

Precision jet substructure and machine learning for jets

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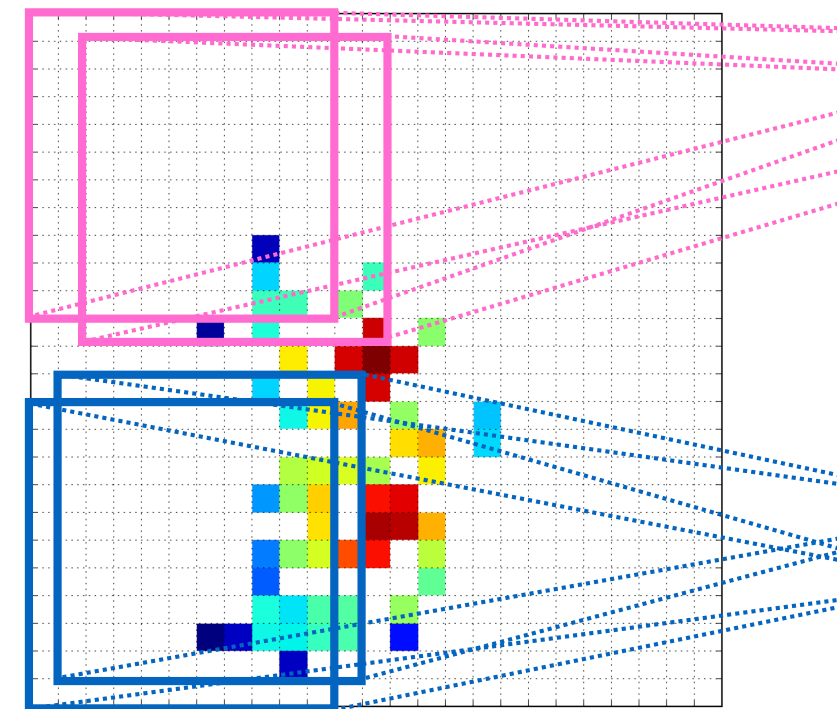
bpnachman@lbl.gov



@bpnachman



bnachman

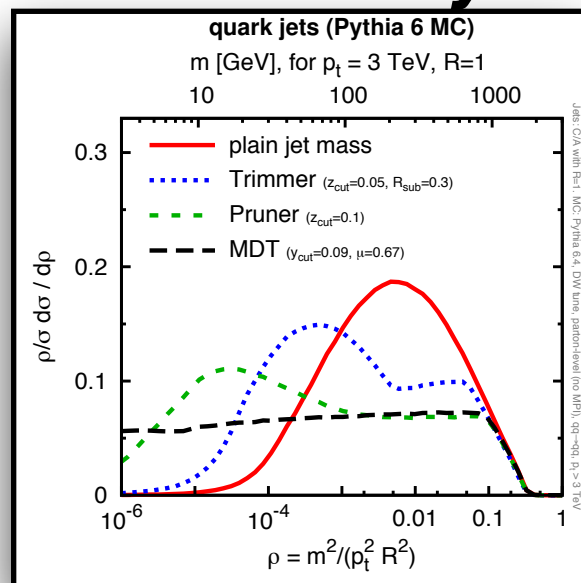


Guido Altarelli
Award, DIS
April 16, 2021

A renaissance in QCD theory

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In Theory



Dasgupta, Fregoso,
Marzani, Salam
JHEP 09 (2013) 029

There has been an explosion of new ideas, paired with an **analytic understanding** of jet substructure (JSS)

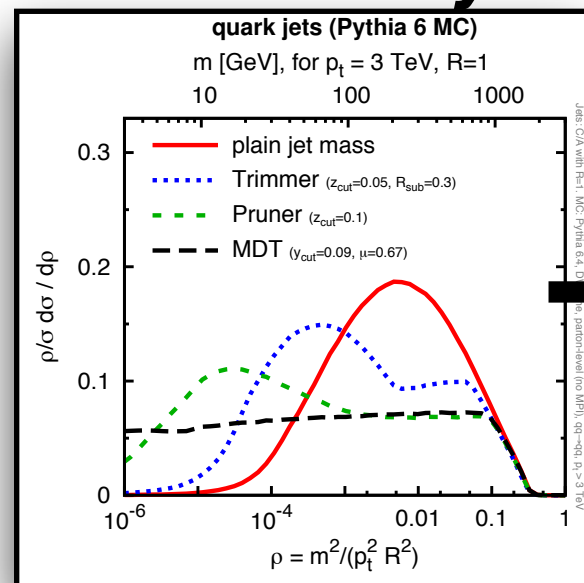
Shameless self-promotion: A. Larkoski, I. Moult, BPN,1709.04464:
JSS at the LHC: A Review of Recent Advances in Theory and ML

A Complex Reconstruction Challenge



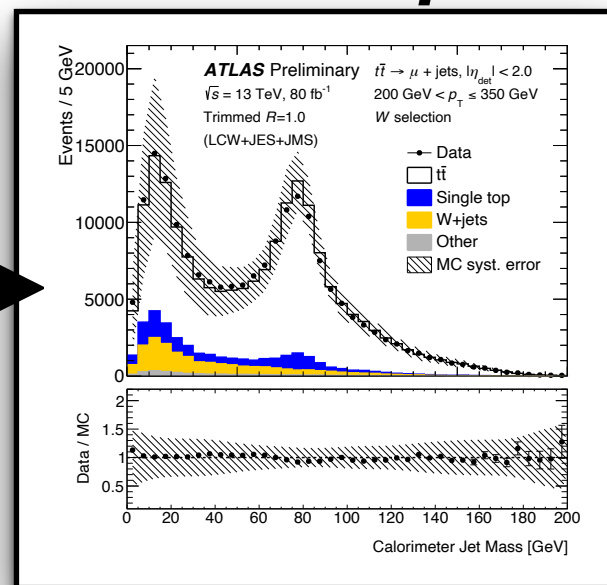
Unlike other objects: no right answer at particle level!

In Theory



Dasgupta, Fregoso,
Marzani, Salam
JHEP 09 (2013) 029

In Principle



ATLAS-
CONF-2020-022

Interesting interplay between algorithm, pileup mitigation strategy, grooming, calibration, resolution...

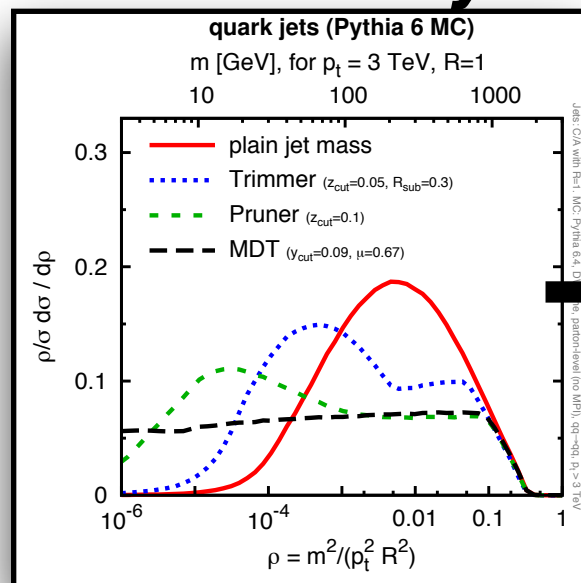
More promotion - R. Kogler, BPN, A. Schmidt (editors), et al., 1803.06991:
Jet Substructure at the Large Hadron Collider: Experimental Review

Applied JSS - searches

4

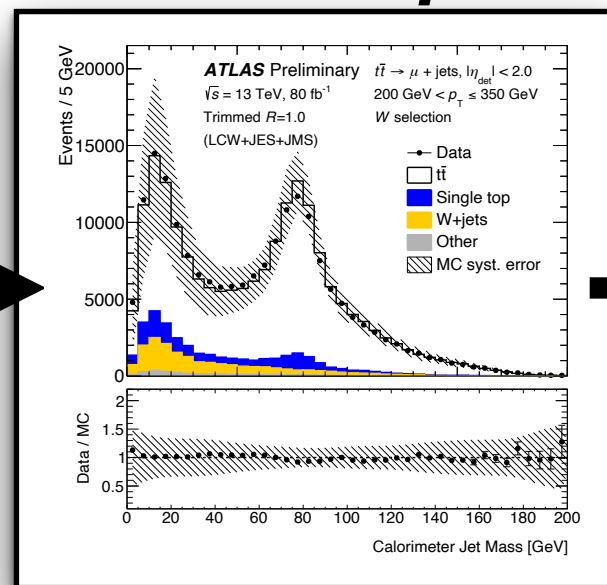
Jet tagging has made a huge impact on the search program

In Theory



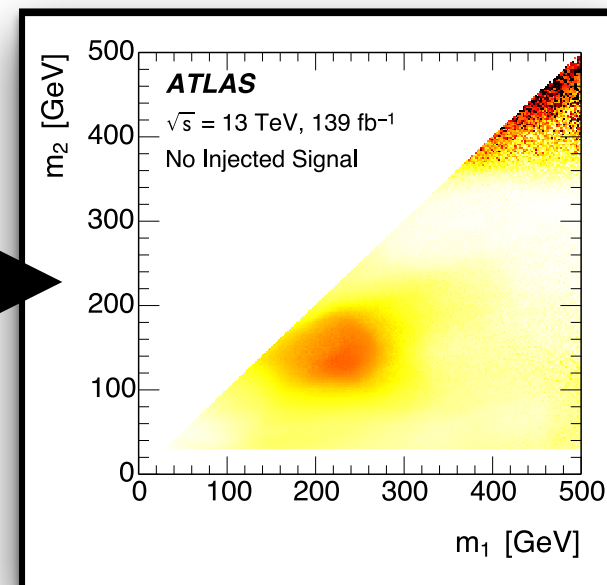
Dasgupta, Fregoso,
Marzani, Salam
JHEP 09 (2013) 029

In Principle



ATLAS-
CONF-2020-022

In Practice



Phys. Rev. Lett. 125
(2020) 131801

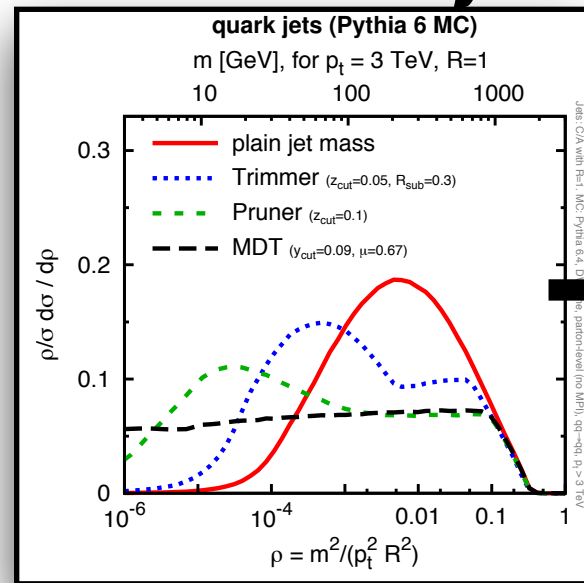
Extending limits for diboson, ditop resonances, stops & gluinos, covering new phase space (many jets, single jets),

...

Precision Jet Substructure

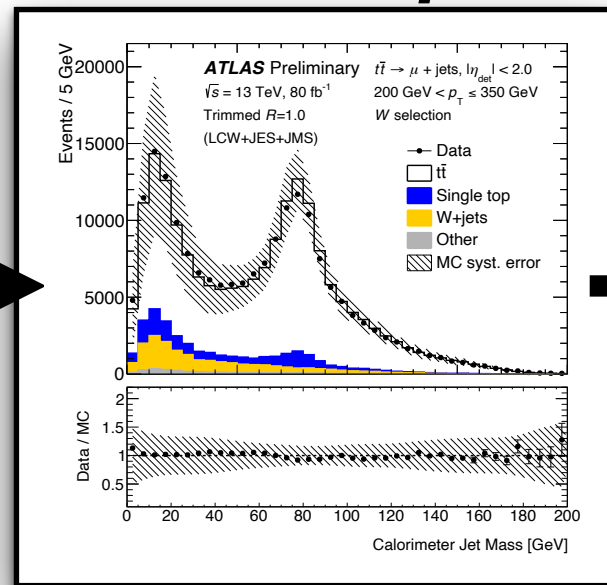
5

In Theory



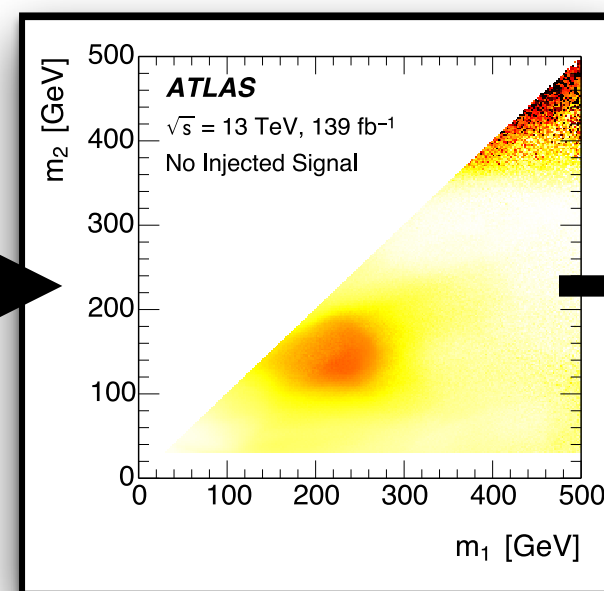
Dasgupta, Fregoso,
 Marzani, Salam
 JHEP 09 (2013) 029

In Principle



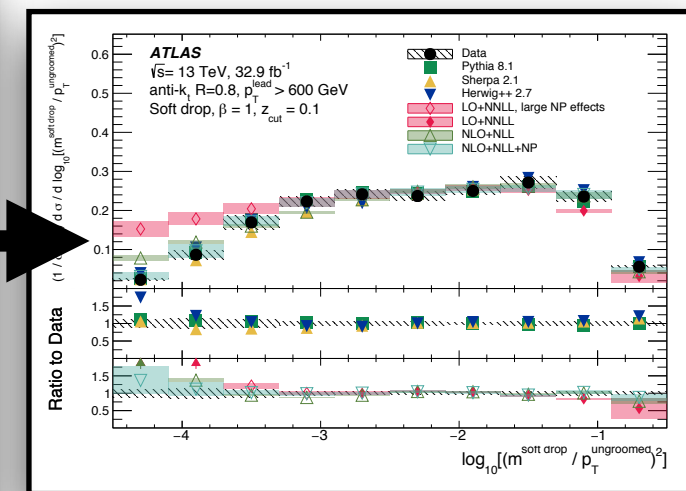
ATLAS-
 CONF-2020-022

In Practice



Phys. Rev. Lett. 125
 (2020) 131801

In Precision

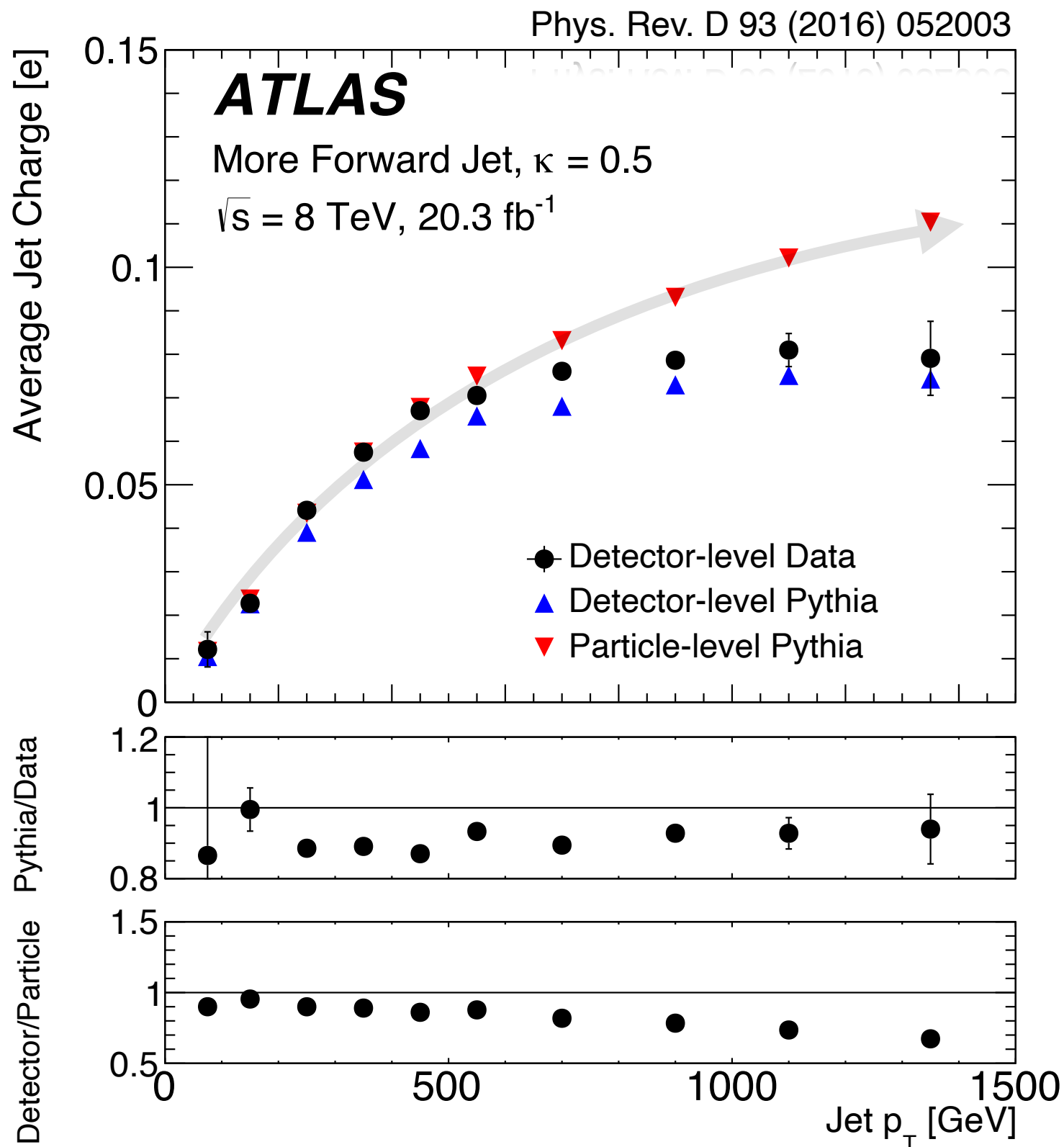


Phys. Rev. Lett. 121
 (2018) 092001

Most of the modern techniques were **motivated by QCD calculations** ... now that those calculations are **becoming precise** (beating the PS formal accuracy) we can start to **use them for measurements!**

Example: jet charge

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Example: **Jet Charge**
(IR safe, C unsafe)

$$Q_J = p_J^{-\kappa} \sum_{i \in J} p_{T,i}^{\kappa} q_i$$

Higher $p_T \rightarrow$ higher x
 $\rightarrow$ more valence quarks
 $\rightarrow$ more up quarks
 $\rightarrow$ more positive

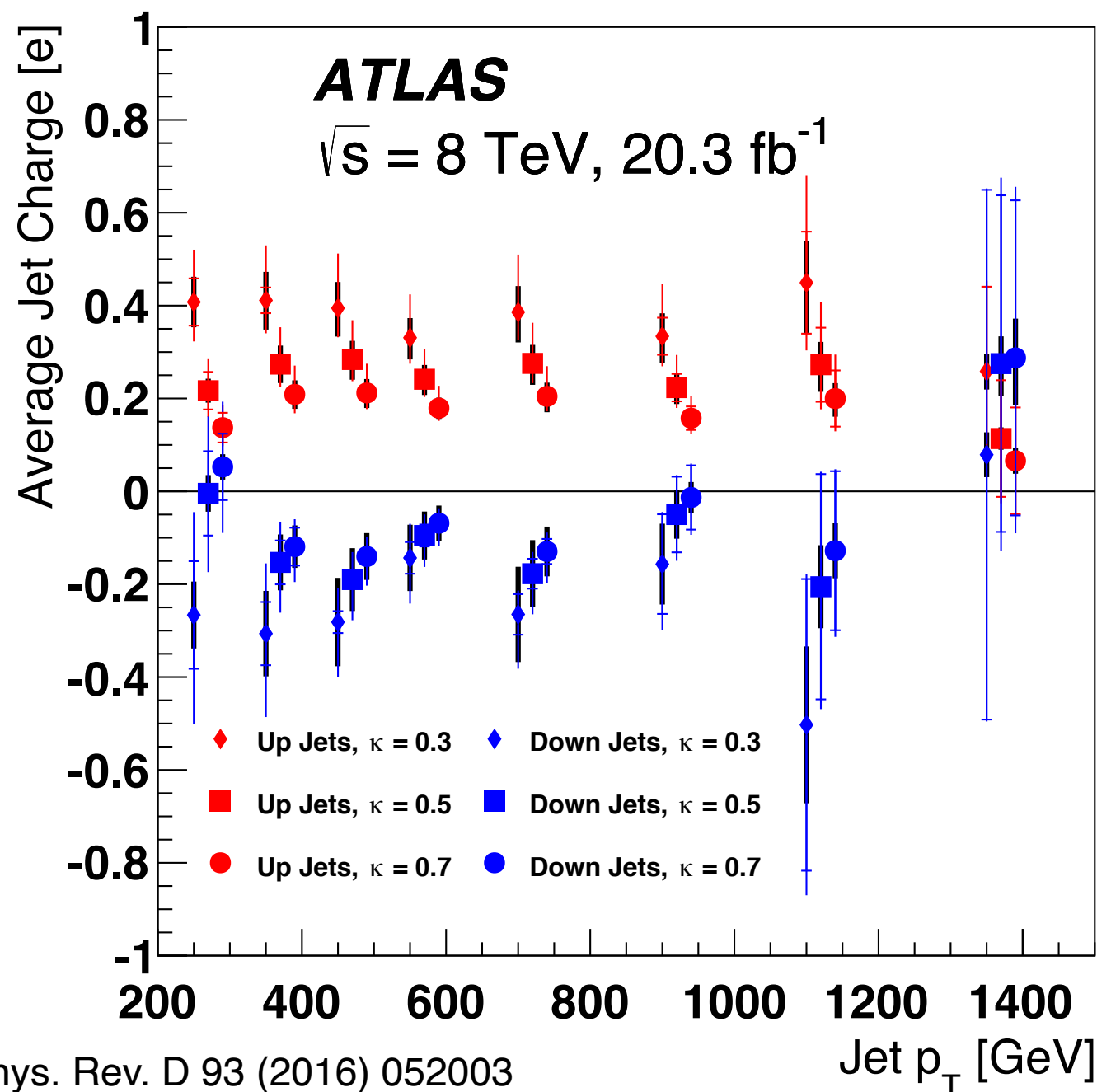
But is there a residual change aside from PDFs?

Example: jet charge

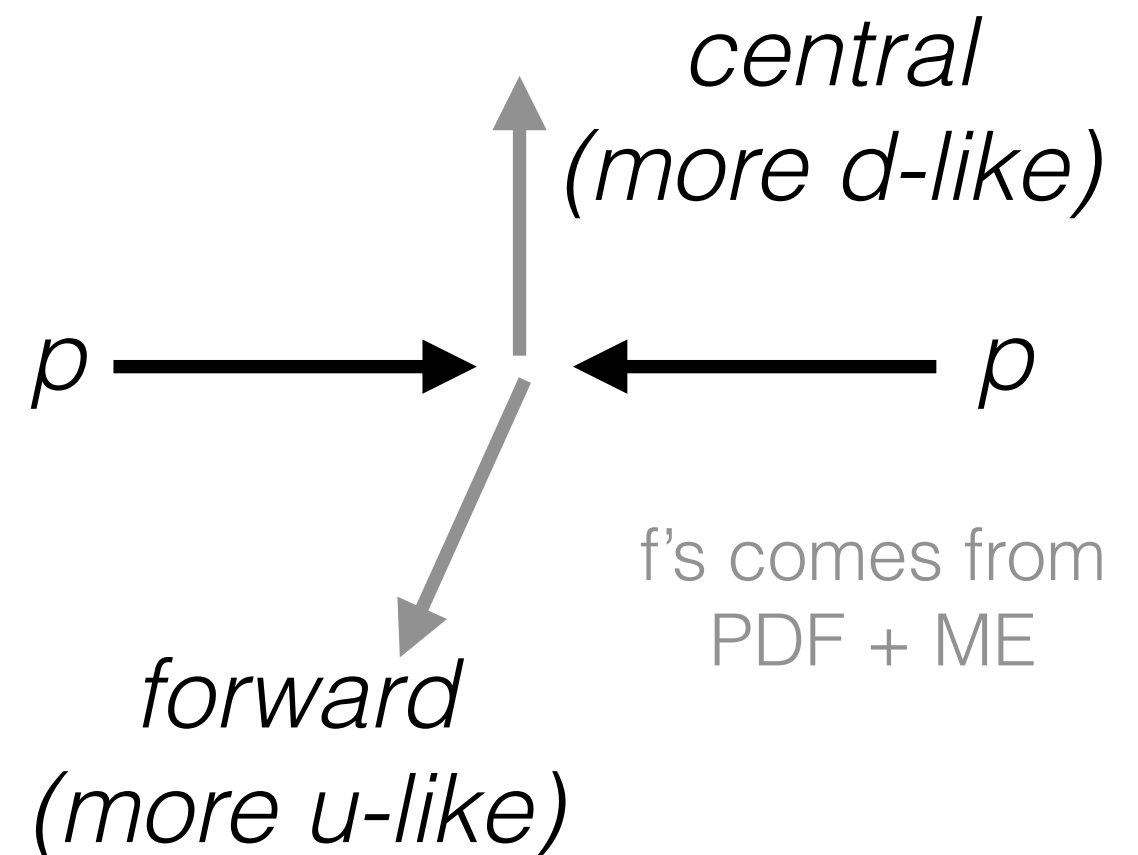
7

$$\langle Q_i^{\text{forward}} \rangle = \left(f_{\text{up},i}^{\text{forward}} - f_{\text{anti-up},i}^{\text{forward}} \right) Q_i^{\text{up}} + \left(f_{\text{down},i}^{\text{forward}} - f_{\text{anti-down},i}^{\text{forward}} \right) Q_i^{\text{down}}$$

$$\langle Q_i^{\text{central}} \rangle = \left(f_{\text{up},i}^{\text{central}} - f_{\text{anti-up},i}^{\text{central}} \right) Q_i^{\text{up}} + \left(f_{\text{down},i}^{\text{central}} - f_{\text{anti-down},i}^{\text{central}} \right) Q_i^{\text{down}}$$



Exploit η -dependence
of u/d/g fractions

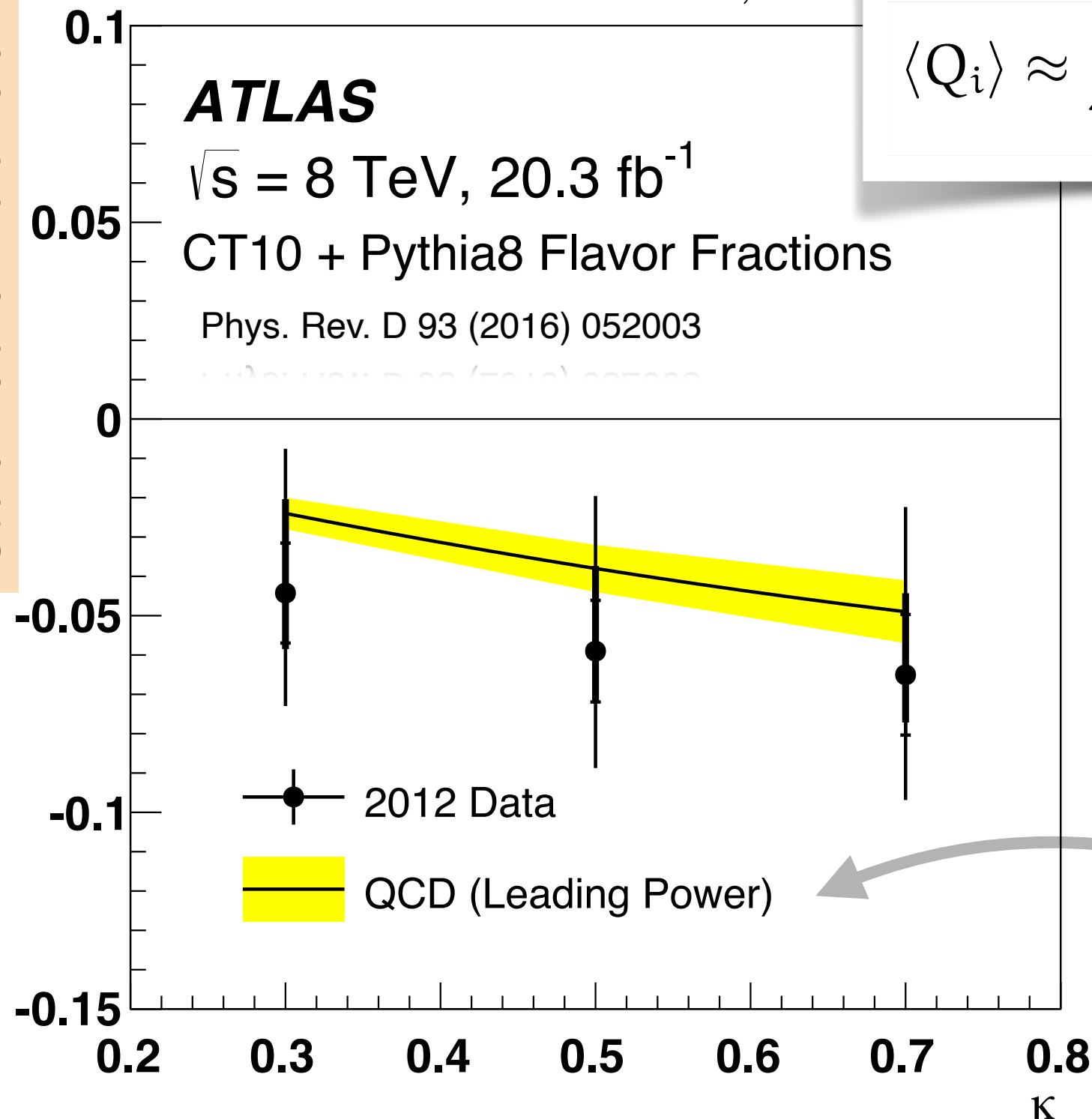


Example: jet charge

8

$$Q_J = p_J^{-\kappa} \sum_{i \in J} p_{T,i}^{\kappa} q_i$$

Scale Violation Parameter



$$\langle Q_i \rangle \approx \sum_f \beta_{f,i} \bar{Q}_f (1 + c_{\kappa} \ln(p_{T,i}/\bar{p}_T))$$

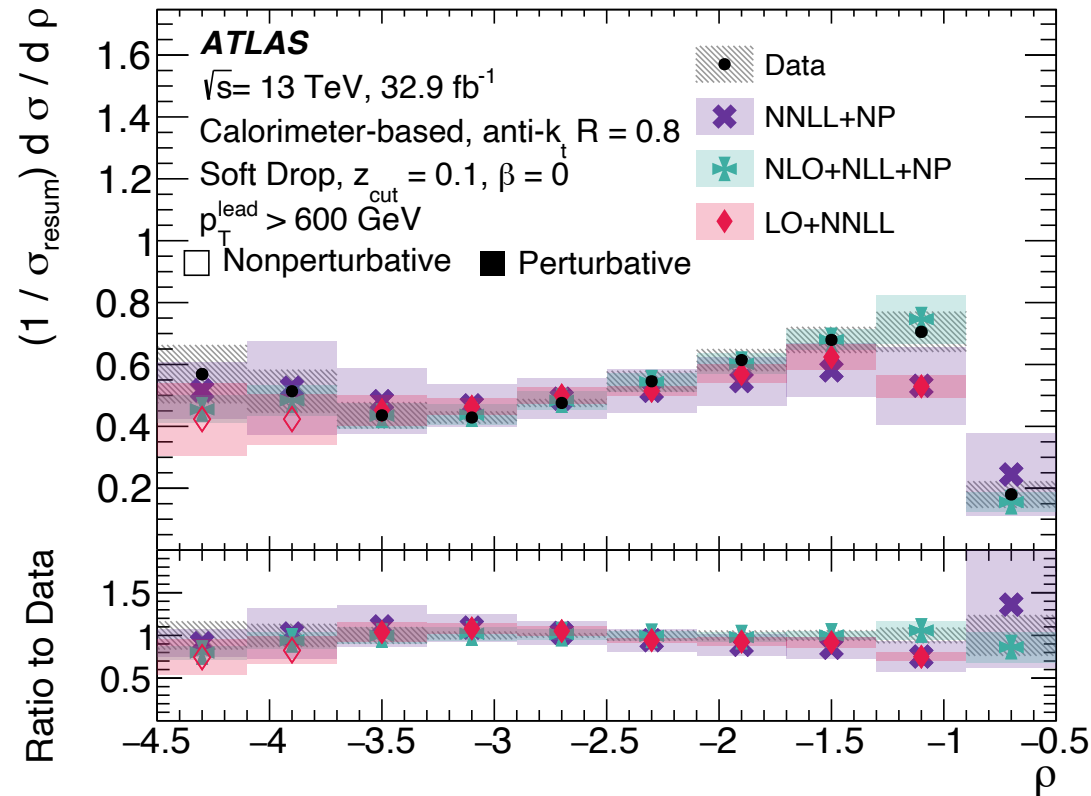
average jet charge per jet type

flavor fractions

$m/E \ll 1$
and LO **Altarelli**-Perisi splitting functions

More examples of precision jSS

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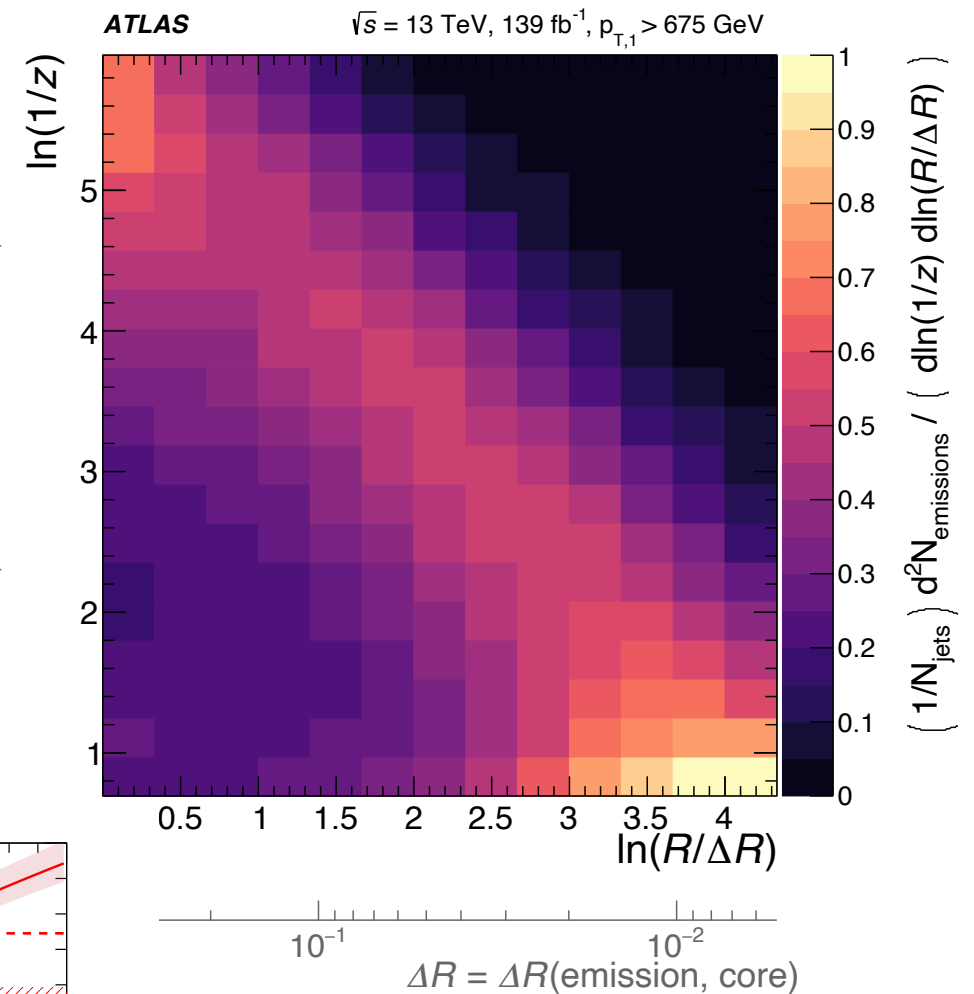
[Phys. Rev. D 101 \(2020\) 052007](#)

[Phys. Rev. Lett. 121 \(2018\) 092001](#)

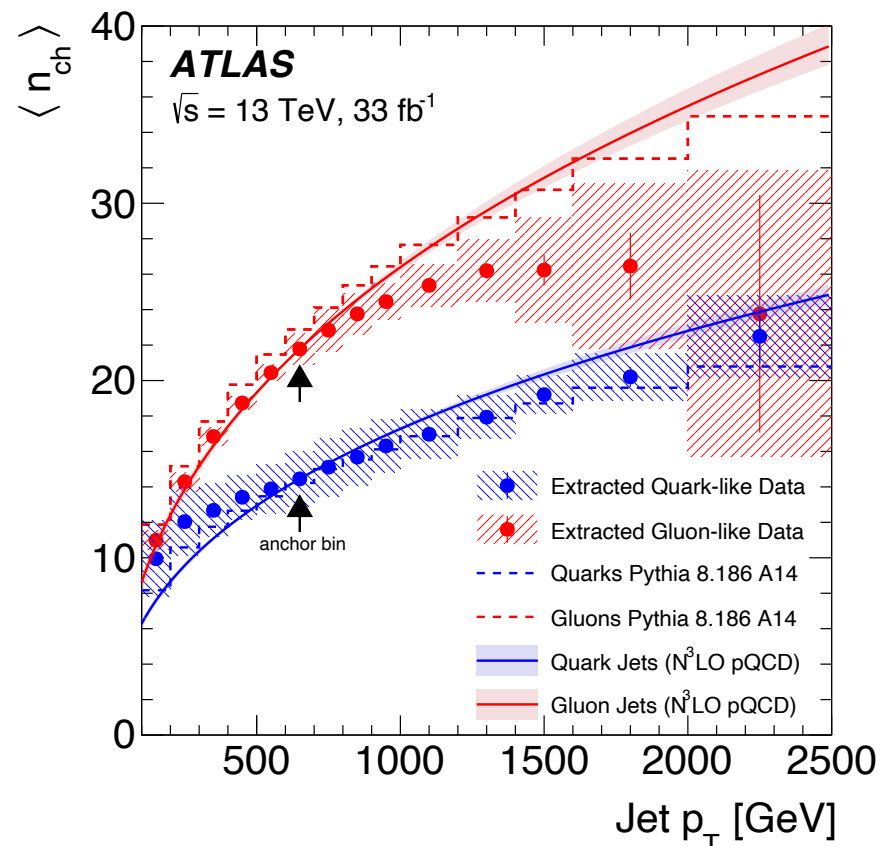
Groomed jet mass

Lund
jet
plane

$$z = p_T^{\text{emission}} / (p_T^{\text{emission}} + p_T^{\text{core}})$$



[Phys. Rev. Lett. 124 \(2020\) 222002](#)



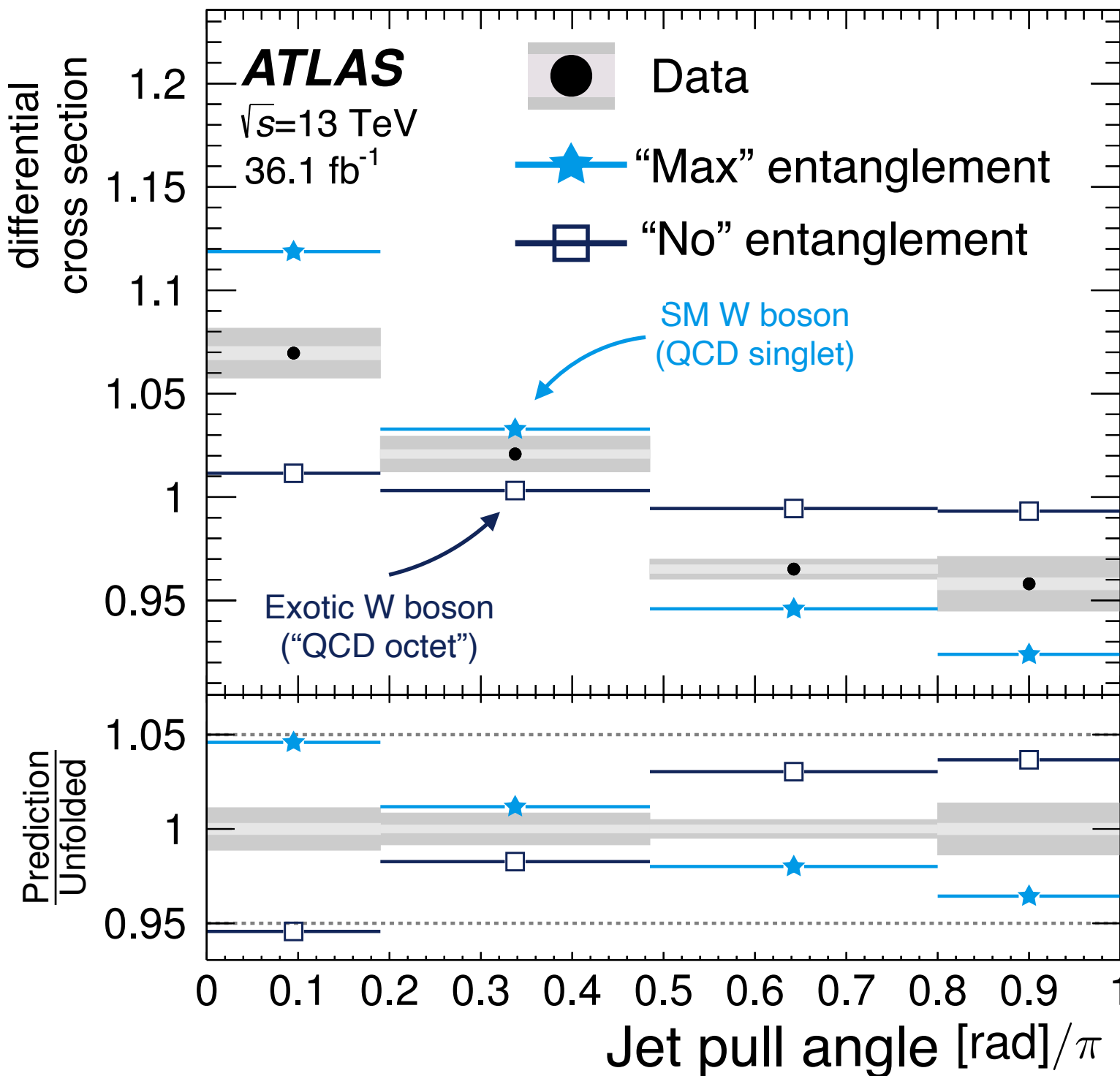
Charged particle
multiplicity

[Phys. Rev. D 100 \(2019\) 052011](#)

The mysteries of QCD

10

Eur. Phys. J. C 78 (2018) 847, Phys. Lett. B (2015) 475



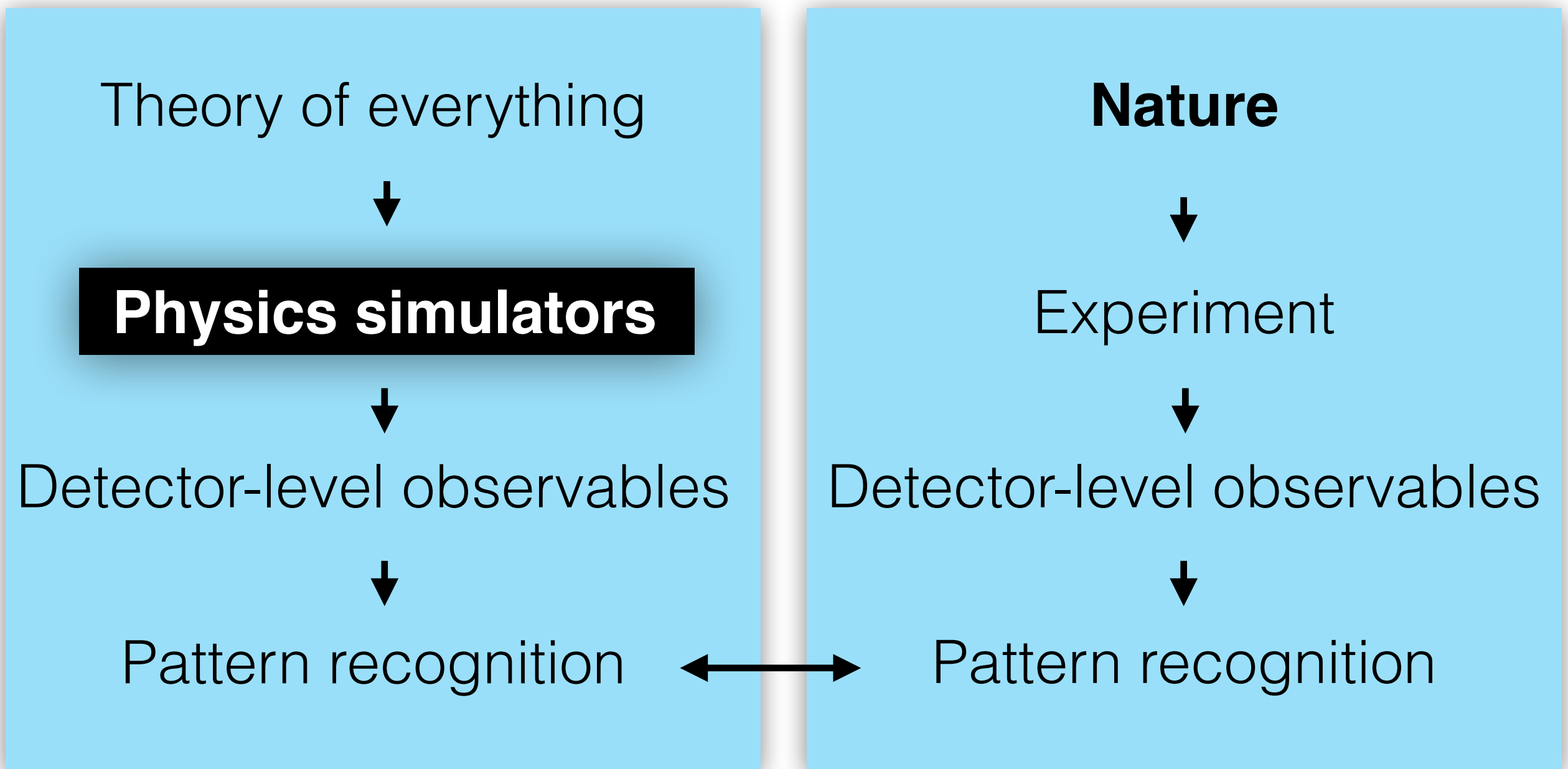
W boson $\rightarrow$ two jets of hadrons

There are many QCD properties that we do not yet understand, even at high energy (!)

How much the radiation from one jet “leans” toward the other.

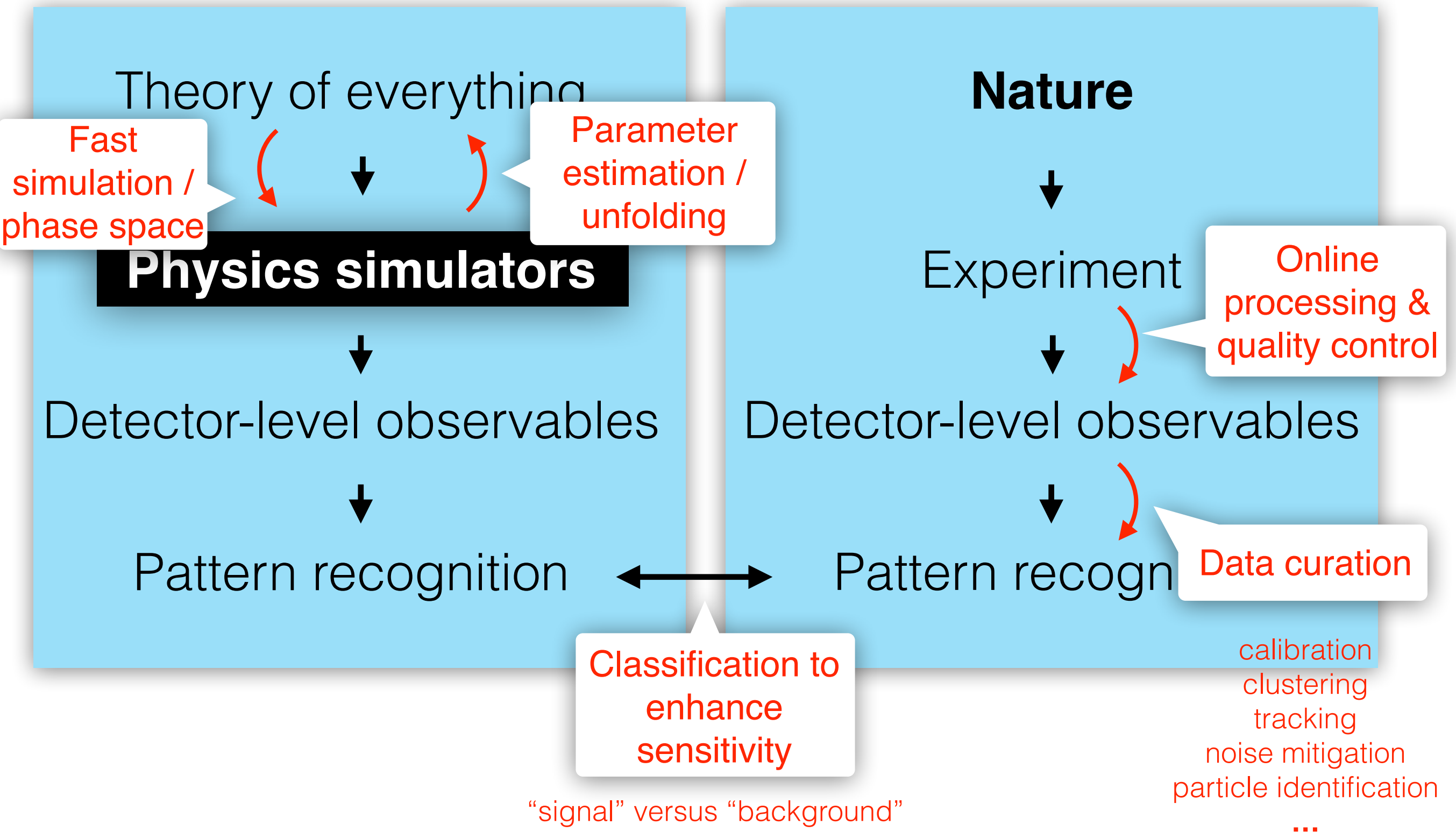
What about ML?





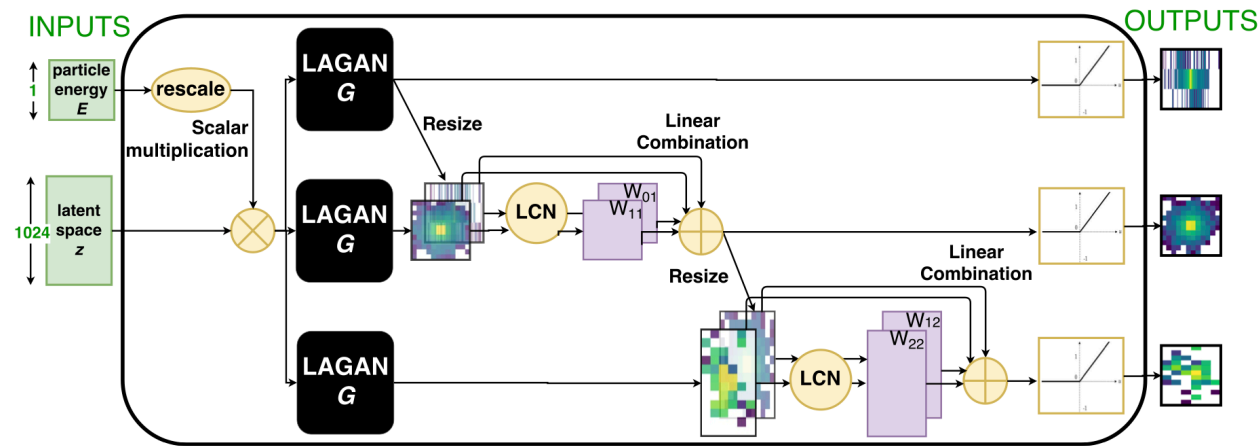
Data analysis in HEP + ML

13



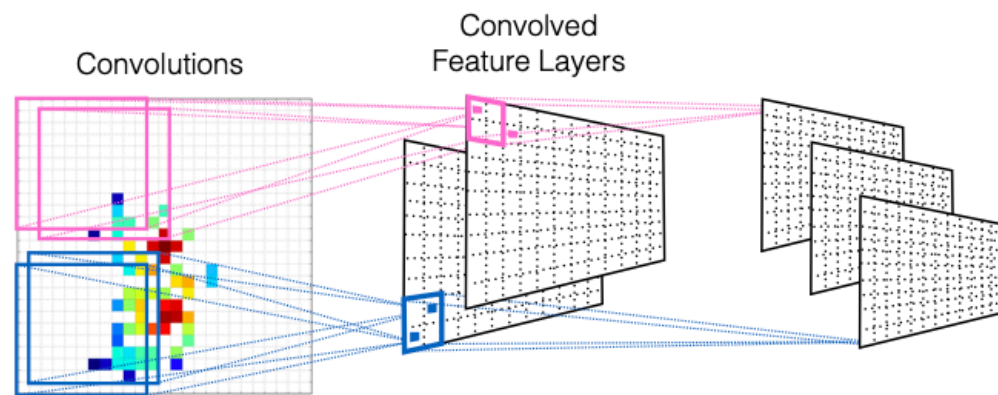
Data analysis in HEP + ML

14



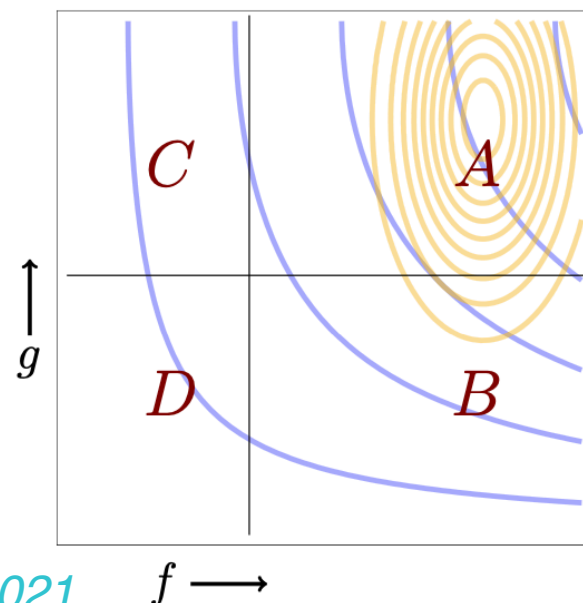
Phys. Rev. Lett. 120 (2018) 042003
M. Paganini, L. de Oliveira, BPN

CaloGAN

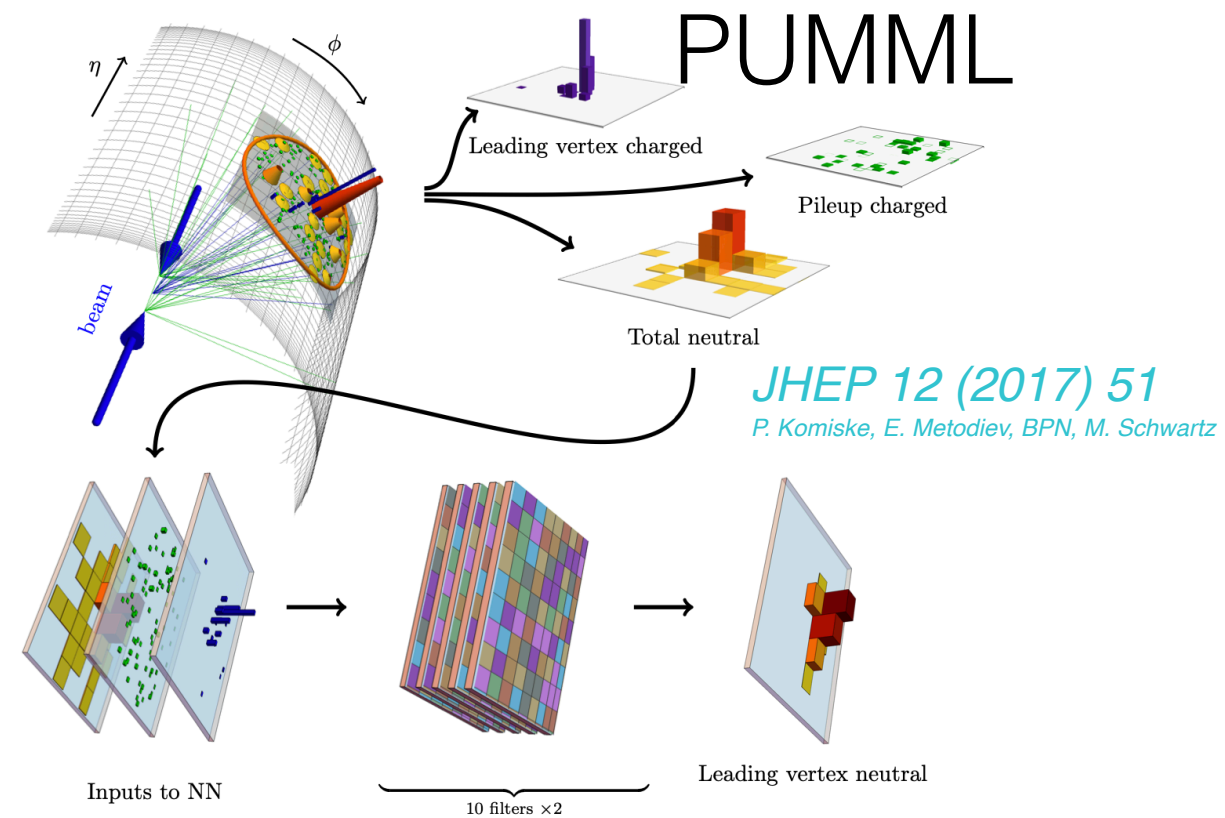


JHEP 07 (2016) 069
L. de Oliveira, M. Kagan, L. Mackey, BPN, A. Schwartzman

Double DisCo



Phys. Rev. D 103 (2021) 035021
G. Kasieczka, BPN, M. Schwartz, D. Shih

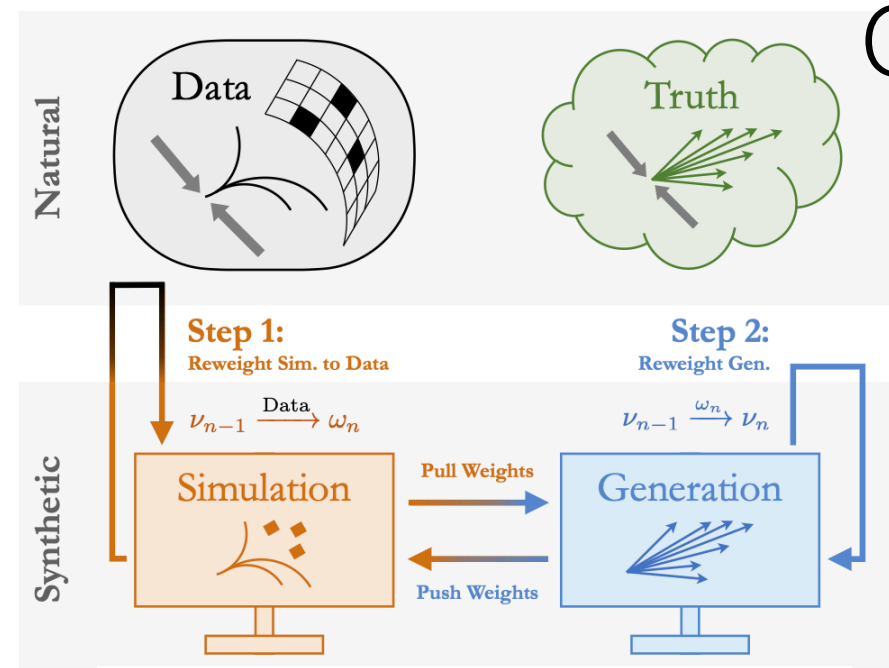


JHEP 12 (2017) 51
P. Komiske, E. Metodiev, BPN, M. Schwartz

Detector-level

Particle-level

OmniFold

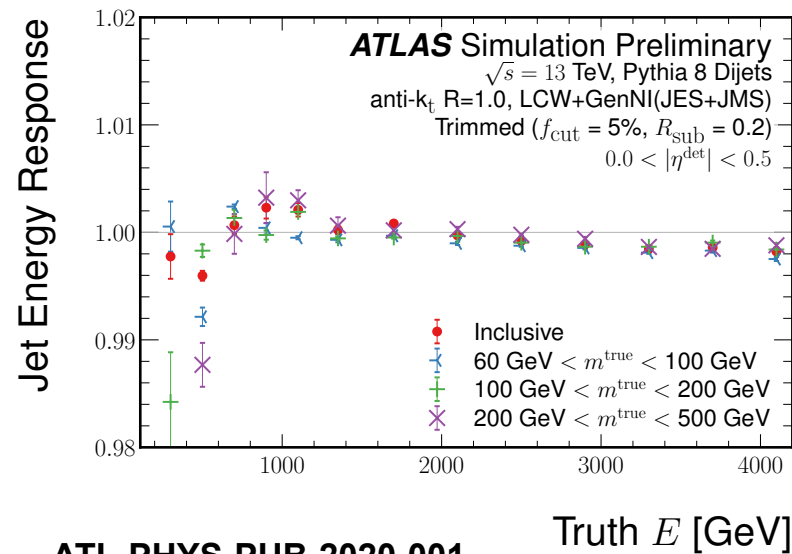


Phys. Rev. Lett. 124 (2020) 182001
A. Andreassen, P. Komiske, E. Metodiev, BPN, J. Thaler

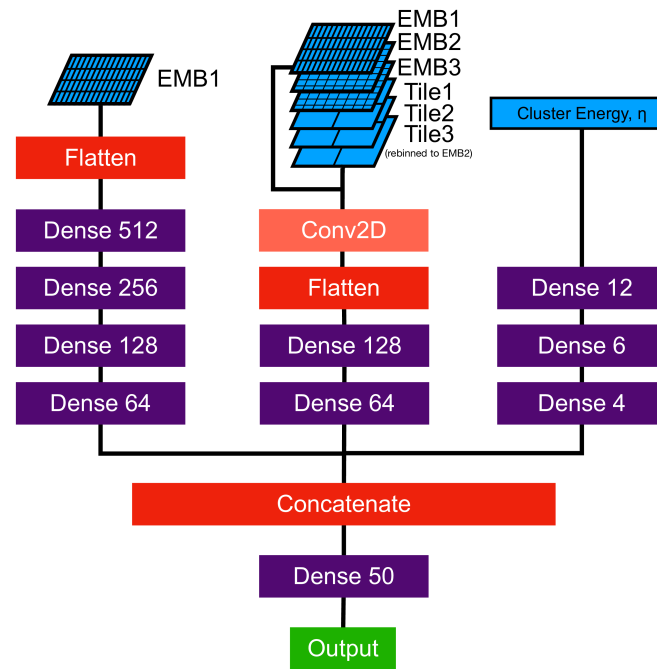
+...

Data analysis in HEP + ML

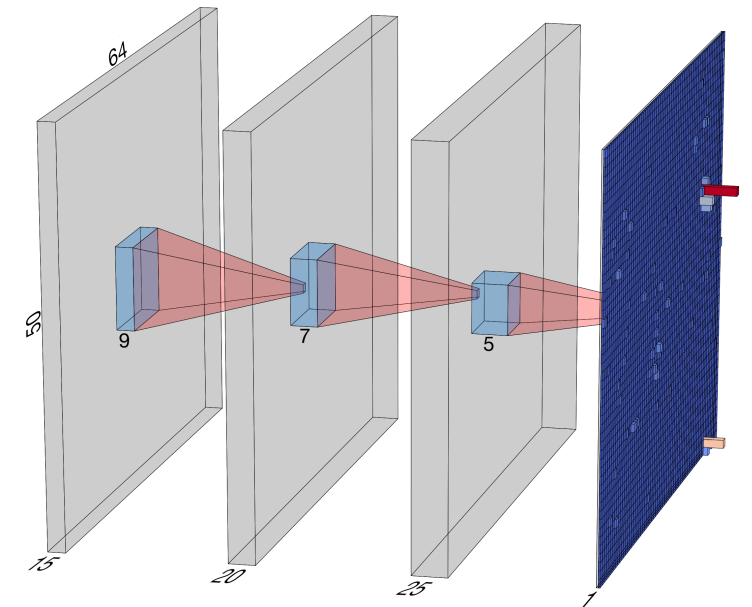
15



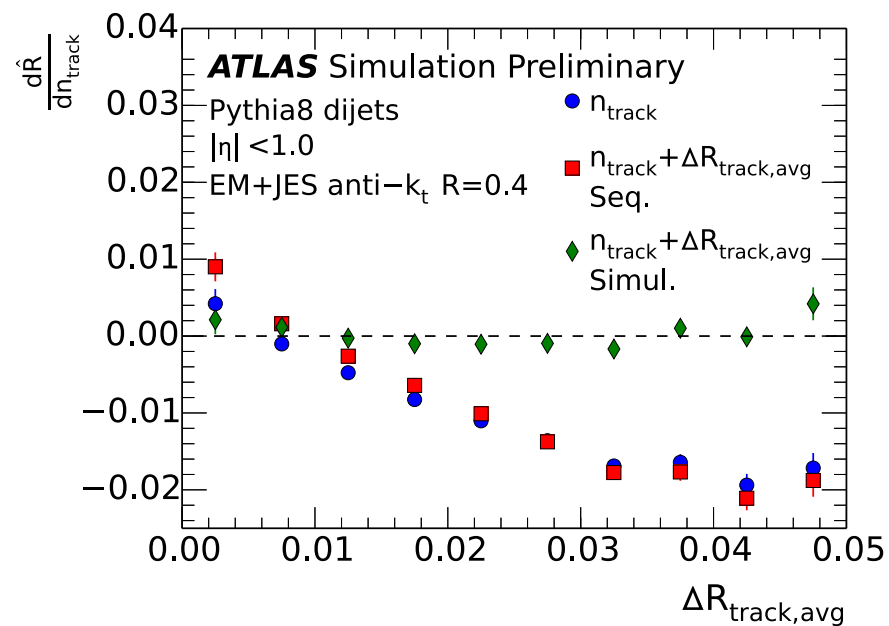
ATL-PHYS-PUB-2020-001



ATL-PHYS-PUB-2020-018

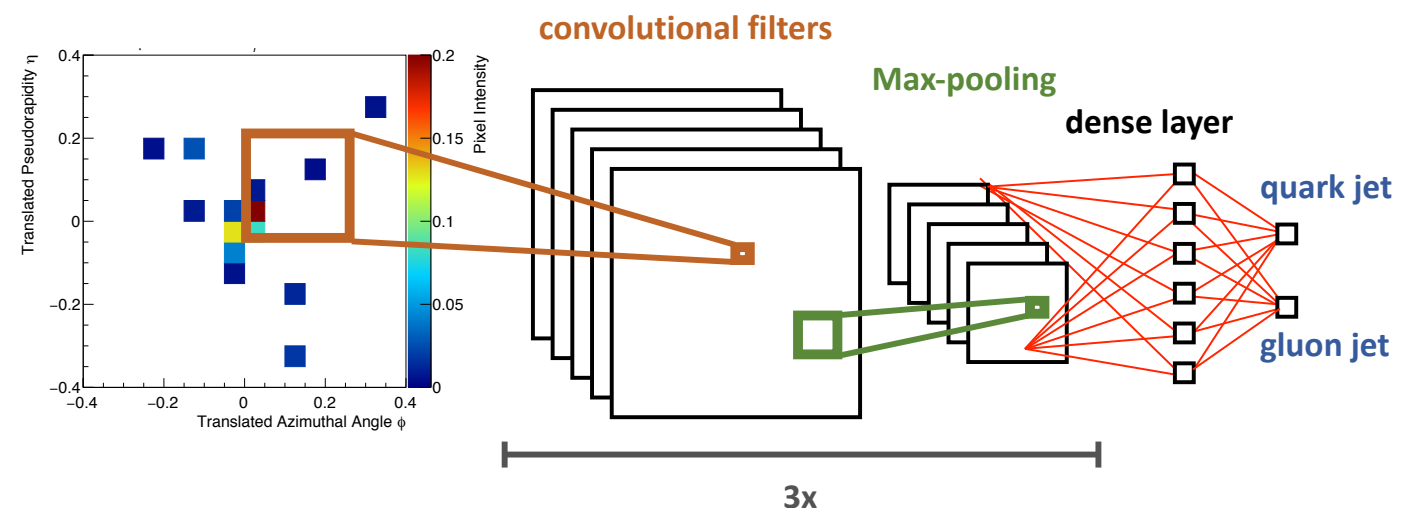


ATL-PHYS-PUB-2019-028



ATL-PHYS-PUB-2018-013

ATLAS Simulation Preliminary



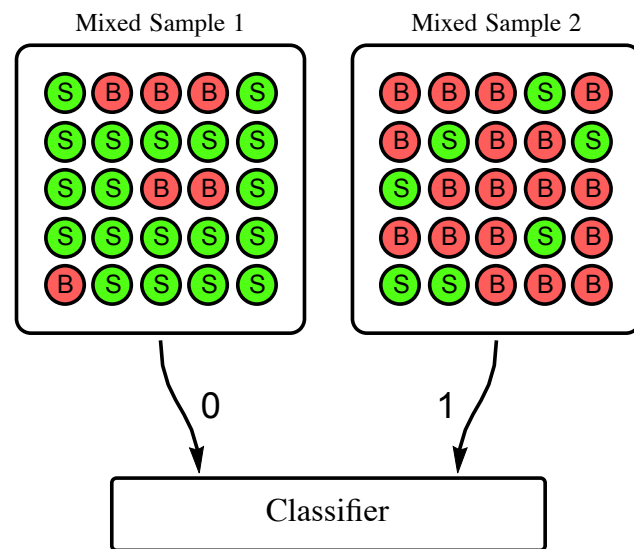
ATL-PHYS-PUB-2017-017

Analysis example: anomaly detection

16

JHEP 10 (2017) 174

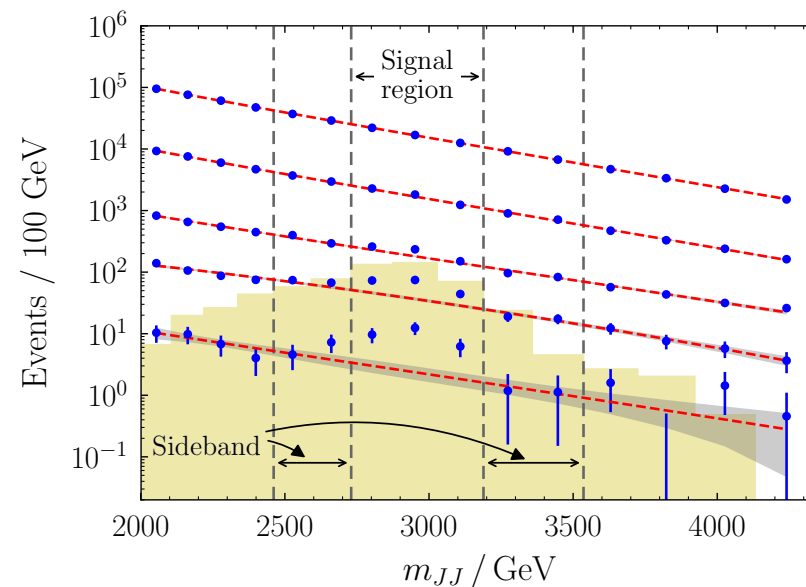
E. Metodiev, BPN, J. Thaler



2017

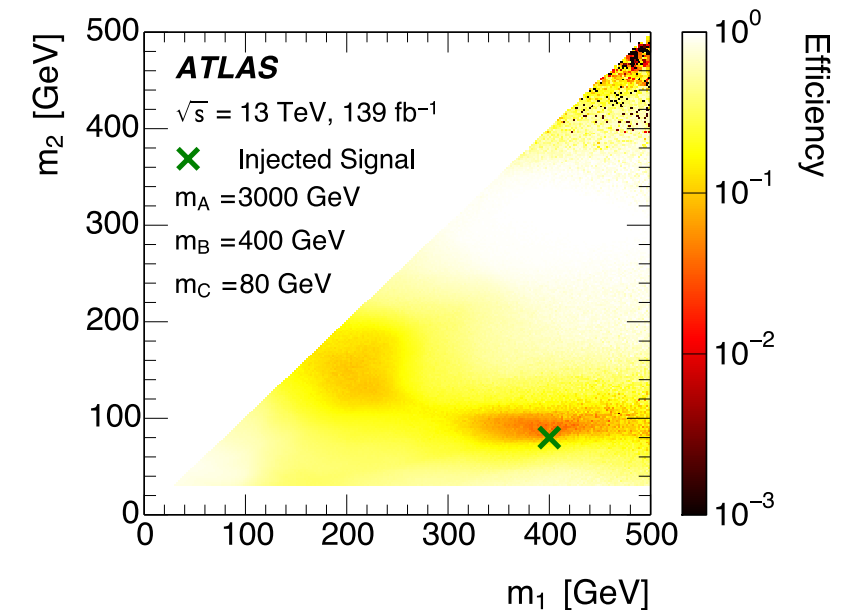
Phys. Rev. Lett. 121 (2018) 241803

J. Collins, K. Howe, BPN



2018

Phys. Rev. Lett. 125 (2020) 131801



2020

2101.08320

G. Kasieczka, BPN, D. Shih (ed), et al.

Complete pipeline
from methods to data!

*...but this is not the end, we
need new methods and
more applications to data!*

The LHC Olympics 2020

A Community Challenge for Anomaly
Detection in High Energy Physics



Now is the time to think big !



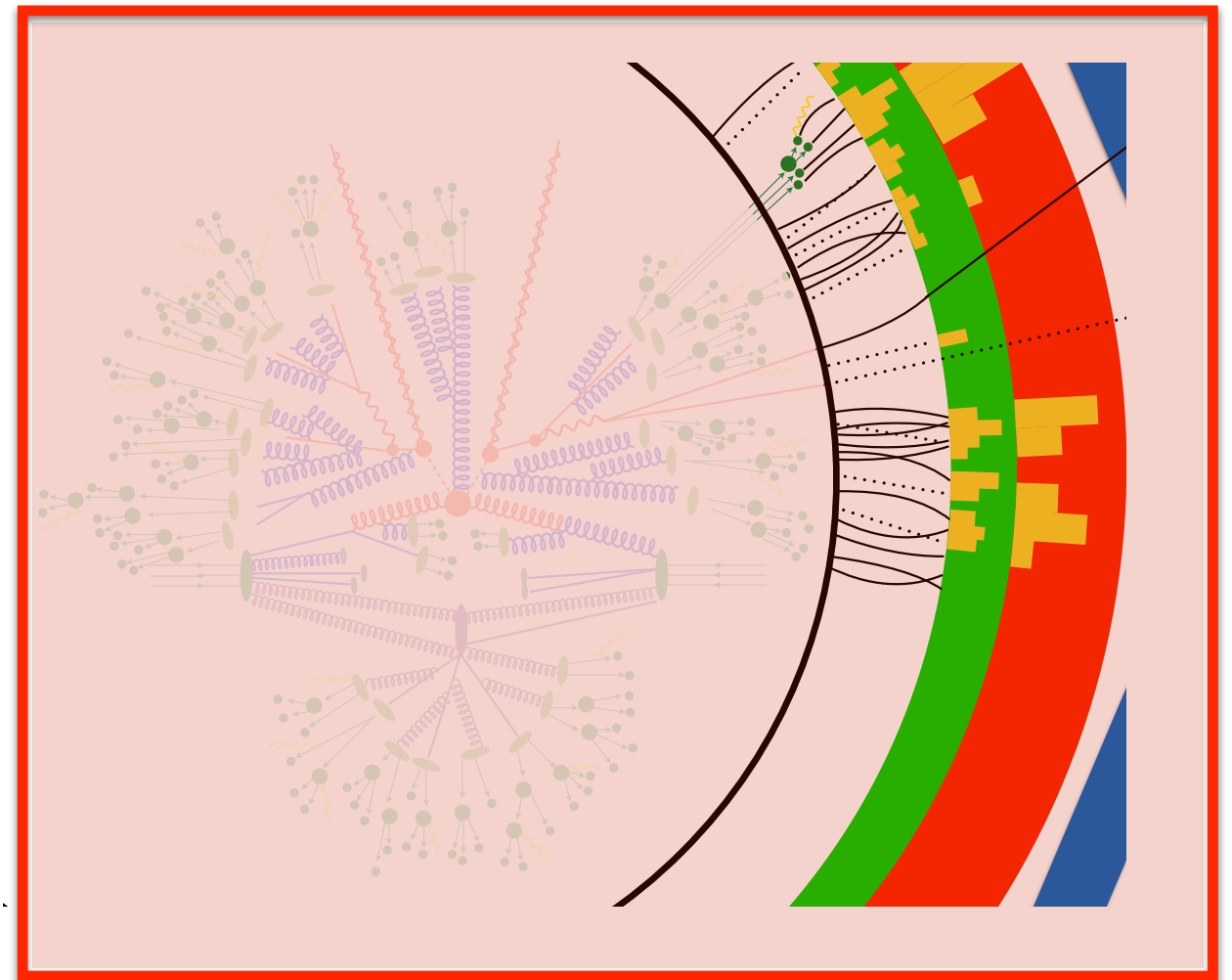
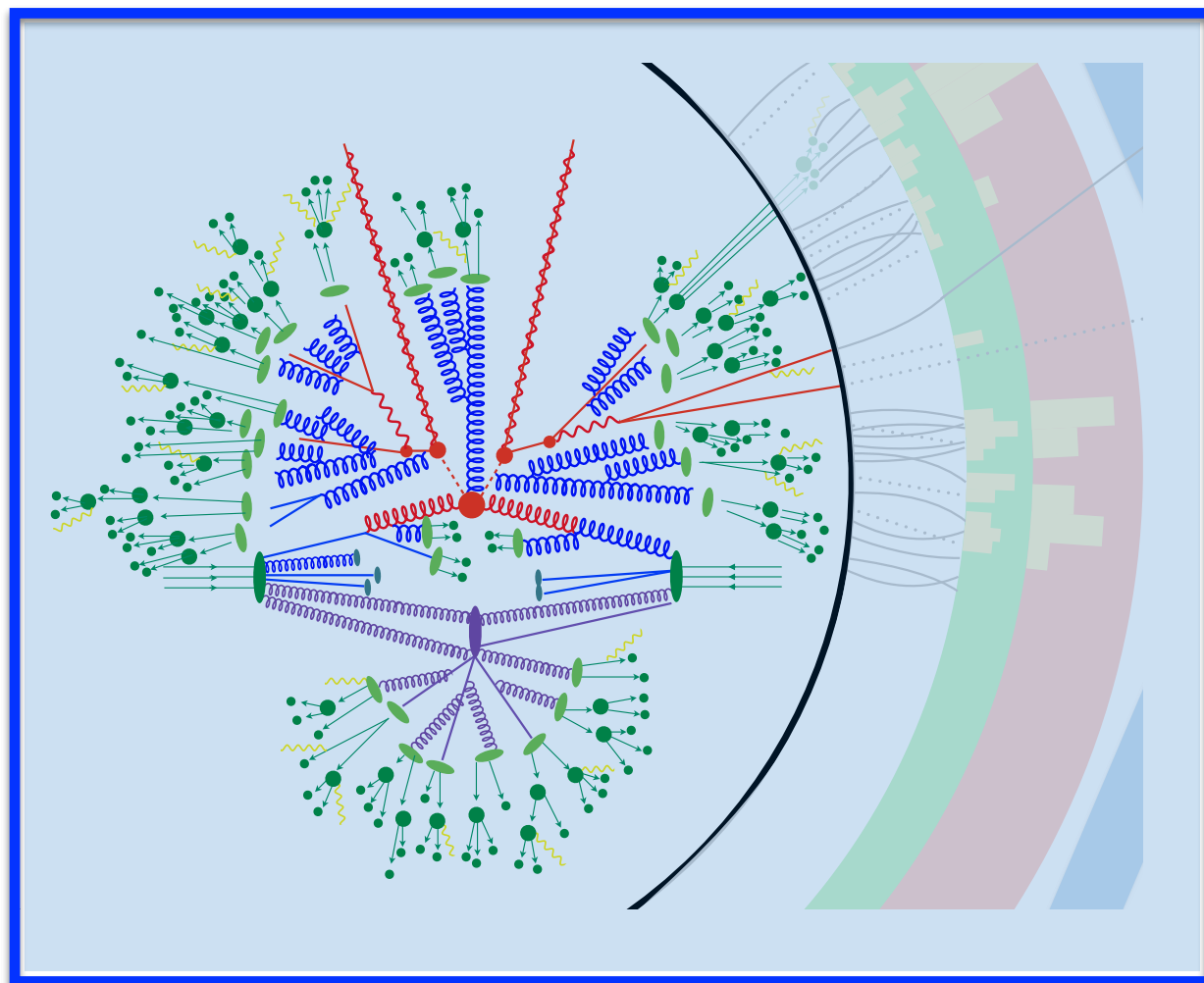
Measure what is measurable, and make measurable what is not so
-Galileo

Now is the time to think big !

18

Measure what is measurable, and make measurable what is not so
-Galileo

What if we can use machine learning to make measurements, unbinned, in variable-dimensions, using low-level information?

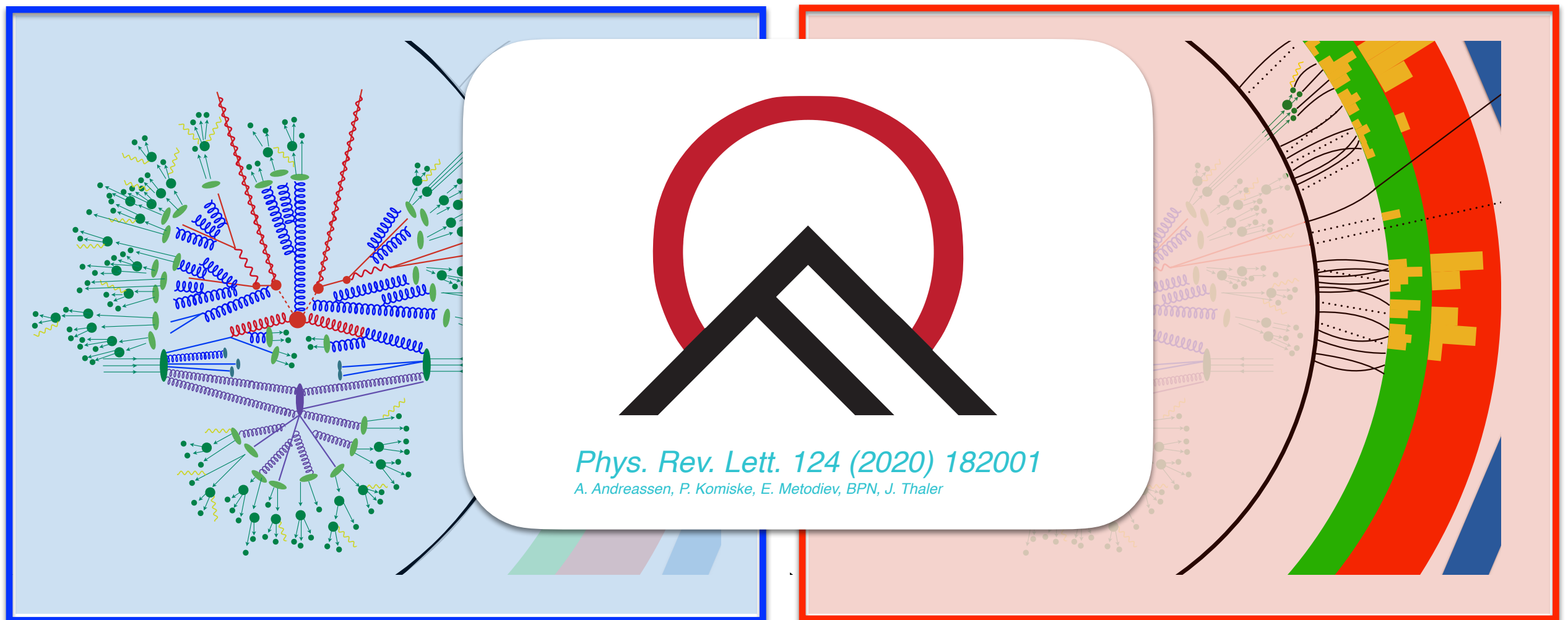


Now is the time to think big !

19

Measure what is measurable, and make measurable what is not so
-Galileo

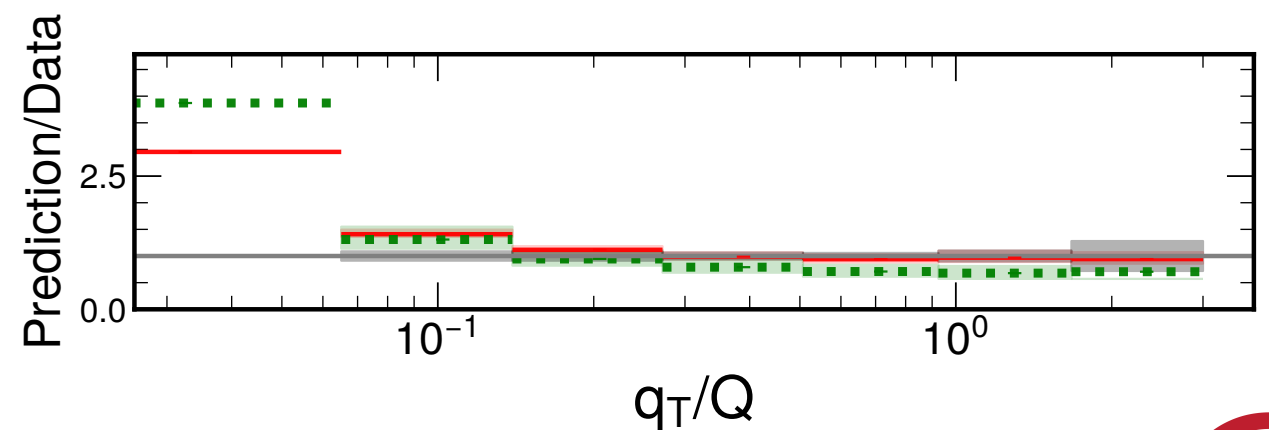
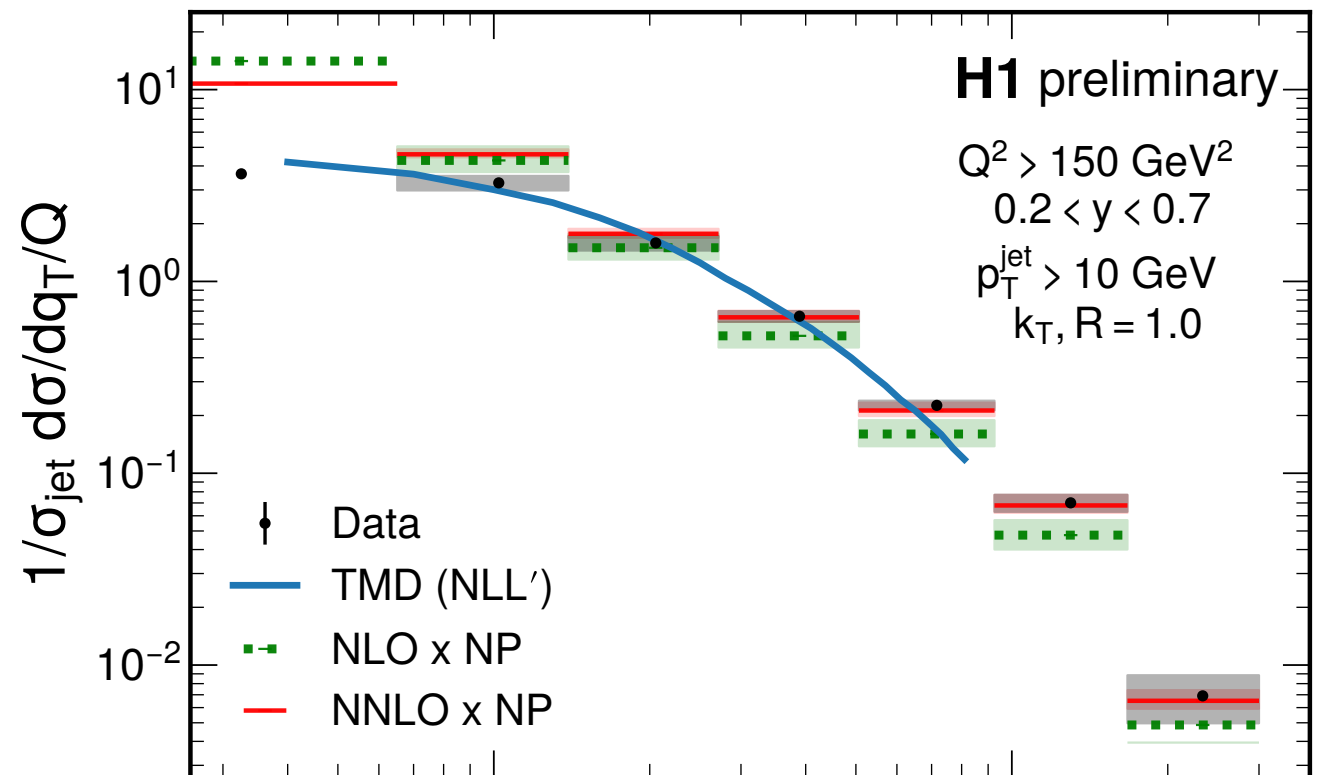
What if we can use machine learning to make measurements, unbinned, in variable-dimensions, using low-level information?



First collider results at this workshop !

20

See Miguel Arratia's talk from Thursday!



H1prelim-21-031
April 8, 2021

Measurement of lepton-jet correlations in high Q^2 neutral-current DIS with the H1 detector at HERA

The H1 Collaboration

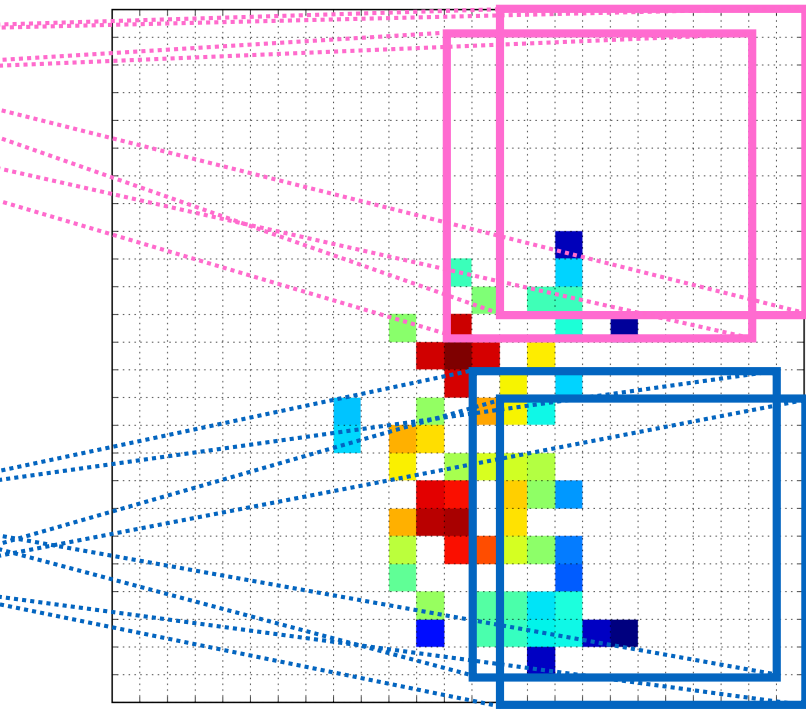
Abstract

A measurement of jet production in high Q^2 neutral-current DIS events close to the Born-level configuration $\gamma^* q \rightarrow q$ (Born kinematics) is presented. This cross section is measured differentially as a function of the jet transverse momentum and pseudorapidity, as well as lepton-jet momentum imbalance and azimuthal angle correlation. The jets are reconstructed in the laboratory frame with the k_T algorithm and a distance parameter of 1.0. The data are corrected for detector effects using the OMNIFOLD method, which incorporates a simultaneous and unbinned unfolding in four dimensions using machine learning. The results are compared with leading order Monte Carlo event generators and higher order calculations performed within the context of collinear or transverse-momentum-dependent (TMD) factorization in Quantum Chromodynamics (QCD). The measurement probes a wide range of QCD phenomena, including TMD parton-distribution functions (PDFs) and their evolution with energy.

*“Only” 6-dimensions
simultaneously and unbinned
 - the future is bright!*



(maybe not with the collider you had in mind!)

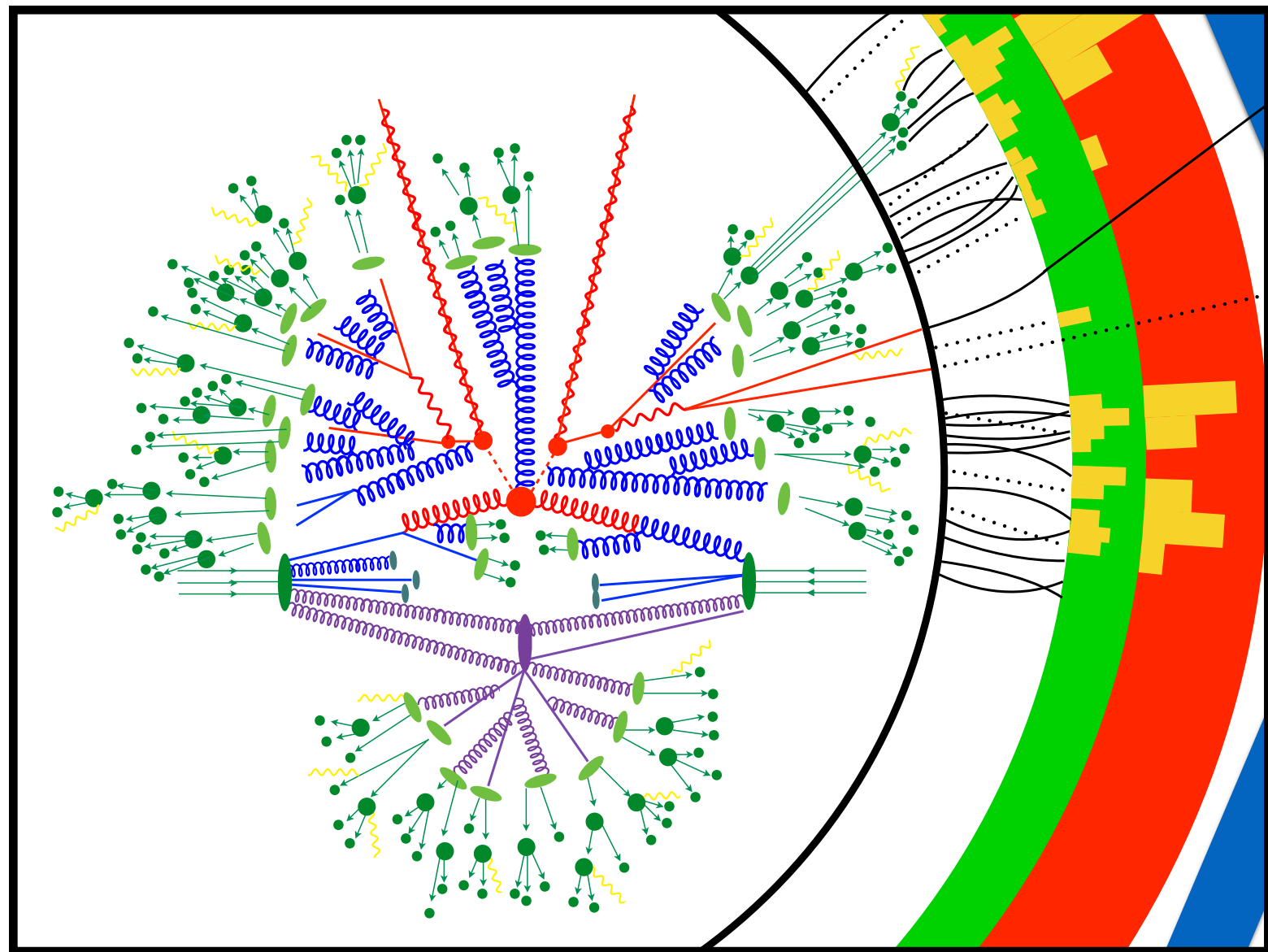


Jets and jet substructure are essential tools for the future of high energy particle/nuclear physics

Jets have provided a catalyst for machine learning in HEP; we now have access to our data in their natural high-dimensionality!

visit ML4Jets 2021!

<https://indico.cern.ch/event/980214/>



**Thank you for the great honor of sharing
a prize in the name of Dr. G. Altarelli!**

*...and a deep gratitude to my
collaborators, mentors, and mentees for
a wonderful research environment!*

Jets have
catalysed
learning
we now have access to
our data in their natural
high-dimensionality!

visit ML4Jets 2021!

<https://indico.cern.ch/event/980214/>