Tracking in Run 2a
Implications for Run 2b

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- Summary of current tracking algorithms
- Consideration of detector material
- 3D tracking
- Conclusions

Run 2b silicon workshop
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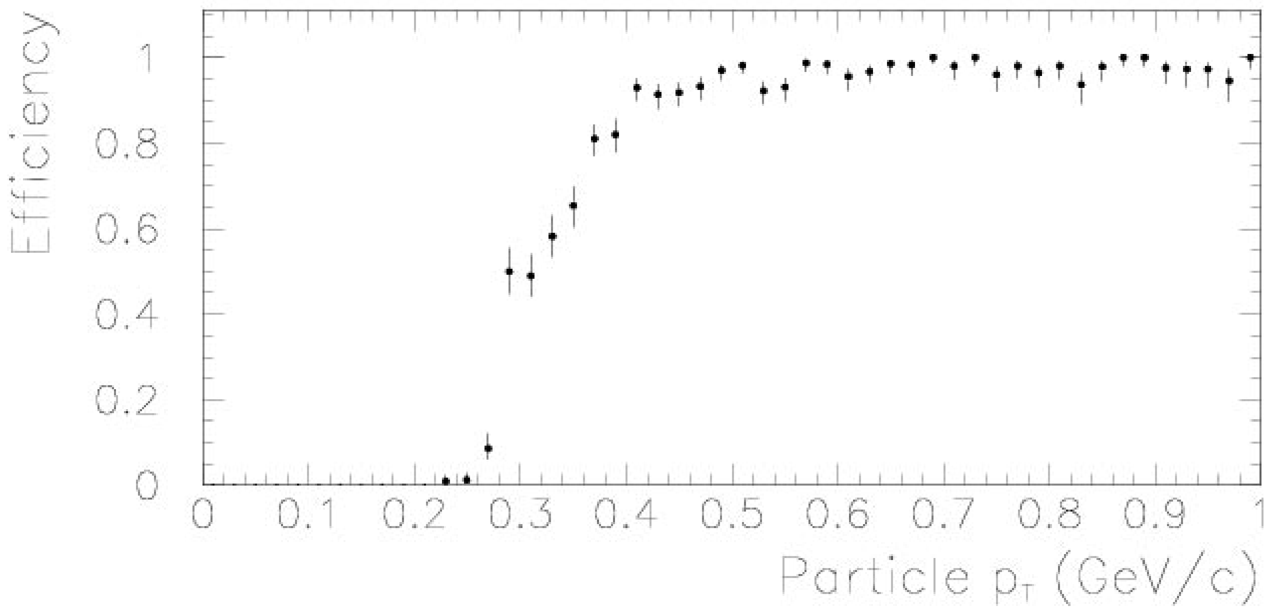
Disclaimers/qualifications

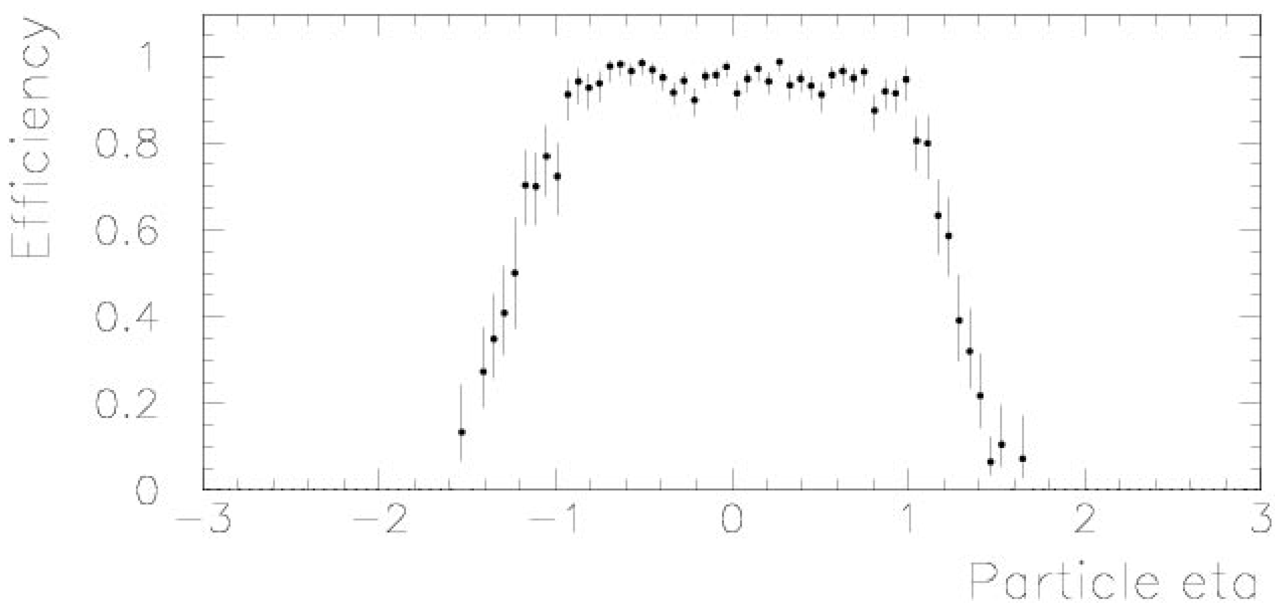
- Tracking is a work in progress
  - Details will change, things will improve with timeq
  - Some major fqeatures may change
- Will not prove everything I will assert as true
  - Will try to make a general case

COT tracking

- Segment linking algorithm
  - Fully implemented, stable
  - Concentrating on system integration, final fit.
  - Performance in top events
    - Require
      - Particles pass through inner, outer SL
      - Find > 50% of hits from fiducial particle
    - Results
      - Efficiency is about 96% for Pt > 1 GeV/c.
      - About 1.2% of tracks are duplicates.
      - About 4.4% of tracks have no match.
    - Results are sensitive to drift speed and hit width (drift model)
      - Efficiency varies by 10% over range of reasonable drift model parameters.

COT tracking efficiency

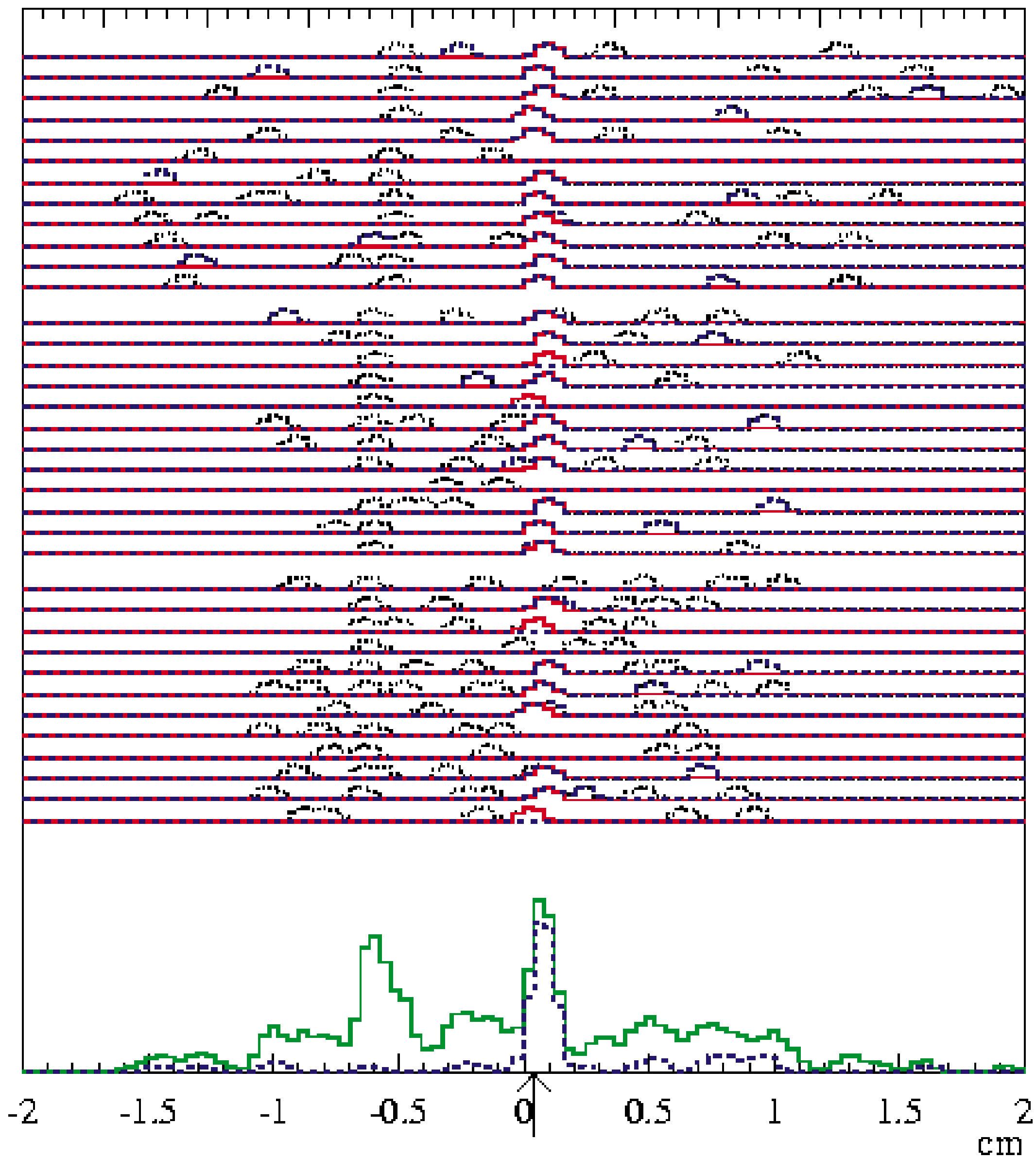




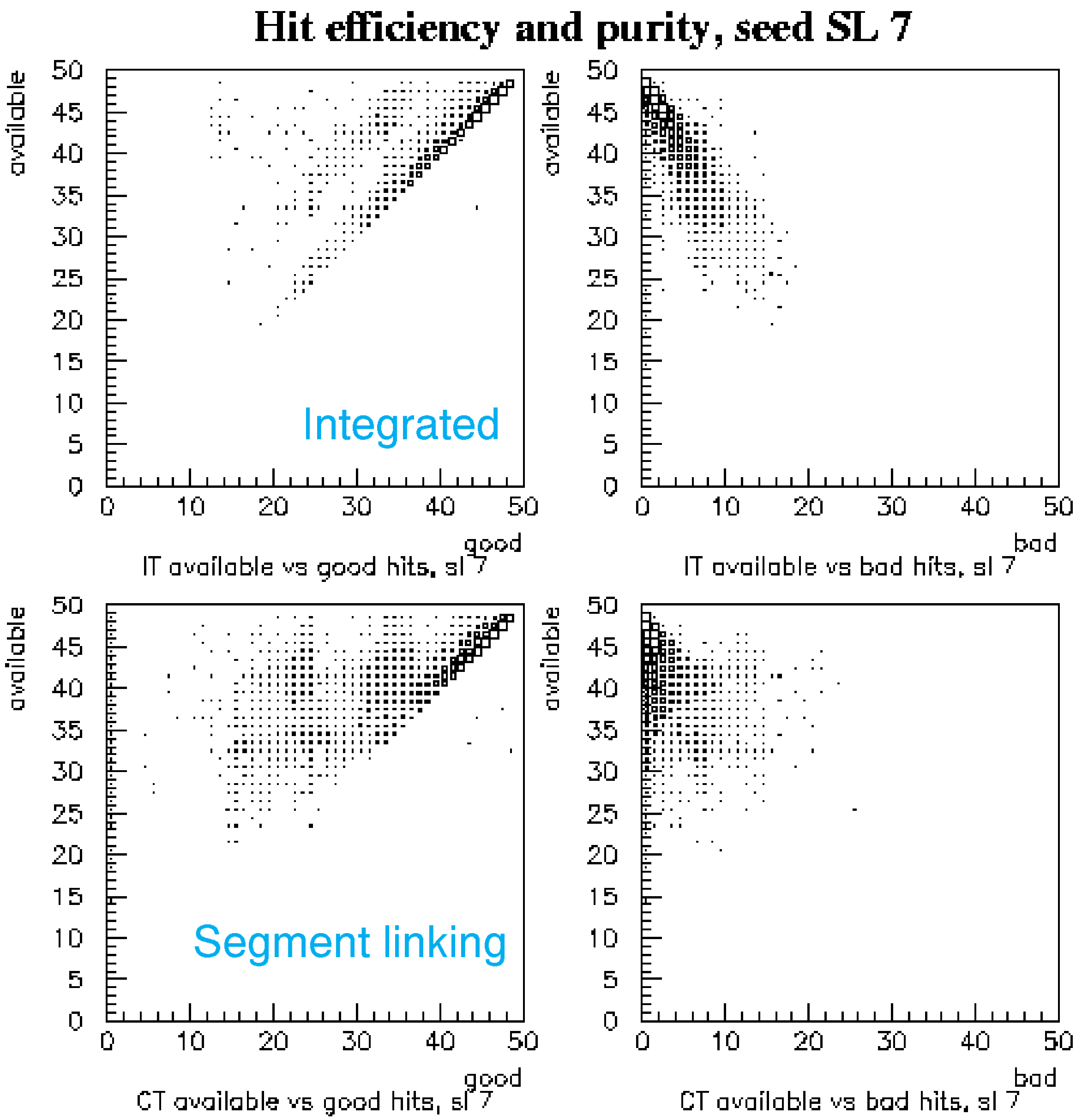
COT tracking

- Histogram algorithm ("integrated" or "TDR" algorithm)
  - Finds hits -- requires no segments (except for a single seed segment)
  - Should find tracks lost due to segment/linking errors
  - Still under development
  - Performance in top events:
    - Require
      - Pt > 500 MeV, |Z0| < 50 cm, origin r < 2 cm
      - Track generated a seed segment
      - Seed segment with unambiguous MC parent
      - At least 5 COT axial hits outside seed SL
    - Calculate efficiency by comparing to track with perfect pattern recognition. (5 sigma, 10 sigma)
      - Seed SL 2: 91%, 94%
      - Seed SL 4: 91.5%, 94.5%
      - Seed SL 6: 96.5%, 98.5%
      - Seed SL 8: 97.5, 99%

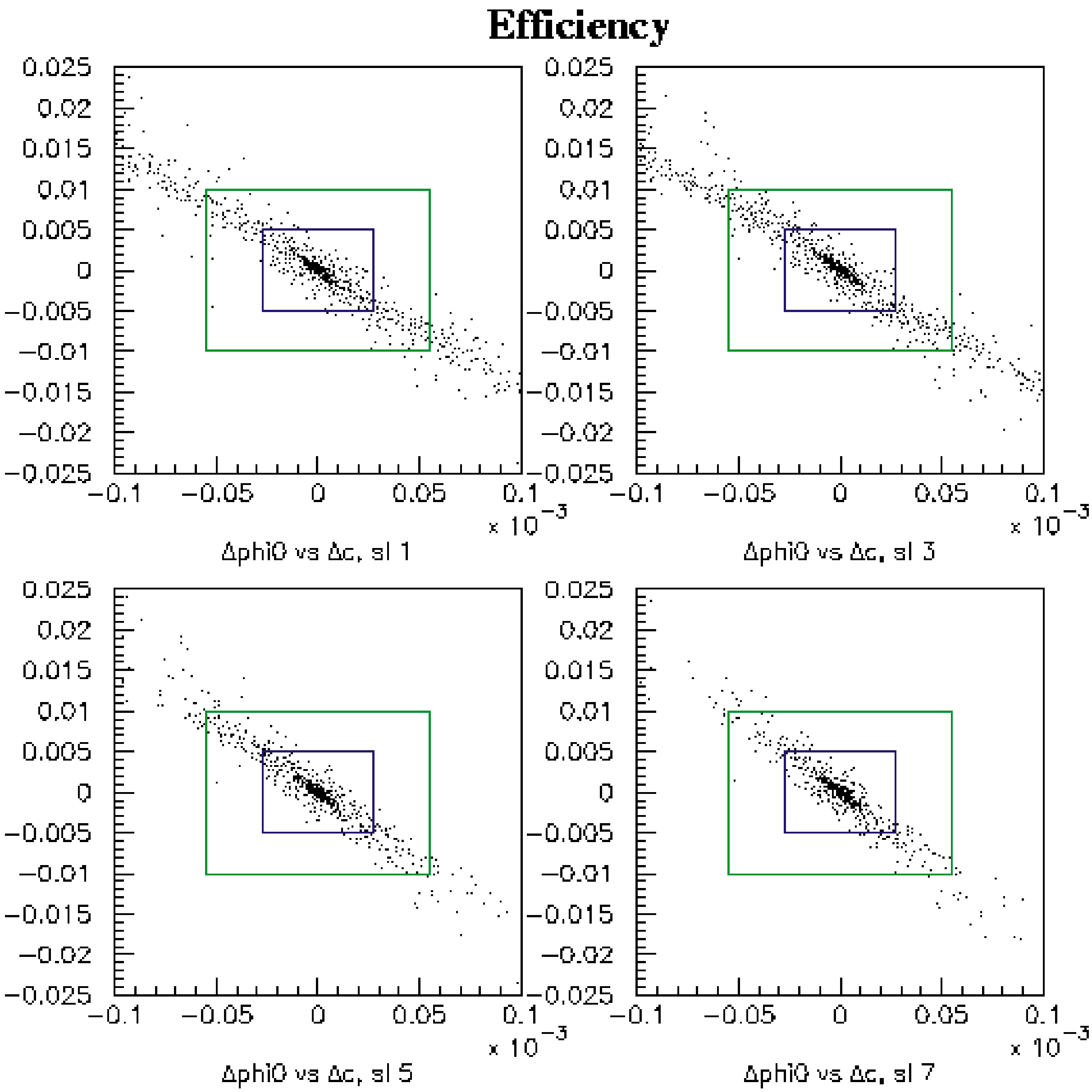
Histogram COT algorithm



Histogram COT tracking



Histogram COT algorithm



COT tracking

- Final fit issues.
  - Contributions to Pt measurement error for uncorrected 1 GeV/c muons (in %)

Source	Bias	Resolution
Hit resolution	0.002±0.007	0.16±0.01
B-field variation	0.173±0.019	0.43±0.08
Energy loss	-0.093±0.003	0.07±0.03
Wrong hits	0.002±0.004	0.12±0.04
Scattering	0.009±0.006	0.38±0.04
Drift model	0.004±0.014	0.23±0.07
Interaction time	-0.005±0.008	0.03±0.05

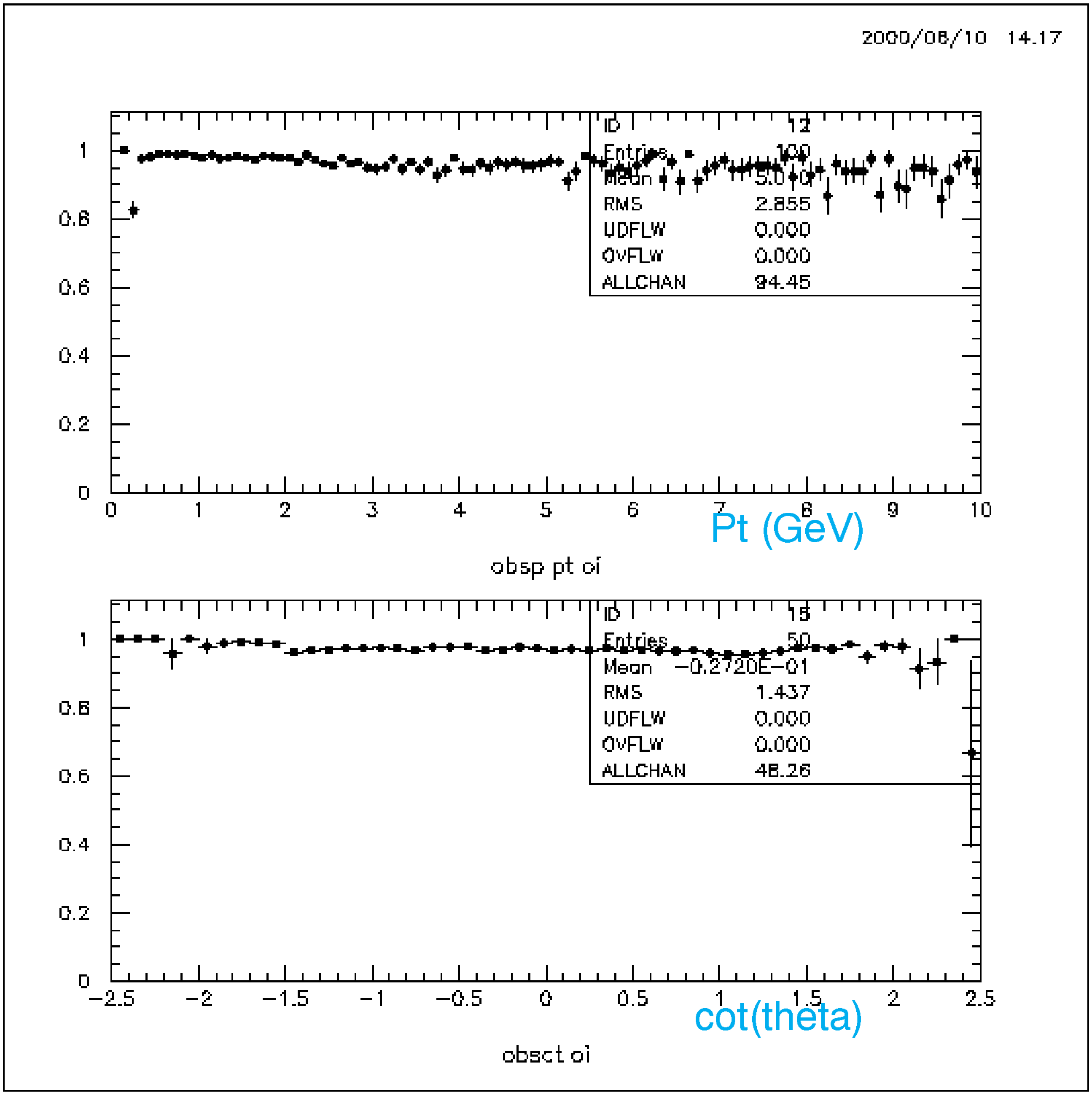
Silicon tracking

- Three commonly used algorithms available
  - Histogram algorithm ("Integrated" or "TDR")
  - Outside-in (OI)
  - Stand-alone silicon
- Integrated algorithm
  - Uses same basic approach as in COT
    - Use COT tracks to seed histogram hit search
  - Operates independently in R-Phi and R-Z
  - Not clearly complementary to Run 1 approach in terms of efficiency
    - Does less fitting of tracks
    - No combinatorial loops
      - Scales linearly with hit multiplicity
  - Performance in top events
    - Require
      - Pt > 0.5
      - At least 4 hits deposited in silicon
      - At least 3 correct hits found
    - Results (not the most current...)
      - Efficiency = 85% (R-Phi)
93% (R-Z)
      - Purities in the mid 90% range

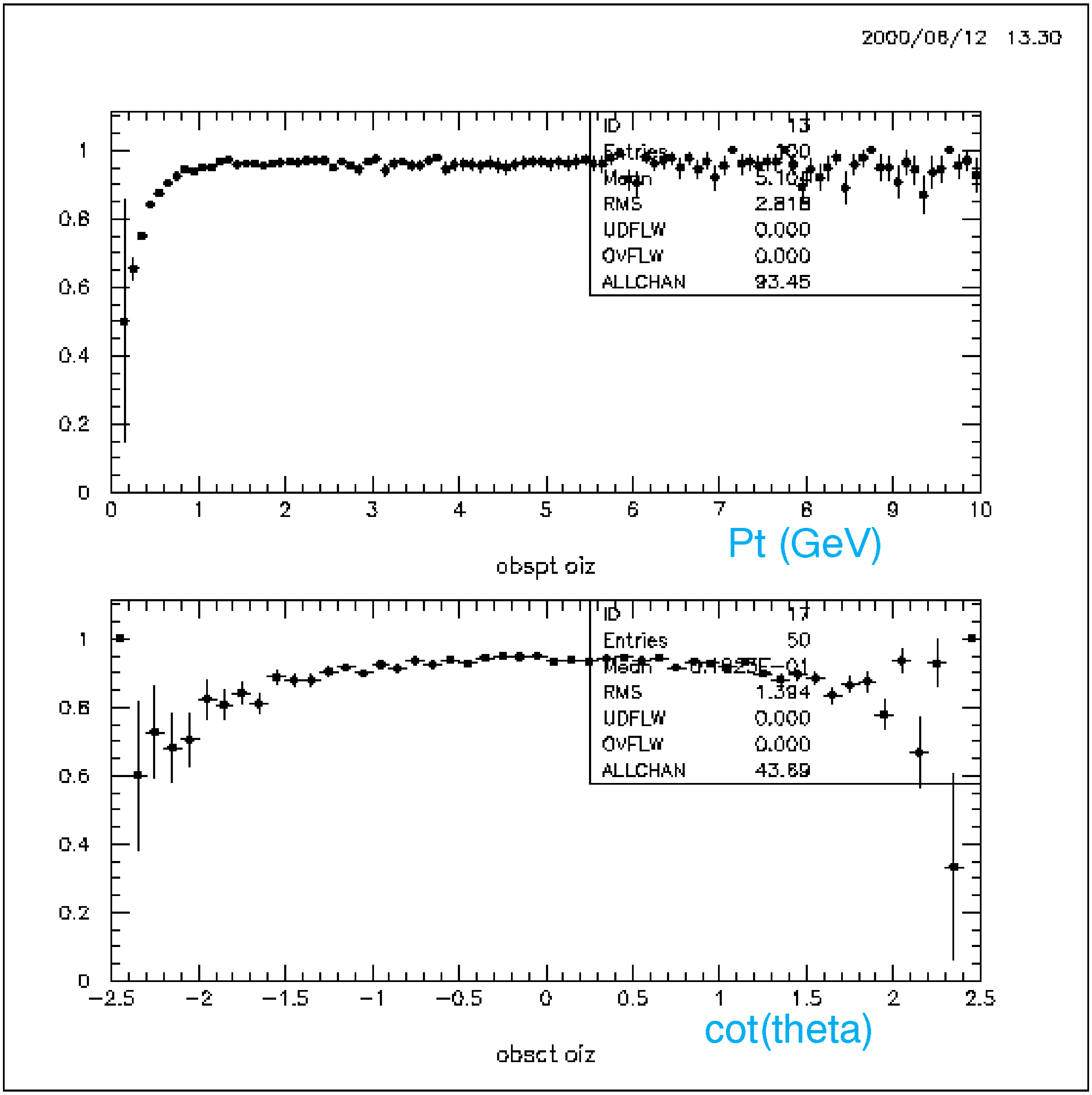
Silicon tracking

- Outside-in
  - Modelled after the Run 1 algorithm
    - Searches for hits in R-Phi using COT tracks as seeds
    - Hits in R-Z are added in a separate pass using one of the integrated algorithms
  - Performance in top events
    - Require:
      - COT track with unambiguous MC parent
      - At least 4 R-Phi hits deposited in silicon detector
      - Find at least 4 hits
    - Efficiency (R-Phi):
      - At least 4 hits associated: 97%
      - All hits correct: 89%
      - Frac. of correct hits overall: 97%
  - Adding R-Z hits (sm. ang. st. + 90 deg stereo)
    - Require:
      - At least 4 hits on wafers with corresponding R-Phi hit
    - Results:
      - At least one R-Z hit: 93%
      - At least 3 hits: 85%
      - At least one hit, all correct: 78%

OI tracking efficiency (R-Phi)



OI tracking efficiency (R-Z)



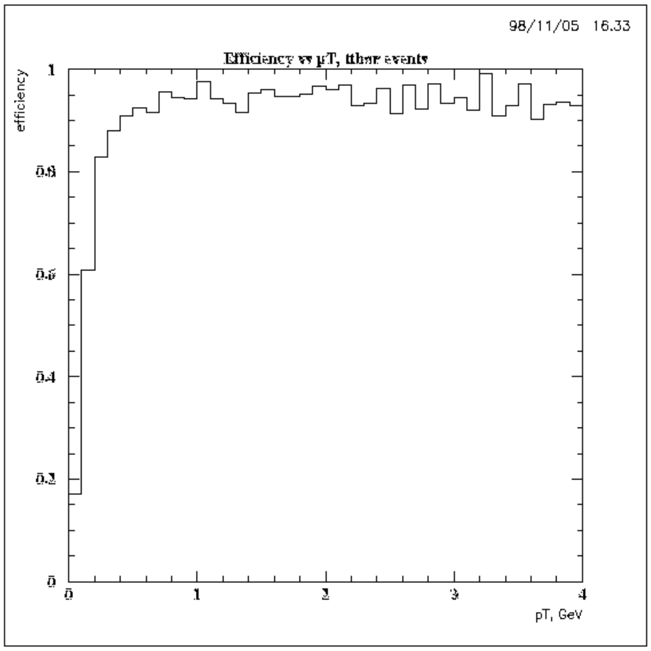
Silicon tracking

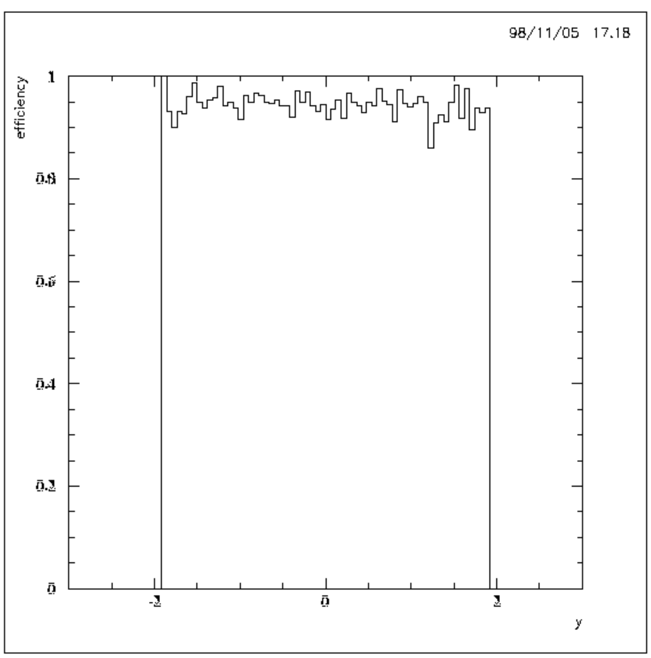
- OI tracking
  - Consider tracks with seven hits in silicon
    - 97.5% are "found" with at least four hits
    - 93% have no incorrect hits
    - 95.5% have an ISL hit
      - 99% of these have the correct ISL hit
      - 95.7% have no incorrect hits
    - 4.5% do not have an ISL hit
      - 38% of these have no incorrect hits
    - Almost half of the impurity arises from the small fraction of tracks in which the ISL hit is missed.
  - A significant fraction of the inefficiency is from tracks that miss associating the outermost ISL hit
    - Integrated approach may find these better
    - Will get better as effects in COT are understood
    - Limited by material in inner COT can

Silicon tracking

- Stand-alone silicon tracking: triplet algorithm
  - Generates 3D roads using triplets of 3D hits
    - 3D hit = R-Phi hit + small angle stereo hit
  - Triplet of 3D hits over-constrains the trajectory
    - Impose Pt cut
    - Require loose pointing toward primary vertex
  - Adds both stereo and R-Phi hits simultaneously
    - Does not aggressively add R-Z hits
      - Skips R-Z hits when choice is ambiguous
    - Attempted to use integrated approach to adding R-Z hits
      - Failed because polar angle of triplet is insufficiently precise.

Stand-alone Si tracking efficiency

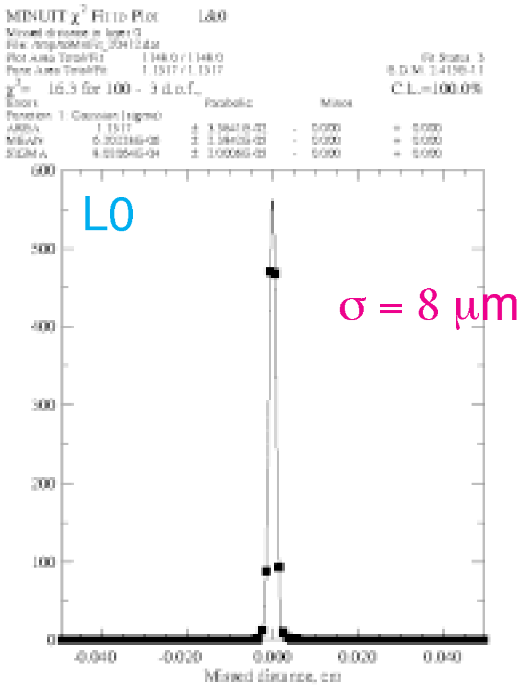


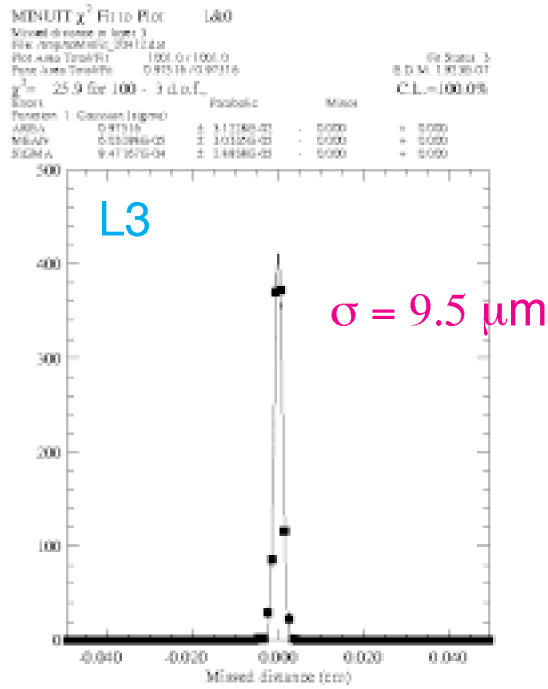


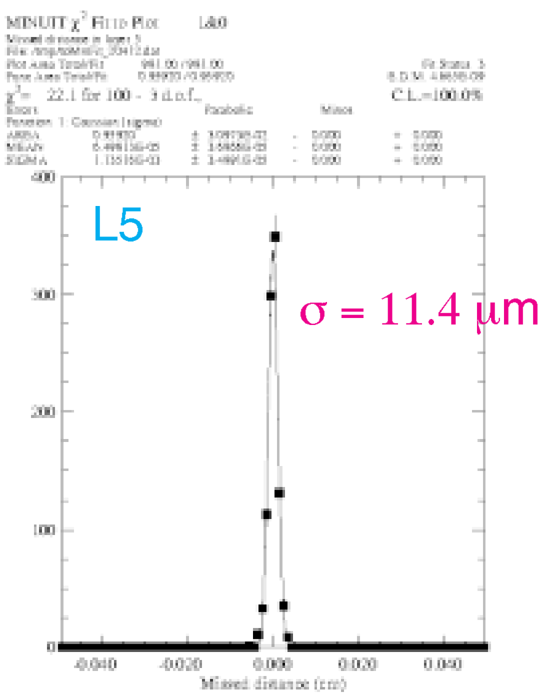
Pattern recognition issues

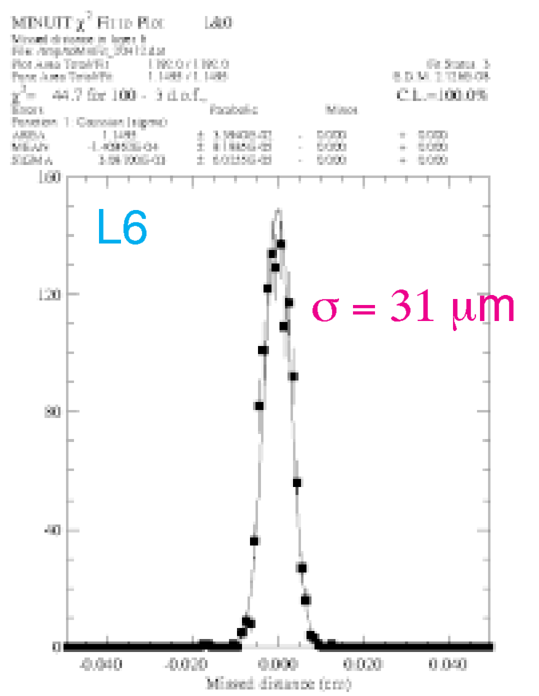
- Material
  - Unlike SVX/SVX', material must be taken into account during pattern recognition phase
    - Extrapolating over longer distances
    - Significantly more material per layer
    - Road sizes at 500 MeV are about 20 to 30 x the intrinsic resolution
      - Asymptotic size is about 8 x intrinsic resol.
    - Comparable contributions from intrinsic hit resolution and multiple scattering at about 4 GeV/c
      - *(See scattering plots)*
    - Complicates pattern recognition at low momentum.
      - Low momentum is important.
        - *(See SECVTX)*
  - Secondary interactions
    - Factor of two increase in charged multiplicity
      - Tracks from secondary interactions are highly correlated with tracks from underlying physics processes
        - *Produce hits close to tracks of interest*
        - *Low momentum => loopers*
        - *(See pictures)*

Distance from hit to ideal trajectory at 40 GeV/c



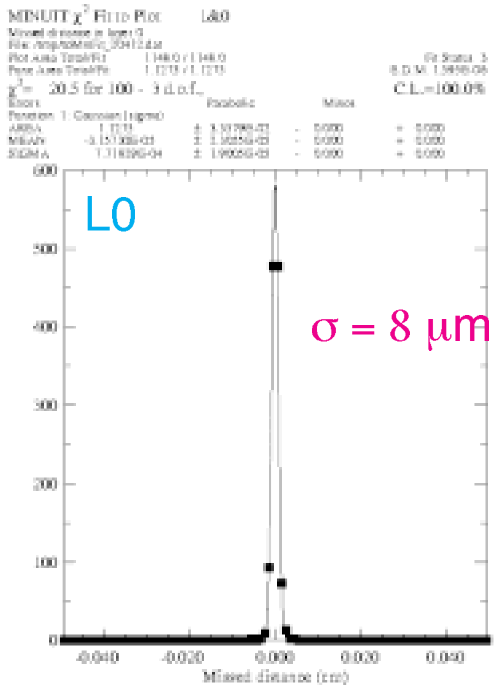


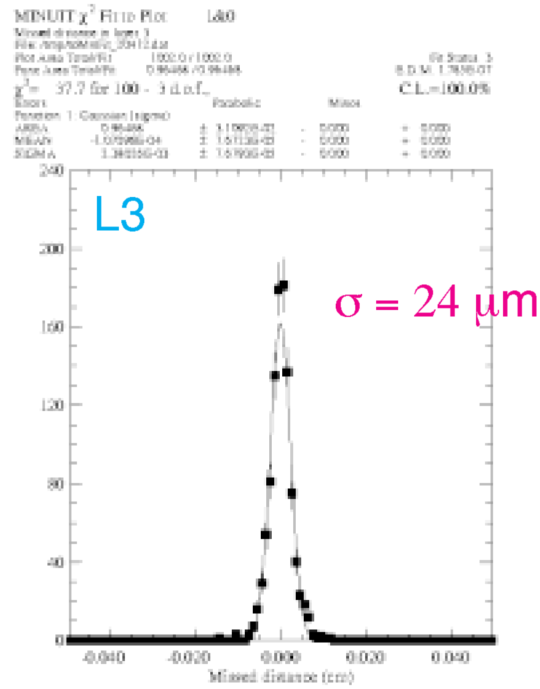


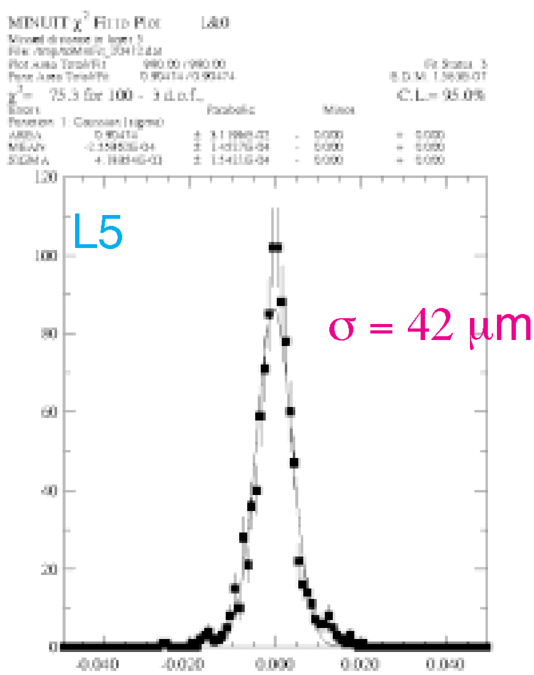


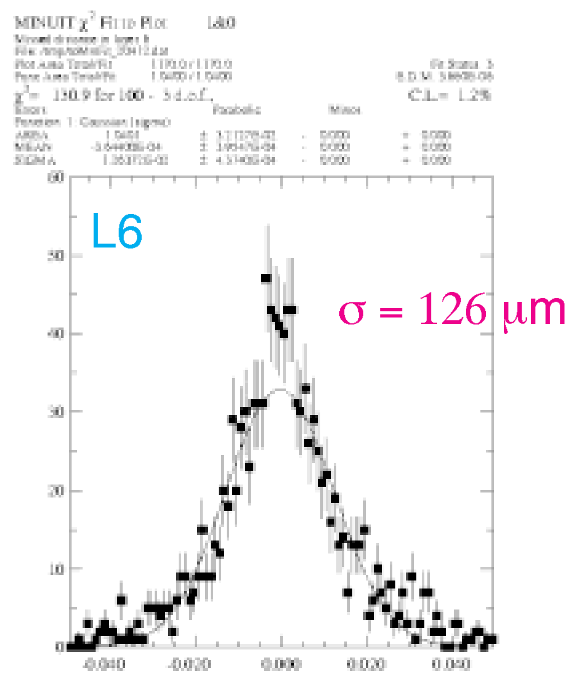
$\sigma \approx$ intrinsic resolution in all cases

Distance from hit to ideal trajectory at 4 GeV/c







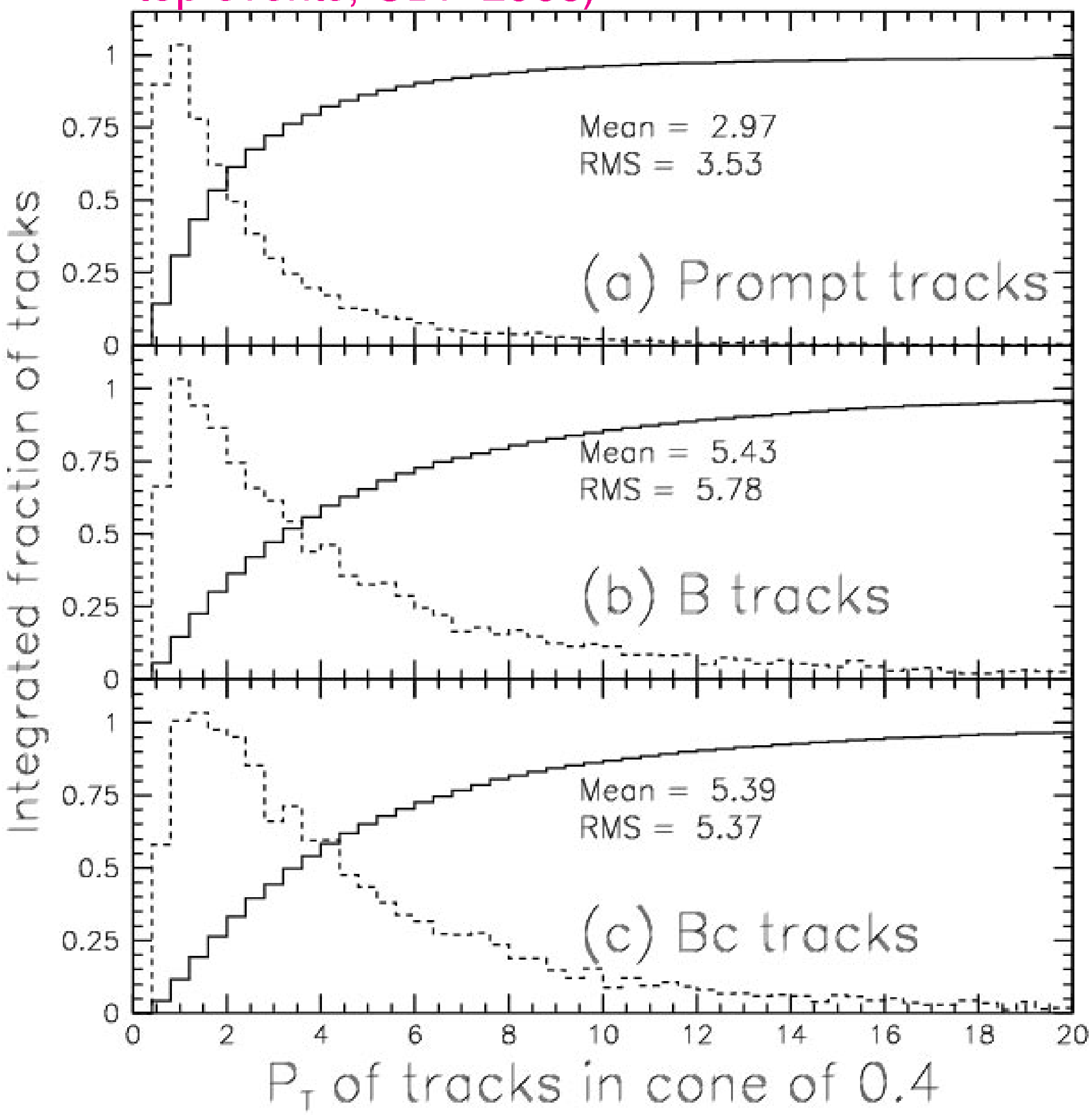


The problem scales approximately as 1/Pt from here
=> at 0.5 GeV/c, deviation at L6 ≈ 1 mm.

What is "low Pt"?

What is the relevant momentum scale?

(From generator-level study of B-decays in top events, CDF-2568)



25% of tracks from B decay in top events have Pt < 2 GeV/c

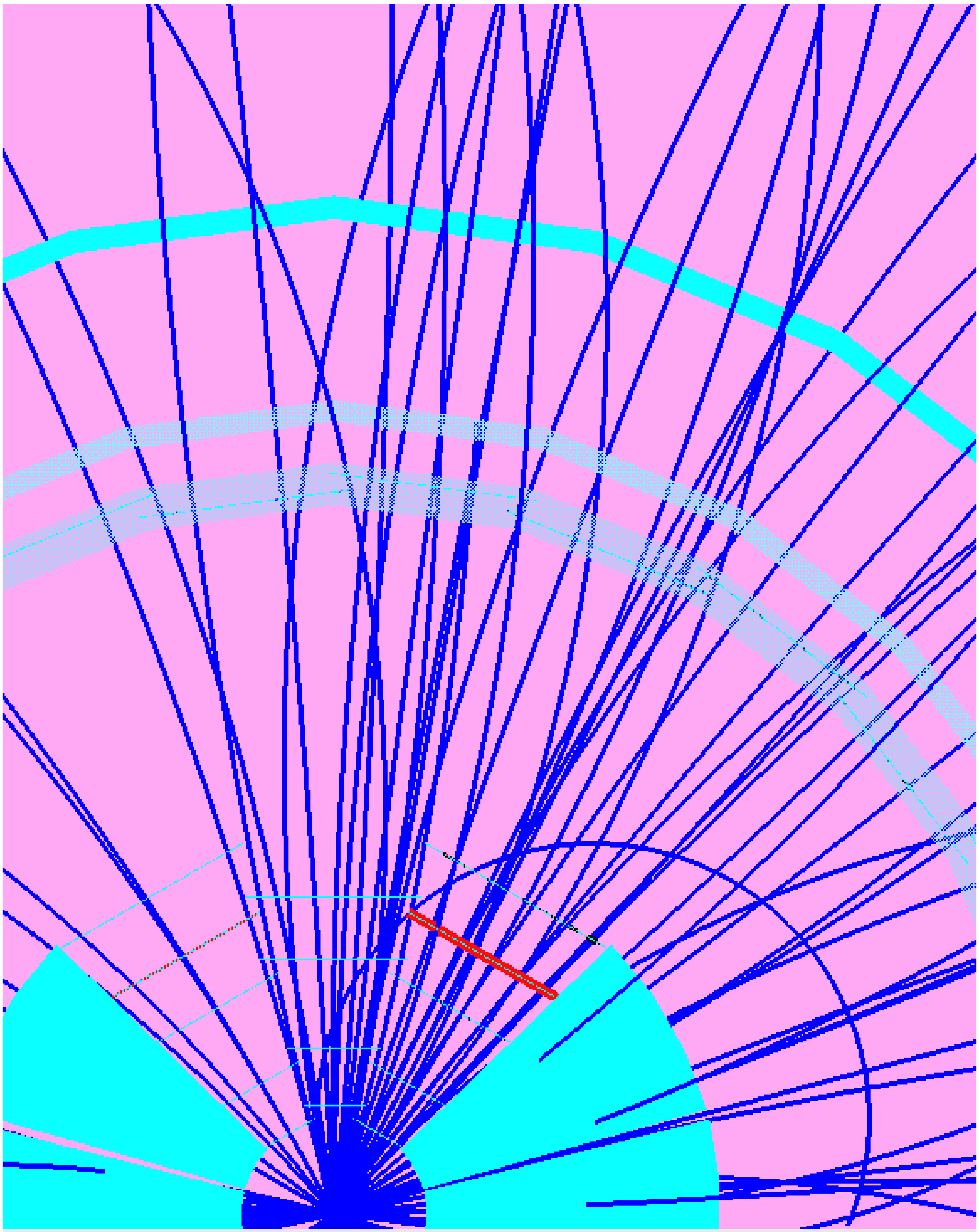
What is "low Pt"?

$P_T \geq$	$\sigma_d \geq$	$r\Delta\phi \geq 0.$		$r\Delta\phi \geq 0.024cm$	
		total	3tk vtx	total	3tk vtx
0.5	2.0	0.64	0.56	0.55	0.45
	2.5	0.60	0.50	0.52	0.39
	3.0	0.58	0.46	0.50	0.35
1.0	2.0	0.61	0.52	0.52	0.40
	2.5	0.58	0.46	0.49	0.35
	3.0	0.57	0.43	0.48	0.32
1.5	2.0	0.58	0.45	0.49	0.33
	2.5	0.56	0.41	0.48	0.29
	3.0	0.56	0.37	0.47	0.27
2.0	2.0	0.56	0.39	0.47	0.28
	2.5	0.55	0.35	0.46	0.25
	3.0	0.55	0.32	0.46	0.23

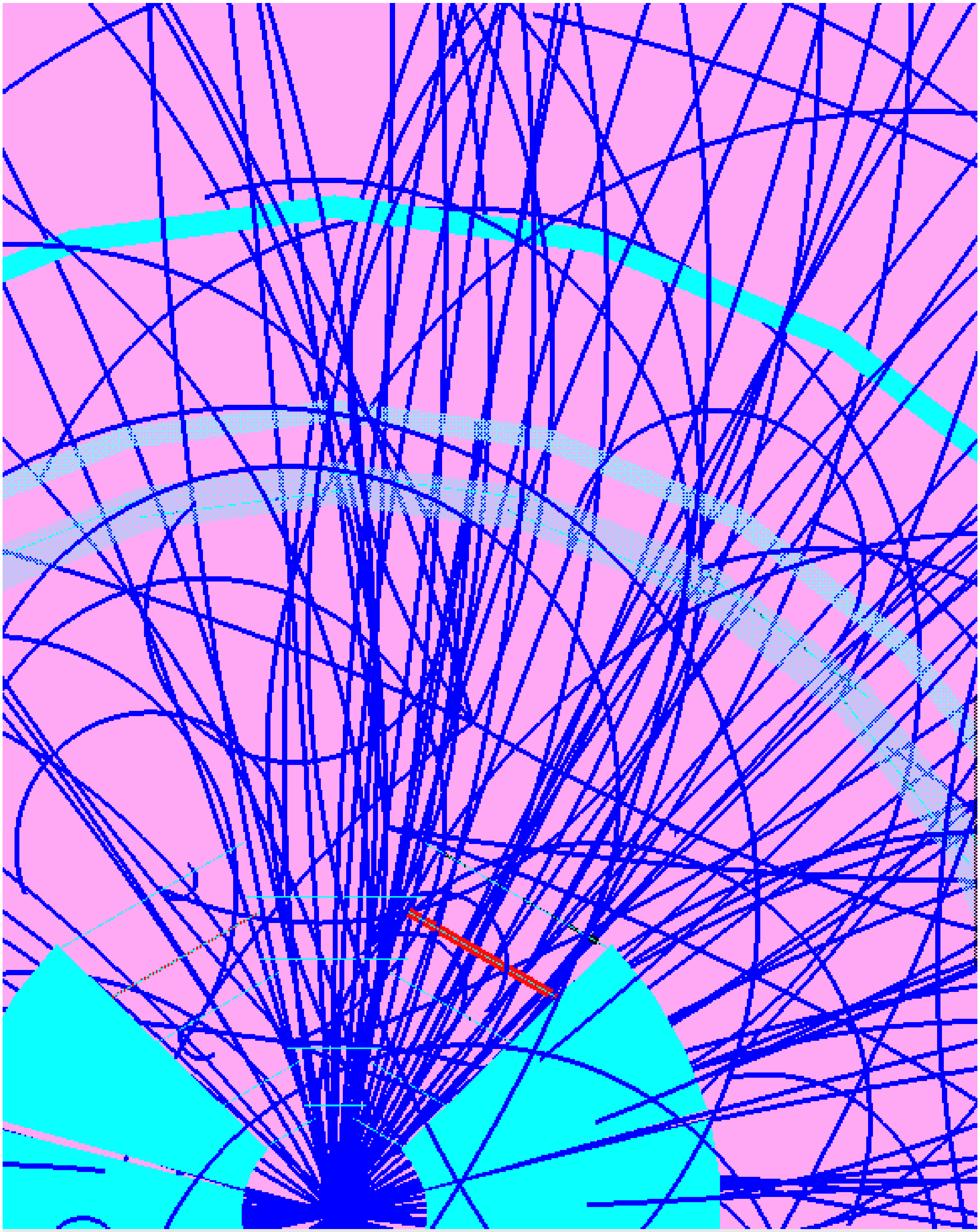
Table 1: The acceptance as a function of P_T and σ_d cut for b jets in $t\bar{t}$ events ($M_{top} = 160GeV/c^2$), per b jet.

- The table (from CDF-2568) shows the generator-level efficiency of a SECVTX-like algorithm ("3tk vtx" column) vs. Pt and impact parameter significance cuts.
  - Efficiency is a strong function of Pt cut
  - Efficiency improves even as Pt cut is lowered to 0.5 GeV/c.
    - Tracks down to 0.5 GeV/c are important to the physics
    - Need to solve the pattern recognition problem at least to the level of 0.5 GeV/c
    - Multiple scattering in pattern recognition will be an important effect.

No secondary interactions



With secondary interactions



Pattern recognition issues

- 90-degree stereo hits
  - Only three 90-degree stereo layers available
    - A single incorrect, high-precision 90-degree stereo hit added to a track typically renders the track unusable.
    - Purity of hits added is critical
      - Better to ignore 90-degree stereo than to make mistakes.
  - Clusters in forward region are difficult to use.
    - Difficult to find due to small signal per strip
    - Large => overlap with good high-angle clusters
    - Largest ganging factor at innermost layer.
      - *(See track separation plot)*
  - Why are 90-degree stereo hits important?
    - Consider SECVTX
      - Required three tracks at a 2D vertex
      - The third "confirmation" track significantly improves background rejection
        - *1C fit to vertex*
      - Allowed loosening of Pt, track quality cuts that more than compensated for loss from requiring additional track
    - Consider 3D tracks:
      - Two 3D tracks at a 3D vertex: 1C fit.
      - Expect comparable background rejection by two 3D tracks to that afforded by three 2D tracks
        - *Can loosen 2-track tag requirements*

Pattern recognition issues

- Why are 90-degree stereo hits important?
  - Consider multi-vertex B-decay
    - Each 3D vertex can be propagated in 3D back to parent vertex
    - Background rejection provided at each vertex as each additional track is added.
- Important distance scale for all these problems is 10's of microns to 100 microns
  - Comparable to 90-degree stereo resolution
  - Much smaller than small-angle-stereo resolution

Conclusions/suggestions

- Material matters:
  - not only for precision of track parameters
  - but also for pattern recognition

  Make reduction of material in the tracking volume a high priority
- Keep robust, high-precision 3D tracking a high priority
  - Can likely find ways to improve over the current situation
- Detector configuration issues
  - Did not have time to consider, e.g., gap between ISL, SVXII
  - No evidence at the moment of adverse PR effects related to the gap