Nuclear Modification of anti-kT jets from R=0.2 to R=1.0

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for the

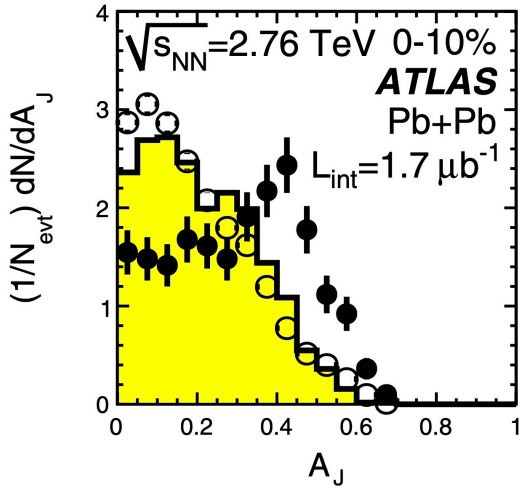
CMS Collaboration

ICHEP 2022, Bologna, Italy
July 6th – July 13th 2022

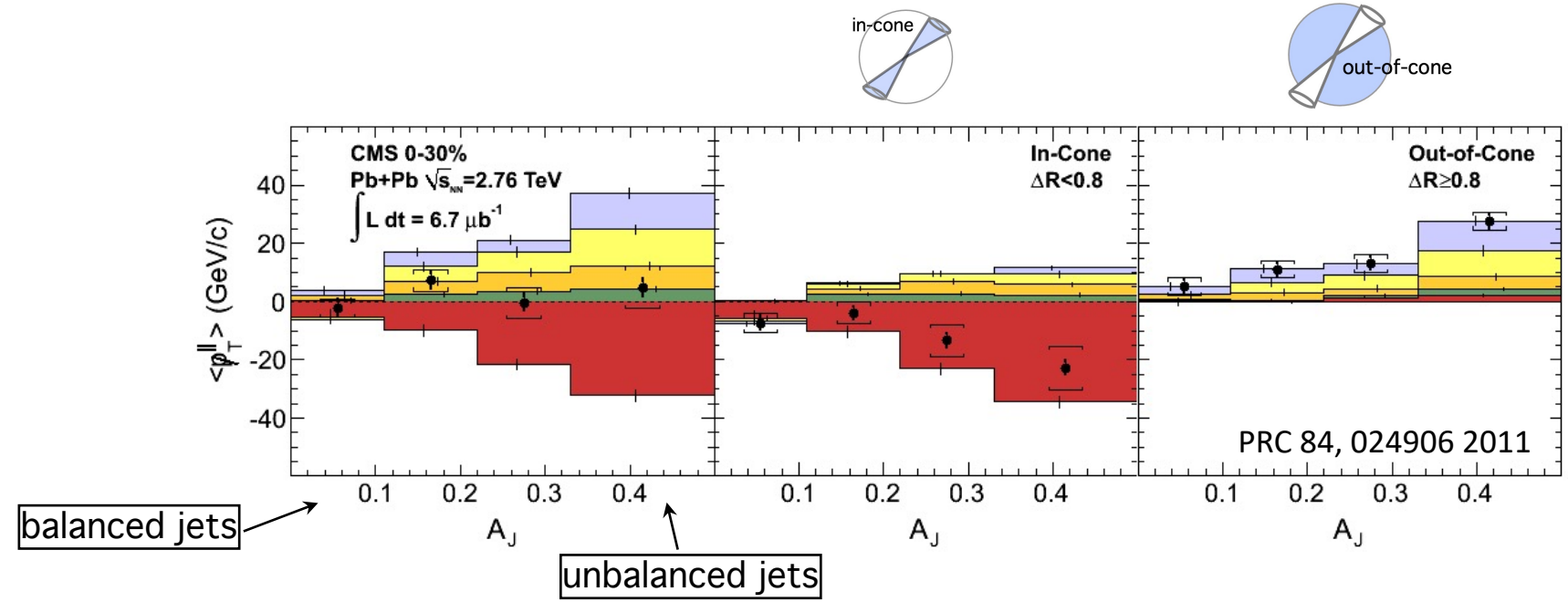
Some ancient history…

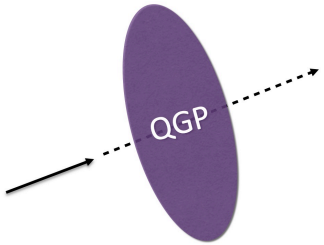
Dijet Balance

Phys. Rev. Lett. 105 (2010) 252303.



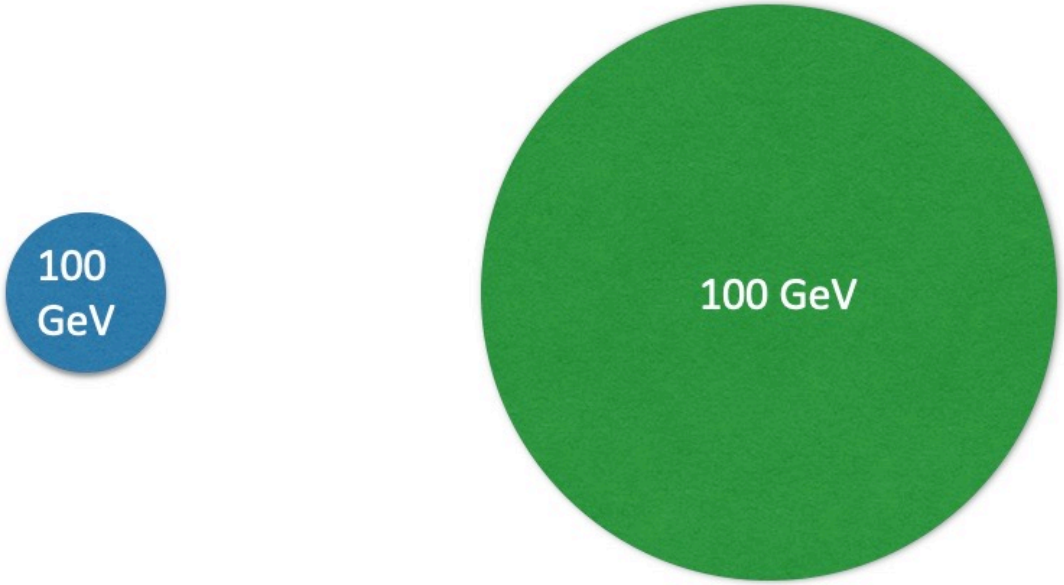
Missing p_T





- 2010: Direct observation of parton energy loss
  - The mantra:
    - The energy lost by fast partons is balanced by soft particles at large angles…
  - The challenge:
    - How to turn the observation into knowledge about the inner workings of the QGP?

Jet production vs jet radius



Small R
Collimated Jets

Large R
Collimated, or diffuse Jets

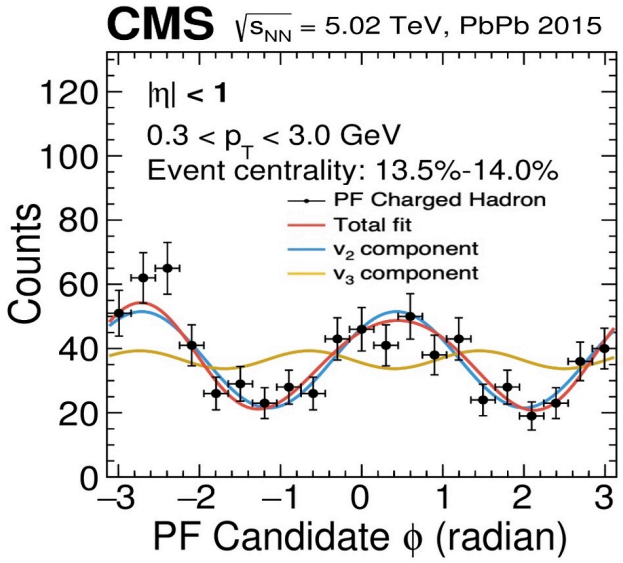
- Naively: increase jet radius to capture the ”lost” energy
- In detail: Study of different jet R is a study of different types of jets

  Do different types of jets quench differently?

Jet Reconstruction and Background Subtraction

Reconstruct jets from particle-flow candidates with anti-k_t algorithm using R = 0.2, 0.3, 0.4, 0.6, 0.8, 1.0

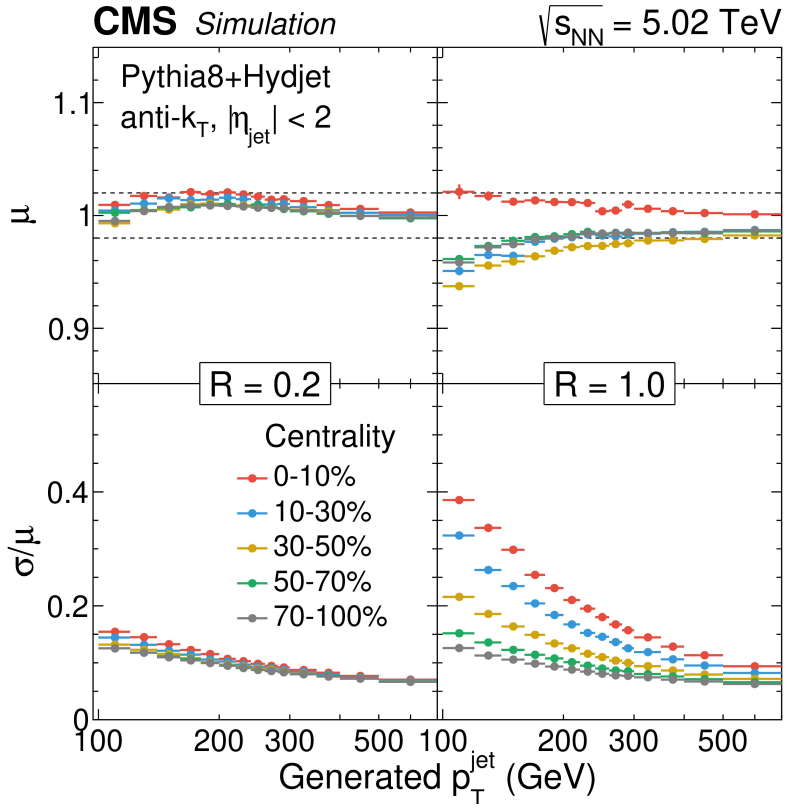
Use **constituent subtraction** with **flow-modulated ρ** to account for underlying event fluctuations from elliptic and triangular flow (v_2 and v_3)



- Flow modulation improves jet energy resolution ~10-20%
- Evidence of over-subtraction for large R at low p_T since amount subtracted scales with area
- Jets can bias the flow modulation fit leading to additional nonclosure

$$\mu = \langle p_T^{reconstructed} / p_R^{truth} \rangle$$

$$\sigma = \sigma\left(p_T^{reconstructed} / p_R^{truth}\right)$$



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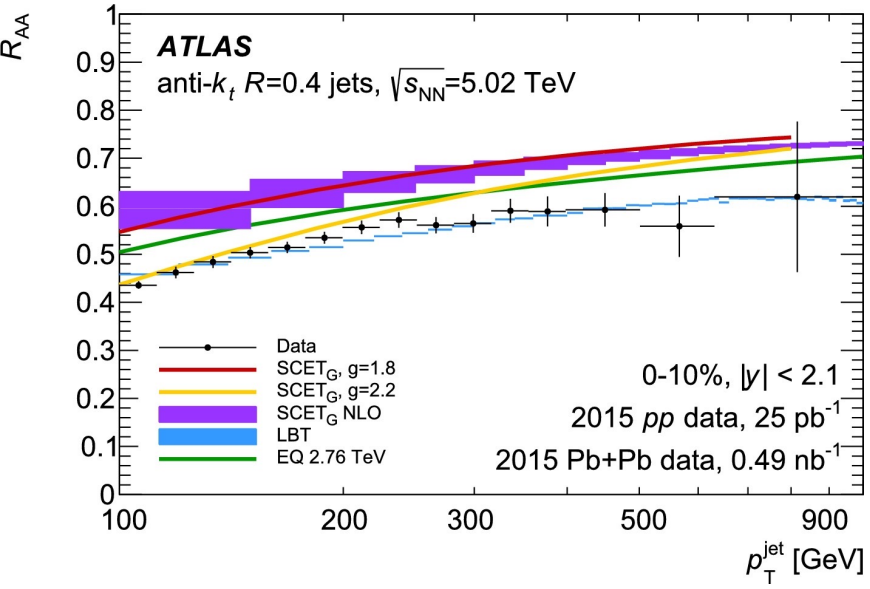
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Theory Predictions: Jet R_{AA}

Phys. Rev. B 790 (2019) 108



Jewel: JHEP 1707 (2017) 141

Factorization: Phys. Lett. 122 (2019) 252301

Hybrid: arXiv:1907.12301 & JHEP03 (2017) 135

LBT: Phys. Rev. C 99 (2019) 054911

CCNU coupled jet-fluid: Phys. Rev. C 94 (2016) no.2, 024902

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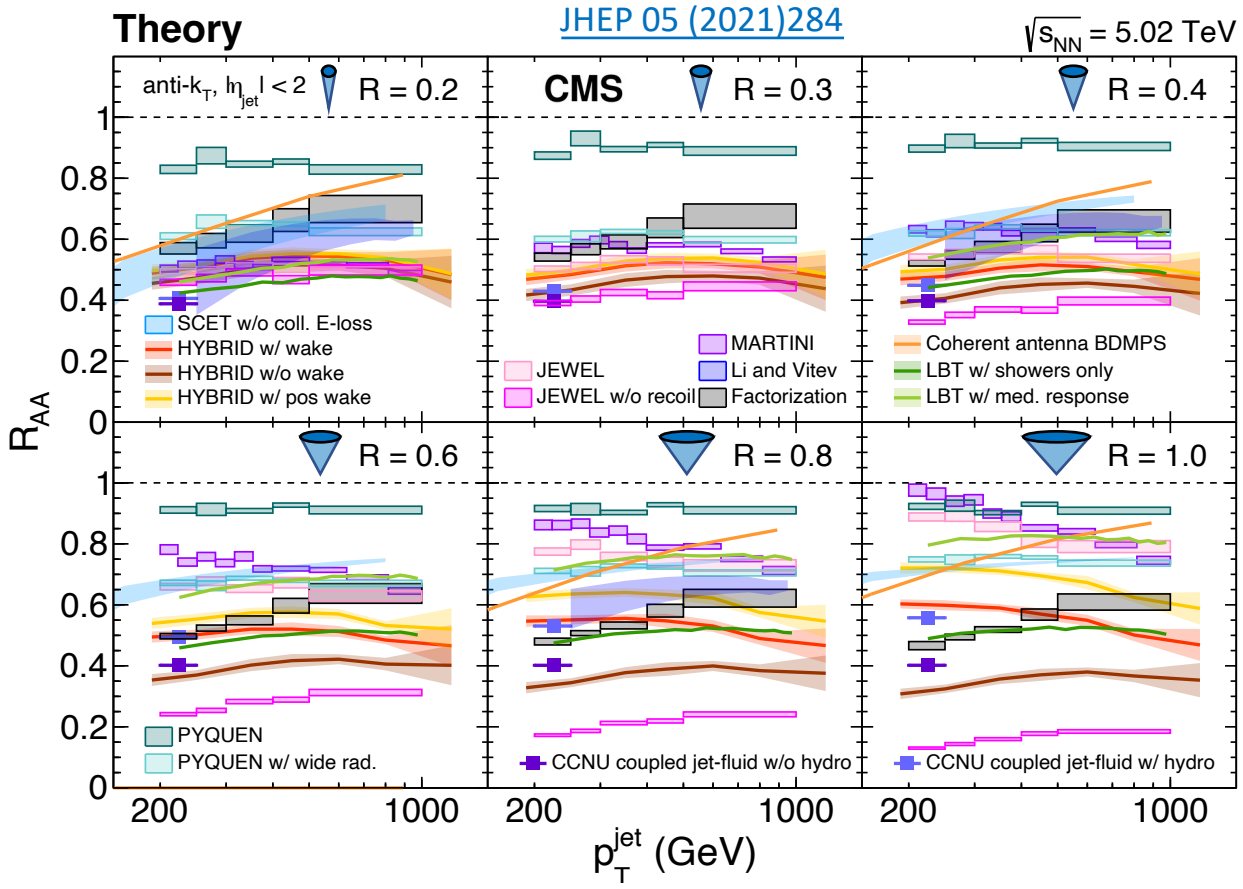


Theories follow general R_{AA} trend for R = 0.4

They yield very different predictions with increasing p_T and R -> 1.0

MARTINI: Phys. Rev. C 80 (2019) 054913

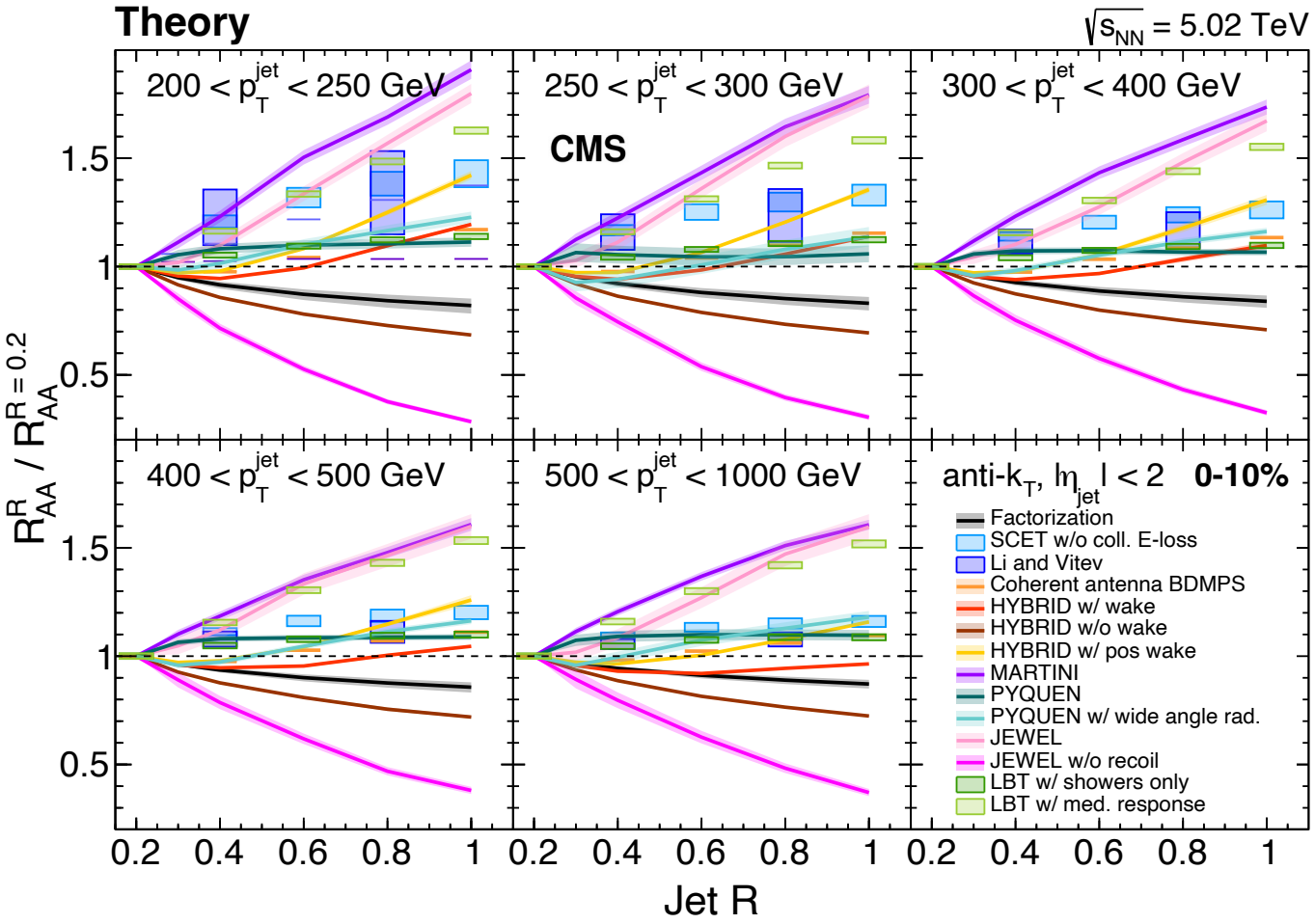
Li and Vitev: JHEP 1907 (2019) 148 & Phys. Lett. B 795 (2019) 502-510

SCET$_G$ w/o coll. E-loss: JHEP05 (2016) 023

Pyquen: Eur. Phys. J C16 (2000) 527-536 & Eur. Phys. J C46 (2006) 211-217 & SINP MSU 2004-14/753

BDMPS: Phys. Rev. D 98 (2018) no.5, 051501

Theory Predictions: Jet $R_{AA}^{R}/R_{AA}^{0.2}$



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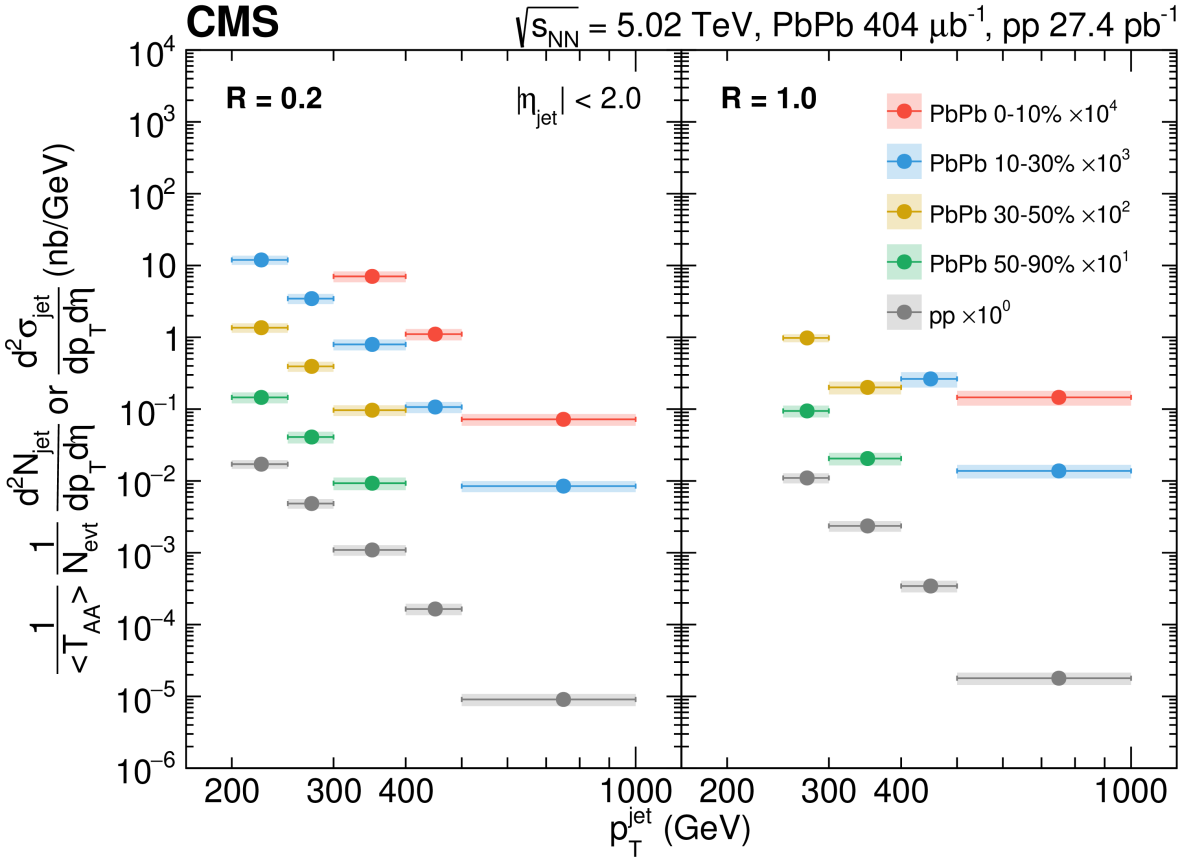
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Effects as R increases:

- Energy more spread out
- Jet splitting emerging
- Gluon radiation and medium response recovered
- Quark vs. gluon contributions change

Results: Spectra



- Past results showed R_{AA} has a weak p_T dependence
- ⇒ Don't expect much modification in spectra shape, mostly in yield
- Production for R = 1 is increased as expected since more energy is included in the jet cone

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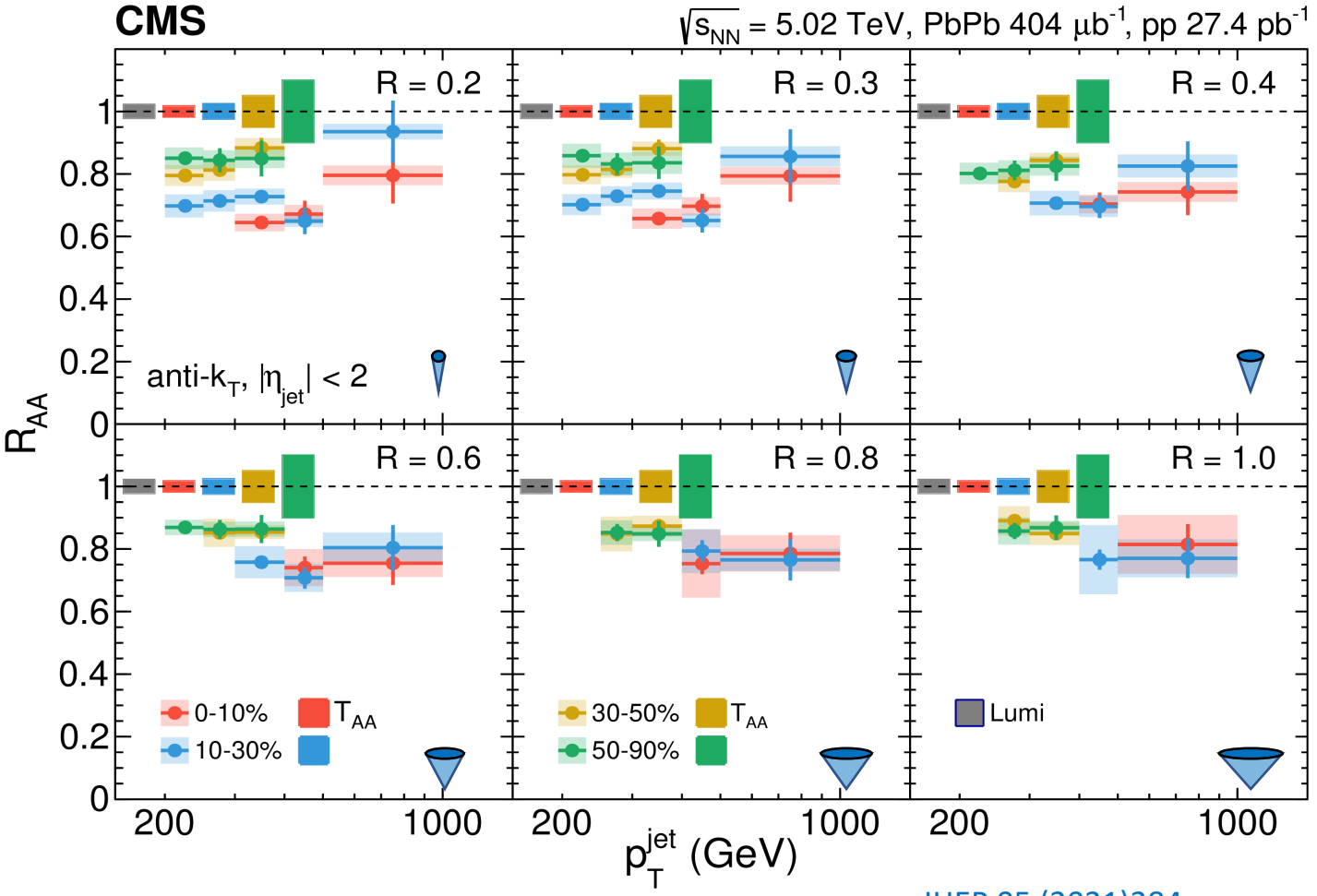
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Results: Jet R_{AA}



$$R_{AA}(p_T) = \frac{\text{PbPb jet yield}}{\text{scaled pp jet yield}}$$

- Systematic uncertainties partially cancel
- Central collisions show **strong suppression** for all R

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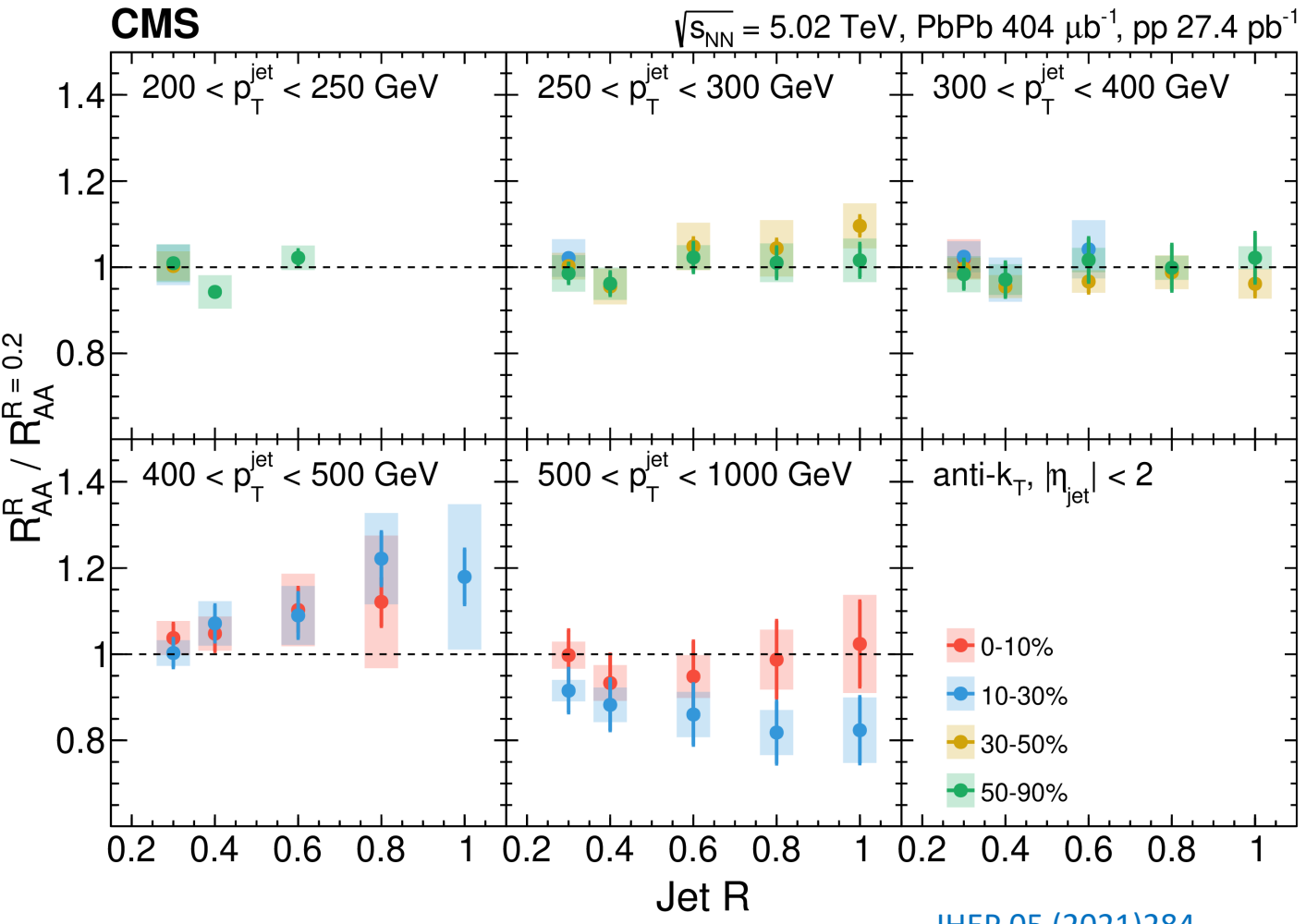
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Results: Jet $R_{AA}^{R}/R_{AA}^{R=0.2}$



- Double ratio allows further cancellation of systematics
- **Increases if PbPb recovers energy faster than pp** with increasing R
- Peripheral collisions **consistent with unity**
- Central collisions weak R dependence at high p_T

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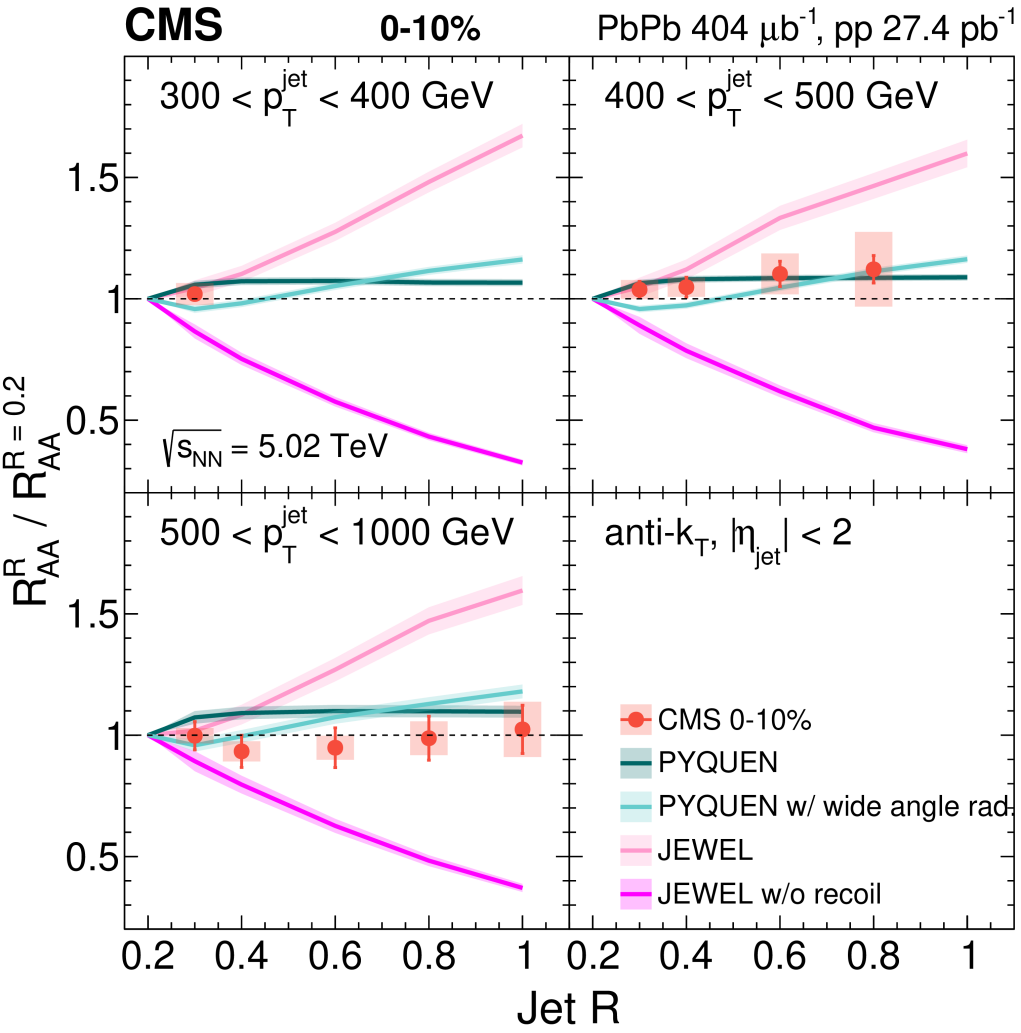
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Theory Comparison: Event Generators



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http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Jewel:

- Scattering and radiative energy loss for hard partons
- Recoiling medium that carries energy away
- Overestimates R dependence

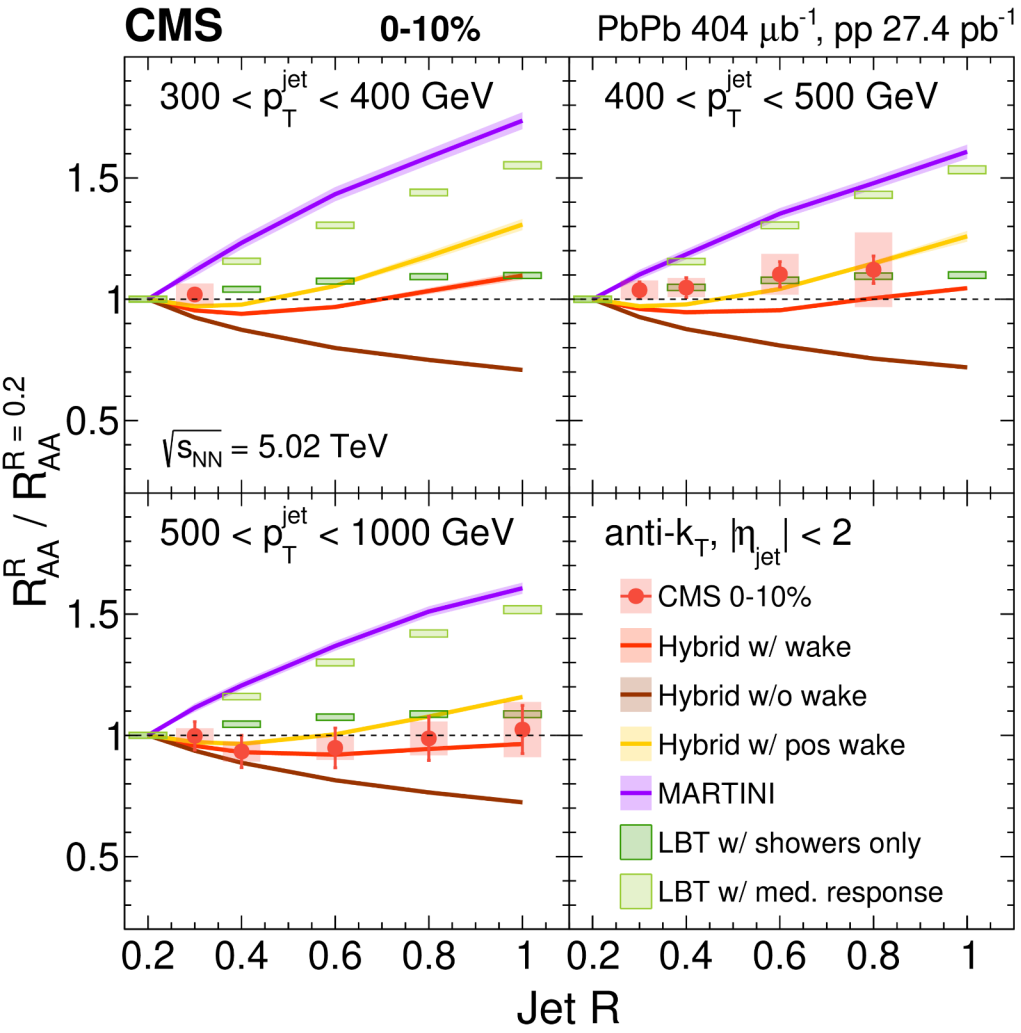
Jewel: JHEP 1707 (2017) 141

Pyquen:

- Rescattering and radiation for hard partons
- Decent description of R dependence
- Lost energy of rescattering process not put in event record

Pyquen: Eur. Phys. J C16 (2000) 527-536 & Eur. Phys. J C46 (2006) 211-217 & SINP MSU 2004-14/753

Theory Comparison: Monte Carlo



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http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Hybrid:

- Soft contribution + pert. jets
- Wake = full medium response
- Overestimates suppression

Hybrid: arXiv:1907.12301 & JHEP03 (2017) 135

MARTINI:

- Hydrodynamic model
- Jets propagate in evolving med.
- Overestimates R dependence

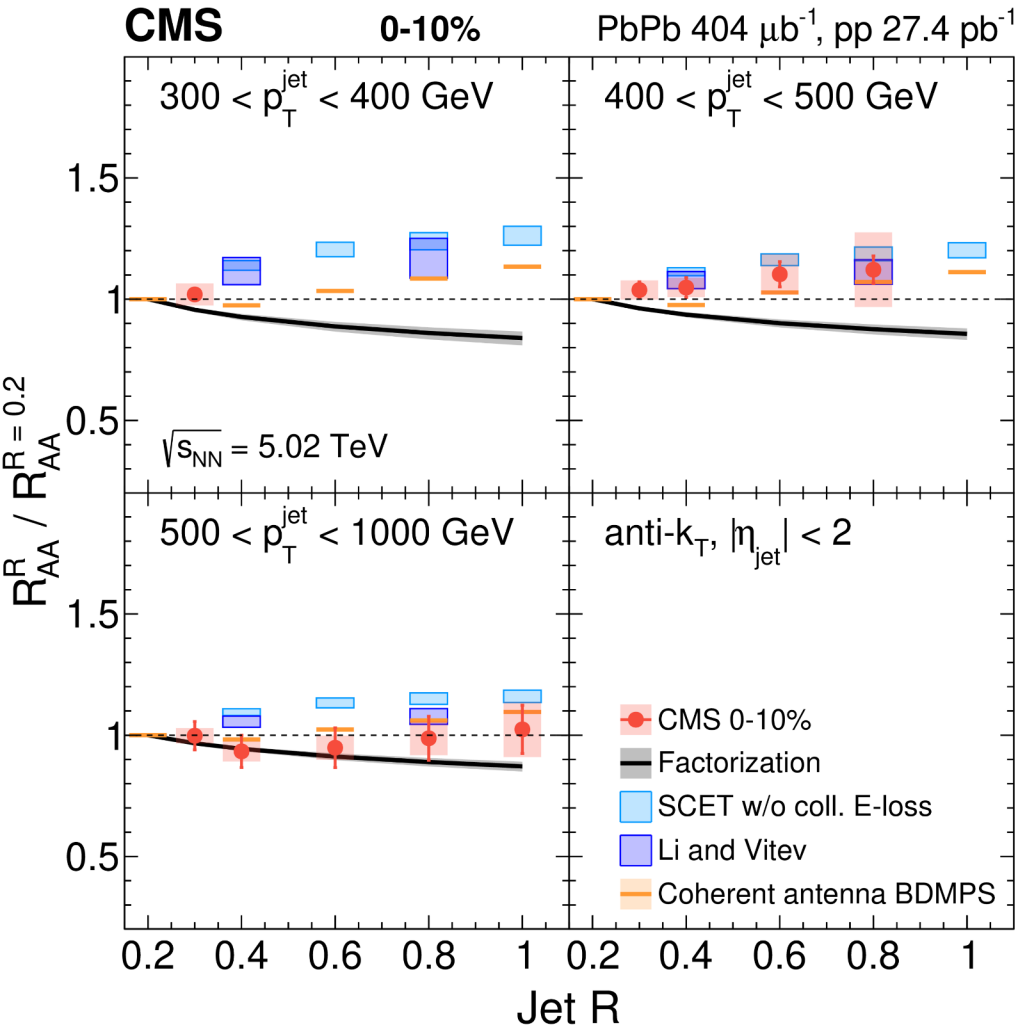
MARTINI: Phys. Rev. C 80 (2019) 054913

LBT:

- Hydrodynamic medium
- pQCD jets and med. recoil
- Overestimates R dependence

LBT: Phys. Rev. C 99 (2019) 054911

Theory Comparison: Calculations



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Factorization:

- Factorization of jet cross sections
- Jet func. extracted from small R
- Underestimates R dependence

Factorization: Phys. Lett. 122 (2019) 252301

$SCET_G$ w/o coll. energy loss:

- $SCET_G$ models interaction of hard partons with soft gluons
- Decent agreement with data

$SCET_G$ w/o coll. E-loss: JHEP05 (2016) 023

Li and Vitev:

- Use $SCET_G$ framework
- Coll. energy loss & CNM
- Decent agreement with data

Li and Vitev: JHEP 1907 (2019) 148 & Phys. Lett. B 795 (2019) 502-510

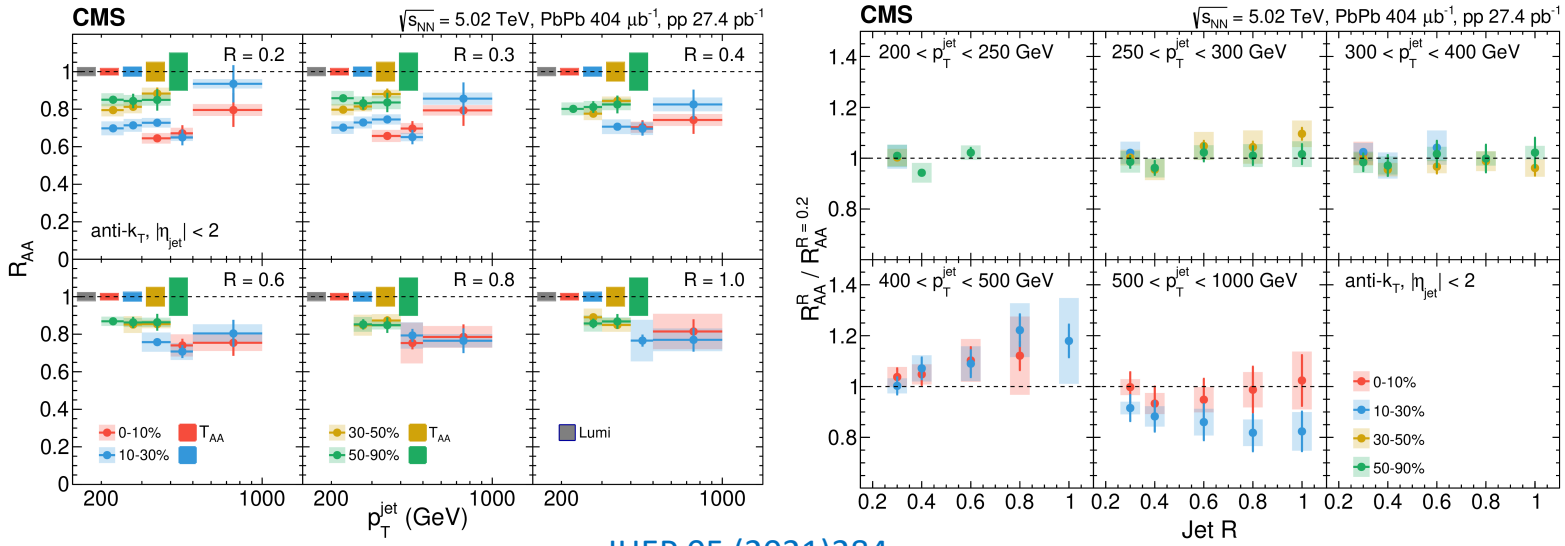
Coherent antenna BDMPS: Phys. Rev. D 98 (2018) no.5, 051501

Conclusions

- Measured nuclear modification factor R_{AA} for jets with R = 0.2, 0.3, 0.4, 0.6, 0.8, 1.0 based on pp and PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Strong suppression of high p_T jets for all R
- Weak dependence of suppression on jet R in central events

Measurements sensitive to jet quenching mechanism, medium response, wide angle radiations

Significant constraining power to models



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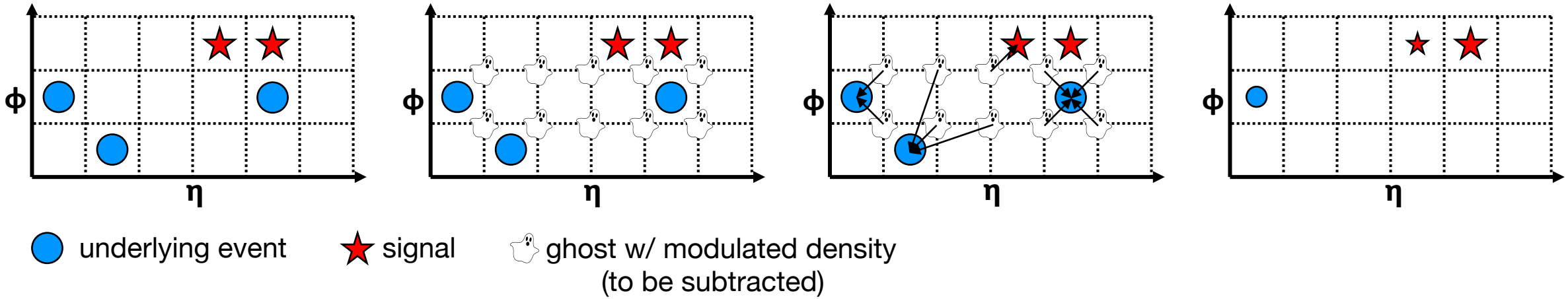
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-18-014/index.html

Acknowledgements: The MIT group's work was supported by US DOE-NP.

BACKUP

Analysis Strategy

1. Reconstruct jets from particle-flow candidates with anti-k_t algorithm using R = 0.2, 0.3, 0.4, 0.6, 0.8, 1.0
2. Subtract underlying event using constituent subtraction and flow modulation



3. Apply jet energy correction
4. Unfold raw data with d'Agostini's algorithm to account for detector effects

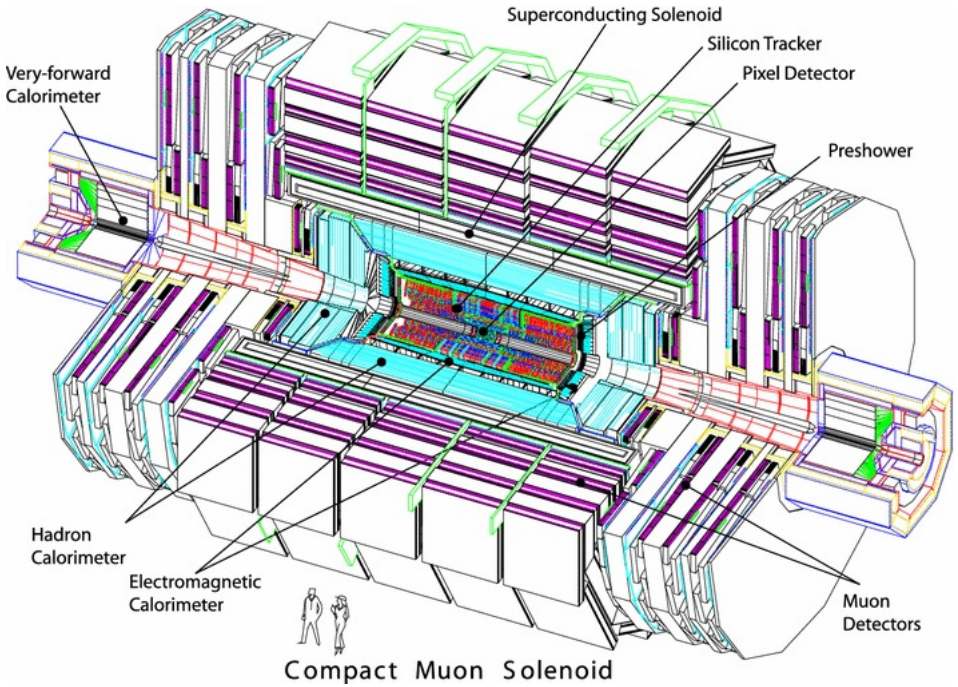
Background Subtraction

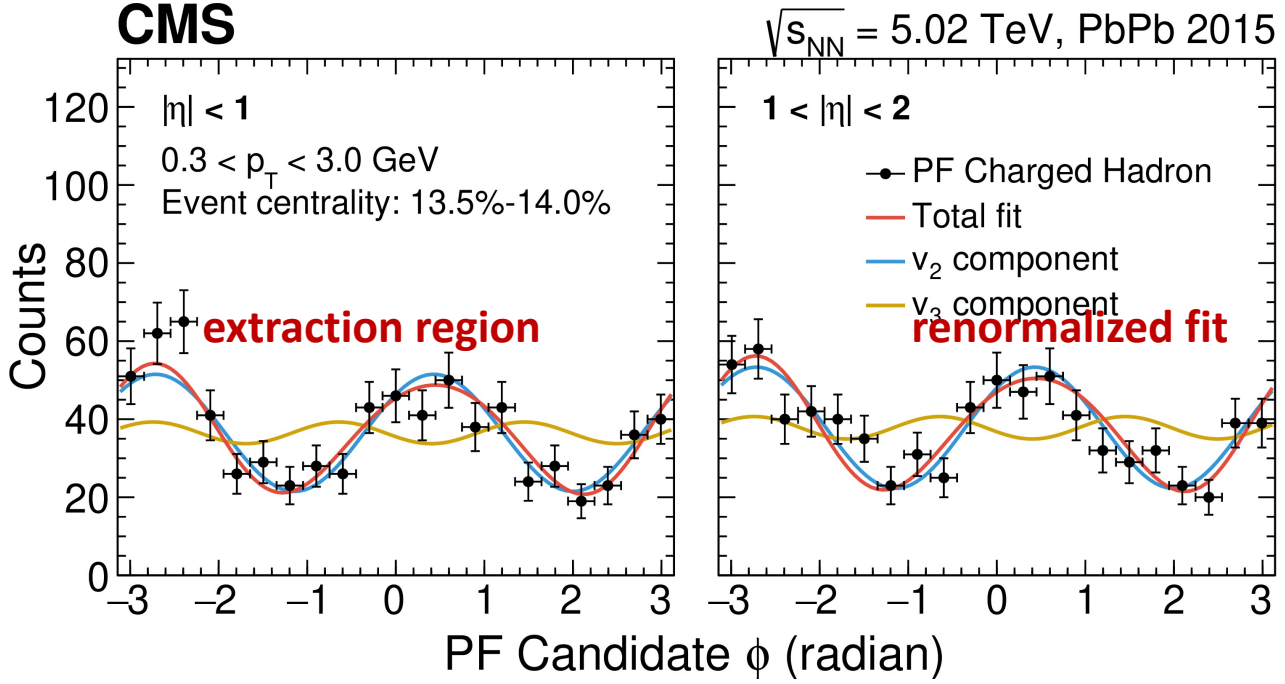
Use **constituent subtraction** with **flow-modulated ρ** to account for underlying event fluctuations from elliptic and triangular flow (v_2 and v_3):

JHEP06 (2014) 092

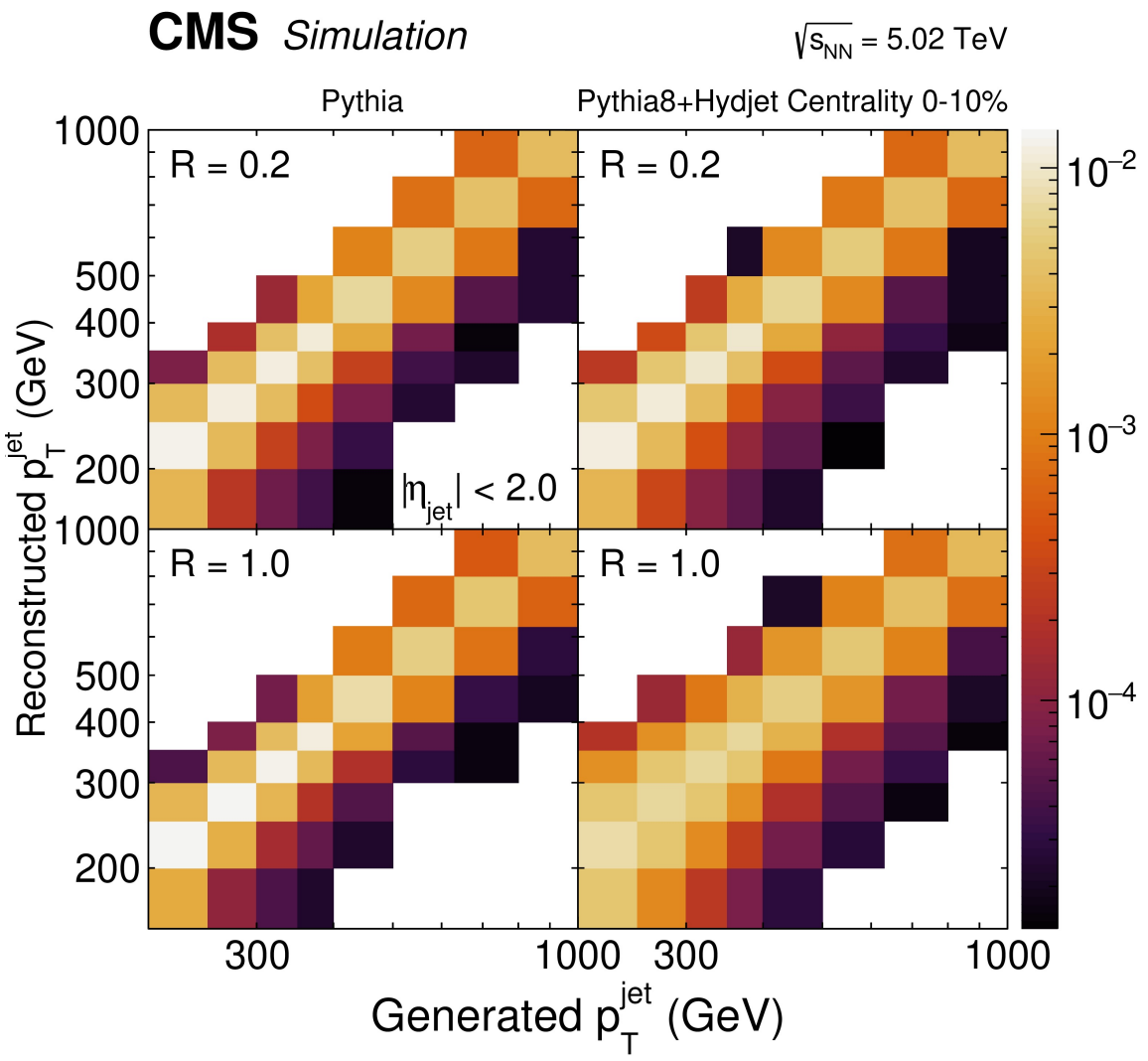
Phys. Lett. B 753 (2016) 424

$$\rho(\eta,\phi) = \rho(\eta)\times(1 + 2v_2\cos(2[\phi - \Phi_{EP,2}]) + 2v_3\cos(3[\phi - \Phi_{EP,3}]))$$





Response Matrices



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Jet Scale and Resolution

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$$\mu = \langle p_T^{reconstructed} / p_R^{truth} \rangle$$

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