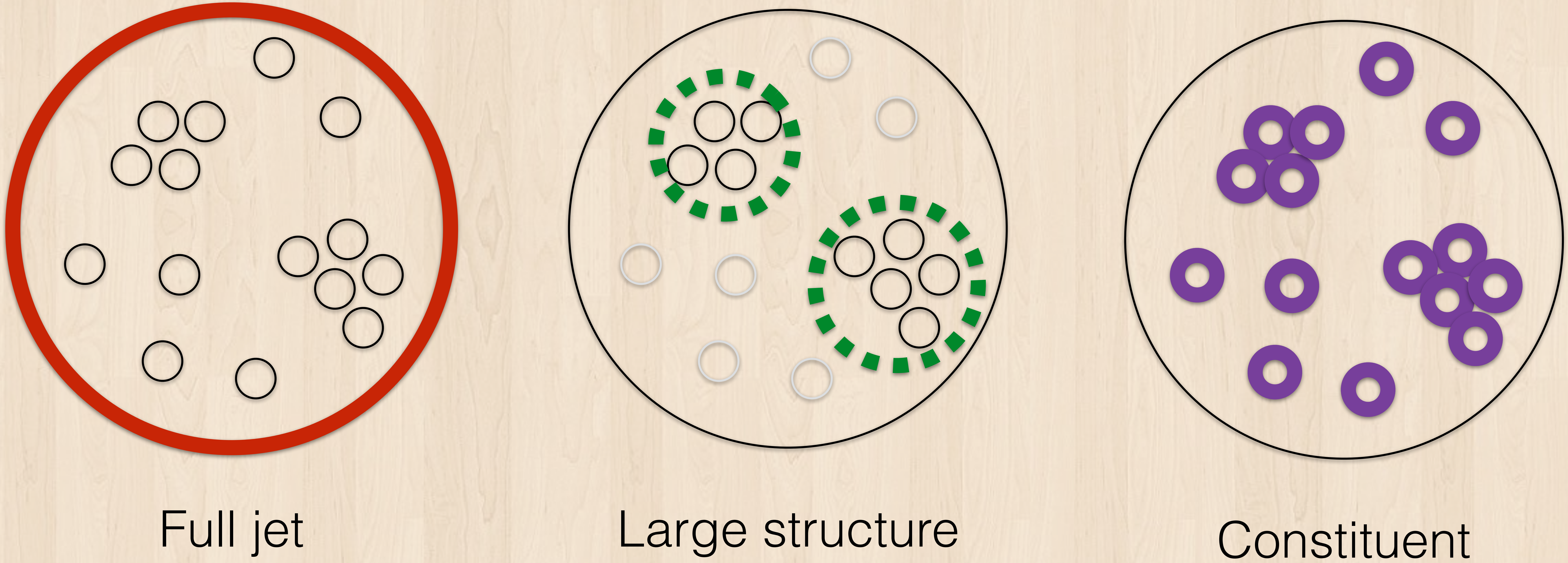
Probing properties of the medium using jet substructure techniques in pp and PbPb collisions at 5.02 TeV with CMS

Yi Chen (CERN) for the CMS Collaboration

Quark Matter, May 16, 2018

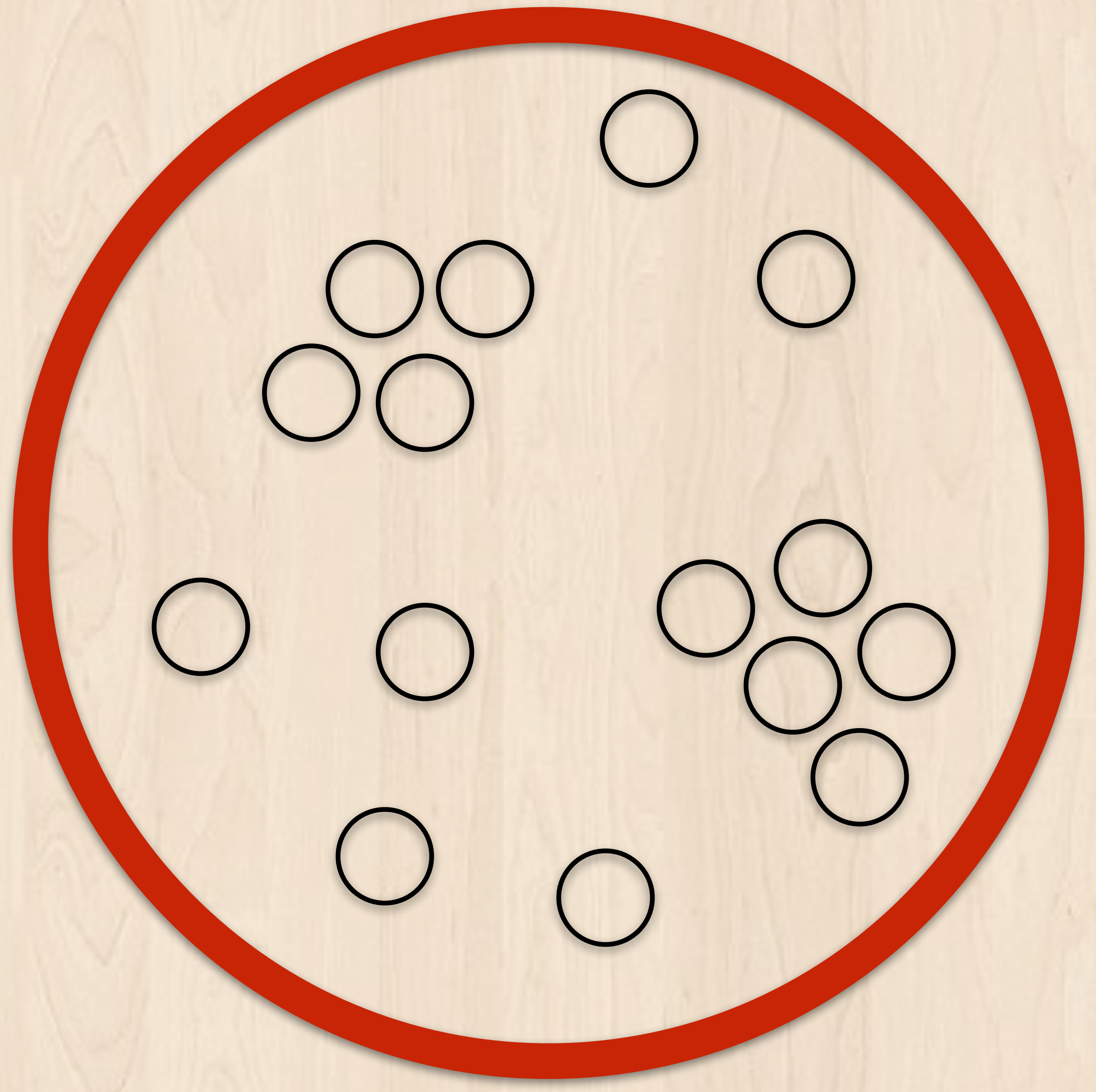
Jets quench — but how?

Level of detail



PRL 119 (2017) 082301
CMS-PAS-HIN-16-014
…

Full jet

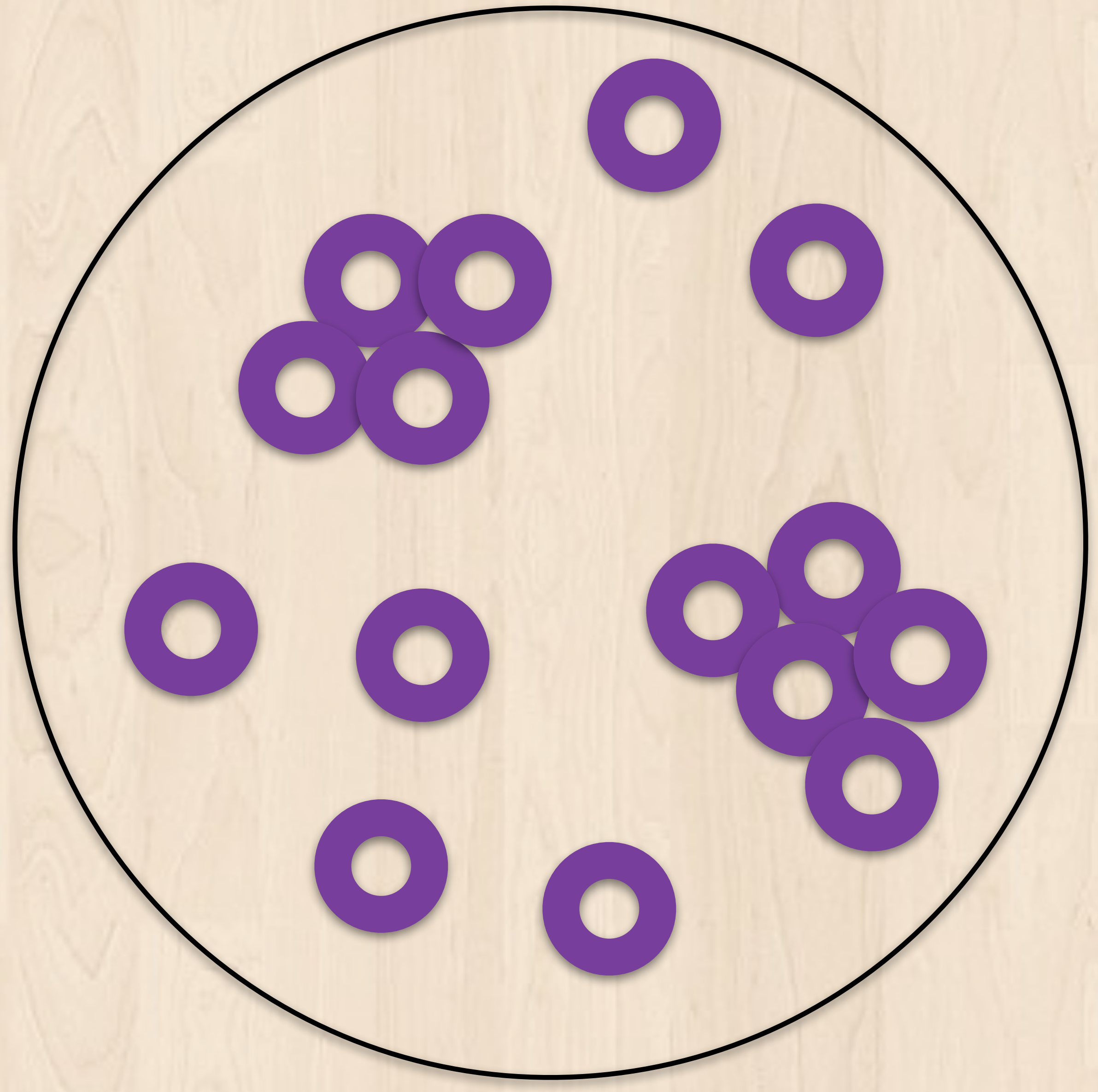


Full jet

Jet R_{AA}
Z/γ+Jet
Dijet balancing
…

1803.00042
HIN-PAS-18-006
1801.04895
...

Constituent

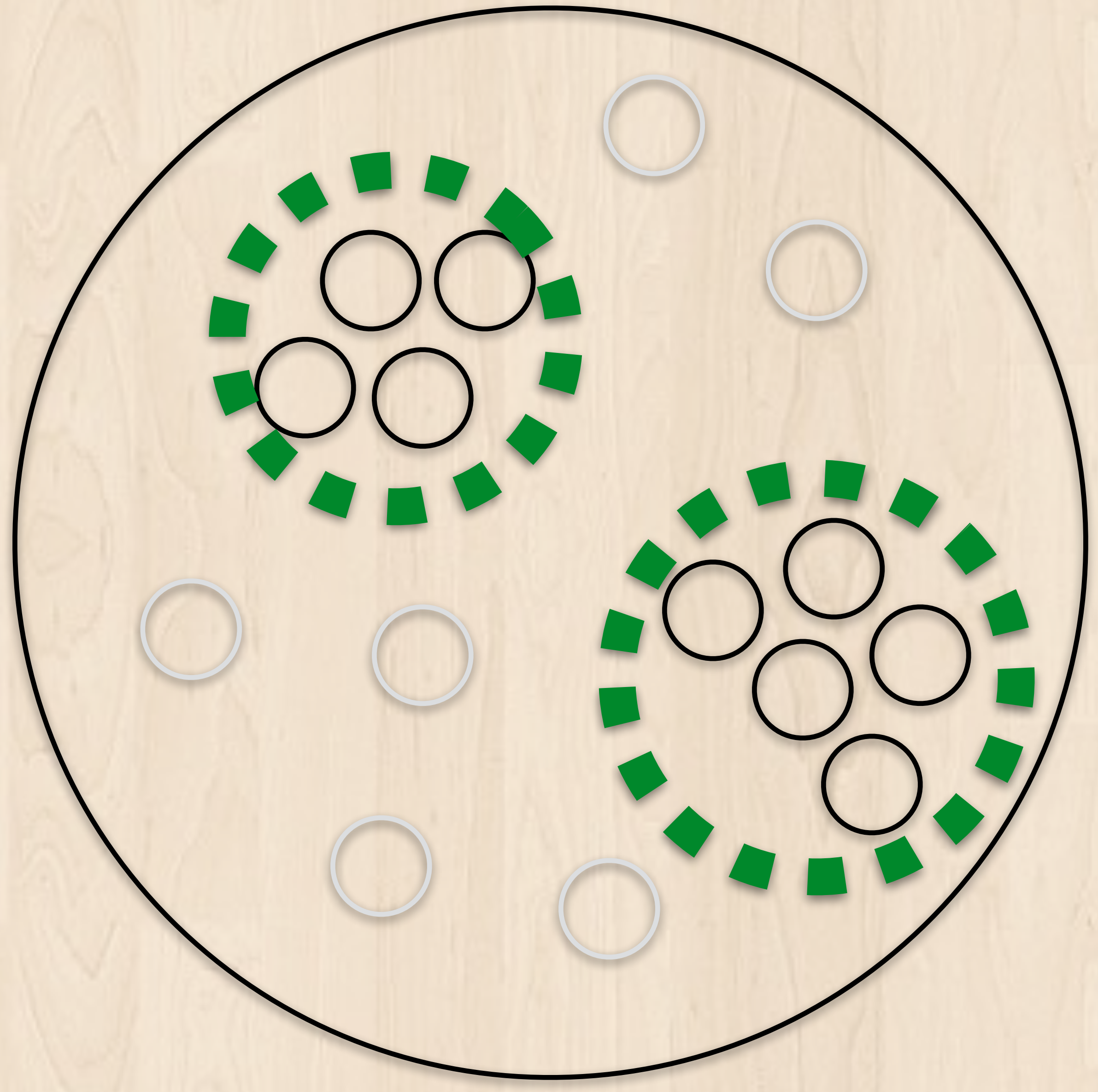


Constituent

Inclusive jet shape
Photon-tagged jet shape
Fragmentation function
...

PRL 120 (2018) 142302
HIN-16-024, arXiv 1805.05145

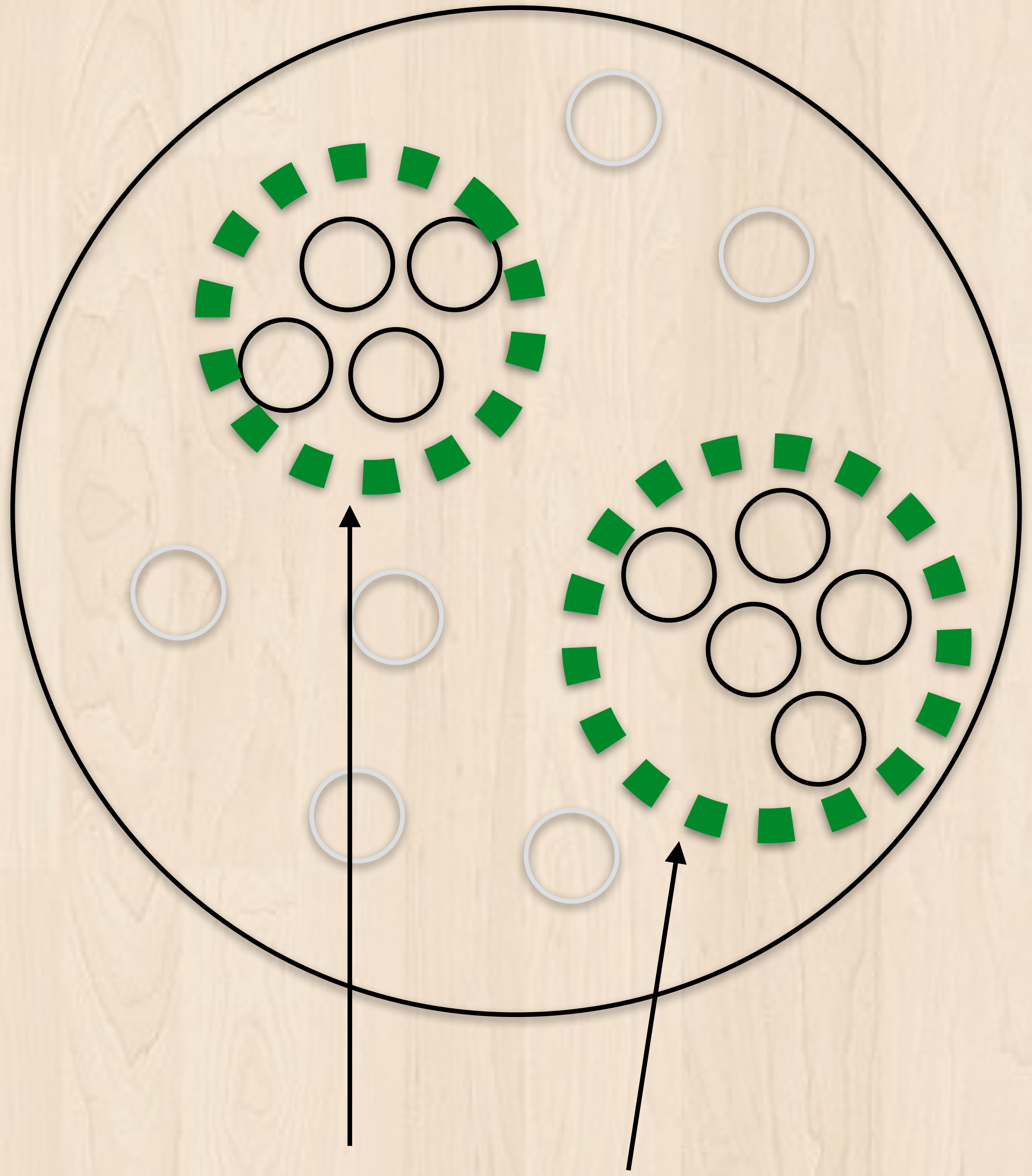
Substructure



Large structure

Momentum sharing
Jet mass
Opening angle

Substructure



Subjets with momenta p_1^μ, p_2^μ

Momentum Sharing

$$z_g \equiv \frac{\min(p_{T\,1}, p_{T\,2})}{p_{T\,1} + p_{T\,2}}$$

Groomed Jet Mass

$$M_g^2 \equiv p_{1\mu}\, p_2^\mu$$

We measure $\frac{M_g}{p_T^{jet}}$

Better cancellation of systematics

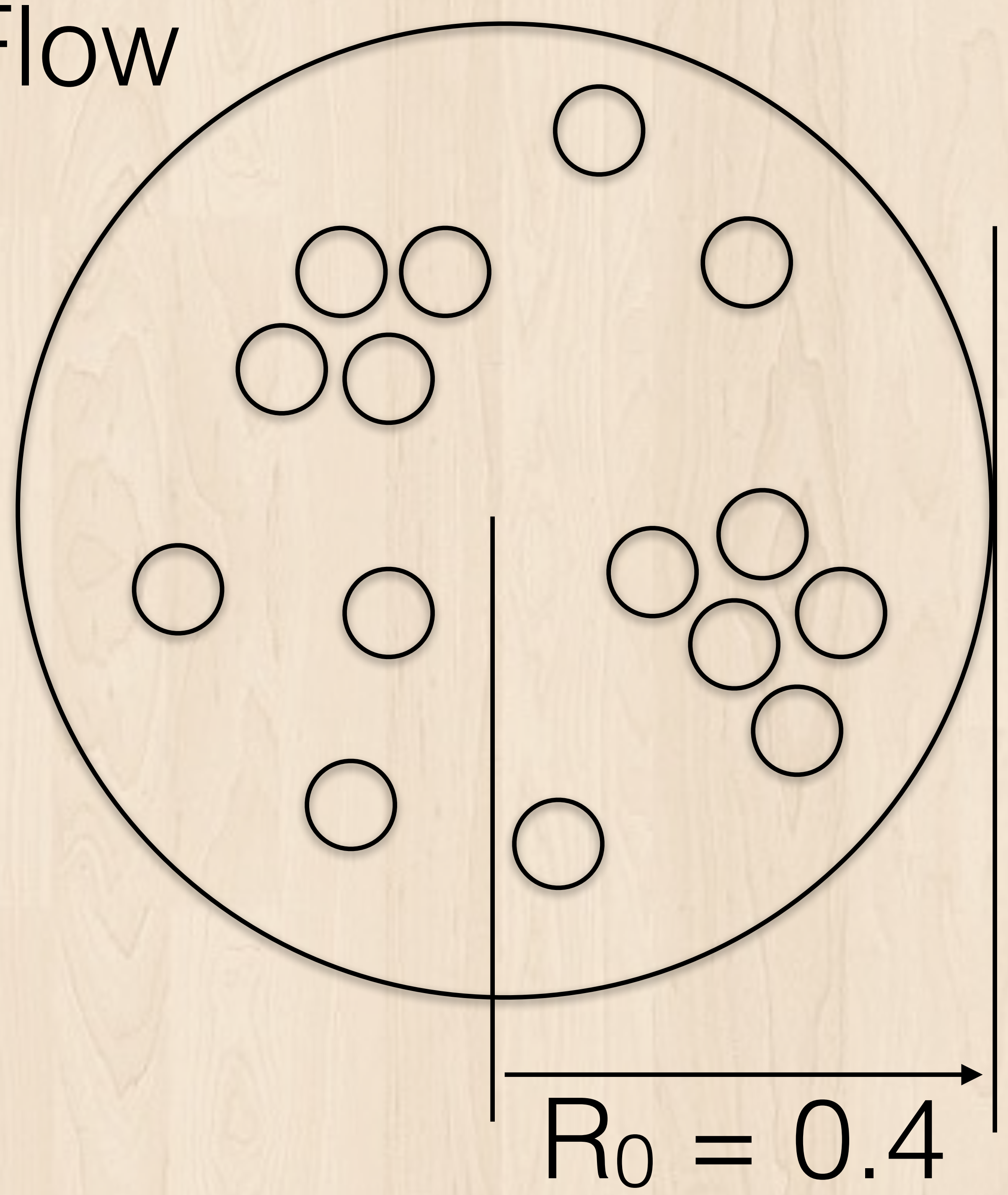
Mass scales with jet p_T in vacuum

How do we do it?

First, we find a good jet

Talk by Chris McGinn Wed 11:50

Particle Flow
anti-k_T



Jet $p_T > 140$ GeV

Constituent Subtraction

Remove average expected energy from underlying events

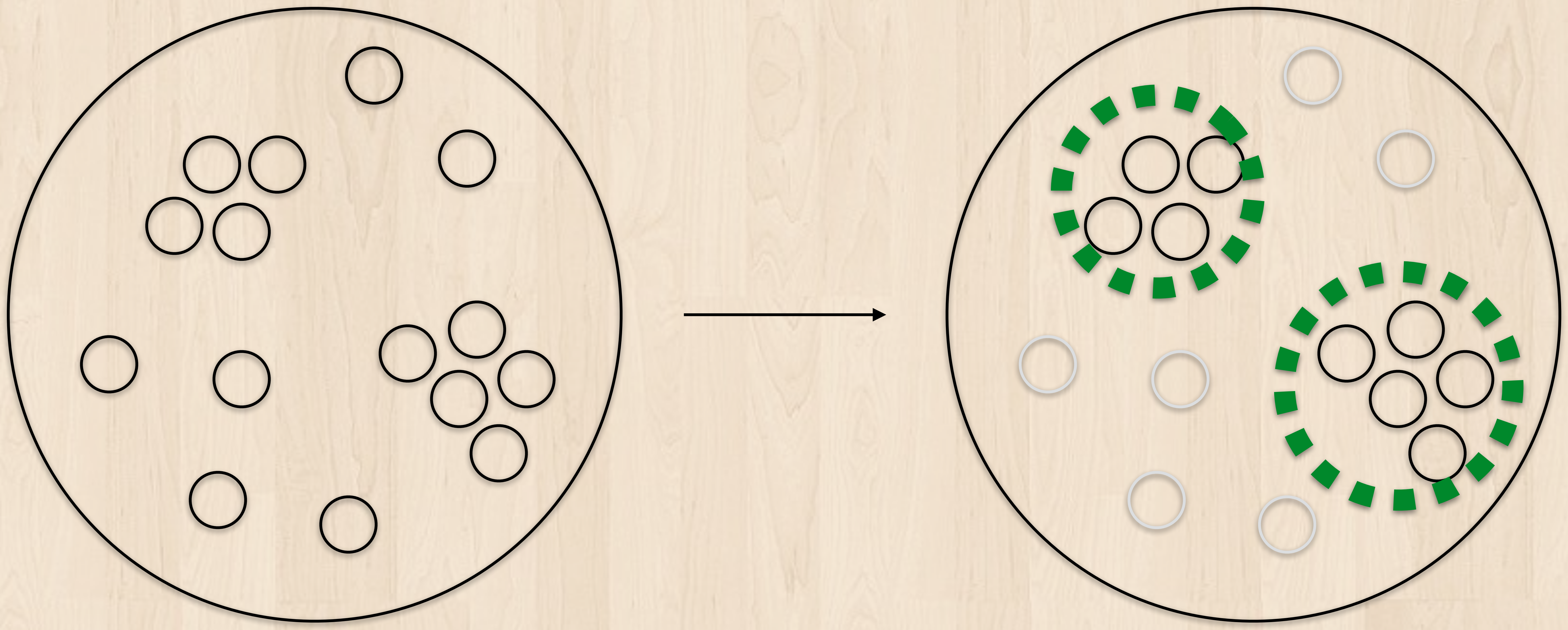
mMDT / Soft drop Grooming

Further cleans up jets

Requires subjet separation $\Delta R_{12} > 0.1$

mMDT / soft drop grooming

Soft drop condition: $z_{\mathrm{g}} \equiv \frac{\min(p_{\mathrm{T}\,1}, p_{\mathrm{T}\,2})}{p_{\mathrm{T}\,1} + p_{\mathrm{T}\,2}} > z_{\mathrm{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$



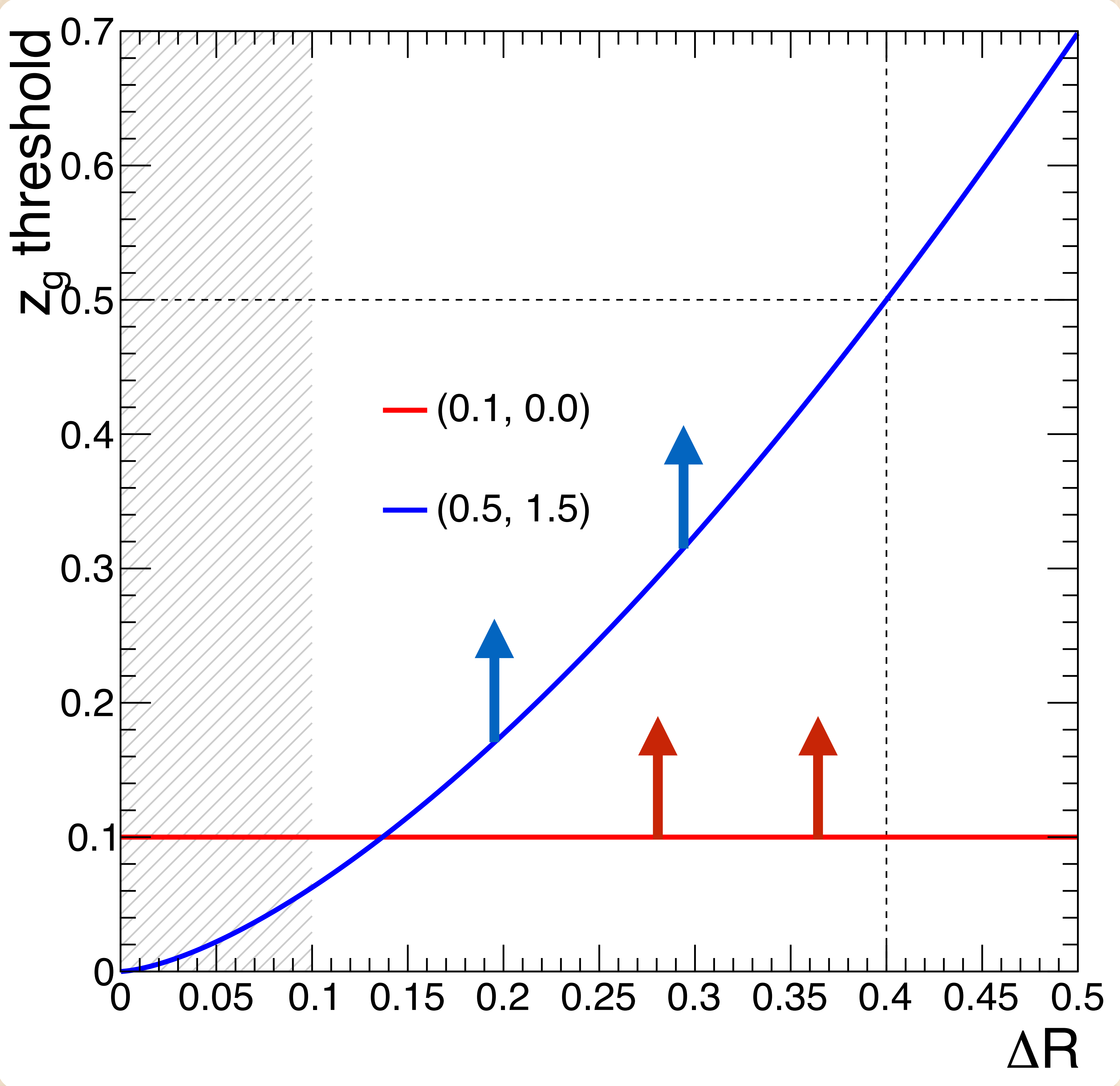
Grooming Settings

(z_{cut} = 0.1, β = 0.0)

Angle-independent

Good theoretical properties

"Flat grooming"



(z_{cut} = 0.5, β = 1.5)

Stronger grooming at large angle

More resilient to large angle soft radiation

"Jet core"

Comparison between the two can tell us something interesting

Analysis Strategy

PbPb vs. smeared pp

Smeared pp = what we would have gotten if PbPb events were simply superposition of pp jets and PbPb minimum bias events

Smearing

Momentum sharing z_g

pp vs embedded pp

↓

smearing matrix

↓

apply on data

Groomed mass $M_g/p_{T,jet}$

event mixing:
pp + PbPb background

↓

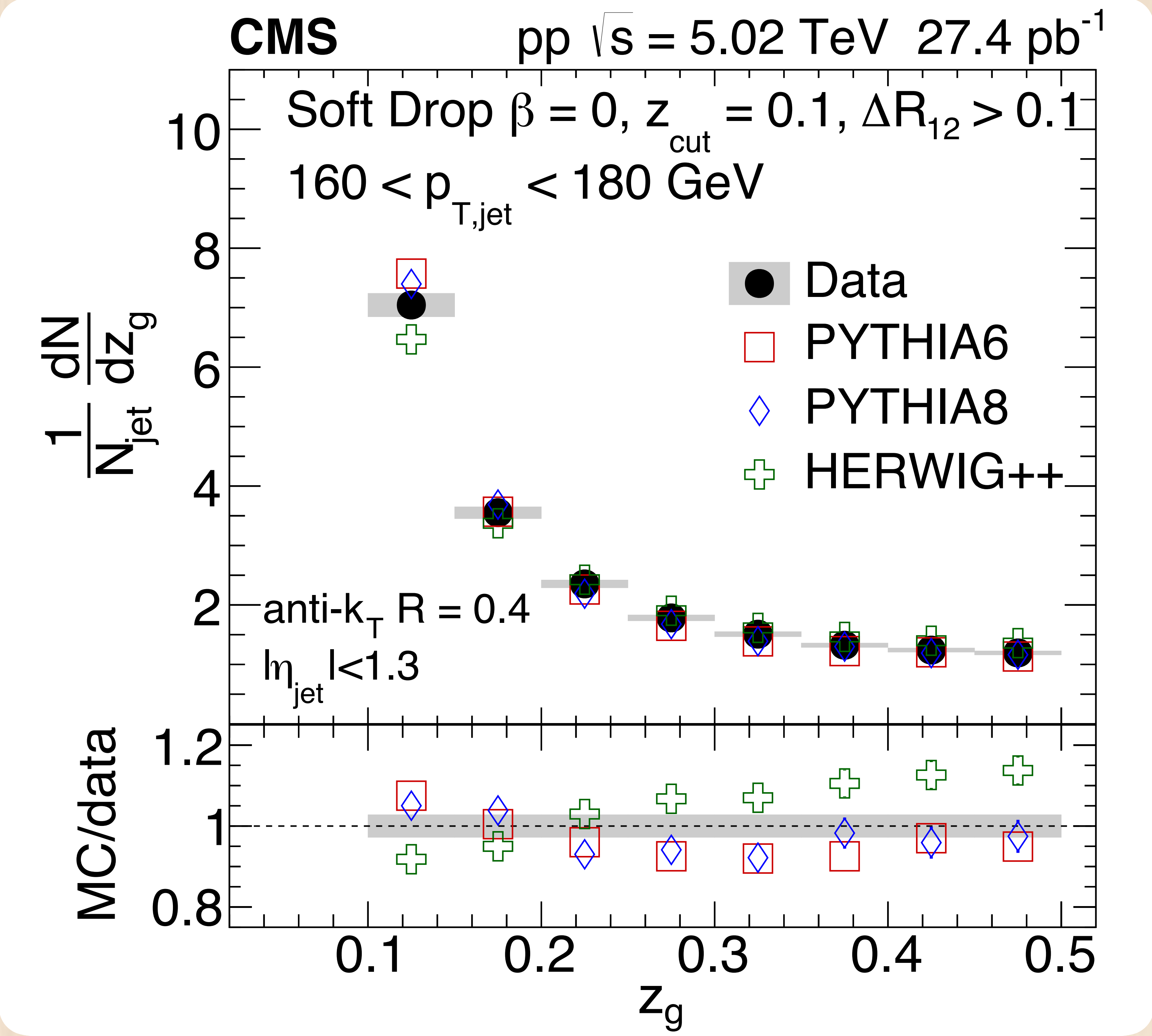
subtraction and grooming

Internal cross check: the two methods give consistent z_g result

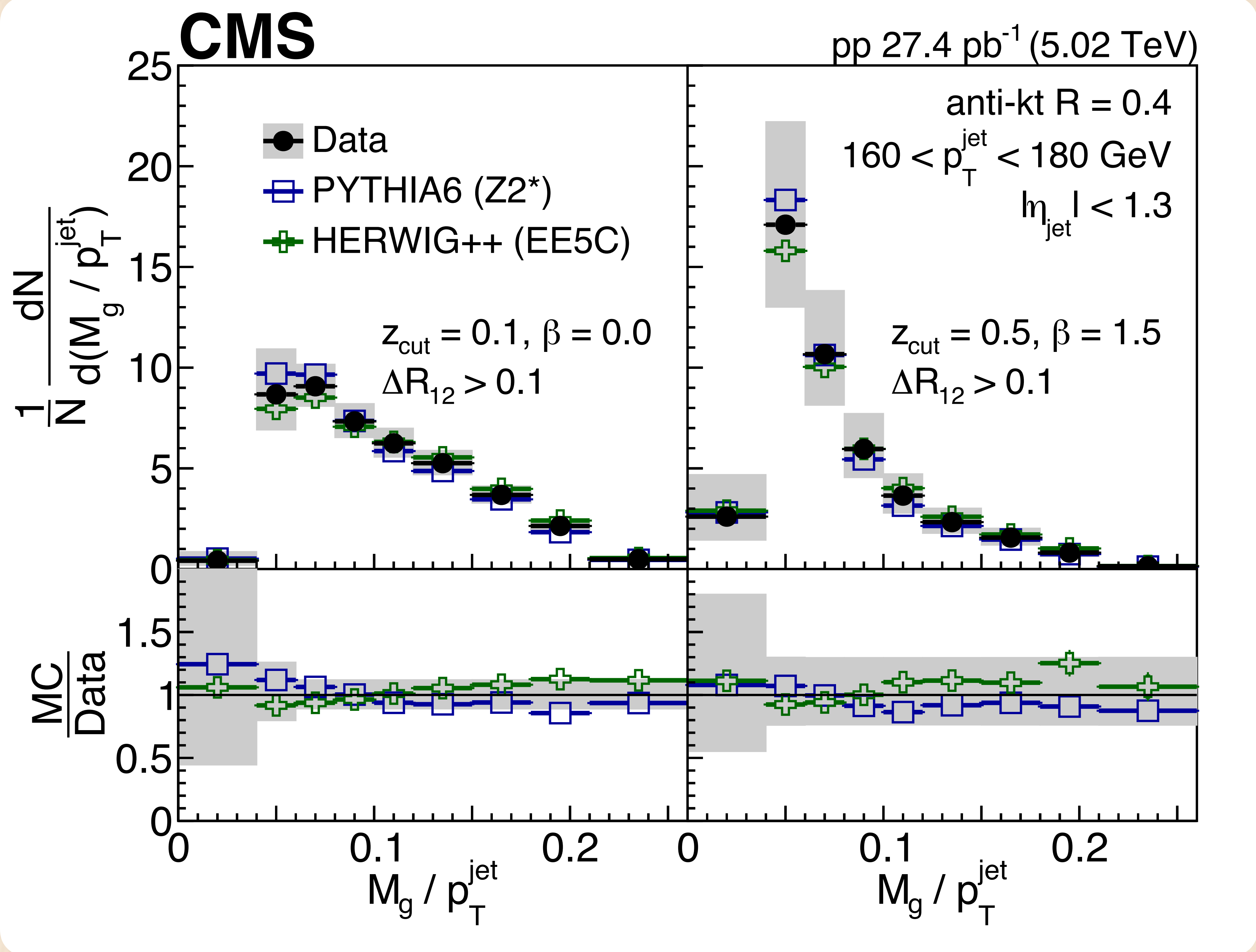
Results

Data vs MC in pp collisions

(z_{cut} = 0.1, β = 0.0)



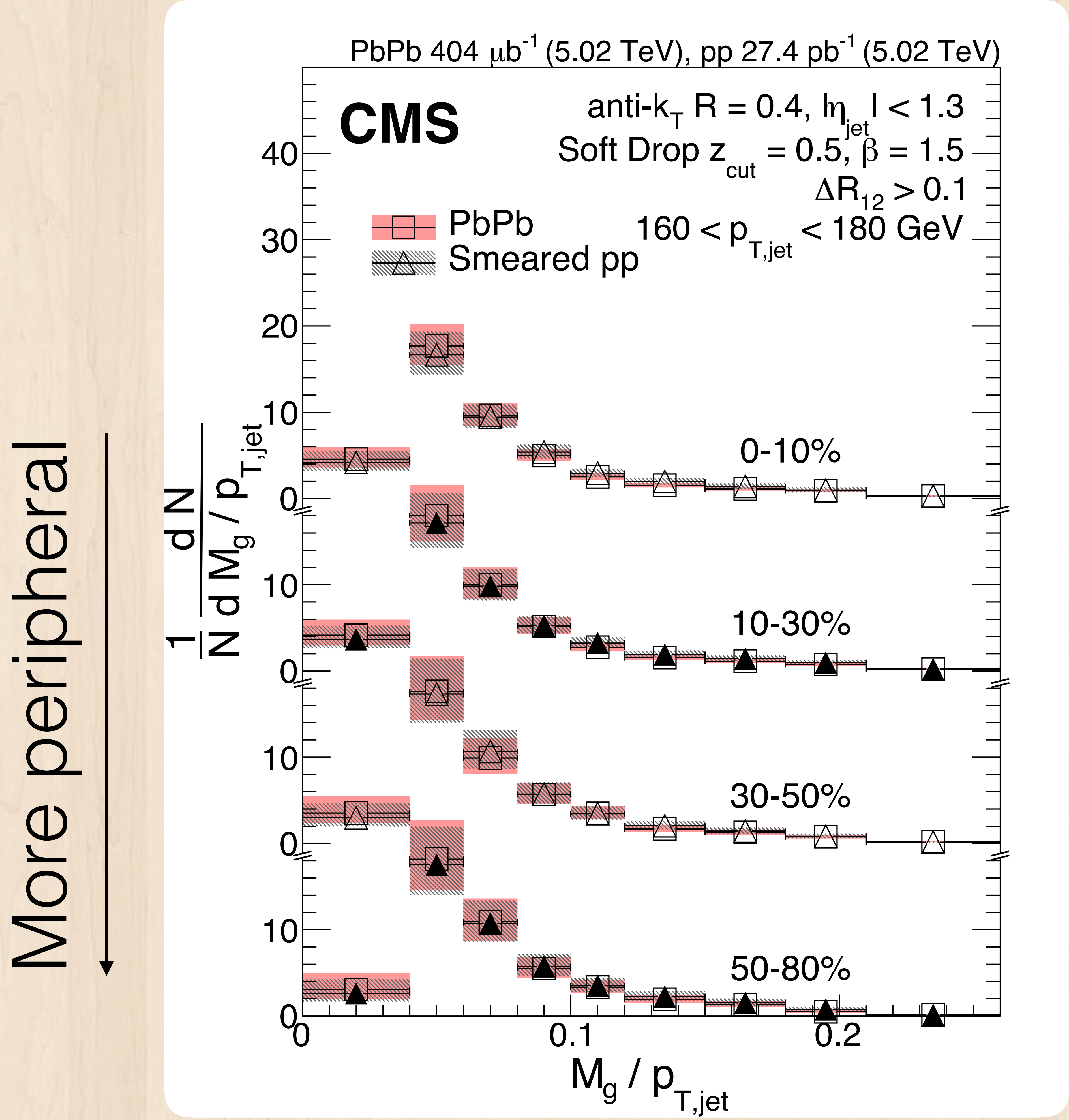
(z_{cut} = 0.1, β = 0.0) (z_{cut} = 0.5, β = 1.5)



MC generally describes data well

Pythia tends to have smaller amount of hard radiation

(z_{cut} = 0.5, β = 1.5): core of the jet



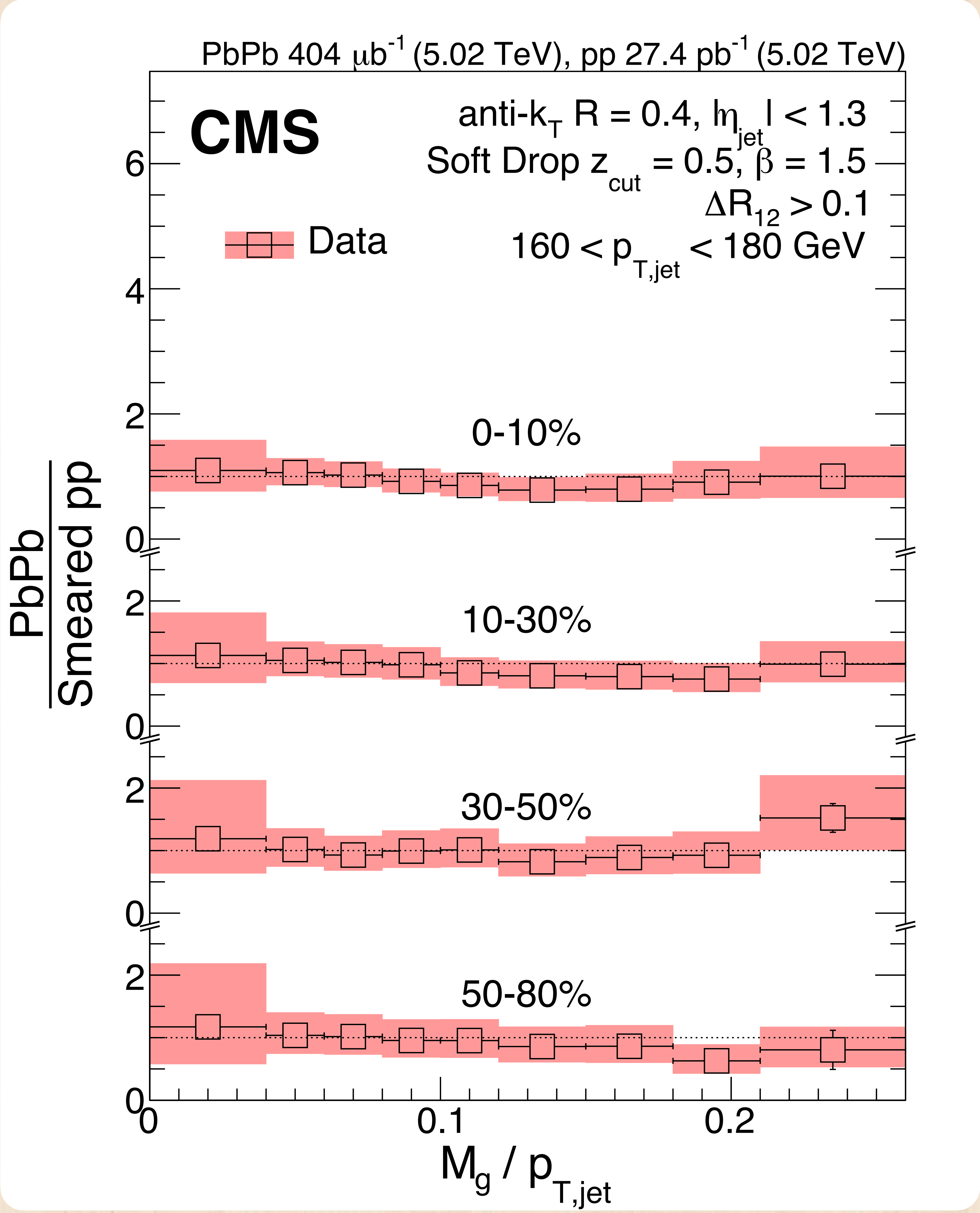
Jet P_T = 160–180 GeV

Different centrality ranges

Good agreement between PbPb and smeared pp

(z_{cut} = 0.5, β = 1.5): core of the jet

More peripheral



Jet P_T = 160–180 GeV

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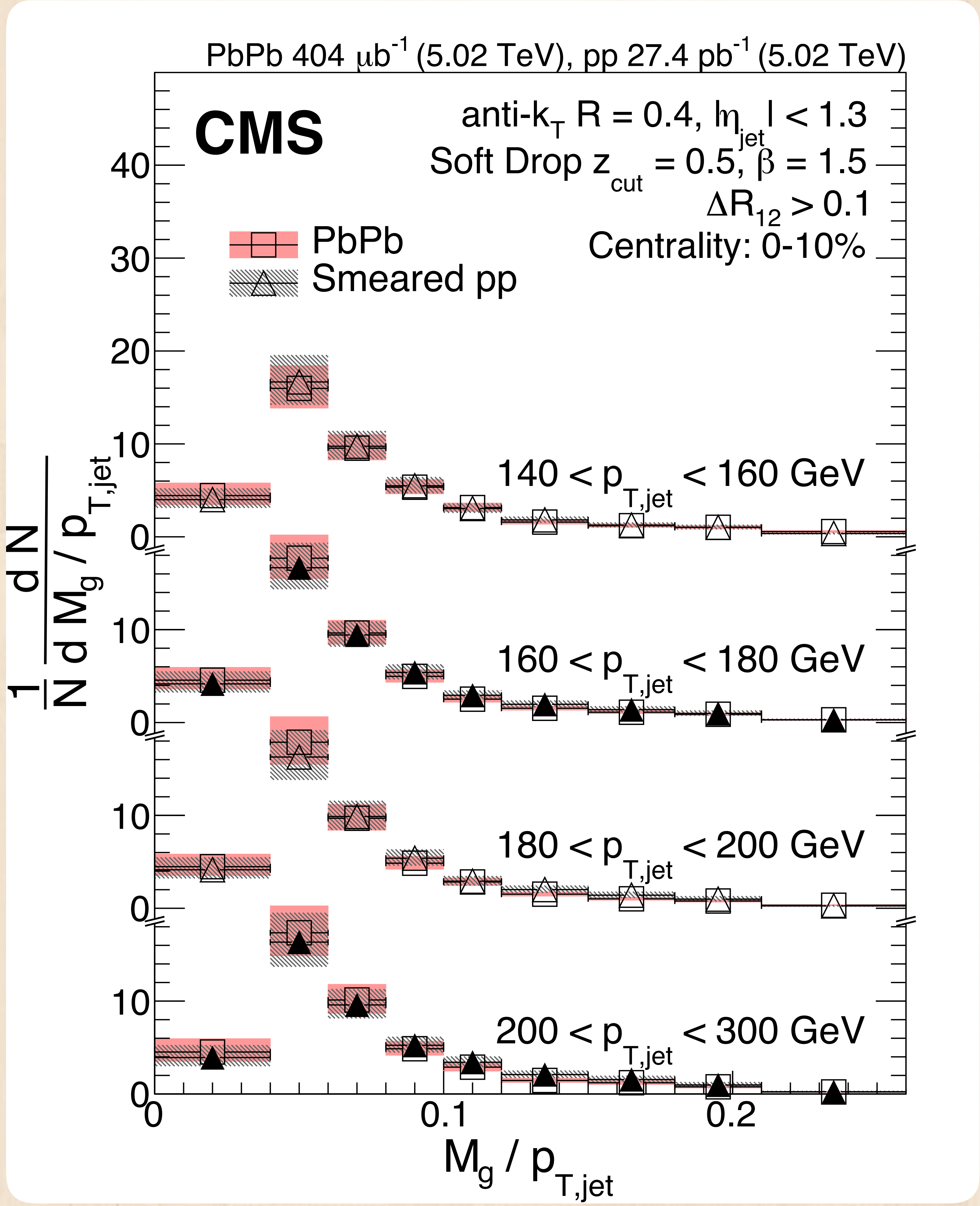
(z_{cut} = 0.5, β = 1.5): core of the jet

Higher jet p_T



10% most central events

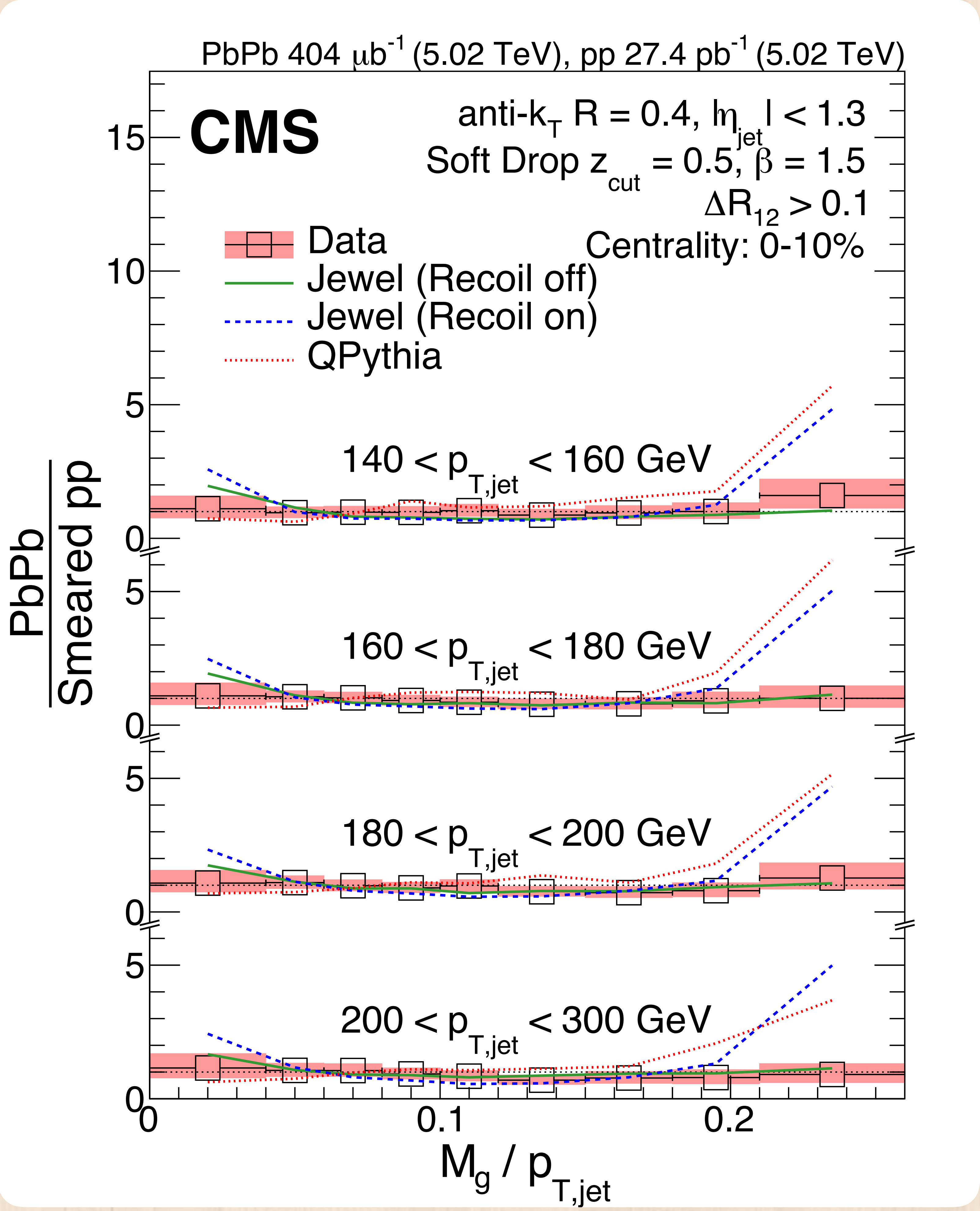
Different energy ranges

No significant modifications to the core of the jets

EPJC 74 (2014) 2672
EPJC 63 (2009) 679

(z_{cut} = 0.5, β = 1.5): core of the jet

Higher jet p_T



10% most central events

Different energy ranges

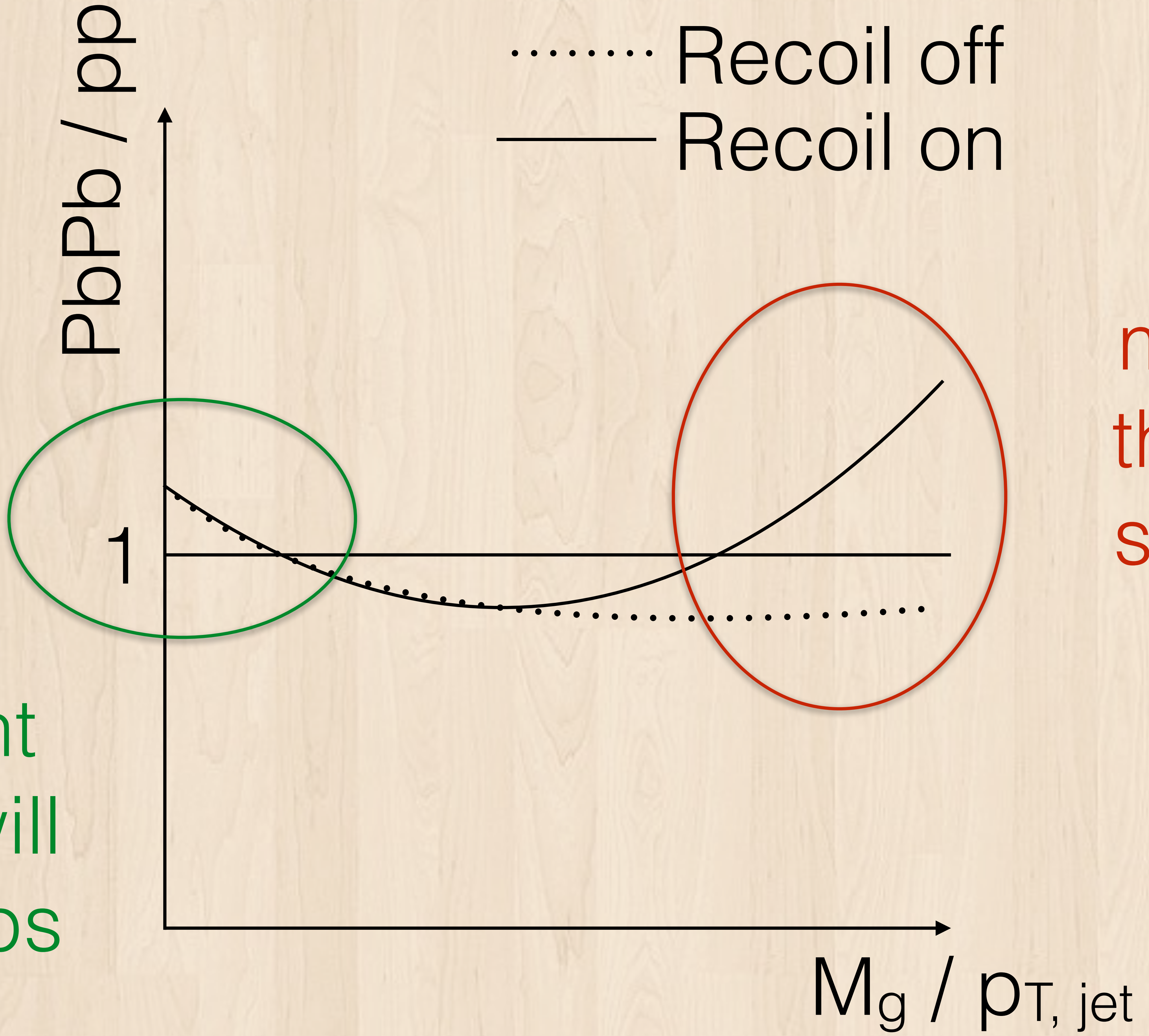
No significant modifications to the core of the jets

Generators tend to predict large modification

Shape in JEWEL / Q-Pythia

Partons lose energy — bulk moves to smaller mass compared to ungroomed jet P_T

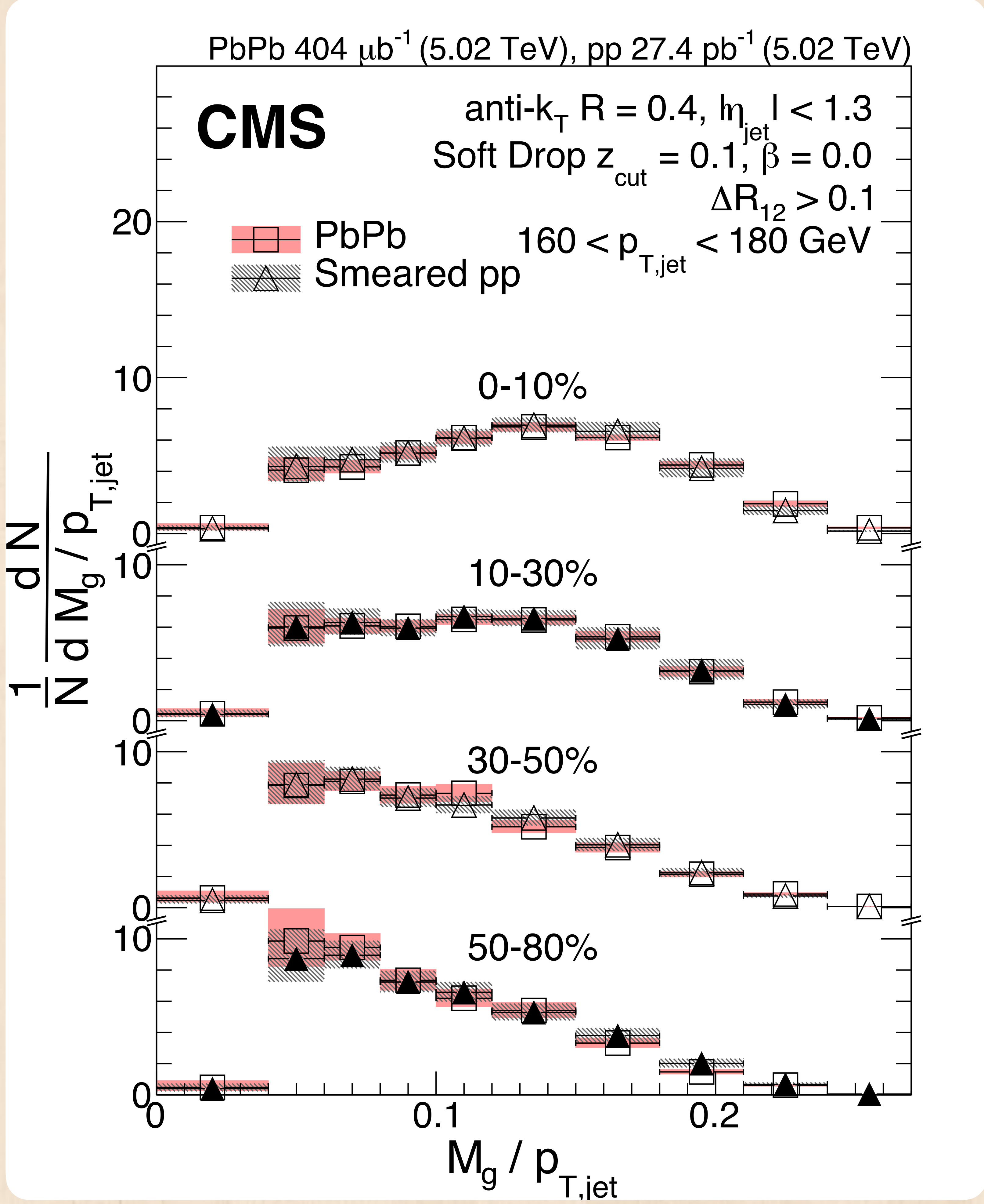
If there is large amount of broadening, mass will increase and ratio drops



The rise in large mass tail is due to the recoil particles scattered at larger angles

$(z_{cut} = 0.1, \beta = 0.0)$: flat grooming

More peripheral



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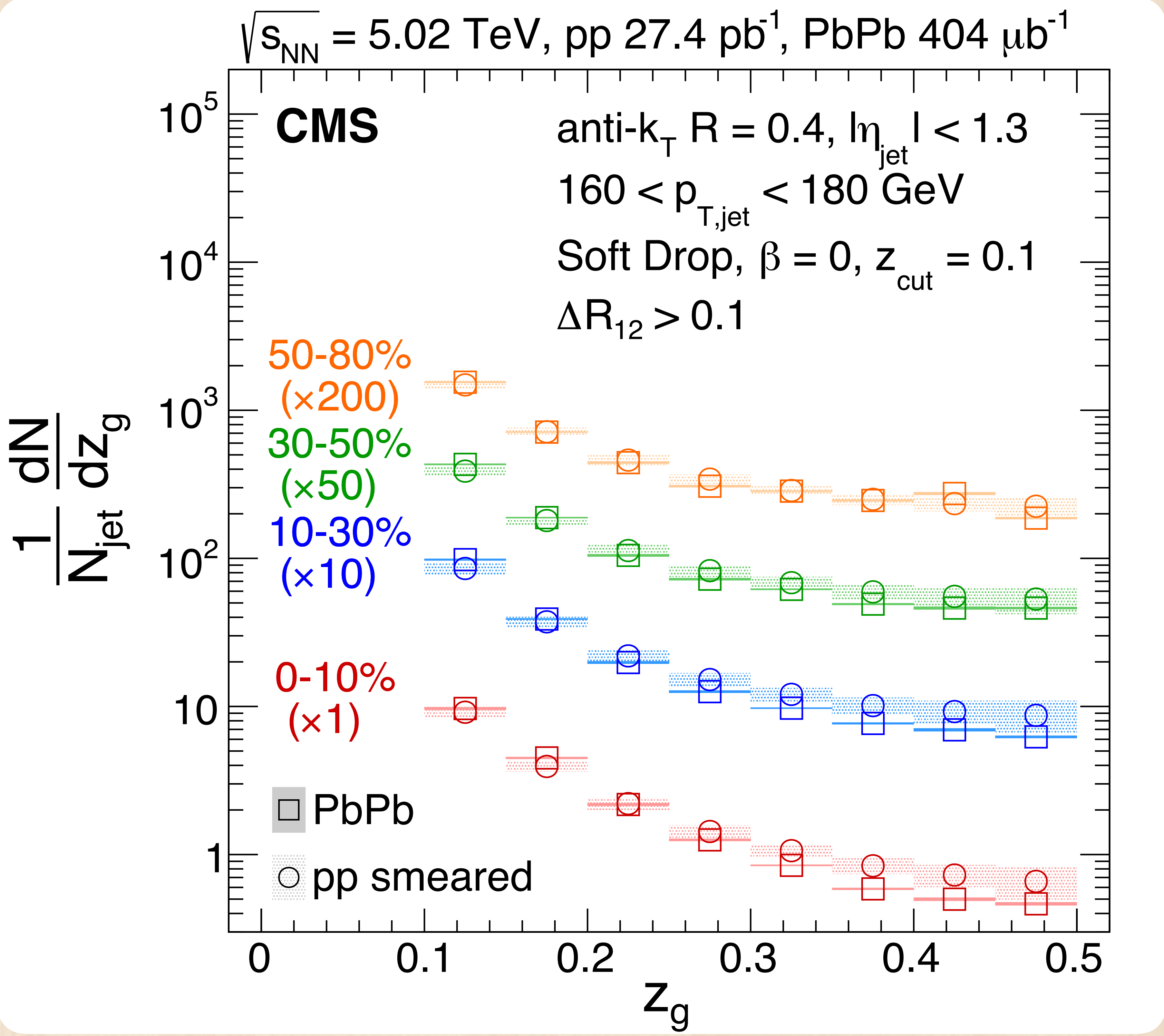
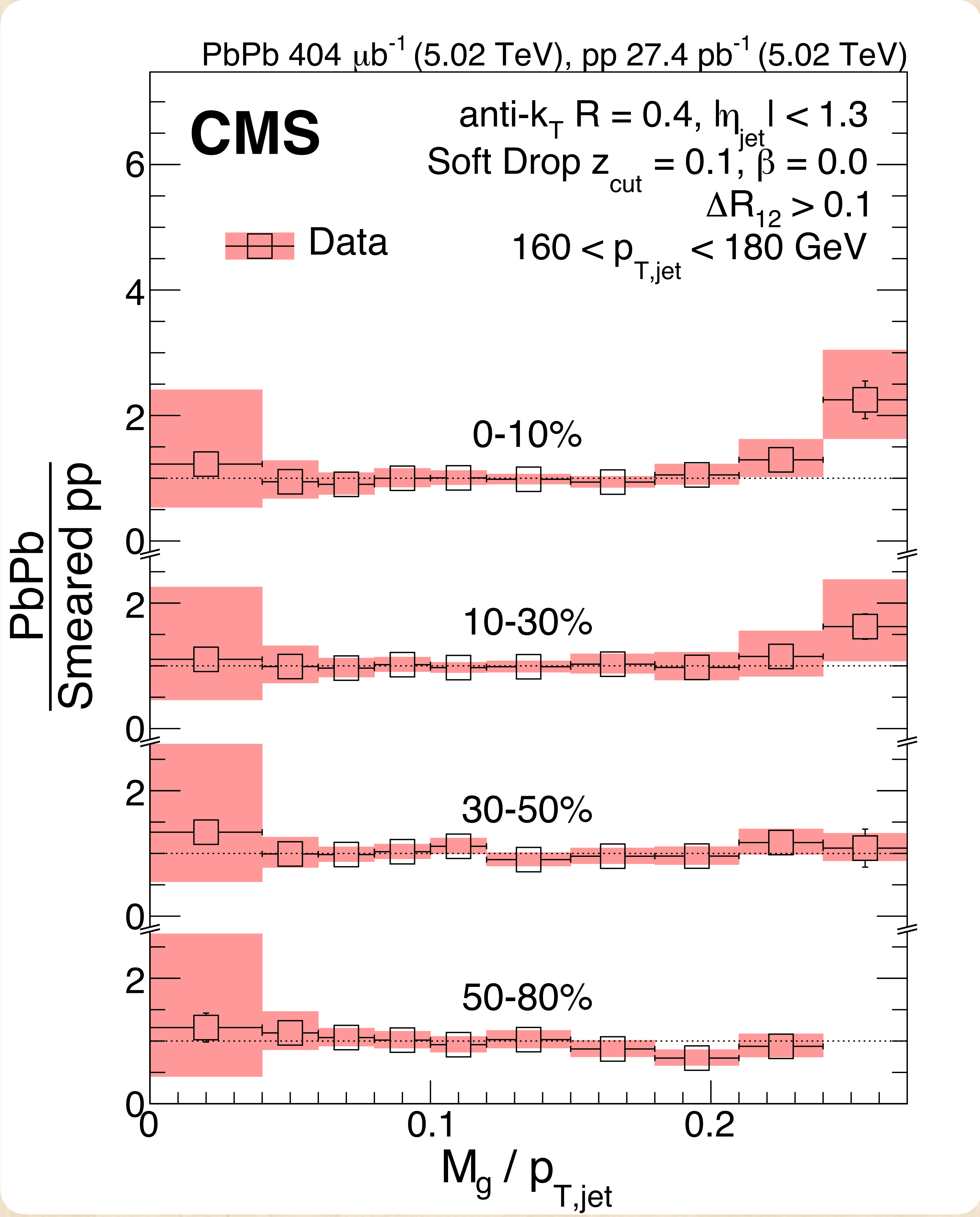
Different centrality ranges



More peripheral

(z_{cut} = 0.1, β = 0.0): flat grooming

More peripheral

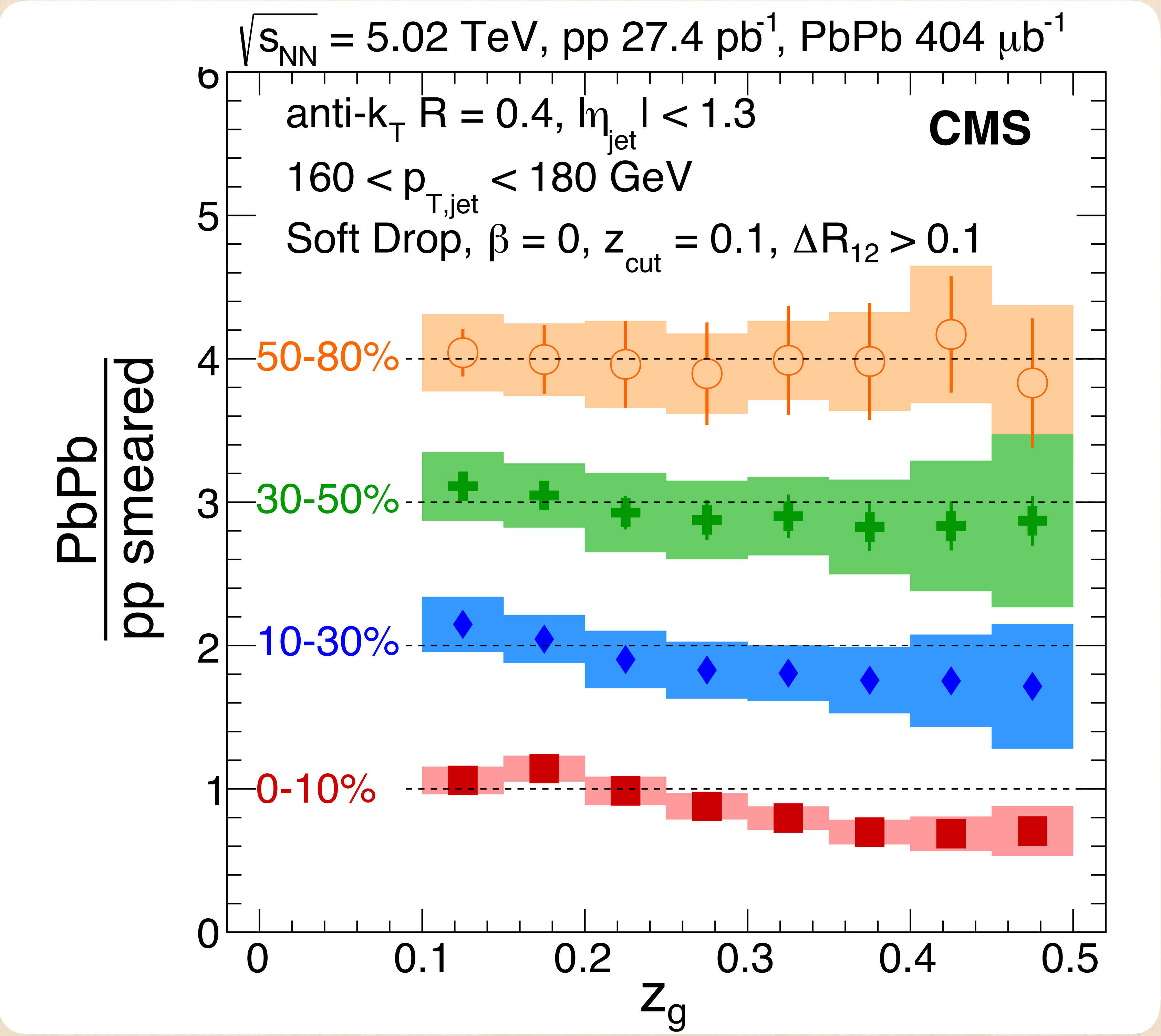


Deviation in more central events

Imbalanced subjets, Larger mass

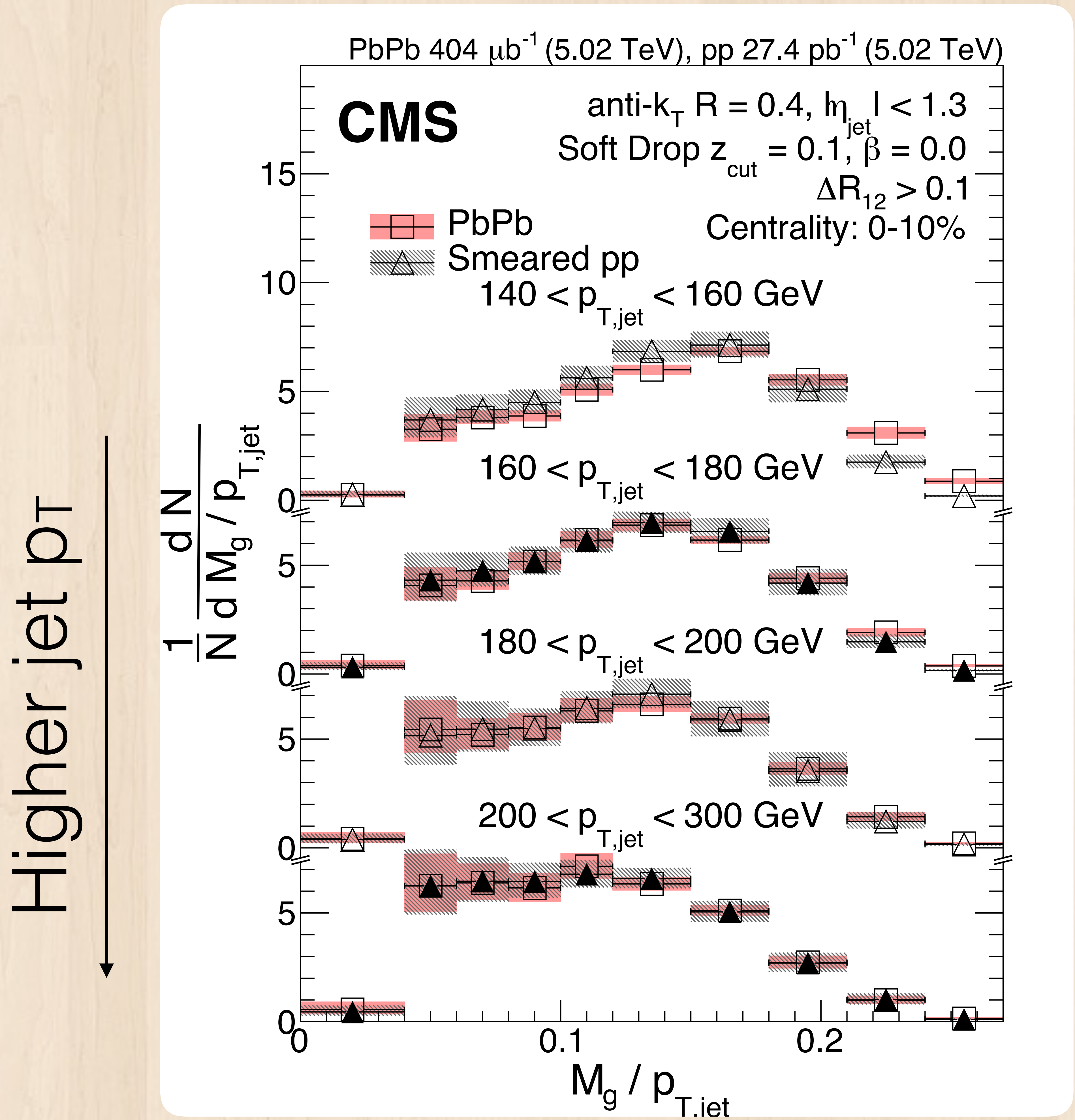
Jet P_T = 160–180 GeV

Different centrality ranges



More peripheral

(z_{cut} = 0.1, β = 0.0): flat grooming



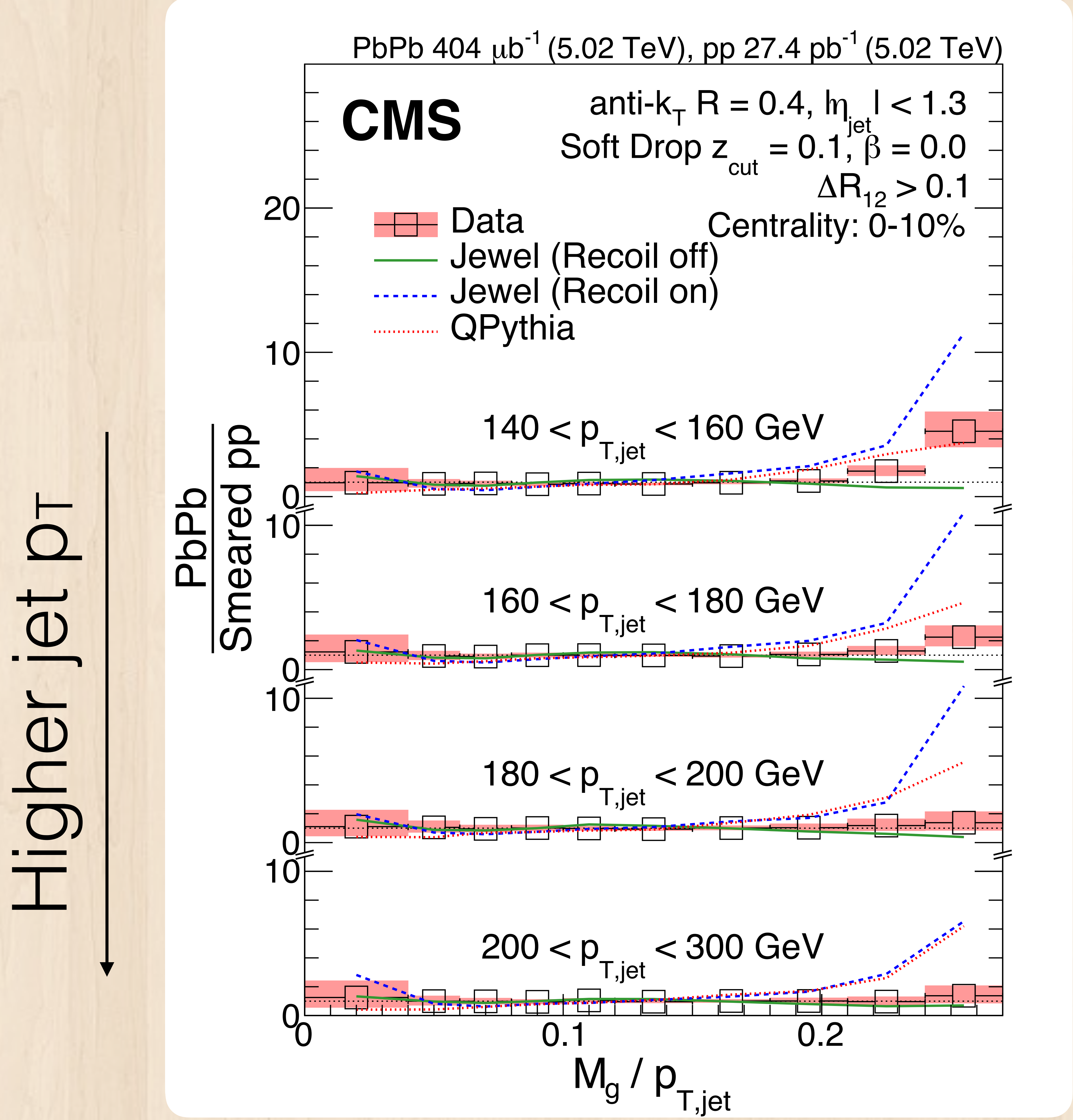
10% most central events

Different energy ranges

Modification diminishes with higher jet energy

EPJC 74 (2014) 2672
EPJC 63 (2009) 679

(z_{cut} = 0.1, β = 0.0): flat grooming



10% most central events

Different energy ranges

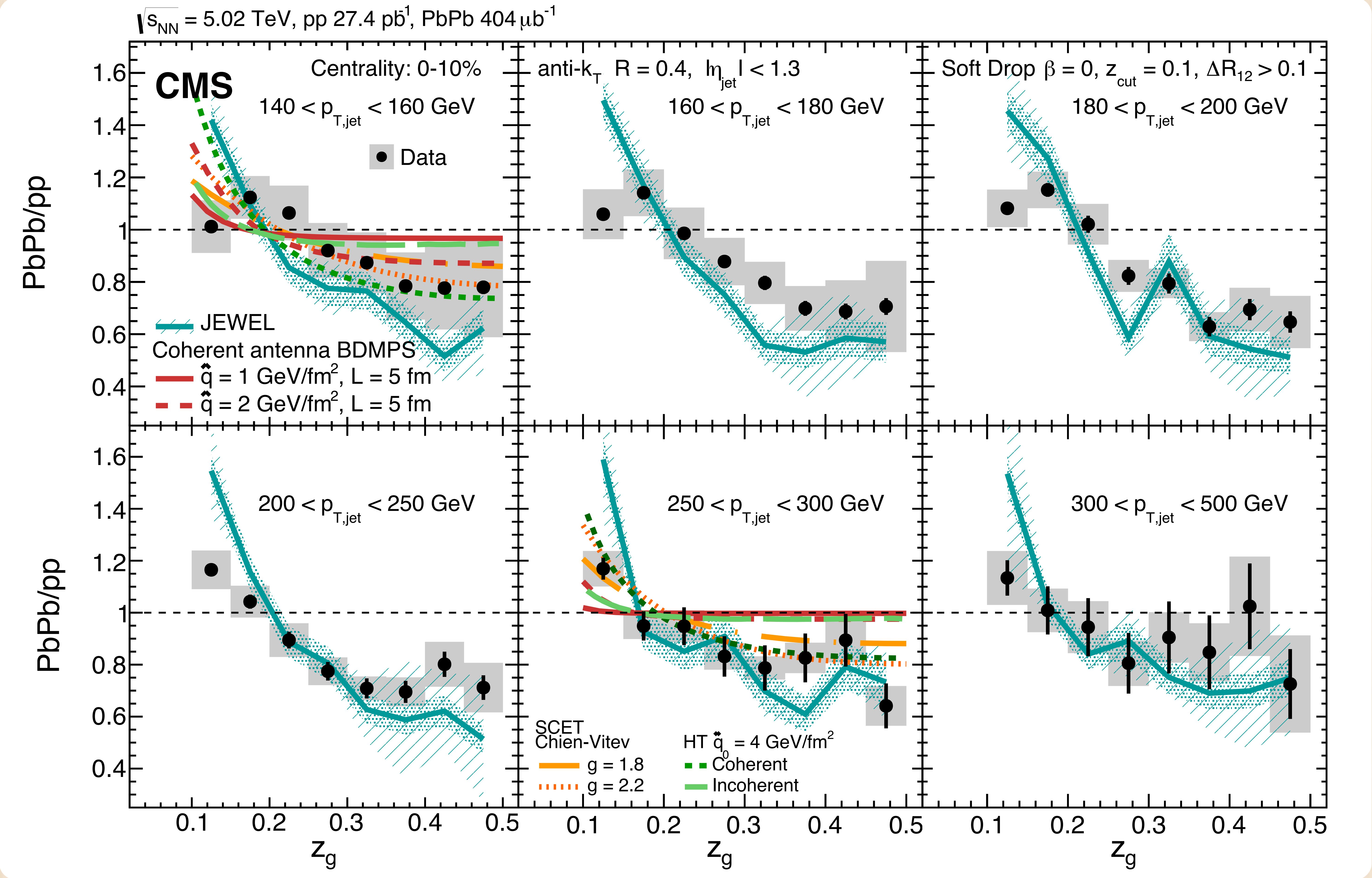
Modification diminishes with higher jet energy

Generators tend to predict large modification

Large amount of broadening in q-pythia, mass generally larger

Phys. Lett. B 345 (1995) 277
Nucl. Phys. B 483 (1997) 291
Nucl. Phys. B 484 (1997) 265
JHEP 04 (2017) 125
arXiv:1707.04142
JHEP 03 (2013) 080
arXiv:1707.01539
arXiv:1707.03767
arXiv:1608.07283

(z_{cut} = 0.1, β = 0.0): flat grooming



10% most central events

Different energy ranges

Generator tend to predict large modification

JEWEL generator
Multiple medium-induced gluon bremsstrahlung (coherent)
Soft collinear effective theory: modified gluon splitting function
Higher twist calculation

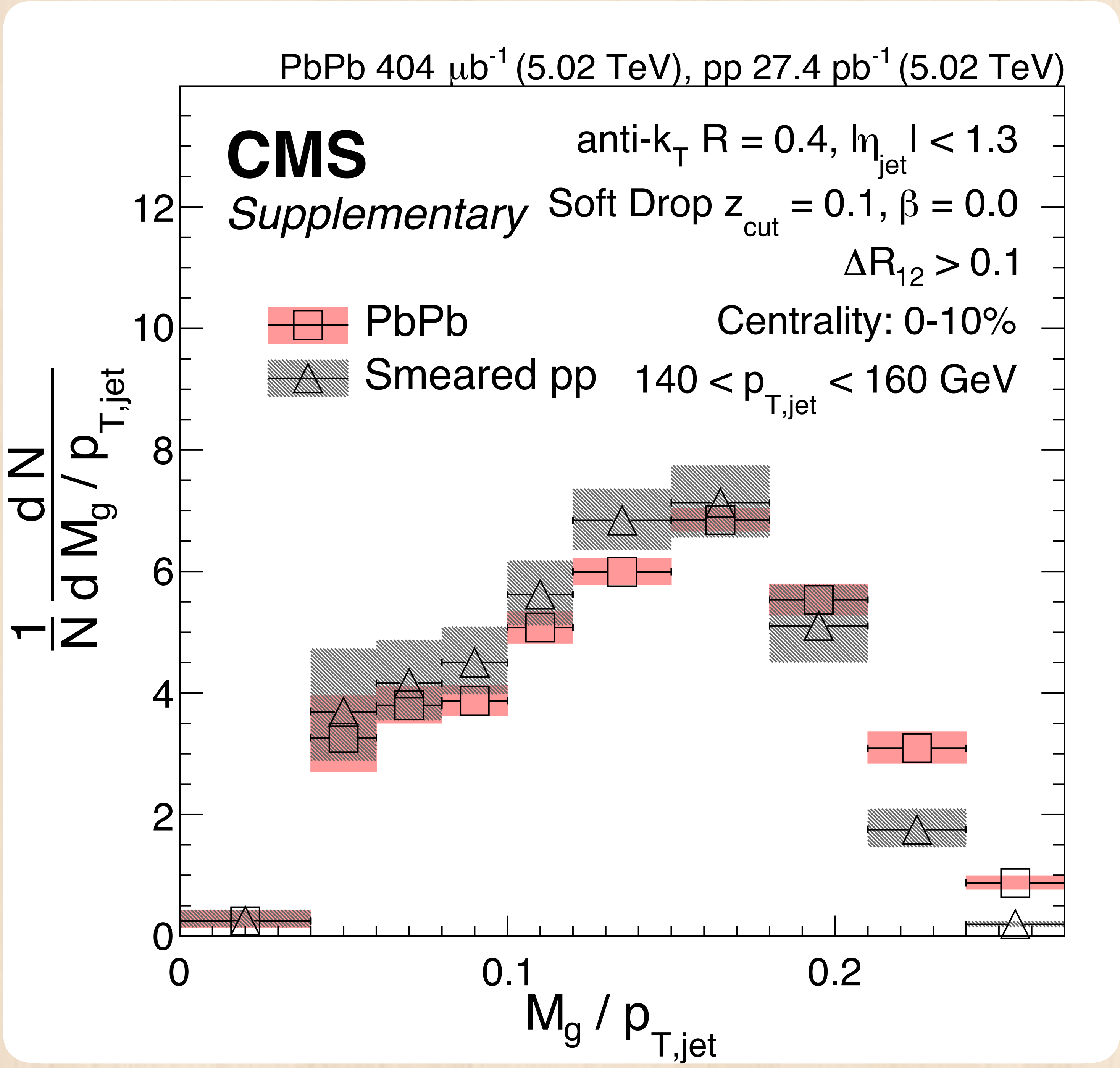
To summarize…

Summary

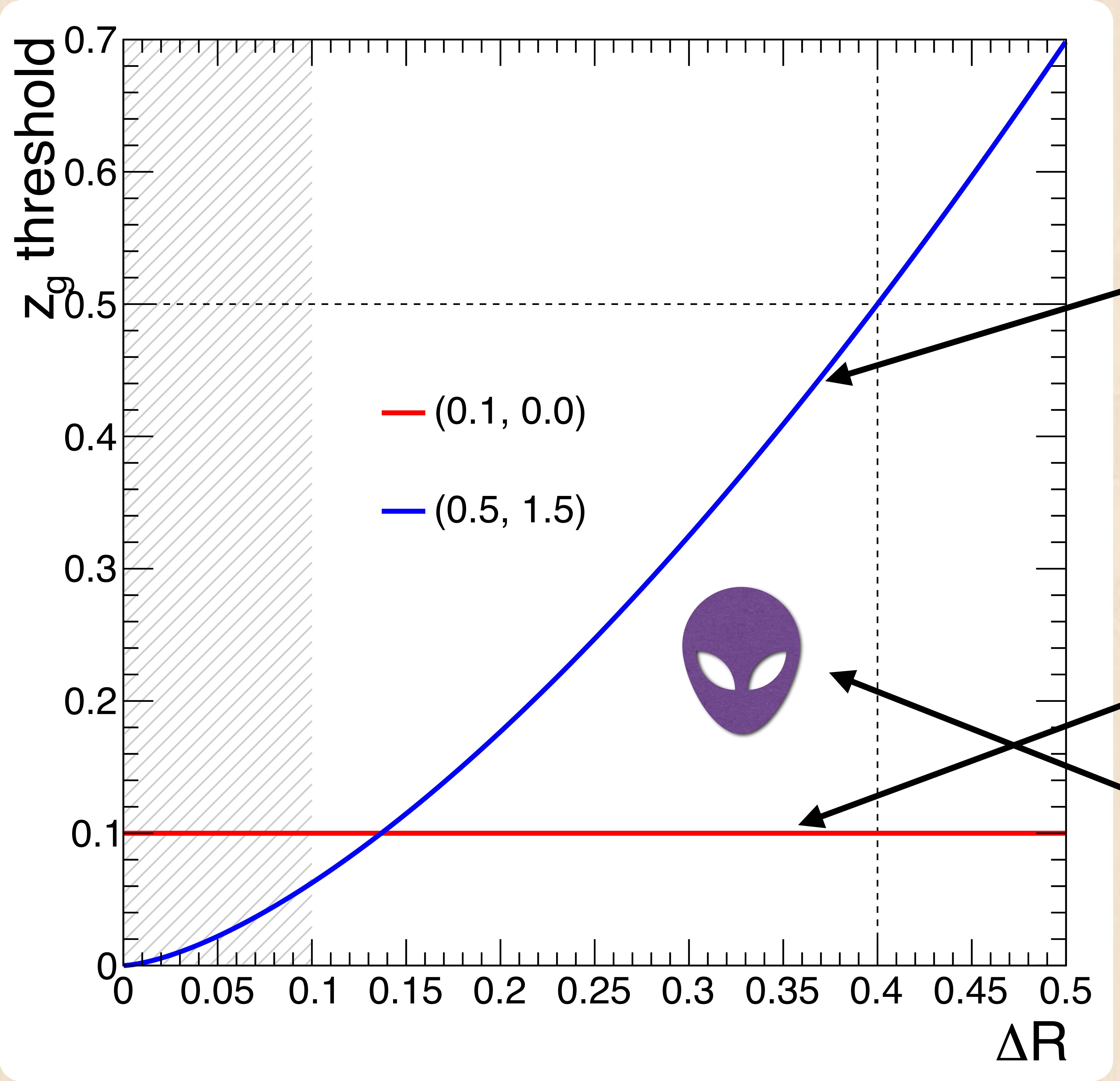
Jet mass and splitting function measurements with substructure techniques in pp and PbPb collisions with the CMS detector at the LHC is presented using 5.02 TeV data

We see no modification for the mass of the core of the jet in PbPb

For the flat grooming setting, some modification is seen for z_g and to a lesser extent jet mass



Different grooming settings



No significant modification for (z_{cut} = 0.5, β = 1.5) grooming setting

Some modification for (z_{cut} = 0.1, β = 0.0) grooming setting

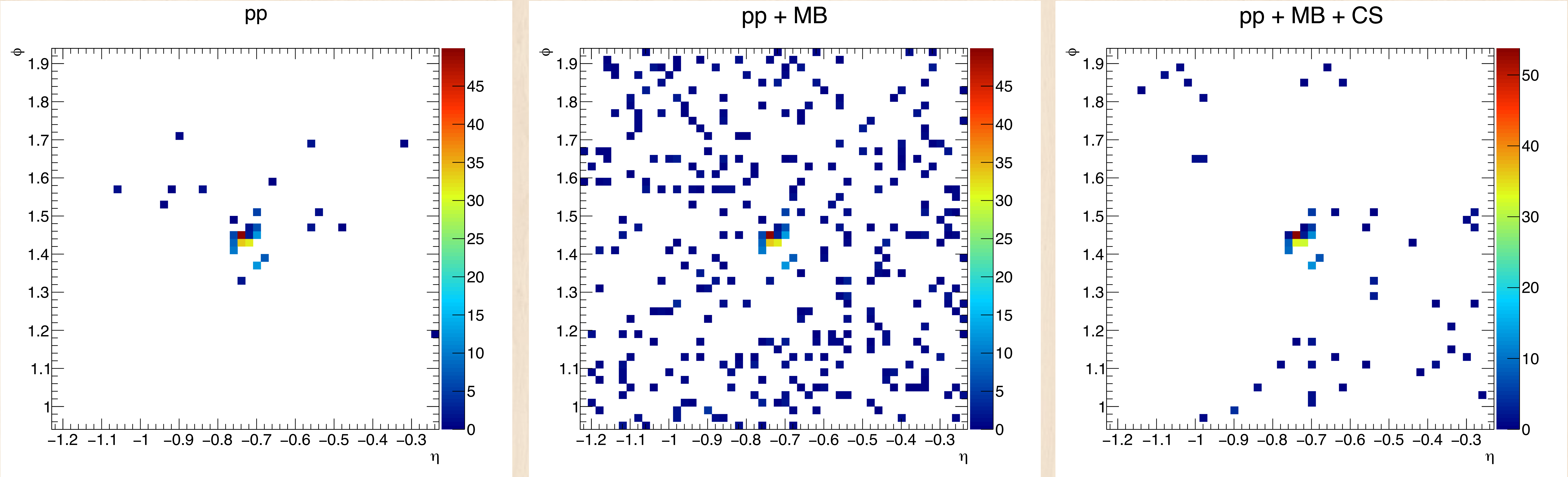
This region could be interesting!
Future analyses might tell us more

Thank you!

Backup Slides Ahead

Redistribution of Energy

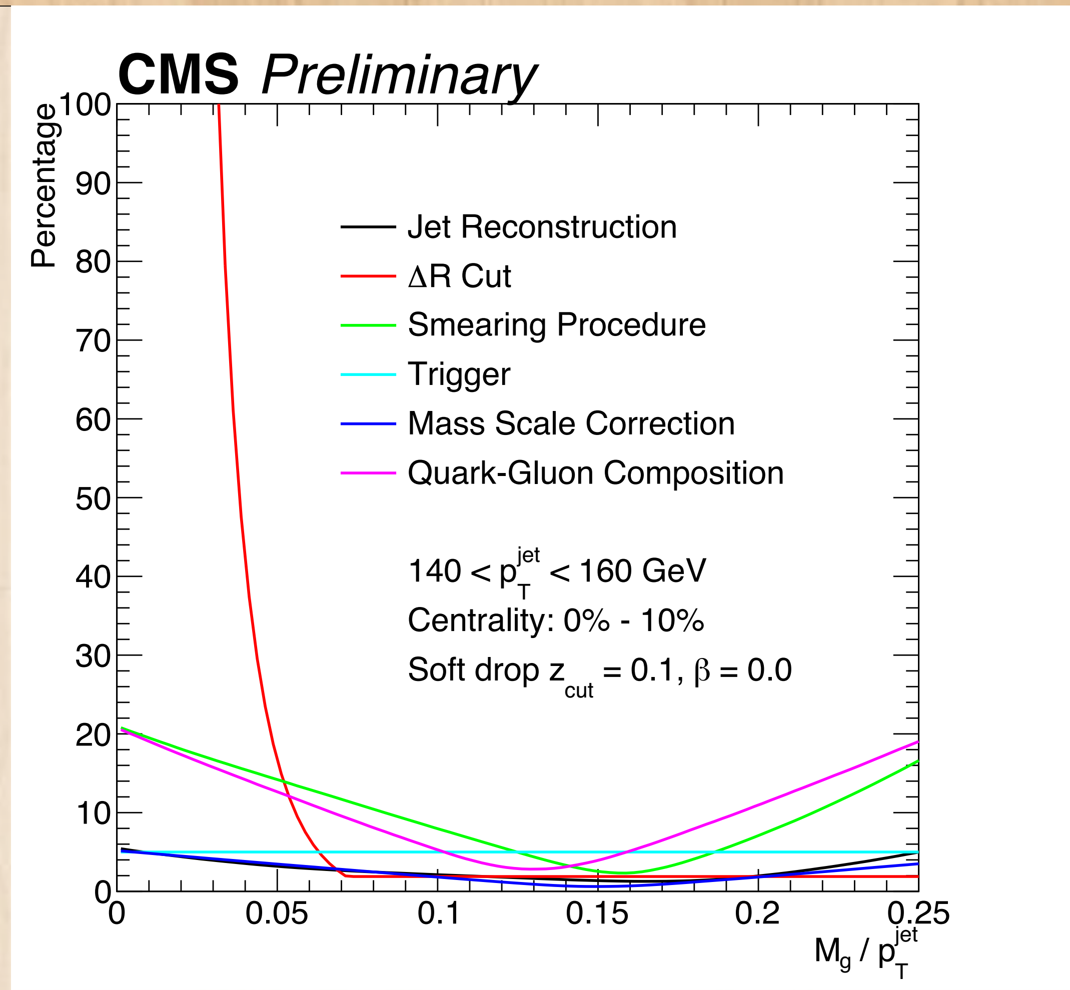
Probability of having a subjet consist of redistributed energy is increased in central events

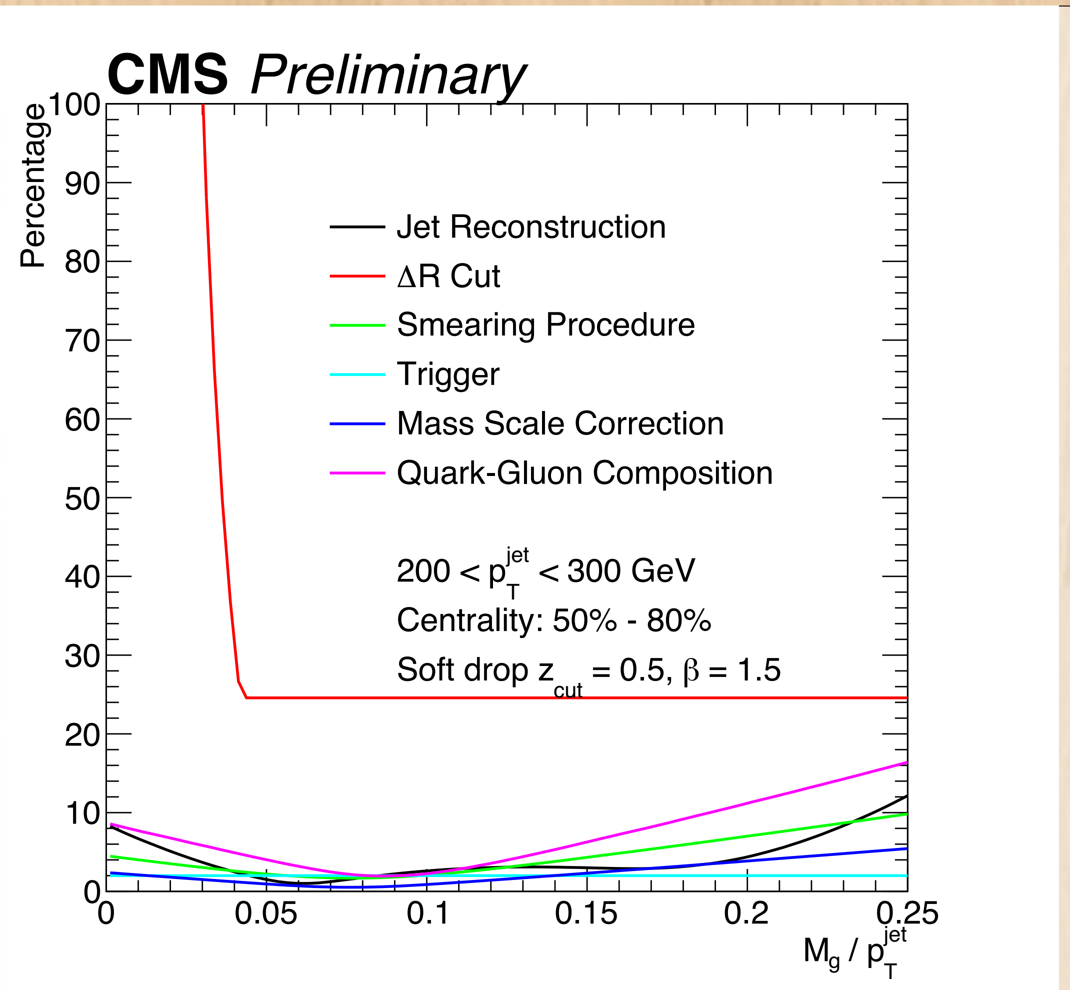


Expect enhancement of jets with large groomed subjet separation ($\Delta R \sim 0.3$)

Systematic Uncertainties

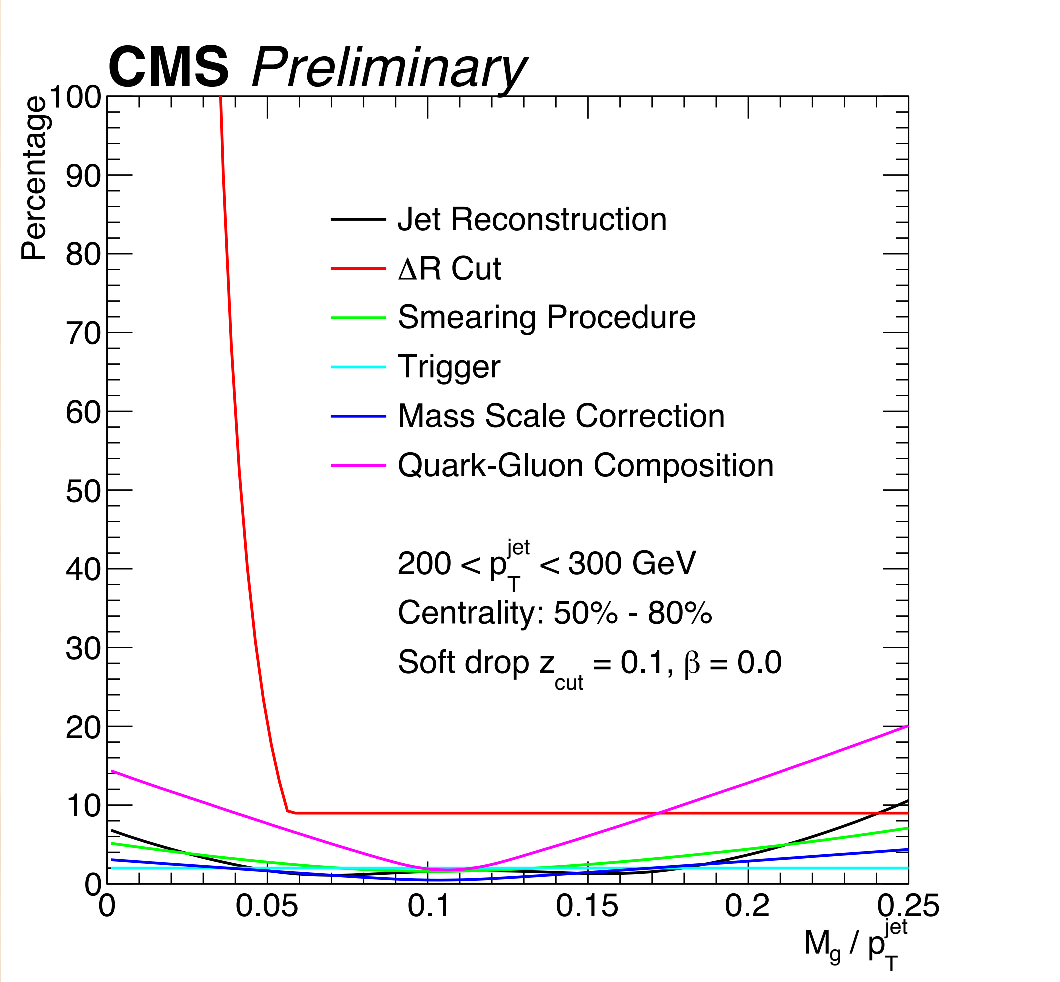
140-160 GeV
0-10%
(z_{cut} = 0.1, β = 0.0)

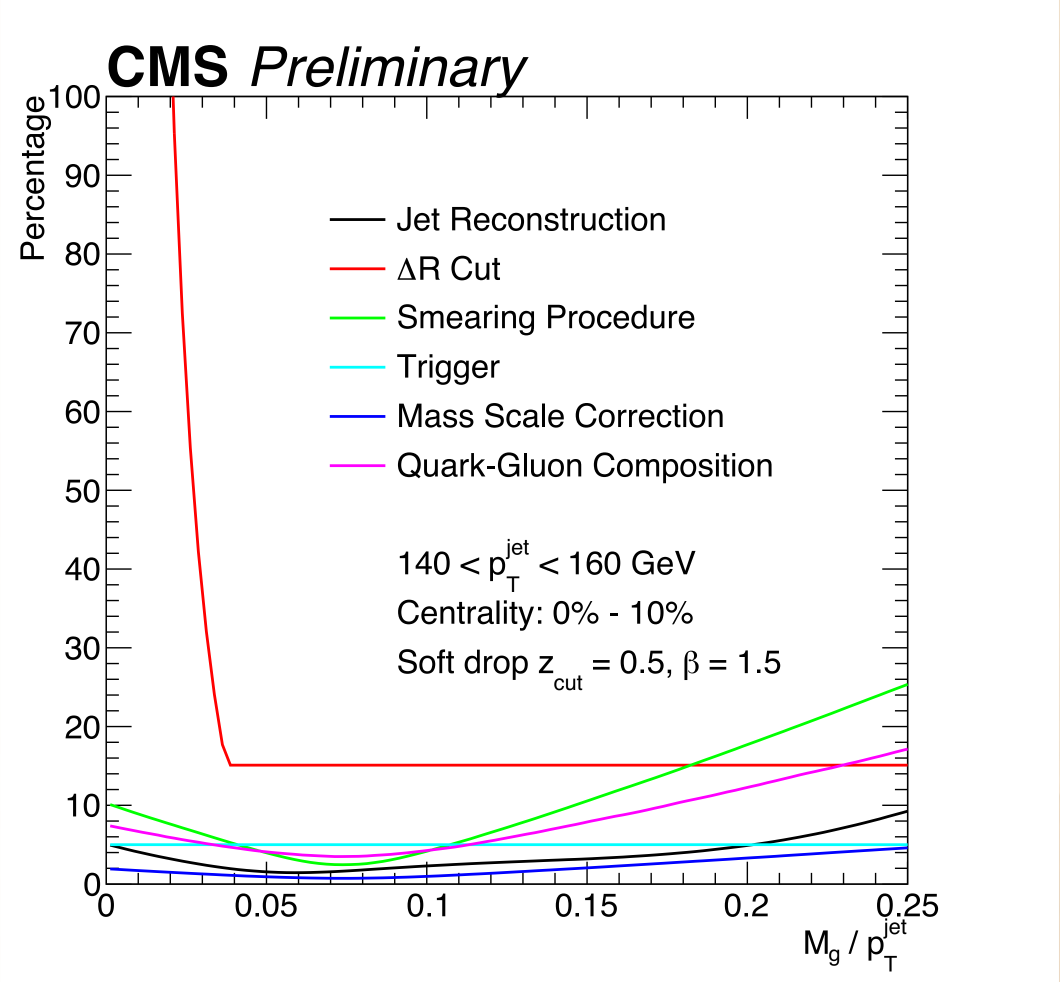




140-160 GeV
0-10%
(z_{cut} = 0.5, β = 1.5)

200-300 GeV
50-80%
(z_{cut} = 0.1, β = 0.0)

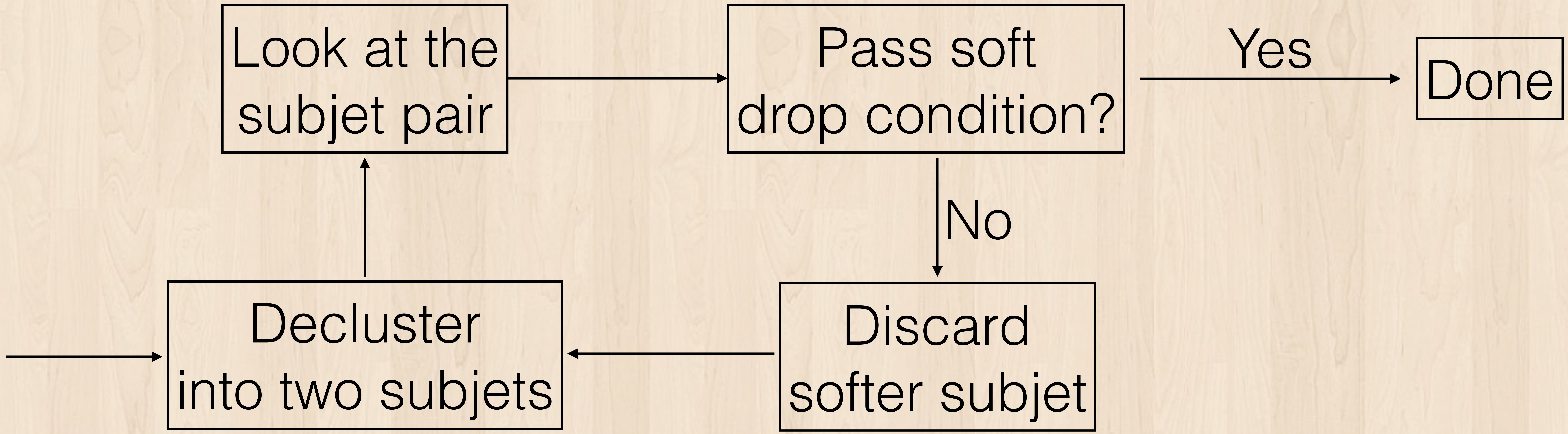




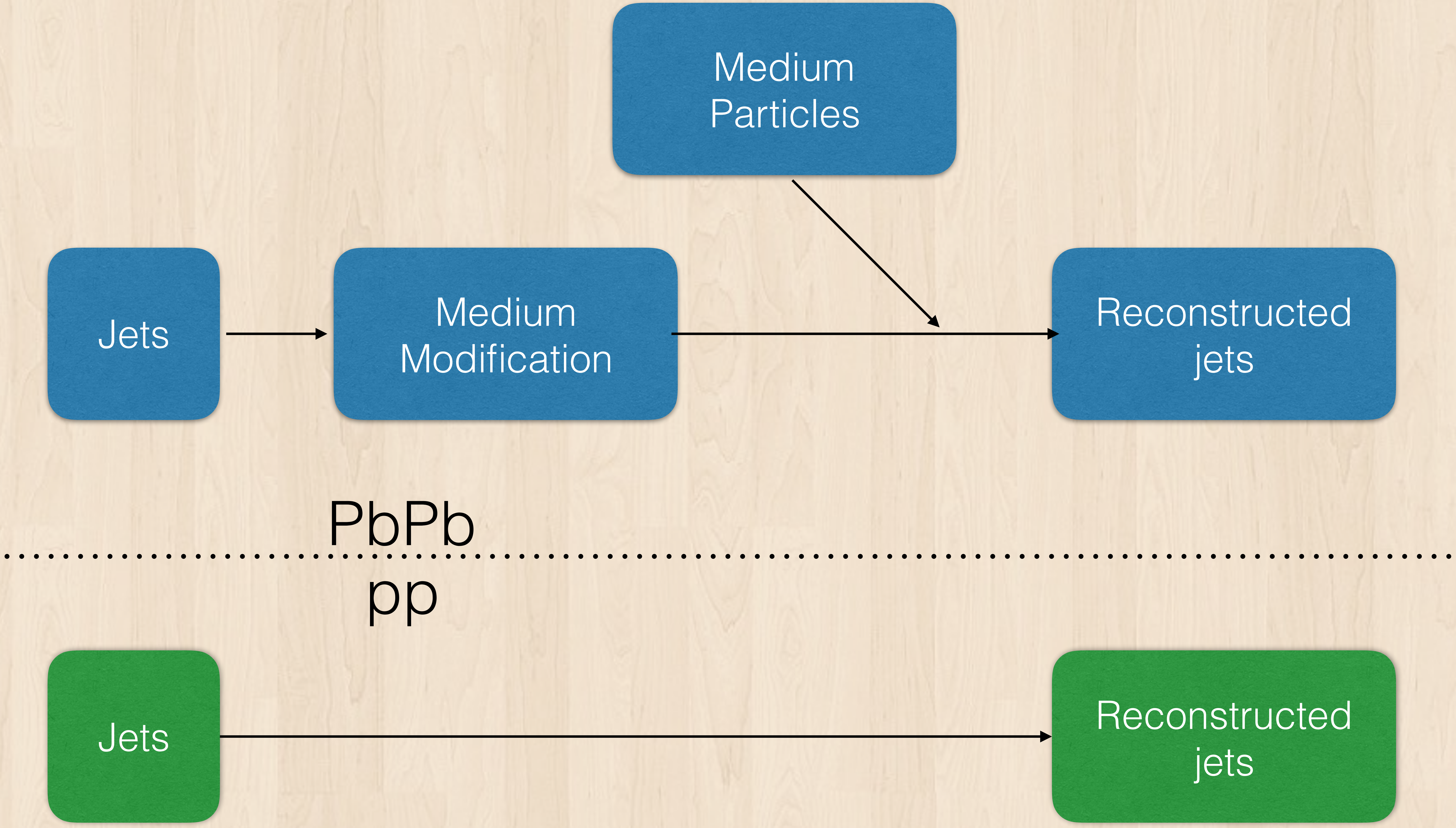
200-300 GeV
50-80%
(z_{cut} = 0.5, β = 1.5)

mMDT / soft drop grooming

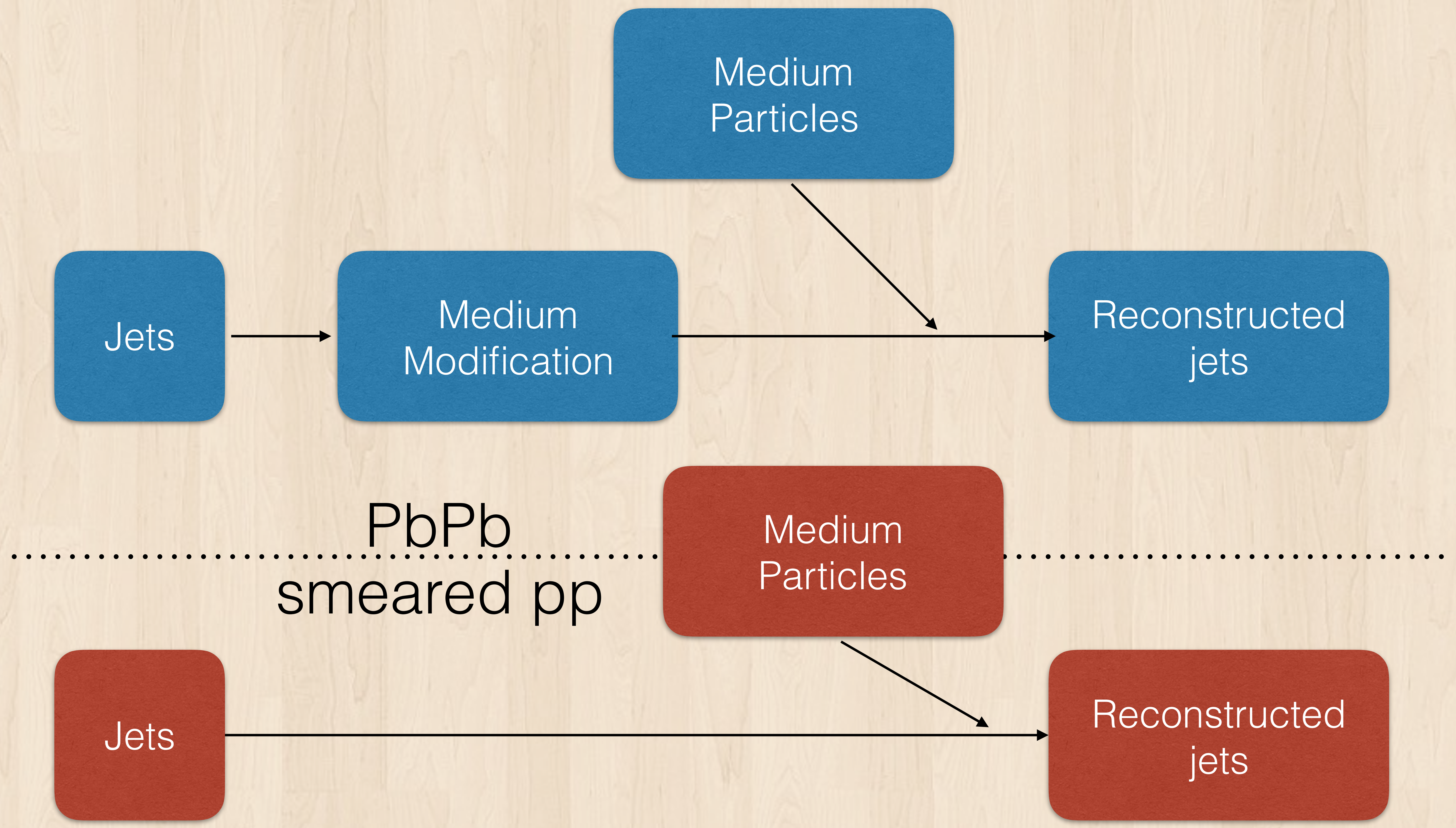
Soft drop condition: $z_g \equiv \frac{\min(p_{T\,1}, p_{T\,2})}{p_{T\,1} + p_{T\,2}} > z_{\rm cut} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$



The strategy



The strategy



The strategy (validation)