Measurement of the Lund jet plane and its properties

July 3rd, 2023

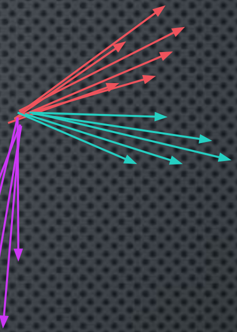
Lund Jet Plane Institute 2023

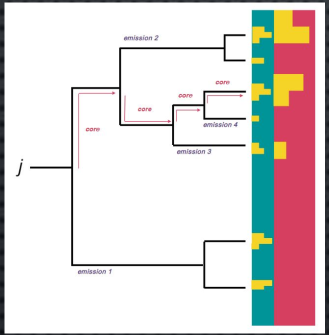
Emily Smith

On behalf of the ATLAS collaboration

Outline

Jets



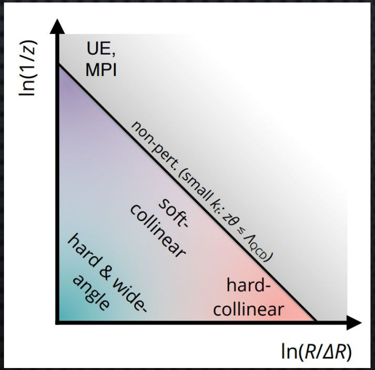


ATLAS soft-drop mass + observables

PRL 121, 092001 (2018), PRD 101, 052007 (2020)

ATLAS Lund Jet Plane

PRL 124, 222002 (2020)



LHC and jets: complex yet crucial

Extreme hadronic environment = many jets! 

~1500 results using jets at the LHC: omnipresent and inescapable!

Jets are <u>challenging</u> physics objects!

Both experimentally:

composite objects, multiple sub-detectors, multiple scales, pile-up, etc…

Many many tools: grooming / tagging / pileup mitigation / triggering

And theoretically:

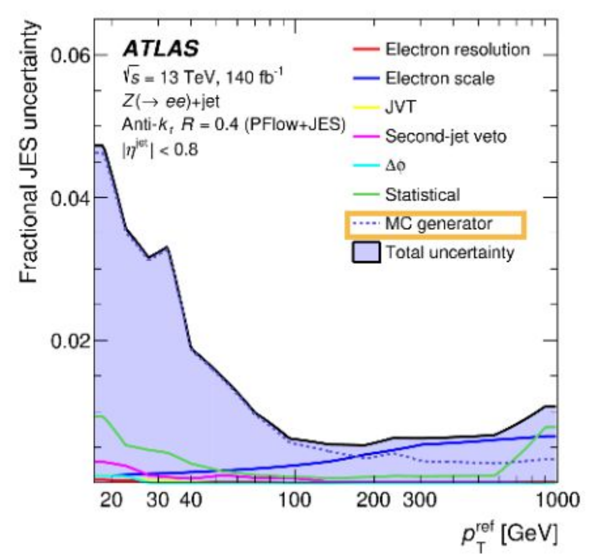
Non-perturbative aspects

Fixed-order calculations

Resummation dominated

High Modelling Impact

Extensive work done by LHC physicists to calibrate the jet energy scale (JES)



JES uncertainty still driven by nominal MC model in many regions

Many analyses have modelling / JES dominated uncertainties

Top mass m_t
EPJC 79 (2019) 290

		$\sqrt{s}$ = 8 TeV		
		$m_{top}^{dilepton}$ [GeV]	$m_{top}^{\ell+jets}$ [GeV]	$m_{top}^{alljets}$ [GeV]
k	Results ($i = 0 \ldots, 5$)	172.99	172.08	173.72
0	Statistics	0.41	0.39	0.55
	– *Stat. comp.* (m_{top})		0.11	
	– *Stat. comp.* (JSF)		0.11	
	– *Stat. comp.* (bJSF)		0.35	
1	Method	0.05 ± 0.07	0.13 ± 0.11	0.11
2	Signal Monte Carlo generator	0.09 ± 0.15	0.16 ± 0.17	0.18 ± 0.21
3	Hadronization	0.22 ± 0.09	0.15 ± 0.10	0.64 ± 0.15
4	Initial- and final-state QCD radiation	0.23 ± 0.07	0.08 ± 0.11	0.10 ± 0.28
5	Underlying event	0.10 ± 0.14	0.08 ± 0.15	0.12 ± 0.16
6	Colour reconnection	0.03 ± 0.14	0.19 ± 0.15	0.12 ± 0.16
7	Parton distribution function	0.05 ± 0.00	0.09 ± 0.00	0.09 ± 0.00
8	Background normalization	0.03 ± 0.00	0.08 ± 0.00	
9	W/Z+jets shape	0	0.11 ± 0.00	
10	Fake leptons shape	0.07 ± 0.00	0	
11	Data-driven all-jets background			0.17
12	Jet energy scale	0.54 ± 0.04	0.54 ± 0.02	0.60 ± 0.03
13	Relative b-to-light-jet energy scale	0.30 ± 0.01	0.03 ± 0.01	0.34 ± 0.02
14	Jet energy resolution	0.09 ± 0.05	0.20 ± 0.04	0.10 ± 0.04
15	Jet reconstruction efficiency	0.01 ± 0.00	0.02 ± 0.01	0
16	Jet vertex fraction	0.02 ± 0.00	0.09 ± 0.01	0.03 ± 0.01
17	b-tagging	0.04 ± 0.02	0.38 ± 0.00	0.10 ± 0.00
18	Leptons	0.14 ± 0.01	0.16 ± 0.01	0.01 ± 0.00
19	Missing transverse momentum	0.01 ± 0.01	0.05 ± 0.01	0.01 ± 0.01
20	Pile-up	0.05 ± 0.01	0.15 ± 0.01	0.01 ± 0.00
21	All-jets trigger			0.08 ± 0.01
22	Fast vs. full simulation			
	Total systematic uncertainty	0.74 ± 0.05	0.82 ± 0.06	1.02 ± 0.11
	Total	0.85 ± 0.05	0.91 ± 0.06	1.16 ± 0.11

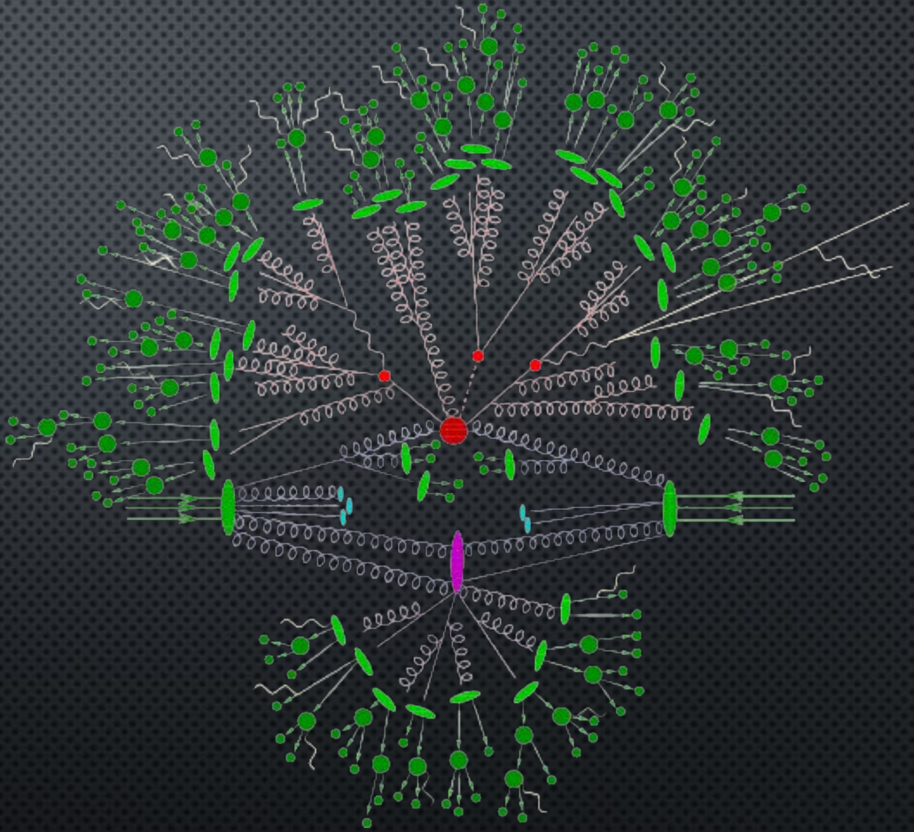
Jet Clustering

Many emissions from hadronization obscure the hard structure of a jet

Want to study this structure as part of JSS measurements!

Early jet reconstruction and grooming algorithms didn't work well for theory calculations

first perturbative splitting of the jet is interesting!

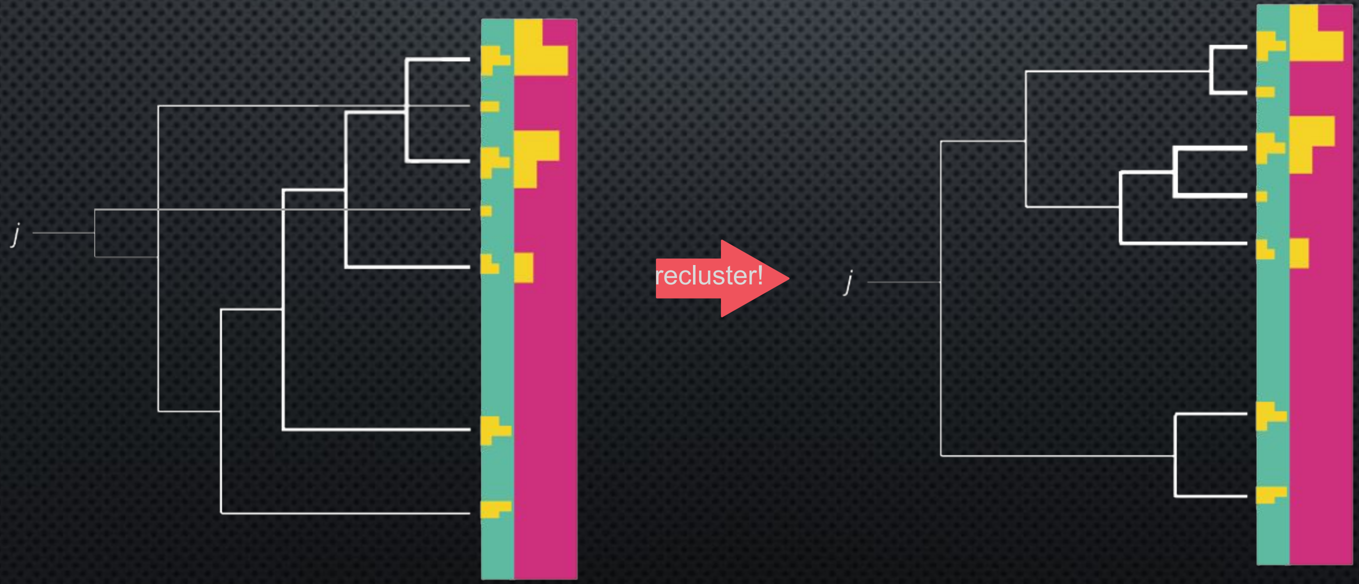


Jet Clustering

anti-k_T default ATLAS reconstruction algorithm

- Non-physical picture
- Can't easily see the "earliest" splitting

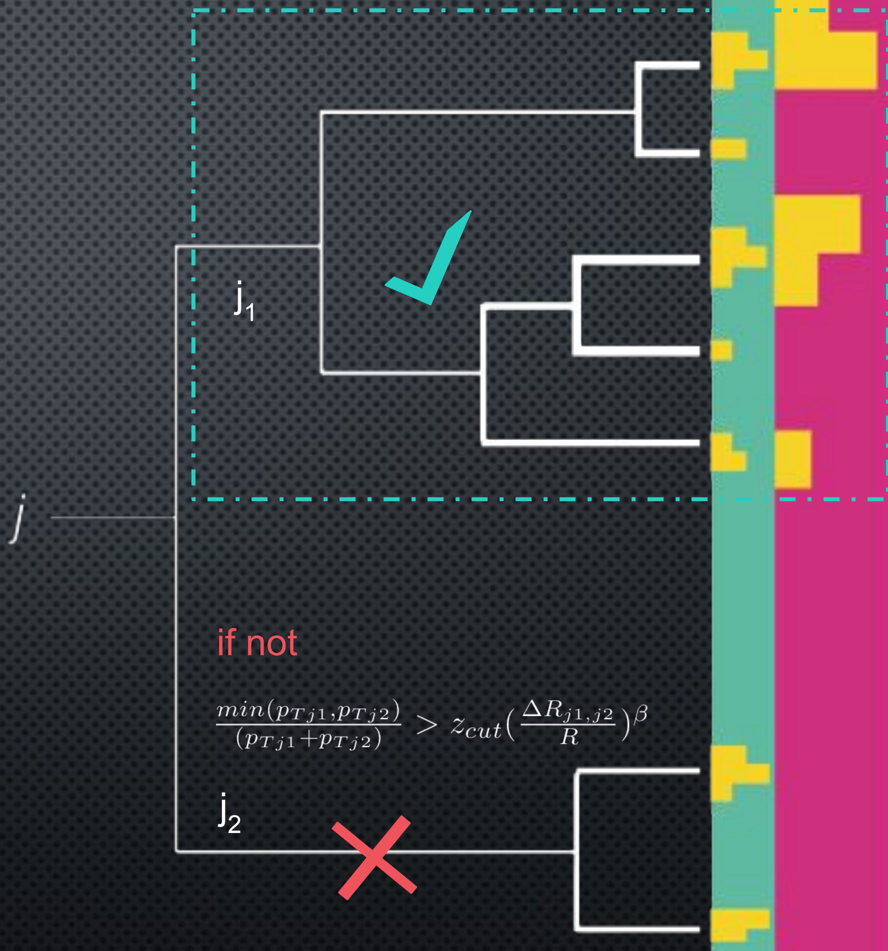
Angular ordered algorithms such as C/A are a nice alternative for JSS studies



Soft-Drop / modified Mass-Drop Algorithm

1. Obtain an anti-k_T clustered jet
2. Recluster using C/A
3. Check soft-drop condition at each node, starting with widest angled emission

⇒ Stop when an emission passes!



Soft-Drop Observables

Experimental measurement of first >LL predictions for JSS!

ATLAS: PRL 121, 092001 (2018), PRD 101, 052007 (2020)

"relative mass" ϱ

- **Mass** $\varrho = \log_{10}(m_{SD}^2 / p_T^2)$

  NLL: 1704.02210 1712.05105 1803.03645

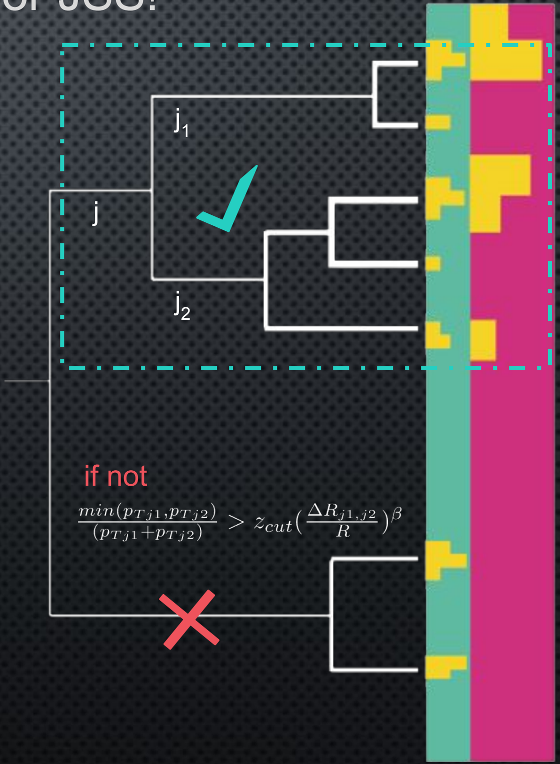
  NNLL: 1603.06375 1603.09338 1803.03645 1811.06983

- **Angle** $R_g = \Delta R(j_1, j_2)$

  NLL: 1908.01783

- **Balance** $z_g = p_T^{j2} / p_T^{j1}$

  NLL: 2106. 0459



Soft-Drop Observables

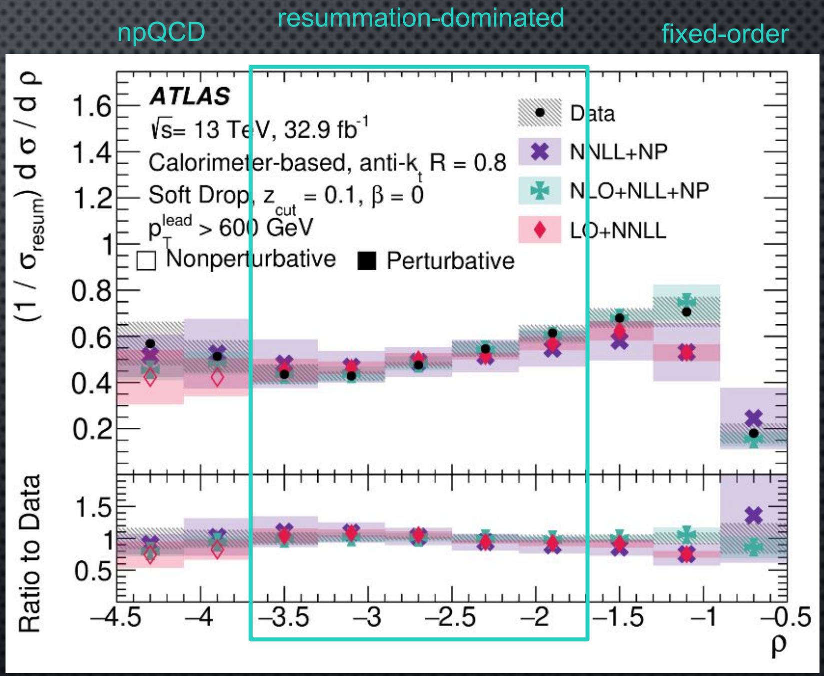
ATLAS PRL 121, 092001 (2018), ATLAS PRD 101, 052007 (2020)

Measurement made in dijet events

- No backgrounds
- Includes jets with p_T of ~300 GeV - 2 TeV
- Different values of β allow for more or less application of perturbative QCD
- Calorimeter and track-based

Observable defined as “relative mass” $\rho = \log_{10}(m_{SD}^2 / p_T^2)$
dimensionless, and only weak correlation with p_T

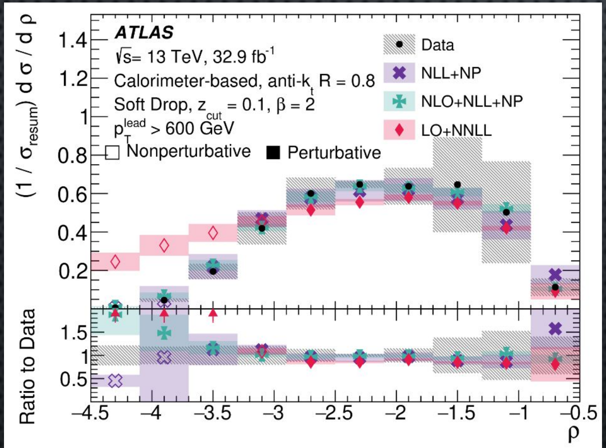
$$\frac{min(p_{Tj1},p_{Tj2})}{(p_{Tj1}+p_{Tj2})} > z_{cut}\left(\frac{\Delta R_{j1,j2}}{R}\right)^{\beta}$$

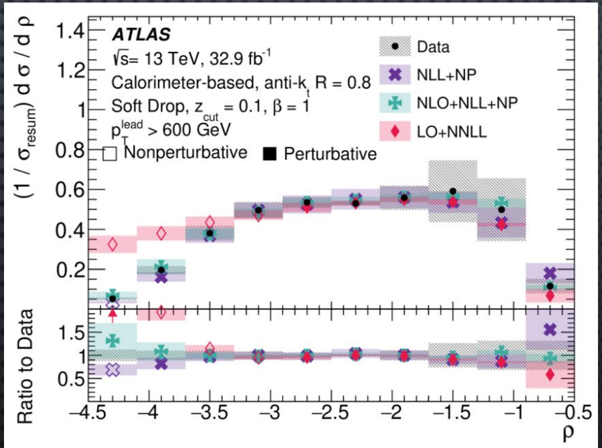


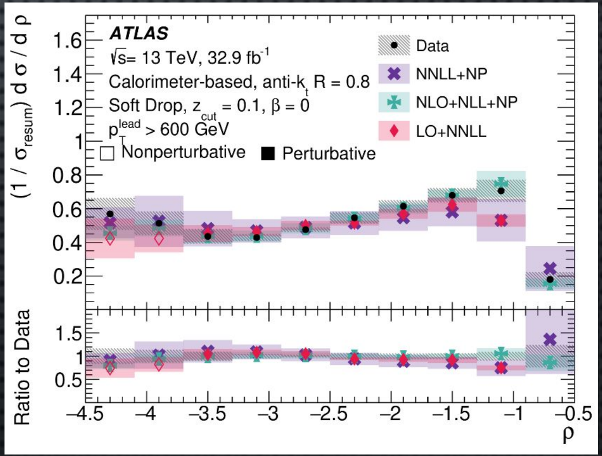
Soft-Drop Relative Jet Mass

ATLAS PRL 121, 092001 (2018), ATLAS PRD 101, 052007 (2020)

decreasing β leads to increased region for valid perturbative calculations





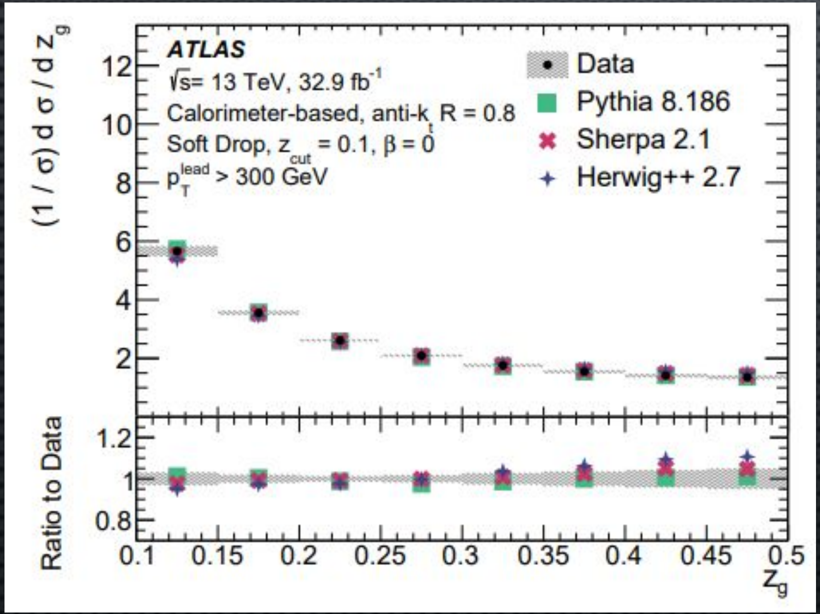


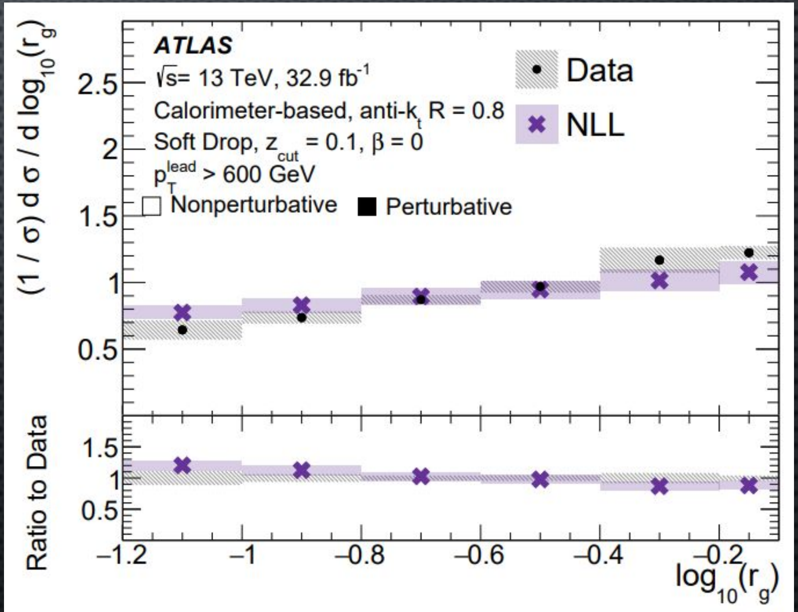
"relative mass"

$\varrho = \log_{10}(m_{SD}^2 / p_T^2)$

Soft-Drop Angle & Balance

ATLAS PRL 121, 092001 (2018), ATLAS PRD 101, 052007 (2020)

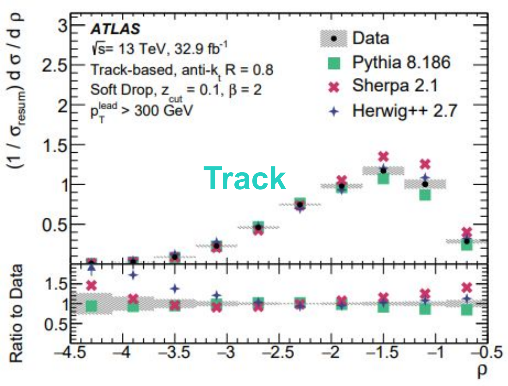


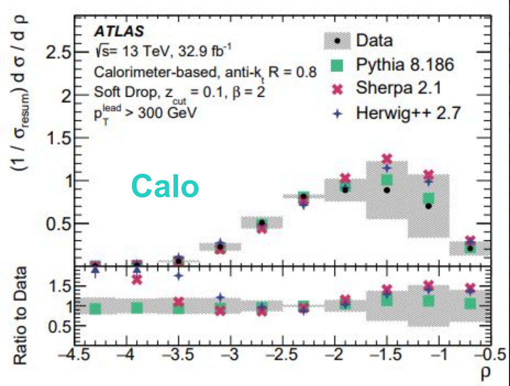


No >LL predictions for z_g that can be directly compared to this measurement

Calorimeter-based vs Track-based JSS

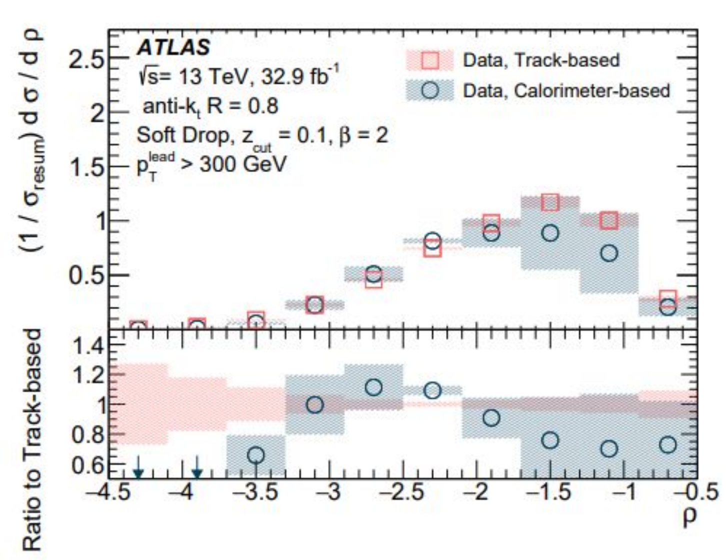
ATLAS PRD 101, 052007 (2020)





Track-based ⇒ much better resolution

… but charged particles only, so collinear-unsafe



- Reduced uncertainties!
- Nice cross-check of calorimeter measurements
- More precise reference data for improving MC models

Lund Jet Plane

Lund Plane

theory tool used for many years, particularly by MC authors

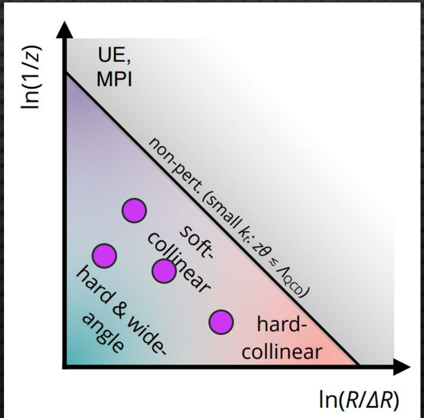
Andersson et al. Z.Phys.C 43 (1989) 625

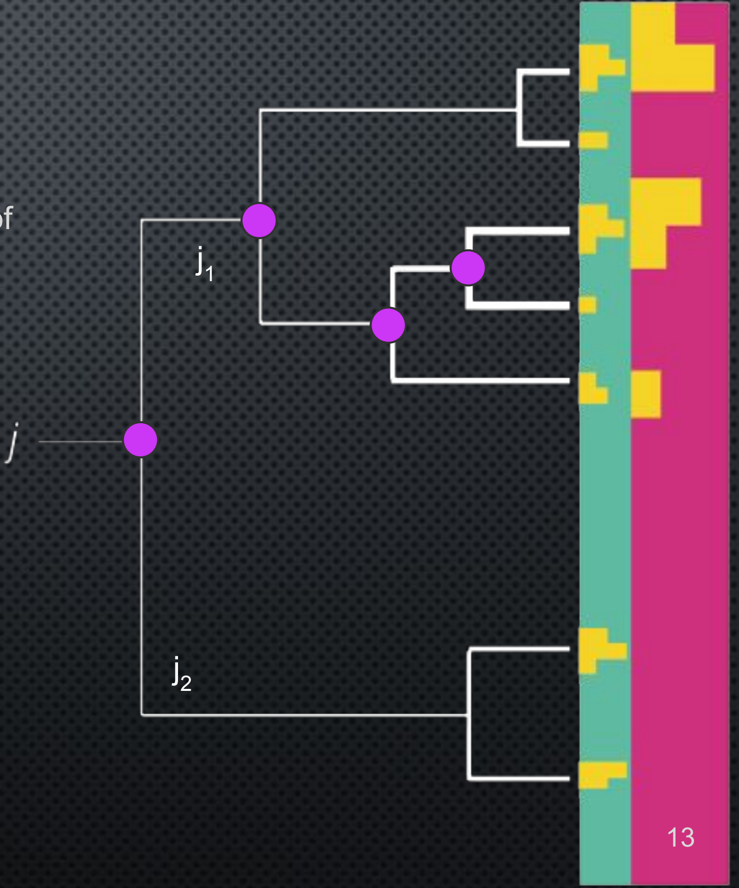
Lund Jet Plane

applied to jet substructure, probe entire emission history of originating parton

Dreyer, Salam & Soyez JHEP 12 (2018) 064

Parameterize emissions of angle-ordered jet in terms of relative energies (z) and angles (ΔR)





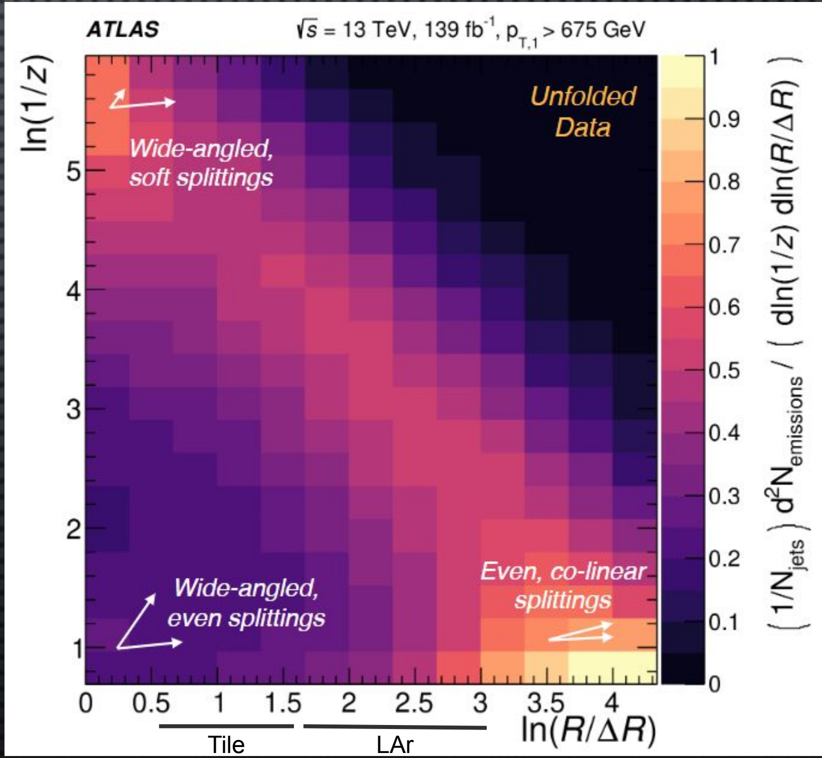
Lund Jet Plane Measurement

ATLAS PRL 124 222002 (2020)

Physics effects factored into different regions of the plane

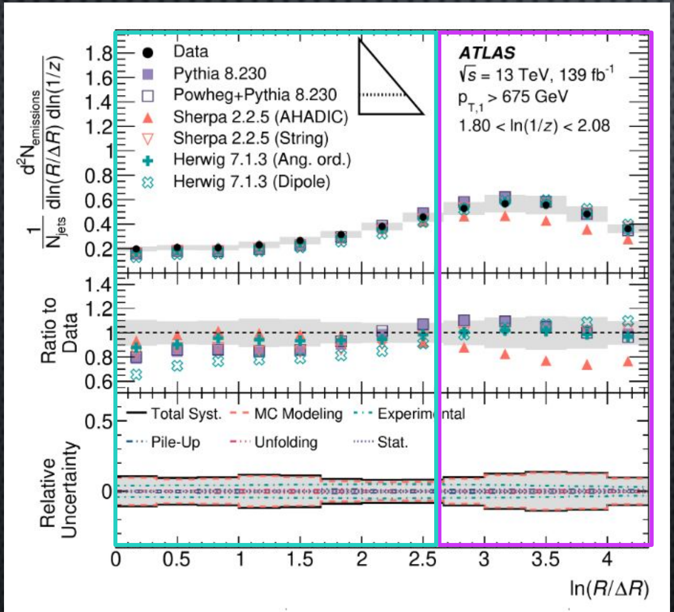
Measurement performed in dijets using only charged tracks

Limited calorimetry cell granularity → very coarse grained angular splittings



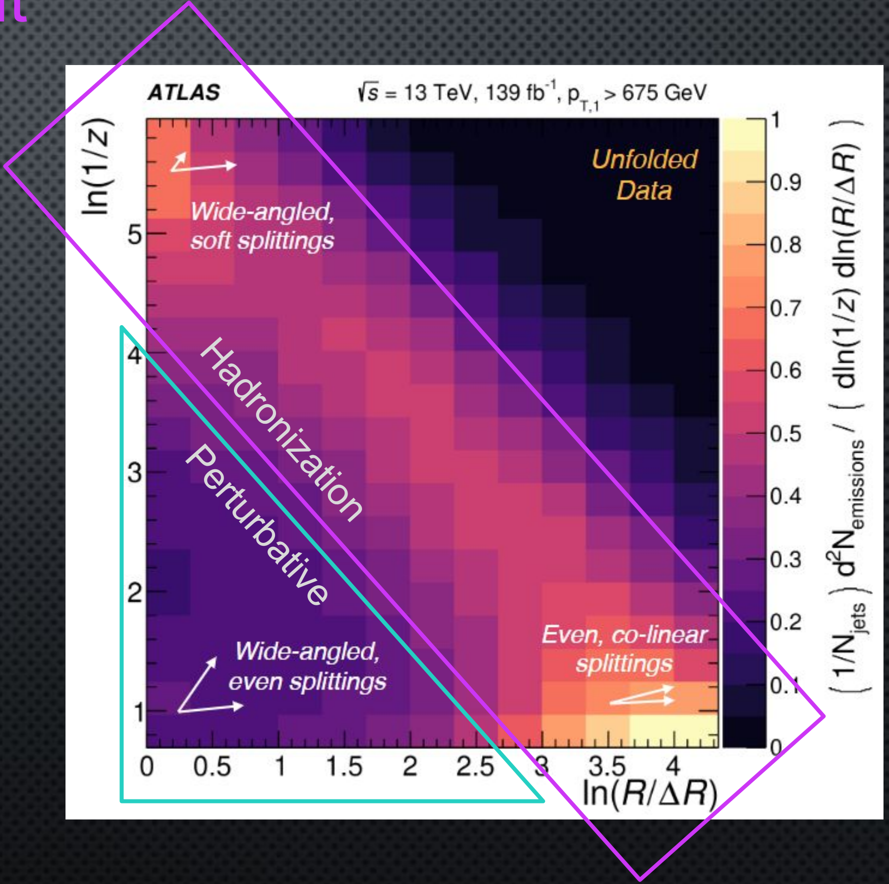
Lund Jet Plane Measurement

ATLAS PRL 124 222002 (2020)



differences in parton shower models

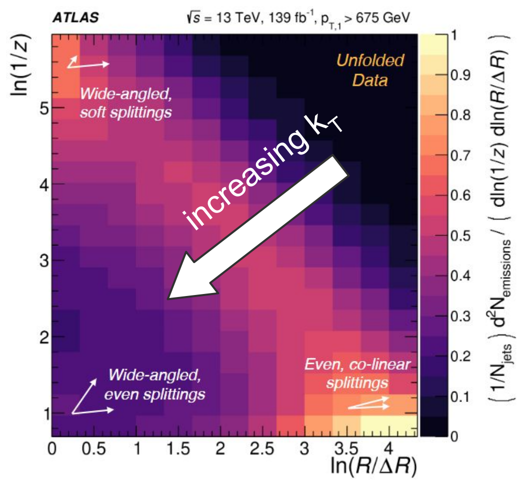
differences in hadronization models

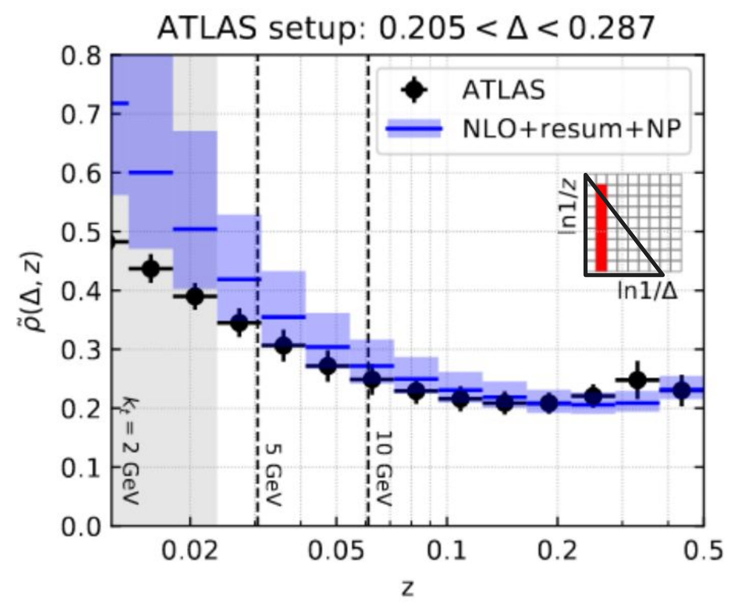


Lund Jet Plane Measurement

ATLAS PRL 124 222002 (2020)

Non perturbative corrections to NLL resummation small despite measurement with charged tracks only





NLL Lund Jet Plane calculation

Lifson, Sala, Soyez, JHEP 10 (2020) 170

Conclusions

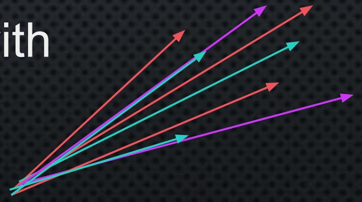
Many examples of collaboration between theory and experiment!

Substantial progress in the measurement of JSS observables and comparisons to NLL predictions!

Illustrates the widespread effects of parton shower models and hints at next generation tools

LL ⇒ NLL parton showers!

Extend Lund jet plane to different observables that can help with this goal!



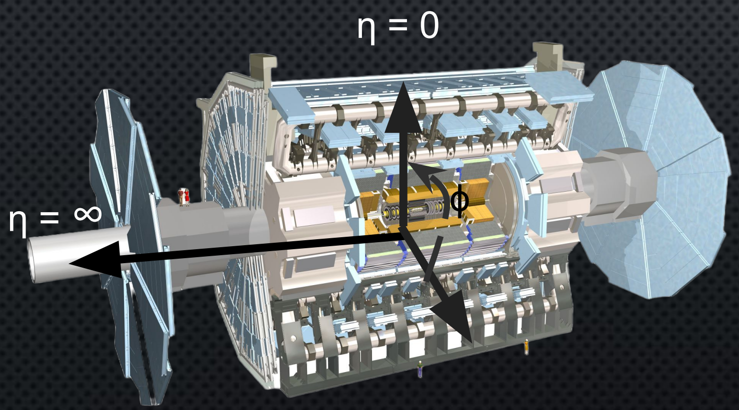
Thank You!

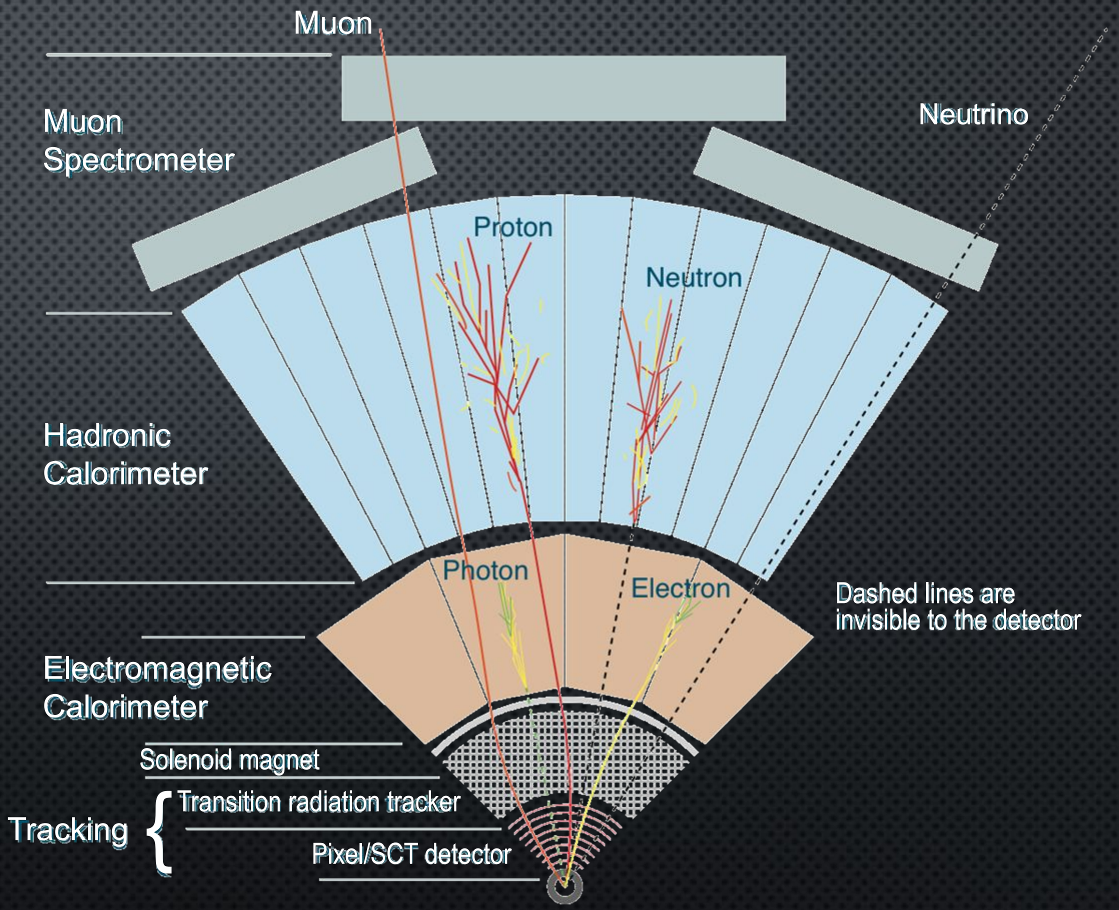
Backup

The ATLAS Detector

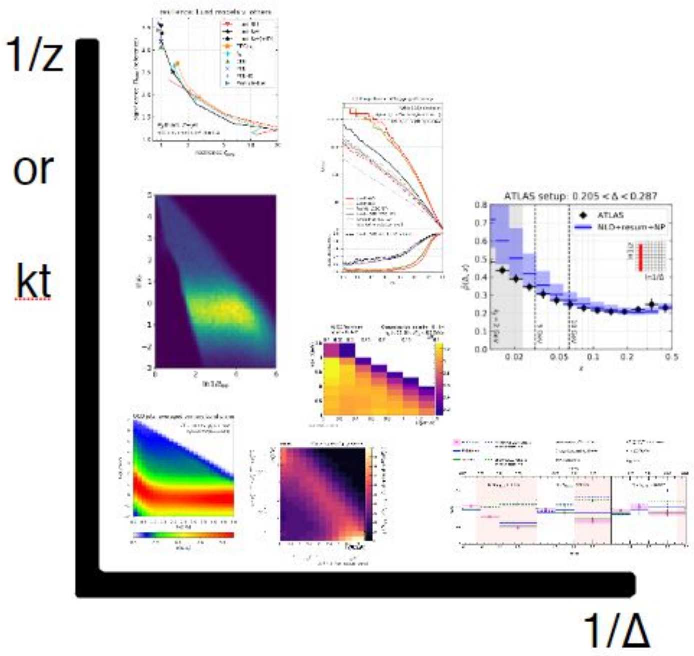
p_T - momentum in the transverse plane

E_T^{miss} - missing transverse momentum, calculated from momentum conservation





Lund Jet Plane
Lund Jet Plane*



*** I do not mean to imply that any results are 'non-perturbative'**

Courtesy of Matt Leblanc @ BOOST 2022!