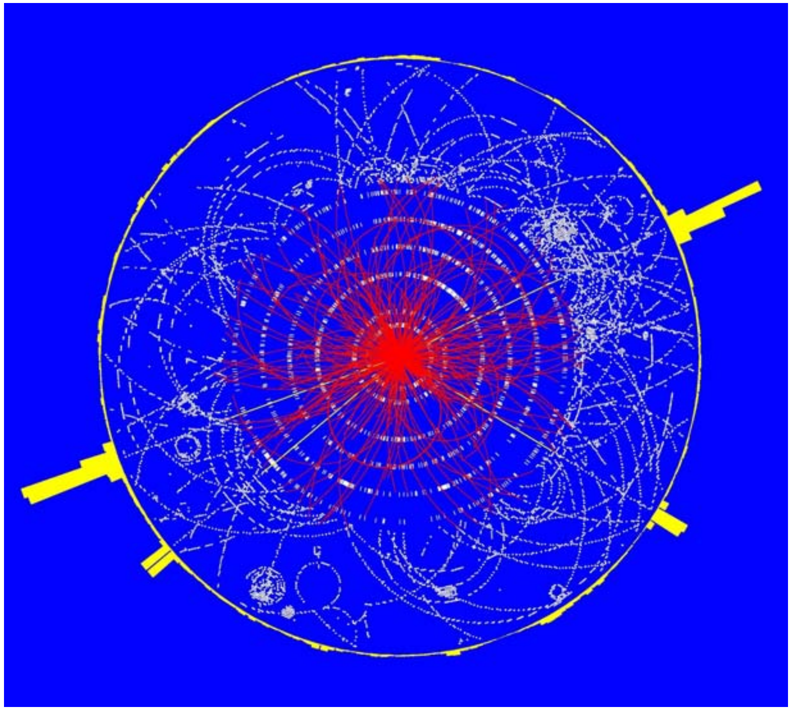
Position Sensitive Detectors in Particle Physics

- "2002 will be a watershed year… Detector systems for the Large Hadron Collider will be in advanced stages of construction and particle physicists will be considering the detector requirements of the next generation of accelerators, such as the Next Linear Collider…"

- The Future Linear Collider.
- Vertex and Track Detectors for the Linear Collider.
- Calorimetry.
- Summary.

The Future Linear Collider

- The LHC and its detectors will be extremely impressive.
- Allow detection of $H \rightarrow ZZ \rightarrow e^+e^-e^+e^-$

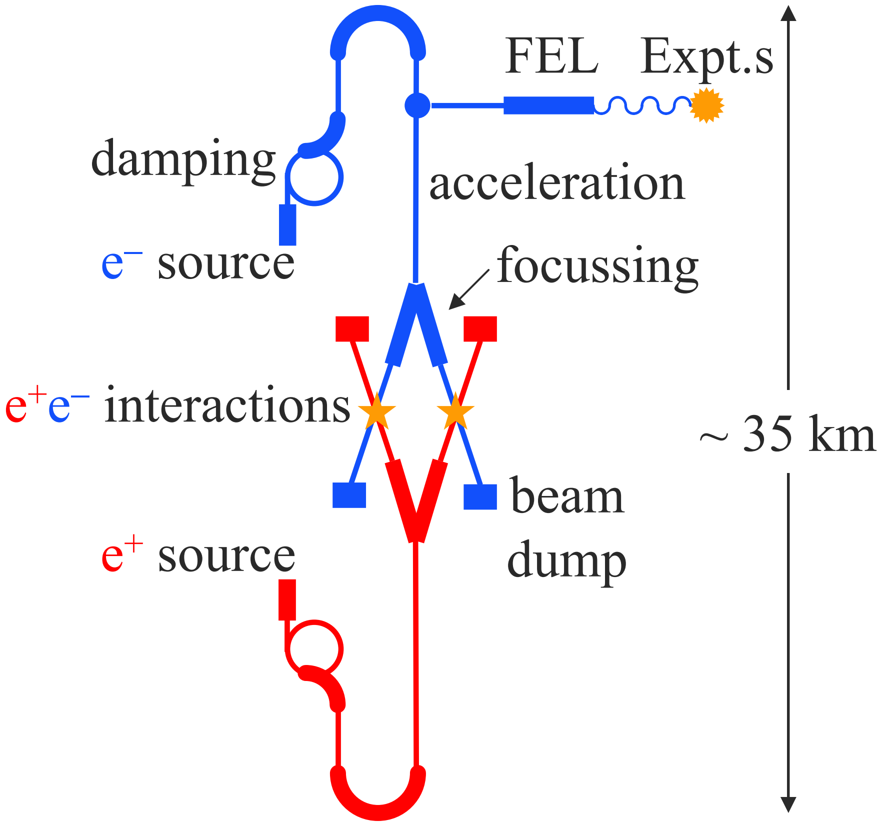


- Why go further?

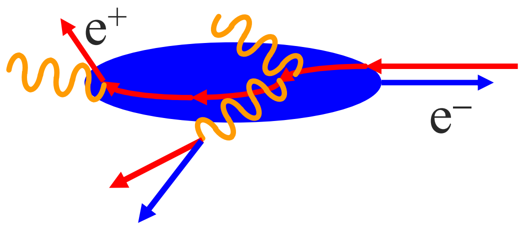
- Many remaining questions!
- Assume Higgs boson is found at LHC, is it:
  - As expected in Standard Model?
  - First evidence for supersymmetry?
- If couplings to u-type quarks suppressed, to d-type enhanced, w.r.t. SM expectation $\Rightarrow$ SUSY.
- Must measure branching ratios of $H \rightarrow c\bar{c}$, $H \rightarrow b\bar{b}$.
- Requires:
  - Linear e^+e^- Collider with ~ 500 GeV beams.
  - Improved detector technology.

The Future Linear Collider

- Generic LC:

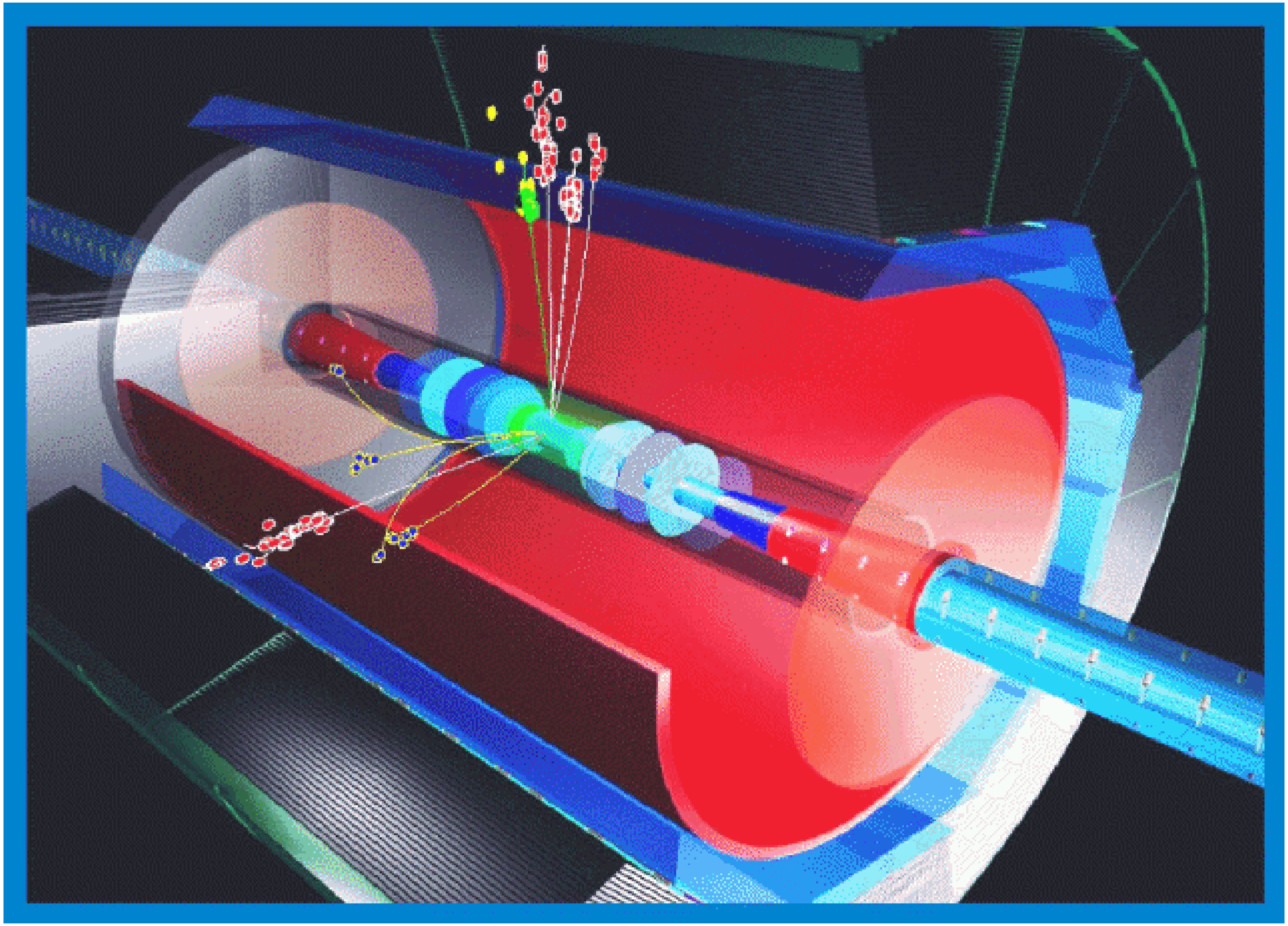


- New problems for experiments:
  - Neutron background from interactions of e^+ and e^- in beam dump (10^9 n/cm^2 p.a.).
  - Beam-strahlung and $e^+ e^-$ pair production.



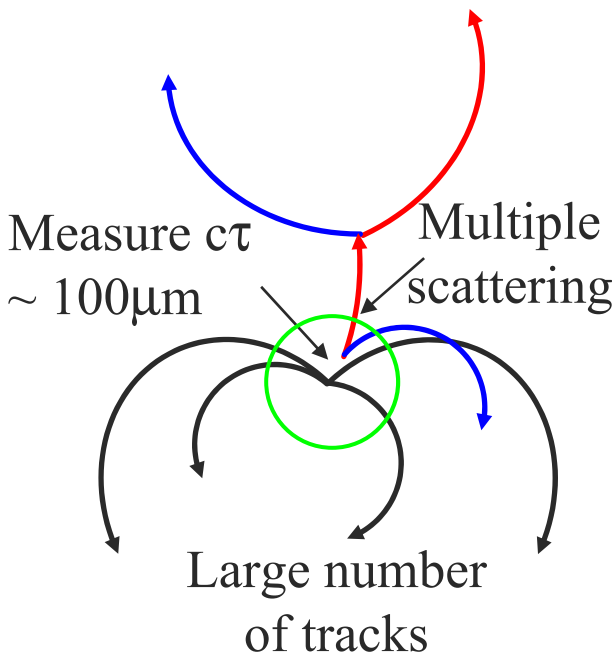
  - "Curl up" $e^+ e^-$ pairs in strong (4T) solenoidal magnetic field.

A Detector for the Linear Collider



Identifying Charmed Quarks

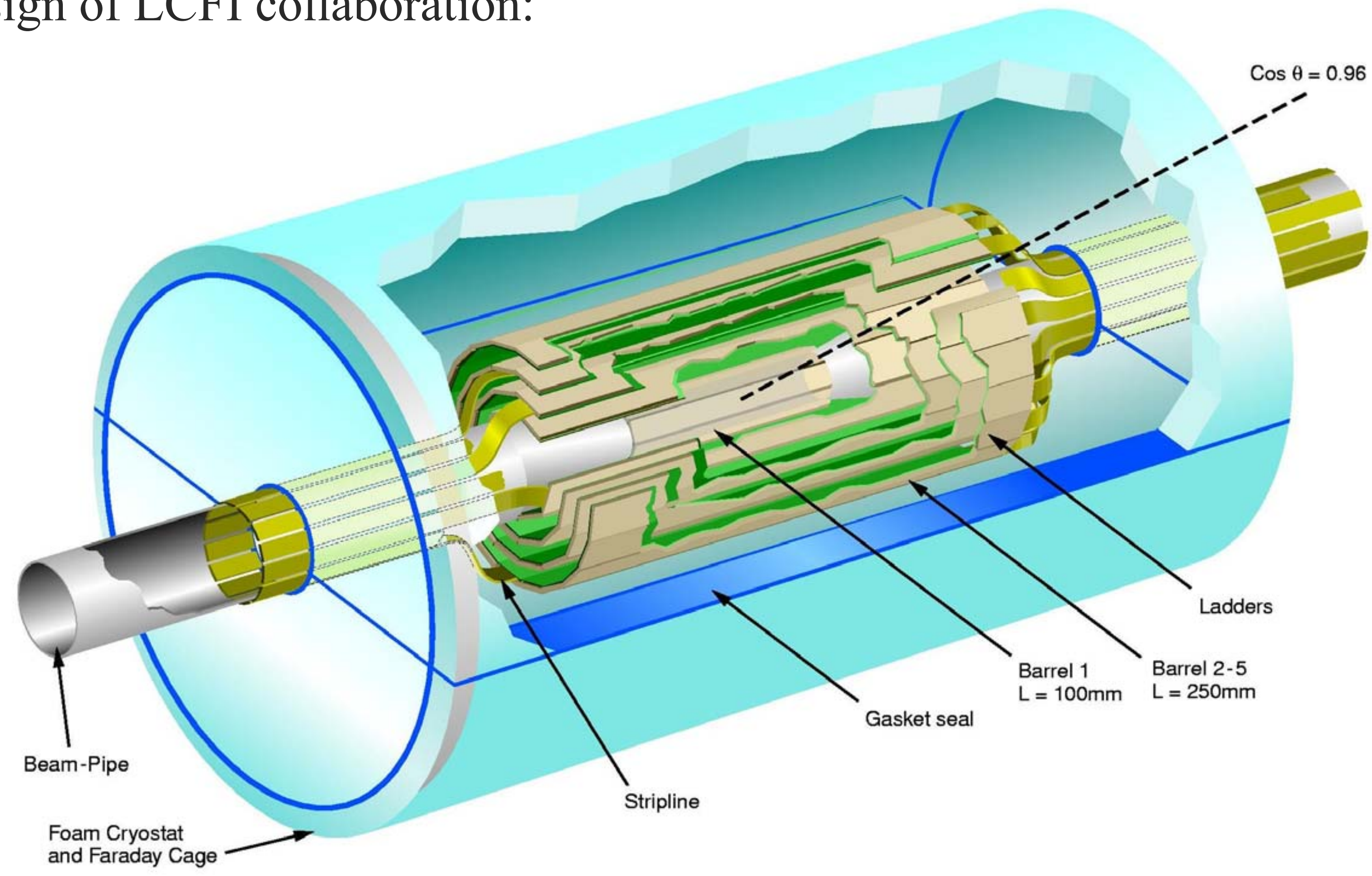
- The challenge: p ~ 1 GeV



- Need vertex detector with:
  - Point precision ~ 5 μm.
  - About five sensor layers.
  - Minimum possible inner radius (~ 10…15 mm).
  - Two track separation ~ 40 μm (⇒ pixel size ~ 20 x 20 μm^2).
  - Max. possible polar angle coverage (~ $|\cos\theta| < 0.96$).
  - Minimum possible amount of material (⇒ gas cooling).
  - Adequate radiation tolerance.
  - Readout in 50 μs (TESLA) or 8 ms (NLC) for 1% occupancy.

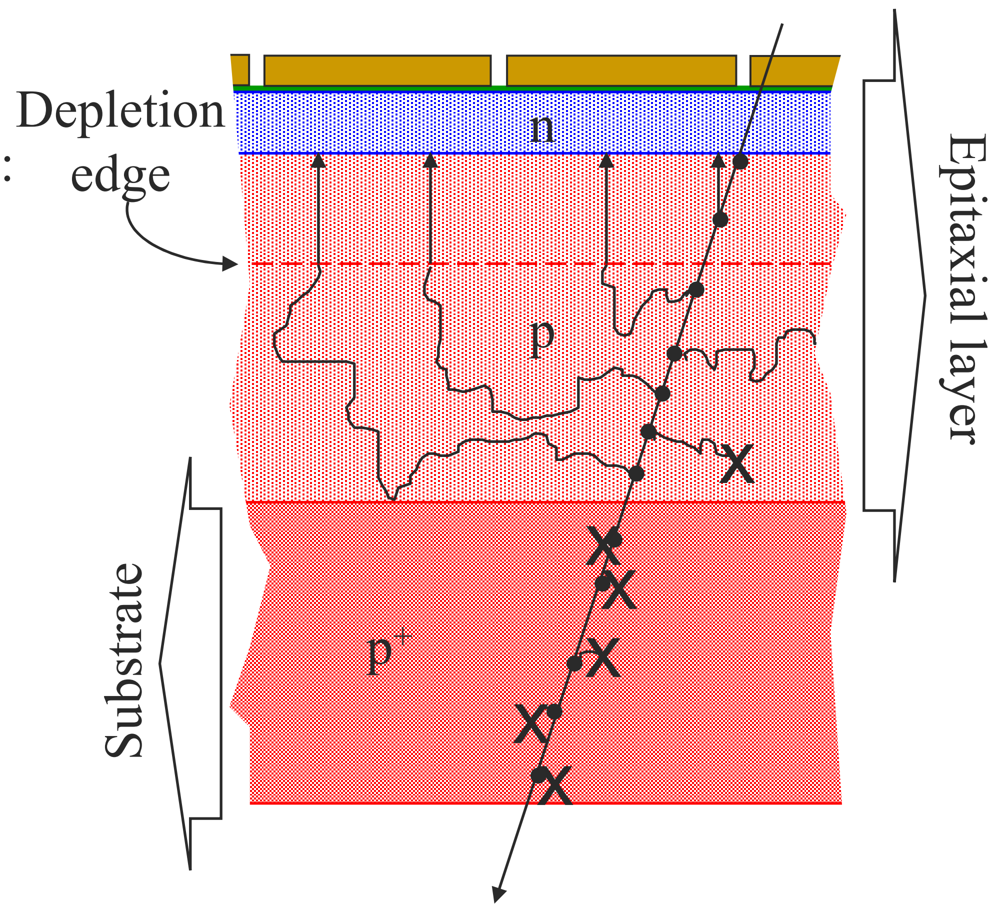
Vertex Detector for the Future LC

- E.g. design of LCFI collaboration:



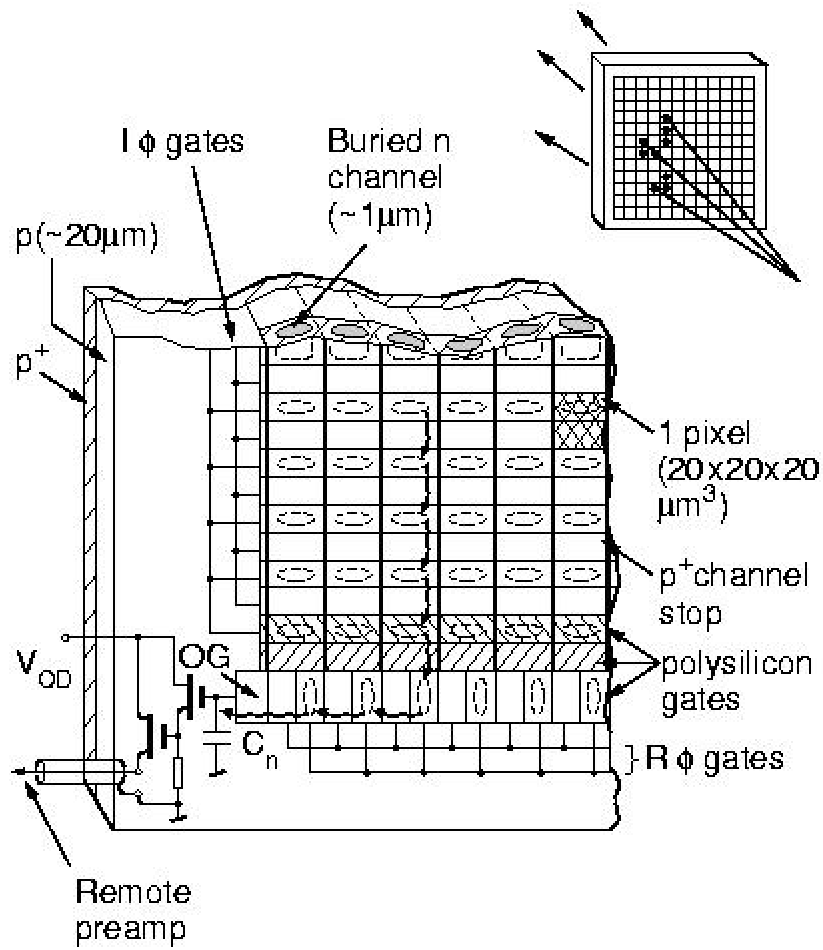
CCDs

- Best VXD to date is VXD3 of SLD collaboration.
- Pros of CCDs as particle detectors:
  - Efficiency ~ 100%.
  - Point precision ~ 3.5 µm.
  - Pixel size 20 x 20 μm^2.
  - Small material budget (VXD3 ~ 180 µm Si + Be support ⇒ 0.4% X_0).

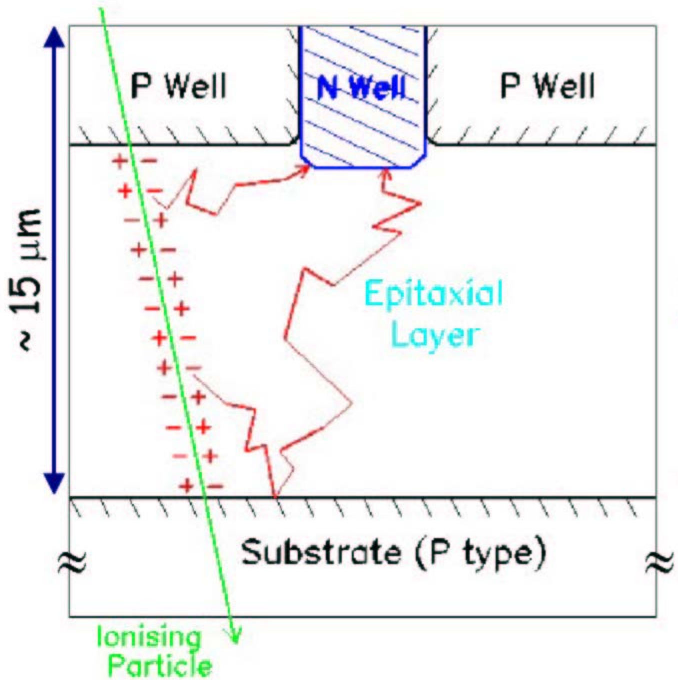


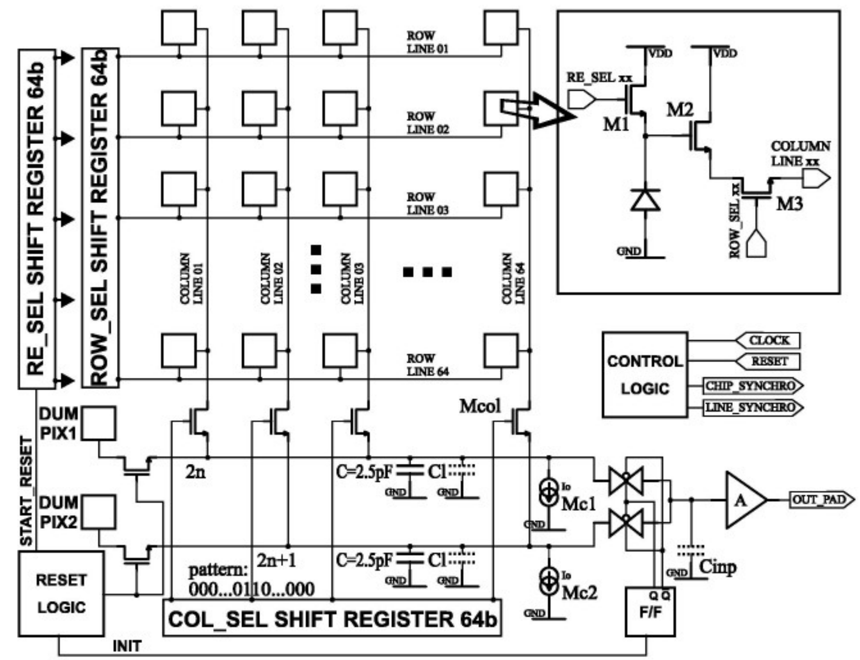
CCDs

- Problems with CCDs:
  - Readout speed too low.
  - Susceptible to radiation damage.
- R&D underway.
- Goals:
  - Increase readout speed by factor of ~ 1000 ⇒ column parallel readout, high frequency low voltage drive signals, bump bonding…
  - Decrease thickness to 0.1% X_0 ("unsupported" CCDs?).
  - Demonstrate CCDs sufficiently radiation hard.



CMOS Monolithic Active Pixel Sensors

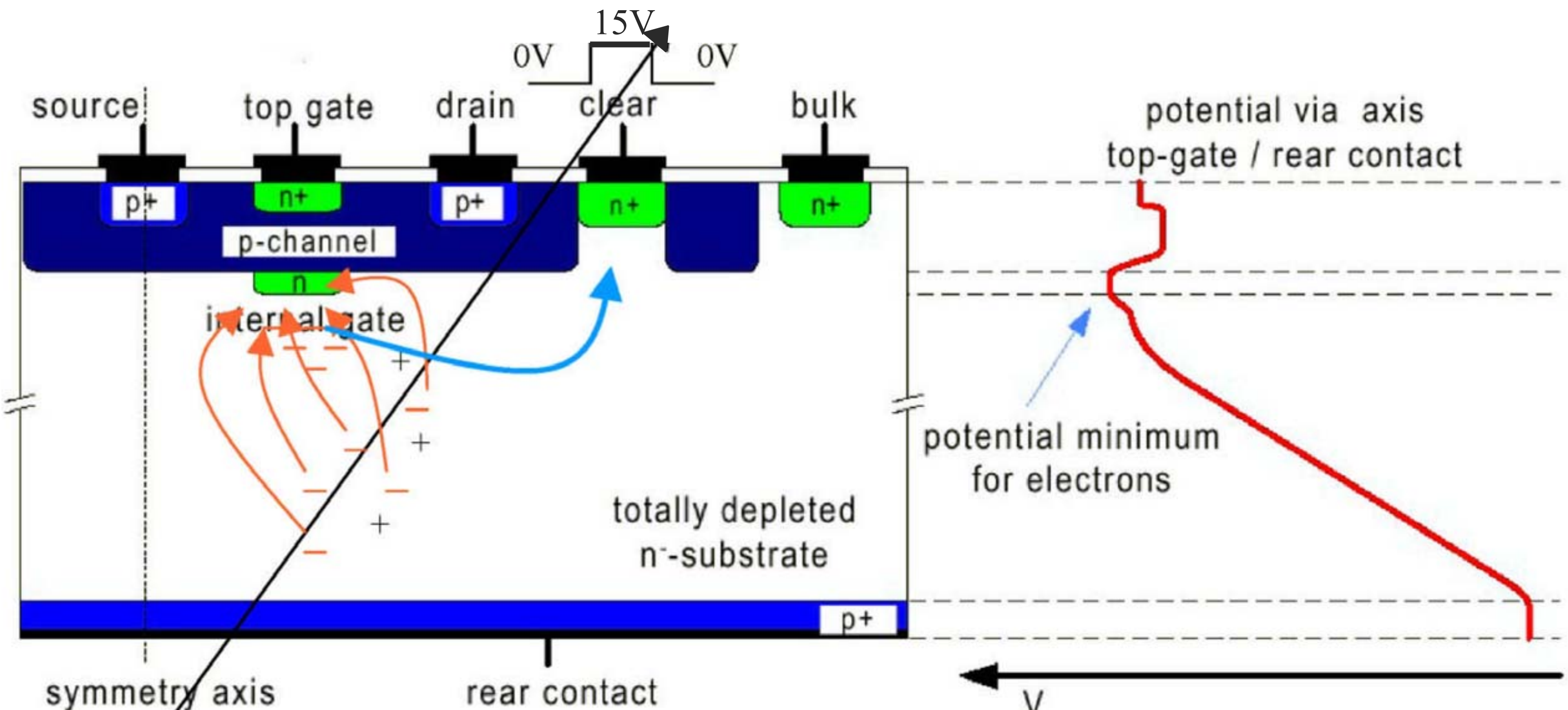




- Small pixel sizes achievable.
- CCD-like precision.
- On-pixel processing.
- Thinning possible.

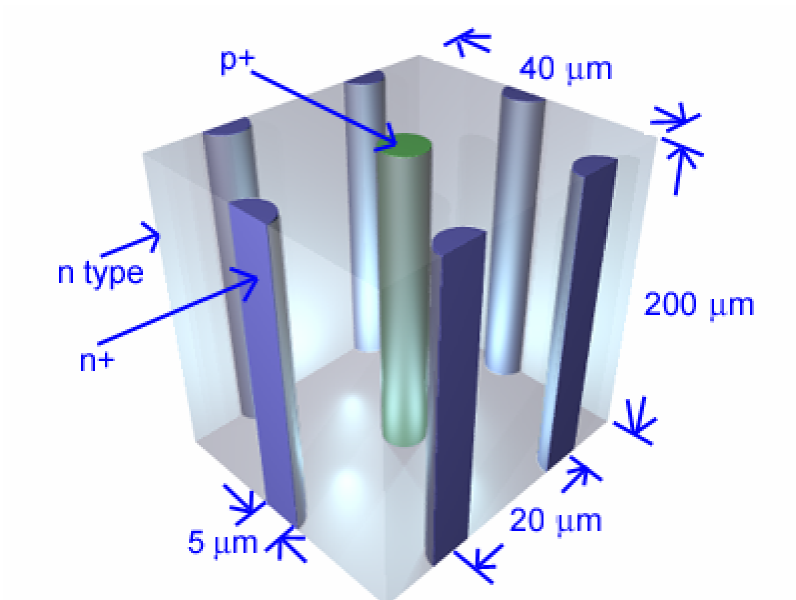
- Possible problem, higher power consumption than CCDs?
- Impressive progress from small test devices in 1999 to Mpixel devices now, by team from F, UK, D, NL, CH.

DepFET Sensors



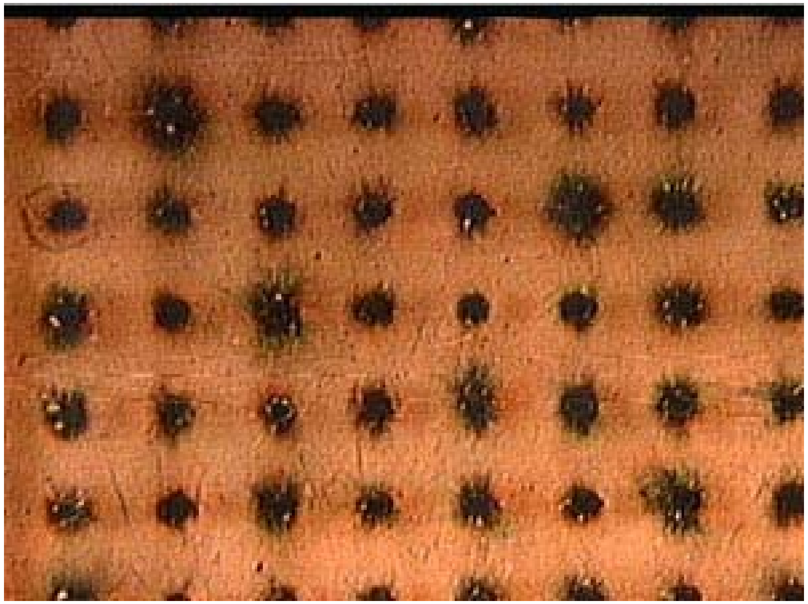
- Amplifying transistor integrated into high ρ Si.
- 64 x 64 50 x 50 μm² prototype tested for biomedical imaging, σ_{pt} 10μm.
- Team from Bonn and MPI Munich hope to have prototype of size 128 x 128 30 x 30 μm² by end 2002.

3D Detector

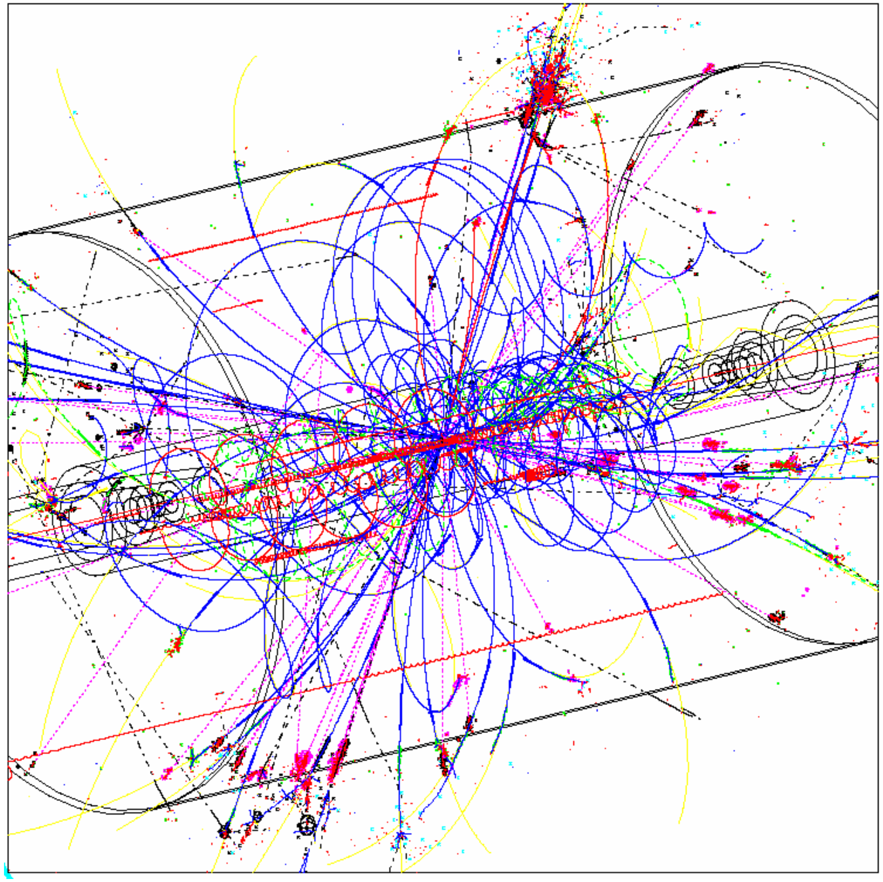


- 3D structure allows close electrodes.
- Reduces bias voltage.
- Speeds up readout.
- Radiation hard.

- Hawaii/Glasgow investigating possible fabrication techniques.
- E.g. laser drilling…



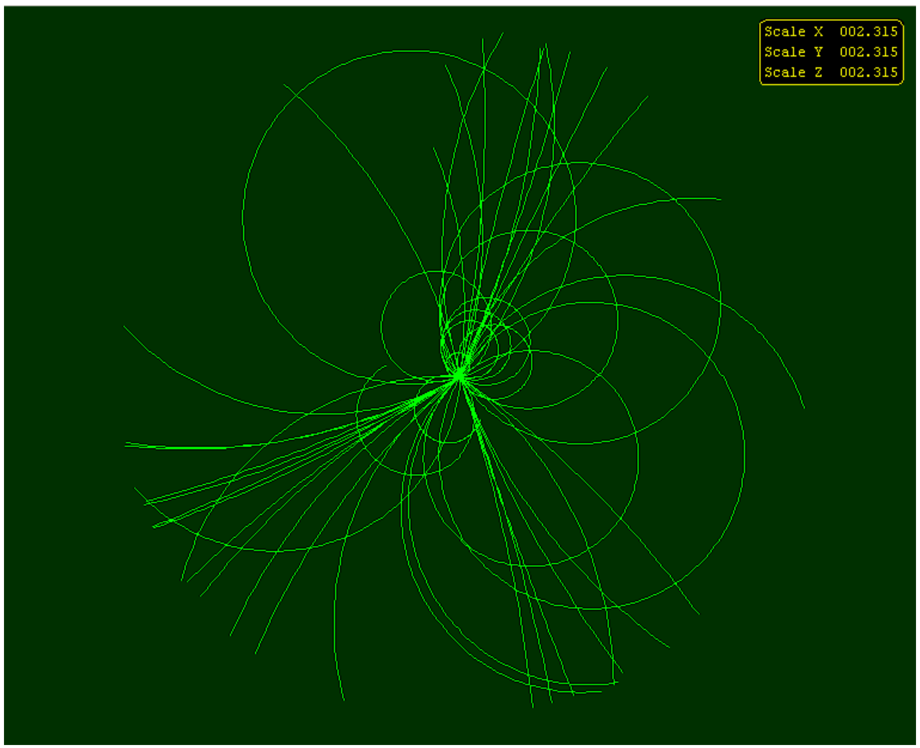
Central Tracker for the Future LC

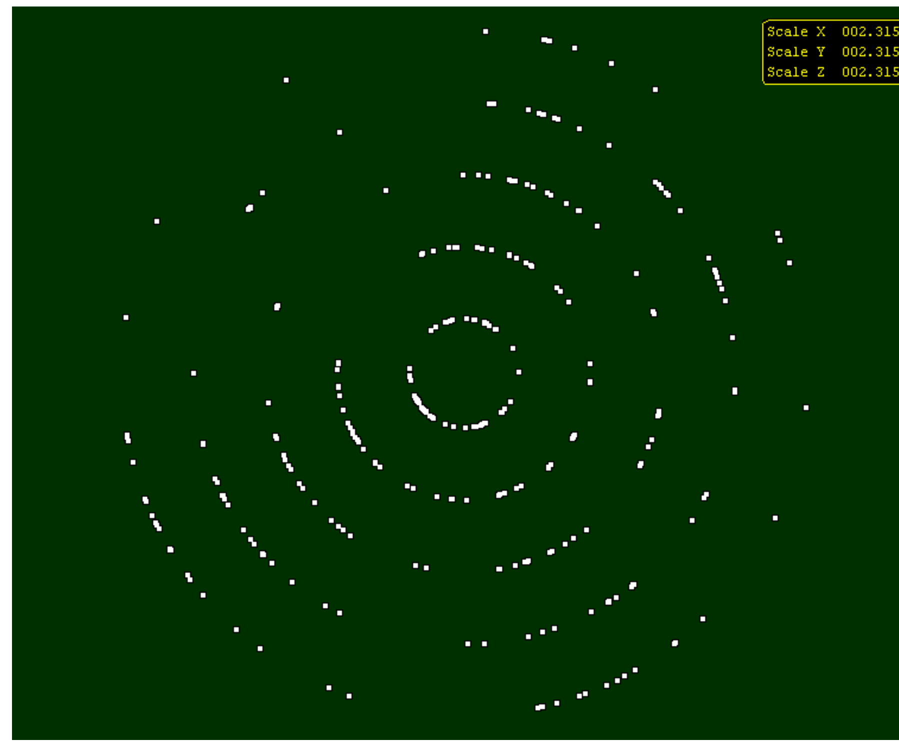


- Excellent pattern recognition and two-track resolution needed (high energy high density jets).
- Tracking system needs momentum res. of $\delta(p_T^{-1}) \approx 5 \times 10^{-5}\,GeV^{-1}$ to determine “invisible mass” in ZH events.
- But no consensus yet on some basic issues…

Central Tracker for the Future LC

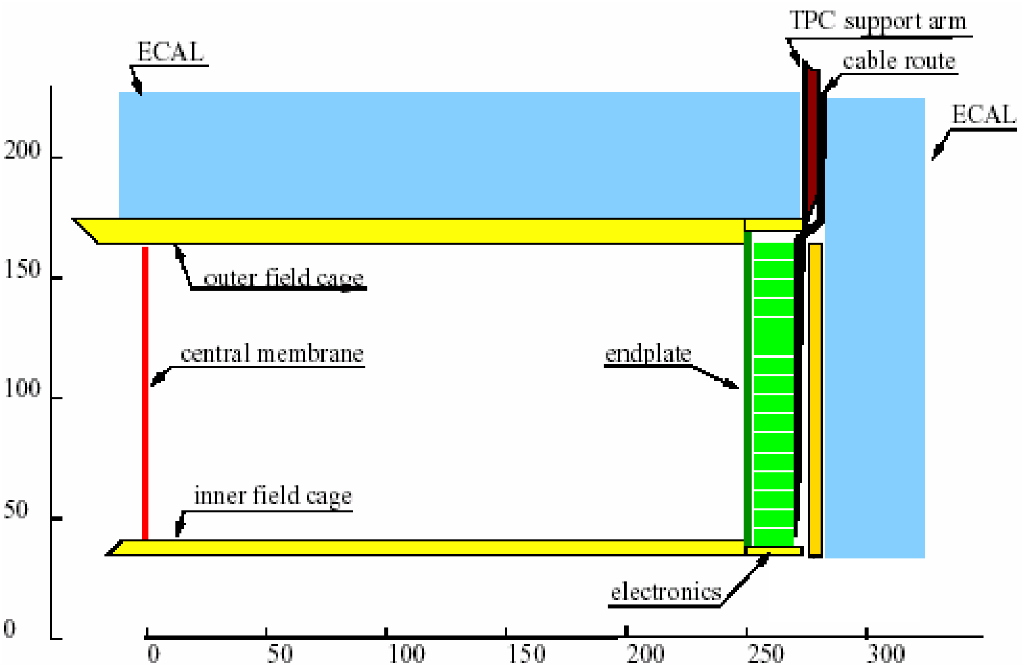
- Is it better to use a gaseous detector…
- … or one based on silicon sensors?





Gaseous Central Detector

- Possibilities drift chamber…
- …or TPC



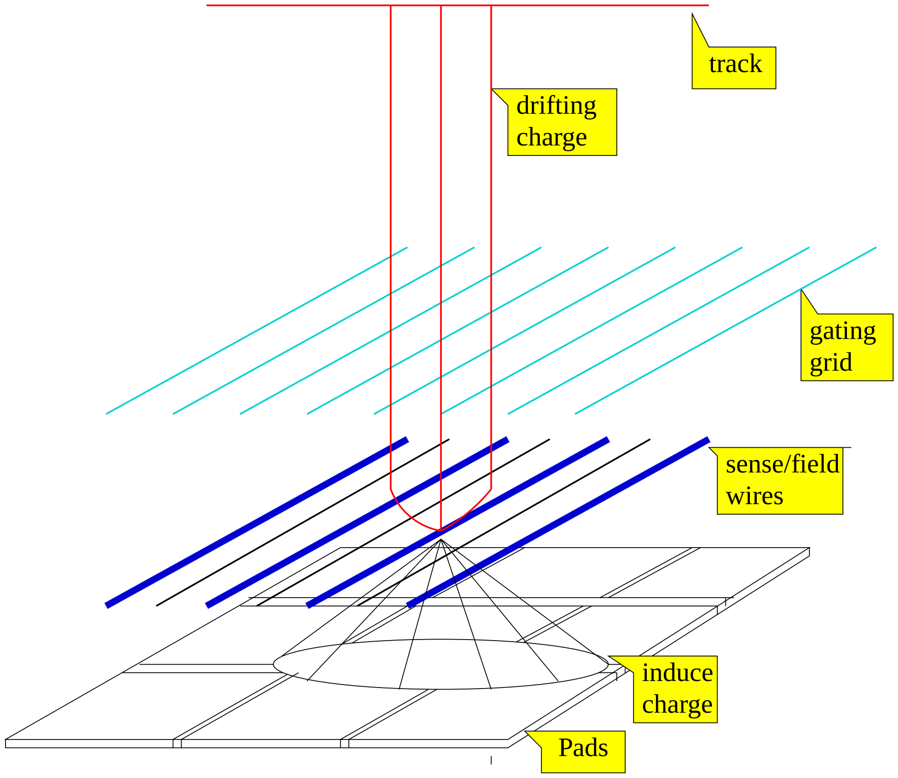
- Pros:
  - Material budget ~ $3\%X_0$.
  - Large sensitive volume.
  - High tracking efficiency (pattern recognition).
  - Particle ID via dE/dx.

Contras:

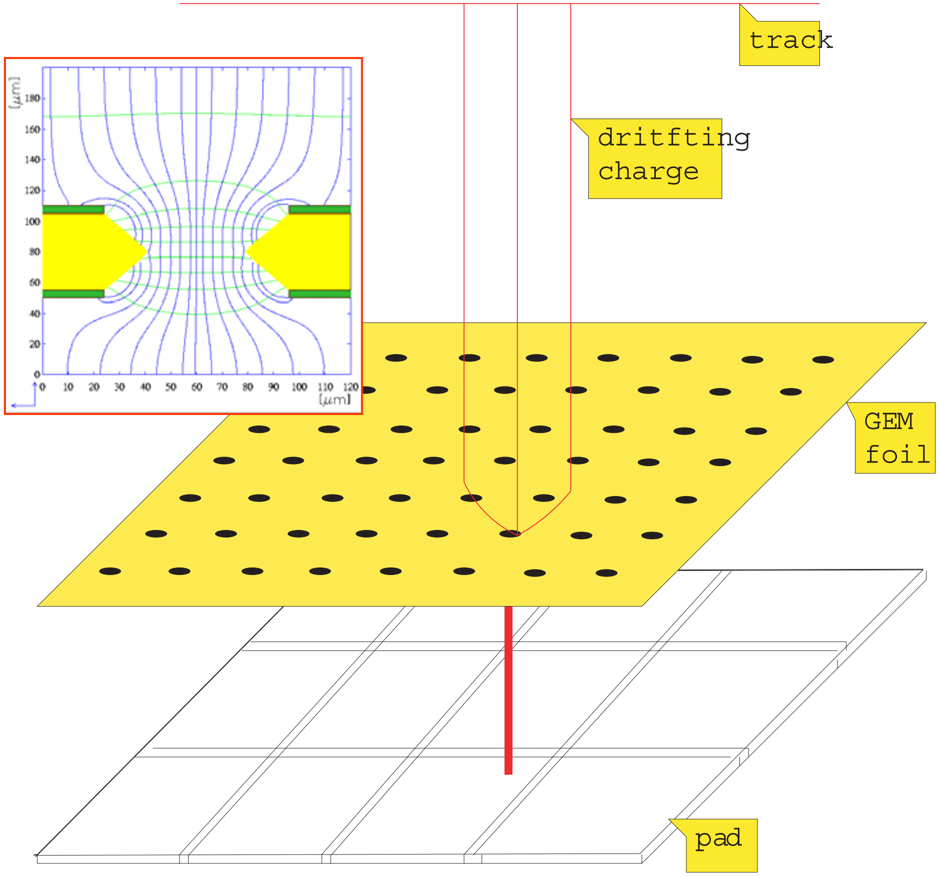
  - Point resolution poorer than silicon.
  - Readout slow (55 μs).

TPC Readout

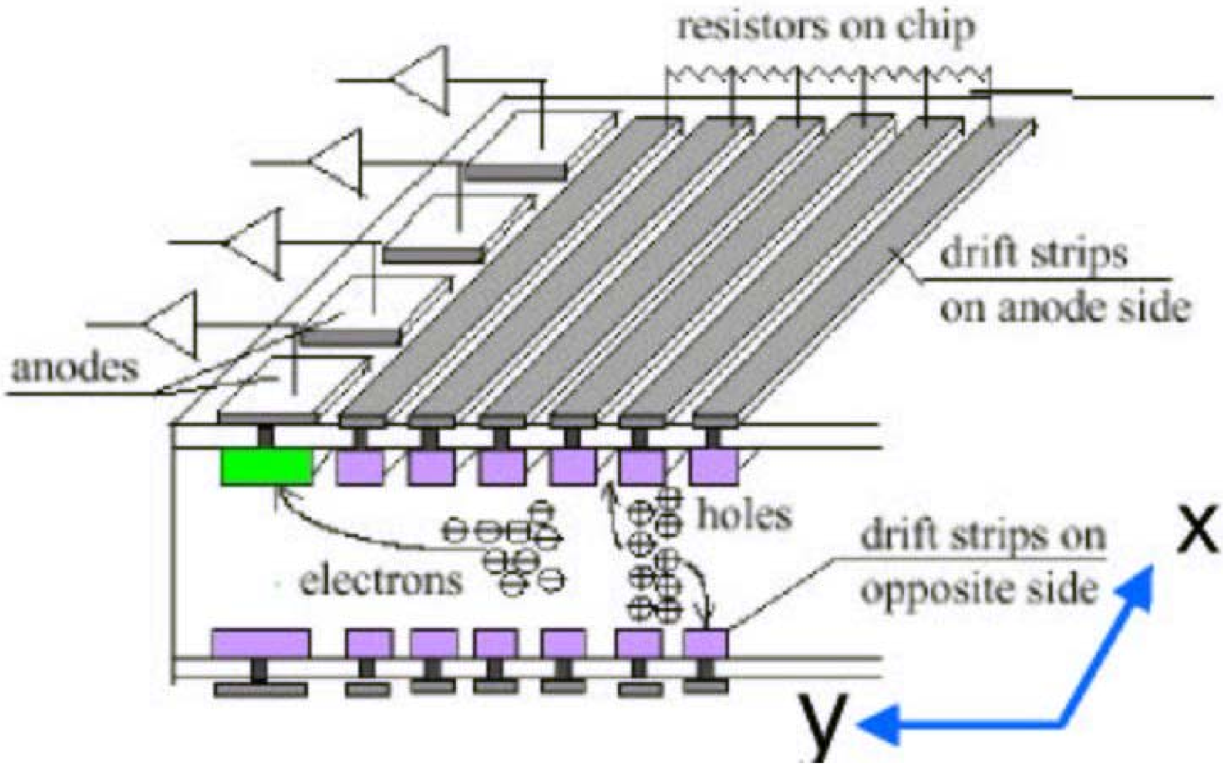
- MWPC, signal induced on pads.
- Gating grid prevents ions entering drift volume.



- Alternative MPGD, e.g. GEM or Micromegas.



Silicon Drift Detectors

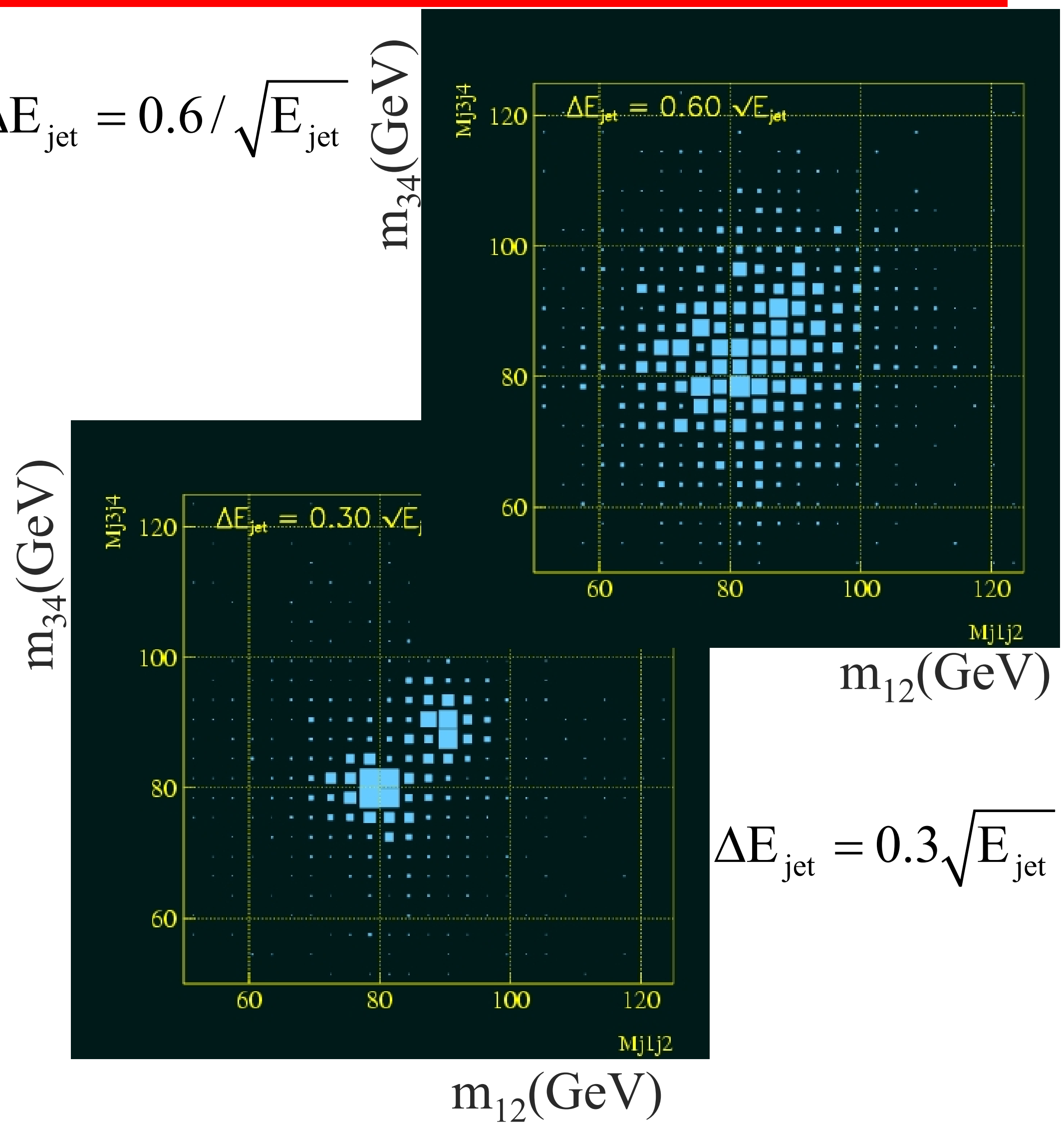


- SDD functioning in STAR for nearly two years.
- 216 wafers, total area 0.7 m^2.
- Need 5 precise layers to replace TPC, ~ 56 m^2.
- Improve resolution to 5 μm.
- Improve radiation hardness.

Calorimetry

- Distinguish $e^+e^- \rightarrow WW\nu\nu$ from $e^+e^- \rightarrow ZZ\nu\nu$
- Measure energies of "jets" of particles from decays such as $Z \rightarrow u\bar{u}$ or $W^+ \rightarrow u\bar{d}$.
- Measure charged particles in tracking system, photons and neutral hadrons in calorimeter.

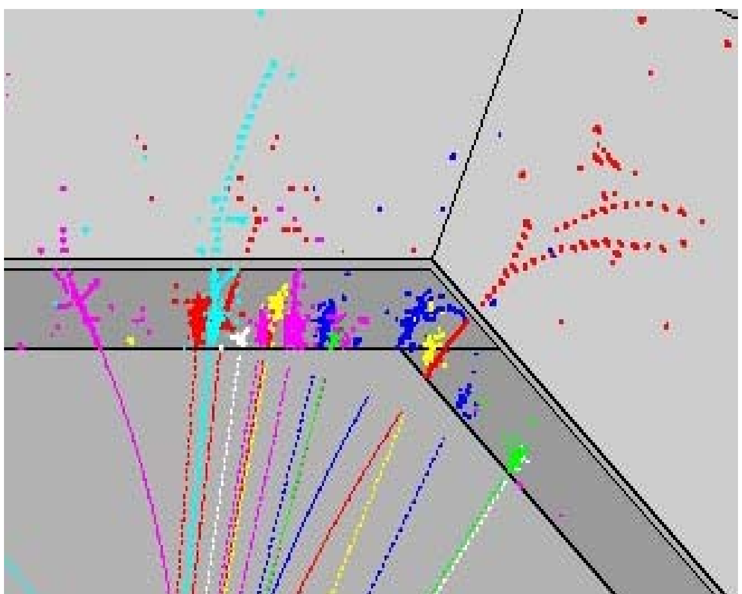
$$\Delta E_{jet} = 0.6/\sqrt{E_{jet}}$$



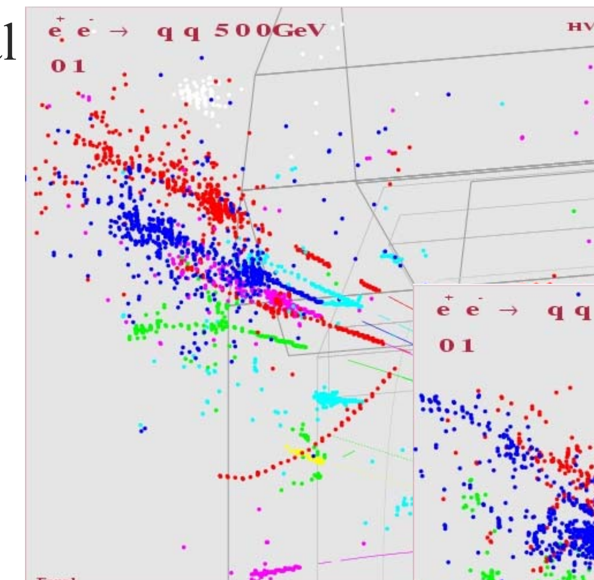
$$\Delta E_{jet} = 0.3\sqrt{E_{jet}}$$

Calorimetry

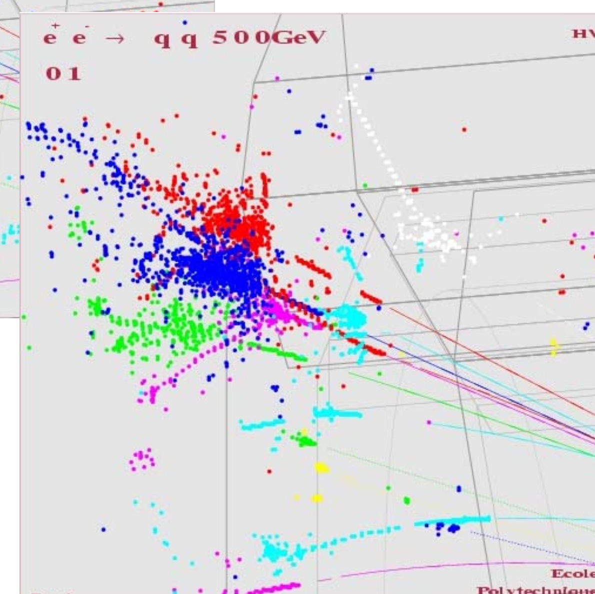
- Crucial to obtaining necessary resolution is to avoid "double counting".
- Need calorimeter with good spatial resolution.



- Use material with small Moliere radius and fine segmentation, readout 50×10^6 1×1 cm^2 Si pads.



tungsten



iron

Summary

- Particle Physics (e.g. the LC) continues to provide challenges for detector designers.
- None of the existing detector technologies are yet capable of providing the performance necessary to exploit the LC; thankfully there is still time to remedy this!
- Particle Physics has benefited from progress in other fields…and has and will continue to provide developments that are useful elsewhere.
- The LC detector may use as much as 3000 m^2 of silicon. (C.f. all LHC detectors ~ 300 m^2).
- Will we be able to afford it?
- Cost evolution for Si microstrips…