Jet Measurements at the HL-EIC

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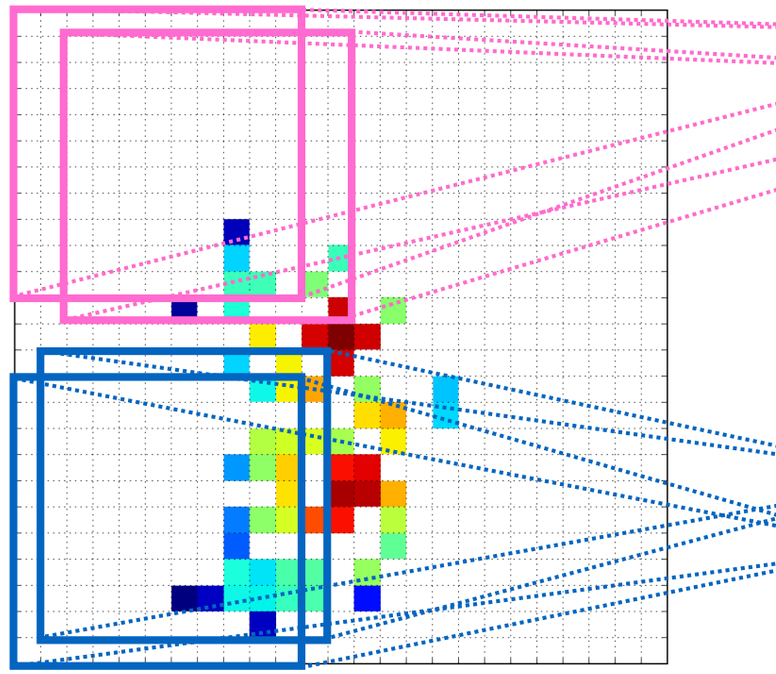

HL-EIC Workshop

June 22, 2022

Overview: jets at the EIC

To first order, the *ep* jet physics program at the EIC is the jet physics program of HERA

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…of course, EIC can do more: eA and polarized beams!

(HERA had runs with polarized leptons)

Uses of jets: (1) as proxies for quarks/gluons (some advantages over exclusive hadrons) and (2) as composite objects whose structure we want to explore

Jets at the HL-EIC

To first order, the *ep* jet physics program at the HL-EIC is whatever was stats-limited at HERA/EIC

(presumably, the detector-limited measurements will be done during the Run I of the EIC, although maybe detector upgrades will only come during the HL-EIC era)

Jets at the HL-LHC

To
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H1 and ZEUS

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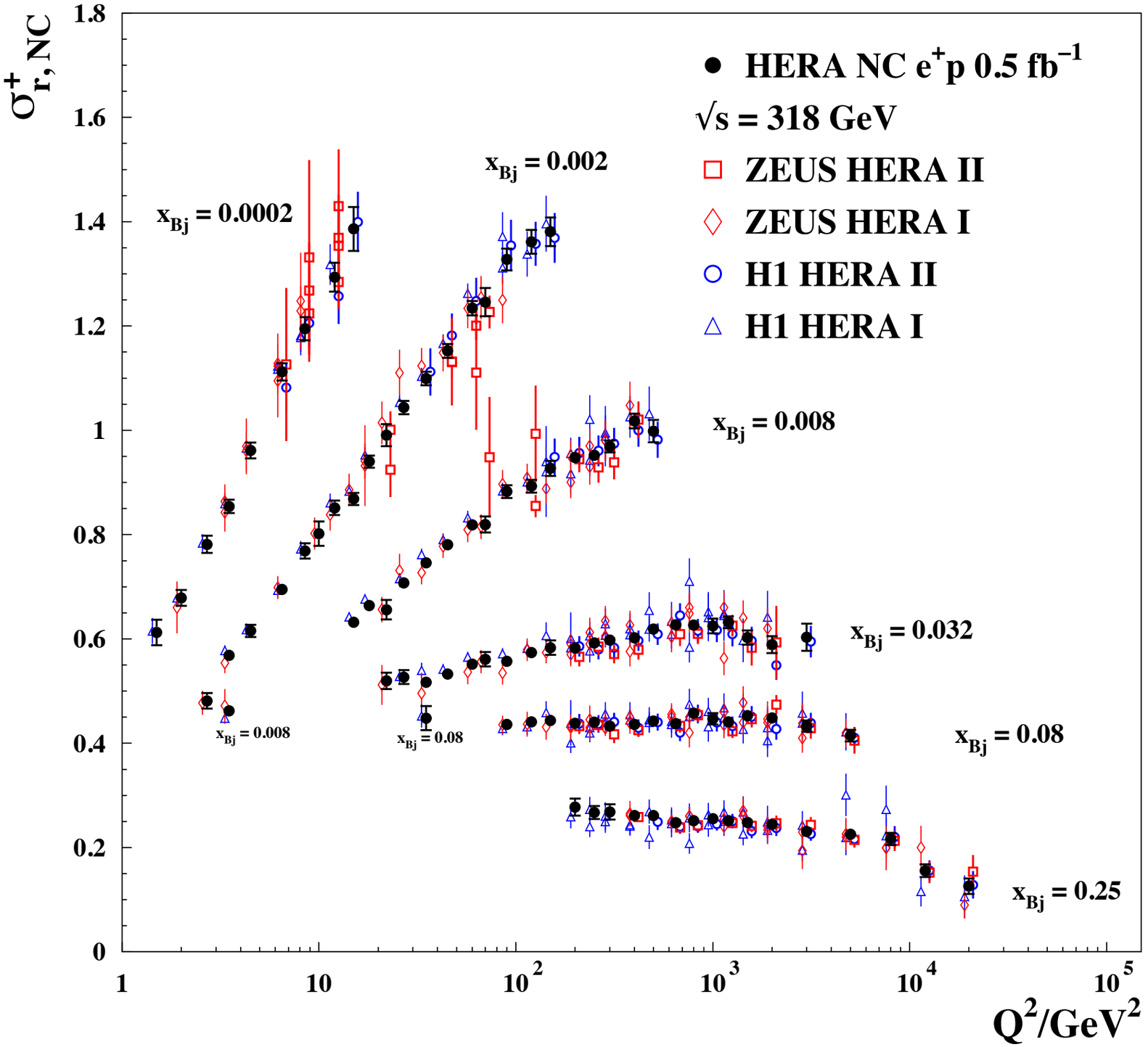

Jets at the HL-EIC

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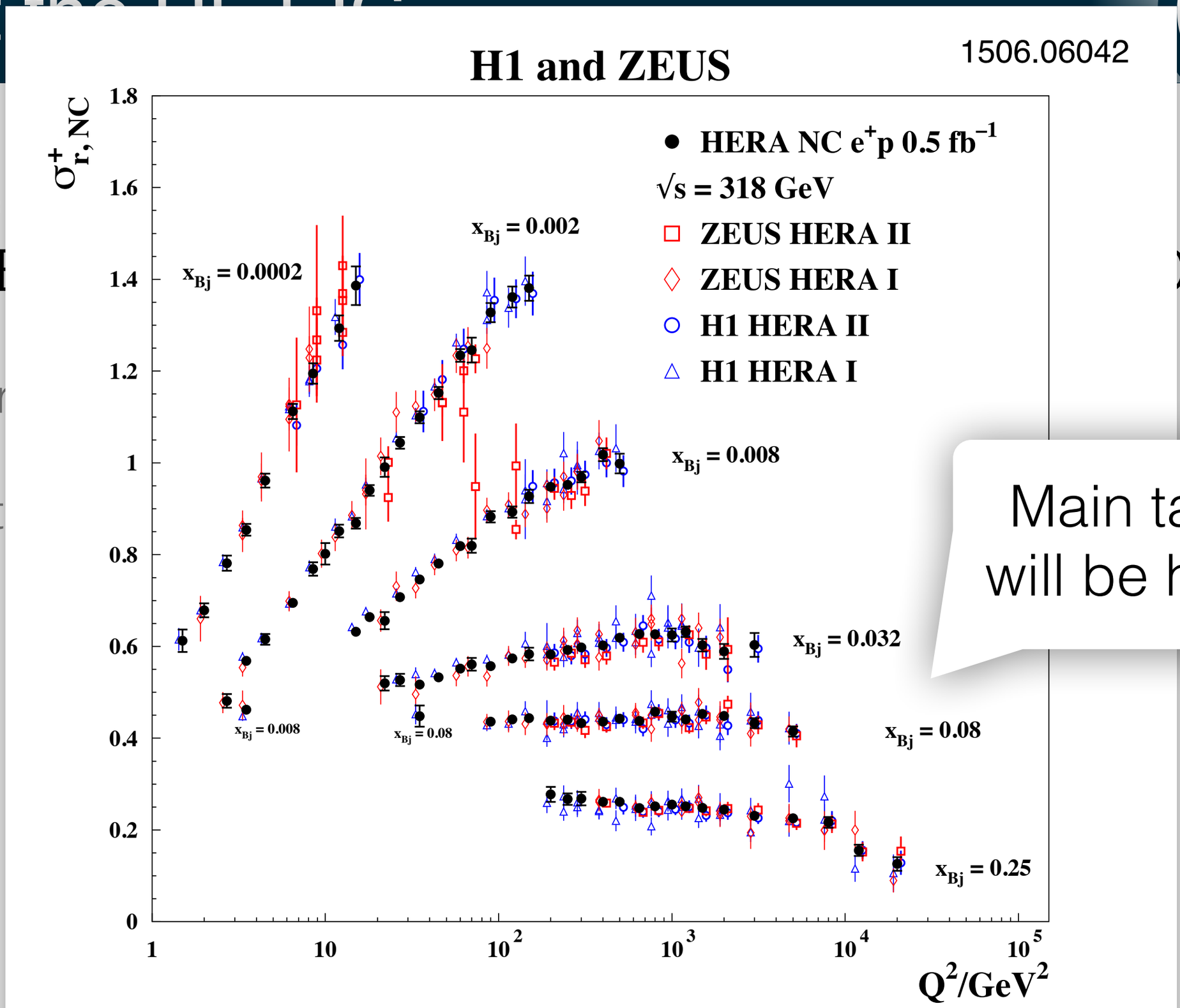

Main target will be high-x

Jets at the HL-EIC

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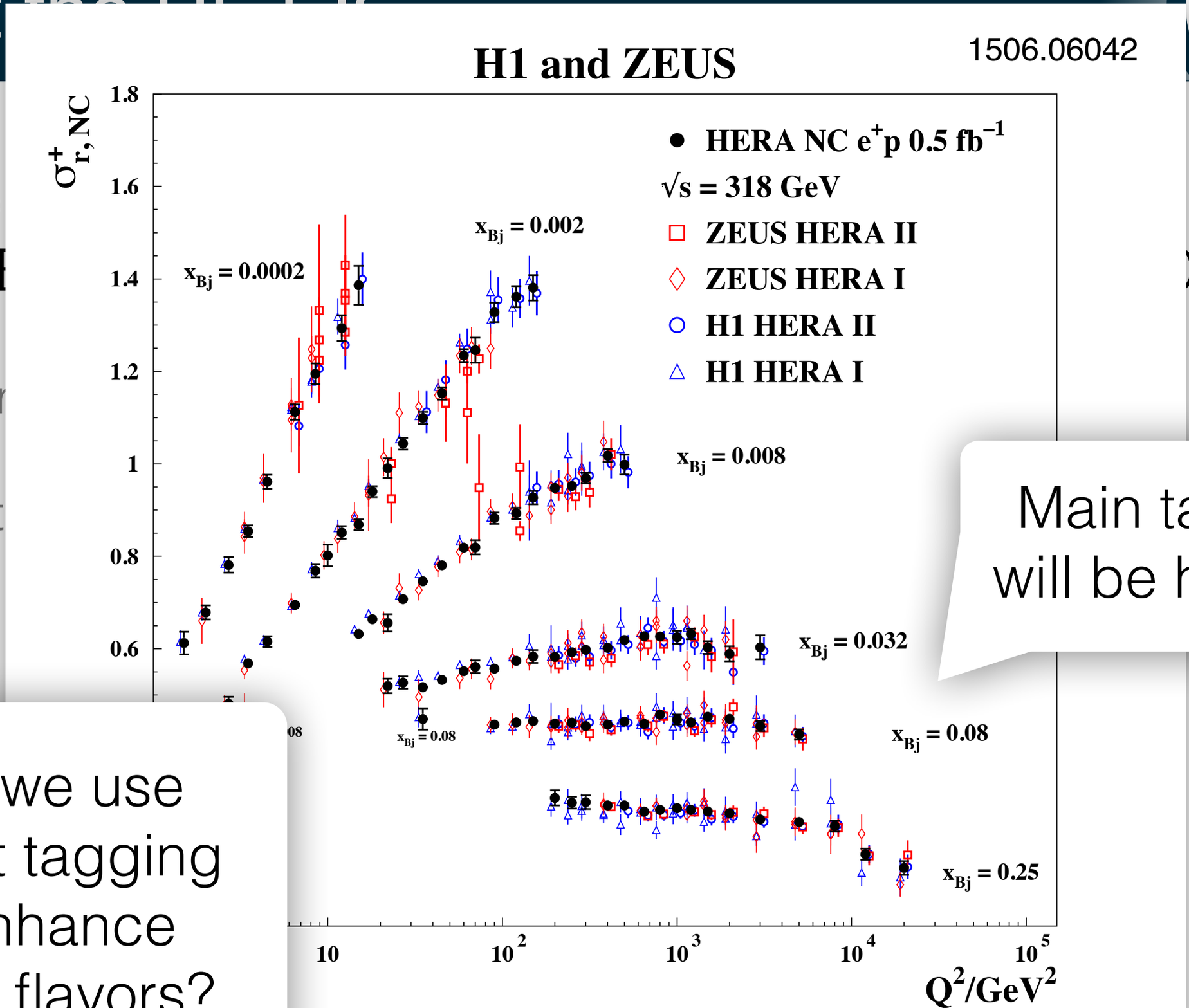

Main target will be high-x

Can we use jets/jet tagging to enhance target flavors?

See e.g. 2003.01700

Methods in addition to Stats

Word of warning: in order to make the most of increased stats, we also need method innovation!

(this plot shows how we can access high-x with more stats and/or better methods)

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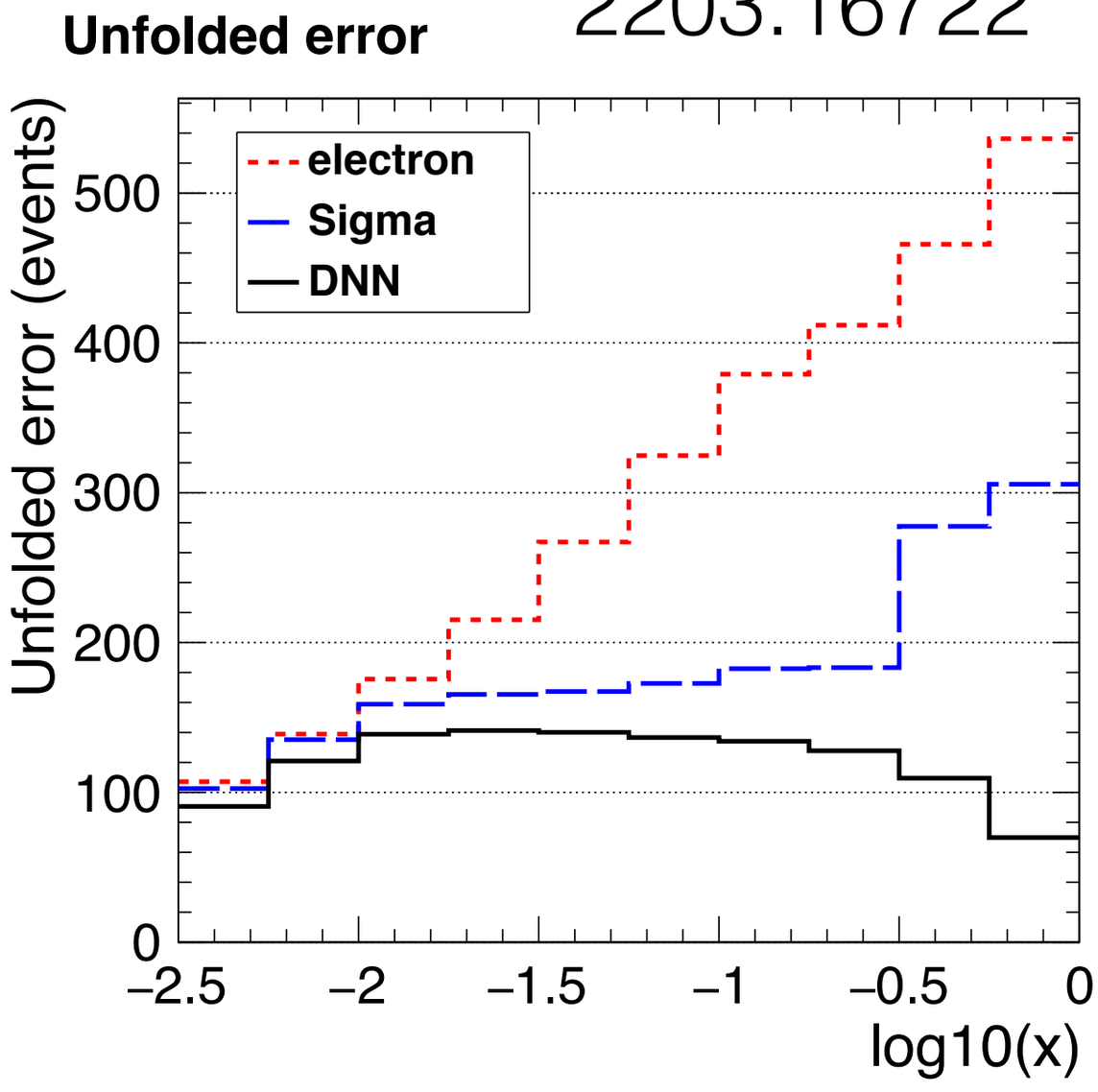
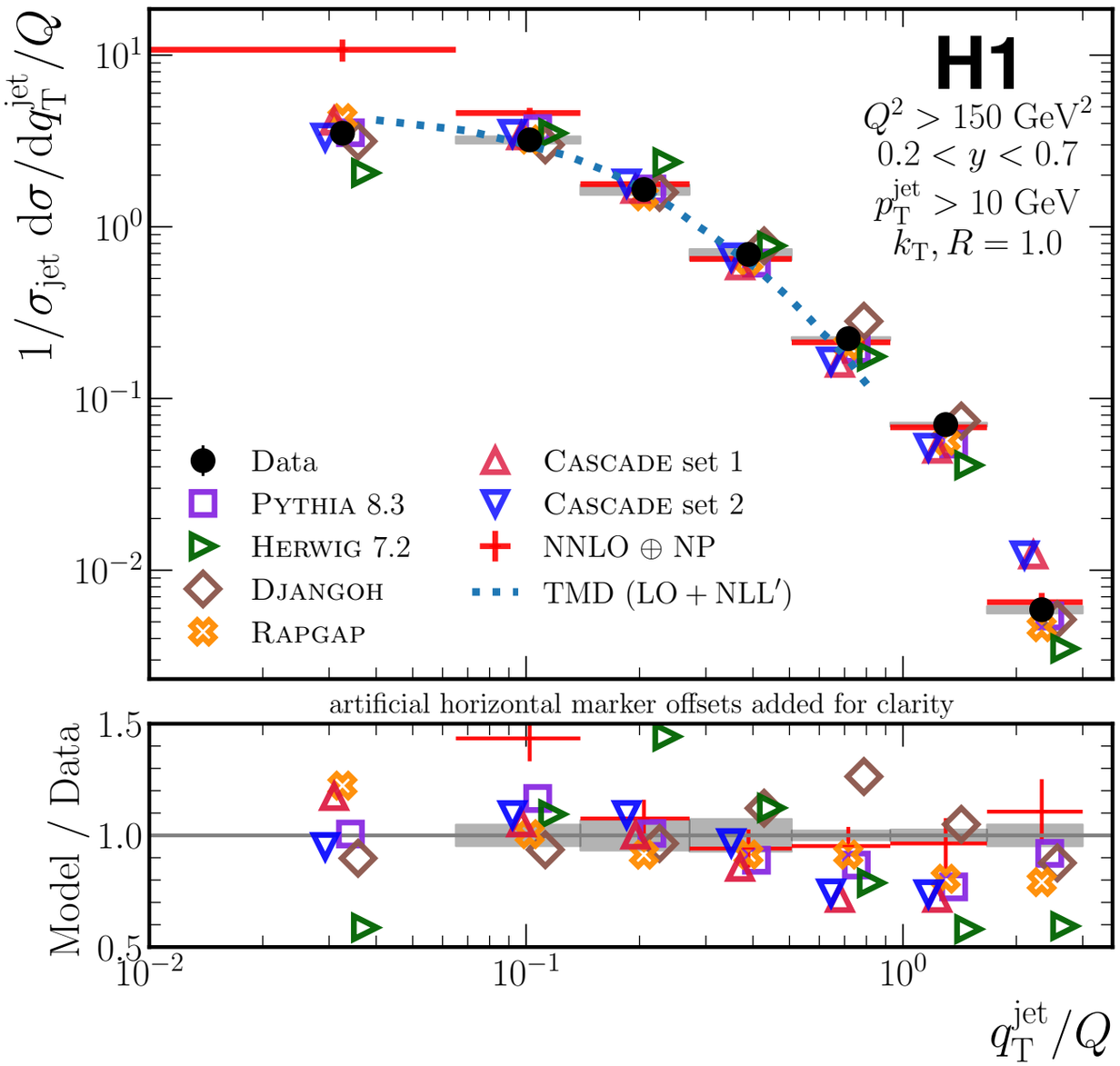


Jets at the HL-EIC

Word of warning 2: many interesting regimes are not stats-limited at HERA/EIC

We will need to reduce uncertainties to make the most of higher stats data!

(the lowest bin here is most TMD-sensitive and is not stats limited)



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Need for stats in *ep*

I'm not going to go through the entire HERA jet physics program, but you can imagine that stats are limited at extreme phase space regions (high x, high Q^2) and/or going highly differential / exclusive.

(e.g. quarkonia in jets, multi-differential jet cross sections, …)

Jet substructure

Physics program of jet substructure:

1. *Fundamental parameters of the SM*
2. *BSM searches using small deviations from SM*
3. *Quantum properties of inherently exciting emergent pheno*
4. *Develop / tune Parton Shower Monte Carlo (to aid other searches / measurements)*

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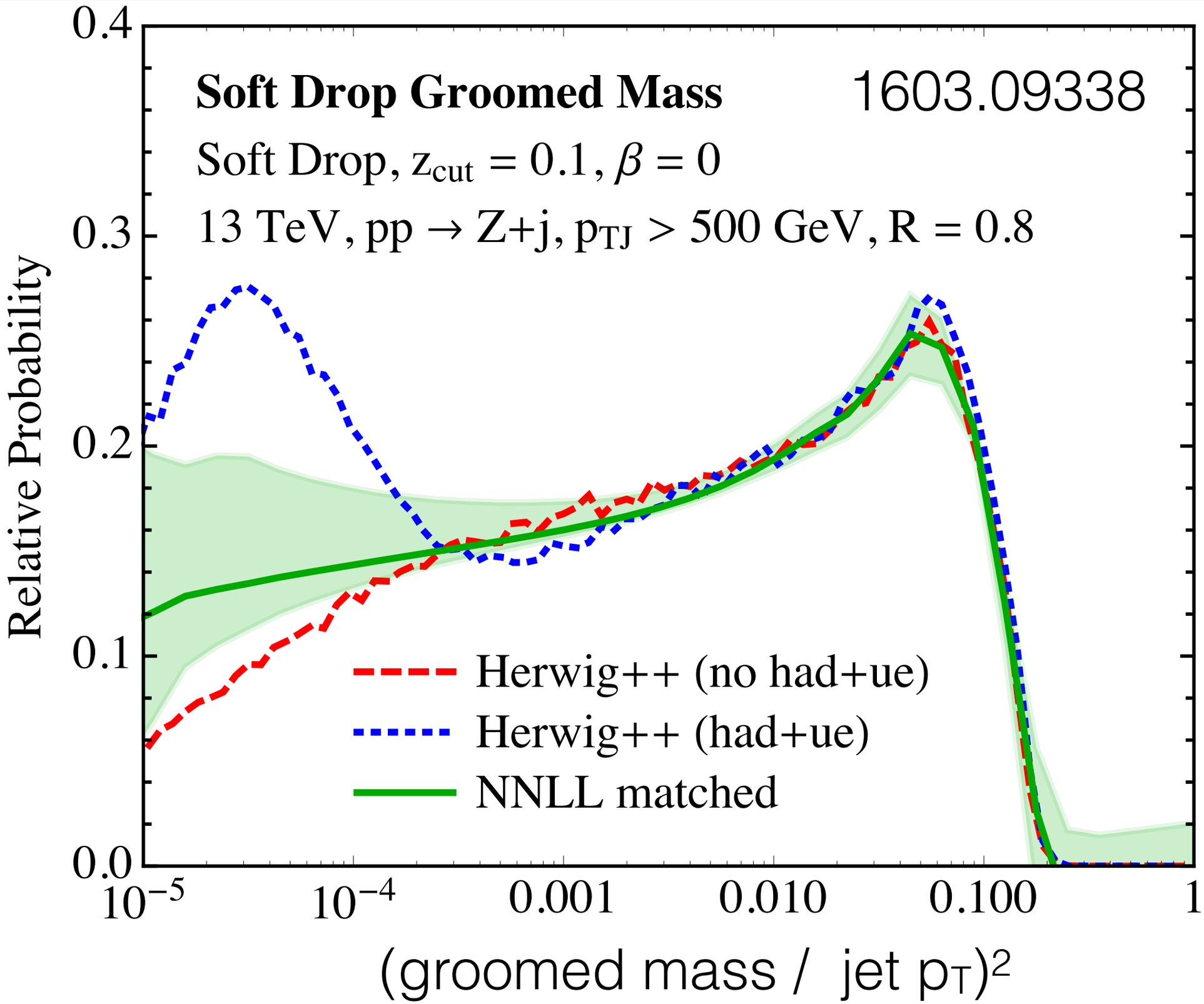
Can we do 1?

Jet substructure



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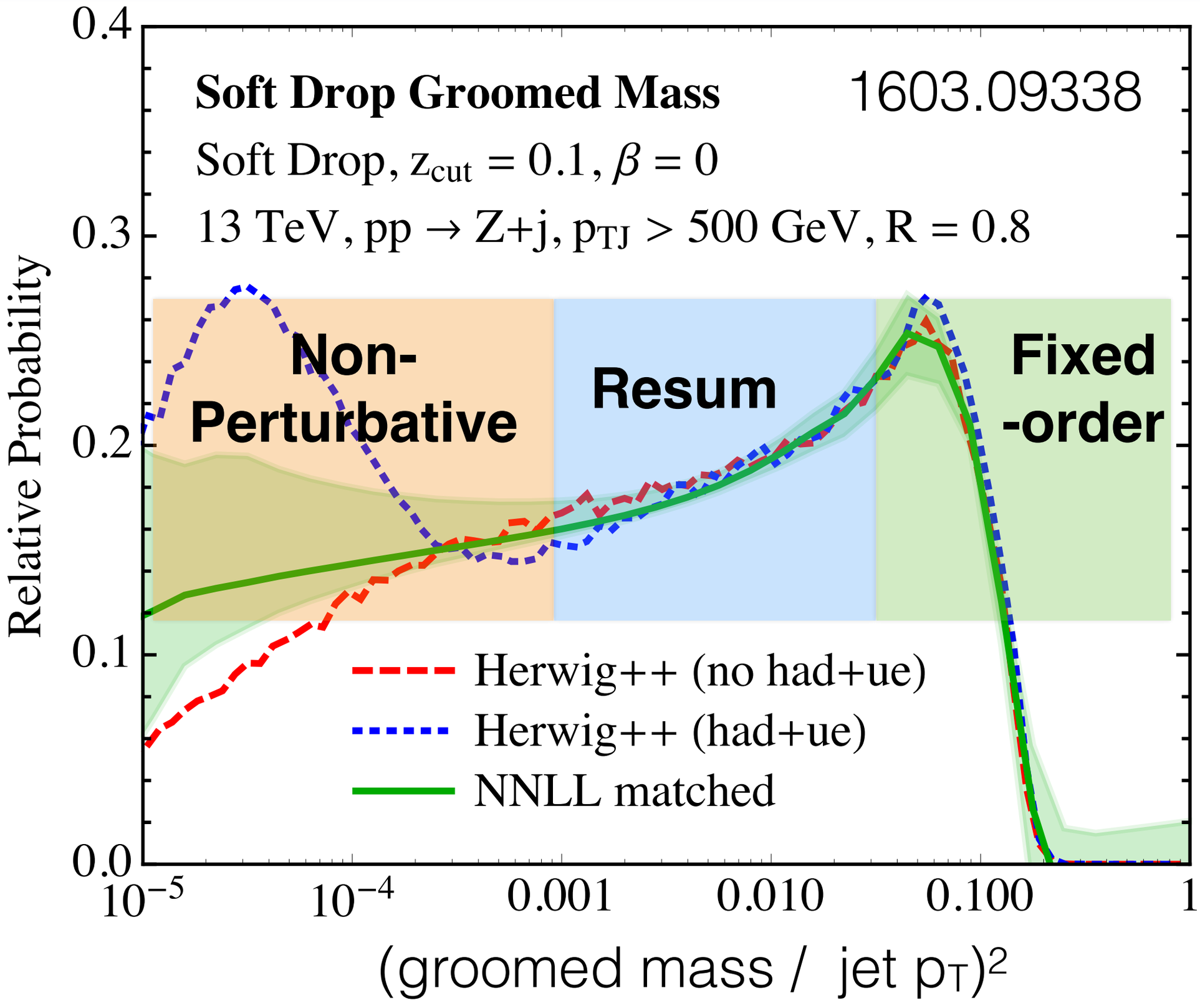
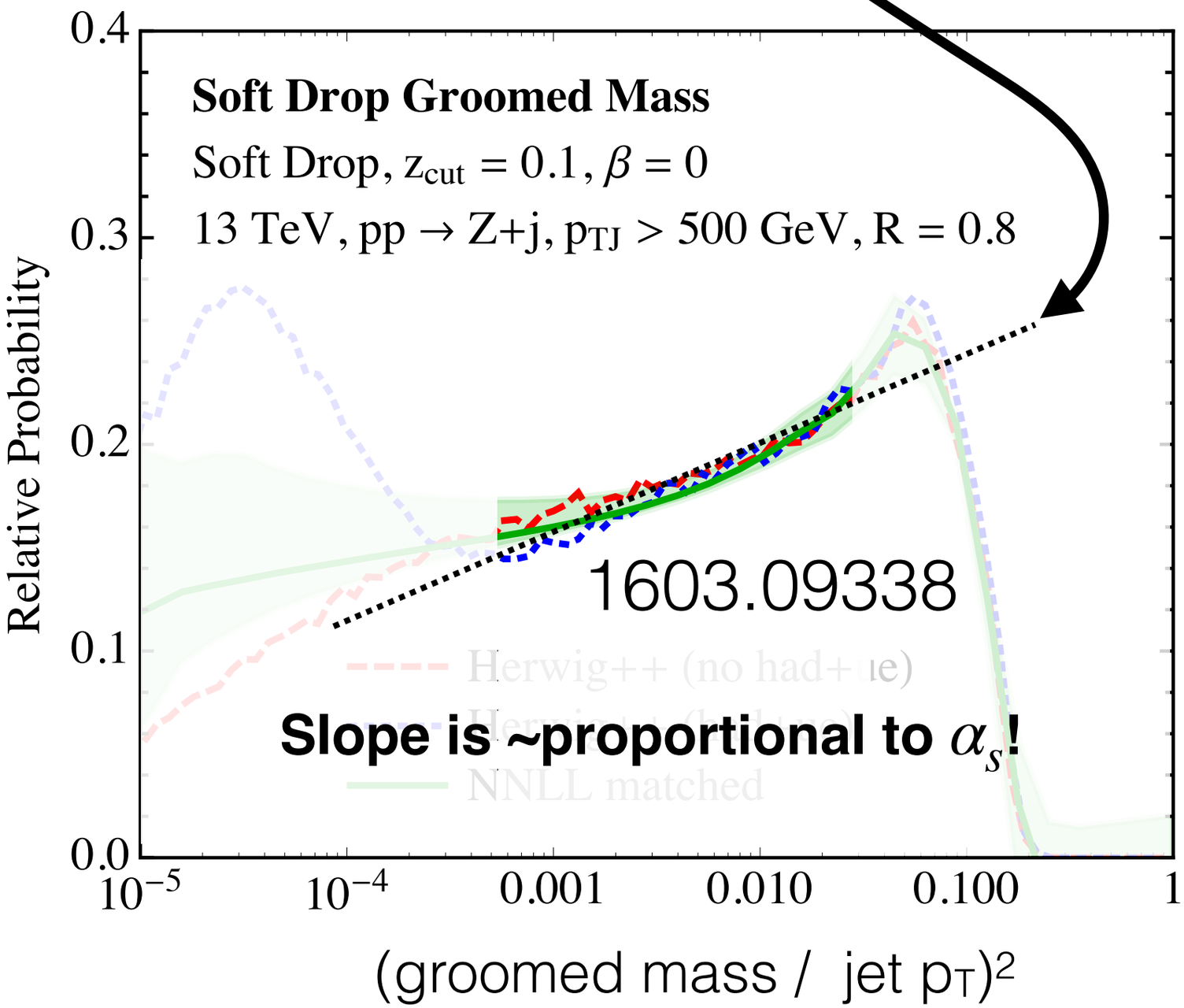


Groomed Jet Mass for α_s

$$\frac{e_2^{(2)}}{\sigma}\frac{d\sigma}{de_2^{(2)}} \approx -\frac{\alpha_s C_i}{\pi}[\log(z_{\text{cut}}) - B_i]\exp\left[-\frac{\alpha_s C_i}{\pi}[\log(z_{\text{cut}}) - B_i]\log(e_2^{(2)})\right]$$

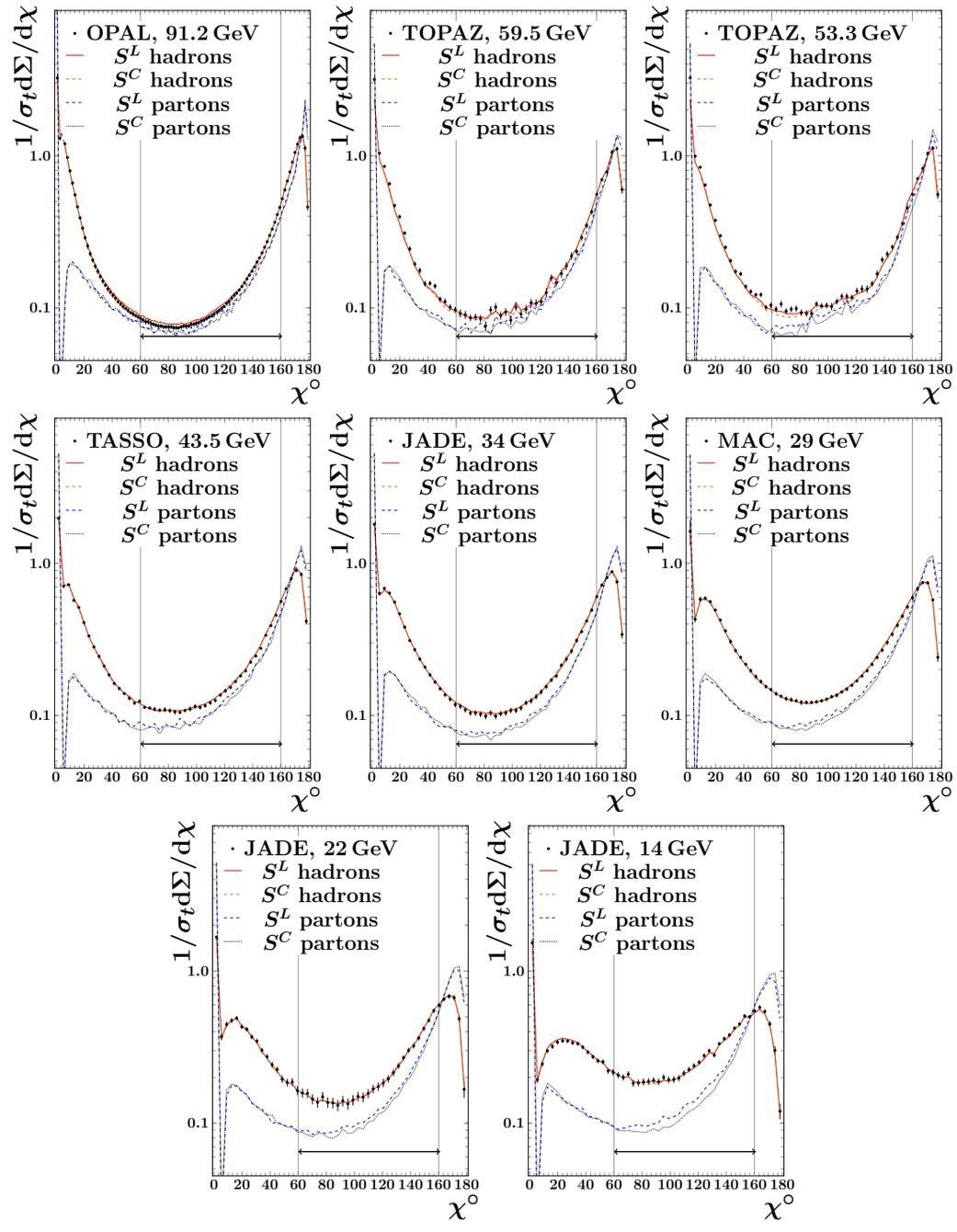


Precision, perturbative QCD

If you want to do perturbative QCD, better to go to higher energy than higher luminosity (!)

(any chance we can do both??)

Nonetheless, get nearly all of the benefits of e^+e^-!



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A clean environment for QCD

Can we use the clean environment
to address challenges in *pp*?

A clean environment for QCD

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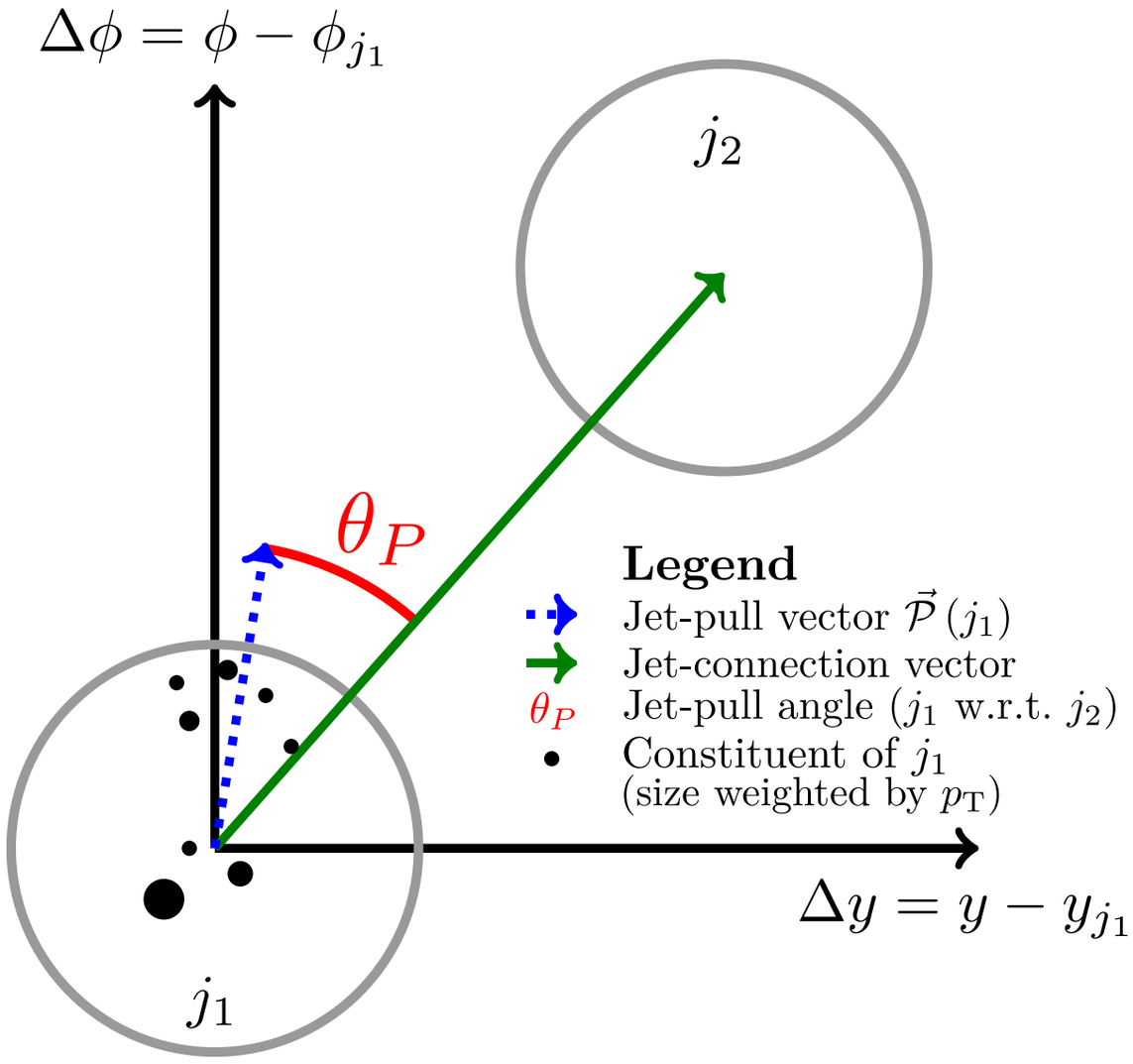
to address challenges in *pp*?

For example, studying correlations between jets is difficult due to the highly varying flavor fractions and the underlying event.

Correlations Part I: Jet Pull

As in many other areas of physics, studying correlations gives us a handle on emergent properties of QCD

Example 1: Jet pull



We can study QCD **entanglement** from correlations in the radiation patterns of pairs of jets.

An exciting laboratory for this work is boosted W bosons, a copious source of **singlet** → jets.

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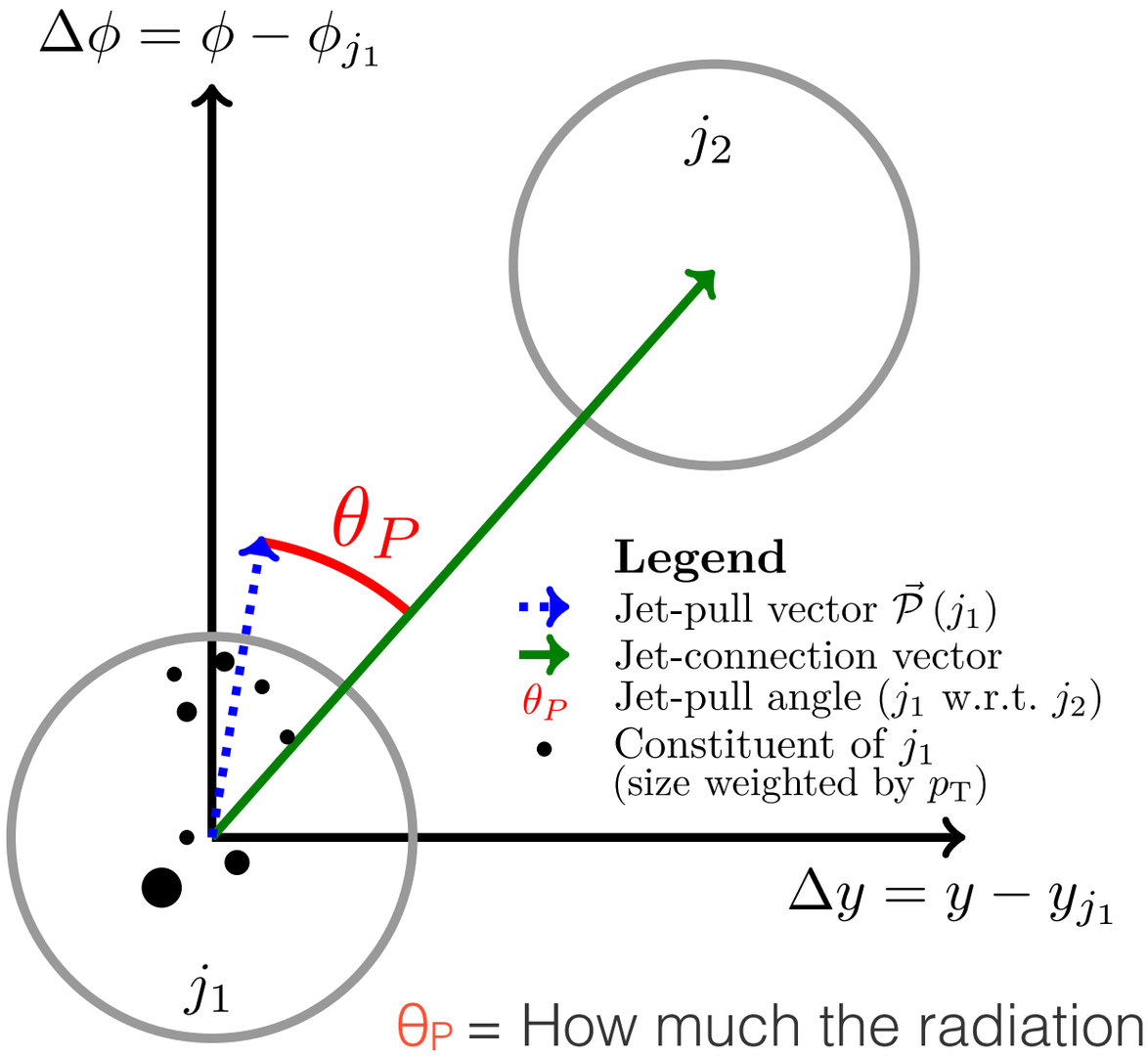

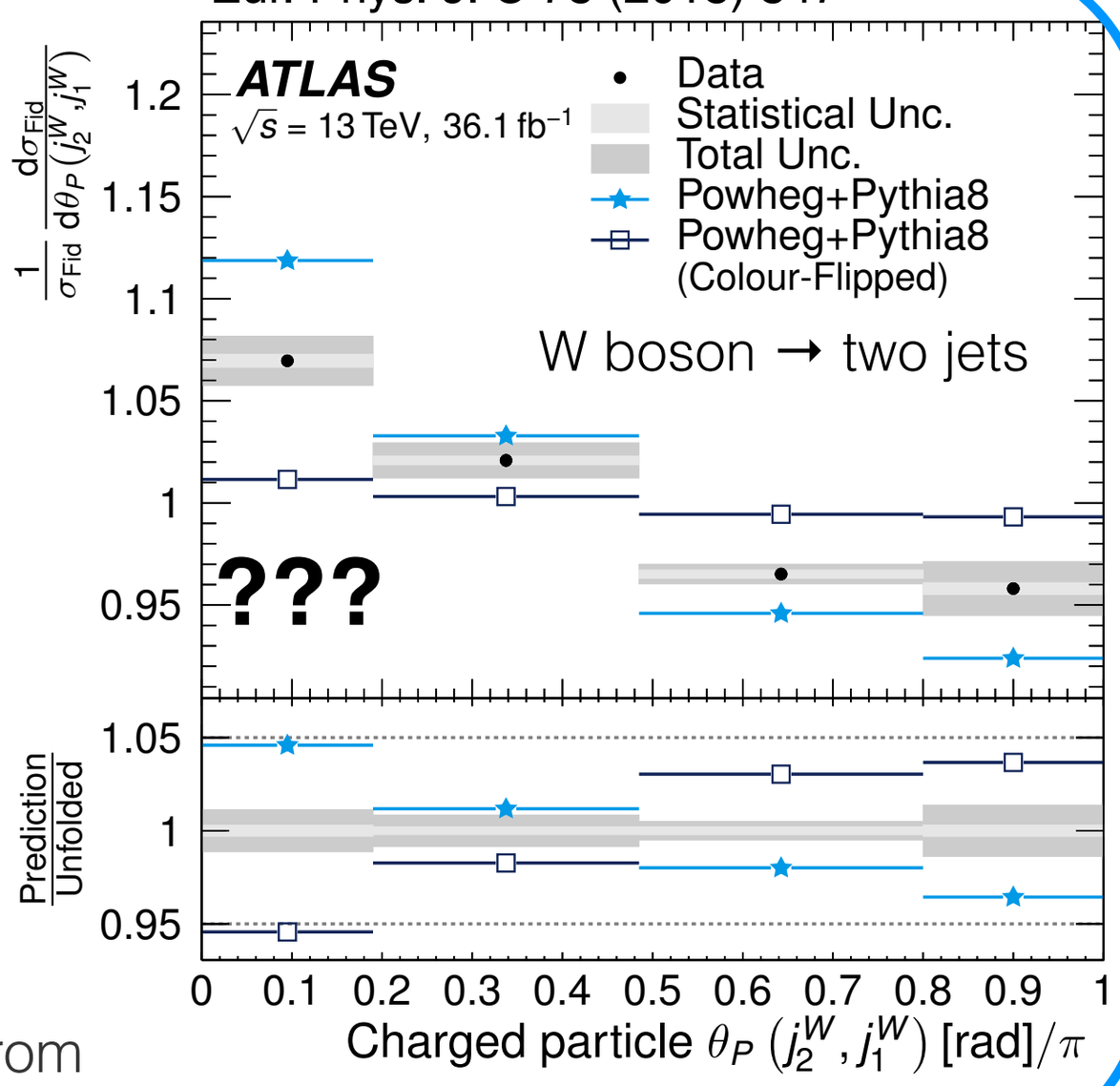

θ_P = How much the radiation from one jet "leans" toward the other.

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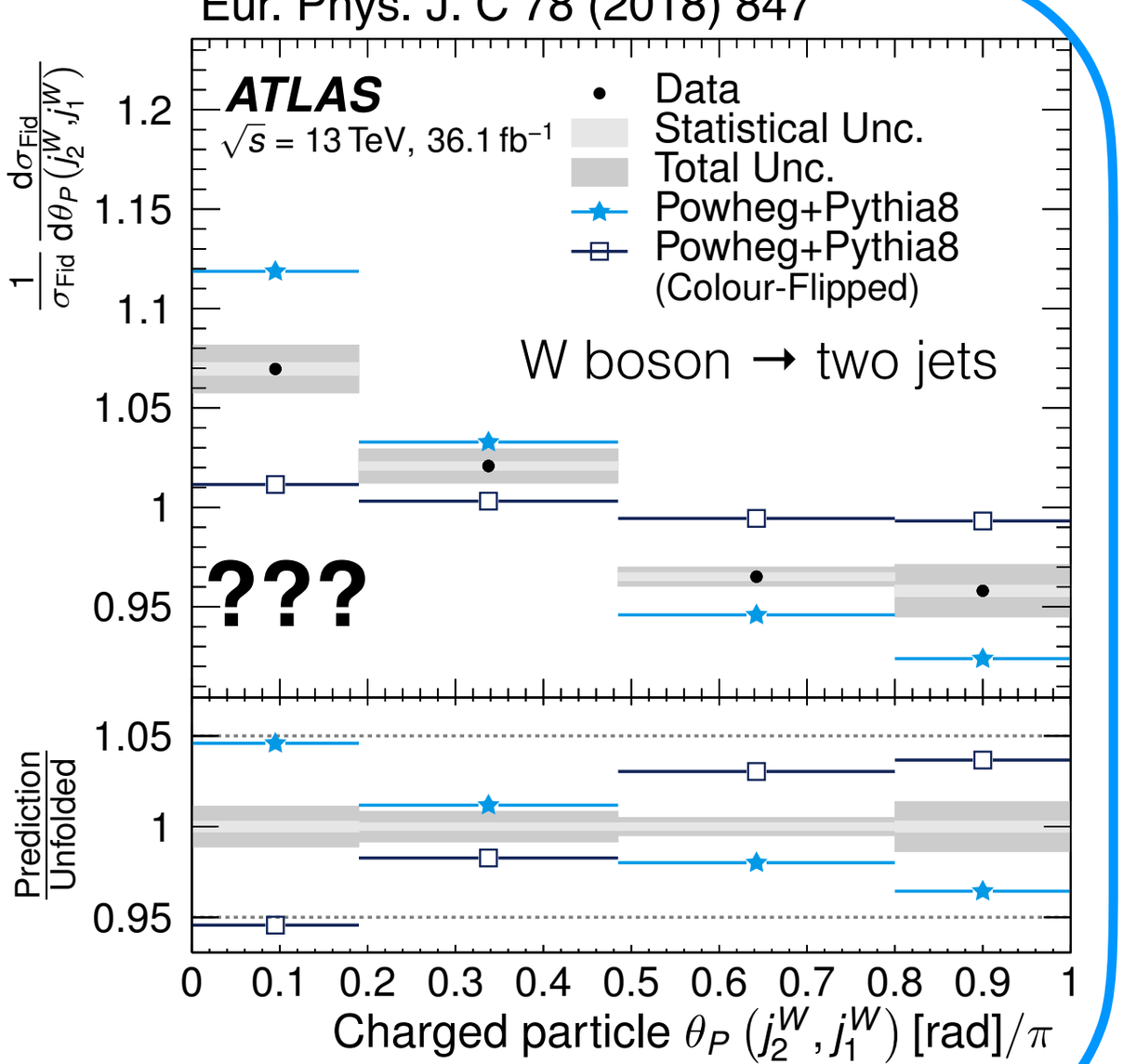
Example 1: Jet pull

Here is an observable where we can't distinguish between "entanglement" turned **"on"** and **"off"** !

Theory predictions are challenging, but in development

(see A. Larkoski, S. Marzani, C. Wu, PRD 99 (2019) 091502)



Correlations Part II: $g \to b\bar{b}$

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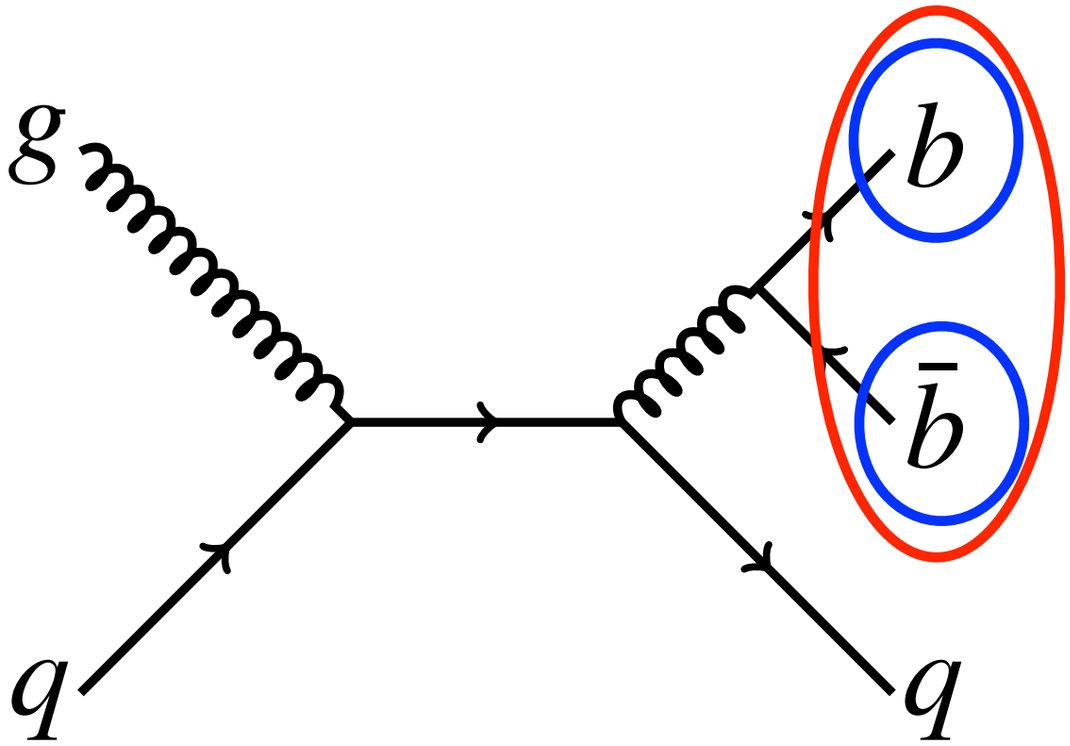
Example 2: g → bb



Gluon splitting to bottom quarks gives us the only ~pure access to QCD splitting functions.

(and of course, this is a very important process for Higgs)

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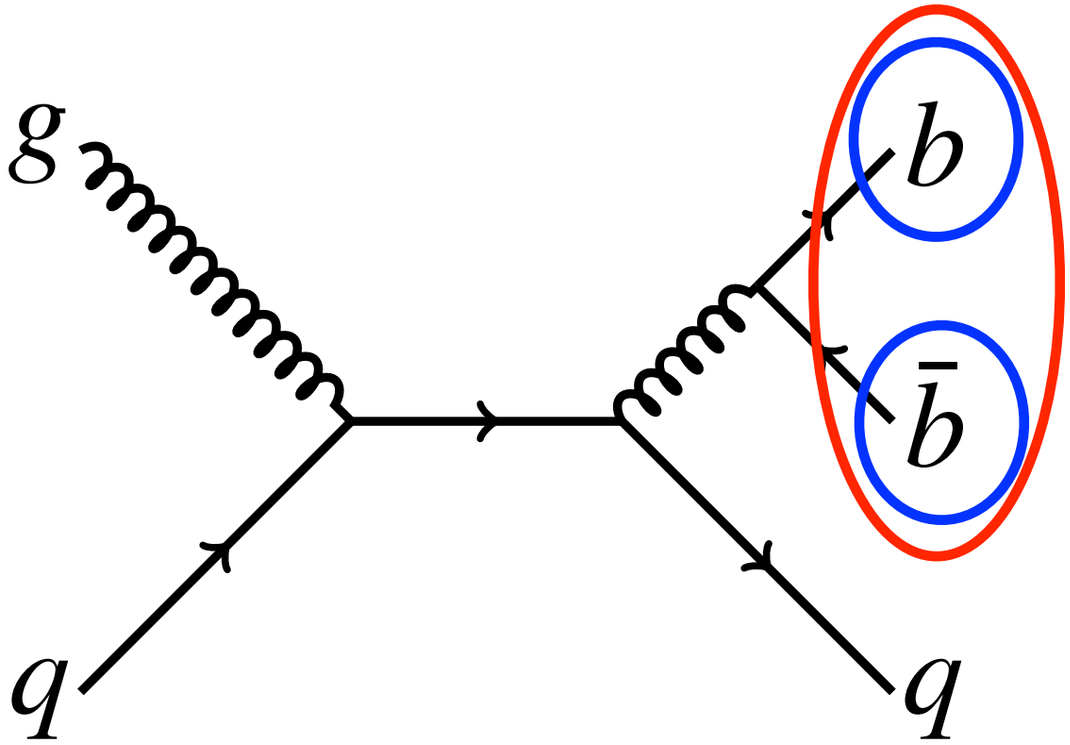
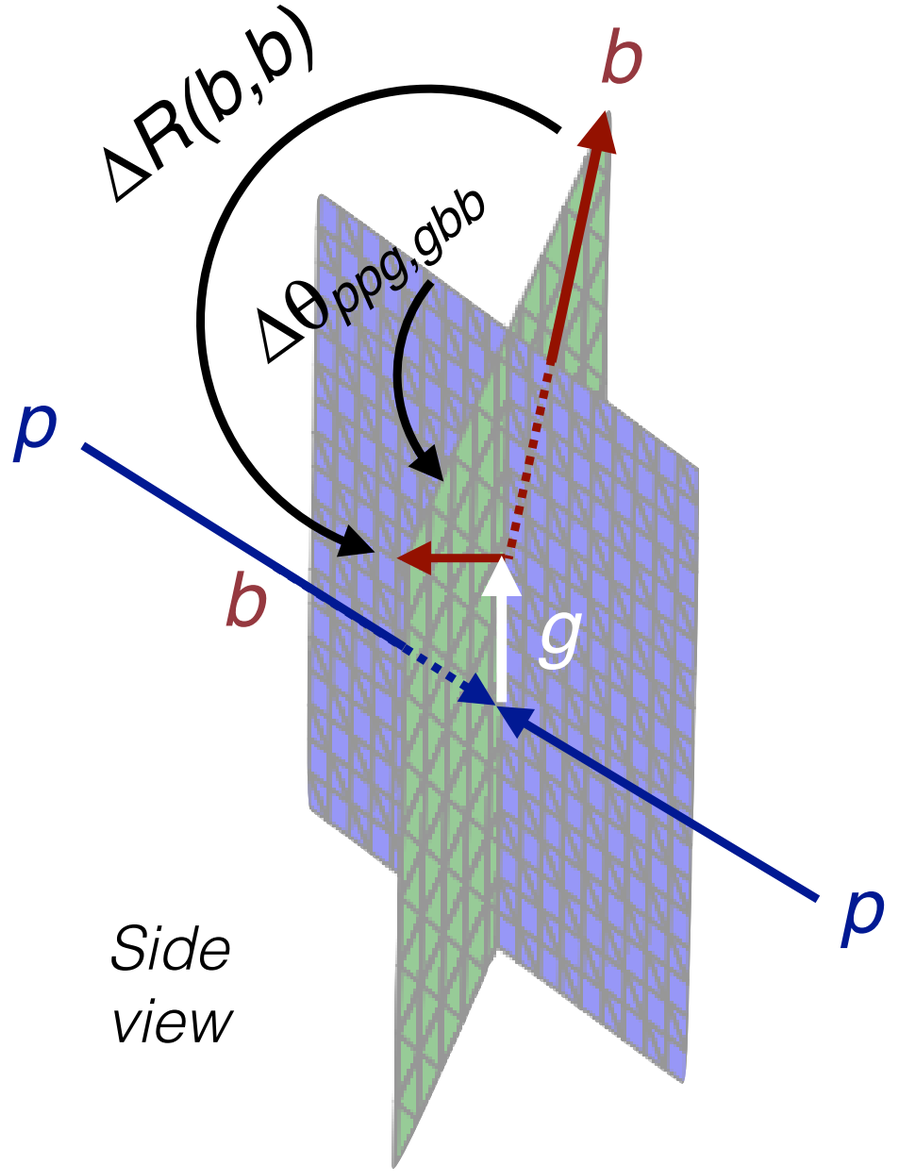


Relative angles to probe polarization



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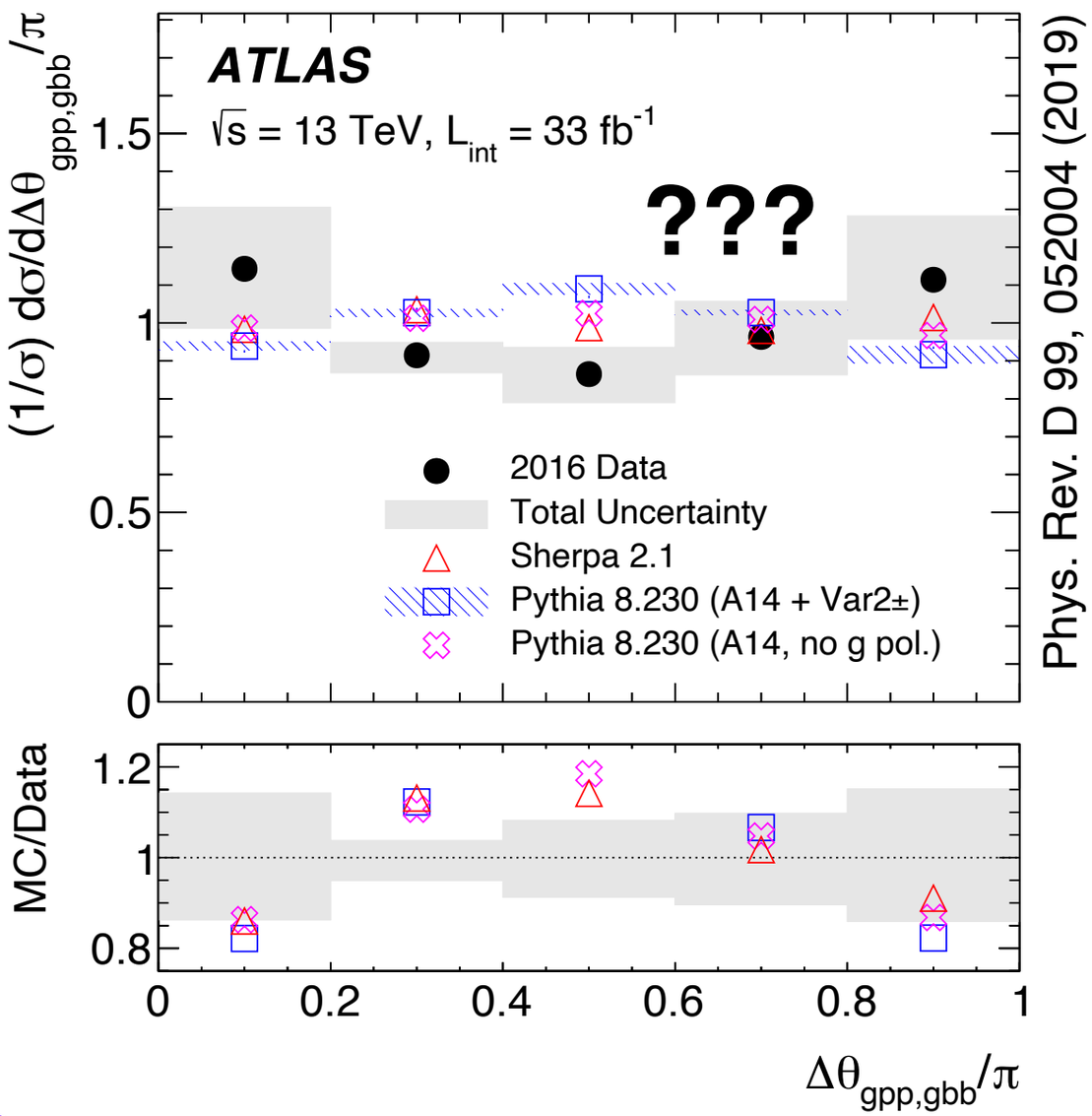

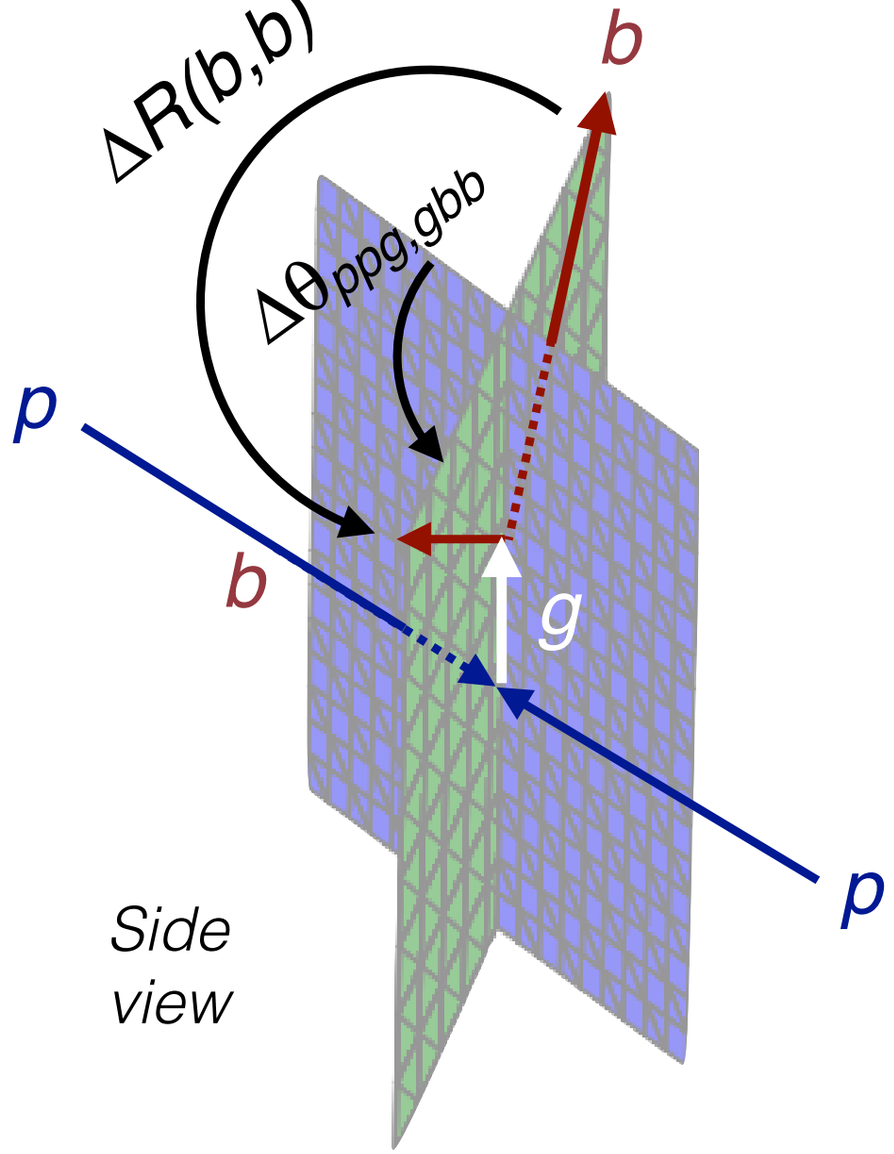

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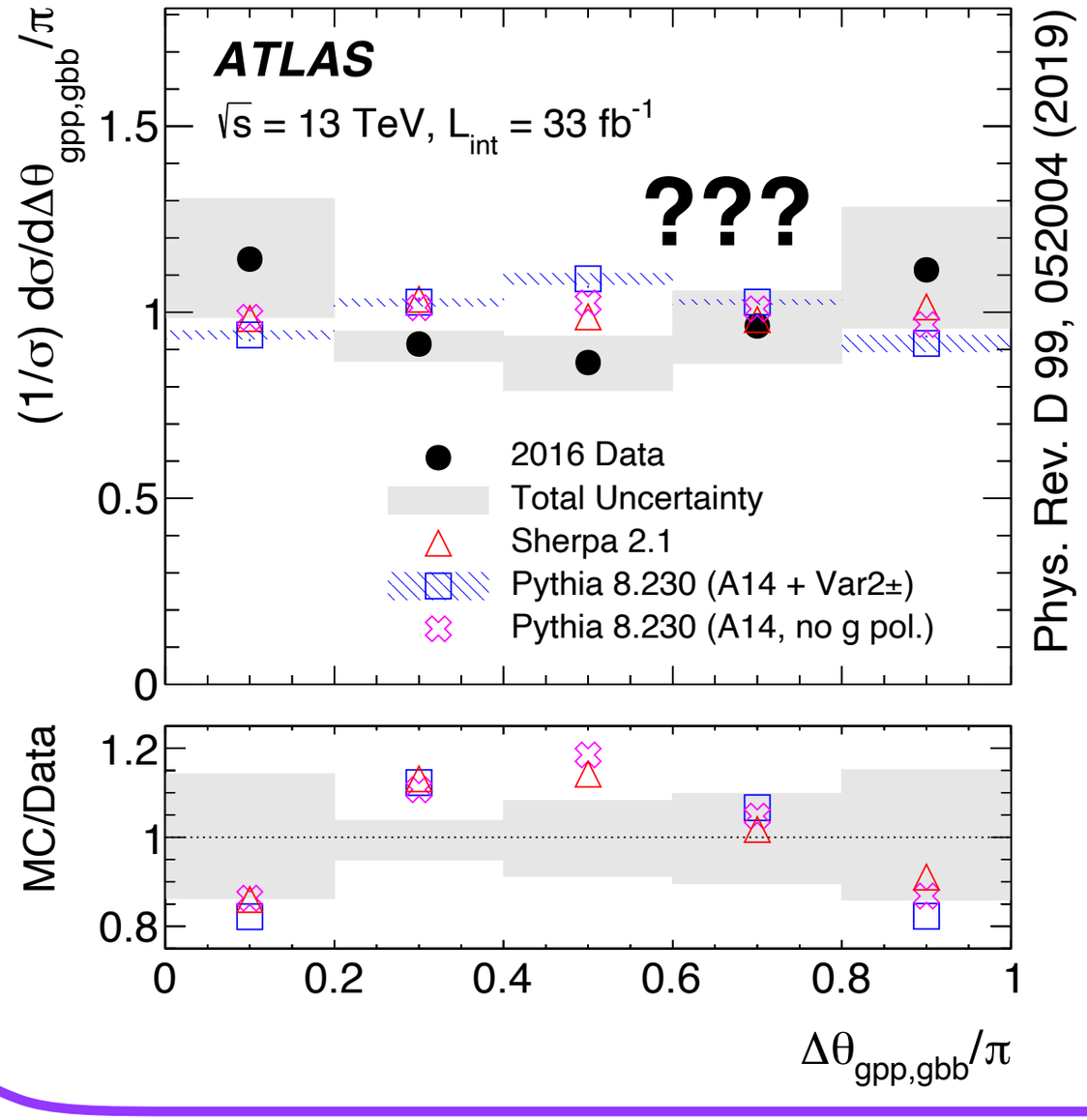

Gluons seems "more polarized" in data than in our predictions. Slight improvement from matrix element corrections (Sherpa 2 → 3).

See also Fischer, Lifson, Skands, EPJC 77 (2017) 719

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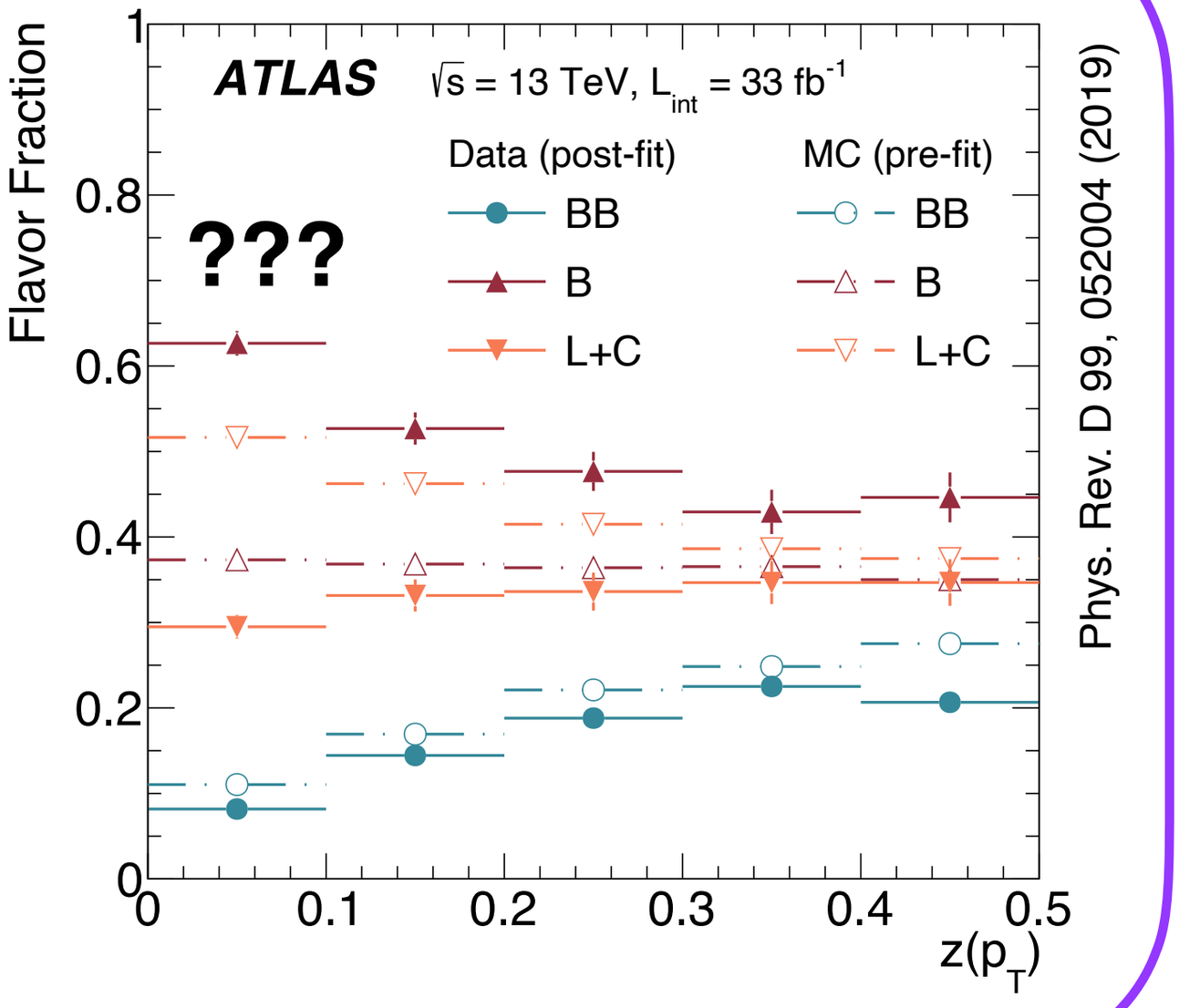
Also find that the flavor fractions are not quite correct?

(determined from a fit to the displacement of tracks inside jets)



Jets in eA at the HL-EIC

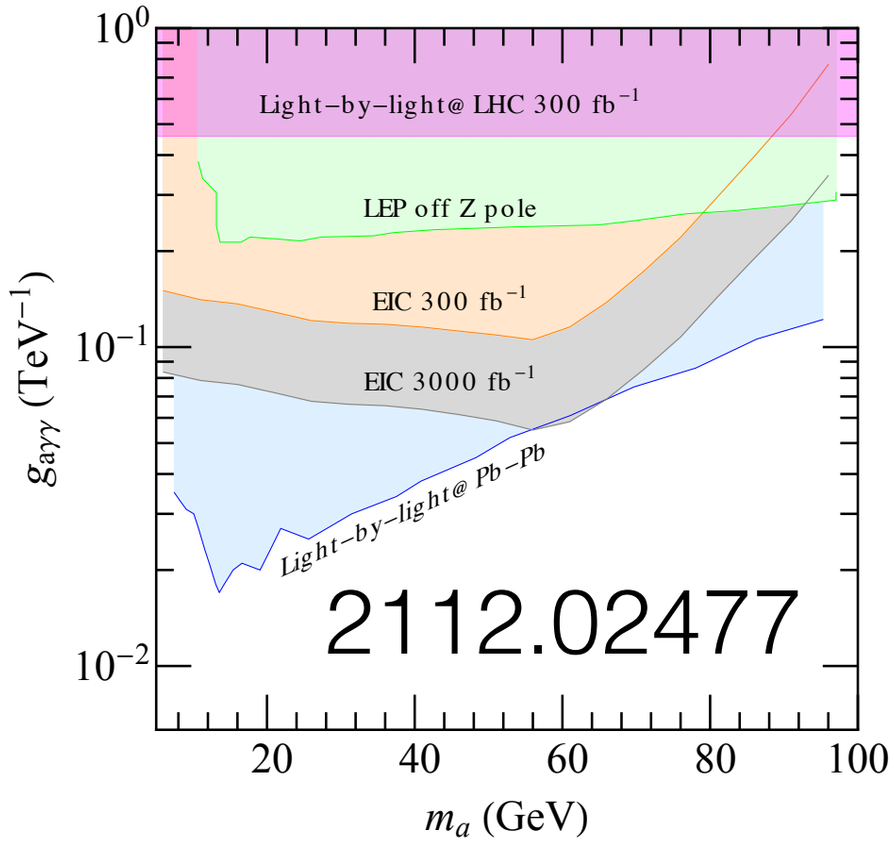
One of the goals will be to study collective effects.

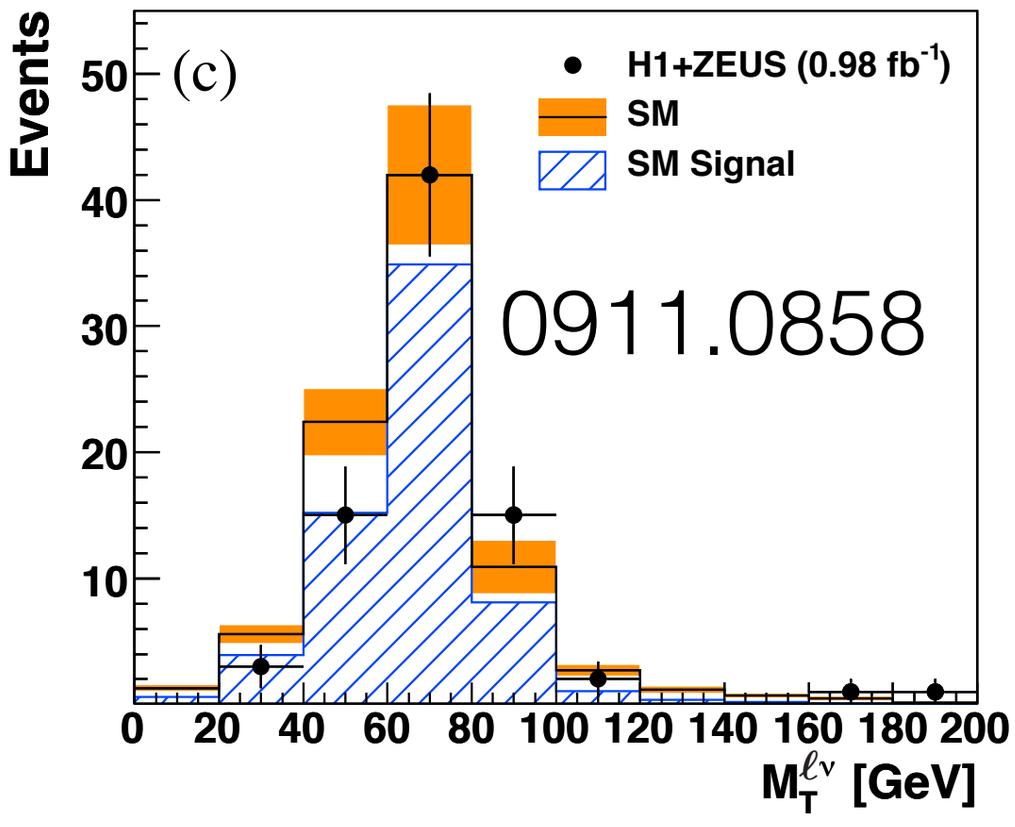
If they exist for jets, then we know
so far that they must be small.

Therefore, we will need a lot of data!

Crazy ideas

What about BSM? Maybe there are places where (HL)EIC could compete, e.g. axions?





What about W mass? On-shell W production too low at HERA, but maybe can be done at HL-EIC?

Overview

The EIC will be a fantastic facility for studying QCD.

Jet physics will be one component of this exploration. **Higher stats will allow us to probe more extreme regions of phase space more differentially.**

At the same time, it is worth revisiting HERA data (see e.g. https://indico.bnl.gov/event/9370/) and/or improving methods to make the most of limited stats!

(It's time for me to make an *ep* version of this figure!)