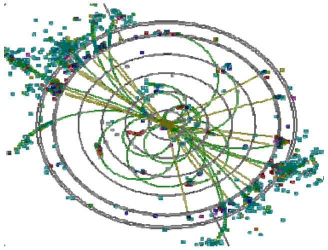
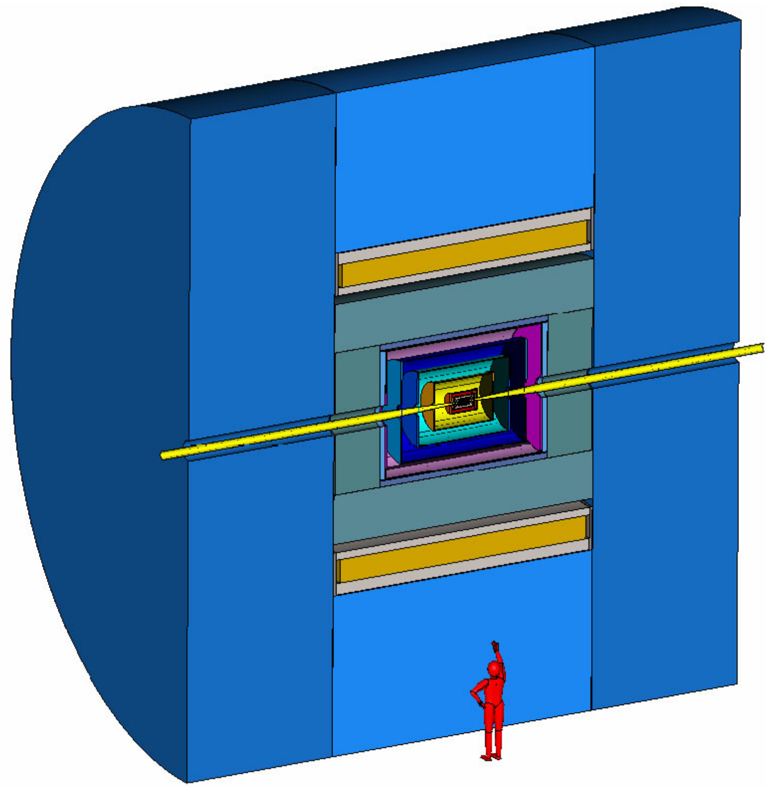


SiD: A Robust, Optimized ILC Detector

Design Study for International Linear Collider (ILC) detector

SiD - High performance, uncompromised, cost contrained

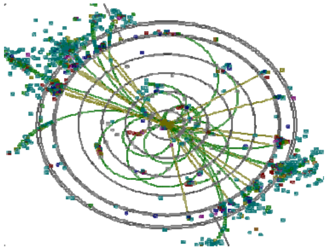
Jim Brau
University of Oregon



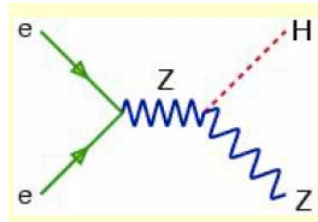
SiD web page:
http://www-sid.slac.stanford.edu/

Physics at the Linear Collider

- **Top**
  - **Mass measured to ~ 100 MeV (threshold scan)**
  - **Yukawa coupling**
- **EWSB**
  - **Higgs**
    - Mass (~50 MeV at M_h = 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**

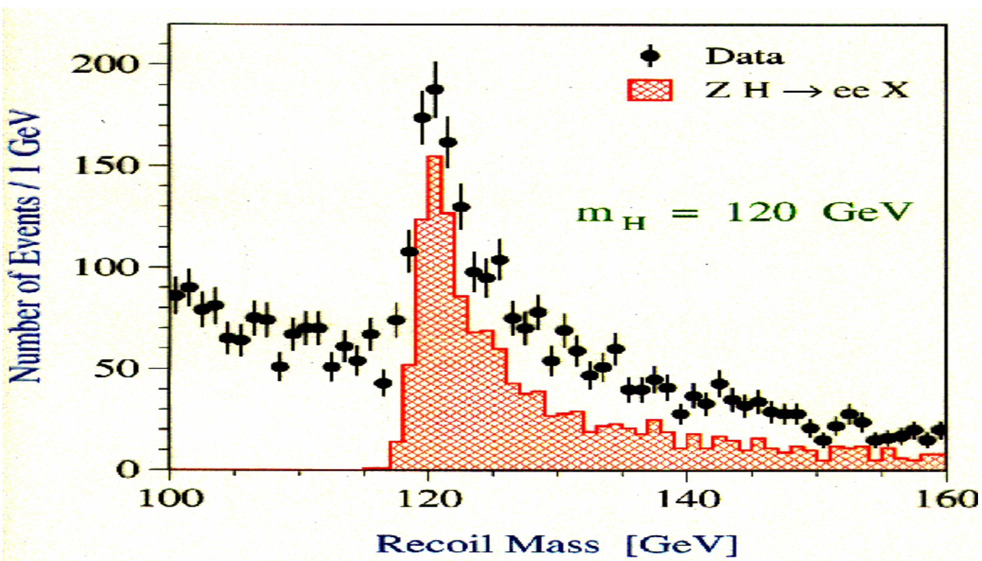


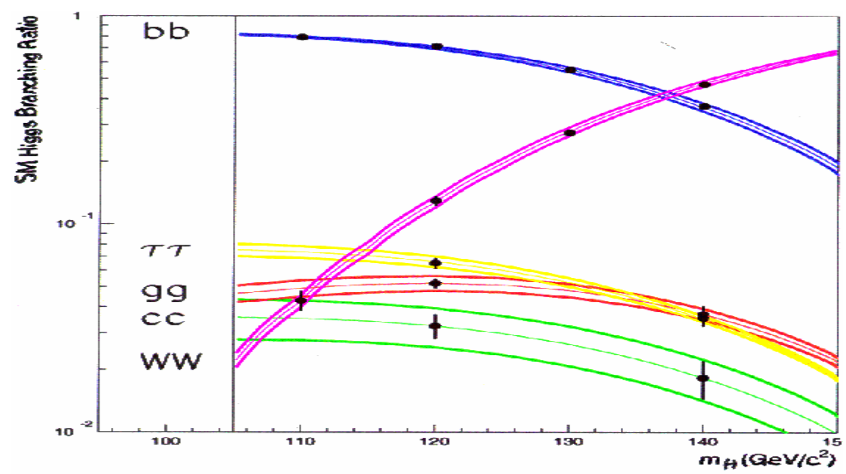
Power of the Constrained Initial State and Simple Reactions



- 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)



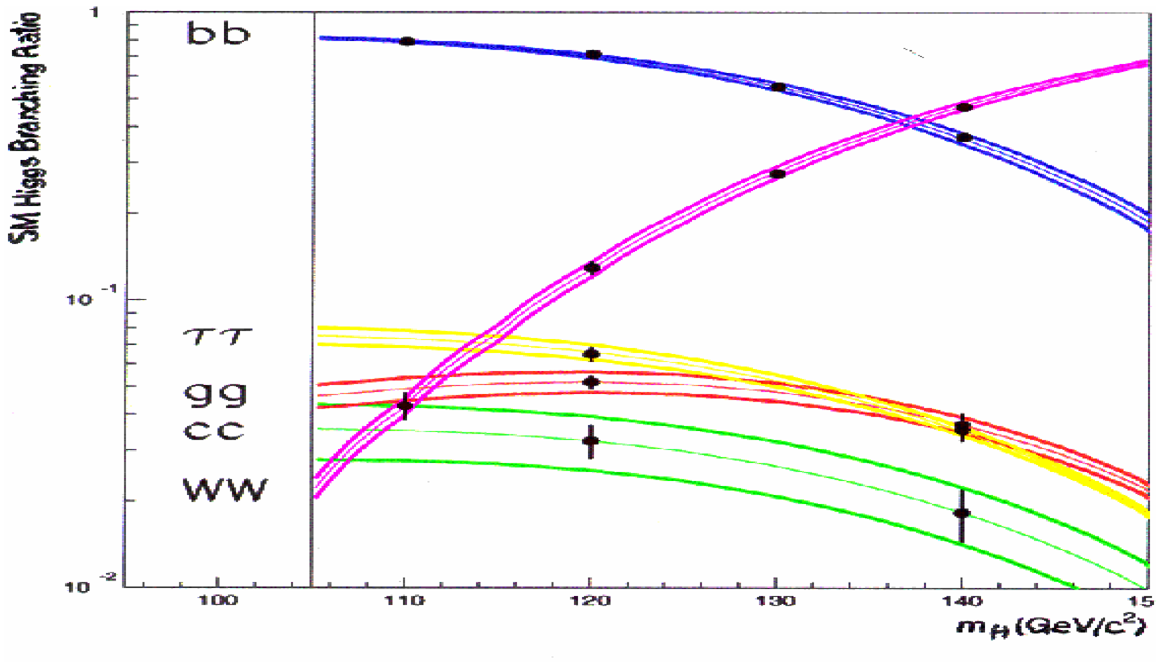


500 fb^{-1} @ 500 GeV, TESLA TDR, Fig 2.1.4

The Electroweak Precision Measurements Anticipate a Light Higgs – Then What?

- Measurement of BR's is powerful indicator of new physics

  e.g. in MSSM, these differ from the SM in a characteristic way.
- Higgs BR must agree with MSSM parameters from many other measurements.



Is This the Standard Model Higgs?

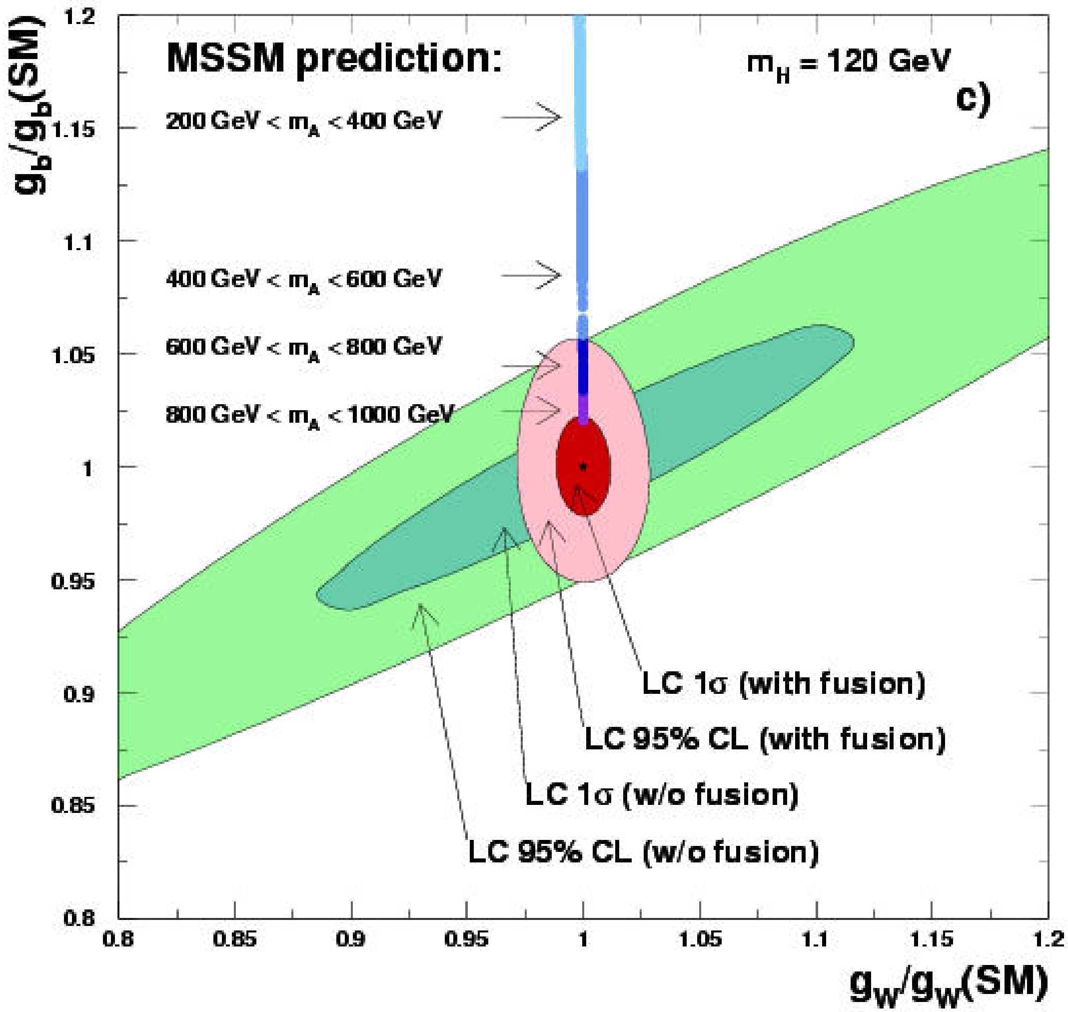
b vs. W

TESLA TDR, Fig 2.2.6

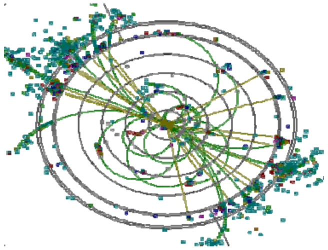
Arrows at:
- M_A = 200-400
- M_A = 400-600
- M_A = 600-800
- M_A = 800-1000

HFITTER output

conclusion:
for M_A < 600,
likely to distinguish



Is This the Standard Model Higgs?



TESLA TDR, Fig 2.2.6

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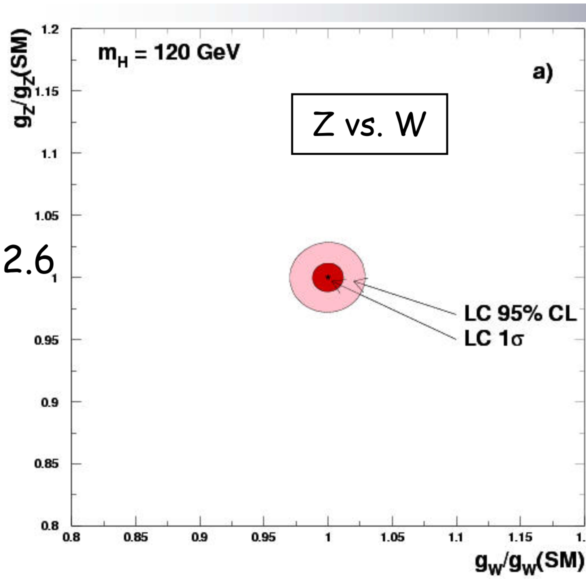
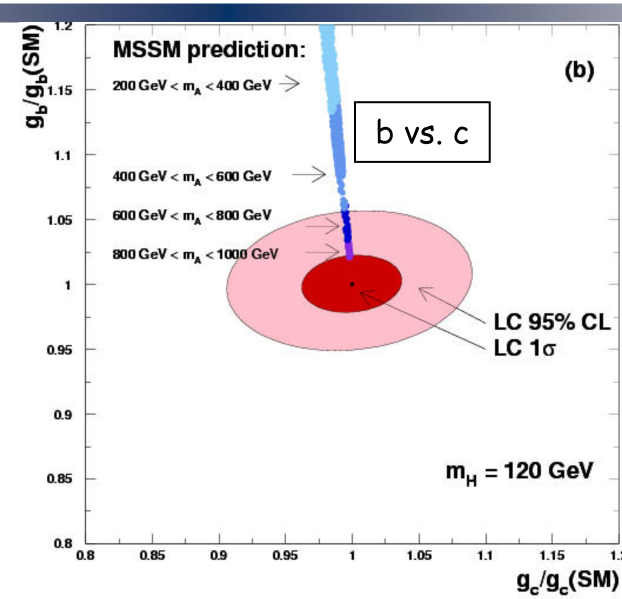
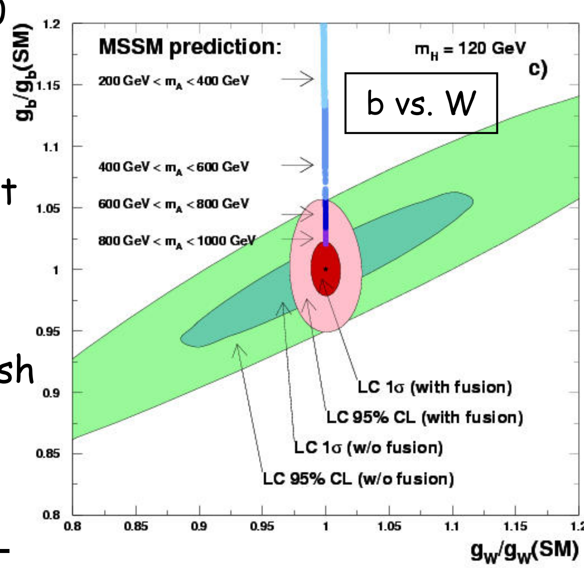
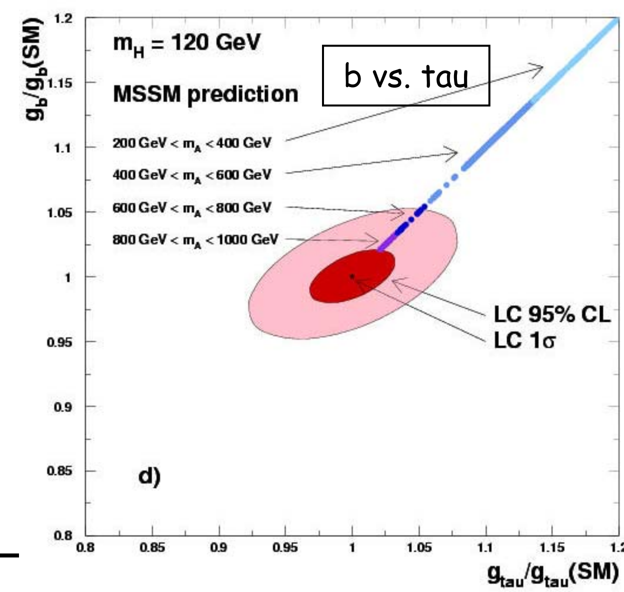


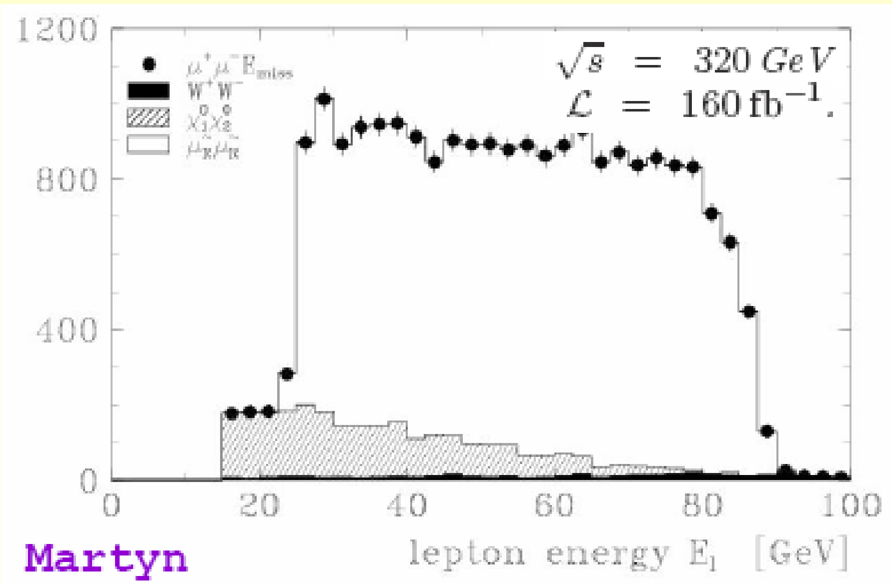




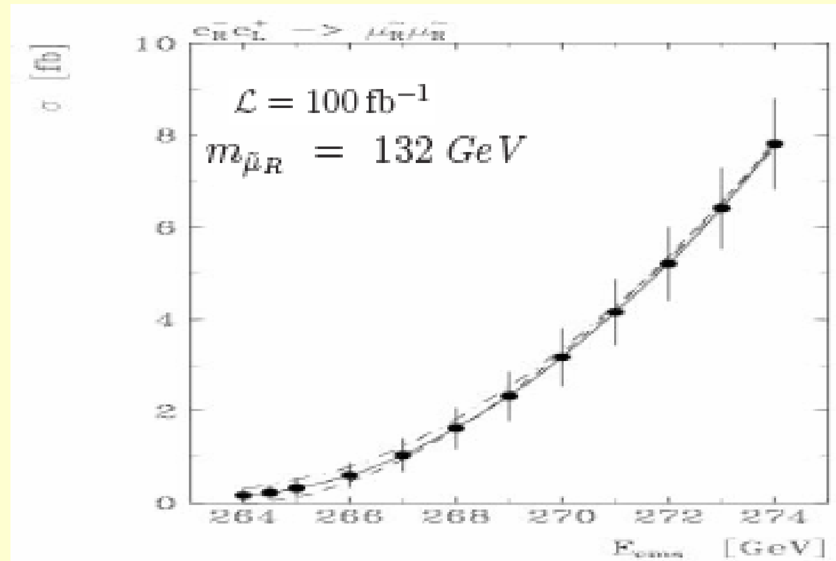


Clean signals from sleptons and charginos/neutralinos

in continuum:

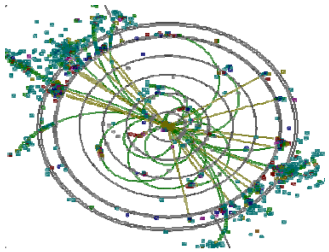


and from threshold scan:



$$e^-_R e^+_L \rightarrow \tilde{\mu}_R \tilde{\mu}_R \rightarrow \mu^- \tilde{\chi}^0_1 \mu^+ \tilde{\chi}^0_1.$$

$$\delta m_{\tilde{\mu}_R} < 0.1\,\mathrm{GeV}$$



Special Advantages of Experiments at the International Linear Collider

Elementary interactions at known E_{cm}*

eg. $e^+e^- \rightarrow$ Z H

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 also possible – R&D)

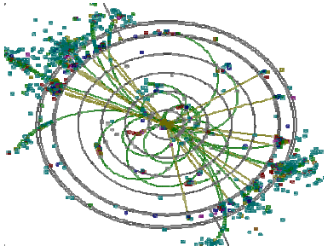
Exquisite vertex detection

eg. $R_{beampipe}$ ~ 1 cm and σ_{hit} ~ 3 mm

Calorimetry with Particle Flow Precision

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

* beamstrahlung must be dealt with, but it's manageable



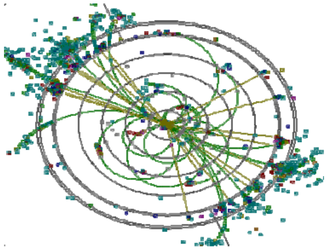
ILC Detector Requirements

Detector Requirements are defined by collider parameters,
and physics goals

ILC creates new challenges and opportunities,
different in many respects from the challenges and opportunities of the LHC detectors

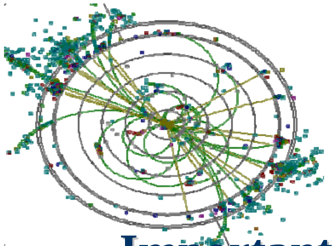
Physics motivates
- Triggerless event collection (software event selection)
- Extremely precise vertexing
- Synergistic design of detectors components:
  - vertex detector, tracker, calorimeters integrated for optimal jet reconstruction
- New technologies based on recent detector inventions

Detector R&D to optimize opportunity is Critically needed



ILC Detector 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 .**



Collider defined by ILC Scope

Important step in moving to a final design for the International Linear Collider was to establish the physics motivated Linear Collider Scope

- **BASELINE MACHINE**
  - E_{CM} of operation 200-500 GeV
  - Luminosity and reliability for 500 fb^{-1} in 4 years
  - Energy scan capability with <10% downtime
  - Beam energy precision and stability below about 0.1%
  - Electron polarization of > 80%
  - Two IRs with detectors
  - E_{CM} down to 90 GeV for calibration
- **UPGRADES**
  - E_{CM} about 1 TeV
  - Allow for ~1 ab^{-1} in about 3-4 years
- **OPTIONS**
  - Extend to 1 ab^{-1} at 500 GeV in ~ 2 years
  - e^-e^-, $\gamma\gamma$, $e^-\gamma$, positron-polarization
  - Giga-Z, WW threshold

Parameters for the Linear Collider

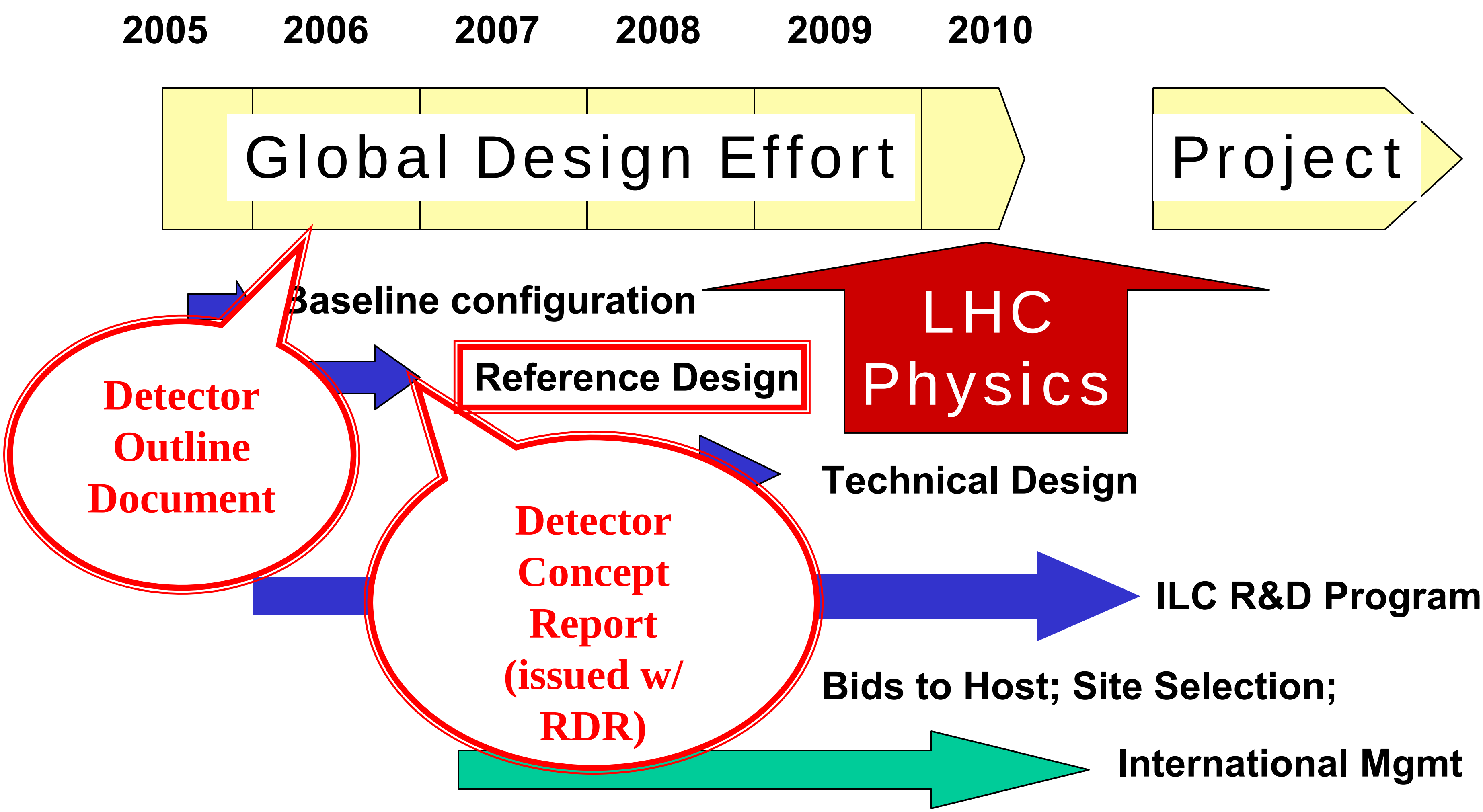
September 30, 2003

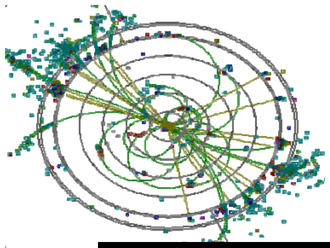
http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

6.1 List of subcommittee members

Asia: Sachio Komamiya, Dongchul Son
Europe : Rolf Heuer (chair), Francois Richard
North America: Paul Grannis, Mark Oreglia

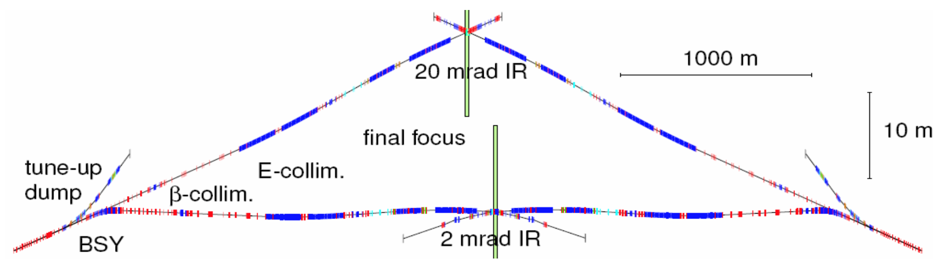
The GDE Plan and Schedule

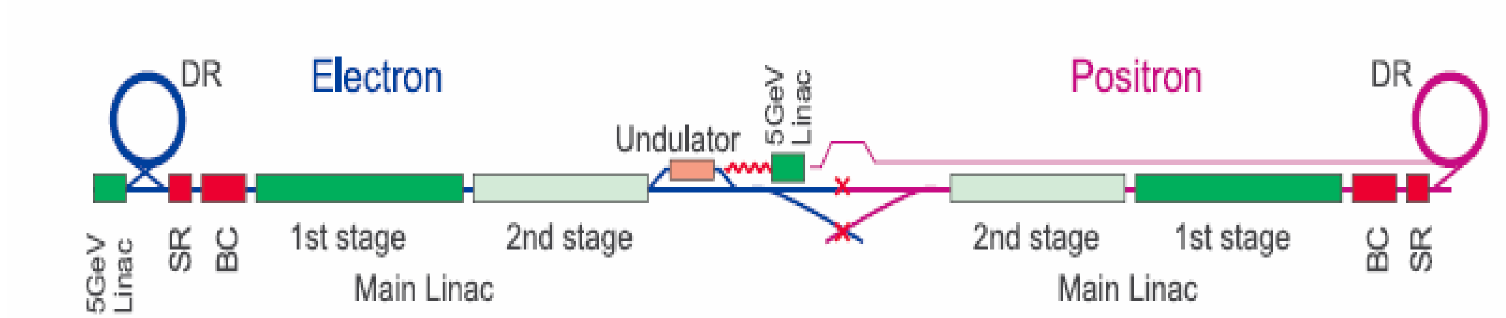




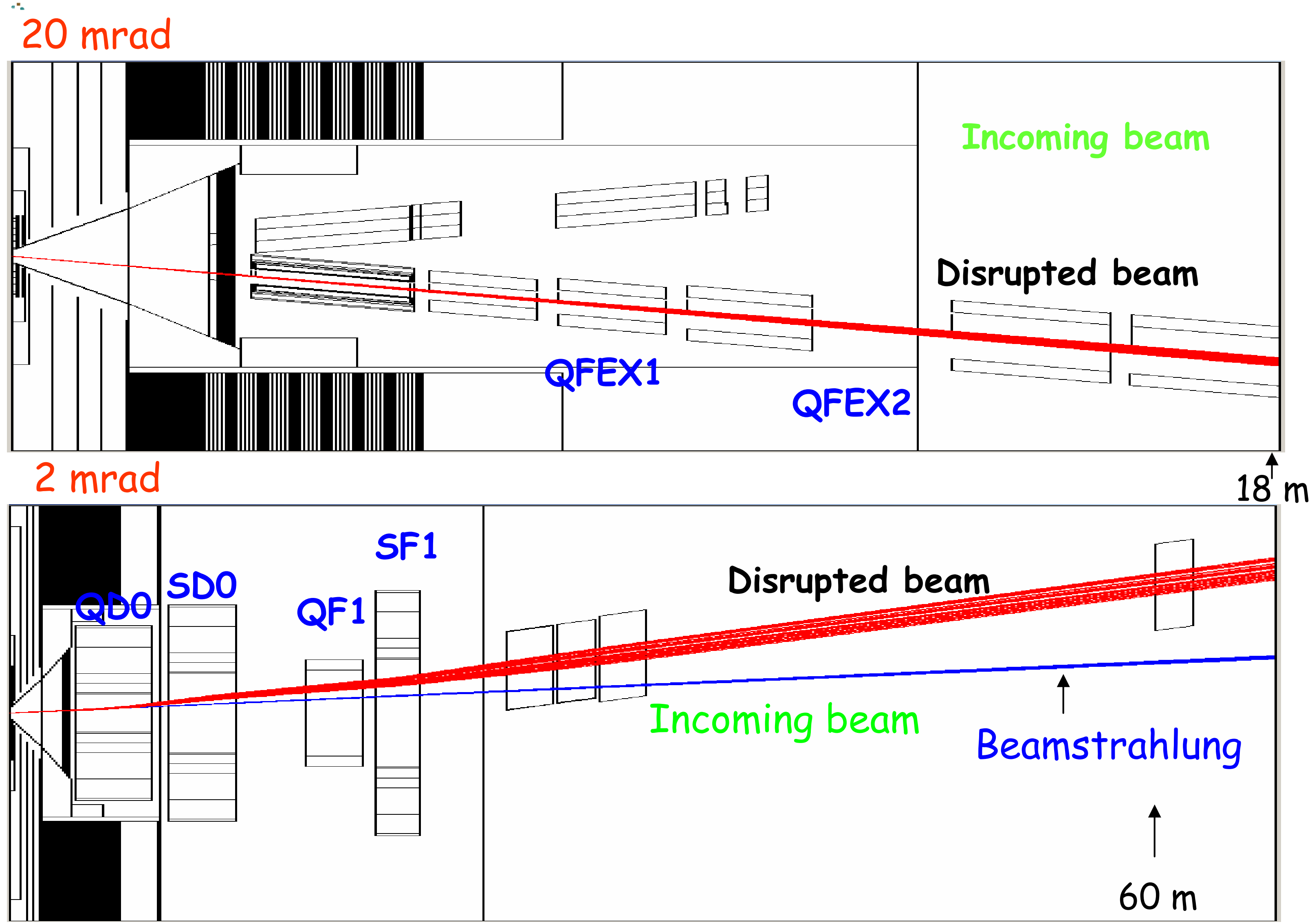
Collider Parameters

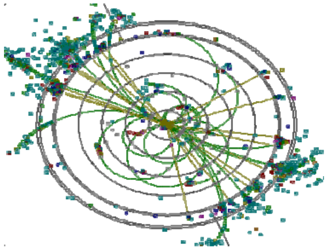
Machine parameter	value
#bunches/train	2820
#trains/sec	5
bunch spacing	308 nsec
bunches/sec	14100
length of train	868 μsec
train spacing	199 msec
crossing angle	0-20 mrad
Luminosity	2 x 10^{34} cm^{-2} s^{-1}





SiD in two crossing schemes





Background Sources

IP Backgrounds

- Beam-beam Interactions
  - Disrupted primary beam
    - Extraction line losses
  - Beamstrahlung photons
  - e+e- pairs
- Radiative Bhabhas
- $\gamma\gamma \rightarrow$ hadrons/μ+μ-

Somewhat manageable -

- Scale with luminosity
- Transport them away from IP
- Shield sensitive detectors
- Exploit detector timing

- Reliable simulations.

Machine backgrounds

- Muon production at collimators
- Collimator edge scattering
- Beam-gas
- Synchrotron radiations
- Neutrons from dumps/extr. line

Harder to handle -

- Don't make them
- Keep them from IP if you do

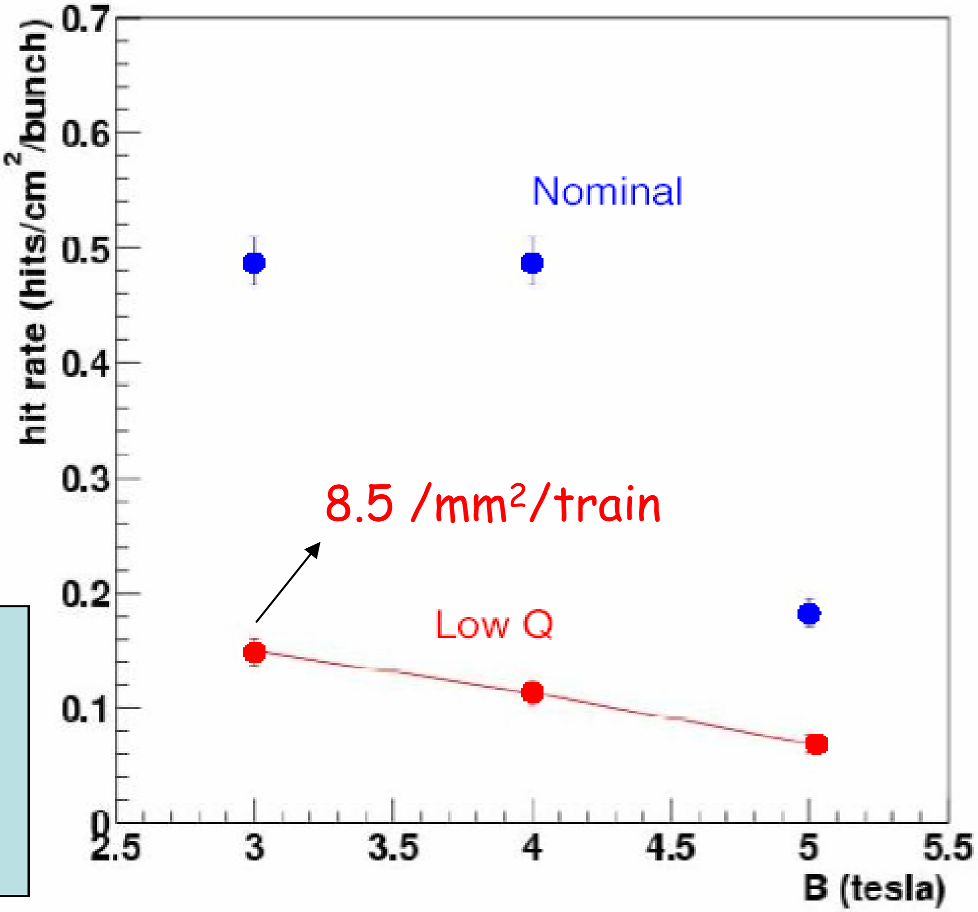
- Dominated by beam halo
- Dependent on assumptions

VXD background hits

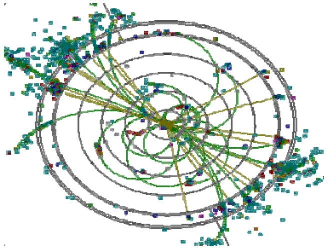
- Pair background hit rate on the 1st layer of the Vertex Detector (R=24mm)
- Simulation using CAIN and JUPITER
- Hit rate of the Low Q option is ~1/3 of the nominal option, as expected

Pair B.G. hit rate (/cm^2/bunch)

B(tesla)	Nominal	LowQ
3	0.488	0.149
4	0.48	0.113
5	0.183	0.069

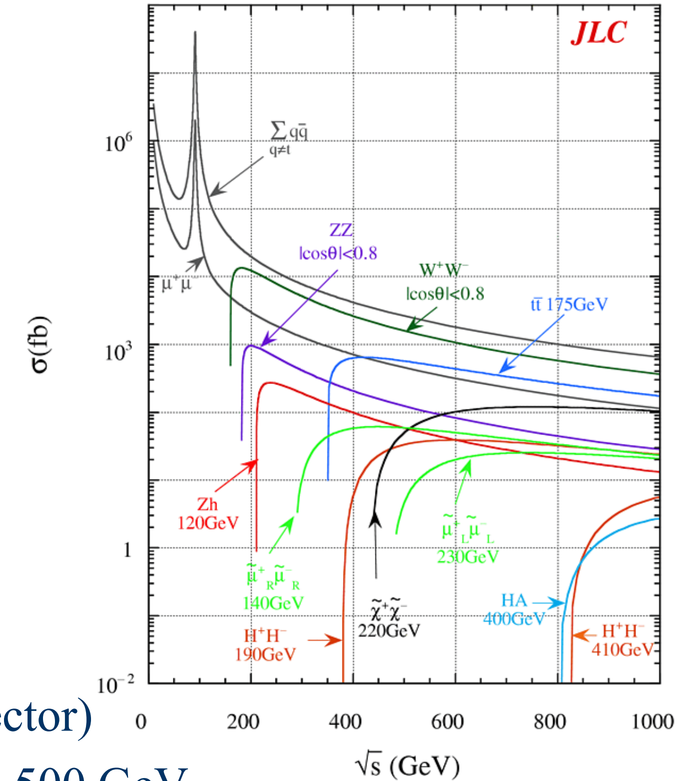


GLD study



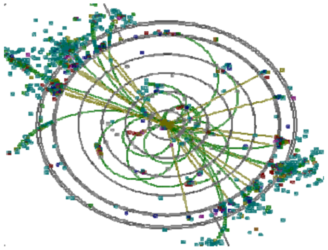
Event Rates and Backgrounds

- **Event rates (Luminosity = 2 x 10^{34})**
  - $e^+e^- \rightarrow$ qq, WW, tt, HX
    - ~ **0.1 event / train**
  - $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^-$ X
    - ~ **200 /train**



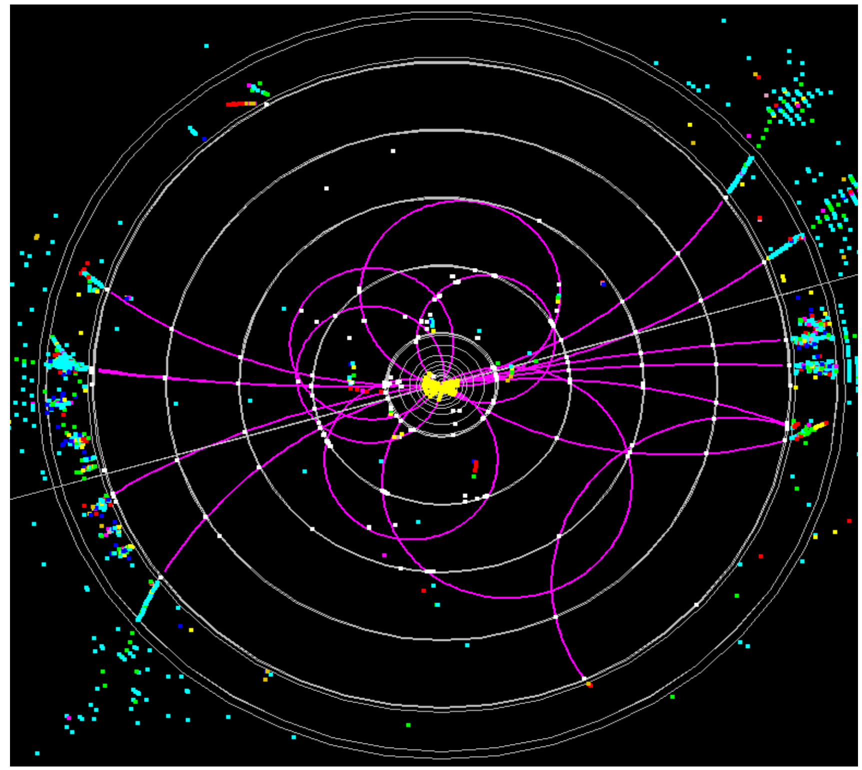
- **Background**
  - 6 x 10^{10} γ / BX (from synchrotron radiation, scatters into central detector)
  - 40,000-250,000 e^+e^- / BX (90-1000 TeV) @ 500 GeV
  - Muons: < 1 Hz/cm^2 (w/ beamline spoilers)
  - Neutrons: ~3 x 10^8 /cm^2/ yr @ 500 GeV

Ref: Maruyama, Snowmass 2005

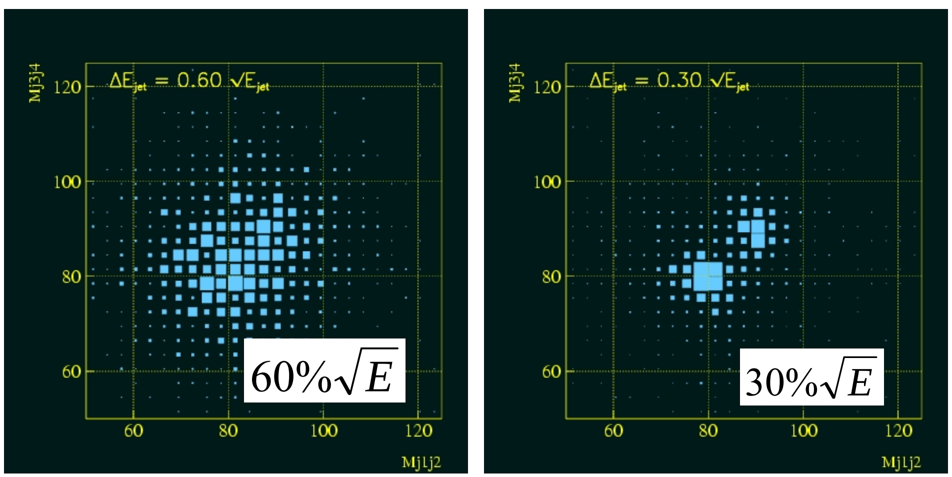


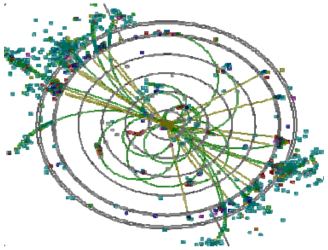
Linear Collider Events

- Simple events (relative to Hadron collider) make particle level reconstruction feasible
- Heavy boson mass resolution requirement sets jet energy resolution goal



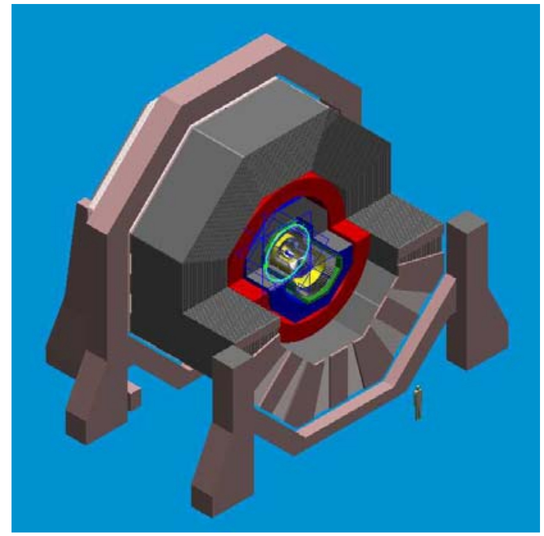
$e^+e^- \to WW\nu\bar{\nu}$, $e^+e^- \to ZZ\nu\bar{\nu}$





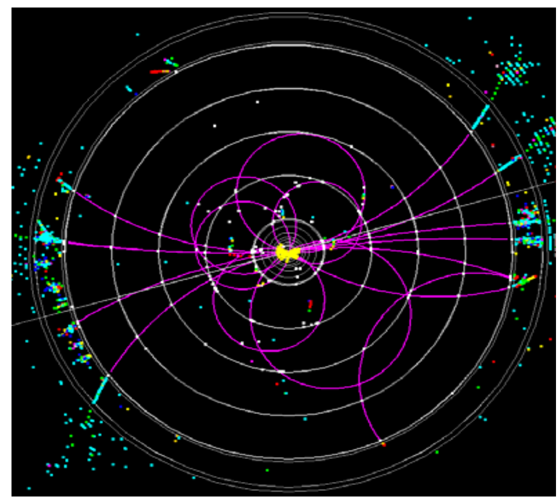
SiD (the Silicon Detector)

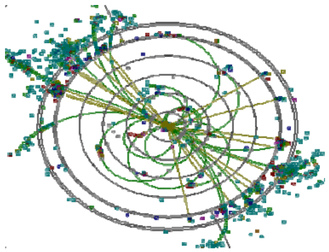
CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN



<u>assumptions</u>

- 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





SiD Design Study Participants

141 registered at Snowmass
Many more on mailing list

SiD DESIGN STUDY COORDINATORS
J.Jaros, H.Weerts,H.Aihara & J.Karyotakis

EXECUTIVE COMMITTEE
H.Aihara, J.Brau, M.Breidenbach, J.Jaros, J.Karyotakis, H.Weerts & A.White

ADVISORY COMMITTEE
All names on this chart

R& D COORDINATOR
A. White

VERTEXING
Su Dong
--

SILICON TRACKER
M.Demarteau
R.Partridge
--

CALORIMETERS
R.Frey
J.Repond
--

SOLENOID
FLUX RET
R.Smith
--

MUON
H.Band
H.E.Fisk
--

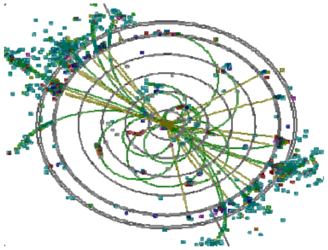
VERY FORWARD
--
--

BENCHMARKING
T.Barklow
--

SIMULATION
N.Graf
--

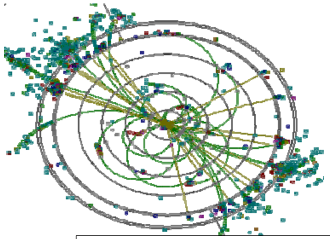
COST
M.Breidenbach
--

MDI
P.Burrows
T.Tauchi
--

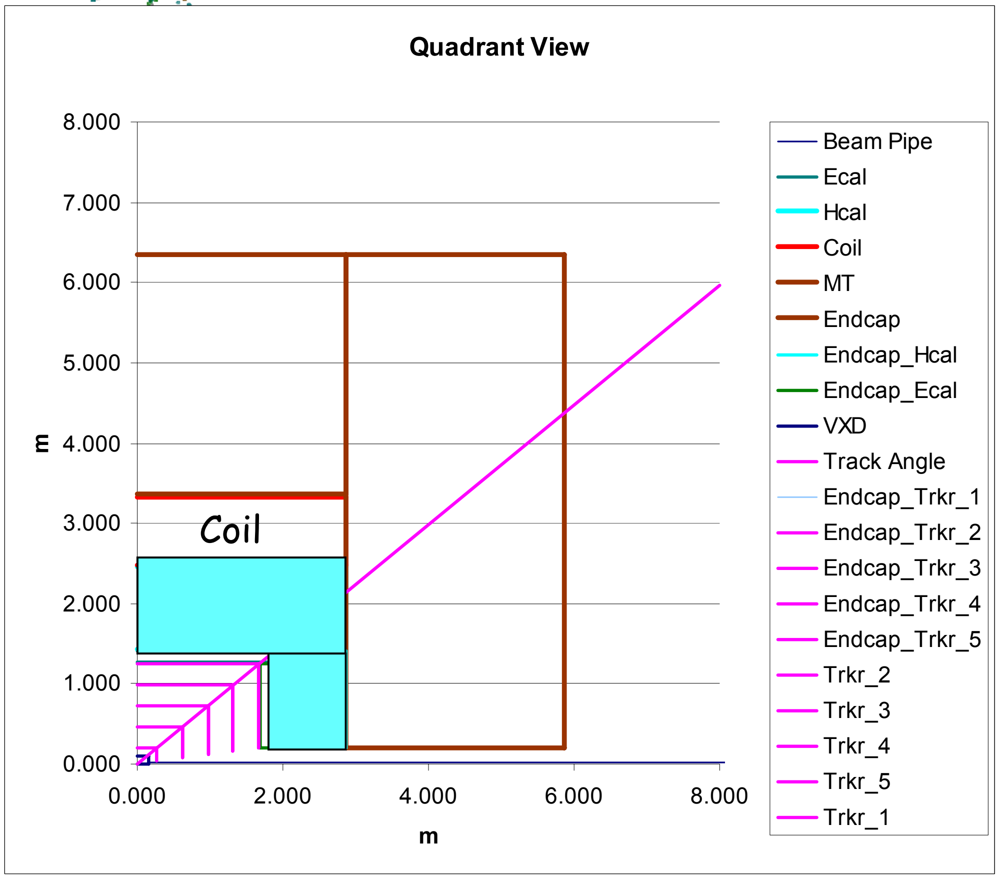


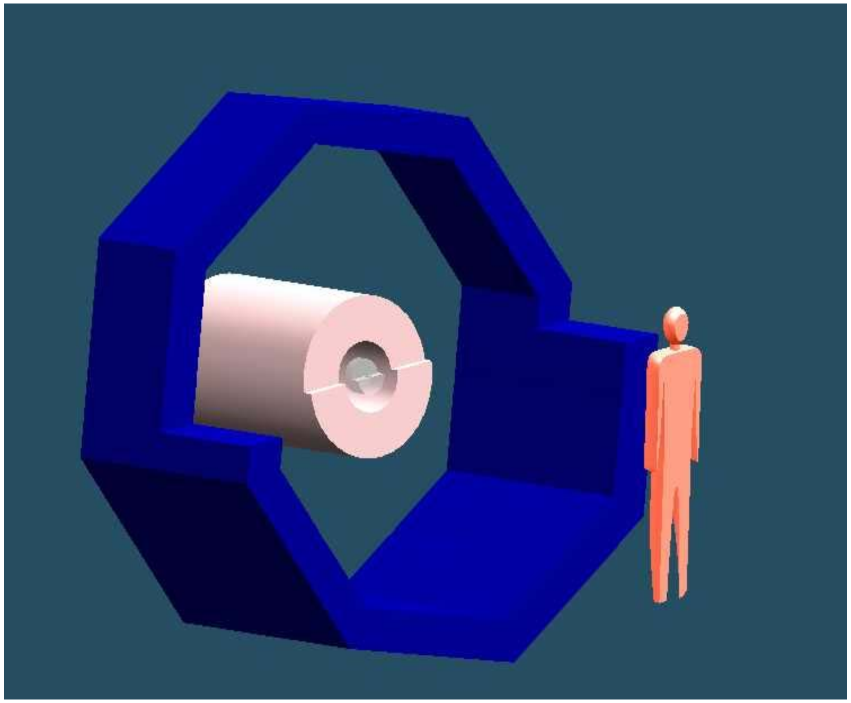
SiD Architecture Arguments

- Silicon is expensive, so limit area by limiting radius.
- Maintain BR^2 by pushing B (~5T).
- Excellent tracking resolution with precision of silicon strips.
- Vertex detector backgrounds limited with the 5T B-field.
- Track finding begins with 5 vertex detector 3D space points.
  - Tracker measures sagitta.
  - EM calorimeter also contributes to tracking for neutral strange particles due to high spatial segmentation.



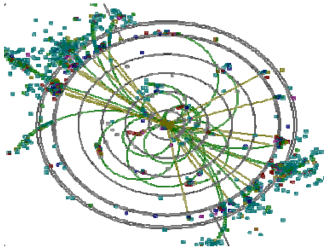
SiD Configuration





Scale of EMCal & Vertex Detector

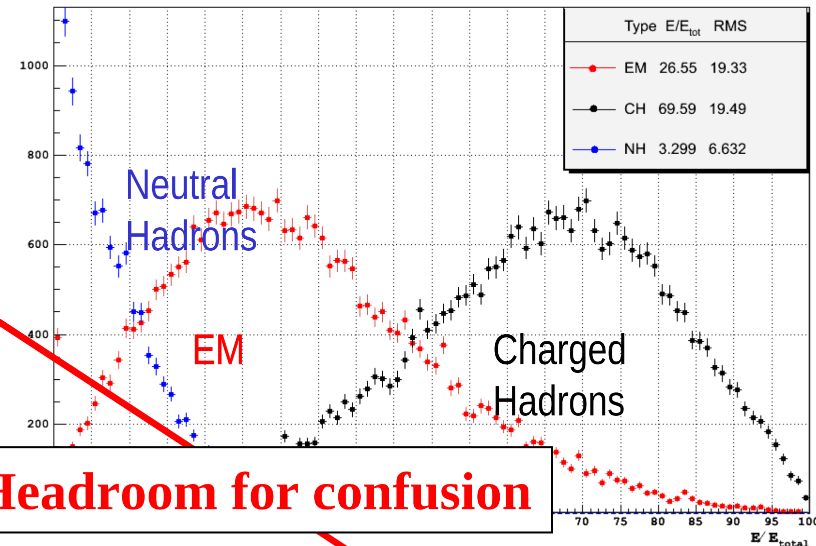
5 Tesla



Calorimetry

Current paradigm: Particle Flow

- Jet resolution goal is 30%/√E
- In jet measurements, use the excellent resolution of tracker, which measures bulk of the energy in a jet



Headroom for confusion

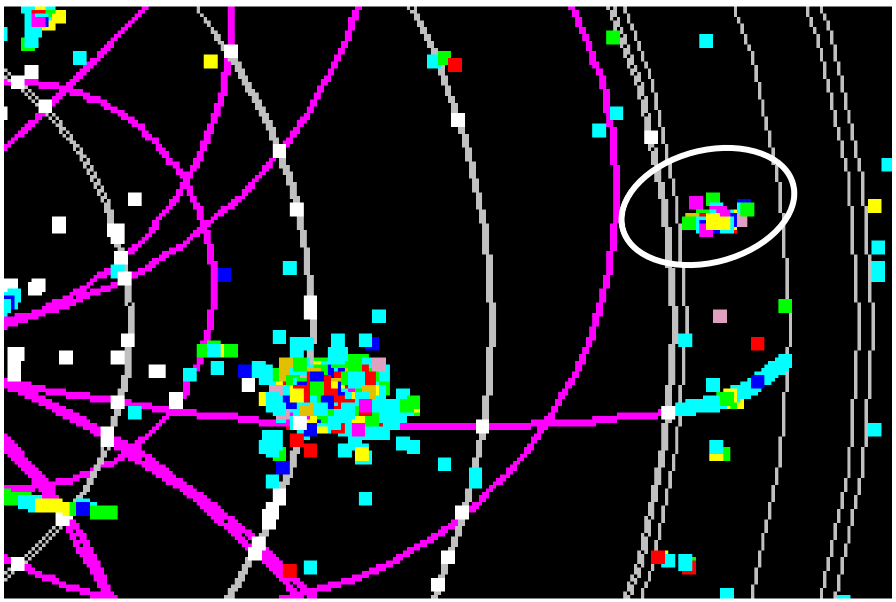
Particles in Jet	Fraction of Visible Energy	Detector	Resolution
Charged	~65%	Tracker	< 0.005% p_T negligible
Photons	~25%	ECAL	~ 15% / √E
Neutral Hadrons	~10%	ECAL + HCAL	~ 60% / √E

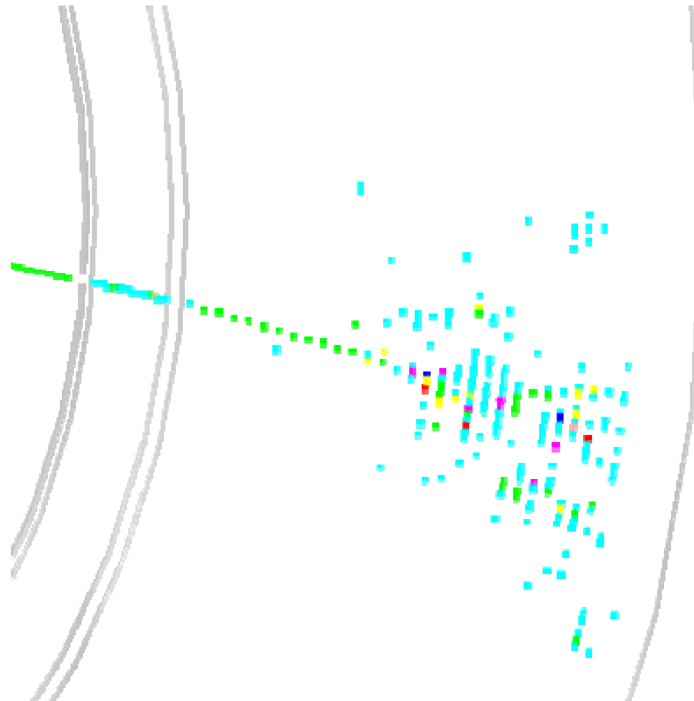
< 20% / √E

Energy/Particle Flow Calorimetry

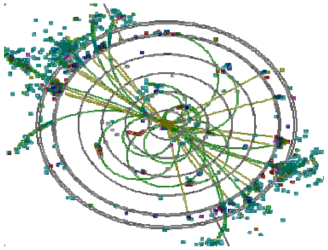
Identify EM clusters not associated with charged tracks (gammas)

Follow charged tracks into calorimeter and associate hadronic showers





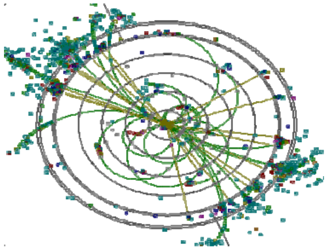
Remaining showers will be the neutral hadrons



EM Calorimetry

- Physics with isolated electron and gamma energy measurements require ~10-15% / $\sqrt{E} \oplus 1\%$
- Particle Flow Calorimetry requires fine grained EM calorimeter to separate neutral EM clusters from charged tracks entering the calorimeter
  - Small Moliere radius
    - Tungsten
  - Small sampling gaps – so not to spoil R_M
  - Separation of charged tracks from jet core helps
    - Maximize BR^2
  - Natural technology choice – Si/W calorimeters
    - Good success using Si/W for Luminosity monitors at SLD, DELPHI, OPAL, ALEPH
    - Oregon/SLAC/BNL
    - Also CALICE

material	R_M
Iron	18.4 mm
Lead	16.5 mm
Tungsten	9.5 mm
Uranium	10.2 mm

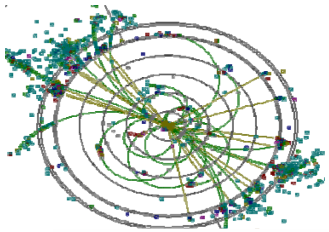


Silicon Tungsten EMCal

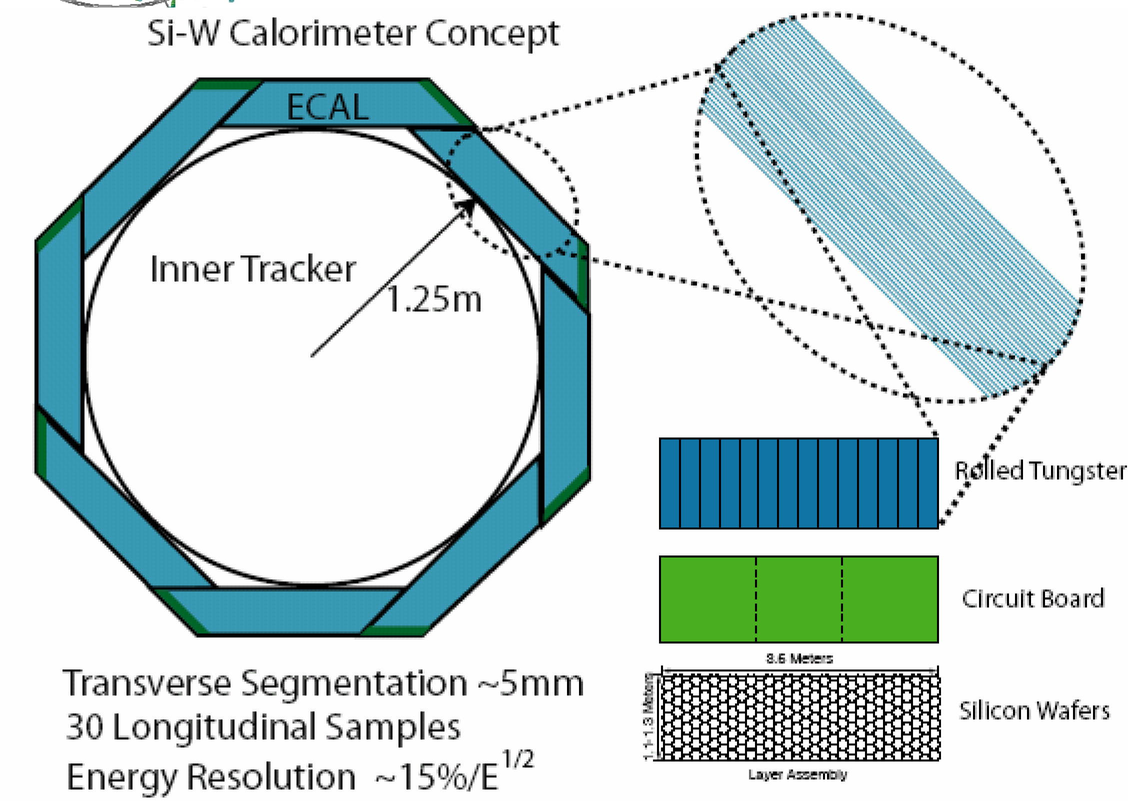
- **Figure of merit something like BR^2/σ,**
  - **where $\sigma = 4\ r_{pixel} \oplus r_{Moliere}$**

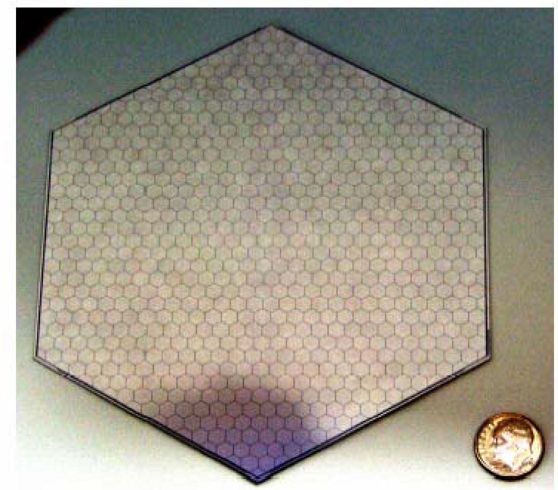
- **Maintain the excellent Moliere radius of tungsten (9.5 mm) by minimizing the gaps between ~2.5 mm tungsten plates. Dilution is $(1+R_{gap}/R_w)$**

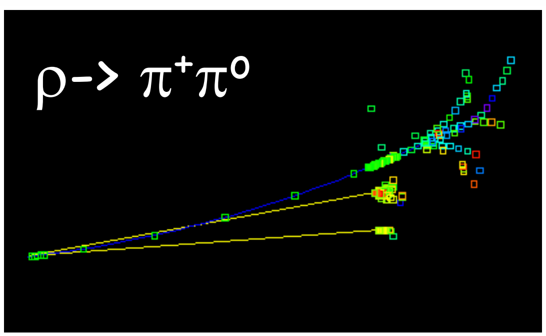
- **Requires *aggressive* electronic-mechanical integration!**



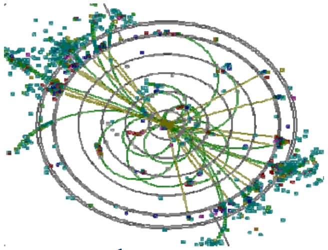
Silicon/Tungsten EM Calorimeter







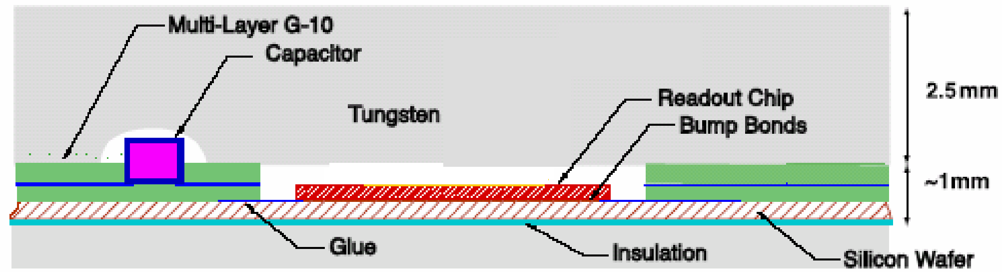
- **SLAC/Oregon/BNL**
- Conceptual design for a dense, fine grained silicon tungsten calorimeter well underway
- First silicon detector prototypes are in hand
- Testing and electronics design well underway
- Test bump bonding electronics to detectors by end of ’05/early ‘06
- Test Beam begins in ’06



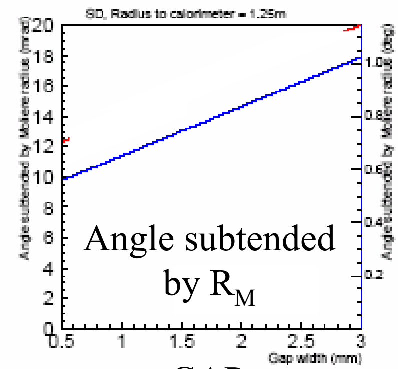
Silicon/Tungsten EM Calorimeter

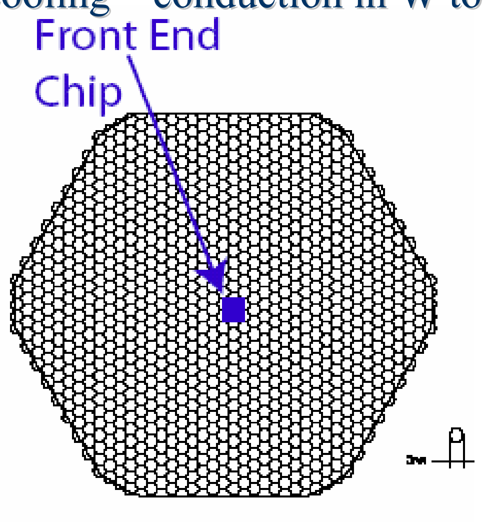
- Pads ~5 mm to match Moliere radius
- Each six inch wafer read out by one chip
- < 1% crosstalk
- Electronics design
- Single MIP tagging (S/N ~ 7)
- Timing < 200 nsec/layer
- Dynamically switchable feedback capacitor scheme (D. Freytag) achieves required dynamic range: 0.1-2500 MIPs
- 4 deep buffer for bunch train
- Passive cooling – conduction in W to edge

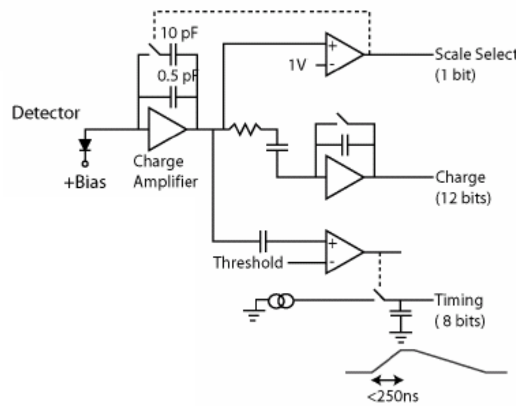
Critical parameter: minimum space between tungsten layers.



Config.	Radiation length	Molière Radius
100% W	3.5mm	9mm
92.5% W	3.9mm	10mm
+1mm gap	5.5mm	14mm

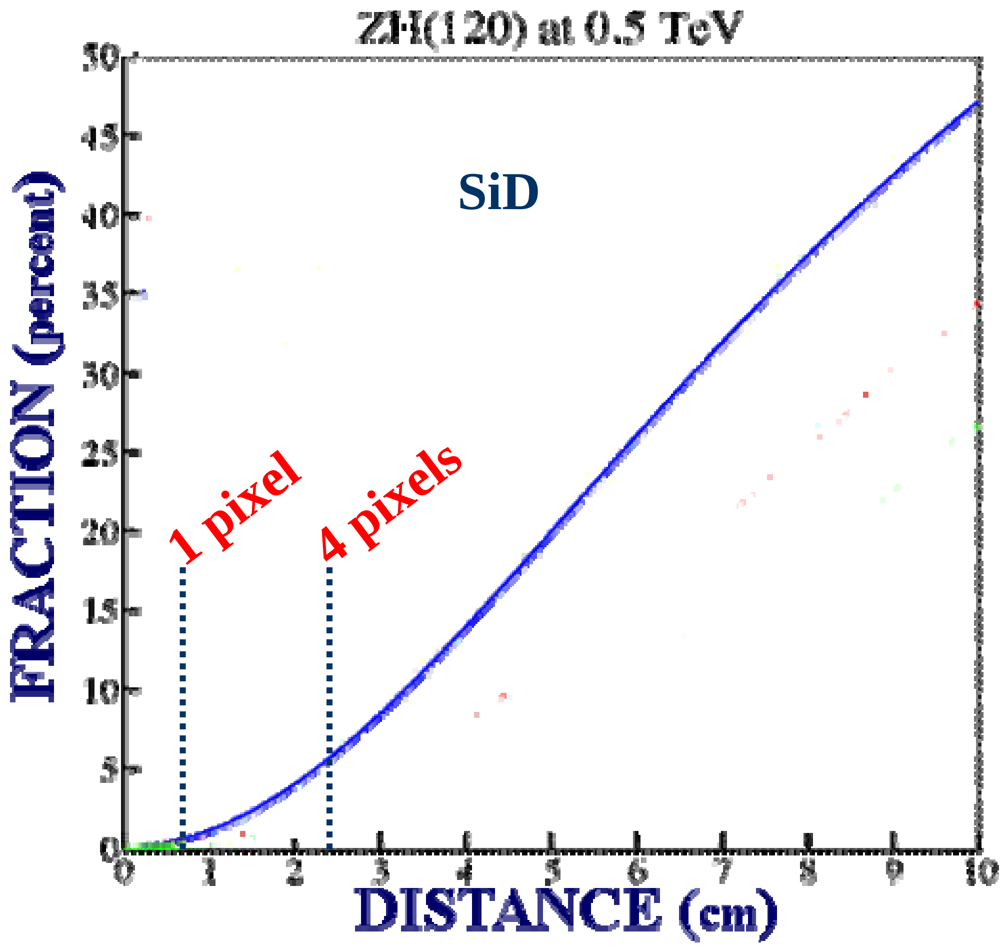


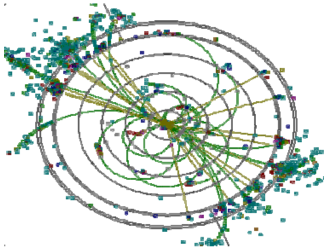




Isolation of Photons

Fraction of the photon(s) energy per event , closer to a charged track than some distance





Hadron Calorimetry

- **Role of Hadron Calorimetry in the Energy/Particle Flow**
  - **Isolate and measure neutral hadrons**

- **Approaches**

  Technology
  - **RPCs**
  - **GEMs**
  - **Tile-fiber w/ APD SiPM HPD EBCCD**
  - **Scintillator strips**

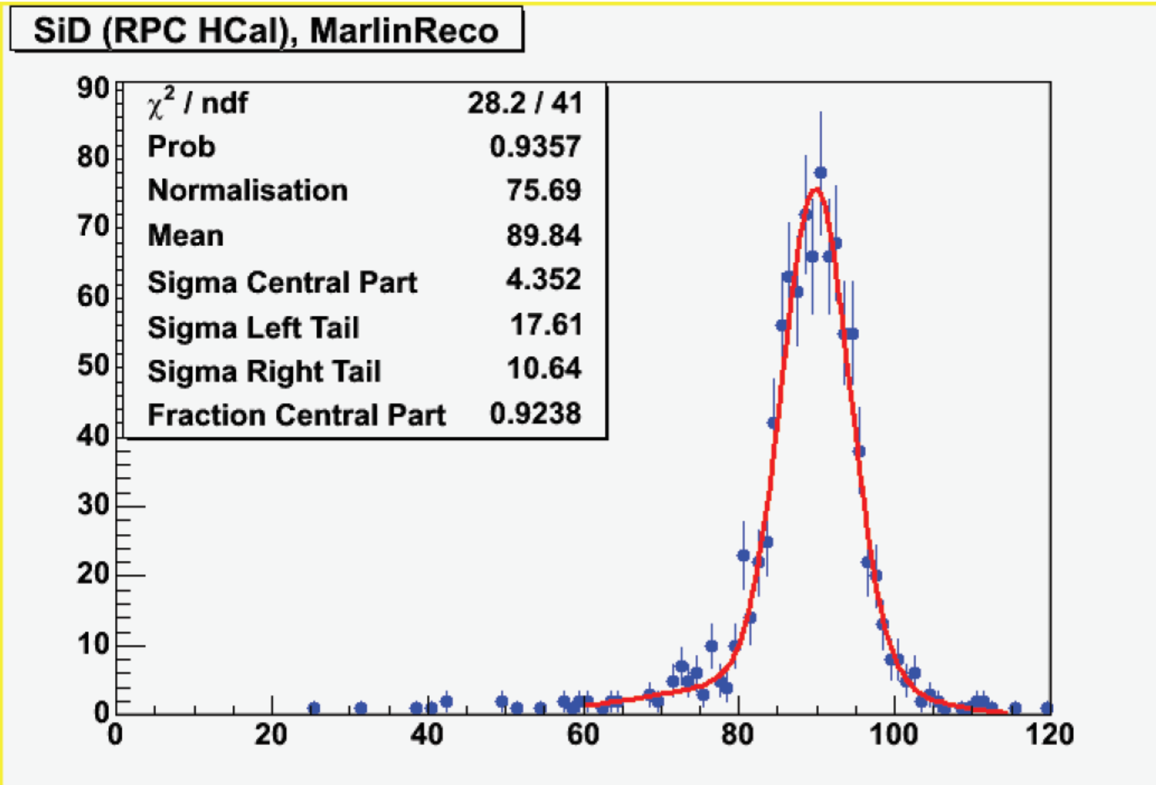
  Readout
  - **Analog**
  - **Digital – high granularity**

Hadron Calorimetry (~4λ)

Considering several options for HCal: SS or Tungsten / 3 readout technologies

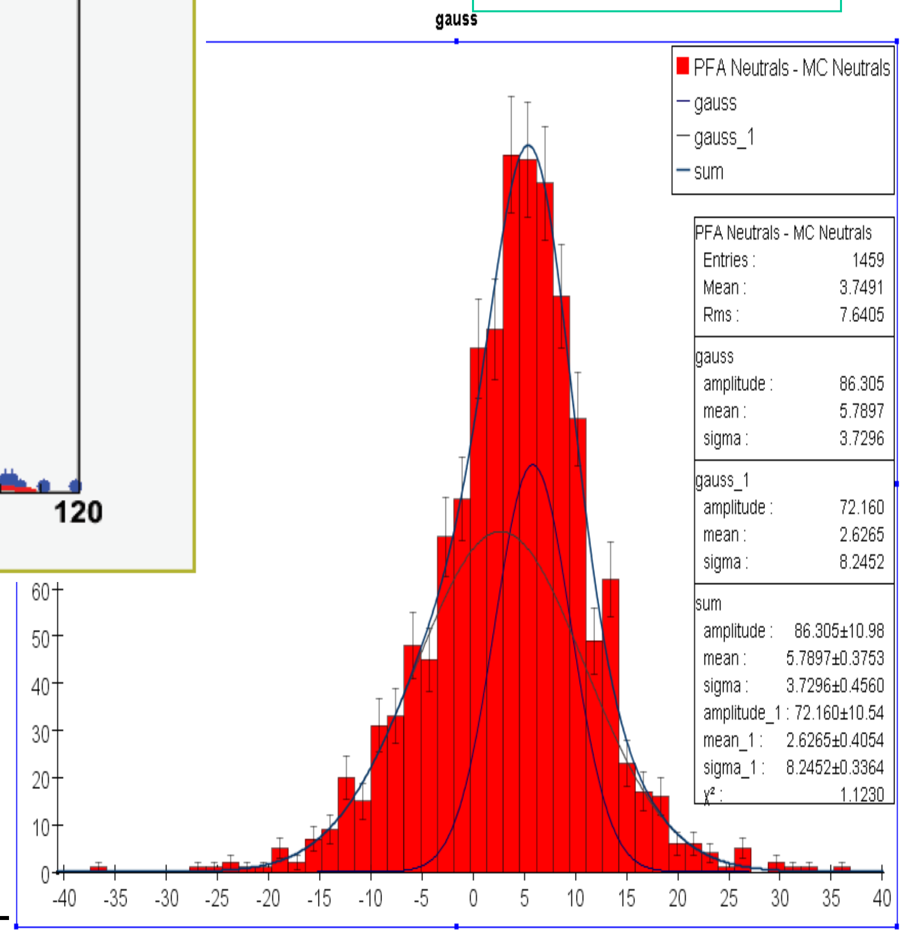
	Scintillator	GEMs	RPCs
Technology	**Proven (SiPM?)**	**Relatively new**	**Relatively old**
Electronic readout	**Analog (multi-bit) or Semi-digital (few-bit)**	**Digital (single-bit)**	**Digital (single-bit)**
Thickness (total)	**~ 8mm**	**~8 mm**	**~ 8 mm**
Segmentation	**3 x 3 cm^2**	**1 x 1 cm^2**	**1 x 1 cm^2**
Pad multiplicity for MIPs	**Small cross talk**	**Measured at 1.27**	**Measured at 1.6**
Sensitivity to neutrons (low energy)	**Yes**	**Negligible**	**Negligible**
Recharging time	**Fast**	**Fast?**	**Slow (20 ms/cm^2)**
Reliability	**Proven**	**Sensitive**	**Proven (glass)**
Calibration	**Challenge**	**Depends on efficiency**	**Not a concern (high efficiency)**
Assembly	**Labor intensive**	**Relatively straight forward**	**Simple**
Cost	**Not cheap (SiPM?)**	**Expensive foils**	**Cheap**

Calorimetry - PFA's applied to SiD_{00}



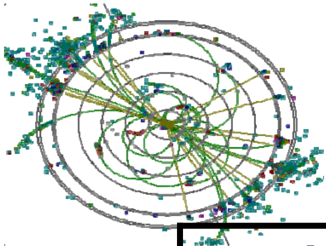
A. Respereza

S. Magill



Note: Z→u,d,s

Area of intense work in SiD



PFA activities

Photons:

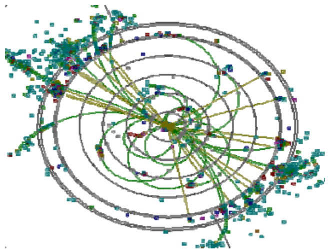
MST clustering (follow up with H-matrix id?)	N. Meyer, Iowa
H-matrix id development	N. Graf, SLAC
H-matrix id (preceded by n-n'bor clustering) Photon sep ⇒pi0 kinematic fit ⇒ improved res. !	G. Wilson, E. Benavidez, Kansas
H-matrix based id	S. Kuhlmann, S. Magill, ANL

hadrons:

MST clustering and fragments association	M. Charles, Iowa
density-weighted clustering	Lei Xia, ANL
density-weighted clustering	V. Zutshi, G. Lima, NIU
Neural-net based id – 15 discriminators – based on Bower, Cassel, Pathek NN	S. Kuhlmann, S. Magill, ANL

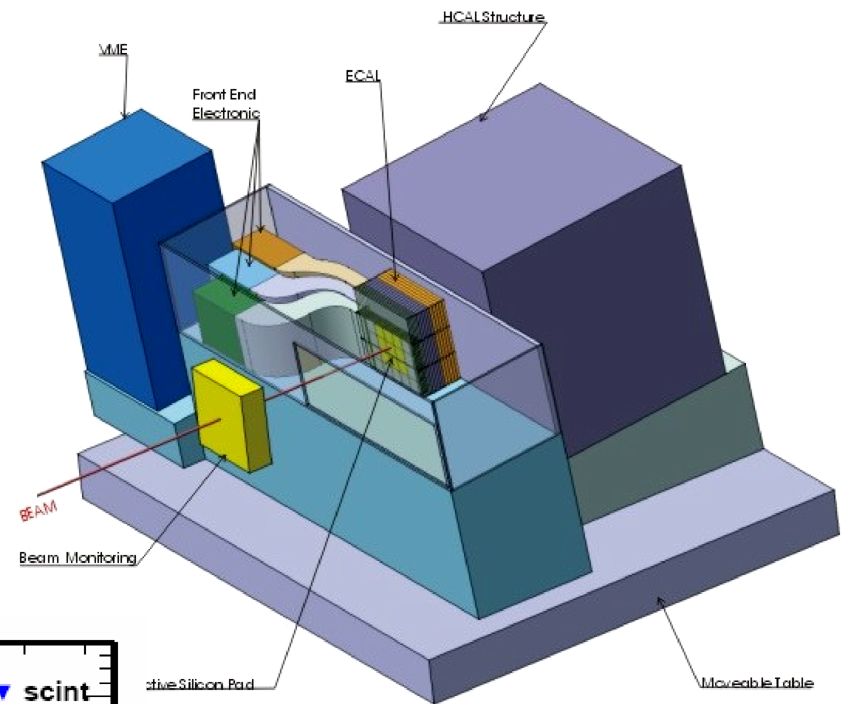
Full PFA's under development for SiD:

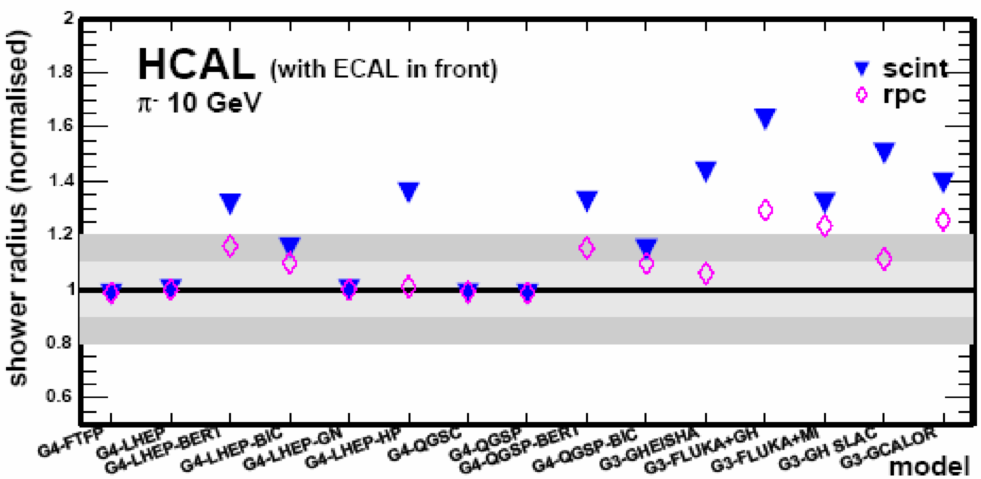
- ANL, SLAC – Magill, Graf, Cassell, Kuhlmann
    - H-matrix, track extrapolation, and nearest n'bor had. clust.
- ANL – Lei Xia – cluster based
- NIU – Chakraborty, Lima, Zutshi – cluster based



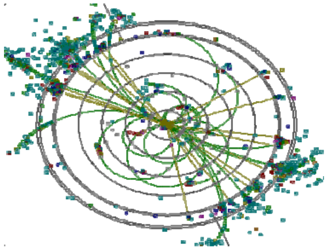
Digital Hadron Calorimetry

- **1 m^3 prototype proposed to test concept**
  - Lateral readout segmentation: 1 cm^2
  - Longitudinal readout segmentation: layer-by-layer
  - Gas Electron Multipliers (GEMs) and Resistive Plate Chambers (RPCs) evaluated
- **Objectives**
  - Validate RPC approach (technique and physics)
  - Validate concept of the electronic readout
  - Measure hadronic showers with unprecedented resolution





Argonne National Laboratory
Boston University
University of Chicago
Fermilab
University of Texas at Arlington

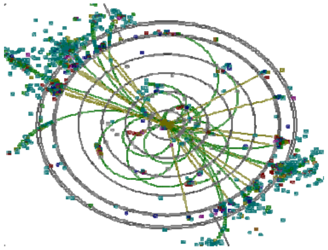


Tracking

- Tracking for SiD is conceived as an integrated system, combined optimization of:
  - the inner tracking (vertex detection)
  - the central tracking
  - the forward tracking
  - the integration of the 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 being planned for the linear collider

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



Inner Tracking/Vertex Detection

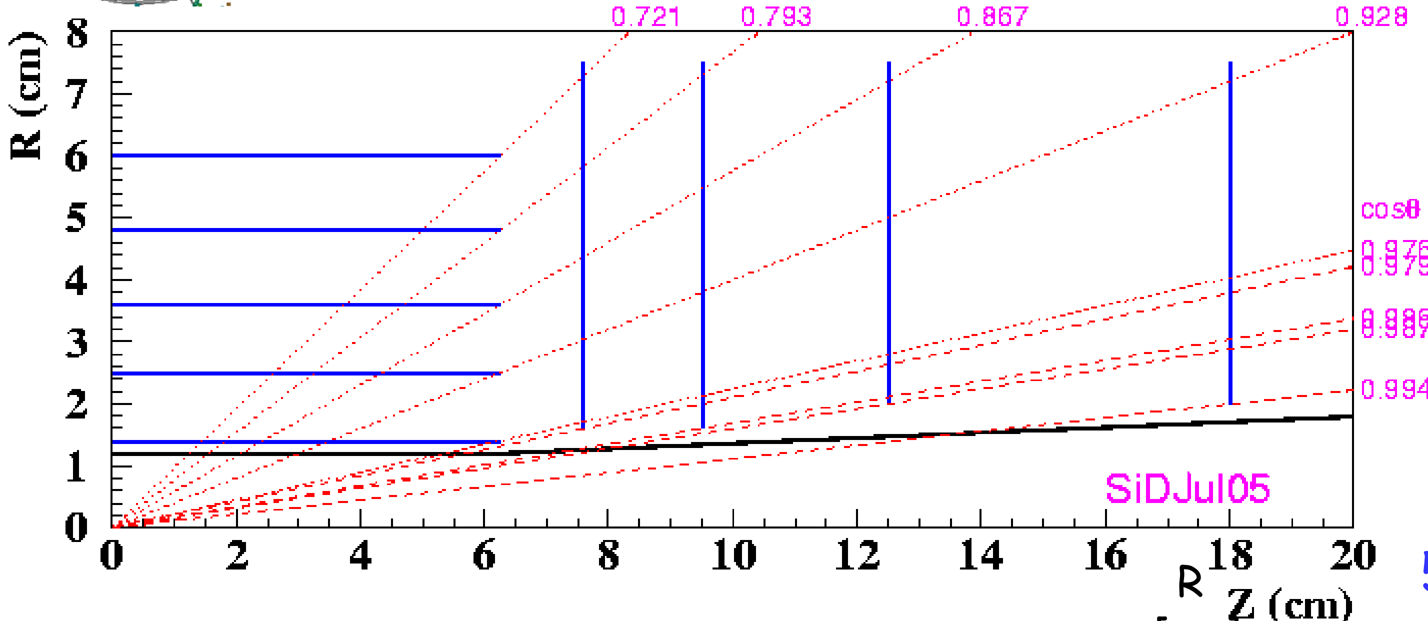
Detector Requirements

- Excellent spacepoint precision (**< 4 microns**)
- Superb impact parameter resolution (**5μm ⊕ 10μm/(p sin$^{3/2}$θ)**)
- Transparency **(~0.1% X_0 per layer**)
- Track reconstruction (**find tracks in VXD alone**)

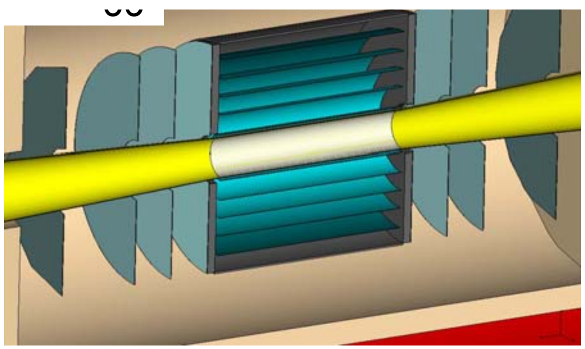
Concepts under Development for International Linear Collider

- Charge-Coupled Devices (CCDs)
  - demonstrated in large system at SLD, but slow
- Monolithic Active Pixels – CMOS (MAPs)
- DEpleted P-channel Field Effect Transistor (DEPFET)
- Silicon on Insulator (SoI)
- Image Sensor with In-Situ Storage (ISIS)
- HAPS (Hybrid Pixel Sensors)
- Macro/Micro Pixel Arrays

SiD Vertex Layout

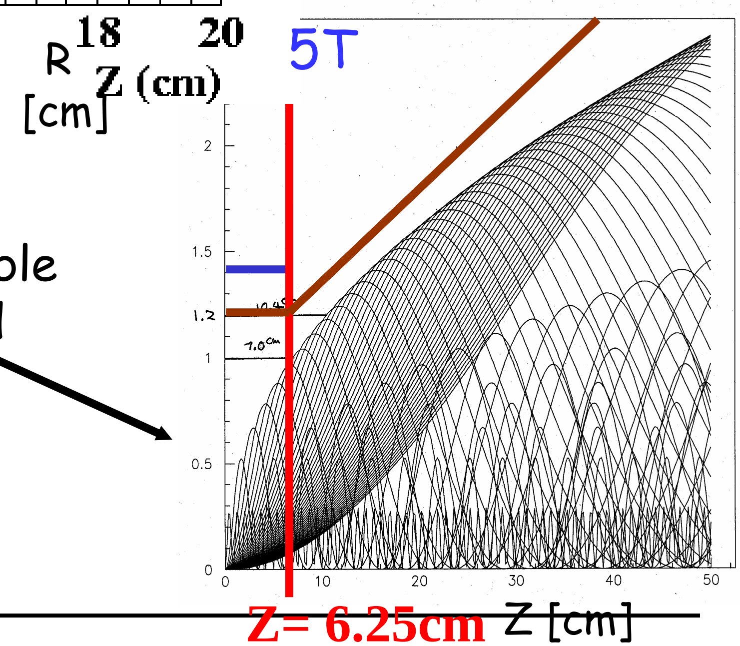


5 barrel layers
4 end disks



Design drivers:

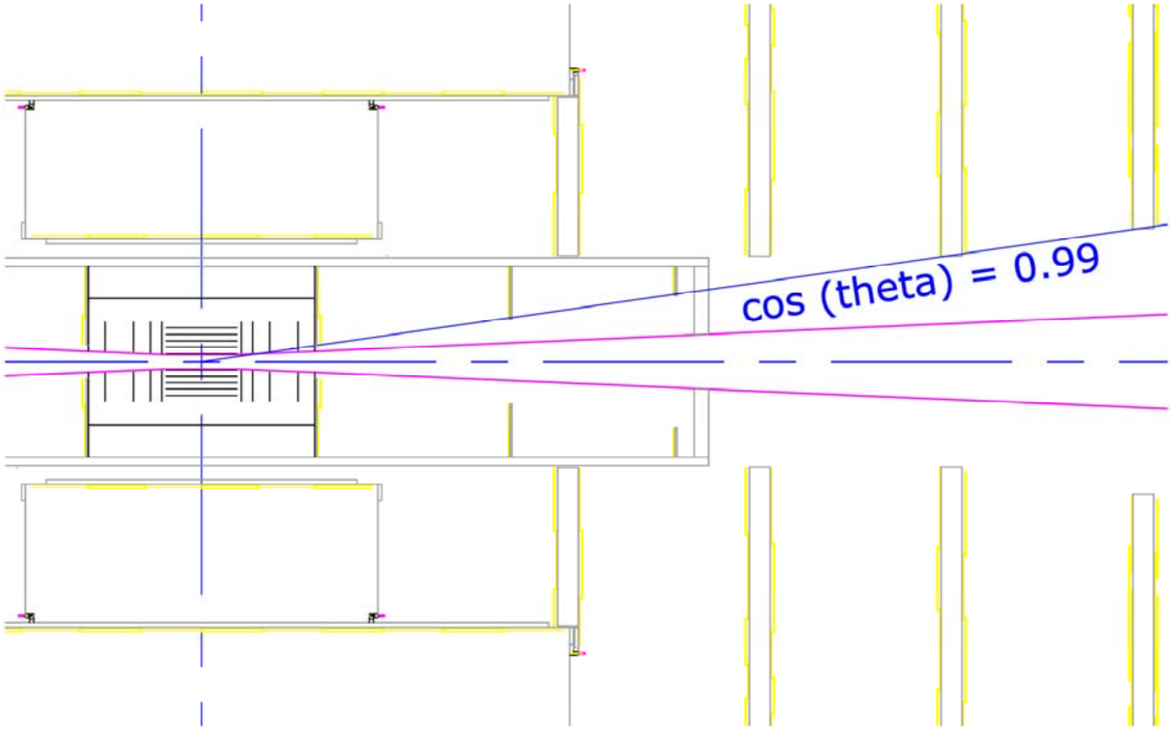
Smallest radius possible
Clear pair background



Role:
Seed tracks & vertexing
Improve forward region

Work on mechanical layout of VXD

Vertex Detector Support



Issues considering:

- Thickness and mechanical design of endplate & support
- Sensor technology (several being pursued by many groups)
- Increase # layers by 1 in barrel & endcap

Inner Tracking/Vertex Detection (CCDs)

Issues

- Readout speed and timing
- Material budget
- Power consumption
- Radiation hardness

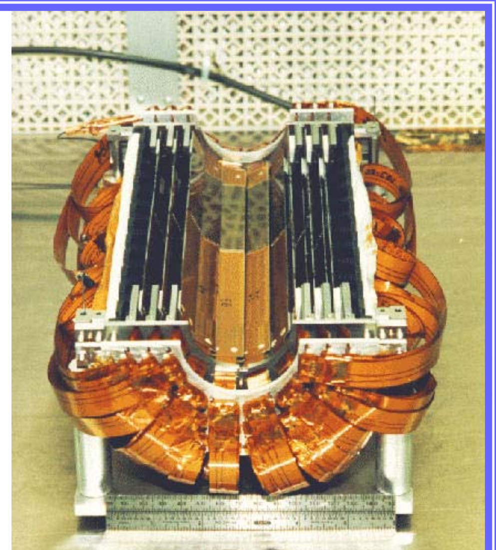
R&D

- Column Parallel Readout
- ISIS
- Radiation Damage Studies

SLD VXD3

307 Mpixels
5 MHz ⊗ 96 channels
0.4% X_0 / layer
~15 watts @ 190 K

3.9 μm point res.
av. - 2 yrs and 307 Mpxl



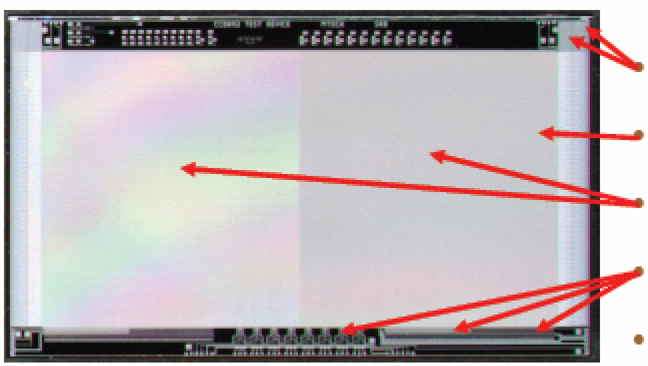
Column Parallel CCD

SLD Vertex Detector designed to read out
800 kpixels/channel at 10 MHz, operated at 5 MHz => readout time = 200 msec/ch

Linear Collider demands 250 nsec readout for Superconducting RF time structure

Solution: Column Parallel Readout

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

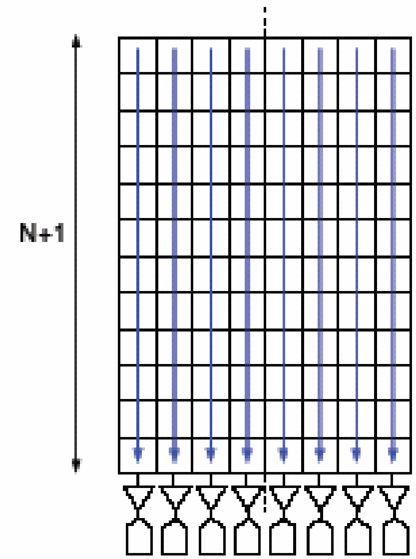


CPC1 produced by E2V

- **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**

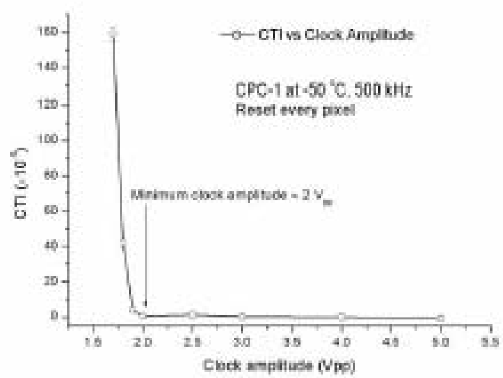


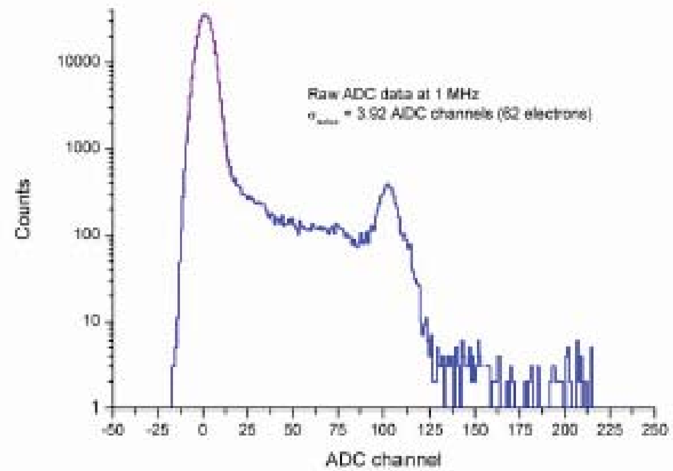
Column Parallel CCD
Readout time = $(N+1)/F_{out}$

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

Column Parallel CCD (2)

- Noise ~ 100 electrons (60 after filter)
- Minimum clock ~1.9 V





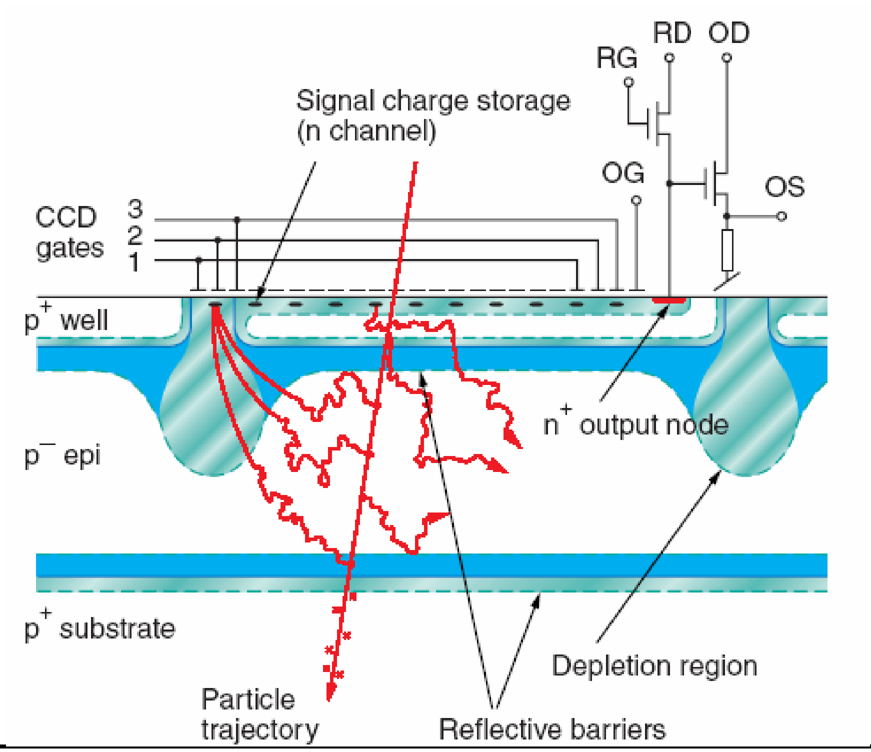
- Maximum frequency > 25 MHz
  - inherent clock asymmetry

Next Steps for LCFI R&D

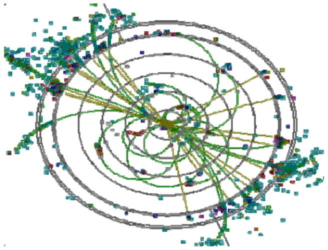
- Bump bonded assemblies
- Radiation effects on fast CCDs
- High frequency clocking
- Detector scale CCDs w/ASIC & cluster finding logic; design underway – production this year
- In-situ Storage Devices
  - Resistant to RF interference
  - Reduced clocking requirements

Image Sensor with In-situ Storage (ISIS)

- EMI is a concern (based on SLC experience) which motivates delayed operation of detector for long bunch trains, and consideration of ISIS
- Robust storage of charge in a buried channel during and just following beam passage (required for long bunch trains)
- 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.



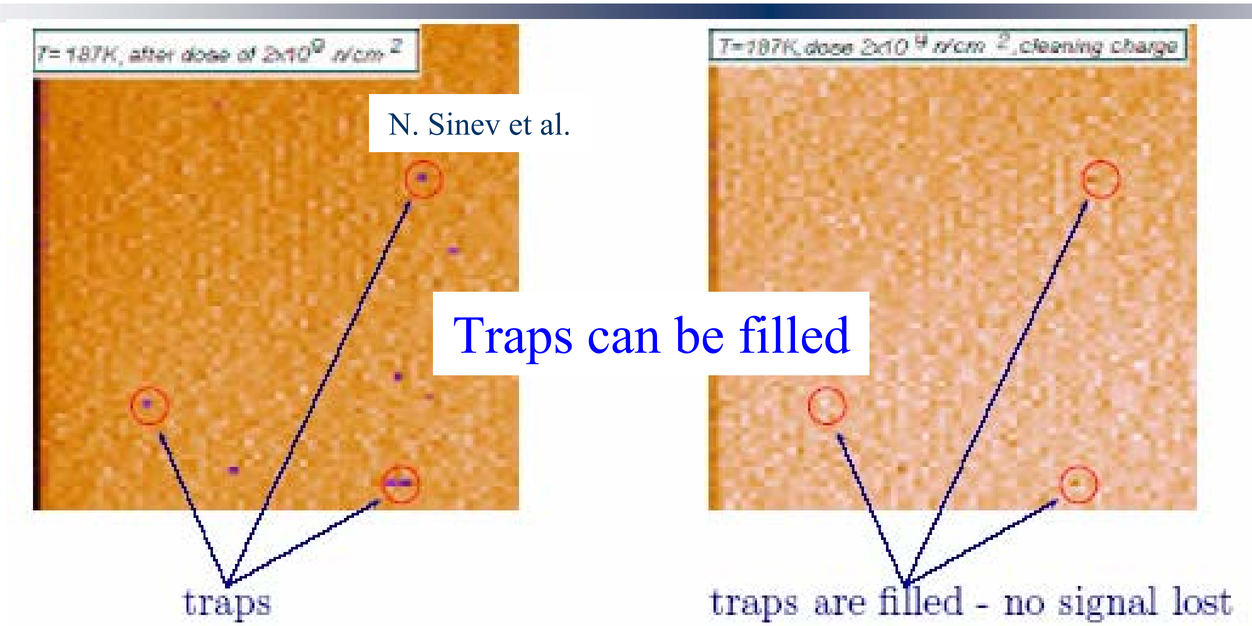
- charge collection to photogate from 20-30 μm silicon, as in a conventional CCD
- signal charge shifted into stor. register every 50μs, providing required time slicing
- string of signal charges is stored during bunch train in a buried channel, avoiding charge-voltage conversion
- totally noise-free charge storage, ready for readout in 200 ms of calm conditions between trains for COLD LC design
- particles which hit the storage register (~30% area) leave a small ‘direct’ signal (~5% MIP) – negligible or easily corrected



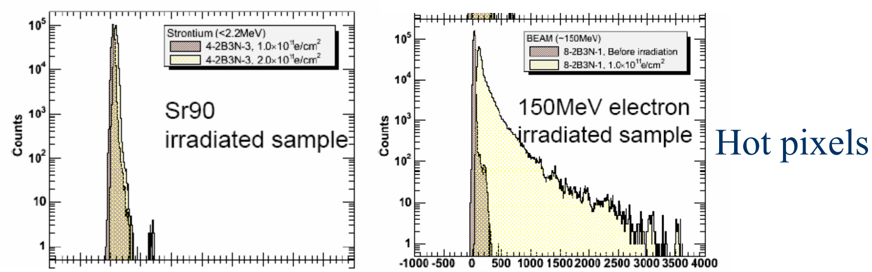
Radiation Effects in CCDs

Drift of charge over long distance in CCD makes detector very susceptible to effects of radiation:

- Transfer inefficiency
- Surface defects



- **neutrons induce damage clusters**
- **low energy electrons create point defects – but high energy electrons create clusters – Y. Sugimoto et al.**
- **number of effective damage clusters depends on occupation time – some have very long trapping time constants – modelled by K. Stefanov**



- **Expect ~$1.5 \times 10^{11}/cm^2/yr$ of ~20 MeV electrons at layer-1**
- **Expect ~$10^9/cm^2/yr$ 1 MeV-equivalent dose from extracted beamline**

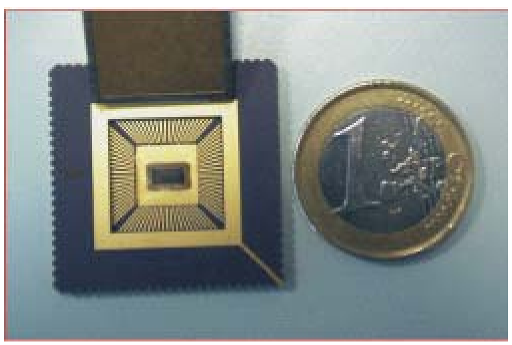
Inner Tracking/Vertex Detection (MAPs)

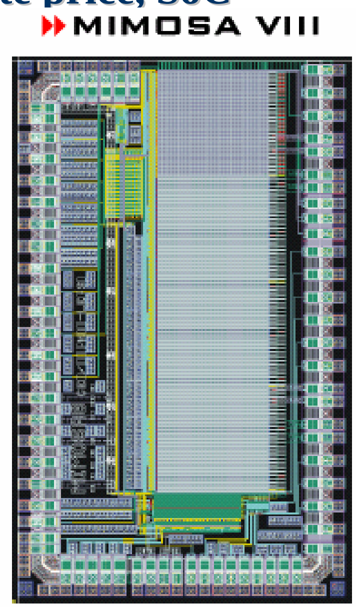
Concept

- **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, SoC**





R&D

- Strasbourg IReS has been working on development of monolithic active pixels since 1989; RAL also now.
- First IReS prototype arrays of a few thousands of pixels demonstrated the viability of technology and its high tracking performances.
- First large prototypes now fabricated and being tested.
- Current attention focussed on readout strategies adapted to specific experimental conditions.

Technology will be used at STAR

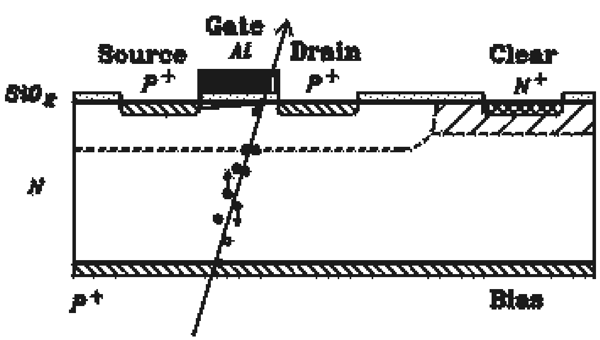
Parallel R&D: FAPS (RAL)

- 10-20 storage capacitors/pixel

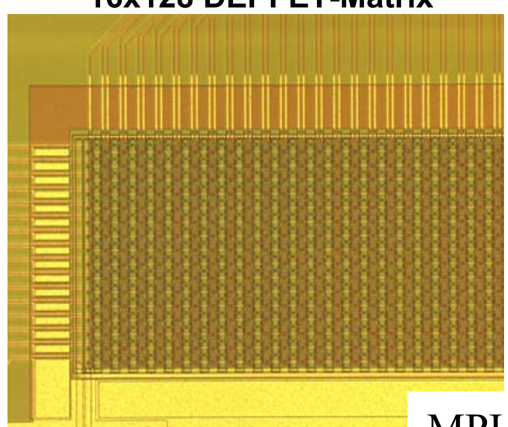
Inner Tracking/Vertex Detection (DEPFET)

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



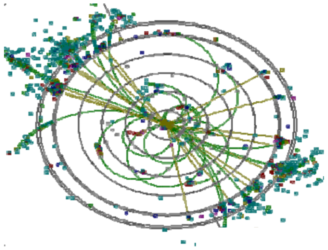
16x128 DEPFET-Matrix



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



CMOS Arrays

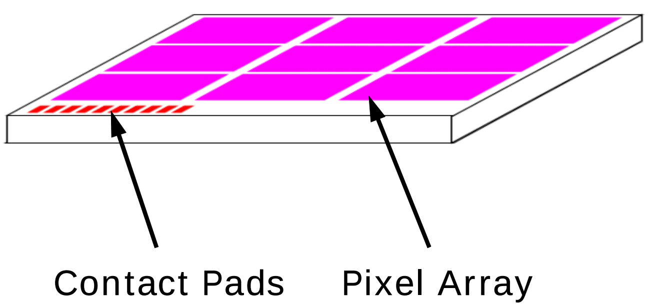
- Many vertex detector concepts being investigated.
- An example – macro/micro arrays. (Yale/Oregon/Sarnoff)

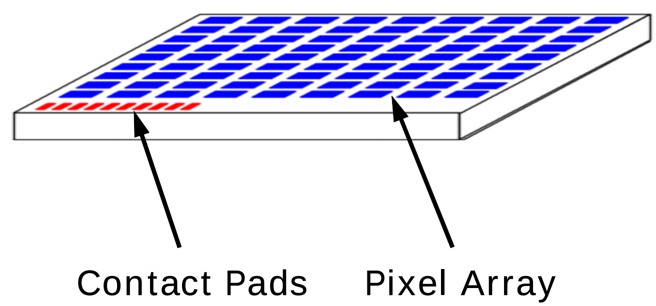
High-speed arrays

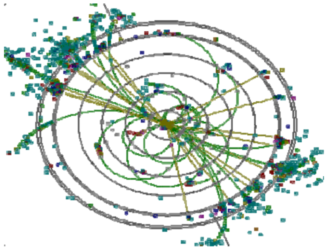
- Designed for quick response.
  - Threshold detection only.
  - Large pixels (~50 x 50 μm).
- Transmits X,Y location and time stamp of impact.

High-resolution arrays

- Designed for resolution and querying.
  - Smaller pixel size (~5 x 5 μm).
  - Random access addressability.
  - Records intensity.
- Provides intensity information only for pixel region queried.







Central Tracking (Silicon)

Expecting the machine backgrounds (esp. beam loss occurrences) of the ILC to be erratic (based on SLC experience),

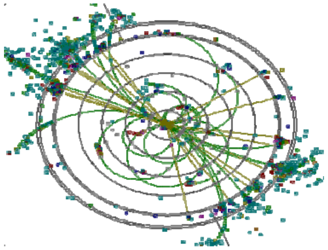
robustness of silicon is very attractive.

The barrel tracking is baselined as 5 layers of pixellated vertex detector and 5 layers of Si strip detectors (in ~10 cm segments) going to 1.25 m.

With superb position resolution, compact tracker is possible which achieves the linear collider tracking resolution goals

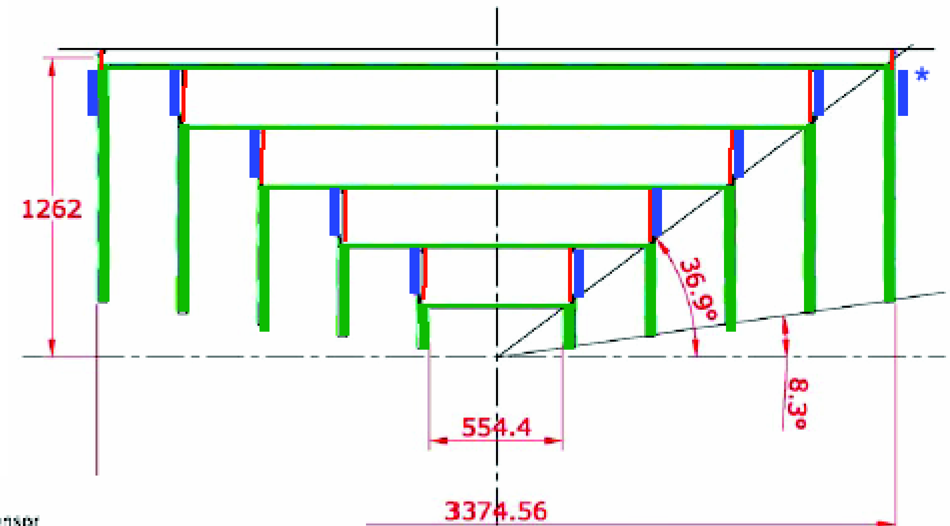
Compact tracker makes the calorimeter smaller and therefore cheaper, permitting more aggressive technical choices (assuming cost constraint)

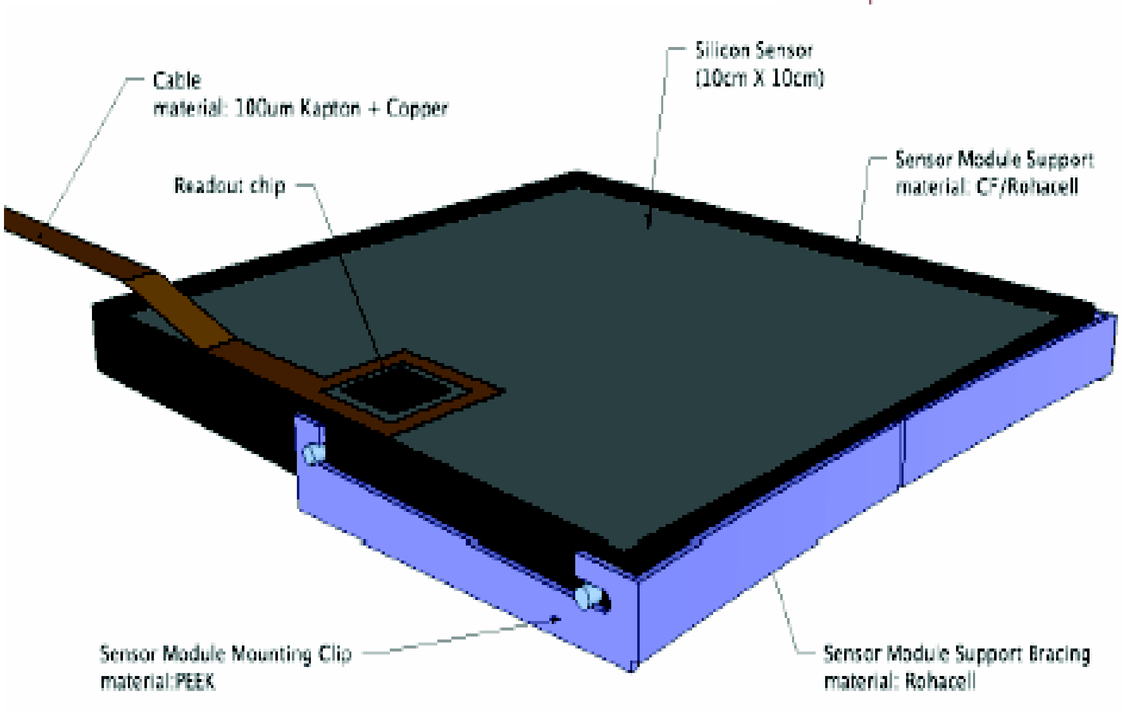
Silicon tracking layer thickness determines low momentum performance



SID$_{00}$ Tracking

- Closed CF/Rohacell cylinders
- Nested support via annular rings
- Power/readout motherboard mounted on support rings

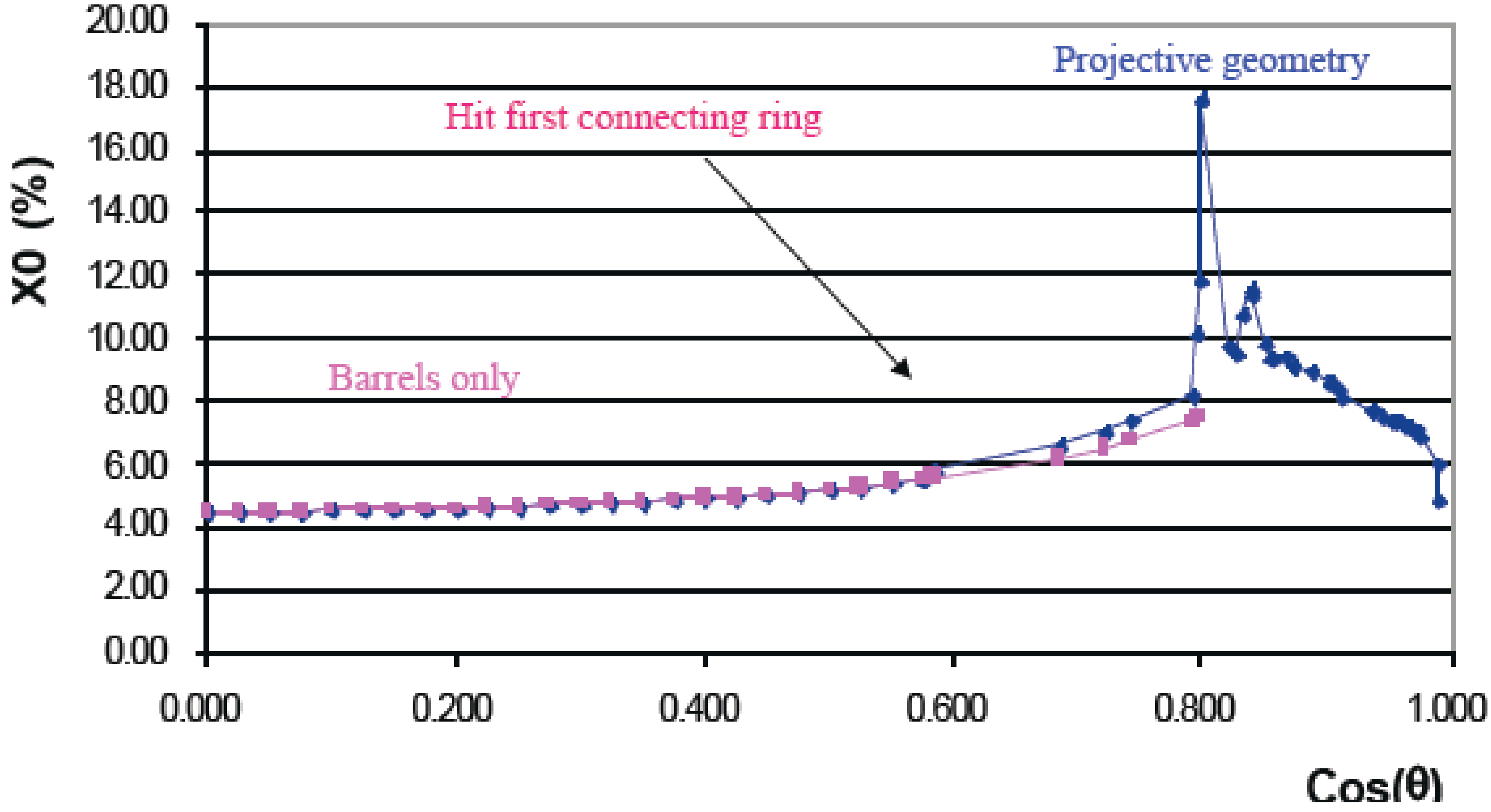


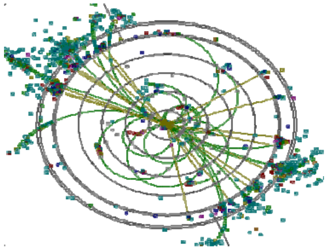


- Cylinders tiled with 10x10cm sensors with readout chip
- Single sided (ϕ) in barrel
- R, ϕ in disks
- Modules mainly silicon with minimal support (0.8% X_0)
- Overlap in *phi* and *z*

Material Budget of Tracker

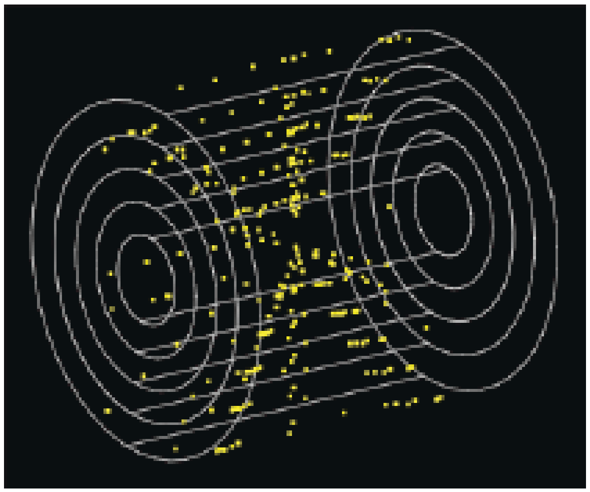
~ 0.8 %/layer at normal incidence

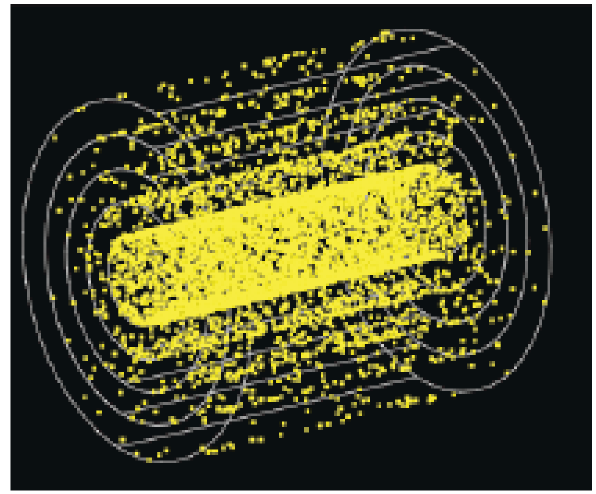




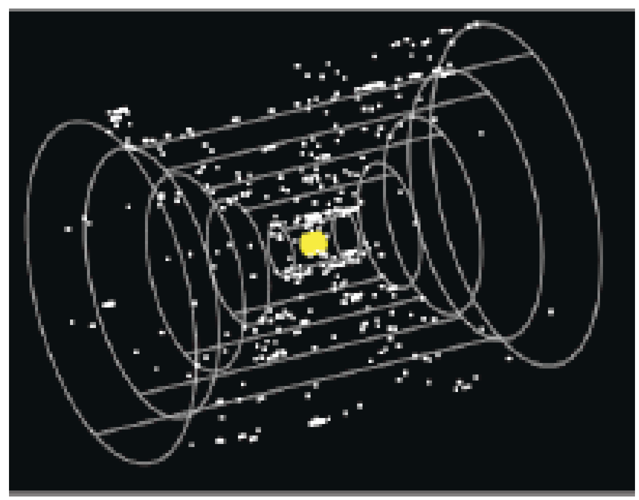
Robust Pattern Recognition

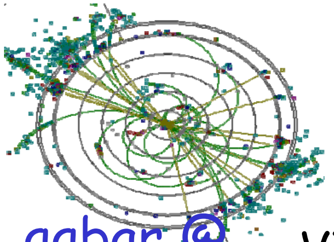
- t tbar event w/ backgrounds from 150 bunch crossings





clean detection with time stamping, even for 150 nsec spacing

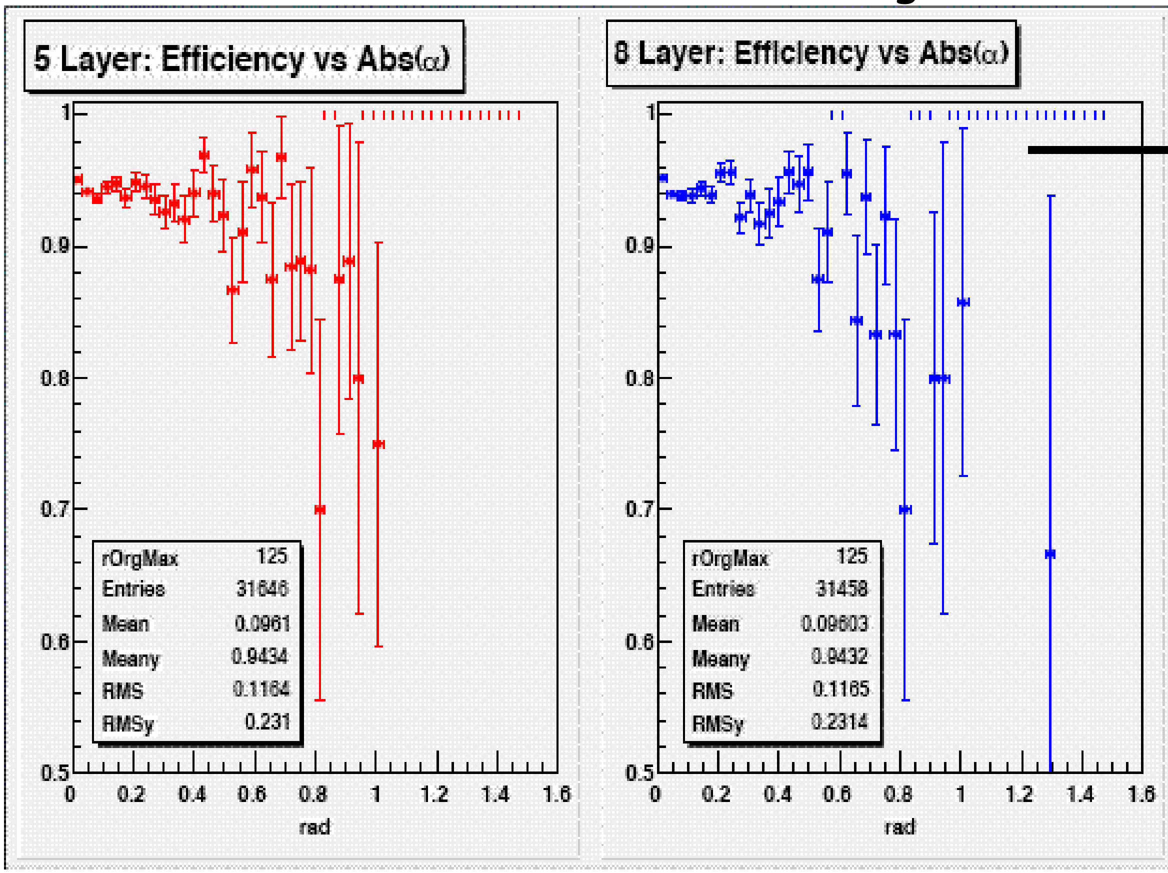




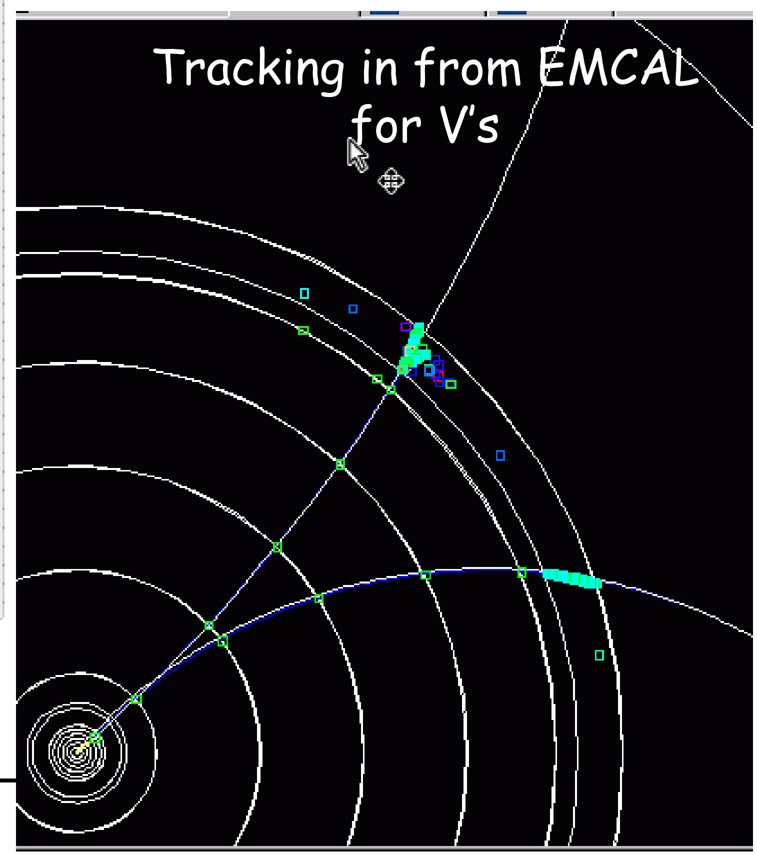
qqbar @ 500GeV

Tracking Reconstruction

VXD seeded tracking efficiency for 5 and 8 layer tracker as function of angle from Thrust axis.

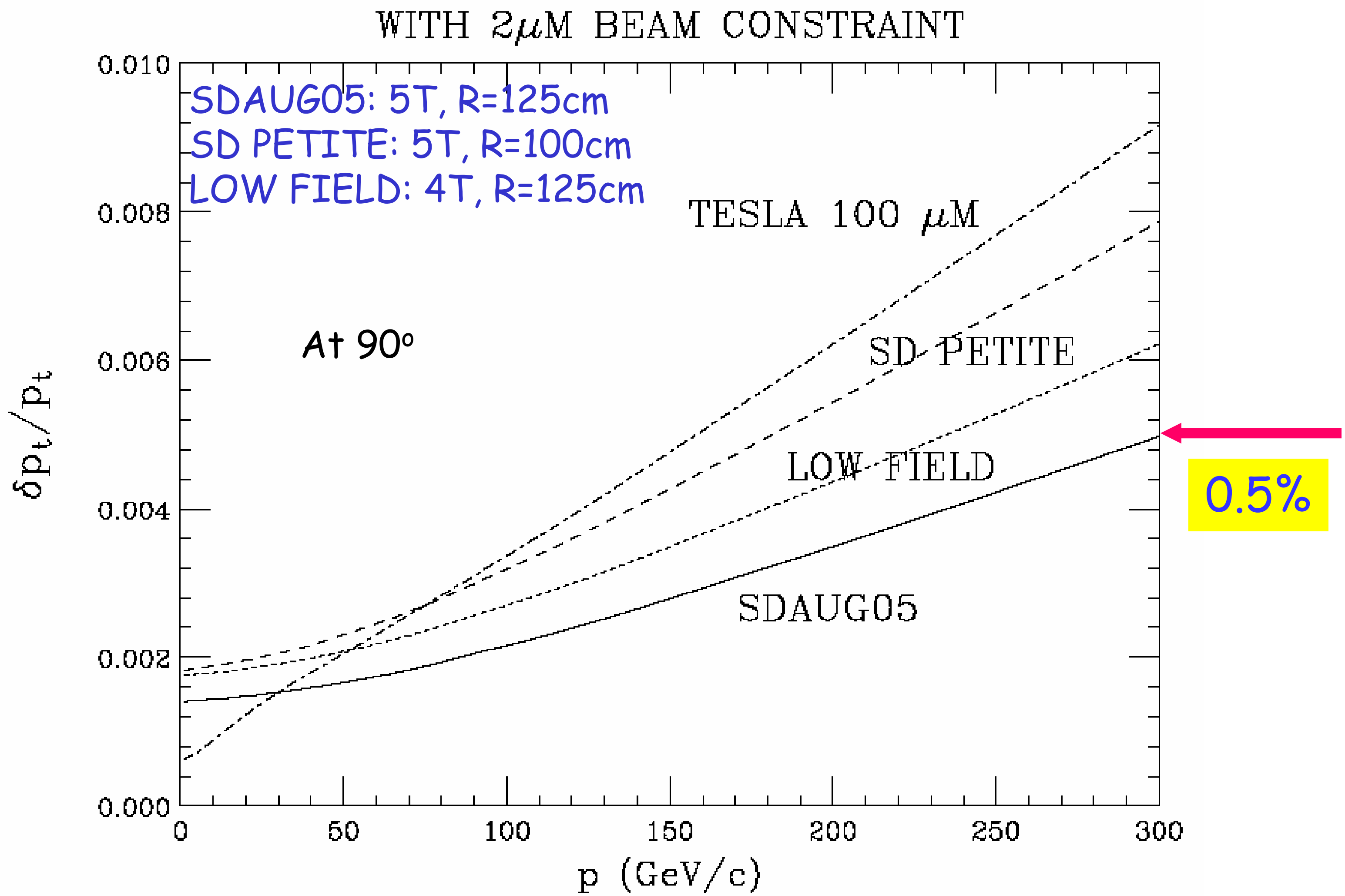


Use other track seeding for "missing" fraction (outside -in)



Many other studies; see summaries on SiD concept page

Excellent momentum resolution



Effect of Tracking Resolution

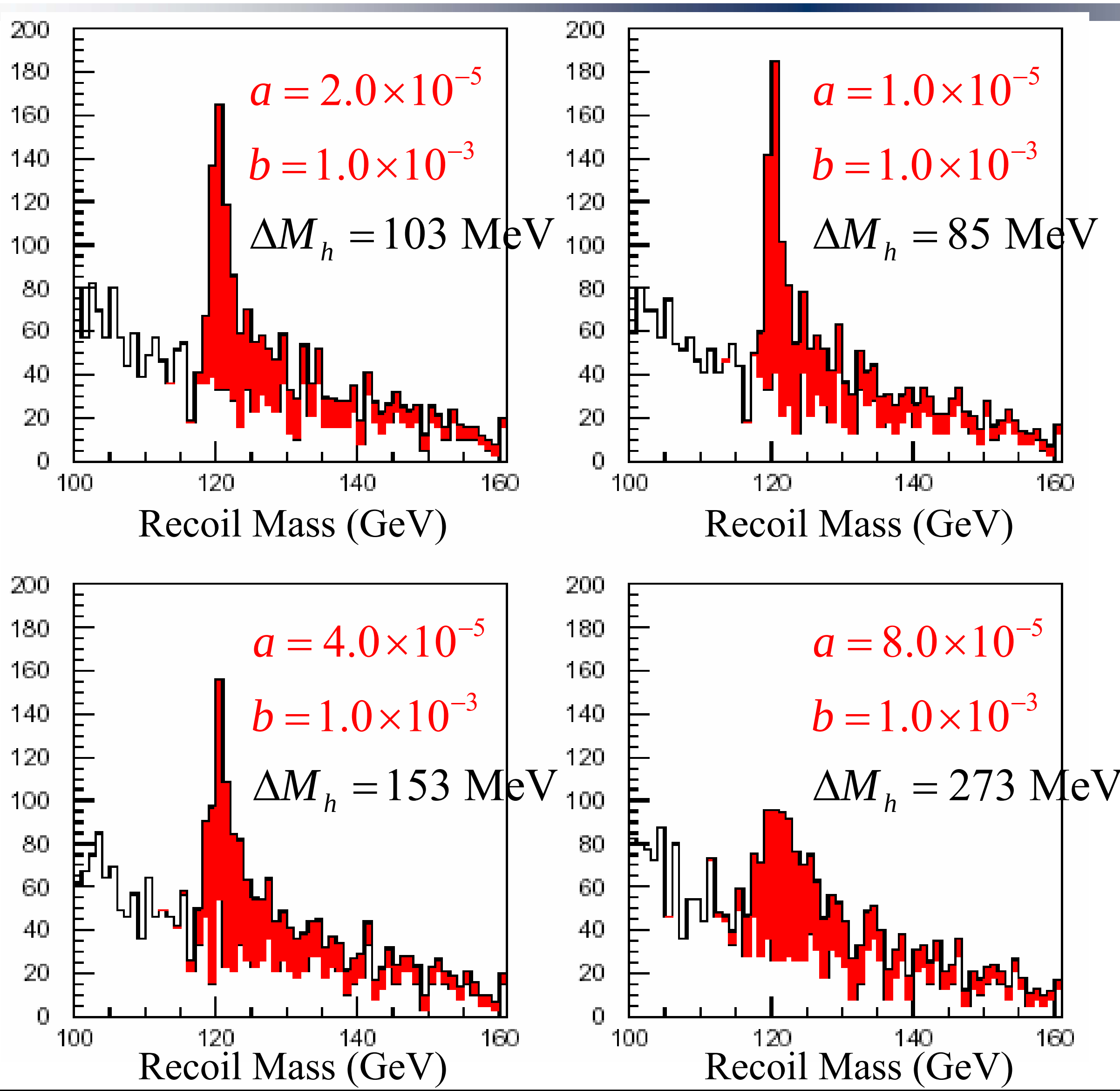
$$e^+e^- \rightarrow ZH$$

$$\rightarrow \mu^+\mu^- X$$

$$\sqrt{s} = 350\ GeV$$

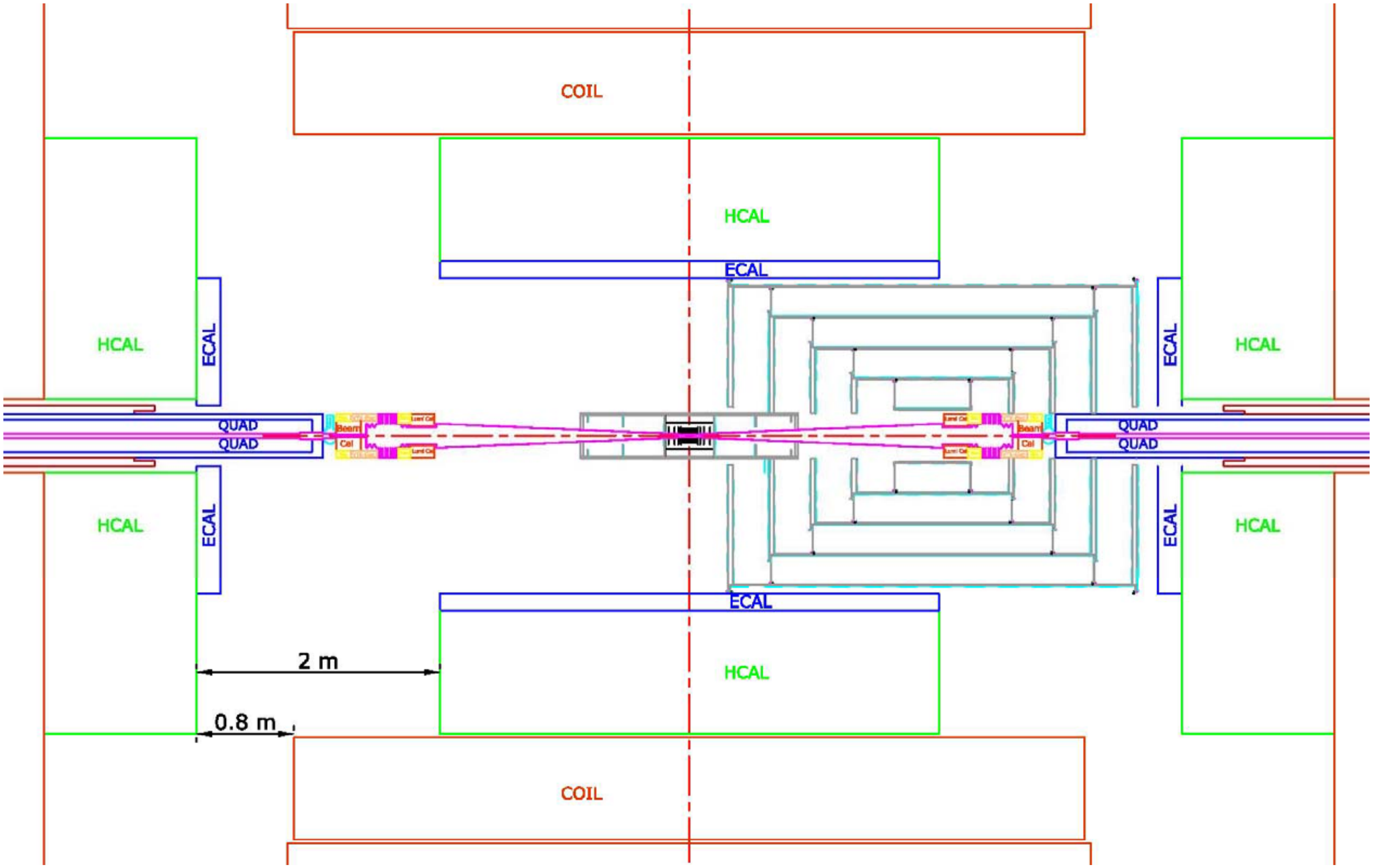
$$L = 500\ fb^{-1}$$

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

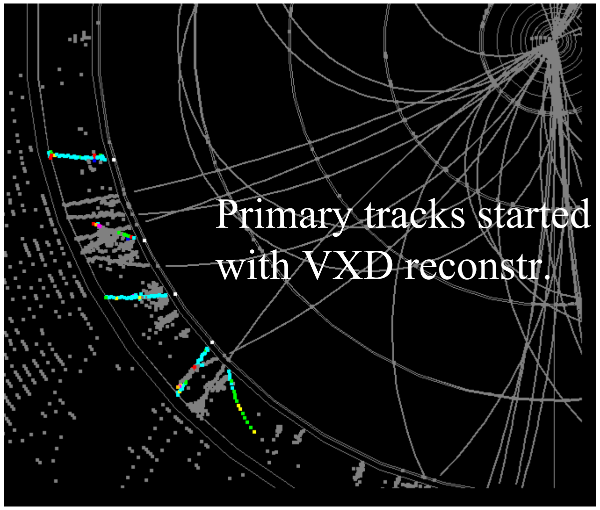


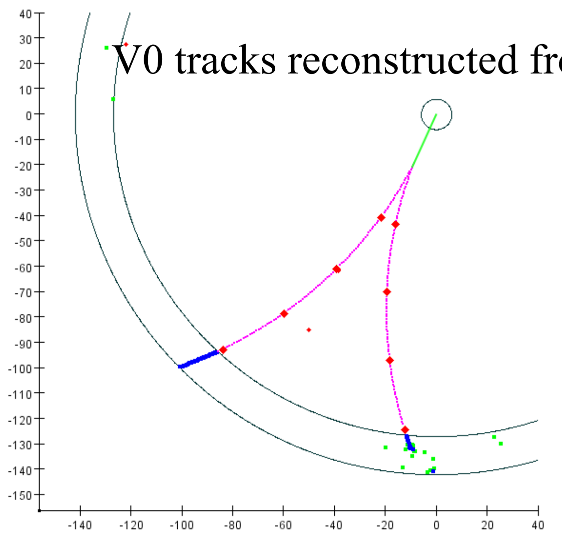
Tracking Access

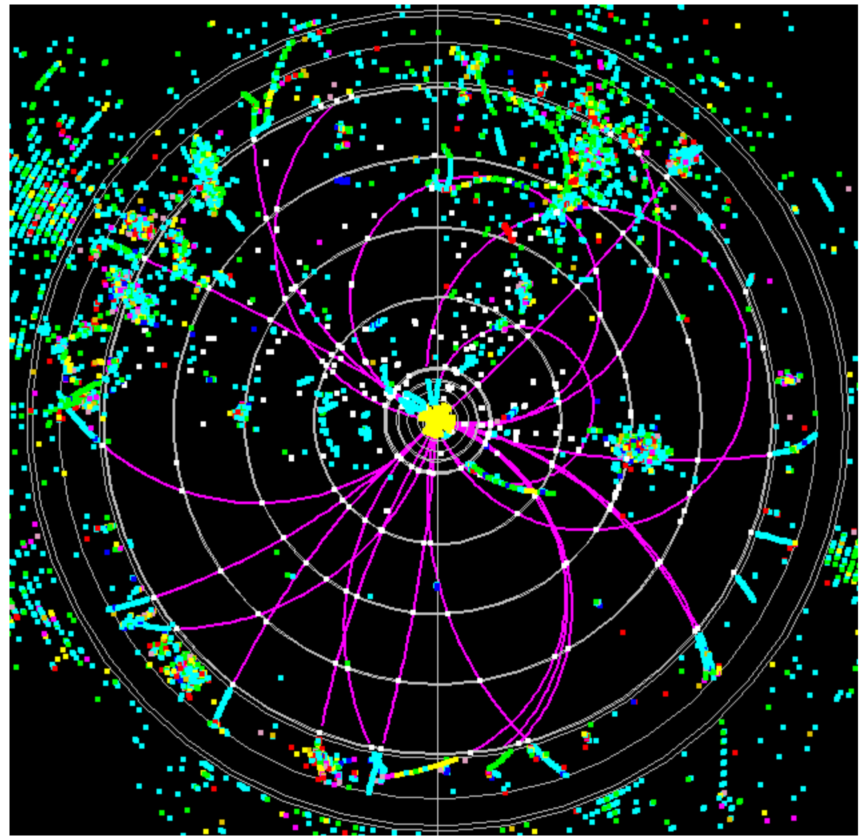
March '05 concept of open tracker; allow access to VXD



Silicon Tracking w/ Calorimeter Assist





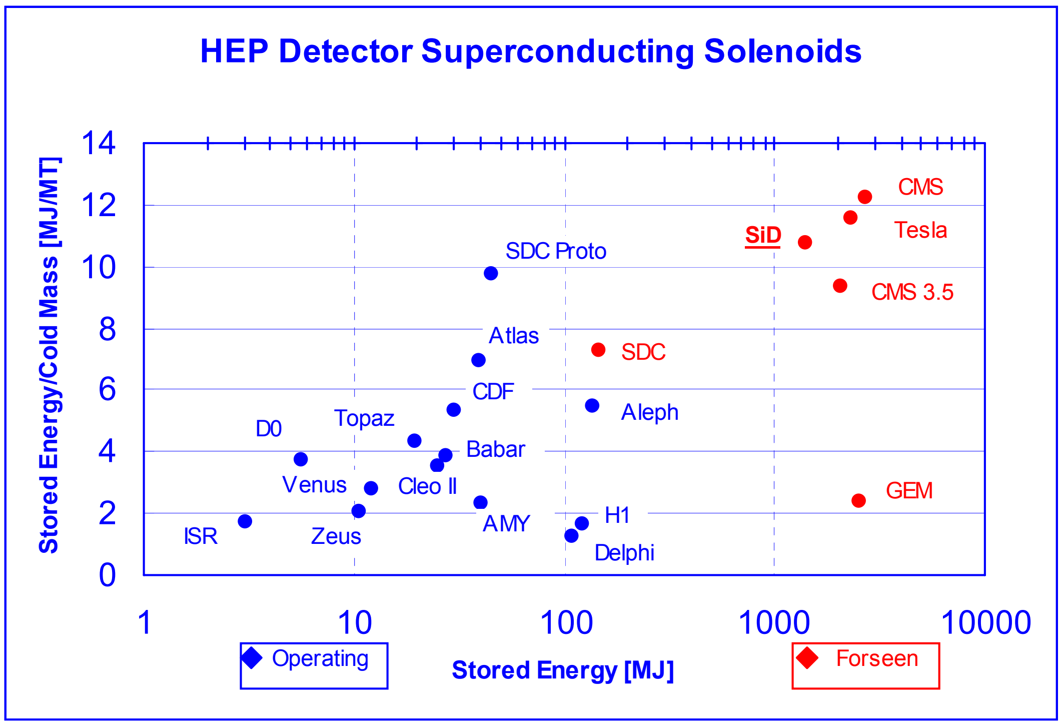


E. von Toerne

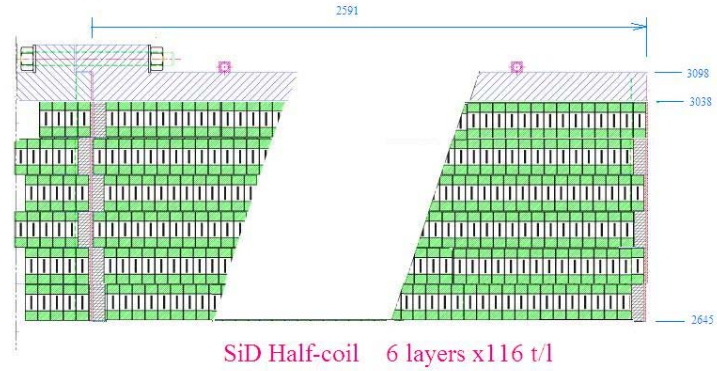
Solenoid

Radius: ~ 2.5m to ~3.32m, L=5.4m; Stored energy ~ 1.2 GJ

Feasibility study at Fermilab demonstrated that this 5T solenoid can be built, based on CMS design & conductor.



SiD coil



- **Same conductor as CMS**
- **CMS (4 layer)→ SiD (6 layer)**
- **CMS 5 modules 2.5 m long →SiD 2 modules 2.6 m long**

Stresses and forces comparable to CMS.

Solenoid

- ANSYS modeling of solenoid (2d, 3d)

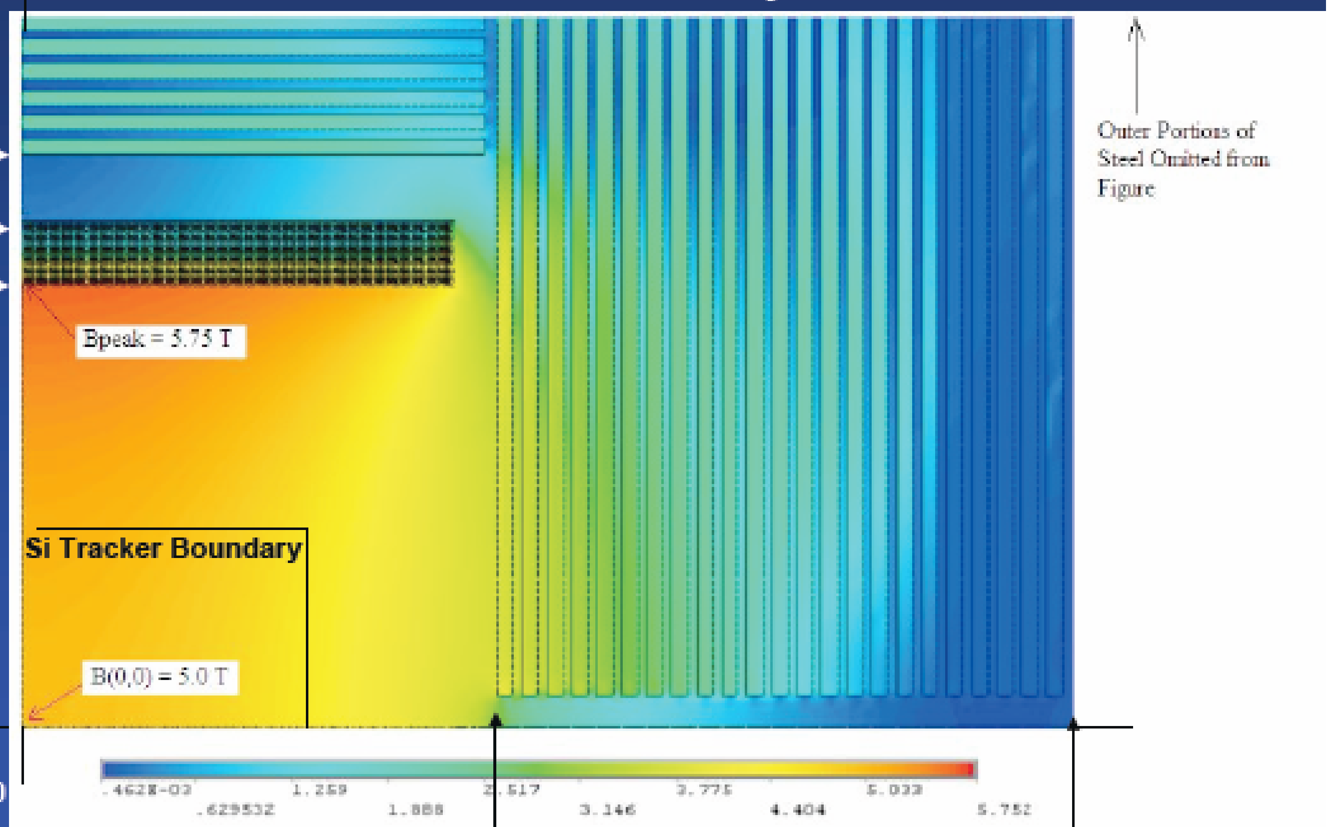
23 Layers Barrel Steel

23 Layers End Steel

R = 3428 mm

R_{out} = 3098 mm

R_{in} = 2645 mm



Z = 0

Z = 2847 mm

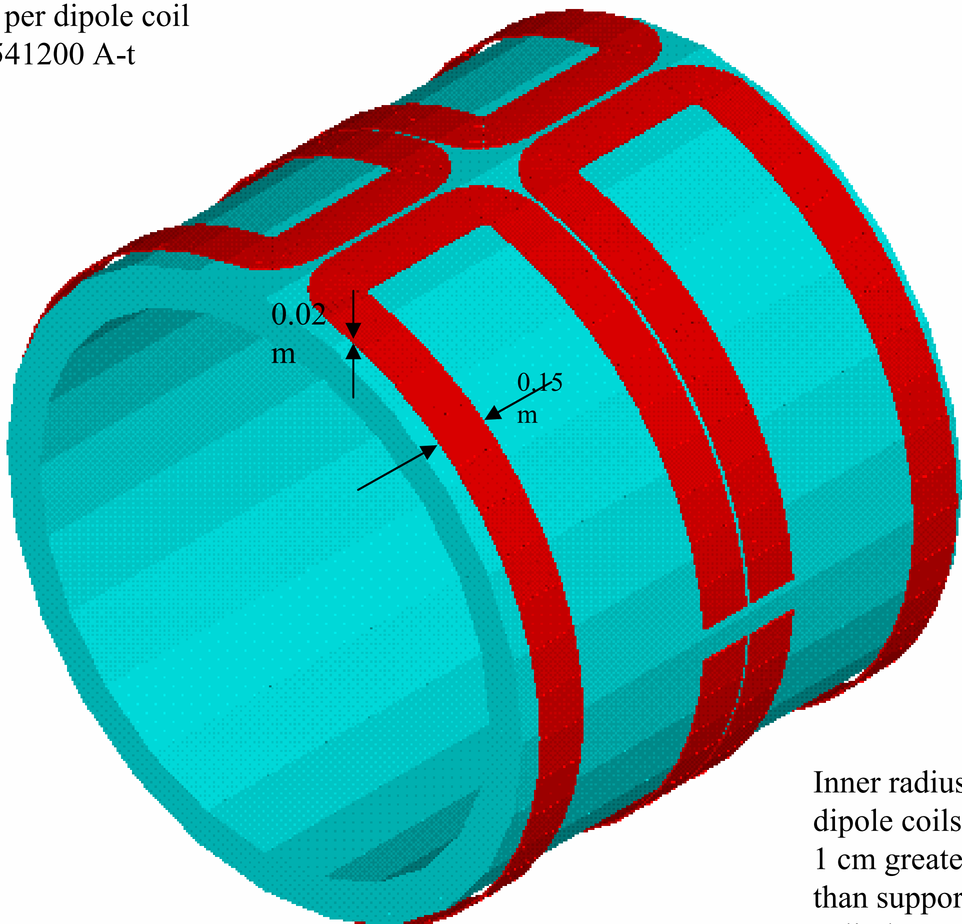
Z = 6247 mm

Solenoid next steps

Provides field maps for SiD and for MDI questions

Design of Detector-Integrated-Dipole (DID) for beam X-angle 9-20mrad)

NI per dipole coil
= 541200 A-t



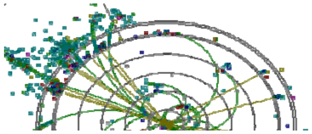
Inner radius of dipole coils is 1 cm greater than support cylinder radius

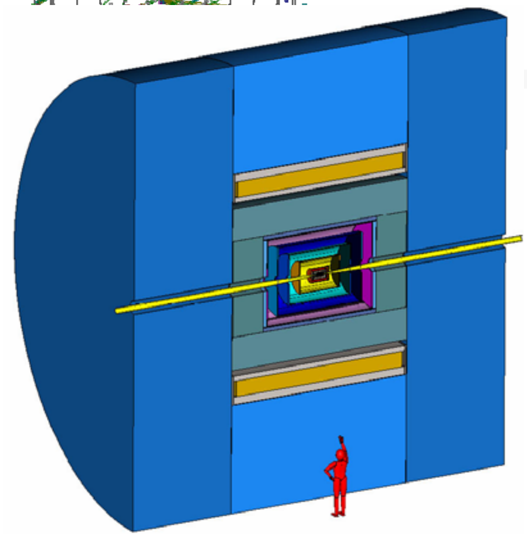
Wrap saddle coils on support cylinder

Provides required field

Forces are manageable

Developing parametric cost model based on CMS cost; solenoid is cost driver for SiD





Muon system

SiD Muon System Strawman

- 24 10cm plates w/23 gaps. Muon ID studies done to date with 12 instrumented gaps. ~1cm spatial resolution? Start with 12 planes, more when needed (e.g. 1TeV).
- 6-8 planes of x,y, u or v upstream of Fe flux return for xyz and direction of charged particles that enter muon system.

μ Detector Technologies

Strips vs. pixels

- Glass & Bakelite RPCs –
- Scintillator and Photo-detectors
- GEMs
- Wire Chambers

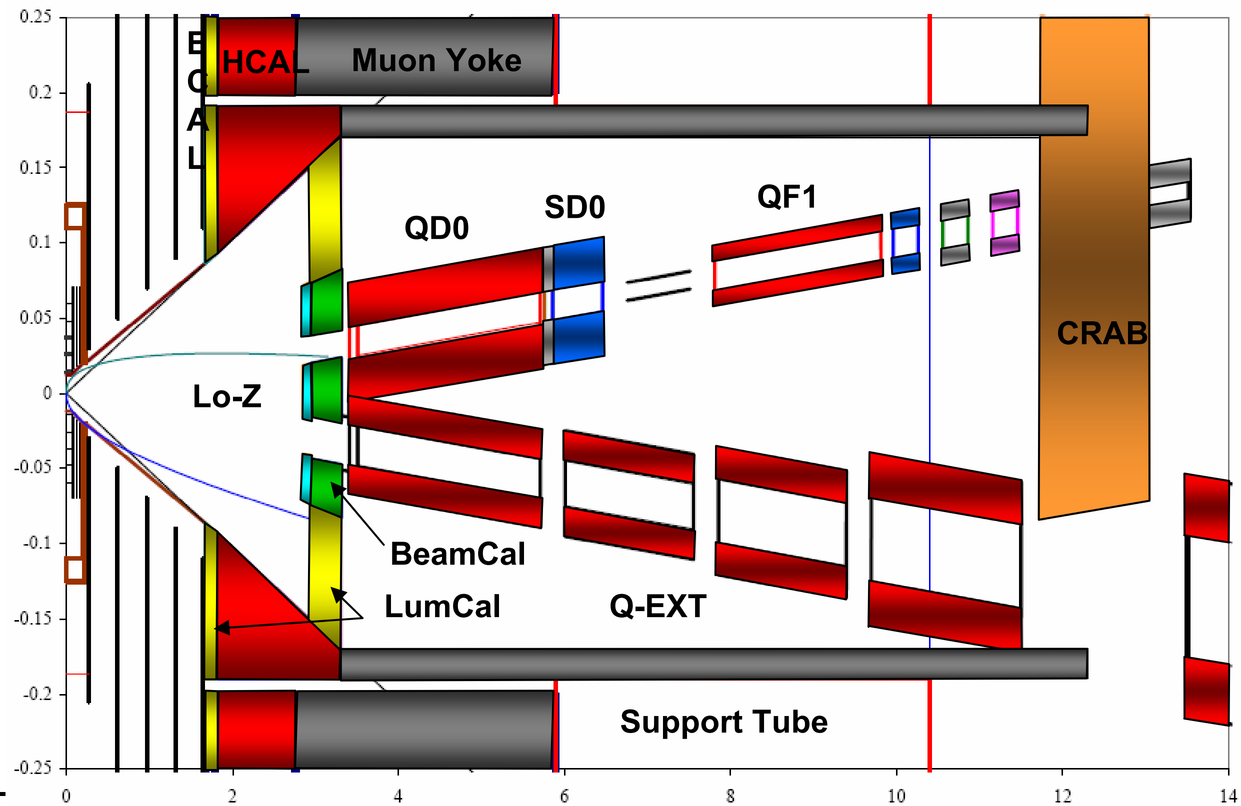
Questions

- Is the muon system needed as a tail catcher?
- How many layers are needed (0-23)? Use HCAL ?
- Position resolution needed?

Machine Detector Interface (MDI)

- A critical area of detector R&D which must be optimized is where the detector meets the collider
  - Preserve optimal hermiticity
  - Preserve good measurements
  - Control backgrounds
  - Quad stabilization

20 mr crossing angle
$L^* = 3.51$ m



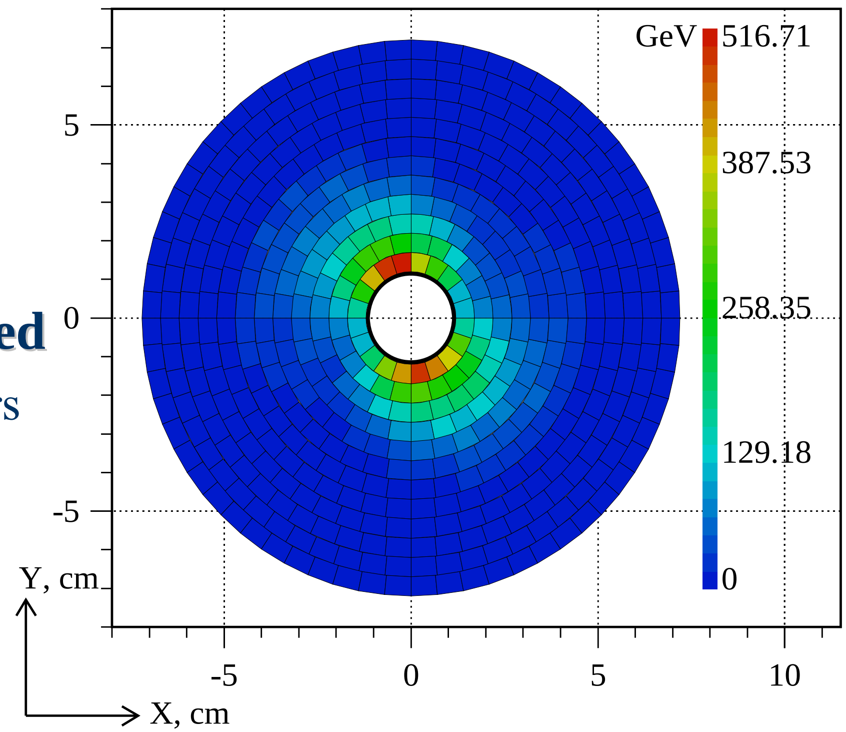
MDI

- 18 ‘urgent’ questions issued by WWS/MDI to 3 detector concepts
- Written responses provided pre-Snowmass
- Responses digested and summarised by WG4/MDI at Snowmass

- L* range under discussion by WG4: 3.5m < L* < 4.5m
  Range is acceptable to SiD
- Beampipe radius:
  effectively discussing 12 < r < 25 mm
  if backgrounds allows: SiD prefers smallest r
- Bunch spacing: 150-300 ns acceptable to SiD

Very Forward Instrumentation

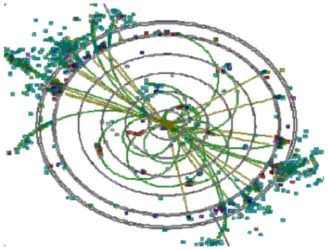
- **Hermiticity depends on excellent coverage in the forward region, and forward system plays several roles**
  - maximum hermiticity
  - precision luminosity
  - shield tracking volume
  - monitor beamstrahlung
- **High radiation levels must be handled**
  - 10 MGy/year in very forward detectors



TESLA Goal: $\Delta L/L$: 10^{-4} (exp.)
$\Delta L/L$: 10^{-4} (theo.)

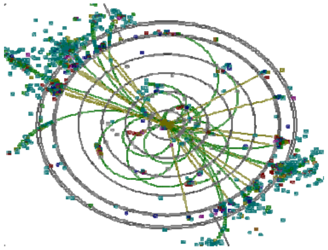
Ref: OPAL (LEP)
$\Delta L/L$: 3.4×10^{-4} (exp.)
$\Delta L/L$: 5.4×10^{-4} (theo.)

NEEDS EFFORT



Beamline Instrumentation

- dL/dE analysis
  - complete analysis to extract both tail and core
  - understand external inputs (asymmetries, offsets)
  - possible to extract correlations (energy, polarization)?
- Extraction line studies
  - expected distributions with disrupted beam
  - expected backgrounds at detectors
- Forward Tracking/Calorimetry
  - Realistic conceptual design for ILC detector
  - Expected systematics eg: alignment
- Beam Energy Width
  - Understand precision of beam-based techniques
  - Possible with x-line WISRD?

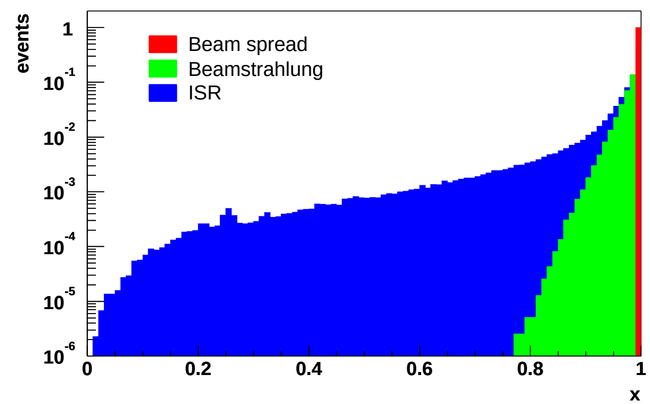


Detector Beamline Instrumentation

- **Polarized electrons (and perhaps positrons)**
  - ⇒ **Polarimeter**
    - ⇒ 0.2% goal

- **Electron energy**
  - ⇒ **Energy spectrometer**
    - ⇒ 200 ppm required

- **Beam energy profile**
  - ⇒ **Differential luminosity measurement**
    - ⇒ knowledge of beamstrahlung effects required

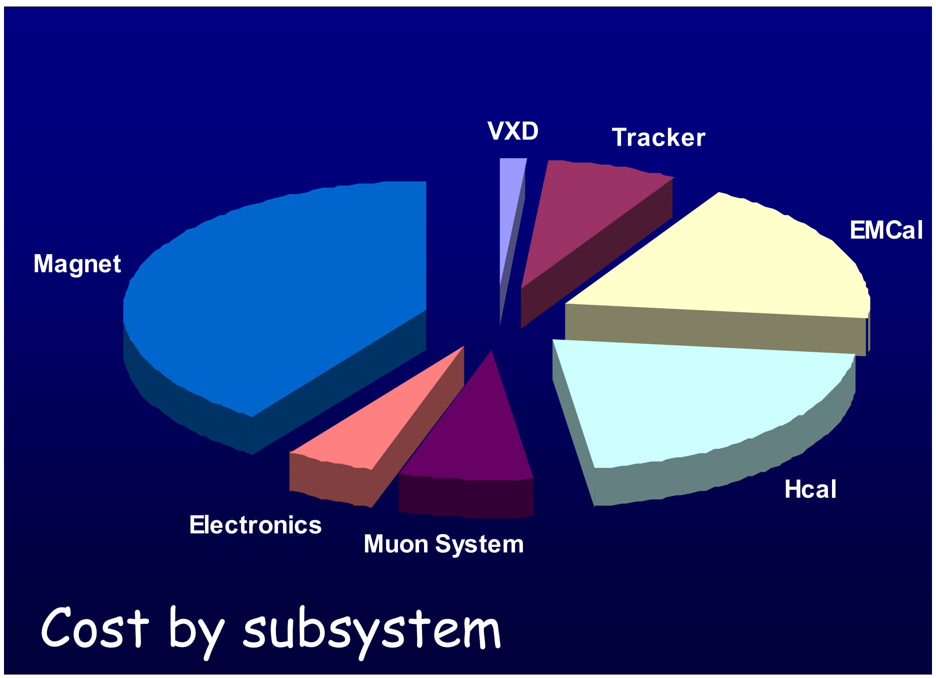


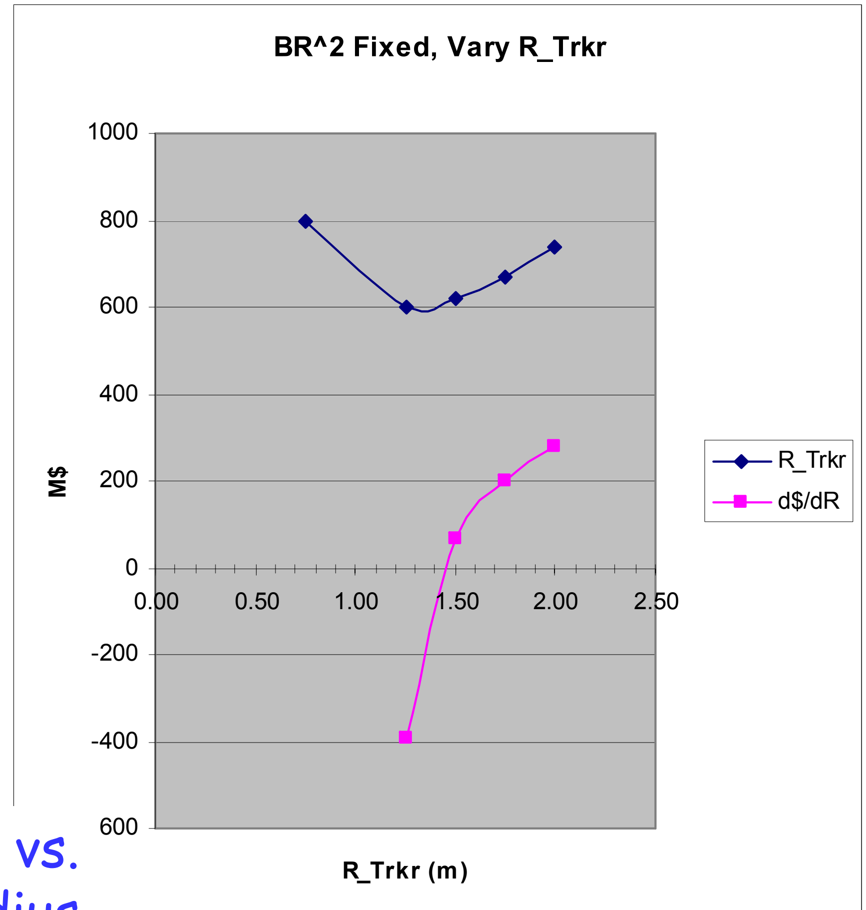
S. Boogert

Cost

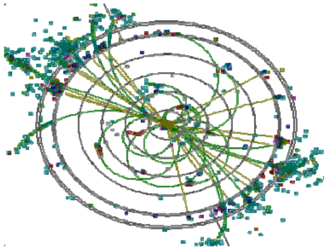
Parametric Cost Model

Cost = f (B-field, R_{TRK}, ….)



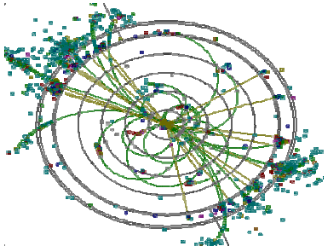


Cost minimum vs.
tracker radius



SiD: salient features

- Smallest L*, compatible with crossing-angle reach
- VXD: smallest radius (5T helps)
- Tracker: excellent $\delta p/p$; silicon robust; minimize material uniformly over $\cos(\theta)$; demonstrated pattern recog (in → out; out→ in, stand alone)
- ECAL: excellent segmentation 4x4 mm, $R_{Moliere}$=13mm
- HCAL: excellent segmentation
- Calorimetry: imaging, hermetic
- Solenoid: feasible, 5T
- Instrumented flux return & imaging HCAL: excellent muon ID
- Time stamp/digitize bunch by bunch
- Cost: constrained cost, with parametric model



Summary

- SiD is a robust, optimized, ILC detector
  - Aggressive
  - Fast
  - Background tolerant
  - Cost controlled

- Optimization studies remain
  - December 16, 17, at Fermilab (SiD meeting)
  - March, 2006 → Detector Outline → DCR end of ‘06
  - Prototypes
  - Beamtests