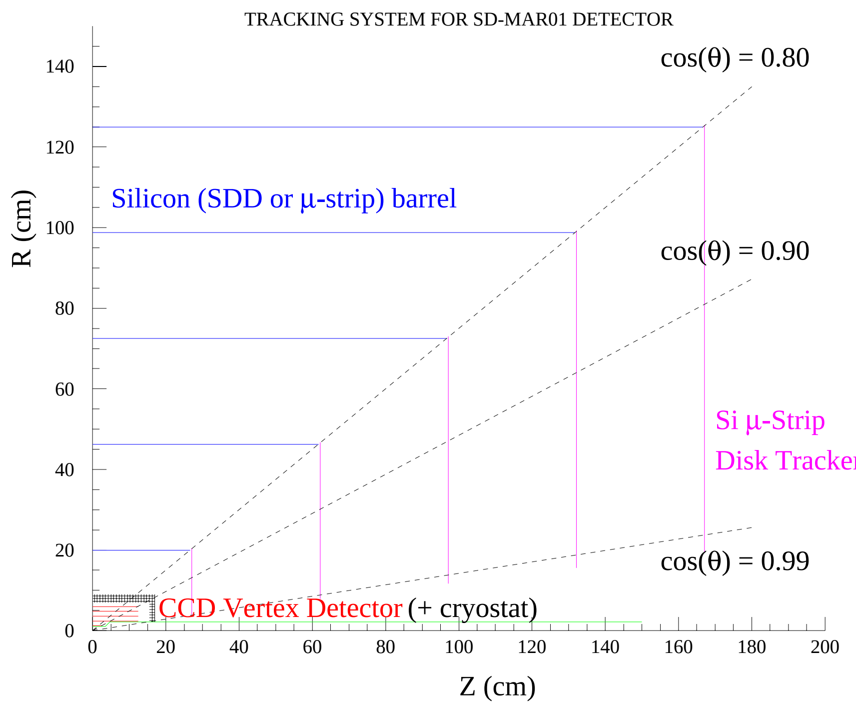
Pattern Recognition Studies for a Silicon Outer Tracker

Steve Wagner, SLAC

- One version of the SiD barrel outer tracker has 5 $single - sided$ layers of Si ($R_i = (20, 46.25, 72.5, 98.75, 125)$ cm) in 5 Tesla field

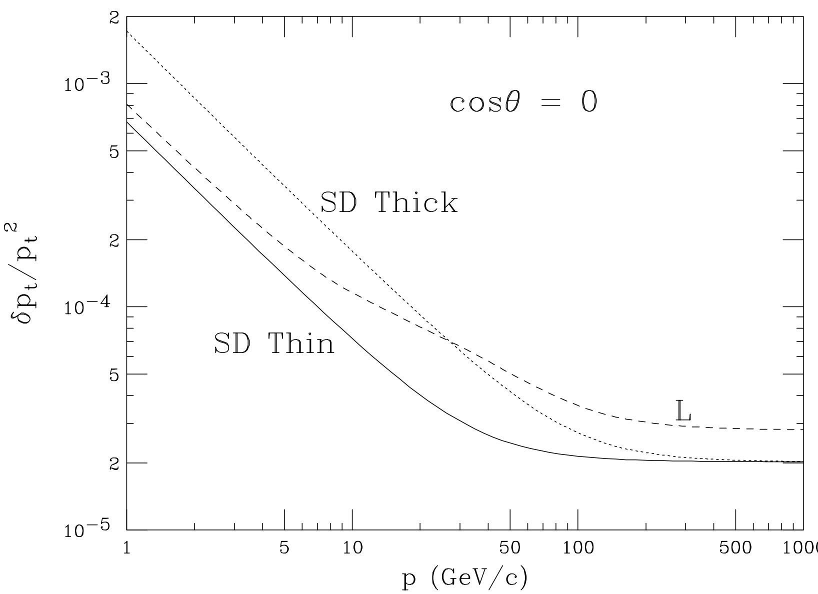
- I call this the SOD, mostly to keep people from confusing it with other versions of the SiD outer tracker which have $some$ z information, ranging from almost as good as the $r\phi$ measurement (Si drift, z strips) to good-but-not-great (small-angle stereo)



Why a Si Outer Tracker?

- The version of the SOD I've done the most studies on has *long* ladders. Each barrel is *split* at $z = 0$ and read out at each end
- The driving force for this detector is excellent momentum resolution for charged tracks (see plot below and various talks by Bruce Schumm)
- But to many people this seems like too minimal an outer tracker

- Backgrounds and other tracks pile up, making pattern recognition problematic. I said I'd spend some time and see if the problem was tractable
- A new variant of the SOD has recently appeared. Each 10 cm long wafer on a ladder is read-out separately

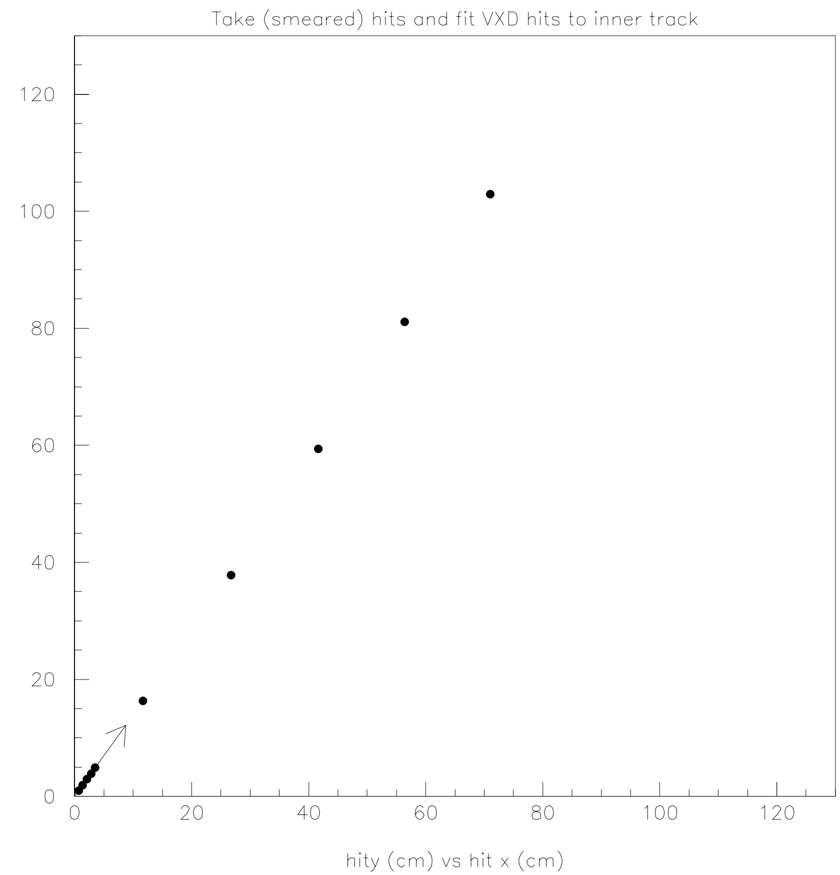


What's been done so far?

- All other SiD studies I know of have been done for 3D outer detectors
- Vladimir Rykov at the Santa Cruz workshop (outer tracker similar to a 5-layer Si drift detector)
- Norman Graf at September 26, 2002 SLAC LC meeting (inner CCD detector and tracks projected out to outer, 3D endcap detector)
- I've been working for ~ 6 months (part time). Started out learning $java$, writing stand-alone pat rec, finding K_s^0 in (pristine) SOD
- Was convinced more immediate problem was just extending inner tracks into fully occupied SOD
- I'm don't have a huge amount of time to sink into writing pat rec for a detector that may never be built (steal or reuse as much as possible)
- Report to the SLAC 2PM Friday SiD Tracking meeting about once a month. All trivial first steps, mistakes can be found at **http://www.slac.stanford.edu/~stevew/nlc.html**
  Will not repeat most of that here

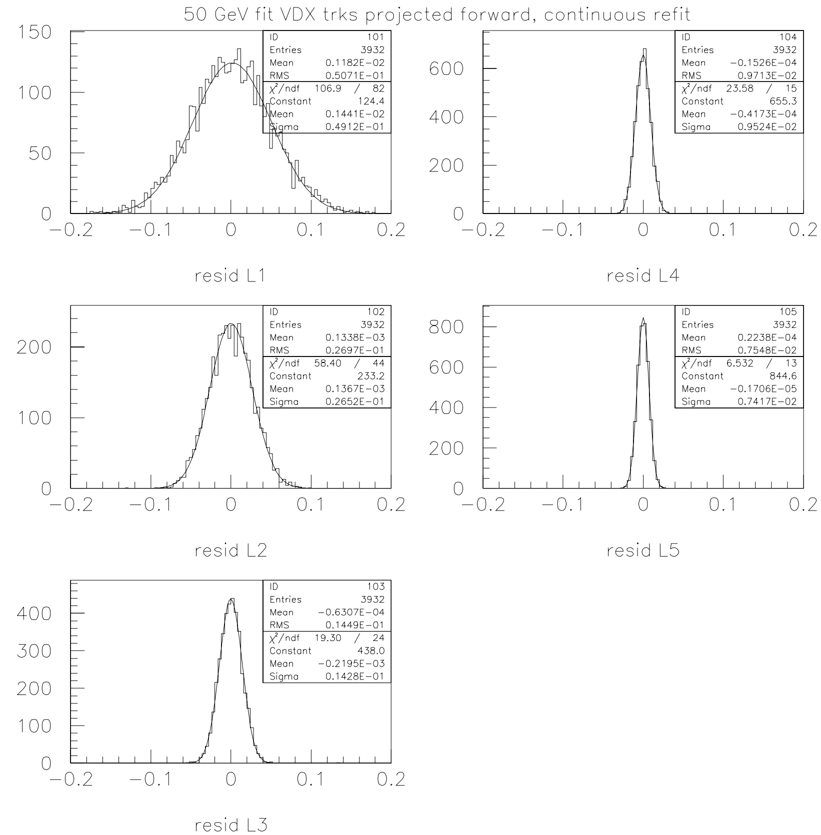
$p_T = 50$ GeV Track in Quadrant of SOD

- Working in JAS using SDJan03 MC data (and just ignoring the z info that's there for SOD 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 SOD
- Add (closest) hit and refit trk at each SOD layer



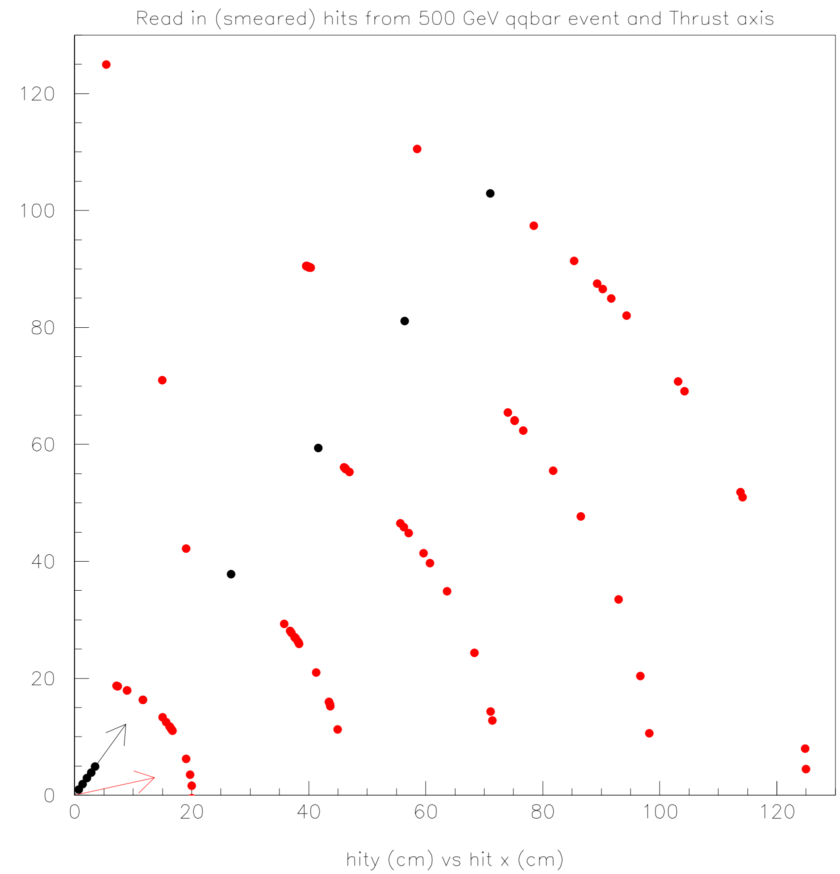
Adding SOD Hits to Projected VXD Tracks

- 50 GeV/c tracks (shown) gobble up SOD hits, get better as they go out ($\sigma_{resid} = 490\ \mu\text{m}$ at L1 to $\sigma_{resid} = 74\ \mu\text{m}$ 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
- But no one really cares about tracking in trivial evts



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

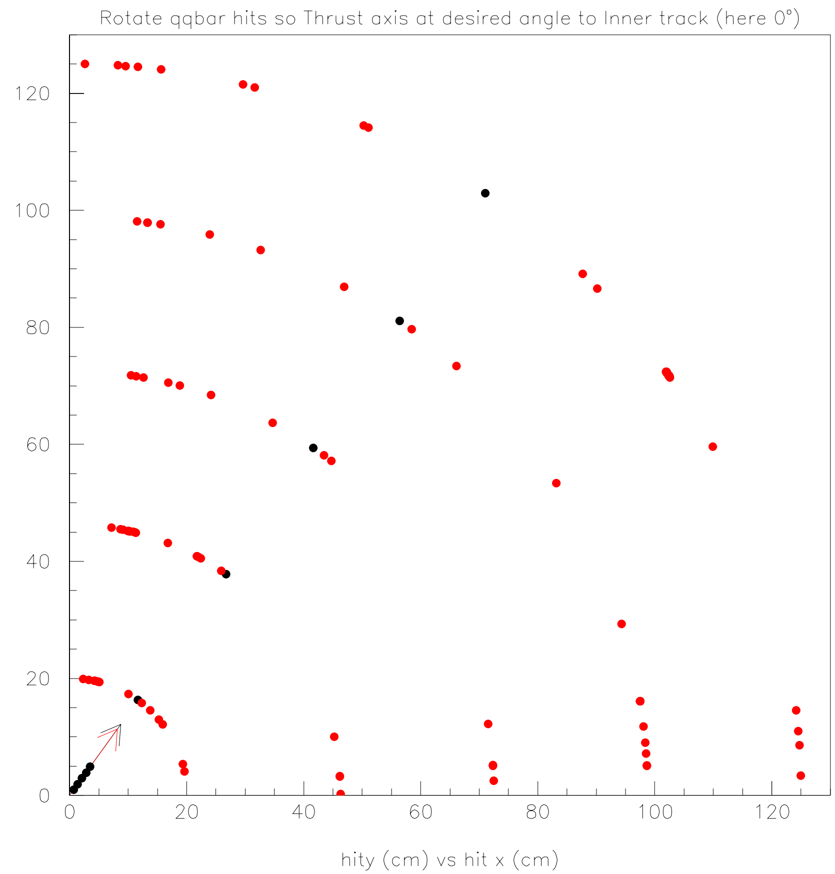
- Write out hits and T(hrust) axis for $\sqrt{s} = 500$ GeV $q\bar{q}$ evts if T axis of evt in SOD barrel.
- 1810 evts to work with, about 45 hits in each SOD layer
- Read in hits from $q\bar{q}$ evts, rotate them in ϕ so T axis is a pre-determined angle from probe track
- Mix together SOD hits for 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 SOD L1. Past L1 the trials pick up closest hit in each layer and continuously re-fit. Trials often share hits past L1 (no poisoning except in L1)

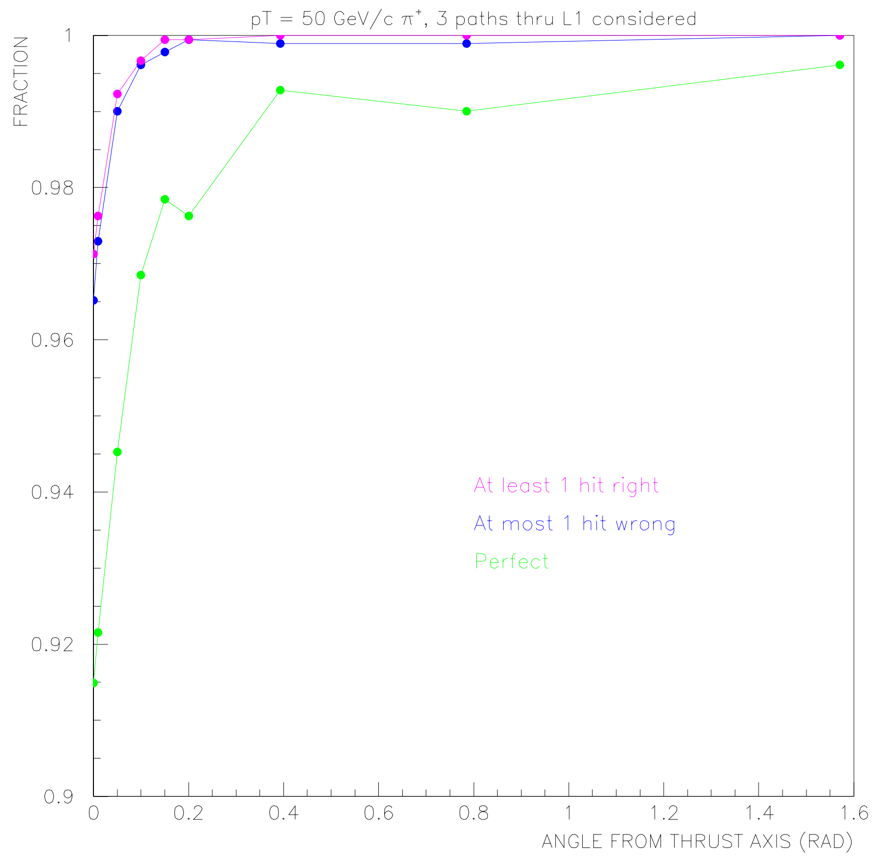


- Pick final trk on χ^2/dof

- 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)

Use 3 Closest Hits in SOD L1 for Trial Trajectories

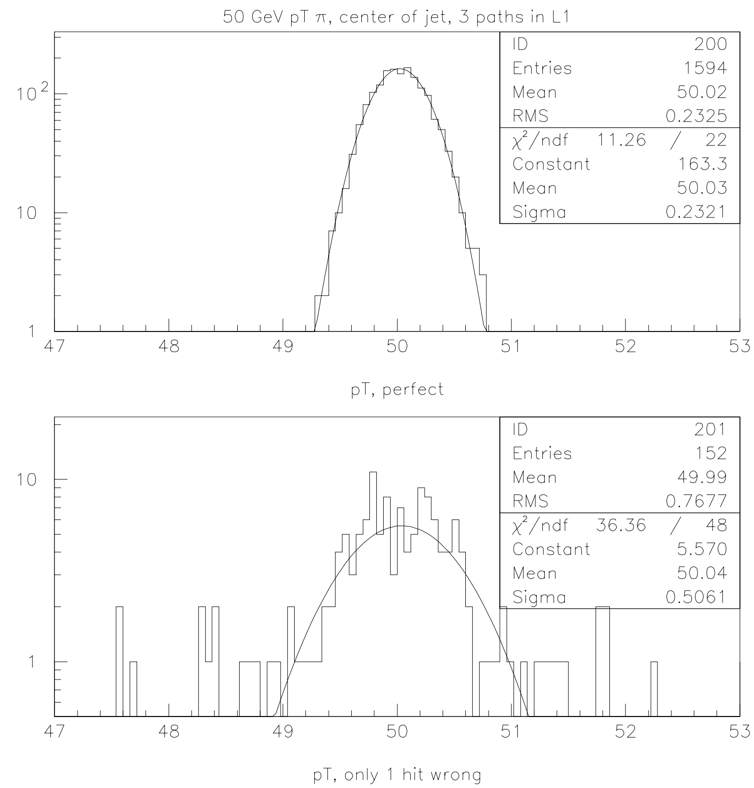
- For green curve, require found trk have *all* its correct hits (be "perfect")
- The blue curve is where at most 1 hit in SOD is wrong. Often call trks where 1 hit is wrong "close;" blue curve is perfect+close
- Purple curve is trks where at least 1 hit in SOD is right - area above purple curve is fraction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



- VDX trk has latched onto wrong trk in SOD 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 SOD 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



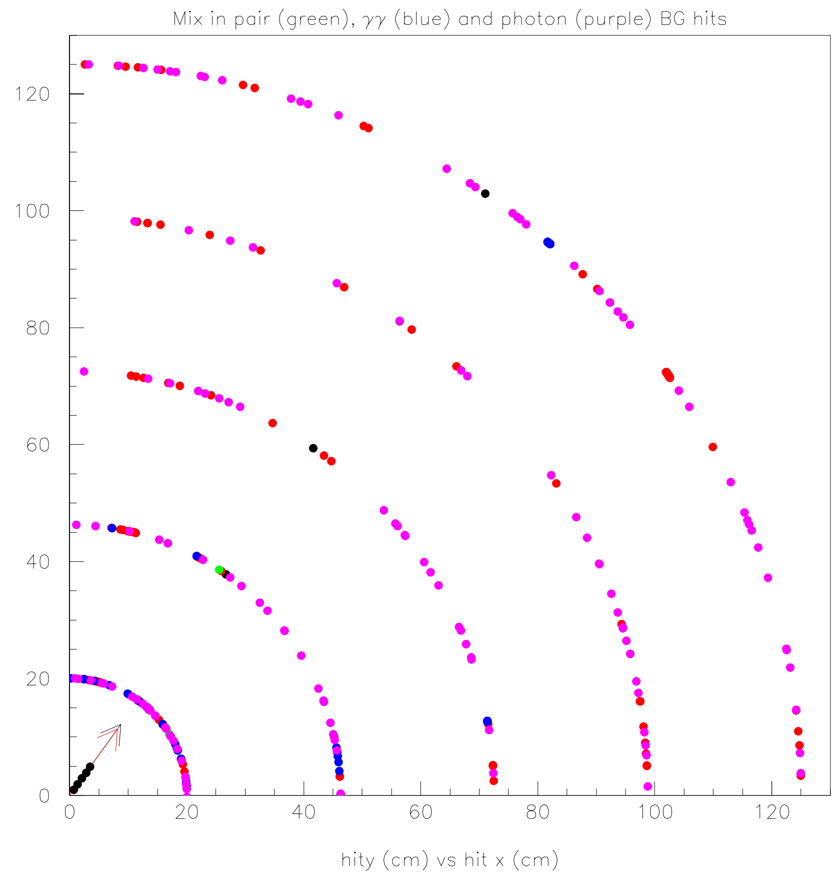
- A χ^2 comparator to MC truth would consider *most* of the close trks properly found - I will also, but I won't consider trks with $\geq 2/5$ SOD hits wrong properly found

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

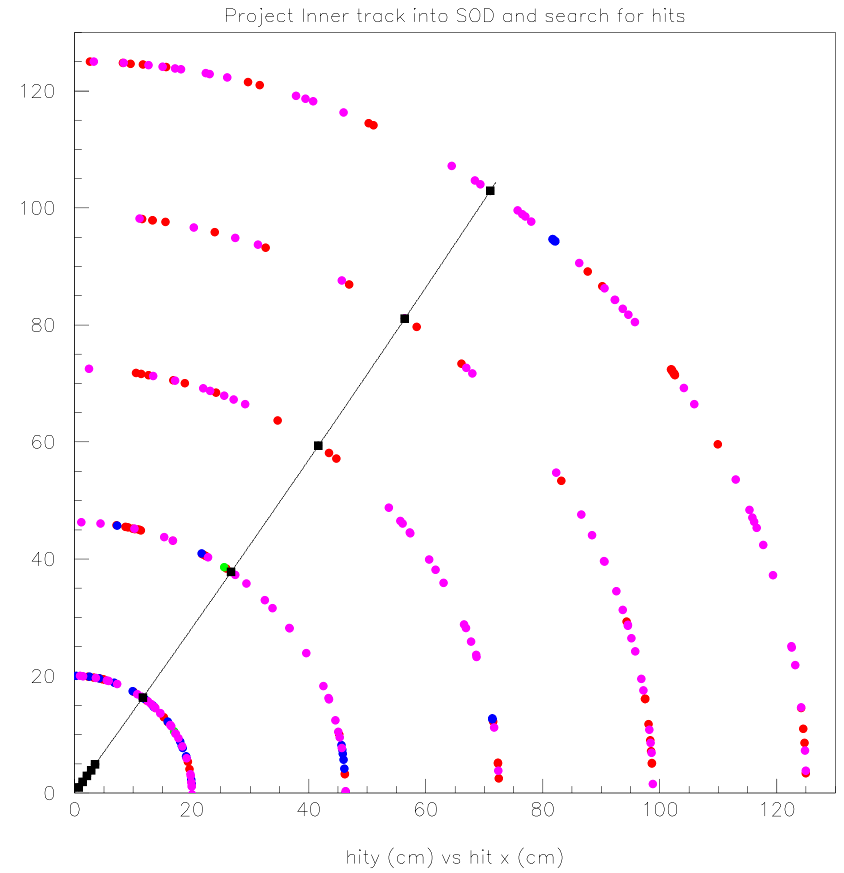
- Hits generated are for 1/2 of barrel - VXD trks have excellent z resolution and know which 1/2 of the SOD they're pointing into
- Take pair and $\gamma\gamma$ interactions from old files; mix in enough of each to get specific occupancy in L1 correct (as cal by Takashi Maruyama and shown by John Jaros Tuesday)



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

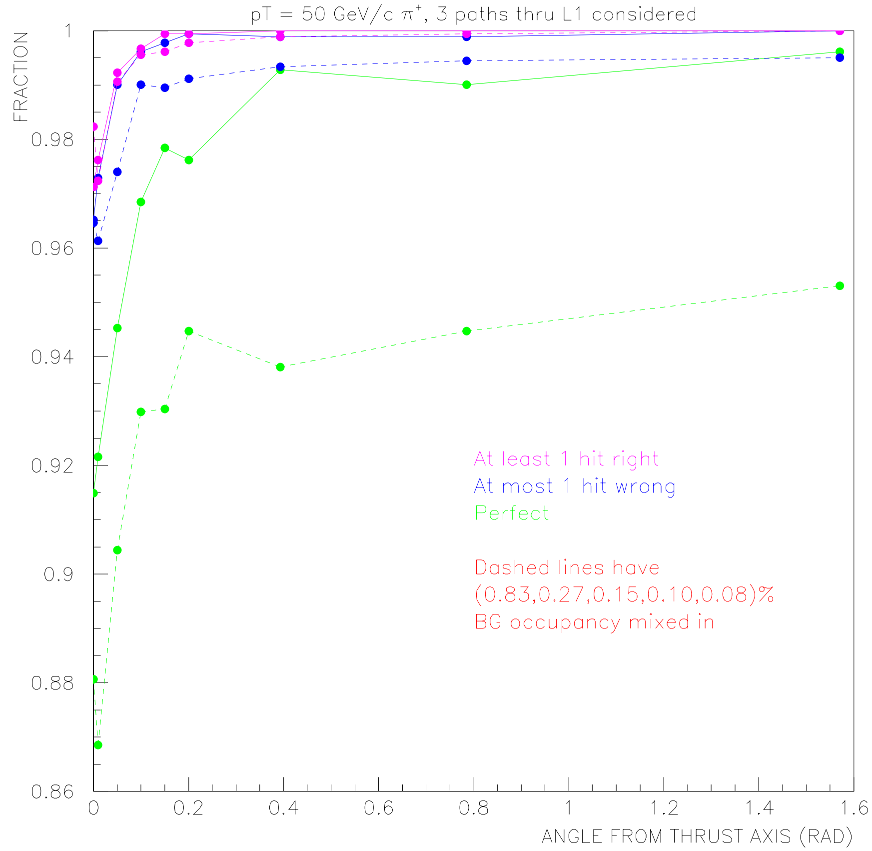
Project inner trk to SOD and try to pick up correct hits

- 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



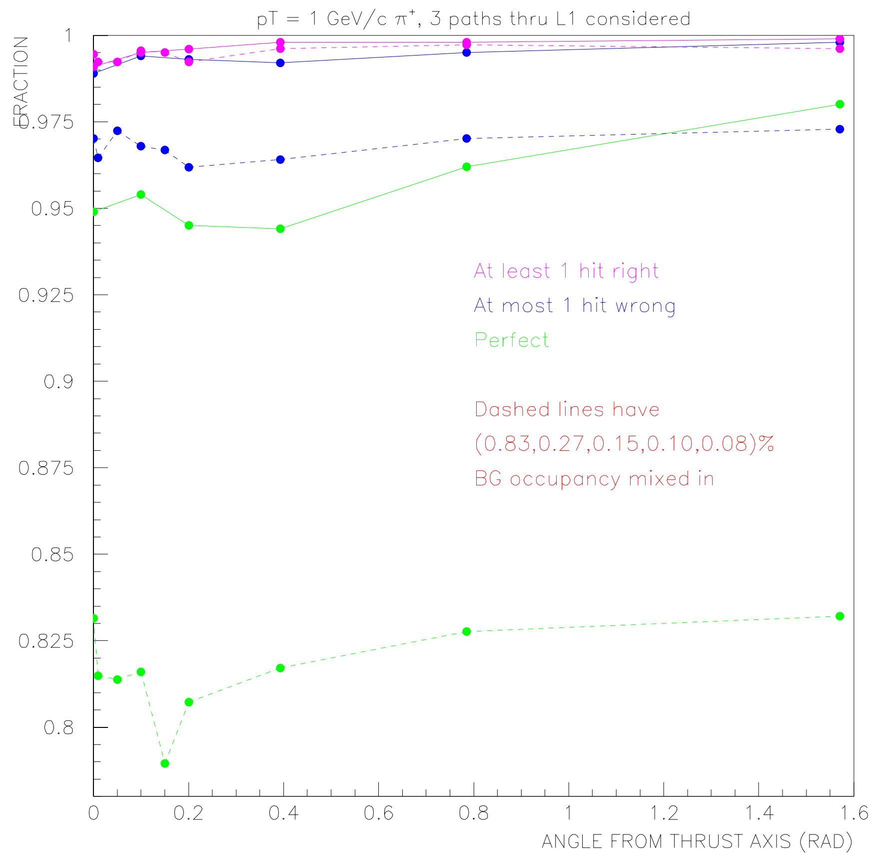
Effect of Full BGs on 50 GeV Tracks

- 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

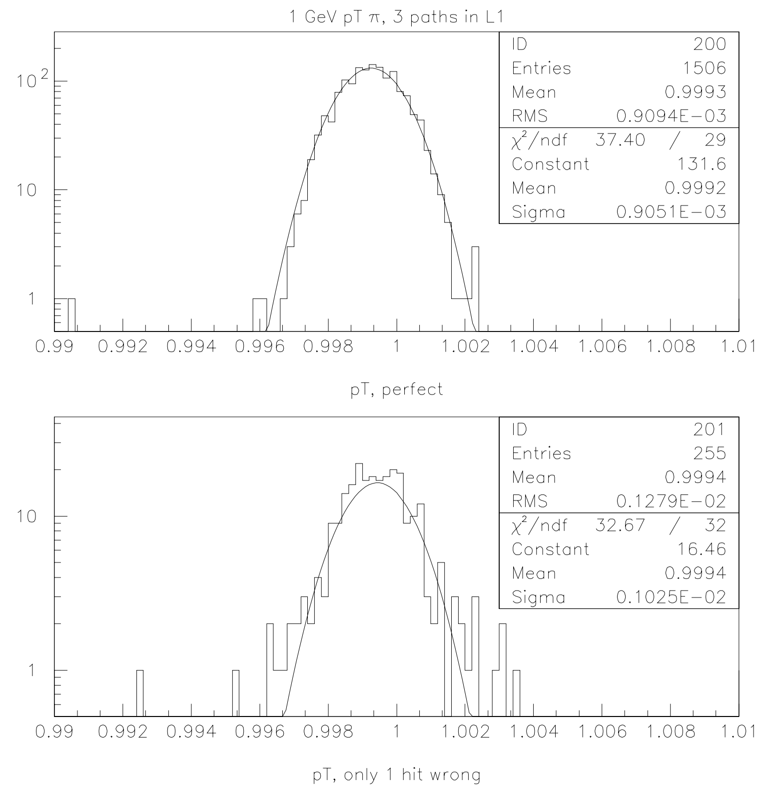
- Eff more uniform for $q\bar{q}$ evts without BG, but not as high outside jet. May just be an un-optimized windows
- But effect of BG is quite dramatic, especially on "perfect" trks
- Pattern of bad hits is different here (with BGs) than elsewhere. Usually it's L1 bad; here mostly L5 bad



- 1 GeV p_T trks almost don't exit SOD; 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

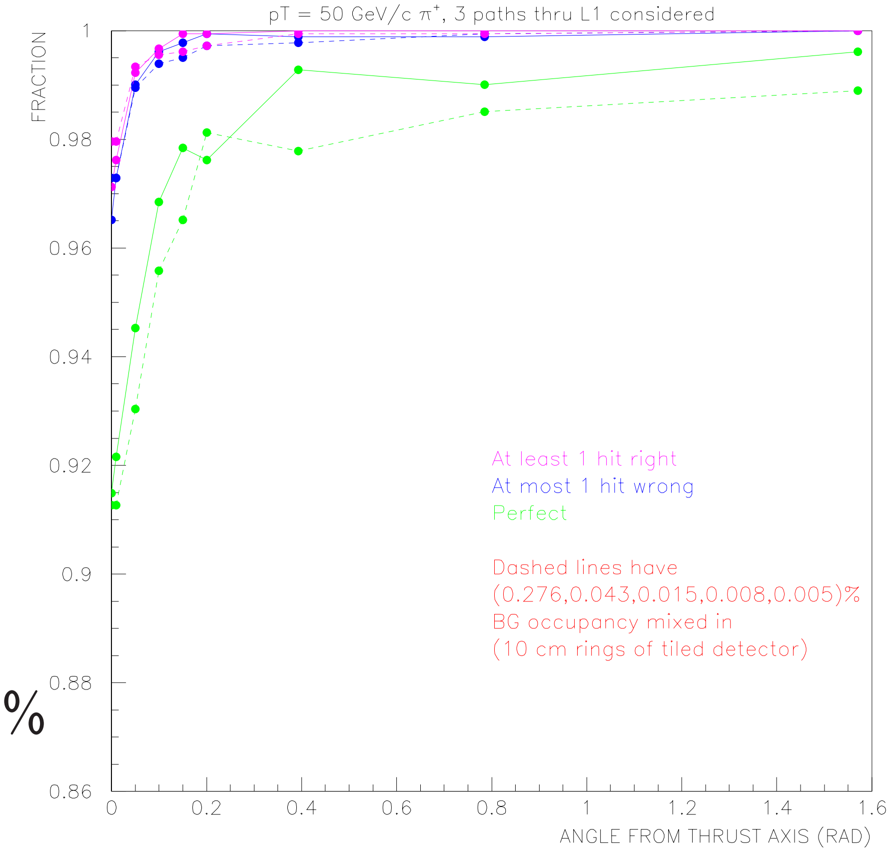
But Close $p_T = 1$ GeV Tracks are Pretty Good

- 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



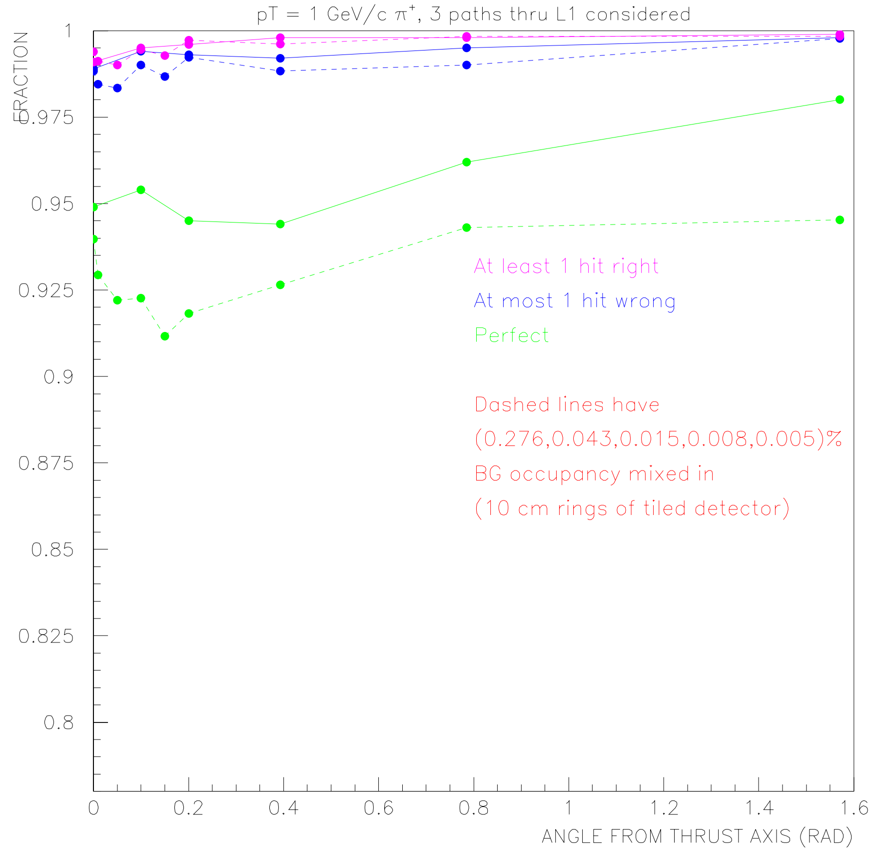
Effect of Tiling SOD on $p_T = 50$ GeV Tracks

- 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 $q\overline{q}$ hits mixed in



Effect of Tiling SOD on $p_T = 1$ GeV Tracks

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



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 $> 96.5\%$
- Timing info (limiting BGs to approx 4 crossings rather than 192) prob gets us back near no BG case (or to tiled effs if timing used by no tiling)
- Dip at 0^o to T axis swapping $real$ trk SOD hits (or whole SOD 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

Future Studies

- Lots more things to try (10 yrs, lots of smart people writing pat rec), but hit adding to inner trks viable with current SOD $at\ full\ BGs$
- Back to seeing if, once cleaned of SOD hits belonging to inner trks, stand-alone pat rec (K_s^0, ...) in SOD viable with tiled, timed detector
- Also need to repeat tests with more realistic hit simulation (coming soon)