PFA Performance for SiD

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Overview

- Quick guide to PFA "benchmark" modes and conventions
- Current performance with sid02
  - All results obtained with LOI production version of PFA.
- Comparisons with Pandora
- Conclusions

Next talk: The algorithm itself & plans for improvement.

PFA metrics

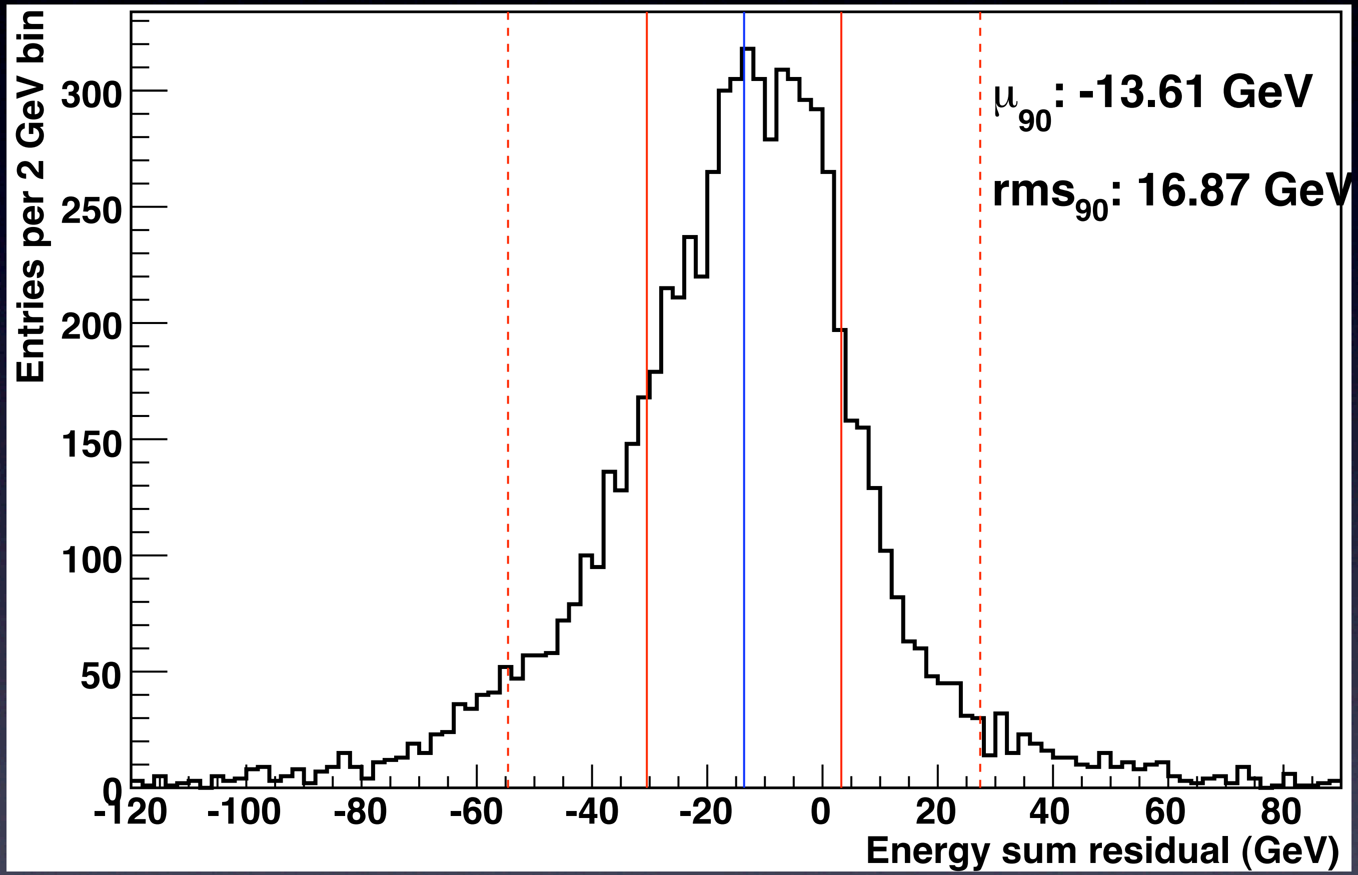
- There isn't just one single number for performance.
  - Which physics process and beam energy?
  - Which detector? (sid01, sid01_scint, sid02, ...)
  - Using which subsystems? (Muon endcaps? Muon barrel? Beamcal? ...)
  - Which angular range?
  - How is tracking done?
  - Quoting resolution how? (full RMS vs rms_{90} vs single Gaussian σ...)
  - Noise, thresholds, other detector effects
  - ... etc

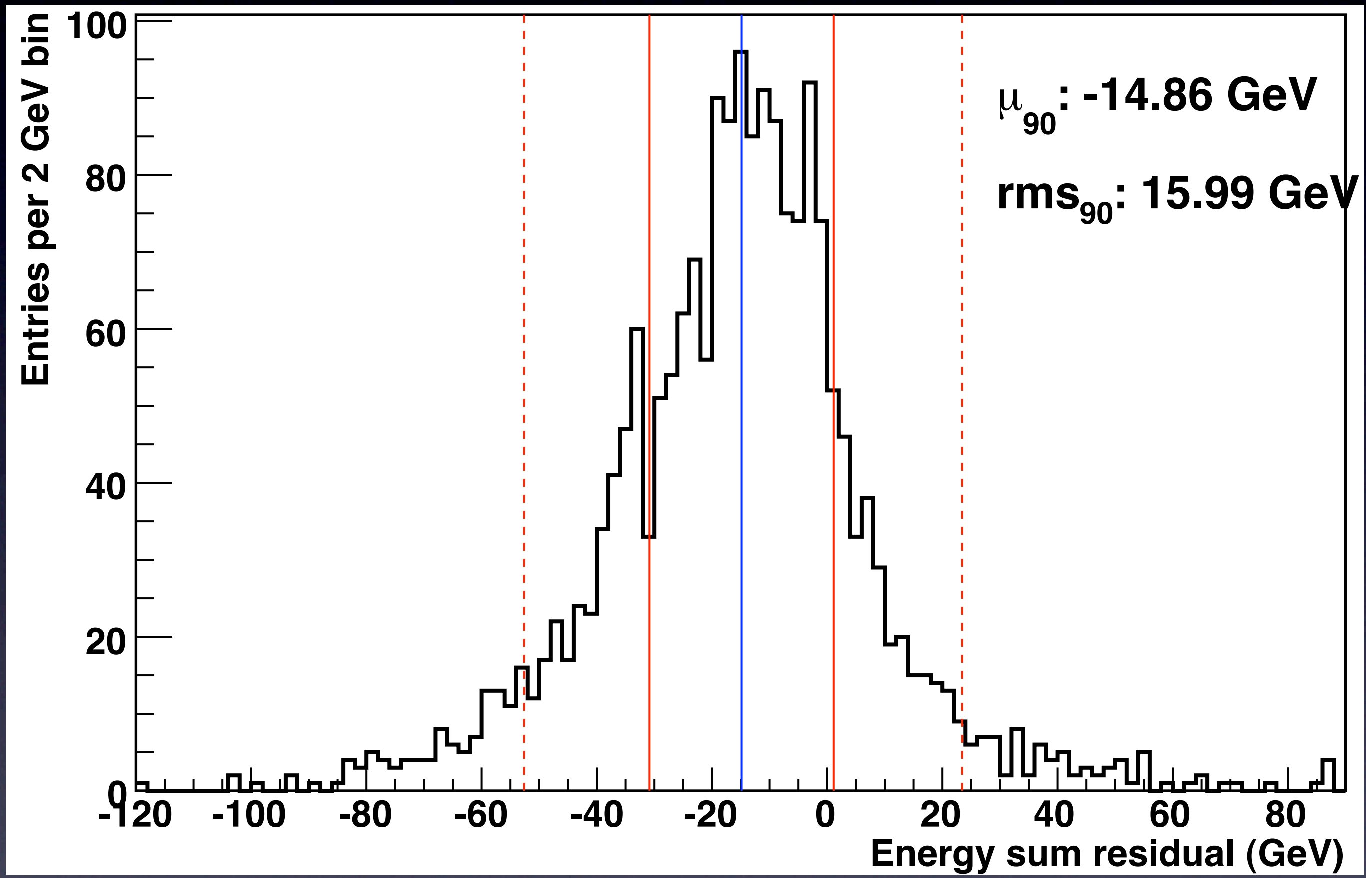
PFA metrics

- What is "acceptable physics performance"?
- The real answer will come from benchmark analyses.
  - ... including jet-finding, jet flavour ID, PID, efficiency, etc etc etc
- 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.
- 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.

Example performance plots

$e^+e^- \to qq$ (q=u,d,s) @ 500 GeV for sid02 including muon endcaps
(real tracking; no use of truth information at all)





$|\cos\theta|<0.8$: $\Delta E_{CM}/E_{CM}$ = 3.5%

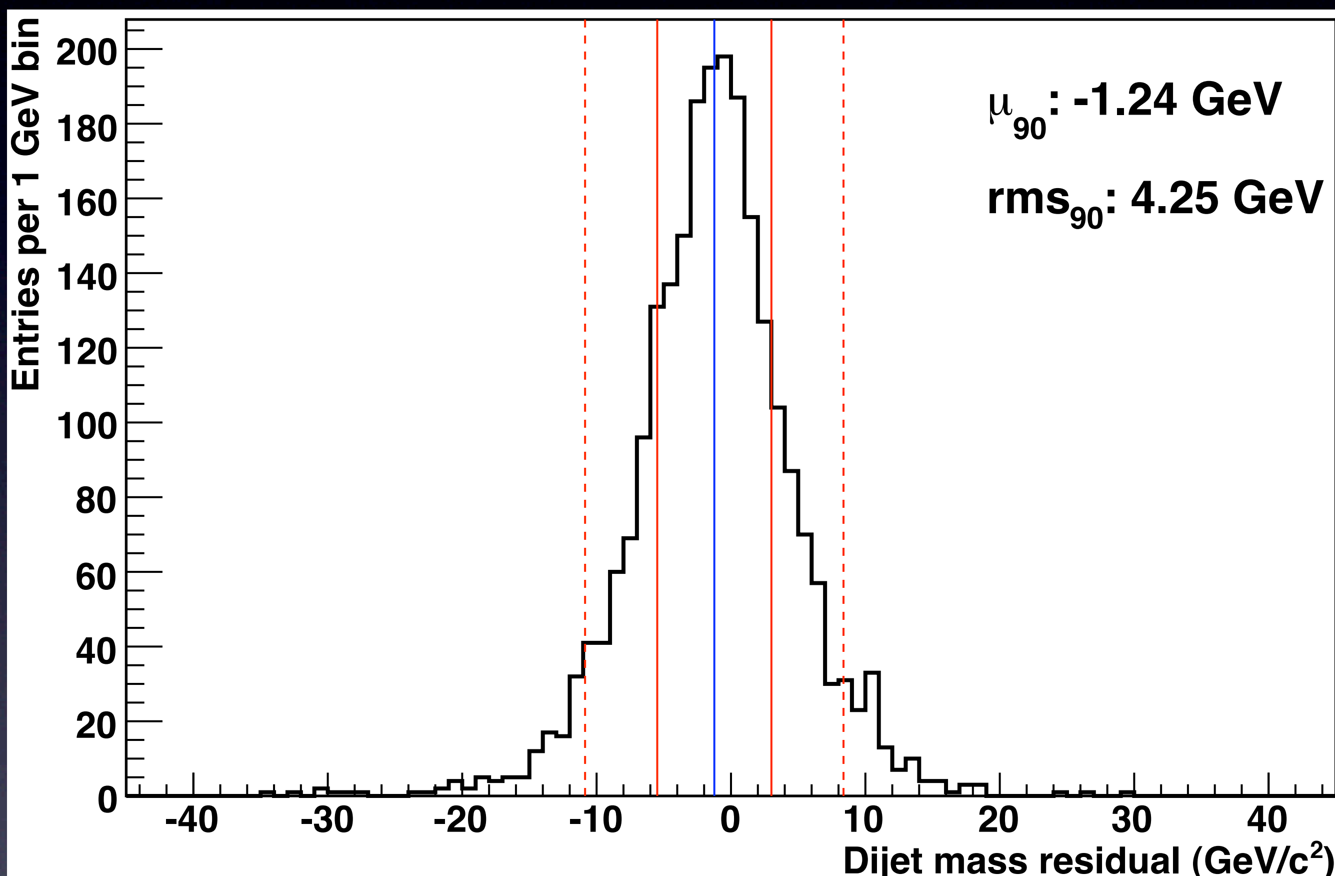
$0.8<|\cos\theta|<0.95$: $\Delta E_{CM}/E_{CM}$ = 3.3%

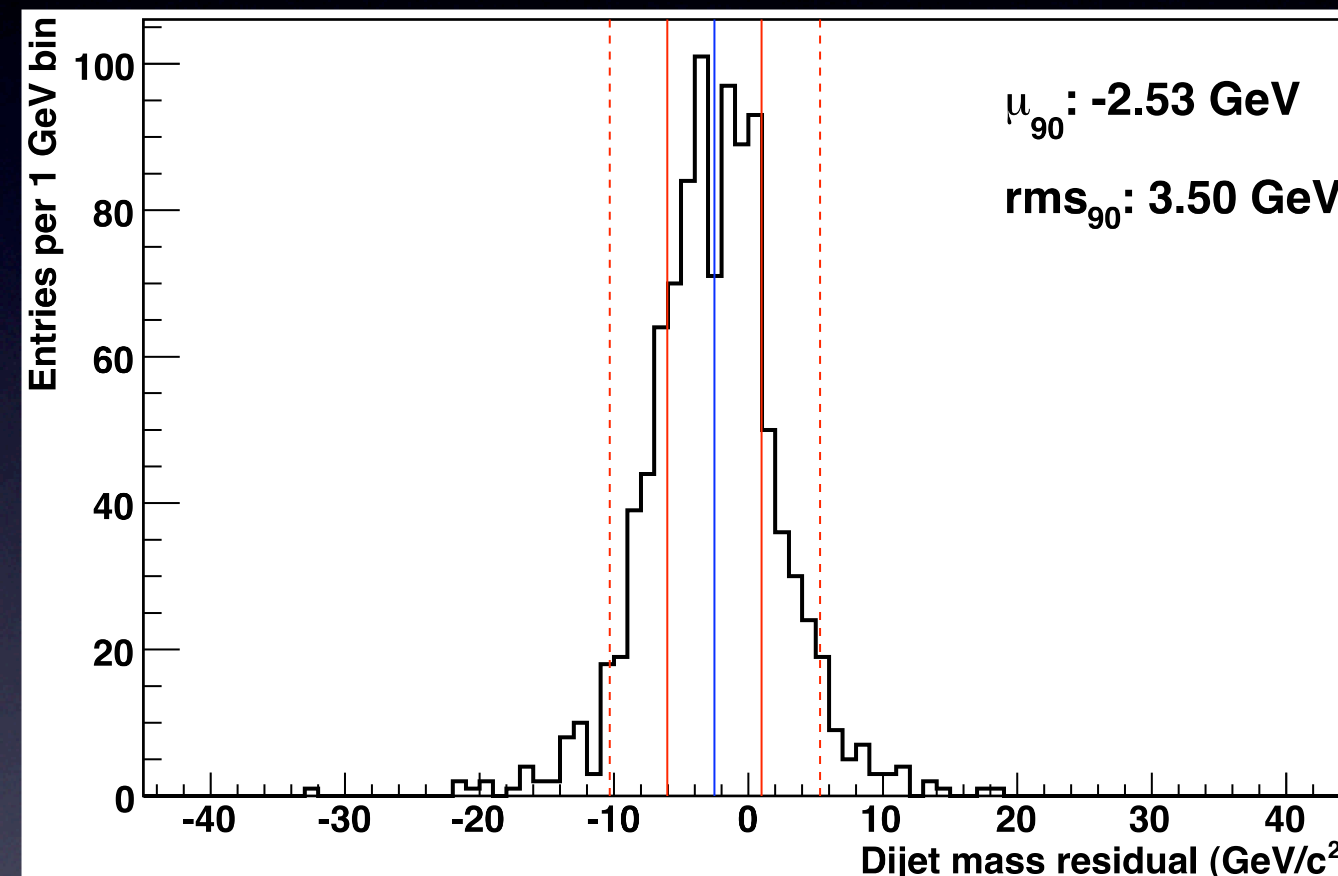
- Significant difference between barrel and forward regions.

(Watch out: Quoting ΔE_{CM}, not ΔE_{jet}. Difference is factor of $\sqrt{2}$.)

Example performance plots

$e^+e^- \rightarrow Z(\nu\nu)\ Z(qq)$ @ 500 GeV for sid02 including muon endcaps
(real tracking; no use of truth information at all)





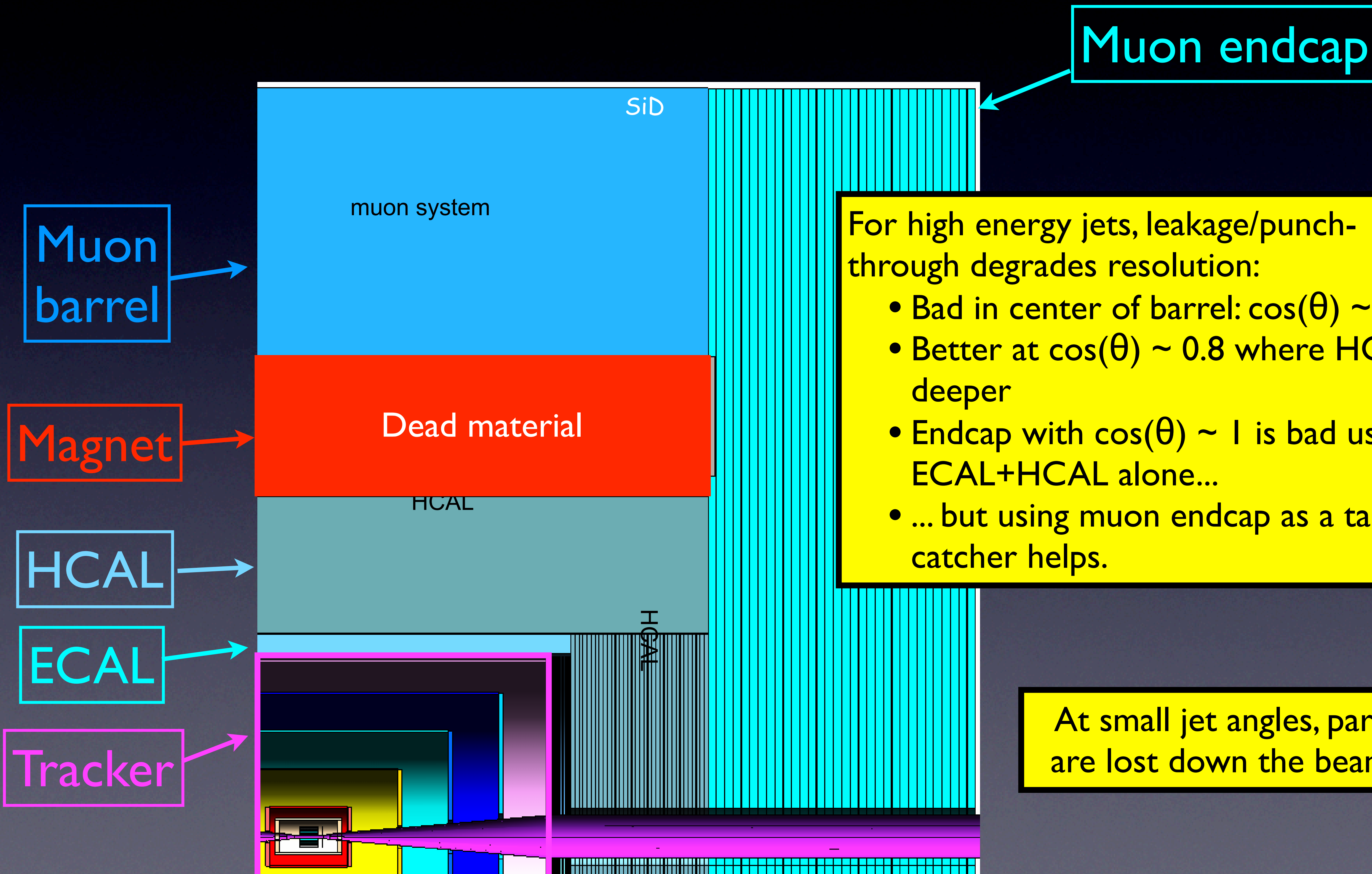
$|\cos\theta|<0.8$: dM/M = 4.7%

$0.8<|\cos\theta|<0.95$: dM/M = 3.9%

- Very large difference between barrel and forward regions (partly due to event kinematics this time).
- Let's investigate further...

sid02: Angular dependence

Aside from tracking, two main issues for PFA:



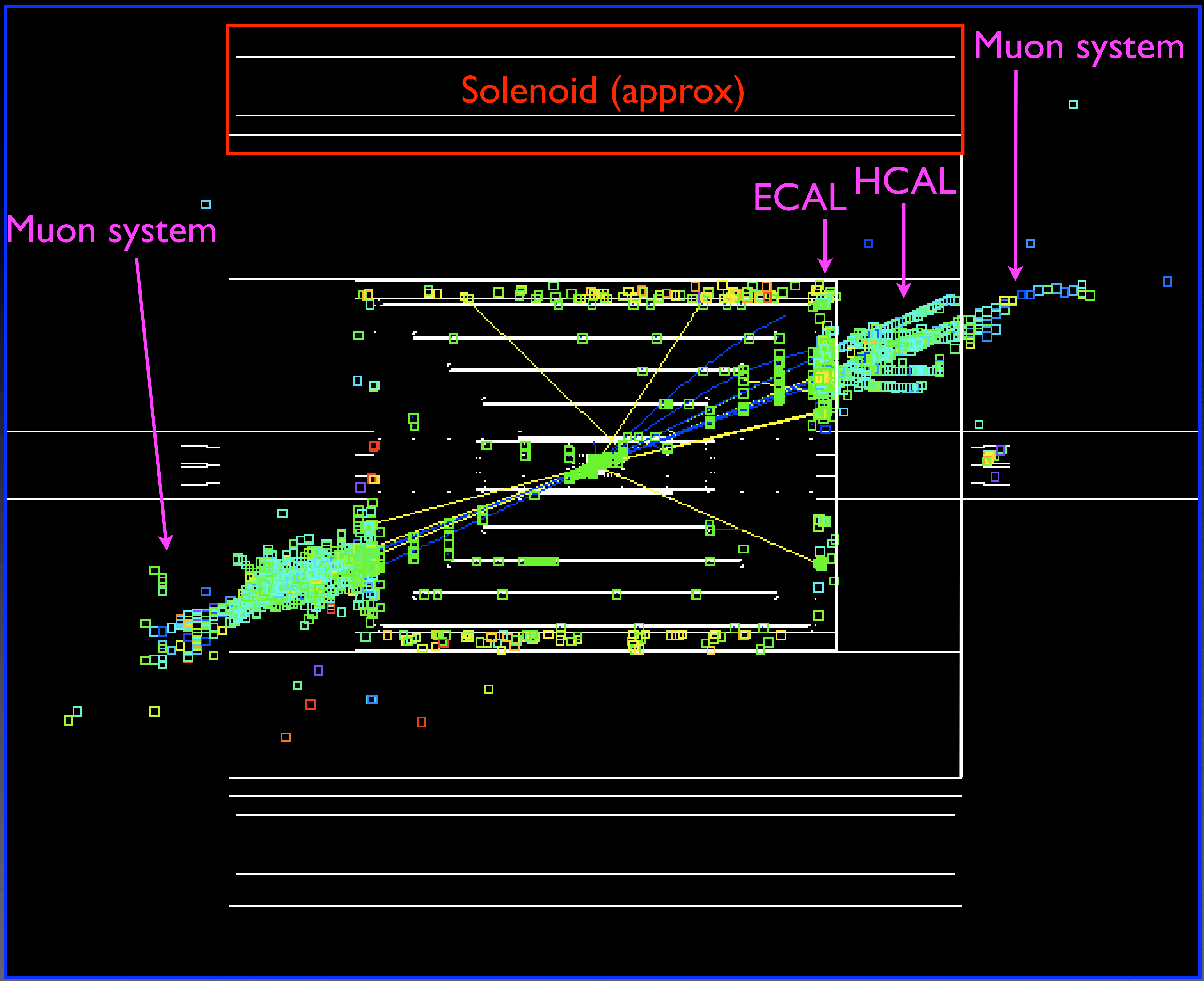
For high energy jets, leakage/punch-through degrades resolution:

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

At small jet angles, particles are lost down the beampipe

Angular dependence

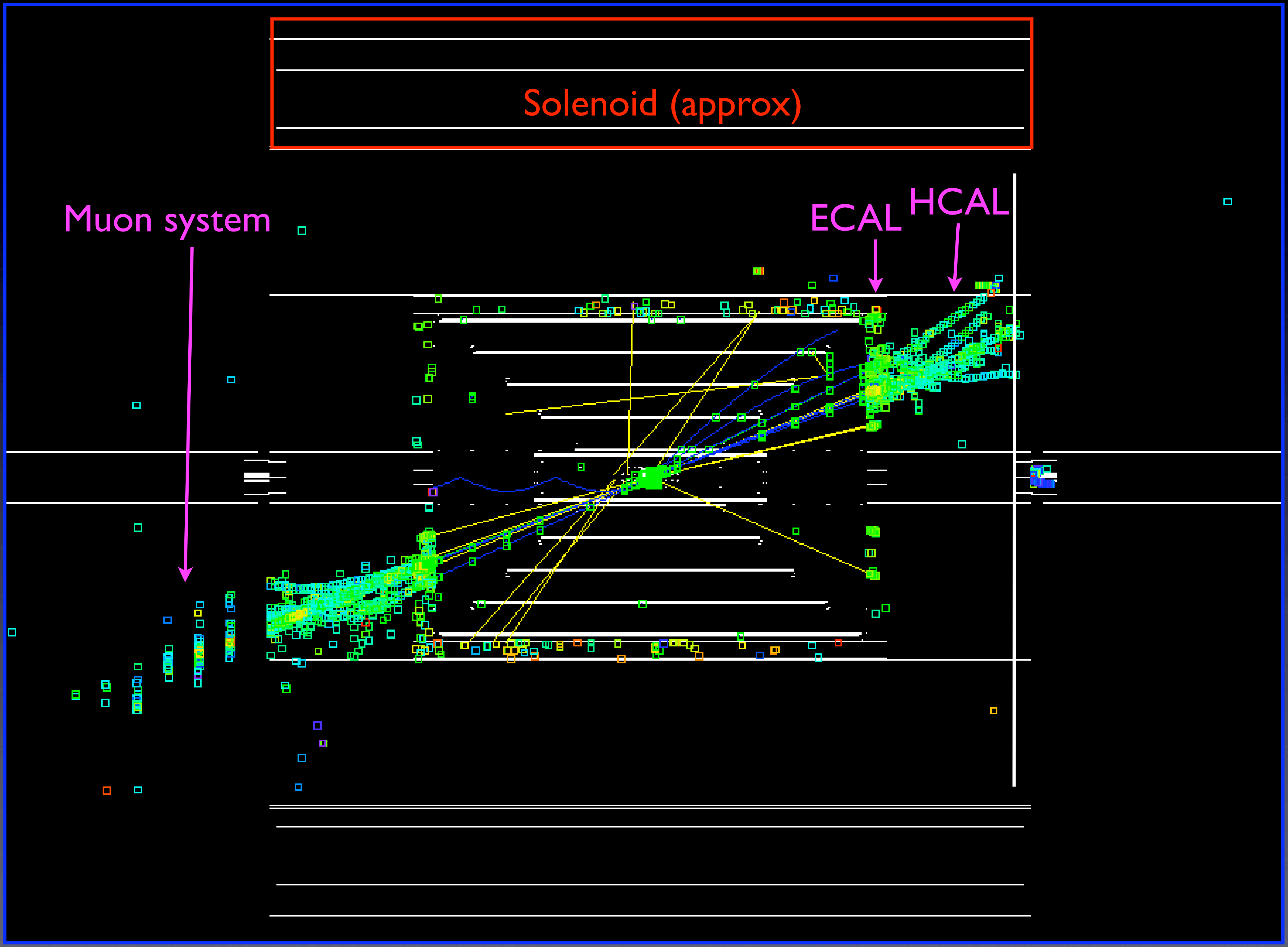
ρ-z projection of sid01, showing a qq500 event:



This is with the sid01 muon system (5cm steel plates).

Angular dependence

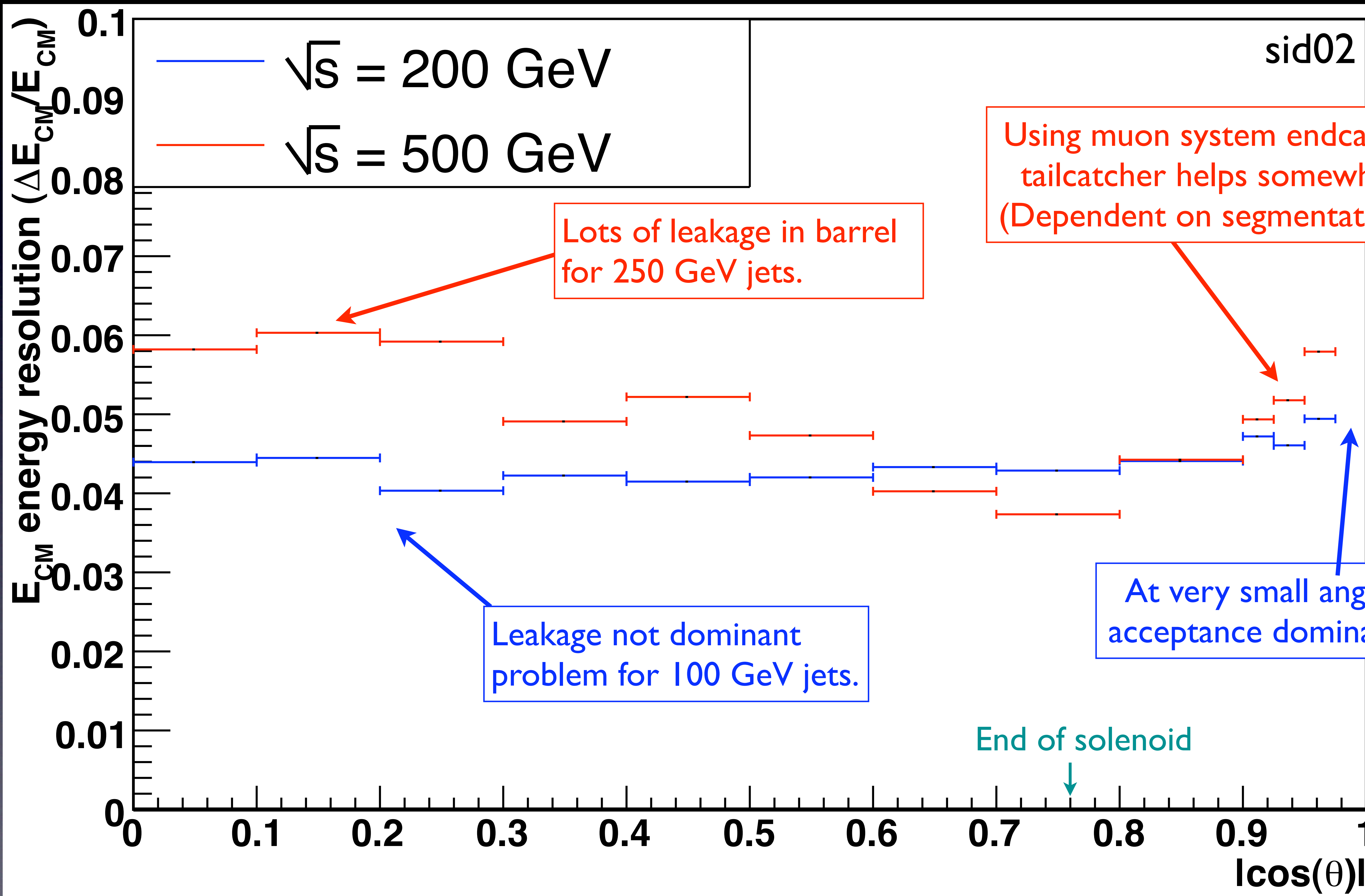
ρ-z projection of sid02, showing a qq500 event:



This is with the sid02 muon system (20cm steel plates).

Angular dependence

$e^+e^- \rightarrow qq$ (q=u,d,s) @ 200/500 GeV for sid02 including muon endcaps



Energy dependence

- Remember that for PFA, energy resolution looks roughly like:

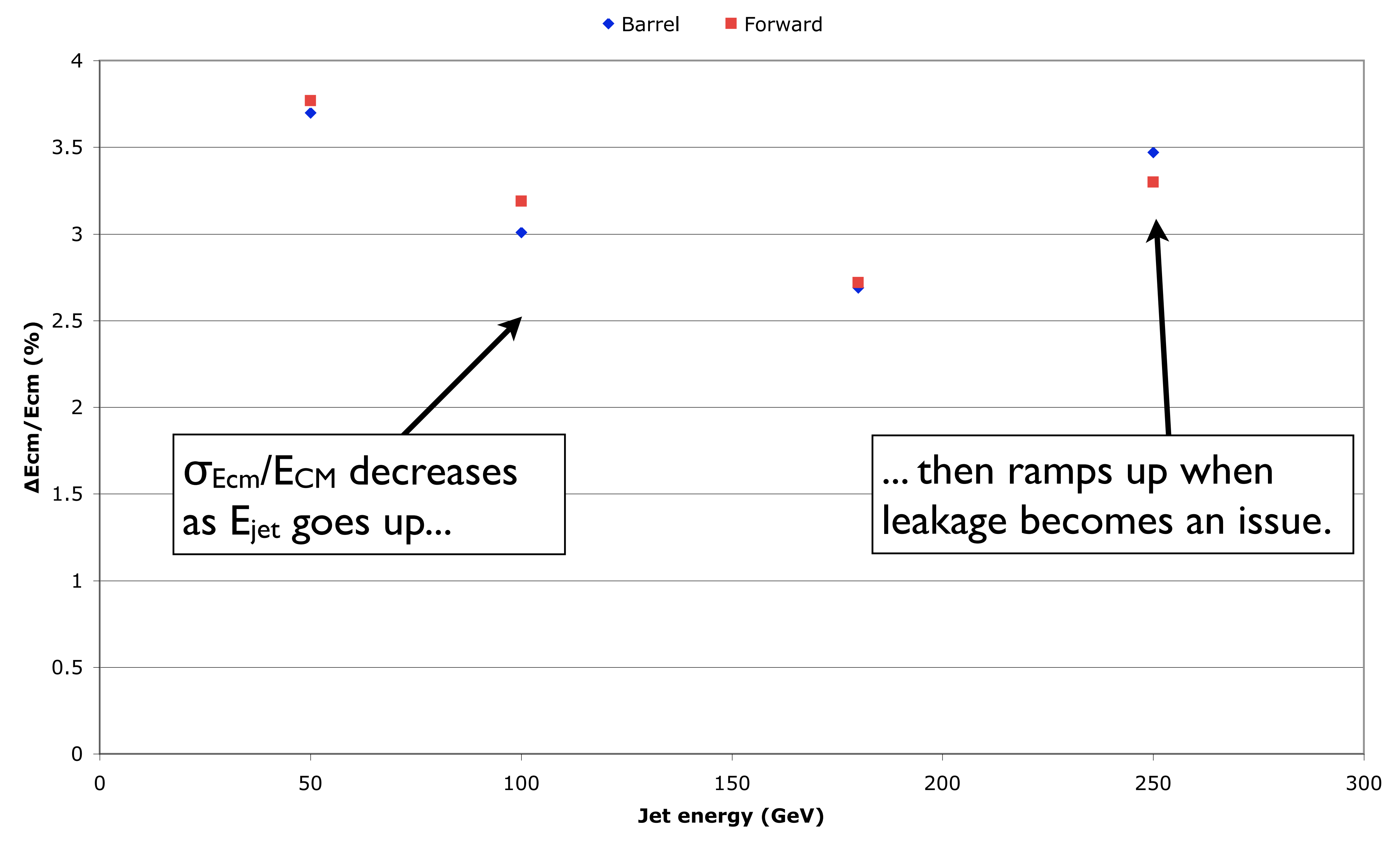
  $\sigma = \sigma_{EM} \oplus \sigma_{\text{Neutral hadrons}} \oplus \sigma_{\text{Confusion}}$

- For σ_{EM} and $\sigma_{\text{Neutral hadrons}}$, the energy dependence is understood. But we are dominated by $\sigma_{\text{Confusion}}$ -- this is less clear.

- For pure calorimetry, $\sigma \propto \sqrt{E}$.
  - Our PFA uses calorimeter energy measurements (for E/p), but is not controlled by them.
  - So expect PFA to scale somewhere between $\sigma \propto \sqrt{E}$ and $\sigma \propto E$ (such that σ/E will improve slowly with energy).

- Eventually σ_{Leakage} appears and dominates everything.

Energy dependence



- So event energy sum resolution is between 2.5% and 4.0% across the board.
- ... hence so is estimated mass resolution for mono-energetic, back-to-back jets.
- Compare to real mass resolution in ZZ events of typically 4.4%.

Within the approximation $m_{12} = 2E_1E_2(1\text{-}\cos\theta_{12})$, 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: $\Delta E_{jet}/E_{jet} = \sqrt{2}(\Delta E_{CM}/E_{CM})$

Real vs Cheat Tracking

- Recently switched from cheat to real tracking.
- Real tracking performing well: [See talk by Rich Partridge]
  - Cheat tracking somewhat better in $e^+e^- \to qq$ events at lower jet energies, minimal difference at higher jet energies.
  - Cheat tracking significantly better for Z dijet mass resolution in $e^+e^- \to Z(qq)\ Z(\nu\nu)$ events.
- Calorimeter-assisted tracking for V/kinks/secondaries in progress but not yet integrated into PFA. [See talk by Dmitry Onoprienko]

	Real tracking		Cheat tracking		
	barrel	forward	barrel	forward	
qq100	3.7%	3.8%	3.4%	3.5%	$\Delta E_{CM}/E_{CM}$
qq200	3.0%	3.2%	2.8%	3.0%	$\Delta E_{CM}/E_{CM}$
qq360	2.7%	2.7%	2.6%	2.6%	$\Delta E_{CM}/E_{CM}$
qq500	3.5%	3.3%	3.5%	3.4%	$\Delta E_{CM}/E_{CM}$
ZZ	4.7%	3.9%	4.2%	3.7%	$\Delta M/M$

Comparison with Pandora

- This is a hard thing to do properly! So far no true apples-to-apples comparison has been done:
  - Difficulties in getting the fine details of LDC00Sc etc right -- we haven't been able to simulate them in org.lcsim properly.
  - Mokka geometry description complex -- haven't succeeded to build SiD from scratch. Marcel Stanitzki has made several SiDish detectors by deforming LDC00Sc, but none is a true sid02.
- And there are other issues too, e.g.
  - Tracking (TPC vs silicon, handling of secondaries, etc)
  - 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: sid02 for $0.0<|\cos(\theta)|<0.8$ vs ILD for $0.0<|\cos(\theta)|<0.7$

B=3.5T, Z=2x2.4m, R=1.85m, 30 layer ECAL with 5x5mm Si pixels, 48 layer HCAL with 3x3cm scintillator cells.

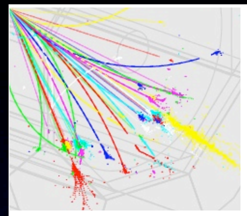
sid01	org.lcsim sid02	Pandora v03-β ILD CLIC08, 15 Oct 2008
qq90		$\Delta E_{CM}/E_{CM}$ = 2.5%
qq100	$\Delta E_{CM}/E_{CM}$ = 3.7%	
qq200	$\Delta E_{CM}/E_{CM}$ = 3.0%	$\Delta E_{CM}/E_{CM}$ = 2.1%
qq360	$\Delta E_{CM}/E_{CM}$ = 2.7%	$\Delta E_{CM}/E_{CM}$ = 2.0%
qq500	$\Delta E_{CM}/E_{CM}$ = 3.5%	$\Delta E_{CM}/E_{CM}$ = 2.0%

So our PFA on sid02 is outclassed by Pandora on ILD.

Comparison with Pandora

What about a fairer comparison: sid02 vs a SiDish detector?

Caution: This is an older version of Pandora.



The variants

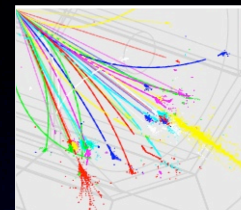
TAG	Layers	total thickness	Iron thickness	Scintillator thickness	HCAL thickness	λ_{tot}
SIDish_v2_hcal30	30	32.7	26.2	6.5	980	4.92
SIDish_v2_hcal40	40	24.5	18.0	6.5	980	4.61
SIDish_v2_hcal50	50	19.6	13.1	6.5	980	4.45
SIDish_v2_hcal30_l45	30	31.7	25.2	6.5	951	4.75
SIDish_v2_hcal40_l45	40	25.4	18.9	6.5	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

Many variants to choose from! Let's look at the closest to sid02.

Comparison with Pandora

What about a fairer comparison: sid02 vs a SiDish detector?

Caution: This is an older version of Pandora.



The variants

NB: Scintillator HCAL

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SIDish_v2_hcal60_I50	60	20.5	14.0	6.5	1230	5.49
SIDish_v2_hcal30_I55	30	37.3	30.8	6.5	1119	5.75
SIDish_v2_hcal40_I55	40	29.6	23.1	6.5	1184	5.83
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SIDish_v2_hcal60_I55	60	21.9	15.4	6.5	1314	5.99
SIDish_v2_hcal30_I40	30	28.9	22.4	6.5	867	4.25
SIDish_v2_hcal40_I40	40	23.3	16.8	6.5	932	4.33
SIDish_v2_hcal50_I40	50	19.9	13.4	6.5	997	4.41
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These lines straddle the right number of layers (40) and iron thickness (20mm)

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Marcel Stanitzki

Many variants to choose from! Let’s look at the closest to sid02.

Comparison with Pandora

	org.lcsim sid02 Real tracking	org.lcsim sid02 Cheat tracking	Pandora SiDish pair A (mean)
qq90			$\Delta E_{CM}/E_{CM}$ = 3.1%
qq100	$\Delta E_{CM}/E_{CM}$ = 3.7%	$\Delta E_{CM}/E_{CM}$ = 3.4%	
qq200	$\Delta E_{CM}/E_{CM}$ = 3.0%	$\Delta E_{CM}/E_{CM}$ = 2.8%	$\Delta E_{CM}/E_{CM}$ = 2.8%

So numbers are not so far apart for similar detectors.

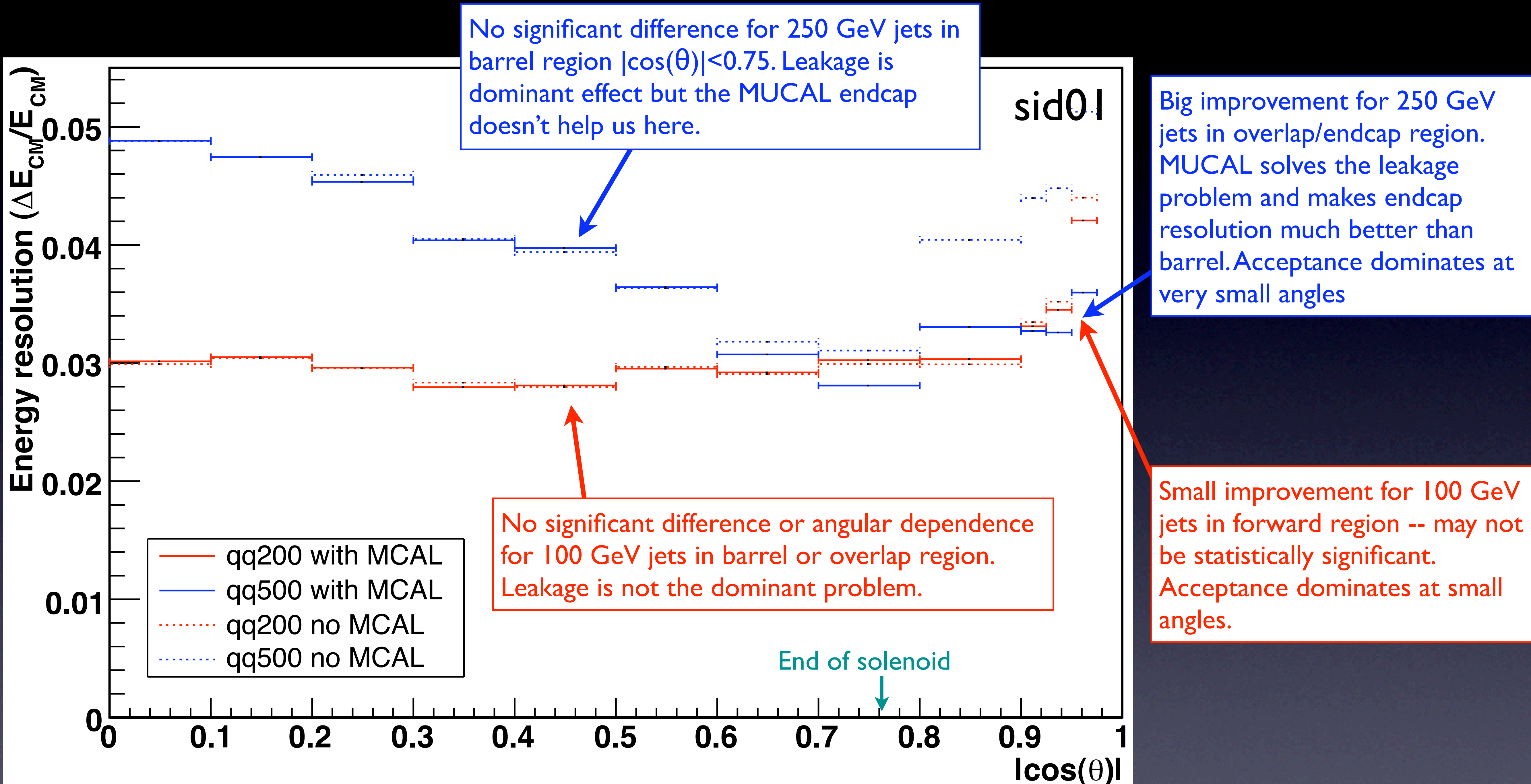
(... but what about qq360/qq500? No SiDish data yet -- CPU time limitations.)

Summary

- SiD PFA now uses real tracking code.
  - Very impressive work by SiD tracking group.
- PFA performance is getting there.
  - Event energy resolution O(3.0-3.5%) for qqbar events up to E_{jet}=250 GeV
  - Some degradation from leakage at E_{jet}=250 GeV, esp. in barrel.
  - Dijet mass resolution ~ 4.4% for ΣE_{jet}~250 GeV.
- Getting competitive with Pandora on SiDish detector for $E_{jet} \leq 200$ GeV
  - ... but performance comparison at higher energies not yet clear.
  - ... and Pandora is a fast-moving target!
- We still have a lot of improving to do.
  - Already some post-LOI fixes queued up.

Backups

Angular dependence for sid01



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.

PFA metrics

- Processes we use for quick benchmarking of PFAs:
  - $e^+e^- \to qq$ @ 100/200/360/500 GeV, looking at energy sum
  - $e^+e^- \to Z(\nu\nu)\ Z(qq)$ @ 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
  - $e^+e^- \to qq$ 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) & are closer to real analysis needs (e.g. have to measure direction for opening angle)
- 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.