Recent SiD Tracking Studies at CU (and Ancient Outer Tracker Studies at SLAC)

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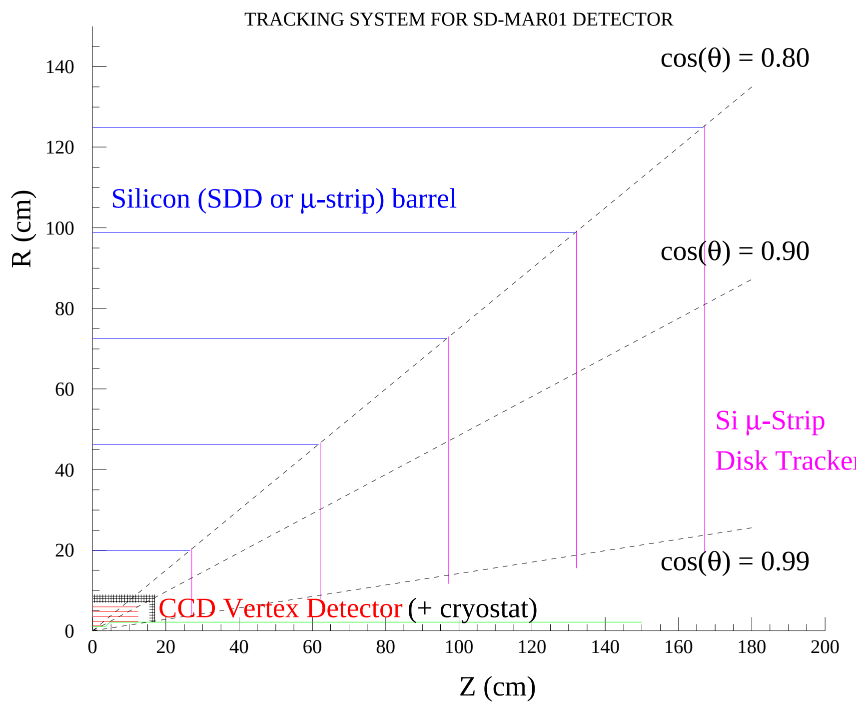
- I did realistic pattern recognition studies for the SiD Barrel Outer Tracker for Paris 2004 LCWS
- These studies included the effects of the full (fierce) machine backgrounds (BGs) associated with the warm LC
- I wrote these up as SLAC-PUB-10991 and submitted to the proceedings
- They seem to be totally forgotten now



Ancient History

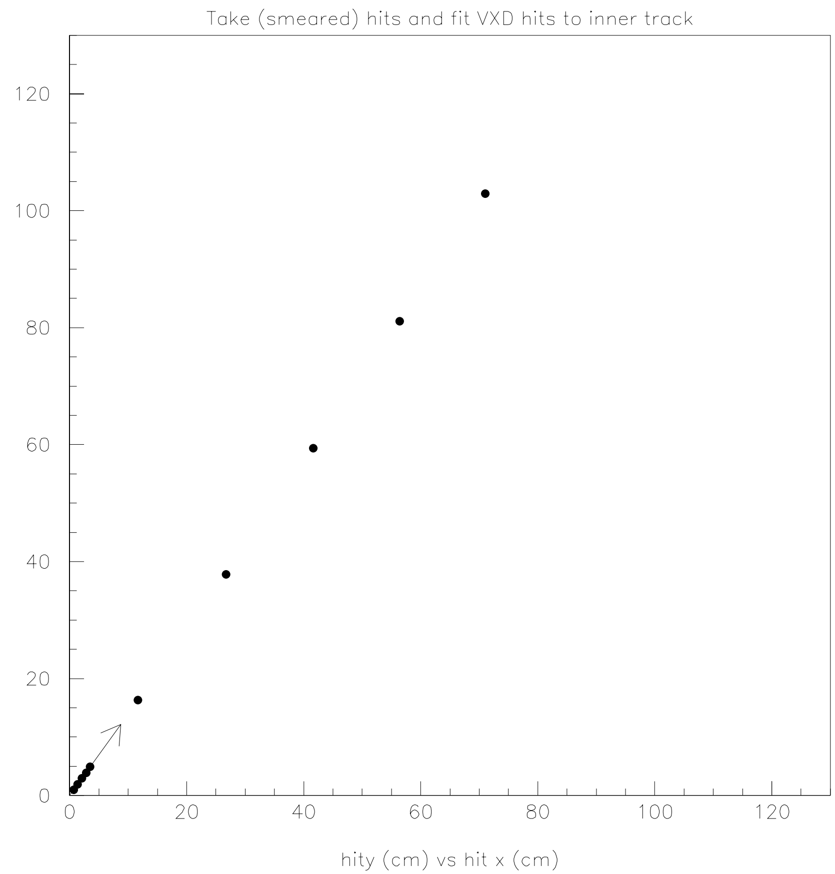
- I used the SDJan03 version of the SiD barrel outer tracker. 5 T field, 5 $single-sided$ layers of Si ($R_i = (20, 46.25, 72.5, 98.75, 125)$ cm)
- The version of the outer tracker I did the most studies on had $long$ ladders and $no\ z$ information. Each barrel is $split$ at $z = 0$ and read out at its outboard end
- Near the end of my studies a new variant of the outer tracker appeared. Each 10 cm long wafer on a ladder was read-out separately ("tiled"). This was an attempt to deal with the BGs at the warm machine and still appears in many (all?) of the new detector variations
- I started out writing stand-alone pat rec for the outer tracker, finding K_s^0 in a pristine detector
- Was convinced (by others) more immediate problem was just extending inner tracks into fully occupied outer tracker
- To many people the SiD outer tracker seems like too minimal a detector. Backgrounds and other tracks pile up, making pattern recognition problematic. I said I'd see if the problem was tractable

Code Used For Studies (SODHitAdder)

- Took tracks (perfect pat rec but realistic resolutions) reco-ed in the vertex det (SODTrackFinder) and projected them out into the outer tracker - added hits and refit tracks
- May sound like I just used Nick's code but I didn't - wrote my own, including fitter, from scratch in java (actually rewrote a lot I had written in c++ for BaBar)
- Predates Nick's patt rec code but my patt rec has never been in general (or for that matter, any) release for others to use
- My code deals with barrel tracking only - Nick's does forward too. But good to have two different algorithms (even if very similar) to beat against each other
- And mine is definitely "prototype" code - easy to change if you've got a new better idea

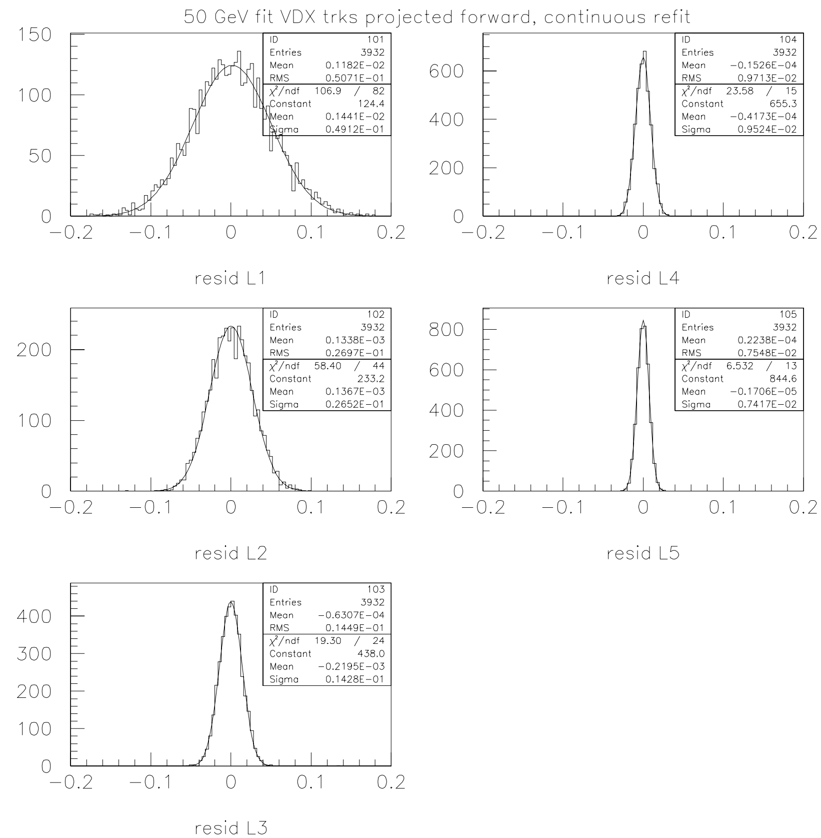
$p_T = 50$ GeV Track in Quadrant of Outer Tracker

- Worked in JAS2 using SDJan03 MC data (and just ignored the z info that's there for outer tracker hits)
- MC simulation includes resolution, scattering and E-loss (deltas), interactions (inc. calorimeter splash-back), decays
- Take trks found and (helix) fit in VXD and project out to outer tracker
- Add (closest) hit and refit trk at each outer tracker layer



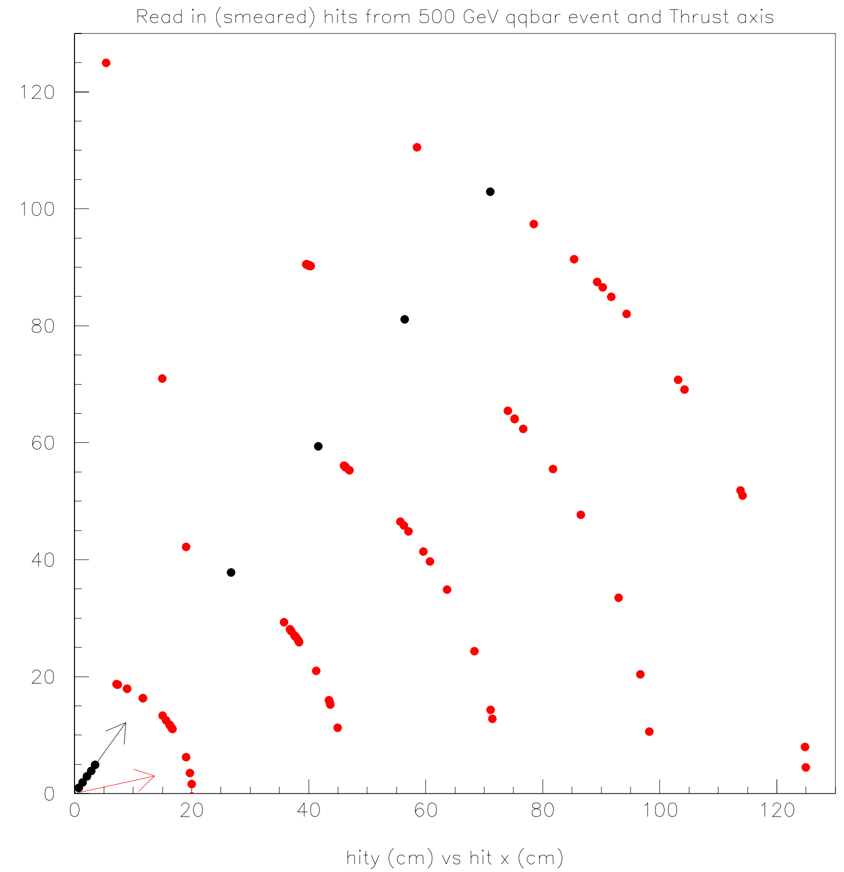
Adding Outer Tracker Hits to Projected VXD Tracks

- 50 GeV/c tracks (shown) gobble up outer tracker hits, get better as they go out ($\sigma_{resid} = 490\ \mu\mathrm{m}$ at L1 to $\sigma_{resid} = 74\ \mu\mathrm{m}$ at L5)
- Will only get a little better with full Kalman fits
- Run it on clean tracks (1 and 50 GeV/c p_T) projected out and projected back; picks up all hits and fits correctly (eff $= 100\%$)
- But no one really cares about tracking in trivial evts



Mix in Hits from $\sqrt{s} = 500$ GeV $q\bar{q}$ Events

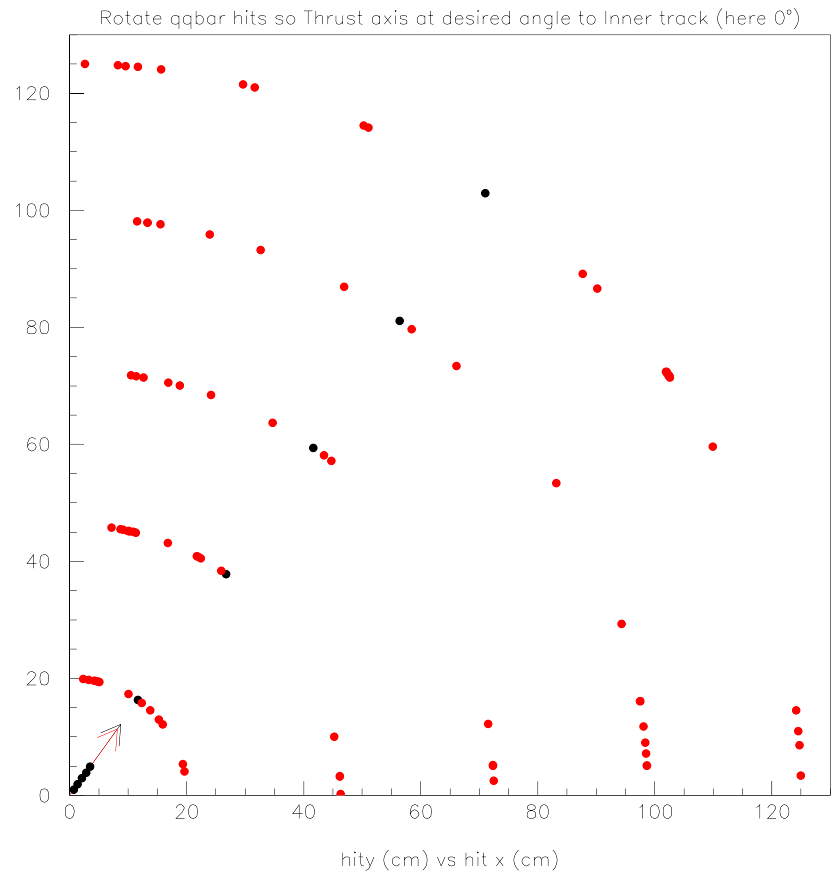
- Write out outer tracker hits and T(hrust) axis for $\sqrt{s} = 500$ GeV $q\bar{q}$ evts if T axis of evt in outer tracker barrel.
- 1810 evts to work with, about 45 hits in each outer tracker layer
- Read in hits from $q\bar{q}$ evts, rotate them in ϕ so T axis is a pre-determined angle from probe track



- Mix together outer tracker hits for probe trk and $q\bar{q}$ hits. Probe trk hits flagged, but only inspected after all pat rec is over

Rotate $q\bar{q}$ hits so Thrust Axis at Set Angle to Probe Track

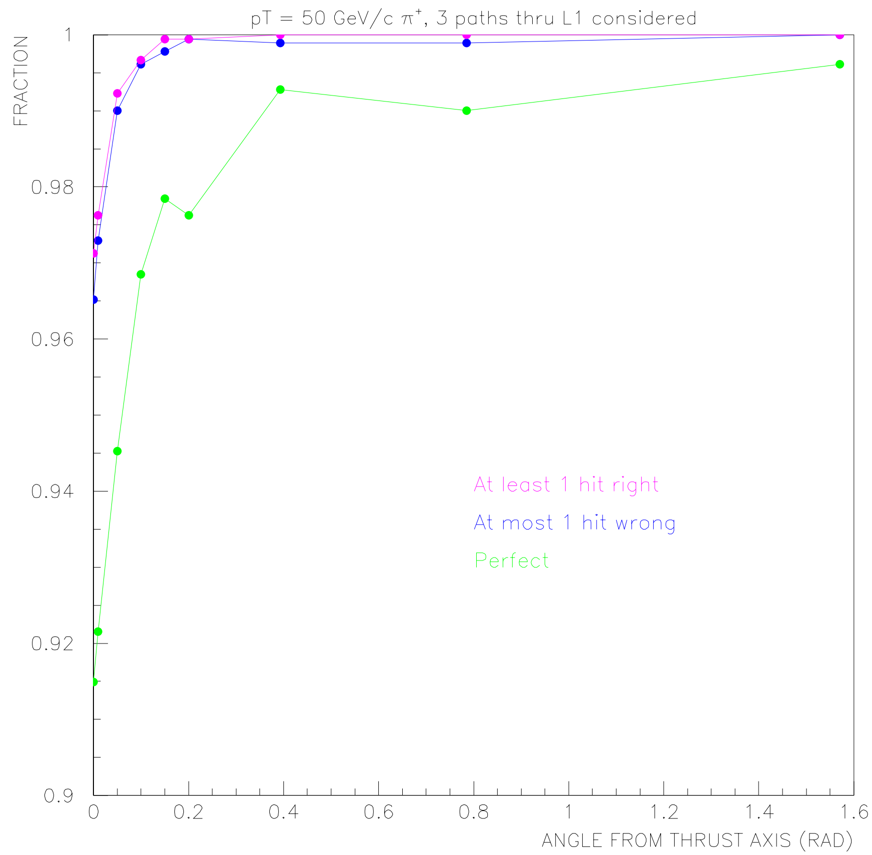
- Allows to scan eff measurement from more problematic regions (T axis approx center of jet) to easiest (90^o from T axis)
- Change pat rec algorithm to make 3 trial trks using 3 closest hits in outer tracker L1. Past L1 the trials pick up closest hit in each layer and continuously refit. Trials often share hits past L1 (sharing *not* allowed in L1)



- Pick final trk on χ^2/dof. Also throw preference for more hits into arbitration process (reject L2-L5 duplicates which achieve lower χ^2/dof because no additional L1 hits available)

Efficiency for Reco-ing 50 GeV Probe Trk with Hit Adding

- For green curve, require found trk have *all* its correct hits (be "perfect").
- The blue curve is where at most 1 hit in outer tracker is wrong. Often call trks where 1 hit is wrong "close;" blue curve is perfect+close
- Purple curve is trks where at least 1 hit in outer tracker is right - area above purple curve is fraction at that angle (to T axis) where *all* outer tracker hits are wrong

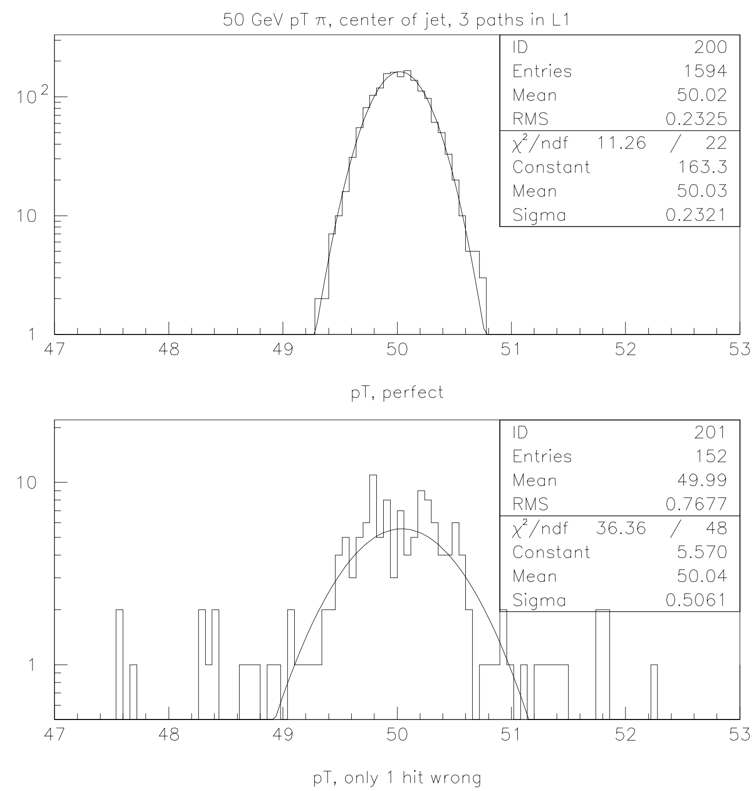


Fraction = Efficiency

- VDX trk has latched onto wrong trk in outer tracker here. VDX trk (short stub) does not have great momentum resolution for high p_T trks

Close Tracks Not Really That Bad

- Tracks with 4/5 outer tracker hits right still have all 5 VXD hits right
- Momentum resolution for these trks is about a factor of 3 worse if track is high p_T
- These are the sort of occurrences that give us unwanted but always observed "tails" on our measured p_T resolution, but still usable (and used) trks



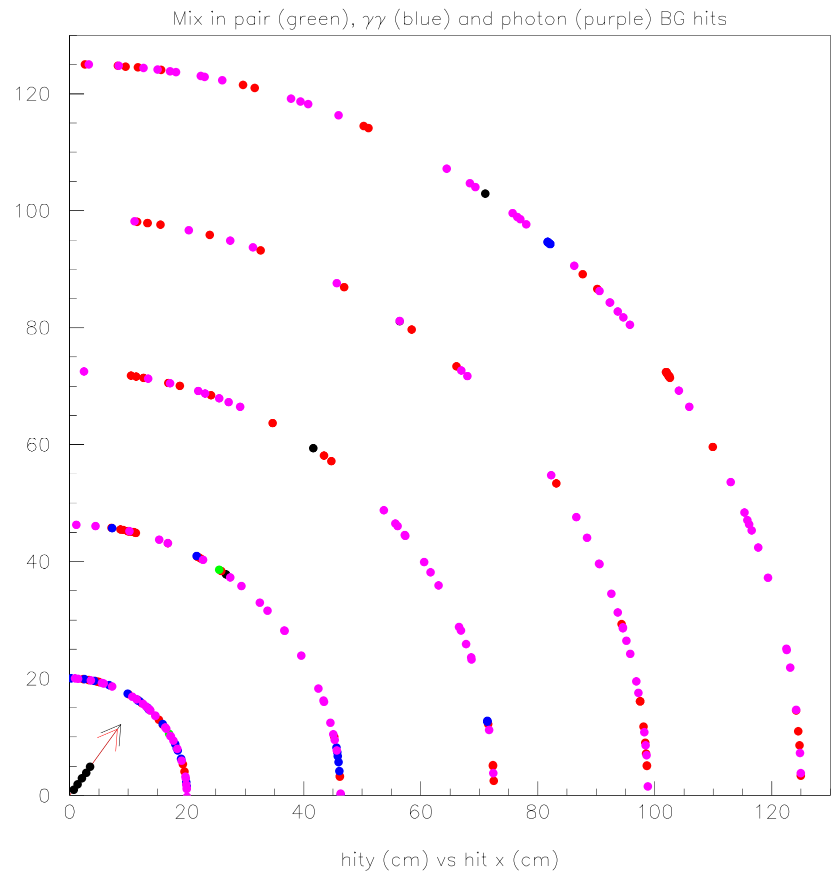
- A χ^2 comparator to MC truth would consider *most* of the close trks properly found - I will also, but I won't consider trks with $\geq 2/5$ outer tracker hits wrong properly found

Future Project: Hit Arbitration

- And at least so far, there's another real trk that wants (produced) the bad hit on the "close" trk, and the correct hit for this trk is also close by - hit can be arbitrated away later in pat rec to lower global χ^2
- This is also the case where it's latched on to completely wrong trks (1-purple curve); there's another trk that wants all those hits
- Approx 60% of time next best trial to completely bad trk is correct "perfect" trk, χ^2 a *little* worse; approx 20% of time next best is correct "close" trk

Mix in Pair, $\gamma\gamma$ and Photon BGs

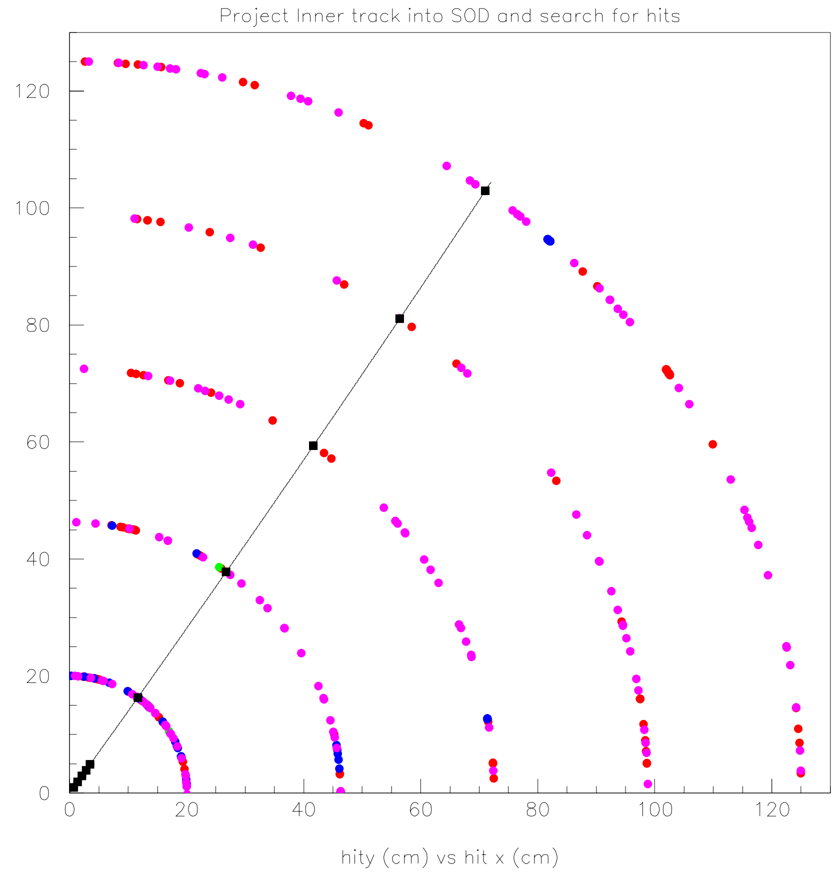
- Hits generated were for 1/2 of barrel - VXD trks have excellent z resolution and know which 1/2 of the outer tracker they're pointing into
- Take pair and $\gamma\gamma$ interactions from old files; mix in enough of each to get specific occupancy in L1 correct (calc by Takashi Maruyama for warm LC)



- Add in photons (random salt-and-pepper) and dial in enough to match correct total occupancy in each layer
- Total occ by layer for split outer tracker was (0.83,0.27,0.15,0.10,0.08)%
- Dominated by photon BGs - $\gamma\gamma$ and pairs only significant in L1

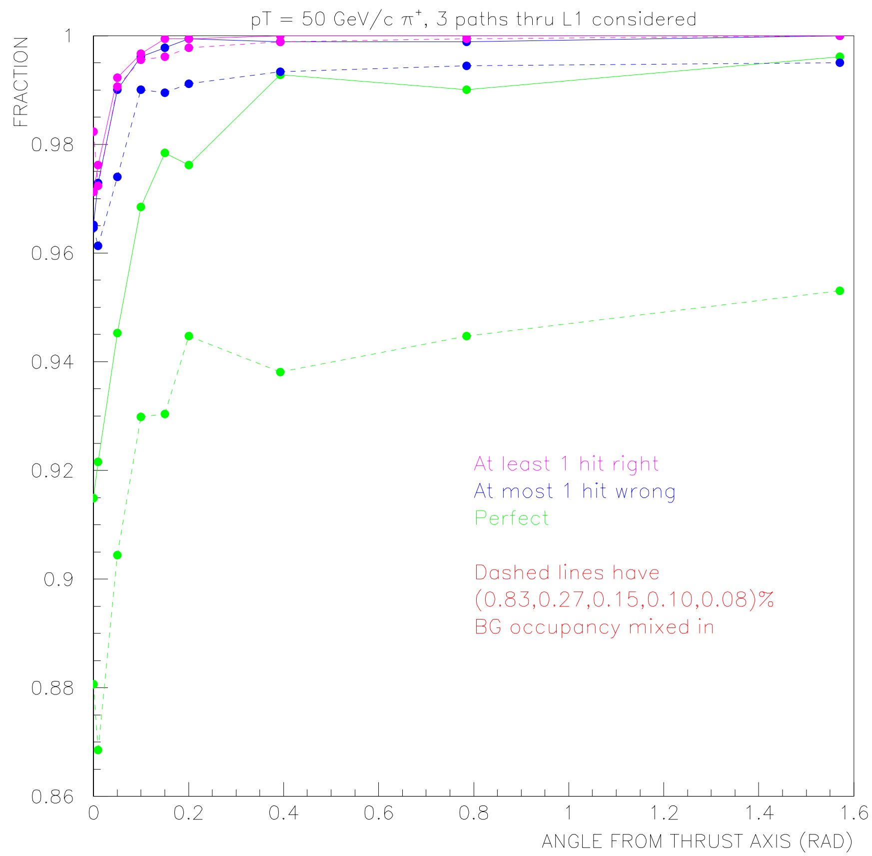
Project VTX Trk to Outer Tracker and HitAdd in Heavy BG

- Same algorithm as before
- For this evt, it was easy. It's a perfect trk all the way out
- Next best trial trk has χ^2 factor of 5×10^5 worse, 2 bad hits (and 3 good ones, shared with best trial track)
- But not all this easy



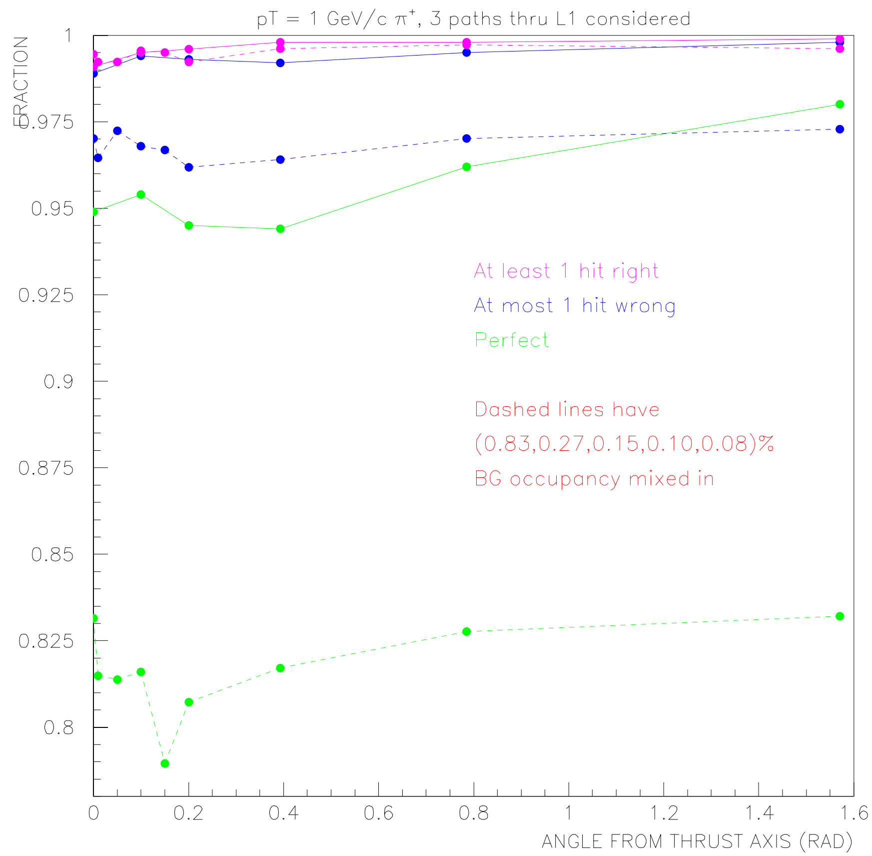
Effect of Full BGs on 50 GeV Tracks

- Solid curves are for only $q\overline{q}$ evt overlaid (shown earlier), dashed curves are with full BGs mixed in also
- Noticeable effect on "perfect" eff, but "perfect+close" eff $>$ 99% over most of solid angle; "wrong trk" effect still dominates ineff near jet core



Effect of Full BGs on $p_T = 1$ GeV Tracks

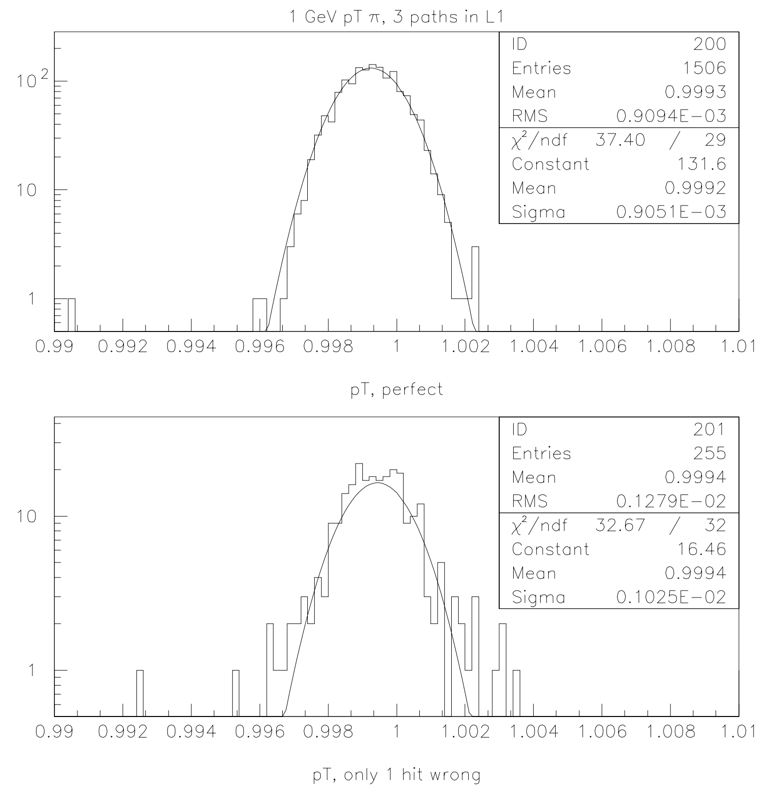
- Eff more uniform for $q\bar{q}$ evts without BG, but not as high outside jet. May just be an un-optimized windows
- But effect of BG is quite dramatic, especially on "perfect" trks
- Pattern of bad hits is different here (with BGs) than elsewhere. Usually it's L1 bad; here mostly L5 bad



- 1 GeV p_T trks almost don't exit outer tracker; they enter L5 at a very steep angle, and have *lots* of BG to pick from in L5
- Here's probably the one place a full Kalman extrapolator, which I haven't written yet, would really help

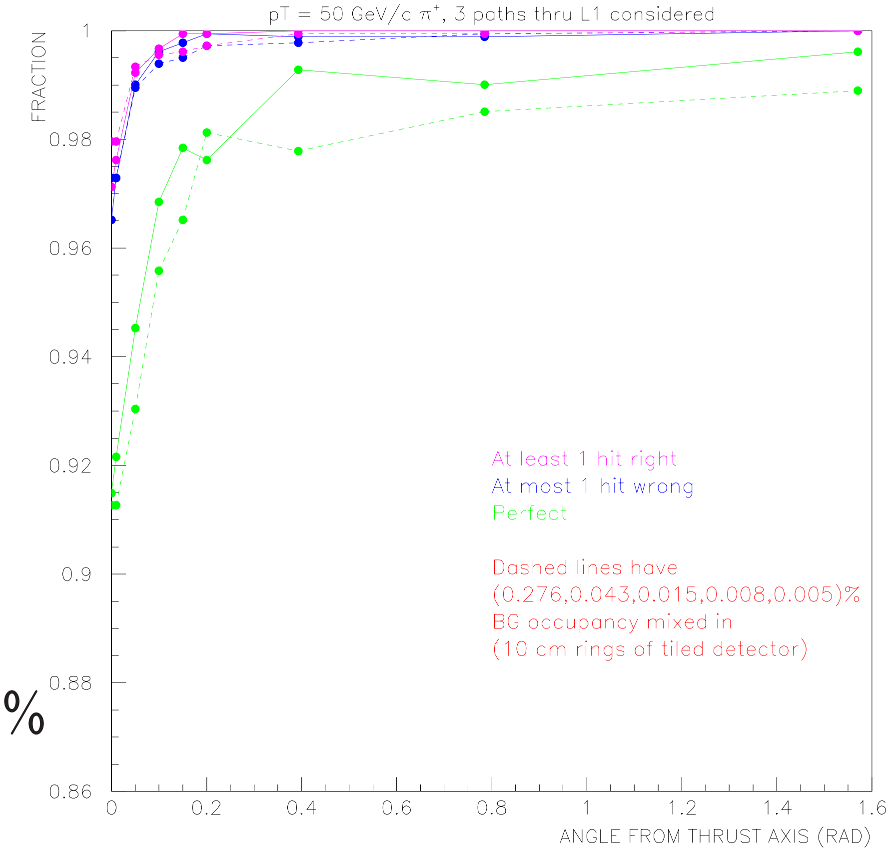
But Close $p_T = 1$ GeV Tracks are Pretty Good

- Picked-up bad hit (mostly in L5) doesn't effect 1 GeV p_T trk as much as high p_T trk
- p_T res only degraded $20 - 30\%$, probably worse when full Kalman fit done



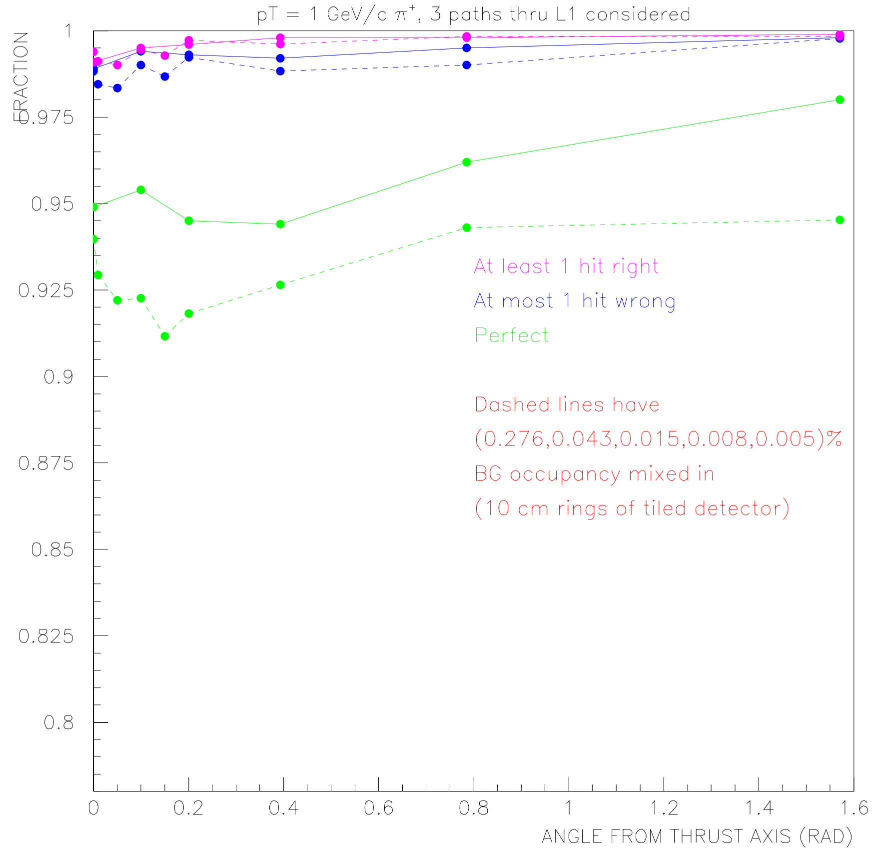
Effect of Tiled Outer Tracker on $p_T = 50$ GeV Tracks

- Concept is to read out each 10 cm x 10 cm wafer separately rather than chain them together in half-barrels
- Number of BG hits remains the same, but number of strips really increases
- Occupancy now (0.276,0.043,0.015,0.008,0.005)%
- Effs return to near what they were with only $q\bar{q}$ hits mixed in



Effect of Tiled Outer Tracker on $p_T = 1$ GeV Tracks

- Really helps lower p_T trks
- Occupancy reduced a factor of 16.7 in L5



Paris Conclusions

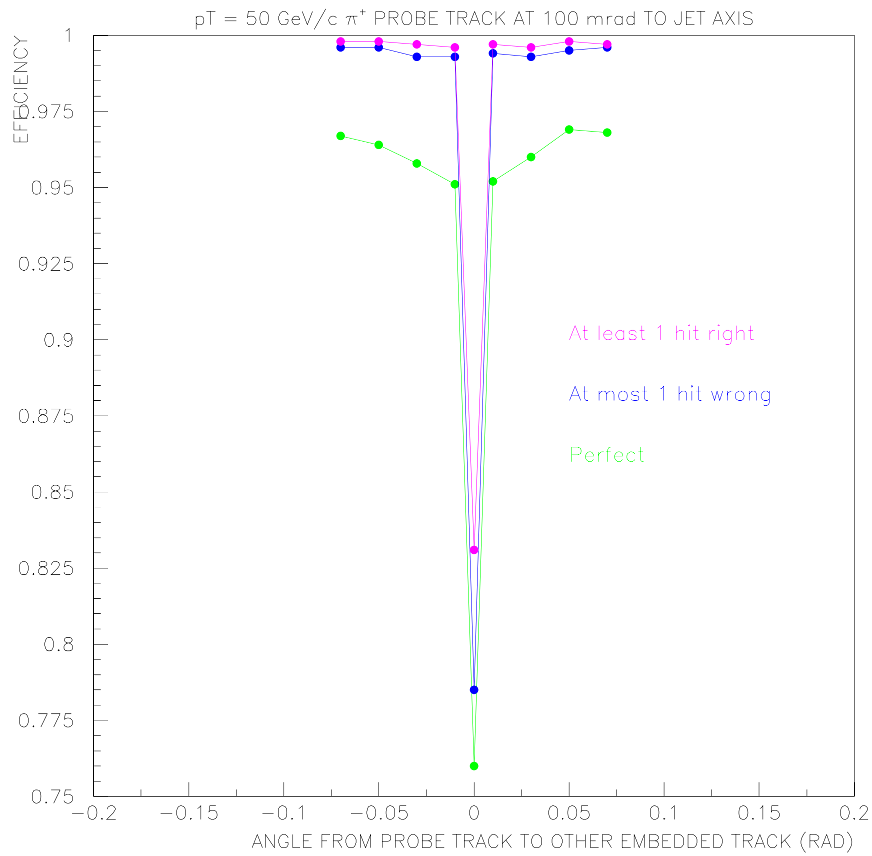
- If willing to define eff as $\geq 9/10$ hits correct ($> 90\%$ of trks have ideal res, $< 10\%$ slightly degraded), then eff $> 98.5\%$ for tiled detector across jet, indep of p, except for high p_T trks in core of jet (< 50 mrad), where eff drops to $> 96.5\%$
- Dip at 0^o to T axis swapping $real$ trk outer tracker hits (or whole outer tracker trks) between VXD trks. If carry around multiple viable candidate trks with hits, should be able to arbitrate most/all of effect away (not proven yet)
- Effect overestimated anyway, as probe trk not subject to momentum conservation of entire $q\overline{q}$ evt - not as many dual high p_T trks near jet core in real world

What I Tried (And Failed) To Do Last Week

- Tried to migrate to JAS3 and org.lcsim so I could look at new detectors in slcio
- Wanted to get new expected BG levels in outer tracker and repeat some old studies with new (cold) numbers
- Was unable to get my old code running even on old sio files in this environment
- Too many things I needed were missing. Got some explanations yesterday; still need a few more

What I Did Last Week: Two-Track Resolution Studies

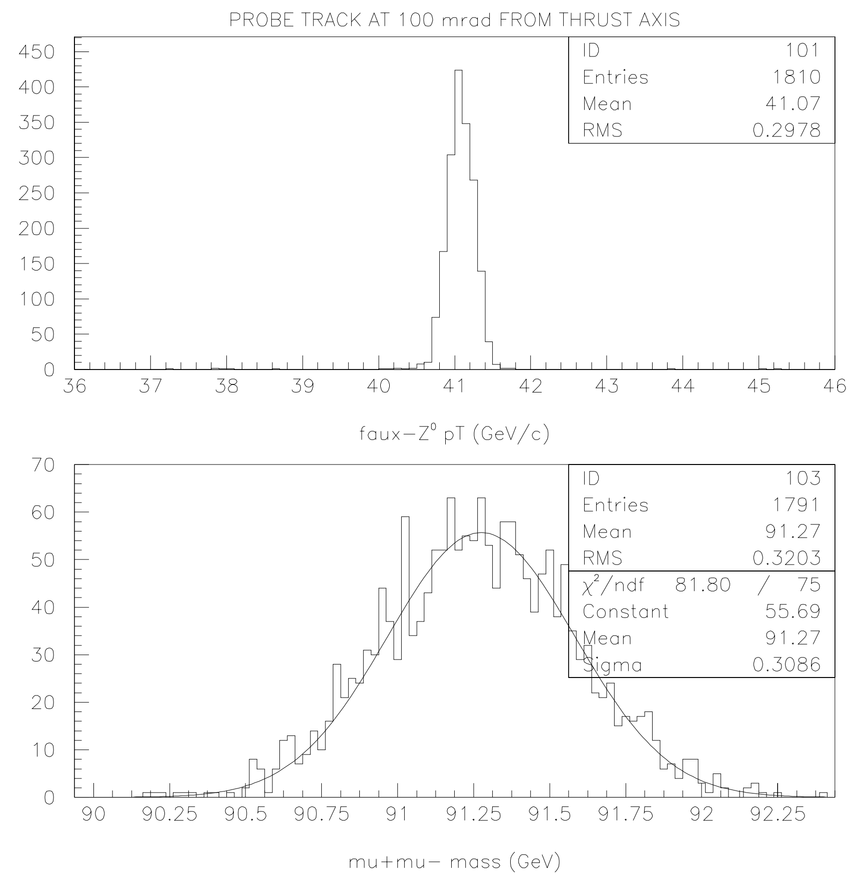
- Went back to JAS2/hep.lcd and tried to resolve some outstanding questions from Paris studies
- Stop mixing in BGs, but keep mixing probe track and hits from $q\bar{q}$ evts
- Rather than figure out navigation of hits back to MC truth in $q\bar{q}$ evts, add yet *another* track's hits (at an arb ang to probe trk)



- Park probe trk just outside (100 mrad) jet core and sweep other embedded 50 GeV/c trk past it and measure probe trk reco eff

Can Make Z^0 From Probe and Embedded Tracks

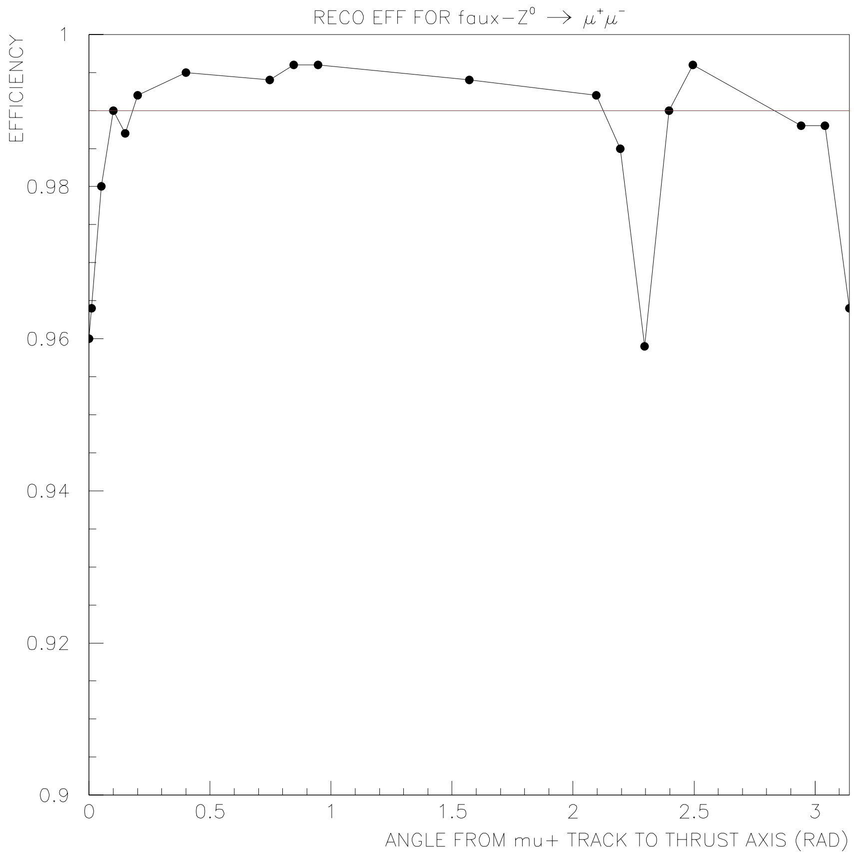
- Can reconstruct both probe and embedded trk in outer barrel from their VTX trk and hit adding
- Two 50 GeV tracks at the specific angle (131.5^o) wrt each other make a ($p_T = 41$ GeV/c) $Z^0 \rightarrow \mu^+\mu^-$ decay
- I call this a "faux-Z" mostly because it covers a tiny amount of available Z^0 phase space



- But it allows me to define a trking efficiency (or a Z^0 reconstruction eff) without having to resort to arguing whether a "close" trk is well-enough reconstructed

Look at faux-Z^0 Efficiency vs $\mu^+ - \vec{T}$ Angle

- Define correctly reco-ed Z^0 as one within ± 1.25 GeV $(\pm\Gamma/2)$ of nominal mass
- Note I gave Z^0 no natural width. Reco-ed width is just detector resolution
- Averaged (over ϕ) reconstruction eff for these Z^0 (remember, in Z^0 $jet\ jet$ events - average multiplicity ~ 47) is 99.1%



What to do at Snowmass?

- My code isn't very tied to hep.lcd. Can continue port now that I have experts close by. May have results for new detectors by end of next week
- Get correct BG levels for cold machine from Takashi and turn BGs back on
- Can try hit arbitration to try to improve two-track resolution
- Any other suggestions (for the tools I have)?