FCC Higgs & BSM Workshop

CERN, March 2015

Principles of tagging multi-TeV boosted objects

Gavin Salam (CERN)

Introduction

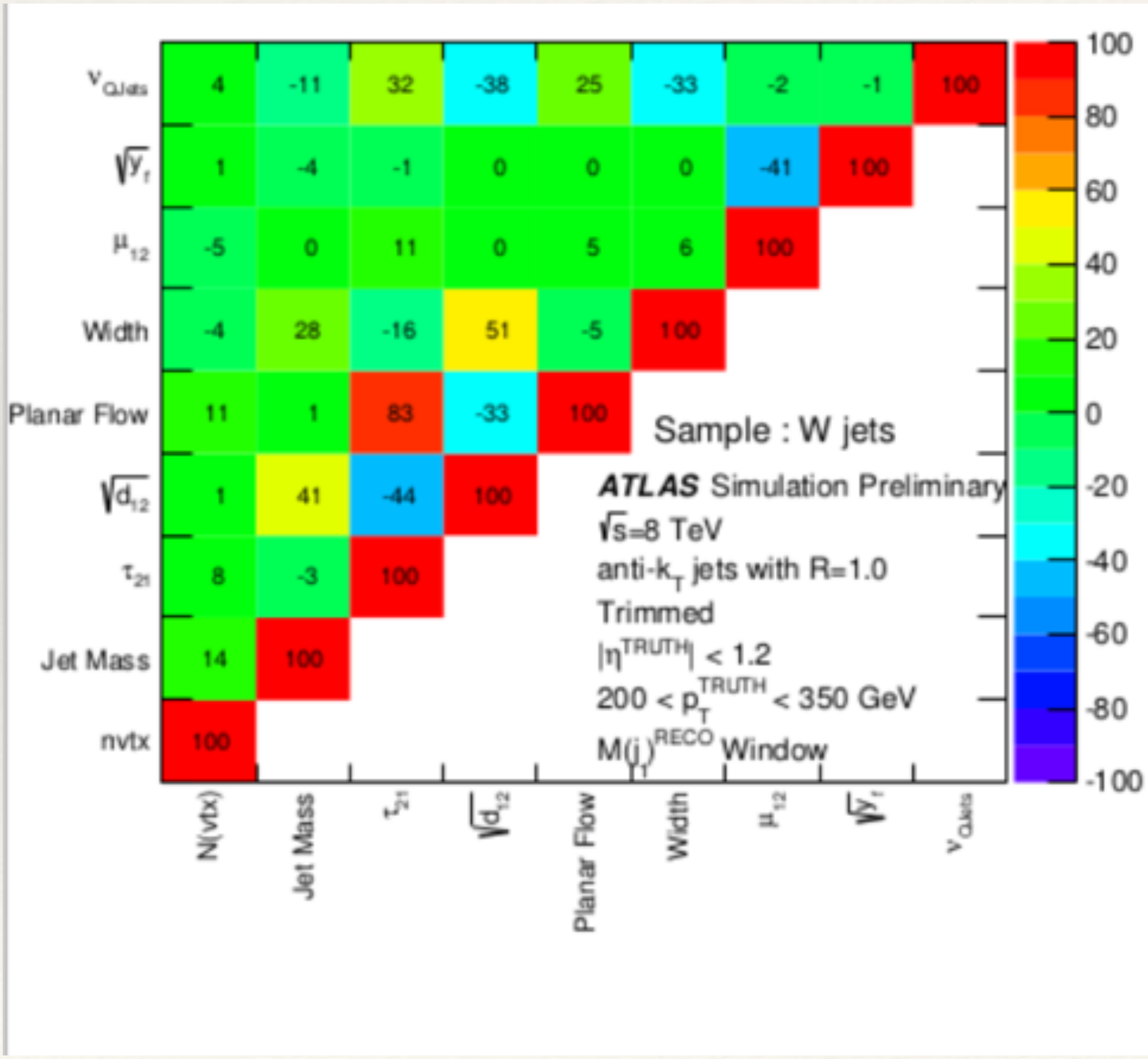
- At LHC8, searches rely on boosted techniques to identify hadronic W/Z/H/top (etc.) with p_t's $\gtrsim$ 300 GeV – 1.5 TeV
- FCC-hh ($3ab^{-1}$) will explore pt's 12 times higher: $3ab^{-1}/20fb^{-1} \simeq (100TeV/8TeV)^2$.
- **Boosted techniques will be ubiquitous**

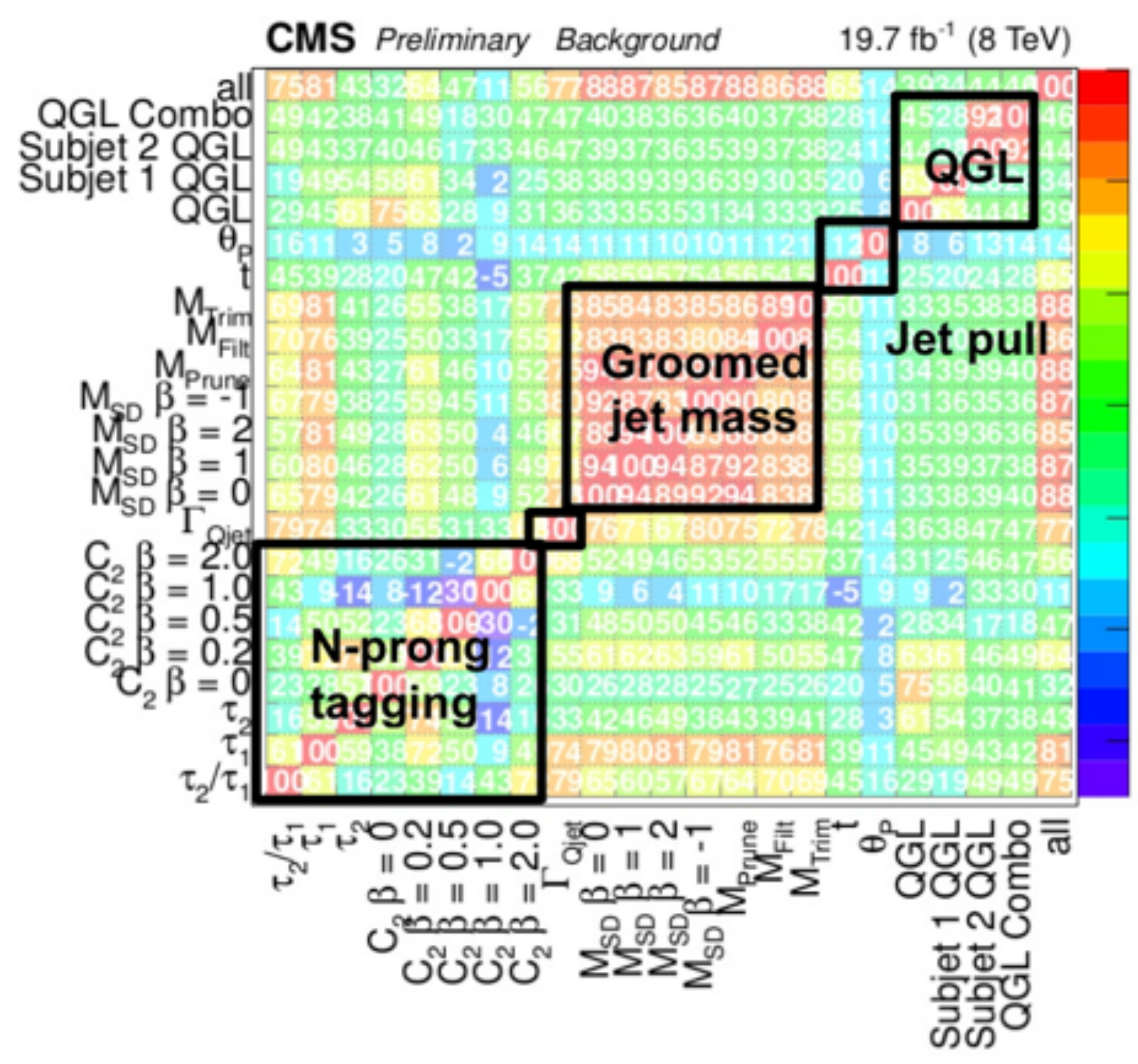
This talk

- State of the art for LHC
- Core lessons that carry over to FCC
- Elements that are new at FCC

Range of techniques studied by ATLAS & CMS

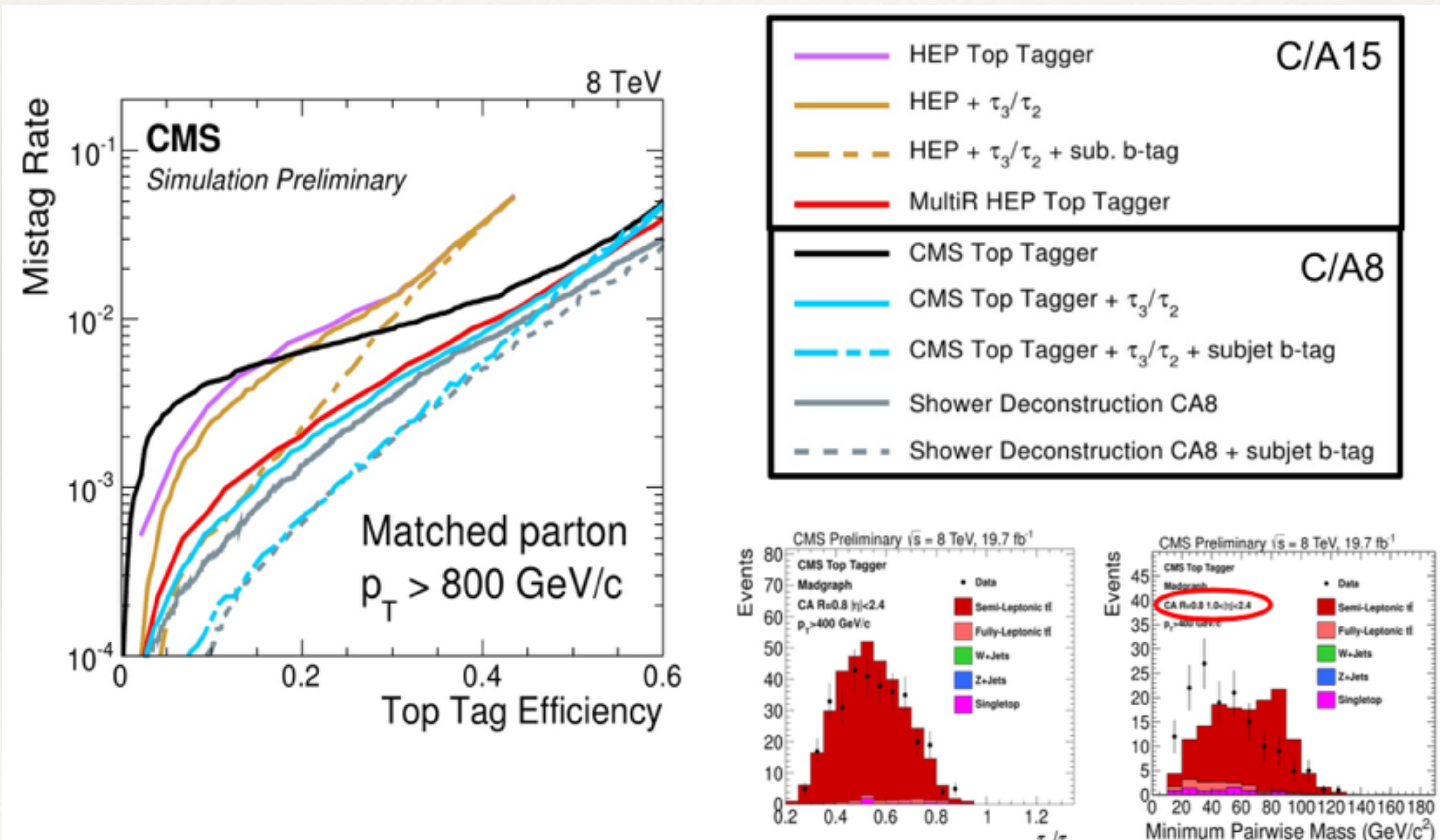
W/Z taggers (and correlations between them)





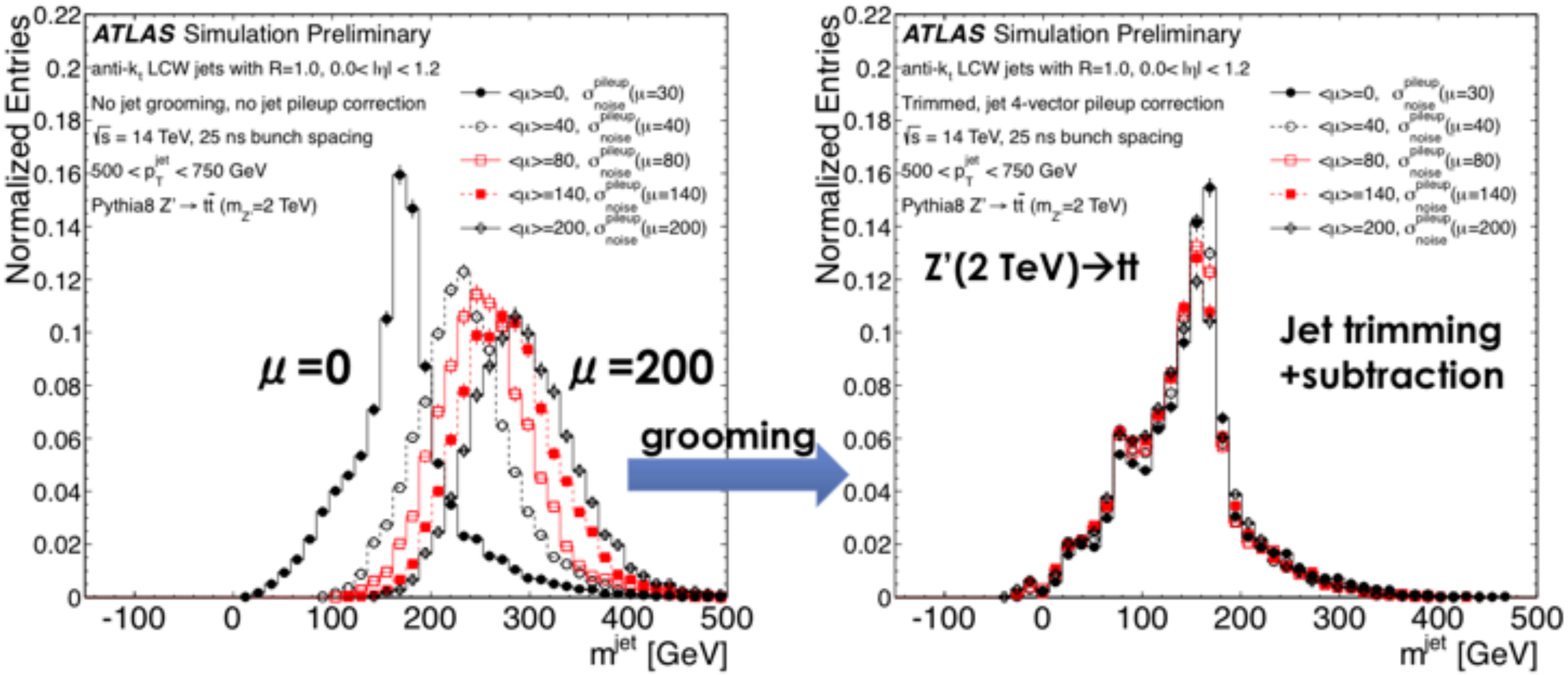
Range of techniques studied by ATLAS & CMS

a subset of top taggers



Range of techniques studied by ATLAS & CMS

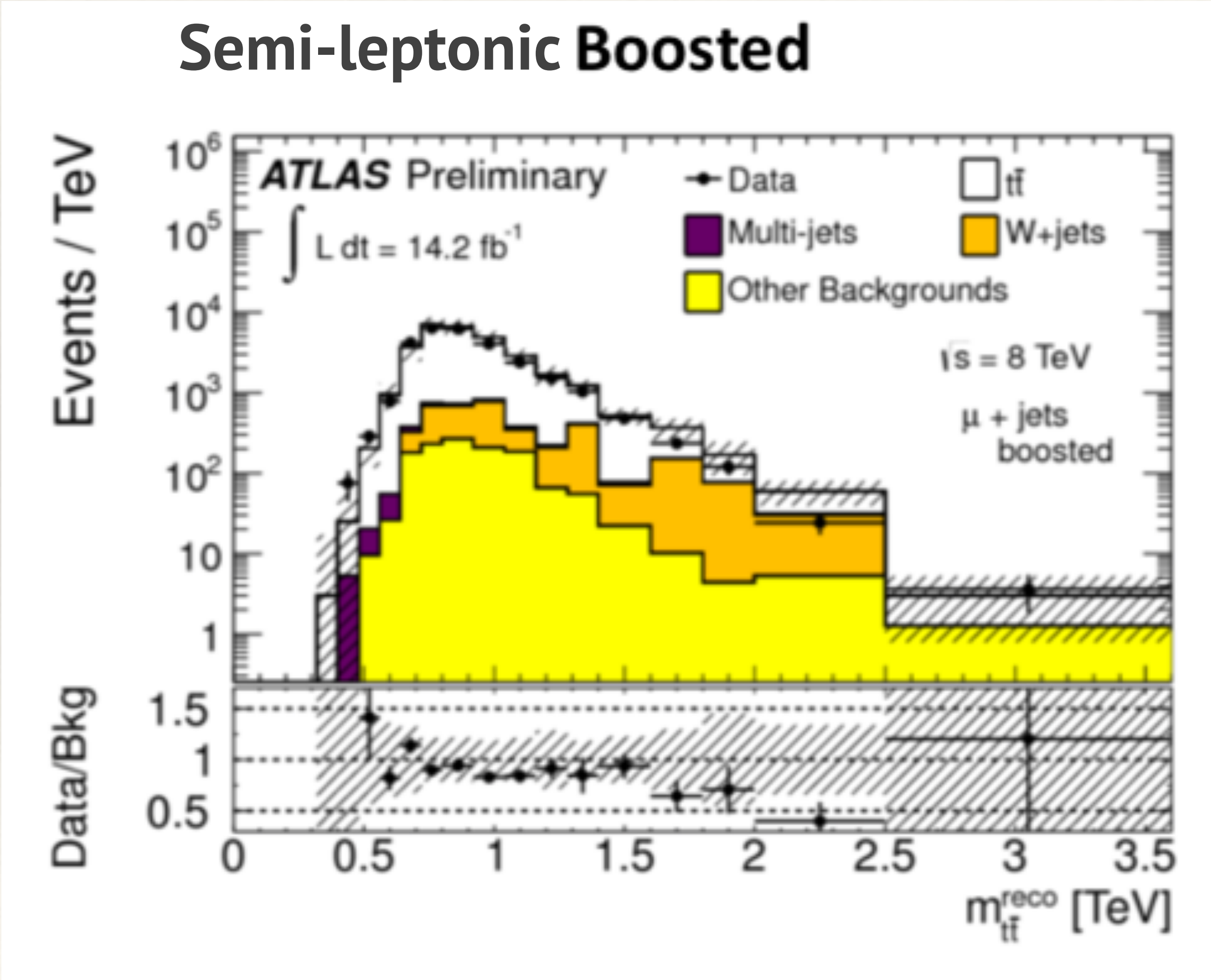
top-mass reconstruction at high pileup

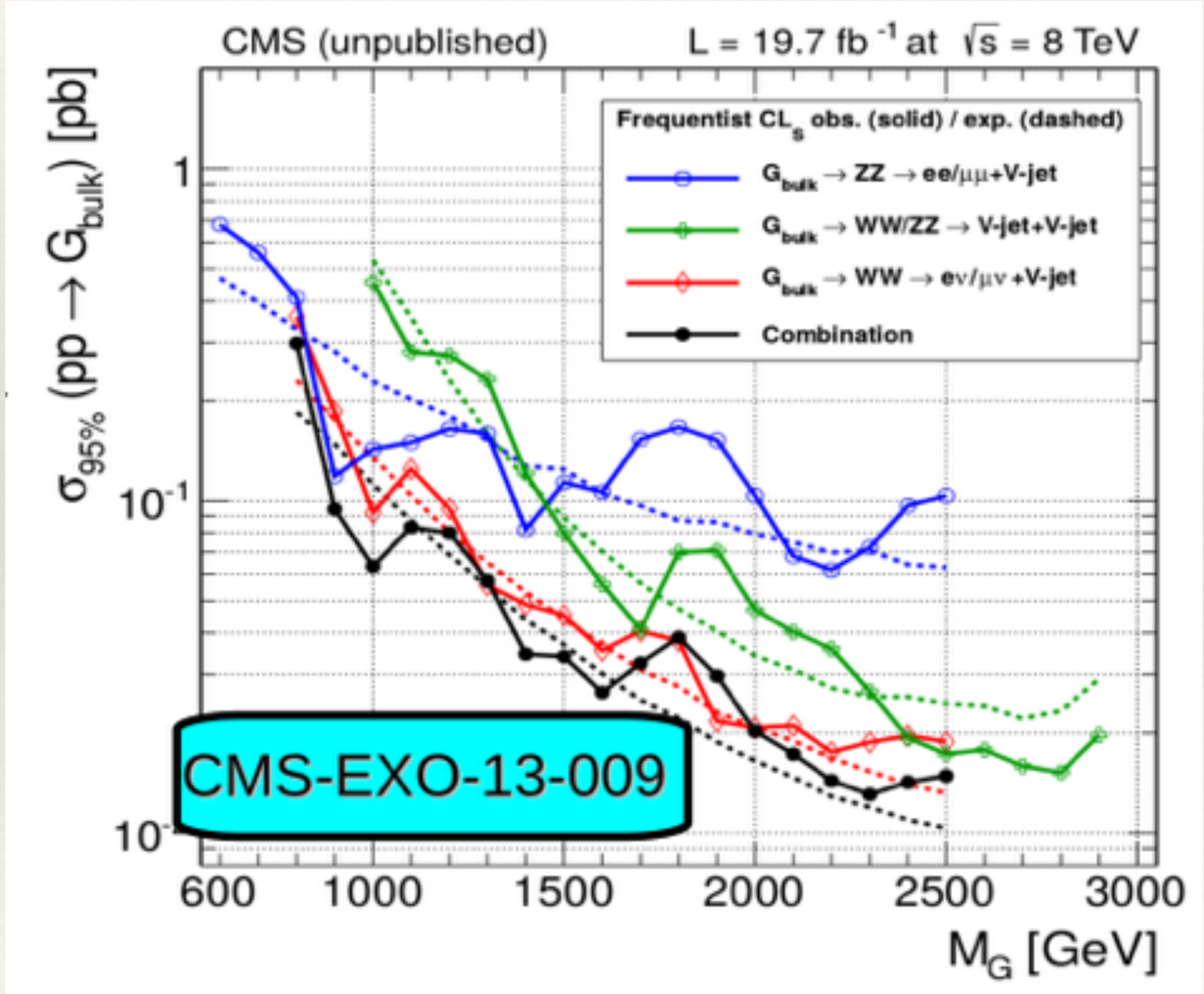


topoclustering + grooming + area subtraction shows very good performance up to 200 PU

Range of techniques studied by ATLAS & CMS

Use in searches





Comments from Boost

- More rigorous comparisons to focus on just a few taggers, before we move on to Run2
- Caveat: need to add systematics to these curves!
  - This is non trivial! Correlations also need to be properly taken into account

Emily Thompson

i think we agree on this point: "be careful how we extend our conclusions to the larger community" (david m.)

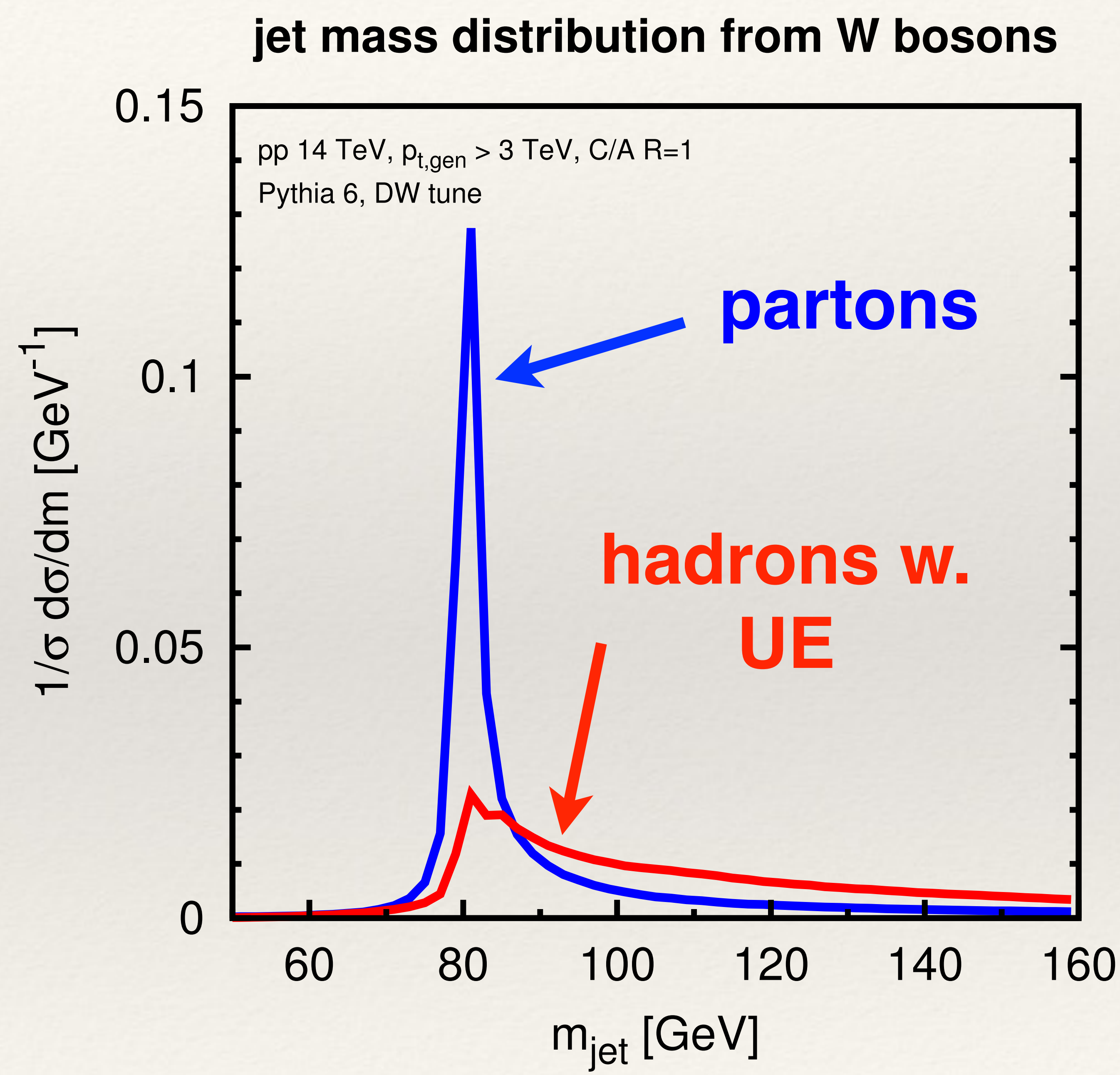
Bottom line

We have many good tools

Balance between simplicity and performance still to be found?

Principles in use today

#1: the jet mass is a fragile observable.



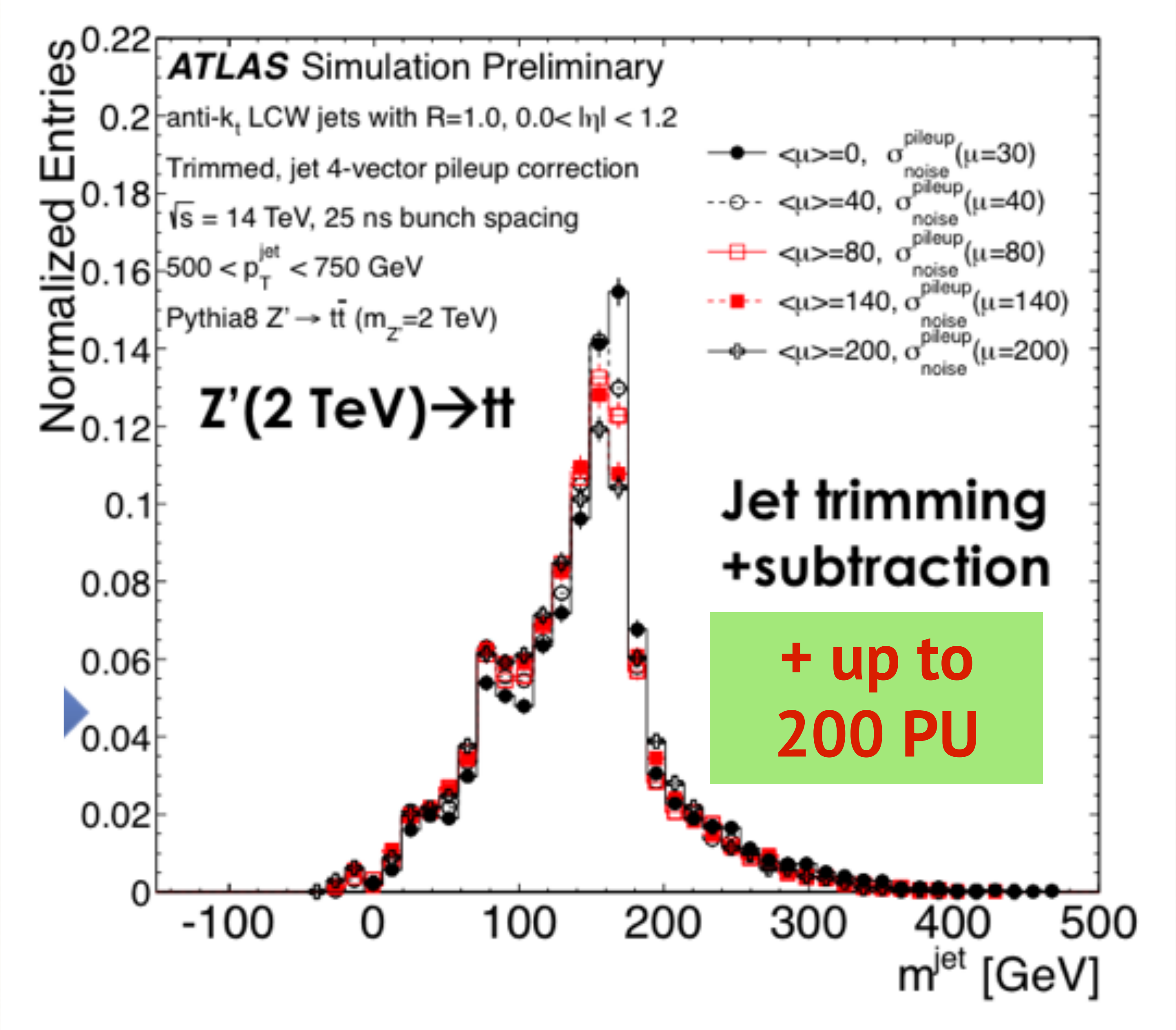
Principles in use today

#1: the jet mass is a fragile observable.

So people usually use a **groomed mass**:

filtering/trimming/pruning

(or you can go to smaller R ~ few x M/p_t)

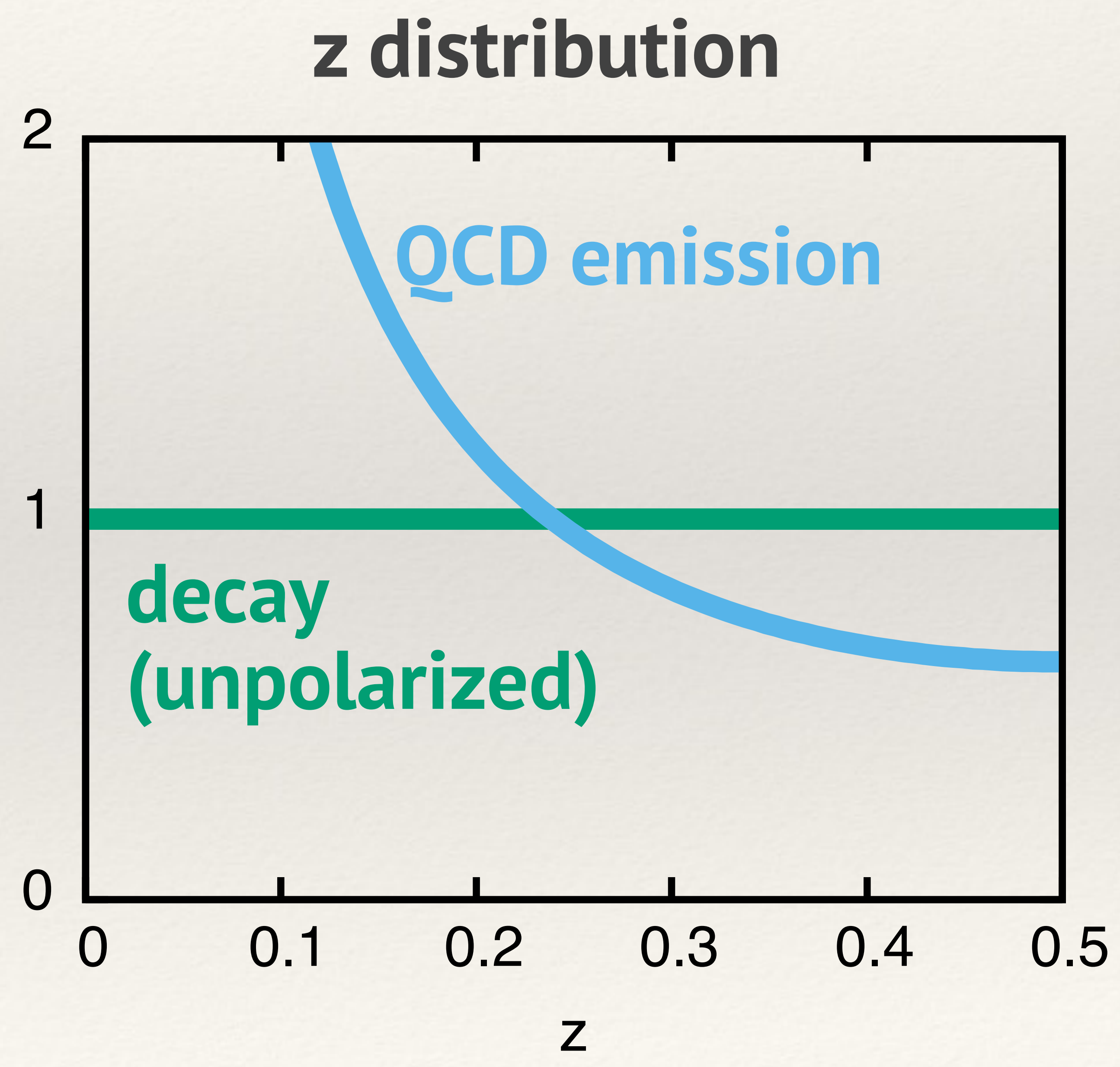


Principles in use today

#2: QCD gluon emission is soft; V/H→qq is not

Identify two-prong structure and cut on "z" (momentum fraction between prongs)

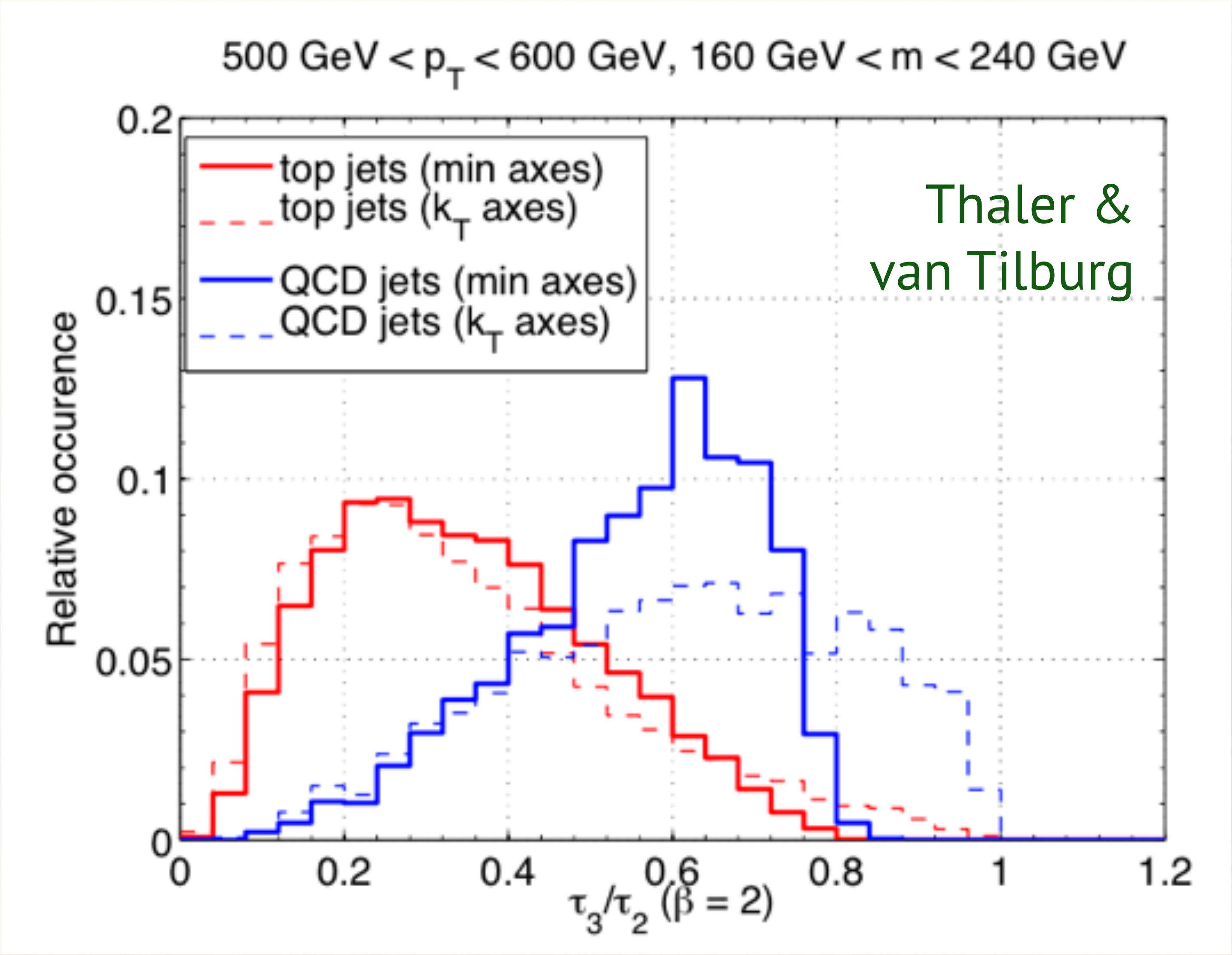
[done by mass-drop taggers/pruning/trimming/]



Principles in use today

#3: Radiation patterns differ in V/H/top v. QCD

Cut on variables sensitive to deviation from exact n-prong structure, e.g. N-subjettiness



$$\frac{\tau_n}{\tau_{n-1}}; \quad \tau_n = \min_{\text{n axes}} \sum_i p_{ti} \min(\Delta R_{i,\text{axis-1}}, \ldots, \Delta R_{i,\text{axis-n}})$$

What changes at FCC?

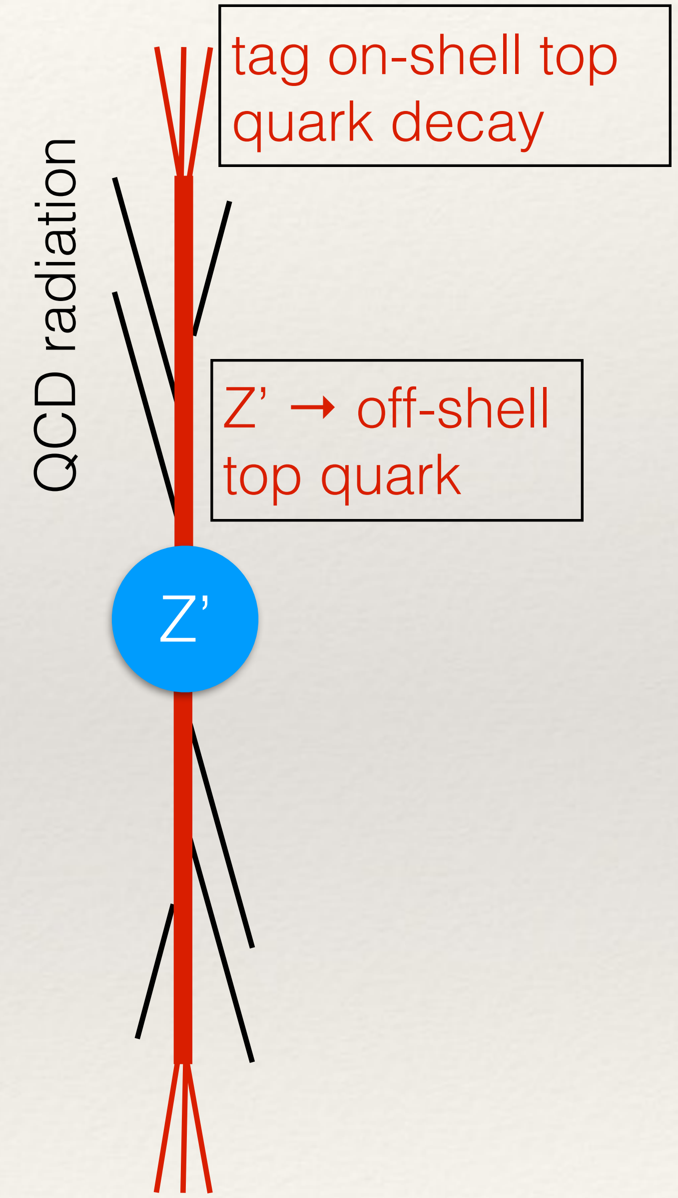
Much higher boost means decay opening angles ~ 0.02 instead of 0.2-0.3 relevant today

- Detector **granularity** becomes a critical issue
- W/Z/H become as collimated as τ leptons at LHC — can use similar "**isolation**" procedures (cut on radiation)
- top decay as collimated as b-decay at LHC — need to consider difference between **top quarks v. top jets**

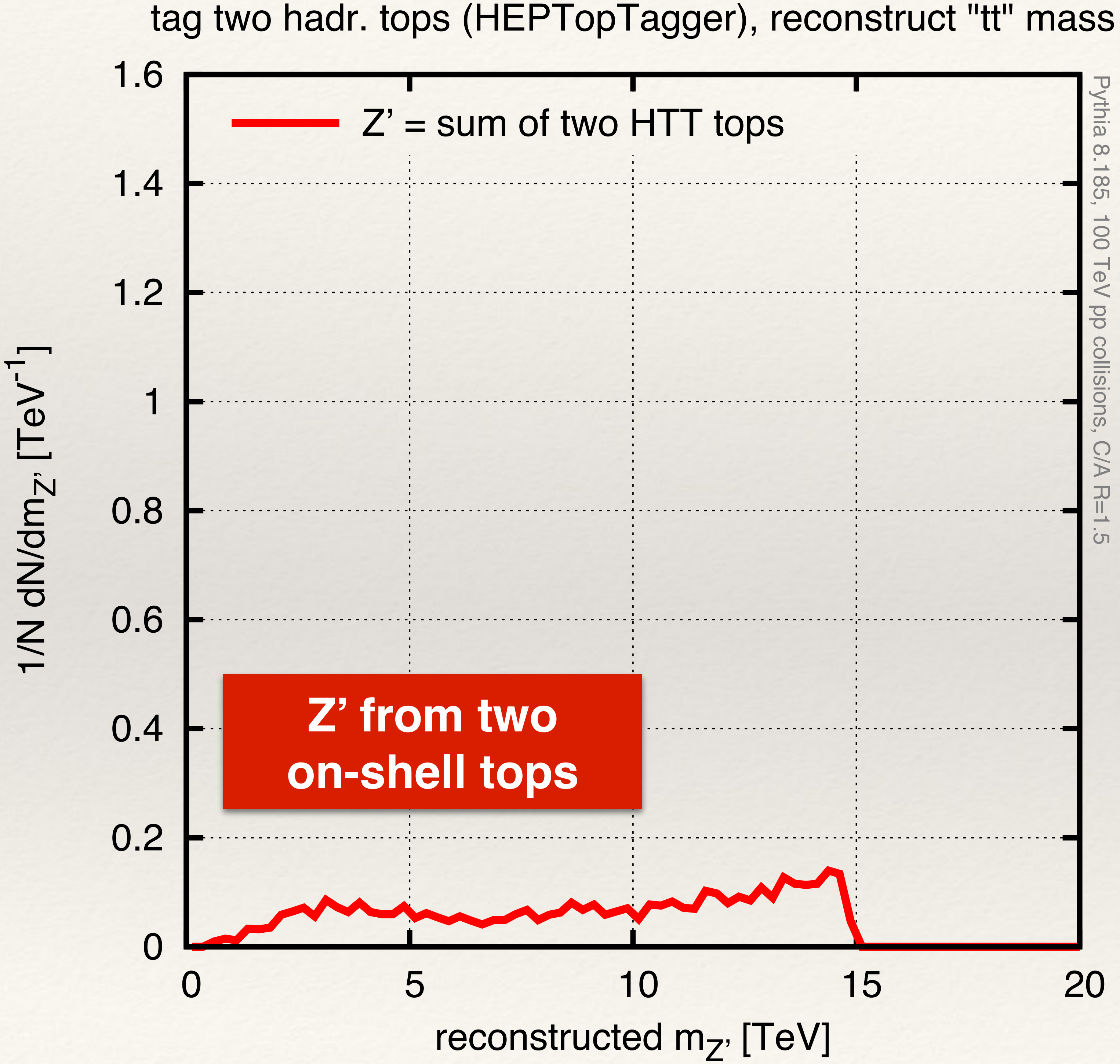
Top quarks v. Top jets

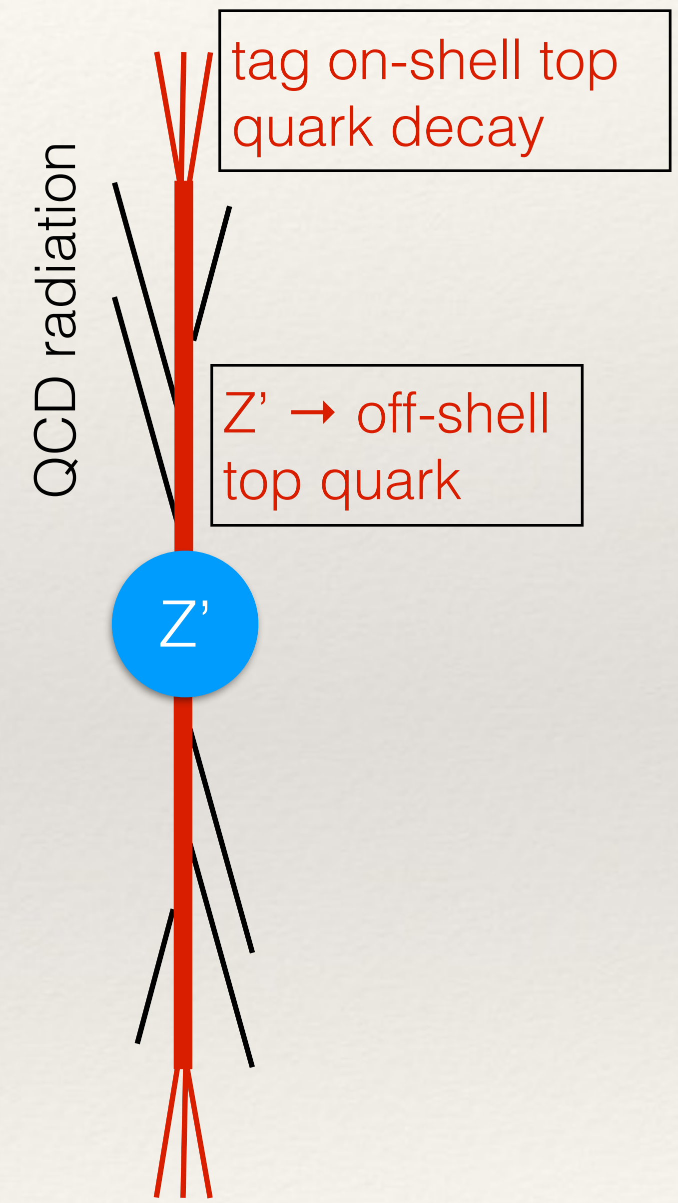
Top taggers often tag the top quark
at the moment of decay

But many boosted top studies are resonance searches and resonance reconstruction needs
top at the moment of production

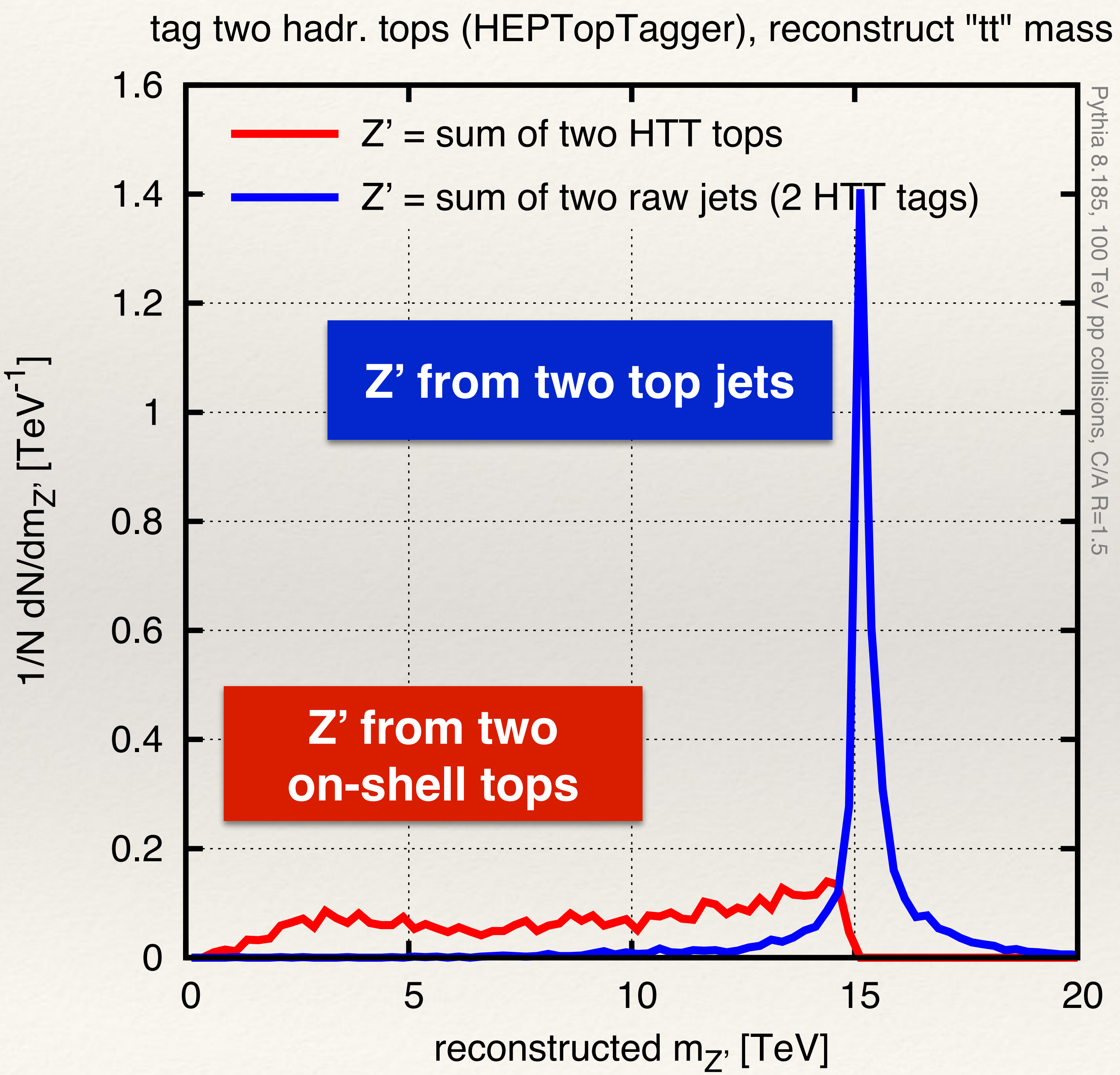


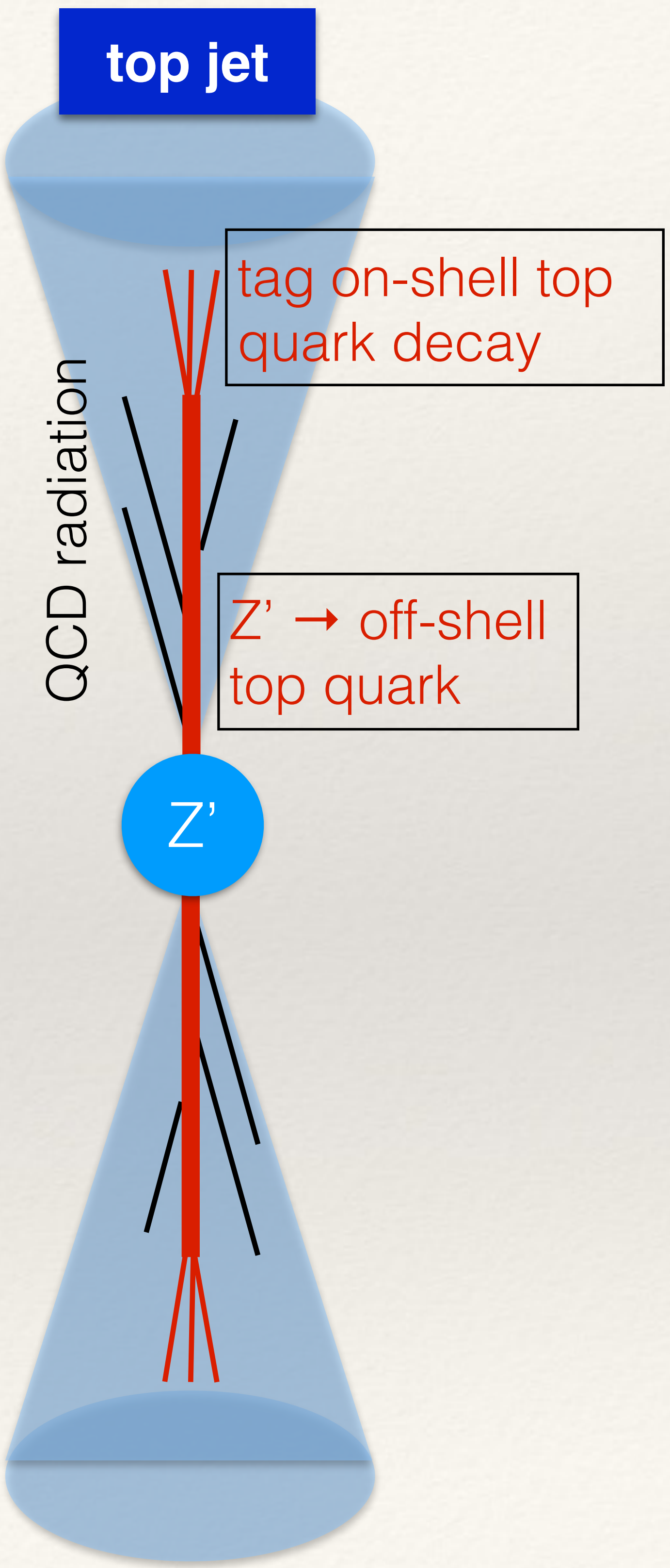
Top quarks v. Top jets





Top quarks v. Top jets





cf work in progress Kasieczka et al

colour-neutral objects

cf. talk to follow by Maurizio Pierini

Colour neutral objects don't radiate outside cone defined by their opening angle.

QCD jets radiate at all angles.

That leaves a radiation gap of size $\sim \ln \frac{p_t}{4m}$

Like a rapidity gap in VBF, but much less affected by pileup, multiple interactions, etc.

Also like isolation cone around tau-leptons

Granularity

[how can do boosted physics on angular scales ~ 0.01 when calo granularity is ~ 0.1?]

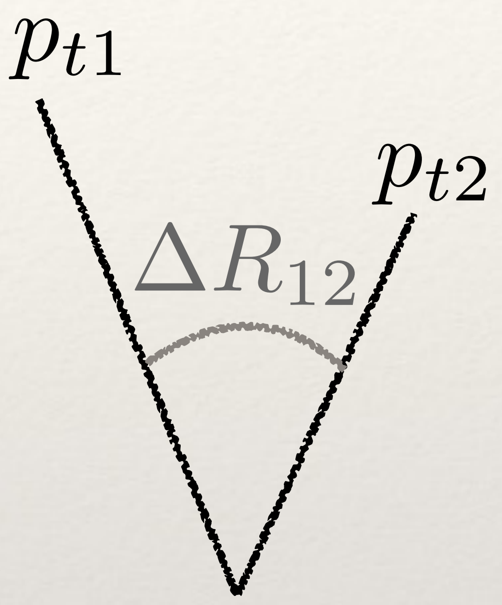
Material available from:

- Katz, Son & Tweedie, http://arxiv.org/abs/1010.5253
- Son, Spethmann, Tweedie, http://arxiv.org/abs/1204.0525
- http://arxiv.org/abs/1307.6908 (Snowmass study)
- Schaetzel & Spannowsky, http://arxiv.org/abs/1308.0540
- An earlier talk of mine
- Larkoski, Maltoni & Selvaggi, http://arxiv.org/abs/1503.03347
- CMS particle flow studies

Calo-granularity issue

Two-prong mass formula

$$m \simeq \sqrt{p_{t1} p_{t2}} \Delta R_{12}$$



Problems:

- Full calorimeter (say 0.1x0.1) can't resolve prongs
- Tracking can, but it gives poor p_t measurement (sees only 60% with large fluctuations)

Beating calo-granularity

Rewrite mass two-prong mass formula as

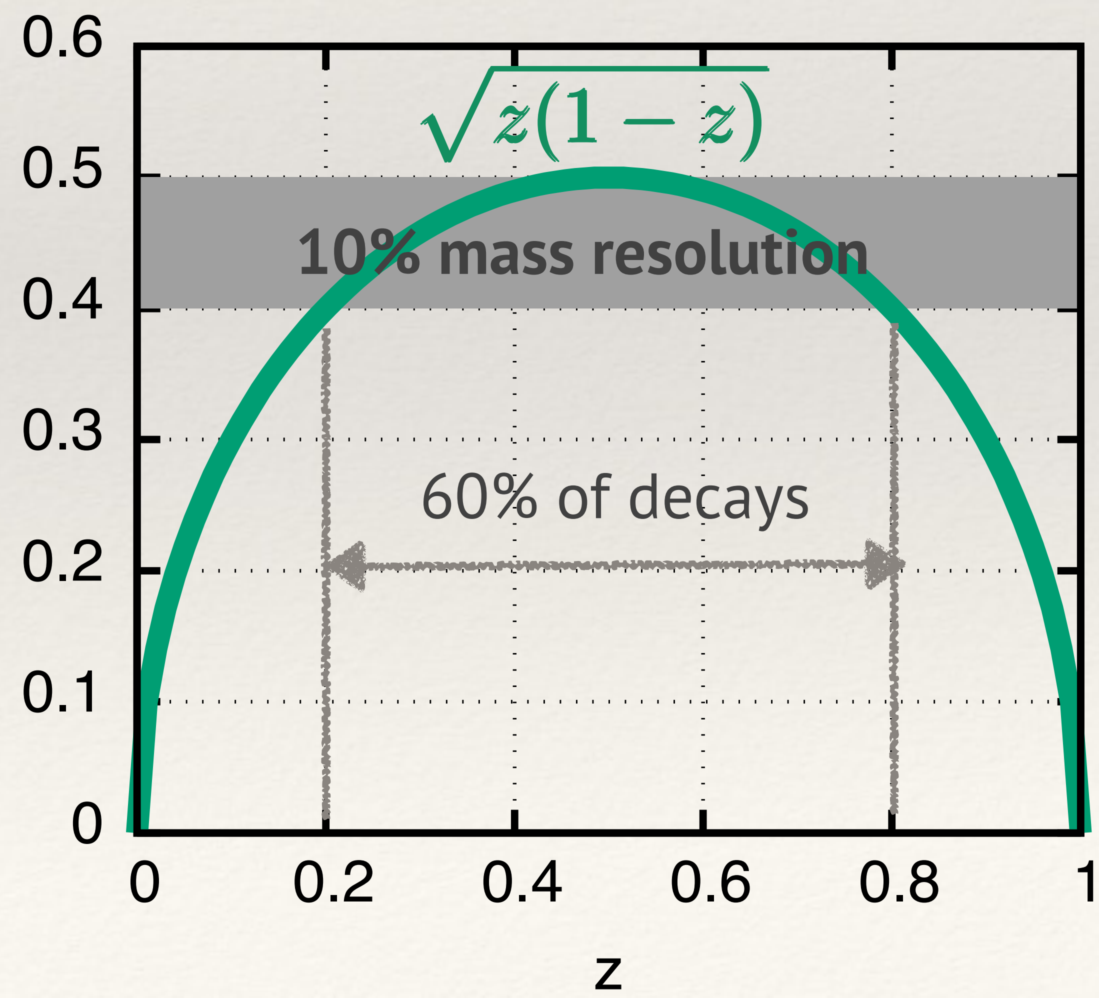
$$m = \sqrt{z(1-z)}\,p_{t,\text{jet}}\Delta R_{12}$$

$$p_{t,\text{jet}} \equiv p_{t1} + p_{t2}$$

$$z \equiv \frac{p_{t1}}{p_{t,\text{jet}}}$$

Use different detector subsystems to for different parts of formula:

- Calo for $p_{t,\text{jet}}$
- Tracks (and/or EM) for ΔR_{12}
- Tracks (and/or EM) for z
  (fluctuations on on z doen’t matter so much)



Beating calo-granularity

Rewrite mass two-prong mass formula as

$$p_{t,\text{jet}} \equiv p_{t1} + p_{t2}$$

$$m = \sqrt{z(1$$

Use diffe

subsystems

parts

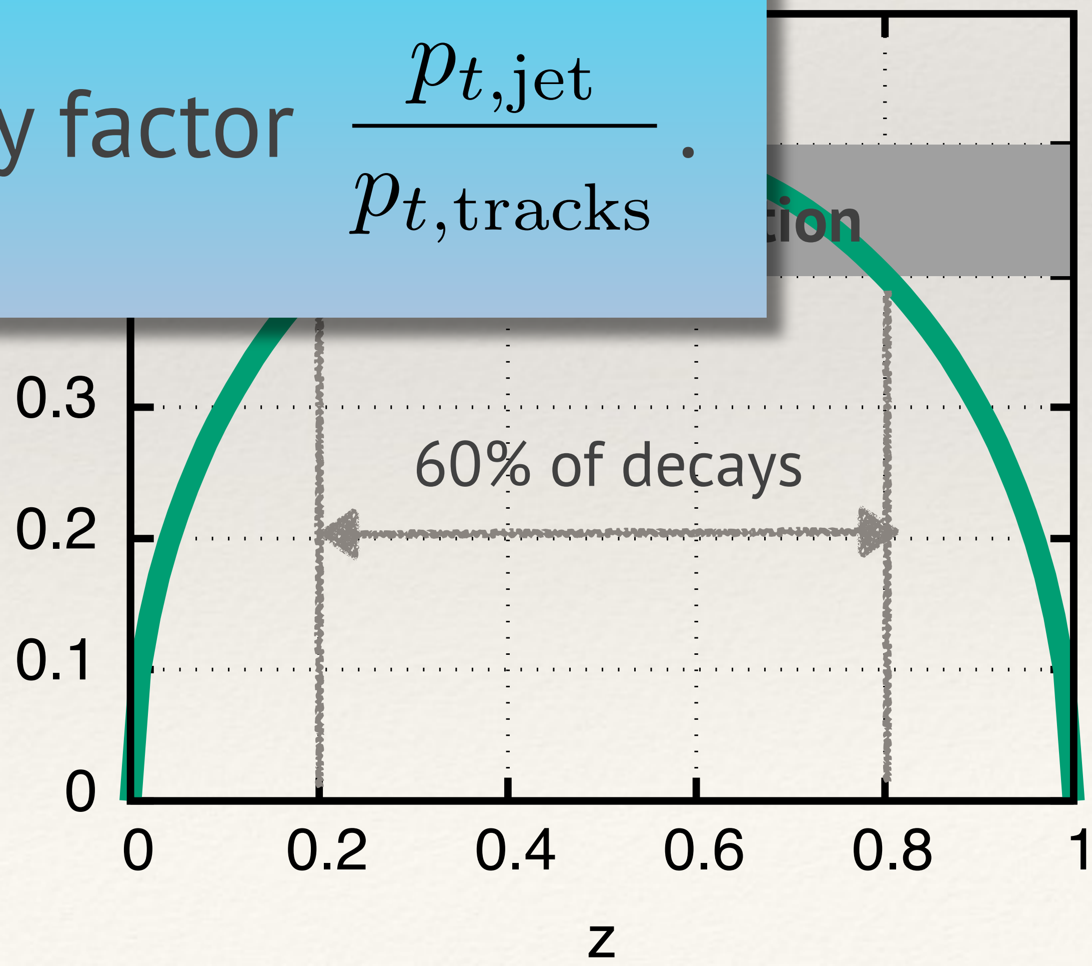
Practical approach:

1) Take track constituents of jet

2) Rescale them by factor $\frac{p_{t,\text{jet}}}{p_{t,\text{tracks}}}$.

- Calo for $p_{t,\text{jet}}$
- Tracks (and/or EM) for ΔR_{12}
- Tracks (and/or EM) for z

(fluctuations on on z doen't matter so much)



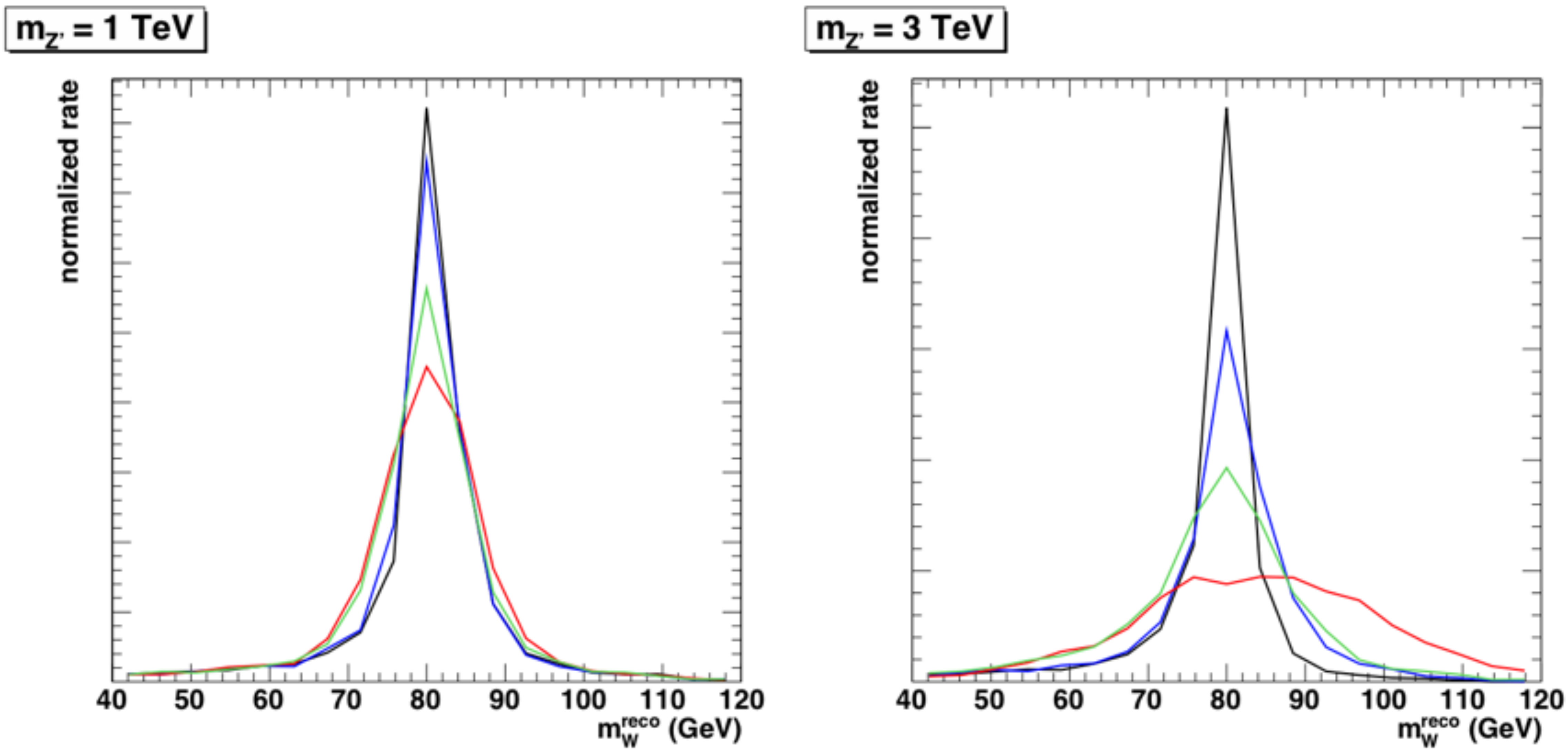


FIG. 12: *Distributions of the reconstructed hadronic W mass for 1 and 3 TeV* $Z' \to WW \to (l\nu)(q\bar{q}')$. *Displayed are particle-level (black), idealized particle-flow (blue), rescaled ECAL (green), and pure HCAL (red). Detector models are described in more detail in the text.*

Katz, Son & Tweedie, 1010.5253

Conclusions

- Boosted techniques will be essential at 100 TeV
- In some respects maybe even more powerful than at lower energies (e.g. isolation for colour-neutral objects)
- Apparent danger-zones, e.g. calorimeter resolution, perhaps not as dangerous as one might fear
- Some subtleties remain: e.g. top-jets v. top quarks