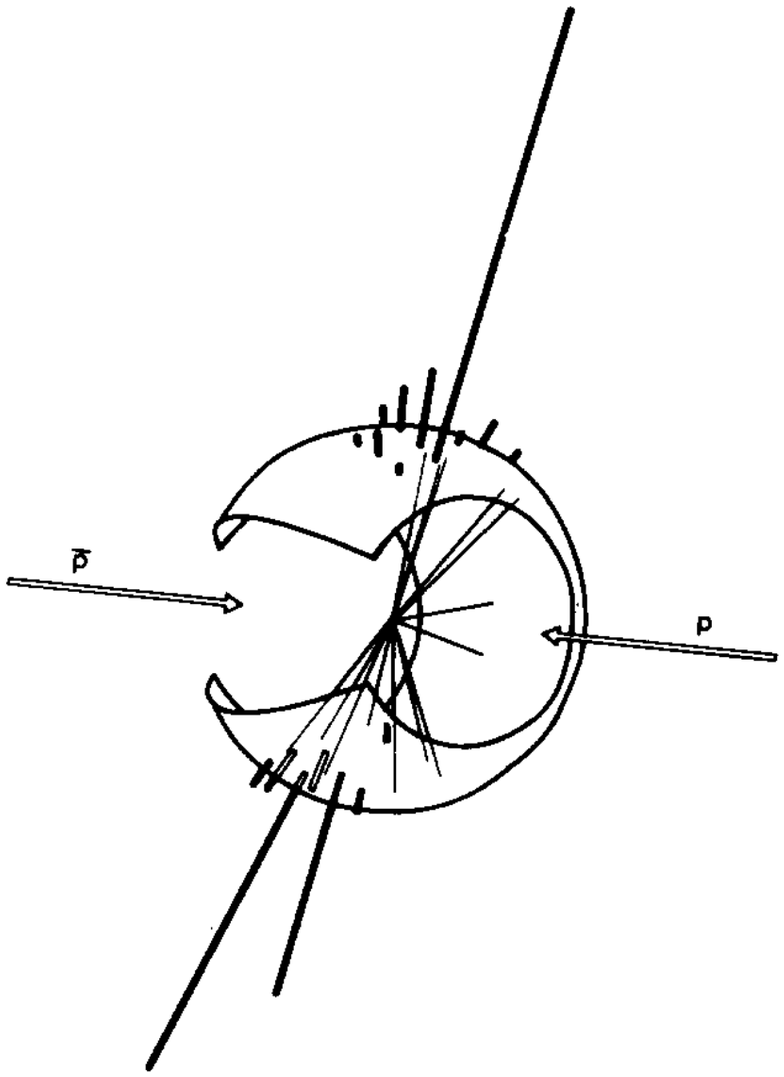
Jet Studies for Les Houches

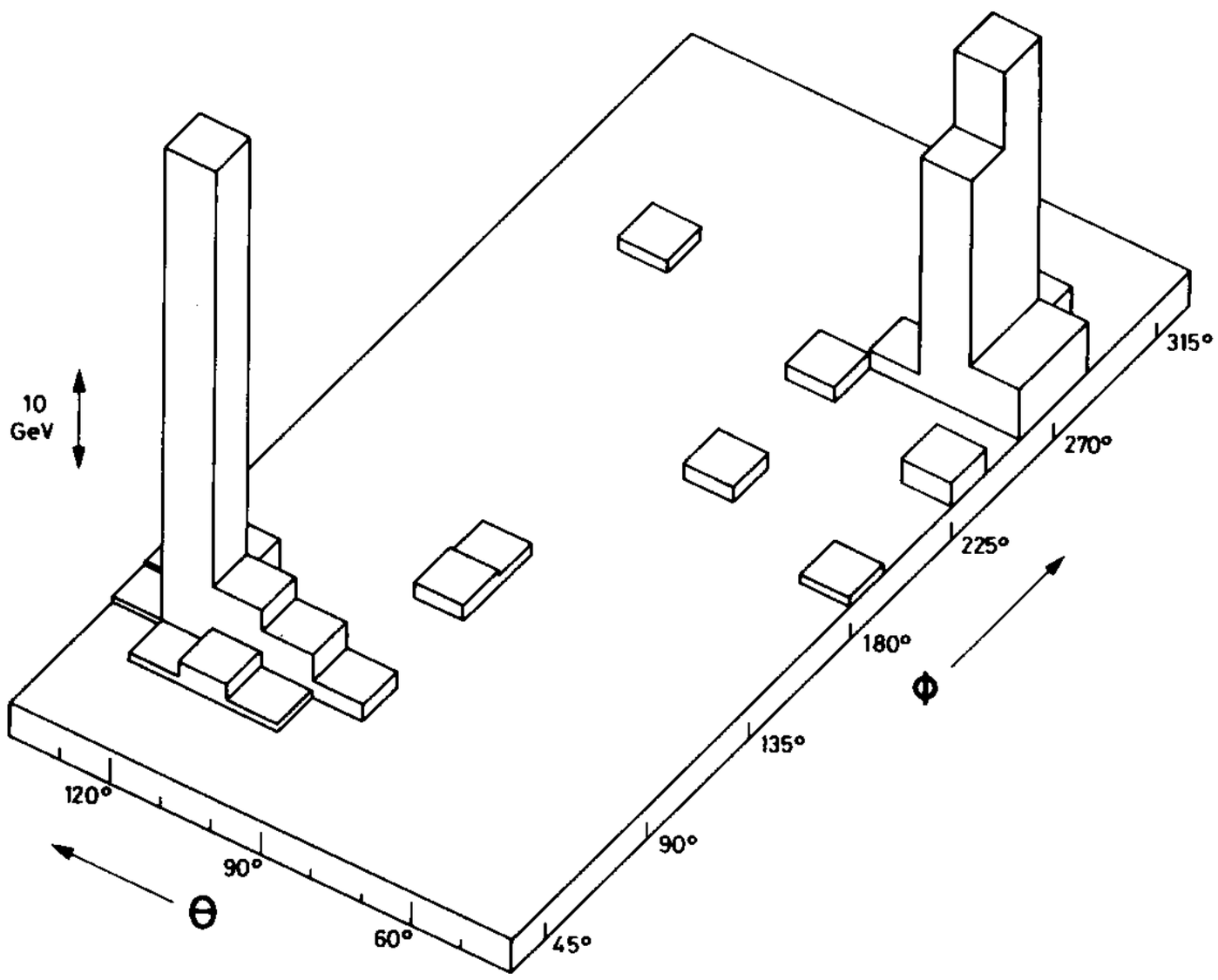
Jesse Thaler

Les Houches Workshop — June 2, 2015

Four Decades of Jets and QCD

UA2, 1982



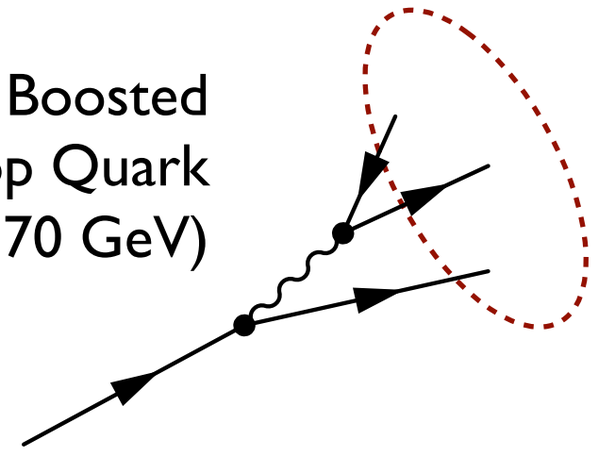


[see also SPEAR, 1975; PETRA, 1979]

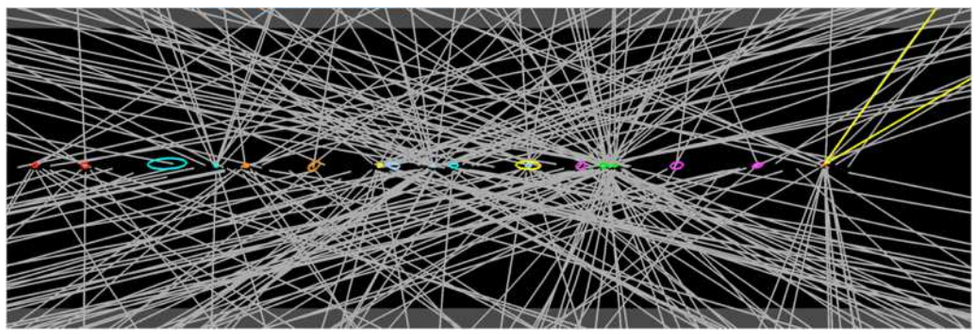
An example thread of progress in jet physics

Pileup Inspires Techniques…

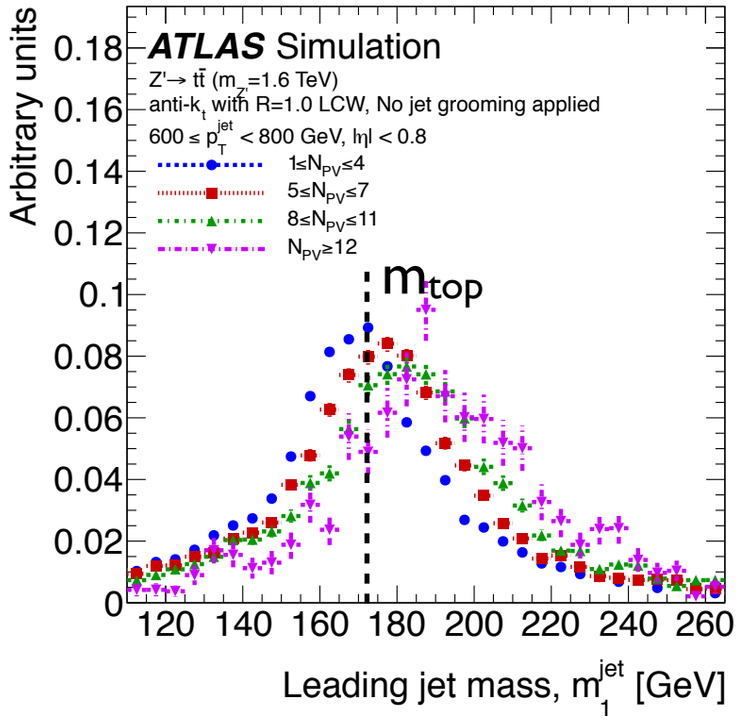
Boosted
Top Quark
($m_{top} \approx 170$ GeV)



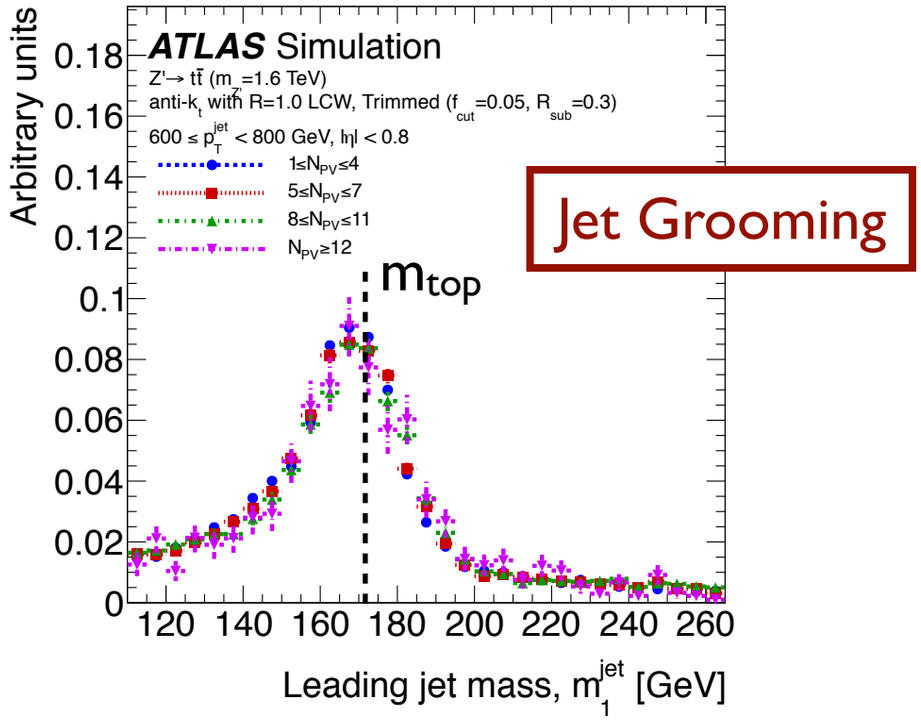
+



Secondary Collision Debris



⇒

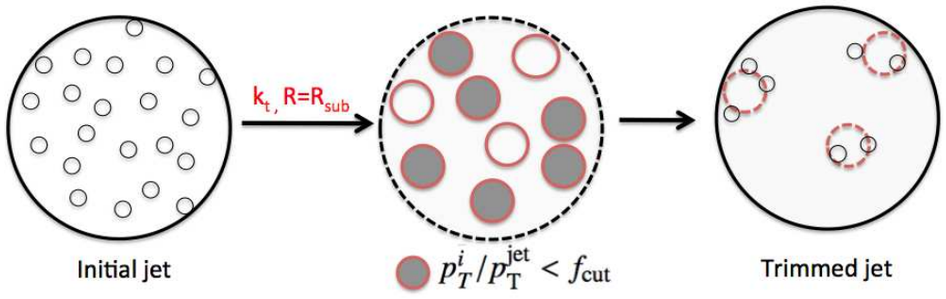


Jet Grooming

[ATLAS PERF-2012-02]
[using Krohn, JDT, Wang, 0912.1342]

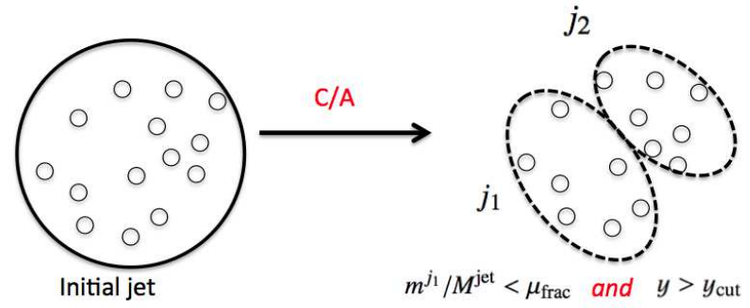
…Inspire Analytics…

Jet Trimming



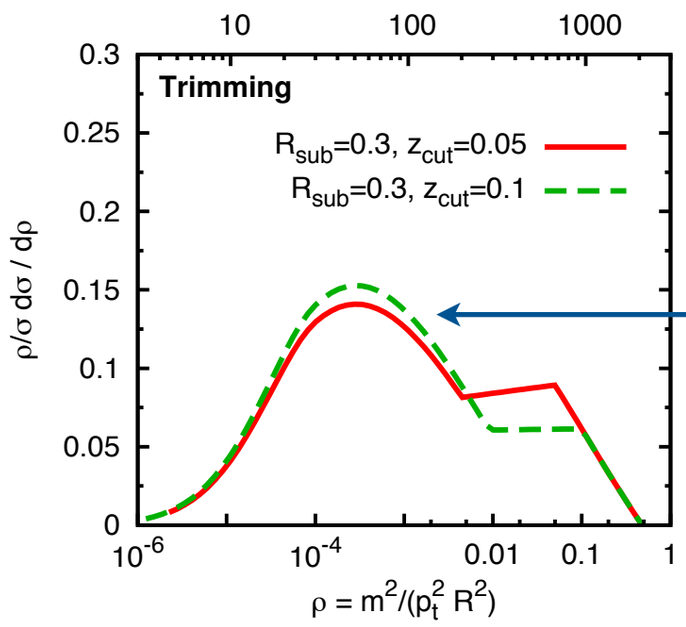
[Krohn, JDT, Wang, 0912.1342]

(Modified) Mass Drop



[Butterworth, Davison, Rubin, Salam, 0802.2470]

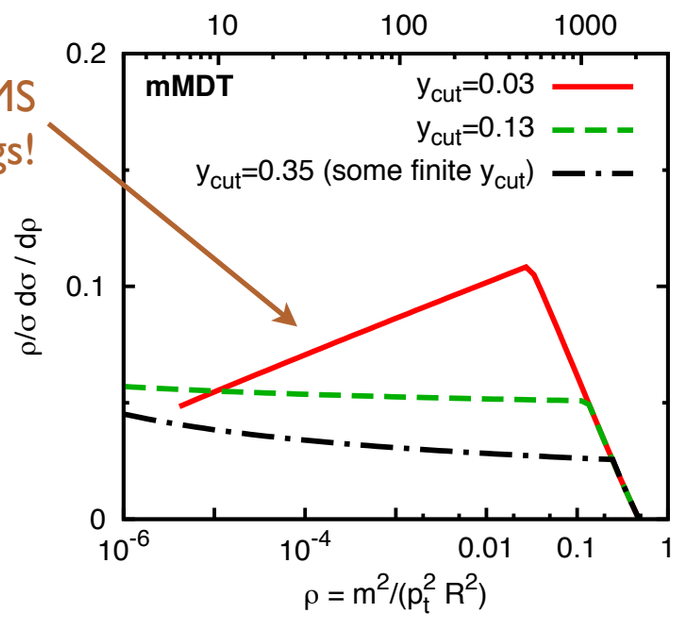
Trimmed Jet Mass



Sudakov Double Logs

Mass-Dropped Jet Mass

DFMS Single Logs!



[Diagrams from ATLAS, 1306.4945]
[Dasgupta, Fregoso, Marzani, Salam, 1307.0007]

…Inspire Techniques (and Analytics)…

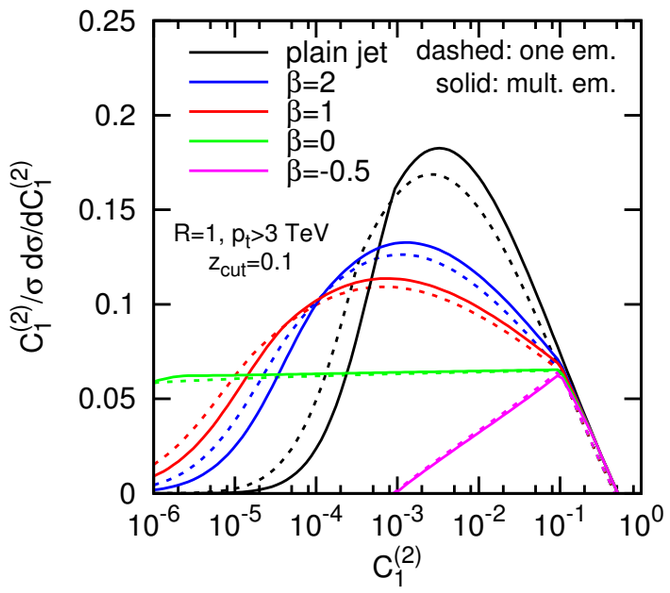
Soft Drop

$\beta = 0$ $\beta > 0$ $\beta \to \infty$

Adjustable — Jet Unchanged

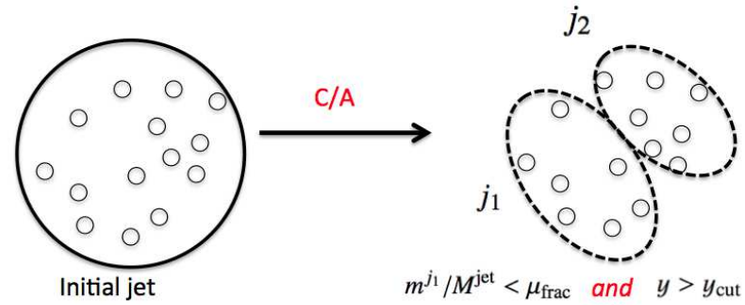
Mass Drop

Soft-Dropped Jet Mass



[Larkoski, Marzani, Soyez, JDT, 1402.2657]

(Modified) Mass Drop



[Butterworth, Davison, Rubin, Salam, 0802.2470]

Mass-Dropped Jet Mass

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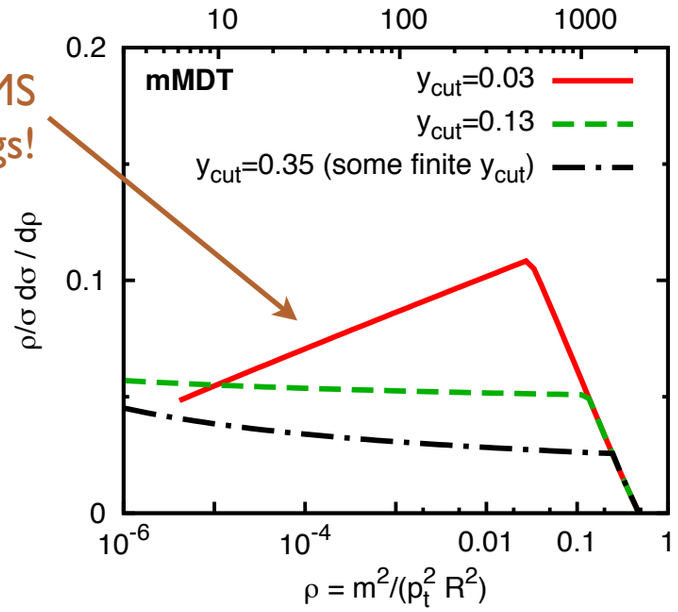


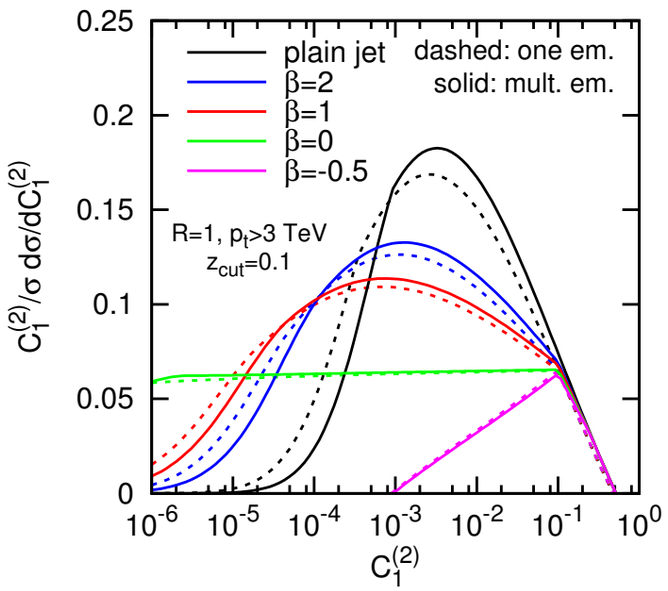
[Diagrams from ATLAS, 1306.4945]
[Dasgupta, Fregoso, Marzani, Salam, 1307.0007]

…Inspire Measurements…

Soft Drop

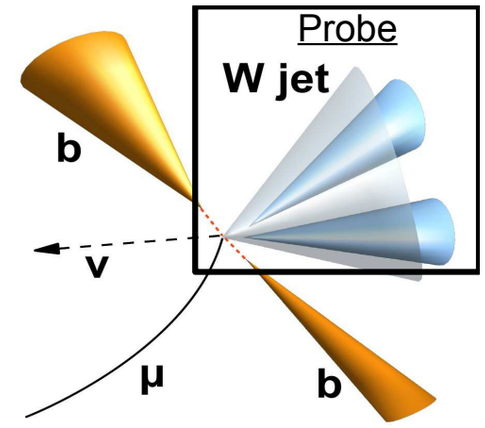
$\beta = 0$ $\beta > 0$ $\beta \to \infty$

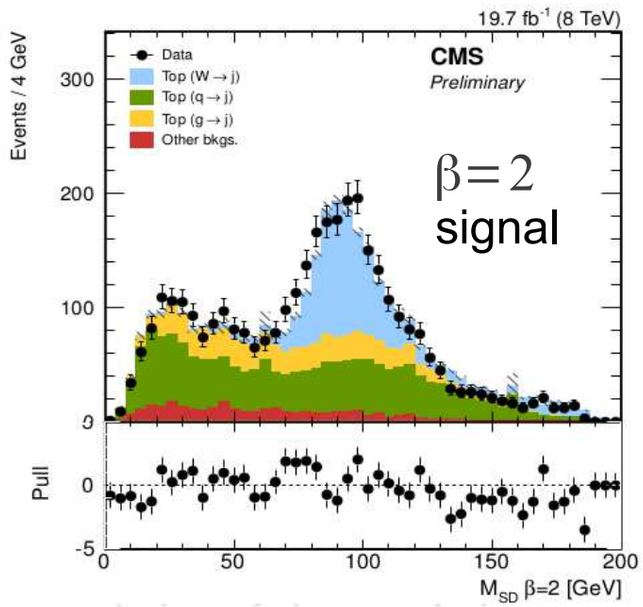
Soft-Dropped Jet Mass



[Larkoski, Marzani, Soyez, JDT, 1402.2657]

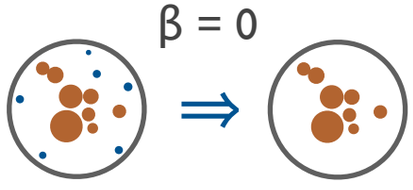
CMS W-Tagging Study





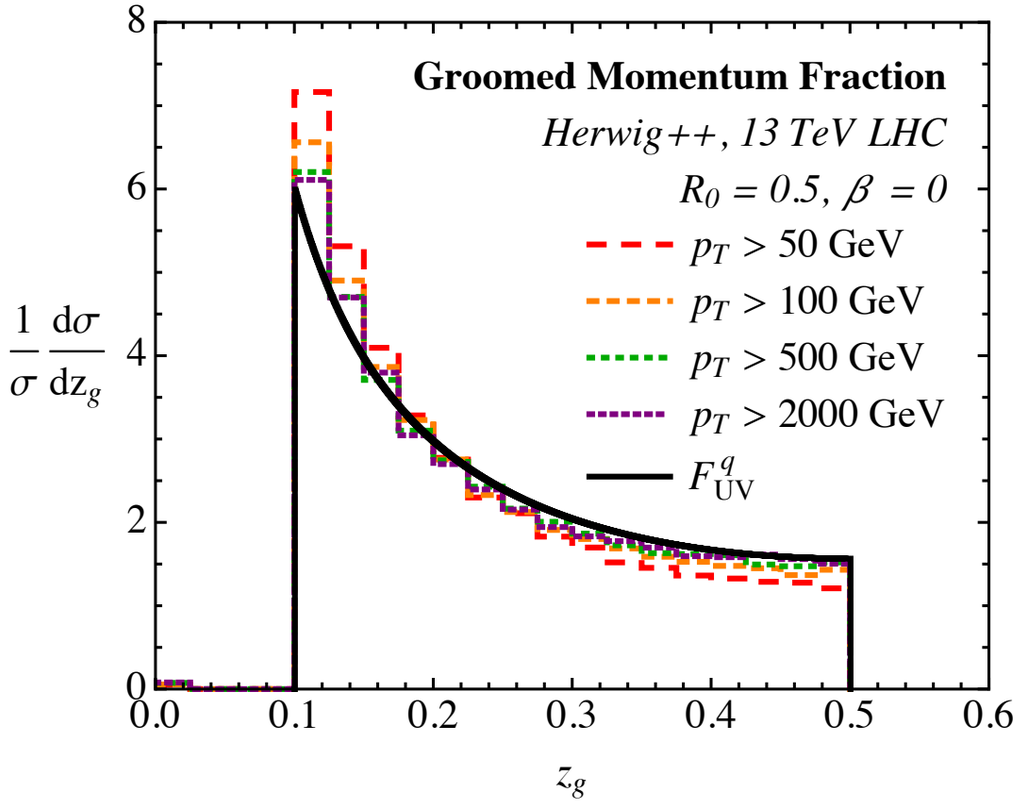
[CMS PAS JME-14-002]

…Reveal a Standard Candle for Jets



$z > z_{\text{cut}}$

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}z_g} = \frac{\overline{P}_i(z_g)}{\int_{z_{\text{cut}}}^{1/2} dz\, \overline{P}_i(z)} \quad + \ldots$$



Measuring the QCD splitting function

≈ independent of α_s (!)
≈ independent of jet p_T and radius
≈ same for quarks and gluons

calculable deviations from universality

[Larkoski, Marzani, JDT, 1502.01719]

So what jet studies at Les Houches?

Possible Points for Discussion

Pulled from the wiki…

Jets as a Tool for (B)SM Physics

Importance/relevance of jet radius variation, multiple jet algorithms
Making jet substructure part of everyday analyses (e.g. pileup mitigation, jet shapes)
Improved VBF tagging, jet vetoes for Higgs physics
…

Jets as a Precision Probe of QCD

Wishlist of jet shape measurements (e.g. angularities)
Interplay between fixed order and resummation for jet observables (esp. PS/ME matching)
IRC Unsafe but Sudakov Safe observables where resummation is essential
Analytic handles on soft QCD (e.g. underlying event, hadronization)
…

Many points of contact with other working groups

My goal for Les Houches:

Hunt the white whale of jet physics

Quarks vs. Gluons on One Slide

Cartoon:

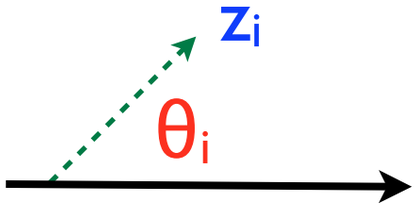
Quark: $C_F = 4/3$ **vs.** Gluon: $C_A = 3$

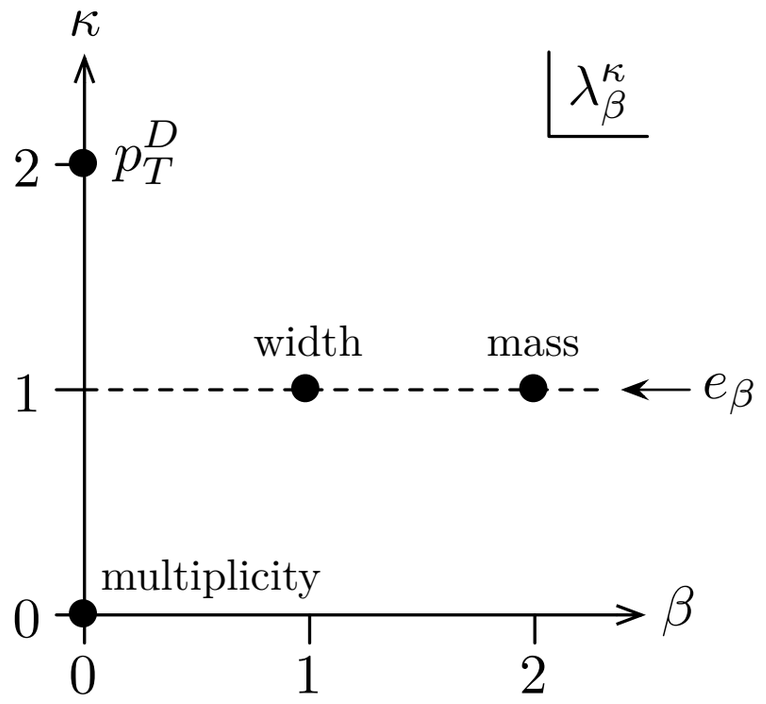
Probe radiation pattern with
e.g. Generalized Angularities

$$\lambda_\beta^\kappa = \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\beta$$

momentum fraction

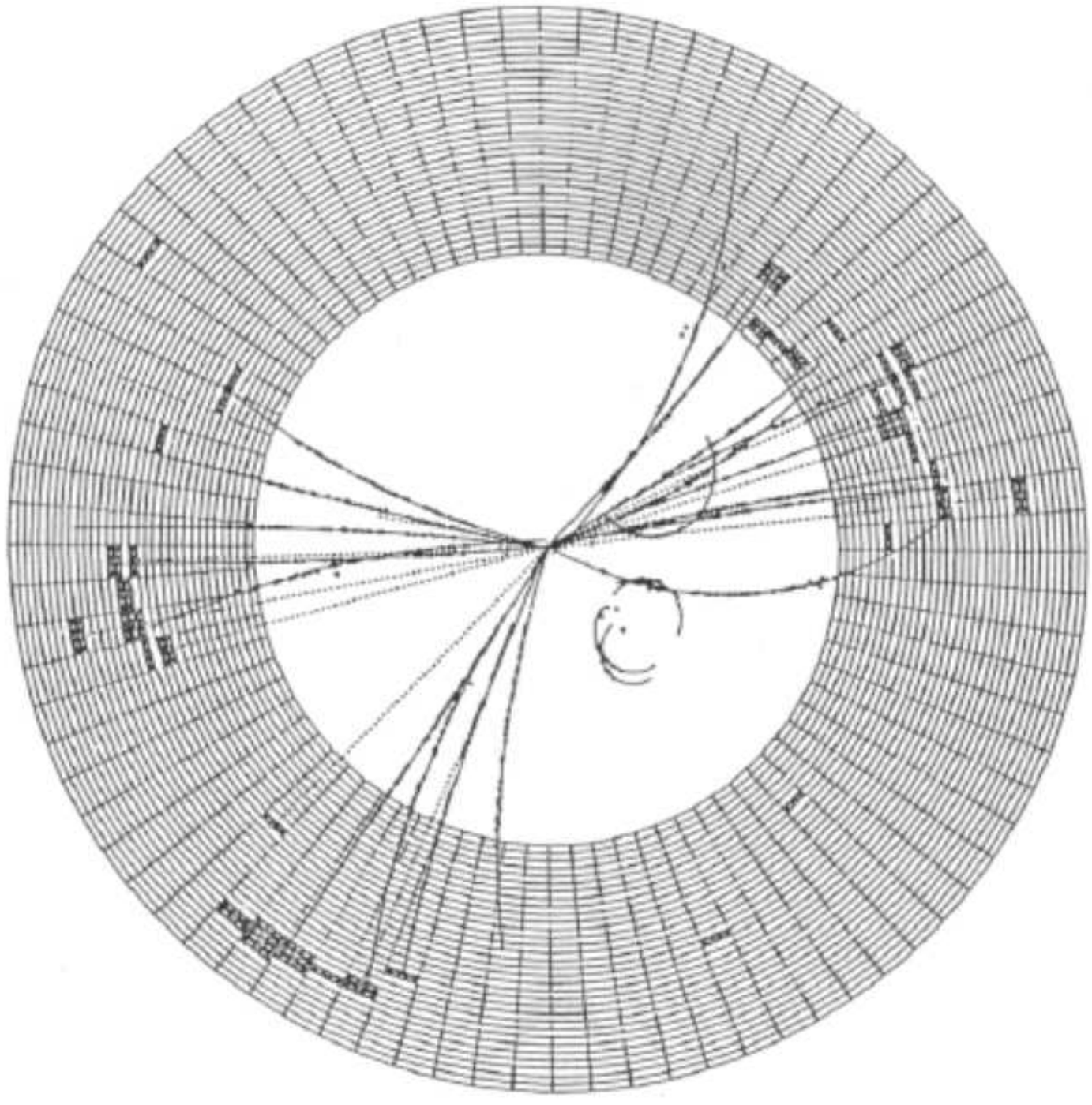
angle to recoil-free axis





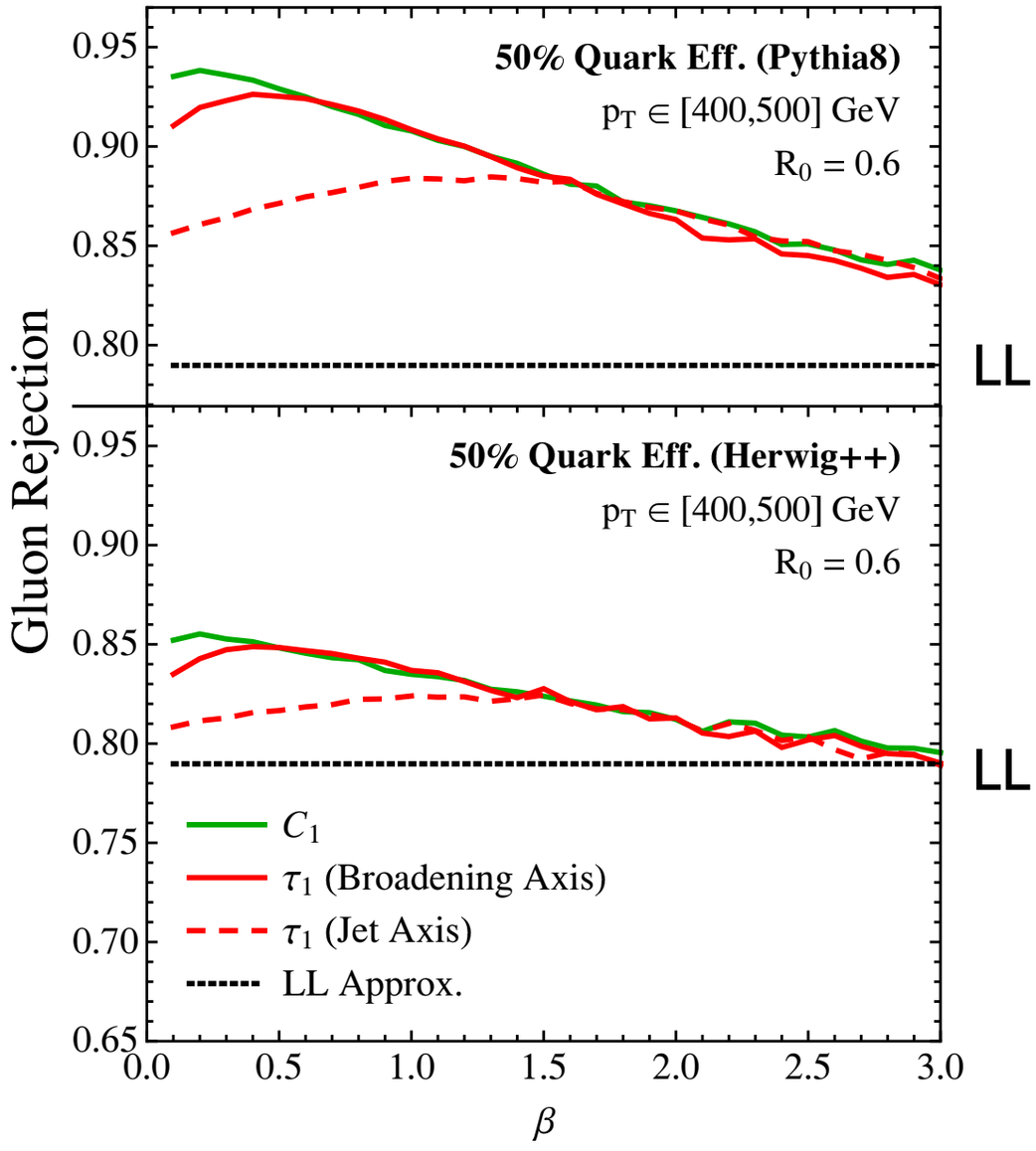
[Larkoski, JDT, Waalewijn, 1408.3122]
[based on Berger, Kucs, Sterman, hep-ph/0303051; Ellis, Vermilion, Walsh, Hornig, Lee, 1001.0014]
[see also Larkoski, Salam, JDT, 1305.0007; Larkoski, Neill, JDT, 1401.2158]
[For a more complete catalog, see Gallicchio, Schwartz, 1106.3076, 1211.7038]

Easy, right?



[JADE, 1979]

Theory vs. Experiment



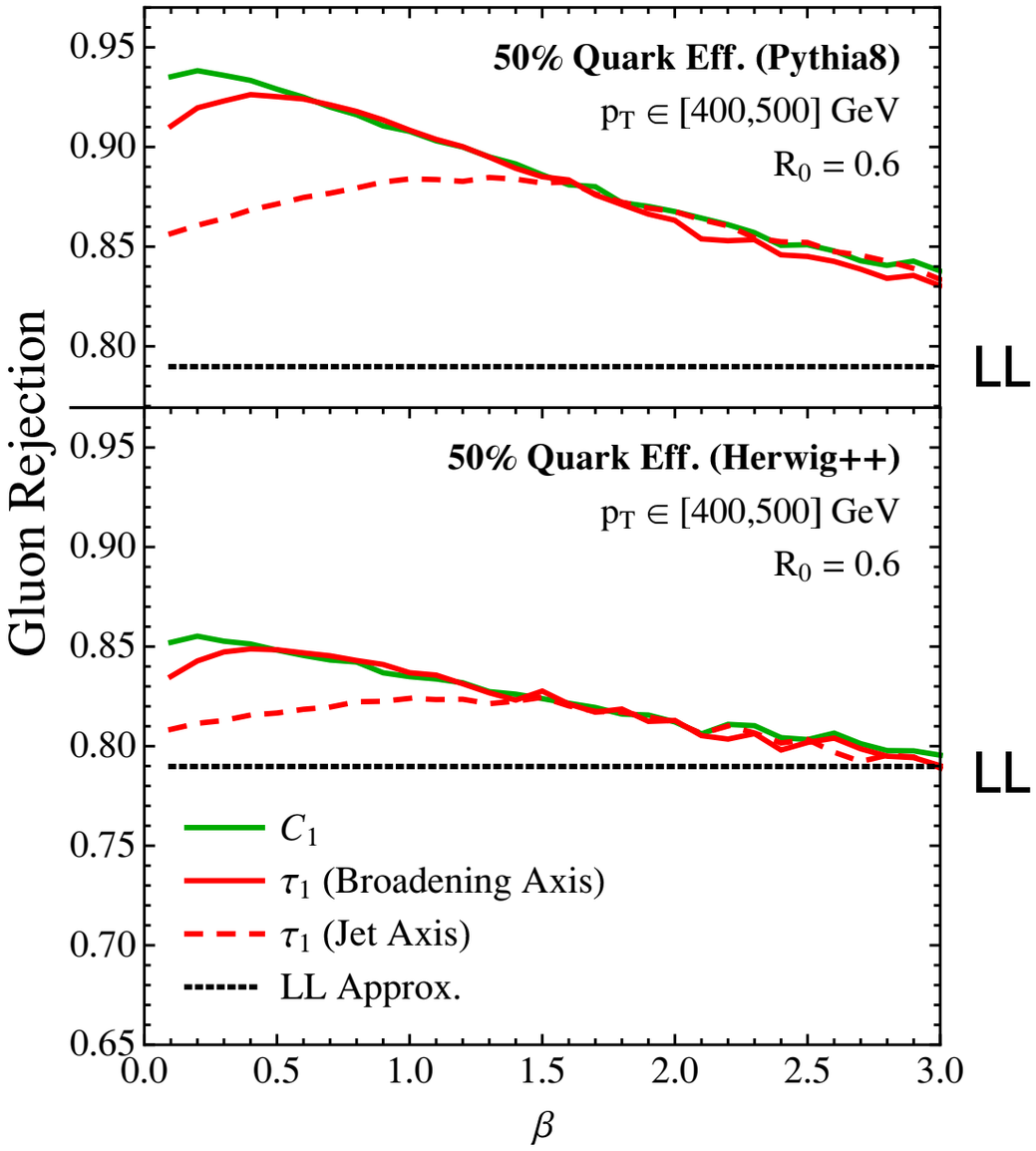
[Larkoski, Salam, JDT, 1305.0007]

To Leading Log Accuracy

Quark Efficiency = 50%

Gluon Mistag = $(50\%)^{9/4}$ ← C_A/C_F

Theory vs. Experiment



[Larkoski, Salam, JDT, 1305.0007]

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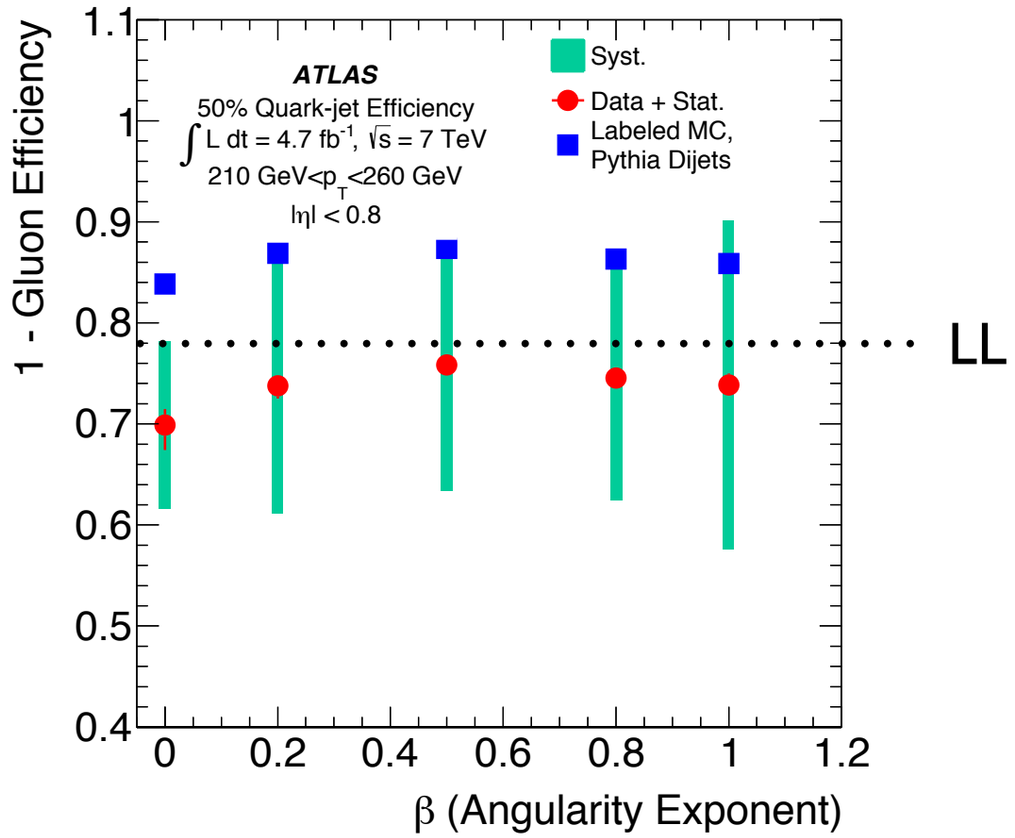
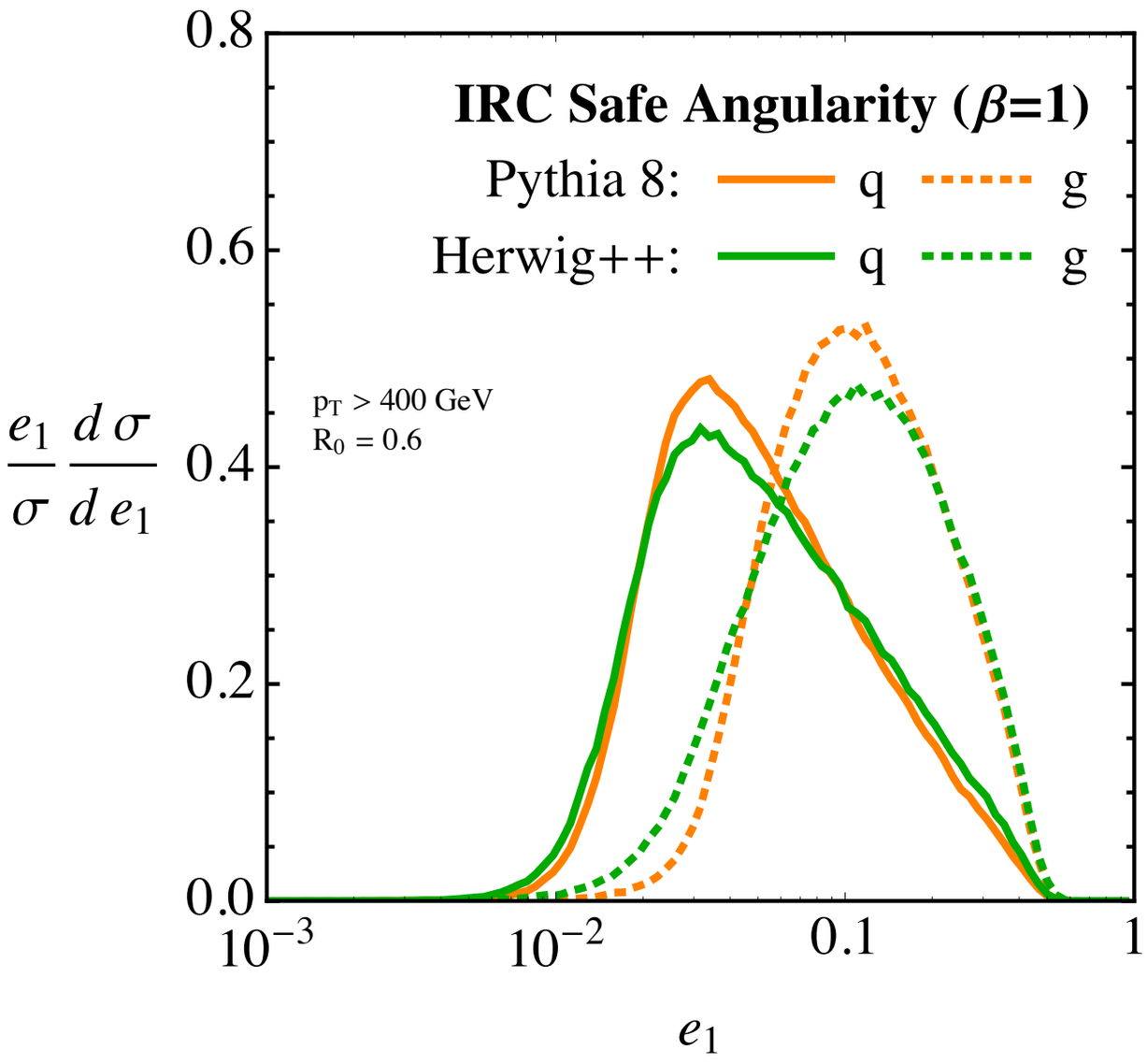


[ATLAS, 1405.6583]

MC vs. MC



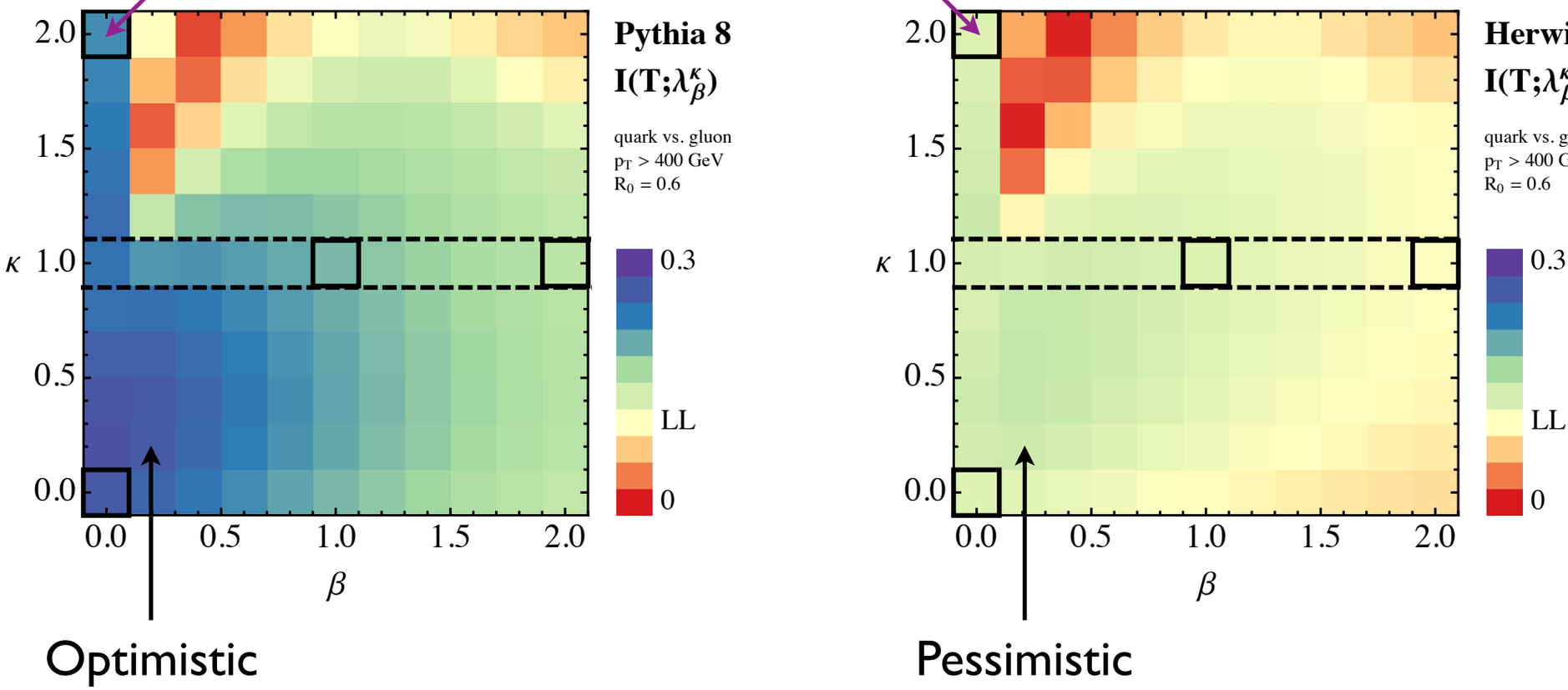
Small effect in distribution yields large effect in predicted quark/gluon discrimination power

Effect of incomplete MC tuning?
ISR/UE modeling? FSR modeling? Evolution variable? Choice of α_s?
Different "truth" definitions of quarks vs. gluons?
What about dijets (gluon-enriched) vs. W/Z/γ + jets (quark-enriched)?

Qualitative Differences

Quantified using mutual information

Used by CMS in Higgs analysis



What physics drives this MC difference?
Needs Les Houches study.
Does this impact other measurements performed with jets?

[Larkoski, JDT, Waalewijn, 1408.3122]

Bottom Line

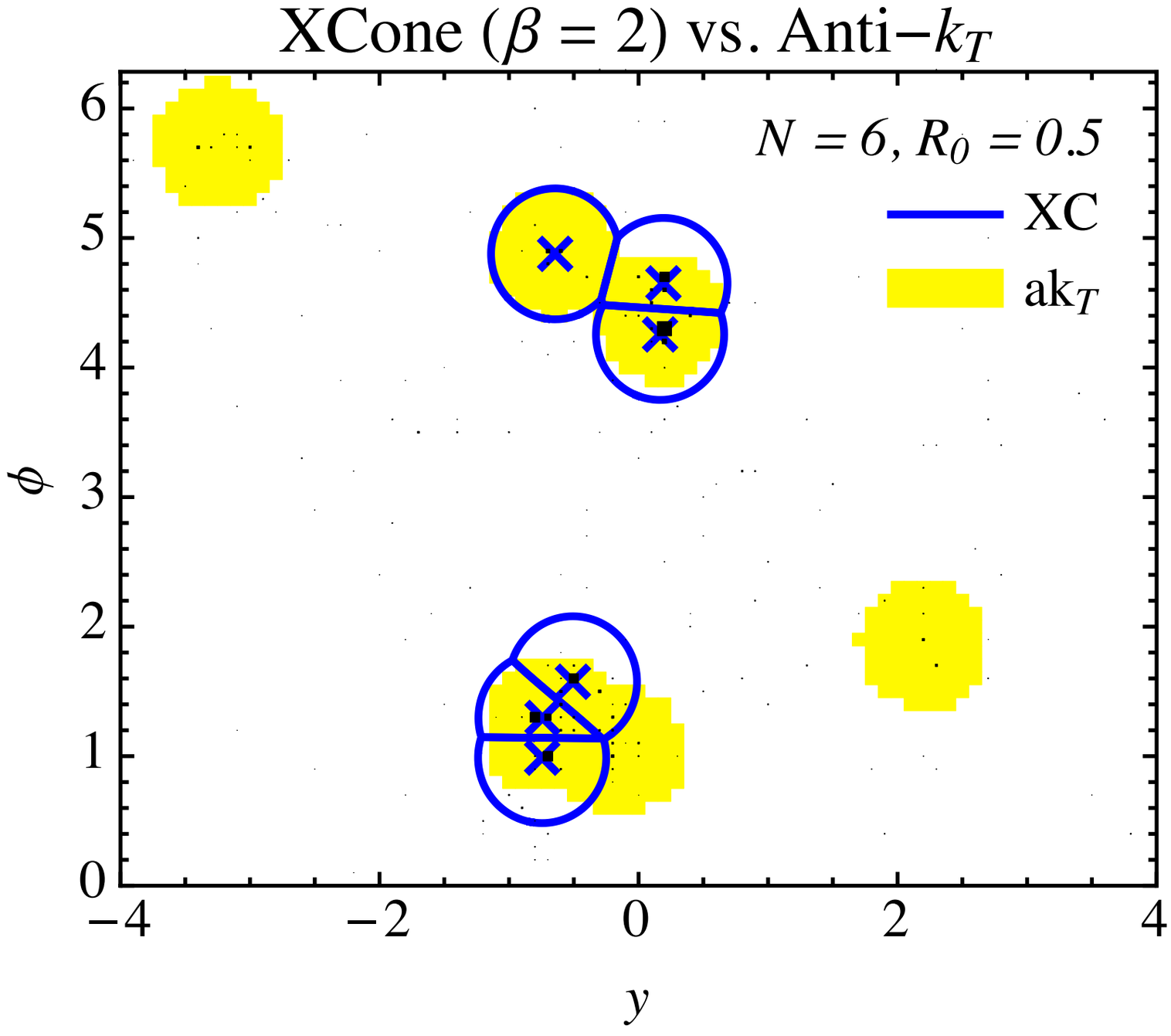
Wide array of jet physics tools, both new and old

Steadily gaining improved analytic understanding

Something amiss in quark/gluon radiation patterns

Looking forward to a fun workshop!

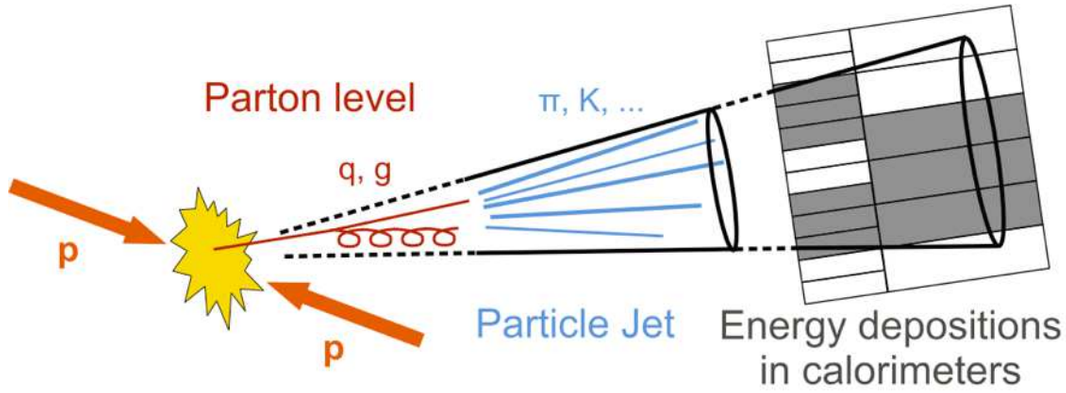
(My other goal for Les Houches)



[Stewart, Tackmann, JDT, Vermilion, Wilkason, 1506.xxxxx]

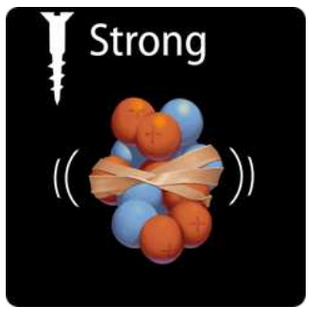
A QCD Renaissance

c. 2008–present



LHC *(vs. Tevatron)*

Higher Energy *(≈ x3.5–7)*
Higher Luminosity *(≈ x10–20)*
Finer Segmentation *(≈ x5)*



Theoretical Progress

New Jet Algorithms (esp. anti-k_T)
Loop/Leg/Log Explosion
Jet Substructure

[Anti-kT: Cacciari, Salam, Soyez, 2008; see also Delsart, 2006]
[BDRS: Butterworth, Davison, Rubin, Salam, 2008; see also Seymour, 1991, 1994]