Experimental studies of energy correlators and spin effects at LHC

Benjamin Nachman

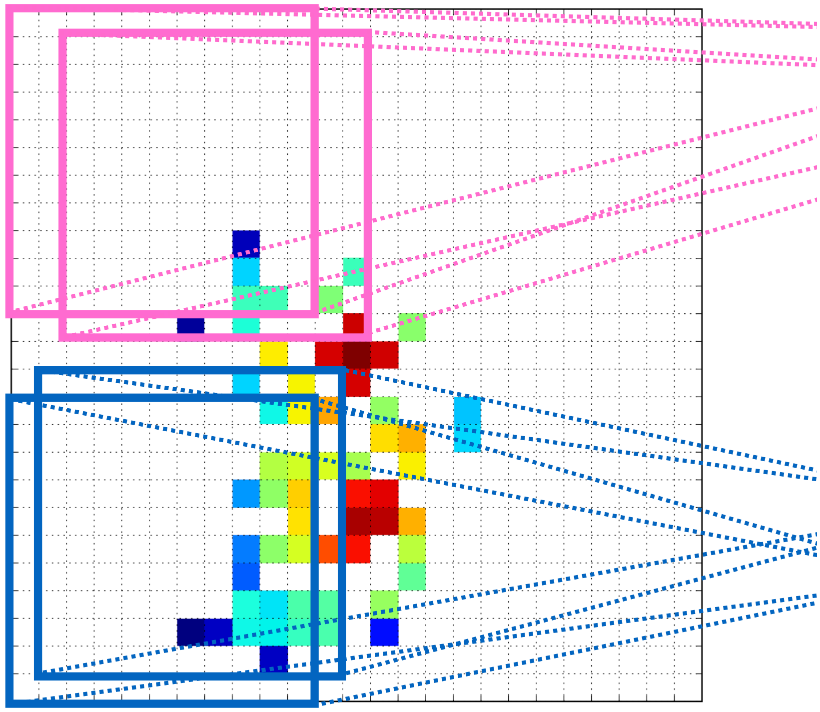
Lawrence Berkeley National Laboratory

bpnachman.com

bpnachman@lbl.gov

@bpnachman

bnachman



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EF05 Topical Group Meeting

September 27, 2021

Disclaimer

This talk is not meant to be comprehensive. I will give a few examples and comments to spark discussion.

I will use examples entirely from ATLAS (but this is not on behalf of ATLAS). Some (but not all) of the time, CMS has a corresponding measurement with similar precision.

(although we don't always agree on core analysis decisions - let's discuss that, but another day!)

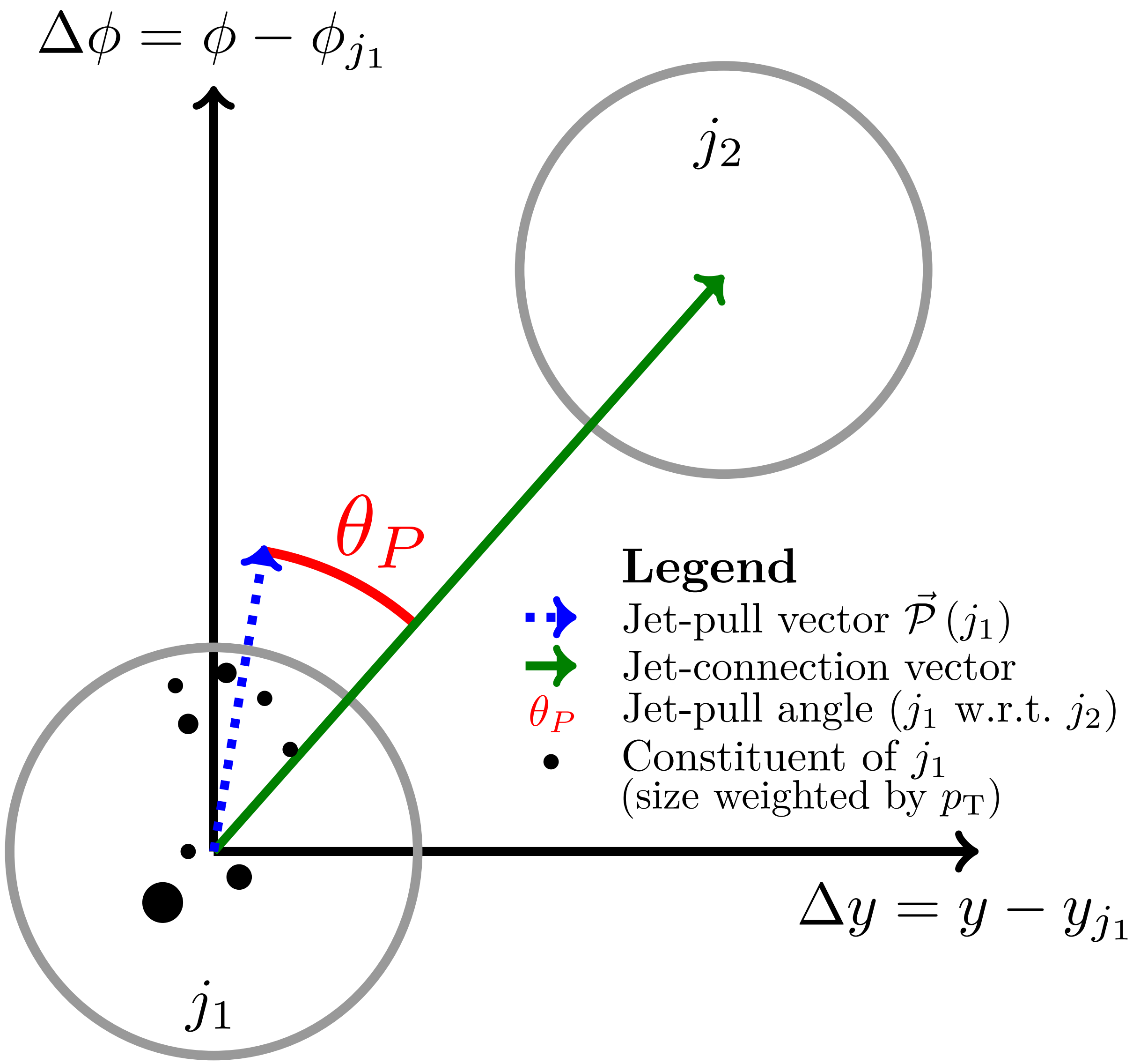
Why correlations?

We can use correlations between jets/hadrons as a way to expose emergent quantum properties

Correlations Part I: Jet Pull

We can use correlations between jets/hadrons as a way to expose emergent quantum properties

Example 1: Jet pull



We can study QCD **entanglement** from correlations in the radiation patterns of pairs of jets.

An exciting laboratory for this work is boosted W bosons, a copious source of **singlet** → jets.

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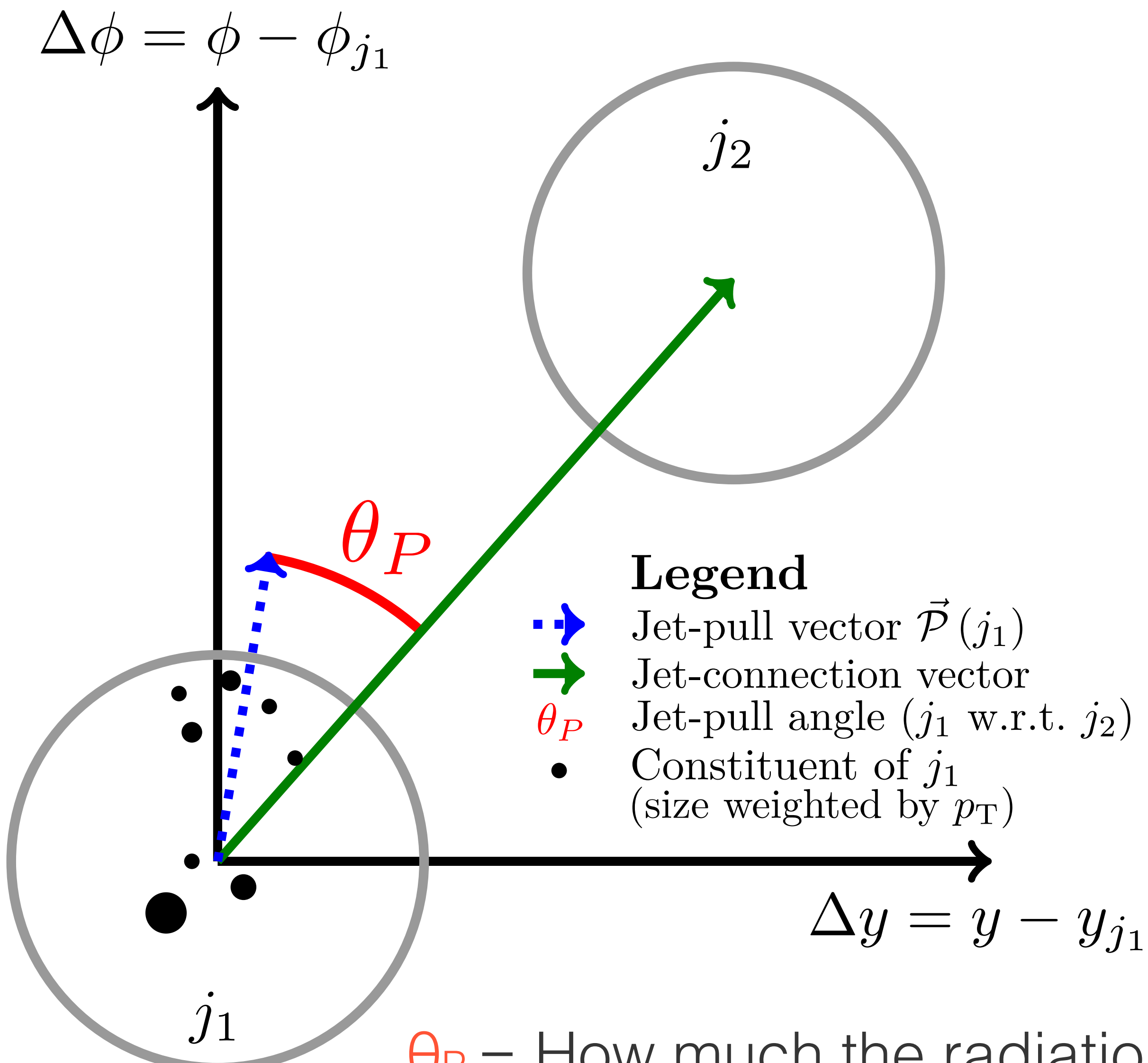
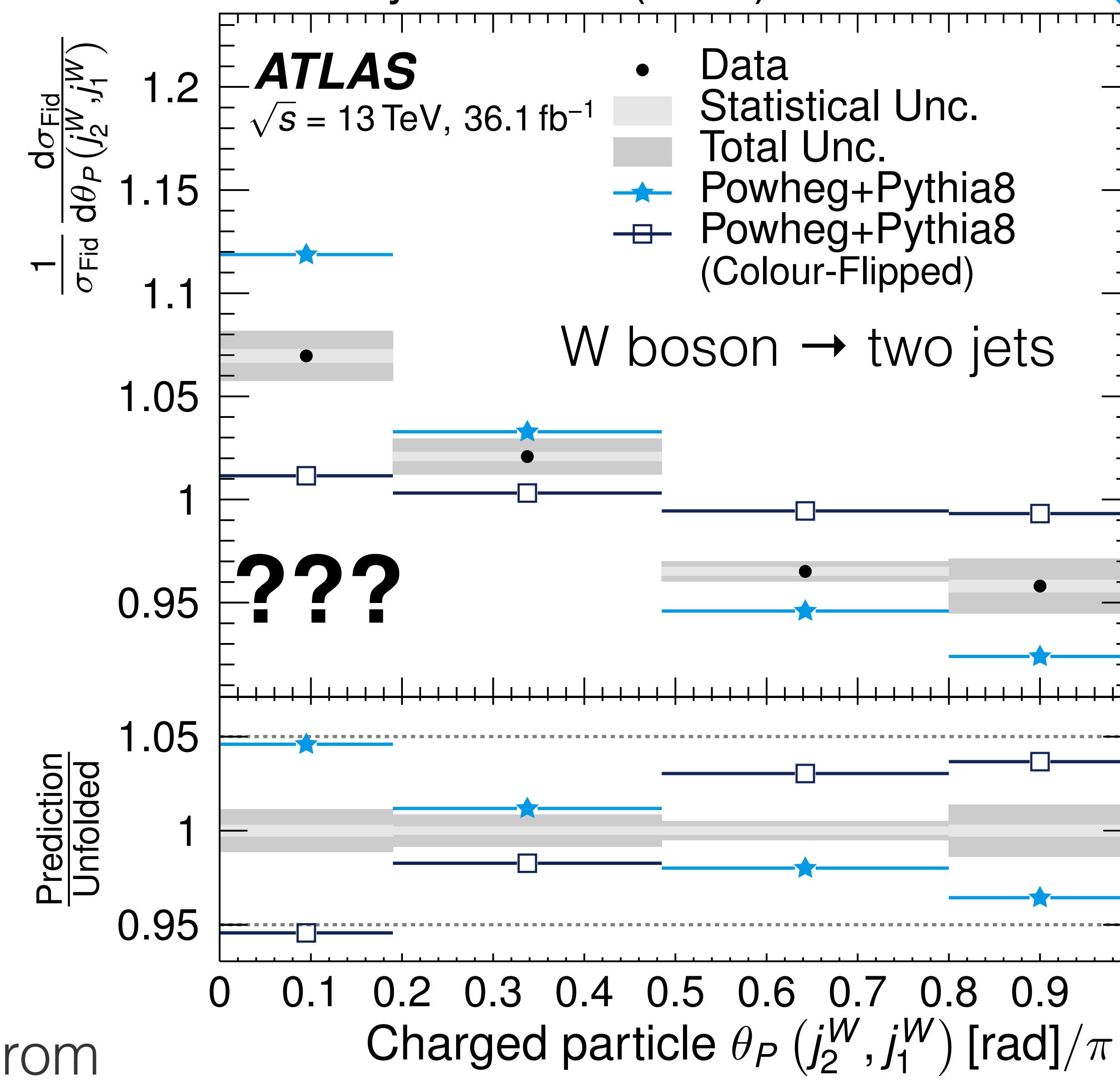


Eur. Phys. J. C 78 (2018) 847



θ_P = How much the radiation from one jet "leans" toward the other.

Correlations Part I: Jet Pull

We can use correlations between jets/hadrons as a way to expose emergent quantum properties

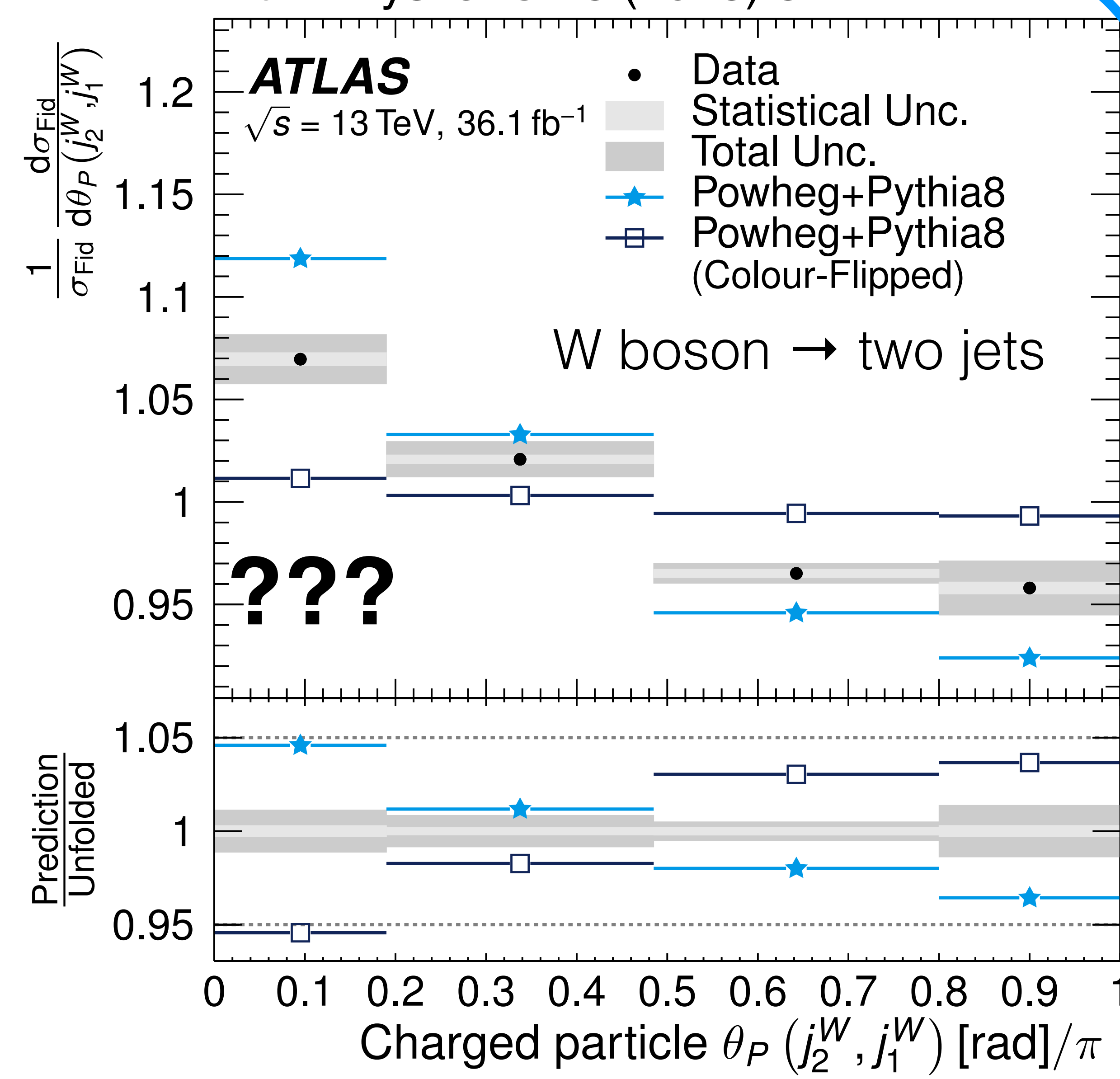
Example 1: Jet pull

Here is an observable where we can't distinguish between "entanglement" turned **"on"** and **"off"** !

Theory predictions are challenging, but in development

(see A. Larkoski, S. Marzani, C. Wu, PRD 99 (2019) 091502)

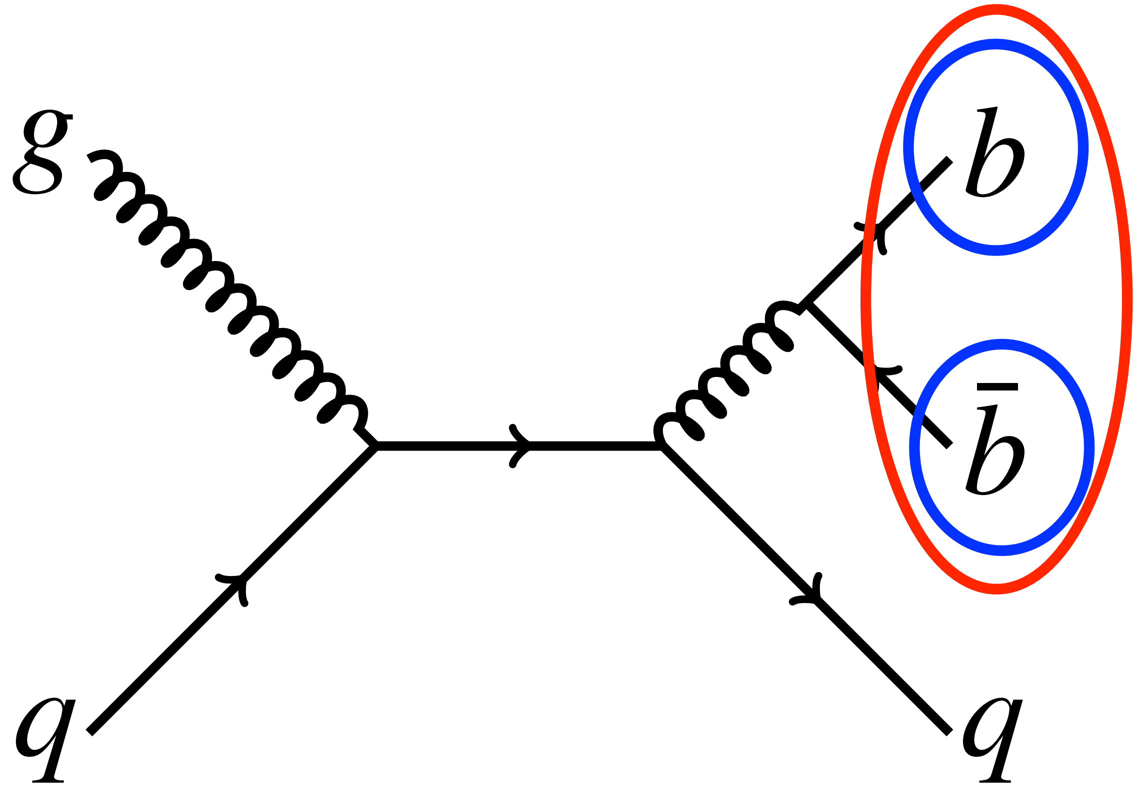
Eur. Phys. J. C 78 (2018) 847



Correlations Part II: $g \to b\bar{b}$

We can use correlations between jets/hadrons as a way to expose emergent quantum properties

Example 2: g → bb



Gluon splitting to bottom quarks gives us the only ~pure access to QCD splitting functions.

(and of course, this is a very important process for Higgs)

Correlations Part II: $g \to b\bar{b}$

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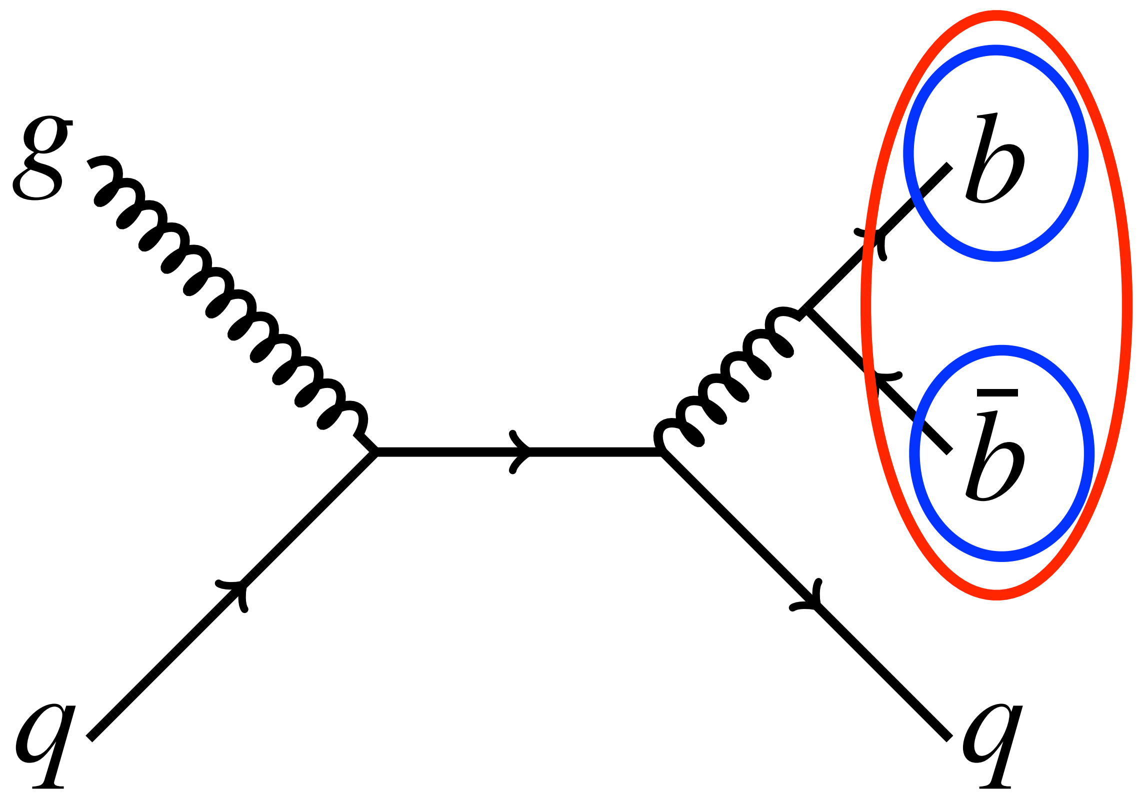
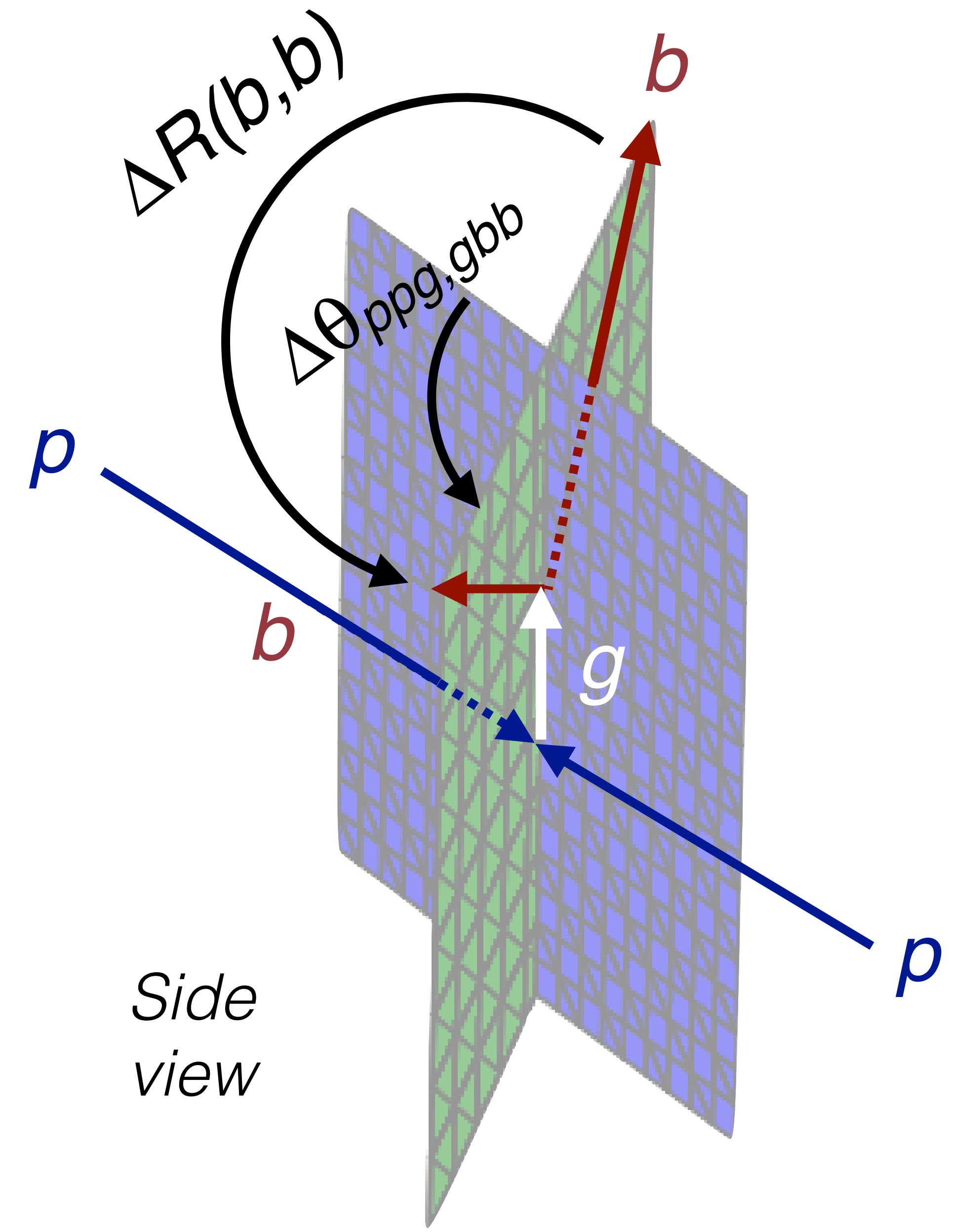


Relative angles to probe polarization



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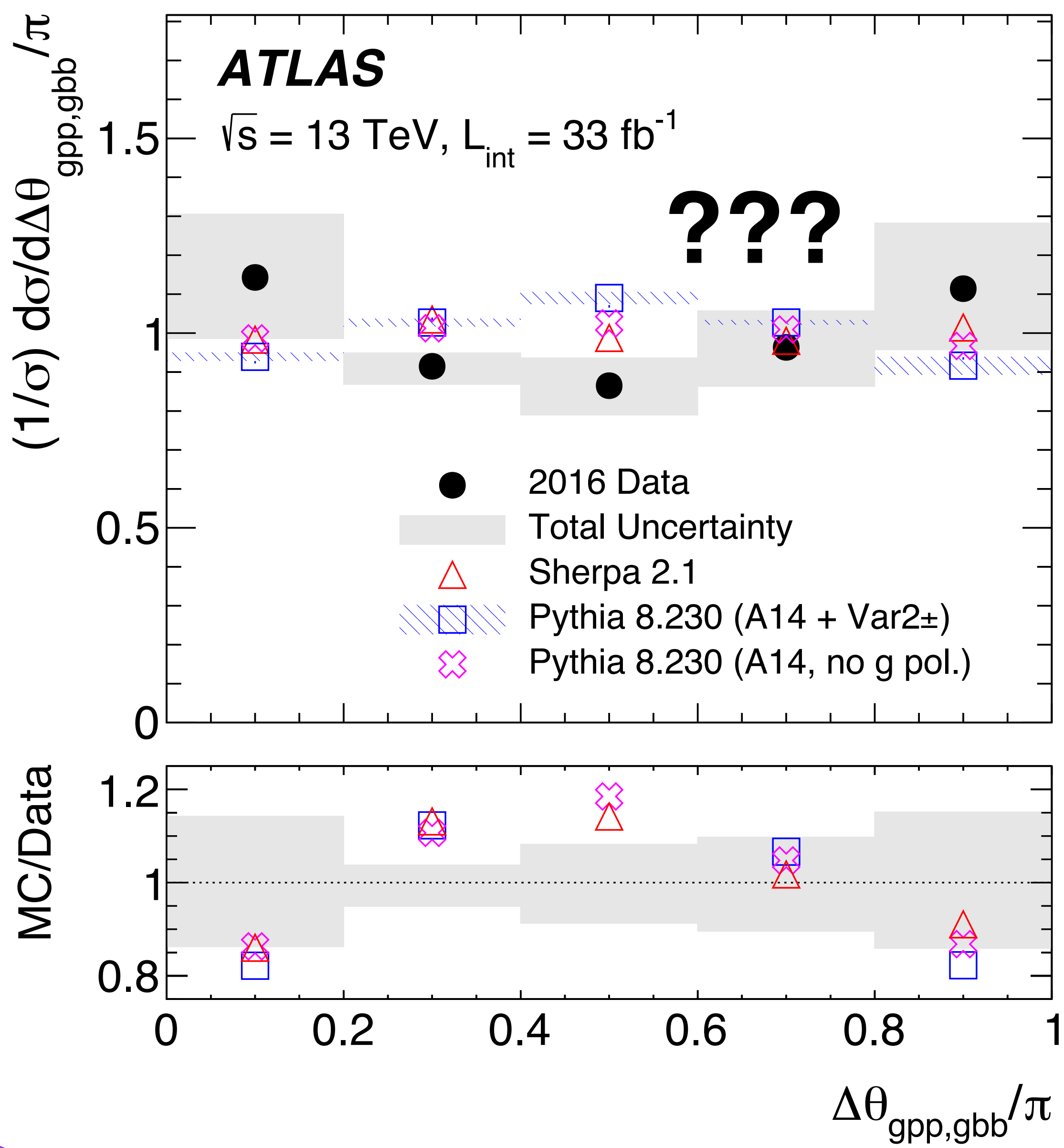
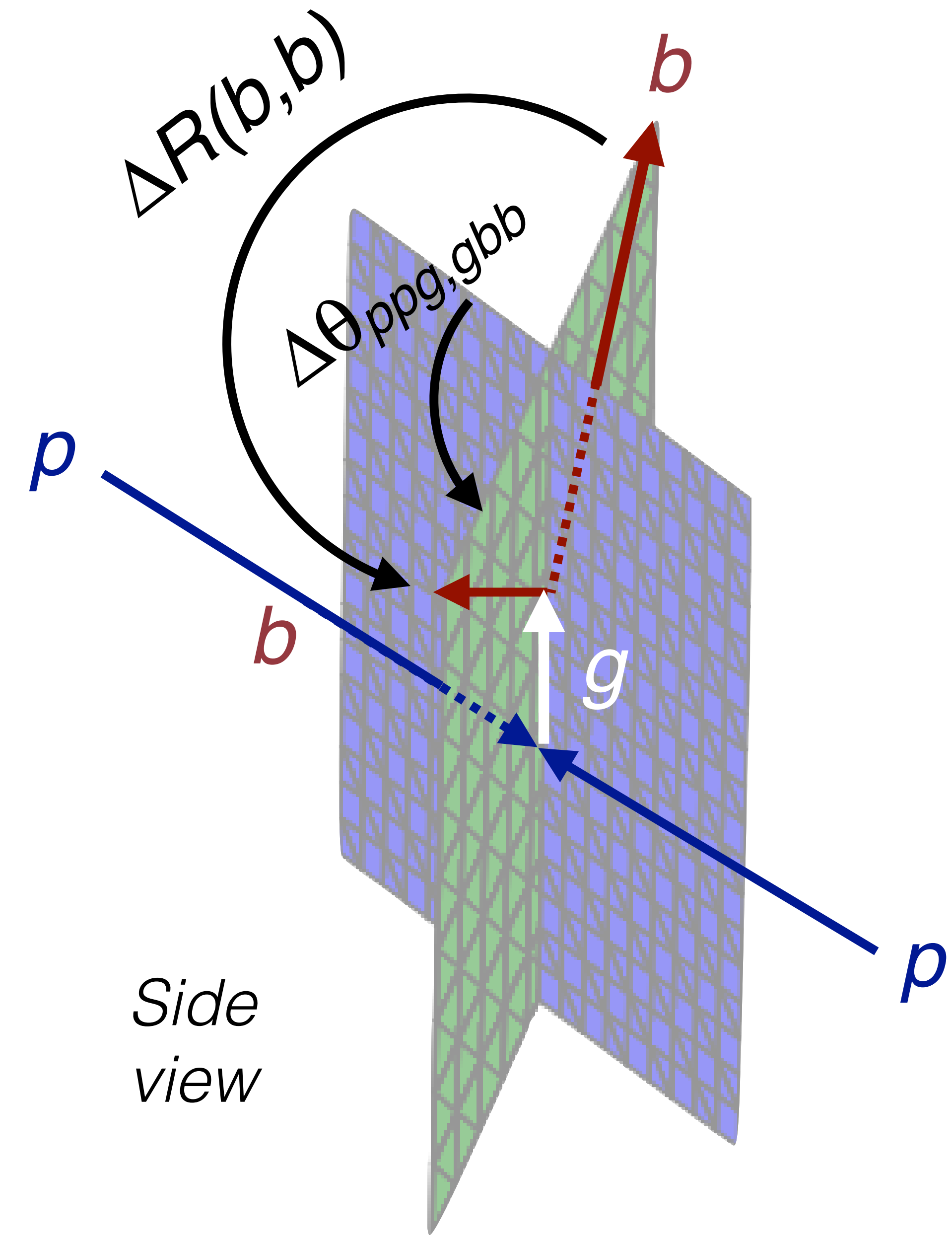


Phys. Rev. D 99, 052004 (2019)



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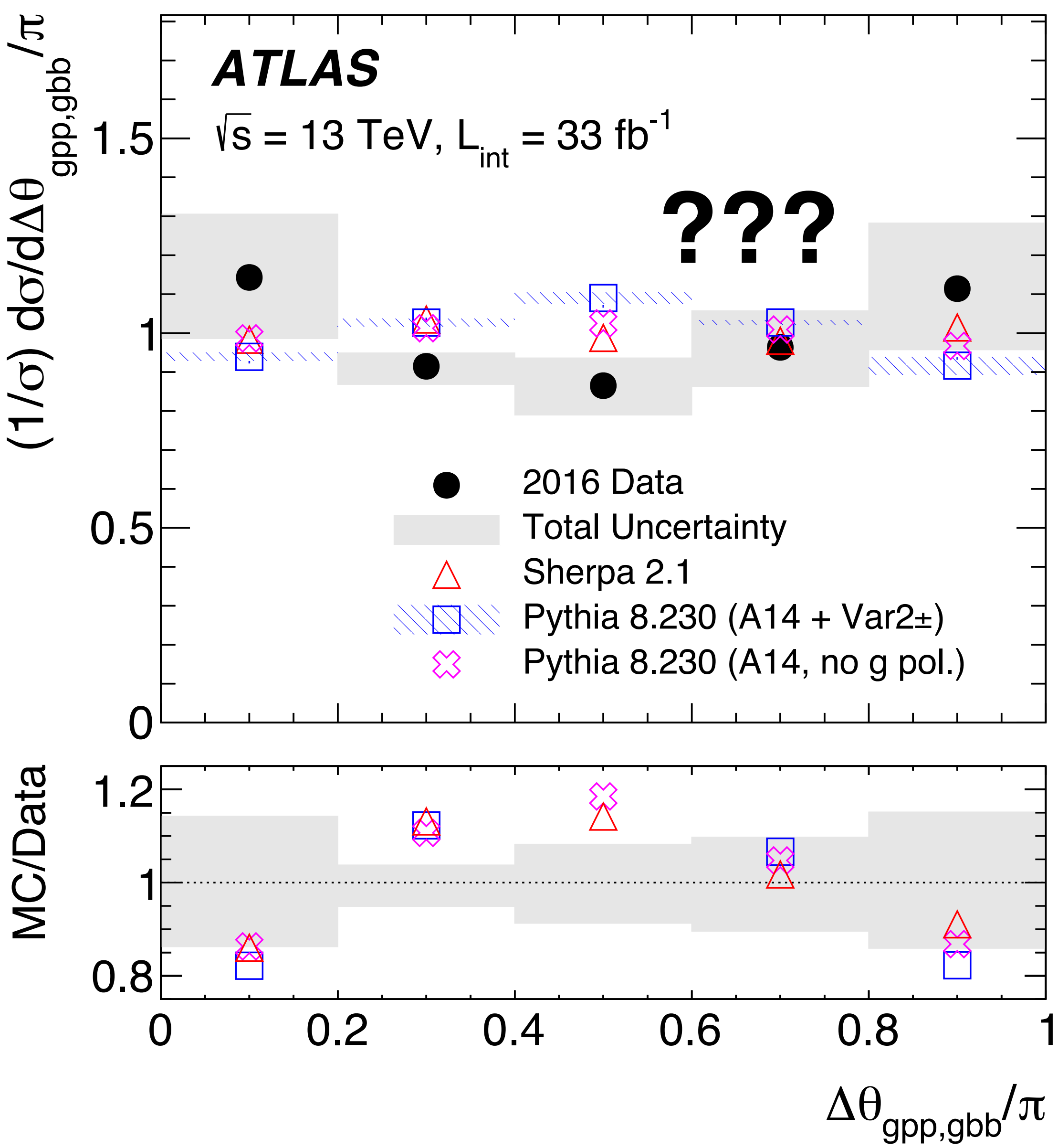


Phys. Rev. D 99, 052004 (2019)

Gluons seems "more polarized" in data than in our predictions. Slight improvement from matrix element corrections (Sherpa 2 → 3).

See also Fischer, Lifson, Skands, EPJC 77 (2017) 719

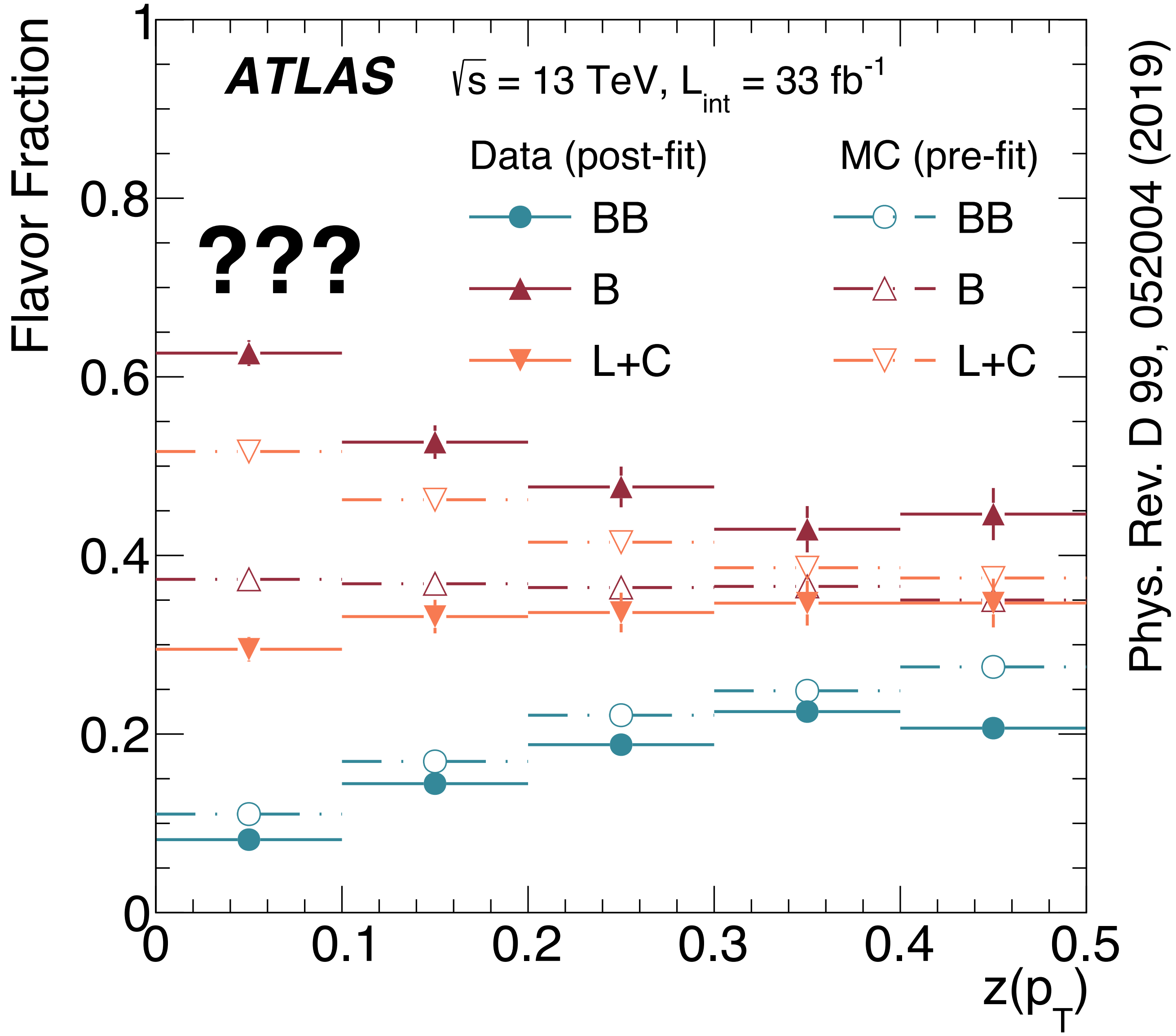
Correlations Part II: $g \to b\bar{b}$

We can use correlations between jets/hadrons as a way to expose emergent quantum properties

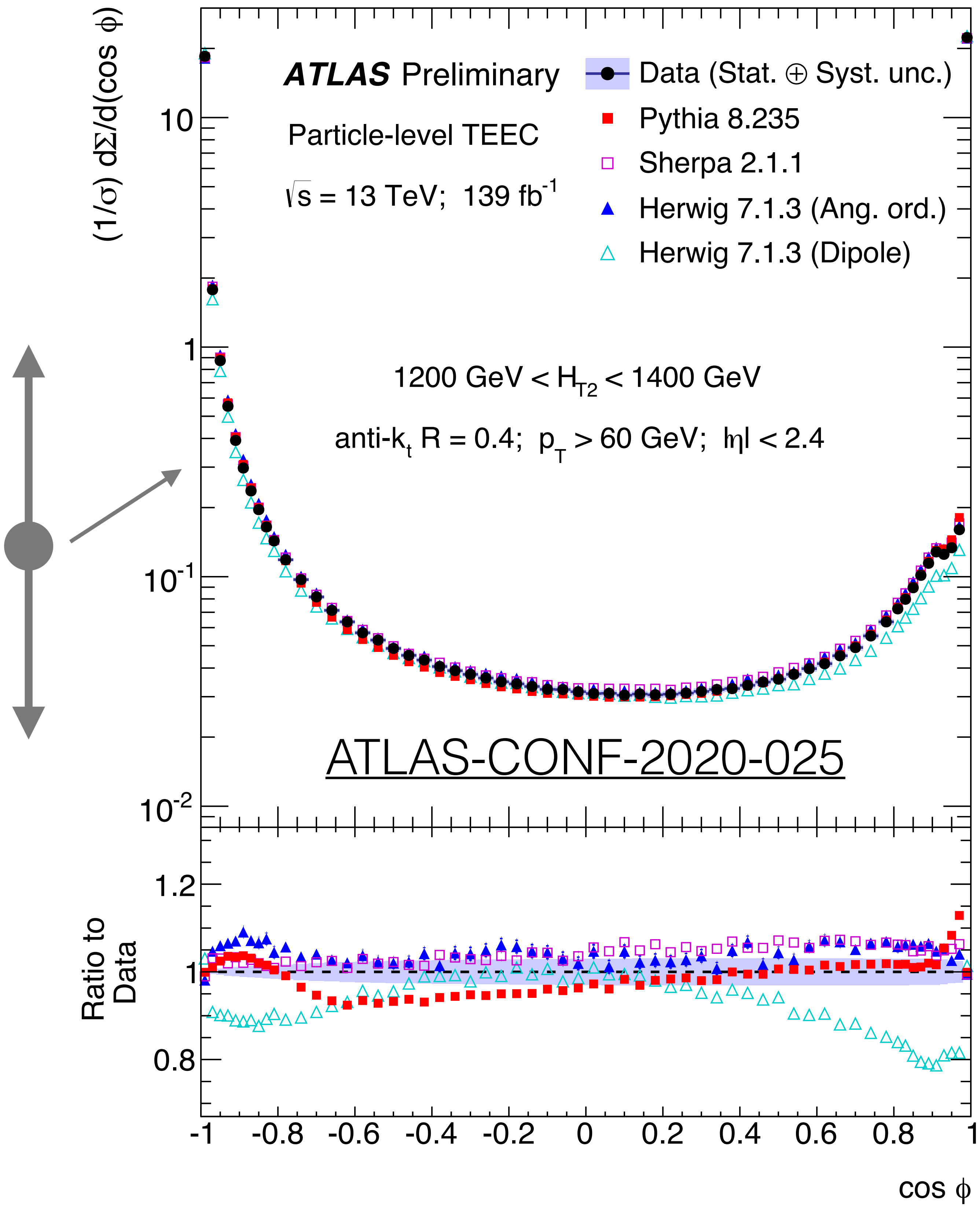
Example 2: g → bb

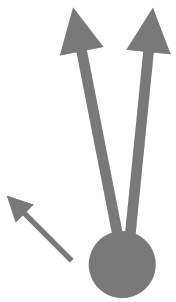
Also find that the flavor fractions are not quite correct?

(determined from a fit to the displacement of tracks inside jets)



Correlations Part III: TEECs





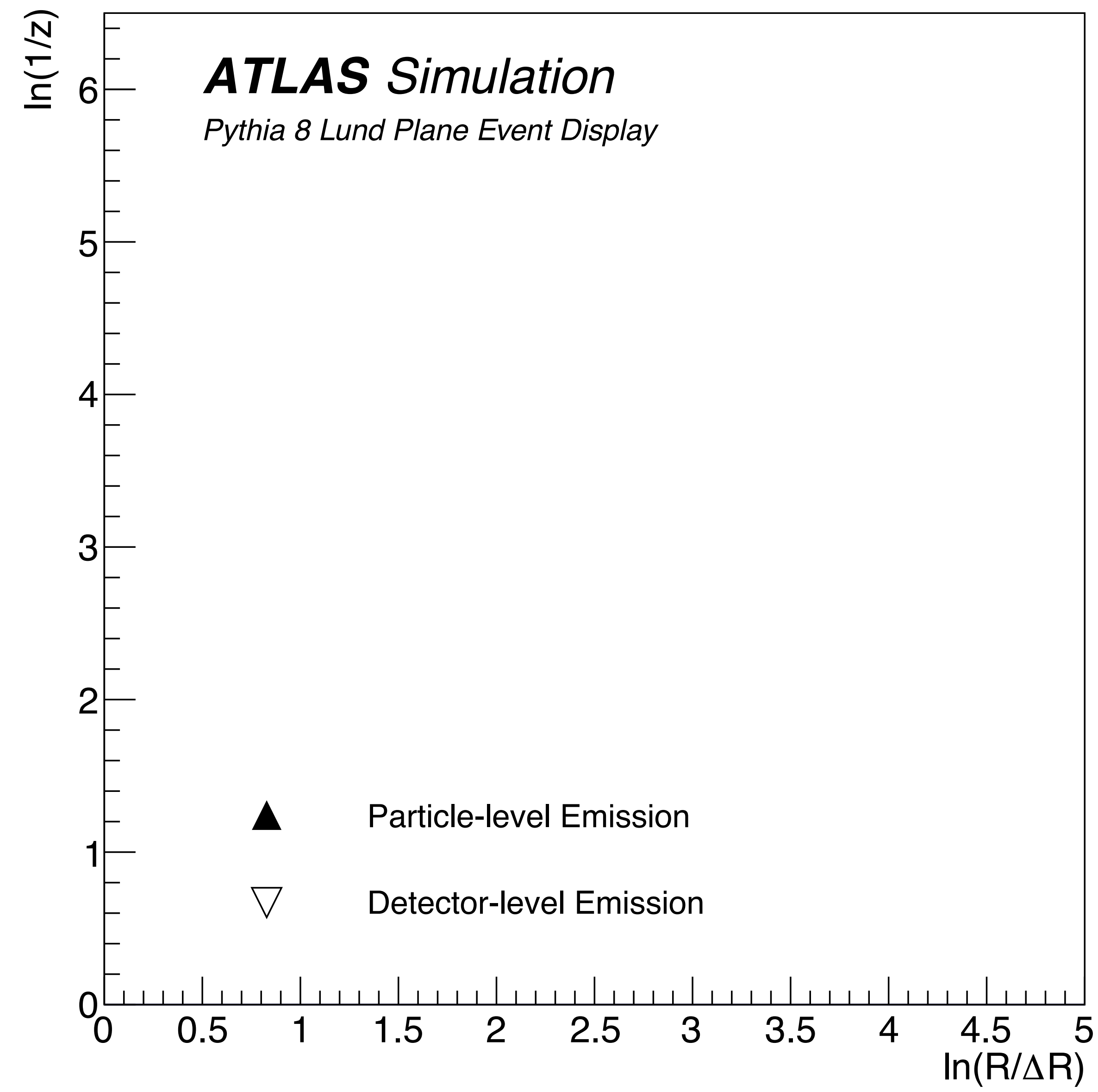
For probing angular scales larger than the jet radius, we can use jets to precisely probe event-level correlations

See also JHEP 01 (2021) 188 for jet-based event shapes measurements

Correlations Part IV: Isolate the Physics

Important: isolate effects with different physical origin

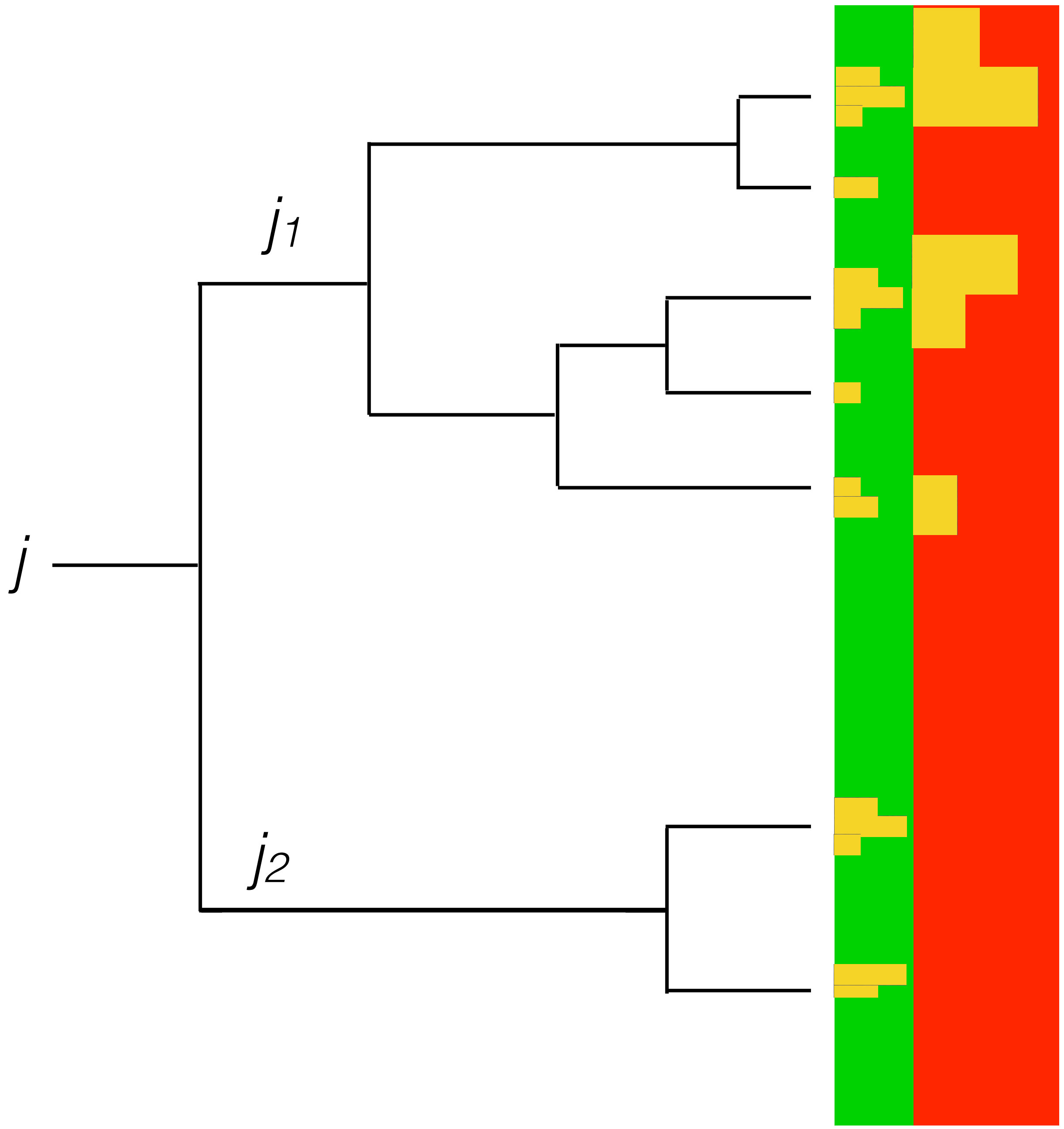
Tool: Lund plane to categorize all hard splittings at once

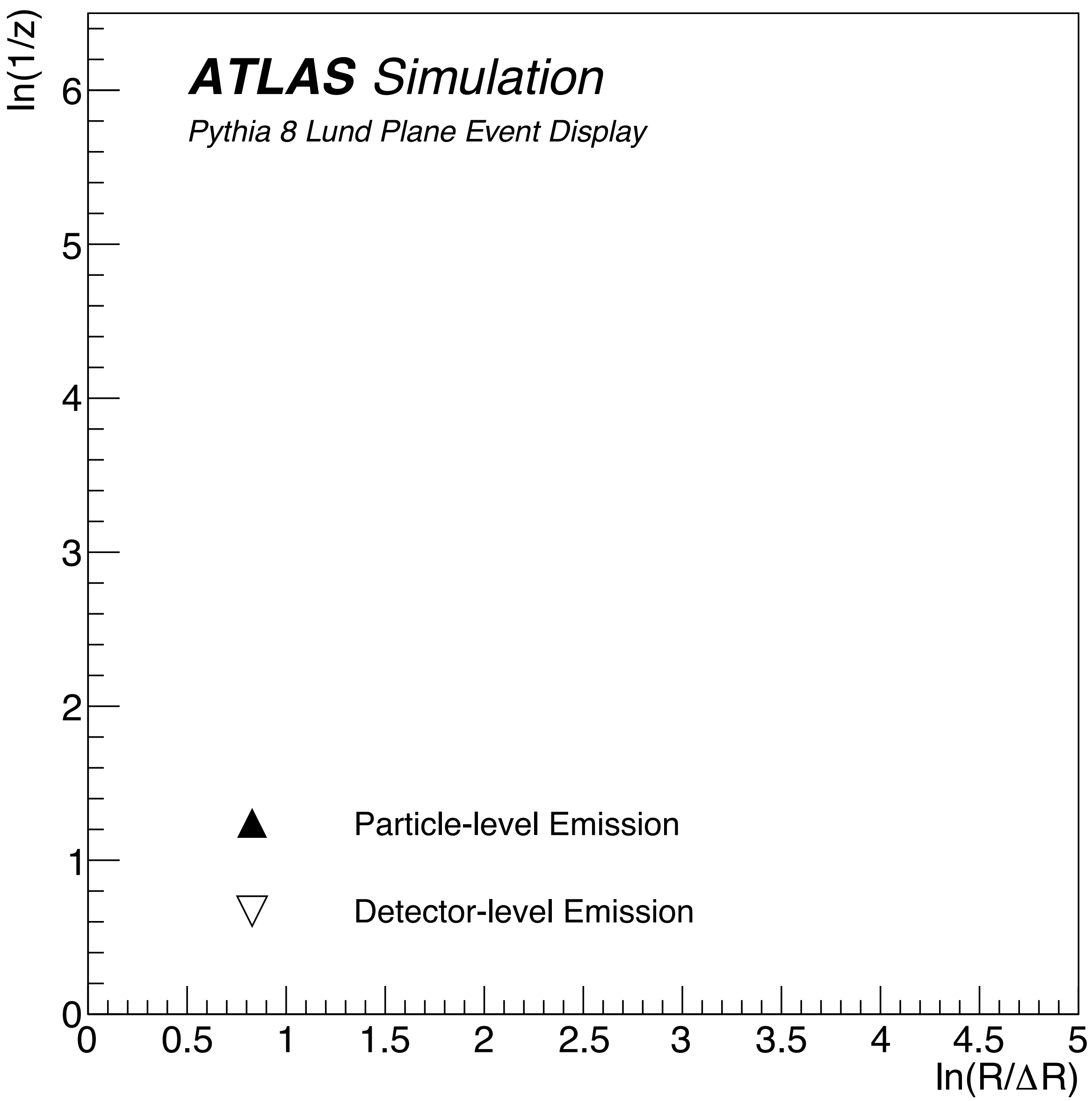


[Dreyer, Salam, Soyez, JHEP 12 (2018) 064]

Phys. Rev. Lett. 124, 222002 (2020)

Correlations Part IV: Isolate the Physics





z = j_1 momentum fraction of j

ΔR = angle between j_1 and j_2

Phys. Rev. Lett. 124, 222002 (2020)

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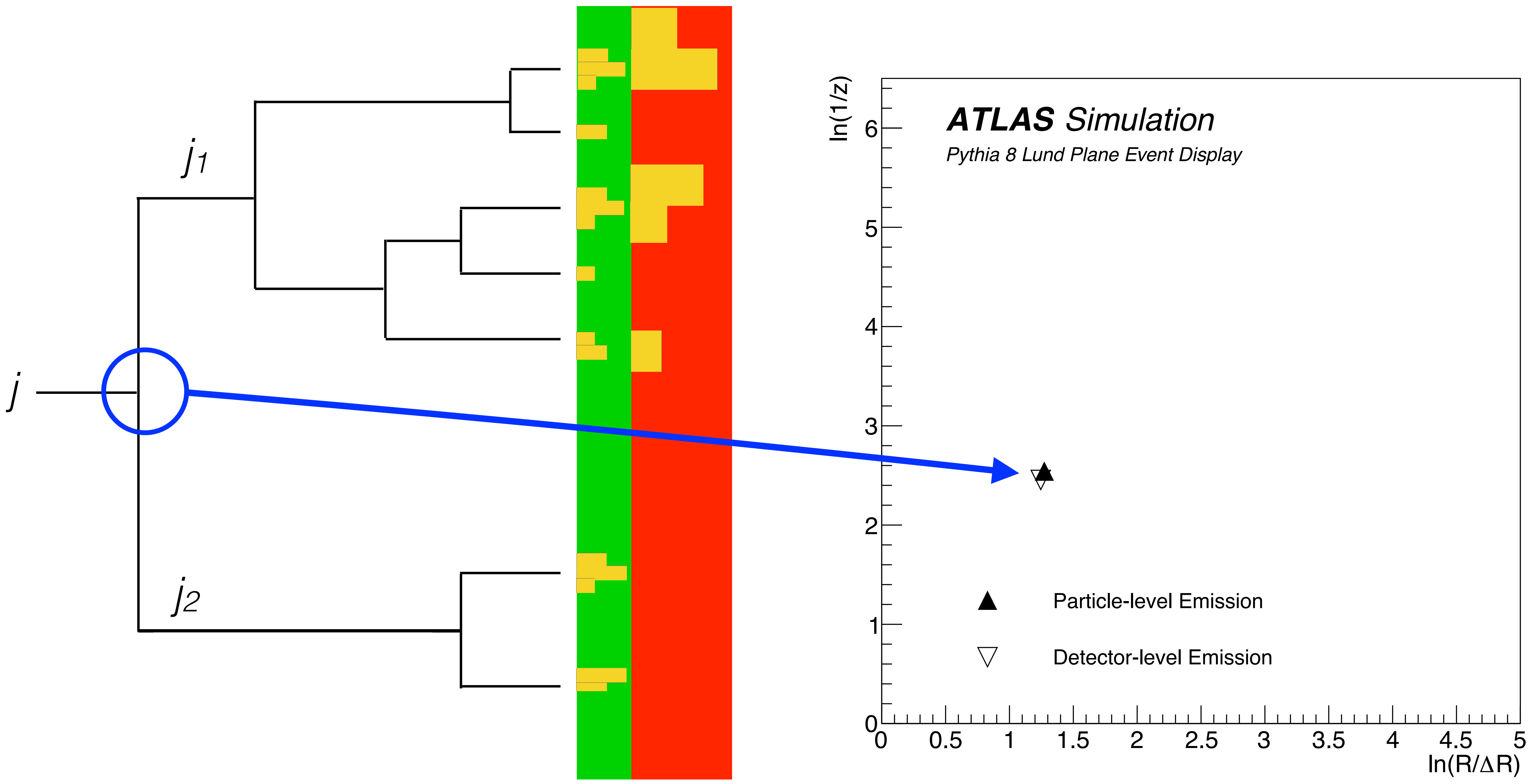

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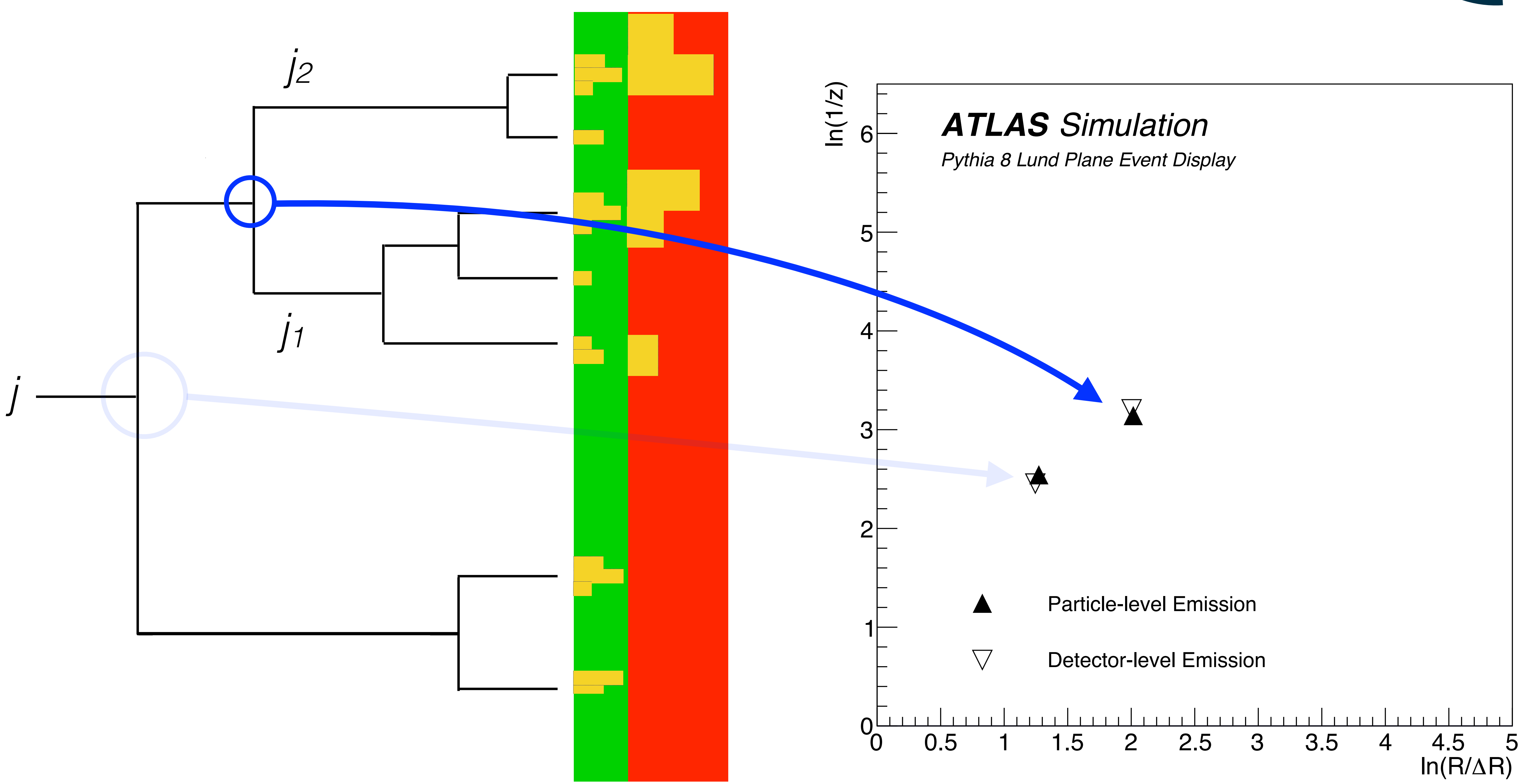

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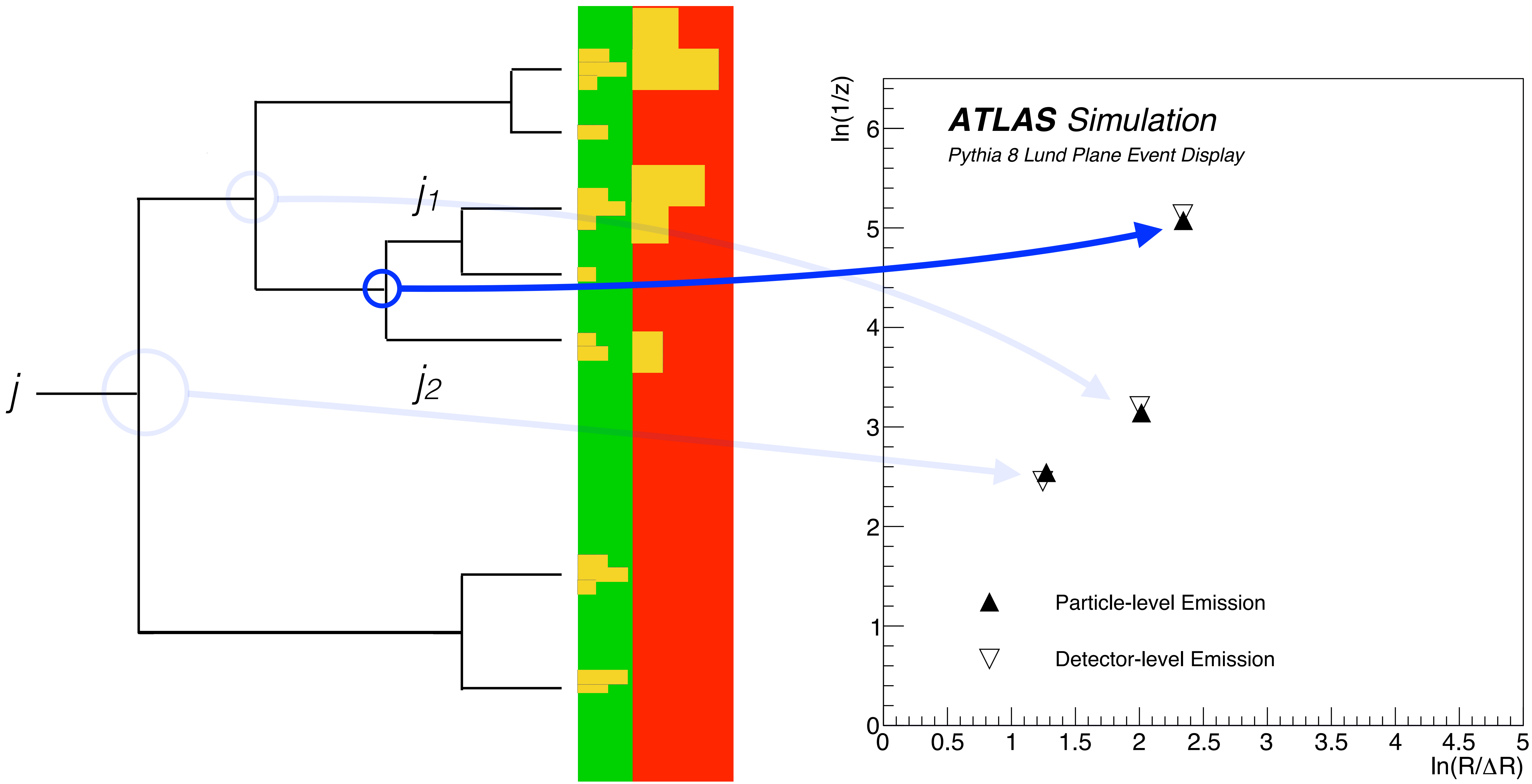

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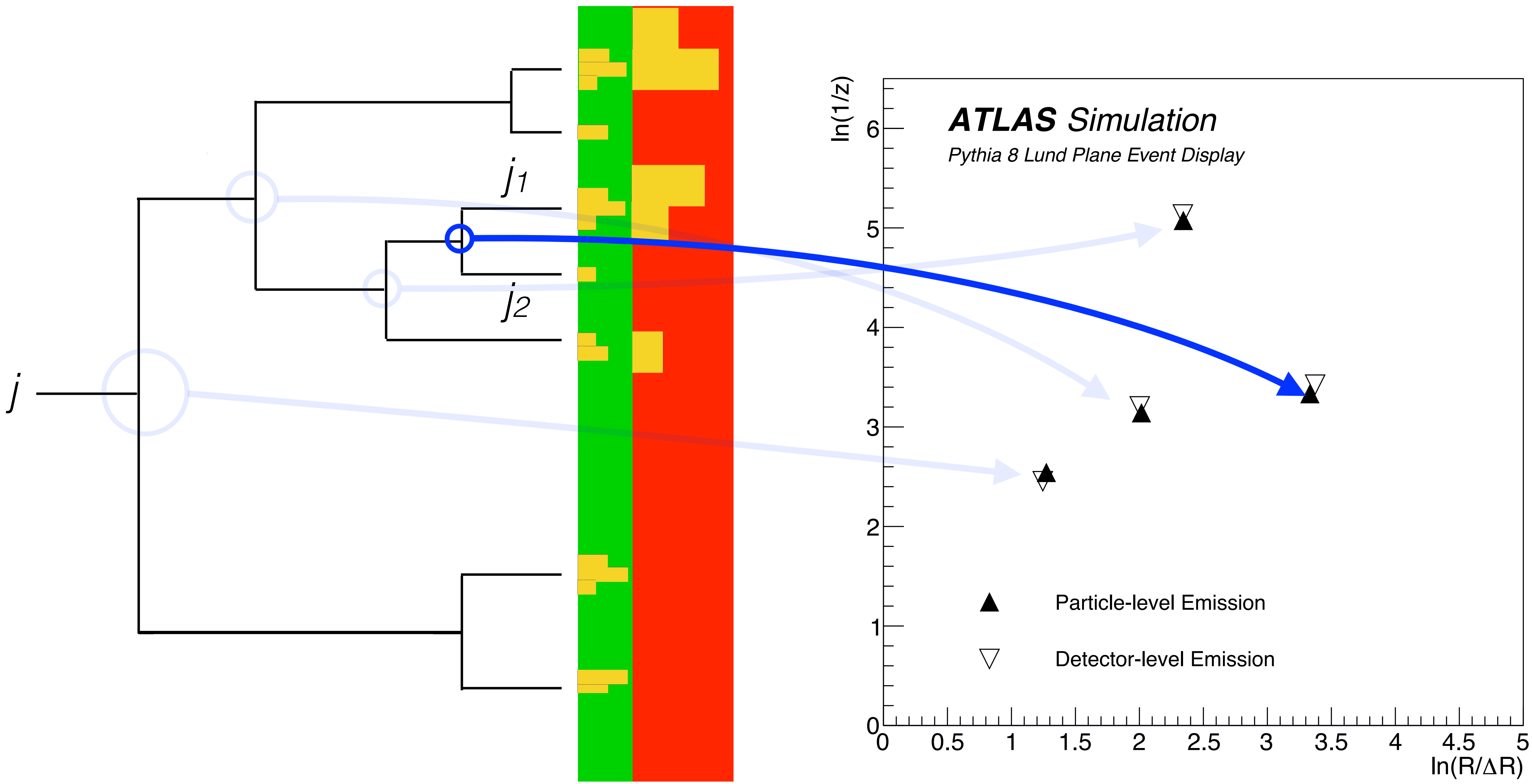

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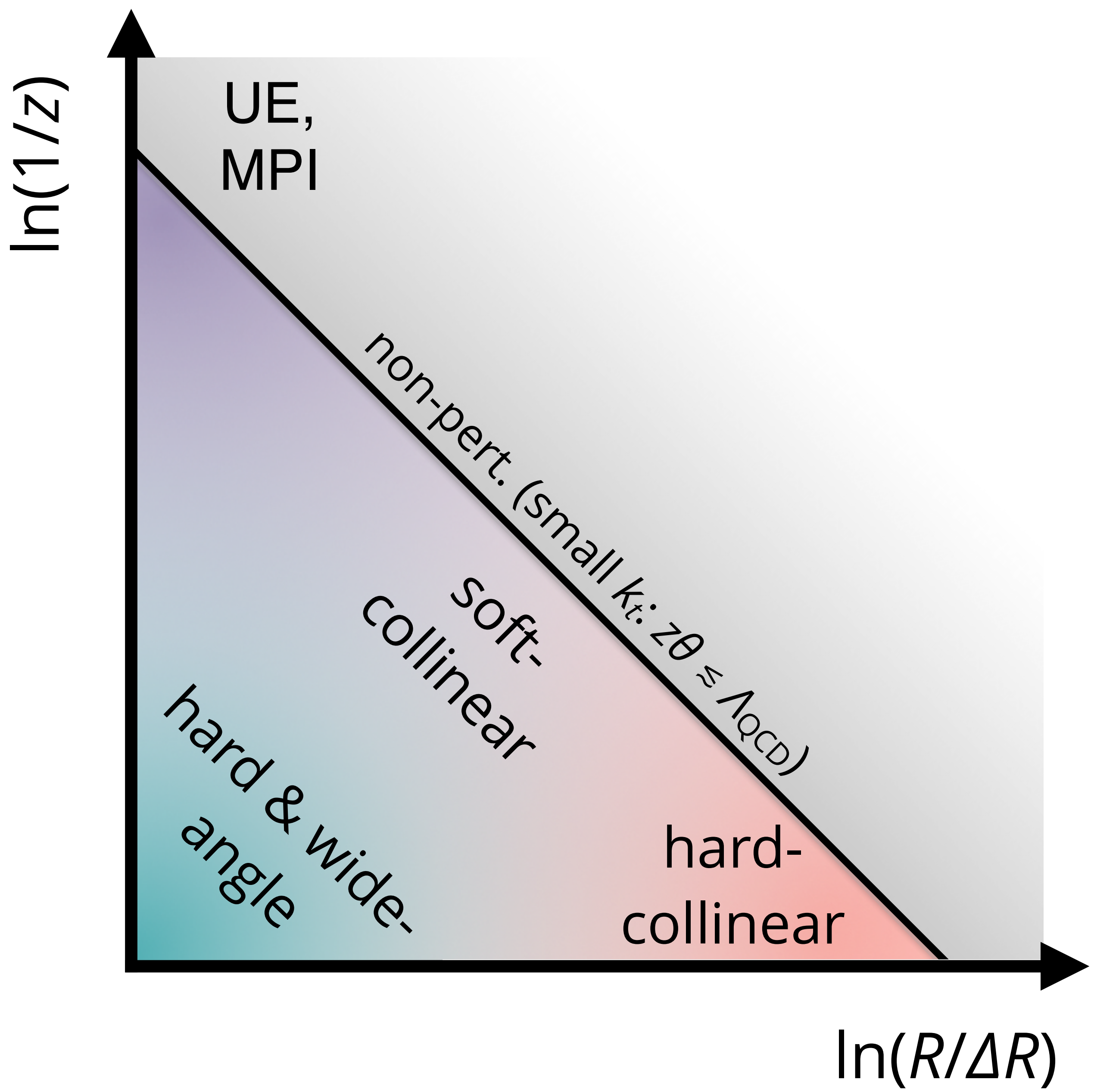
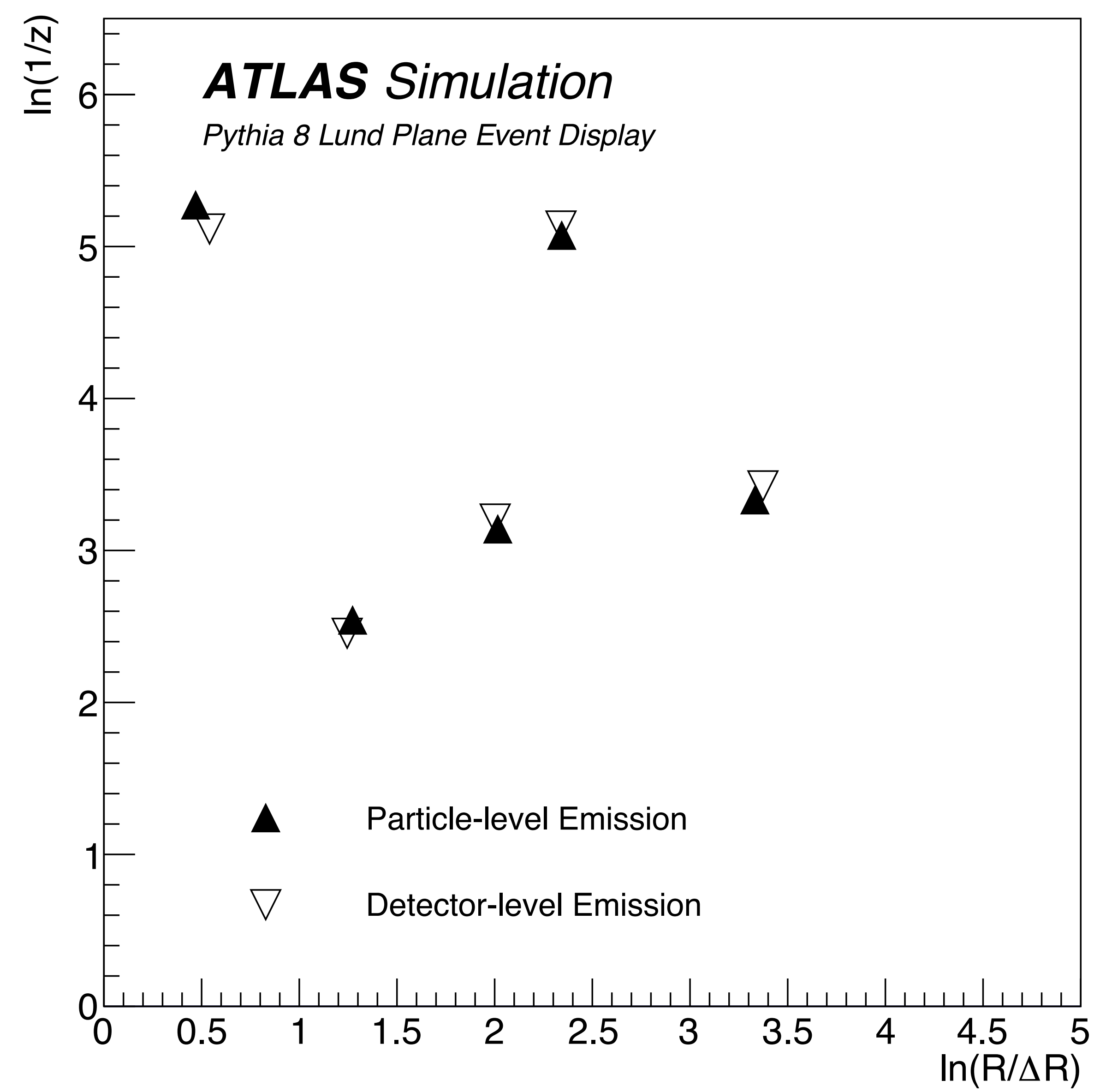
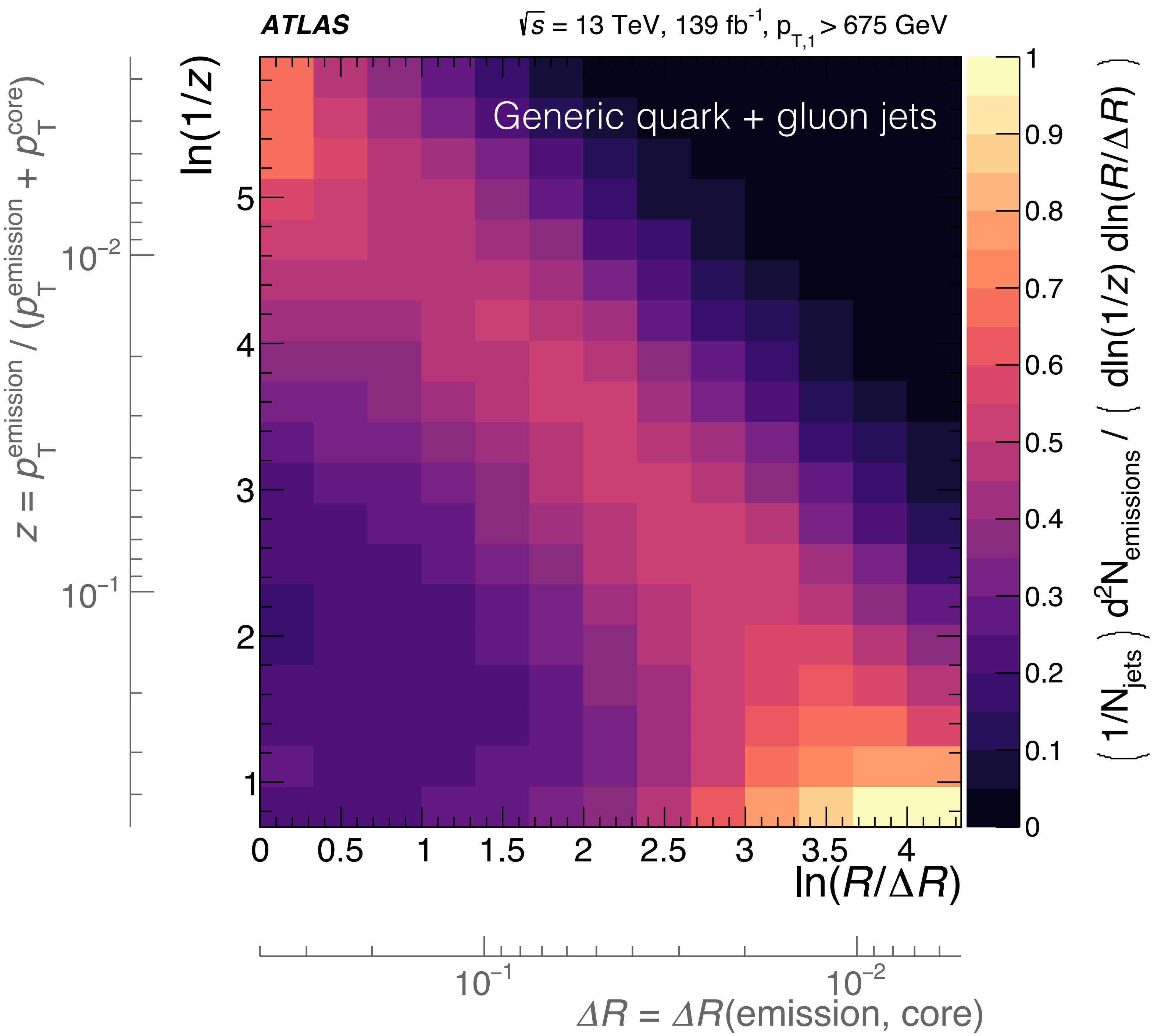




Factorize physical processes!

Phys. Rev. Lett. 124, 222002 (2020)

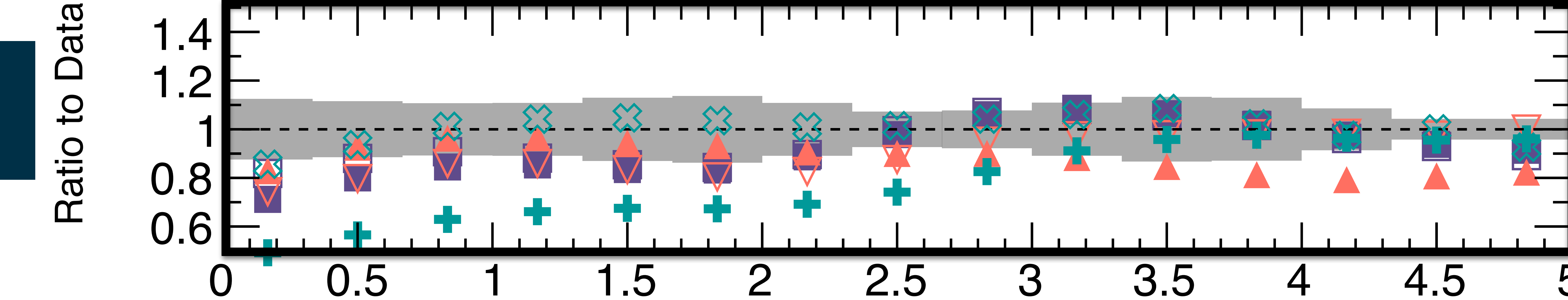
Correlations Part IV: Isolate the Physics

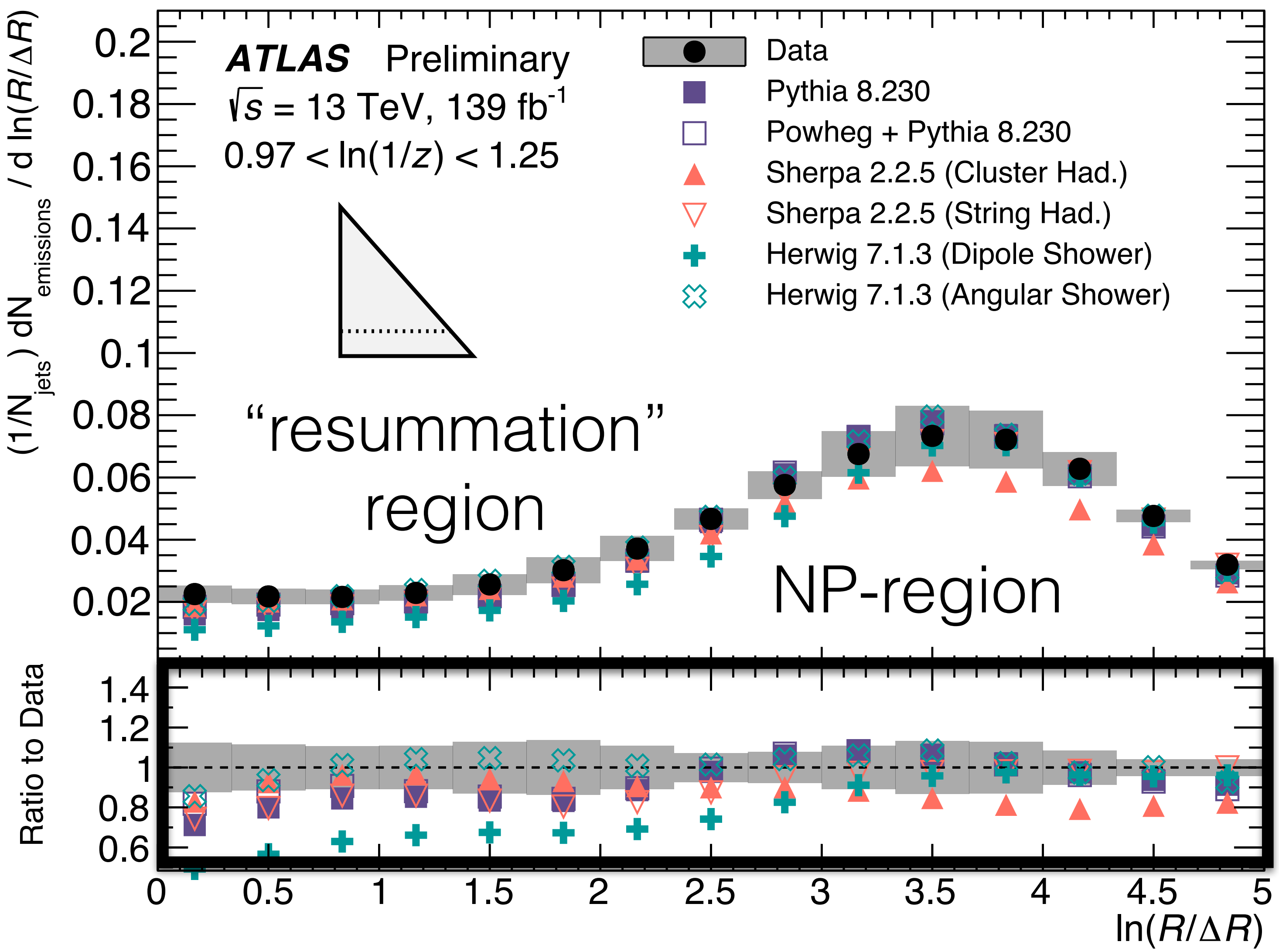


First measurement of the Lund jet plane!

…powerful tool for isolating hadronization, parton shower effects, and fixed-order effects

Key experimental challenge: **tracking inside dense environments**





▲ vs. ▽ hadronization

✚ vs. ✖ parton shower

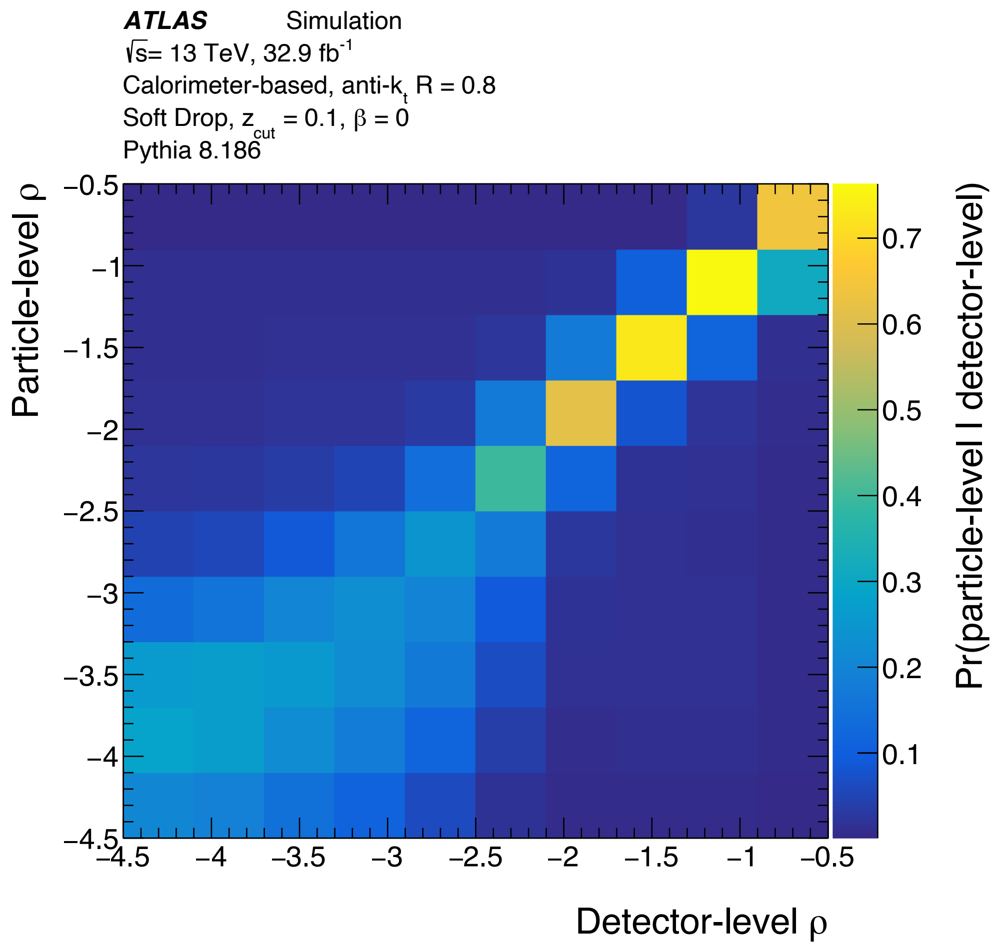
First measurement of the Lund jet plane!

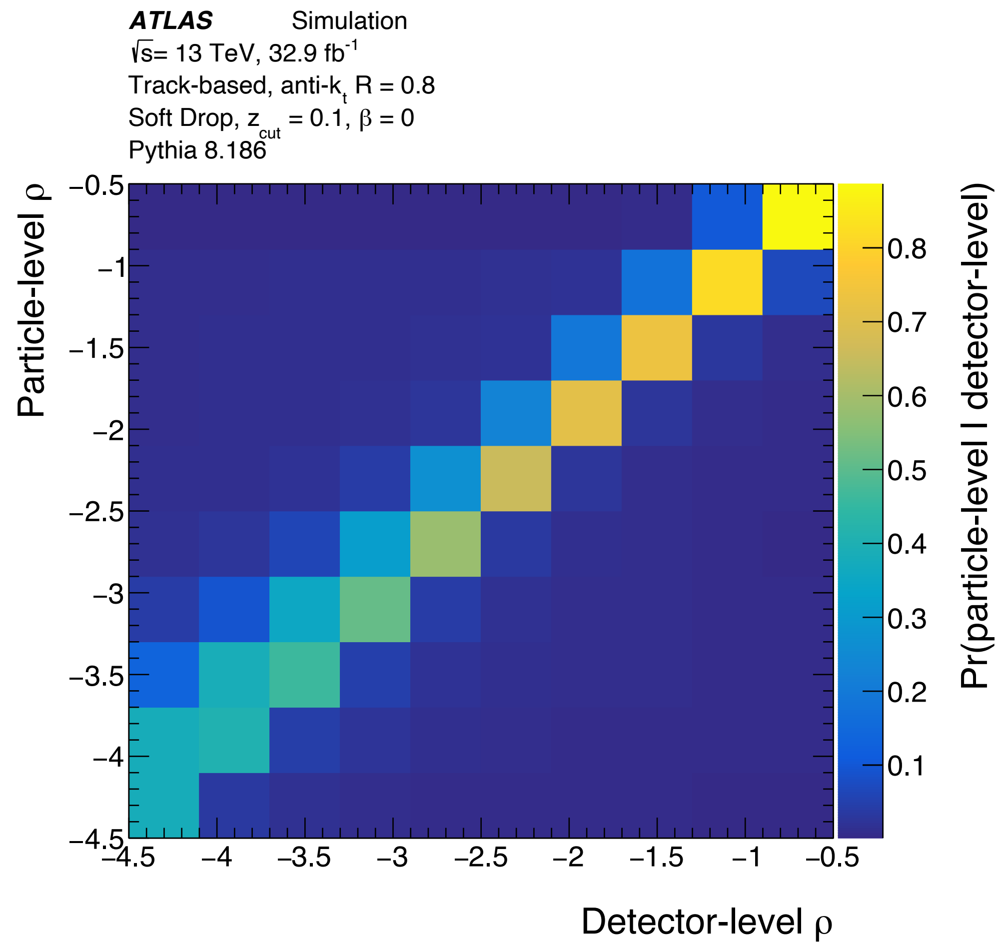
*…powerful tool for isolating **hadronization**, **parton shower effects**, and fixed-order effects*

Key experimental challenge:

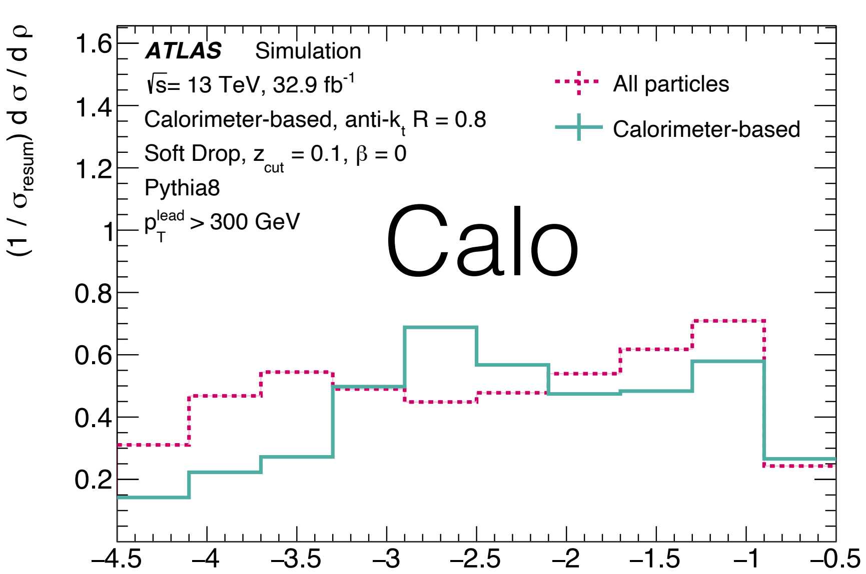
tracking inside dense environments

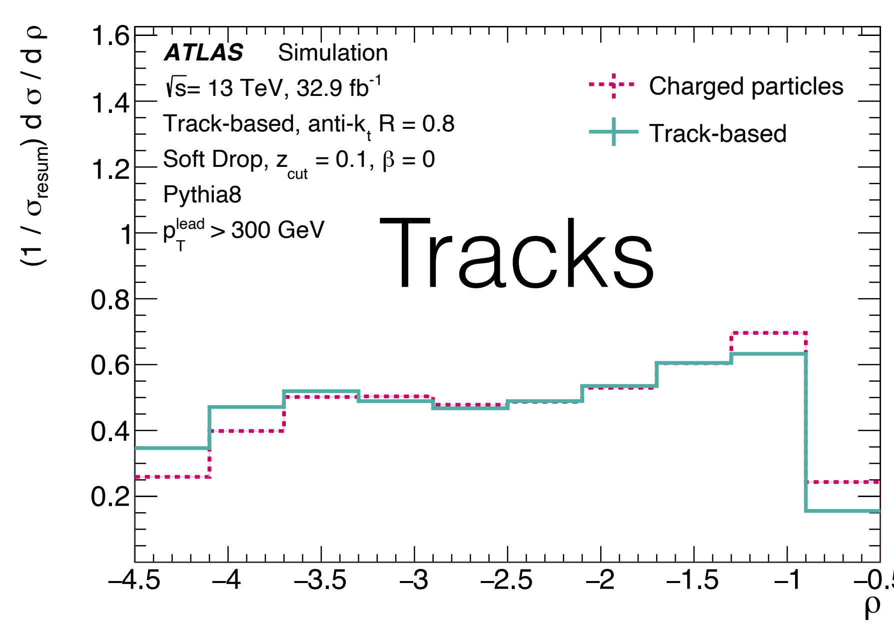
Correlations Part V: Tracks





PRD 101 (2020) 052007





ρ is (log) jet mass normalized by p_T

Correlations Part V: Tracks

ATLAS Simulation
$\sqrt{s}$= 13 TeV, 32.9 fb^{-1}
Calorimeter-based, anti-k_t R = 0.8
Soft Drop, z = 0.1, β = 0

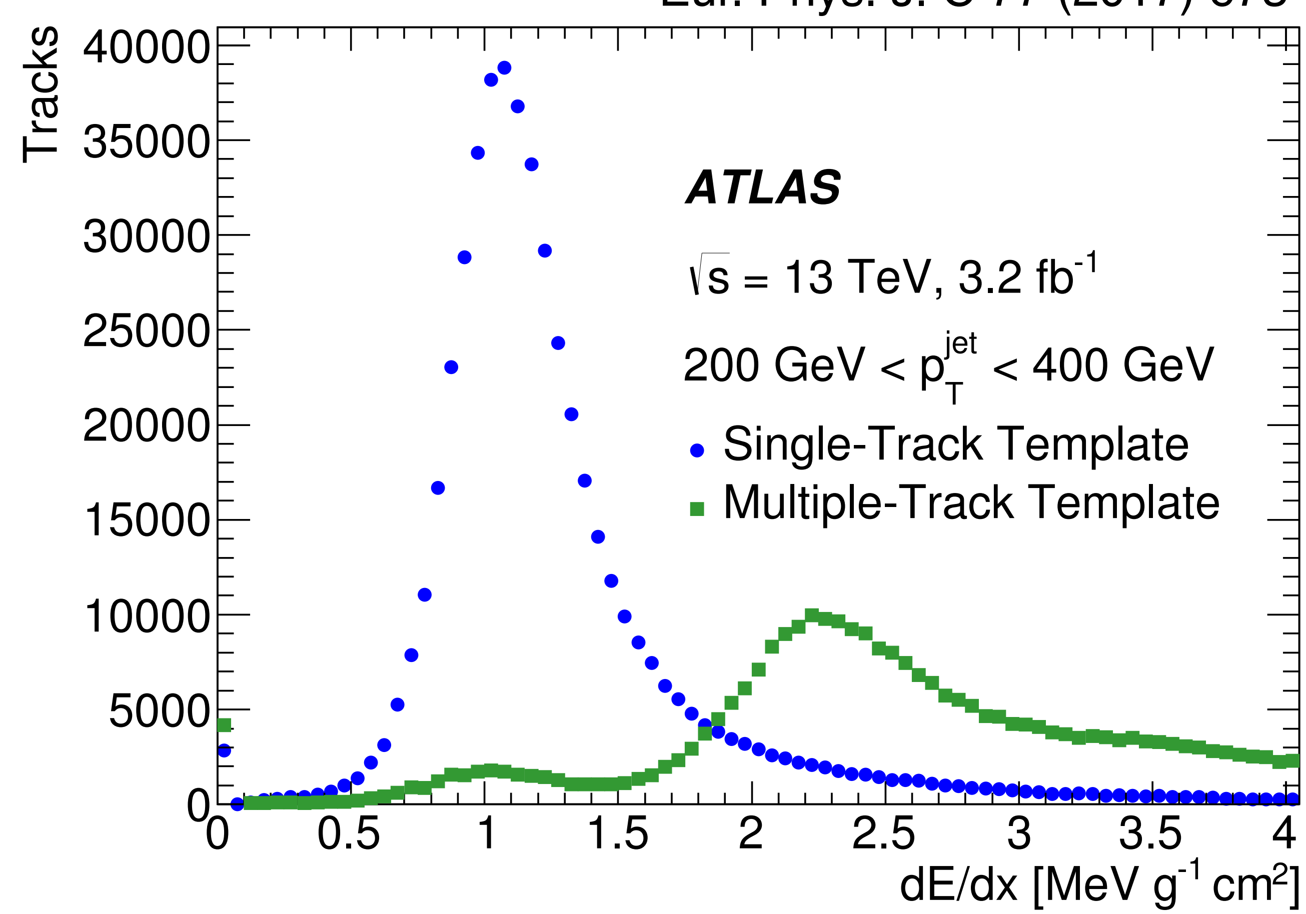
ATLAS Simulation
$\sqrt{s}$= 13 TeV, 32.9 fb^{-1}
Track-based, anti-k_t R = 0.8
Soft Drop, z = 0.1, β = 0

PRD 101 (2020) 052007

It is not just about resolution - we have rigorous per-track uncertainties, also taking into account density effects.

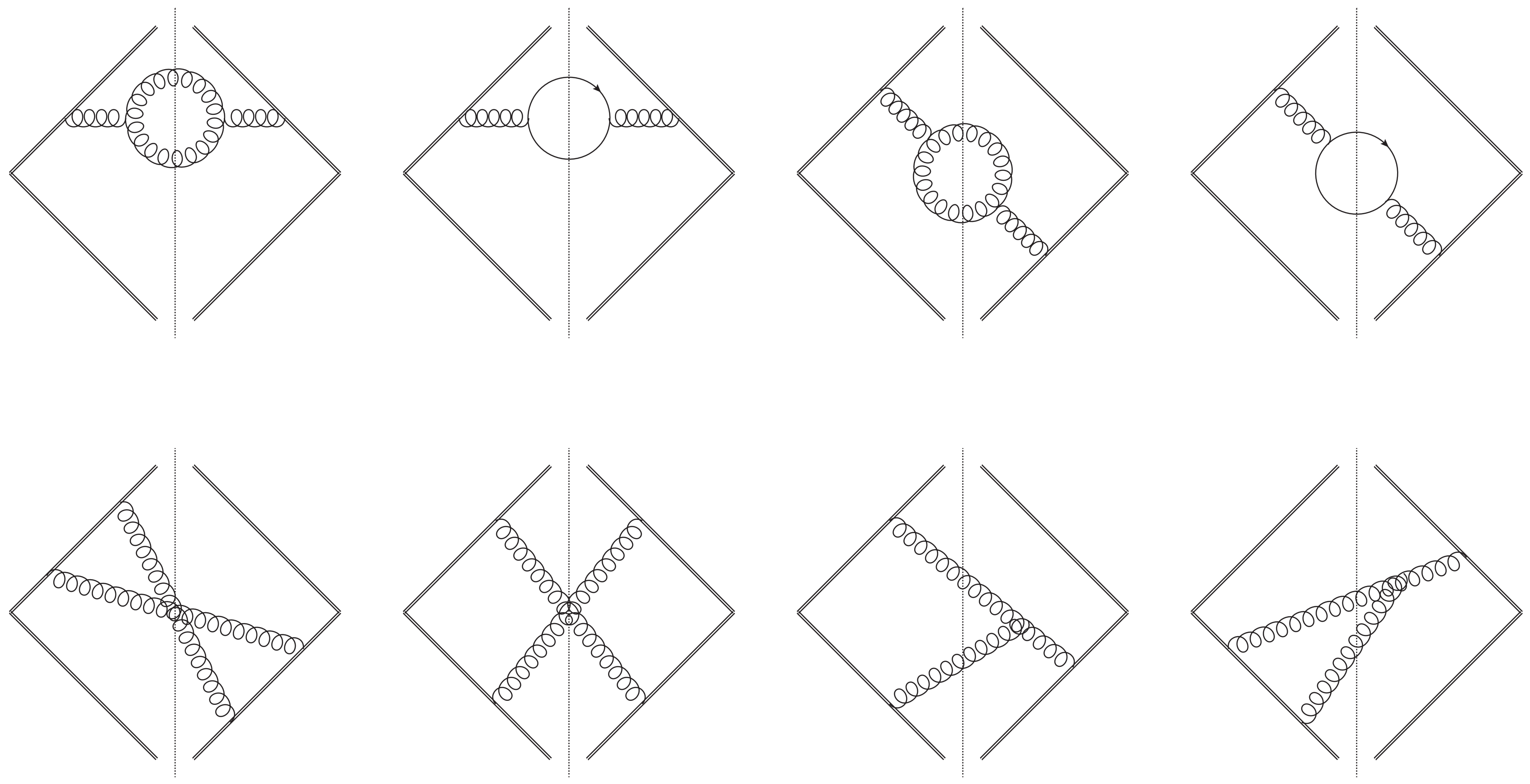
…we do not have the same level of rigor for calorimeter deposits.

Eur. Phys. J. C 77 (2017) 673



Correlations Part VI: Machine Learning

Impressive improvements in PSMC. How do we know the best observables to probe new effects?



Les Houches, 2003.01700

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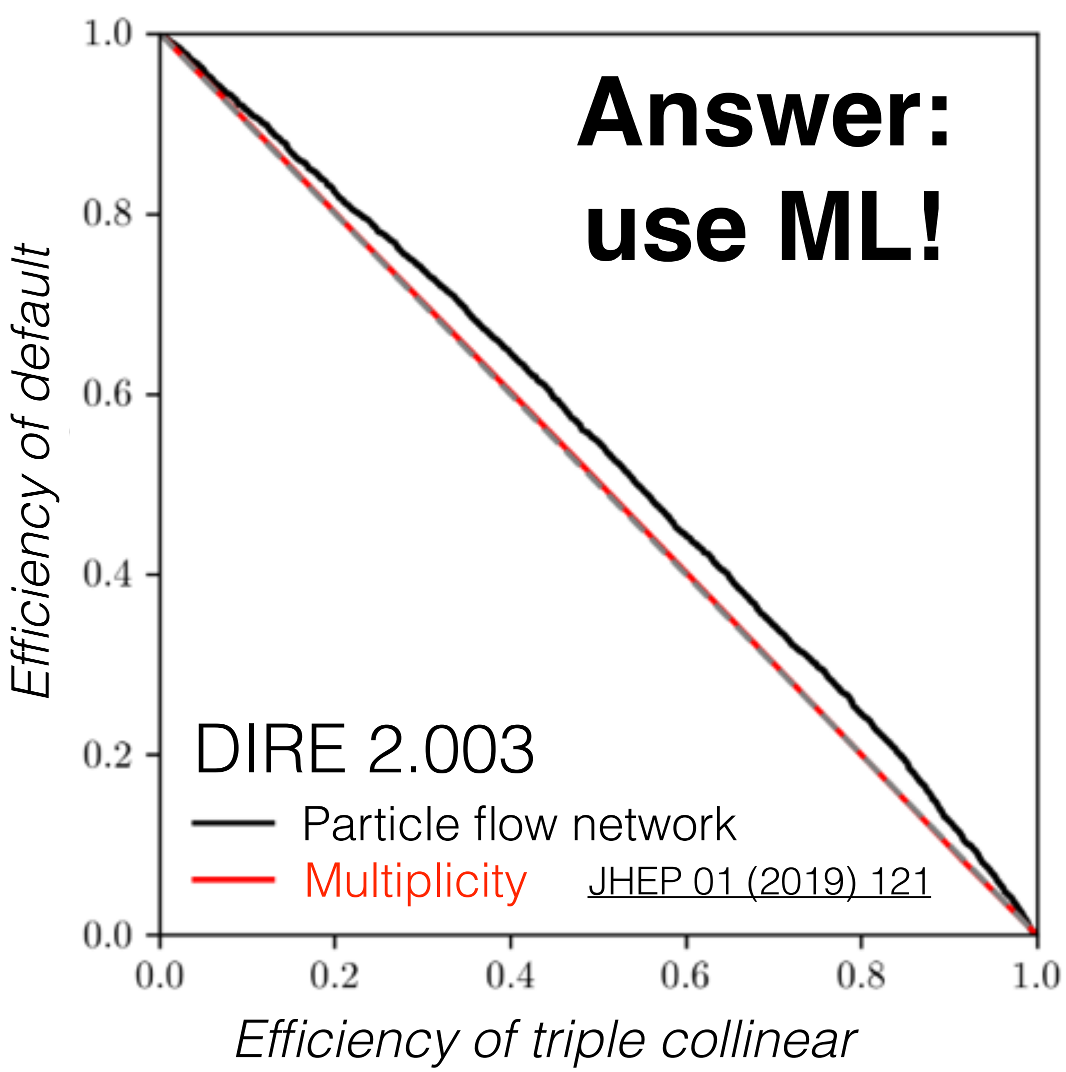
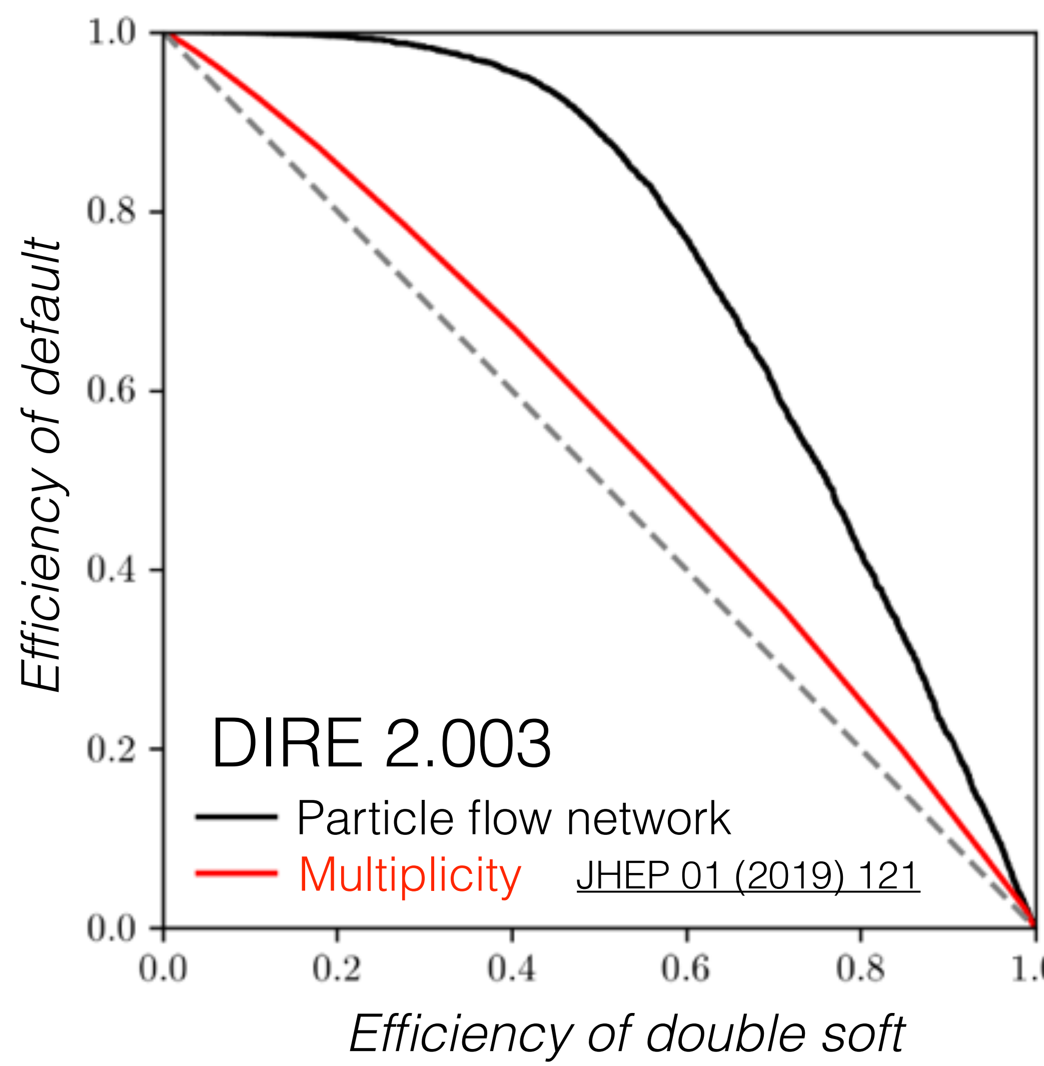
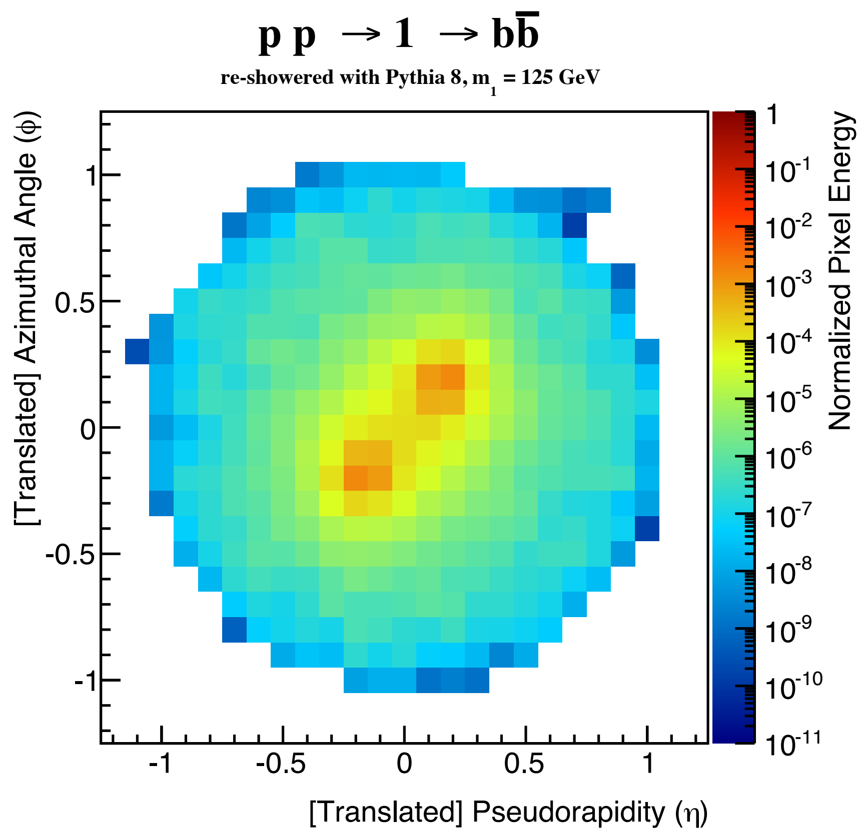


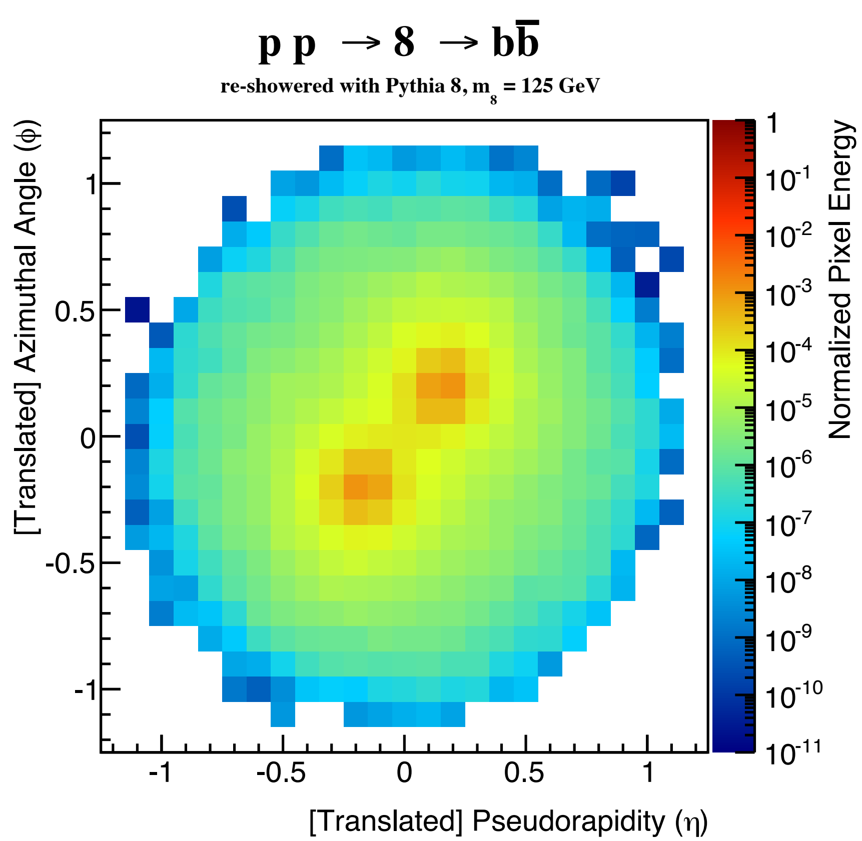


Les Houches, 2003.01700

Maybe **not** observable? Should be observable?

Correlations Future

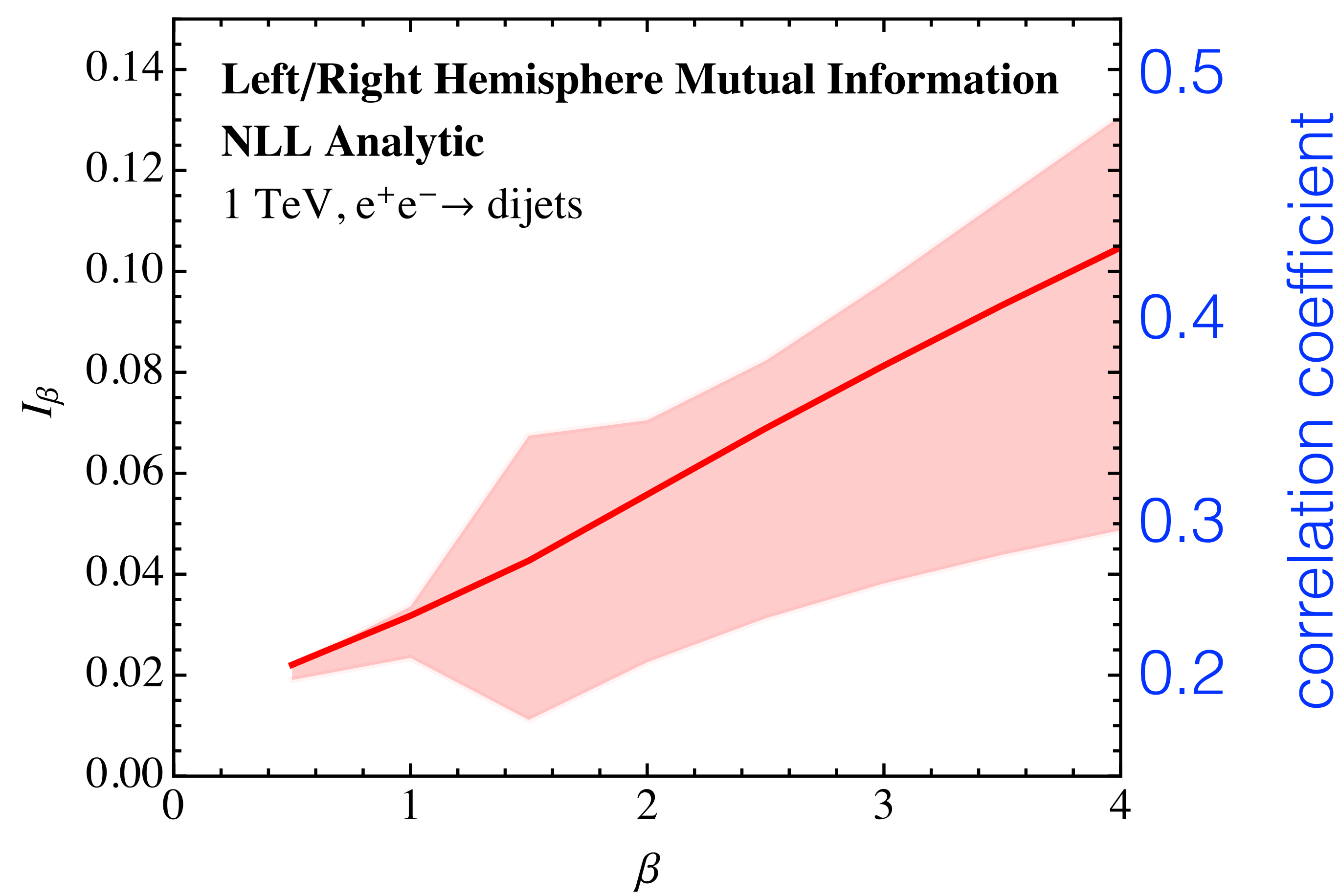




Colorflow more pronounced when boosted;
→ differential measurement (+tagging?)

Other observables: jet substructure correlations probe non-global effects in a clean way

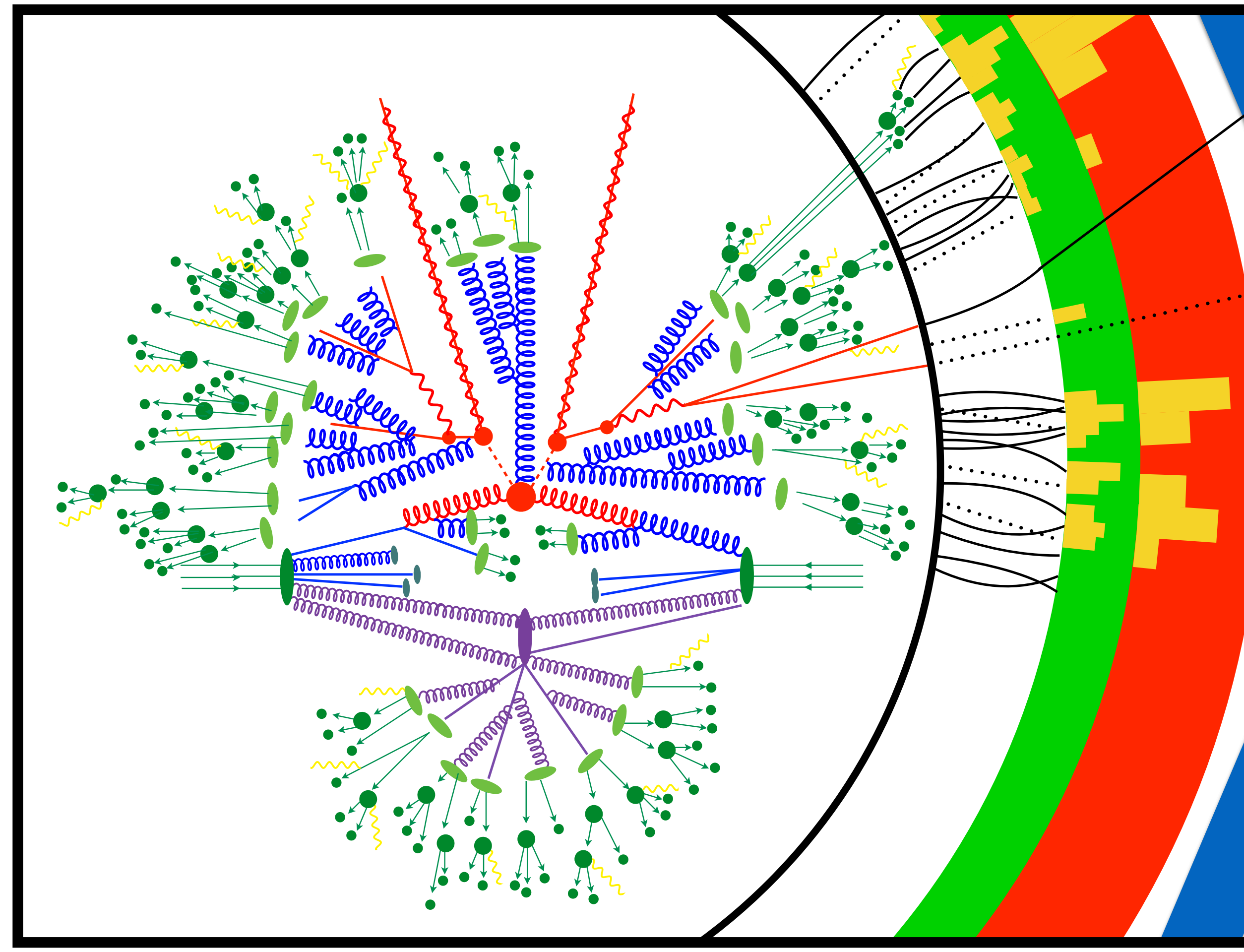
A. Larkoski, I. Moult, PRD 93, 014012 (2016)



← more jet grooming

Conclusions

High energy, hadronic final states are unique probes of QCD's emergent quantum properties



We need to think now about how we can design detectors, software, and computing to ensure future experiments can expand this growing physics program!

Backup