Dealing with Large backgrounds

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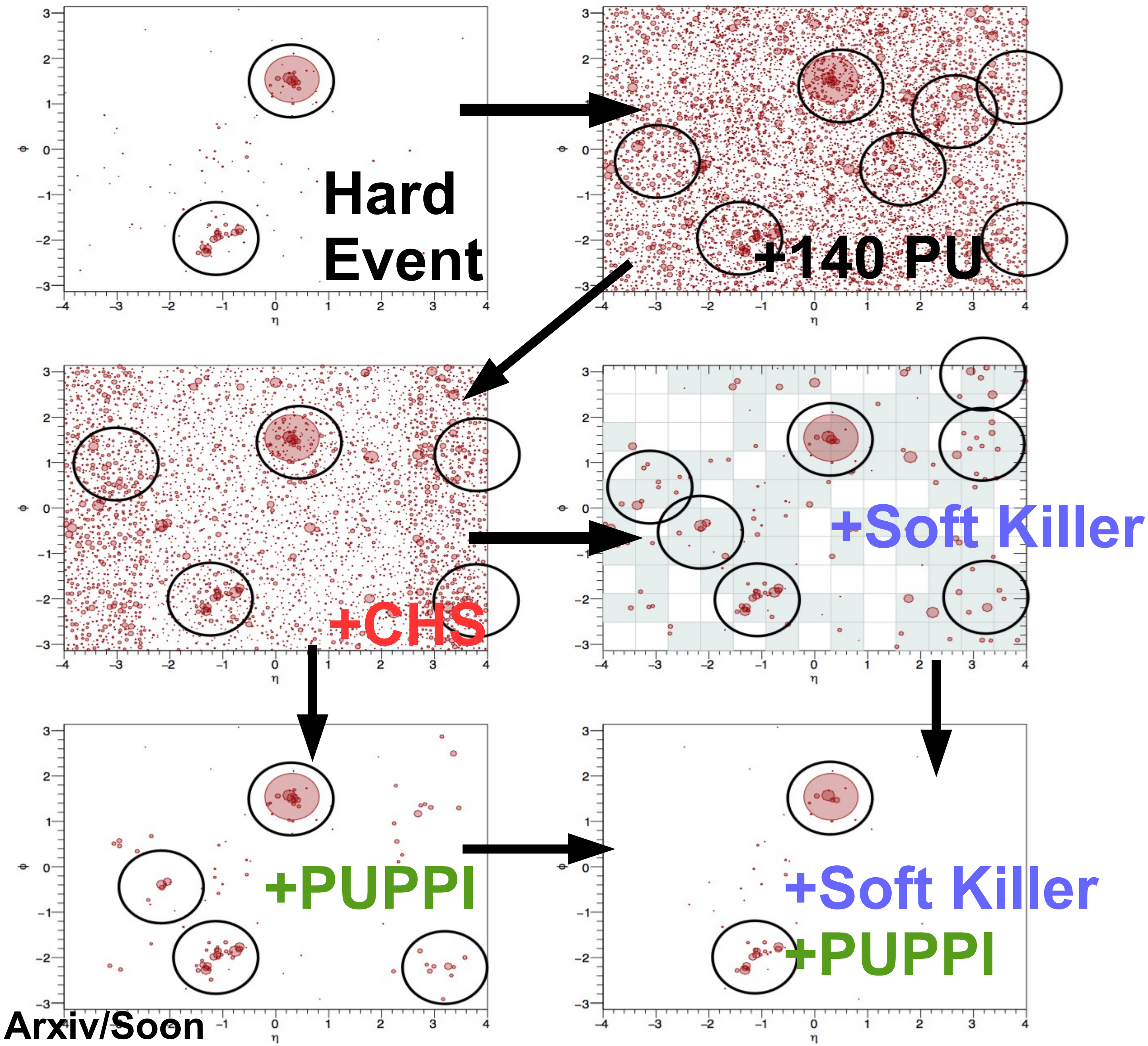
Overview

- Contending with UE makes jet properties difficult
  - Typical energy densities have $\rho > 200$ GeV
    - That translates to > 100 GeV/AK4 jet area
  - Inside the jet UE still does not look like a jet
    - Jets contain most of their energy in $\Delta R < 0.1$ (7 GeV)
  - Means there are ways to highlight jet specifics
  - However we cannot necessarily remove everything
- Dealing with large backgrounds in pp
  - In pp collisions there are a few more handles
  - However the challenges and precision are different
  - In this talk we draw an analogy with a problem in pp

What are the features of UE?

- UE is the result of many low energy processes
  - Consists of low energy particles
  - Spread roughly uniformly over the event
  - Not part of the hard core of a jet
  - For PP : not part of the primary vertex
- This has led to a number of core algorithms
  - Soft Killer : cut particles below a p_T threshold
  - Constituent/ρ subtraction : remove avg energy/particle
  - PUPPI : compute likelihood from a jet fragmentation
  - CHS : remove charged particles not from PV
- Note: at this stage pp prefers prticle based sub.

How does this look?



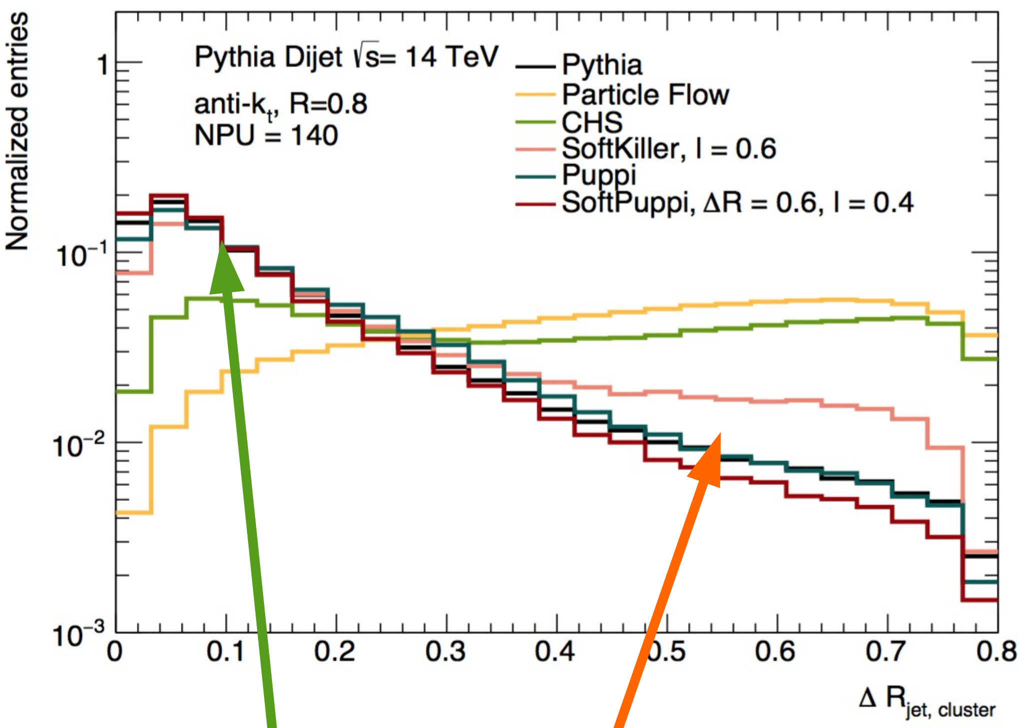
Effectively :

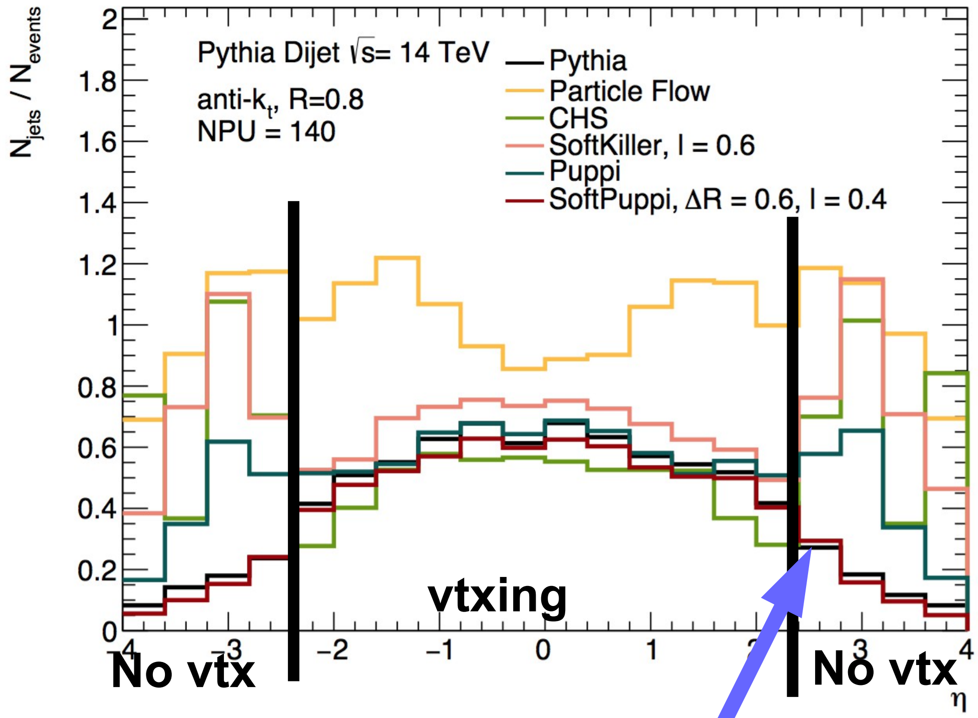
Fragmentation uses radial information

p_T uses hard scatter

Combination of the two brings most robust performance

How does this affect the shape?





- Using radial information biases jets narrow
- Using p_T information biases jets wide
- Using p_T information removes fake jets

Arxiv/Soon

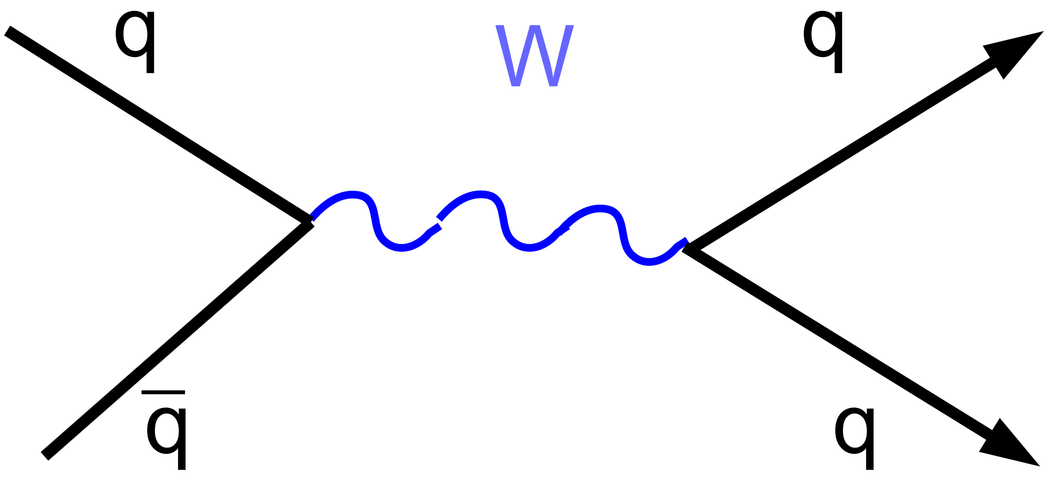
Drawing the analogy with HI

- Despite the success of pp PU(UE) removal algos
  - PP physics still has to contend with degradation
    - Not all UE removal can be performed perfectly
    - Forward region is still an active area of study
  - However impact is much smaller than in HI

- Background subtraction is still a critical issue :
  - This critical issue occurs in jet physics
  - Tools we use to resolve this issue are relevant to HI
  - Lets consider a relevant example with a lot of bkg
    - This is a measurement I would love to do in the future

The Problem

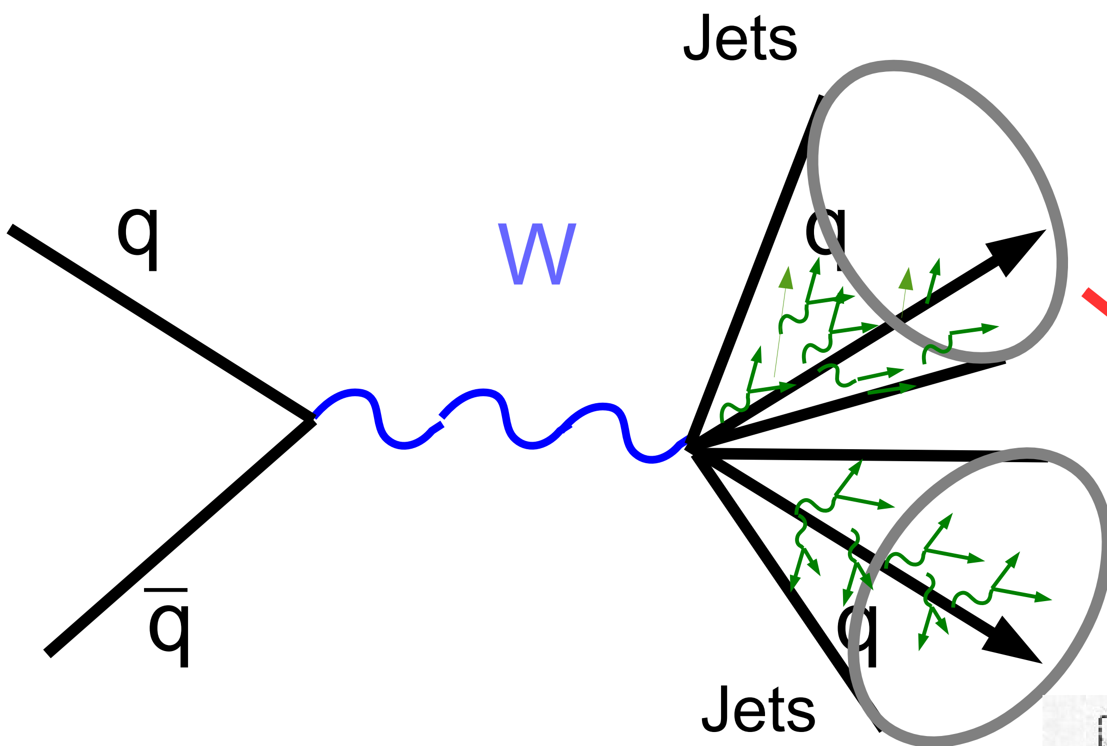
Find:



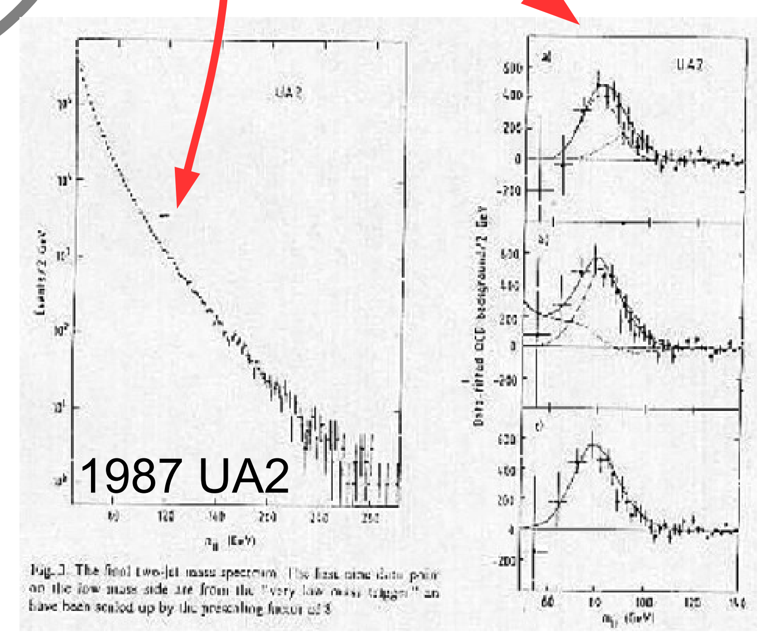
A W boson decaying to quarks

In an experiement

Find:



Resolved as a tiny bump on a huge background



A W boson decaying to quarks

A low p_T we resolve them as jets

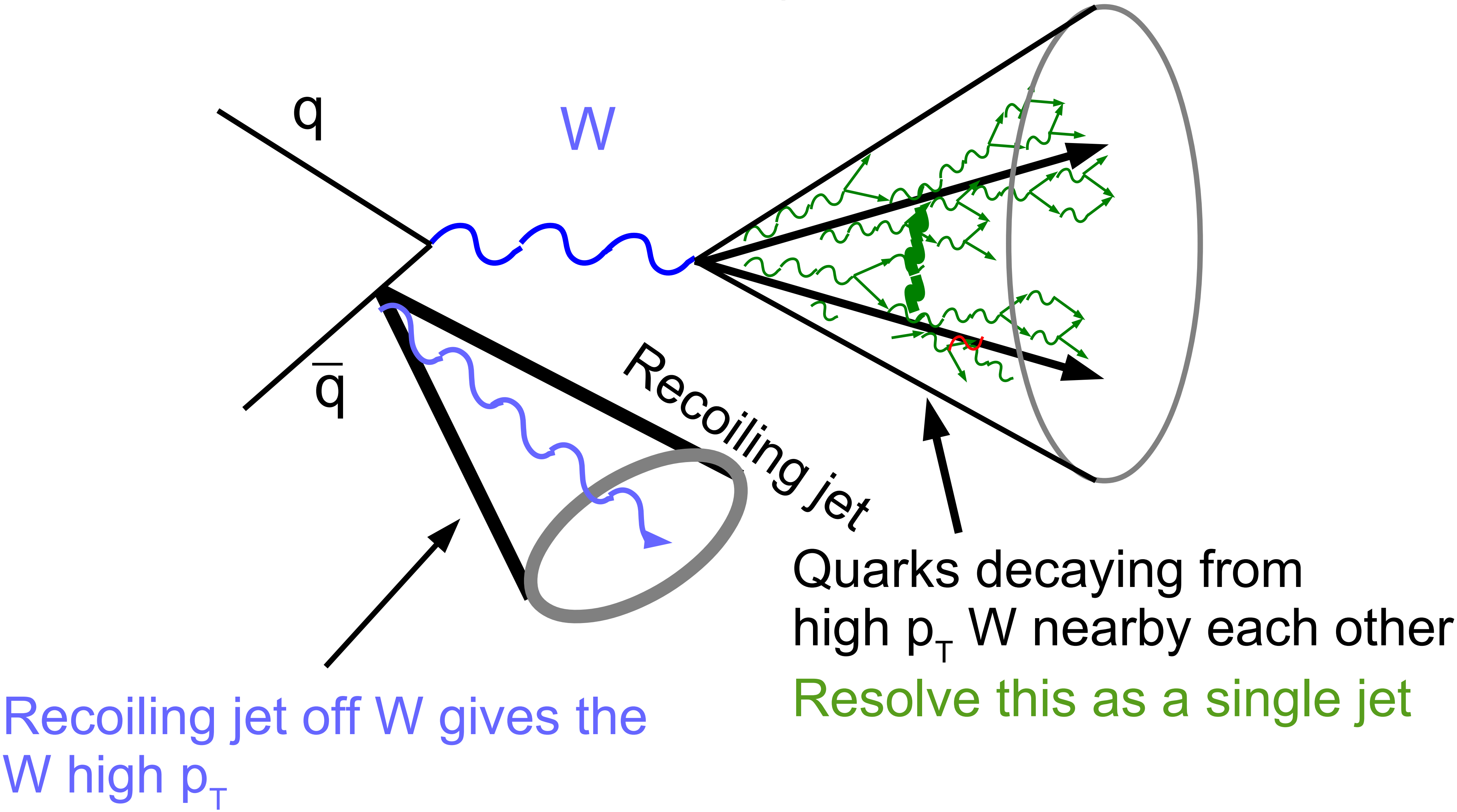
Was last observed 30 years

Result was not very convincing

Have not seen this since

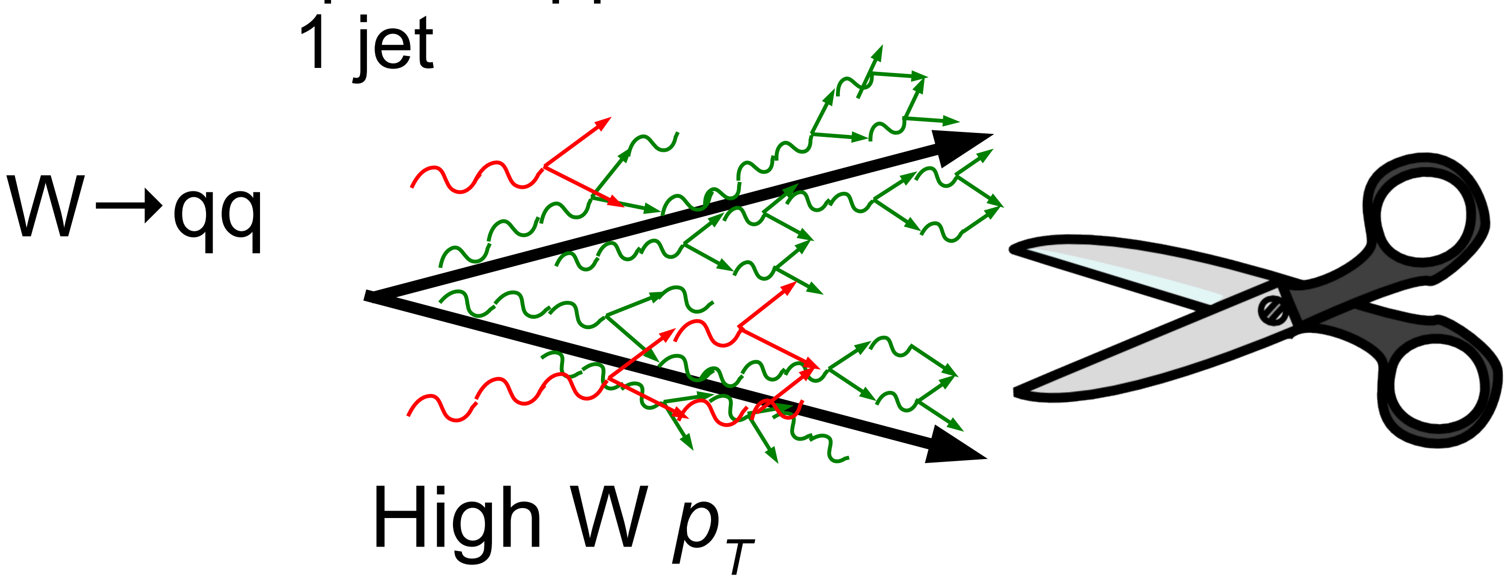
Whats the first goal?

Require W to be a high p_T



Jet grooming

- In order get a clean mass peak:
  - Adopt an approach that cleans excess radiation in a jet

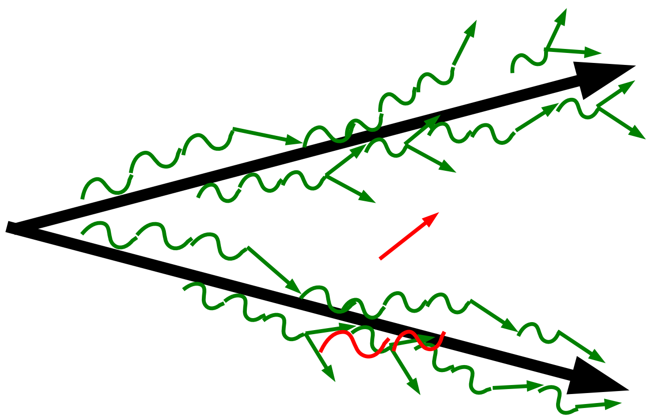


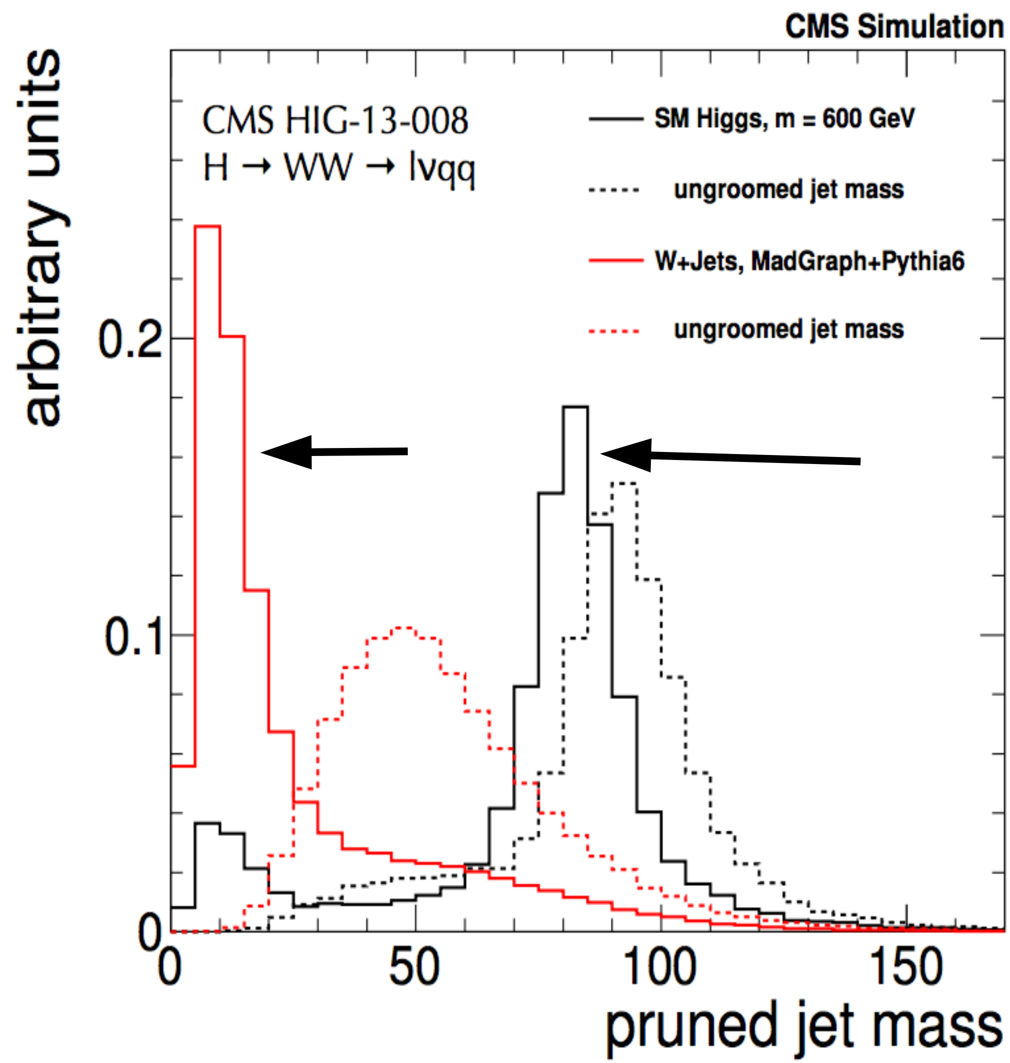
Pileup/QCD radiation

Jet grooming

- In order get a clean mass peak:
  - Adopt an approach that cleans excess radiation in a jet

W→qq





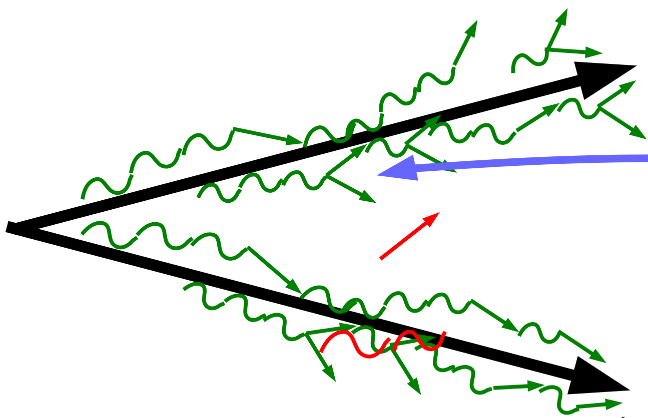
Jet grooming improves the resolution of jets

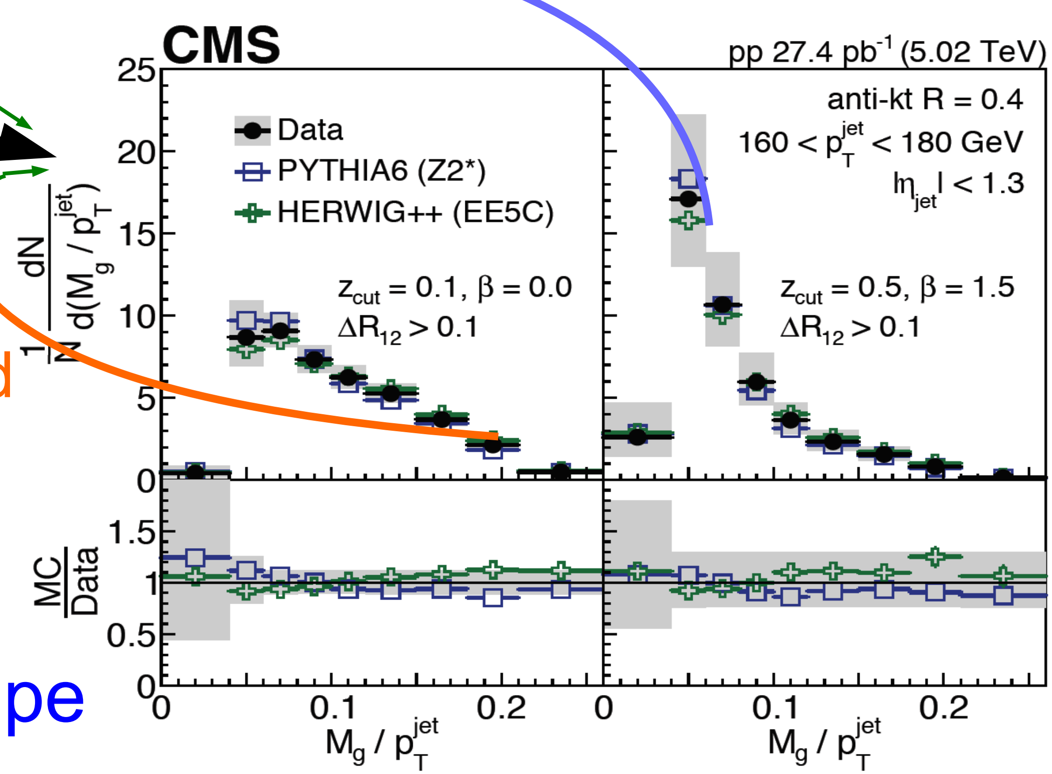
Pileup/QCD radiation

Jet grooming

- In order get a clean mass peak:
  - Adopt an approach that cleans excess radiation in a jet

W→qq

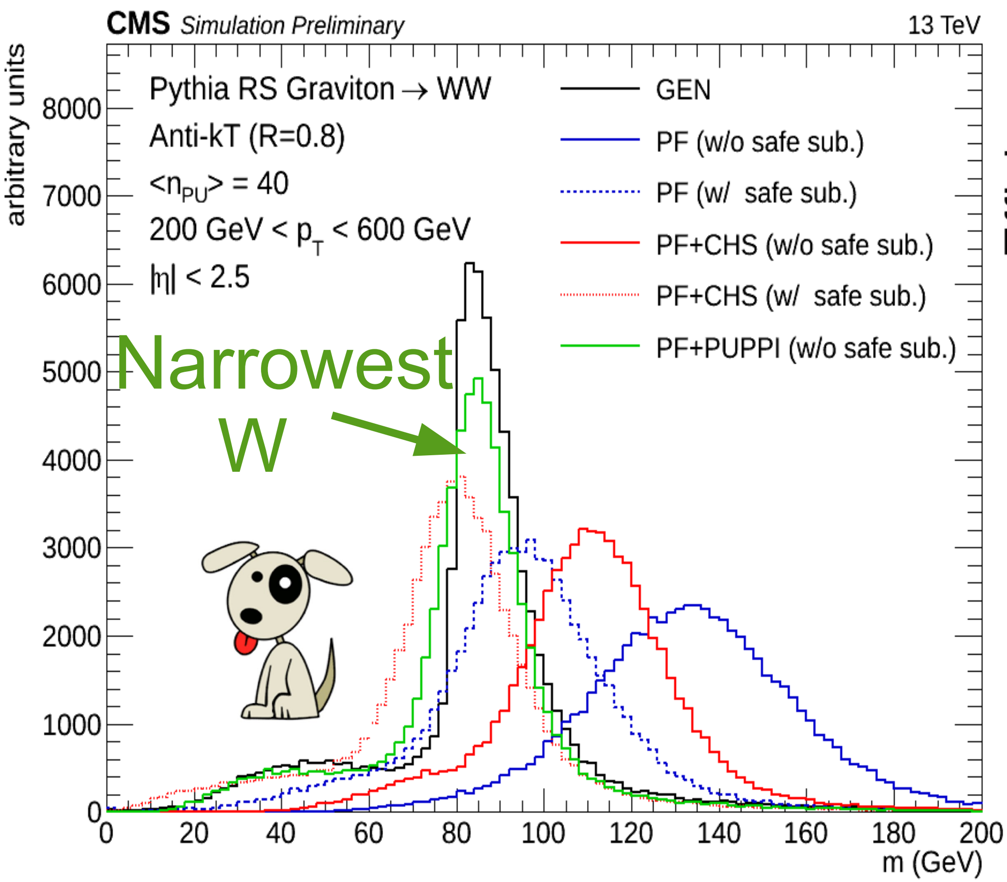


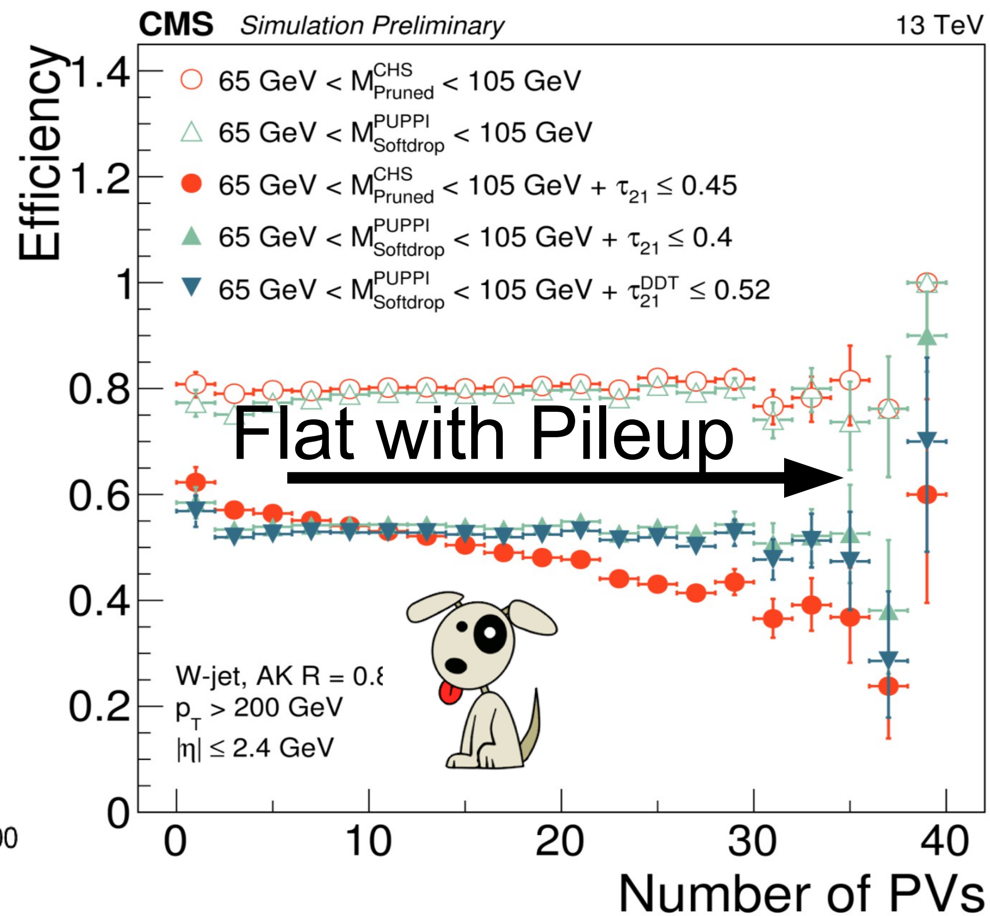


Changing the grooming
Parameter changes the shape

Additional Useful point in PP

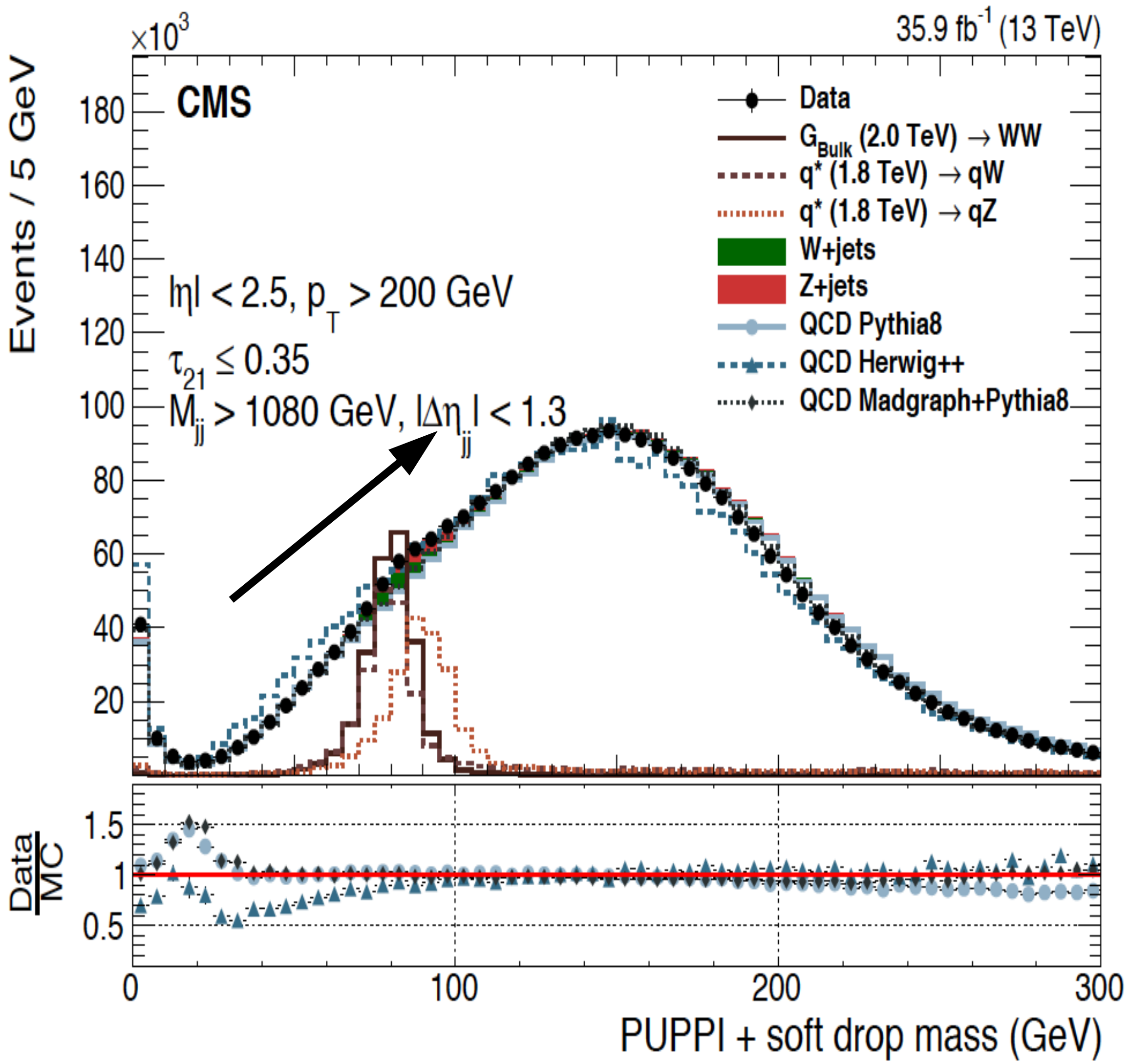
- To reduce impact of pileup on substructure
  - Utilize the PUPPI algorithm + Softdrop β=0





PUPPI gives best performance under PU conditions

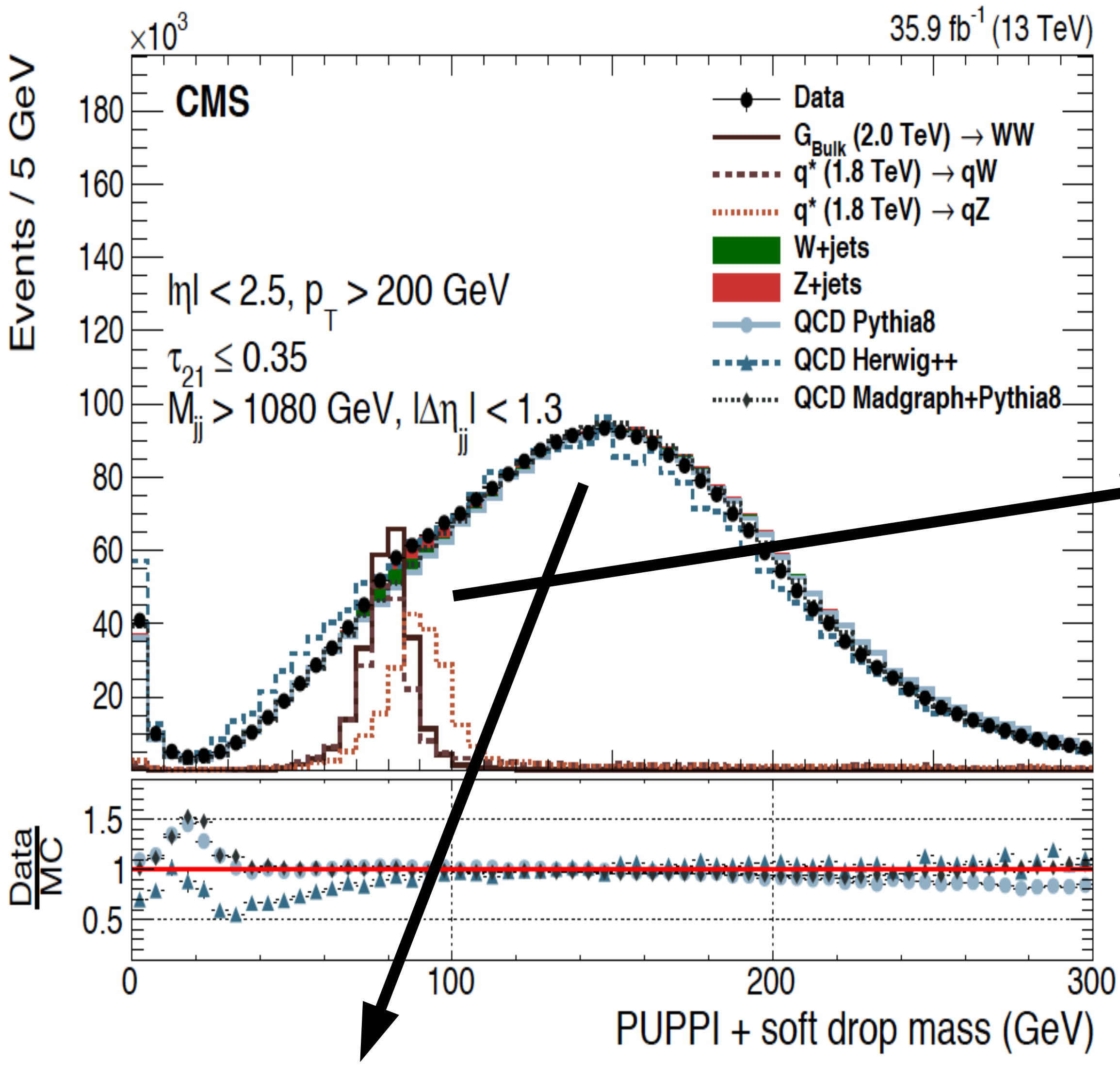
Finding the W/Z on a slope



Background is peaking after the bump

helps to improve reduce background at W

Finding the W/Z on a slope



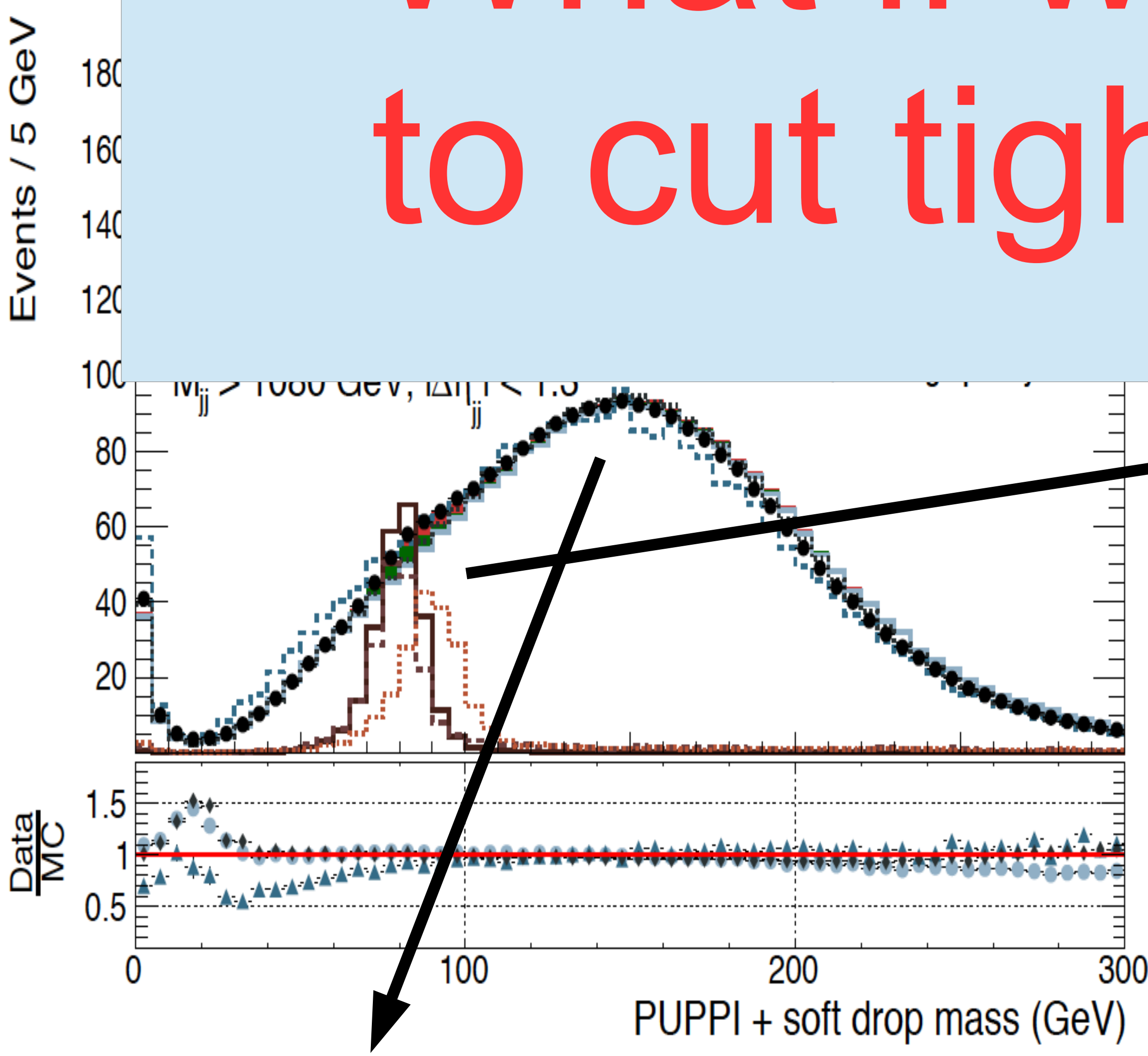
How does the upward slope impact the search for a resonance?

Background is peaking after the bump

helps to improve reduce background at W

...ope

What if we want to cut tighter?



upward slope impact the search for a resonance?

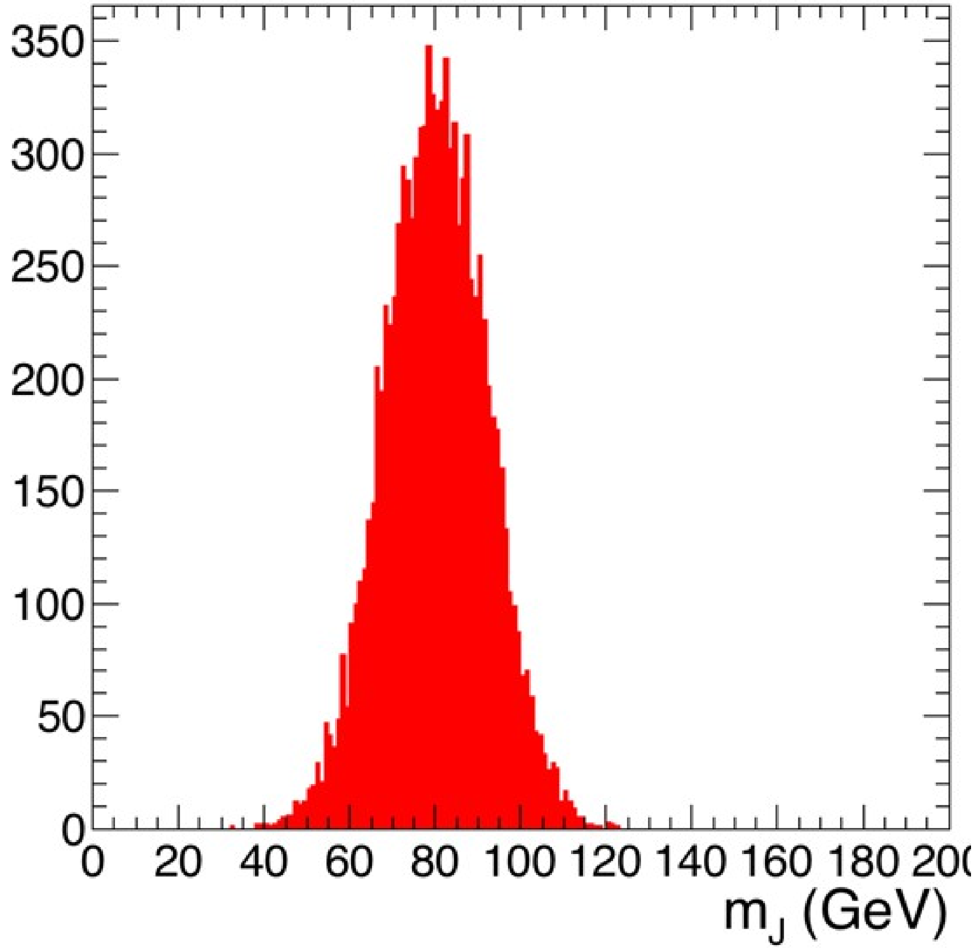
Background is peaking after the bump

helps to improve reduce background at W

A Quick Game

Lets play a game

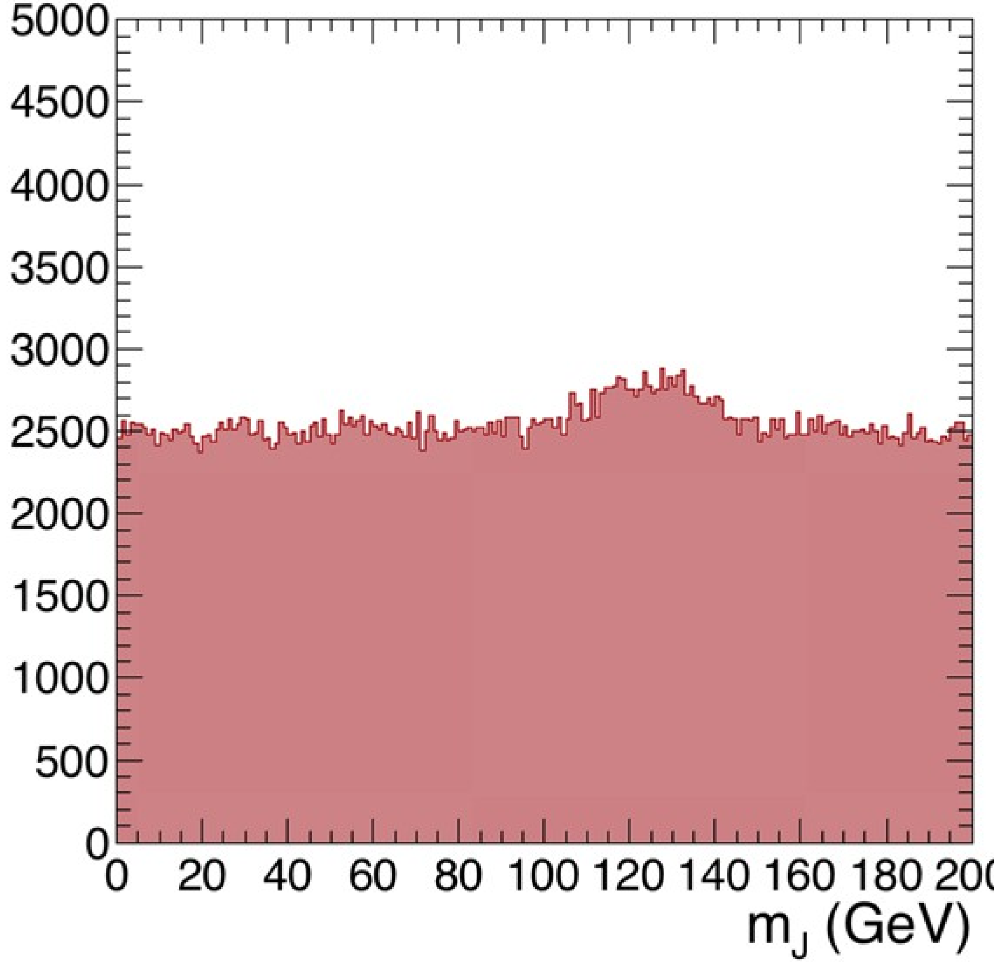
- Lets try to inject a signal likes this



Into a background 50 times larger than this
This signal looks very much like a W peak

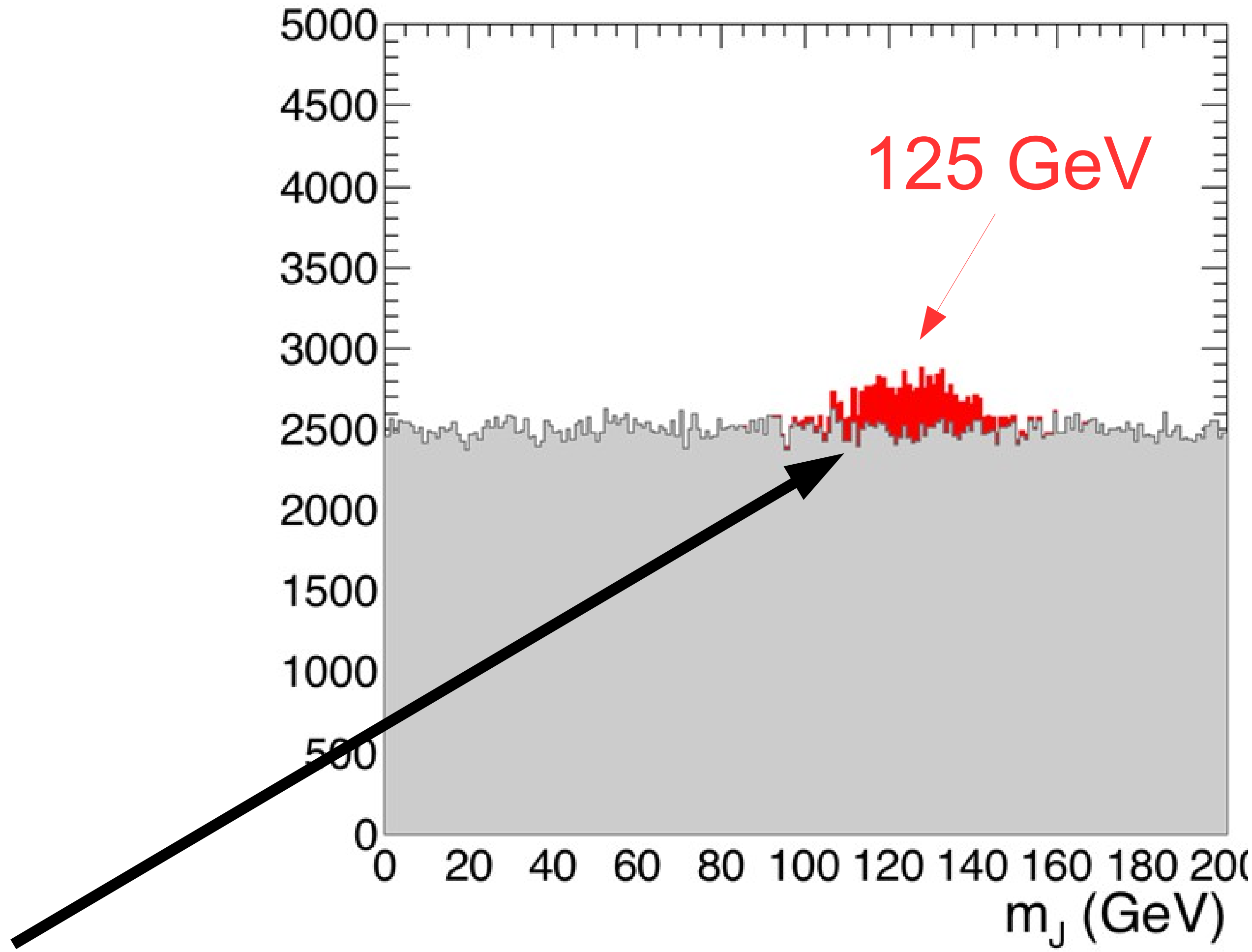
Find the signal

- Can you see the signal?



Find the signal

- Can you see the signal?

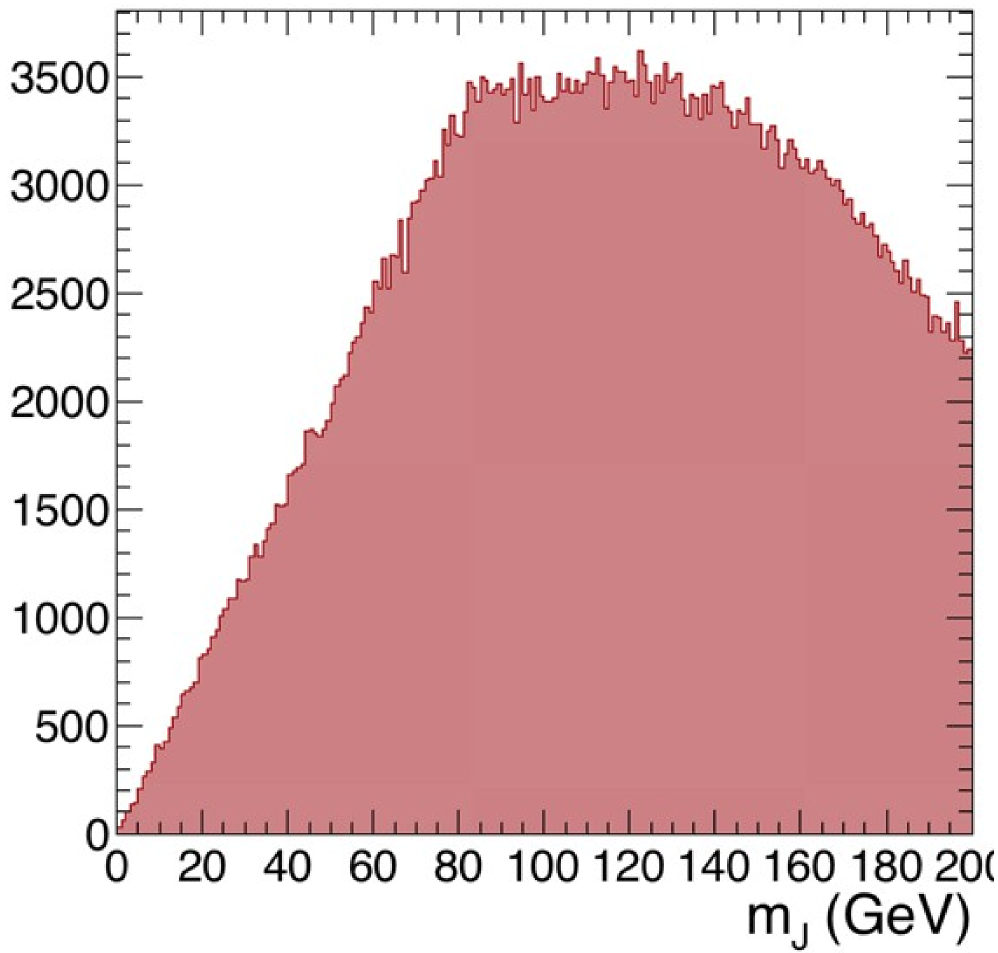


Here is the signal at 125 GeV on a flat background

That was an easy one!

Find the signal

- Can you see the signal?

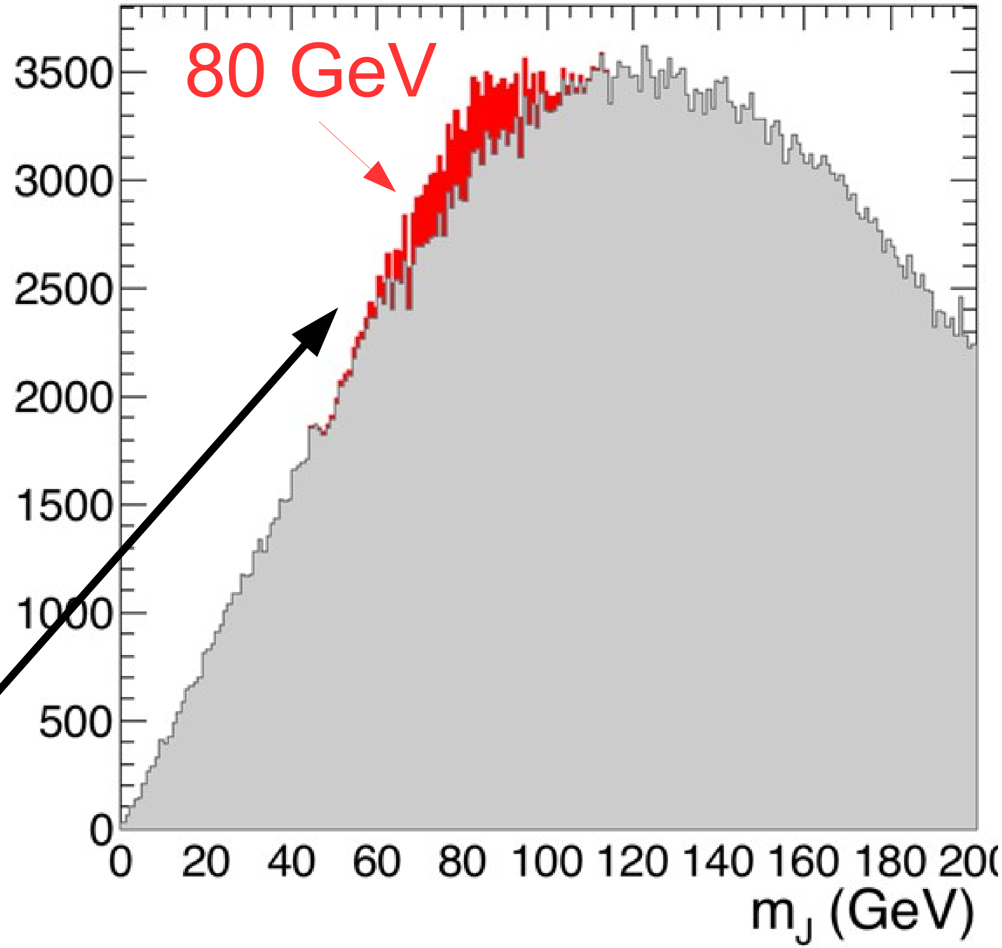


Here is the signal at 125 GeV on a flat background

Now the background peaks just after the signal

Find the signal

- Can you see the signal?

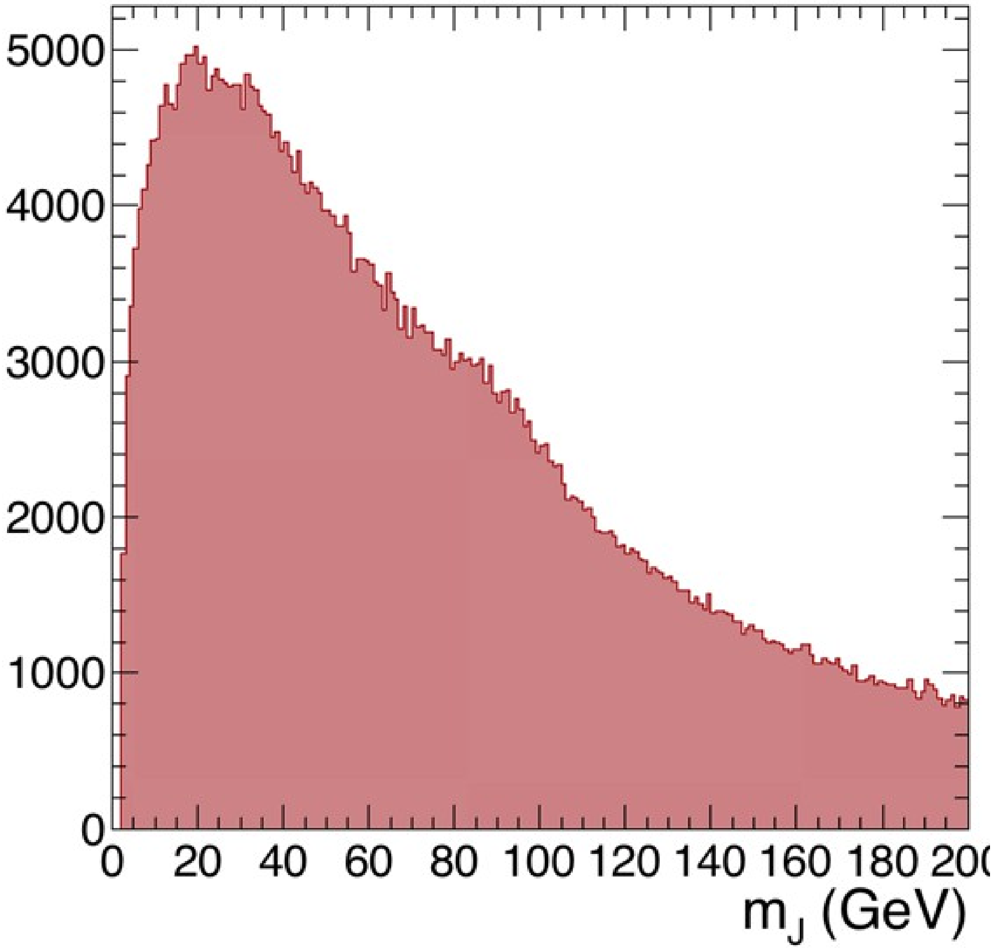


Here it is. This one is a bit harder.

Note exact same amount of background and signal

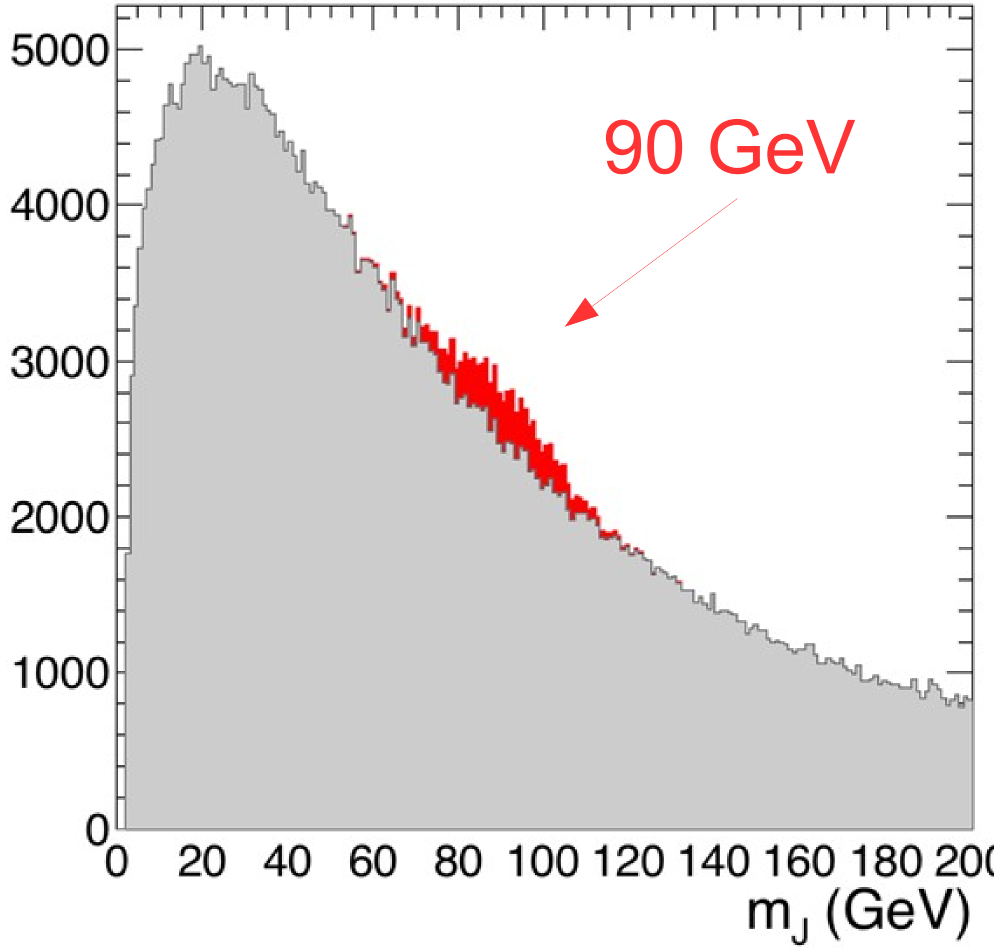
How about now?

- Can you see the signal?



How about now?

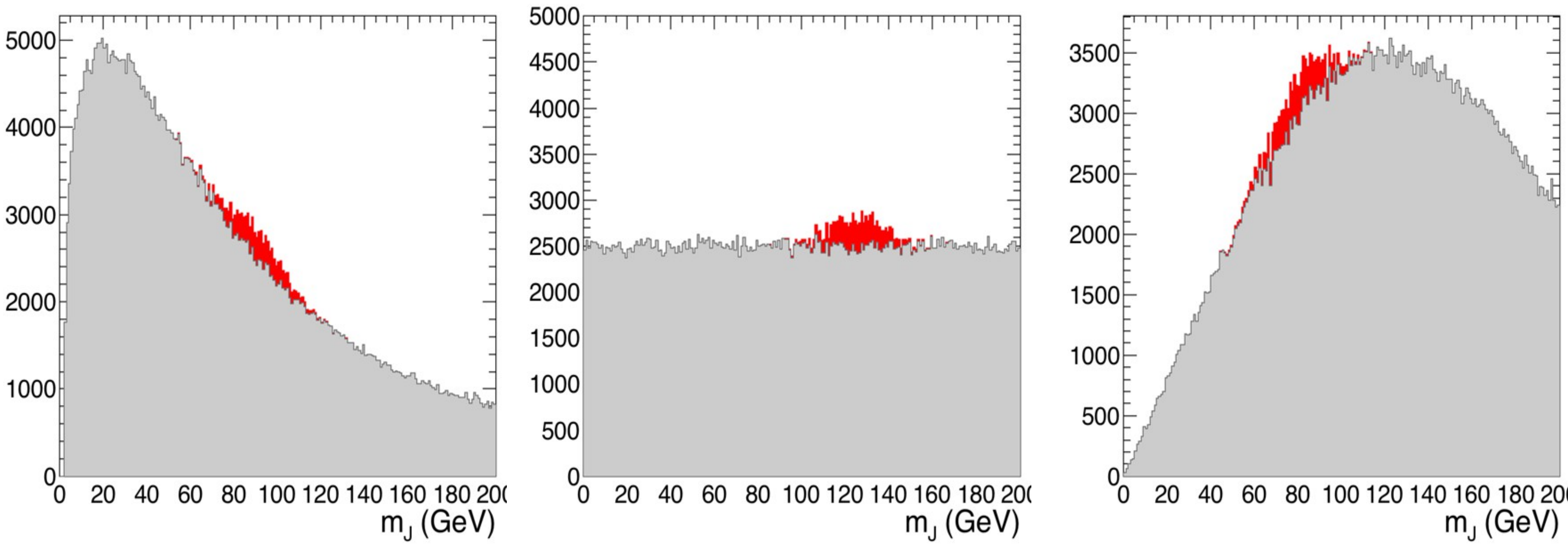
- Can you see the signal?



Background

Note exact same amount of background and signal

Whats best background?



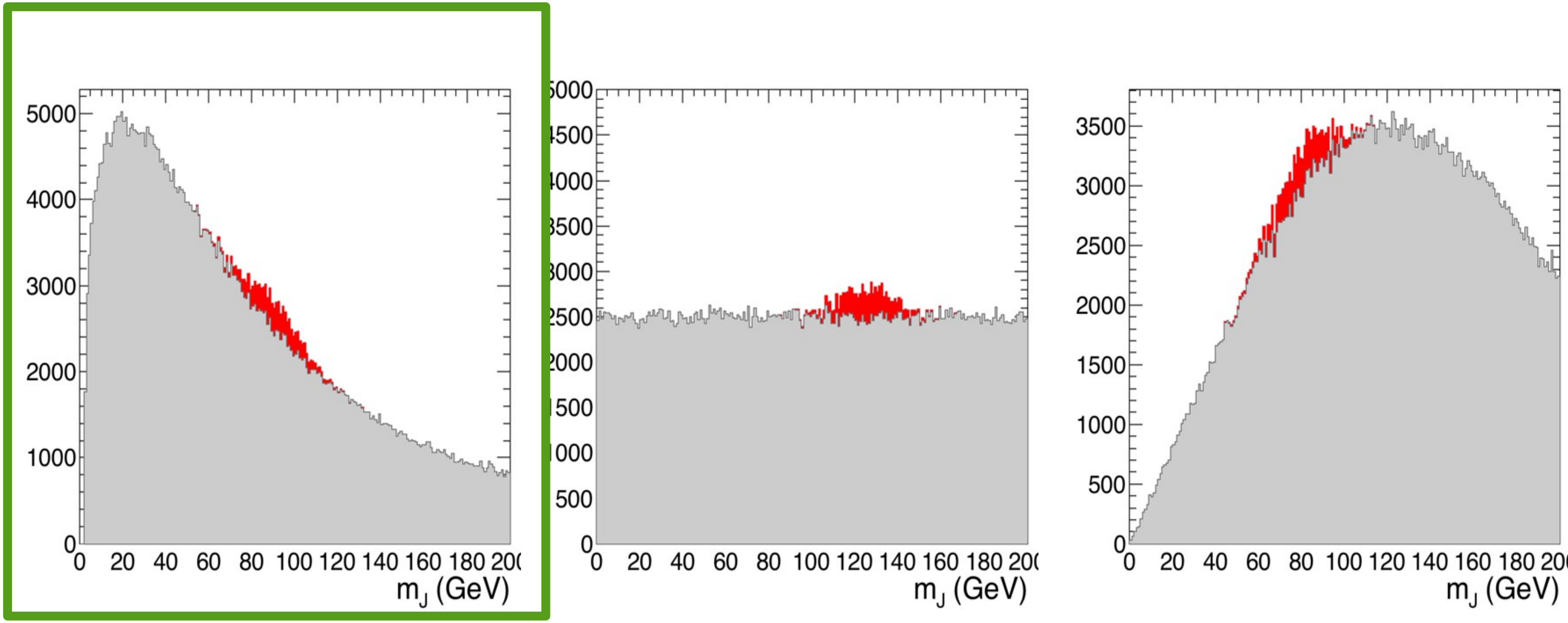
All variables yield roughly the same performance

- Exactly the same background yield
- Exactly the same signal yield

What if we could tune background shape to what we want?

What would be our best choice of shape?

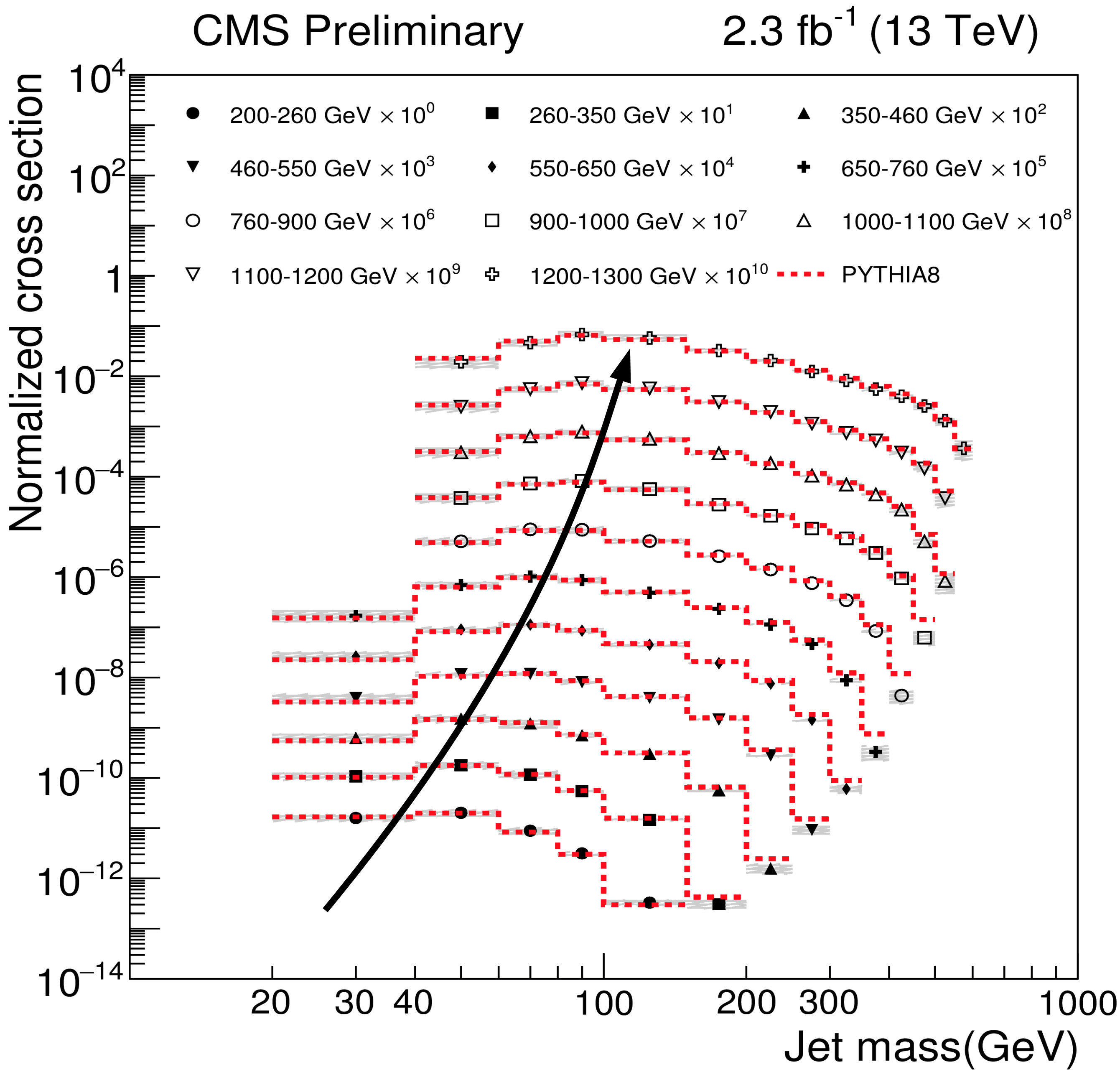
Whats best background?



This one

Evolution of Mass Peak

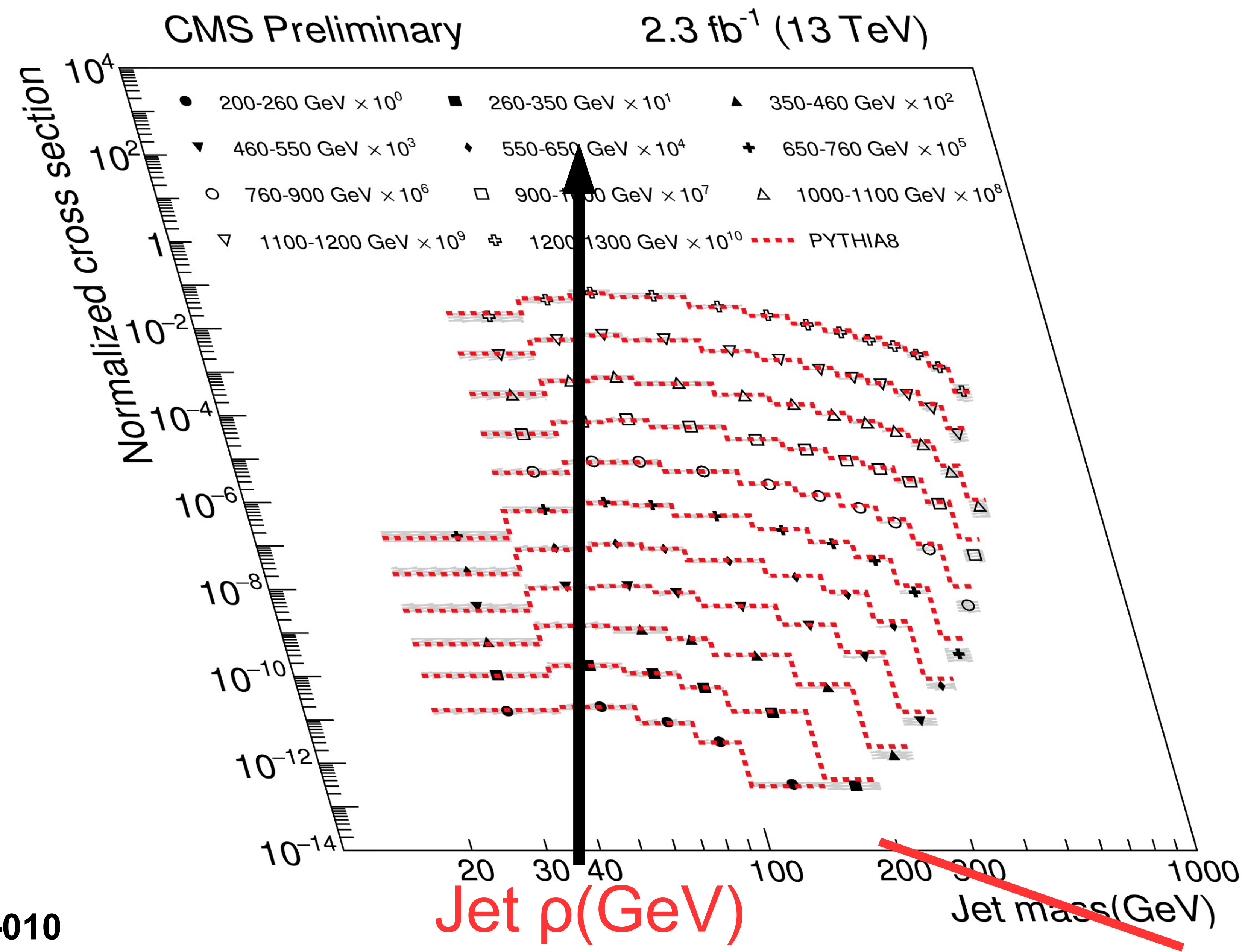
Clear trend in observed mass



CMS-SMP-16-010

Evolution of Mass Peak

Use QCD to got to modified
Jet phase space



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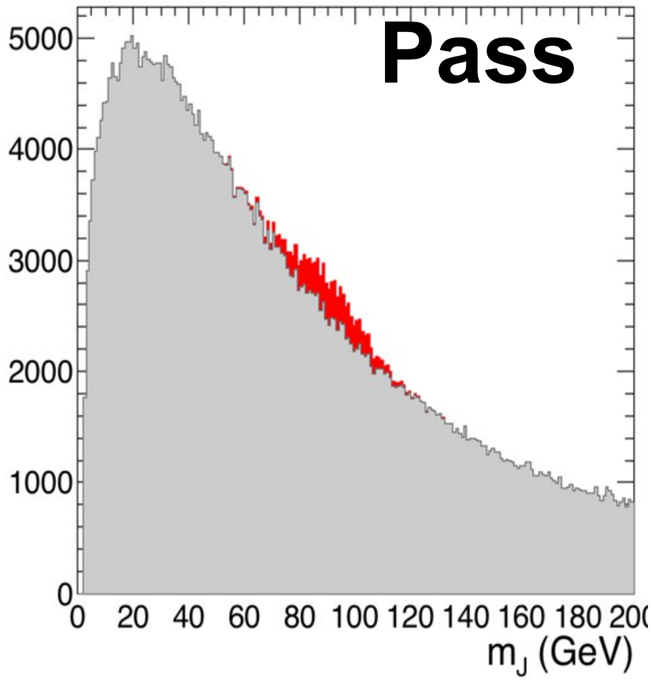
One last ingredient

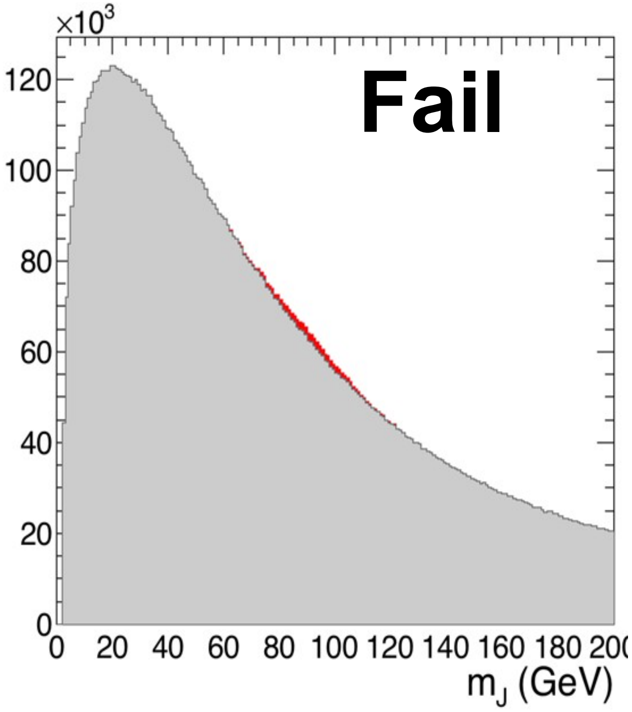
- Cutting on a variable gives us another advantage

A < Cut



Rich in signal

A > Cut



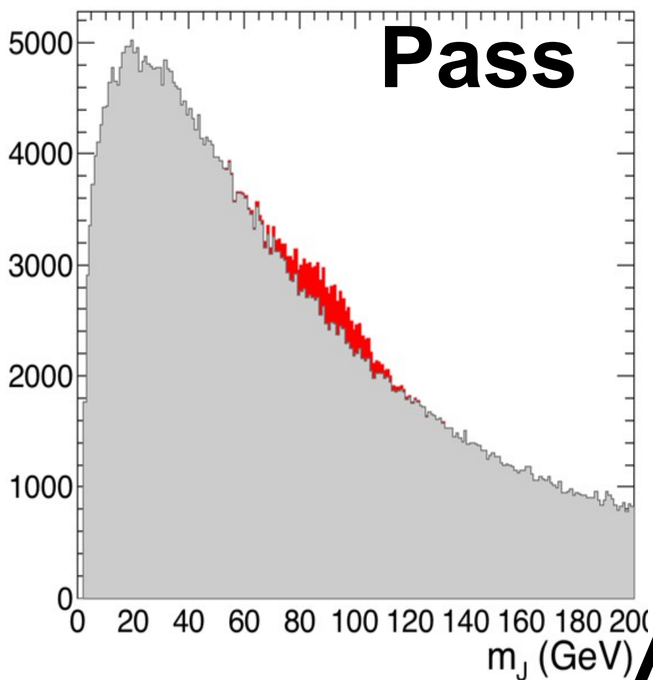
Poor in signal

We get two regions that we can study

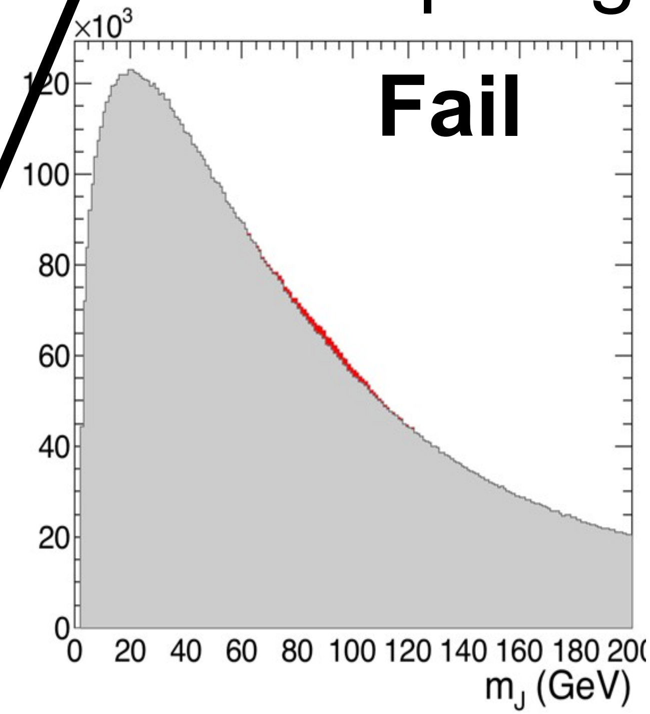
One last ingredient

- Cutting on a variable gives us another advantage

A > 2-pronginess



A < 2-pronginess



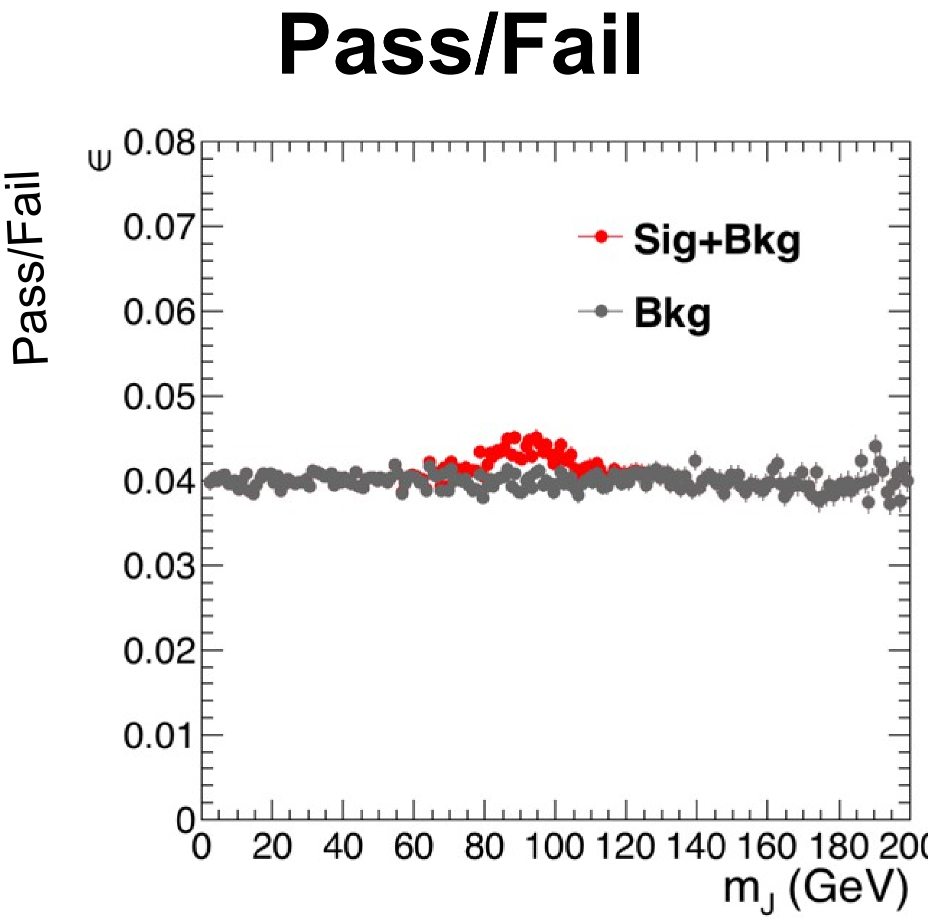
Rich in signal

Poor in signal

We can merge these regions into one

Pass/Fail Ratio

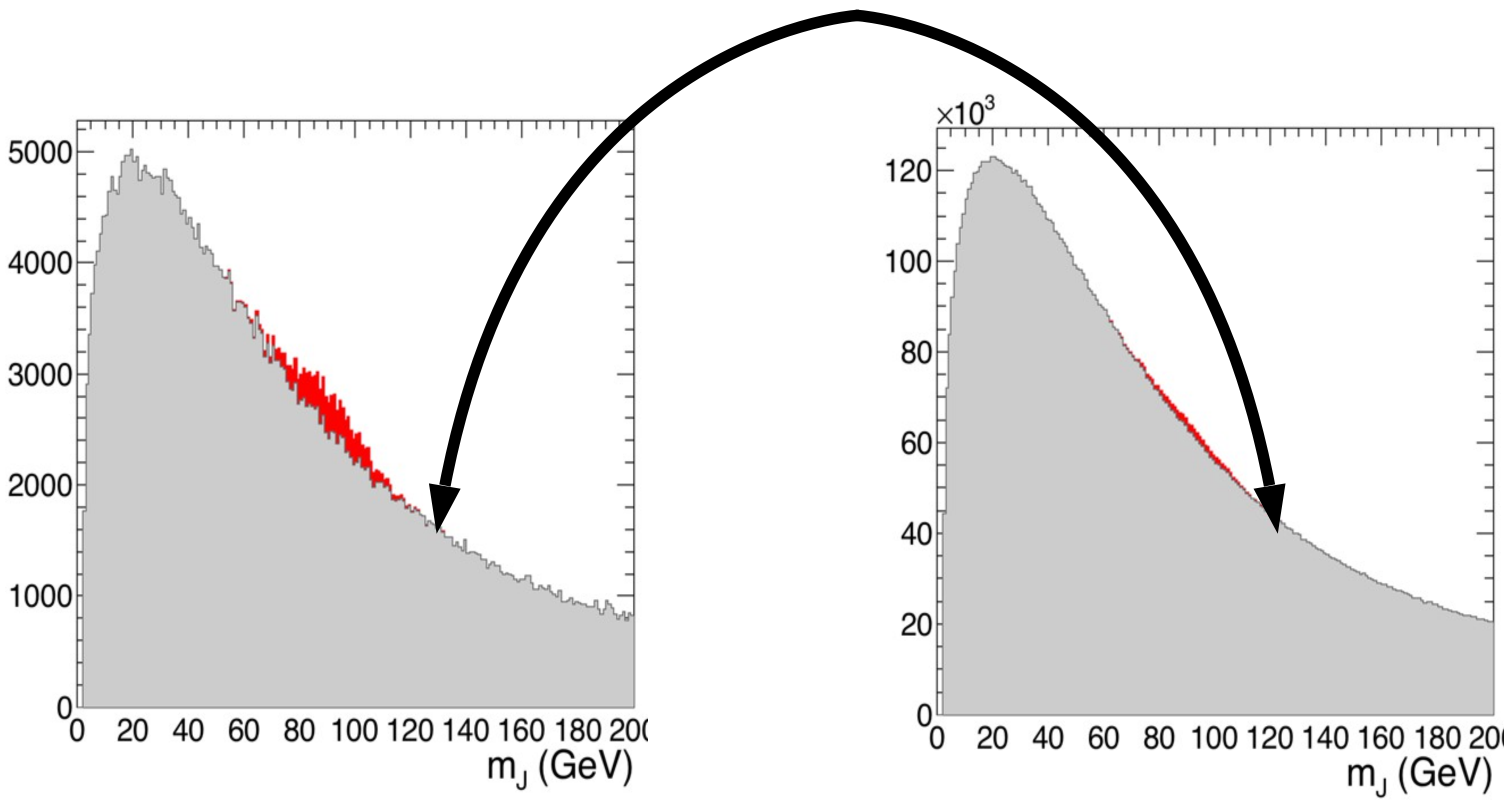
- Combination of the two yield a single distribution



This gives us a new combined region

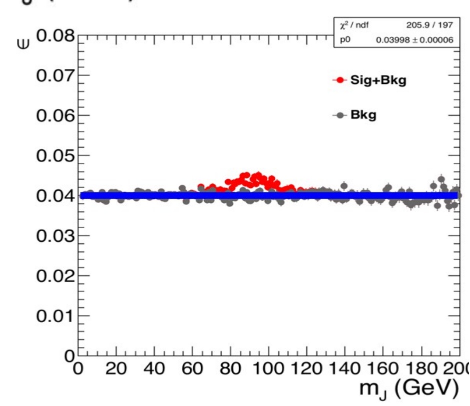
How do you fit the ratio

- Fit both distributions at the same time



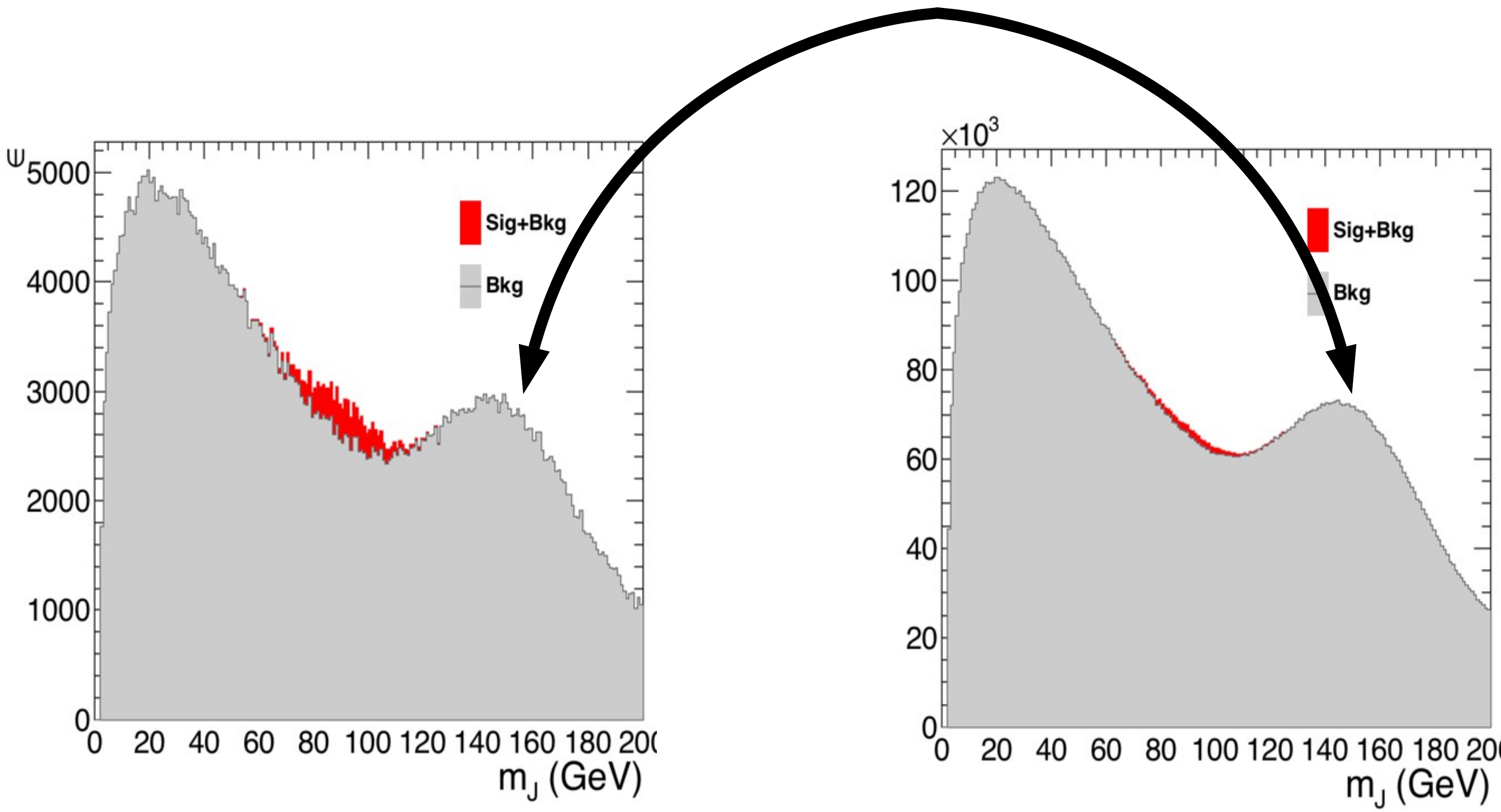
Tie bin in passing to bin in failing

$\text{Bin}^i_{\text{Pass}} = \varepsilon\ \text{Bin}^i_{\text{Fail}}$



How do you fit the ratio

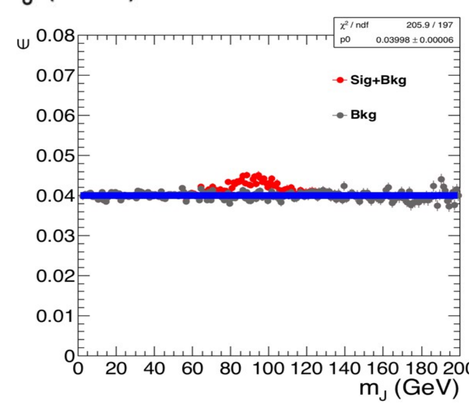
- Fit both distributions at the same time



If one bin moves up the other moves up

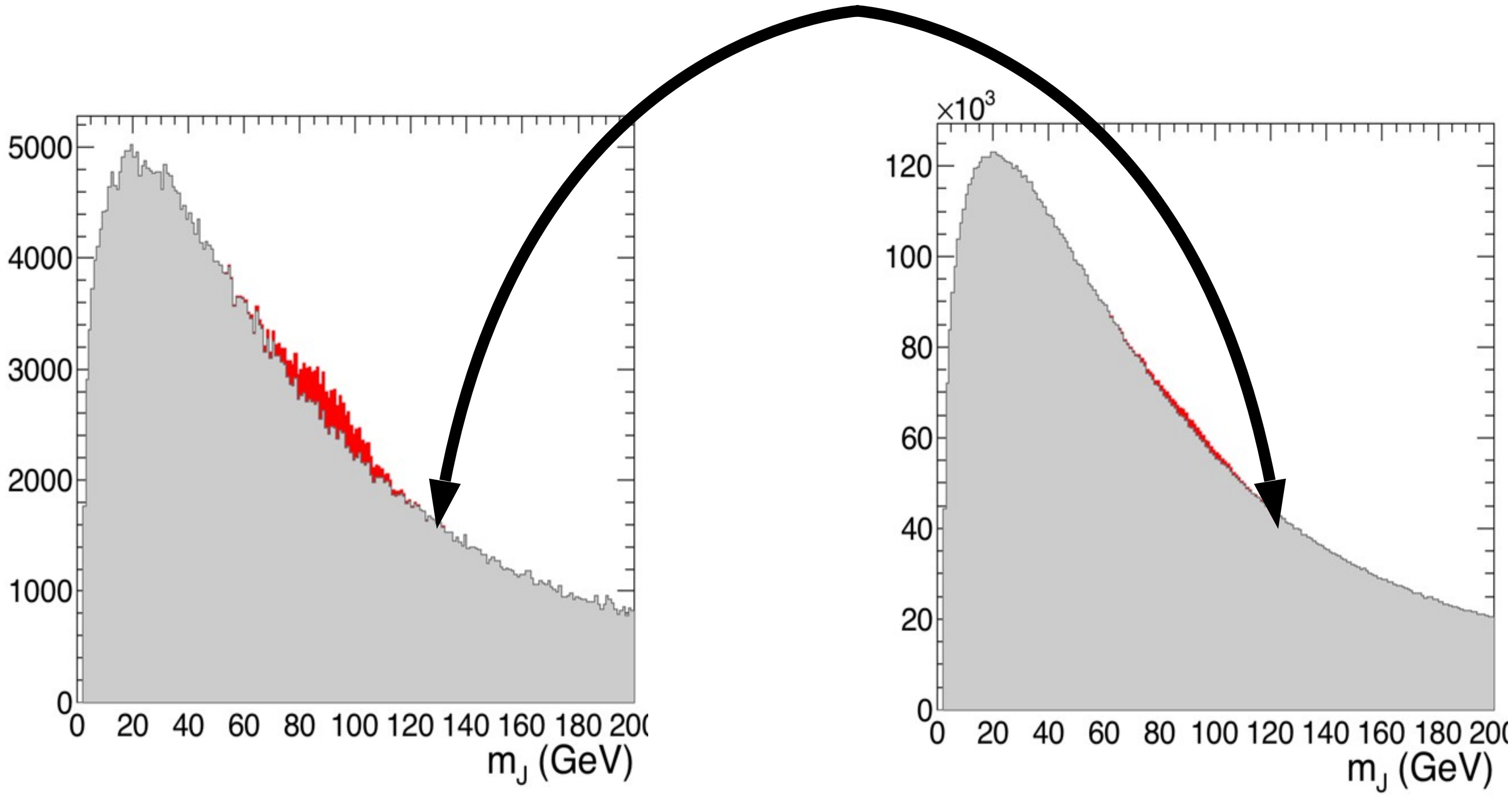
Even for weird shapes we fit a flat eff

$Bin^{i}_{Pass} = \varepsilon \, Bin^{i}_{Fail}$

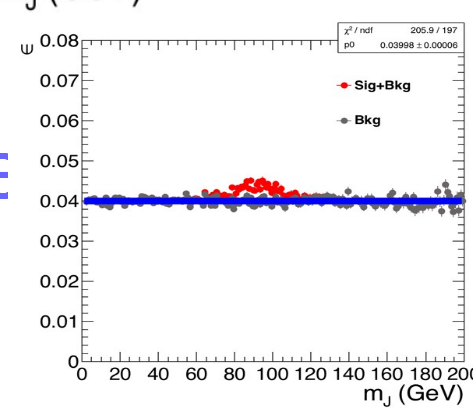


Forcing the ratio flat

- With a large MC sample we can make this flaot

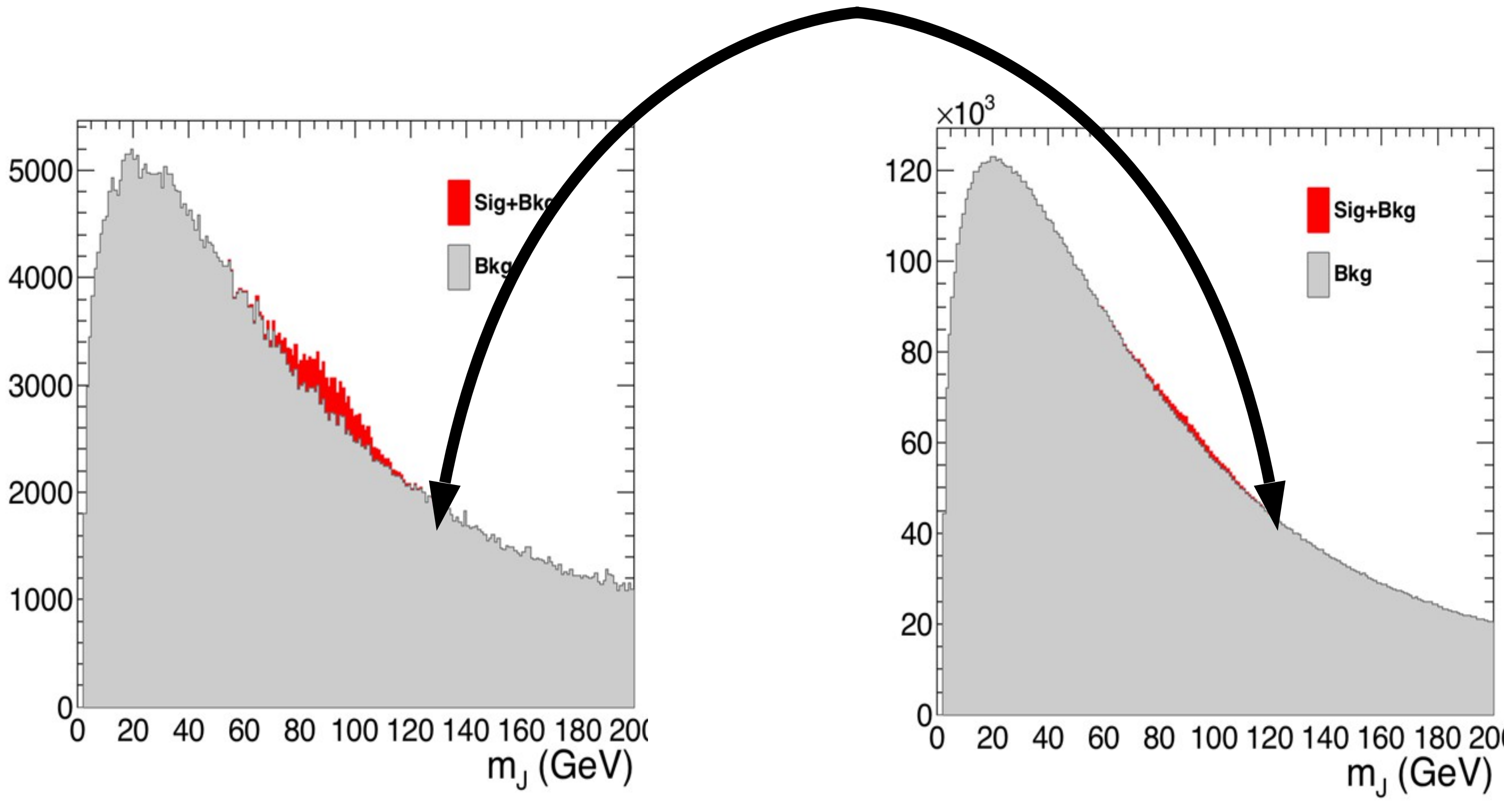


Can construct a substructure observable to have a flat efficiency over mass



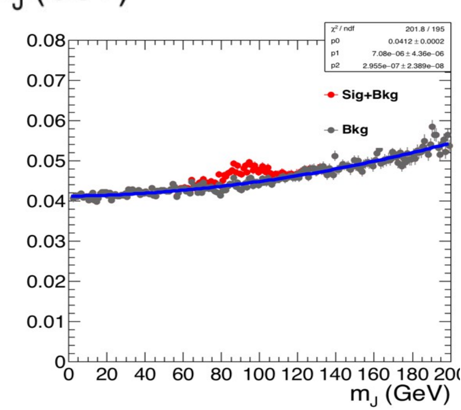
In data

- We can tune the efficiency to be flat in MC



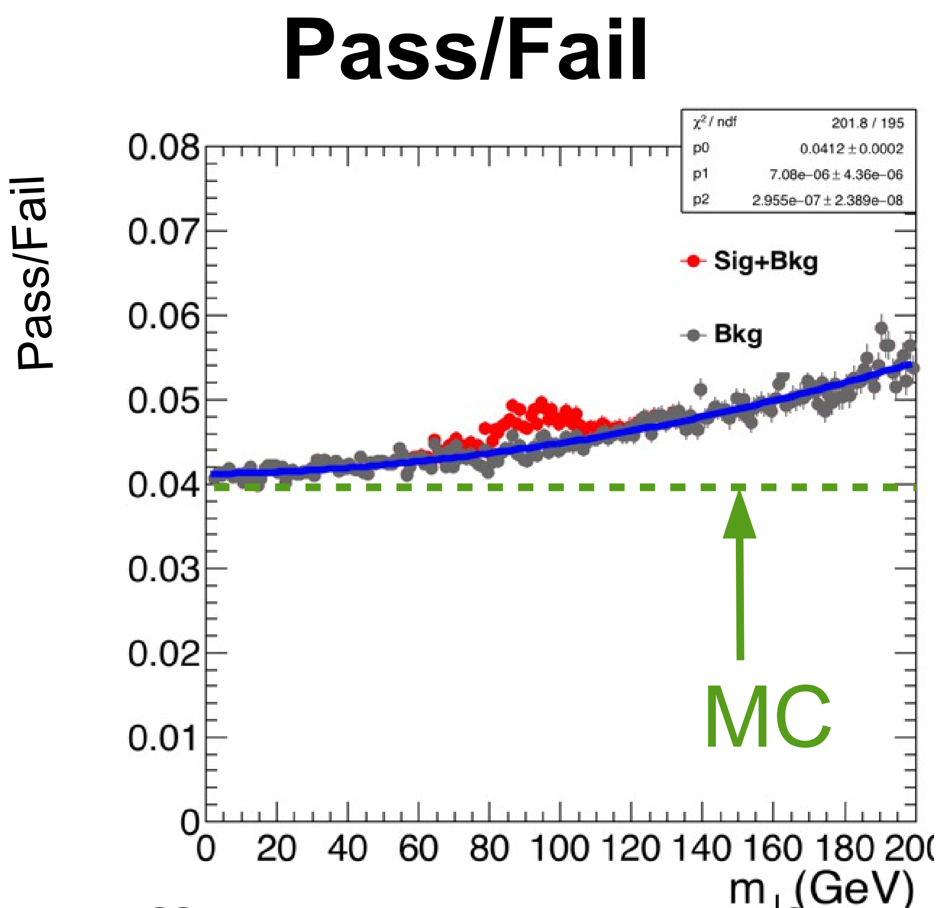
However in data it might not be flat

We can fit for this deviation over mass



Pass/Fail Ratio

- Parametrize data/MC deviations with function

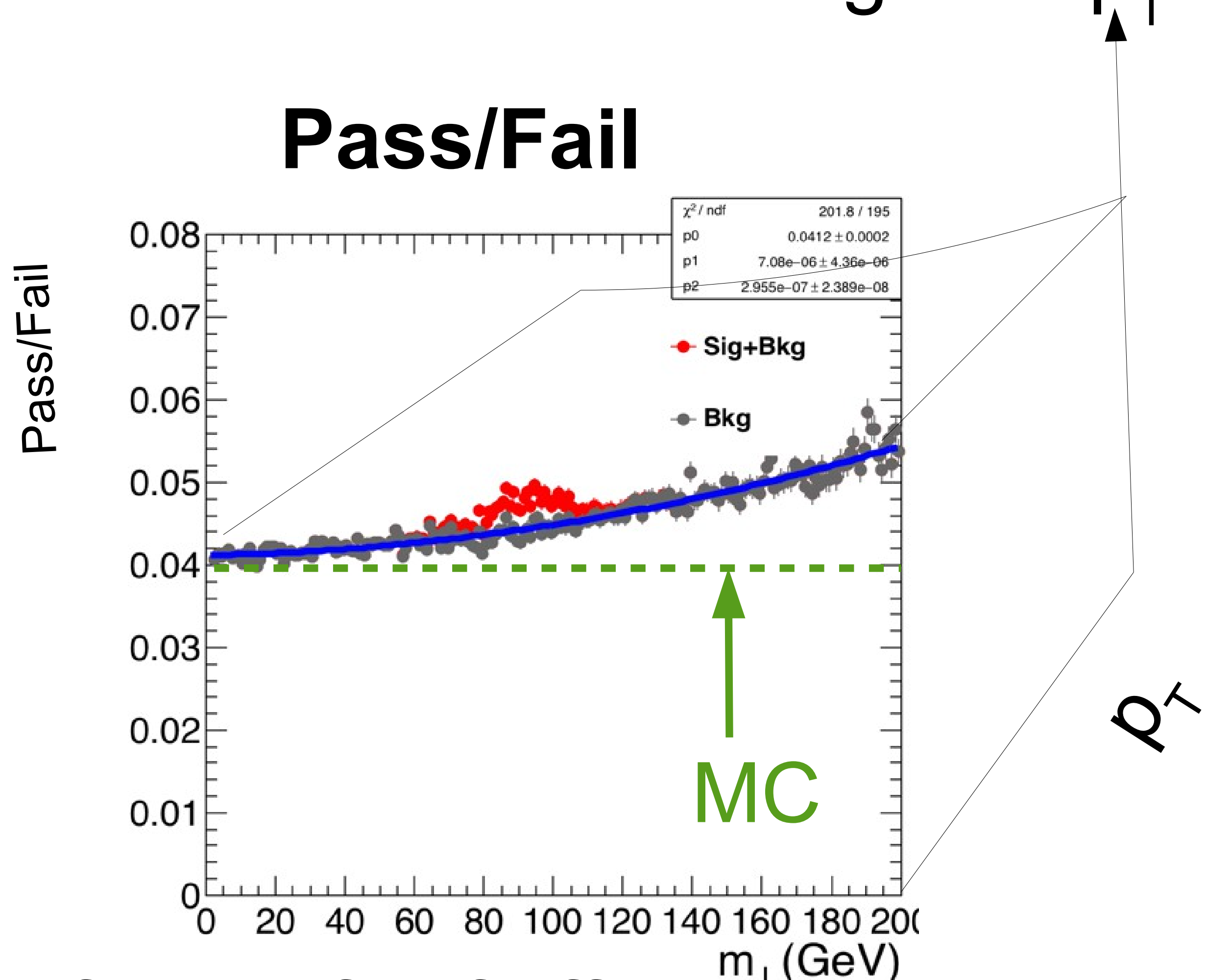


Parametrize efficiency by a surface in ρ and p_T

$$N^{QCD}_{pass}(m_{SD}, p_T) = R_{p/f}(\rho, p_T) \times N^{QCD}_{fail}(m_{SD}, p_T)$$

Pass/Fail Ratio

- Perform fit in 3 dimensional fit against p_T



Final fit is a full 3D fit of efficiency ρ vs p_T

$$N^{QCD}_{pass}(m_{SD}, p_T) = R_{p/f}(\rho, p_T) \times N^{QCD}_{fail}(m_{SD}, p_T)$$

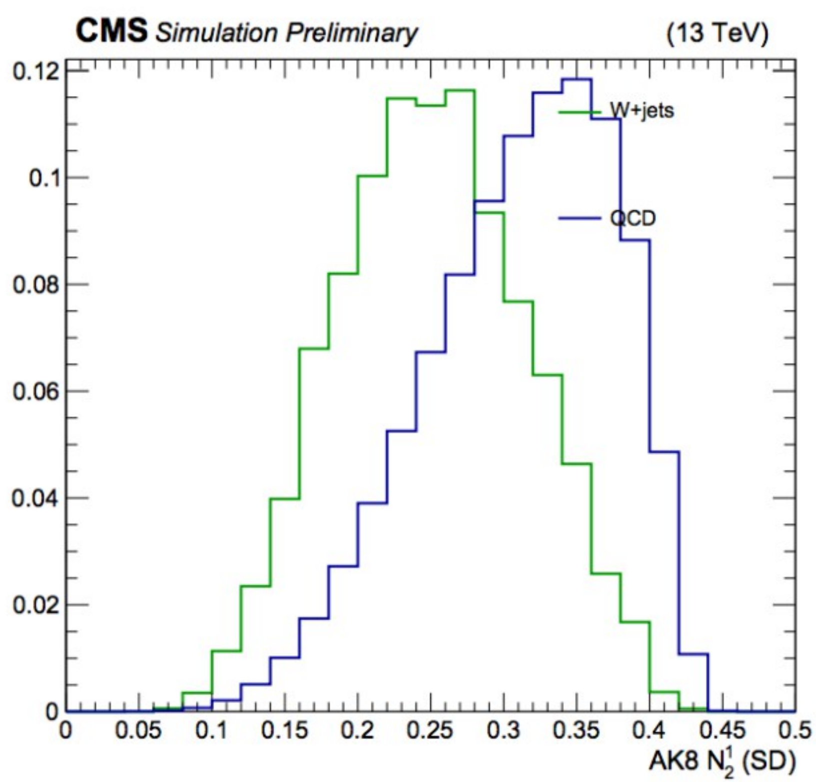
New Substructure Observables

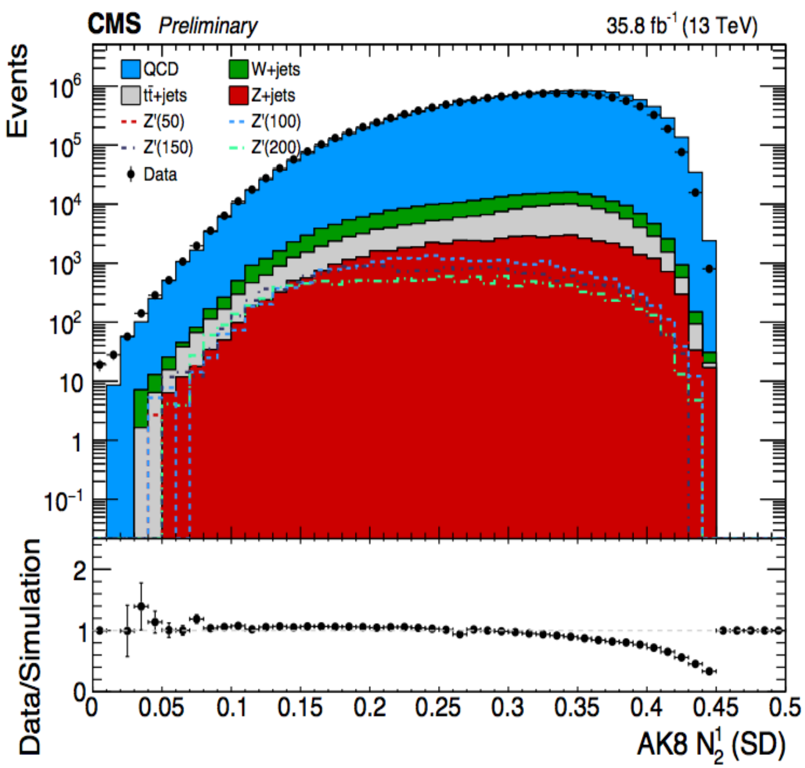
$$N_2(\beta) = \frac{{}_2e_3^\beta}{(e_2^\beta)^2}$$

$${}_1e_2^\beta = e_2^\beta = \sum_{1\le i<j\le n_J} z_i z_j \Delta R_{ij}^\beta \qquad z_i \equiv \frac{p_{Ti}}{\sum_{j\in \text{jet}} p_{Tj}}$$

$${}_2e_3^\beta = \sum_{1\le i<j<k\le n_J} z_i z_j z_k \min\{\Delta R_{ij}^\beta \Delta R_{ik}^\beta, \Delta R_{ij}^\beta \Delta R_{jk}^\beta, \Delta R_{ik}^\beta \Delta R_{jk}^\beta\}$$

Using AK8 PUPPI jets

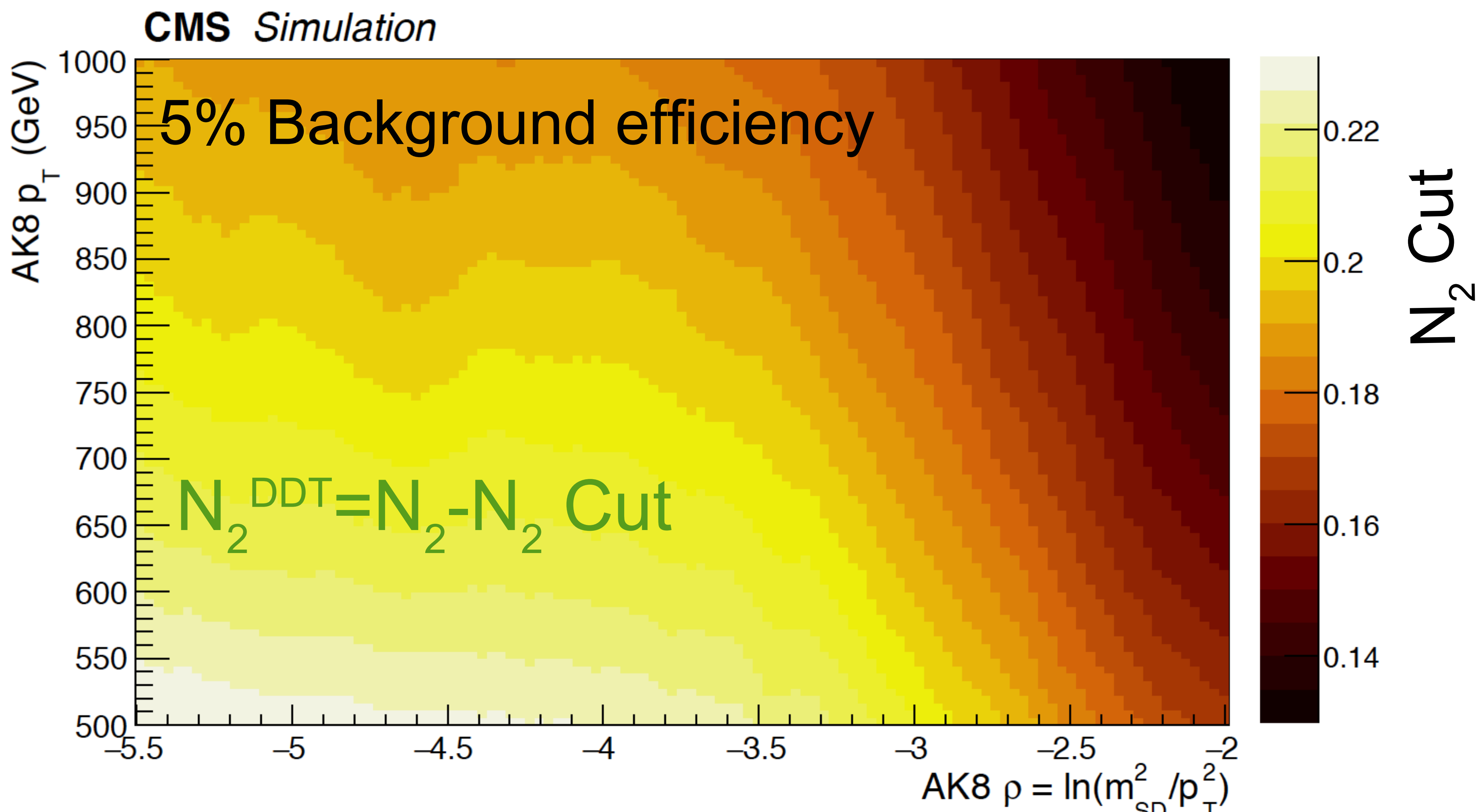




Arxiv/1609.07483

We use N_2 to see the W peak

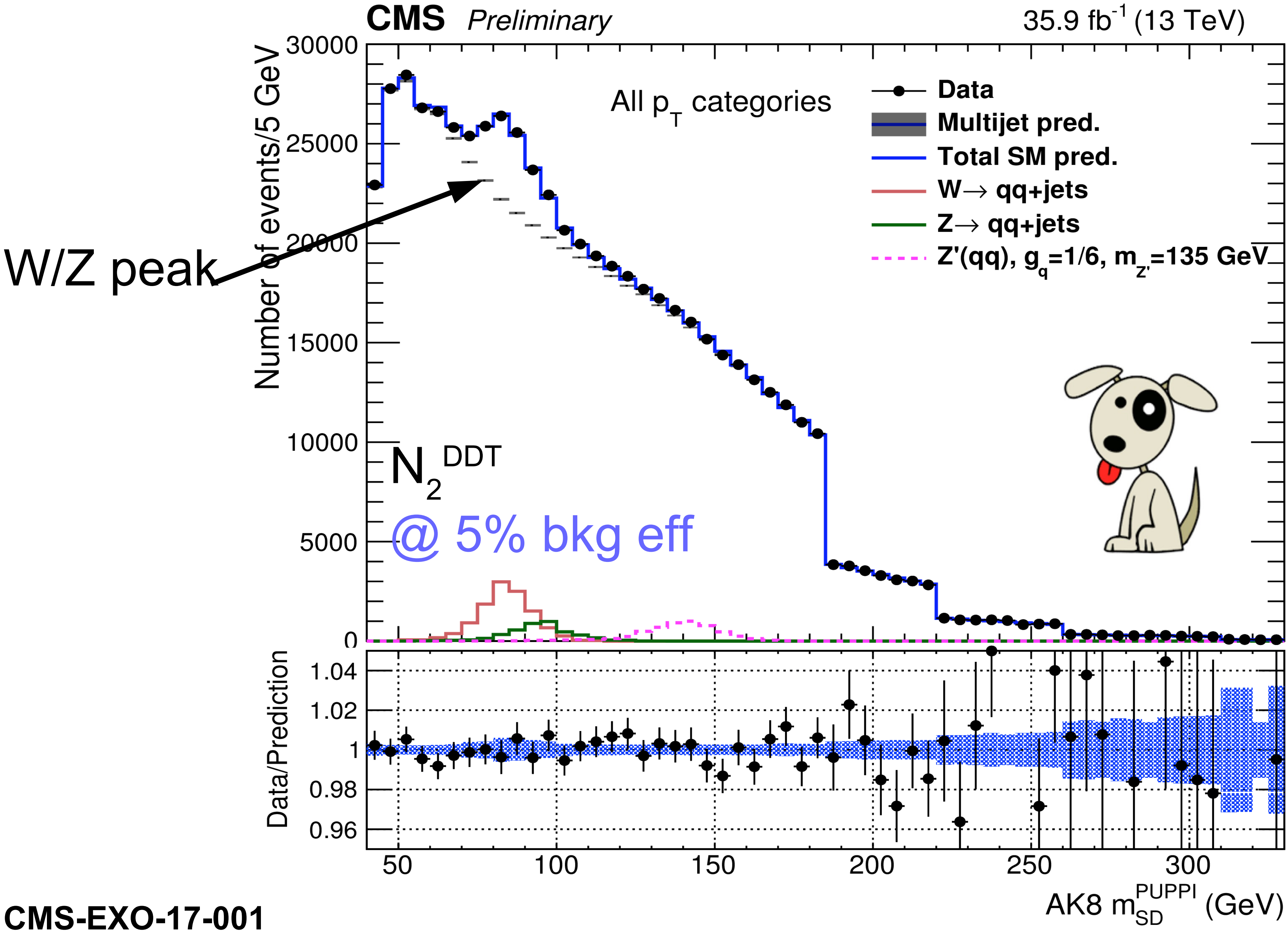
Modifty N_2 to have a flat bkg efficiency



Use the k-Nearest Neighbor approach to determine N_2 cut

EXO-17-001

Two pronged Jets



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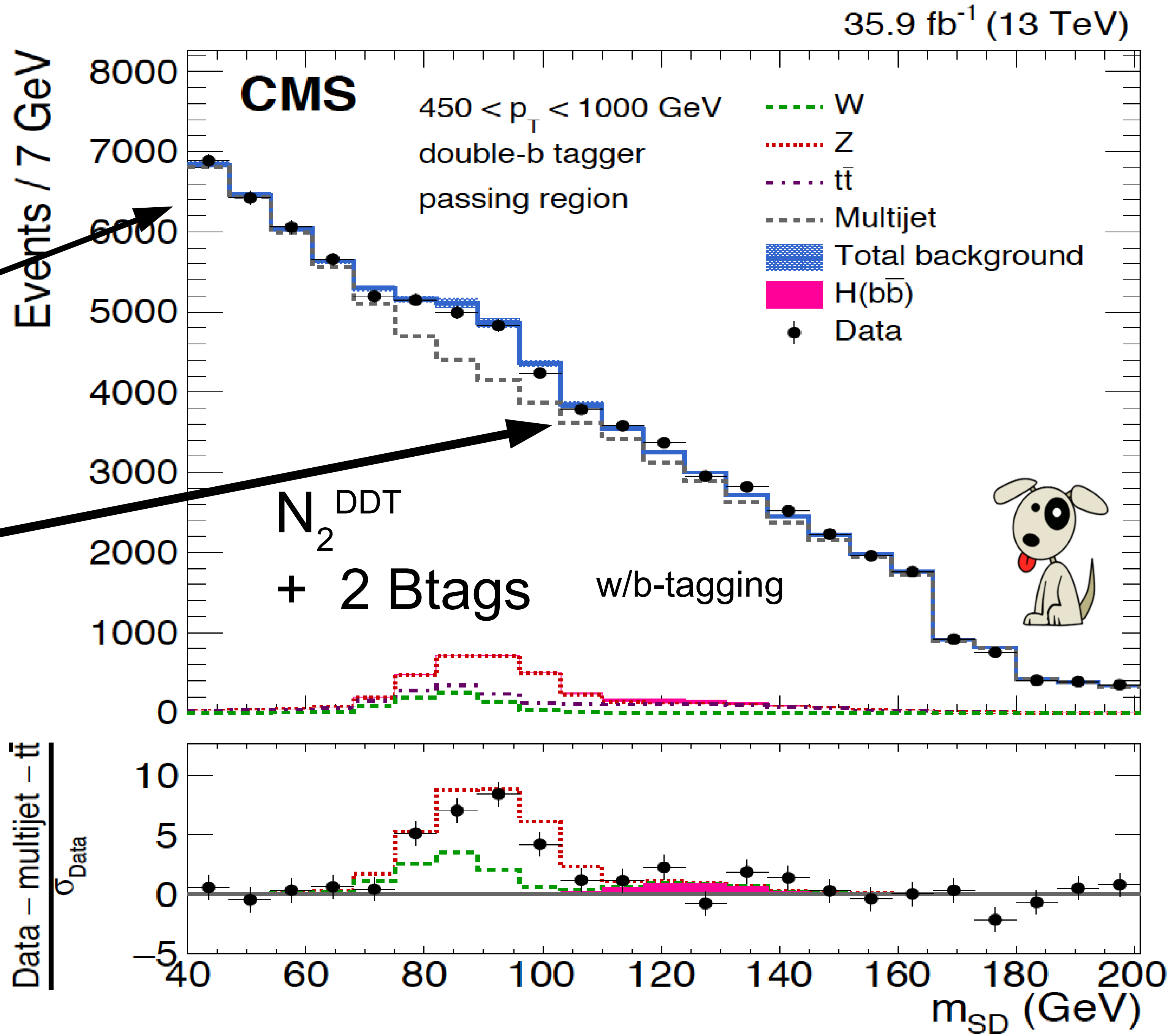
Two pronged Jets+2 b-tags

Zbb peak

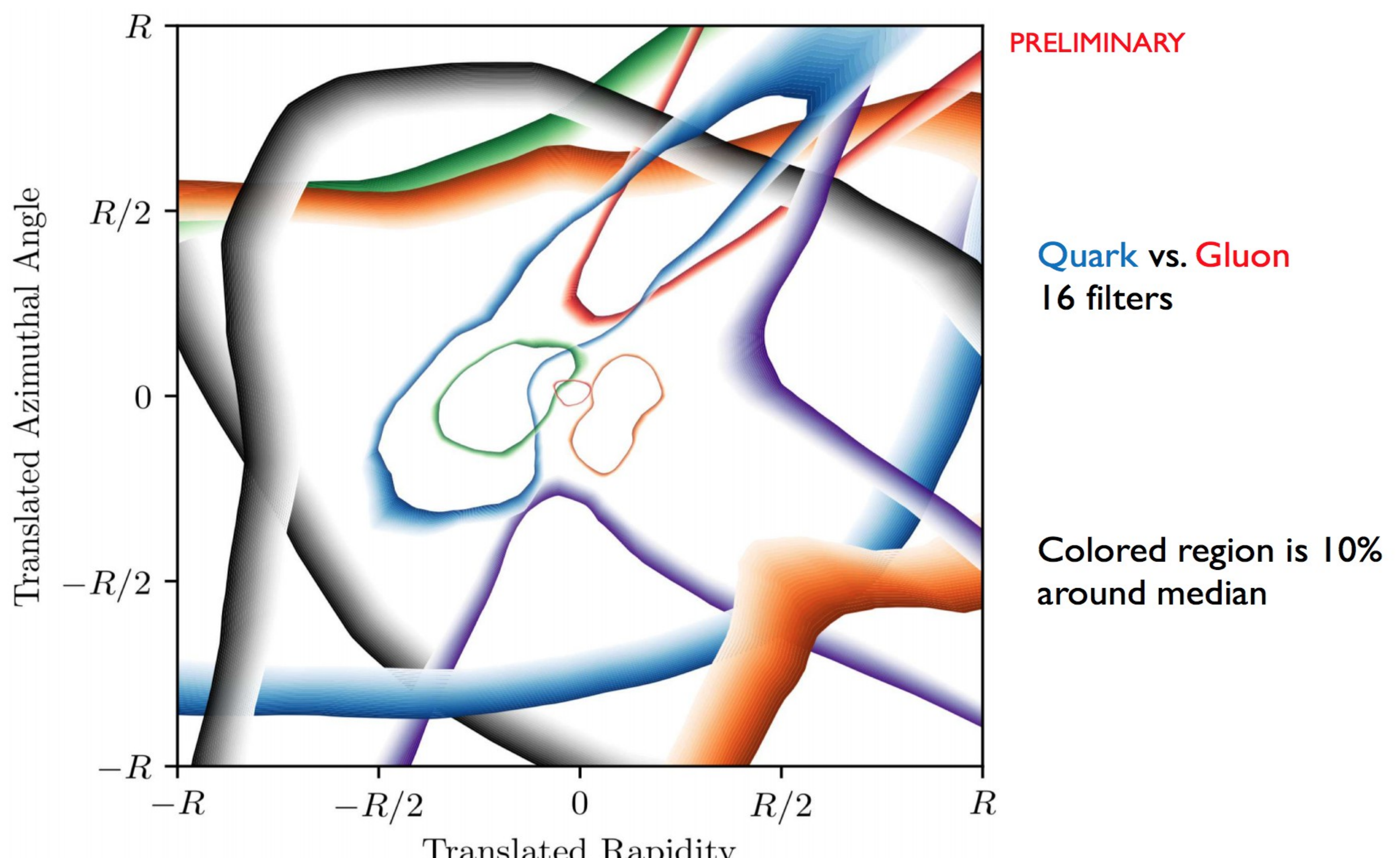
Gluon
Fusion
Hbb peak?



CMS-HIG-17-010

Follow up

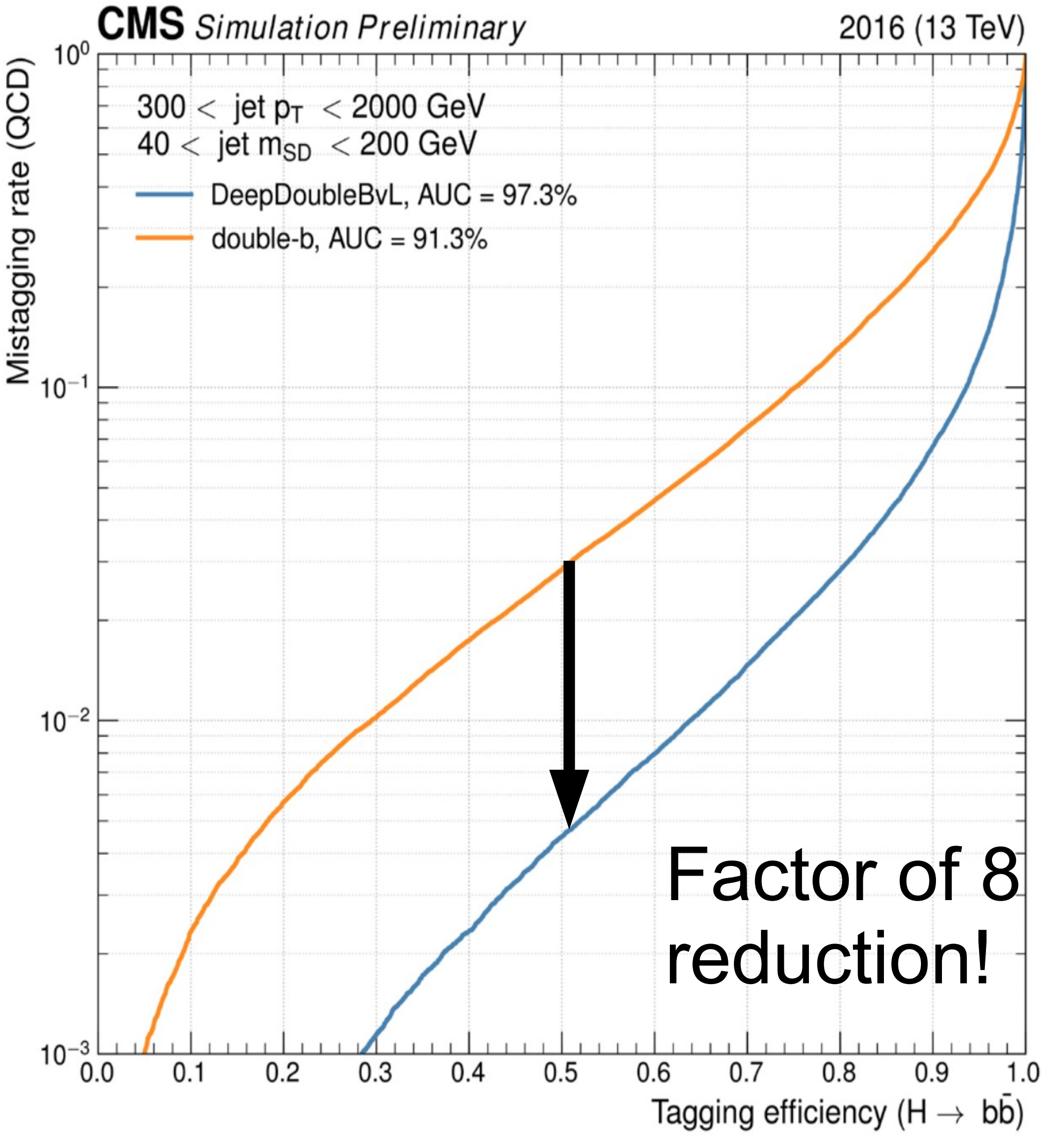
- Where can you improve the analysis?
  - In pp, people are going full deep learning



https://indico.cern.ch/event/649482/contributions/2993313/attachments/1689067/2717141/PTK_B

P. Komiskie, E. Metodiev, J. Thaler Boost 2018 (last week!)

What are the prospects?



Machine learning algo:

All the particles in a jet (PF candidates in CMS +2nd ary vertices)

LSTM on all particles
Train for Higgs boson

Impacts of ML can be very substantial

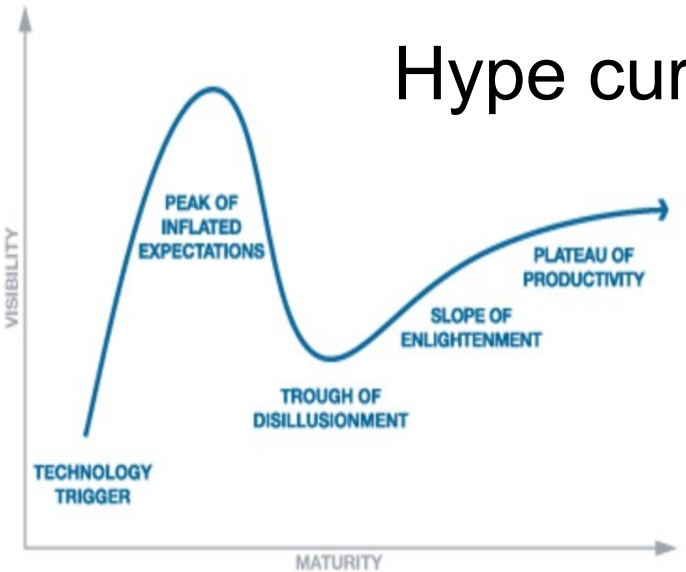
CMS-DP-2018-046

Towards a Realistic use of ML in jets

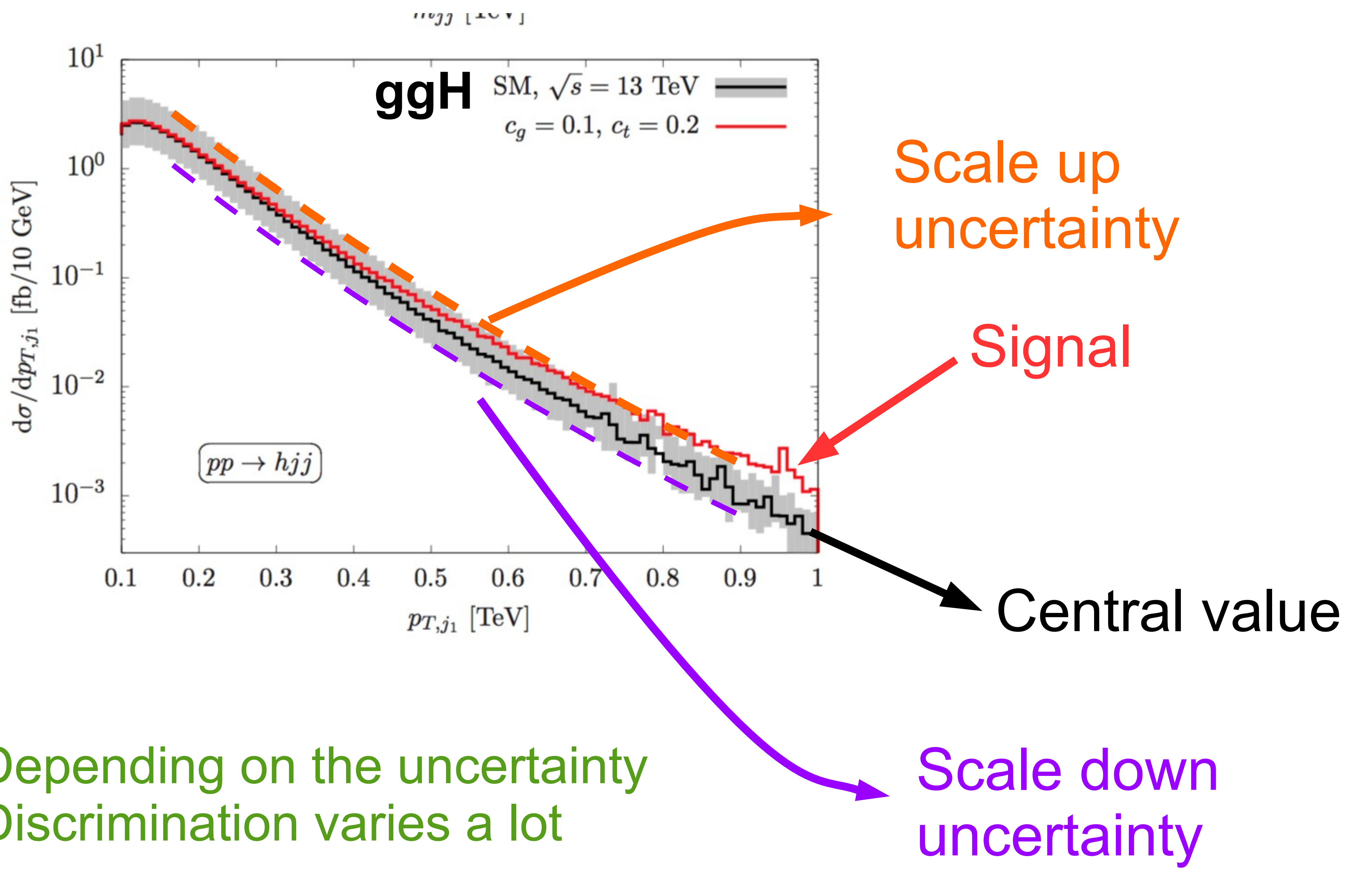
- Despite the big excitement about ML
  - People are hesitant to use these
  - Simply because its not clear where we are going
  - Universal thing: is that all ML algos give ~same gain

- In lieu of this....
  - Focus has been on physics
  - How can we restrict MLs
    - Avoid unphyscial gains
    - Ensure physics is preserved
  - Use our bkg methods

Hype curve



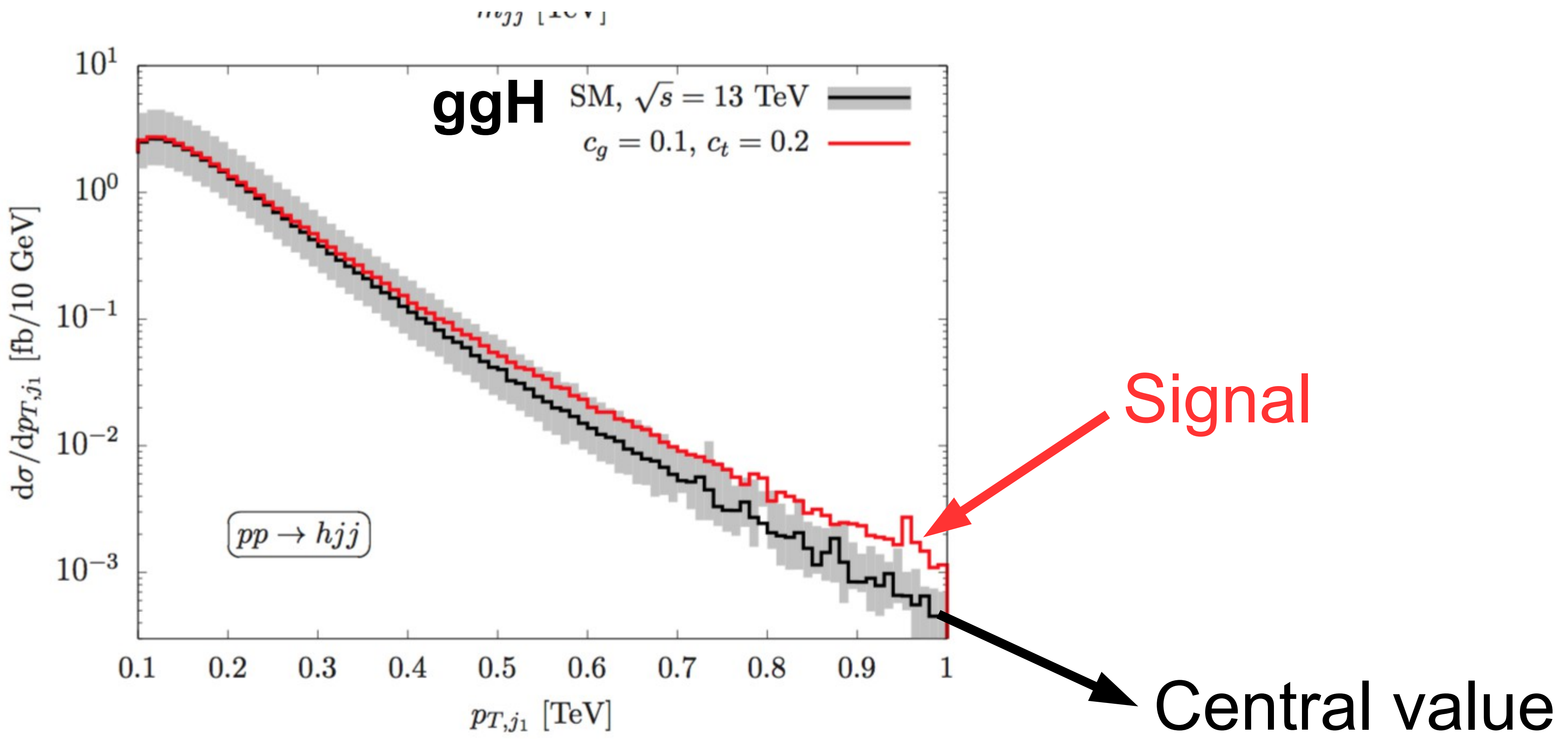
Importance of Adversaries



Depending on the uncertainty
Discrimination varies a lot

Arxiv/today!

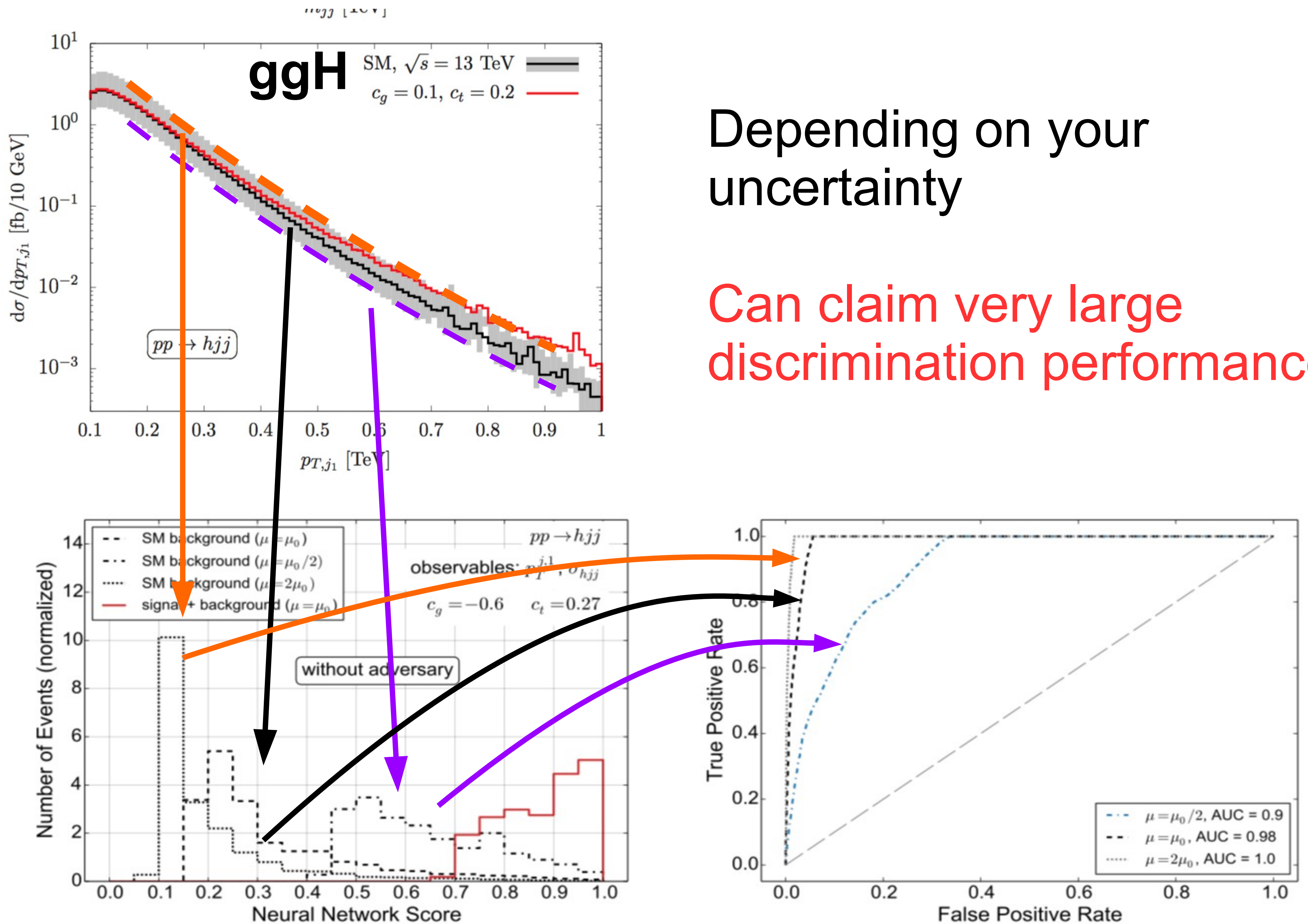
Importance of Adversaries



Depending on the uncertainty
Discrimination varies a lot

Arxiv/today!

Impact on discrimination



Depending on your uncertainty

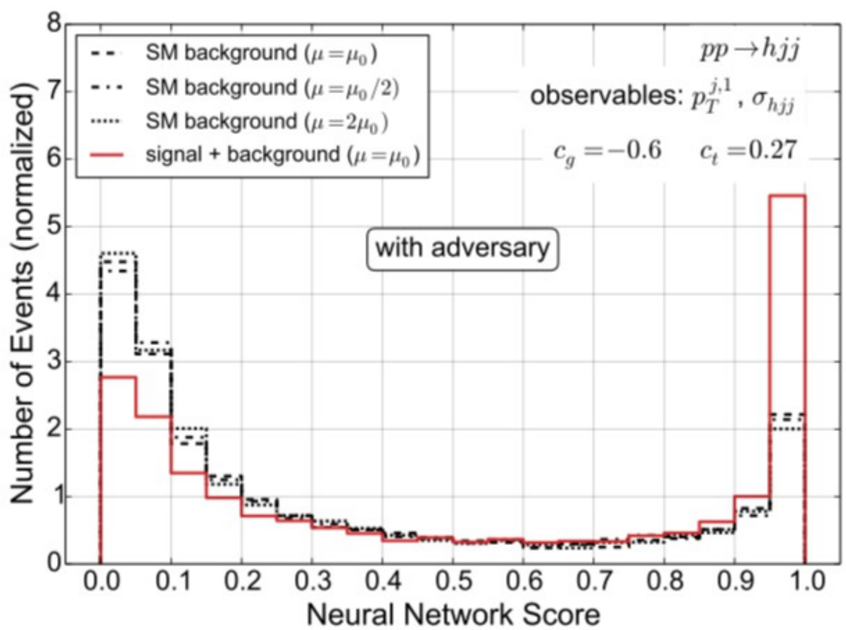
Can claim very large discrimination performance

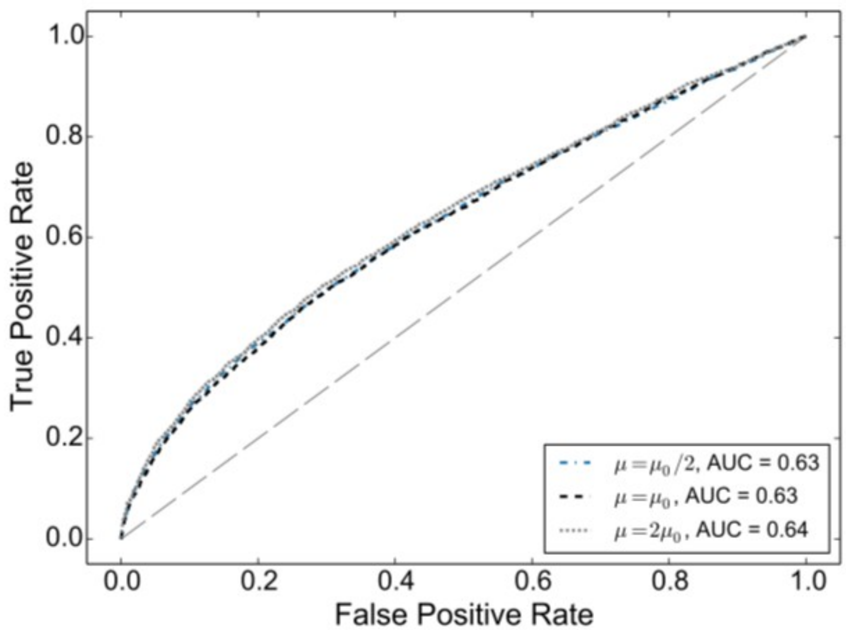
Arxiv/today

Impact on discrimination

Through the use of adversarial neural networks

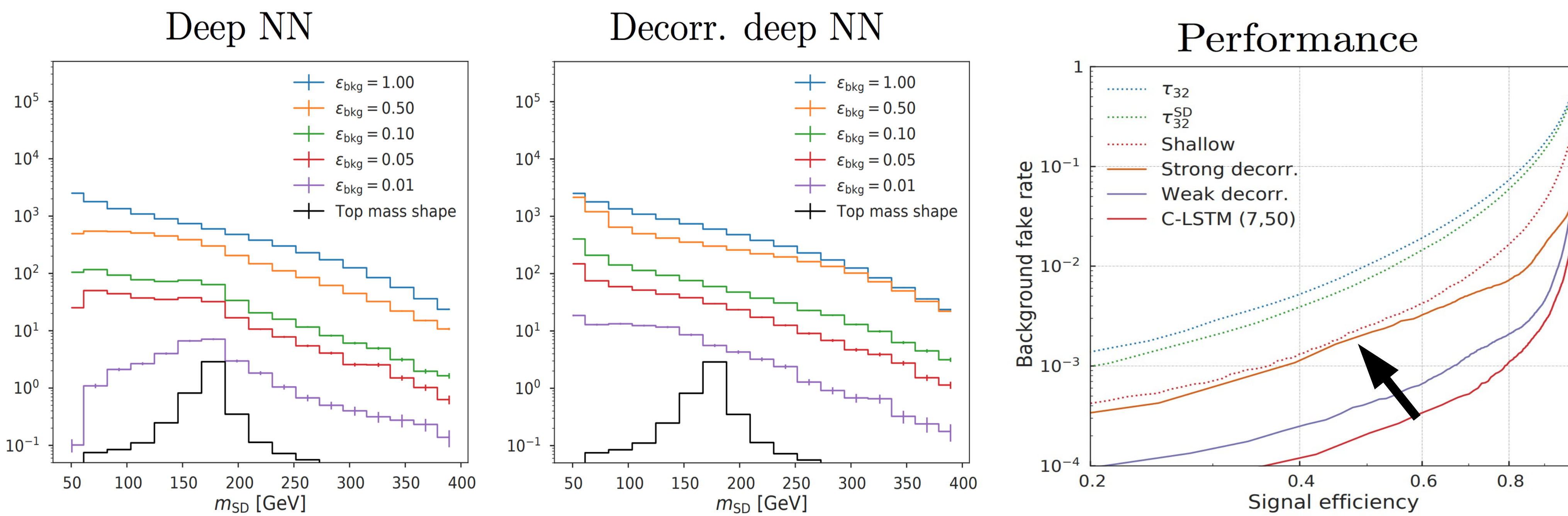
Can implicitly build in uncertainties
This allows for directed measurements
Preserve ability to account high dimensional inputs





Arxiv/today

In the context of Jets decorrelation

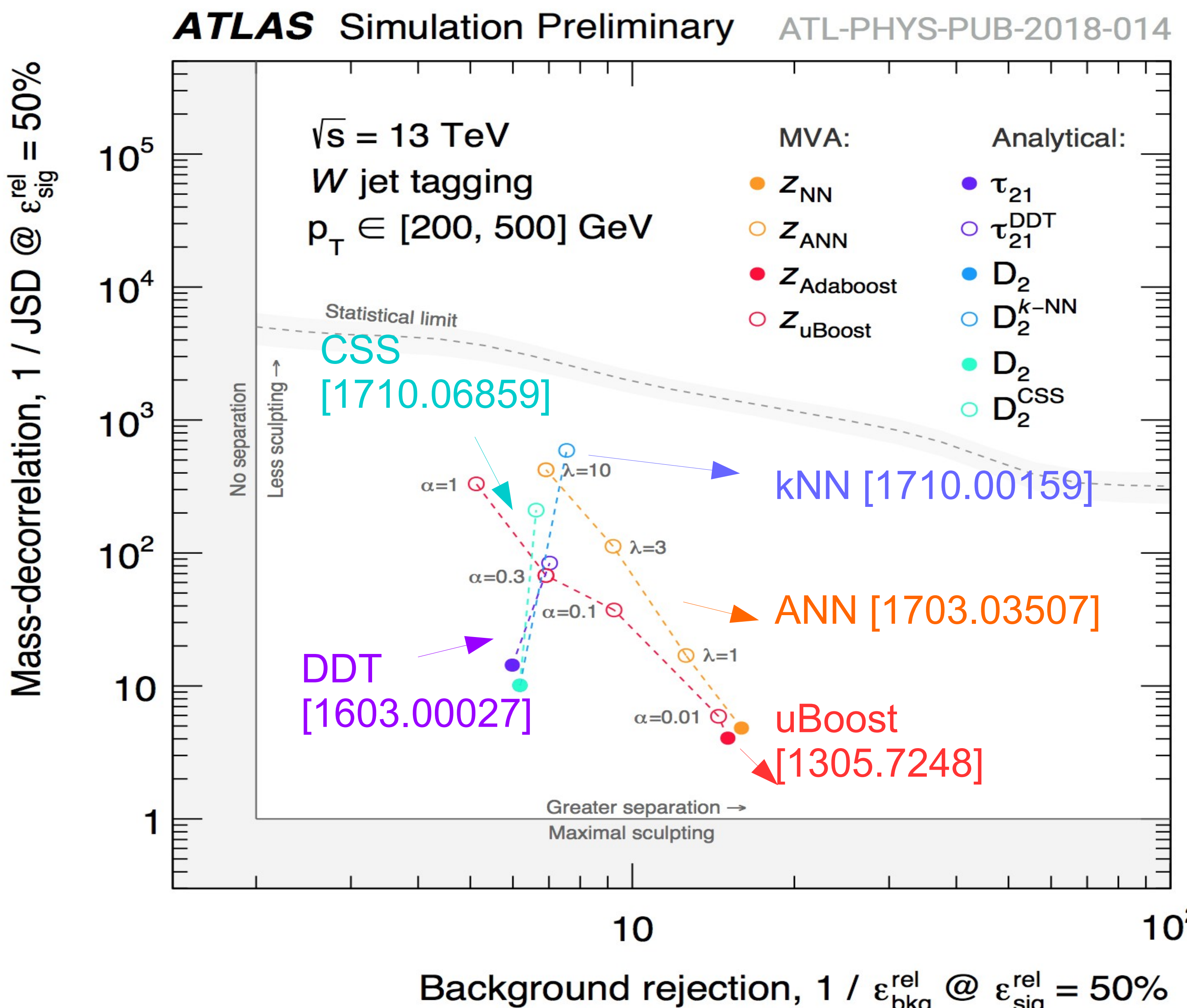


Following the paradigm of V+jets search

- We build a giant NN (> 100 particles inputs)
- Decorrelate NN against mass
- Scale of decorrlation drives perf.

S. Narayanyan

Scanning the decorrelation schemes

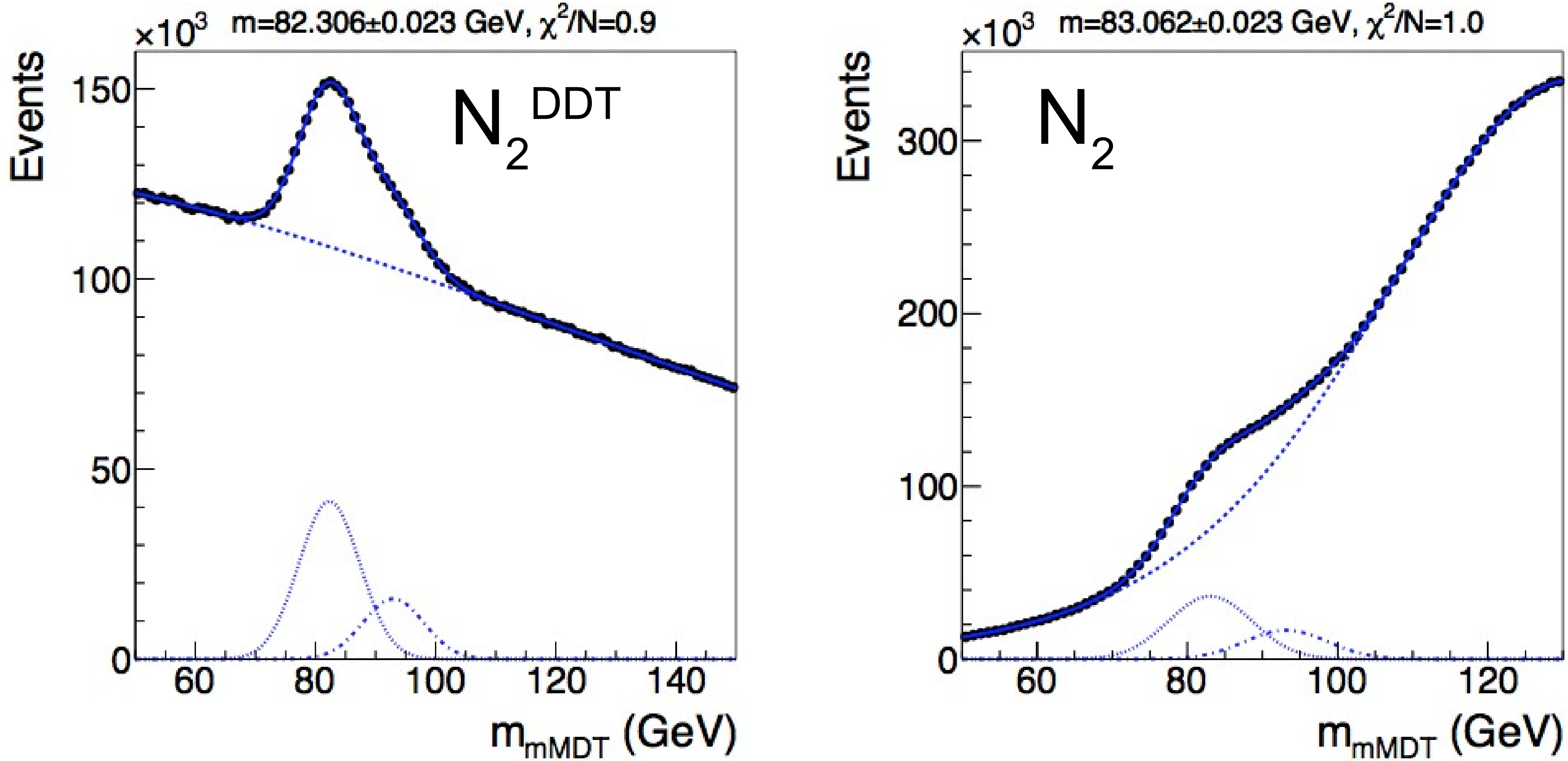


Decorrelation of mass seen to be important for new taggers

A. Sogaard (Boost 2018)

Can we do a fundamental meas.?

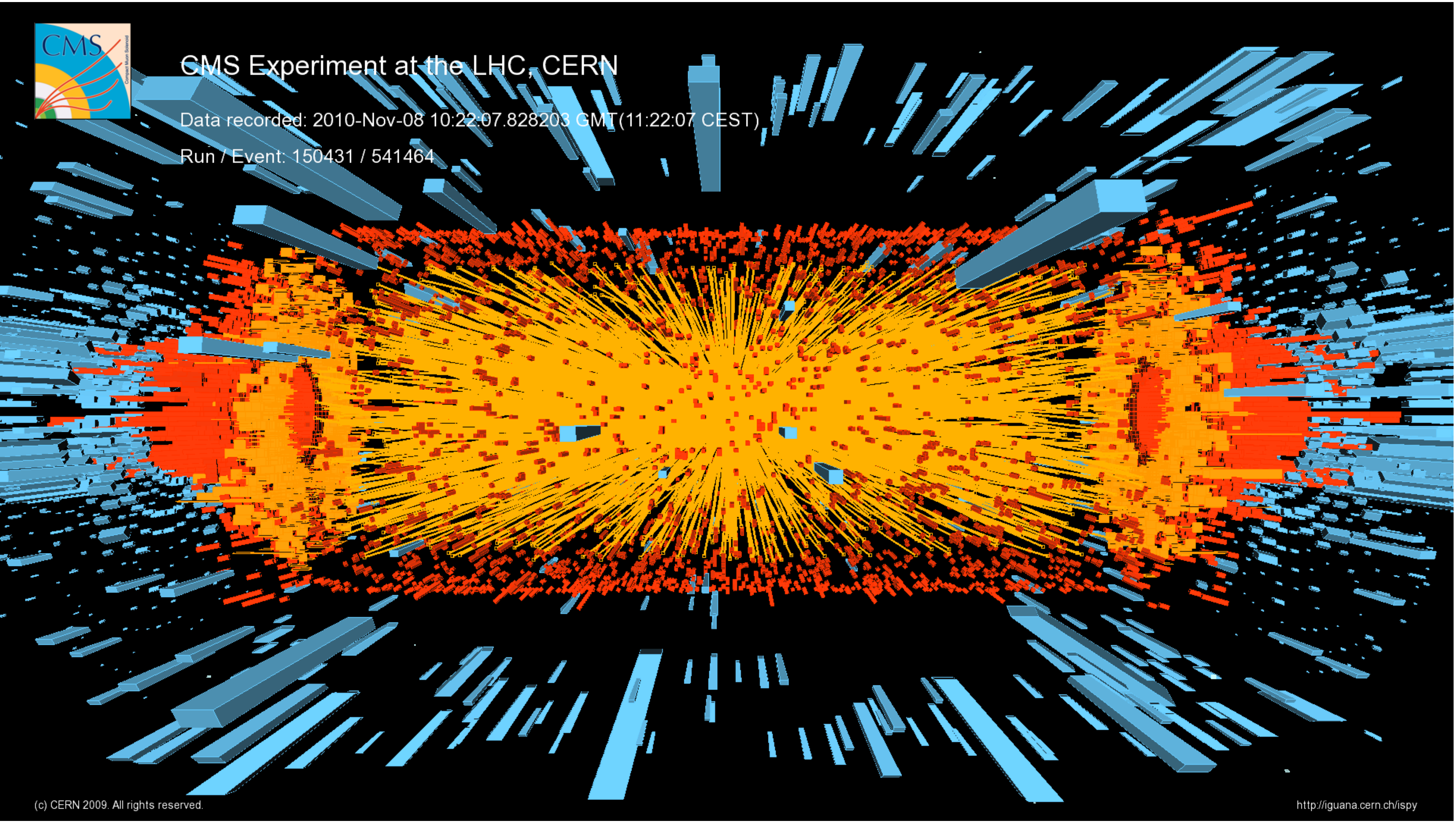
- Would it be possible to apply this to W mass?



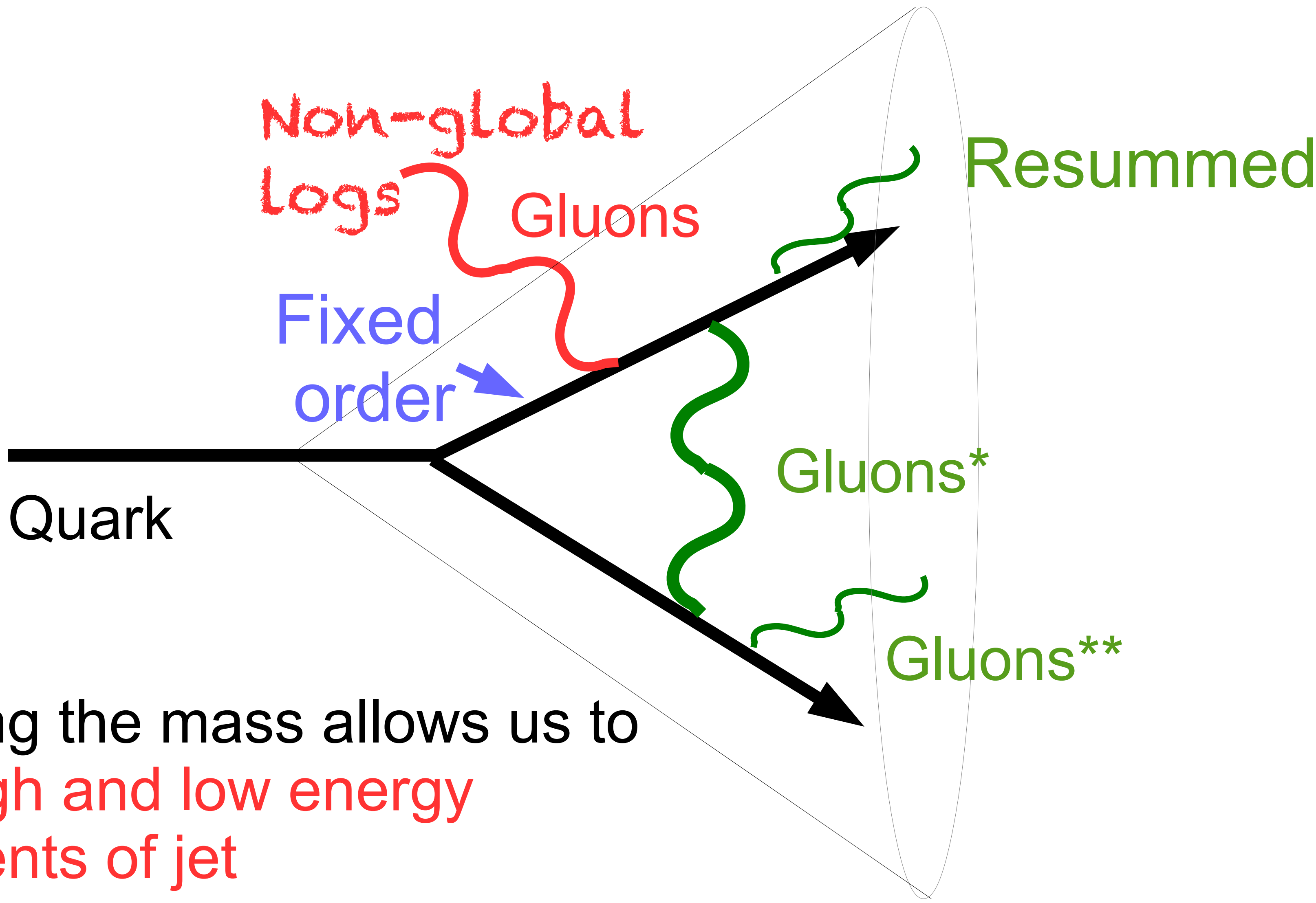
With 3/ab and p_T > 500 GeV have a statistical precision of 23 MeV and **systematics?**

Arxiv/1807.07454 (last week)

Heavy Ion Collisions



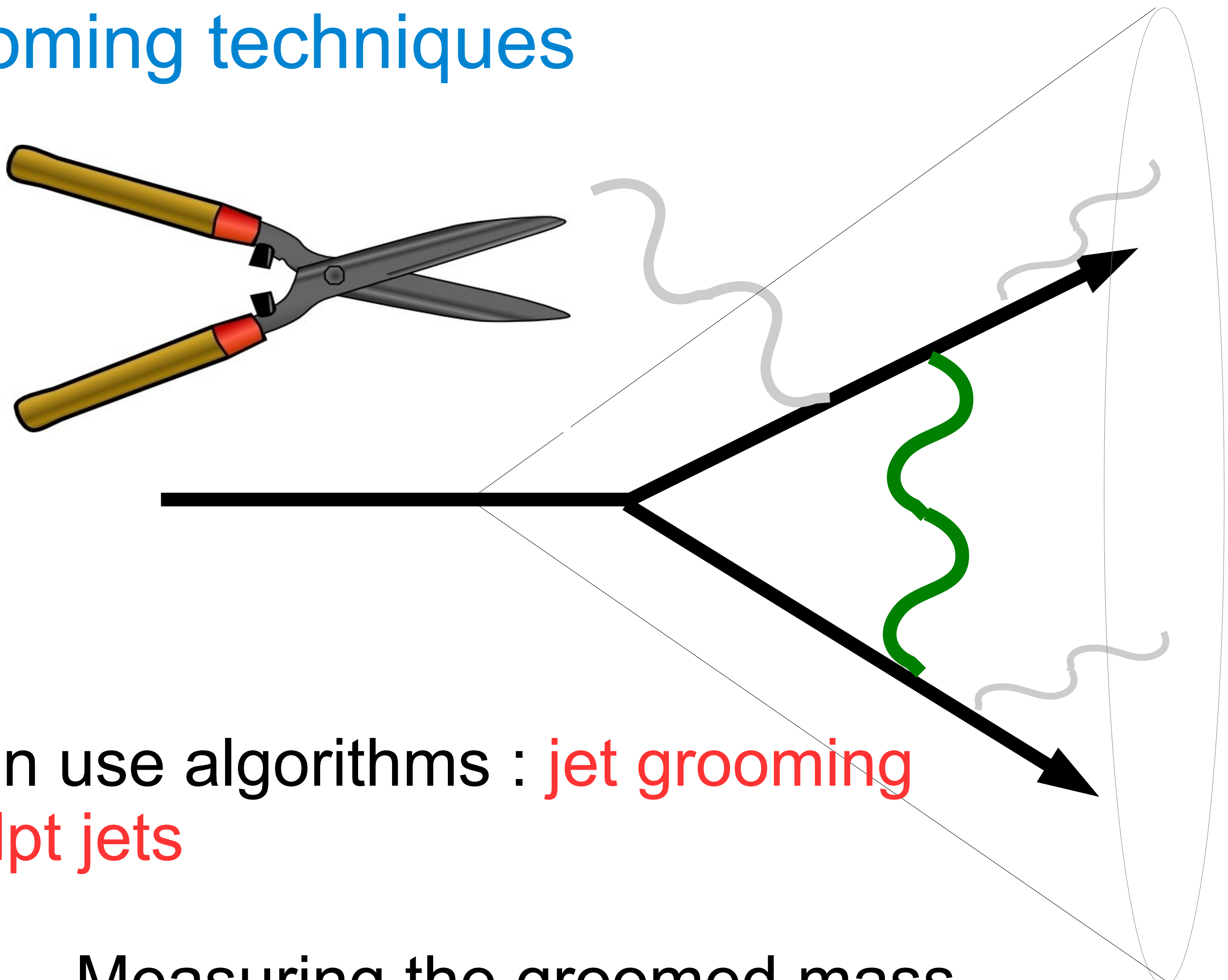
Visualizing Jet Mass



Measuring the mass allows us to probe high and low energy components of jet

Grooming Jet Mass

Grooming techniques

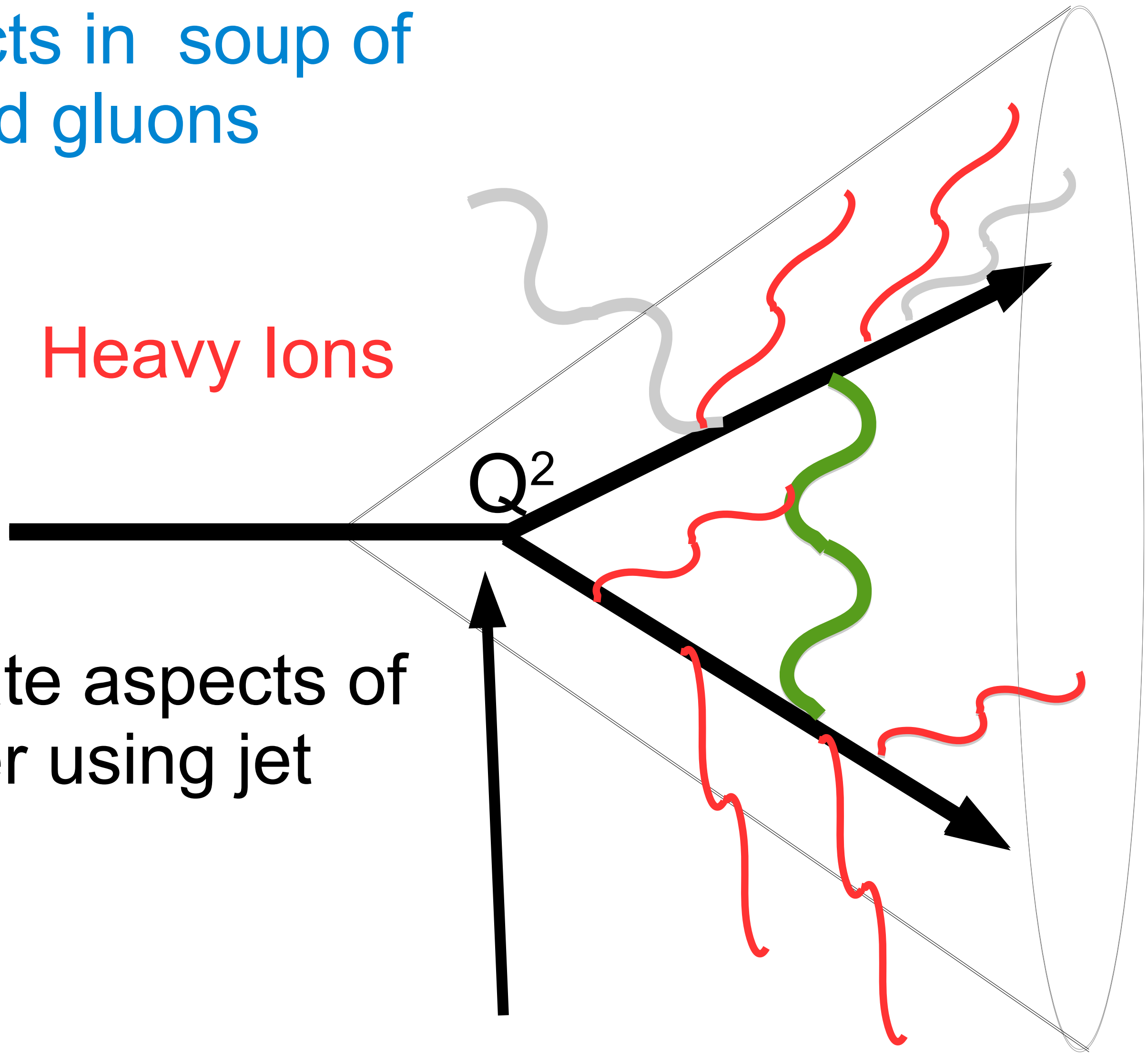


We can use algorithms : jet grooming to sculpt jets

Measuring the groomed mass allows us to probe the hard component

Heavy Ion Collisions

Jet interacts in soup of quarks and gluons

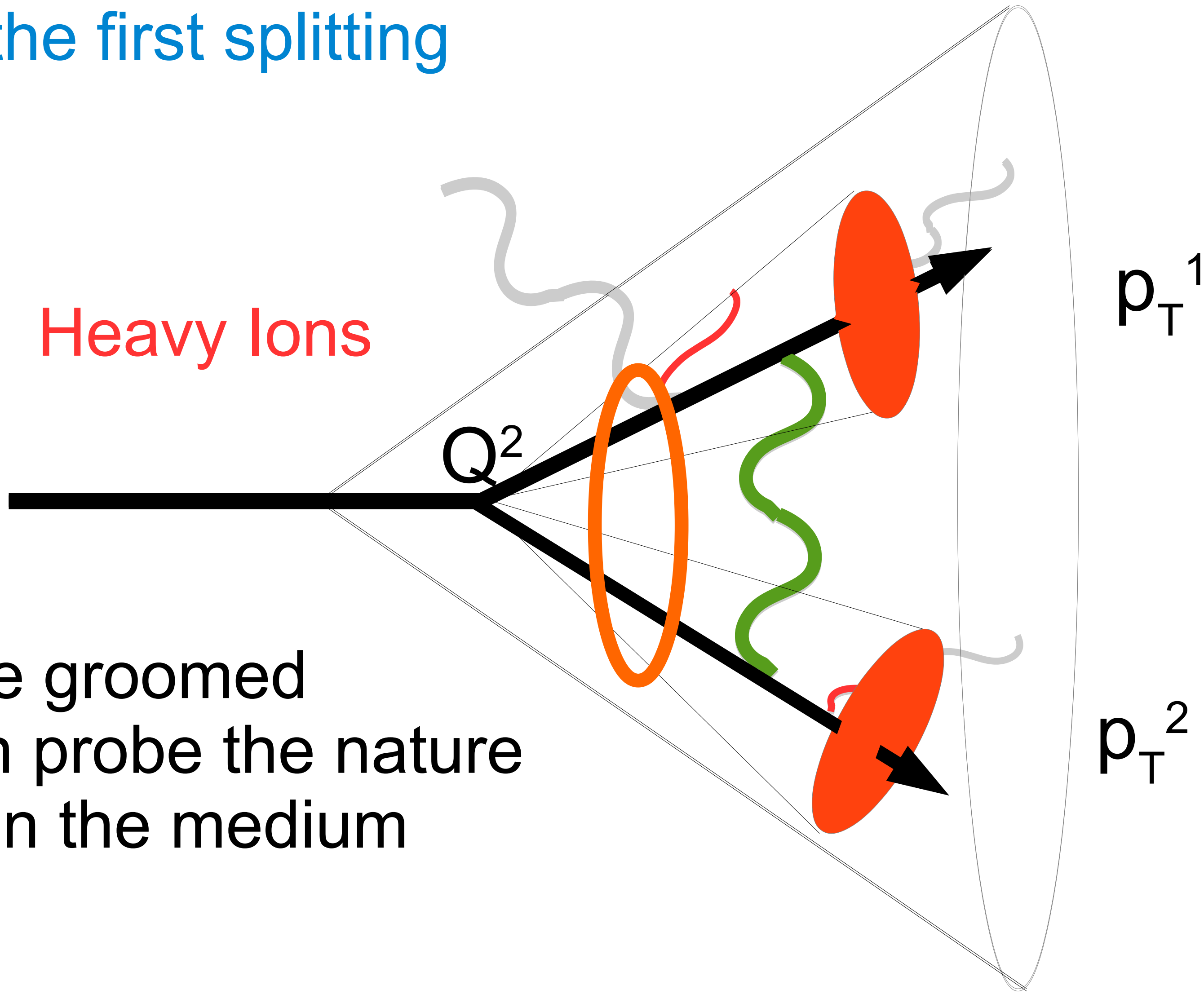


try to isolate aspects of the shower using jet grooming

Properties of the jet allow us to define Medium modifications

Heavy Ion Collisions

Consider the first splitting in jet

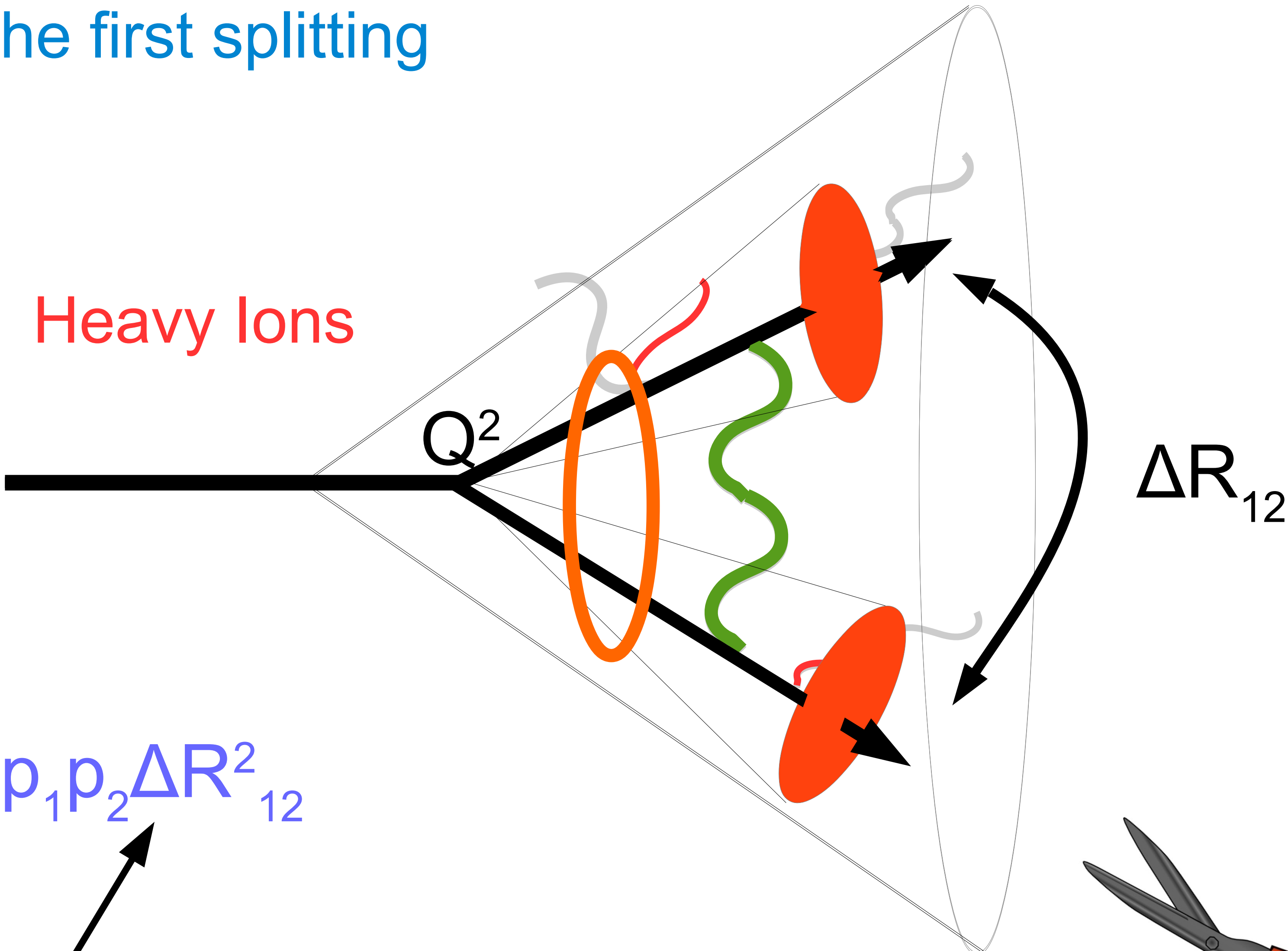


Isolating the groomed Subjets can probe the nature of the loss in the medium

Heavy Ion Collisions

Consider the first splitting in jet

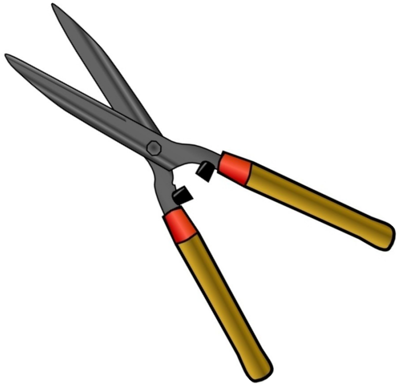
Heavy Ions



Jet Mass

$M^2 \sim p_1 p_2 \Delta R^2_{12}$

Tells us about the medium

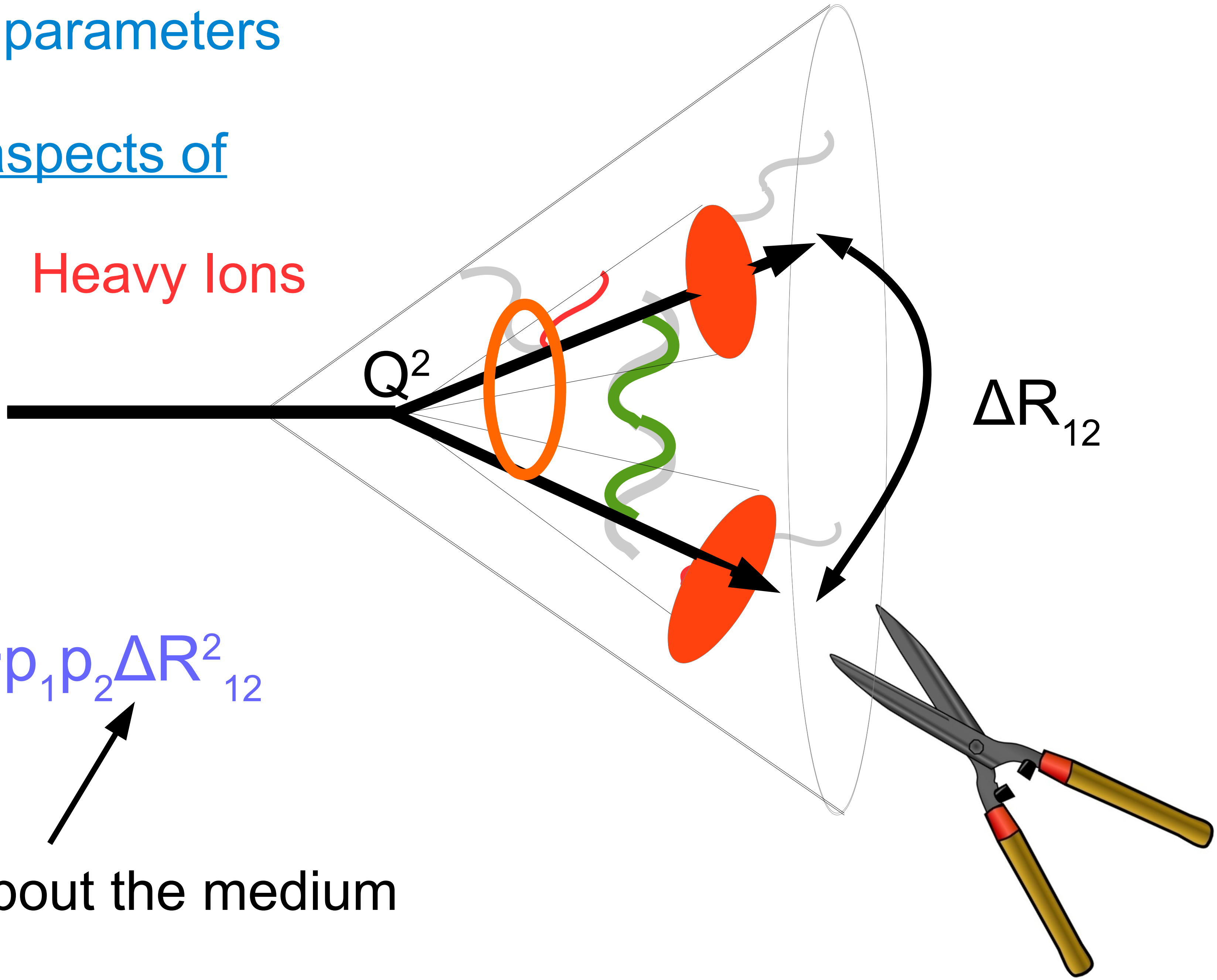


Heavy Ion Collisions

Modifying parameters

Different aspects of medium

Heavy Ions

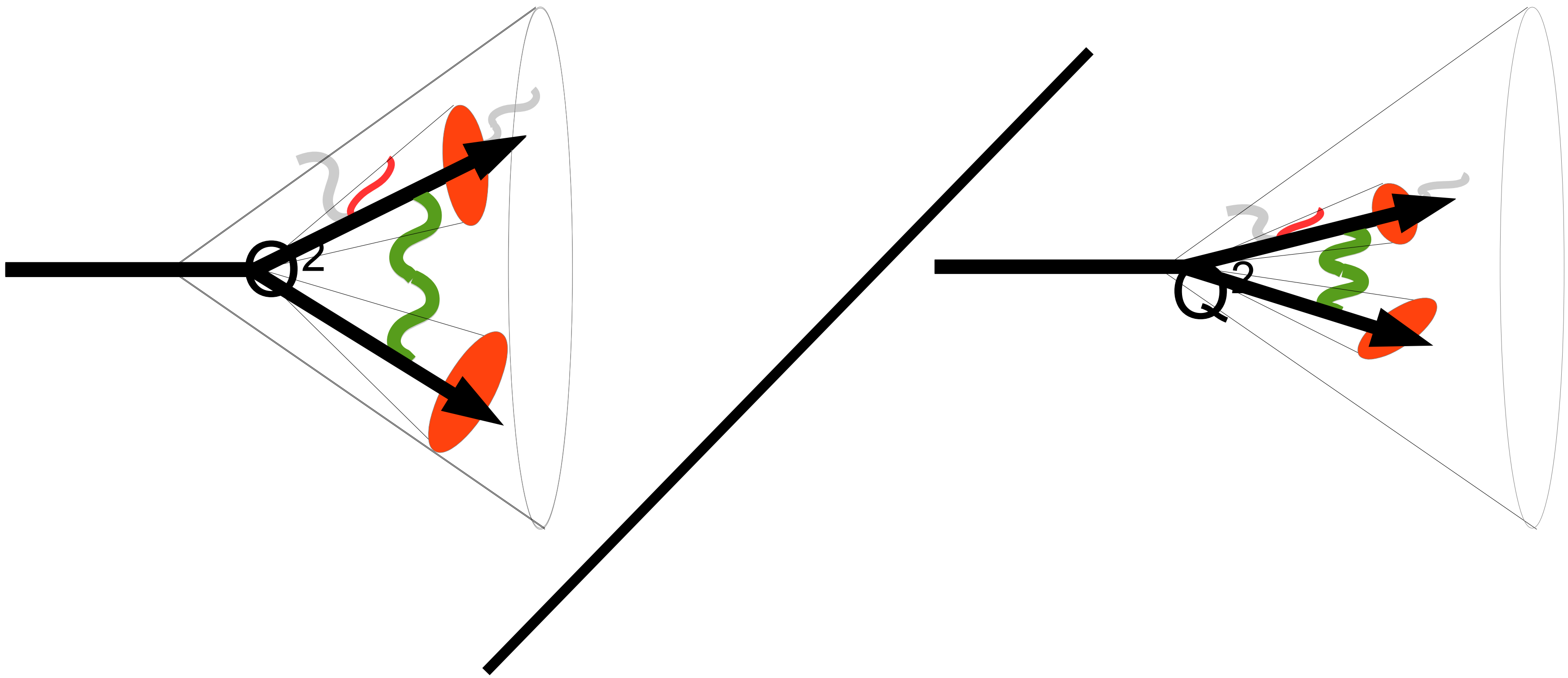


Jet Mass

$M^2 \sim p_1 p_2 \Delta R^2_{12}$

Tells us about the medium

Performing Measurements in HI



Many ideas to decorrelate jets against observables

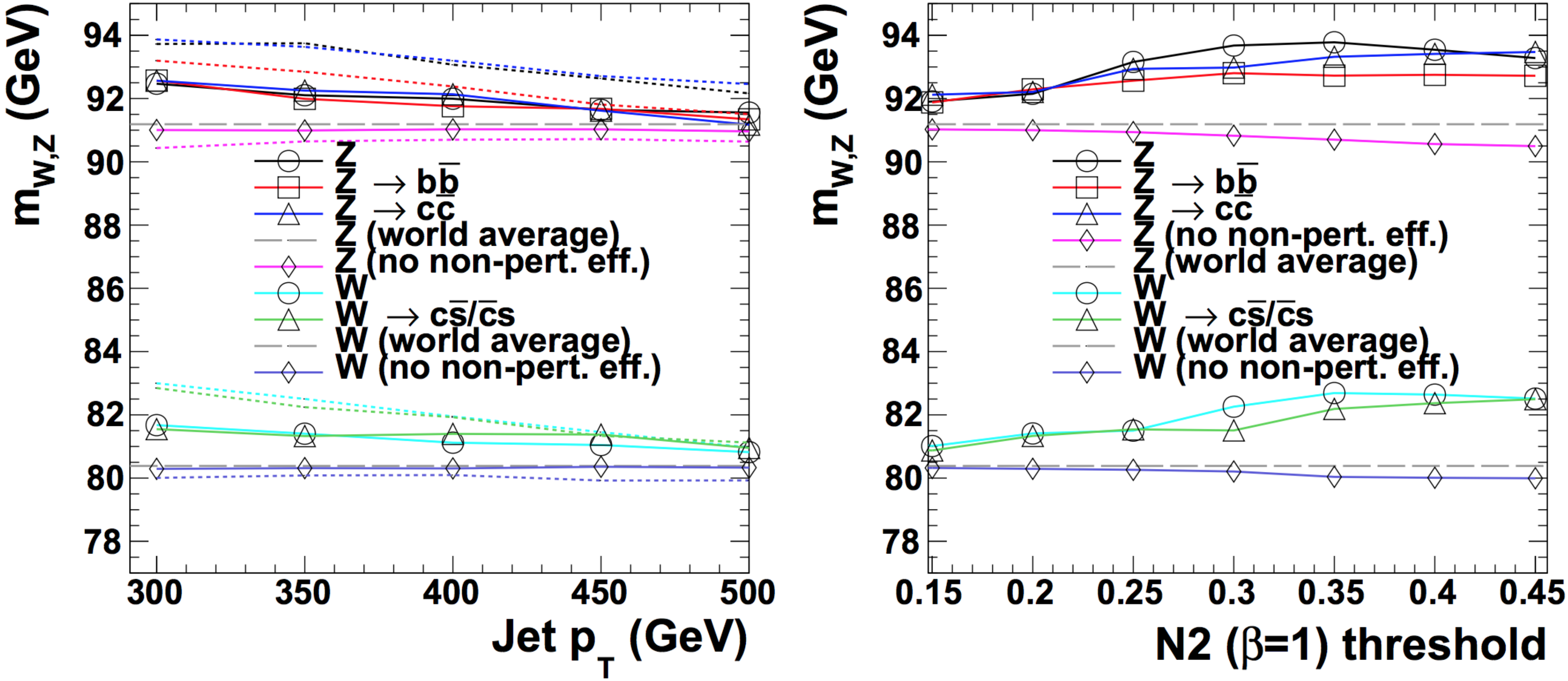
Decorrelation allows for data based ratios

Allows us to be sensitive to small features

Summary

- The act of substructure is a tool that we can use
  - Allows us to sculpt jets to isolate specific physics
- For recent hadronic resonances
  - Constructed decorrelated observables agains m_{SD} p_T
  - With ML we can decorrelate in higher dimensions
    - This can allow us to take care of systematics
    - Can lead to improved discrimination + decorrelation
- Extending beyond that....
  - Can we use decorrelation schemes to enhance HI?

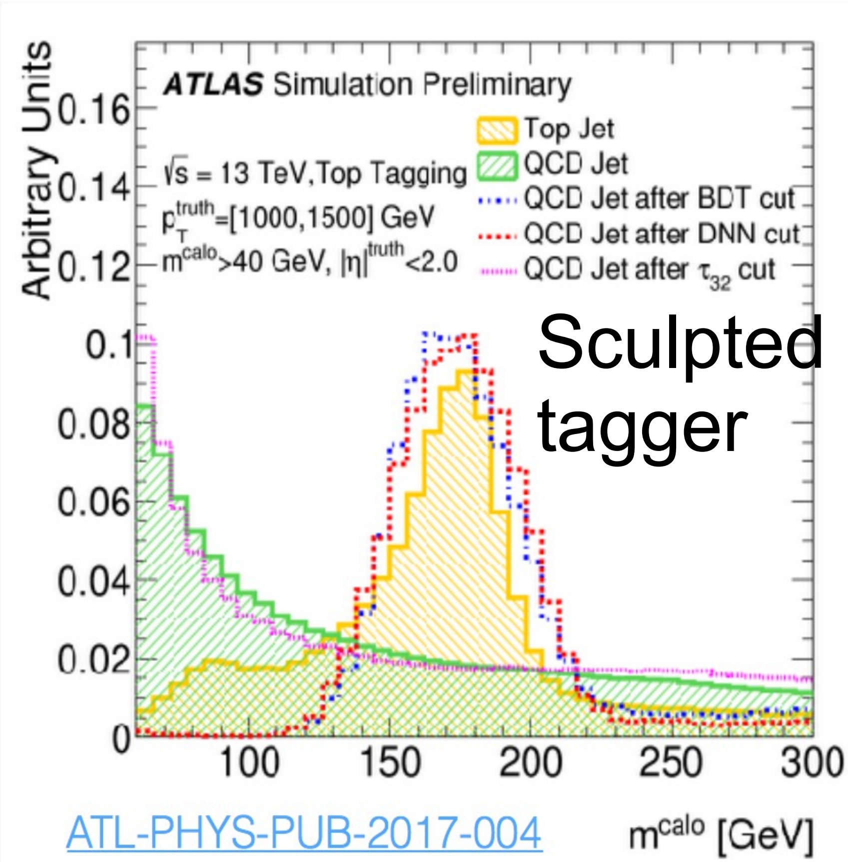
Thanks!



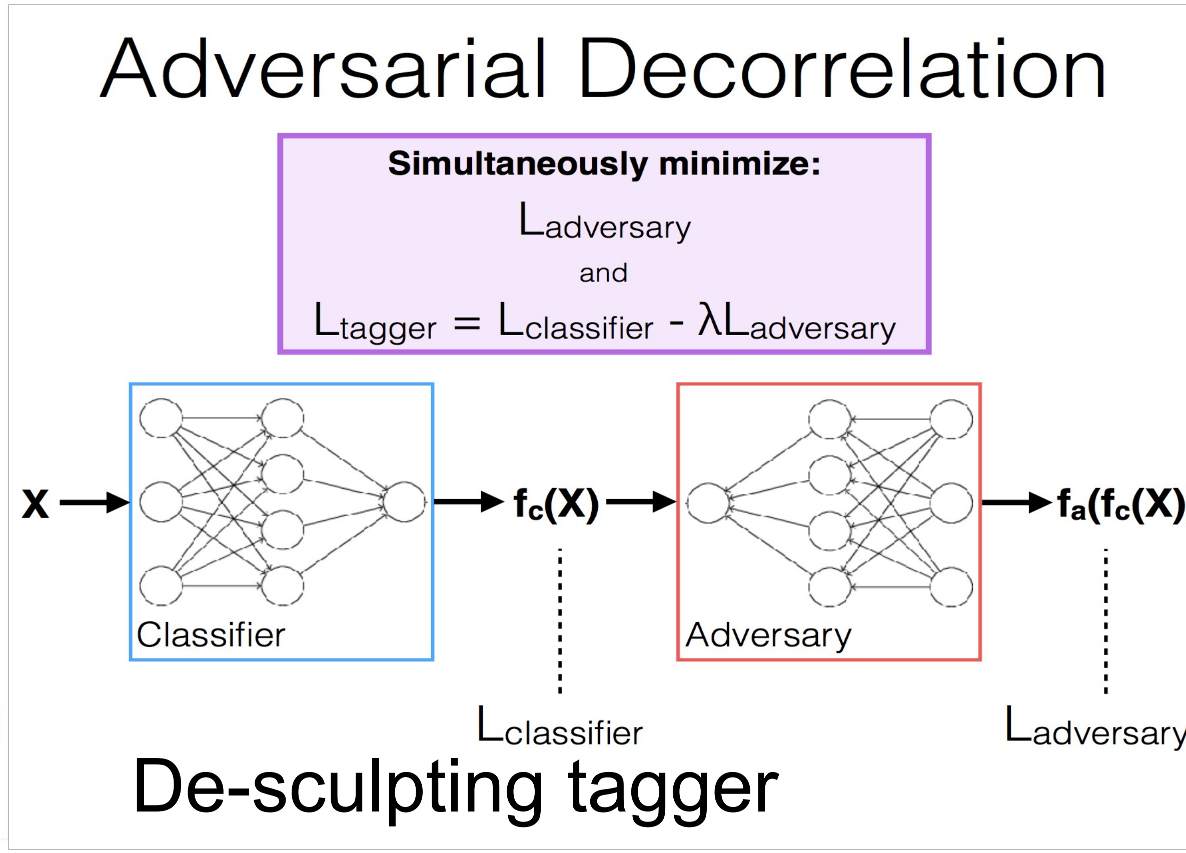
94
92
90
88
86
84
82
80
78
300
350
400
450
500
Jet p_T (GeV)
$m_{W,Z}$ (GeV)
Z
Z → $b\bar{b}$
Z → $c\bar{c}$
Z (world average)
Z (no non-pert. eff.)
W
W → $c\bar{s}/\bar{c}s$
W (world average)
W (no non-pert. eff.)
0.15
0.2
0.25
0.3
0.35
0.4
0.45
N2 (β=1) threshold

New Directions

- Key concept was modifying jet substructure



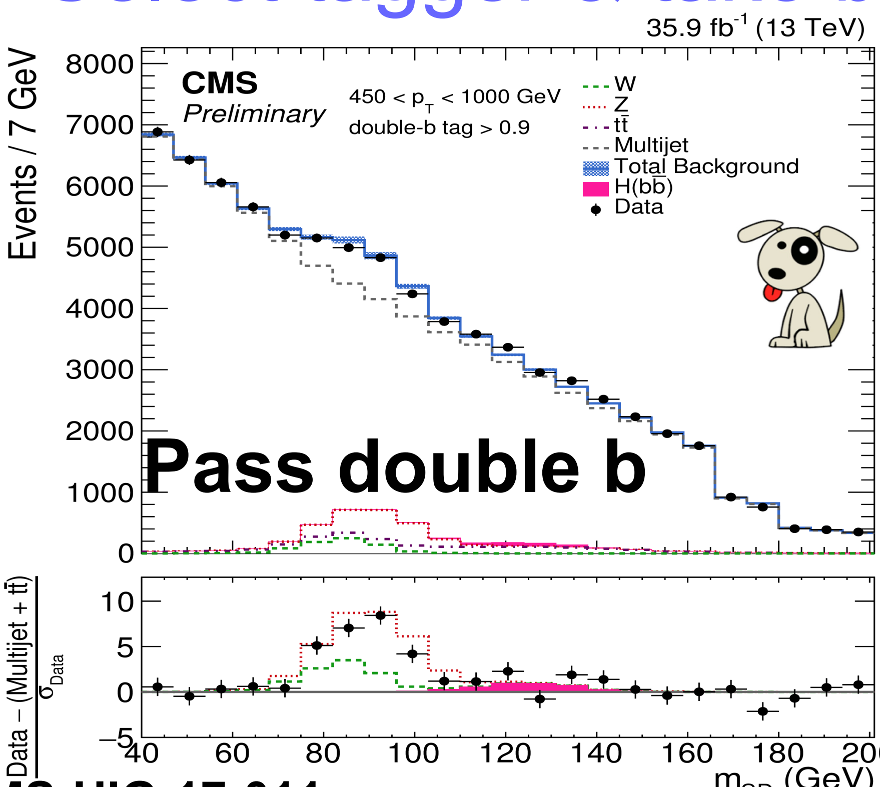
ATL-PHYS-PUB-2017-004

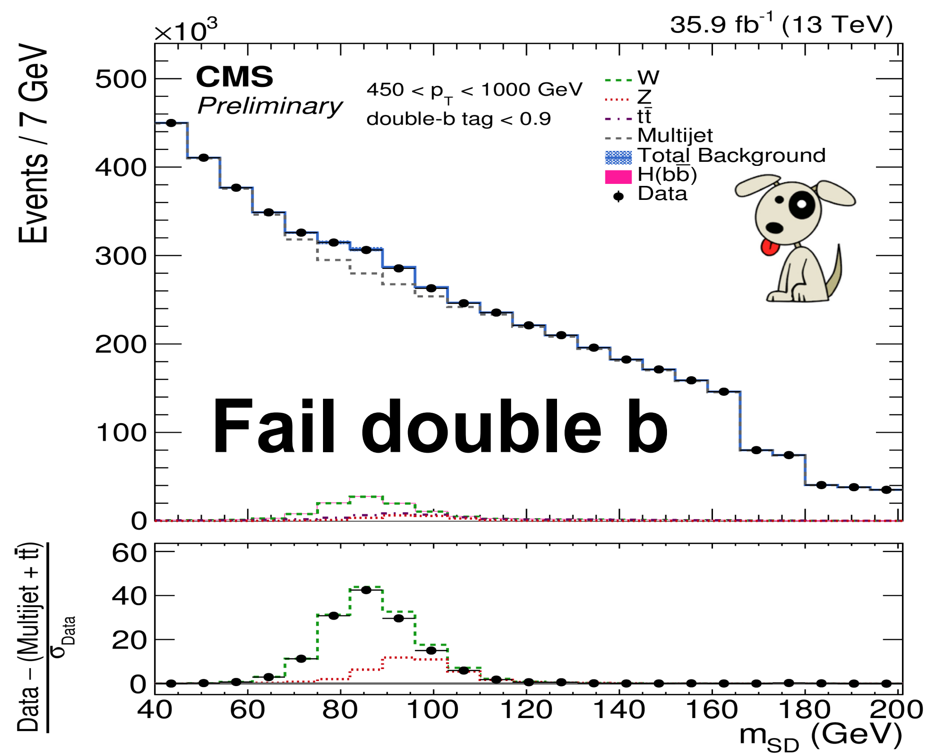


New approaches w/deep learning can decorrelate observables

Ingredients to see Higgs

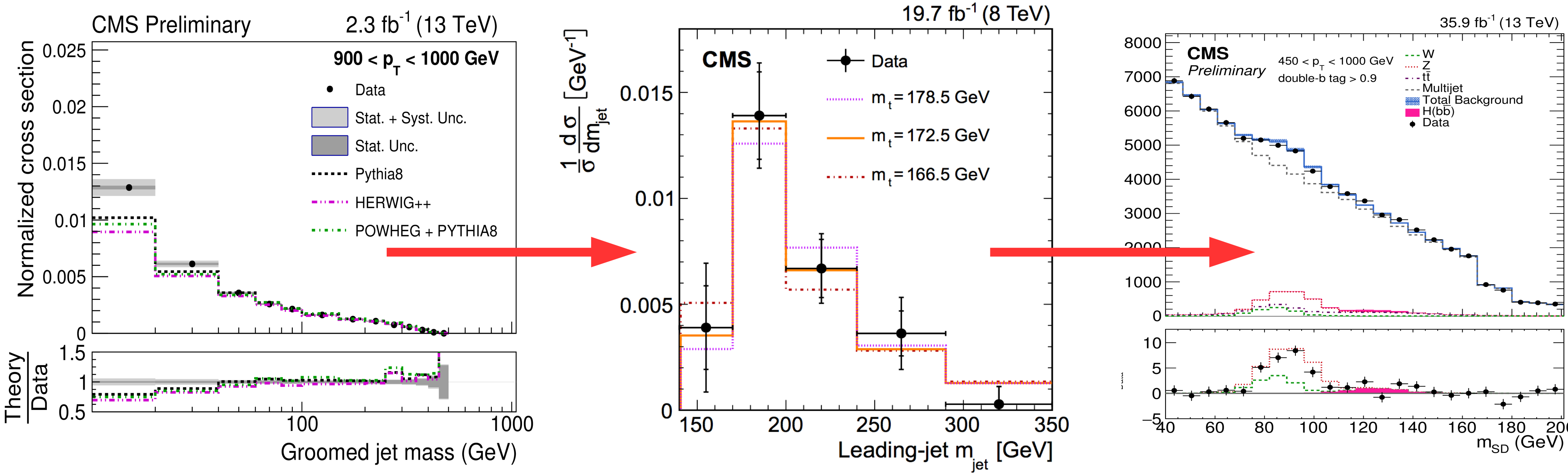
- Select a jet p_T > 450 GeV (single massive jet trigger)
- Require the jet to pass a 2 prong tag
- Require jet to be double b-tagged
- Select tagger & take both pass and failing selection





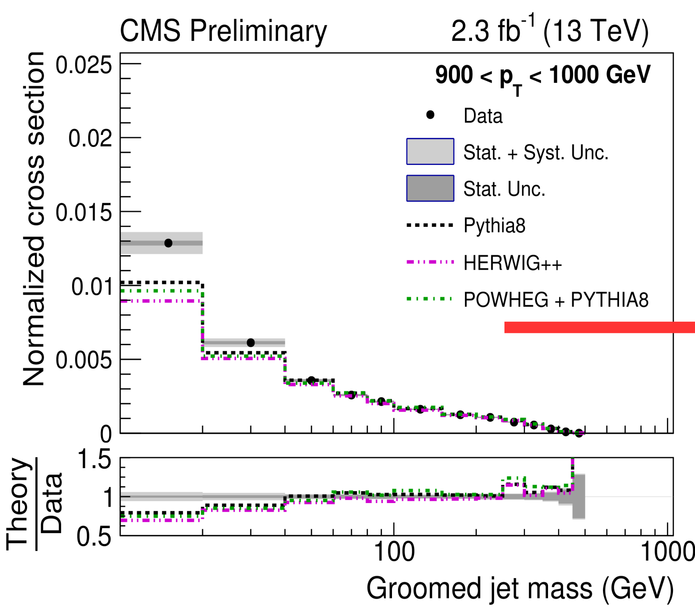
CMS-HIG-17-011

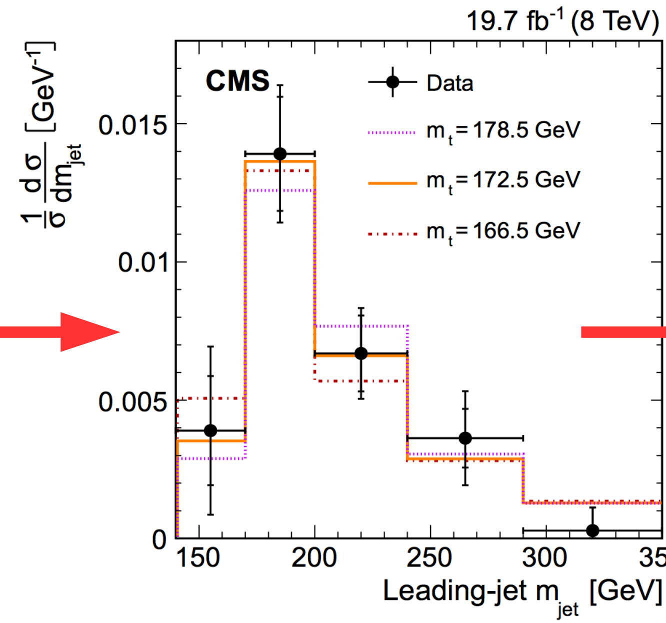
PDF ME Resum. EWK NP?

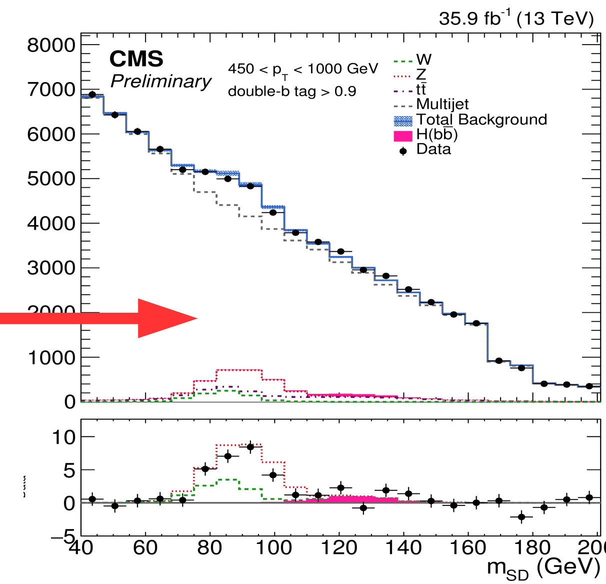


QCD meas. probing ever smaller event scale
Going smaller build on previous measurements

PDF ME Resum. EWK NP?







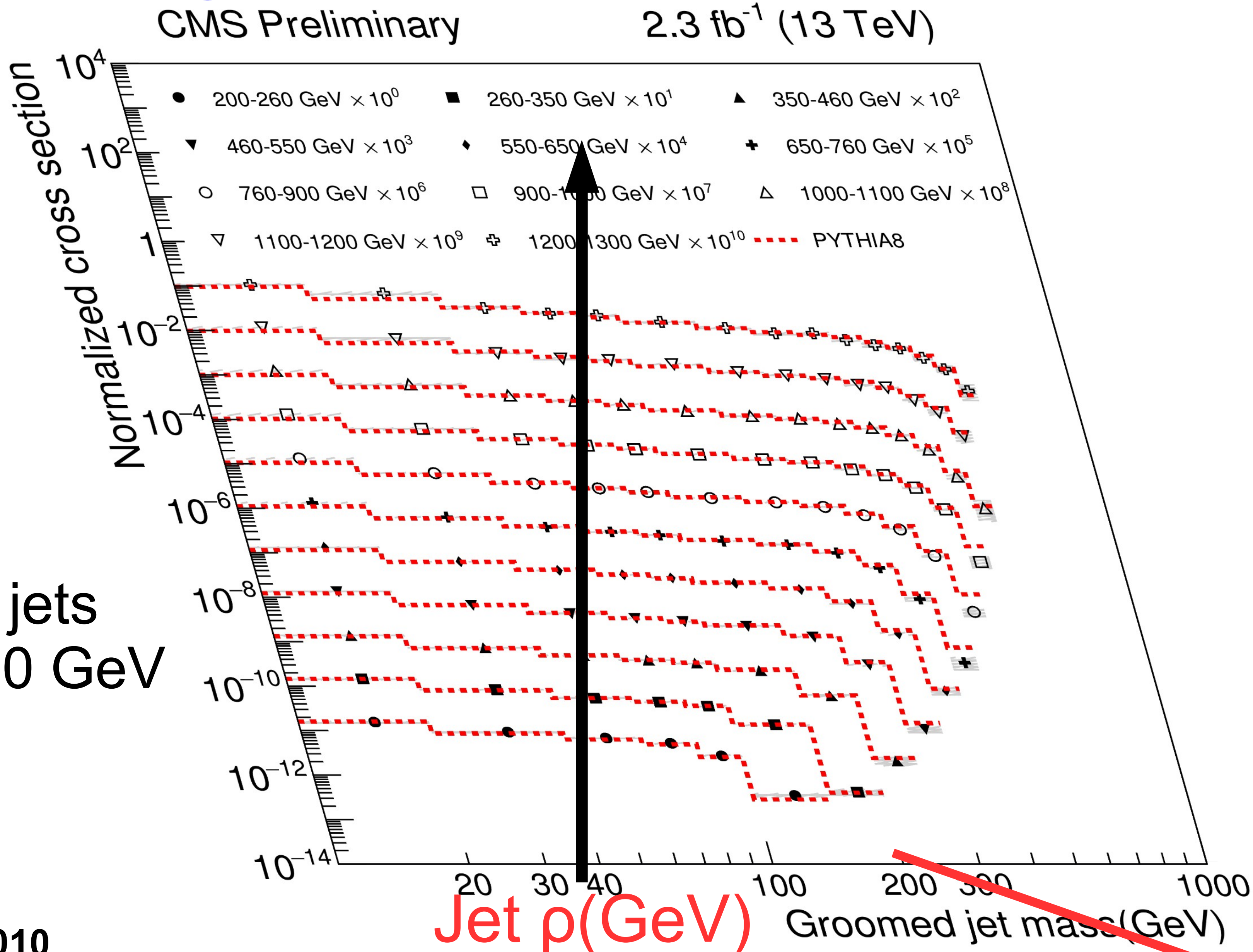
QCD meas. probing ever smaller event scale
Going smaller build on previous measurements

A wealth of new and exciting results

- Standard model mass measurements
- Probing the Quark/Gluon medium
- High p_T Higgs

Groomed Evolution

When grooming the mass becomes even flatter in ρ

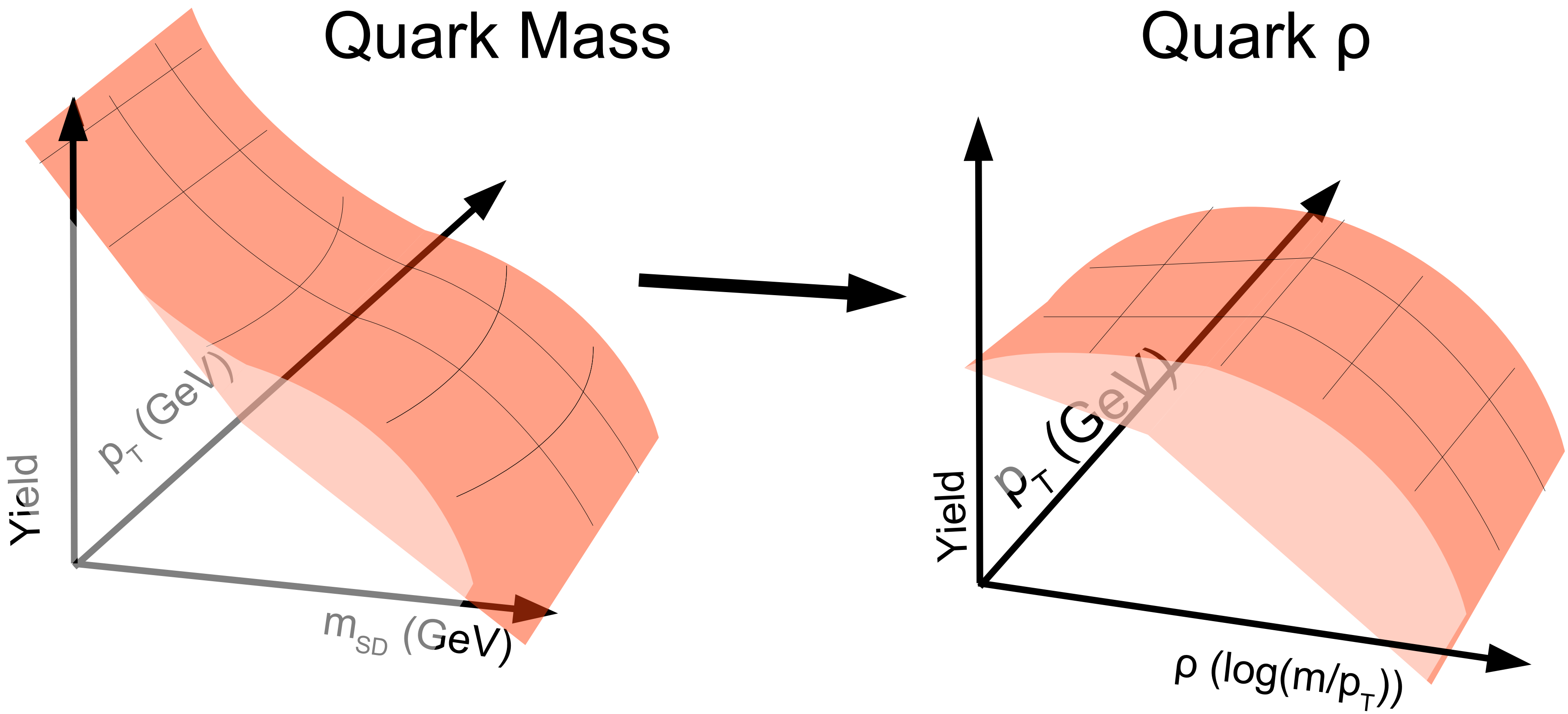


Consider jets w/p_T > 450 GeV (trigger)

CMS-SMP-16-010

Merging with ρ

- Merging to ρ makes imposes invariance over p_T

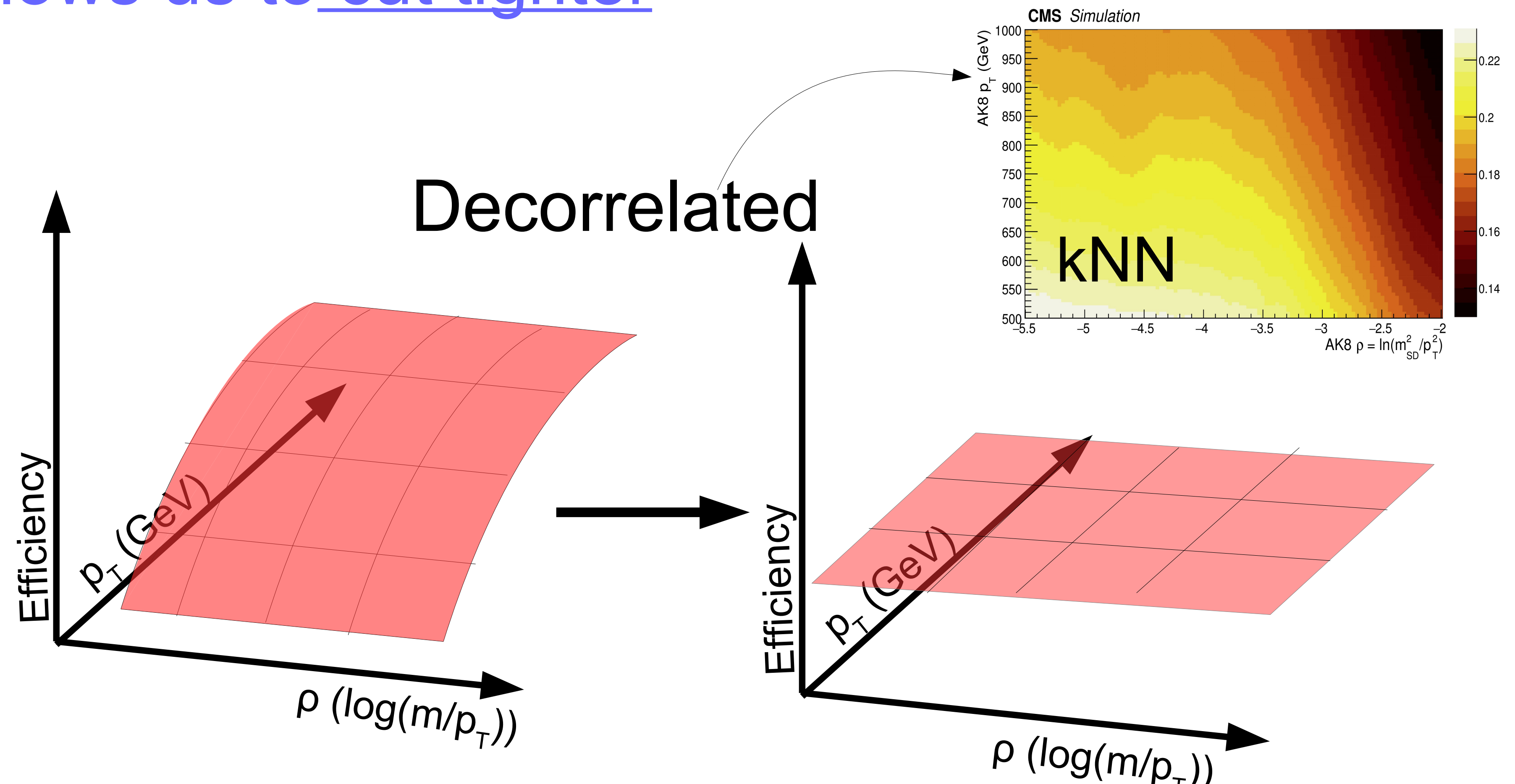


When translating to ρ distributions over p_T are also invariant

This allows us to extend our fit from 1D mass to 2D p_T and ρ

Design a transform to decorrelate against mass and p_T

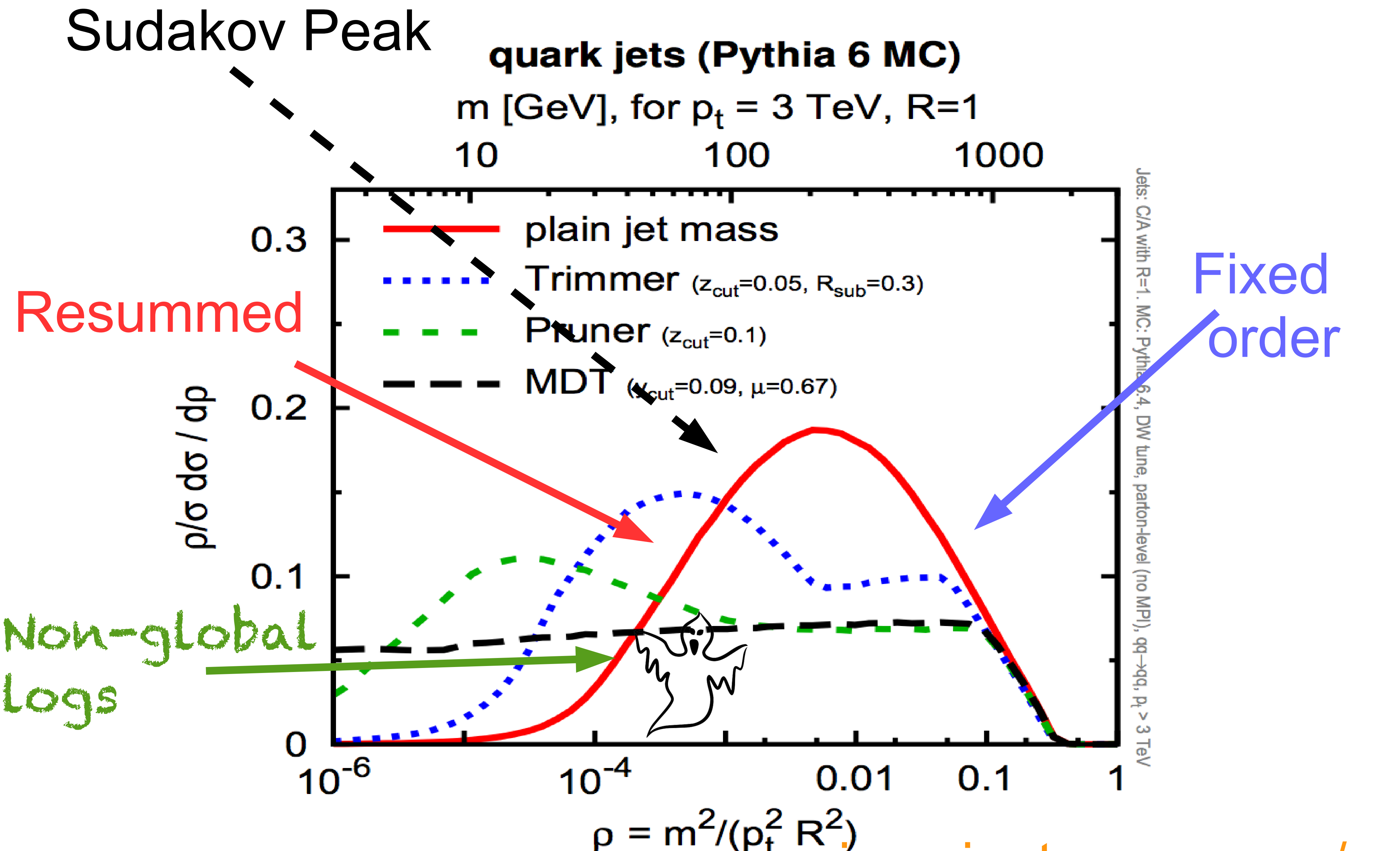
Decorrelating avoid mass sculpting allows us to cut tighter



As a first example decorrelate $N_2 \rightarrow N_2^{DDT} = N_2 - \varepsilon(x\%)$

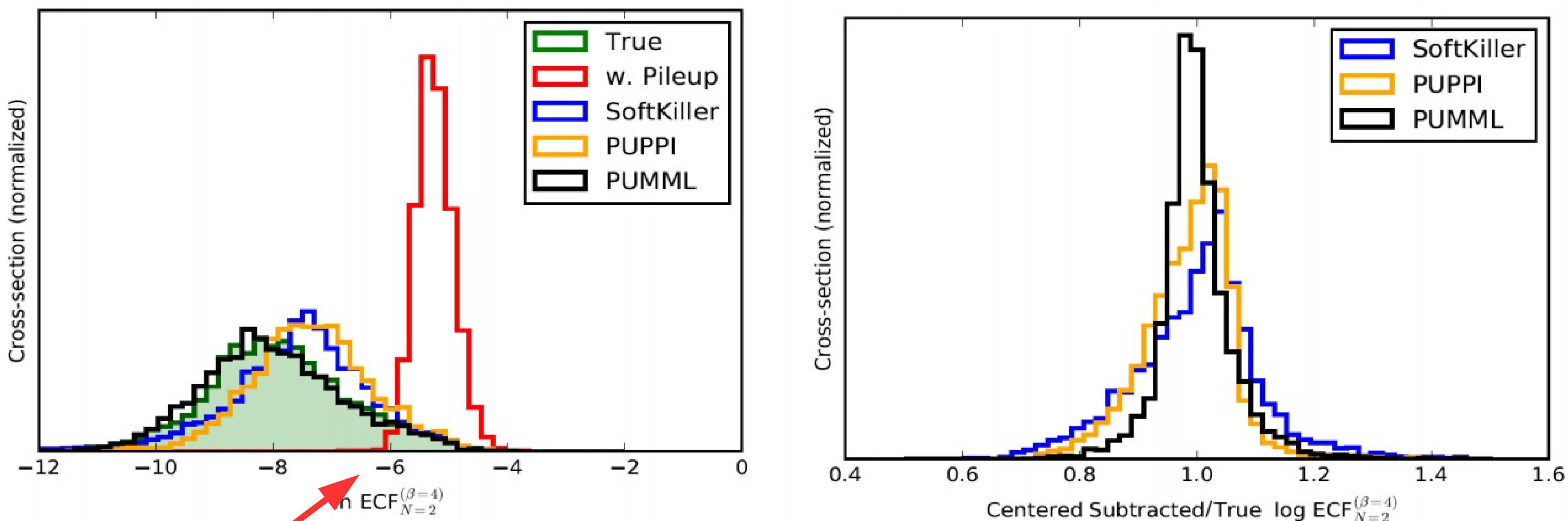
arXiv:1603.00027

Anatomy of Jet Mass: Theory



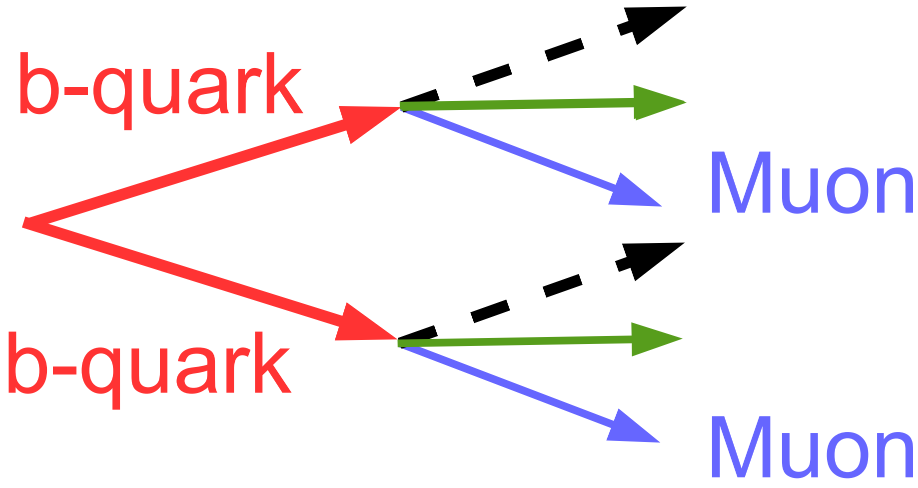
Calculate in ρ invariant over mass/p_T

New directions II: PUMML
PU mitigation w/Machin Leaning

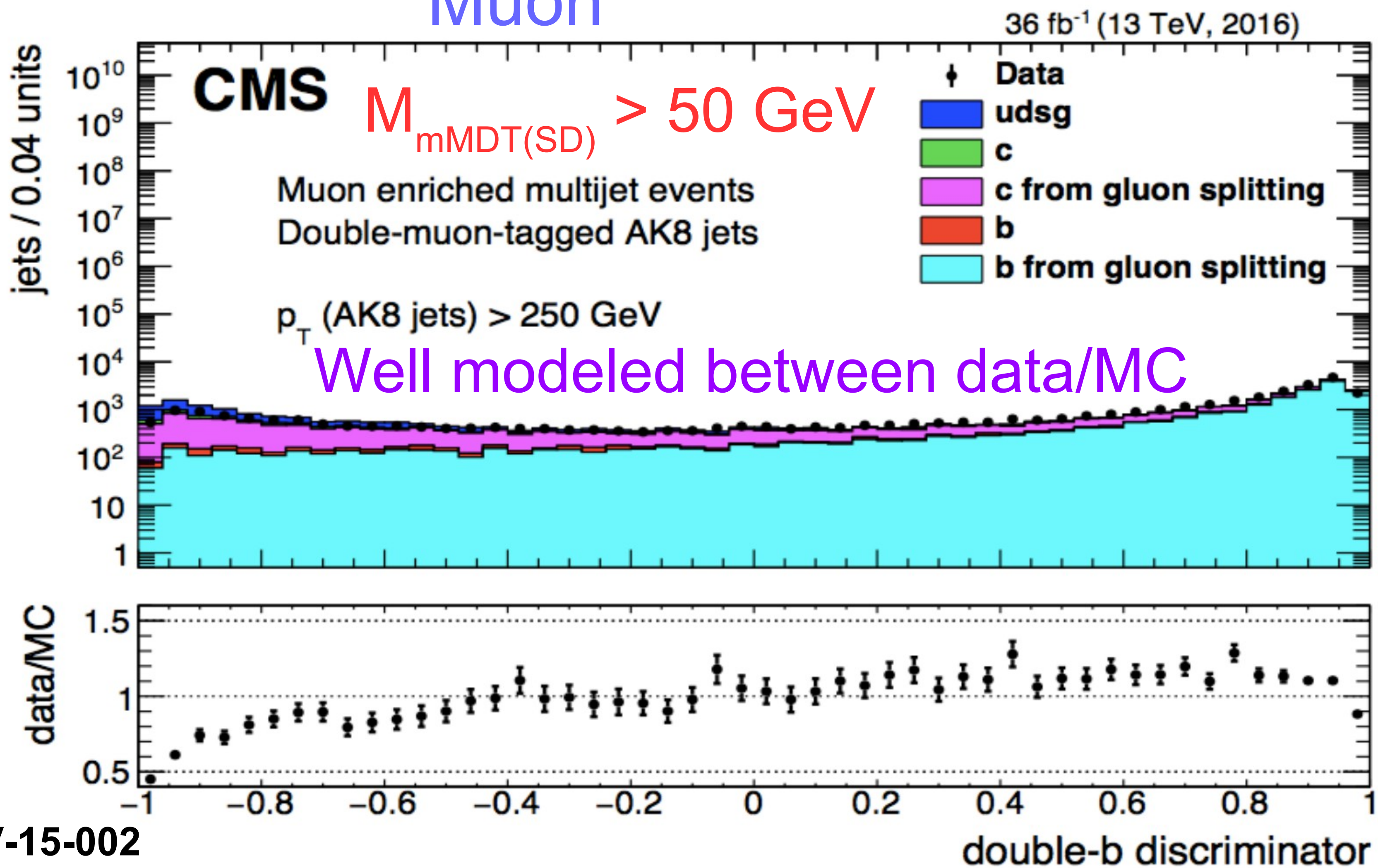


Understanding jets requires resolving jet properties in the dense environment of the LHC (known as pileup)

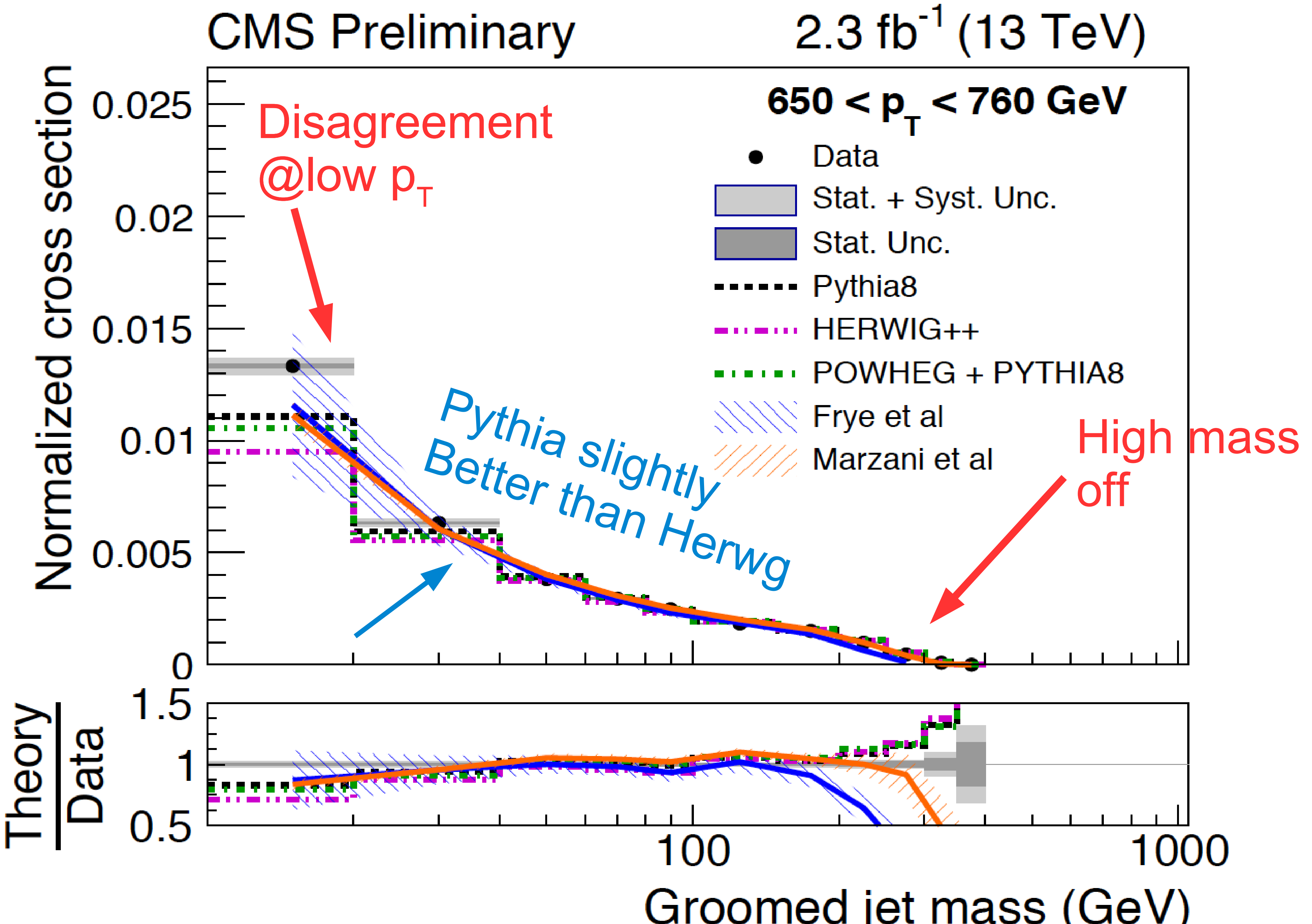
What about data/MC



Tag two muons in a jet
Use this to infer signal-like
2 b-quarks in a jet



CMS-BTV-15-002

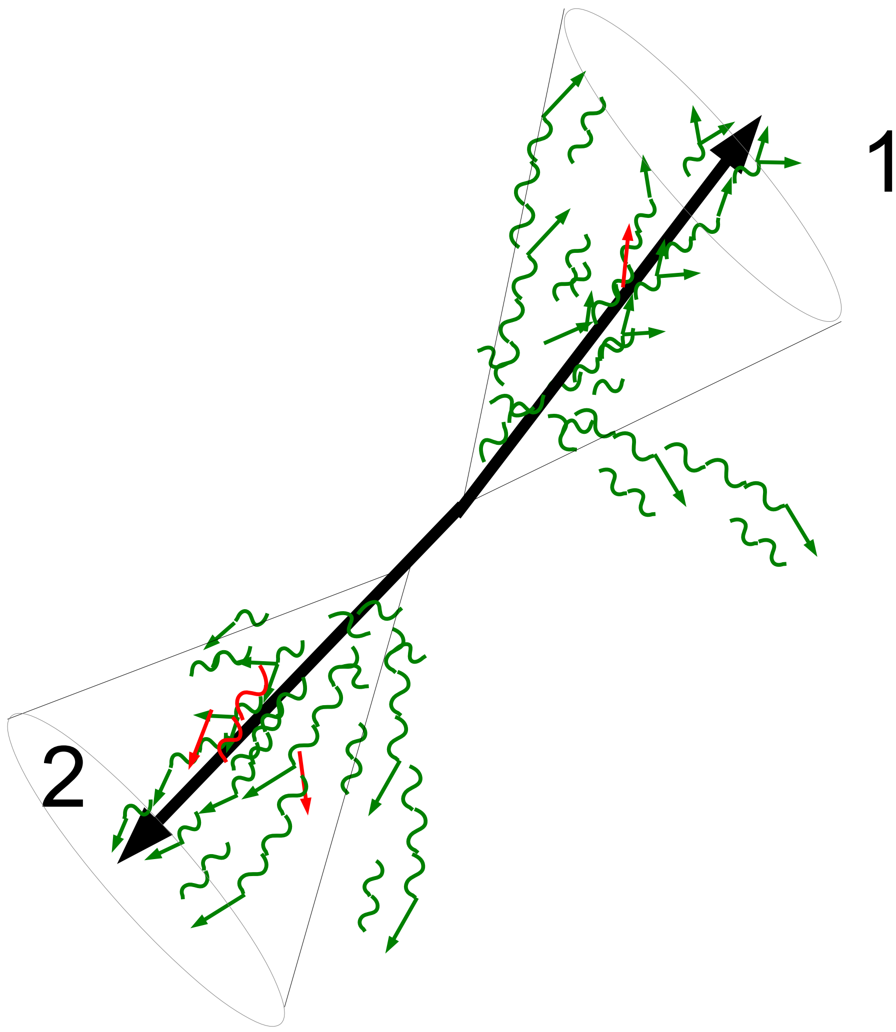


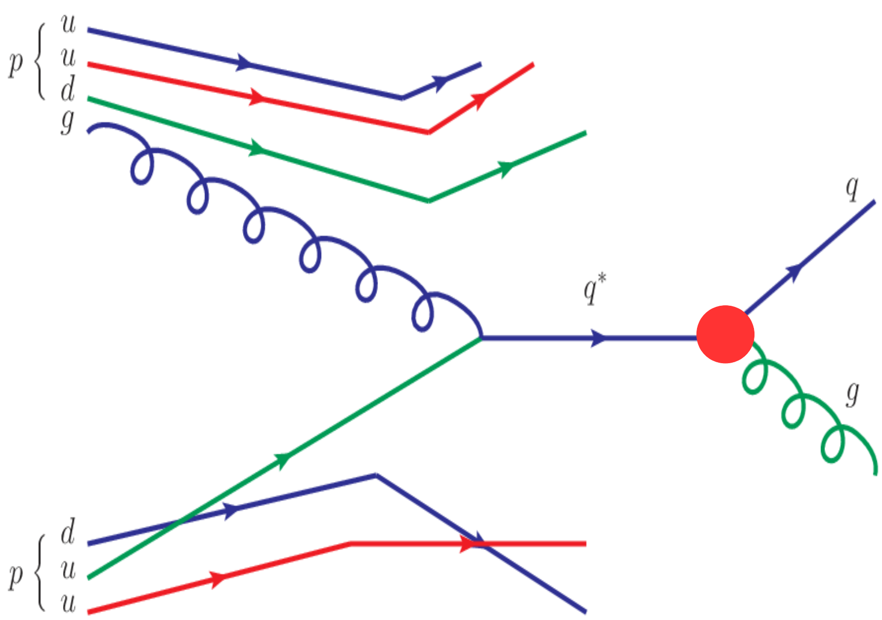
CMS-SMP-16-010

Basic Jet Measurements

In olden days :
Cared about the dijet process

The concern here :
good jet reconstruction to
resolve partons

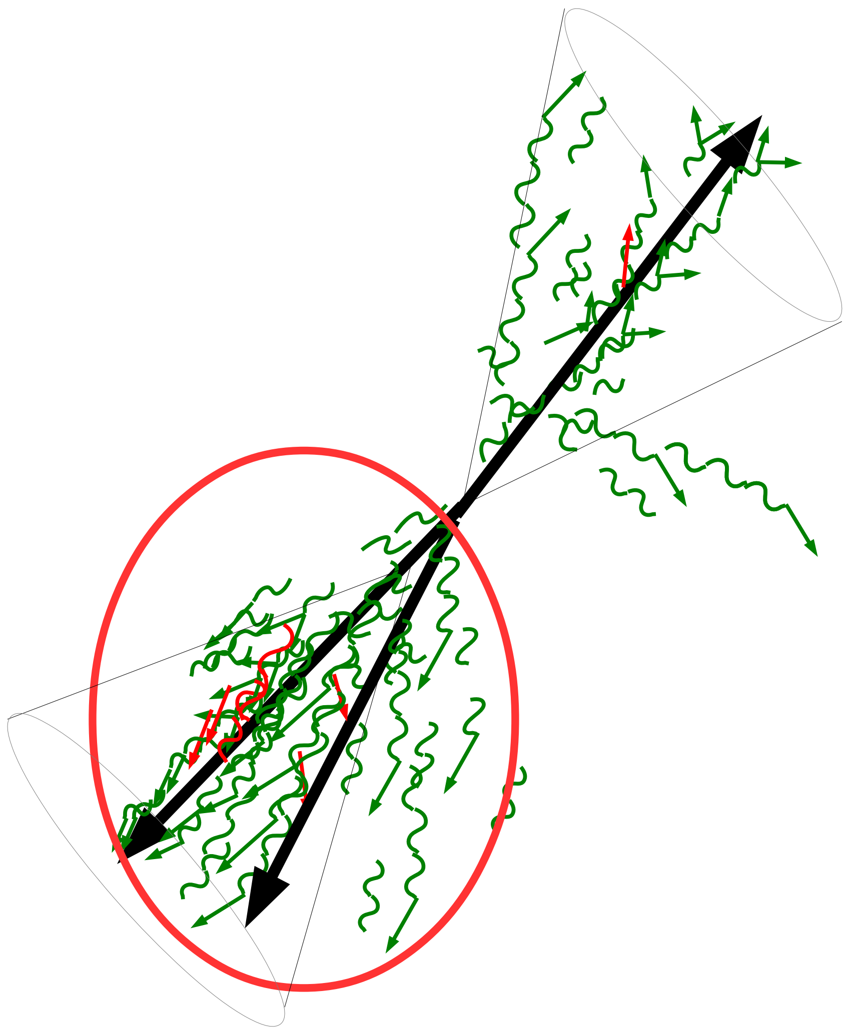




Collinear splittings

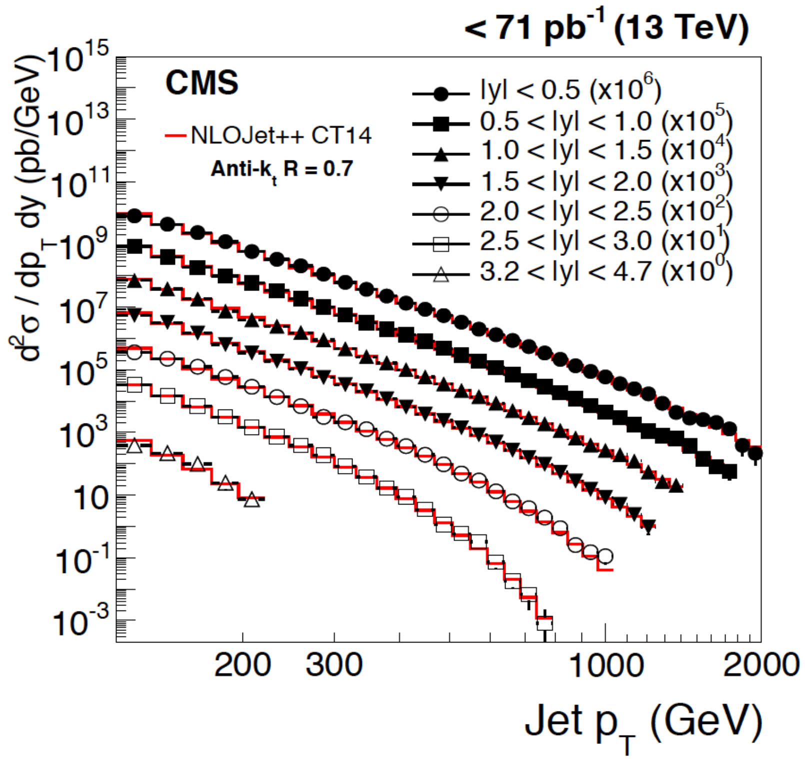
Currently:
Care about collinear splittings

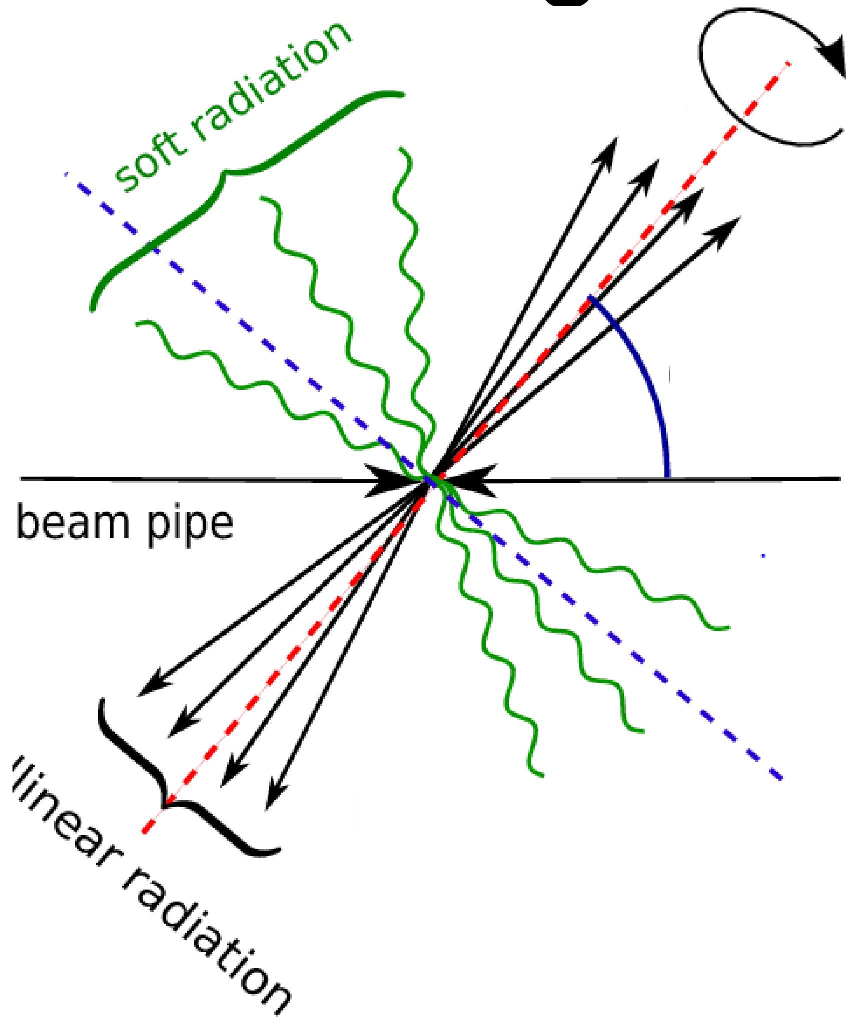
The concern here :
Jet mass is a fundamental test of QCD
Also a tool for more?

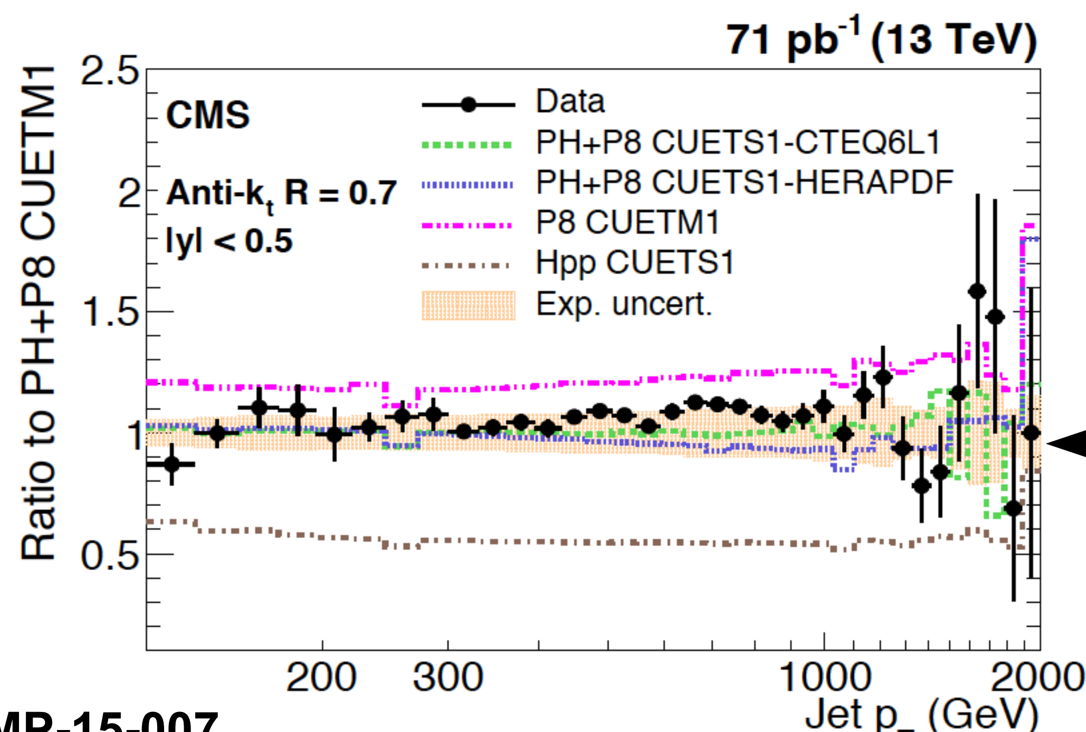


In the case about the individual process of the jet
This will be focus of the rest of this talk

Understanding them



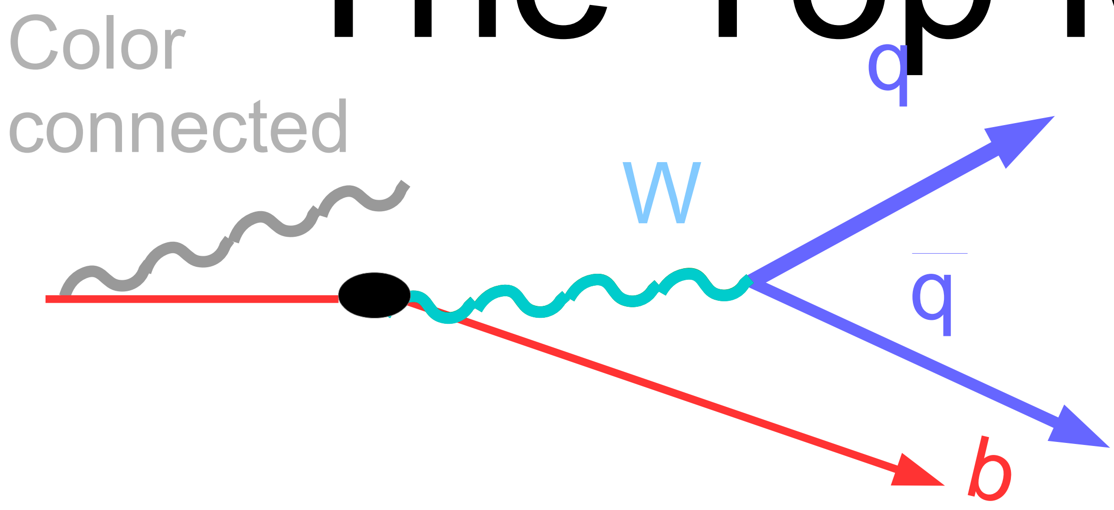




Basic jet measurements Allow us to probe the production

SMP-15-007

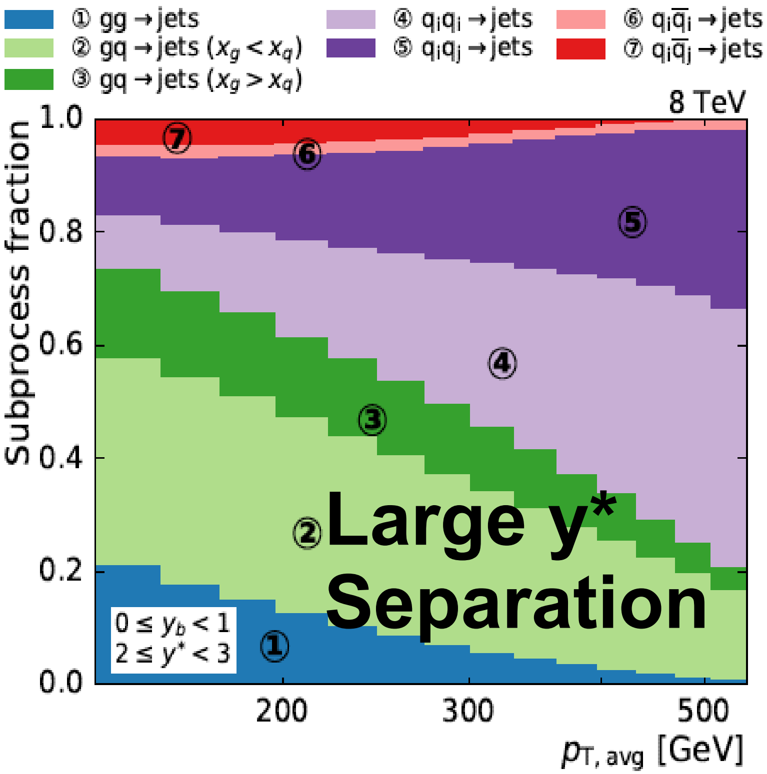
The Top Mass



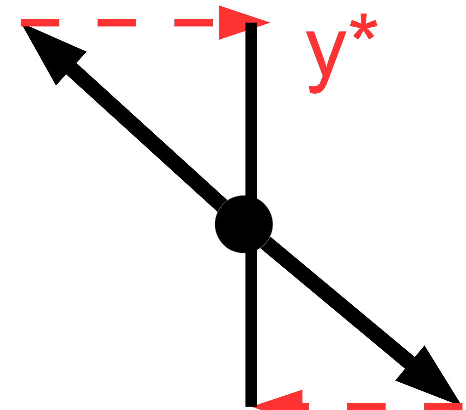
Top decays are a great probe of complicated objects

Complicated object with rich topology
Mass measurement requires understanding them

Understanding them

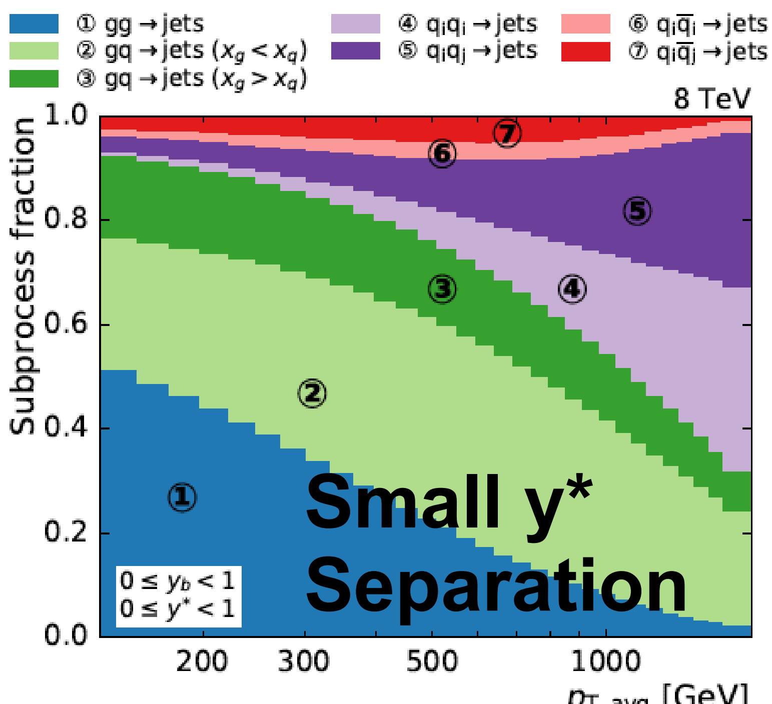


Quark initiated

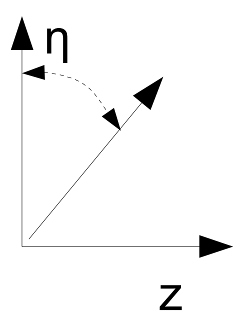


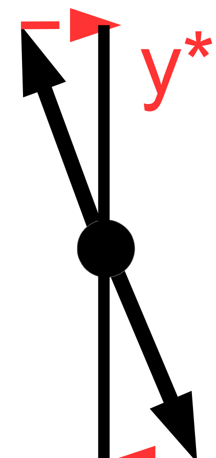
$$y_b = |y_1 + y_2|/2,$$
$$y^* = |y_1 - y_2|/2,$$

Binning the dijet kinematics allows for constraints on different diagrams



Gluon Initiated



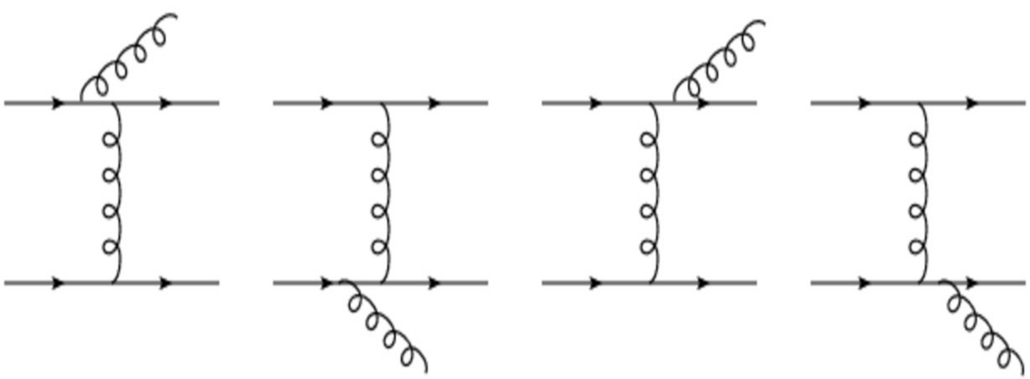


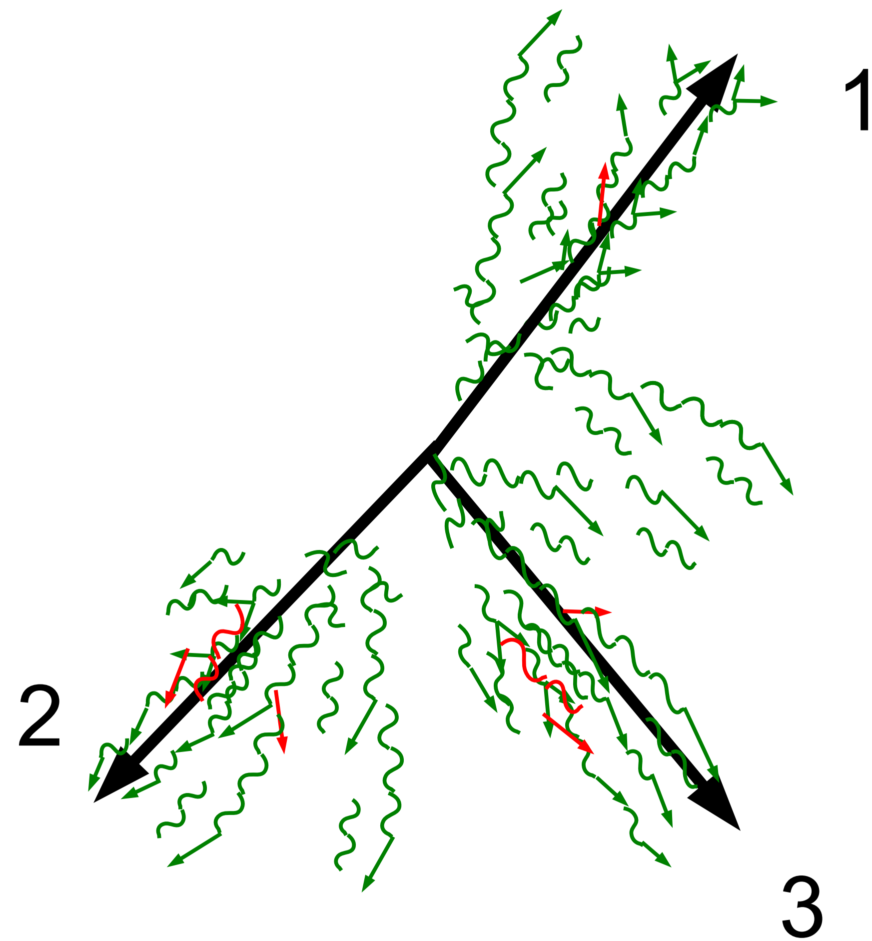
SMP-16-011

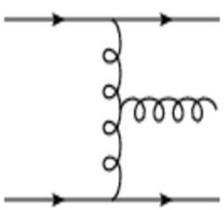
Basic Jet Measurements

In slightly less old days:
  Cared about 3 jet process

The concern here :
  Split out partons by type and study additional QCD properties







Now we can probe the 3rd radiated jet :
Gives insight into ME splittings

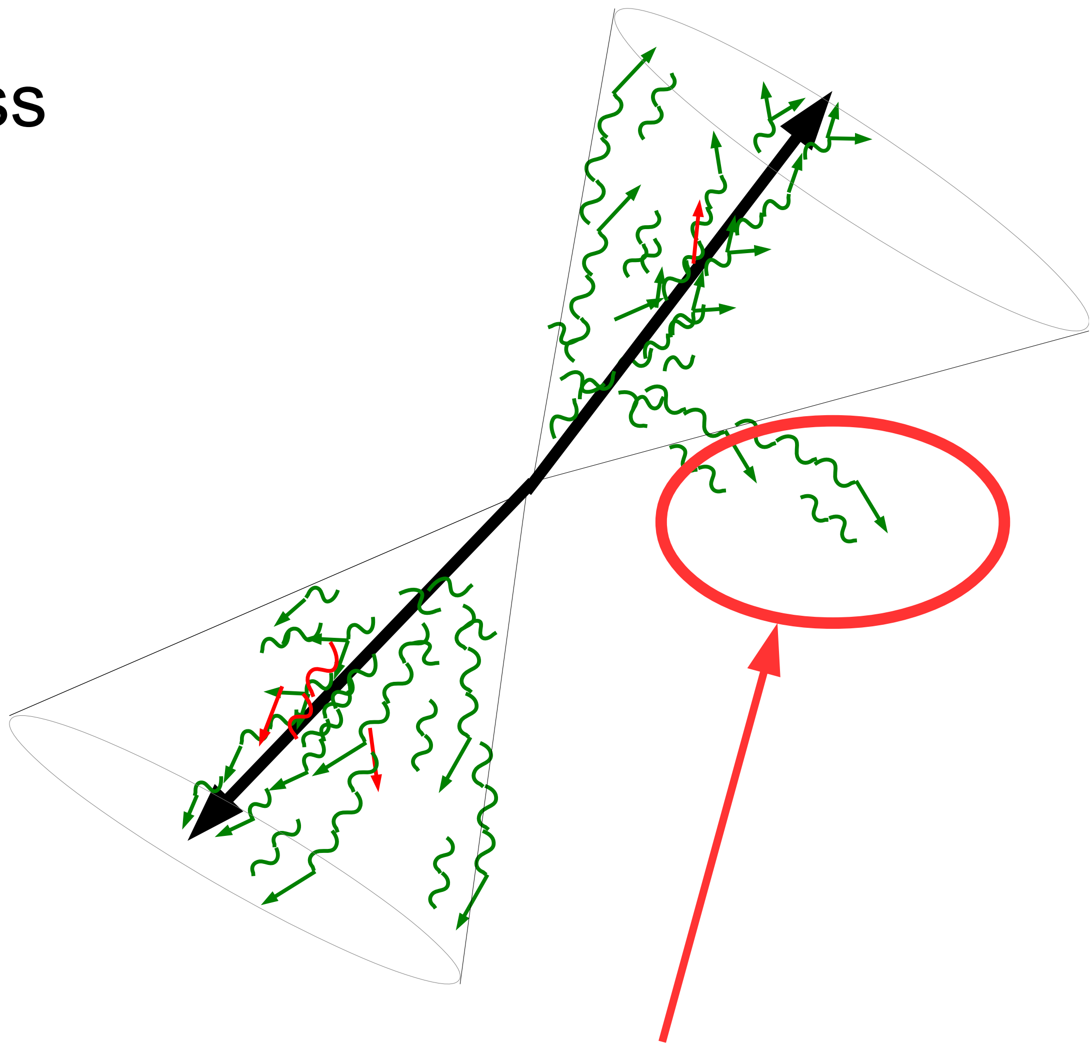
Basic Jet Measurements

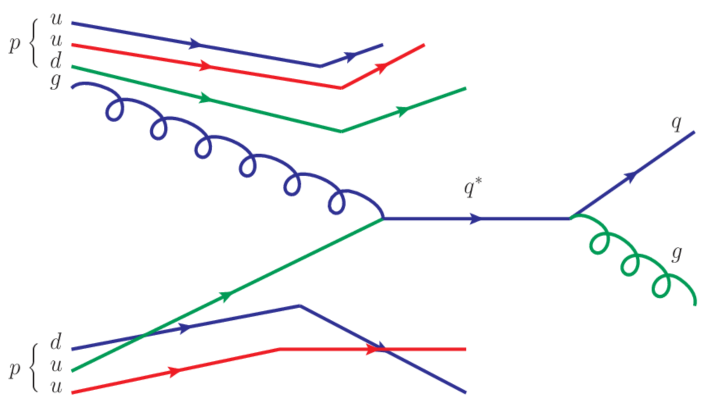
In olden days :

Cared about the dijet process

The concern here :

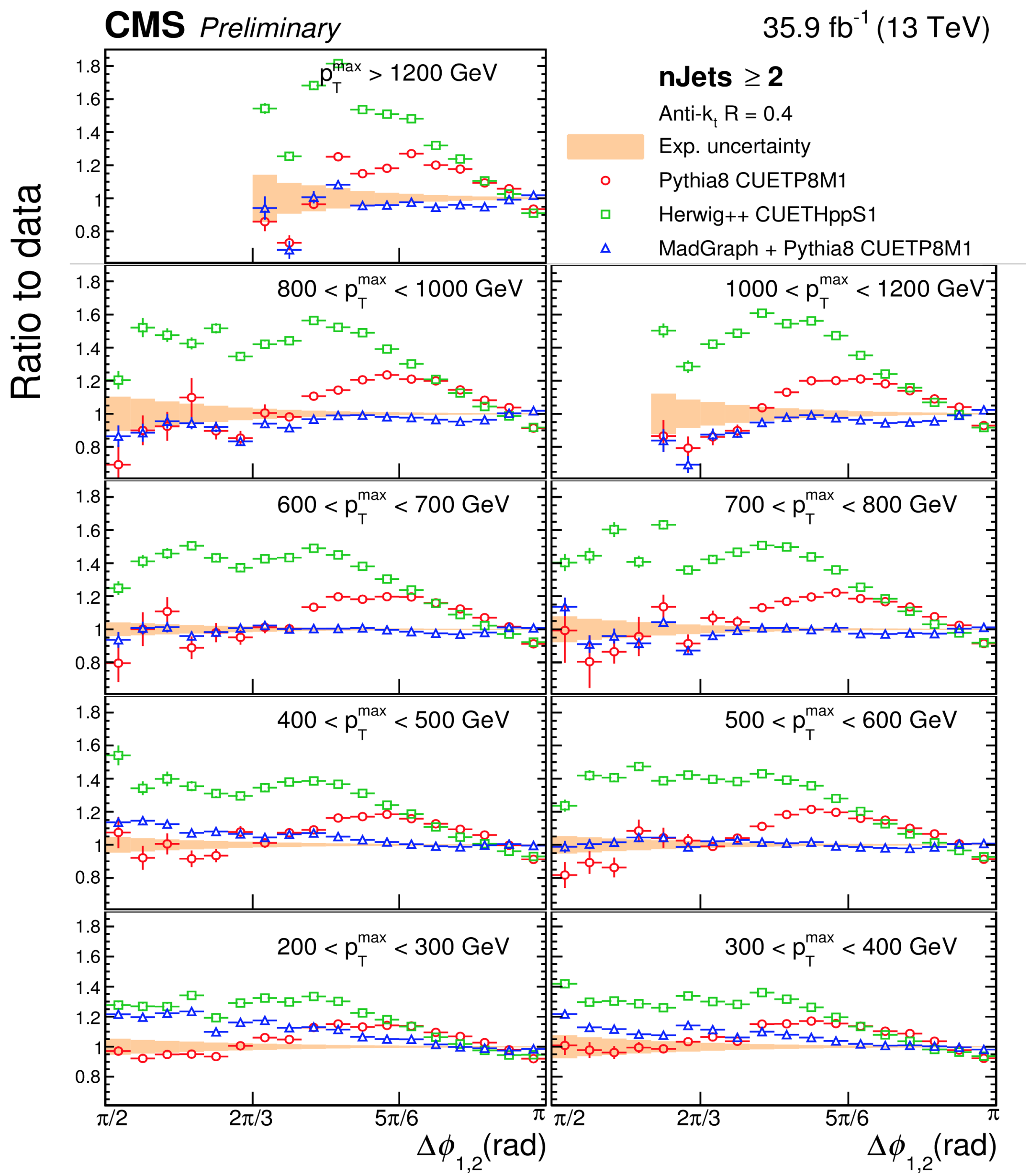
good jet reconstruction to resolve partons

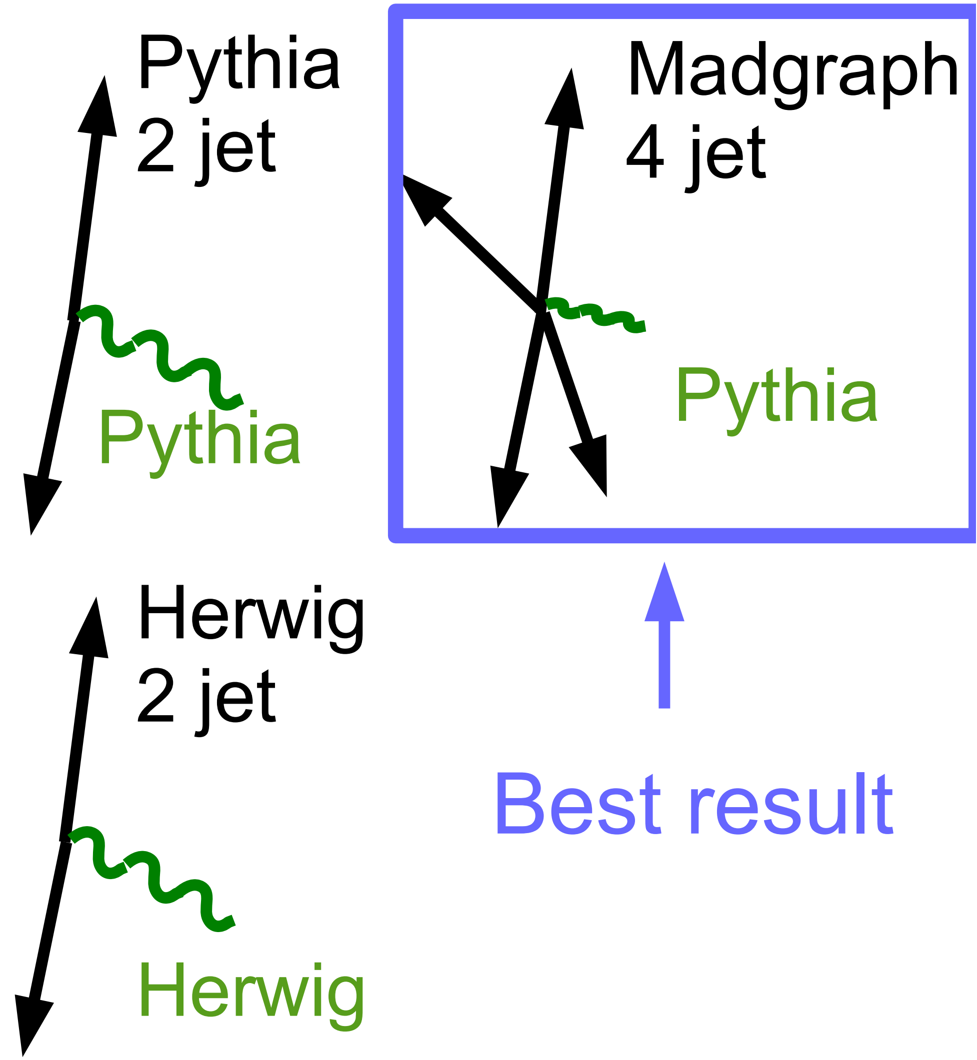




Aim of the game is to capture the full parton

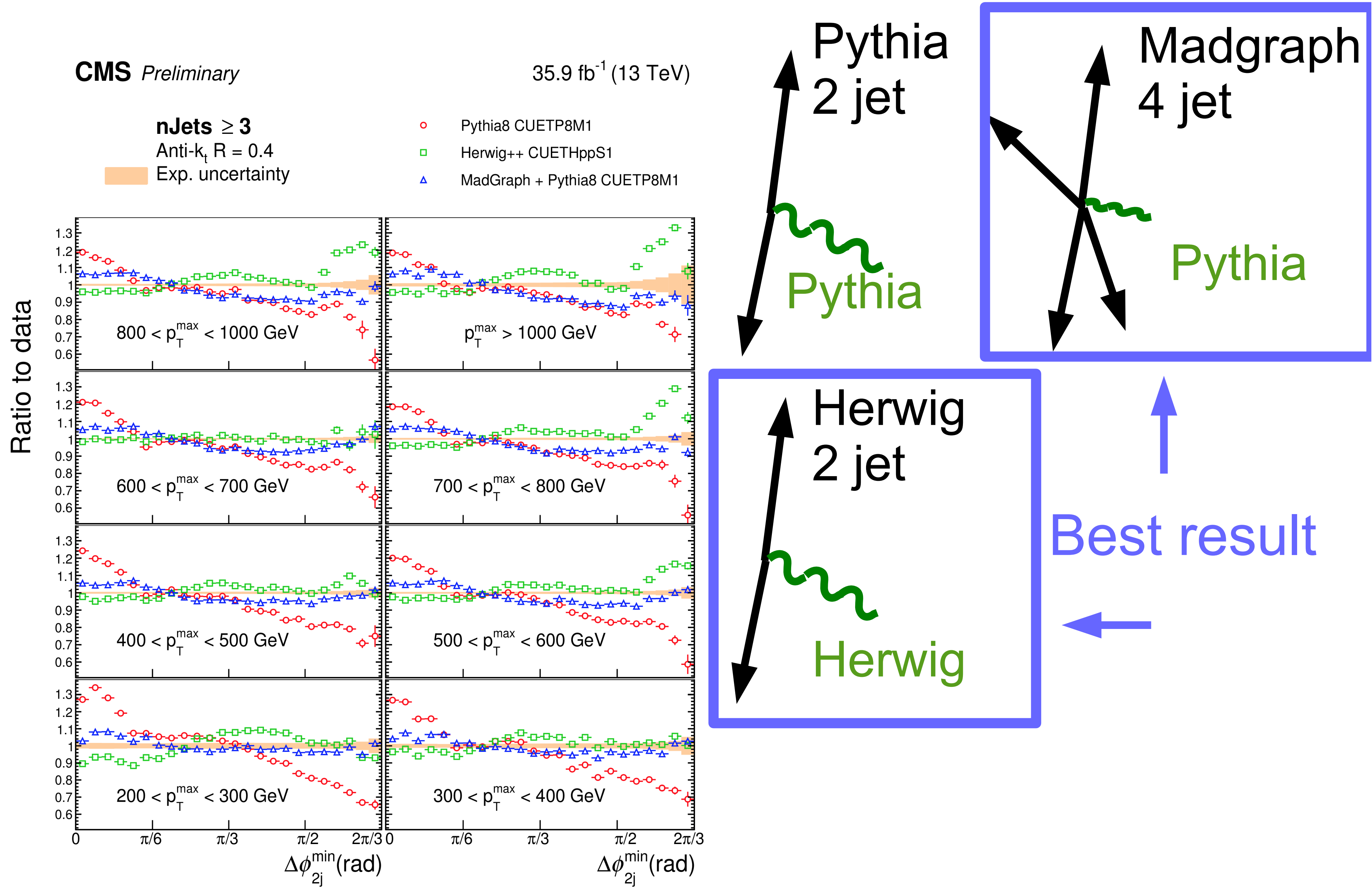
2 Jet Measurement



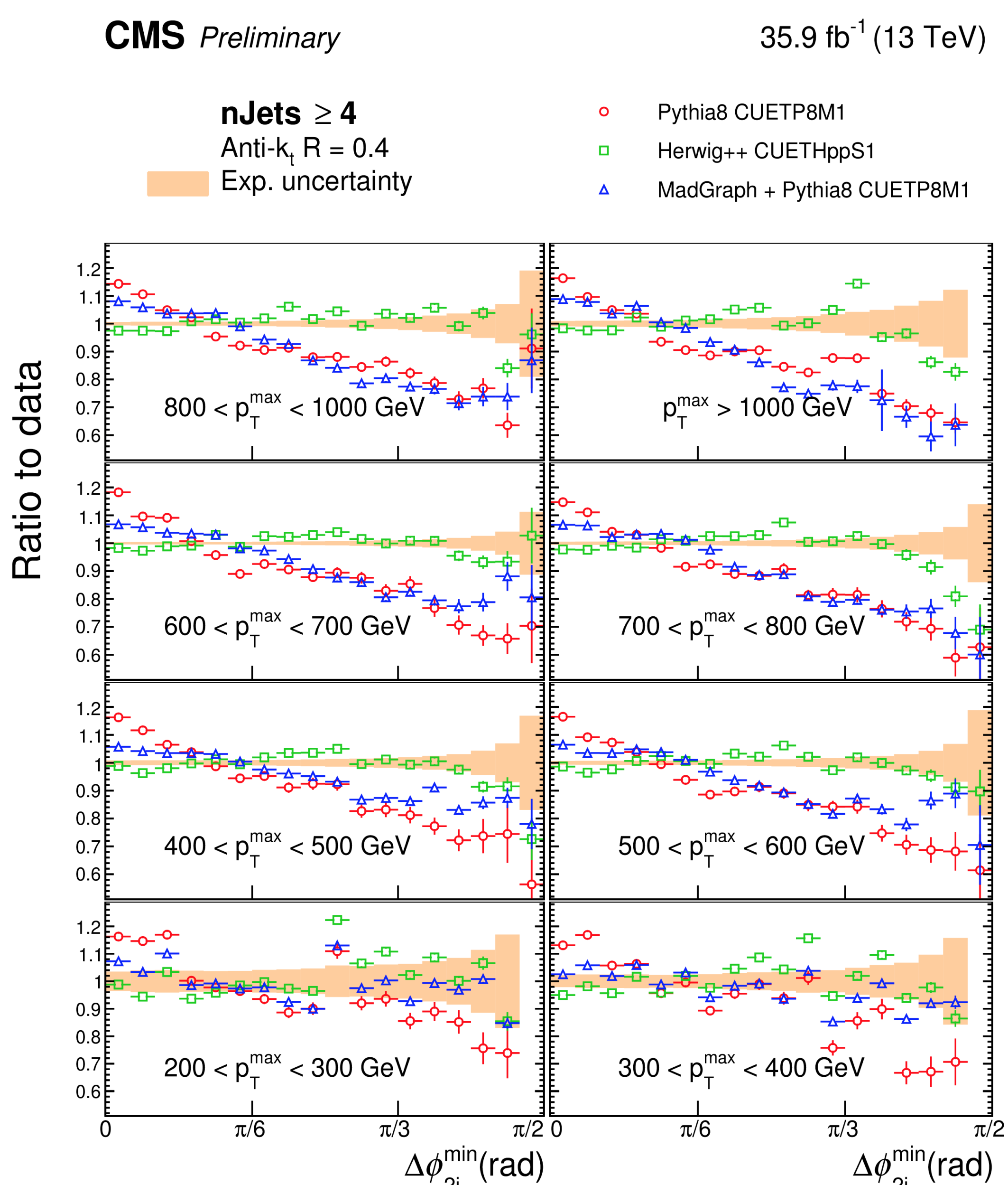


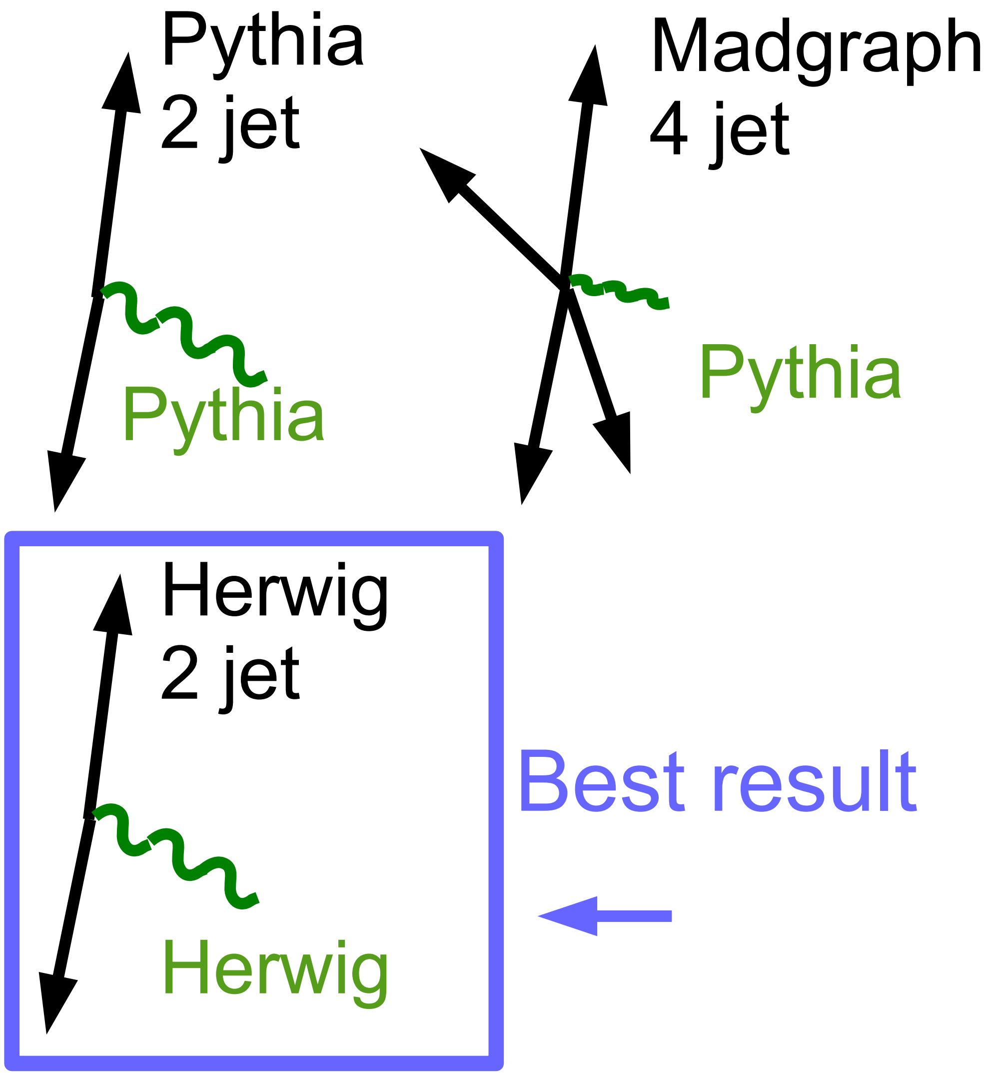
SMP-16-014

3 Jet Measurement



4 Jet Measurement





Observation:

Herwig models parton shower

ME level an improvement

Collinear splittings

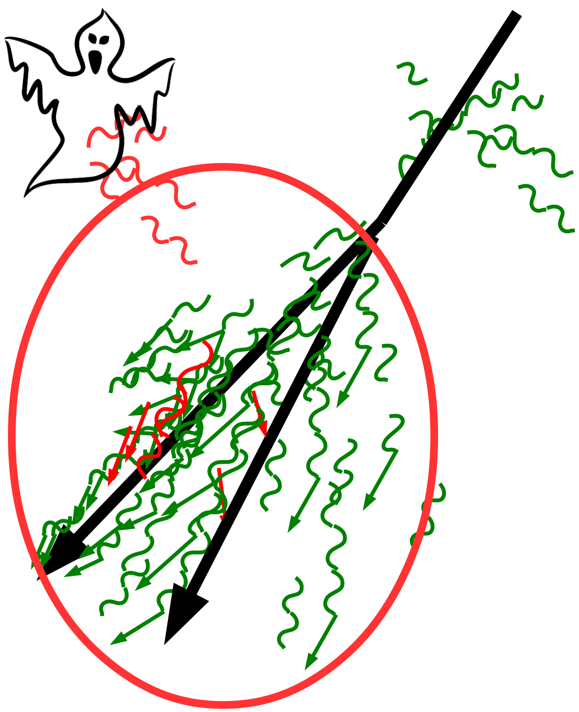
Currently:
Care about collinear splittings

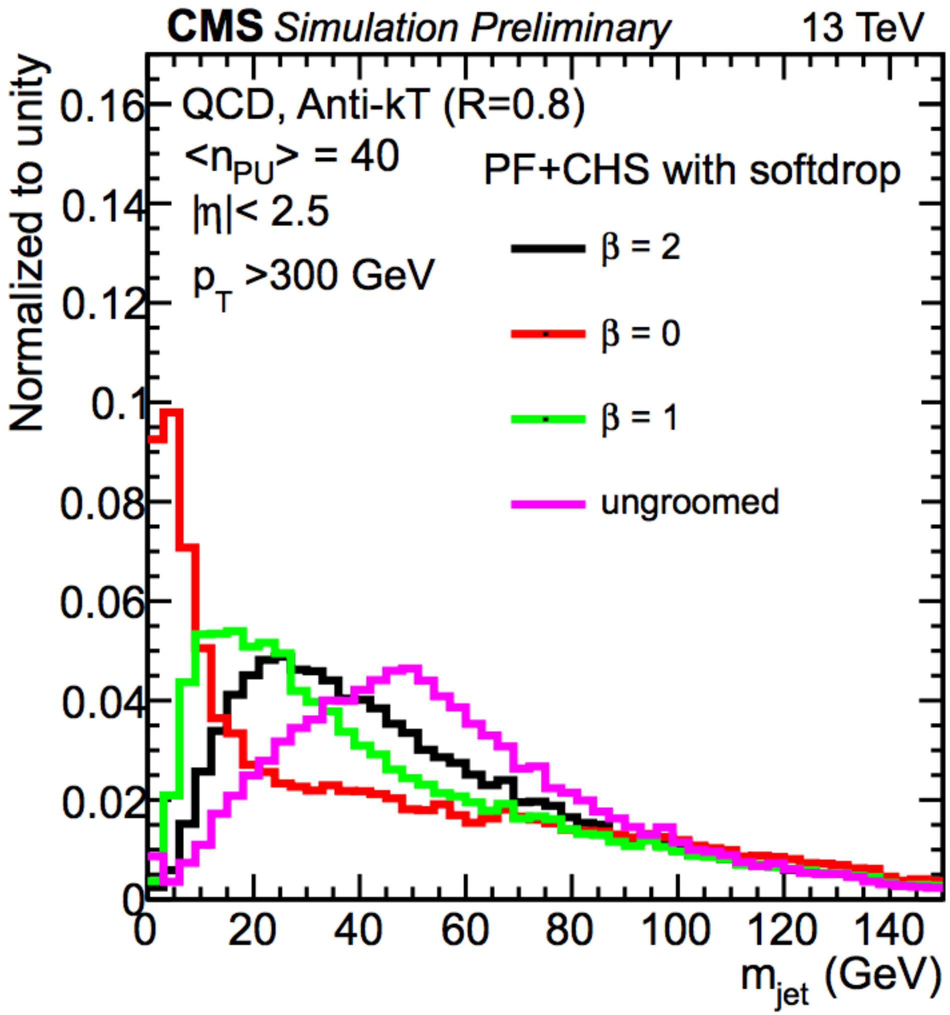
The concern here :
Jet mass is a fundamental test of QCD
Also a tool for more?

In the case about the individual process of the jet
This will be focus of the rest of this talk

Jet Mass Measurement

- Improving the measurement

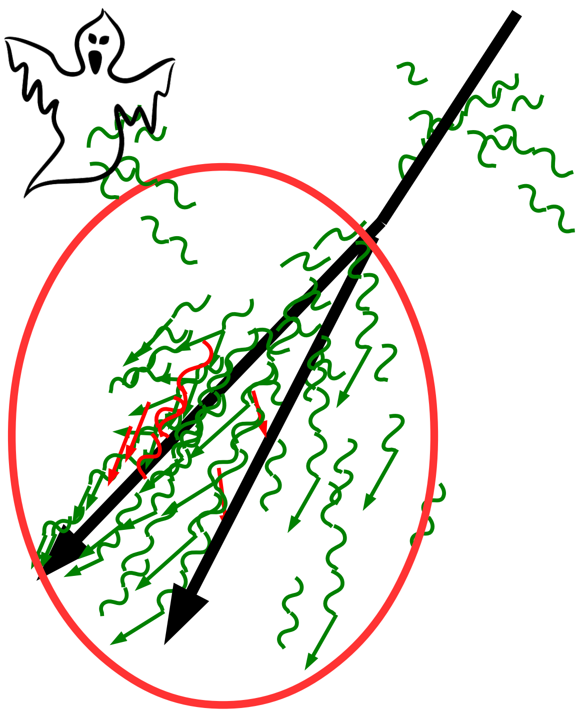


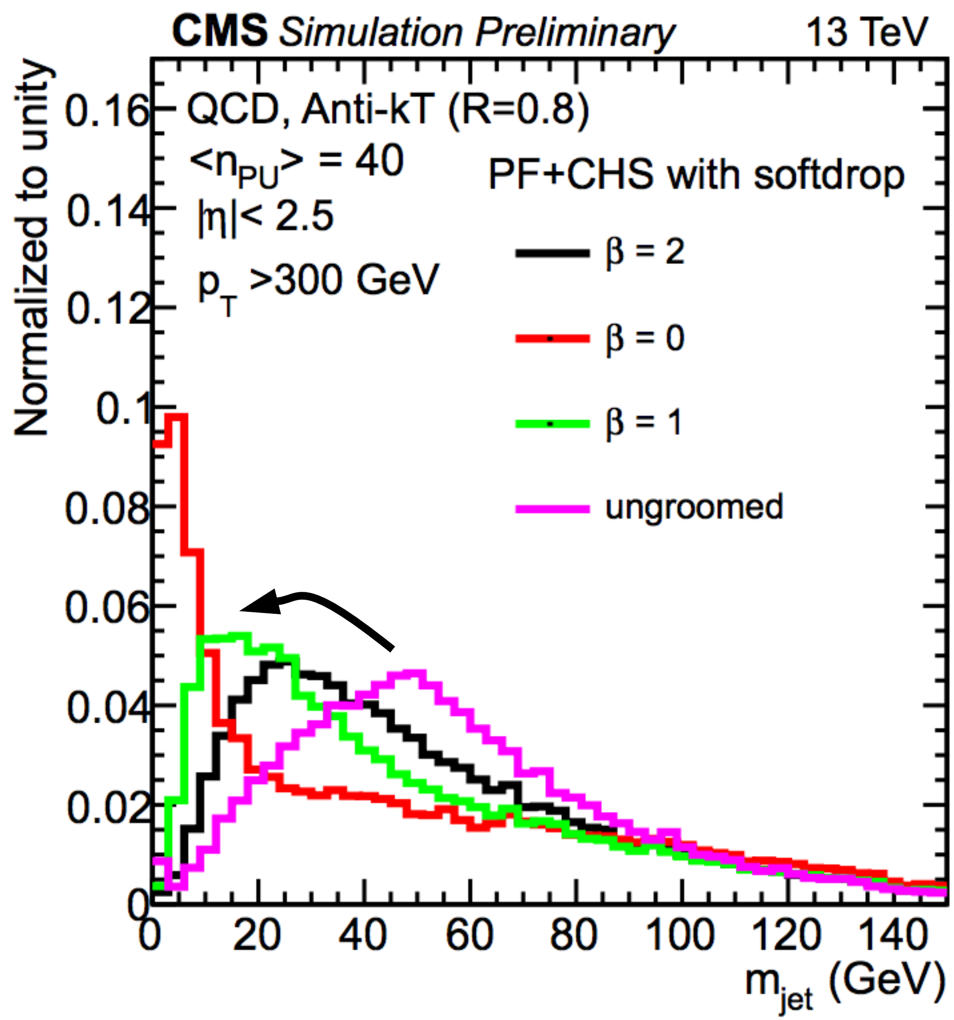


CMS-JME-14-001

Jet Mass Measurement

- Improving the measurement

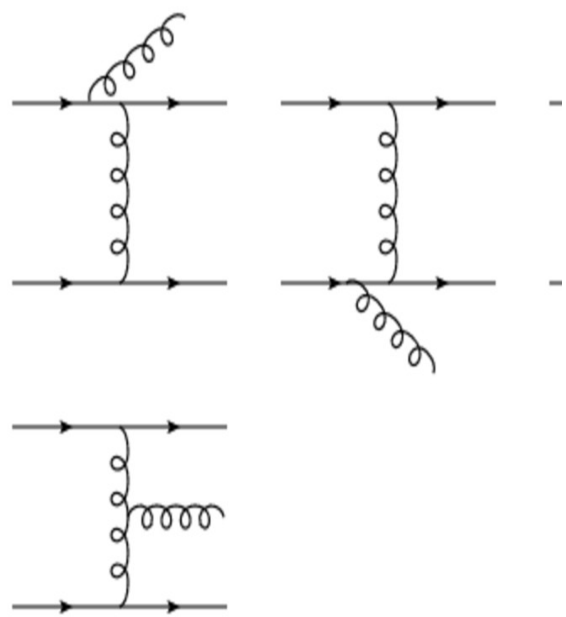


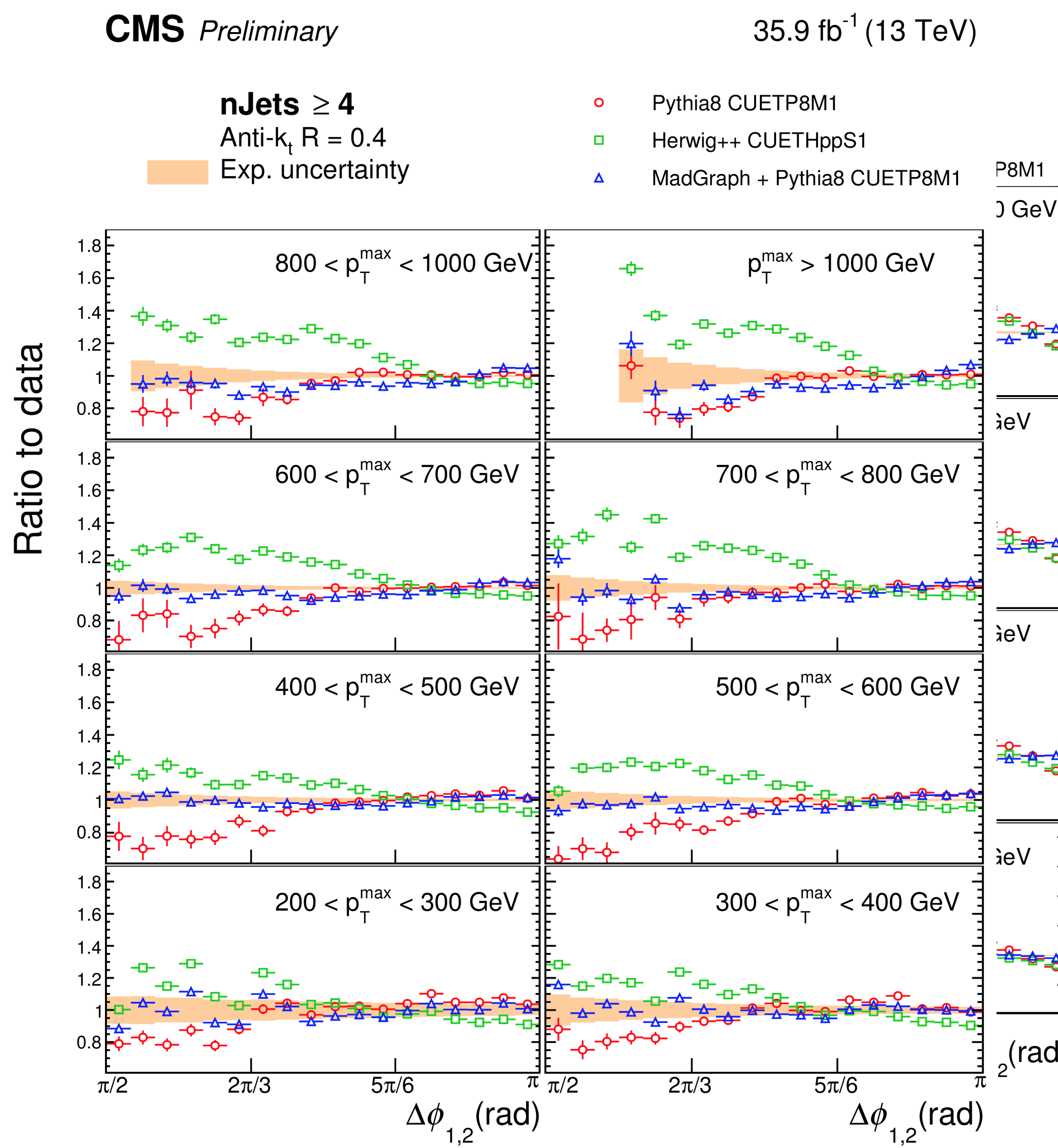


CMS-JME-14-001

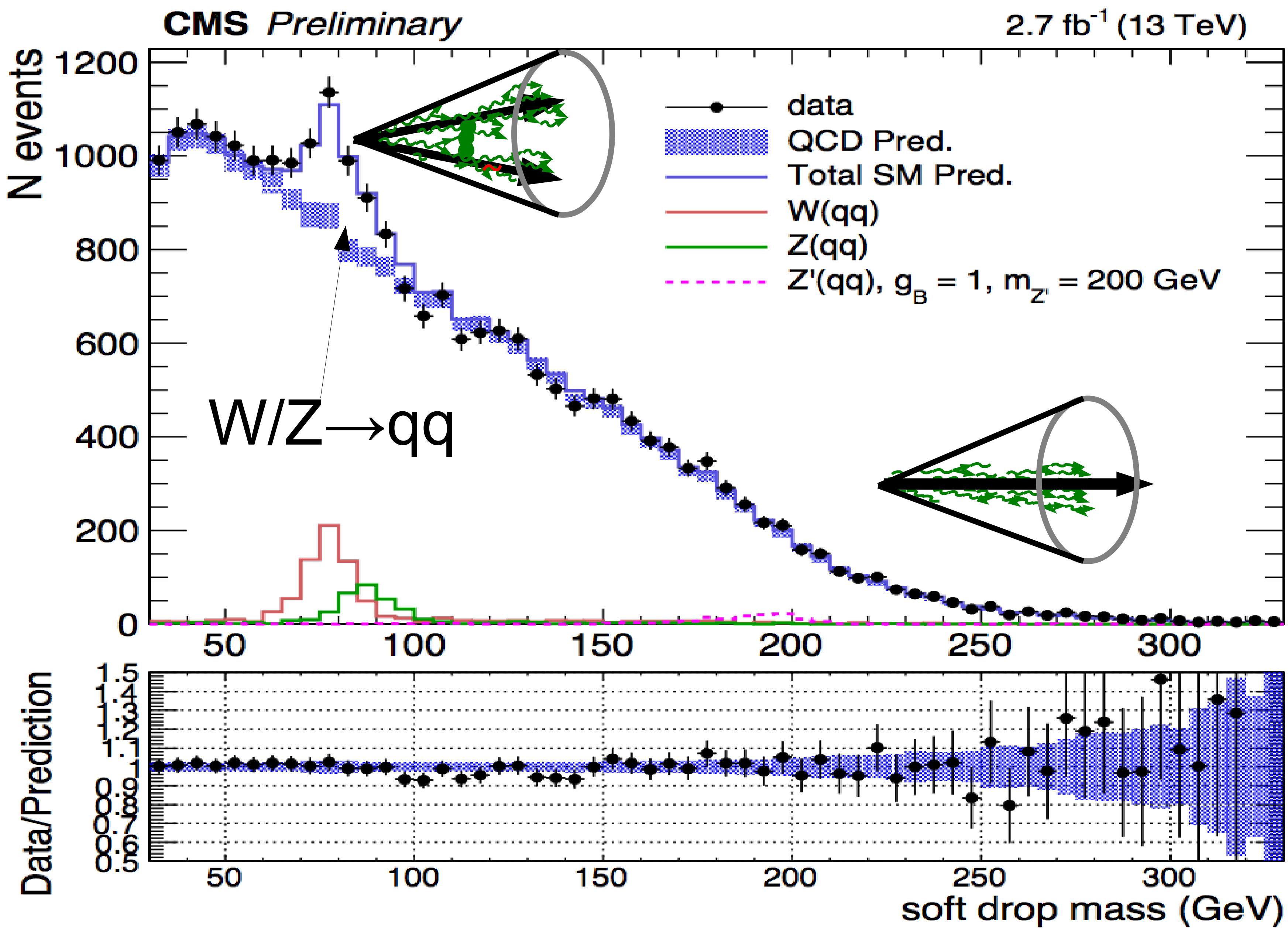
In slightly less olc
Cared about 3 j

The concern here
Split out parto
study additior
properties

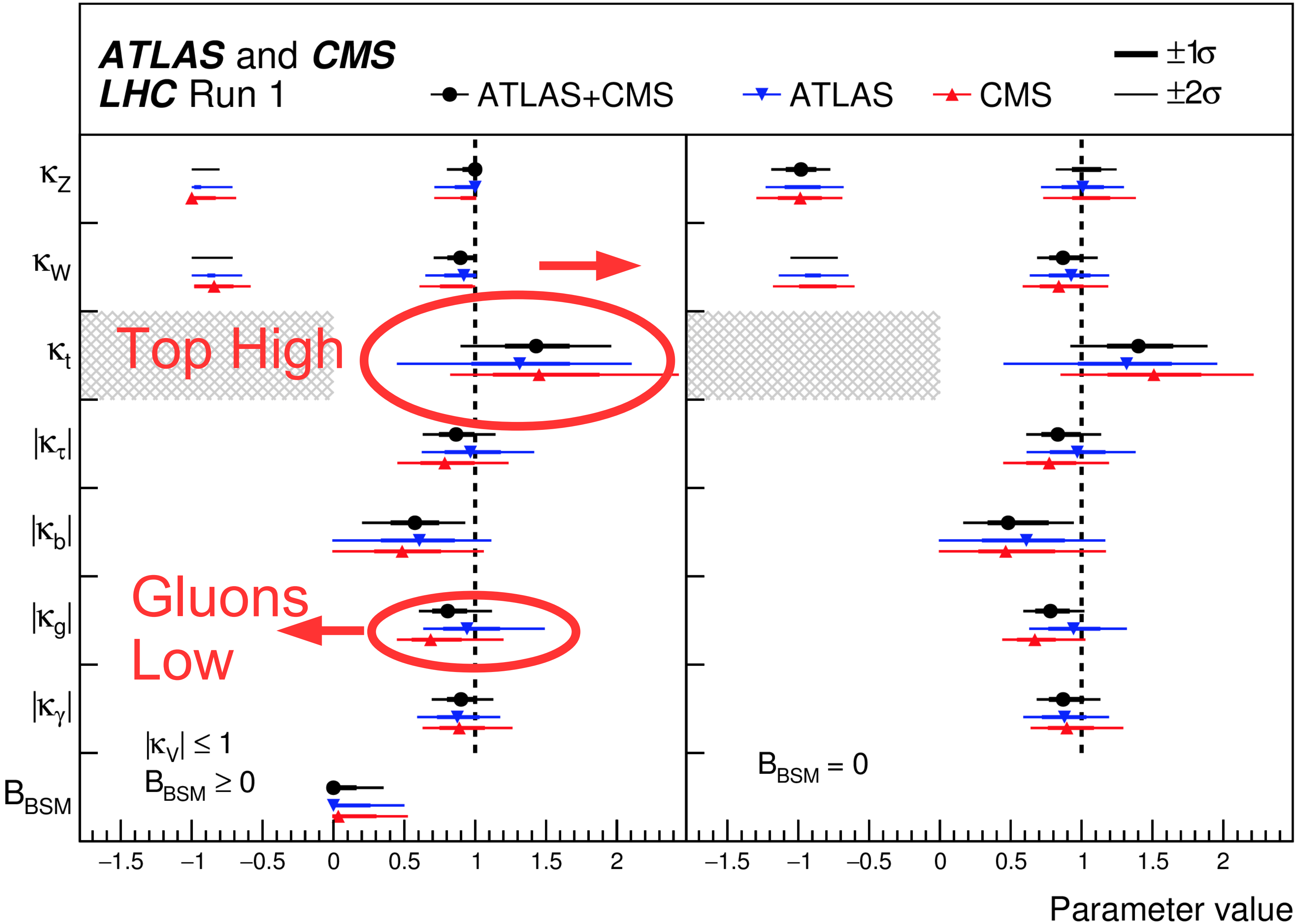




Jet Mass distribution

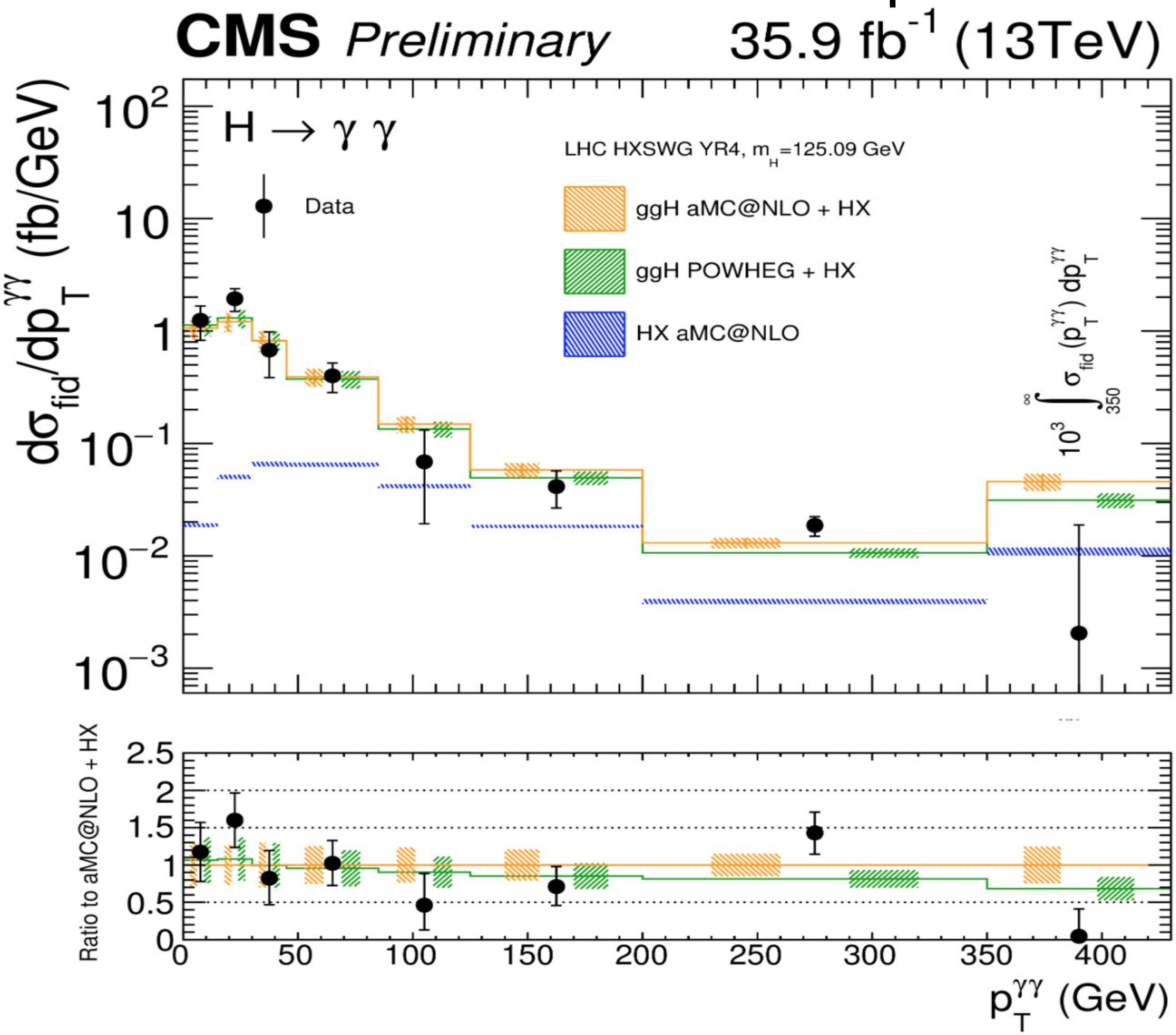


Hints?



ATLAS and CMS
LHC Run 1
ATLAS+CMS
ATLAS
CMS
±1σ
±2σ
κZ
κW
κt
|κτ|
|κb|
|κg|
|κγ|
BBSM
Top High
Gluons
Low
|κV| ≤ 1
BBSM ≥ 0
BBSM = 0
−1.5 −1 −0.5 0 0.5 1 1.5 2
Parameter value

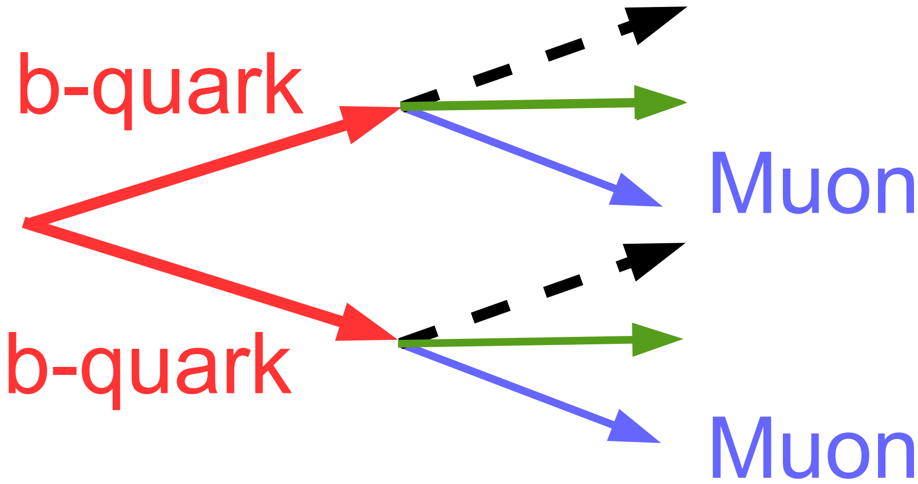
Current Best Higgs p_T measurement



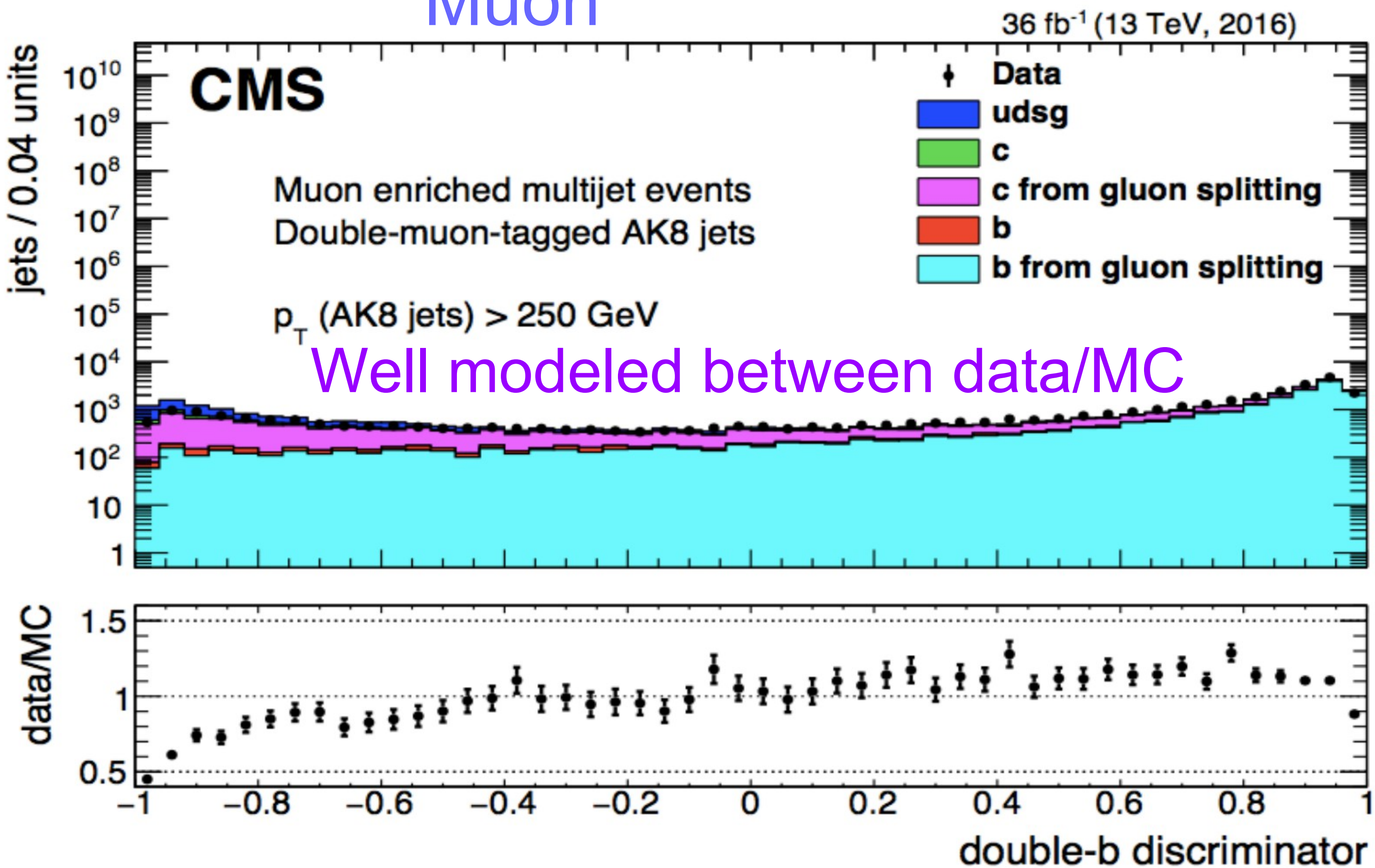
Analysis starts here

No other way to look for events in this region

What about data/MC

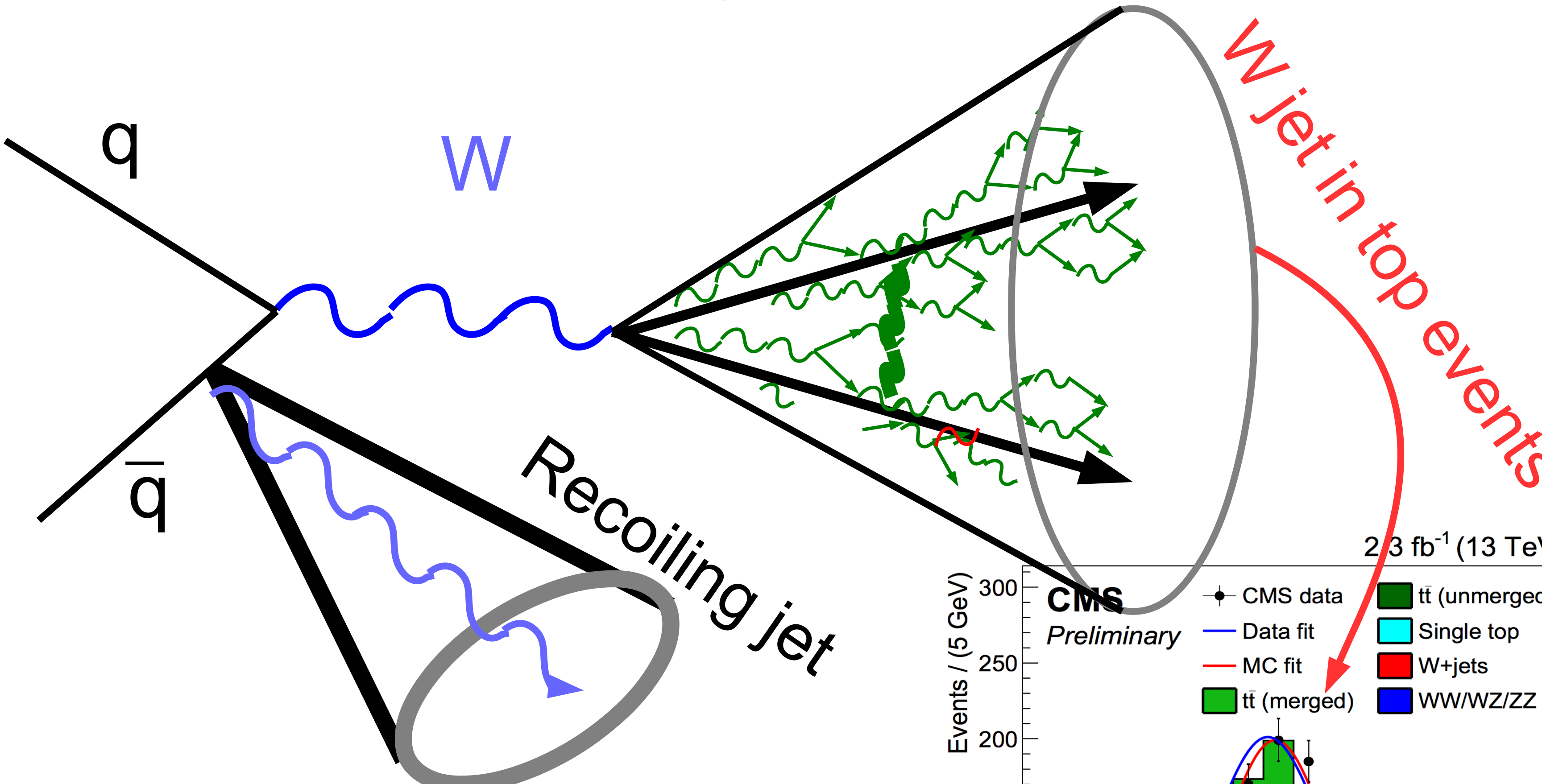


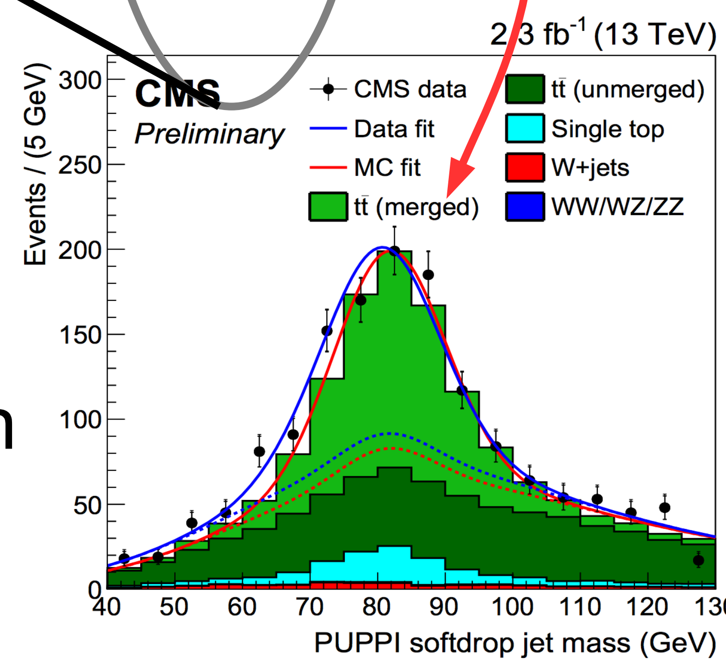
Tag two muons in a jet
Use this to infer signal-like
2 b-quarks in a jet



Whats the first goal?

Require W to be a high p_T

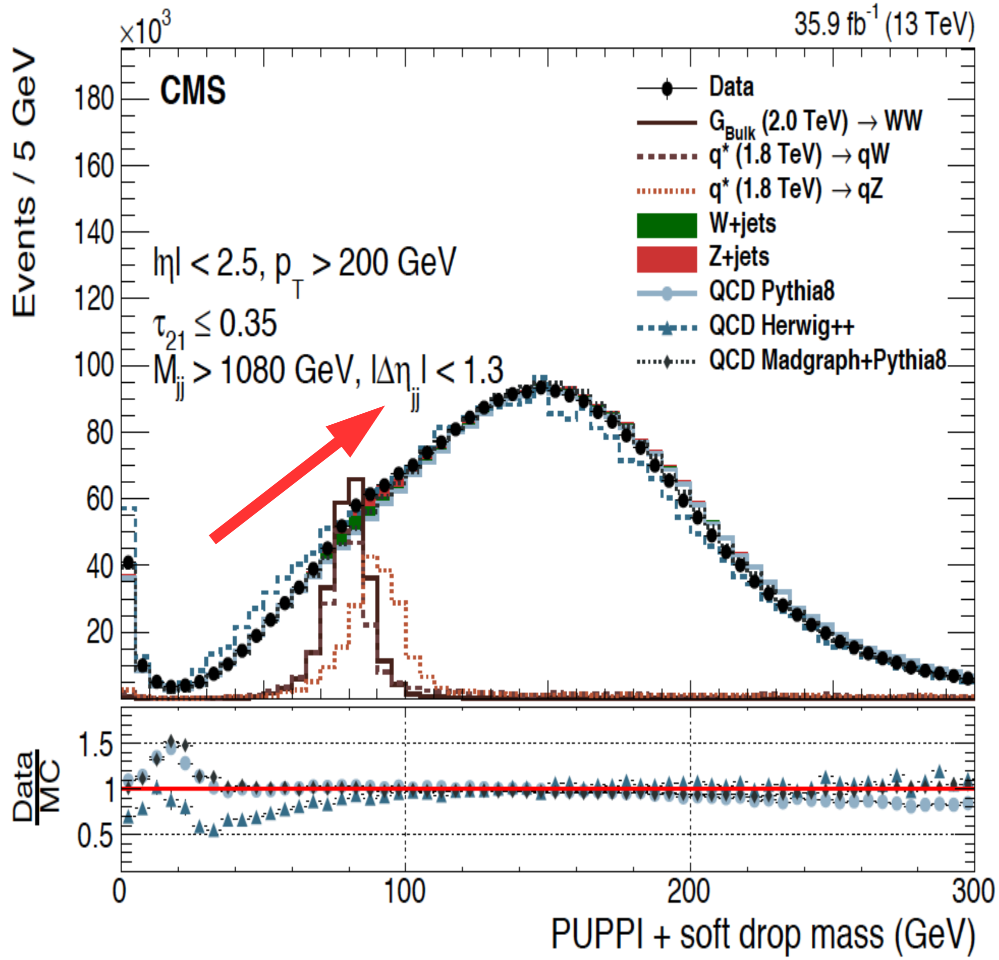


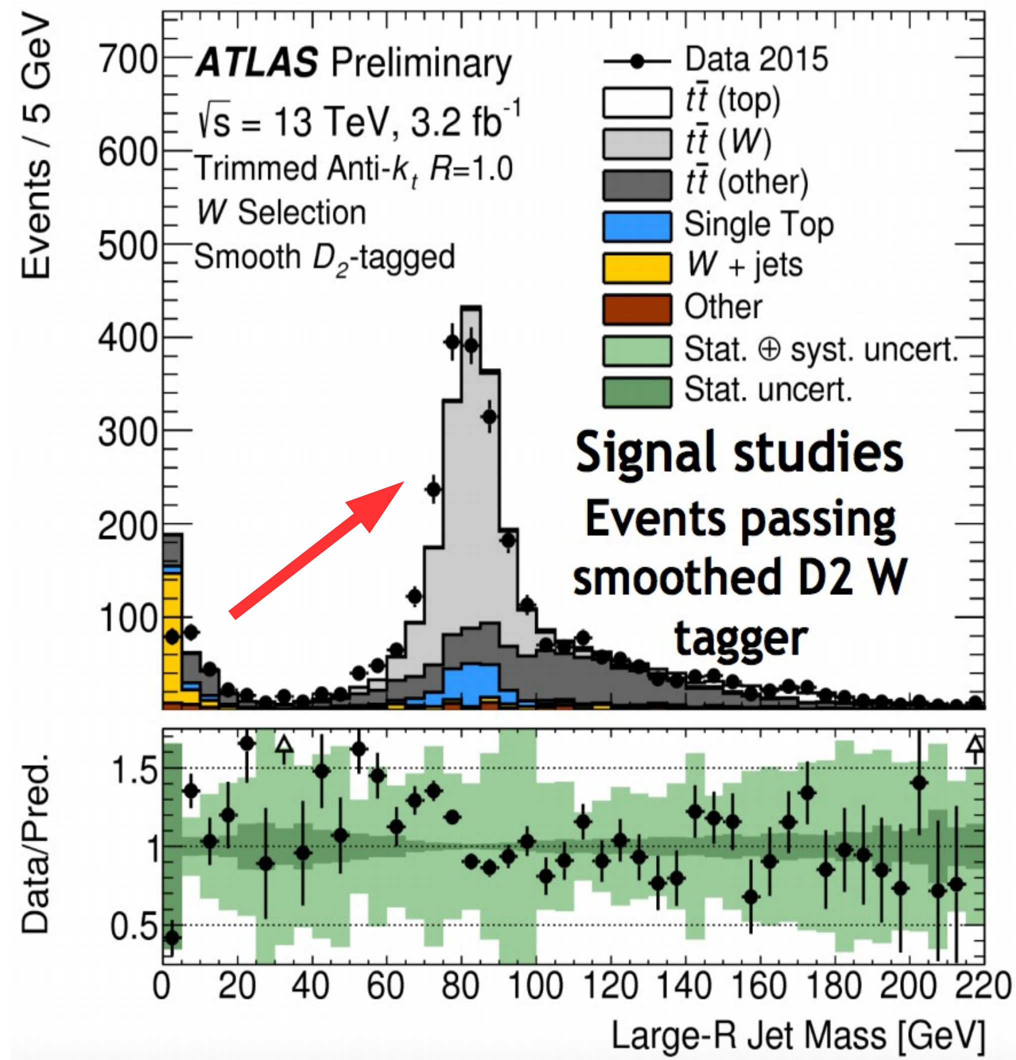


Have not observed a single W jet boson event from SM produce
(Have only seen W jets in top events)

.....at the same time on CMS

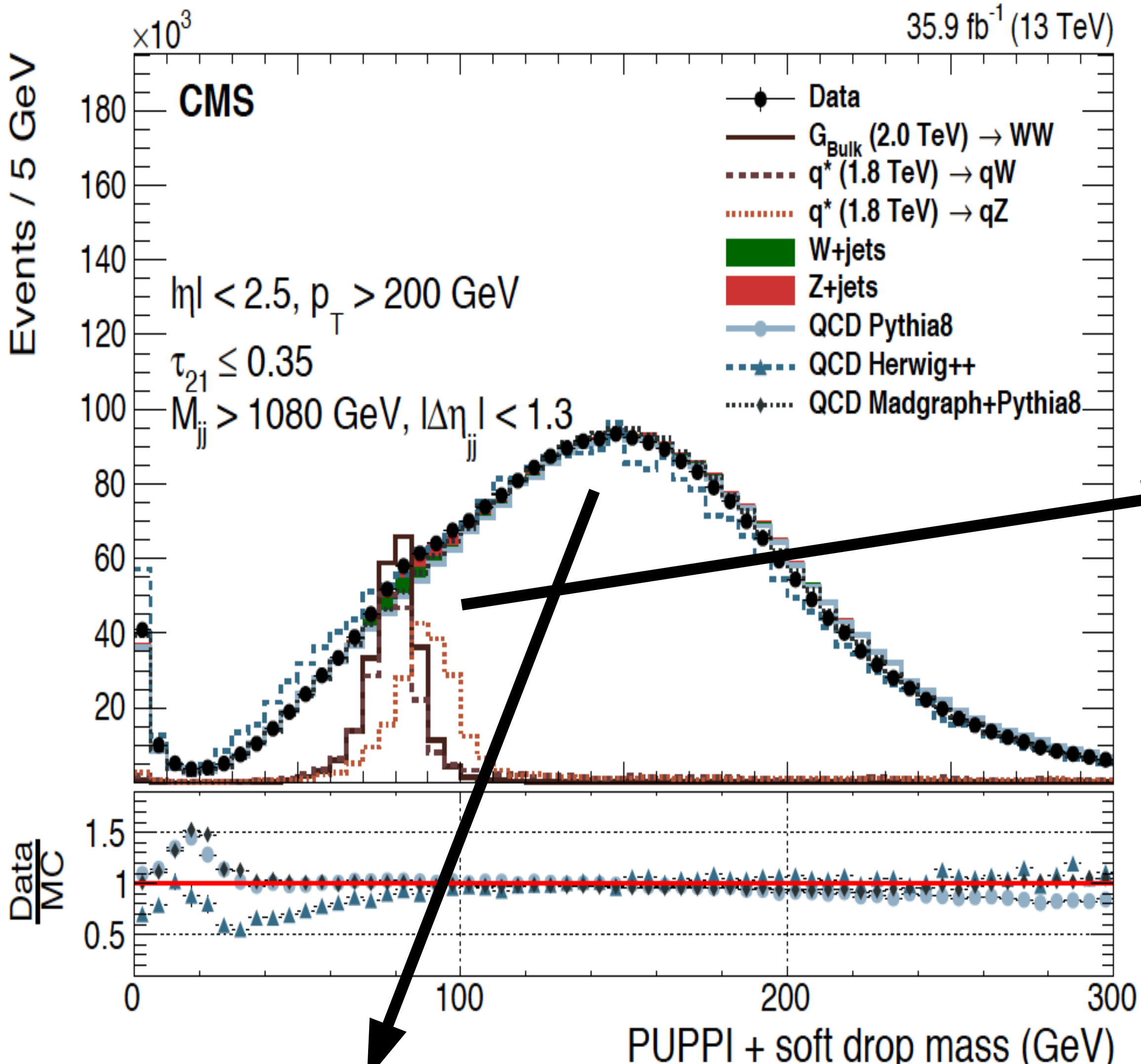
- An observation was being made





Background with current cuts force an upward slope

Finding the W/Z on a slope

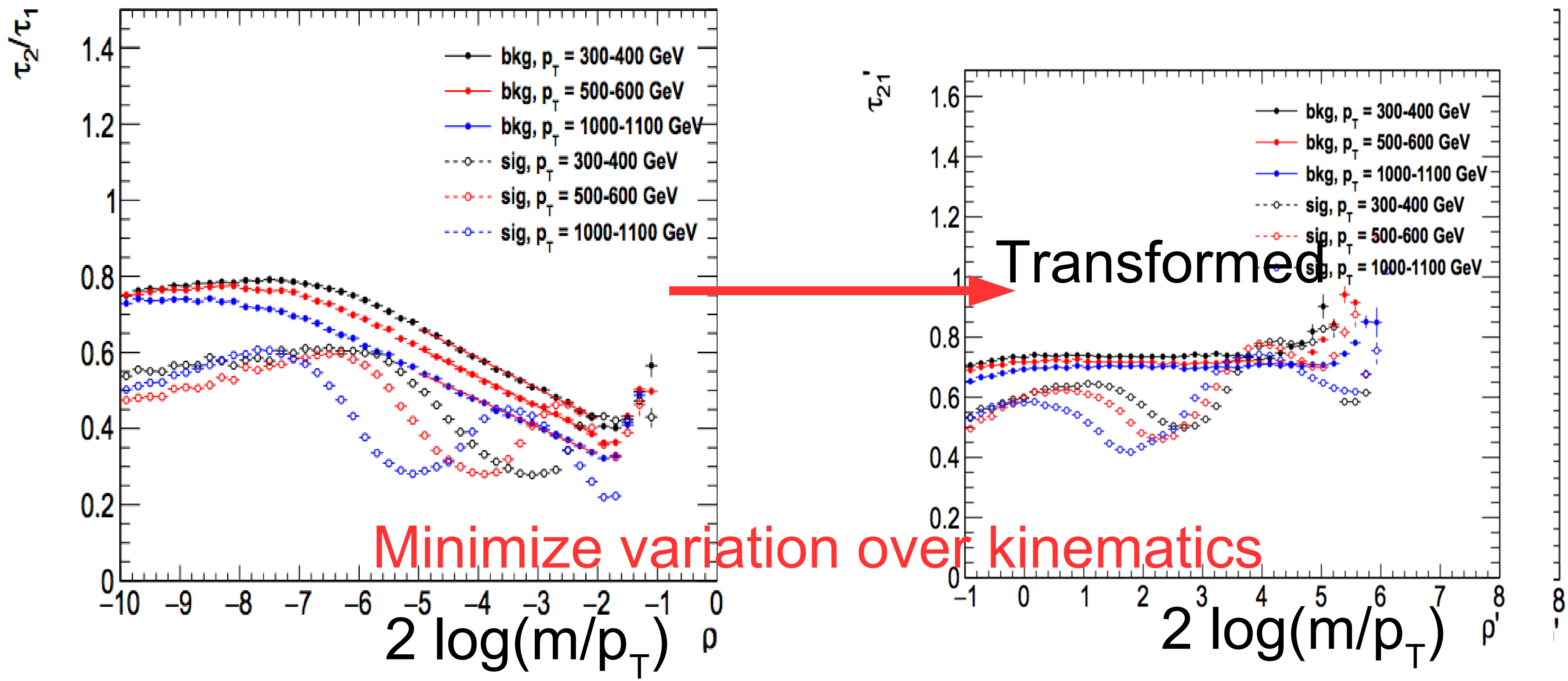


How does the upward slope impact the search for a resonance?

Background is peaking after the bump

helps to improve reduce background at W

Designing a new tagger?



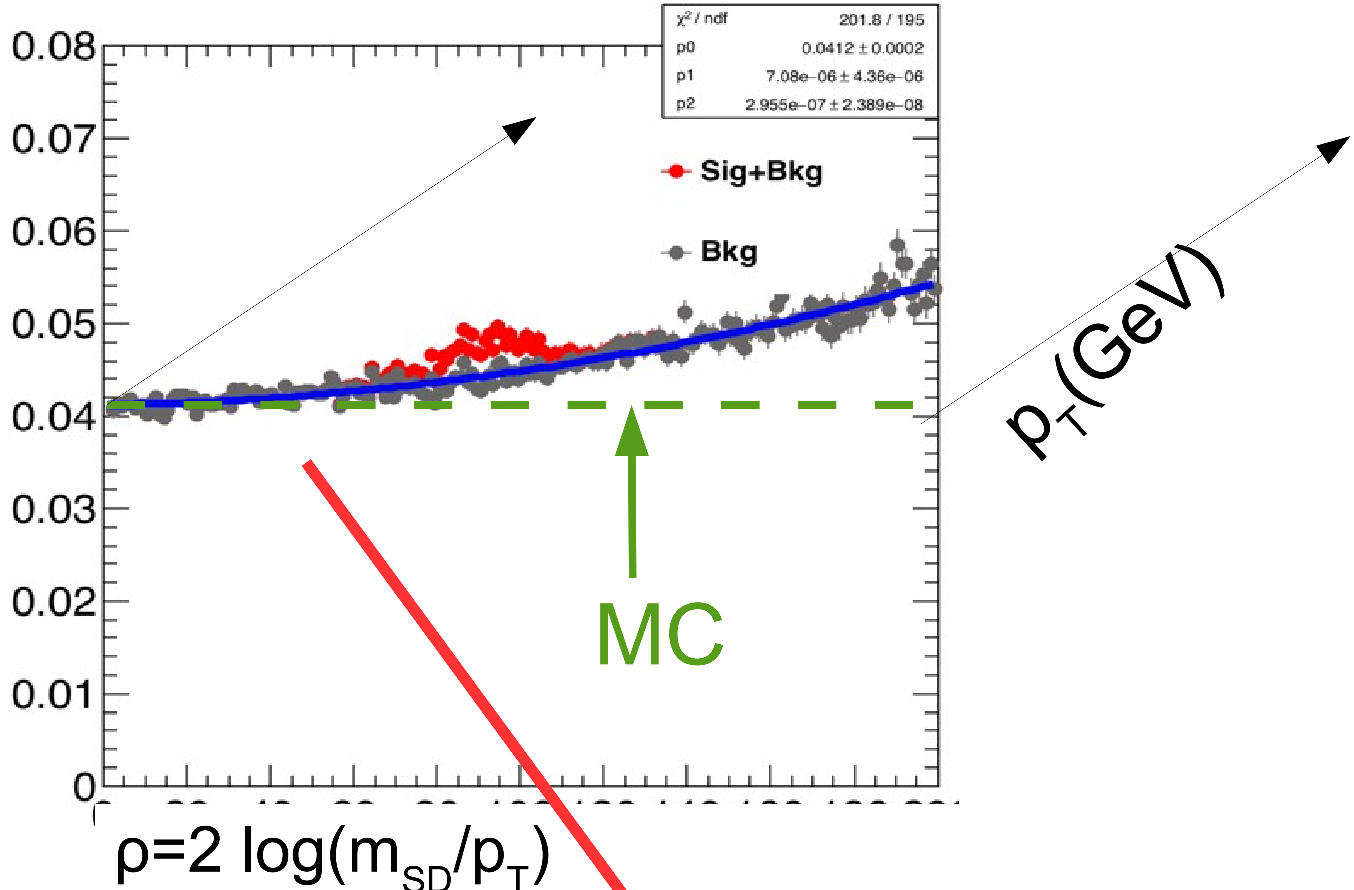
$$\tau'_{21} = \tau_2/\tau_1 - M \times \rho'$$

$$\rho' = \rho + \log\frac{p_T}{\mu} = \log\left(\frac{m^2}{p_T\mu}\right)$$

To minimize sculpting we minimize the variation over mass and p_T

In data

- We can tune the efficiency to be flat in MC

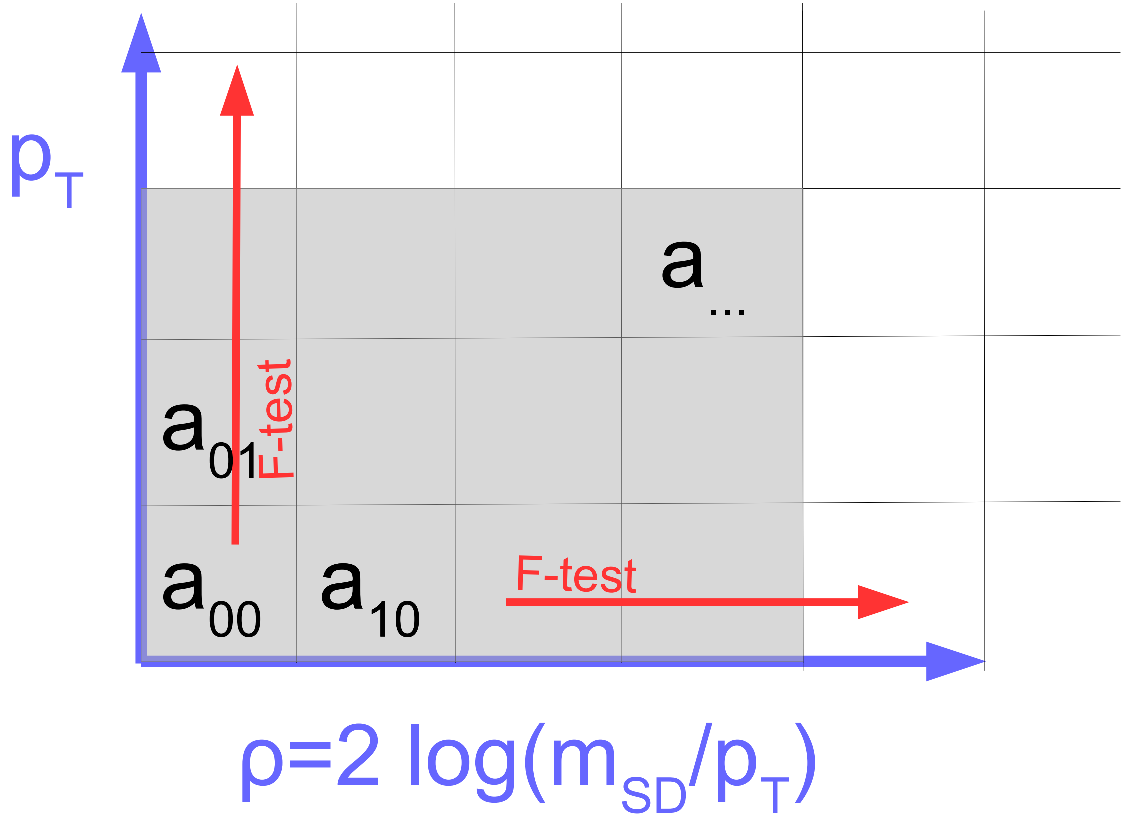


Utilize a polynomial in ρ and p_T

$$N_{\text{pass}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j}) = \epsilon^{\text{QCD}} \cdot \left(\sum_{k,\ell} a_{k\ell} \rho_{ij}^{k} {p_{\text{T}}}_{j}^{\ell} \right) \cdot N_{\text{fail}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j})$$

In data

- Interatively expand in ρ & p_T order with an f-test



For W peak
Using
4^{th} order in ρ
And
3^{rd} order in p_T

Utilize a polynomial in ρ and p_T

$$N_{\text{pass}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j}) = \epsilon^{\text{QCD}} \cdot \left(\sum_{k,\ell} a_{k\ell} \rho_{ij}^{k} {p_{\text{T}}}_{j}^{\ell} \right) \cdot N_{\text{fail}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j}) .$$

Ingredients to see W peak: Recp

- Select a jet (p_T > 500)
- Require the jet to pass a 2 prong tag
  - Tune the tagger to be flat across the mass
- Select tagger & take both pass and failing selection
- Simultaneously fit for pass and failing
- Parametrize the difference between data and MC
- Use a 4^{th} , 3^{rd} order polynomial in ρ,p_T to model data

Now are we ready to fit the W peak?

The End Game

Meanwhile...

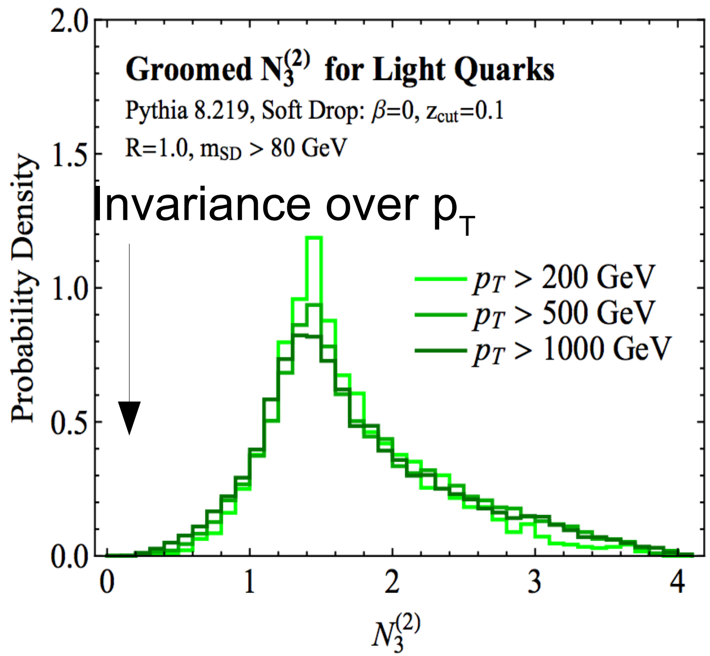
- Theorists decided to build in the scale invariance

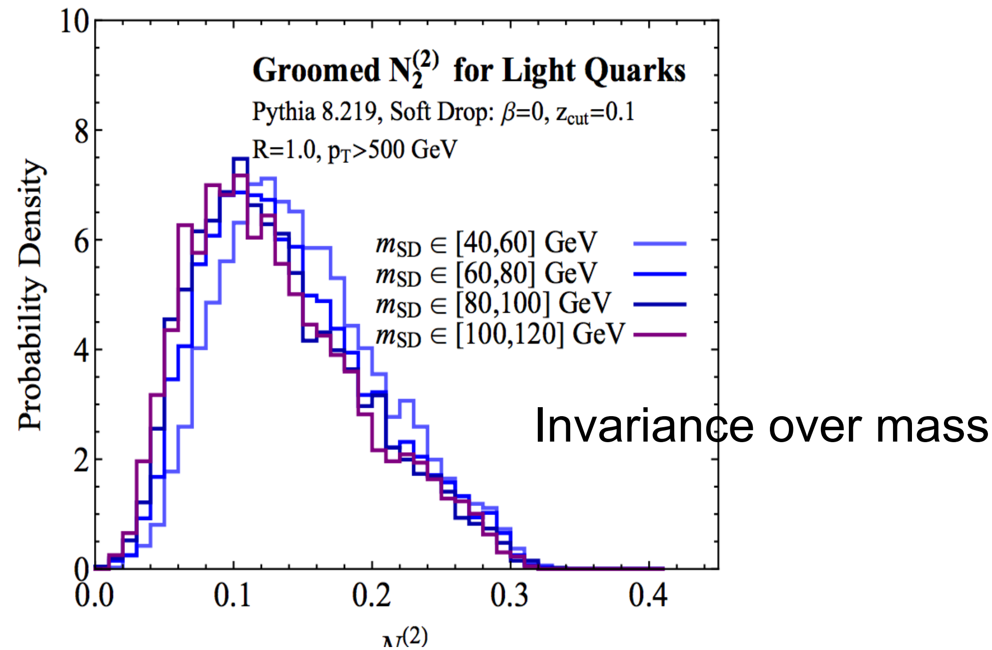
New Angles on Energy Correlation Functions

Ian Moult, Lina Necib, Jesse Thaler

(Submitted on 23 Sep 2016)

  - Into a new set of substructure observables
  - Guiding principles are to exploit invariances in QCD





New Substructure Observables

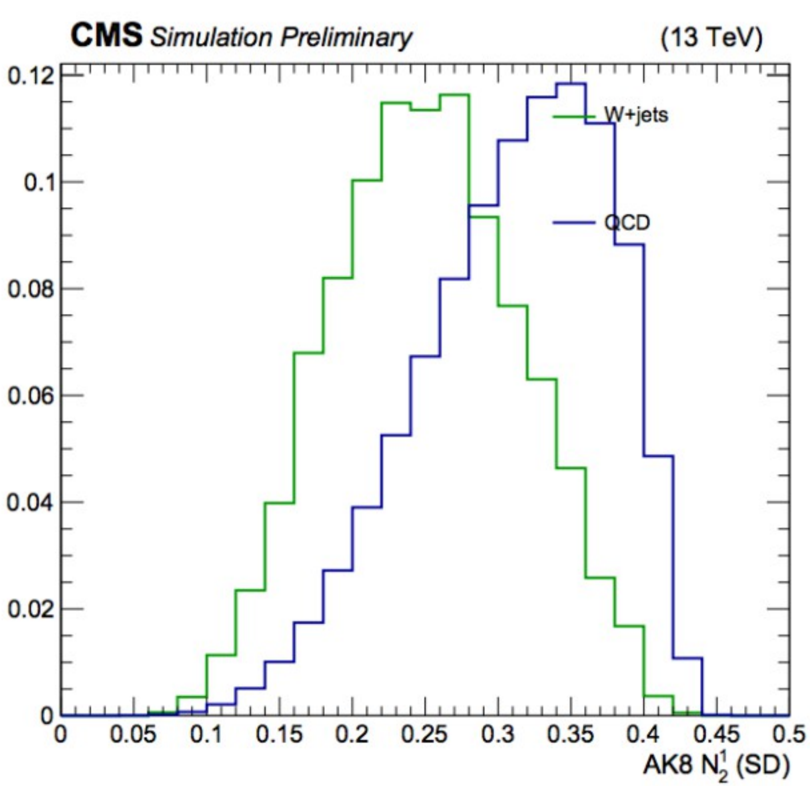
$$N_2(\beta) = \frac{{}_2e_3^{\beta}}{(e_2^{\beta})^2}$$

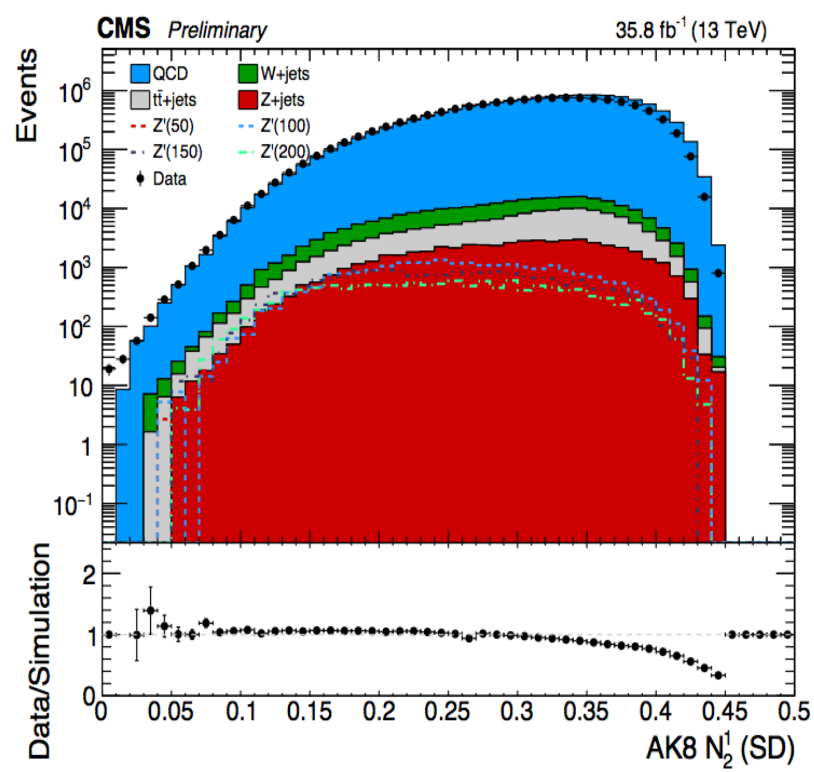
$${}_1e_2^{\beta} = e_2^{\beta} = \sum_{1 \le i < j \le n_J} z_i z_j \Delta R_{ij}^{\beta}$$

$$z_i \equiv \frac{p_{Ti}}{\sum_{j \in \text{jet}} p_{Tj}}$$

$${}_2e_3^{\beta} = \sum_{1 \le i < j < k \le n_J} z_i z_j z_k \min\{\Delta R_{ij}^{\beta} \Delta R_{ik}^{\beta}, \Delta R_{ij}^{\beta} \Delta R_{jk}^{\beta}, \Delta R_{ik}^{\beta} \Delta R_{jk}^{\beta}\}$$

Using AK8 PUPPI jets

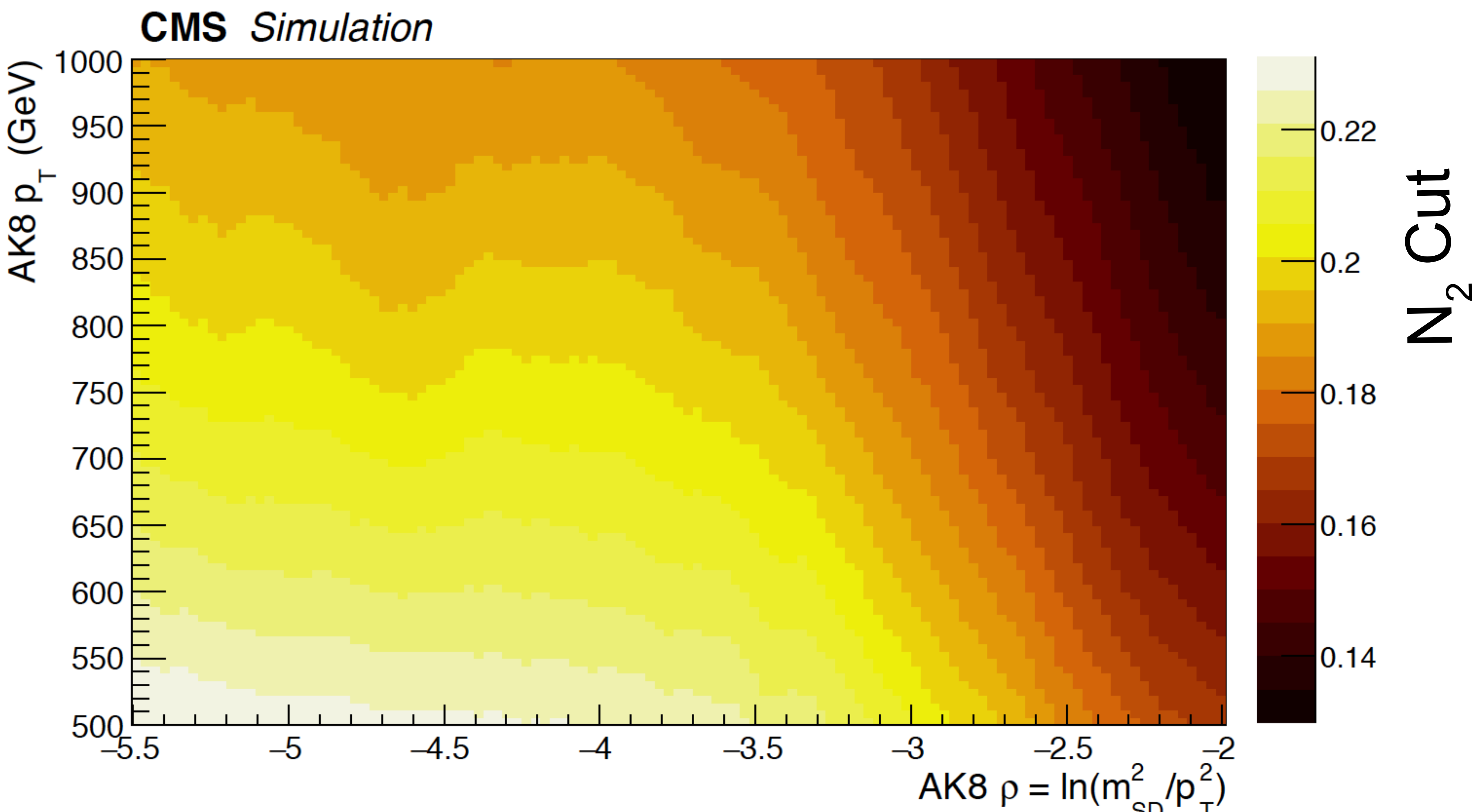




Arxiv/1609.07483

We use N_2 to see the W peak

Full Decorrelation scheme

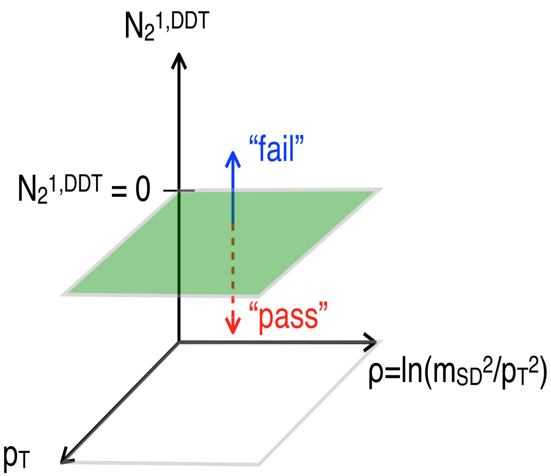


Use the k-Nearest Neighbor approach to determine N_2 cut

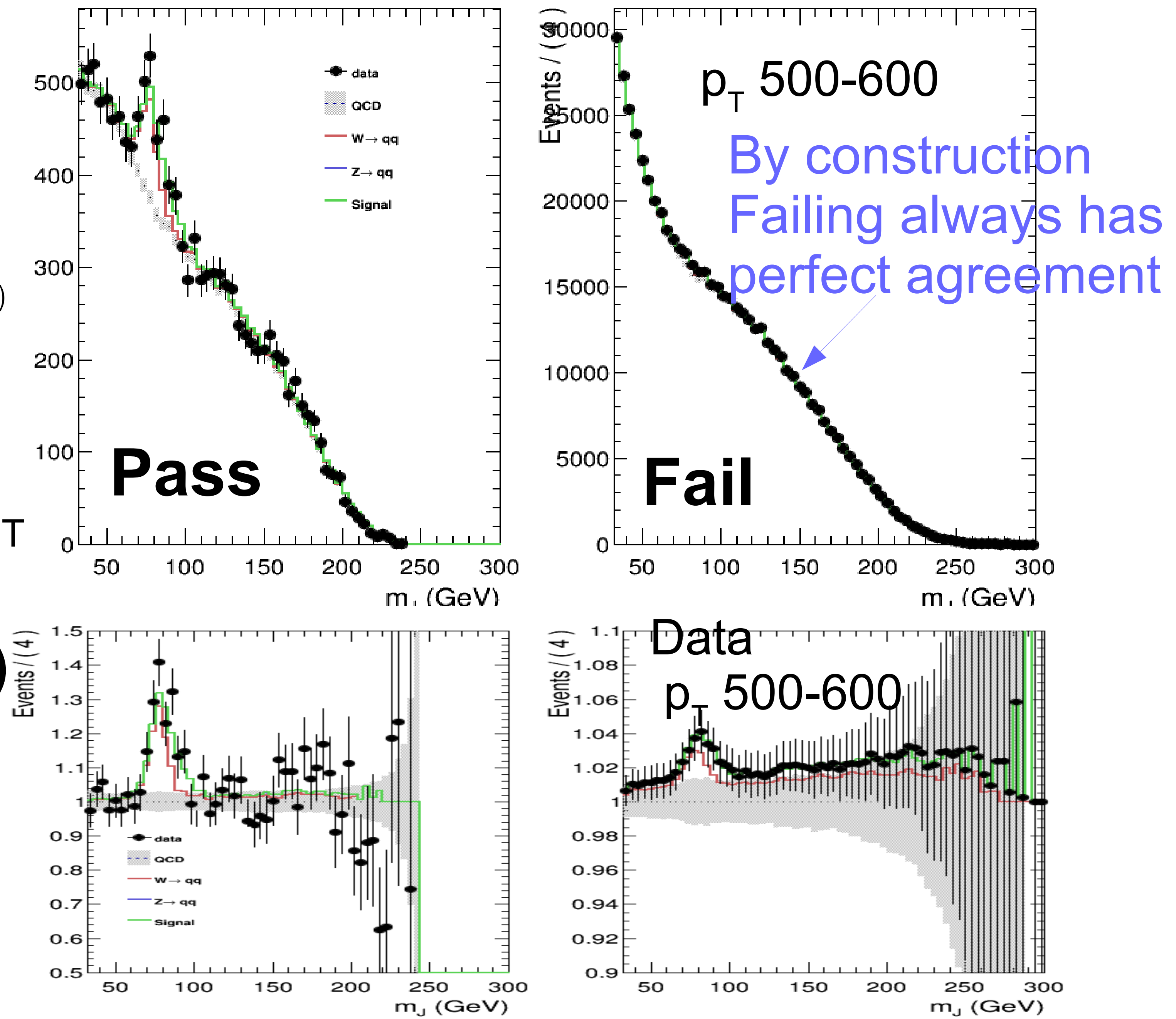
EXO-17-001

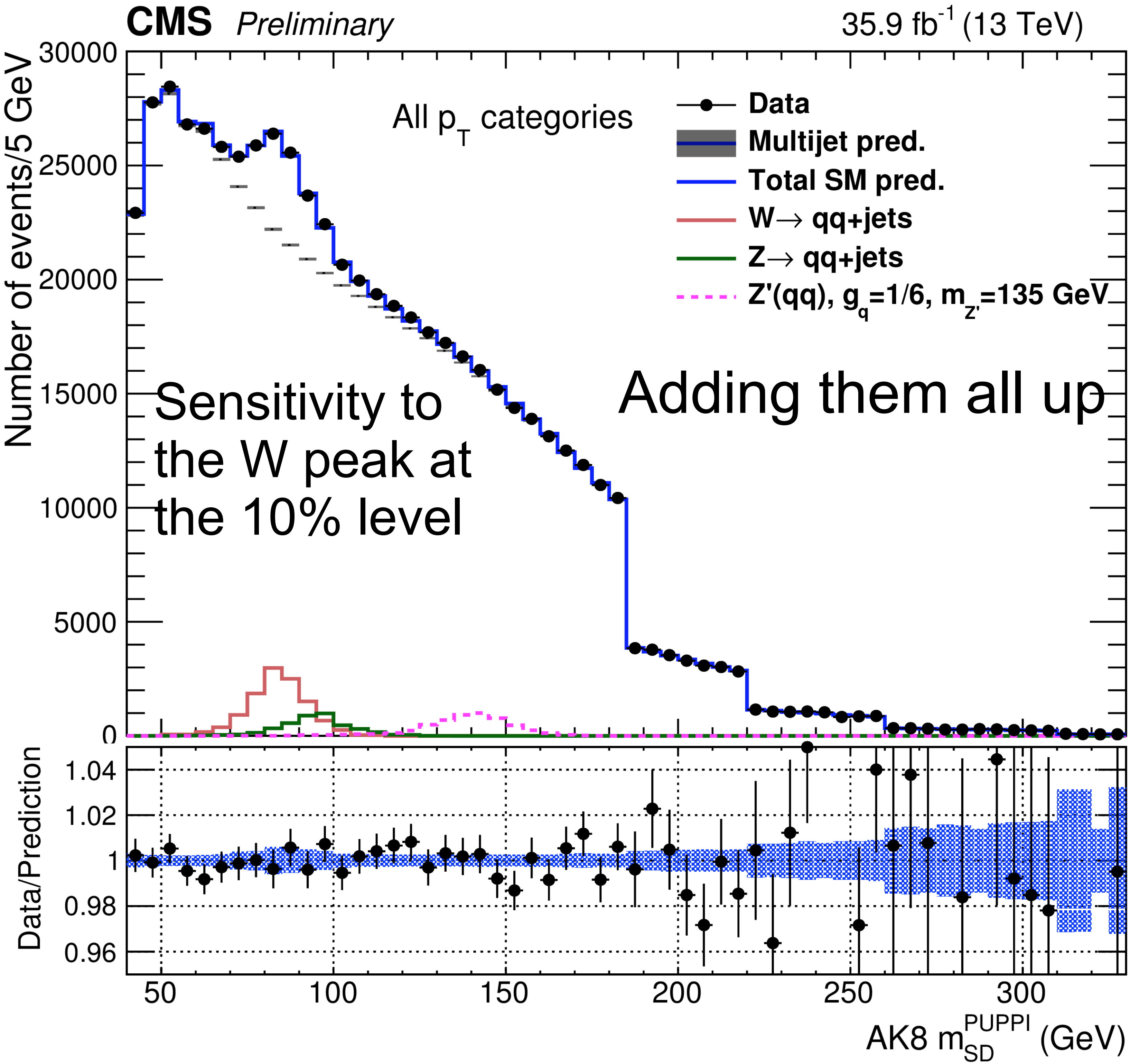
All Pieces are in Place

- The final fit

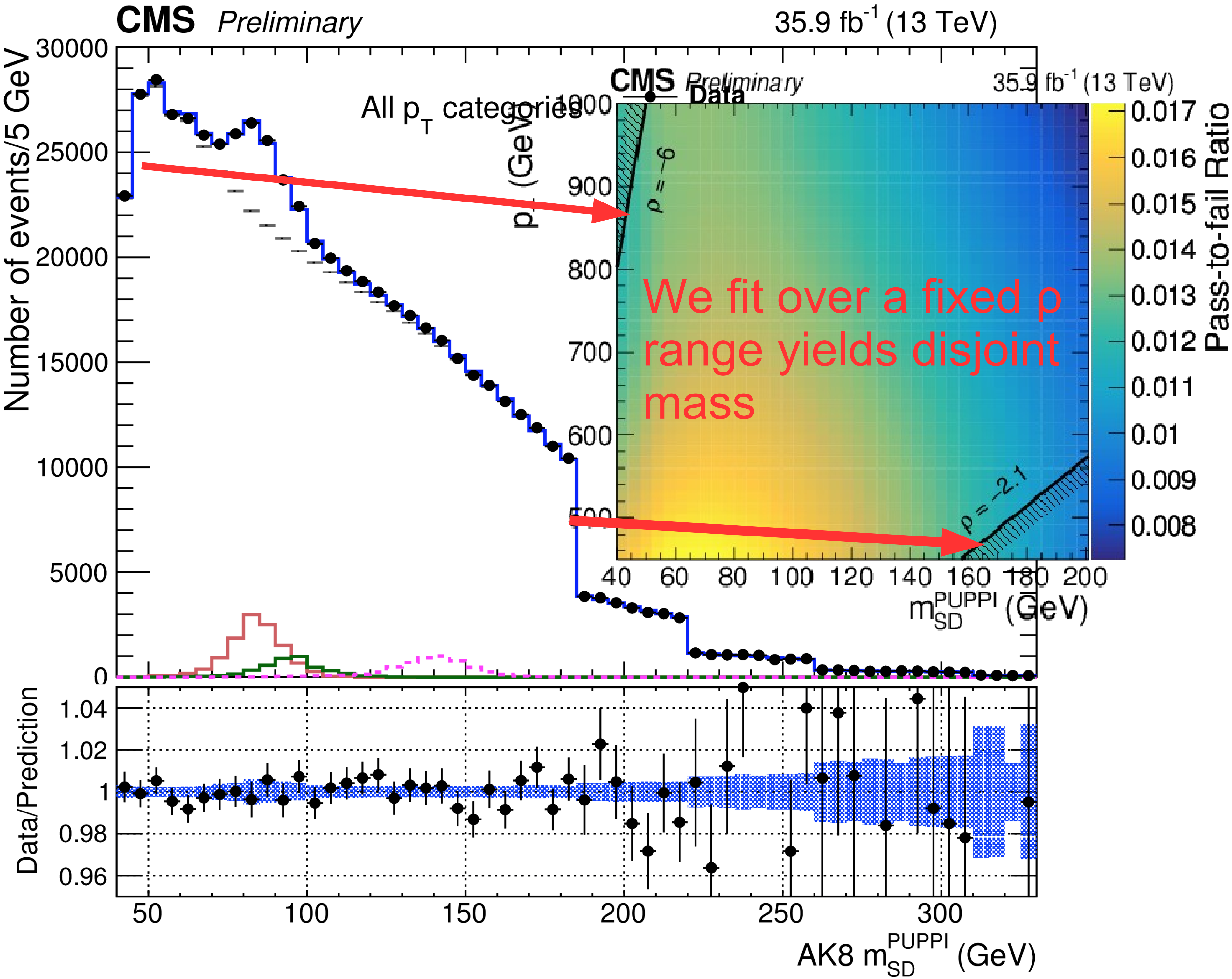


Use 5 bins in p_T 500-1000 GeV (100 GeV bins)

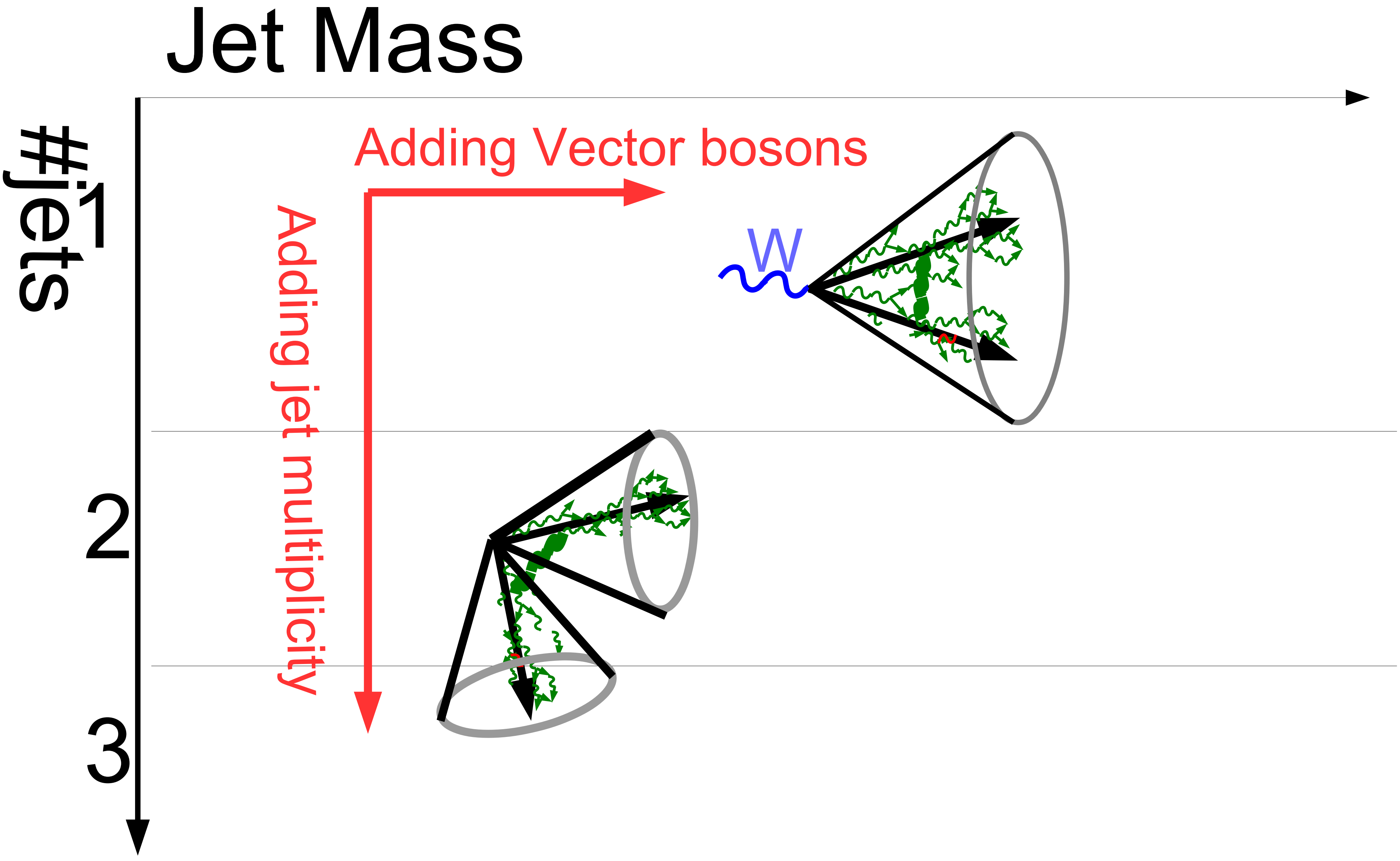




CMS Preliminary
35.9 fb-1 (13 TeV)
All pT categories
Data
Multijet pred.
Total SM pred.
W→ qq+jets
Z→ qq+jets
Z'(qq), gq=1/6, mZ'=135 GeV
Sensitivity to the W peak at the 10% level
Adding them all up
Number of events/5 GeV
Data/Prediction
AK8 m_SD^PUPPI (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
All pT categories
Number of events/5 GeV
Data/Prediction
AK8 mSD PUPPI (GeV)
CMS Preliminary
35.9 fb-1 (13 TeV)
Data
pT (GeV)
ρ = −6
ρ = −2.1
mSD PUPPI (GeV)
Pass-to-fail Ratio
We fit over a fixed ρ range yields disjoint mass

Monojet Extenstion Plane

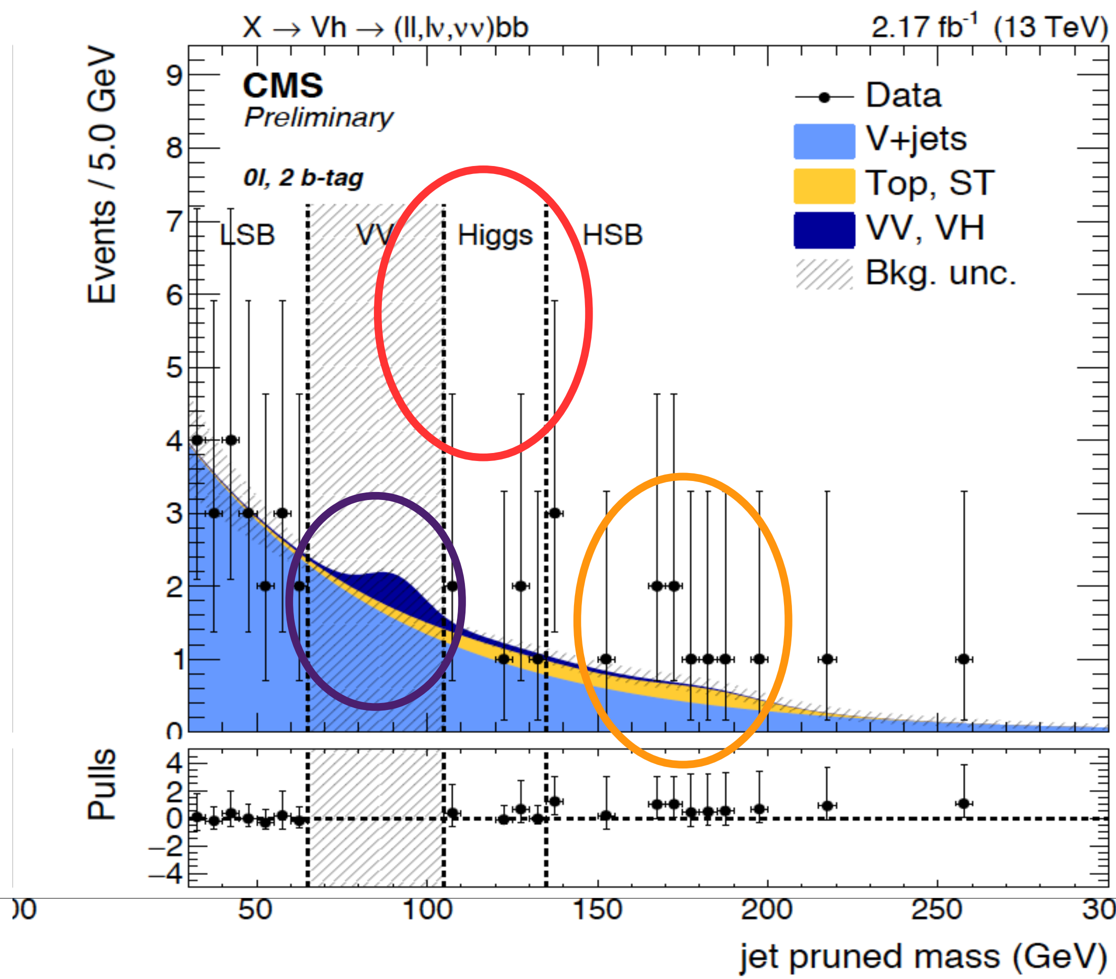


Monojet Extenstion #1 (V→qq)

Jet Mass

#jets

1

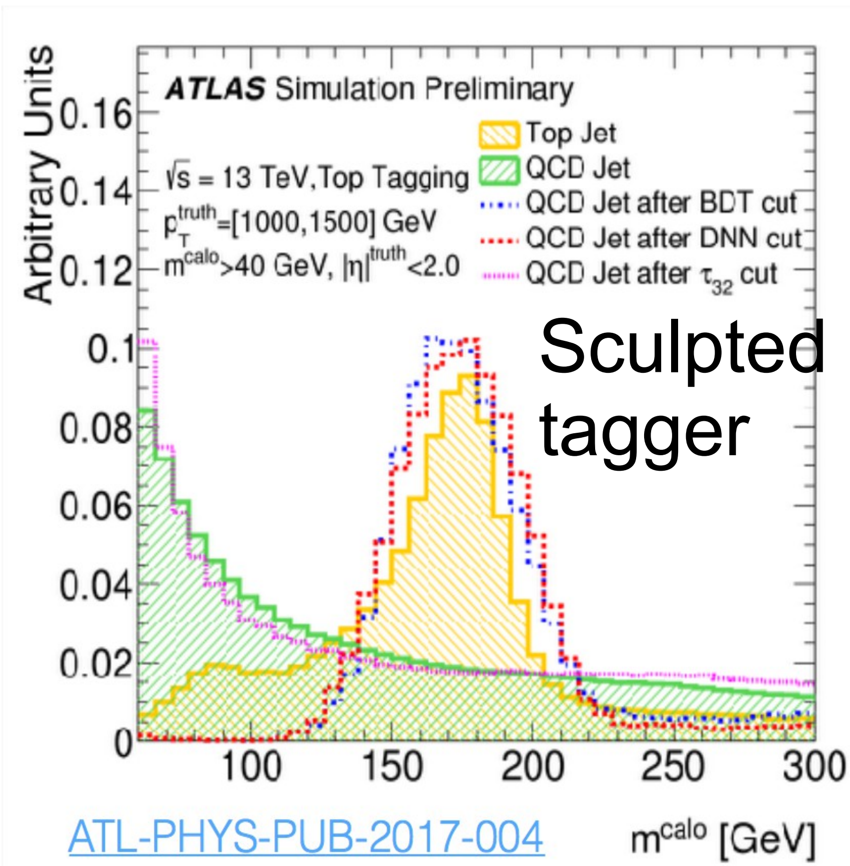


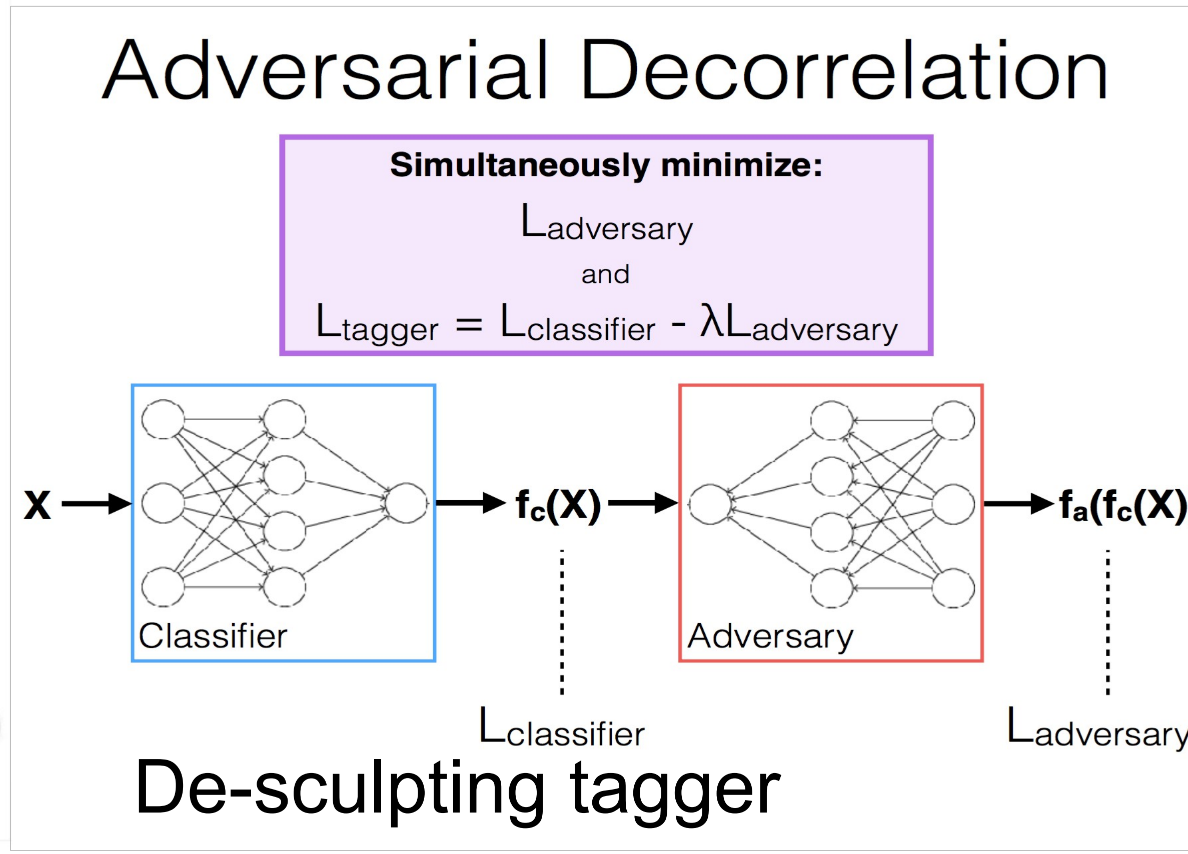
2

MET+V(qq),*MET*+H(bb),*MET*+t(qqb)

New Directions

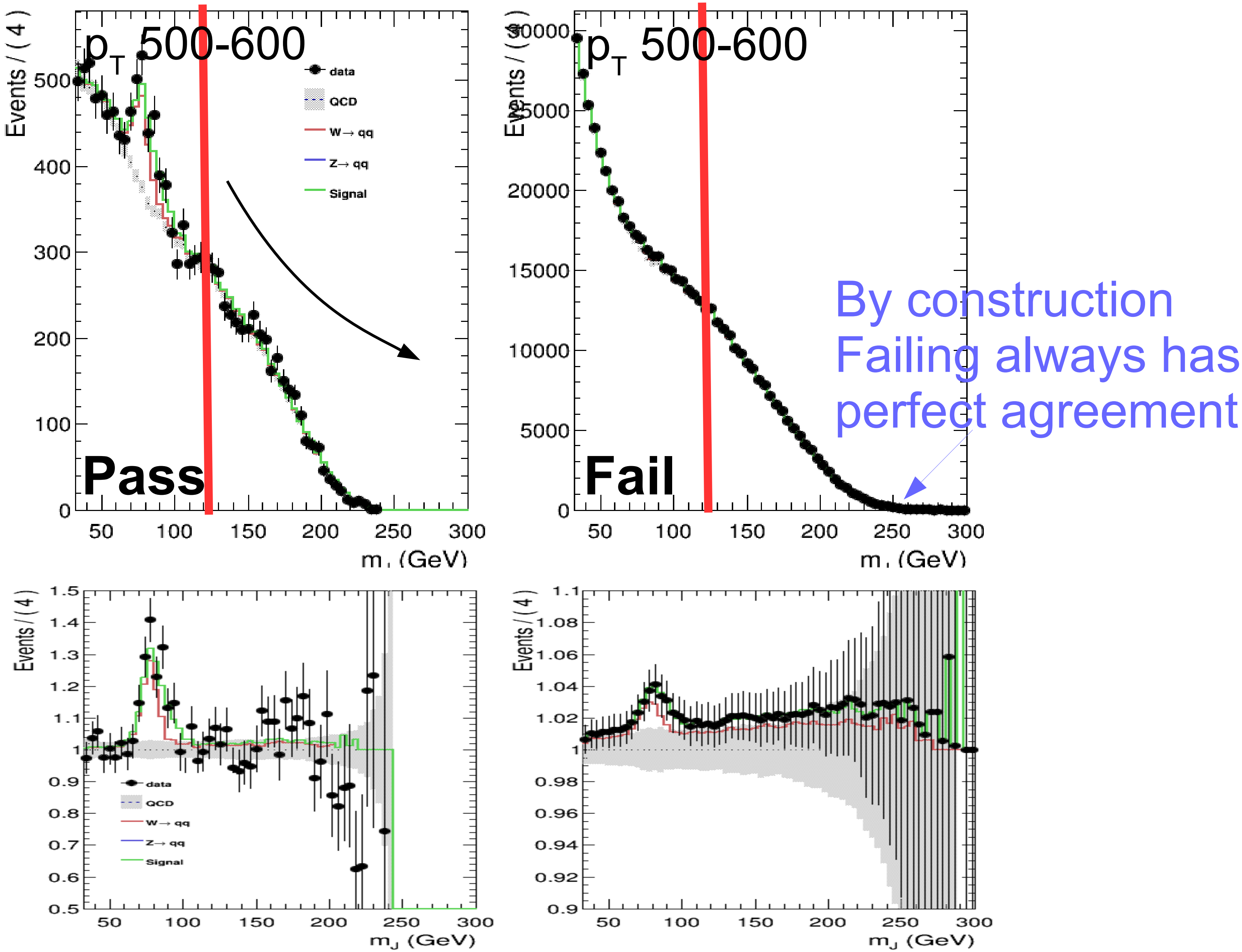
- Key concept was modifying jet substructure



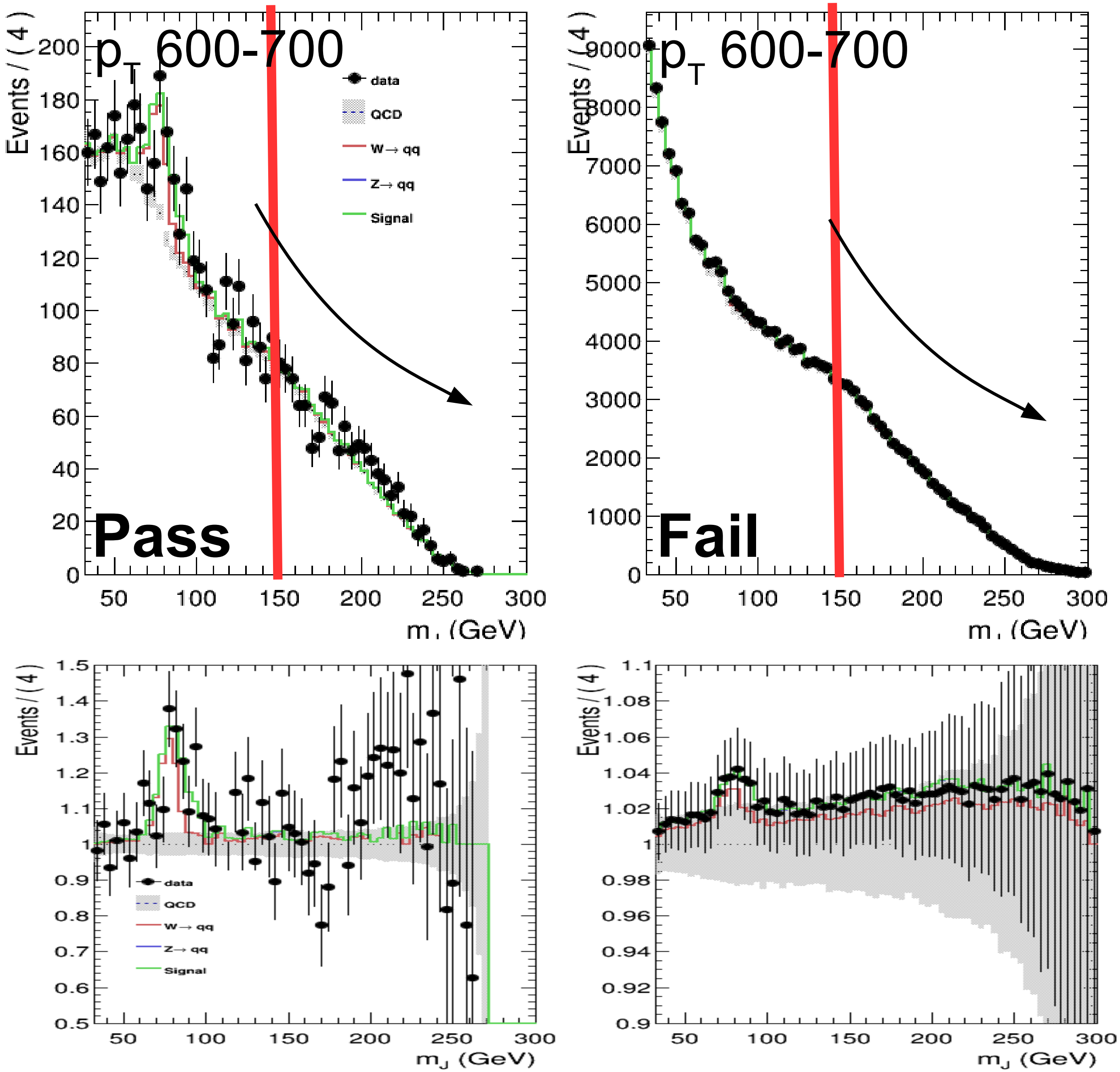


New approaches w/deep learning can decorrelate observables

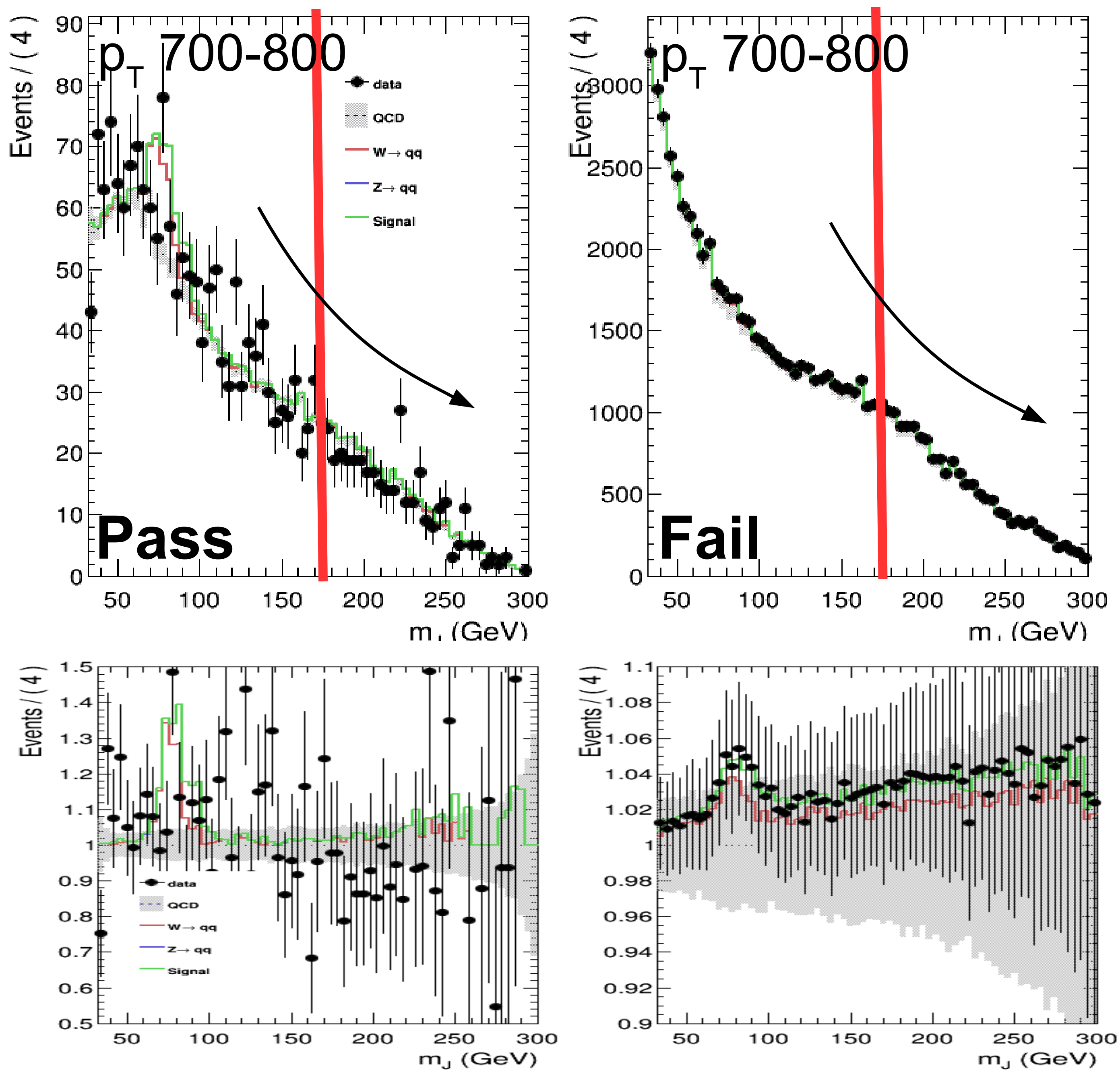
Motion of the Sudakov Peak



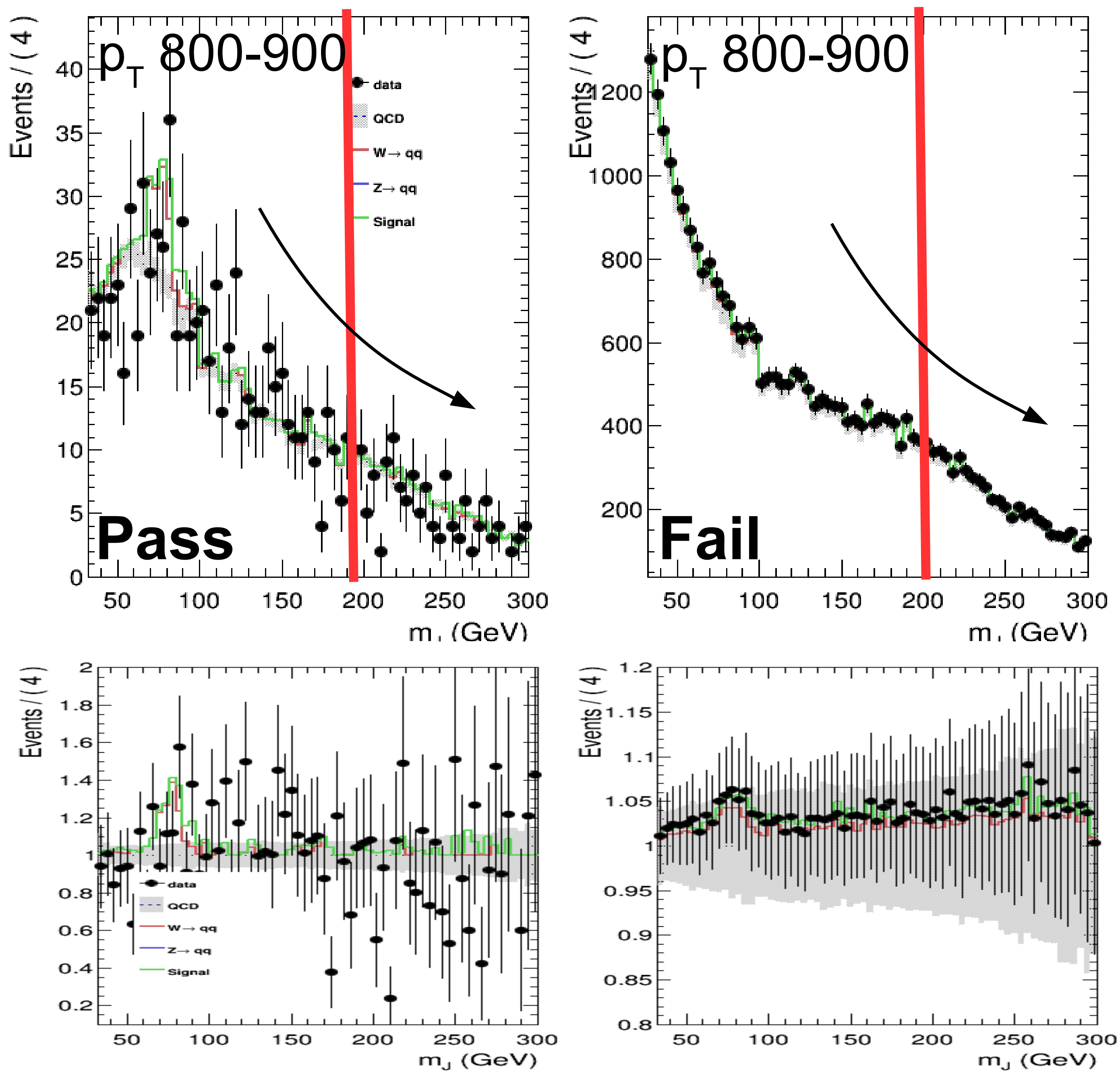
Motion of the Sudakov Peak



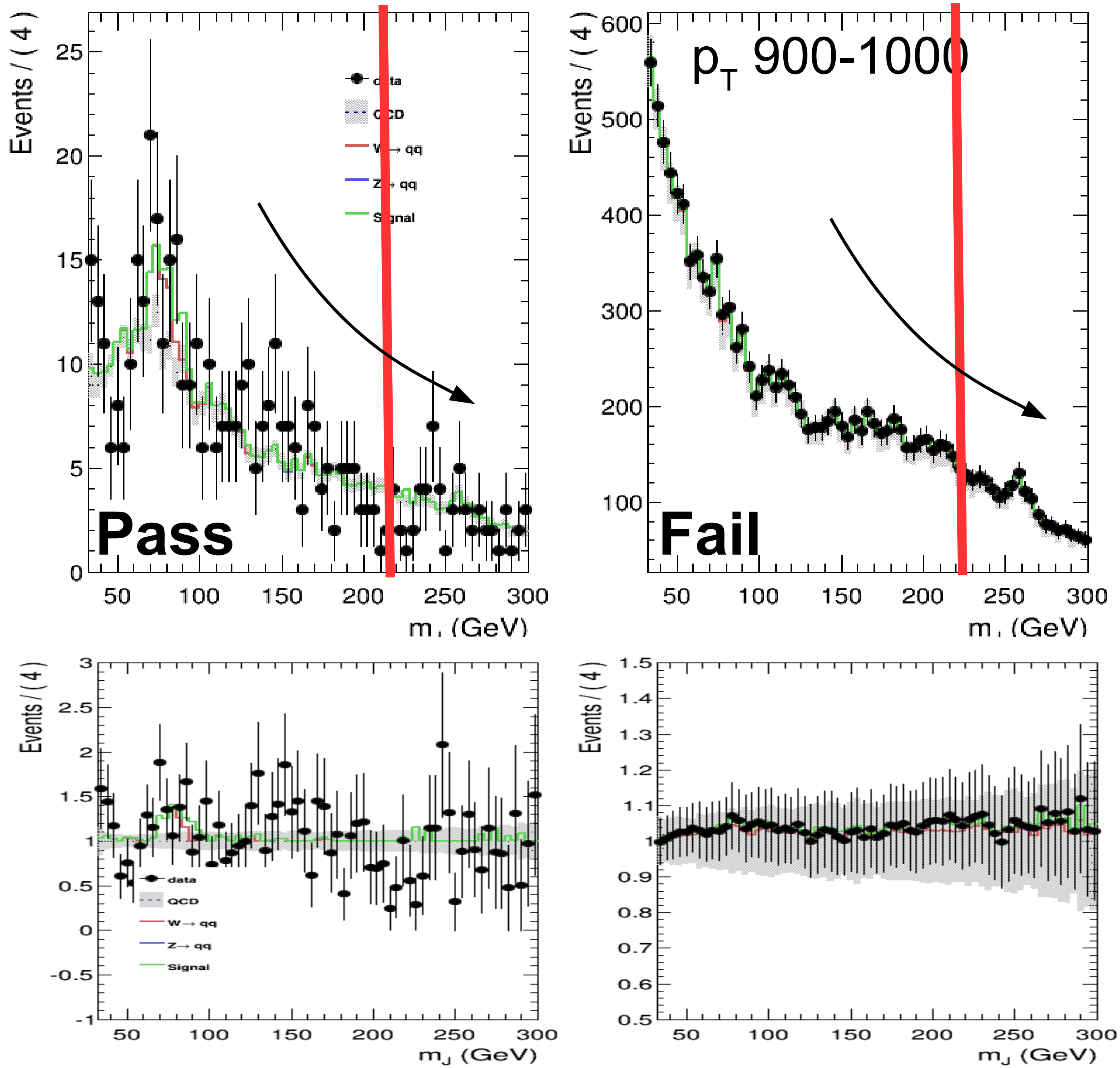
Motion of the Sudakov Peak



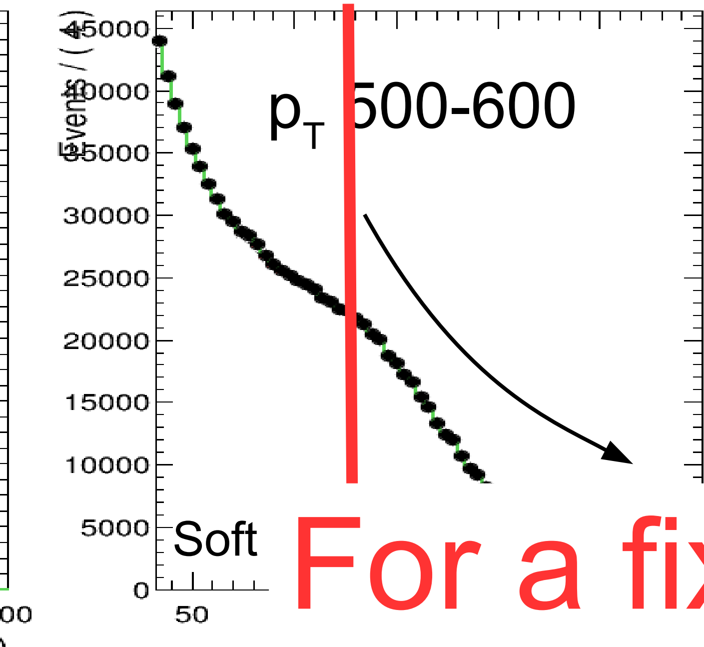
Motion of the Sudakov Peak

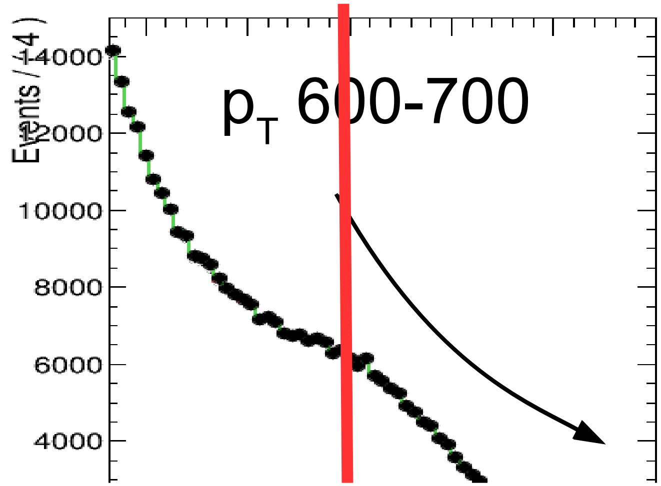


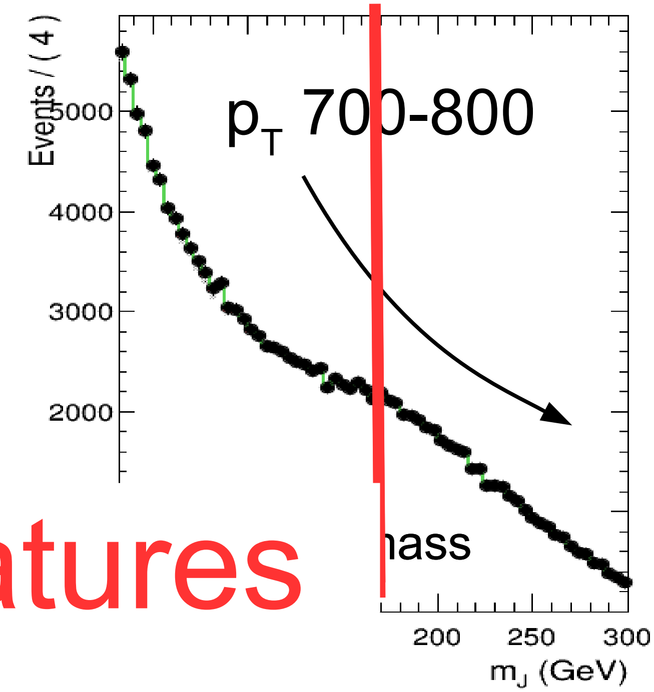
Motion of the Sudakov Peak



Sudakov peak variation over p_T



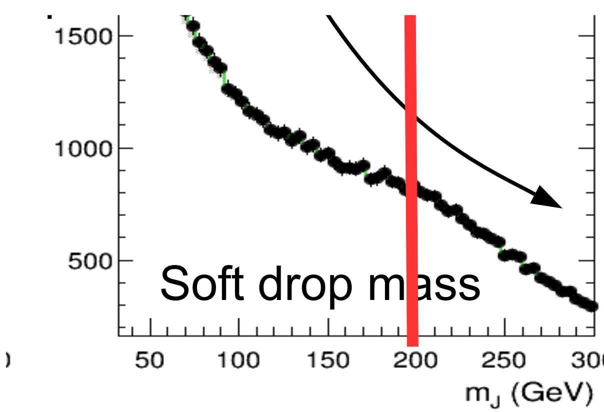


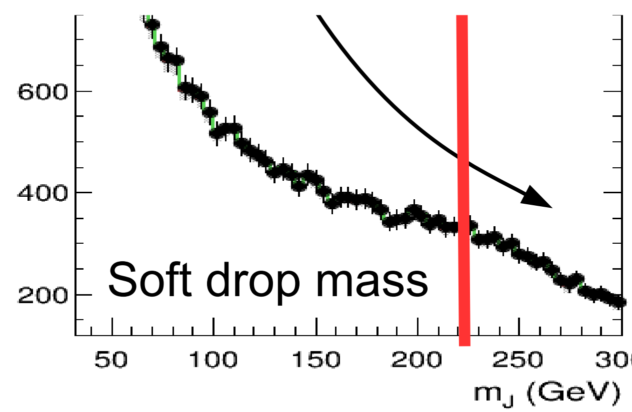


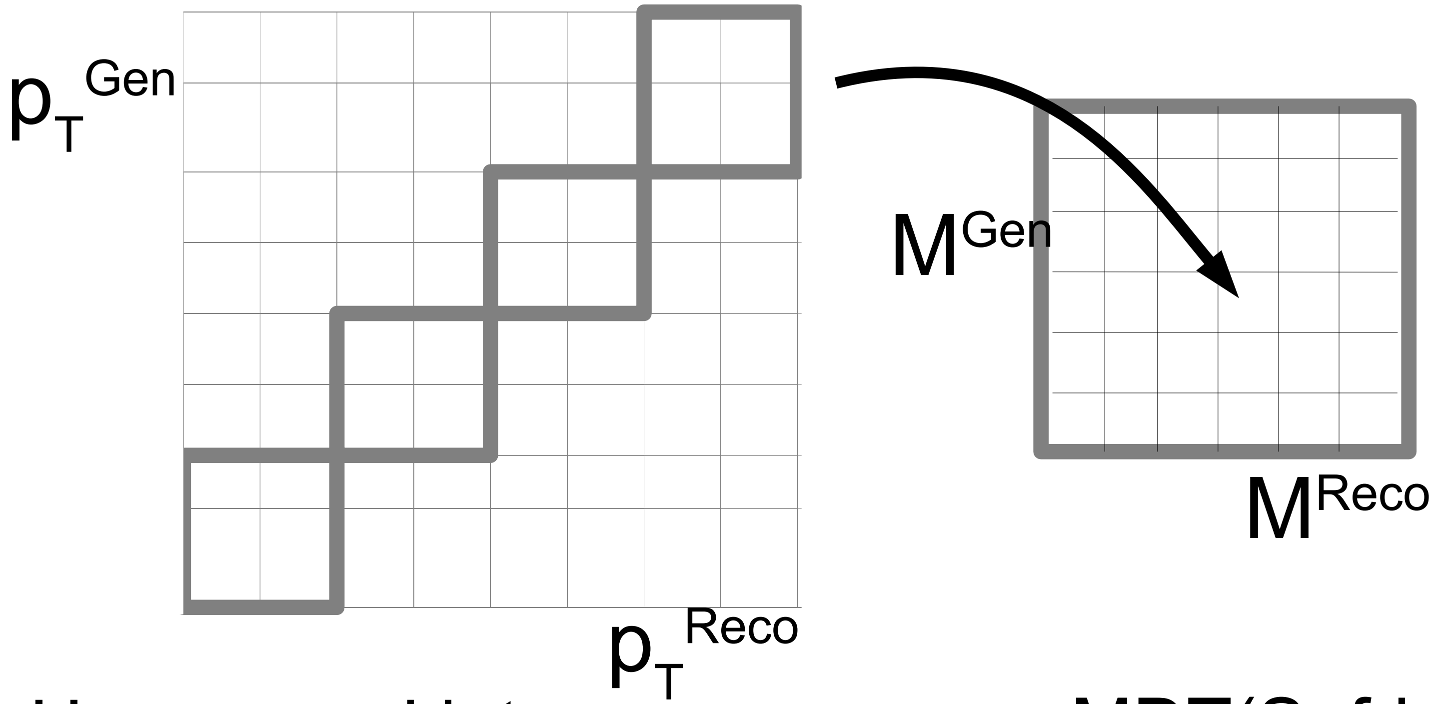
For a fixed p the features invariant over p_T

Jet Mas
distribut
varies w

n to make
flat
ains
Mass & p_T







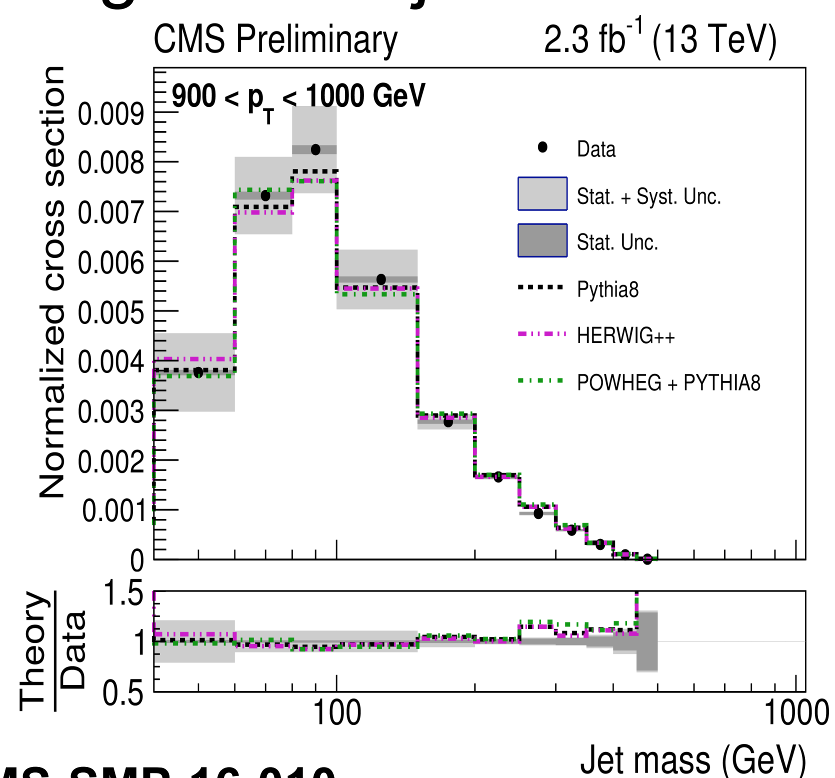
Unfolded

4D unfolding

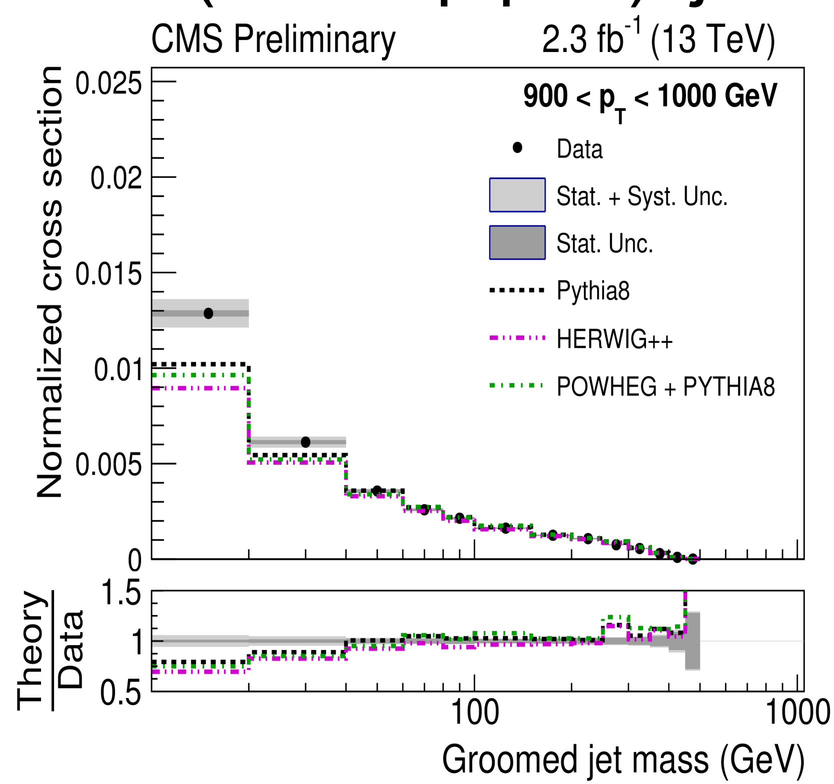
M^{reco}, p_T^{reco} to

M^{Gen}, p_T^{Gen}

Ungroomed jet mass



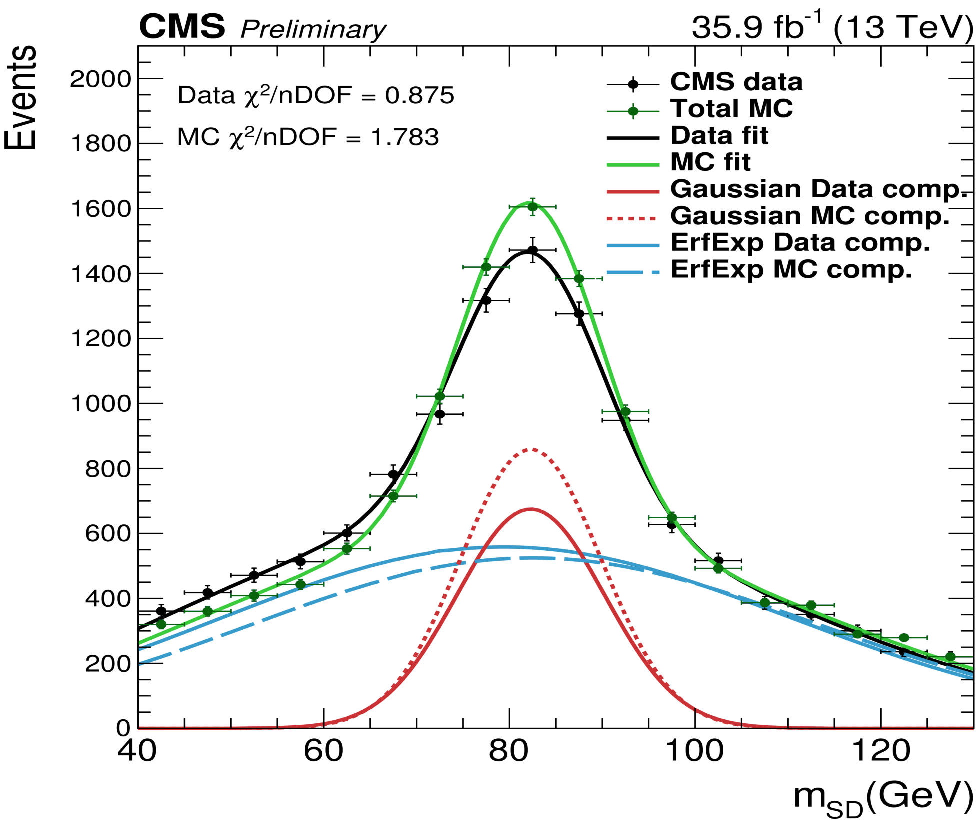
mMDT(Sofdrop β=0) jet mass



CMS-SMP-16-010

Jet Mass Resolution

- Mass resolution obtained with top events



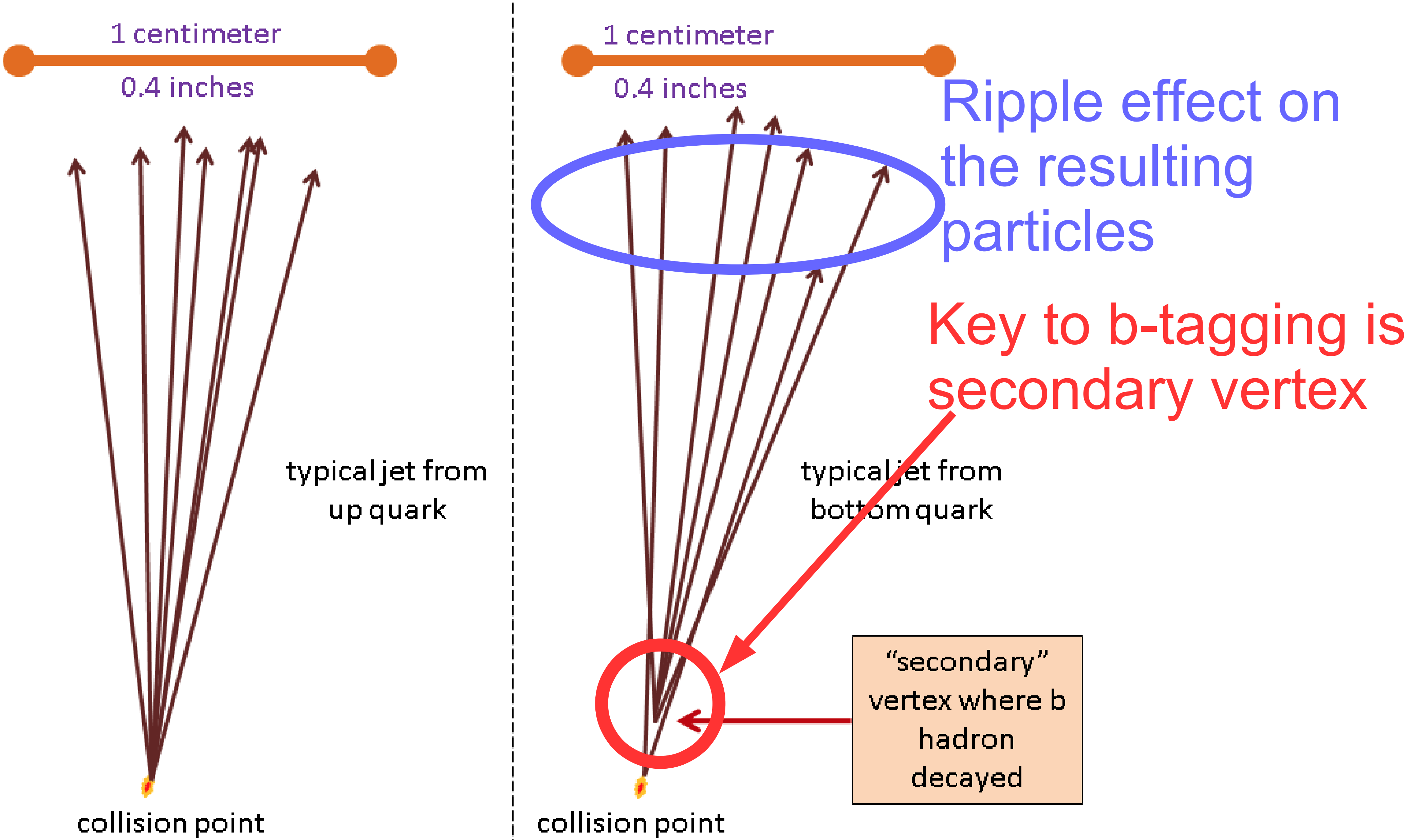
Jet mass and resolution calibrated on W peak in ttbar events

Unc extrapolated to all phase space

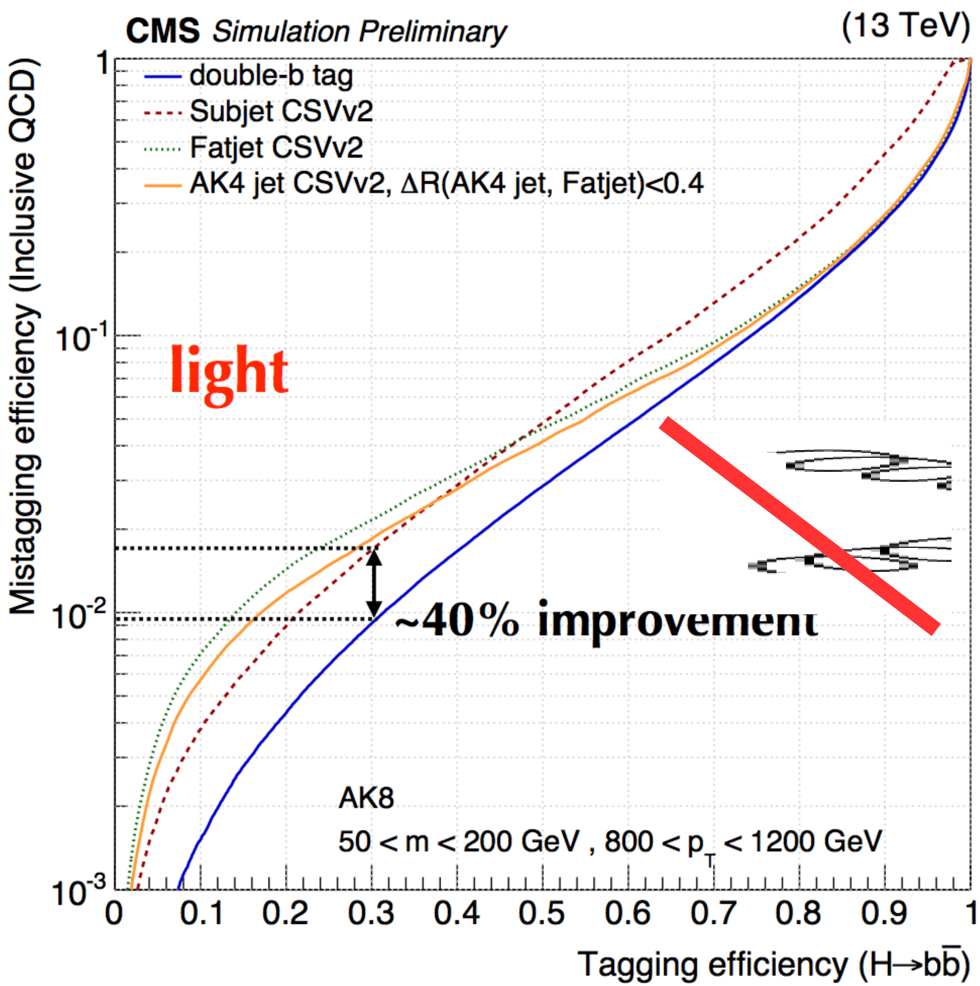
In addition compute uncertainty based :
Jet energy corrections/resoultion,Pileup,
PDF and Physics model

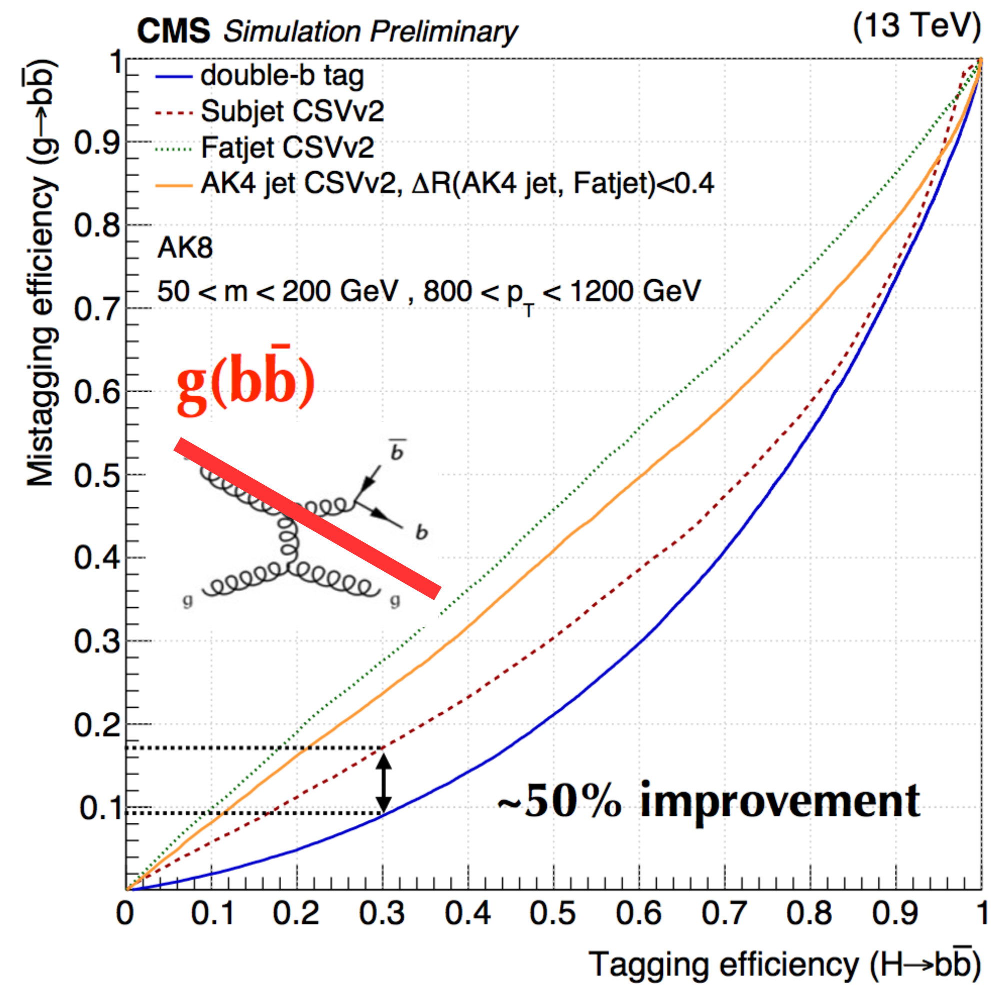
CMS-SMP-16-010

A b-tag?


1 centimeter
0.4 inches
typical jet from up quark
collision point
1 centimeter
0.4 inches
Ripple effect on the resulting particles
Key to b-tagging is secondary vertex
typical jet from bottom quark
"secondary" vertex where b hadron decayed
collision point

Double B-tagger

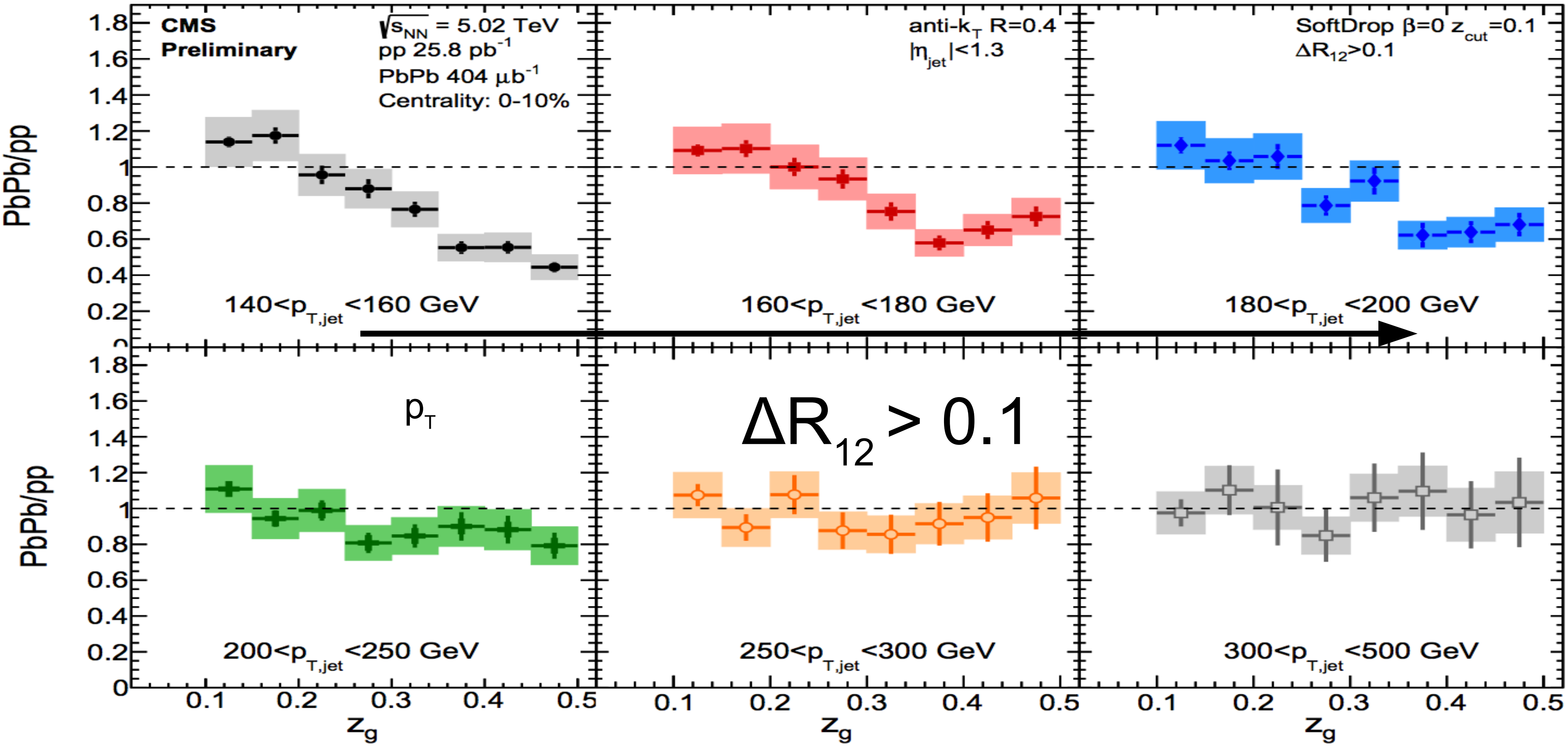




Resulting combination gives 50% improvement over previous

CMS-BTV-15-002

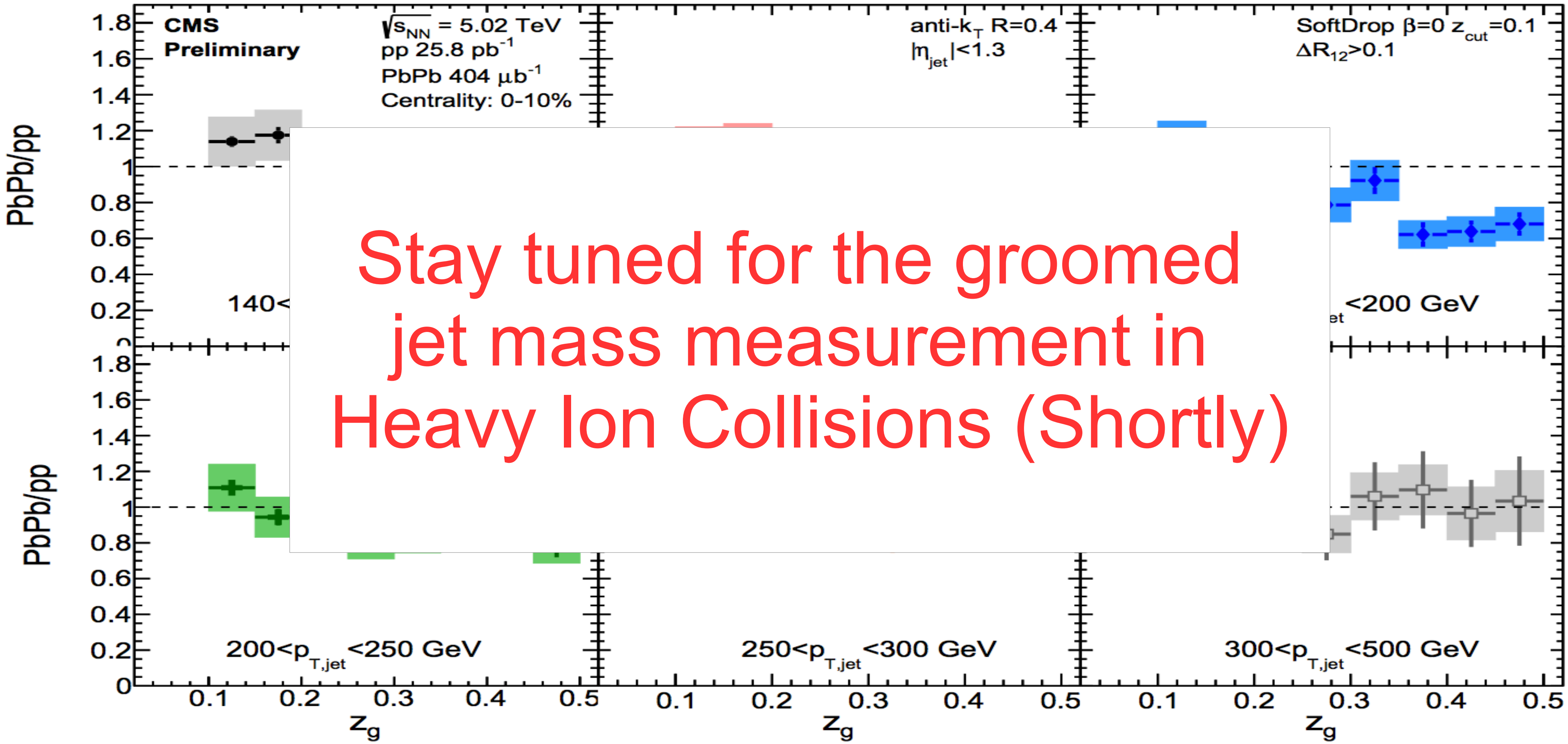
Modification in the medium



A clear modification is present with subsides at high p_T

CMS-HIN-16-004

Modification in the medium

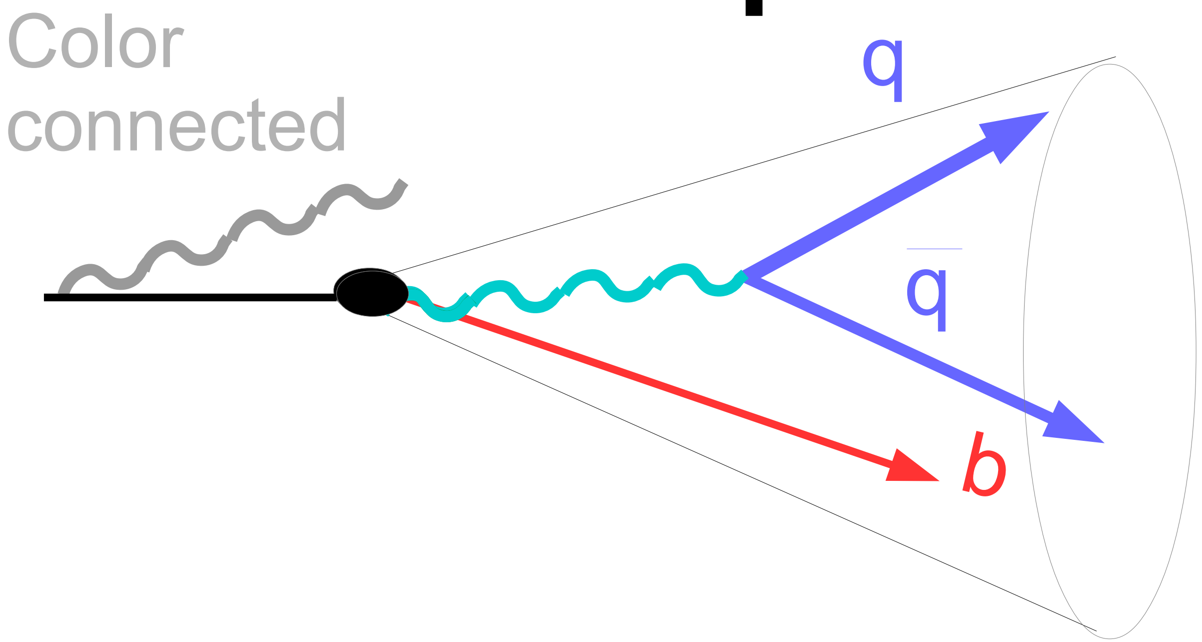


Stay tuned for the groomed jet mass measurement in Heavy Ion Collisions (Shortly)

A clear modification is present with subsides at high p_T

CMS-HIN-16-004

The Top Jet Mass



Top jet decays are a great way to test top mass

High p_T regime allows us to factorize effects
Potential for a better understanding of mass

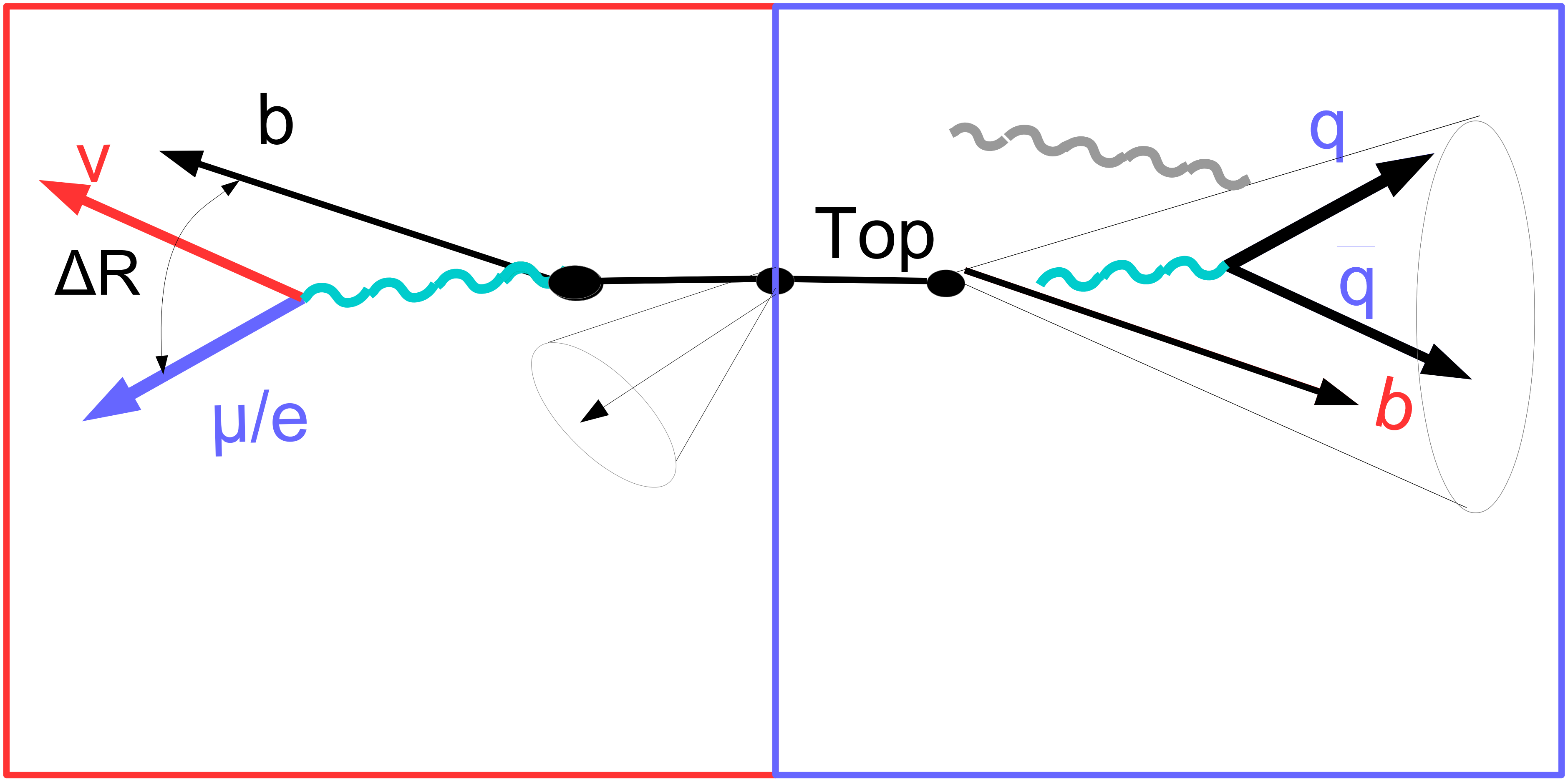
Question: How sensitive are we to top mass?

CMS-TOP-15-015

Selecting top events

Name of the game : don't bias the top mass

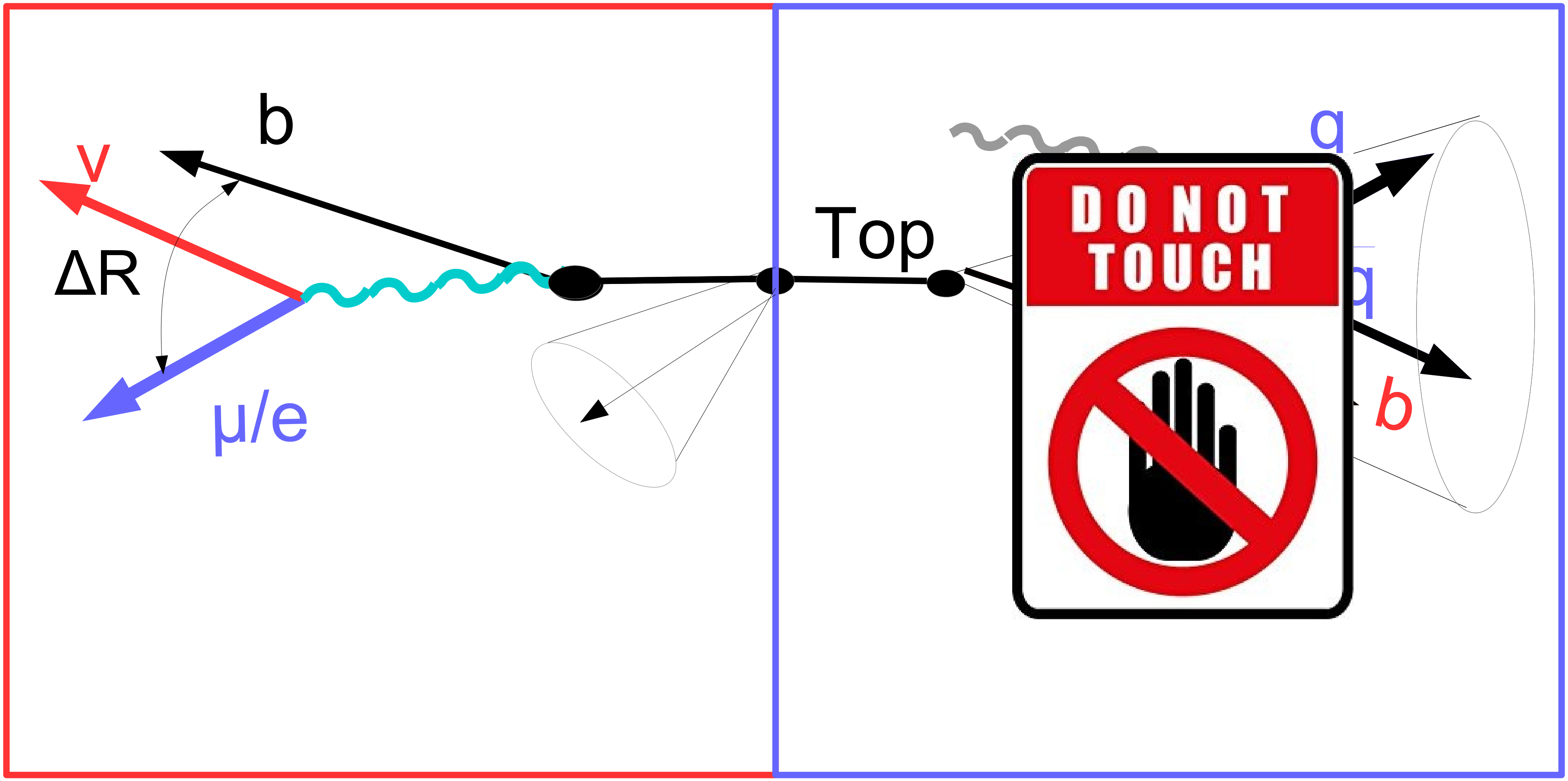
- Goal here is to isolate a pure sample of boosted tops



Selecting top events

Name of the game : don't bias the top mass

– Goal here is to isolate a pure sample of boosted tops



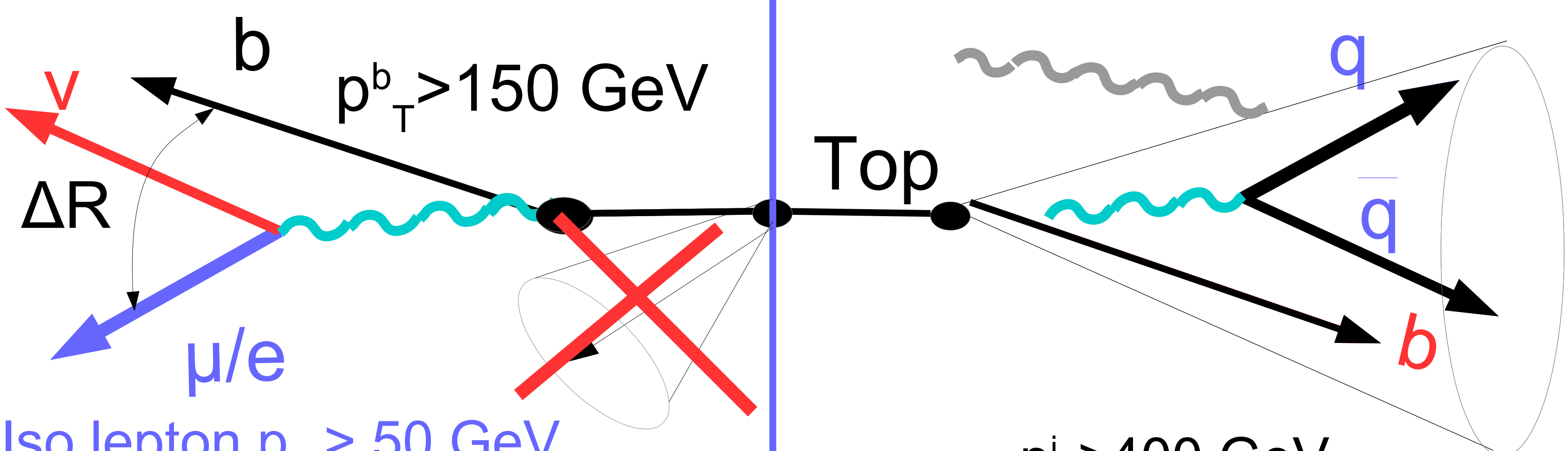
Cut on many parameters

Minimize cut on parameters

Selecting top events

Name of the game : don't bias the top mass

- Goal here is to isolate a pure sample of boosted tops



Iso lepton p_T > 50 GeV

ΔR_{lb} < 1.2

MET+lepton > 150 GeV

No additional jet p_T > 150 GeV

p^j_T>400 GeV

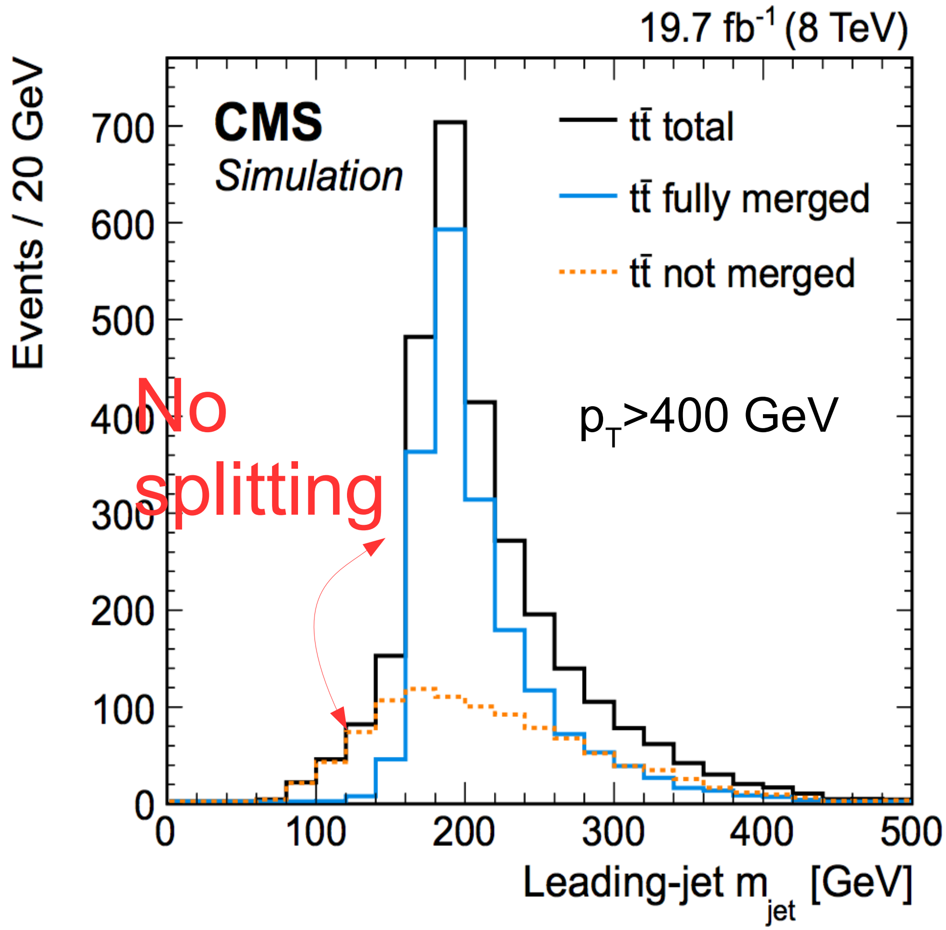
$m^j > m^j_b$

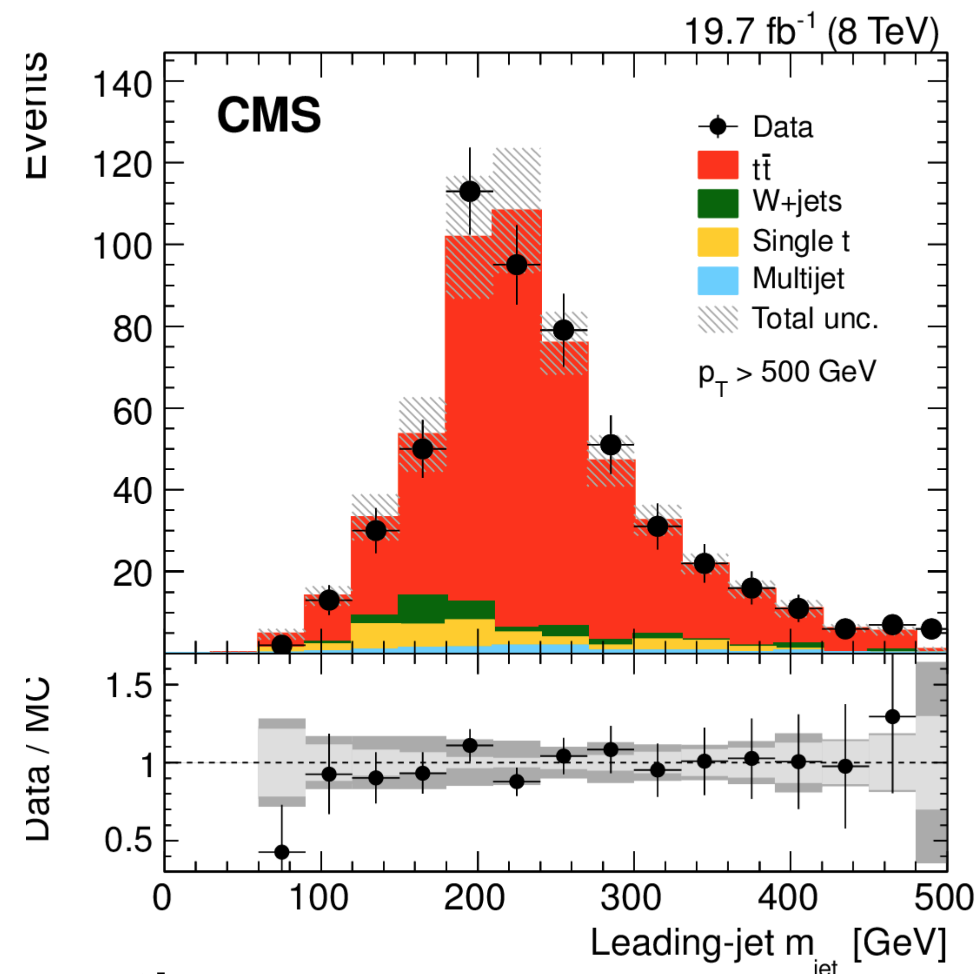
ΔR_{cone} =1.2

Cut on many parameters

Minimize cut on parameters

Top Mass





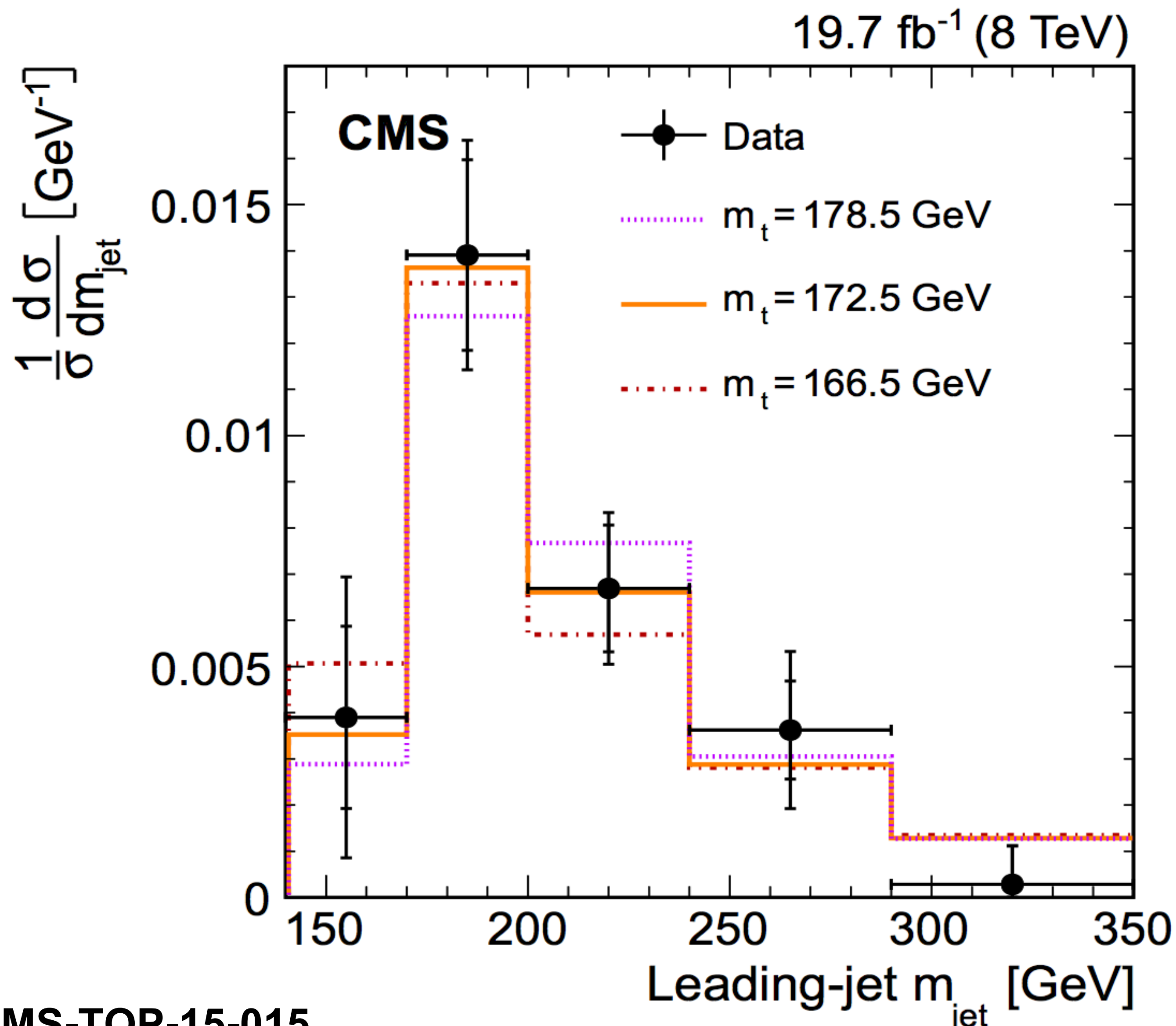
Analysis done inclusive on the mass

Avoid splitting merged and unmergd @ all cost

Goal is unfold mass model independently

CMS-TOP-15-015

Top Mass Unfolded



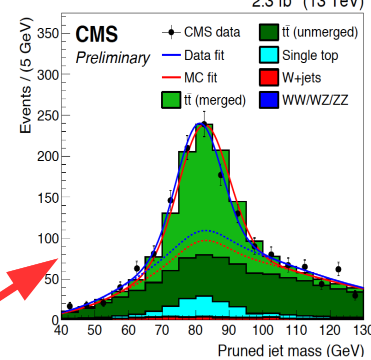
Same scheme as QCD jet mass

+ accounting for migration from tight cuts

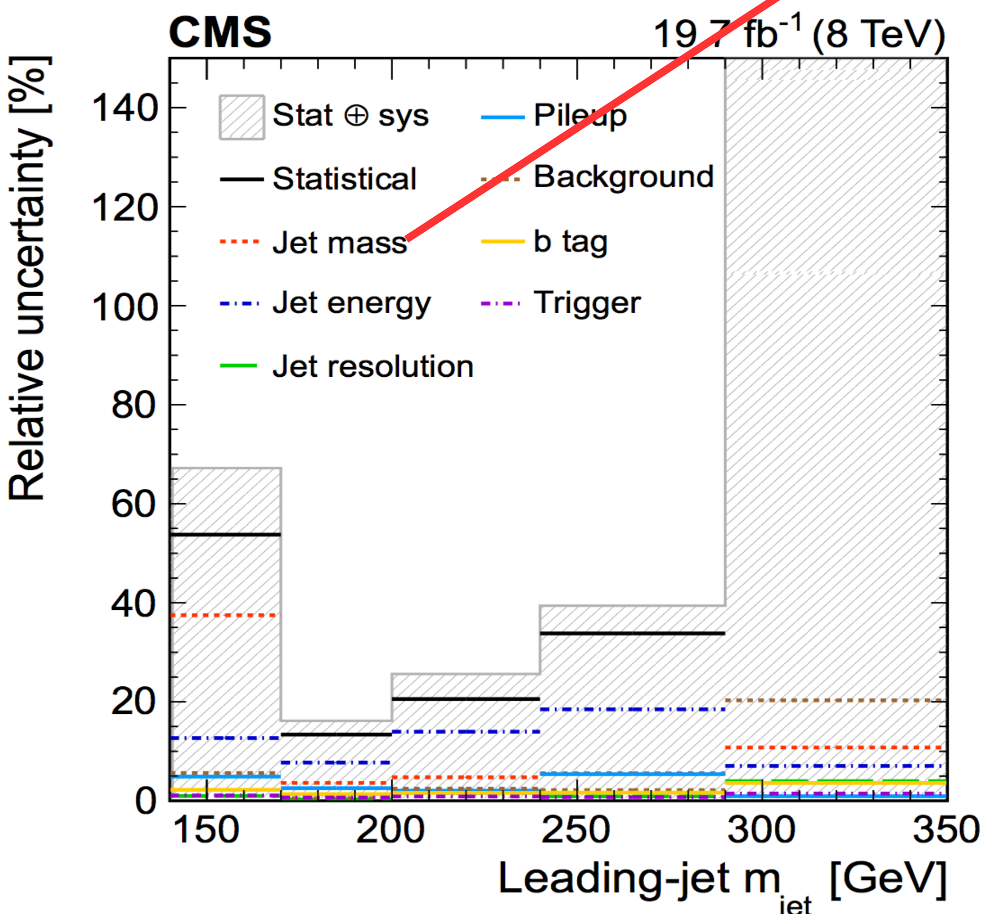
CMS-TOP-15-015

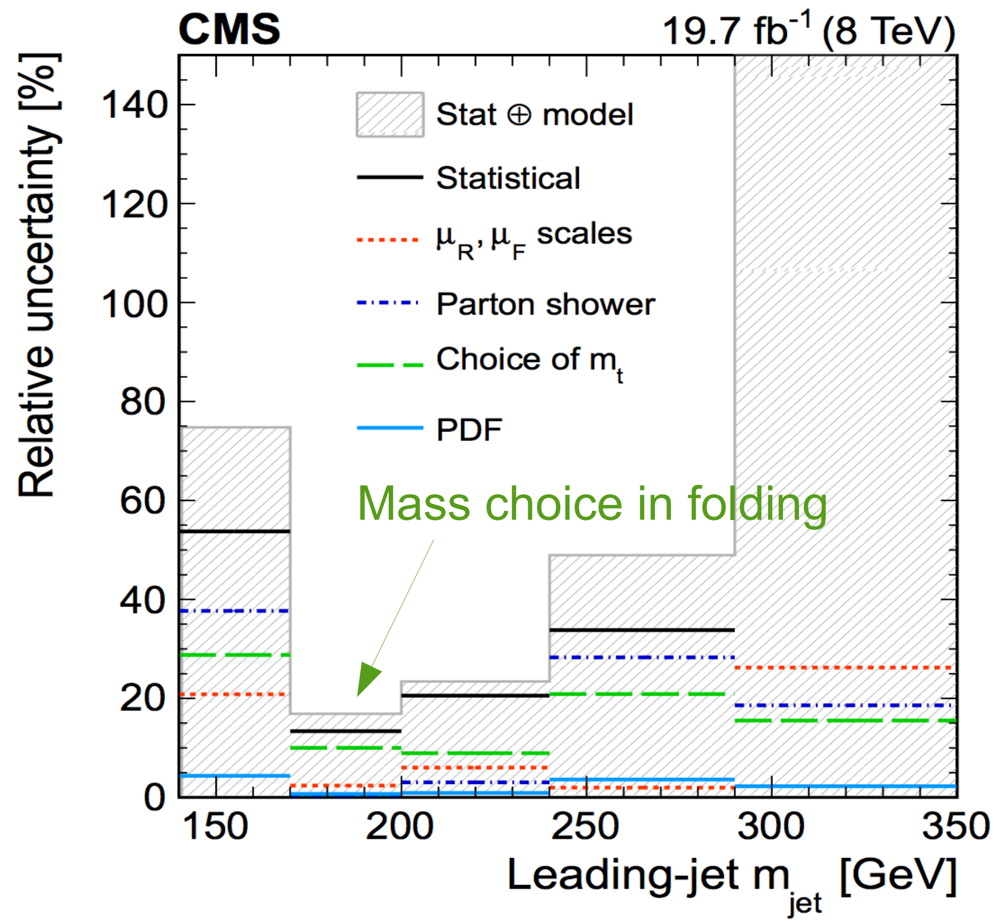
Top Mass

- The unfolded result



(ungroomed)





CMS-TOP-15-015

$$m_t = 170.8 \pm 6.0\,(\text{stat}) \pm 2.8\,(\text{syst}) \pm 4.6\,(\text{model}) \pm 4.0\,(\text{theo})\ \text{GeV}$$

$$= 170.8 \pm 9.0\ \text{GeV},$$

$$m_t^{SM} = 173.34 \pm 0.27\,(\text{stat}) \pm 0.71\,(\text{syst})\ \text{GeV}$$

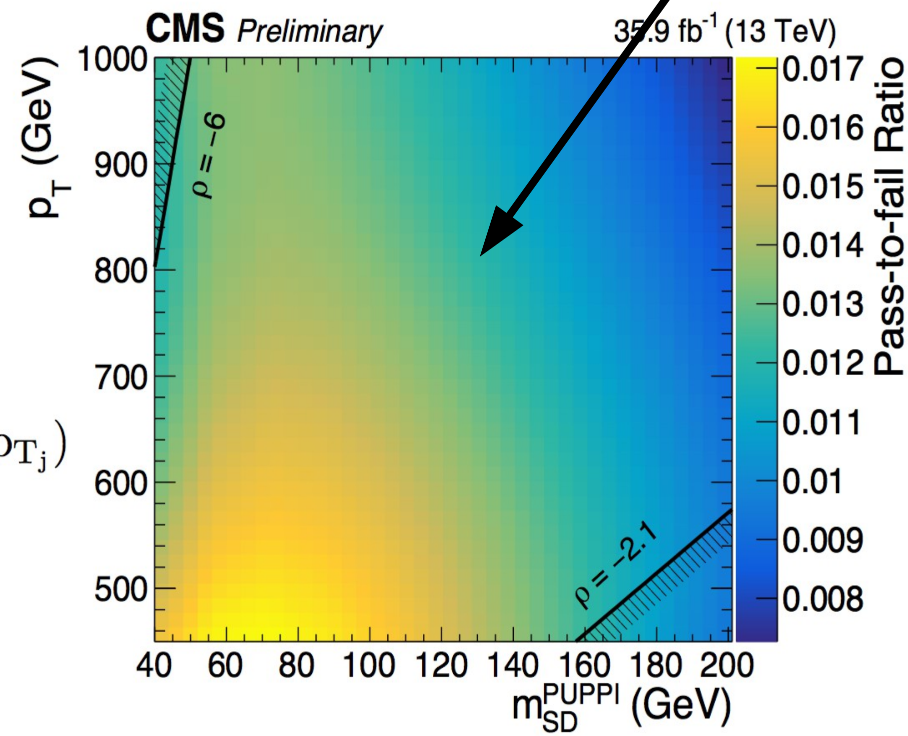
For H peak

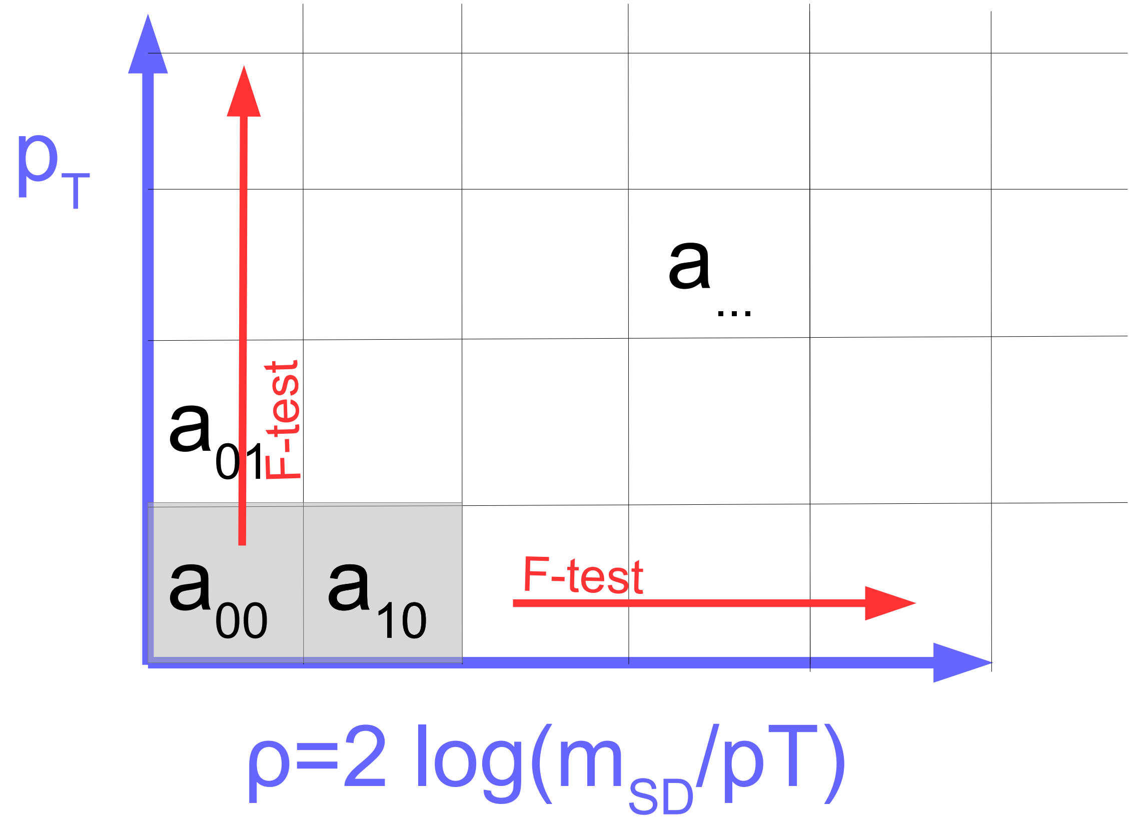
2^{nd} order in ρ

1^{st} order in p_T

Fitted Surface

In data





Following

$$N_{\text{pass}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j}) = \epsilon^{\text{QCD}} \cdot \left(\sum_{k,\ell} a_{k\ell} \rho_{ij}^{k} p_{\text{T}}{}_{j}^{\ell} \right) \cdot N_{\text{fail}}^{\text{QCD}}(m_{\text{SD}i}, p_{\text{T}j}) .$$

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