European Research Council
Established by the European Commission

SAPIENZA
UNIVERSITÀ DI ROMA

Highlights: Jets and jet substructure

Leticia Cunqueiro

HP2024
NAGASAKI

Outline

Currently, two main languages for looking inside jets: EEC and Lund Plane

*Big effort on experimental techniques: multidimensional unfolding, background subtraction
*Better understanding of detector and model-dependency limitations

Measurements in pp:

*Precision physics (α_S extraction), constraint on first-principle pen-and-paper calculations

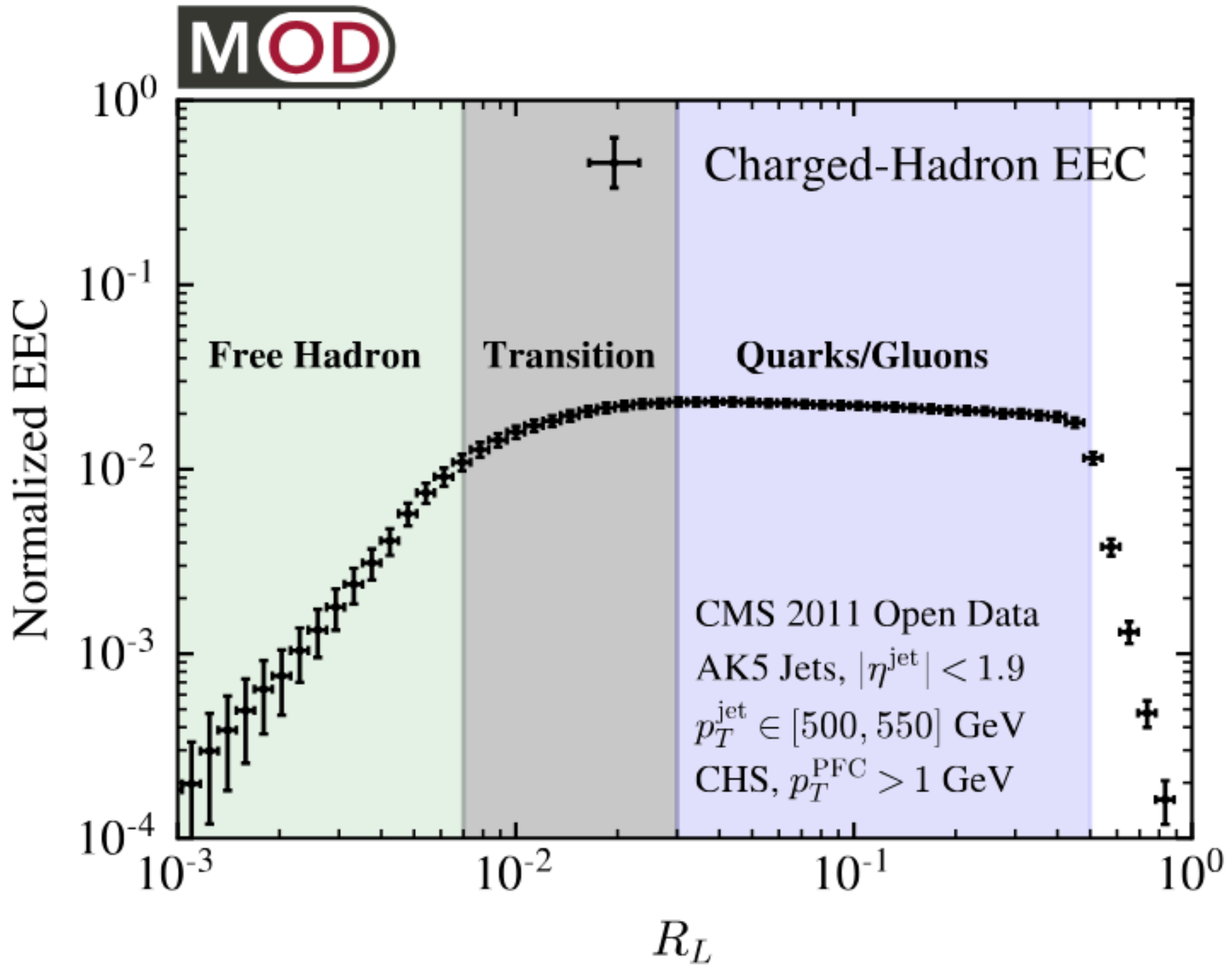
*Expose the Q->Qg splitting. First evidence of quark mass sensitivity for D-jet and b-jets for high-p_T jets via the suppression of collinear emissions

Measurements in PbPb:

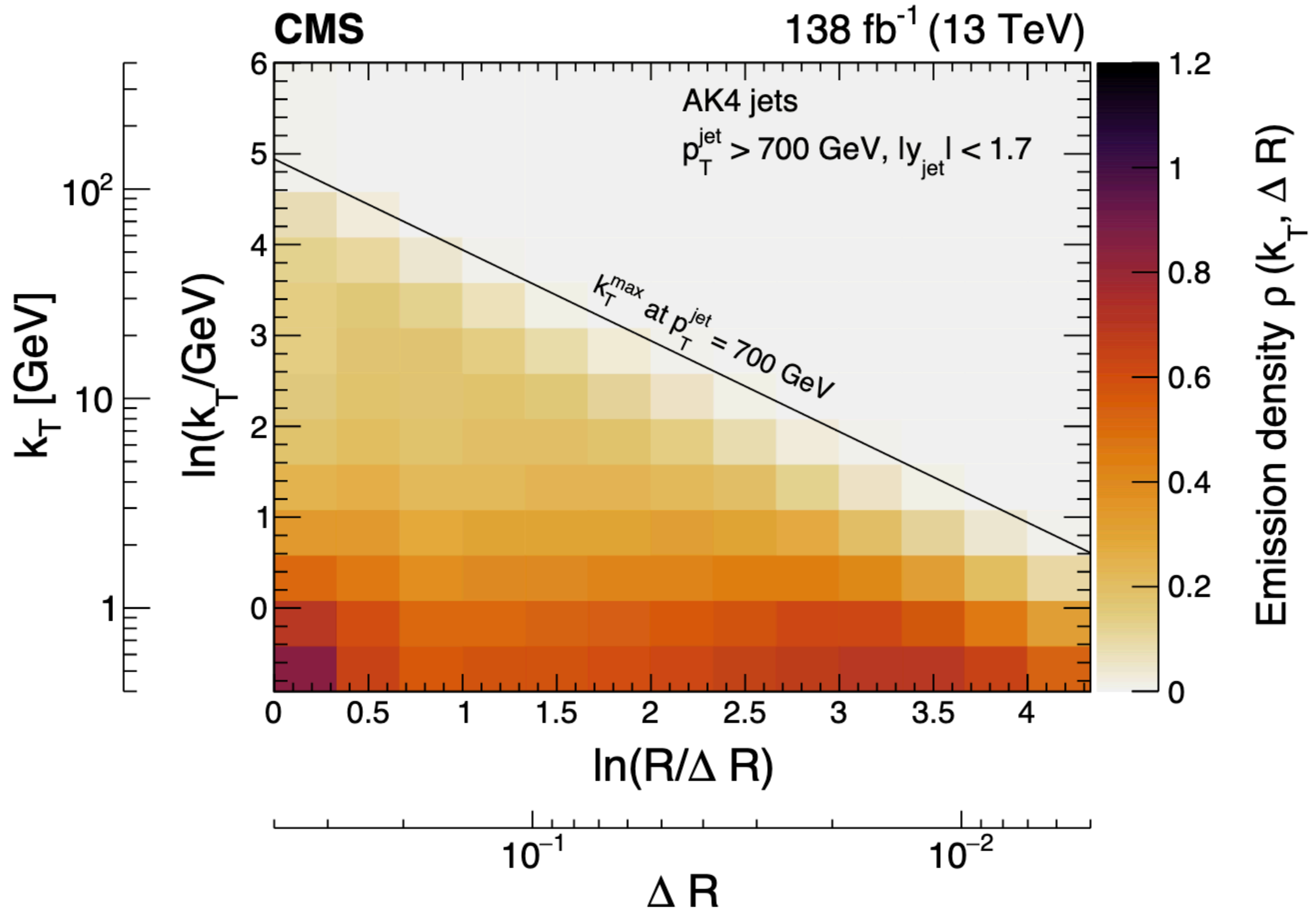
* Medium-induced radiation not yet characterized
* No yet unambiguous evidence of color coherence and θ_C
* Selection bias understood, clear path forward
* Medium response experimentally isolated: chance to improve the modeling

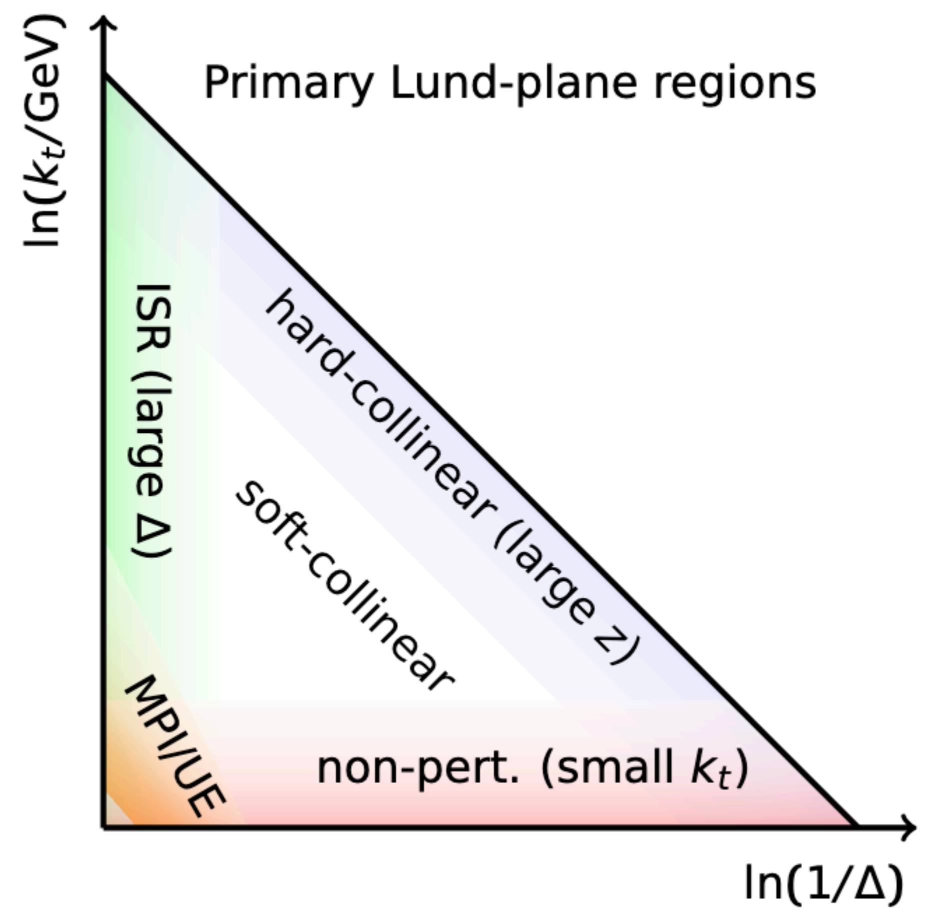
HP2024: Two languages for jet substructure

Energy Energy Correlators



The Lund jet plane





EEC: p_T-weighted particle correlations
Lund jet Plane: proxy for parton shower via Cambridge-Aachen declustering

Separation large angle/small angle and soft/hard modes
Calculable in pp

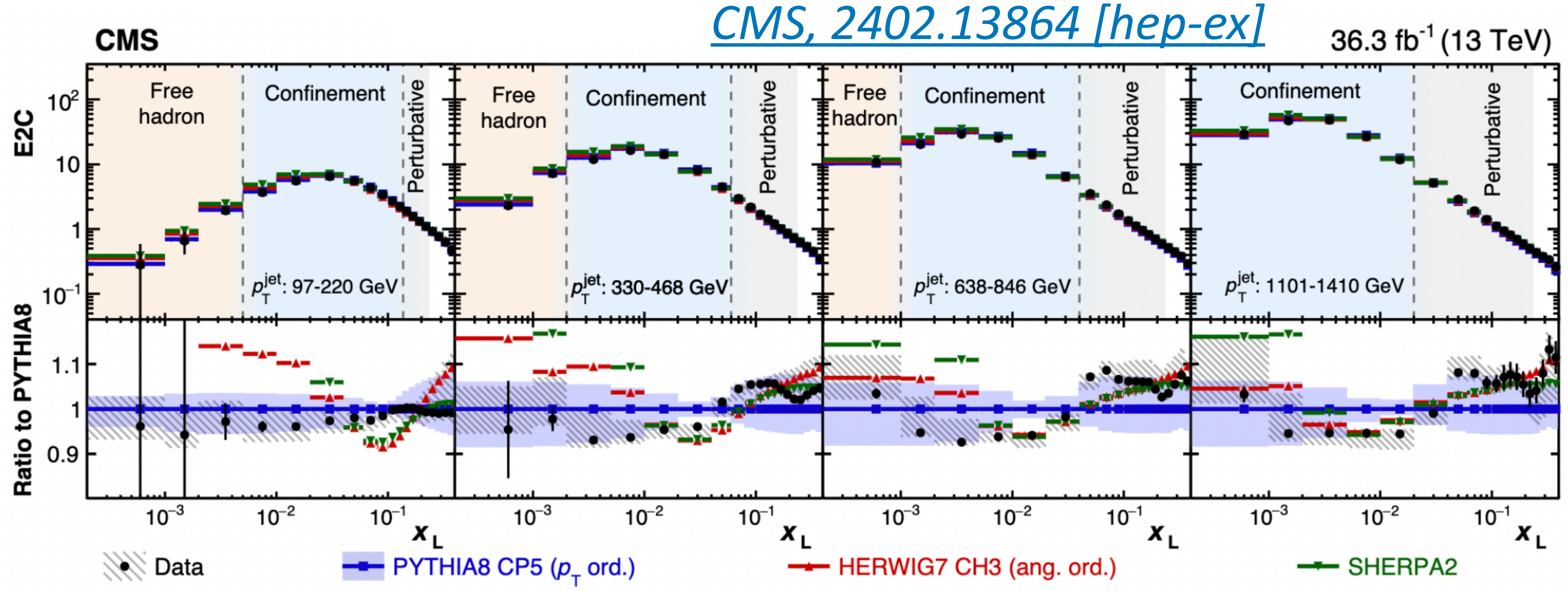
Two languages for jet substructure

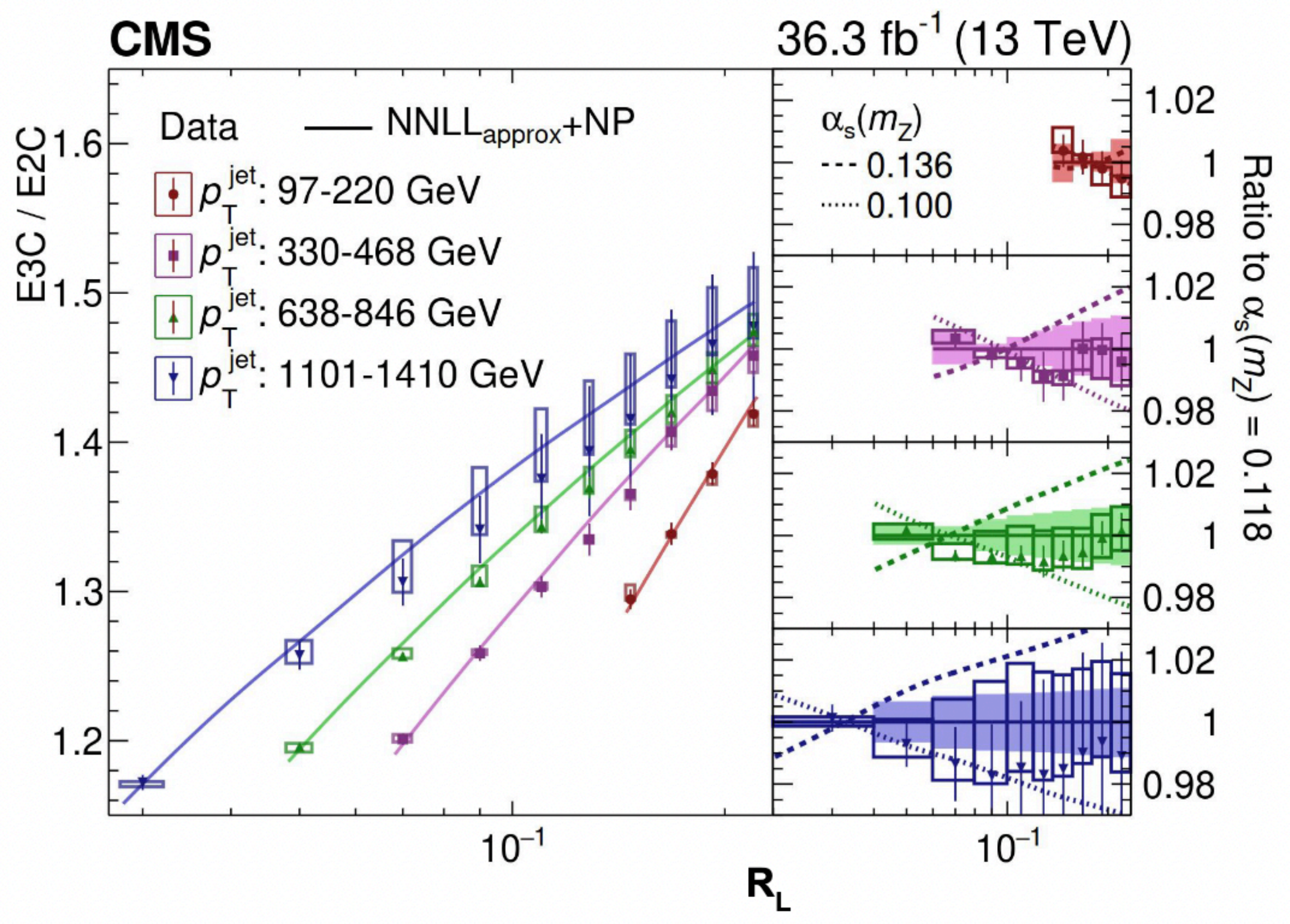
Systematics cancel out in the ratio E3C to E2C

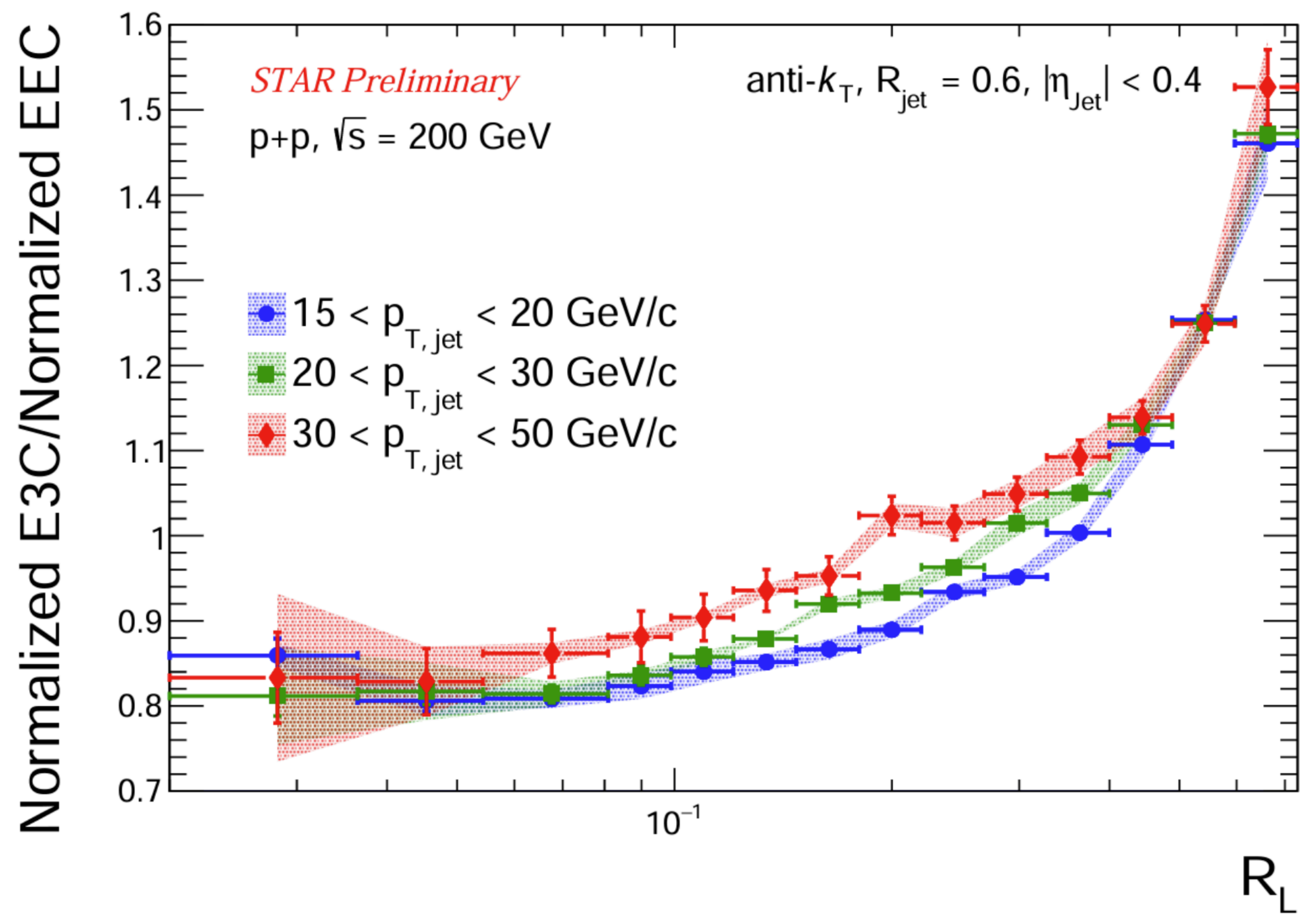
Ratio in the perturbative region proportional to α_S

Comparisons to NLO+ NNLL +NP allow for the most precise value of the strong coupling constant using jet substructure today

CMS, 2402.13864 [hep-ex]



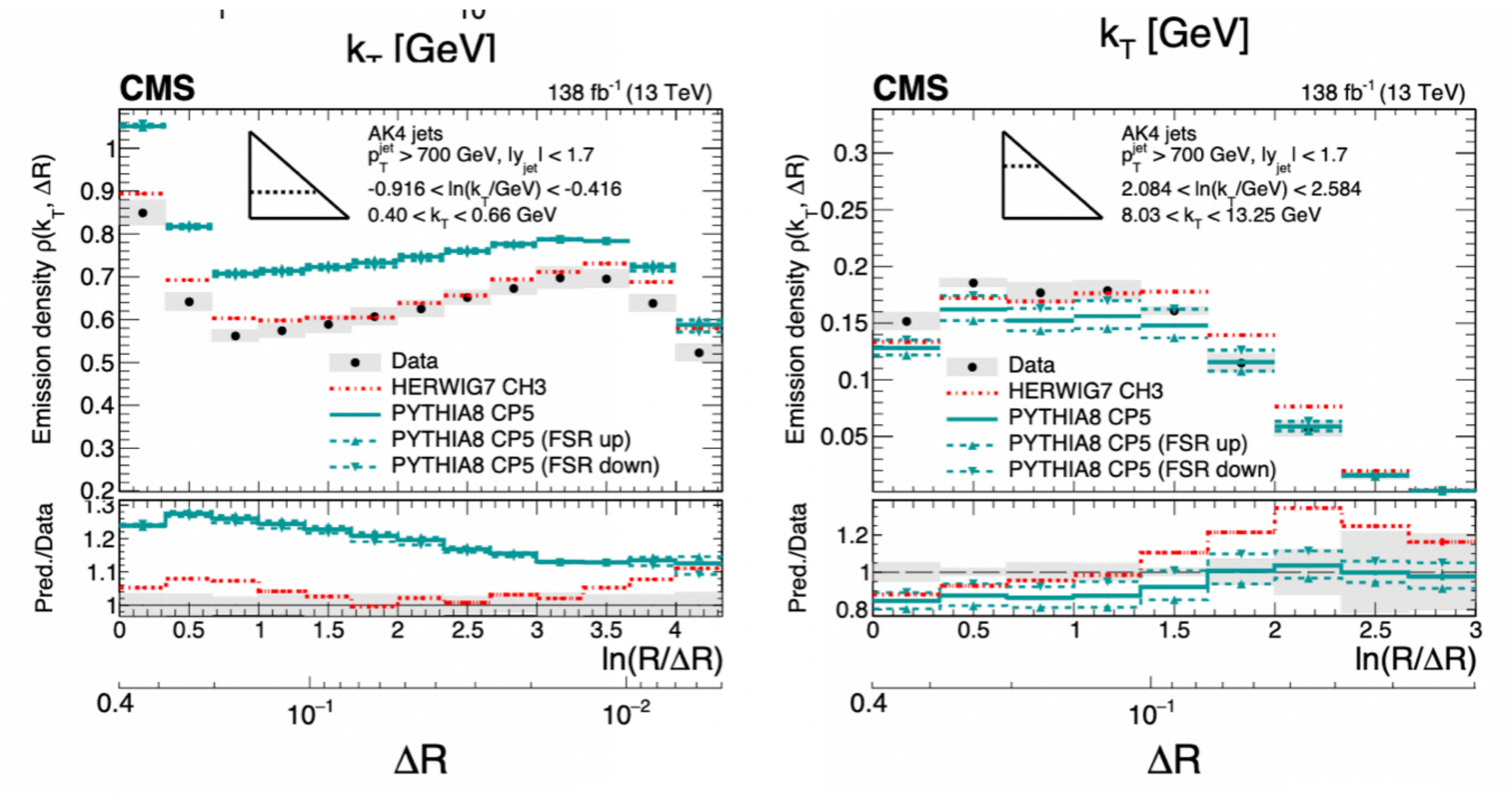




See talks by Andrew Tamis and Ananya Rai for α_S sensitive measurements at low jet momentum

Two languages for jet substructure

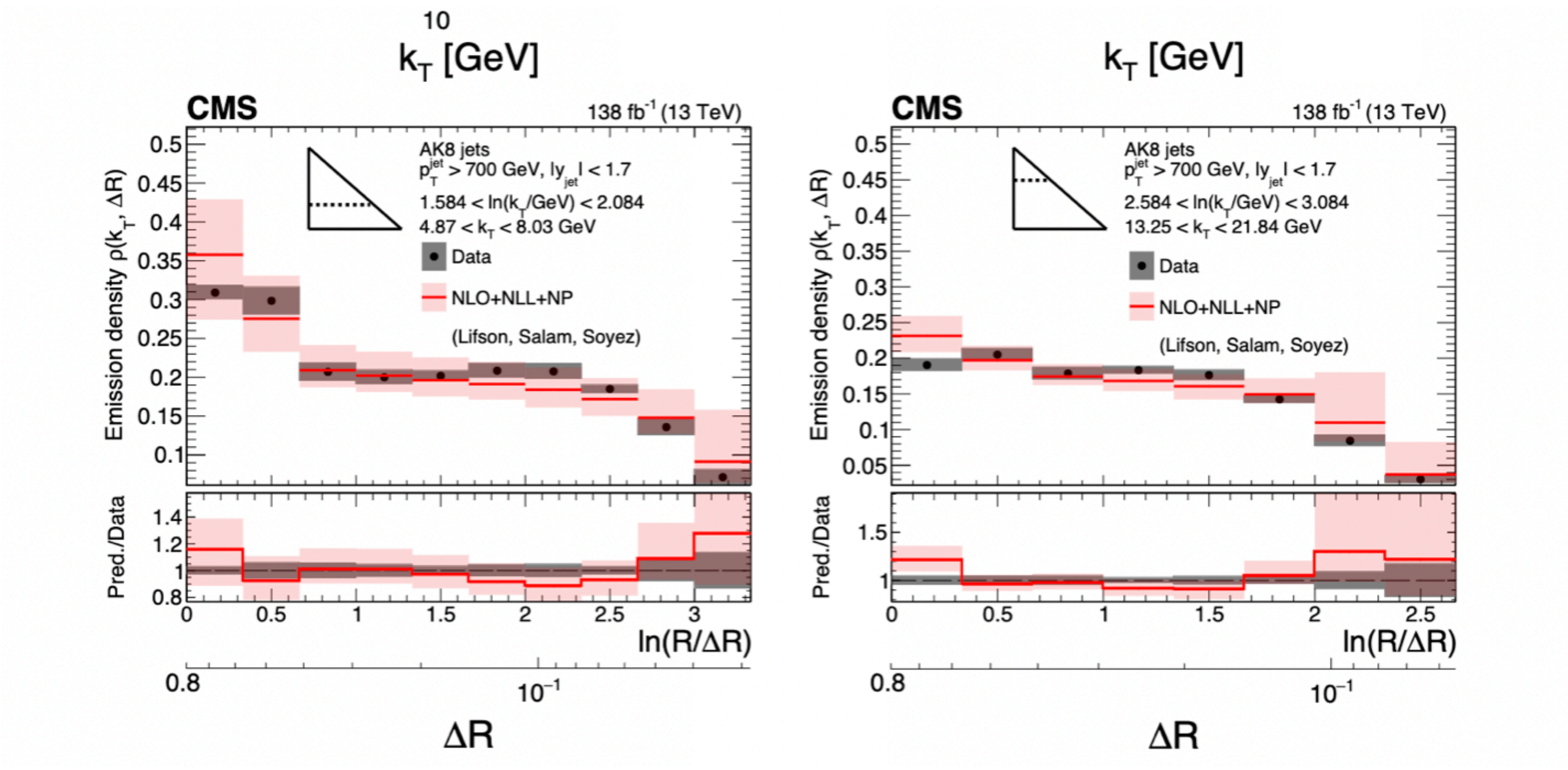
CMS, JHEP 05 (2024) 116



As an example, see comparison between Herwig7 CH3 and Pythia8 CP5 :

In the nonperturbative region, Pythia overestimates the number of emissions and Herwig describes better the data

In the perturbative region, sensitivity to FSR scale variations



Comparison to NLO+NLL+NP analytical calculations adapted from *Lifson et al, JHEP 10 (2020) 170*

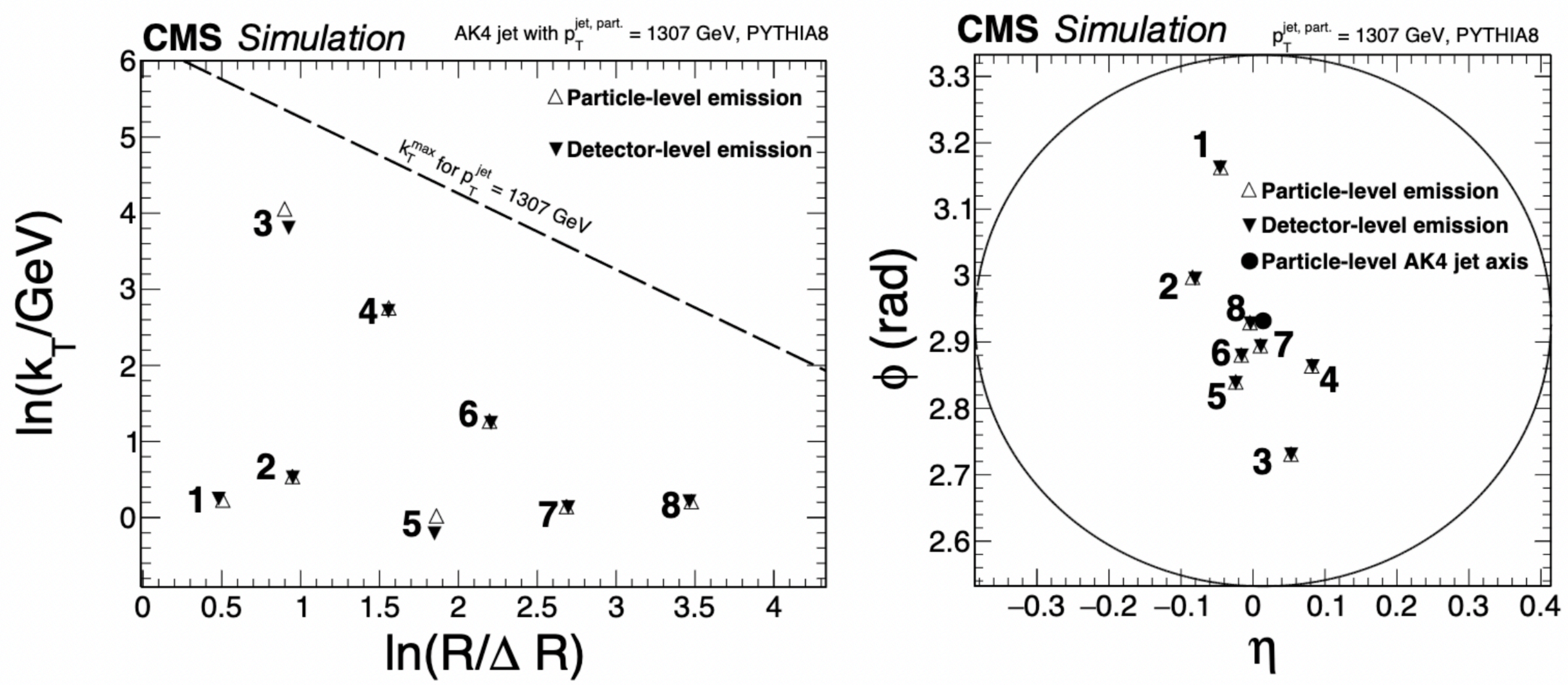
Predictions in agreement with the data within theoretical and experimental uncertainties

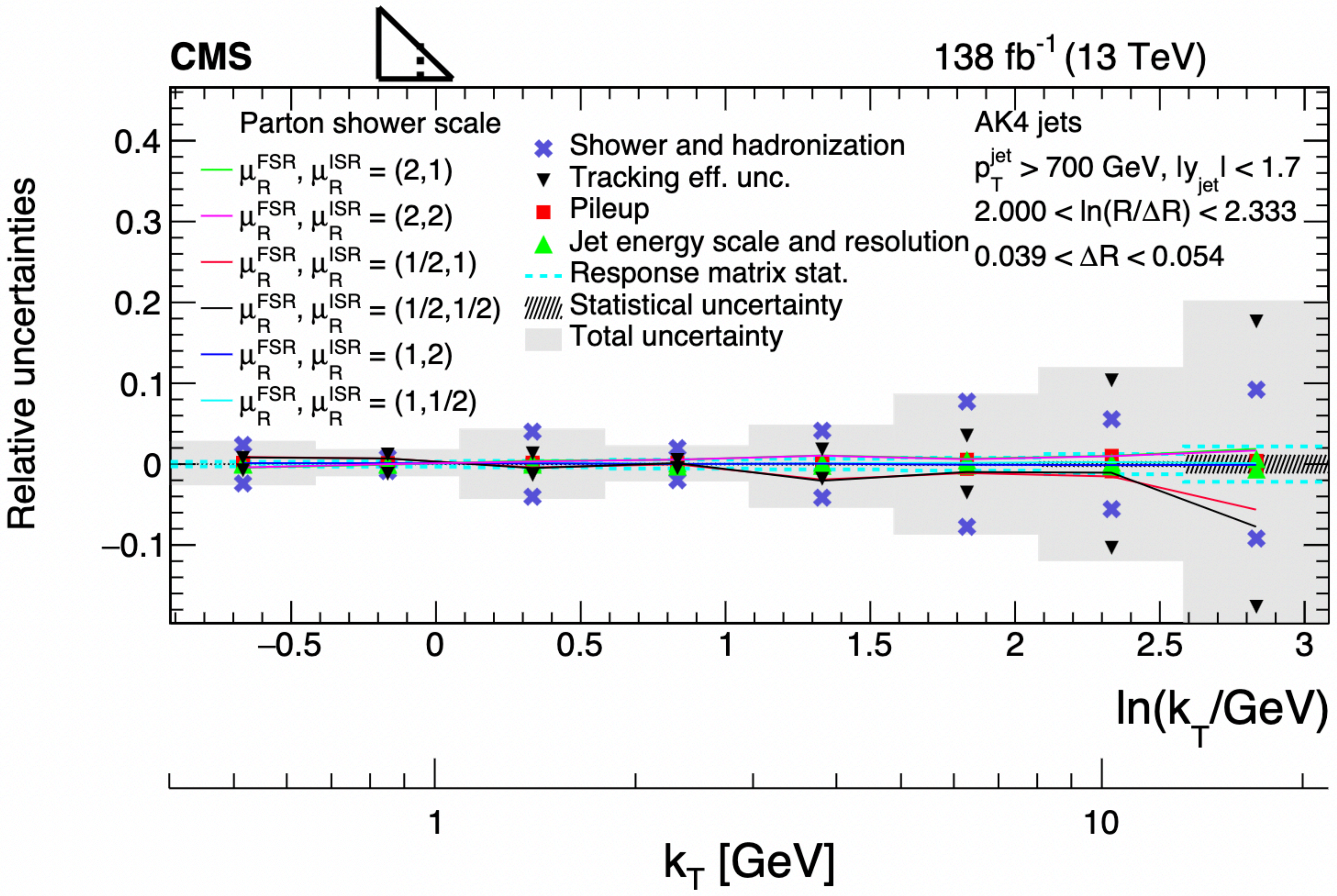
[CMS, JHEP 05 (2024) 116](https://doi.org/10.1007/JHEP05(2024)116)

Technical challenges: the Lund Jet Plane in pp

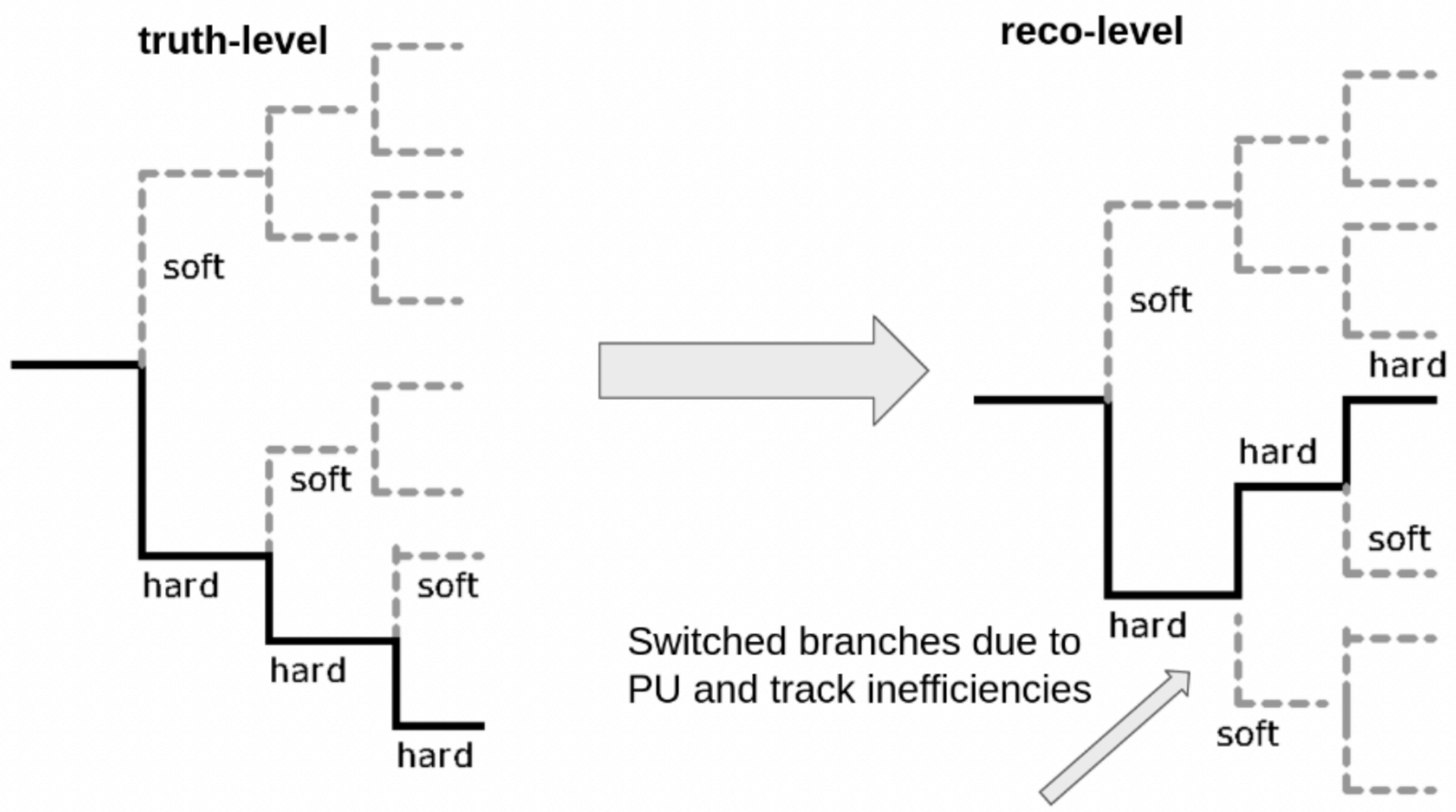
Vangelis Vladimirov

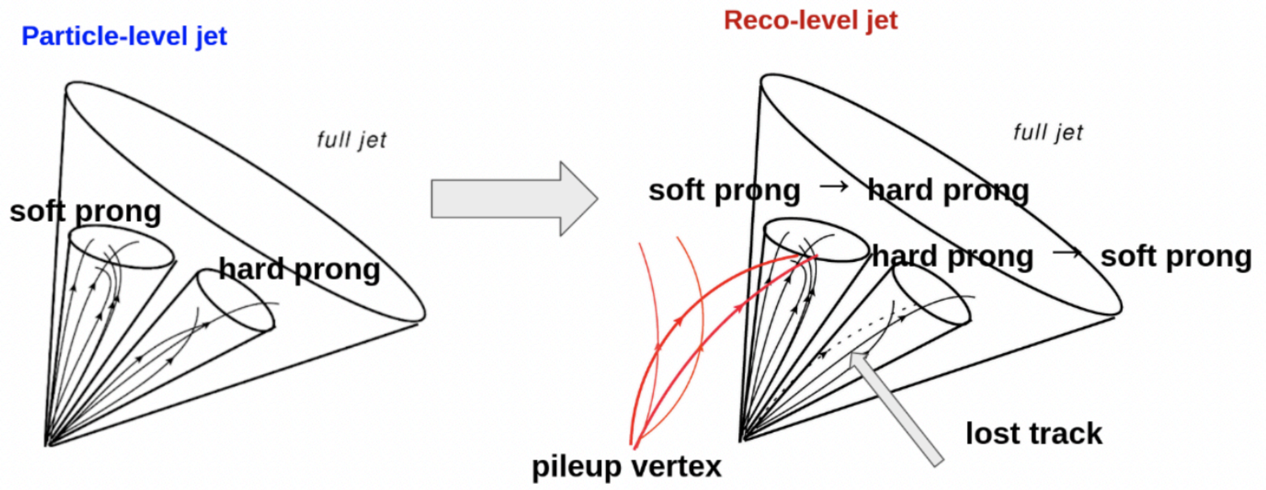
Flat geometrical matching of prongs





Residual mismatches, induce offdiagonalities in the response

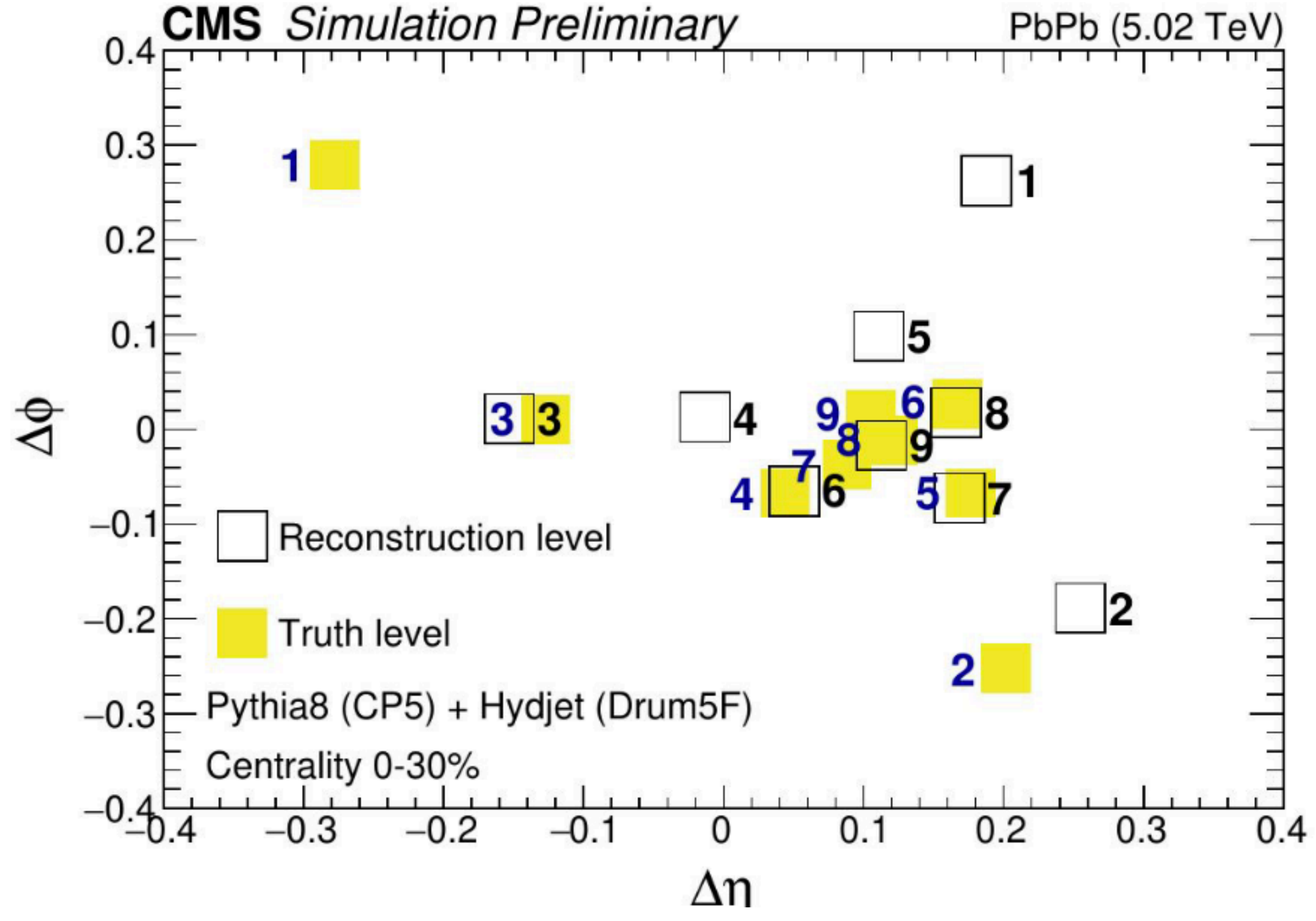


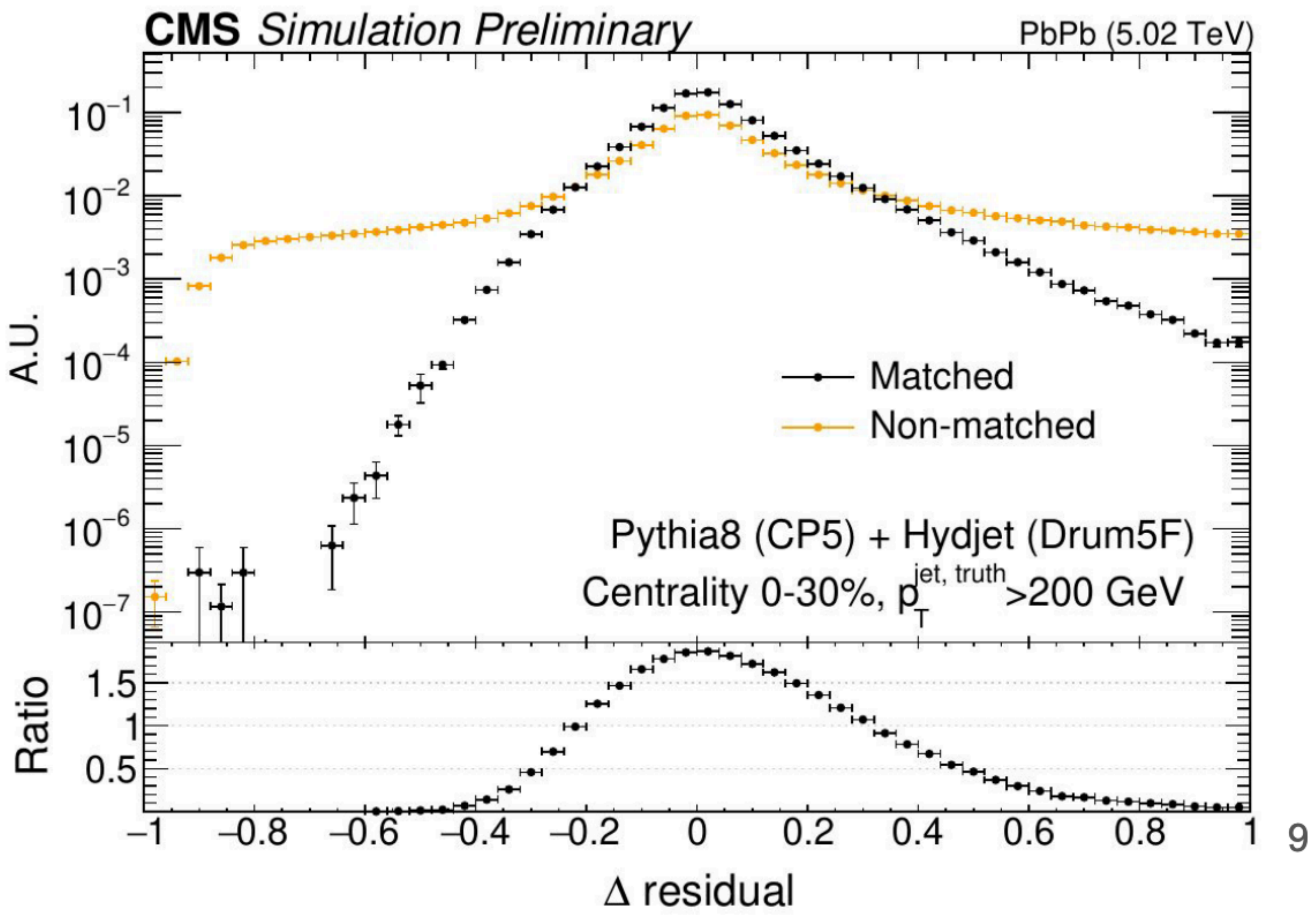


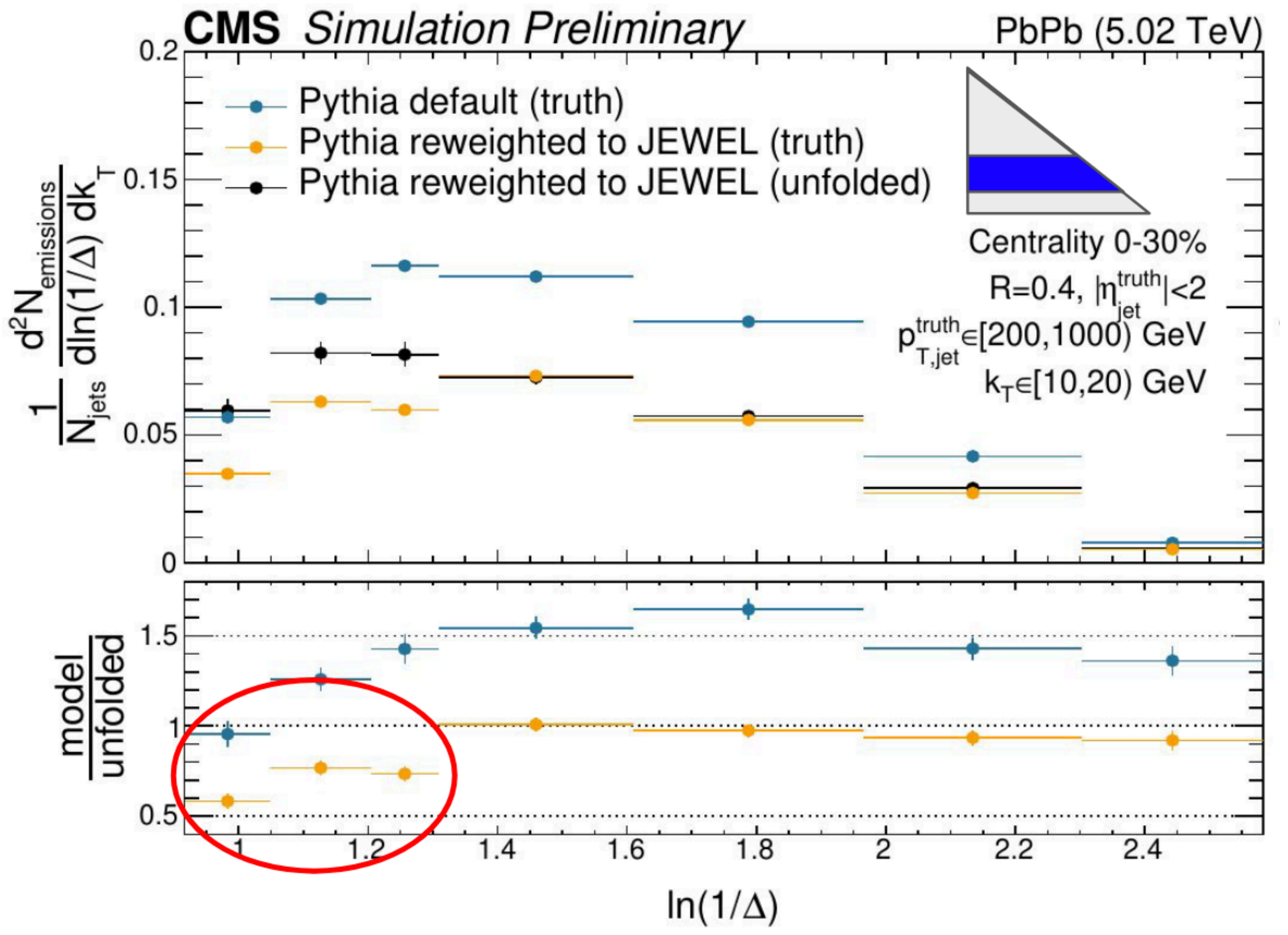
In the high k_T perturbative domain:
track. eff. uncert ~20%
model uncert ~10%

Technical challenges: The Lund Jet Plane in PbPb

Vangelis Vladimirov







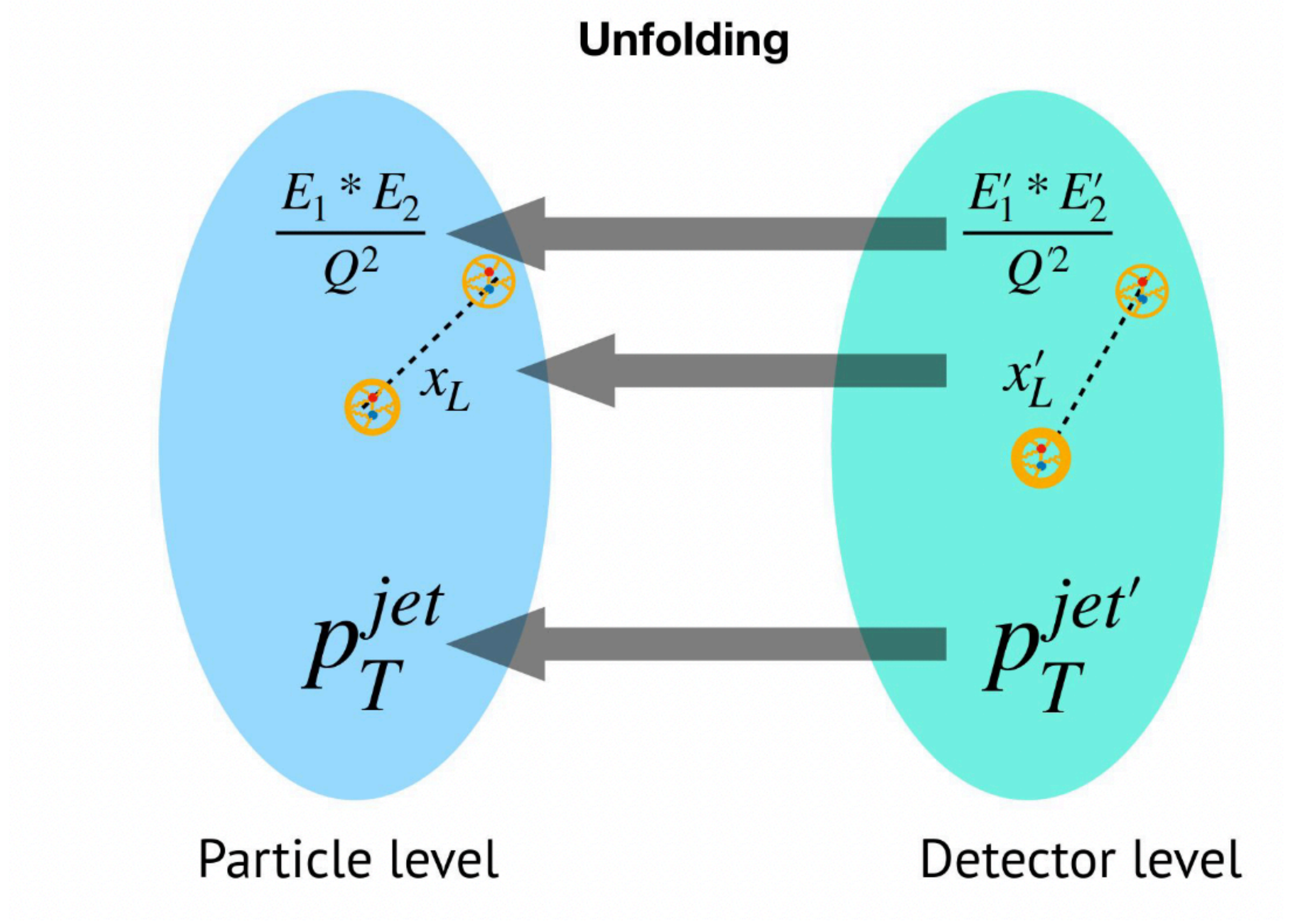
The mapping between detector and true level emissions gets strongly distorted by detector and underlying event background effects

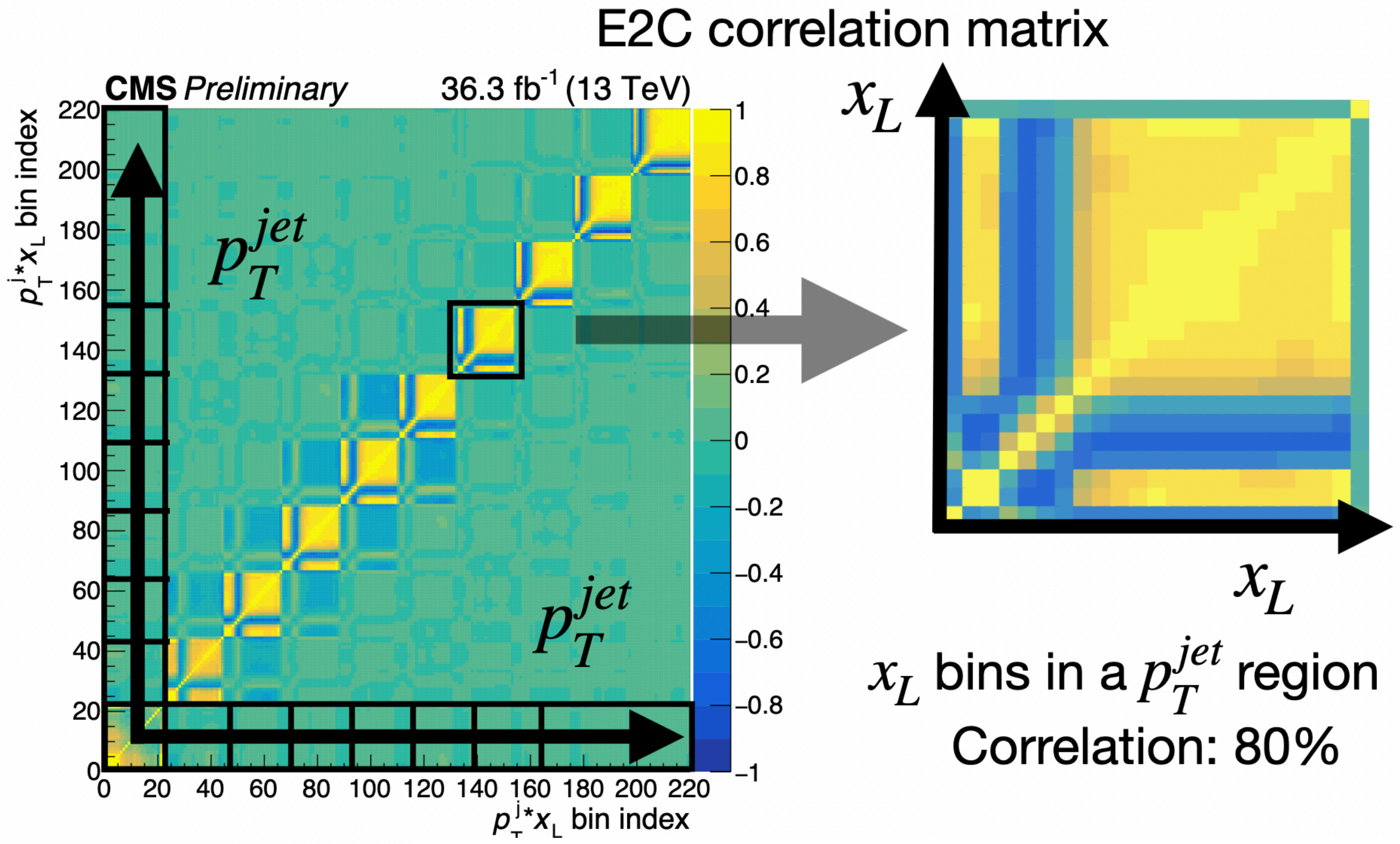
Splitting purity very low at low k_T and large angles

Strong prior dependence at low k_T and large angles

Technical challenges EEC

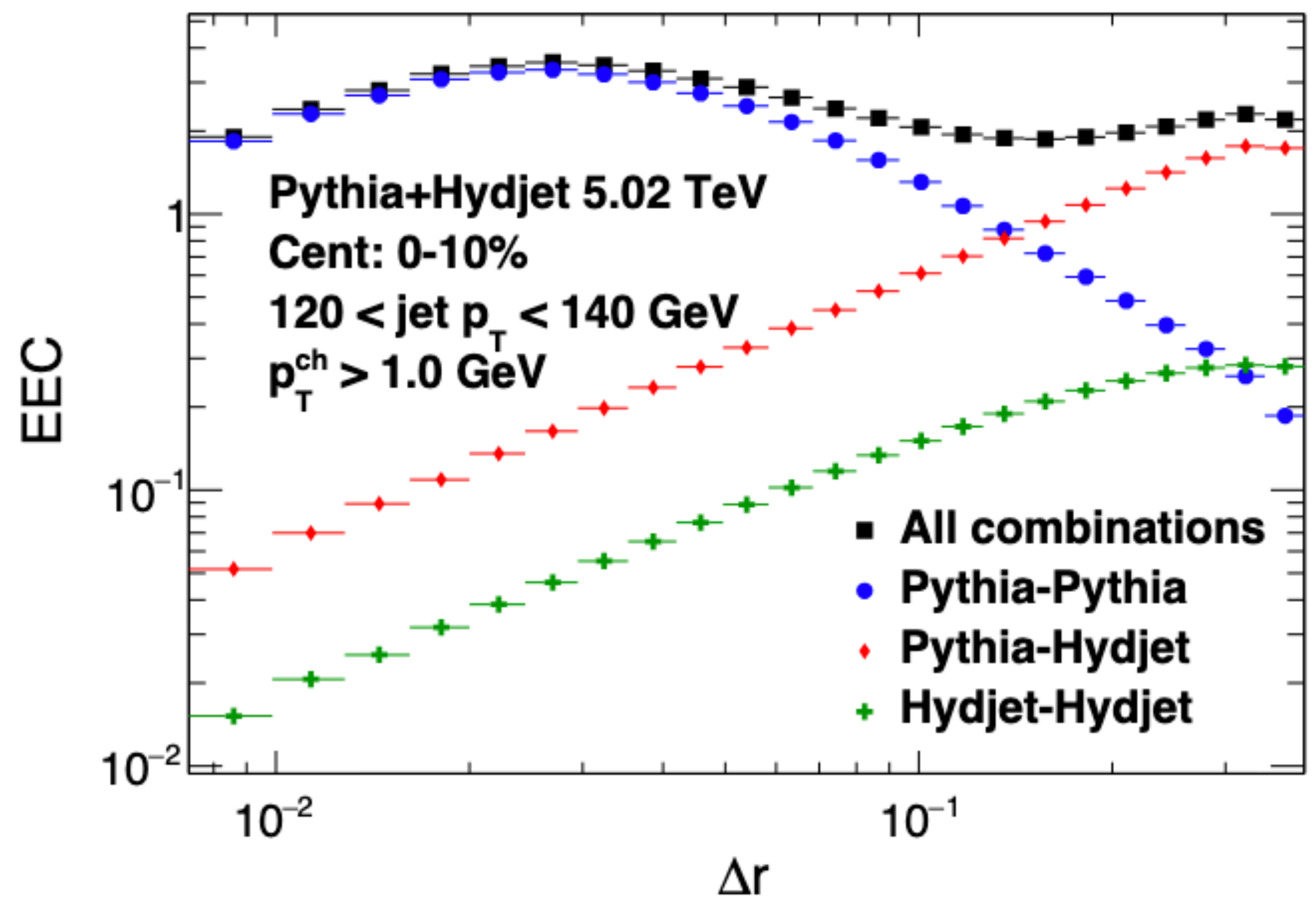
[CMS, 2402.13864 [hep-ex]](#)



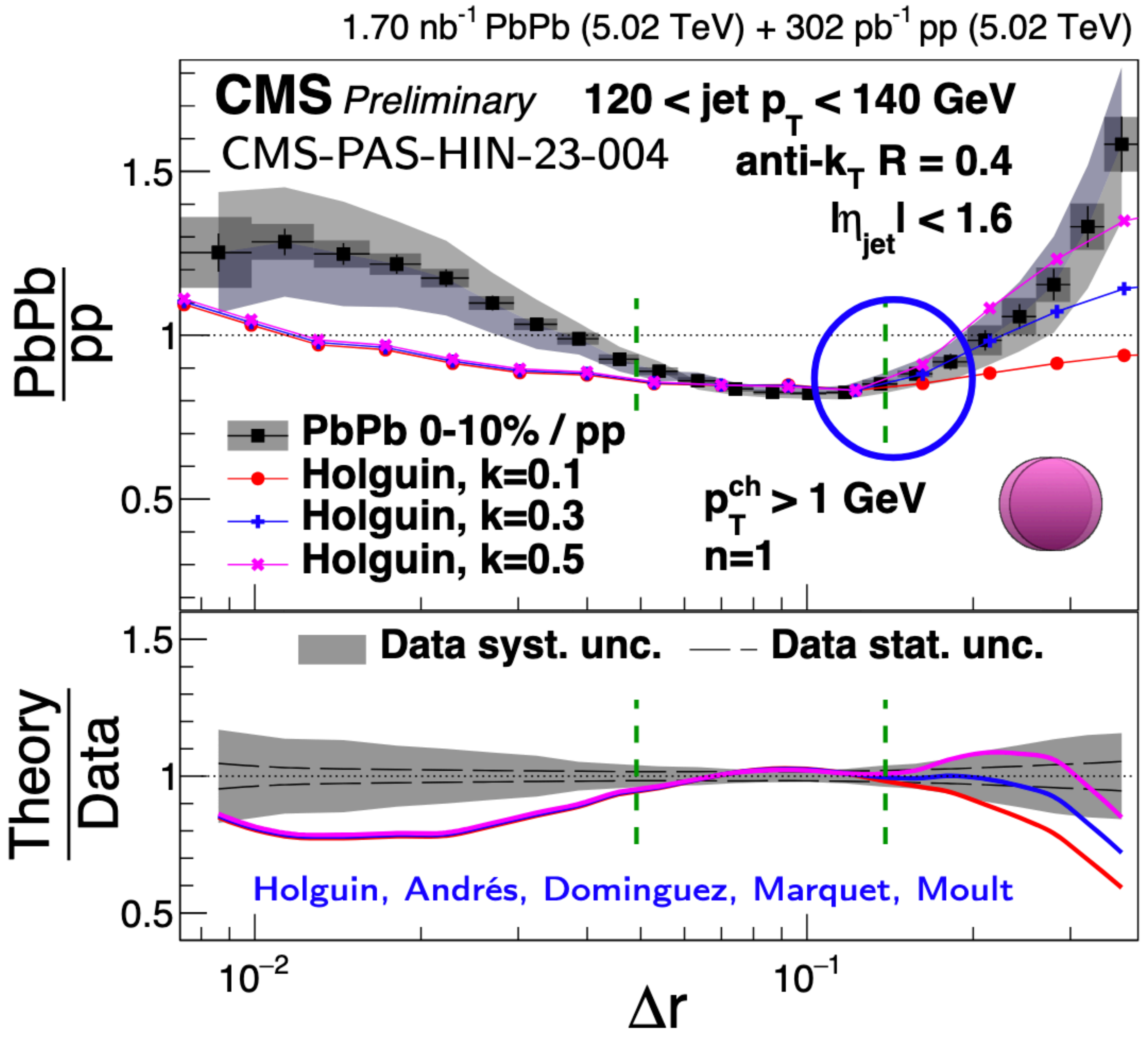


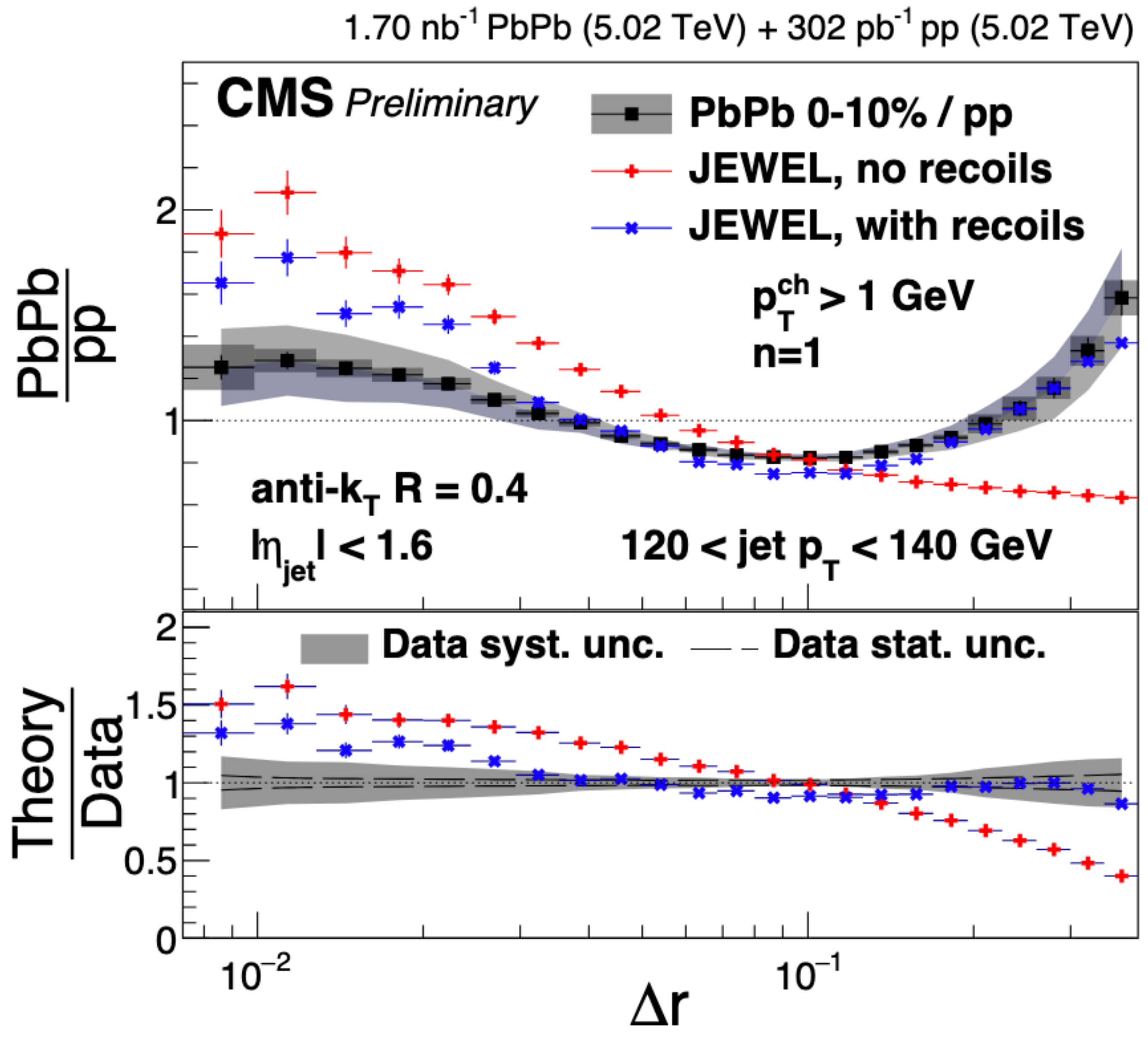
3-dimensional unfolding of jet p_T, x_L and weight (4400 bins)
Multi entry distribution for every jet, statistical correlations important

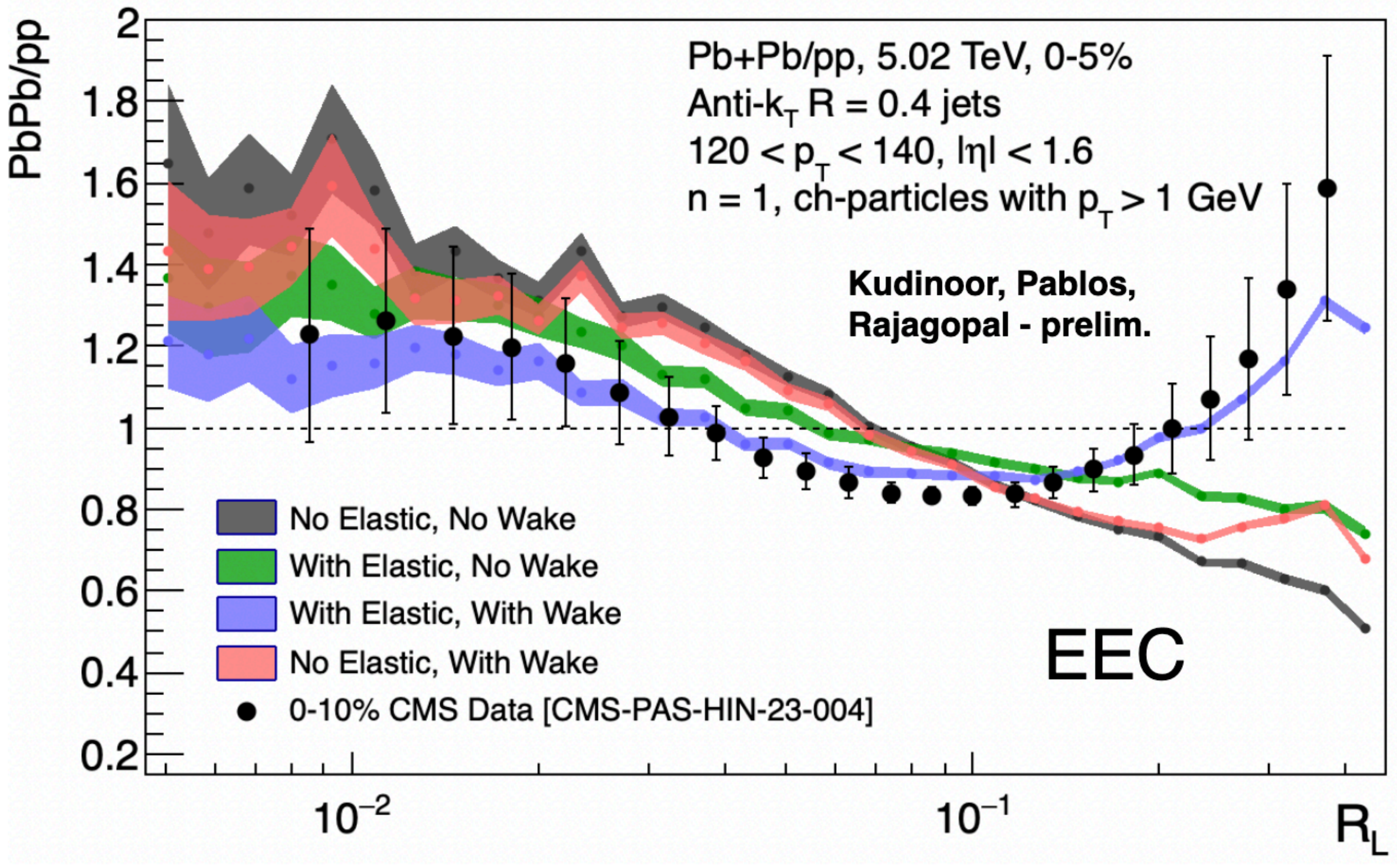
Subtraction of the different background components,
see *talks by Jussi Viinikainen and Andrew Tamis*



EEC in PbPb

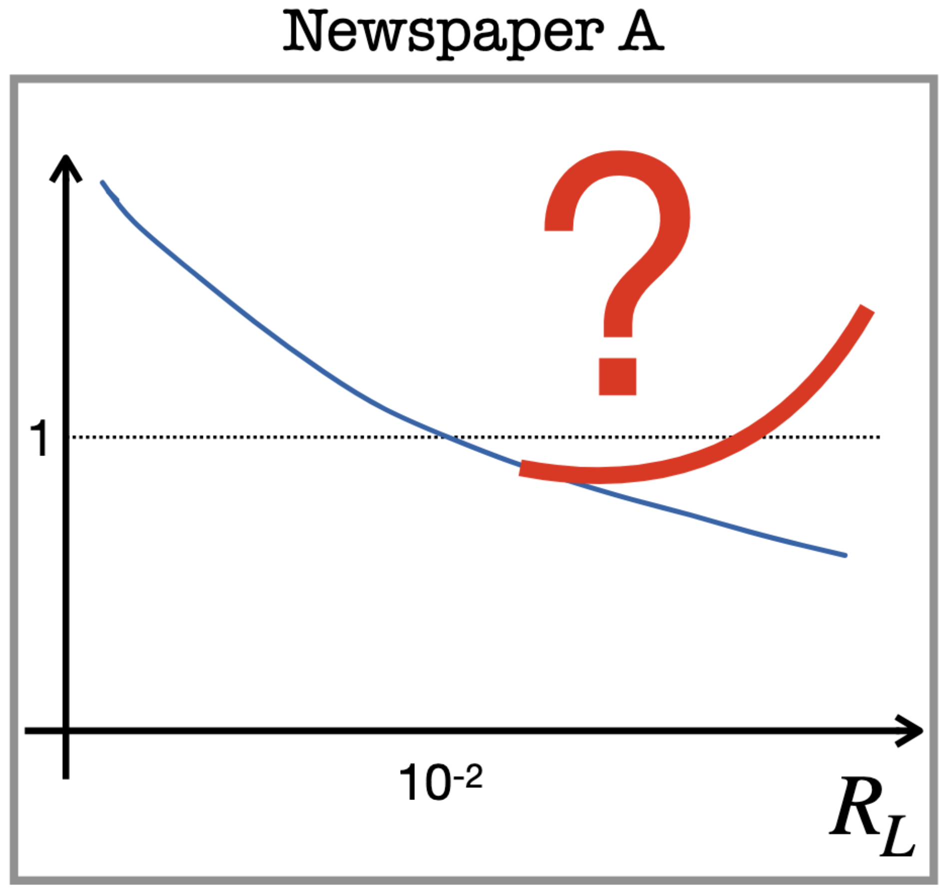






Several competing mechanisms contributing to large angles

Why not a small-R measurement to suppress the medium response?

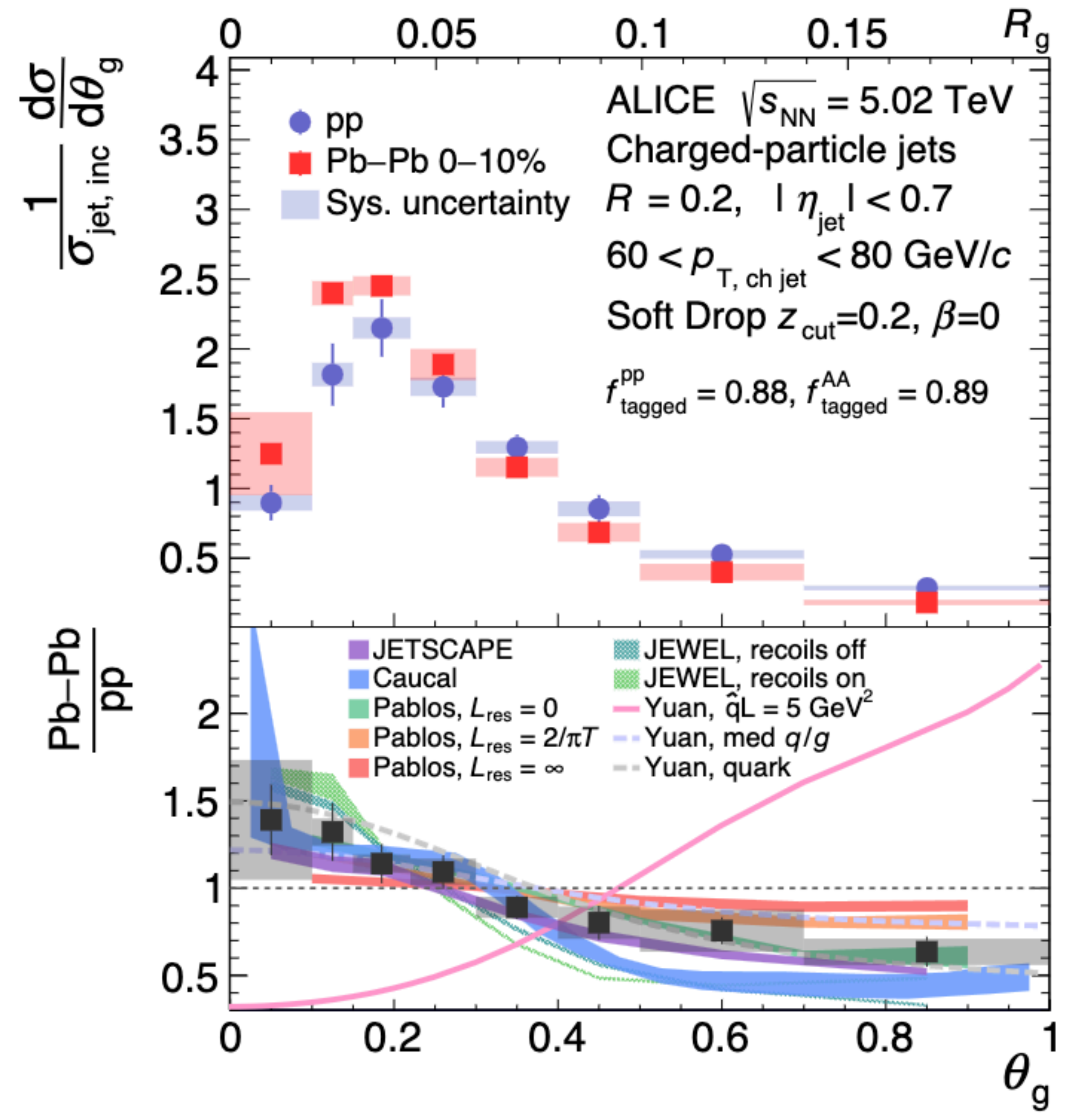


Alba Ontoso's newspaper: survivor bias+large angle enhancement

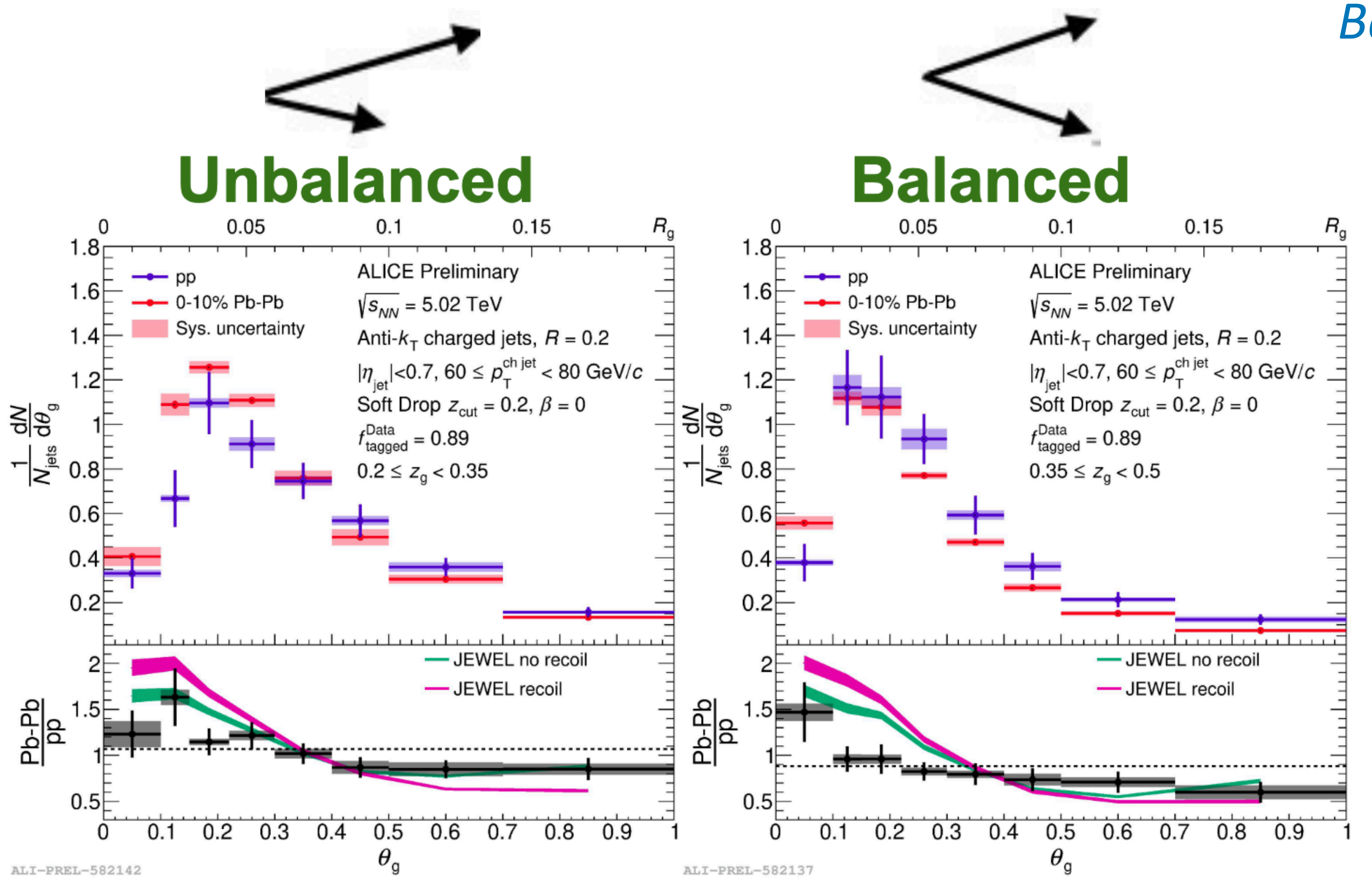
Observables related to the Lund Plane in PbPb

Bas Hofman

ALICE,Phys.Rev.Lett.128(2022)



previous measurement



current measurement

unfolded in 3D, can look at θ_g as function of z_g

Stronger narrowing for more balanced jets

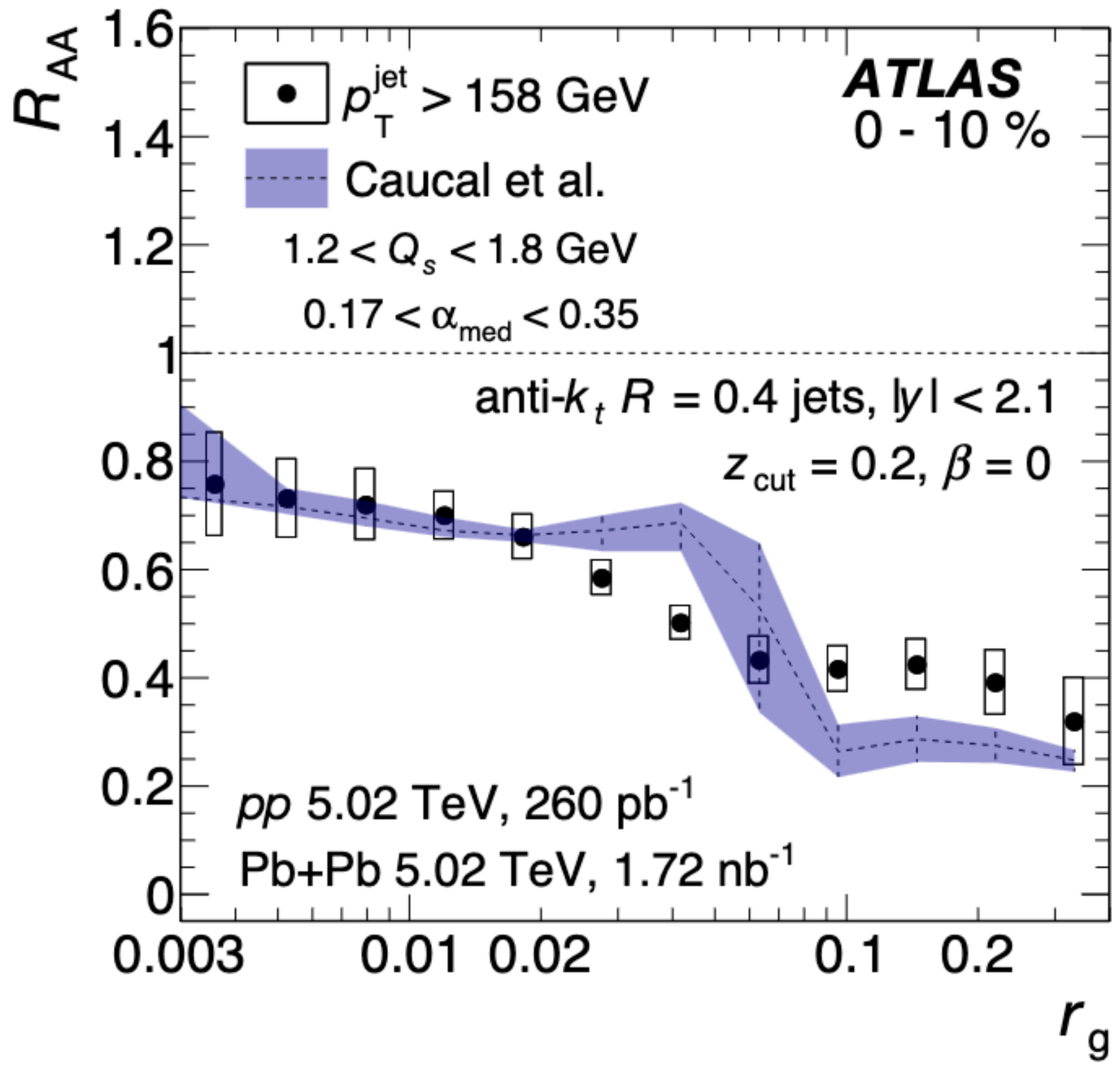
Probably jets with a broad and balanced splitting are more "active" jets, more strongly quenched

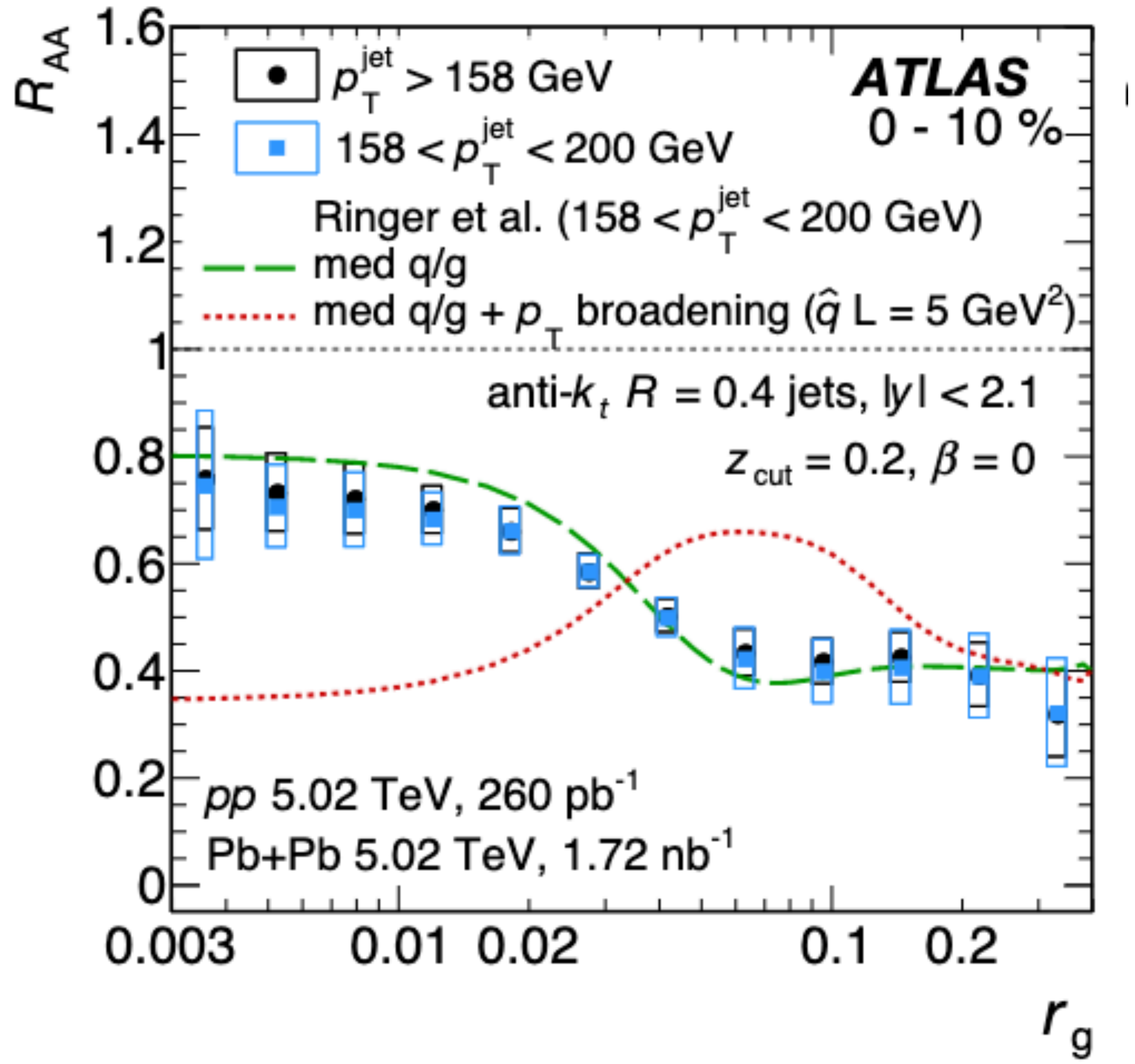
Sensitivity to different theoretical ingredients like color coherence but probably obscured by selection bias

Observables related to the Lund Plane in PbPb

Martin Rybar

ATLAS, Phys. Rev. C 107 (2023) 054909

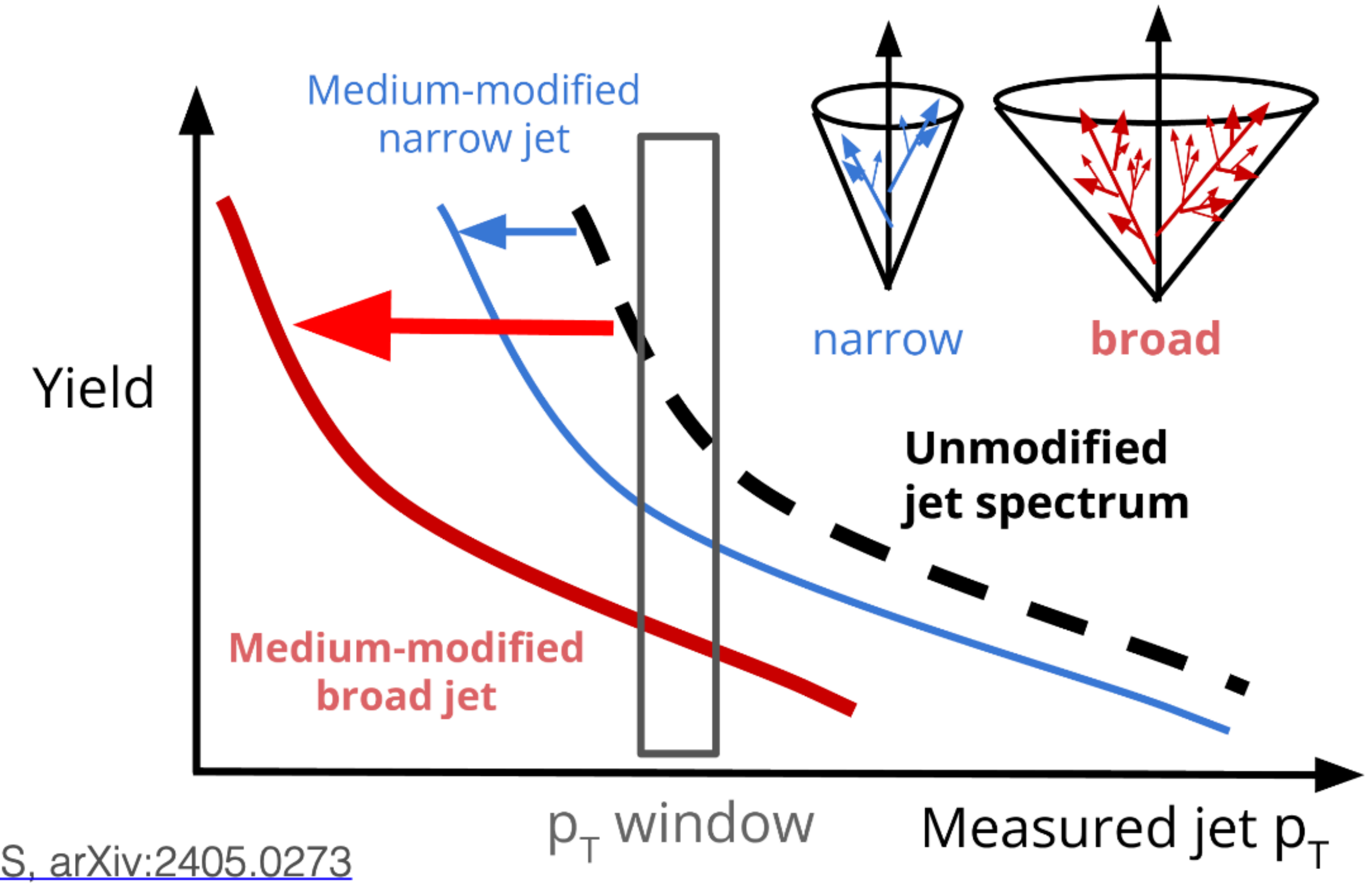




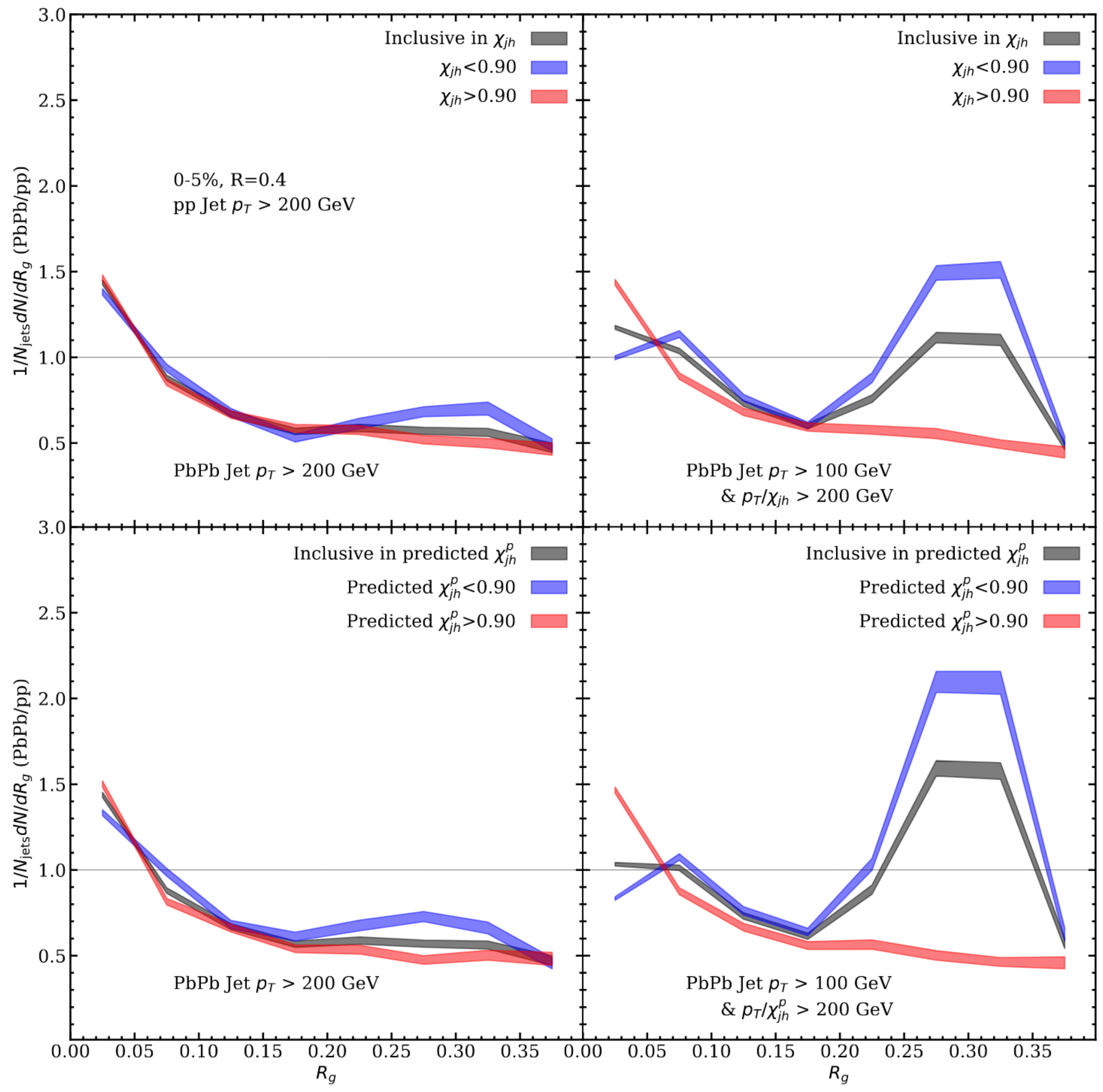
An intriguing step behaviour around the coherence angle in the implementation of Caucal et al
But step function also present in a model with no explicit implementation of coherence angle

Matthew Nguyen

The selection bias



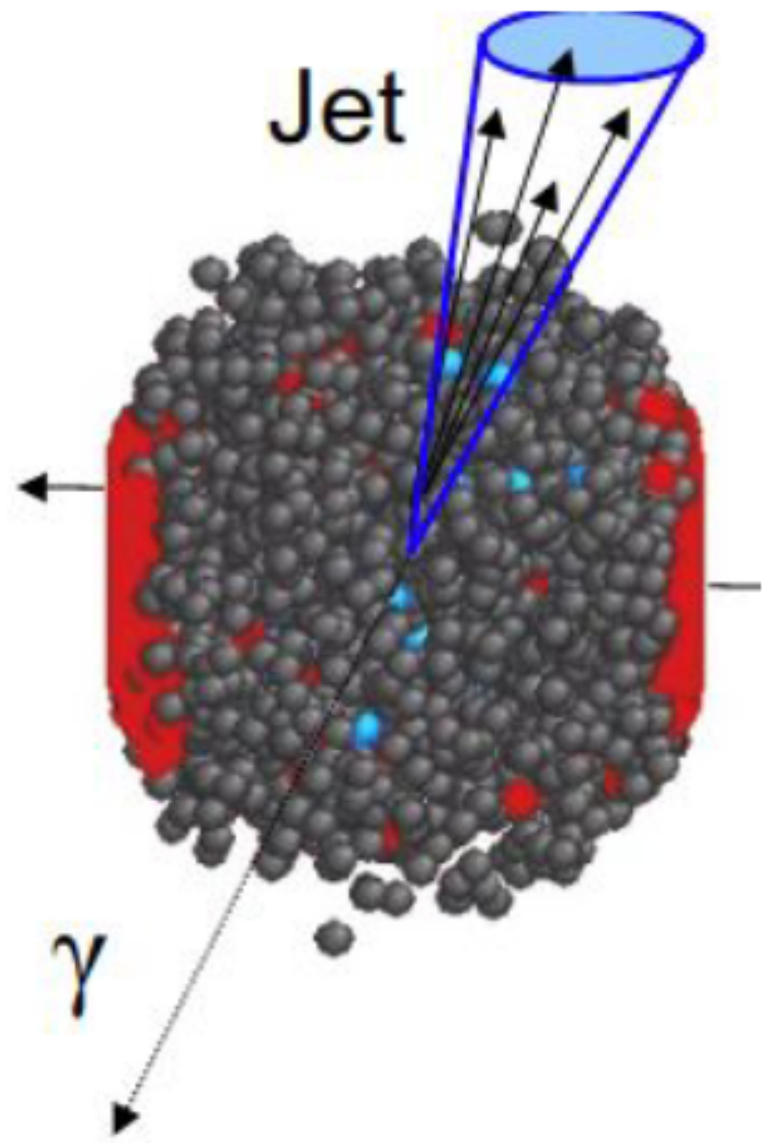
CMS, arXiv:2405.0273



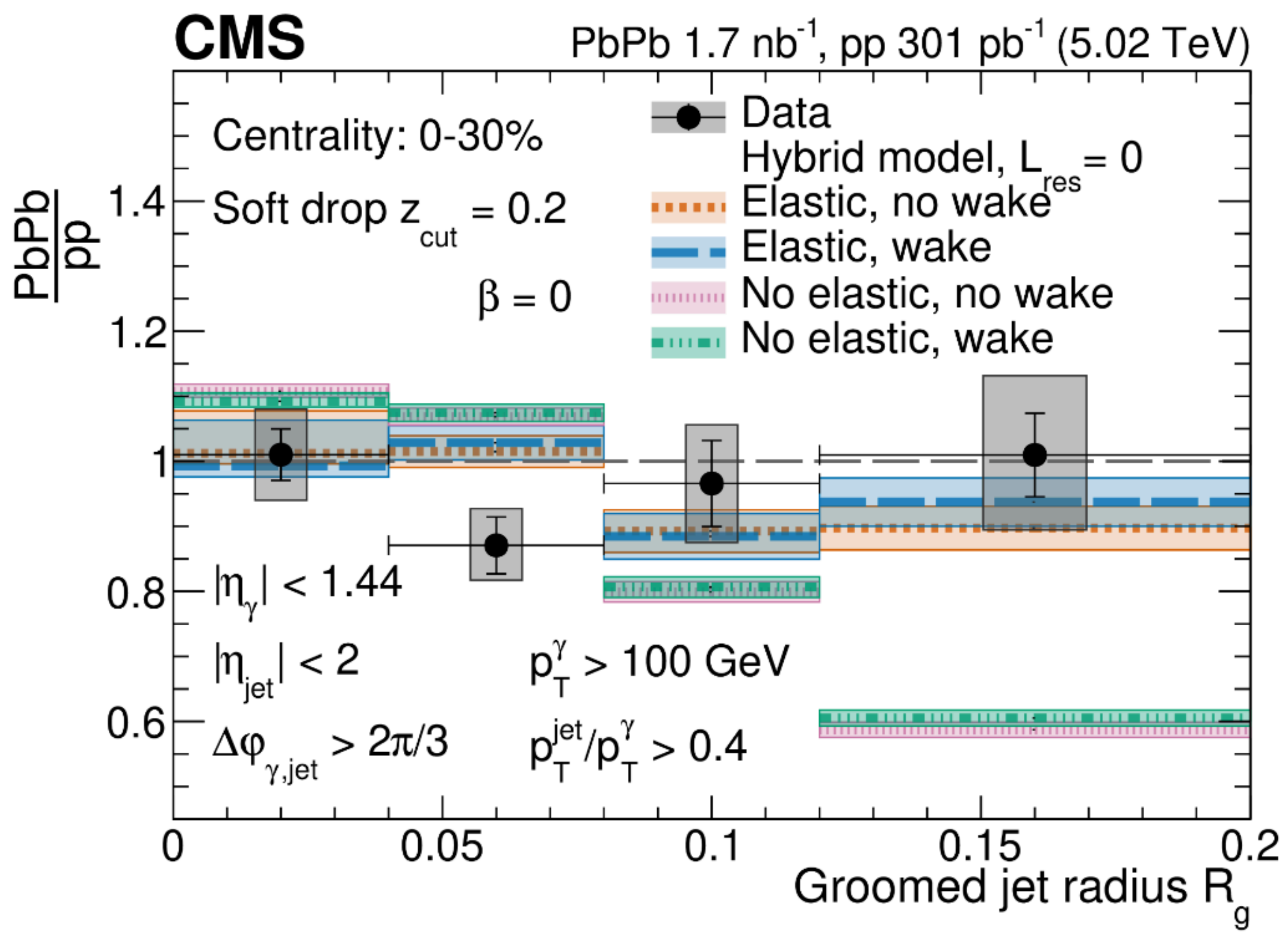
Du et al, 2106.11271, Brewer et al, 2009.03316

The selection bias

Matthew Nguyen

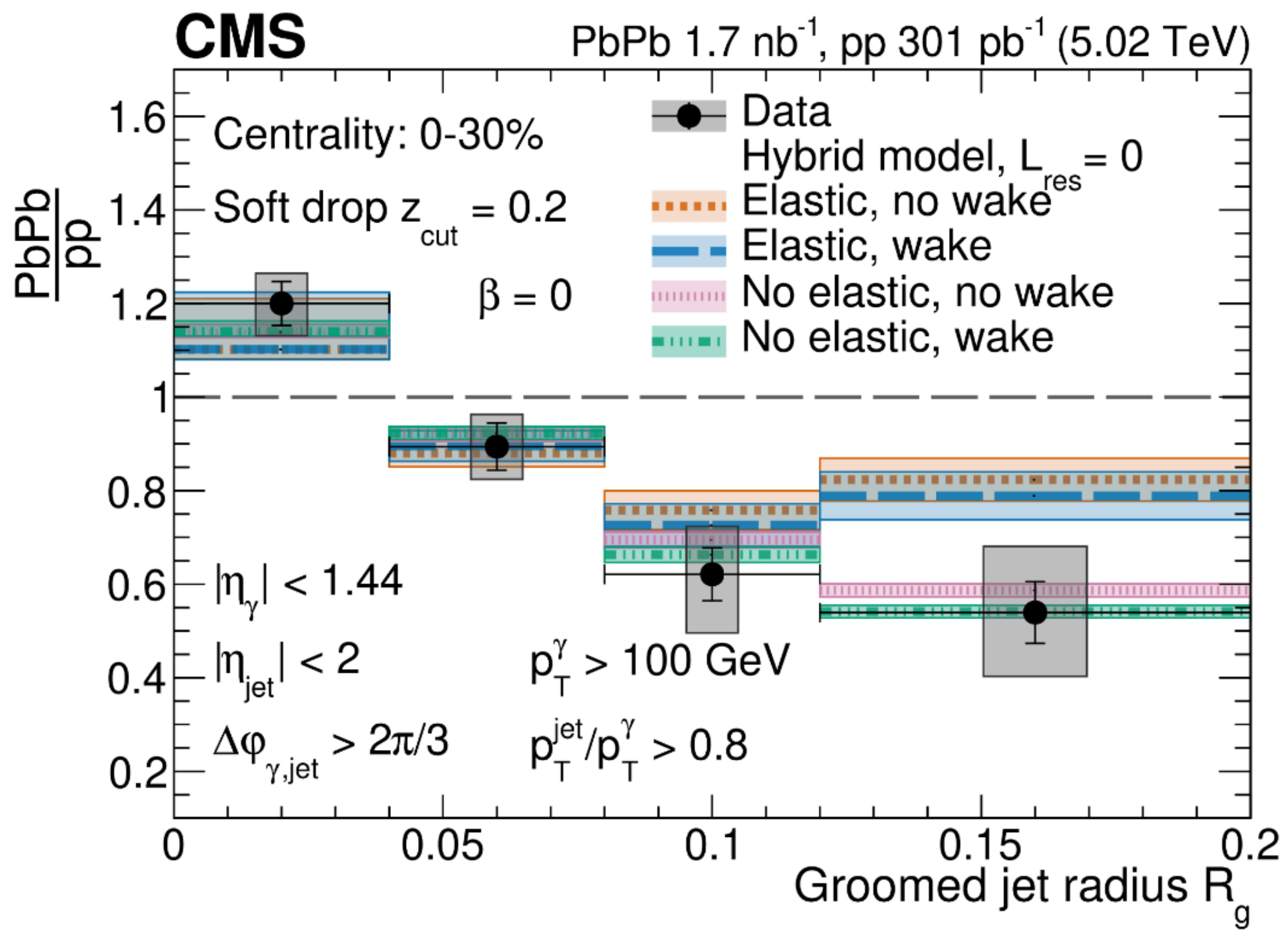


$x_{\gamma j}$ > 0.4 (w/ quenched jets):
no narrowing observed



CMS, arXiv:2405.0273

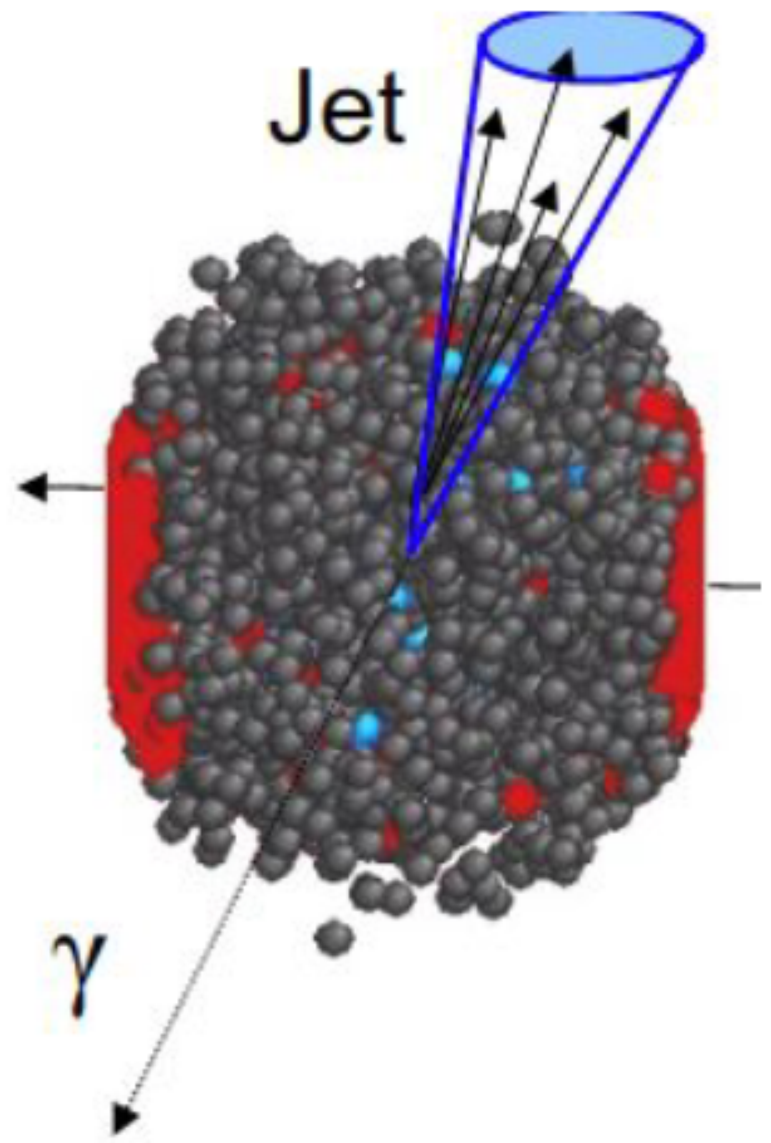
$x_{\gamma j}$ > 0.8 (less quenched jets):
narrowing is restored



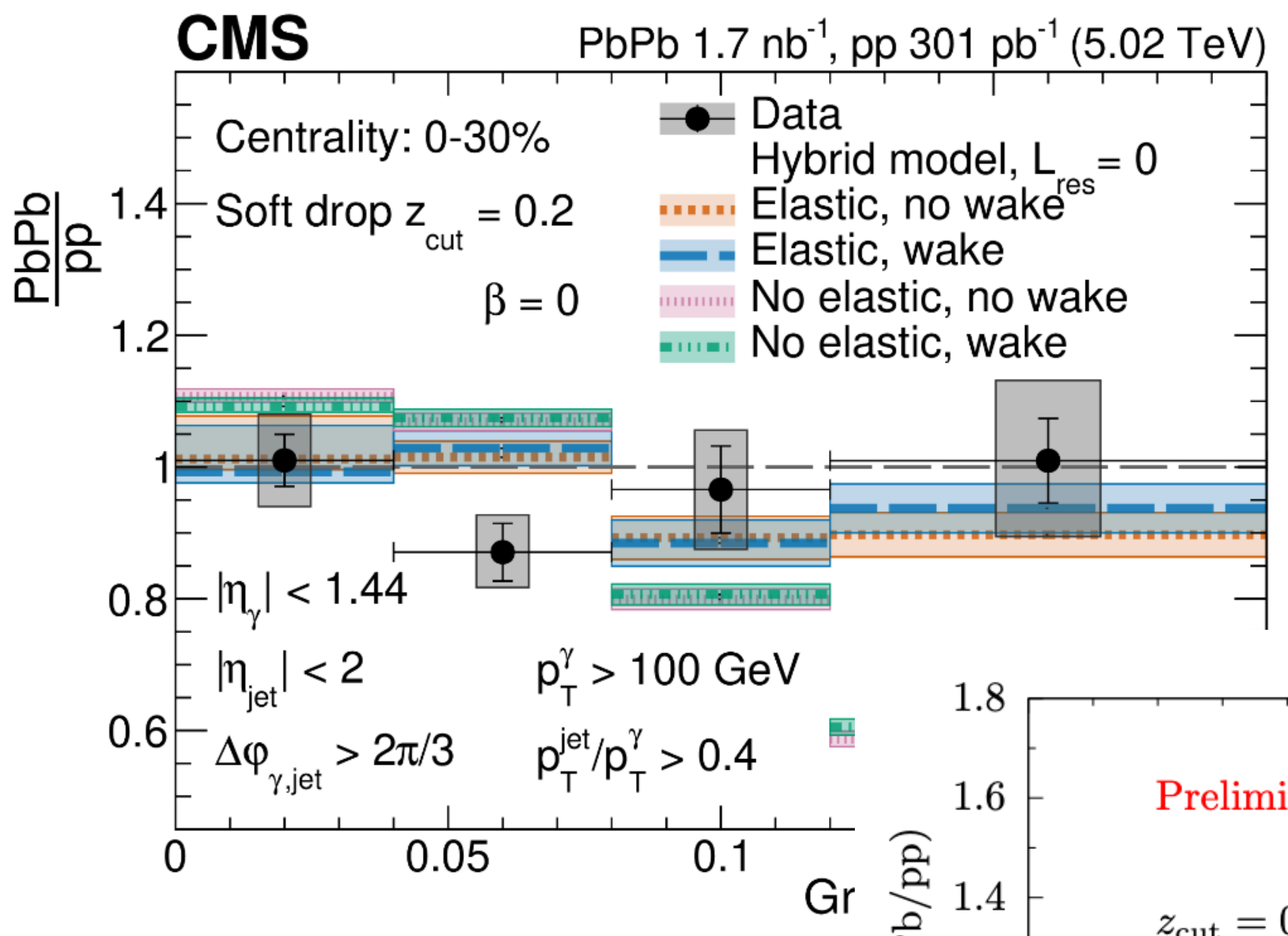
Not a single set of parameters describes the differential data consistently
Great constraining power of the data

Matthew Nguyen

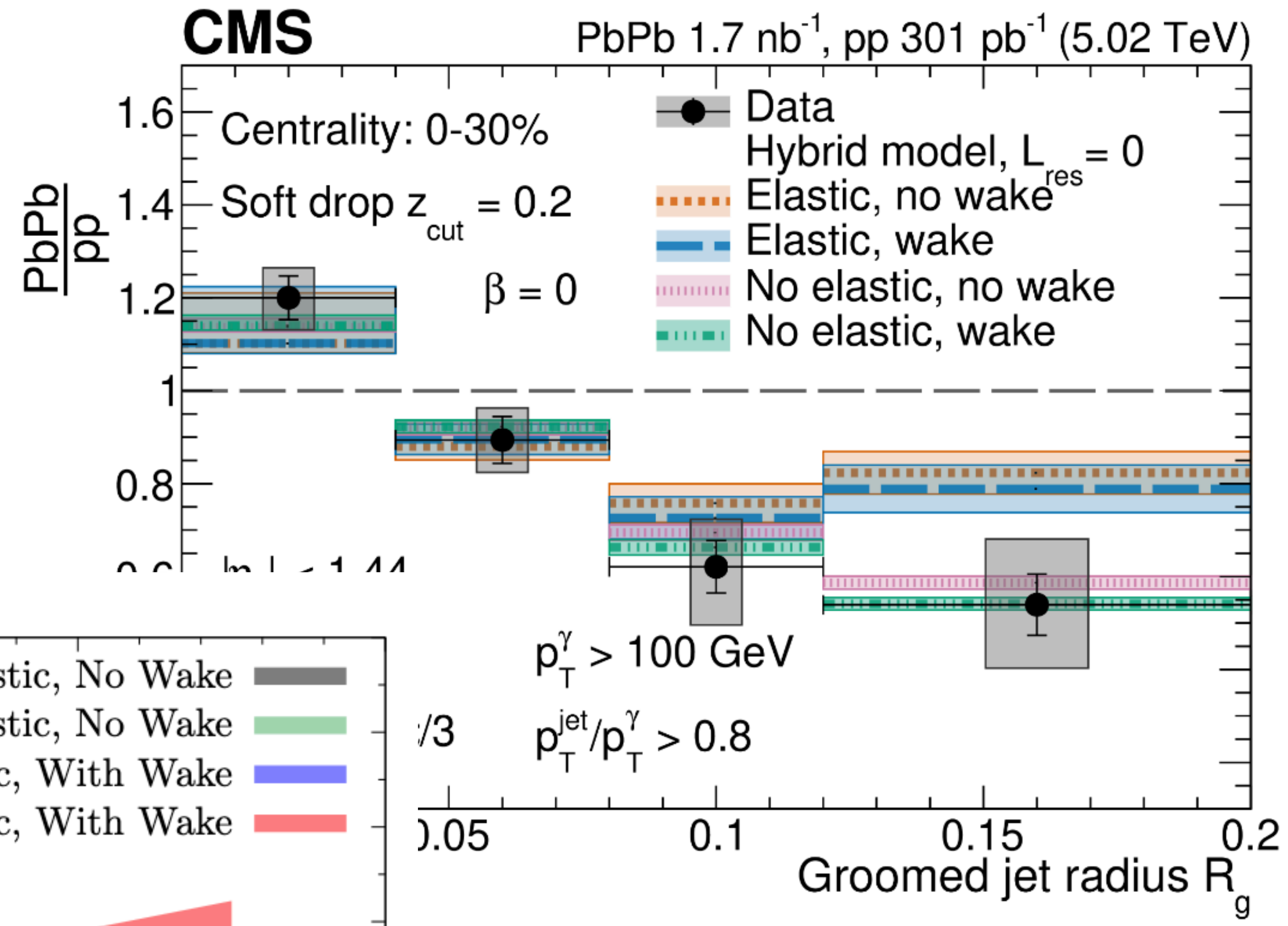
The selection bias

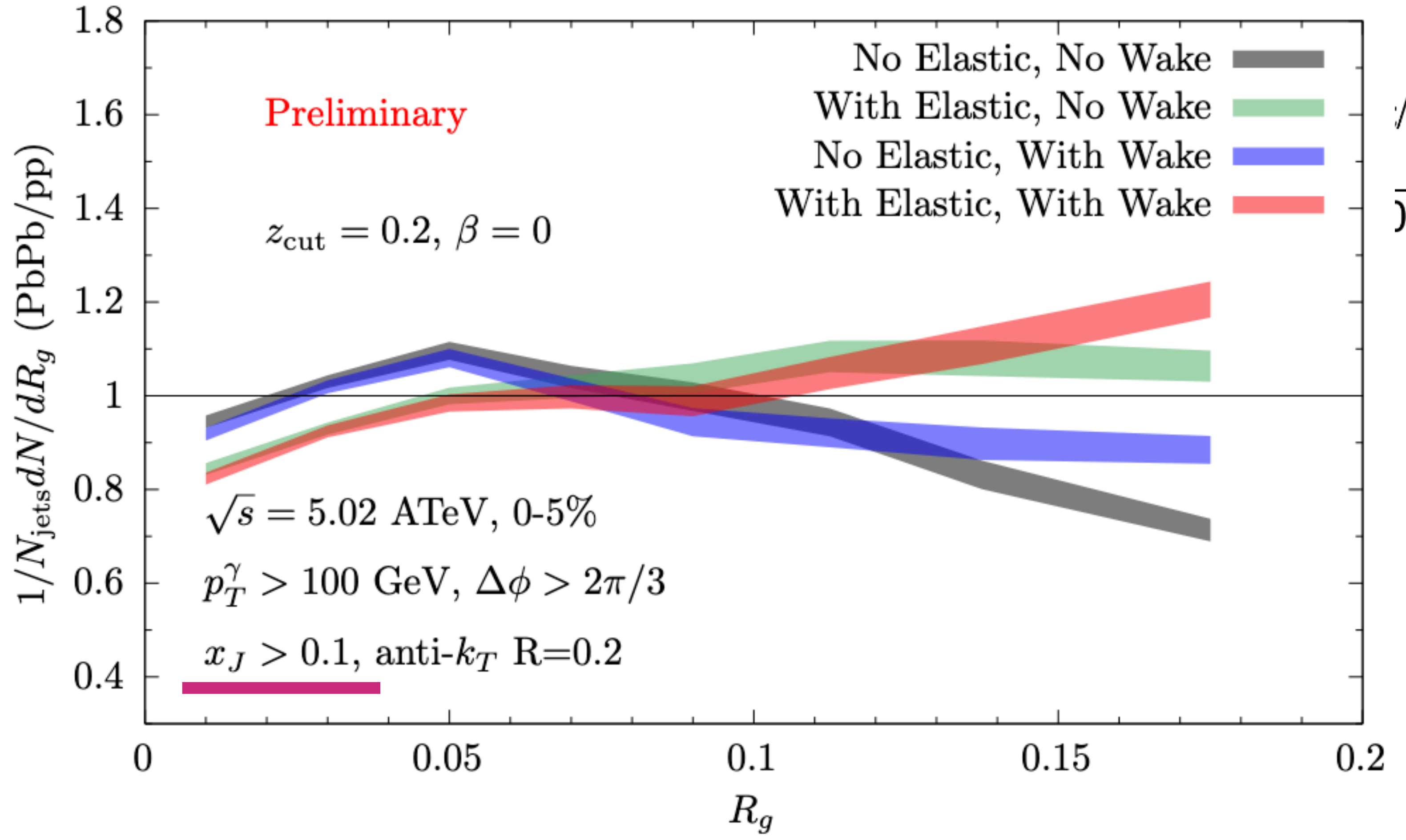


$x_{\gamma j} > 0.4$ (w/ quenched jets):
no narrowing observed



$x_{\gamma j} > 0.8$ (less quenched jets):
narrowing is restored



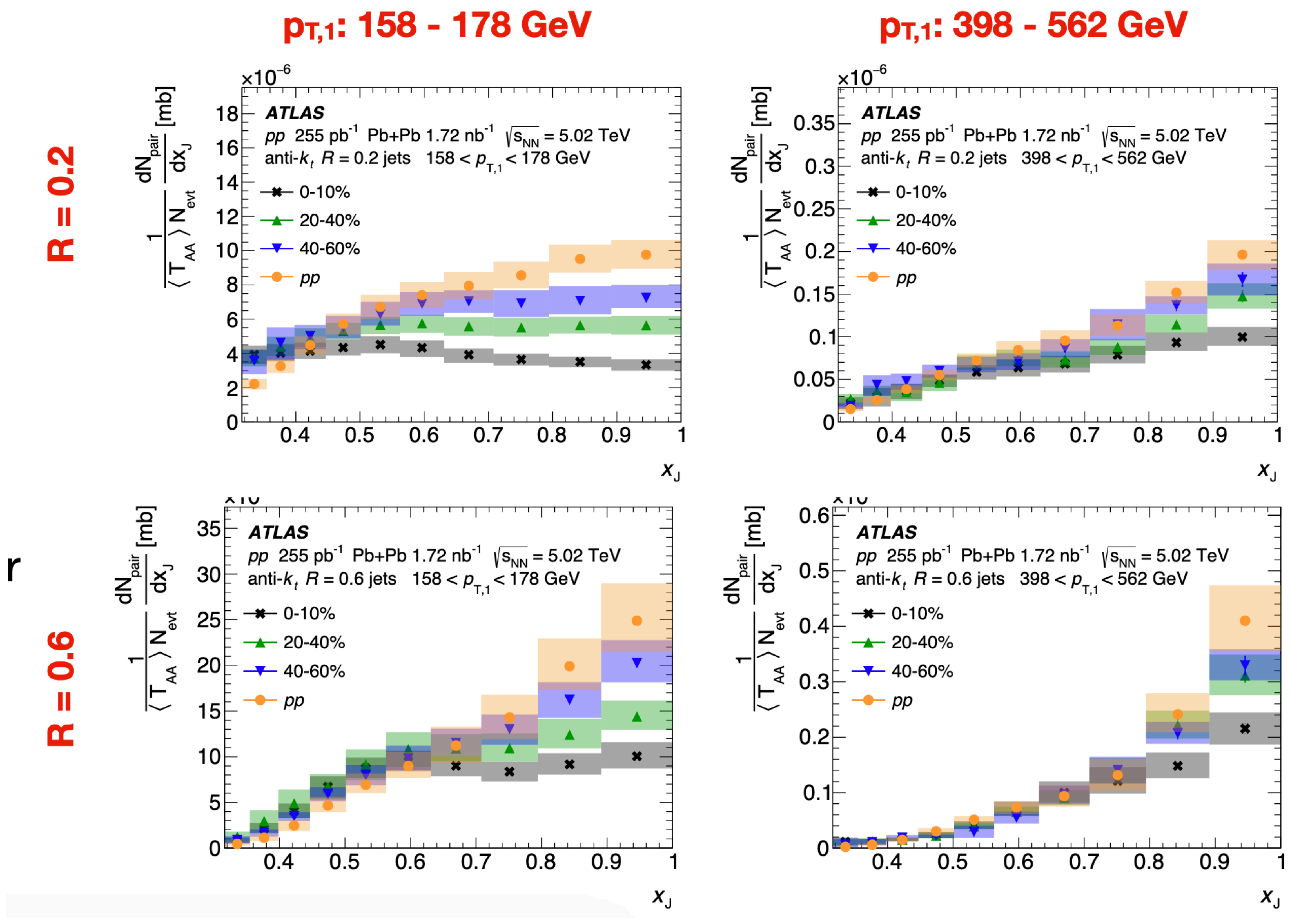


Is there significant “leaking” below xJ=0.4?

The imbalance distributions

Anne Sickles

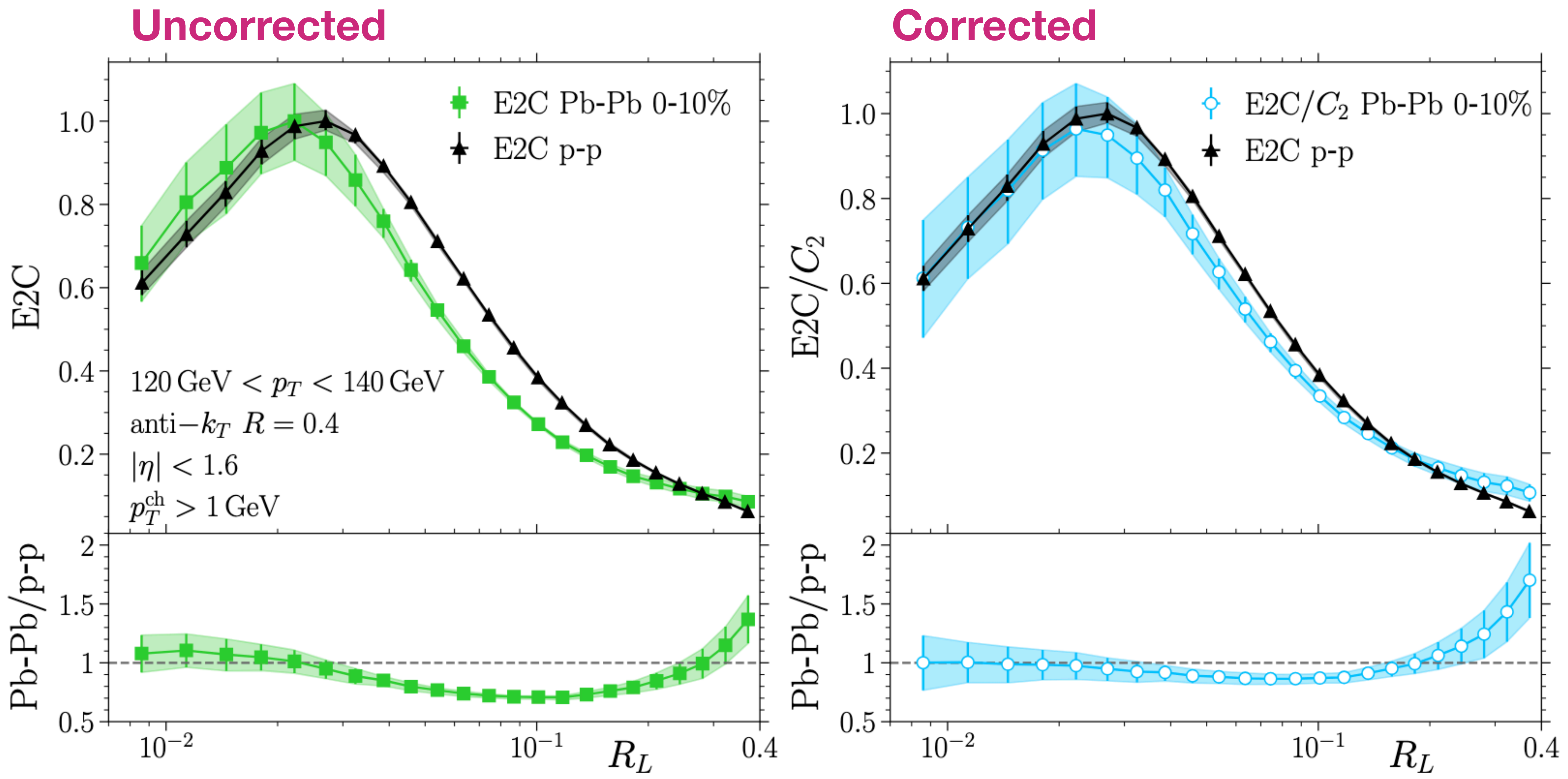
arXiv:2407.18796



Example of a systematic study of momentum balance in dijet events as a function of jet radius

Fundamenal to measure the xJ distributions in γ-jet for the models to calibrate the amount of selection bias

Mitigation of selection bias for inclusive jets



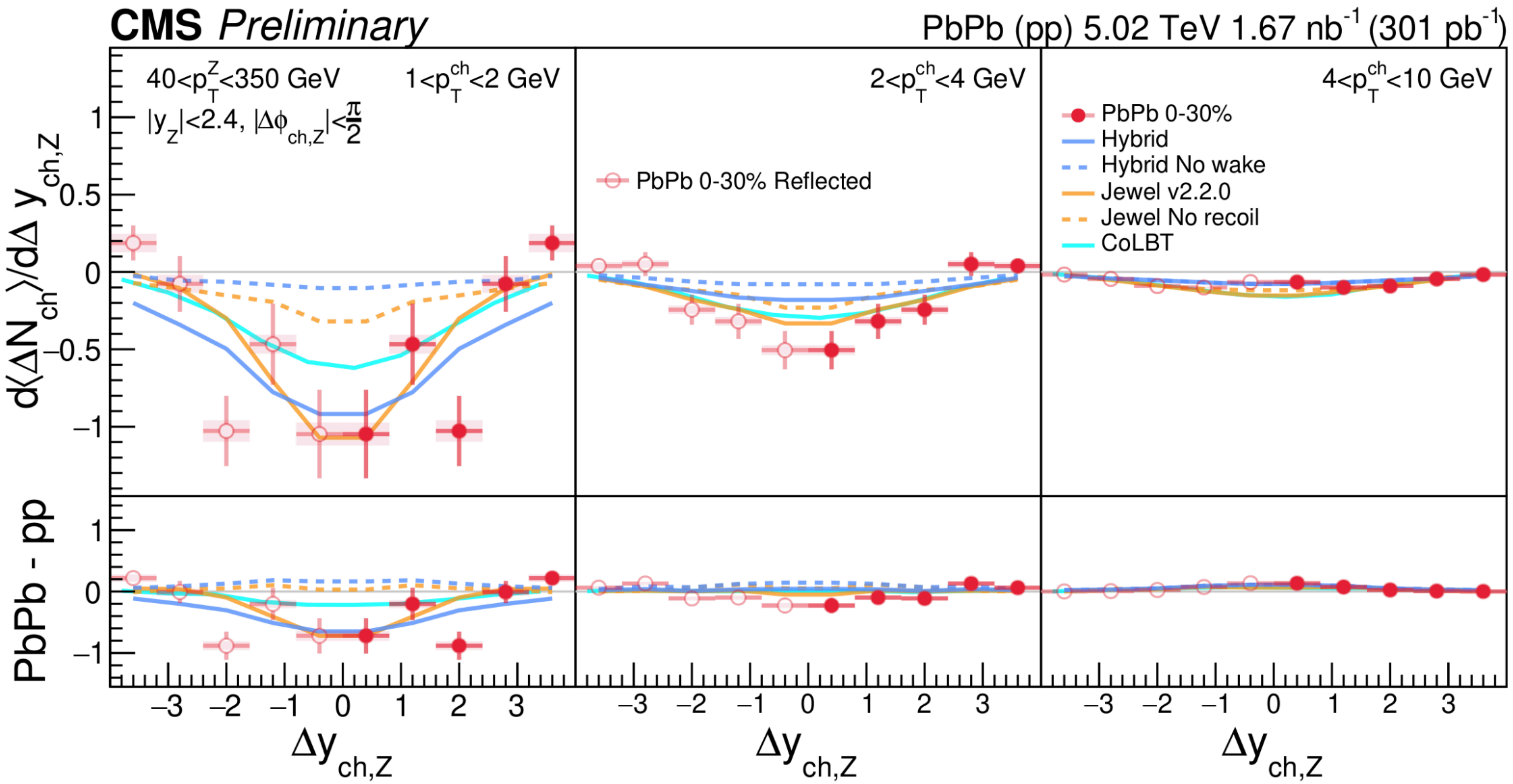
Carlota Andres, Holguin, Kunnawalkam Elayavalli, Viinikainen arXiv:2409.07514

Exploit scaling properties of the observable to suppress the effect of energy loss

Or one can avoid it completely by measuring the EEC in the full Z-tagged event, see *talk by Yi Chen for the upcoming measurement*

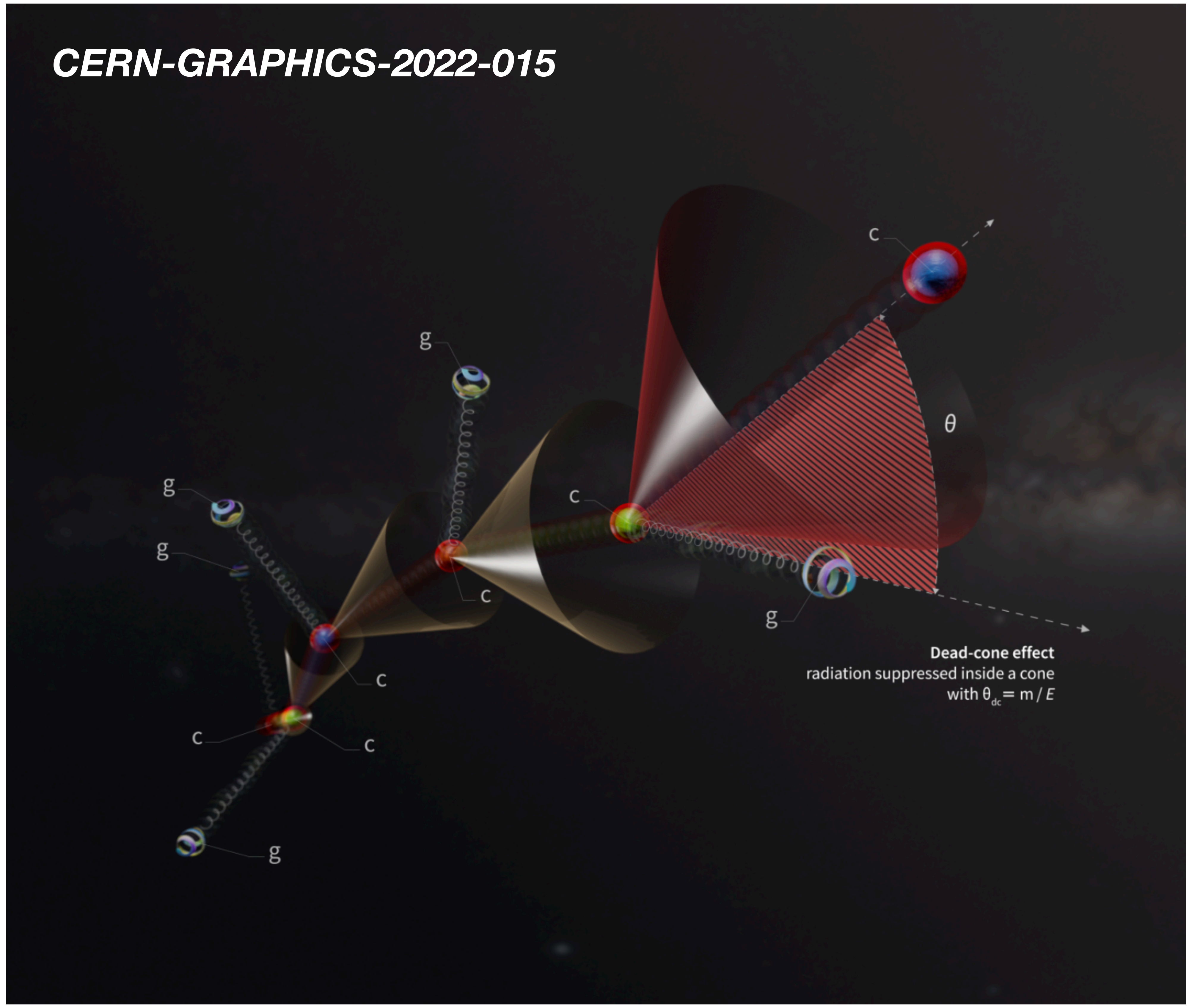
The medium response

Yen-Jie Lee



No jet, no selection bias but also lack on handle on energy loss
New opportunity to calibrate the medium response in models
Different models drag the QGP, but is there a way to distinguish the different underlying physics?

Heavy flavours and the Lund plane



CA jet tree for heavy flavour hadrons

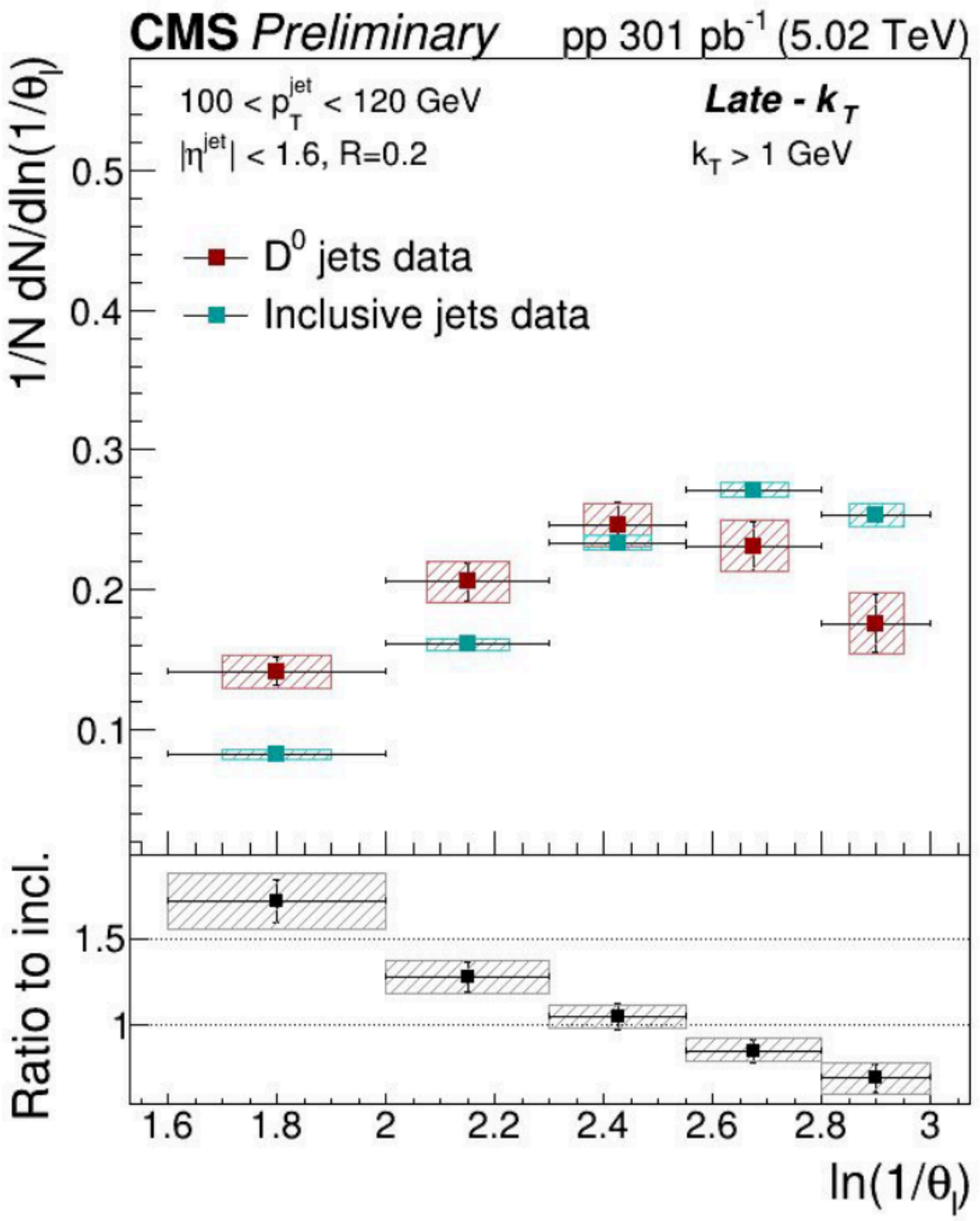
m_Q/p_{Tjet} sets the scale of the minimum
dead cone angle in the jet tree, ie that of the first emission

Nodes deeper in the tree ($E_{emitter} << p_{Tjet}$) have bigger dead cones

Sensitivity to quark mass ->access hard&collinear emissions

Heavy flavours and the Lund plane

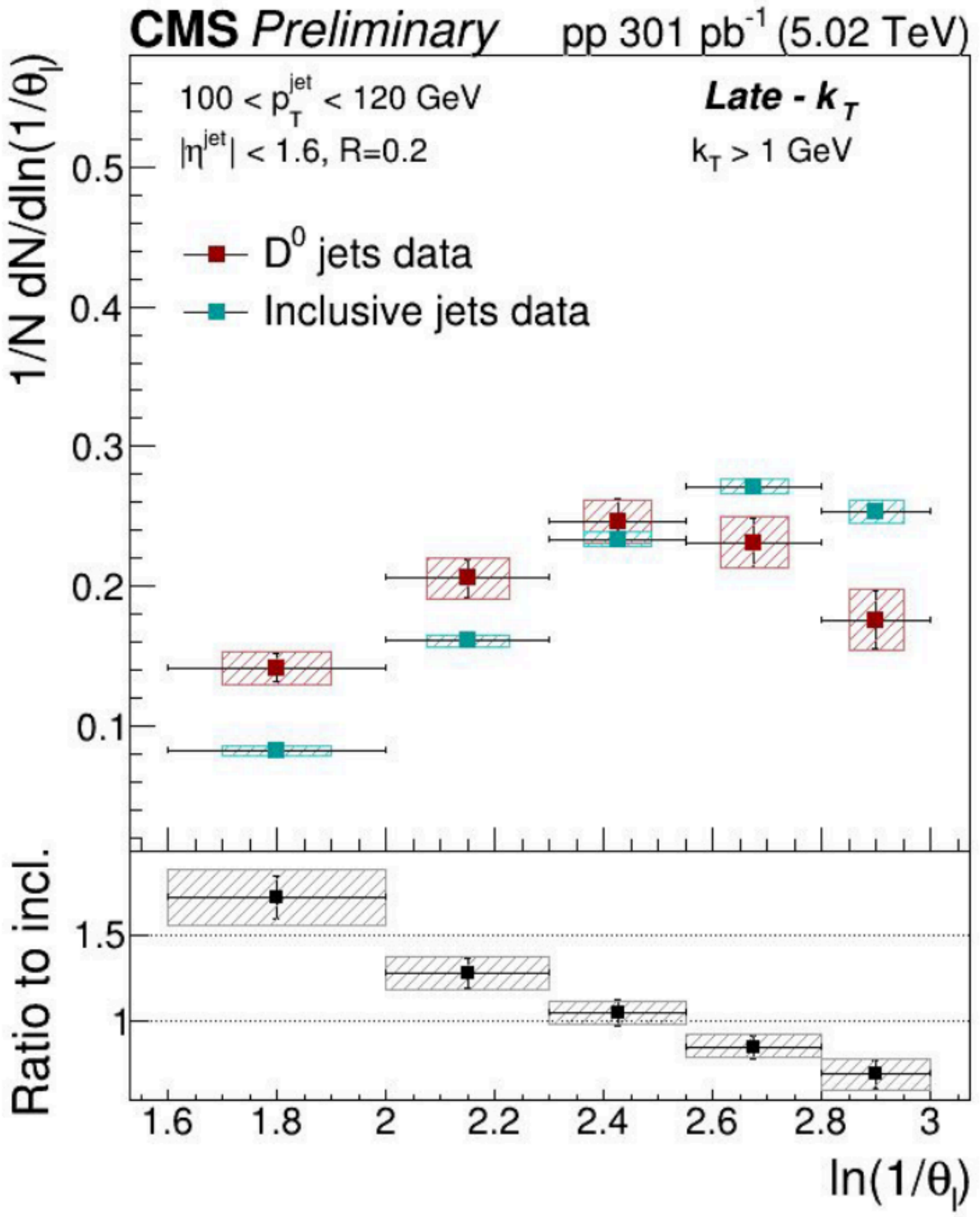
Jelena Mijuskovic



Algorithm designed to select hard&collinear emissions
Charm quark mass effects for energetic jets
No impact of gluon splittings, contrary to SoftDrop

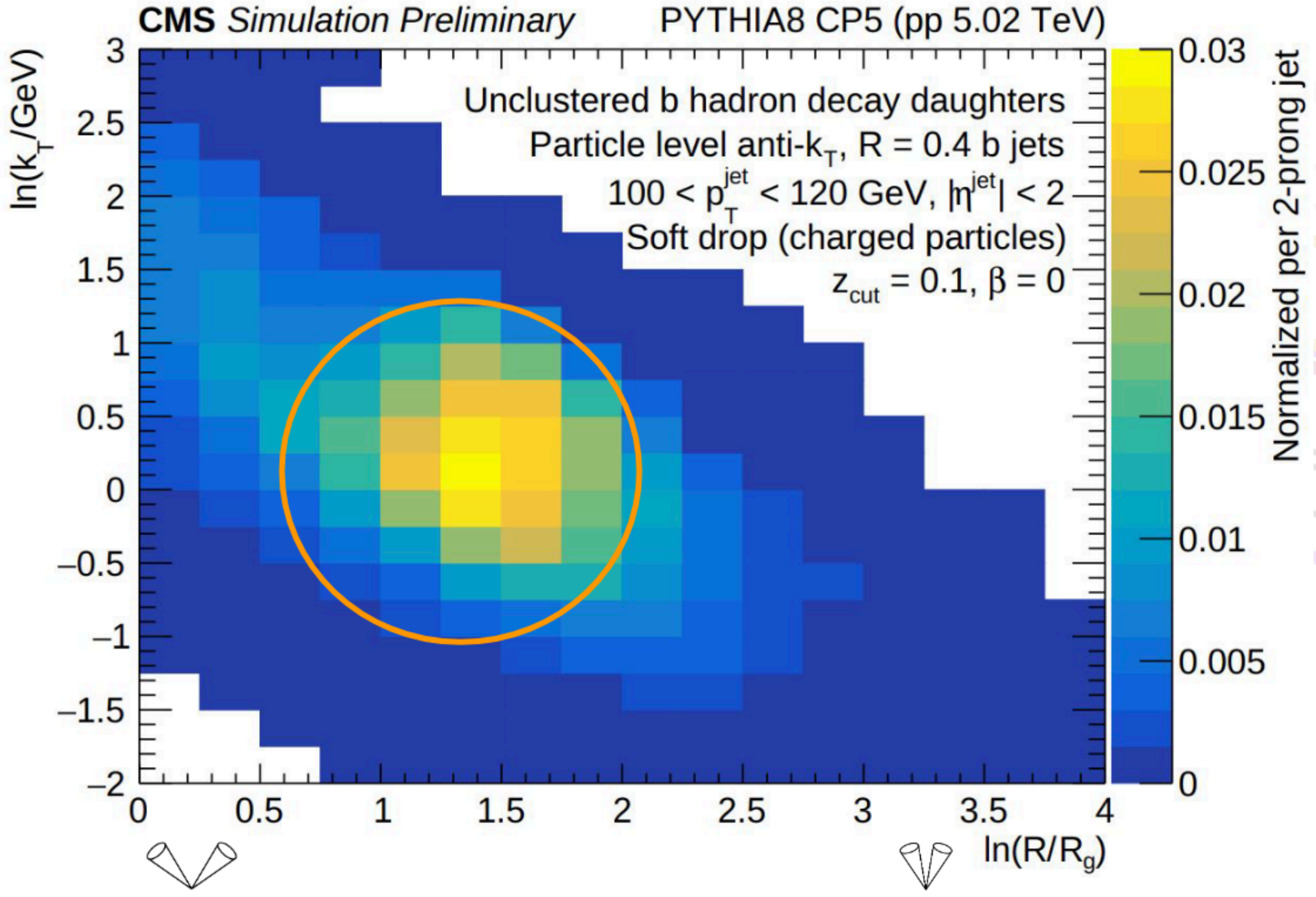
Heavy flavours and the Lund plane

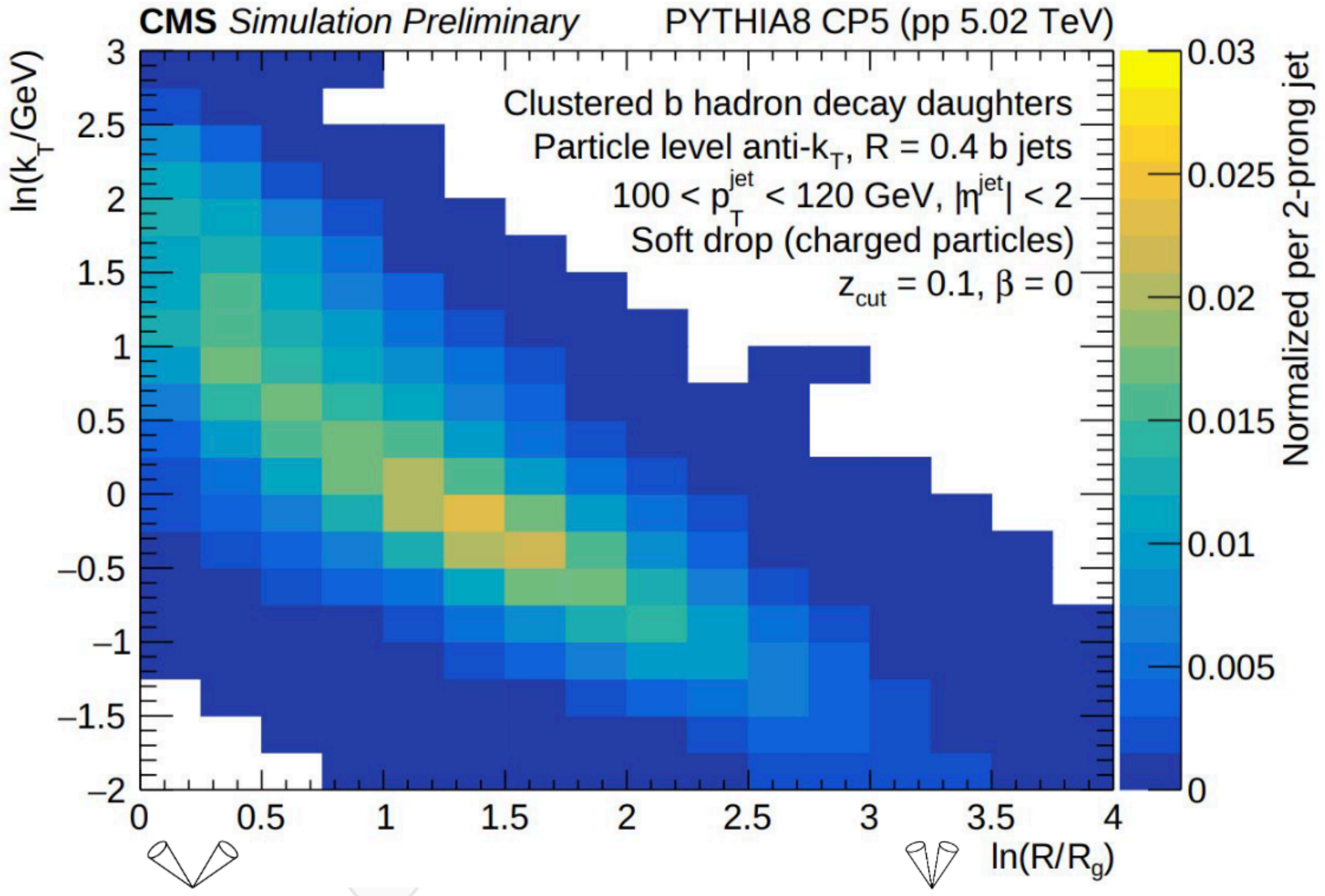
Jelena Mijuskovic



Algorithm designed to select hard&collinear emissions
Charm quark mass effects for energetic jets
No impact of gluon splittings, contrary to SoftDrop

Lida Kalipoliti



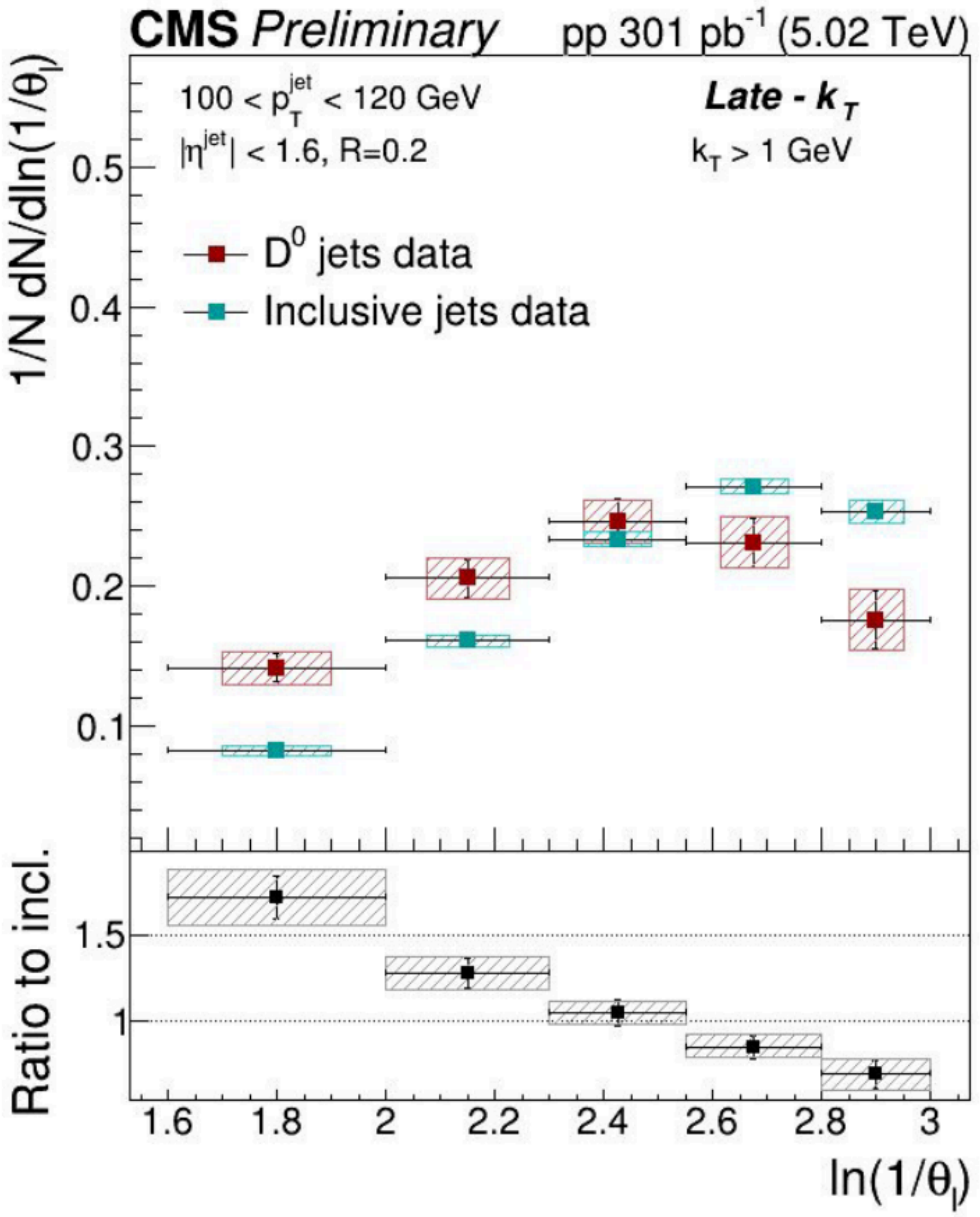


New method to aggregate the particles from the secondary vertex into a B pseudohadron

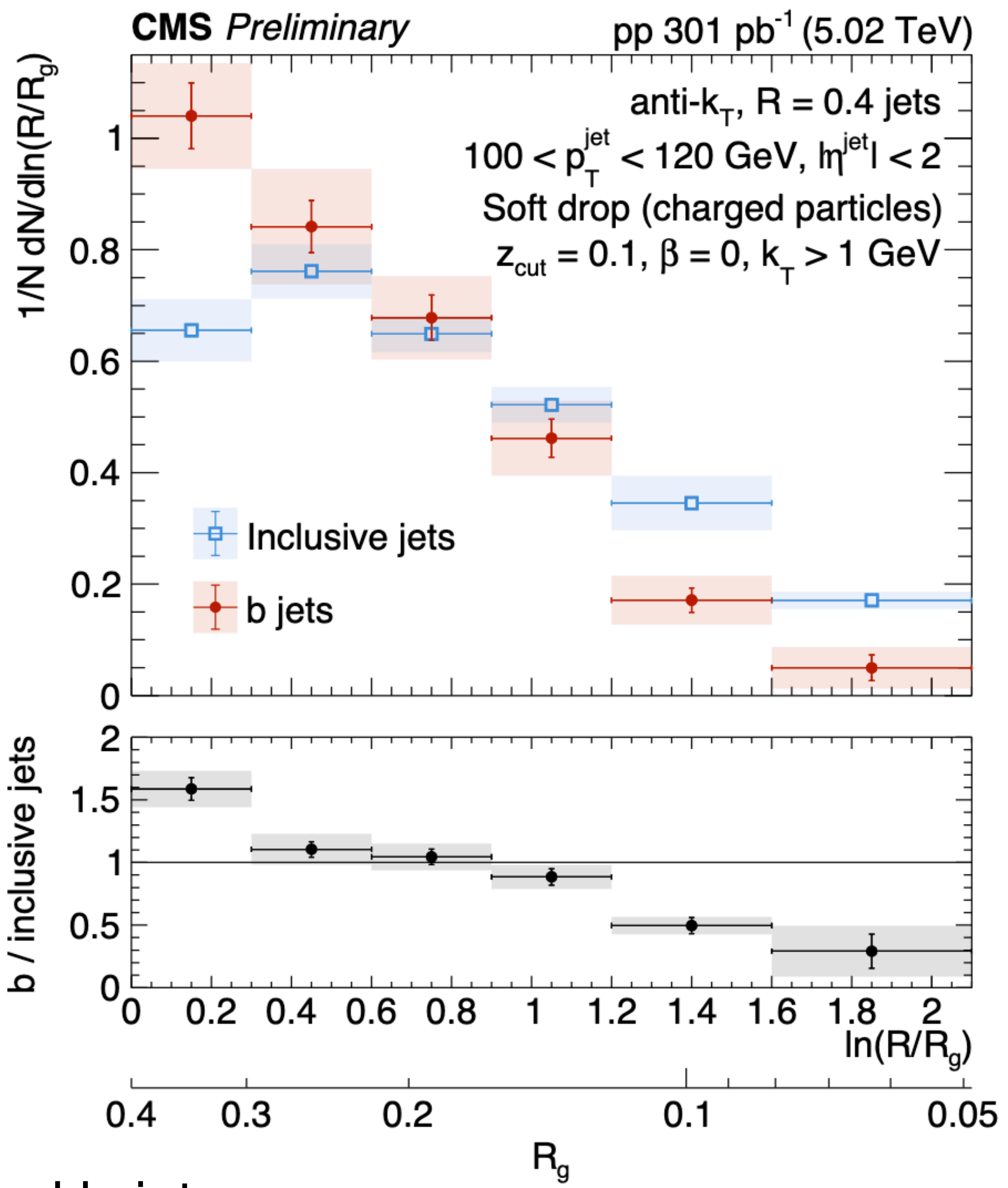
Allows to exploit the high statistics of b-tagging

Heavy flavours and the Lund plane

Jelena Mijuskovic



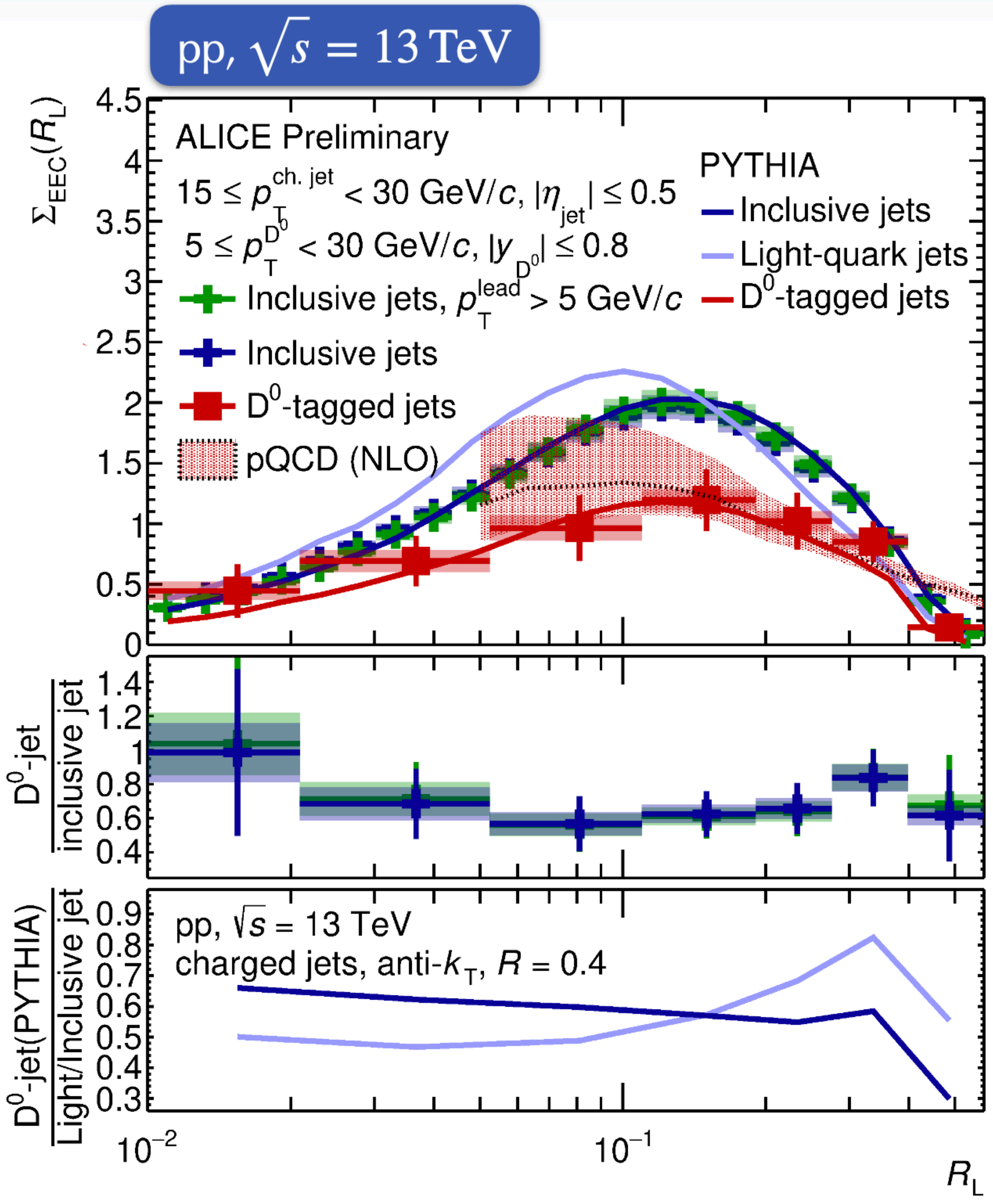
Lida Kalipoliti

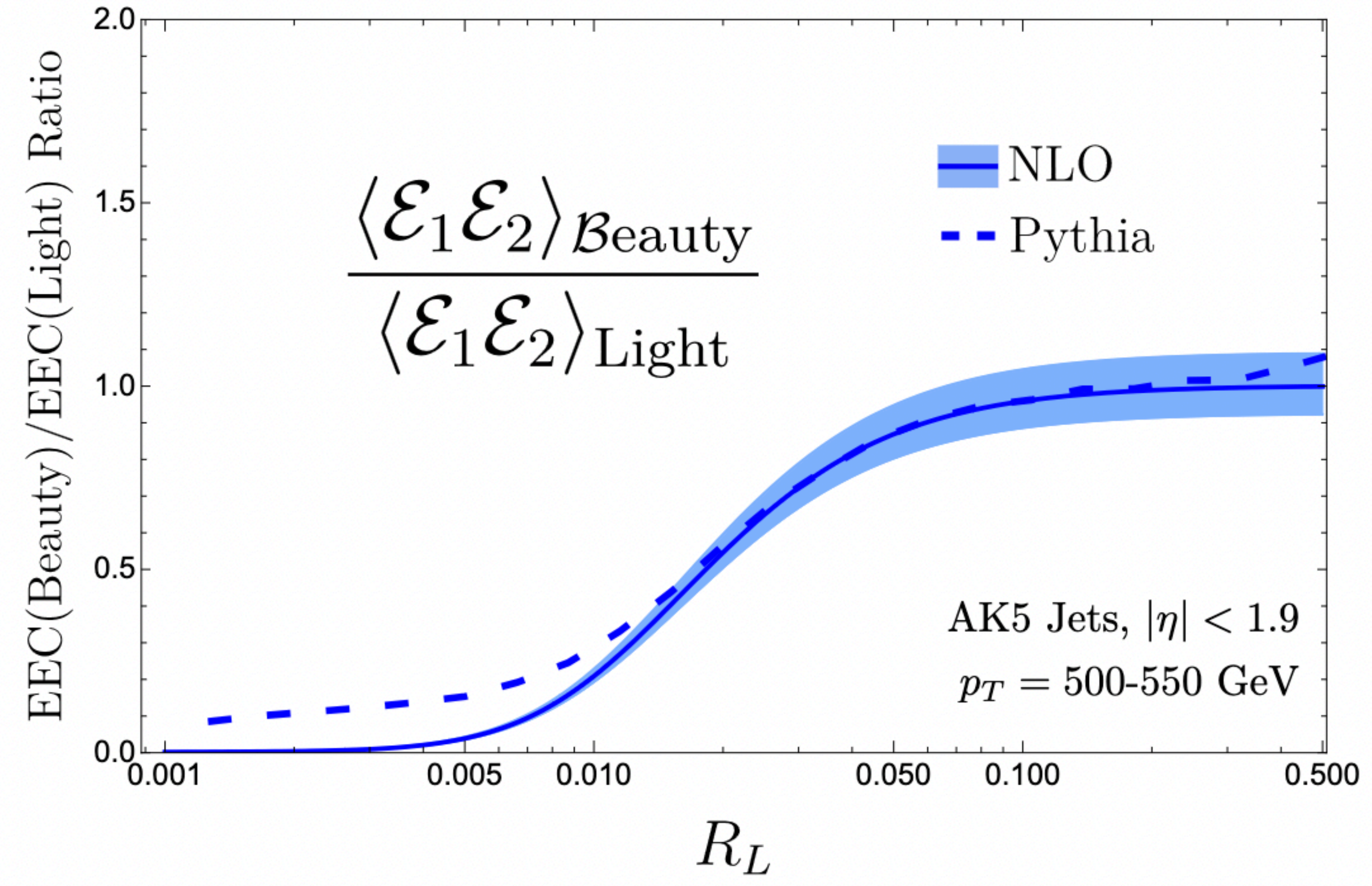


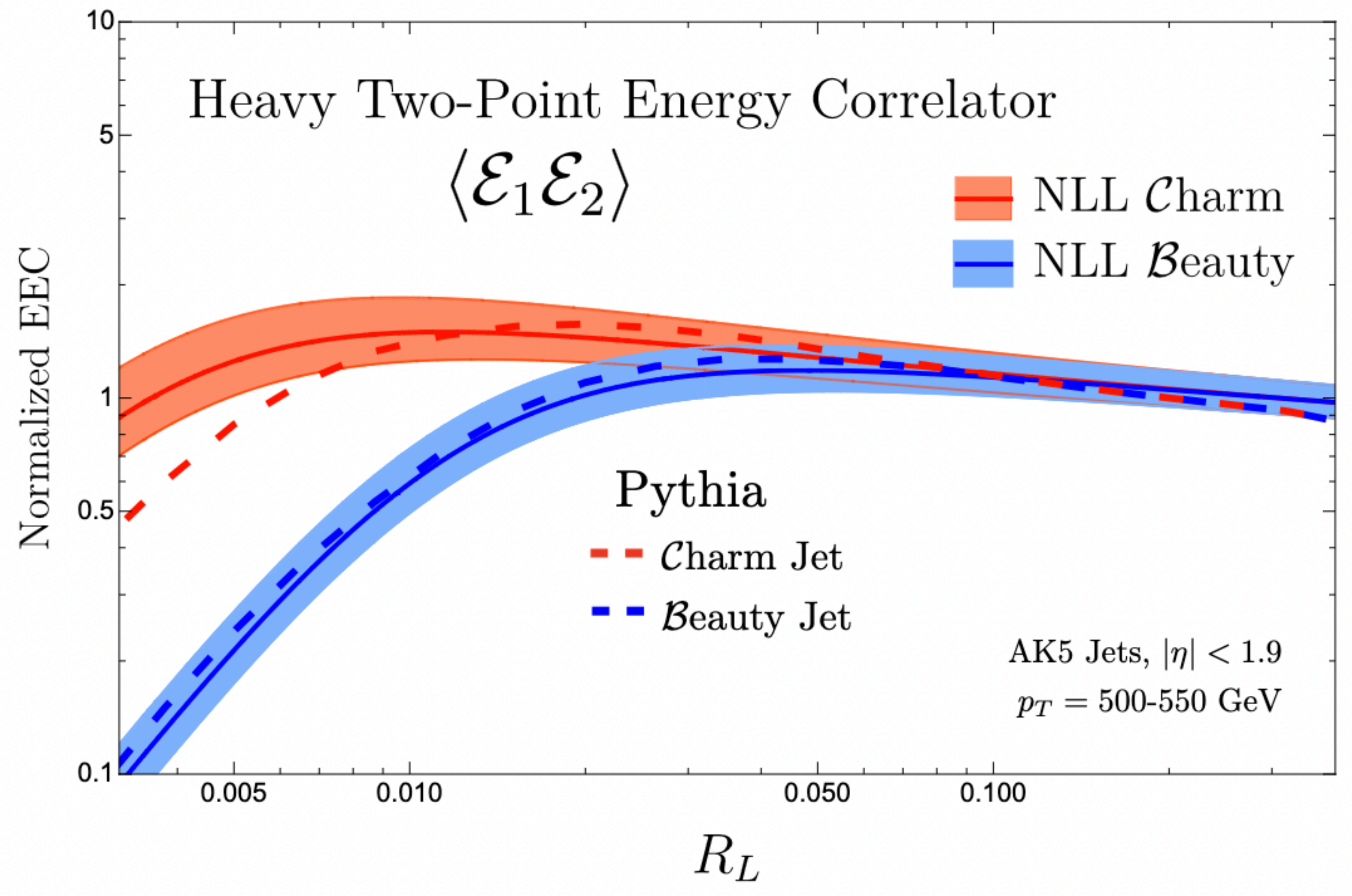
Suppression of collinear emissions for both D-jets and b-jets
Need consistency of selections (algorithm, jet R, full vs charged) for a direct comparison of effects

Anjali Nambrath

Heavy flavours and the EEC







Strong suppression of the yield of emissions
Reference is currently PYTHIA

Heavy flavour jet substructure prospects for HIN

In medium, an interesting interplay of scales appeares:

$$\theta_C < \theta < \theta_{dead}$$

Salgado et al, Phys.Rev.D 69 (2004) 114003
Ontoso et al, Phys.Rev.D 107 (2023) 9, 094008
Andres et al, Phys.Rev.D 110 (2024) 3, L031503

To be filled by medium-induced radiation, the dead cone angle needs to be larger than the decoherence angle

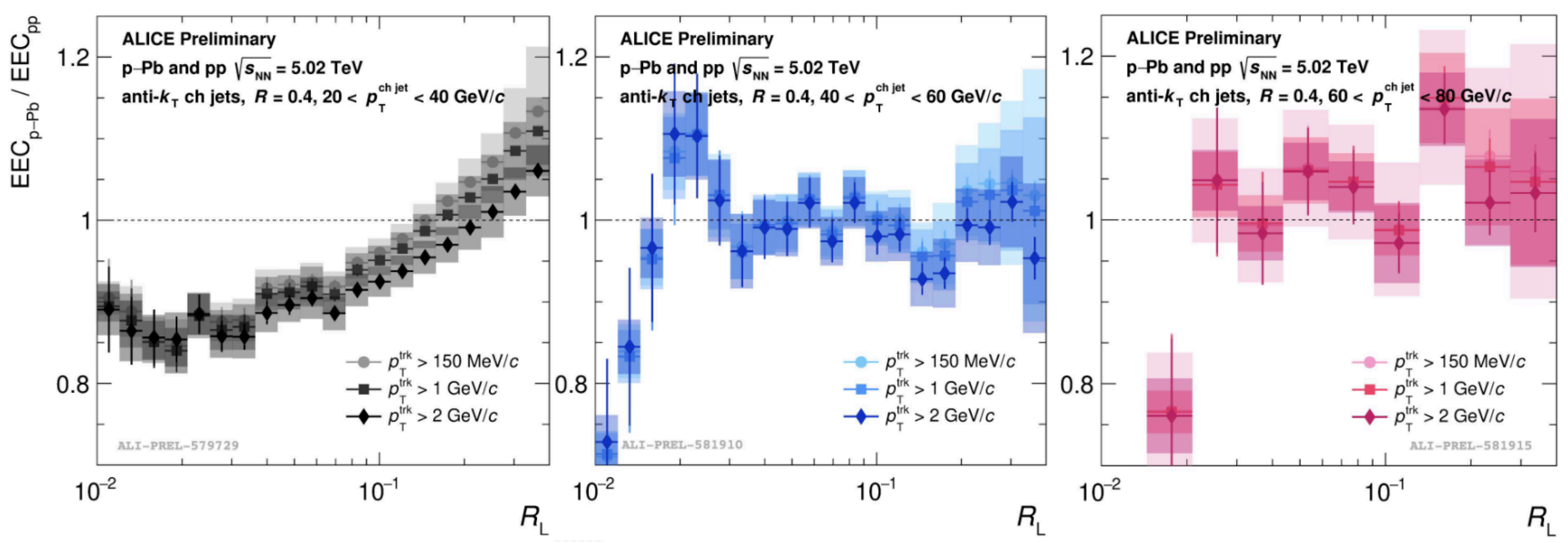
Strong enhancement of collinear splittings is expected for b-jets while c-jets dead cone remains intact
Predictions from both the Lund Plane and EEC languages

Jean F.Du Plessis, modeling finite mass heavy quark energy loss in the strongly coupled QGP
No notion of Dead Cone in strongly coupled description. Observing it, would it be a validation of weakly coupled approaches?

Many other things not covered in this talk

Many interesting new results for low p_T heavy flavour jet substructure and fragmentation with ALICE run3 data *Jochen Klein*

Checkout also interesting results on pPb EECs by ALICE showing a strong modificaion at small angles relative to pp
Tension with mass measurements in pPb at 60 GeV?



Anjali Nambrath

New LHCb results for heavy flavour jets in an almost unexplored kinematic regime
Also, first studies of IRC-safe flavour definition algorithms in our community *Ezra Lesser*

Jet theory highlights already discussed by Daniel de Pablos in yesterday's talk

Soon-arriving sPHENIX jet physics program. Good to hear that the experiment is taking good data, looking forward to results next HP!