Status of PFA in SiD

Mat Charles
U. Iowa

Overview

- What are the goals?
- PFA implementations
- Current performance (mostly sid01)
- Use in benchmarking & analysis
- Planning for the LOI

What are the goals?

- Most critical: Demonstrate acceptable physics performance for LOI
  - Without this we are dead in the water
  - Not the end, though: Algorithms will continue to improve post-LOI
- Give guidance on detector design choices
  - Input given on some sid02 decisions (e.g. HCAL depth)
  - Now is not the time to start another round of detailed optimization!
  - ... but post-LOI we may want to think again.

What are the goals?

- So what is "acceptable physics performance"?
- The real answer will come from benchmark analyses.
  - ... including jet-finding, jet flavour ID, PID, efficiency, etc etc etc
  - Both absolute performance & performance relative to ILD/4th matter
- We use some PFA-centric tests as a prerequisite:
  - Look for dijet mass resolution of 3-4% (comparable to Γ for W, Z)
    - Want $\Delta M_Z/M_Z$ ~ 3-4% for dijet mass residuals in $e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV (q=u,d,s)
    - Want $\Delta E_{CM}/E_{CM}$ ~ 3-4% for $e^+e^- \rightarrow qq$ (q=u,d,s)
- This is not the physics -- this is what you need before it makes sense to try and do the physics.

PFA implementations

- Pandora
  - See Marcel's talk.
  - Caveat: We can run Pandora on "SIDish" but we can't run it on SiD.
- Steve's PFA
  - Track-based PFA developed by Steve Magill.
- Iowa PFA
  - PFA development led by Iowa group (Usha, Mat, Tae Jeong)
  - Several crucial pieces provided by other groups, e.g. photon-finding, PPR-tracking, calibration by Ron; DTree clusterer by NIU; shower point finder & MIP ID evolved from Steve's code.

Steve's PFA

- Extrapolate tracks into calorimeters & find MIP component
  - Uses semi-cheated track list & standard helix swimming
- Find photons among non-MIP ECAL hits
- For each track, build a shower by adding clusters until E/p balanced
- Check for charged shower fragments mis-ID'd as photons
  - Merge cluster into shower if close to track and E/p would be valid
- Build neutral hadrons from leftover clusters
- Check for charged shower fragments mis-ID'd as n. hadrons
- Make reconstructed particles for output

For more detail, see Steve's talk in parallel session.

Iowa PFA

For more detail, see Tae Jeong's talk in parallel session.

- Find photons. Set to one side.
- Run DTreeClusterer on remaining hits
- Within each DTreeCluster, look for substructure
  - MIP segments, clumps, etc
  - Define score to link them based on geometric quantities
  - Fuzzy clustering for individual / small-cluster / halo hits
- Extrapolate tracks to calorimeter, match to "seed" clusters
  - Uses semi-cheated track list (FSReconTracks) and custom local helix extrapolation
  - Try to break up seeds if flagged as photon but not electron, or if just plain too big
- Build charged showers outwards from seeds
  - Use links based on score, E/p
  - Parameters adjusted iteratively if cluster has wrong E/p
  - If multiple charged showers overlap, bundle them together for E/p checks etc
  - Second & third passes to pick up clusters missed earlier
- Build neutral hadron showers from remaining clusters
- Uses muon system endcap as tail-catcher

Current performance

- There isn't just one single number for performance.
  - Which PFA?
  - Which physics process and beam energy?
  - Which detector? (sid01, sid01_scint, sid02, ...)
  - Using the muon system?
  - Which angular range?
  - What tracking?
  - Quoting resolution how? (full RMS vs rms_{90} vs single Gaussian σ...)

Metrics

- Processes we use for quick benchmarking of PFAs:
  - $e^+e^- \rightarrow qq$ @ 91/100/200/500 GeV, looking at energy sum
  - $e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV, looking at dijet invariant mass
- These are chosen to be simple to analyze
  - Force q=u,d,s -- so no primary neutrinos
  - Only two jets -- so no penalty for jetfinding mistakes
  - $e^+e^- \rightarrow qq$ events offer direct comparison with Pandora results
  - ZZ events give nice, mixed range of jet energies (harder but more realistic -- exposes non-linearities in response etc)
- We always quote results as rms_{90} (or α_{90} etc)
  - It's weird but this is the convention now.
  - Remember that rms_{90} is only ~80% of full RMS for a Gaussian.

Baseline performance

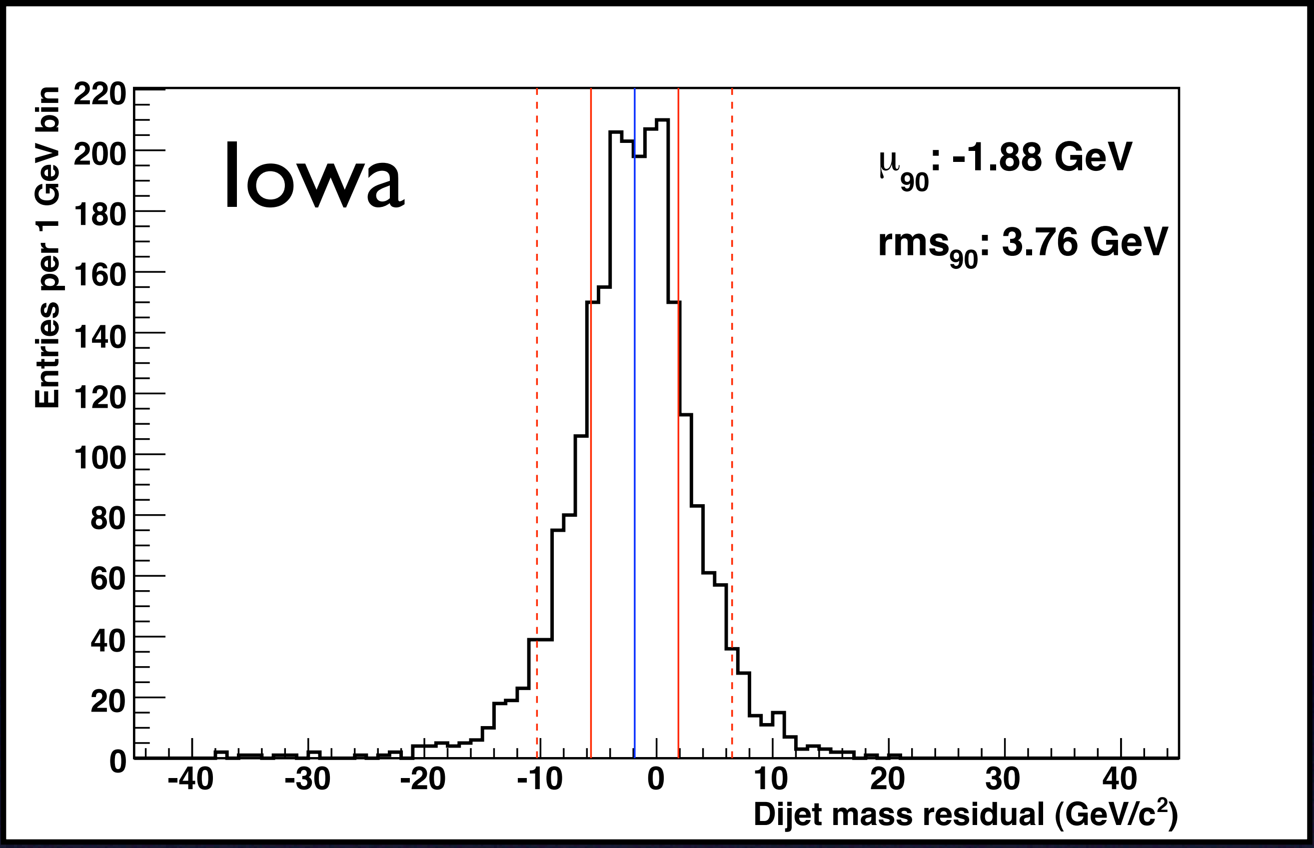
If I had to pick one measure of performance, this would be it.

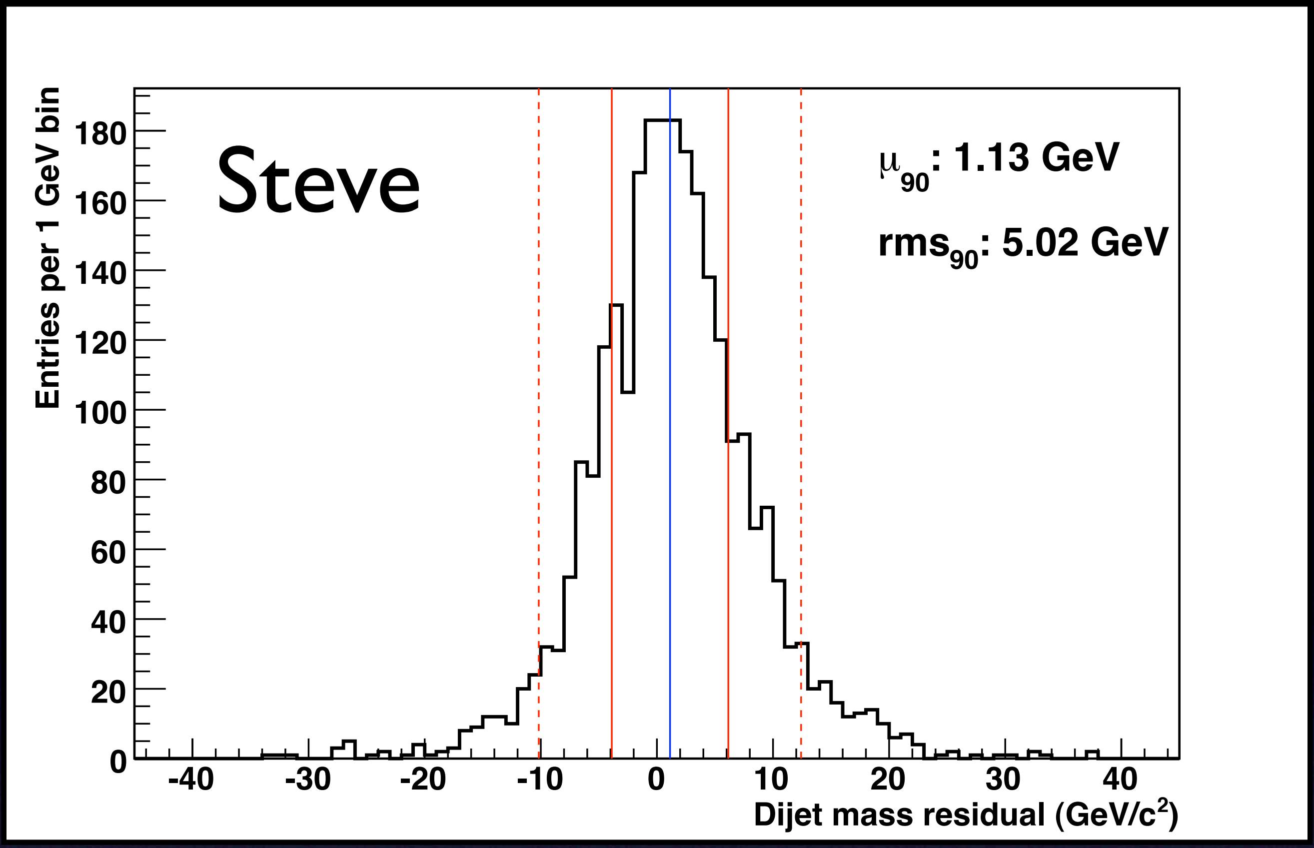
$e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV for sid01

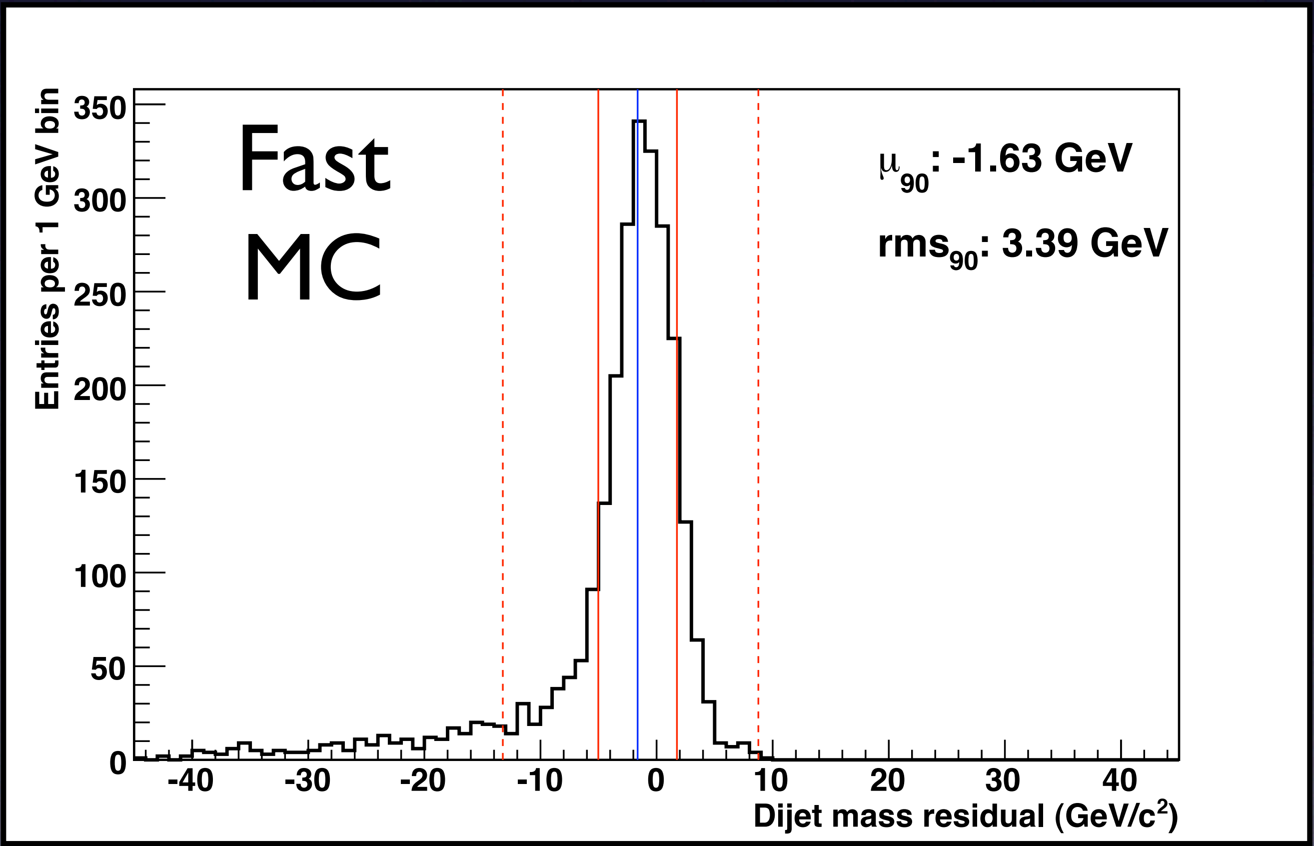
Plotting (reco-true) residuals for m(qq)

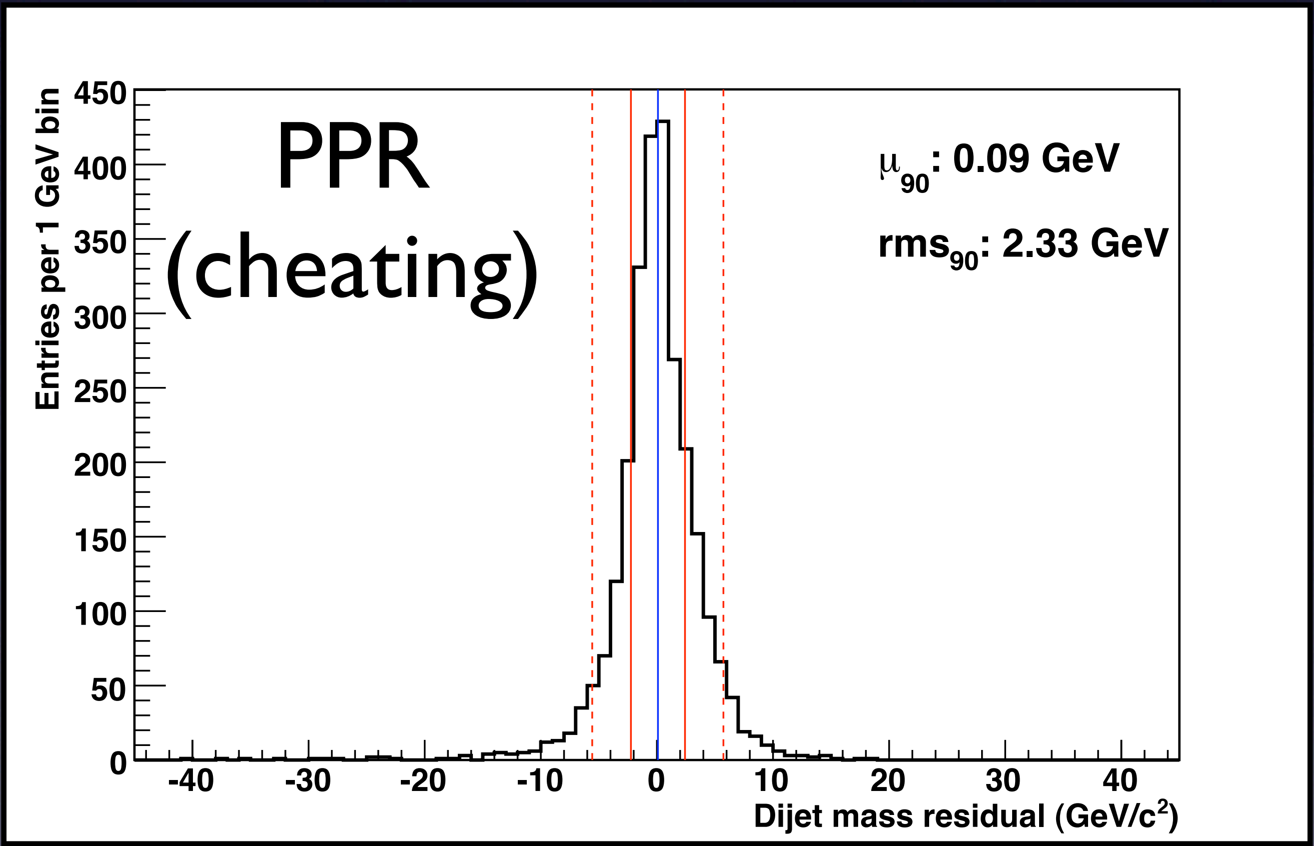
Let's look at this for the various PFAs...

$e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV for sid01, $|\cos\theta|<0.8$







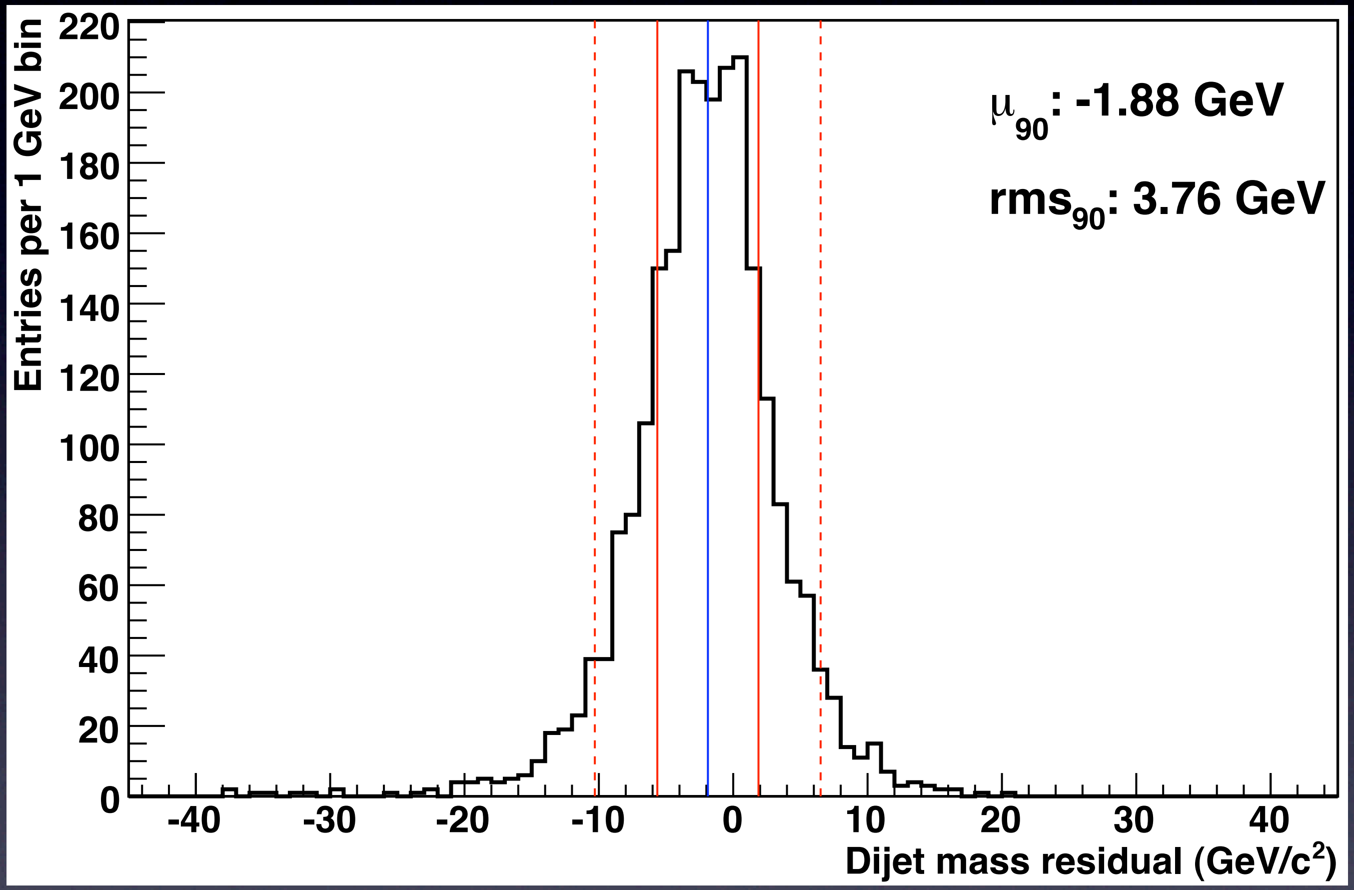


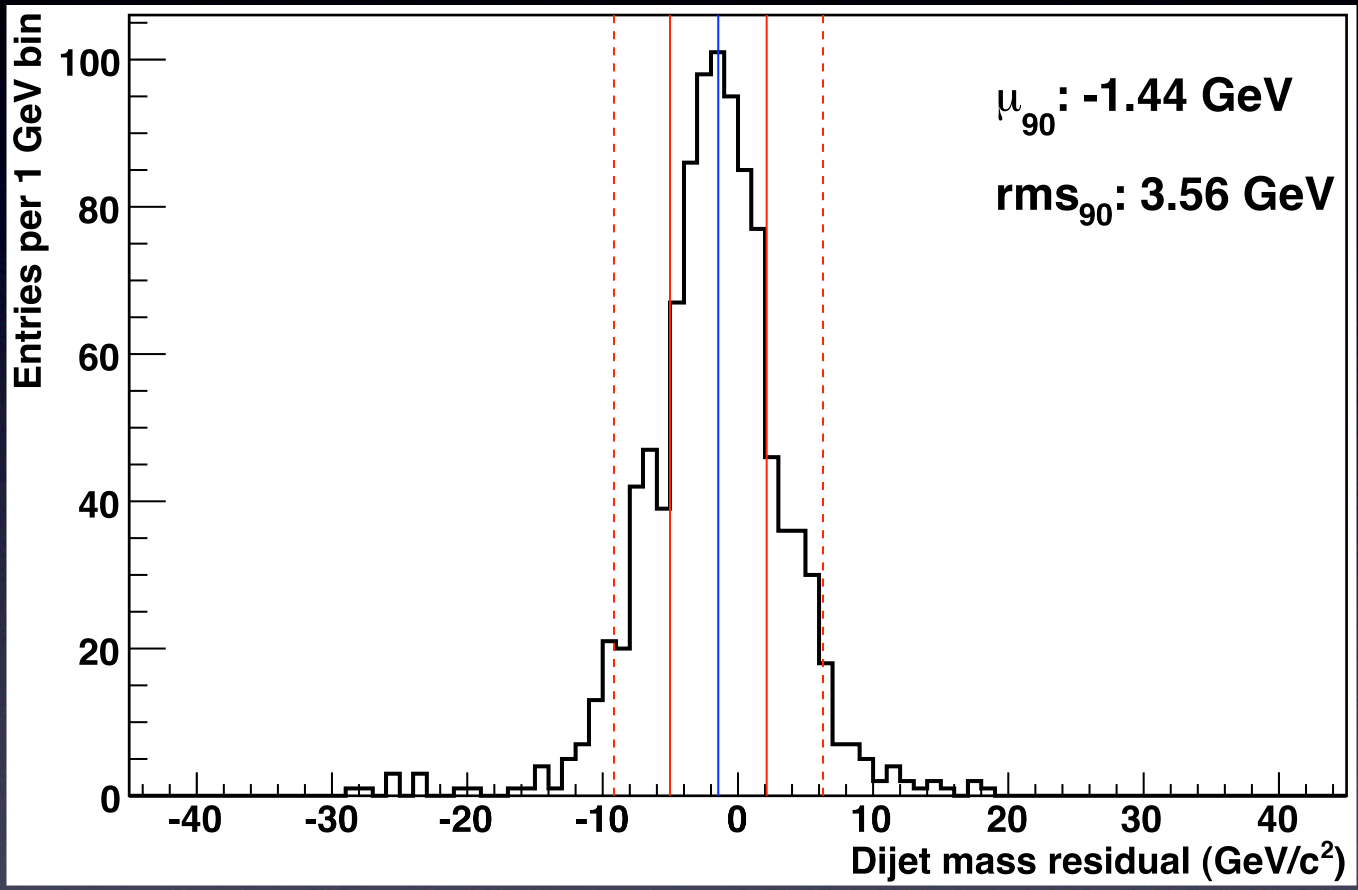
I will focus mostly on Iowa PFA performance for the rest of the talk.

Baseline performance

If I had to pick one measure of performance, this would be it.

$e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV for sid01 including muon endcaps





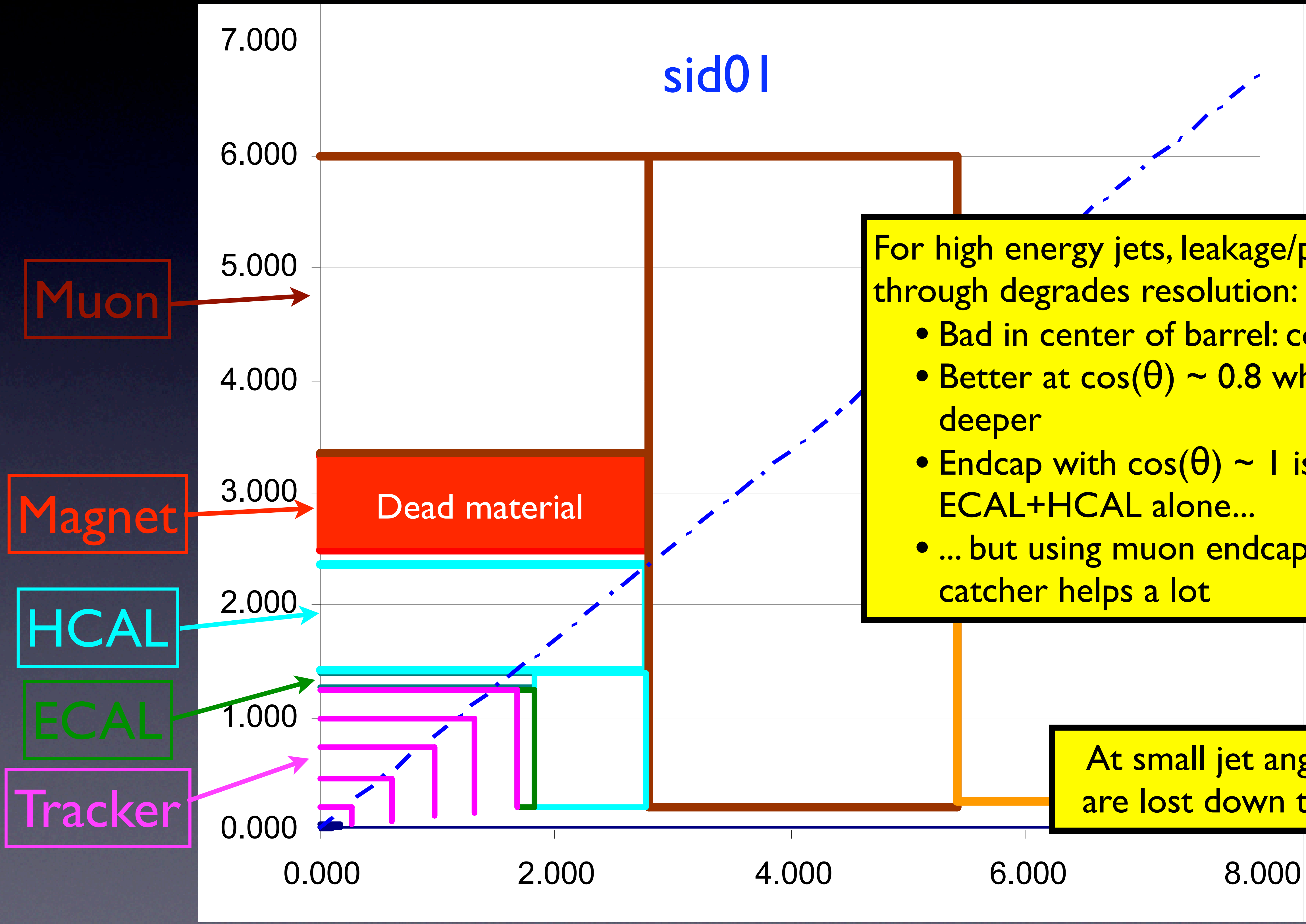
$|\cos\theta|<0.8$: dM/M = 4.2%

$0.8<|\cos\theta|<0.95$: dM/M = 4.0%

- We are close to the upper edge of the "acceptable for physics" range (with numerous caveats, especially rms_{90} vs RMS)
- But in the longer term, we want to be doing significantly better.

Angular dependence

Aside from tracking, two main issues:



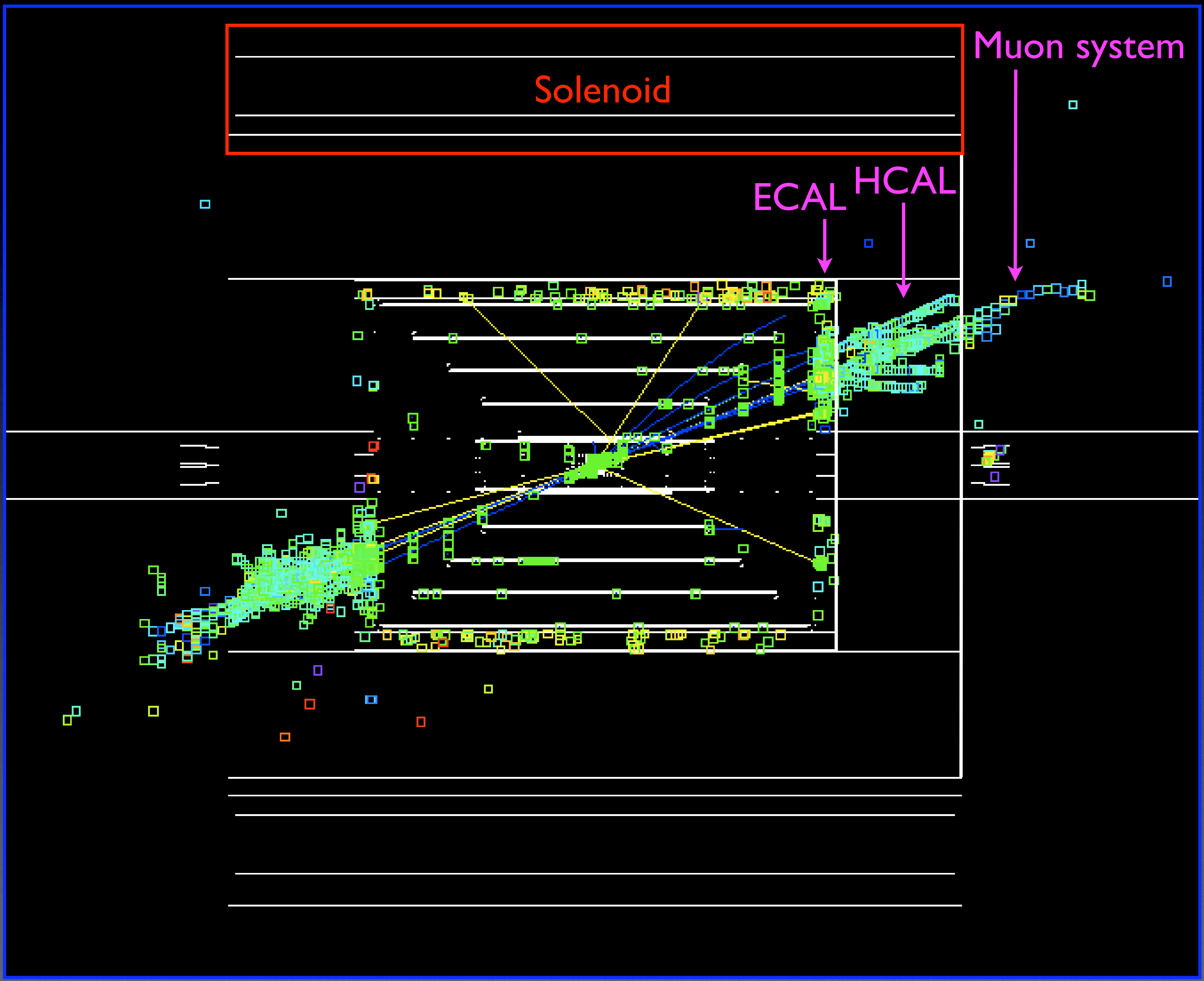
For high energy jets, leakage/punch-through degrades resolution:

- Bad in center of barrel: cos(θ) ~ 0
- Better at cos(θ) ~ 0.8 where HCAL is deeper
- Endcap with cos(θ) ~ 1 is bad using ECAL+HCAL alone...
- ... but using muon endcap as a tail-catcher helps a lot

At small jet angles, particles are lost down the beampipe

Angular dependence

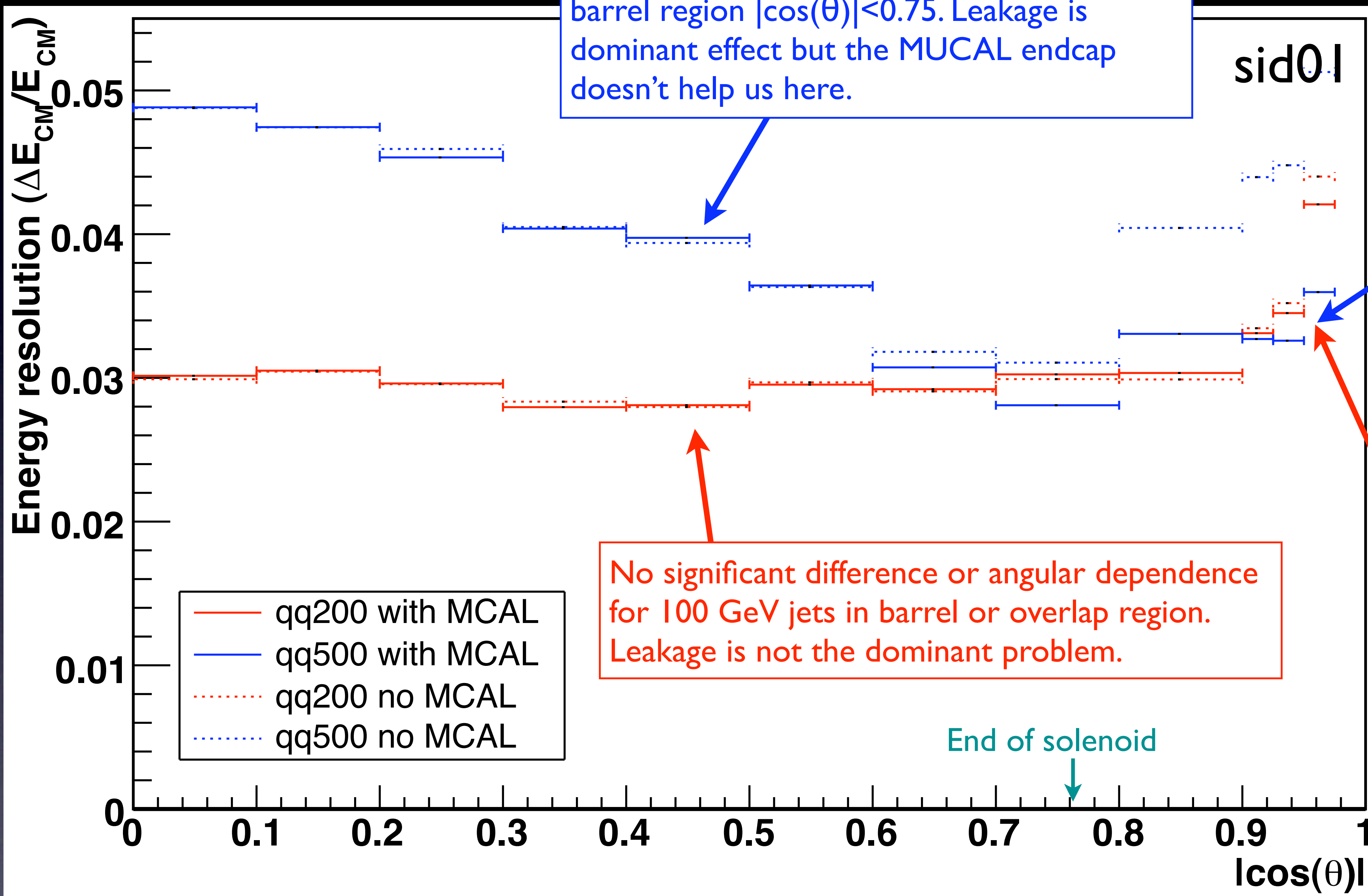
ρ-z projection of sid01, showing a qq500 event:



This is with the sid01 muon system (5cm steel plates). The sid02 baseline uses 20cm plates.

Angular dependence

No significant difference for 250 GeV jets in barrel region $|\cos(\theta)|<0.75$. Leakage is dominant effect but the MUCAL endcap doesn't help us here.



No significant difference or angular dependence for 100 GeV jets in barrel or overlap region. Leakage is not the dominant problem.

Big improvement for 250 GeV jets in overlap/endcap region. MUCAL solves the leakage problem and makes endcap resolution much better than barrel. Acceptance dominates at very small angles

Small improvement for 100 GeV jets in forward region -- may not be statistically significant. Acceptance dominates at small angles.

Important caveat: These results are for sid01 which has an unrealistic muon system (3x3cm transverse & 5cm longitudinal segmentation). It's not clear how performance will look for sid02.

Energy dependence

Caveat: strong angular dependence for 250 GeV jets.

sid01	$\|\cos(\theta)\|$	rms_{90} of E_{CM} (GeV)	$\Delta E_{CM}/E_{CM}$
qq100	0.0-0.8	3.47	3.5%
qq200	0.0-0.8	5.76	2.9%
qq500	0.0-0.8	18.86	3.9%
qq500	0.8-0.95	16.19	3.3%

- So aside from leakage problems for 250 GeV jets in sid01 barrel, energy resolution is between 3.0% and 3.5% across the board.
- ... and therefore so is estimated mass resolution for mono-energetic jets.
- Compare to real mass resolution in ZZ events of 4.0-4.2%.

Within the approximation $m_{12} = 2E_1E_2(1-\cos\theta_{12})$, and for qq dijet events with $E_1=E_2=E_{CM}/2$ and $\Delta E_1=\Delta E_2=\Delta E_{CM}/\sqrt{2}$: $\Delta M/M=\Delta E_{CM}/E_{CM}$. Watch out: $\Delta E_{jet}/E_{jet} = \sqrt{2}(\Delta E_{CM}/E_{CM})$

HCAL technology

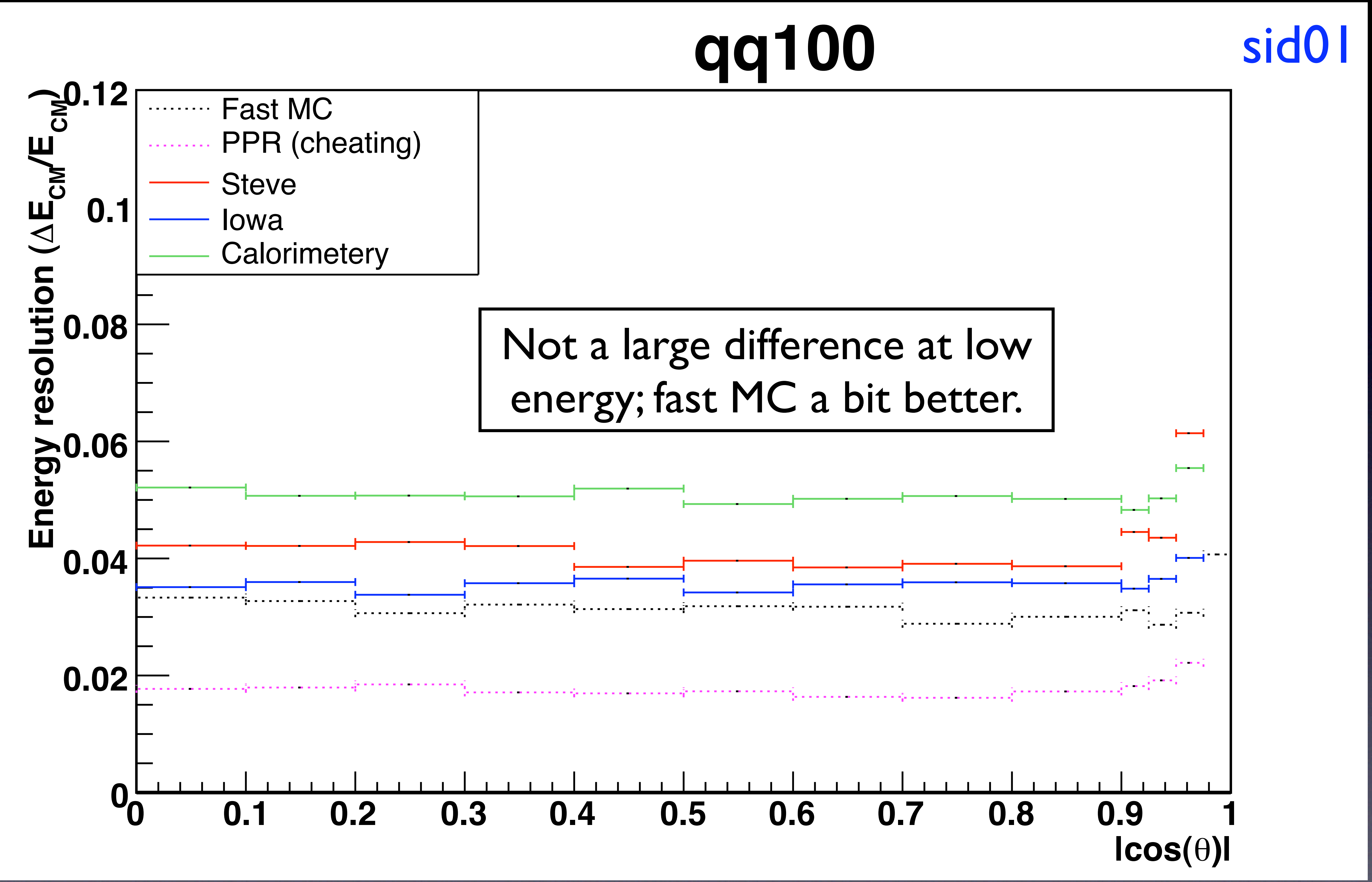
Important caveats:

- 1cm x 1cm segmentation assumed for both RPC & scintillator.
- Currently, algorithm leans heavily on E/p -- this favours a scintillator HCAL. This advantage may go away with better pattern recognition.
- Can only compare results in barrel region (muon endcaps turned off) due to typo in muon system description for sid01_scint.

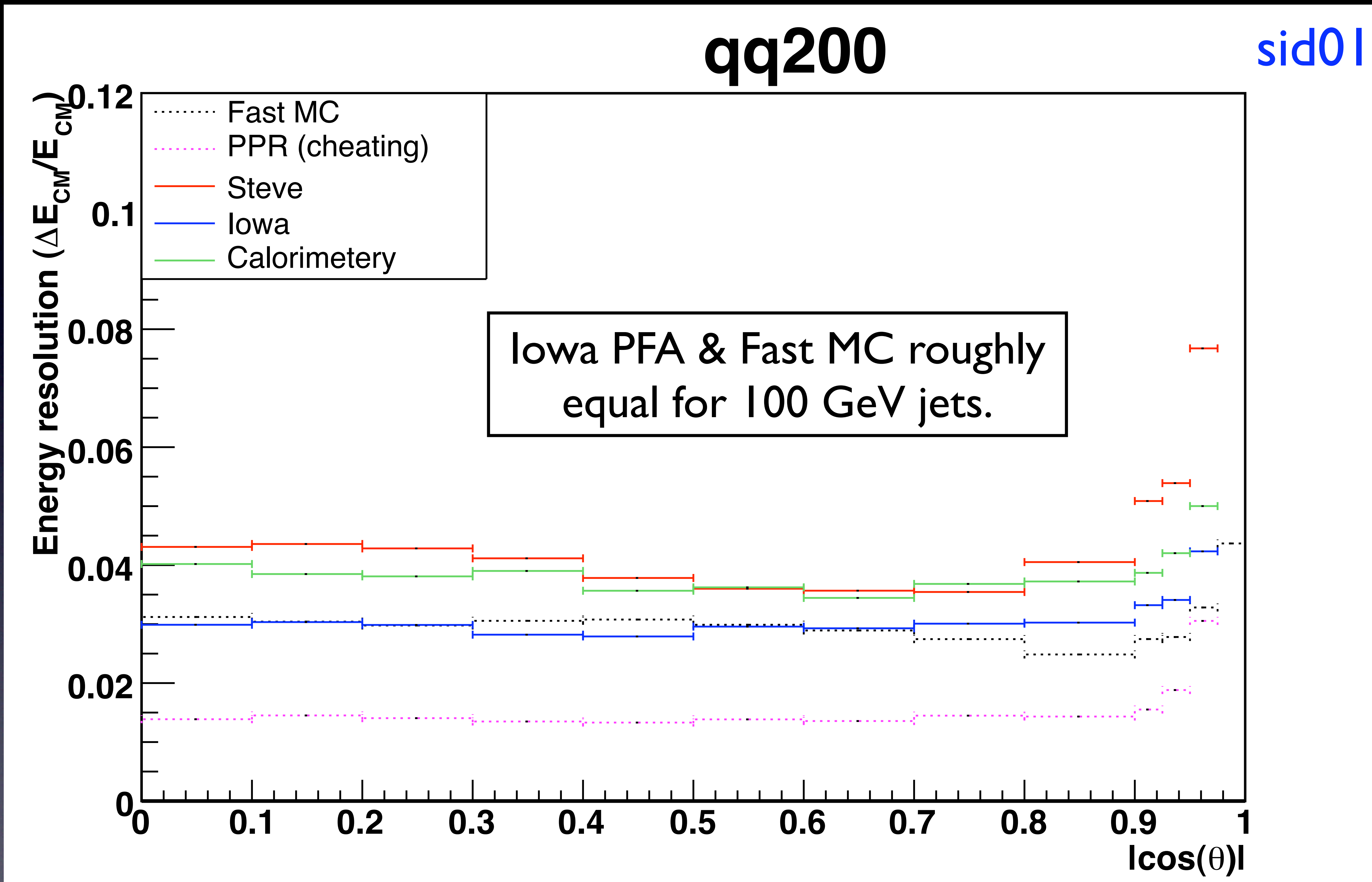
sid01	sid01	sid01_scint
qq100	$\Delta E_{CM}/E_{CM}$ = 3.5%	$\Delta E_{CM}/E_{CM}$ = 3.1%
qq200	$\Delta E_{CM}/E_{CM}$ = 2.9%	$\Delta E_{CM}/E_{CM}$ = 2.8%
qq500	$\Delta E_{CM}/E_{CM}$ = 3.9%	$\Delta E_{CM}/E_{CM}$ = 3.5%
ZZ	$\Delta M/M$ = 4.2%	$\Delta M/M$ = 3.8%

Scintillator gives ~ 10% better performance.

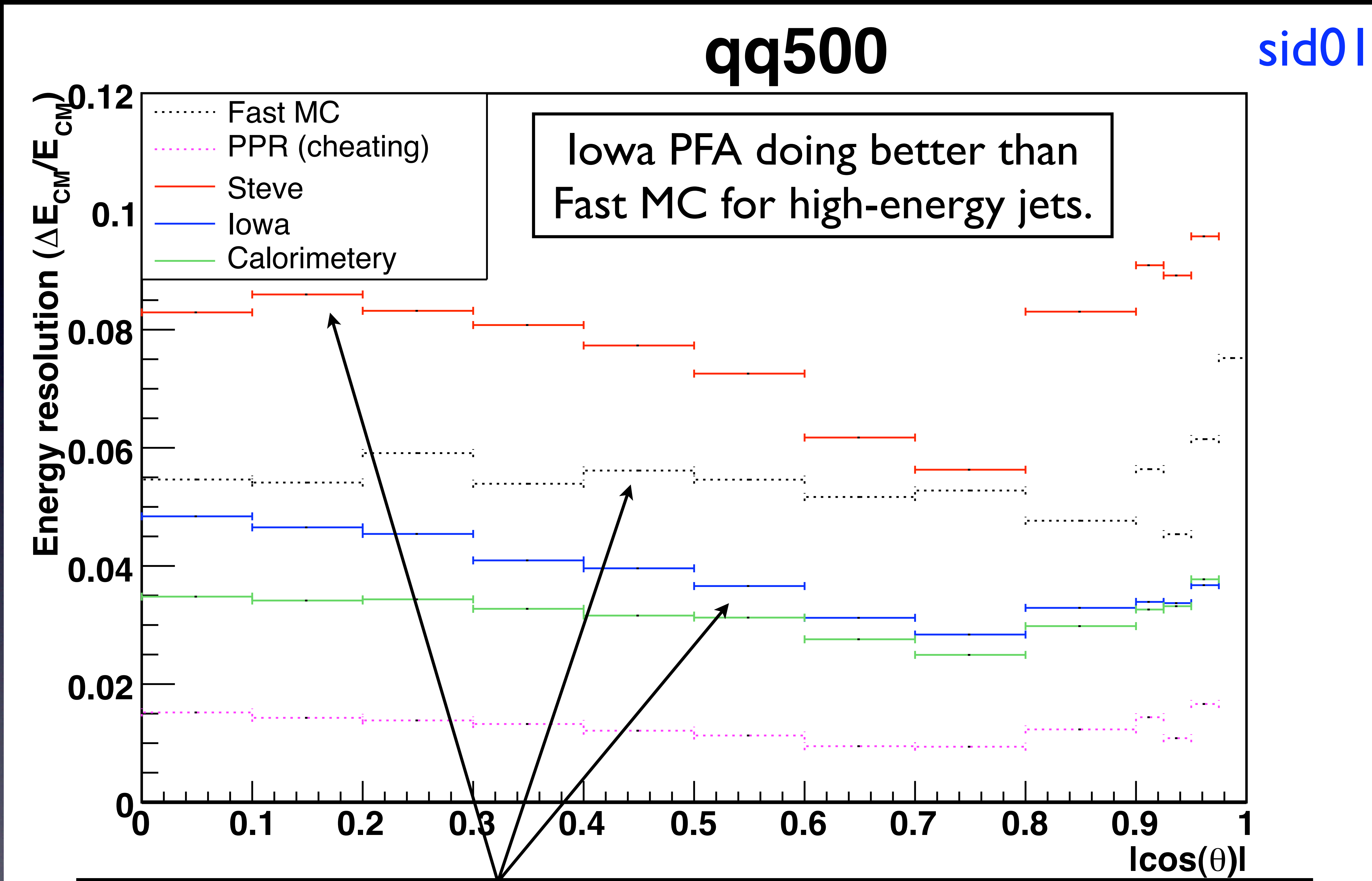
PFA comparison: qq100



PFA comparison: qq200



PFA comparison: qq500



Leakage affects real PFAs strongly, but not Fast MC. (Calorimetry uses barrel and endcap muon systems as tail-catchers.)

Huge table of results

(Many of these numbers from Ron -- thanks!)

sid01	qq100 barrel	qq100 forward	qq200 barrel	qq200 forward	qq500 barrel	qq500 forward	ZZ barrel	ZZ forward
Cheating (PPR)	1.7 GeV 1.7%	1.8 GeV 1.8%	2.8 GeV 1.4%	3.0 GeV 1.5%	5.8 GeV 1.2%	6.2 GeV 1.2%	2.3 GeV 2.6%	2.5 GeV 2.8%
Fast MC (default)	3.1 GeV 3.1%	3.0 GeV 3.0%	5.9 GeV 3.0%	5.1 GeV 2.6%	26.6 GeV 5.4%	23.8 GeV 4.8%	3.4 GeV 3.8%	3.5 GeV 3.9%
Iowa PFA	3.5 GeV 3.5%	3.6 GeV 3.6%	5.8 GeV 2.9%	6.2 GeV 3.2%	18.9 GeV 3.9%	16.2 GeV 3.3%	3.8 GeV 4.2%	3.6 GeV 4.0%
Steve PFA	4.0 GeV 4.0%	4.1 GeV 4.0%	7.7 GeV 3.9%	9.0 GeV 4.5%	39.0 GeV 7.6%	48.5 GeV 9.1%	5.0 GeV 5.4%	5.7 GeV 6.1%

"Barrel" means $|\cos(\theta)|<0.8$; "forward" means $0.8<|\cos(\theta)|<0.95$.

Improvement over time

What's been shown today is just a snapshot.
PFA implementations are continually improving!
For example, here is the ZZ resolution in the Iowa PFA:

	sid01 barrel	sid01_scint barrel
Sep 2008	4.2%	3.8%
Aug 2008	4.3%	3.9%
July 2008	4.6%	4.2%
June 2008	5.0%	4.8%
April 2008	4.9%	4.9%
March 2008	5.3%	
Feb 2008	5.8%	
Jan 2008	5.7%	
Nov 2007	5.9%	
Oct 2007	6.3%	

We expect to reach zero resolution some time in 2010. :)

Tracking

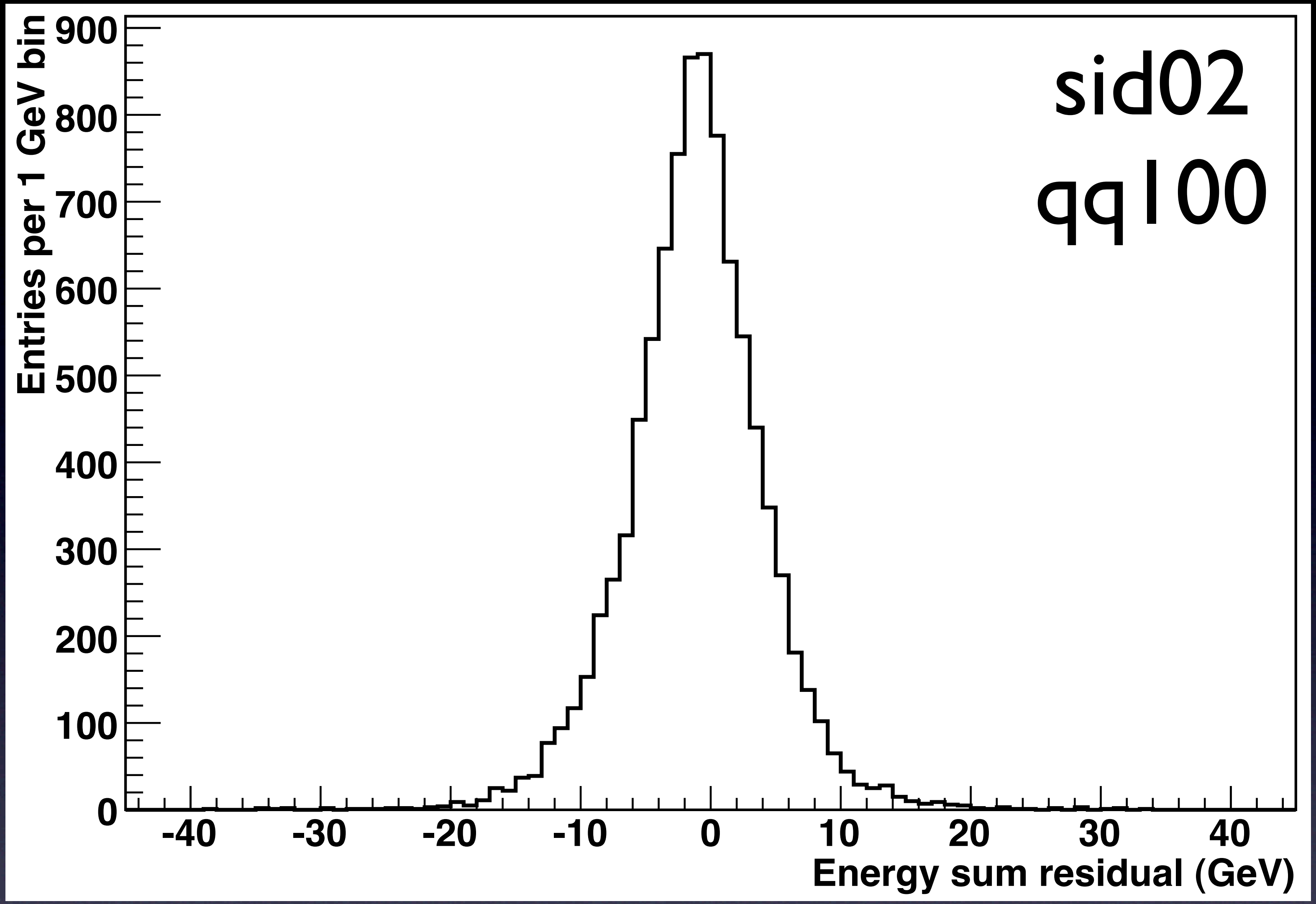
- PFA depends heavily on tracking.
- Current results based on ReconFSTracks list (requires 4+ hits in tracker; smeared with fast MC; final-state particles)
- Various ways to use these tracks:
  - Extrapolate smeared track as helix. [Steve]
  - Take last 3 SimTrackerHits & fit local helix. [Iowa stable]
  - Extrapolate smeared track to last tracker hit, correct for offset, continue extrapolation. [Iowa testing]
- Now testing out the brand new real tracking algorithm
  - PFA track extrapolation/matching code re-written for this.
  - Proof-of-principle: PFA compiled & run with new tracking code.
  - Hard part comes next: understanding PFA differences w.r.t. cheat tracks.
- Obvious but worth bearing in mind: switching to real tracking will degrade our resolution.

Tracking

Concrete evidence! Here is a plot made with real tracking.

Next step: Testing with benchmarking group.

But...

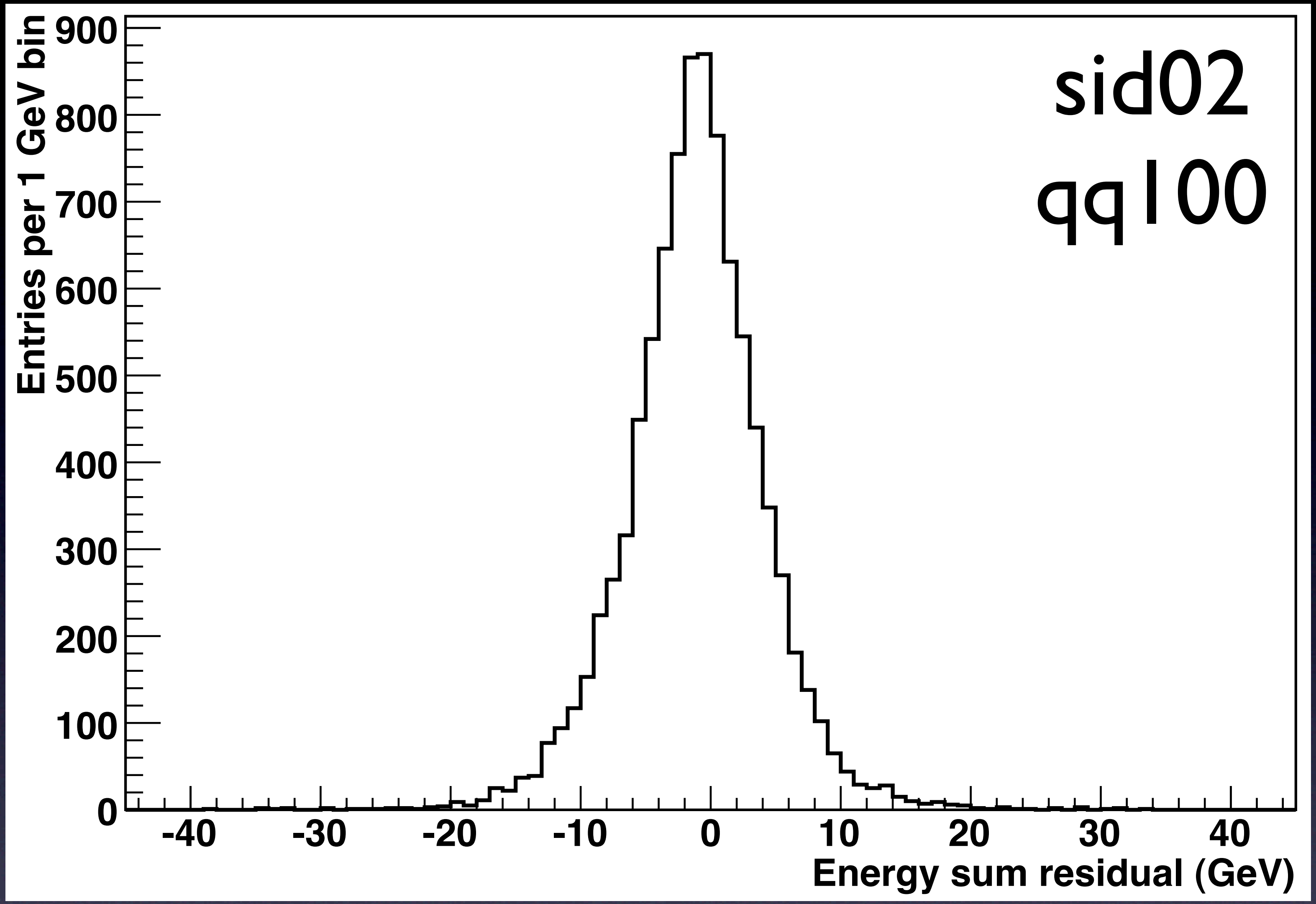


Tracking

Concrete evidence! Here is a plot made with real tracking.

Next step: Testing with benchmarking group.

But...



- Not clear if we should use real tracking for the bulk of the production PFA reconstruction for the LOI.
  - Interactions with PFA not yet understood.
  - Reconstruction of kinks/V^0/interactions needed in general...
  - ... but some modes might be suitable (e.g. $e^+e^- \rightarrow ZH, Z \rightarrow \mu^+\mu^-$)
  - If we had another couple of months, this might be a different story.

sid02

- Caveat: Still very preliminary & certain to change!
- Main differences (for PFA) between sid01 & sid02:
  - Better acceptance (inner r=26cm → 20cm for calorimeter endcaps)
  - Deeper HCAL (34 → 40 layers)
  - Coarser muon system segmentation (5cm → 20cm steel plates)

	sid01 barrel	sid02 barrel	sid01 forward	sid02 forward
qq100	3.5%	3.5%	3.6%	3.4%
qq200	2.9%	2.8%	3.2%	2.9%
qq500	3.9%	3.5%	3.3%	3.8%
ZZ	4.2%	4.2%	4.0%	3.8%

Comparison with Pandora

- This is a hard thing to do properly! So far no true apples-to-apples comparison has been done:
  - While we know the general parameters of the LDC00Sc detector Mark uses, it's been nigh impossible to get the fine details -- therefore we haven't been able to simulate LDC00Sc in org.lcsim properly.
  - European geometry description complex -- too hard to build a detector from scratch. Marcel has made several SiDish detectors by deforming LDC00Sc, but none is a true sid01.
- And there are other issues too, e.g.
  - Tracking (TPC vs silicon, details of cheating)
  - HCAL segmentation
  - Pandora is tuned for LDC00Sc, not SiD.
- Bottom line: impossible to completely decouple comparing detectors from comparing algorithms.
- That said...

Comparison with Pandora

Let's start with a very unfair comparison: sid01 and sid01_scint (excluding muon endcaps) for $0.0<|\cos(\theta)|<0.8$ vs LDC00Sc for $0.0<|\cos(\theta)|<0.7$

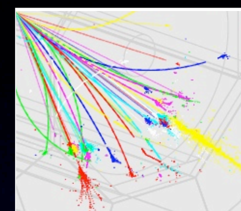
B=4T, Z=2.7m, R=1.7m, 30+10 layer ECAL, 40 layer HCAL with 3x3cm scintillator cells.

sid01	org.lcsim sid01	org.lcsim sid01_scint	Pandora LDC00Sc
qq90	$\Delta E_{CM}/E_{CM}$ = 3.9%	$\Delta E_{CM}/E_{CM}$ = 3.4%	$\Delta E_{CM}/E_{CM}$ = 2.5%
qq100	$\Delta E_{CM}/E_{CM}$ = 3.5%	$\Delta E_{CM}/E_{CM}$ = 3.1%	
qq200	$\Delta E_{CM}/E_{CM}$ = 2.9%	$\Delta E_{CM}/E_{CM}$ = 2.8%	$\Delta E_{CM}/E_{CM}$ = 2.2%
qq360			$\Delta E_{CM}/E_{CM}$ = 2.3%
qq500	$\Delta E_{CM}/E_{CM}$ = 3.9%	$\Delta E_{CM}/E_{CM}$ = 3.5%	$\Delta E_{CM}/E_{CM}$ = 2.5%

So our PFA on sid01 is outclassed by Pandora on LDC00Sc.

Comparison with Pandora

What about a fairer comparison: sid01 vs a SiDish detector?



The variants

TAG	Layers	total thickness	Iron thickness	Scintillator thickness	HCAL thickness	λ_{tot}
SIDish_v2_hcal30	30	32.7	26.2	6.5	980	4.92
SIDish_v2_hcal40	40	24.5	18.0	6.5	980	4.61
SIDish_v2_hcal50	50	19.6	13.1	6.5	980	4.45
SIDish_v2_hcal30_l45	30	31.7	25.2	6.5	951	4.75
SIDish_v2_hcal40_l45	40	25.4	18.9	6.5	1016	4.83
SIDish_v2_hcal50_l45	50	21.6	15.1	6.5	1081	4.91
SIDish_v2_hcal60_l45	60	21.6	15.1	6.5	1081	4.91
SIDish_v2_hcal30_l50	30	34.5	28.0	6.5	1035	5.25
SIDish_v2_hcal40_l50	40	27.5	21.0	6.5	1100	5.33
SIDish_v2_hcal50_l50	50	23.3	16.8	6.5	1165	5.41
SIDish_v2_hcal60_l50	60	20.5	14.0	6.5	1230	5.49
SIDish_v2_hcal30_l55	30	37.3	30.8	6.5	1119	5.75
SIDish_v2_hcal40_l55	40	29.6	23.1	6.5	1184	5.83
SIDish_v2_hcal50_l55	50	25.0	18.5	6.5	1249	5.91
SIDish_v2_hcal60_l55	60	21.9	15.4	6.5	1314	5.99
SIDish_v2_hcal30_l40	30	28.9	22.4	6.5	867	4.25
SIDish_v2_hcal40_l40	40	23.3	16.8	6.5	932	4.33
SIDish_v2_hcal50_l40	50	19.9	13.4	6.5	997	4.41
SIDish_v2_hcal60_l40	60	17.7	11.2	6.5	1062	4.49
SIDish_v2_hcal30_l35	30	26.1	19.6	6.5	783	3.75
SIDish_v2_hcal40_l35	40	21.2	14.7	6.5	848	3.83
SIDish_v2_hcal50_l35	50	18.3	11.8	6.5	913	3.91
SIDish_v2_hcal60_l35	60	16.3	9.8	6.5	978	3.99

Science & Technology Facilities Council
Rutherford Appleton Laboratory

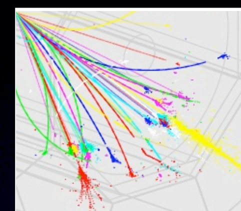
2

Marcel Stanitzki

Many variants to choose from! Let’s look at the closest to sid01.

Comparison with Pandora

What about a fairer comparison: sid01 vs a SiDish detector?



The variants

NB: Scintillator HCAL

TAG	Layers	total thickness	Iron thickness	Scintillator thickness	HCAL thickness	λ_{tot}
SIDish_v2_hcal30	30	32.7	26.2	6.5	980	4.92
SIDish_v2_hcal40	40	24.5	18.0	6.5	980	4.61
SIDish_v2_hcal50	50	19.6	13.1	6.5	980	4.45
SIDish_v2_hcal30_l45	30	31.7	25.2	6.5	951	4.75
SIDish_v2_hcal40_l45	40	25.4	18.9	6.5	1016	4.83
SIDish_v2_hcal50_l45	50	21.6	15.1	6.5	1081	4.91
SIDish_v2_hcal60_l45	60	21.6	15.1	6.5	1081	4.91
SIDish_v2_hcal30_l50	30	34.5	28.0	6.5	1035	5.25
SIDish_v2_hcal40_l50	40	27.5	21.0	6.5	1100	5.33
SIDish_v2_hcal50_l50	50	23.3	16.8	6.5	1165	5.41
SIDish_v2_hcal60_l50	60	20.5	14.0	6.5	1230	5.49
SIDish_v2_hcal30_l55	30	37.3	30.8	6.5	1119	5.75
SIDish_v2_hcal40_l55	40	29.6	23.1	6.5	1184	5.83
SIDish_v2_hcal50_l55	50	25.0	18.5	6.5	1249	5.91
SIDish_v2_hcal60_l55	60	21.9	15.4	6.5	1314	5.99
SIDish_v2_hcal30_l40	30	28.9	22.4	6.5	867	4.25
SIDish_v2_hcal40_l40	40	23.3	16.8	6.5	932	4.33
SIDish_v2_hcal50_l40	50	19.9	13.4	6.5	997	4.41
SIDish_v2_hcal60_l40	60	17.7	11.2	6.5	1062	4.49
SIDish_v2_hcal30_l35	30	26.1	19.6	6.5	783	3.75
SIDish_v2_hcal40_l35	40	21.2	14.7	6.5	848	3.83
SIDish_v2_hcal50_l35	50	18.3	11.8	6.5	913	3.91
SIDish_v2_hcal60_l35	60	16.3	9.8	6.5	978	3.99

A

B

C

These pairs straddle the right number of layers (34) and iron thickness (20mm)

Science & Technology Facilities Council
Rutherford Appleton Laboratory

2

Marcel Stanitzki

Many variants to choose from! Let's look at the closest to sid01.

Comparison with Pandora

$\Delta E_{CM}/E_{CM}$

sid01	org.lcsim sid01	org.lcsim sid01_scint	Pandora SiDish pair A (mean)	Pandora SiDish pair B (mean)	Pandora SiDish pair C (mean)
qq90	3.9%	3.4%	3.1%	3.1%	3.1%
qq100	3.5%	3.1%			
qq200	2.9%	2.8%	2.8%	2.8%	2.8%

So we're actually getting competitive with Pandora in this energy range.

(... but what about qq500? No SiDish data yet -- CPU time limitations.)

Performance summary

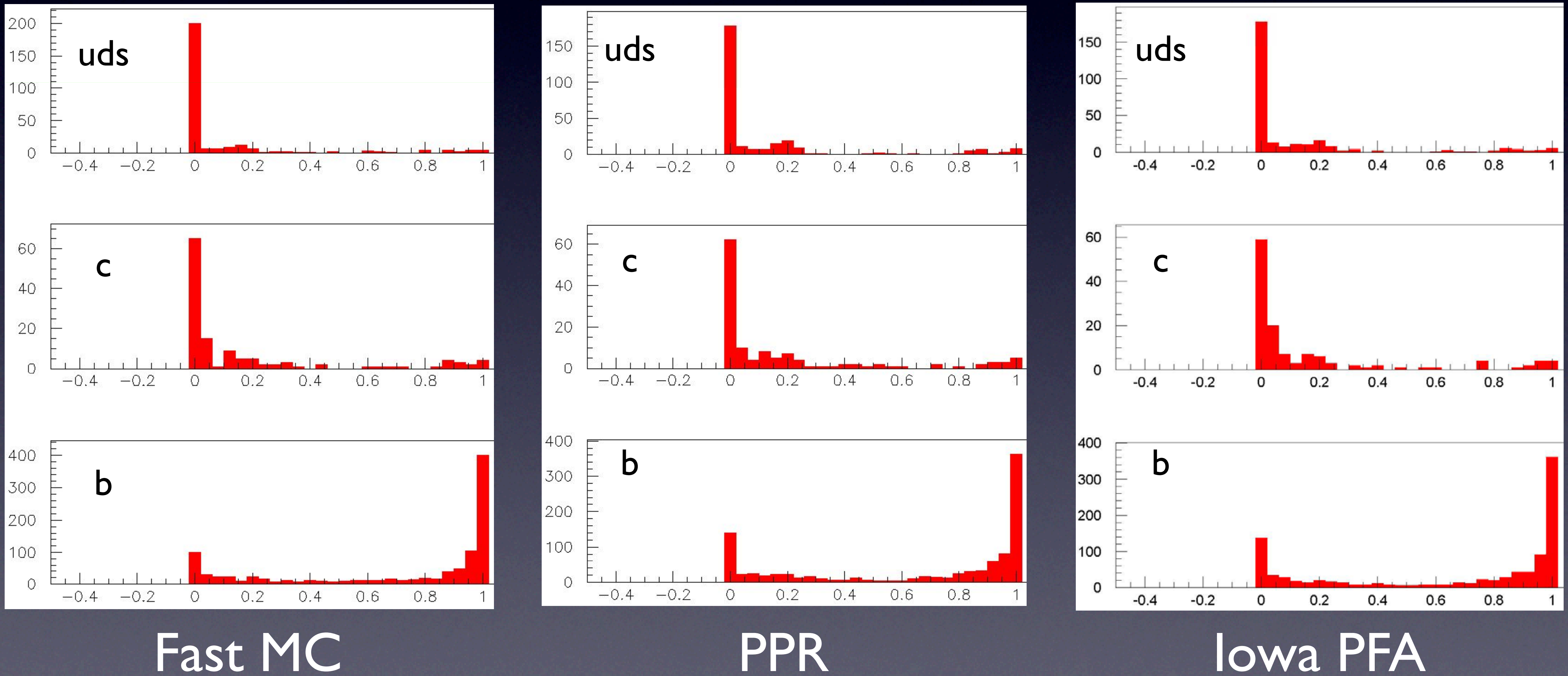
- PFA performance is getting there.
  - Energy resolution 3.0-3.5% for qqbar events up to E_{jet}=100 GeV
  - For E_{jet}=250 GeV, resolution similar in endcaps but degraded by leakage in barrel. (sid01)
  - Dijet mass resolution ~ 4.0-4.2% for ΣE_{jet}~250 GeV.
  - Performance roughly same as Fast MC.
- Competitive with Pandora on similar detector for $E_{jet} \leq 200$ GeV -- but performance at higher energies not yet clear.
- We still have a lot of improving to do...
- ... but we're not in too bad shape to do physics studies for the LOI with appropriate disclaimers.
- Caveat: Results shown today use cheated tracking.

Physics analysis

- Light quark jets are all very well, but what about physics?
- Lots of work to do for the LOI benchmarks!
- Some analyses already started (see upcoming slides)
- But we need to be moving much faster here.

LCFI tests: B-tagging

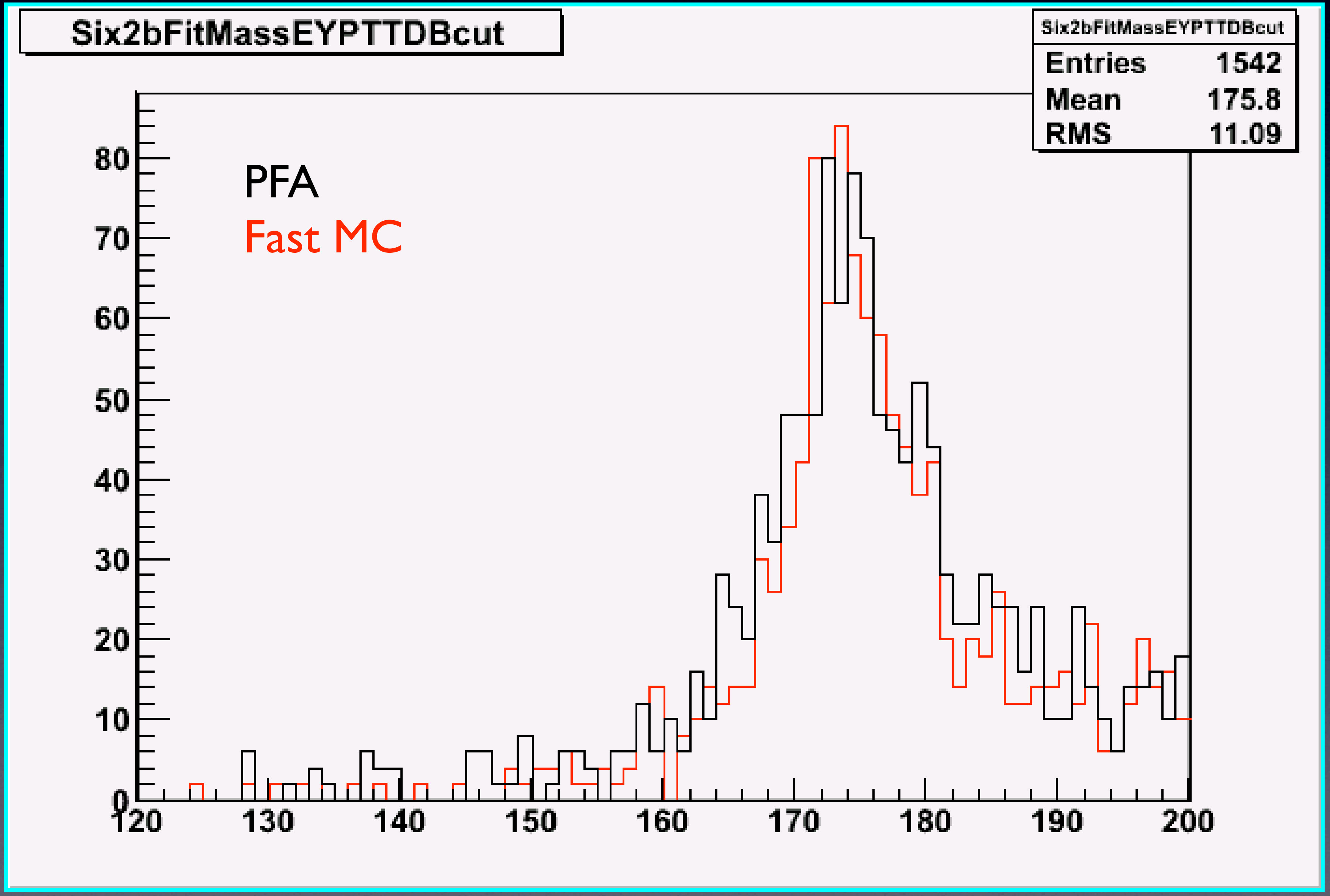
- Study by Keith Fratus (working with Tim Barklow)
- Processed ZZH events with Fast MC, PPR, Iowa PFA.
- Fed output reconstructed particles into LCFI (Marlin).



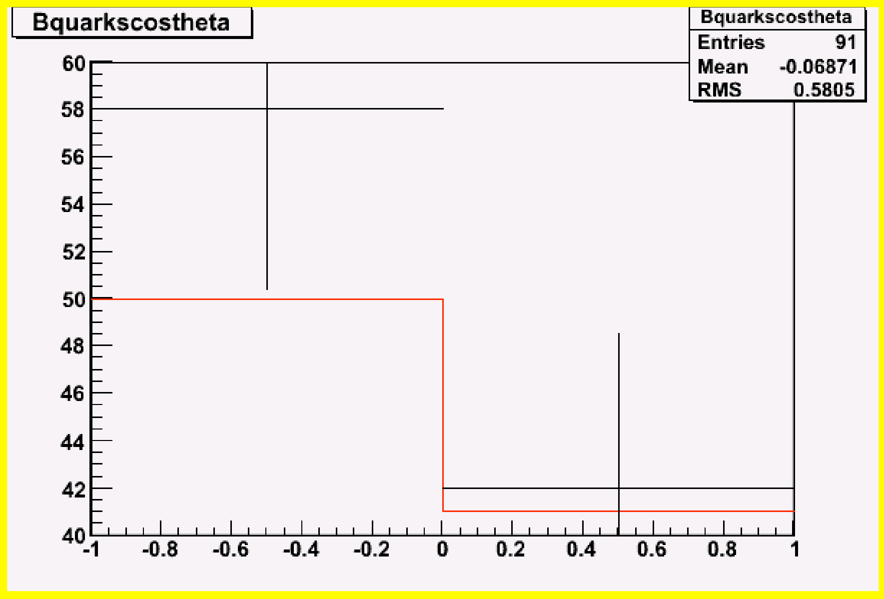
Proof of principle: PFA output processed OK.

ttbar analysis

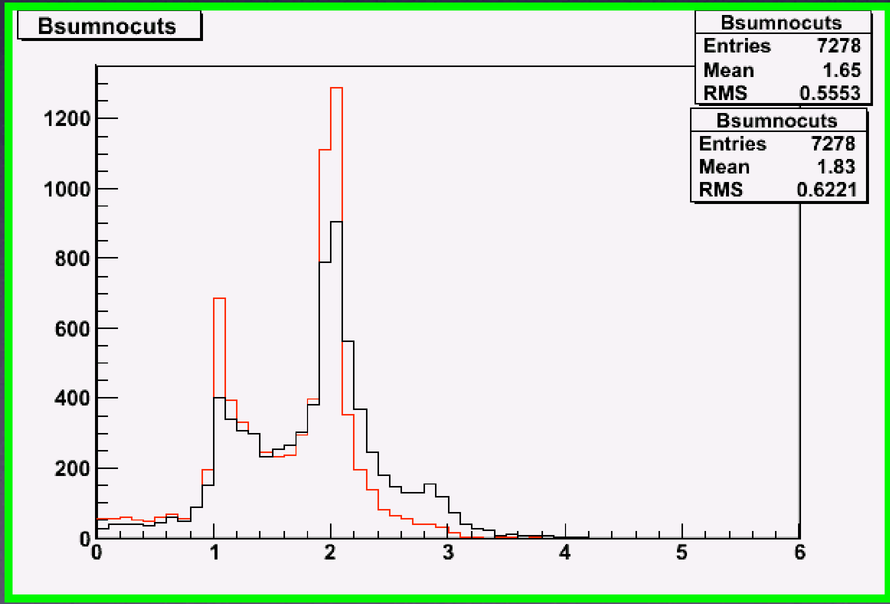
Erik Devetak has used both Fast MC & PFA reconstructed particles as inputs to his analysis. Comparing the two:



Top mass looks pretty good.



A_{FB} measurement works fine.



Some discrepancies in flavour-tagging...

Issues for analysis use

- Lots of effort put into getting PFA output into a form that can be plugged into physics analysis
  - Ron has done a lot here
  - Special thanks to our guinea pigs (Erik, Kevin, Tim)
- Reconstructed particles for PFA vs for physics
  - This turns out to be quite complicated -- still figuring it out.
  - Basic issue is that PFA is designed to reconstruct the final-state particles, whereas physics analysis needs the initial-state particles.
  - Example: Charged secondaries from kinks, V^0s, material interactions, etc may be screwing up the jet flavour tagging.
- Please start testing your analysis as soon as possible!
  - Chances are good it will uncover some new teething problem.
  - We are happy (eager!) to help, but it may take time to understand & fix.

The LOI

- Broadly, PFA group has four things to do:
  1. Converge on a stable PFA version, freeze it, and use for production.
  2. Help analysts use the PFA output & fix inevitable bugs/problems
  3. Document the work done
  4. Continue improving PFA
- Note that there is some tension (esp. #1 vs #4). Care needed.
- Usual plan: Long supporting note + LOI contributions.
- Details & responsibilities to be thrashed out in the next few days.

III Subsystems: for each, to include:

- Performance requirements, pointers to physics benchmarks
- Design outline, including engineering details, drawings etc
- Technology options
- Baseline choice(s)
- Front-end electronics
- Performance: spatial resolution, efficiencies, energy/momentum resolution

…

Tracking system (10+)

EM calorimeter (10+)

HCAL (10+)

Forward systems (5?)

Magnet (5 or less)

Muon system (5)

DAQ (1)

Simulation tools + infrastructure, PFA … (5)

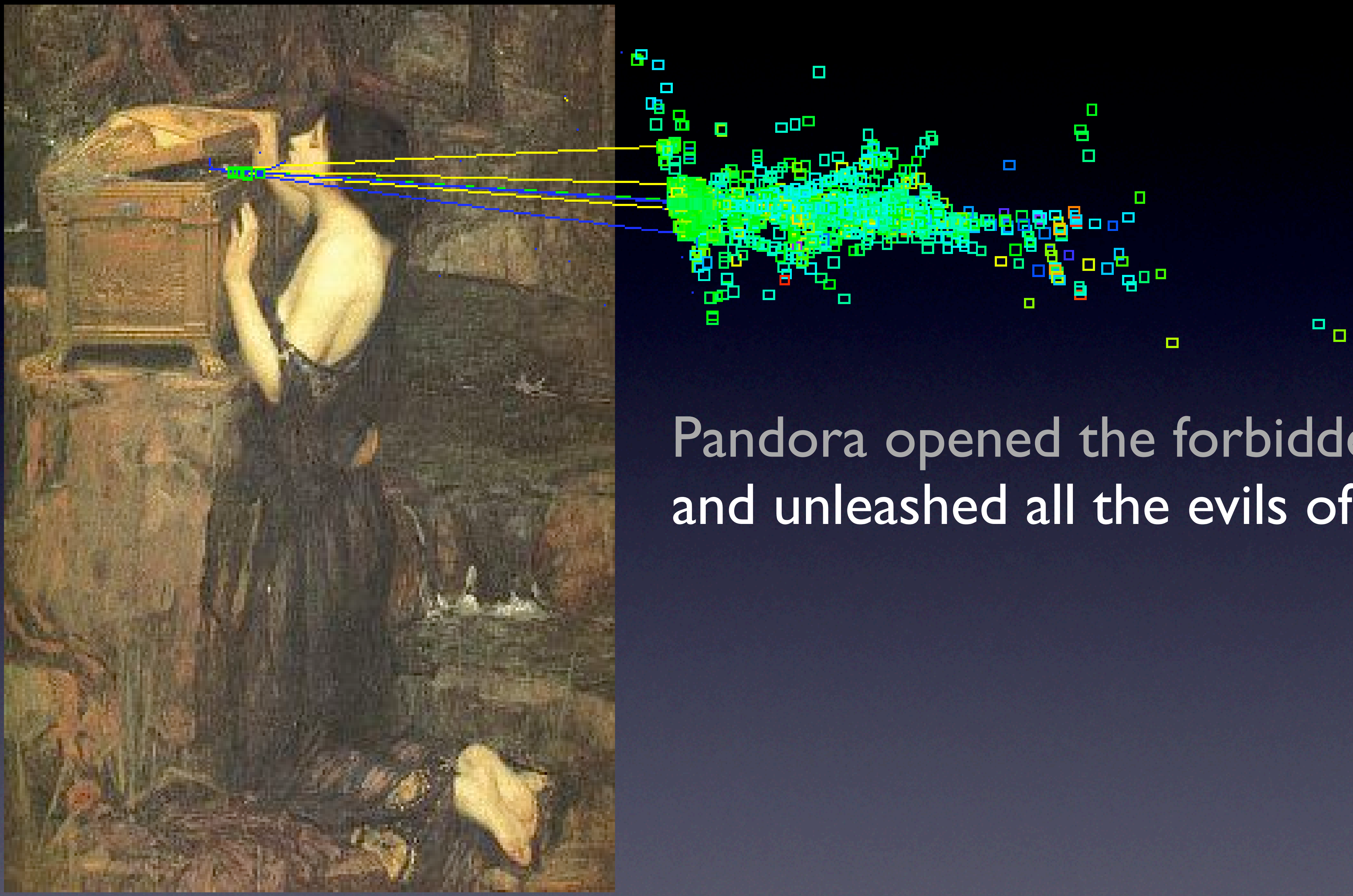
(+ input to many subsystem sections)

IV Benchmarking results (25?)

Afterword

Pandora opened the forbidden box

Afterword



Pandora opened the forbidden box
and unleashed all the evils of the world.

Afterword

Pandora opened the forbidden box and unleashed all the evils of the world. But after all the evils had fled, at the bottom of the box, she found Hope.