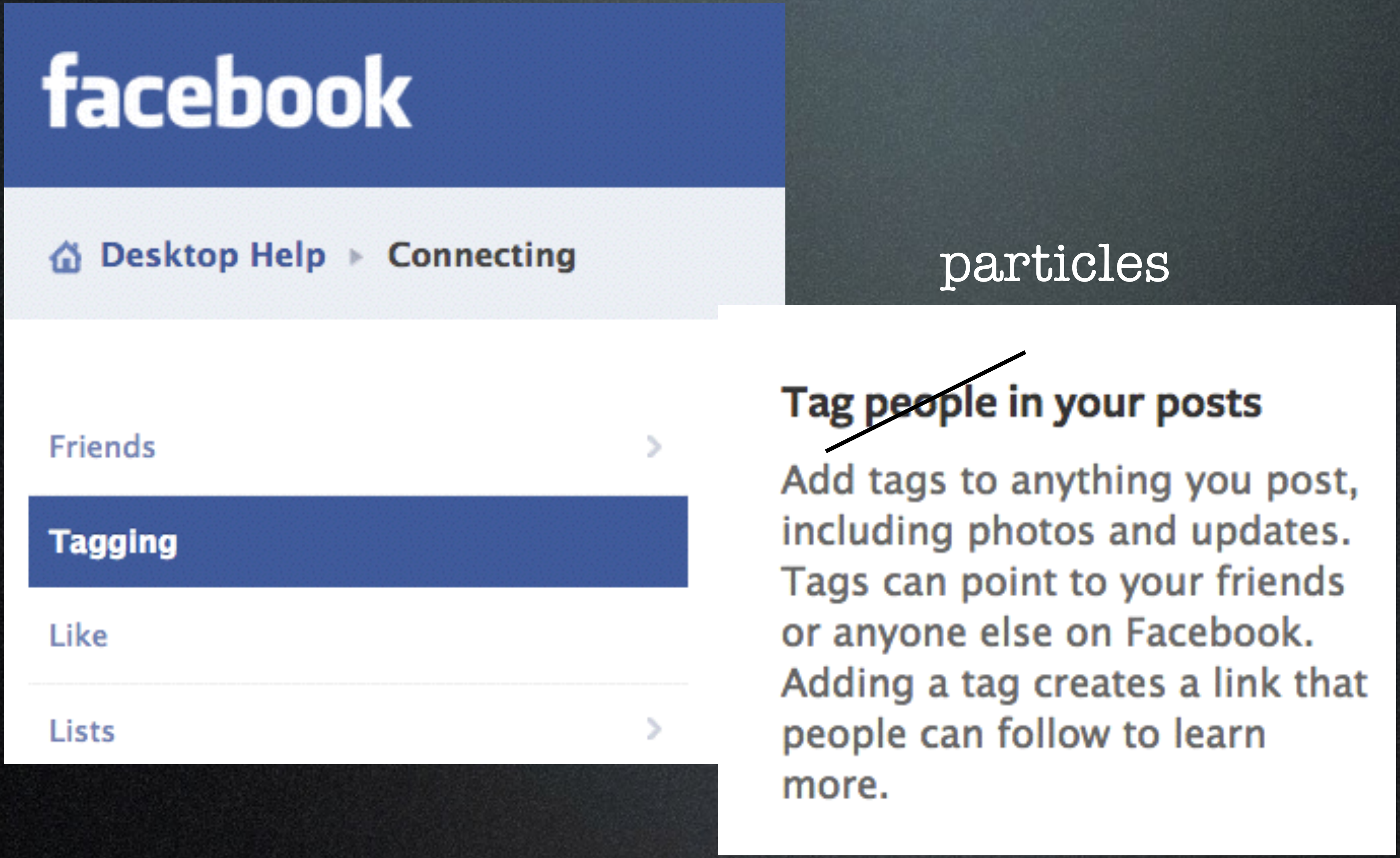
# Recent Developments in Tagging

Deepak Kar
Based on: arXiv:1704.03878 (accepted in JHEP) and work-in-progress

SAIP 2017 Meeting
3rd - 7th June, 2017

# Tag the Big Five

# Tagging Particles



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**Tagging**

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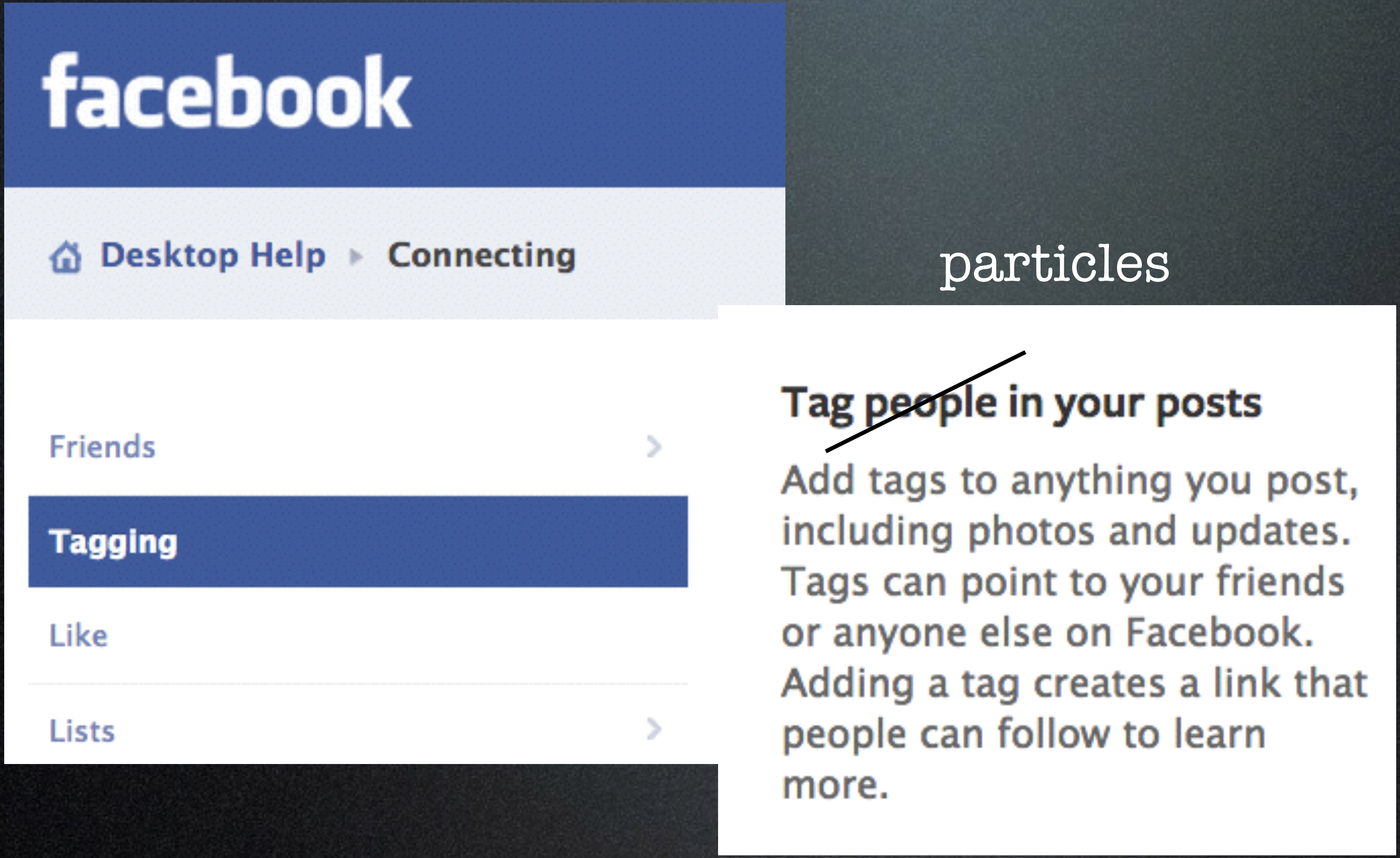
Lists

particles

**Tag ~~people~~ in your posts**

Add tags to anything you post, including photos and updates. Tags can point to your friends or anyone else on Facebook. Adding a tag creates a link that people can follow to learn more.

# Tagging Particles



particles

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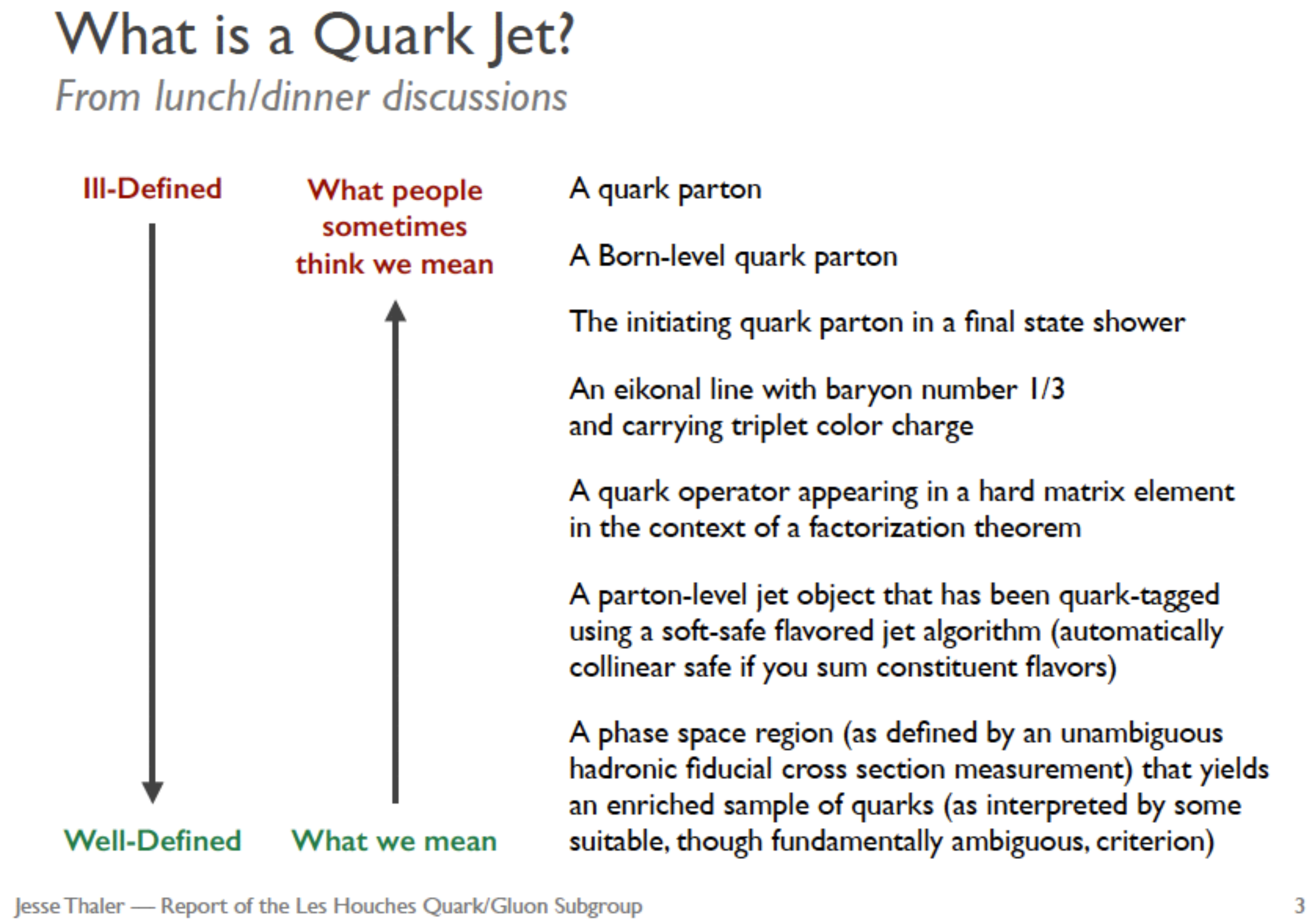
1. Tag quark/gluon initiated jets
2. Detailed study of two-pronged tagging

# Quark/gluon discrimination

- Ideally: identify quark-initiated or gluon initiated jets.
- Is that well defined or fundamentally ambiguous?



# What is a Quark Jet?

*From lunch/dinner discussions*

**Ill-Defined** → **Well-Defined**

**What we mean** → **What people sometimes think we mean**

A quark parton

A Born-level quark parton

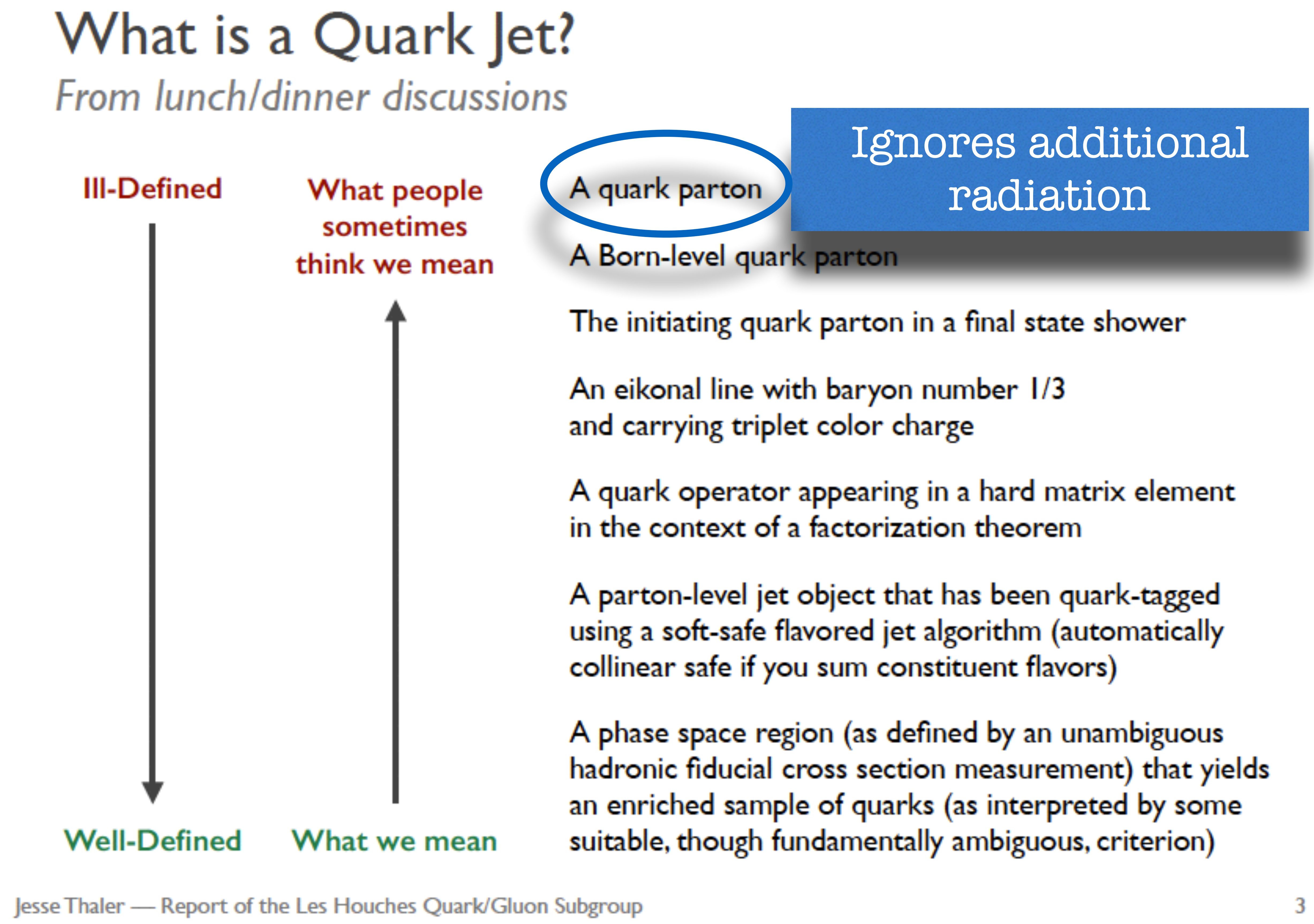
The initiating quark parton in a final state shower

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)

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)



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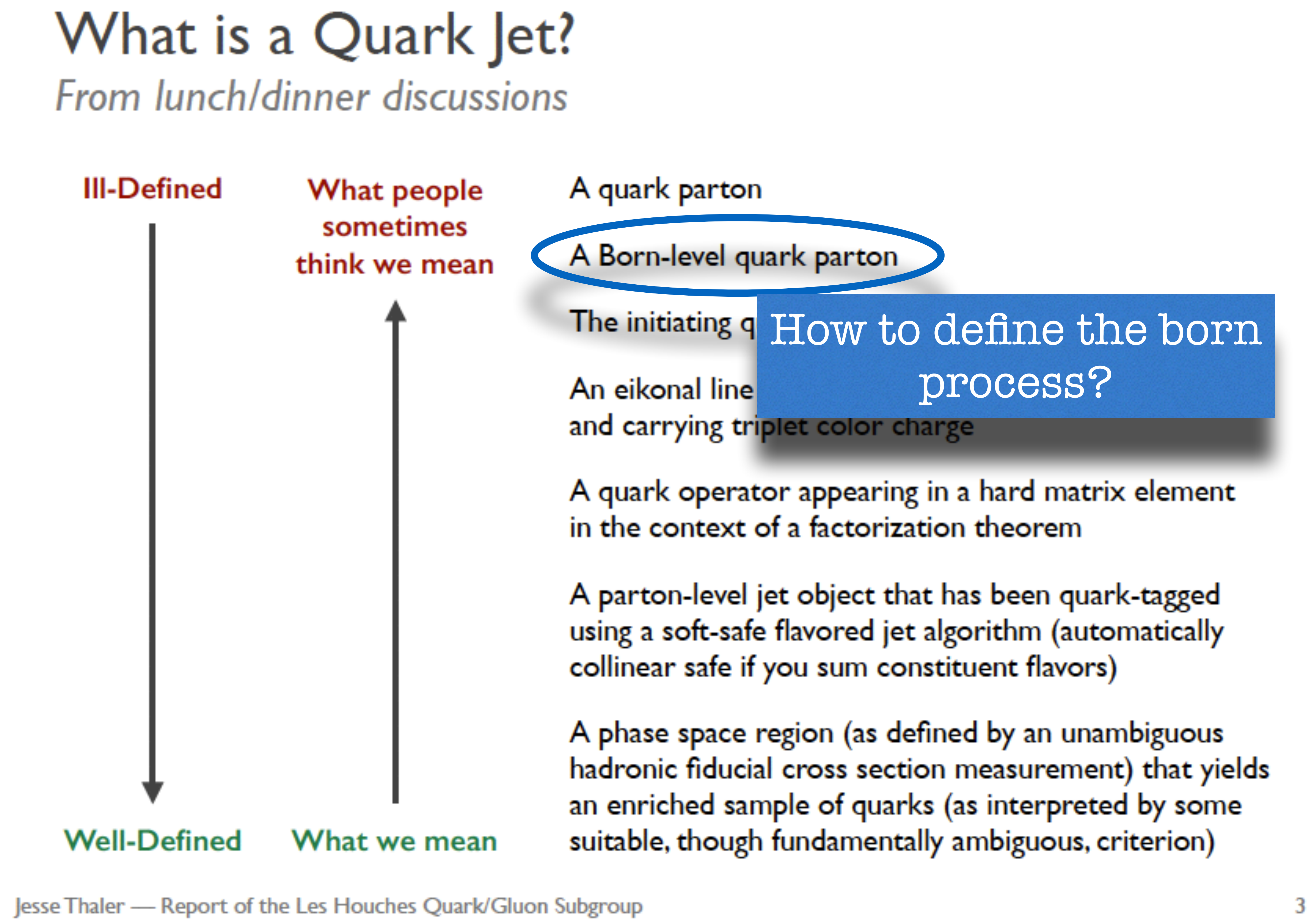
Ignores additional radiation



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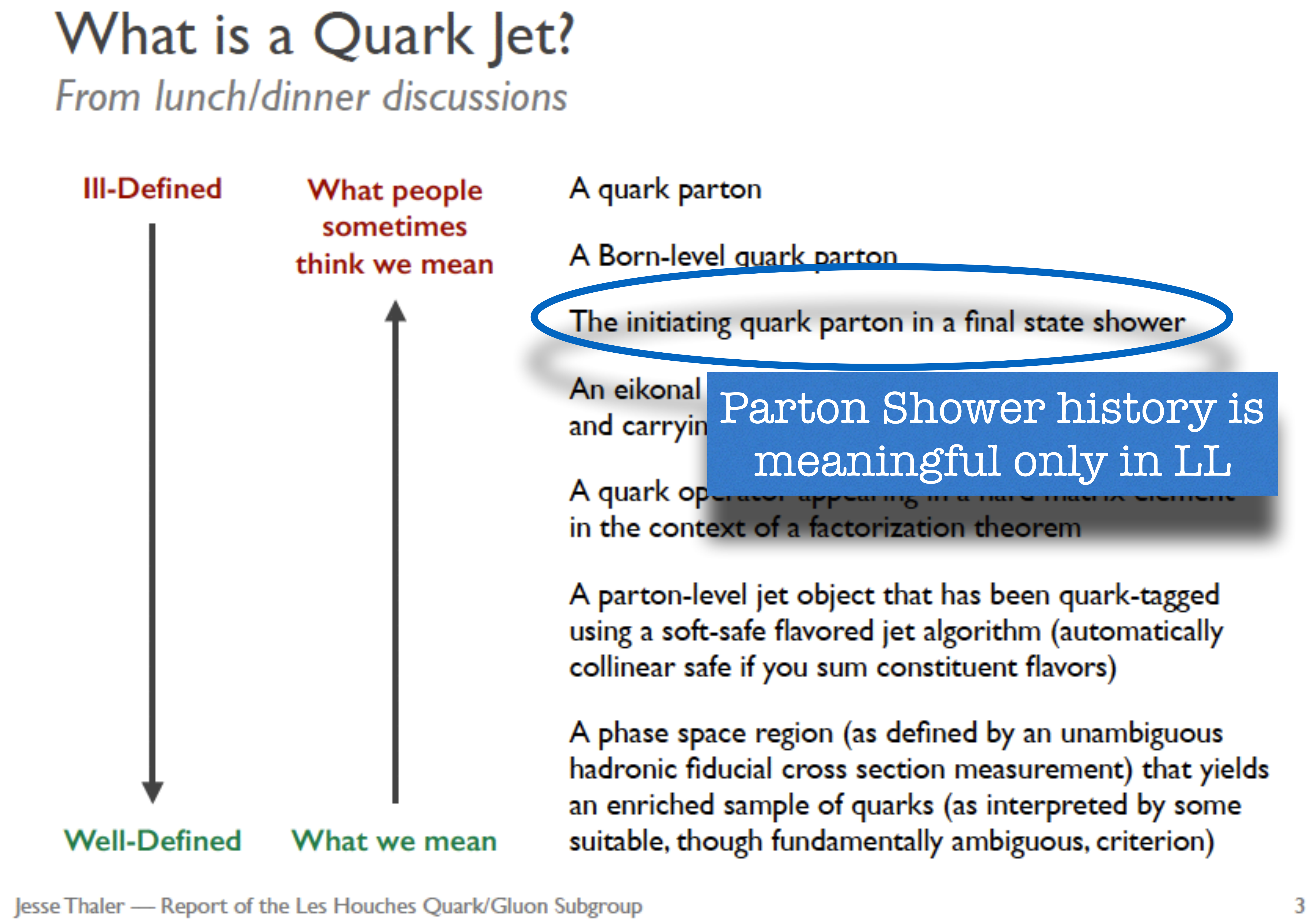
Jesse Thaler — Report of the Les Houches Quark/Gluon Subgroup

3

How to define the born process?



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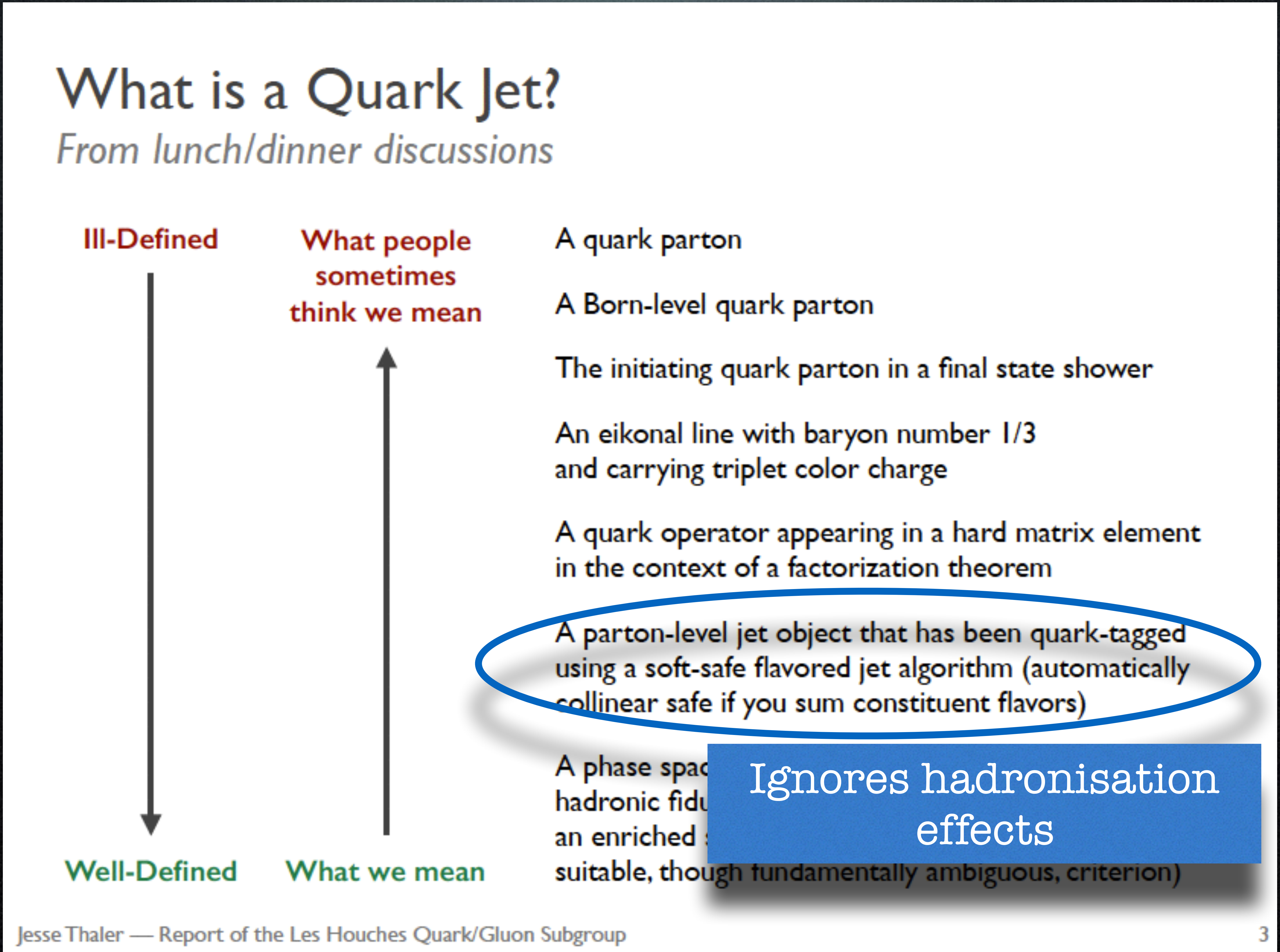
Parton Shower history is meaningful only in LL



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Ignores hadronisation effects

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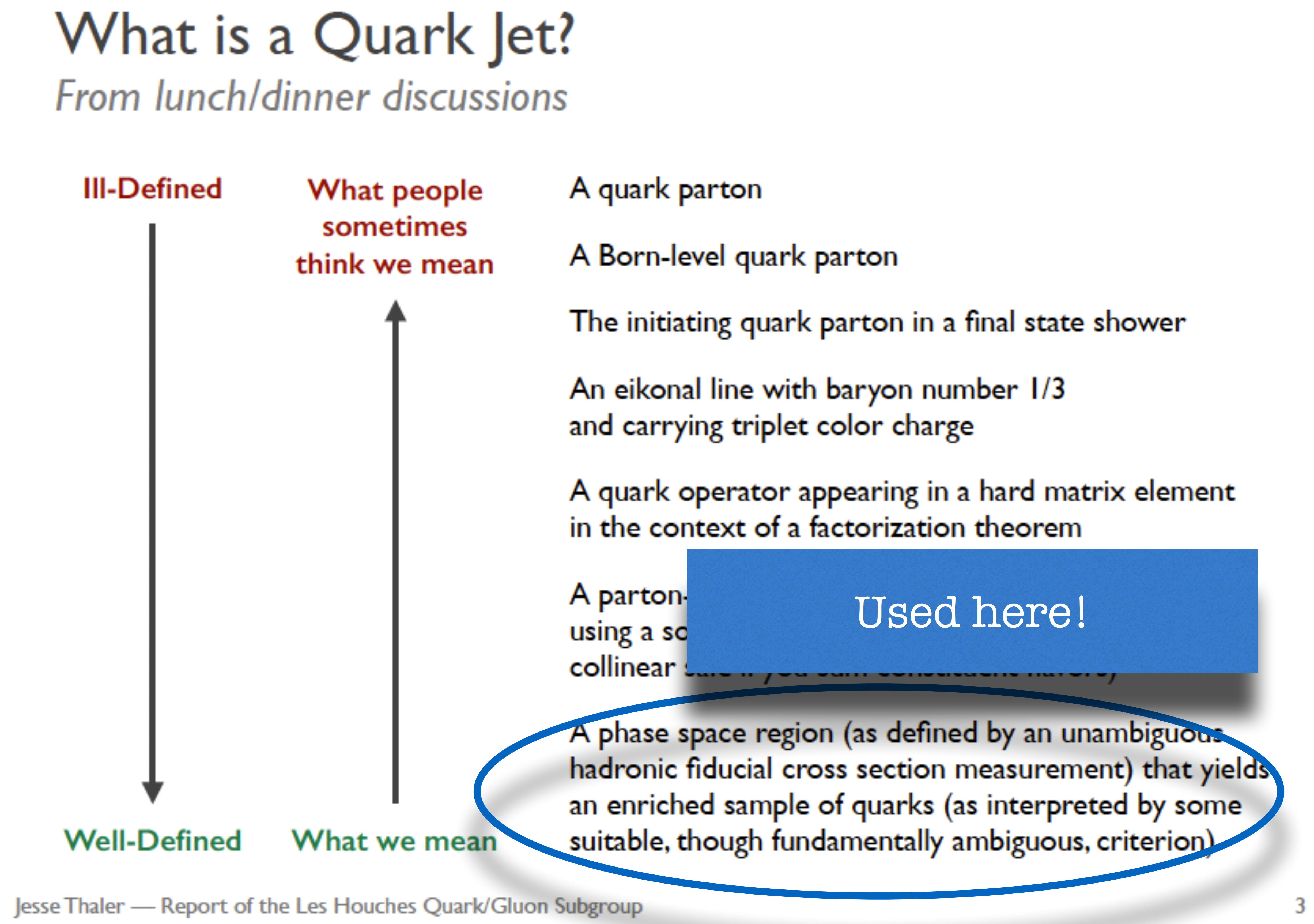

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Used here!

# The study

- In leading order:

quark radiation ∝ $C_F$, gluon radiation ∝ $C_A$ (4/3 vs 3)

- Affected strongly by subleading (perturbative and non-perturbative) effects
- Modelled in MC generators, but needs constraining by data
- Highlights modelling deficiencies

# Variable Used

Generalised angularities:

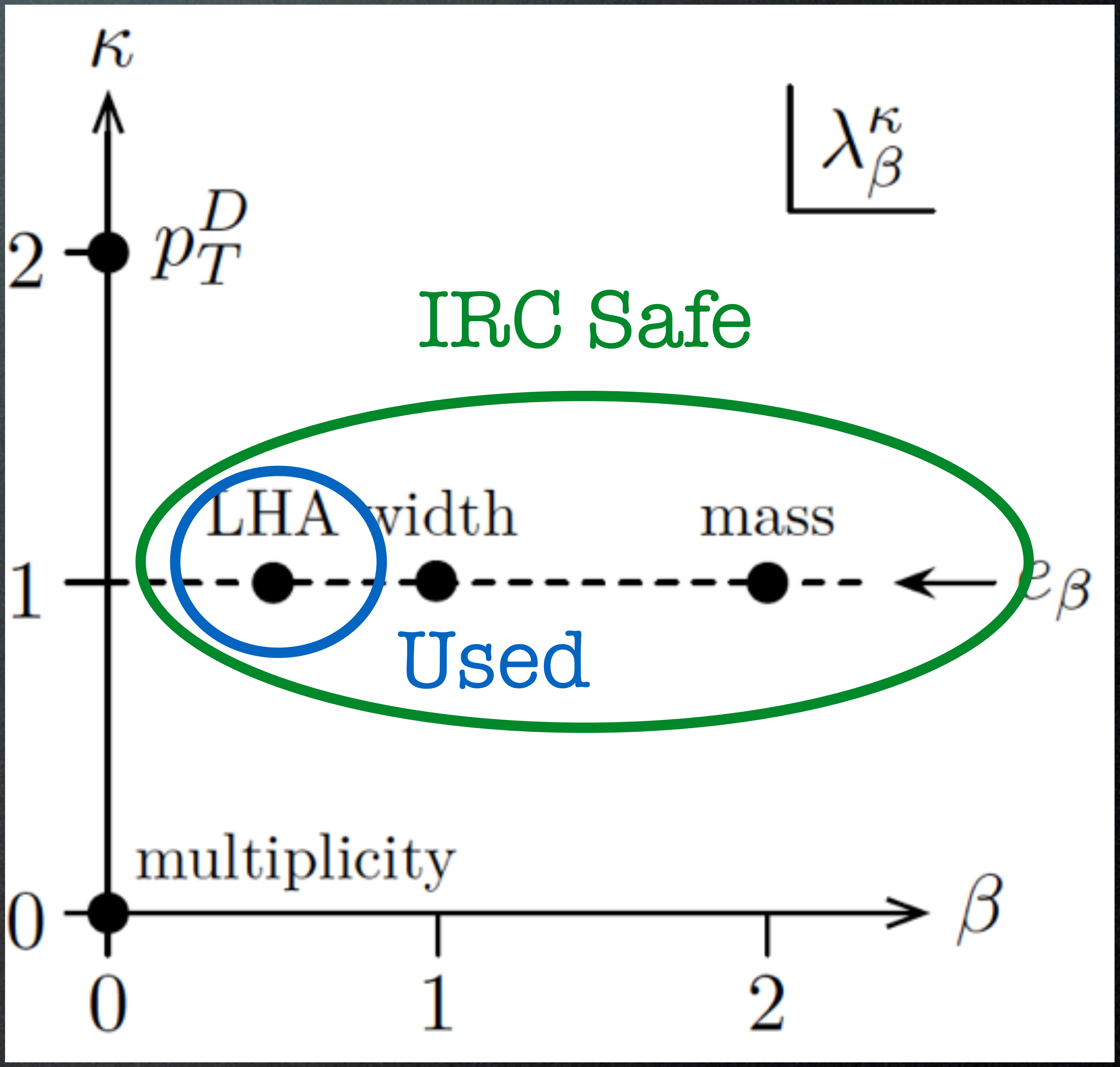
$$\lambda^{\kappa}_{\beta} = \sum_{i \in \text{jet}} z_i^{\kappa} \theta_i^{\beta},$$

Define:

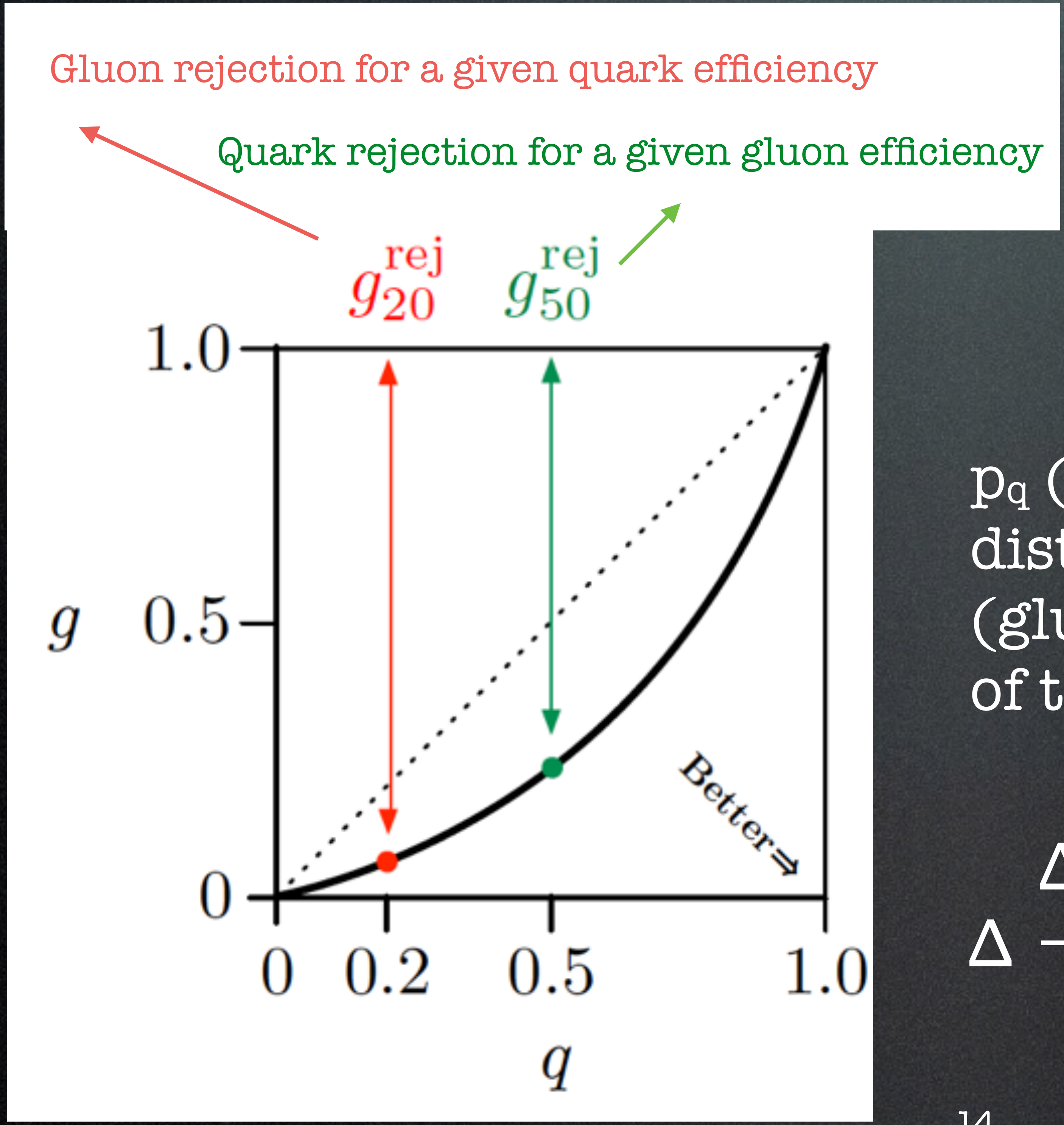
$$z_i \equiv \frac{E_i}{E_{\text{jet}}}, \qquad \theta_i \equiv \frac{\Omega_{i\hat{n}}}{R},$$

For hadron colliders:

$$z_i \equiv \frac{p_{Ti}}{\sum_{j \in \text{jet}} p_{Tj}}, \qquad \theta_i \equiv \frac{R_{i\hat{n}}}{R},$$



# Discriminant



Discriminator:

$$\Delta = \frac{1}{2}\int \mathrm{d}\lambda\, \frac{\left(p_q(\lambda) - p_g(\lambda)\right)^2}{p_q(\lambda) + p_g(\lambda)},$$

$p_q$ ($p_g$) is the probability distribution for the quark jet (gluon jet) sample as a function of the classifier λ

Δ → 0: no discrimination

Δ → 1: perfect discrimination

# Idealised $e^+e^-$ collider

Quark: $e^+e^- \to (\gamma/Z)^* \to u\bar{u}$

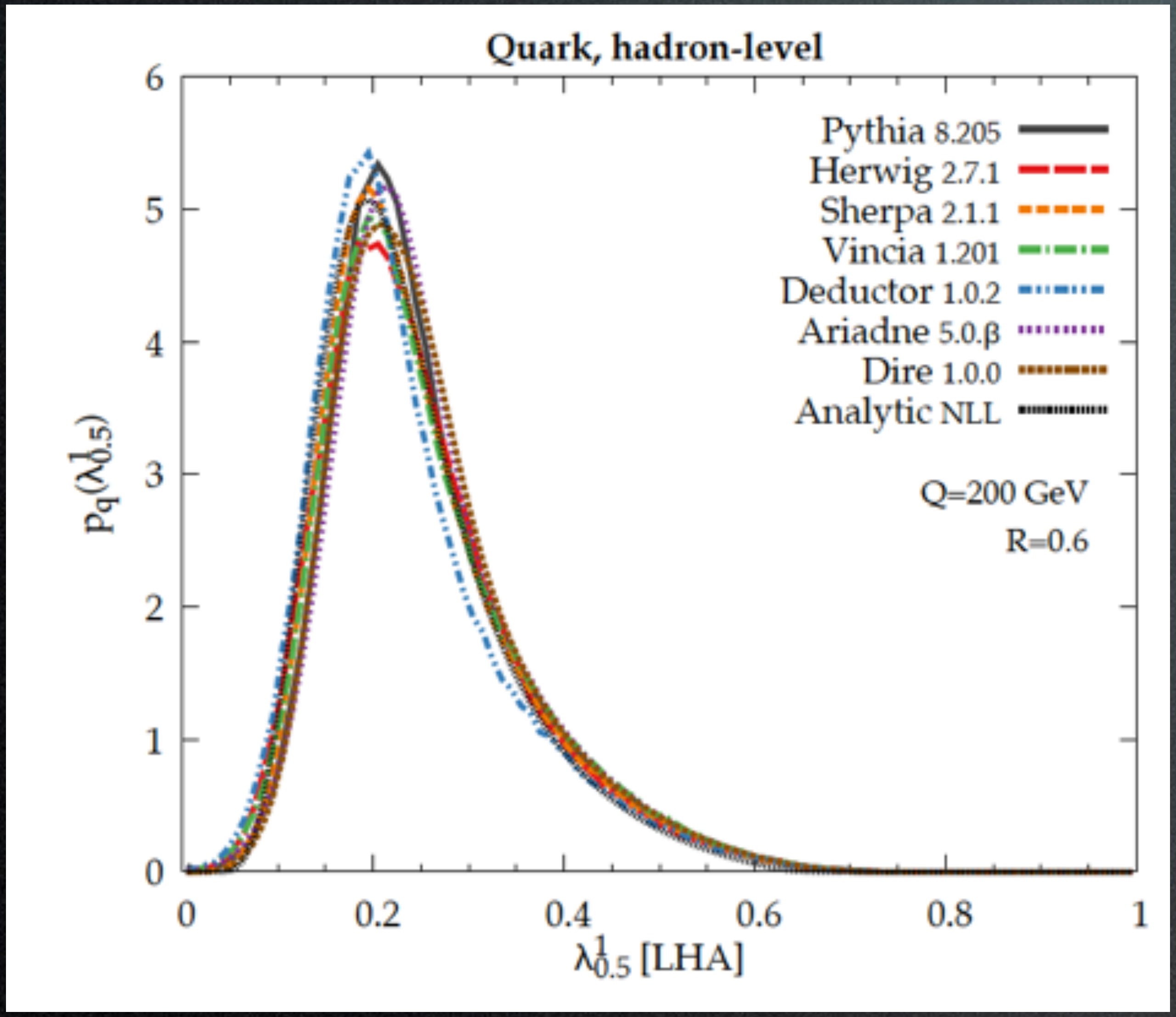
Gluon: $e^+e^- \to H^* \to gg$

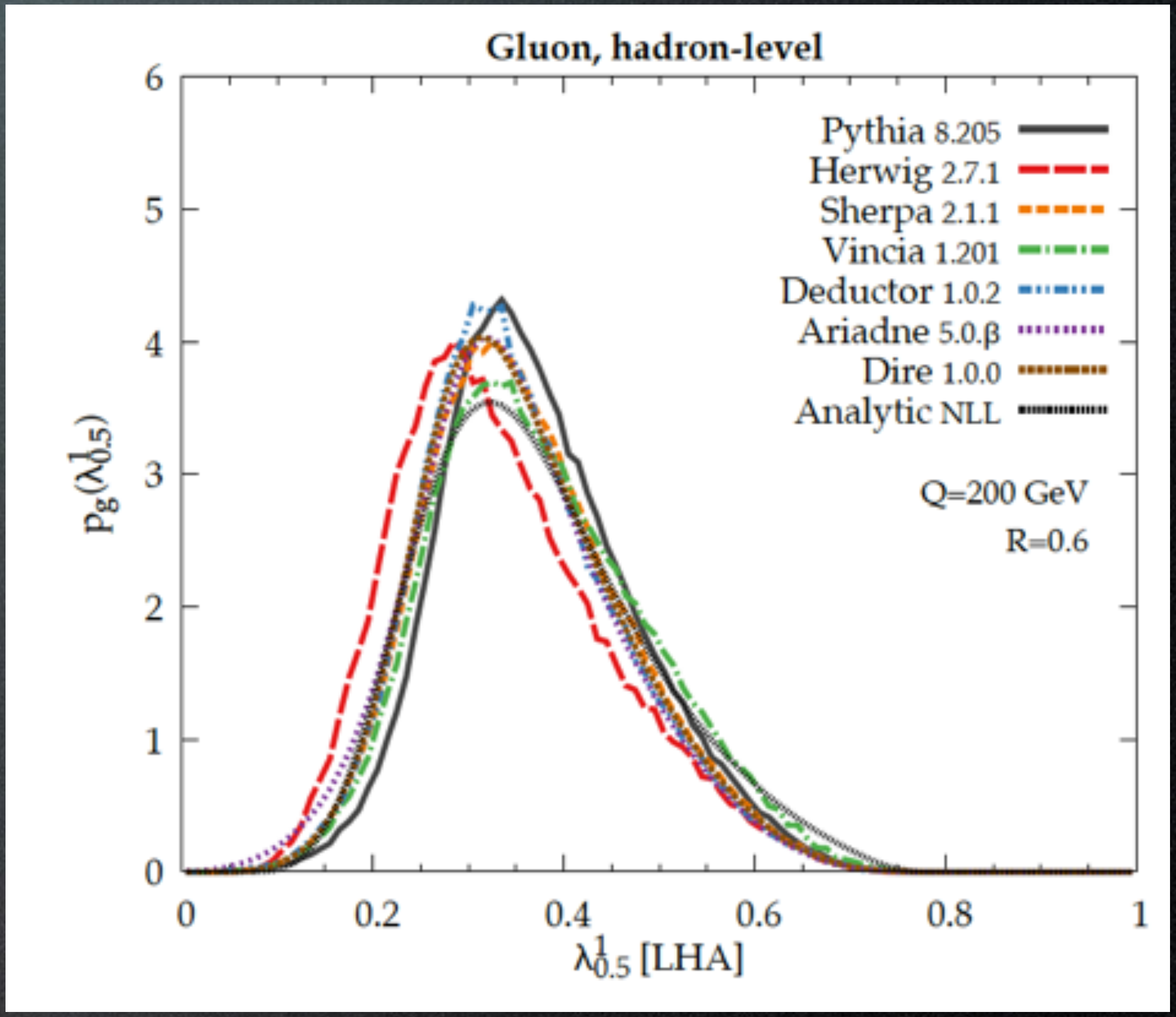
$$\frac{E_{\rm jet}}{Q/2} > 0.8,$$

Suppress wide angle radiation

- Useful to understand final state evolution (ignoring initial state complications)
- Vary collisions energy (Q), jet radius (R)
- Look at both hadron and parton level

# Hadron Level $\lambda_{LHA}$

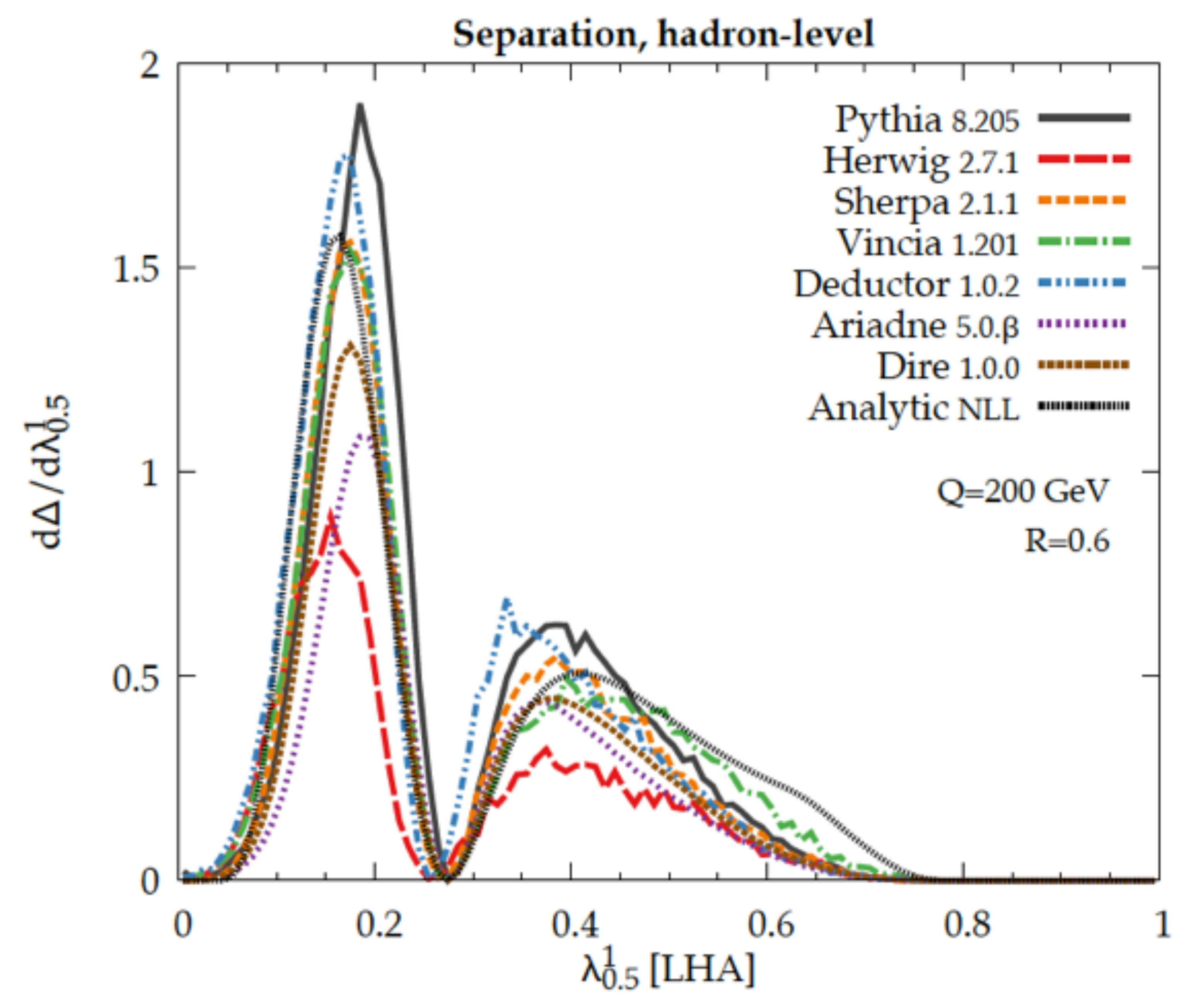




Good agreement
LEP data available

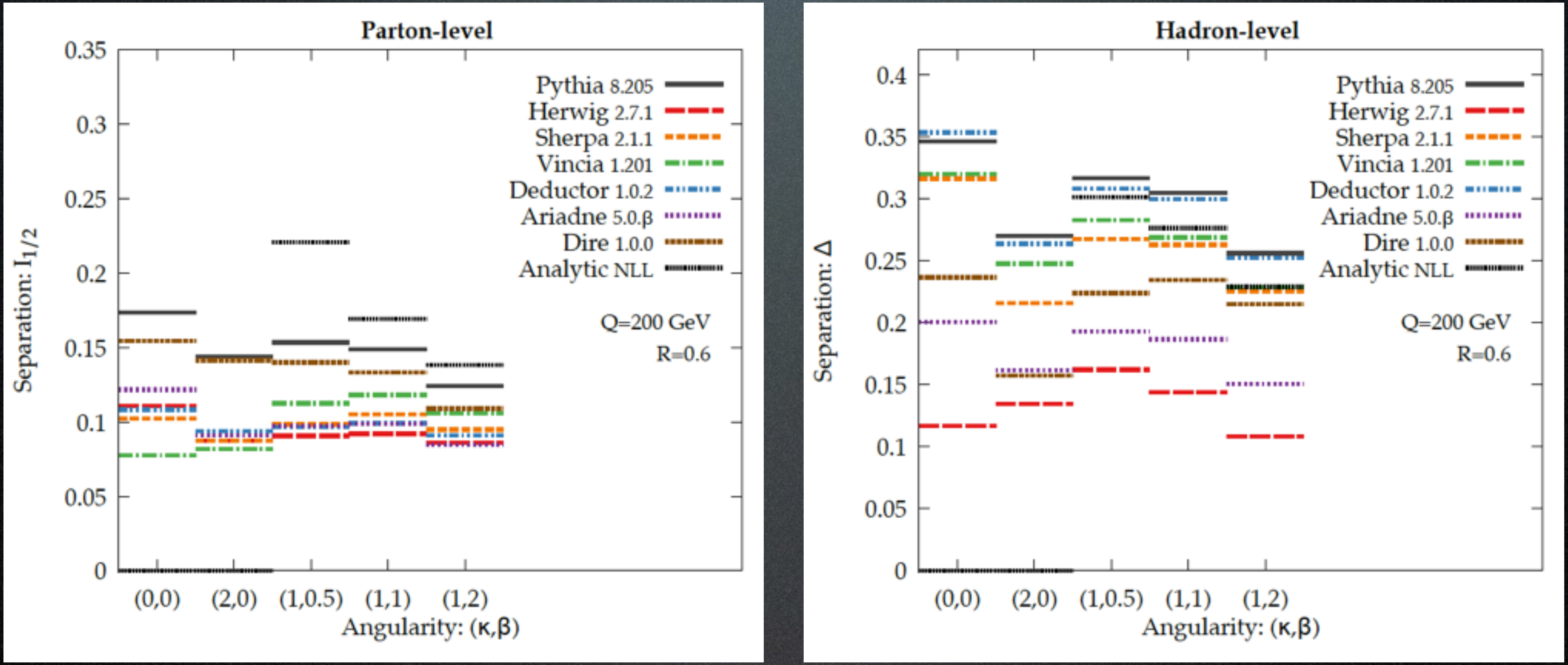
Larger spread
No data available

# Seperation



Pythia8 more optimistic, Herwig++ more pessimistic

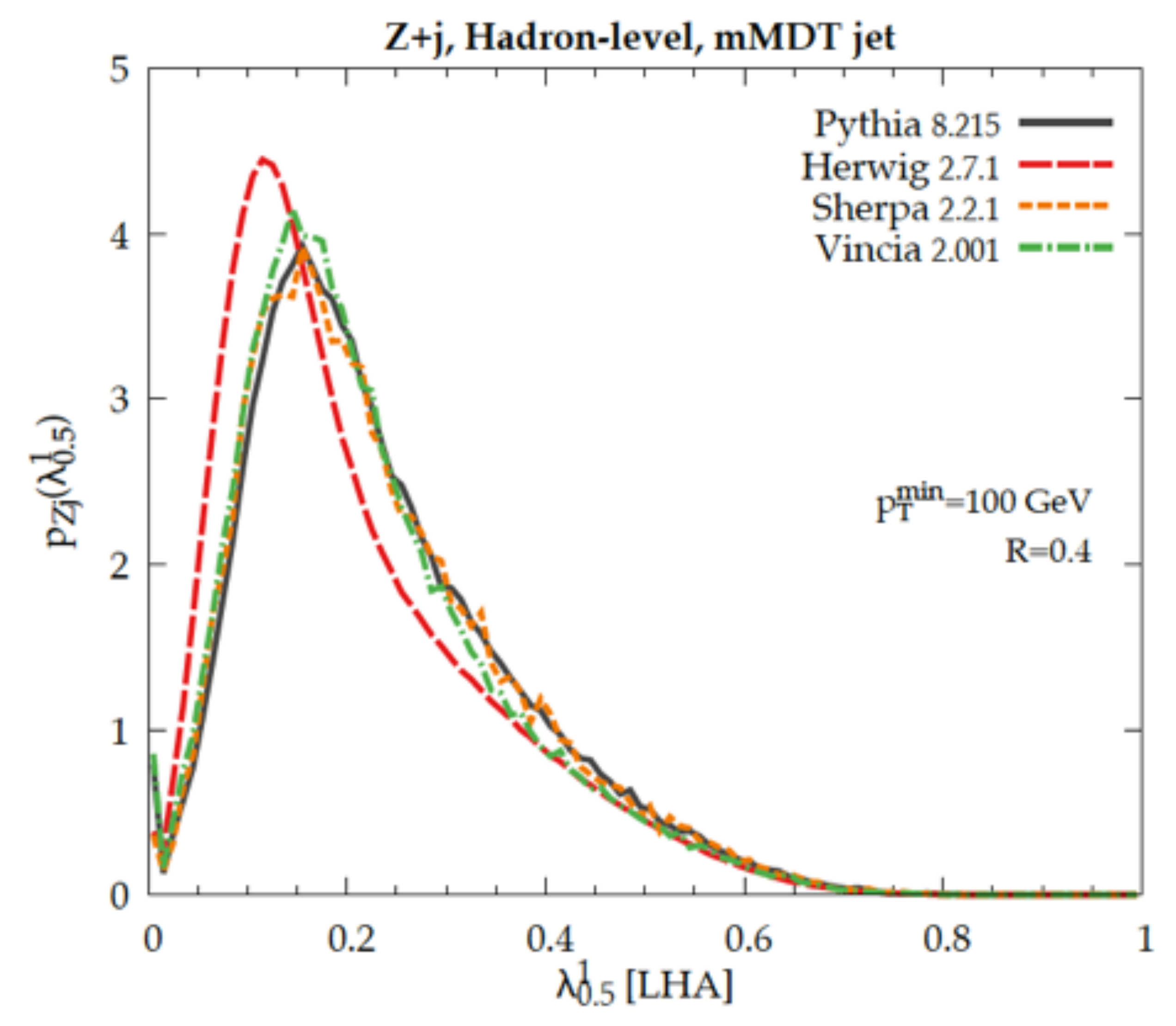
# Overall Separation



Large spread in discrimination power
(even more at hadron level, but not only due to hadronisation)

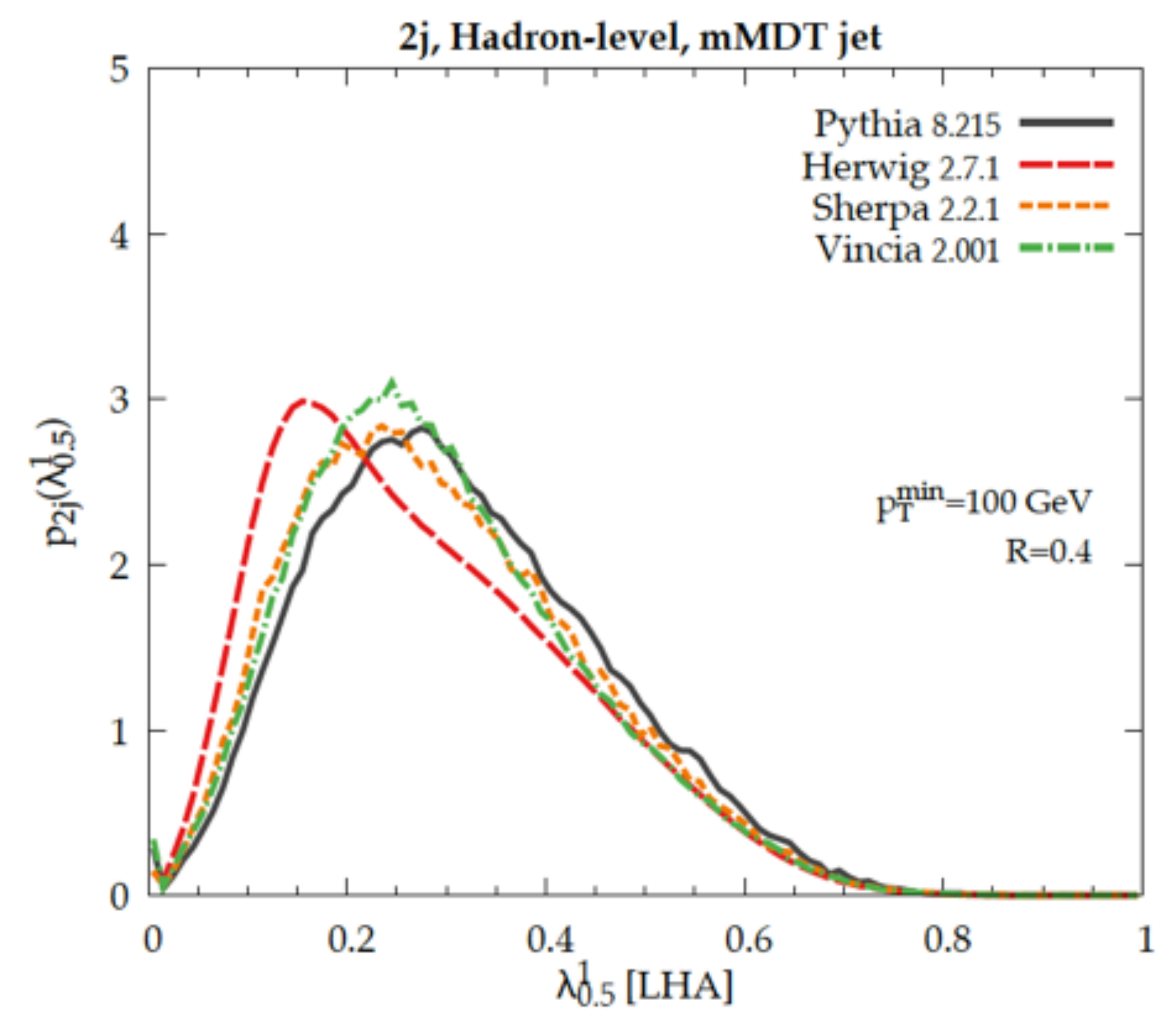
# At the LHC

Z+jets (quark enriched)



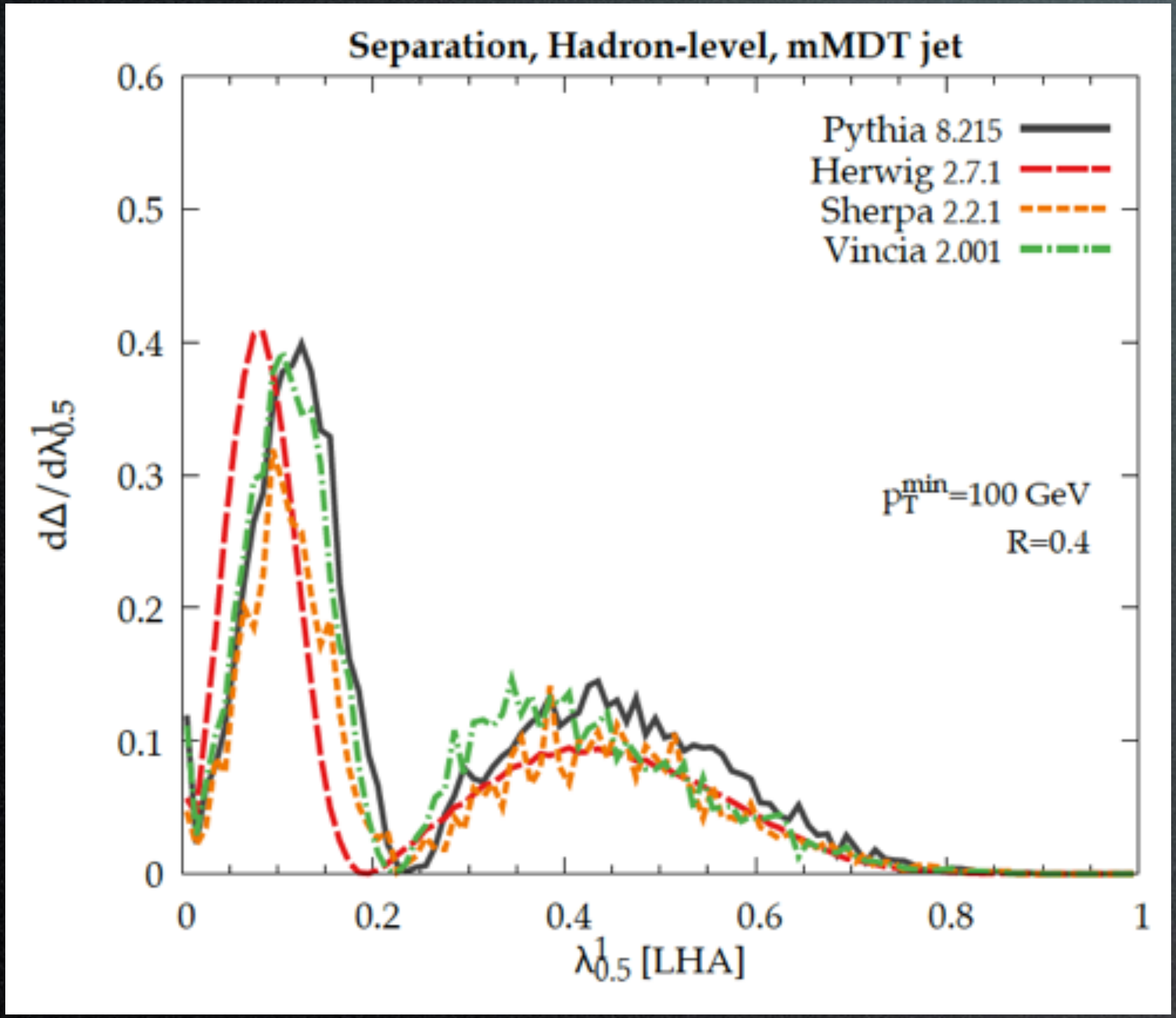
Decent agreement

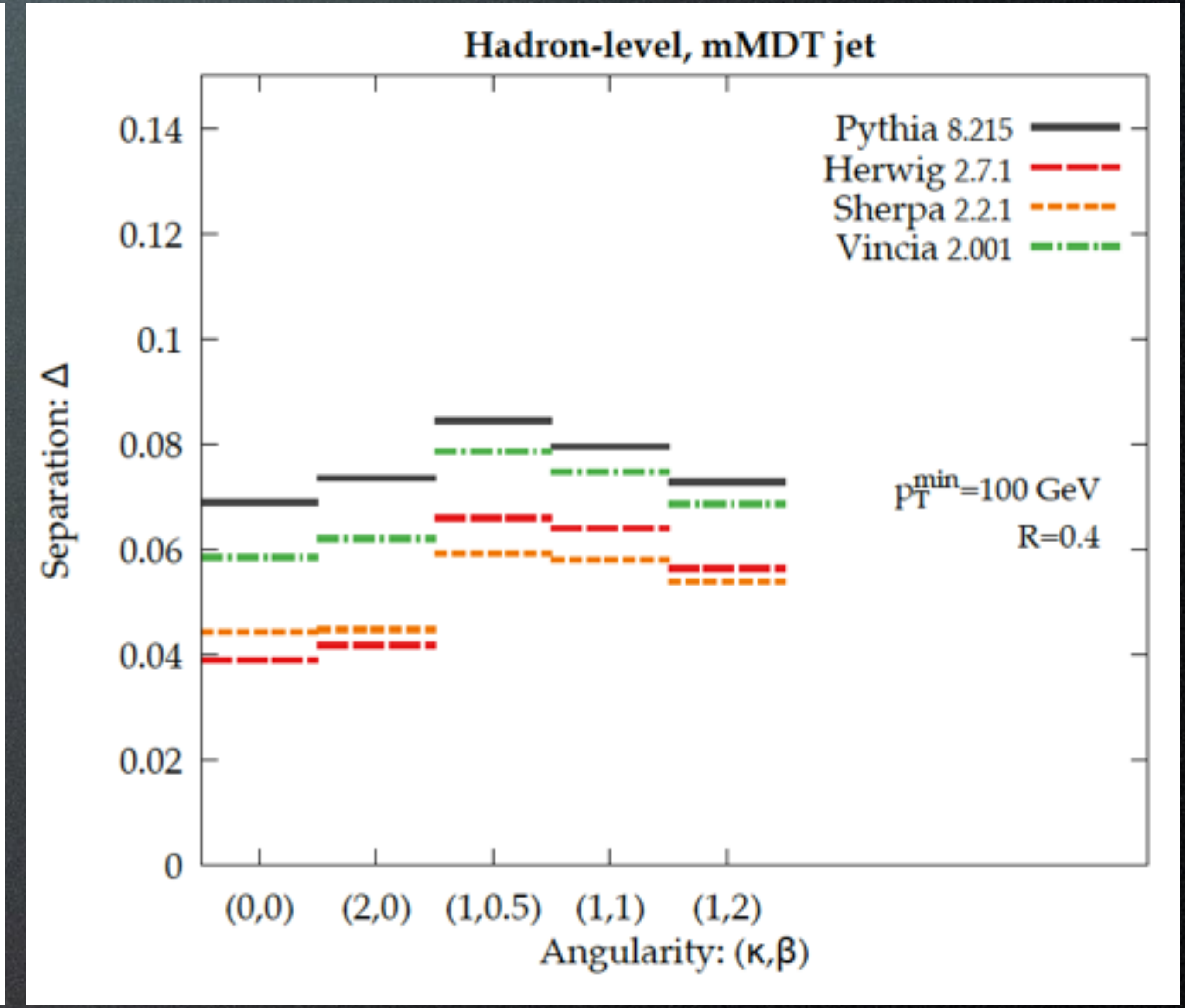
dijets (gluon enriched)



Larger Difference

# Seperation





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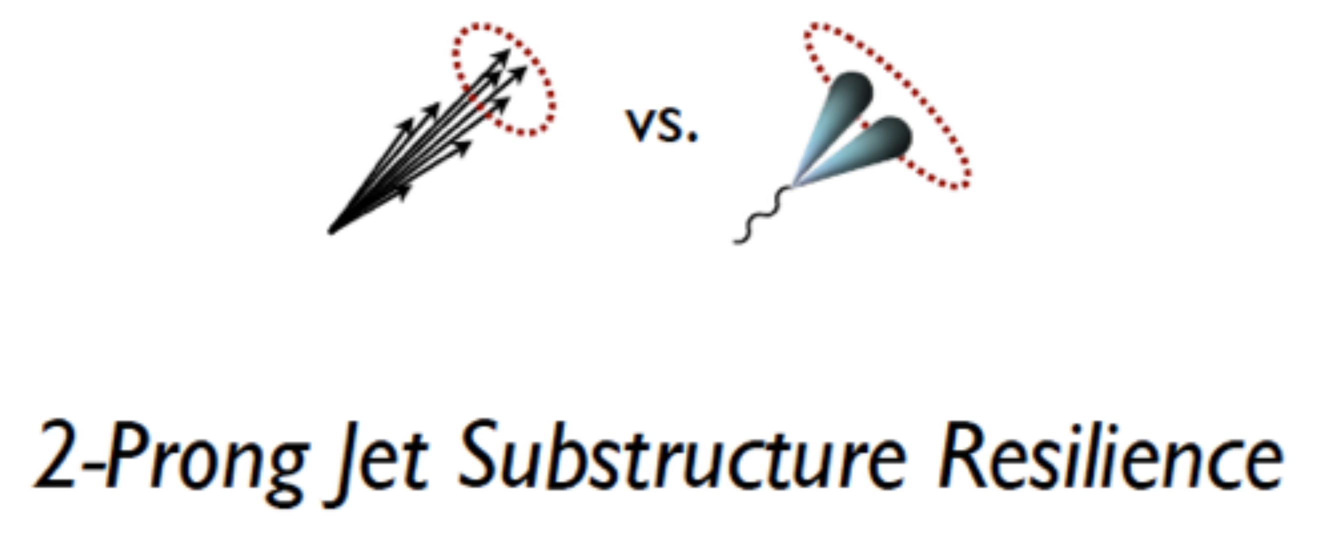
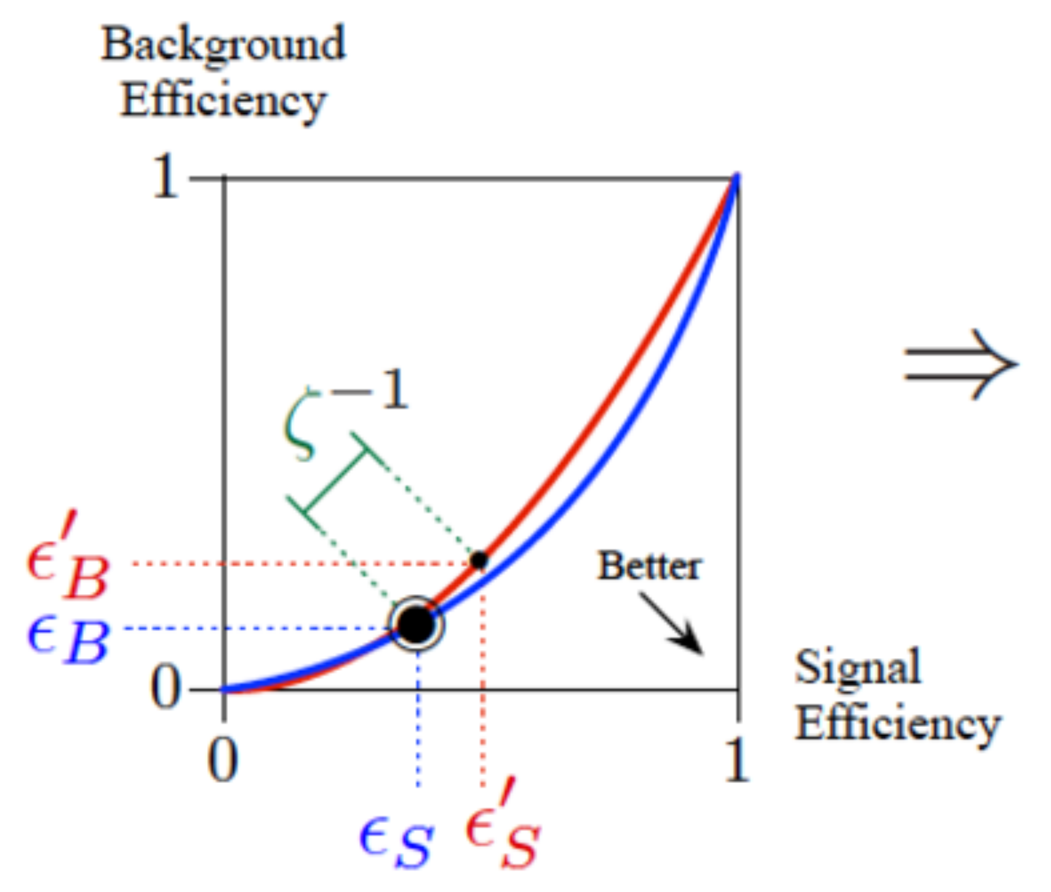
# Very Very New (LH2017)





Resilient when ROC does not shift from parton to hadron level, or with adding MPI, pileup, detector effects

# Baseline

**Ratio Observables:** $D_2$ $N_2$ $\tau_{21}$ $M_2$

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

Background: QCD Dijets

Signal: WW in Standard Model

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

**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**

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

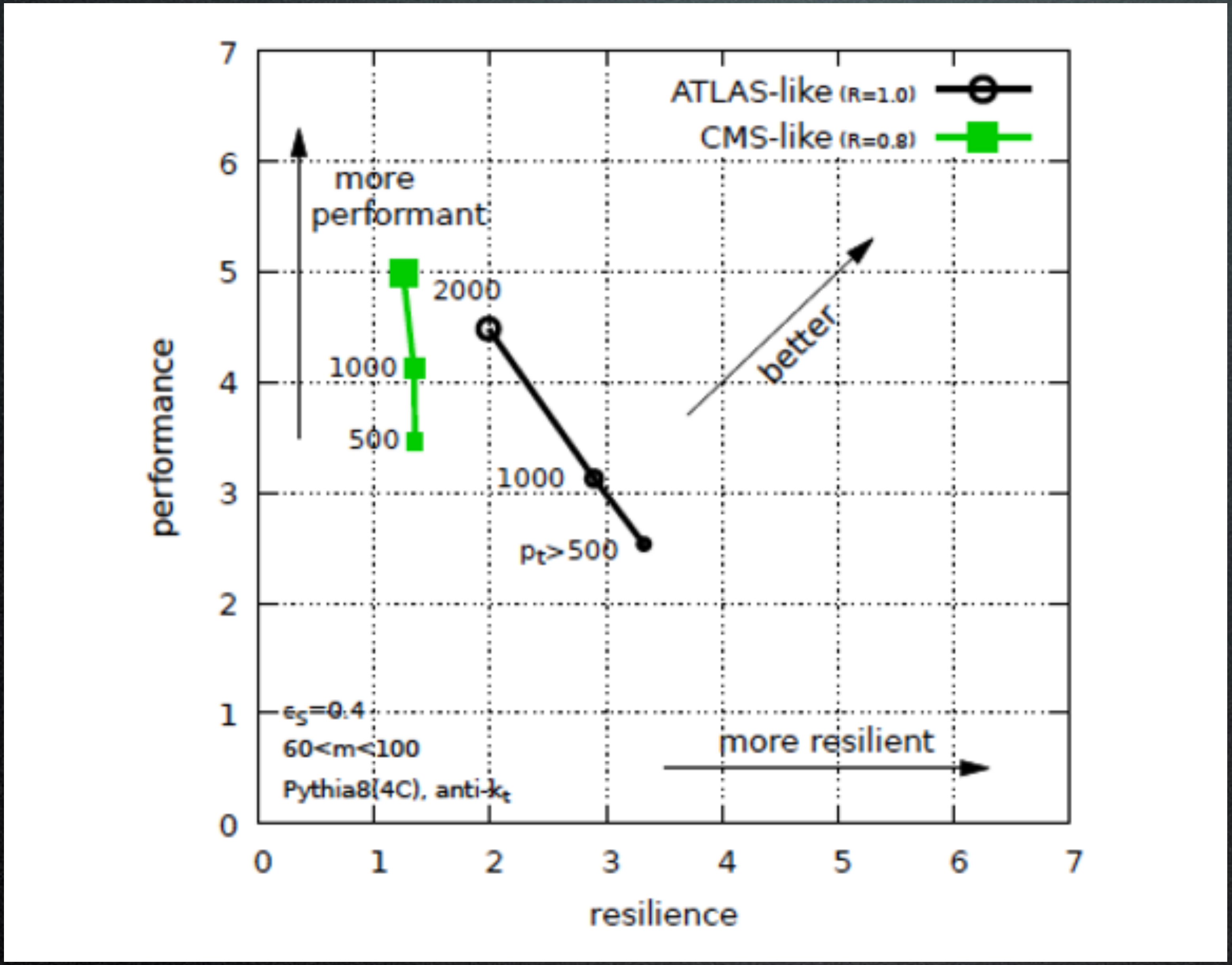
**Dichroic**

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

**All Loose**

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

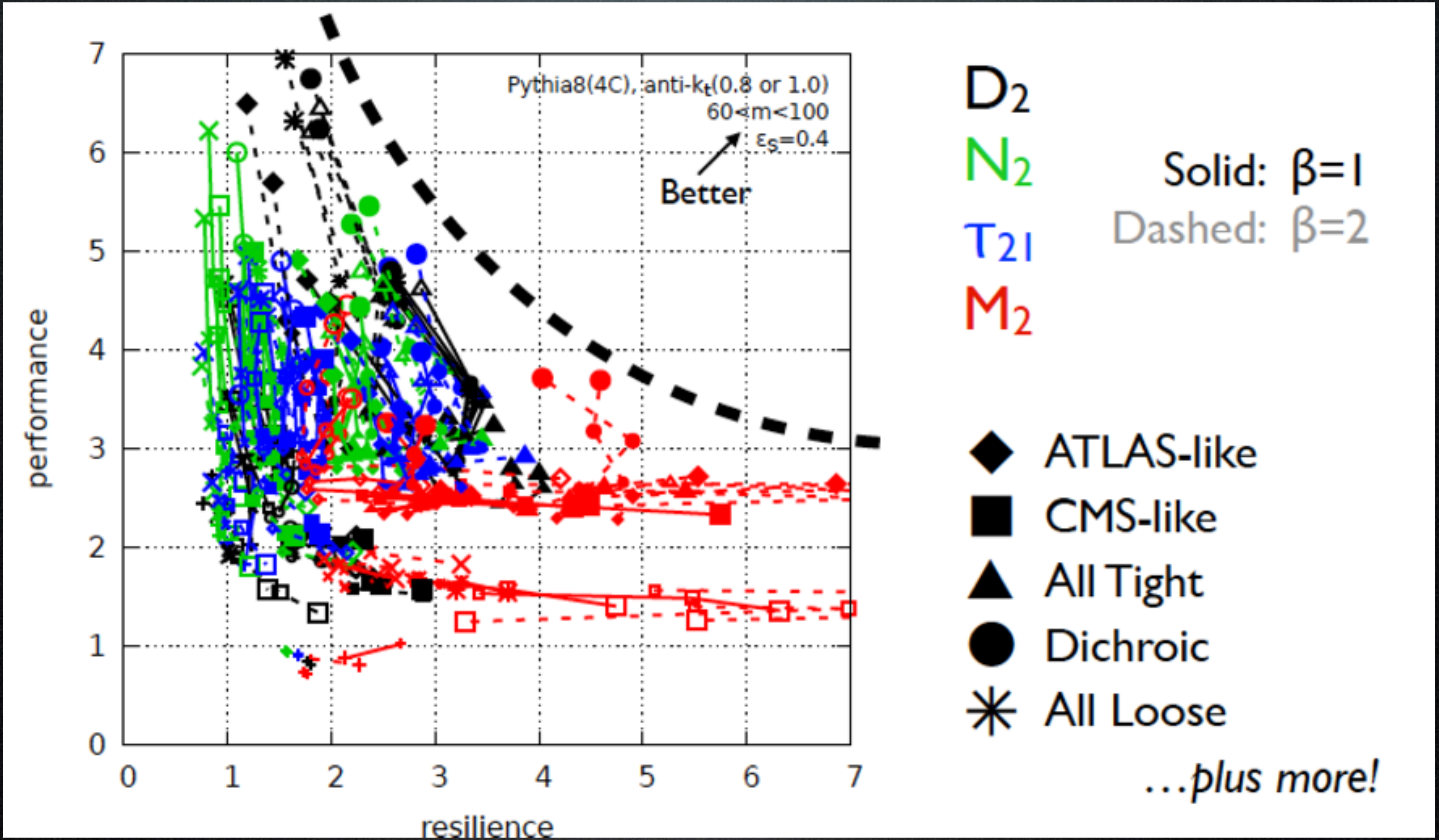
# Performance vs Resilience



parton
->
particle

Performance improves at higher $p_T$

# Grand Summary: Performance/Resilience Tradeoff



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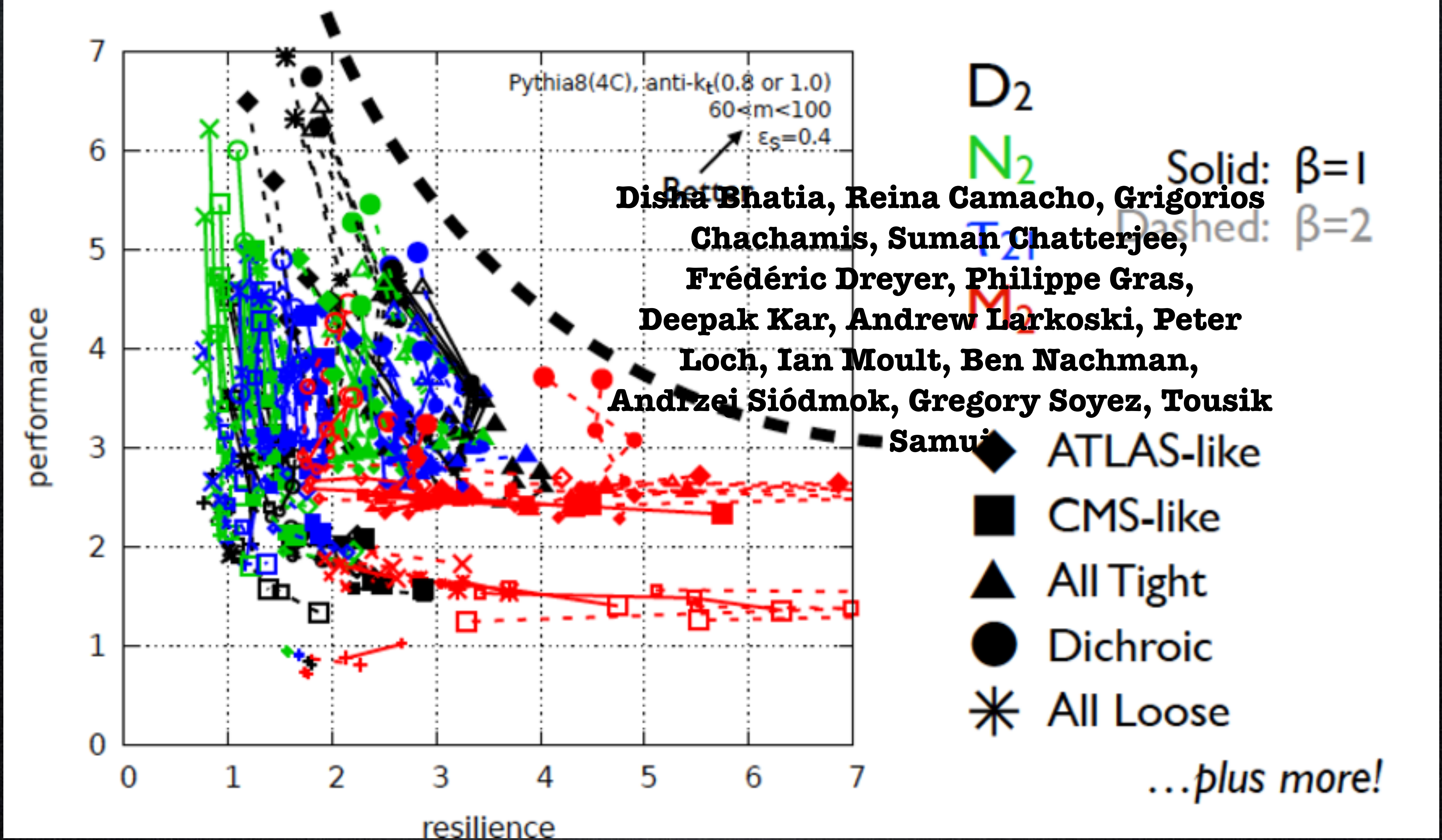


**Disha Bhatia, Reina Camacho, Grigorios Chachamis, Suman Chatterjee, Frédéric Dreyer, Philippe Gras, Deepak Kar, Andrew Larkoski, Peter Loch, Ian Moult, Ben Nachman, Andrzej Siódmok, Gregory Soyez, Tousik Samui**

# Summary

- Important physics applications, especially for "discovery physics", where new signals are often quark-dominated, while background in gluon-dominated, or need optimal tagging of two prong-substructure.

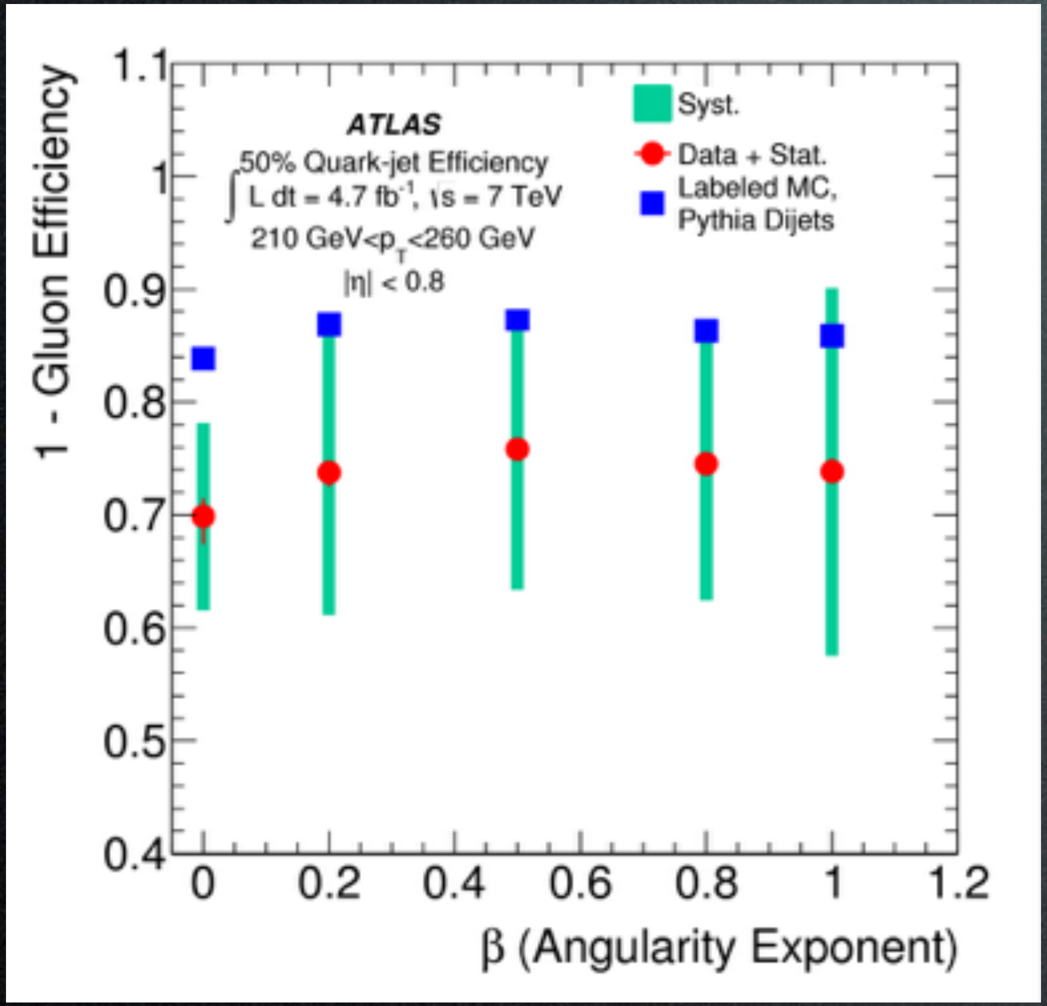
- Large effect for generator setting, non-perturbative/shower effects.

- Need (unfolded) measurements, specially for gluon processes.

- LH2017: goal is to find optimality contour for parton to detector level with pileup, and suggest best strategies for experiments.

# Backup

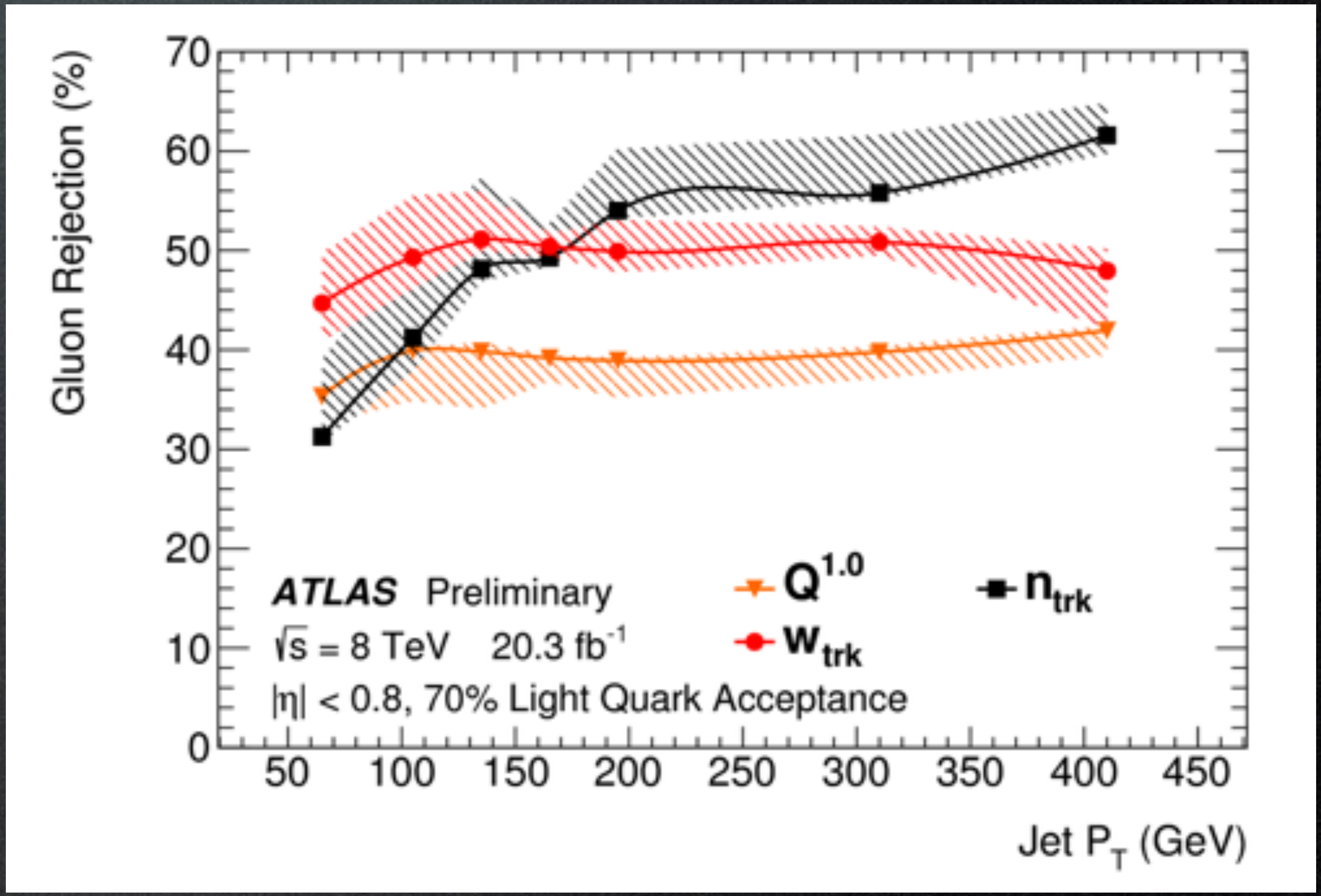
# ATLAS Result(s)



Eur. Phys. J. C (2014) 74: 3023

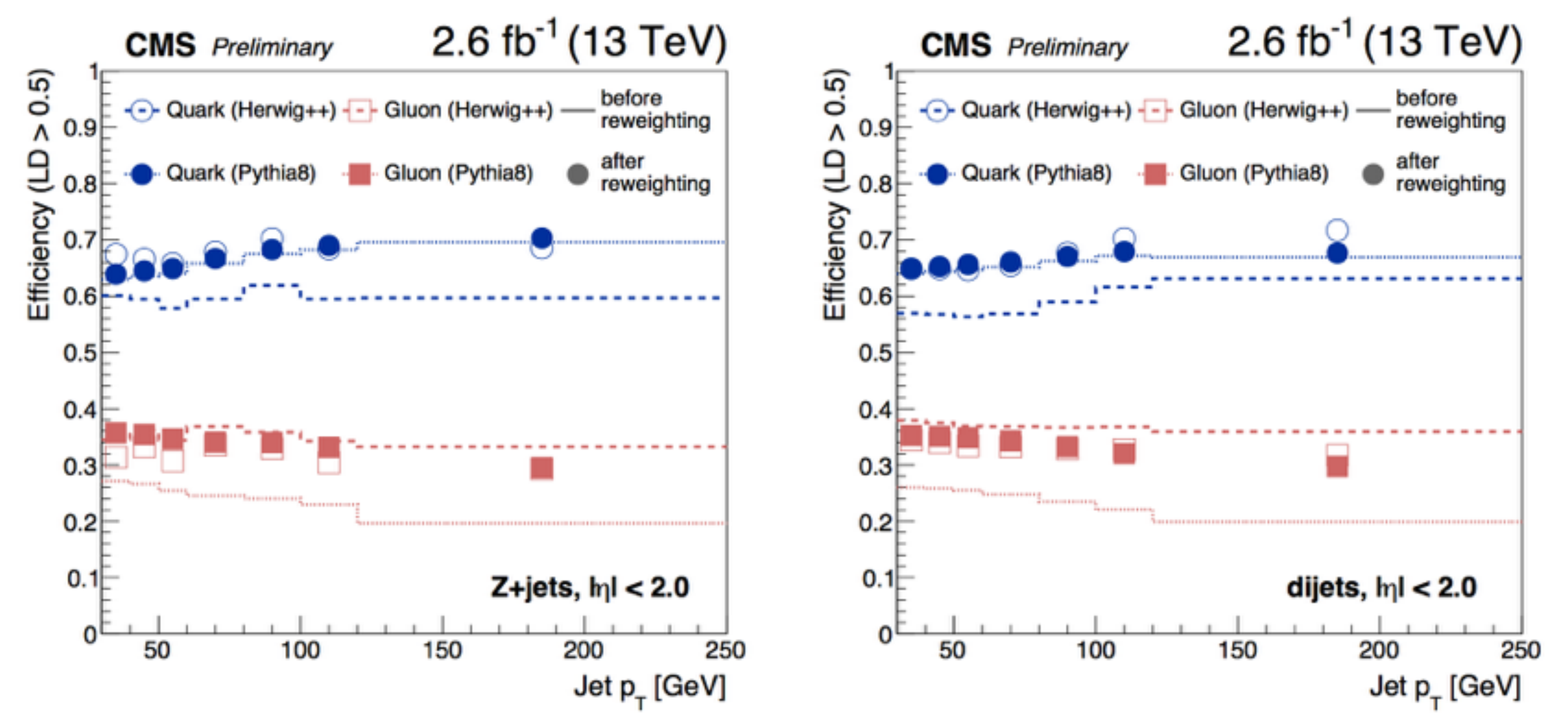
Data-MC difference
(but very optimistic!)

Discriminant composed
of different observables



ATLAS-CONF-2016-034

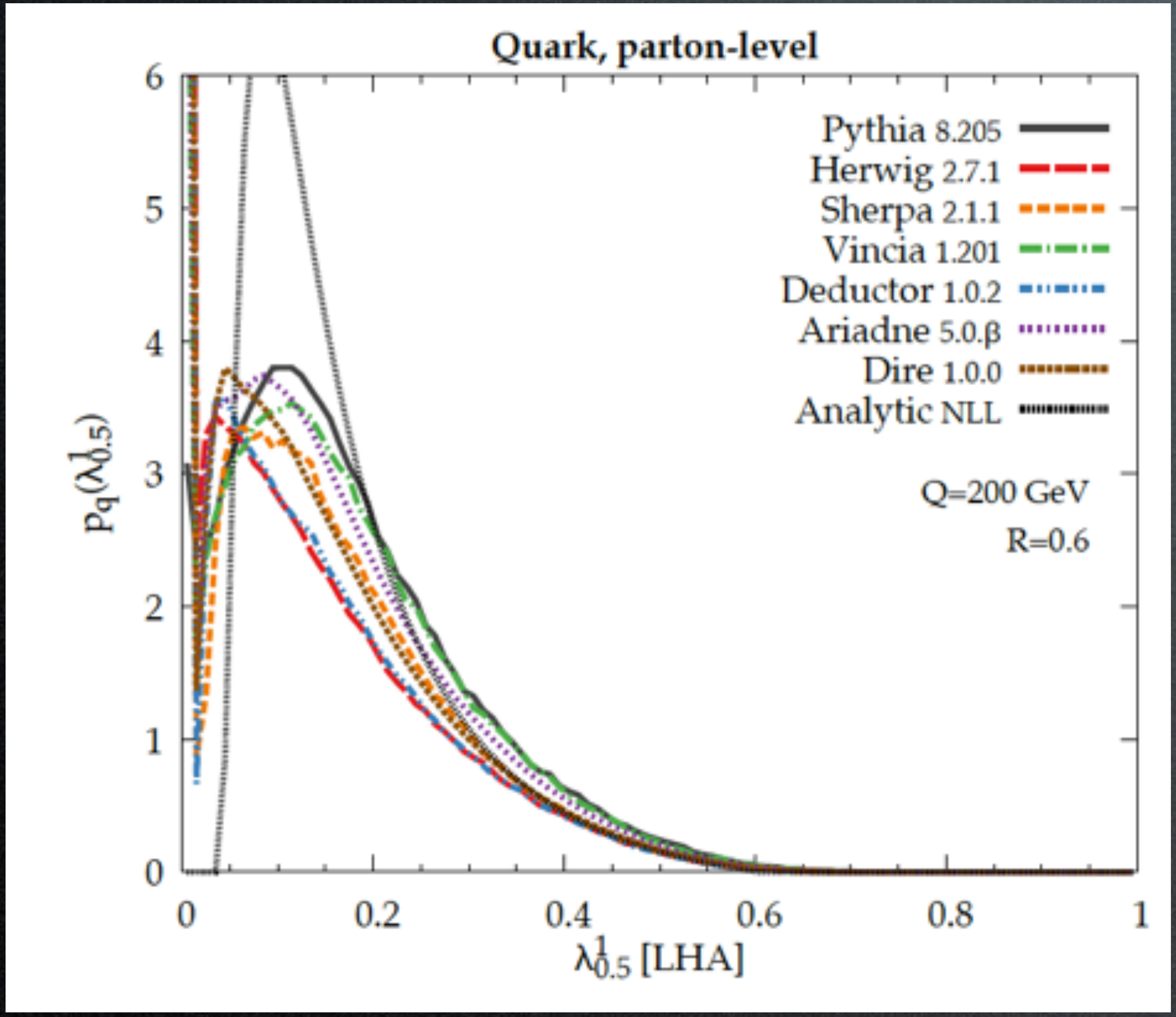
# CMS Result

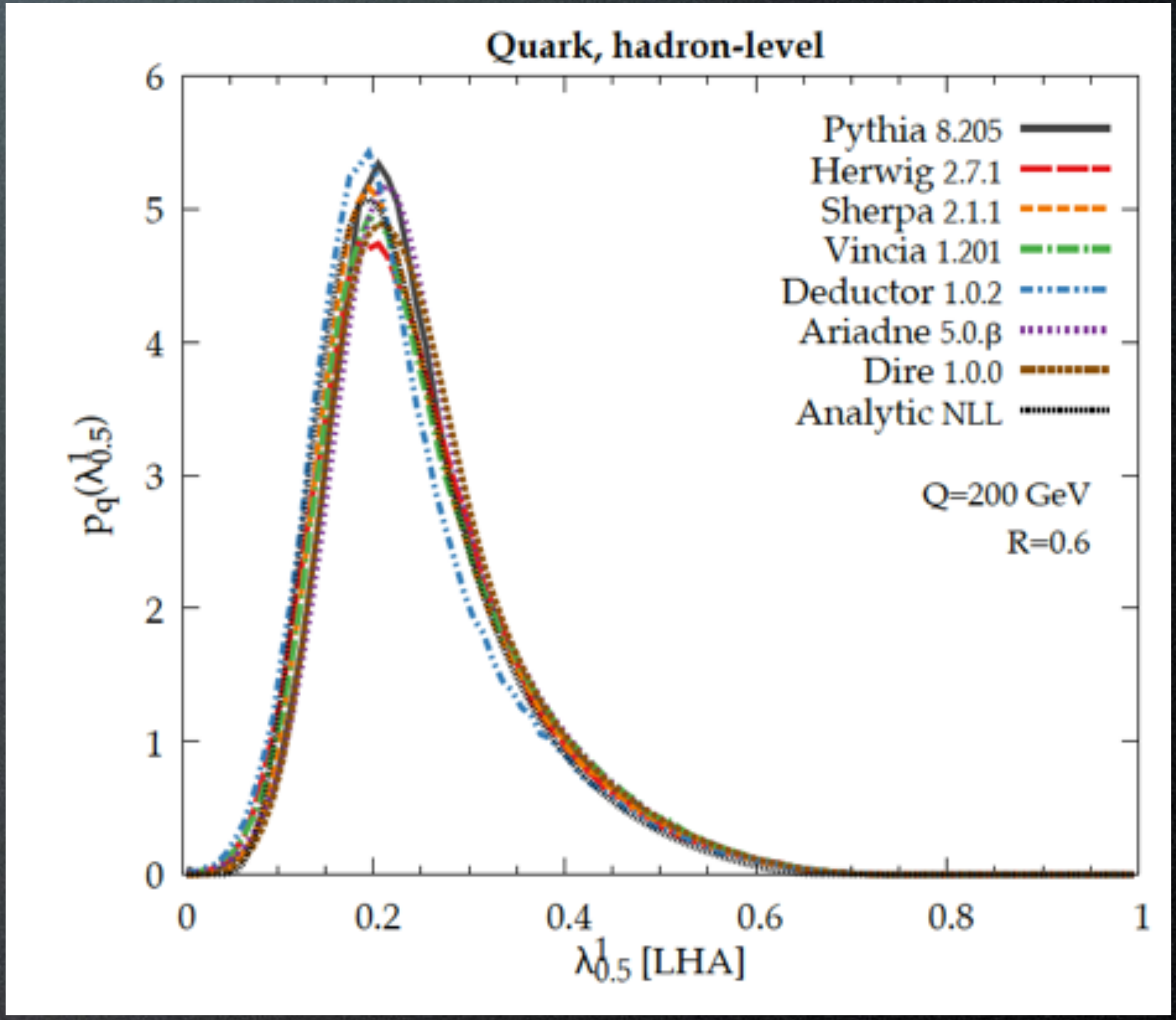


CERN-CMS-DP-2016-070

Need MC reweighting to match (data) efficiencies

# Non-Perturbative Effects





Large effect of hadronisation

More difference among MC models as well

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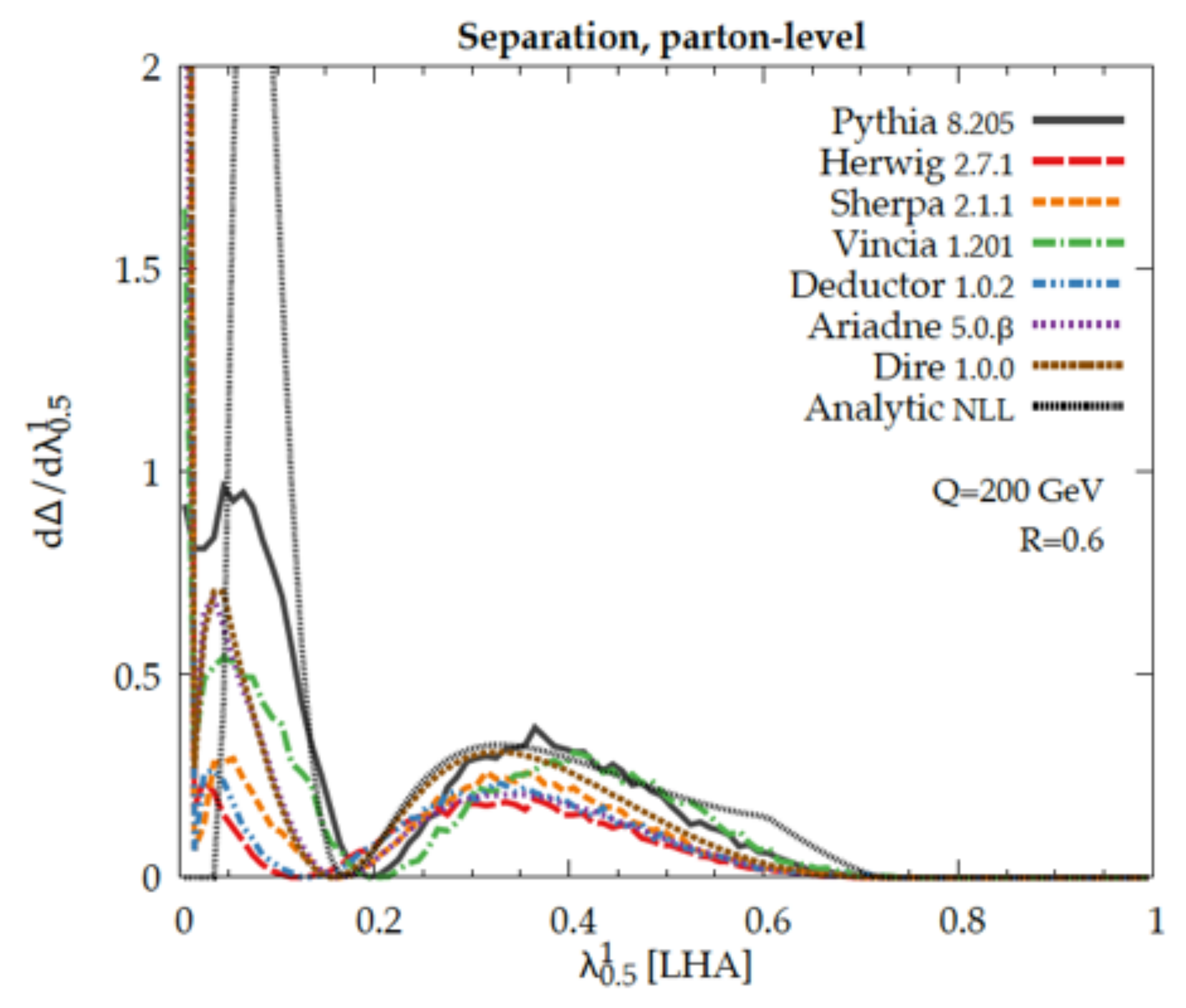

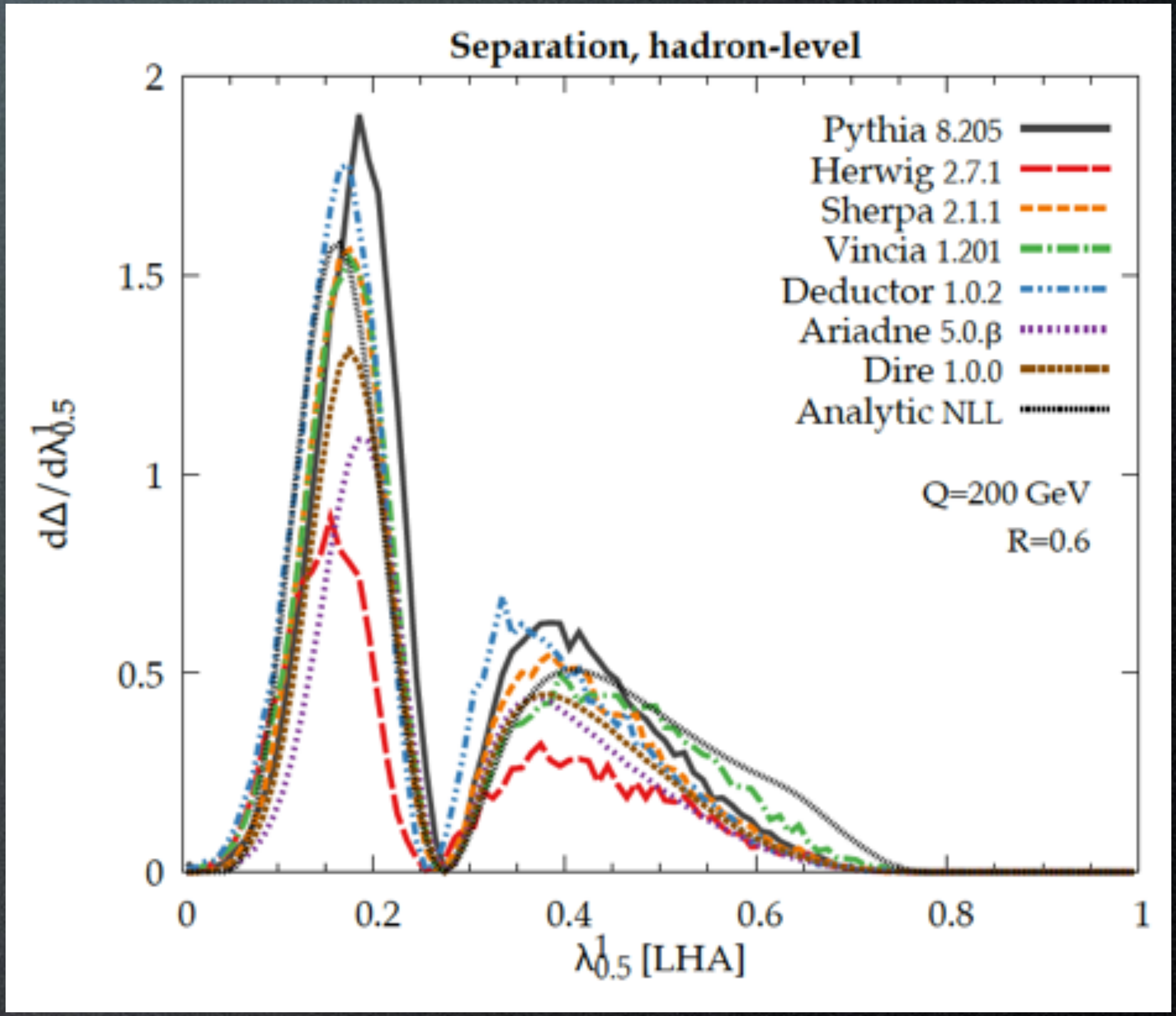

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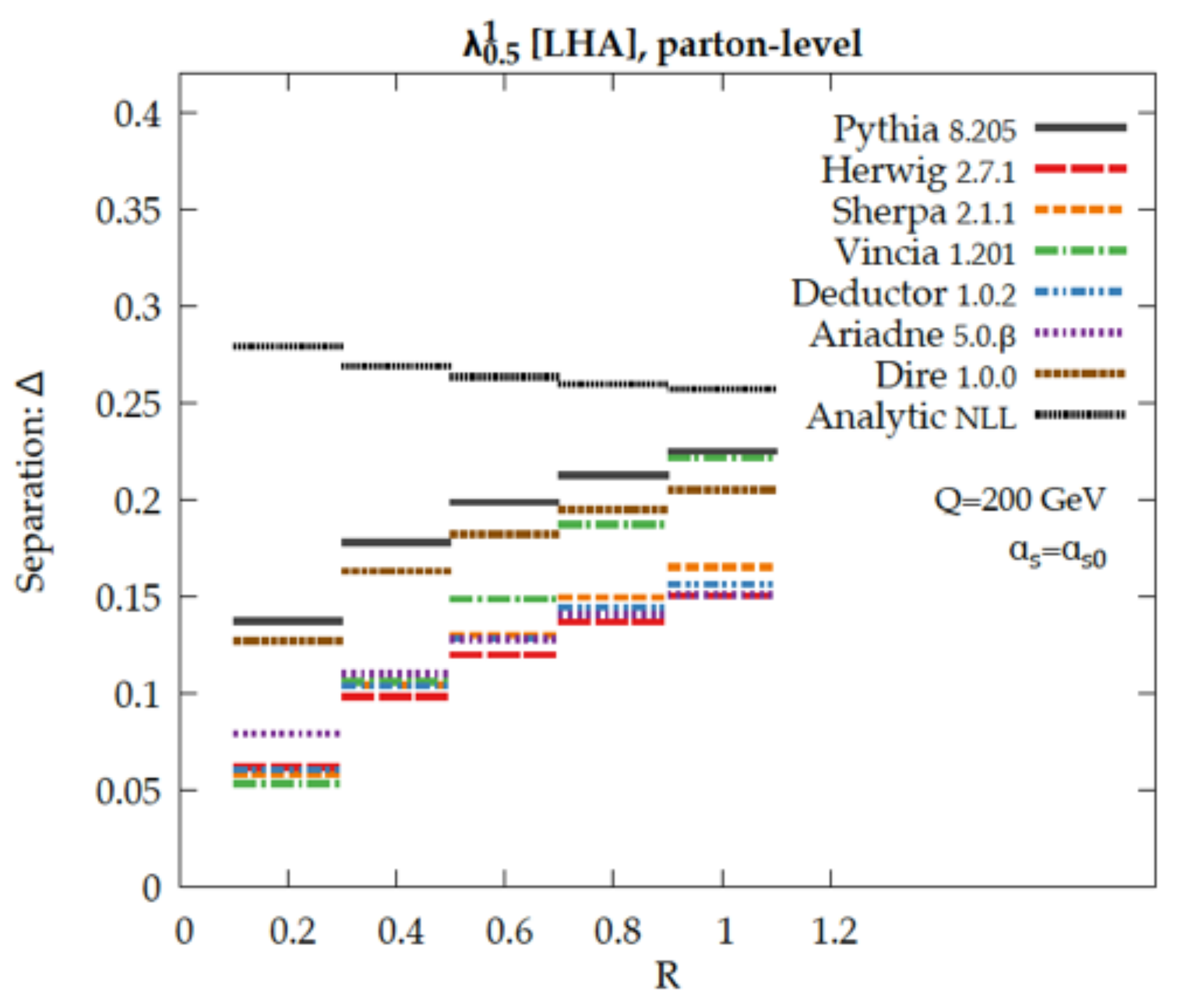
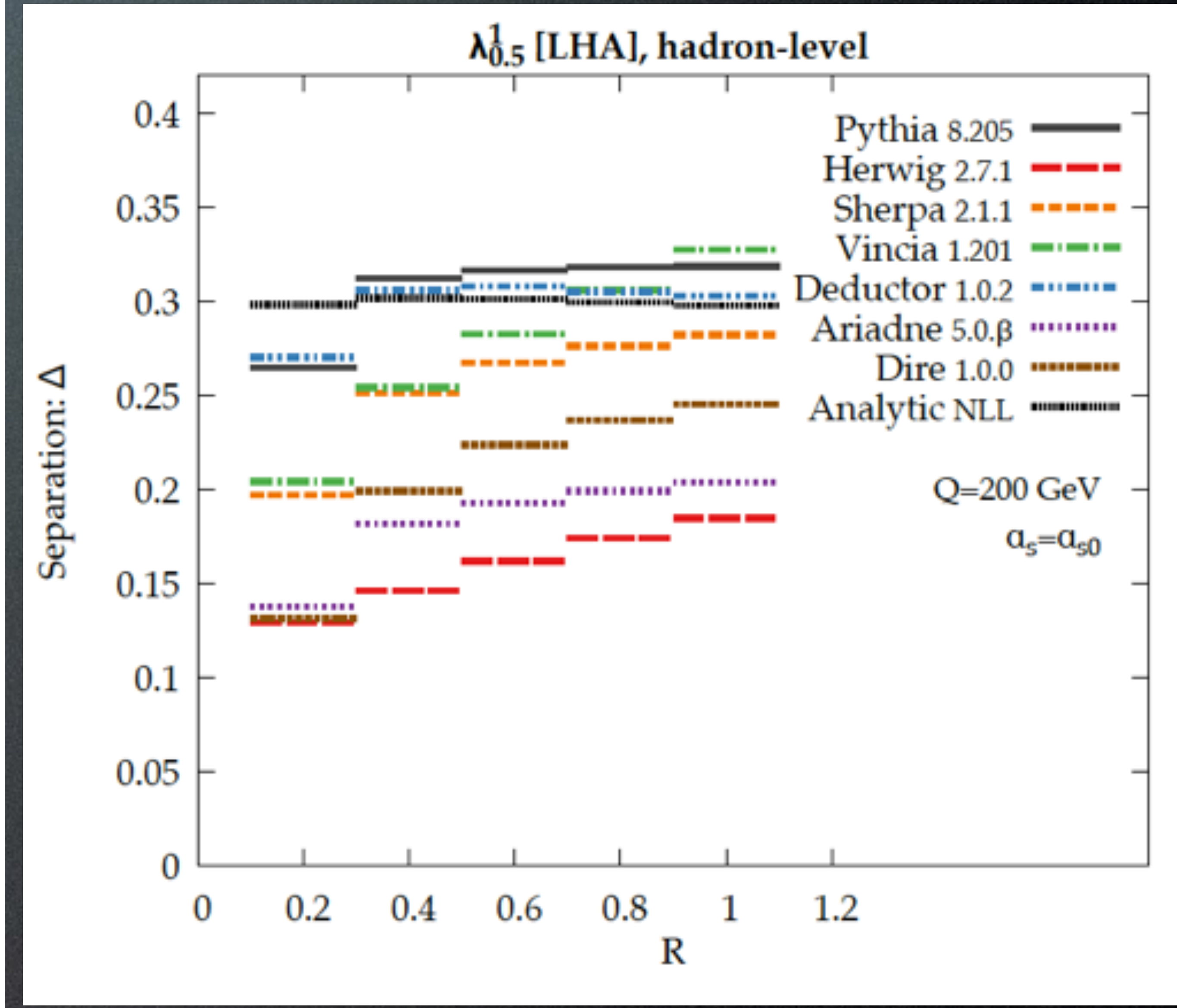
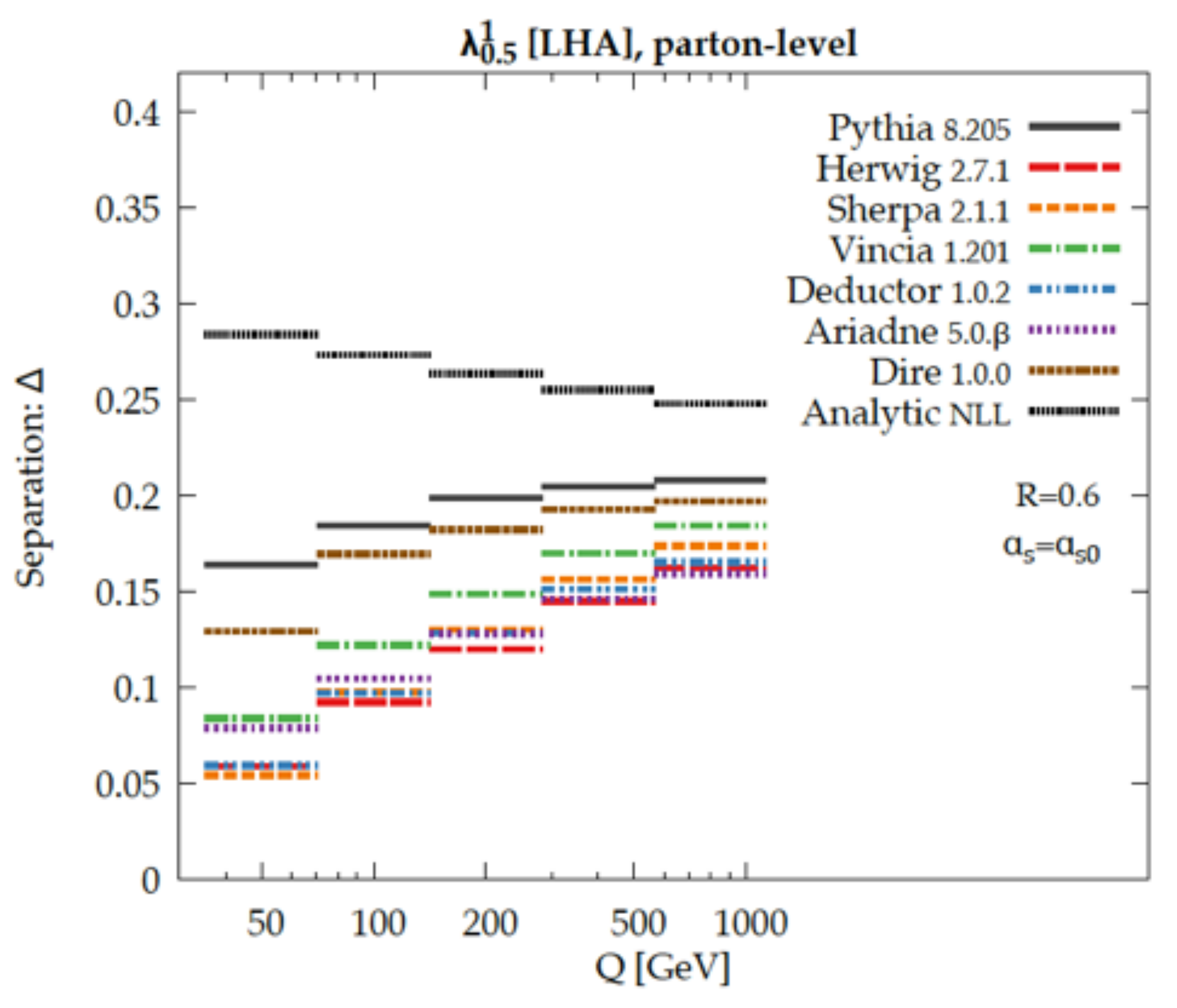
# Dependance on R

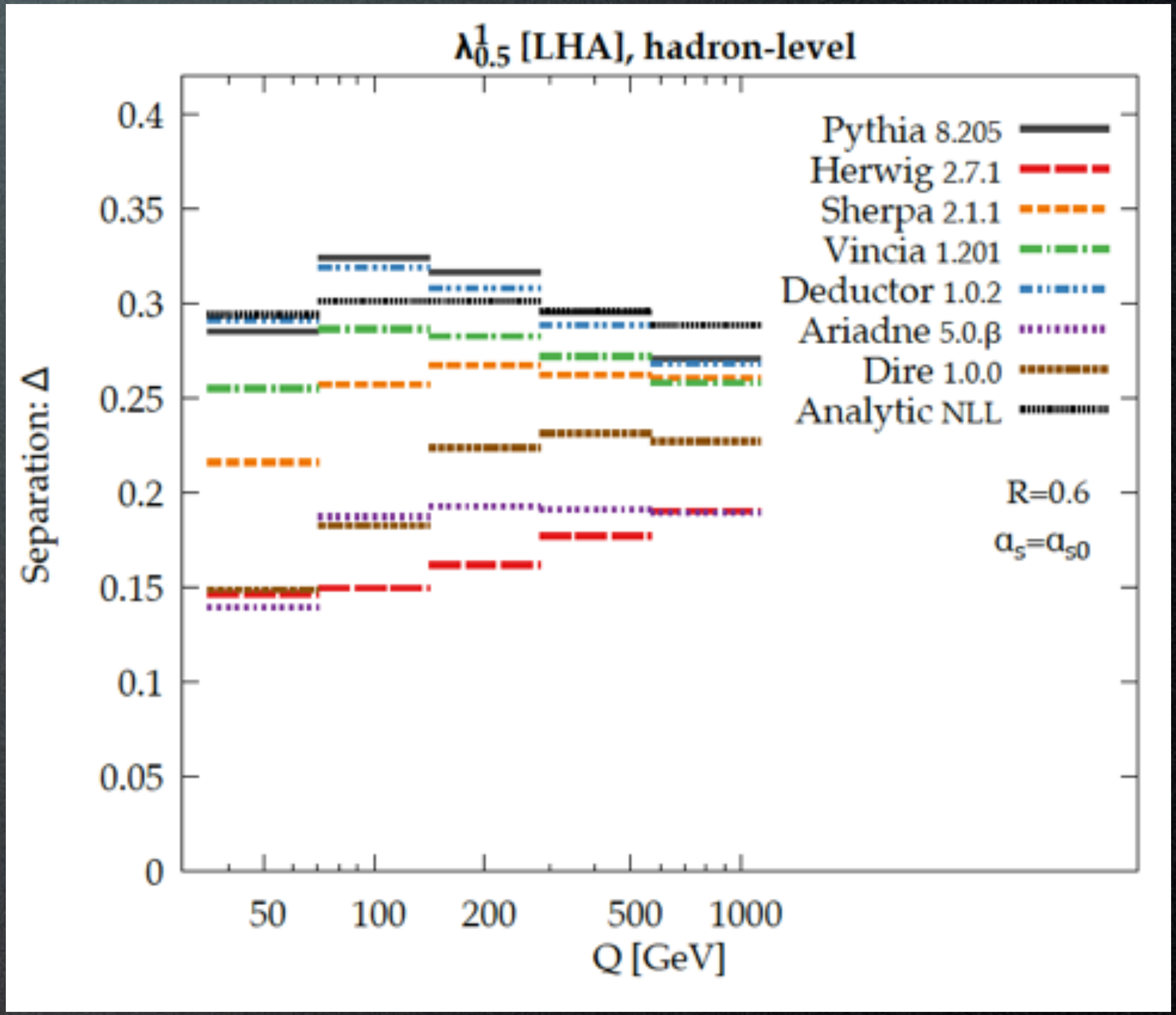




Separation increases with R (more phase space?)

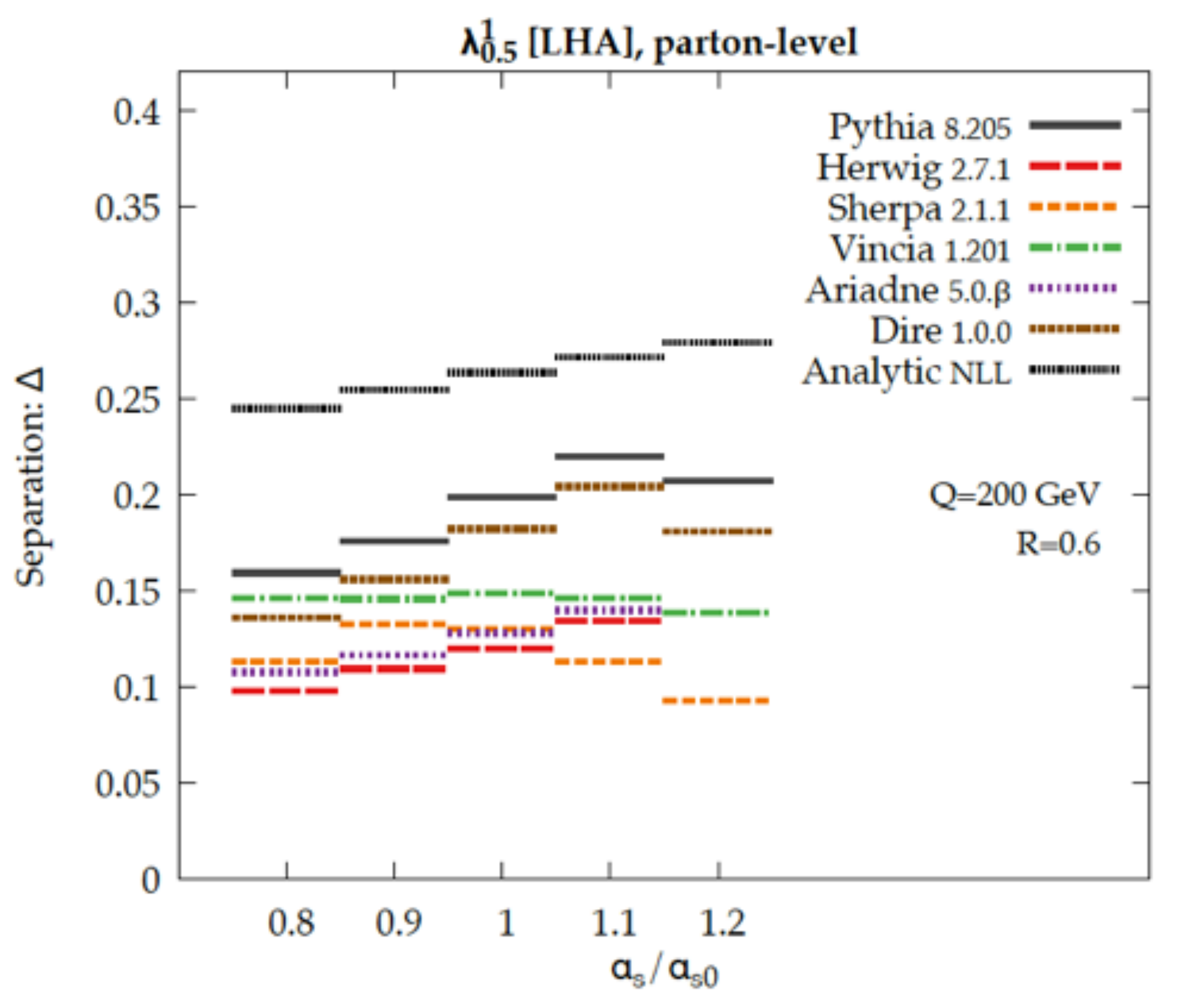
# Dependance on Q

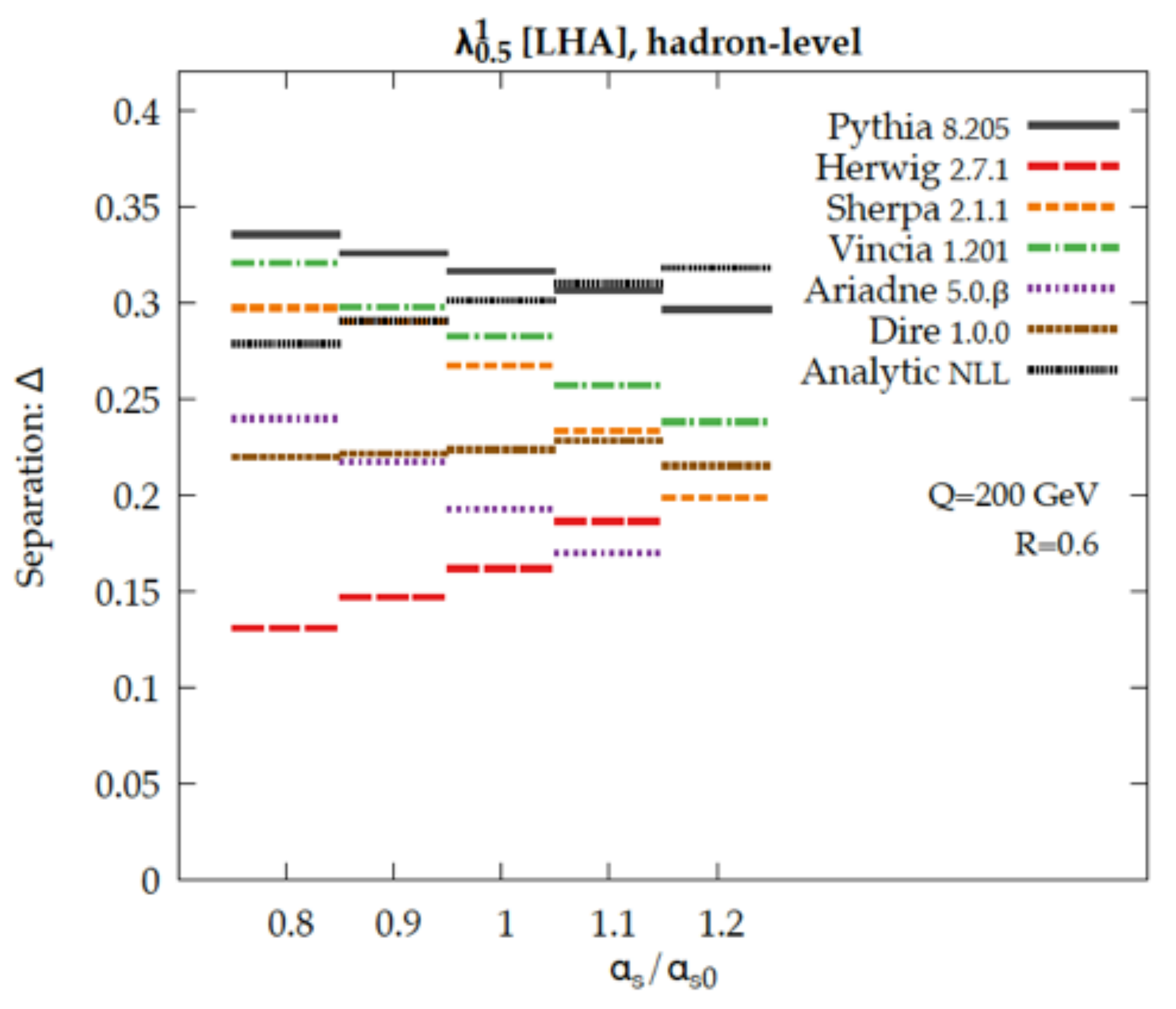




Separation increases with Q at parton level
(more phase space?)

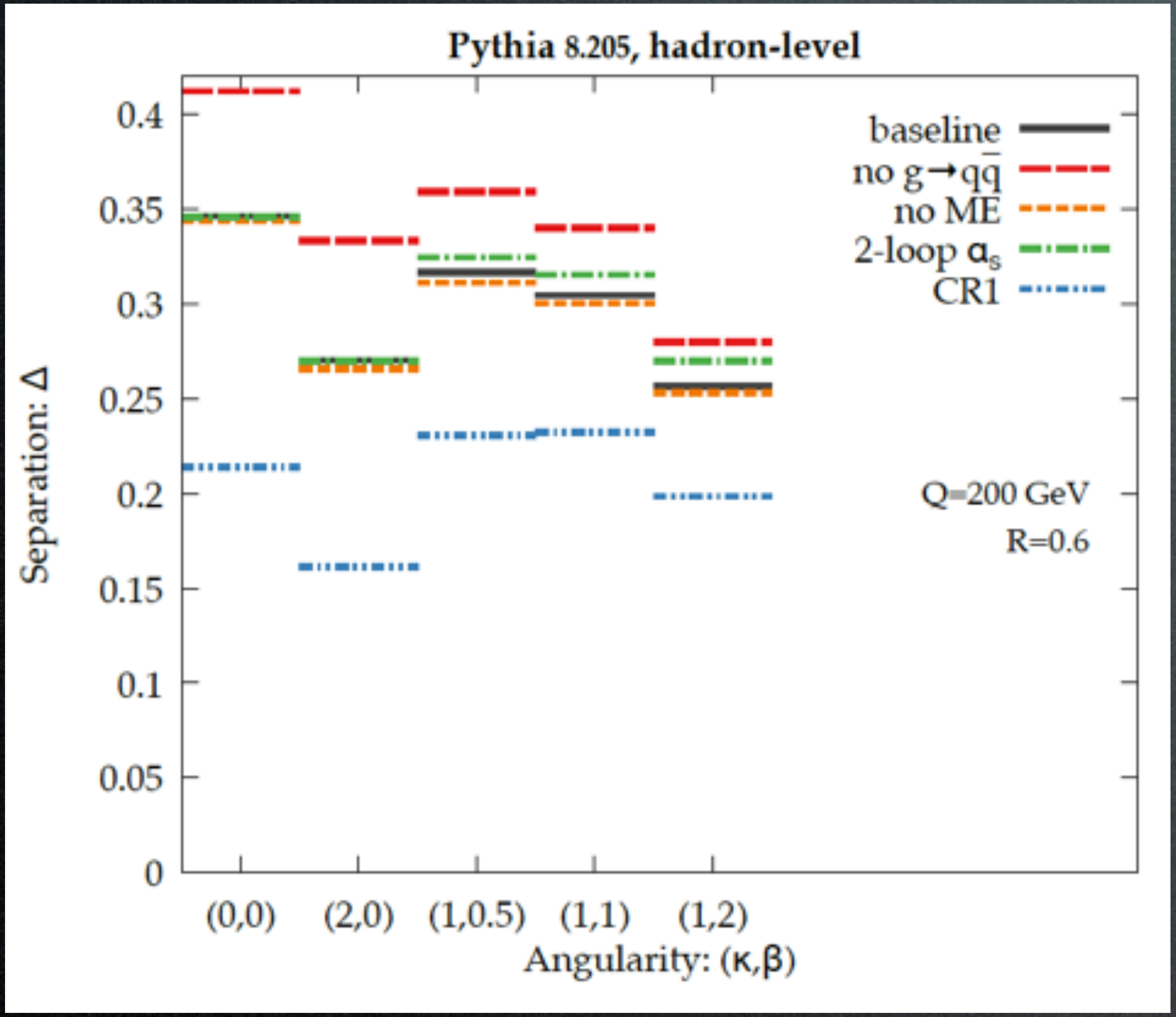
# Dependance on $\alpha_S$

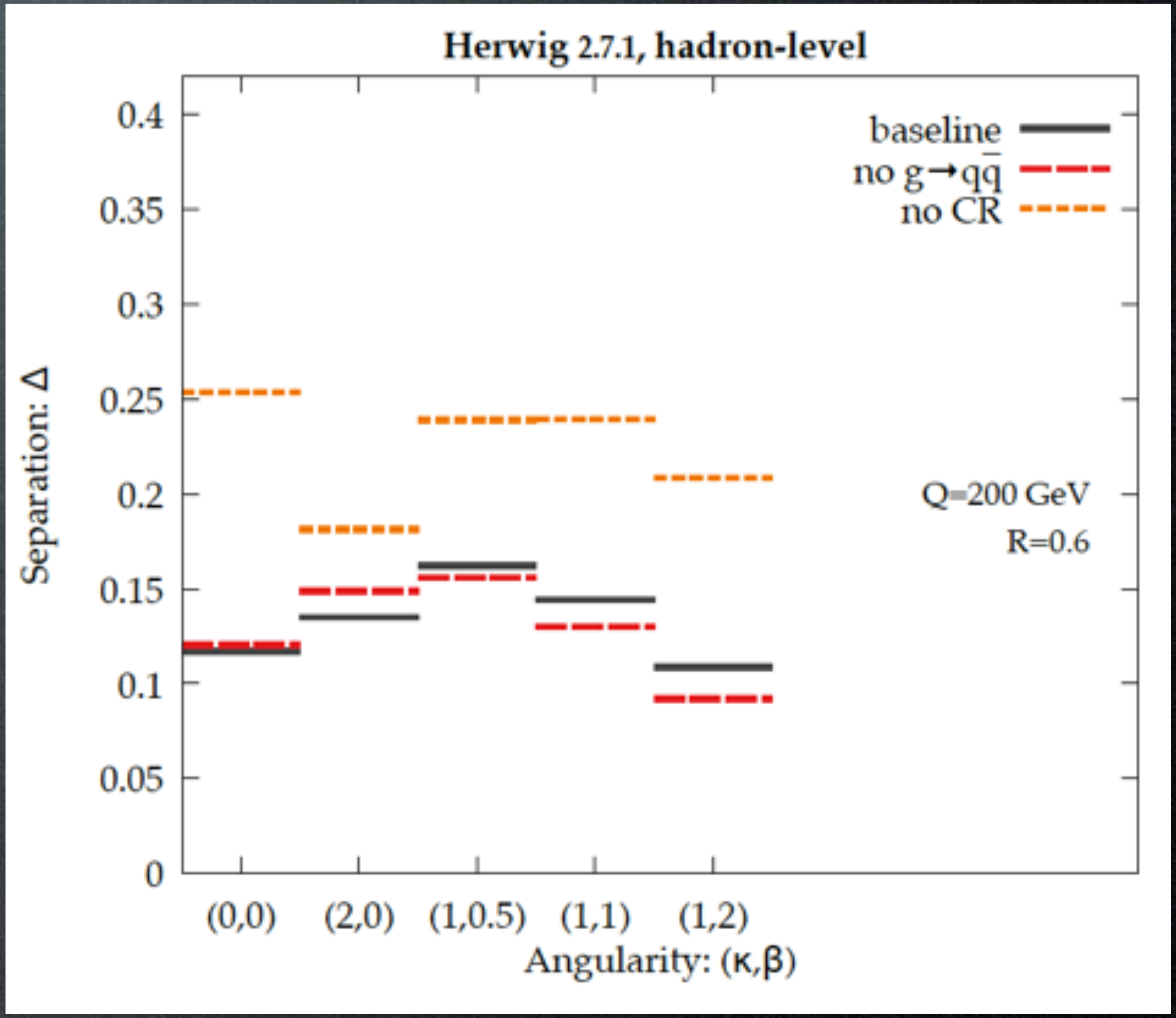




No clear trend at parton level, except Herwig++,
rest decreases at hadron level

# Generator Setting





Indication of what drives the separation

# Proton-proton Rates