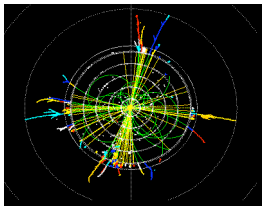


The Physics and Detectors of the International Linear Collider

Jim Brau
University of Oregon

**Invited plenary talk presented at the 2007 IEEE Nuclear Science Symposium
Honolulu, Hawaii, October 29, 2007**



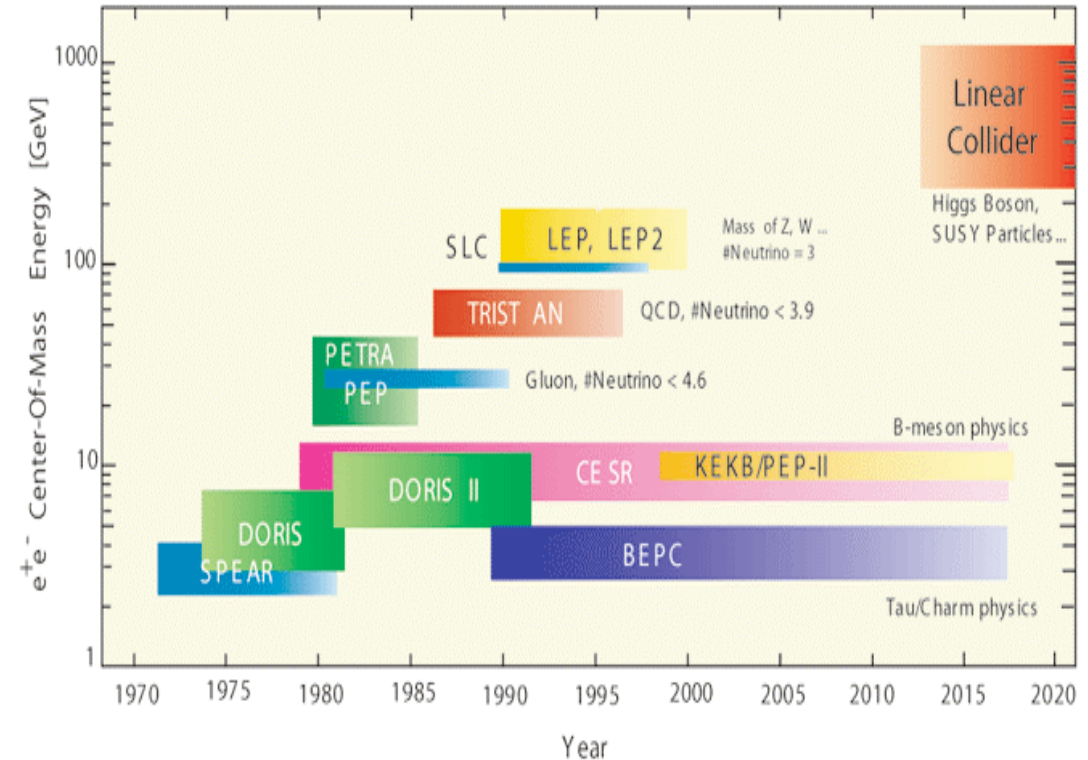
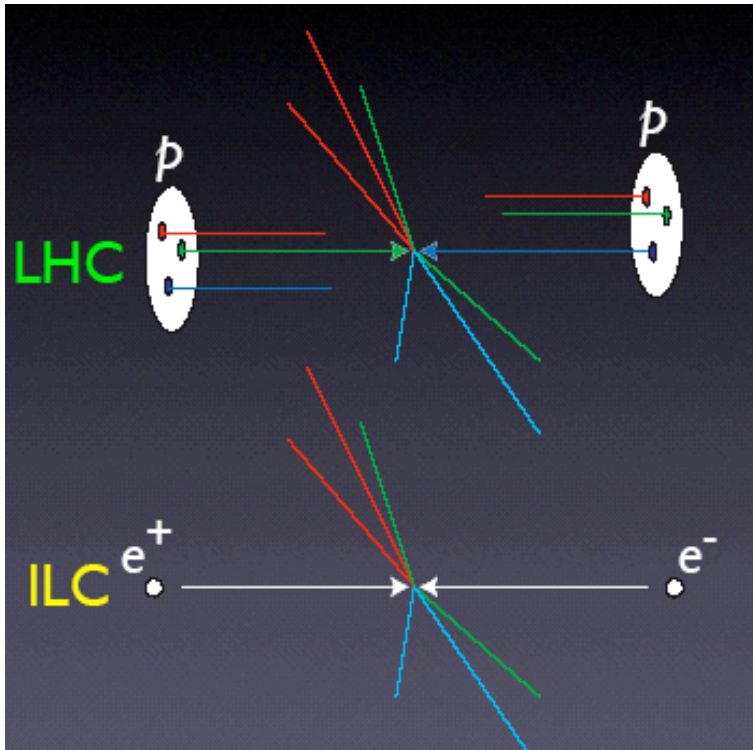
Physics and Detectors of the International Linear Collider



- **LHC will open exploration of Terascale physics**
 - **Revolution in fundamental physics awaits!**
 - **What is nature of Electroweak Symmetry Breaking?**
 - **Are there new symmetries of space and time?**
 - **Are there hidden extra dimensions?**
 - **Do dark matter particles explain astrophysical observations?**
 - **Do all forces unify at high energy? - Einstein's dream**
- **ILC is needed to elucidate and explore nature of Terascale**
 - ↪ **Deeper and complementary look at Terascale questions**
 - ↪ **Precision exploration of new physics**
- **Sophisticated, precise detectors are required to exploit the scientific opportunity of the ILC**
 - R&D required/underway**

ENORMOUS EFFORTS ON MANY ASPECTS
THIS TALK IS NECESSARILY SELECTIVE DUE TO BREADTH OF SUBJECT

Complementarity of Electron Colliders



**As astronomers examine the universe with different wavelengths
(visible, radio, X-ray, IR, etc.),
particle physicists use different initial states**

The Large Hadron Collider and the ILC

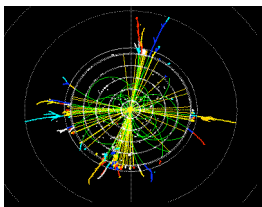


- LHC at CERN, colliding protons
first collisions – next year
- History demonstrates the
complementarity of
hadron and **electron** experiments

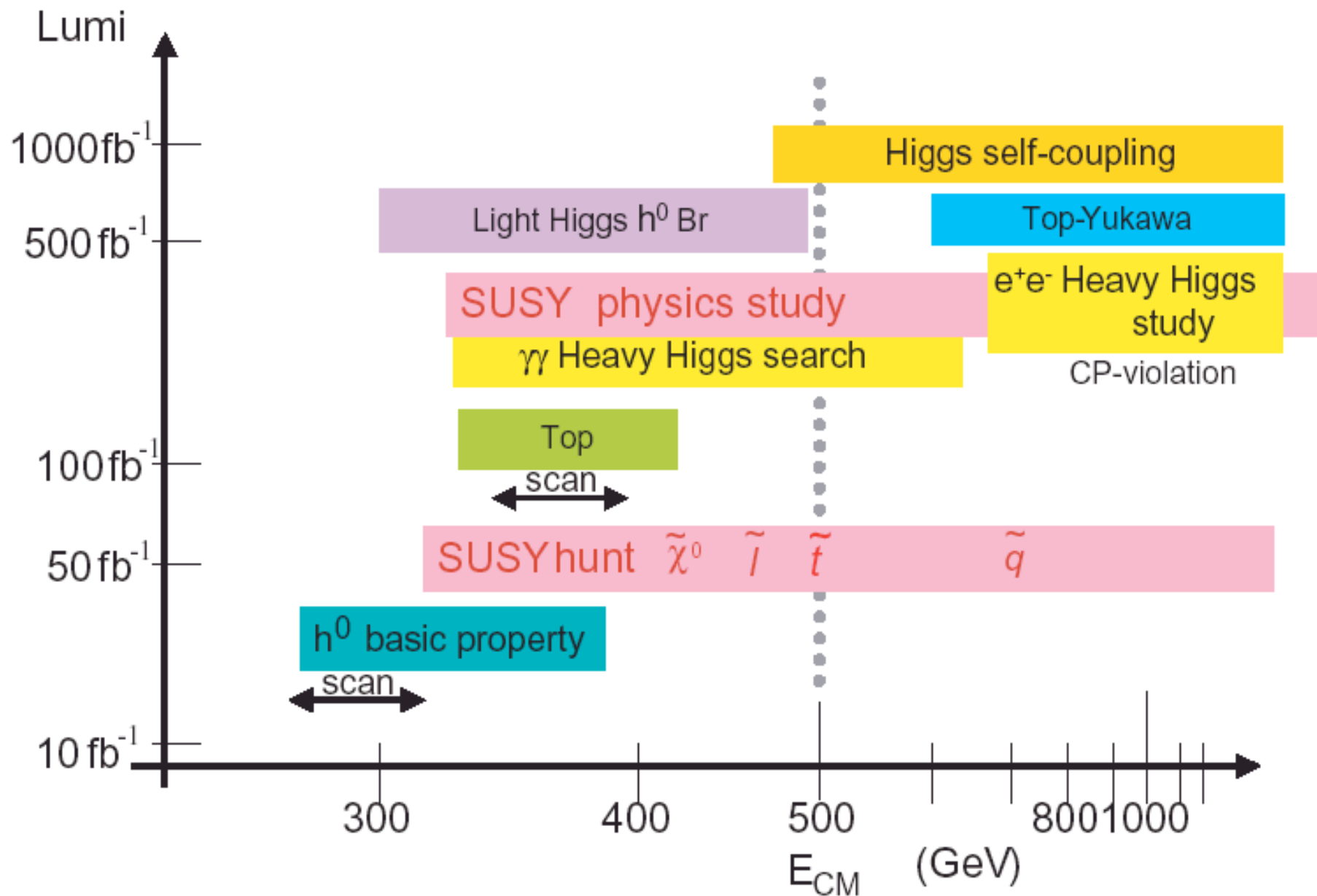


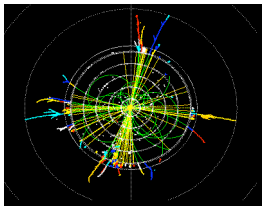
<u>discovery</u>	<u>facility of discovery</u>	<u>facility of detailed study</u>
charm quark	BNL + SPEAR	SPEAR at SLAC
tau lepton	SPEAR	SPEAR at SLAC
bottom quark	Fermilab	Cornell/DESY $\Rightarrow$ B Factories
Z^0 boson	SPPS/CERN	LEP and SLC

- Electron experiments have frequently provided most precision



ILC Physics

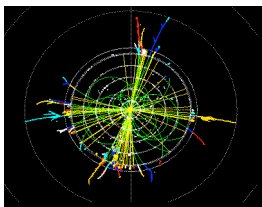




Electroweak Symmetry Breaking



- **A central topic of particle physics research today is the origin of Electroweak Symmetry Breaking**
 - ⇒ **The weak nuclear force and the electromagnetic force have been unified into a single description** **gauge group $SU(2) \times U(1)_Y$**
 - ⇒ **Why is this symmetry hidden?**
 - ⇒ **The answer to this promises deep understanding of fundamental physics**
 - ❖ Origin of mass
 - ❖ Supersymmetry (new particles) and possibly the elements of dark matter
 - ❖ Additional unification (strong force, gravity) - Einstein's Dream
 - ❖ and possibly hidden space-time dimensions

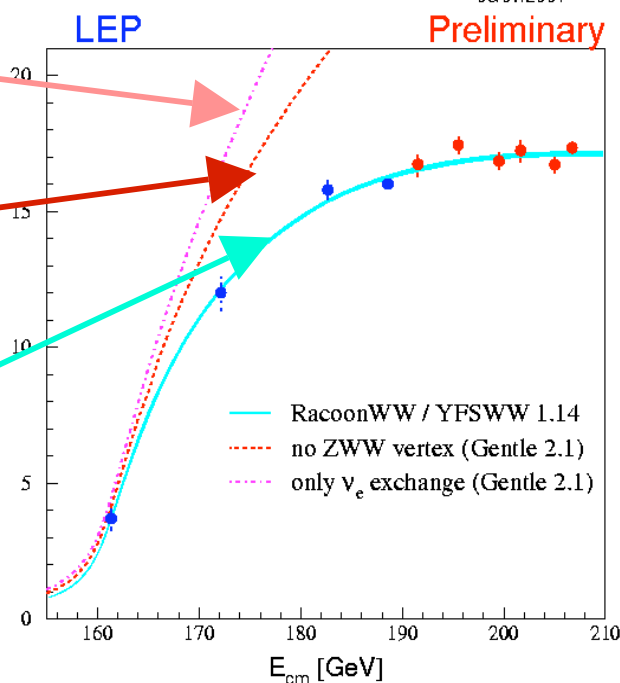
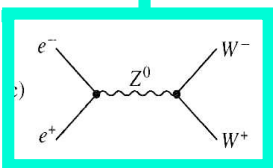
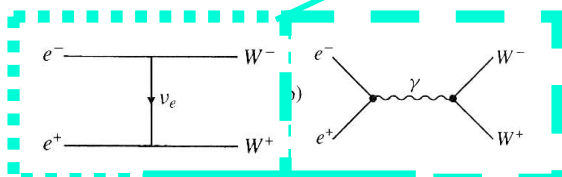
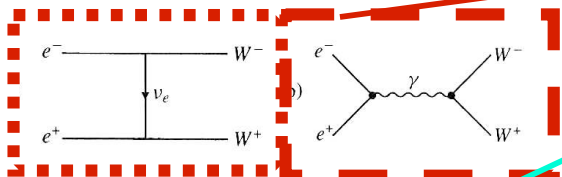
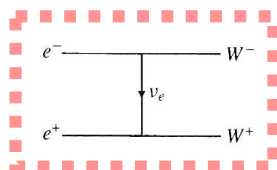


Electroweak Symmetry Breaking



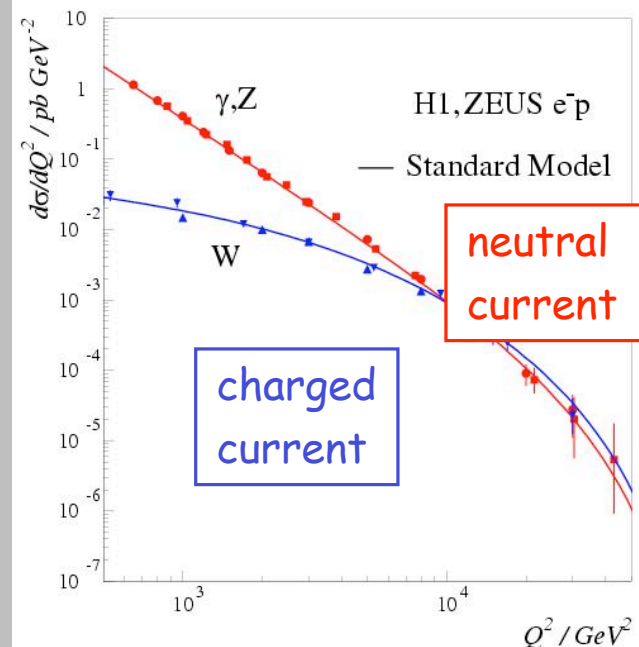
Confirmation of the completeness of the Standard Model

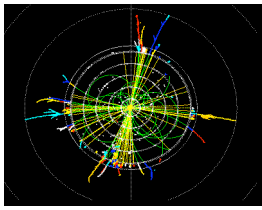
$$e^+e^- \rightarrow W^+W^- \quad (\text{LEP2})$$



Demonstration of unification of EW forces (HERA)

$$e^-p \rightarrow e^-X \rightarrow \nu_e X \quad (\text{HERA})$$





The Higgs Boson

- Why is the underlying $SU(2) \times U(1)$ symmetry

$$L = g \mathbf{J}_\mu \cdot \mathbf{W}_\mu + g' J_\mu^Y B_\mu$$

Beyond
Terascale

broken

Low Energy

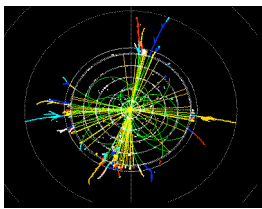
$$=$$

$$- \frac{g}{2\sqrt{2}} \sum_i \bar{\psi}_i \gamma^\mu (1 - \gamma^5) (T^+ W_\mu^+ + T^- W_\mu^-) \psi_i$$

$$- e \sum_i q_i \bar{\psi}_i \gamma^\mu \psi_i A_\mu$$

$$- \frac{g}{2 \cos \theta_W} \sum_i \bar{\psi}_i \gamma^\mu (g_V^i - g_A^i \gamma^5) \psi_i Z_\mu .$$

- Theoretical conjecture is the Higgs Mechanism:
a non-zero vacuum expectation value of a scalar field,
gives mass to W and Z and leaves photon massless



The Higgs Boson

- This scalar field, like any field, has quanta, the Higgs Boson or Bosons

- The Higgs boson properties

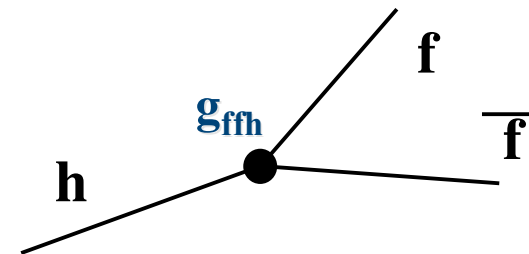
- ↪ Mass < $\sim 800 \text{ GeV}/c^2$ (unitarity arguments)

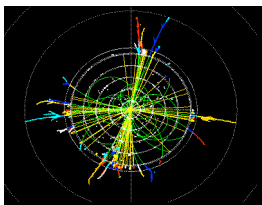
- ❖ but hierarchy problem

- ↪ Strength of Higgs coupling increases with mass

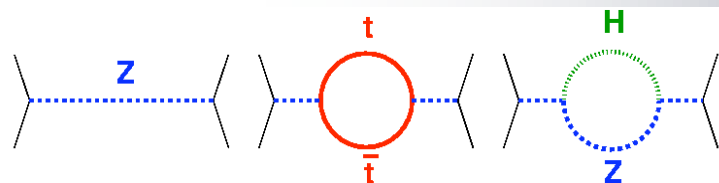
- ❖ fermions: $g_{ffh} = m_f / v$ $v = 246 \text{ GeV}$

- ❖ gauge boson: $g_{wwh} = 2 m_Z^2 / v$



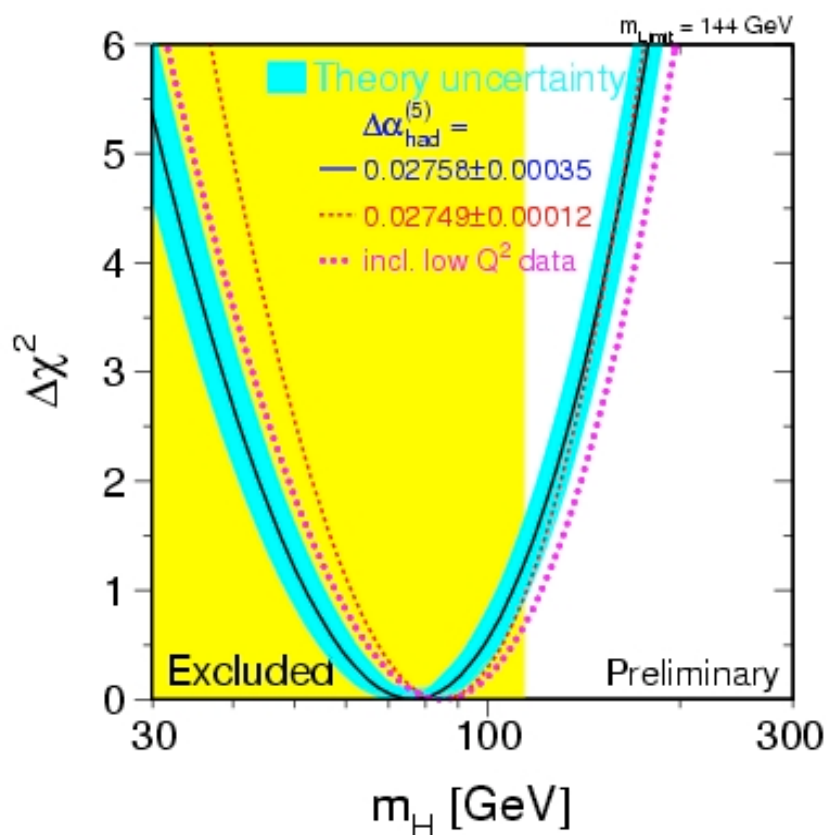


Standard Model Fit

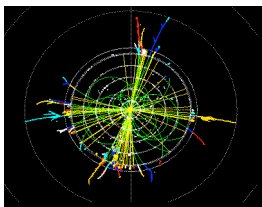


JULY 2007

○ $M_H = 76^{+33}_{-24} \text{ GeV}/c^2$



	Measurement	Fit	$10^{\text{meas}} - 0^{\text{fit}} / \sigma^{\text{meas}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	
$m_Z [\text{GeV}]$	91.1875 ± 0.0021	91.1875	
$\Gamma_Z [\text{GeV}]$	2.4952 ± 0.0023	2.4957	
$\sigma_{\text{had}}^0 [\text{nb}]$	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\nu)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A_{\text{fb}}^{0,b}$	0.0992 ± 0.0016	0.1038	
$A_{\text{fb}}^{0,c}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1481	
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	
$m_W [\text{GeV}]$	80.398 ± 0.025	80.374	
$\Gamma_W [\text{GeV}]$	2.140 ± 0.060	2.091	
$m_t [\text{GeV}]$	170.9 ± 1.8	171.3	



Anticipated Particles

Positron

Neutrino

Pi meson

Quark

Charmed quark

Bottom quark

W boson

Z boson

Top quark

Higgs boson

Dirac theory of the electron

missing energy in beta decay

Yukawa's theory of strong interaction

patterns of observed particles

absence of flavor changing neutral currents

Kobayashi-Maskawa theory of CP violation

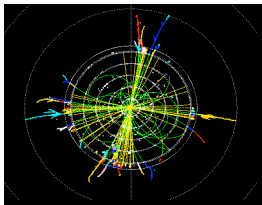
Weinberg-Salam electroweak theory

“ “

Mass predicted by precision Z^0 measurements

Electroweak theory and experiments





ILC Higgs Studies

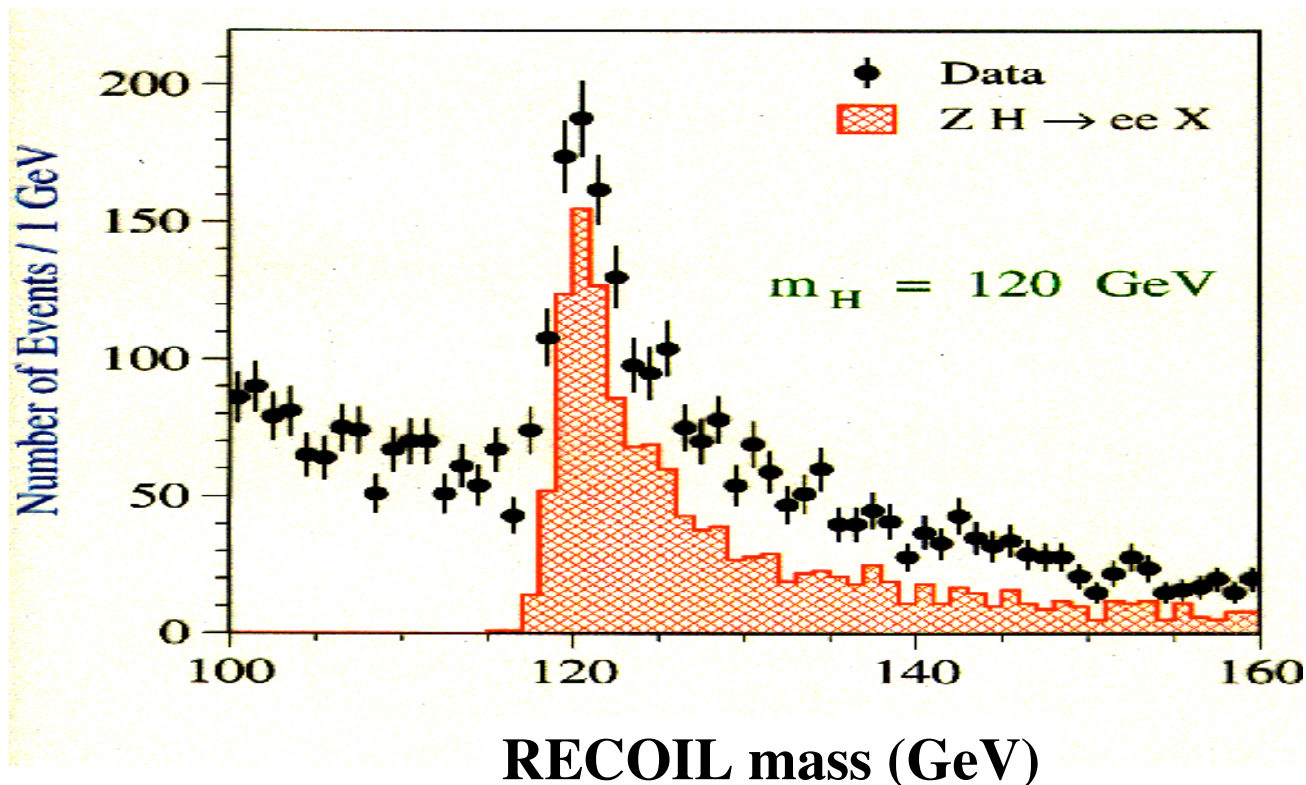
- the Power of Simple Interactions



ILC observes Higgs recoiling from a Z, with known CM energy $\downarrow$

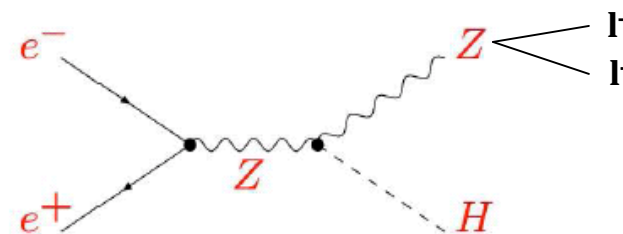
- powerful channel for unbiased tagging of Higgs events
- measurement of even invisible decays

($\downarrow$ - some beamstrahlung)



**1. KNOWN INITIAL
STATE**

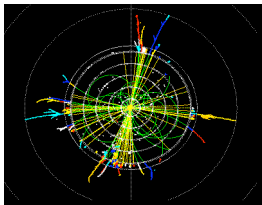
2. MEASURE $Z \rightarrow l^+ l^-$



3. CALCULATE RECOIL

Invisible decays are included

500 fb⁻¹ @ 500 GeV, TESLA TDR, Fig 2.1.4



Effect of Tracking Resolution on RECOIL Higgs Reconstruction



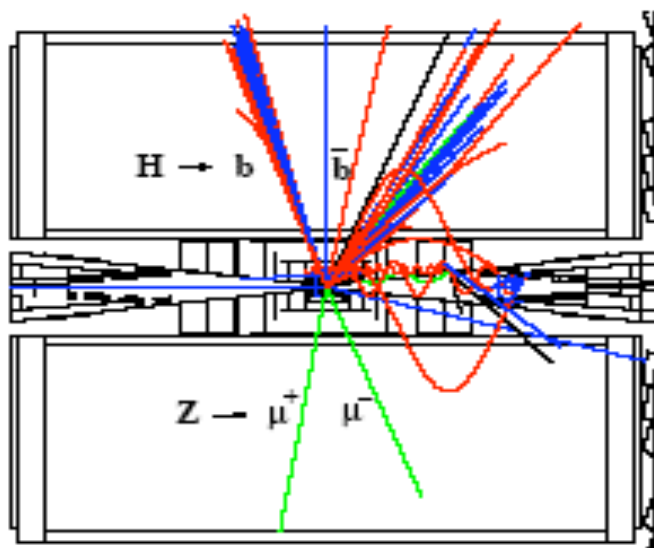
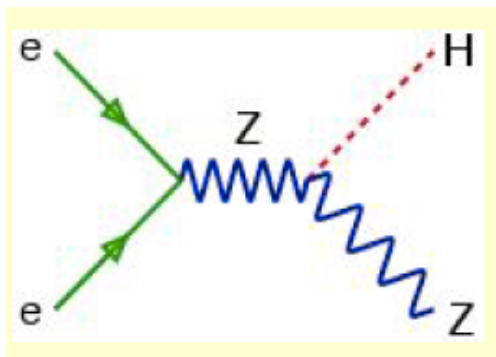
$$e^+e^- \rightarrow ZH$$

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

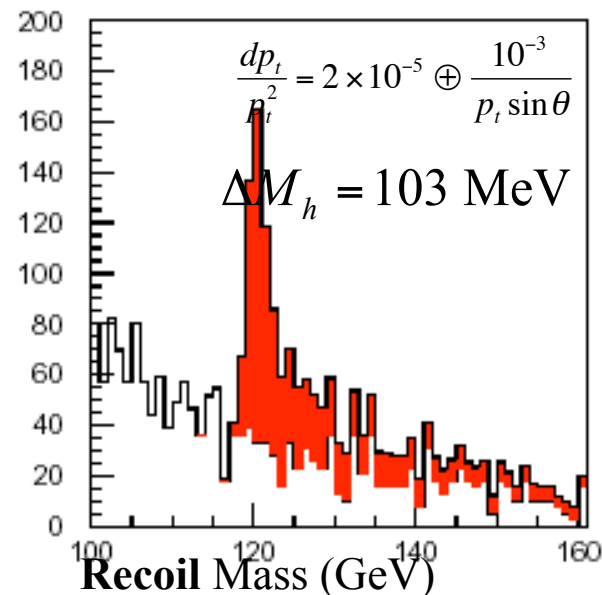
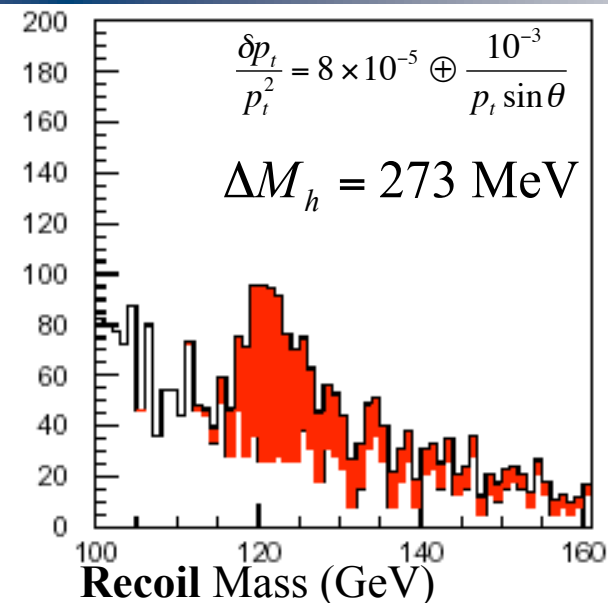
$$\sqrt{s} = 350 \text{ GeV}$$

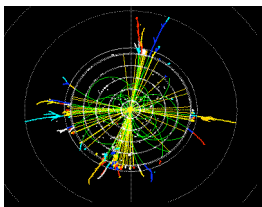
$$L = 500 \text{ fb}^{-1}$$

*$\sim 6 \times \text{LEP}$
Tracking
precision*



**INCLUDES
INVISIBLE
HIGGS DECAYS**



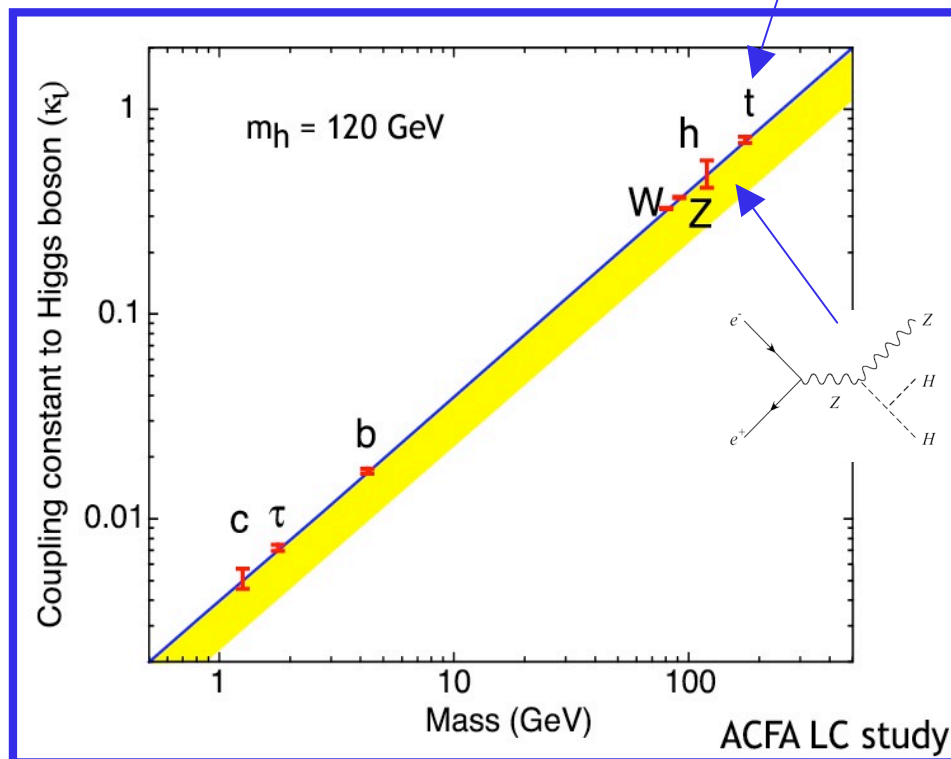
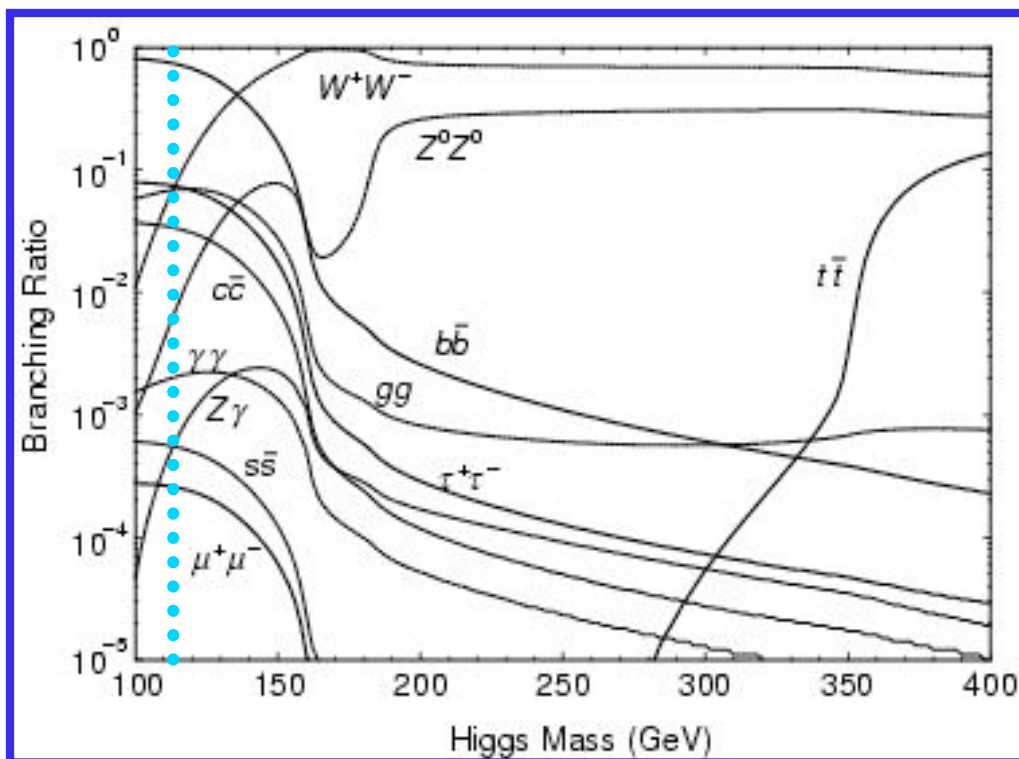
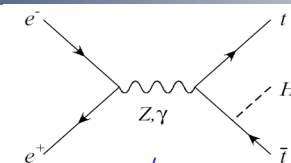


Higgs Couplings the Branching Ratios

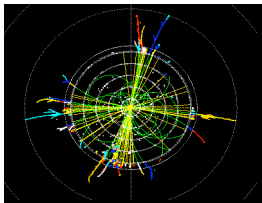


$$g_{ffh} = m_f / v$$

$$v = 246 \text{ GeV}$$

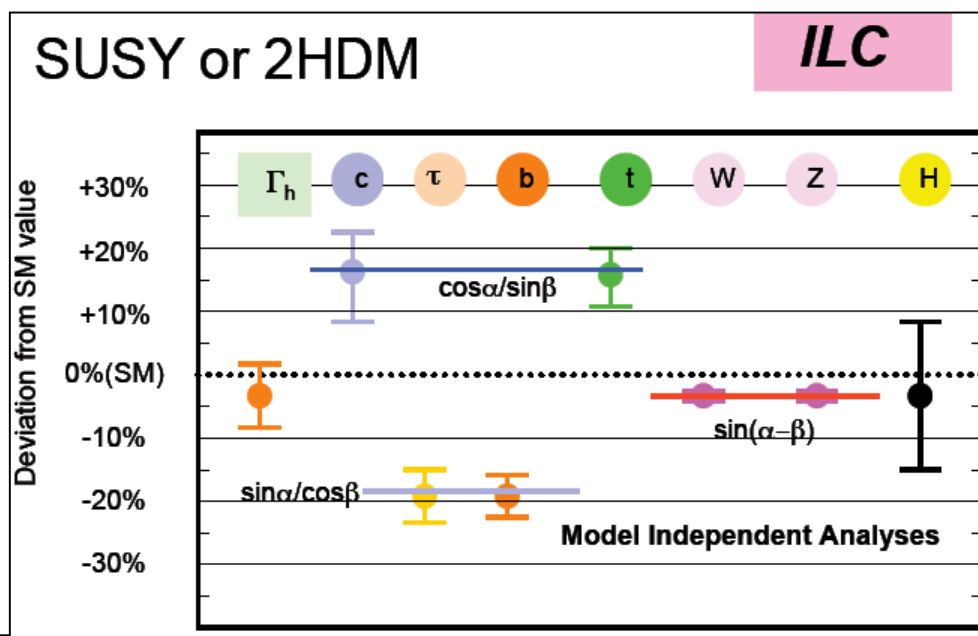
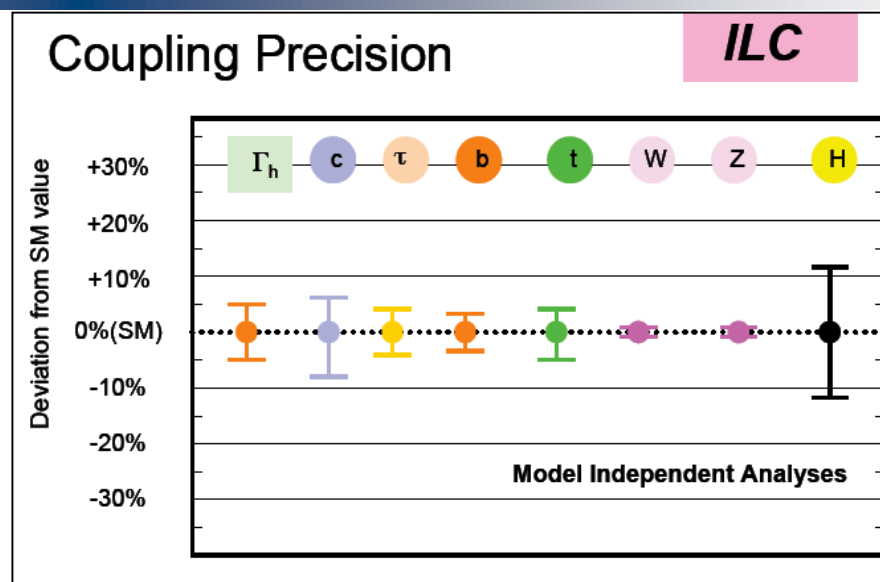
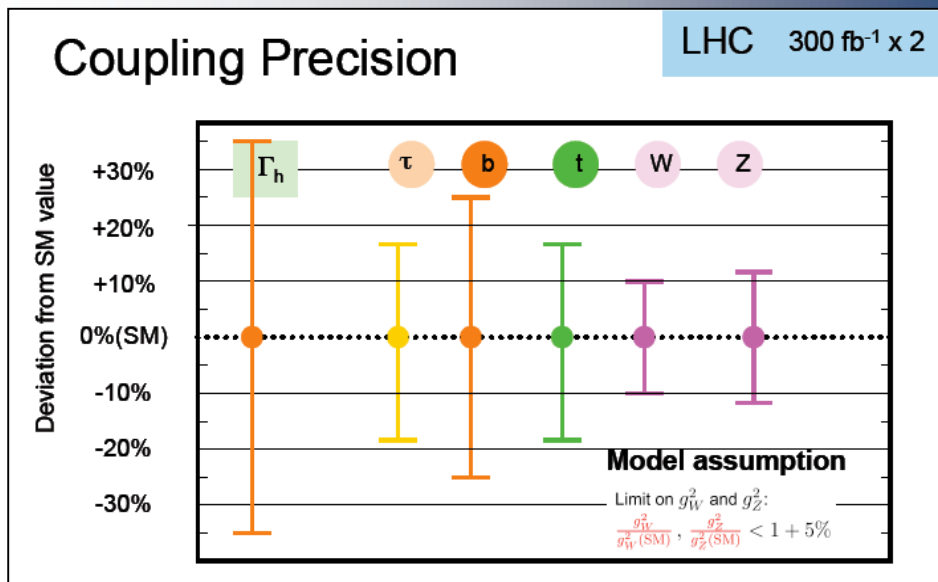


Measurement of BR's is powerful indicator of new physics
e.g. in MSSM, these differ from the SM in a characteristic way.
Higgs BR must agree with MSSM parameters from many other measurements.

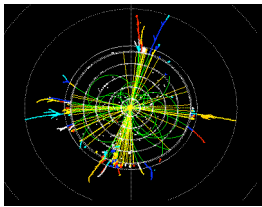


Is This the Standard Model Higgs?

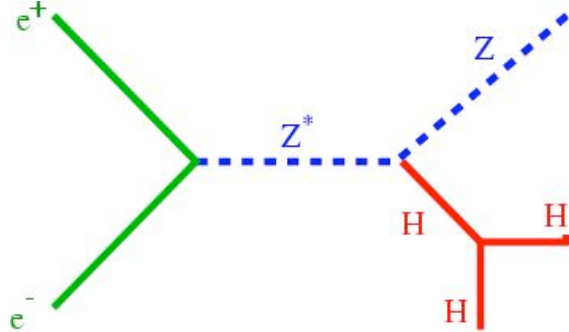
Precision tells us!



Yamashita

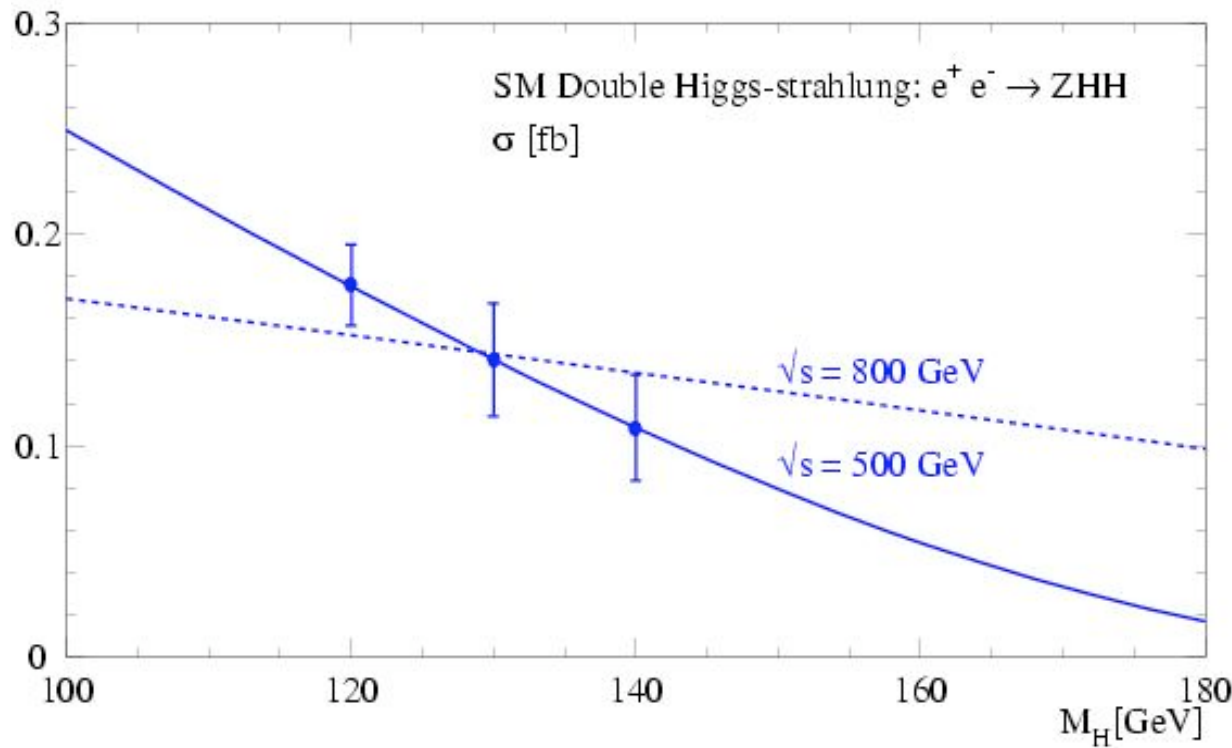
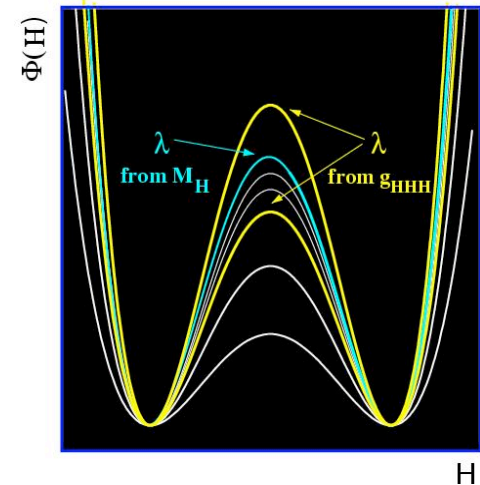


Higgs Self Coupling

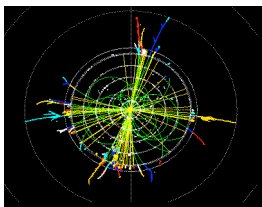


$$\Phi(H) = \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4} \lambda H^4$$

SM: $g_{HHH} = 6\lambda v$, fixed by M_H



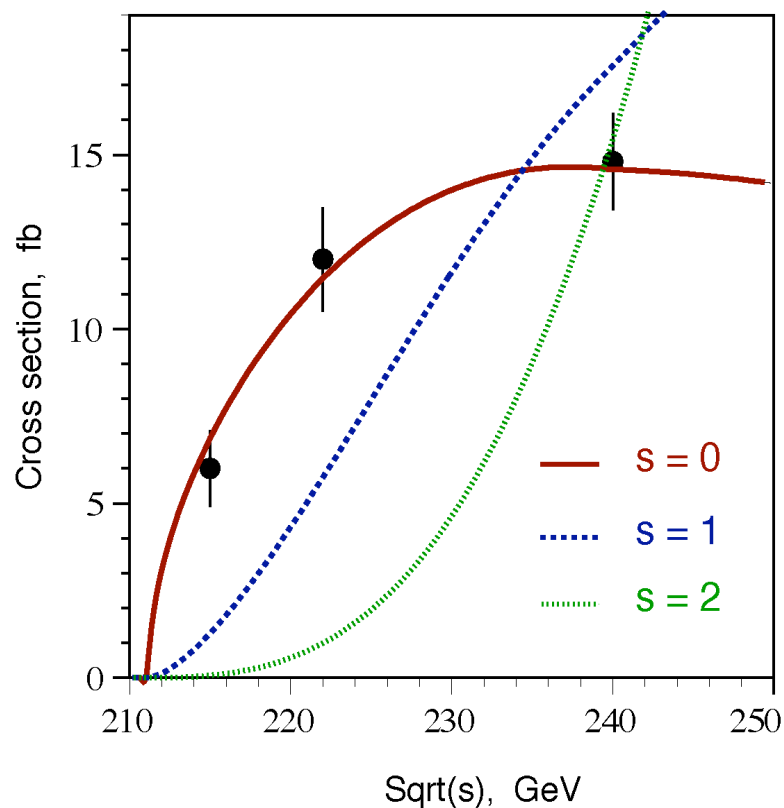
$\Delta\lambda/\lambda \sim 10\text{-}20\%$
 for 1 ab^{-1}



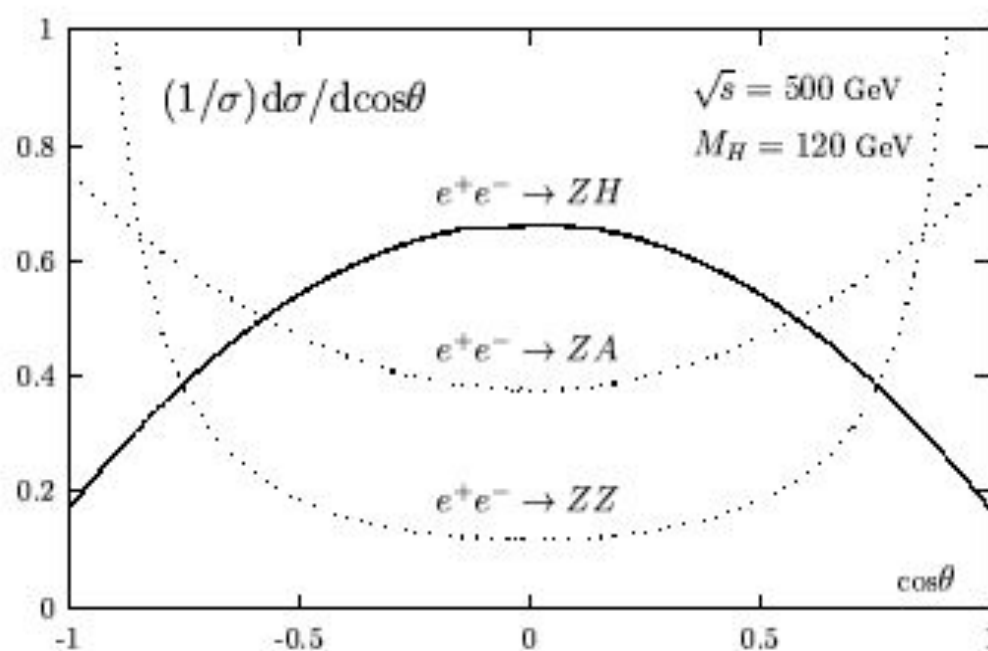
Higgs Spin Parity and Charge Conjugation (J^{PC})



$H \rightarrow \gamma\gamma$ or $\gamma\gamma \rightarrow H$
rules out $J=1$ and indicates $C=+1$

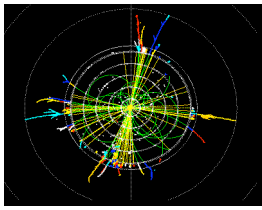


Production angle (θ) and Z
decay angle in Higgs-strahlung
reveals J^P ($e^+ e^- \rightarrow Z H \rightarrow ffH$)



TESLA TDR, Fig 2.2.8

LC Physics Resource Book,
Fig 3.23(a)



New Physics Beyond the Higgs

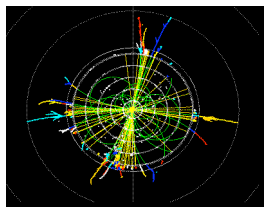


- **Motivated by “Hierarchy Problem”**
 - ↗ **Gigantic Mismatched between Electroweak Scale (100 GeV) and the Planck Scale of gravity (10^{19} GeV)**
 - ↗ **Expect More New Physics**

- **Supersymmetry?**
 - **new space-time symmetry with new particles**

- **New Strong Interactions?**

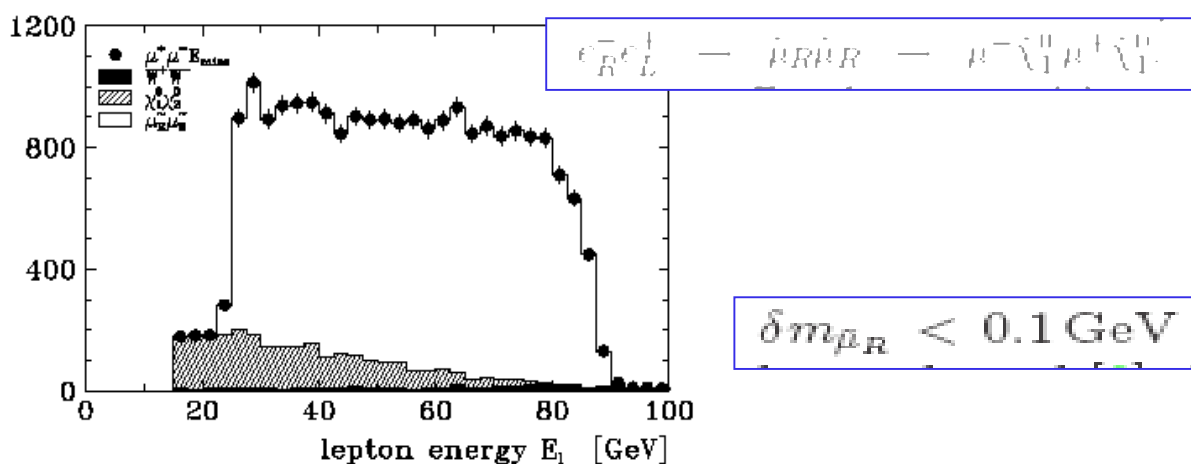
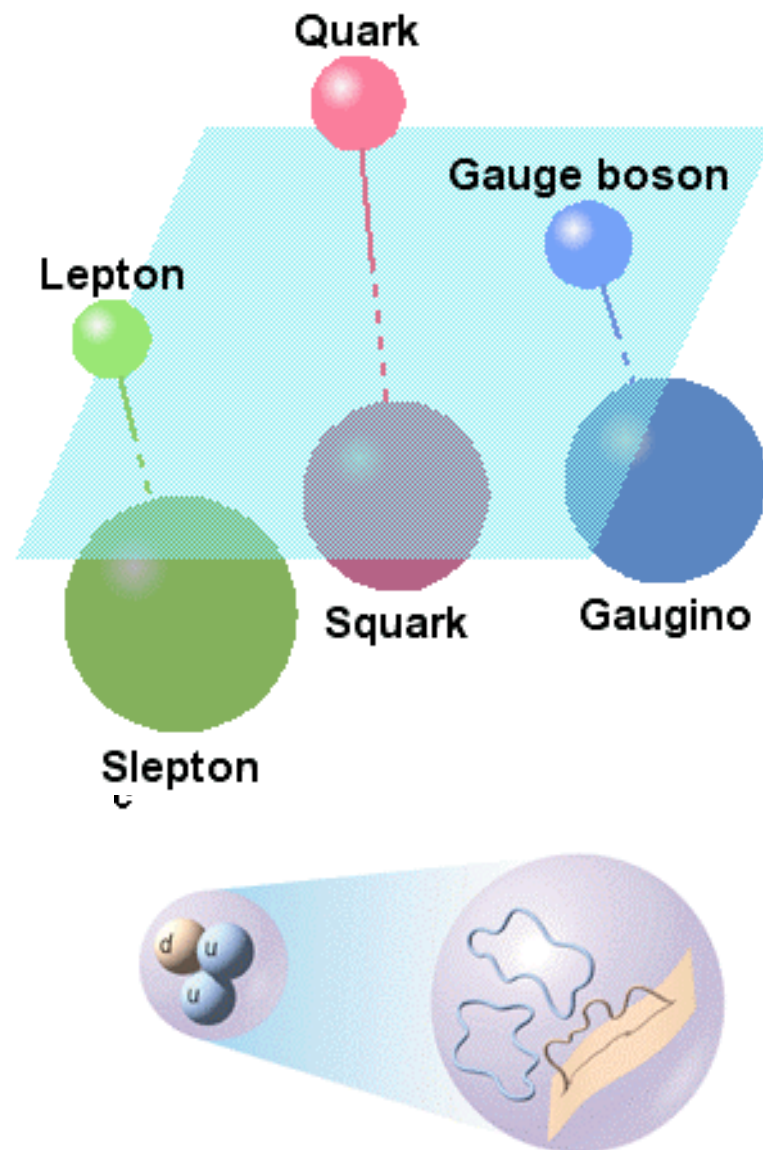
- **Hidden Dimensions?**

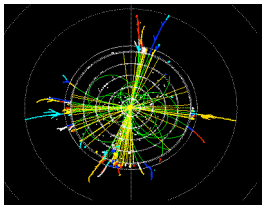


Supersymmetry



- New particles matched by super-partners
 - ↳ super-partners of fermions are bosons
 - ↳ super-partners of bosons are fermions
- Cancellation of divergences
 - ↳ Solves “hierarchy problem”
- Dark matter candidate
- Also inspired by string theory
- Many new particles
 - ↳ ILC could detail properties



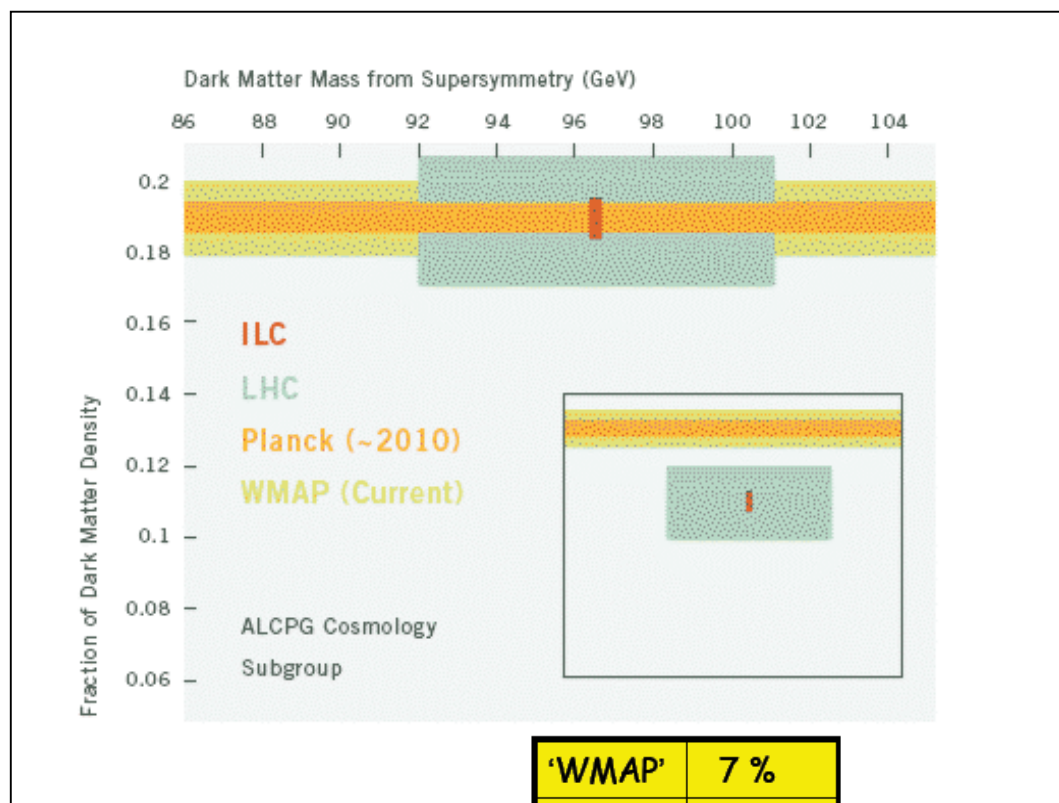


Complementarity with LHC



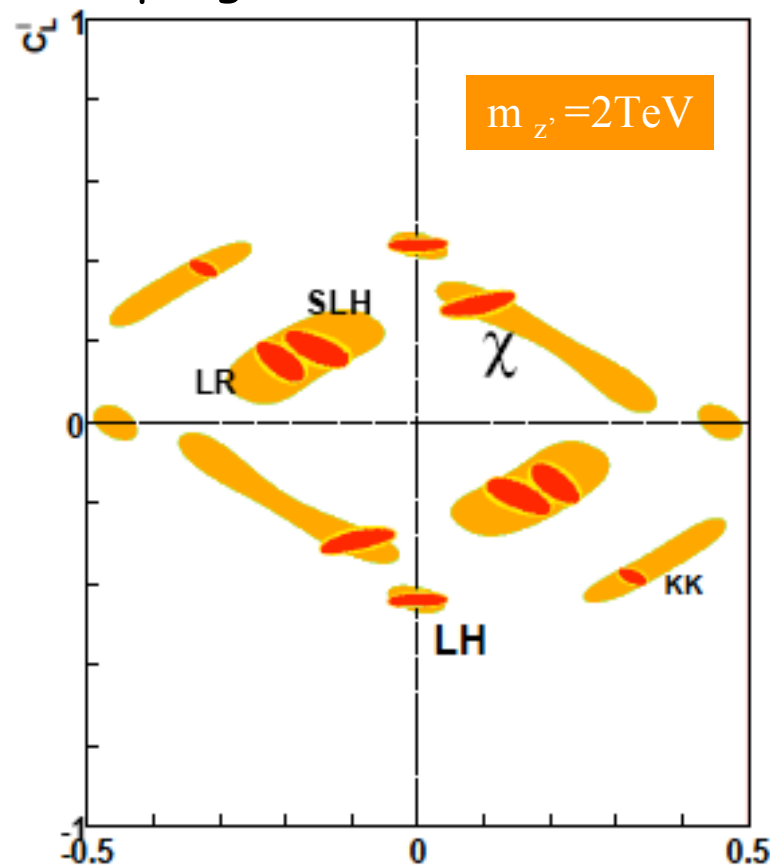
Identification of dark matter

SUSY mass and coupling measurements



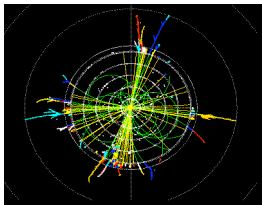
'WMAP'	7 %
LHC	~15 %
'Planck'	~2 %
ILC	~3 %

Z' discovered at LHC
Couplings determined at ILC

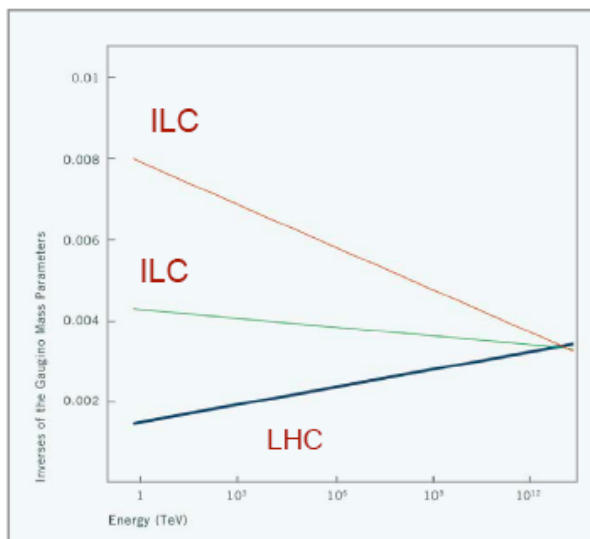
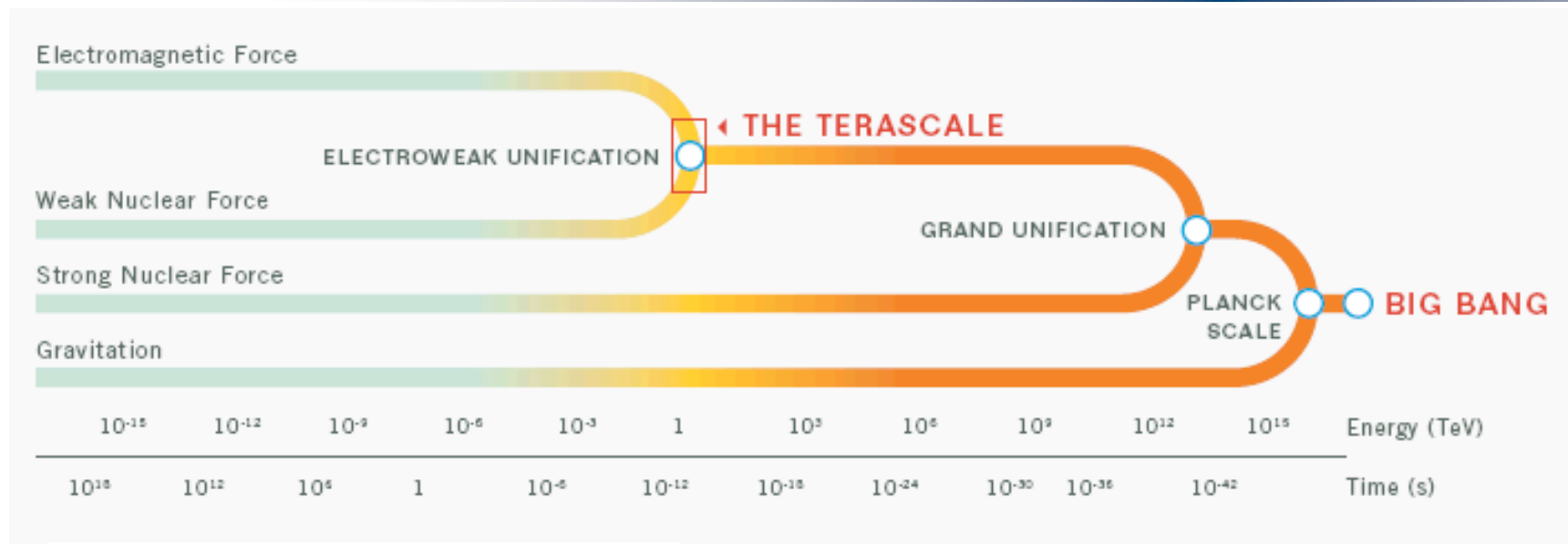


$m_{Z'} = 2\text{TeV}, E_{\text{cm}} = 500\text{ GeV}, L = 1\text{ab}^{-1}$
with and w/o beam polarization

S.Godfrey, P.Kalyniak, A.Tomkins

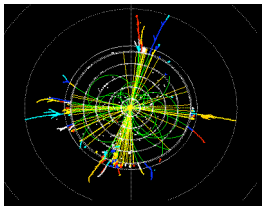


Ultimate Unification



SUSY Gaugino Unification

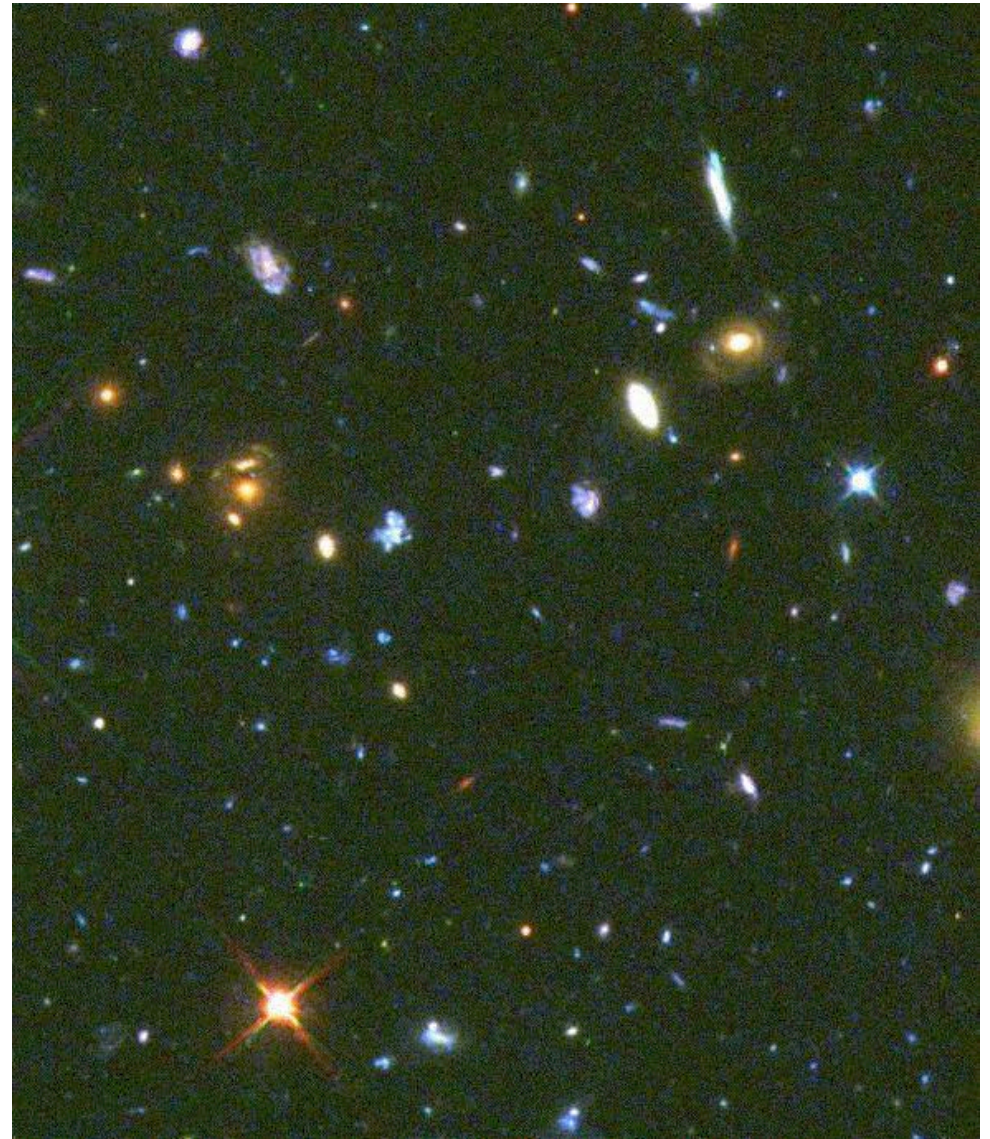
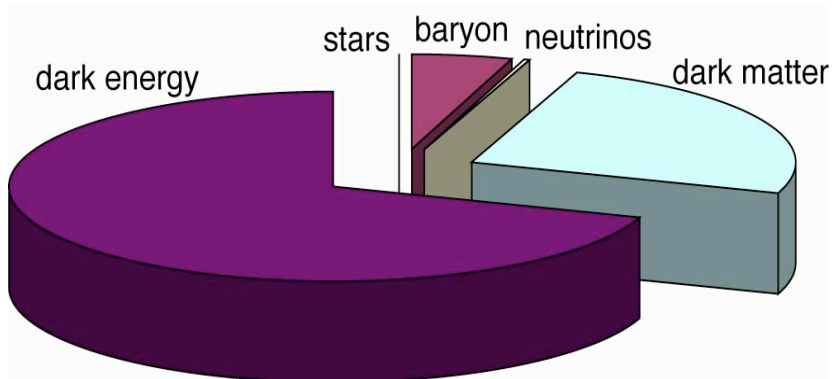
- Do Gaugino masses unify?
 - ⇒ Working together, the ILC and LHC will test this
 - ⇒ LHC → gluino
 - ⇒ ILC → wino, zino, photino
- Do quark and lepton couplings unify, as well?

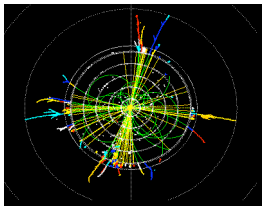


Cosmic connections

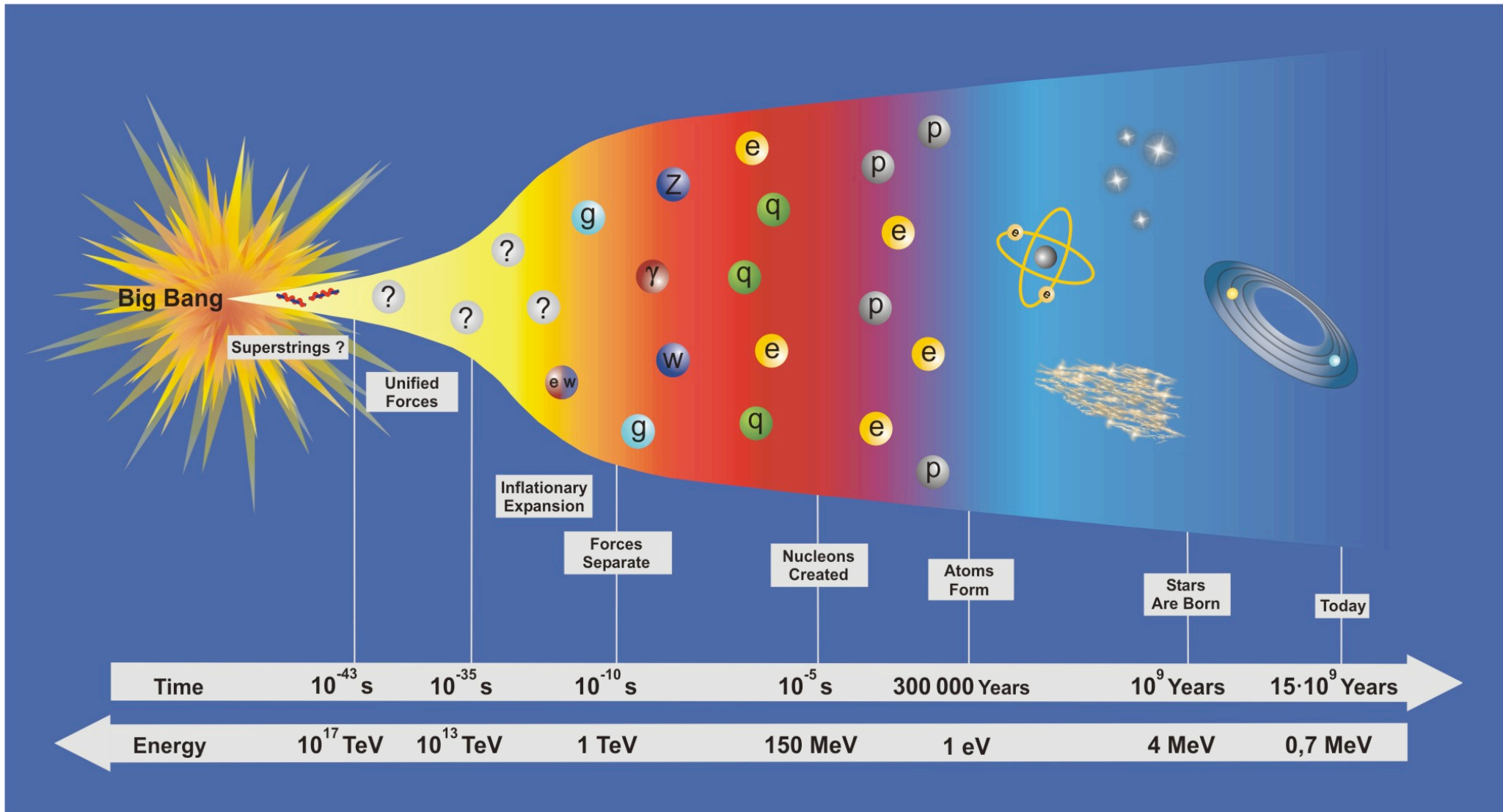


- Early universe
- GUT motivated inflation
- Dark matter
- Accelerating universe
- Dark energy
- What happened to the anti-matter?



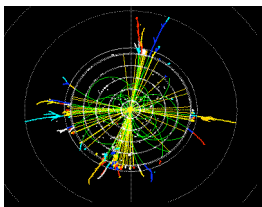


History of the Universe



extrapolation via
precision measurement

LHC, ILC
RHIC, HERA



The International Linear Collider



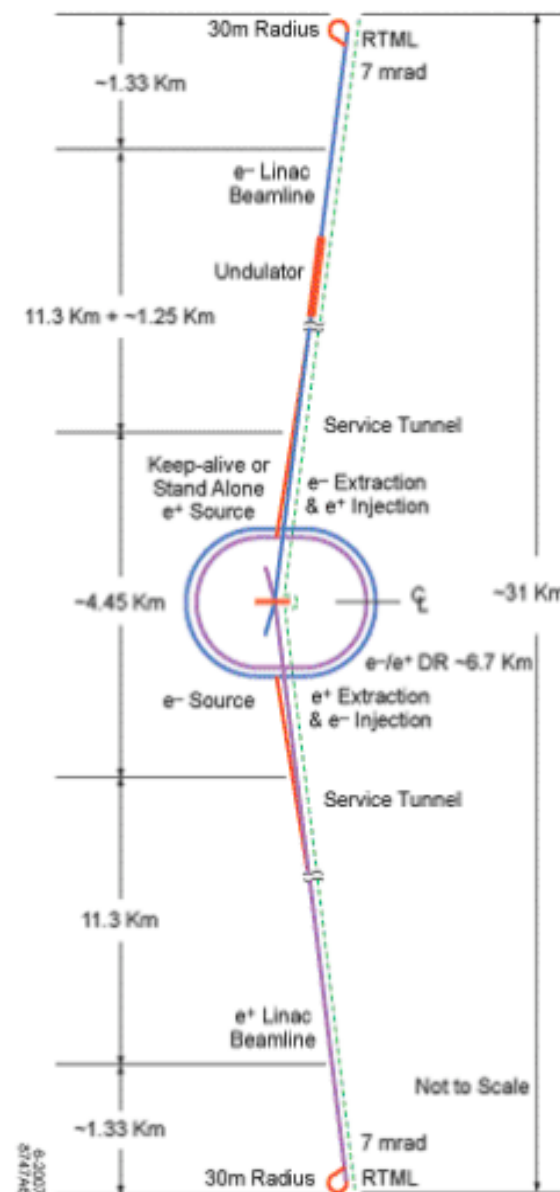
○ 500 GeV E_{cm}

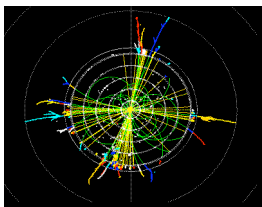
- ✦ Two 11 km SuperRF linacs at 31.5 MV/m
- ✦ Centralized injector (polarized electrons)
- ✦ Circular damping rings
- ✦ Undulator based positron source (polarized)
- ✦ Single IR for two detectors (push-pull) w/ 14 mr crossing angle
- ✦ Dual tunnel

○ Upgradable to 1 TeV

○ Options

- ✦ Hi luminosity at M_Z / W pair threshold
- ✦ $\gamma\gamma$, $e\gamma$, e^-e^-





ILC Experimental Advantages



Elementary interactions at known E_{cm}^*
 eg. $e^+e^- \rightarrow ZH$ * beamstrahlung manageable

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

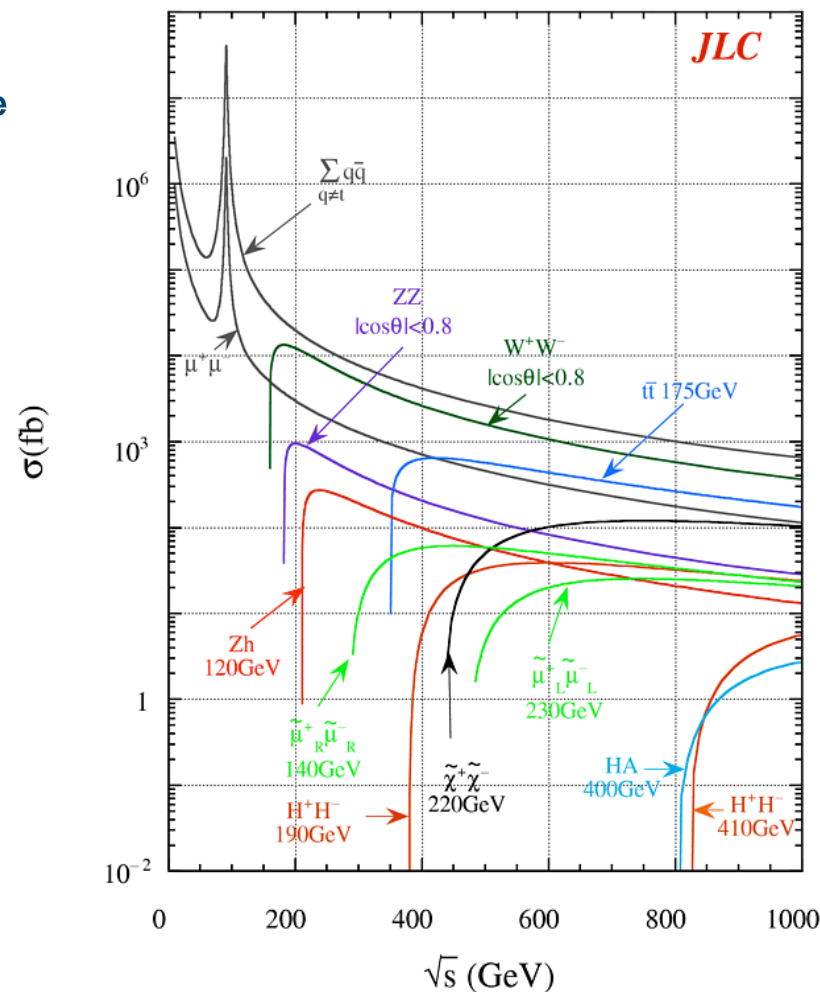
Inclusive Trigger
 total cross-section

Highly Polarized Electron Beam
 $\sim 80\%$ (positron polarization? – R&D)

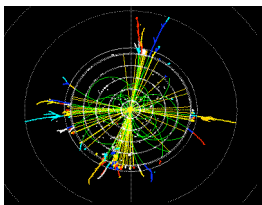
Exquisite vertex detection
 eg. $R_{beampipe} \sim 1 \text{ cm}$ and $\sigma_{hit} \sim 3 \mu\text{m}$

Calorimetry with Particle Flow Precision
 $\sigma_E/E_{jet} \sim 3\%$ for $E_{jet} > 100 \text{ GeV}$

Advantage over hadron collider on precision meas.
 eg. $H \rightarrow c\bar{c}$



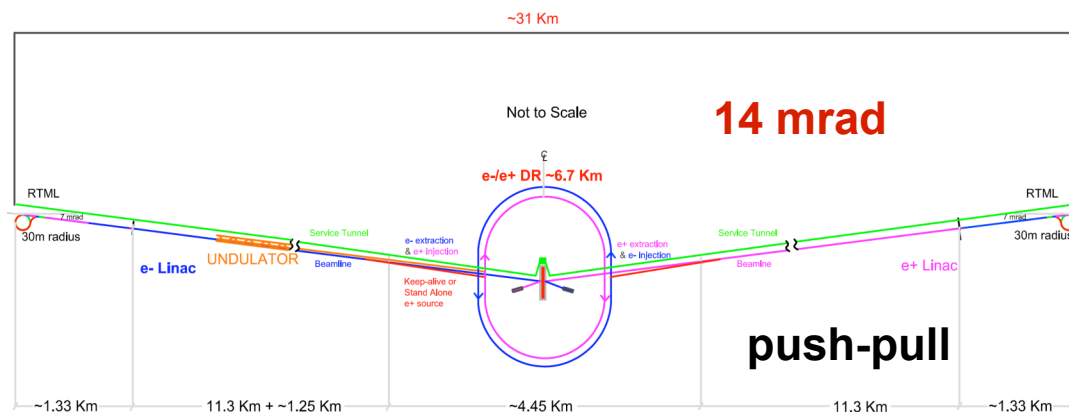
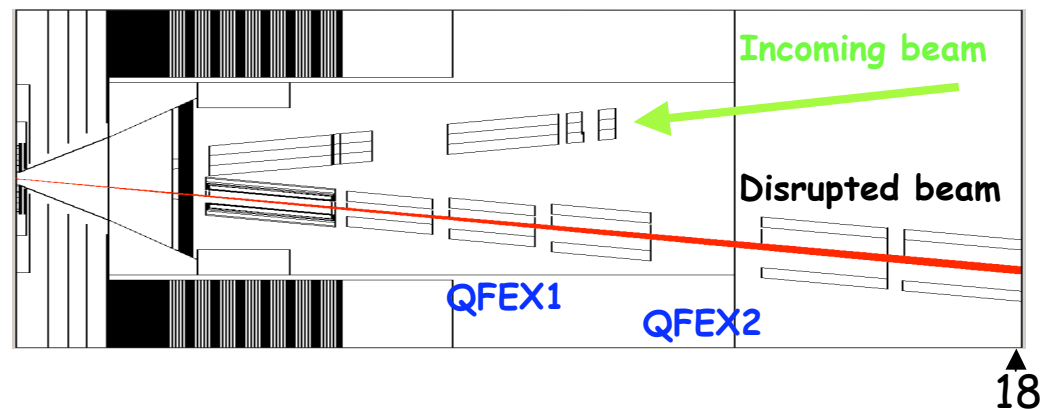
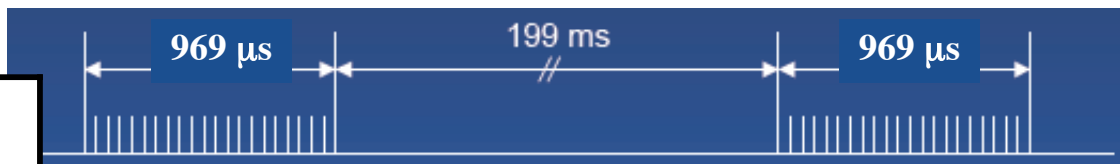
Detector performance translates directly into effective luminosity

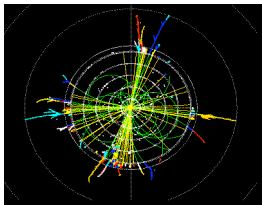


Collider Parameters

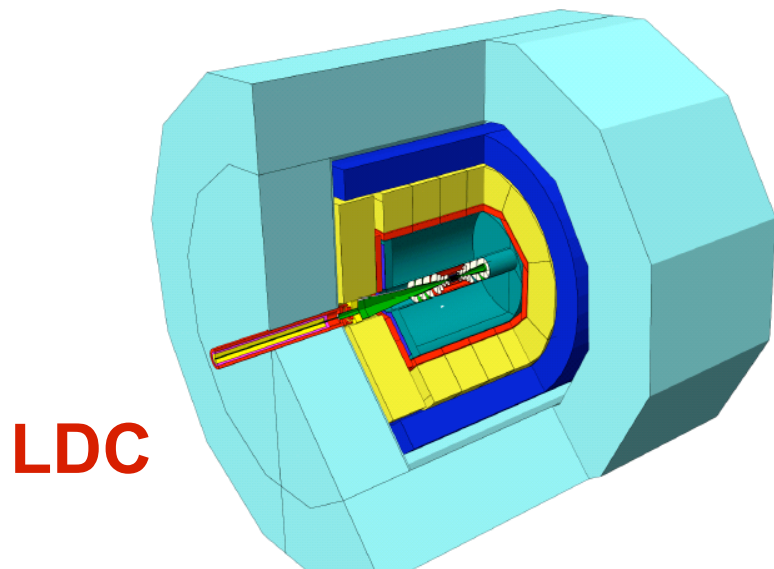


Machine parameter	Value (RD.)
#bunches/train	2625
#trains/sec	5
bunch spacing	369 nsec
bunches/sec	13125
length of train	969 μ sec
train spacing	199 msec
crossing angle	14 mrad
Luminosity	$2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

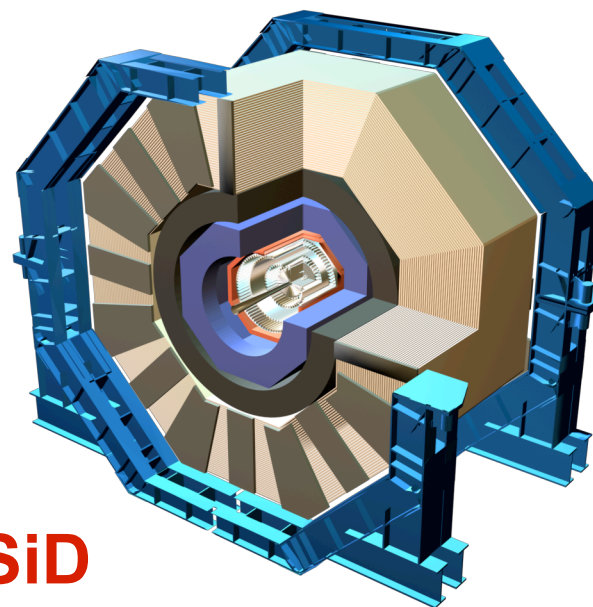




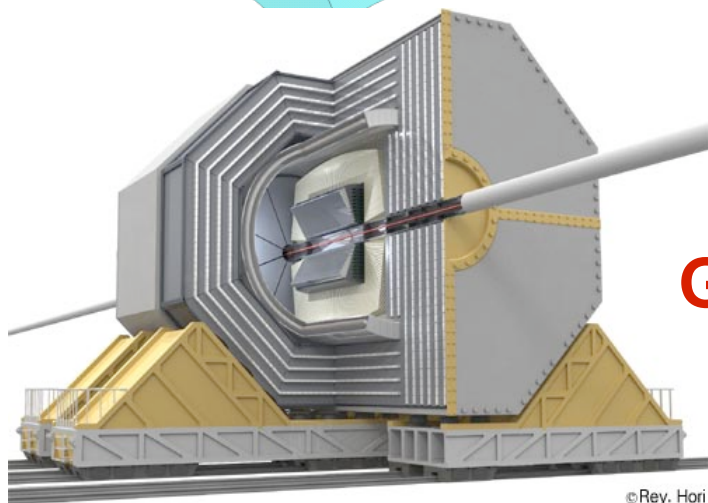
The Concepts



LDC



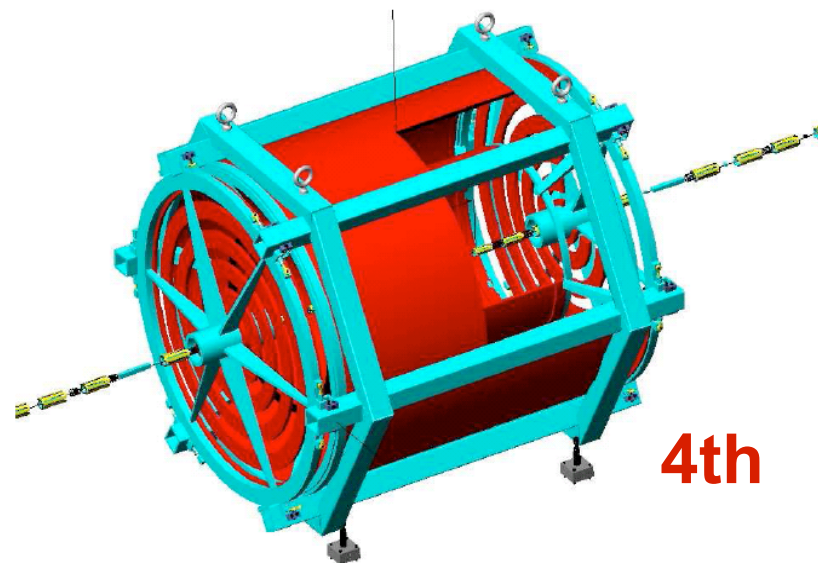
SiD



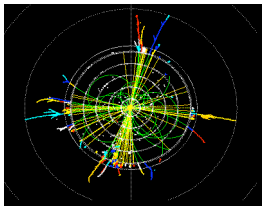
GLD

©Rev. Hori

Teams working on LDC and GLD
are in the process of merging
→ ILD



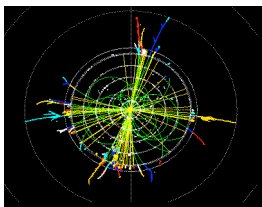
4th



ILC Detector Requirements



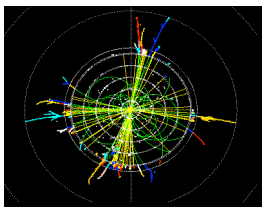
- Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.
- Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).
- Momentum resolution capable of reconstructing the recoil-mass to 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 .



The Detector Concepts



	Tracking	ECal Inner Radius	Solenoid	EM Cal	Hadron Cal	Other	
ILD {	SiD	silicon  	5 Tesla 	Si/W	Digital (RPC..)	Had cal inside coil	
	LCD	TPC gaseous  	4 Tesla 	Si/W	Digital or Analog	Had cal inside coil	
	GLD	TPC gaseous	2.1 m	3 Tesla	W/ Scin.	Pb/ Scin.	Had cal inside coil
	4th	TPC gaseous	1.5 m	3.5 Tesla	 crystal	Dual readout fiber	Double Solenoid (open μ)

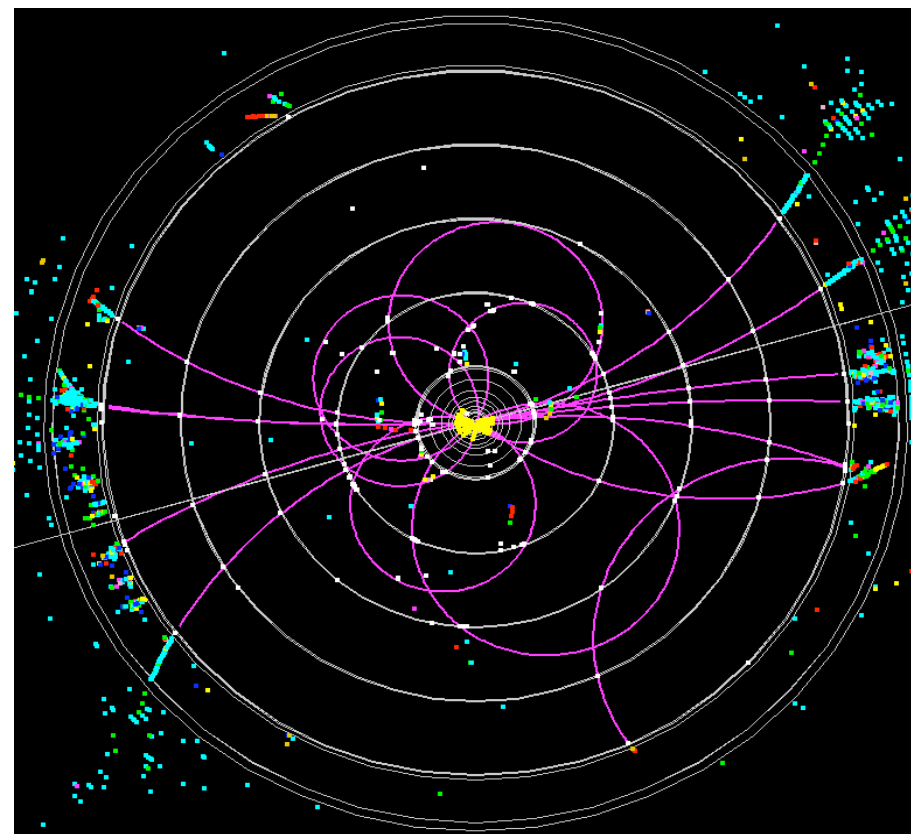
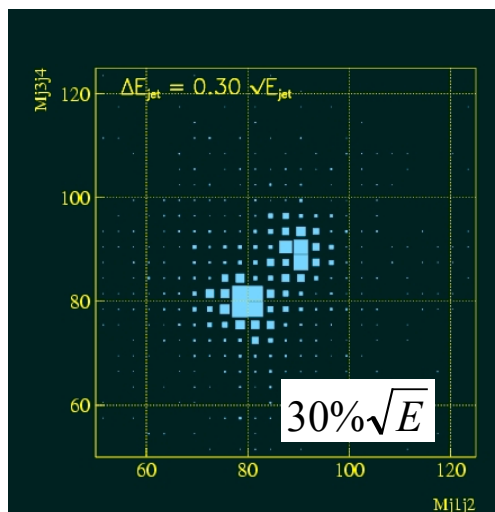
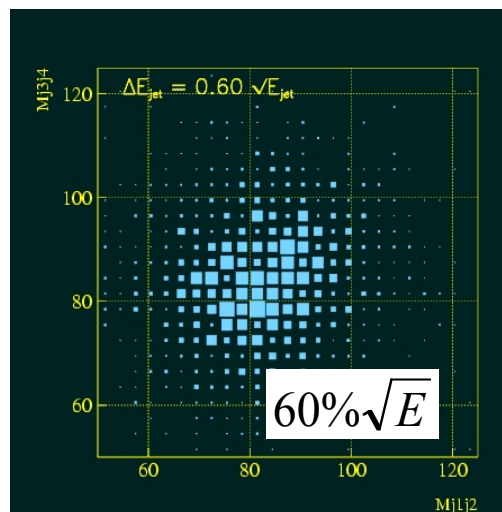


Linear Collider Events

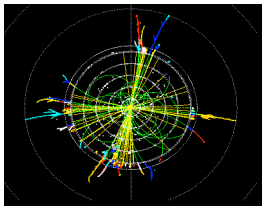


- Simple events (relative to Hadron collider) make particle level reconstruction feasible
- Heavy boson mass resolution requirement sets jet energy resolution goal

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



**This event shows
single bunch crossing in tracker,
150 bunches in the vertex detector**



Detector R&D Required

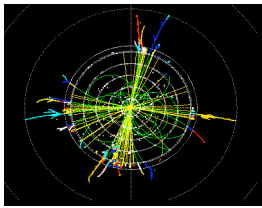


- Performance requirements for ILC Detector exceed state-of-the-art
 - Calorimeters with ~100 million cells being developed for PFA
 - Jet resolution goal $\sim 3\text{-}4\%$ for $E_{\text{jet}} > 100 \text{ GeV}$
 - Pixel Vertex Detector with $\sim 10^9 \leq 20 \text{ }\mu\text{m}$ pixels
 - Impact parameter resolution $5 \text{ }\mu\text{m} \oplus 10 \text{ }\mu\text{m}/(p \sin^{3/2} \theta)$
 - Sensitivity to full 1 msec bunchtrain
 - Tracking resolution $\sigma(1/p) \leq 5 \times 10^{-5} / \text{GeV}$
 - TPC with silicon
 - Silicon microstrips
 - High Field Solenoid up to 5 Tesla
 - High quality forward tracking systems
 - Triggerless readout

- R&D Essential

DISCOVERY OPPORTUNITY IS GREAT

- limited by detector performance
 - small cross sections/significant backgrounds
- advances different from LHC required

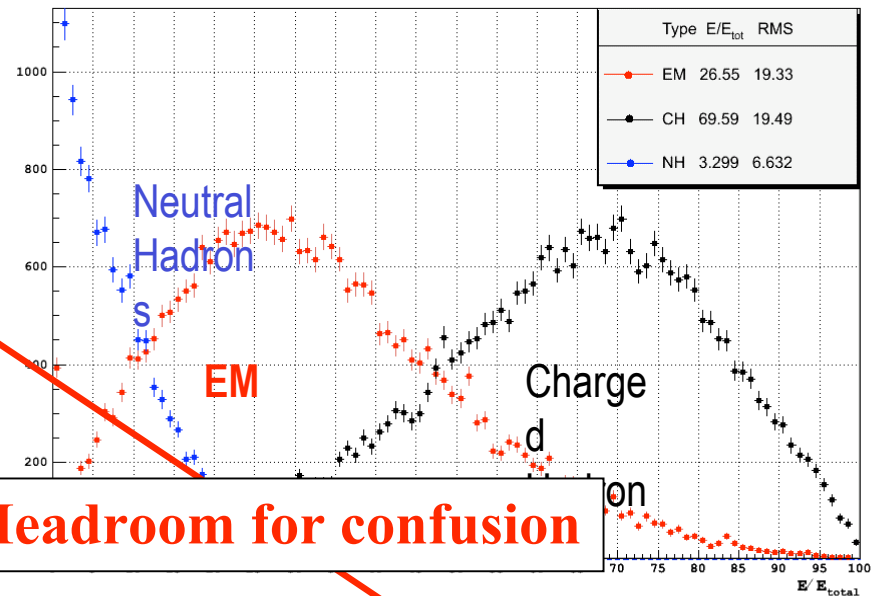


Jet Energy Measurement via Particle Flow



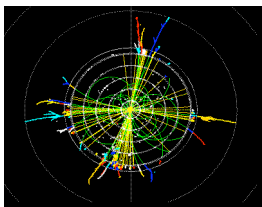
Current paradigm: Particle Flow

- Jet resolution goal is 3-4% above 100 GeV
- In jet measurements, use the excellent resolution of tracker, which measures bulk of the energy in a jet



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

< 2% @ 100 GeV



EM Calorimetry

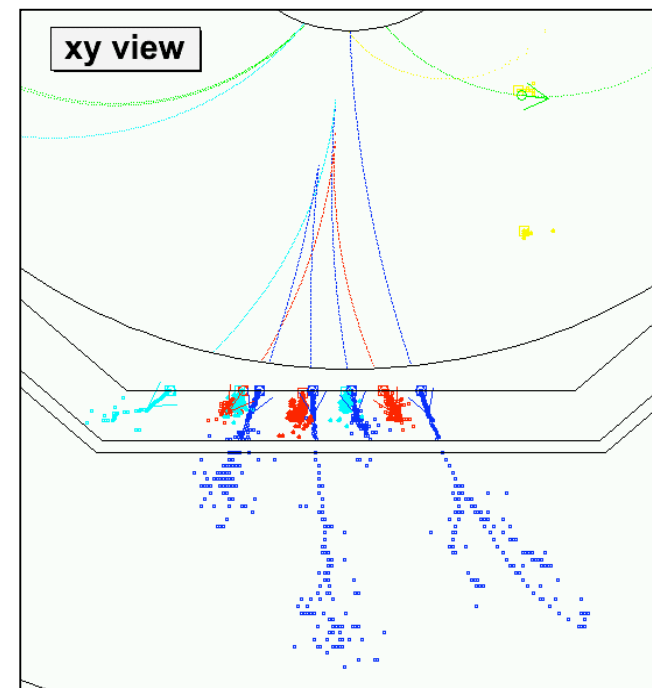


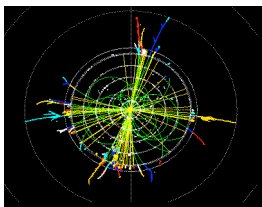
- **Physics with isolated electron and gamma energy measurements require $\sim 10\text{-}15\% / \sqrt{E} \oplus 1\%$**
- **Particle Flow Calorimetry requires fine grained EM**

calorimeter to separate neutral EM clusters from charged tracks entering the calorimeter

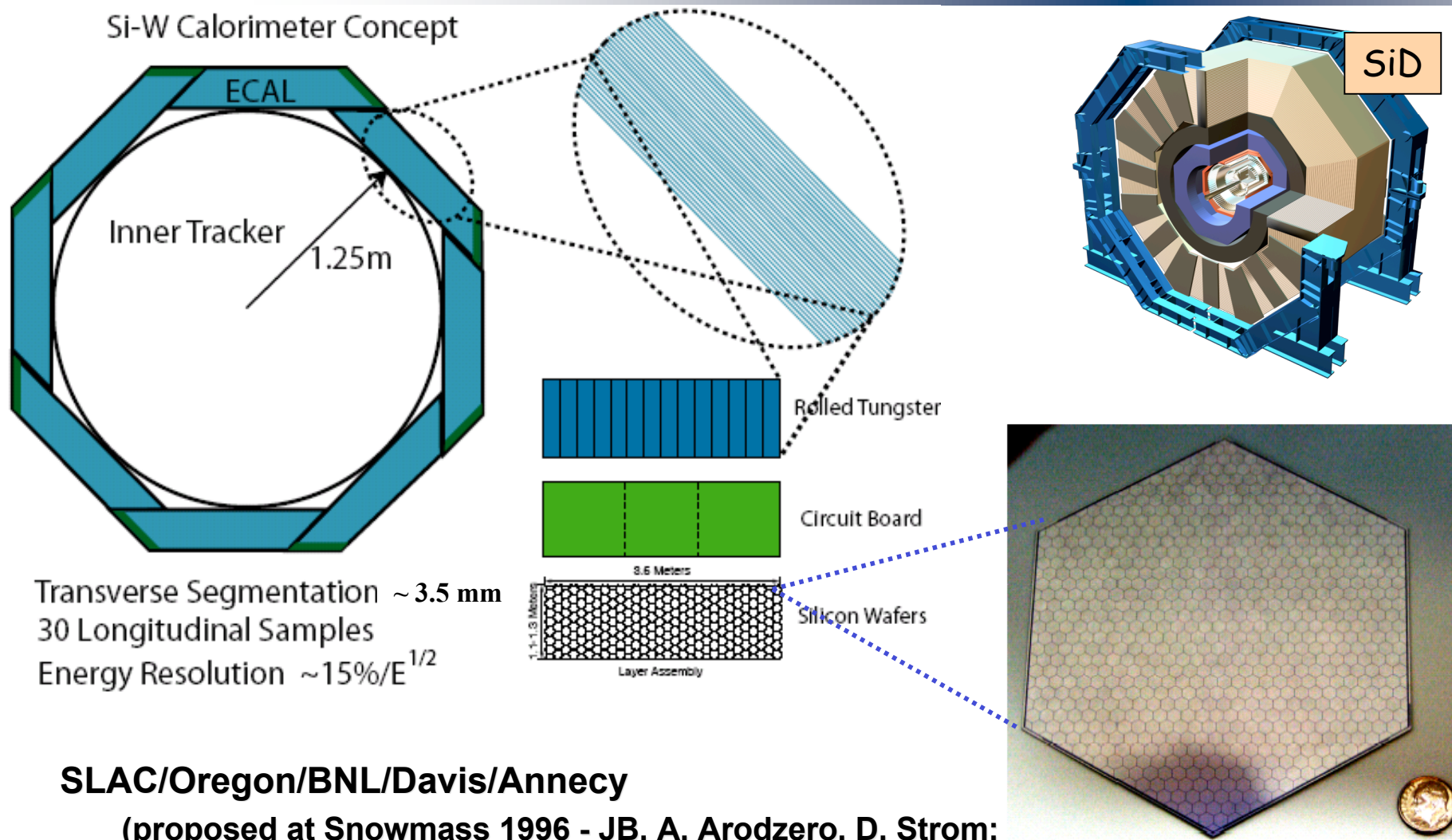
- ↪ **Small Moliere radius**
 - ❖ Tungsten
- ↪ **Small sampling gaps – so not to spoil R_M**
- ↪ **Separation of charged tracks from jet core helps**
 - ❖ Maximize BR^2
- ↪ **One technology choice – Si/W calorimeter**
 - ❖ Good success using Si/W for Luminosity monitors at SLD, DELPHI, OPAL, ALEPH
 - ❖ Oregon/SLAC/BNL/Davis/Annecy
 - ❖ CALICE Si/W - also MAPS
- ↪ **Another approach - Scintillator sampling**

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





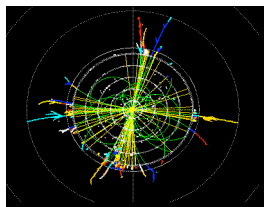
Silicon/Tungsten EM Calorimeter



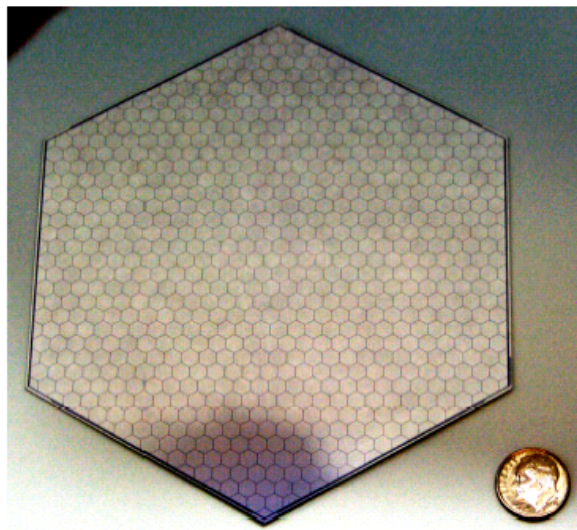
SLAC/Oregon/BNL/Davis/Annecy

(proposed at Snowmass 1996 - JB, A. Arodzero, D. Strom:
Proceedings - 1996 DPF/DPB Summer Study, pg. 437 (1997))

Si/W also being developed by CALICE Collaboration



Silicon/Tungsten EM Calorimetry for ILC



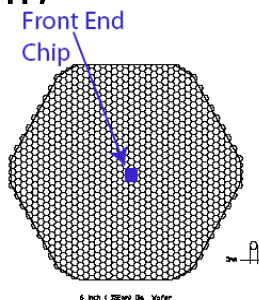
SLAC/Oregon/BNL/Davis/Annecy

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

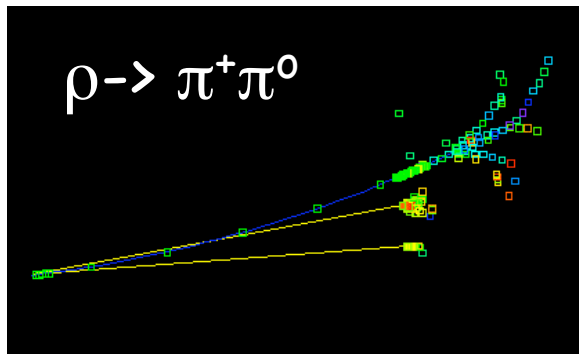
- Pads: 12 mm² to match Moliere radius ($\sim R_m/4$)
- Each six inch wafer read out by one chip
- < 1% crosstalk

Electronics design

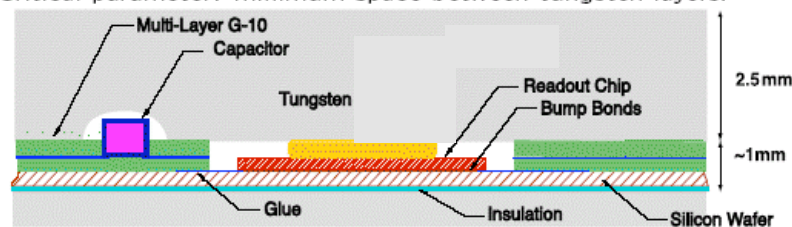
- Noise < 2000 electrons
- Single MIP tagging (S/N ~ 7)
- Dynamically switchable feedback capacitor scheme achieves required dynamic range: 0.1-2500 MIPs – 4 deep storage/bunch train

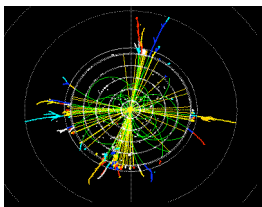


Passive cooling – conduction in W to edge



Critical parameter: minimum space between tungsten layers.

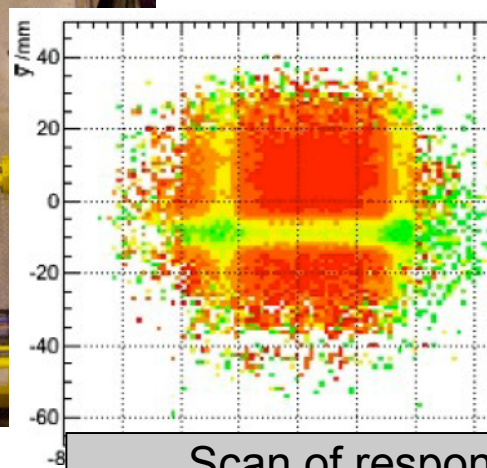
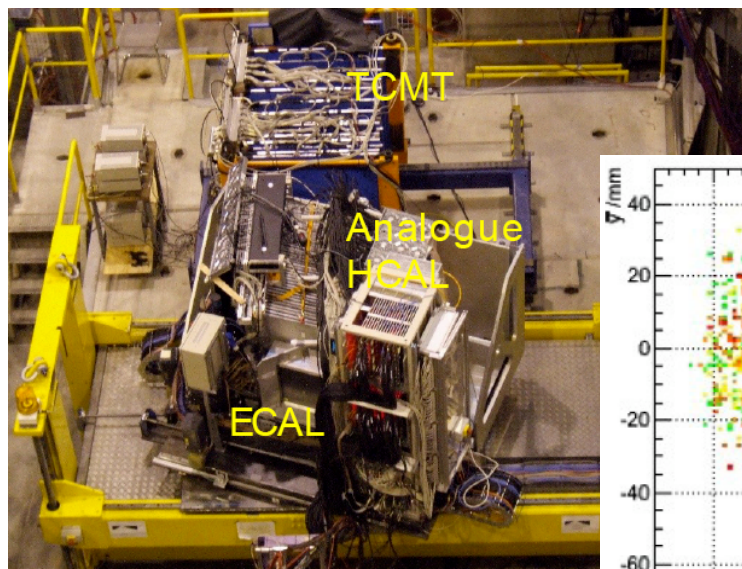




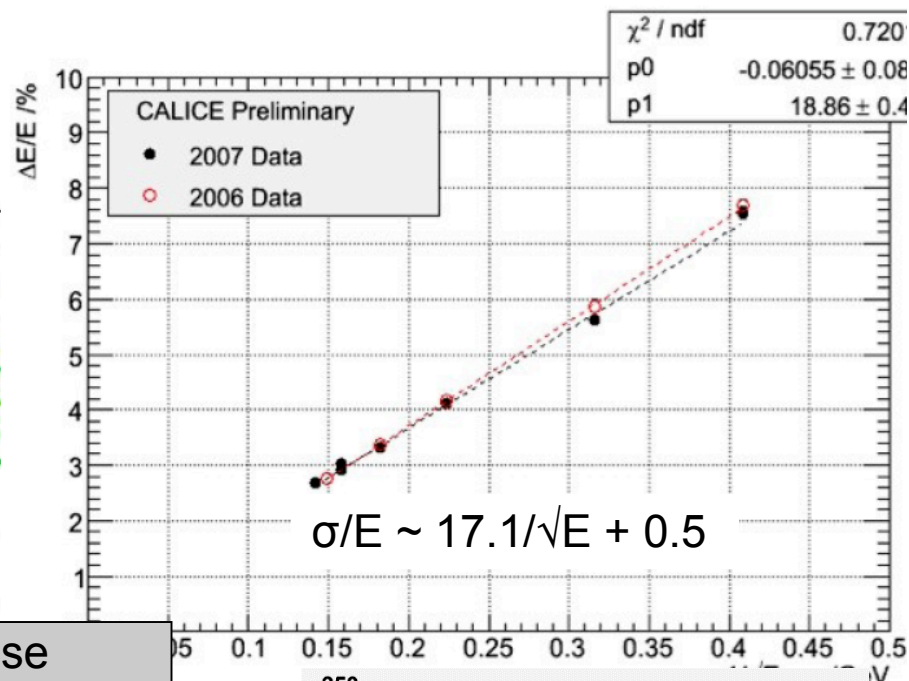
CALICE EM Cal Beamtest



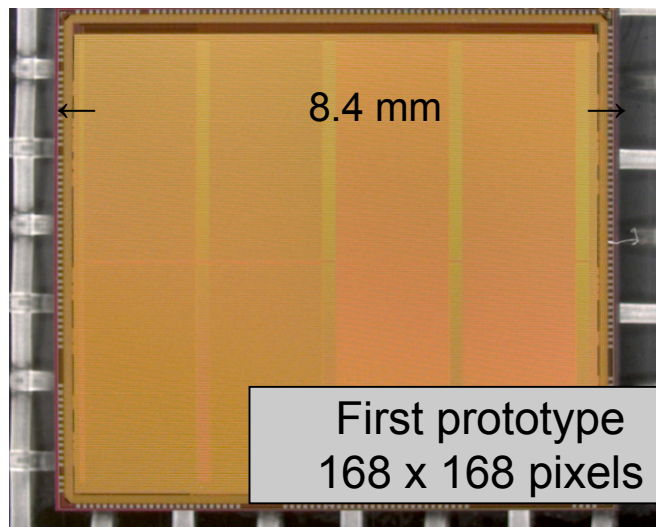
○ Silicon



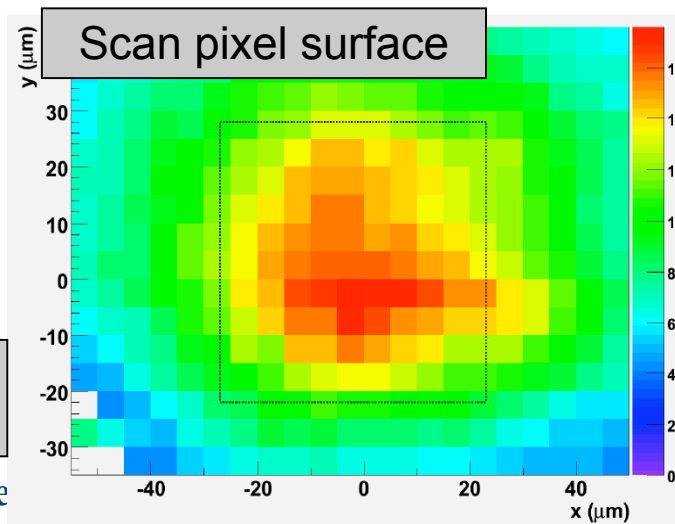
Scan of response
between wafer



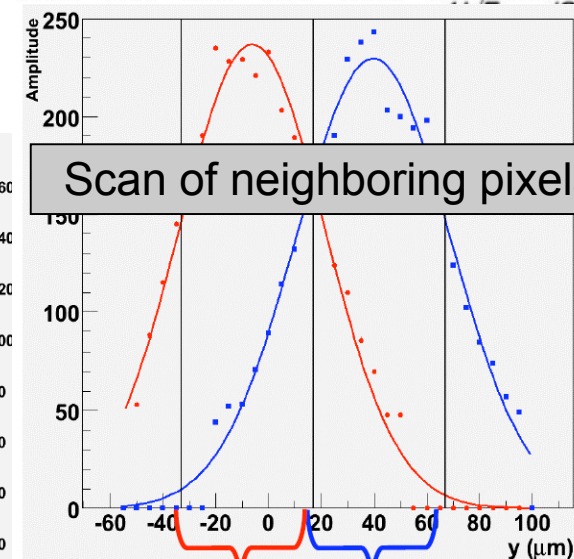
○ MAPS



First prototype
168 x 168 pixels

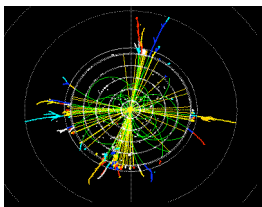


Scan pixel surface



Scan of neighboring pixels

Pixel A Pixel B



Hadron Calorimetry

Again Highly Segmented – for Particle Flow

- Longitudinal: ~ 40 samples
- $4 - 5 \lambda$ (limited by cost - coil radius)
- Would like fine (1 cm^2 ?) lateral segmentation
- For 10000 m^2 of 1 cm^2 HCAL = 10^8 channels – cost !

Two Main Options:

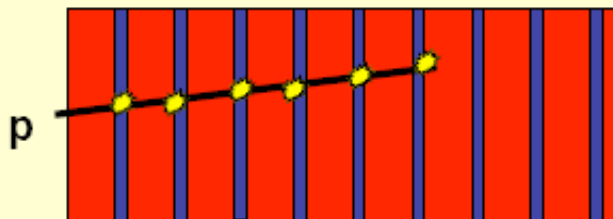
- ★ **Tile HCAL (Analogue readout)**
Steel/Scintillator sandwich
Lower lateral segmentation
 $\sim 3 \times 3 \text{ cm}^2$ (motivated by cost)
- ★ **Digital HCAL**
High lateral segmentation
 $\sim 1 \times 1 \text{ cm}^2$
digital readout (granularity)
RPCs, wire chambers, GEMS...

OPEN QUESTION

★ **Third Option: Dual Readout**
Dream or FNAL/Pb Glass

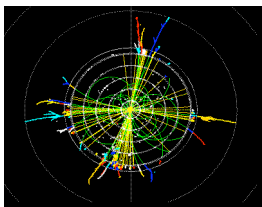
The Digital HCAL Paradigm

- Sampling Calorimeter:
Only sample small fraction of the total energy deposition



- Energy depositions in active region follow highly asymmetric Landau distribution

M. Thomson



CALICE Hadron Calorimetry

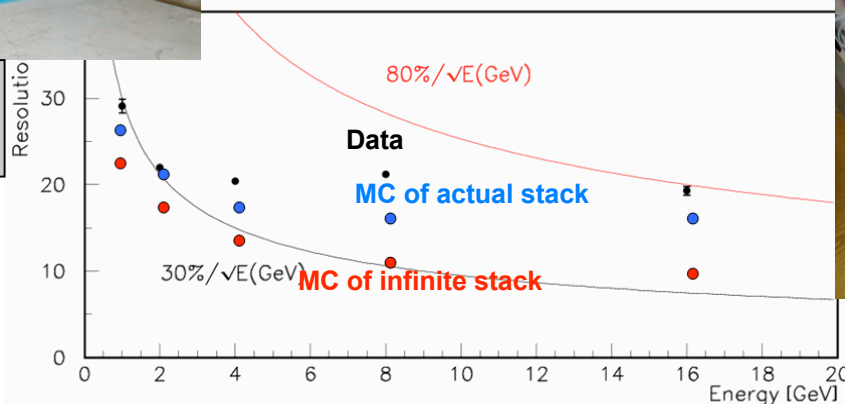


RPC HCAL

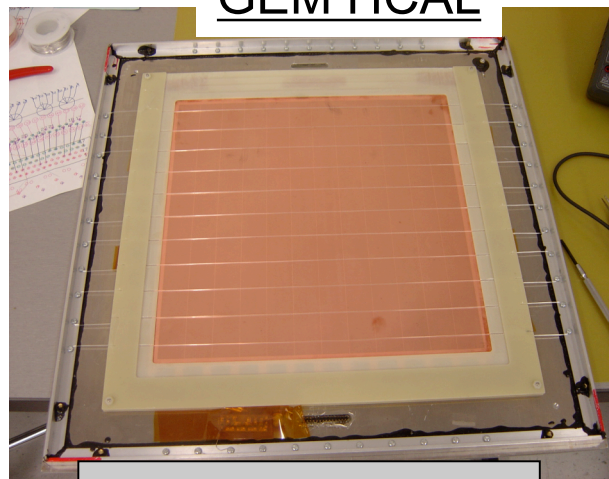


Scintillator HCAL

Vertical Slice Test
at FNAL



GEM HCAL



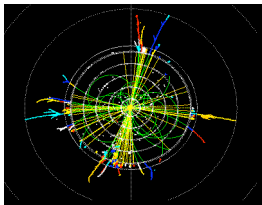
New GEM chamber

Scintillator HCAL

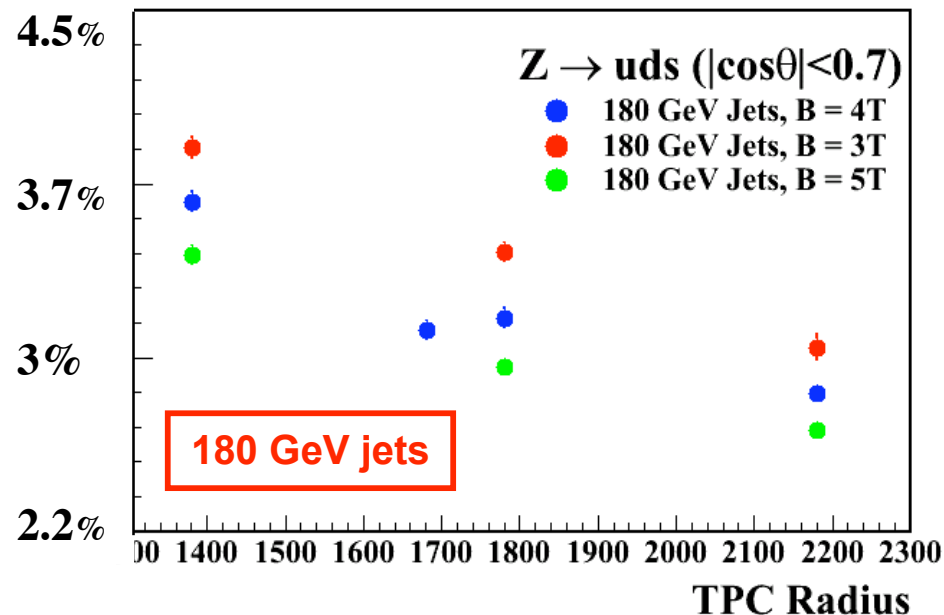
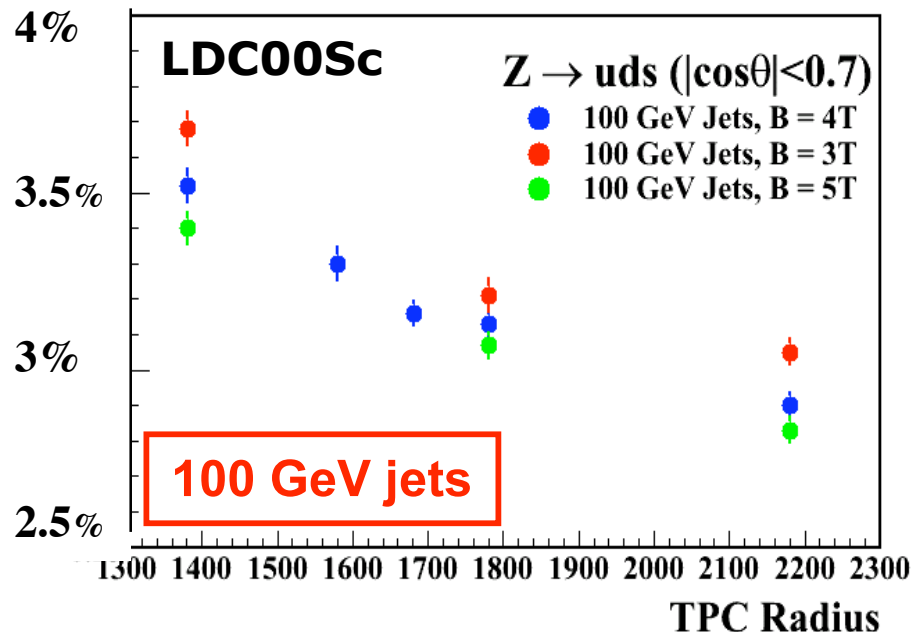


Employs SiPM

One of 40 layers
of the prototype section



Simulated Jet Measurement via Particle Flow



★ LDC Jet energy performance
found to depend mainly on:

- ♦ HCAL thickness
- ♦ TPC Radius
- ♦ B-field

100 GeV Jets

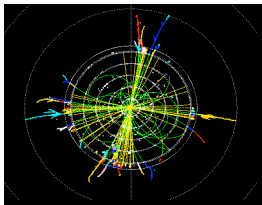
$$\alpha = 0.315 \left(\frac{B}{4} \right)^{-0.19} \left(\frac{R}{1.68} \right)^{-0.49} \left(1 + 6.3e^{-\frac{N}{8.0}} \right)$$

180 GeV Jets

$$\alpha = 0.42 \left(\frac{B}{4} \right)^{-0.31} \left(\frac{R}{1.78} \right)^{-0.61} \left(1 + 21.6e^{-\frac{N}{7.1}} \right)$$

← Empirical Parametrizations

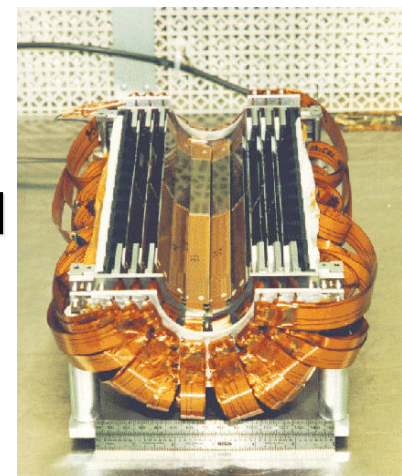
M. Thomson



Tracking



- **Tracking for any modern experiment should be conceived as an integrated system, combined optimization of:**
 - ↗ **the inner tracking (vertex detection)**
 - ↗ **the central tracking**
 - ↗ **the forward tracking**
 - ↗ **For ILC, 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 ILC**
- **Track reconstruction in the vertex detector impacts the role of the central and forward tracking system**



Inner Tracking/Vertex Detection for the ILC

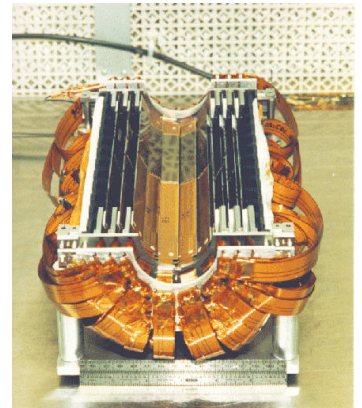


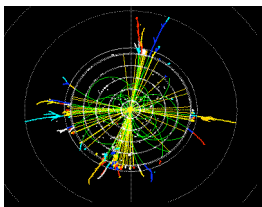
Detector Requirements

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

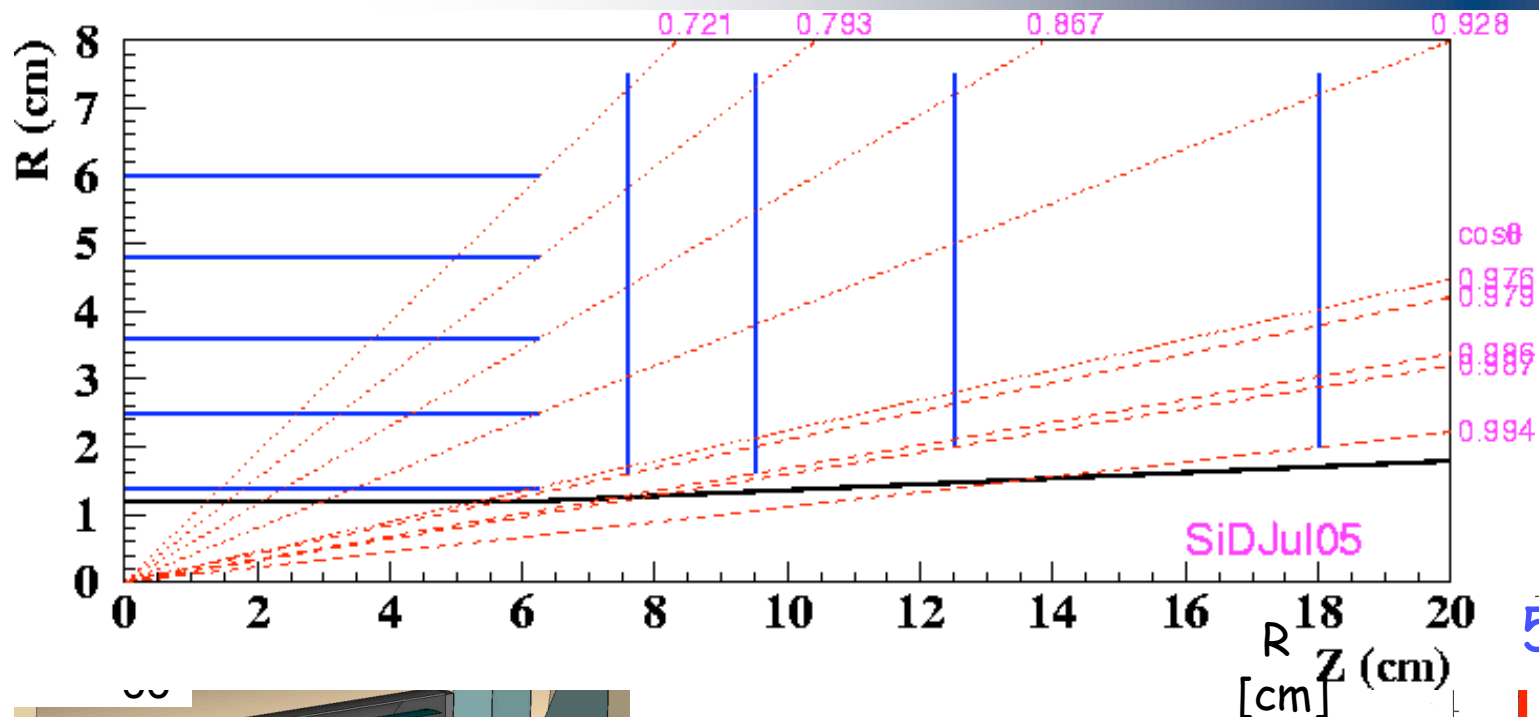
Concepts under Development for International Linear Collider

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

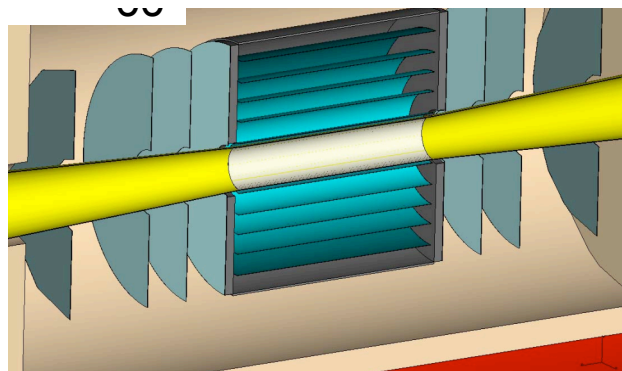




SiD Vertex Detector Layout



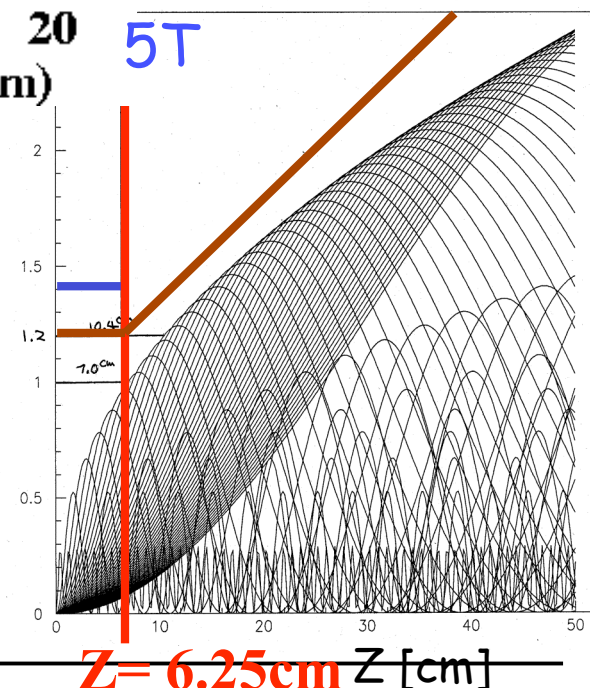
5 barrel layers
4 end disks

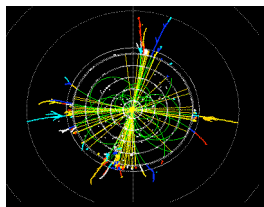


Design drivers:

Smallest radius possible
Clear pair background

Role: Seed tracks & vertexing
Improve forward region

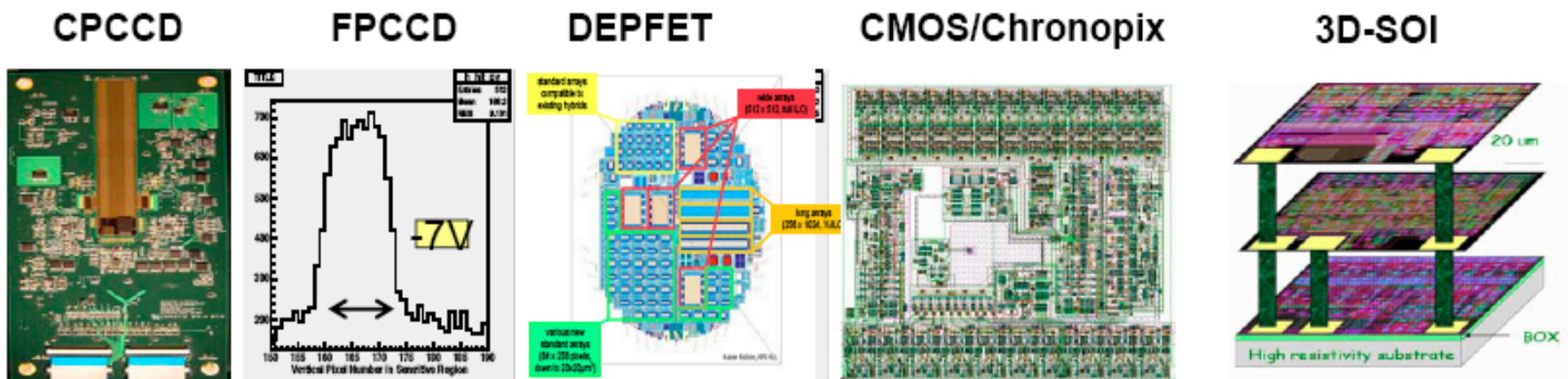




ILC Vertex Detector R&D

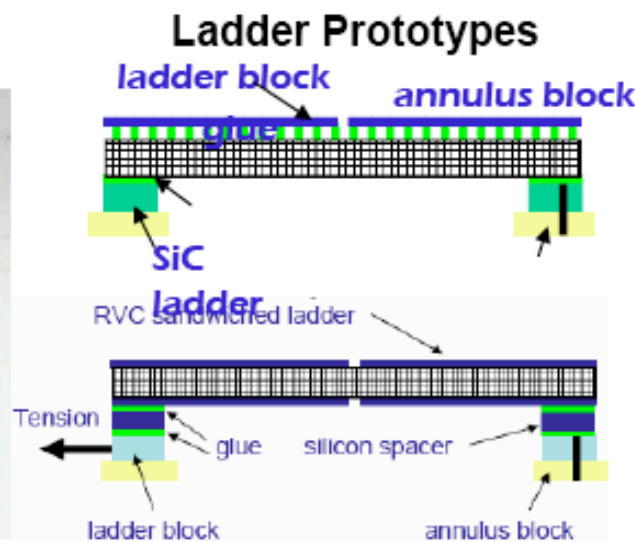


- Development of ILC compatible VXD Sensors

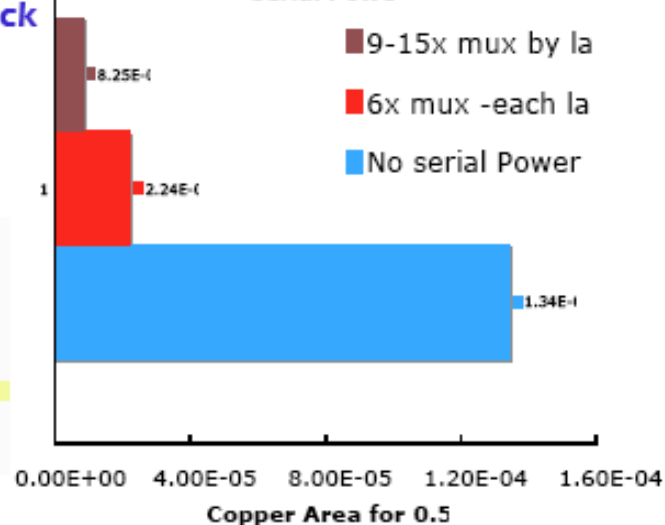


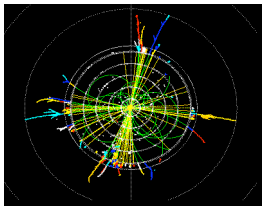
- Progress on Integration Issues (mechanics, power, heat,...)

Structures



Serial Power





Central Tracking



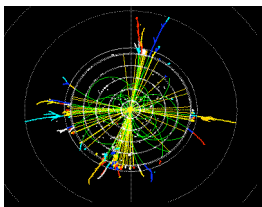
○ Two general approaches being developed for the ILC

TPC (GLD, LDC, 4th)

- Builds on successful experience of PEP-4, ALEPH, ALICE, DELPHI, STAR,
- Large number of space points, making reconstruction straightforward
- $dE/dx \Rightarrow$ particle ID, bonus
- Minimal material, valuable for calorimetry
- Tracking up to large radii

Silicon (SiD)

- Superb spacepoint precision allows tracking measurement goals to be achieved in a compact tracking volume
- Robust to spurious, intermittent backgrounds
 - ILC is not a storage ring



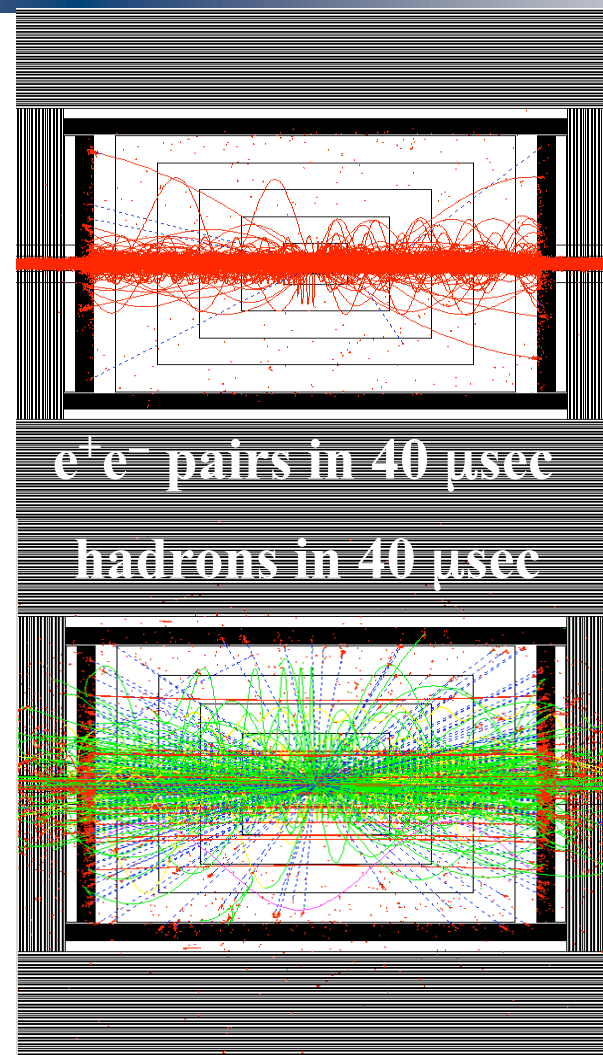
Central Tracking with TPC

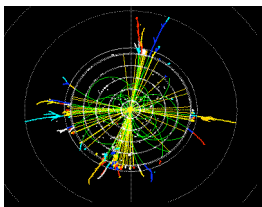


Issues for an ILC TPC

- Optimize novel gas amplification systems
 - ✦ Conventional TPC readout based on MWPC and pads
 - ❖ limited by positive ion feedback and MWPC response
 - ✦ Improvement by replacing MWPC readout with micropattern gas chambers (eg. GEMs, Micromegas, Medipix)
 - ❖ Small structures (no E×B effects)
 - ❖ 2-D structures
 - ❖ Only fast electron signal
 - ❖ Intrinsic ion feedback suppression
- Neutron and gamma backgrounds (~100 bunch crossings)
- Optimize single point and double track resolution
- Performance in high magnetic fields
- Demonstrate large system performance with control of systematics
- Minimize impact of endplate

GLOBAL COLLABORATION ADDRESSING THESE ISSUES WITH COORDINATED R&D (LCTPC)



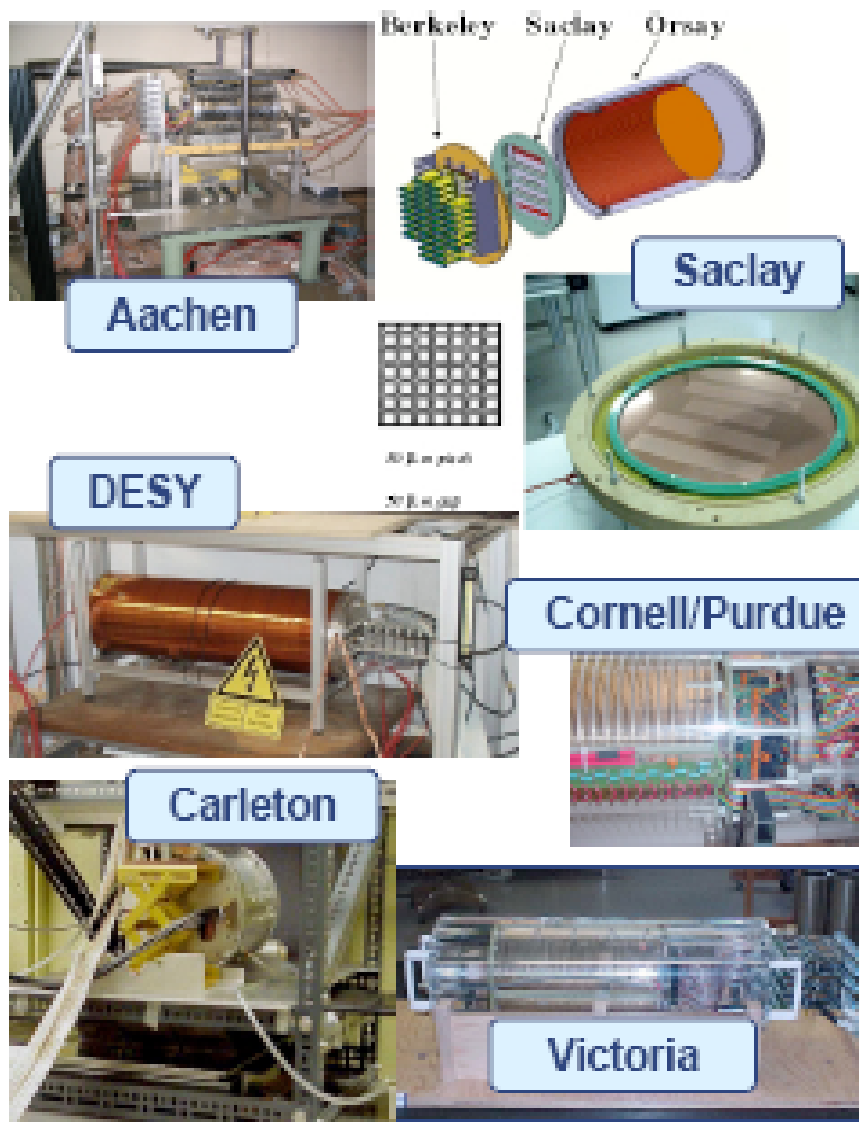


Central Tracking with TPC



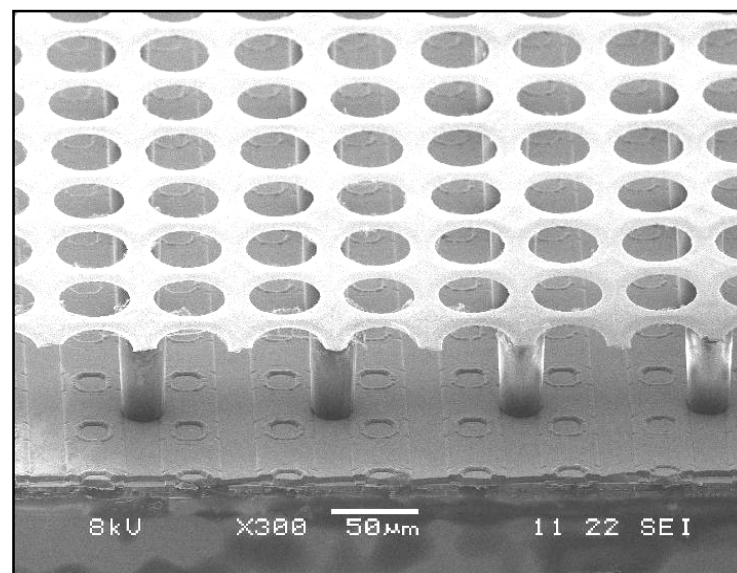
Spatial Resolution Studies

Small prototypes



Medipix / timepix

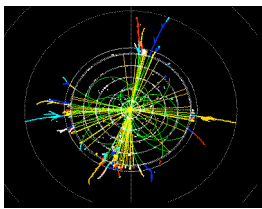
Very fine segmentation with silicon sensors
 $55 \mu\text{m} \times 55 \mu\text{m}$ pixels



Large Prototype Being Constructed

test beams/cosmic ray oper. in a magnet

- tiled endplate
- modules/different ampl. tech.
- high density electronics



Central Tracking with 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.

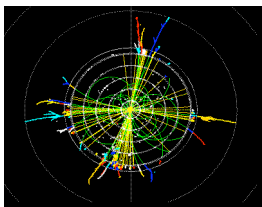
single bunch timing

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

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

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

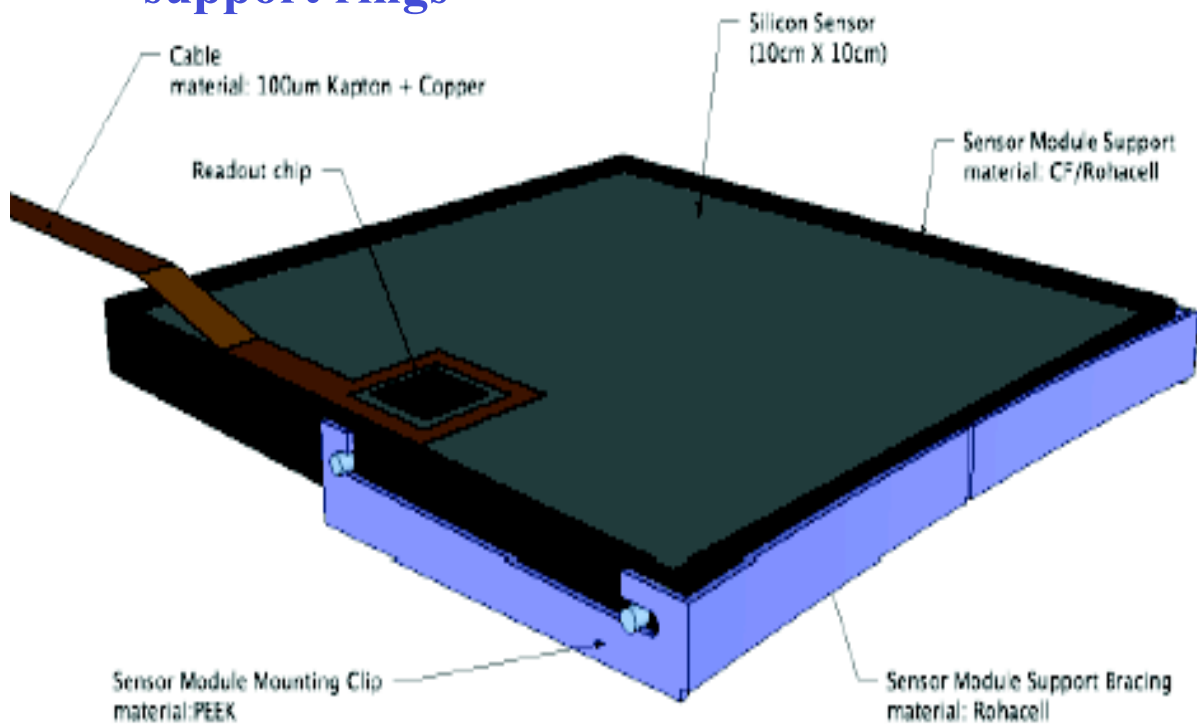
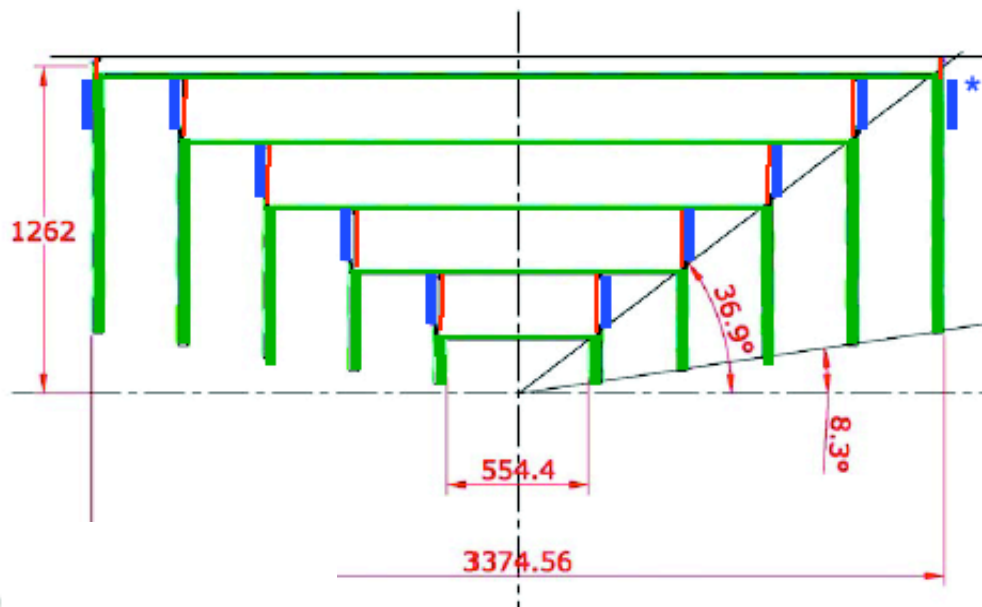


Silicon Tracking (SiD)

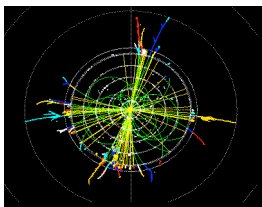


- No cooling
- Closed CF/Rohacell cylinders
- Nested support via annular rings
- Power/readout motherboard mounted on support rings

SID_{00}



- Cylinders tiled with 10x10cm sensors with readout chip
- Single sided (ϕ) in barrel
- R, ϕ in disks
- Modules mainly silicon with minimal support (0.9% X_0)
- Overlap in ϕ and z



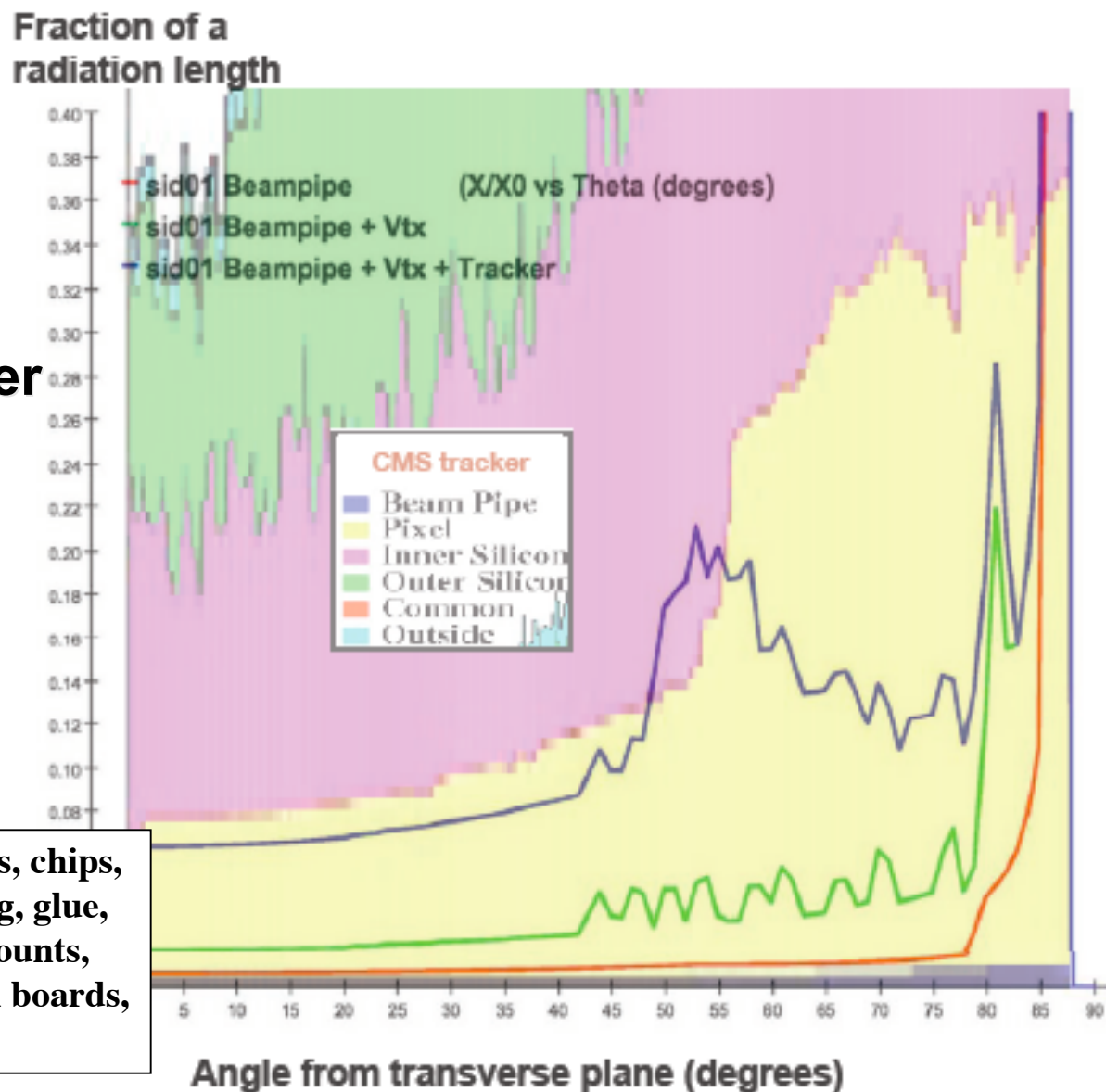
Material Budget of Silicon Tracker (SiD)



~ 0.9 %/layer
at normal incidence

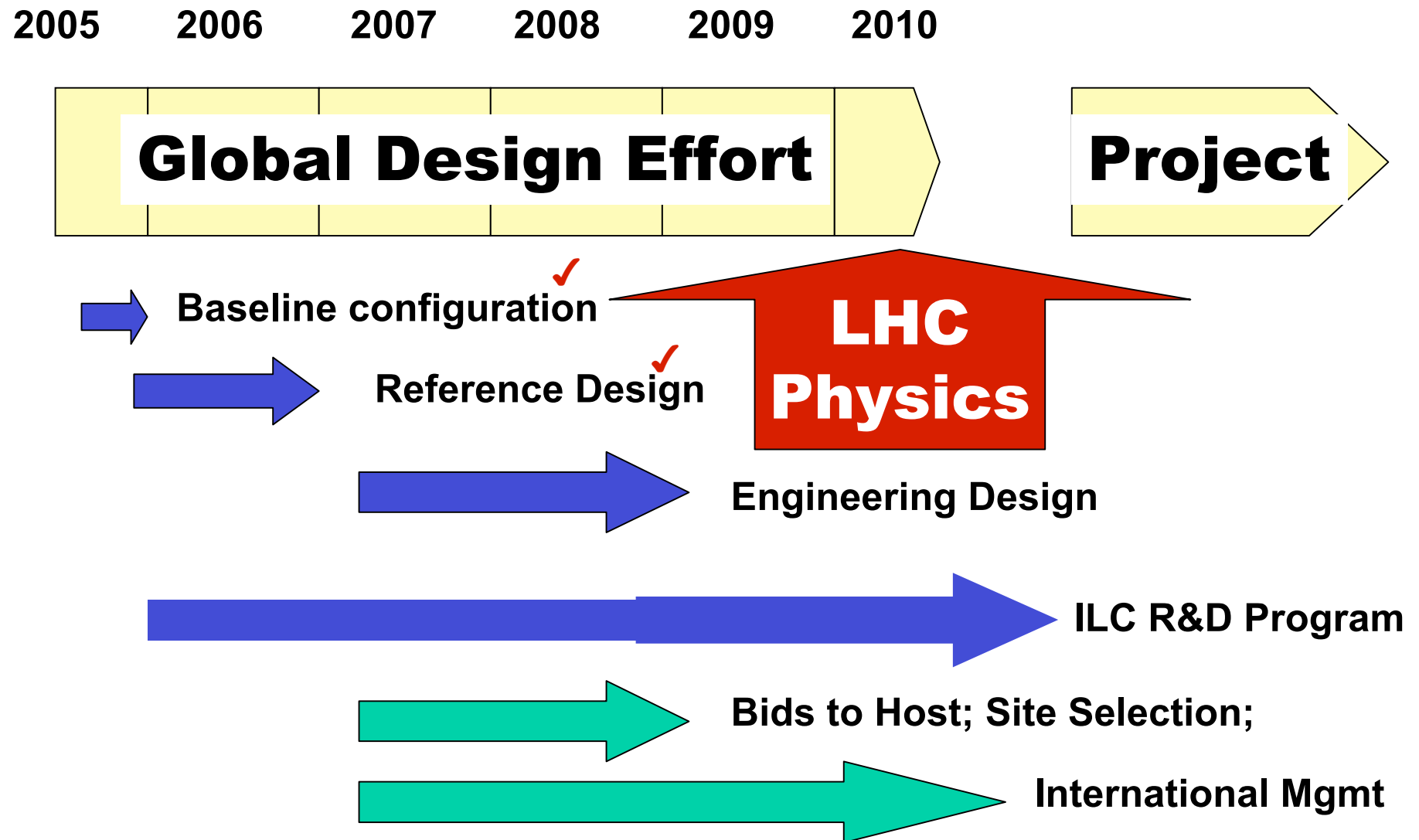
- No Cooling
- Reduced Readout / Power
 - ↗ Chips
 - ↗ Hybrids
 - ↗ Cables
- Minimal Support
- Thin Sensors

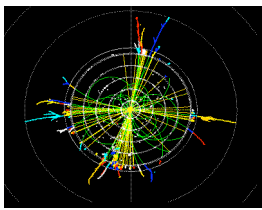
Included in GEANT: sensors, chips, cables, connectors, bypassing, glue, module supports, module mounts, overlaps, power distribution boards, DAQ for baseline design.



The GDE Plan and Schedule

focused on collider

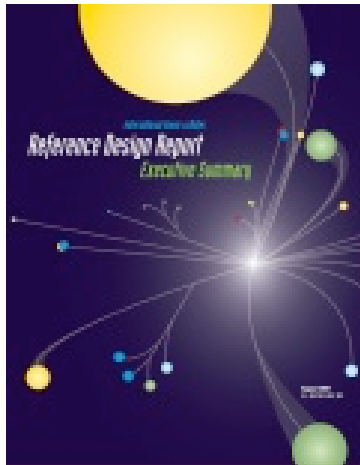




ILC Reference Design Report



- **Four volume report released**
- **Available at <http://linearcollider.org>**



**1. Executive
Summary**



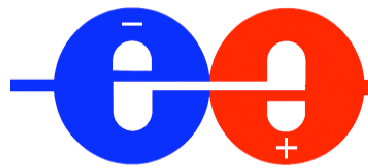
2. Physics



3. Accelerator



4. Detectors



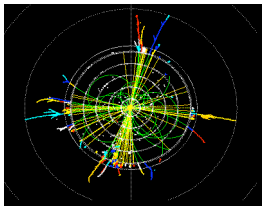
Worldwide Study of
the Physics and Detectors

for Future Linear
e⁺ e⁻ Colliders

Detector Roadmap

- 2007 – Writing of Physics and Detector volumes (2 vol. of RDR) ✓
Call for Letters of Intent for ED from Detector groups (due 10/1/08) ✓
ILCSC, Research Director Sakue Yamada
- 2008 – Letters of Intent received by ILCSC, RD
International Detector Advisory Group reviews LOIs
Guides community to the definition of two detectors for
EDR preparation
Collaborations formed to develop EDRs
- 2009-2010/11 – Development of two engineered designs,
produce first engineering design reports (EDRs) for the two overall detectors,

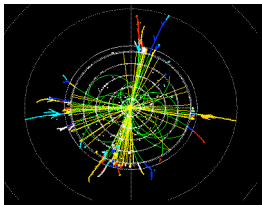
*NOTE - THESE EFFORTS NEED NOT REPRESENT THE FINAL SELECTION OF DETECTORS
FOR THE ILC EXPERIMENTAL PROGRAM*



Conclusion

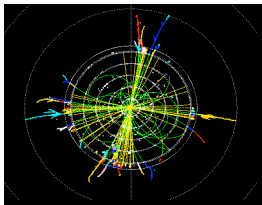


- **Electroweak precision measurements indicate the physics at the LHC and ILC will be rich**
- **The International Linear Collider will be a powerful tool**
 - ↳ **Electroweak Symmetry Breaking**
 - origin of mass**
 - other fundamental physics**
 - advance understanding of LHC discoveries**
- **DISCOVERY OPPORTUNITIES at the ILC will be limited by detector performance**
 - advances different from LHC required**
 - program of ILC Detector R&D is developing these capabilities**



BACK UP

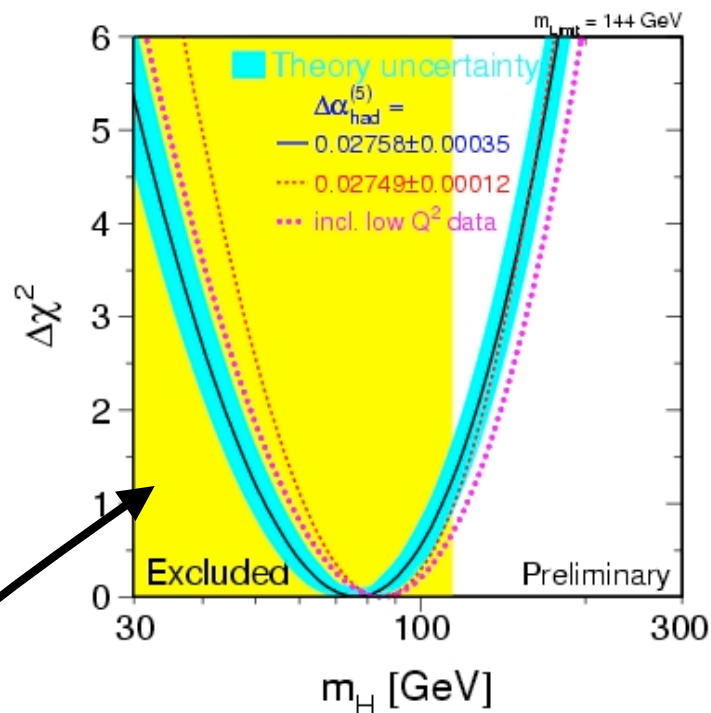




Light Standard Model-like Higgs

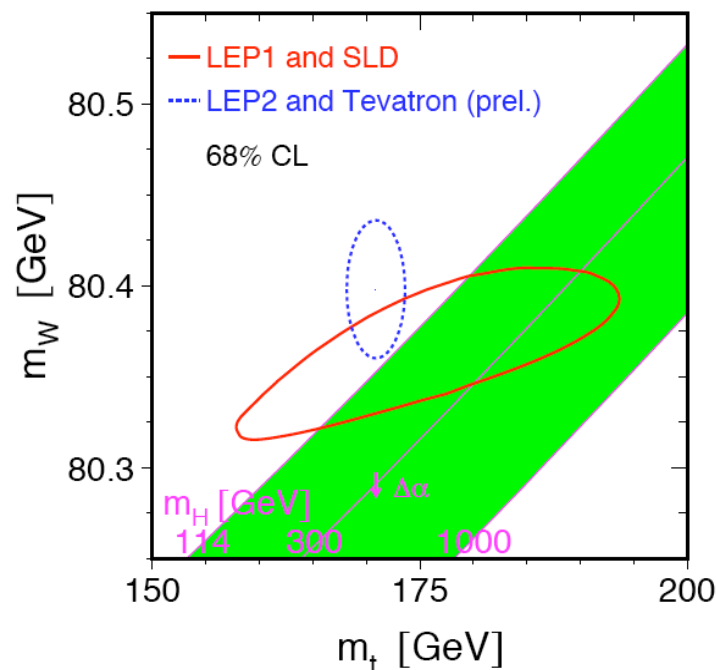


JULY 2007

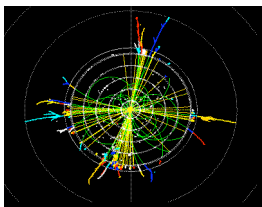


(SM) $M_{\text{higgs}} < 144 \text{ GeV}$ at 95% CL.

LEP2 direct limit $M_{\text{higgs}} > 114.4 \text{ GeV}$.



W mass ($\pm 25 \text{ MeV}$)
and top mass ($\pm 2 \text{ GeV}$)
consistent with precision measures
and indicate low SM Higgs mass



Event Rates and Backgrounds



○ Event rates (Luminosity = 2×10^{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

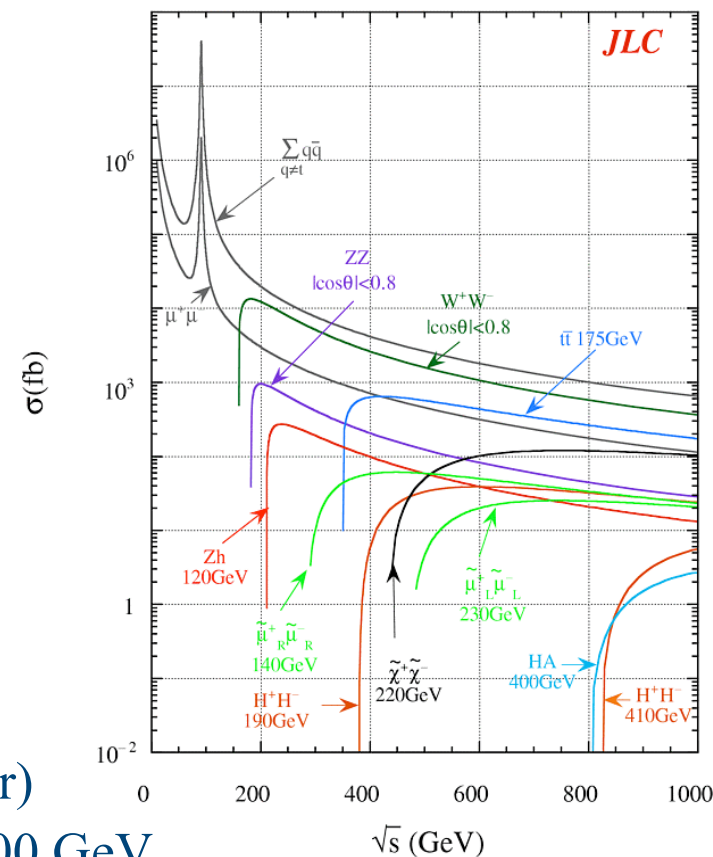
○ Background

➤ $6 \times 10^{10} \gamma$ / BX (from synchrotron radiation,
scatters into central detector)

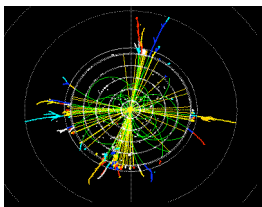
➤ 40,000-250,000 e^+e^- / BX (90-1000 TeV) @ 500 GeV

➤ Muons: < 1 Hz/cm² (w/ beamline spoilers)

➤ Neutrons: $\sim 3 \times 10^8$ /cm²/ yr @ 500 GeV



Ref: Maruyama, Snowmass 2005



An example: Chronopixel (CMOS)



Yale/Oregon/Sarnoff

○ Completed Macropixel design last year

⇒ Key feature – stored hit times (4 deep)

⇒ 645 transistors

⇒ Spice simulation verified design

⇒ TSMC 0.18 μm ⇒ ~50 μm pixel

❖ Epi-layer only 7 μm

❖ Future >15 μm epi-layer

⇒ 90 nm ⇒ 20-25 μm pixel

○ January, 2007

⇒ Completed design - Chronopixel

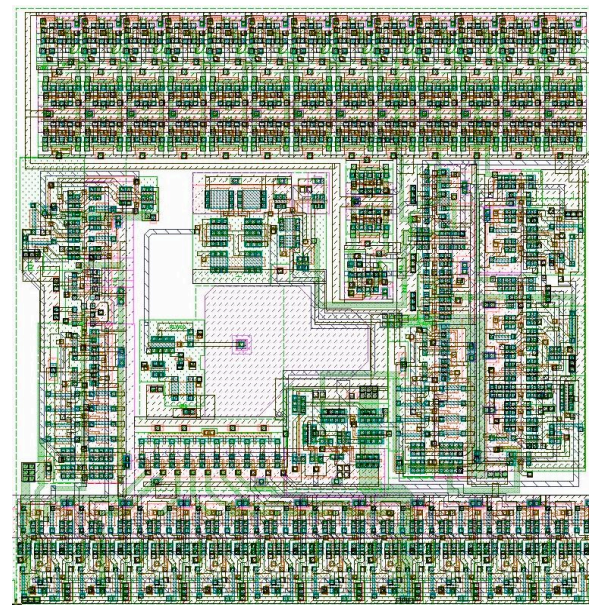
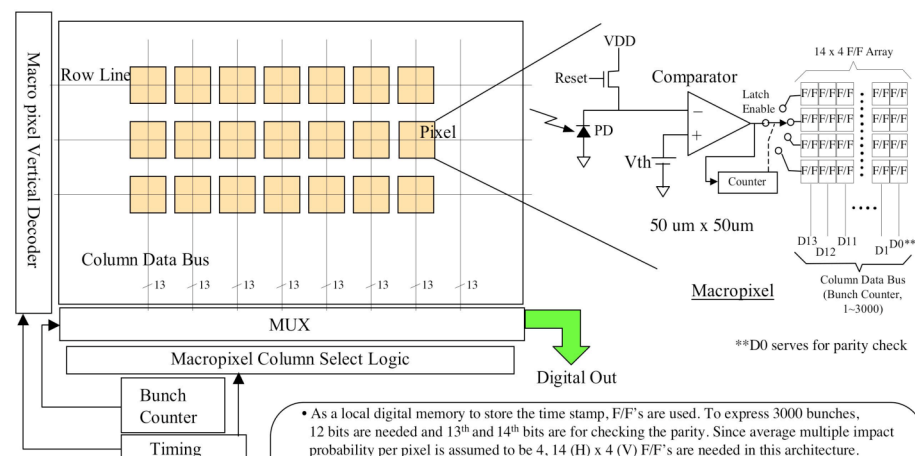
⇒ Deliverable – tape for foundry

○ Fab underway

⇒ 50 μm Chronopixel array

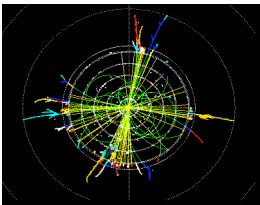
❖ Demonstrate performance

⇒ Then, 10-15 μm pixel



563
Transistors

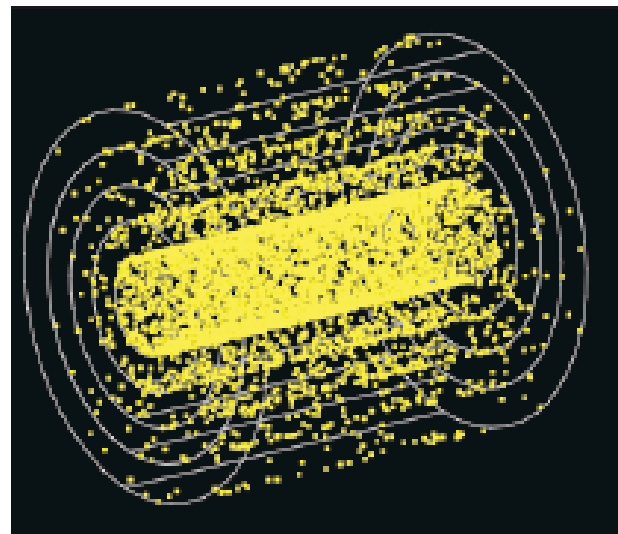
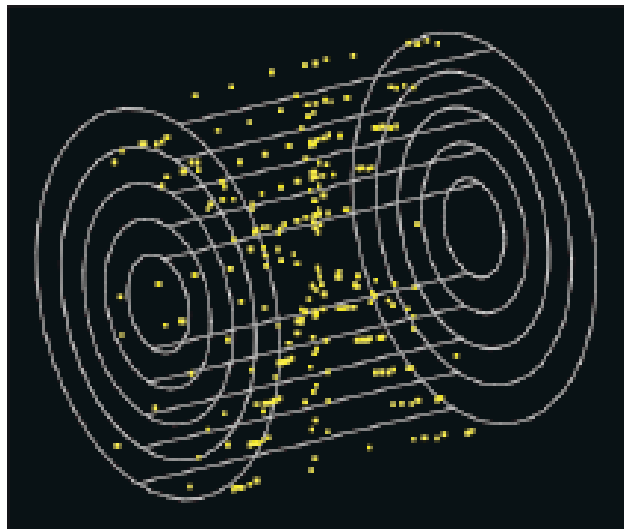
50 μm



Robust Pattern Recognition with Silicon



- $t\bar{t}$ event in VXD w/ backgrounds from 150 bunch crossings
- BUT 1 billion pixels!



clean detection with
time stamping

