Jet Reconstruction and Triggering

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Fine print

- I was asked to give this talk on Monday
- The charge:

  Broadly speaking, the aim of the talk is to give the theorists in the audience an introduction to state-of-the-art reconstruction (e.g. particle flow, techniques for dealing with high pile-up, the status of tau reconstruction) and their implications for searches. A discussion of triggering (whether focused on hadronic or more general) would also be very useful. Beyond these vague suggestions, you can define the scope of the talk however you think will do best to motivate, focus, and inform discussions about possible future analyses. The theorists in the audience will have a mix of BSM and SM expertise, and a somewhat more appetite than average for experimental details.

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= I know a lot, could talk for hours, but won't
= I know little
= I have little public material

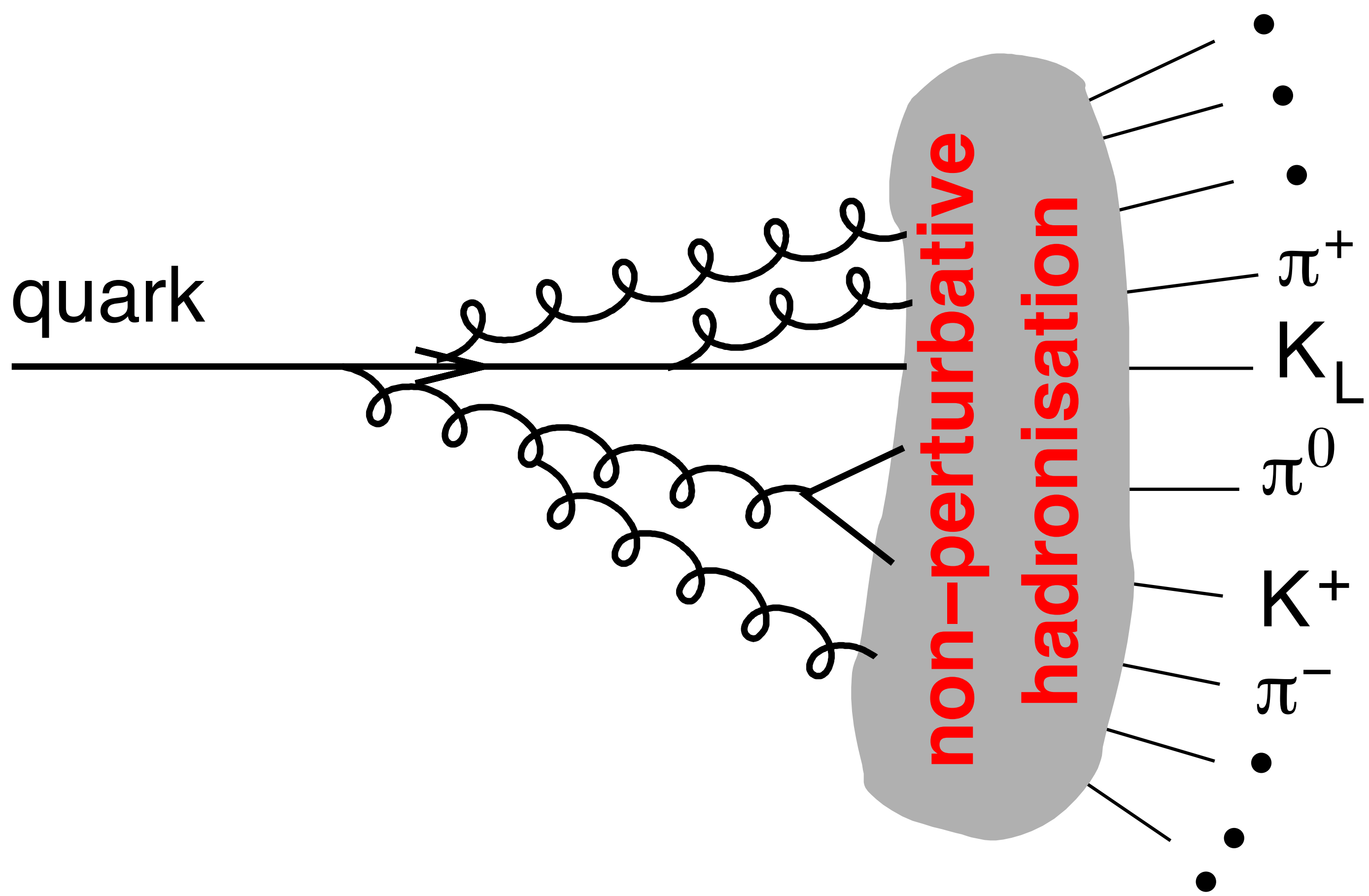
Outline

- Jet reconstruction
- Particle flow
- Pileup mitigation
- Advanced techniques
- Trigger strategies
- Prospects

Jet reconstruction

- From Gavin Salam:

Parton fragmentation



Gluon emission:

$$\int \alpha_s \frac{dE}{E} \frac{d\theta}{\theta} \gg 1$$

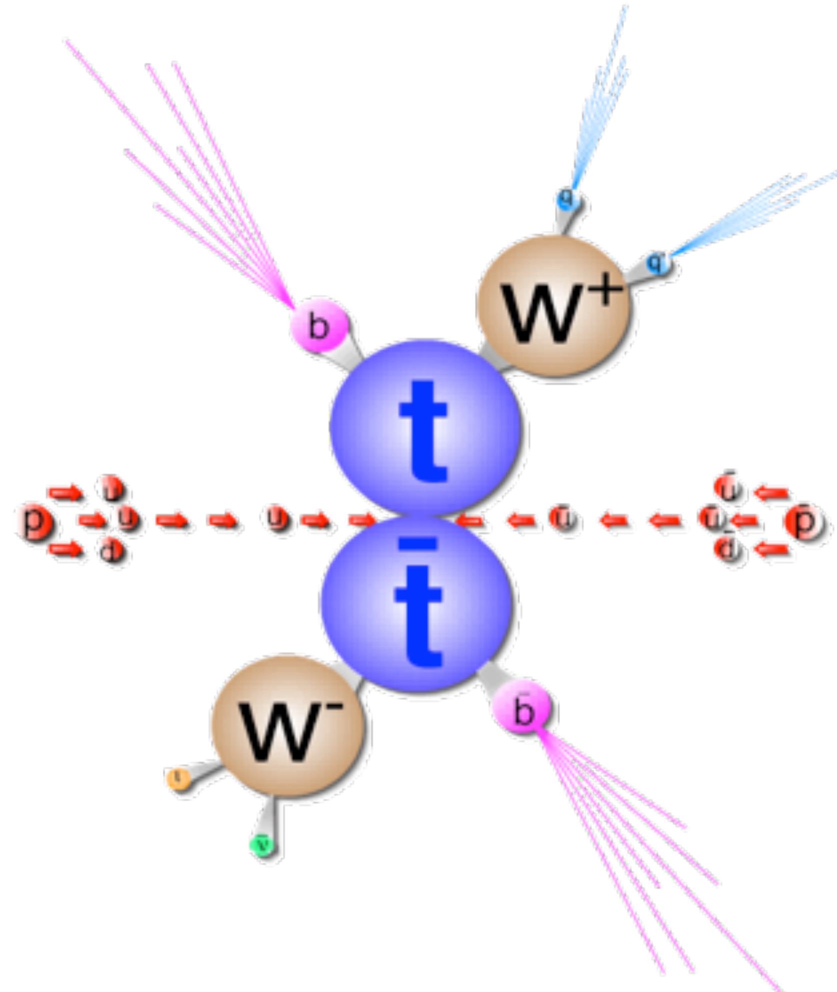
At low scales:

$$\alpha_s \to 1$$

This is a jet

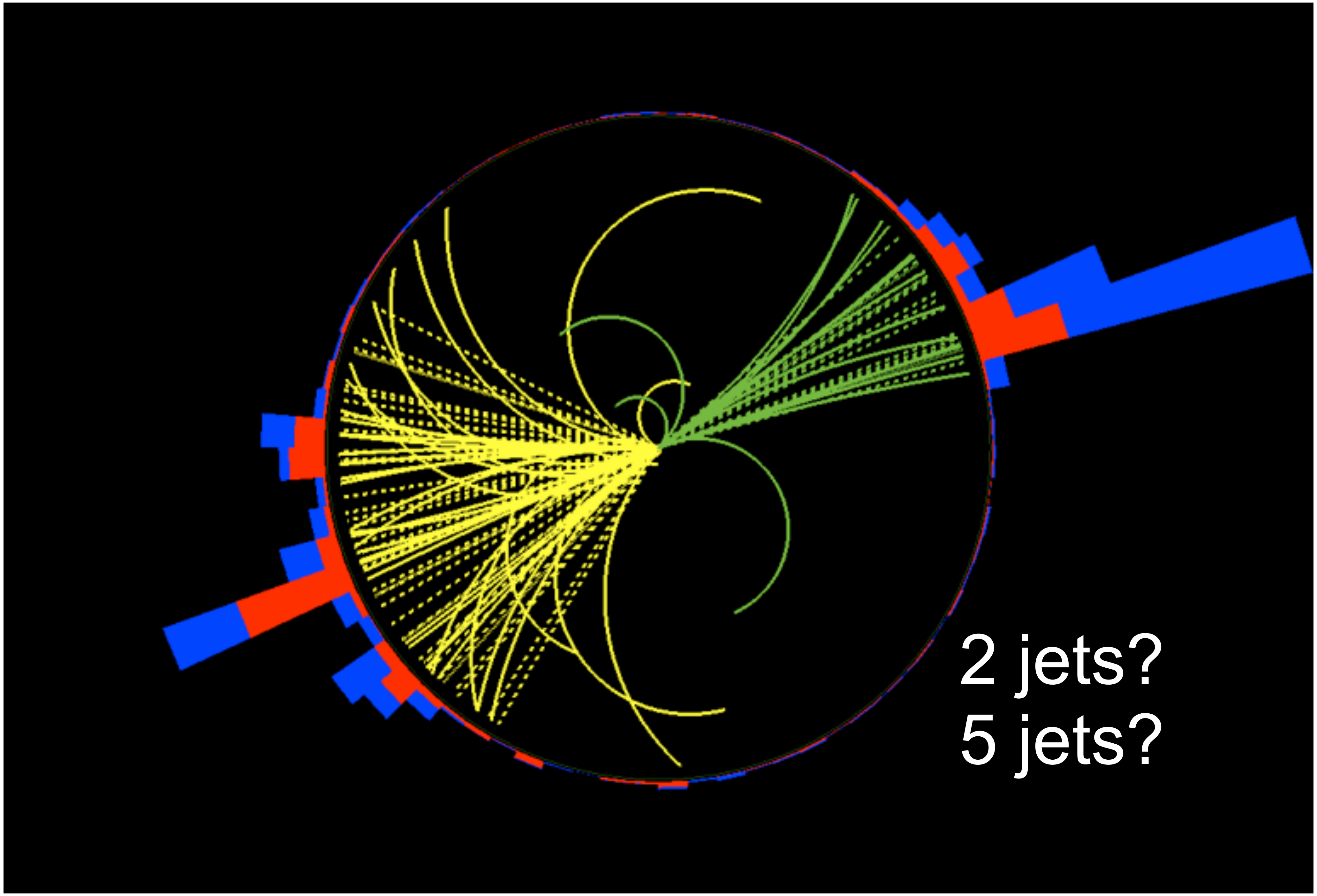
Jet reconstruction

- Idea of reconstruction is to map N jets to M partons
  - Ideally, one-to-one!
- How to define “M” ? LO? NLO? Something else?
- Definition of “N” is dependent on the algorithm you’re interested in
  - Also on the distance parameter!
- Different algorithms are useful for different things
- I’m often asked “What is the best kind of jet algorithm”?
  - I reply “This is like asking what is the best tool in the toolbox”



Jet reconstruction

- Not always trivial!
- More on this later



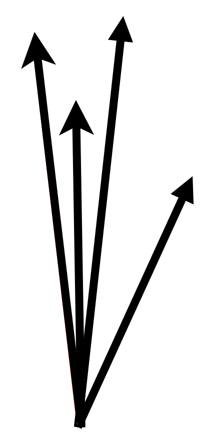
Jet reconstruction

- Most modern jet algorithms are sequential clustering algorithms
- Pairwise examination of input 4-vectors
- Calculate d_{ij}

$$d_{ij} = min(k_{ti}^n, k_{tj}^n)\Delta R_{ij}^2/R^2$$

- Also find the "beam distance"

$$d_{iB} = k_{T,i}^n$$



- Find min of all d_{ij} and d_{iB}
  - If min is a dij, merge and iterate
  - If min is a d_{iB}, classify as a final jet
- Continue until list is exhausted

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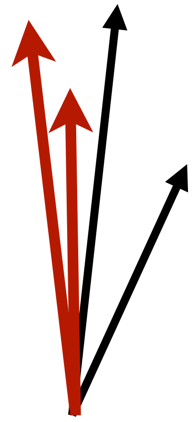

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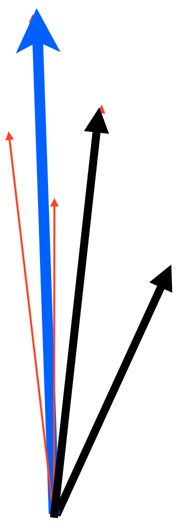

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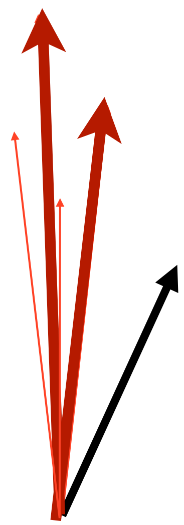

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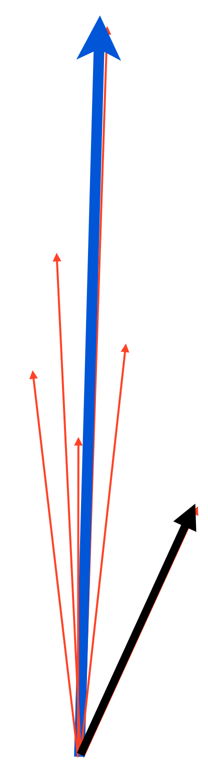

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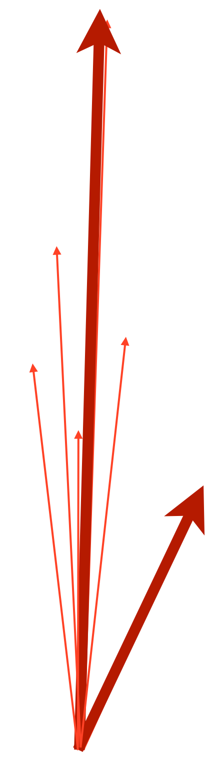

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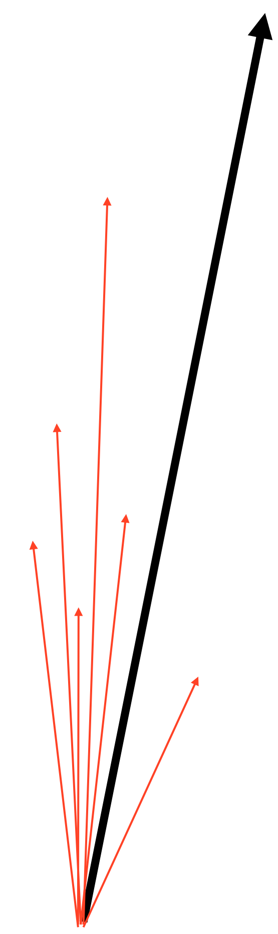

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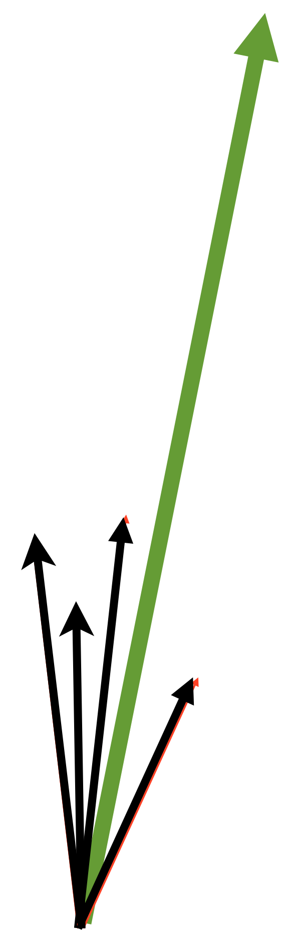
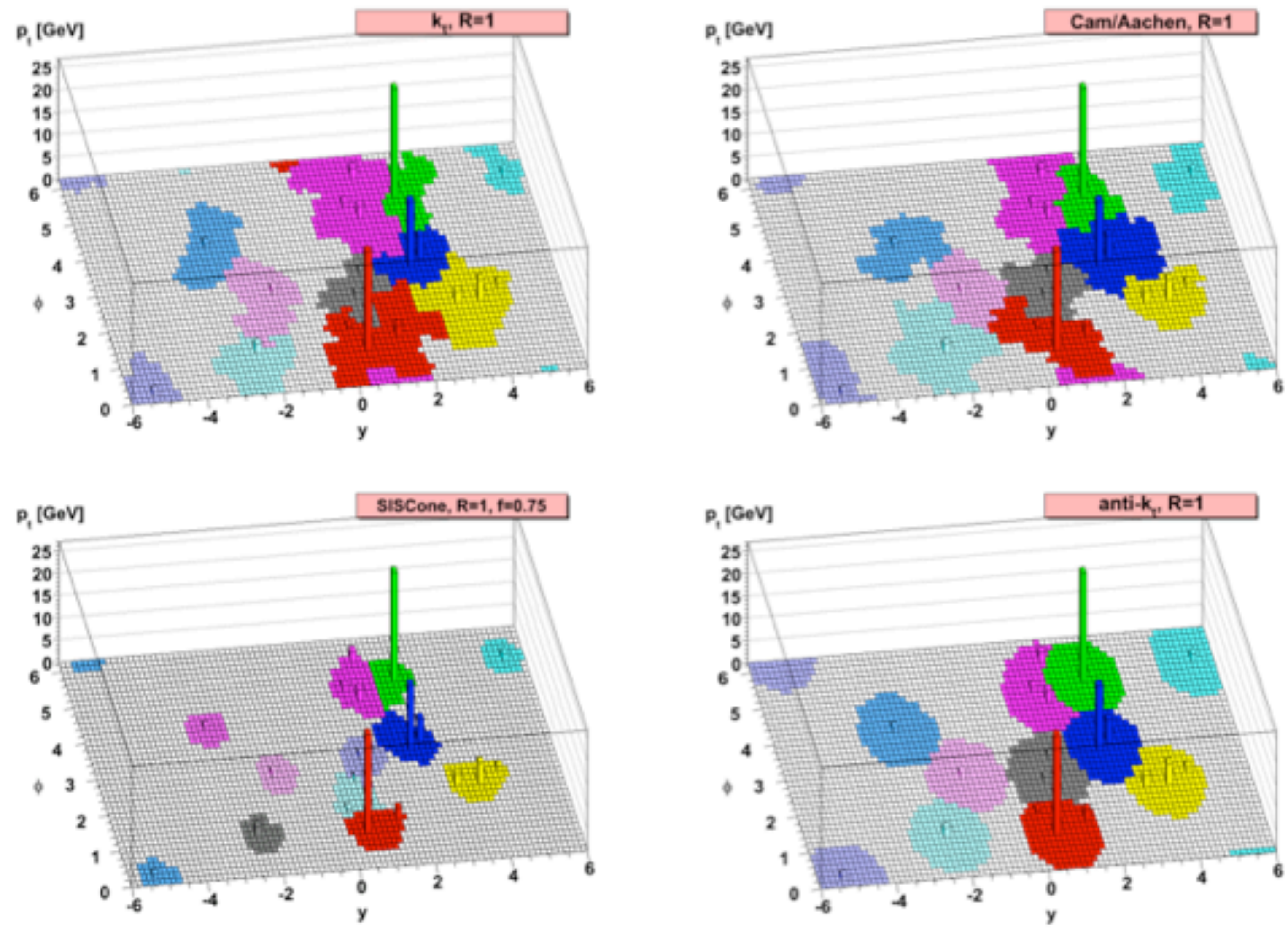


Jet reconstruction

- Properties depend on sequence
  - N = 2:
    - “kT”
  - N = 0 :
    - “Cambridge-Aachen” (CA)
  - N = -2:
    - “anti-kT”



arXiv:0802.1189v2 [hep-ph]
Cacciari, Salam, Soyez

Jet reconstruction

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  - N = 2:
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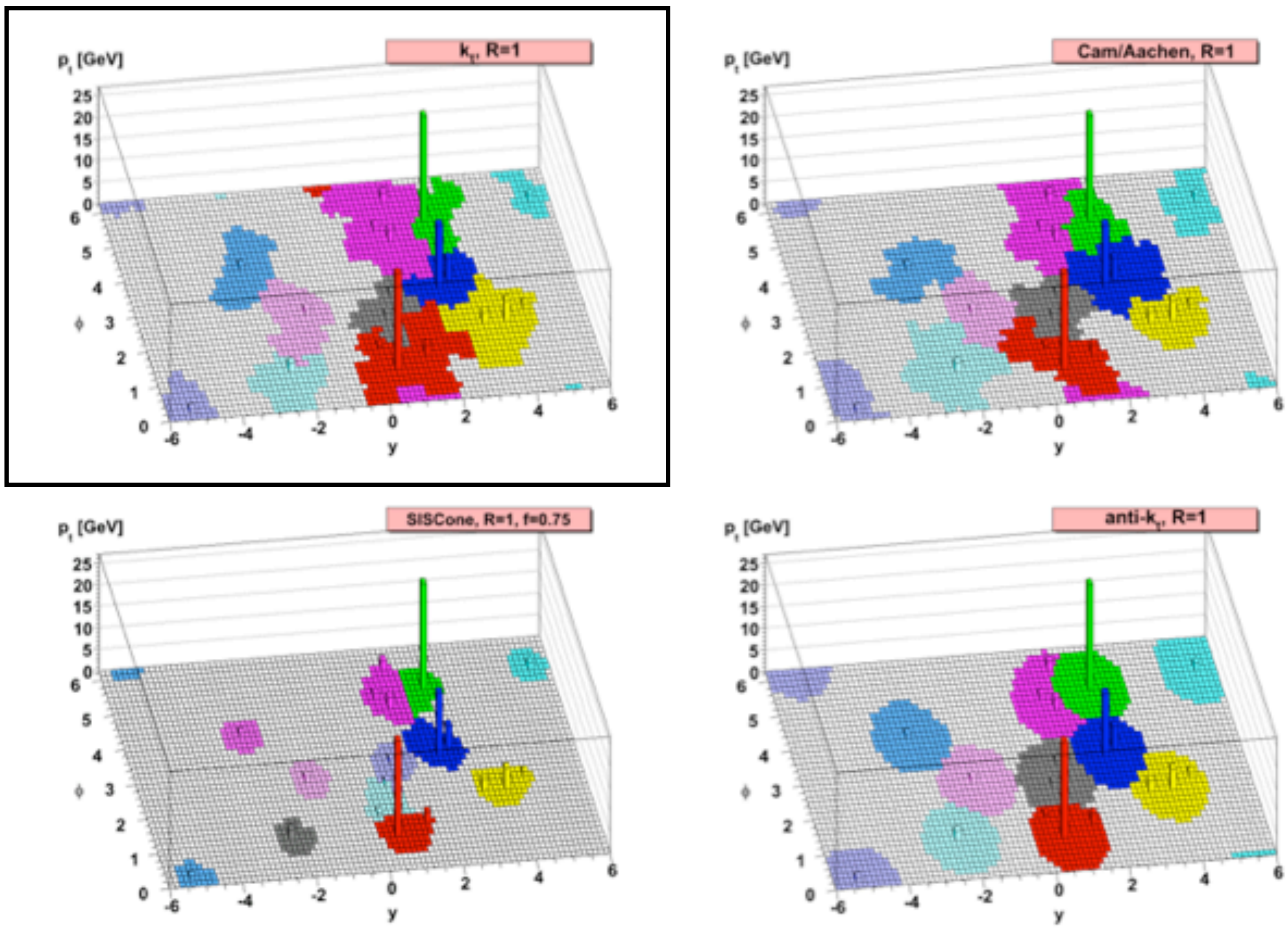
  - N = -2:
    - "anti-kT"
      - Clusters soft particles first
      - Good for low-pt jets
        - Good for jet area computation



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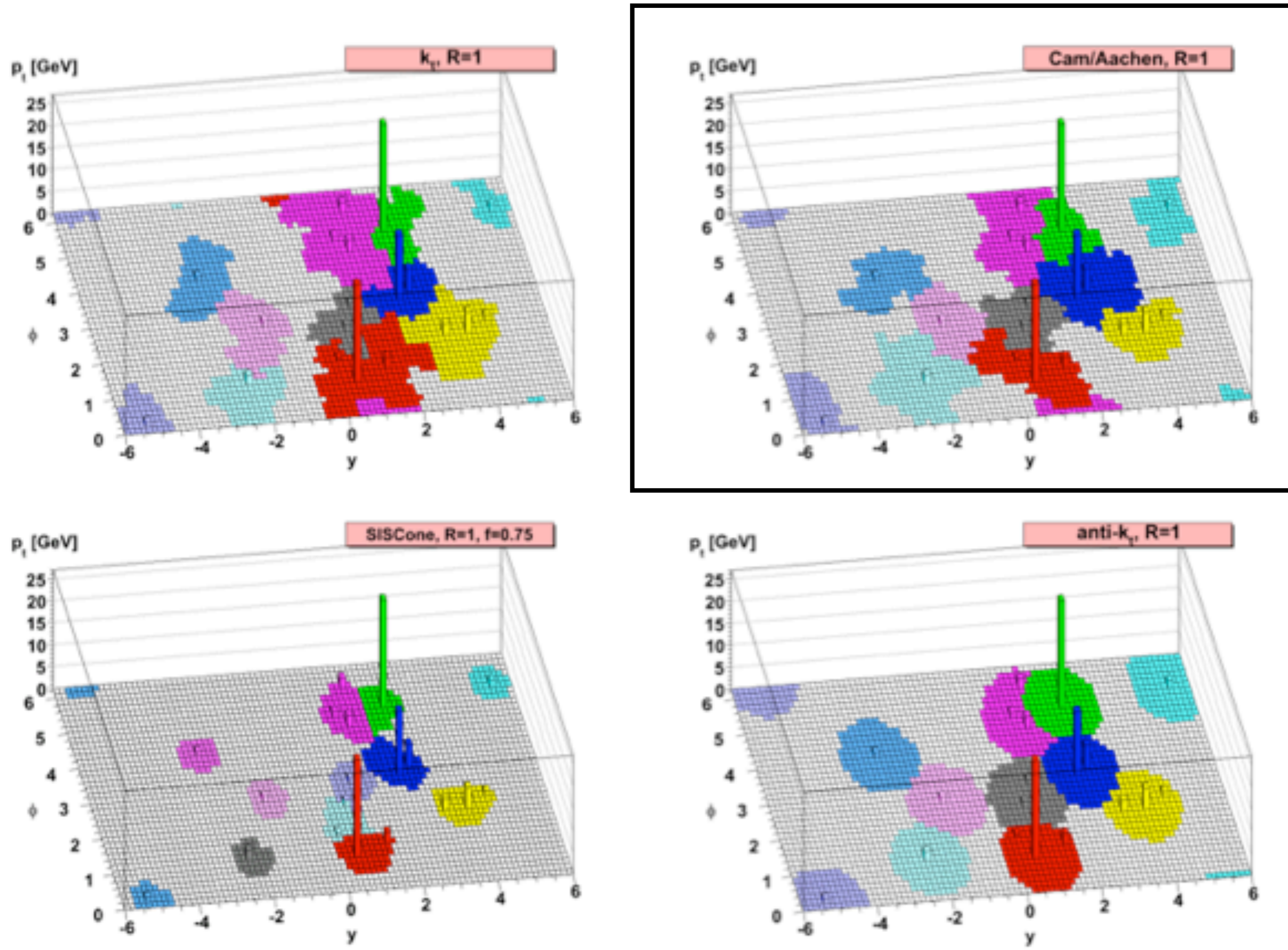

arXiv:0802.1189v2 [hep-ph]
Cacciari, Salam, Soyez

- Angular information only
- Good for finding substructure!

Jet reconstruction

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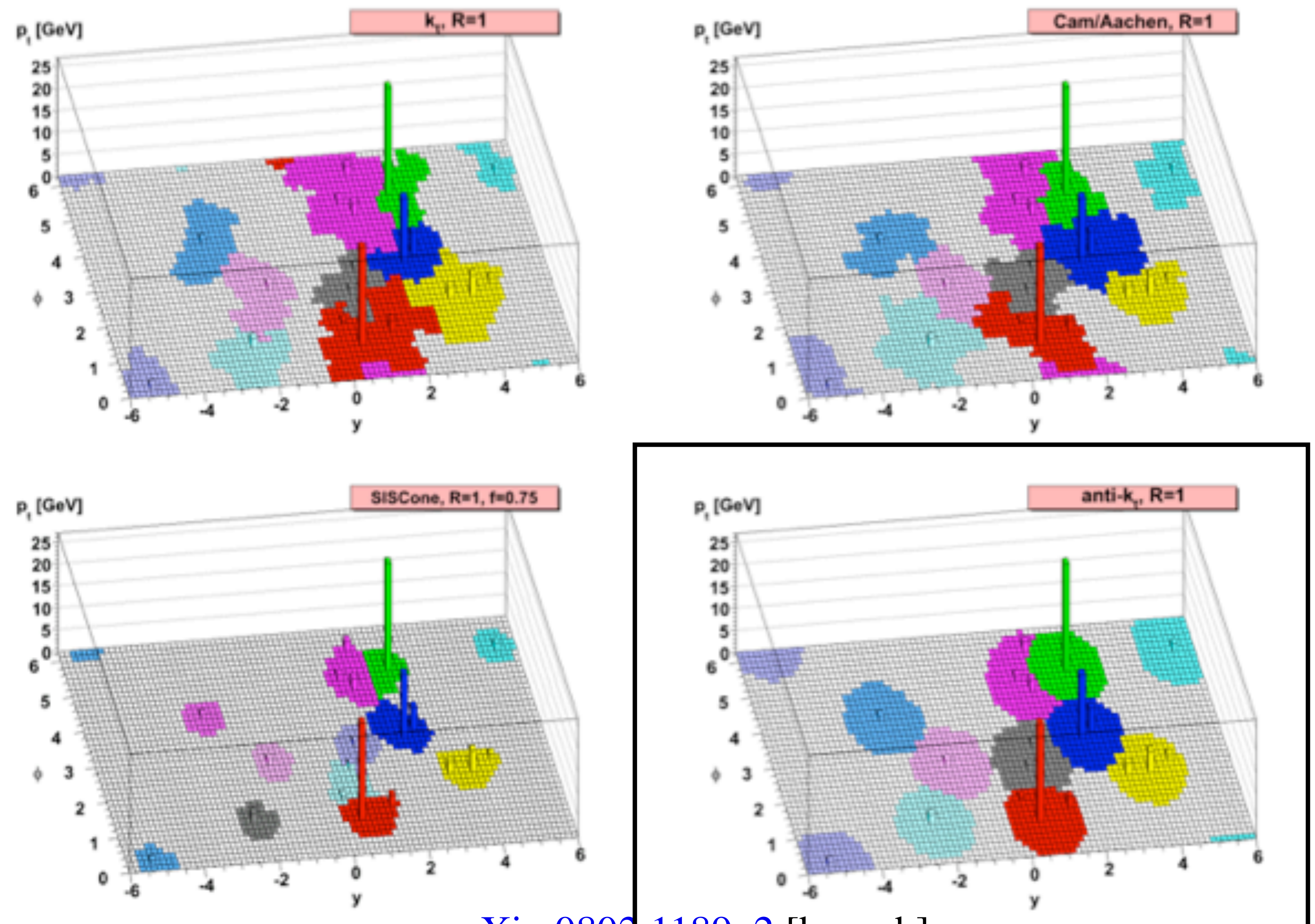


arXiv:0802.1189v2 [hep-ph]
Cacciari, Salam, Soyez

- Clusters hard particles first
- Idealized cone algorithm
- Best for jet counting

Jet reconstruction

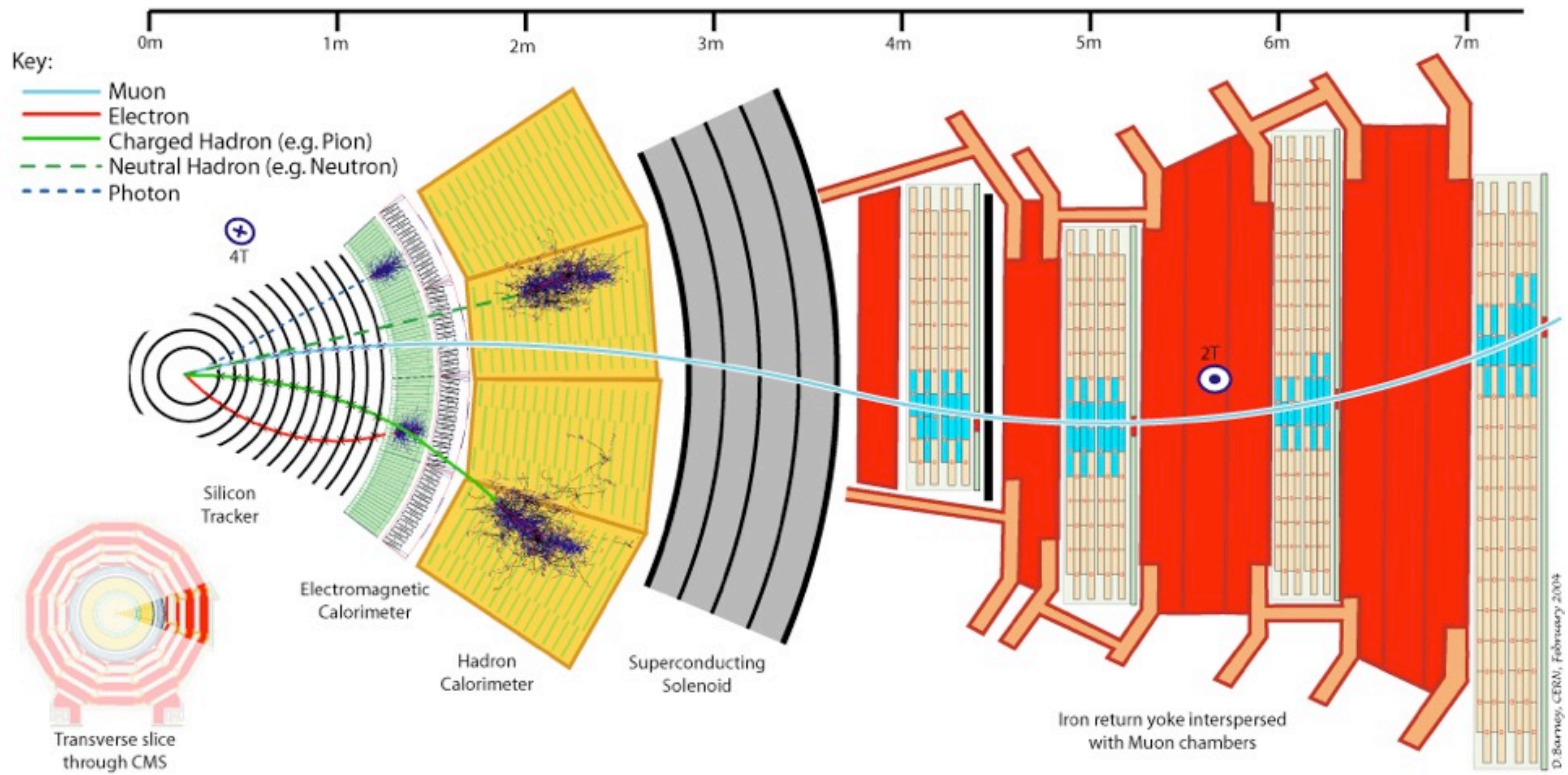
- For most analyses on CMS, use anti-kT jets
- Median-pt-per-unit-area in the event uses kT jets
  - Used for pileup computations
- For substructure, use CA jets
  - More later

Outline

- Jet reconstruction
- Particle flow
- Pileup mitigation
- Advanced techniques
- Trigger strategies
- Prospects

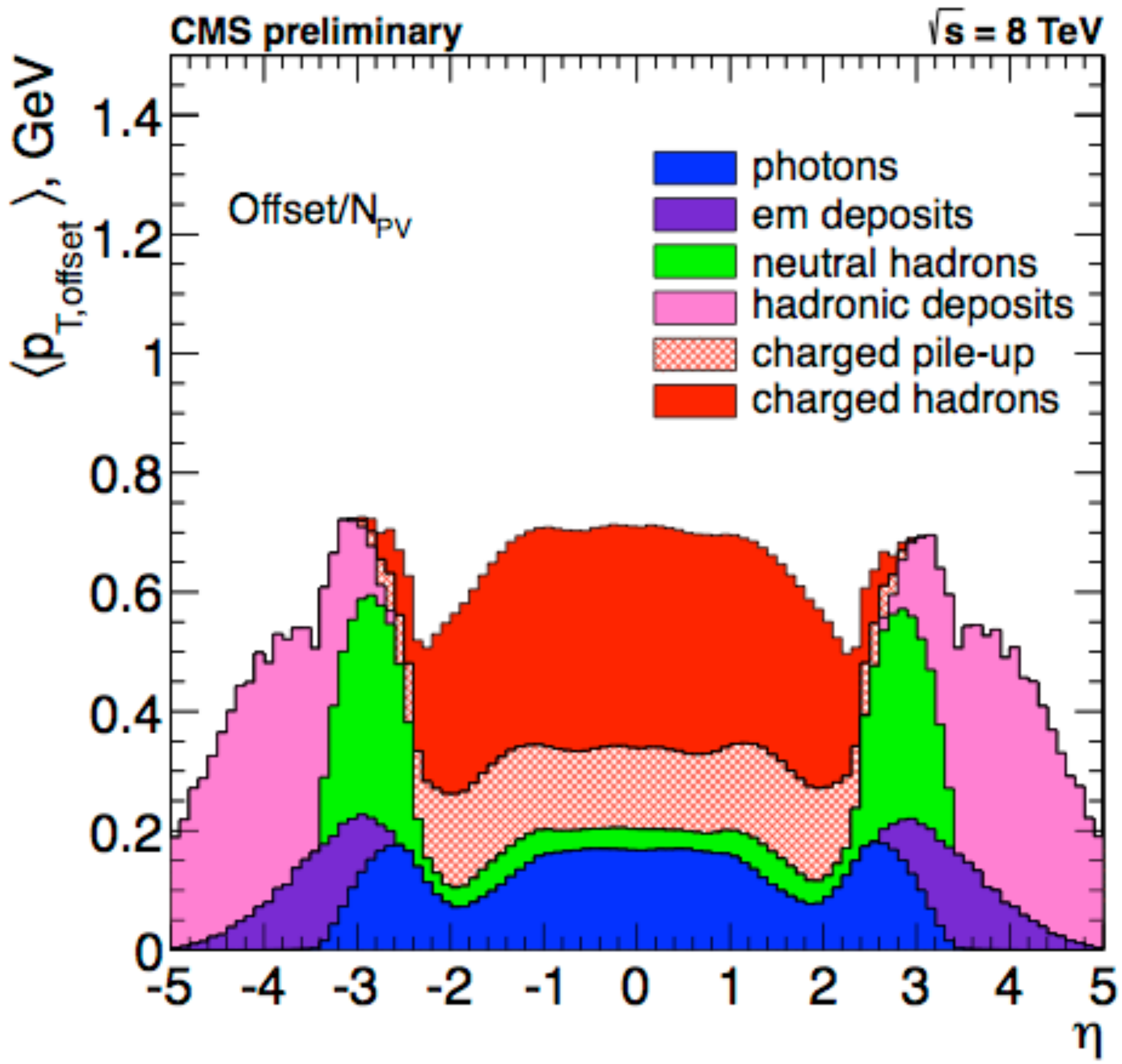
Particle Flow

Classify objects into 5 categories



"Holistic" approach to reconstruction at CMS: Particle flow!

- Simulation of PF composition of jets is astonishingly good!

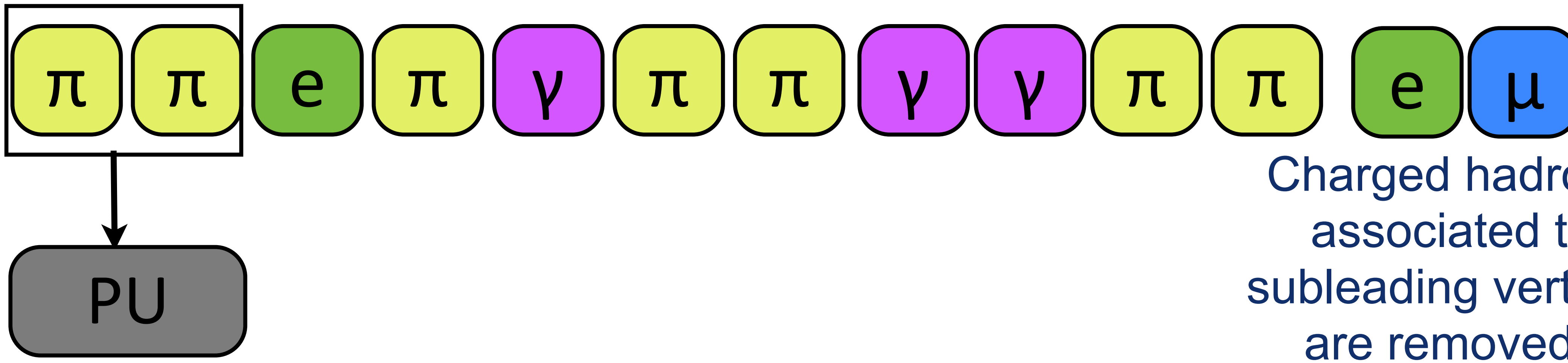


Particle Flow

π π e π γ π π γ γ π π e μ

- "Top Projections" : Identify objects sequentially
  - Each level is removed from previous

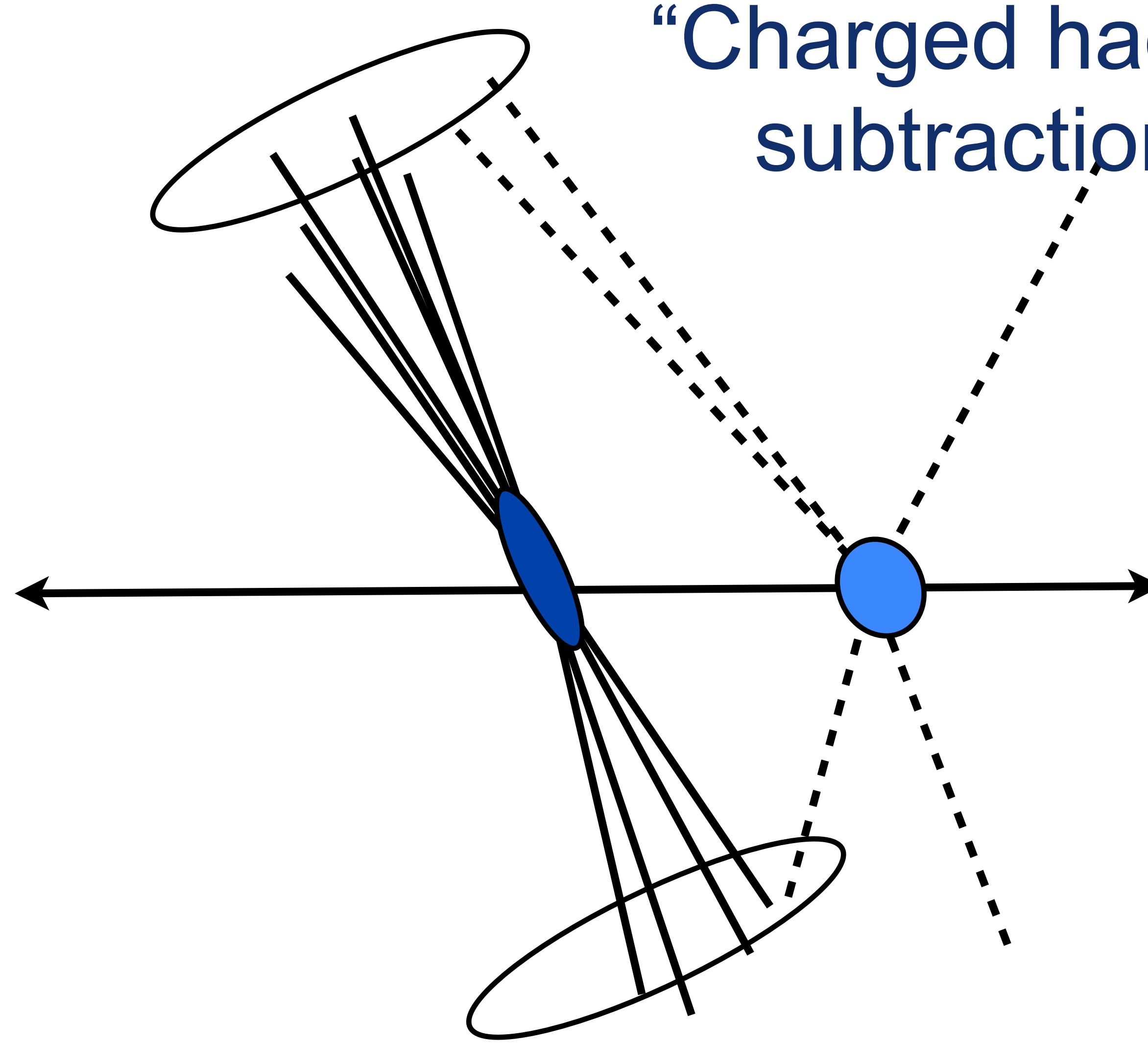
Particle Flow



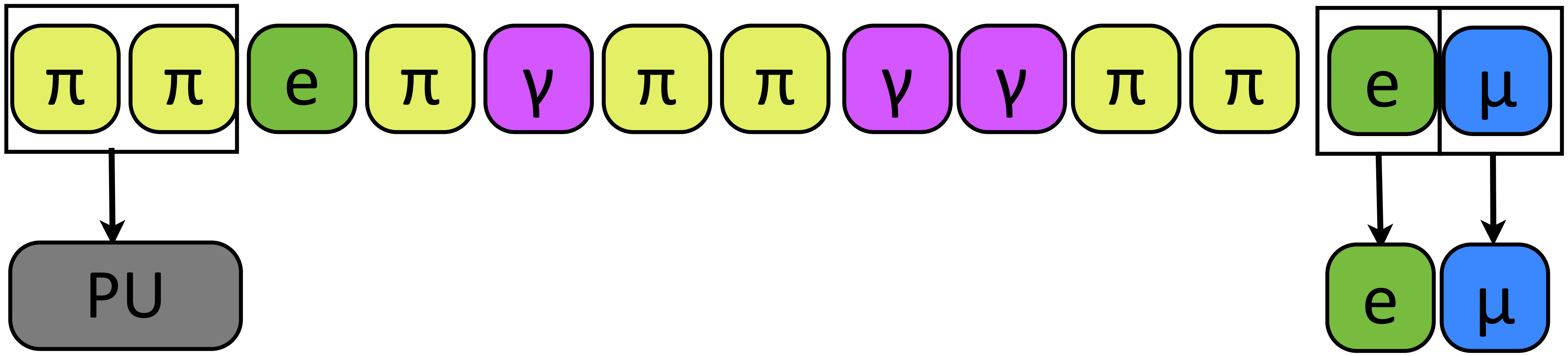
Charged hadrons associated to subleading vertices are removed :

“Charged hadron subtraction”

- “Top Projections” : Identify objects sequentially
  - Each level is removed from previous
  - Pileup is removed



Particle Flow



- “Top Projections” : Identify objects sequentially
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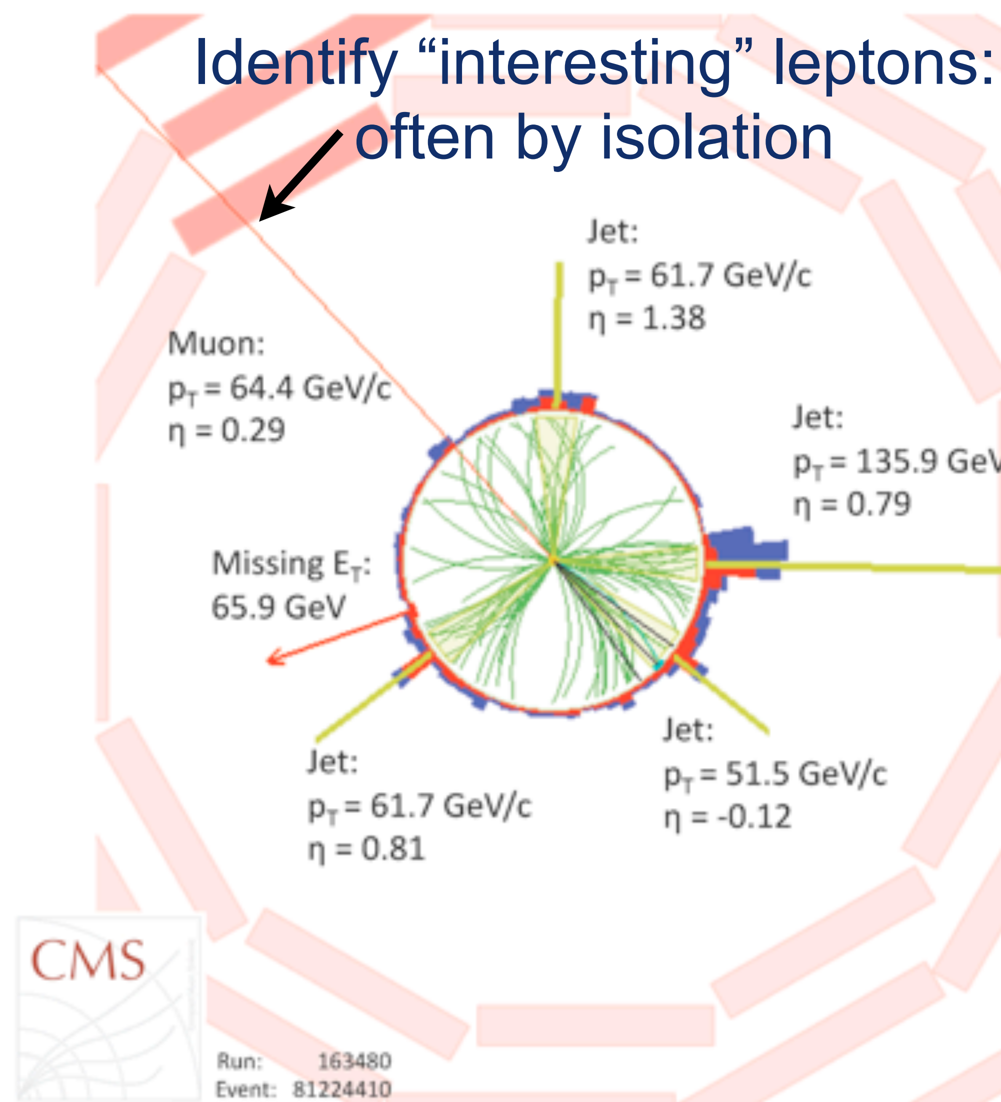
  - Leptons are identified



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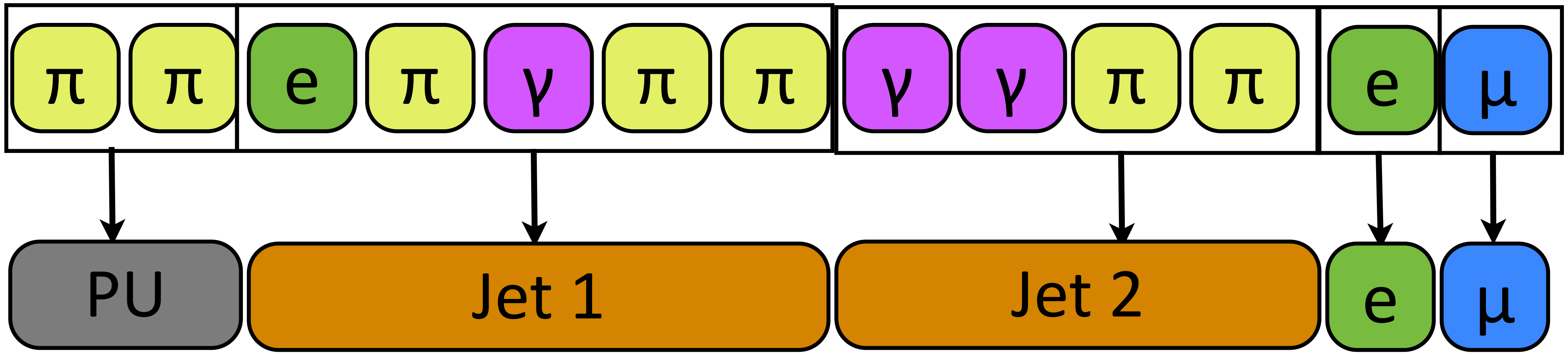

- "Top Projections" : Identify objects sequentially
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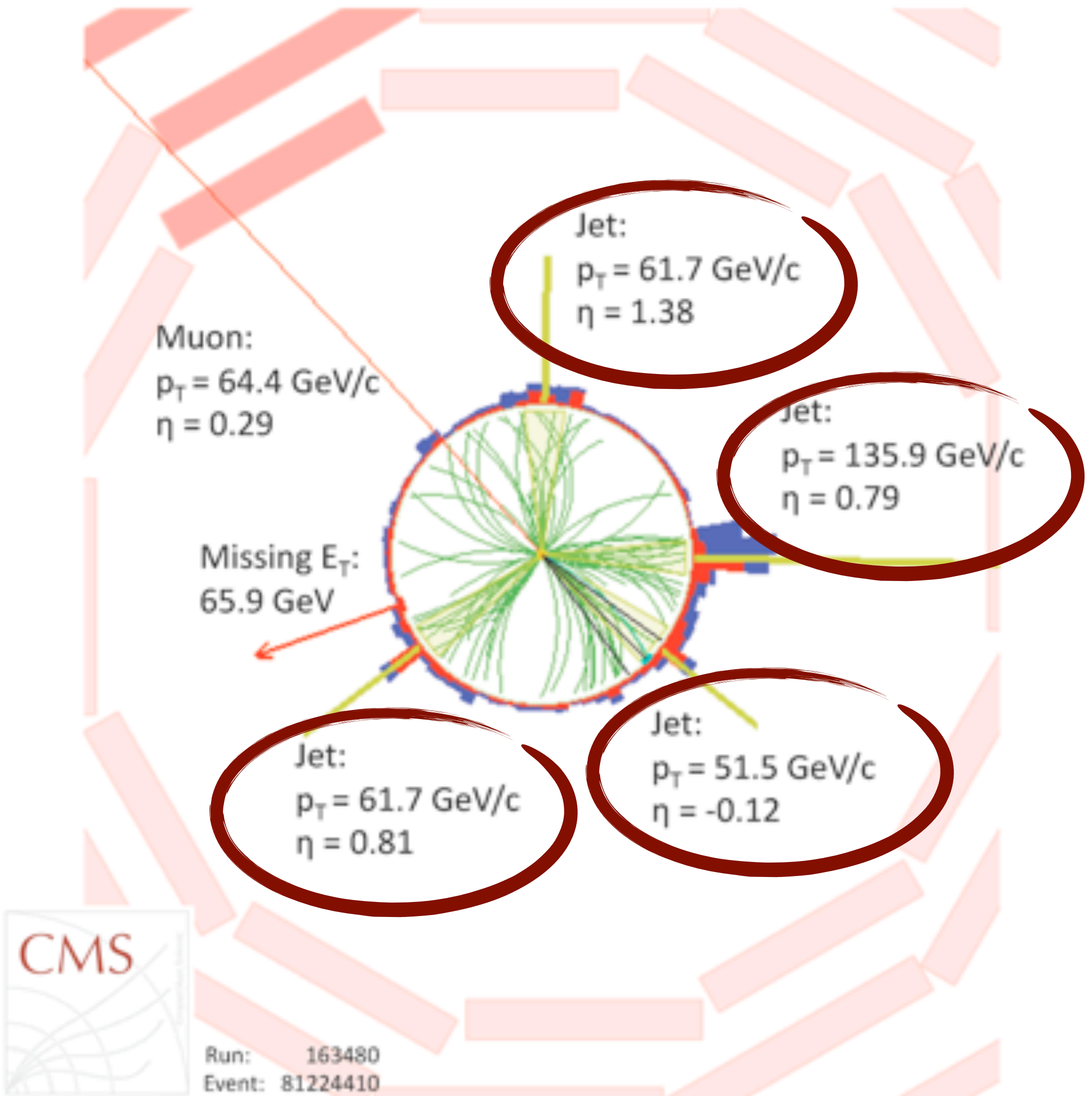
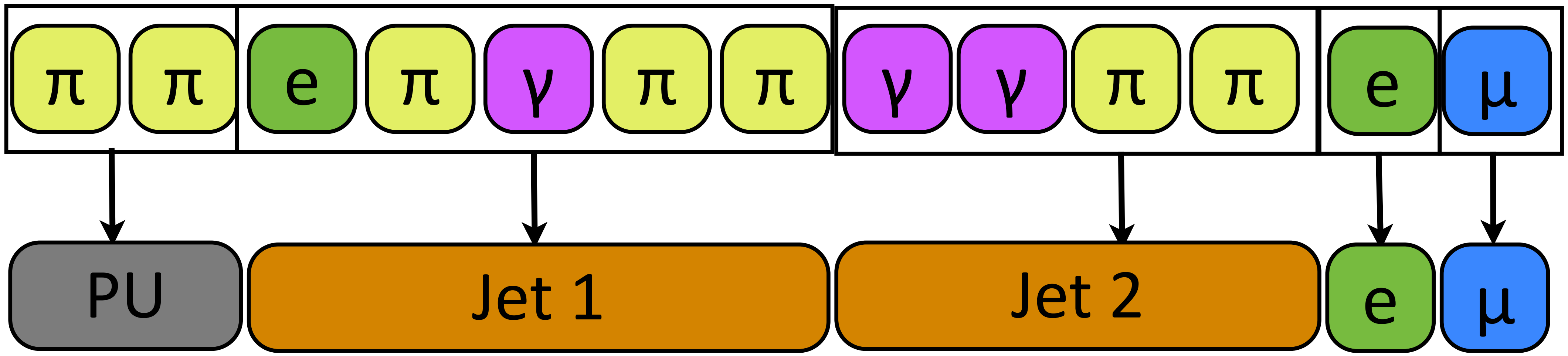
  - Jets reconstructed



Particle Flow



- "Top Projections" : Identify objects sequentially
  - Each level is removed from previous
  - Pileup is removed
  - Leptons are identified
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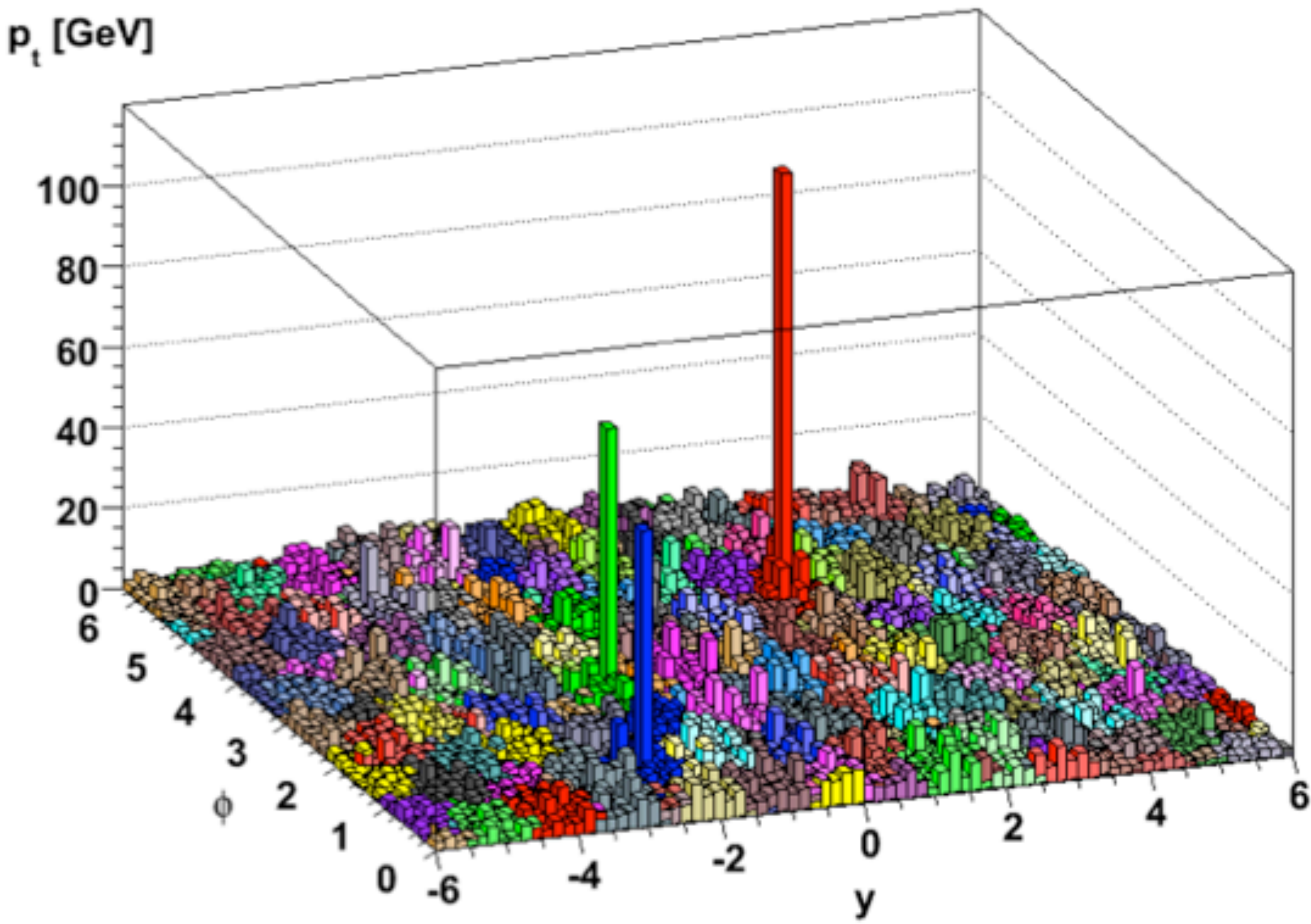
- What's in the jets?
  - Charged hadrons
  - Neutrals from pileup
  - Nonisolated leptons

Outline

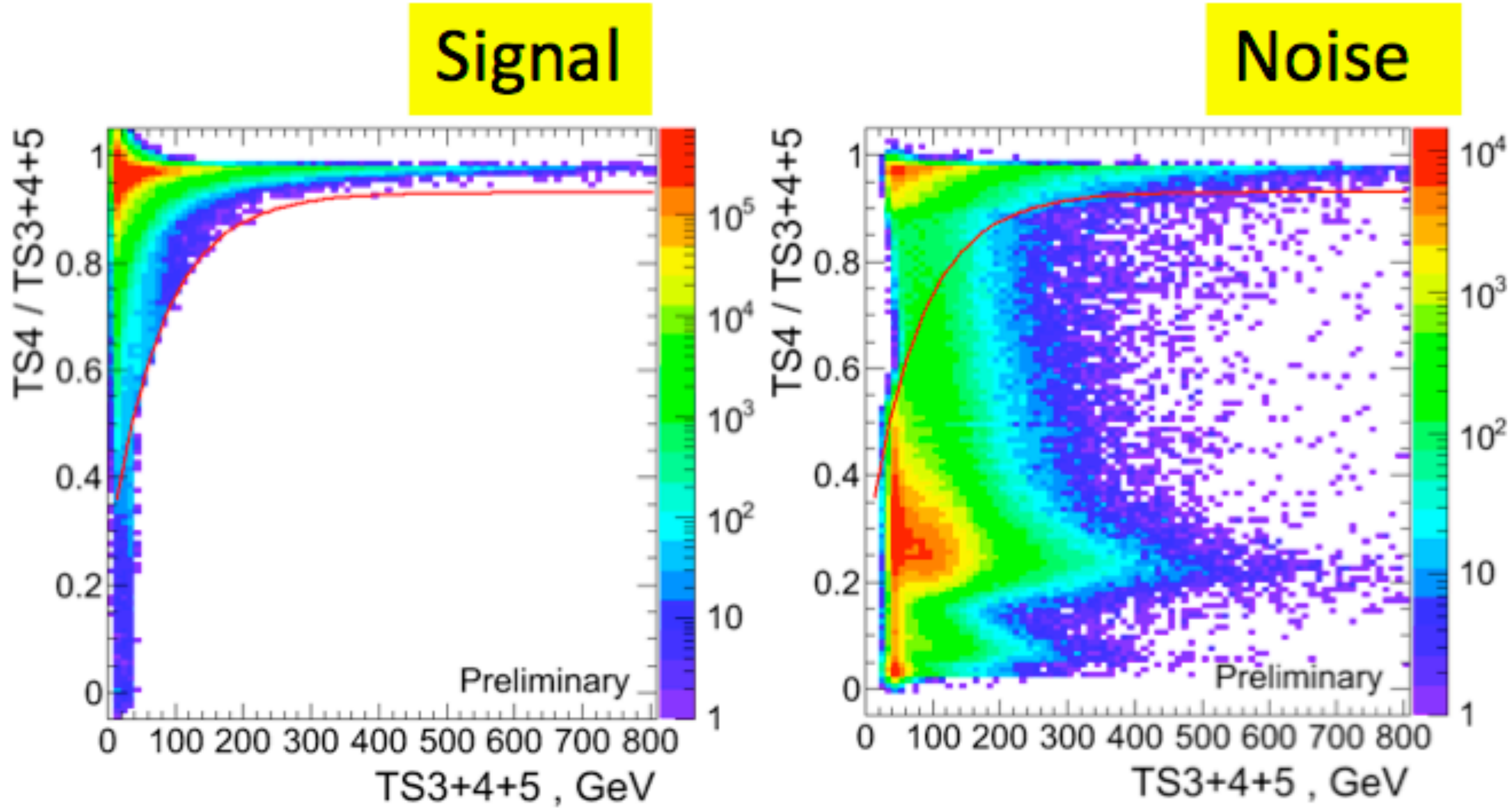
- Jet reconstruction
- Particle flow
- Pileup mitigation
- Advanced techniques
- Trigger strategies
- Prospects

- Falls into a few categories :
  - Explicit removal
  - "Average" corrections
  - Pileup jet ID
  - Advanced techniques

Image from Gavin Salam



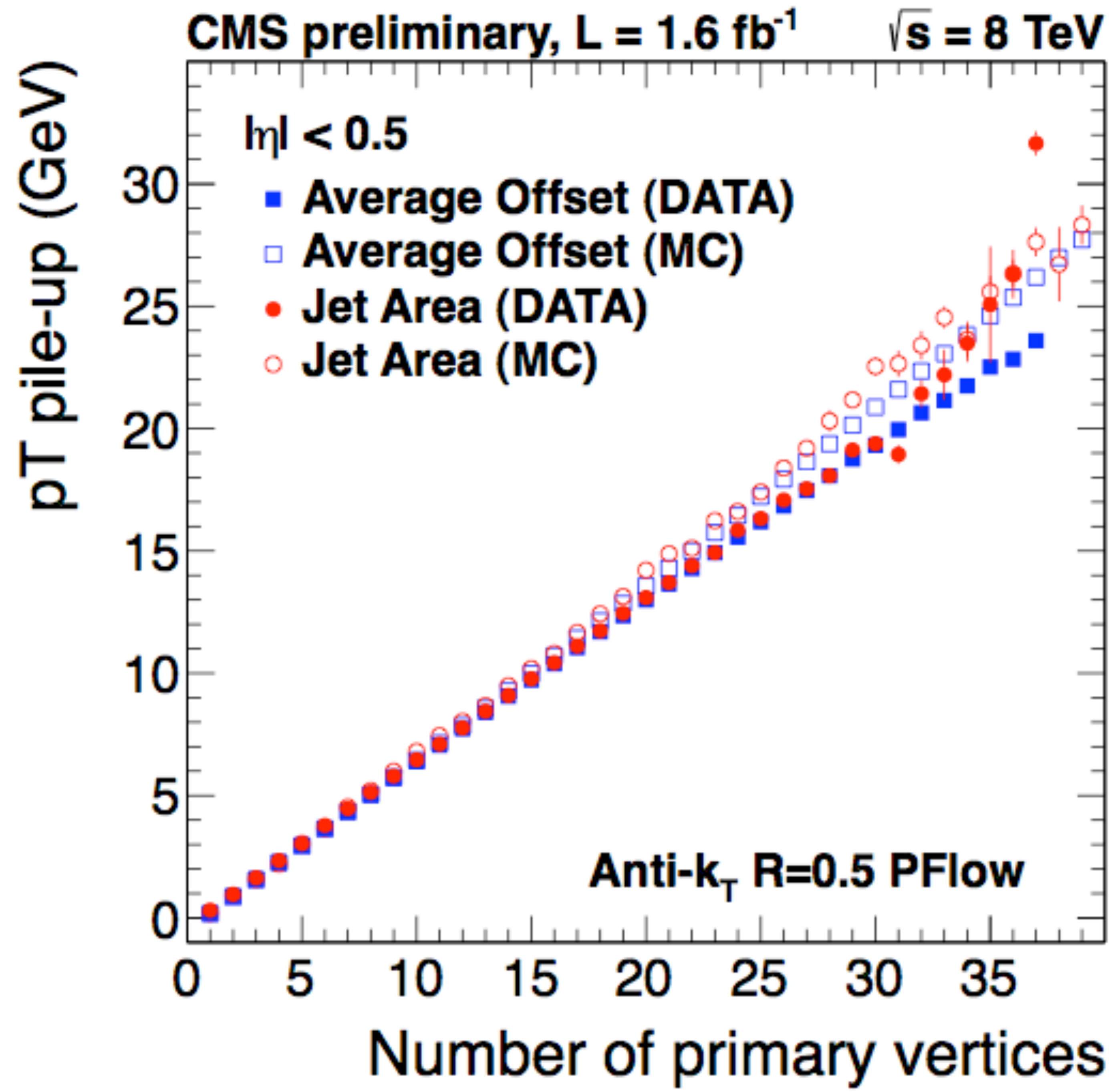
Pileup Mitigation



- Explicit removal:
  - Timing selections on HCAL and ECAL signals
    - Especially useful for out-of-time pileup
  - PF CHS and other PF techniques
    - Especially useful for in-time pileup, but only for charged hadrons so far!

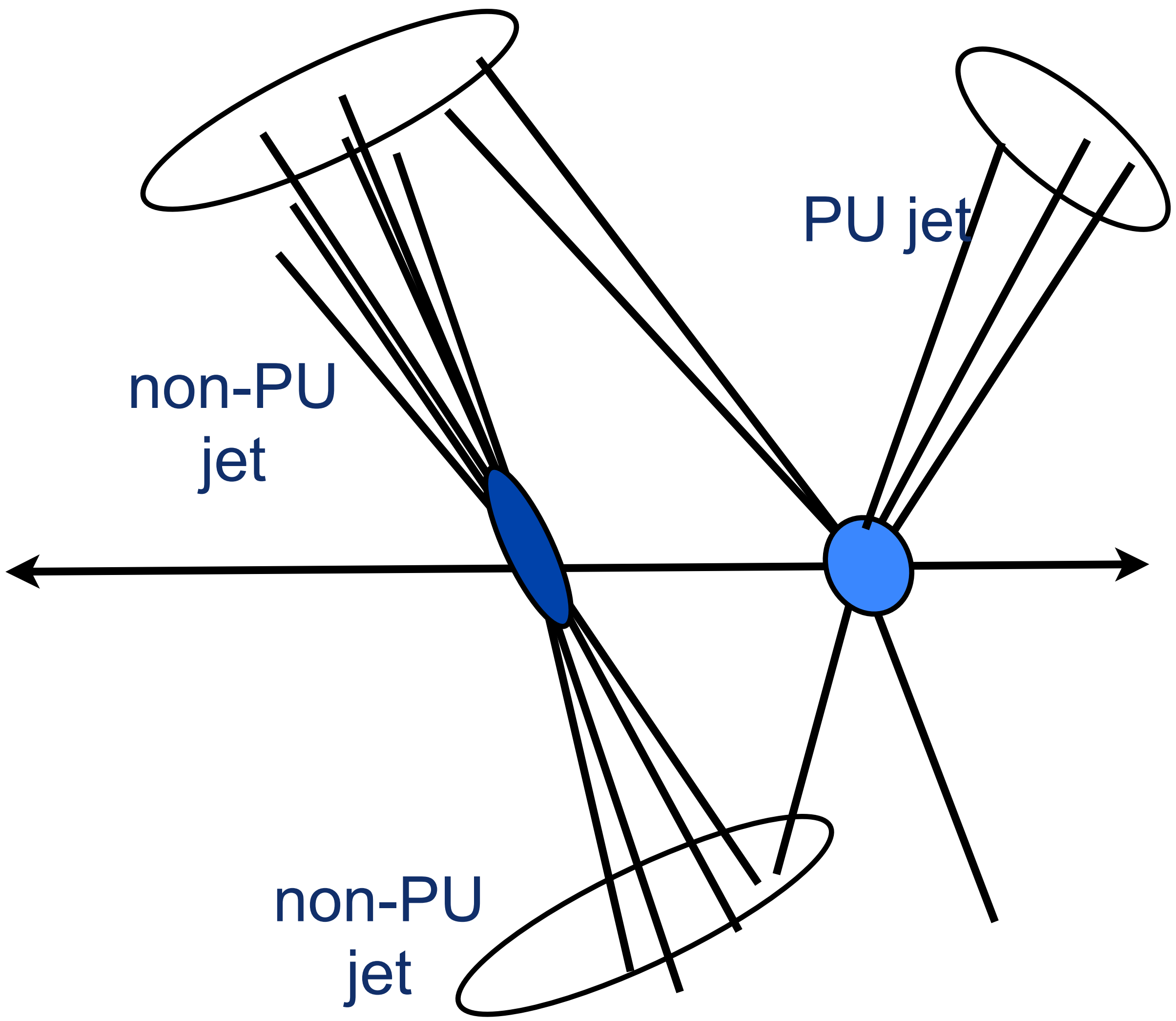
Pileup Mitigation

- Average corrections:
  - Offset correction :
    - Use minimum-bias data
    - Subtract linear amount of pileup per PV
  - Area correction :
    - Subtract median-pt-per-unit-area times area of the jet



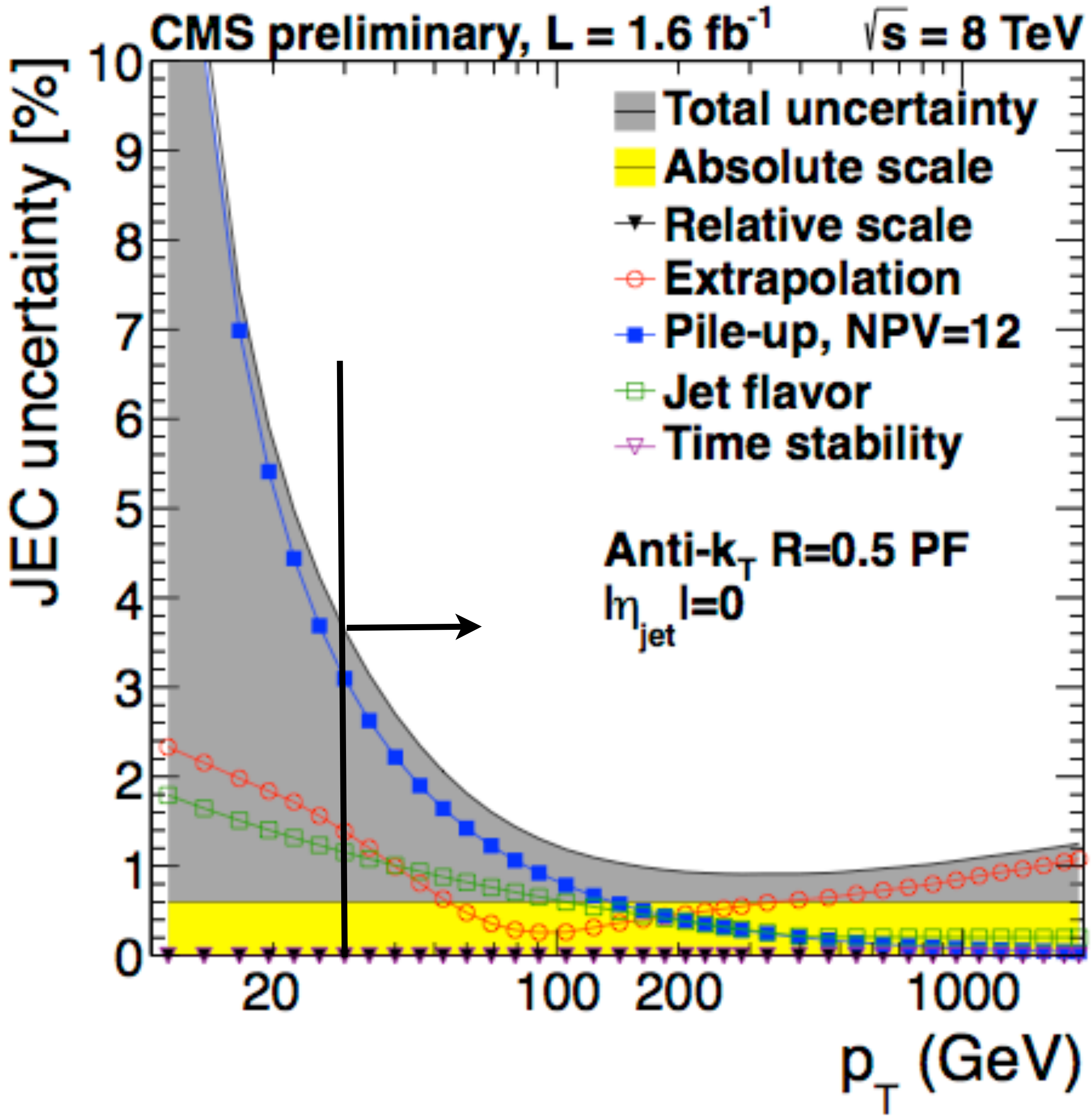
Pileup Mitigation

- Pileup jet ID
  - Beta* correction
    - Ratio of energy from leading PV to other PV's
    - Essentially similar to CHS, but removes at per-jet level, rather than constituent level
    - Similar performance against pileup on average, but no improvement to jet energy resolution
  - Shape information
    - Number of constituents, energy weight, etc
    - Can be used outside of tracker volume!



State-of-the-art PFJets

- Uncertainty on JES is ~1-4% depending on pt
- Pileup uncertainties dominate at low pt, but at high pt, no catastrophic problems



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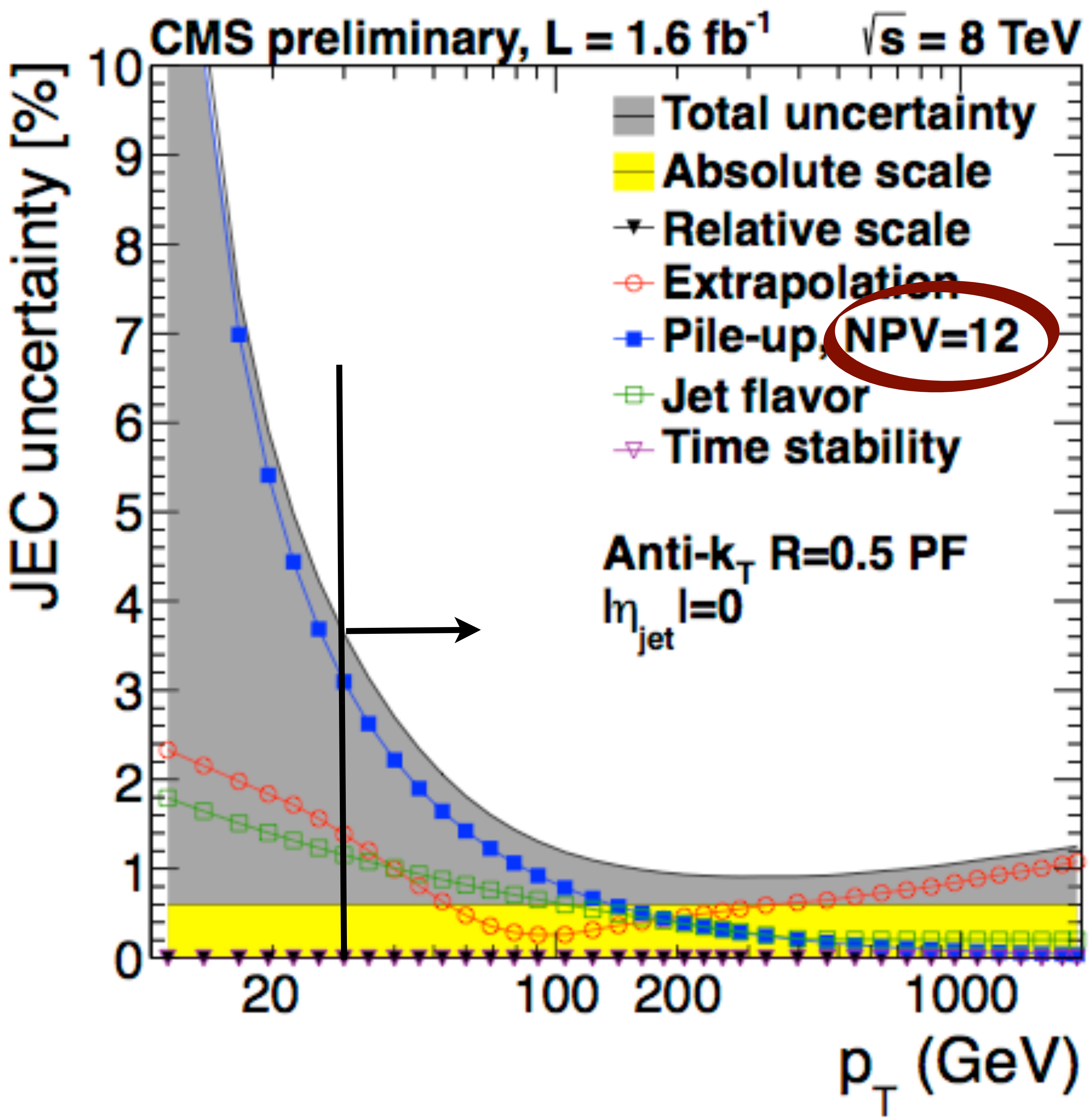
YET.



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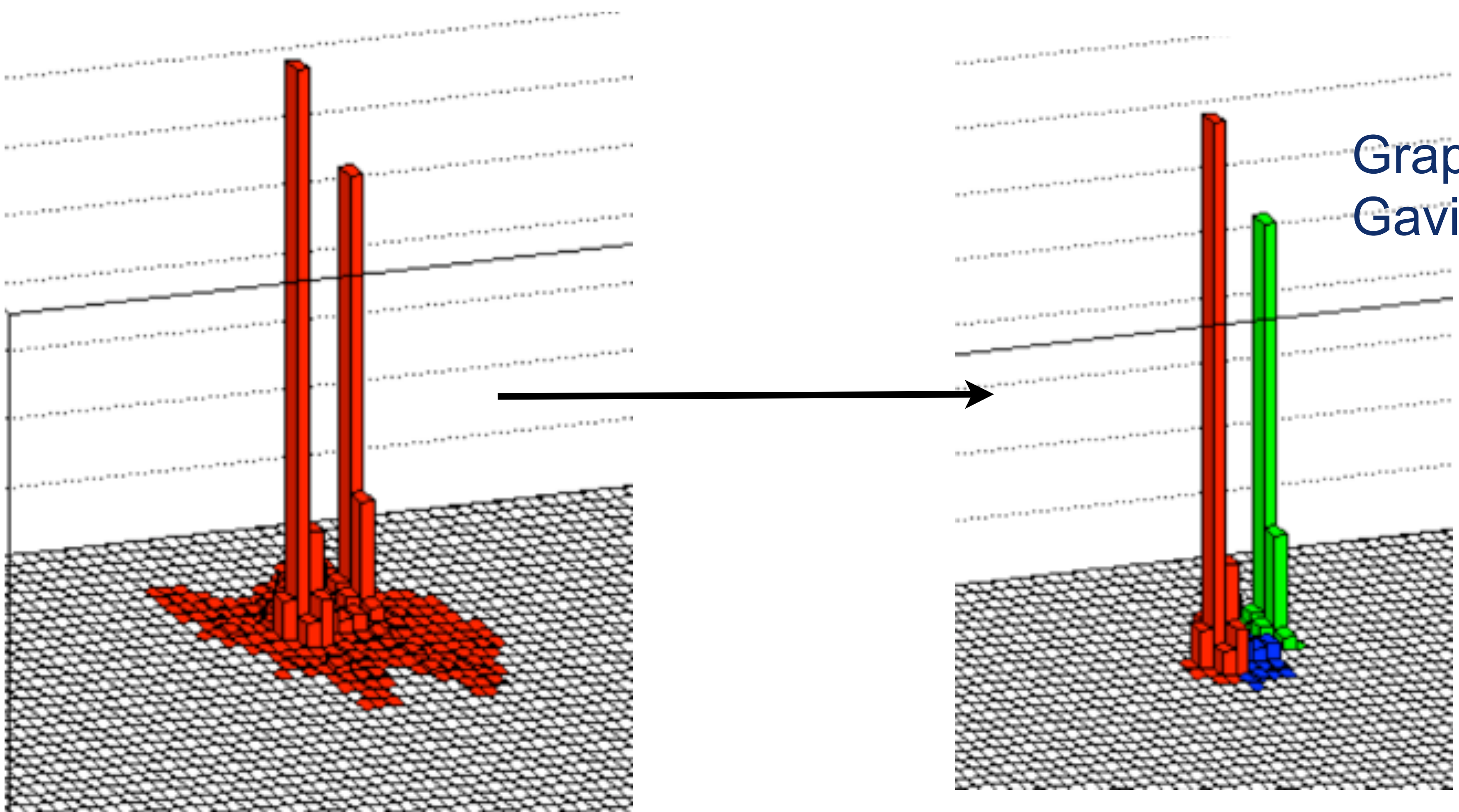
Advanced pileup techniques

- In the future, we may be faced with even higher pileup than we have now
- What other techniques are out there to deal with this?
- Hot topic: Jet grooming!
  - e.g. BOOST2012 in Valencia, last week
  - http://ific.uv.es/~boost2012/

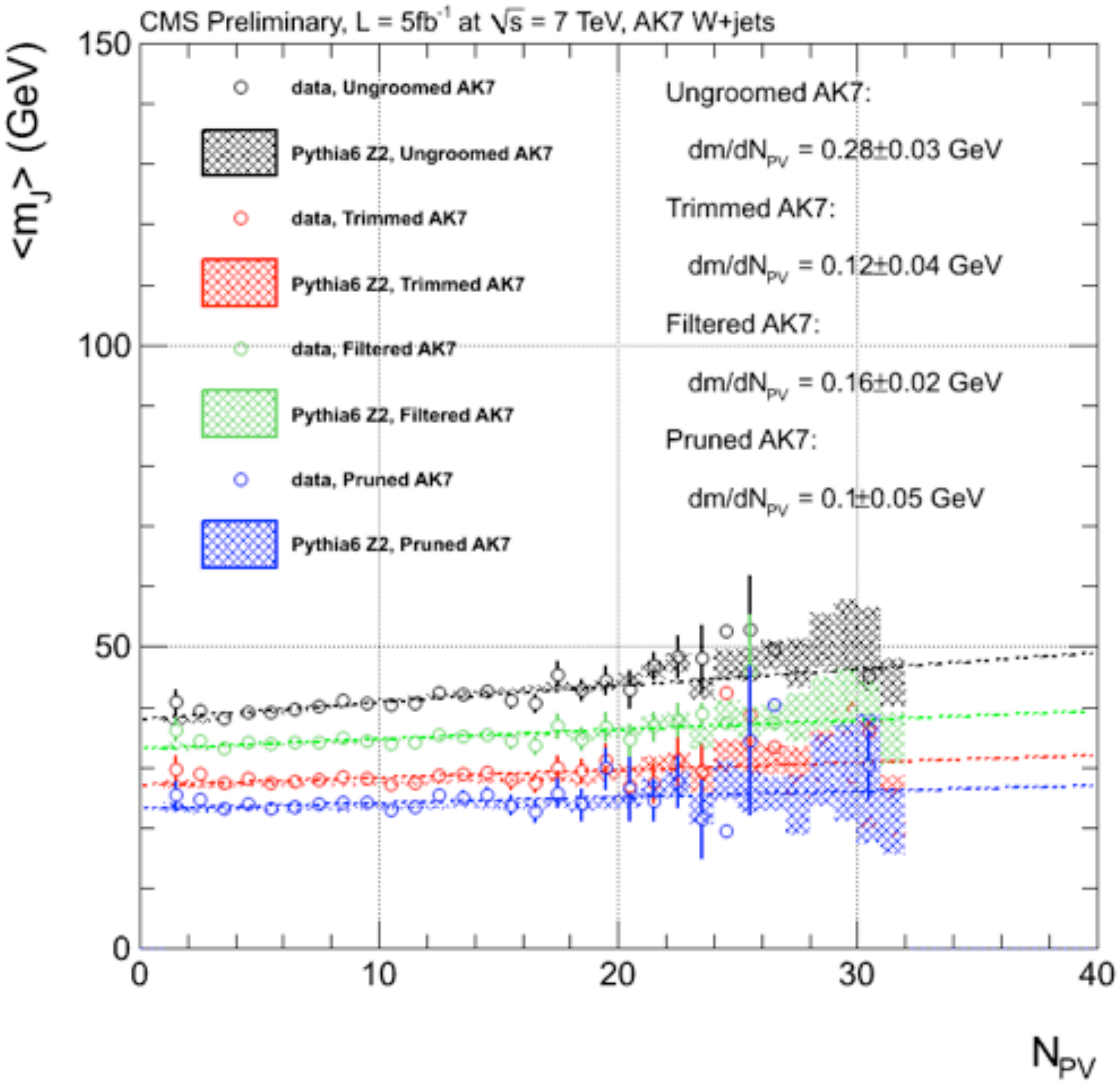
Cambridge/Aachen jet algorithm used extensively for substructure!



Graphic from Gavin Salam

Advanced pileup techniques

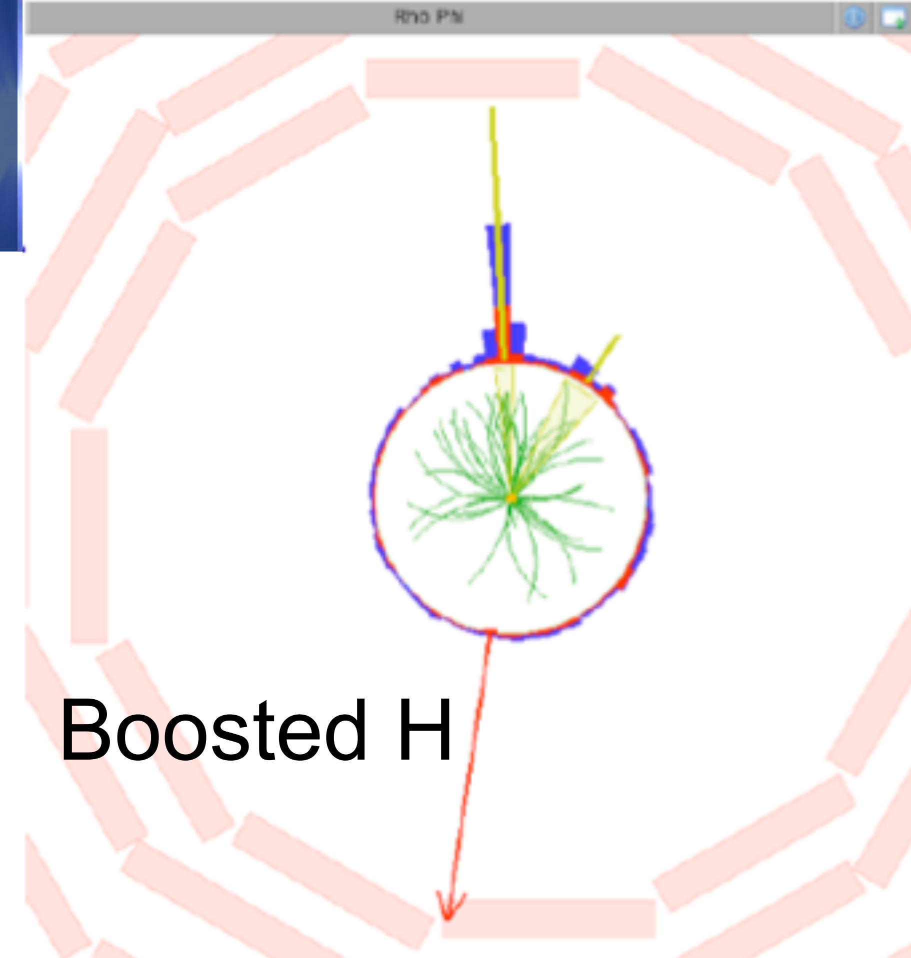
- Different flavors of doing this:
  - Filtering : Butterworth, Davison, Rubin, Salam
    - http://arxiv.org/abs/0802.2470
  - Trimming : Krohn, Thaler, Wang
    - http://arxiv.org/abs/0912.1342
  - Pruning : Ellis, Walsh, Vermilion
    - http://arxiv.org/abs/0903.5081

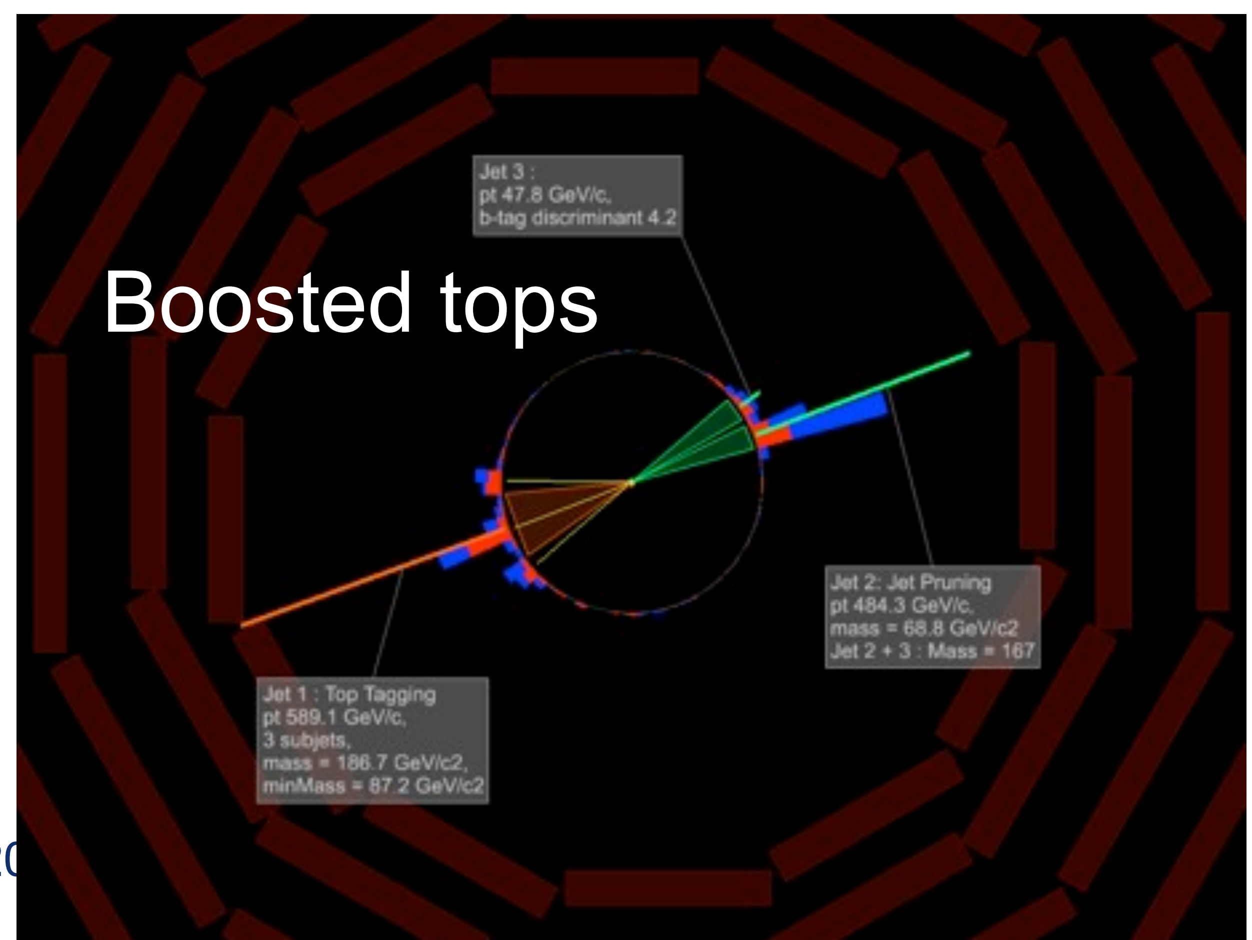


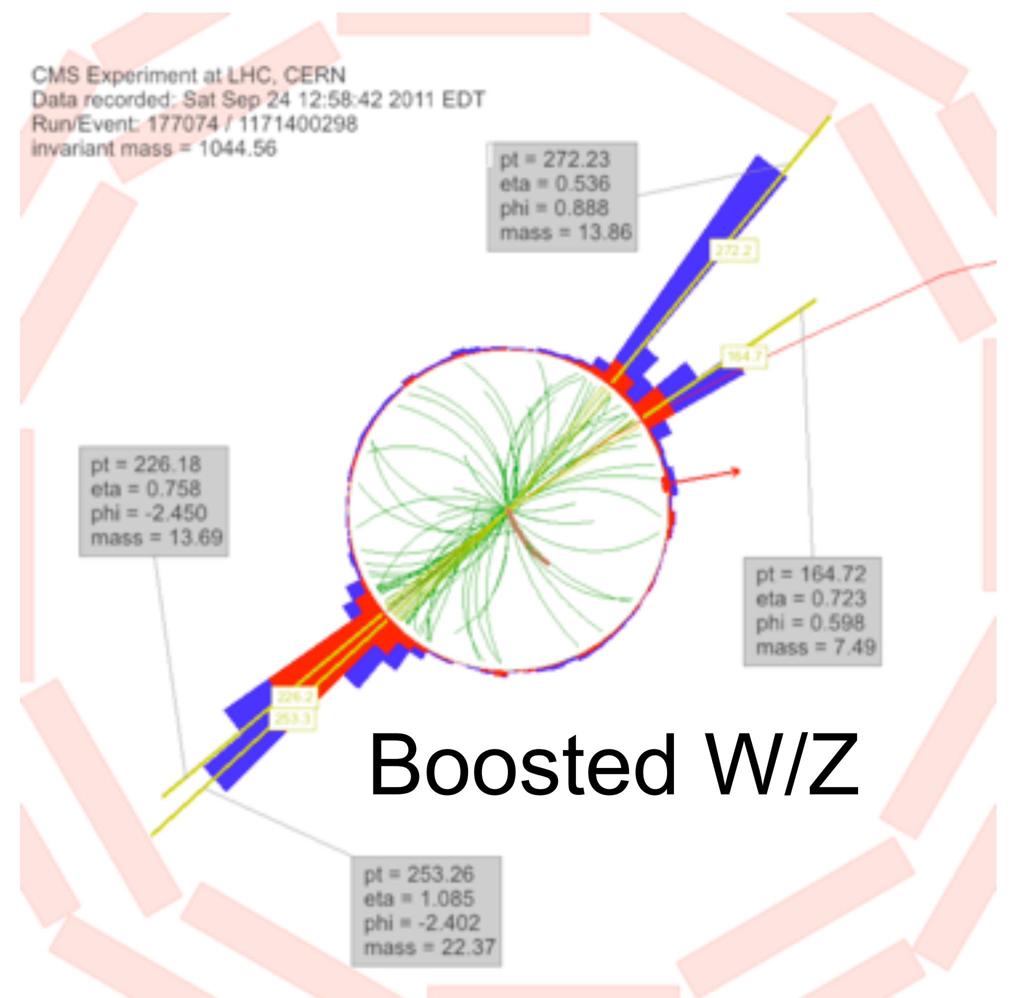
Significantly reduced pileup dependence!

Boosted jets

- Heavy resonances to top, W, Z, Higgs all result in boosted topologies
- Also can help in S/B in "non-boosted" final states (Higgs analyses make significant use of this)







Boosted jets

- This kind of analysis is still in infancy
- A handful of analyses are mindful of this regime
  - Several Higgs analyses
  - ttbar (all-hadronic, semileptonic)
  - VV (all-hadronic, jet+MET, jet+dilepton)
  - boosted Z (dilepton)
  - More to come, but much more possible!
- Most other analyses assume “resolved” kinematic structure
  - This puts an UPPPER CUT on the mass of the particle you’re looking at!
- Boosted techniques need much more deployment!
  - Could have new physics hidden “in plain sight” even available for 7 TeV data, but we just aren’t sensitive because we’re not looking!

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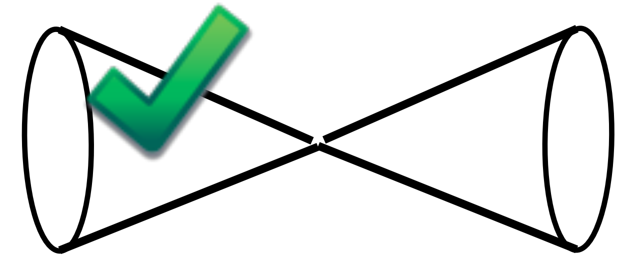
Trigger Strategies

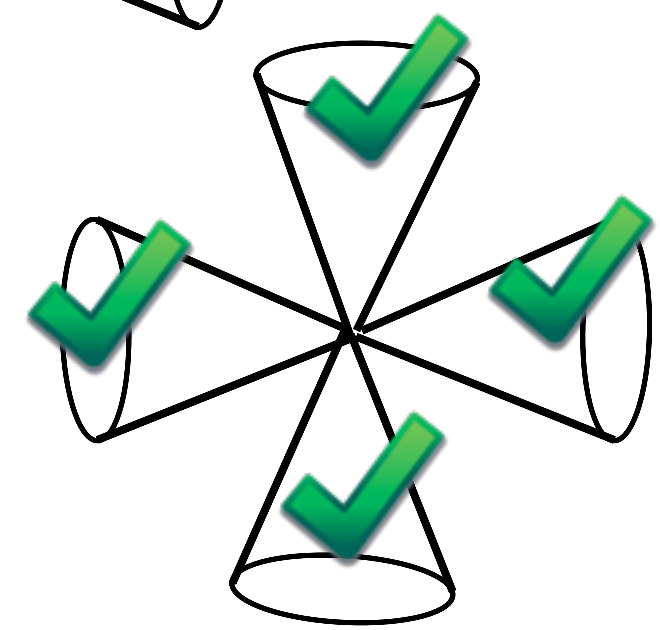
- Caveat:
  - Many of our triggers are tailor-made per analysis
    - Very efficient for a single analysis, not very useful for others
    - Examples: H->bb, alpha_T, Razor, etc
  - I'm not necessarily familiar with all of them
  - I'll go over the broad overview of what I am familiar with instead

Trigger Strategies

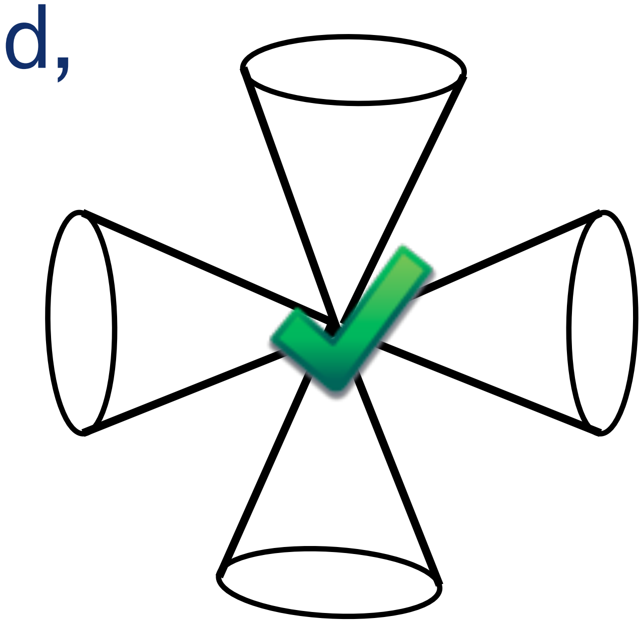
- Single-jet triggers
  - e.g. 1 PFJet, pt > 400 GeV



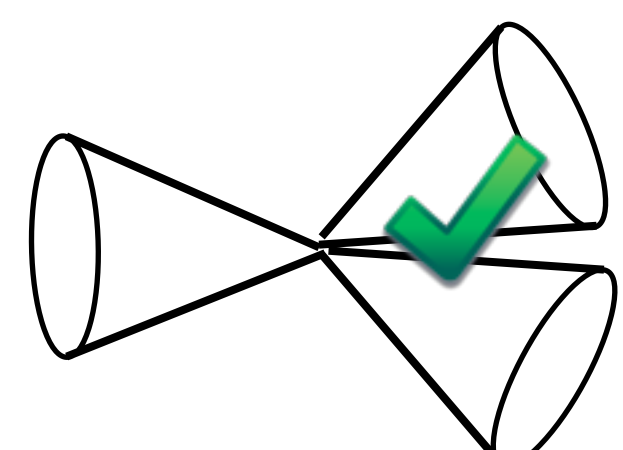
- Multiple-jet triggers
  - e.g. 4 PFJets, 1 b-tagged, pt > 82, 65, 48, 35



- HT triggers
  - e.g. HT > 750 GeV



- Topological triggers
  - e.g. “wide jet” pt > 750



Trigger Strategies

- Two problems with hadronic triggers recently:
  - Turn-on of efficiency of PFJets (offline) wrt Calo-only Jets (online)
  - Rates increasing with pileup

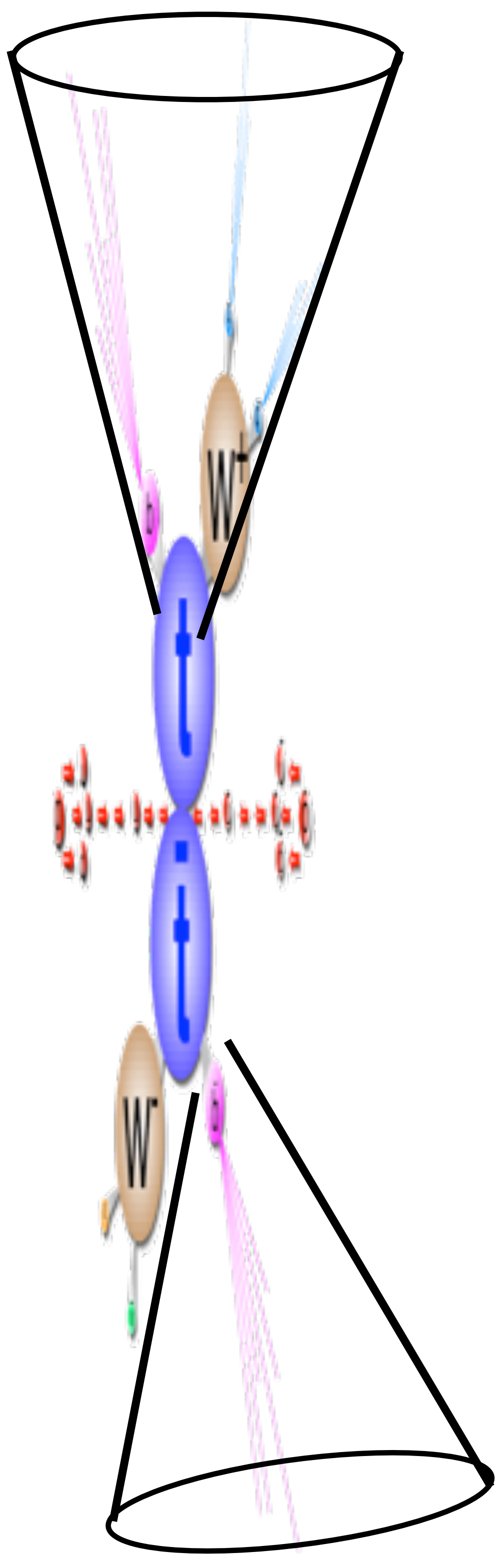
- Solutions:
  - Development of fast tracking at HLT : can use PFJets at trigger level!
    - Turn-on of efficiency sharper
  - Introduce “area” correction, and use PF CHS at trigger level
    - Flattens rates with pileup

Nothing approved
to show, unfortunately

Trigger Strategies

- New physics needs new strategies

- Example:
  - "Semileptonic top sample" usually means "lepton + >= 3 jets"… reasonable, right?
  - This removes the most interesting part of the sample. At trigger level. Forever.
    - Luckily, so far we can survive with single-lepton triggers, but for how long will this last?
    - Will we need to "park" the most interesting parts of the sample here?
  - Maybe not so lucky with things we're not paying attention to!



Trigger Strategies

- What keeps me up at night: what if we've missed the new physics at the trigger level because we've designed triggers without accounting for "easily accessible" new physics?

Outline

- Jet reconstruction
- Particle flow
- Pileup mitigation
- Advanced techniques
- Trigger strategies
- Prospects

Prospects

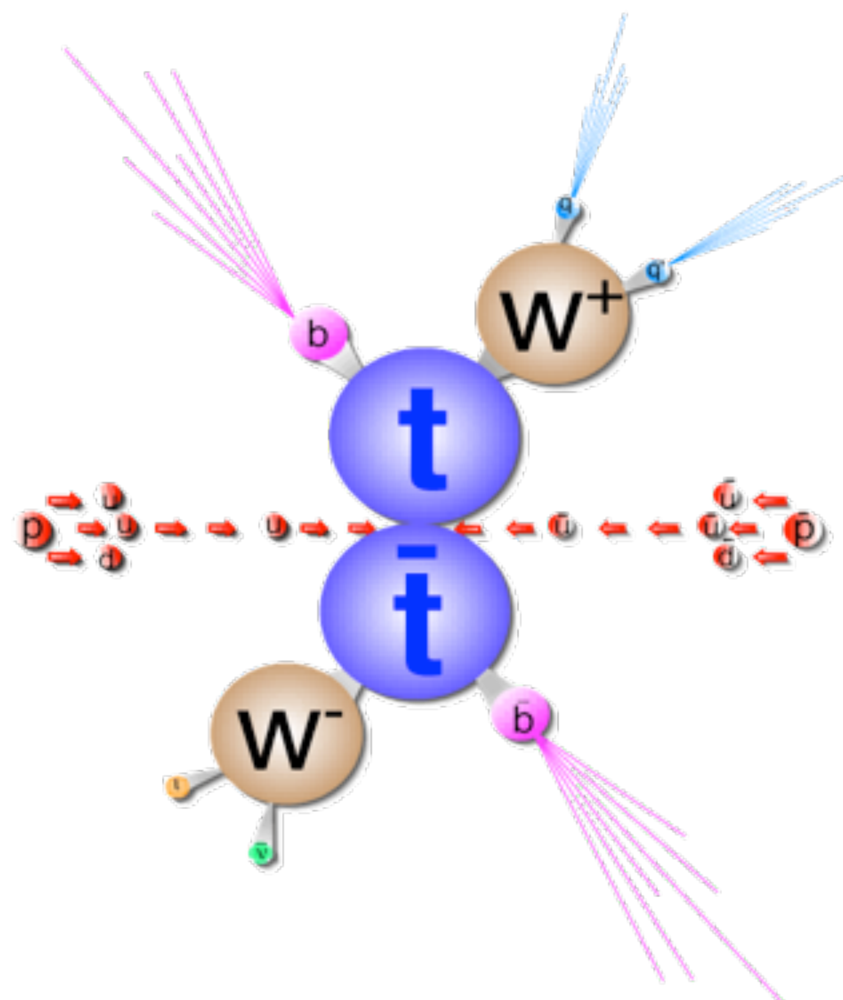
- Summary of the hadronic program for the last few years: “So far, so good”
- This is due to huge amounts of effort on the part of many people at CMS
- Constant, difficult war against pileup. We’re winning. So far.
- Lots of new jet tools available
- We’re in a new physics regime, be mindful of the possible invalidity of previous assumptions about kinematics!

Many thanks to the PI for the wonderful opportunity!

Backup

Boosted jets

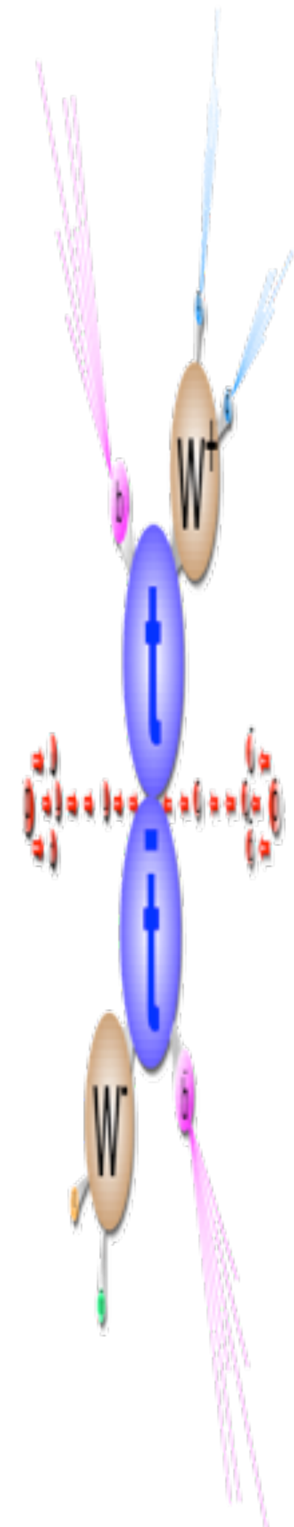
- Let's go back to our "N" partons to "M" jets mapping



Boosted jets

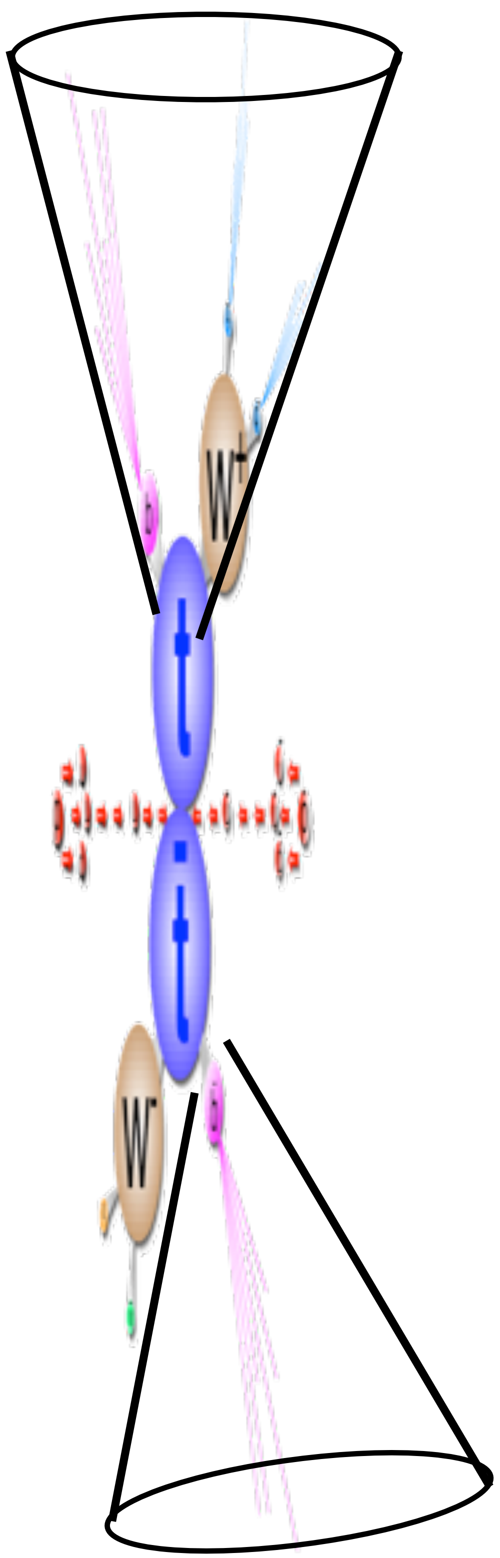
- Let's go back to our "N" partons to "M" jets mapping

- What if it looks like this?



Boosted jets

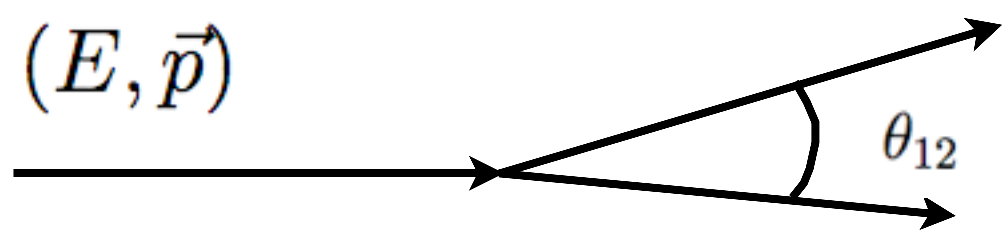
- Let's go back to our "N" partons to "M" jets mapping
- What if it looks like this?
- Try to cluster with fixed-size jets, and you don't recover "N" partons!
- Does this really happen often?



Boosted jets

- Simple two-body decay kinematics
- Assume massless decay products

$$p^\mu = (E, \vec{p})$$



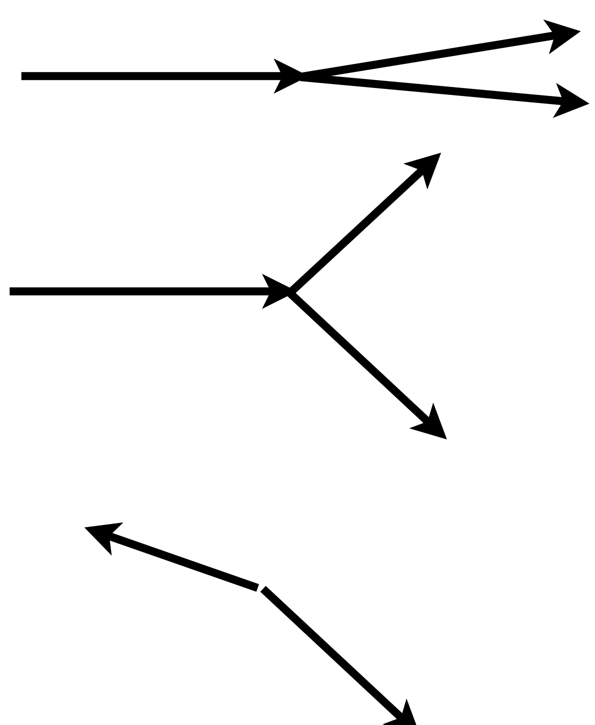
$$p_1^\mu = (E_1, \vec{p_1})$$

$$p_2^\mu = (E_2, \vec{p_2})$$

- Assume E1 ~ E2

$$\begin{aligned} m^2 &\approx E^2(1 - \cos(\theta_{12})) \\ \cos(\theta_{12}) &\approx 1 - \frac{m^2}{E^2} \end{aligned}$$

$$\begin{aligned} m/E &\rightarrow 0 \\ m/E &\rightarrow 1 \\ m/E &\rightarrow \infty \end{aligned}$$



Trigger Strategies

- Example 2:
  - "W + 1 jet" sample
  - Previous strategy would have been prescaled in late 2011
  - Explicit awareness allowed us to save this data!