General Thoughts About Tracking for the Linear Collider Detector(s)

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OUTLINE

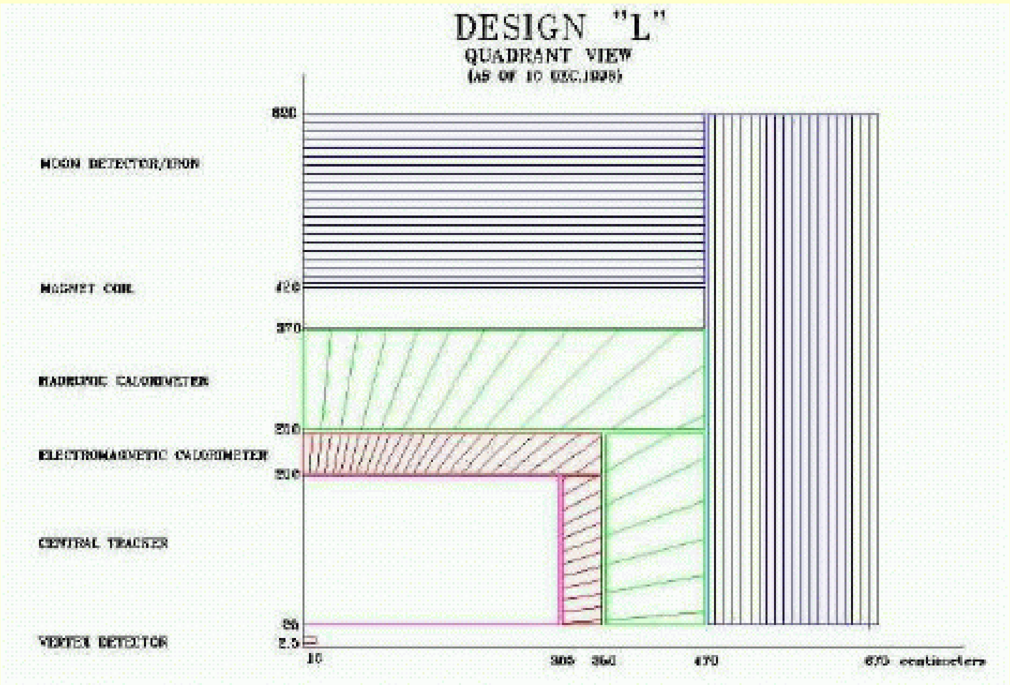
Physics drivers for tracking: what should we be shooting for?

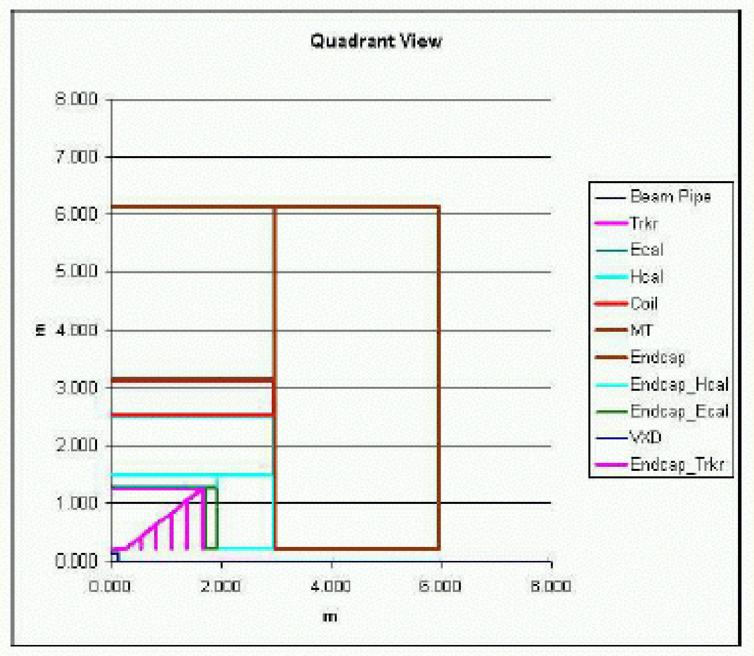
“Apples-to-apples” comparison of gaseous and solid-state tracking

A new look at optimization: hybrid tracking

Some conclusions

Linear Collider Detectors (very approximate)





"L" Design:

Gaseous Tracking (TPC) R_{max} ~ 170cm

4 Tesla Field

Precise (Si/W) EM Calorimeter

"S" Design:

Solid-State Tracking R_{max} = 125cm

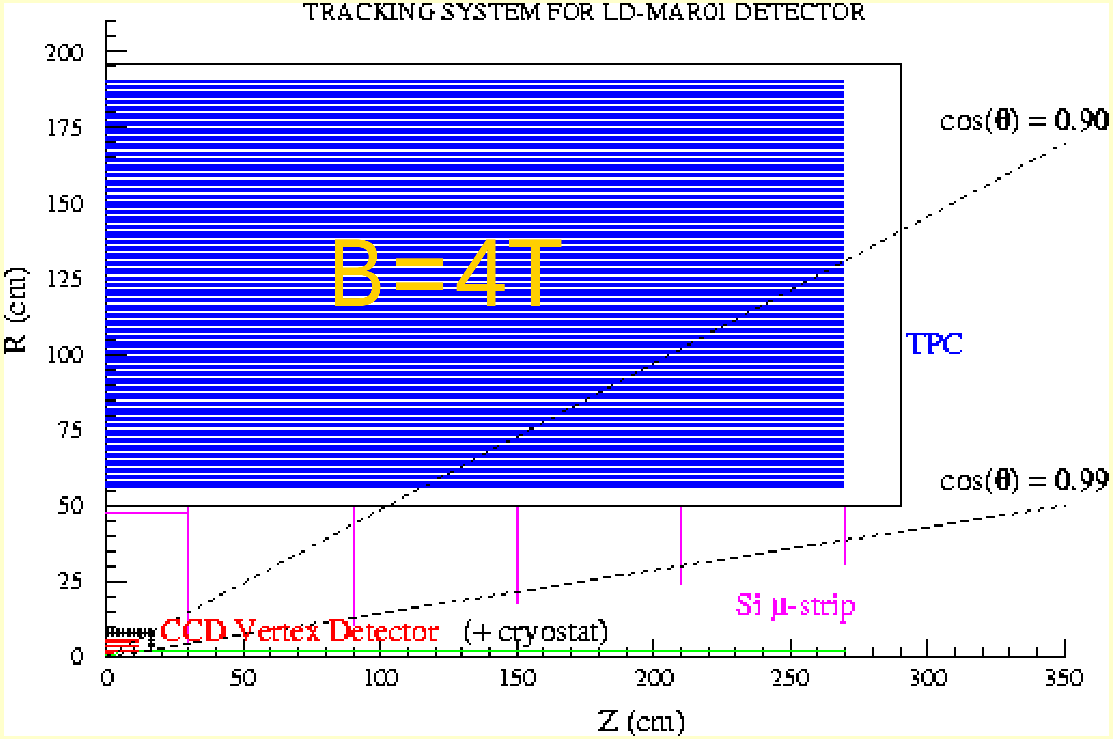
5 Tesla Field

Precise (Si/W) Calorimeter

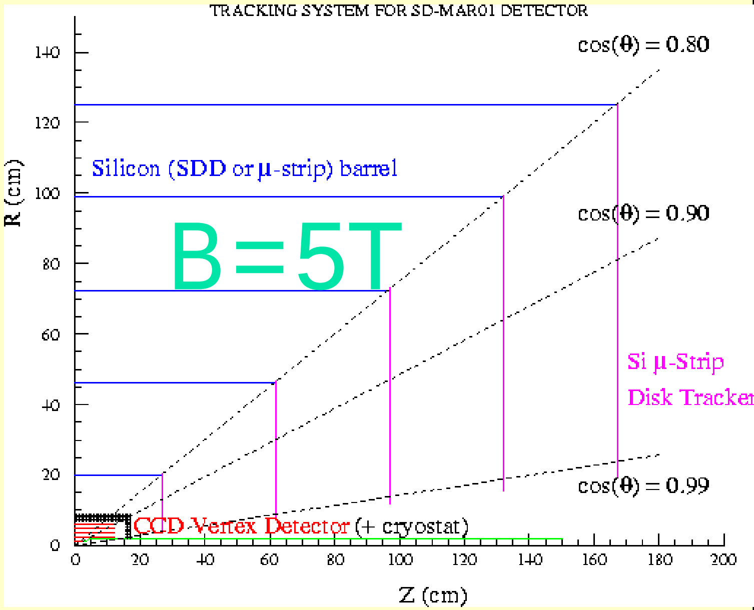
The Trackers

Gaseous (GLD, LDC, ...)

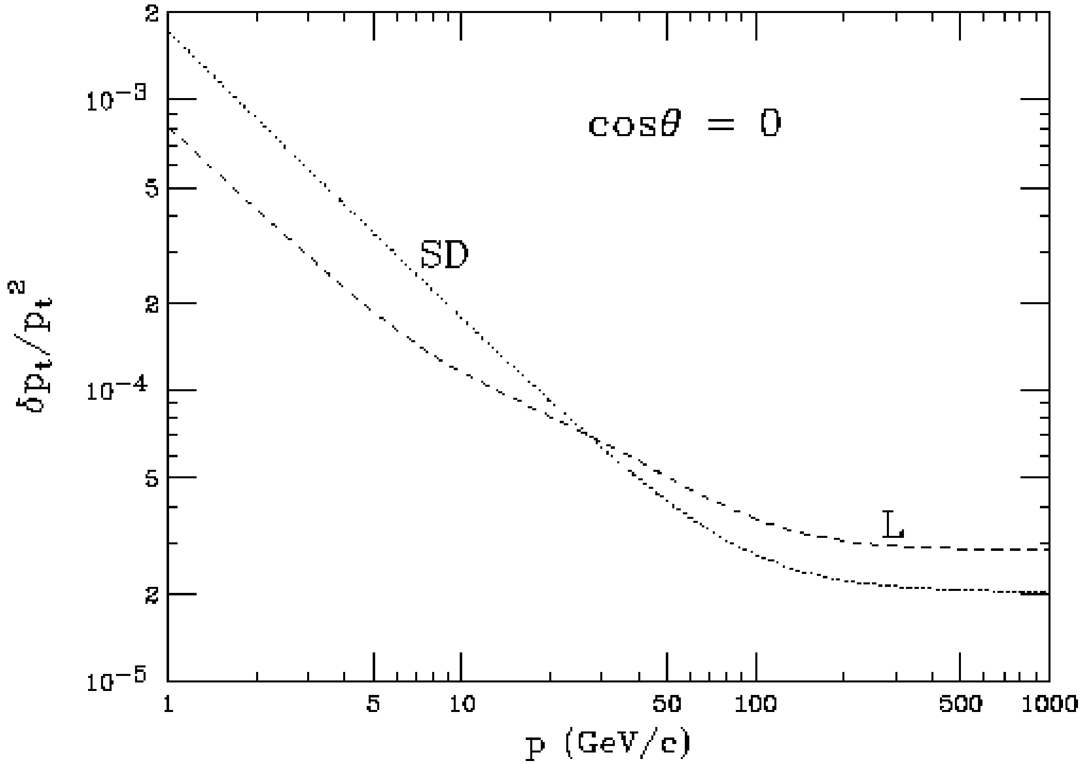
Solid-State (SD, SiD, ...)



The SD-MAR01 Tracker



… and Their Performance



Error in curvature ω is proportional to error in $1/p_\perp$, or $\delta p_\perp / p_\perp^2$.

This is very generic; details and updates in a moment!

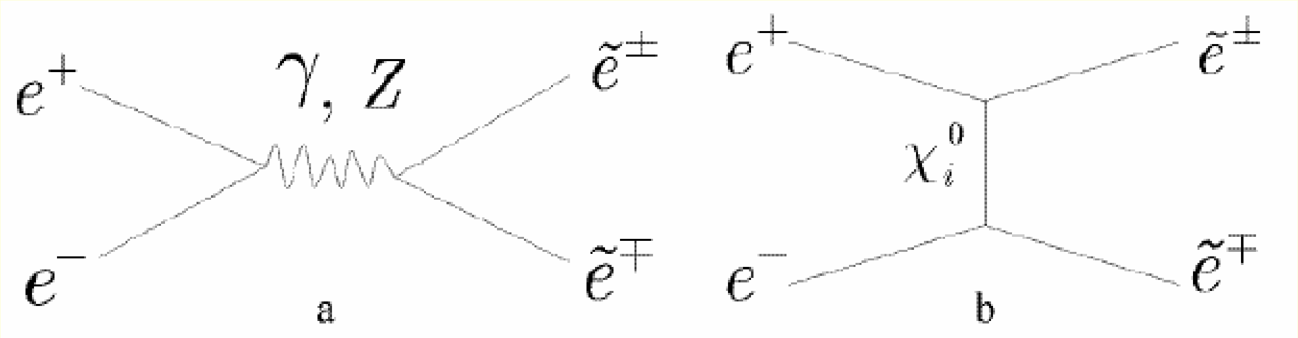
Code: http://www.slac.stanford.edu/~schumm/lcdtrk.tar.gz

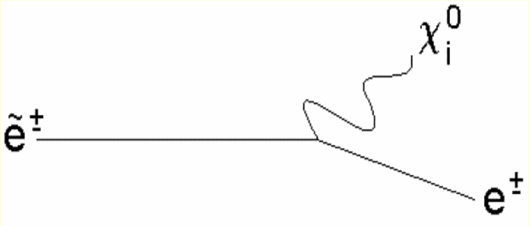
Linear Collider Physics...

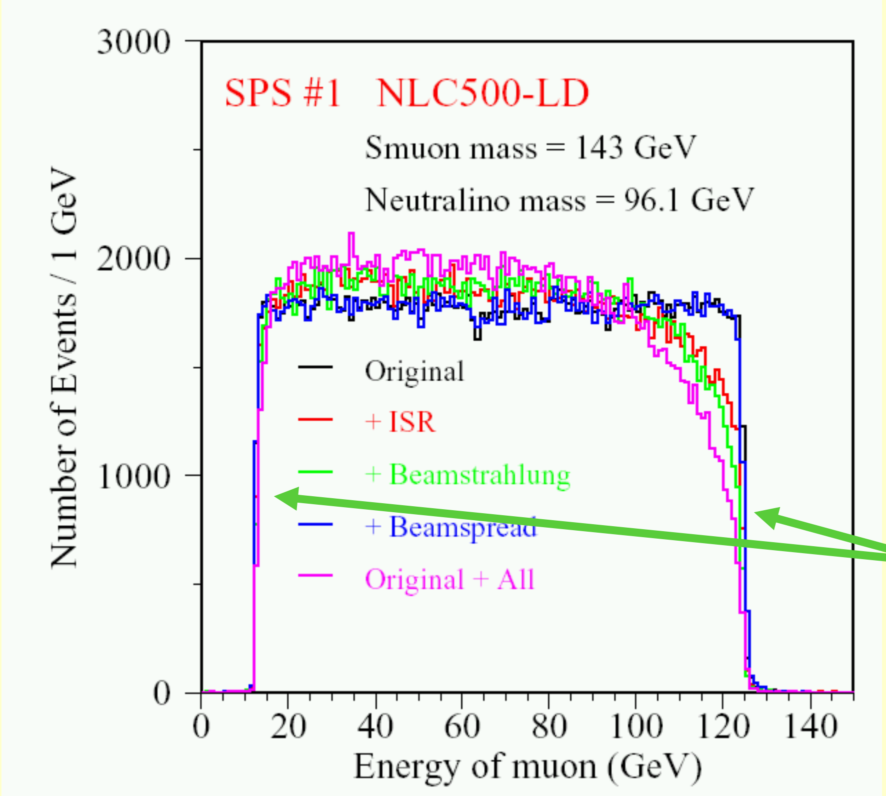
At leading order, the LC is a machine geared toward the elucidation of Electroweak symmetry breaking. Need to concentrate on:

- Precision Higgs Physics
- Strong WW Scattering
- SUSY

Supersymmetry: Slepton Production



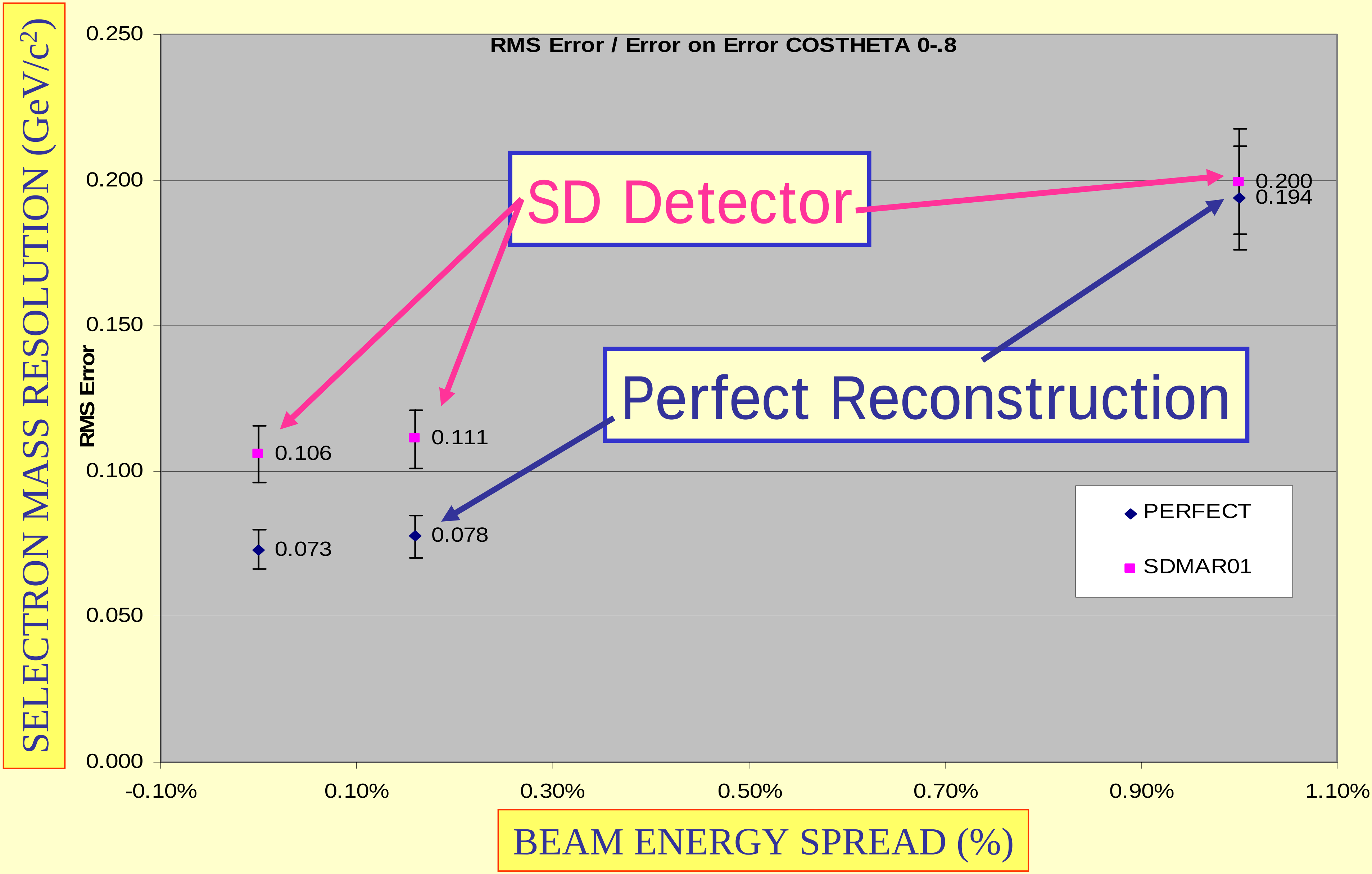




Slepton production followed by decay into corresponding lepton and "LSP" (neutralino)

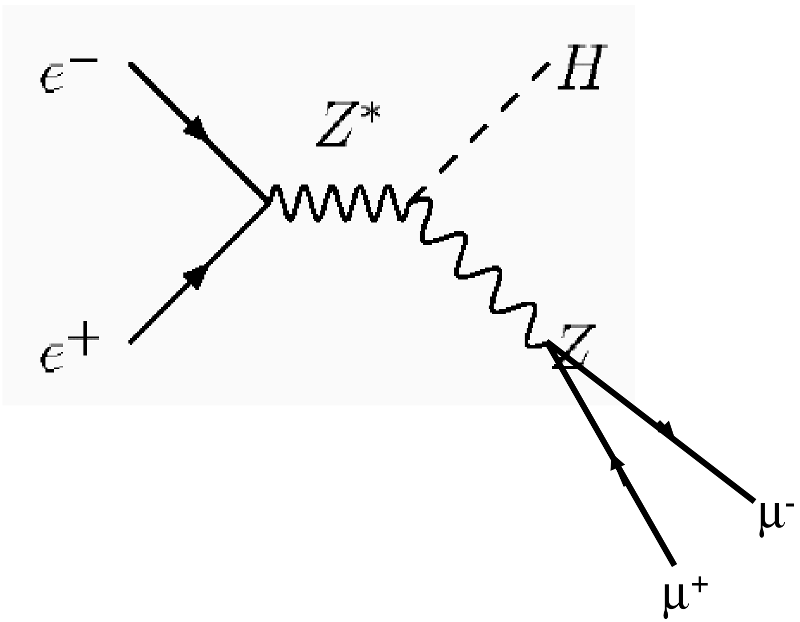
Endpoints of lepton spectrum determined by slepton, neutralino masses

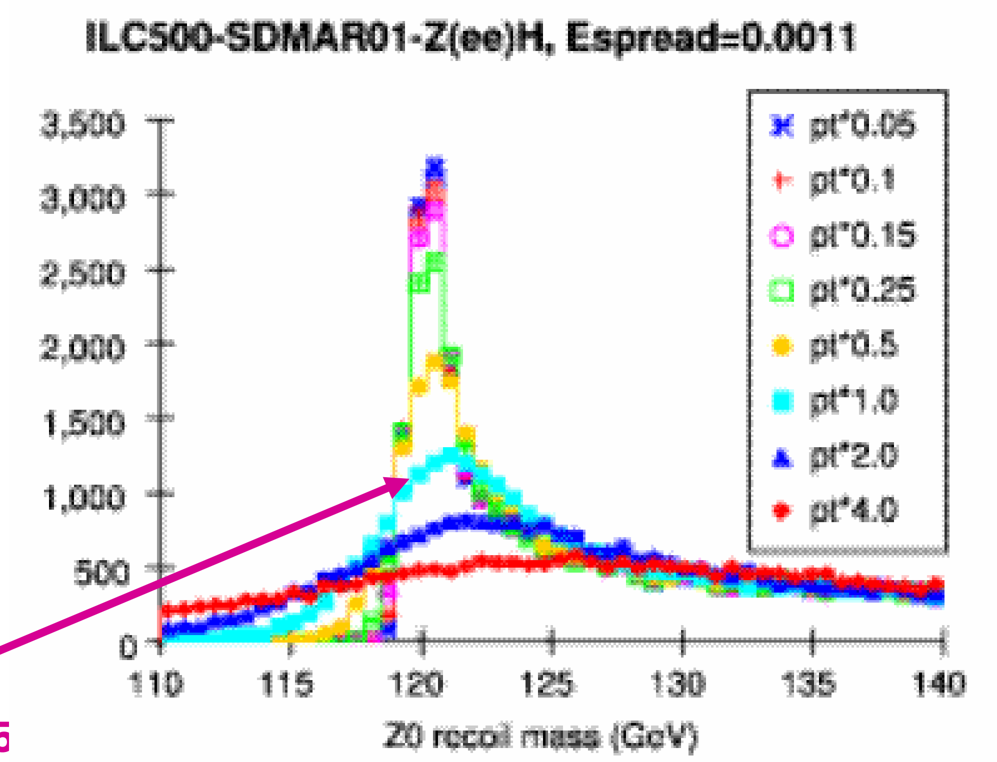
SUSY Point “SPS1a” at E_{cm}=1TeV



Reconstructing Higgsstrahlung

Haijun Yang, Michigan





$M_{\mu\mu}$ for

$\delta p_{\perp} / p_{\perp}^{2} = 2\times10^{-5}$

Choice of Tracking Techonolgy (Si, Gas)

Tracker needs excellent *pattern recognition* capa-bilities, to reconstruct particles in dense jets with high efficiency.

But as we've seen, recent physics studies (low beam-energy spread) also suggest need to push momentum resolution to its limits.

Gaseous (TPC) tracking, with its wealth of 3-d hits, should provide spectacular pattern recognition – but what about momentum resolution? Let's compare.

In some cases, conventional wisdom may not be correct...

Some “facts” that one might question upon further reflection

1. Gaseous tracking is natural for lower-field, large-radius tracking

In fact, both TPC’s and microstrip trackers can be built as large or small as you please. The calorimeter appears to be the cost driver.

High-field/Low-field is a trade-off between vertex reconstruction (higher field channels backgrounds and allows you to get closer in) and energy-flow into the calorimeter (limitations in magnet technology restricts volume for higher field). The assignment of gaseous vs solid state tracking to either is arbitrary.

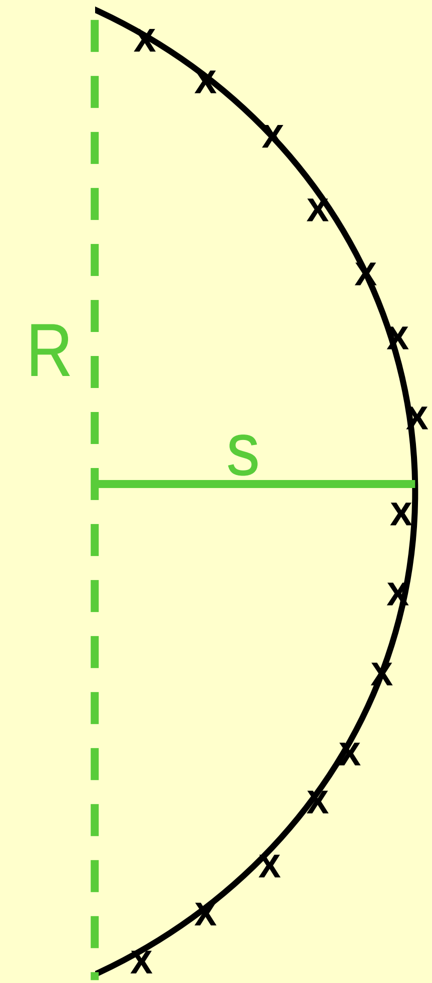
2 Gaseous tracking provides more information per radiation length than solid-state tracking

For a given track $p_\perp$ and tracker radius R, error on sagitta s determines $p_\perp$ resolution

Figure of merit is $\eta = \sigma_{point} / \sqrt{N_{hit}}$.

Gaseous detector: Of order 200 hits at σ_{point}=100 μm ➔ η = 7.1 μm

Solid-state: 8 layers at σ_{point}=7μm ➔ η = 2.5μm



Also, Si information very localized, so can better exploit the full radius R.

For gaseous tracking, you need only about 1% X_0 for those 200 measurements (gas gain!!)

For solid-state tracking, you need 8x(0.3mm) = 2.6% X_0 of silicon (signal-to-noise), so 2.5 times the multiple scattering burden.

BUT: to get to similar accuracy with gas, would need $(7.1/2.5)^2$ = 8 times more hits, and so substantially more gas. Might be able to increase density of hits somewhat, but would need a factor of 3 to match solid-state tracking.

Solid-state tracking intrinsically more efficient (we'll confirm this soon), but you can only make layers so thin due to amp noise ➔ material still an issue.

③ Calibration is more demanding for solid-state tracking

The figure-of-merit η sets the scale for calibration systematics, and is certainly more demanding for Si tracker (2.5 vs. 7.1 μm).

But, η is also the figure-of-merit for $p_\perp$ resolution.

For equal-performing trackers of similar radius, calibration scale is independent of tracking technology.

Calibrating a gaseous detector to similar accuracy of a solid-state detector could prove challenging.

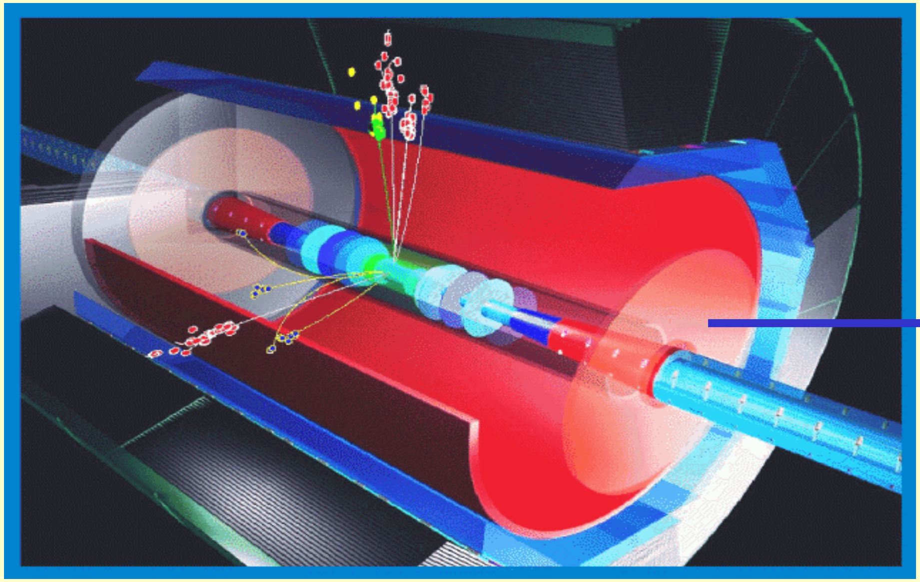
4 All Other Things Equal, Gaseous Tracking Provides Better Pattern Recognition

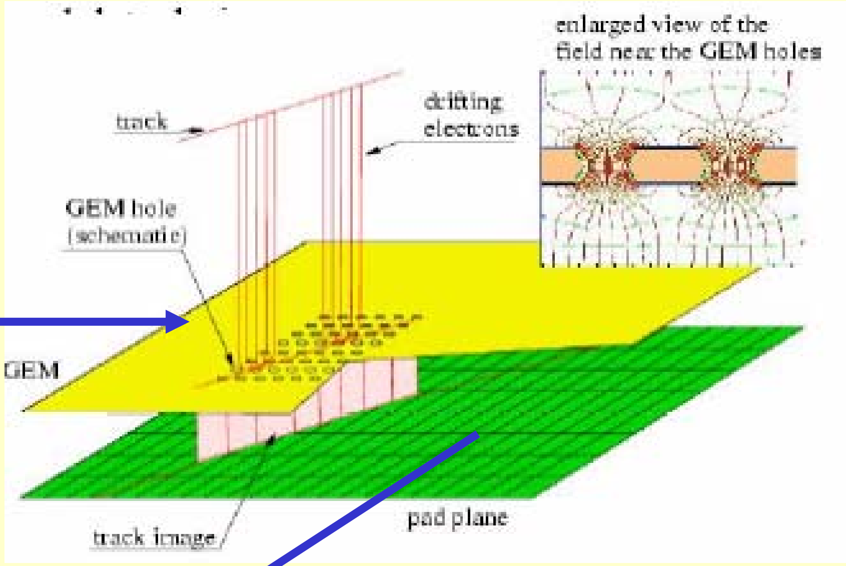
It's difficult to challenge this notion. TPC's provide a surfeit of relative precise 3d space-points for pattern recognition.

They do suffer a bit in terms of track separation resolution: 2mm is typical, vs 150 μm for solid-state tracking. Impact of this not yet explored (vertexing, energy flow into calorimeter).

For solid-state tracking, still don't know how many layers is "enough" (K^0_S, kinks), but tracking efficiency seems OK evevn with 5 layers (and 5 VTX layers)

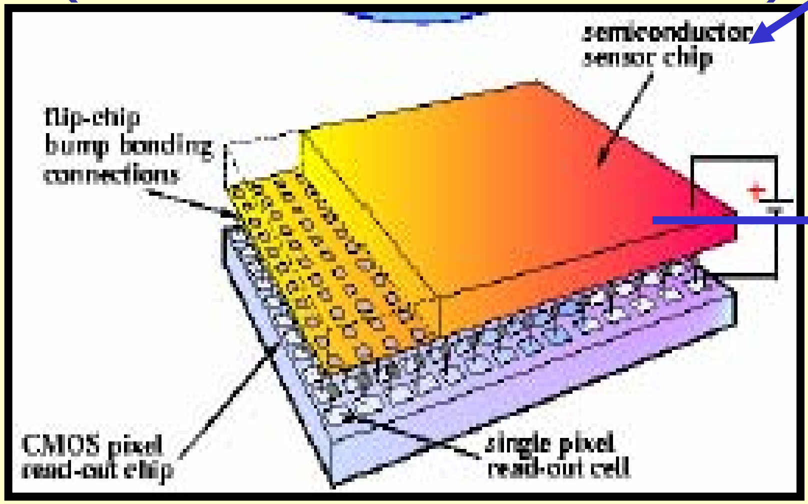
Caveat: What can gaseous tracking *really* do?

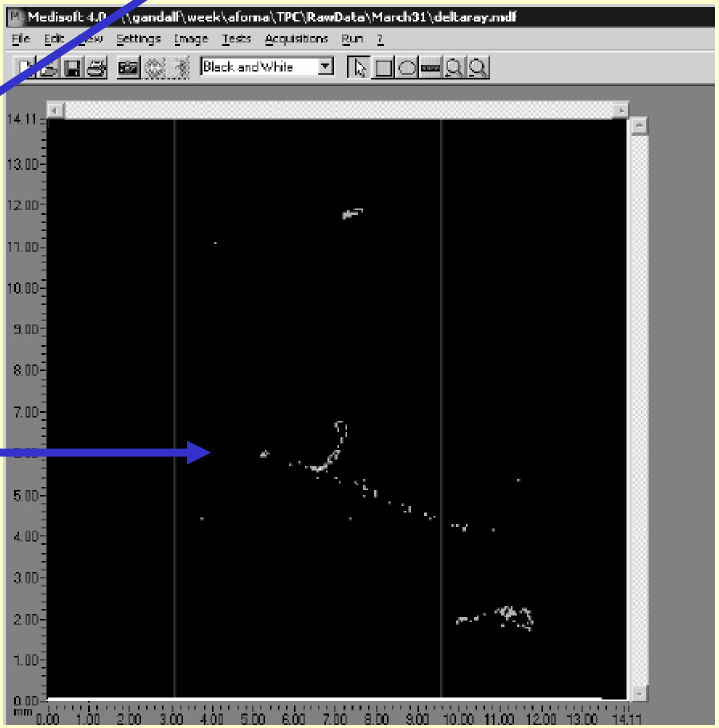




55µm^2 MediPix2 Pixel Array (Timmermans, Nikhef)

?

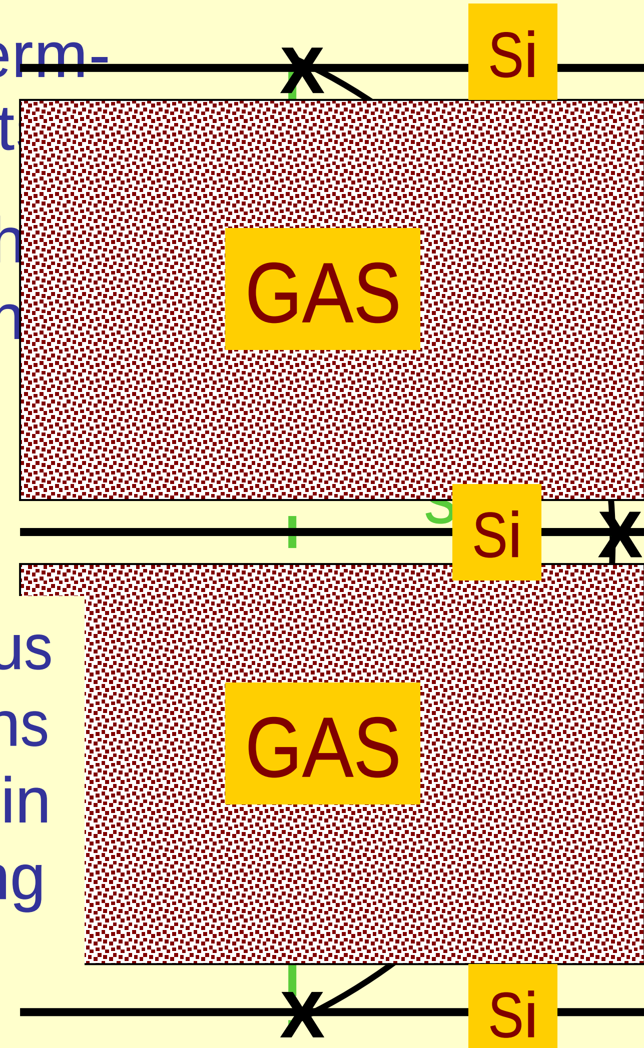


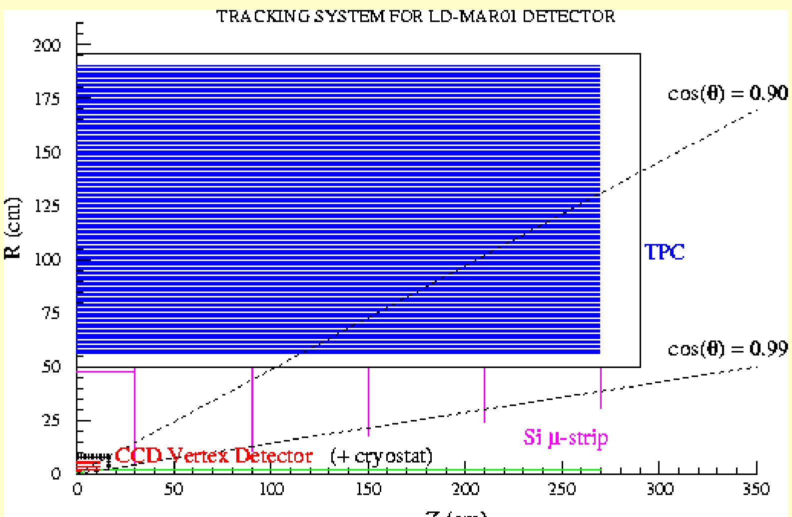


Hybrid Trackers – the Best of Both Worlds?

In an ideal world, momenta would be determ-ined from three arbitrarily precise r/ϕ points.

Optimally, you would have Si tracking at these points, with “massless” gaseous tracking in between for robust pattern recognition ➔ Si/TPC/Si/TPC/Si “Club Sandwich”.



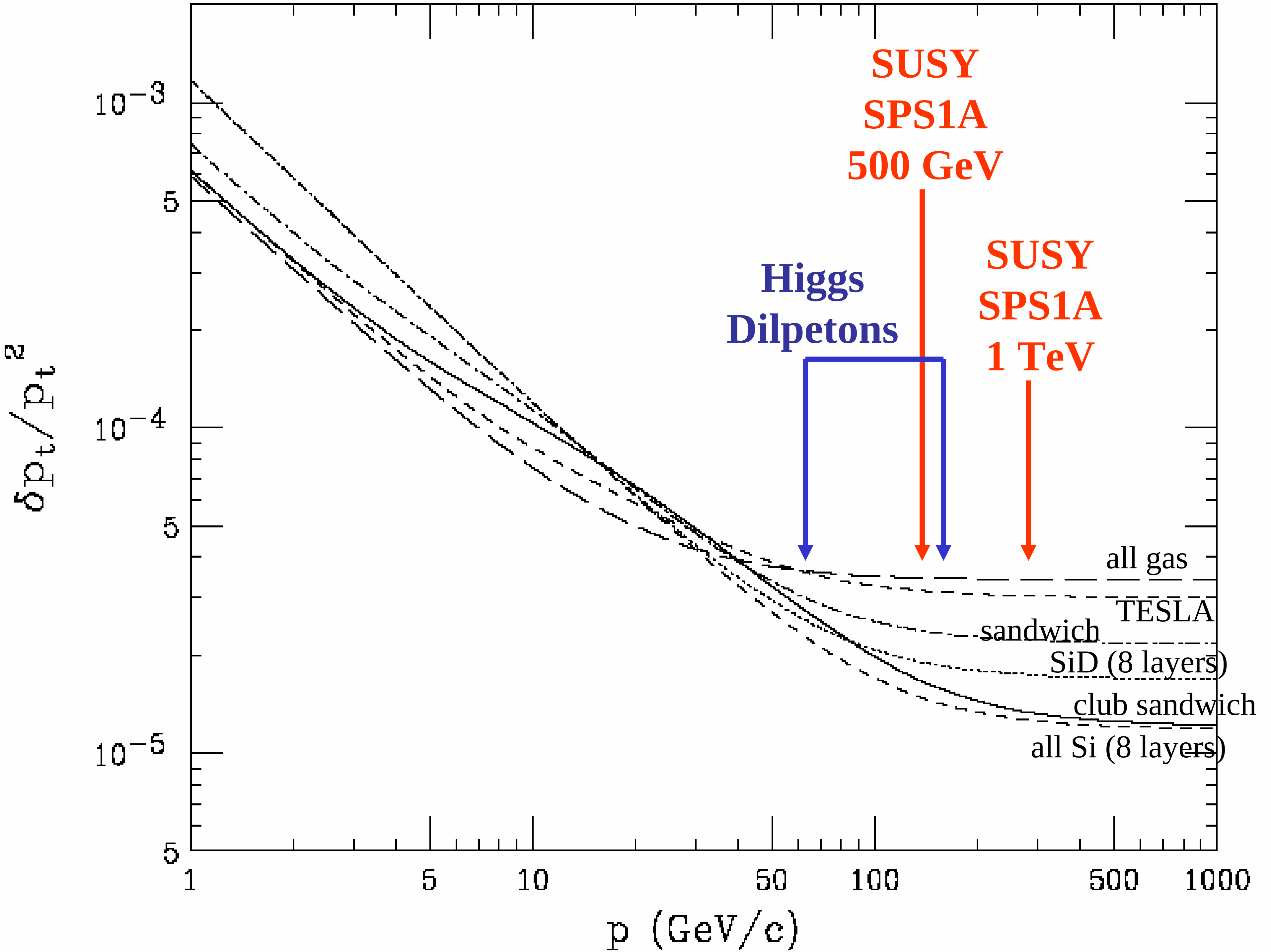


Current gaseous tracking designs recognize this in part (Si tracking to about R/4).

Hybrid Tracker Optimization

Let's try filling the Gaseous Detector volume (R=20cm-170cm) with various things...

- All gas: No Si tracking (vertexer only)
- TESLA: Si out to 33cm, then gas (100 μm resolution)
- Sandwich: Si out to 80cm, and then just inside 170cm
- Club Sand: Si/TPC/Si/TPC/Si with central Si at 80cm
- All Si: Eight evenly-spaced Si layers
- SD: Smaller (R=125cm) Si design with 8 layers



SUSY
SPS1A
500 GeV
SUSY
SPS1A
1 TeV
Higgs
Dilpetons
all gas
TESLA
sandwich
SiD (8 layers)
club sandwich
all Si (8 layers)
$\delta p_t / p_t^2$
10^{-3}
5
10^{-4}
5
10^{-5}
5
1
5
10
50
100
500
1000
p (GeV/c)

And so…

Preliminarily, it looks as if high-momentum tracking resolution make be a driving issue. **We need to continue to explore and confirm this.**

Some “obvious” facts about the relative advantages and disadvantages of gaseous/solid-state tracking are not correct.

If curvature resolution at high $p_{\perp}$ is an important issue, then solid-state tracking should play a role.

If we decide (or are forced) to settle for one detector, **hybrid tracking** may be the way to go. For two detectors, pattern recognition vs. momentum resolution is good case for complementarity.