Report of the Les Houches Jet Physics Subgroup(s)

Jesse Thaler

"The most effective thing he can do is stand by the door and let Gregory do the work."

on behalf of jetsatleshouches2017:

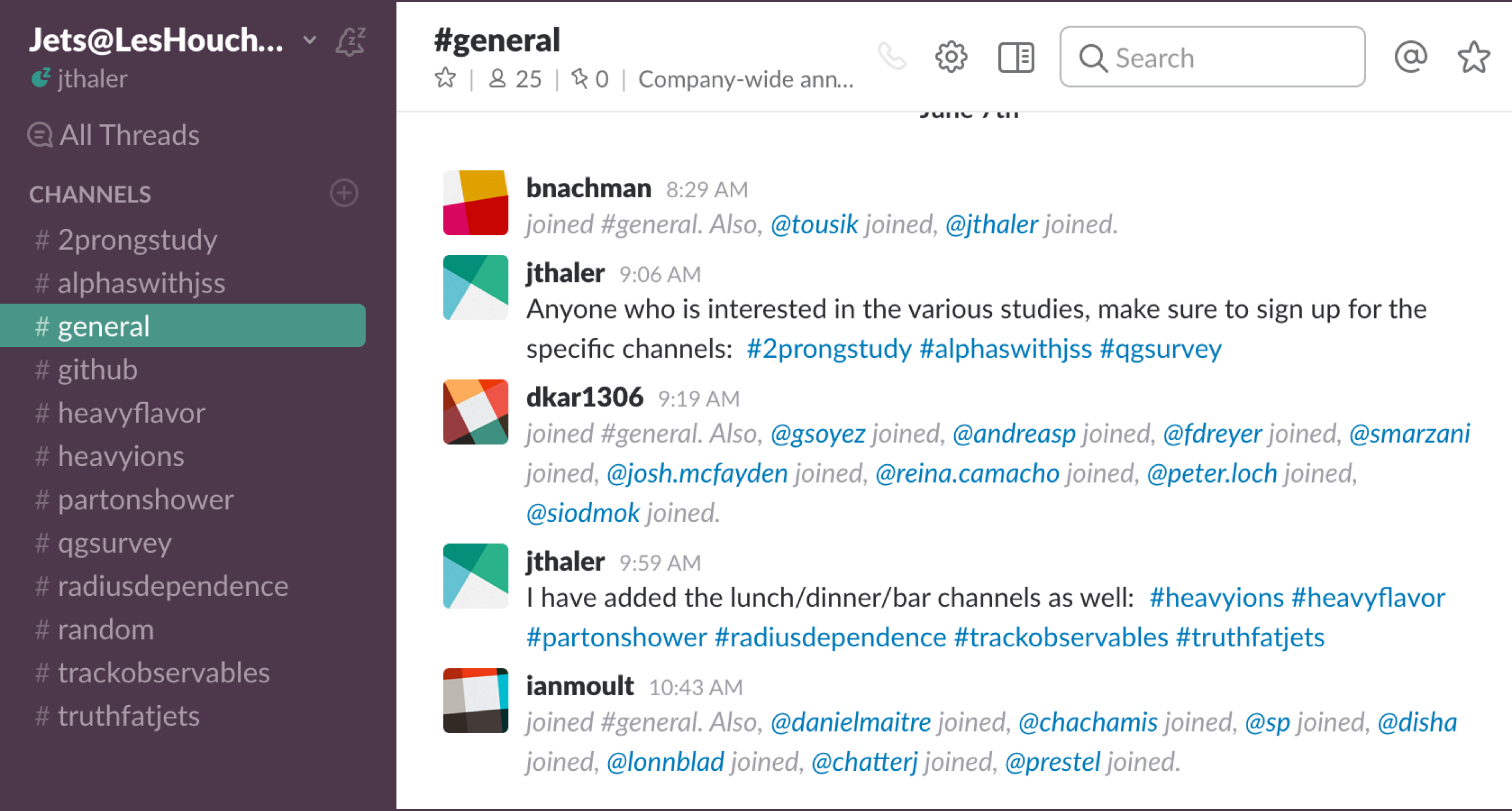
Johannes Bellm, Disha Bhatia, Reina Camacho, Grigorios Chachamis, Suman Chatterjee, Frédéric Dreyer, Maria Vittoria Garzelli, Philippe Gras, Joey Huston, Adil Jueid, Deepak Kar, Andrew Larkoski, **Peter Loch**, Leif Lönnblad, Daniel Maitre, Simone Marzani, Josh McFayden, **Ian Moult**, **Ben Nachman**, Andreas Papaefstathiou, Simon Plätzer, Stefan Prestel, Peter Richardson, Andrzej Siódmok, **Gregory Soyez**, Tousik Samui, Frank Tackmann, …

Les Houches Workshop — June 14, 2017

Jets @ Les Houches

Thanks, Fawzi!

Slacking off on the Wiki…



Active Jet Discussions at Les Houches 2017

More details in this report

2-Prong Jet Substructure Resilience

Extracting the Strong Coupling Constant

Uses for Quark/Gluon Tagging

Advanced Observables for Parton Showers

Other Topics at Les Houches 2017

From initial brainstorming

Jet Radius Dependence in Inclusive Cross Sections

↳ Partially in Standard Model working group

Merging Heavy Flavor with Jet Substructure

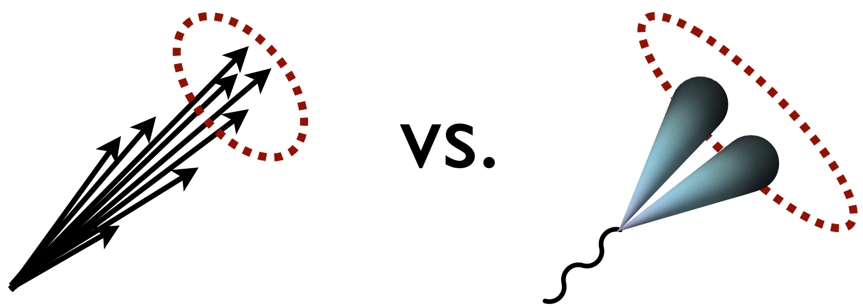
↳ Partially in Tools and MC working group

Jet Substructure in Heavy Ions

Track-Based Observables

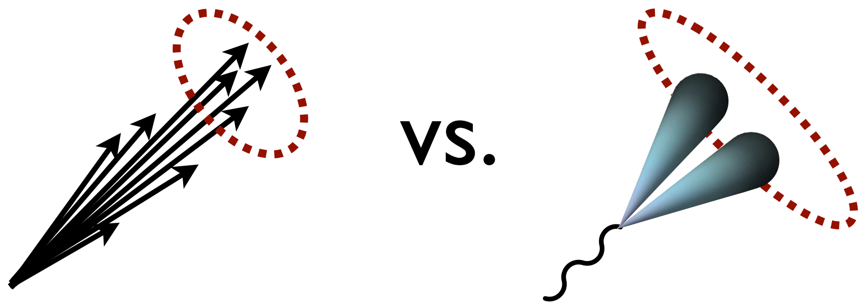
Truth Fat-Jet Definitions

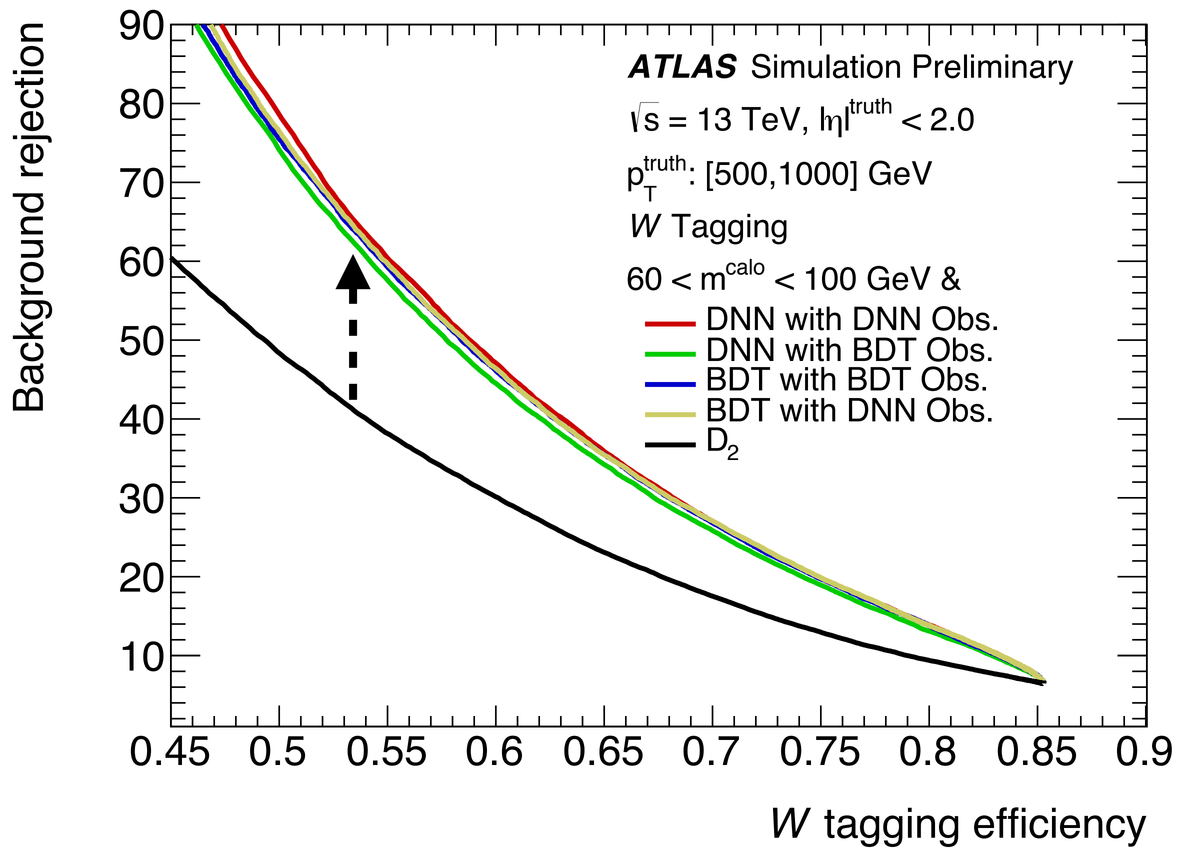
~~Machine Learning~~



2-Prong Jet Substructure Resilience

Deep Learning beats Deep Thinking?





Impressive performance from machine learning

Predictable from first-principles QCD?

Resilient to detector effects?

[ATL-PHYS-PUB-2017-004; sorry Larkoski, Moult, Neill, 1409.6298]

Levels of Jet Understanding

Late night in the QCD room (and jet room)

Simplified
Partial
Perturbative
Calculable

↑ **More Idealized**

↓ **More Realistic**

Complex
Complete
Nonperturbative
Machine Learnable

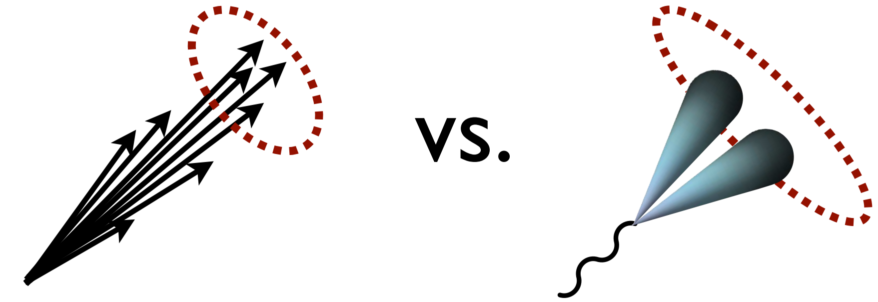
Parton	(after shower)
Hadron	(without MPI)
Particle	(with MPI)
Detector	
Pileup	

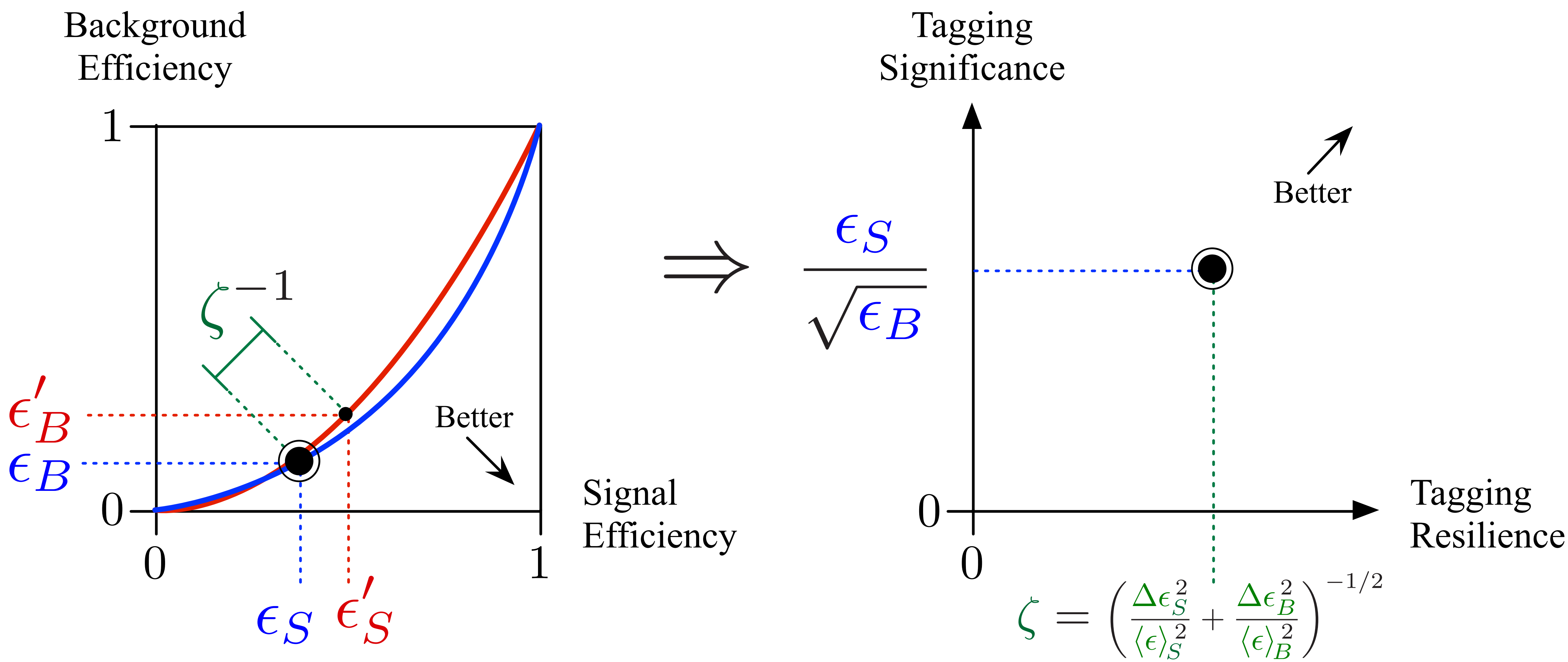
More precise naming? (for Parton, Hadron, Particle)

Resilient jet strategies exhibit similar behavior at all levels

Defining Resilience

Based on fixed observable cut value





Definition subject to change!

Blue: More realistic

Red (primed): Less realistic

Green: Difference

Parton Shower Samples

Pythia 8.223 with Tune 4C

Also have Herwig 7.1 with "The Tune"

Background: QCD Dijets

Signal: WW in Standard Model

$W_L W_L$ } from Spin-2 Resonance
$W_T W_T$

Observables

Anti-k_t Jet Radii: 0.6 **0.8** **1.0** 1.2

Ratio Observables: D_2 N_2 τ_{21} M_2

both $\beta = 1$ and $\beta = 2$

Jet Grooming:

Plain: no grooming

Loose: Soft Drop, $\beta = 2$, $z_{cut} = 0.05$

Tight: mMDT ($\beta = 0$), $z_{cut} = 0.1$

Trim: $R_{sub}(k_T) = 0.2$, $z_{cut} = 0.05$

[Larkoski, Moult, Neill, 1409.6298; Moult, Necib, JDT, 1609.07483; JDT, Van Tilburg, 1011.2268, 1108.2701]
[Larkoski, Marzani, Soyez, JDT, 1402.2657; Dasgupta, Fregoso, Marzani, Salam, 1307.0007; Krohn, JDT, Wang, 0912.1342]

Grooming Strategies for Ratio Observables

$$\text{mass} \otimes \frac{\text{numerator}}{\text{denominator}} \otimes \text{radius}$$

ATLAS-like

$$\text{trim} \otimes \frac{\text{trim}}{\text{trim}} \otimes 1.0$$

CMS-like

$$\text{tight} \otimes \frac{\text{plain}}{\text{plain}} \otimes 0.8$$

All Tight

$$\text{tight} \otimes \frac{\text{tight}}{\text{tight}} \otimes 1.0$$

Dichroic

$$\text{tight} \otimes \frac{\text{loose}}{\text{tight}} \otimes 1.0$$

All Loose

$$\text{loose} \otimes \frac{\text{loose}}{\text{loose}} \otimes 0.8$$

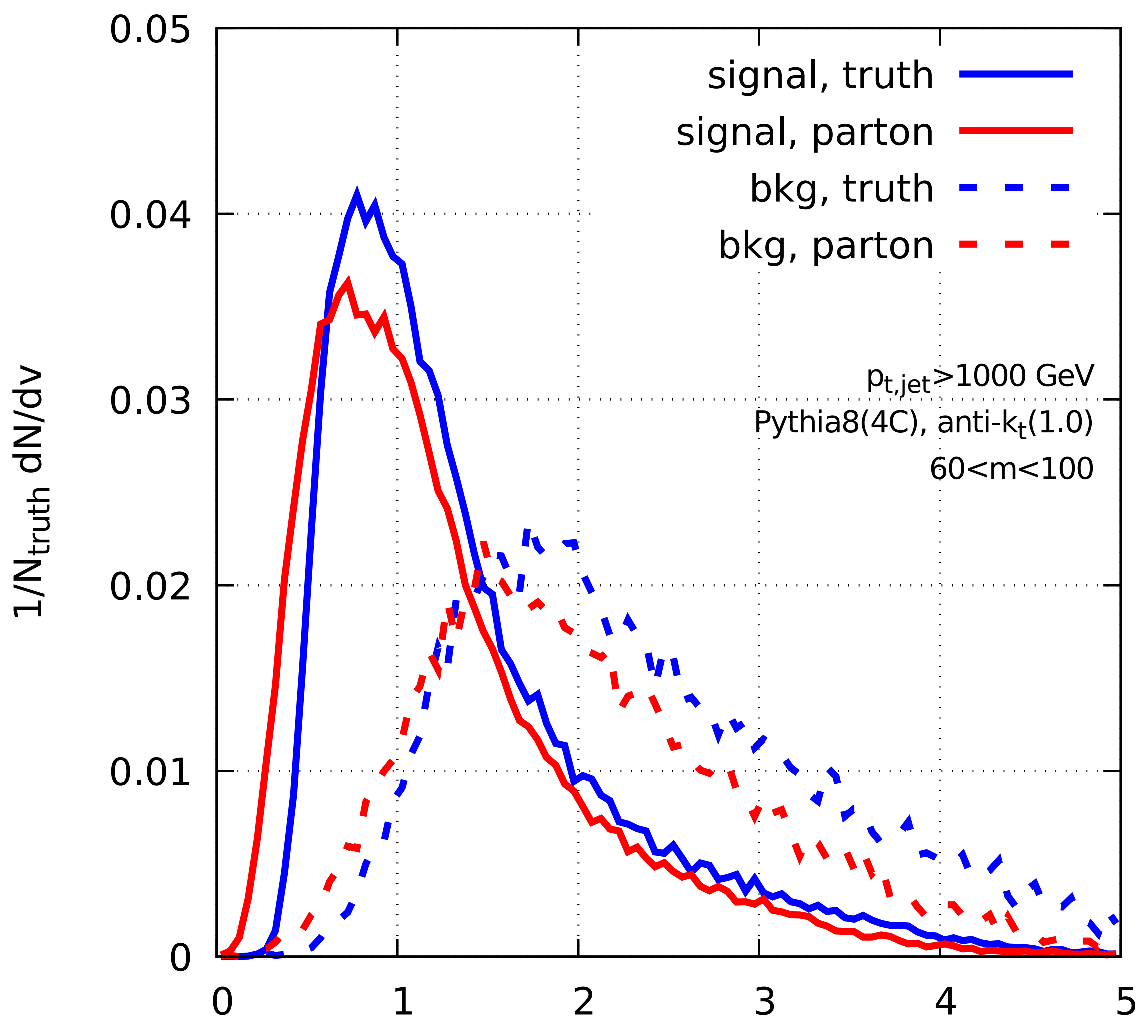
[Salam, Schunk, Soyez, 1612.03917]

The following is a small subset of the (very preliminary) plots we've produced

Impact of Hadronization and MPI

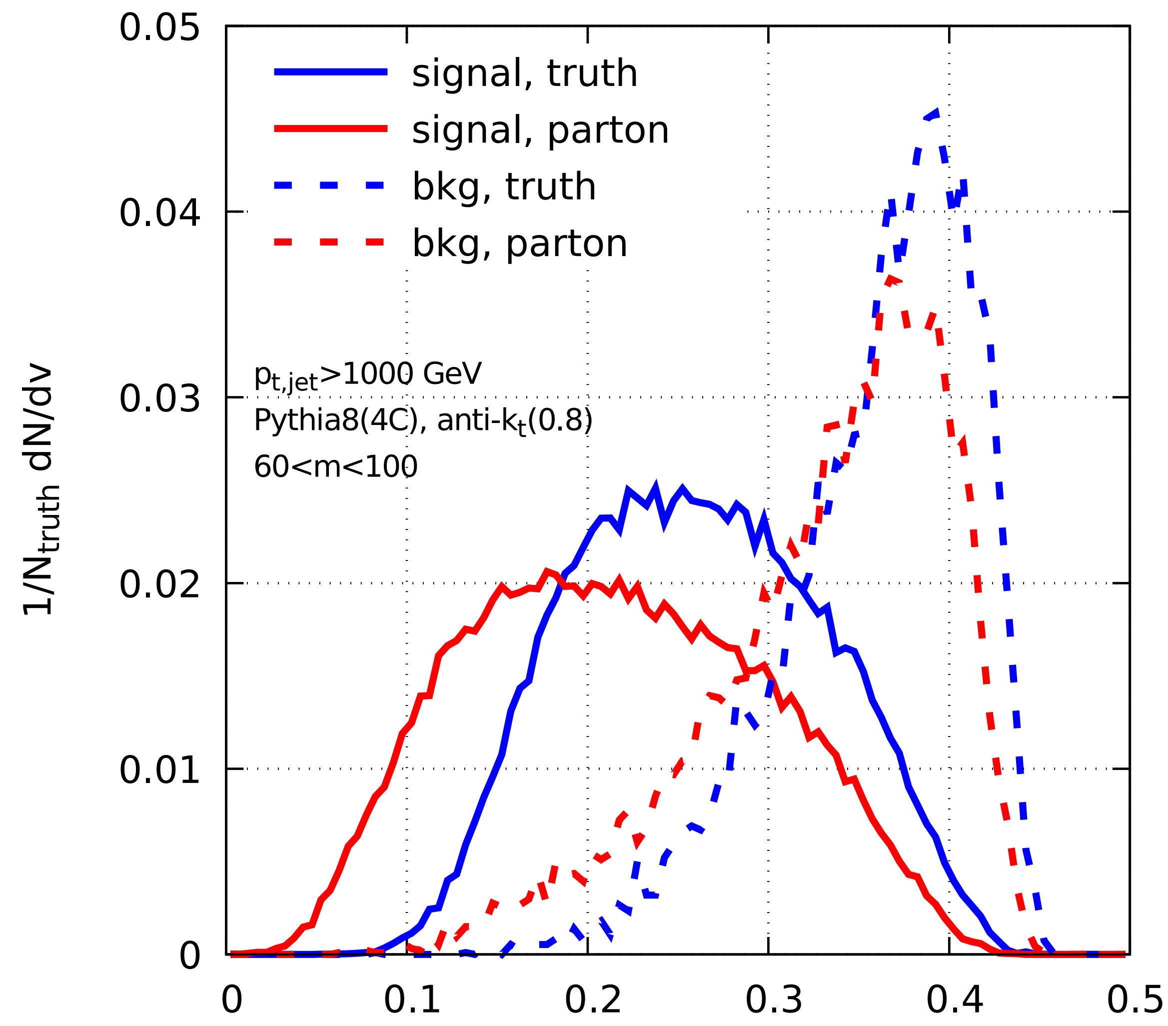
parton ⇒ particle, p_T > 1 TeV

ATLAS-like



D_2 (β = 1)

CMS-like

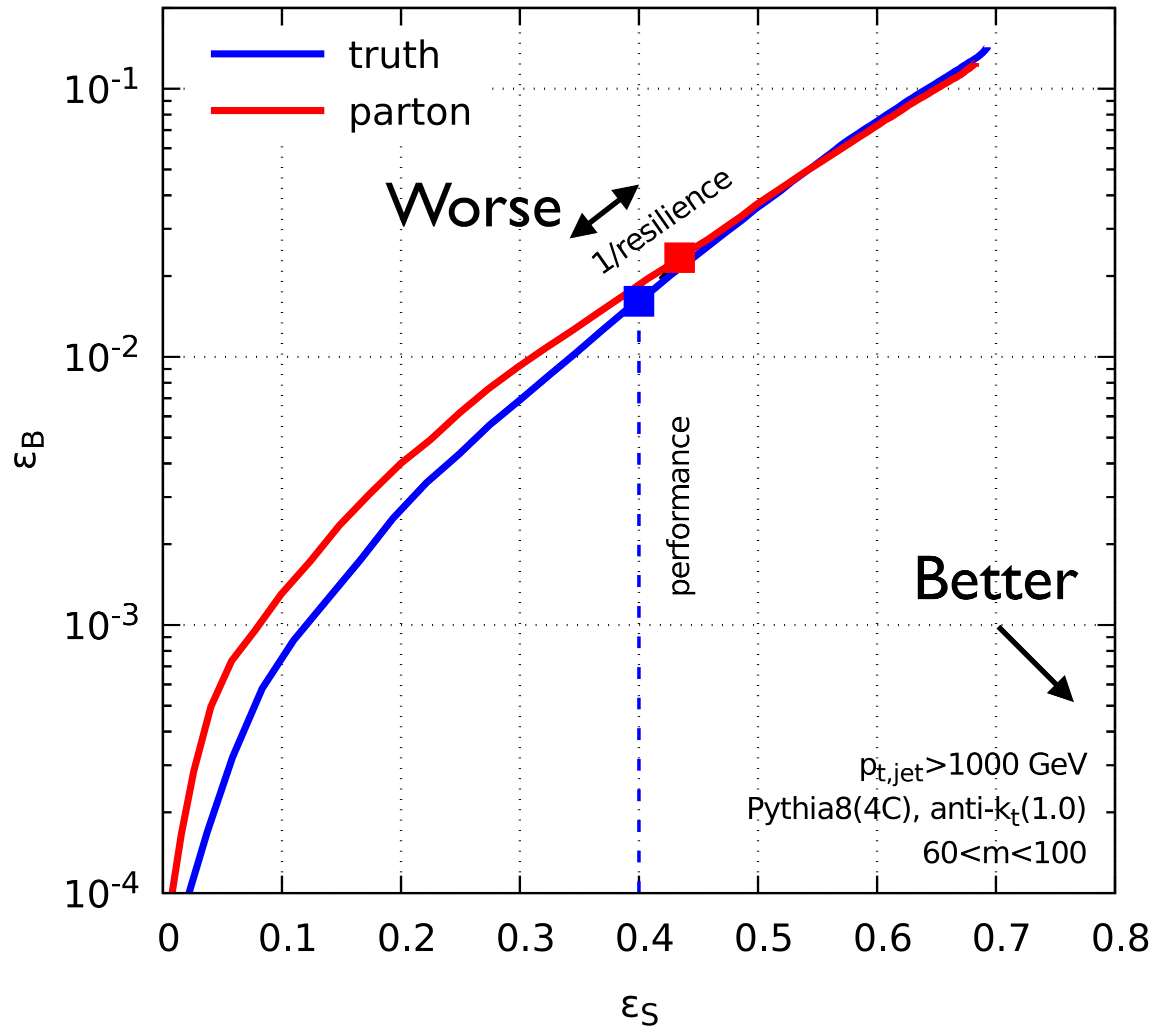


N_2 (β = 1)

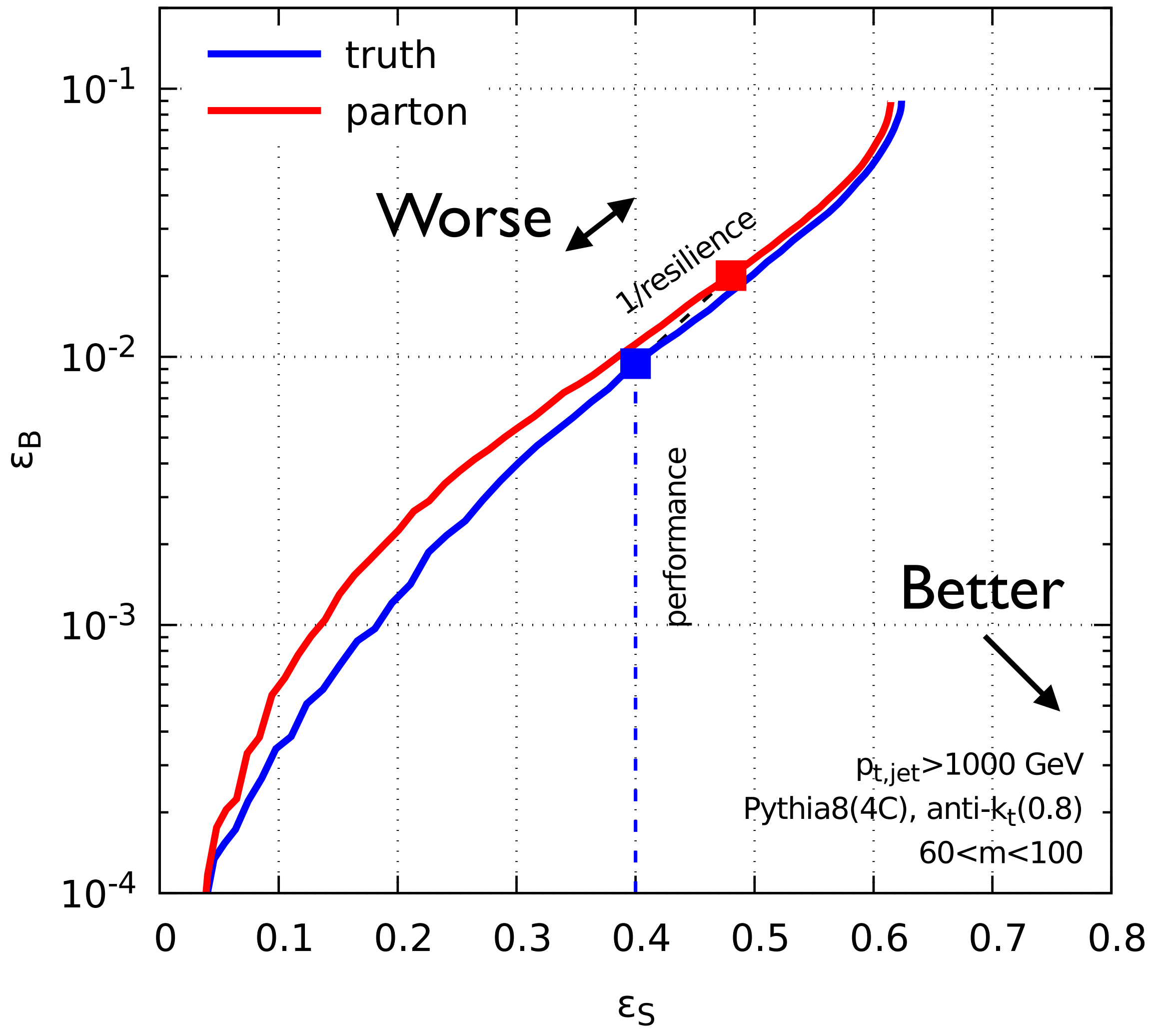
ROC Curves

parton ⇒ particle, p_T > 1 TeV

ATLAS-like

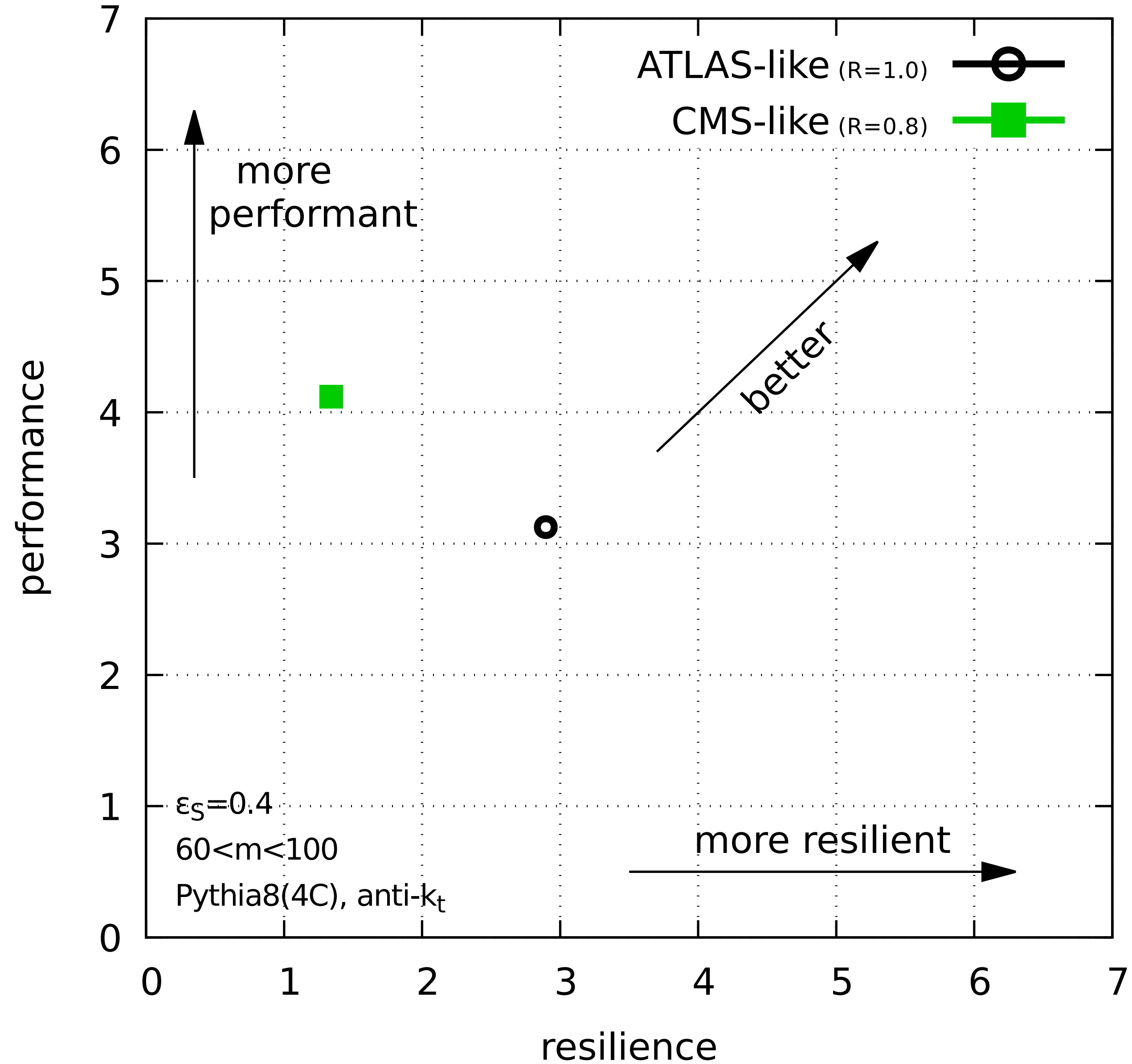


CMS-like



Performance vs. Resilience

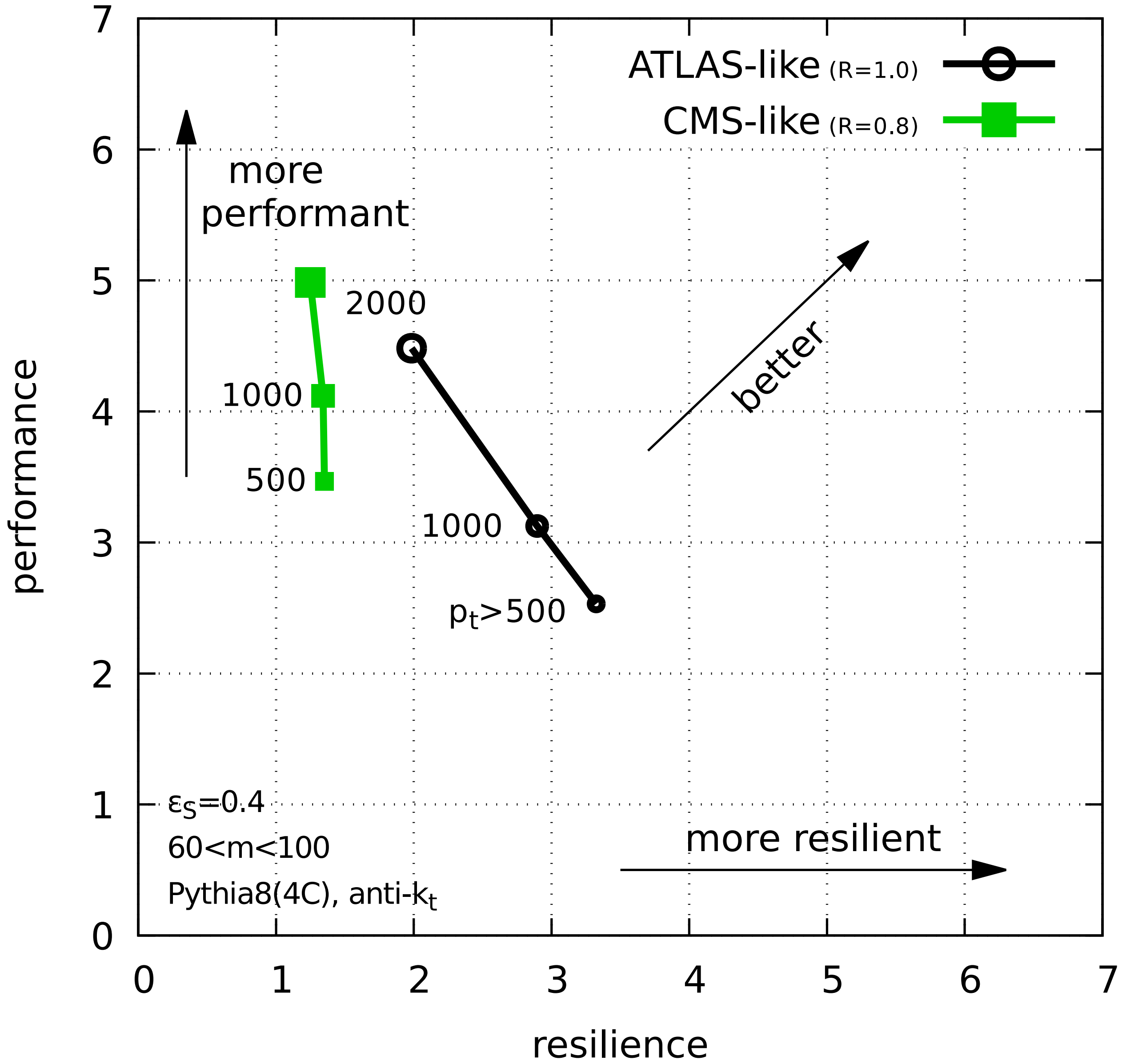
parton ⇒ particle, p_T > 1 TeV



ATLAS-like and CMS-like optimize for complementary features

Performance vs. Resilience

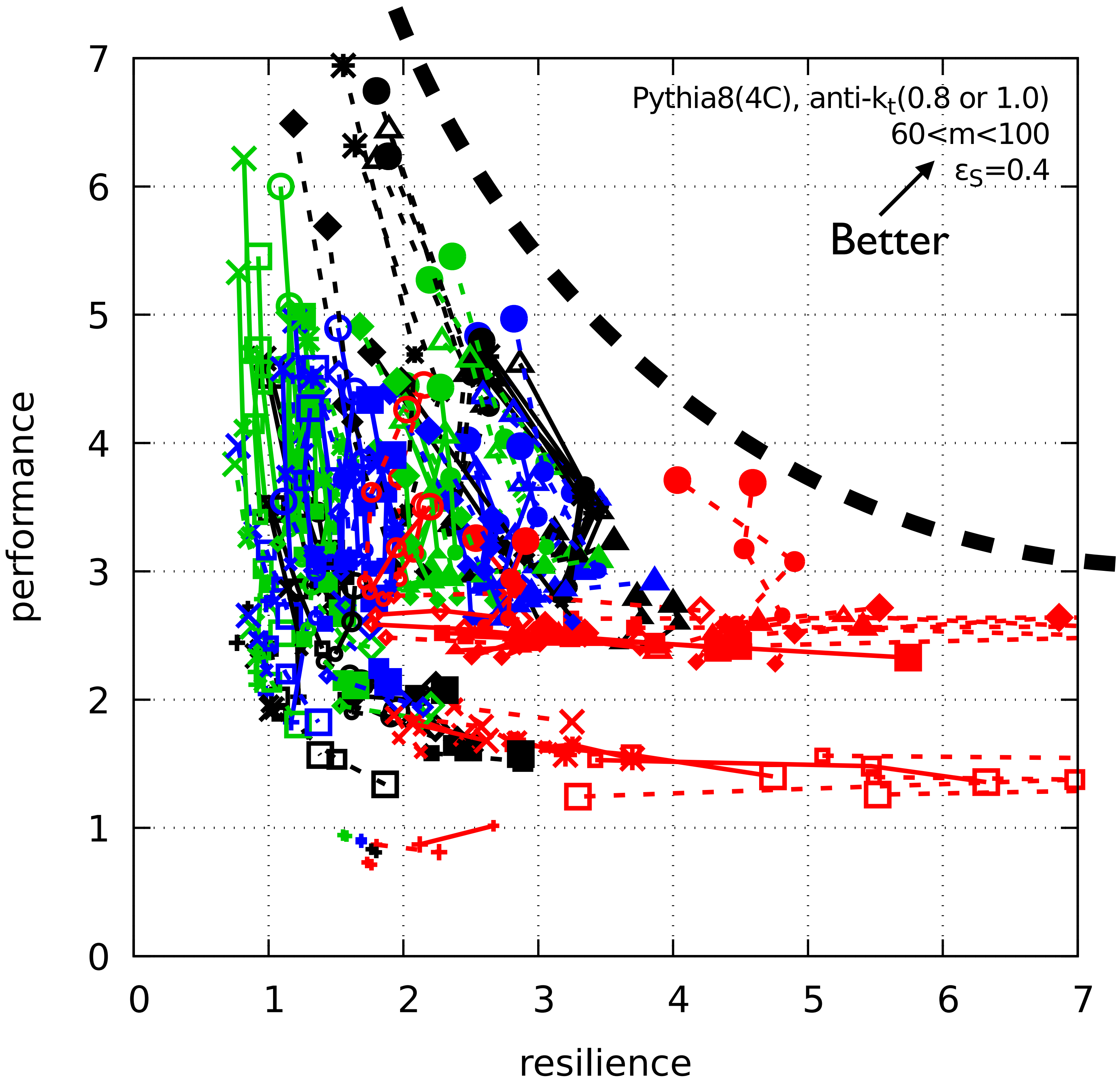
parton ⇒ particle, various p_T scales



Performance tends to improve at higher jet p_T

The Performance/Resilience Tradeoff

parton ⇒ particle



D_2

N_2

τ_{21}

M_2

Solid: β=1

Dashed: β=2

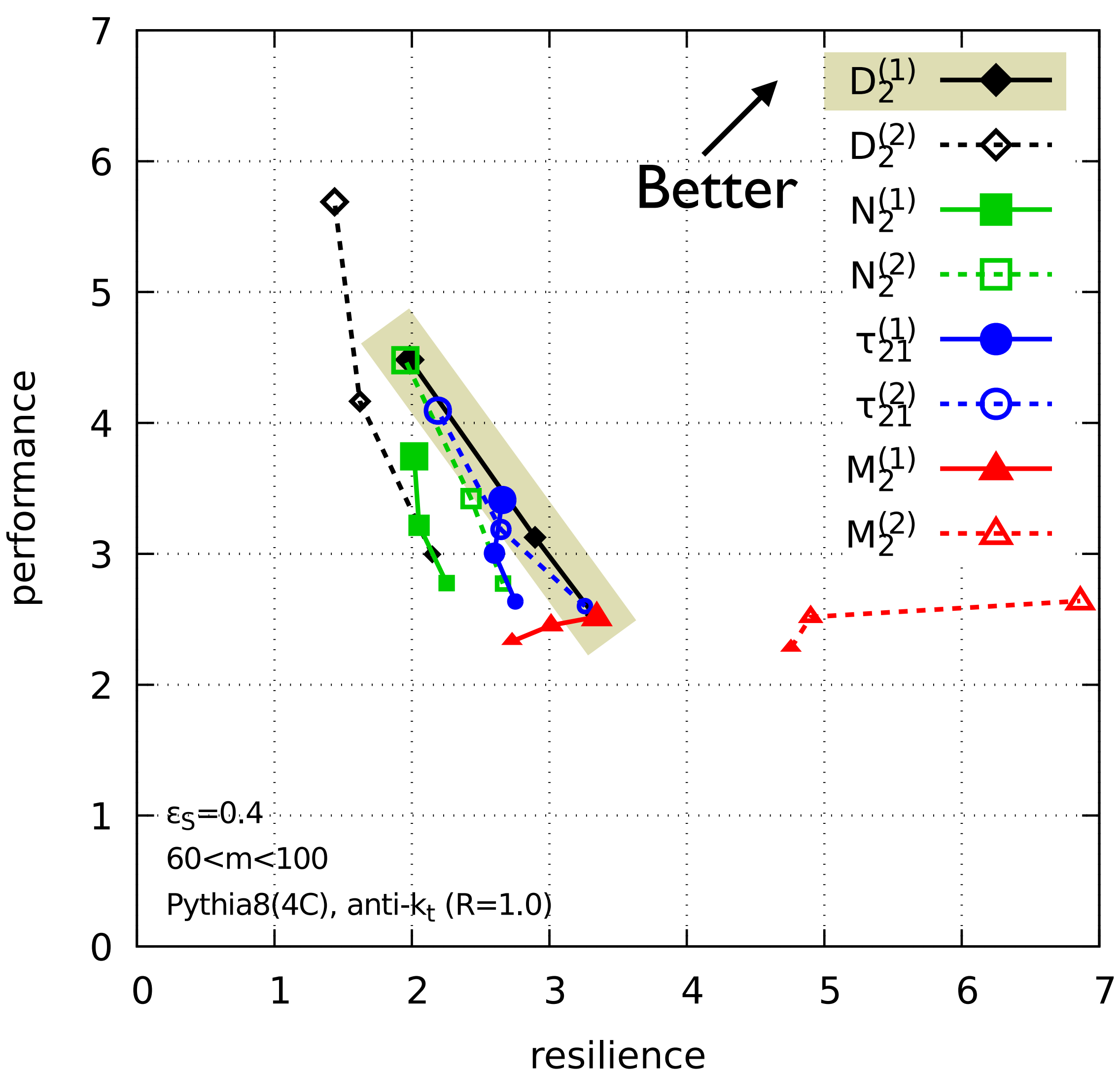
- ATLAS-like
- CMS-like
- All Tight
- Dichroic
- All Loose

…plus more!

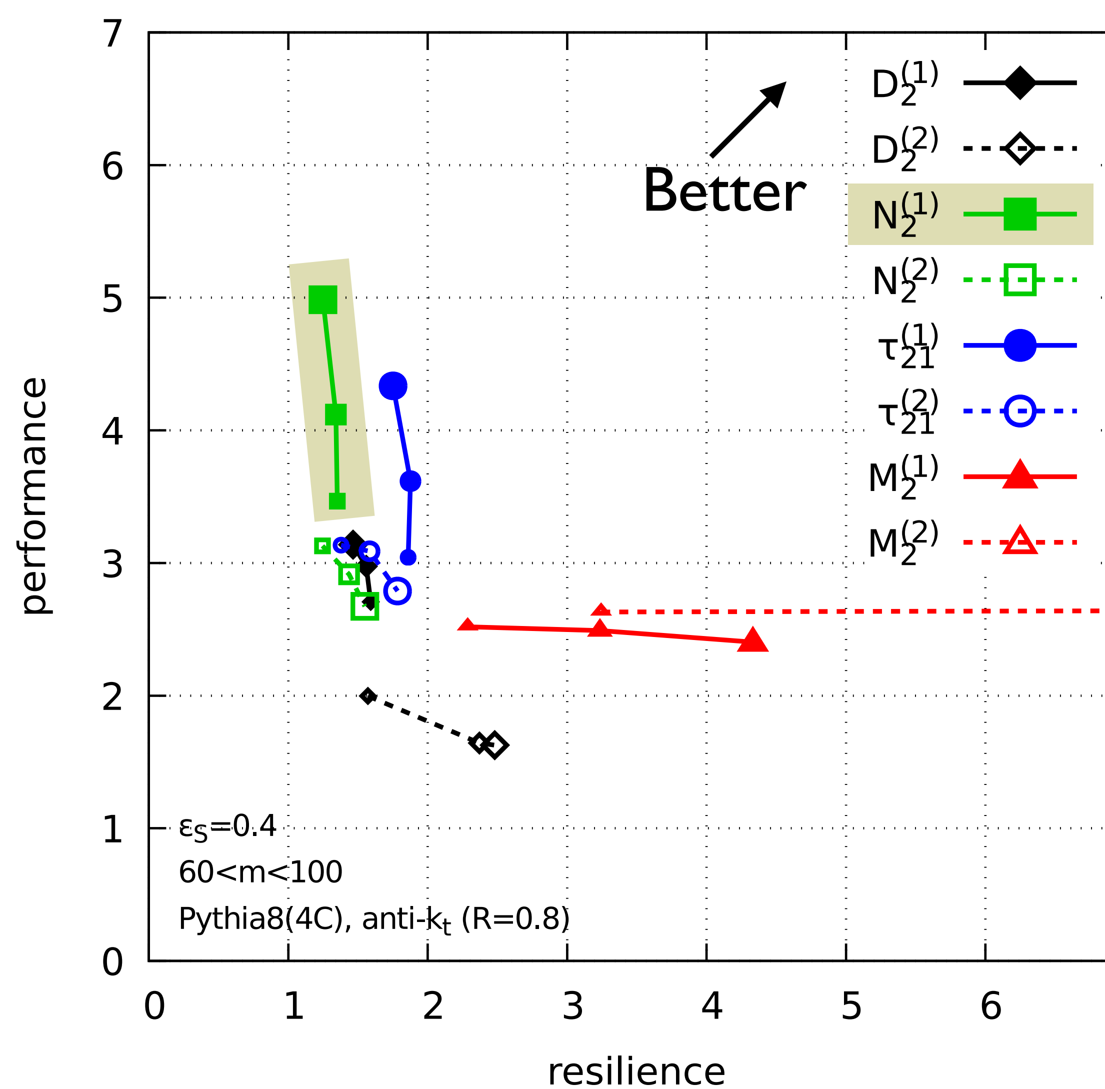
Sweeping the Observable

parton ⇒ particle

ATLAS-like Grooming



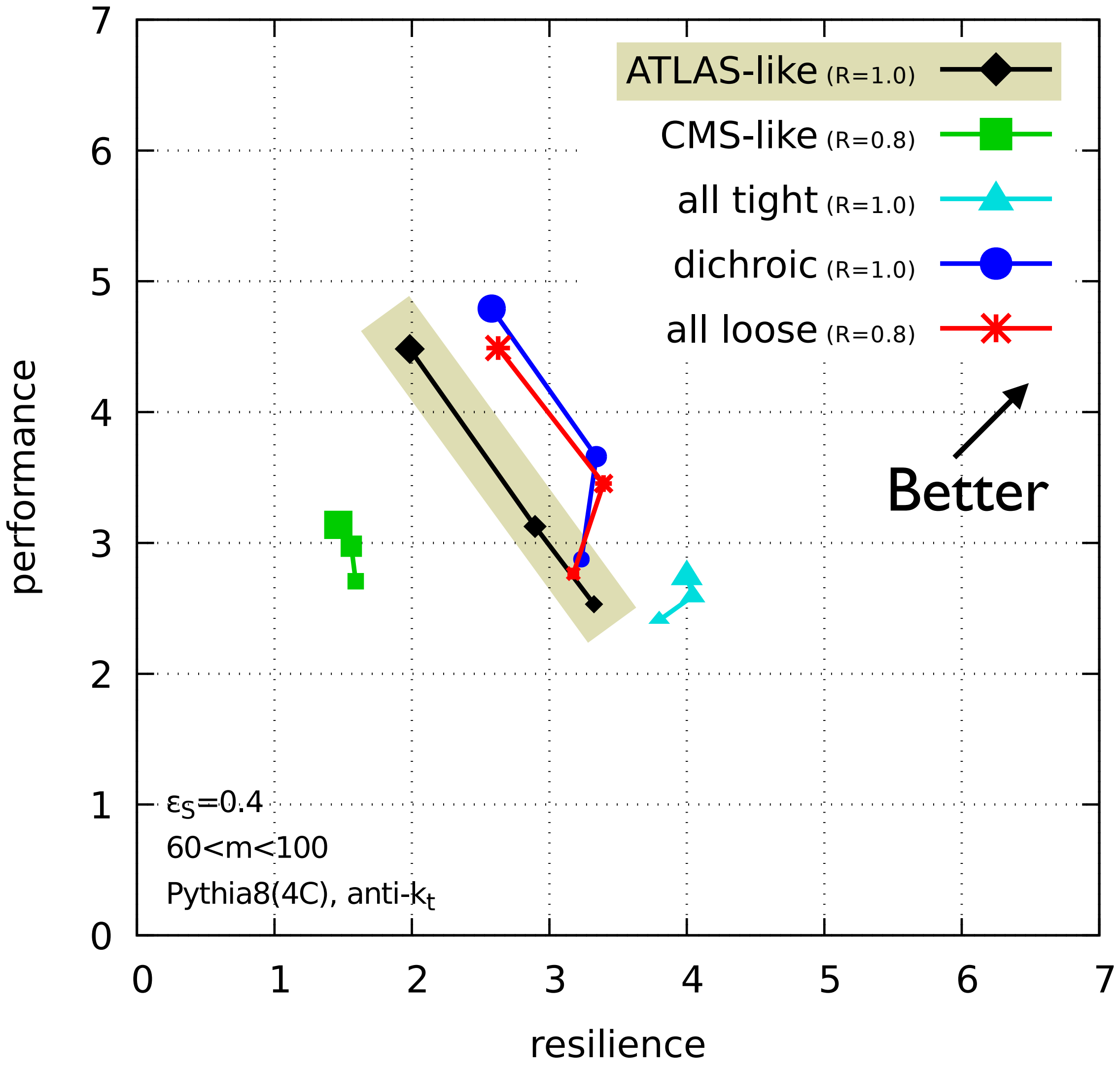
CMS-like Grooming



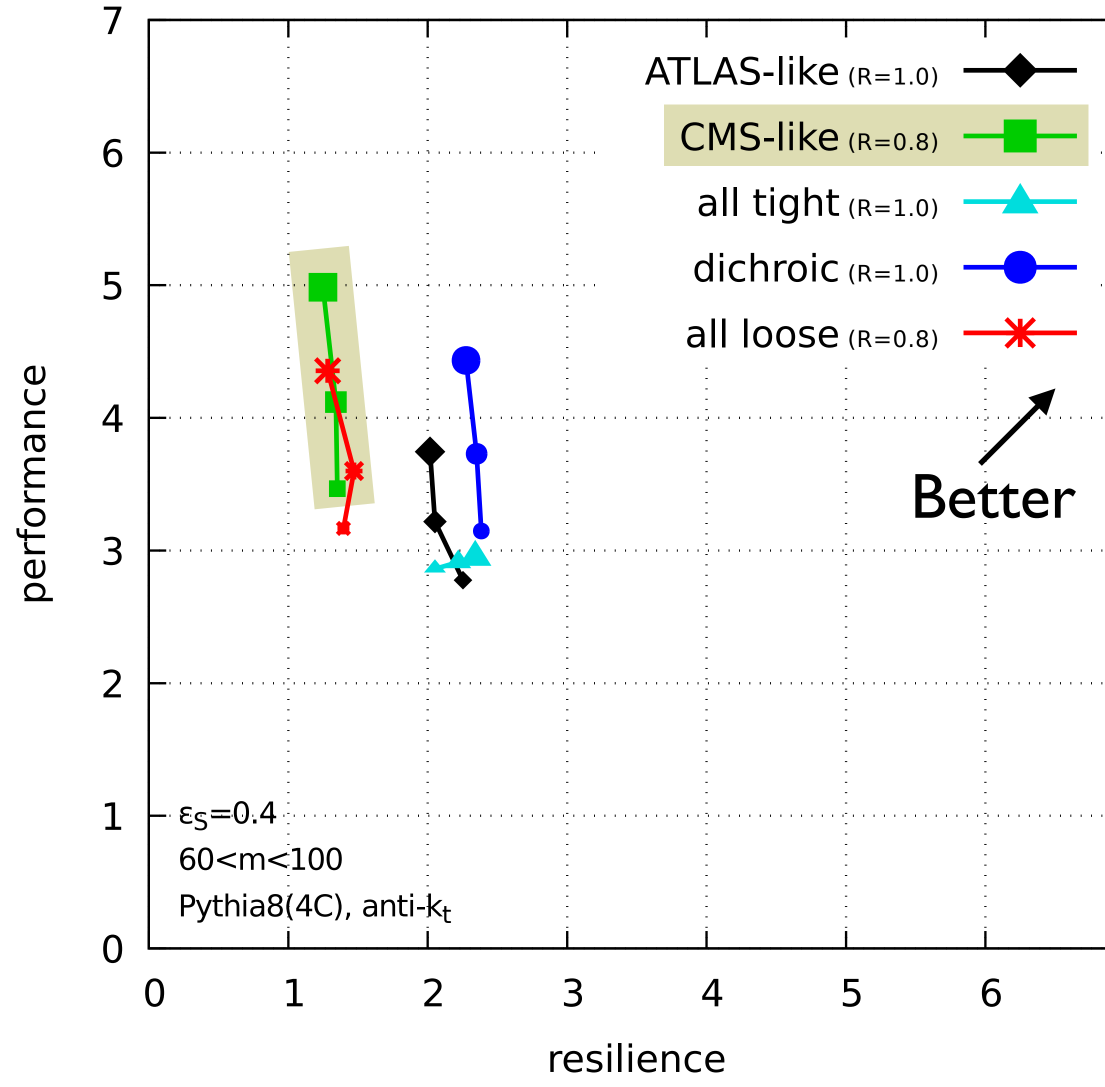
Sweeping the Grooming Strategy

parton ⇒ particle

Pref. ATLAS: D_2 (β=1)

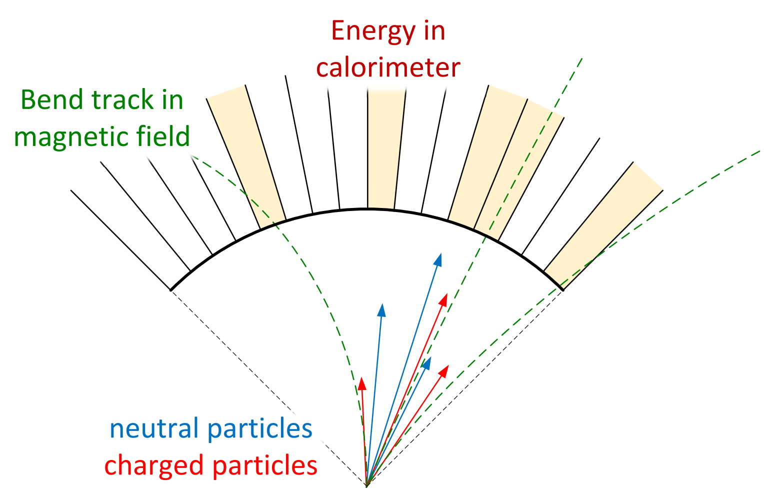


Pref. CMS: N_2 (β=1)

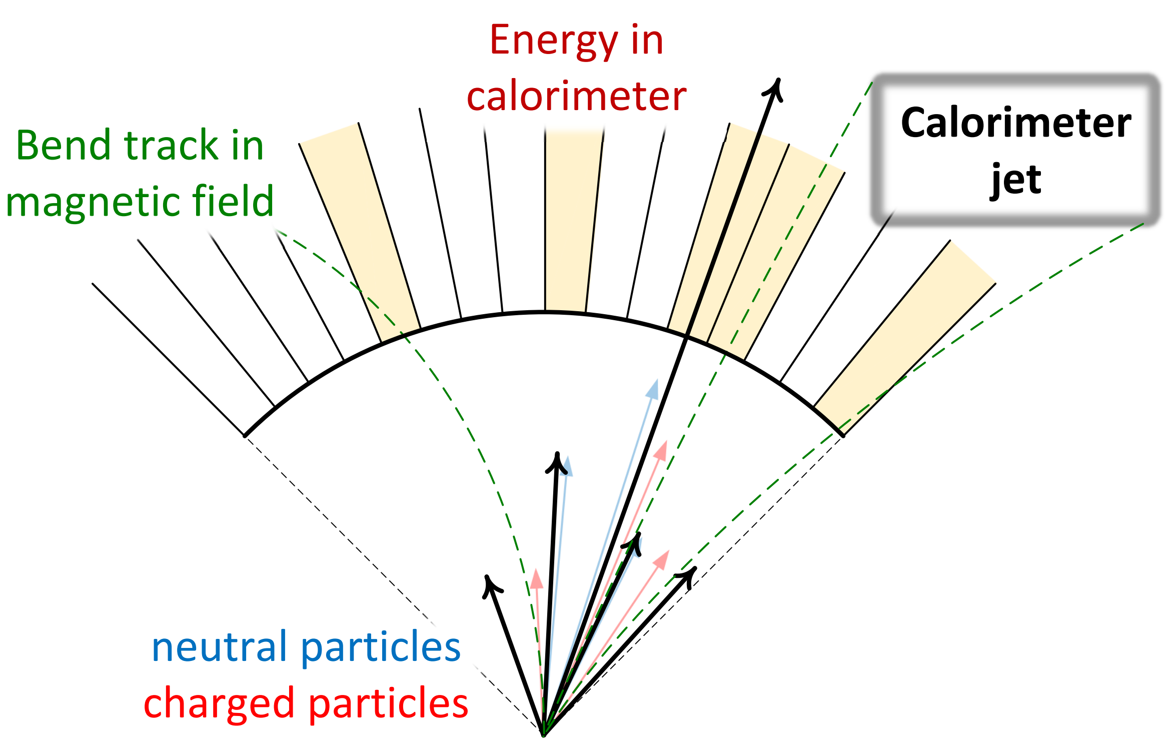


Simplified Detector Simulation

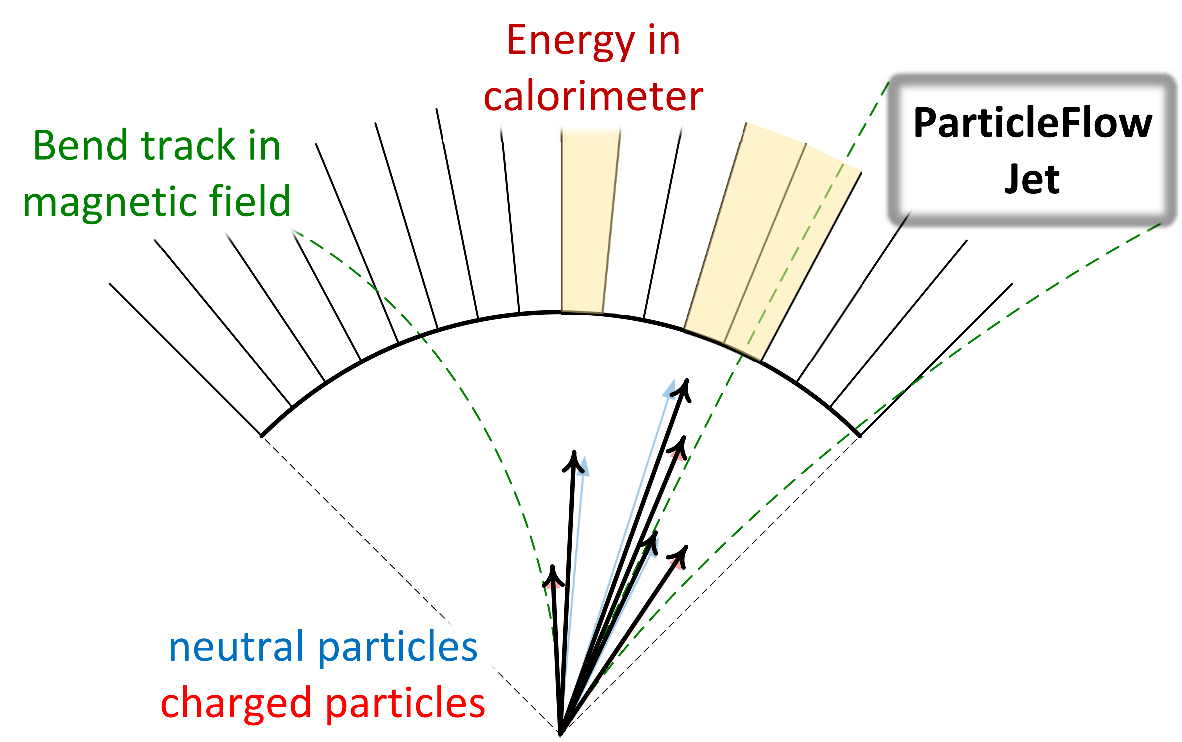
En route to particle ⇒ detector ⇒ pileup



"ATLAS-like"



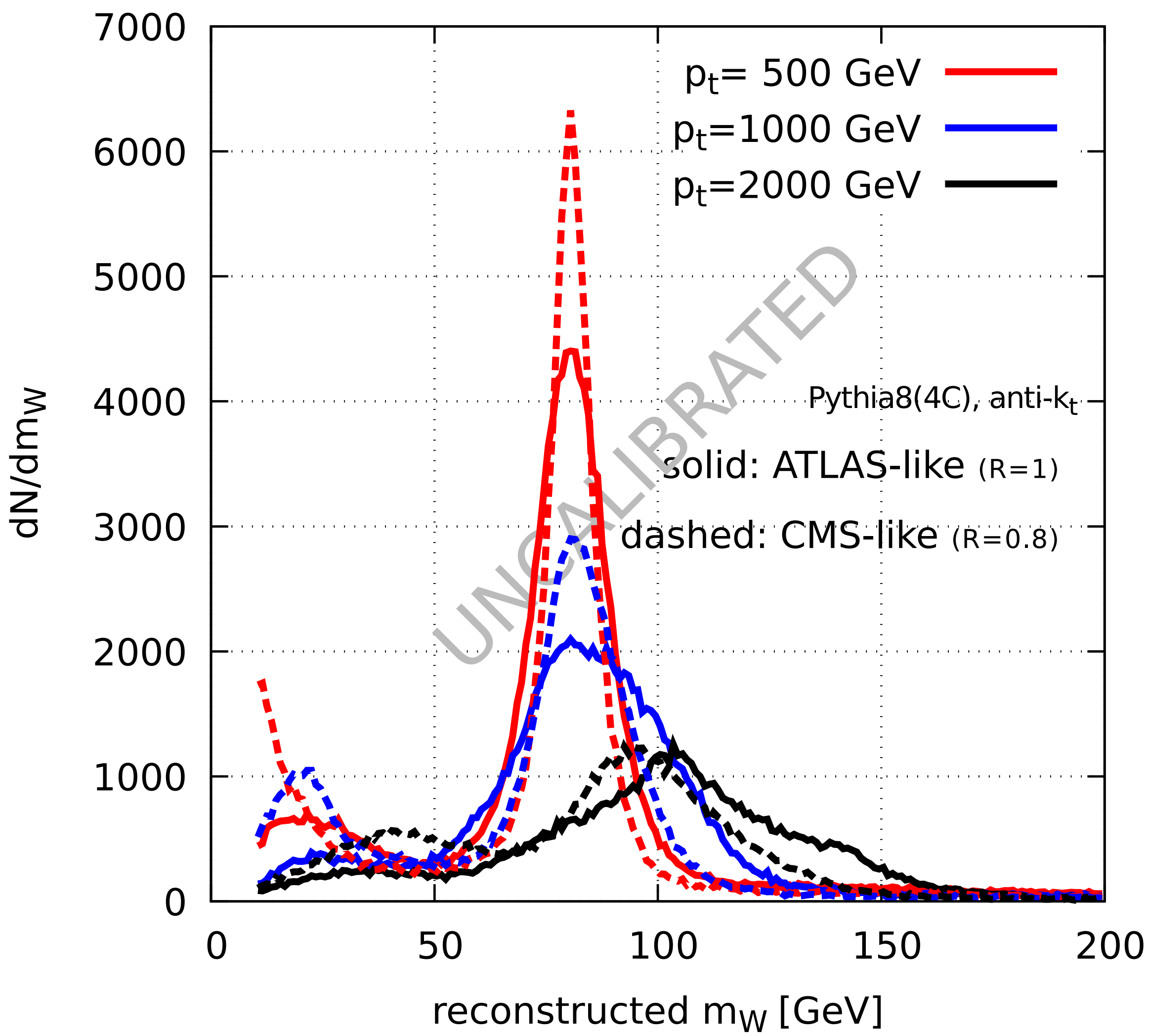
"CMS-like"



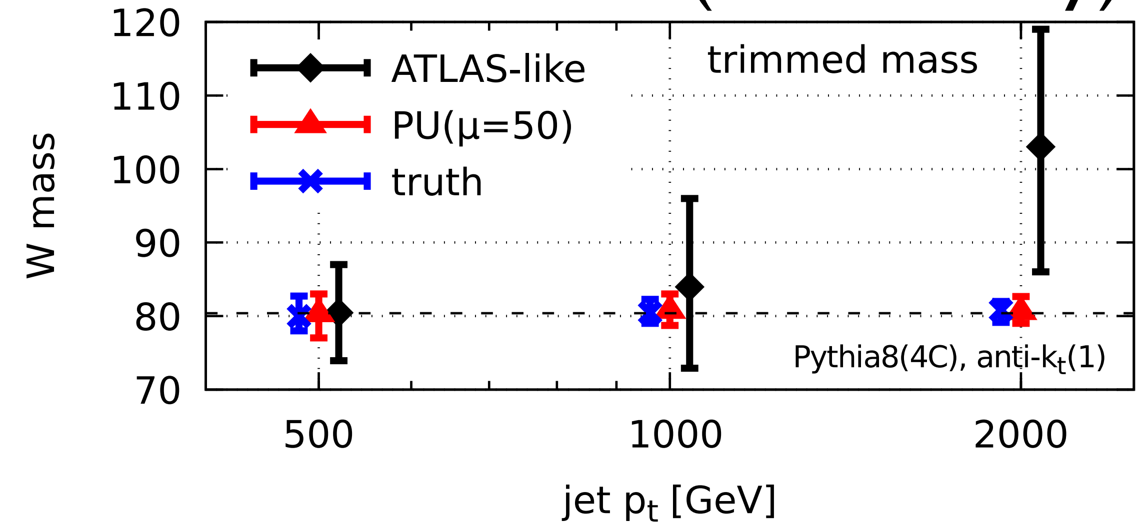
Estimated Detector Performance

En route to particle ⇒ detector ⇒ pileup

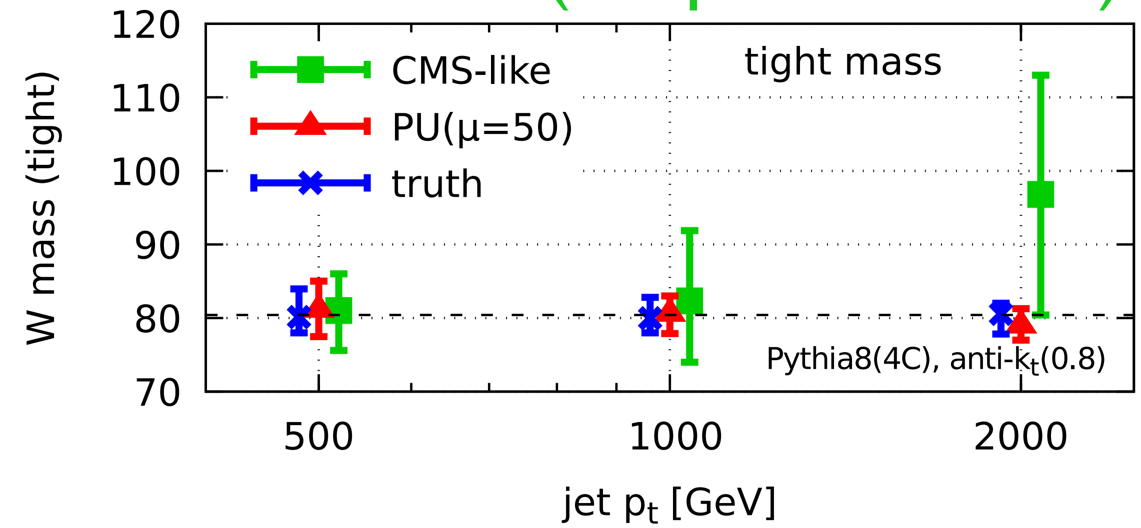
Reconstructed W Mass



ATLAS-like (Tower Only)



CMS-like (Simplified PFlow)



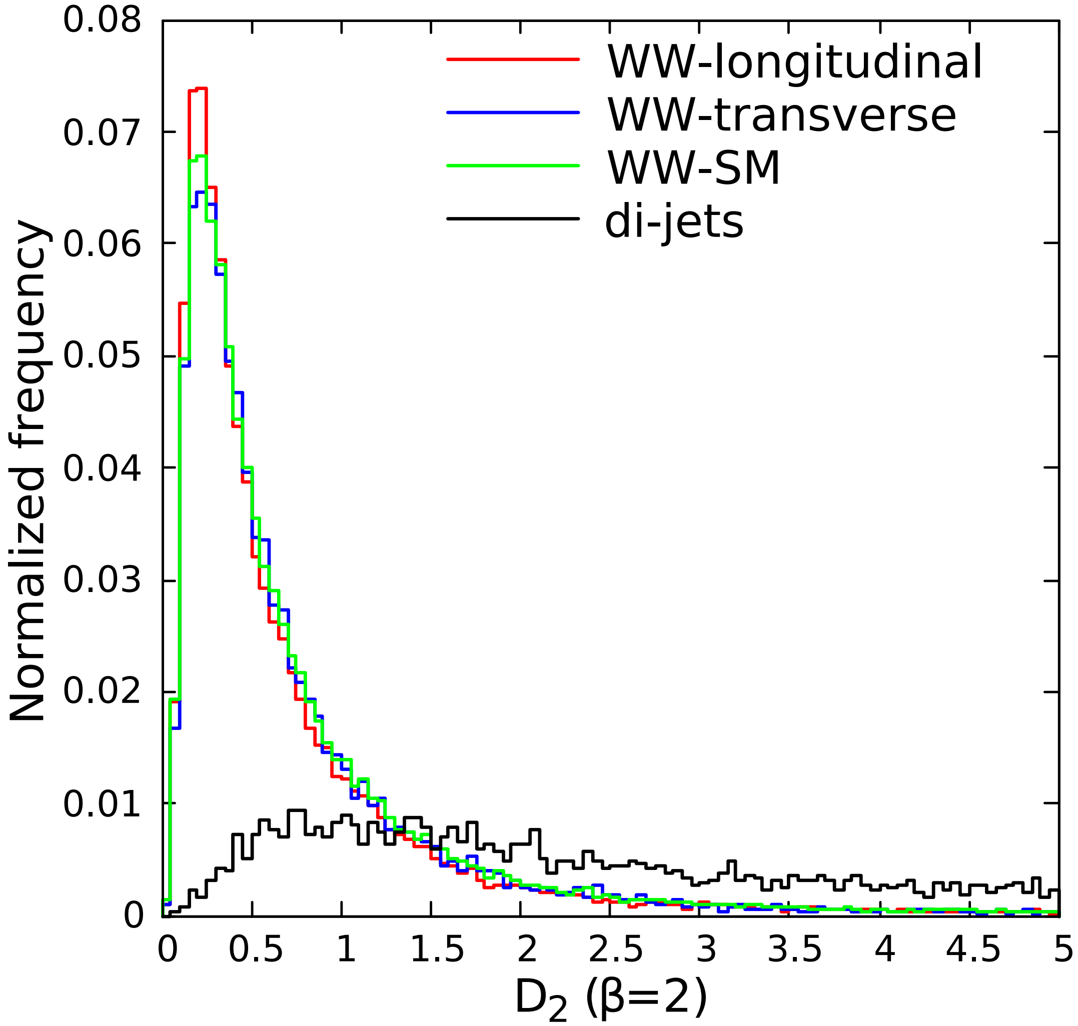
Expected degradation at very high p_T

Possible benefits from particle flow reconstruction?

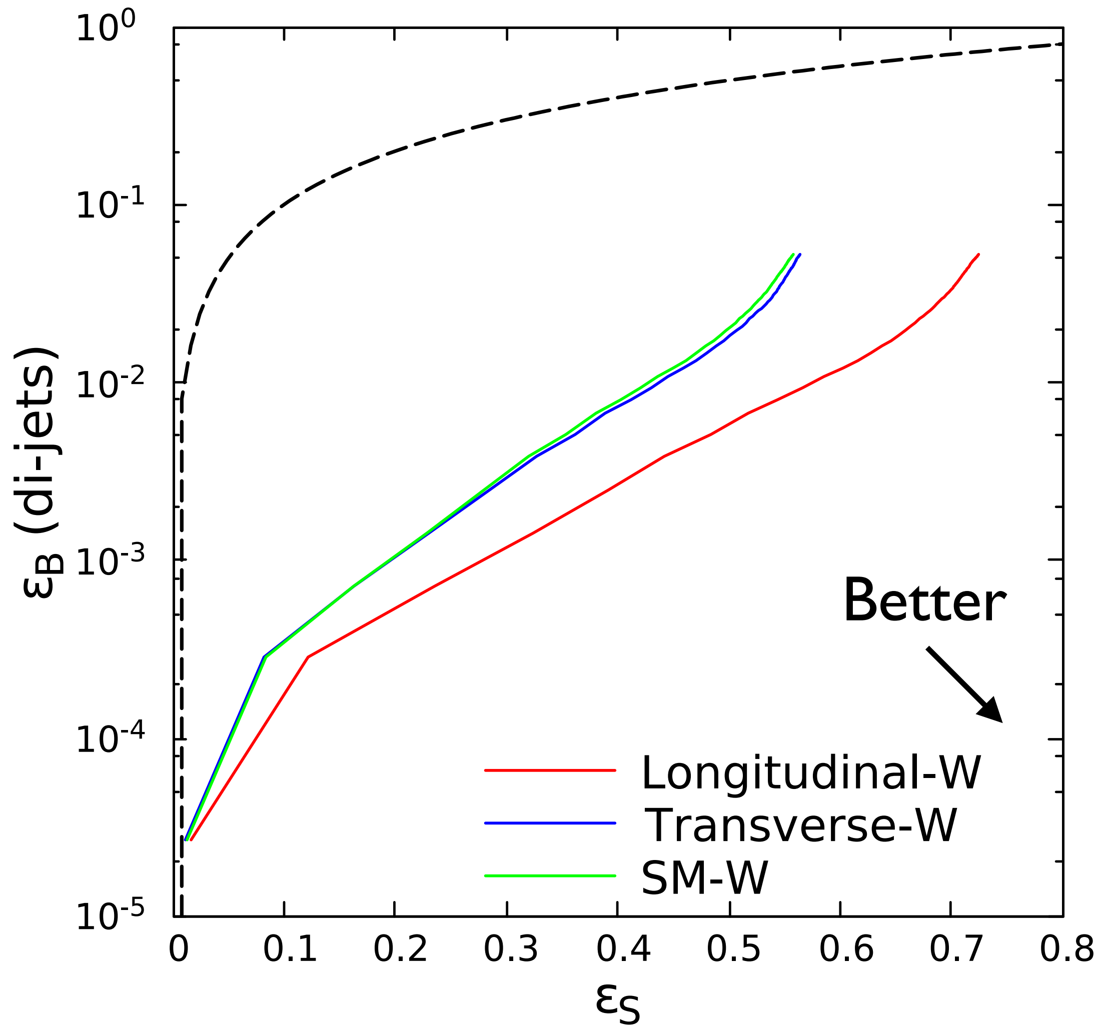
Resilience to Vector Boson Polarization?

Dichroic grooming with D_2 (β=2), p_T > 1 TeV

Distribution



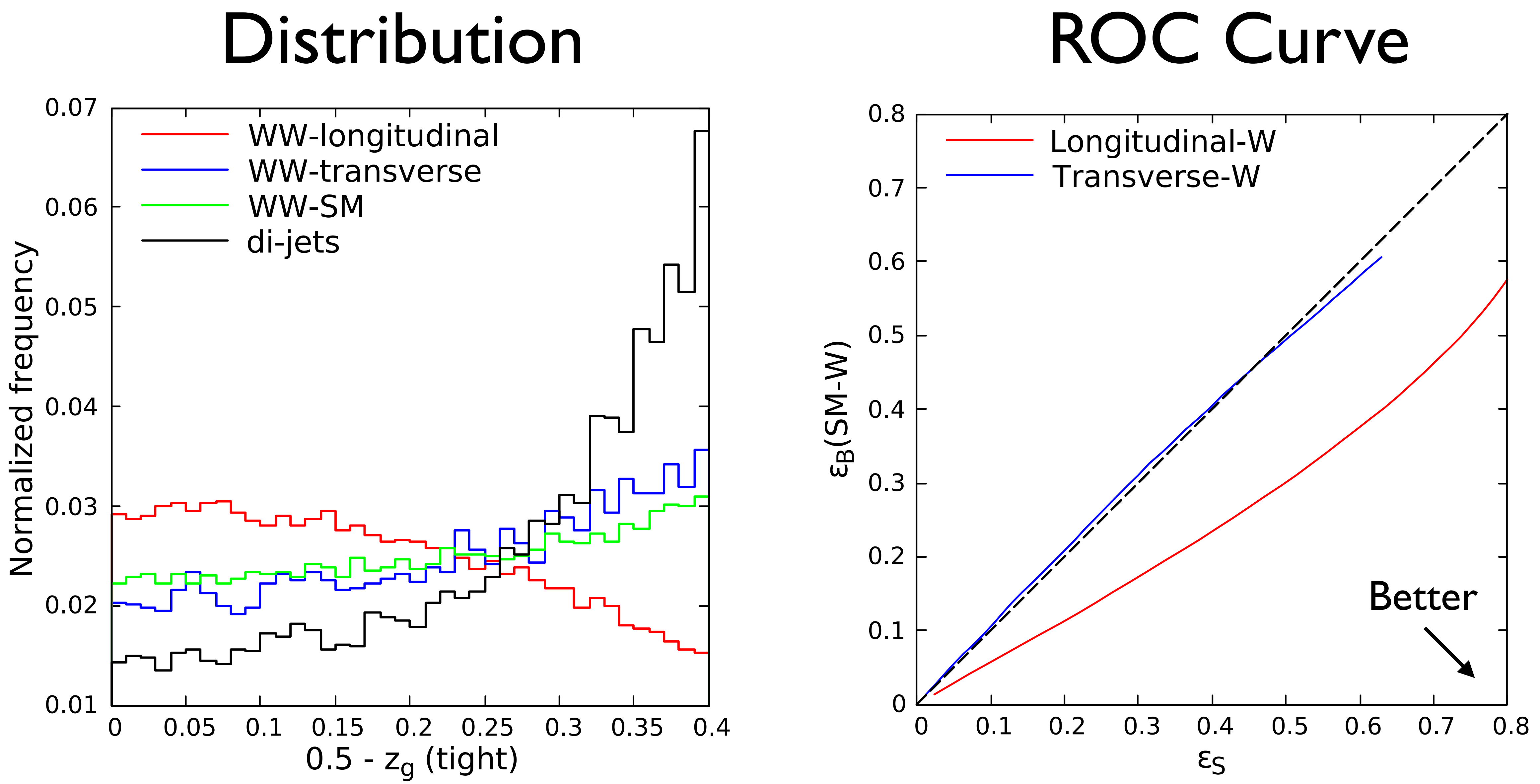
ROC Curve



Longitudinal Ws have larger acceptance for a given groomed mass cut, but very similar jet shapes

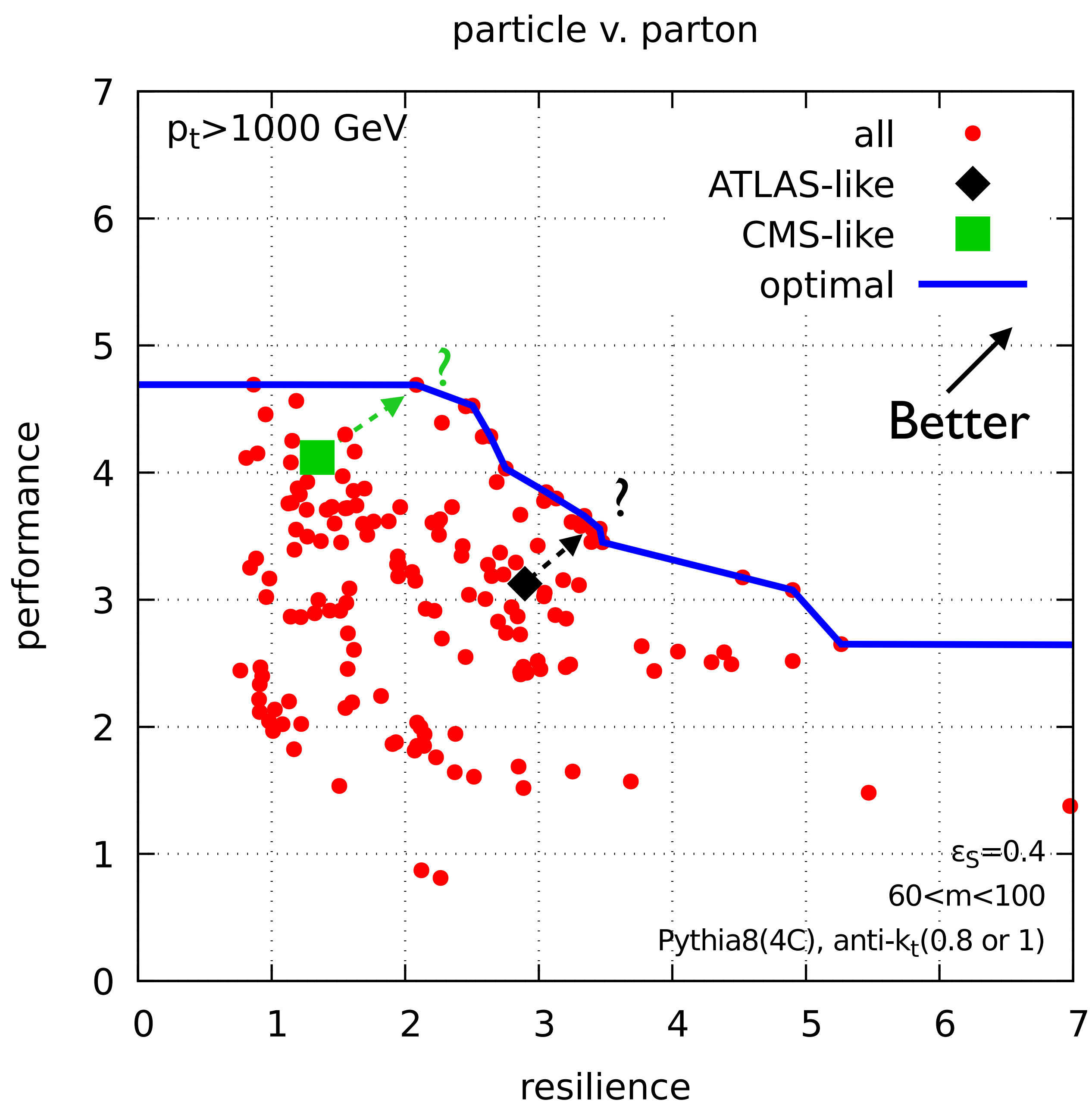
Identify Polarization Structure of Signal?

Tight grooming with momentum balance z_g, p_T > 1 TeV



Decent separation of longitudinal/transverse polarization using subjet balance

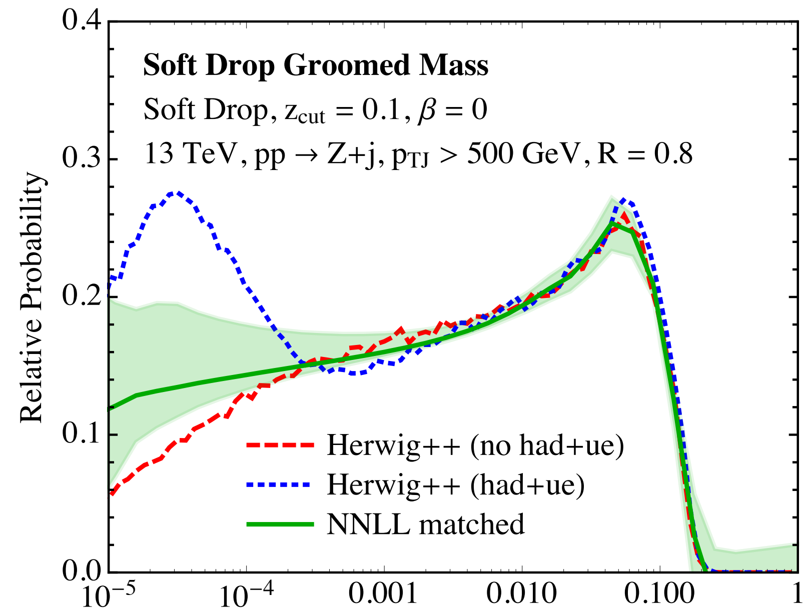
The Resilience Frontier



Looking forward to finding optimality contour for full parton ⇒ hadron ⇒ particle ⇒ detector ⇒ pileup chain

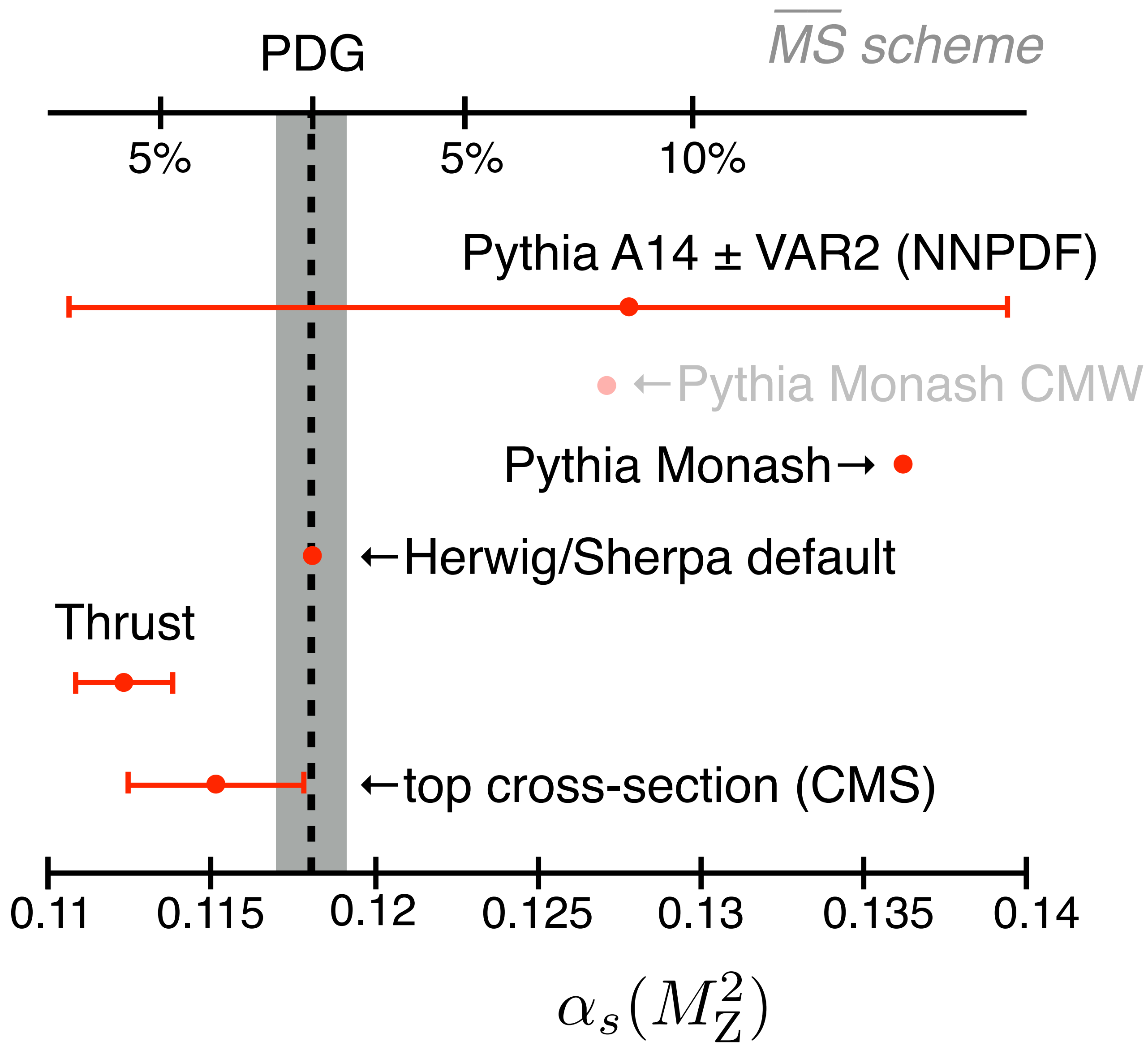
Goal for LH 2017 Proceedings:

Identify, understand, and motivate:
a) resilient 2-prong jet tagging strategies
b) effective W polarimetry methods



Extracting the Strong Coupling Constant

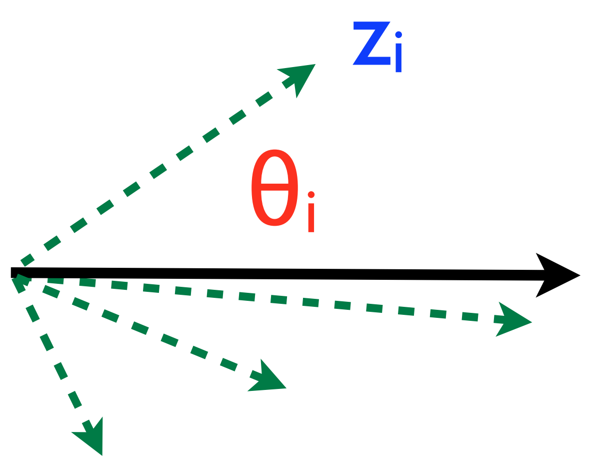
Defining the Target



Even a 10% measurement of α_s from jet shapes would add valuable diagnostic information

Jet Shapes with Grooming

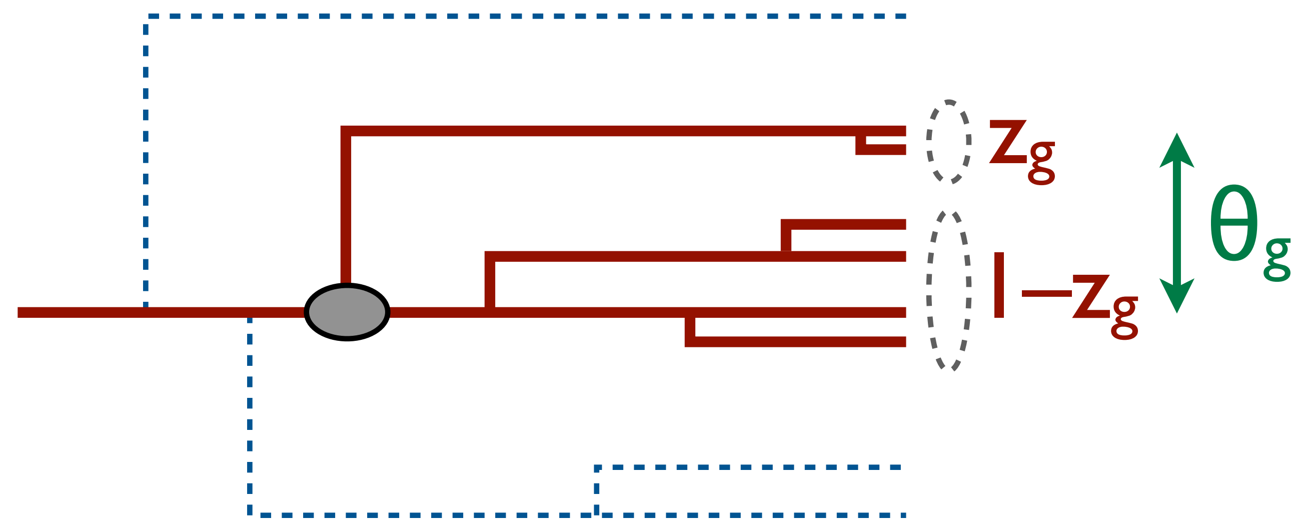
Angularities



$$e_\alpha = \sum_i z_i \theta_i{}^\alpha$$

Sensitive to α_s
through
radiation patterns

Soft Drop/mMDT



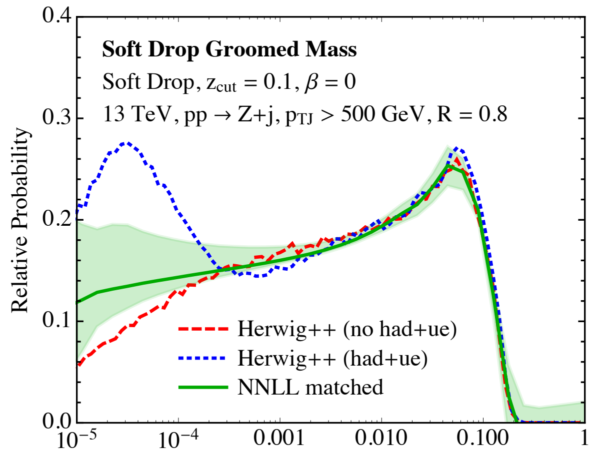
$z_g > z_{cut}\, \theta_g{}^\beta$

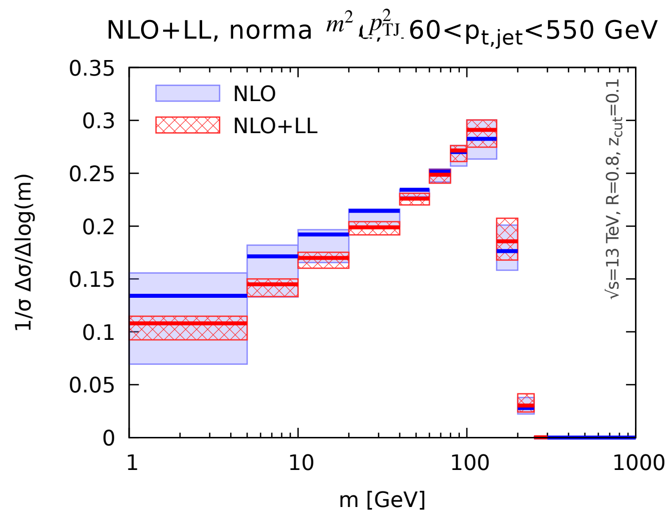
Less sensitive to
complications from
soft/NP effects

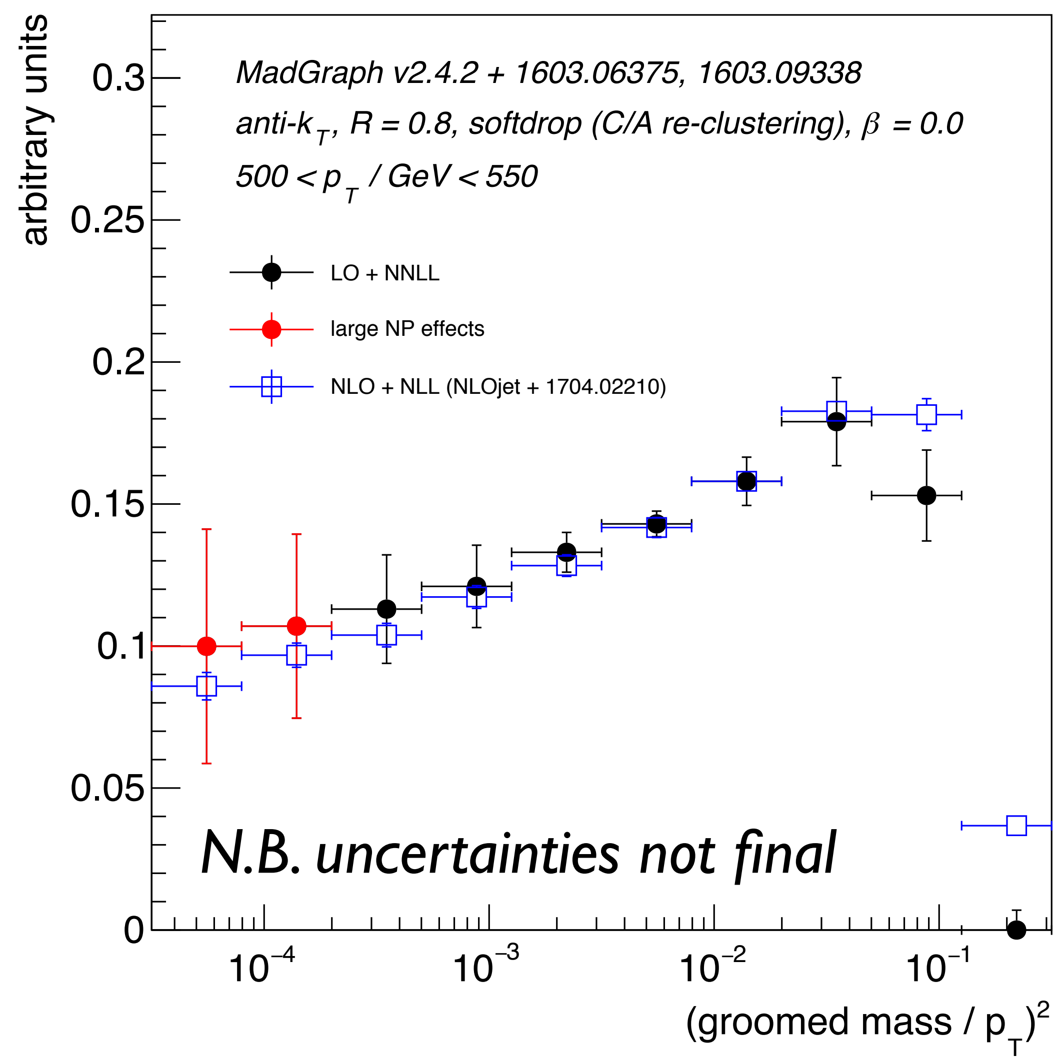
[Larkoski, JDT, Waalewijn, 1408.3122; Gras, Hoeche, Kar, Larkoski, Lönnblad, Plätzer, Siódmok, Skands, Soyez, JDT, 1704.03878,
[Larkoski, Marzani, Soyez, JDT, 1402.2657; see also Butterworth, Davison, Rubin, Salam, 0802.2470; Dasgupta, Fregoso, Marzani, Salam, 1307.0007]

Precision Calculations

Groomed jet mass





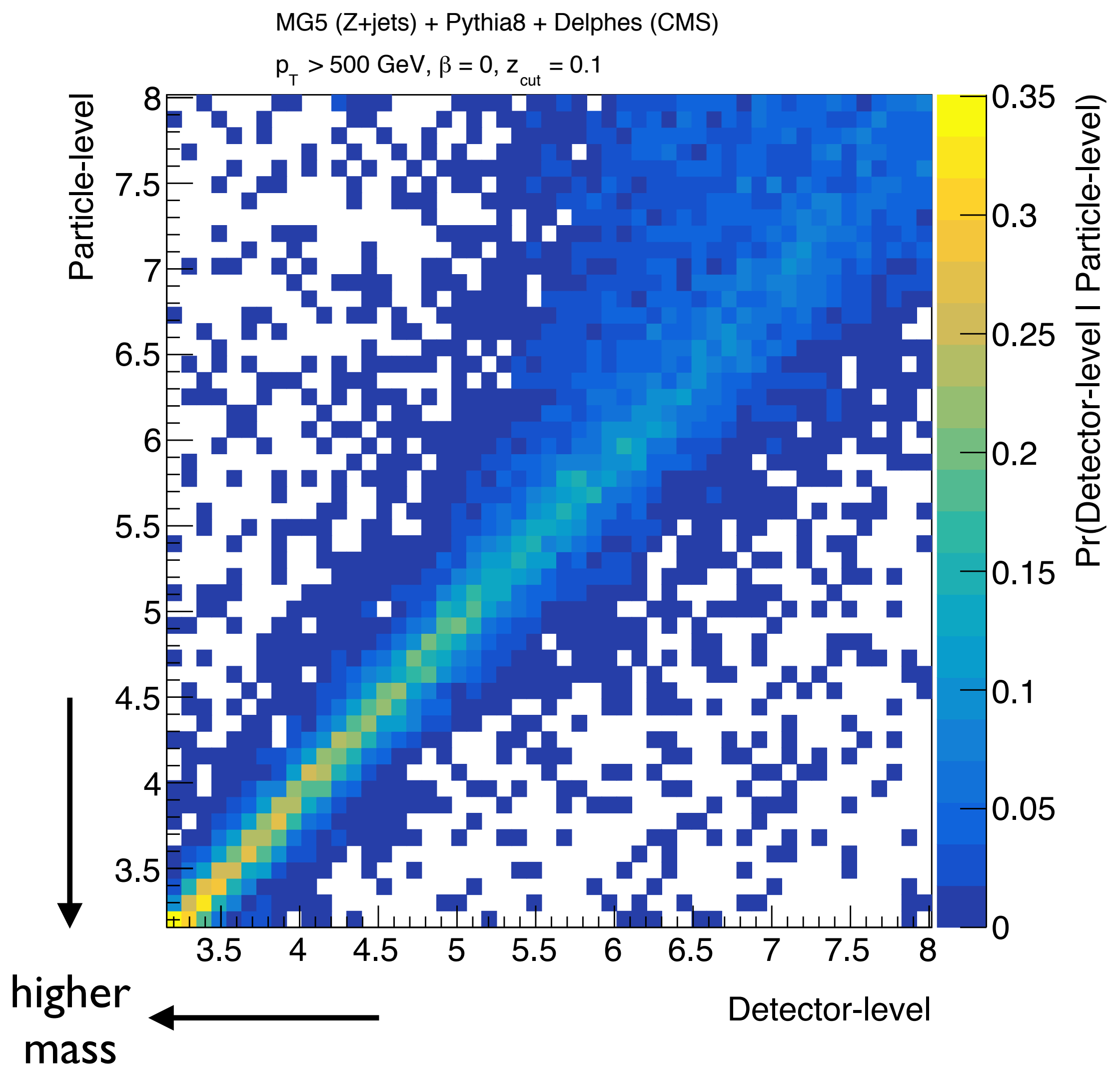


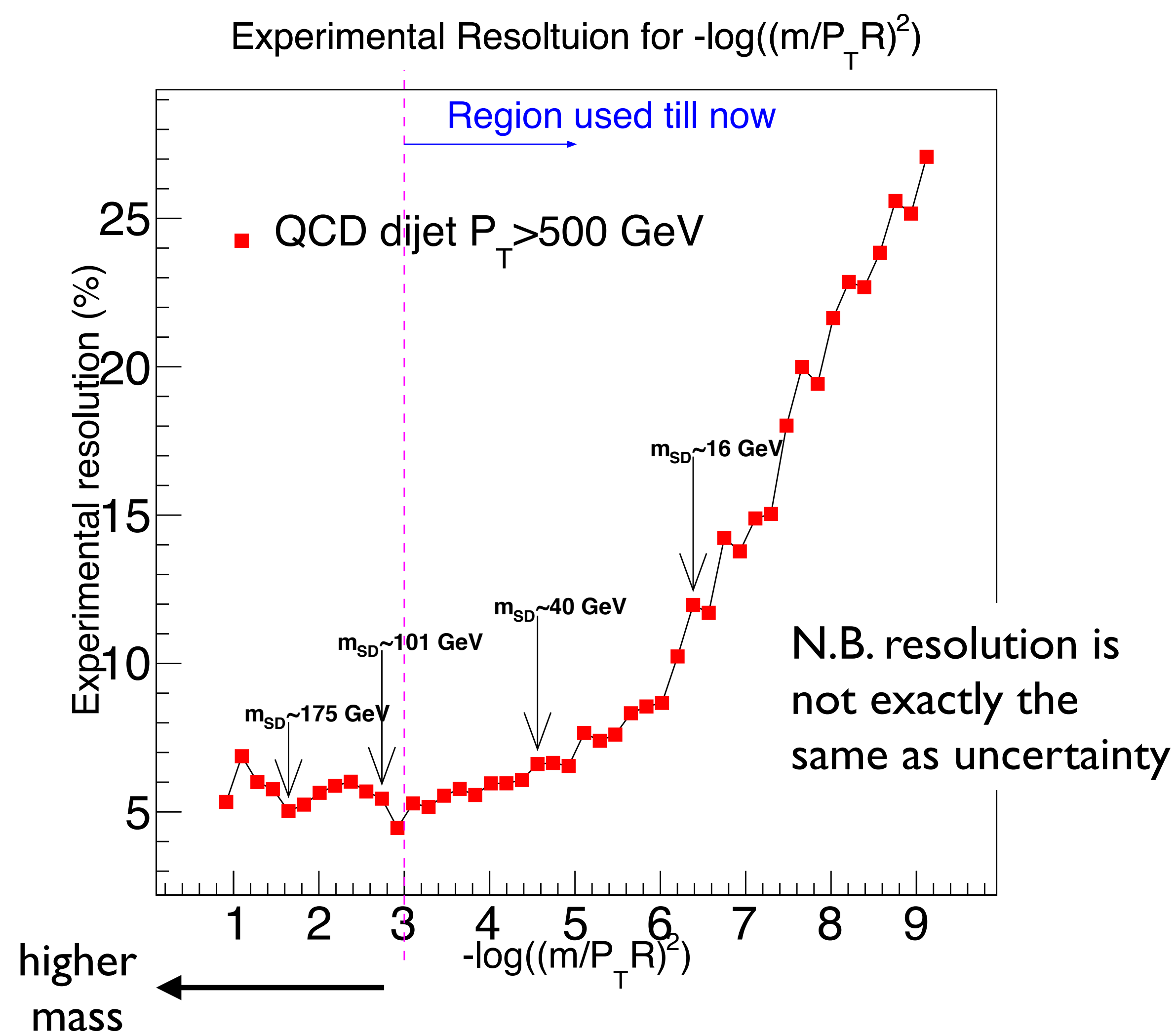
Proof-of-principle that matched resummed/fixed-order jet shapes can achieve target precision

[Frye, Larkoski, Schwartz, Yan, 1603.06375, 1603.09338; Marzani, Schunk, Soyez, 1704.02210]

Experimental Resolution

For groomed mass over ungroomed p_T





In CMS-like simulation, good response to groomed jet shapes
Angular resolution dominates at low mass (track-based observables?)

Tradeoff: Robustness vs. Sensitivity

$$\Delta = \int \mathrm{d}\lambda \, \frac{1}{2} \frac{\big(A(\lambda) - B(\lambda)\big)^2}{A(\lambda) + B(\lambda)}$$

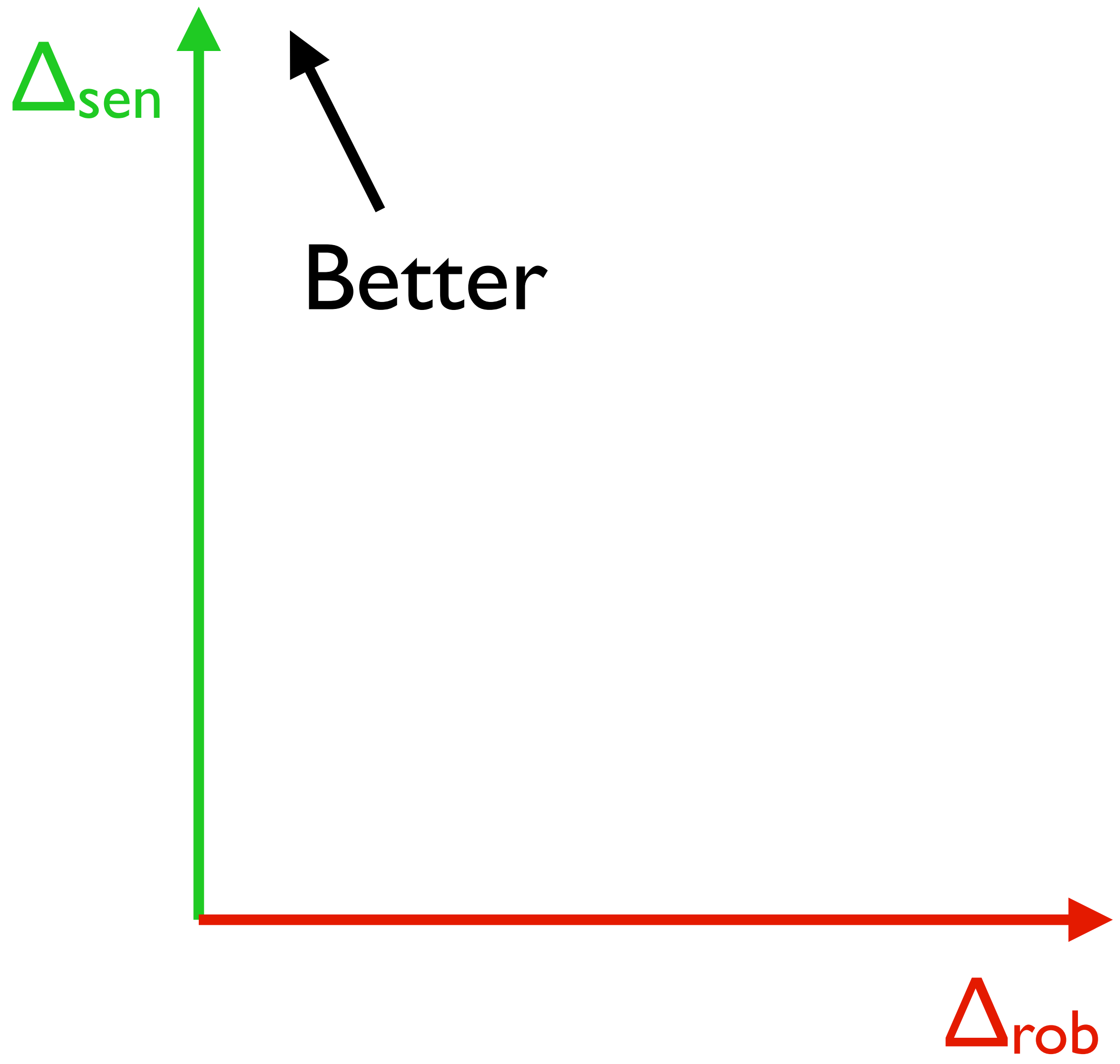
Same metric as LH 2015 quark/gluon study

Robustness:

A = Full Distribution
B = Adjust NP Physics
↳ Want Δ_{rob} to be small

Sensitivity:

A = Nominal α_s value
B = Shifted α_s value
↳ Want Δ_{sen} to be large



Parton Shower and Observables

Testing sensitivity vs. robustness in pure quark/gluon samples

$pp \to Z + \text{quark}$

$pp \to Z + \text{gluon}$

Herwig 7.1 with "The Tune"

Also have Pythia 8.223 with Tune 4C

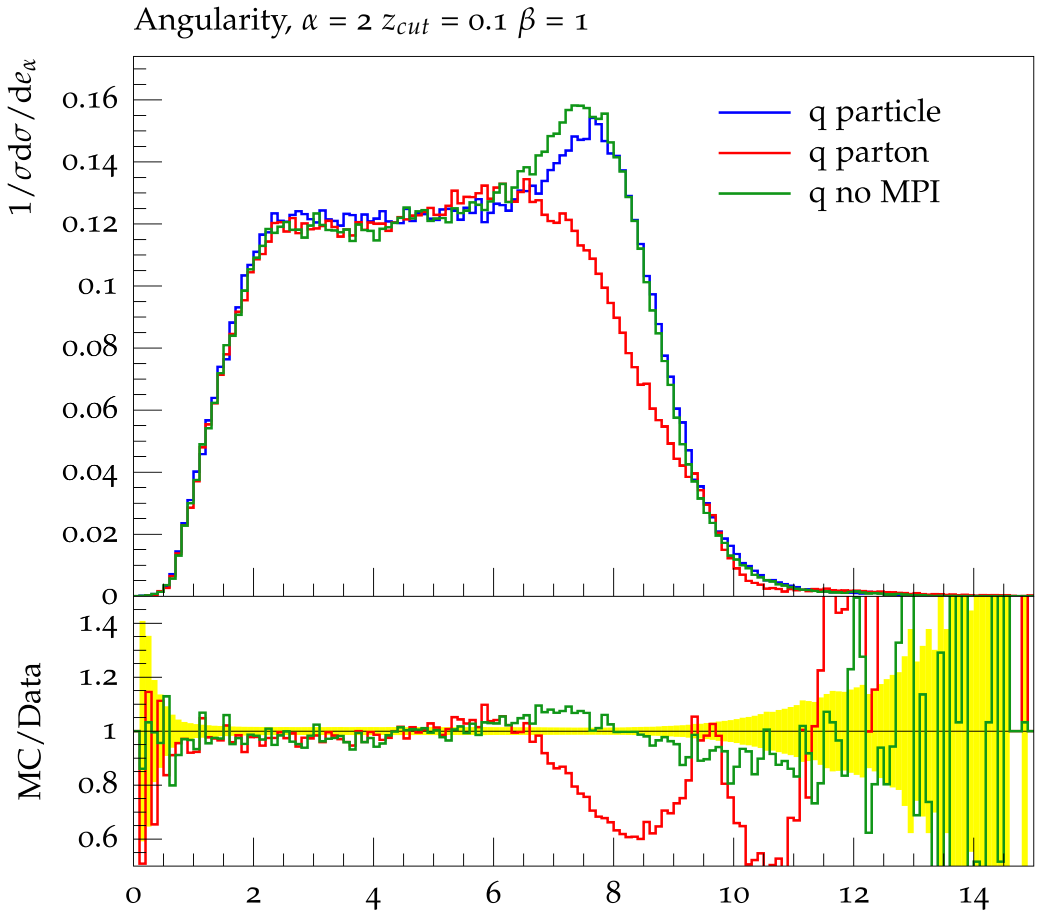
	LHA	width	"mass"	
Angularities: $\alpha =$	0.5	1.0	2.0	and θ_g

	mMDT		
Soft Drop Grooming: $\beta =$	0	1	2
$z_{cut} =$	0.05	0.1	0.2

Impact of Hadronization, MPI, and ISR

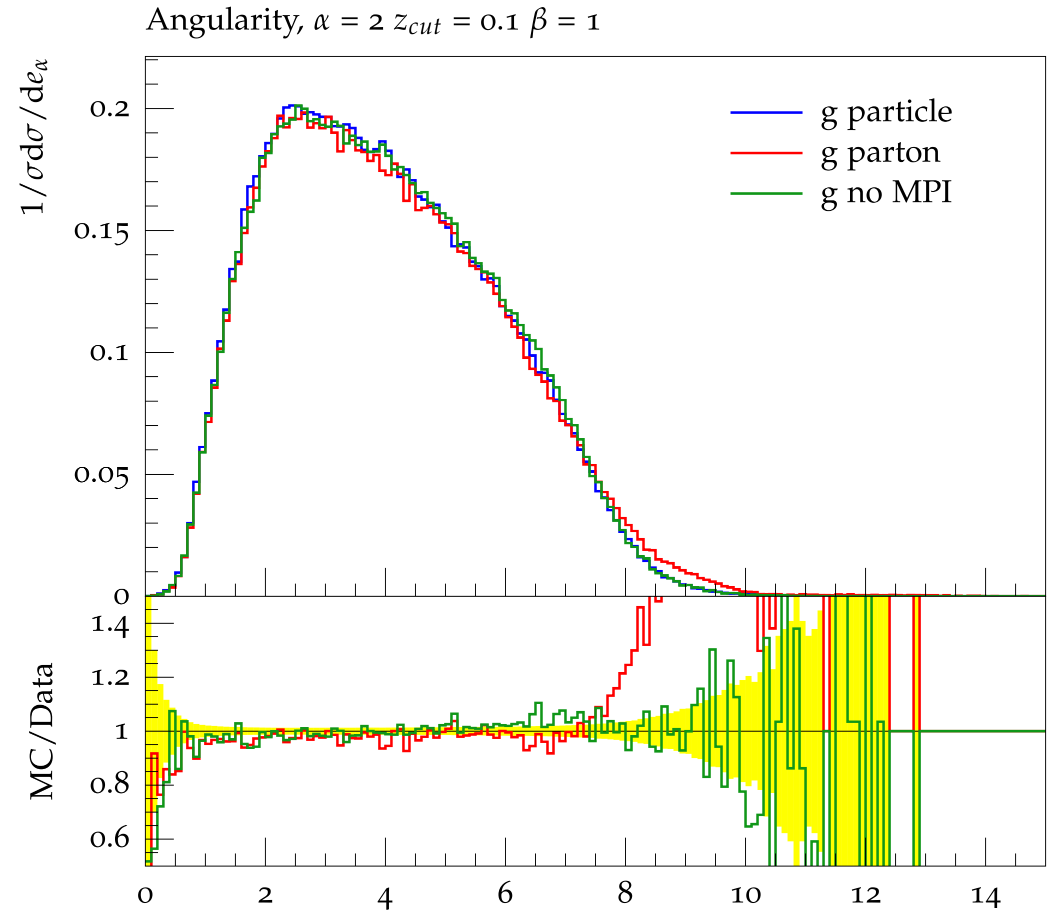
≈ jet mass with α = 2, pure quark/gluon samples

Quark Jets



← higher "mass" $-\log(e_\alpha)$

Gluon Jets



← higher "mass" $-\log(e_\alpha)$

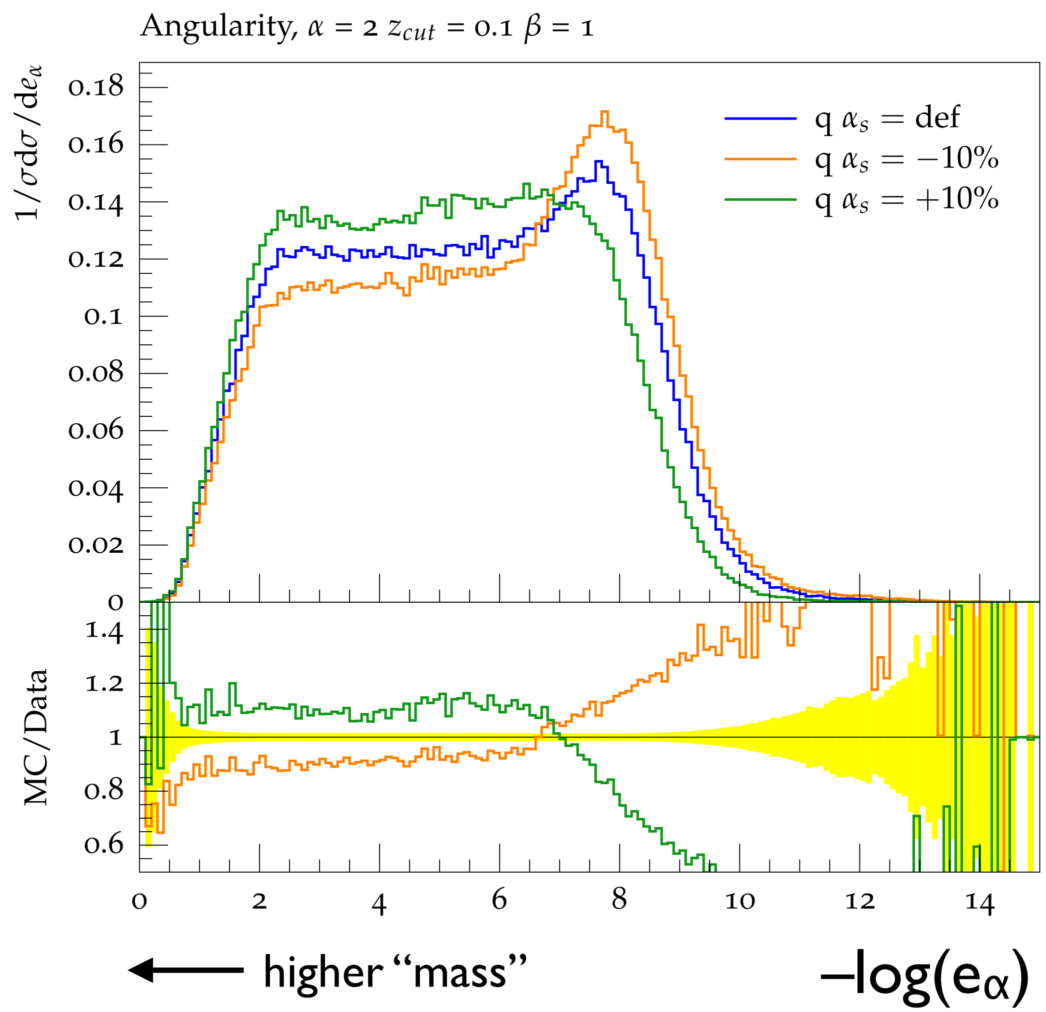
Hadronization distorts groomed angularities, especially in quark sample

Need to cut out NP region of phase space

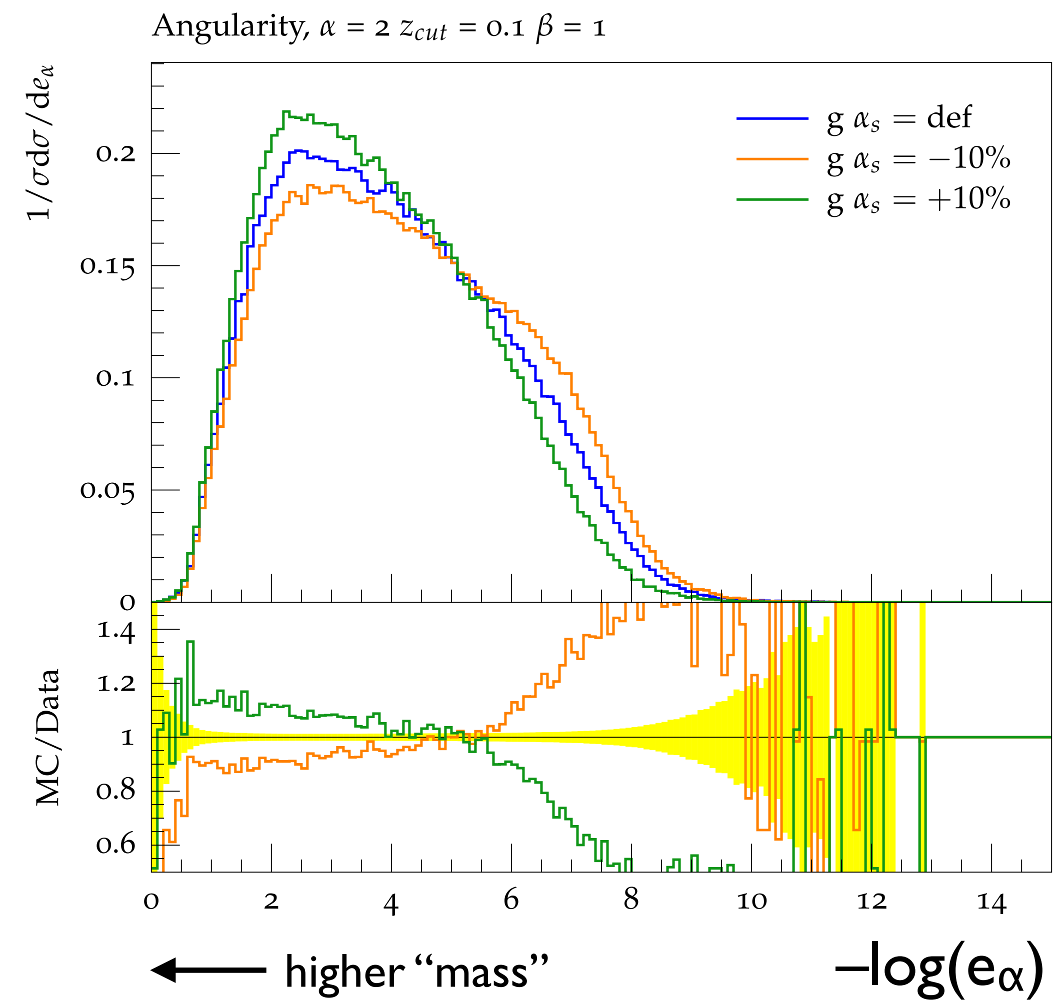
Sensitivity to α_s variations

≈ jet mass with α = 2, pure quark/gluon samples

Quark Jets



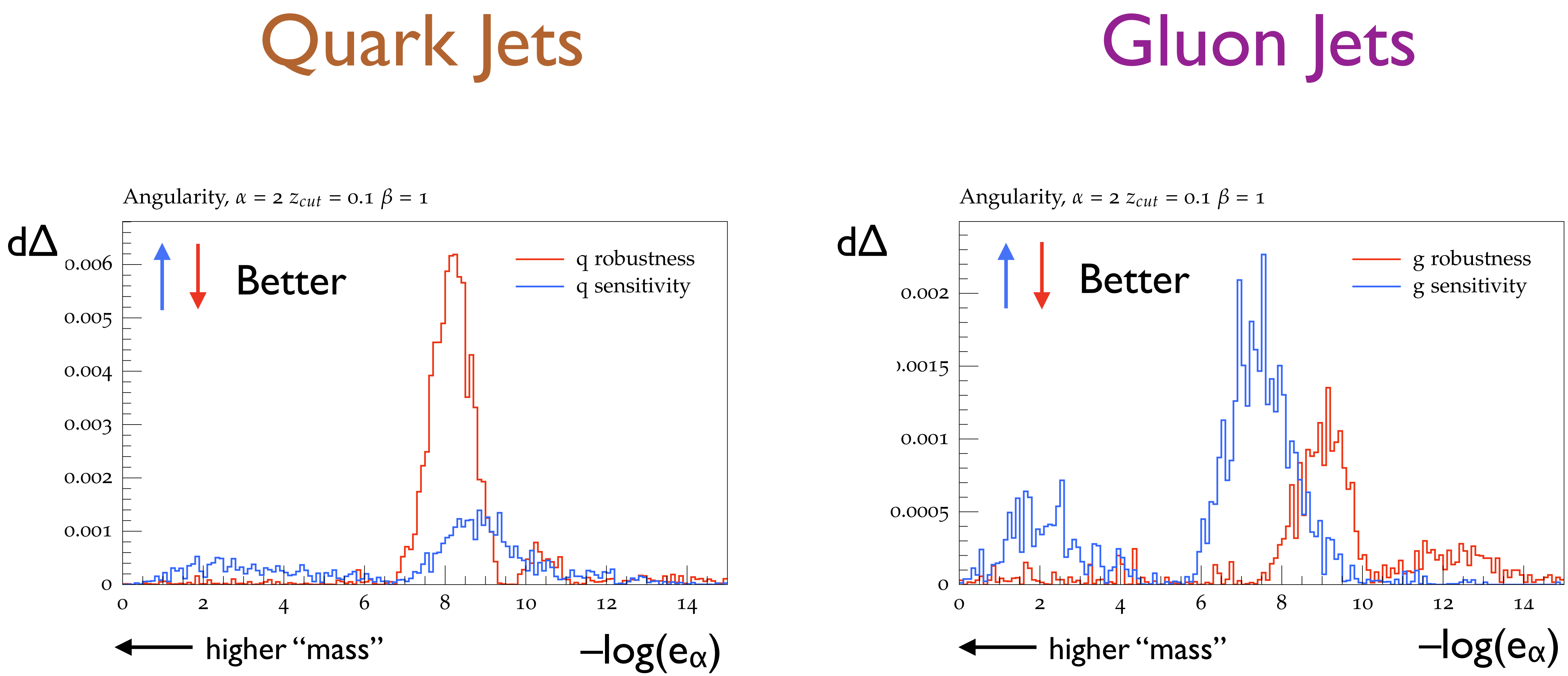
Gluon Jets



Impact of α_s is apparent throughout the distribution, different trends from NP effects

Visualizing Robustness and Sensitivity

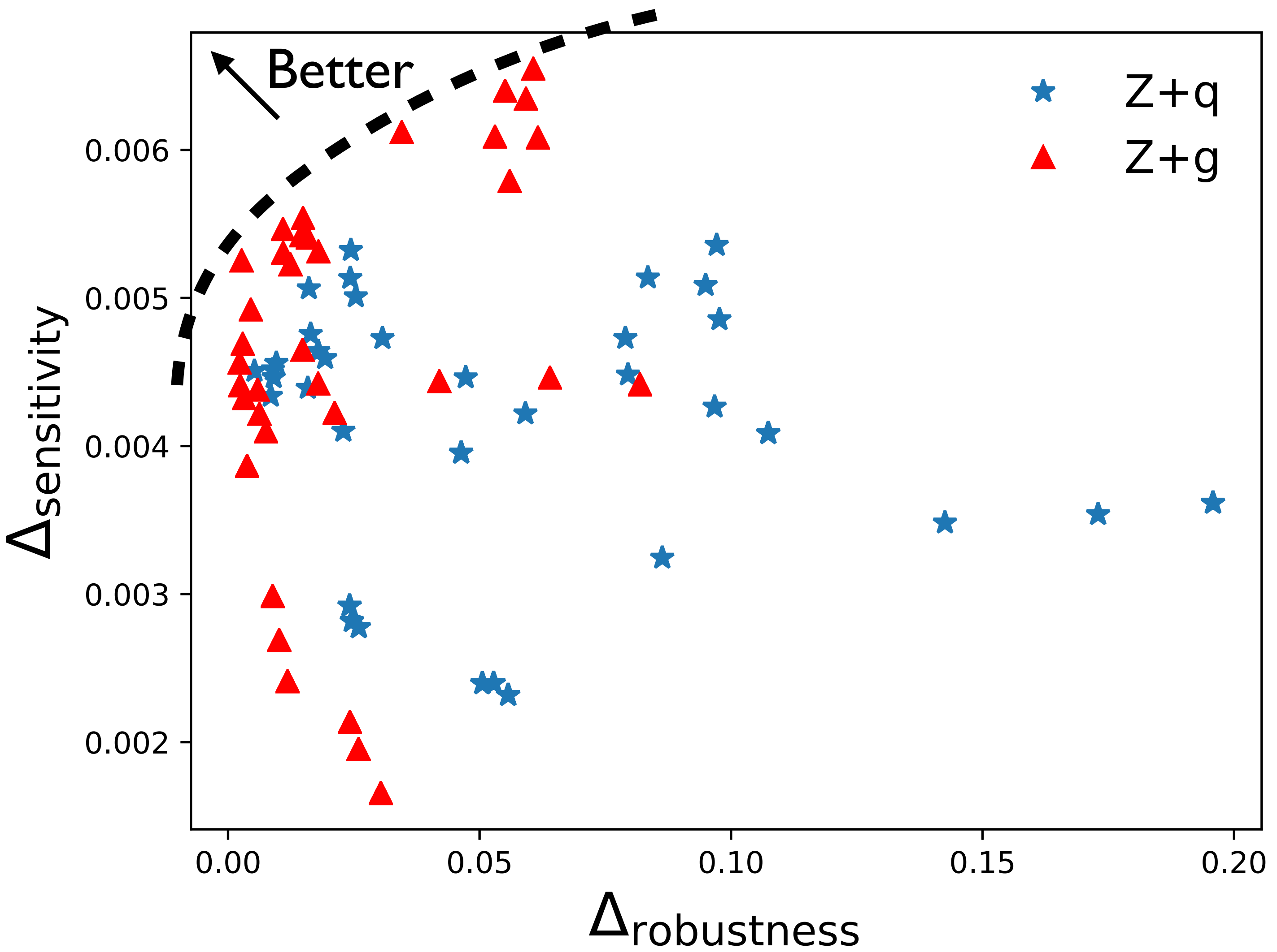
≈ jet mass with α = 2, pure quark/gluon samples



Can identify phase space regions where
blue (sensitivity) is high while red (robustness) is low
Gluon channels are particularly sensitive

Quantifying Robustness and Sensitivity

Testing 36 soft-dropped angularities

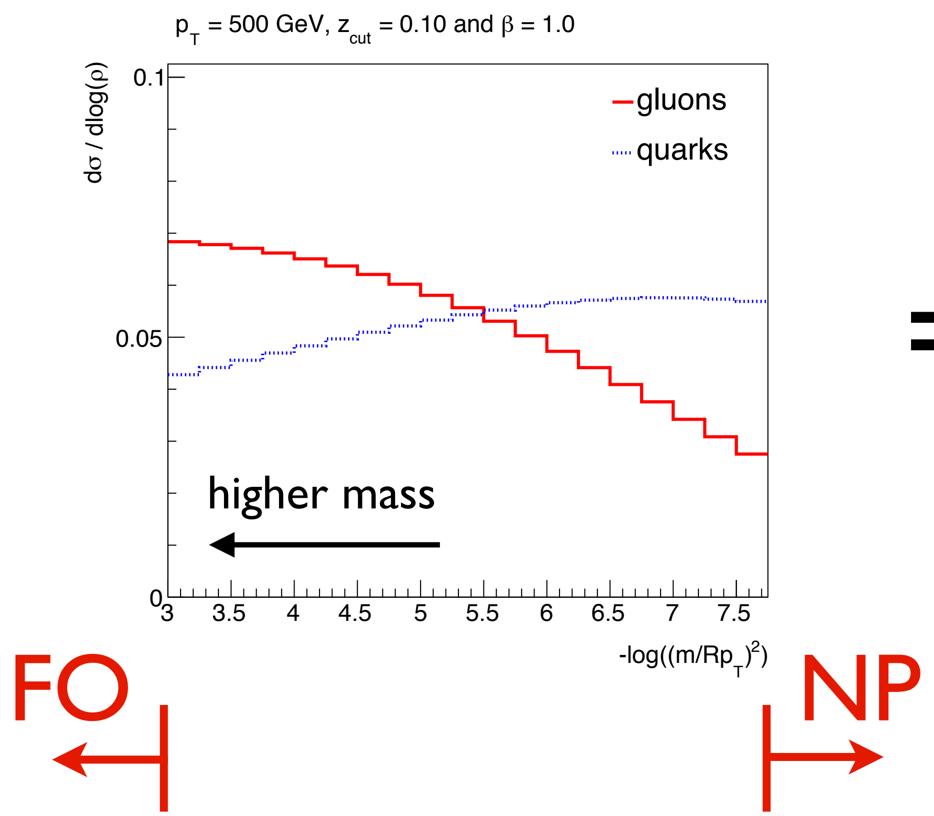


Gluon samples have both better sensitivity and better robustness because more copious perturbative radiation ($C_A > C_F$)

Fitting in Mixed Quark/Gluon Samples?

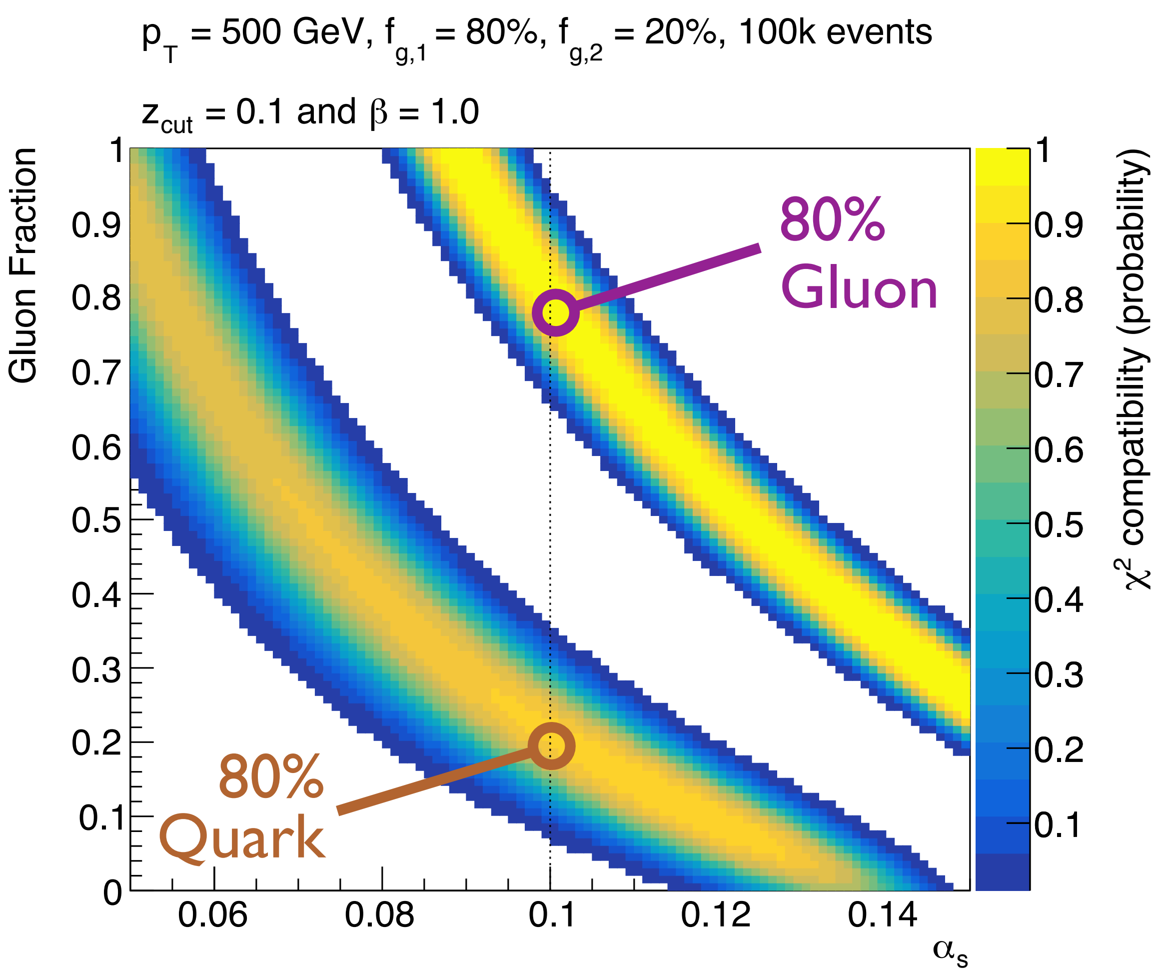
Toy fit with $\alpha_s = 0.1$

Probability Distribution



⇒

Best Fit from Pseudodata

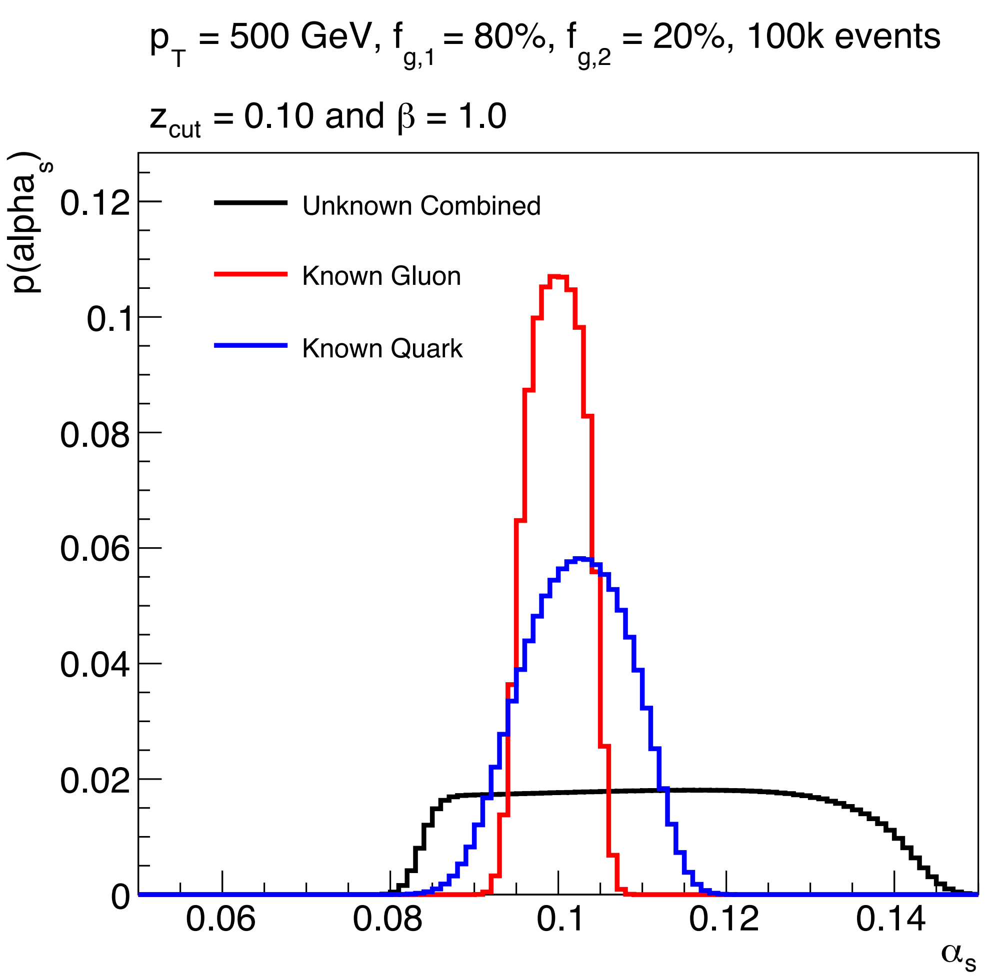


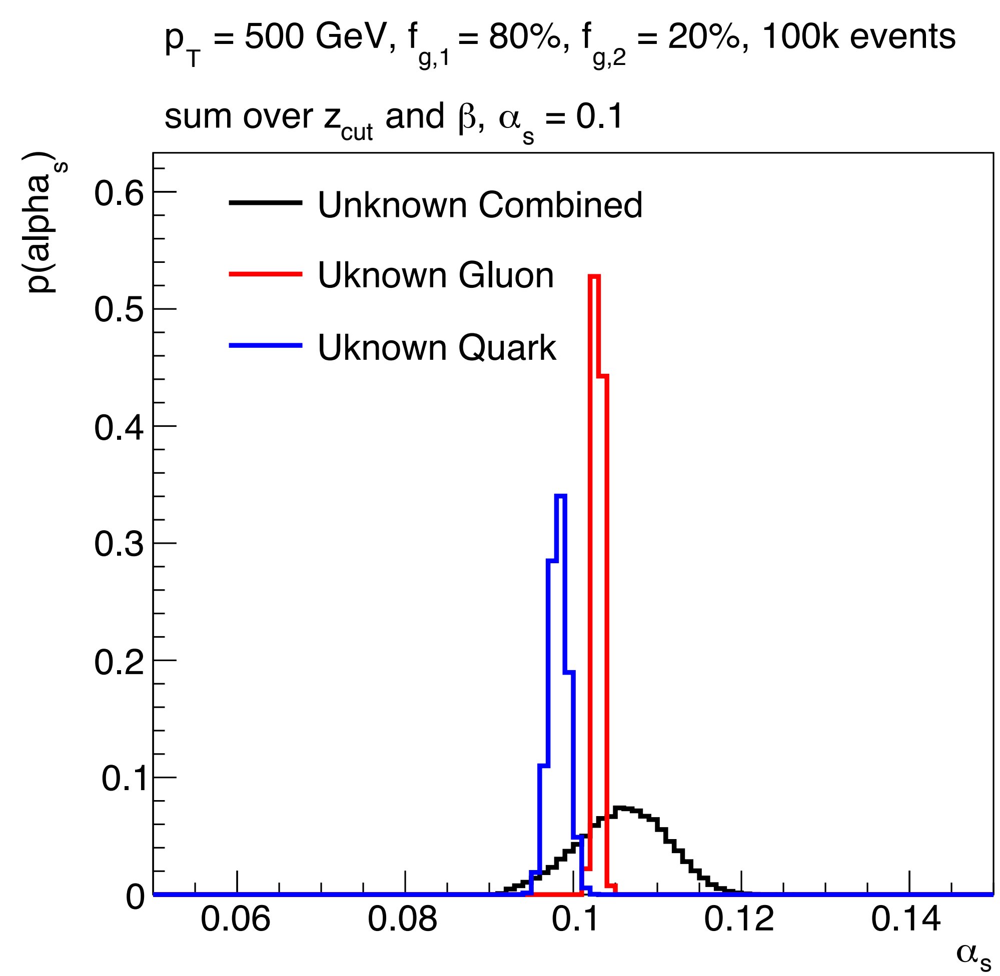
Probability is mainly a function of ($\alpha_s C_{F,A}$) ⇒ Bananas
Dominant systematic likely quark/gluon sample composition

Global Fit to Multiple Groomed Angularities?

Toy fit with $\alpha_s = 0.1$, non-joint probabilities

One Measurement ⇒ Six Measurements





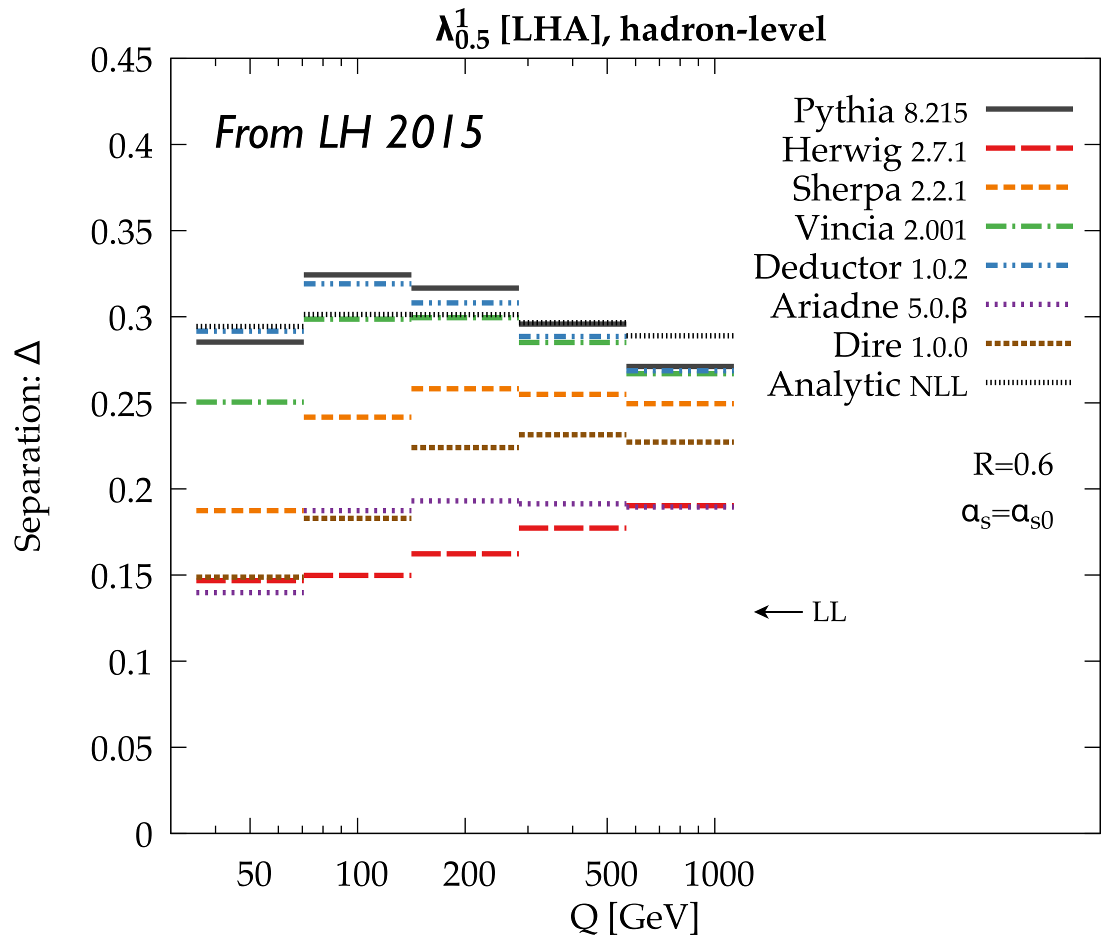
10% uncertainty seems plausible even with current theoretical and experimental technology

Goal for LH 2017 Proceedings:

Identify the leading challenges facing an α_s extraction from LHC jet shapes, including:
a) experimental resolution
b) perturbative uncertainties
c) nonperturbative sensitivity
d) quark/gluon composition

Uses for Quark/Gluon Tagging

New Opportunities for 1-Prong Tagging



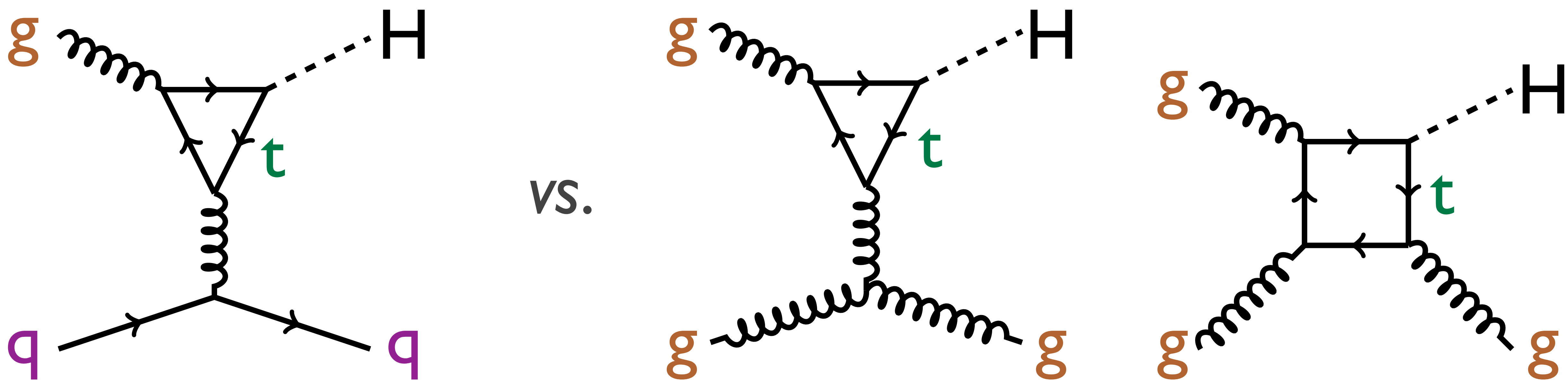
Assuming progress on parton shower modeling by LH 2019…

…what physics analyses might benefit from quark/gluon tagging?

E.g.: dark matter mono-tagged-jet plus MET, quark-rich gluino cascade decays, pileup jet mitigation, double subjet tagging in boosted hadronic W/Z, constrain parton showers using LEP data, resolving combinatorics in tt + jet, forward jet tagging in VBF/VBS, constraining PDFs with (N)NLO interplay, disentangle box/triangle graphs in high p_T Higgs, initial-state tagging using jet vetoes, ...

[Gras, Hoeche, Kar, Larkoski, Lönnblad, Plätzer, Siódmok, Skands, Soyez, JDT, 1704.03878]

E.g. High-p_T Higgs Physics



Possible Strategy:

Tag Final State with Jet Substructure

Tag Initial State with Jet Vetoes

Explore non-trivial interplay

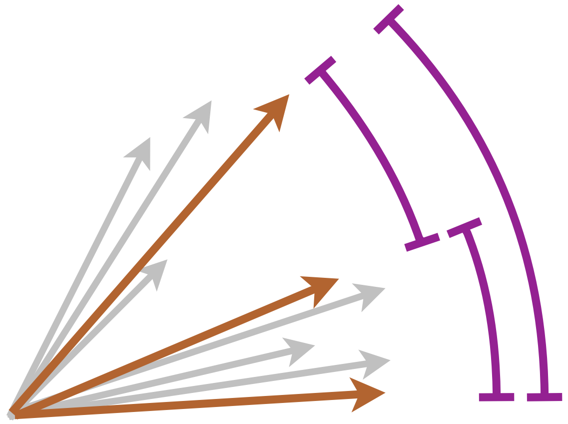
Target:

Disentangle (anomalous) Higgs couplings to top quarks and gluons

[see e.g. Ebert, Liebler, Moult, Stewart, F. Tackmann, K. Tackmann, Zeune, 1605.06114]

Goal for LH 2017 Proceedings:

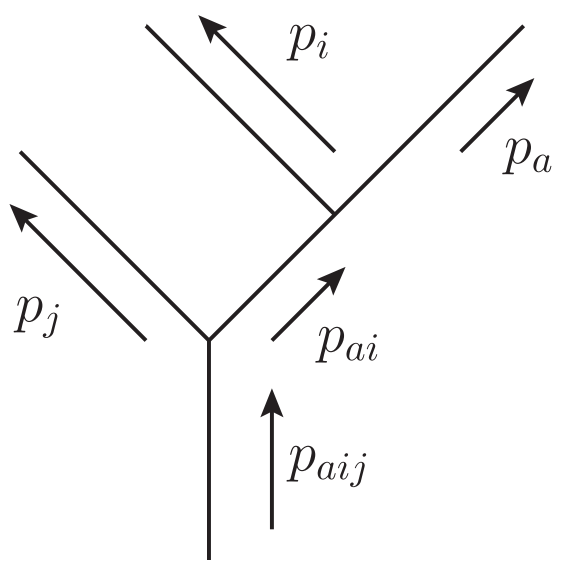
Extensive summary of potential quark/gluon applications and future measurements to constrain jet radiation modeling



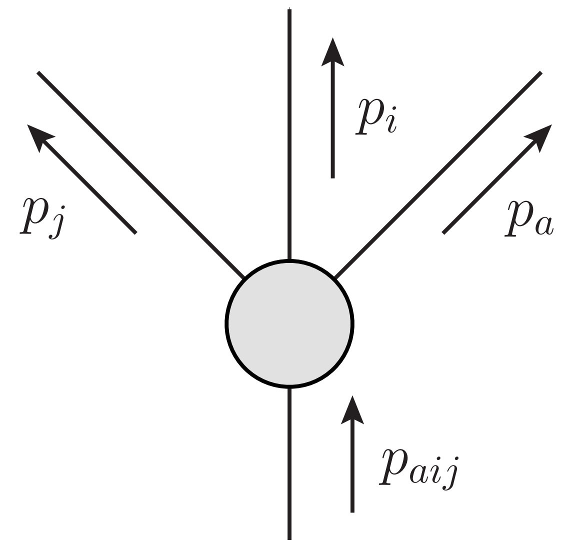
Advanced Observables for Parton Showers

Triple-Collinear Splittings and Jet Substructure?

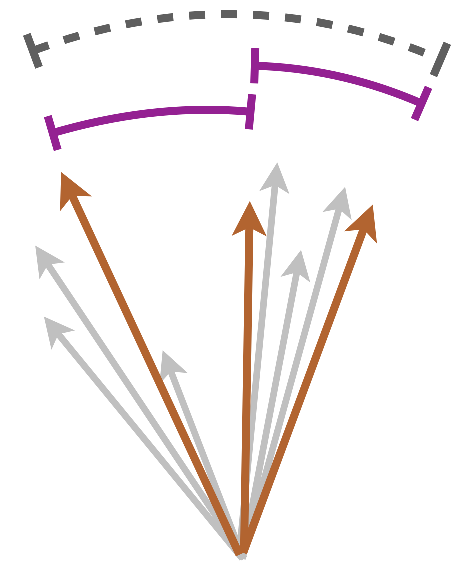
Complementary: non-global correlations in soft physics

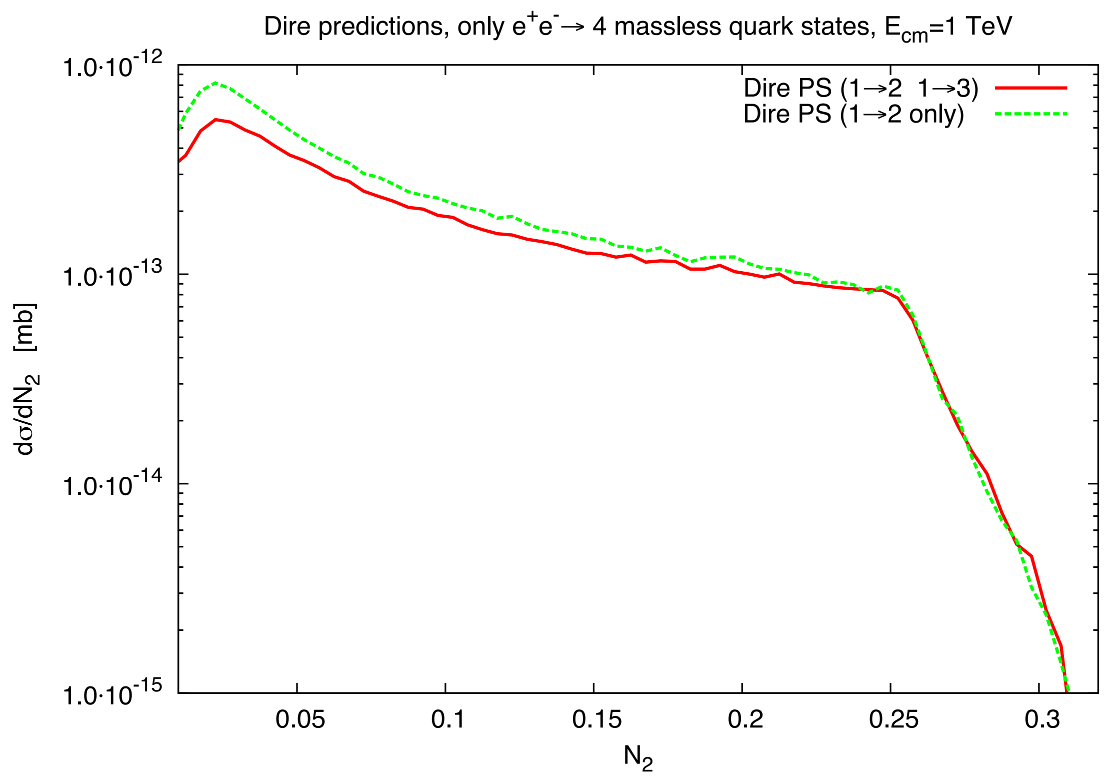


vs.



with





Hmm, little sensitivity with N_2 in $q \to q\, q'\, \bar{q}' \ldots$

Followup study:
Study $g \to g\, g\, g$ with many interference terms

[see Höche, Prestel, 1705.00742; Höche, Krauss, Prestel, 1705.00982]

Active Jet Discussions at Les Houches 2017

More details in this report

2-Prong Jet Substructure Resilience

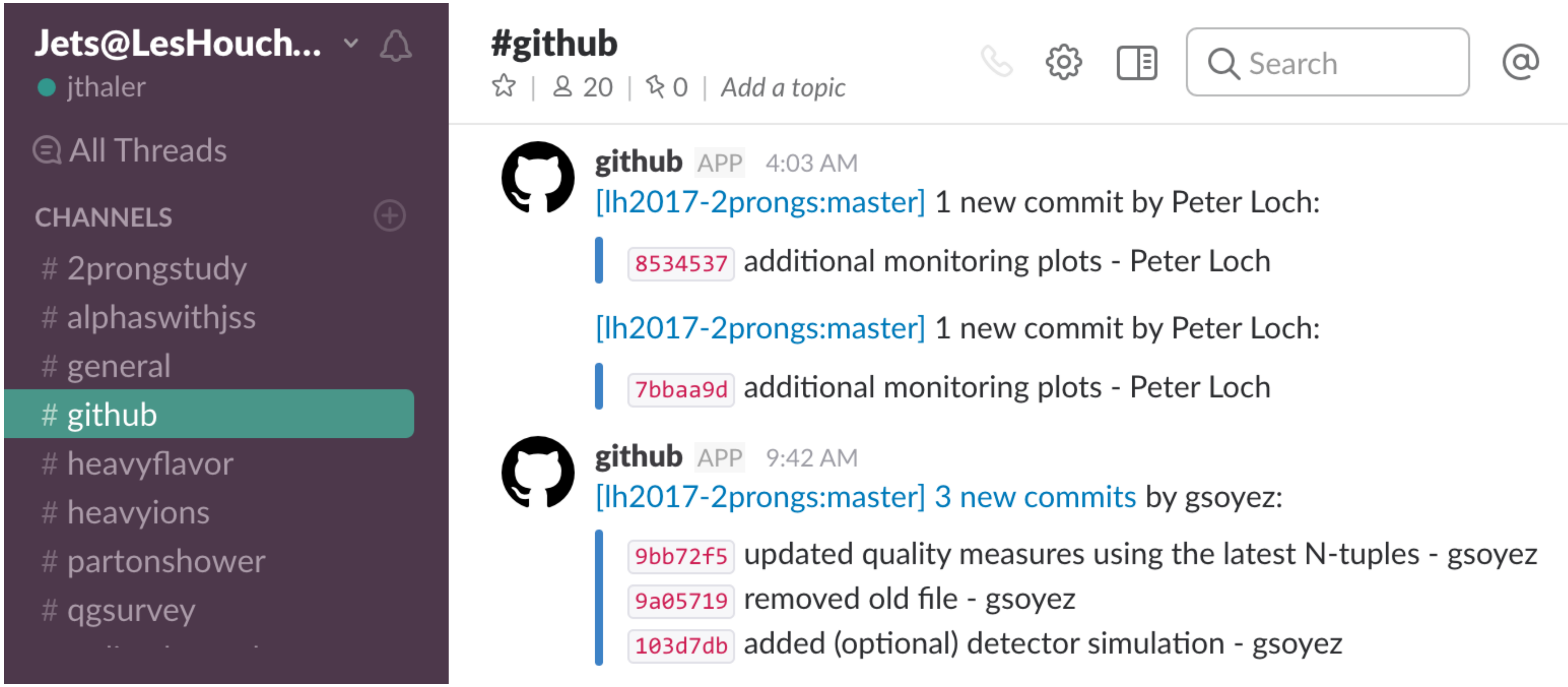
Extracting the Strong Coupling Constant

Uses for Quark/Gluon Tagging

Advanced Observables for Parton Showers

Want to get involved?

Join us on Slack/Github!



https://jetsatleshouches2017.slack.com/

Jet Studies for Les Houches

2015:

Pursuing white whale of quark/gluon discrimination
reveals (non)perturbative uncertainties in jet radiation

2017:

Pursuing 2-prong substructure & α_s extraction & ...
(topic of interest to jet physics community)

reveals ? & ?
(insights with broader implications for QCD and beyond)

Looking forward to a fun, productive ~~workshop~~ proceedings!

Backup Slides

From LH 2015

What is a Quark Jet?

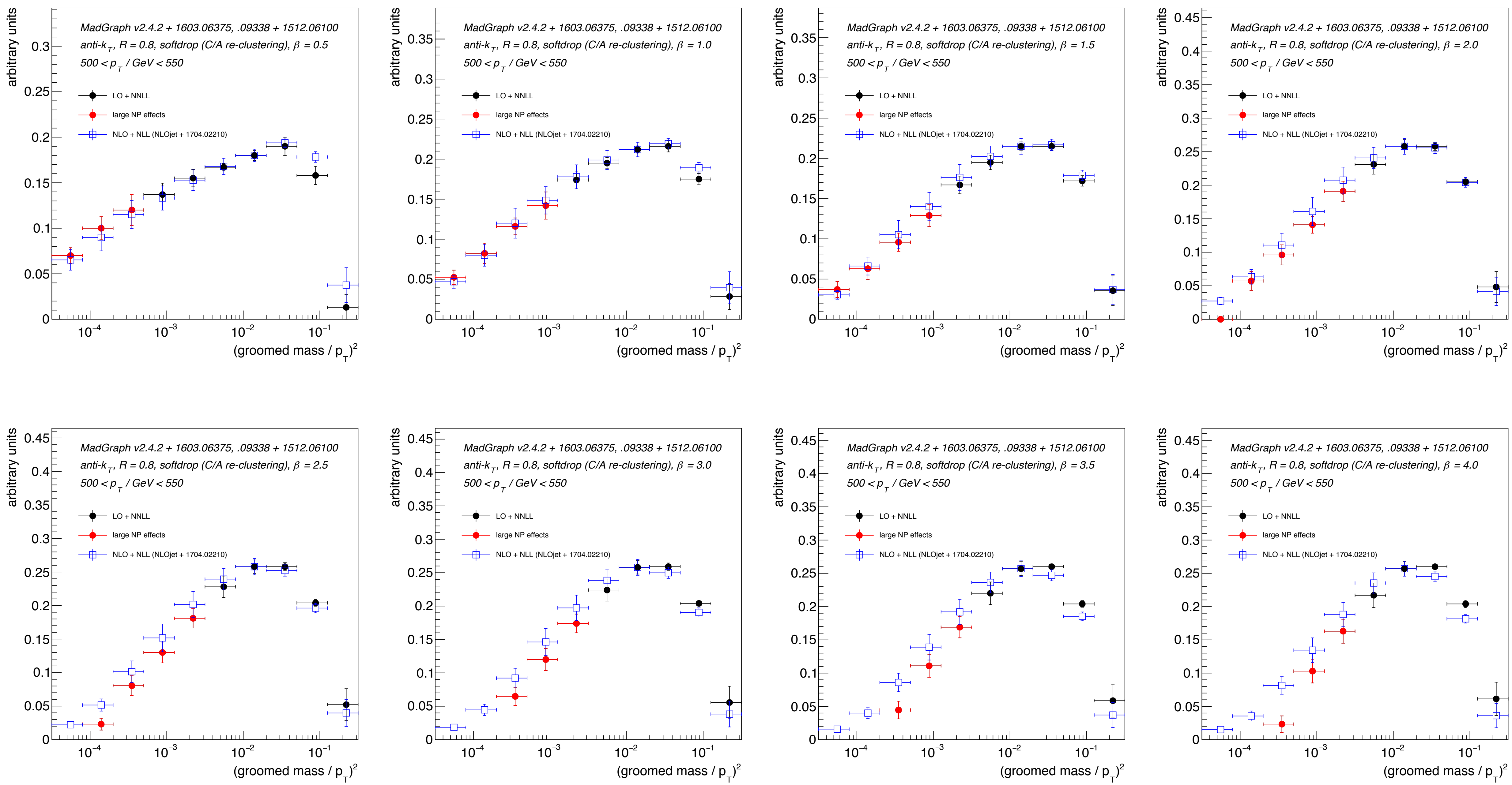
From lunch/dinner discussions

Ill-Defined ↓	**What people sometimes think we mean** ↑	A quark parton
		A Born-level quark parton
		The initiating quark parton in a final state shower
Quark as noun		An eikonal line with baryon number 1/3 and carrying triplet color charge
		A quark operator appearing in a hard matrix element in the context of a factorization theorem
		A parton-level jet object that has been quark-tagged using a soft-safe flavored jet algorithm (automatically collinear safe if you sum constituent flavors)
Quark as adjective		A phase space region (as defined by an unambiguous hadronic fiducial cross section measurement) that yields an enriched sample of quarks (as interpreted by some suitable, though fundamentally ambiguous, criterion)
Well-Defined	**What we mean**	

Jesse Thaler — Report of the Les Houches Quark/Gluon Subgroup 3

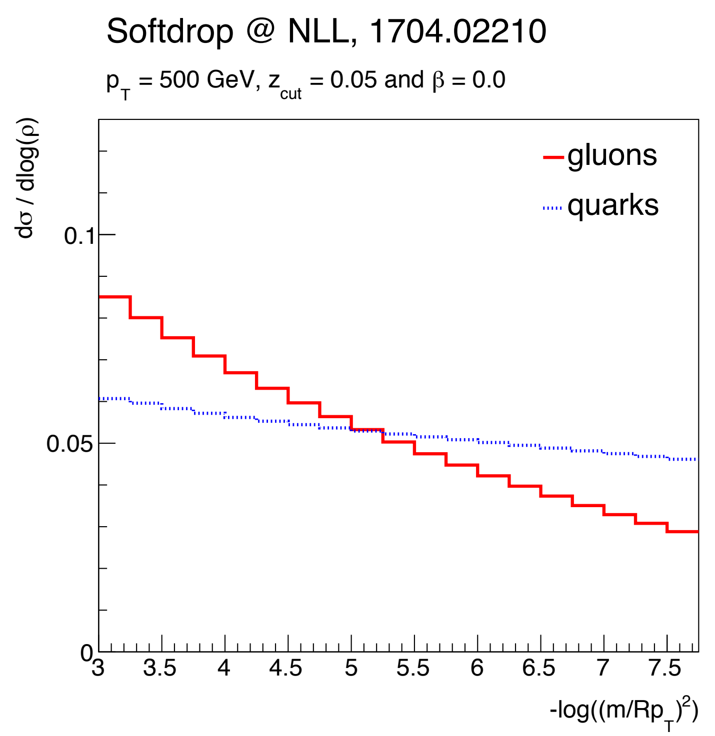
More Groomed Mass Theory Distributions

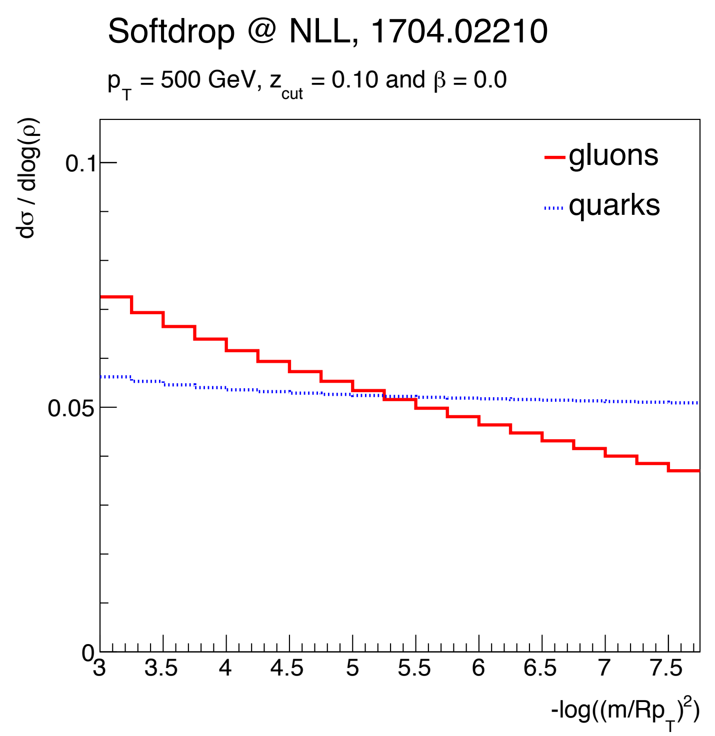
Very preliminary, sweeping β

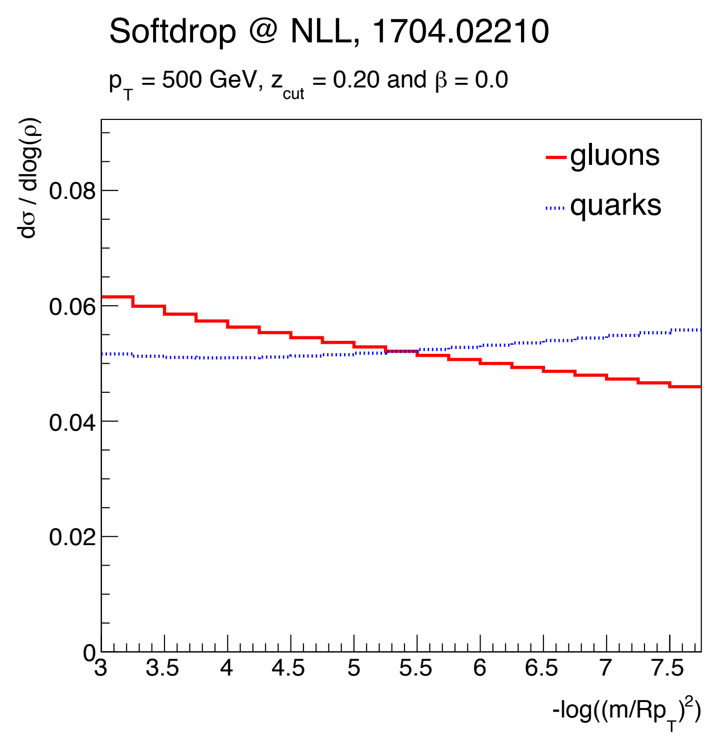


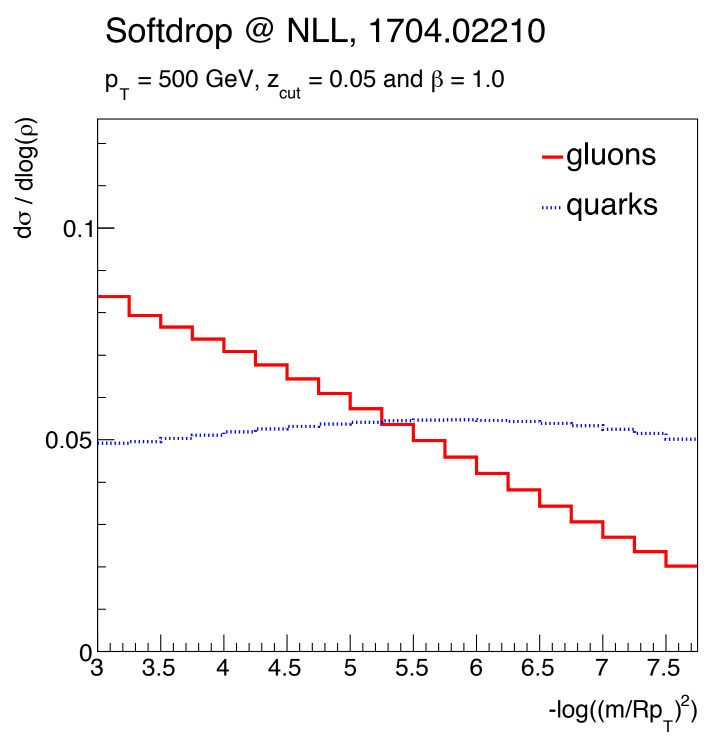
More (Truncated) Probability Distributions

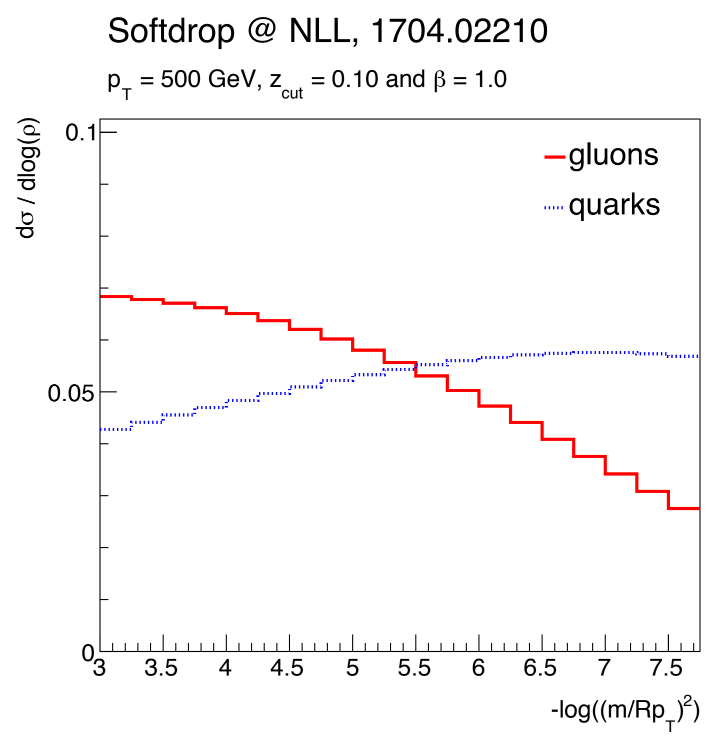
Very preliminary

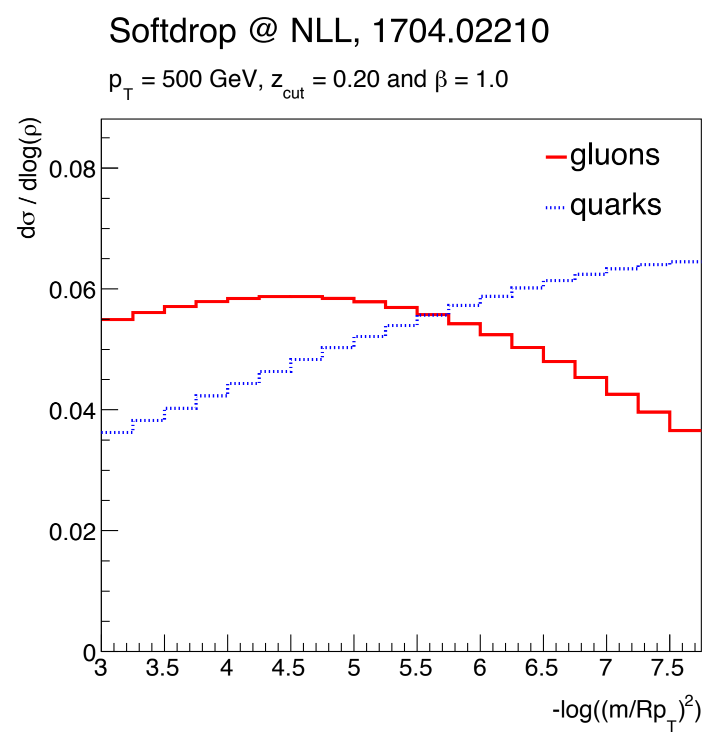






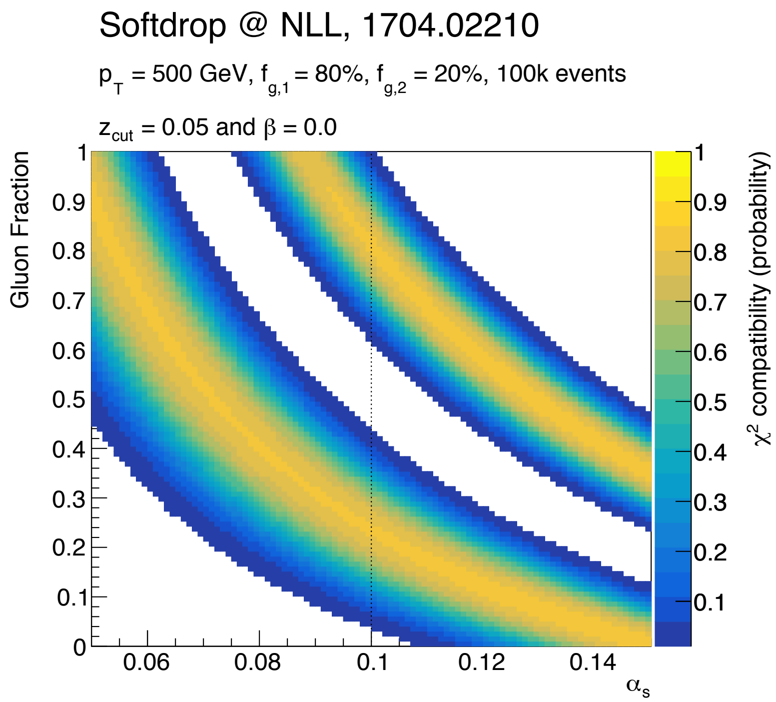


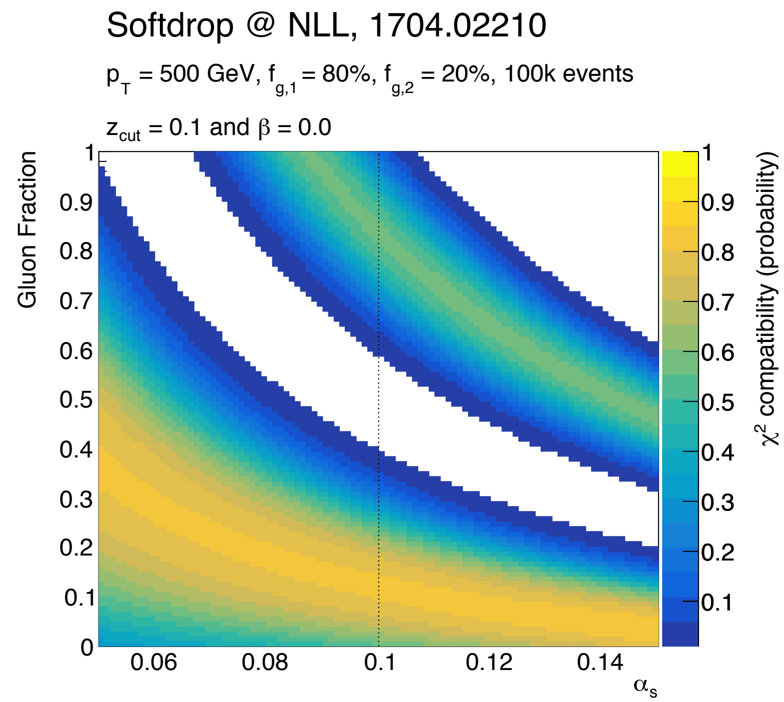


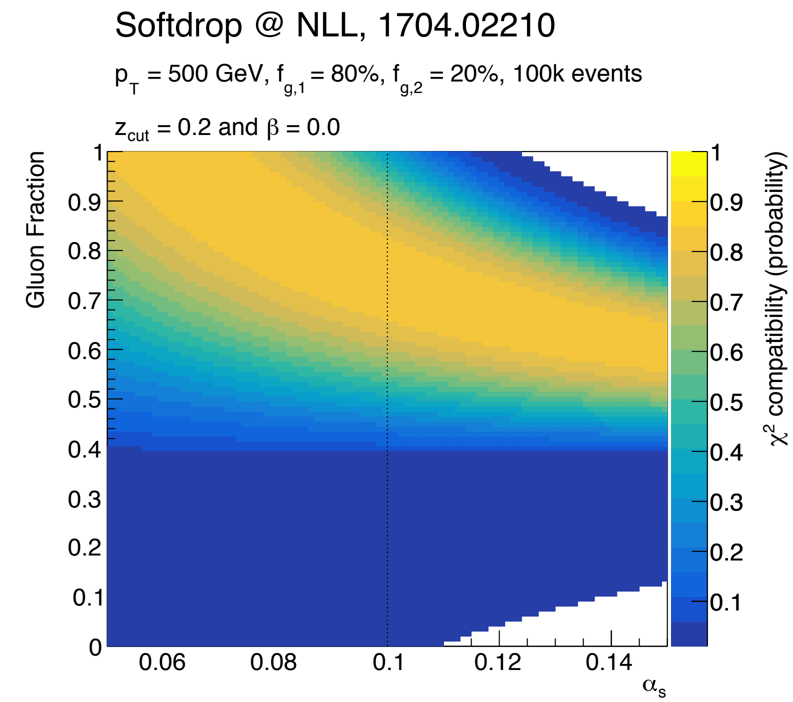


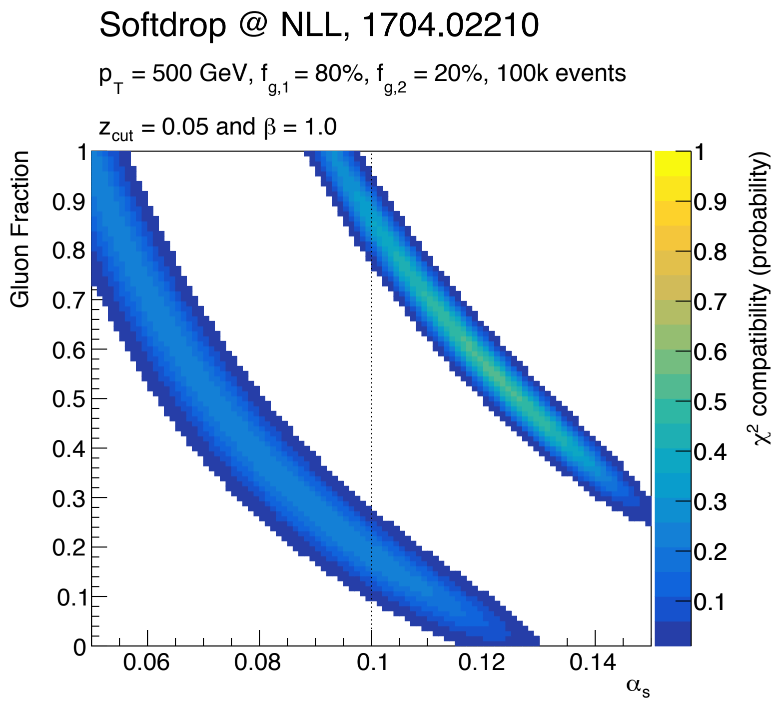
More Banana Plots

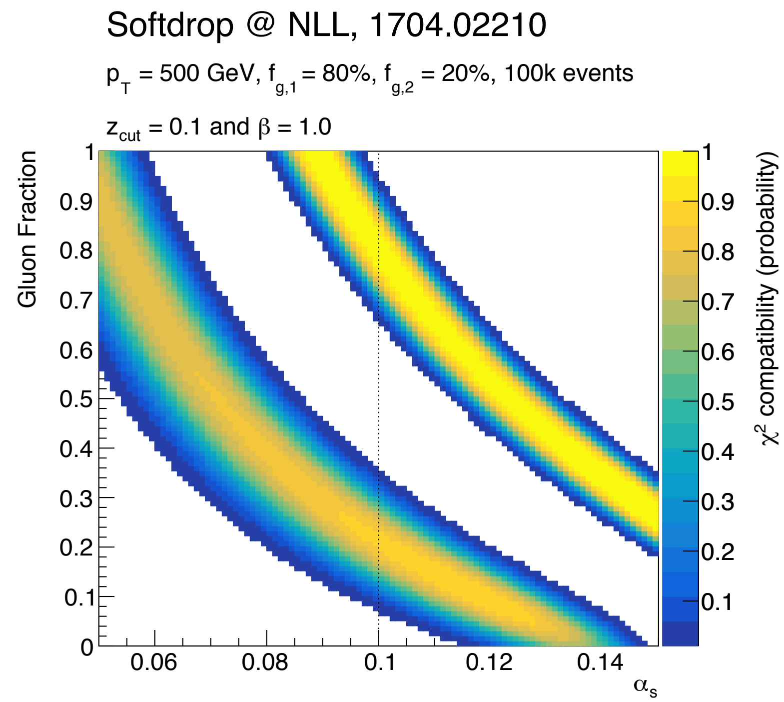
Very preliminary

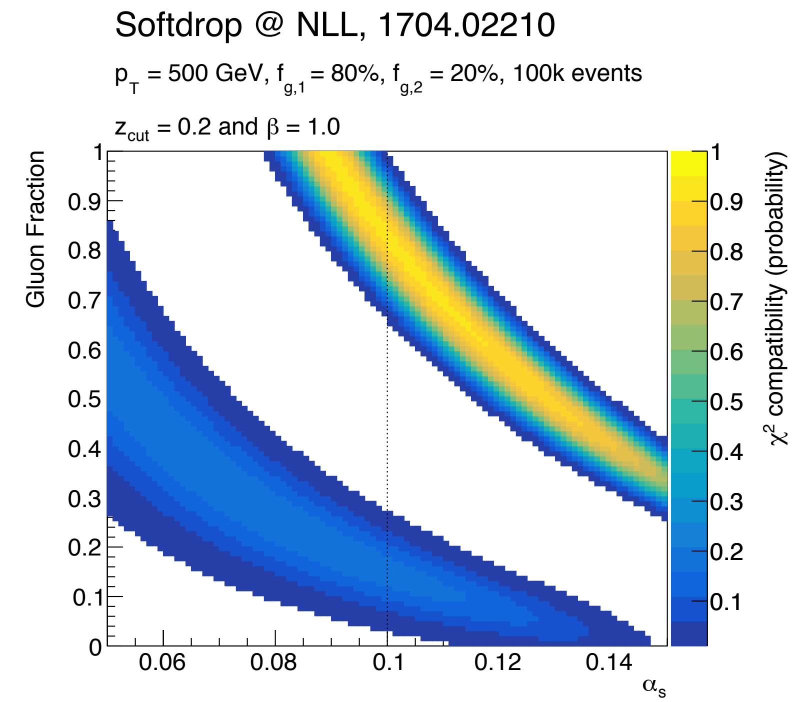






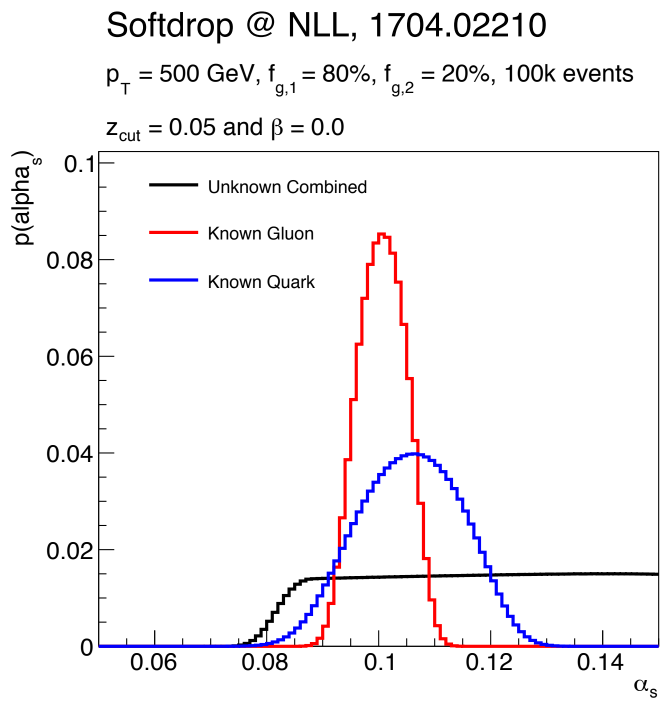


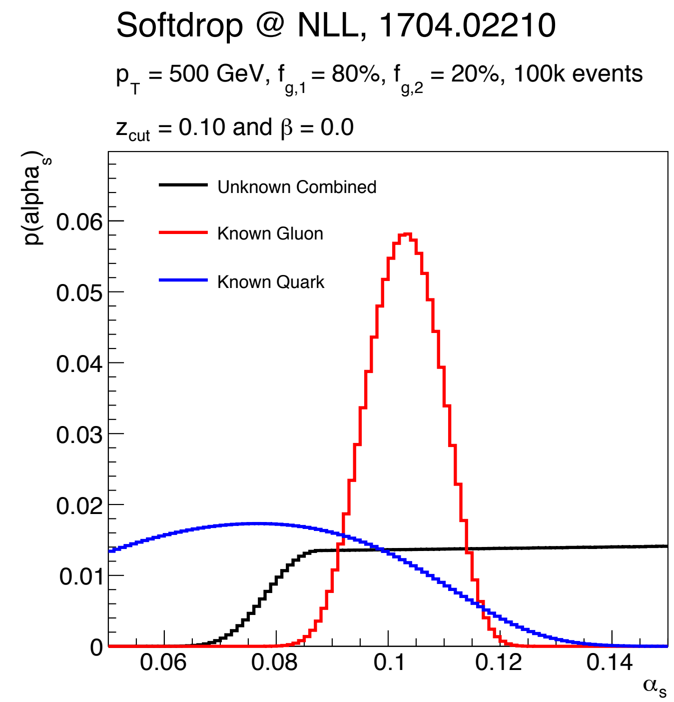


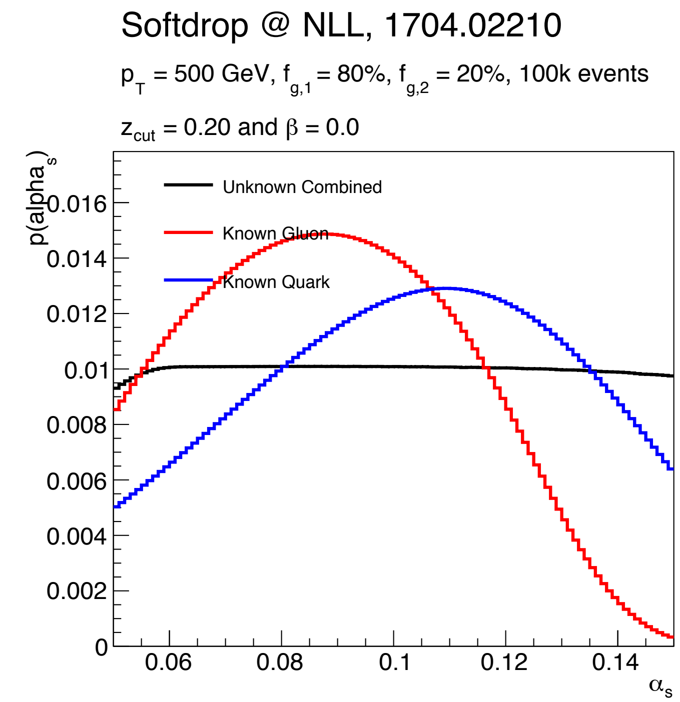


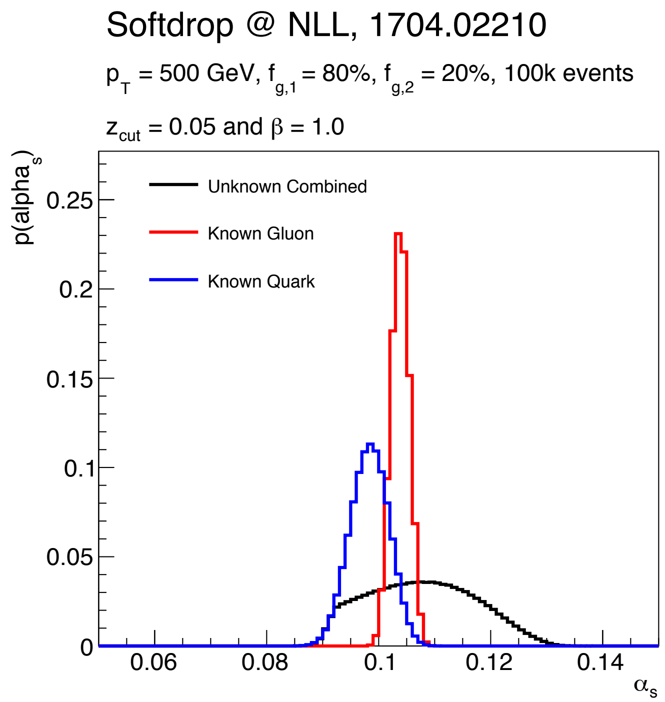
More Best Fit Plots

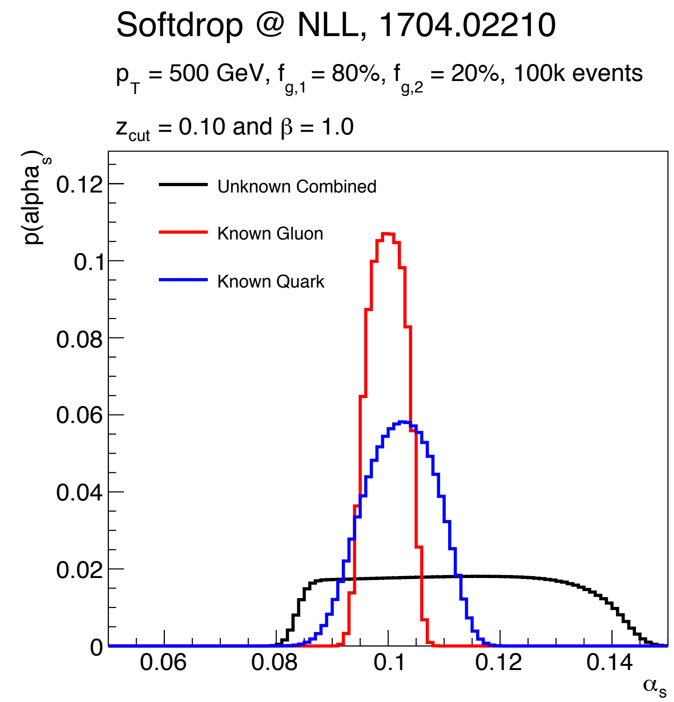
Very preliminary

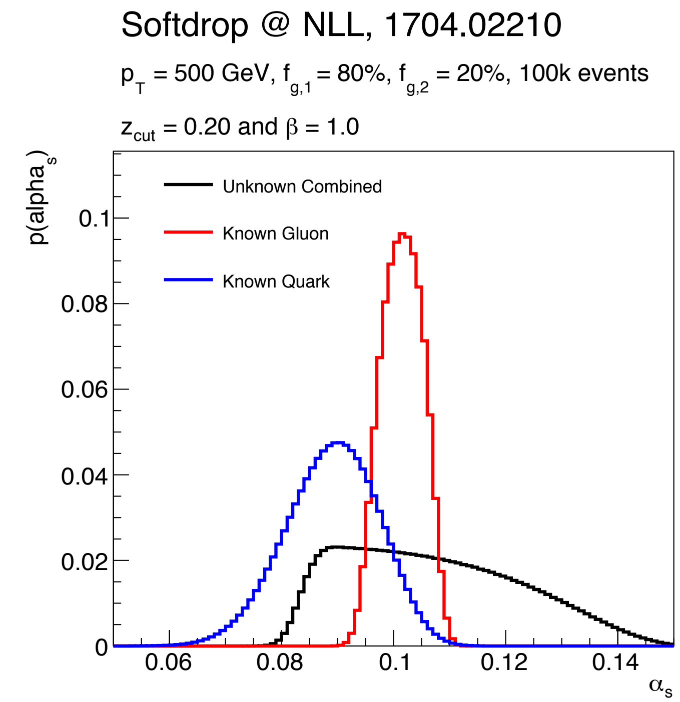












Resolution ⇒ Extraction Uncertainties