

BOOST 2023

Experimental Summary

BOOST 2023, East Bay

Max Swiatlowski

TRIUMF



BoostZilla, a Year Early?



BoostZilla, a Year Early?



BoostZilla, a Year Early?

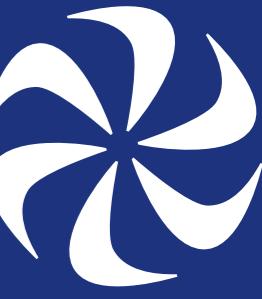


**At least they got the fog right!
(Photo credit to Robin)**



Apologies

- There were ~29 wonderful experimental talks this year
- Impossible to cover them all in any amount of detail
- My apologies if I do not include your result!
 - My selection is forced to be biased and reduced



What a Show!





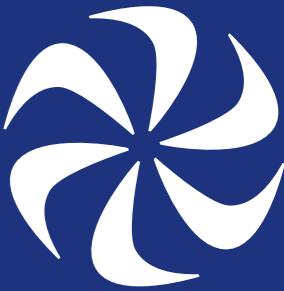
What a Show!



BOOST Conquers All



BOOST Conquers All



(Or at least the ATLAS homepage)

ATLAS EXPERIMENT

ABOUT DISCOVER RESOURCES UPDATES SEARCH

ATLAS Experiment

Exploring the secrets of the Universe

Latest News

Machine learning is revolutionising our understanding of particle "jets"

Physics Briefing | 3 August 2023

Signal and noise

Physics Briefing | 1 August 2023

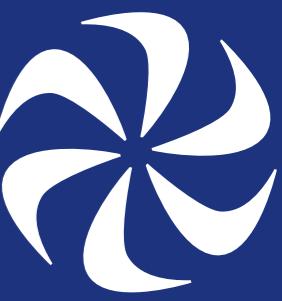
EAST BAY
BOOST 23

LAWRENCE BERKELEY NATIONAL LAB

31 JUL - 4 AUG

See more

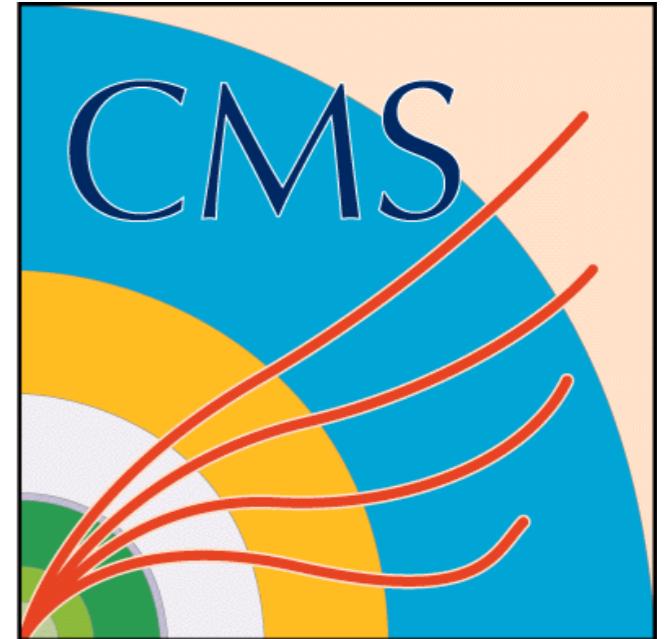
A Thriving Community



A Thriving Community



BOOST 2012:



A Thriving Community

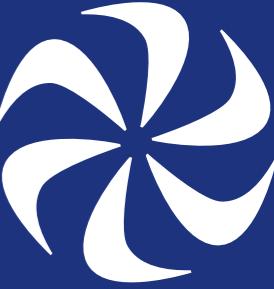


BOOST 2012:

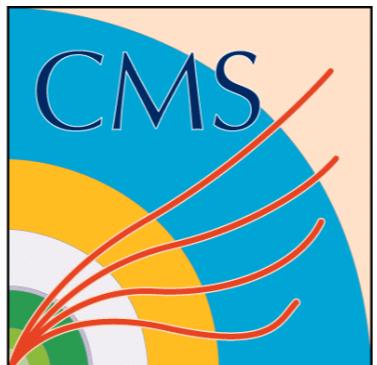
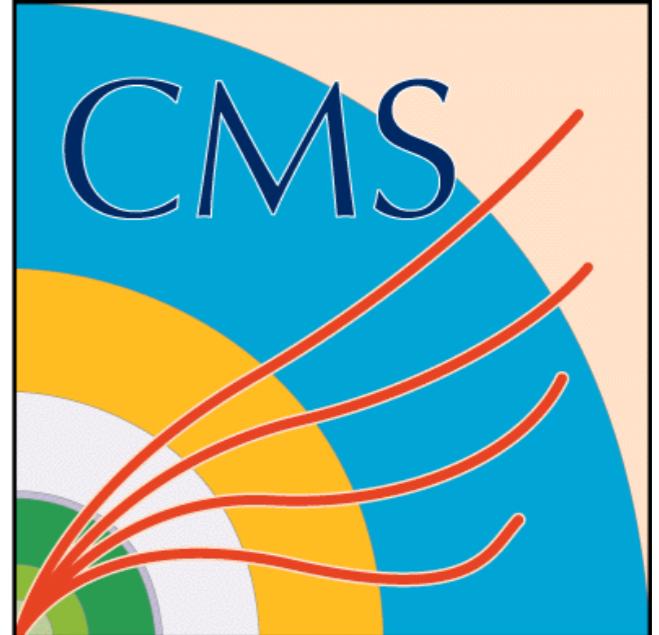


BOOST 2023:

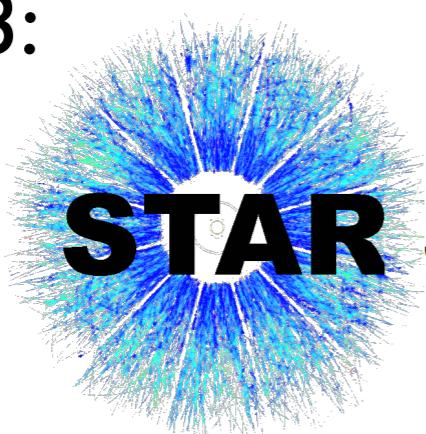
A Thriving Community



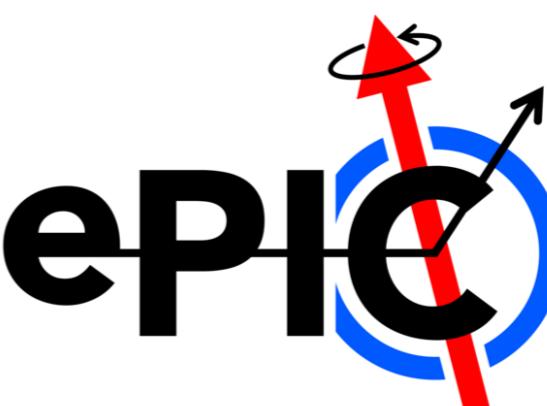
BOOST 2012:



BOOST 2023:



sPHENIX



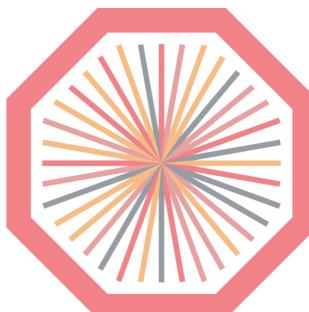
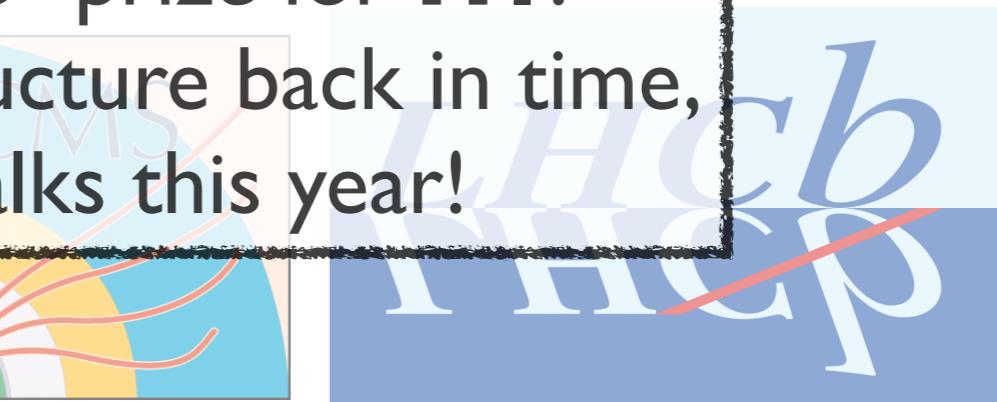
A Thriving Community



BOOST 2012:

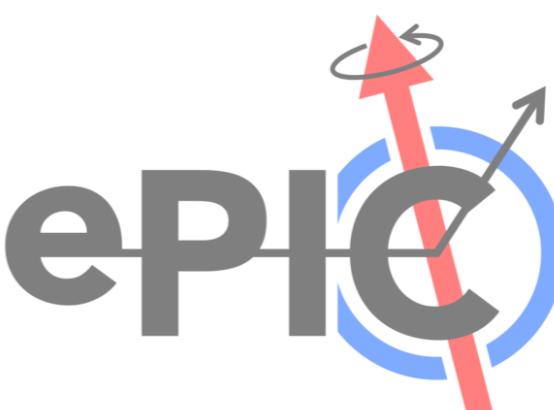
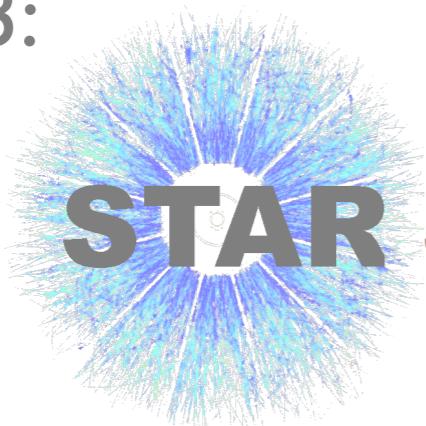


Special “zombie” prize for **H1**:
Bringing jet substructure back in time,
with three talks this year!



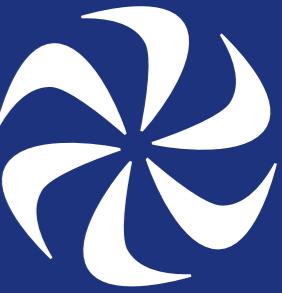
ALICE

BOOST 2023:



Detector Performance

Asking the Big Questions



WHAT IS A DETECTOR?



CMS Detector Performance



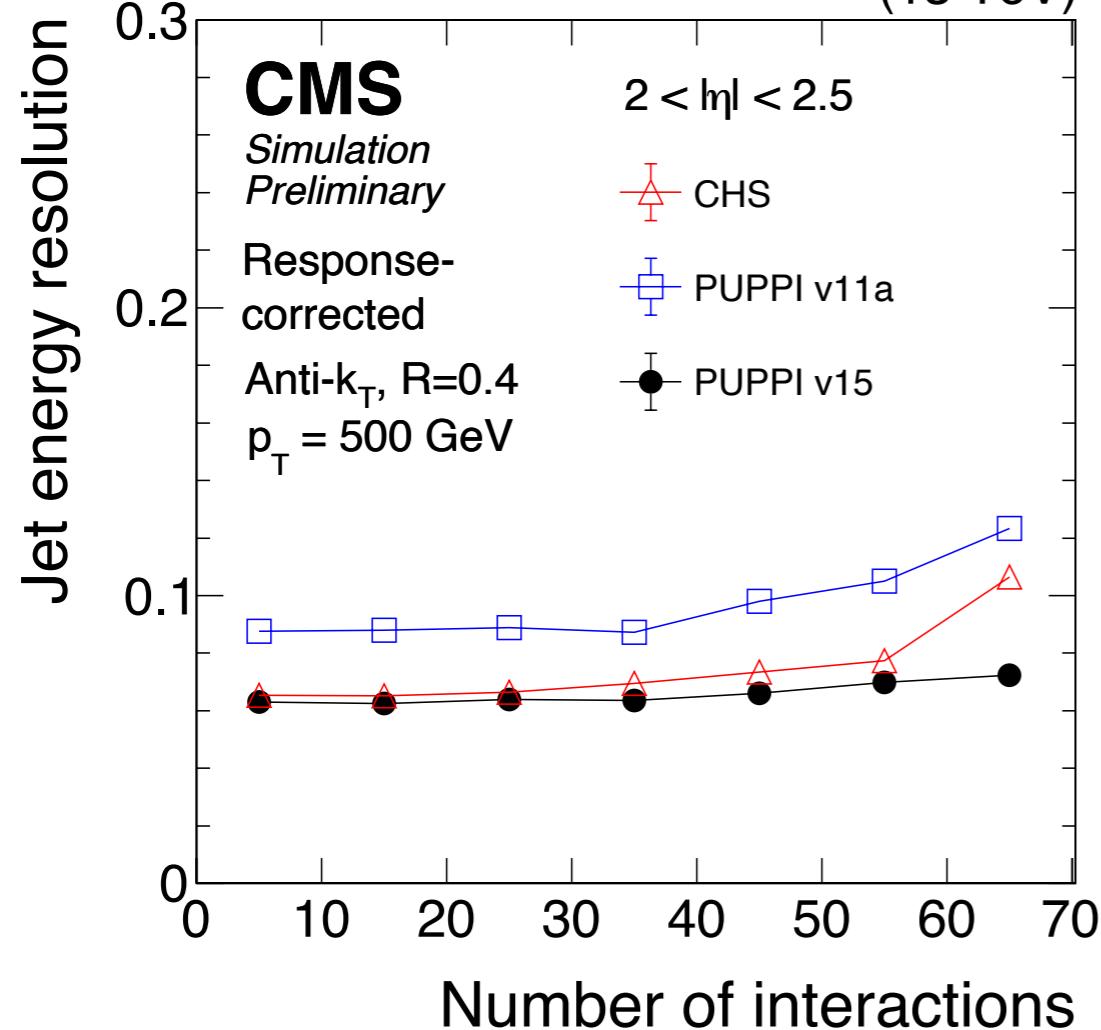
Steffen

CMS Detector Performance



Steffen

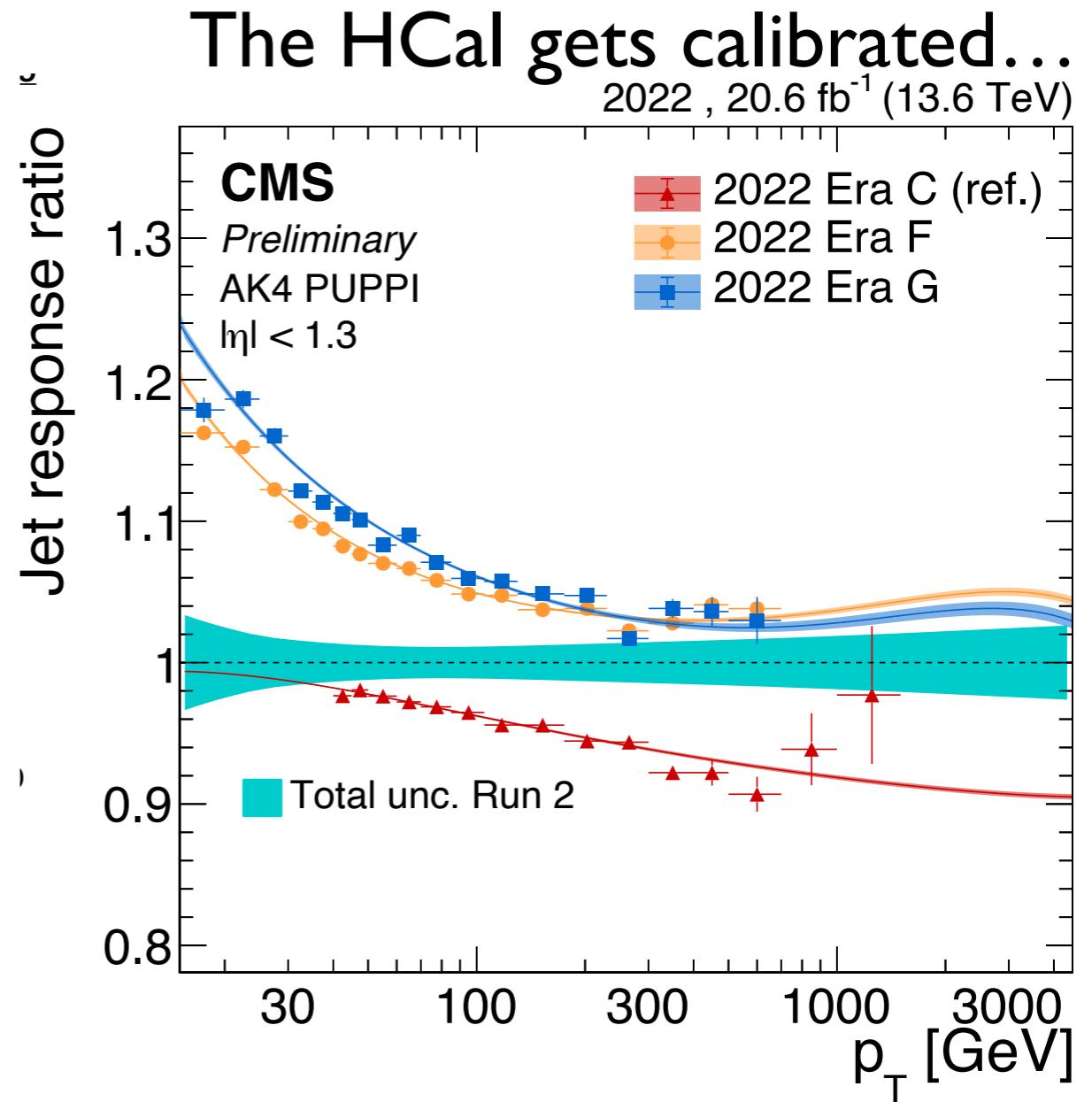
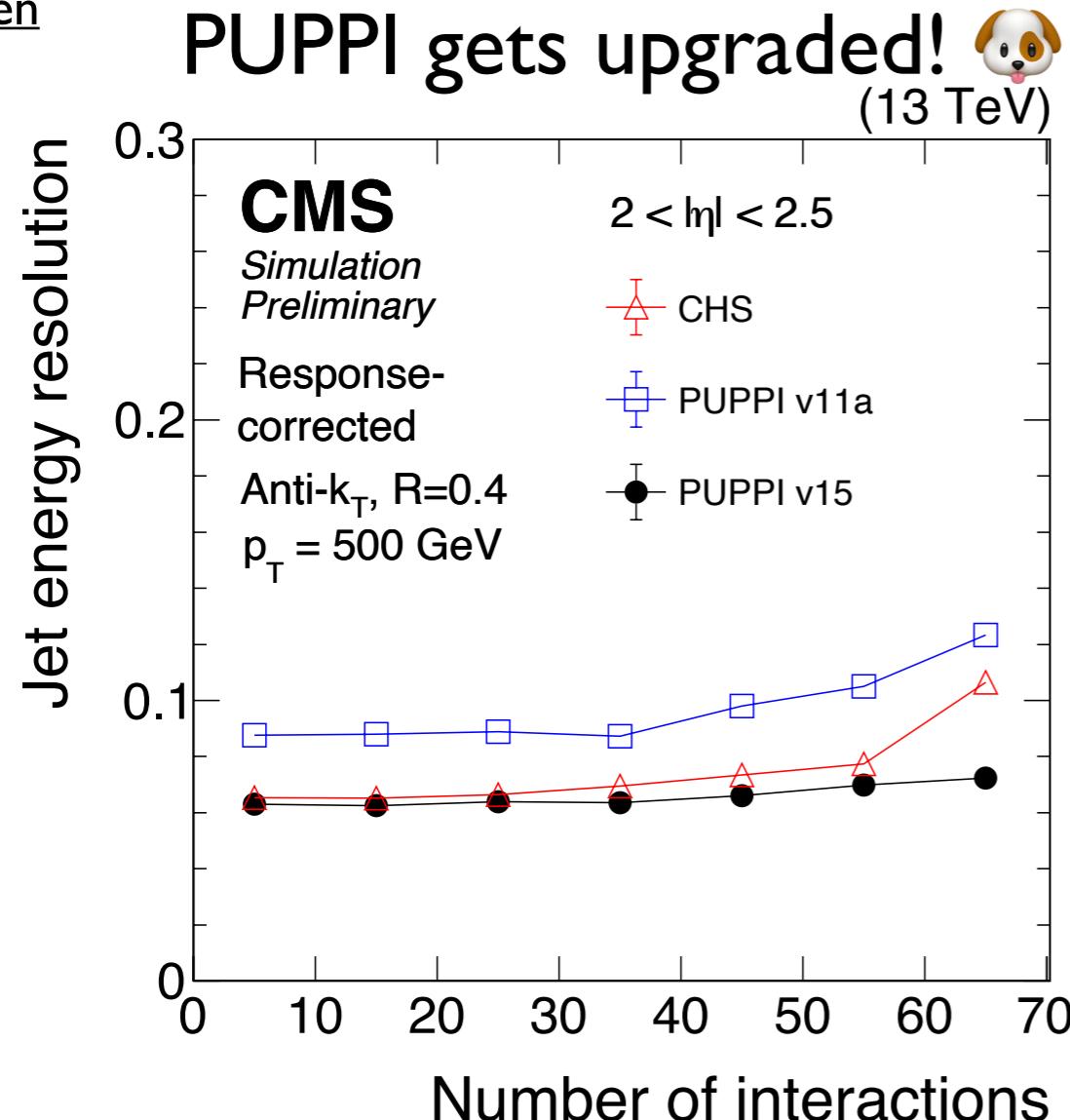
PUPPI gets upgraded! 🐶
(13 TeV)



CMS Detector Performance



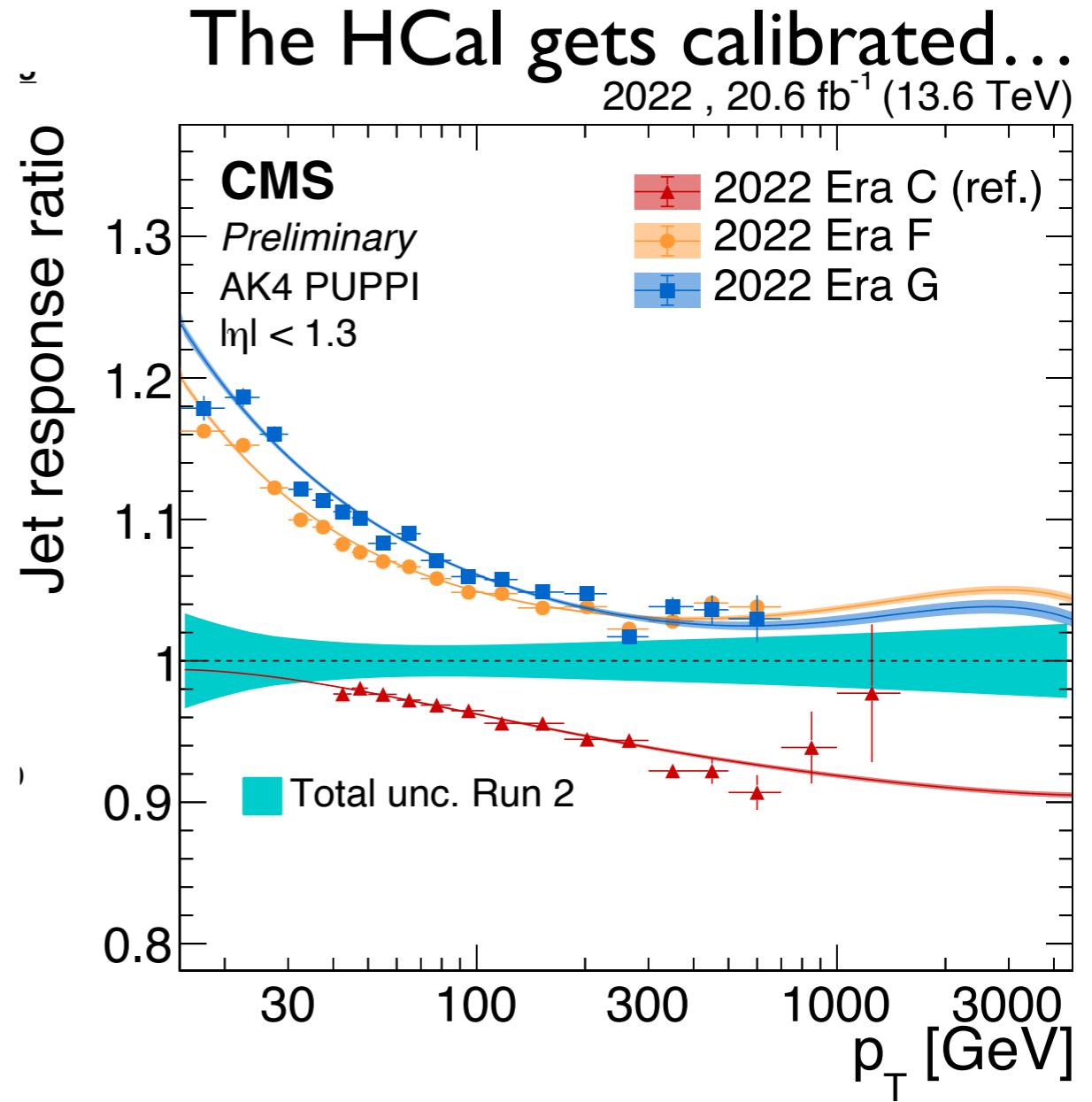
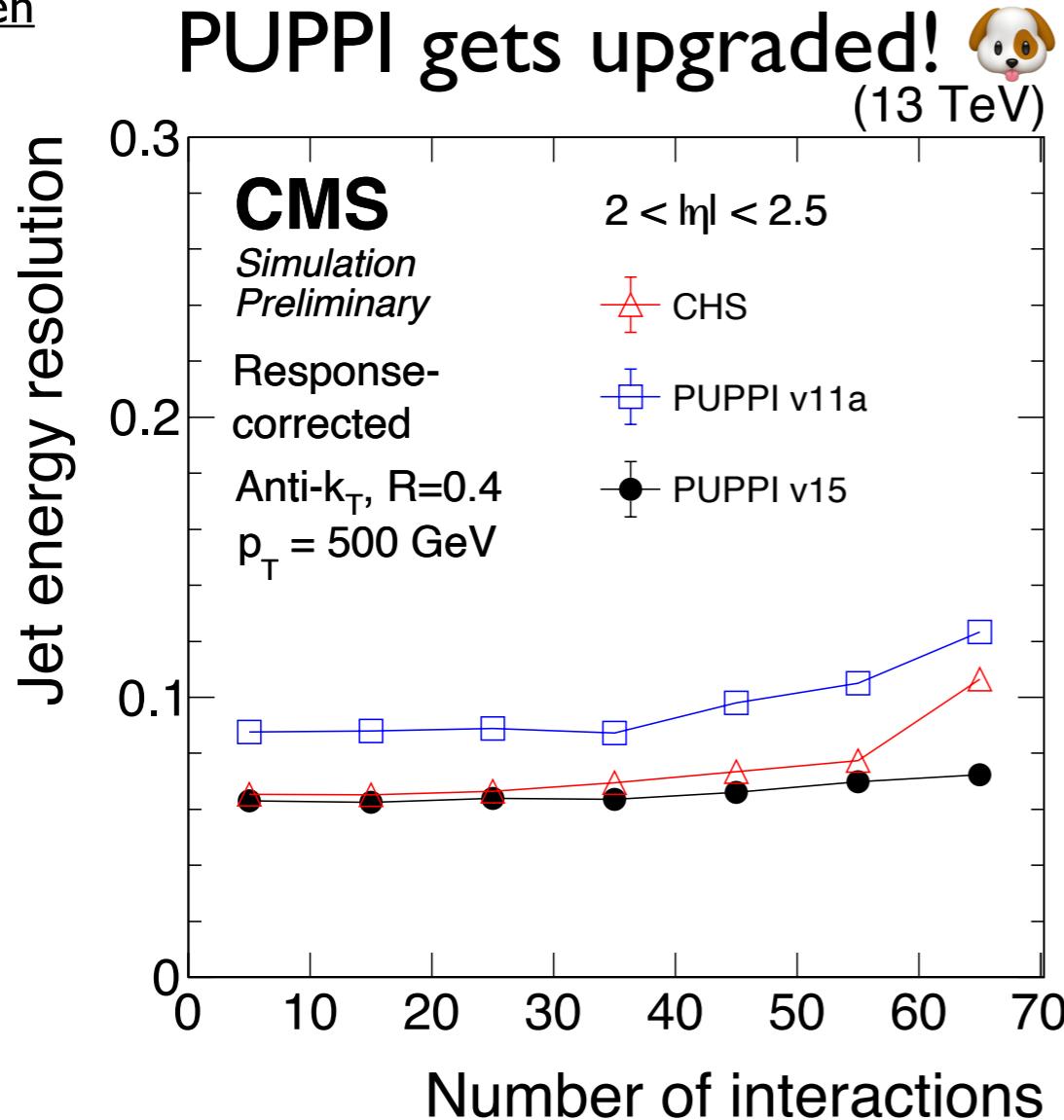
Steffen



CMS Detector Performance

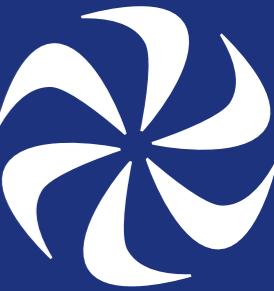


Steffen

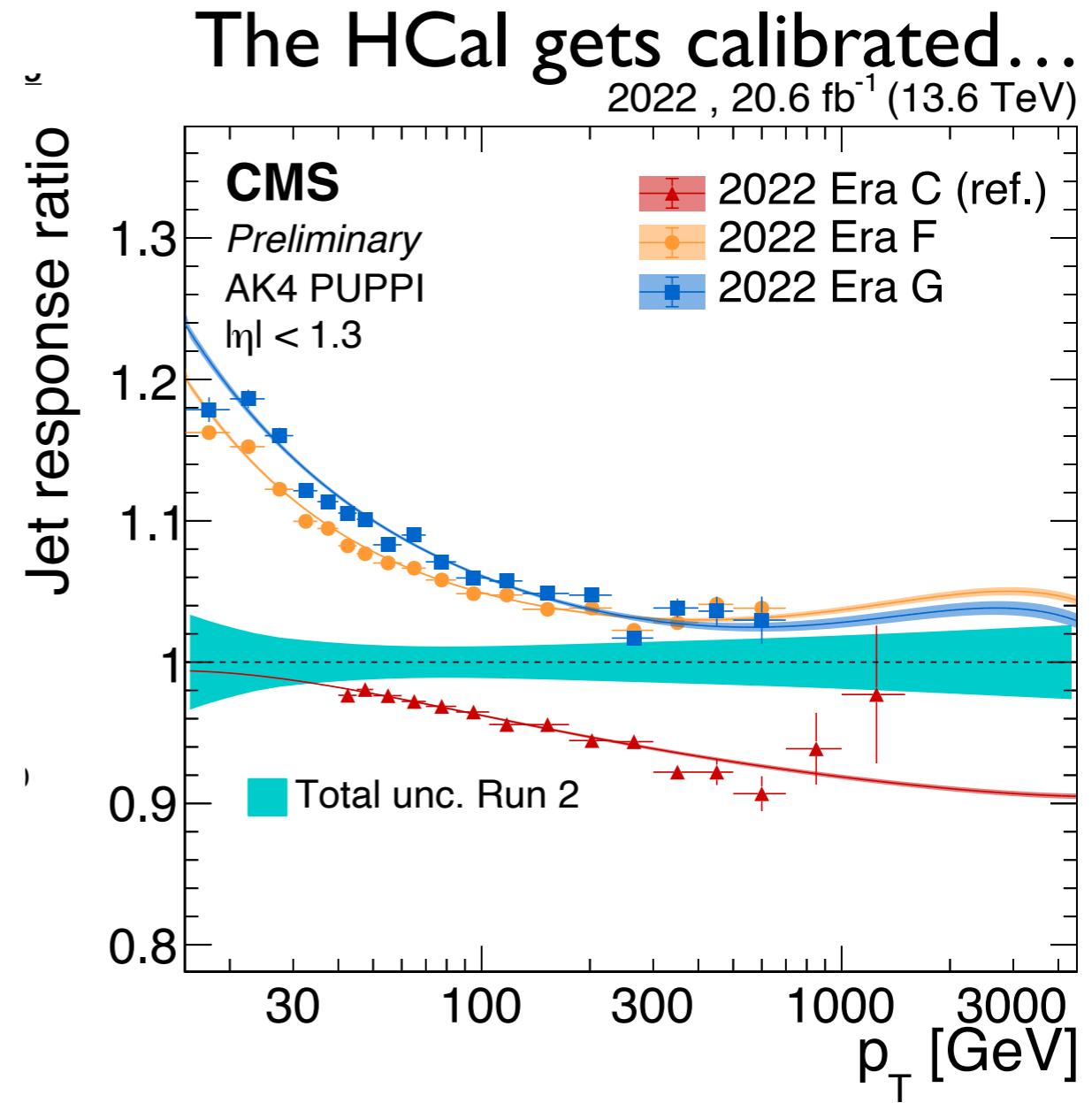
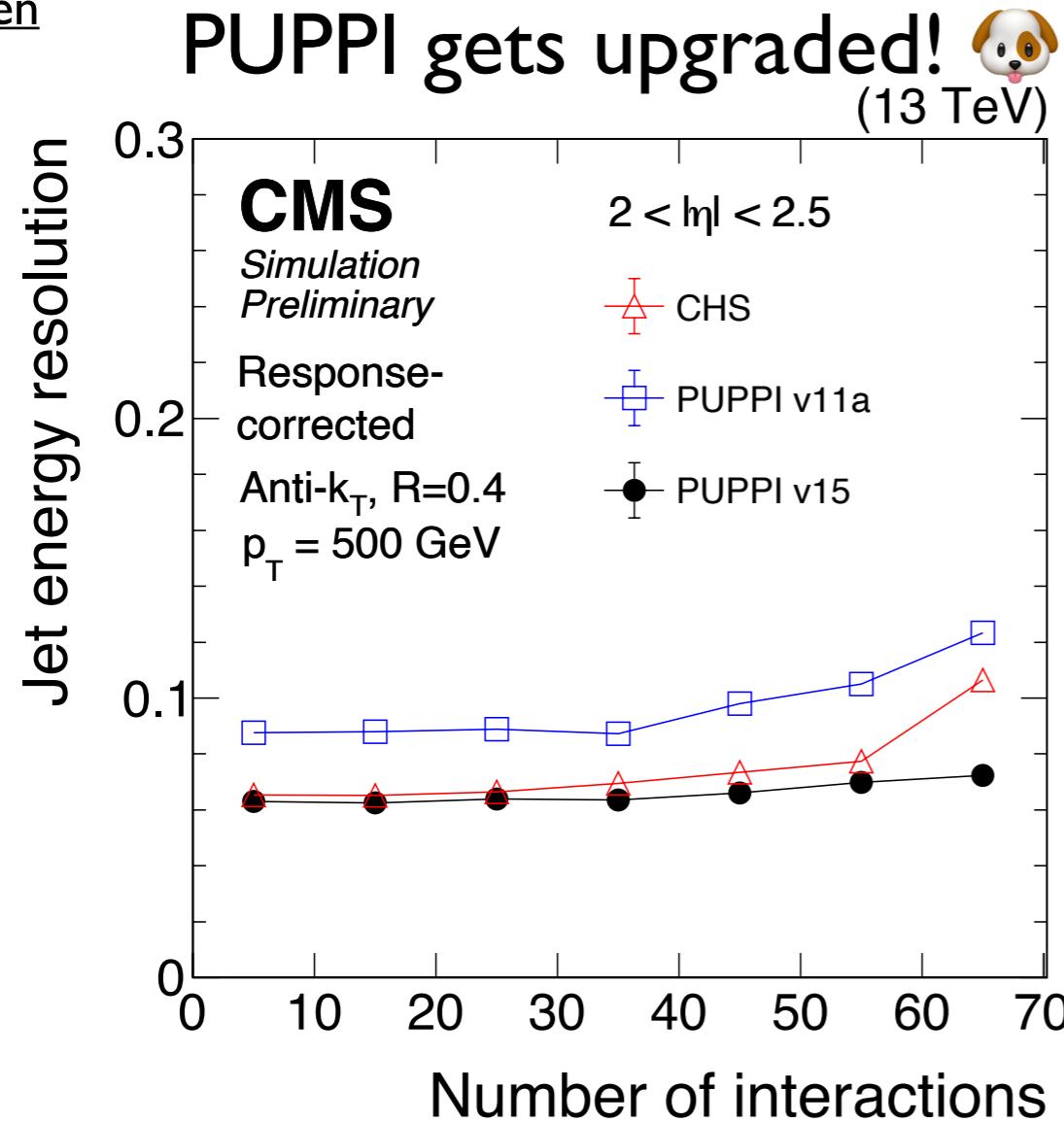


Impressive suite of results: the bread and butter
that makes everything else possible!

CMS Detector Performance



Steffen



Impressive suite of results: the bread and butter
that makes everything else possible!

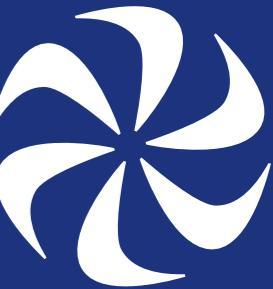
Anna: "When are ATLAS's Run3 calibration plots coming?" 😅

ATLAS Detector Performance

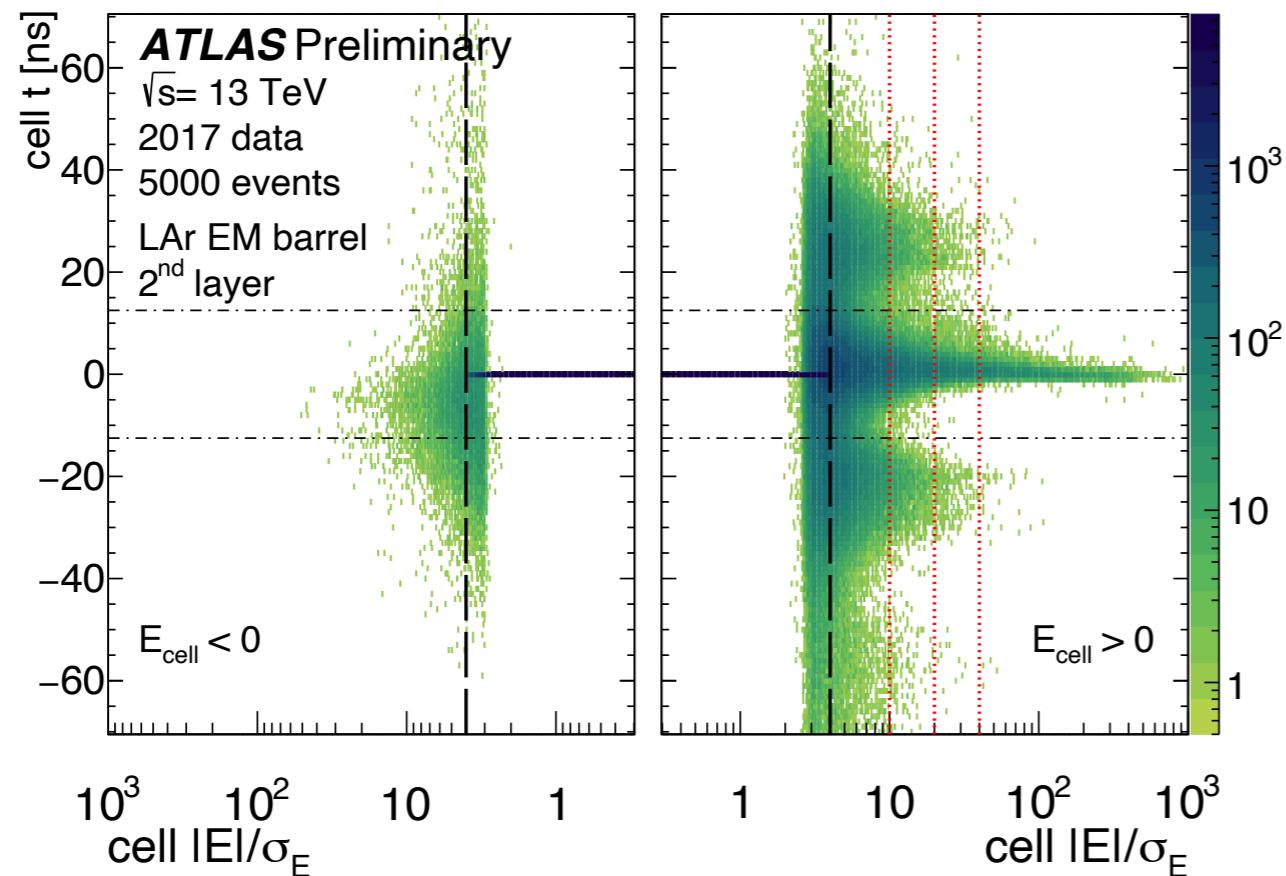


Margherita

ATLAS Detector Performance



Margherita

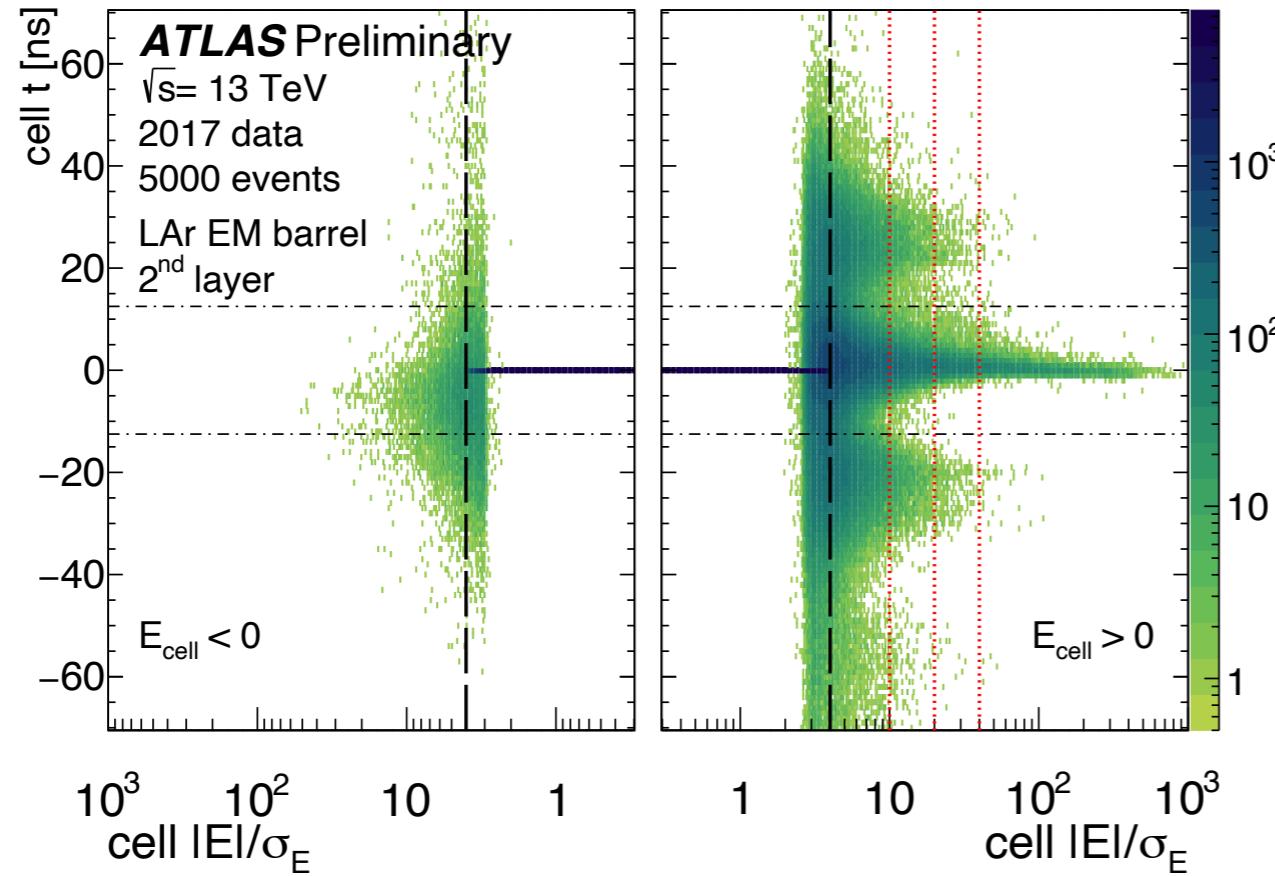


Bringing a new dimension
to pileup suppression!

ATLAS Detector Performance

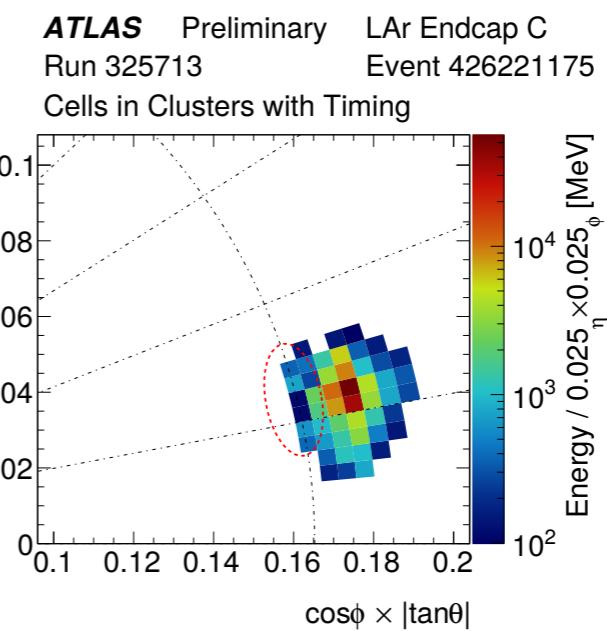
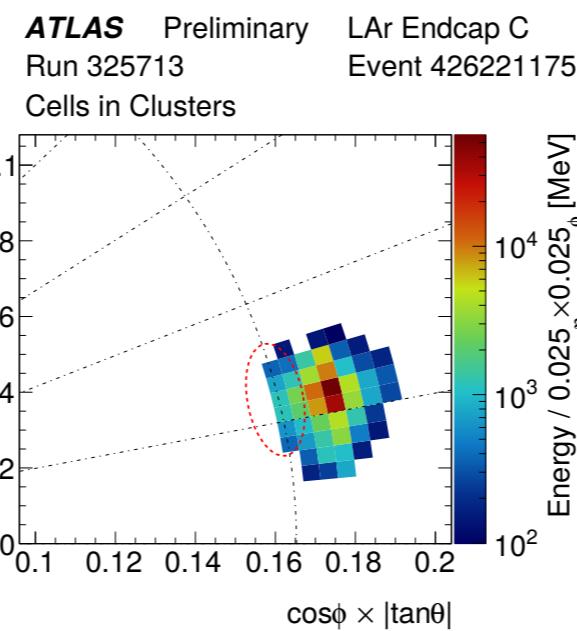
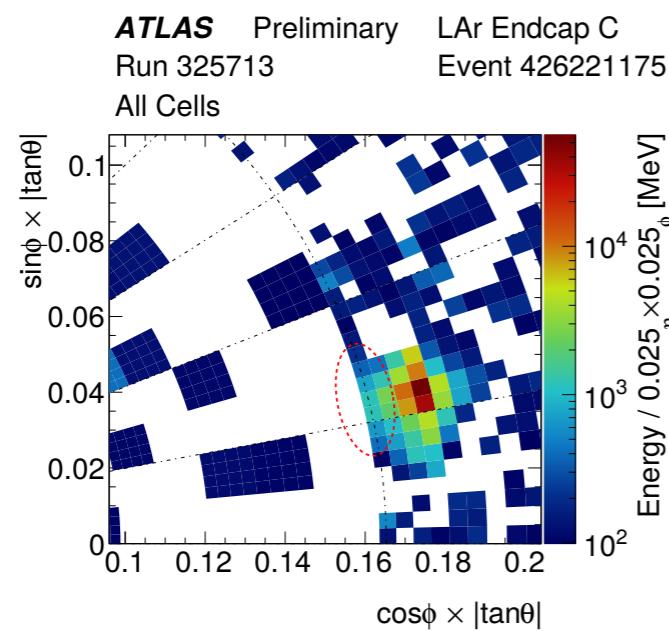


Margherita



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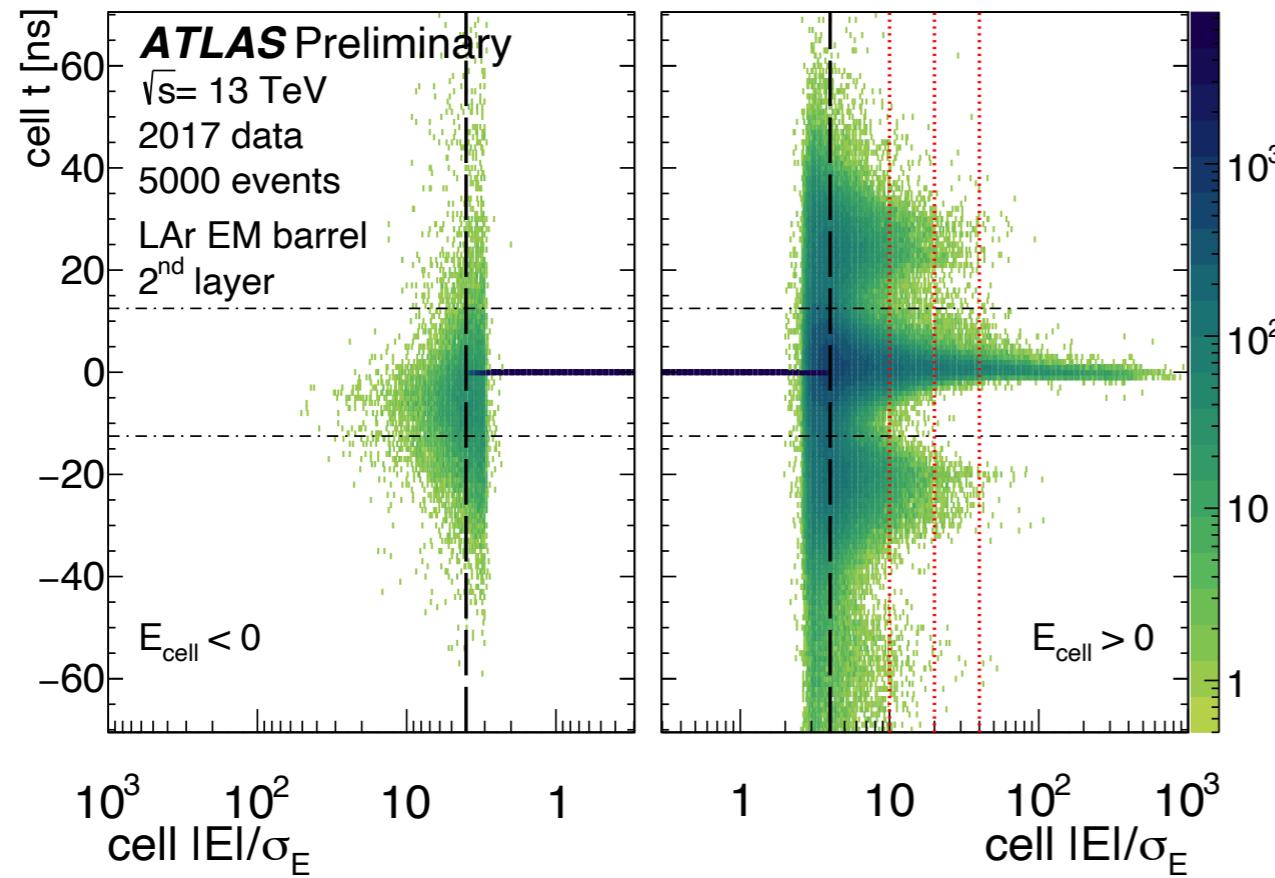
Huge effort over several years
to optimize, validate,
and commission



ATLAS Detector Performance



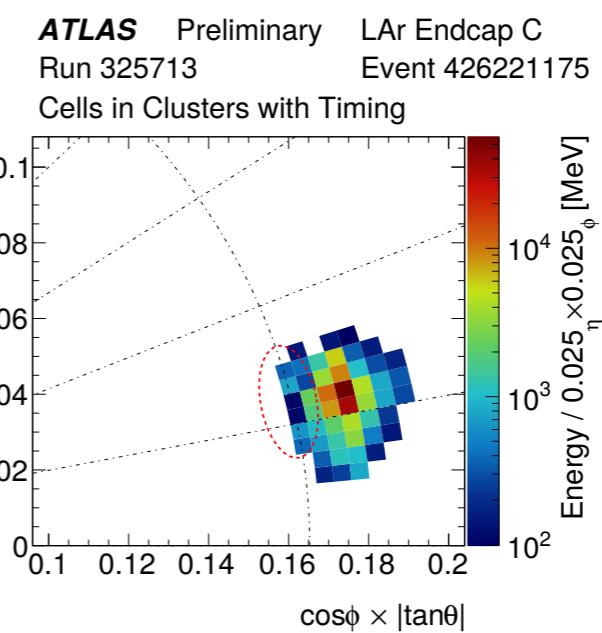
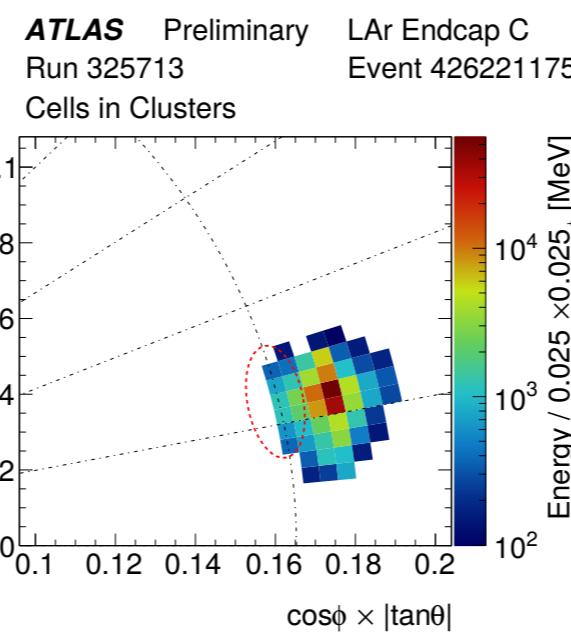
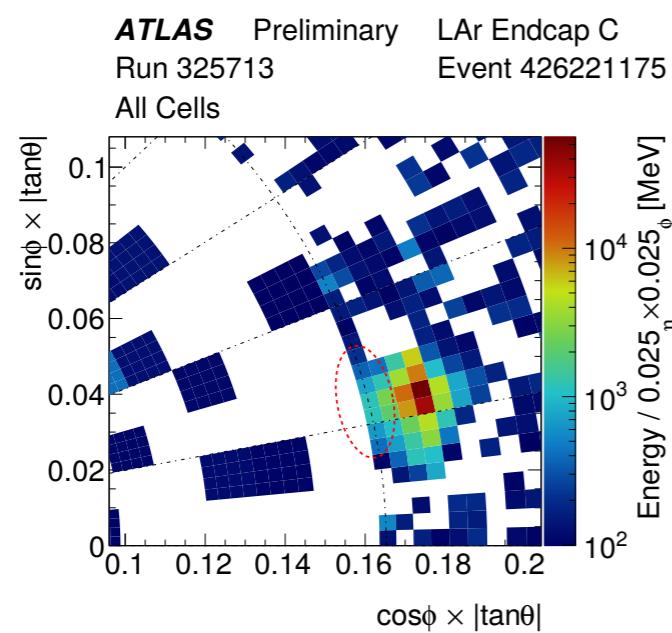
Margherita



Bringing a new dimension
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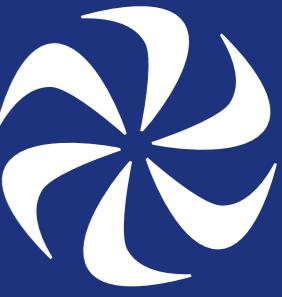
Huge effort over several years
to optimize, validate,
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Live for Run3 data!



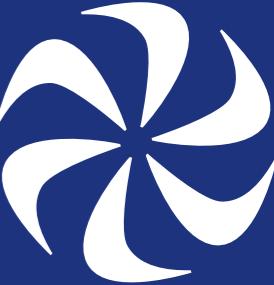
Tagging

CMS: All ParticleNet, All The Time

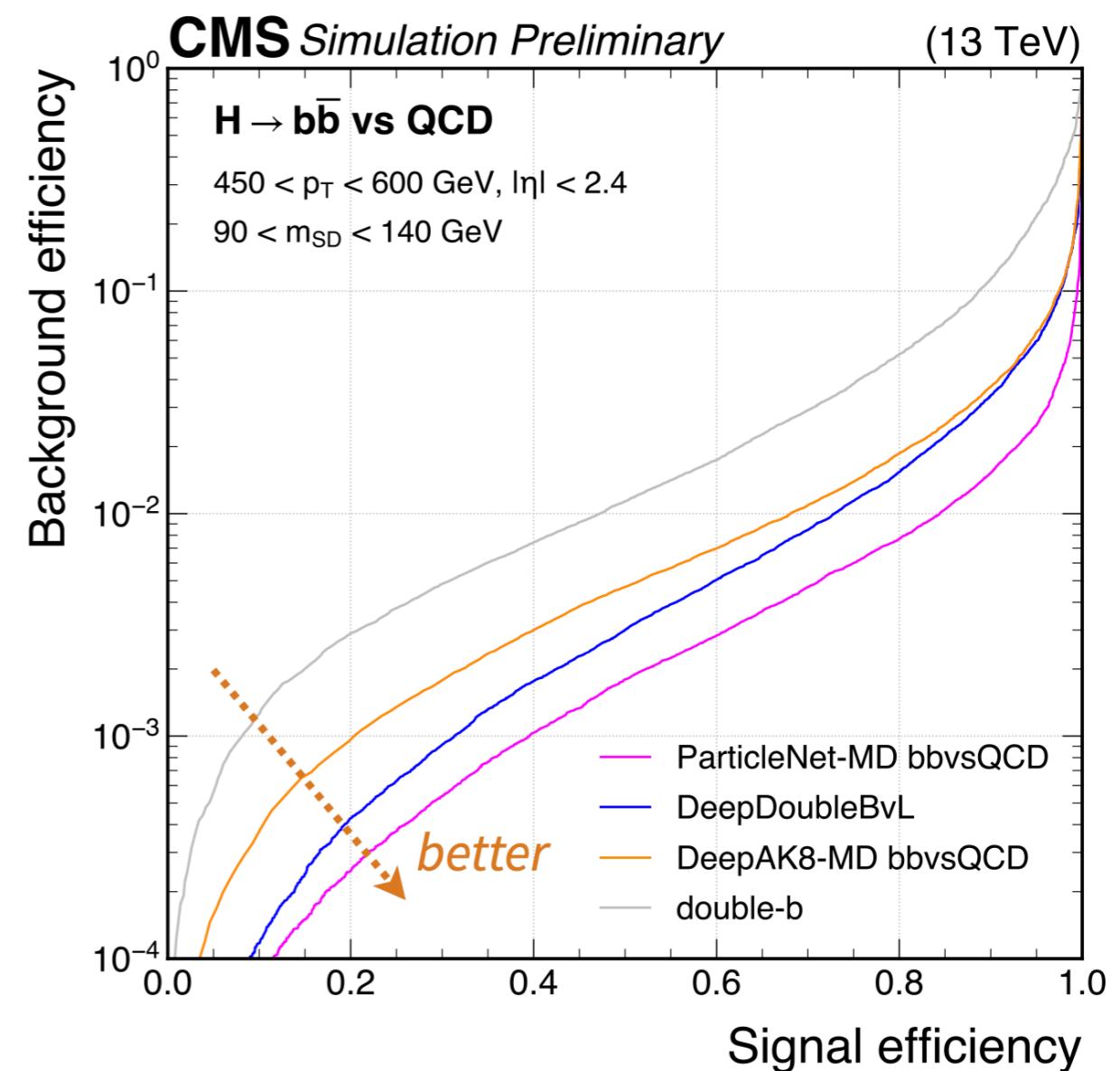
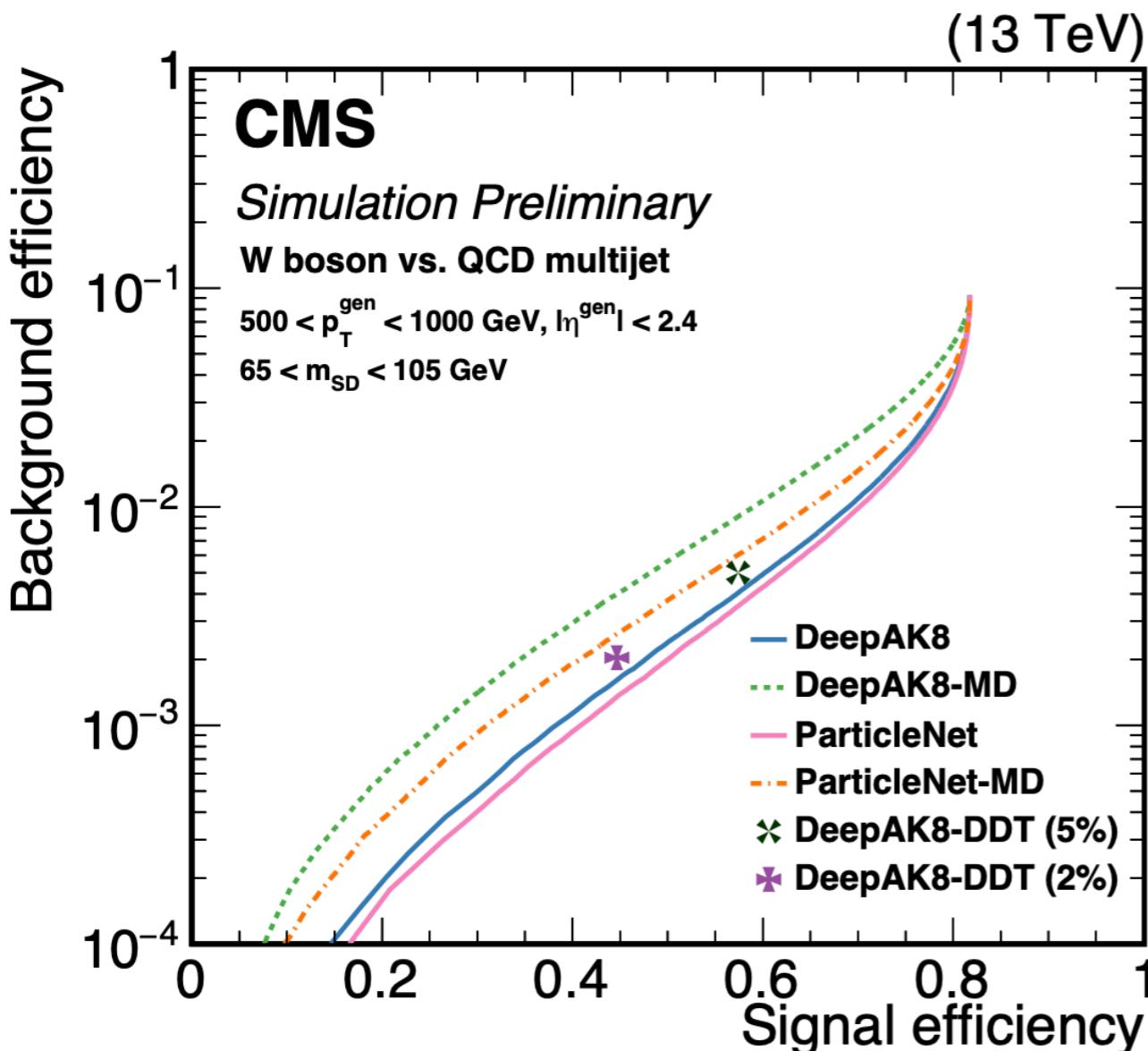


Oz, Congqiao

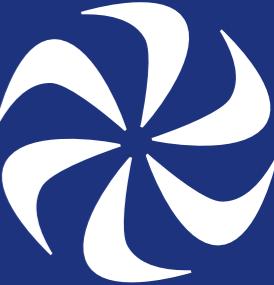
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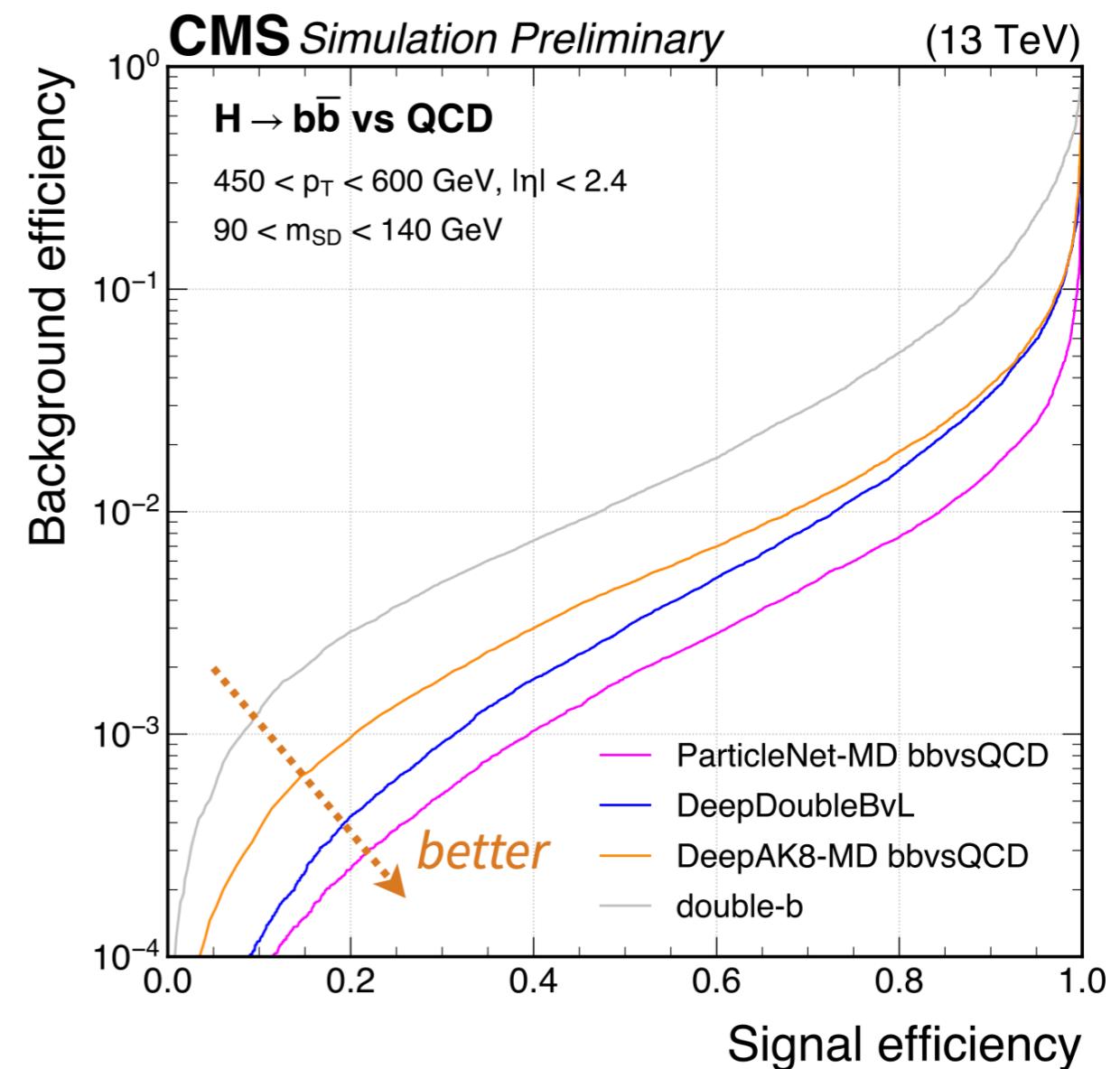
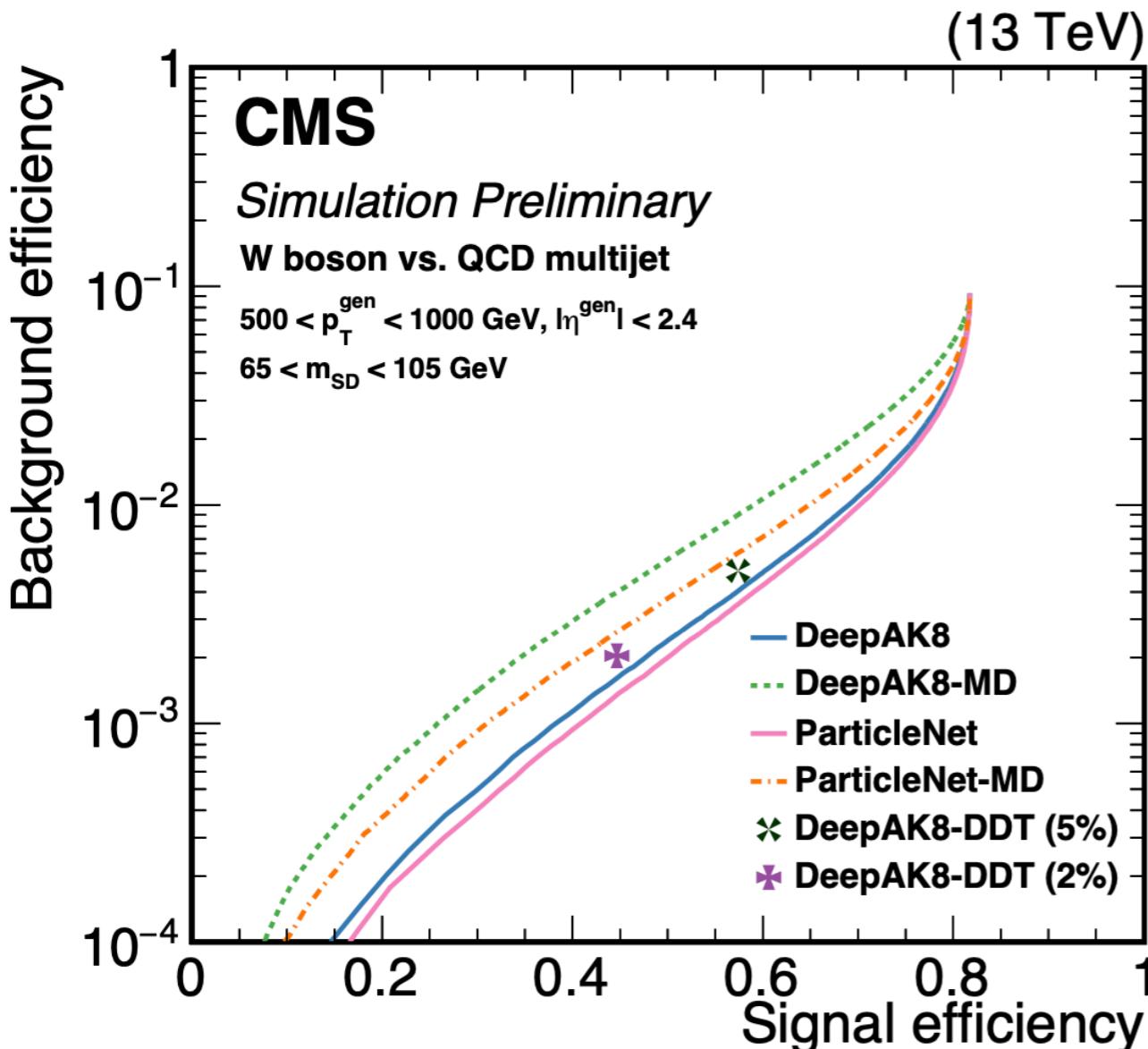
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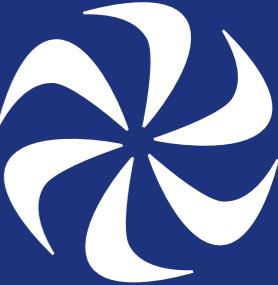


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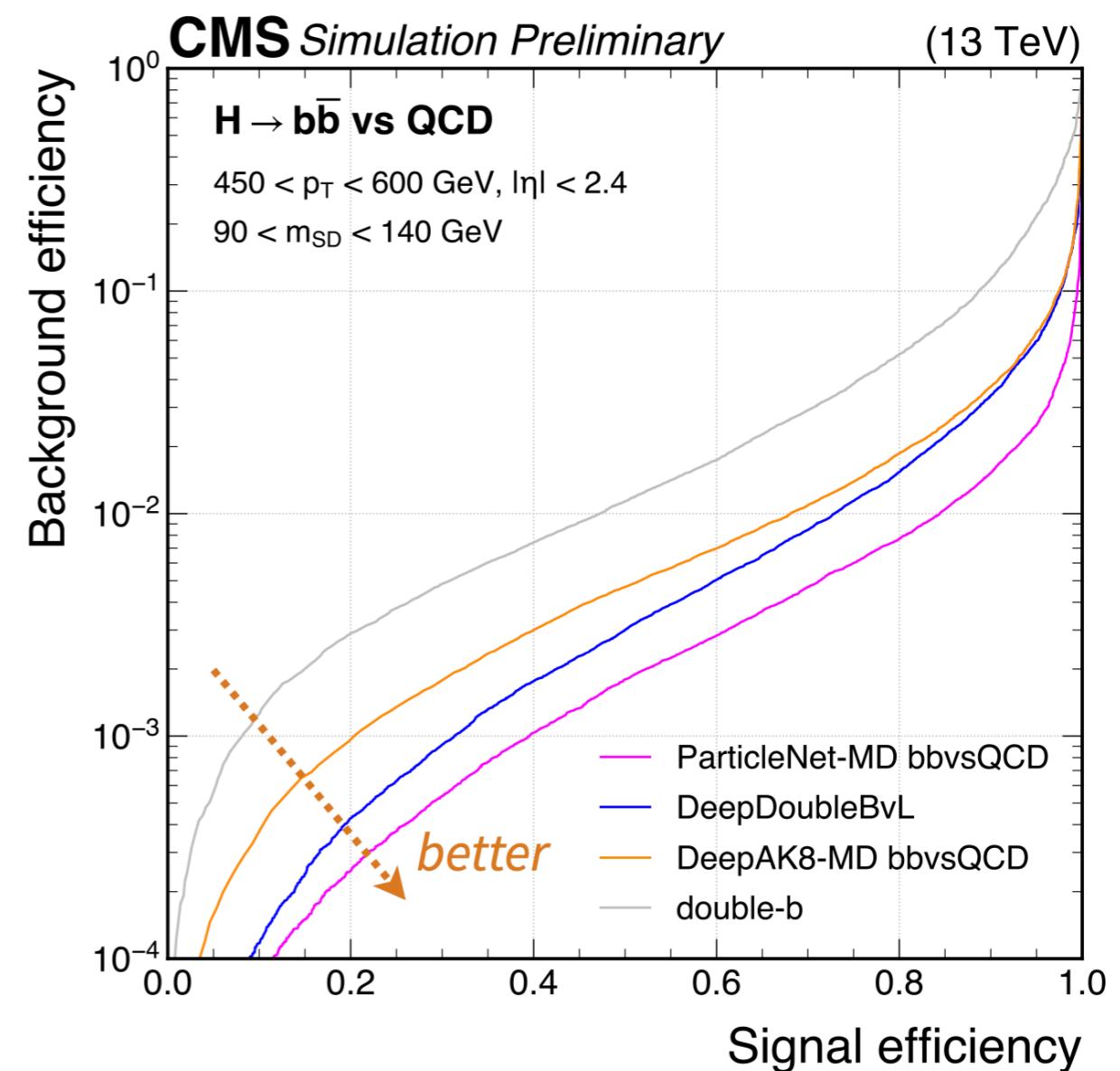
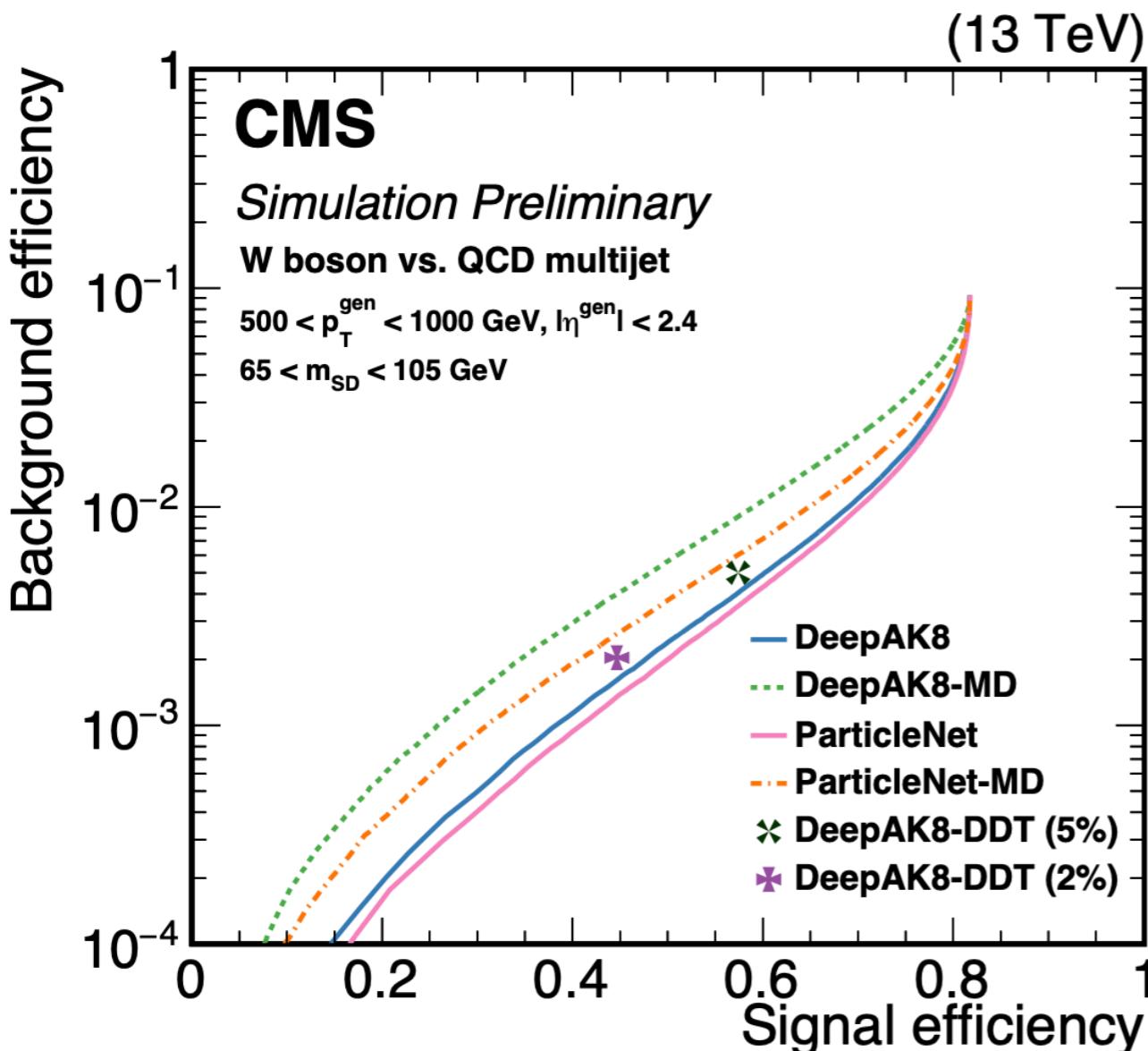


ParticleNet continues to be extremely performant!

CMS: All ParticleNet, All The Time



Oz, Congqiao



ParticleNet continues to be extremely performant!

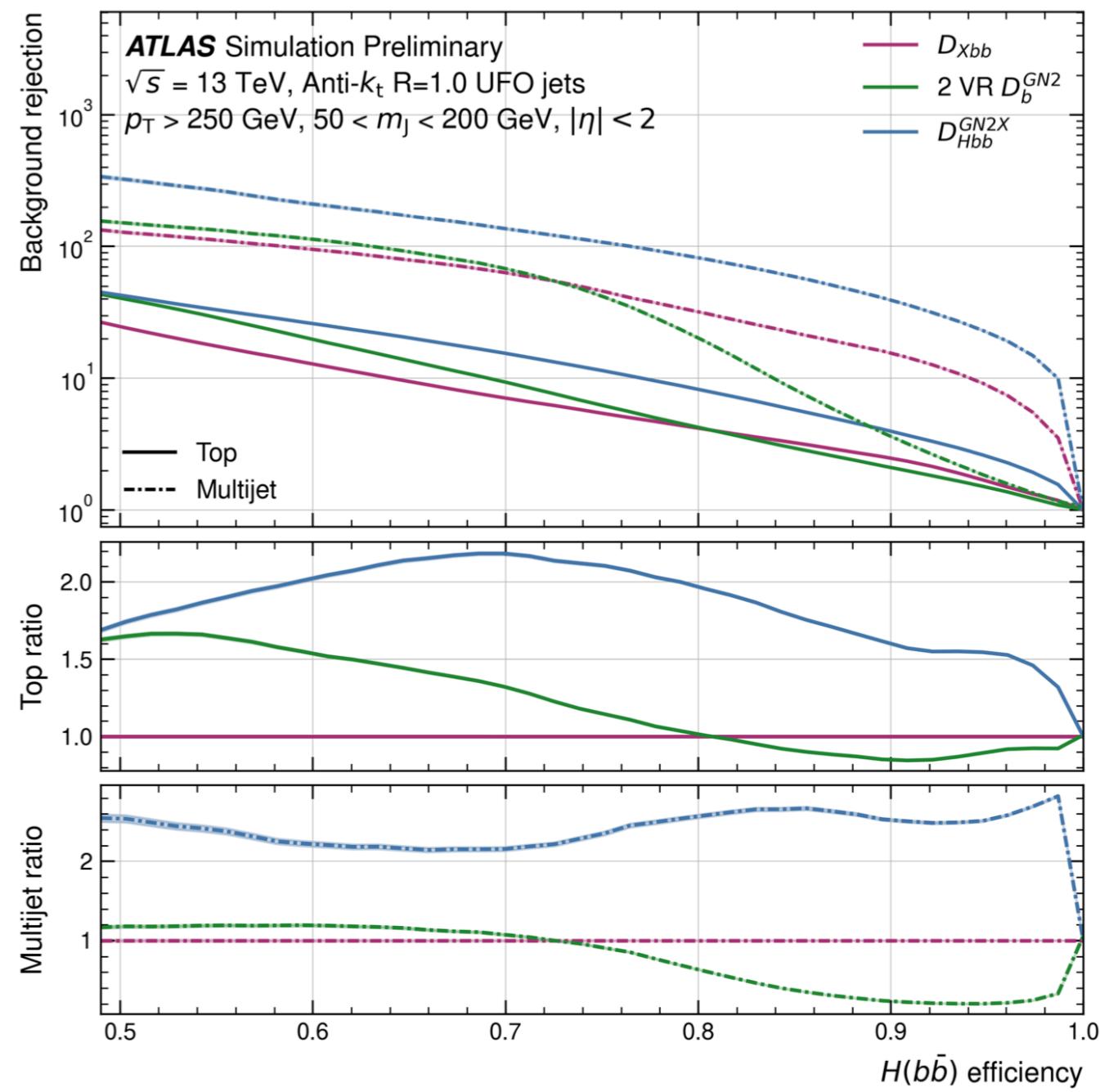
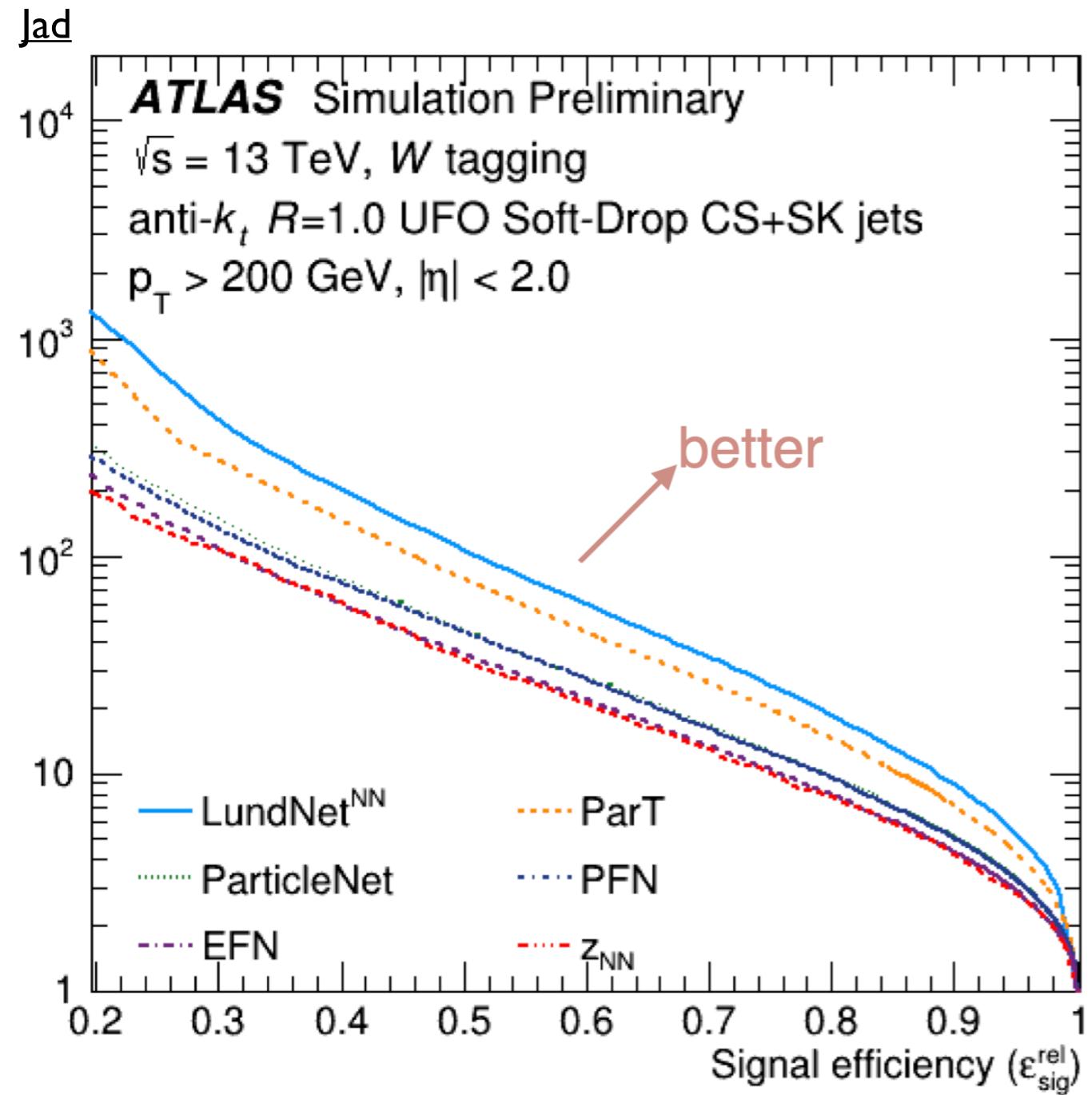
Will we see a calibration for top tagging as well? 🤔

ATLAS: To Lund and Beyond!

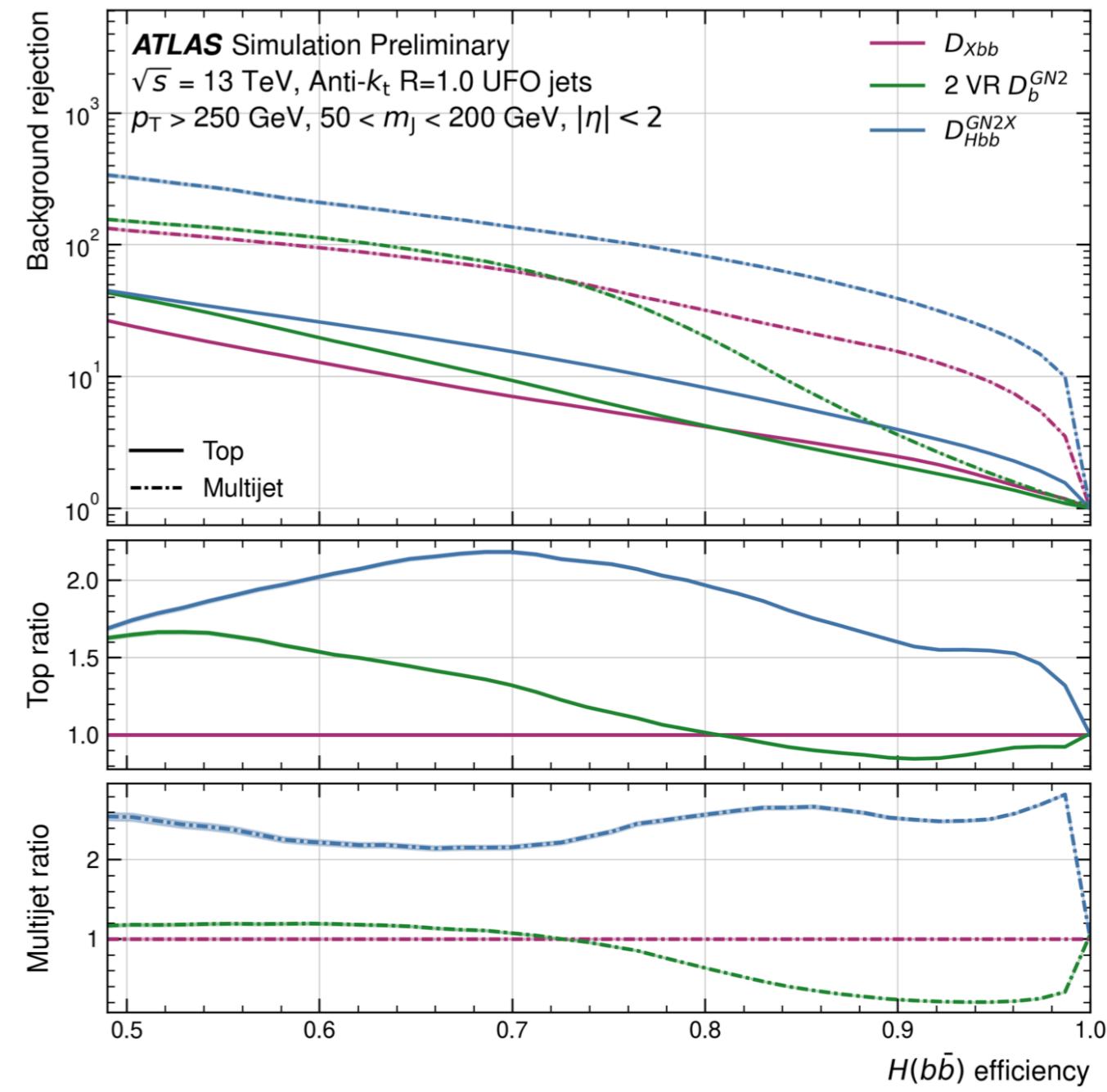
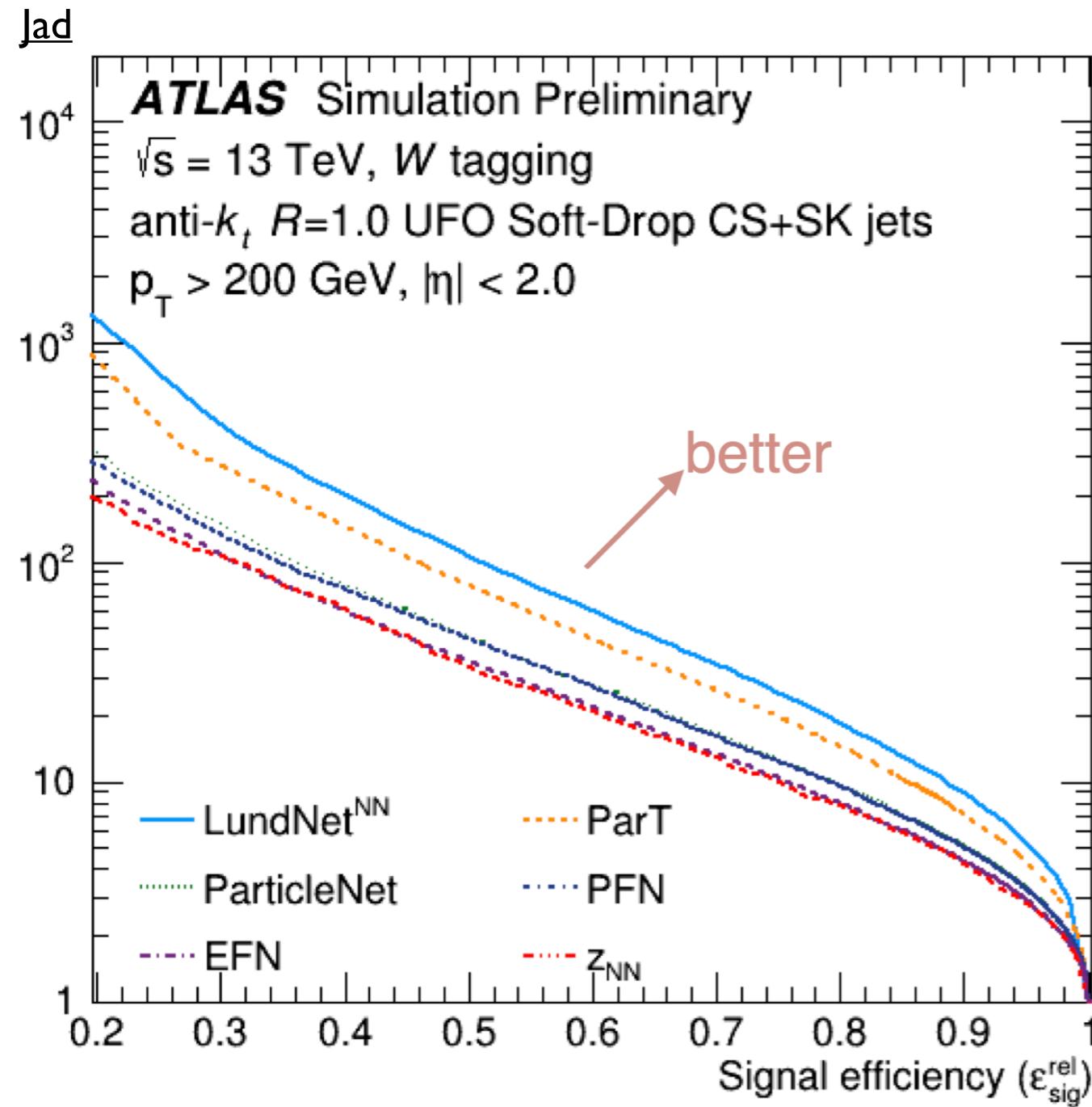


Jad

ATLAS: To Lund and Beyond!

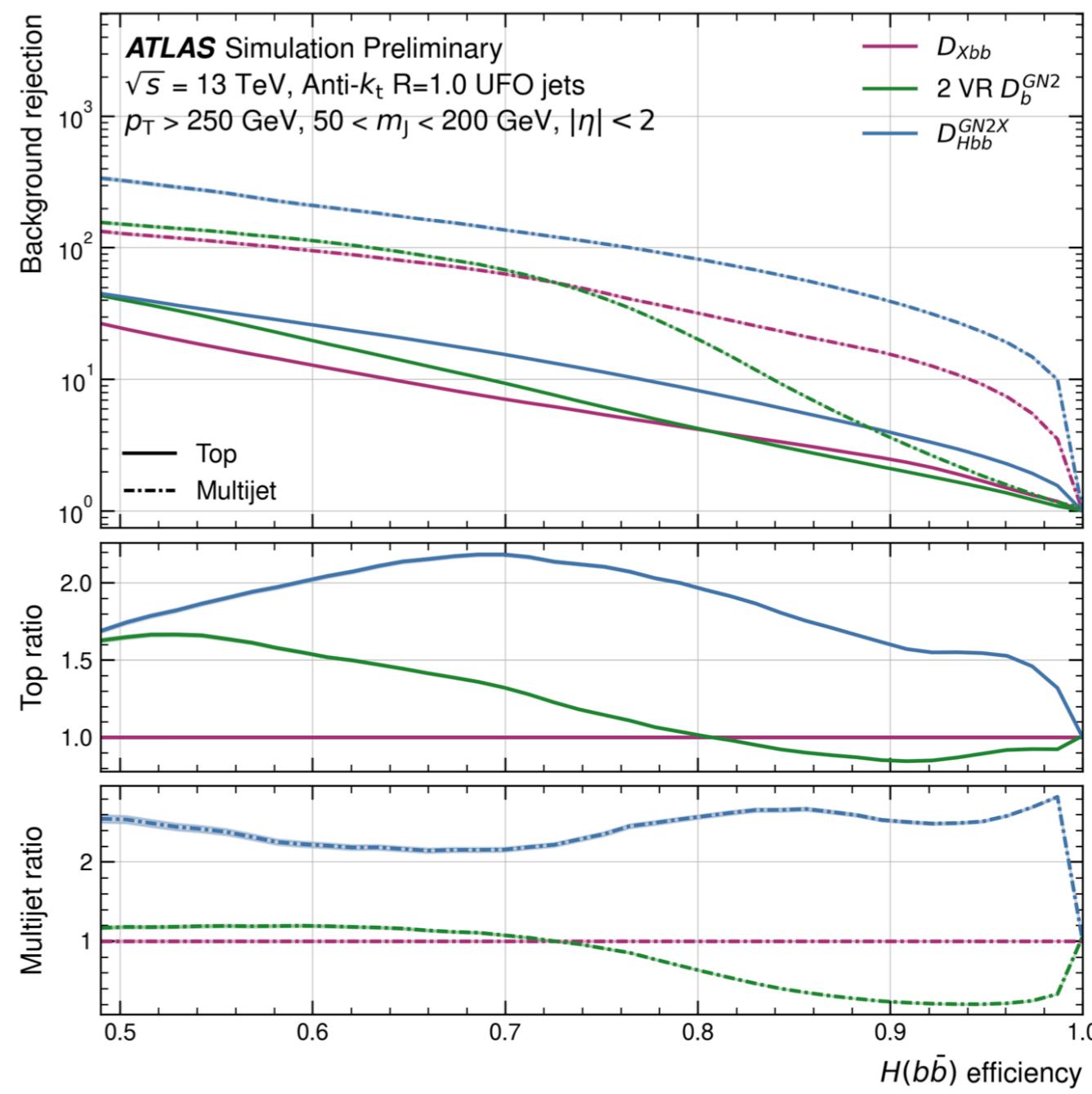
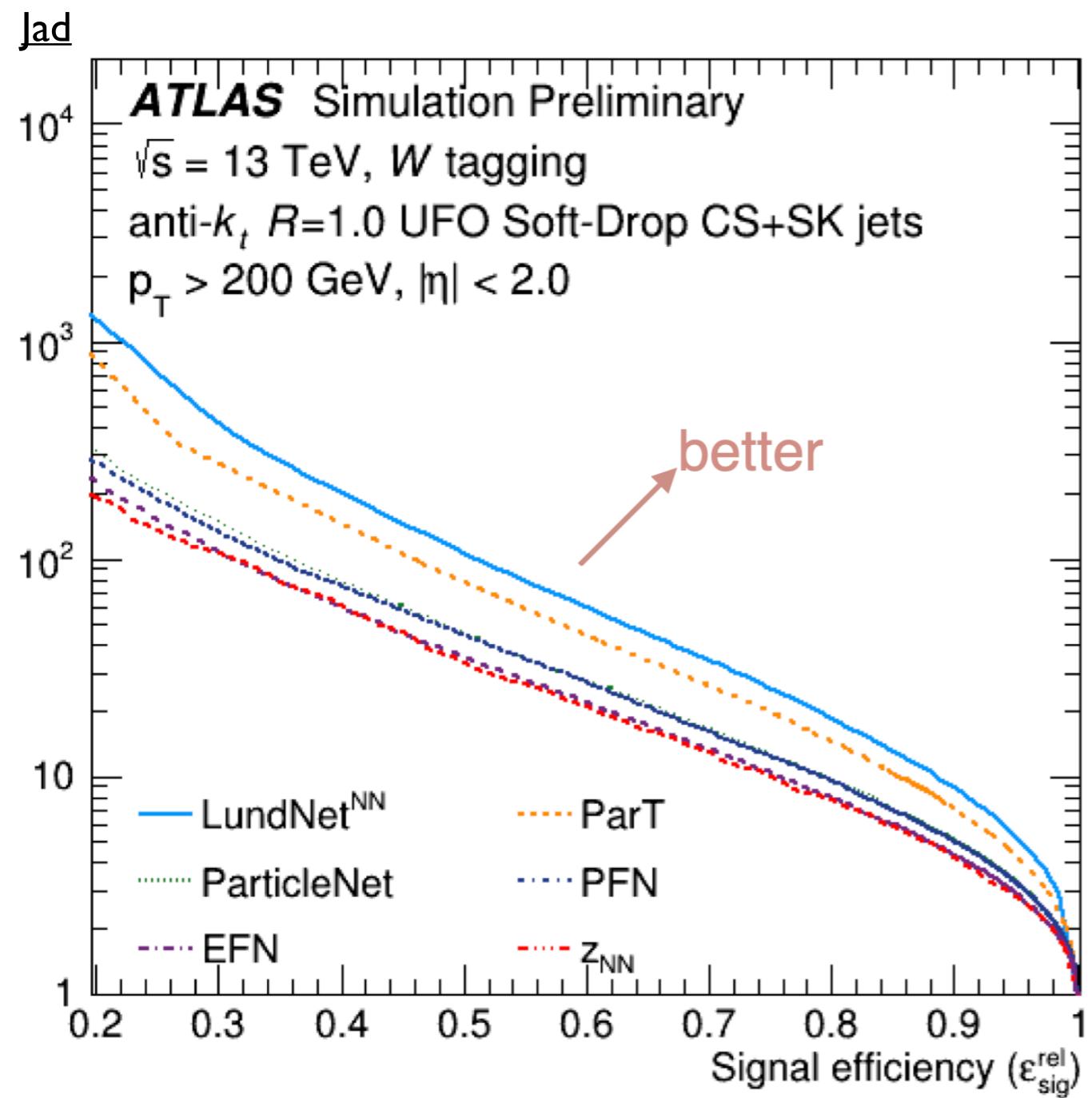


ATLAS: To Lund and Beyond!



LundNet for W -tagging, Transformers for both Hbb and W -tagging

ATLAS: To Lund and Beyond!



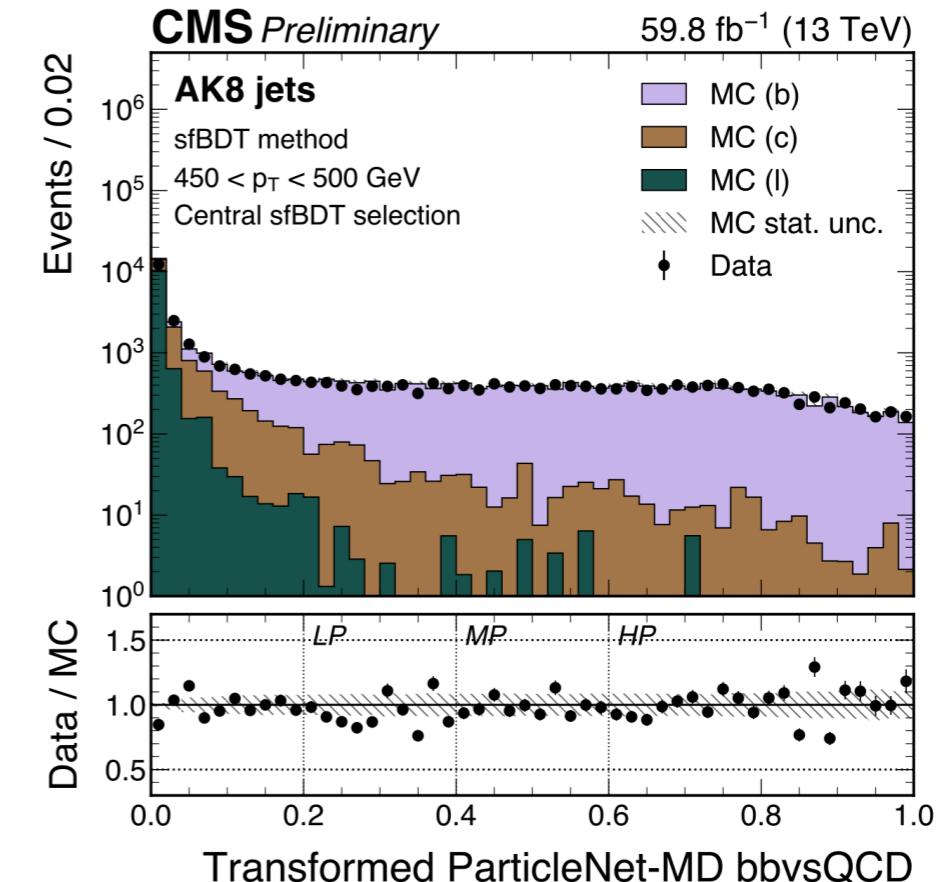
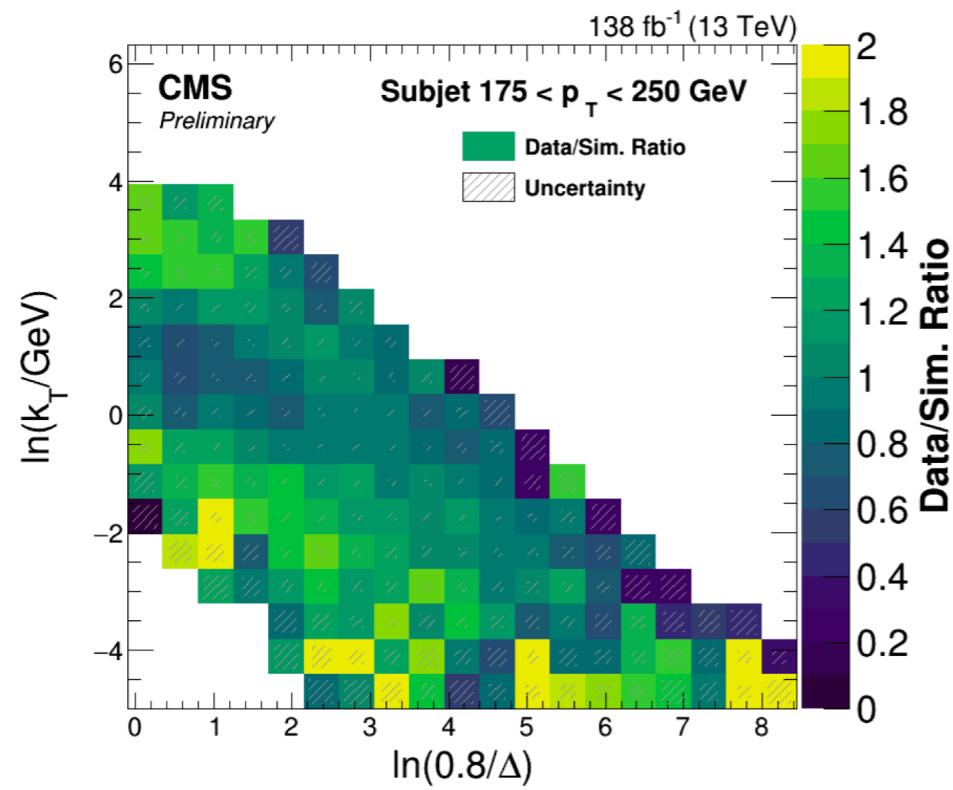
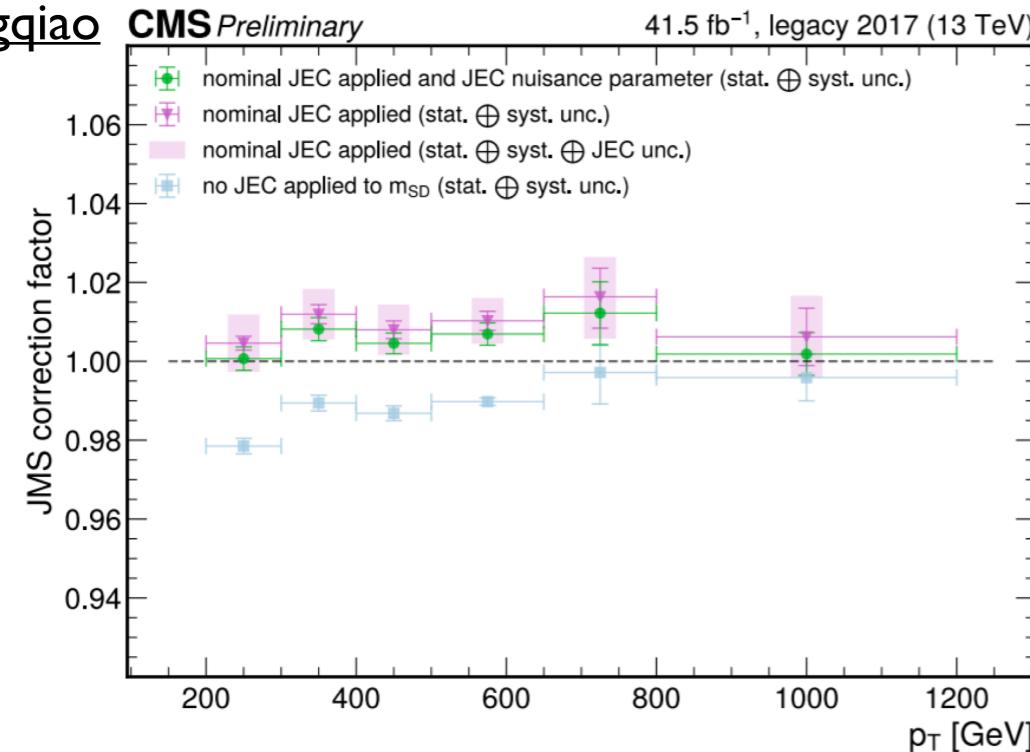
LundNet for W -tagging, Transformers for both Hbb and W -tagging

ParticleNet is great, but there's always a bigger fish?

Calibrations: Ever More Exquisite

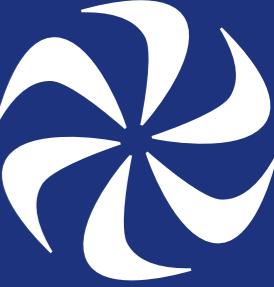


Oz, Congqiao

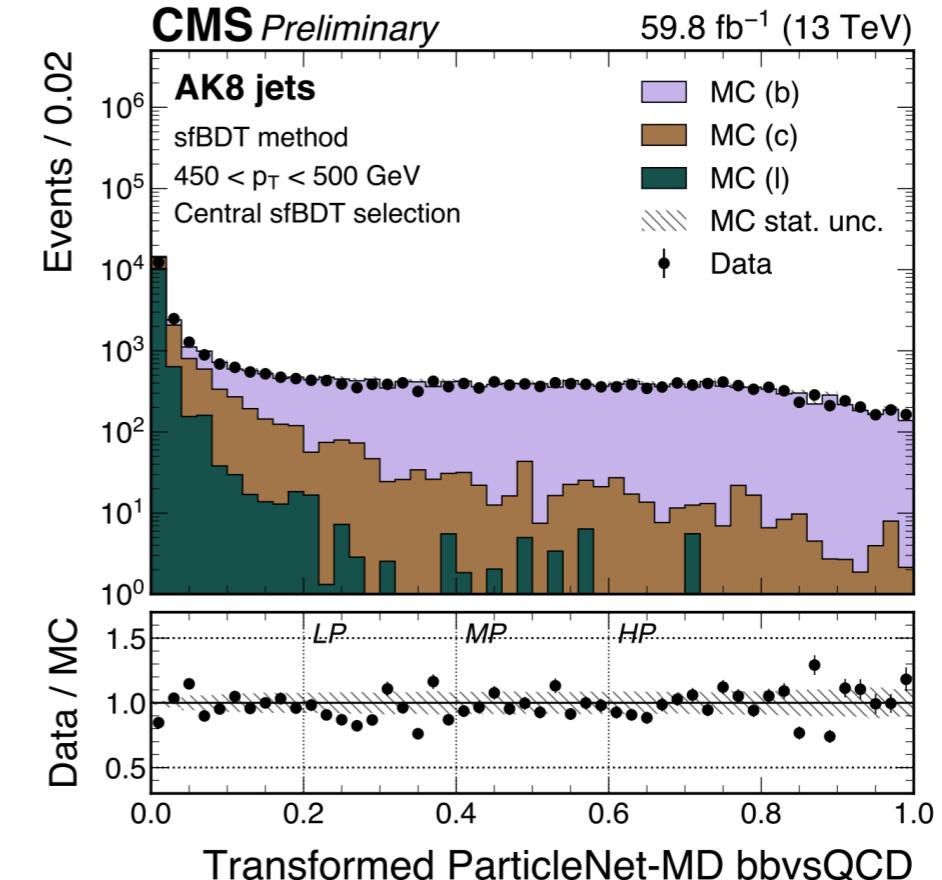
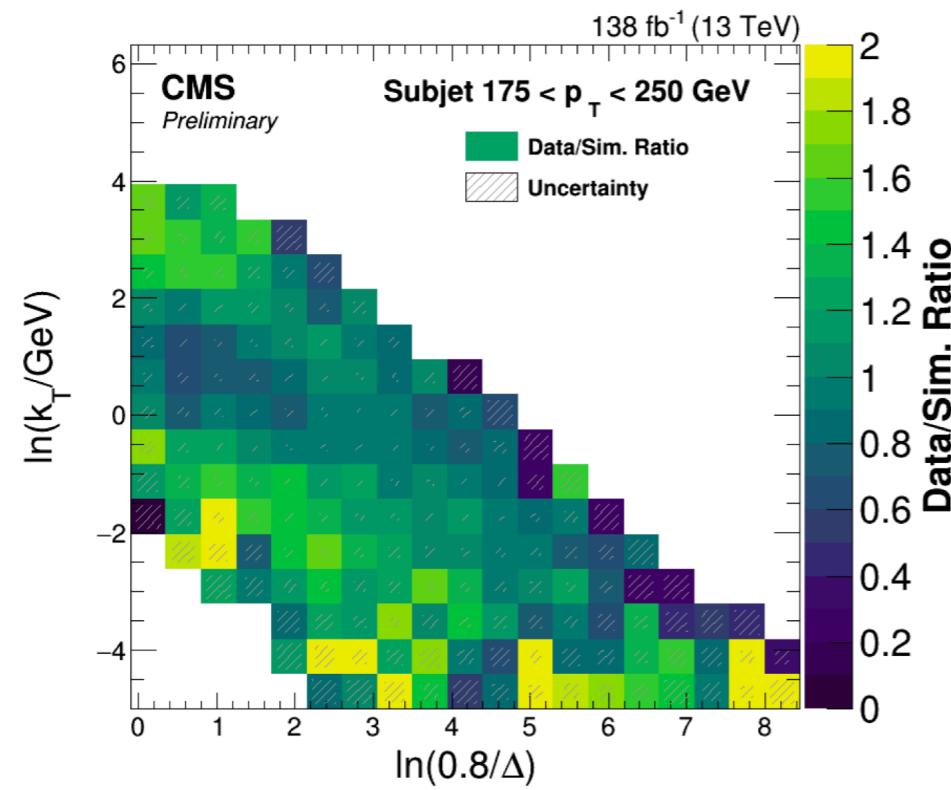
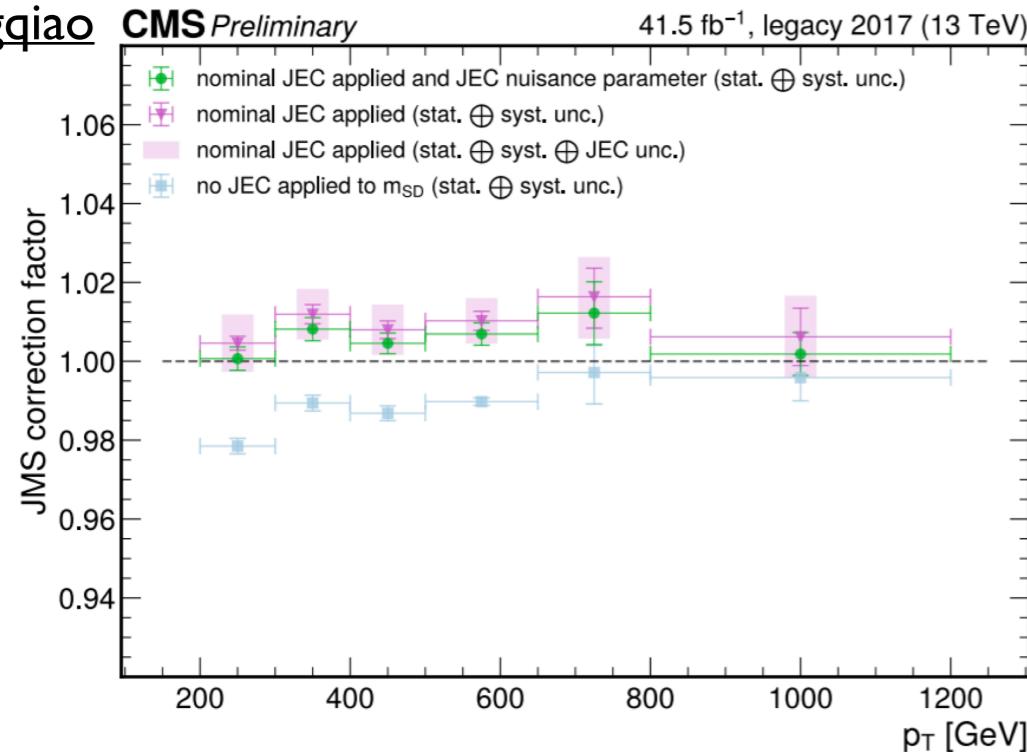


Ever more sophisticated calibrations
being performed for taggers

Calibrations: Ever More Exquisite



Oz, Congqiao



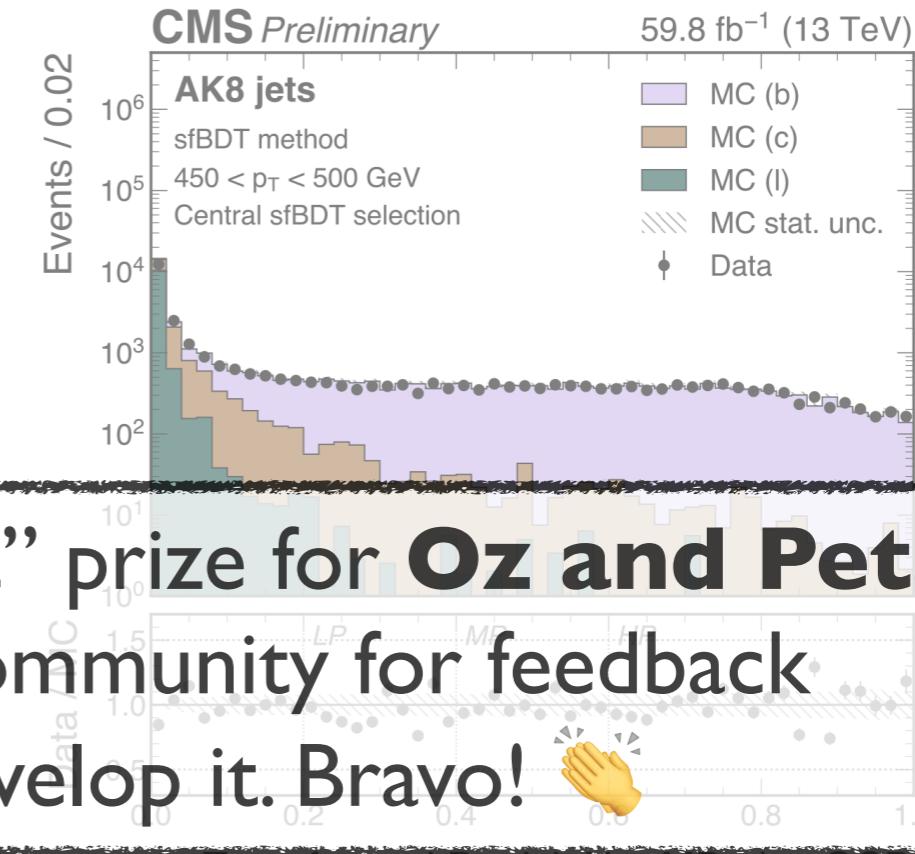
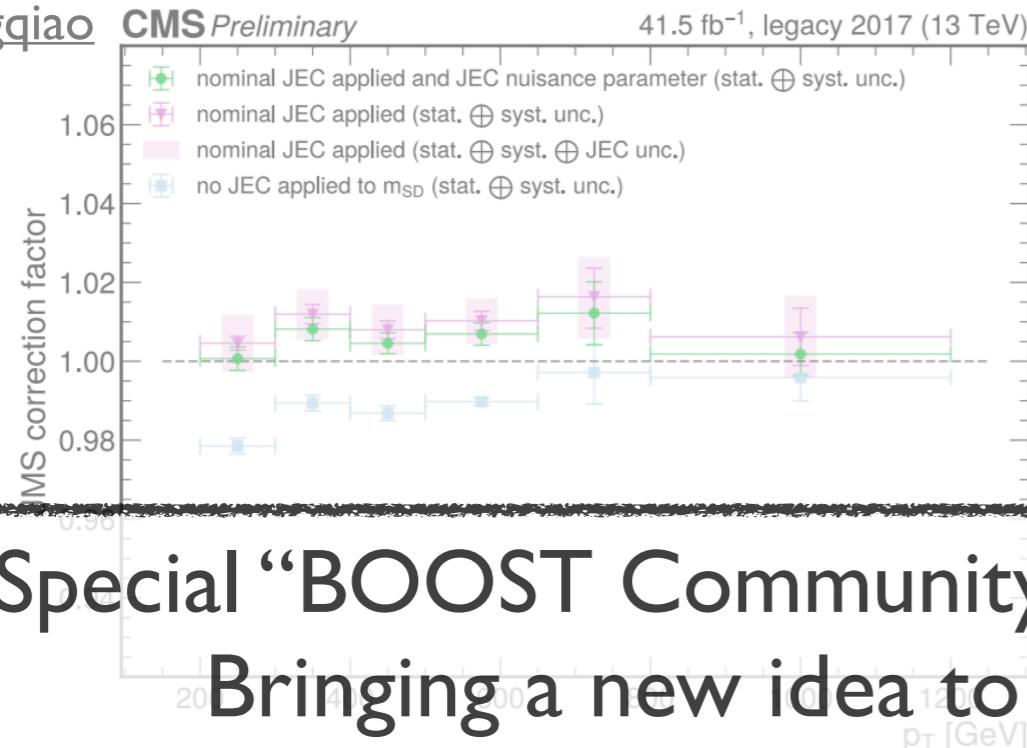
Ever more sophisticated calibrations
being performed for taggers

***This* is the hard part: not the NN!**

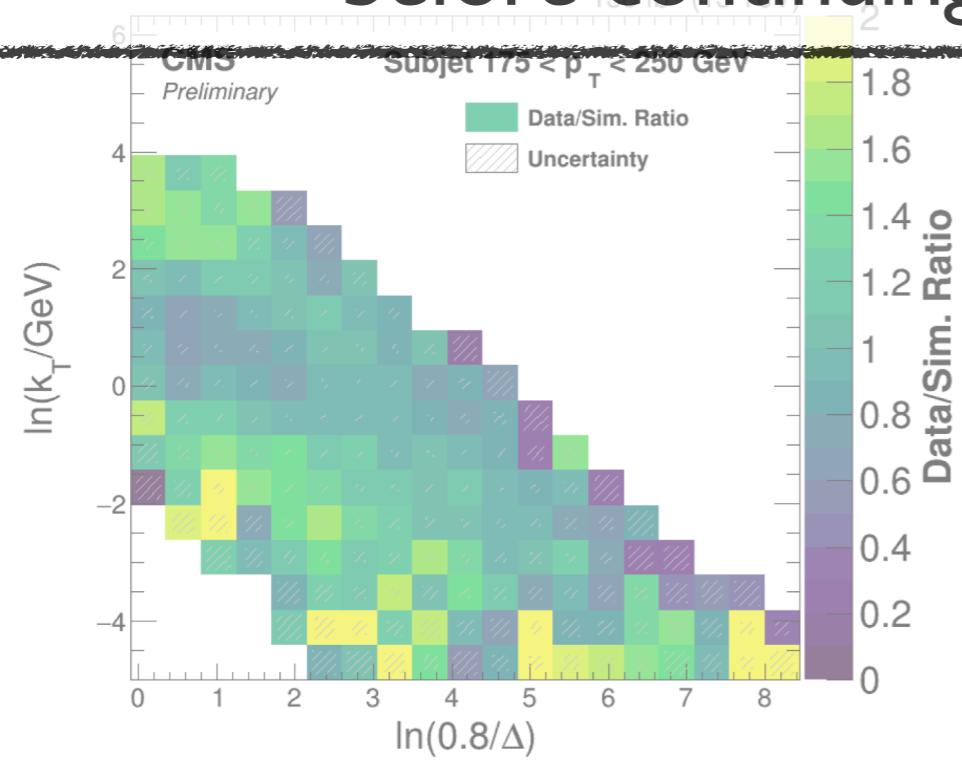


Calibrations: Ever More Exquisite

Oz, Congqiao



Special “BOOST Community Spirit” prize for **Oz and Petar**:
Bringing a new idea to the community for feedback
before continuing to develop it. Bravo!



Ever more sophisticated calibrations
being performed for taggers

This is the hard part: not the NN!

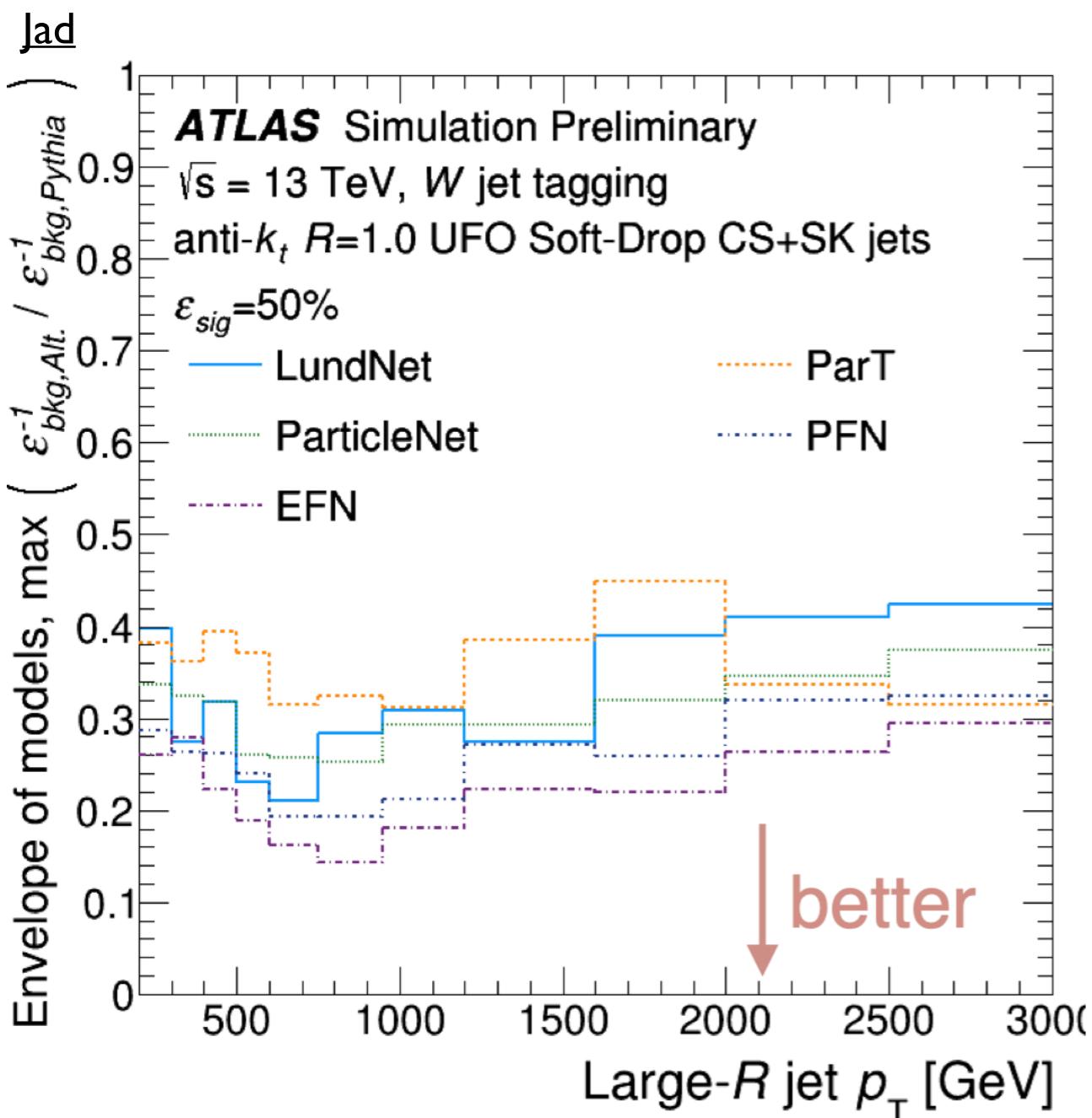
But It's Still About Modeling...



Jad

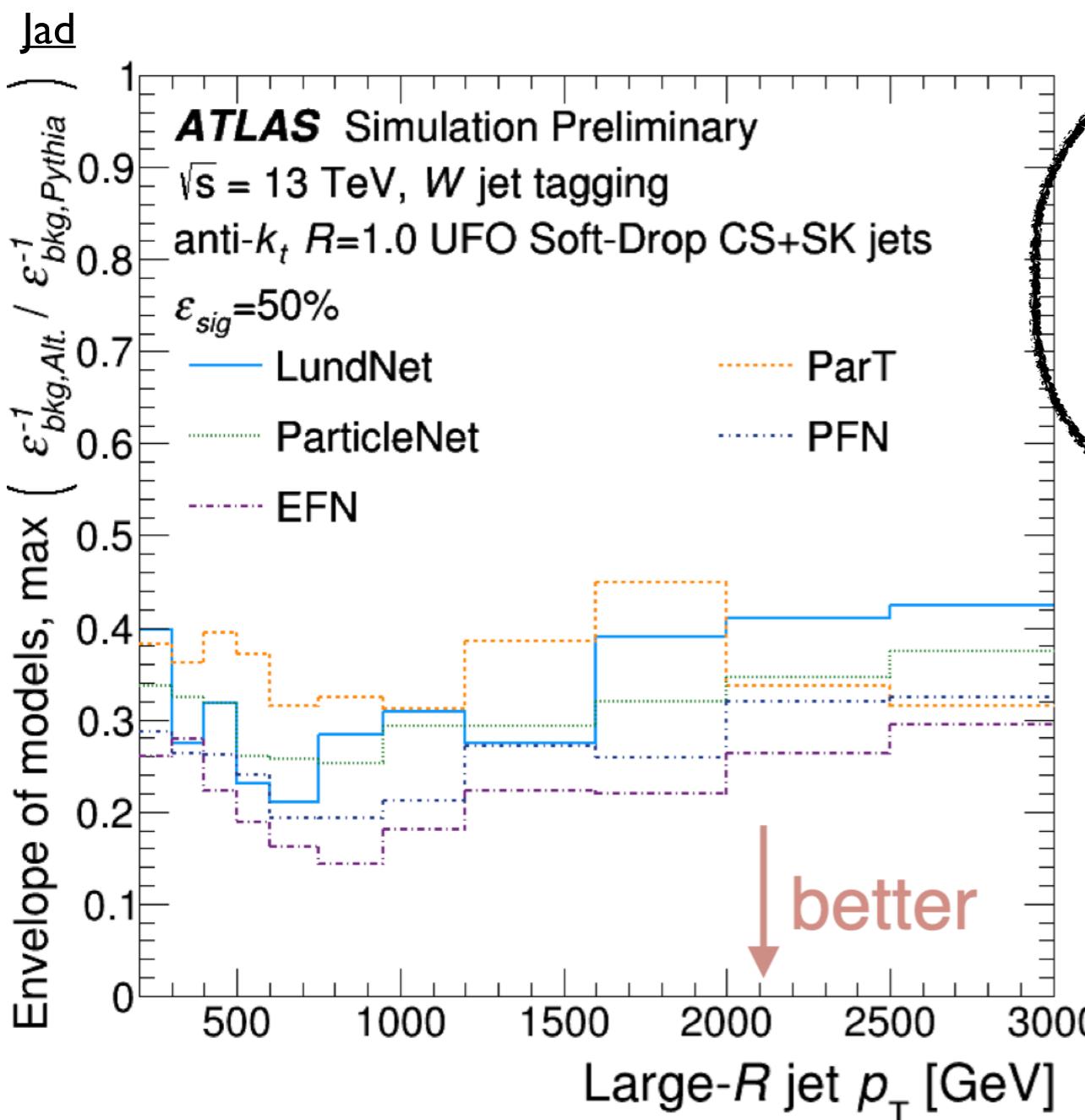


But It's Still About Modeling...





But It's Still About Modeling...

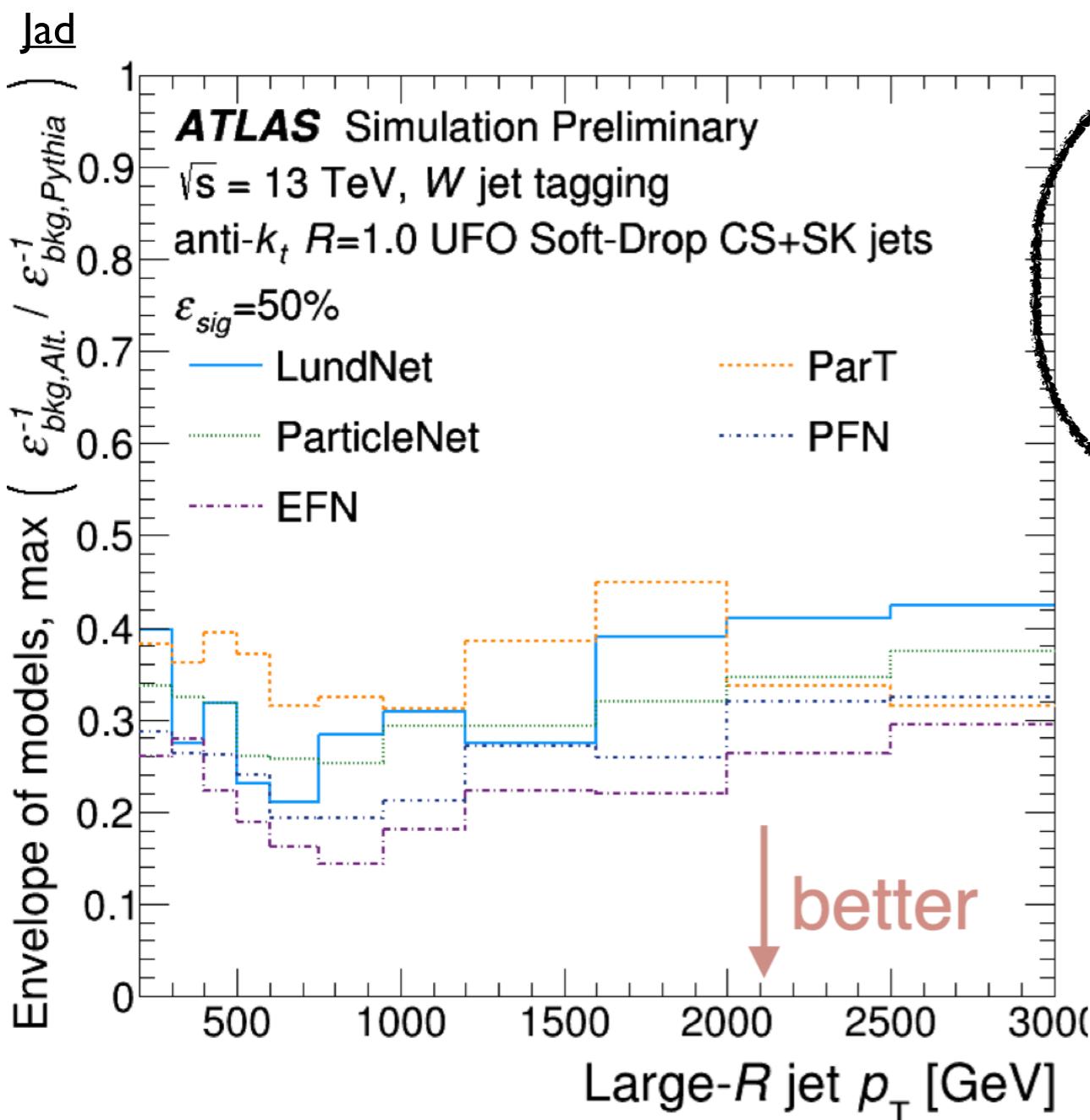


“Your network doesn’t need to be IRC safe, but if it uses IRC un-safe information, it might be less robust”





But It's Still About Modeling...



“Your network doesn’t need to be IRC safe, but if it uses IRC un-safe information, it might be less robust”

Will we reach a point where tagger systematics grow too large?

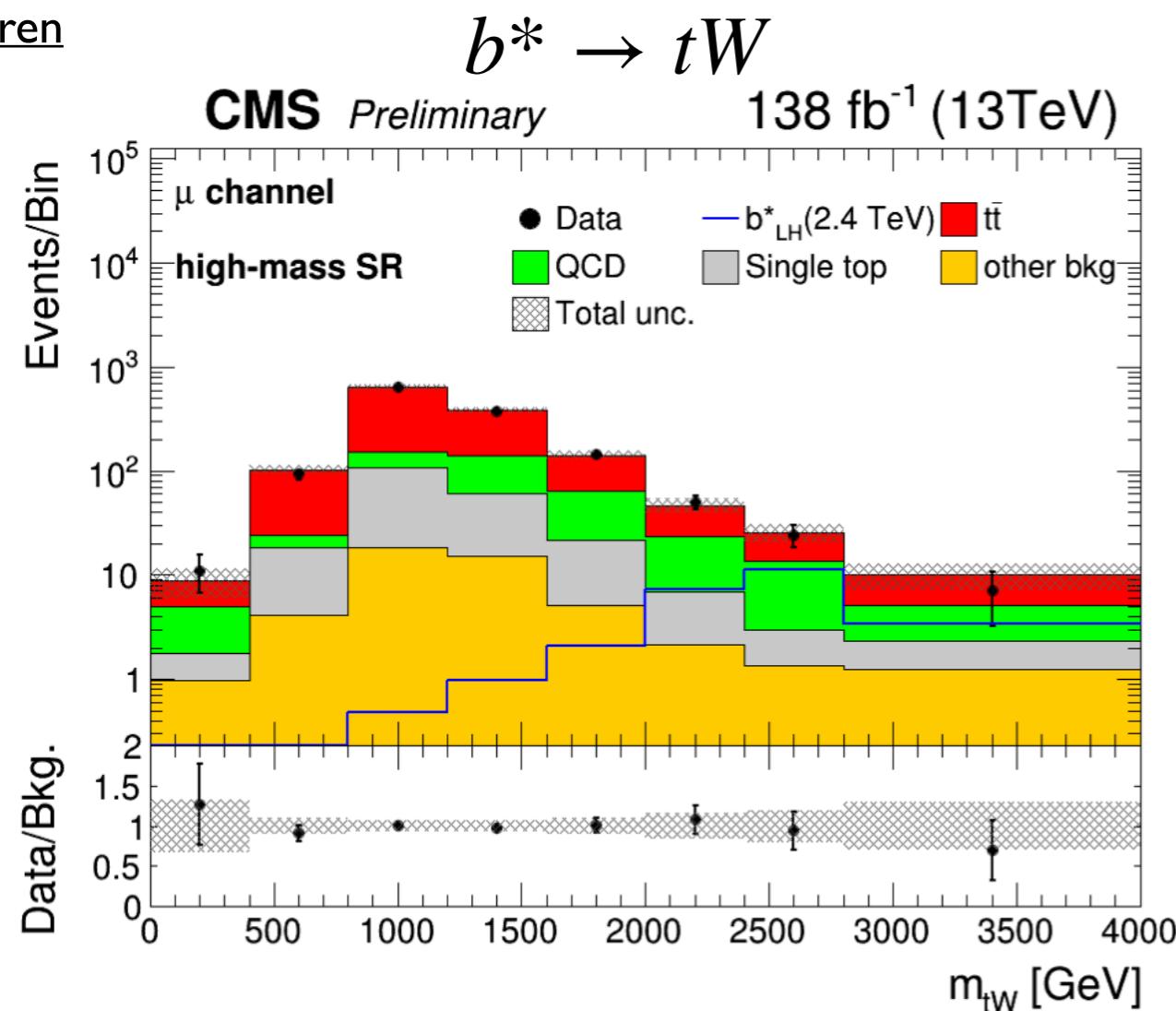


Searches

Searches March Onward...

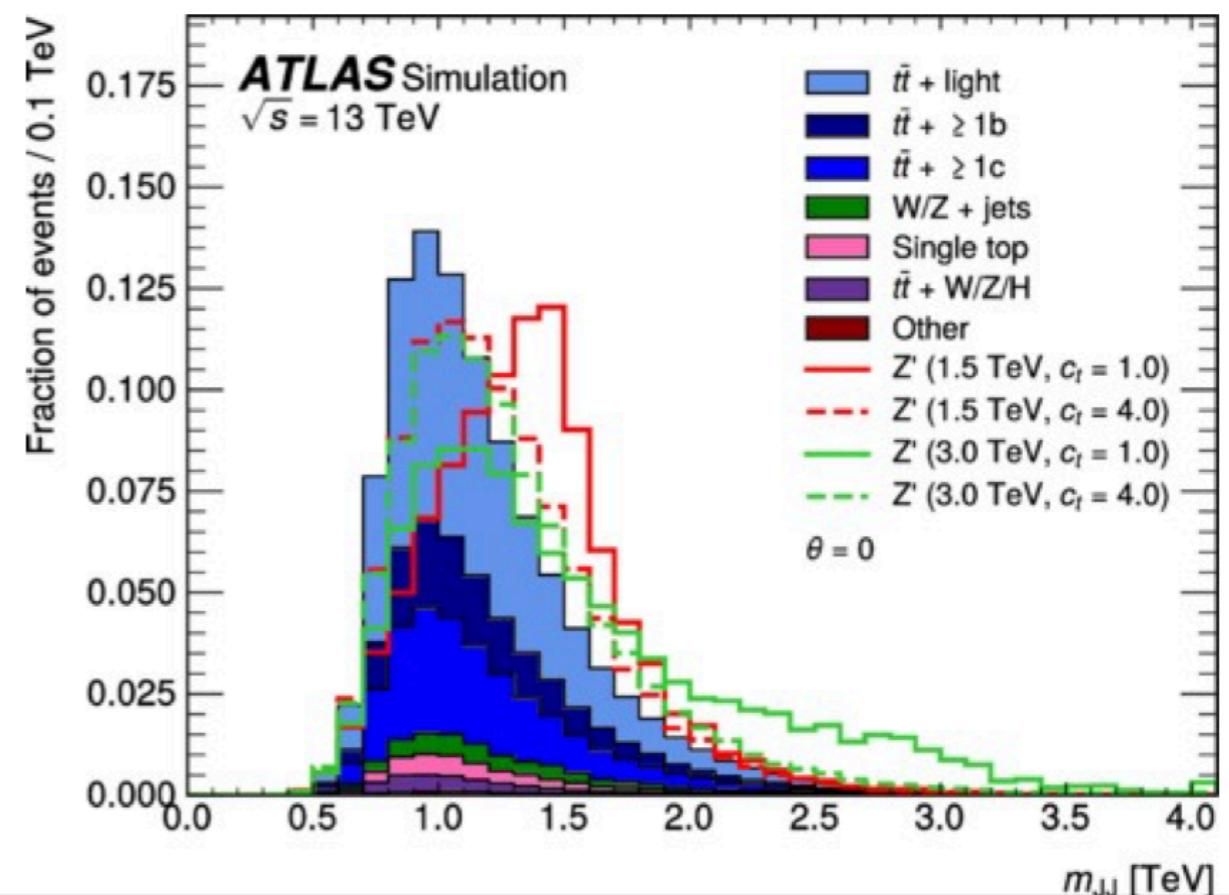


Lauren



Mario

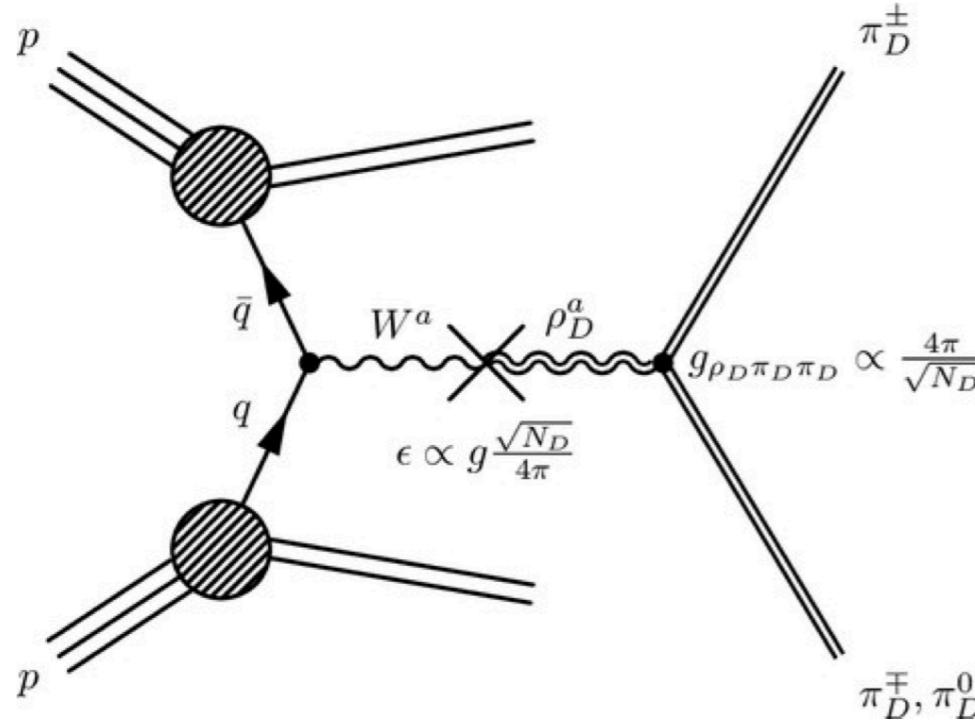
Top-philic Z'



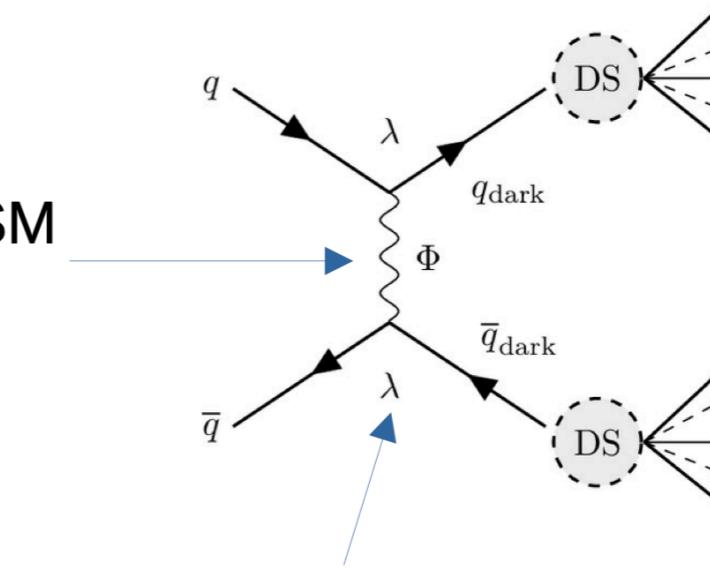
Wide variety of searches continue to march on!

Taggers (even simple ones) are a key part of the analysis toolkit

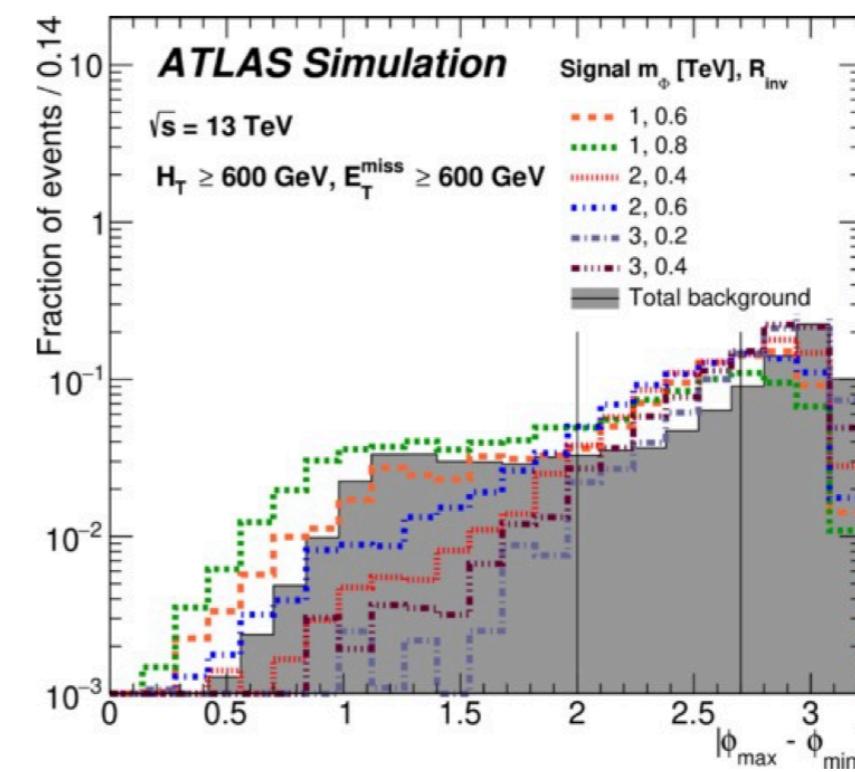
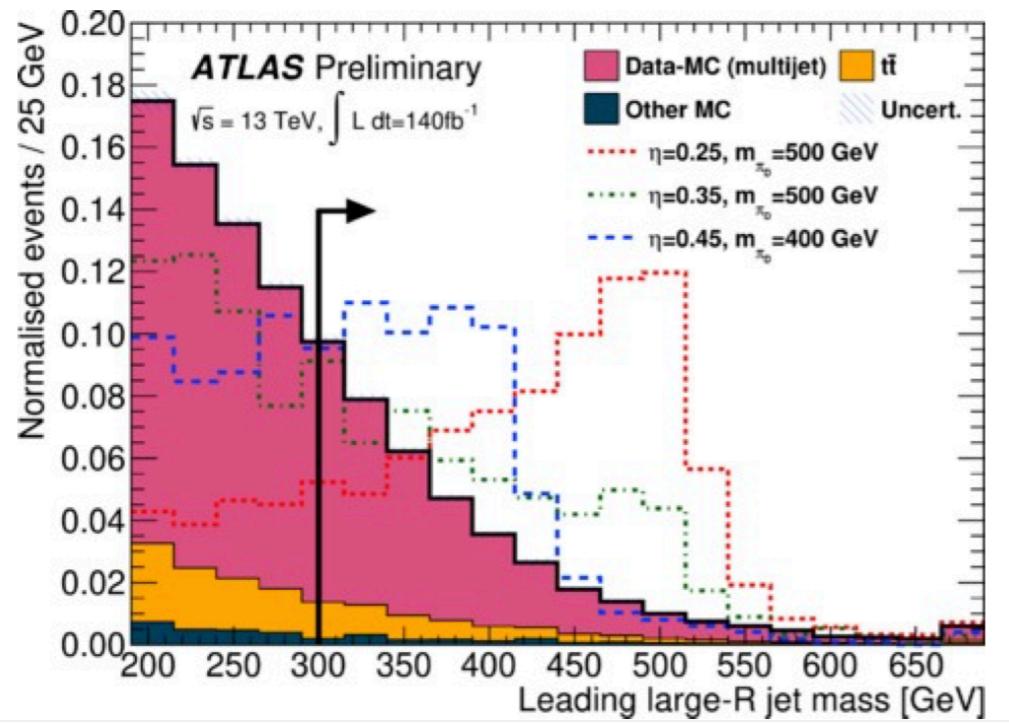
The Rise of Dark QCD



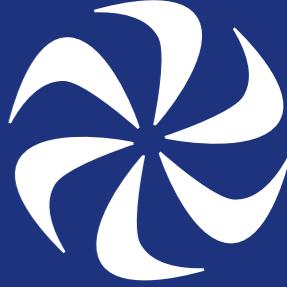
Mediator
between SM
and dark
sector



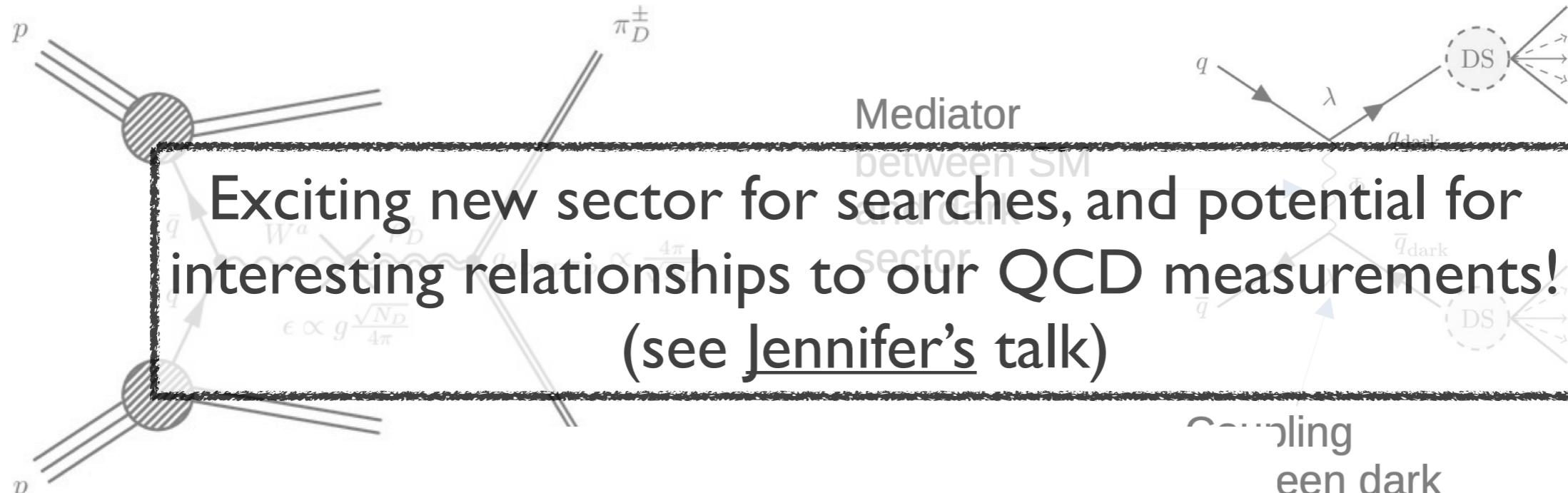
Coupling
between dark
sector and SM



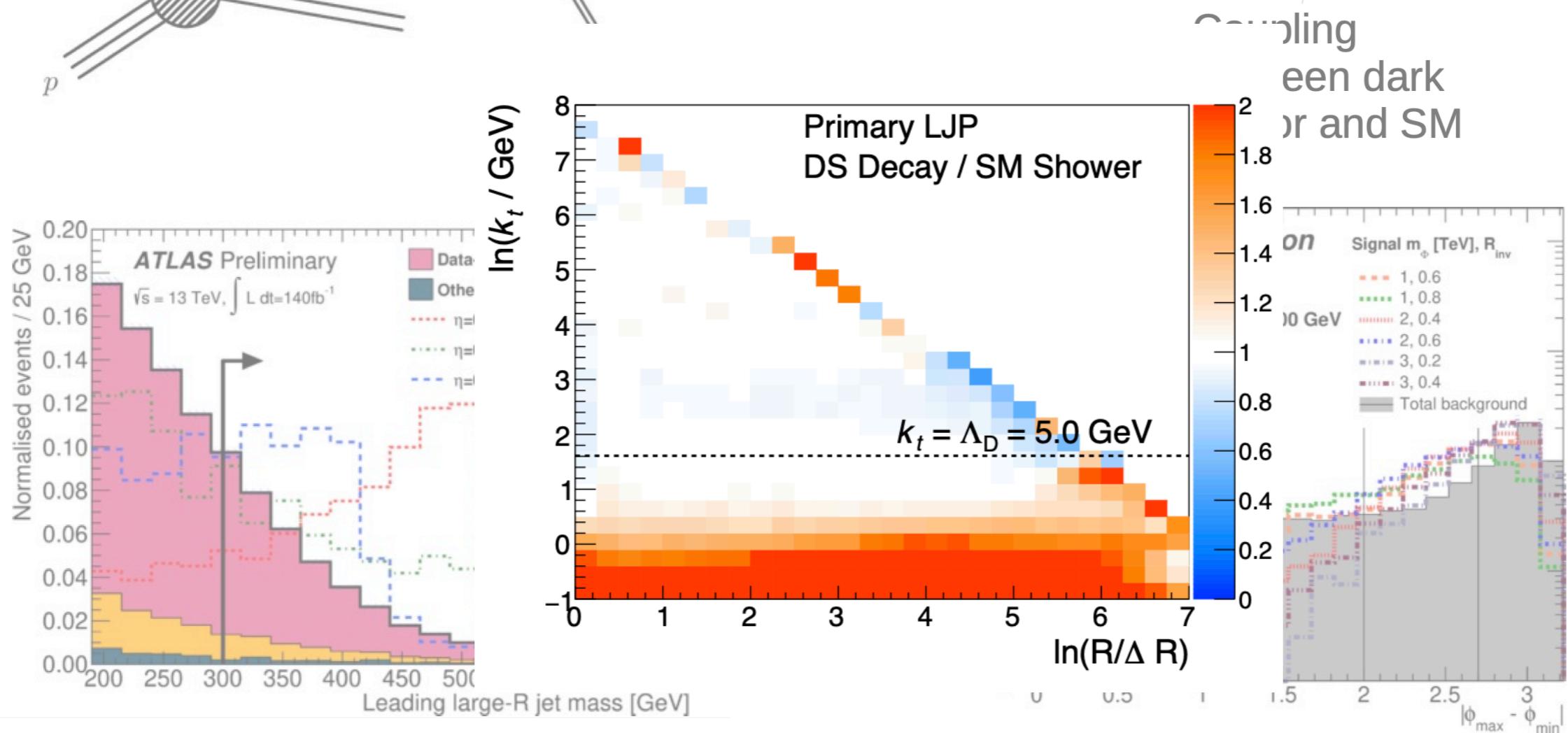
The Rise of Dark QCD



Mario



Exciting new sector for searches, and potential for interesting relationships to our QCD measurements!
 (see Jennifer's talk)



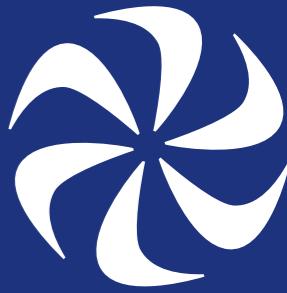
Excesses (?) with Multijets?



Lauren

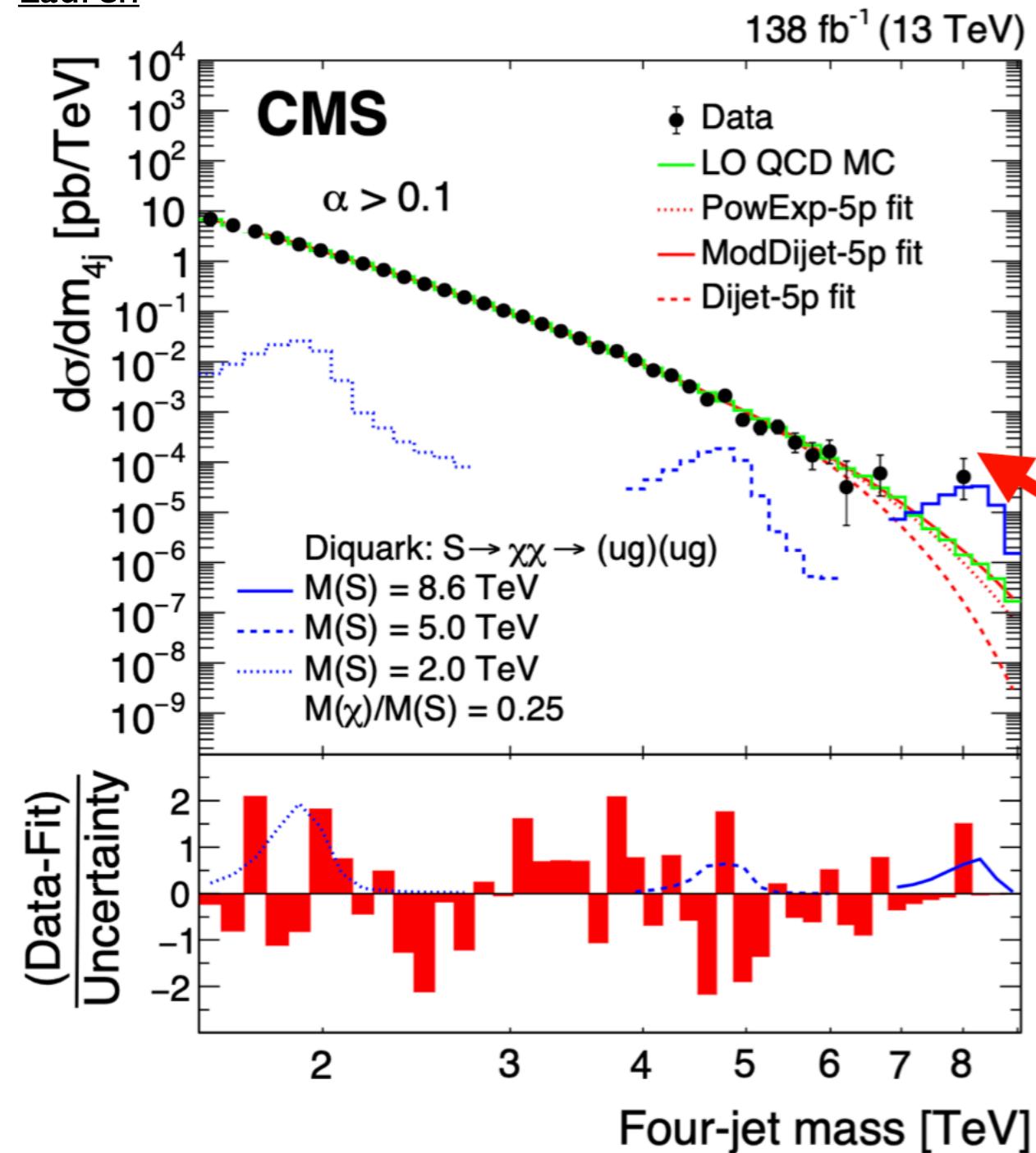
Mario

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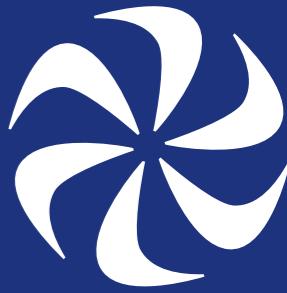


Lauren

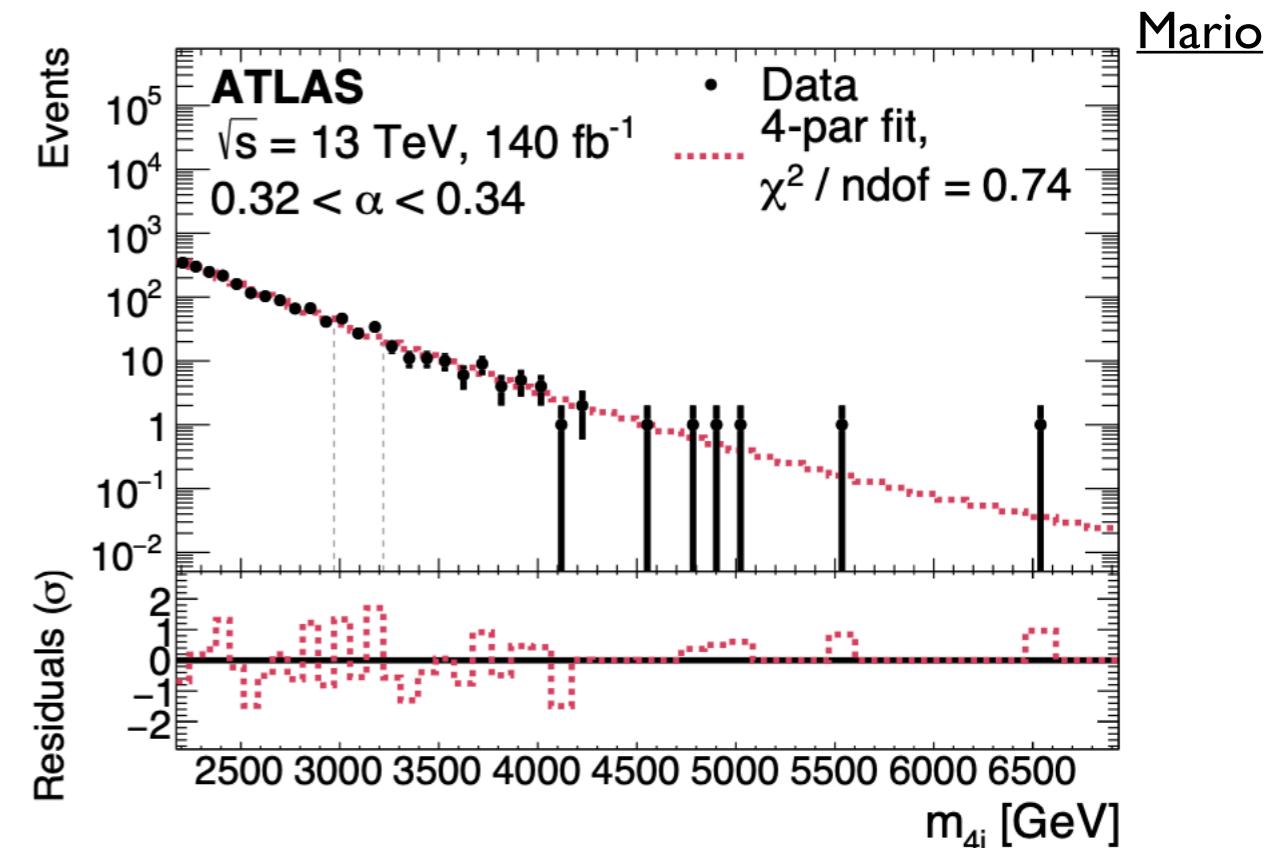
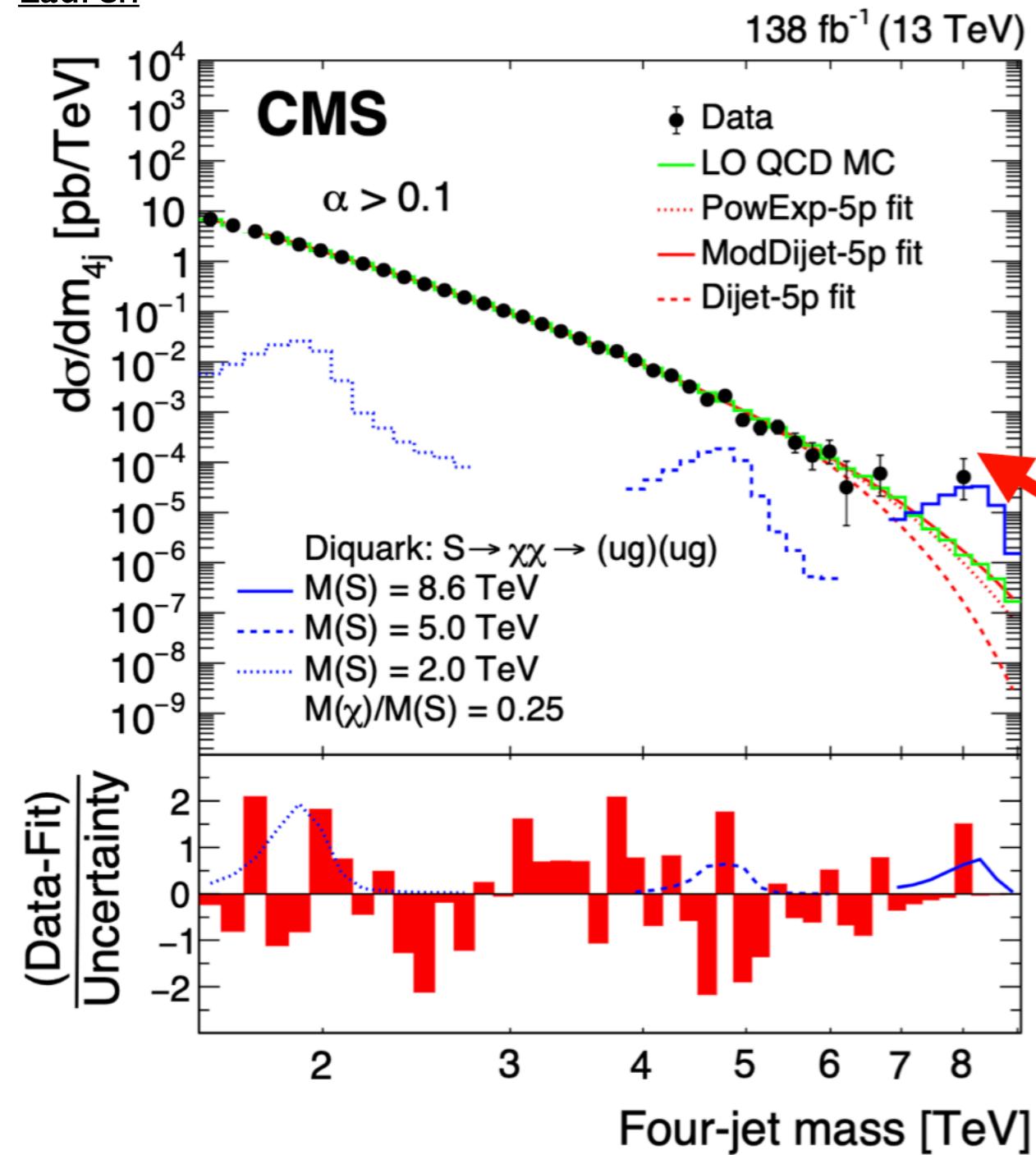
Mario



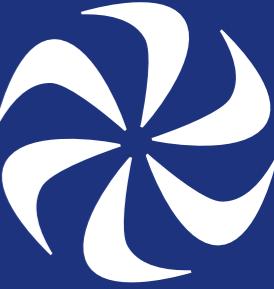
Excesses (?) with Multijets?



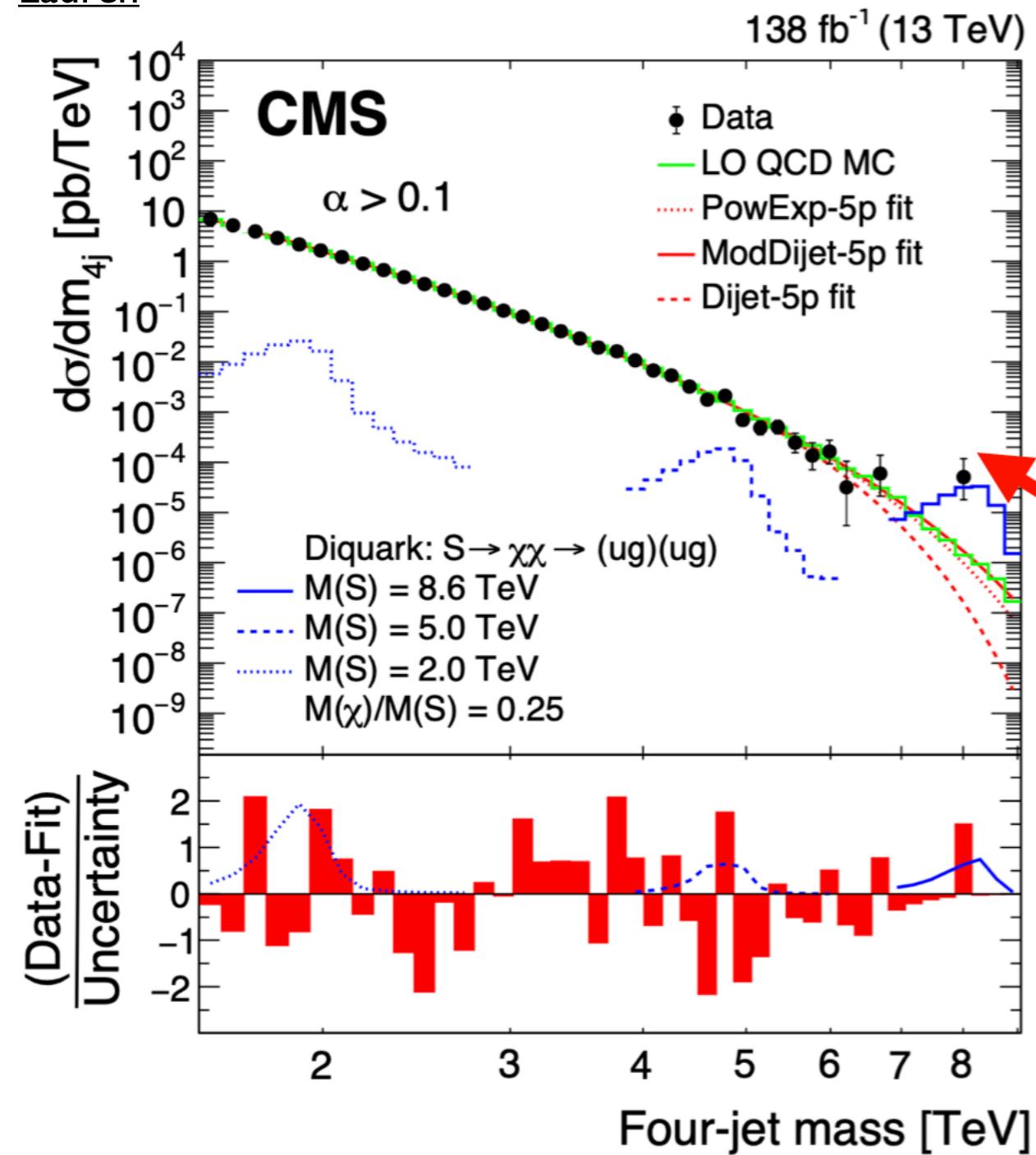
Lauren



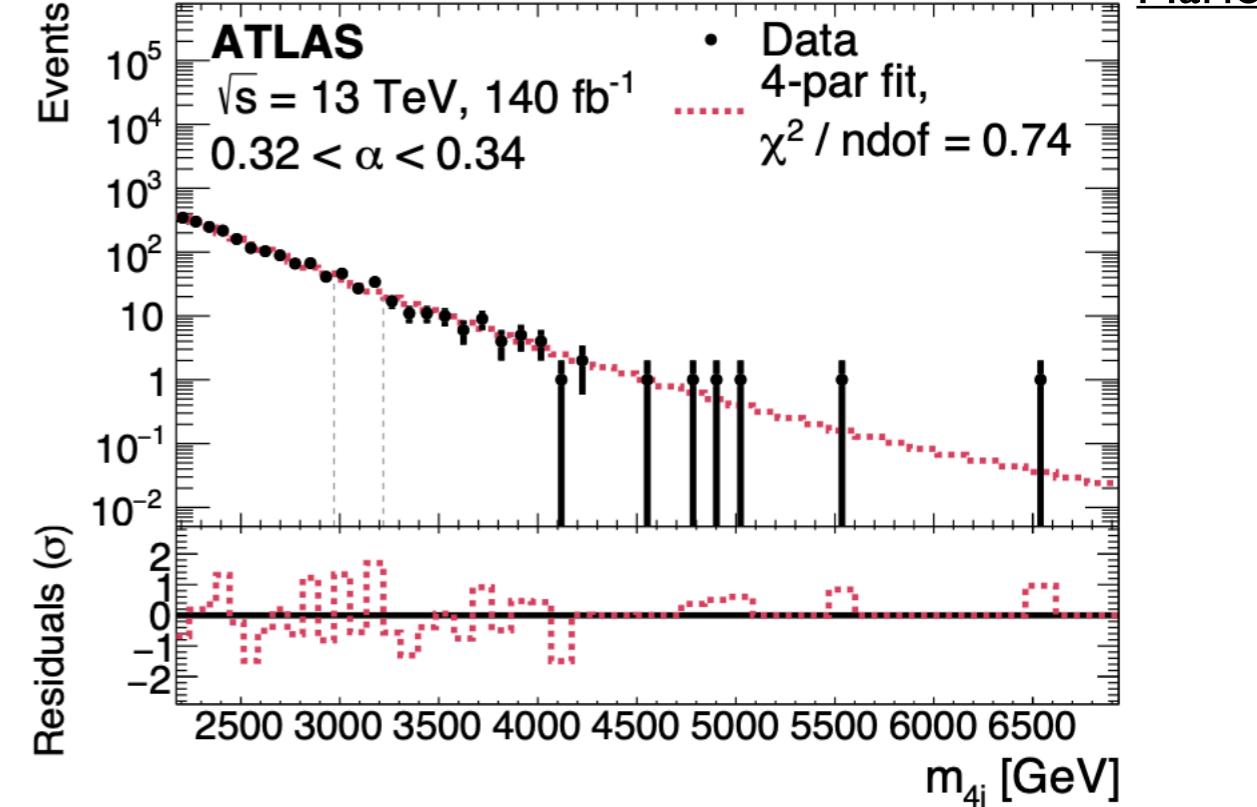
Excesses (?) with Multijets?



Lauren

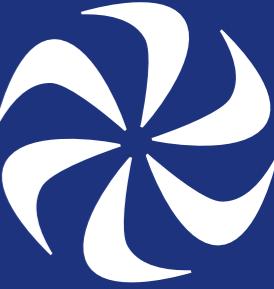


Mario

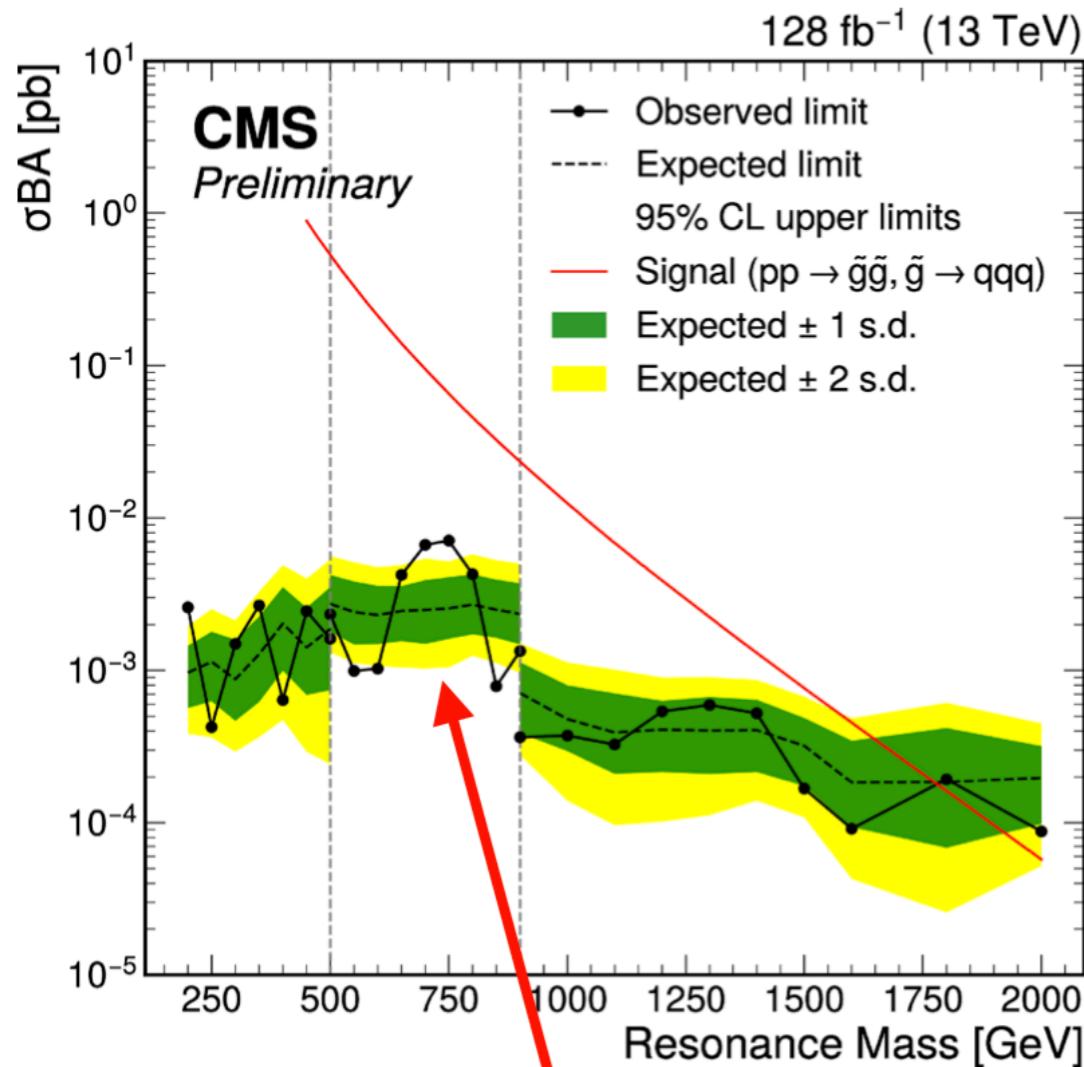


2 is compatible
with 0

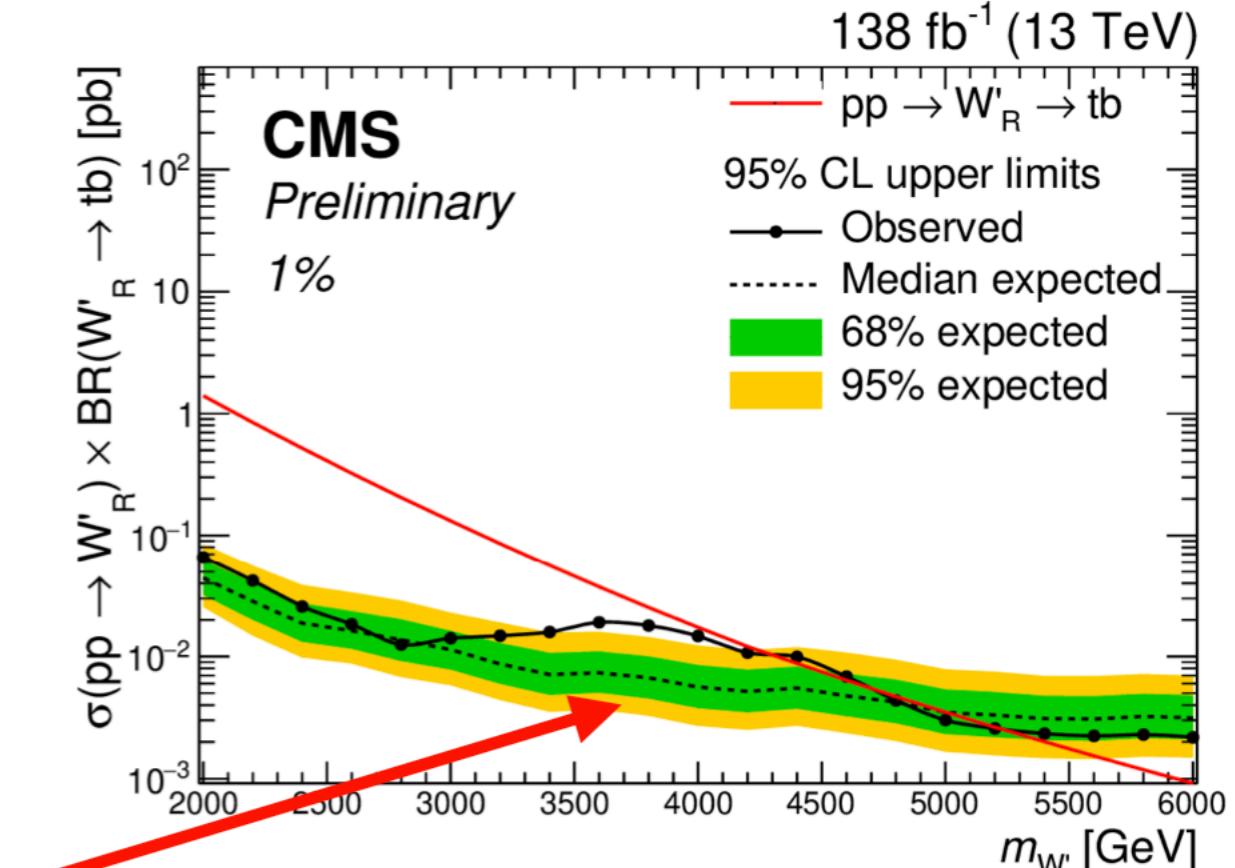
But There's Always More Hope!



Lauren

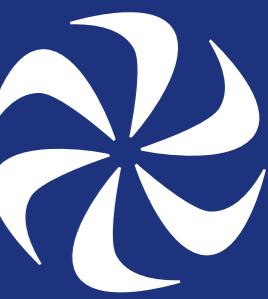


CENSORED local deviation



Even if I'm not supposed
to quote the new 750 GeV CMS
excess, something is back :)

Anomaly Detection

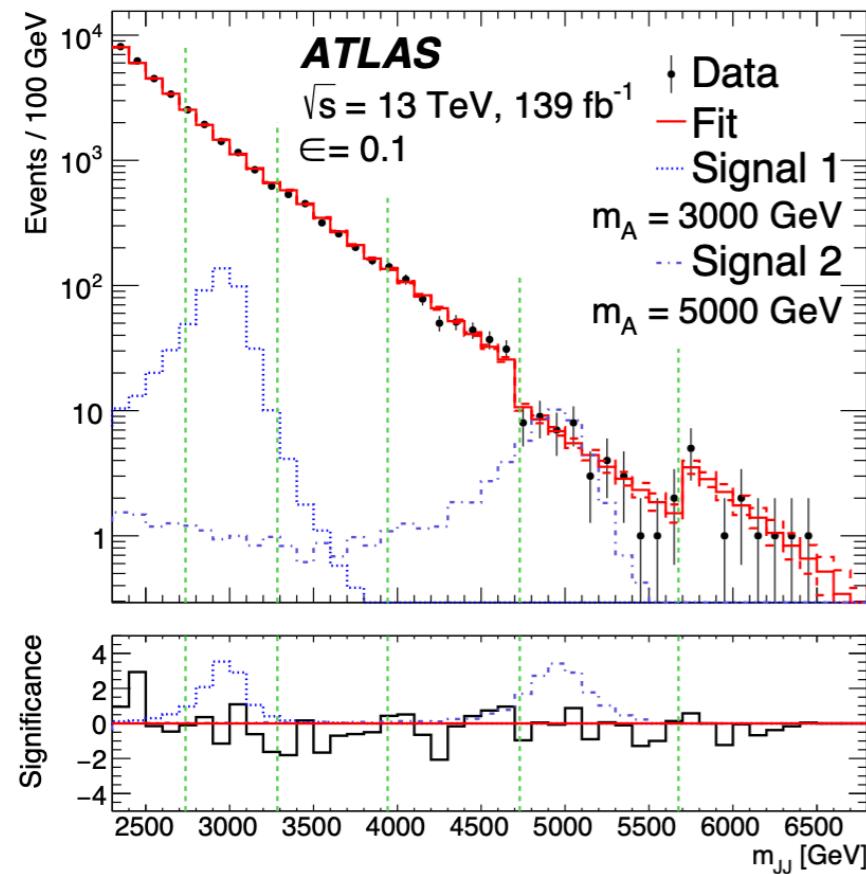


Wasikul, Elham



Anomaly Detection

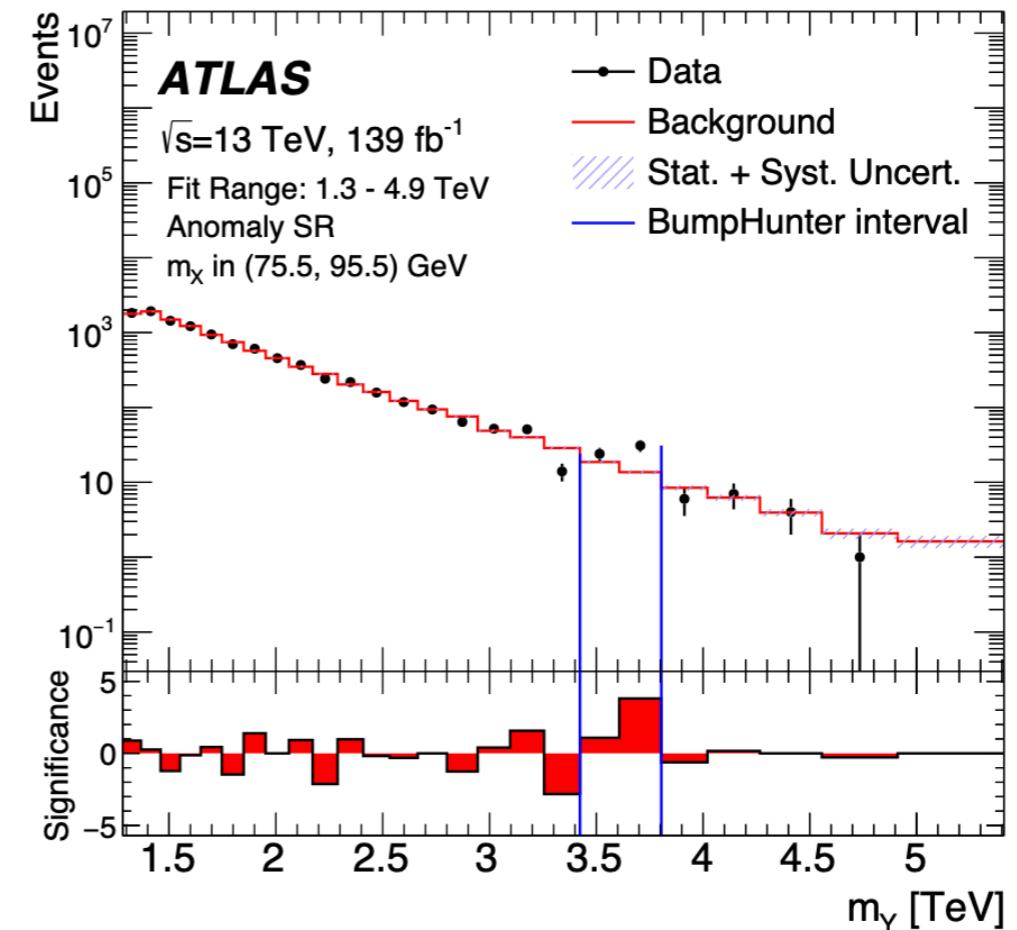
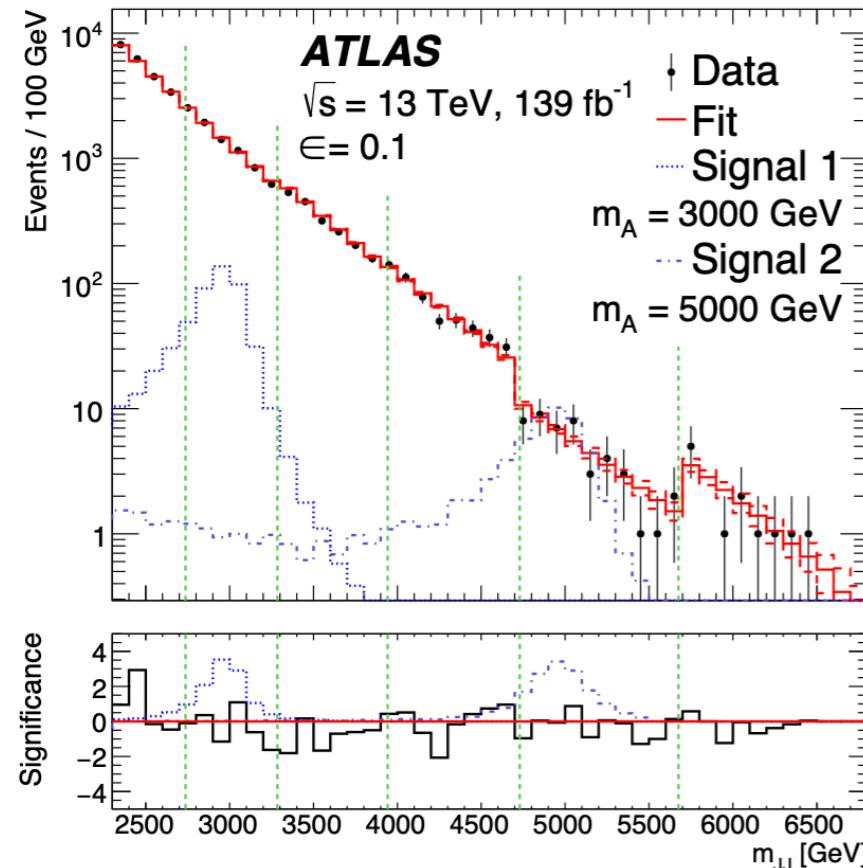
Wasikul, Elham





Anomaly Detection

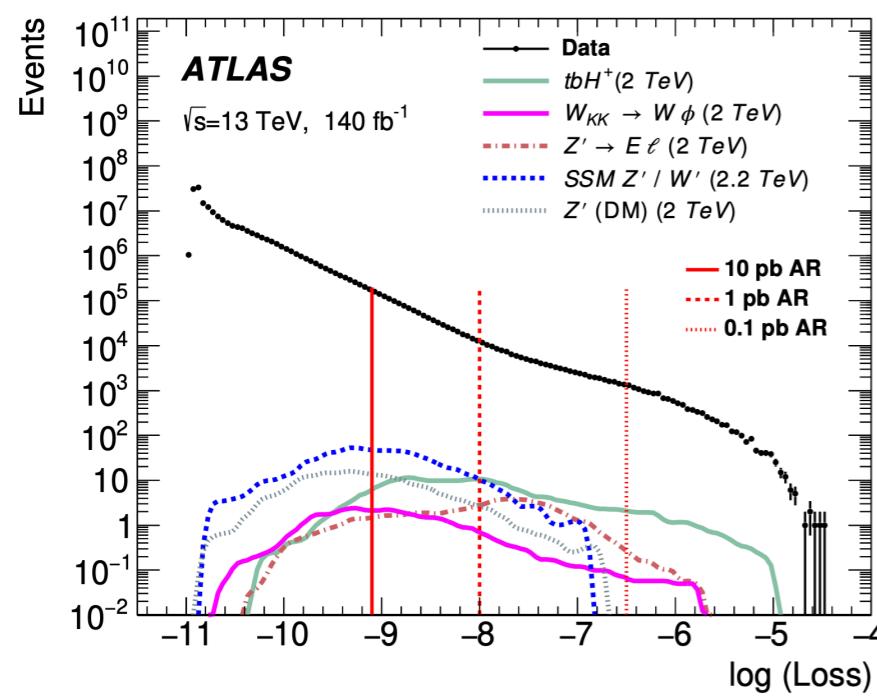
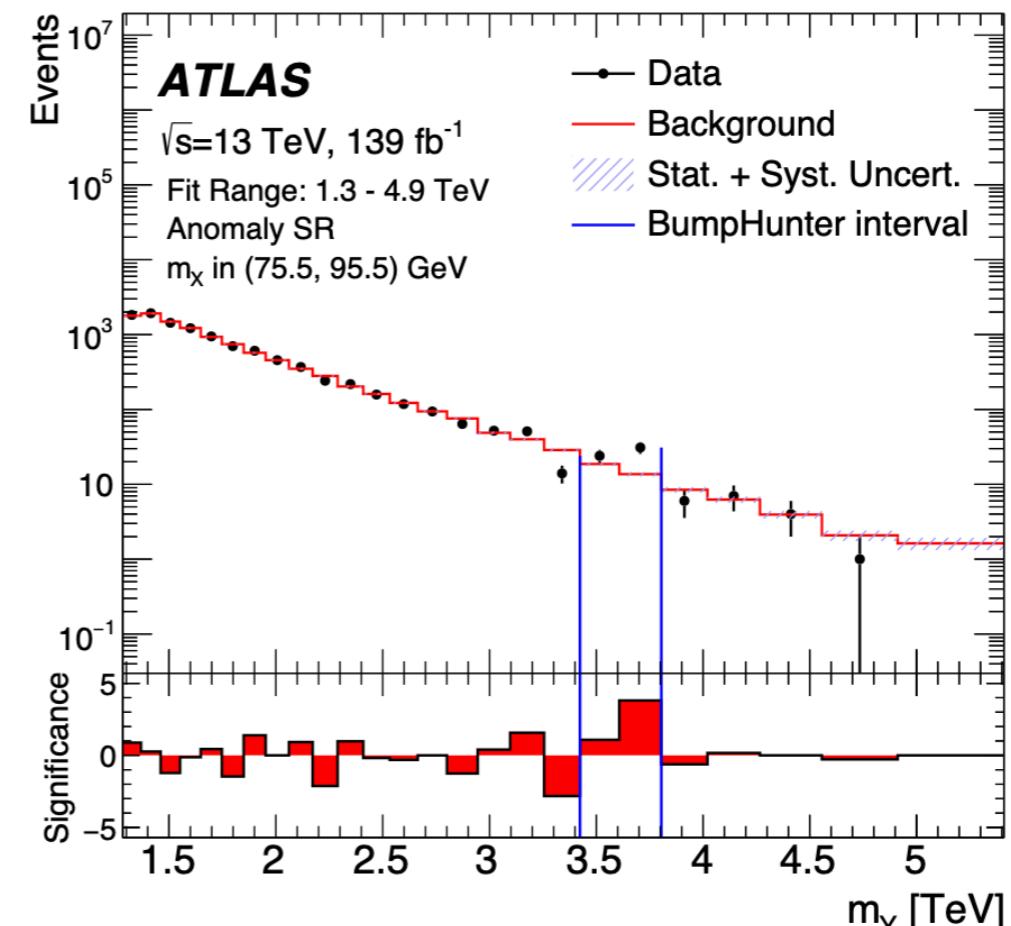
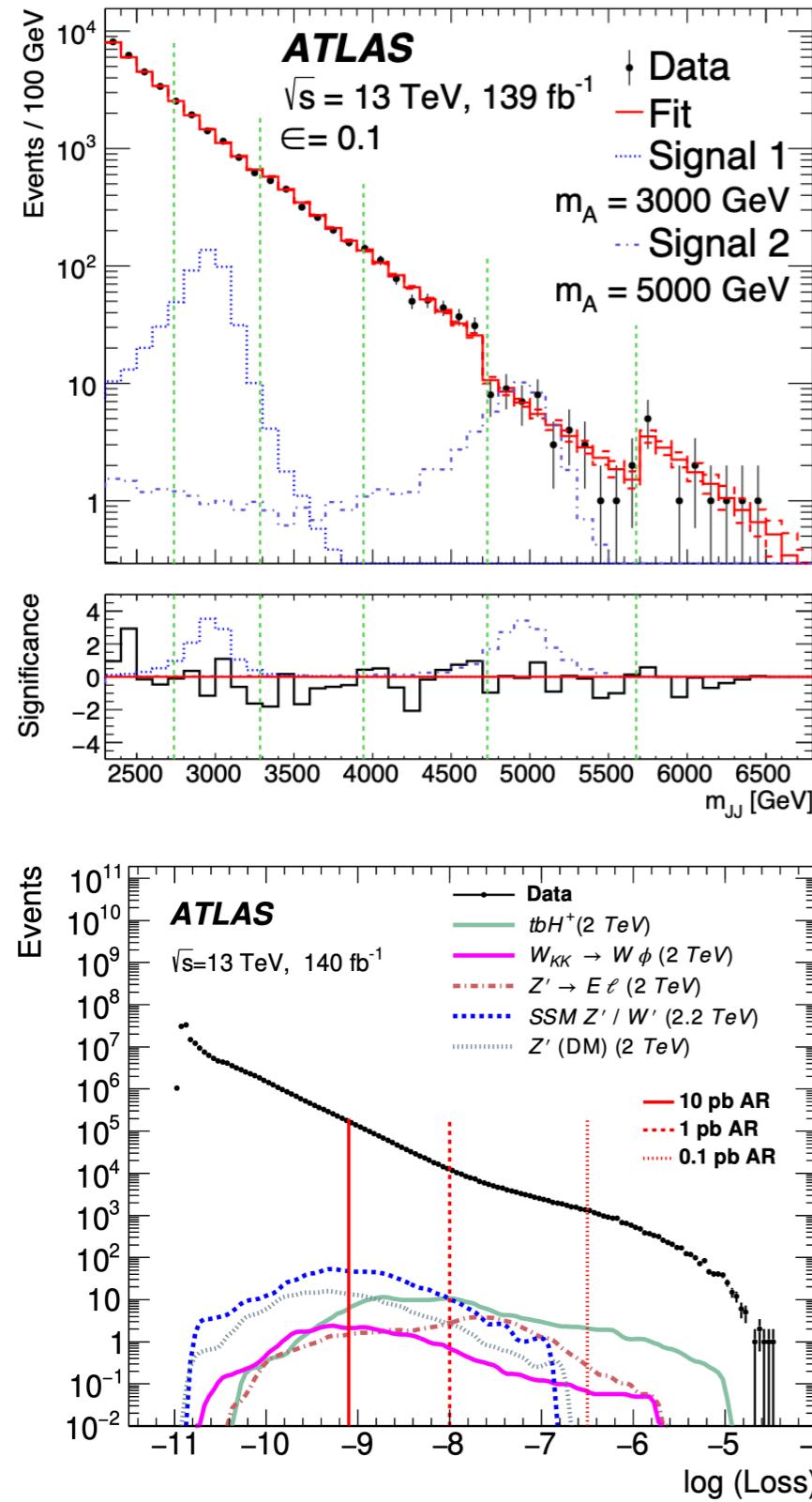
Wasikul, Elham





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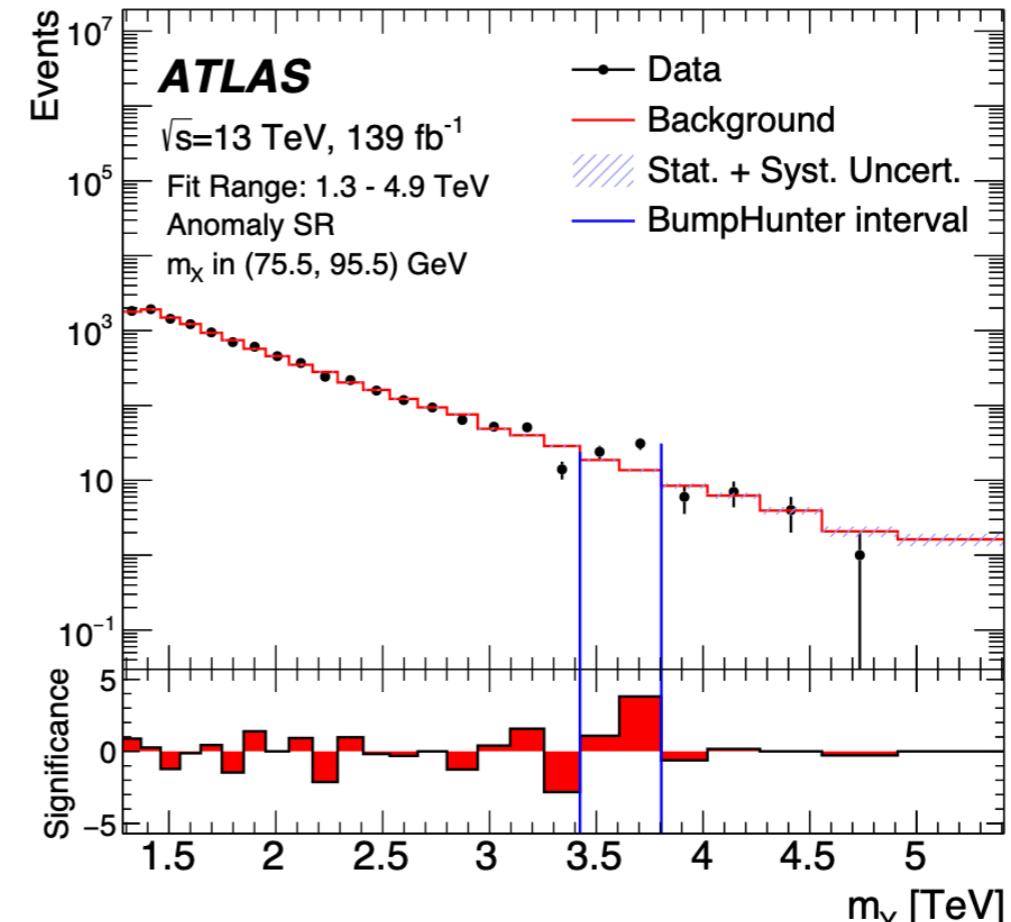
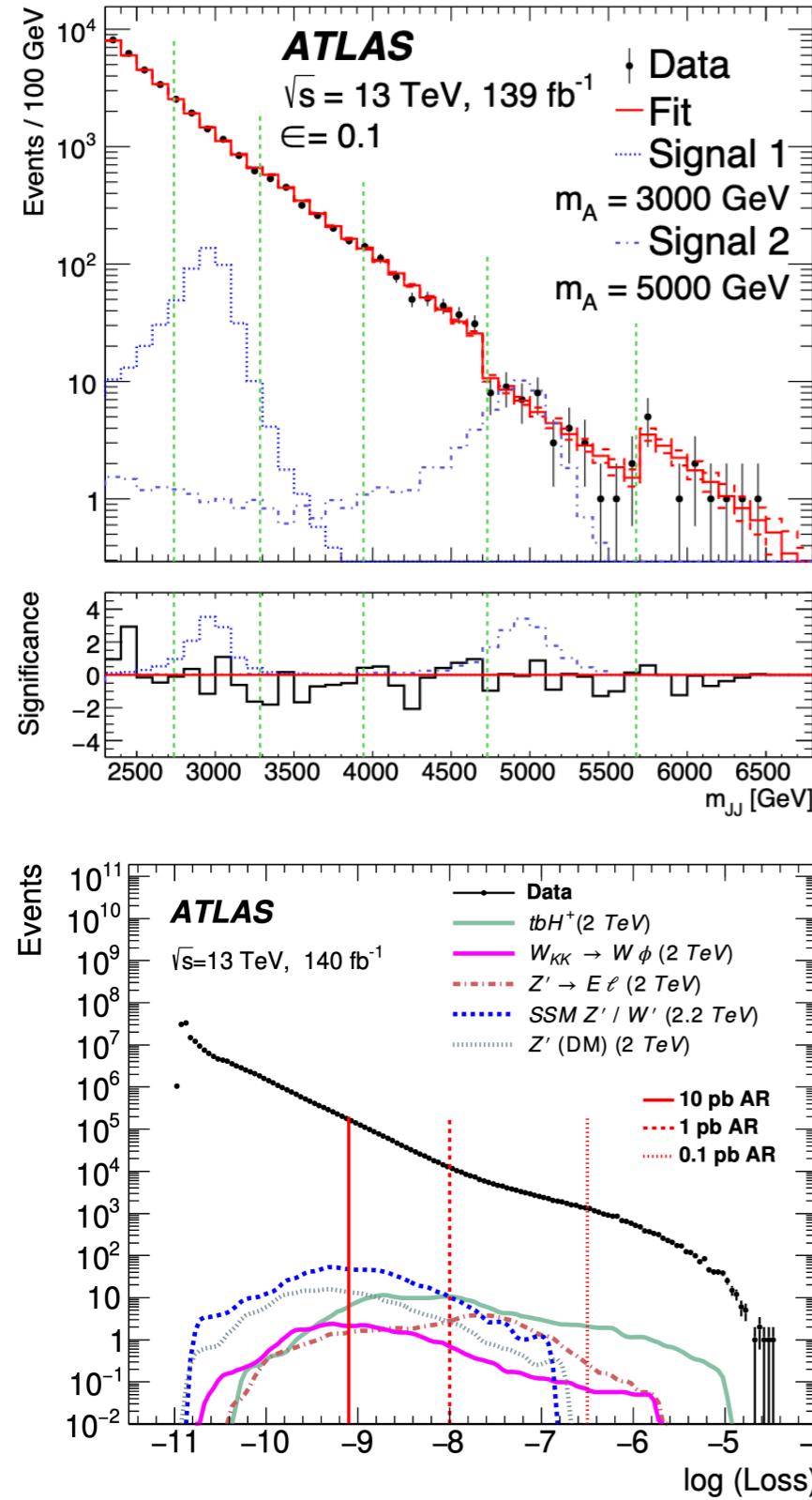
Wasikul, Elham





Anomaly Detection

Wasikul, Elham

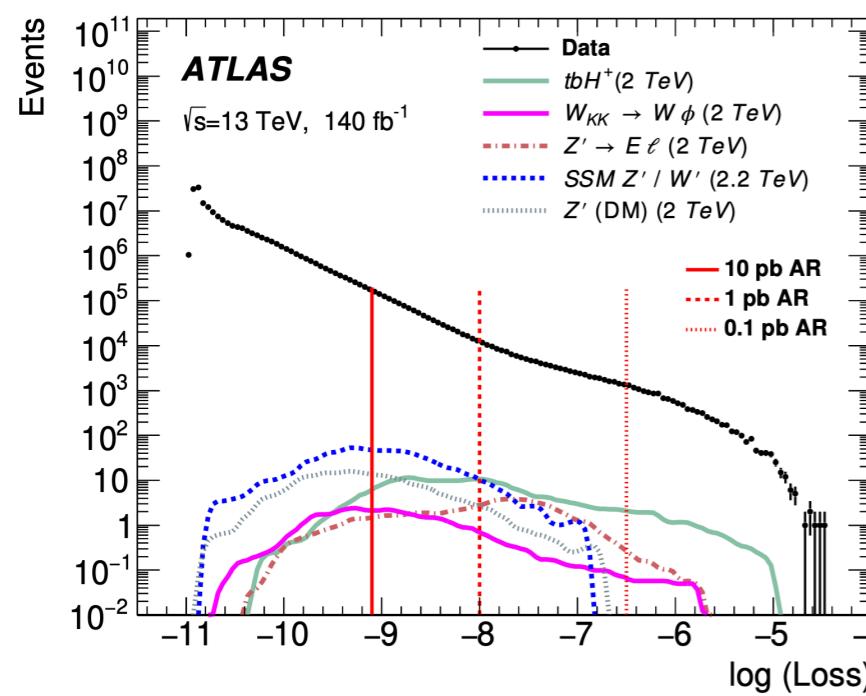
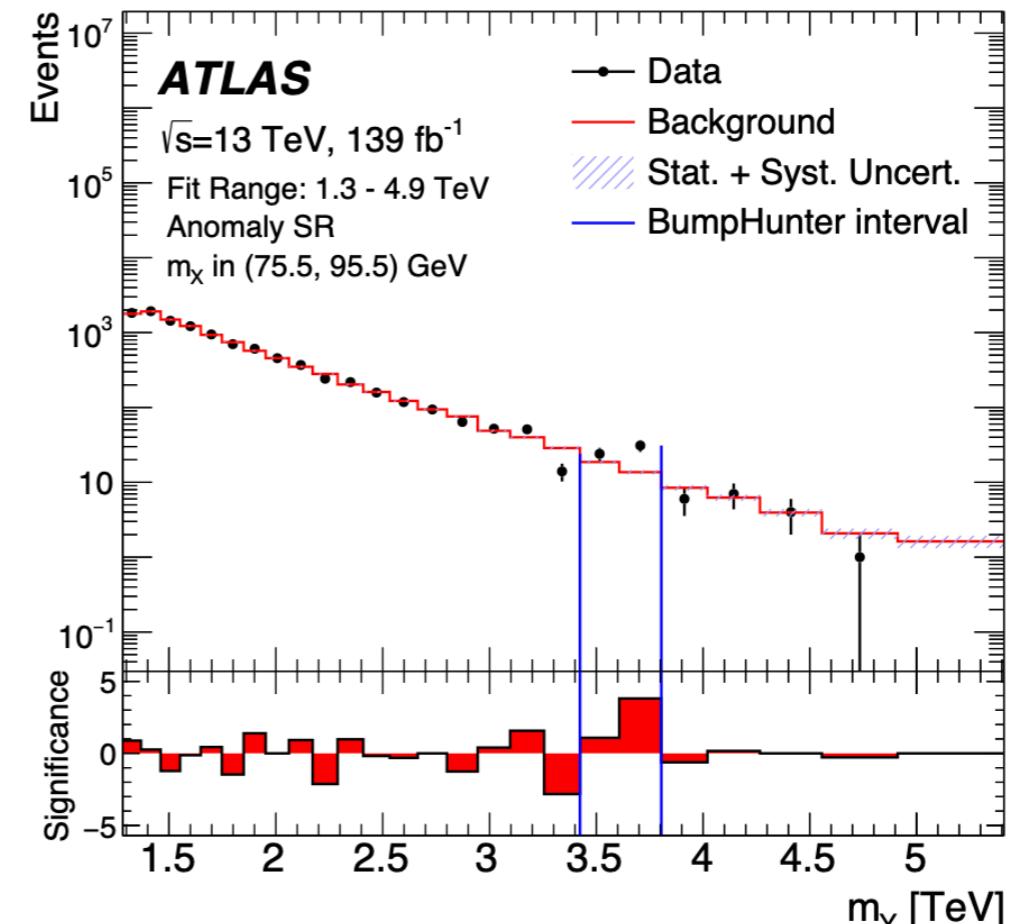
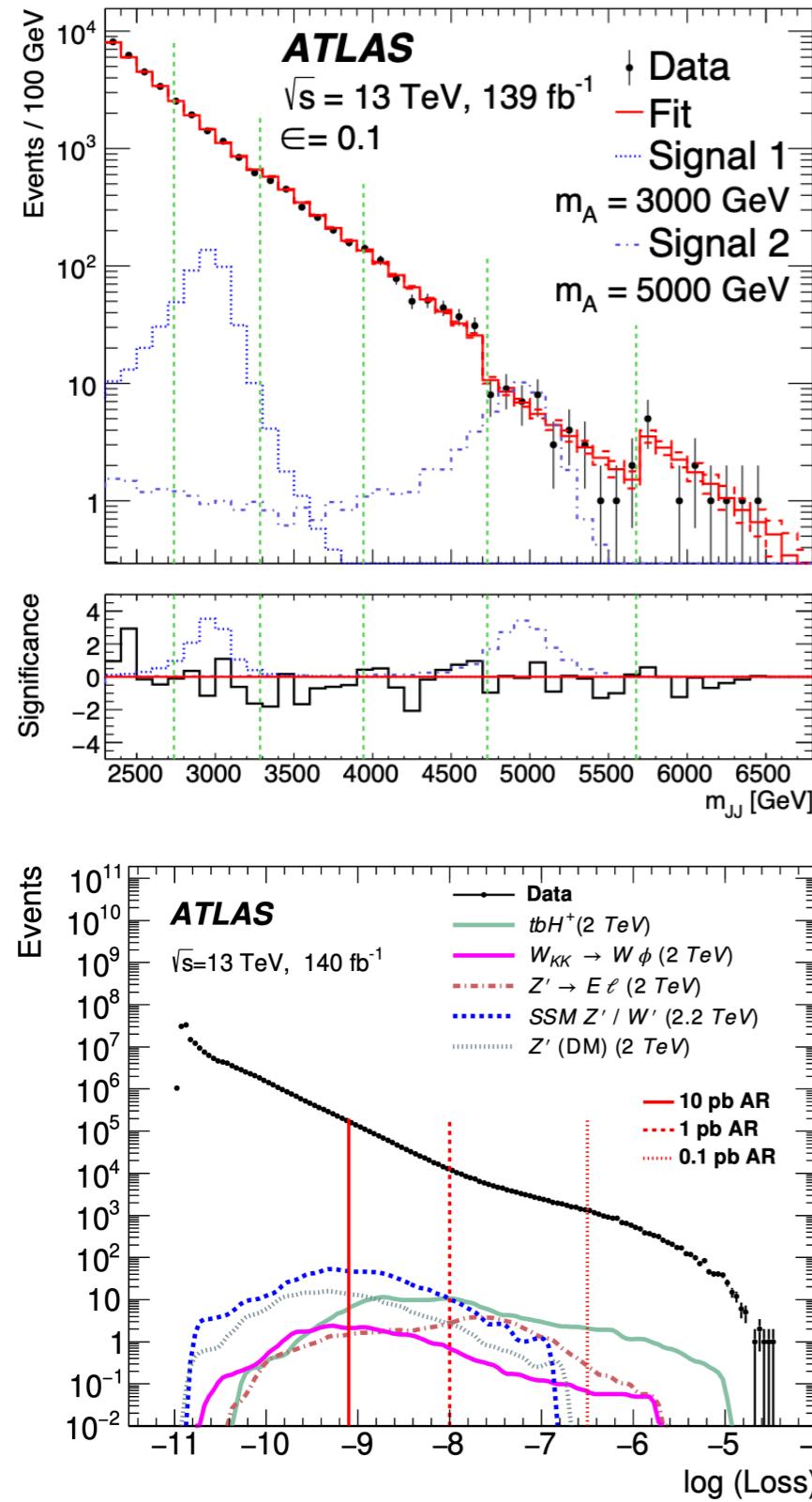


Anomaly detection: not just for
LHC Olympics anymore!



Anomaly Detection

Wasikul, Elham

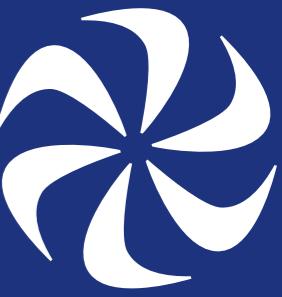


Anomaly detection: not just for LHC Olympics anymore!

When will we find the first confusing bump? 🤔

Higgs/Top Measurements

Higgs-Tagging is Normal



Jennet

Prajita

Higgs-Tagging is Normal



Jennet

Higgs-tagging is becoming a key part of the Higgs toolkit!

Prajita



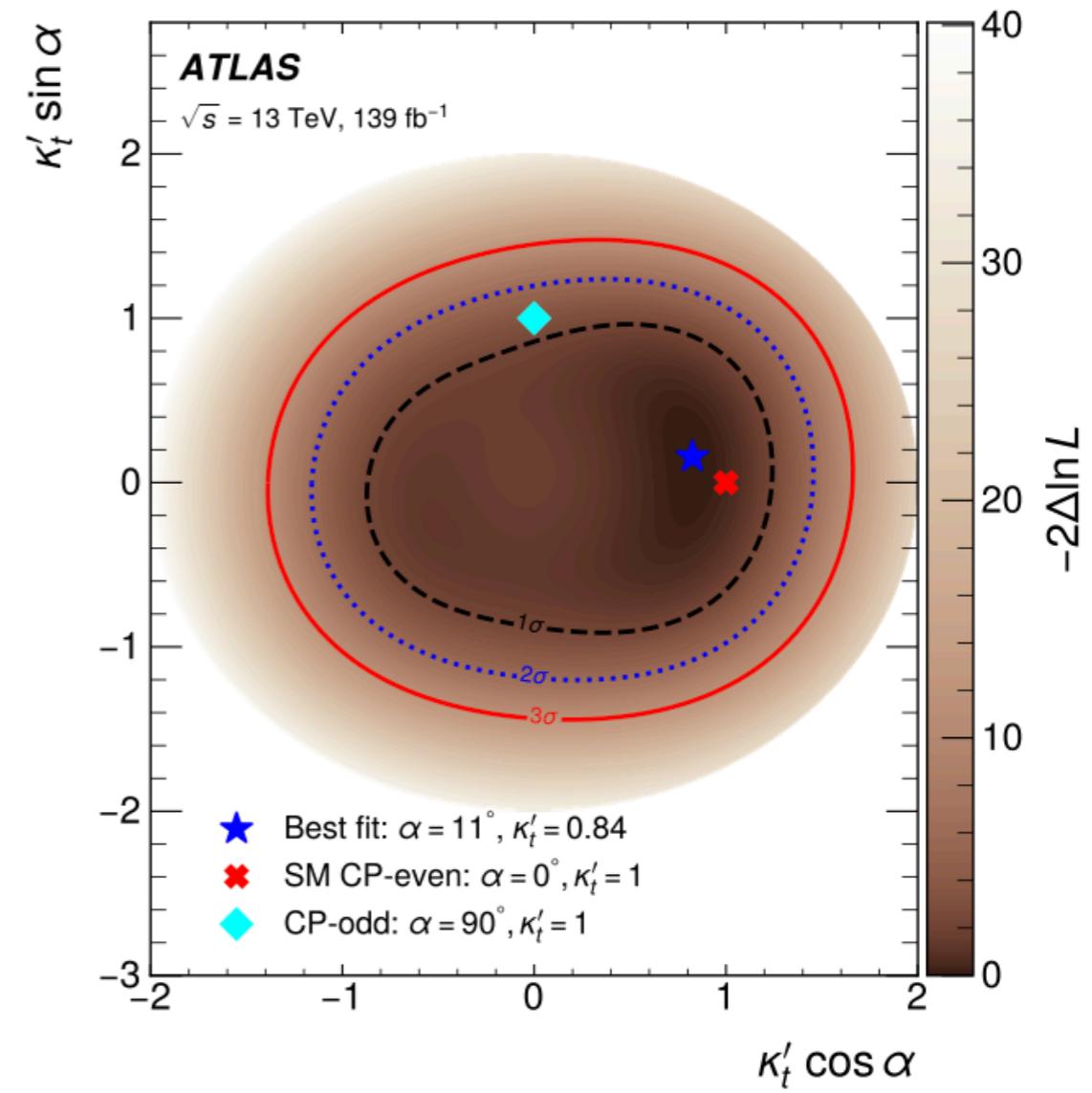
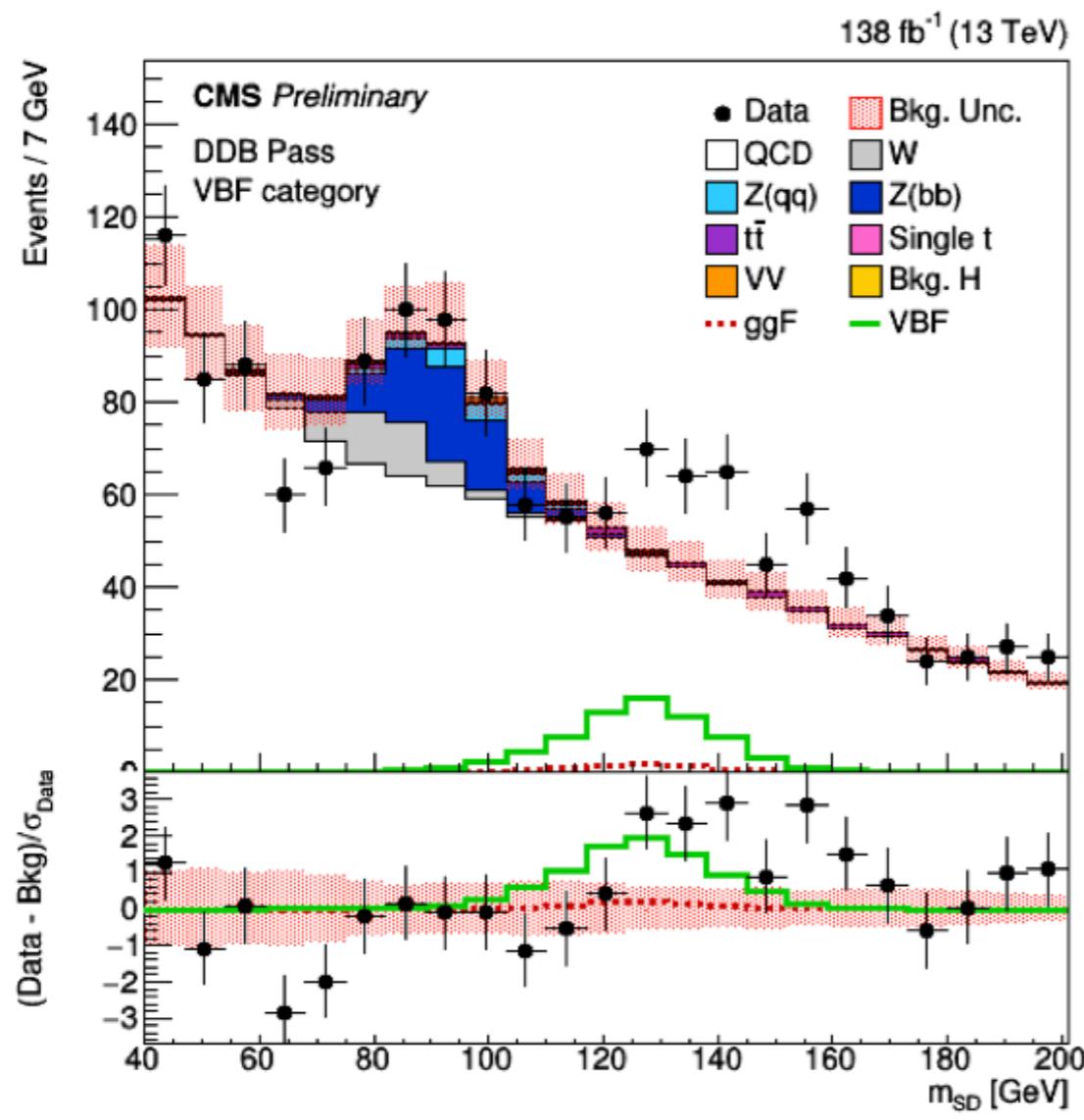
Higgs-Tagging is Normal

Jennet

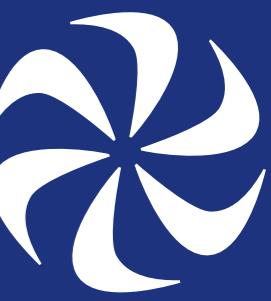
Higgs-tagging is becoming a key part of the Higgs toolkit!

Prajita

Analysis of production modes, Higgs properties, etc. all coming to rely on boosted techniques

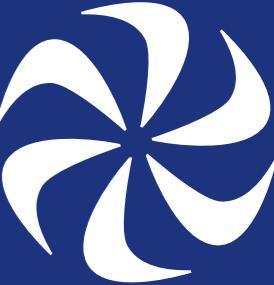


Innovations in Top



Adam

Innovations in Top



Adam

ATLAS Preliminary

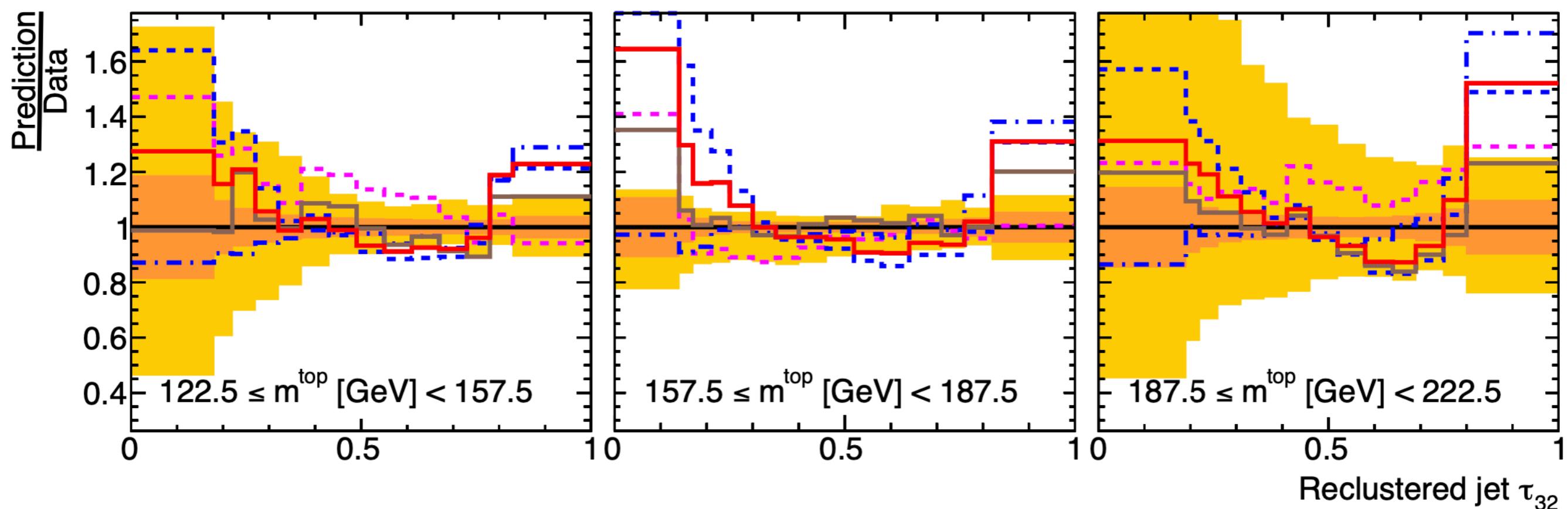
$\sqrt{s} = 13 \text{ TeV}, 140 \text{ fb}^{-1}$

I+jets, $p_T^{\text{top}} > 350 \text{ GeV}$

Fiducial phase-space

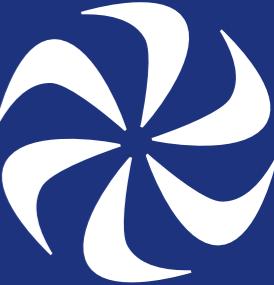
Relative cross-section

- PWG+PY8
- Stat. unc.
- - PWG+H7
- - PWG+PY8 FSR Down
- ██████████ Stat.+Syst. unc.
- Data
- - PWG+PY8 FSR Up
- MC@NLO+PY8



Hugely differential, impressively precise

Innovations in Top



Adam

ATLAS Preliminary

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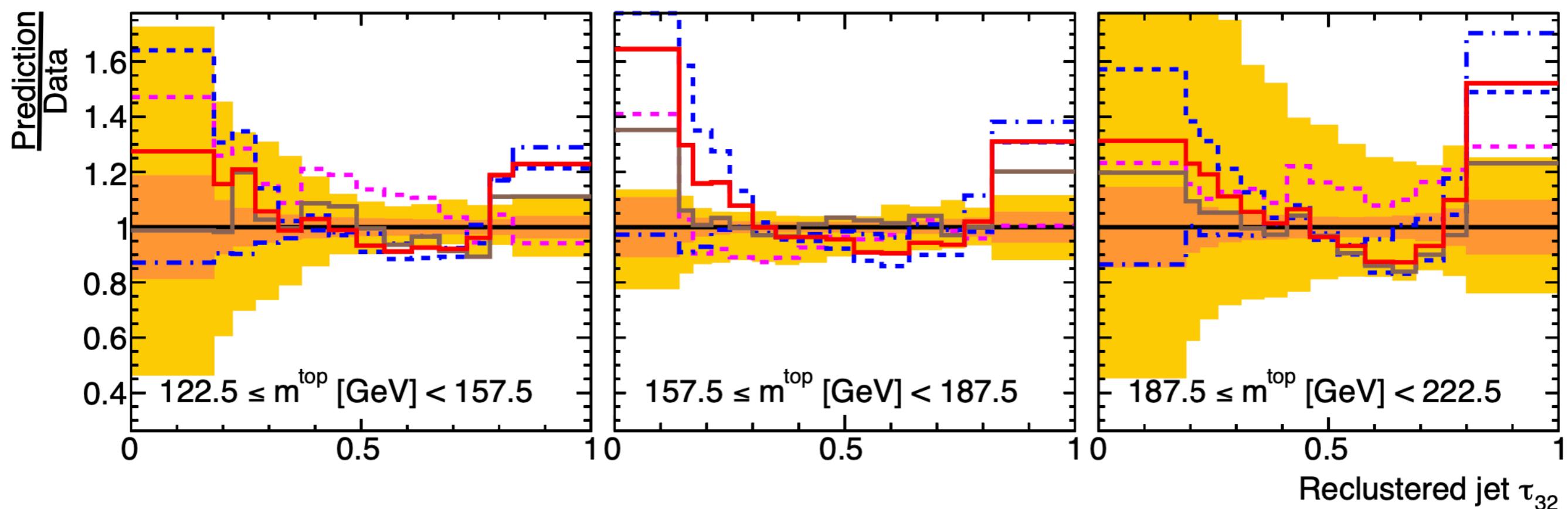
PWG+PY8 FSR Down

Stat.+Syst. unc.

Data

PWG+PY8 FSR Up

MC@NLO+PY8



Hugely differential, impressively precise

This isn't your 2011 measurement!

QCD Measurements

QCD Measurements

Or...

“Everybody get on board the Lund Plane!”



Clipdrop
by stability.ai

Beyond Basic Lund



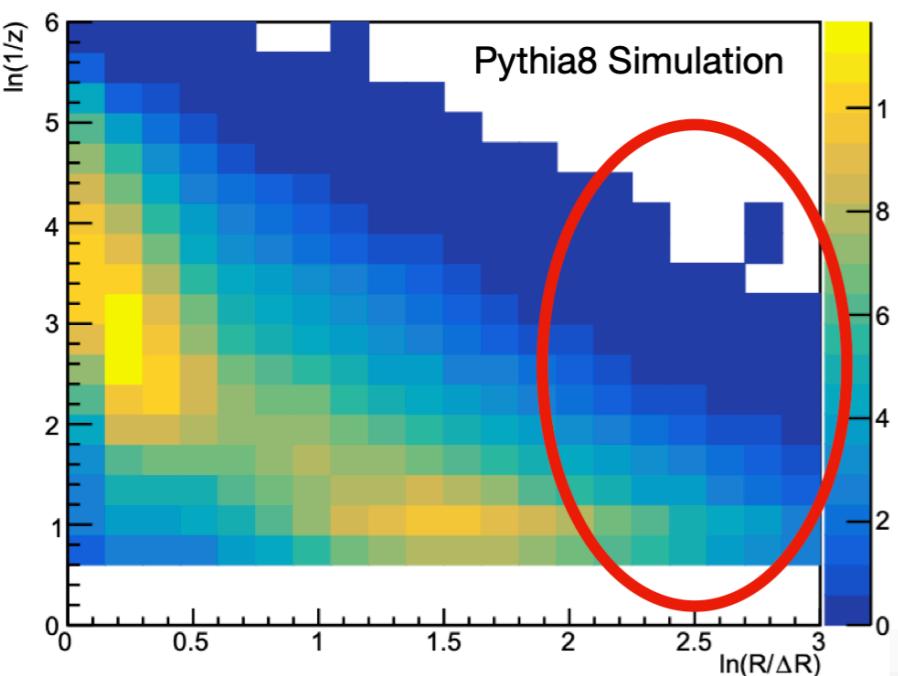
Ibrahim

Cristian

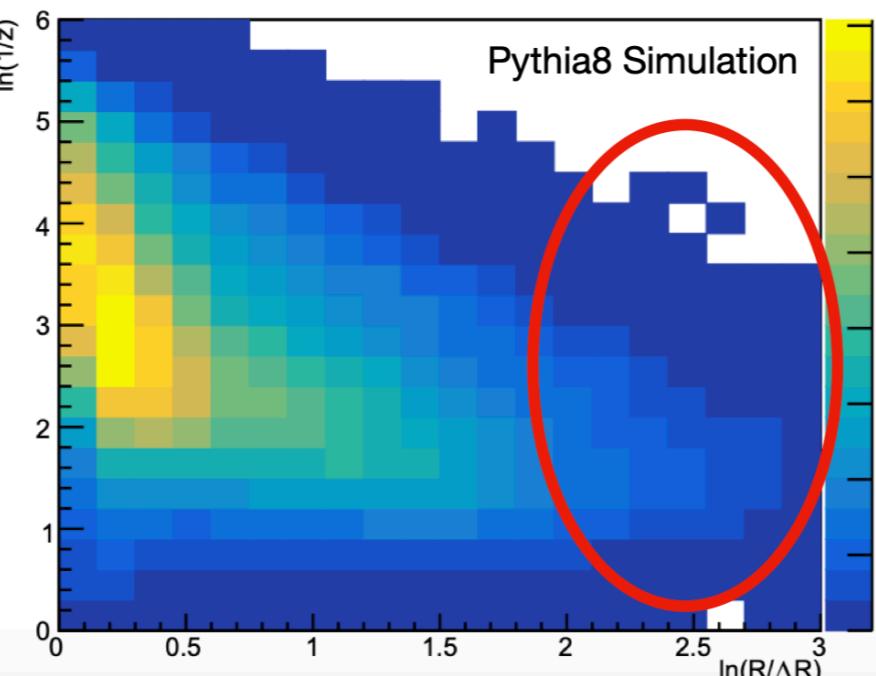


Beyond Basic Lund

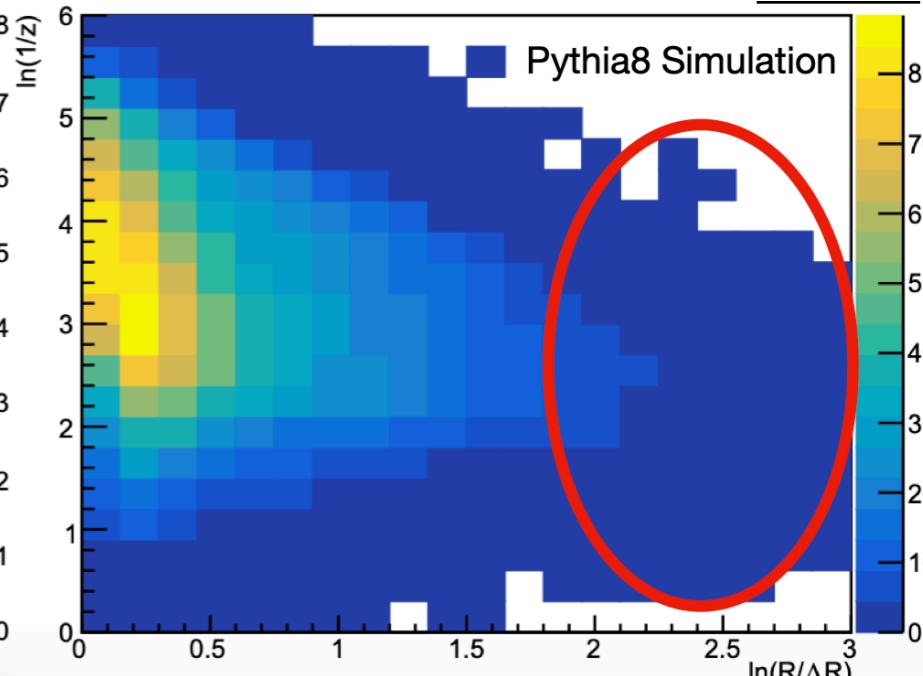
Light quark jets



Charm jets



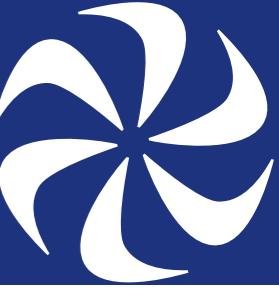
Beauty jets



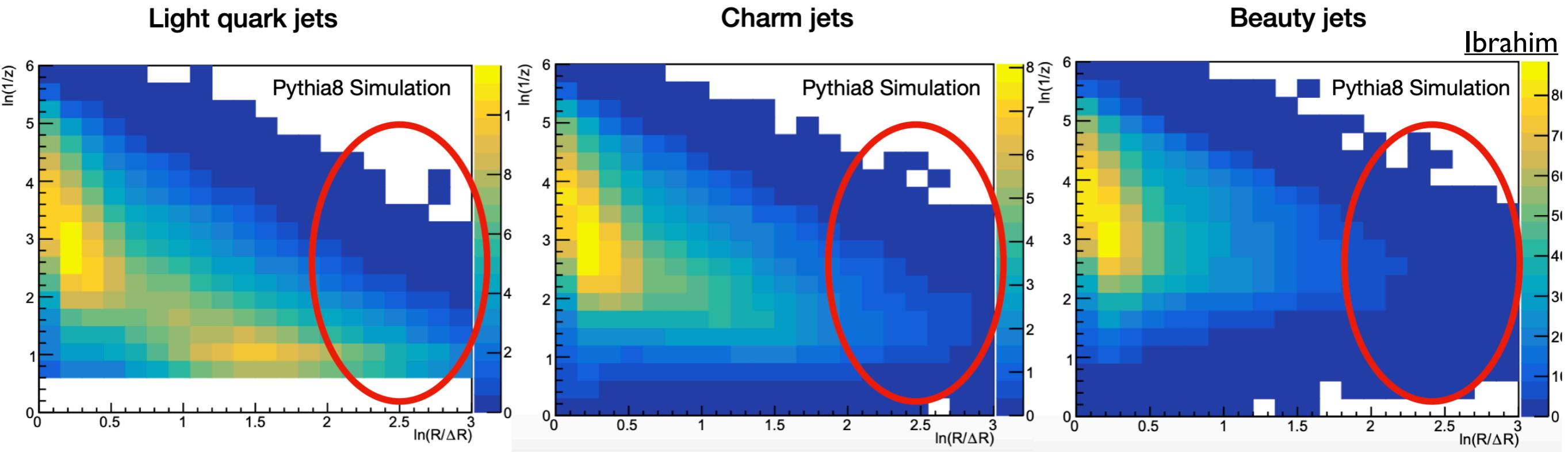
Ibrahim

Suppressed collinear radiation = dead cone effect!

Cristian

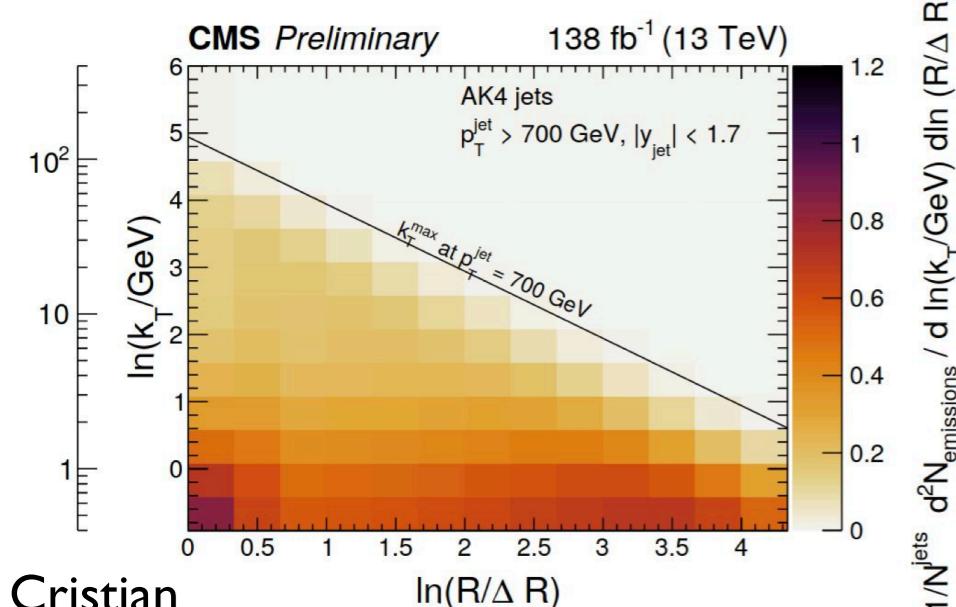


Beyond Basic Lund



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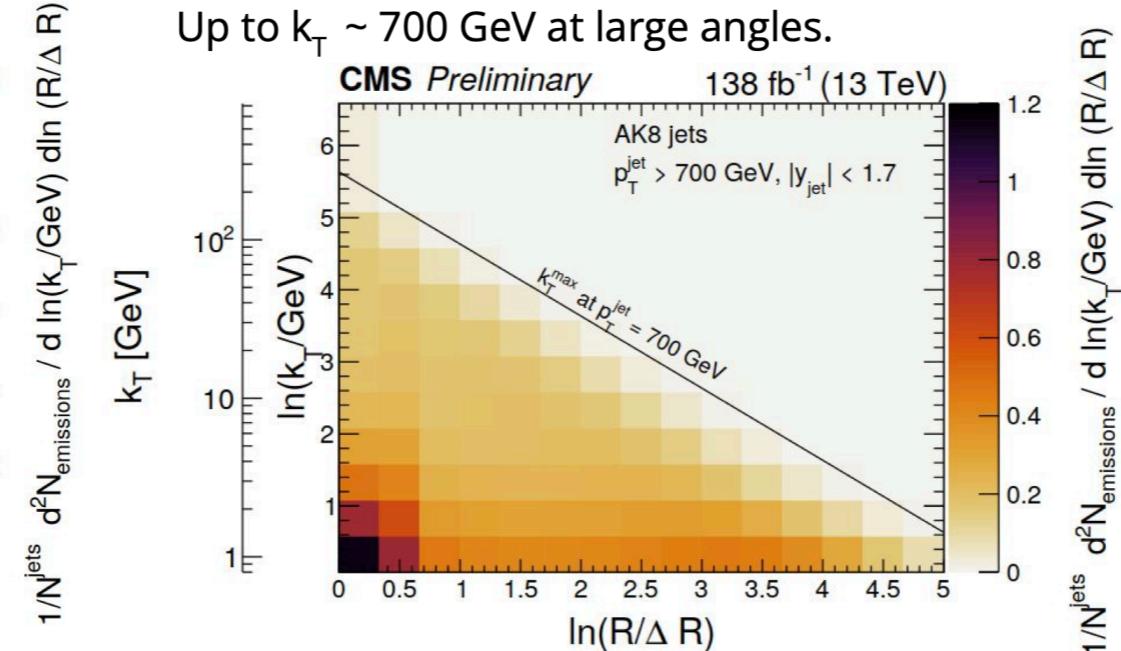
R=0.4 (standard R in Run-2)

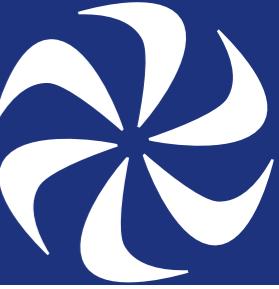


Cristian

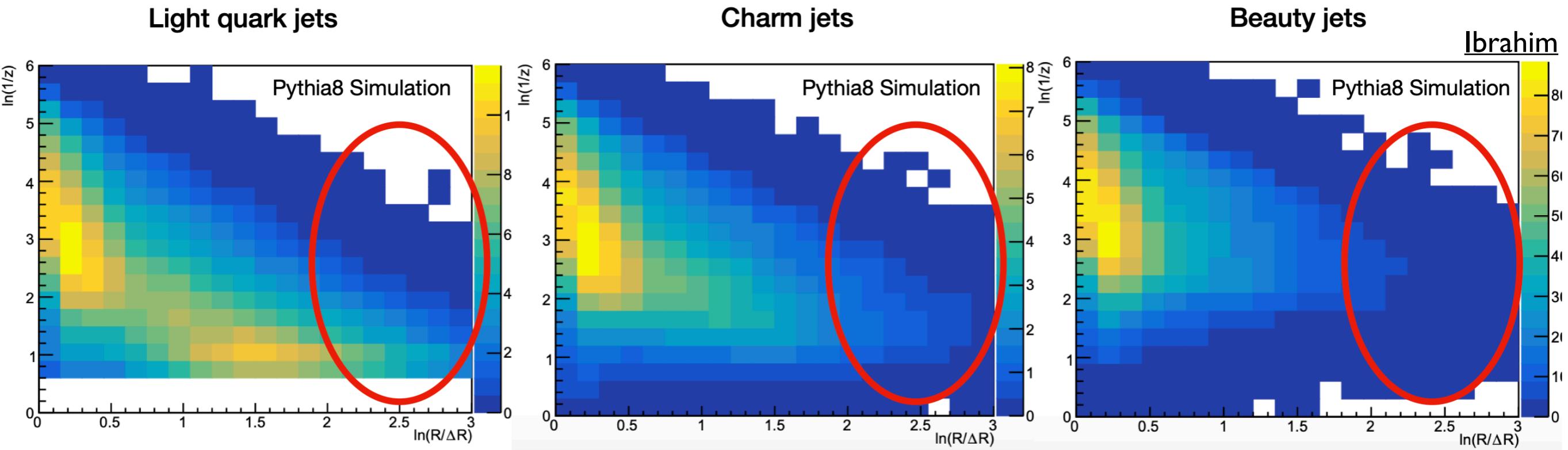
R=0.8 (wider & harder emissions)

Up to $k_T \sim 700 \text{ GeV}$ at large angles.



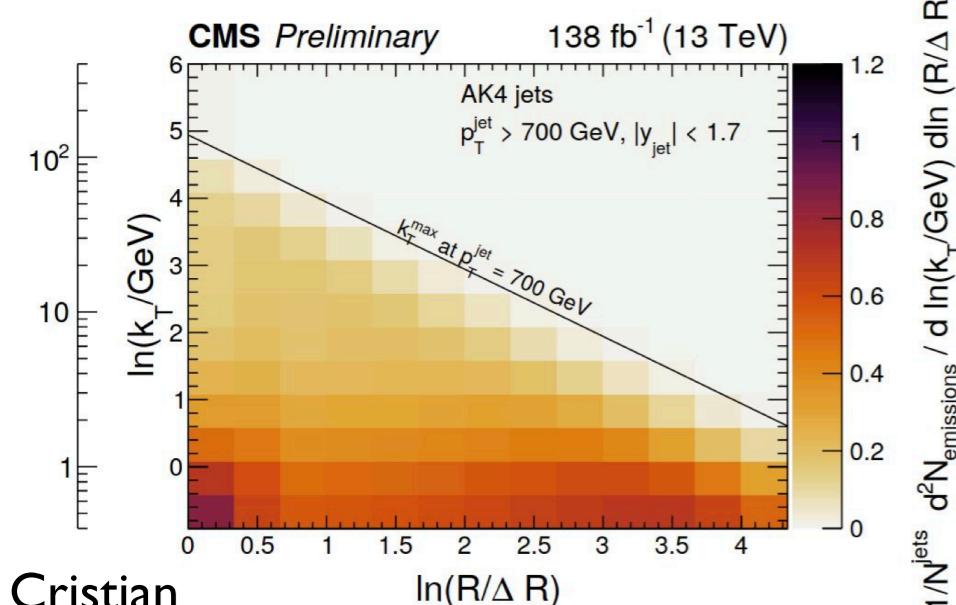


Beyond Basic Lund



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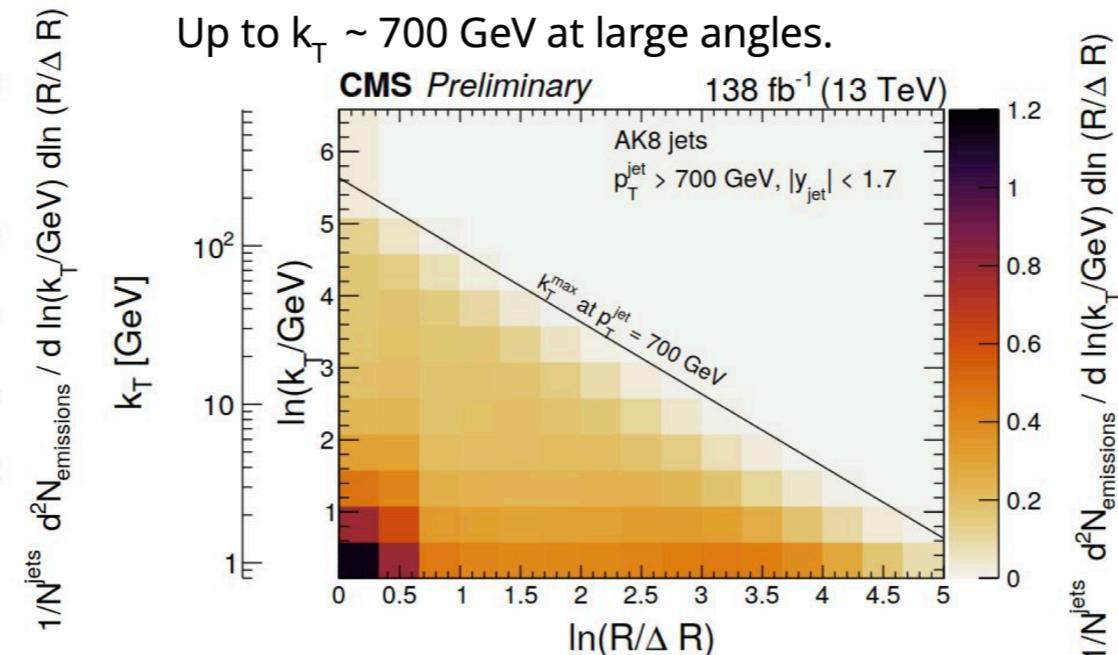
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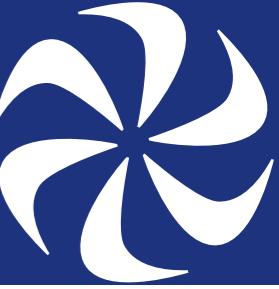
Cristian

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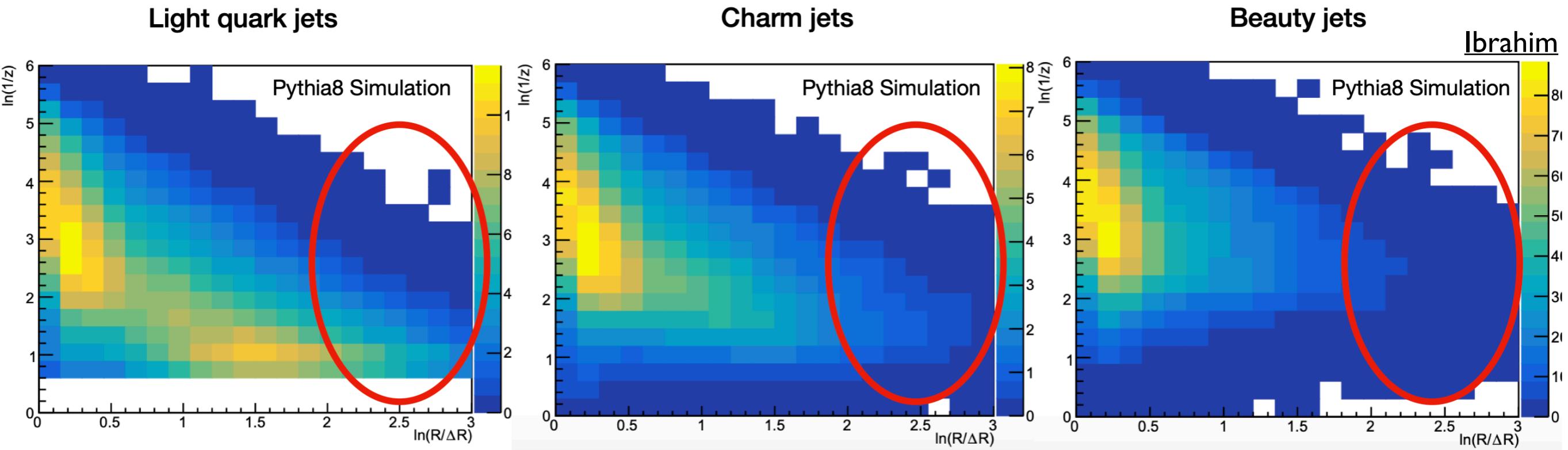
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We started just measuring the plane...

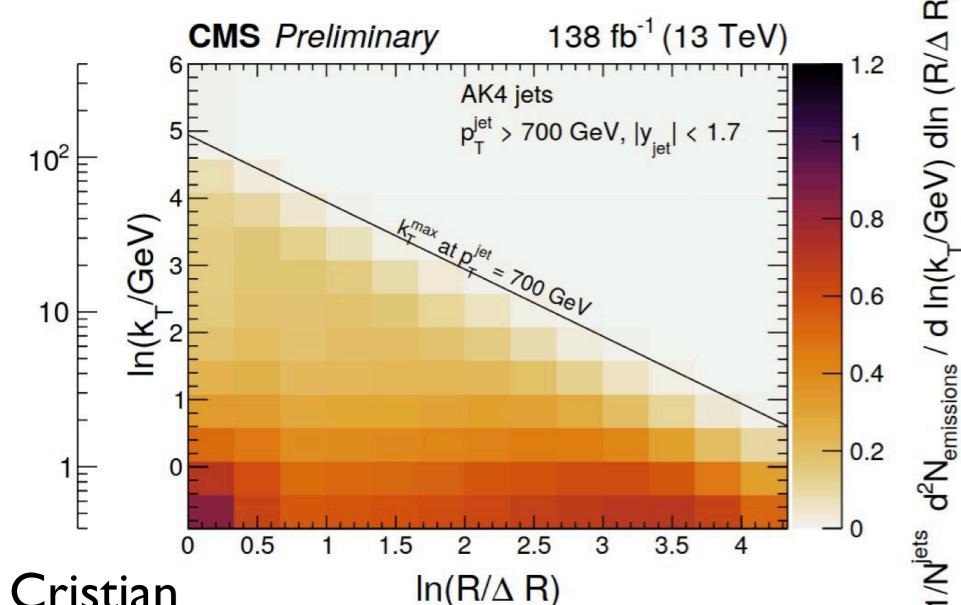


Beyond Basic Lund



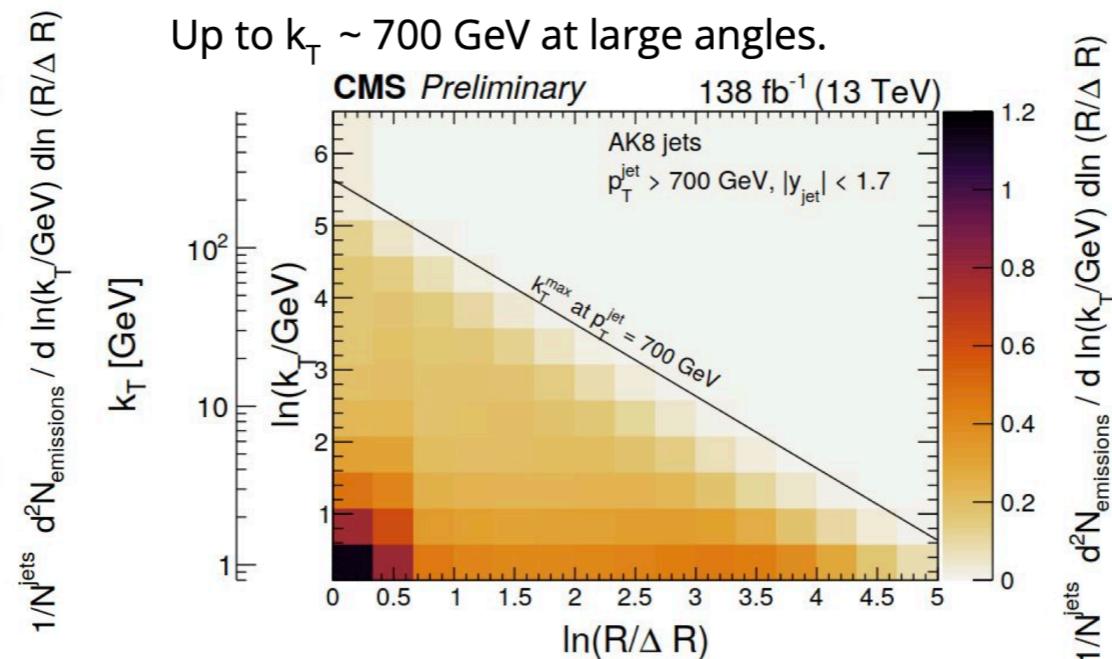
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Up to $k_T \sim 700 \text{ GeV}$ at large angles.



We started just measuring the plane...

Now we can use it to say things about QCD!

Understanding Grooming

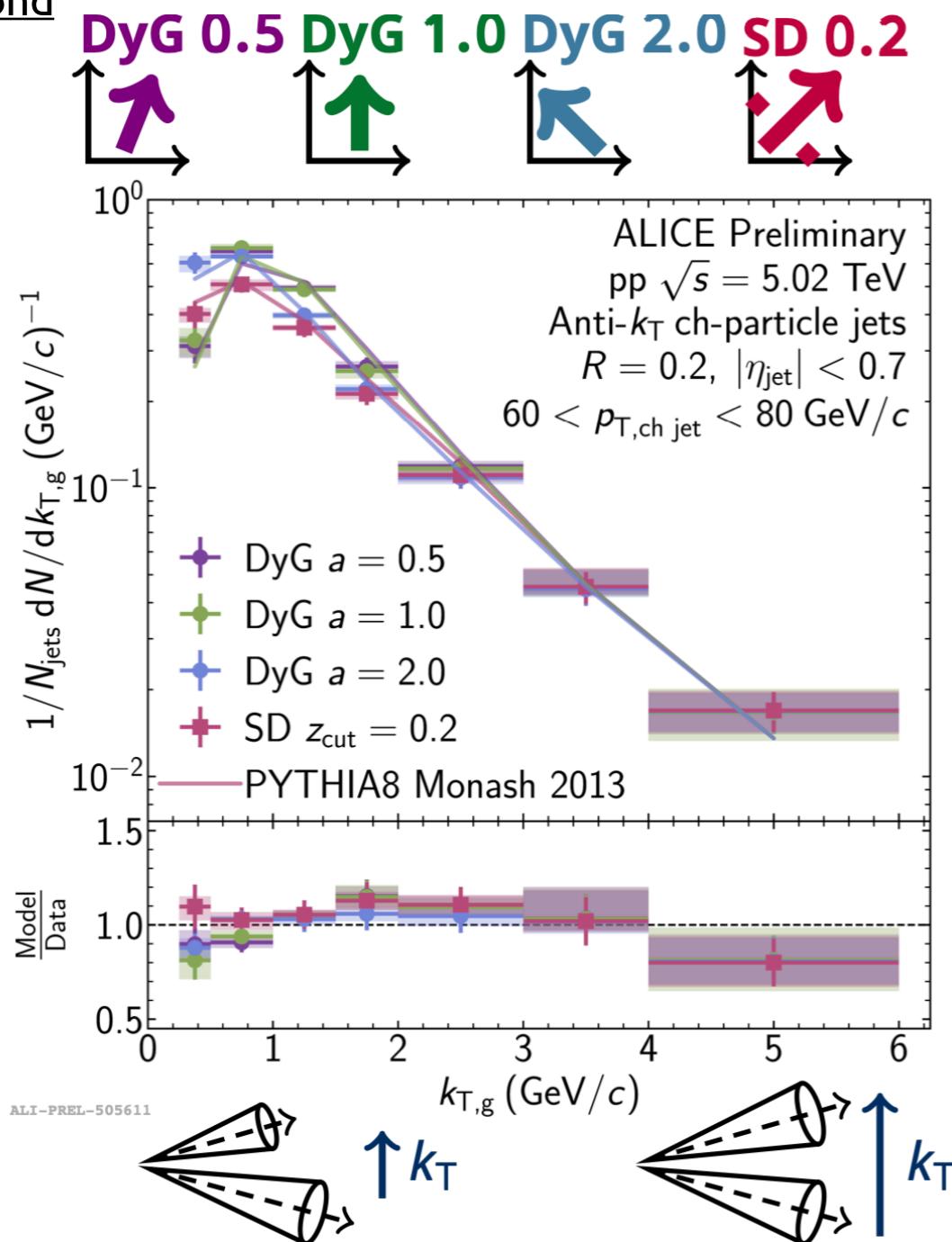


Raymond

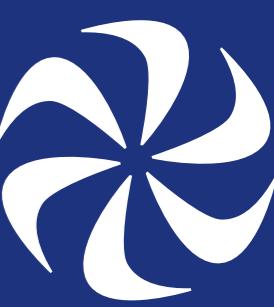


Understanding Grooming

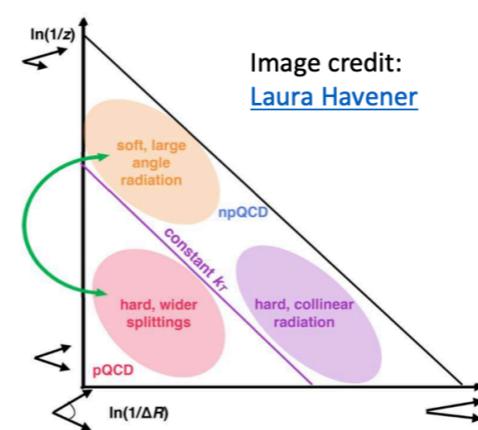
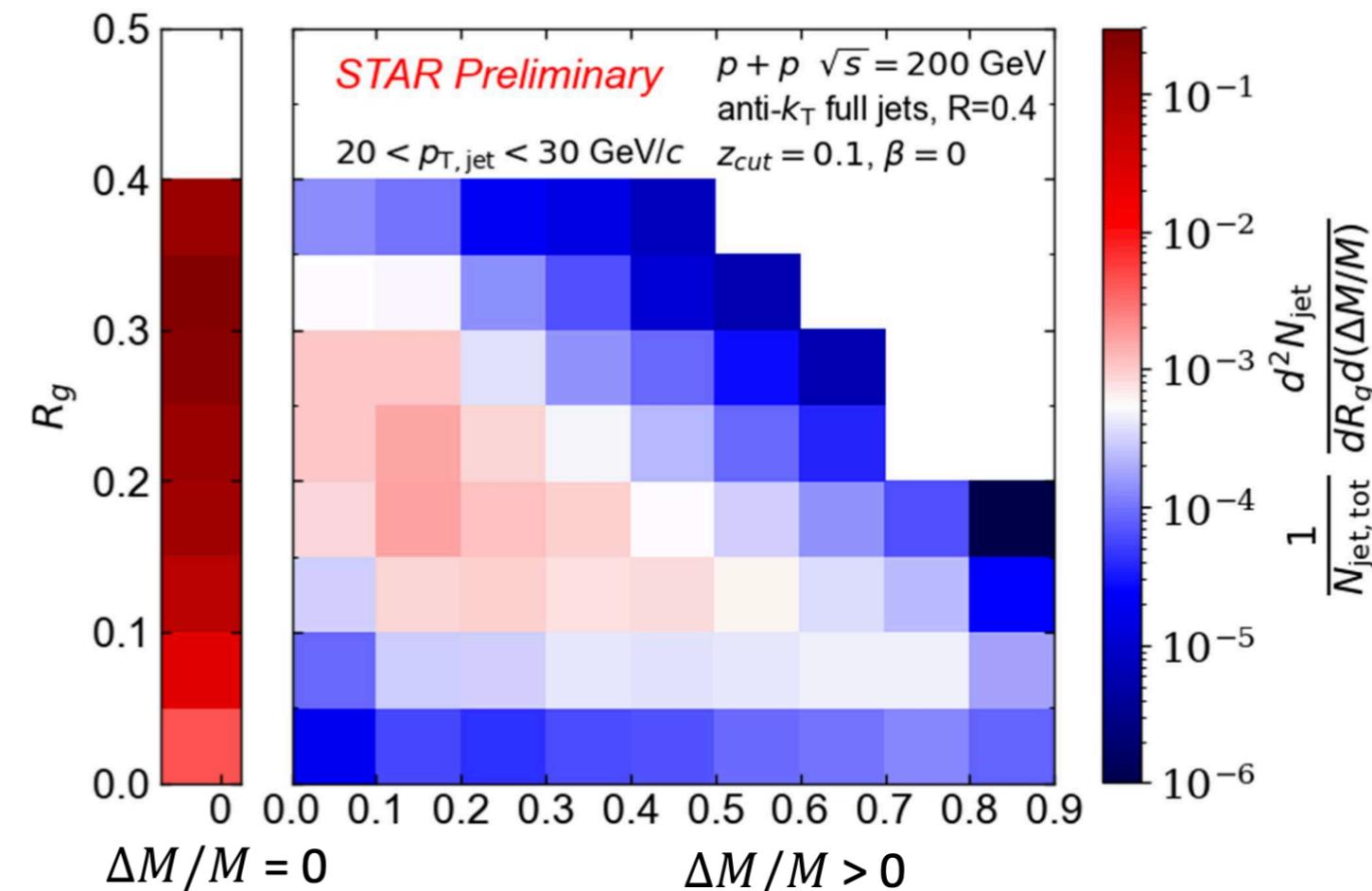
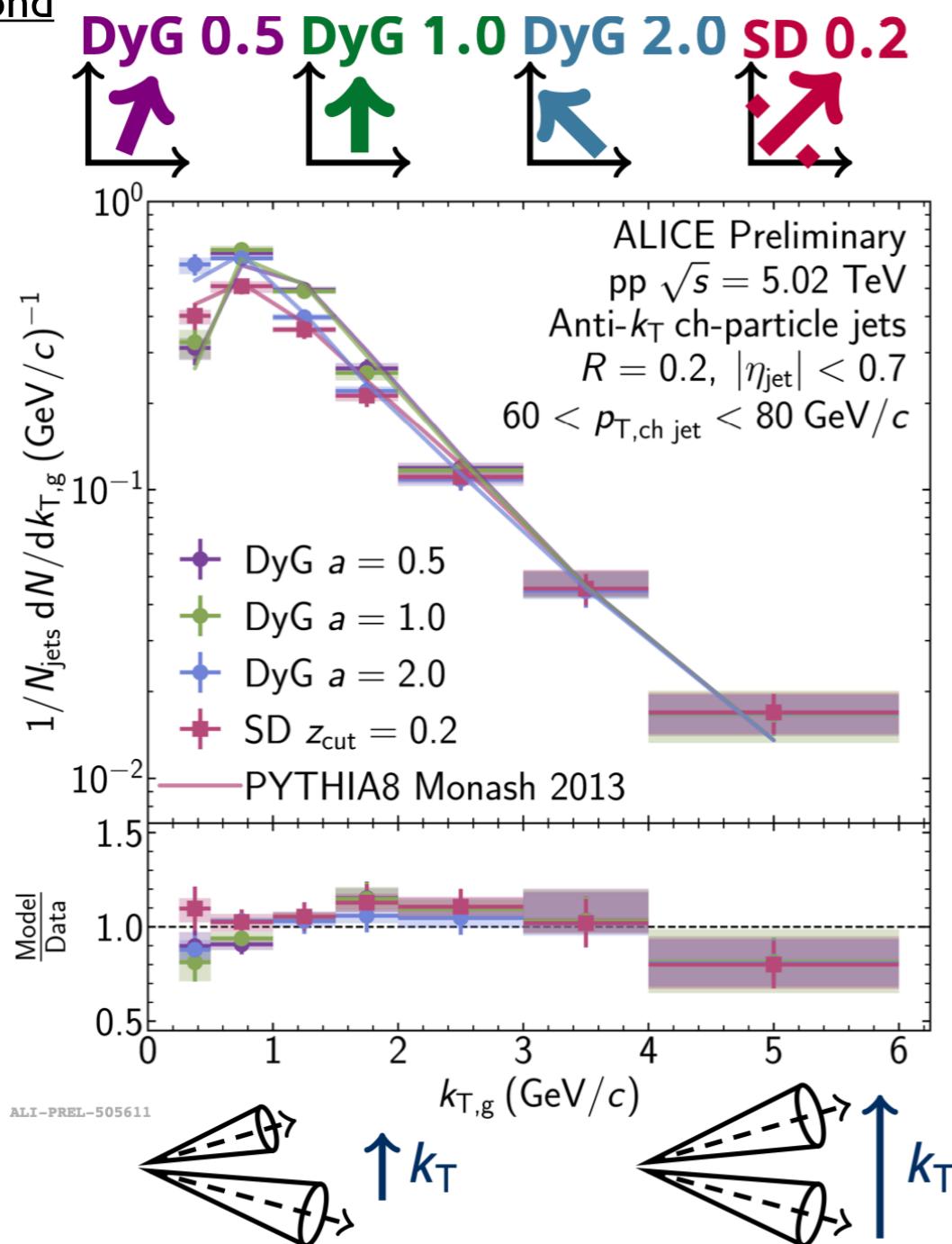
Raymond



Understanding Grooming



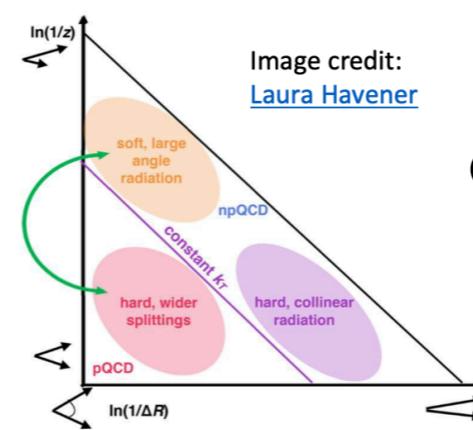
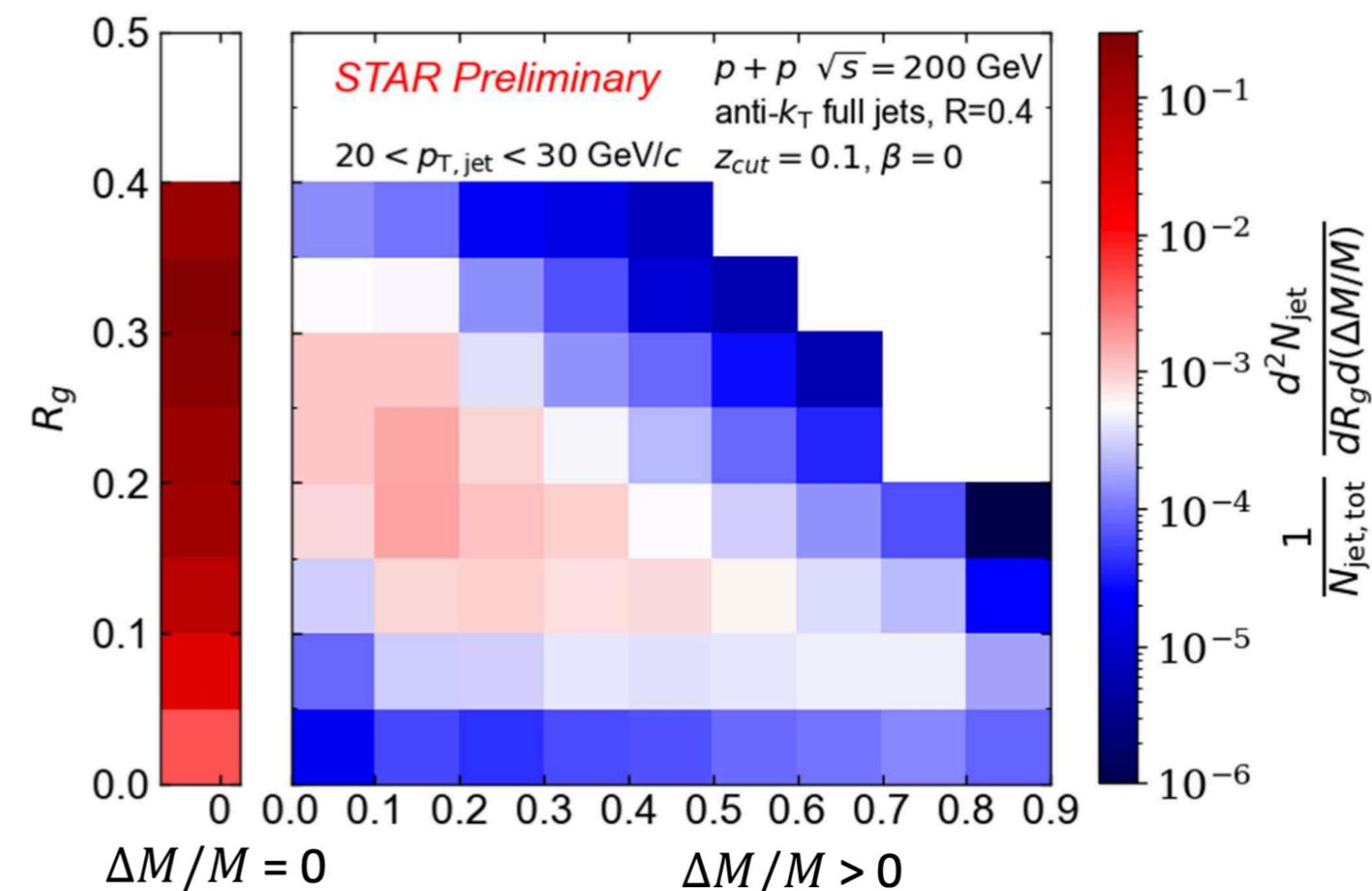
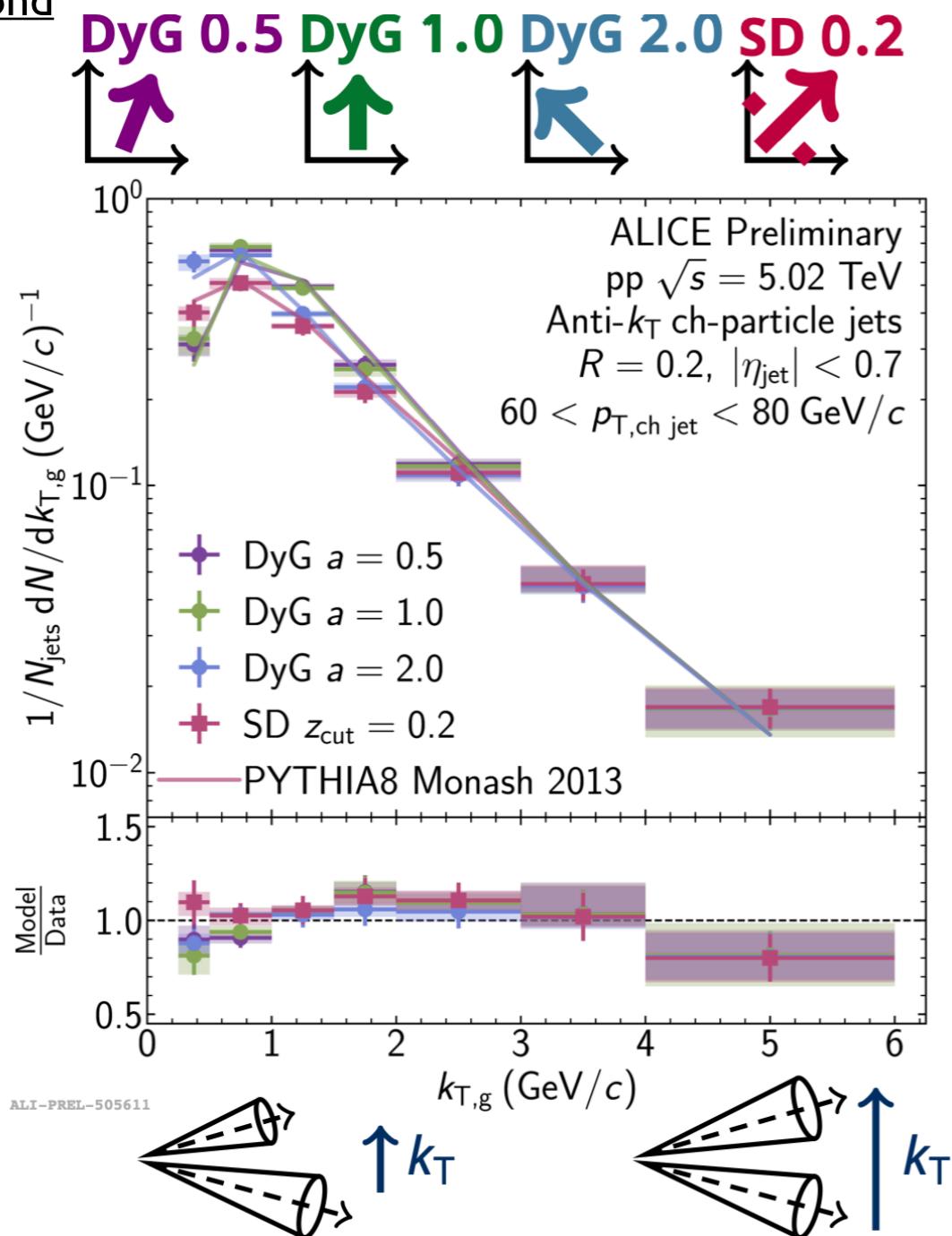
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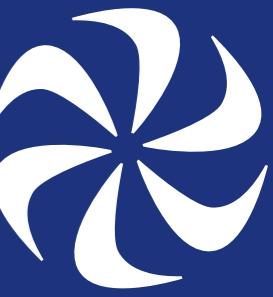


Raymond



Fantastic measurements
of jet grooming properties
even in pp from STAR,
ALICE, and more!

Lund Plane for QGP



Raymond

Cristian

Lund Plane for QGP



Raymond

Patterns of emissions
can be used to search for
“point-like” scattering
in QGP

Cristian

Lund Plane for QGP



Searching for modification

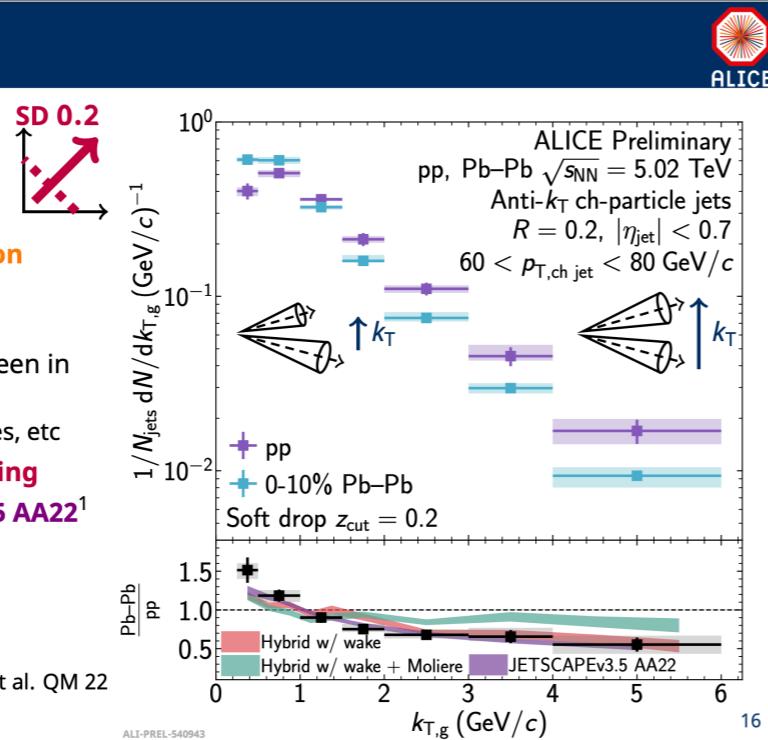
Raymond

- No enhancement at high $k_{T,g}$
- Standard DyG shows little modification
- Modification in methods with $z > 0.2$
 - Larger modification in 0-10%
- Consistent with narrowing picture seen in many substructure analyses.
 - eg. R_g , jet axis difference, angularities, etc
- No clear evidence of Moliere scattering
- 0-10% data described by JETSCAPEv3.5 AA22¹ and Hybrid model² w/out Moliere
- Caveat: pp baseline

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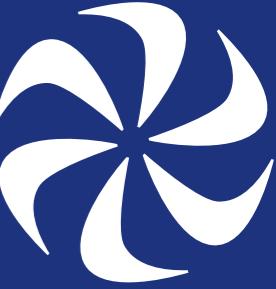
2: D'Eramo et al. JHEP 01 (2019) 172, Hulcher et al. QM 22

Raymond Ehlers (LBNL/UCB) - 3 August 2023



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Cristian



Lund Plane for QGP

Searching for modification

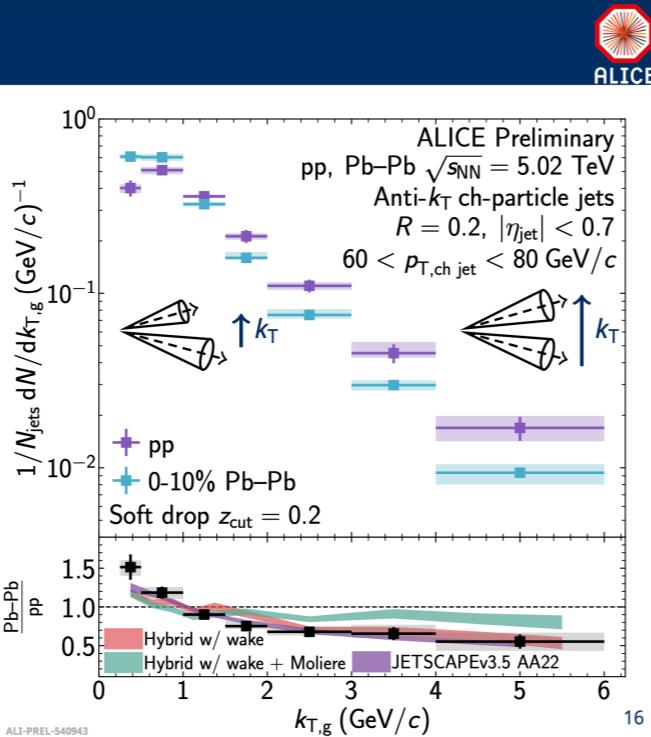
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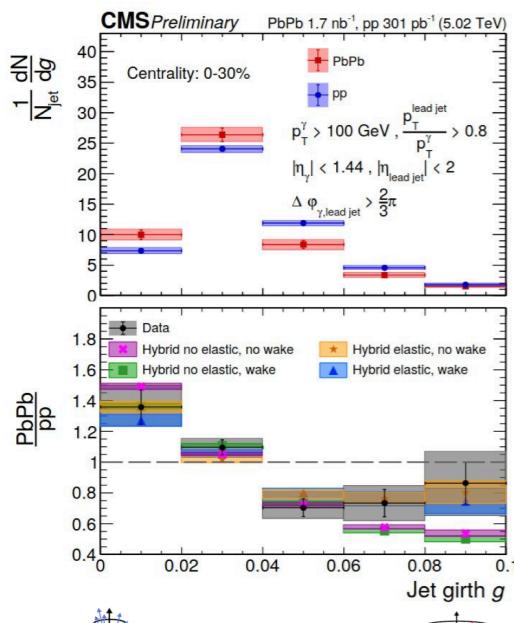
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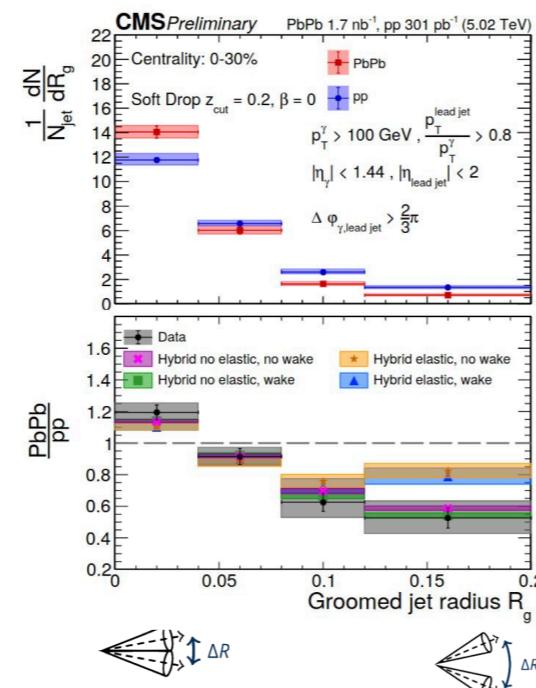
Raymond Ehlers (LBNL/UCB) - 3 August 2023



With stronger selection bias $p_T^{\text{jet}}/p_T^{\gamma} > 0.8$



CMS-PAS-HIN-23-001, link soon



Narrowing

Patterns of emissions
can be used to search for
“point-like” scattering
in QGP

Cristian

Predictions w/ Molière scatterings (large-angle deflections) give best global description ($\theta_c = 0$). No sensitivity to wake effect. [J. Casalderrey-Solana et al, JHEP01\(2020\)044](#)

Cristian Baldenegro (LLR)

BOOST 2023 @ LBNL

Lund Plane for QGP



Searching for modification

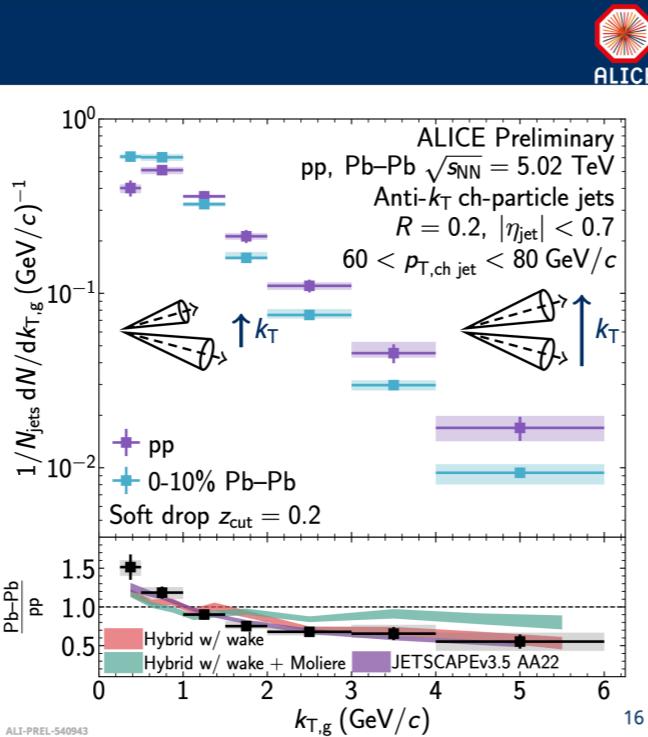
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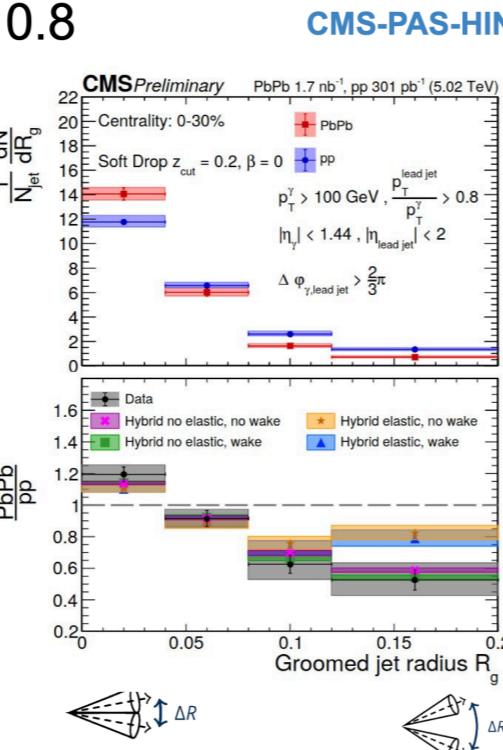
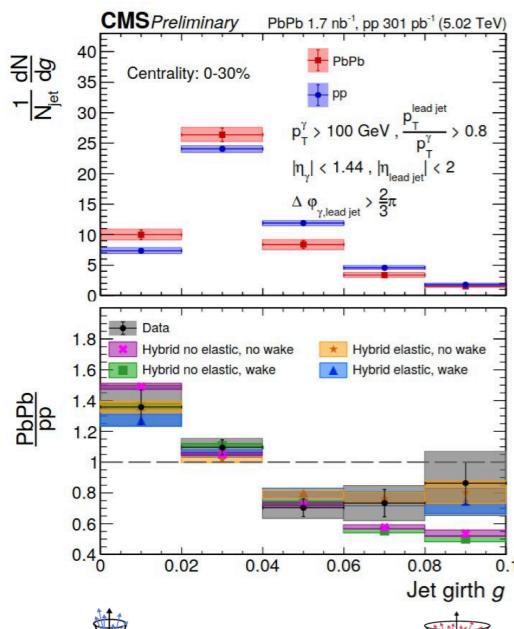
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Raymond Ehlers (LBNL/UCB) - 3 August 2023



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Cristian Baldenegro (LLR)

BOOST 2023 @ LBNL

29

Patterns of emissions can be used to search for “point-like” scattering in QGP

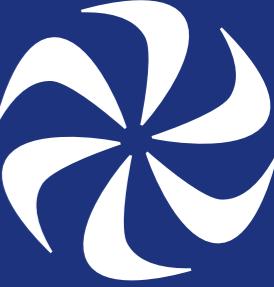
Some disagreement between CMS and ALICE on interpretations here?

Narrowing

29

August 4, 2023

Lund Plane for QGP



Searching for modification

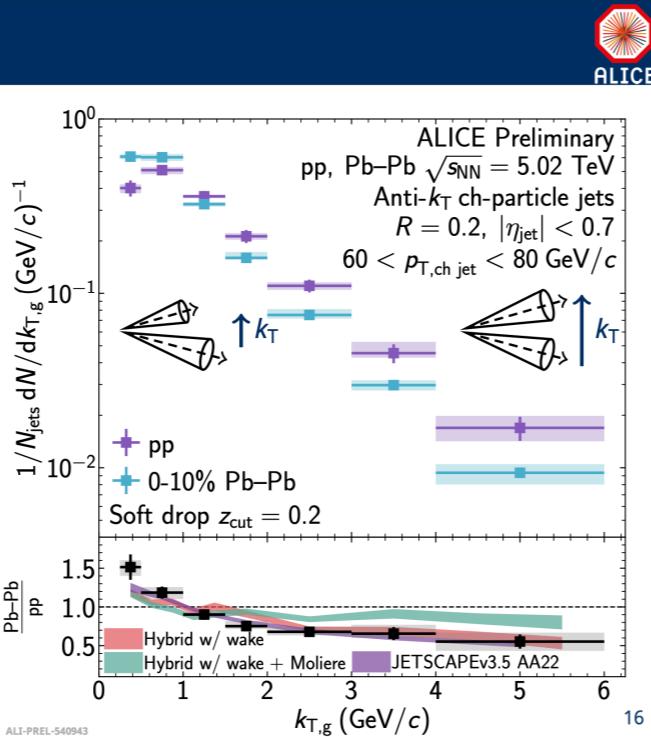
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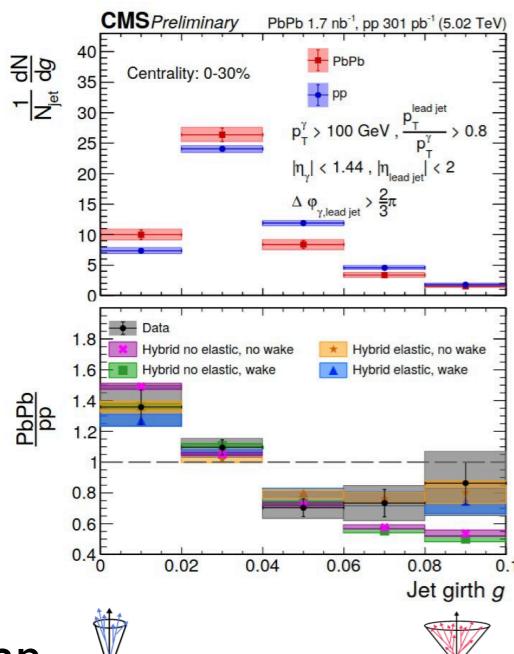
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Raymond Ehlers (LBNL/UCB) - 3 August 2023



With stronger selection bias $p_T^{\text{jet}}/p_T^{\gamma} > 0.8$



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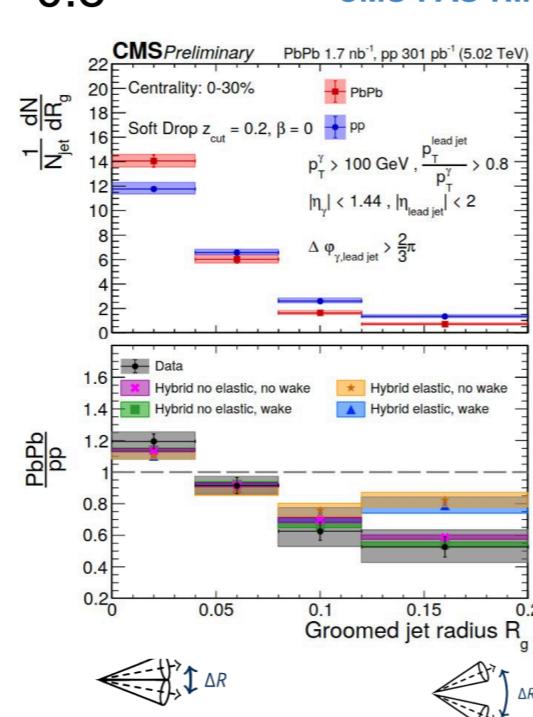
Cristian Baldenegro (LLR)

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Patterns of emissions can be used to search for “point-like” scattering in QGP

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Narrowing

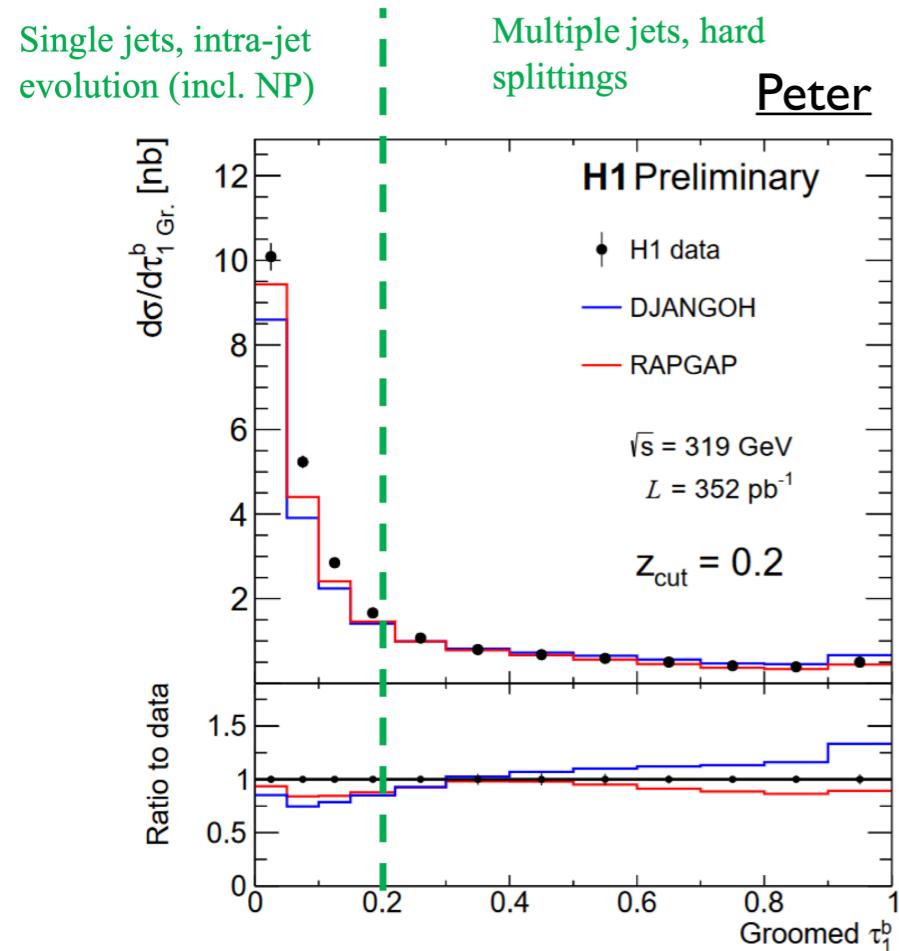


Jet structure telling us something fundamental about QCD— using the Lund Plane!

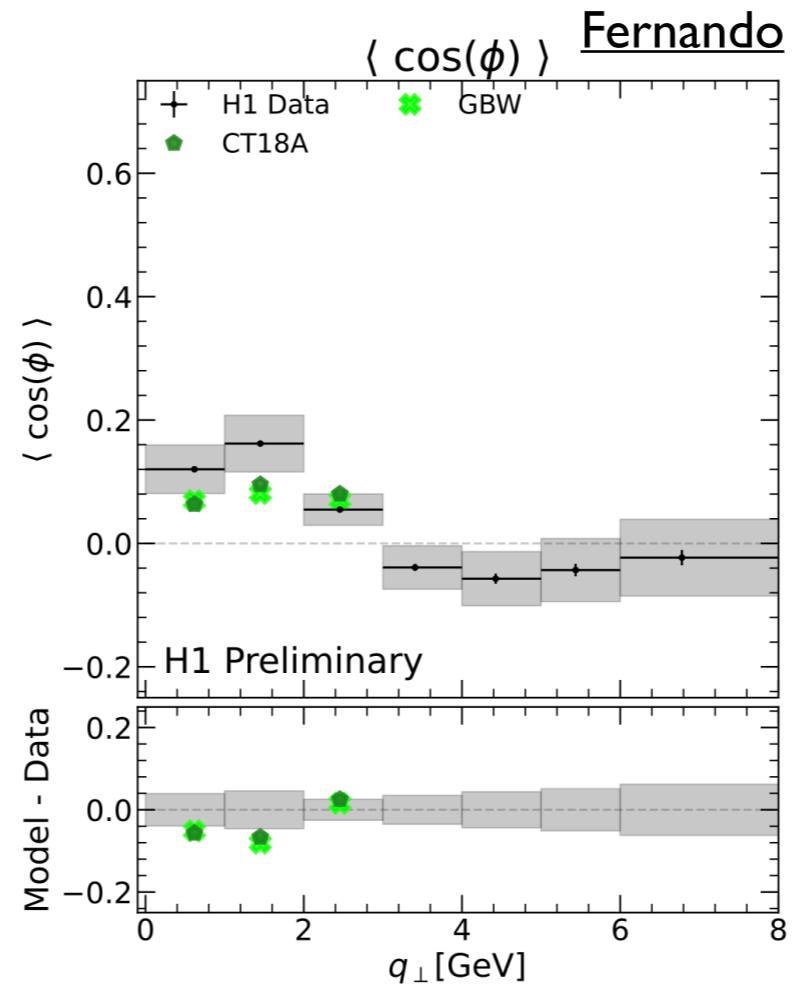
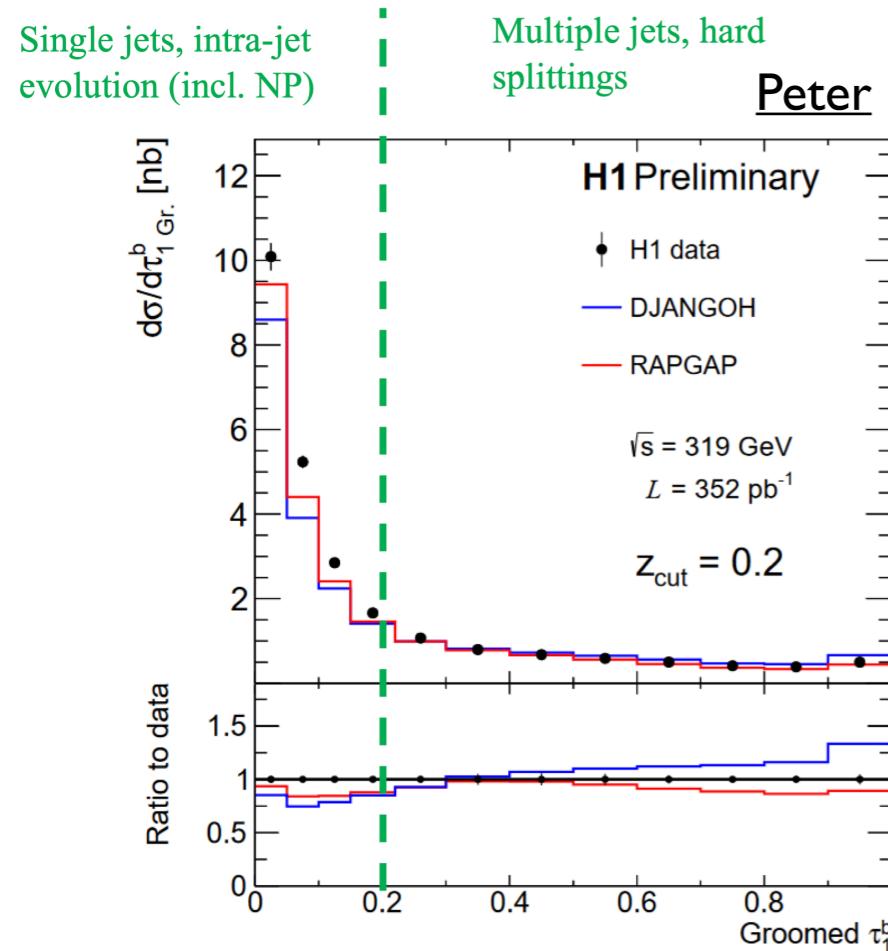
HI's Tour-de-force



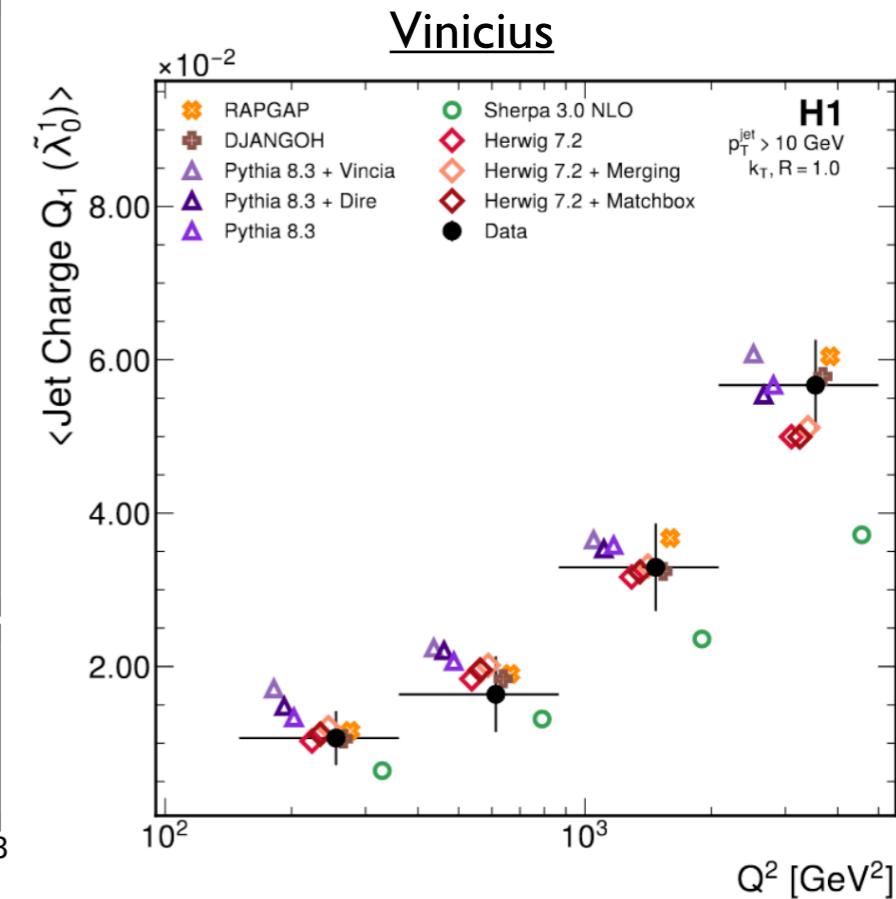
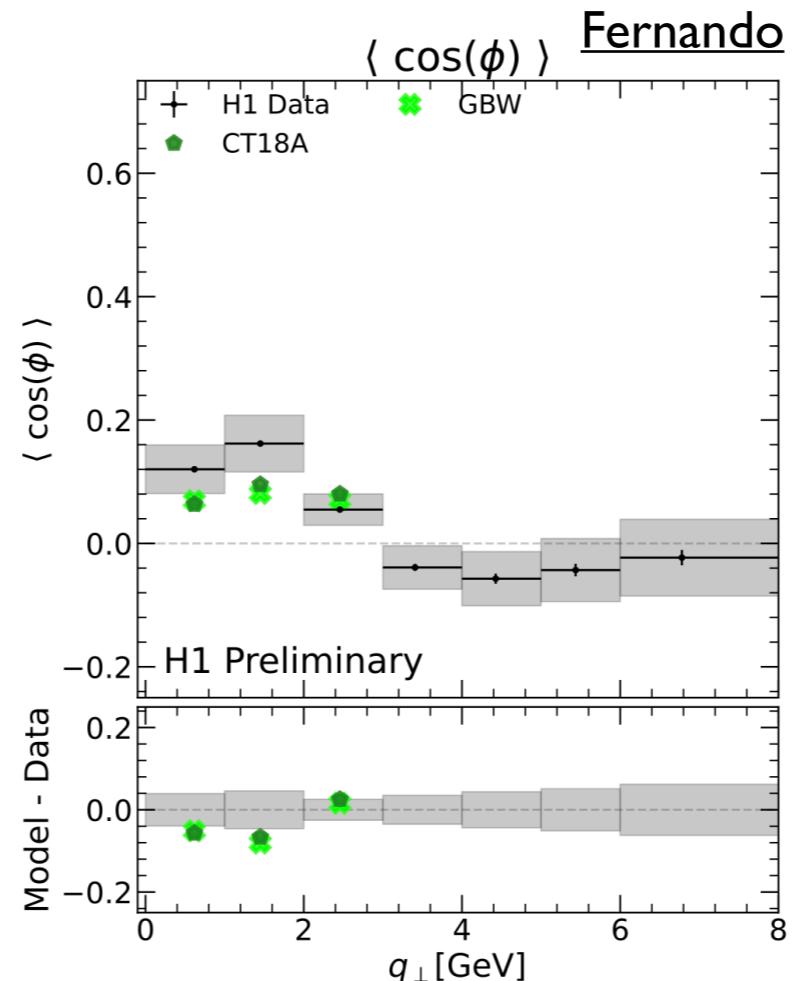
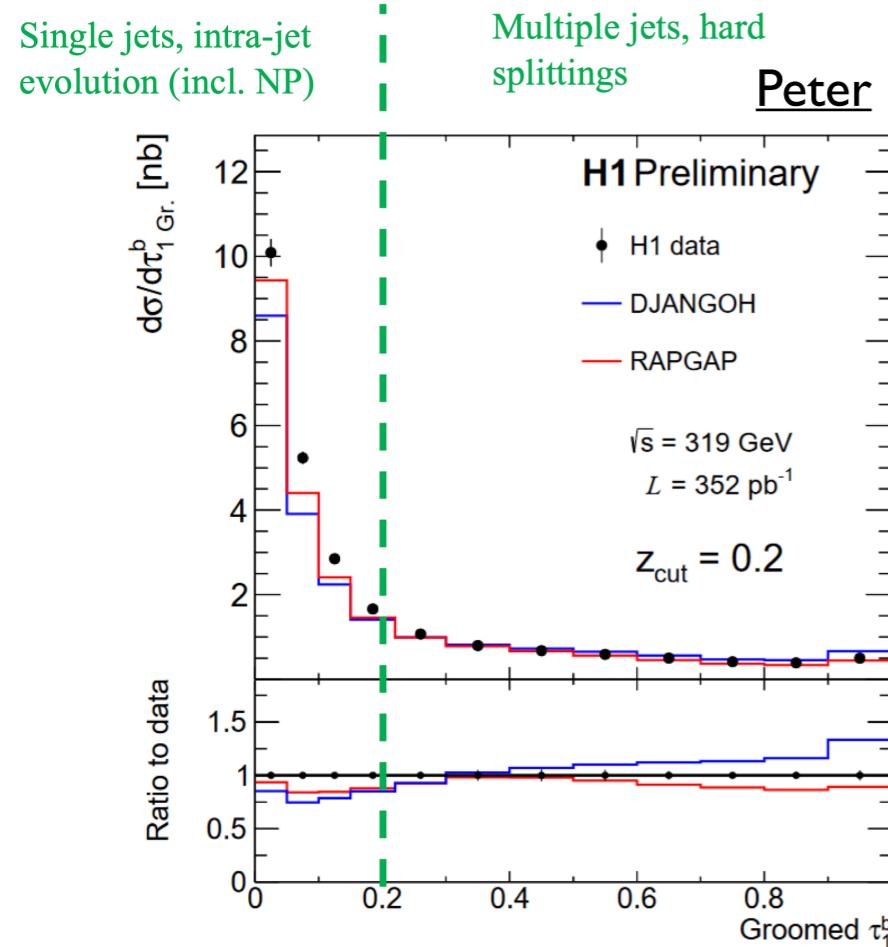
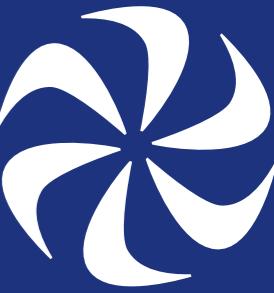
H1's Tour-de-force



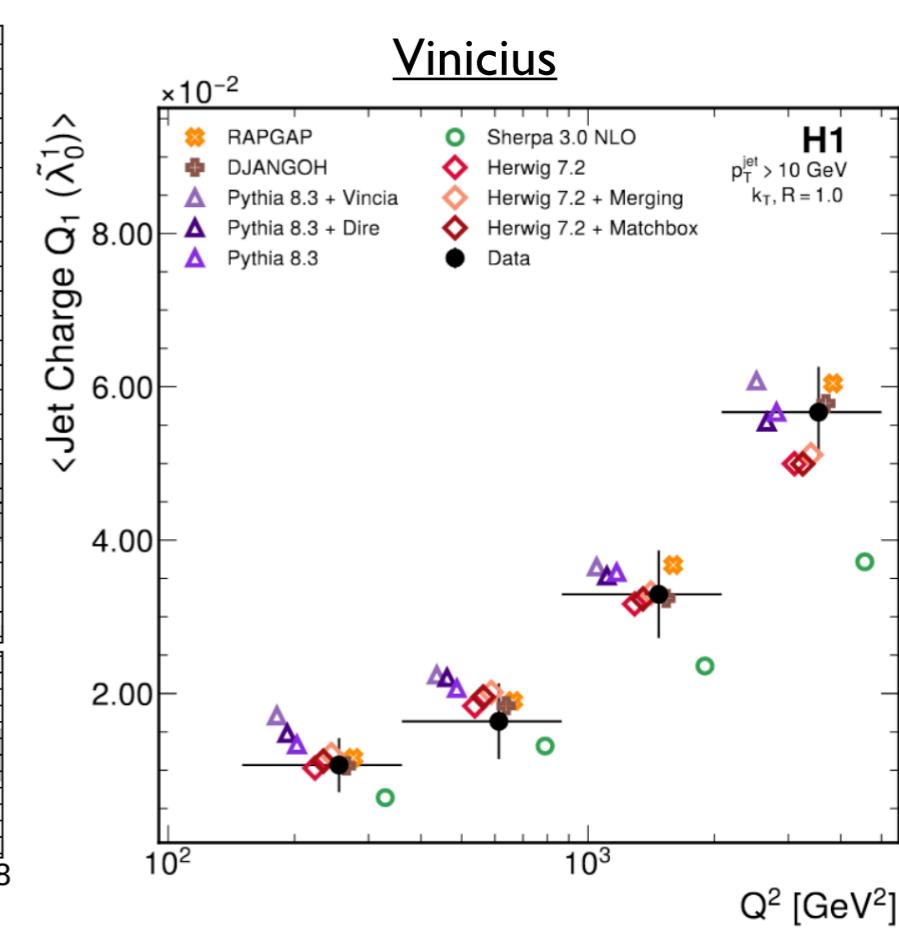
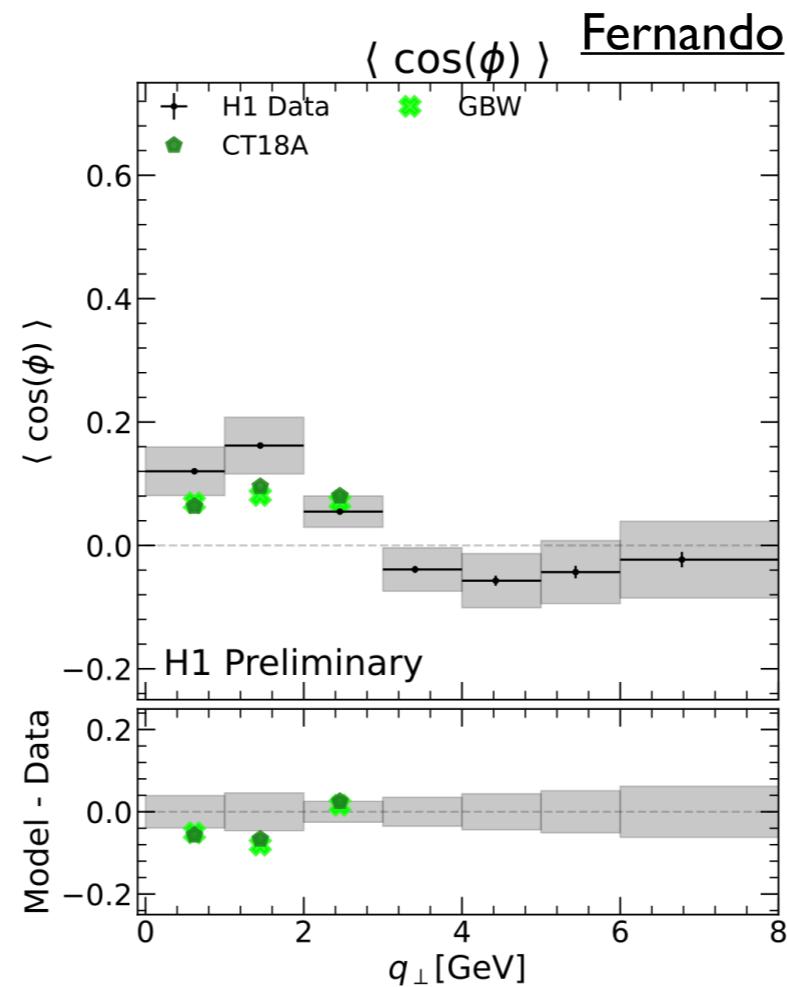
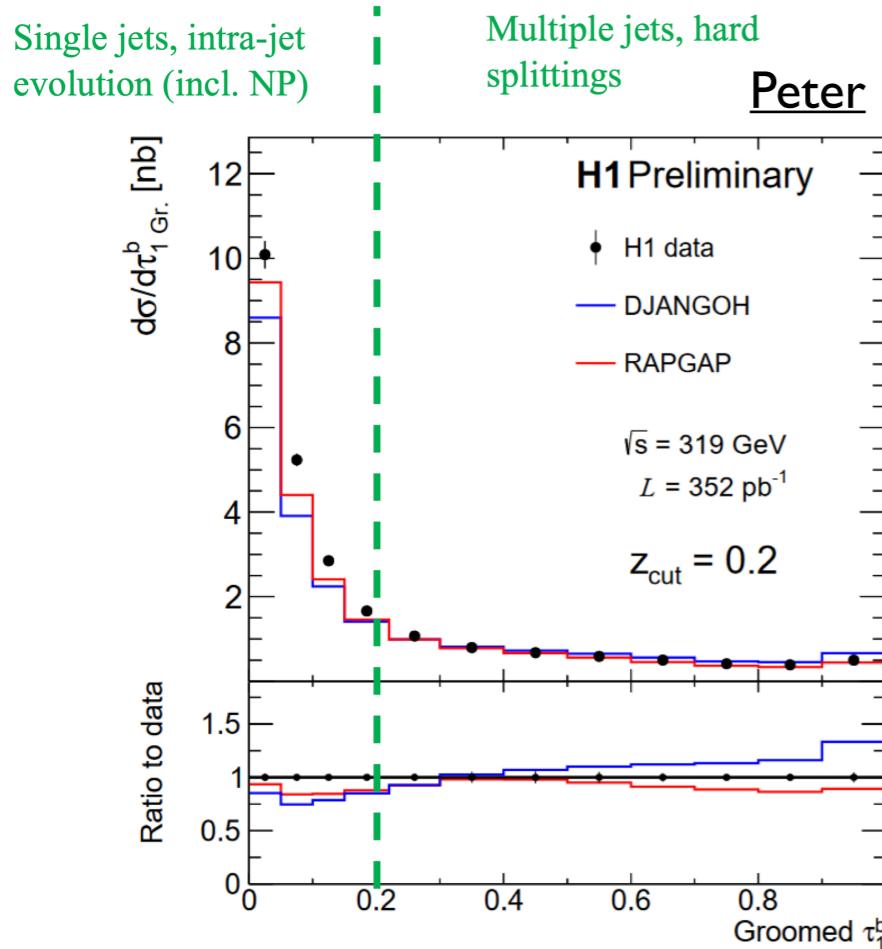
H1's Tour-de-force



H1's Tour-de-force

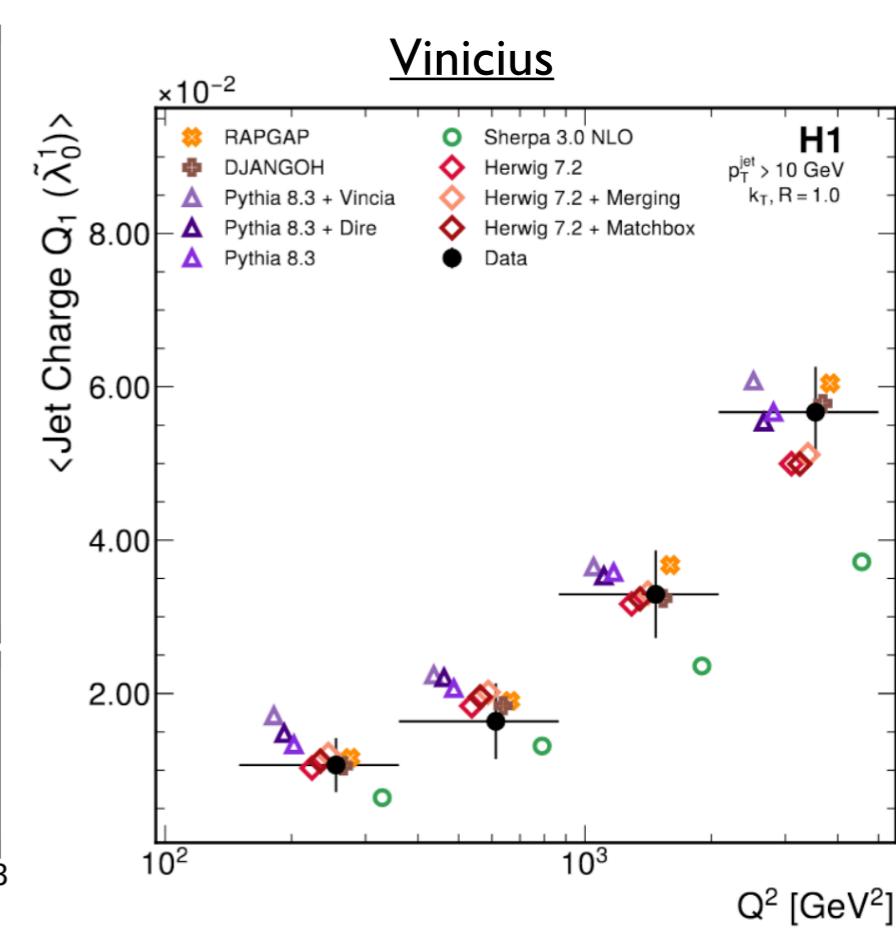
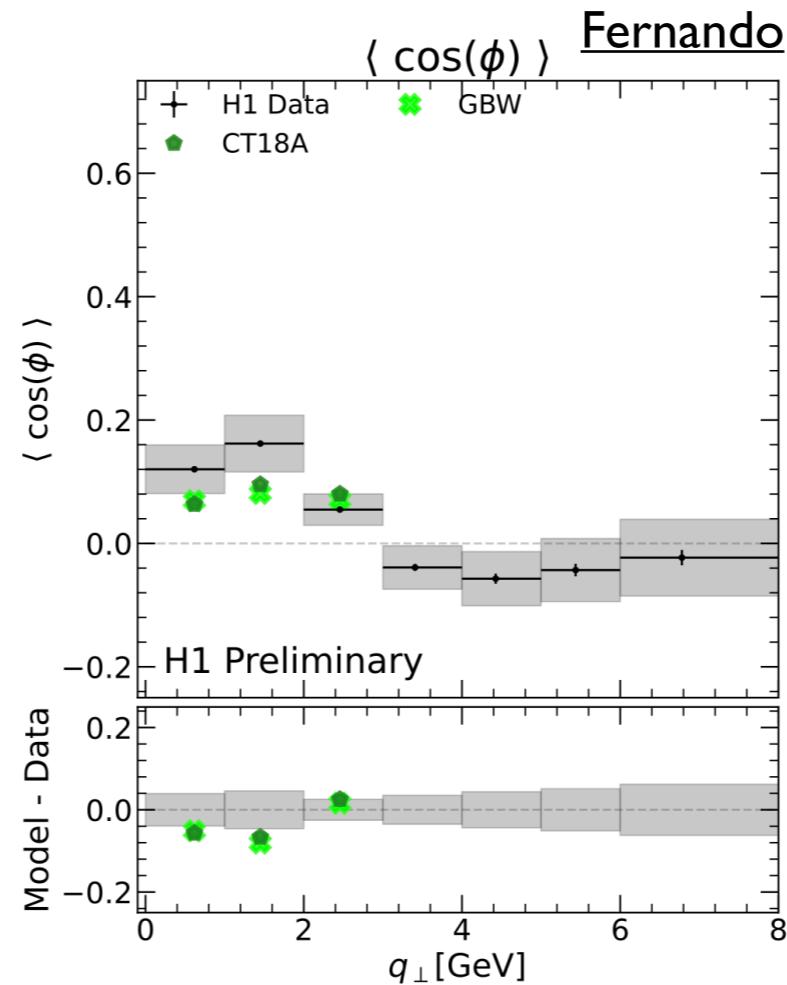
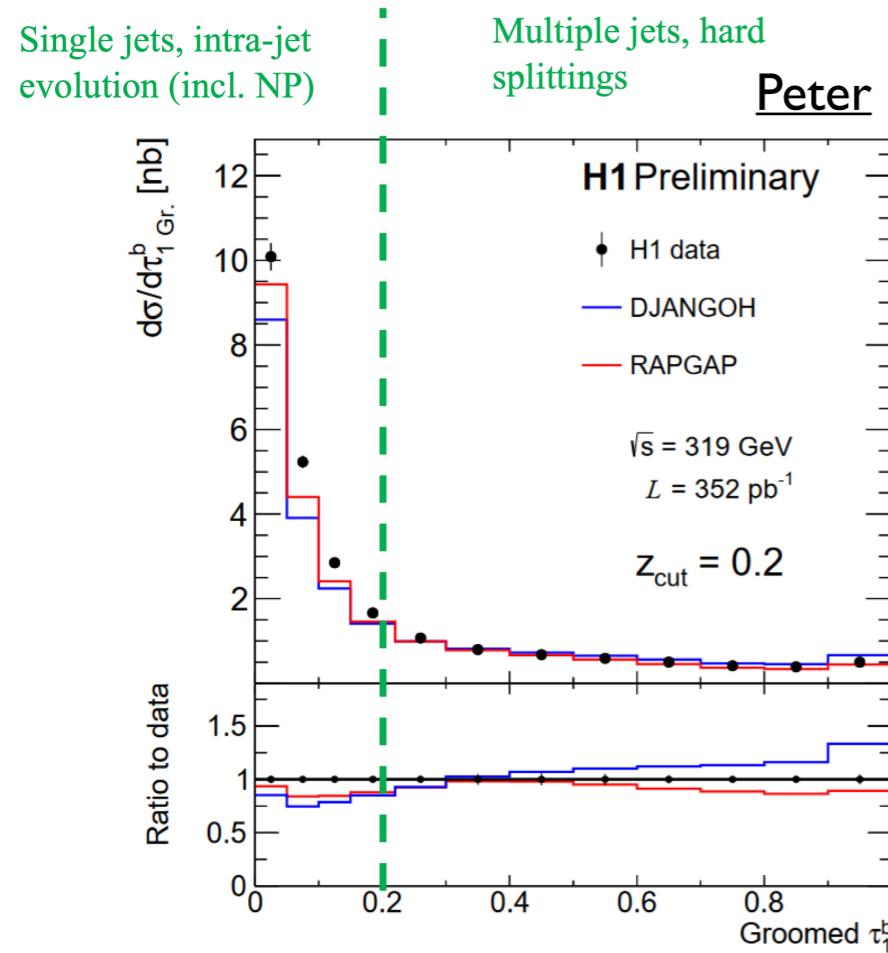
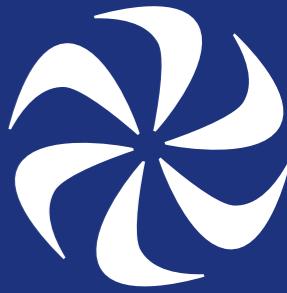


H1's Tour-de-force



Fantastic batch of results— all using modern ML unfolding

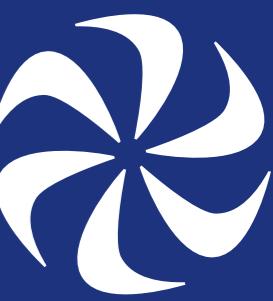
H1's Tour-de-force



Fantastic batch of results— all using modern ML unfolding

Setting the standard for EIC/EPIC?

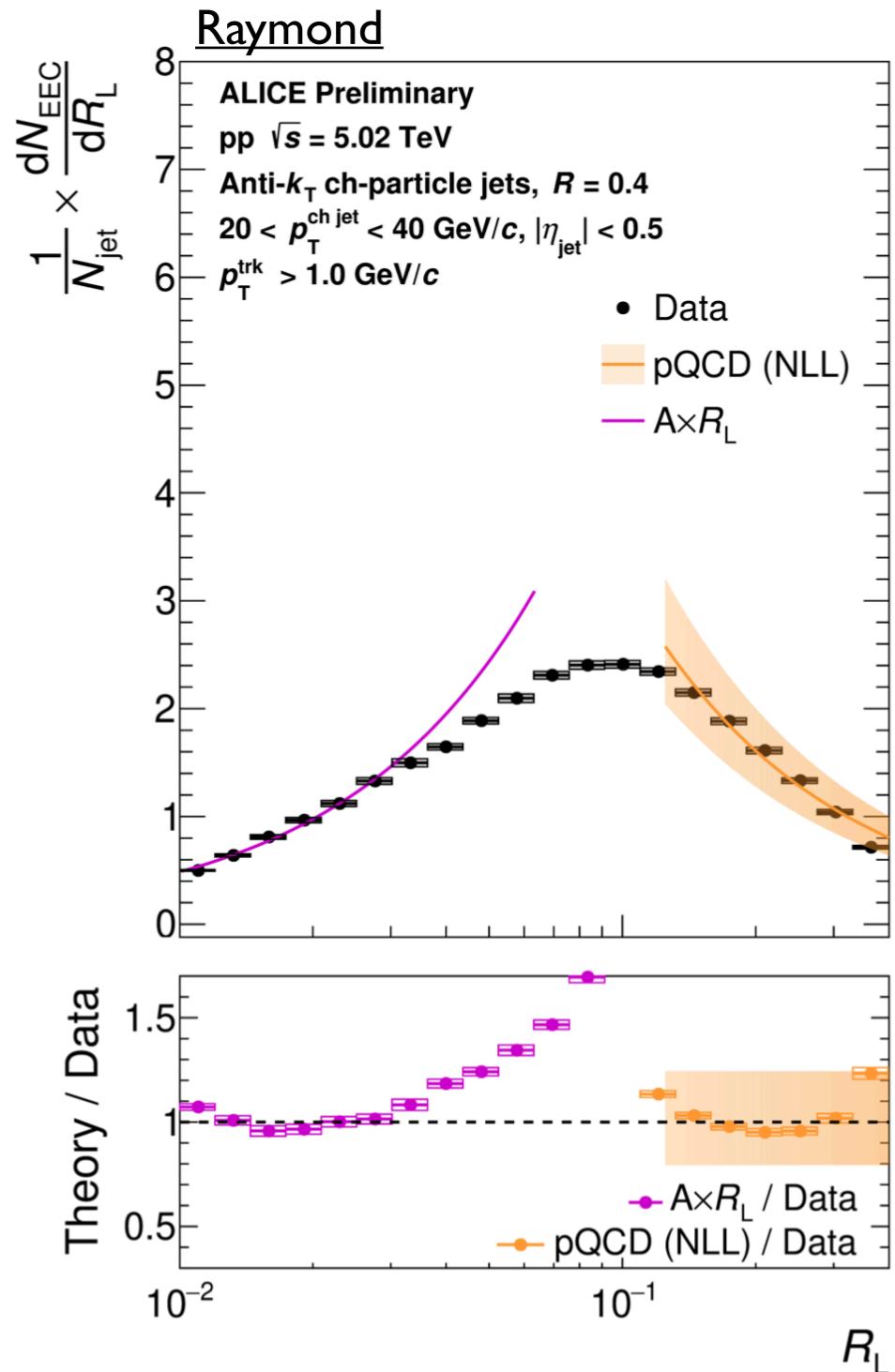
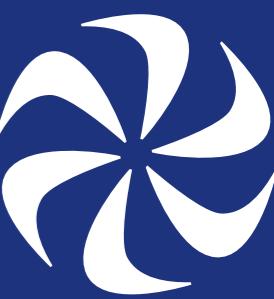
EECs



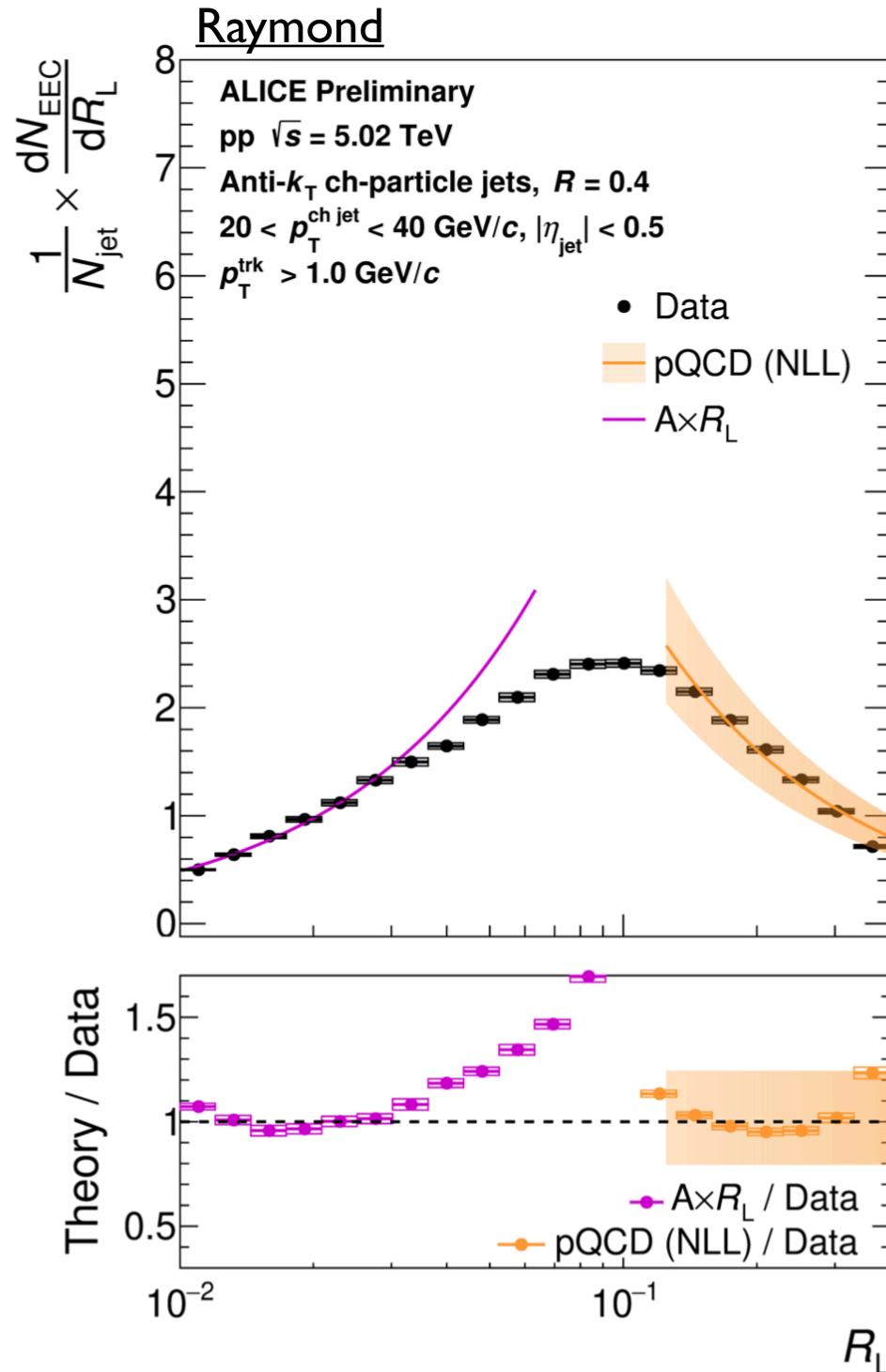
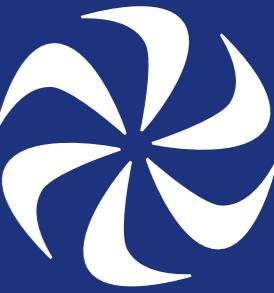
Raymond

Chengfeng

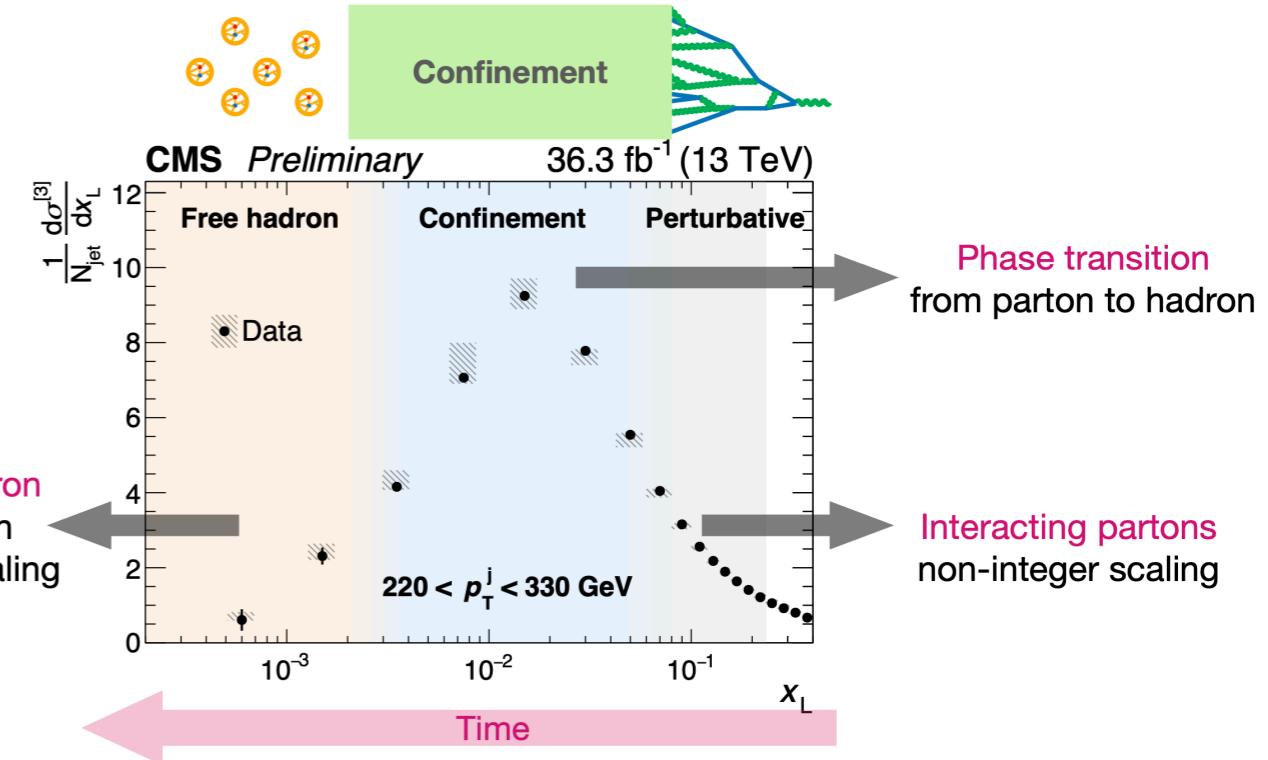
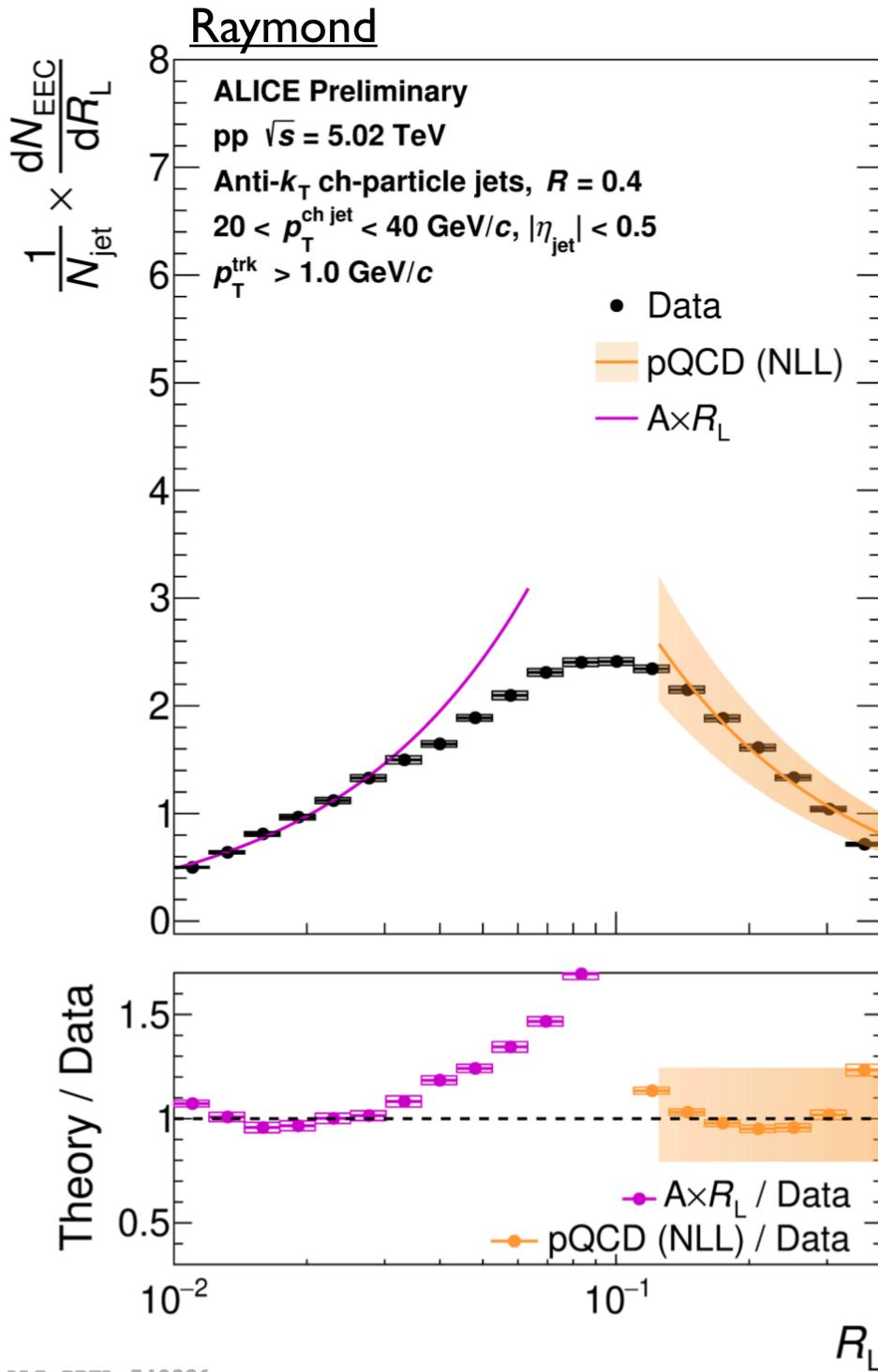
EECs



EECs

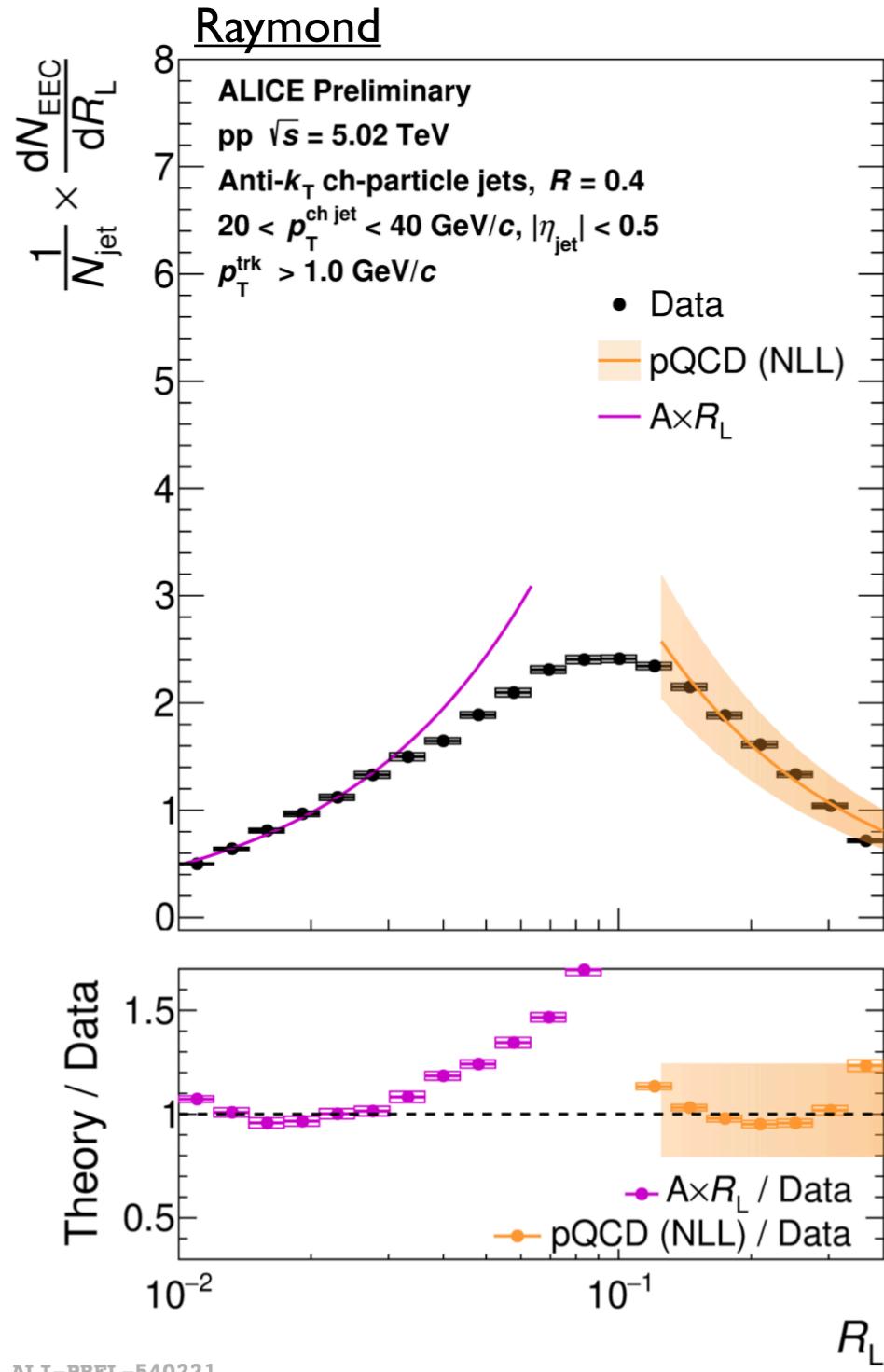


EECs



Fantastic progress on EEC measurements at the LHC as well!

EECs



Fantastic progress on EEC measurements at the LHC as well!

Comparisons to pQCD and expectations of hadronic scaling

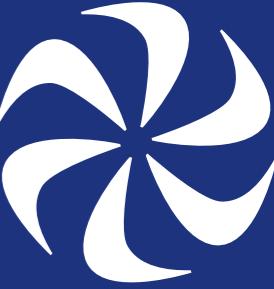
EECs for $\alpha_s \dots$ in theory



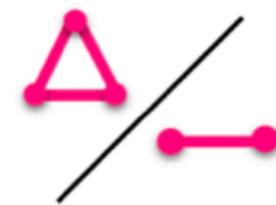
Ratio of E3C and E2C
is proportional to α_s

$$\frac{\Delta}{\text{---}} \propto \alpha_s(Q) \ln x_L + O(\alpha_s^2)$$

EECs for $\alpha_s \dots$ in theory



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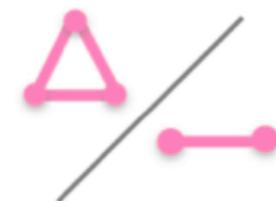
$$\propto \alpha_s(Q) \ln x_L + O(\alpha_s^2)$$



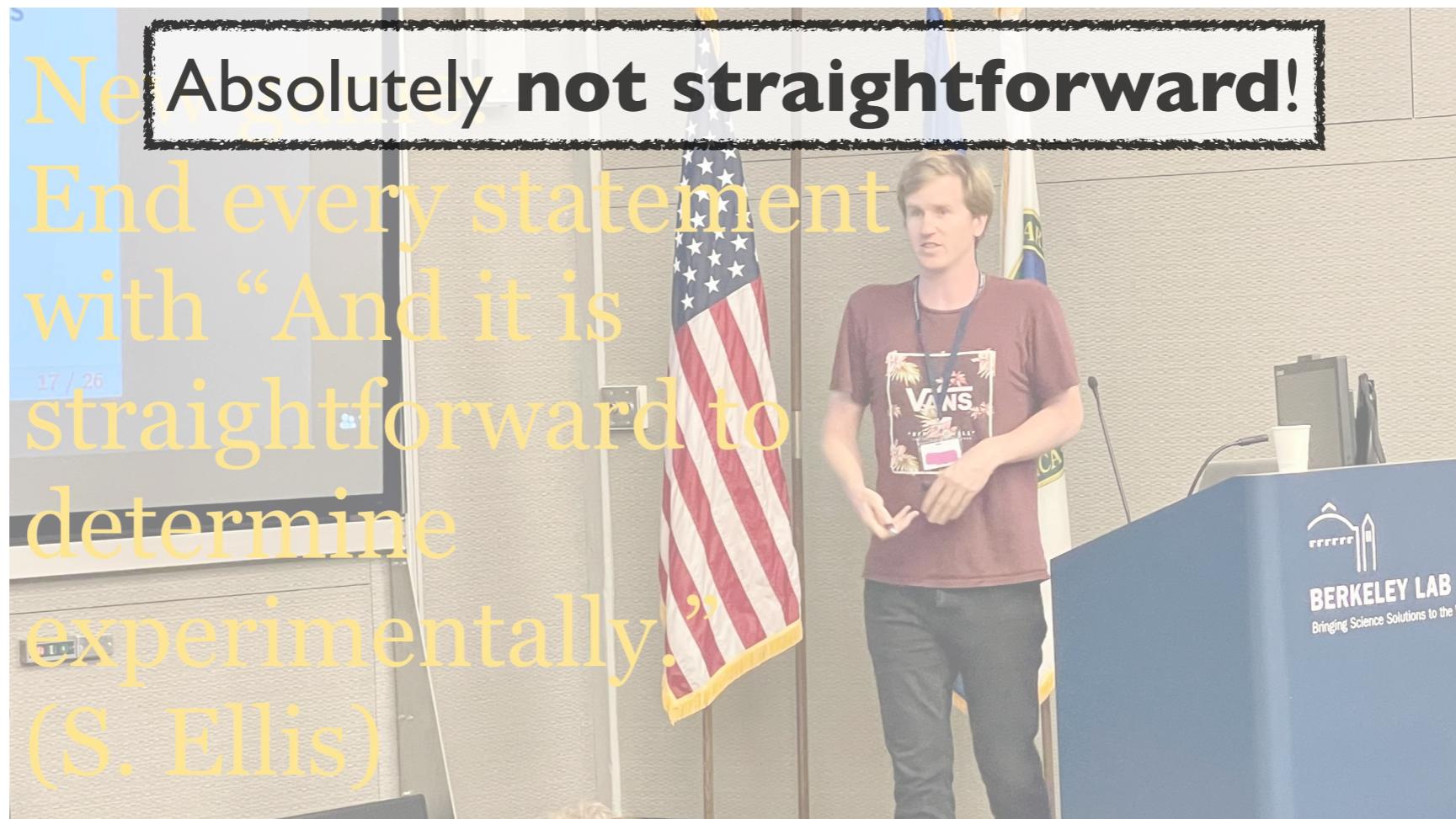
EECs for $\alpha_s \dots$ in theory



Ratio of E3C and E2C
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$$\propto \alpha_s(Q) \ln x_L + O(\alpha_s^2)$$



EECs for α_s ... in practice

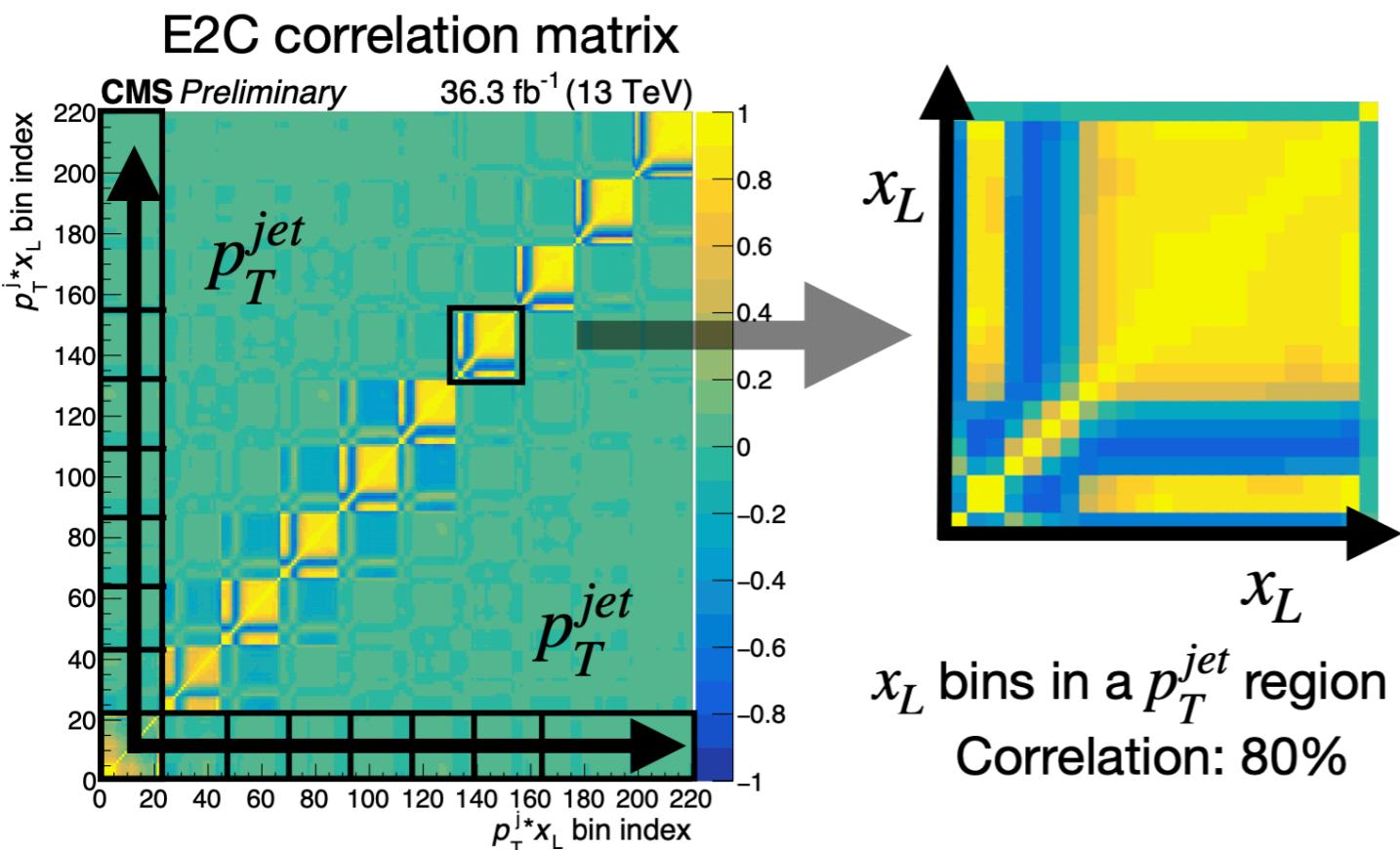


Chengfeng

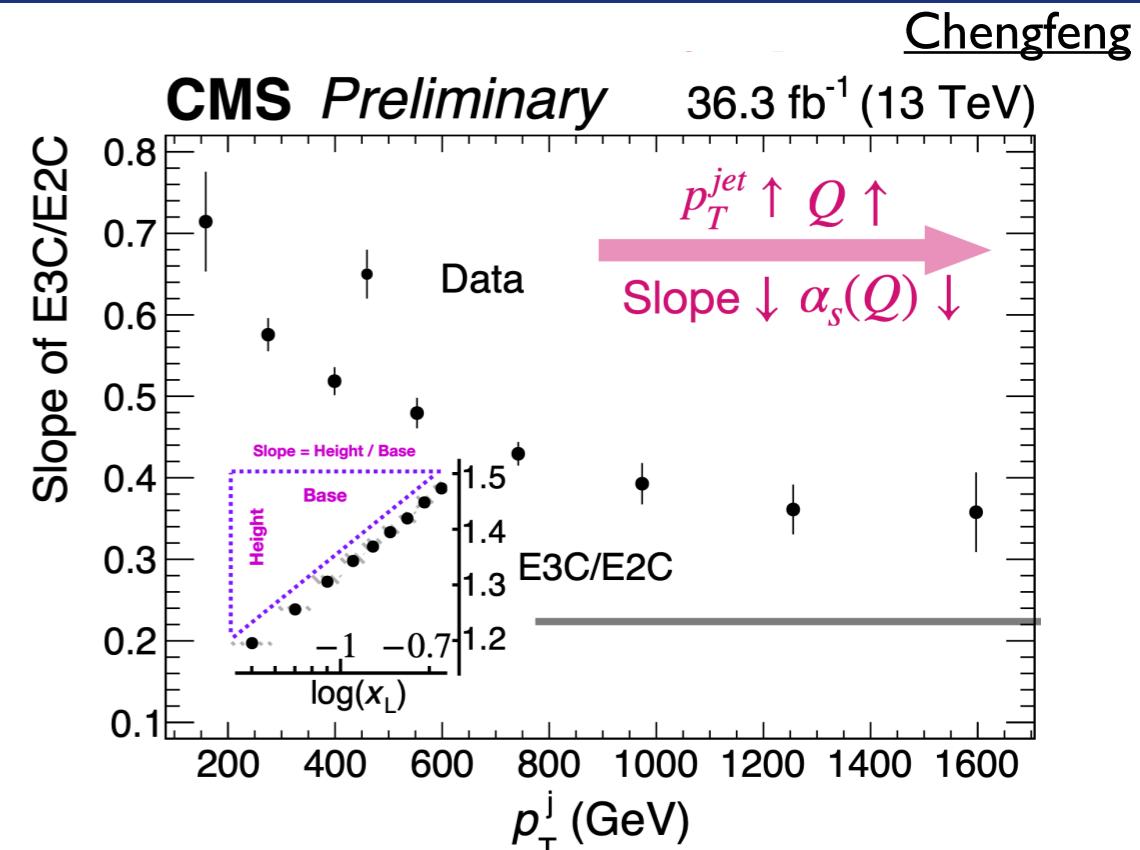
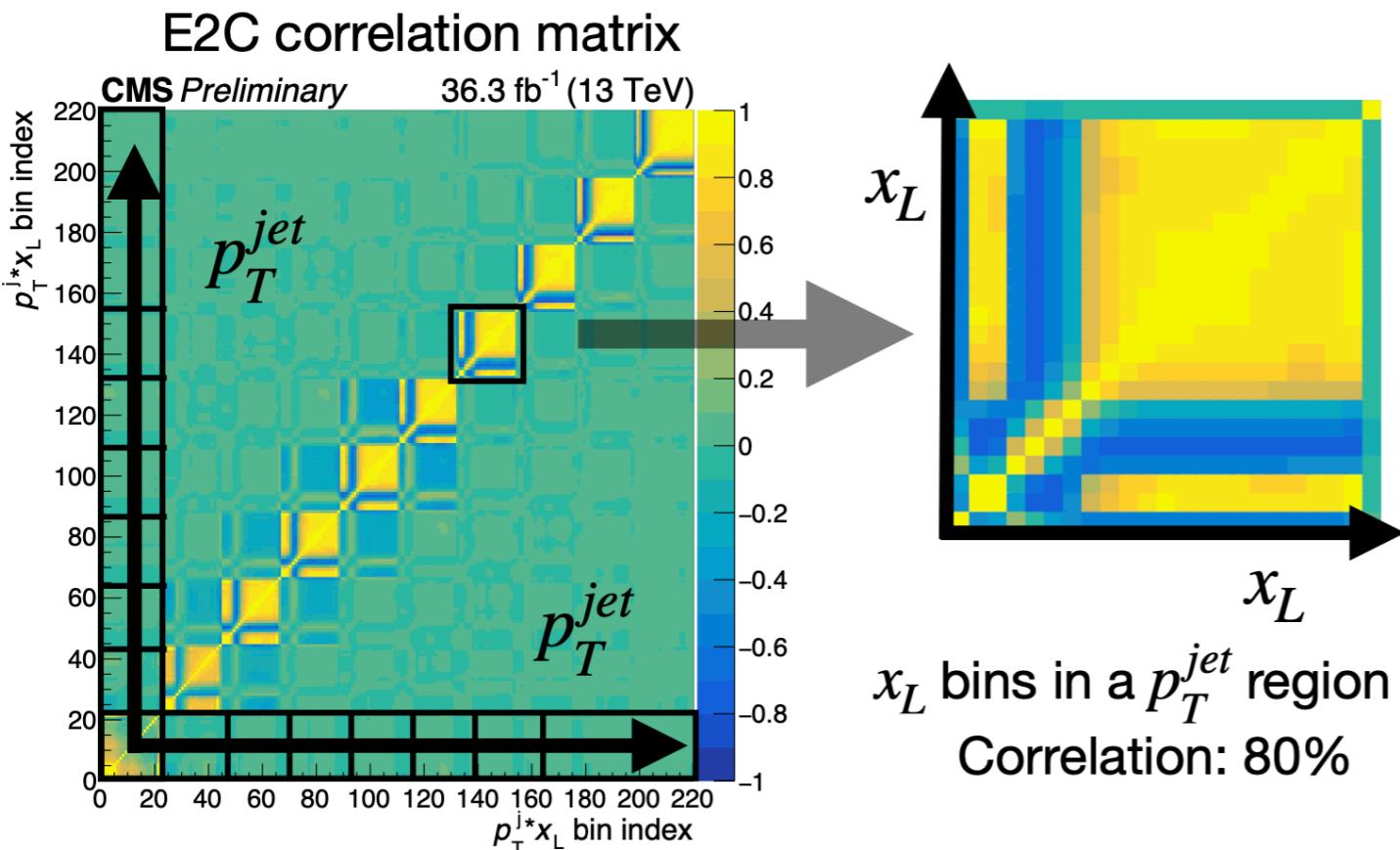
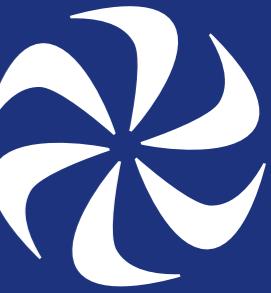
EECs for α_s ... in practice



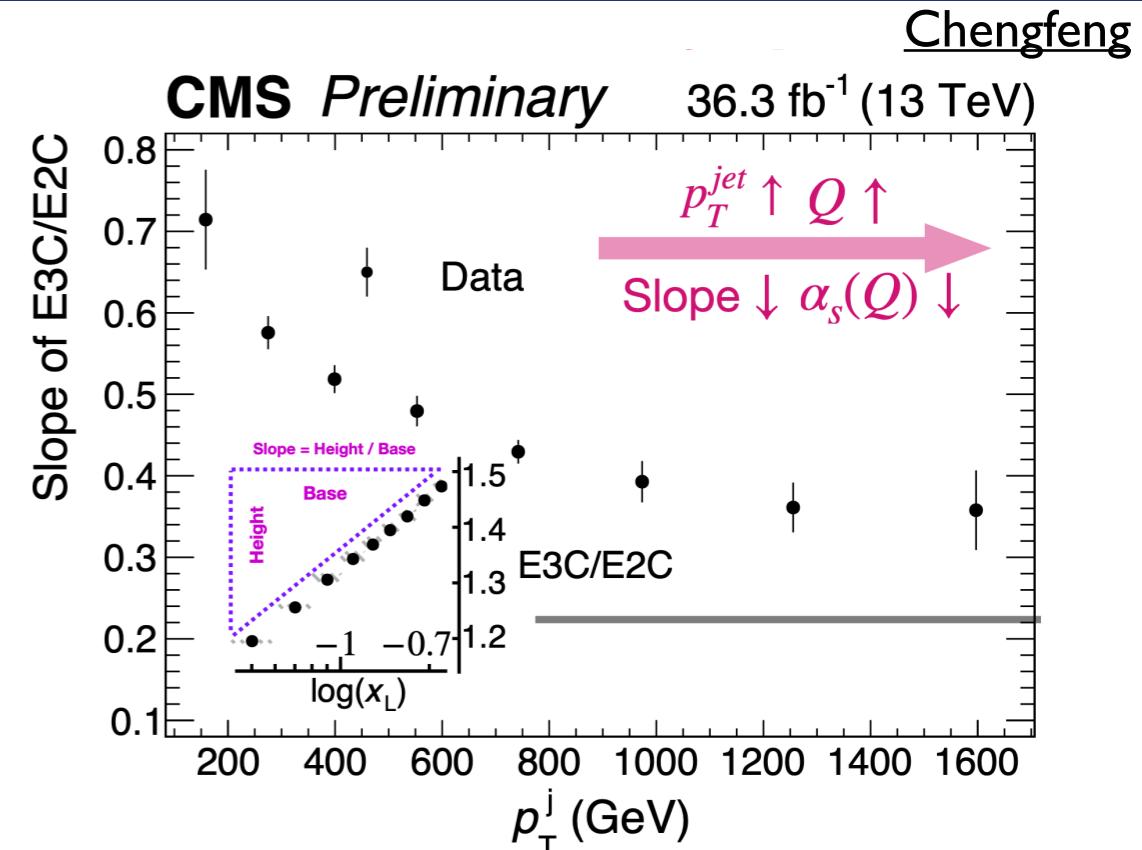
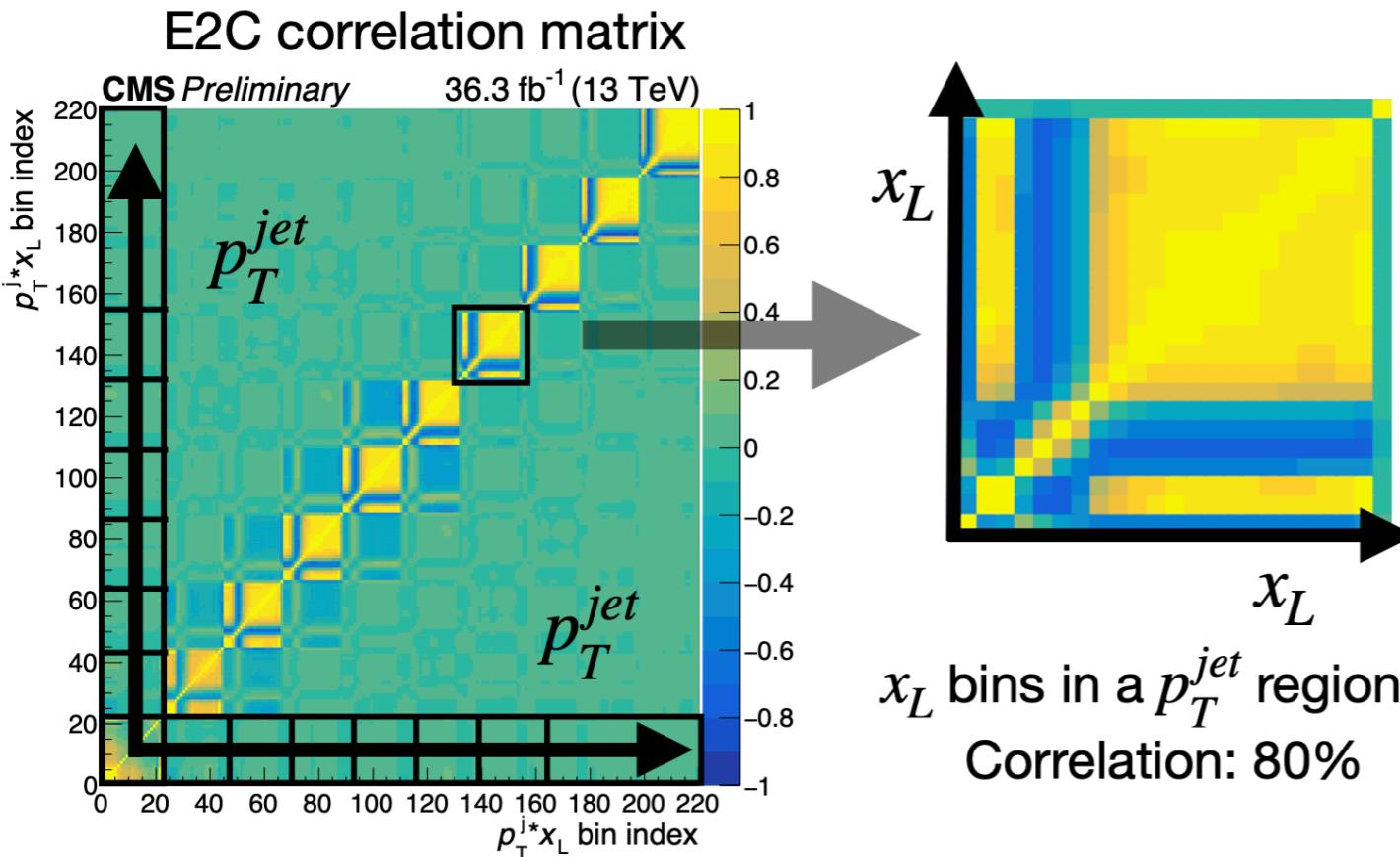
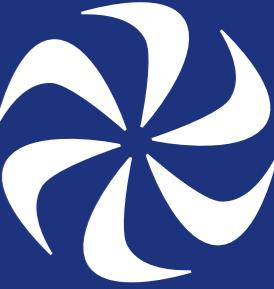
Chengfeng



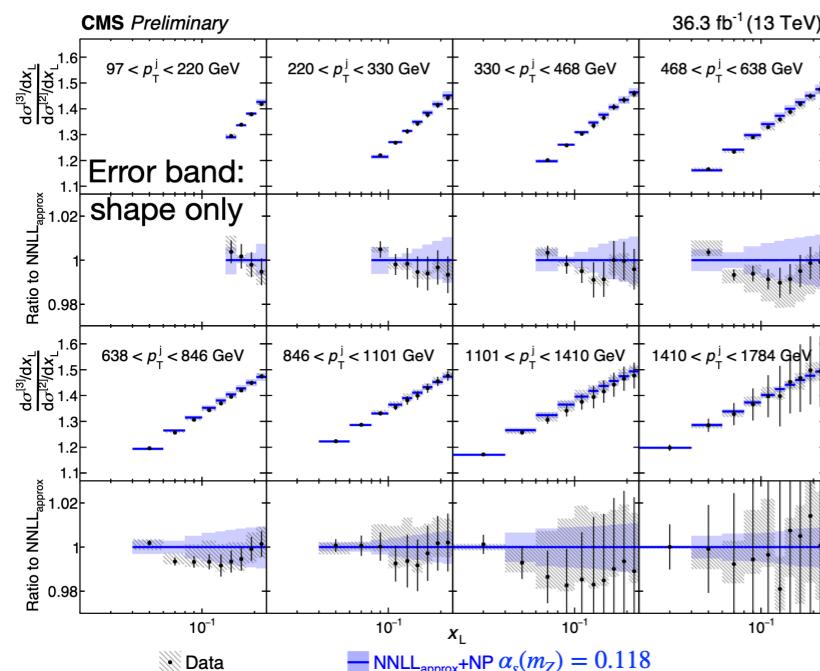
EECs for α_s ... in practice



EECs for α_s ... in practice



Result



$$\begin{aligned} \alpha_s(m_Z) &= 0.1229^{+0.0040}_{-0.0050} \\ &= 0.1229^{+0.0014(\text{stat.})+0.0030(\text{theo.})+0.0023(\text{exp.})}_{-0.0012(\text{stat.})-0.0033(\text{theo.})-0.0036(\text{exp.})} \end{aligned}$$

major source

Covariance matrix

QCD scale of NNLL_{approx}

Neutral hadron energy scale

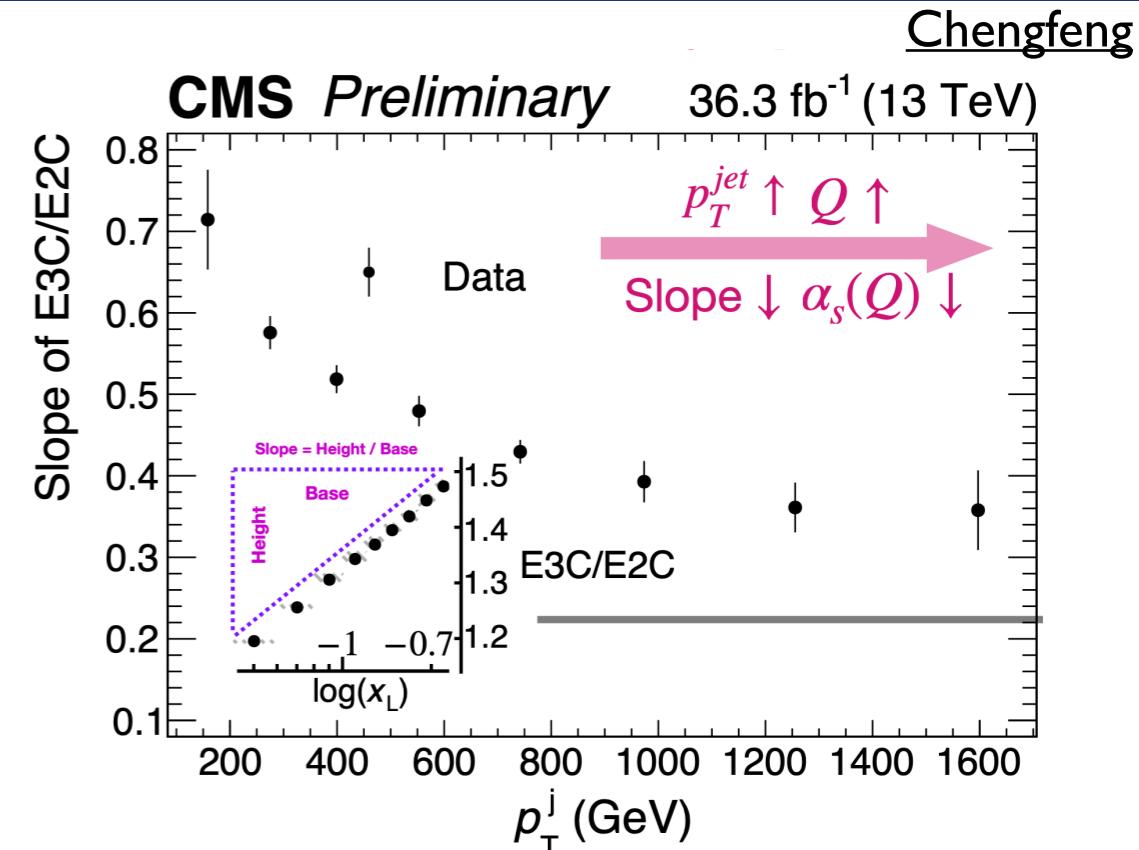
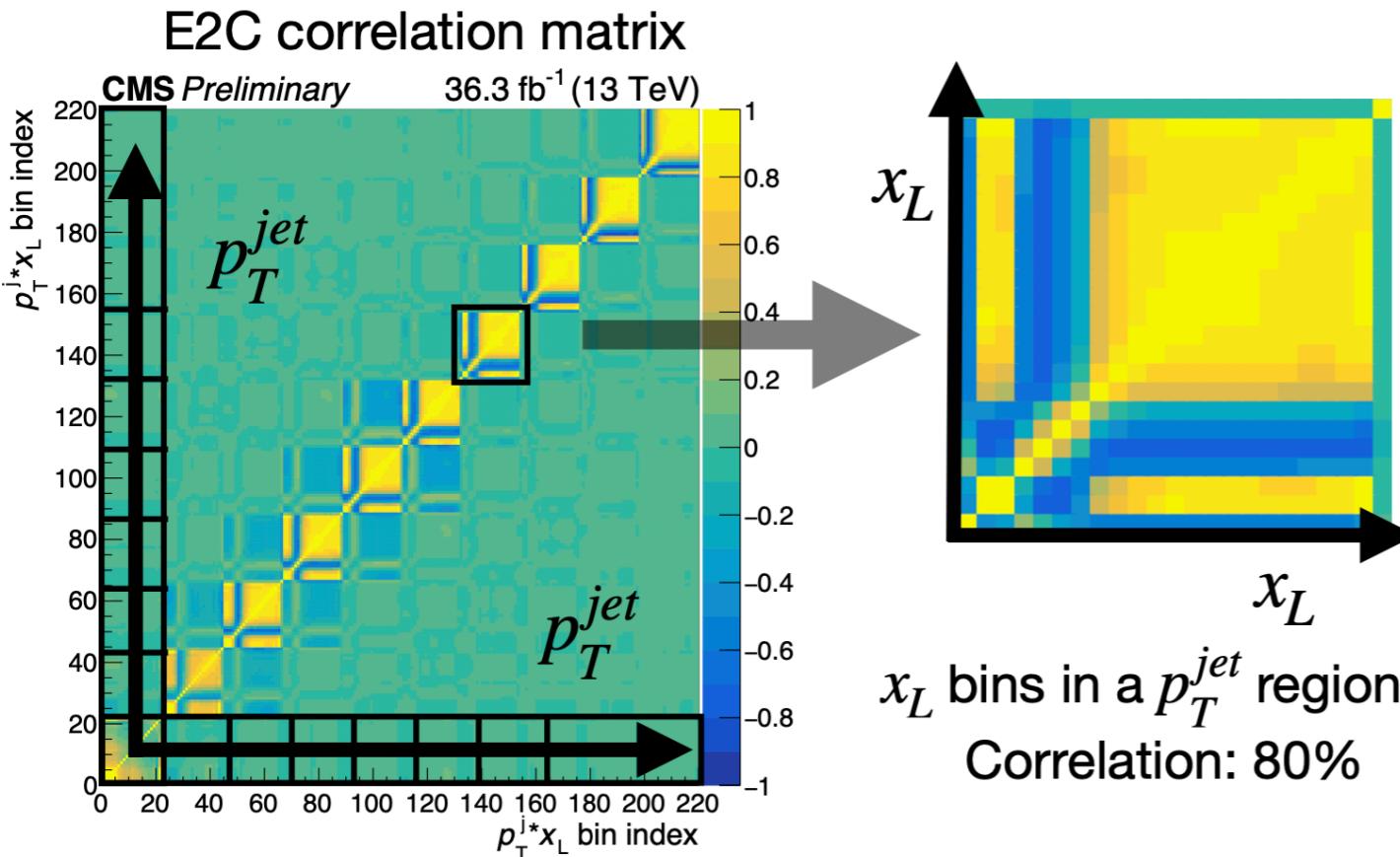
Uncertainty ~ 4%, most precise from jet-substructure measurement to date

Benefit from:

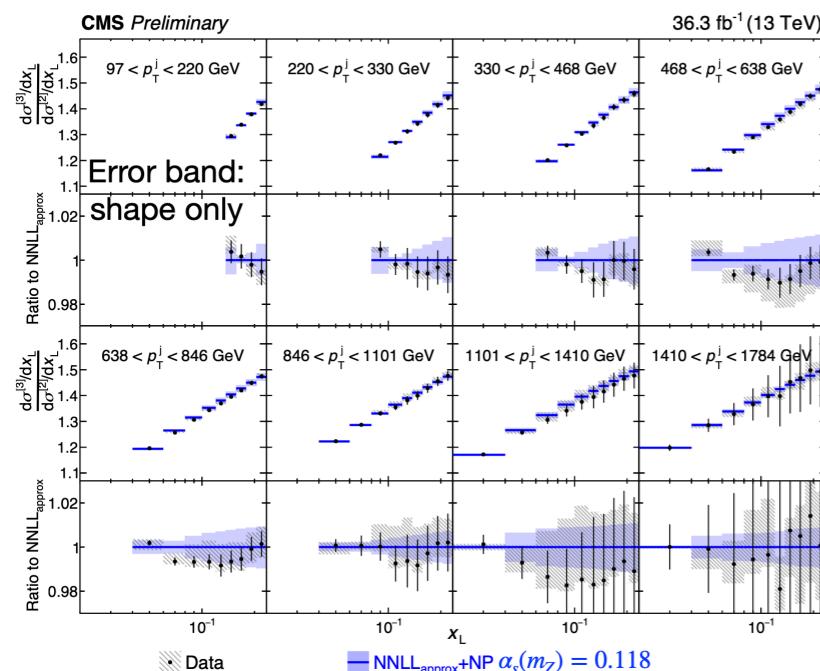
Ratio: most uncertainties cancel out

High precision calculation

EECs for α_s ... in practice



Result



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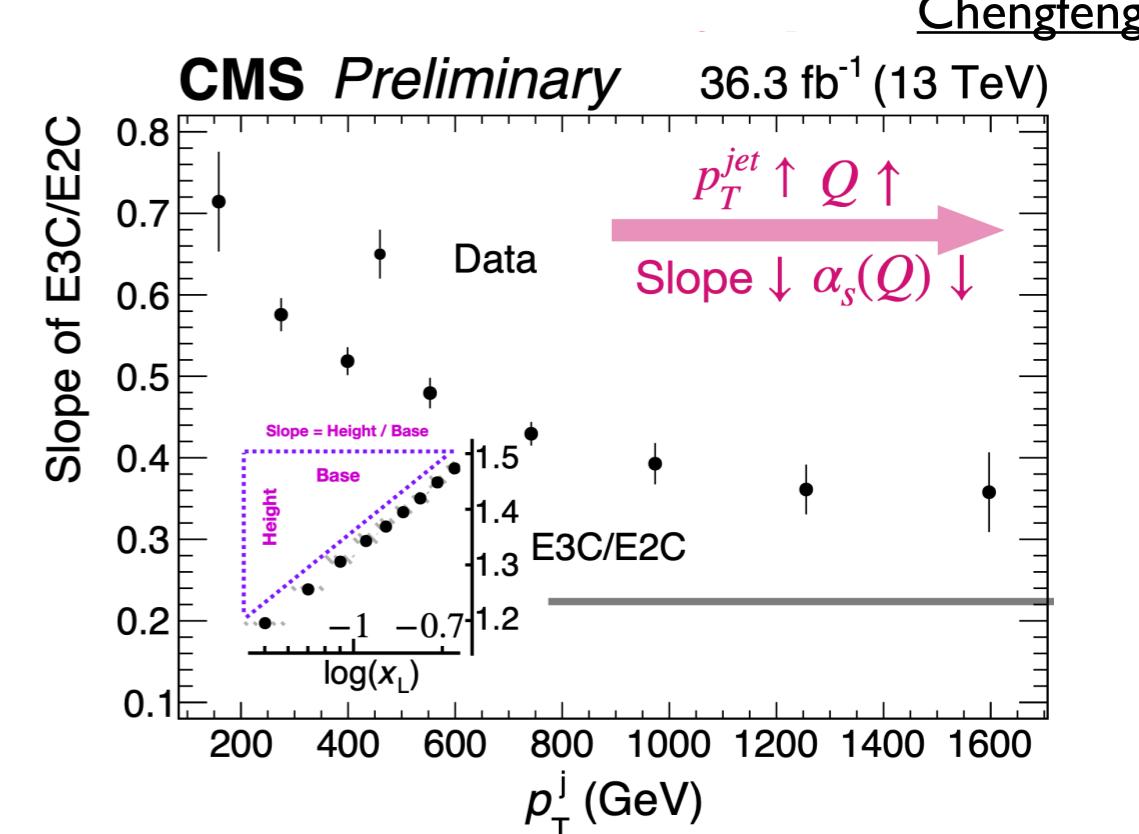
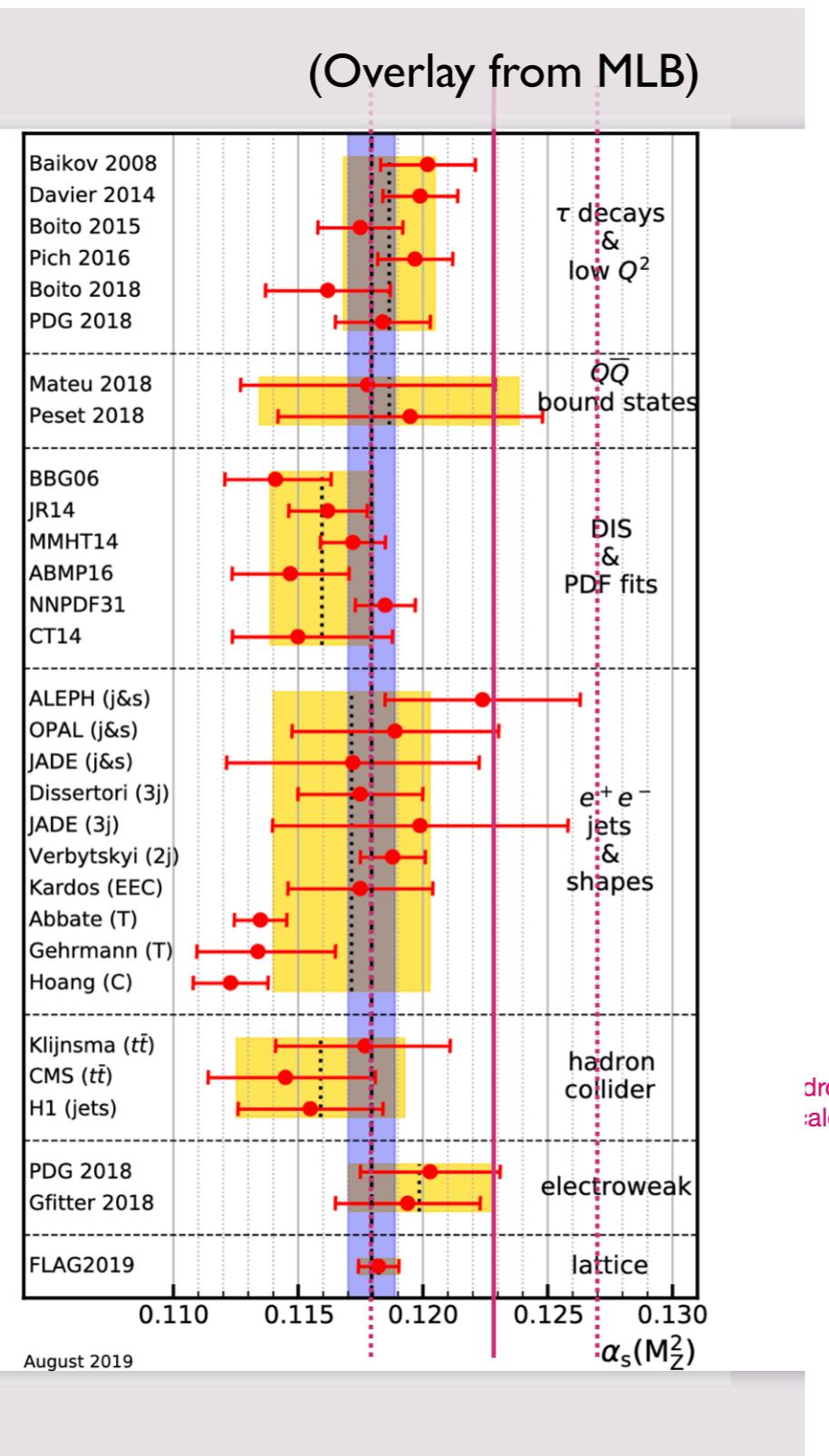
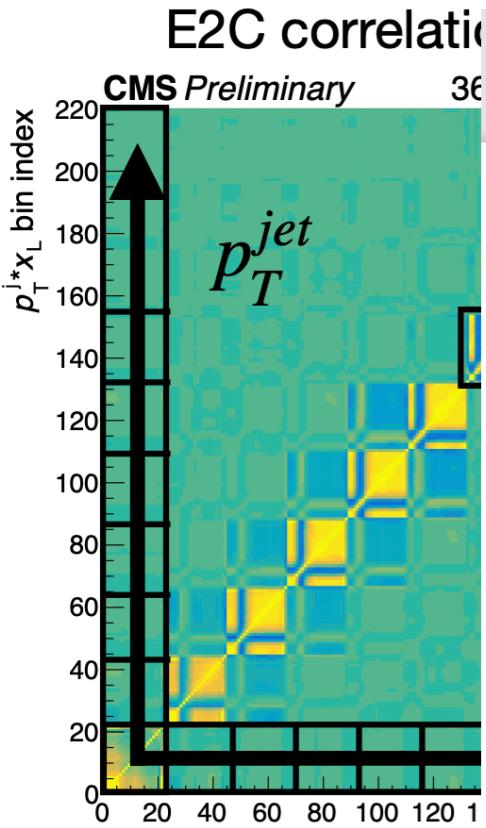
Benefit from:

Ratio: most uncertainties cancel out

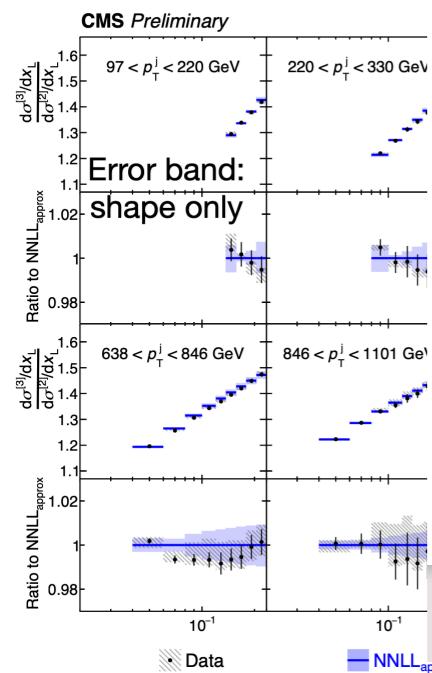
High precision calculation

Huge amount of effort!

EECs for α_s ... in practice



Result



Huge amount of effort! 🙌

Now need to scrutinize
and understand... 🤔

Conclusions



Accomplishments

Anna

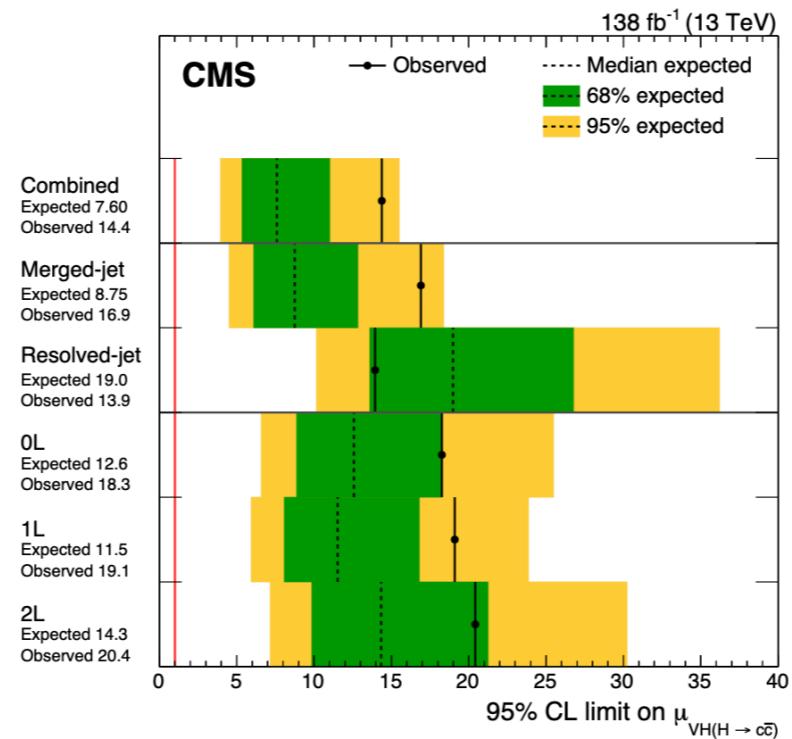
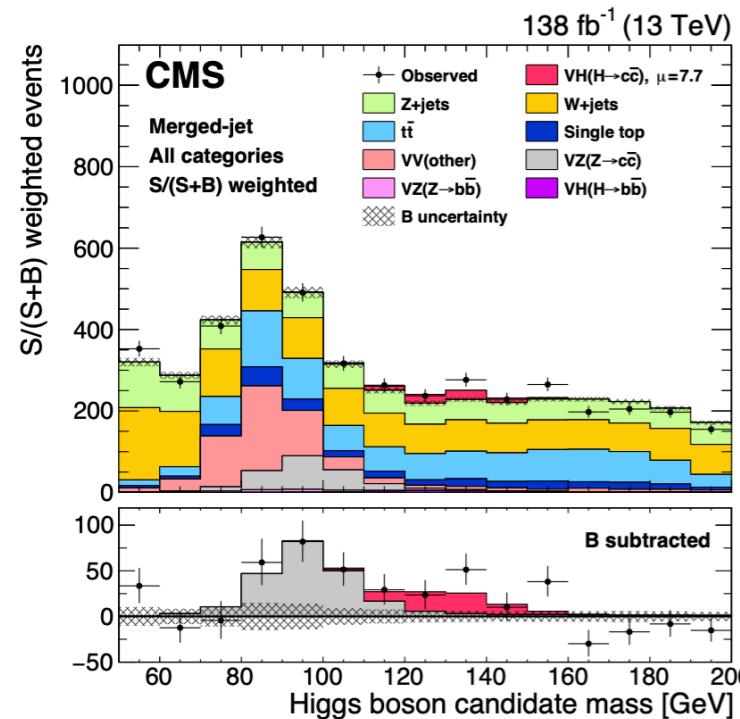


Accomplishments

Anna

Doing the impossible?

[CMS-HIG-21-008](#)



- CMS TDR (2006): “The [Higgs] decay modes into cc [...] pairs [...] do not play a relevant role at the LHC.”
[as pointed out by Clemens last year]
- The BOOST community made it possible :)

Anna Benecke

11



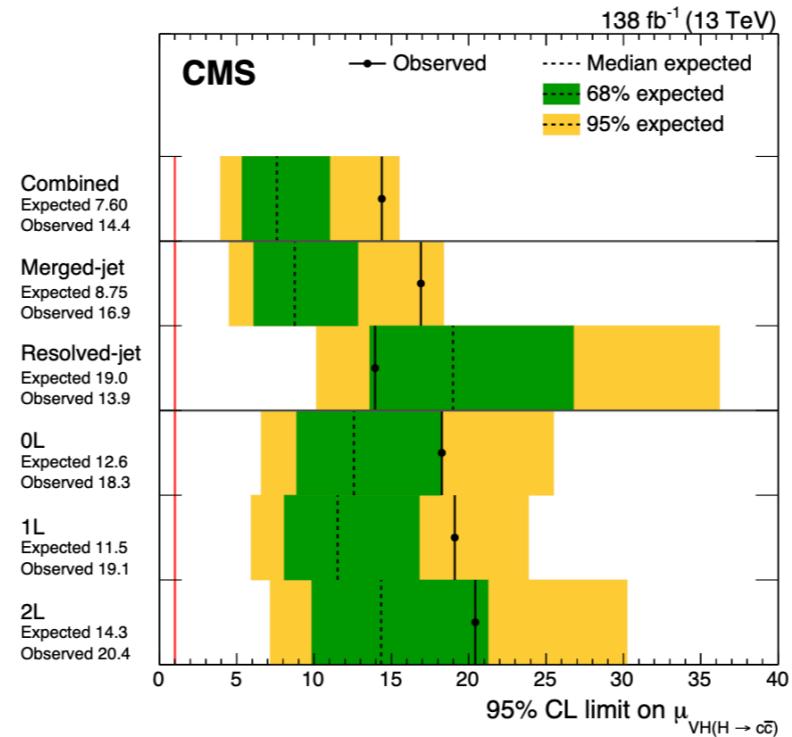
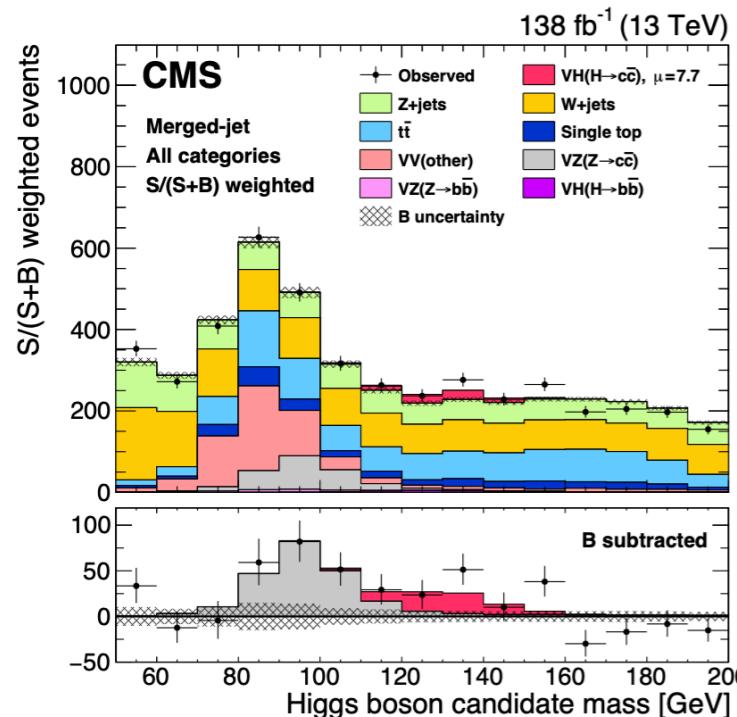
Accomplishments

Anna

Doing the impossible?

And many more!

[CMS-HIG-21-008](#)



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11



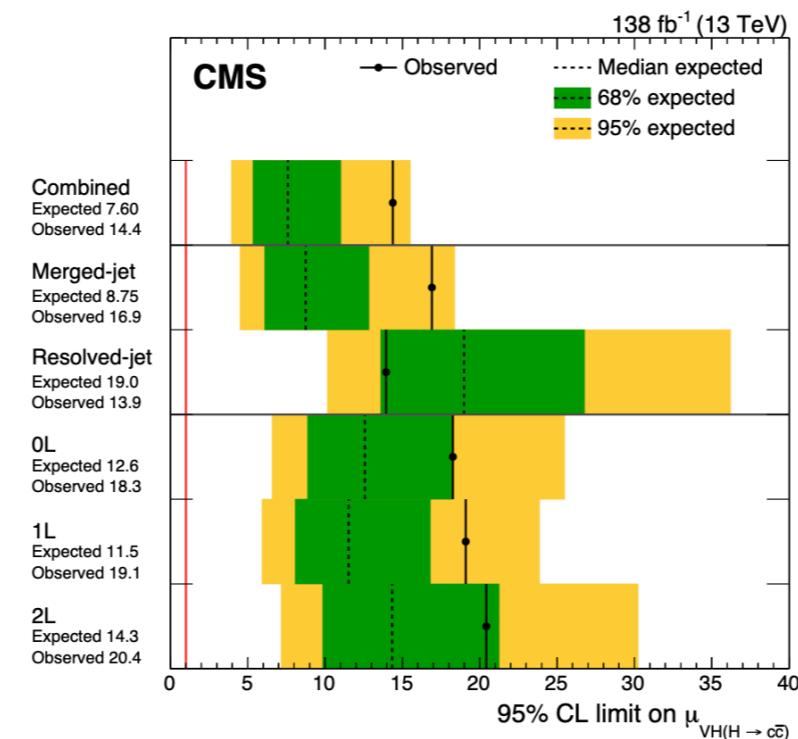
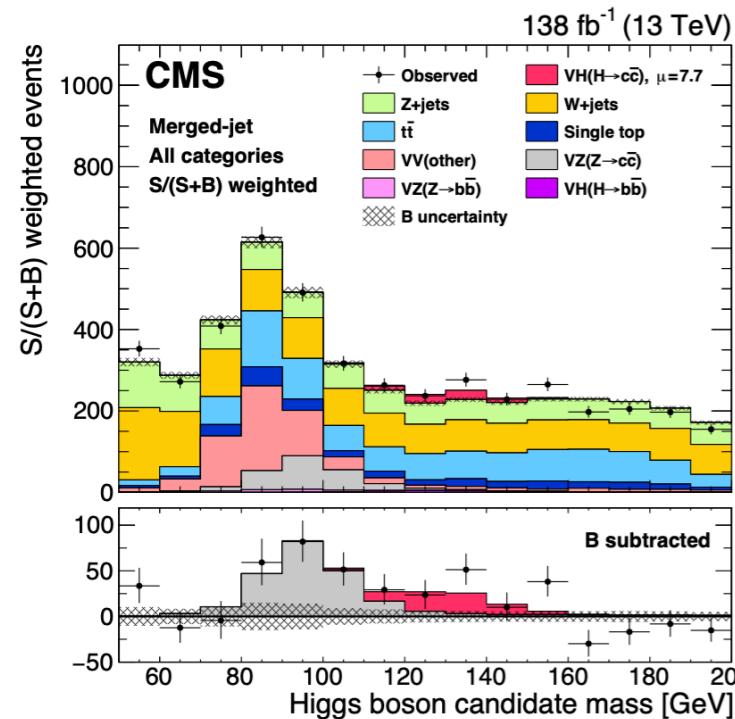
Accomplishments

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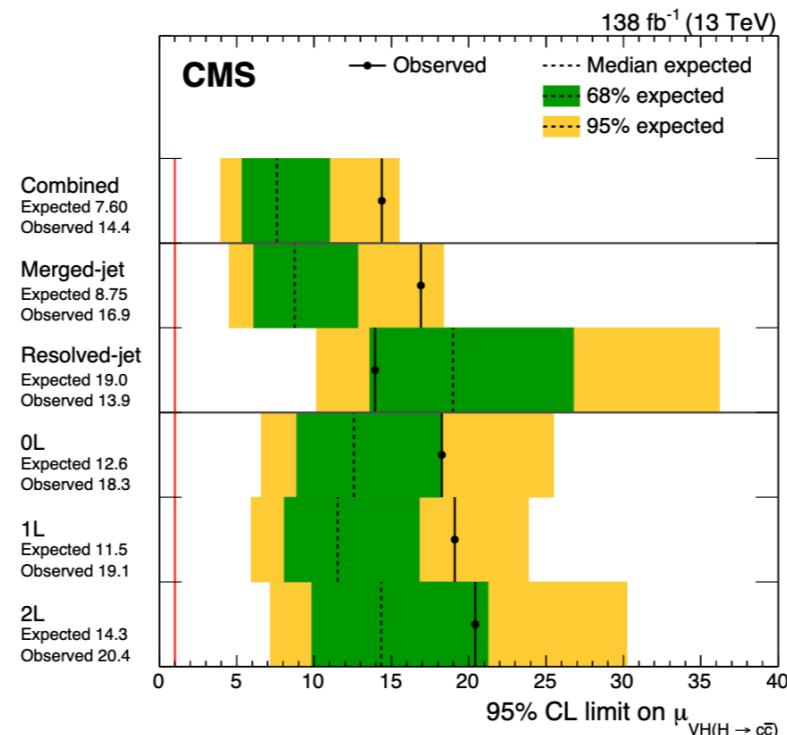
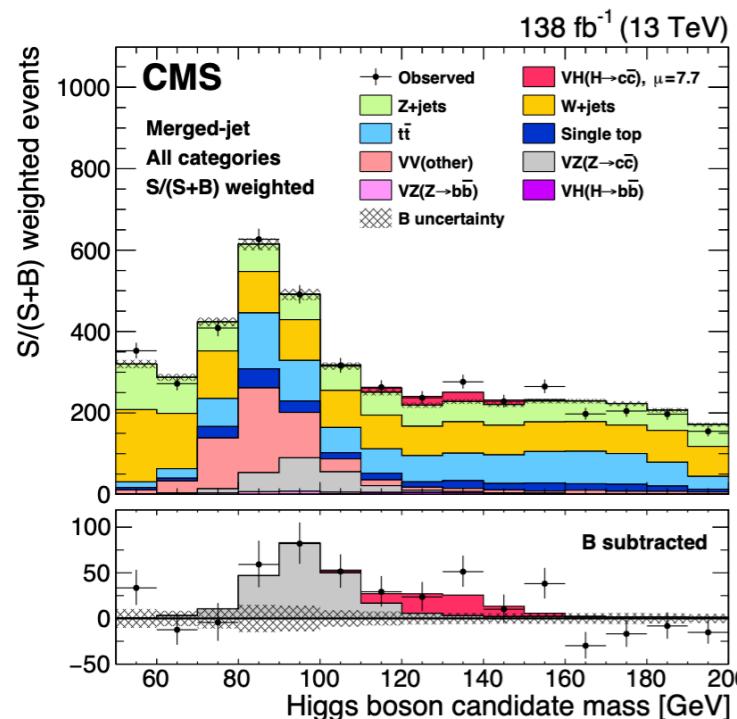
Accomplishments

Anna

Doing the impossible?

And many more!

CMS-HIG-21-008



HH, Higgs measurements,
tagging beyond PNet,
dead-cone, α_s , dark
jets, anomaly detection...

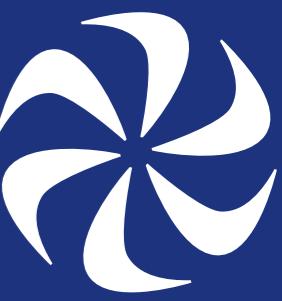
On top of our great
tradition of searches
and measurements!

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- The BOOST community made it possible :)

Anna Benecke

11

The Final Word





The Final Word

BOOST 2010: These aren't your daddy's jets

BOOST 2011: "First" data

BOOST 2012: Kids in a candy store

BOOST 2013: Bringing substructure into the mainstream

BOOST 2014: if you ain't boostin' you ain't livin'

BOOST 2015: What a difference five years makes

BOOST 2016: I got 99 problems but my BOOST ain't one

BOOST 2017: Deep thinking jets, they are among us

BOOST 2018: DeepBOOST

BOOST 2019: If you ain't boostin' in the morning, go back to bed!

BOOST 2020: ..

BOOST 2021: Jet vettin' without jet settin'

BOOST 2022: we are all about that boost (no treble)



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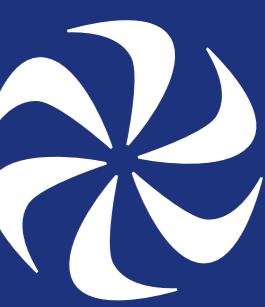
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BOOST 2022: we are all about that boost (no treble)

BOOST 2023: Through BOOST, all things are possible (so jot that down)



See you next year!

