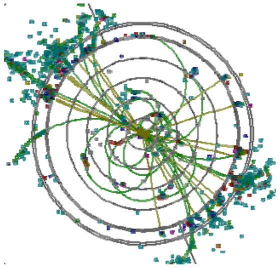
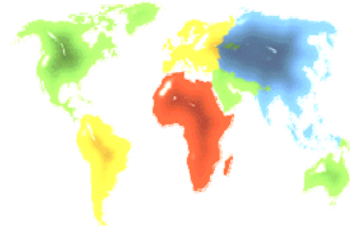
"Abe Fest"

In celebration of the start of Abe's Seventh Decade!

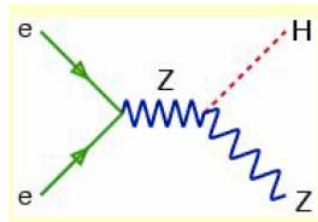


ILC Physics Goals



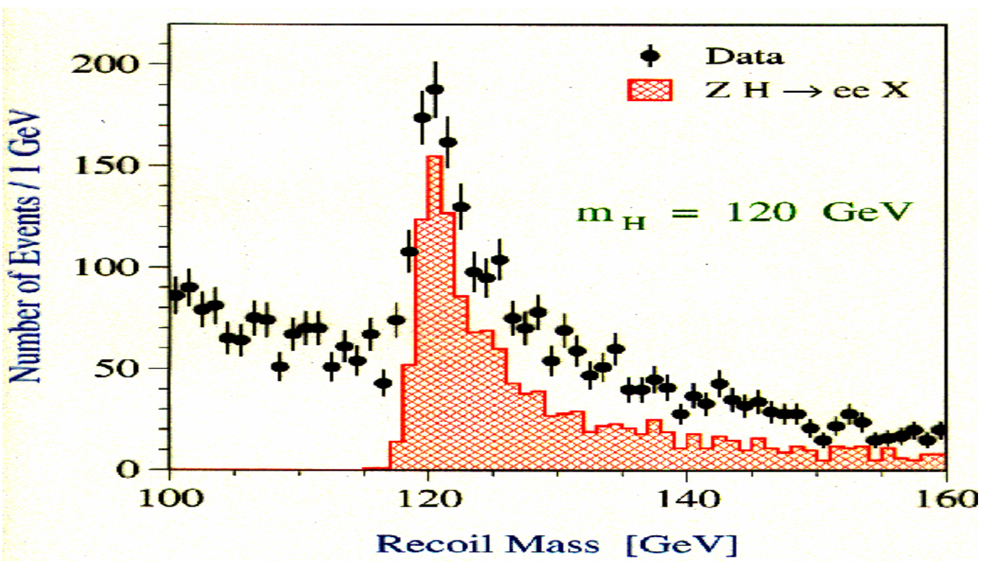
- EWSB
  - Higgs
    - Mass (~50 MeV at 120 GeV)
    - Width
    - BRs (at the few% level)
    - Quantum Numbers (spin/parity)
    - Self-coupling
  - Strong coupling (virtual sensitivity to several TeV)
- SUSY particles
  - Strong on sleptons and neutralinos/charginos
- Extra dimensions
  - Sensitivity through virtual graviton
- Top
  - Mass measured to ~ 100 MeV (threshold scan)
  - Yukawa coupling
- W pairs
  - W mass

Power of the Constrained Initial State and Simple Reactions

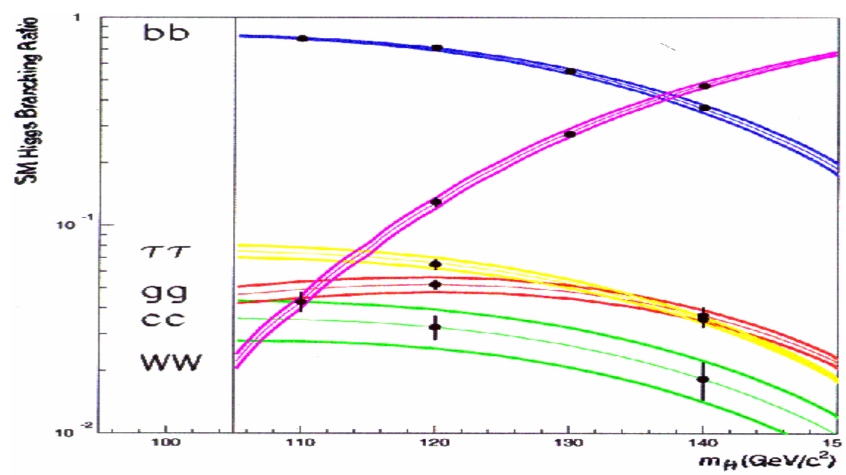


- Well defined initial state
- Democratic interactions

Higgs recoiling from a Z, with known CM energy⇓, provides a powerful channel for unbiassed tagging of Higgs events, allowing measurement of even invisible decays (⇓ - some beamstrahlung)



500 fb^{-1} @ 500 GeV, TESLA TDR, Fig 2.1.4



Measurement of BR's is powerful indicator of new physics

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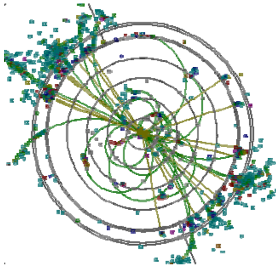
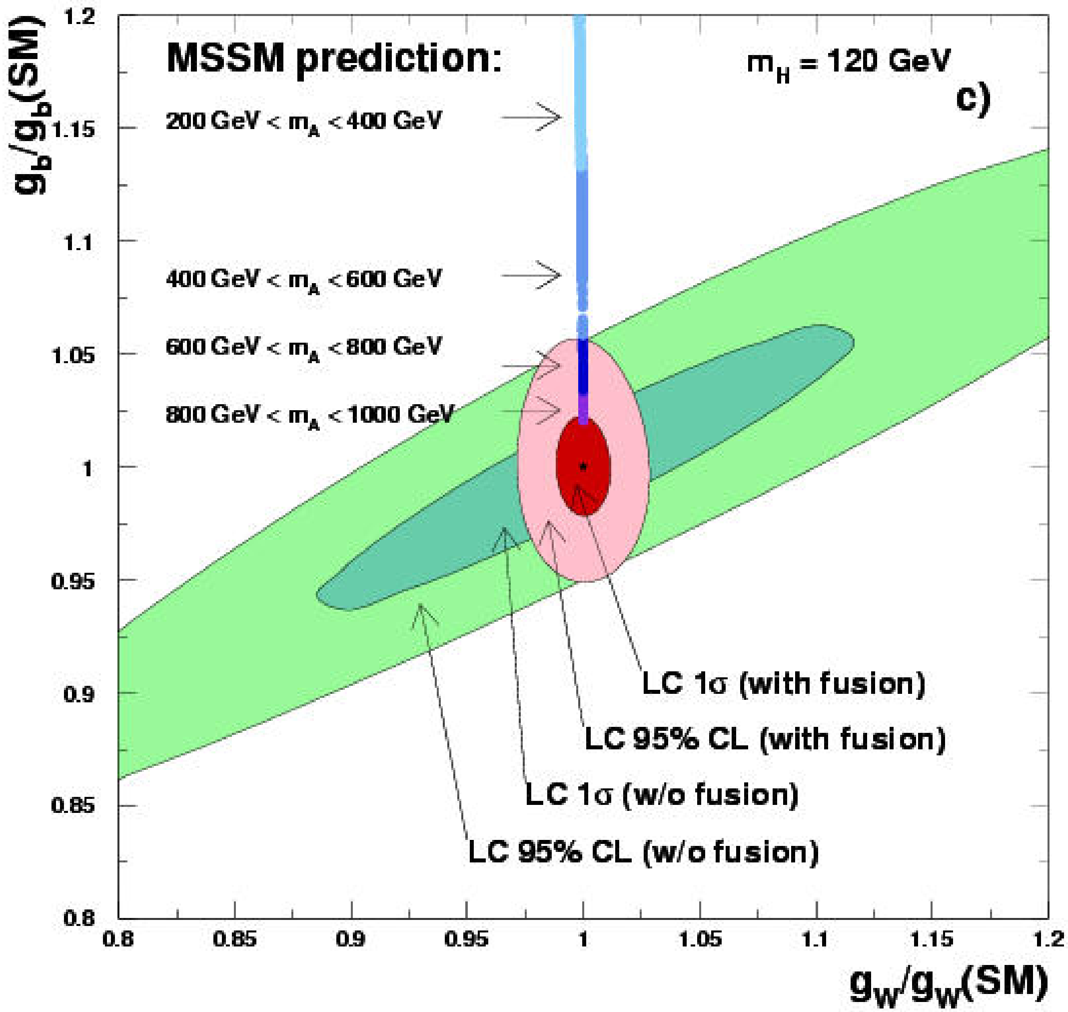


Is This the Standard Model Higgs?

b vs. W

TESLA TDR, Fig 2.2.6



Arrows at:

- M_A = 200-400
- M_A = 400-600
- M_A = 600-800
- M_A = 800-1000

HFITTER output

conclusion:
for M_A < 600,
likely to distinguish

ILC Experimental Advantages

Elementary interactions at known E_{cm}*

eg. $e^+e^- \rightarrow$ Z H * beamstrahlung manageable

Democratic Cross sections

eg. $\sigma(e^+e^- \rightarrow ZH) \sim 1/2\ \sigma(e^+e^- \rightarrow d\bar{d})$

Inclusive Trigger

total cross-section

Highly Polarized Electron Beam

~ 80% (+ positron polarization – R&D)

Exquisite vertex detection

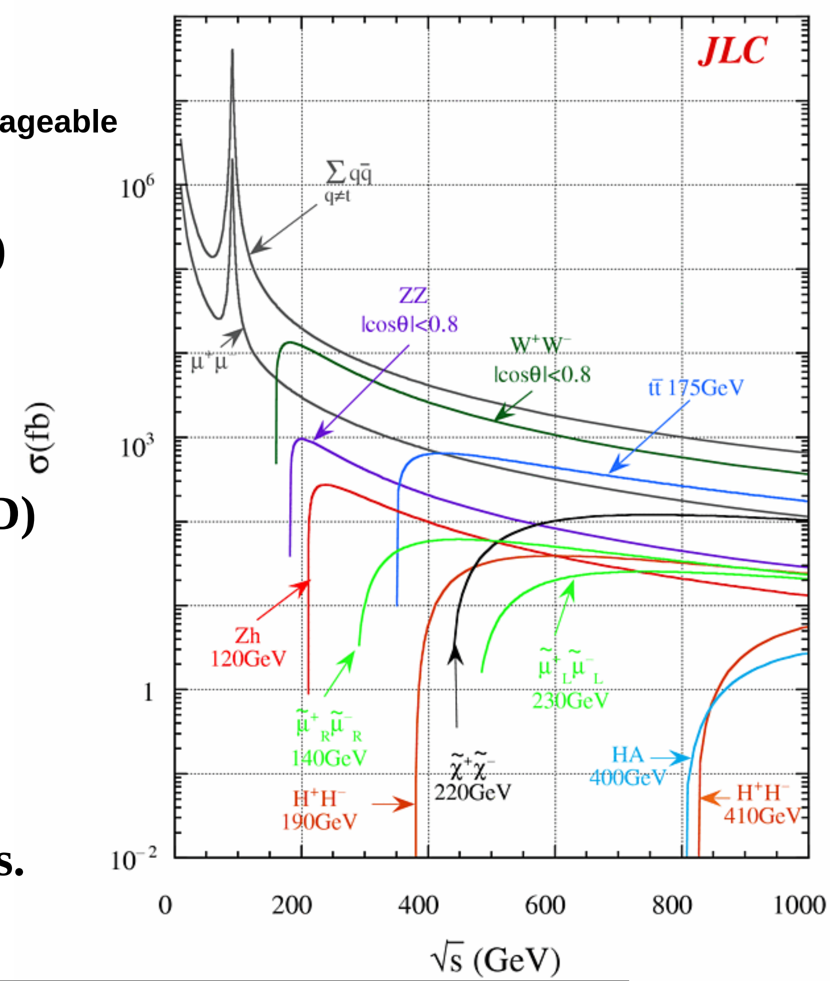
eg. $R_{beampipe} \sim 1$ cm and $\sigma_{hit} \sim 3\ \mu$m

Calorimetry with Particle Flow Precision

$\sigma_E/E \sim 30\text{-}40\%/\sqrt{E}$

Advantage over hadron collider on precision meas.

eg. $H \rightarrow c\bar{c}$



Detector performance translates directly into effective luminosity

ILC Detector Performance Requirements

- **Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.**
- **Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).**
- **Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread.**
- **Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.**
- **Timing resolution capable of separating bunch-crossings to suppress overlapping of events .**

Silicon detectors could contribute in achieving all of these requirements

Silicon Detectors at the ILC

- **Suppress backgrounds**
  - **Fast response (single bunch sensitivity in long bunch trains)**
  - **Pileup of hits – vxd layer 1 - 0.03 hits/mm^2/bunch crossing (~3000 bunches/train)**

- **Precision vertex tracking (1)**
  - **~20 μm^3 sensitive volume**
  - **Depth of 20 μm is very significant in achieving spacepoint precision**

- **Fine tracking resolution (2)**
  - **Precision spacepoint capability enables momentum resolution goal in small volume**
    - Big impact – allowing larger B field and more aggressive calorimetry

- **Millipad segmentation in EM calorimeter (3)**
  - **~10^8 pixel "tracking"calorimeter**

- **Forward Detectors**

Tracking

- Tracking for a modern experiment must be conceived as an integrated system, combined optimization of:
  - the inner tracking (vertex detection)
  - the central tracking
  - the forward tracking
  - the integration of the tracking capabilities of the calorimeter and muon system
    - **For ILC (esp. SiD) high granularity EM Calorimeter**

- Pixelated vertex detectors are capable of track reconstruction on their own, as was demonstrated by the 307 Mpixel CCD vertex detector of SLD, and is central to the tracking concept for the ILC

- Track reconstruction in the vertex detector impacts the role of the central and forward tracking system

Inner Tracking/Vertex Detection for the ILC

Detector Requirements

- Excellent spacepoint precision (**< 4 microns**)
- Superb impact parameter resolution (**$5\mu m \oplus 10\mu m/(p \sin^{3/2}\theta)$**)
- Transparency **(~0.1% X_0 per layer**)
- Track reconstruction (**find tracks in VXD alone**)
- Sensitive to acceptable number of bunch crossings (**<150 = 45 μsec**)
- EMI immunity
- Power Constraint **($\lesssim$ 100 Watts)**

Concepts under Development for International Linear Collider

- Charge-Coupled Devices (CCDs)
  - demonstrated in large system (307Mpx) at SLD, but slow $\Rightarrow$ Column Parallel CCDs
- Monolithic Active Pixels – CMOS
  - MAPs, FAPs, Chronopixels, 3D-Fermilab
- DEpleted P-channel Field Effect Transistor (DEPFET)
- Silicon on Insulator (SoI)
- Image Sensor with In-Situ Storage (ISIS)
- HAPS (Hybrid Pixel Sensors)

Column Parallel CCD for ILC

SLD Vertex Detector designed to read out

800 kpixels/channel at 10 MHz, operated at

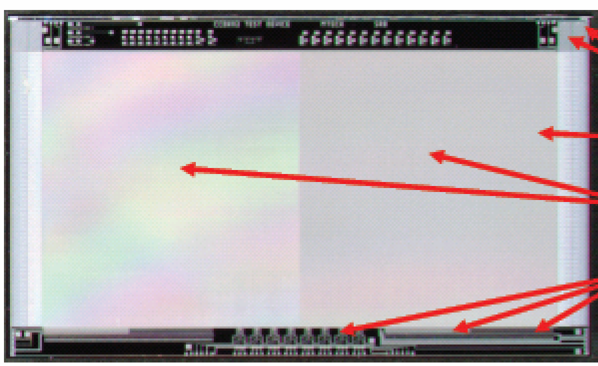
5 MHz => readout time = 200 msec/ch

ILC requires faster readout for 300 nsec bunch spacing

<< 1 msec

Possible Solution: Column Parallel Readout

LCFI (Bristol,Glasgow,Lancaster,Liverpool,Nijmegen,Oxford,RAL)

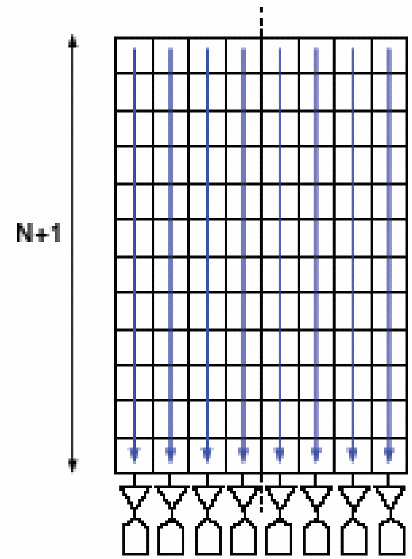


CPC1 produced by E2V

- **Two phase operation**
- **Metal strapping for clock**
- **2 different gate shapes**
- **3 different types of output**
- **2 different implant levels**

➢ ***Clock with highest frequency at lowest voltage***

- **Separate amplifier and readout for each column**

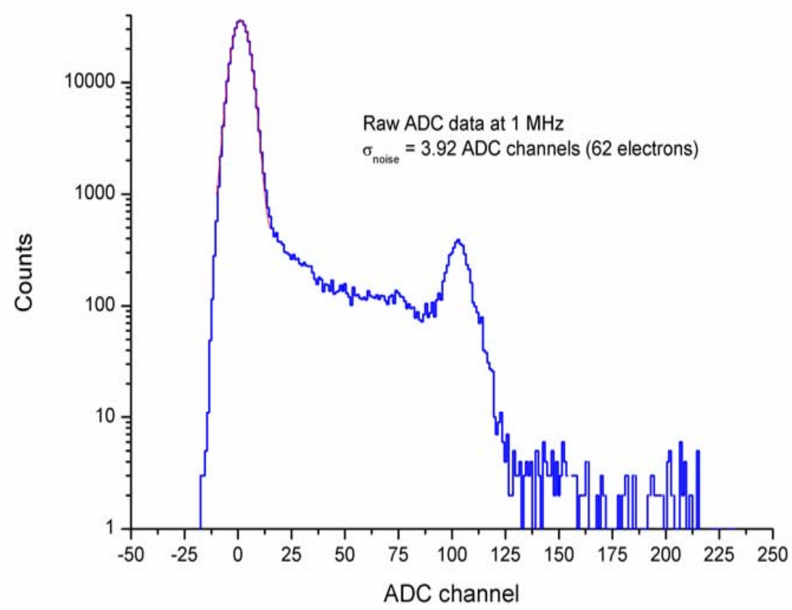


Column Parallel CCD
Readout time = (N+1)/F_{out}

(Whereas SLD used one readout channel for each 400 columns)

CPC2/ISIS1 Wafer

- First-generation tests (CPC1):
  - Noise ~100 e⁻ (60 e⁻ after filter).
  - Minimum clock potential ~1.9 V.
  - Max clock frequency above 25 MHz (design 1 MHz).
  - Limitation caused by clock skew



- CPC2 - 3 CPCCD sizes:
  - CPC2-70: 92 mm x 15 mm image area
  - CPC2-40: 53 mm long
  - CPC2-10: 13 mm long

Currently under test…

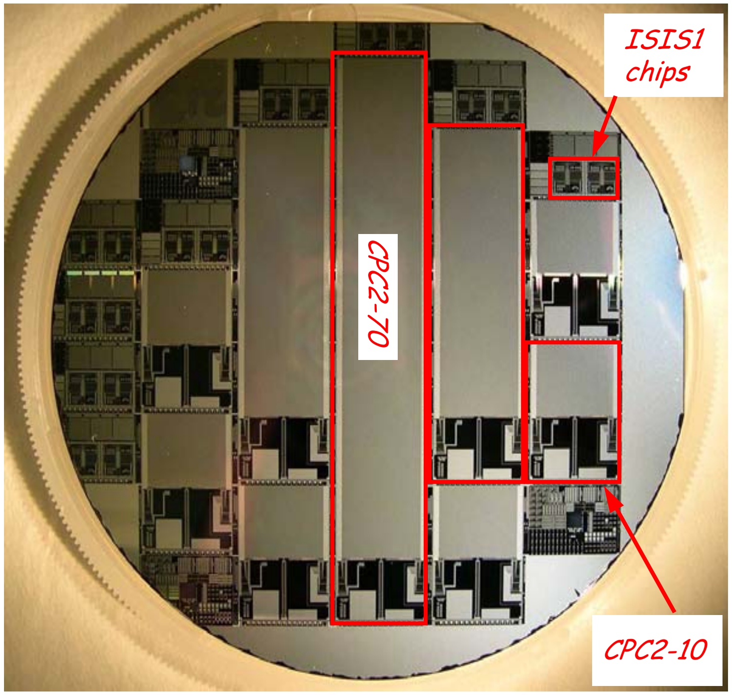
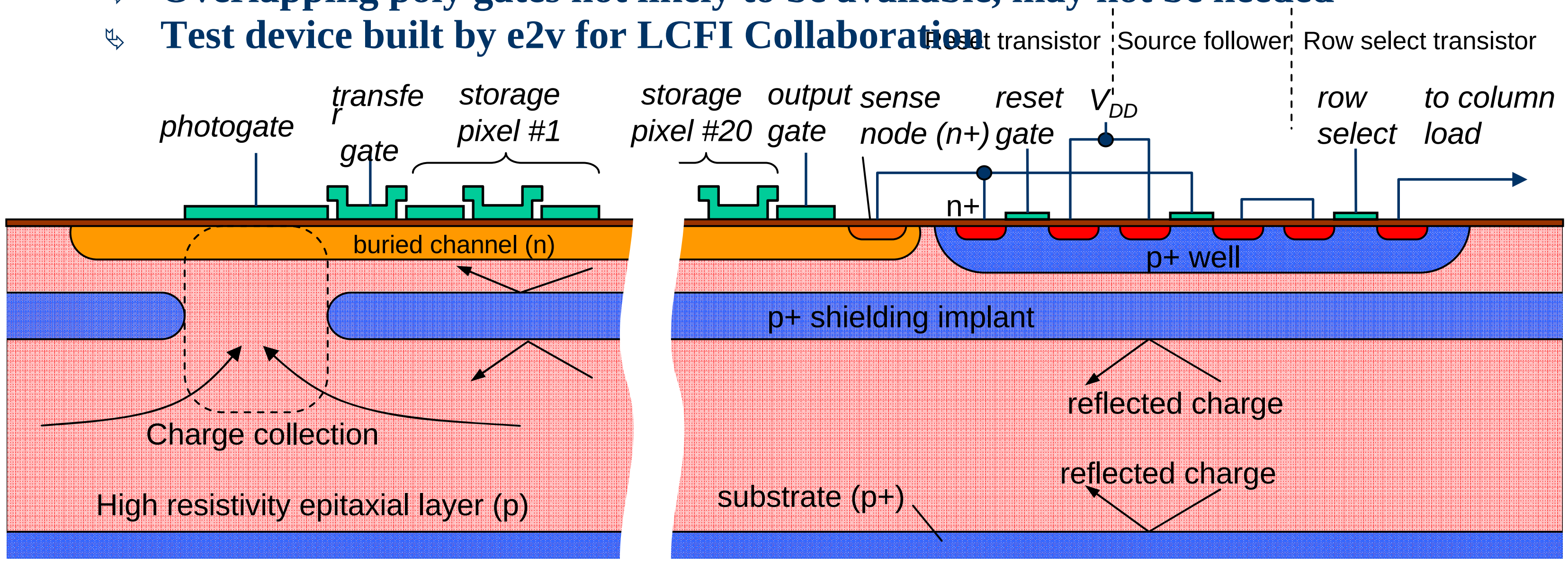


Image Sensor with In-situ Storage (ISIS)

- EMI concern (SLC experience) motivates delayed operation during beam
- Robust storage of charge in buried channel during beam passage
  - Pioneered by W F Kosonocky et al IEEE SSCC 1996, Digest of Technical Papers, 182
  - T Goji Etoh et al, IEEE ED 50 (2003) 144; runs up to 1 Mfps.
- ISIS Sensor details:
  - CCD-like charge storage cells in CMOS or CCD technology
  - Processed on sensitive epi layer
  - p+ shielding implant forms reflective barrier (deep implant)
  - Overlapping poly gates not likely to be available, may not be needed
  - Test device built by e2v for LCFI Collaboration



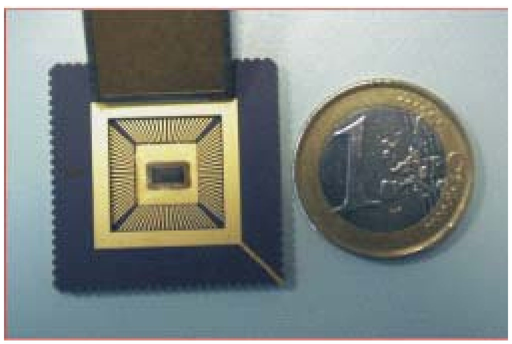
Monolithic CMOS for Pixel Detector

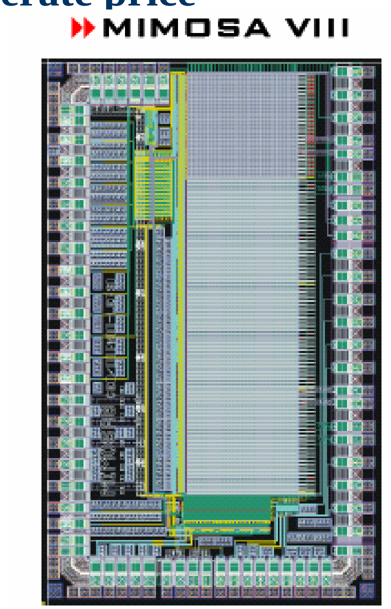
Concept

- **Standard VLSI chip, with thin, un-doped silicon sensitive layer, operated undepleted**

Advantages

- **decoupled charge sensing and signal transfer (improved radiation tolerance, random access, etc.)**
- **small pitch (high tracking precision)**
- **Thin, fast readout, moderate price**





R&D

- Strasbourg IReS has been working on development of monolithic active pixels since 1989; others (RAL, Yale/Or., etc.)
- IReS prototype arrays of few thousands pixels demonstrated viability.
- Large prototypes now fabricated/tested.
- Attention on readout strategies adapted to specific experimental conditions, and transfer to AMS 0.35 OPTO from TSMC 0.25
  - ~< 12 um epi vs. < 7 um
- Application to STAR

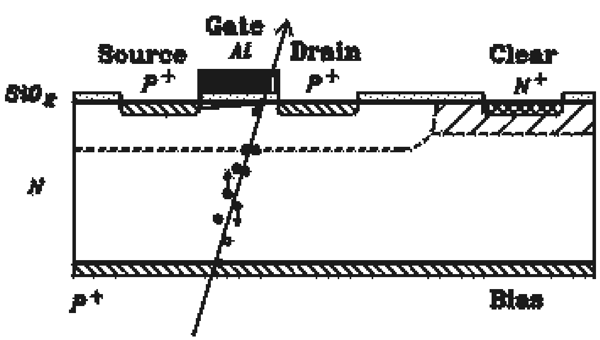
Parallel R&D:

- FAPS (RAL): 10-20 storage caps/pixel

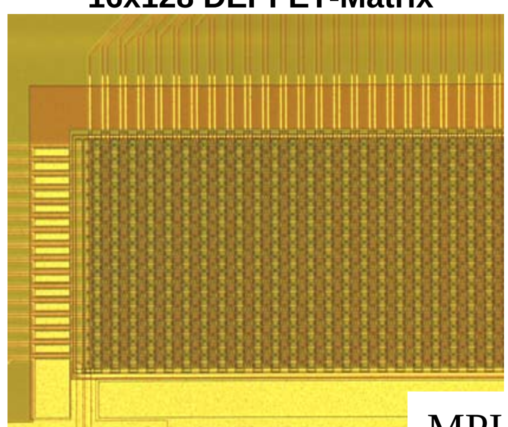
Inner Tracking/Vertex Detection (DEPFET)

Concept

- Field effect transistor on top of fully depleted bulk
- All charge generated in fully depleted bulk; assembles underneath the transistor channel; steers the transistor current
- Clearing by positive pulse on clear electrode
- Combined function of sensor and amplifier



16x128 DEPFET-Matrix



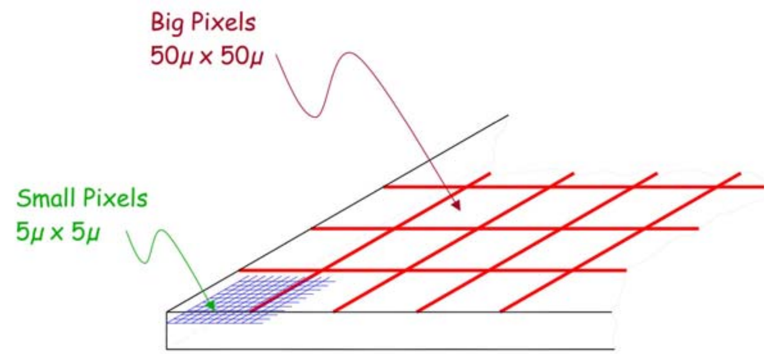
Properties

- low capacitance ► low noise
- Signal charge remains undisturbed by readout ► repeated readout
- Complete clearing of signal charge ► no reset noise
- Full sensitivity over whole bulk ► large signal for m.i.p.; X-ray sens.
- Thin radiation entrance window on backside ► X-ray sensitivity
- Charge collection also in turned off mode ► low power consumption
- Measurement at place of generation ► no charge transfer (loss)
- Operation over very large temperature range ► no cooling needed

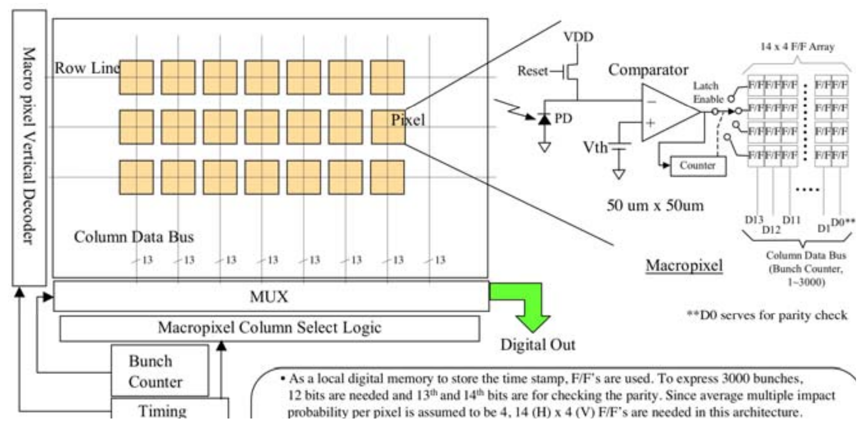
MPI Munich, MPI Halle, U. Bonn, U. Mannheim

Chronopixel

Yale/Oregon/Sarnoff



- **Initially investigated Hierarchical Approach**
  - **Macro/Micro Hybrid (50 um ⊕ ~5 um)**
  - **<u>Macro only</u>, reduced to 10-15 um pixel**
  - **Key feature – stored hit times (4 deep)**
- **Completed Macropixel design**
  - **645 transistors**
  - **Spice simulation verified design**
  - **TSMC 0.18 μm ⇒ ~50 μm pixel**
    - Epi-layer only 7 μm
    - Talking to JAZZ (15 μm epi-layer)
  - **90 nm ⇒ 20-25 μm pixel**
- **Next phase under development**
  - **Complete design Macro pixel Chronopix**
  - **Deliverable – tape for foundry (end of this year)**
- **Near Future (dependent on funding)**
  - **Fab 50 μm (or 25 μm) Chronopixel array**
    - Demonstrate performance
  - **Then, 10-15 μm pixel**

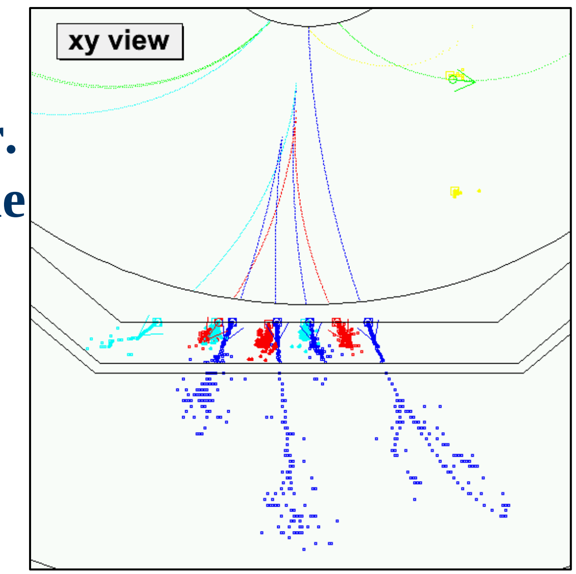


Calorimetry at the ILC

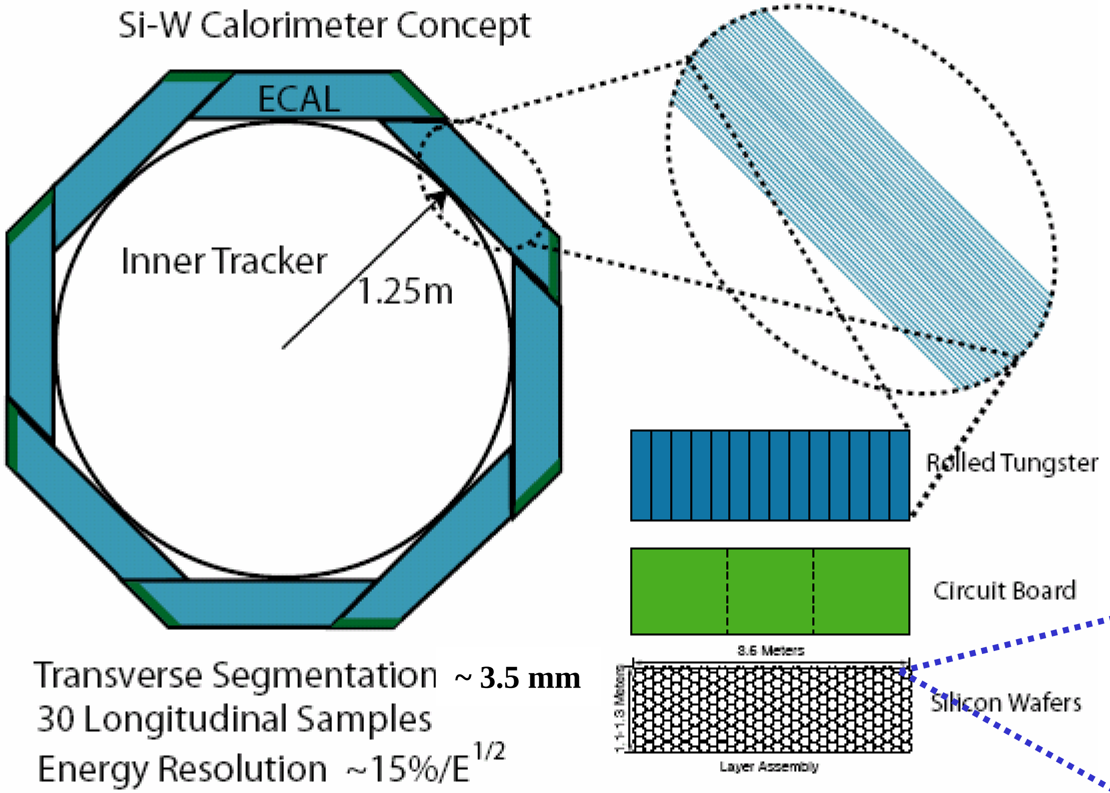
Particles in Jet	Fraction of Visible Energy	Detector	Resolution
Charged	~65%	Tracker	< 0.005% p_T negligible
Photons	~25%	ECAL	~ 15% / √E
Neutral Hadrons	~10%	ECAL + HCAL	~ 60% / √E

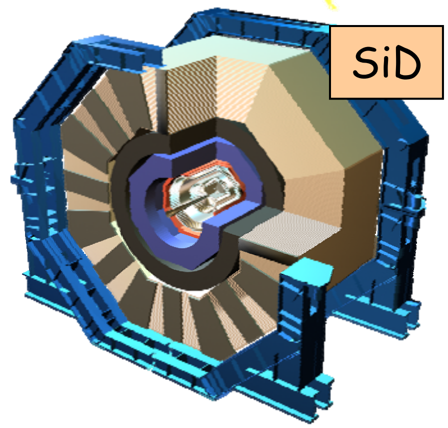
~ 20% / √E

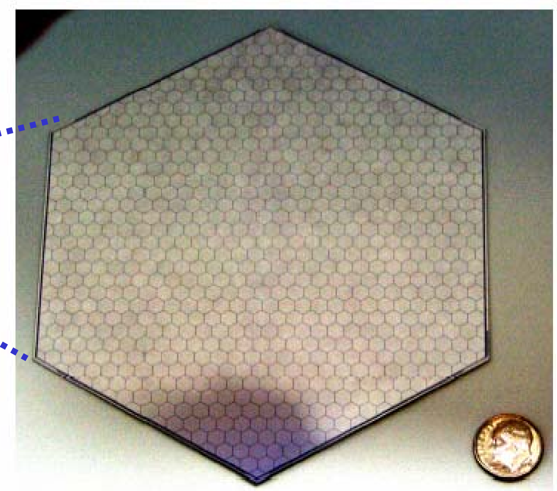
Energy measurement by measuring each component – Particle Flow Calor.
Simplicity of ILC events makes this conceivable
Requires very fine granularity in calorimeter
Natural solution for EM – silicon-tungsten



Silicon/Tungsten EM Calorimeter

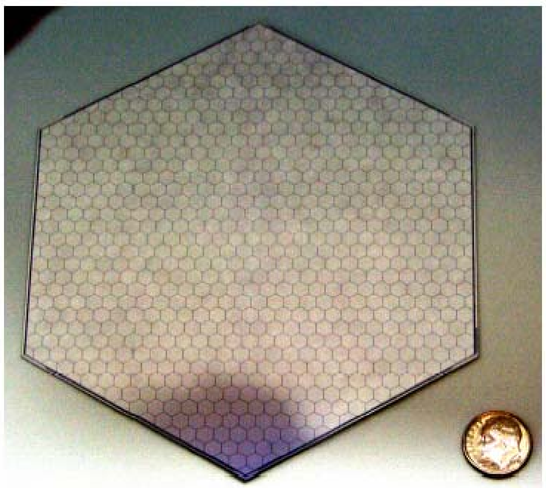






SLAC/Oregon/BNL/Davis/Annecy

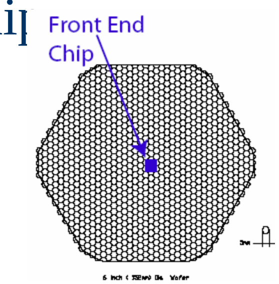
Silicon/Tungsten EM Calorimetry for ILC



SLAC/Oregon/BNL/Davis/Annecy

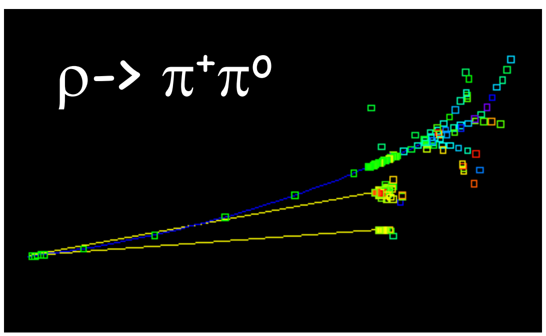
Dense, fine grained silicon tungsten calorimeter (builds on SLC/LEP experience)

- Pads: 12 mm^2 to match Moliere radius (~ R_m/4)
- Each six inch wafer read out by one chip
- < 1% crosstalk

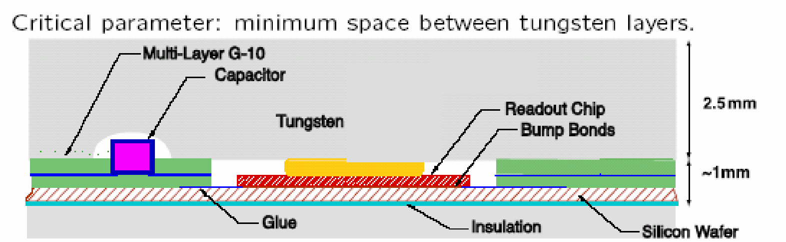


Electronics design

- Noise < 2000 electrons
- Single MIP tagging (S/N ~ 7)
- Dynamically switchable feedback capacitor scheme achieves required dynamic range: 0.1-2500 MIPs – 4 deep storage/bunch train

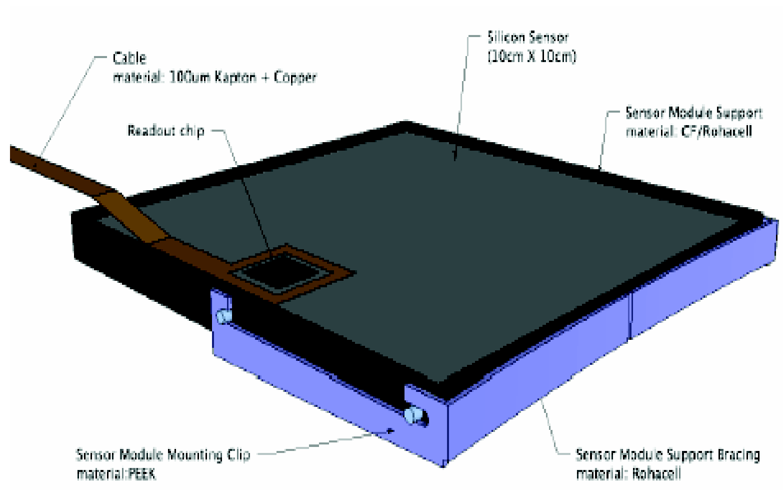


Passive cooling – conduction in W to edge



Silicon Tracking for ILC

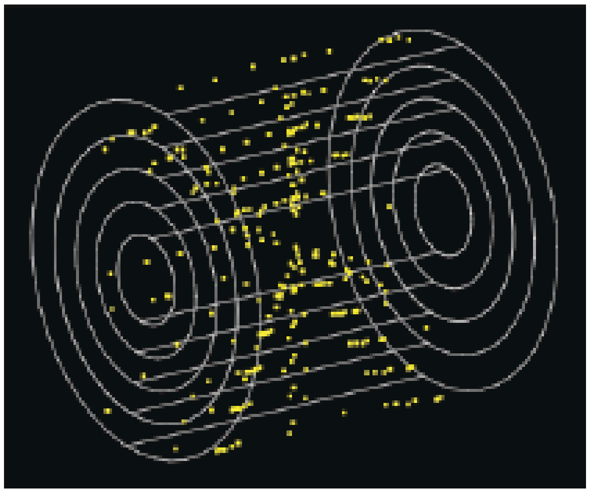
- **Silicon strip and pixel detectors (SiD approach)**
  - **Manage increased radiation and pile-up**
  - **Superb spacepoint precision allows tracking measurement goals to be achieved in a compact tracking volume**
  - **Robust to spurious, intermittent backgrounds, eg. at ILC**
- **Compact tracker**
  - **achieves superb performance**
  - **allows more aggressive technical choices for outer systems (assuming an overall cost constraint)**
- **Robust against ILC backgrounds**
  (esp. beam loss, a la SLC)
- **3rd dimension "measured" and backgrounds suppressed with segmented silicon strips**



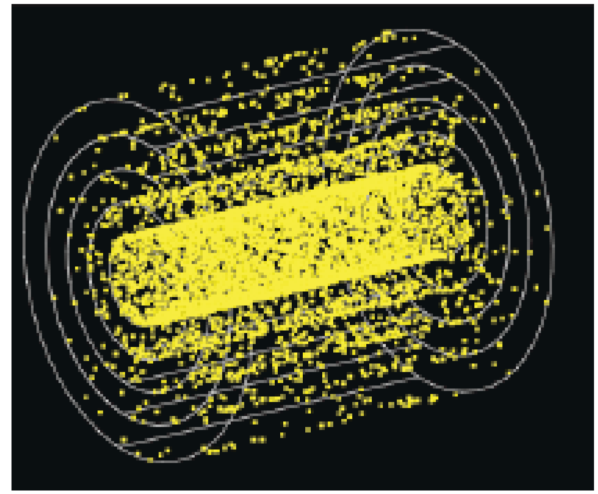
Module ~0.8% X_0

Robust Pattern Recognition

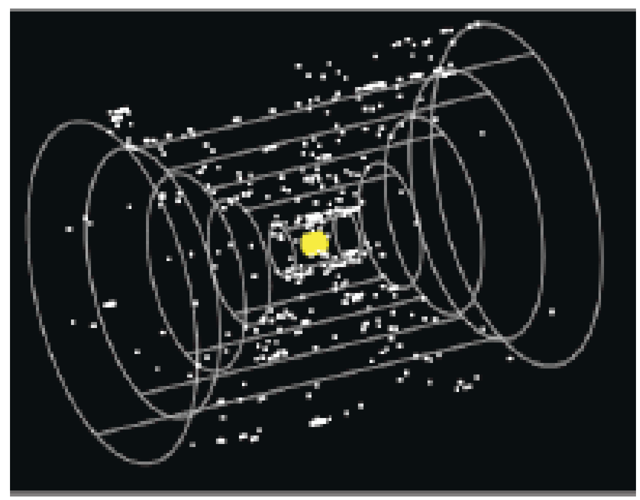
- t tbar event



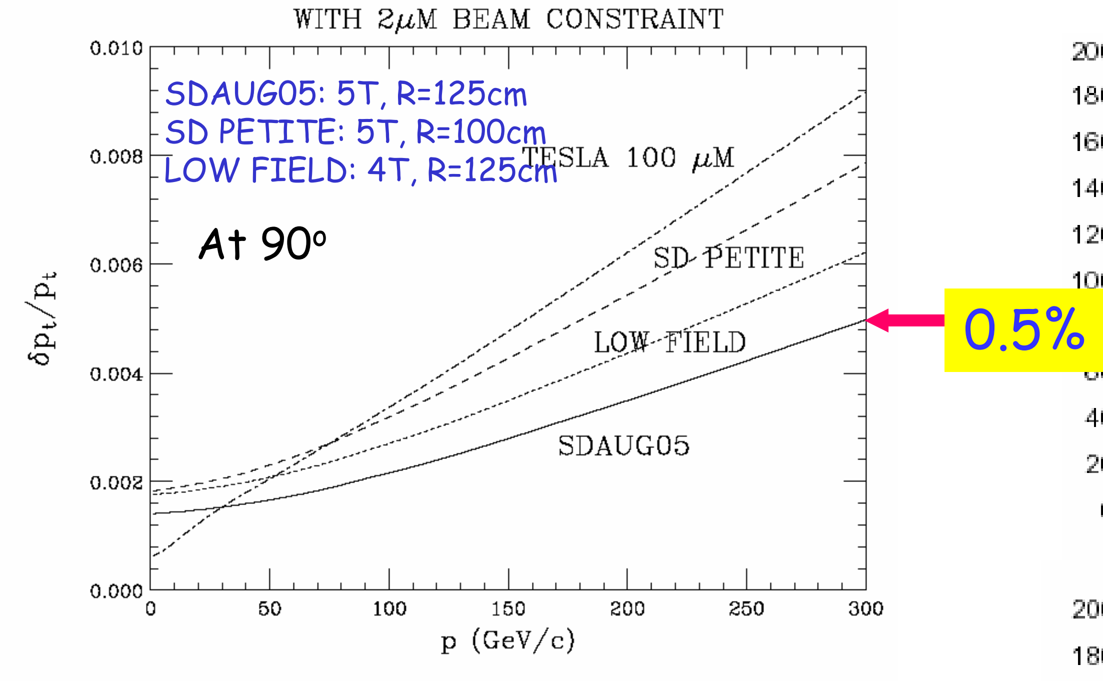
w/ backgrounds from 150 bunch crossings

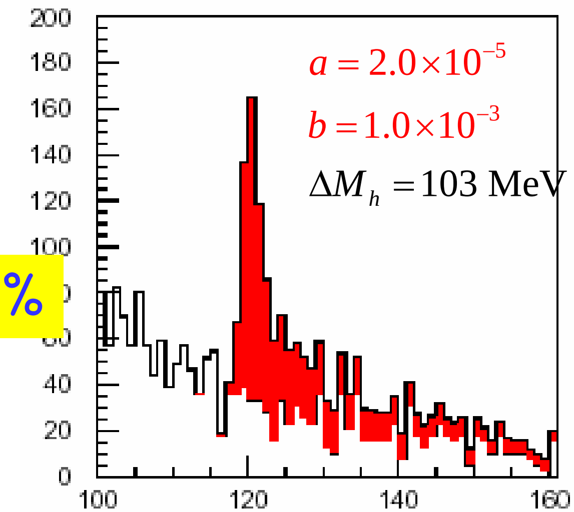


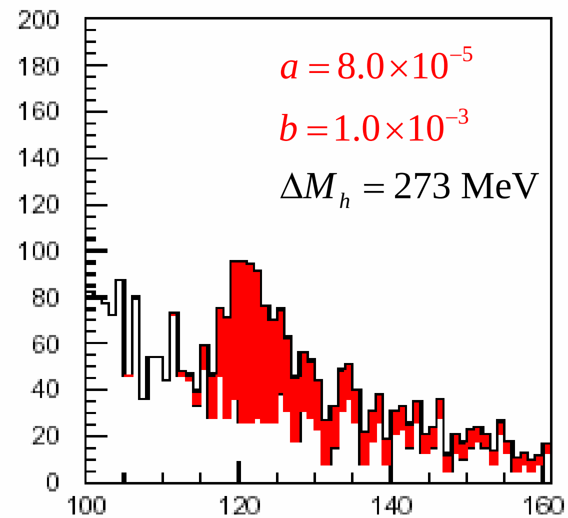
clean detection with time stamping, even for 150 nsec spacing



Excellent momentum resolution





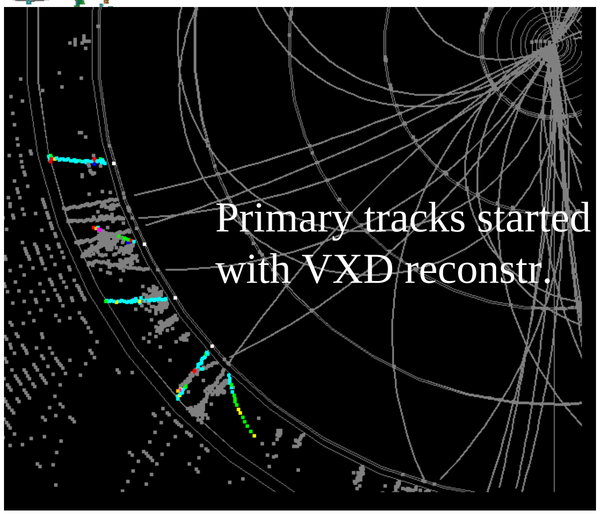


$$e^+e^- \to ZH \qquad \sqrt{s} = 350\ GeV$$

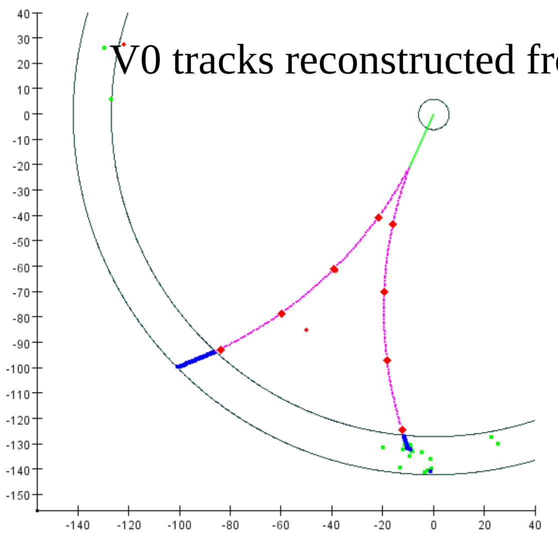
$$\to \mu^+\mu^- X \qquad L = 500\ fb^{-1}$$

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

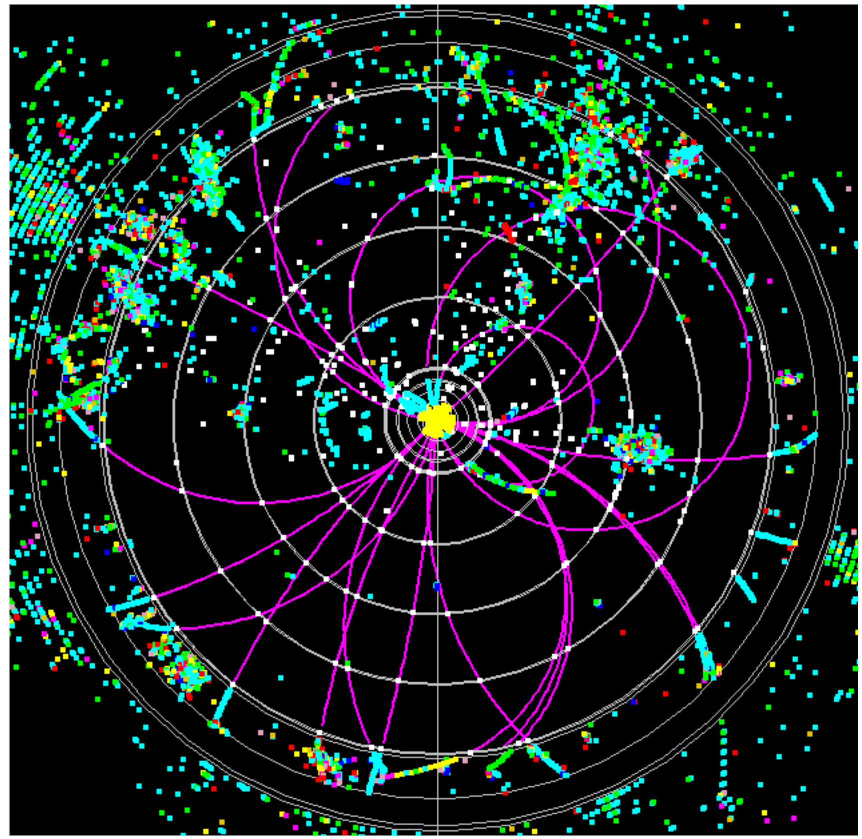
Silicon Tracking w/ Calorimeter Assist



Primary tracks started with VXD reconstr.



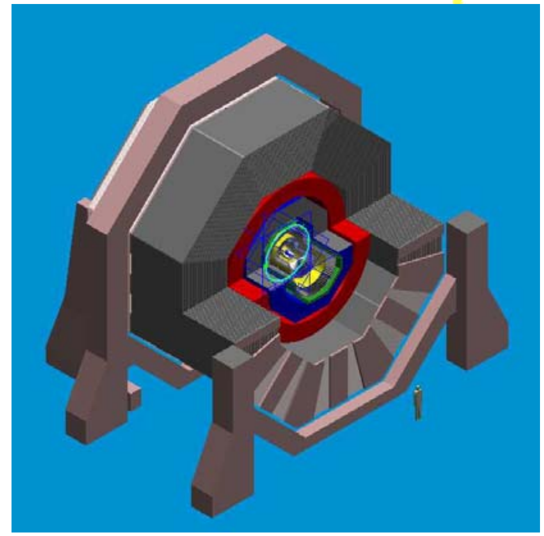
V0 tracks reconstructed from ECAL stubs



E. von Toerne

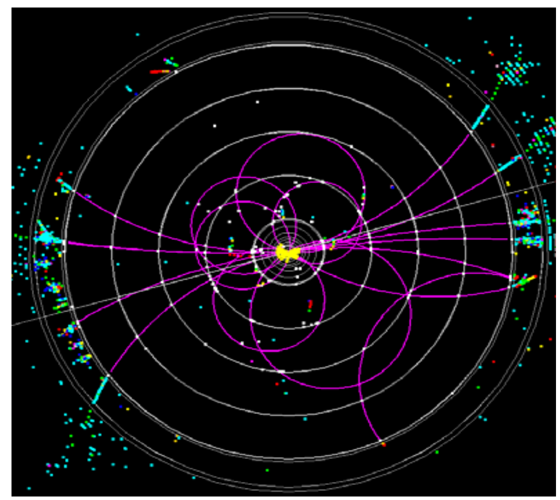
SiD (the Silicon Detector)

CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN



assumptions

- Particle Flow Calorimetry will result in the best possible performance
- Silicon/tungsten is the best approach for the EM calorimeter
- Silicon tracking delivers excellent resolution in smaller volume
- Large B field desirable to contain electron-positron pairs in beamline
- Cost is constrained



Conclusion

- The ILC physics program is poised to benefit from the power of silicon detector technology, with R&D aimed at the needs of the ILC
  - Vertex Detection
  - Tracking
  - EM Calorimetry
  - Forward Detectors

- Congratulations Abe – <u>our best years are yet to come</u>!