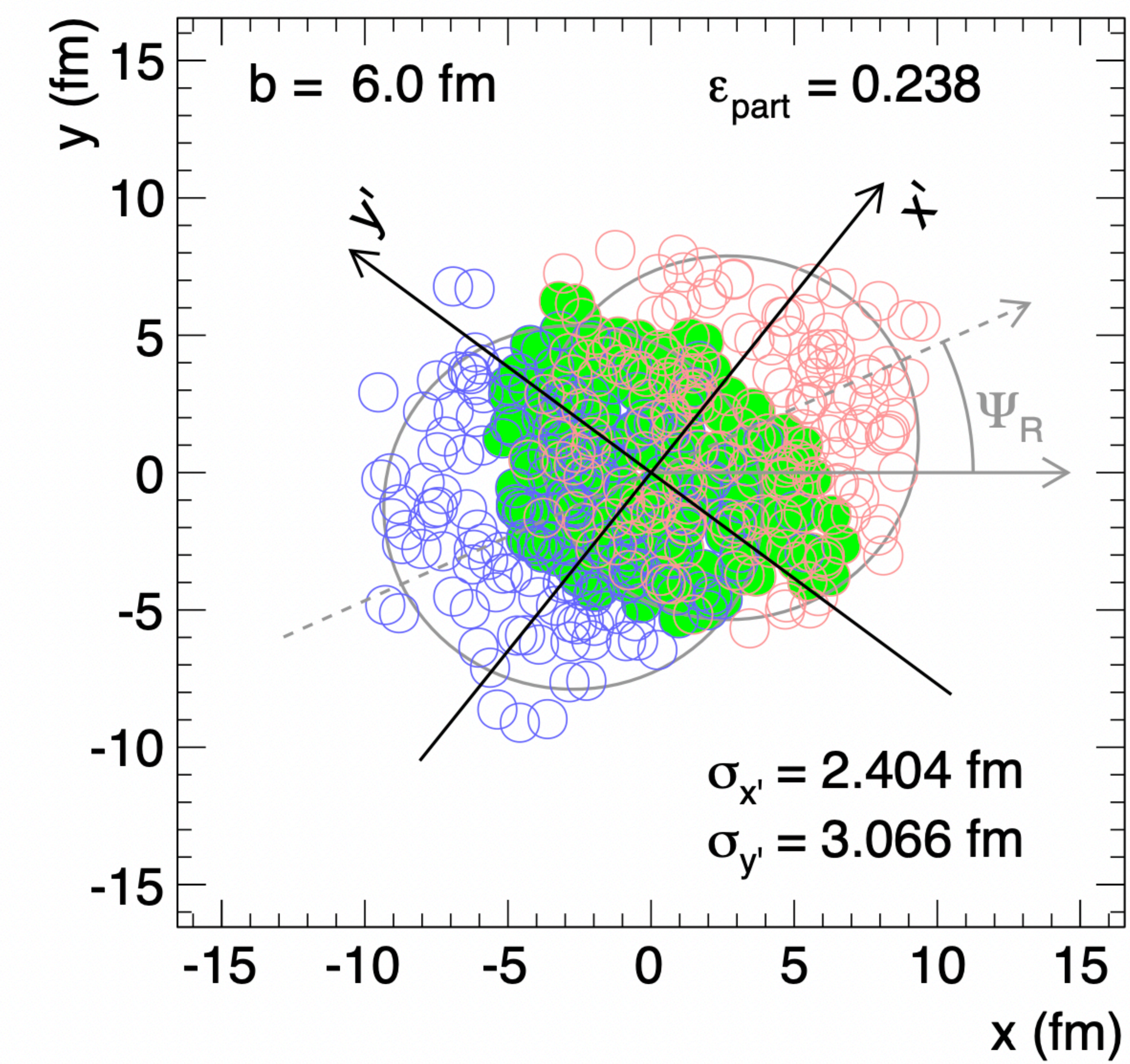
For **Run3** (2022-2024) expected:

- ~6nb^{-1} of Pb+Pb
- p+Pb ~X nb^{-1}
- Short pilot run with O+O and p+O

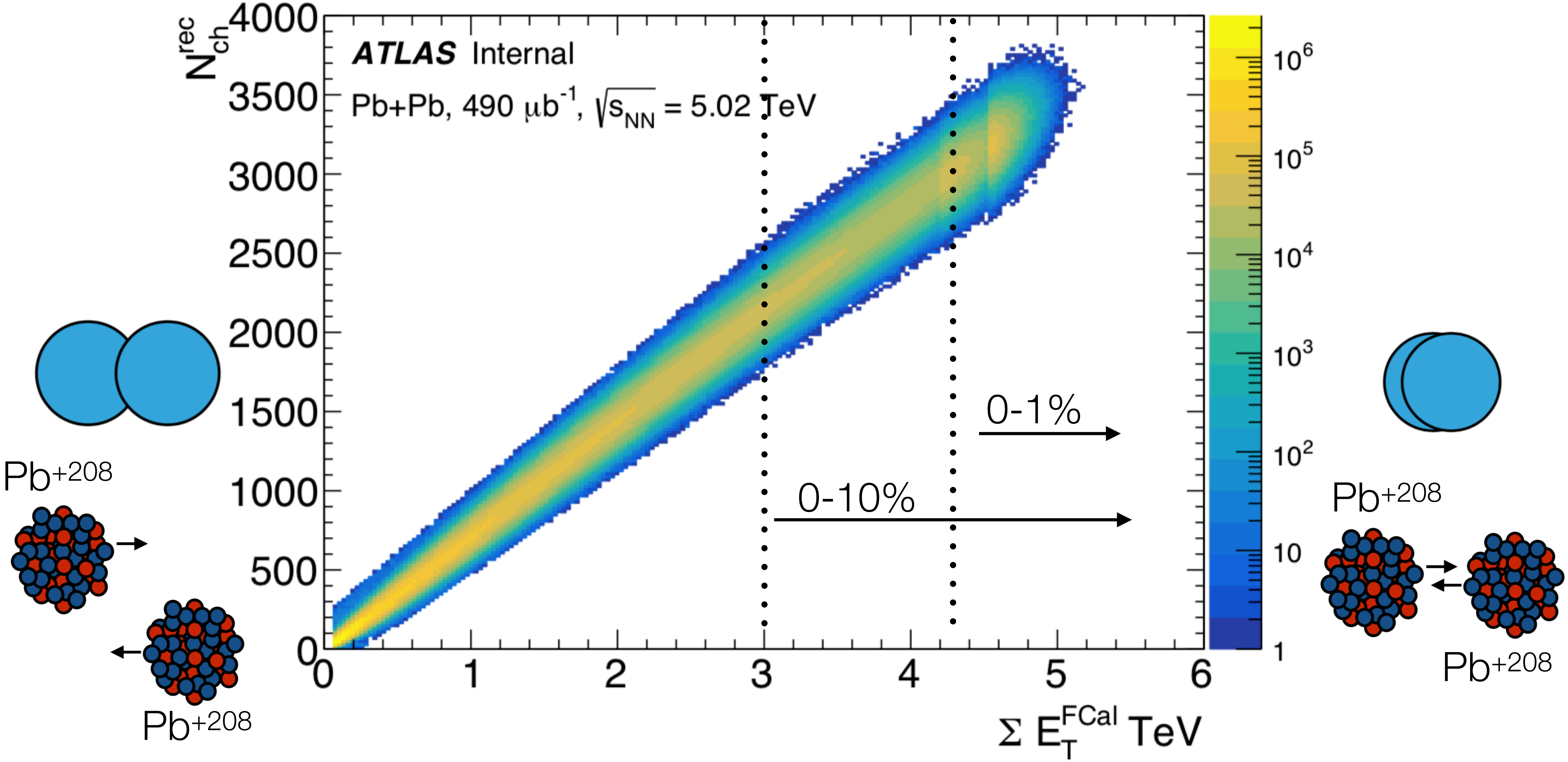
Centrality of heavy ion collision

- One nucleon can interact many times due to the thickness of the other nuclei that he see
- <N_{part}>, <N_{coll}> estimated based on MC Glauber fits to data

arXiv:1204.1409 **[nucl-ex]**



Centrality of heavy ion collision

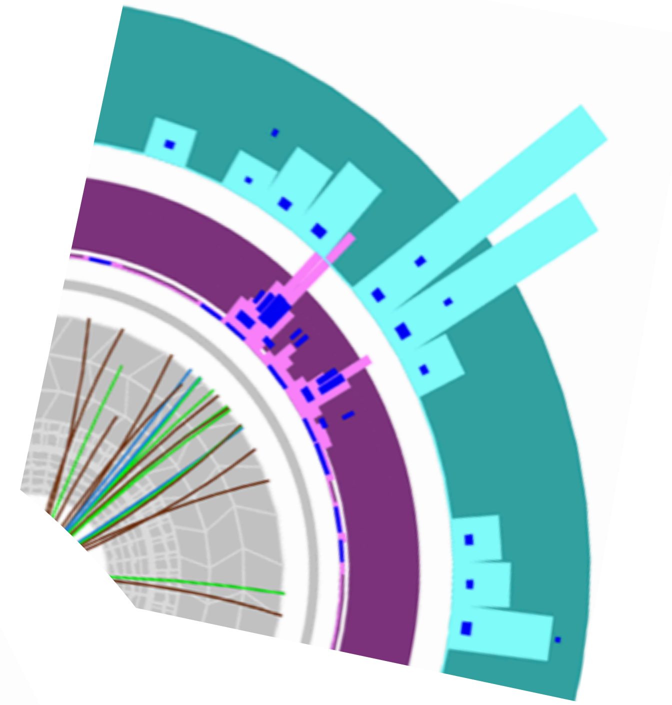


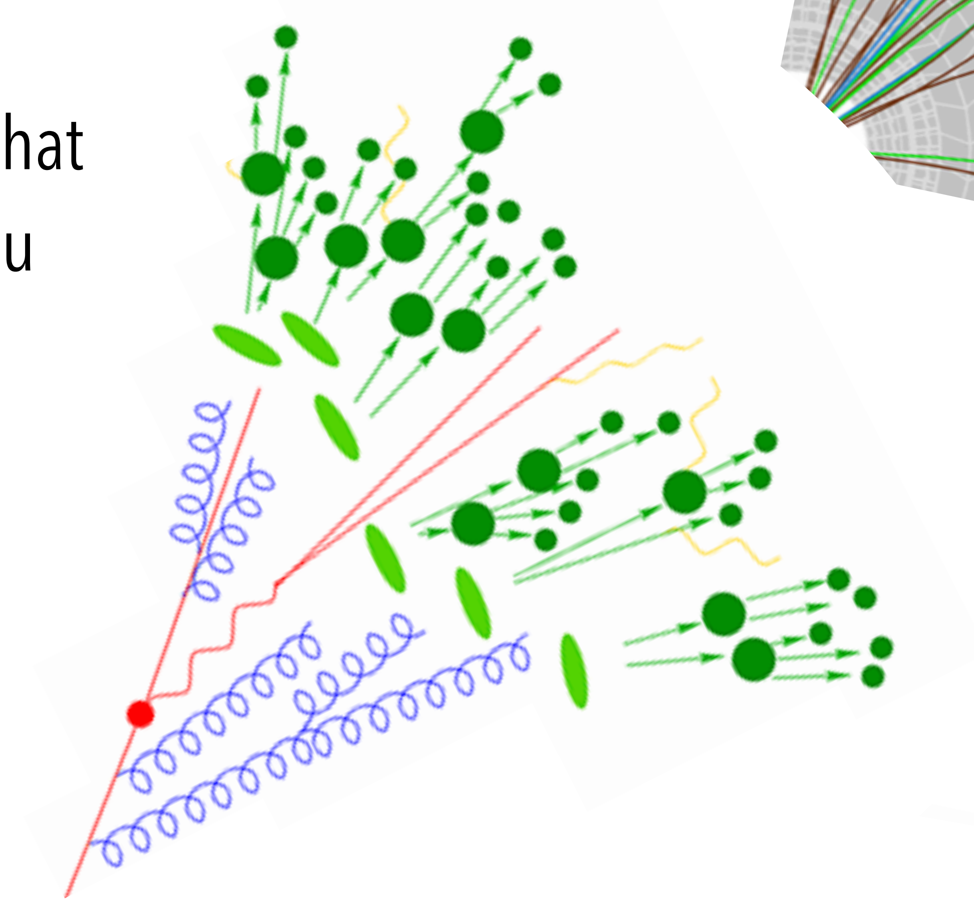
Peripheral collision

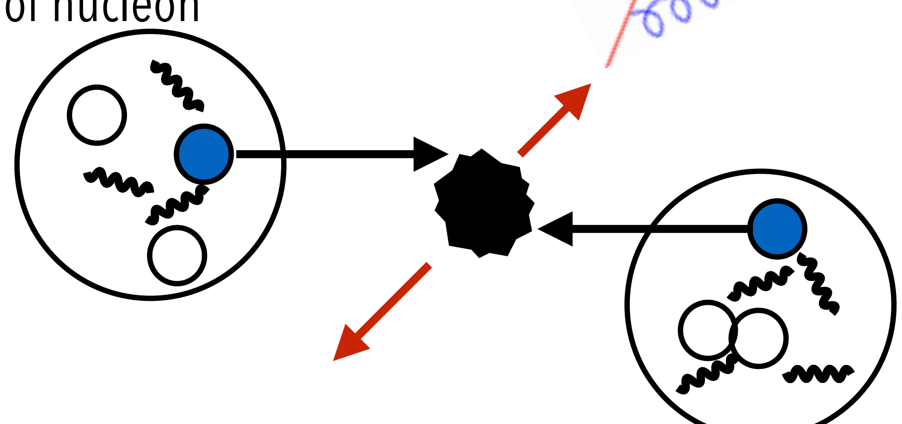
Central collision

Jets: collimated showers of energetic particles that carry a large fraction of the energy available in the collisions

- In Theory: jets are proxies for hard-scattered partons
- In Experiment: jet is what your jet-finder gives you



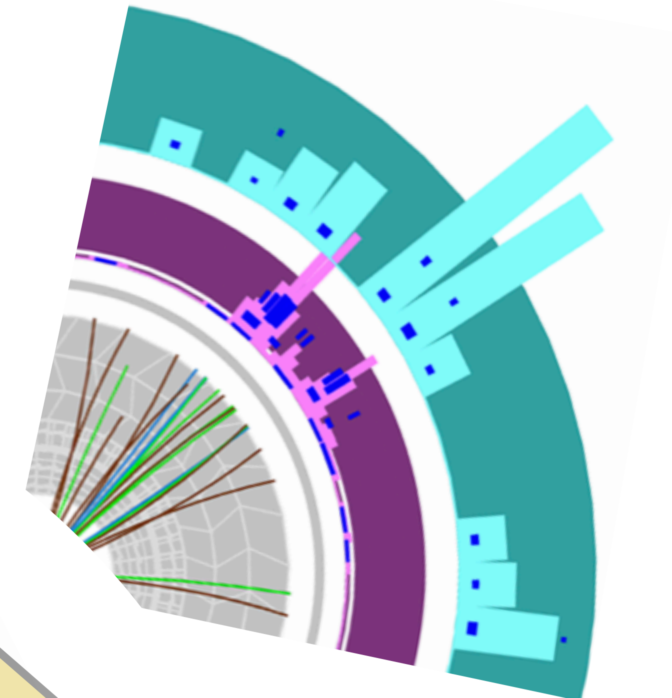


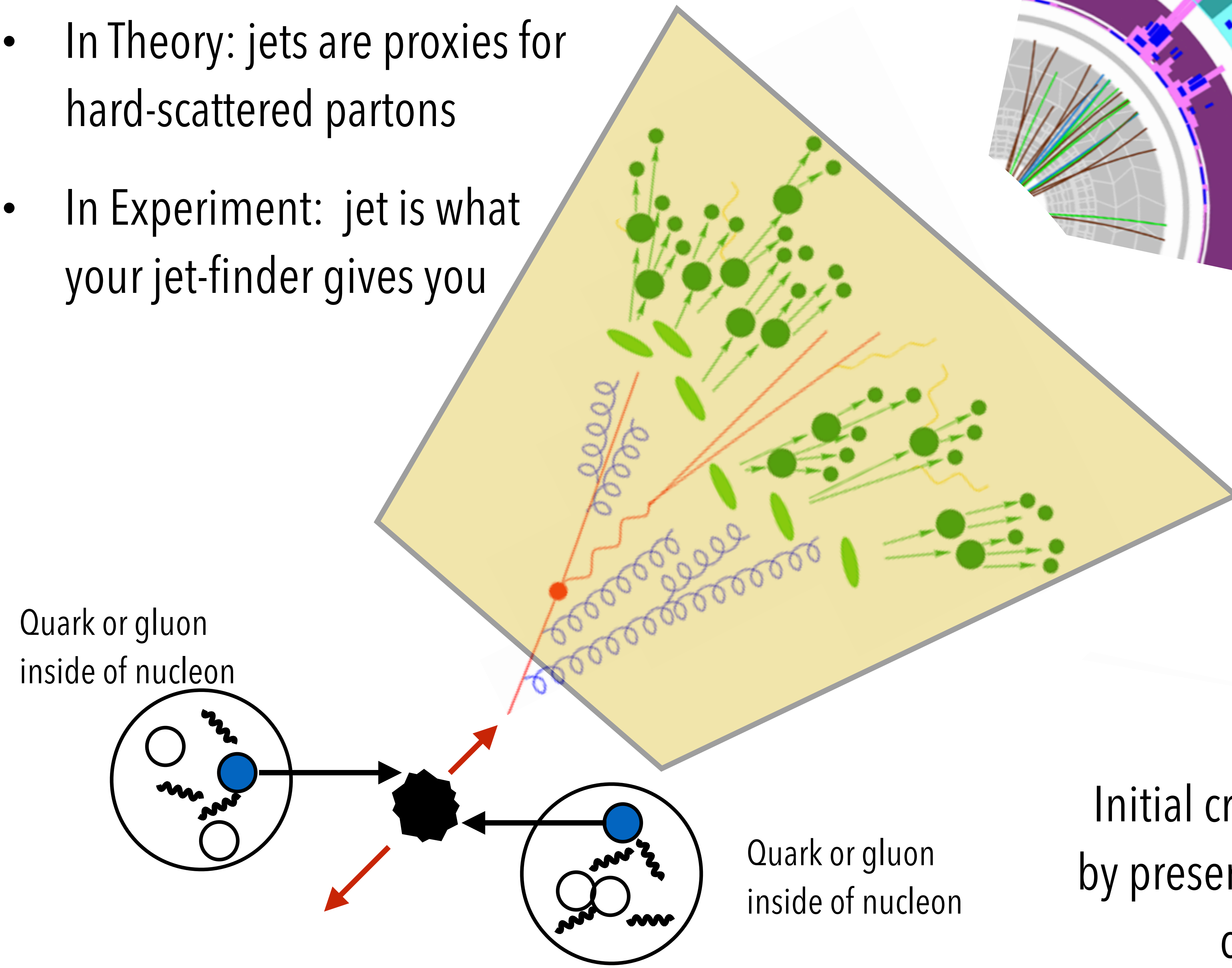


Jets in the medium

Jets: collimated showers of energetic particles that carry a large fraction of the energy available in the collisions

- In Theory: jets are proxies for hard-scattered partons
- In Experiment: jet is what your jet-finder gives you

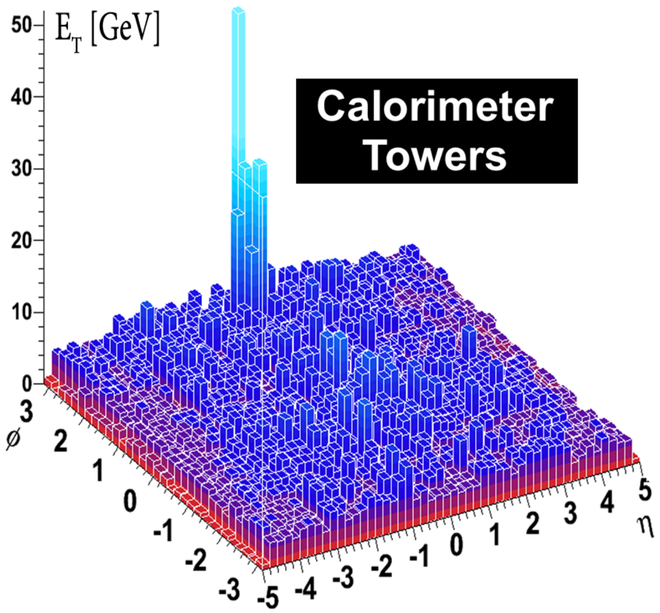




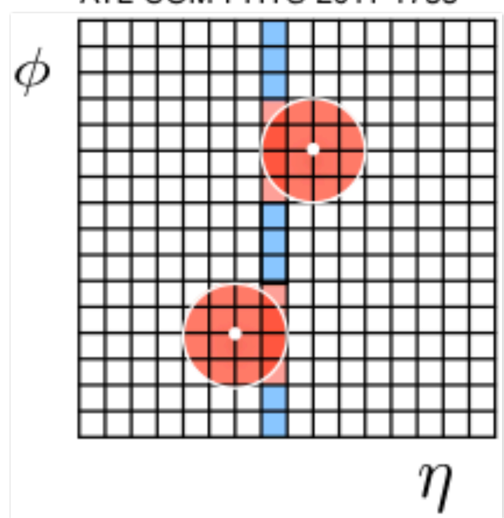
Interactions of medium and colored probe: elastic scattering, medium induced radiation, “drag force”, medium excitation ?

Initial cross-section unchanged by presence of medium (modulo change in nPDF)

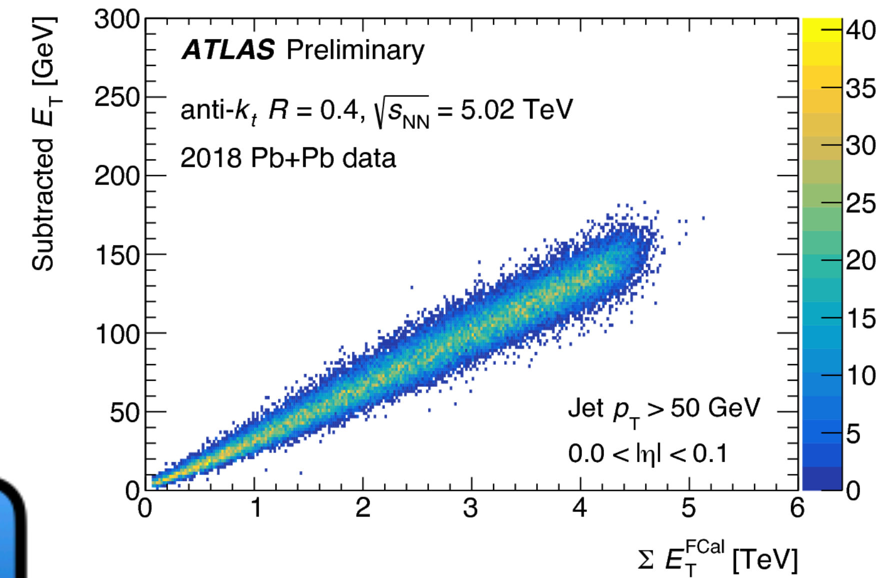
Jets reconstruction - ATLAS heavy ion style



ATL-COM-PHYS-2011-1733

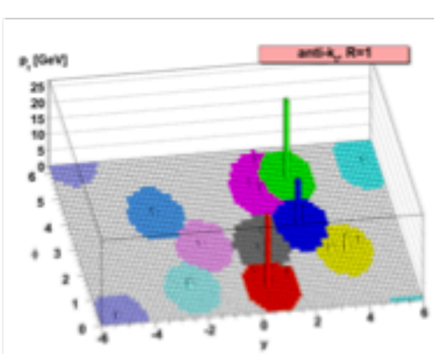


HION-2018-001

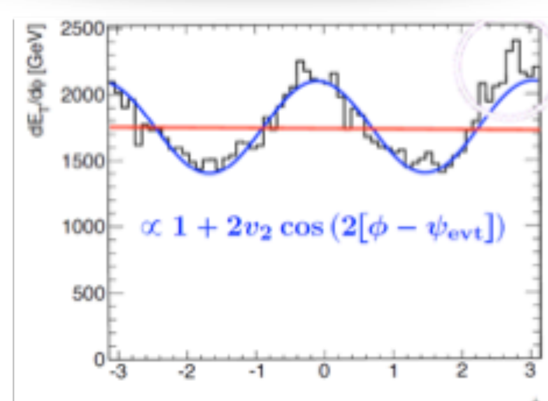


Calorimeter towers + Anti-k_t Algorithm → Jets → Average E_T density: ρ(η, layer) + Flow modulation (v_2, v_3, v_4) → Reconstructed Jets

Iterative subtraction

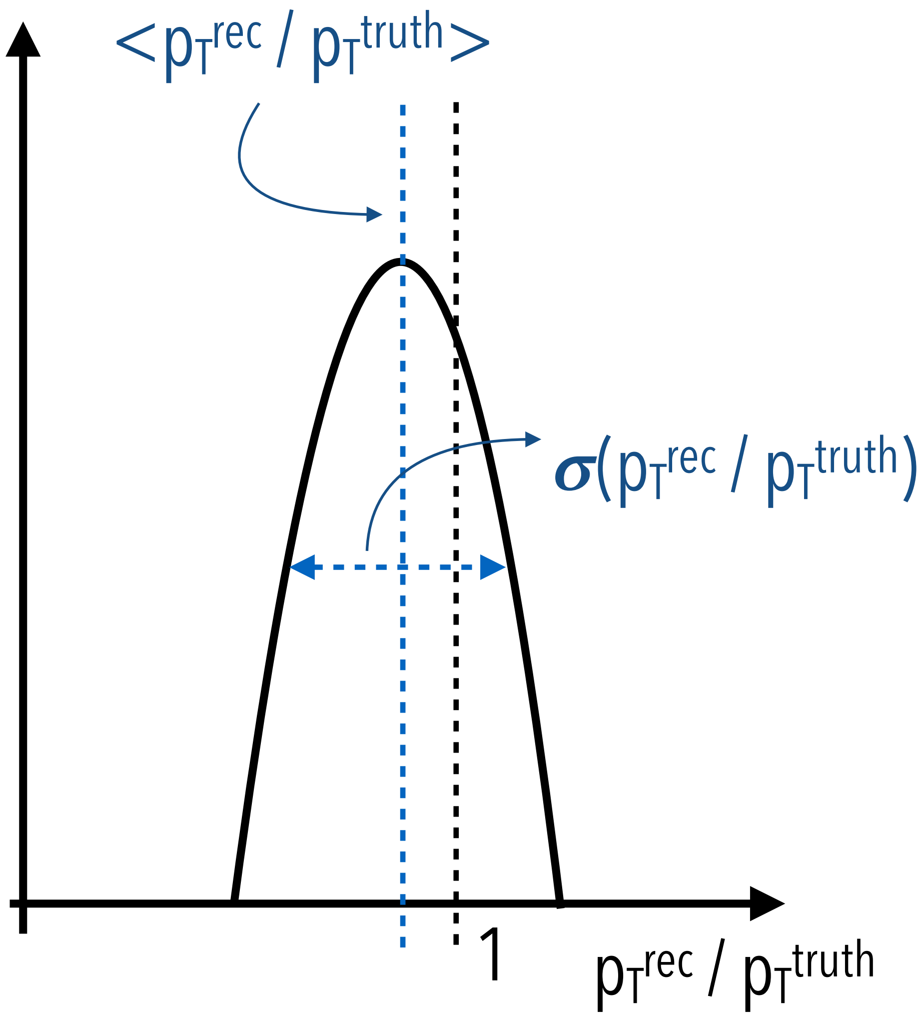


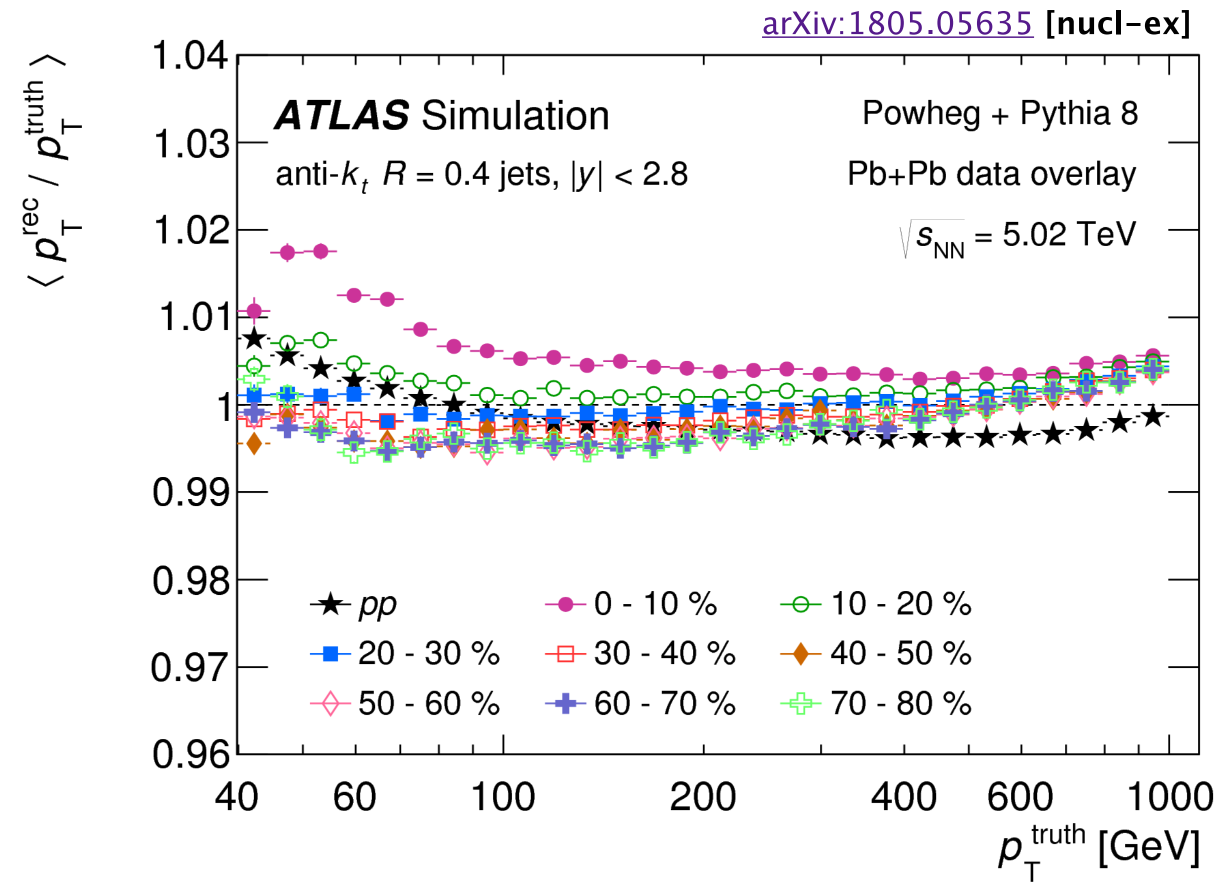
arXiv - 0802.1189

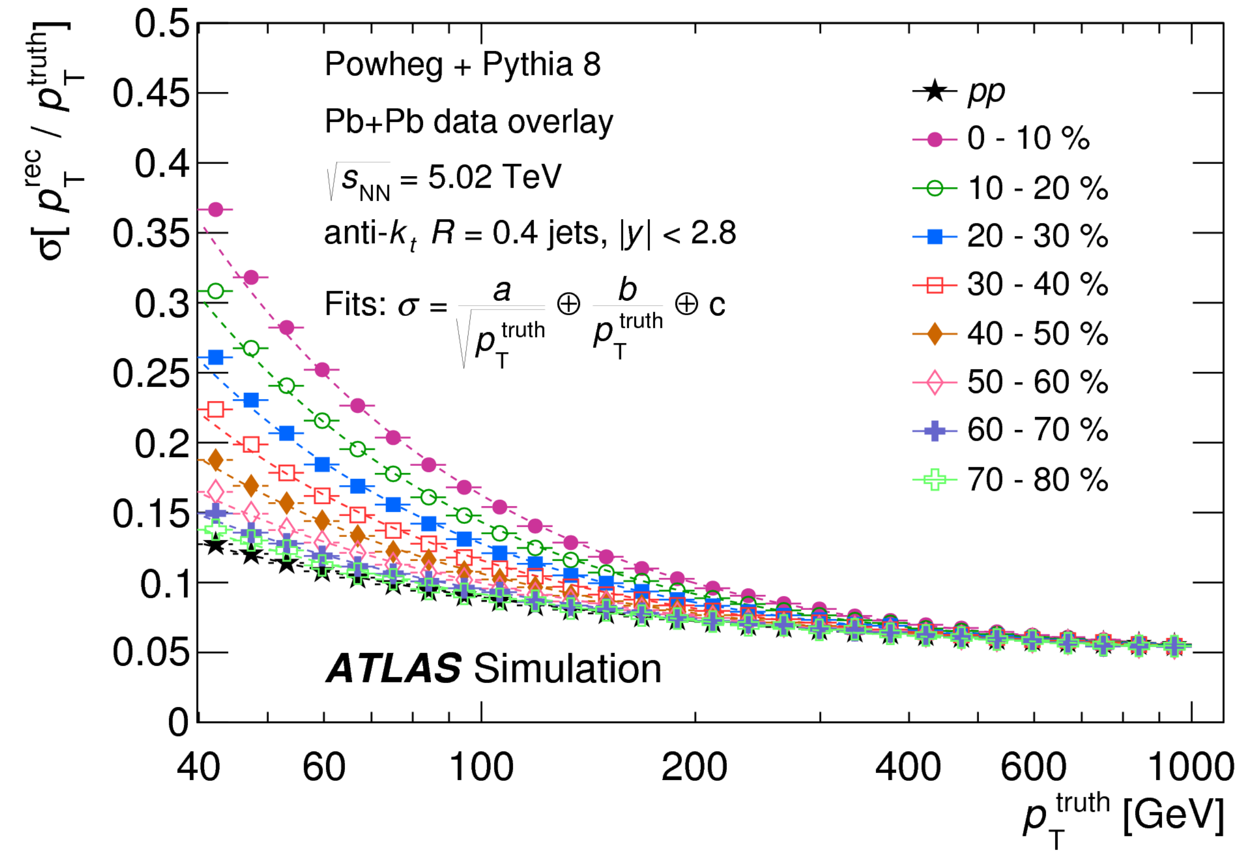


ATL-COM-PHYS-2012-628

Jets reconstruction - ATLAS heavy ion style

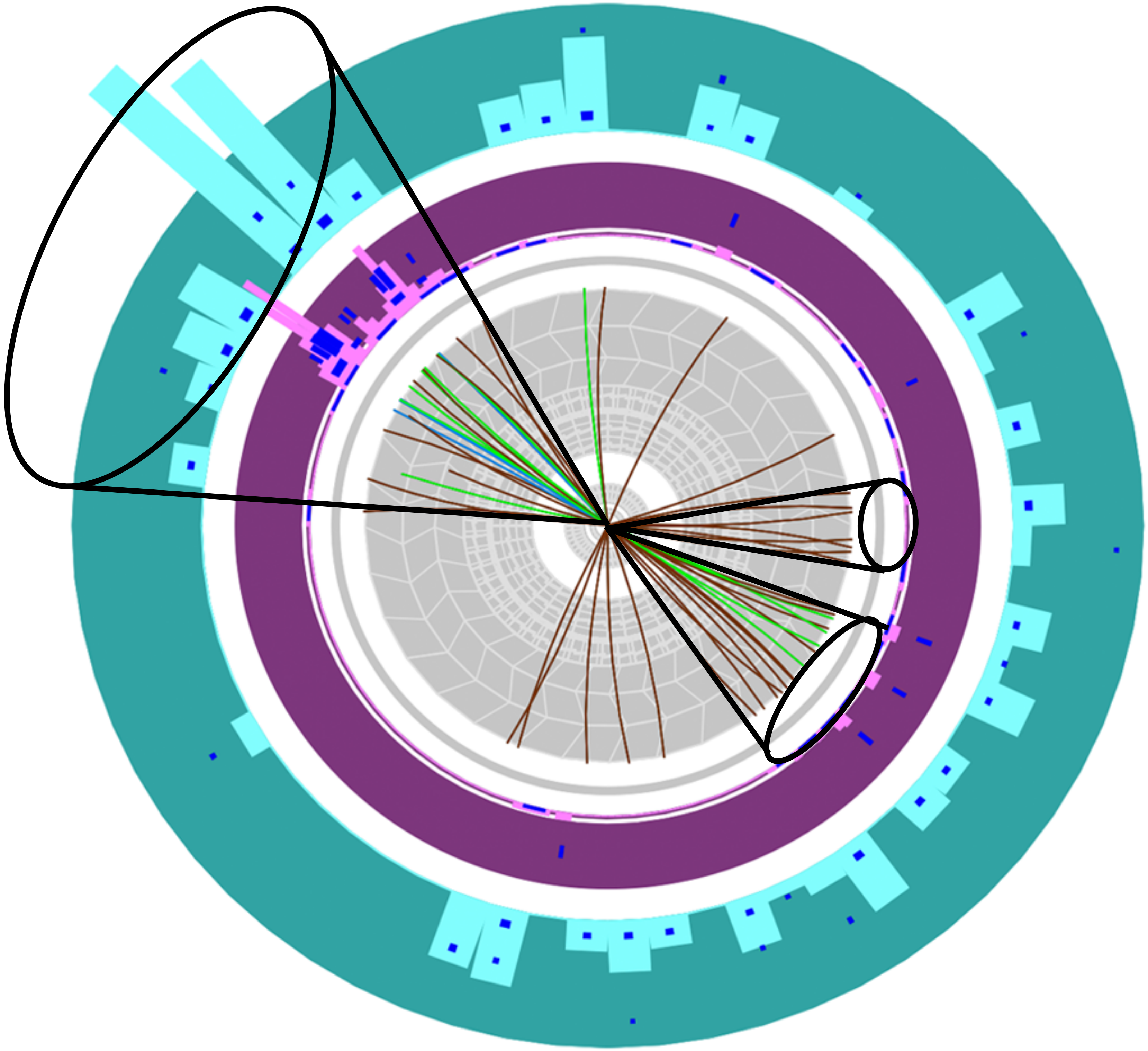






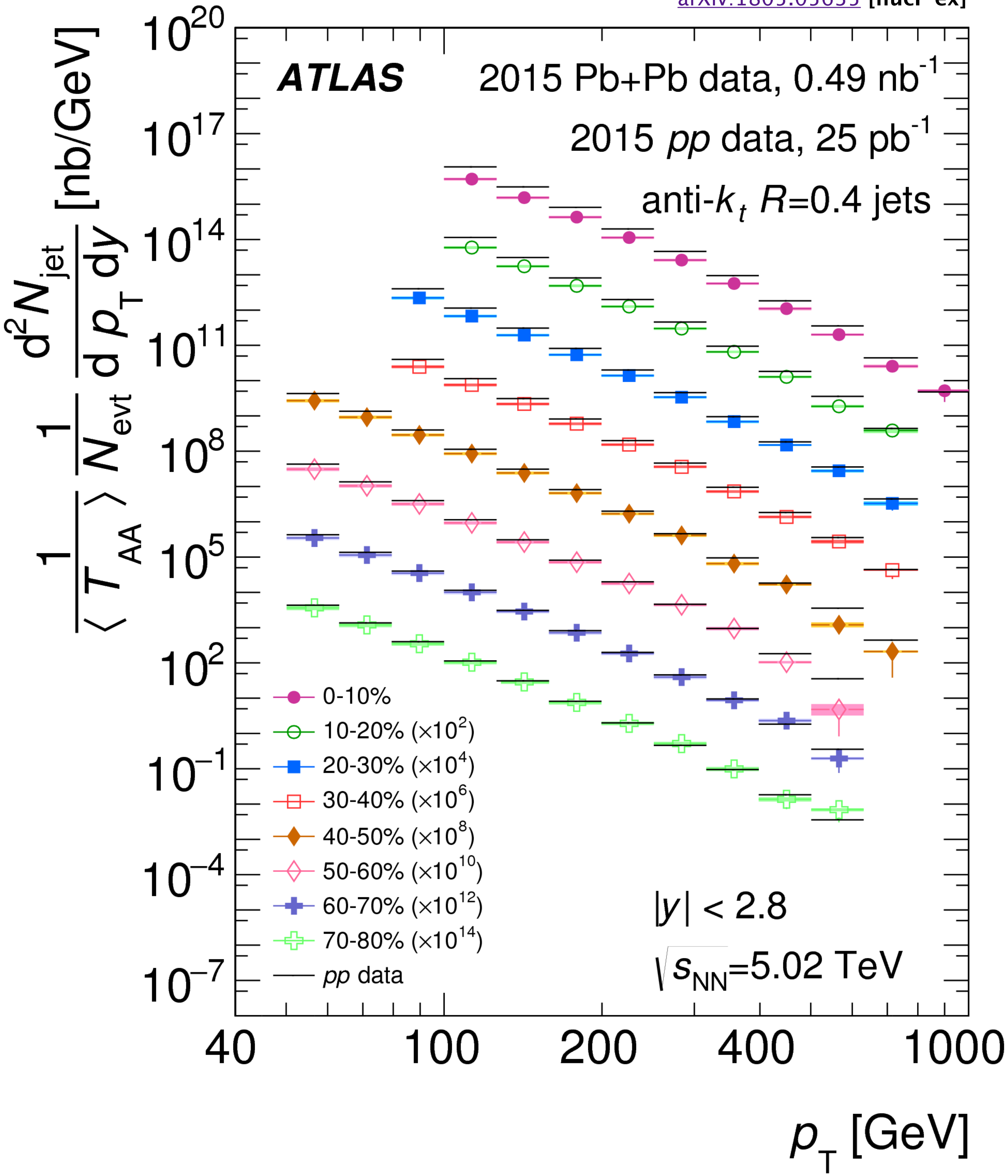
- Average response ($<p_T^{rec} / p_T^{truth}>$) within 1% from unity almost independent on centrality
- Jet energy resolution ($\sigma(p_T^{rec} / p_T^{truth})$) dominated by the underlying event fluctuations.

Inclusive jet spectra



Inclusive jet spectra

arXiv:1805.05635 [nucl-ex]



Nuclear modification factor R_{AA}

$$R_{\mathrm{AA}} = \frac{\left.\frac{1}{N_{\mathrm{evt}}}\frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}}\rangle \left.\frac{\mathrm{d}^2\sigma_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{pp}}$$

Scaled Pb+Pb

Reference p+p

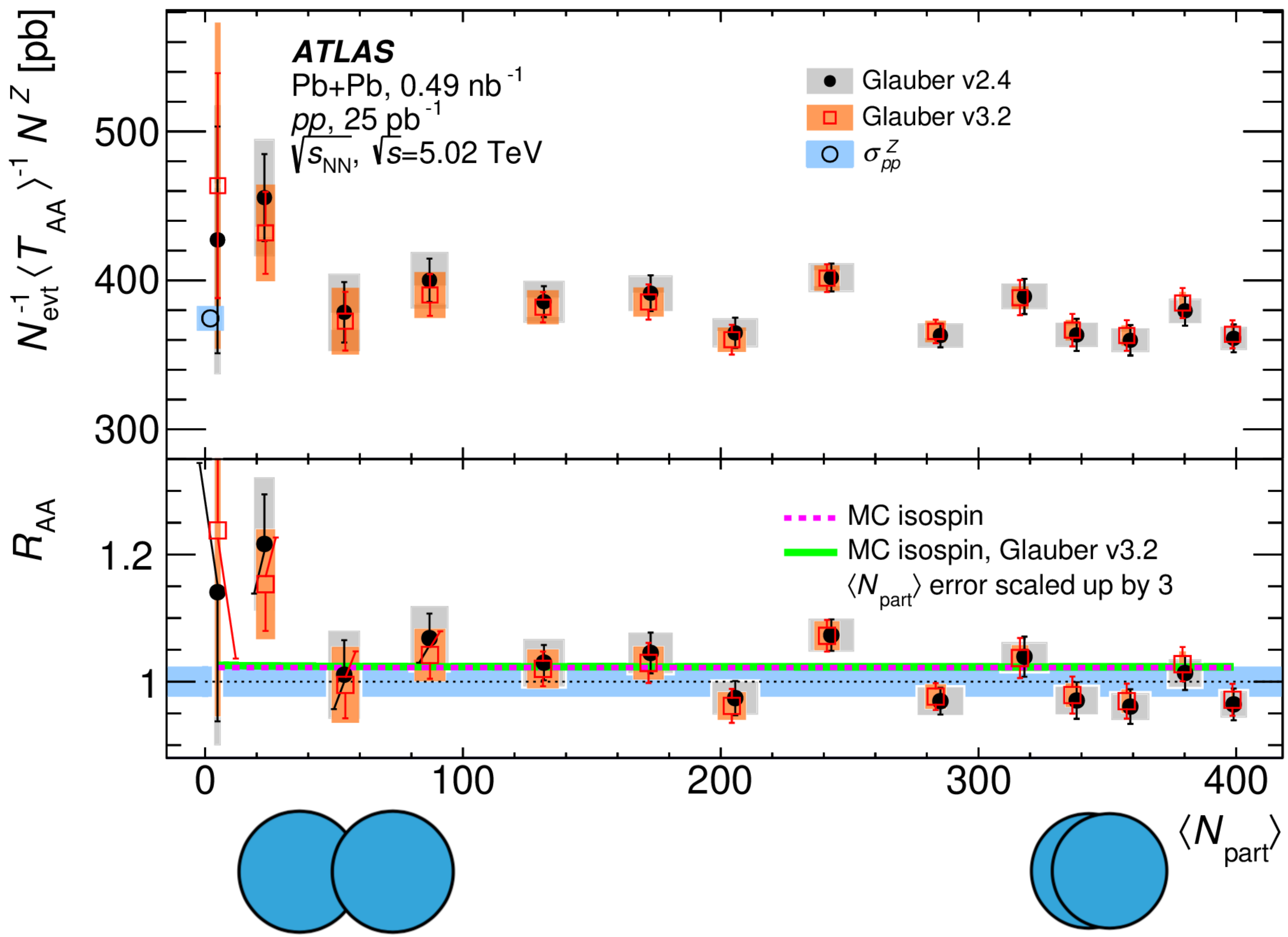
Where nuclear overlap function $<T_{AA}>$

$$\langle T_{\mathrm{AB}}\rangle_{\mathrm{f}} = \langle N_{\mathrm{coll}}\rangle_{\mathrm{f}} / \sigma_{\mathrm{inel}}^{\mathrm{NN}}$$

calculated in the Glauber MC approach (arXiv:nucl-ex/0701025)

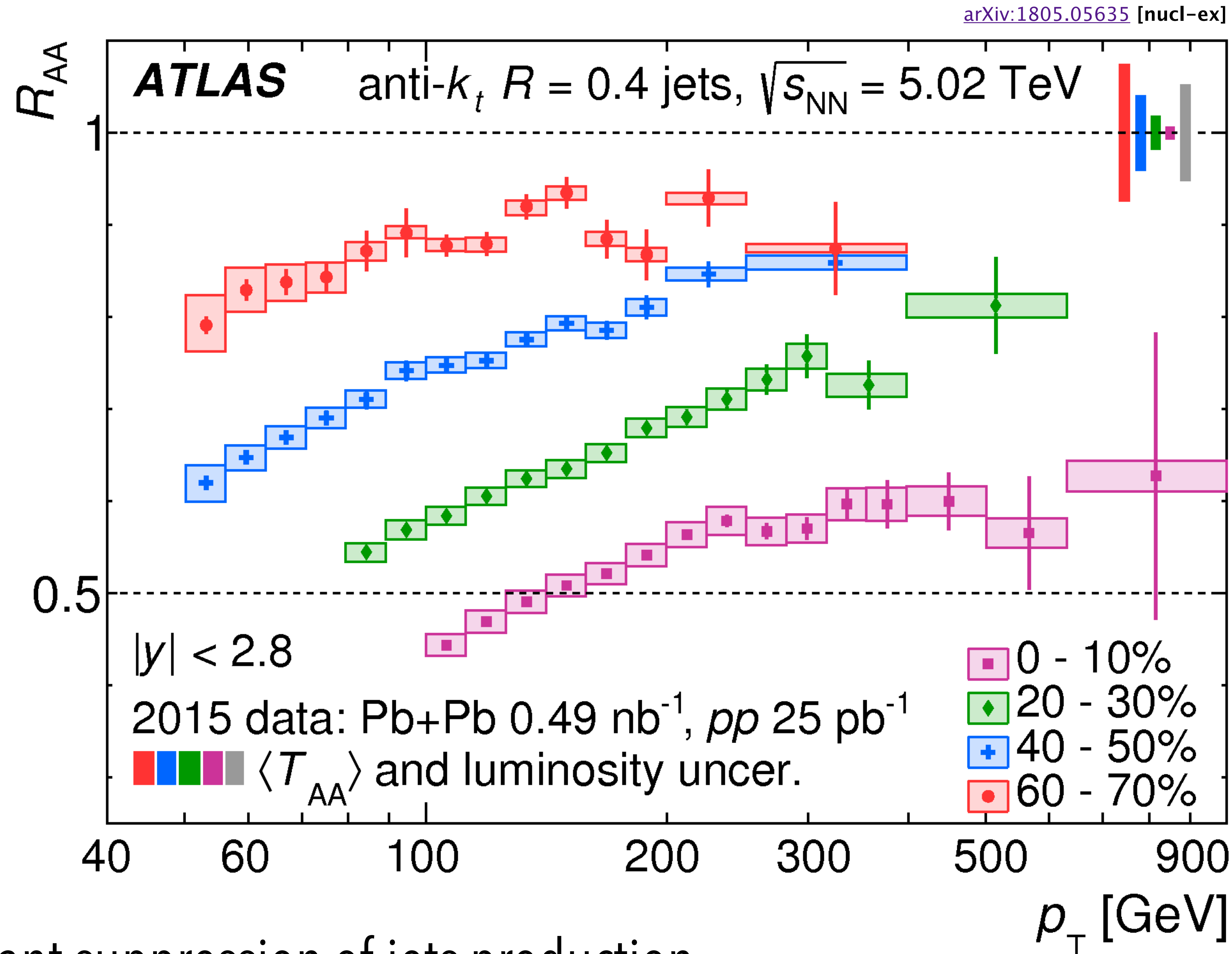
Calibration of the T_{AA} scaling

arXiv:1910.13396 [nucl-ex]



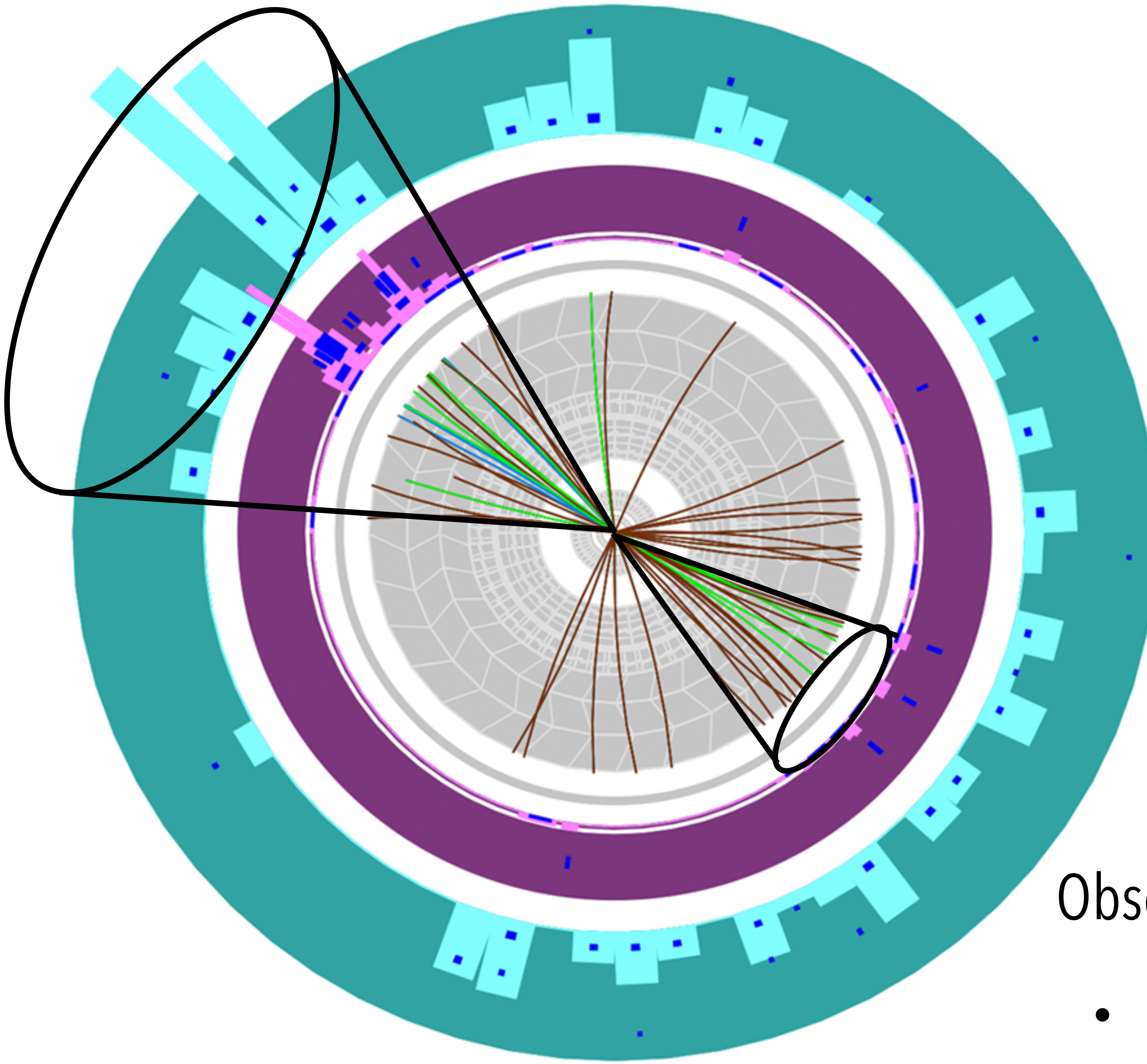
Probes that are not interacting with the QGP medium (W, Z, γ) follows the <T_{AA}> scaling.

Jets R_{AA}



Significant suppression of jets production in the entire kinematic range

Path length dependent energy loss

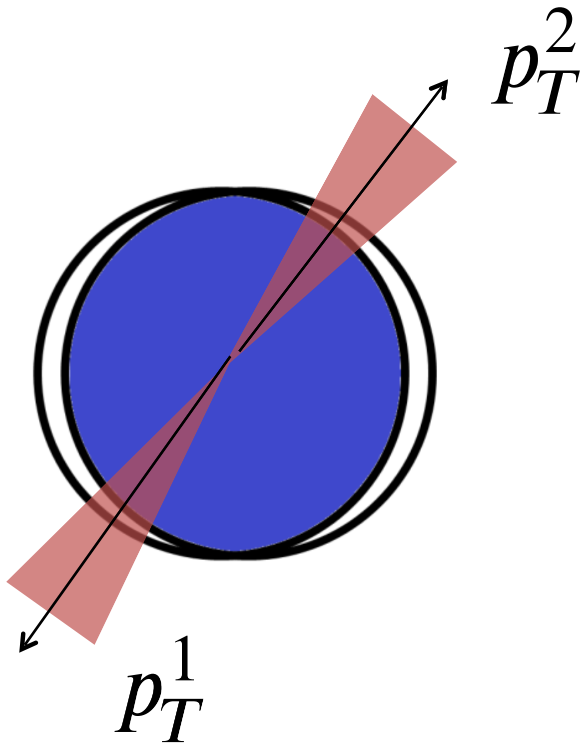


Observables:

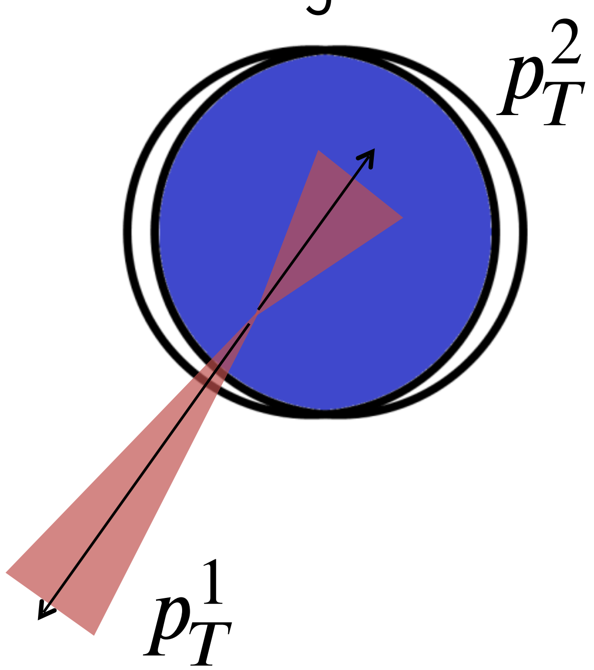
- Dijet asymmetry
- Jet v_n

Dijet asymmetry

Balanced pair of jets produced near the centre of the collisions zone



Unbalanced pair of jets produced near the edge of the collisions zone



Dijet asymmetry

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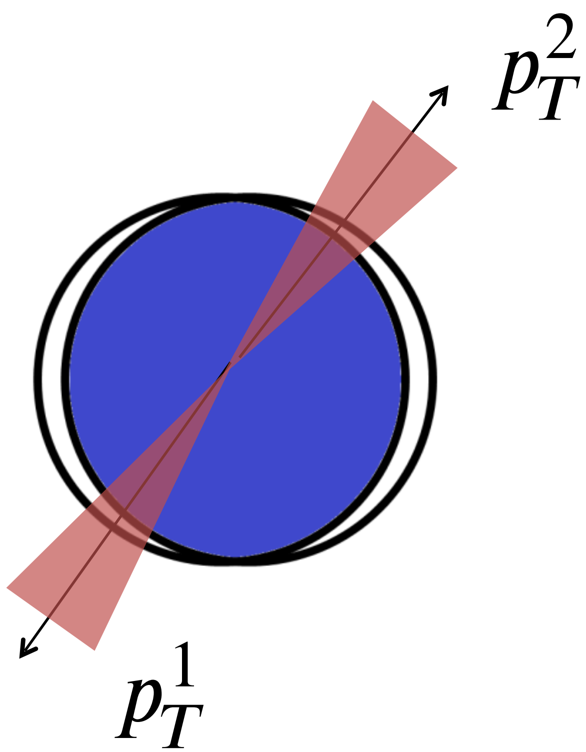

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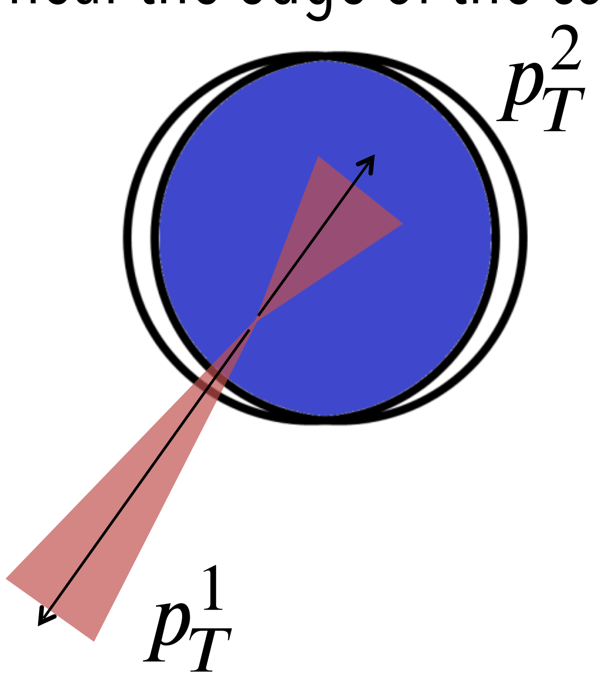
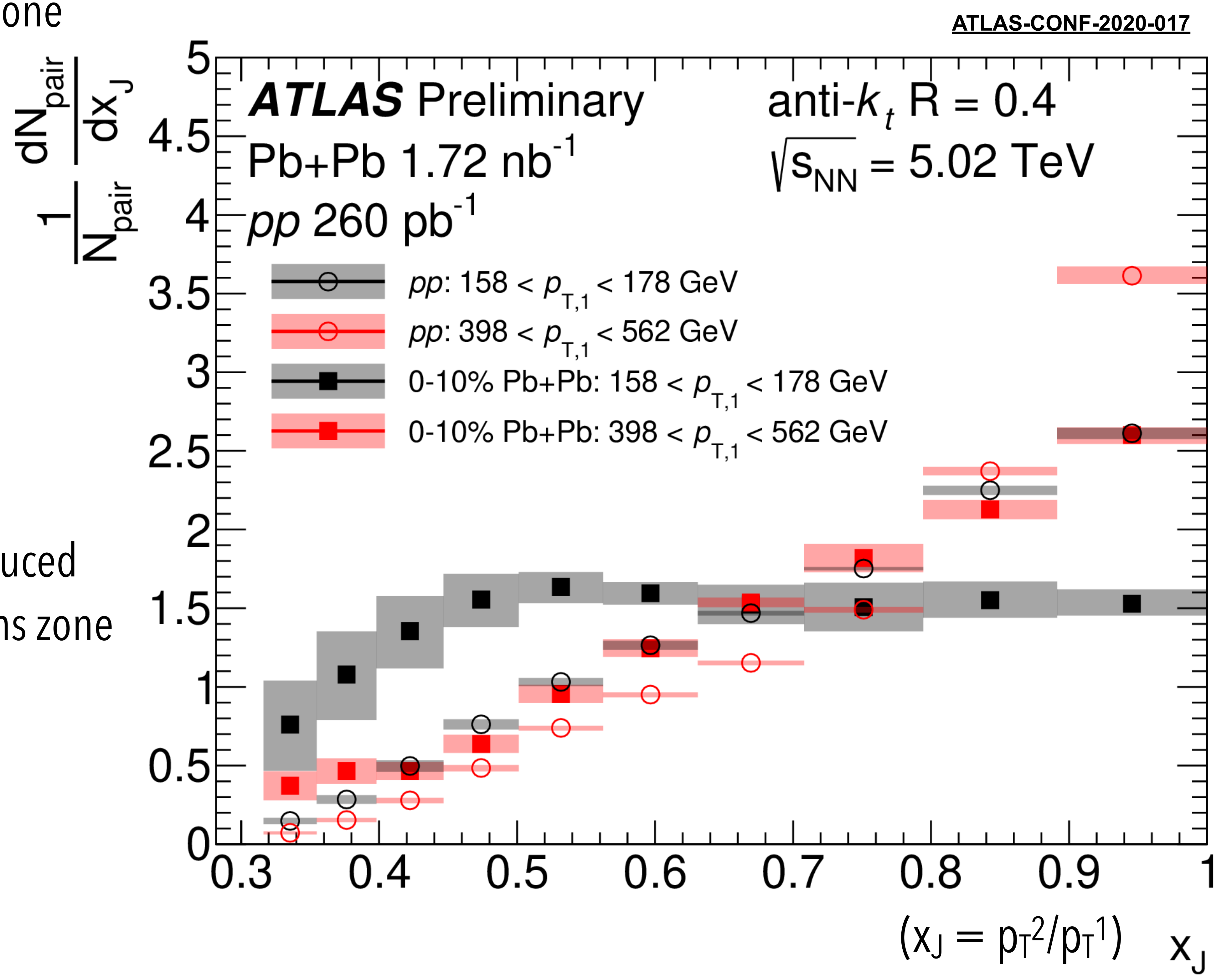


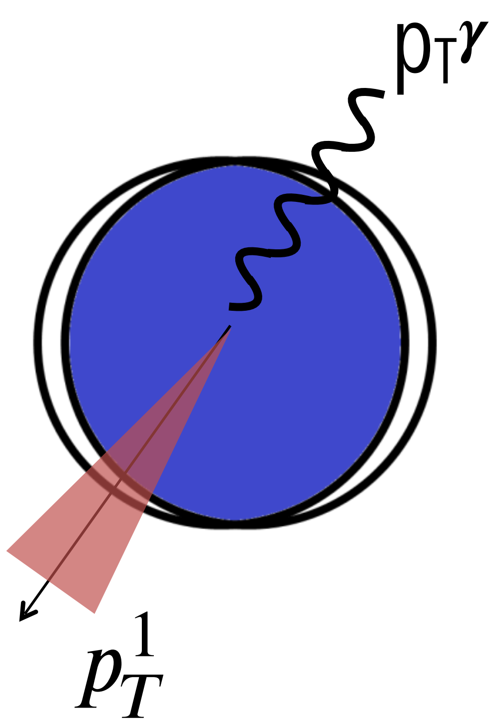


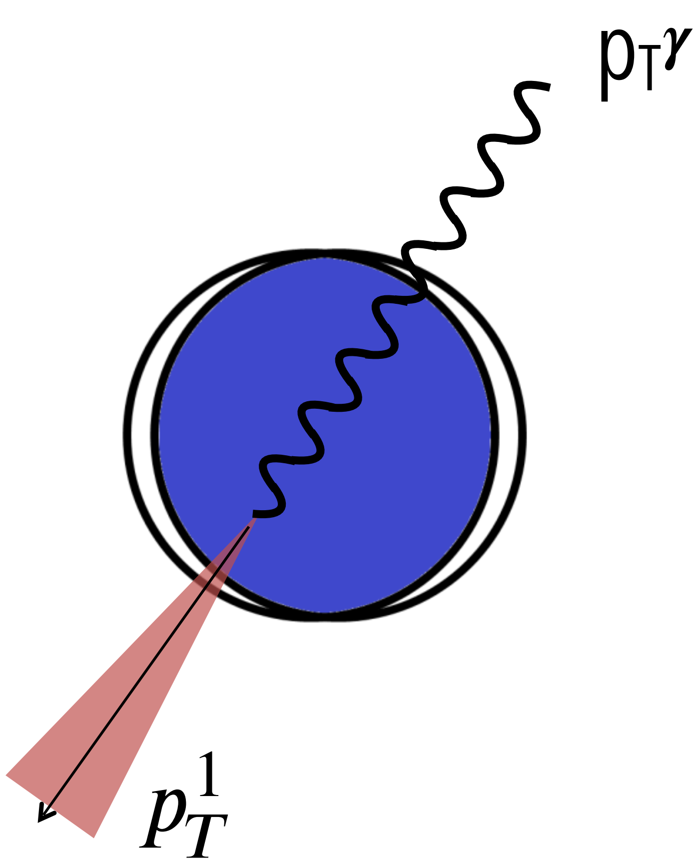
Important for understanding effect of geometry on jet quenching

Photon-jet asymmetry

Photons and Z's can help to calibrate the parton energy, however:

- Flavour fraction differs compared to dijets
- Rare process compared to the dijets production





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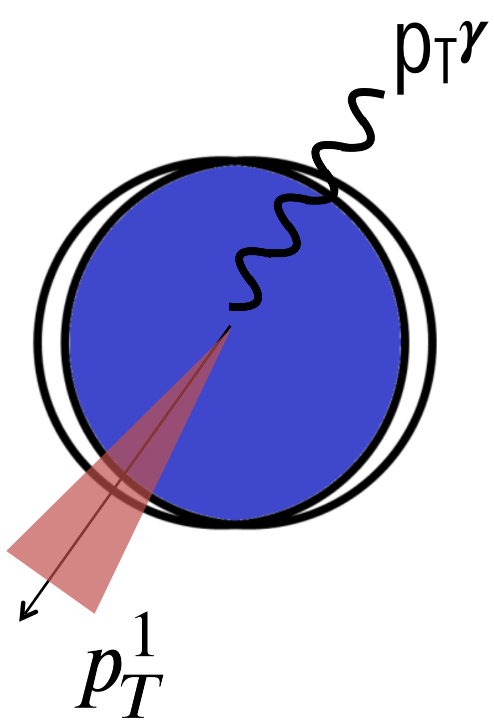
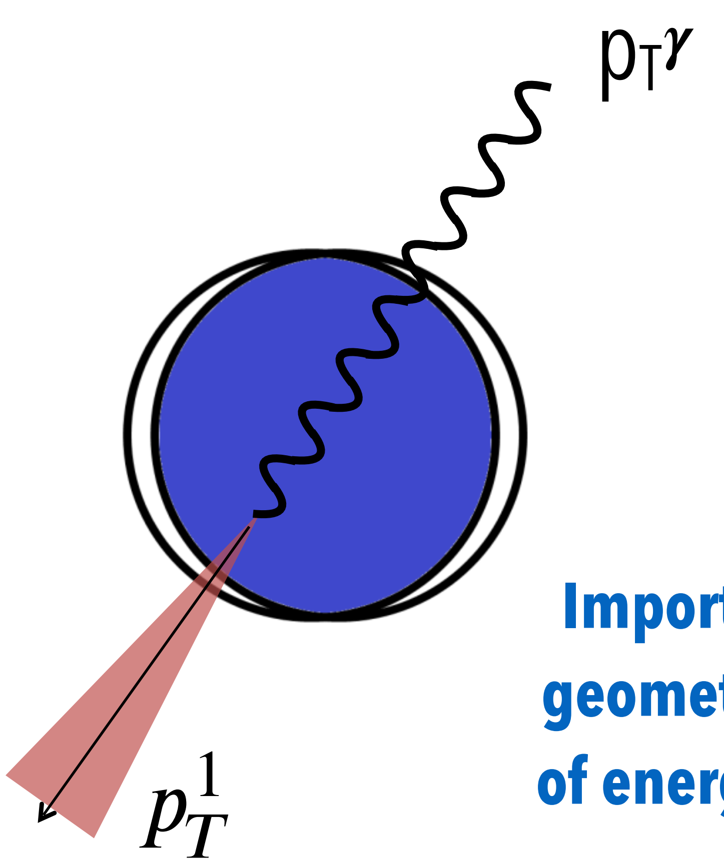
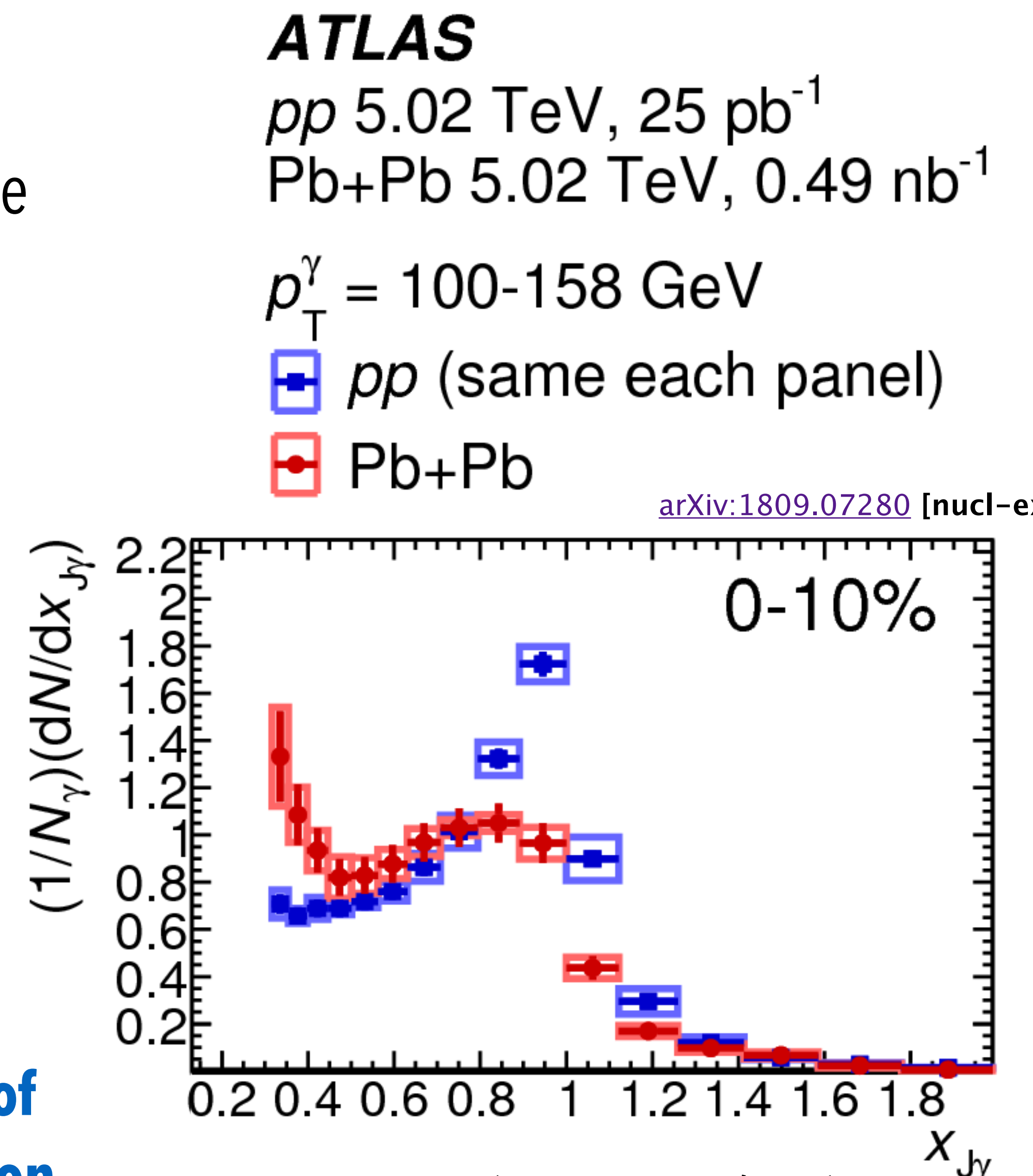




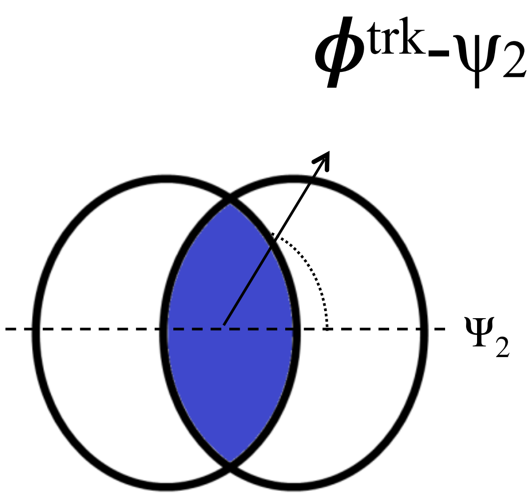


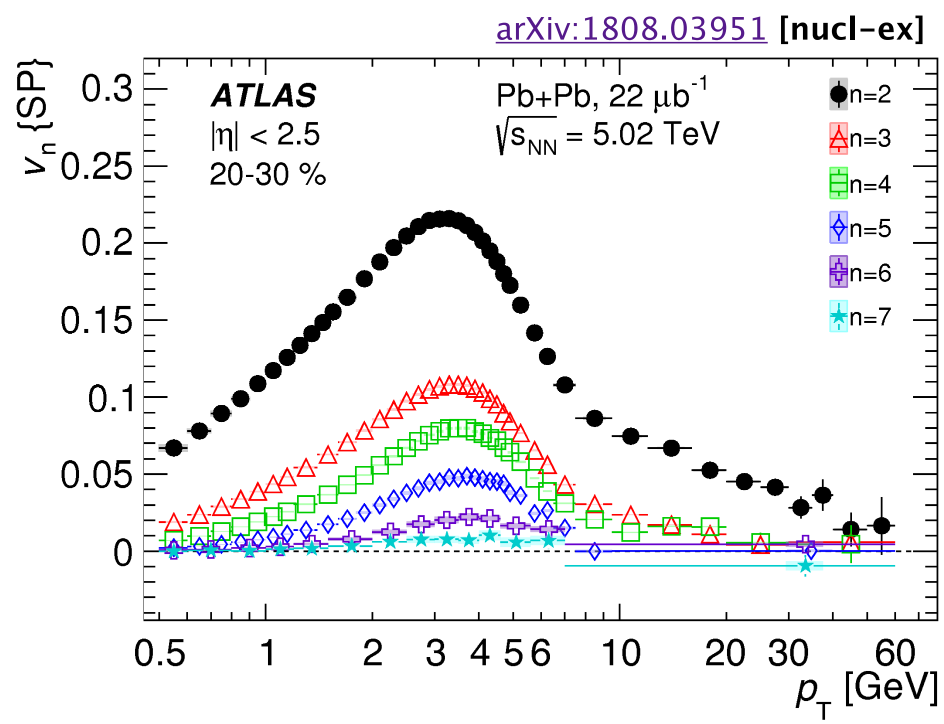
arXiv:1809.07280 [nucl-ex]

$(x_{J\gamma} = p_T{}^1/p_T{}^{\gamma})$

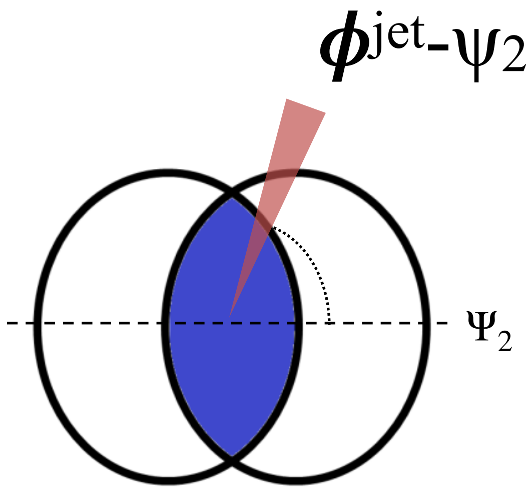
Important for understanding effect of geometry on jet quenching, calibration of energy loss and flavour composition.

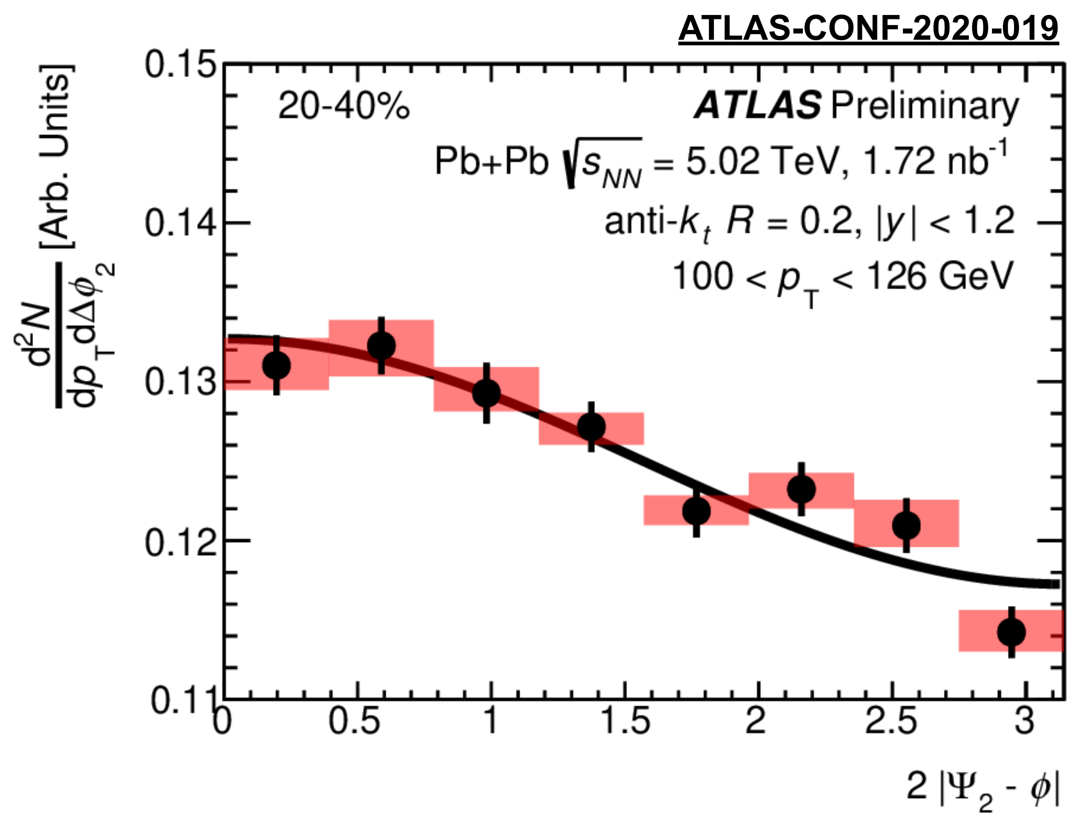
Jet vn





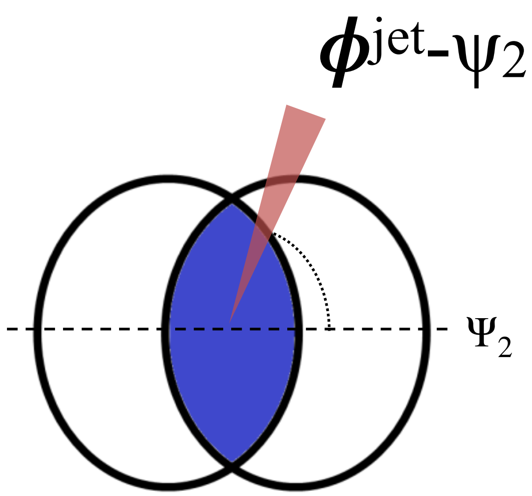
Vn coefficients of charged particles measured to great precisions up to pT ~40 GeV

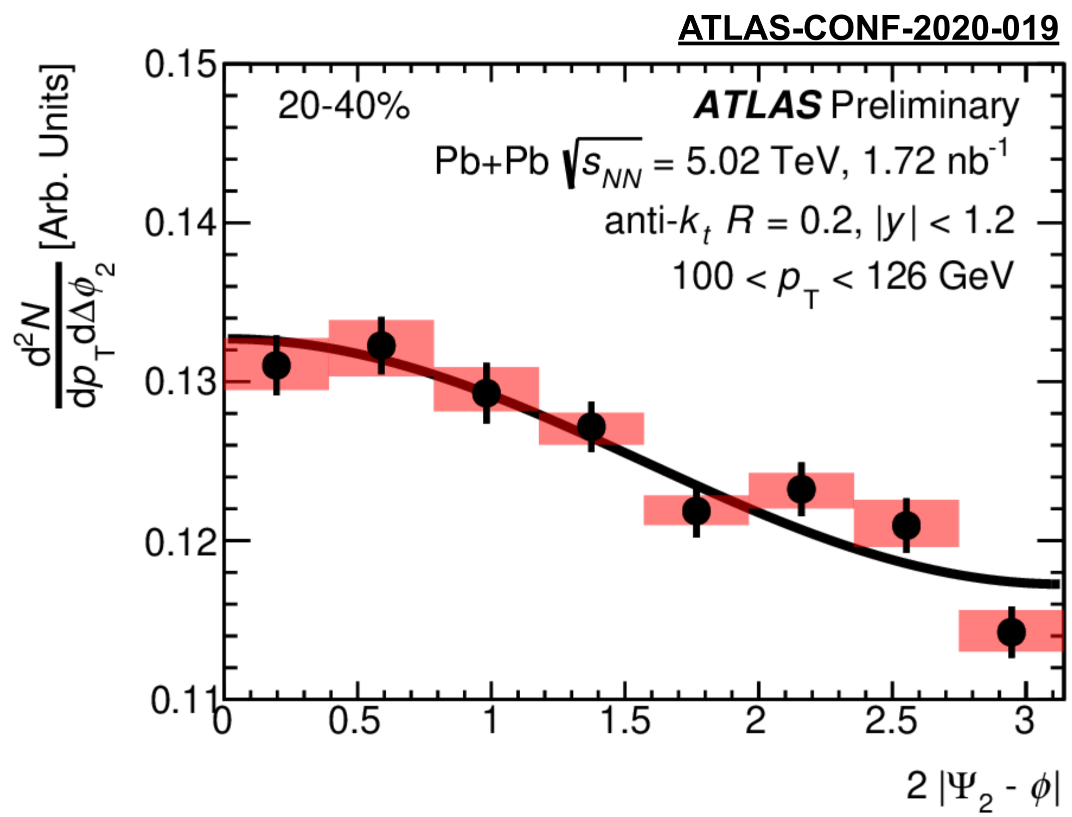




measurement of the jets wrt. collision geometry this varies the amount of QGP that the jet sees

Jet vn





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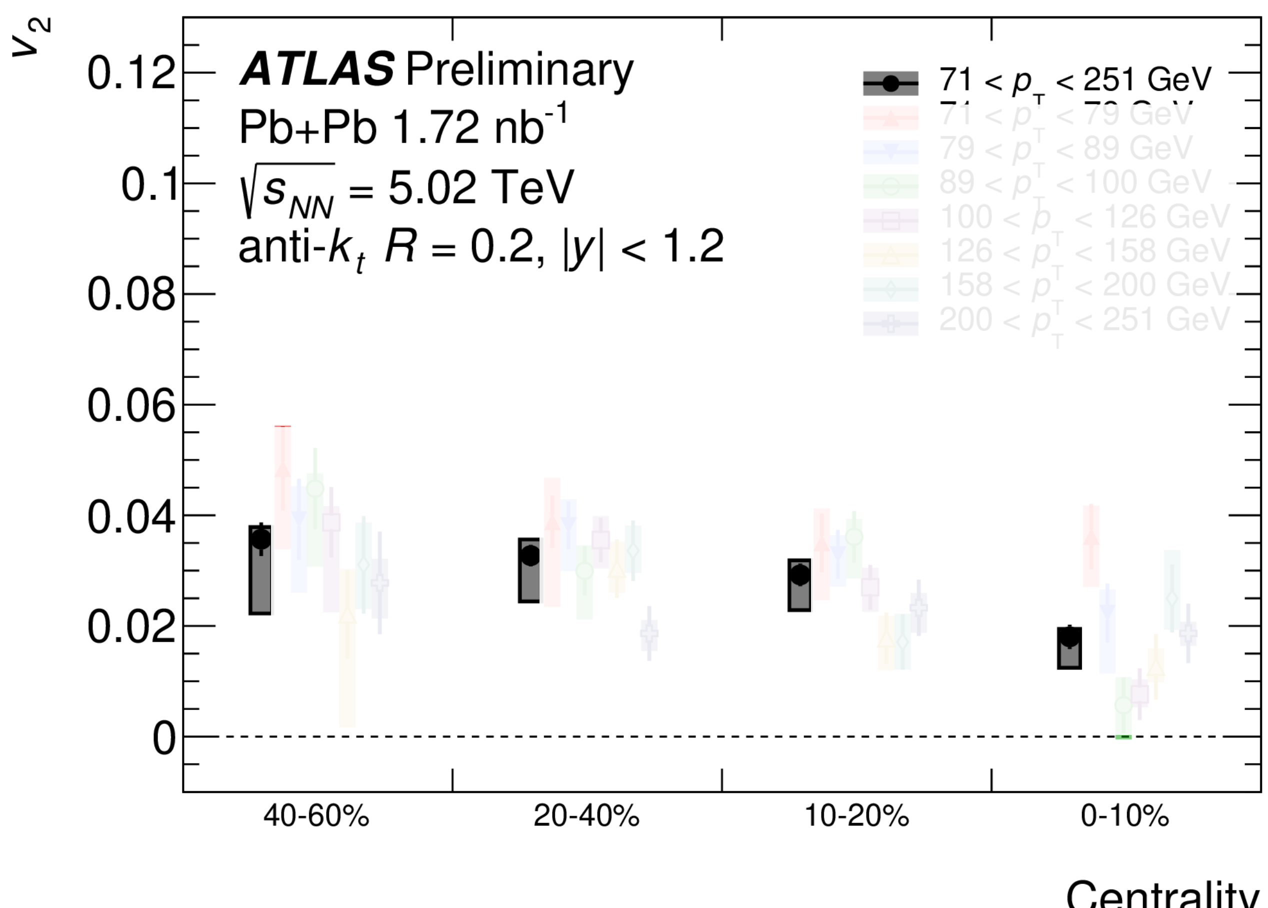
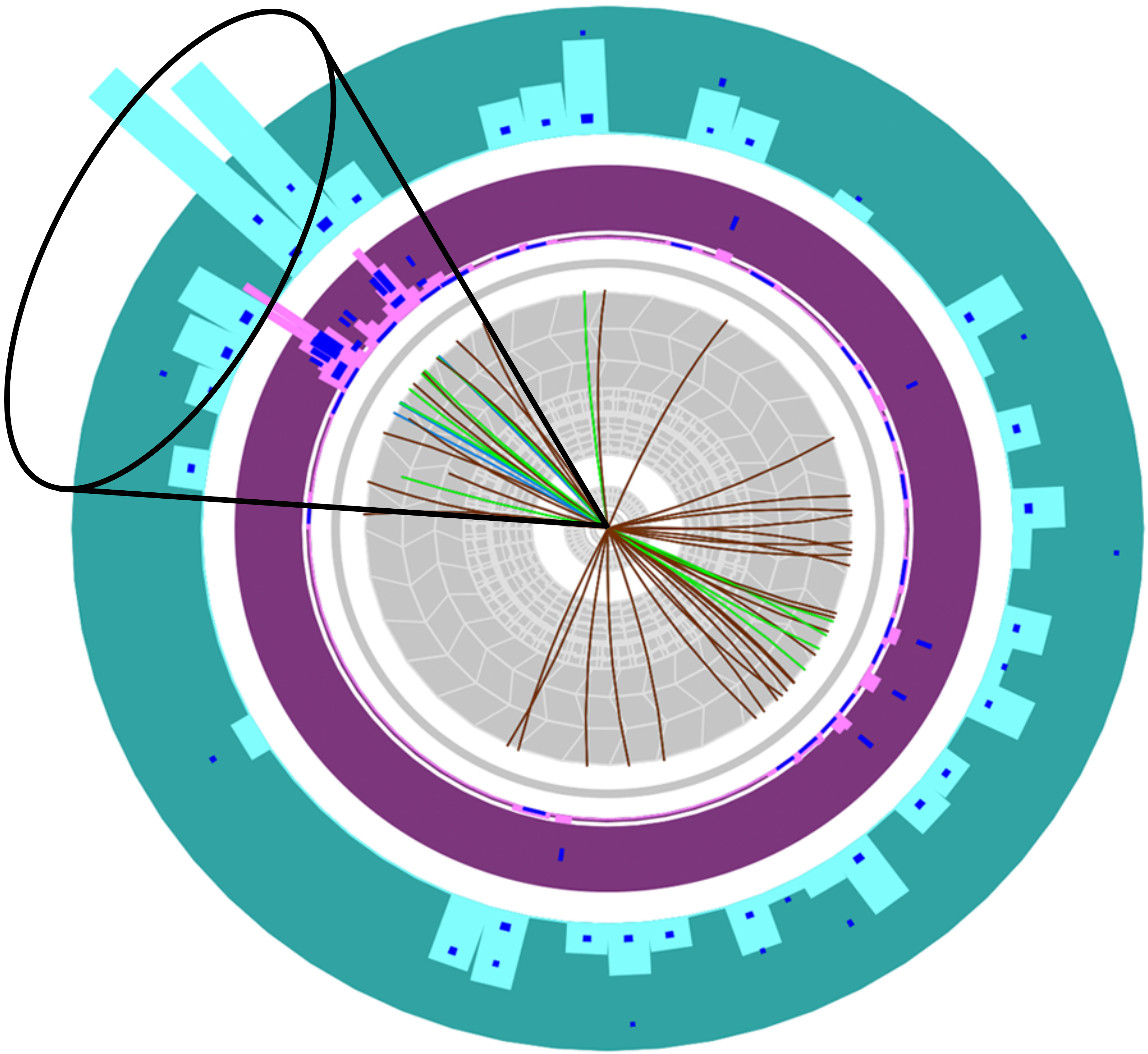


measured jet v_2 to be 1-5% with no significant p_T or centrality dependence

Important for understanding effect of geometry on jet quenching

Jet structure

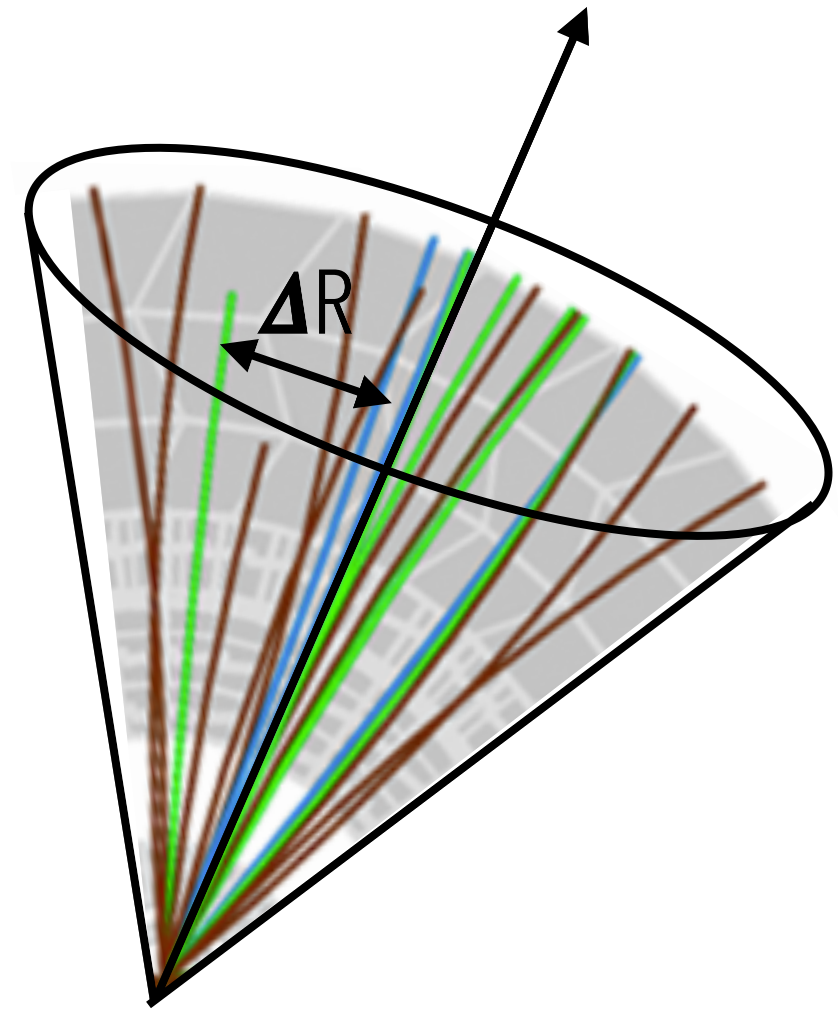


How do the particles in the jet carry its momentum?

$$D(z) \equiv \frac{1}{N_{\rm jet}} \frac{dn_{\rm ch}}{dz}$$

$$z \equiv p_{\rm T} \cos \Delta R \;/\; p_{\rm T}^{\rm jet}$$

$$D(p_{\rm T}) \equiv \frac{1}{N_{\rm jet}} \frac{dn_{\rm ch}}{dp_{\rm T}}$$



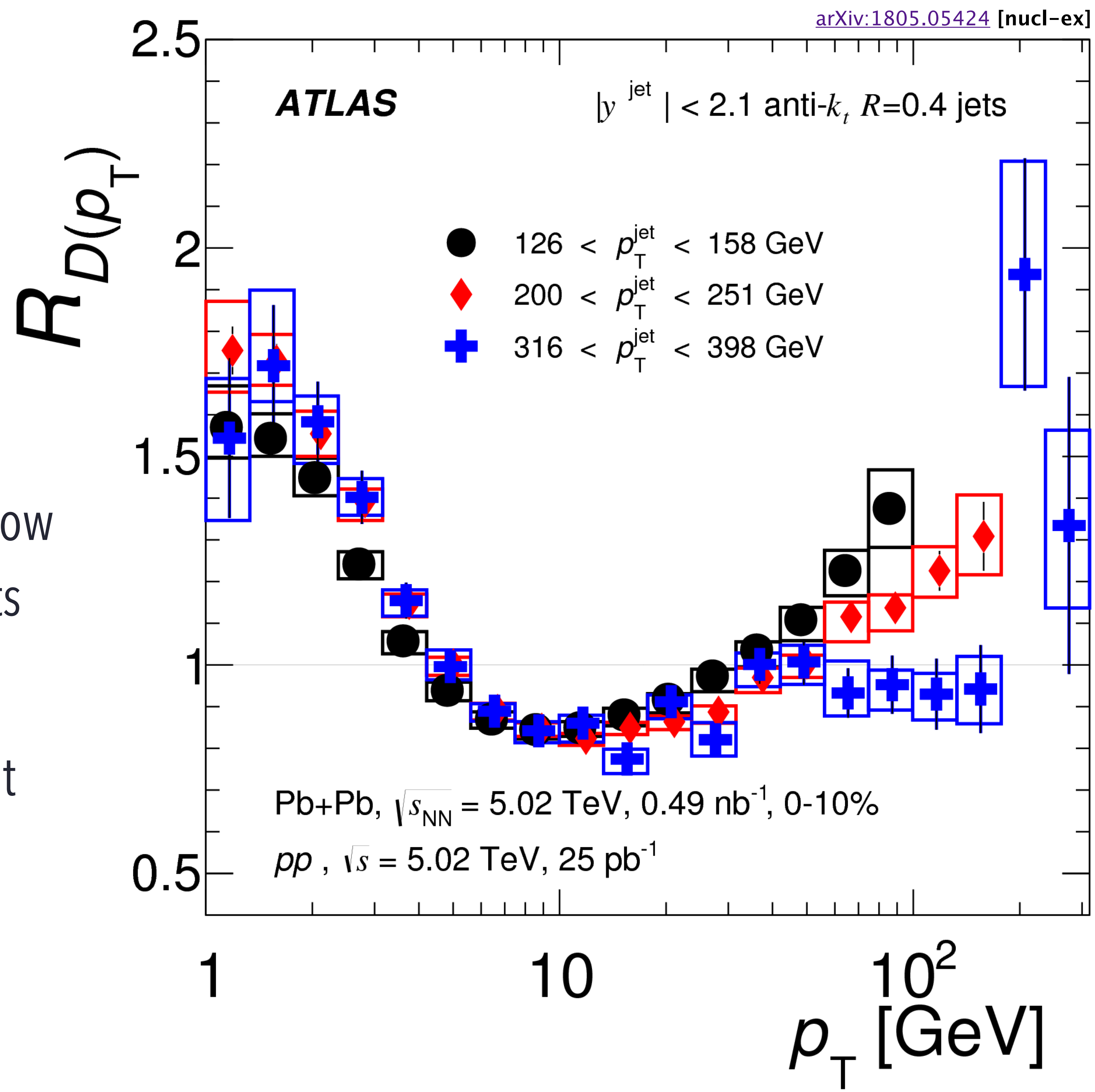
$$R_{D(p_{\rm T})} \equiv \frac{D(p_{\rm T})_{\rm PbPb}}{D(p_{\rm T})_{pp}}$$

Shower in medium

Shower in vacuum

Jet structure

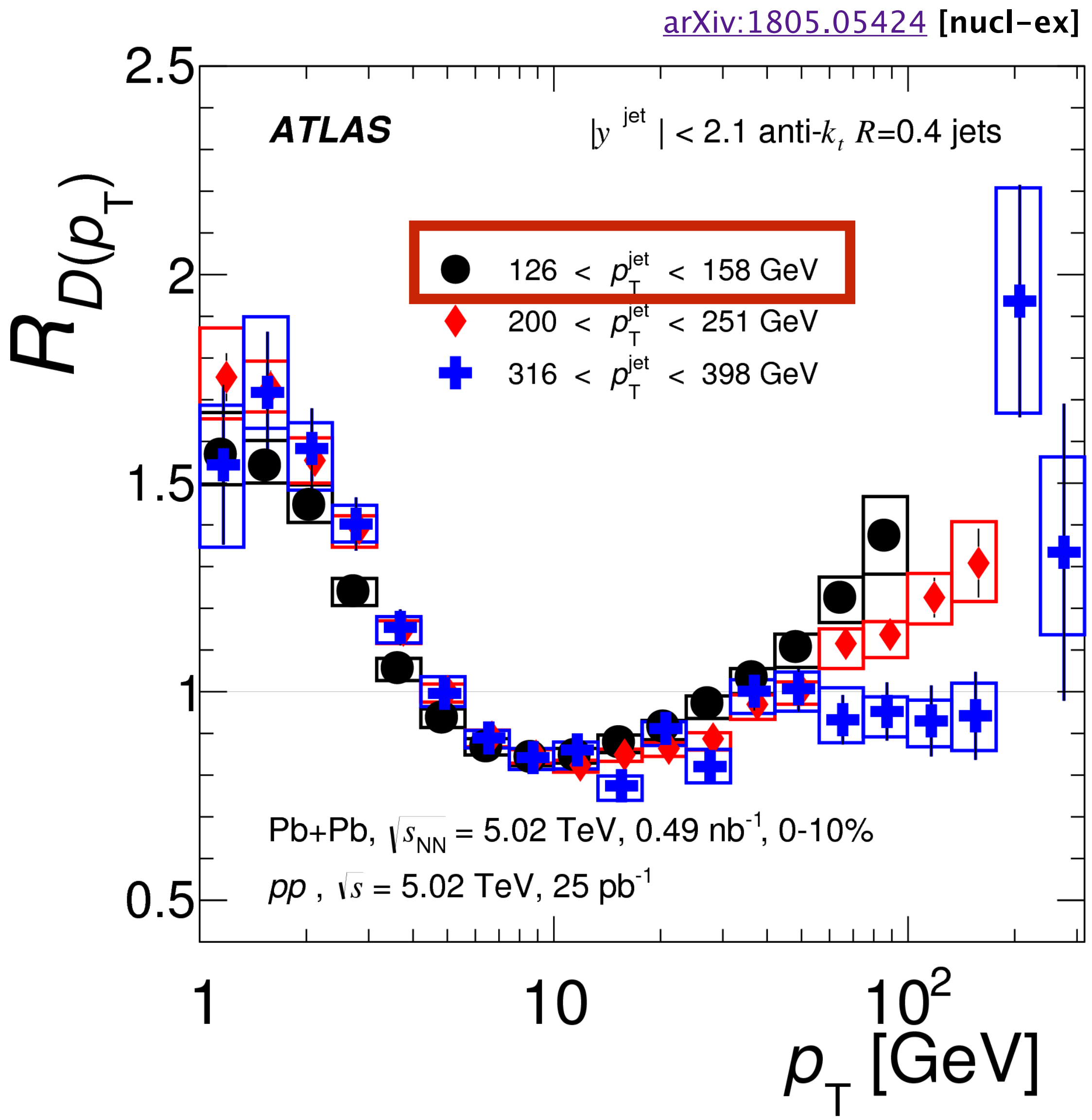
- Enhancement in the low and high pT fragments
- Suppression of the moderate pT fragment

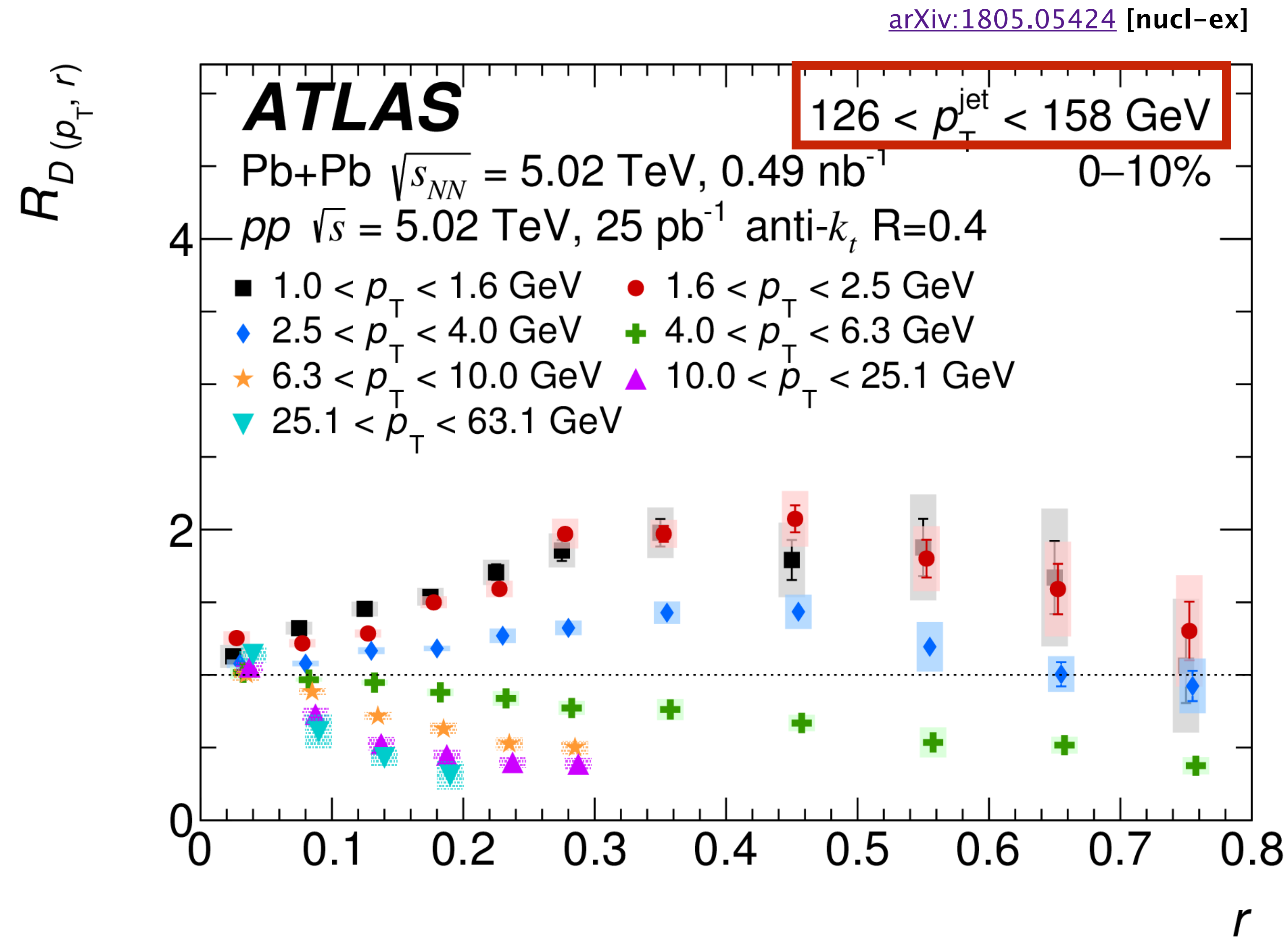


Jet structure

$$D(p_\mathrm{T}) \equiv \frac{1}{N_\mathrm{jet}} \frac{dn_\mathrm{ch}}{dp_\mathrm{T}}$$

$$D(p_\mathrm{T}, r) = \frac{1}{N_\mathrm{jet}} \frac{1}{2\pi r\, dr} \frac{dn_\mathrm{ch}(p_\mathrm{T}, r)}{dp_\mathrm{T}}$$



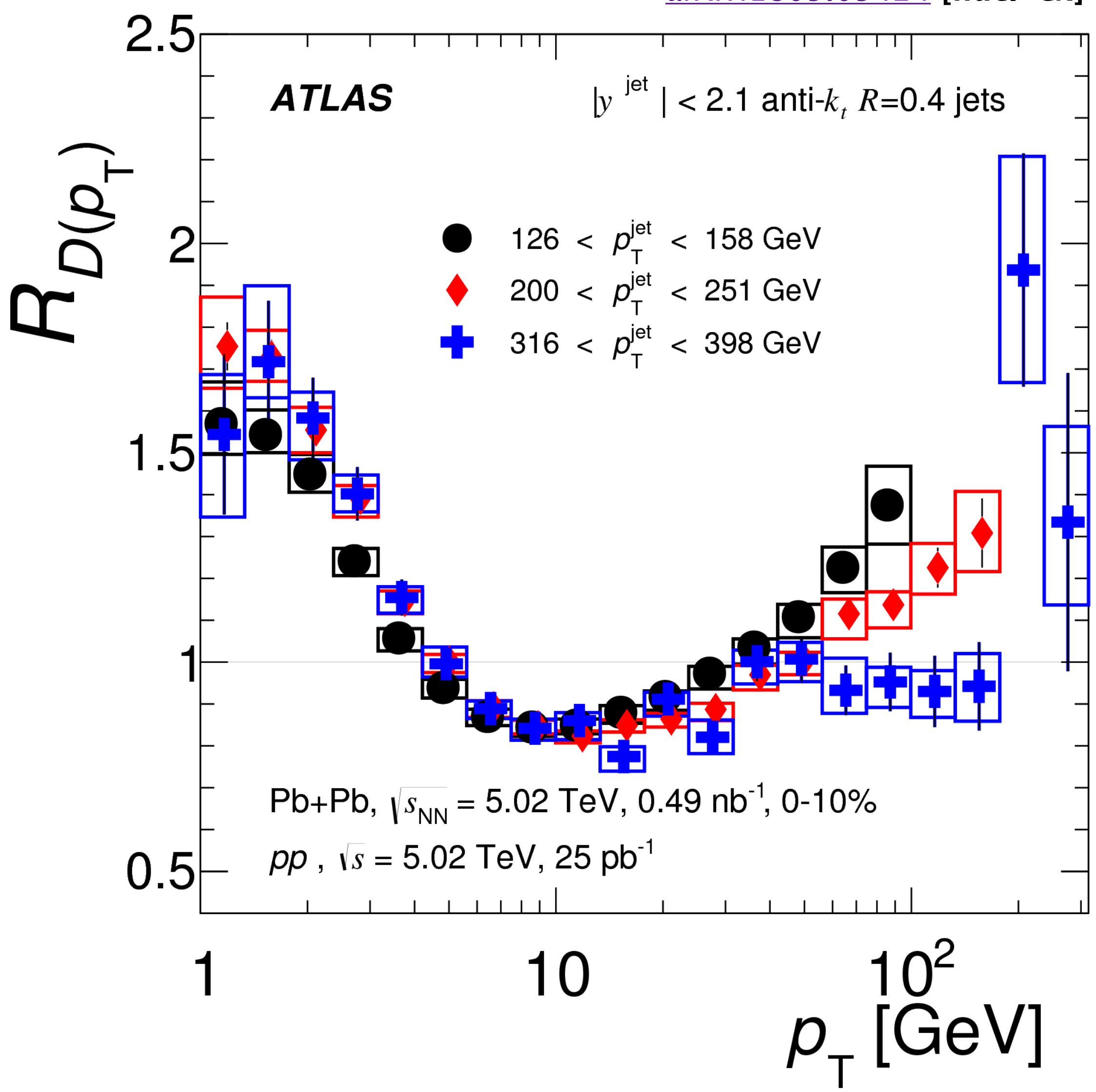


- Modification extend beyond the cone of the jet (low p_T)
- Not much modification in the core of the jet

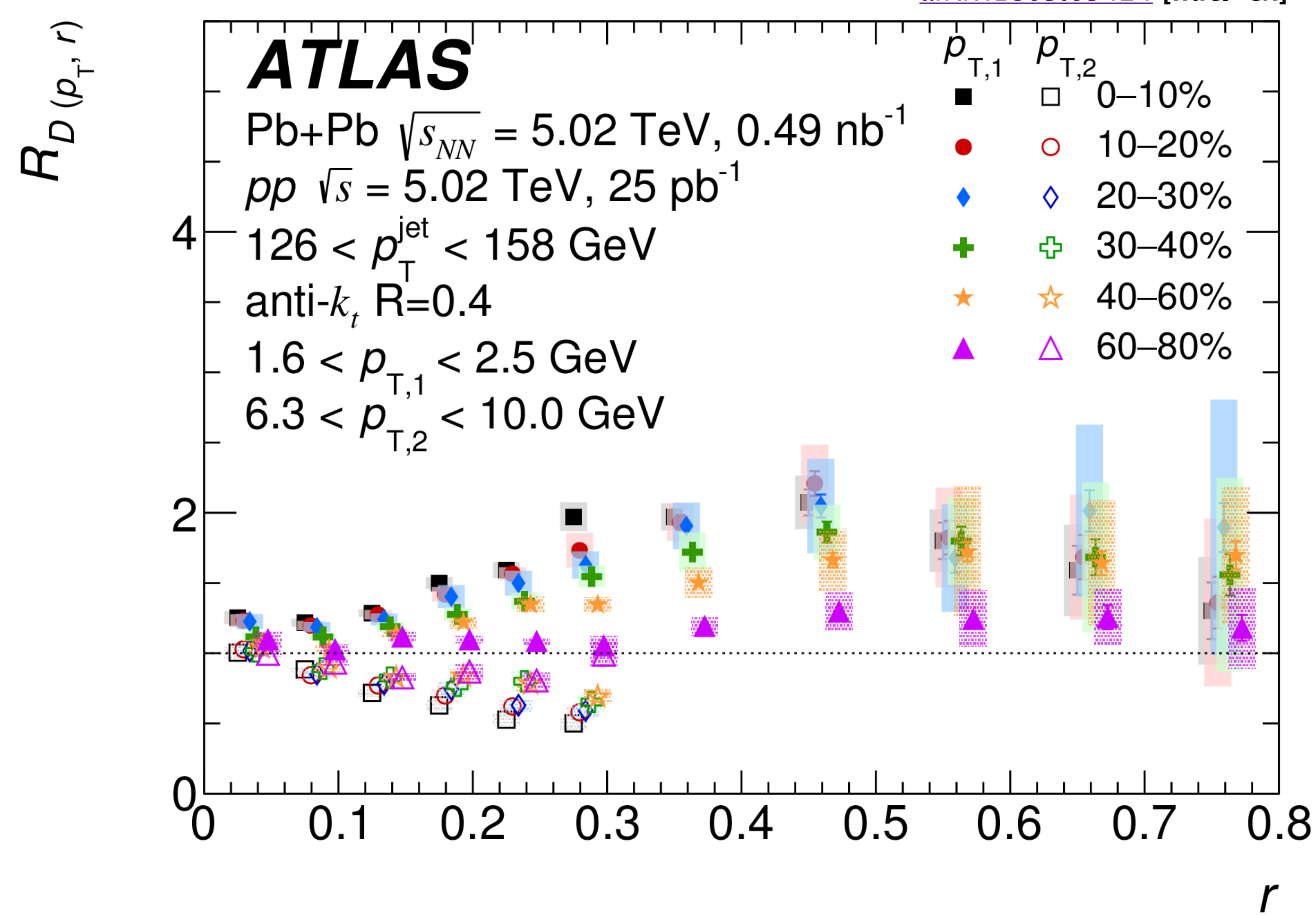
$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dp_T}$$

$$D(p_T, r) = \frac{1}{N_{jet}} \frac{1}{2\pi r\, dr} \frac{dn_{ch}(p_T, r)}{dp_T}$$

arXiv:1805.05424 [nucl-ex]



arXiv:1805.05424 [nucl-ex]

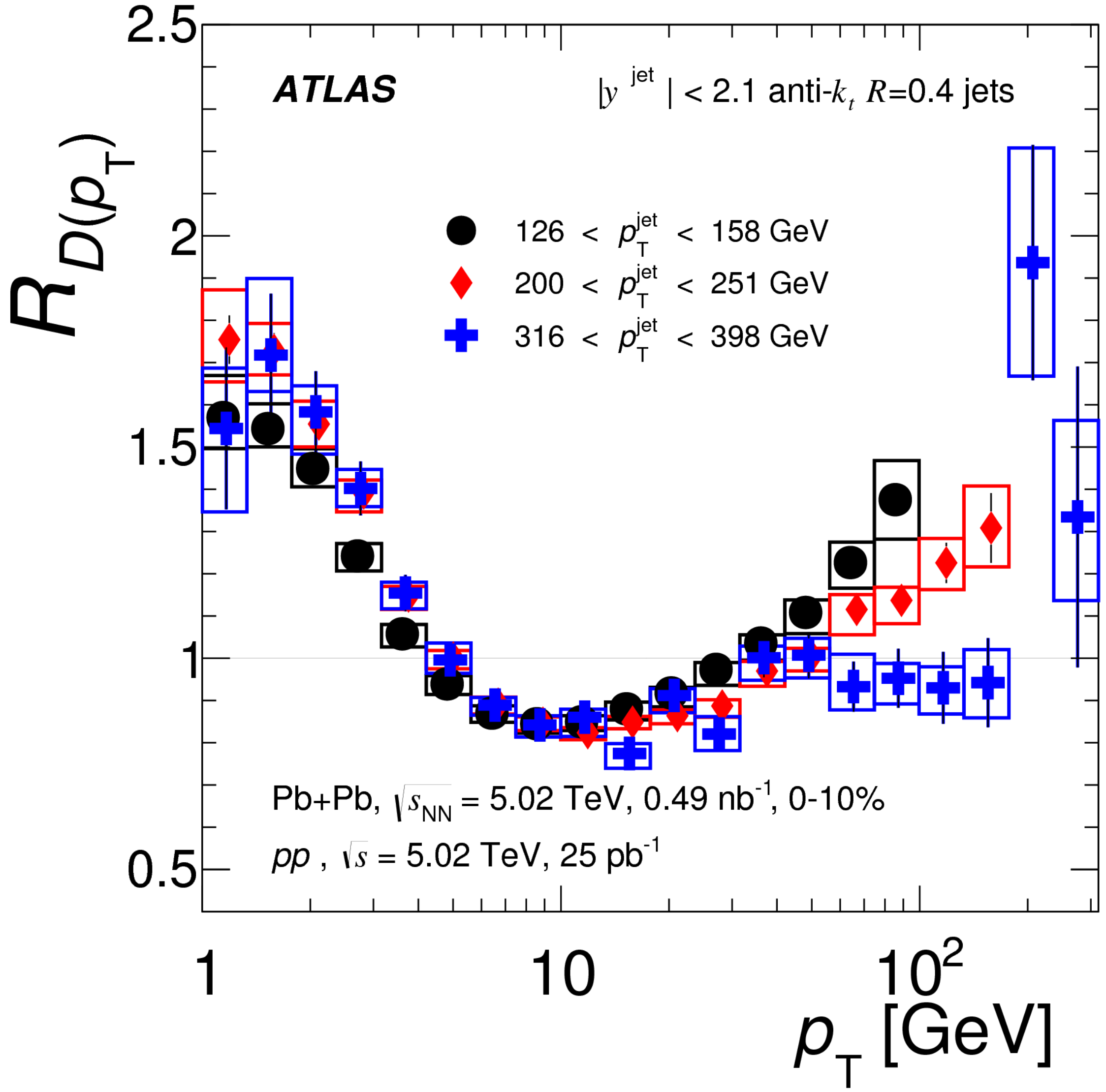


- Peripheral collisions approach vacuum like fragmentation patterns

Jet structure

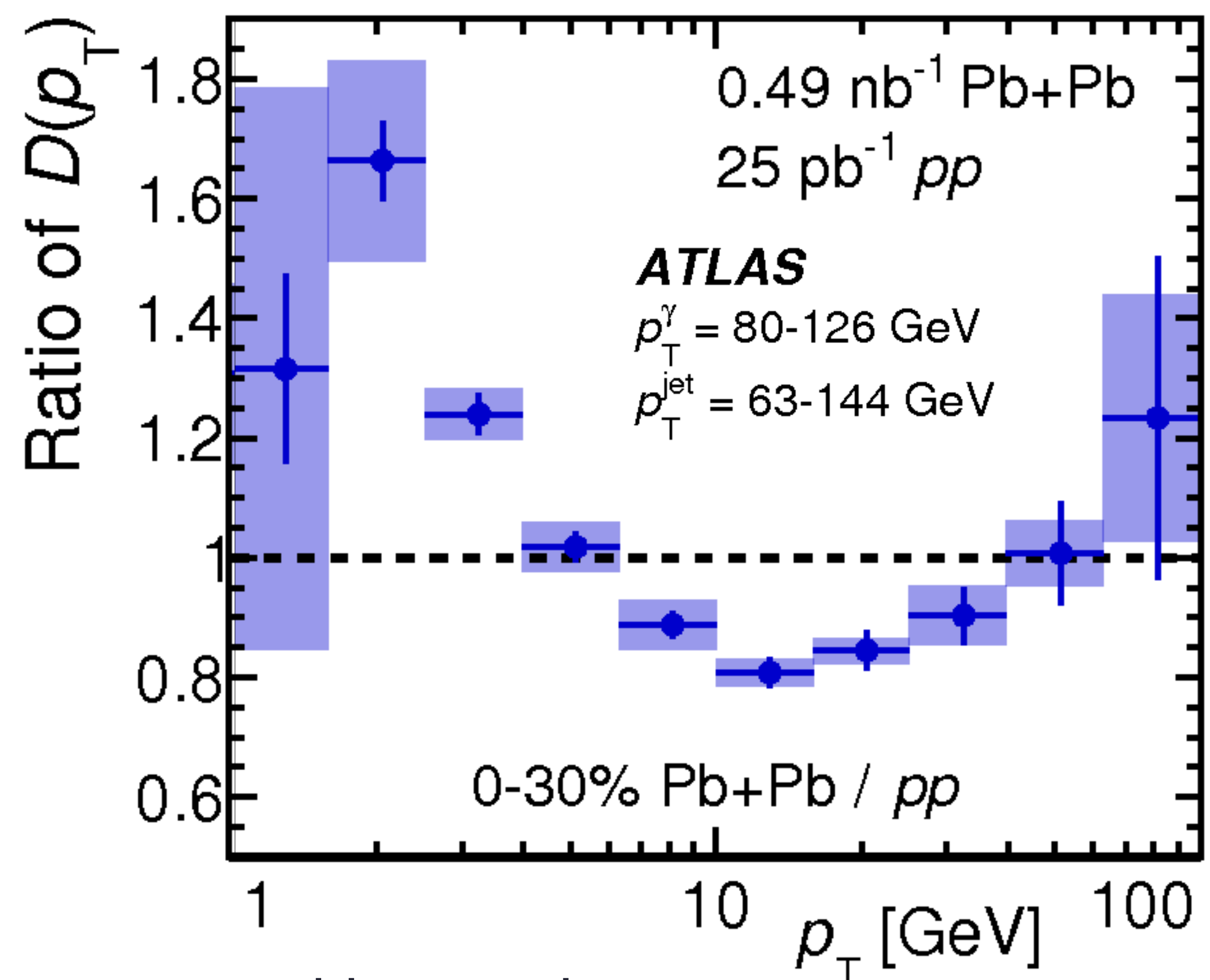
$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dp_T}$$

arXiv:1805.05424 [nucl-ex]



Jets balanced by photons

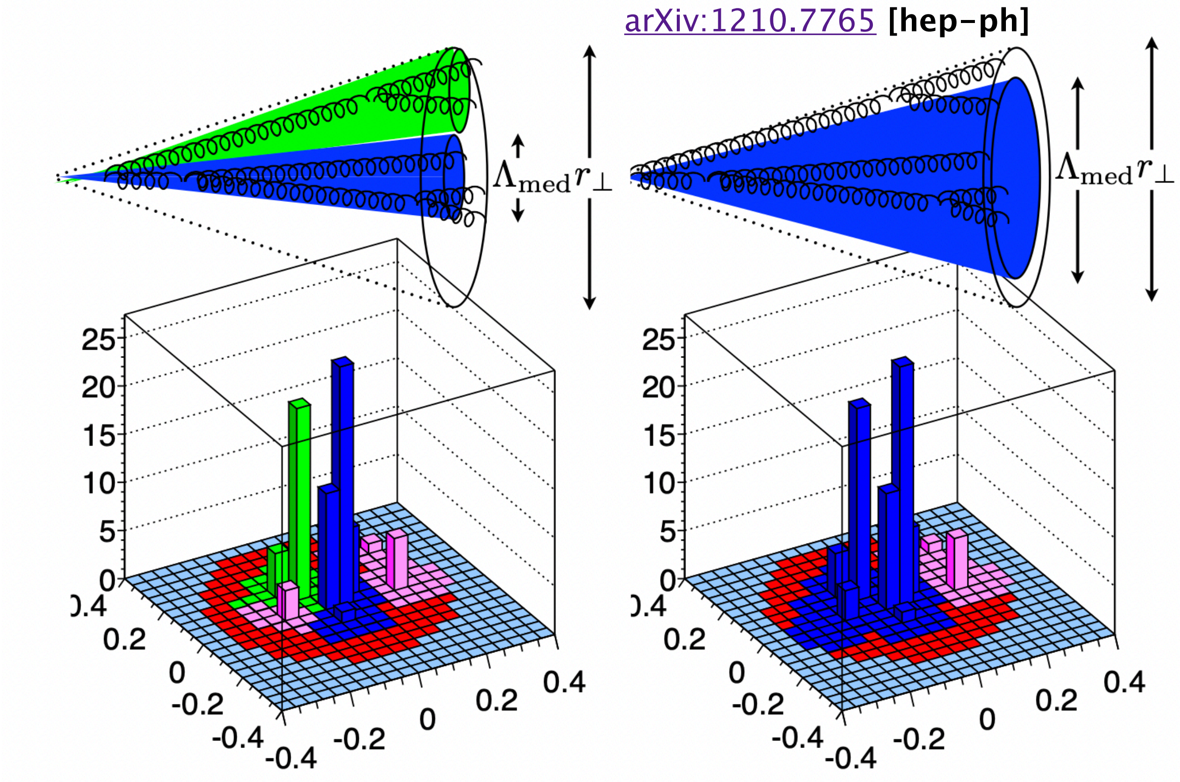
arXiv:1902.10007 [nucl-ex]



- Dominated by quark jets
- Parton color-charge dependence of jet quenching

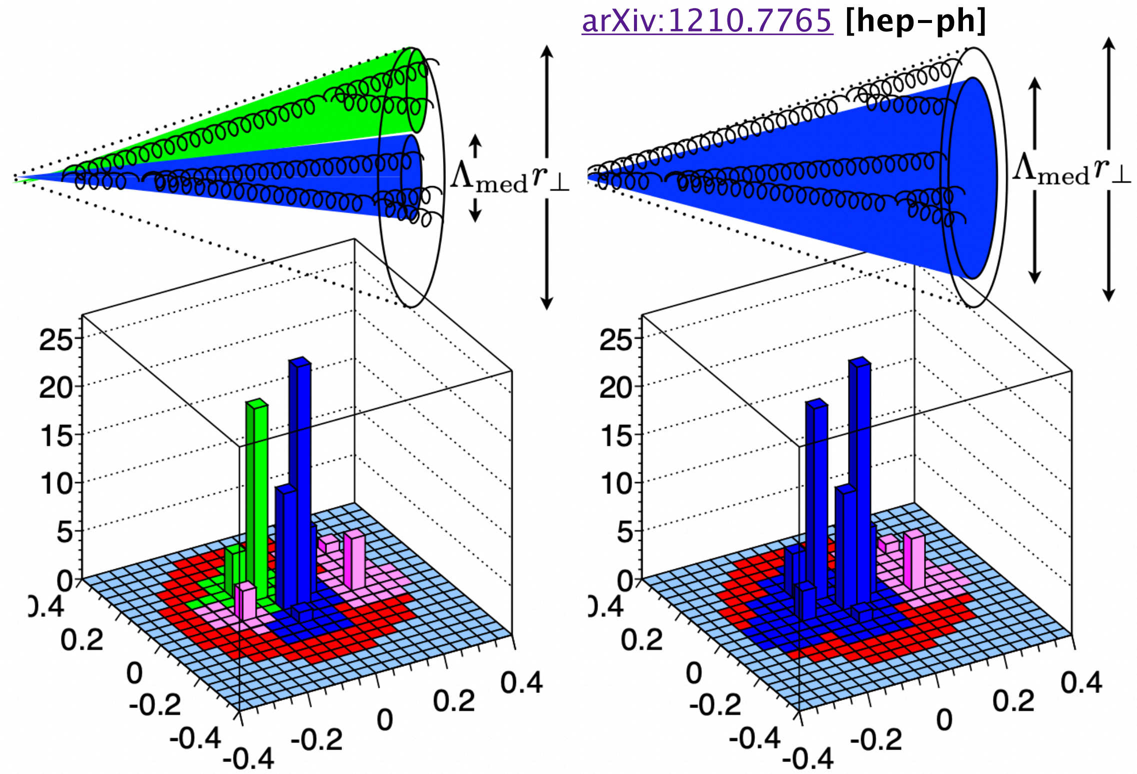
Future measurements

Do jets with different structure lose energy differently?

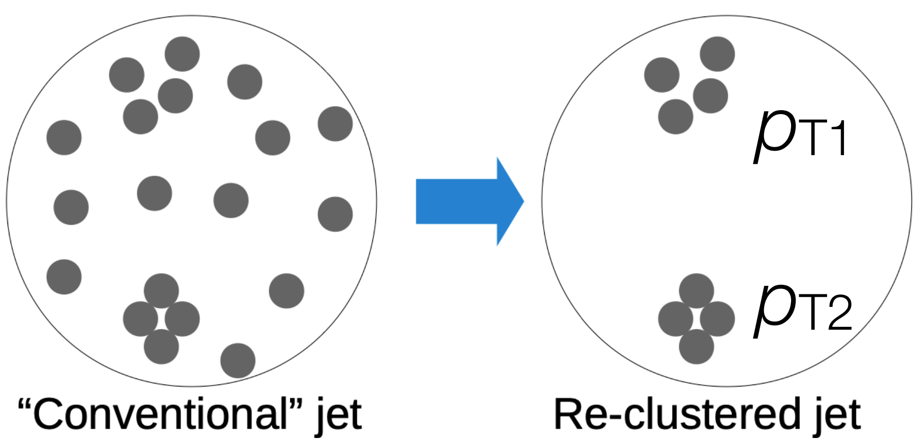


Jets substructure

Do jets with different structure lose energy differently?

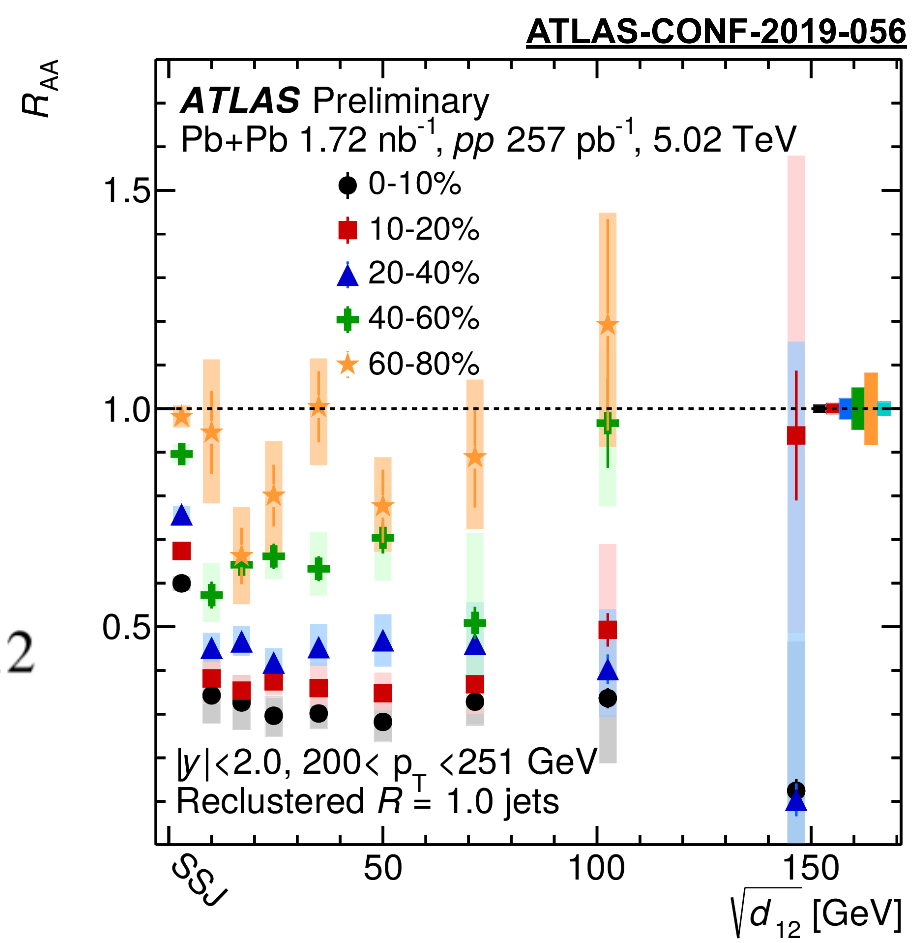


Large R jets - ATLAS way



Splitting scale

$$\sqrt{d_{12}} = \min(p_{T1}, p_{T2}) \times \Delta R_{12}$$



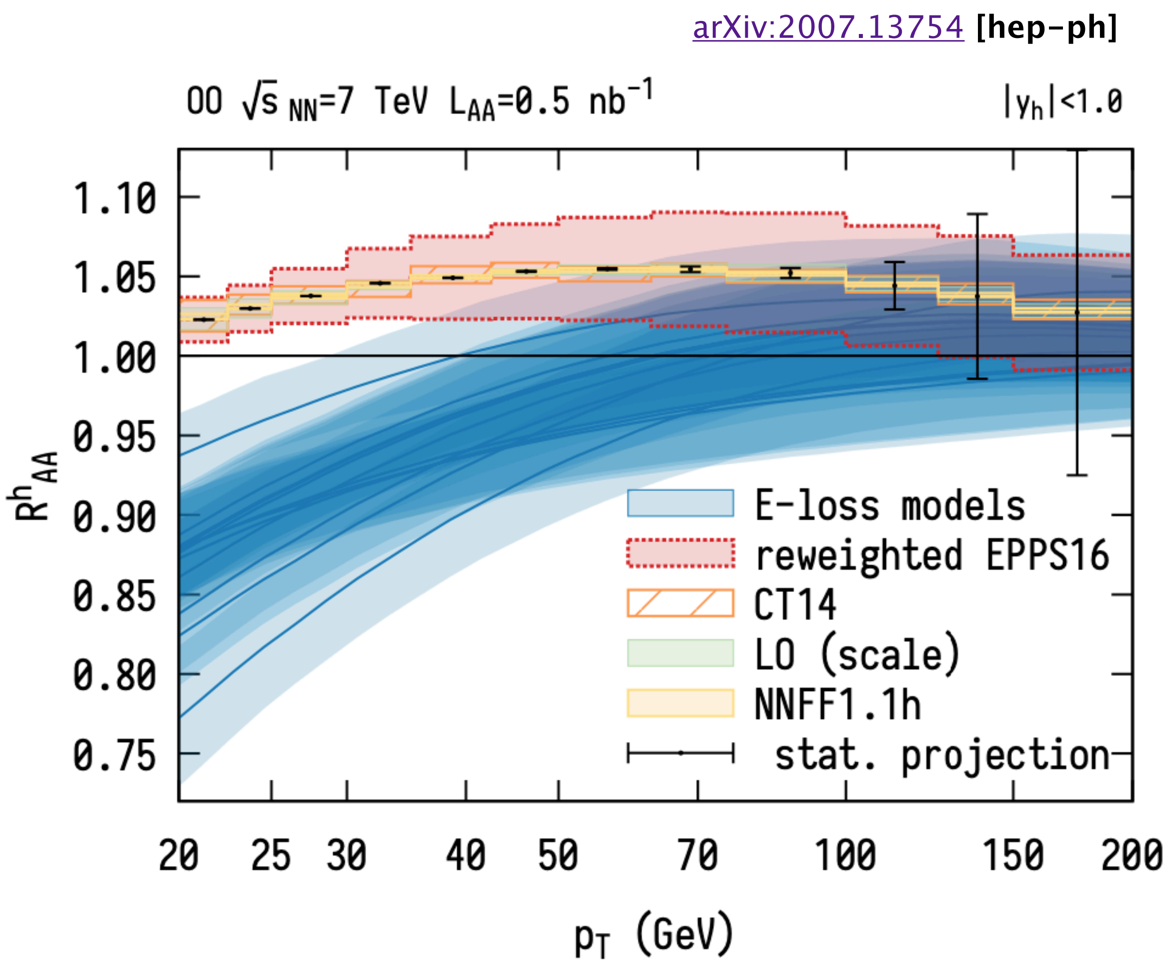
single sub-jet are less suppressed

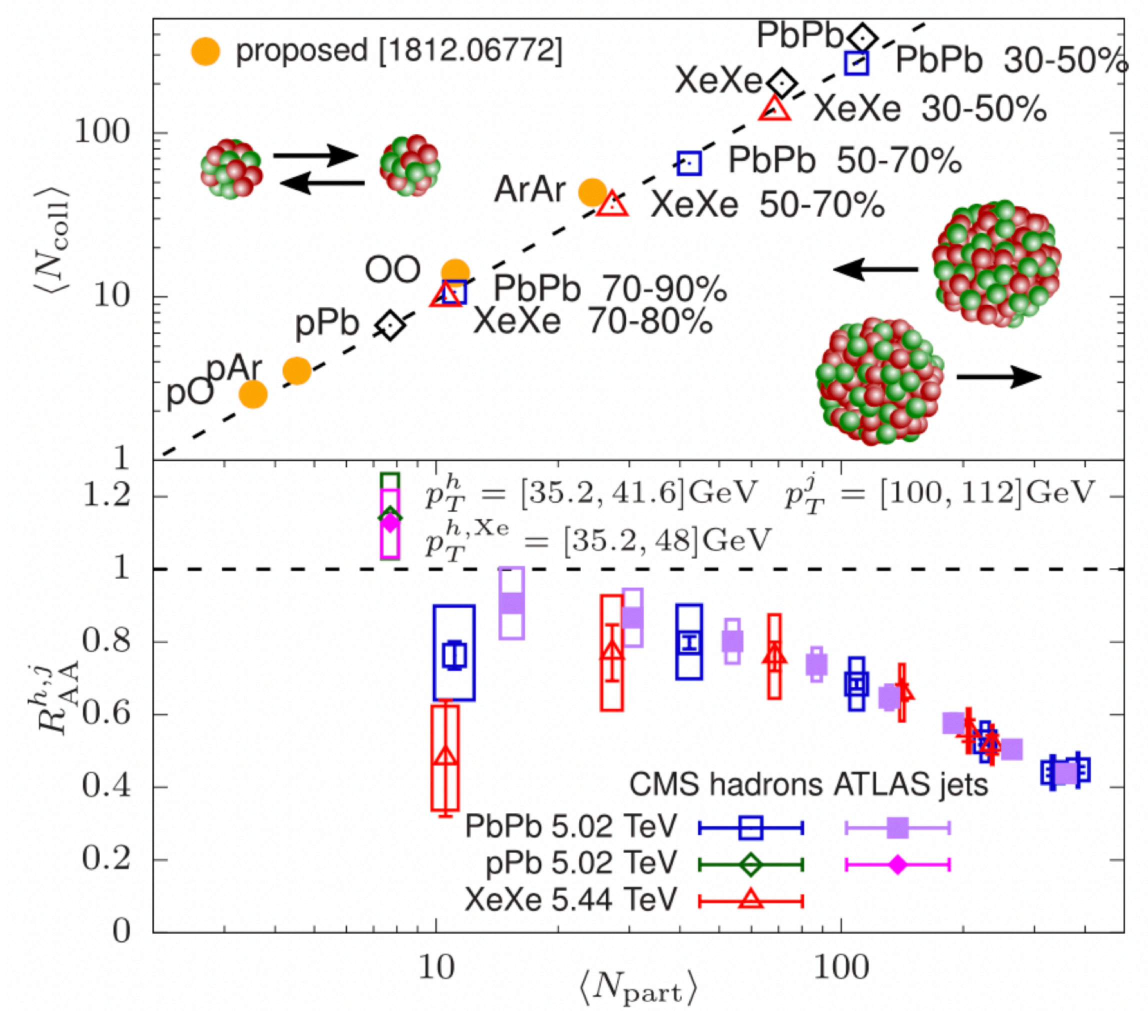
Jet quenching in light ions collisions

Measurements of p+A type of collisions at LHC and RHIC left us with unresolved problem: ***how to connect soft QGP with lack of modification in the hard sector?***

e.g. large heavy flavour v_2 but $R_{pA} \sim 1$

OO is a symmetric system about the size of pPb

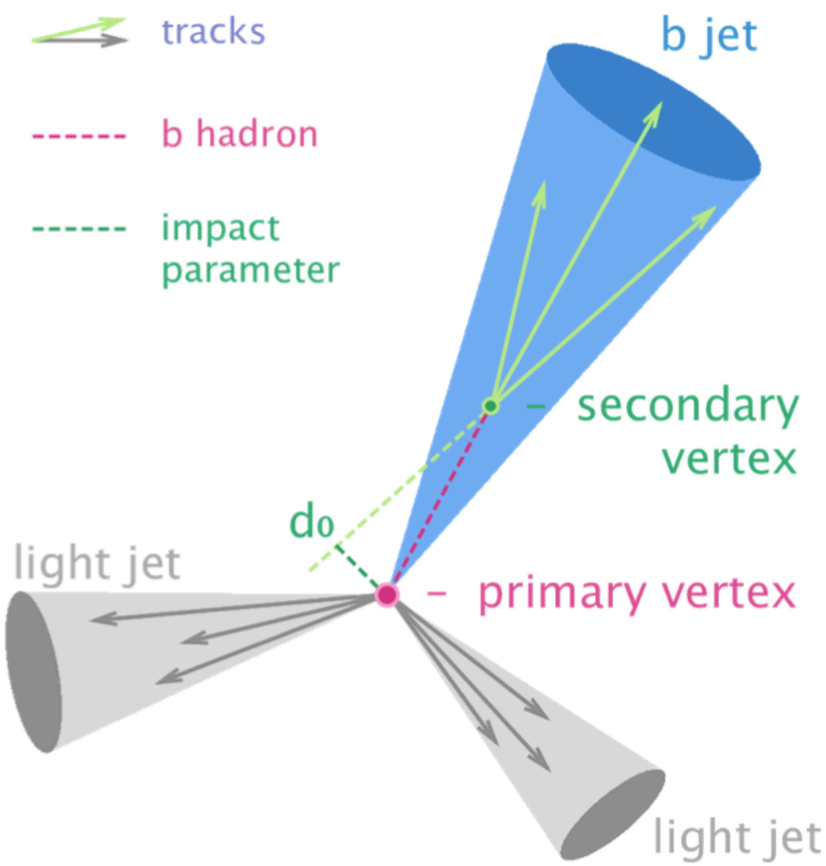




Quenching of b-jets

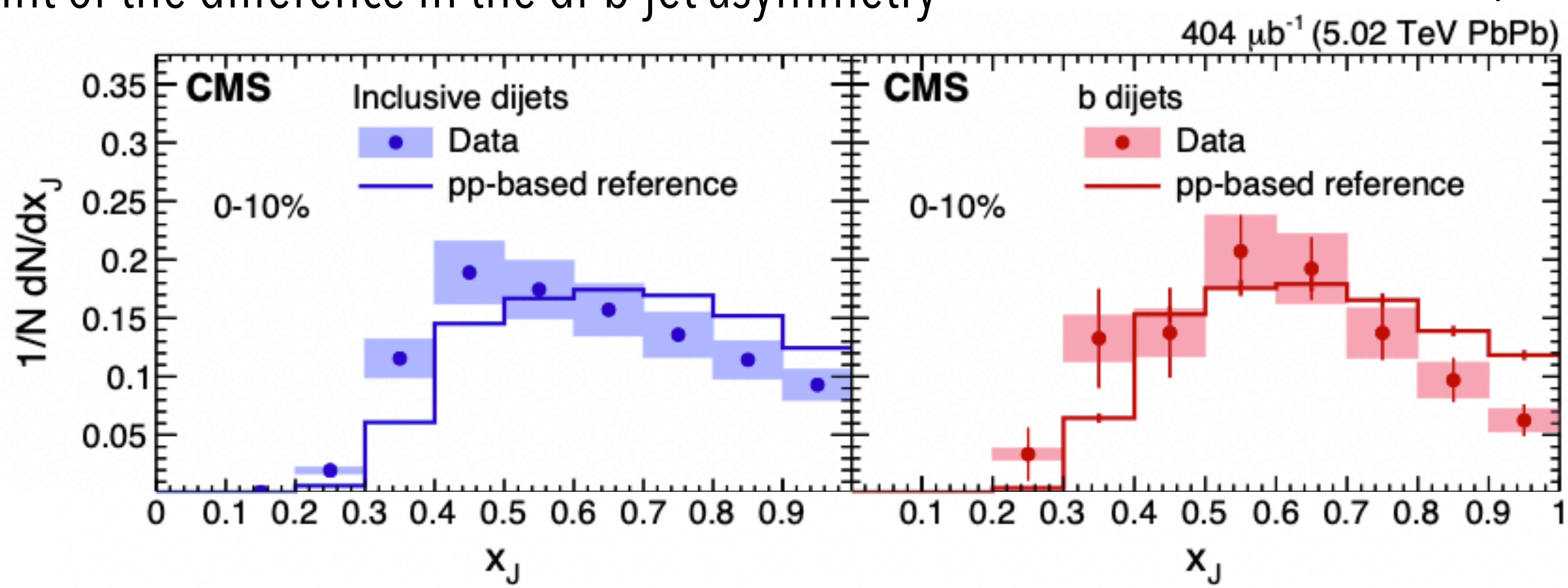
The dependence of quenching on the type of parton that initiates the jet may provide insight into the underlying dynamics

- Type of parton that initiates the jet is difficult to determine experimentally
- Machine learning techniques used in experiments to identify b-jets



A hint of the difference in the di-b-jet asymmetry

arXiv:1802.00707 [hep-ex]



Summary

Using high statistics LHC data and new techniques bring us to era of precise measurements of jet quenching in heavy-ion collisions

- R_{AA} for inclusive jets measured to very high precision
- Measurement seams to support picture of path length dependence of energy loss
- Detailed studies of the modification of the fragmentation patterns for the quenched jets

We still need new measurements

- Each observable is sensitive to different aspect of probing the QGP
- Some observables are statistics hungry - looking forward for more data

More details on ATLAS public results page:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults