Tagging boosted jets at the FCChh

Maurizio Pierini

Which means...

Tagging a boosted jet with

- multi-TeV momenta change the rules of the game
  - we need to tag top-jets, not top quarks
  - color-neutral boosted particles look like τ leptons
  - very-large pileup (up to 1000?)
  - fast detectors (resolution below 100 ps)
  - very powerful computing techniques & a super-granular detector

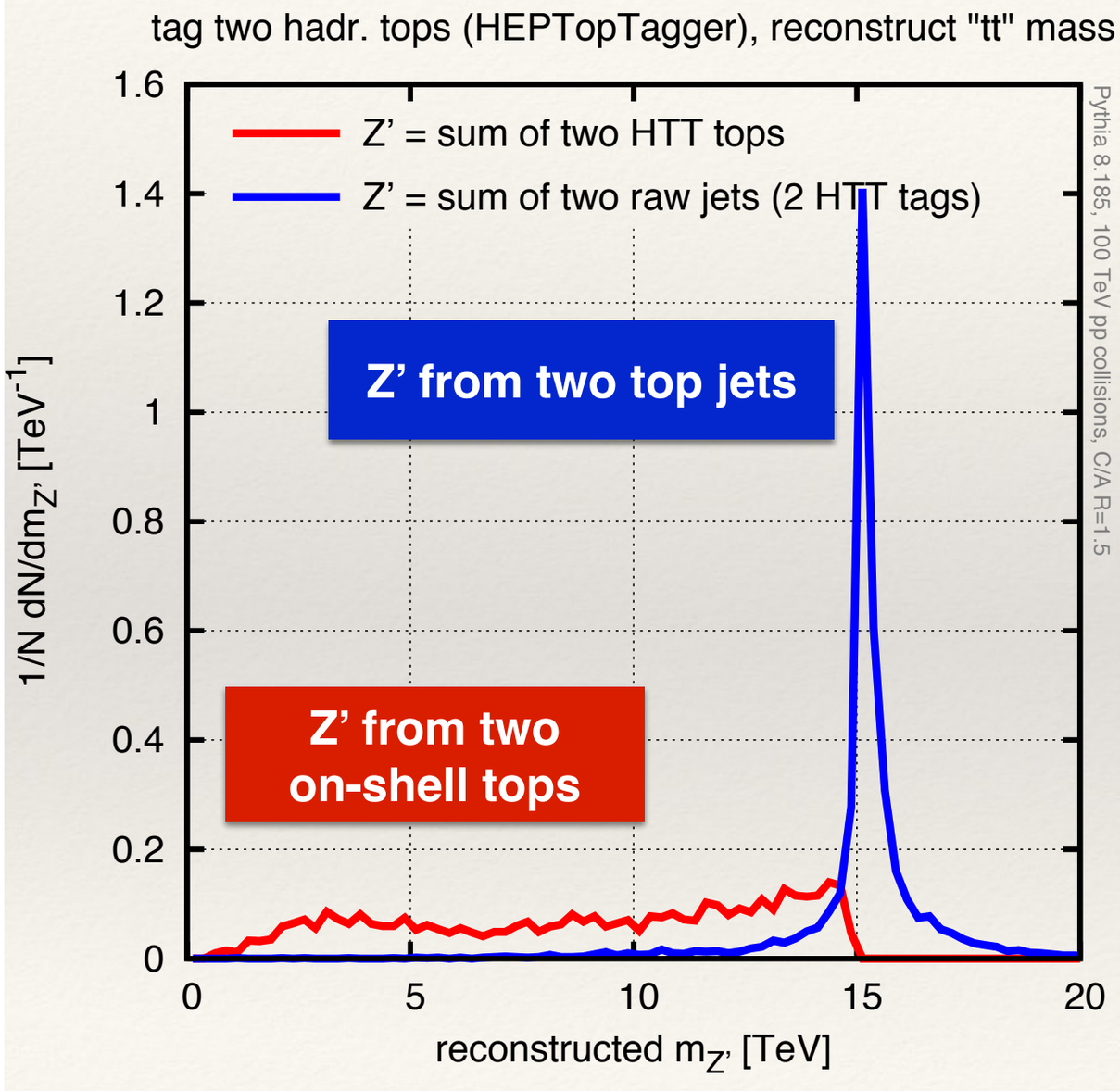
It's clearly going to be a different story than the LHC

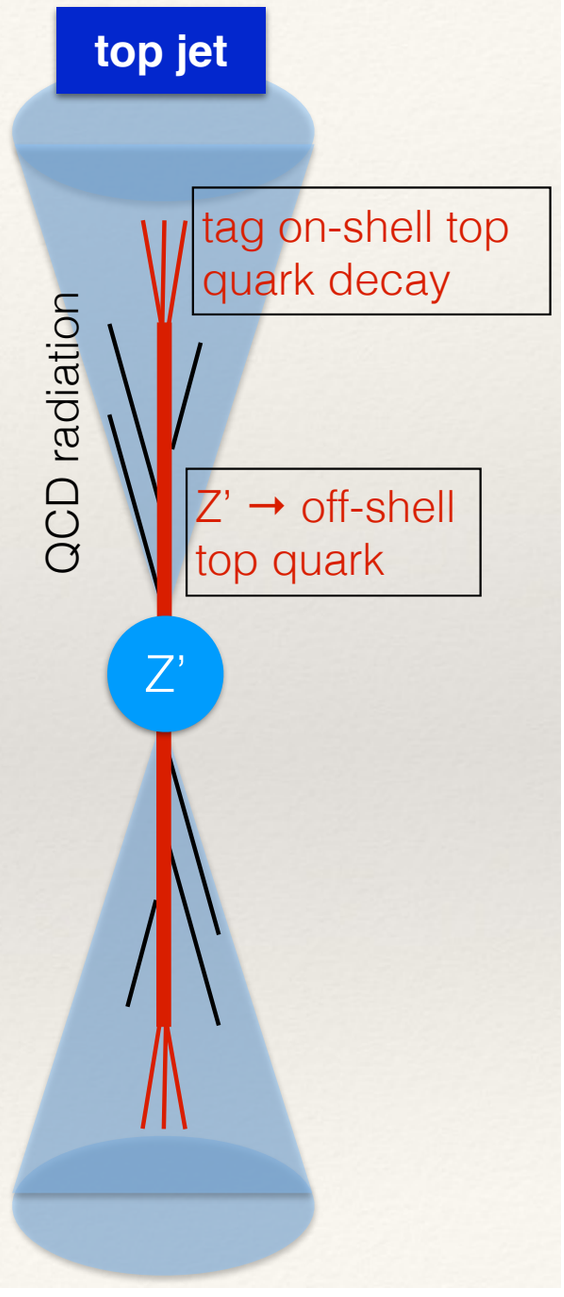
Quite hard to predict what it will look like

Tagging top jets

G. Salam, talk @FCC Higgs&BSM workshop '15

Top quarks v. Top jets

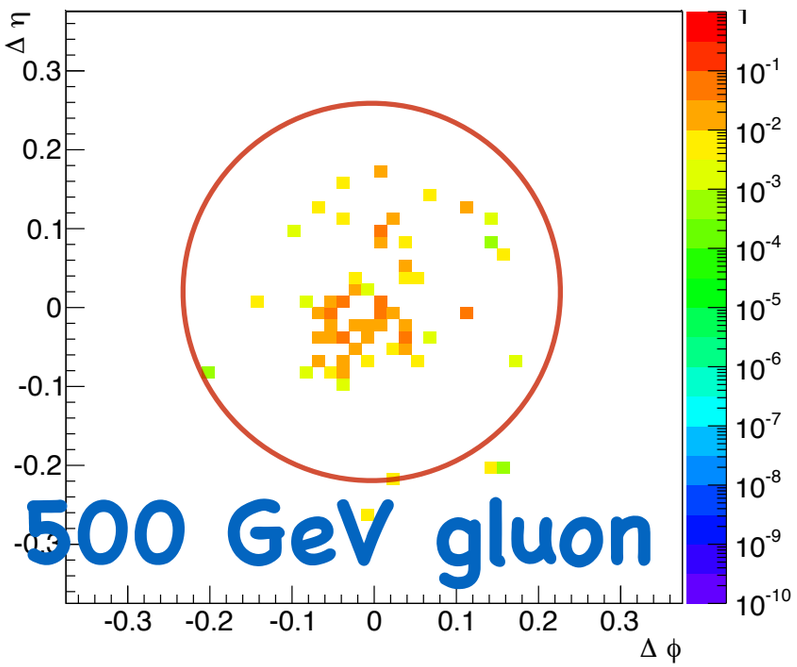


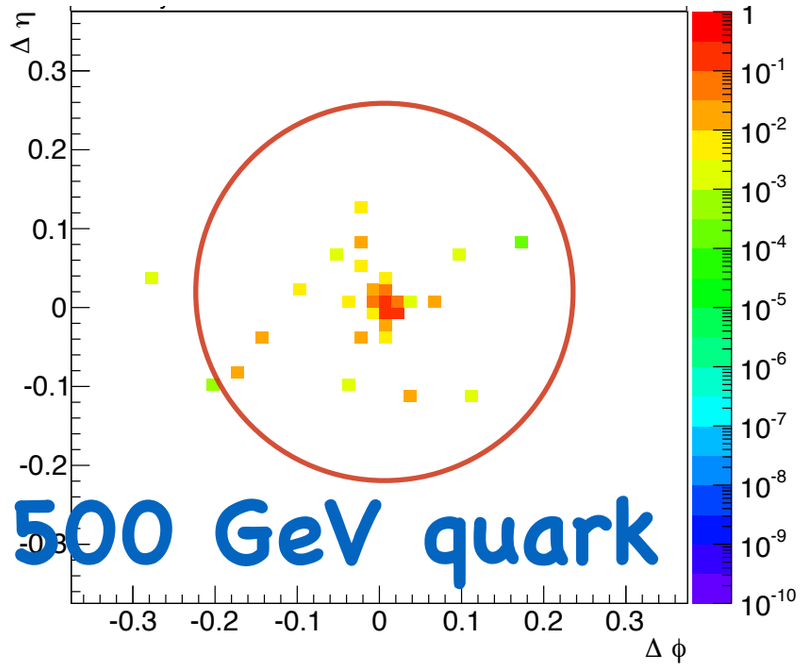


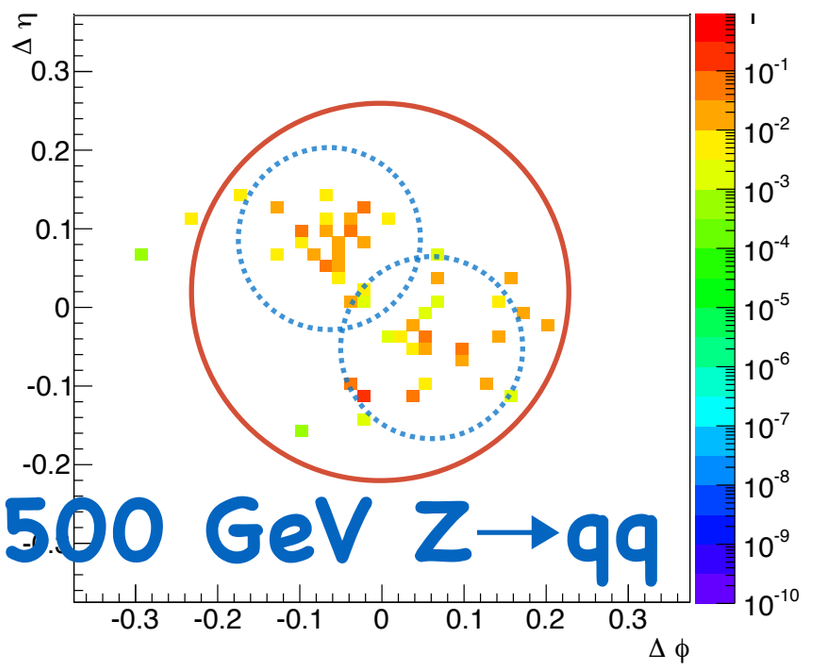
From jet-like to τ-like

Tagging a very-high-momenta boosted jet implies a change of strategy with respect to the LHC. Example: boson tagging:

- Normally, one would look for two sub-jets in the jet
- At intermediate (for FCC) / high (for LHC) pT, this strategy looks still OK
- For large (FCC) pT values, the two sub-jets collapse into a single collimated jet. Boosted vector bosons look like τ's







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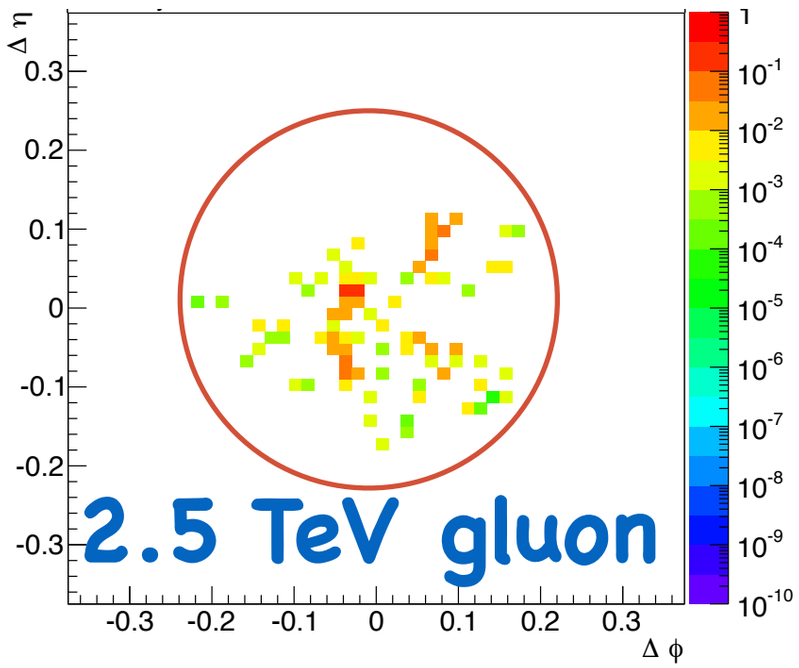

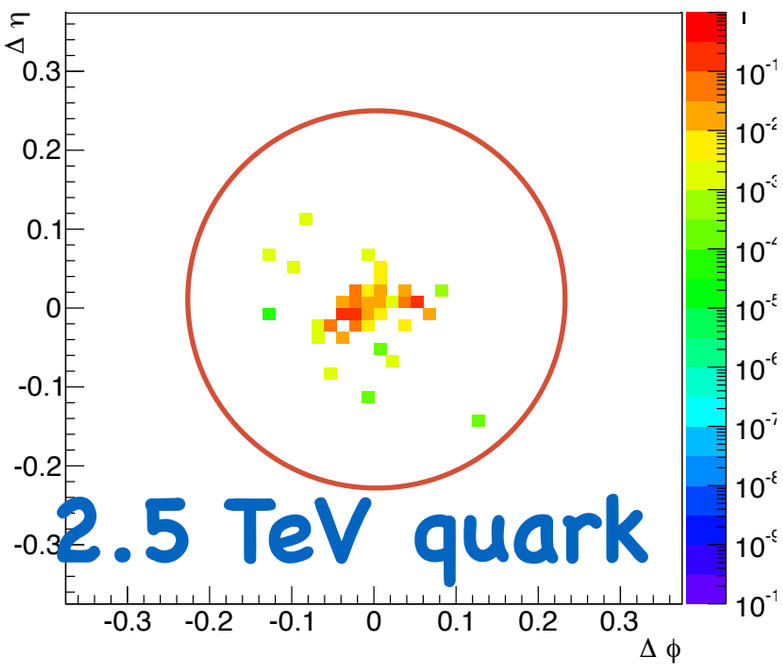

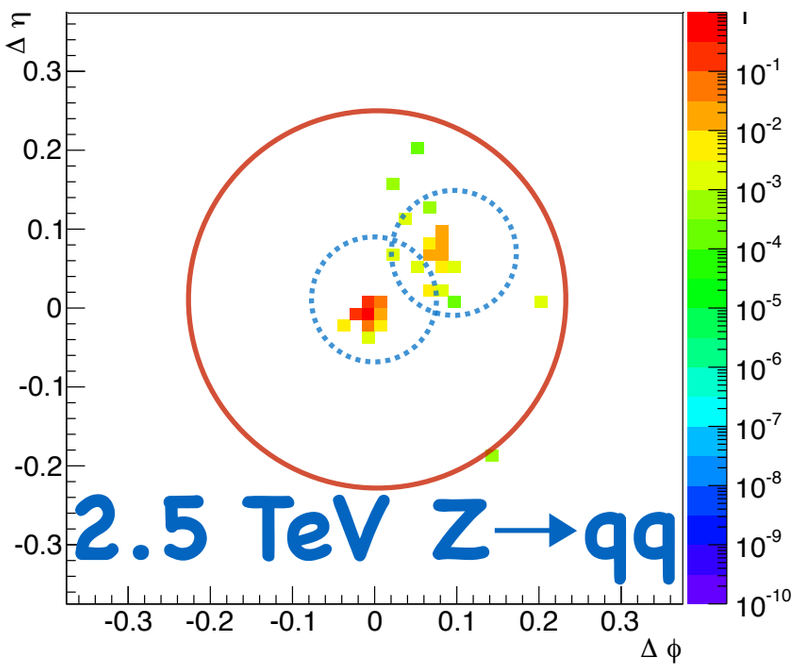

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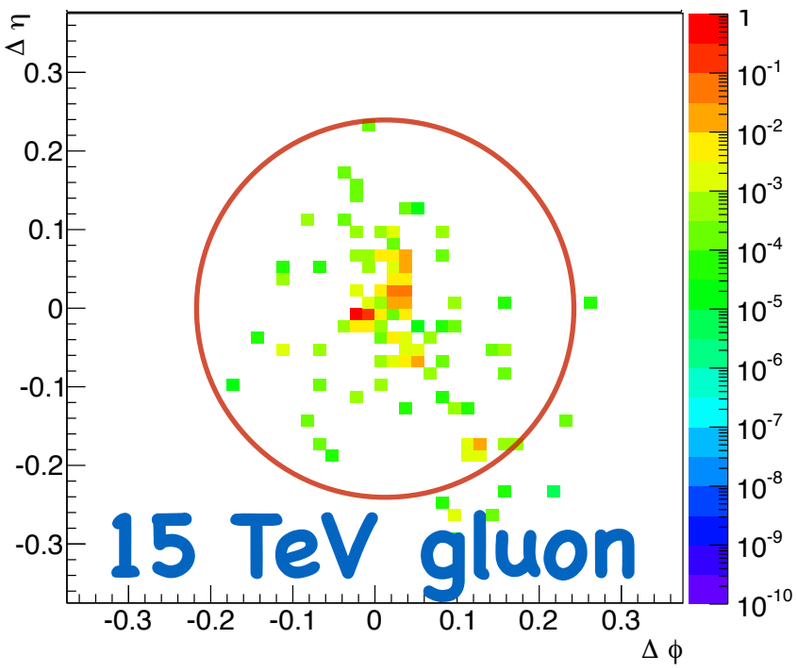
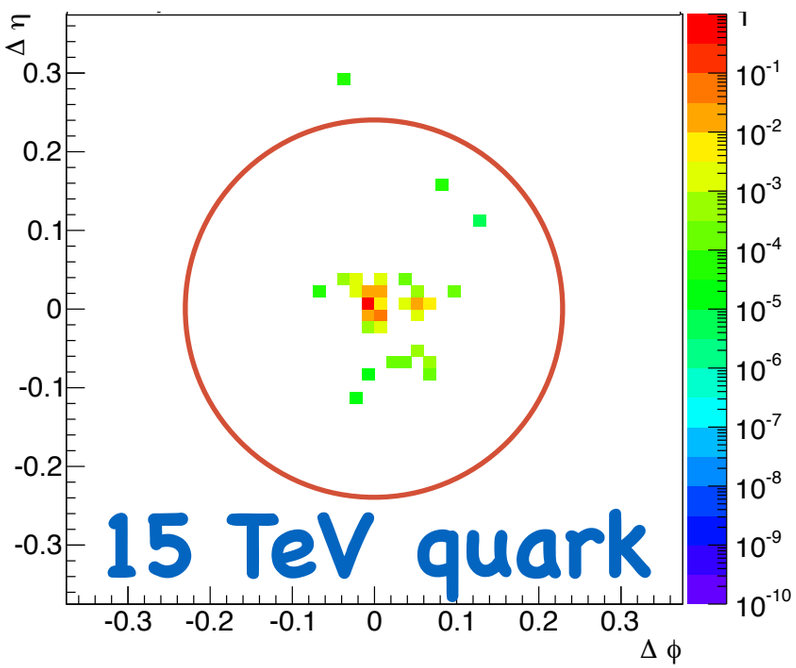
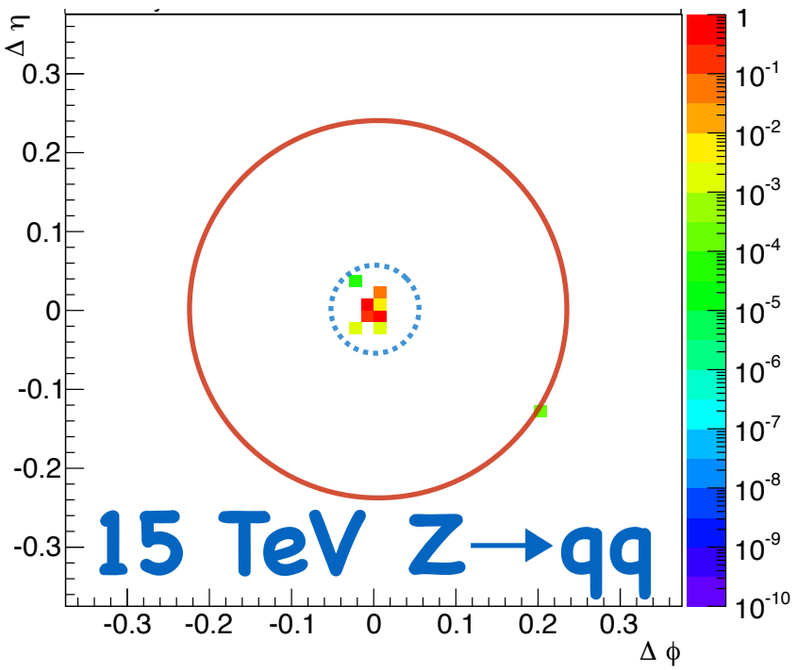






Tagging MultiTeV jets

- Three strategies considered
  - Standard t2/t2 + mass

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} min(\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{N,k}).$$

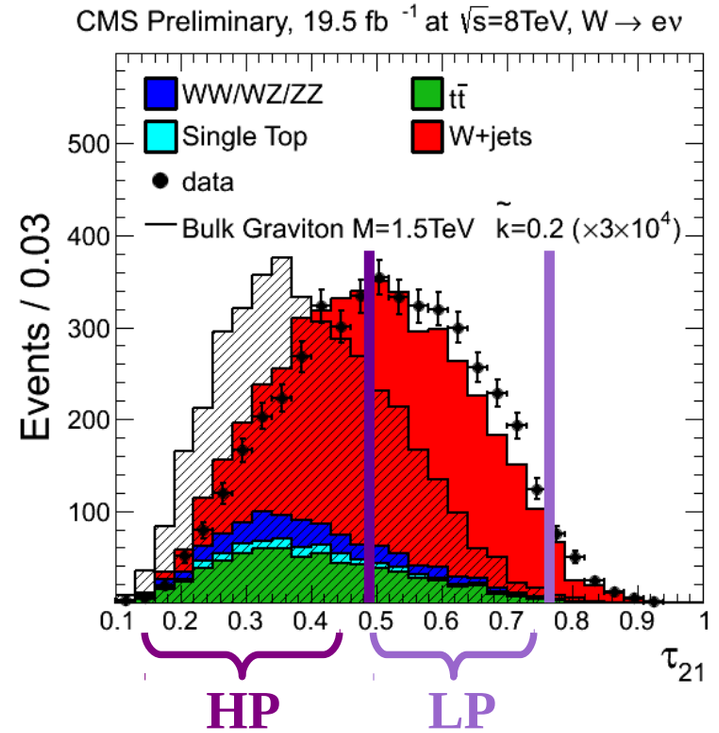
  - transverse momentum flowing in five concentric cones around the jet axis

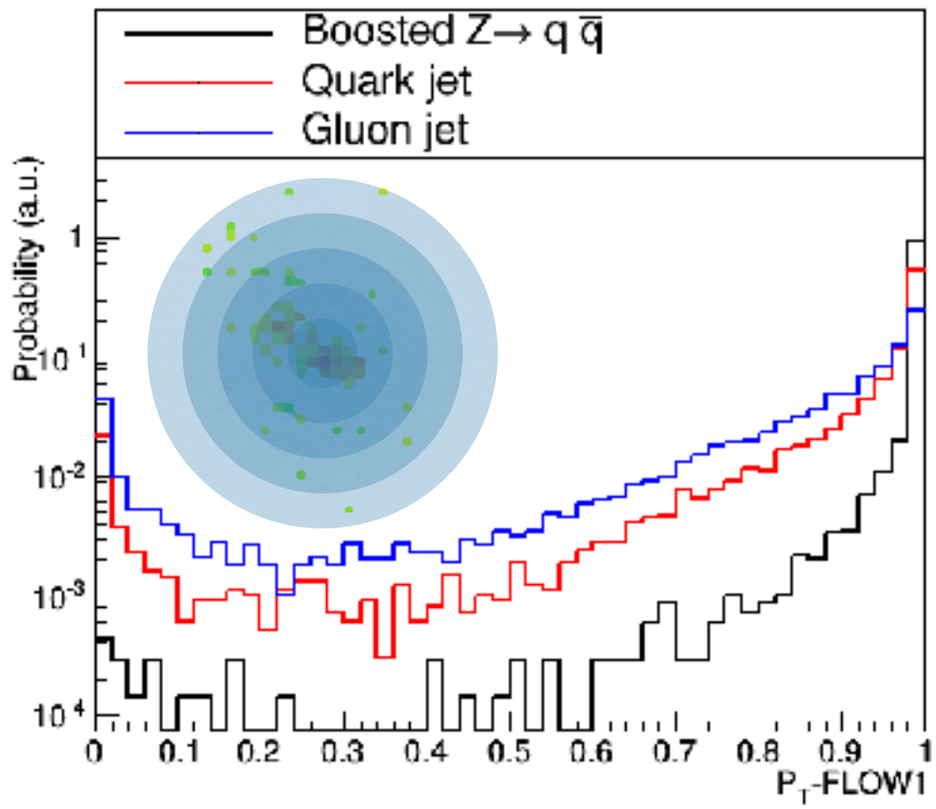
$$p_{t,flow} = \frac{\sum_k \sqrt{p_{k,J}^2 - (\overrightarrow{p_{k,J}} \cdot \overrightarrow{n_J})^2}}{p_{T,J}}$$

  - As above, but with momentum transverse to jet axis

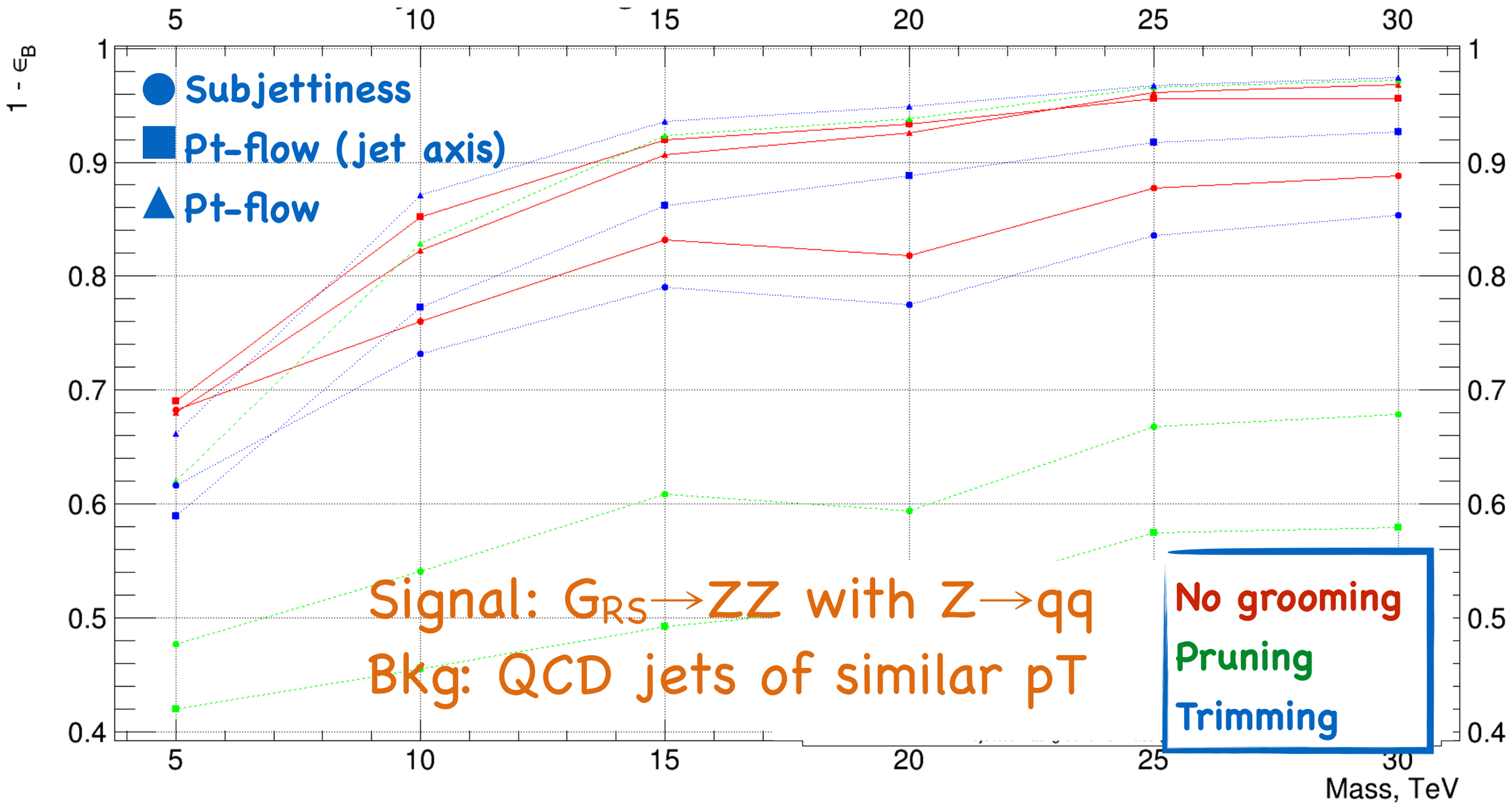
$$p_{T,flowbeam} = \frac{\sum_k p_{T,k,J}}{p_{T,J}},$$

- Procedure applied after grooming (pruning or trimming)





Tagging MultiTeV jets



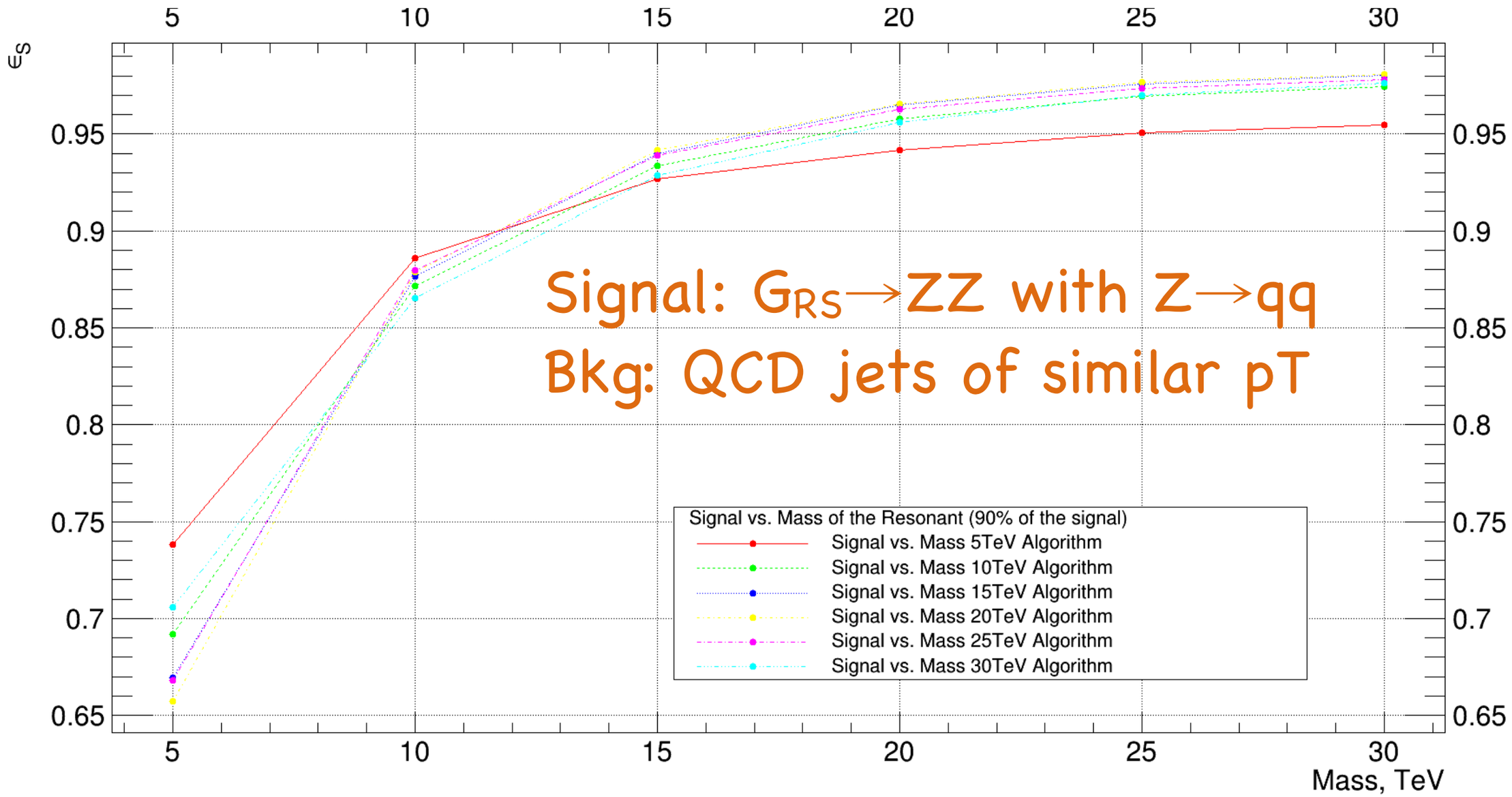
BDT trained with TMVA

Bkg rejection for signal efficiency fixed at 90%

Best option: pT-flow with trimmed jets

Danyyl Brzhechko,
CERN Summer Student '16

Tagging MultiTeV jets



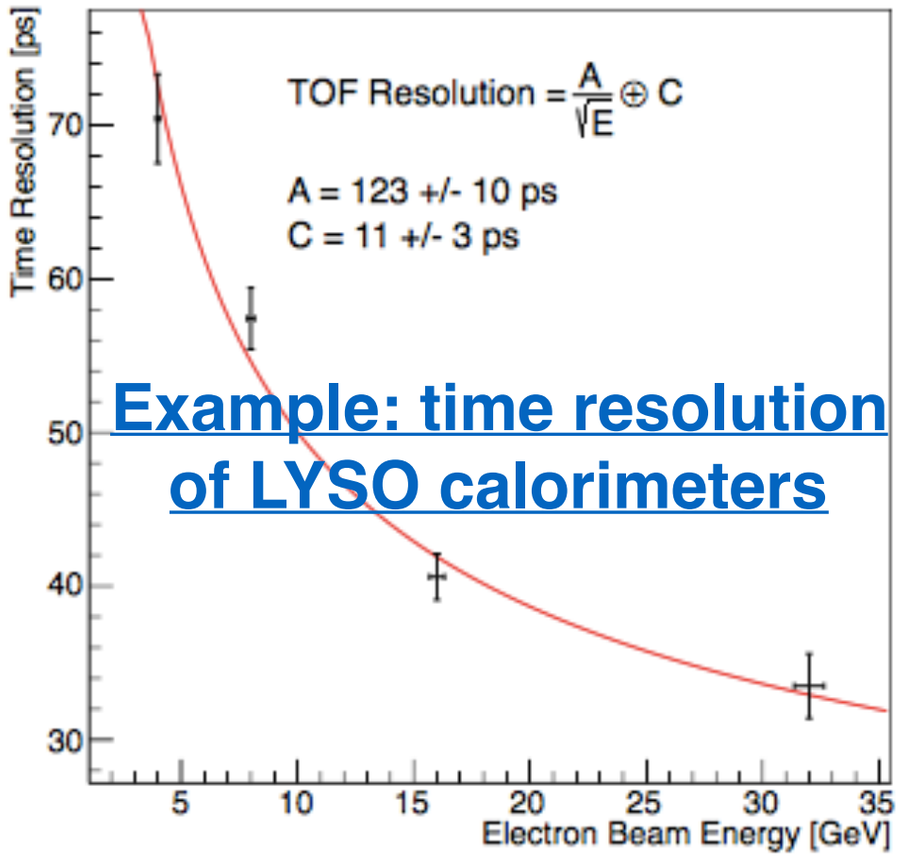
BDT trained with TMVA for different mass values (the applied to all others)

Signal efficiency for bkg rej. fixed at 10%

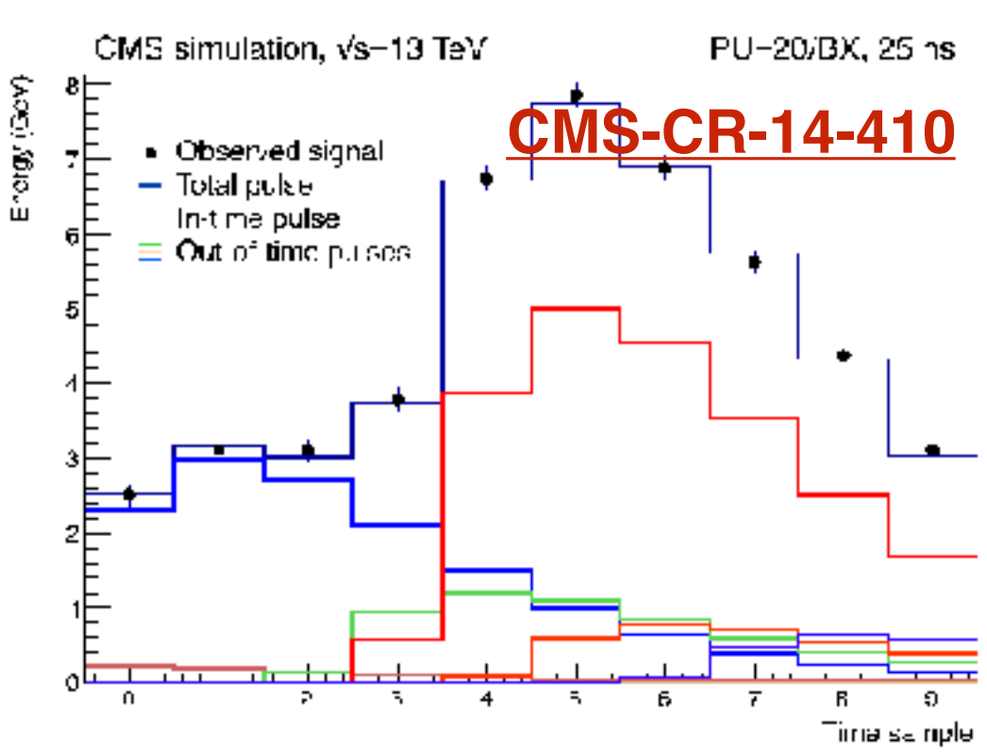
Danyyl Brzhechko,
CERN Summer Student '16

Dealing with out-of-time Pileup

- Out-of-time PU should not be an issue (particularly if we stay @25 ns bunch spacing)
  - Fast detectors under development (for HL-LHC) with time resolution (well) below 100 ps
  - Software techniques in place to subtract the PU (once the time information is available
- Seems like OOT PU mitigation will be at hand by the time of FCChh start



Example: time resolution of LYSO calorimeters



CMS-CR-14-410

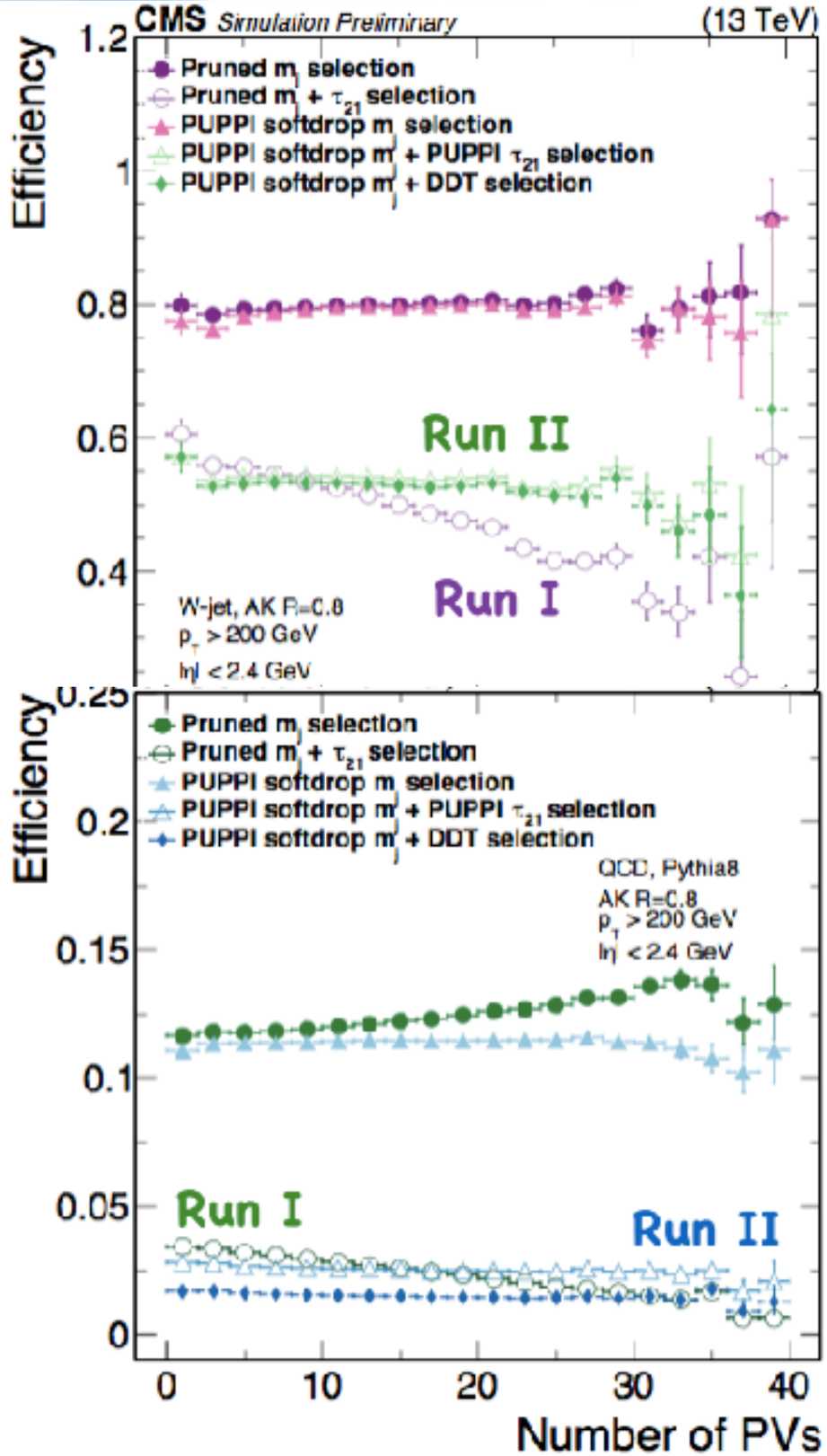
Dealing with in-time Pileup

- When tagging boosted jets, in-time PU is dealt grooming the jets

- Which strategy to adopt depends a lot on the environment (see CMS Run I vs Run II)

- HL-LHC will teach us a lot
  - So far, studies suggest PUPPI could handle the problem

- Premature to address the issue now, but jet-tagging performances depend critically on this

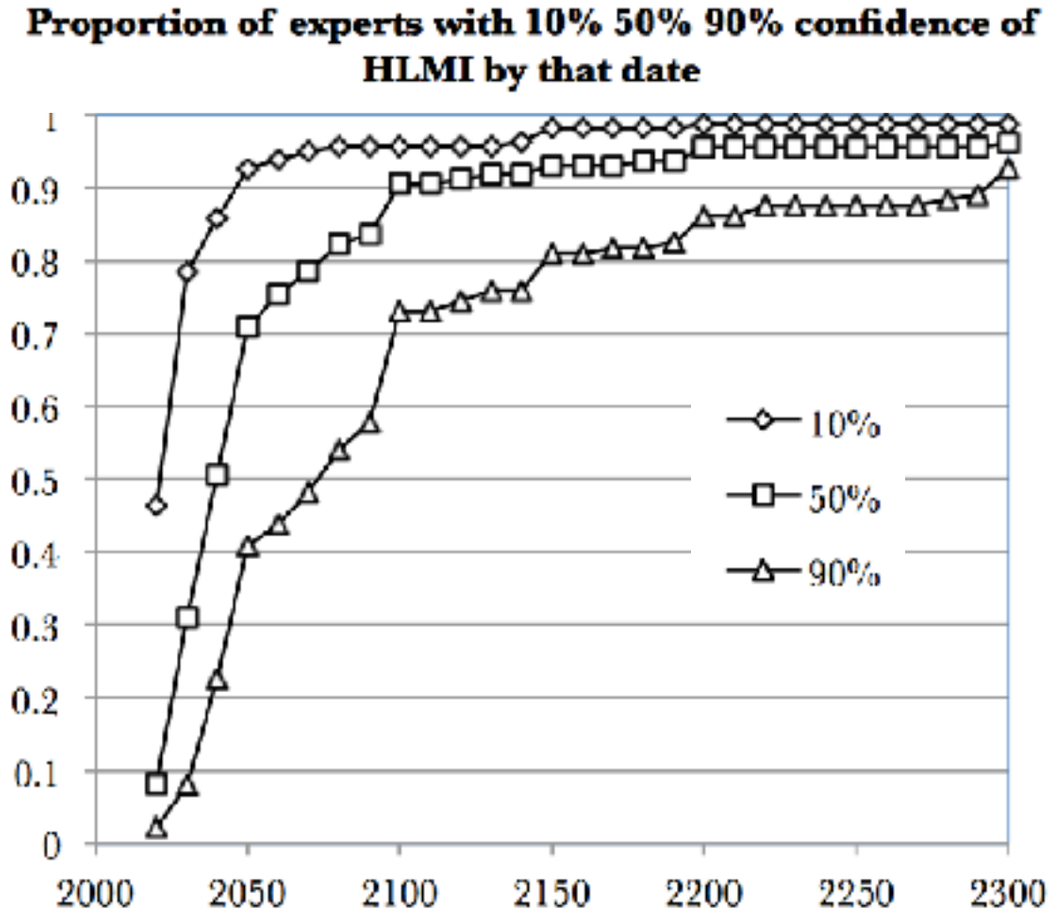


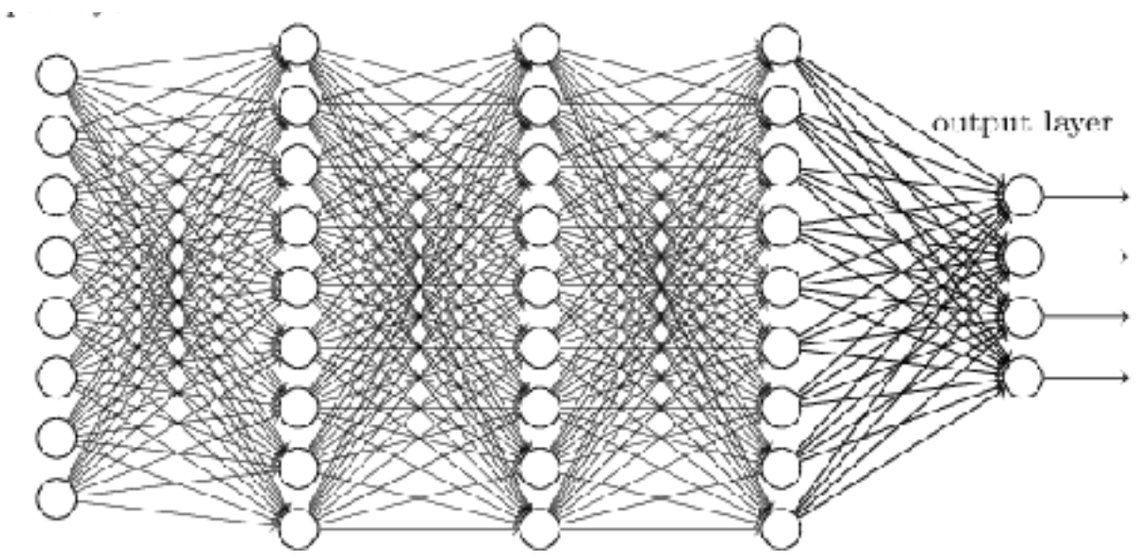
Tagging jets in the era of AI?

- A survey among experts in 2012/13 to quantify by when AI will be developed. Not quite there by 2035, but on track for it

- Along the path to AI, interesting techniques are developed for
  - image detection
  - text analysis
  - …

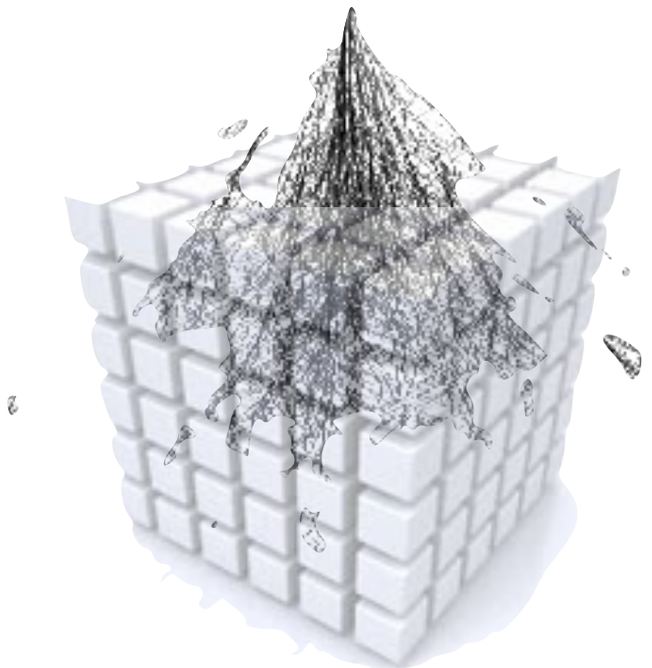
- These technical progresses are opening new paths for jet-tagging techniques



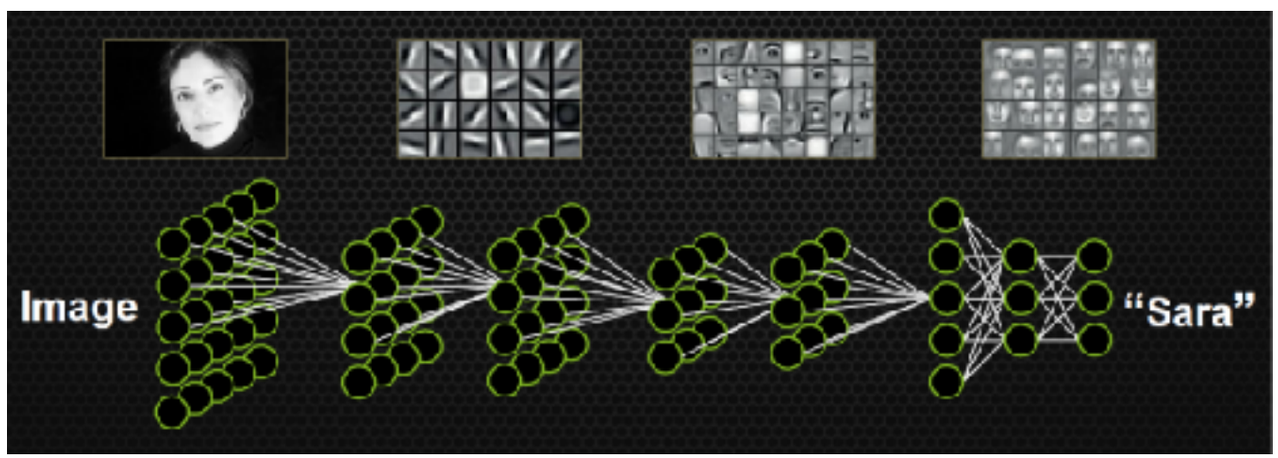


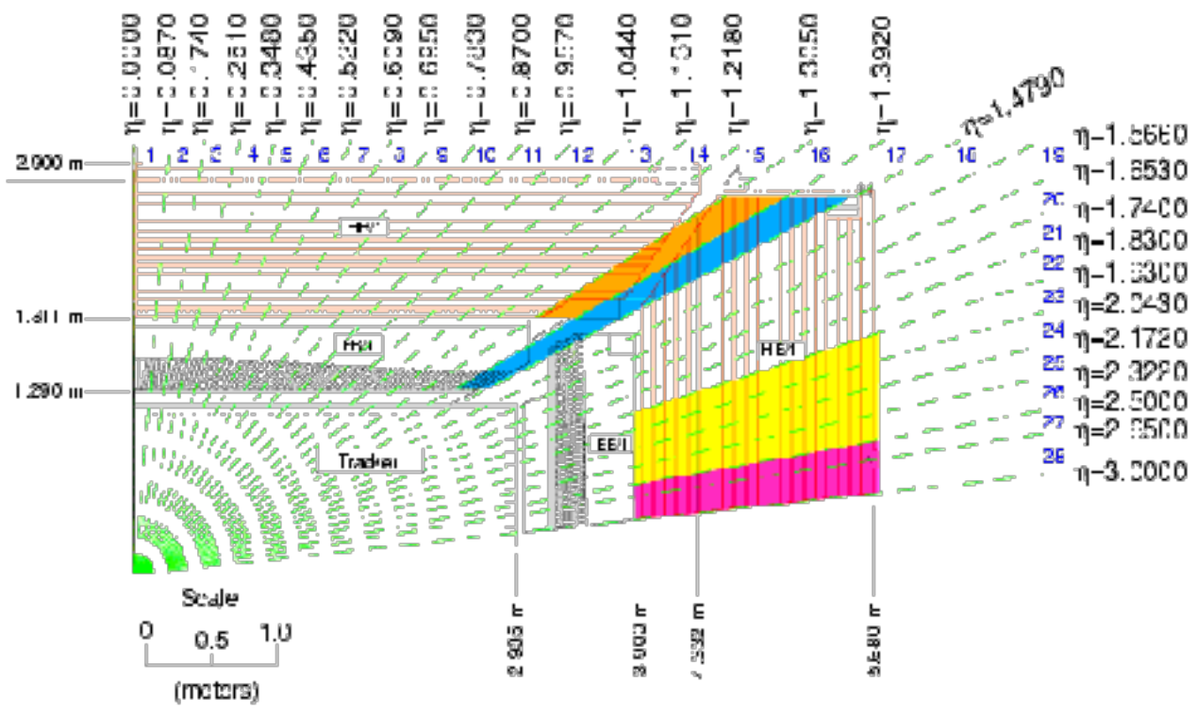
Detector geometry & deep learning

- Next-generation detectors are going to be more granular
  - Similar to 3D arrays of "pixels"
  - Extendable to 4D with fast-detector technology
- Similarity with pixelated images processed with deep learning
  - Could recycle here techniques developed there



- Main complication: detector edges, transition regions, etc





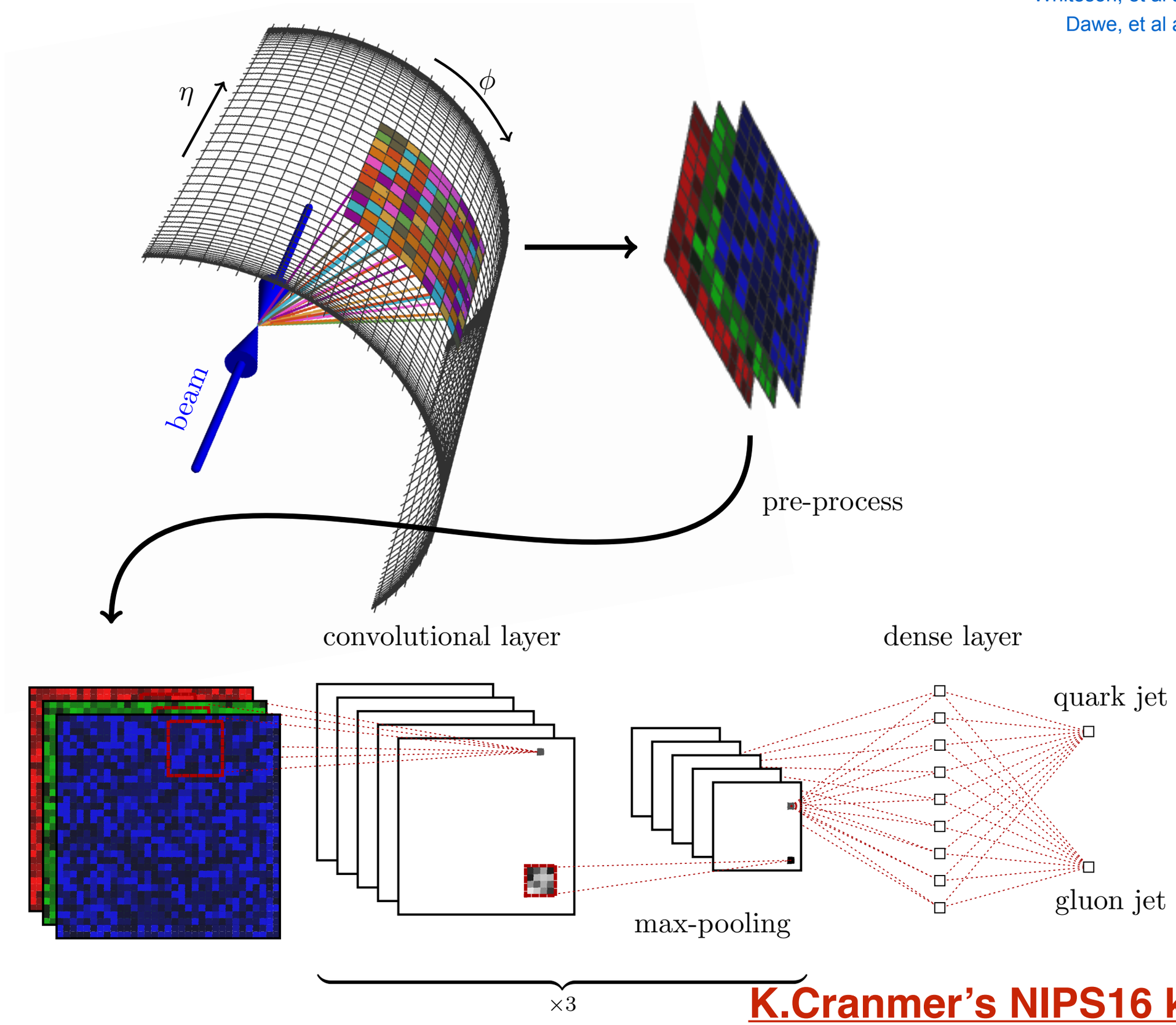
JET IMAGES

image: Komiske, Metodiev, Schwartz arxiv:1612.01551

Oliveira, et. al arXiv:1511.05190

Whiteson, et al arXiv:1603.09349

Dawe, et al arXiv:1609.00607



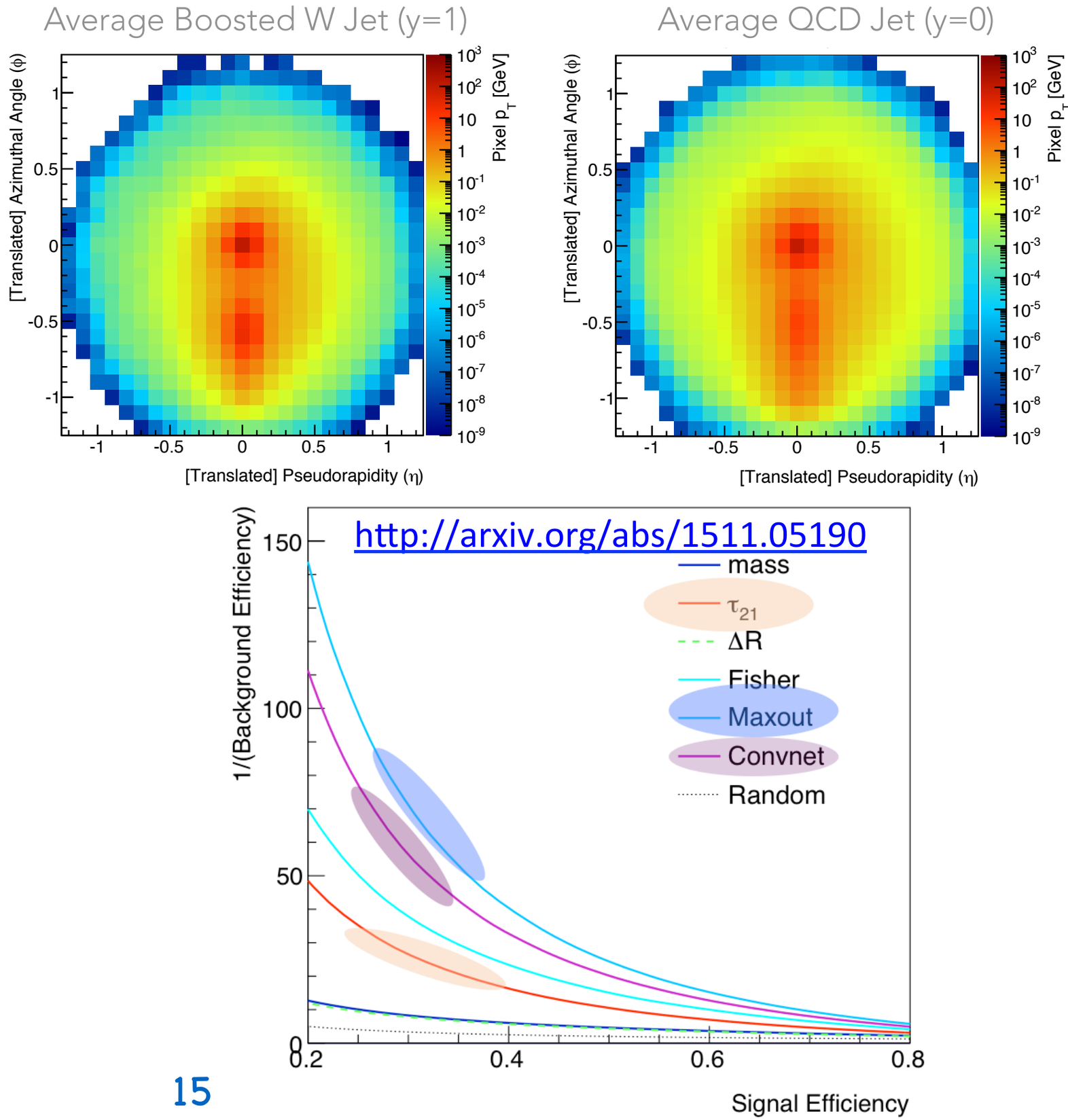
K.Cranmer's NIPS16 keynote

Jets as an image

Jet-images approach

- Treat calorimeter energy depositions as image, and use DNN for classification
- Very promising results
- Assume regular geometry for the detector
- Don't simulate detector effects explicitely

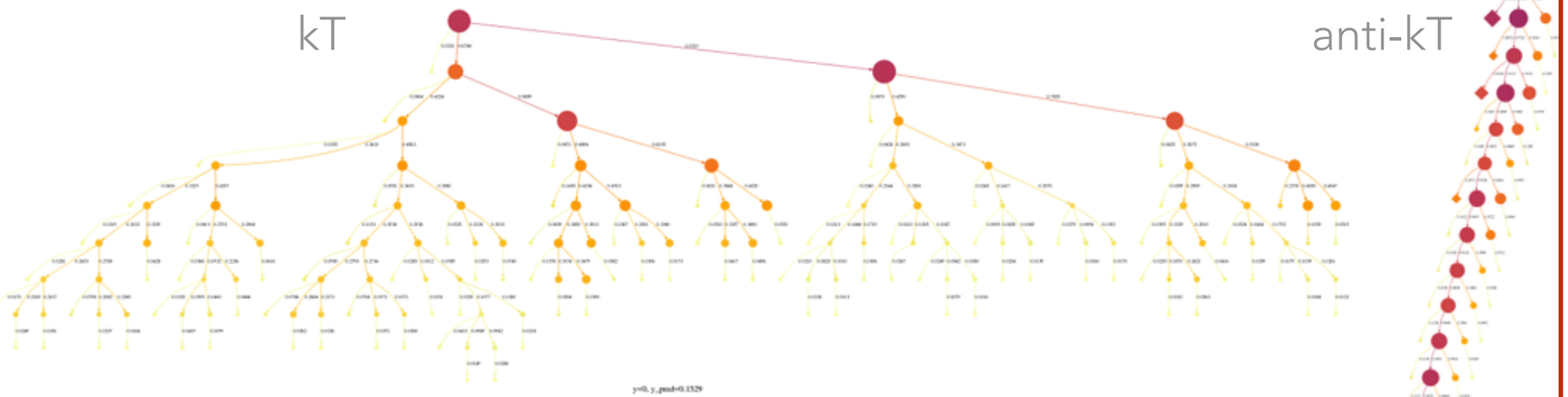
Real life might be more complicated

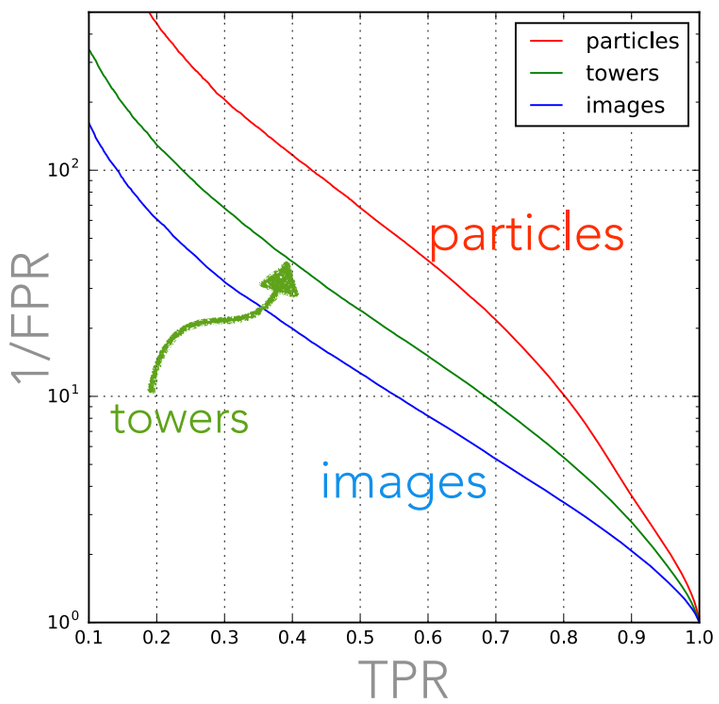


Jets as a sentence

- Describe a jet as a sentence (the constituents being the words)
- Use the jet algorithm as the grammar
- Apply techniques normally used for language processing (e.g., recursive neural networks)

QCD-INSPIRED RECURSIVE NEURAL NETWORKS





- down-sampling by projecting into images looses information
- RNN needs much less data to train!

K.Cranmer's NIPS16 keynote

Conclusions

- Tagging boosted jets at the LHC is going to be quite a different business
  - Different environment condition (e.g., pileup)
  - different pT regime changes the rules of the game
  - Progresses in detector and analysis techniques open new possibilities (e.g., Deep Learning)
- Quite difficult to realistically predict the future, with so many years ahead
- LHC Run III and HL-LHC will be essential to exploit potential of new approach
- TO KEEP IN MIND: optimizing tagging strategies has impact on detector geometry (see DL techniques vs irregular detector geometries)