ILC 実験および国際協力

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23-Jan-2010
将来計画小委員会

ILC Features

- Well defined initial state
  - e+e- system : 4-momentum known
  - Its polarizations also known
- Energy scan – threshold excitations
  - e.g. $e^+e^- \to Zh, t\bar{t}$ etc.
- Relatively low noise rate (clean!)
- Small beam size, small beampipe
  - $\to$ Hermeticity, good vertex resolution
- Long inter-train gap (200 ms) for readout

- Detector can/should take advantage of the above to achieve good performances

ILC Detector Performances

ILC detectors are designed to meet:

- Vertexing (pixel detectors, CCD)
  - 1/5 $r_{beampipe}$, <1/30 pixel size wrt LHC : b,c tag etc.

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p \sin^{3/2}\theta$$

- Tracking (TPC, Silicon trackers)
  - 1/6 material, 1/10 resolution of LHC: tagged Higgs etc.

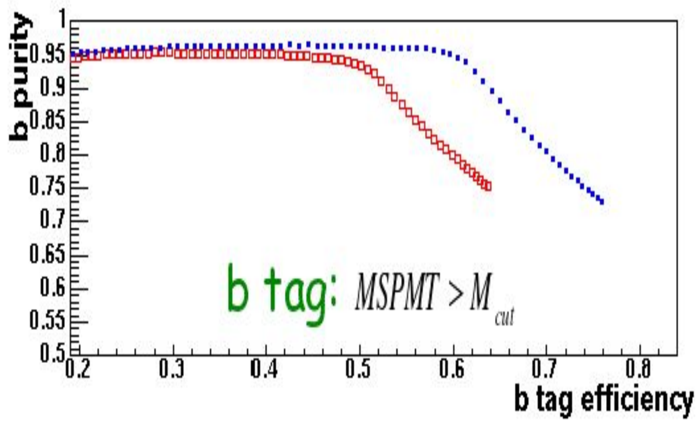
$$\sigma(1/p) = 5 \times 10^{-5} / \mathrm{GeV}$$

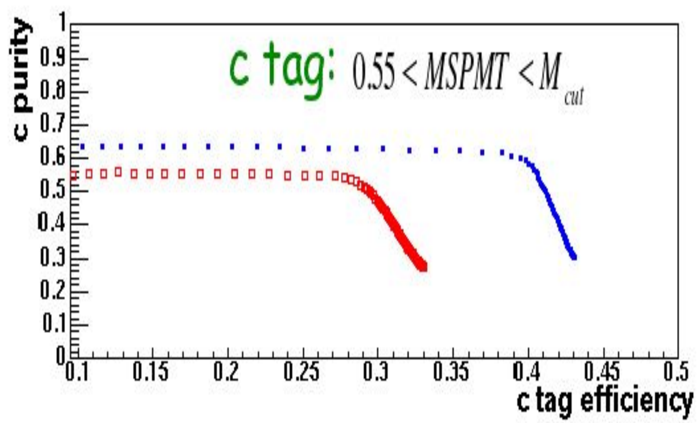
- Jet energy (Fine-grain calorimeters)
  - 1/2 of LHC

$$\sigma_E / E = 0.3 / \sqrt{E(\mathrm{GeV})}$$

(http://blueox.uoregon.edu/~lc/randd.pdf)

Vertexing requirement (bc-tagging)





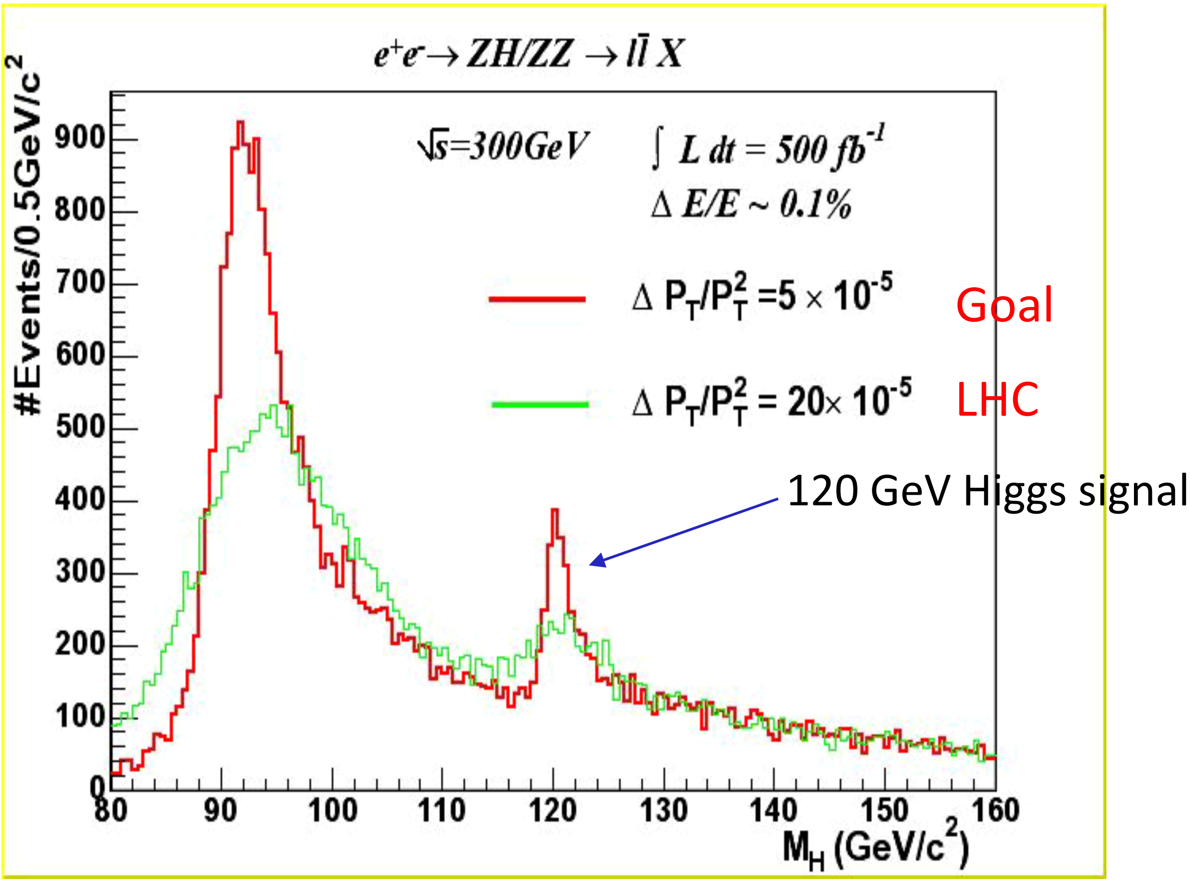
Pixel vertex detector

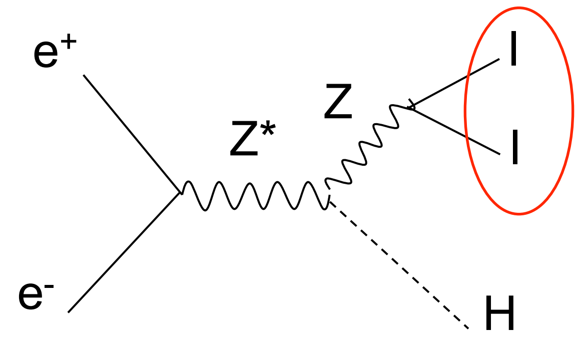
- 4-layer
  0.3 % X_0/ layer
  r_{bp} = 2 cm

- 5-layer
  0.1 % X_0/ layer
  r_{bp} = 1 cm
  (~goal resolution)

Tracking requirement

-Higgs recoil mass resolution (quick simulator)



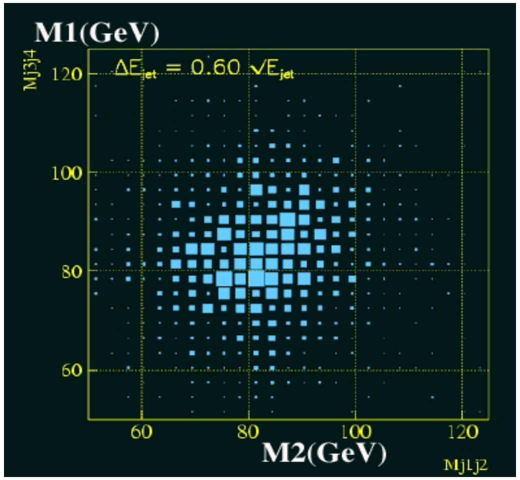


Jet(quark) reconstruction requirement
(quick simulator)

$$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \quad W/Z \to jj$$

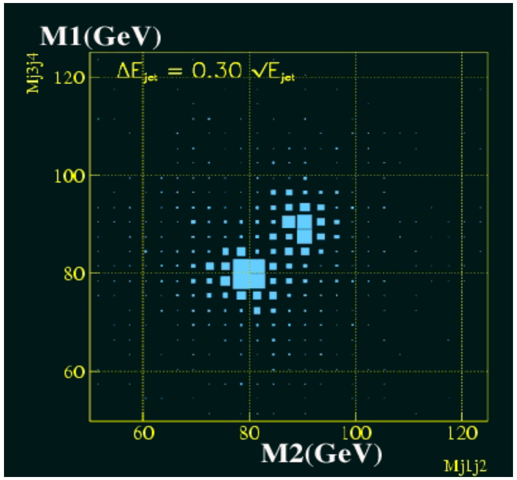
(Important mode if no Higgs is found. Strong EWSB)

LHC



$$\sigma_E / E = 0.6/\sqrt{E(\mathrm{GeV})}$$

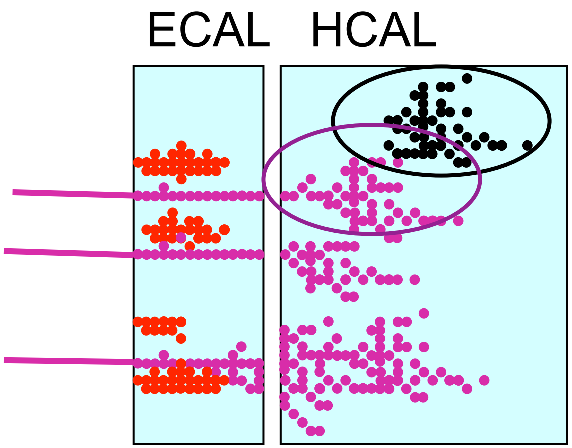
Goal

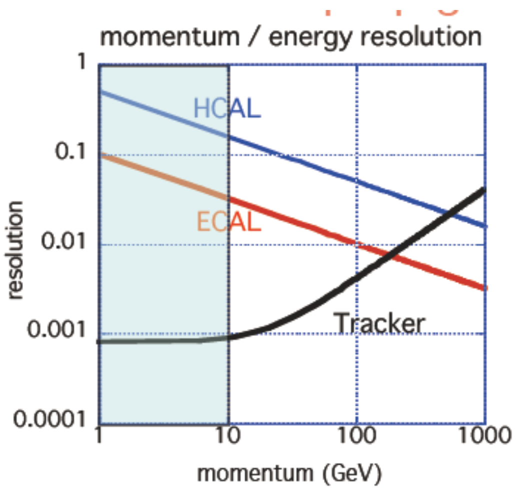


$$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

- $\sigma_E / E = 0.3/\sqrt{E}$ up to ~100 GeV is required for Z/W→jj to be separated
- A promising technique : PFA (particle flow algorithm)

PFA (Particle Flow Algorithm)



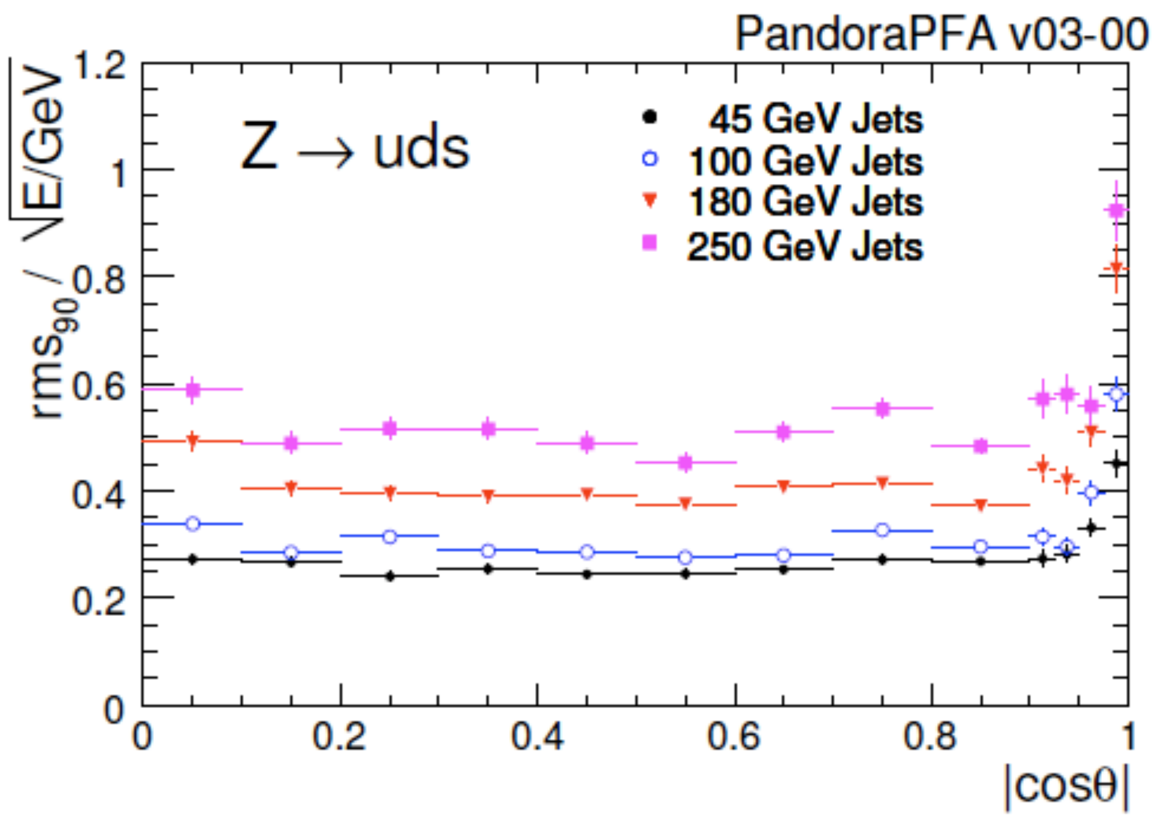


- Use trackers for charged energy:
  - π+,K+,p : 60% of Ejet
- Use calorimeters for neutrals
  - Neutral hadrons, K_L, n : 10% of Ejet
  - Photons : 30% of Ejet
- Remove double countings by pattern rec.

Fine granularity required !

PFA Performance

- Realistic Full Simulation (ILD) -

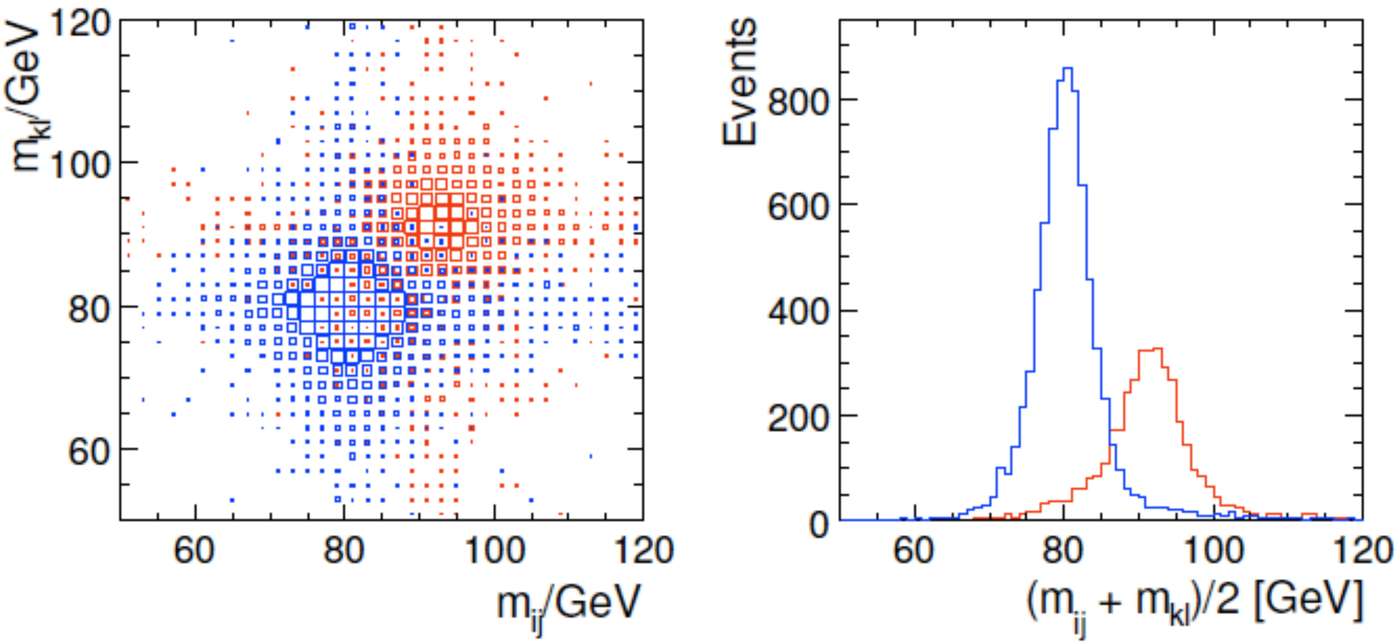


Achieved $\sigma_E / E = 0.3/\sqrt{E}$ at Ejet up to ~100 GeV

PFA Performance

- Realistic Full Simulation -

$$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ\ (SM) \qquad W/Z \to jj$$

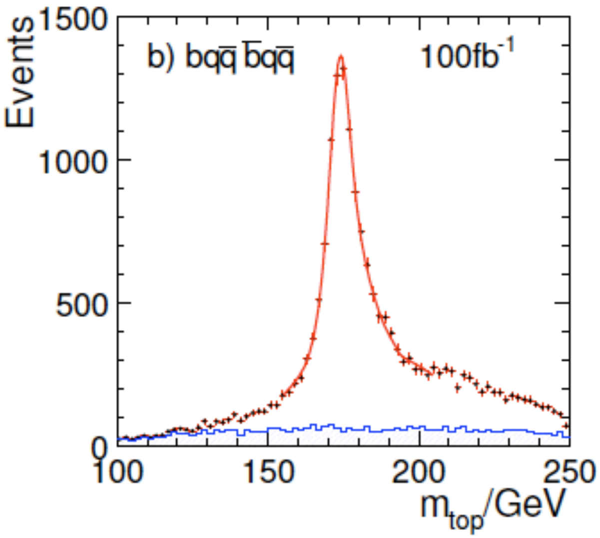


Ecm = 1 TeV, 1 ab^{-1}, Polarization = 0.3 (e+), -0.8 (e-)

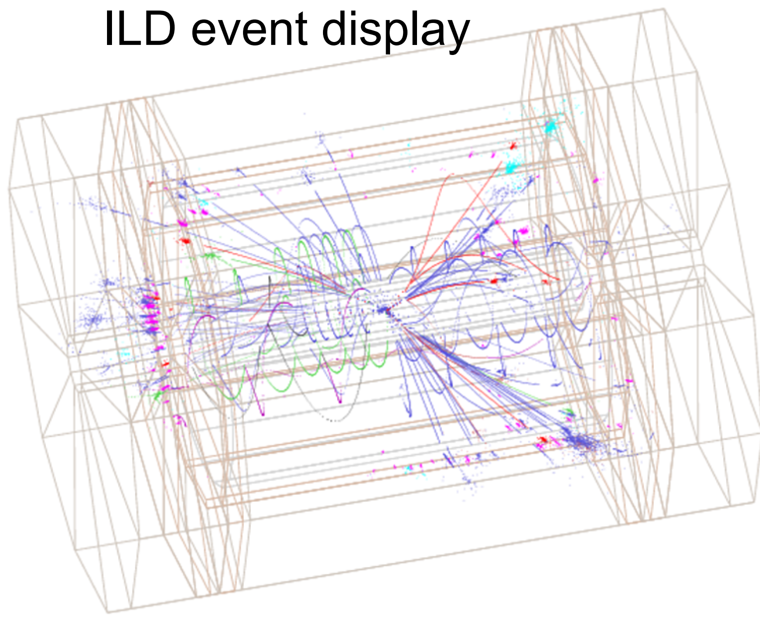
WW/ZZ separation is ~ achieved

Top pair production (PFA test)
- Realistic Full Simulation -

$$e^+e^- \to t\bar{t}, \quad t \to 3j$$



ILD event display



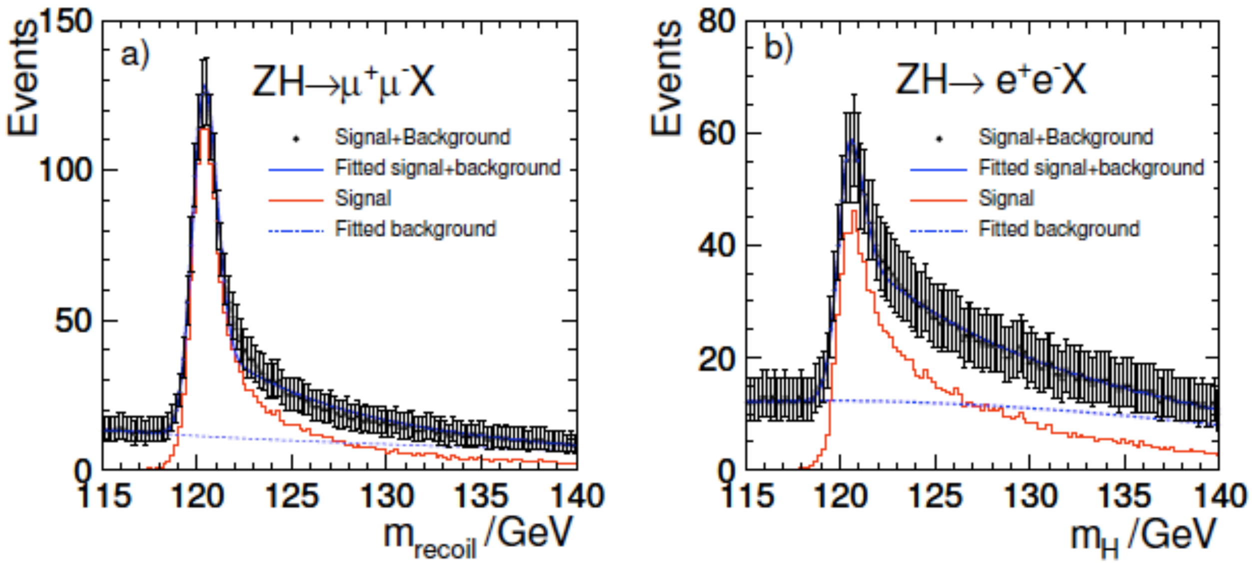
Event 98 File : ../data/tt500-aug06_2x2_2m-100-1.root

Ecm = 500 GeV, 100 fb^{-1}

σ(mt) = 90 MeV, σ(Γt) = 60 MeV

Higgs recoil mass measurement (tracking)

- Realistic Full Simulation -



- Ecm = 250 GeV, 250 fb^{-1}, Polarization = 0.3 (e+), -0.8 (e-)
- $\sigma_{mH} \sim$ 36 MeV ($\mu+\mu-$), 74 MeV (e+e-)
  $\rightarrow$ $\sigma_{mH} \sim$ 32 MeV
- e+e- $\rightarrow$ ZH cross section to 2.5%

Detector Timeline
(by Research Director, Sakue Yamada)

Synchronized with accelerator

- Detector Design Phase I : to 2010
  - Focus on critical R&Ds
  - LOI validation by IDAG (2009)
  - Update physics performance
  - MDI/push-pull
- Detector Design Phase II : to 2012
  - React to LHC results
  - Confirm physics performance
  - Complete necessary R&Ds
  - Cost (more reliable)
  - Produce 'Detailed Baseline Design'

ILC Detectors (LOI)

	ILD	SiD	4th
Main Tracker	TPC	Si-strip	TPC/Si-strip/DC
Calorimeter	PFA	PFA	Compensating
B	3.5 T	5T	3.5T
ECAL Rin	1.83m	1.25m	1.5m
Rout	6.99m	6.20m	5.80m
Zout	6.62m	5.60m	6.08m

(dimensions are approximate)

All: ECAL/HCAL inside solenoid (jet reconstruction)
Pixel detectors for vertexing

Japanese involvement is mostly in ILD

IDAG Review of LOIs

- IDAG (International Detector Advisory Group)
  - Advises the research director (Sakue Yamada) of ILC
  - Chair: Michel Davier, Paul Grannis, Michael Danilov, Rohini Godbole, Dan Green, Sun Kee Kim, Tomio Kobayashi…. 16 total.
  - Evaluated the LOIs that are submitted March 31, 2009, and reported its recommendation to the research director

- The validation result officially announced at Sep, 2009
  - **ILD and SiD are 'validated'** (i.e. endorsed to work toward the 2012 detailed baseline report.)

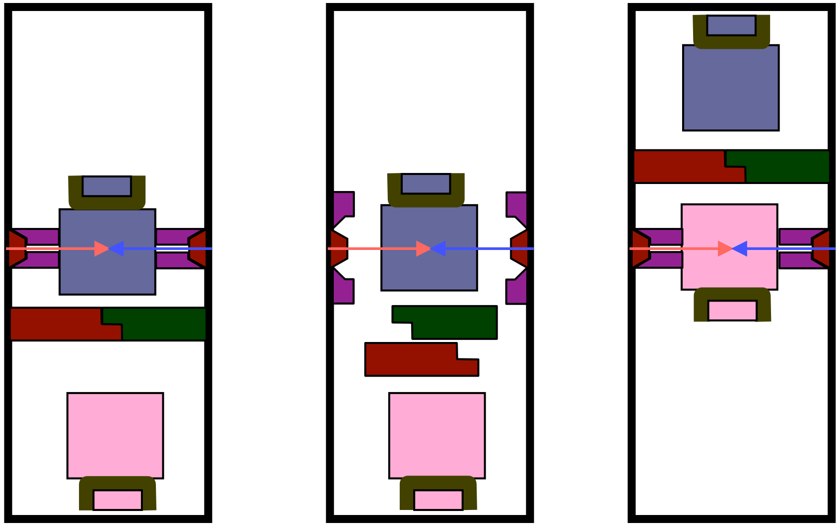
- ILCSC (International Linear Collider Steering Committee) approved the recommendation.

Guideline toward 2012
(by Research Director)

- Demonstrate proof of principle on critical components, and define a feasible baseline design where options may be kept.
- Develop a realistic simulation model including beam backgrounds, dead regions, faults and limitations.
- Cost estimate should be improved.
- Simulate and analyze updated benchmark reactions with the realistic detector model. Study some reactions at 1 TeV.
- Complete basic mechanical integration of the baseline design including push-pull mechanism and integration with machine

1 IR with 2 detectors (push-pull)

- Can save one entire beamline - a large cost saving
  - Scientific cross check to have two detectors
- Intensive studies under way

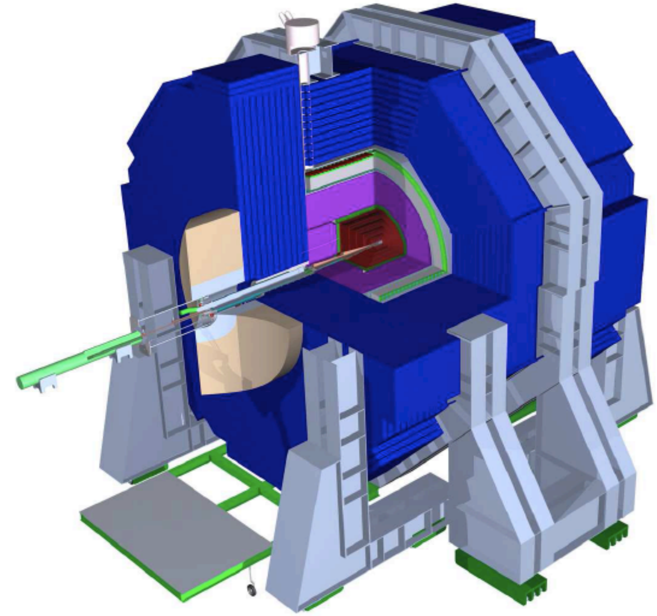


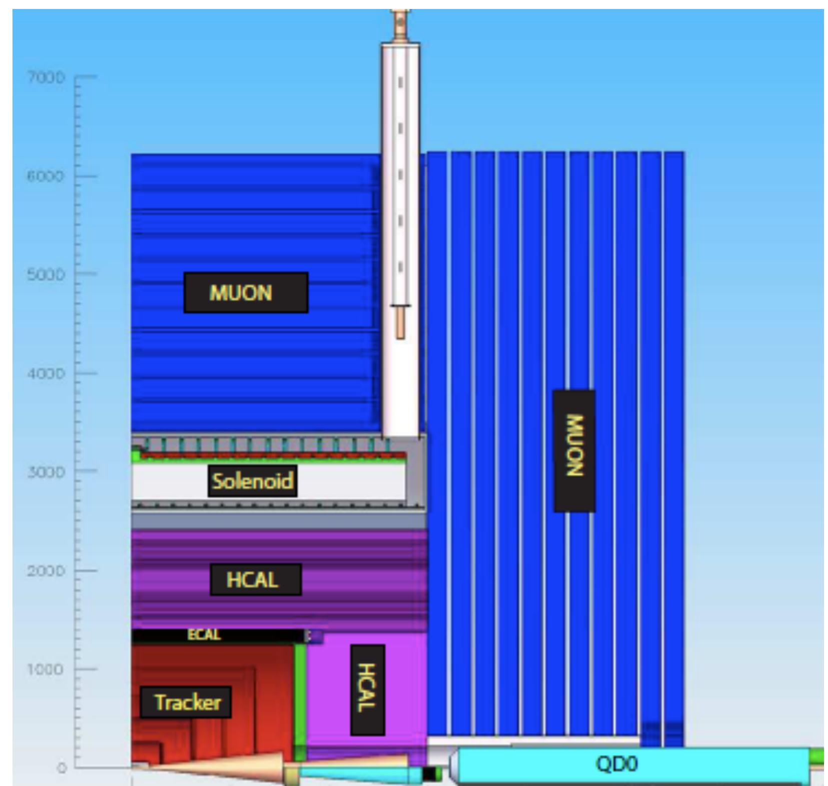
A possible way of switching
2 detectors by A. Seryi

Self-shielded detectors do not need the movable shield

SiD

- Vertex
  - 5 barrel lyrs + 4 disks
  - Pixel: Technology open
- Si-strip-trackers
  - 5 barrel lyrs + 4 forward disks/ side
- EMCAL
  - Si-W 30 lyrs, pixel $(4mm)^2$
- HCAL
  - Digital HCAL with RPC readout with $(1cm)^2$ cell
  - 40 lyrs



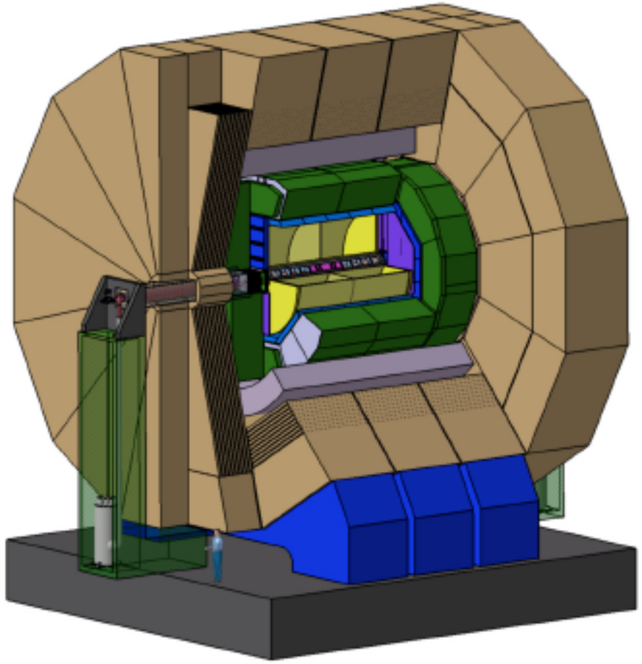


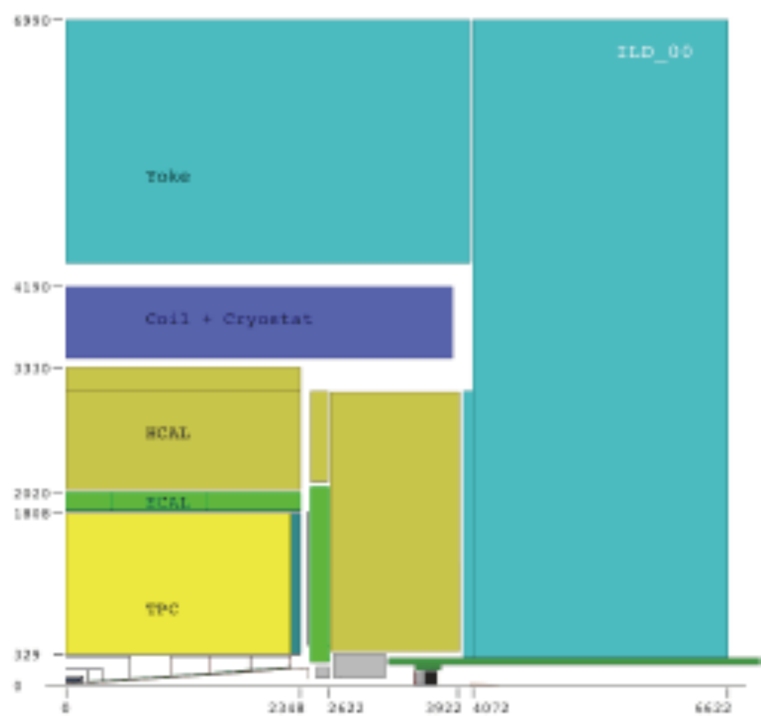
ILD

- Vertex
  - 6 (3 pairs) or 5 layers (no disks)
  - Technology open

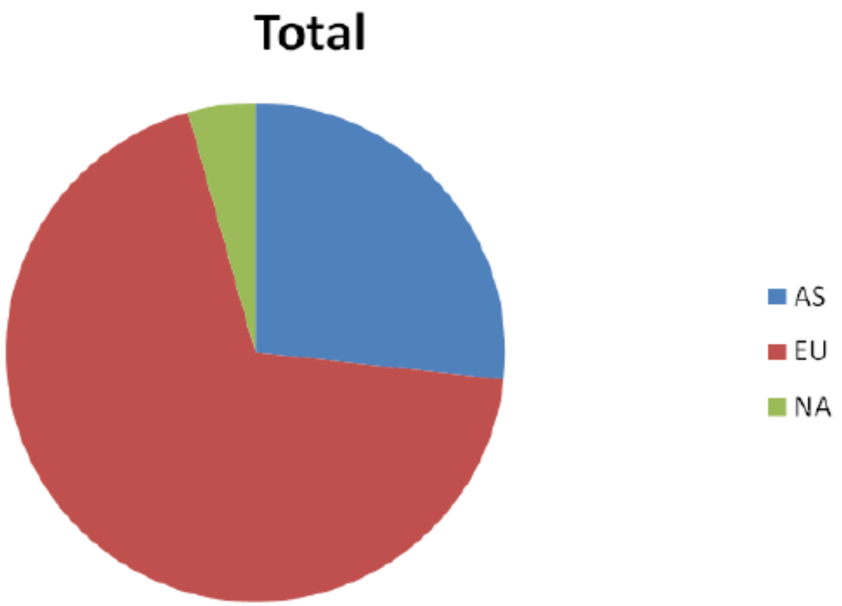
    FPCCD, CMOS, DEPFET…
- Si-strip trackers
  - 2 barrel lyrs + 7 forward disks (3 of the disks are pixel)
  - Outer and end of TPC
- TPC
  - MPGD: GEM or MicroMEGAS
  - Pad (or si-pixel) readout
- ECAL
  - Si-W or Scint-strip-W(w/MPPC)
- HCAL
  - Scint-tile(w/MPPC) or Digital HCAL
- Data rate
  - ~1700 MB/s (triggerless)

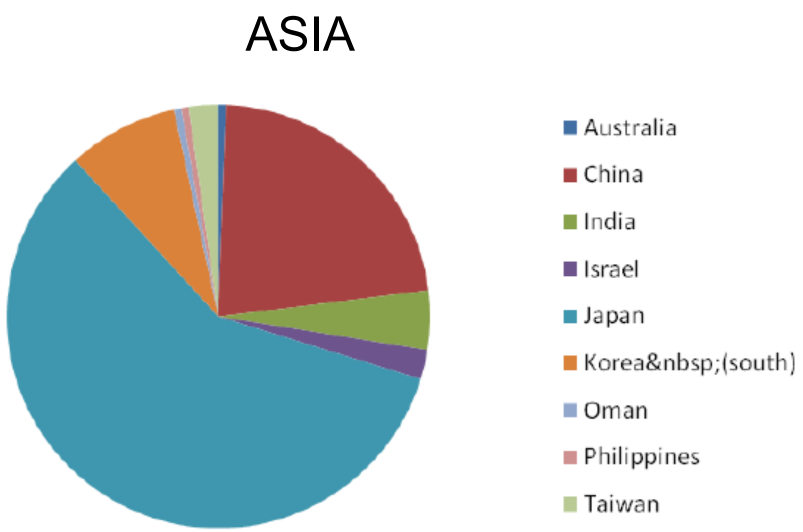
    ~ 320 MB/s for LHC (to tape)





ILD LOI Signatories





695 total, 117 Japan

ILD Japan 実働メンバー (1)

■ バーテックス検出器

- KEK　杉本康博、仲吉一男、宮本彰也
- 東北大学　板垣憲之助（M）、小貫良行、佐藤優太郎（M）、田窪洋介、長嶺忠、山本均
- 宇宙航空研究開発機構　池田博一

■ TPC

- KEK　藤井恵介、小林誠、松田武、池松克昌
- 総研大　与那嶺亮（D）
- 東京農工大　仁藤修、富岡貴（M）
- 工学院大　渡部隆史
- 近畿大　加藤幸弘
- 佐賀大　山晃、黒岩洋敏、山口博史（M）、中島健一（M）
- 長崎総合科学大　房安貴弘

■ シンチレータ・カロリメータ

- 神戸大　川越清以、魚住聖
- 日本歯科大　小野裕明
- 筑波大　小池博子(M)、須藤裕司(D)、高橋優介(M)、田中航平(M)、受川史彦
- 東大　生出秀行(D)、音野瑛俊(D)、村瀬拓郎(M)、田辺友彦、山下了
- 信州大　小寺克茂、西山実穂(D)、大塚規文(M)、佐久間隆幸(M)、竹下徹、戸塚俊介(M)

ILD Japan 実働メンバー (2)

■ 物理解析

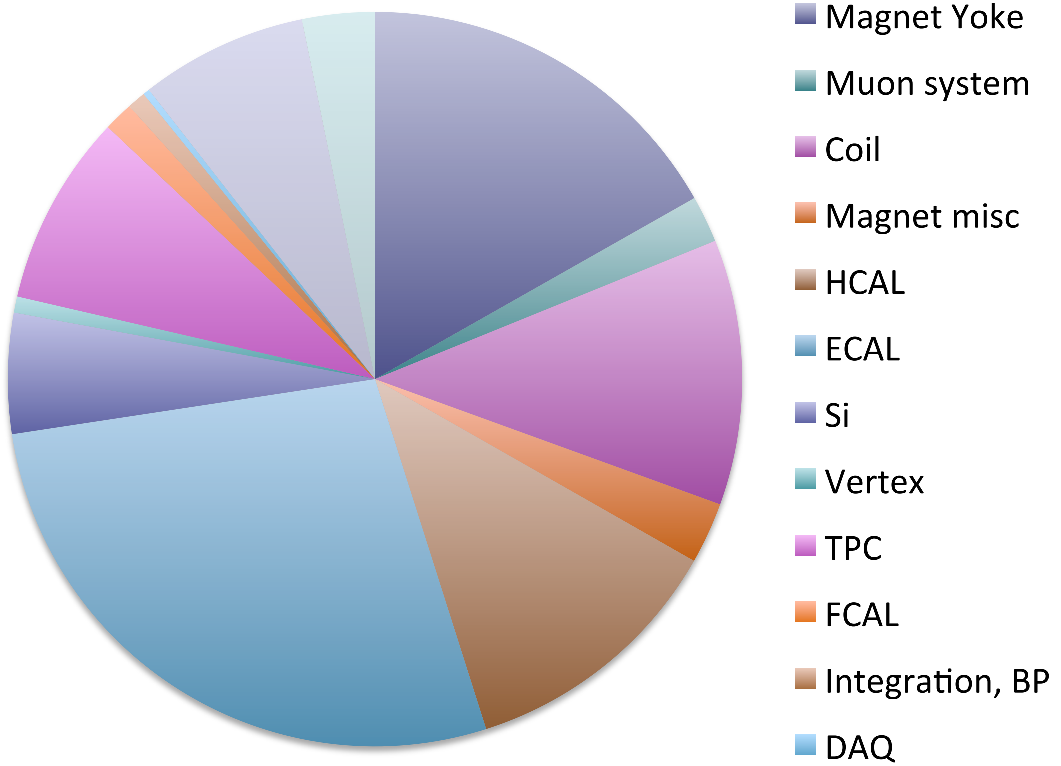
● 東北大	田窪洋介、山本均、斎藤智之（M）、本田喬大（M）、吉田幸平（M）
● KEK	池松克昌、藤井恵介
● 総研大	与那嶺亮（D）
● 東大	末原大幹、高橋武士（M）、田辺友彦、山下了
● 日本歯科大	小野裕明
● 広島大	高橋徹、前田望（M）

■ 測定器最適化

● 東北大	田窪洋介、長嶺忠、山本均、吉田幸平（M）
● KEK	池松克昌、岩井剛、杉本康博、藤井恵介、宮本彰也
● 東大	山下了、末原大幹、田辺友彦
● 日本歯科大	小野裕明
● 信州大	小寺克茂、竹下徹
● 神戸大	川越清以

計53名 (重複は除く)

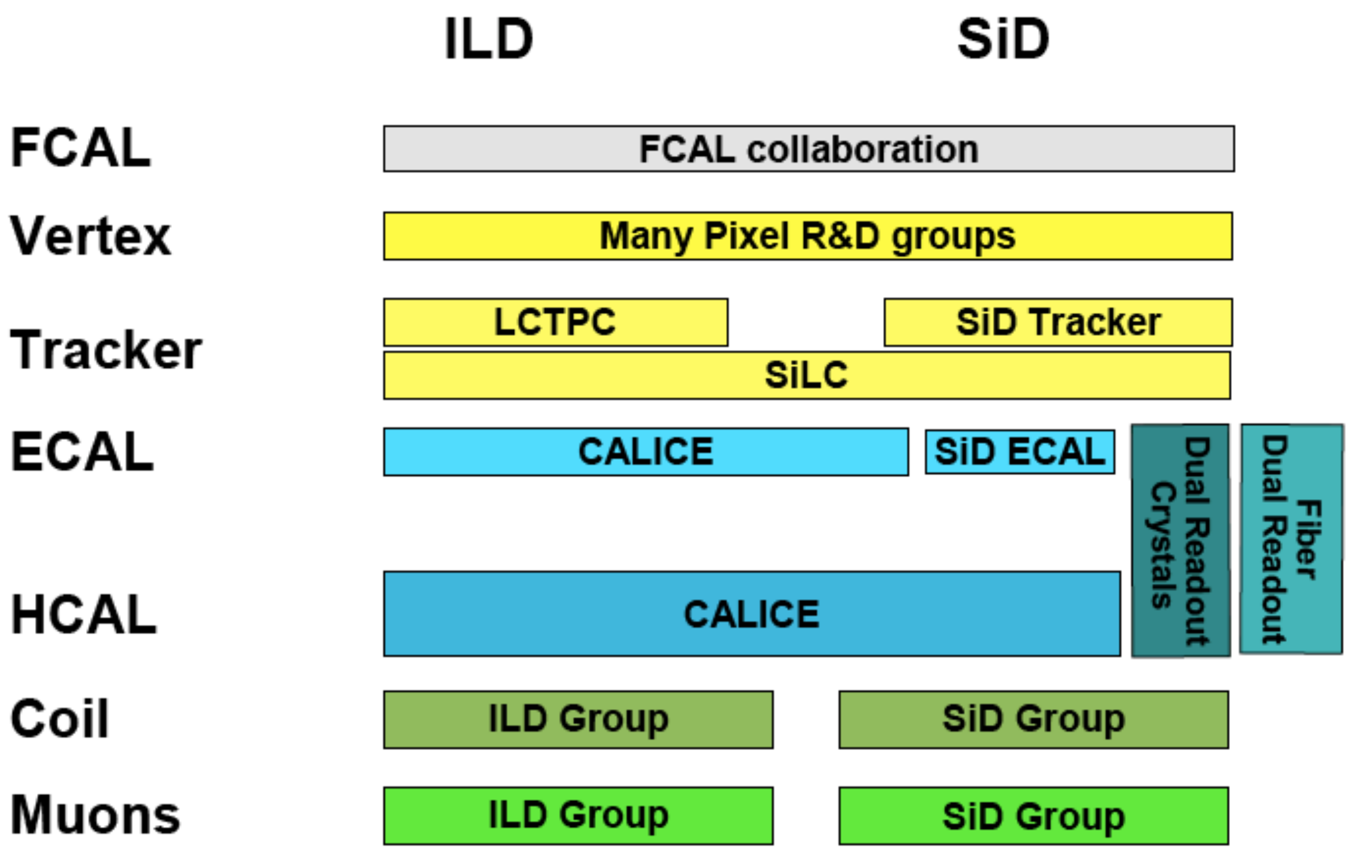
ILD Cost Estimate



$$400 \text{ total } + 130 \text{ (manpower) } = 530 ^{+100}_{-50} M\$$$

1/3 magnet, 1/3 calorimeters, 1/3 rest

ILC Detector R&D Groups

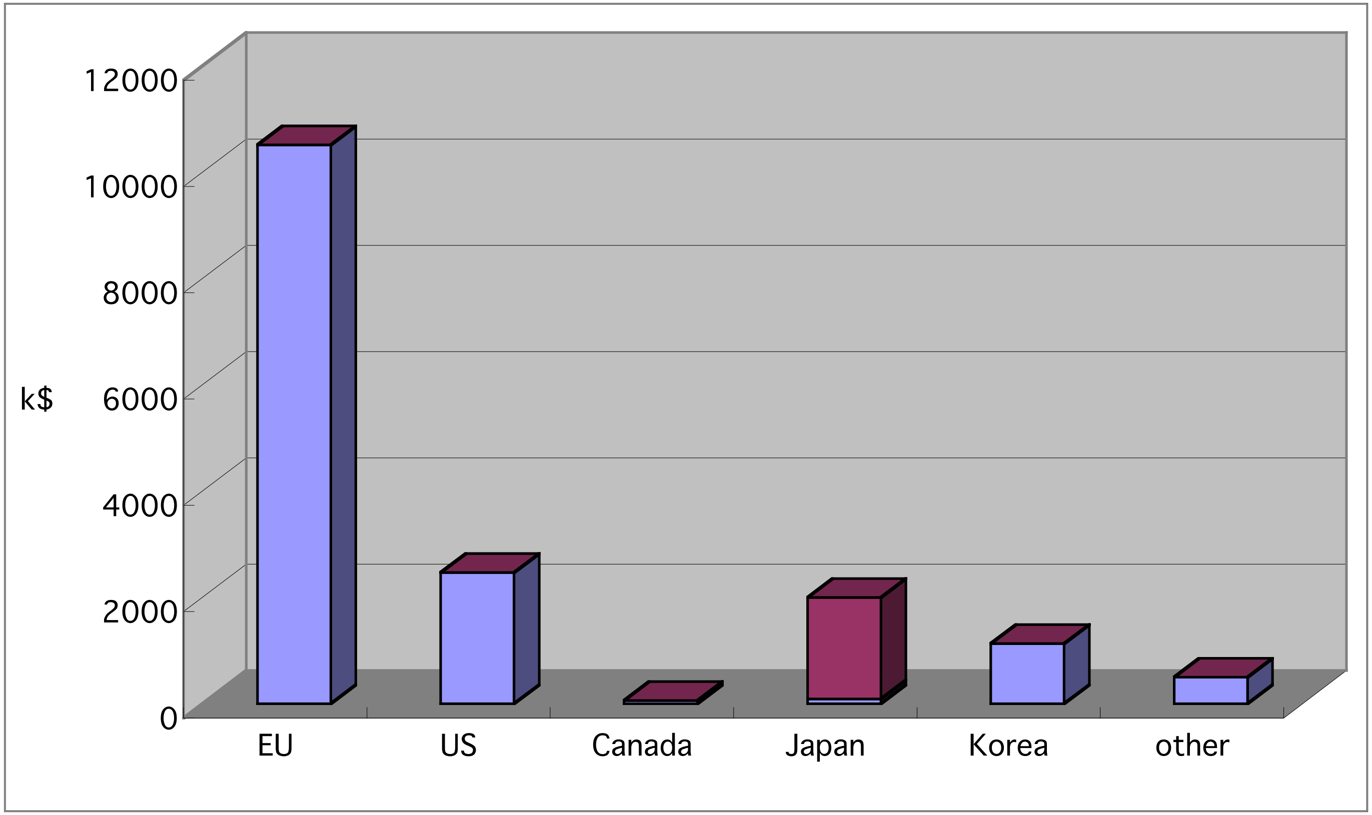


Marcel Stanitzki

Driven by 'horizontal' collaborations
Many are not limited to ILC
Benefitting from R&Ds for other experiments (T2K, Belle, LHC, …)

ILC 測定器研究費(2006~2010)

(Salary not included)



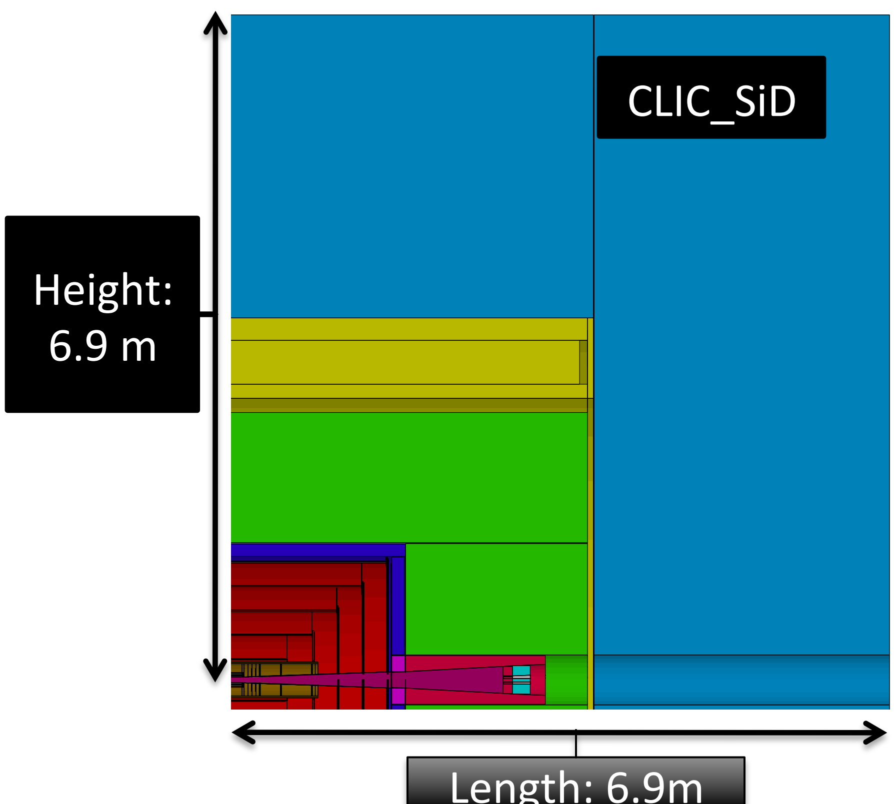
Worldwide Study R&D panel report, 2006/1

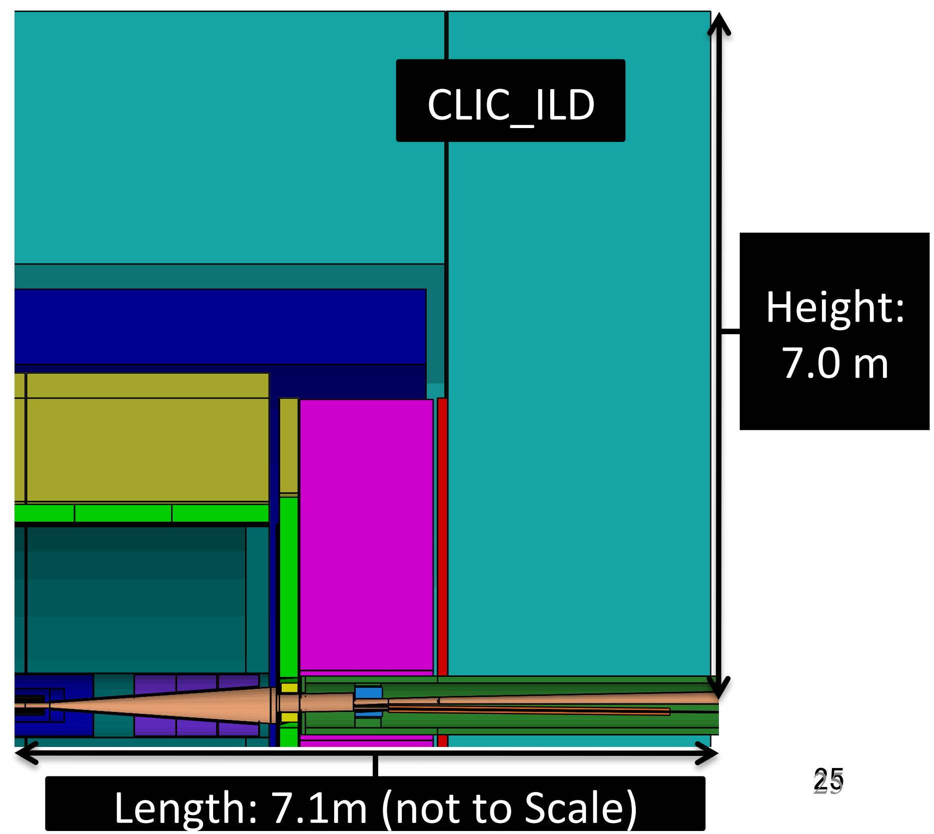
From ILC to CLIC Detectors

■ Created CLIC 3 TeV detector models using SiD and ILD geometries and software

Changes:

- 20 mrad crossing angle (instead of 14 mrad)
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- Hadron Calorimeter, more dense and deeper ($7.5\ \lambda_i$) due to higher energetic Jets

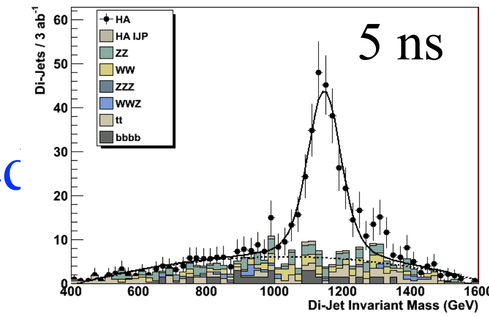


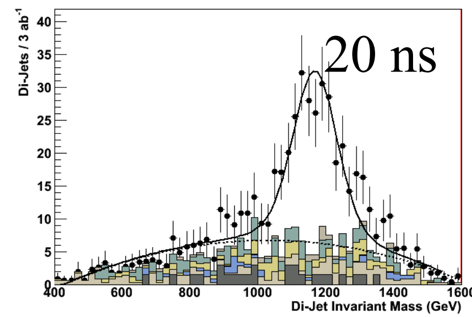


CLIC Detector Issues

- Large e+e- pair backgrounds
  - 3x more pairs with 100x more energy
- Larger 2-photon interactions
- T-channel signal and backgrounds enhancec
  - Forward region rates high
- Time stamping of ~10 ns needed
  - No solutions yet (esp. vertexing)
- Tracker options:
  - Si tracker : pattern recognition?
  - TPC : salt-and-pepper bkg too high?
  - Choice is open

Time stamping





Di-jet mass

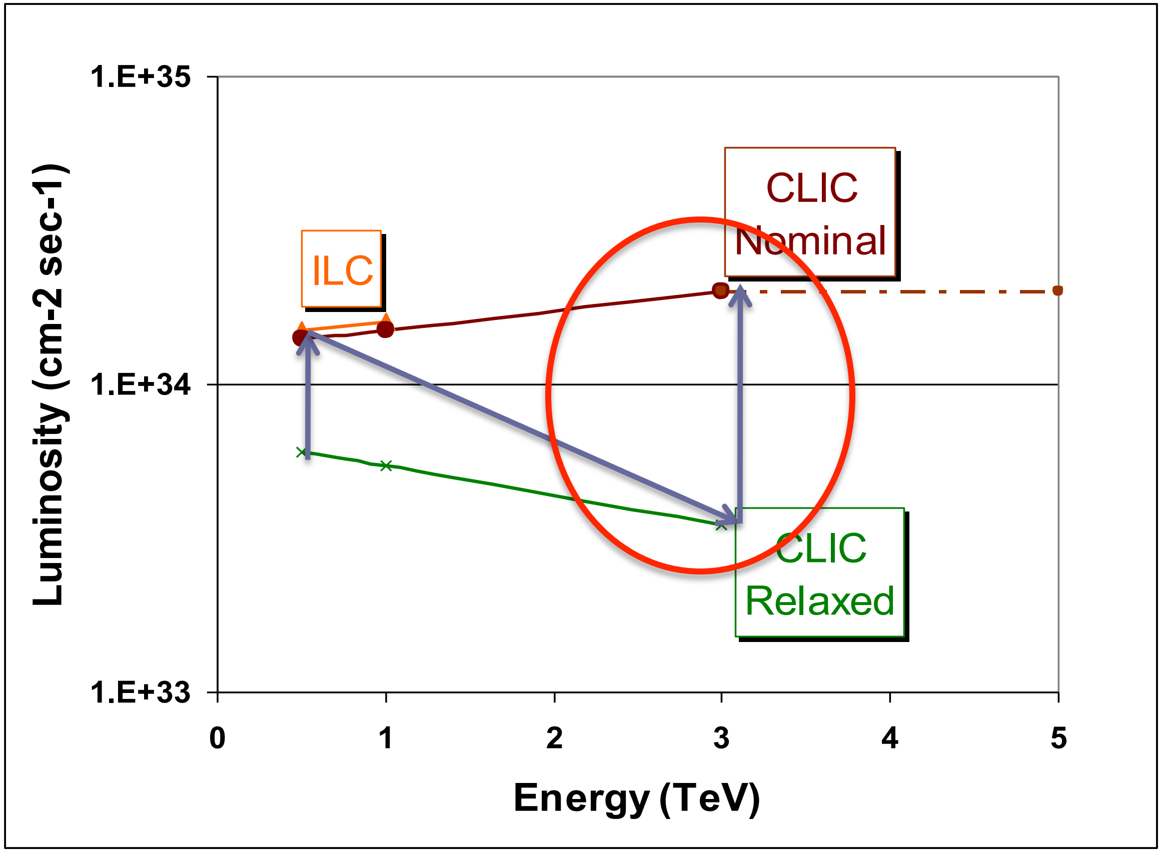
Concluding Remarks

- Organization for ILC detector efforts is in place.
- Two ‘validated’ detector groups ILD and SiD are now moving toward 2012 ‘Detailed Baseline Design.’
- ILC detector R&Ds are carried out in conjunction with those for other experiments, and progressing well toward ‘DBD.’
  - Horizontal detector R&D collborations have been effective in carrying out the efforts. (CALICE, SiLC, FCAL, etc…)

Backup

CLIC Parameters

J.P. Delahaye



Focus is at high energy

Immediate goal: CDR end-2010 (120-150 pages)

ILC-CLIC Collaboration

- ILC detector efforts are indispensable for CLIC detector
  - CLIC detector people want ILC people to ‘work on CLIC.’
- CLIC-ILC working group on general detector issues
  - Ordered by ILCSC
  - In parallel to the one in accelerator issues
  - Members being formed (slow)
- Some difficulties
  - ILC people are already 100% occupied by ILC works
  - CLIC currently at stage to prove principle of two-beam acceleration. Still much at earlier stage than ILC.

Jet reconstruction - PFA (Pandra)

Magnetic field : B = 4 T (3.5 T for ILD)
Thicker HCAL : 8 λ (6 λ for ILD)
No fine tuning of ILD PFA

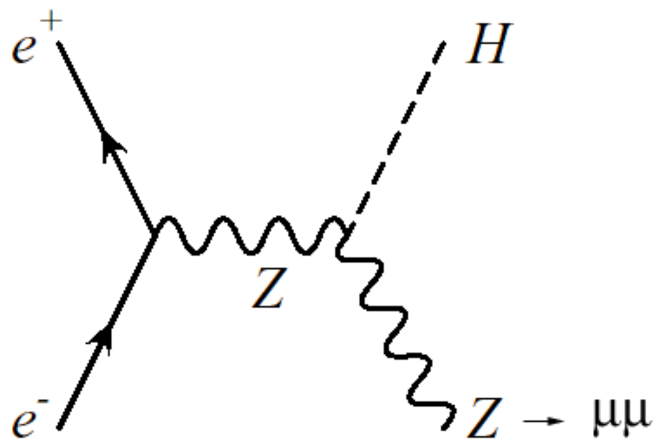
Meets the jet energy resolution goal (3~4%) up to 500 GeV jet.

SiD PFA and Compensating Calorimetry give similar jet resolution

M. Thomson

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ |cosθ|<0.7	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	28.7 %	2.9 %
180 GeV	37.5 %	2.8 %
250 GeV	44.7 %	2.8 %
375 GeV	71.7 %	3.2 %
500 GeV	78.0 %	3.5 %

Higgs at ILC



Golden channel :
'Higgs-straulung'

$$e^+e^- \to Zh, Z \to \mu\mu, ee$$

- Measurement of Higgs mass and production rate - independent of Higgs decay modes
- Then detect Higgs decays - absolute Brs (including invisible mode)
- **Tagged Higgs Factory!**

Supersymmetric Particles at ILC

- ILC can pair-create SUSY particles

$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$

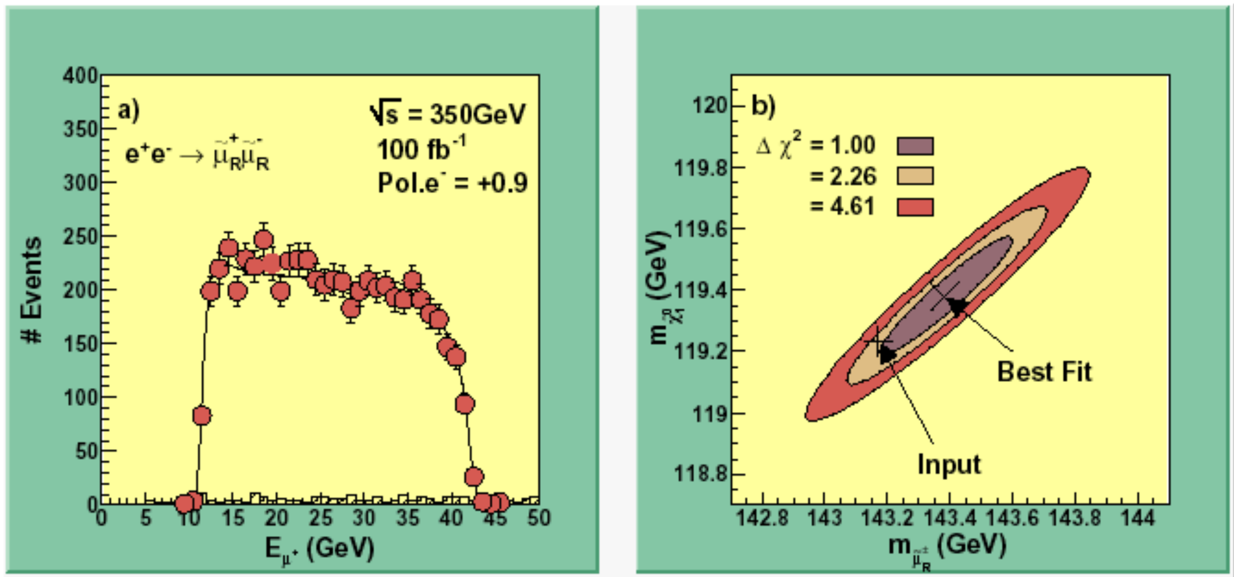
$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-,\ \tilde{\chi}_1^+ \to W^+\tilde{\chi}_1^0$$

etc.

- Precision measurements of masses and mixings
- Determination of spin, hypercharge etc.
- Beam polarization useful. It can also reduce backgrounds

Masses of smuon and LSP

$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$



- Total 4-momentum of smuon pair is known
- Use the endpoints of $\mu^\pm$ for simultaneous determination of $m(\tilde{\mu}_R)$ and $m(\tilde{\chi}_1^0)$

SUSY parameter determination

- Charginos are mix of Wino and Higgsino with mass terms :

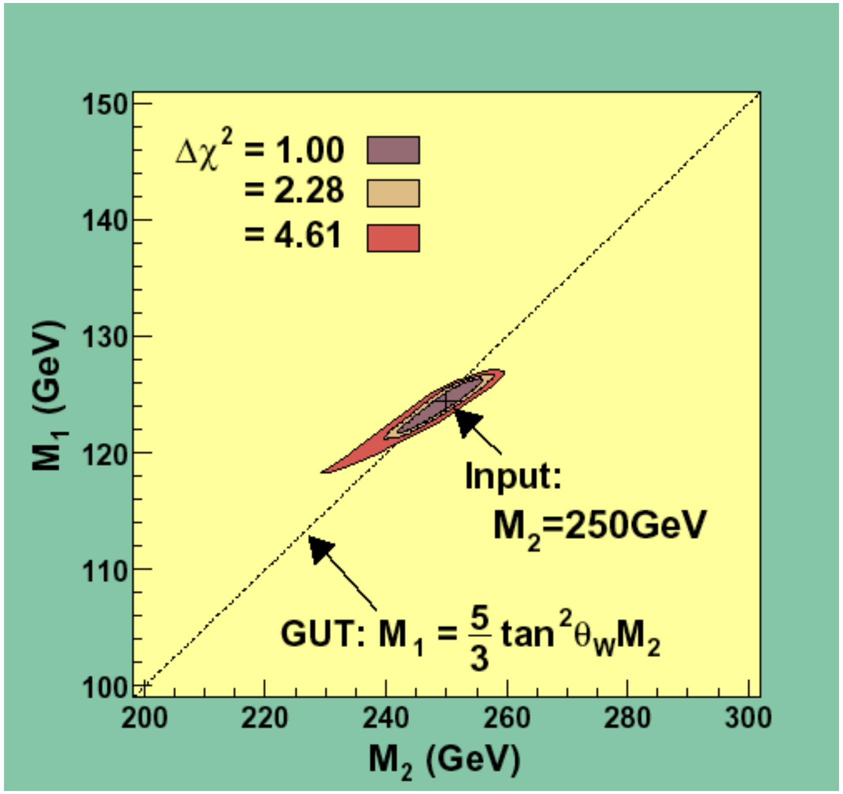
$$(\tilde{W}^+, \tilde{H}_u^+) \begin{pmatrix} M_2 & \sqrt{2} m_W \cos\beta \\ \sqrt{2} m_W \sin\beta & \mu \end{pmatrix} \begin{pmatrix} \tilde{W}^- \\ \tilde{H}_d^- \end{pmatrix}$$

- Use polarized beam (e^-_R)
  - Only Higgsino component of chargino contribute to chargino pair creation
  - Right-handed selectron pair production depends on Bino in S channel only
- Perform global fit of $(M_1, \tan\beta, M_2, \mu)$ to reconstruct the mixing matrix. Measurements are:

$$\sigma(e^+ e^-_R \to \tilde{e}^+_R \tilde{e}^-_R) \qquad \sigma(e^+ e^-_R \to \tilde{\chi}^+_1 \tilde{\chi}^-_1)$$

$$m(\tilde{\chi}^+_1) \qquad m(\tilde{\chi}^0_1)$$

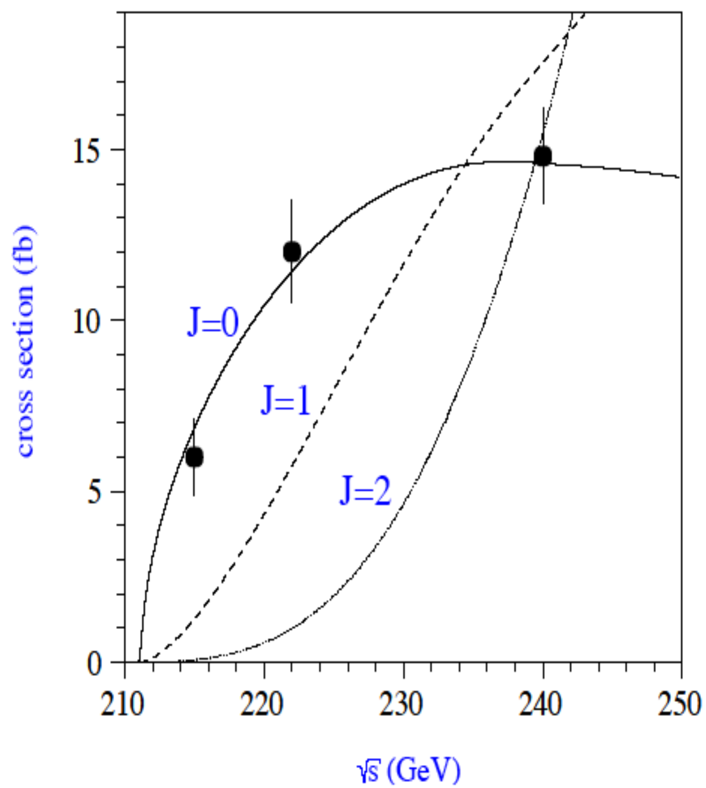
SUSY parameters (cont'd)



- E_{cm} = 500 GeV, 50 fb^{-1}
- M1 and M2 measured to ~2 GeV and ~5 GeV, respectively
- Serves as a test of GUT relation (or other mechanism)
- Lagrangian reconstruction !

Measurement of Higgs parameters

$$e^+e^- \rightarrow Zh,\, Z \rightarrow \mu\mu, ee$$



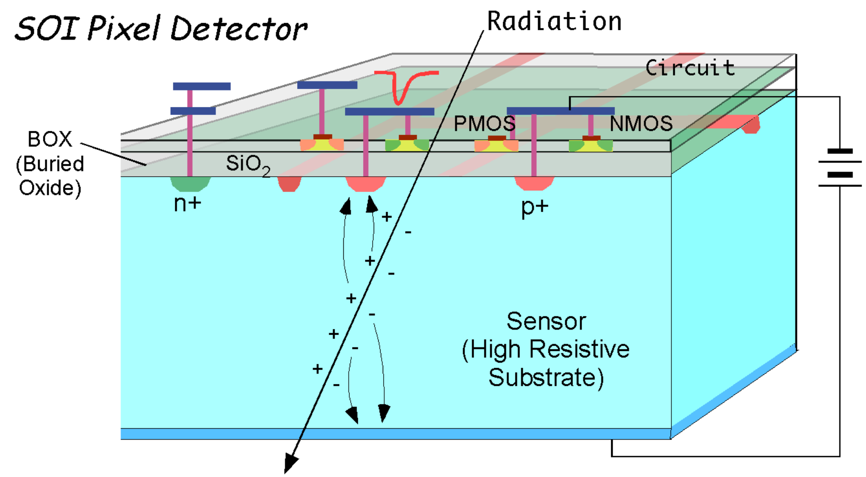
- Higgs mass
  - $\sigma(m_h)$ = 40 MeV
- Higgs spin, parity
  - Threshold scan
  - Higgs decay distribution
  - Zh angular dist.
    ~ $\sin^2\theta$ if J=0+

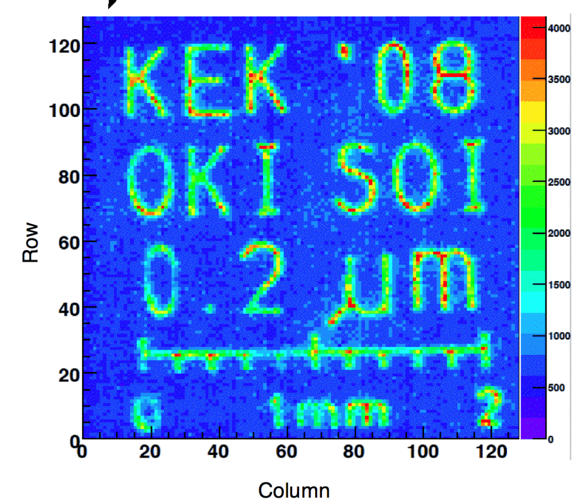
Vertexing

- If one integrates hits over 1 train for (25 μm)^2 pixel,
  - Occupancy too high (by the pair background)
  - Strategies: time slice a train (~20), small pixel, bunch id (ideal)
- Many technological options pursued:
  - Time slicing: CPCCD, ISIS, MAPS, deep N-well, CAP, DEPFET
  - Small pixel: FPCCD
  - Bunch id: Chronopixels, SOI, 3D
- Vertexing Review Report
  - ‘Unable to eliminate any of them (at present)’
  - ‘2-4 technologies to start up, others for upgrades’
  - ‘Some have applications in other fields’
- Promising technologies: vertical integration (3D, SOI)

SOI (Silicon on Insulator)

- Semi vertical integration
- Active area very close to the readout circuit (~200nm)
  - Sensor interferes with the readout circuit (e.g. back gate effect)
- Buried p-well technology:
  - Fixed the back-gate effect
  - A major advance for SOI





3D Integration

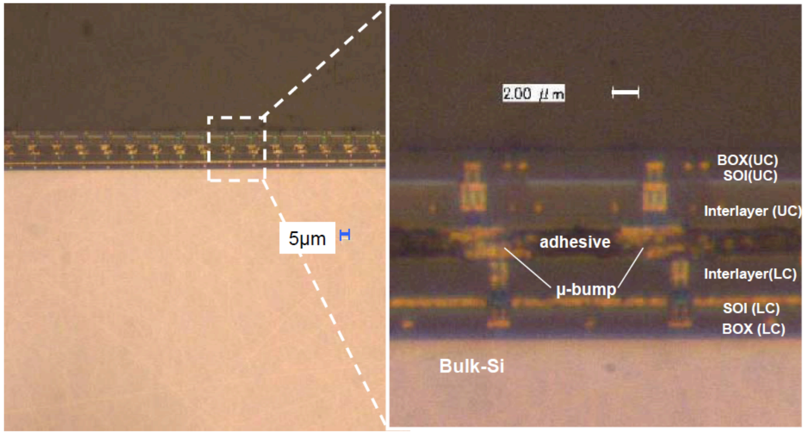
- ➢Via and bonding technologies
  - industry-driven
- ➢Liberation from the process constraints
- ➢Higher integration density
- ➢Radiation tolerance
- ➢Lower power consumption

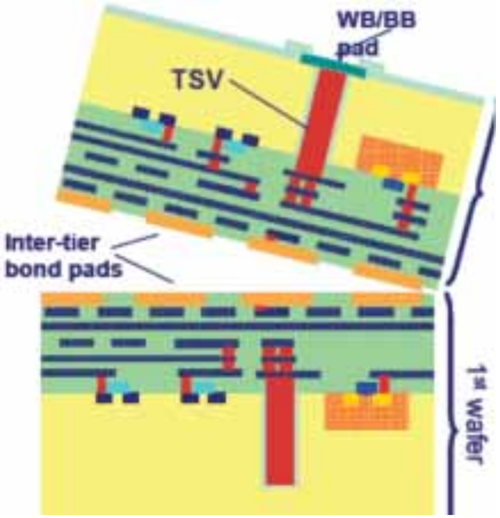
● Zycube (bonding)
Test chip designed by
LBNL/KEK made by OKI
Being tested now

● Terrazon run.
FNAL-based.
Broad range of MAPS and readout
Electronics, being fabricated now

● More to come

Zycube





Main Tracker

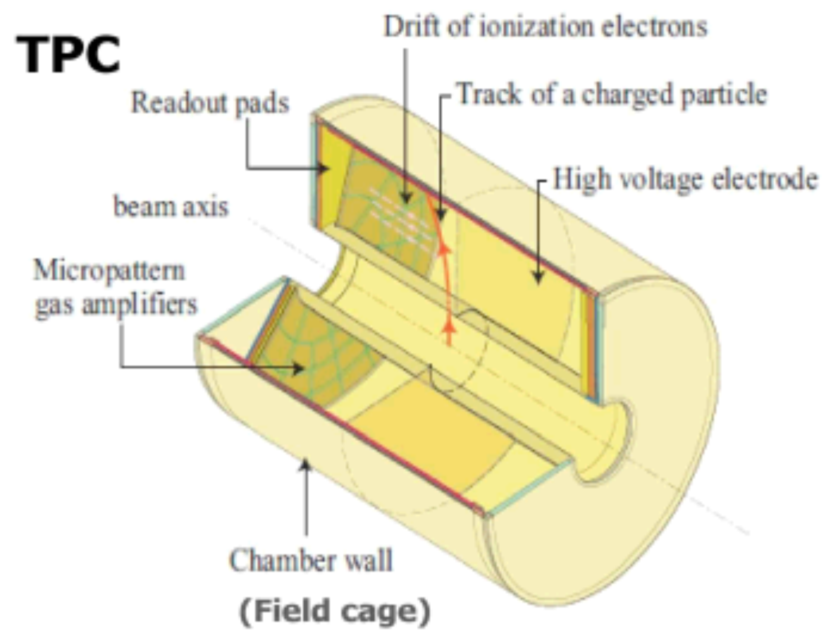
- 3 basic technologies
  - Si strip (SiLC collaboration, SiD tracker)
  - TPC (LC-TPC collaboration)
  - CluCou (cluster-counting DC for 4th)

- WWS review panel report
  - ‘Extremely impressed’
  - ‘Currently far from goals for all options’
  - ‘Forward tracking’ : ‘achieved in practice?’
  - ‘A large prototype (R=1m) in B=3~5 T recommended’

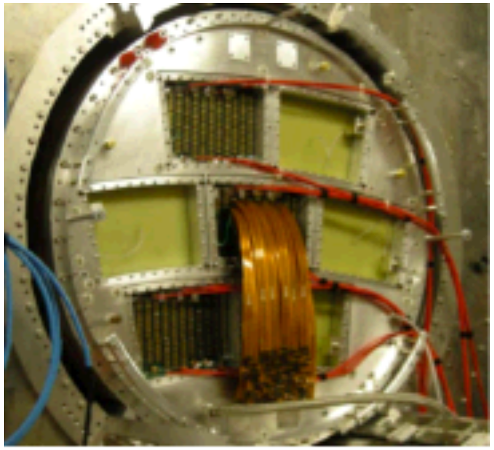
    Not yet: LC-TPC has tested a ‘large-prototype’ with r=38cm in 1T

LC-TPC collaboration

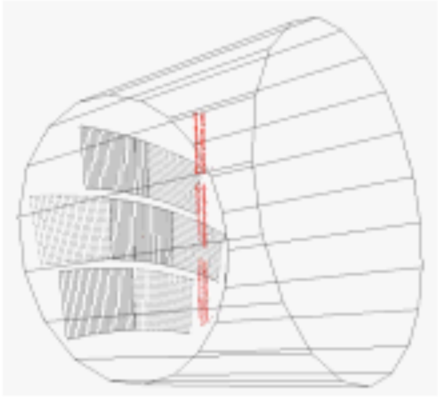
- Goal: develop ILD TPC
  - ~200 points per track
  - R = 1.8m, L=4.3m
  - MPGD
    - – GEM or MicroMEGAS
  - Read out
    - – 1x5 mm^2 pads
    - – CMOS pixel option under R&D
- 'Large' prototype made
  - – D = 0.7m, L=0.6m
  - – Beam test under 1T (DESY)
  - – Both GEM and MicroMEGAS
  - – So far so good. Data is being analyzed.



Prototype endplate



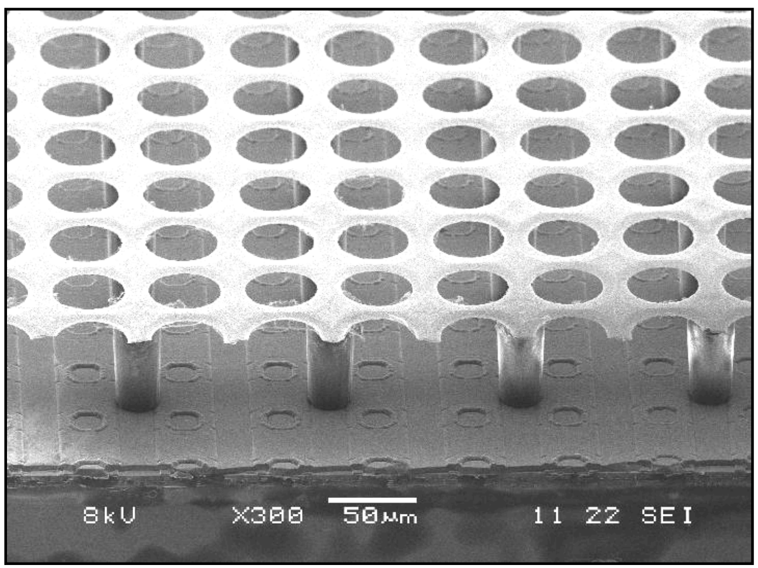
Beam with GEM

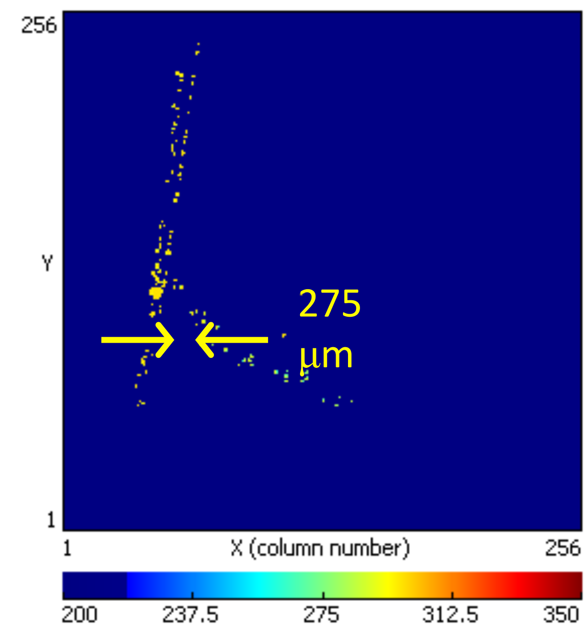


Pixel Readout of TPC

Use pixel sensors instead of pads
Cell size : 1x5 mm^2 → 55x55 μm^2

Good spacial resolution
Good 2-track separation (<1mm)
Possibly cluster counting (dE/dx)



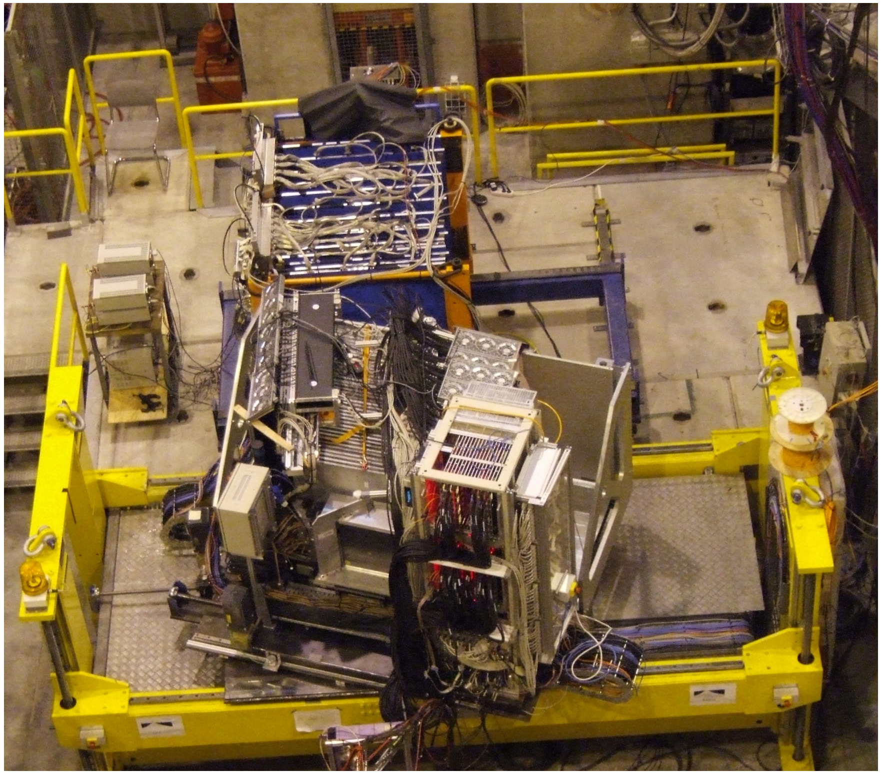


Calorimetry

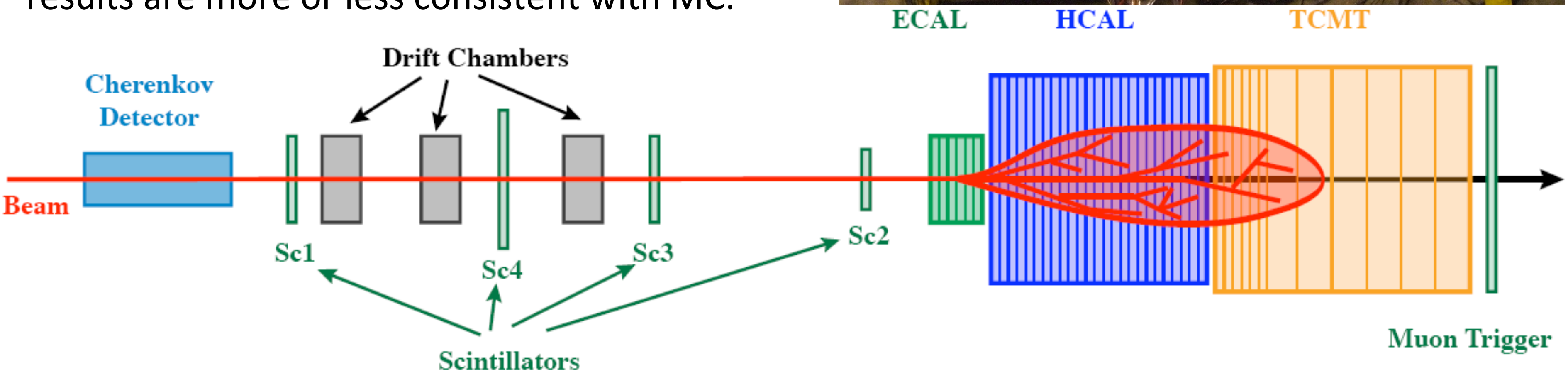
- PFA-based
  - CALICE collaboration (41 groups)
    - Si-W and Scint-W ECAL, Analog and DigitalHCAL
  - SiD-CAL (17 groups, some in CALICE)
    - Si-W ECAL, DHCAL, AnalogHCAL
- Compensating (dual-readout)
  - DREAM collaboration (8 groups)
  - Fermilab group
- WWS review panel report
  - 'PFA and compensating both may be needed – esp. in forward region'
  - Compensating:
    - 'Needs more people', 'The approach could be the outright winner particularly in the … forward region'
  - PFA:
    - 'Extremely promising, but simulation alone cannot be trusted.'
    - 'Use a large-scale physics prototypes'
      – cal part nearly done (CALICE) (tracking not included)

CALICE Beam Tests

- Main beam tests, using π, μ, e beams:
- 2006-7
  - SiW ECAL + AHCAL + TCMT @ CERN
- 2007
  - Small DHCAL test @ Fermilab
- 2008
  - SiW ECAL + AHCAL + TCMT @ Fermilab
- 2009
  - Scint-W ECAL + AHCAL + TCMT @ Fermilab
  - Standalone RPC and Micromegas tests @ CERN
- 2010 planned
  - SiW ECAL + DHCAL + TCMT @ Fermilab



There is no perfect Hadron shower MC, but results are more or less consistent with MC.

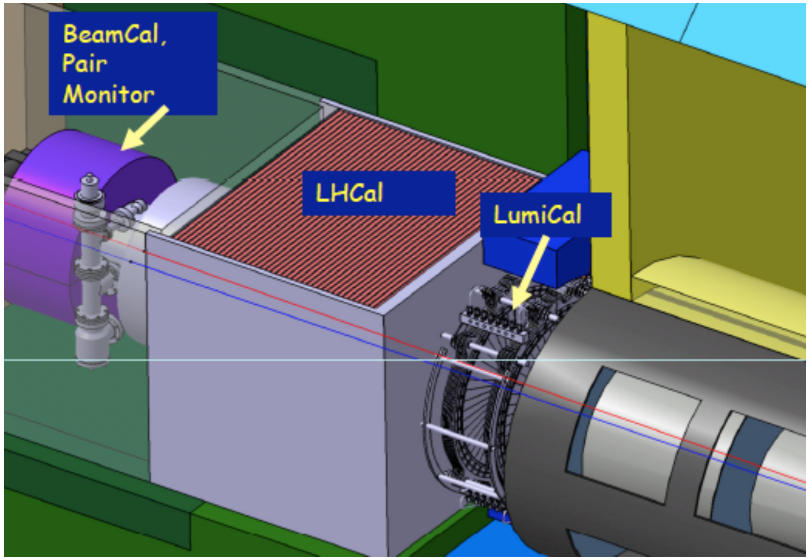


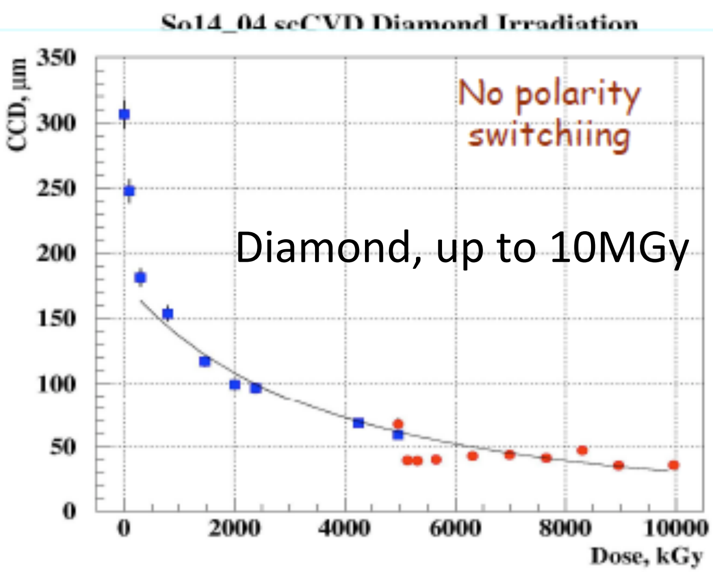
Forward Instrumentation

ILD

FCAL collaboration

- BeamCAL
  - GaAs
  - Diamond (sCVD)
  - Sapphire
- LumiCAL
  - Short Si-strip
- Pair monitor
  - Si pixel
- Applications
  - FLASH, CMS - tested





Diamond, up to 10MGy