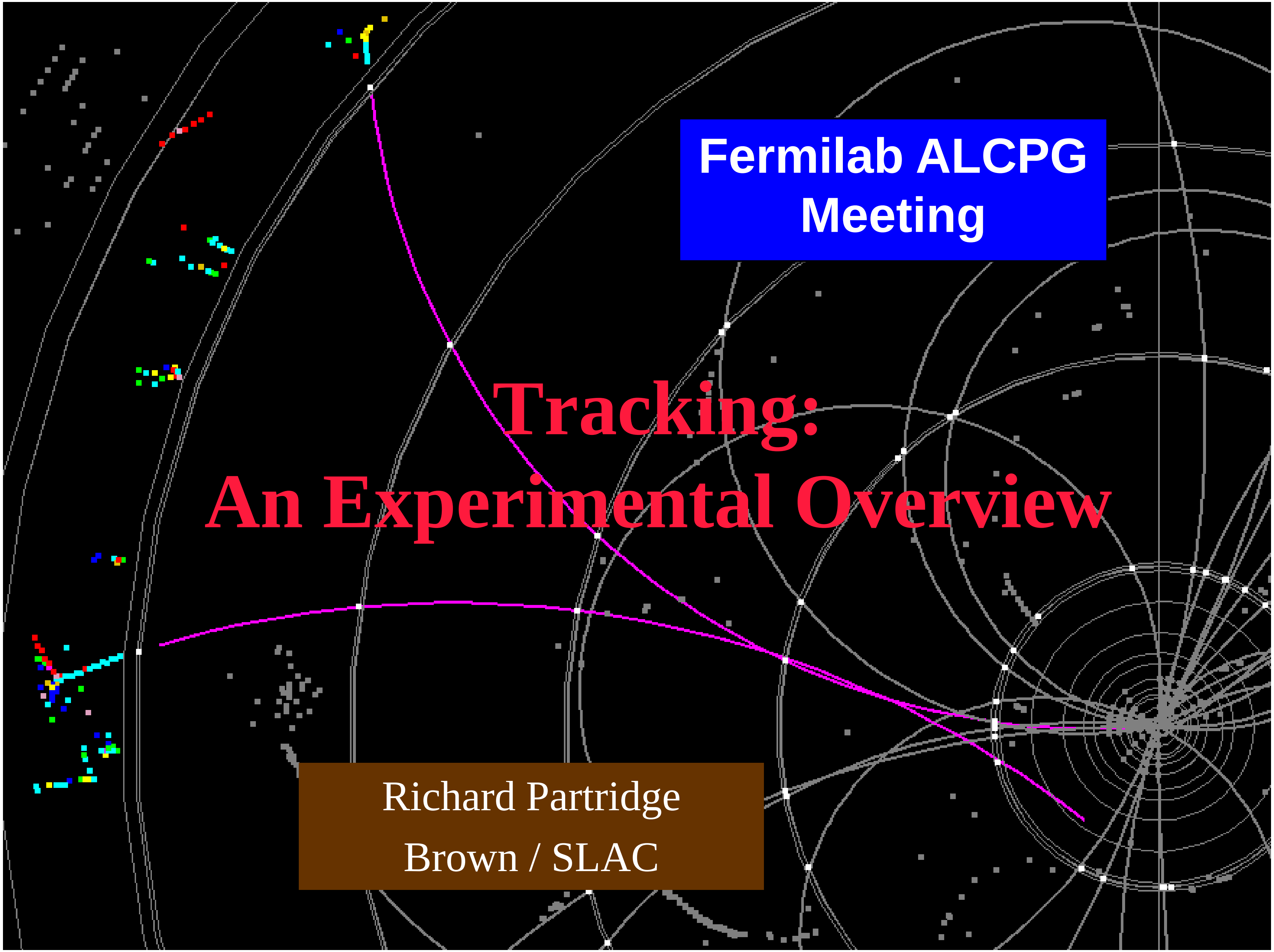

Fermilab ALCPG Meeting

Tracking: An Experimental Overview

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Talk Outline (First Draft)

Figuring out what to include in this talk has been a challenge

- Gee-whiz design and technology for tracking?
  - NO! Extensively covered in Wednesday ALCPG plenary session
- Seductive new physics we can do with the tracker?
  - NO! Extensively covered by talks that follow
- Brilliant algorithms for tracking software?
  - NO! Extensively covered by other talks at this workshop
- Fashionable new bureaucracy prescribed by DOE Order 413.3?
  - NO! There may be some impressionable young minds in the audience
- Anything left?
  - Hope so…it's too early for the coffee break

Talk Outline (Second Draft)

Will try to answer some simple questions:

- What is required to efficiently find tracks?
- How do the vertex detector and outer tracker work together to deliver good tracking resolution?

Or…can we see what goes into a well-designed tracker without writing complex tracking code?

Track Finding Performance

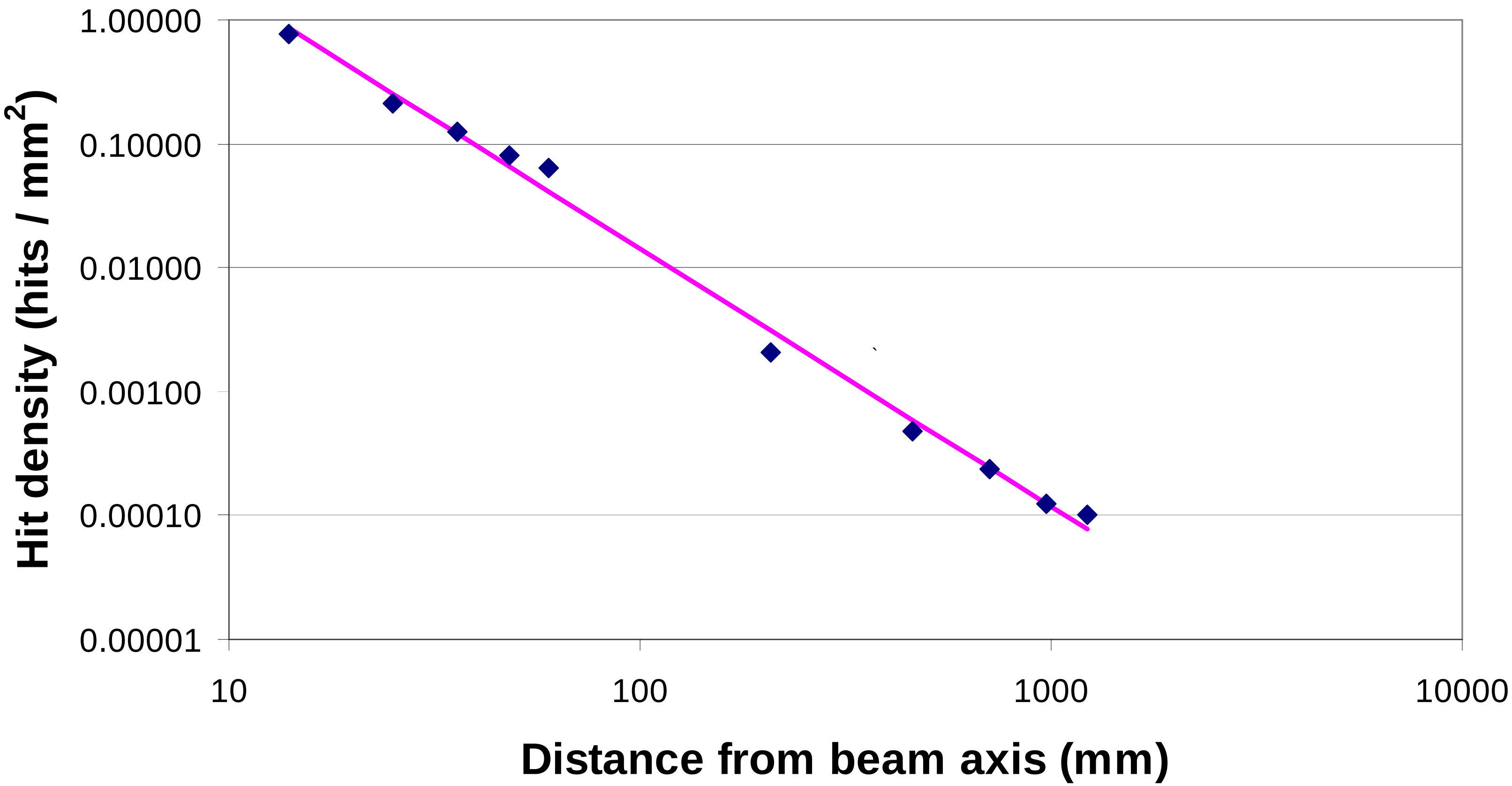
- What determines track finding performance?
- Number of “voxels”?
  - Voxel is essentially a 3D pixel in the tracking volume
  - The number of voxels is a measure of how many distinguishable space points exist in the tracking volume
  - For a TPC, you may have 10^9 or more voxels in the tracker
  - Not clear that voxel counting is useful in a silicon tracker
    - # voxels = # strips? (~30M voxels)
    - What about stereo layers? # voxels = # strips ** 2? (~10^{10} voxels)
    - Distribution of voxels in tracking volume is important
- Number of layers?
  - Required redundancy depends on many factors
    - Occupancy
    - Hit resolution
    - Physics goals (kinks, long lived secondaries)
  - More layers is not necessarily better (more material, power, cost, etc.)
- Need to look deeper…

Finding Tracks

- It is easy to be efficient in finding tracks
  - Need 3 space points to form a helix, so any track with 3 hits can be found…
  - …but there will also be many fake tracks from random associations of 3 hits
- The challenge is maintaining efficiency while rejecting fakes
  - Typically reject fakes by requiring hits in additional tracker layers
- Good resolution reduces the search window
  - For equally spaced tracking layers, three hits with r-ϕ resolution σ yield an uncertainty 5σ in the predicted position for the fourth layer (circle fit)
  - For silicon strips with 7 μm resolution in r-ϕ, a ±3 sigma window for the predicted position of a fourth hit is ±105 μm (~4 strips)
  - A TPC with 100 μm resolution has a wider search window in r-ϕ (±1500 μm), but can also require a consistent position in z (±18 mm for 4 mm z resolution)
  - Low momentum tracks need larger search windows in the outer tracker (due to multiple scattering errors), but the effect is small in the vertex detector
- Low occupancy in the search window reduces the probability of a random hit confirming the track hypothesis

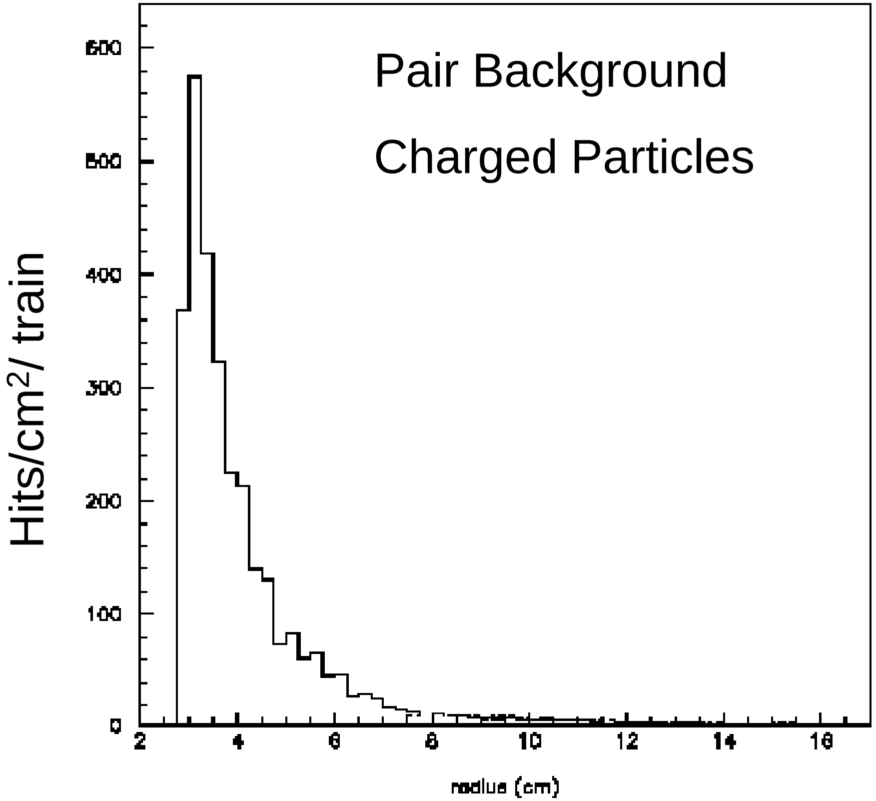
Hit Density in SiD Tracker

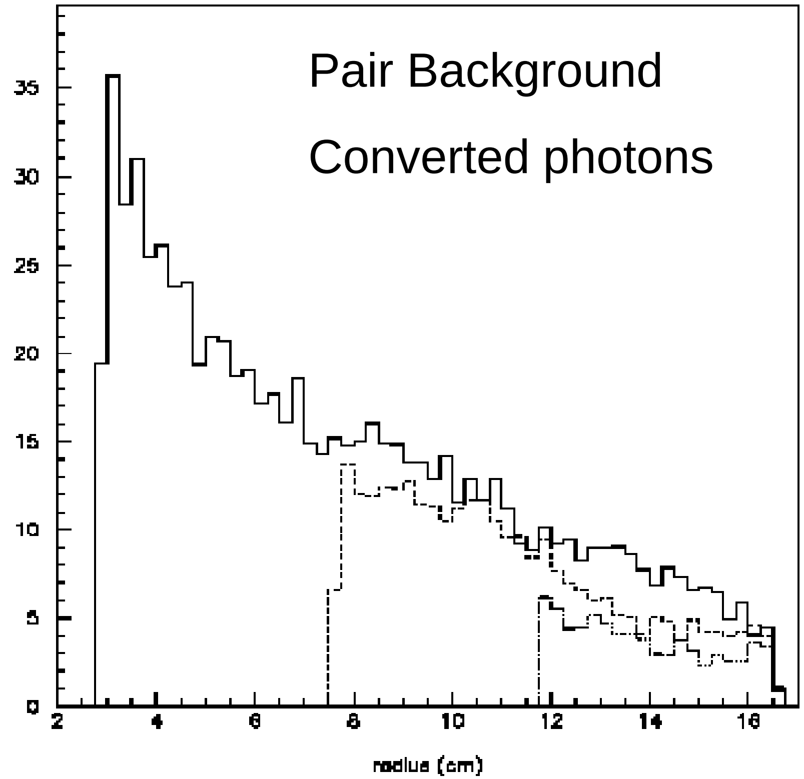
- Look in the core of E_{CM} = 500 GeV qqbar events to estimate peak hit density for physics events
  - Select "2-jet" topology (thrust > 0.94) events in central region ($|\cos(\theta_T)| < 0.5$)
  - Empirically: peak hit density (hits per mm^2) is ~200 / r^2 (r in mm)



What About Machine Backgrounds?

- Takashi Maruyama has calculated the expected machine backgrounds for the nominal ILC parameter set
  - Pair background: 138 e^+e^- per bunch crossing in detector (390K per train)
  - $\gamma\gamma \rightarrow$ hadrons: 0.65 events per bunch crossing (1841 per train)
  - $\gamma\gamma \rightarrow$ muons: 1.3 events per bunch crossing (3779 per train)





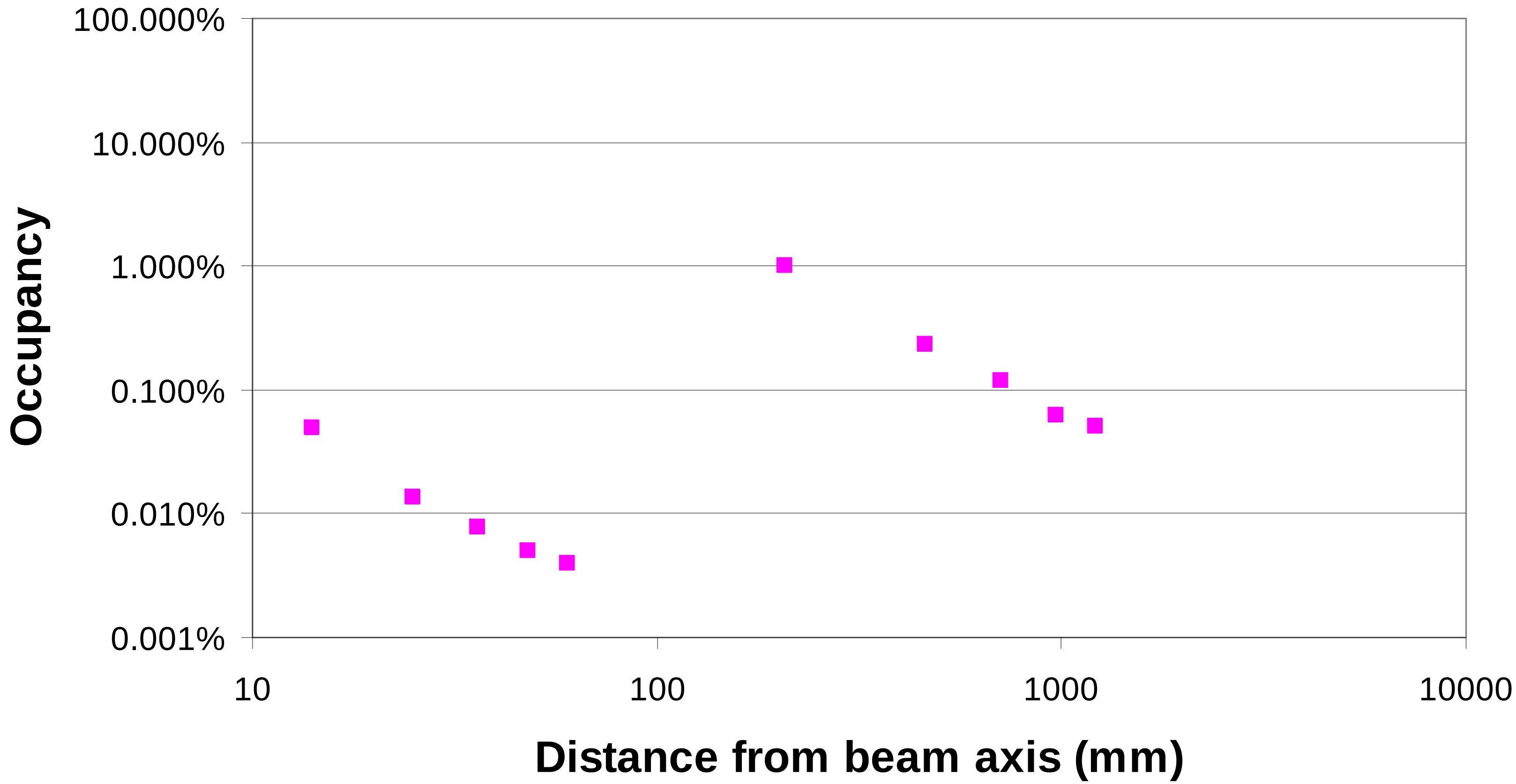
Maximum Hit Density (hits/cm^2/train)

	Pairs	$\gamma\gamma$ -> Had	$\gamma\gamma$ -> $\mu\mu$	Total
Barrel Charged	0.15	0.2	0.13	0.48
Barrel Photons	2.0	<<0.01	<<0.01	2.0
Endcap Charged	0.4	0.3	0.25	1.0
Endcap Photons	1.5	0.02	<< 0.01	1.5
Forward Charged	575.	8.	15.	598.
Forward Photons	35.	0.9	<< 0.01	36.

- Machine backgrounds small for detectors with good timing
- Major challenge for the inner layer of vertex detector

Occupancy in Jet Core

- Pixel area is ~6×10^{-4} mm^2 (assume 25 μm x 25 μm pixels)
- Strip area is ~5 mm^2 (assume 50 μm x 100 mm strips)
- For TPC with 10^9 voxels, voxel cross section is ~10 mm^2



Impact of Occupancy on Tracking

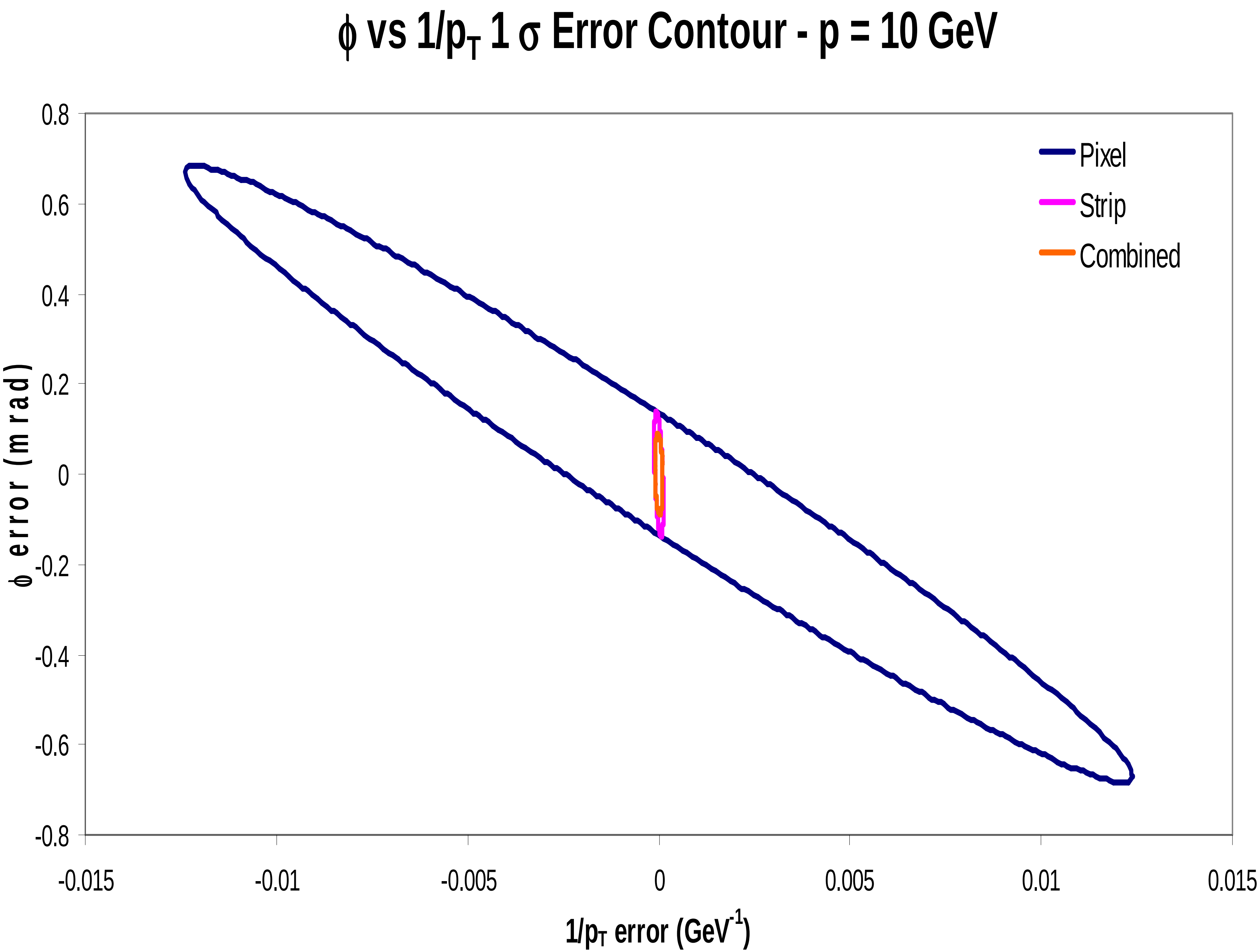
- For both TPC and silicon tracking, occupancies appear to be ~1% or less even in the core of a hard jet
  - Generally, a good sign for tracking
  - The combination of good track extrapolation and low occupancy should allow good suppression of fake tracks by requiring a relatively small number of confirming hits
  - This appears to be born out by the success of preliminary simulation studies
- In the outer layers of the SiD barrel tracker, there is on average only 1 hit per sensor in the jet core
  - If stereo strips are added, there should be little problem with ghosting

Tracker Resolution

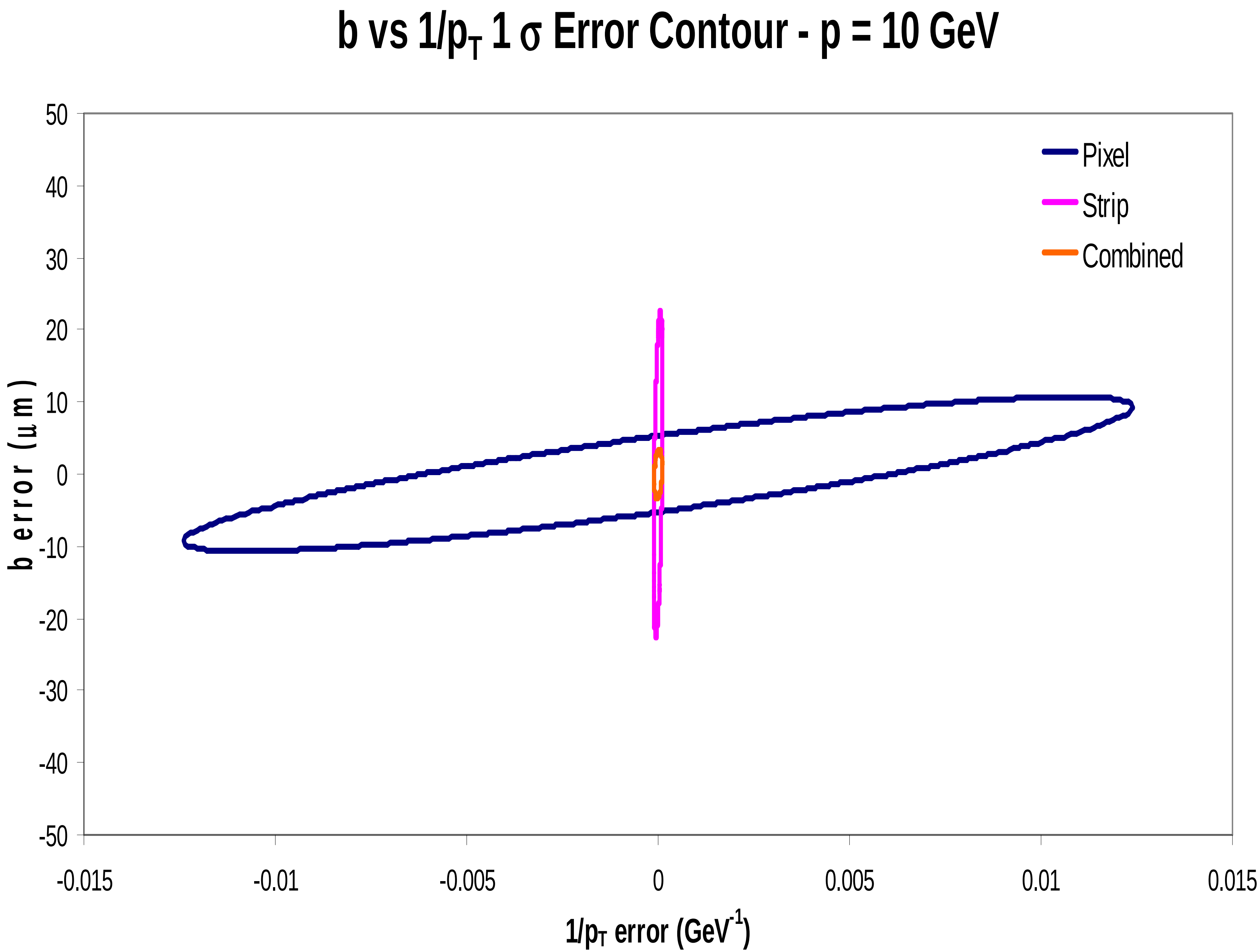
- Expected tracker resolution can be estimated without doing a full detector simulation
- In the small angle approximation, the particle trajectory is linear in the track parameters

$$r\phi \approx b + r\phi_0 + 1/2\, kr^2$$

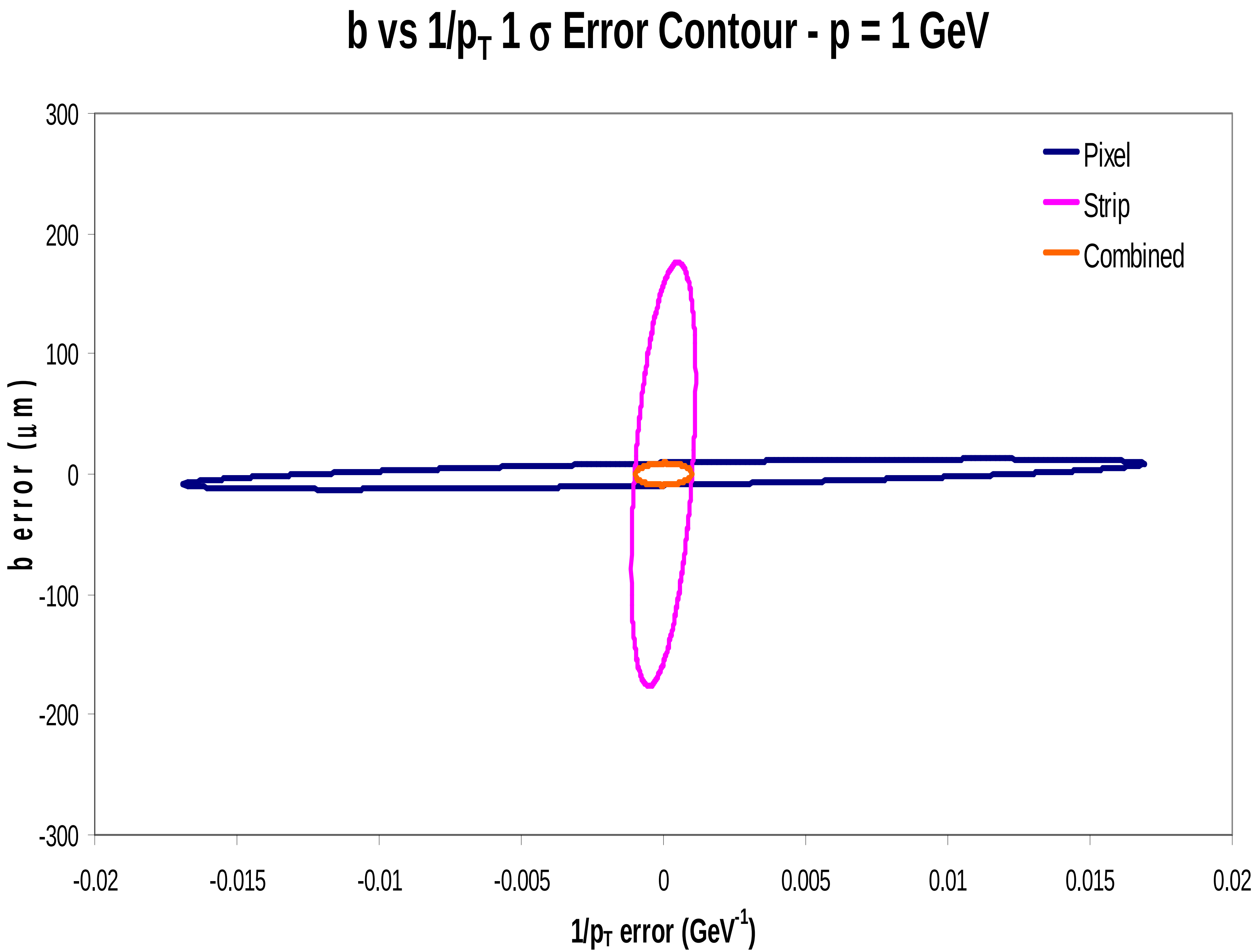
- The fitted error matrix in a least squares fit is independent of the actual measurements, and only depends on the radii and (correlated) measurement errors
- Resolution can be conveniently calculated in a spreadsheet
  - Ron Lipton and I have developed such a spreadsheet:
  - http://www.hep.brown.edu/users/partridge/nlc/sd_tracker_resolution.xls
- Expected error is really a 3x3 correlated error matrix in $1/p_T$, ϕ, and impact parameter b
  - Plot 1 sigma contours to show impact of correlations



ϕ vs 1/p_T 1 σ Error Contour - p = 10 GeV
Pixel
Strip
Combined
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
ϕ error (mrad)
-0.015
-0.01
-0.005
0
0.005
0.01
0.015
1/p_T error (GeV^-1)



b vs 1/pT 1 σ Error Contour - p = 10 GeV
Pixel
Strip
Combined
50
40
30
20
10
0
-10
-20
-30
-40
-50
b error (μm)
-0.015
-0.01
-0.005
0
0.005
0.01
0.015
1/pT error (GeV-1)



b vs 1/p_T 1 σ Error Contour - p = 1 GeV
Pixel
Strip
Combined
b error (μm)
300
200
100
0
-100
-200
-300
-0.02
-0.015
-0.01
-0.005
0
0.005
0.01
0.015
0.02
1/p_T error (GeV^-1)

Error ellipse results

- Strip tracker has excellent ϕ and $1/p_T$ resolution, with little improvement from combining pixel and strip detectors
- Both pixel and strip detectors have pretty good impact parameter resolution for 10 GeV tracks
- Precise momentum determination from strip tracker required to get full resolution out of pixel tracker for 10 GeV tracks
- For 1 GeV tracks, strip tracker impact parameter resolution degrades substantially due to multiple scattering, and only
- Only modest gain in impact parameter resolution from adding strip tracker hits for 1 GeV tracks
- Pixel detector alone has reasonably good p_T resolution at low momentum despite the small lever arm (~1.5% at 1 GeV)

Tracking Observations I

- Both TPC and silicon trackers are likely to be efficient at finding prompt tracks
- Silicon and TPC algorithms under study take somewhat different approaches to track finding
  - The large number of redundant measurements in a TPC allows tracing out a particle’s trajectory
  - The silicon tracker relies on precision measurements to find helicies
  - A TPC tracker will probably be better at finding tracks from K_S / Λ decays and following kinks due to in-flight decays and/or interactions
- The ILC trackers should allow high momentum tracks to be measured with unprecedented precision
  - The expected presence of narrow heavy states (Higgs + others?) lends strong motivation for precision tracking at high momentum
  - Likely that silicon trackers will have an advantage in this regard
  - Less clear that much is to be gained by <1% precision at low momentum

Tracking Observations II

- Both TPC and silicon trackers make ionization measurements allowing some level of particle ID
  - Not clear that this will be useful in the traditional usage of aiding the reconstruction of exclusive final states
  - Possible presence of long-lived heavy particles may provide a new application for ionization / particle ID
    - Heavy particles typically have modest betas and should have a clear ionization signature