BOOST 2017 - Theory Summary

Gregory Soyez

July 21 2017

Deep learning & deep thinking

Shows wonderful performance (and likely more to come)

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"We're not concerned by IRC safety (in ATLAS)"

(undisclosed source)

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"It's time to organize and move forward. It's time for deep thinking, reformation of the Democratic Party"

(K. Vanden Heuvel)

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"More is different: Just because you know the QCD Lagrangian doesn't mean you know all of its physics"

(Andrew's intro on Monday)

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(K. Vanden Heuvel)

"More is different: Just because you know the QCD Lagrangian doesn't mean you know all of its physics"

(Andrew's intro on Monday)

More than "Deep learning v. Deep thinking",
what about "Deep Understanding"?

there would be no BOOST without...

there would be no BOOST without...

- **New Substructure Tools**
  still new ideas after all those years
- **New calculations**
  now mainstream!
- **Progress with pileup mitigation**
  why shouldn't we use $R = 1$ after all?

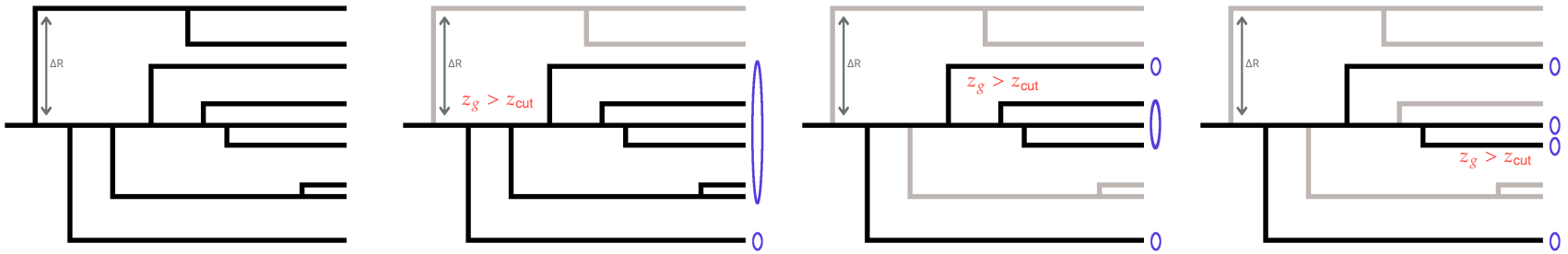
there would be no BOOST without...

new tools

Recursive SoftDrop [Frederic's talk]

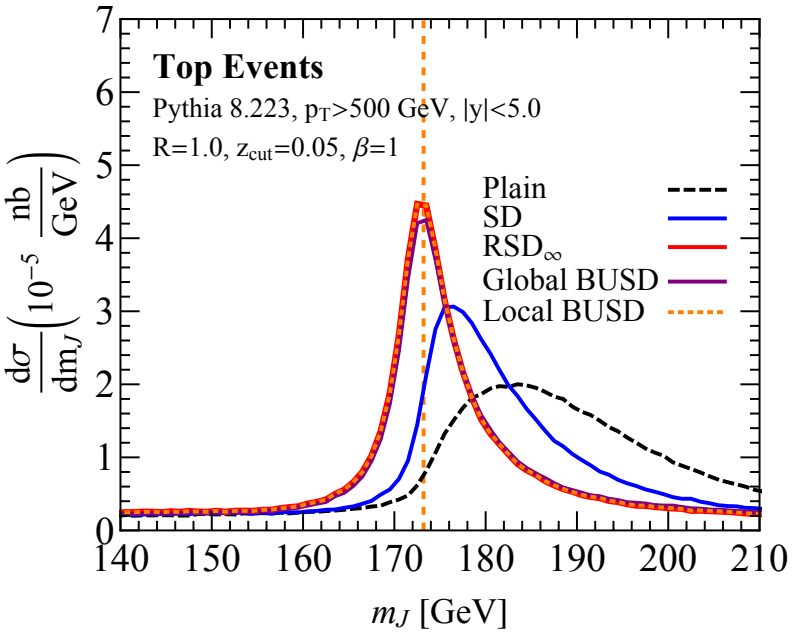
Apply SoftDrop recursively (top-down or bottom-up):

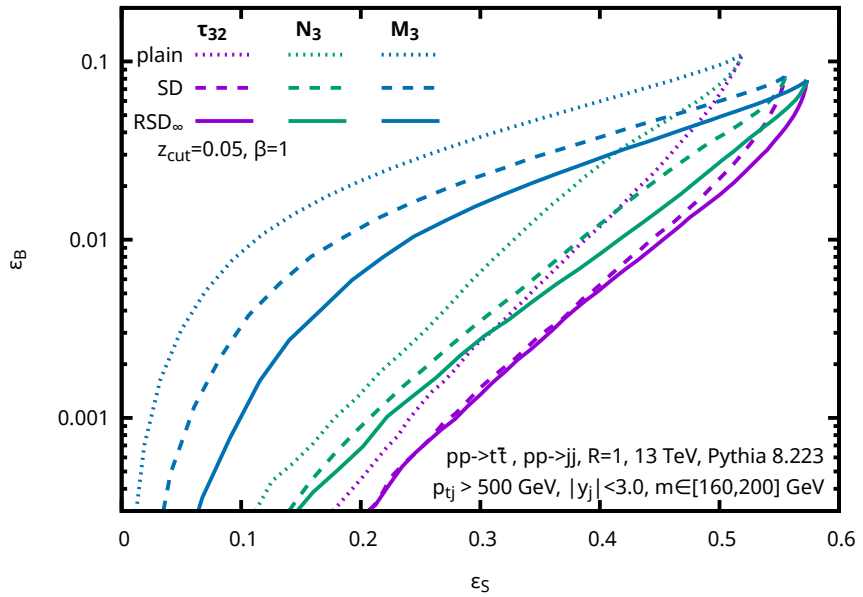
$N = 0 \quad \rightarrow \quad N = 1 \quad \rightarrow \quad N = 2 \quad \rightarrow \quad N \geq 3$



No Boost without... Great New Tools

Recursive SoftDrop [Frederic's talk]

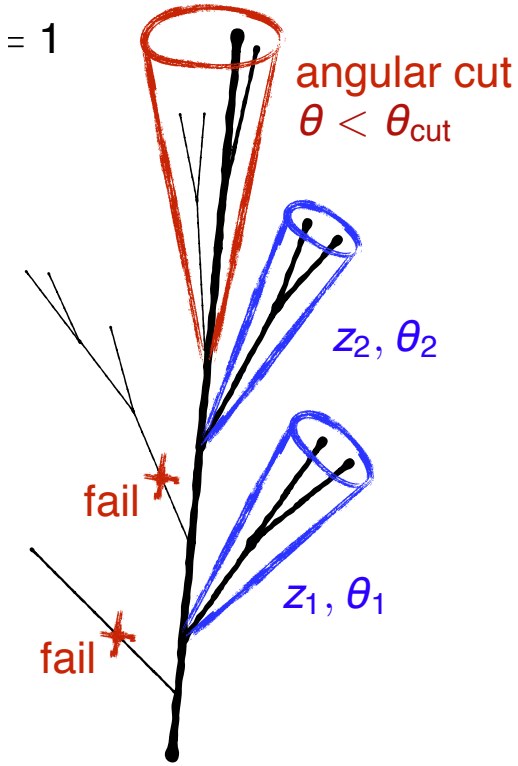




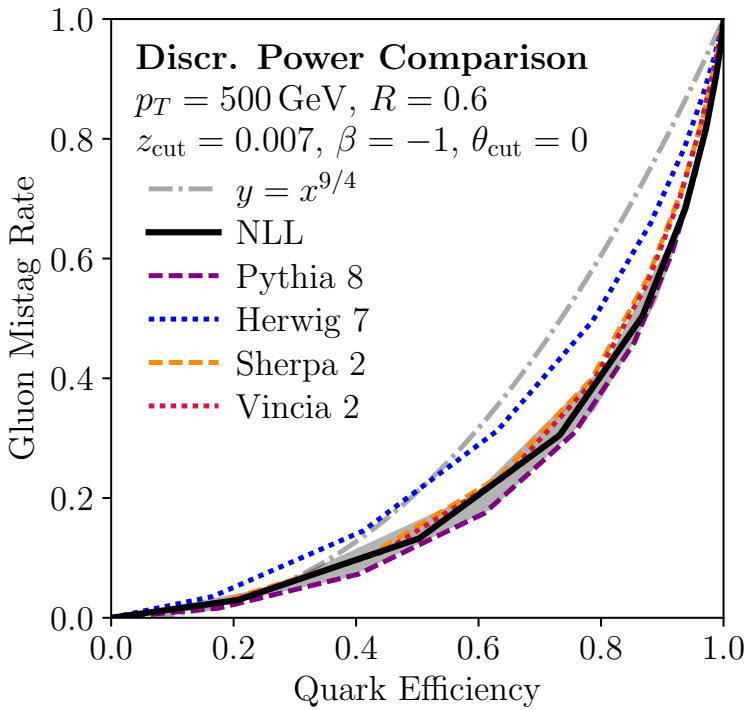
Good resolution for almost any observable (including pileup)

Improved analytic properties

No Boost without... Great New Tools



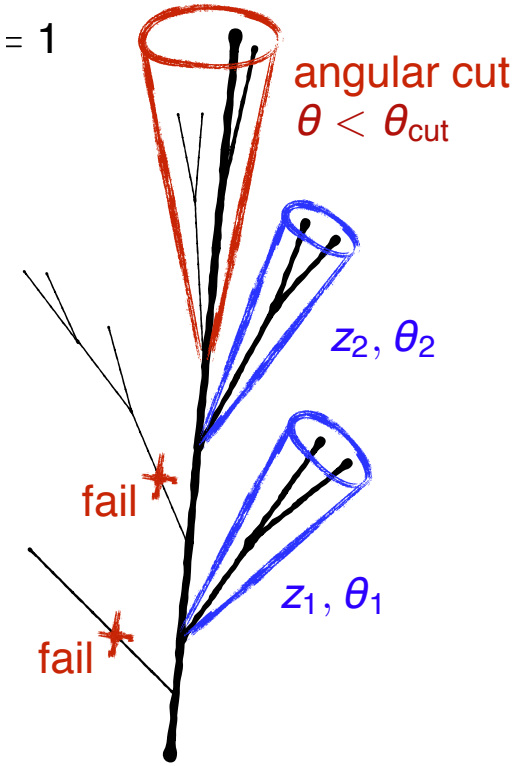
Iterative SoftDrop [Christopher's talk]



- Great performance
- Calculability
- Still large Pythia/Herwig differences

  (Herwig 7.1 to come)

No Boost without... Great New Tools



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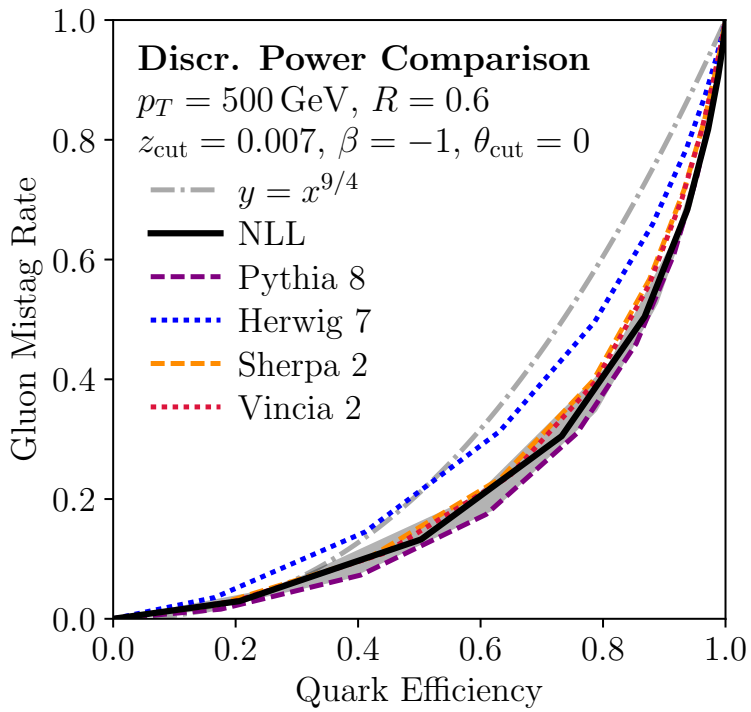

- Great performance
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  (Herwig 7.1 to come)

Starting to explore multiple emissions deep in the jet

"Deep Deep Thinking"

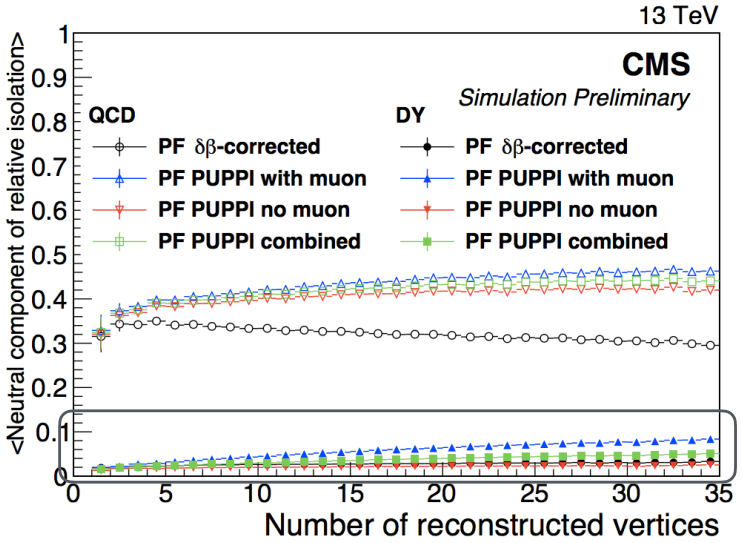
there would be no BOOST without...

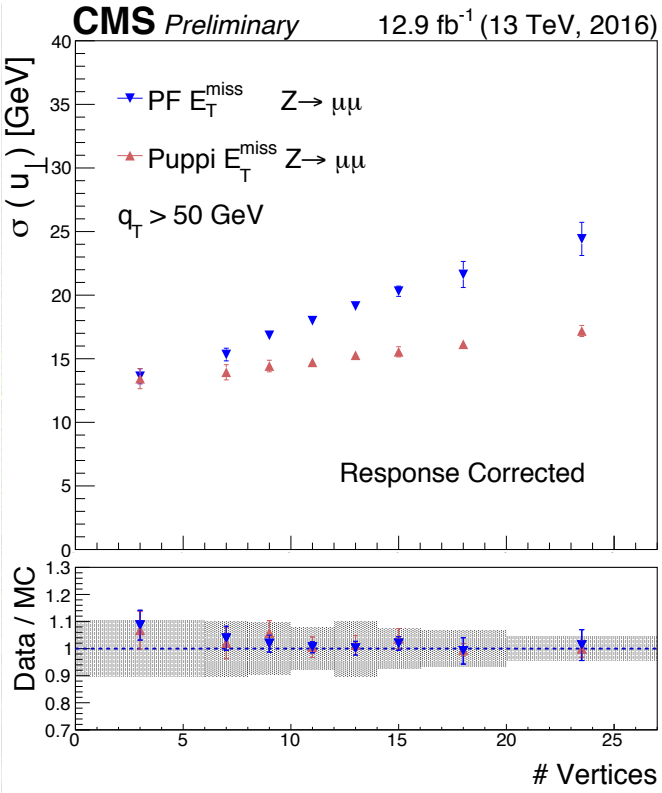
pileup mitigation

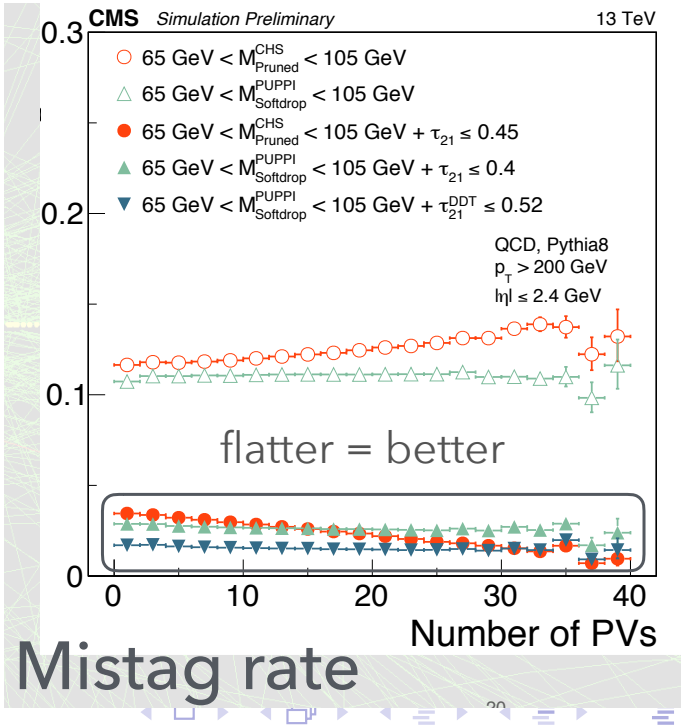
No Boost without... pileup mitigation

Update on PUPPI [Leonora's talk]

- Works great for muon isolation
- Works great for MET
- Works great for substructure
- Does marvel at HL-LHC [Julie's talk]





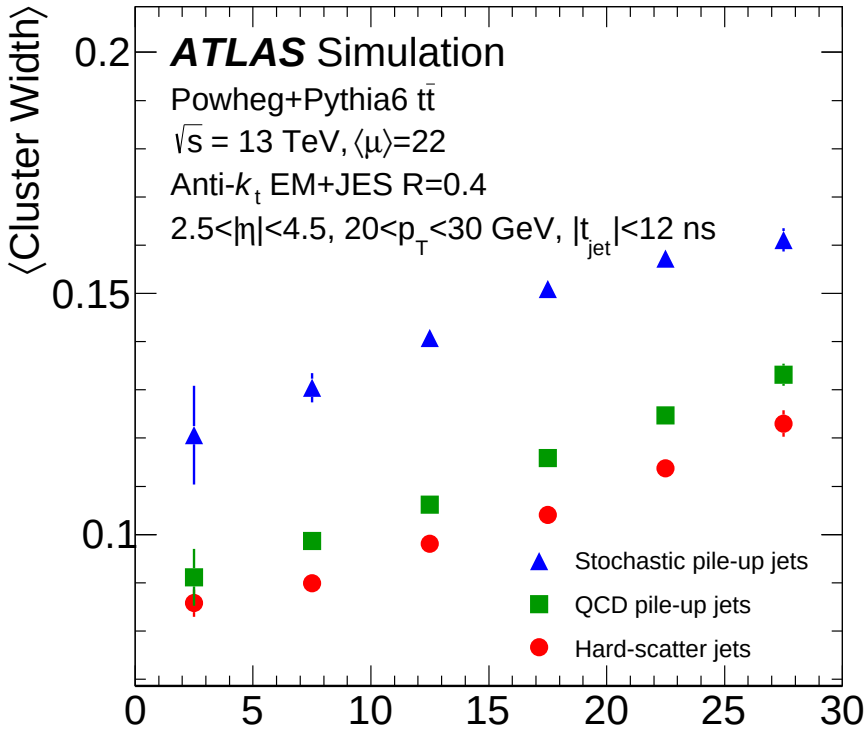


Mistag rate

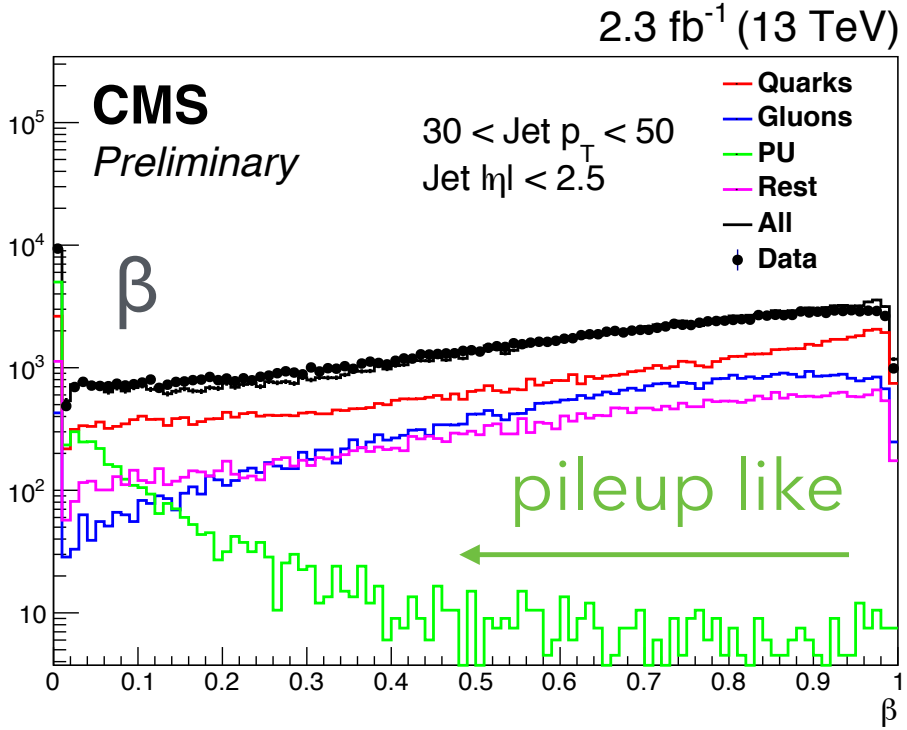
No Boost without... pileup mitigation

PU jet Id

[Leonora's and Jennifer(II)'s talk]



wider time
larger width

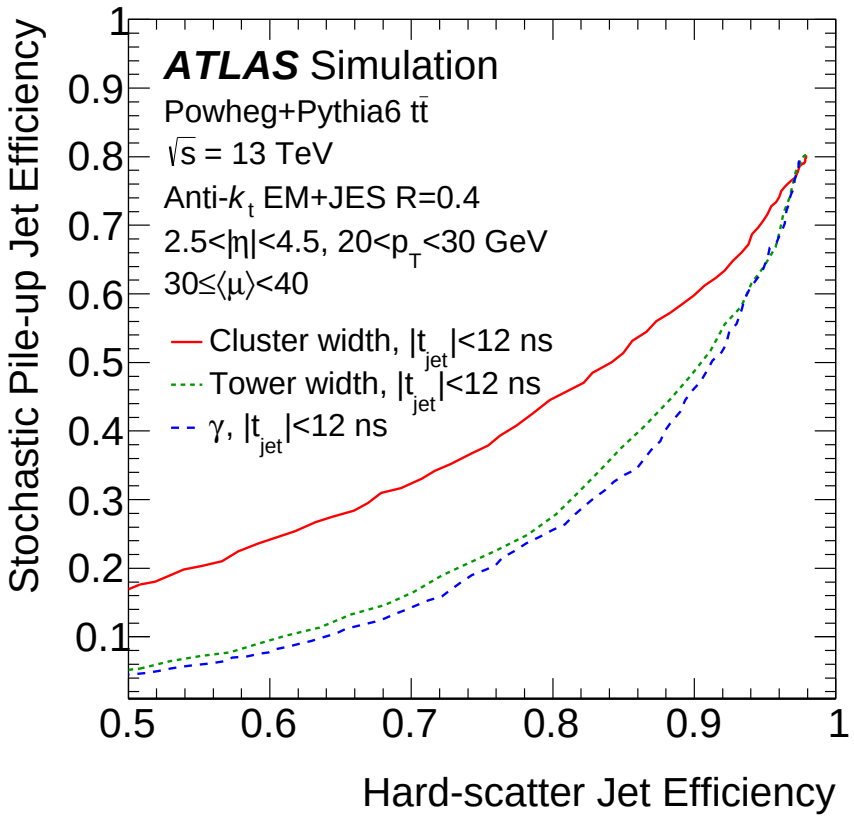


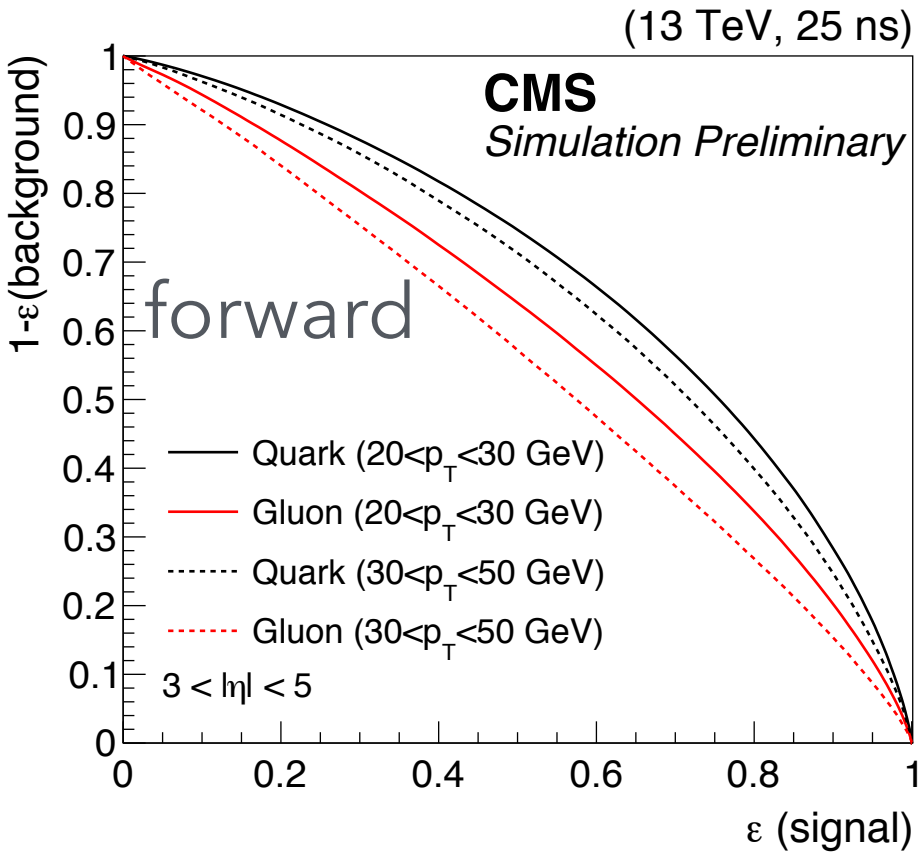
8 jet shapes
+4 track-based

No Boost without... pileup mitigation

PU jet Id

[Leonora's and Jennifer(II)'s talk]

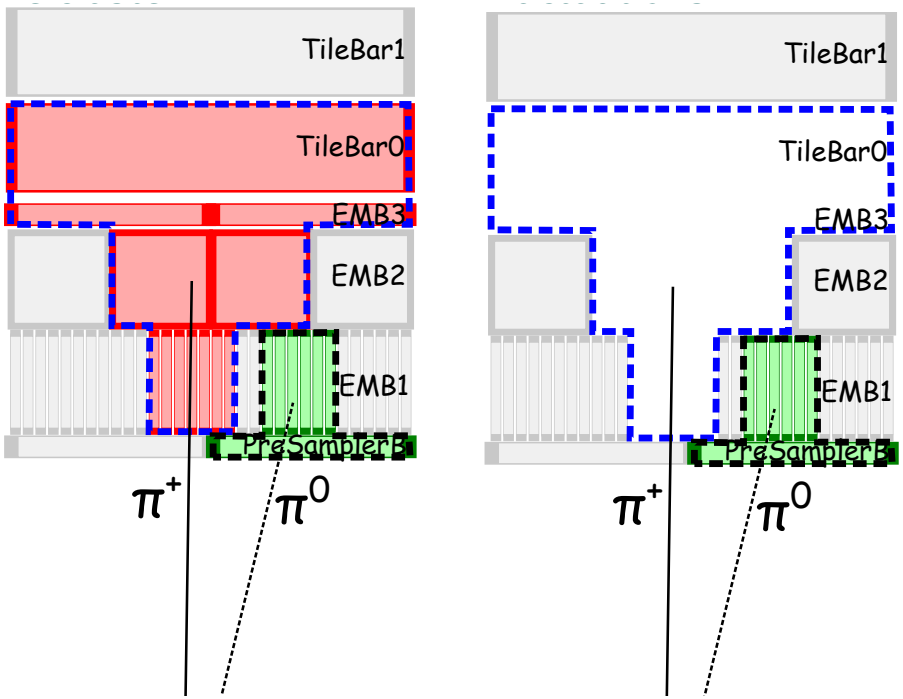


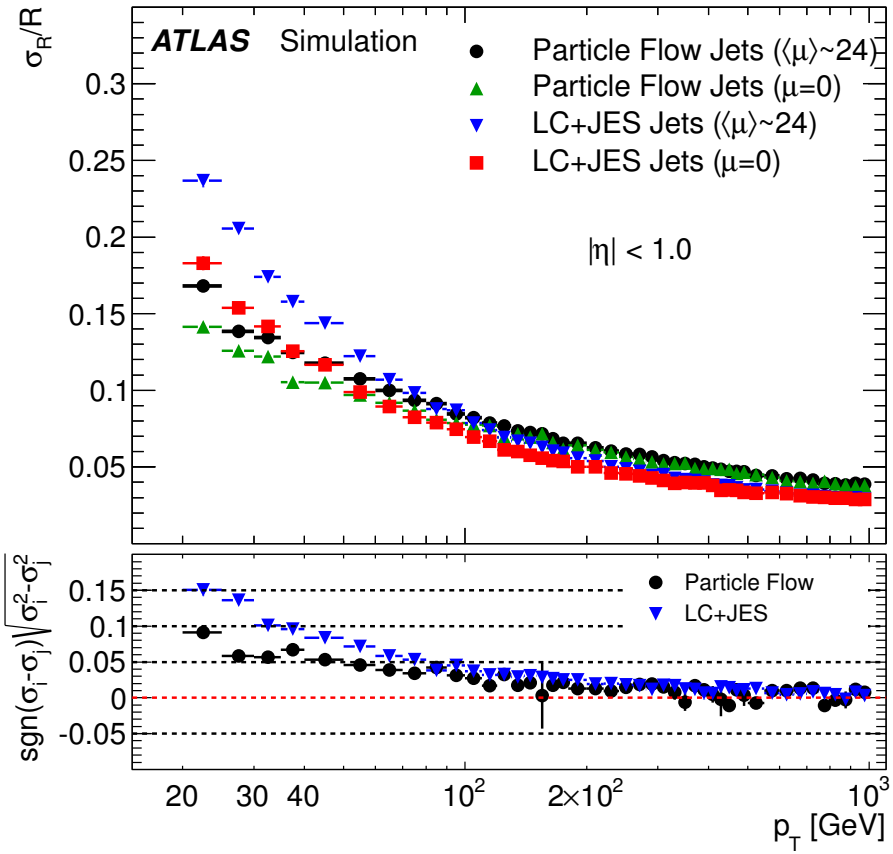


No Boost without... pileup mitigation

ATLAS and particle-flow! [Jennifer(II)'s talk]

- reduces fluctuations in jet resolution
- reduces fake jets





No Boost without... pileup mitigation

[Jennifer(I)'s talk]

SoftKiller

overall p_t cut

Pro: simplicity

Con: too simplistic

PUPPI

1. local reweighting
2. complex cut

Pro: local info

Con: complexity

No Boost without... pileup mitigation

[Jennifer(I)'s talk]

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overall p_t cut

Pro: simplicity

Con: too simplistic

PUPPI

1. local reweighting
2. complex cut

Pro: local info

Con: complexity

married into:

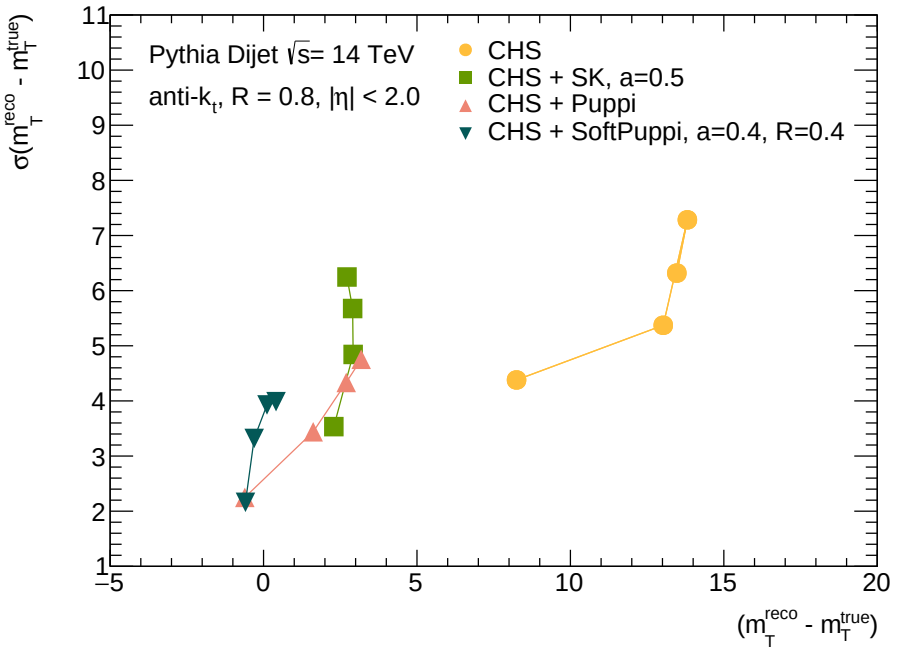
SoftPUPPI (NEW)

(local) PUPPI weights

(global) SoftKiller cut

efficient

& simple

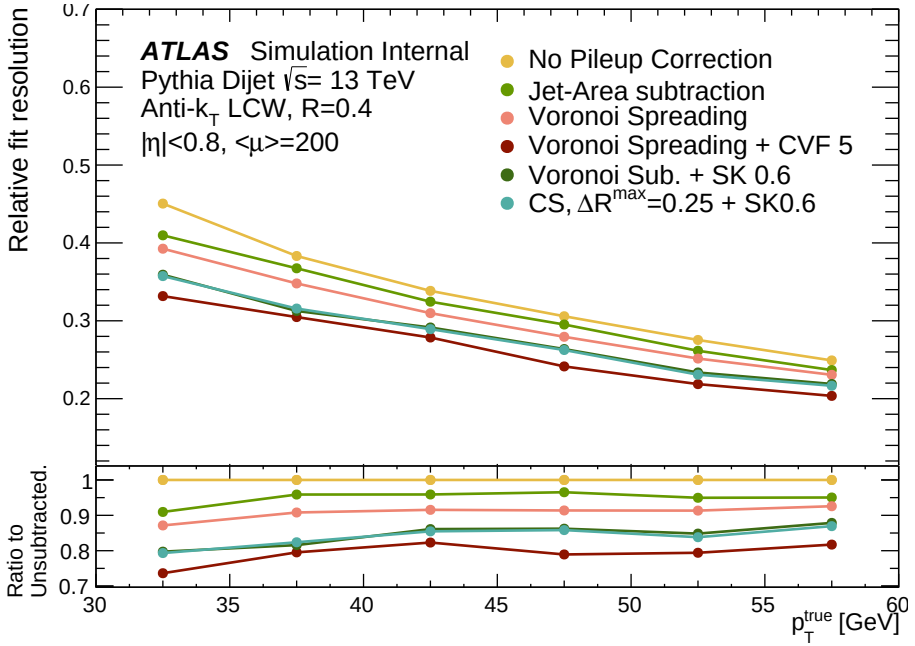


No Boost without... pileup mitigation

Several other ideas [Jennifer(II)'s talk and others]

Based on

- SoftKiller
- ConstituentSubtractor
- Voronoi subtraction
- Cluster Vertex Fraction
- Machine Learning [Eric's talk]



My personal comments:

- May not be optimal now but keep all these ideas in mind!
- local v. global: $\rho_{\text{area–median}}$ v. $\gamma_{\text{ntr/chg}}$
  Both helpful, (marginal) gain in combination

there would be no BOOST without...

calculations

No Boost without... Calculations

Update on top mass measurement w substructure [Aditya's talk]

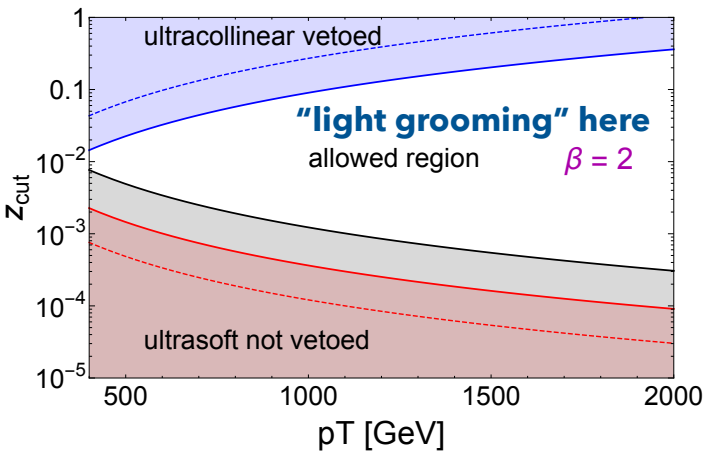
- scheme dependence included in EFT calculation
- Extract from Soft-Drop jets: sweet spot/region

Get Constraints on Soft Drop parameters:

$$\frac{\Gamma_t}{m}\left(\frac{Q}{2m}\right)^{\beta} \gg z_{\rm cut} \gg \frac{2m\Gamma_t}{Q^2}$$

Ensure soft drop does not touch mass

Ensure soft drop removes most contamination



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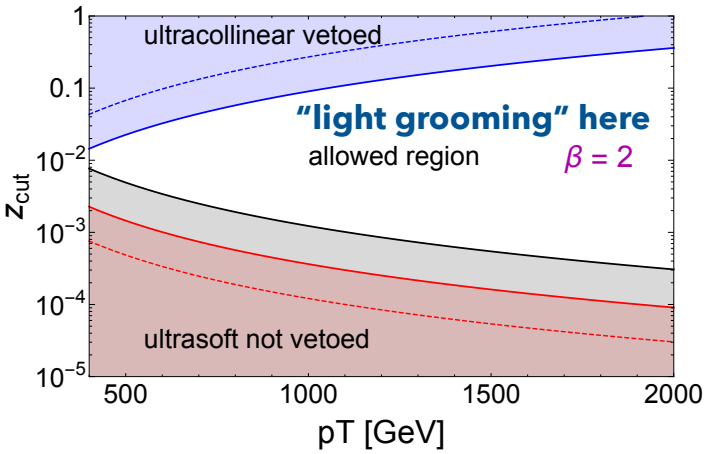
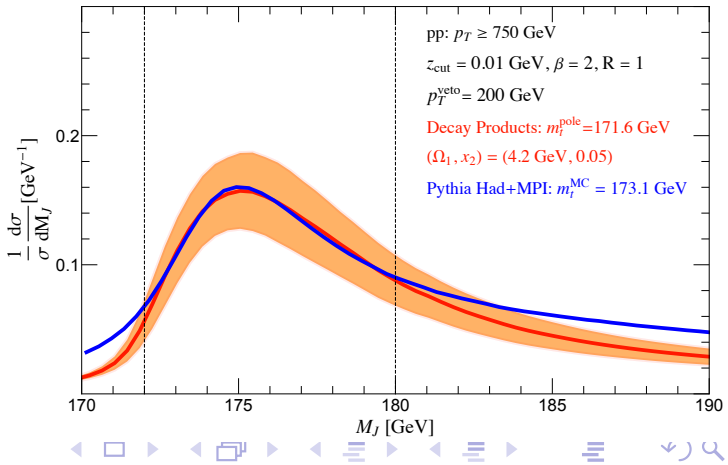


- Non-pert. effects from 1-parameter shape function fitted to Pythia



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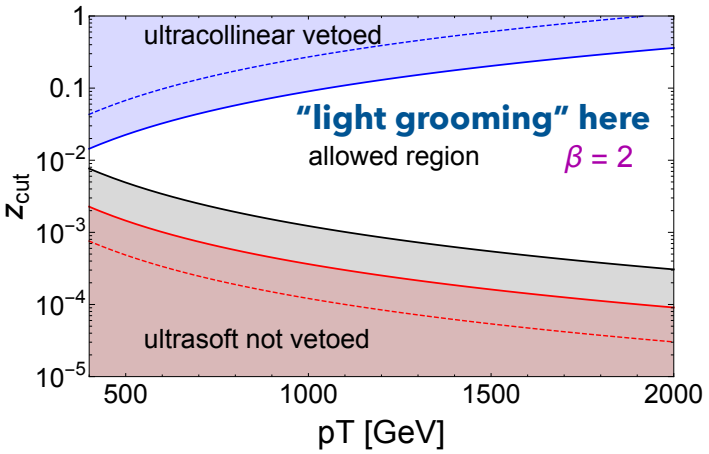

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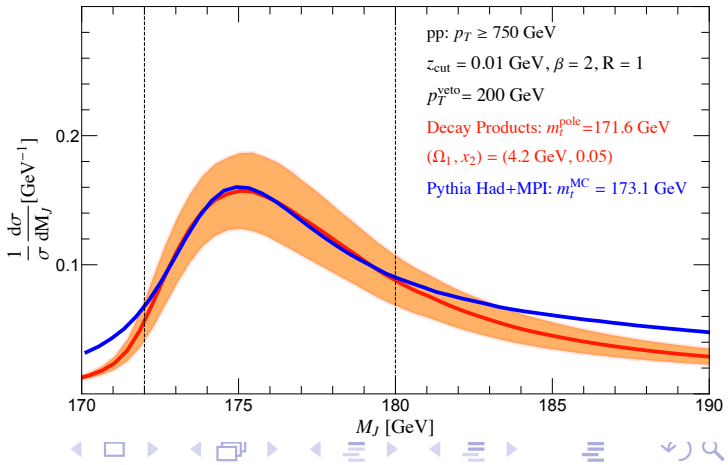


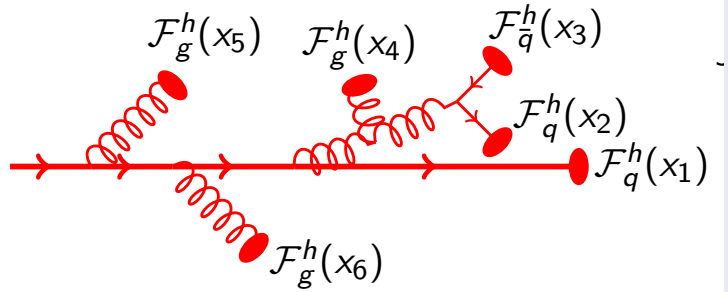
Looks promising so stay tuned

Question: what uncertainty?

Generalised Fragmentation functions

[Benjamin's talk]

Extended Framework for computing substructure observables:

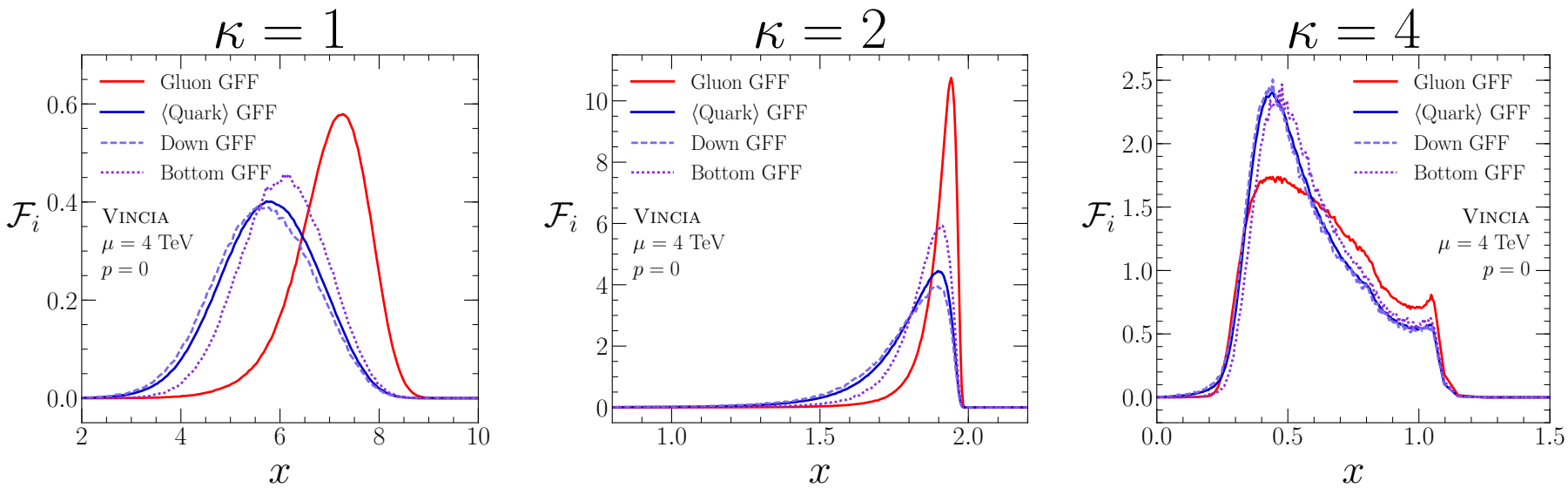


$$\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\mathcal{F}_i(x,\mu) = \frac{1}{2}\sum_{j,k}\int \mathrm{d}z\frac{\alpha_s(\mu)}{\pi}P_{i\to j,k}(z,\alpha_s)\int \mathrm{d}x_1\mathrm{d}x_2\,\mathcal{F}_j(x_1,\mu)\mathcal{F}_k(x_2,\mu)$$
$$\times\,\delta(x-\hat{x}(z,x_1,x_2))$$

No Boost without... Calculations

Generalised Fragmentation functions

[Benjamin's talk]



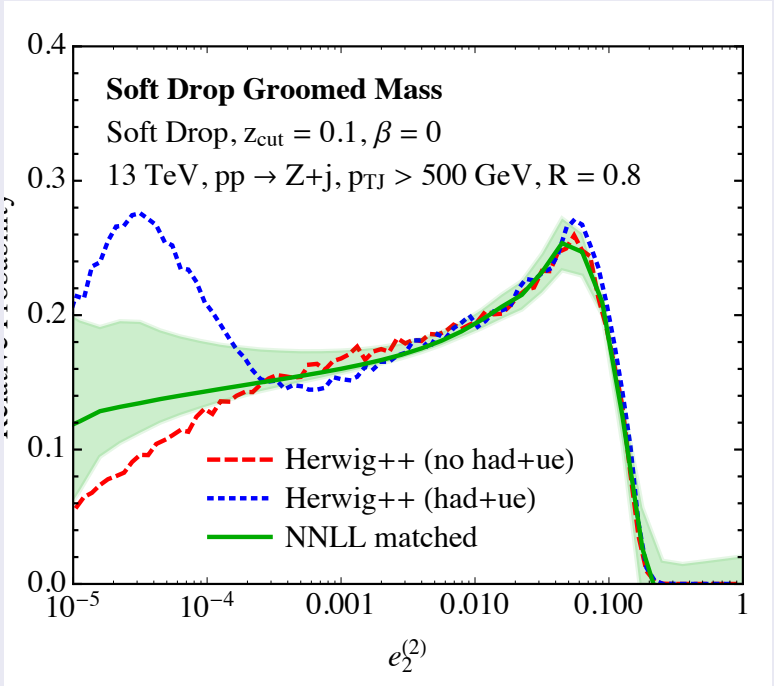
Reproduces collinear evolution for a wide variety of observables

e.g. jet charge, p_t^D, some iterative SD mult./ang., fractal observables,...

No Boost without Calculations

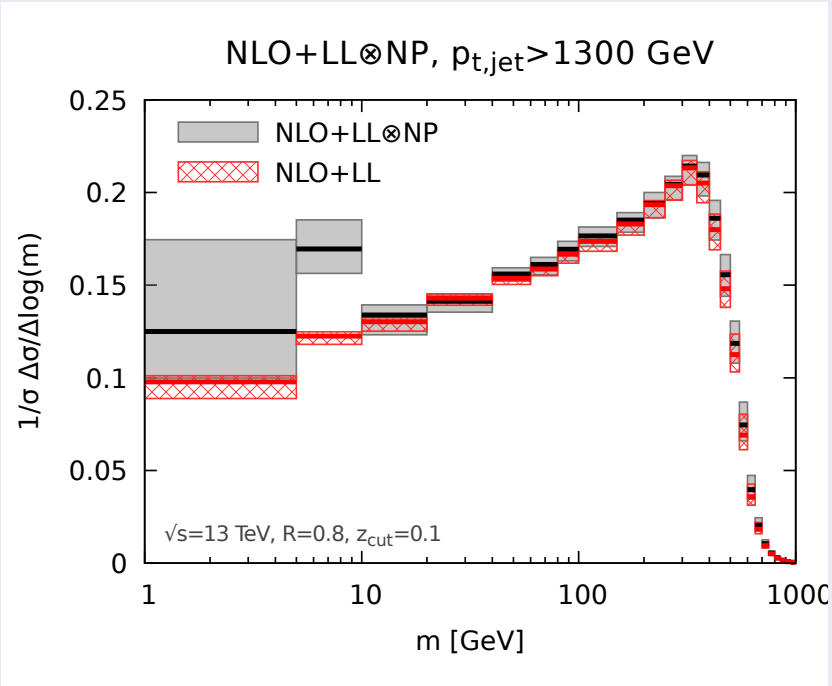
(N)LO+(N)NLL in SCET

[Andrew's talk in 2016]



NLO+(N)LL in "traditional" QCD

[Lais' talk]



Milestone for two reasons:

- we are entering into the precision-physics territory
- we start to address th uncertainties

Personal aside: Uncertainties

Question from BOOST 2014

"What is the uncertainty on the performance of our taggers?"

We start to be able to answer these questions

- Tools to make that possible: mMDT, SoftDrop, Recursive SoftDrop
- Existing calculations: groomed jet mass (NLO+(N)NLL)

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- Existing calculations: groomed jet mass (NLO+(N)NLL)
- Possible calculations: Calculation and measurement is target for 2018
  - Groomed angularities, ...
  - Shapes: τ_{21}, D_2, possibly N_2 ((un)groomed or dichroic) should work at the LO+(N)LL accuracy. NLO probably possible

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  - Shapes: τ_{21}, D_2, possibly N_2 ((un)groomed or dichroic) should work at the LO+(N)LL accuracy. NLO probably possible
- Progress on uncertainties in Parton-Shower as well

We should be able to put a th uncertainty on ROC curves for tagger!

there would be no BOOST without...

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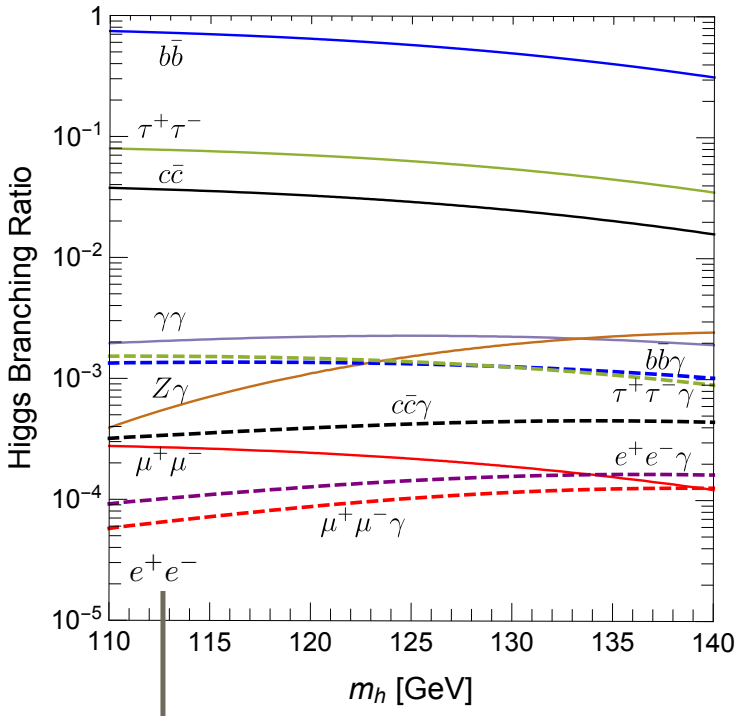
applications of the tools to physics

No Boost without... applications

Many experimental measurements... but SM th are alive as well!

Measure new Higgs decays to light leptons [Xing's talk]



Large due to EW loops

- Measurable at HL-LHC
- $h \to cc\gamma \;>\; h \to J/\Psi\,\gamma$
- constraints on charm Yukawa

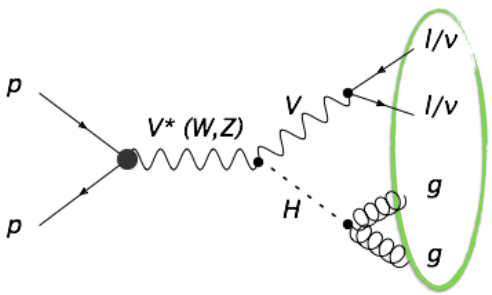
Method	κ_c upper limit projection at HL-LHC (3 ab^{-1})	
$h \to c\bar{c}\gamma$ (this work)	6.3	
$h \to c\bar{c}$+fit	2.5	
$h + c$ production	2.6	Perez et al.
Higgs kinematics	4.2	Brivio et al.
$h \to J/\psi\gamma$	50	Bishara et al
		Bodwin et a

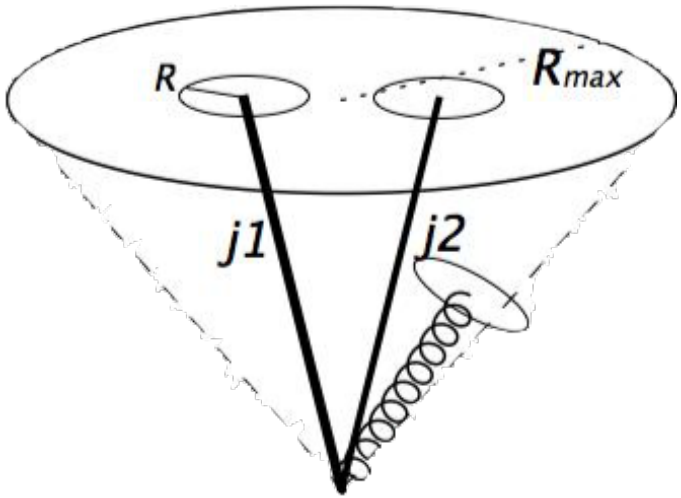
No Boost without... applications

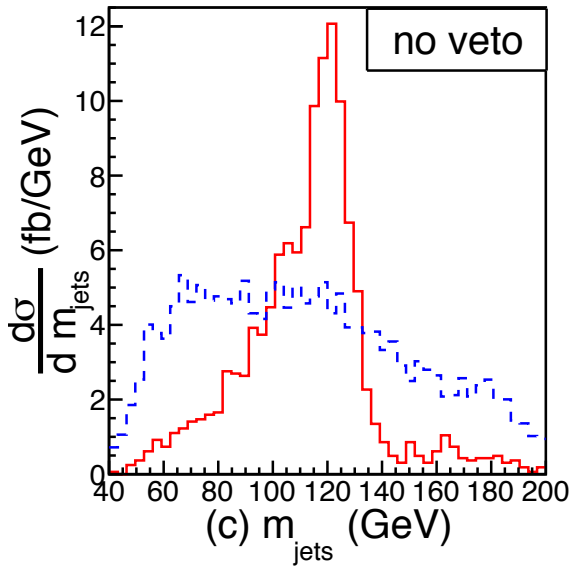
Many experimental measurements... but SM th are alive as well!

Measure new Higgs decay to jets (gg) [Zhuoni's talk]

Resolved$^+$: Two Leading jets & additional jets within R<1.4







In the end: $\frac{S}{\sqrt{B}} \approx 1.08$ at HL-LHC(3 ab^{-1}) after q/g tagging

Question: is there a gain from a shape-like cut?

No Boost without... applications

Many experimental searches... but BSM th are alive as well!

BSM with boosted objects [Bogdan's talk]

- "many possible BSM scenarios, many constraints already"
- many requires a dedicated search
- many boosted topologies: boosted W and boosted t all over the place
  e.g. vector-like quarks: $t' \to t\tau^+\tau^-$ with boosted t

No Boost without... applications

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- More fancy situations:
  - "anomalon" $\to WZ$ or $\to WH$ (4 prongs)
  - $H^+ \to Wb\bar{b}$ or $H^+ \to t\bar{b}$ (4 prongs)
  - $H^0 \to t\bar{t}$ (6 prongs)
  - $W' \to H^+H^0 \to 3$ boosted t
  - $G' \to (b\bar{b})_{\text{jet}} + (t\bar{t})_{\text{jet}}$ or $G' \to (b\bar{b})_{\text{jet}} + (b\bar{b}jj)_{\text{jet}}$

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Very exciting!

Are we ready for this?

there would be no BOOST without...

there would be no BOOST without...

an update on FastJet

Date: Sun, 16 July 2017

Hi Gregory,

I am sorry to bother you with that, but students - at least undergrads in X - seem to prefer python over c++. I was wondering if there is a pthon wrapper for fastjet, or if there is another way of running fj with python?

Cheers,

***

FastJet 3.3.0

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***

Date: Wed, 12 July 2017

Release of FastJet 3.3.0

This is a main release which adds a first version of **a Python interface** to FastJet.

this year's edition of BOOST was special

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the Boost Universe is Expanding

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the Boost Universe is Expanding

- towards the Monte-Carlo community
- towards the Heavy-Ion community
- towards the Les-Houches community

BOOST expands towards...

the Monte-Carlo community

huge progress in fixed-order Monte-Carlo recently

- Reaching NNLO accuracy [John's talk]
  - Available for a series of $2 \to 1$ and $2 \to 2$ processes
    Recently, dijets at NNLO
  - sometimes large NNLO corrections (e.g. $H \to b\bar{b}$ at NNLO in VH)
- Including electro-weak effects [Doreen's talk]
  - Relevant in several cases:
    - $(\alpha/\pi) \sim (\alpha_s/\pi)^2$: as important as NNLO
    - Soft/collinear photon: $\frac{\alpha}{\pi} \log(\frac{m_f^2}{Q^2})$
    - Soft/collinear W/Z: $\frac{\alpha}{\pi} \log(\frac{Q^2}{m_V^2})$
  - automated QCD+EW in fixed-order+parton shower (Recola/OpenLoops+Munich/GoSam)+Sherpa

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- Including electro-weak effects [Doreen's talk]
  - Relevant in several cases:
    - $(\alpha/\pi) \sim (\alpha_s/\pi)^2$: as important as NNLO
    - Soft/collinear photon: $\frac{\alpha}{\pi} \log(\frac{m_f^2}{Q^2})$
    - Soft/collinear W/Z: $\frac{\alpha}{\pi} \log(\frac{Q^2}{m_V^2})$
  - automated QCD+EW in fixed-order+parton shower (Recola/OpenLoops+Munich/GoSam)+Sherpa

all great but not really relevant (yet) for substructure

Personal aside: tentative NNLO timescale?

When will NNLO be relevant for substructure?

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When will NNLO be relevant for substructure?

- we want $2 \to 3$ e.g. W/Z+jet or dijets
  (so as to have at least 2 particles in the jet!)
- $2 \to 2$ is availale
- rule of thumb adding one loop or one leg takes $\mathcal{O}(10)$ years

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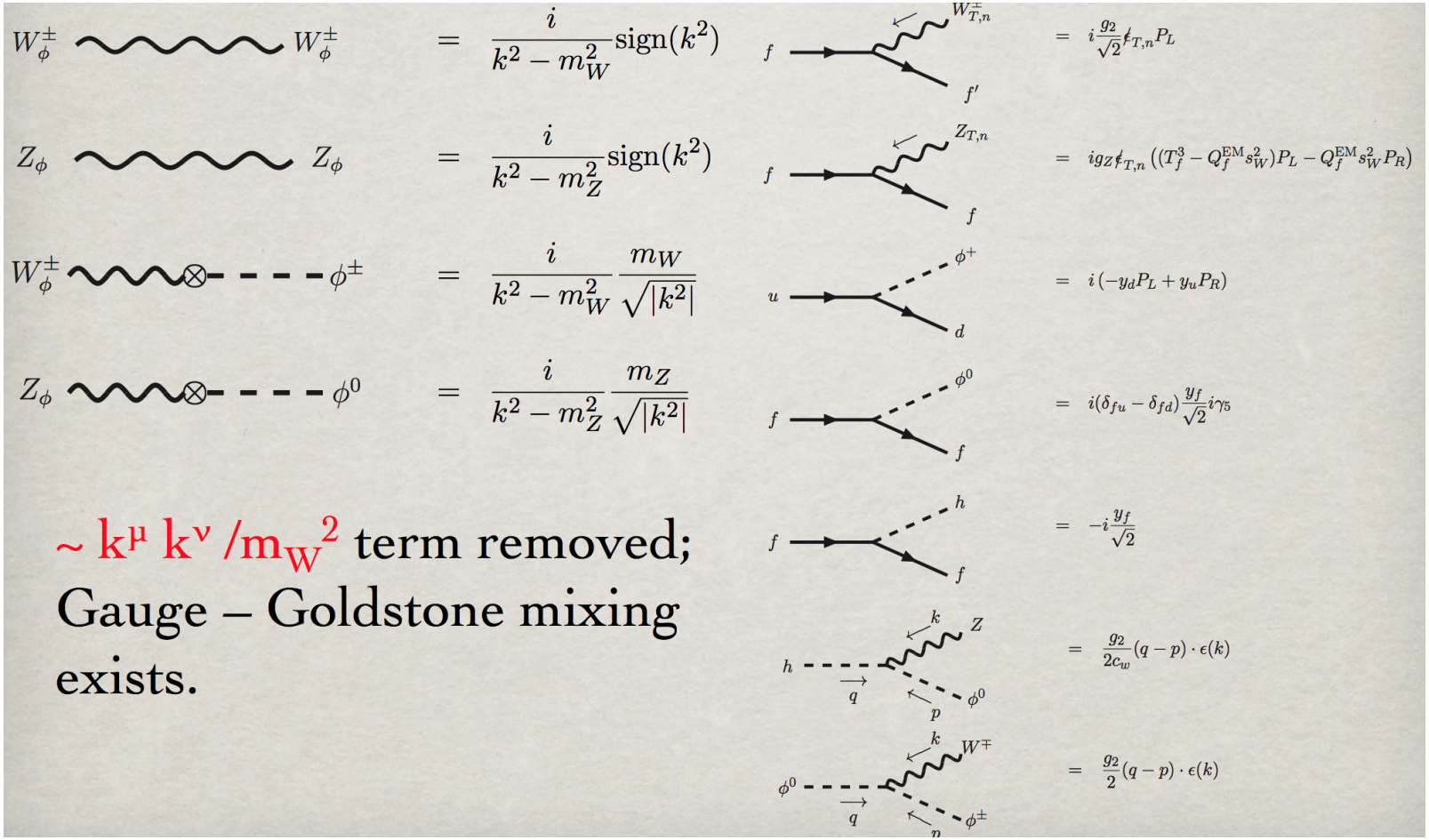
$\Rightarrow$ NNLO meets BOOST around 2025

- Note 1: large community effort so we may hope for better
- Note 2: Boost=small angles $\Rightarrow$ delicate corner of phase space

Expansion 1: Substructure and Monte-Carlo

EW showers [Junmou's talk]

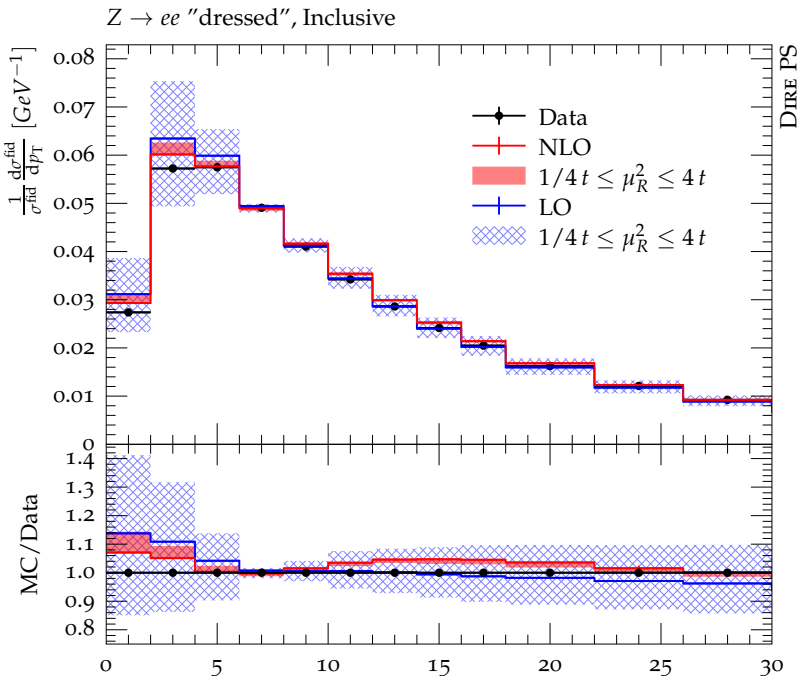


- Main target: 100 TeV collider
- Already relevant for substructure (W in (light) jet) today

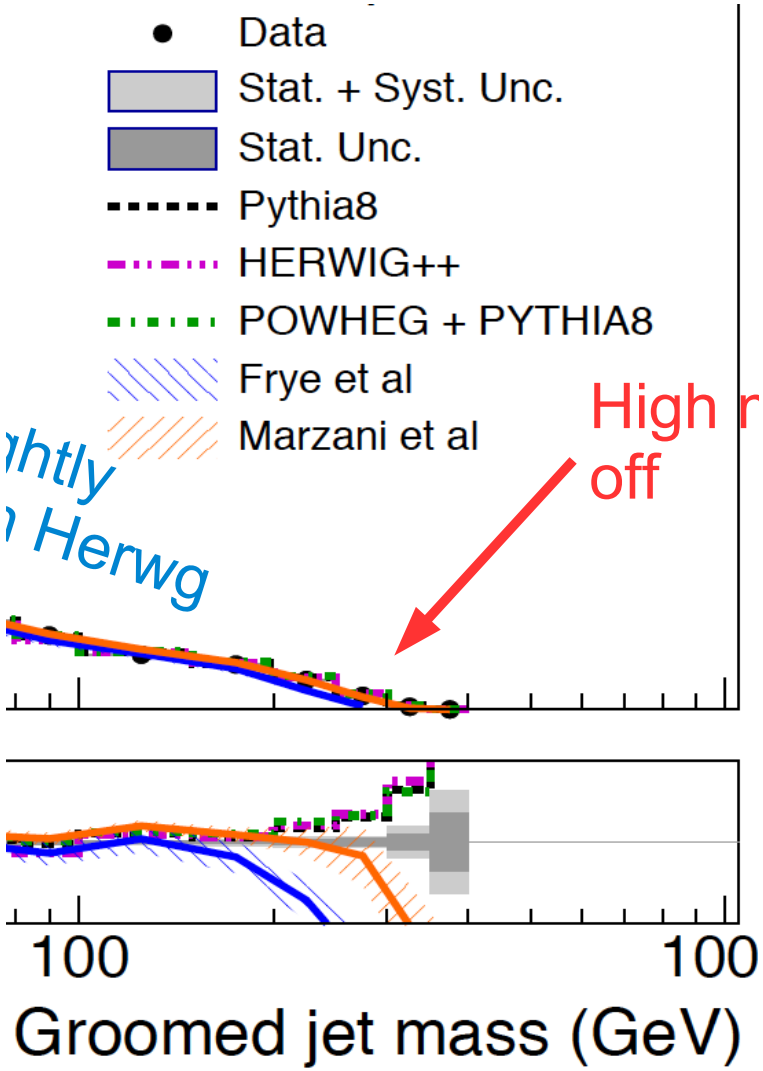
Expansion 1: Substructure and Monte-Carlo

But: NLO+PS and MEPS are available [Marek's talk]

- "NNLO for X in Boost often from NLO X+j"
- (approximate) EW corrections
- NLO DGLAP in DIRE ($1 \to 3$ splitting) **test with substructure??**
- No NLO shower yet (needed for many things)



Personal aside: PS v. ME+PS



[fig from Phil's talk]

Some things are a bit surprising:

- analytic resum:
  gain between LO and NLO
- Parton Shower:
  no difference between Pythia and Powheg+Pythia
- (would be easier to see on $m d\sigma/dm$)

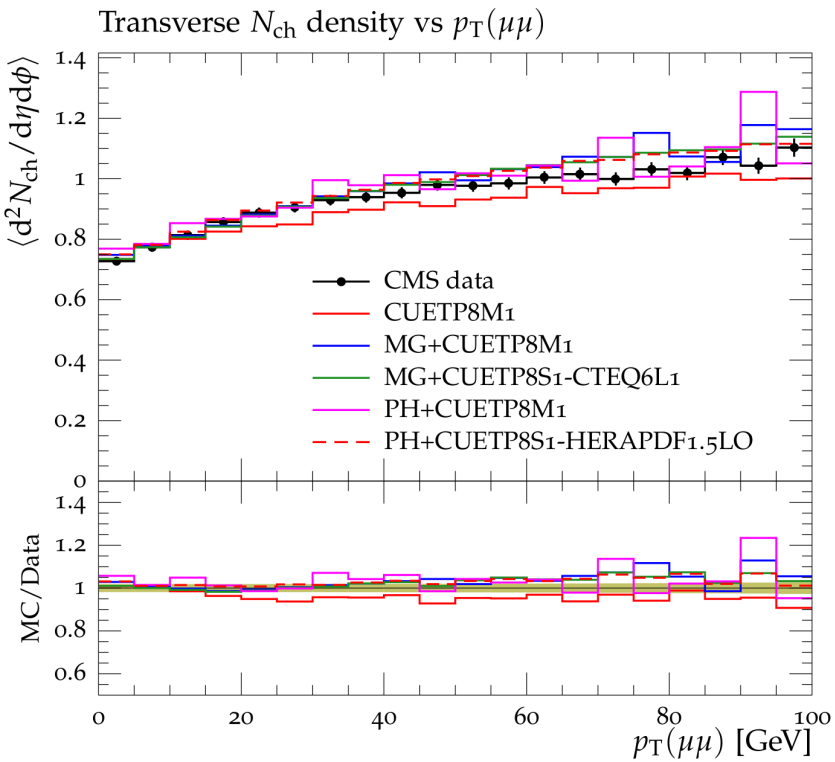
Why? Other observables?

Expansion 1: Substructure and Monte-Carlo

[Stefan's talk]

"Your garbage is my treasure"

Tuning: Adjust parameters to absorb *calculable but unknown* effects ("higher orders").



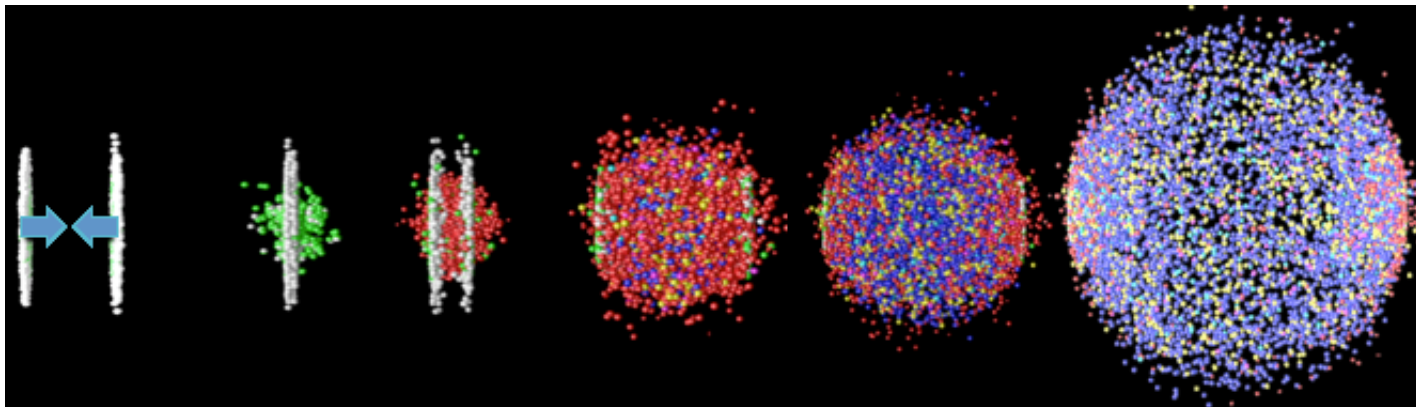
- Tune perturbative params
- Fit hadronisation and MPI
- Things are inter-connected
- Q (Stefan): Can we isolate a MPI region?
- A(?): can we exploit m/p_t dependence for different p_t?
  (similar to using different R for jets)

BOOST expands towards...

the Heavy-Ion community

Expansion 2: Substructure in Heavy-Ions

z_g measurement was (one of the) highlights of Boost 2016
Large interest of the heavy-ion community in jet substructure



What can we learn from the properties of the QGP?

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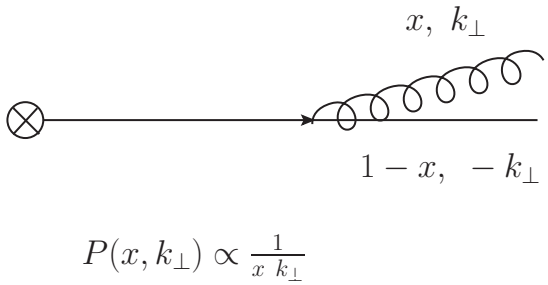
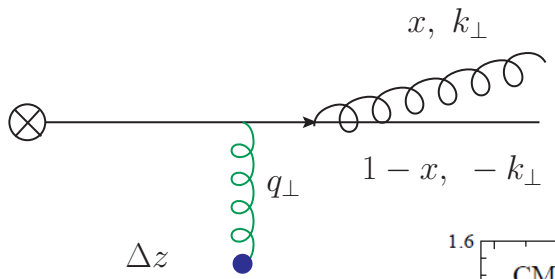
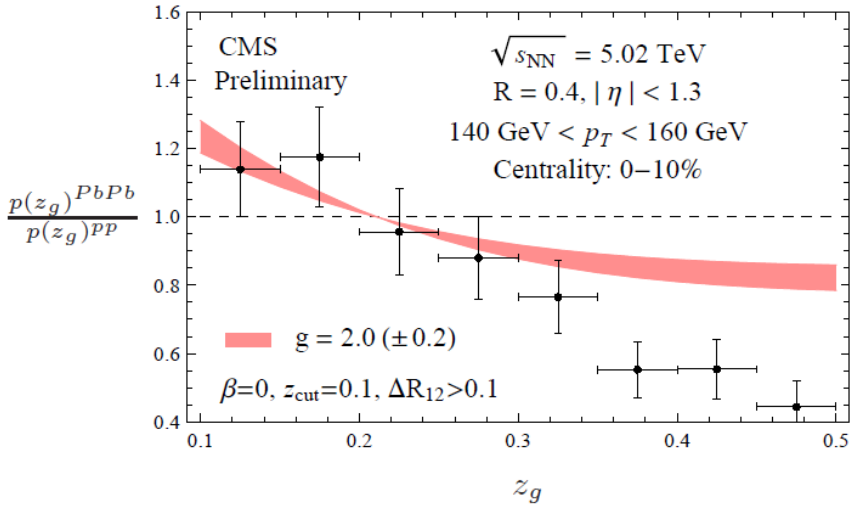




[Yang-Ting's talk]

- medium-induced corrections to split
- predicts the z_g distribution and get "g"
- work towards the jet mass



My concern: nice but just one (LO) splitting potentially over-simplified
qualitatively OK but is it quantitative?

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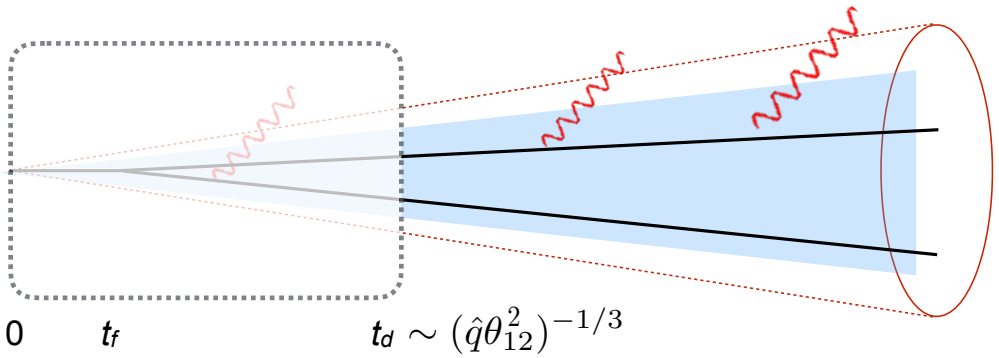
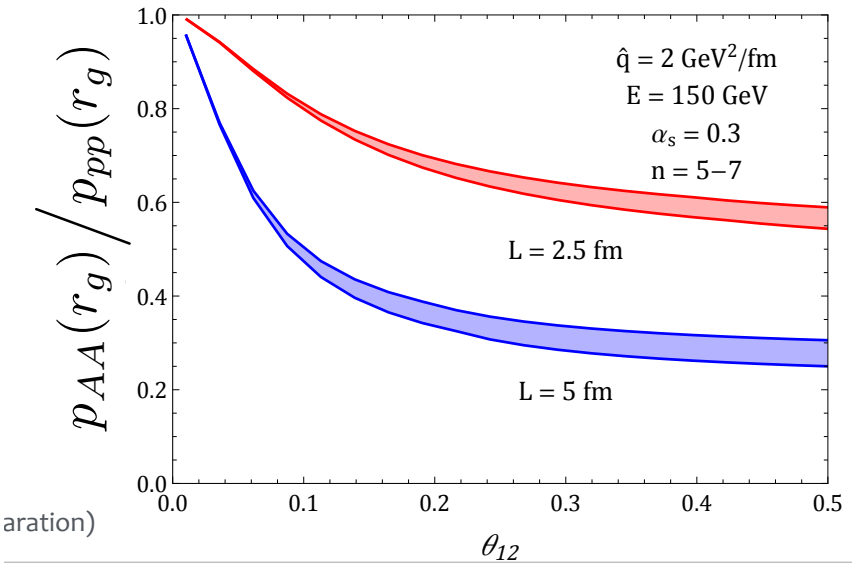


$$\theta_c \sim \sqrt{\frac{1}{\hat{q}L^3}}$$

$$t_{\rm d}(\theta_c) \sim L$$

[Konrad's talk]

a promising step



aration)

- DGLAP/Parton-Shower understood
- Pure medium-induced reasonably understood
- Question: Medium-induced after collinear splitting?
- several "times" in the problem

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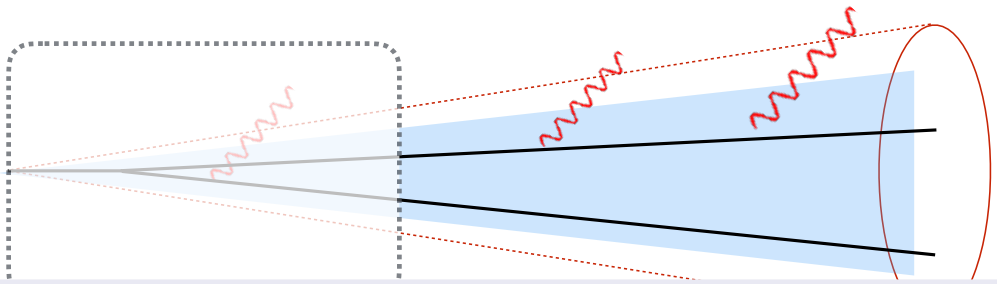

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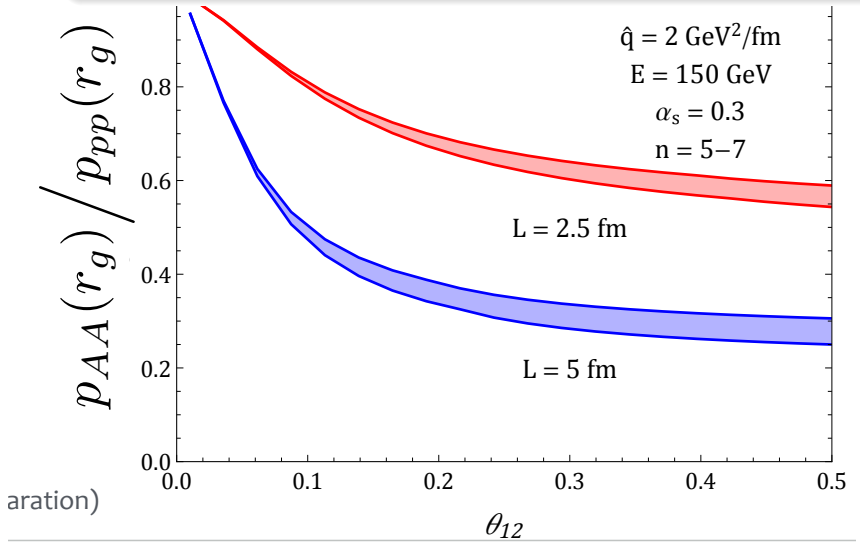
a promising

All this is evolving fast, so stay tuned!



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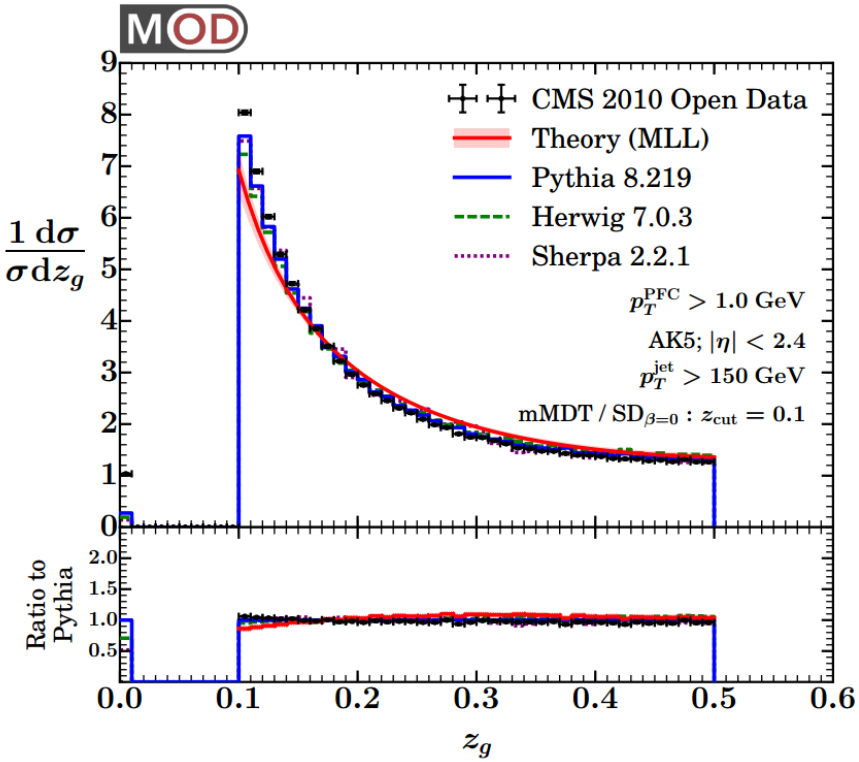
BOOST keeps an open mind

Open Data! or Open Data?

[Aashish's talk]



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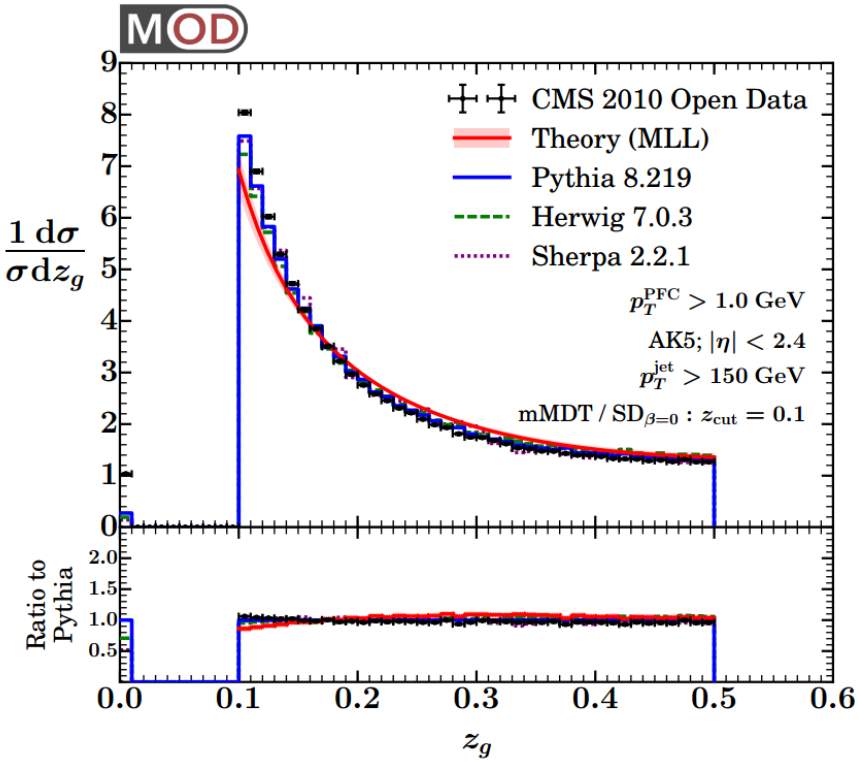

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- Open discussion/controversy
- Massive effort
- Many interesting observations

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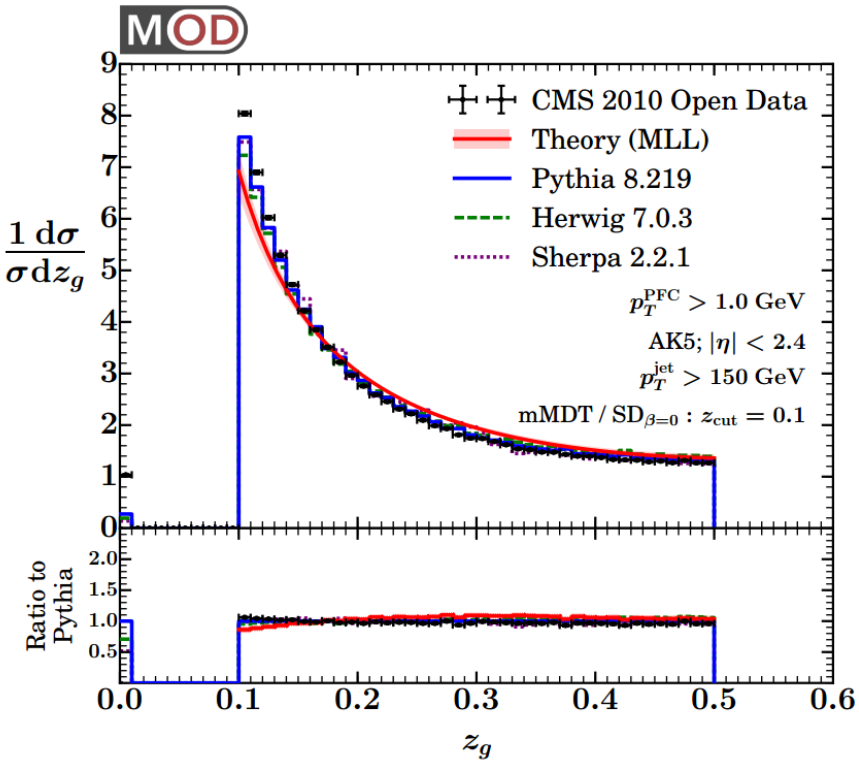

[Aashish's talk]

- Open discussion/controversy
- Massive effort
- Many interesting observations
- Overall message:
  - Do we have Open Data? (my thought: yes, sure!)
  - Educational and research?
  - What timescale?
  - Under what format?
  - Can we make it easier?
- It should in no way kill (proper) measurement by the (real) exp!

Boost beyond Boost

(or my anti-summary)

Substructure tools become mainstream
$\Rightarrow$ things happen outside of this meeting

Foreword

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$\Rightarrow$ things happen outside of this meeting

Example: Les-Houches PhysTev Workshop

- 2015: study of quark-gluon separation
- 2017: study of 2-prong tagging techniques
- 2017: α_s measurement at colliders

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Example: Les-Houches PhysTev Workshop

- 2015: study of quark-gluon separation
- 2017: study of 2-prong tagging techniques
- 2017: α_s measurement at colliders

This is a wonderful community effort
"Boost" should stay connected

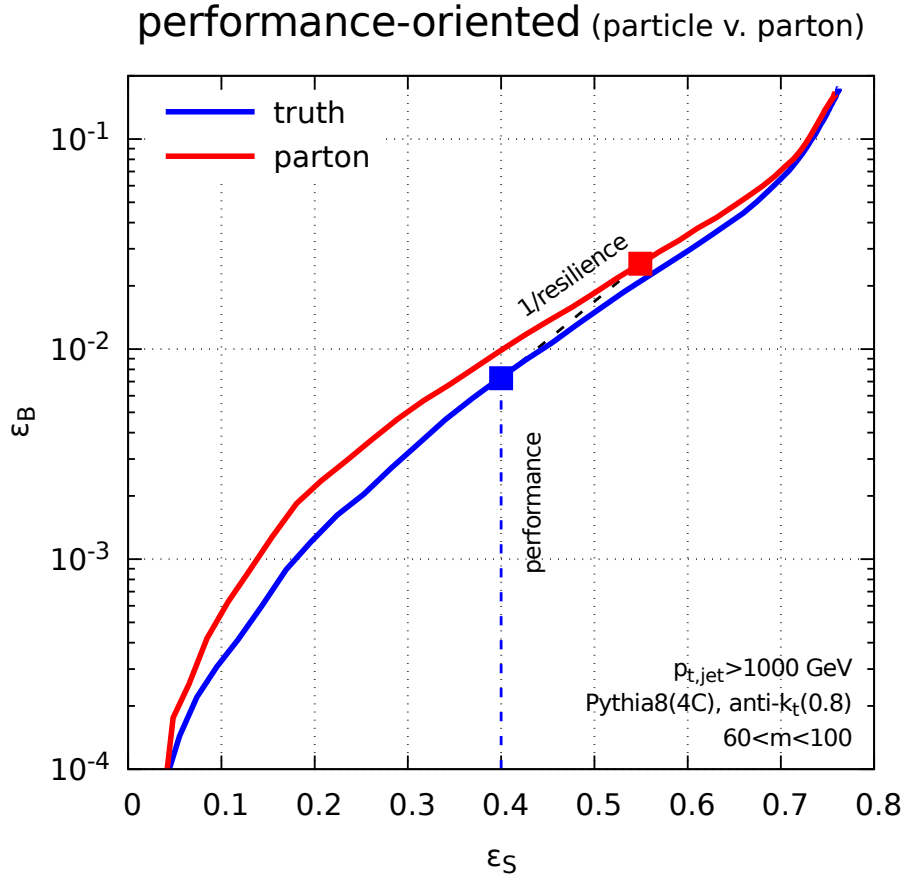
[Jesse's summary in LH 2017]

Comprehensive 2-prong tagging study

[LH2017 in progress]

groomed mass + (vary cut on) shape

- Performance: $S/\sqrt{B}$
- Resilience:
  - against NP effects (here)
  - (possibly) against pileup
  - (possibly) against detector



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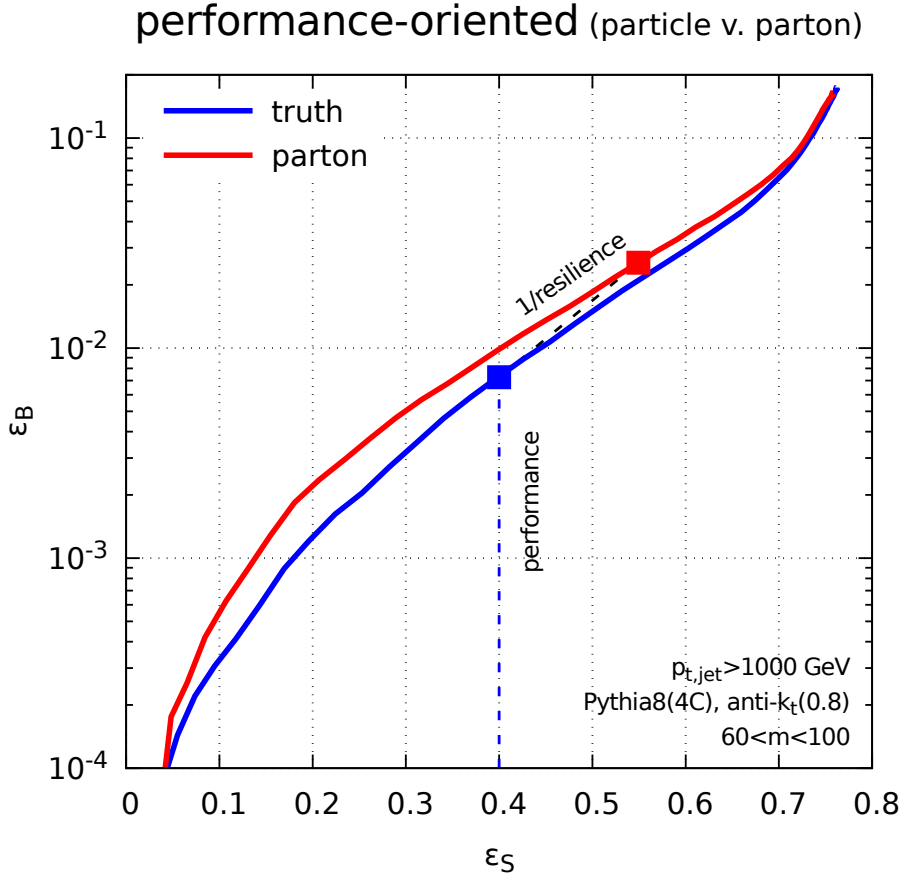

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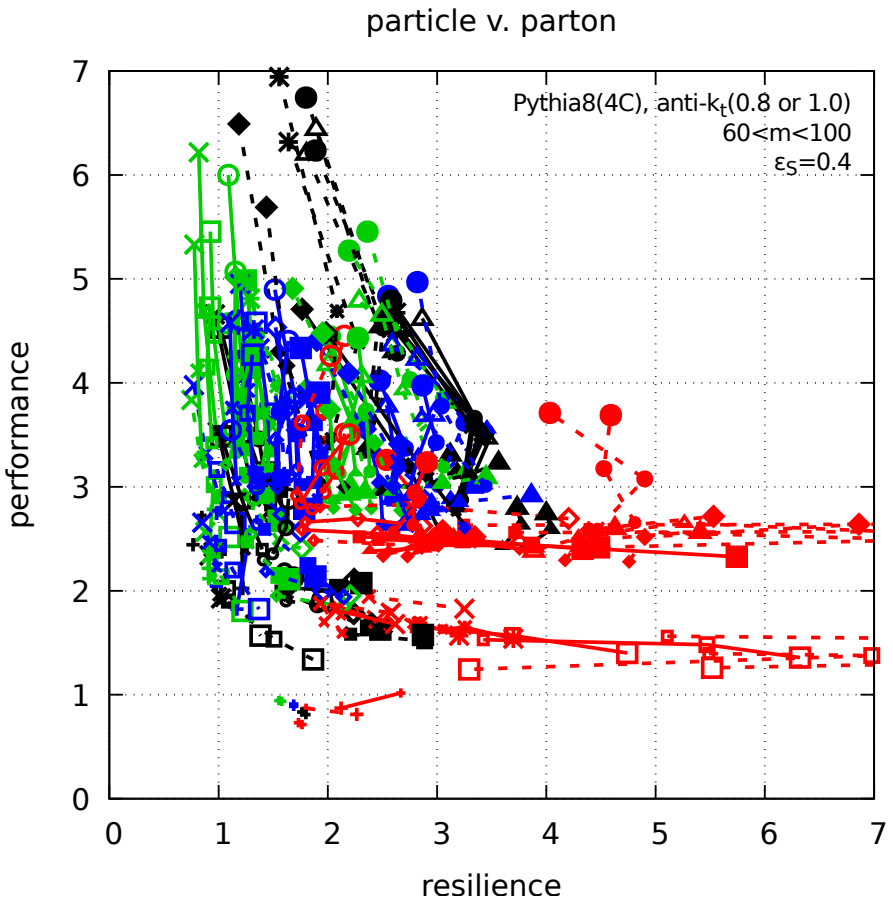
- Need to sort through it!



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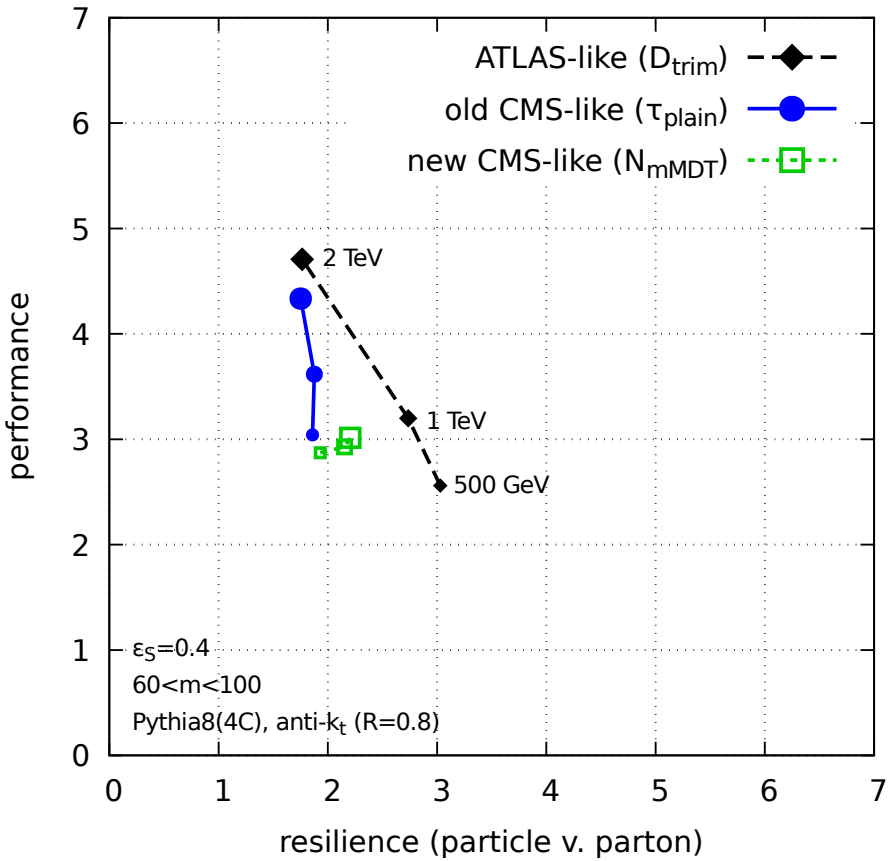

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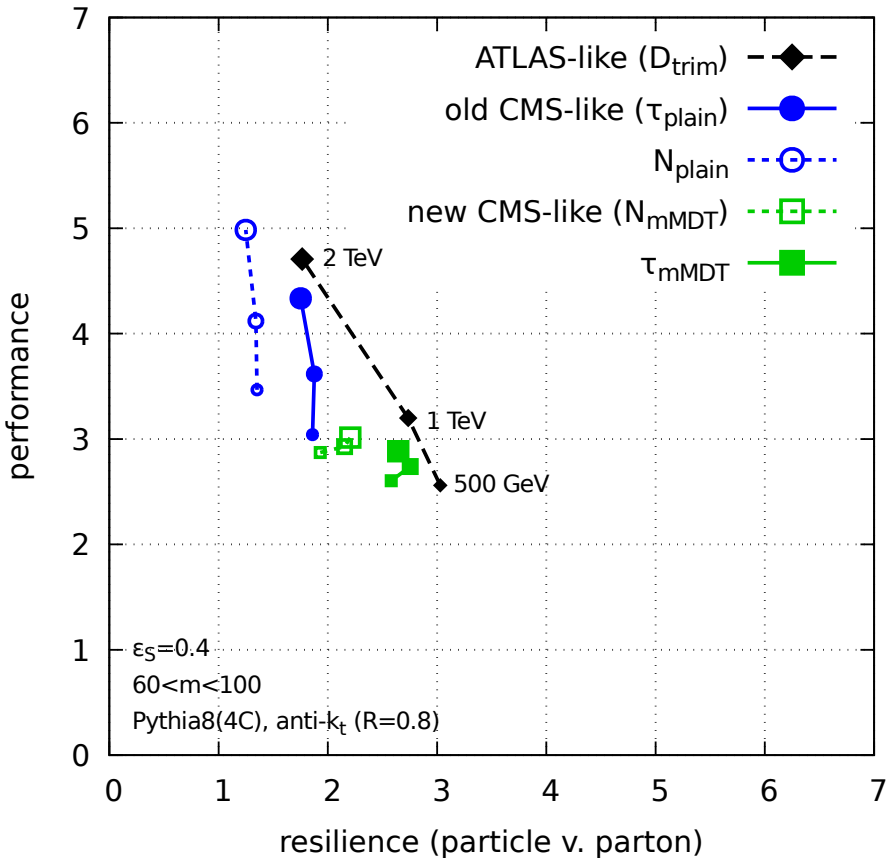

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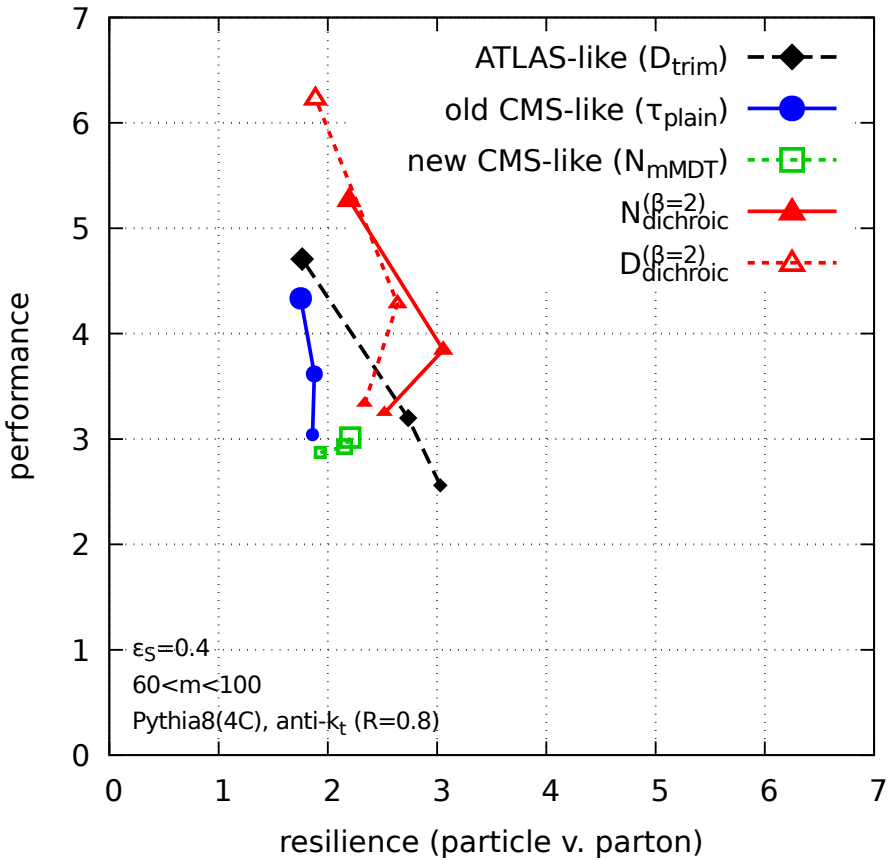

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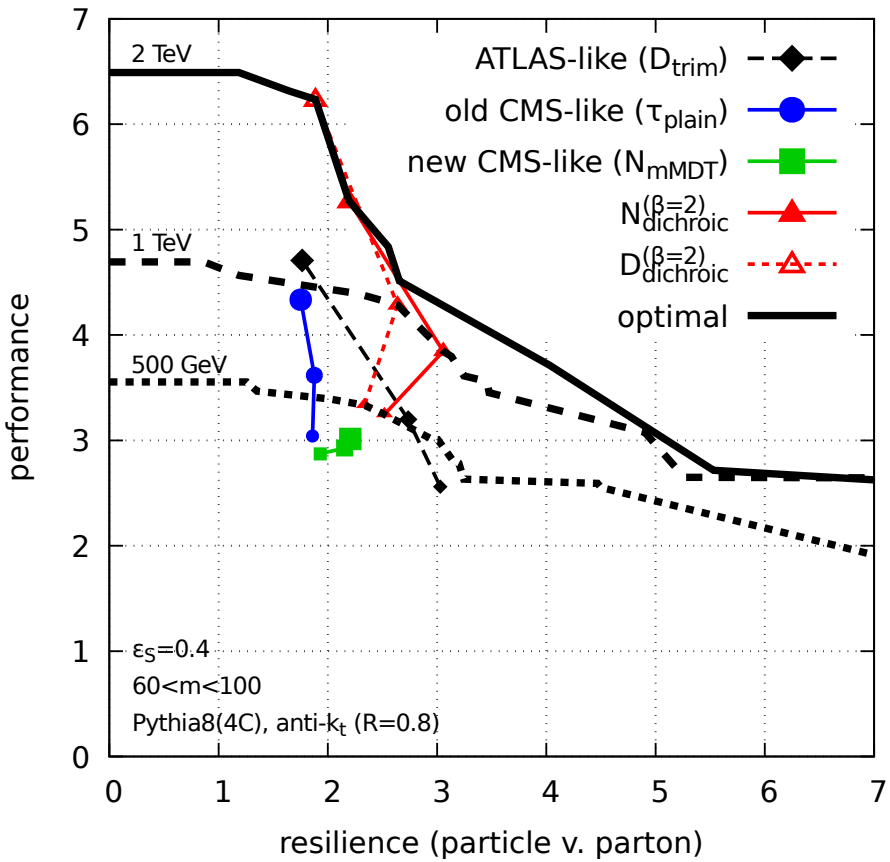

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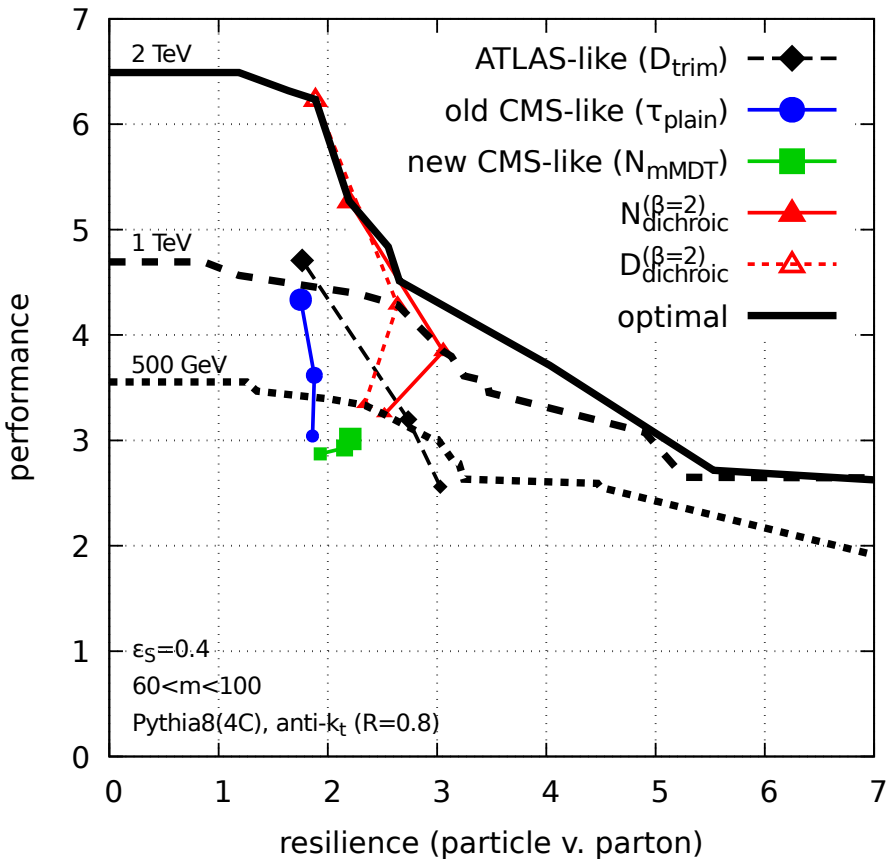
- Q: how does "flatness" fit in?



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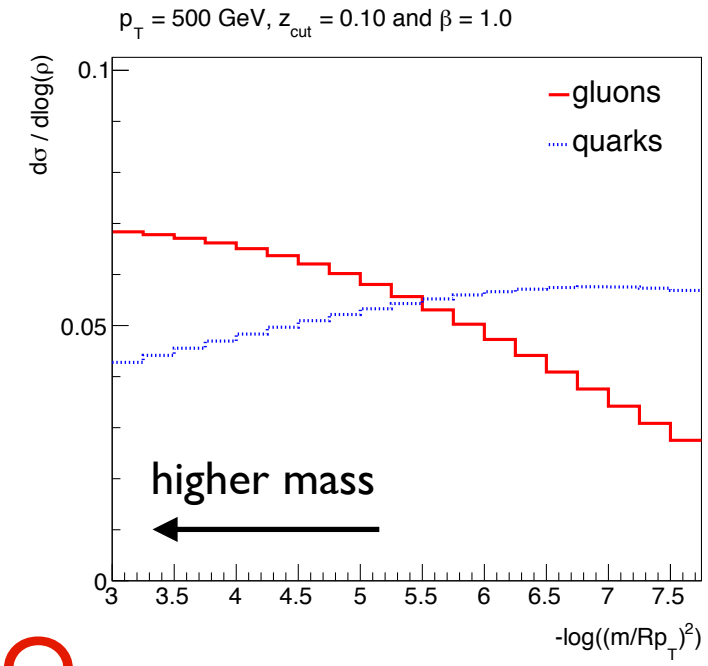
Measurement of α_s

[LH2017 in progress]

Idea: extract α_s from substructure measurements

- Setup:
  - Use mMDT/SD
    - Precise th. calculations
    - small non-pert. effects
  - Use jet mass and angularities
  - Pseudo-data, stat only

Probability Distribution



FO ⟵ | ⟶ NP

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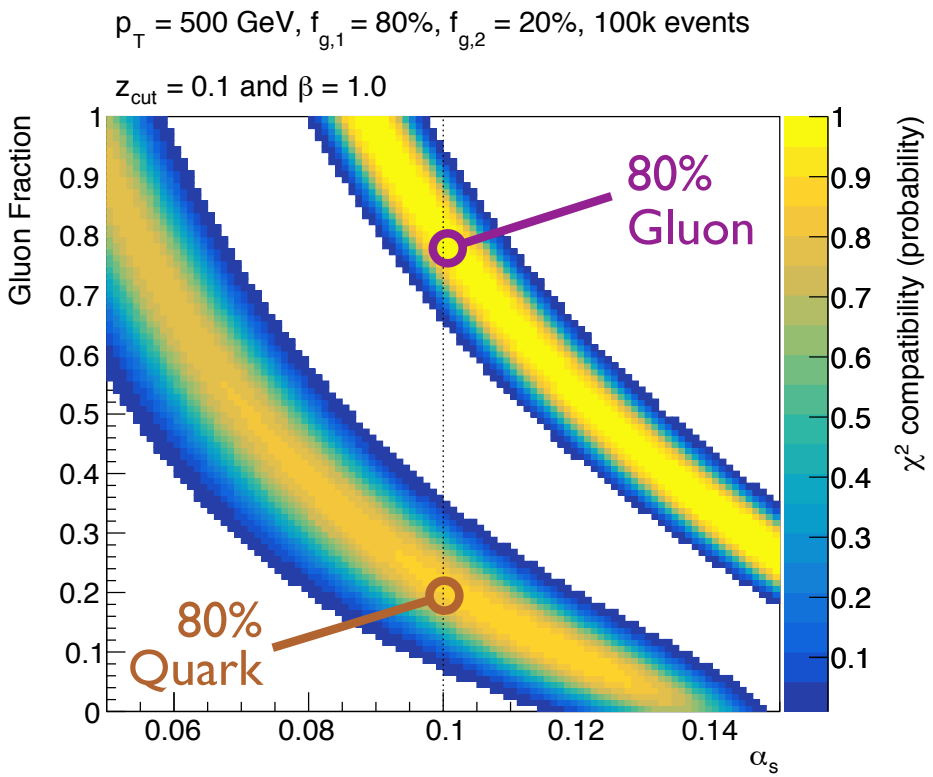
    (depends on $\alpha_s C_R$)
  - how to use fixed order?

Best Fit from Pseudodata



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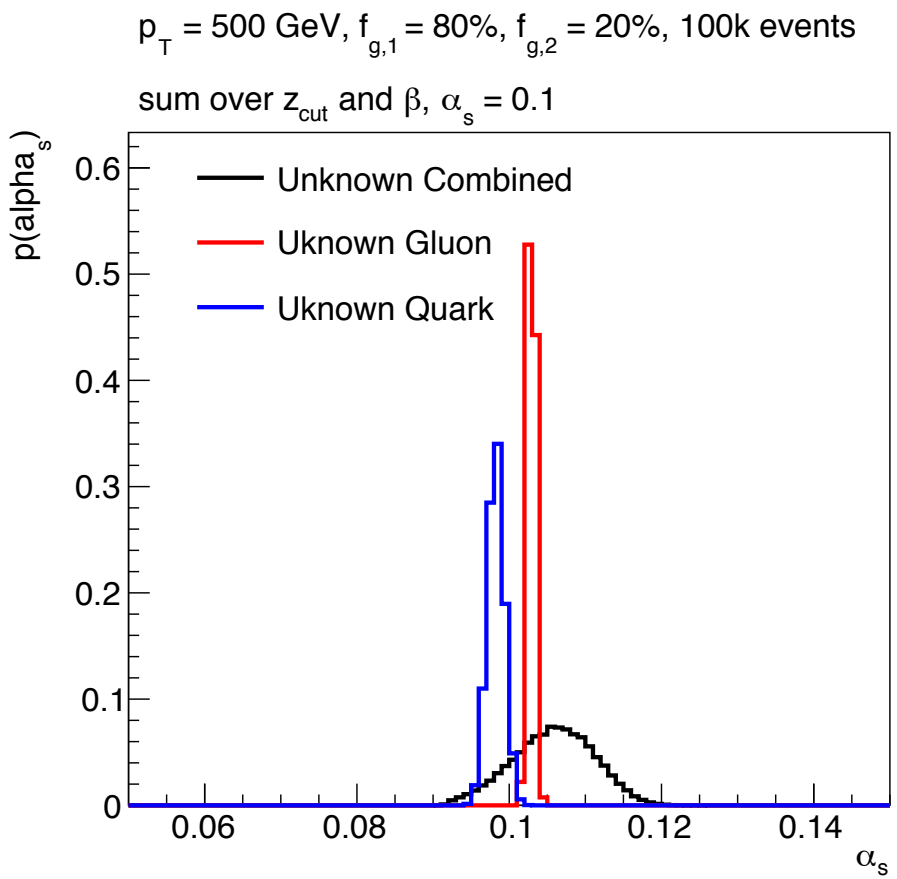
  - how to use fixed order?
- 10% seems plausible!
  - just the tip of the iceberg
  - lots of open questions

➔ Six Measurements



Very Busy Boost $\Rightarrow$ summary of summary (take home messages)

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- amazing understanding
- precision calculation
- theory uncertainties

My Boost is opened

New ideas

- still proposed
- still welcome

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- fast progress in calculations
- expand towards MC
- expand towards HI

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Thanks Sal & Simone for
Beautiful Outstanding Organisation and Superb Time

"I could just go home and implement all of this"

(Rickard)

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Don't: it's already implemented ... play with it, think about it!

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Looking forward for more

We welcome you to Paris in 2018 for the 10^{th} BOOST

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There should/will be this:

[https://indico.cern.ch/e/boost2018]