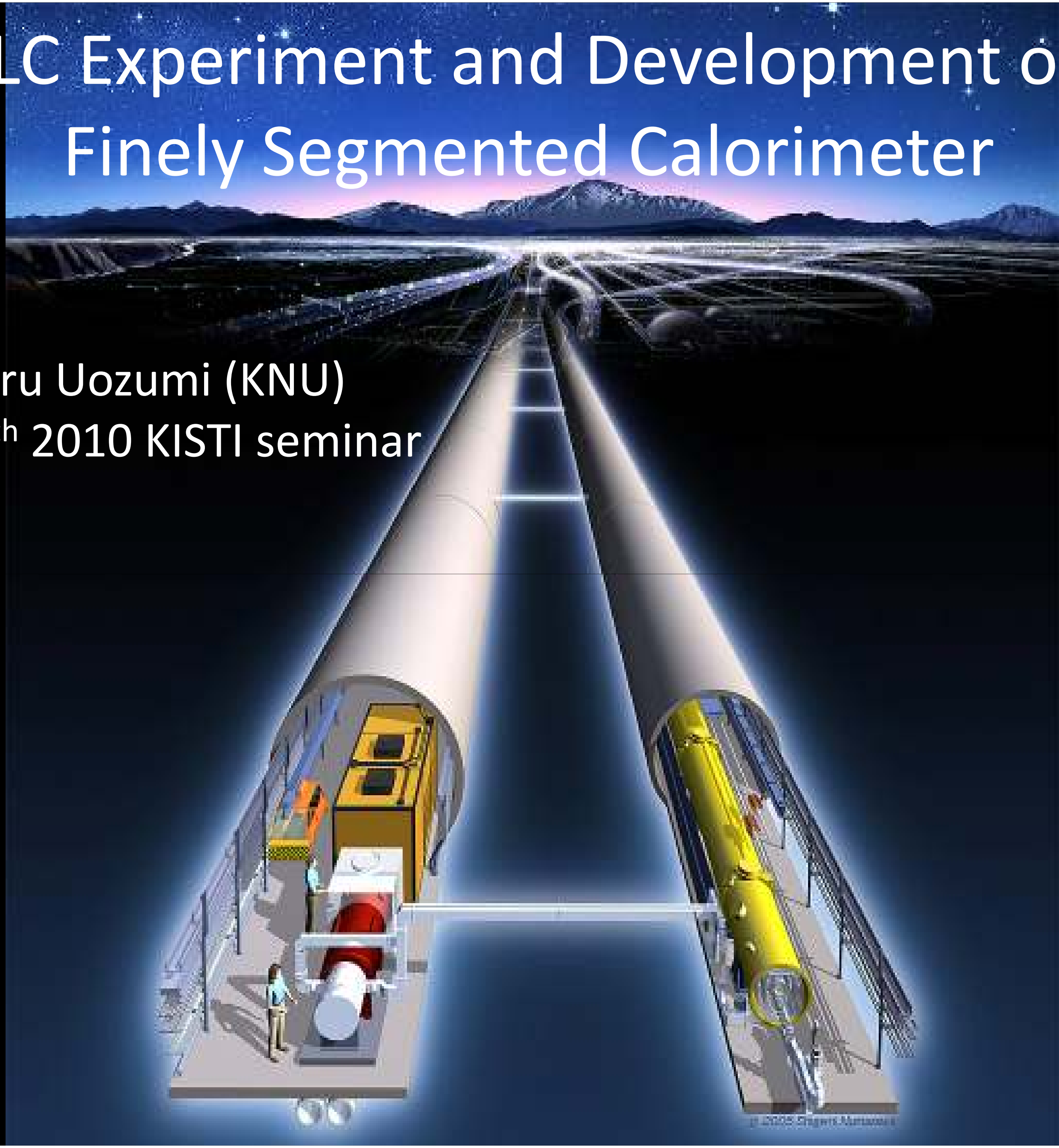
The ILC Experiment and Development of the Finely Segmented Calorimeter



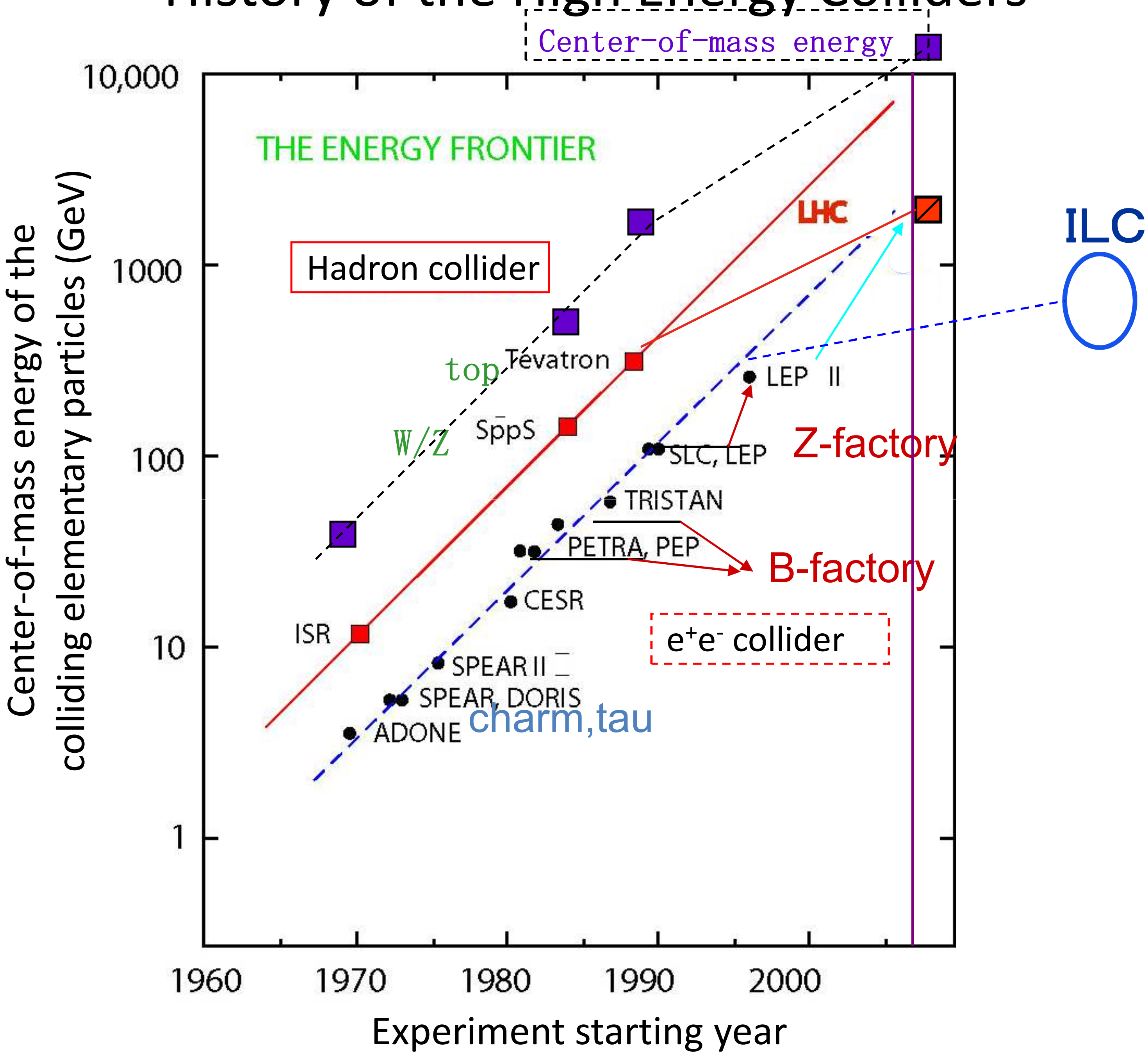
Satoru Uozumi (KNU)

May-24th 2010 KISTI seminar

Outline

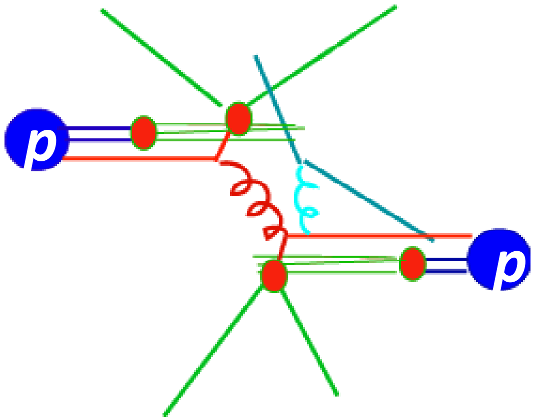
- The linear collider project and its prospects
- Highlights of physics outcomes
- Detector development in KNU collider lab.

History of the High Energy Colliders



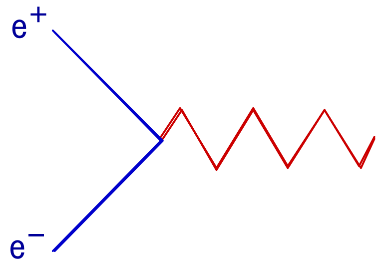
Why ILC?

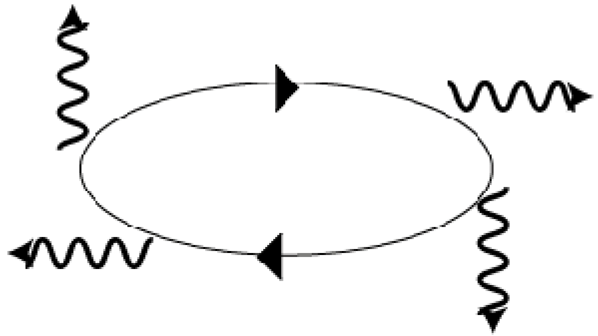
With hadron colliders …



- Relatively easy to increase center-of-mass energy
- Not all the energy can be used for collision
- Large backgrounds

With lepton colliders …





- Collision of elementary particles.
- Good for precise measurement.
- Difficult to increase center-of-mass energy due to synchrotron radiation. $\delta E \sim \frac{E^4}{Rm^4}$

→ **Linear accelerator !**

Discovery of new physics at LHC

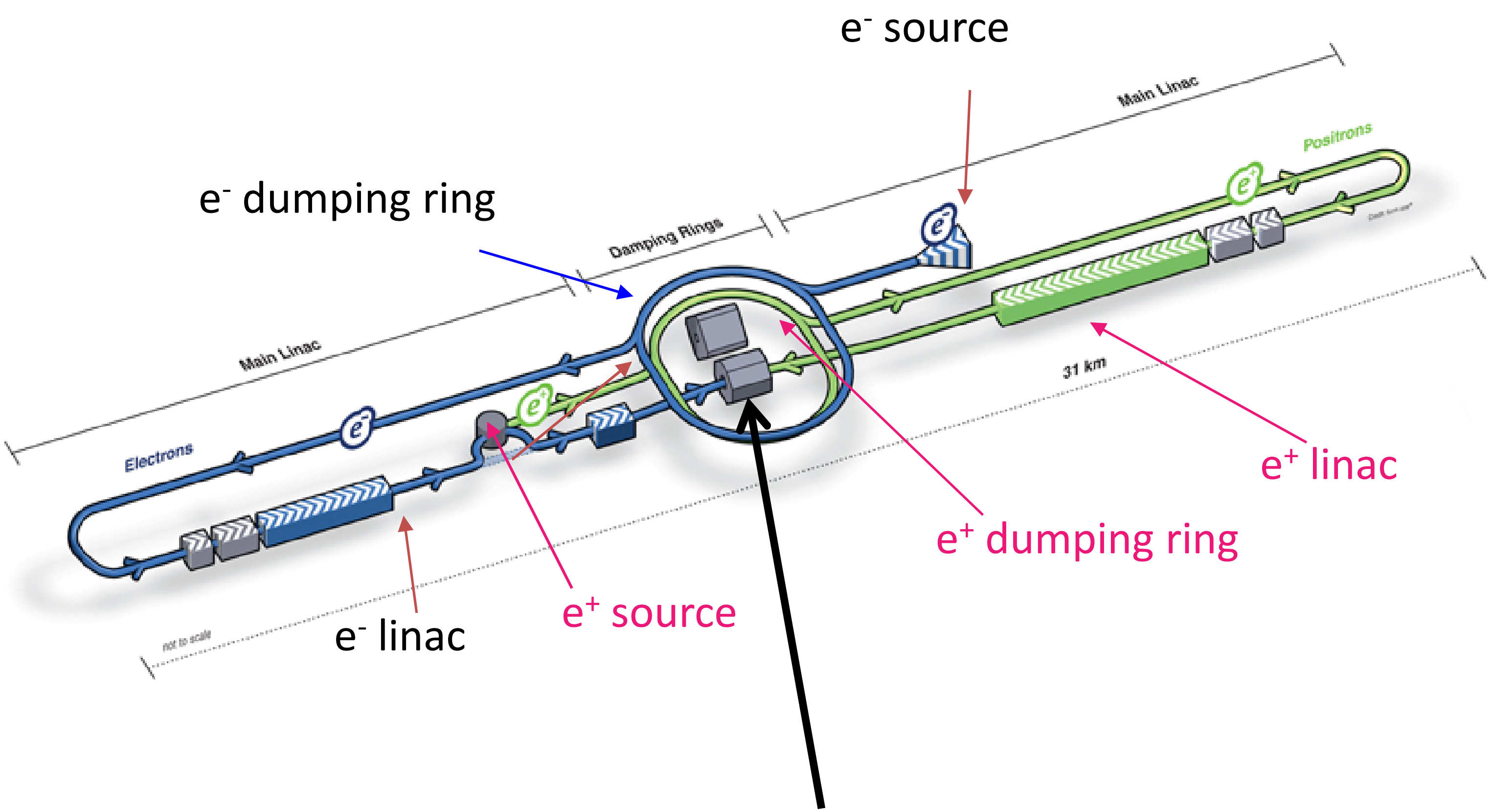
↓

Precise measurement at ILC

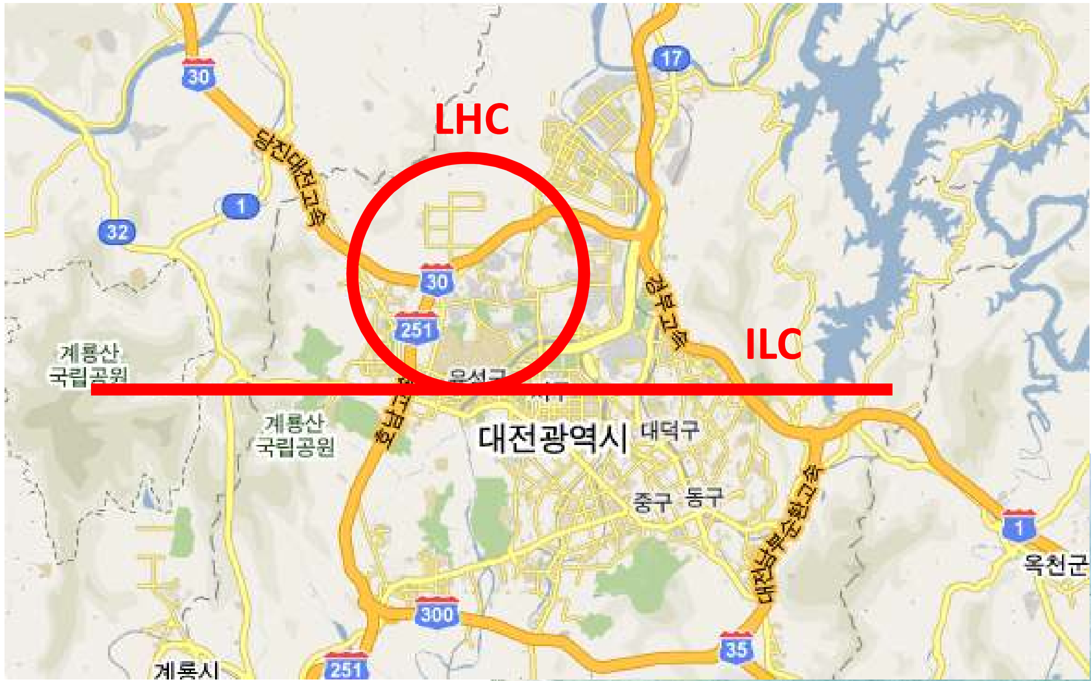
ILC configuration (500 GeV_{CM})

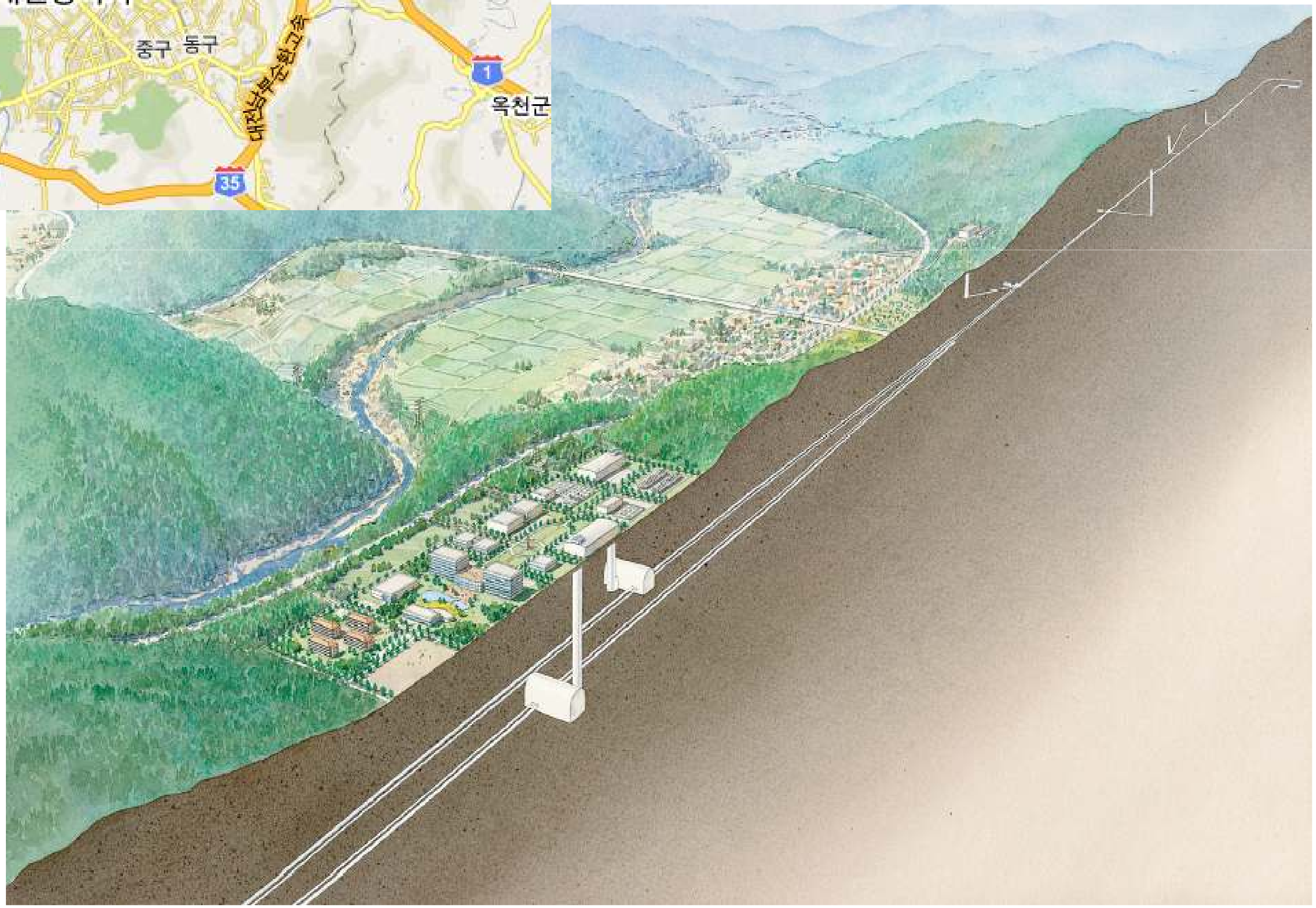
Current baseline (RDR - http://www.linearcollider.org/)

Not to scale

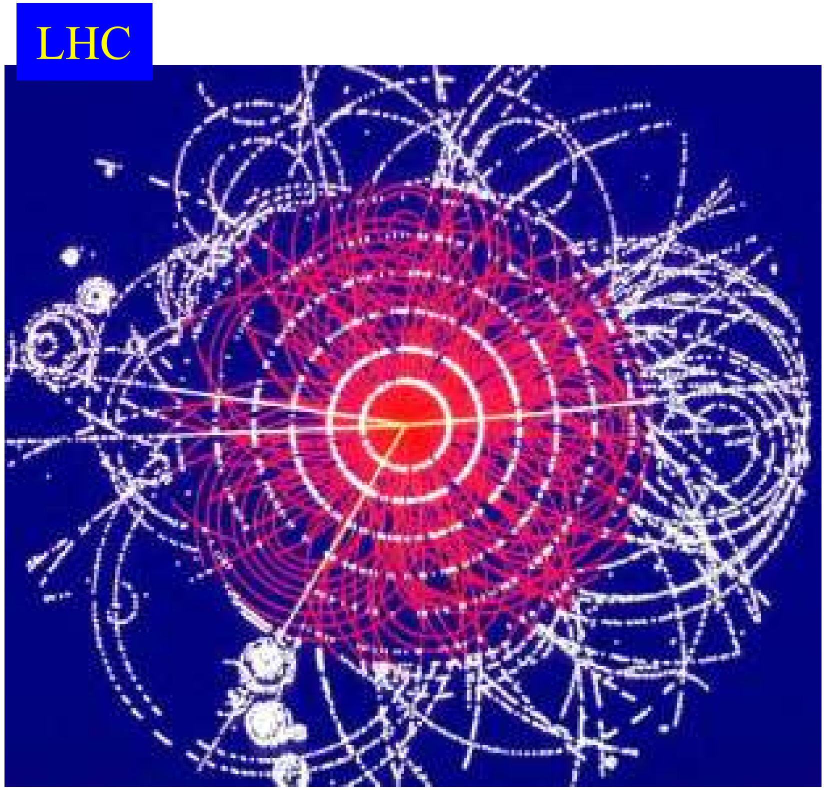


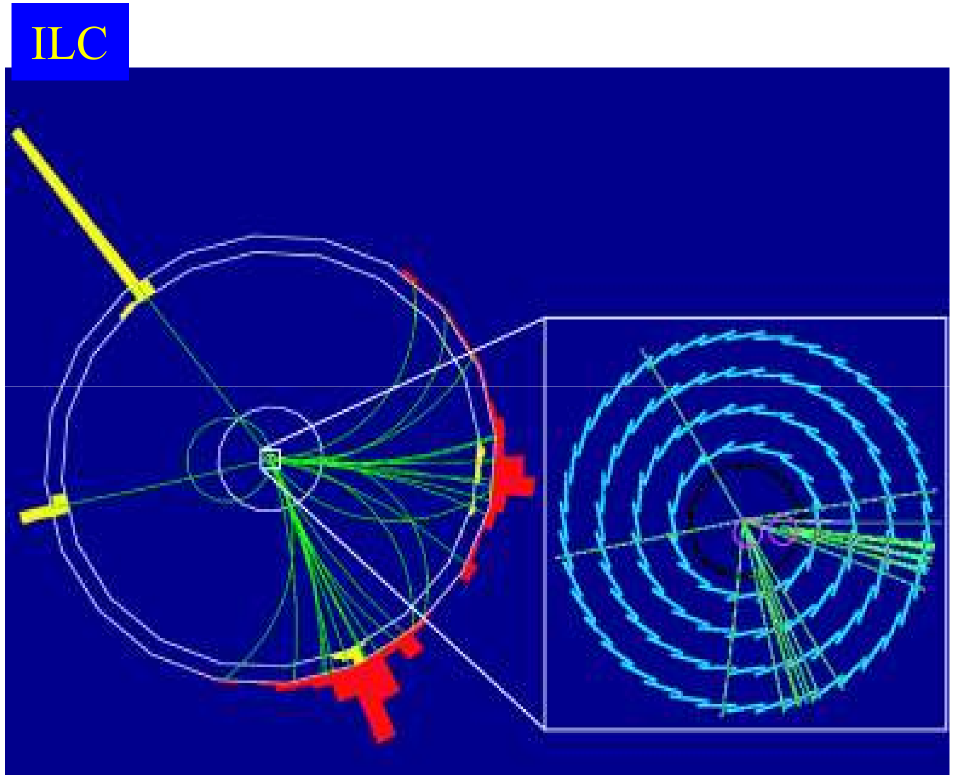
1 collision point with 14 mrad crossing angle


LHC
ILC
계룡산
국립공원
계룡산
국립공원
대전광역시
대덕구
중구
동구
옥천군
계룡시



Higgs event example





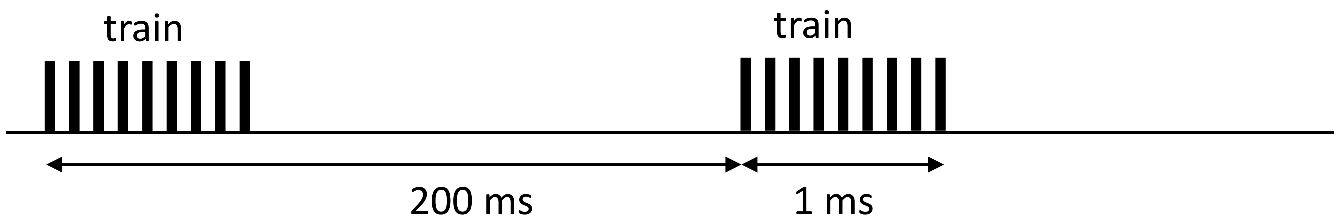
ILC Parameters

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

- 1st phase
  - Energy 200→500 GeV CM, scannable
  - 500 fb^{-1} in first 4 years of physics run
  - Polarized e- (>80%)
- 2nd phase
  - Energy upgrade to ~1TeV
  - 1000 fb^{-1} in 3-4 years
- Options – depending on physics landscape
  - More on 500 GeV CM in 2~3 years
  - $\gamma\gamma$, γe^-, e^-e^-, Giga-Z, WW, polarized e+

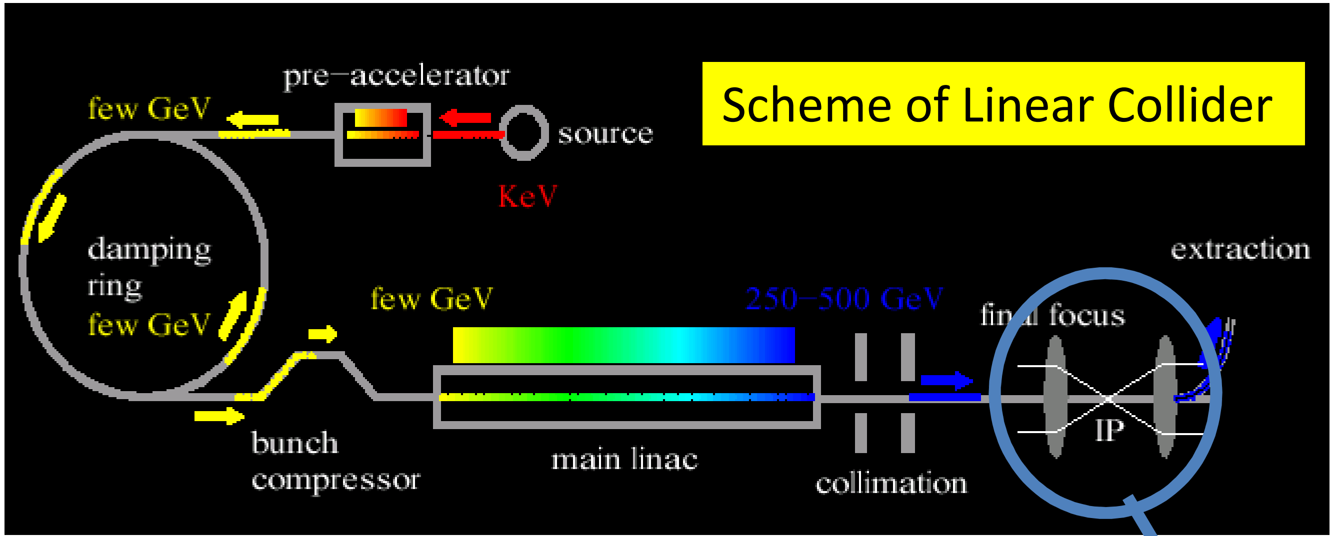
To start commissioning ~ 2020

Beam Parameters (500 GeV_{CM})

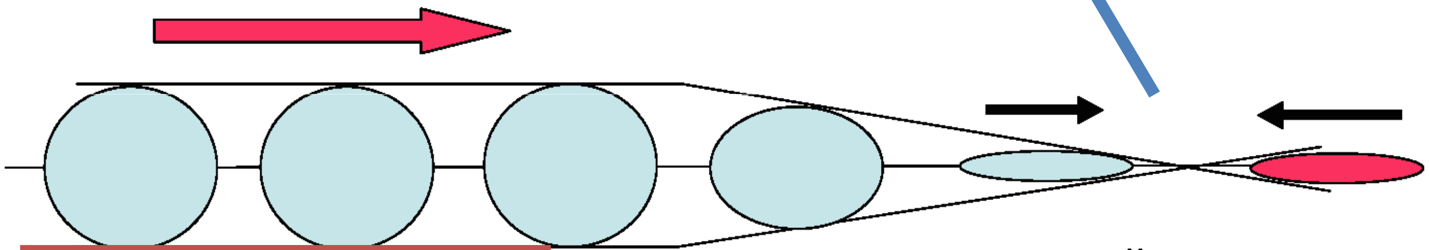


- 5 trains/s, 1 train = 2820 bunches in 1 ms
- #particles/bunch = 2×10^{10}
- σ_x= 550 nm, σ_y= 6 nm, σ_z= 300 µm
- Luminosity = $2 \times 10^{34}/cm^2 s$

	Nominal	Try to accomodate
#bunch/train	2820	5640
Bunch spacing (ns)	308	154
Bunch length (µm)	300	150



Nano-size beam to improve the luminosity



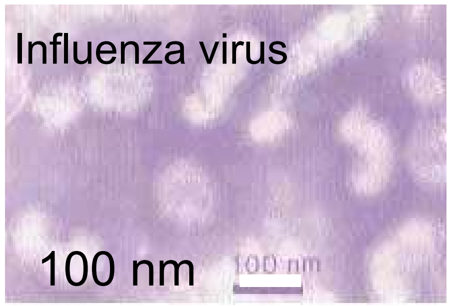
~5 nm

Collision point

Ultra-parallel beam

Even if it reaches to the moon, its spot size is still less than 1 m (x10^4 parallel beam than normal laser)

~x20 of radius of hydrogen atom
<1/10 of influenza virus

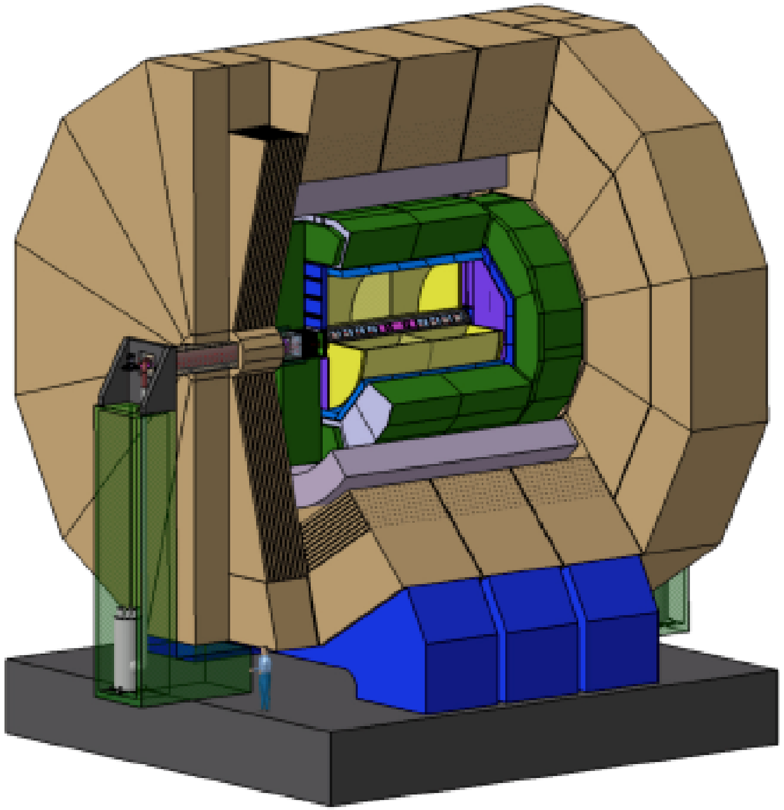


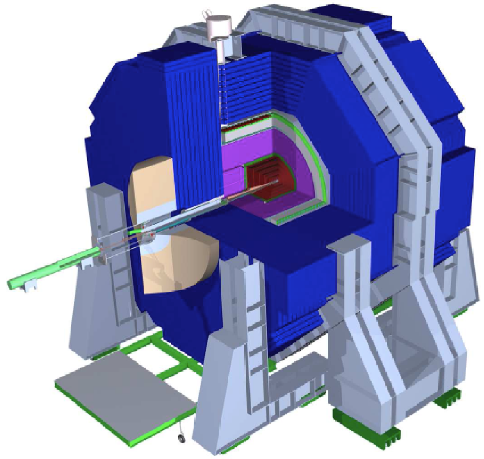
Proposed detector concepts

ILD

Formed in 2007

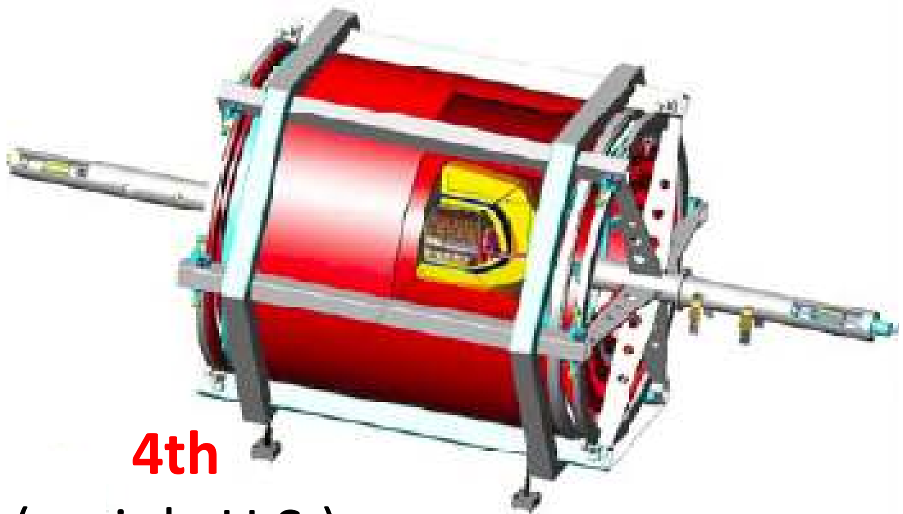
(Asia & Europe & U.S.)





SiD

(mainly U.S.)

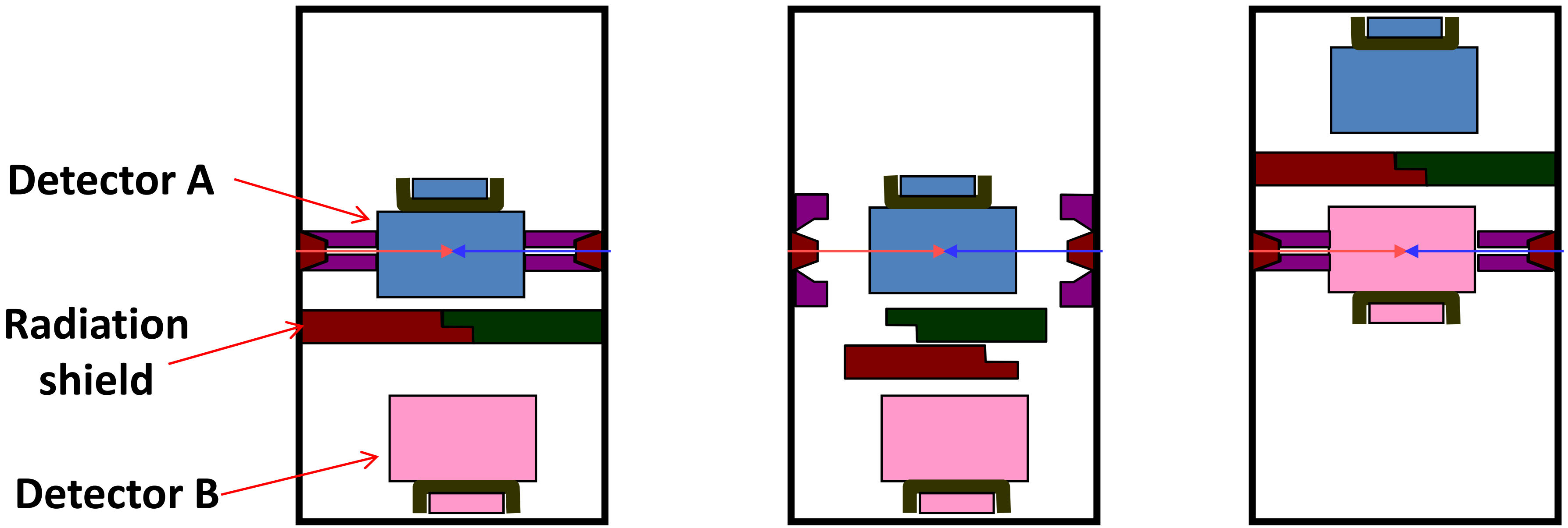


4th

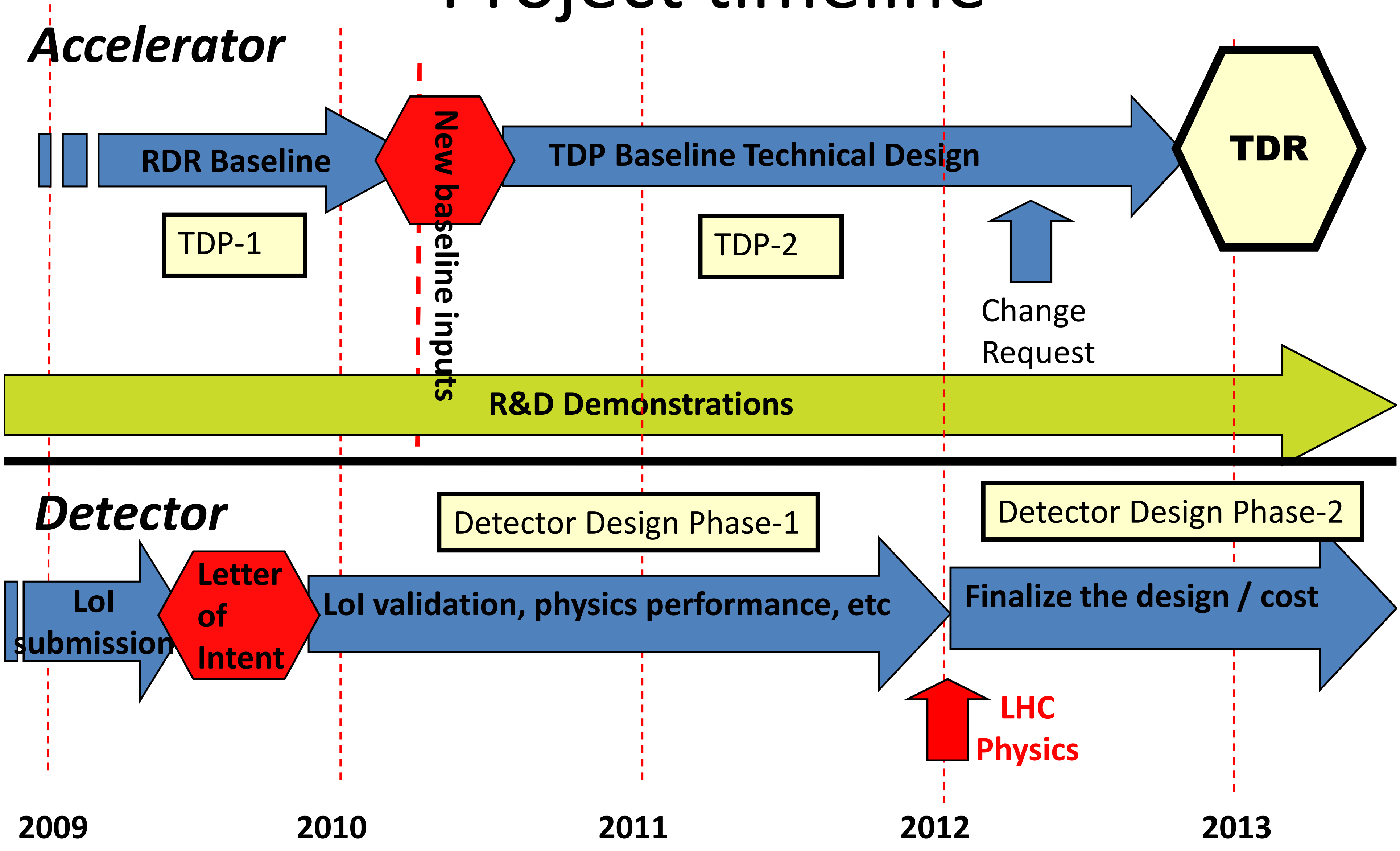
(mainly U.S.)

1 collision point with 2 detectors (push-pull)

- Can save one entire beamline - a large cost saving
  - But will it work?
    - Moving 10000 ton detector in a few days.
  - Historical/political issues, detector design, accelerator design, integration/engineering design, alignment/calibration, etc.
- Intensive studies under way



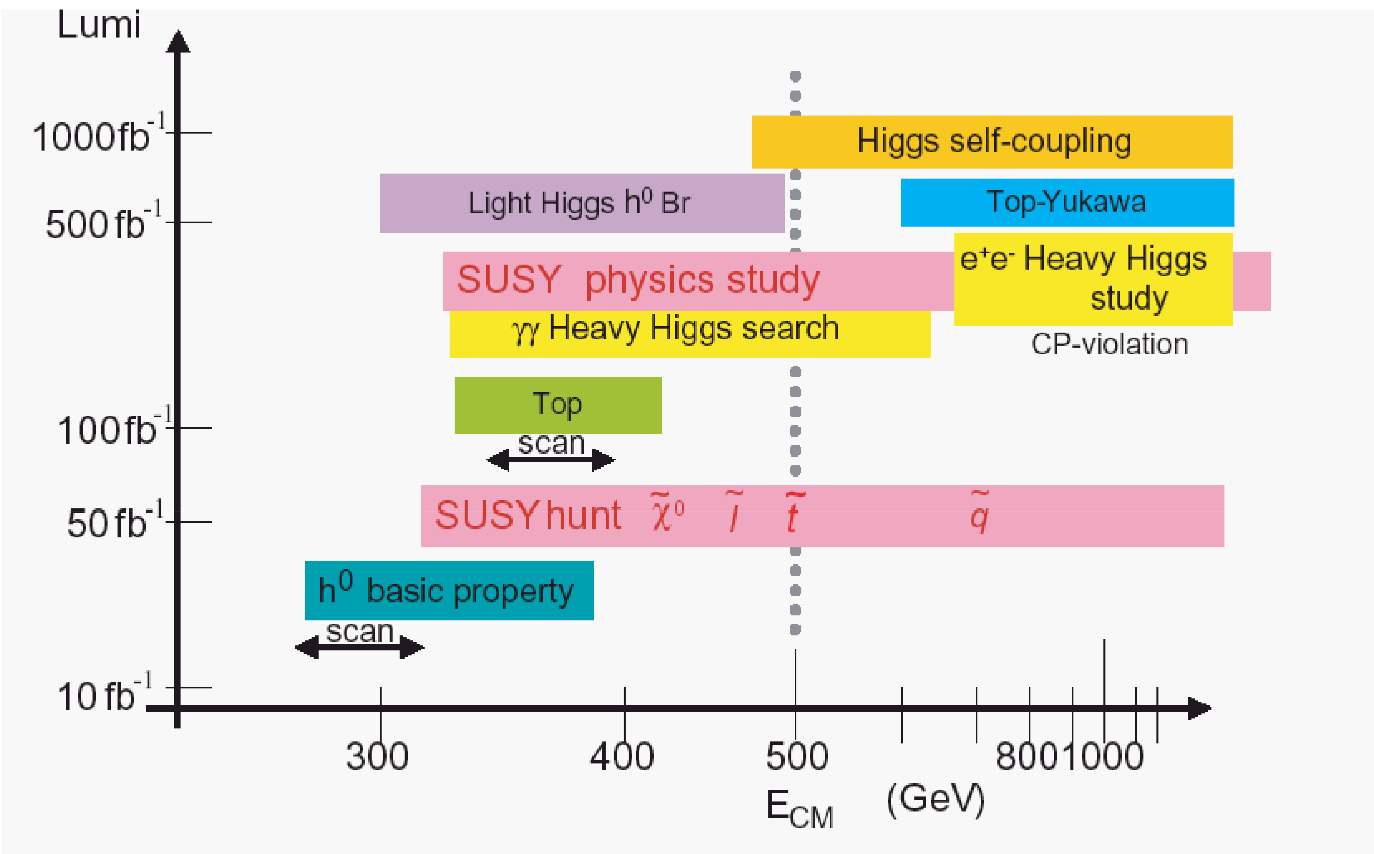
Project timeline



Accelerator Comissioning ~ 2020

Physics highlights

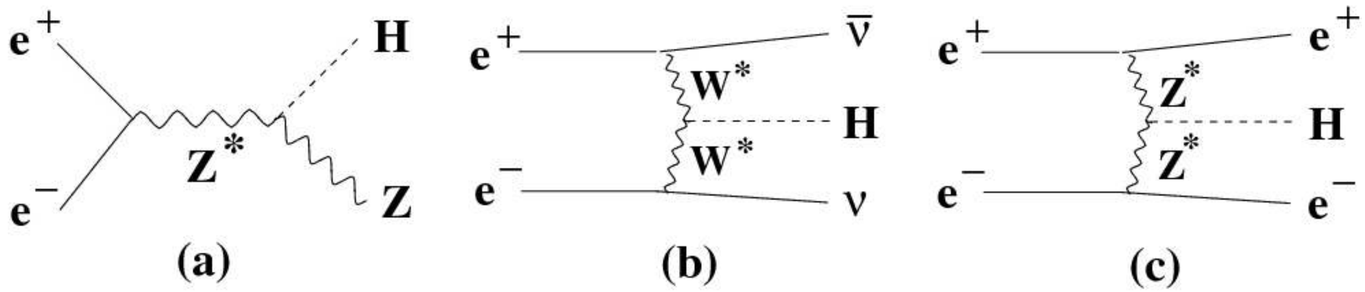
Physics @ ILC



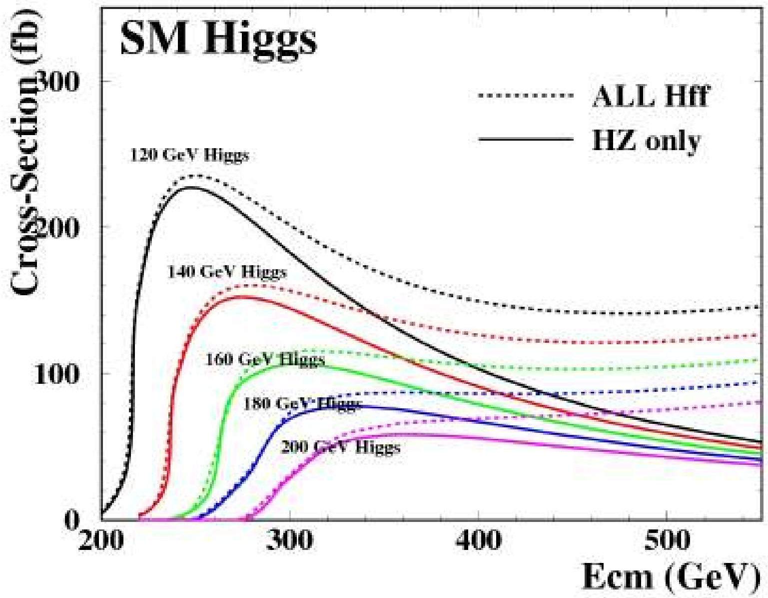
1st stage : Ecm=500GeV (91.2GeV, 200-500GeV changeable)
Luminosity = > 500 / fb / several years
2nd stage : Ecm=1TeV

Higgs Production @ ILC

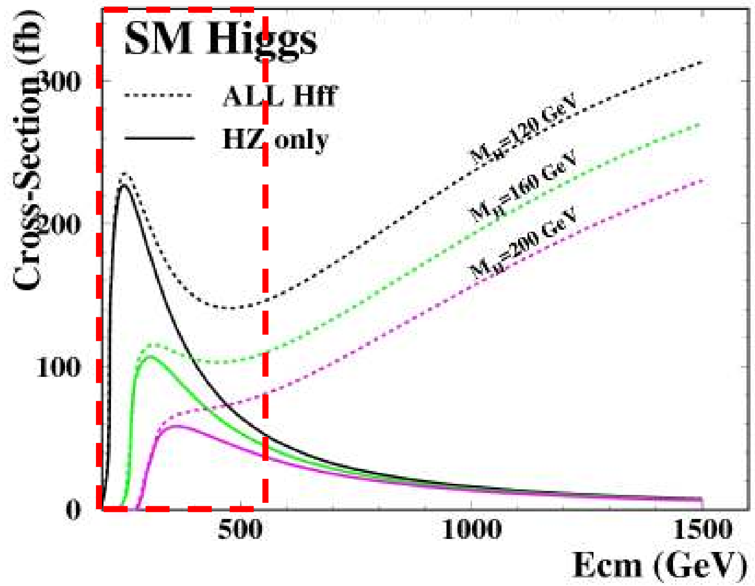
- Diagrams of the Higgs production



- Production cross-section of the Higgs



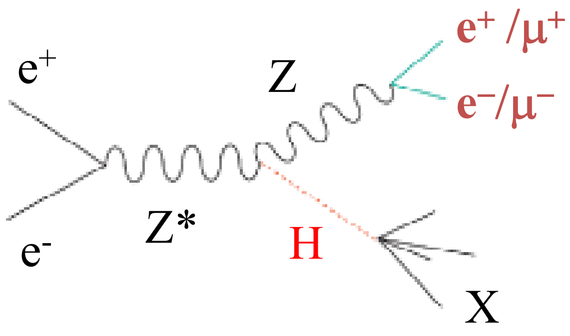
>100k ZH
For 500fb^{-1}



- **Works as the Higgs Factory!**
- Use all modes: 3σ sensitivity in 1 day (1 year at LHC)

Higgs signal @ ILC

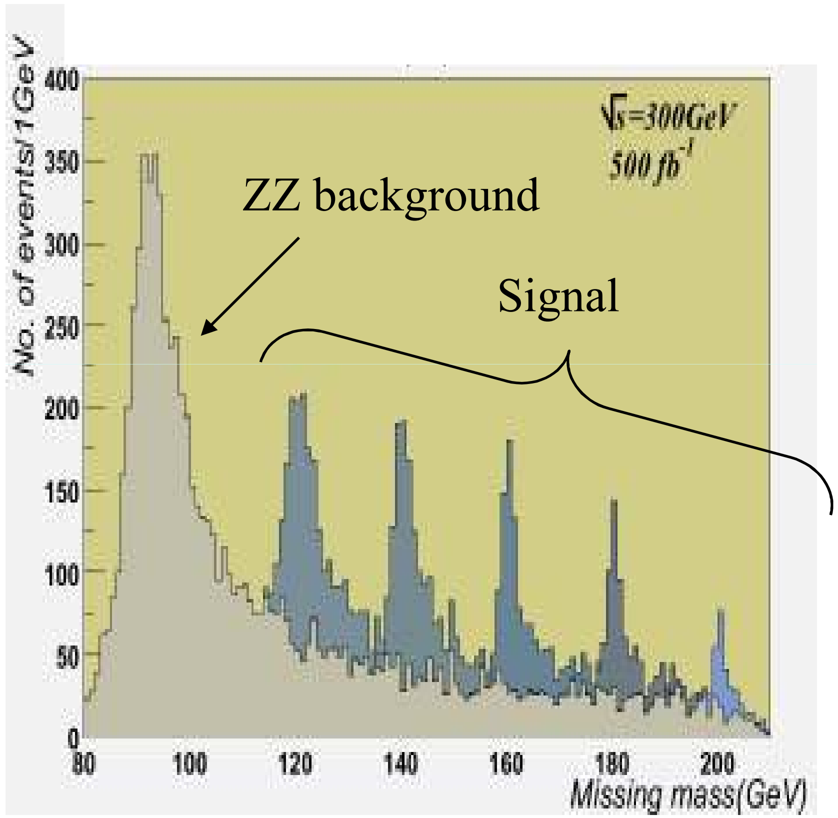
- 2lepton + X mode



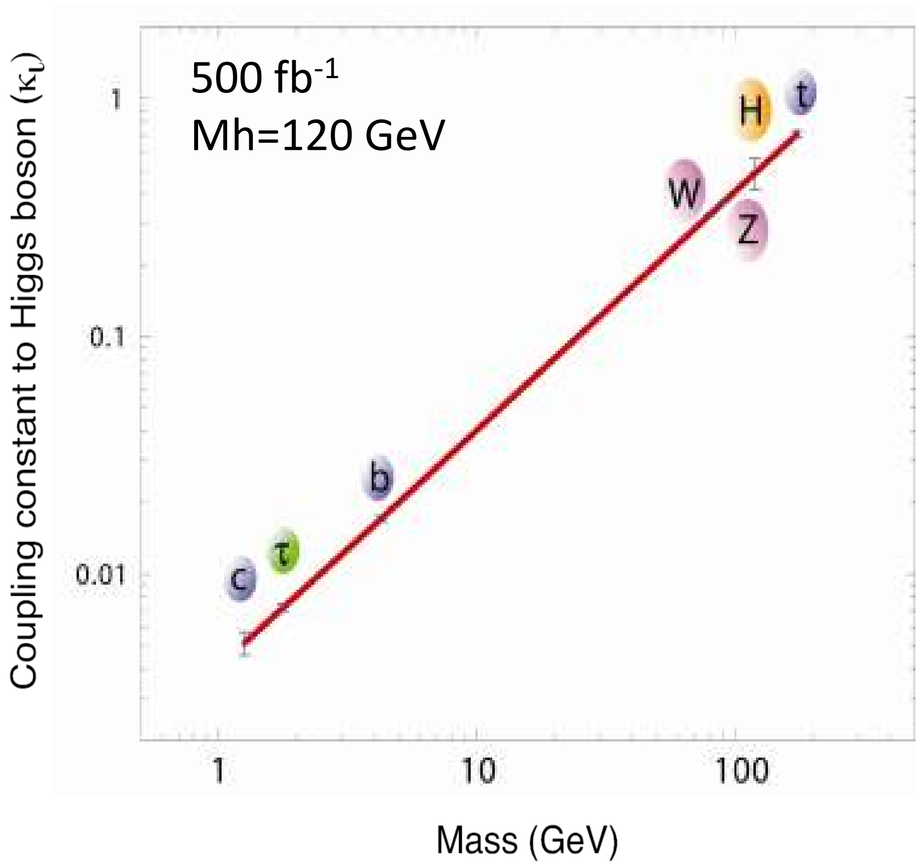
- Identify lepton pair whose invariant mass is consistent with the Z mass.
- Recoil mass

$$M_h^2 = (p_{init} - p_{ll})^2$$

- Model independent,
  Higgs decay mode independent
  No bias.



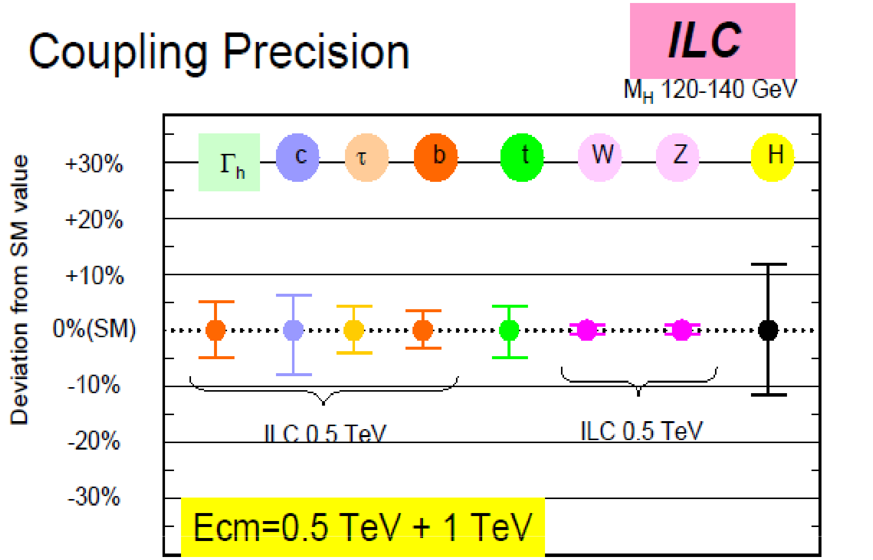
Higgs couplings @ ILC

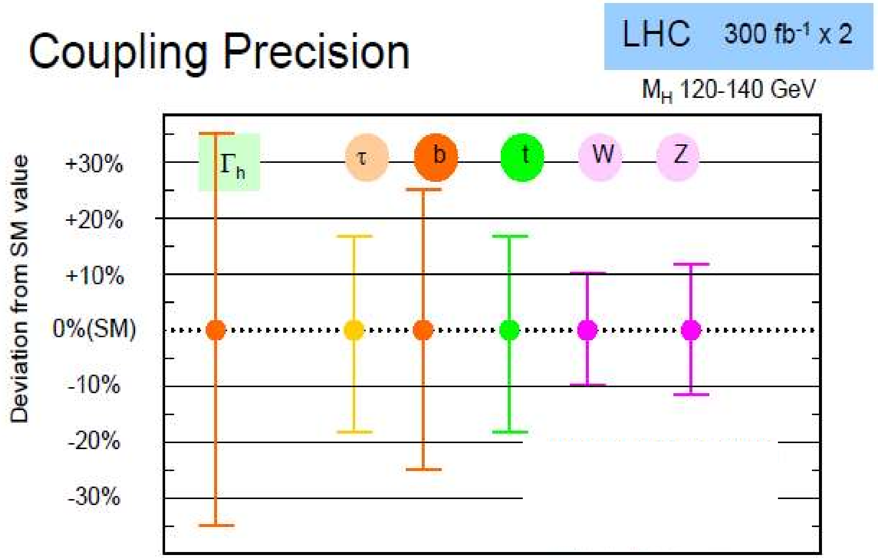


particle mass — Higgs coupling constant

$$m_i = v \times \kappa_i$$ in SM

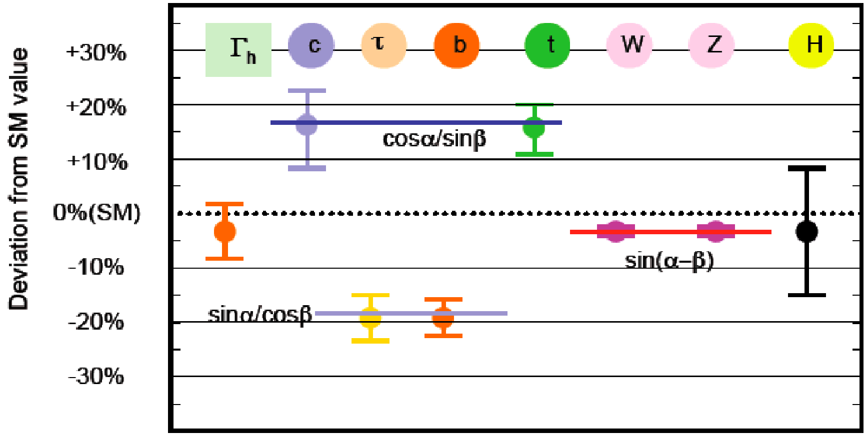
Higgs vacuume-expectation-value

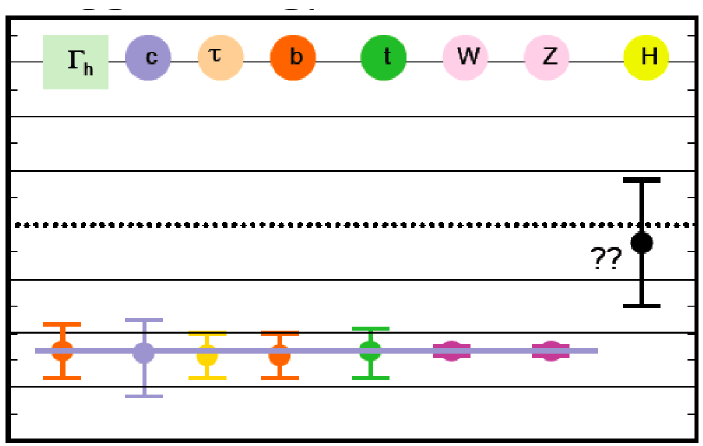




Deviations from SM

(By S. Yamashita)



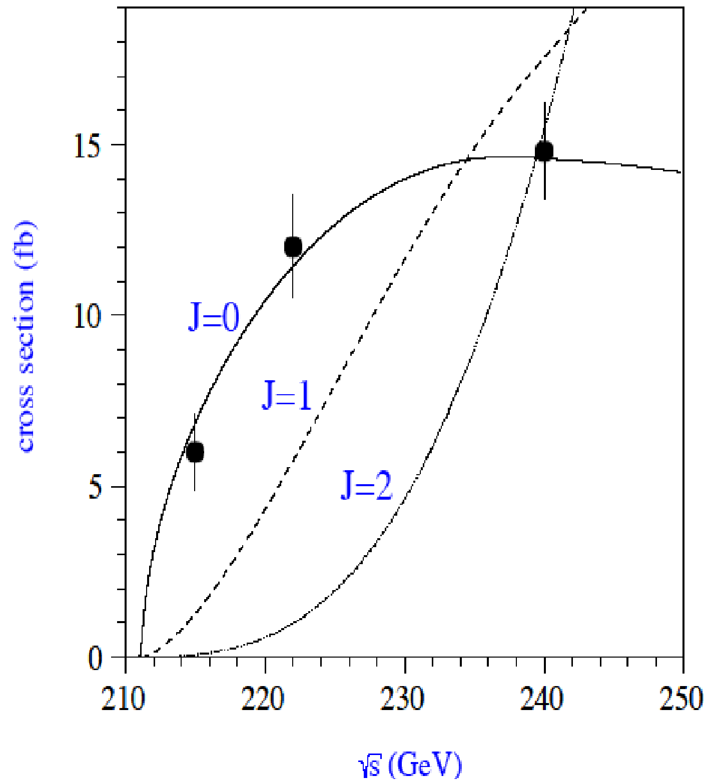


SUSY
(2 Higgs Doulet Model)

Extra dimension
(Higgs-radion mixing)

Measurement of Higgs parameters

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



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

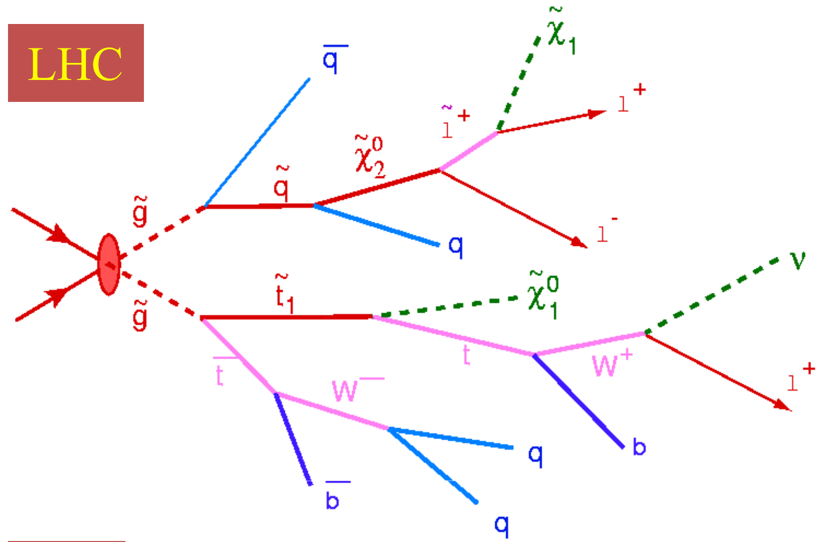
SUSY Study @ ILC

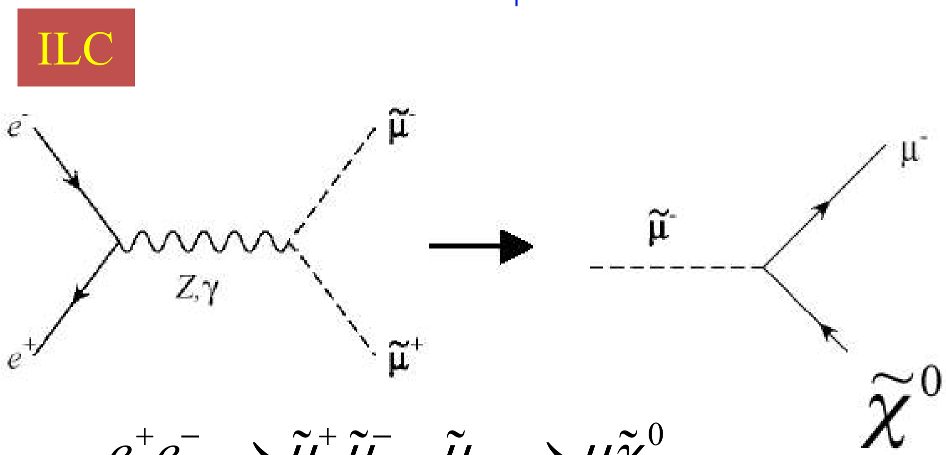
- LHC would discover SUSY or missing-energy phenomena.

- SUSY Study @ ILC
  Precise measurements of the sparticle properties can be done.
  Beam polarization useful.

  It can also reduce backgrounds

- ILC + LHC
  Determine underlying SUSY model and SUSY breaking mechanism.



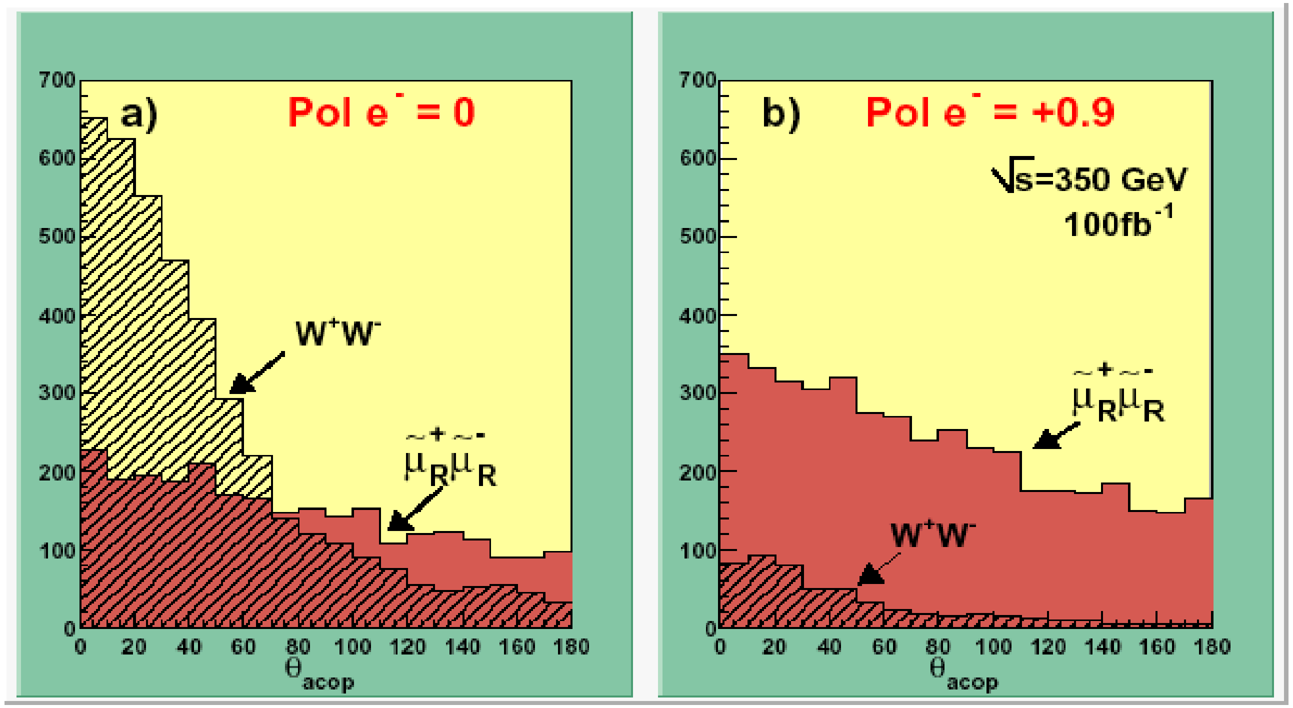


$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$

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

Smuon detection

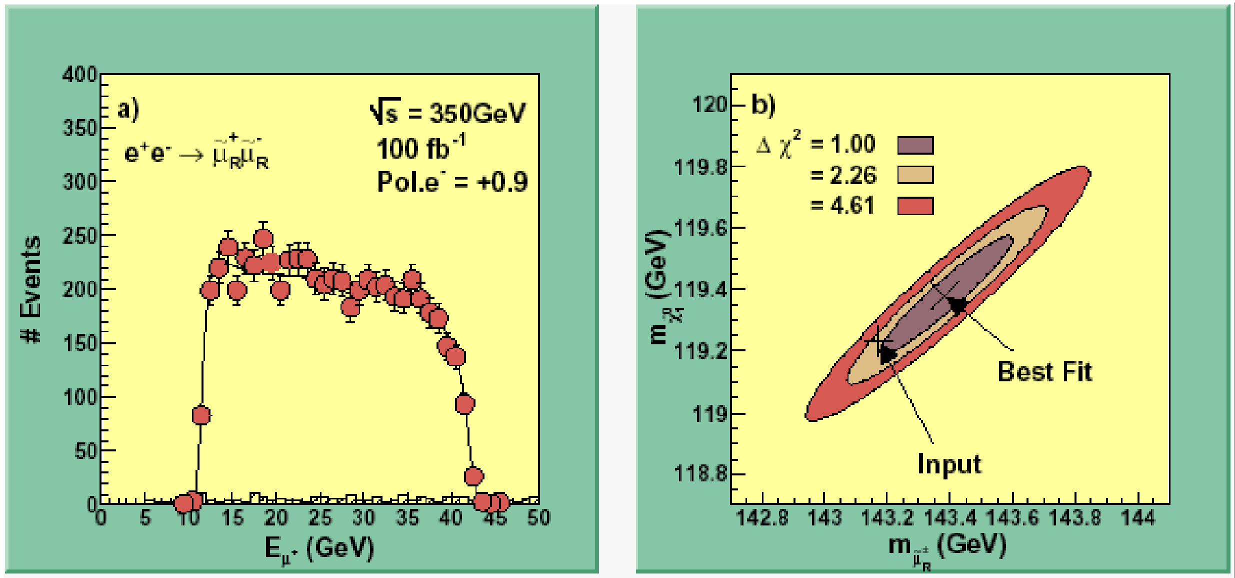
$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$



- Signal : $\mu^+\mu^-$ and nothing. Plot acoplanarity of $\mu^+\mu^-$-beam
- Polarized e^- (R) can reduce $W^+ W^-$ background.

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

Responding to LHC

- Systematic studies needed
  - When are we likely to know what from LHC?

    Possible LHC discovery scenarios
  - For each scenario

    What physics modes to study at ILC

    What exact kind of machine to build

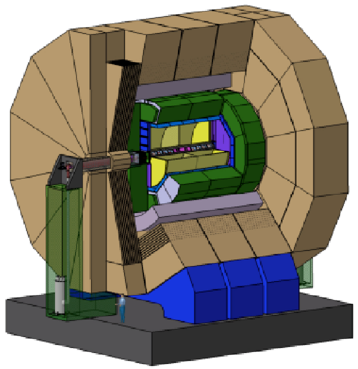
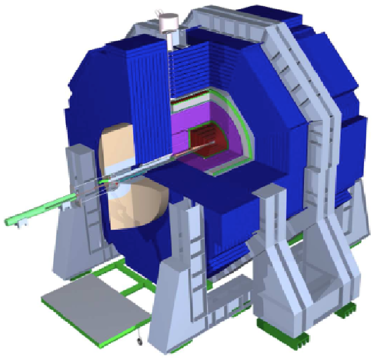
    What exact kind of detector to build

    Priorities and timescale, upgrade paths
  - Cost and political realities to be included

Detector development

Particle Flow Algorithm
Development of Finely granular calorimeter

ILC Detector concepts

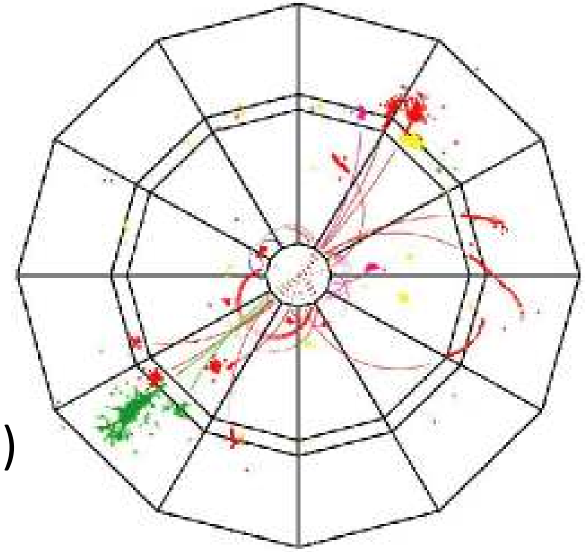
  

	ILD	SiD	4th
Tracker	TPC + Si-strip	Si-strip	TPC or Si-strip or DC
Calorimetry	PFA	PFA	compensating
B	3.5 T	5 T	3.5 T
ECAL Rin	1.84 m	1.27 m	1.5 m
Rout	6.27 m	6.45 m	5.5 m
Zout	6.15 m	6.45 m	6.4 m

Jet Energy Measurement at ILC

- $e^+e^- \rightarrow$ *H*, *W*, *Z*, *tt*, SUSY, etc …
  $\rightarrow$ many quark jets

- Precise jet energy measurement is the key at the ILC.

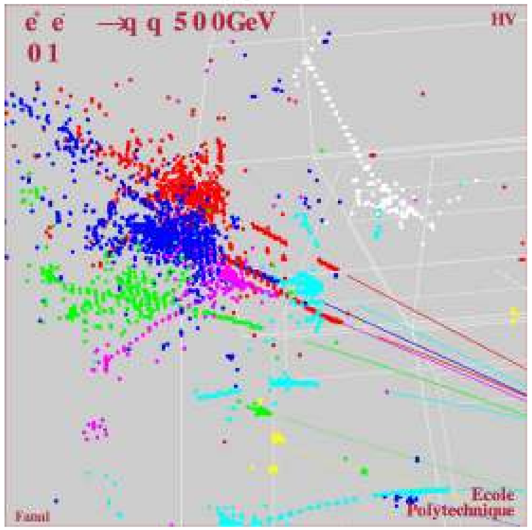


Particle Flow Algorithm … a new method

Constituents of quark jets :

- Charged particles : 65 % … momenta can be precisely measured by tracker

- Neutral particles (Photons … 25 %, neutral hadrons … 10 %) … energies have to be measured by calorimeter



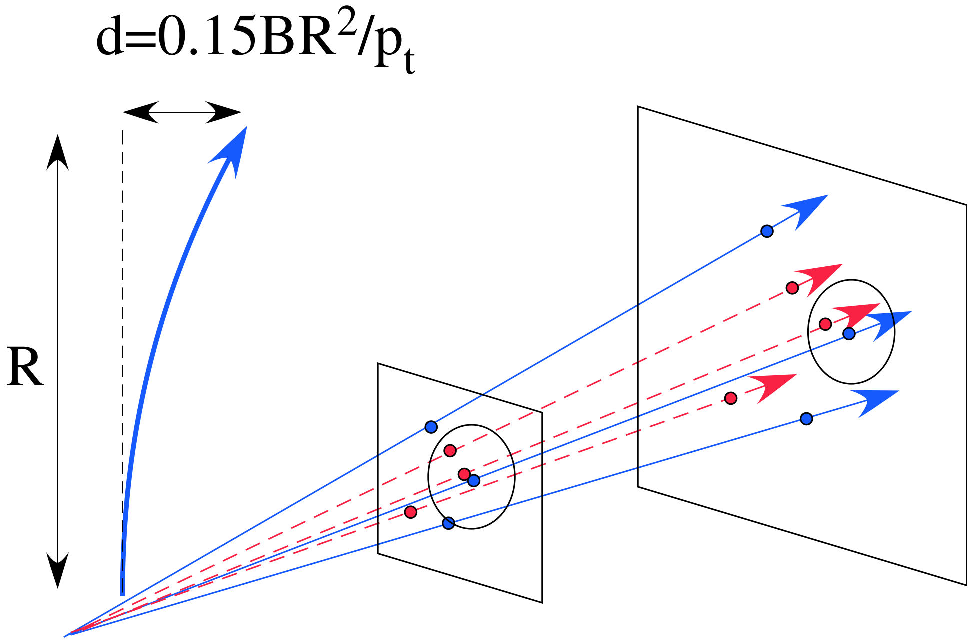
$$E_{jet} = \underbrace{p_e + p_\mu + p_{charged\ hadron}}_{\text{[tracks only]}} + \underbrace{E_\gamma + E_{neutral\ hadron}}_{\text{[calorimeter only]}}$$

- Separation of jet particles in the calorimeter is required for the PFA

→ **Fine granular calorimeter** is necessary.

Calorimeter for the PFA

Separation of jet particles in calorimeter is crucial for the PFA.



"Figure of Merit for the PFA"

$$\frac{BR^2}{\sqrt{\sigma^2 + R_M{}^2}}$$

B : Magnetic field

R : CAL inner radius

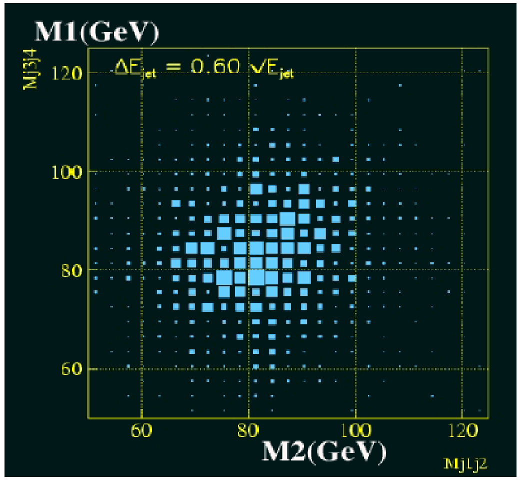
σ: CAL segmentation size

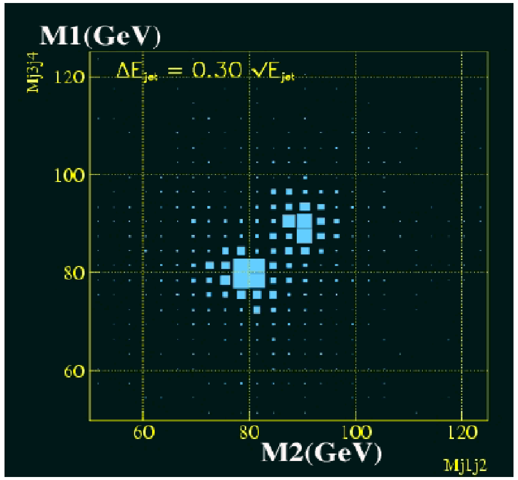
R_M : Effective Moliere radius

For the PFA, finely segmented, large, dense calorimeter is required.

Jet-energy reconstruction by PFA (example)

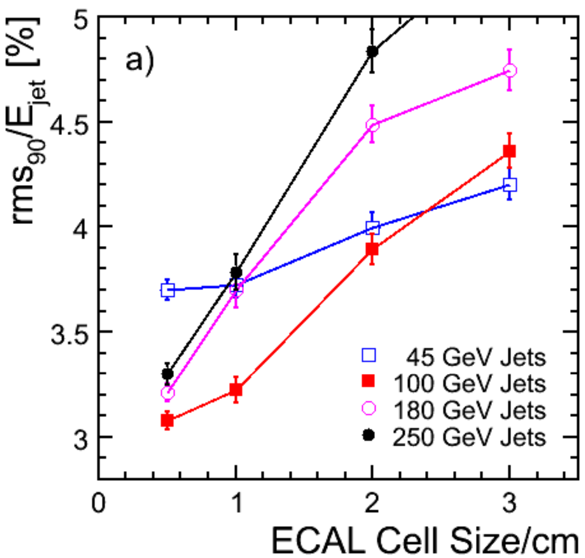
$$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \quad W/Z \to jj$$

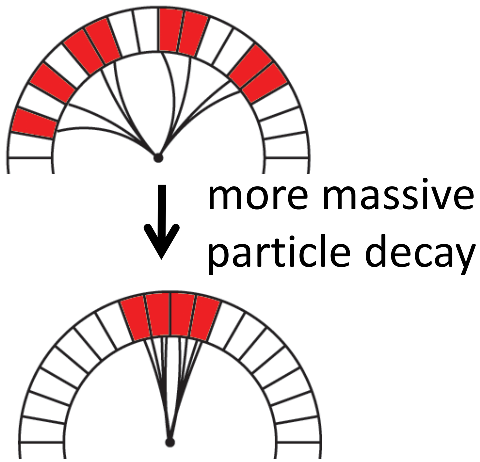




$$\sigma_E / E = 0.6/\sqrt{E(\mathrm{GeV})} \qquad \sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

σ$_E$/E with MC + PFA

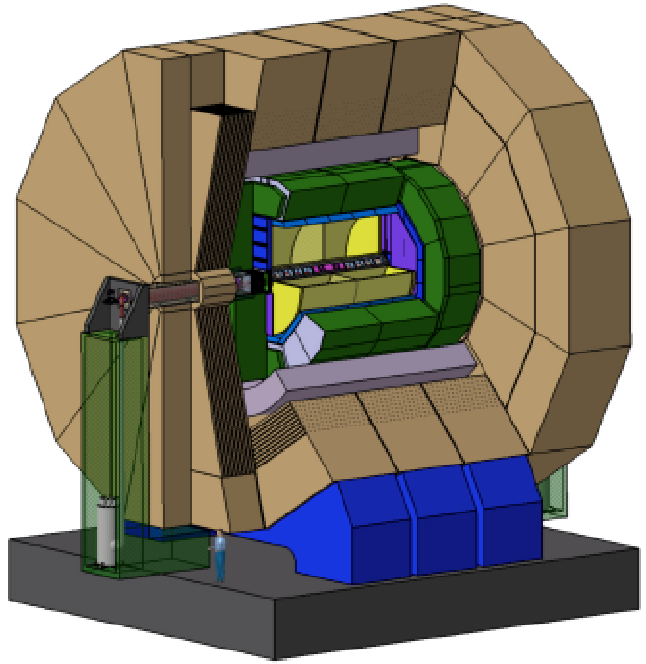


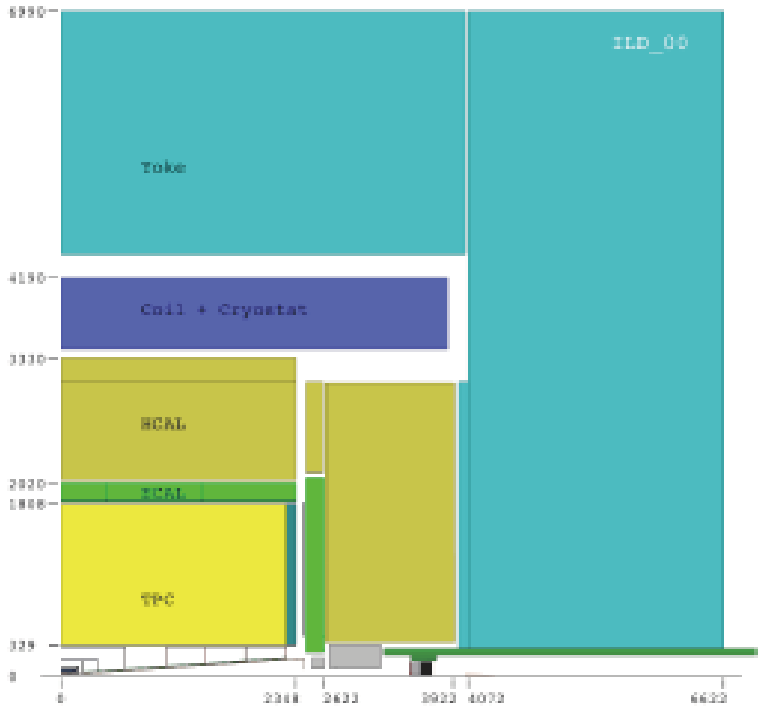


- With $\sigma_E / E = 0.3/\sqrt{E}$, Z/W→jj can be separated.
- 1 - 0.5 cm of ECAL segmentation necessary to get the excellent resolution for higher energy jets.

The ILD Detector

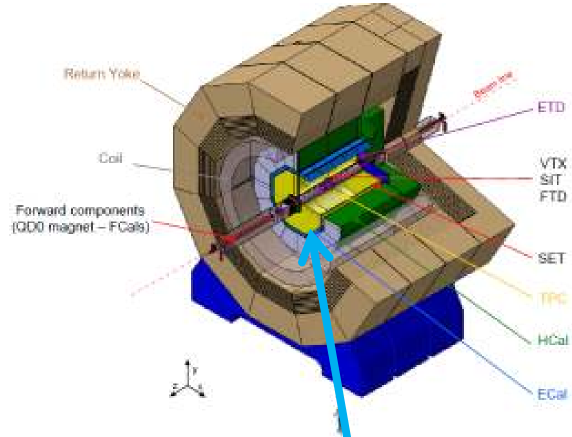
- Vertex
  - 5 or 6 layers
  - Technology open
- Si-trackers
  - 2 barrel + 7 forward disks
  - Outer and end of TPC
- TPC
  - GEM or MicroMEGAS (or Si pixel)
- ECAL
  - Scint-strip or Silicon + Tungsten
- HCAL
  - Scint-tile (or Digital HCAL)

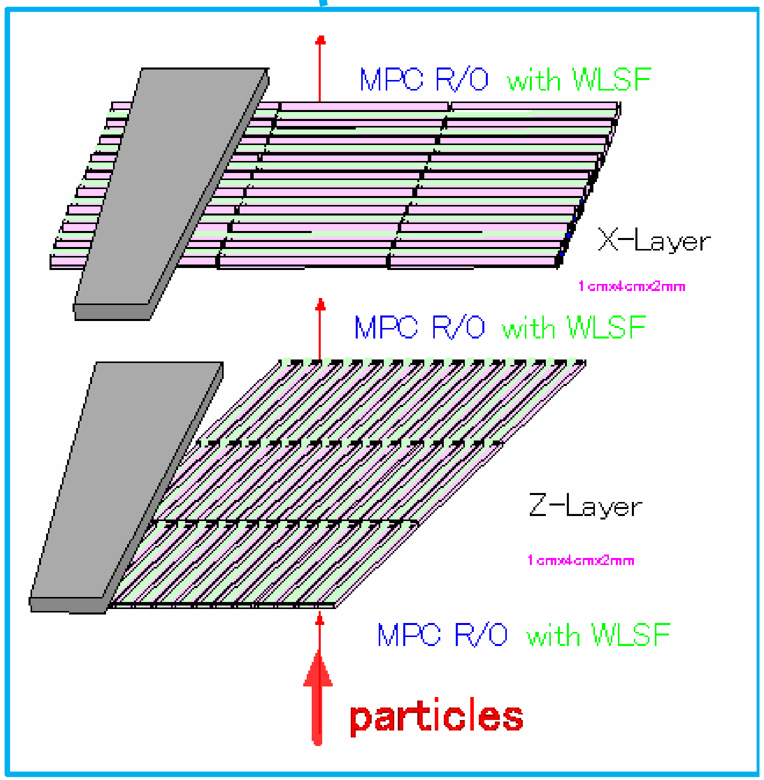


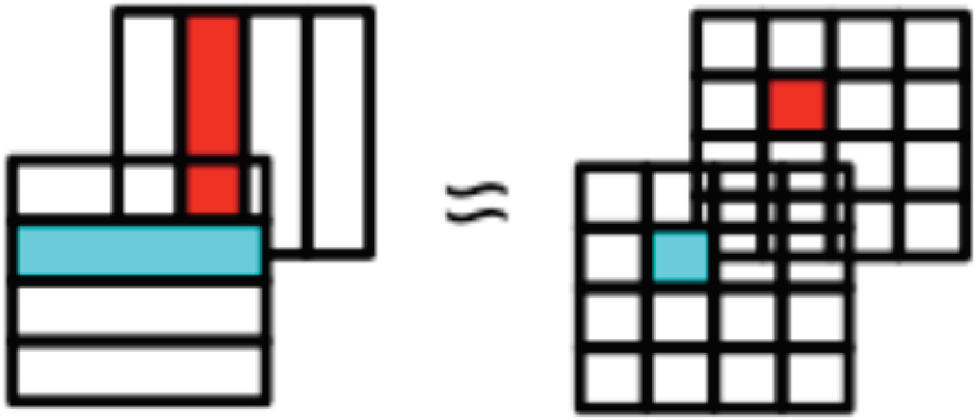


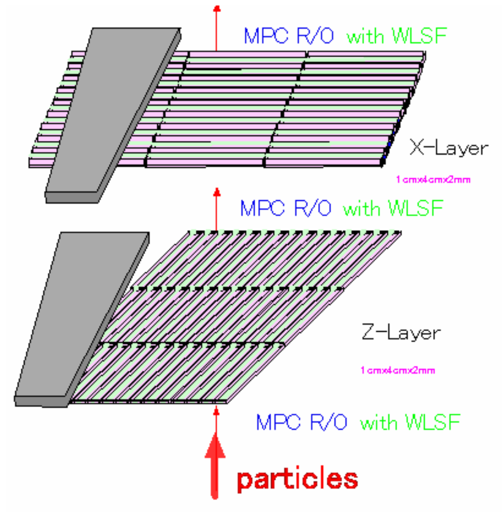
The Scintillator-Strip Electromagnetic Calorimeter

- Sampling calorimeter with Tungsten-scintillator sandwich structure.
- Scintillator-strip technology adopted to achieve fine granularity.
- Lateral Segmentation : 1 ~ 0.5 cm
- Huge Number of channels (~10M channels).
- Need to establish sufficient performance while keeping the low production cost.
- **First need to establish the feasibility!**



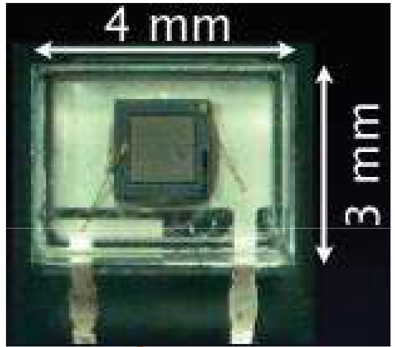






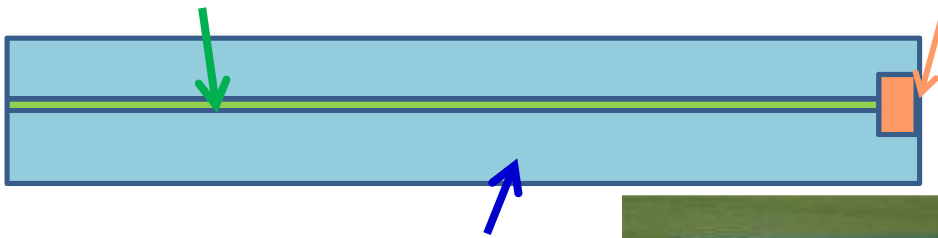
R&D of Elementary Components

New-type photo-sensor (MPPC)



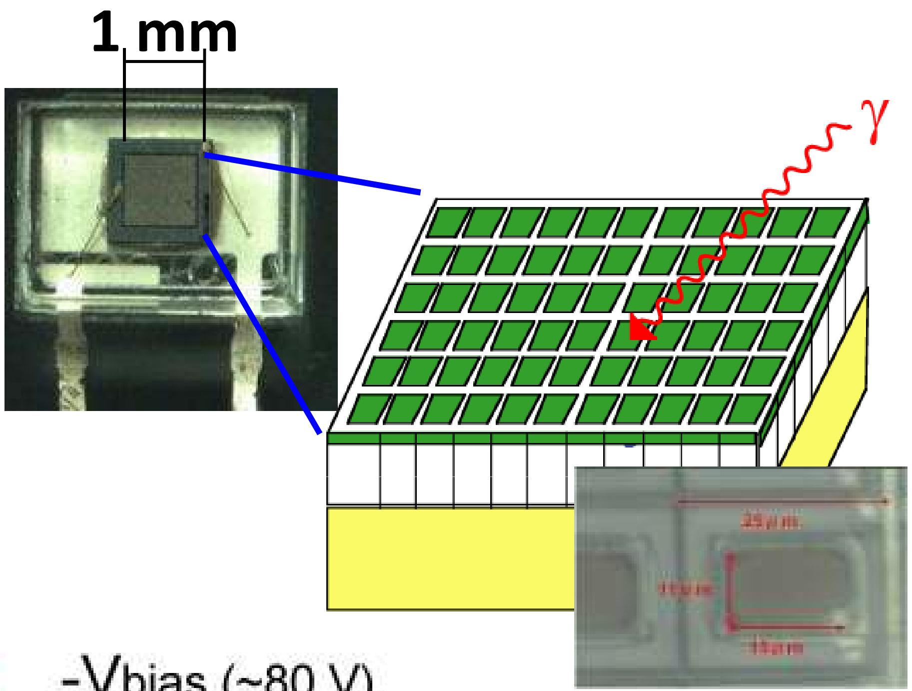
Wavelength Shifting Fiber (Y11 1mmϕ)

4.5 x 1 x 0.2 cm



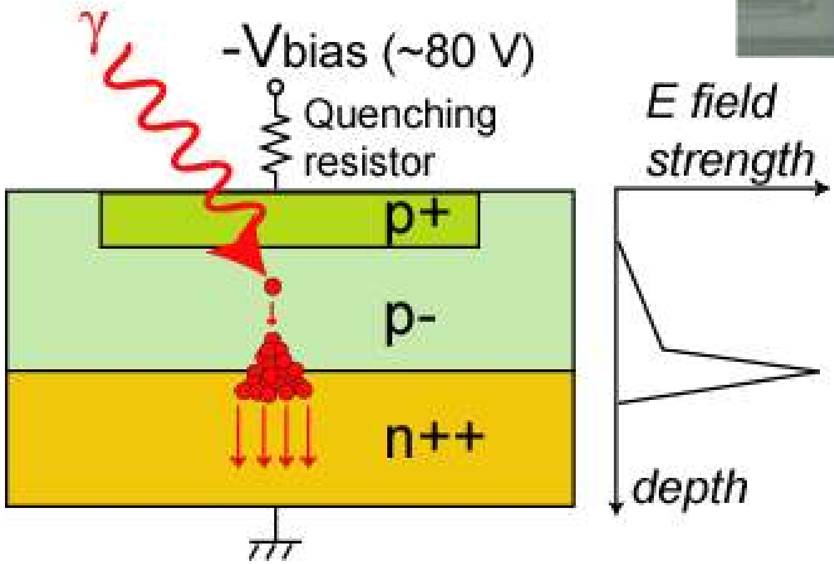
Plastic scintillator strip by extrusion technique

Recent Breakthrough – Novel Semiconductor Photo-sensor, the Multi-Pixel Photon Counter



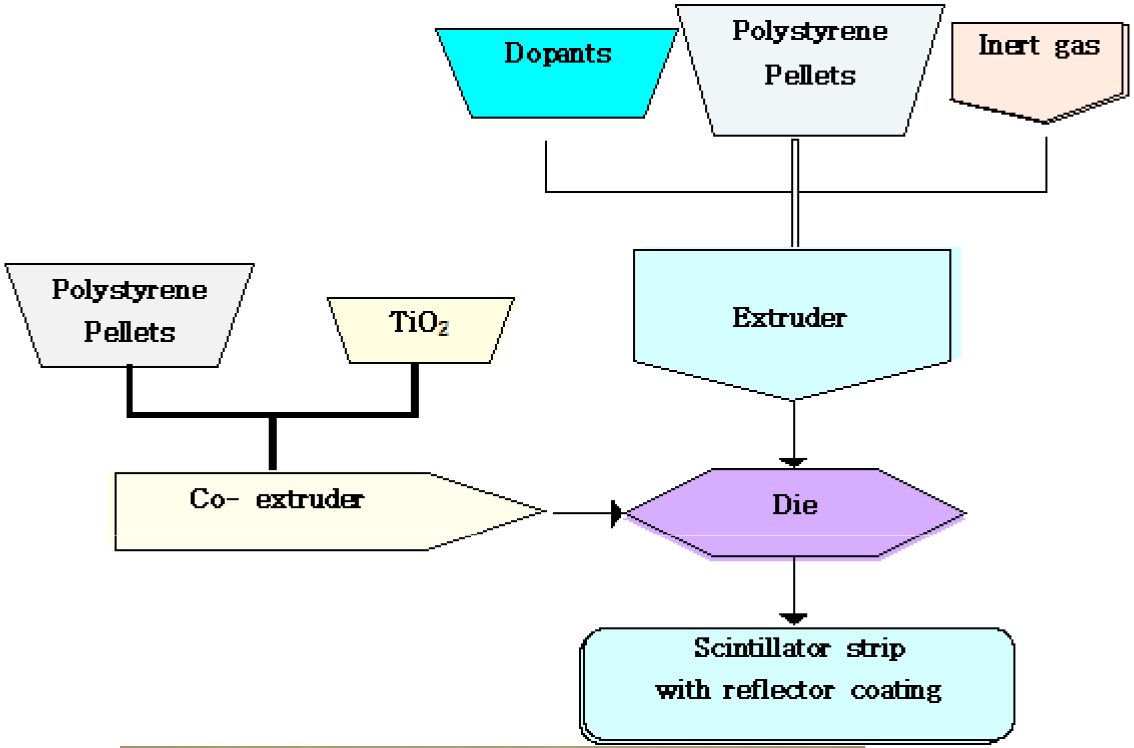
- Consists of Geiger-mode APD pixel matrix (100-3100 pixels).
- **It has many great features which supersedes the photomultipliers.**

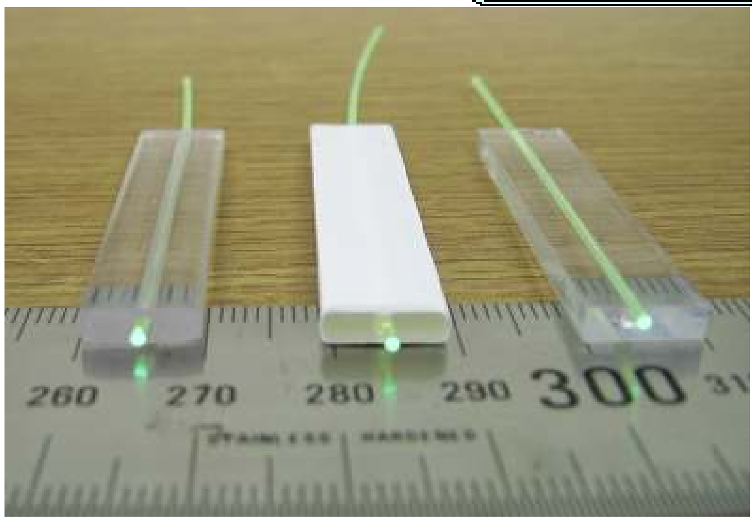
- High Gain (10^5~10^6)
- Compact (package size ~ a few mm)
- Low Cost
- Insensitive to magnetic field
- Dark noise exists (~100 kHz)
- Input vs output is non-linear

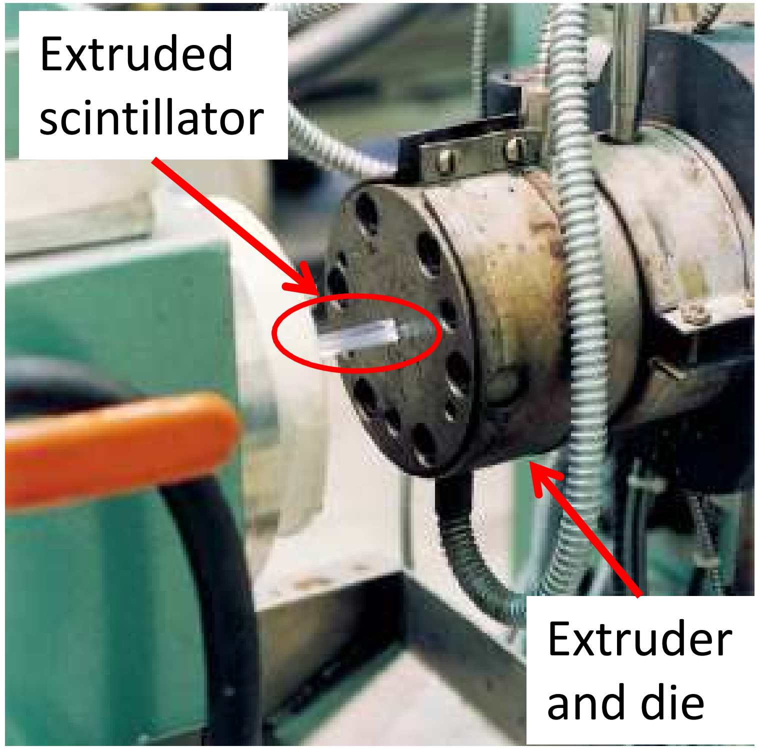


•Ideal for the Scintillator-strip calorimeter.
•Development has started since 5 years ago, and being underway.

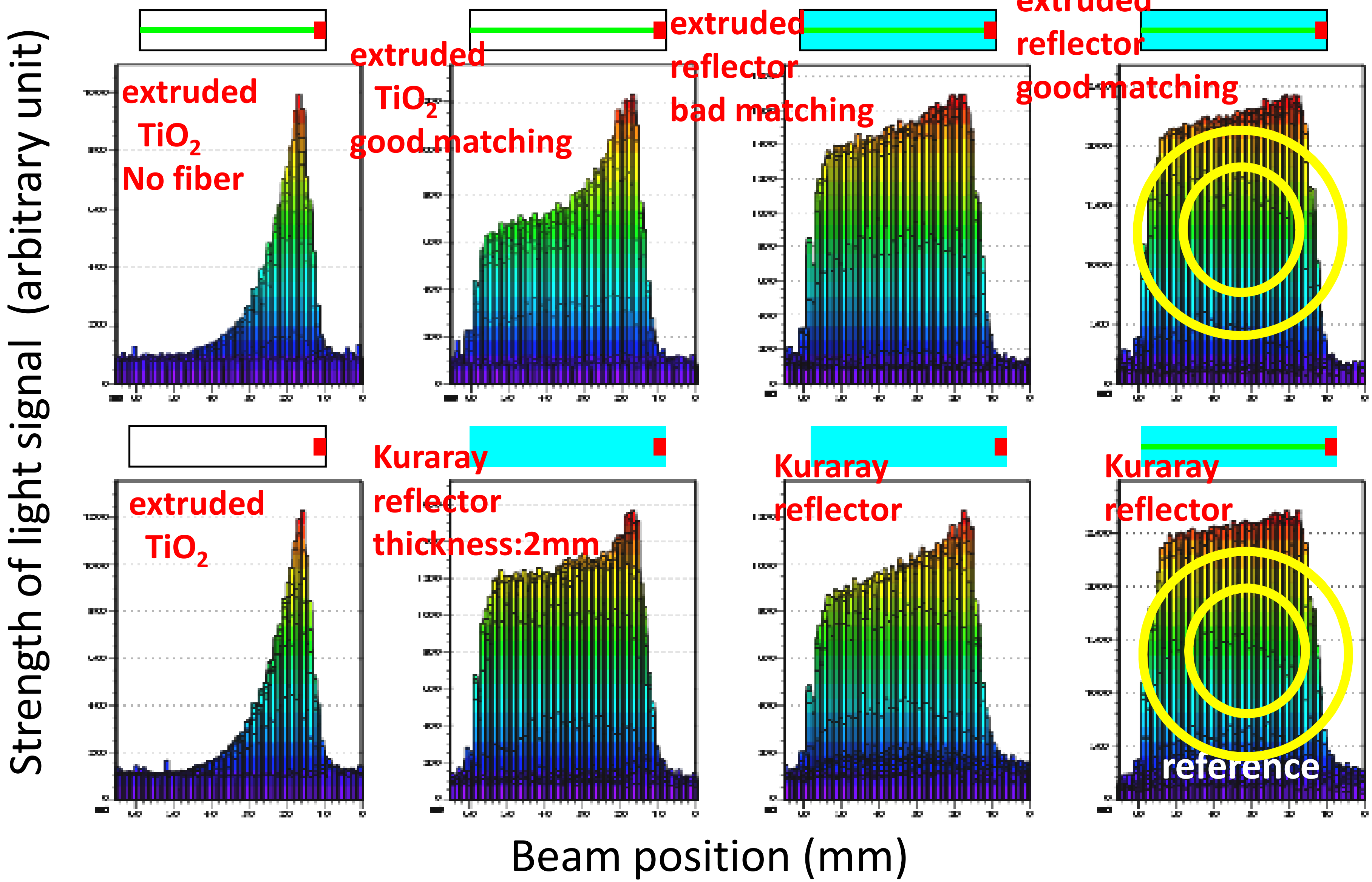
Extruded Scintillator Production







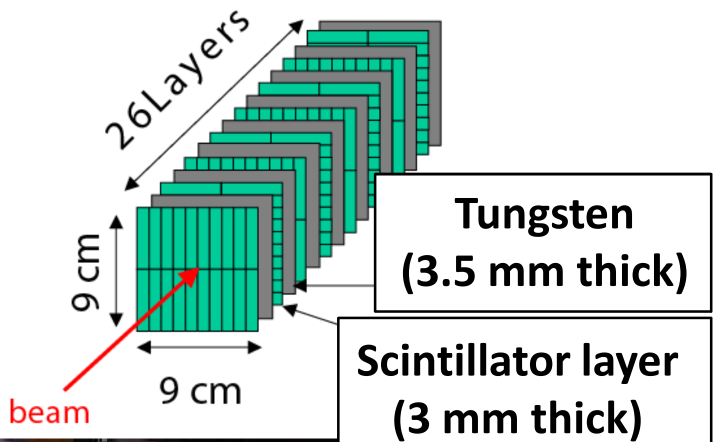
Test results of scintillators

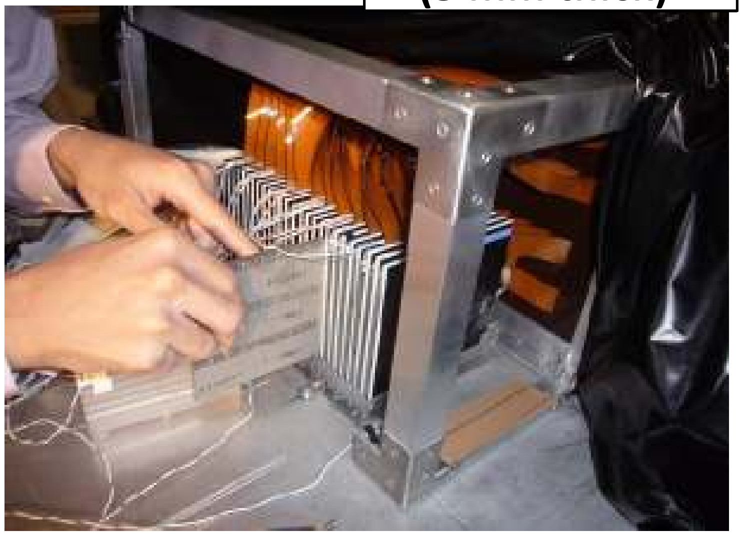


Calorimeter Prototypes

1st prototype (2007 Spring):

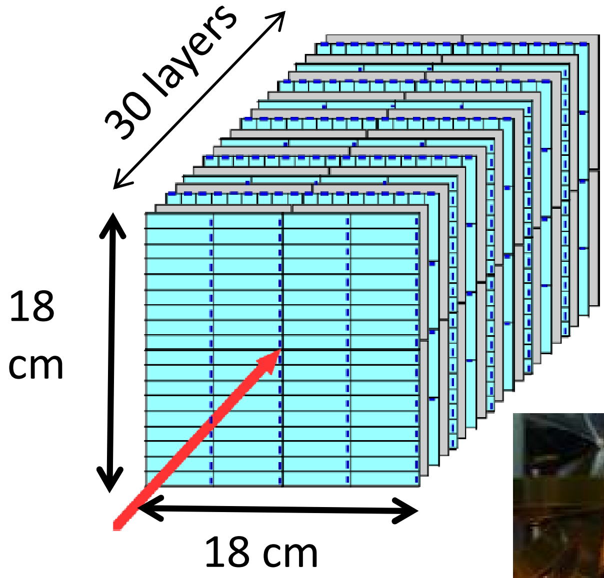
- Test feasibility of the sci-strip calorimeter
- Tested with 1-6 GeV positron beams @ DESY



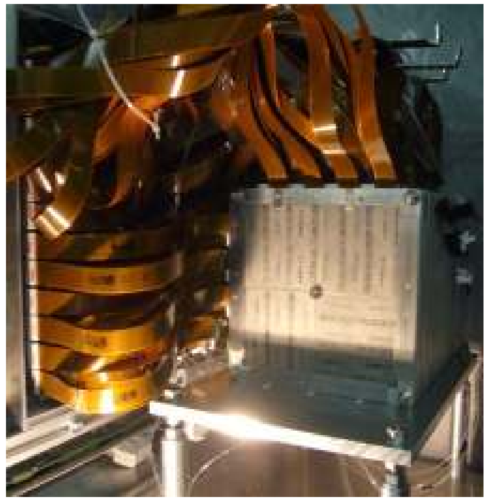


2nd prototype (2008 fall):

- Establish the Sci-strip calorimeter technology
- Tested with 1-32 GeV e^-, π^-, μ^-, p beams @ Fermilab

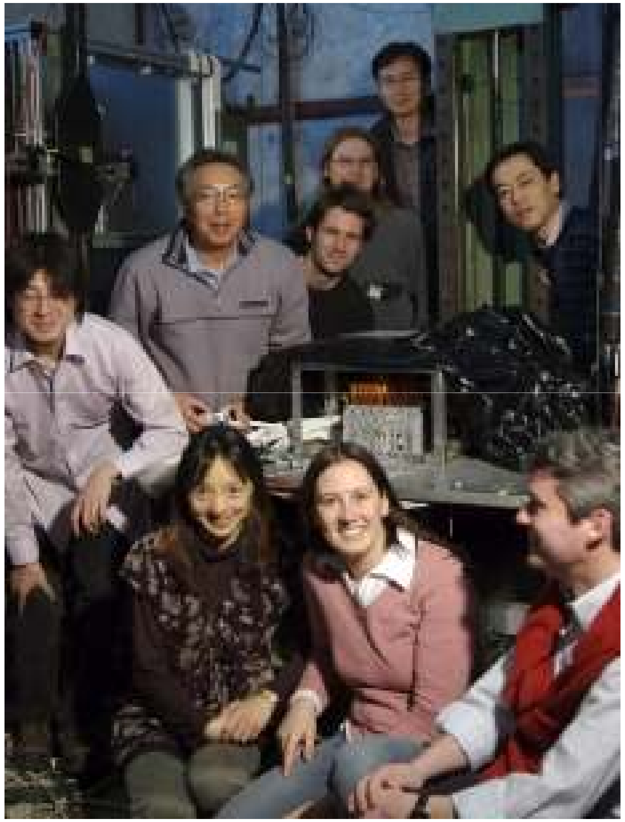


- 2160 channels total
- Realistic structure (including temp/gain monitoring system)



Beam Tests

First prototype test @ DESY in May 2007

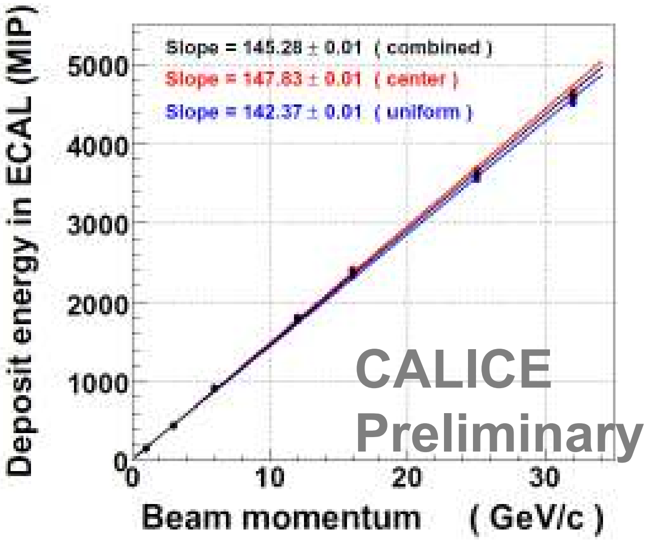


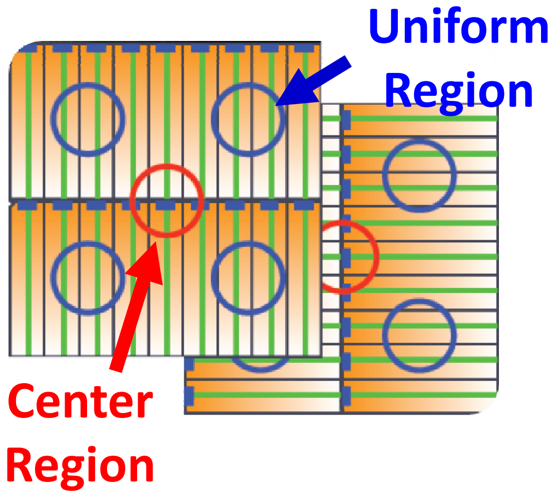
Scintillator-strip test @ KEK in Nov 2007

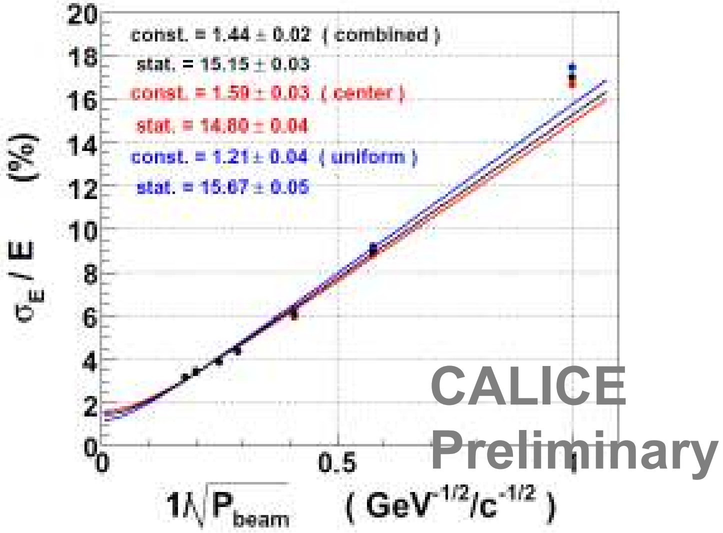
2^{nd} prototype test @ Fermilab in Sep 2008

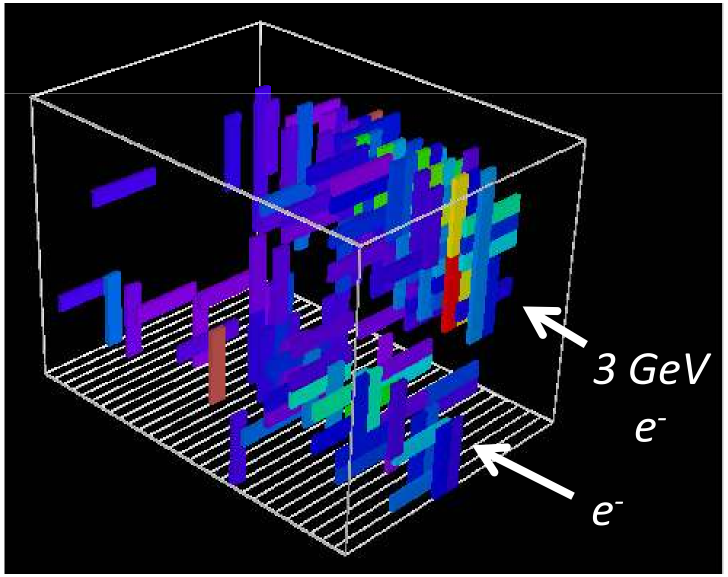
The scintillator-strip calorimeter technology has been Established by the series of beam tests!

Performance of the calorimeter prototype





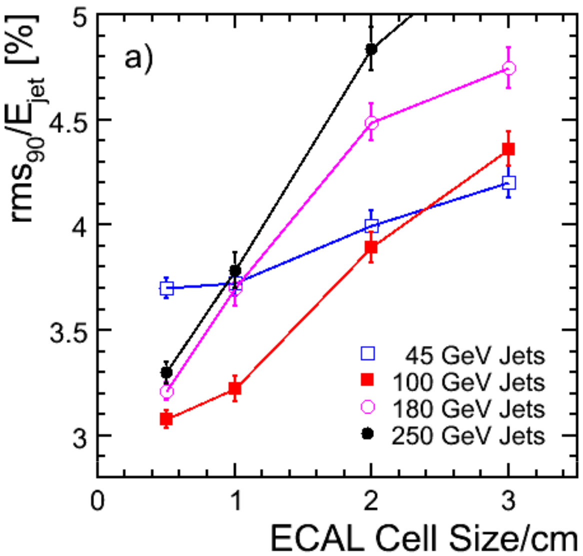




$$\frac{\sigma}{E} = \frac{(15.15 \pm 0.03)\%}{\sqrt{E}} \oplus (1.44 \pm 0.02)\%$$ (preliminary, errors are stat only)

10 mm to 5 mm width strip

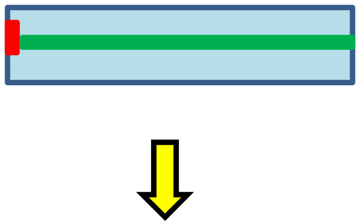
Jet Energy Resolution with PFA



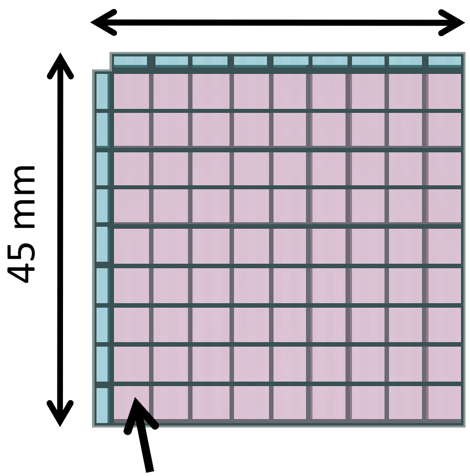
Further step :

- For precise measurement of jets with E > 100 GeV, 5 mm segmentation will be desirable.
- It can be still possible with 5 mm width scintillator strips.
- First measurement the 5mm scintillator strip shows encouraging result.

10 mm width strip with WLS fiber

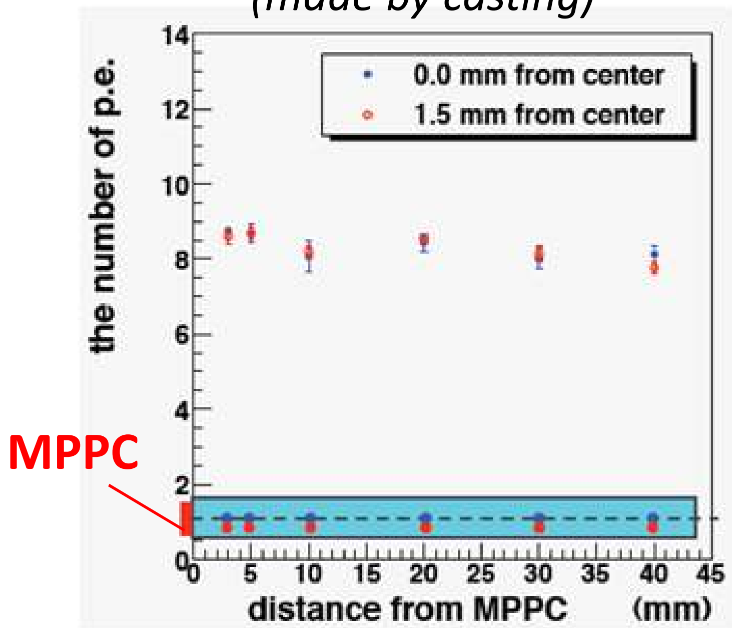


5 mm width strip WITHOUT WLS fiber



5x5 mm^2 virtual cell

Light yield of 45 x 5 x 2 mm strip (made by casting)



Summary

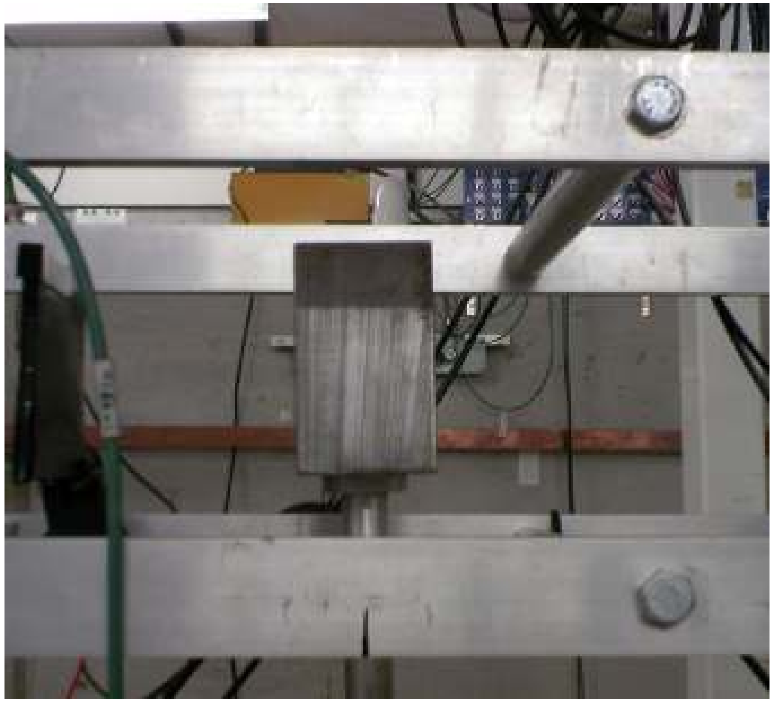
- The Linear Collider is the next-generation collider experiment after the LHC.
- The ILC reveals clear shape of the Higgs and new physics with its excellent precision measurement ability.
- Development of the scintillator-strip EM calorimeter (ScECAL) is extensively ongoing in KNU with world-wide collaboration.
- Test of the calorimeter prototype proves promising performance of the ScECAL.

- Participation of more Korean colleagues are strongly awaited in many fields ! (Accelerator, physics, detector…)

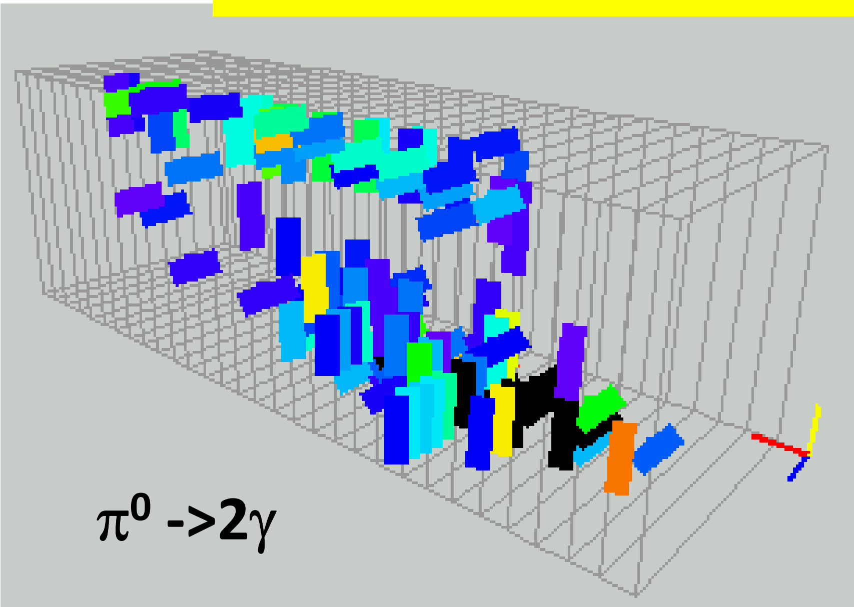
Backups

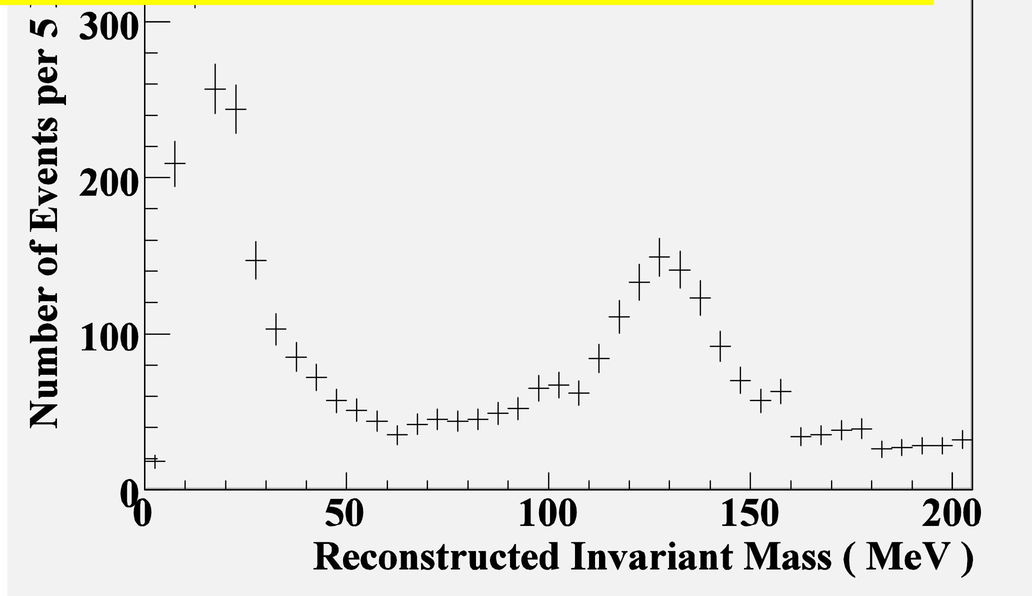
π^0 reconstruction

- Ability of π^0 reconstruction from 2γ might be useful to improve jet energy resolution.
- Generate π^0 by putting iron on beamline and injecting 16-32 GeV π^- beam.
- Try reconstruction of the generated π^0 with Scintillator-ECAL.



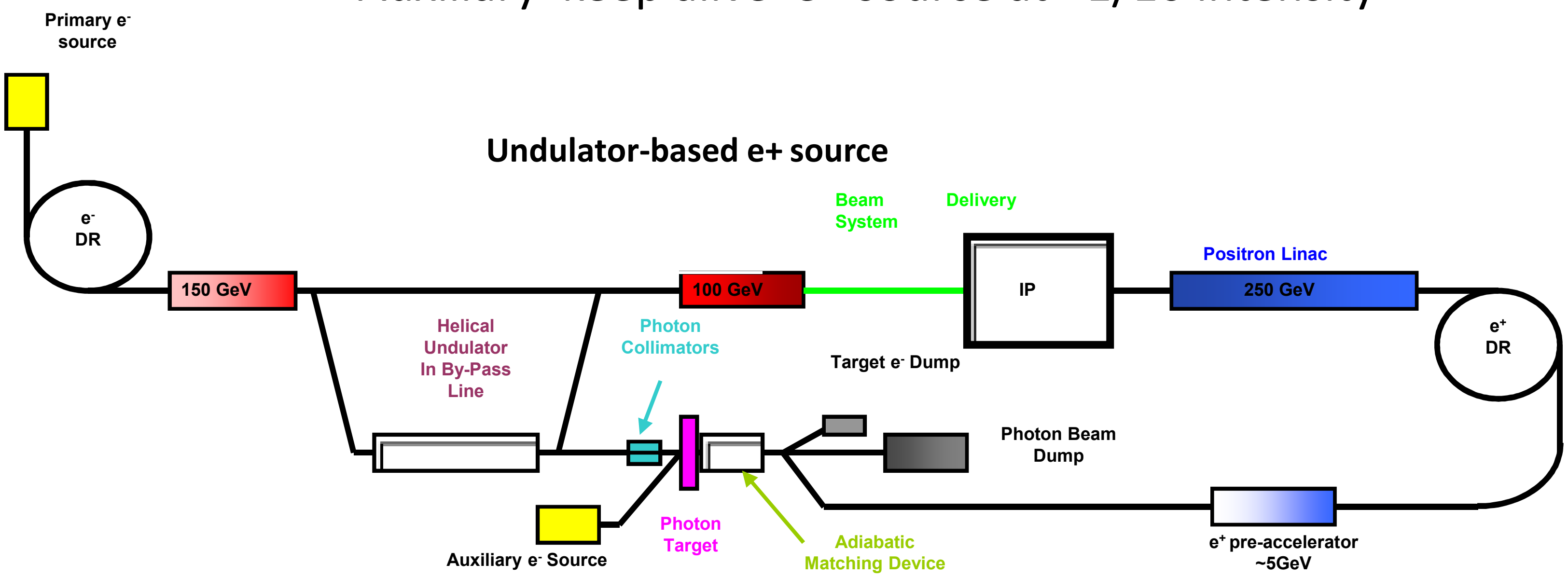
Special feature of the finely segmented calorimeter





Sources

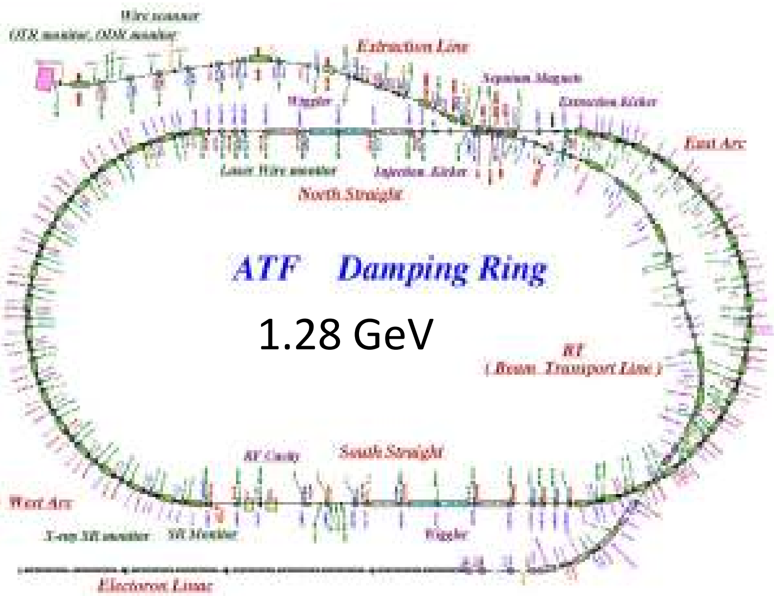
- e- sources
  - Conventional (i.e. photocathode + laser)
- e+ sources
  - Baseline: 150 GeV e- → 100m-long undulator →
  - photon on target → e+
  - Auxiliary 'keep alive' e+ source at ~1/10 intensity



Dumping Rings

- Dumping Rings for e+ and e- located centrally around IP
  - Housed in a single tunnel (~6 km circum.)
  - 5 GeV, entire train is stored compressed

    → fast injection/ extraction kicker
  - $\gamma\varepsilon_y$ reduced to 2 10^{-8} m in 200 ms

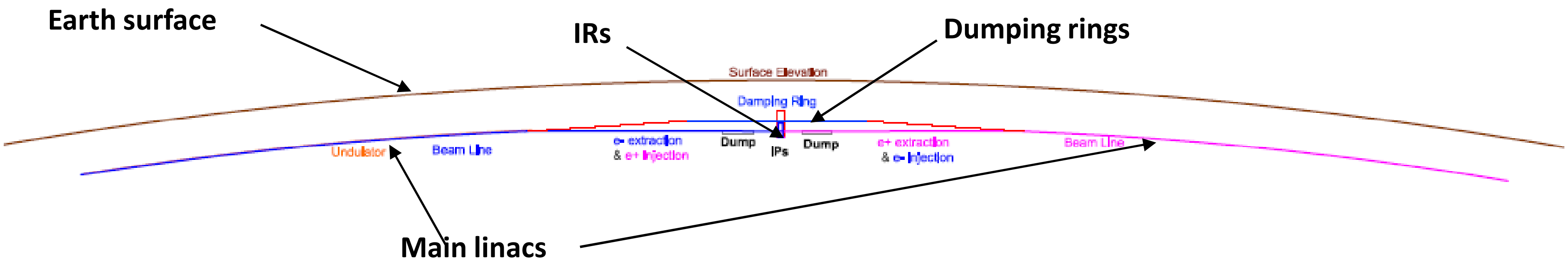


ATF@KEK
(Accelerator Test Facility)
achieved $\gamma\varepsilon_y$ = 2 10^{-8} m

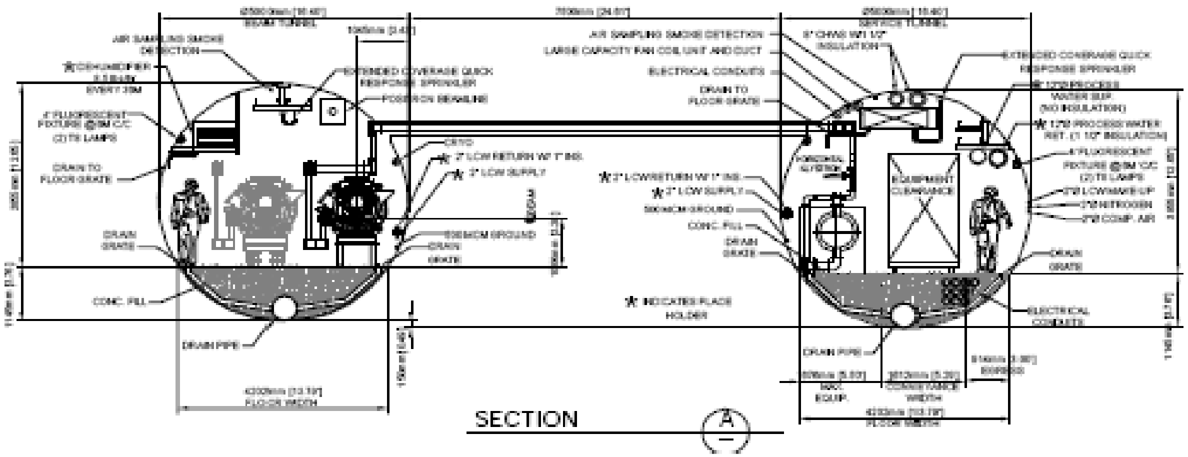
→ ATF2 project
Truly an international effort

Linac Tunnels

Follows the earth curvature - e.g. liq He system
(Beam delivery system is in a plane)



Have a service tunnel - maintenance/repair during running



Main Linacs

- Accelerating unit
  - One 10 MW krystron serving 3 cryomodules with 8 or 9 super-conducting cavities each
  - Accelerating gradient : 31.5 MV/m (35 MV/m max)
  - Default cavity design: 'Tesla design'
    - Achieved ~35 MV/m for a number of multi-cell cavities
  - Alternatives: Improved types are under study
    - Cornell re-entrant type, DESY/KEK low-loss type.

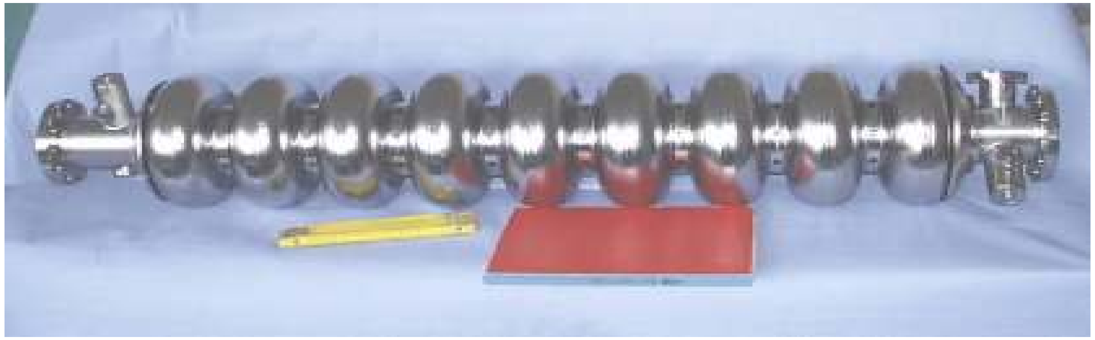
Low-loss multi-cell cavity

Main Linac: SRF Cavity Gradient

	Cavity type	Qualified gradient	Operational gradient	Length*	energy
		MV/m	MV/m	Km	GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

Total length of one 500 GeV linac ≈ 20km

*** assuming 75% fill factor**

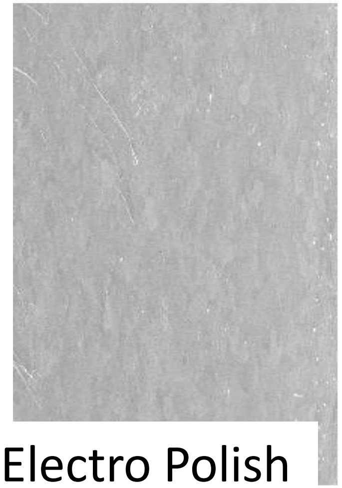


Improved Processing
Electropolishing

KEK / Nomura EP

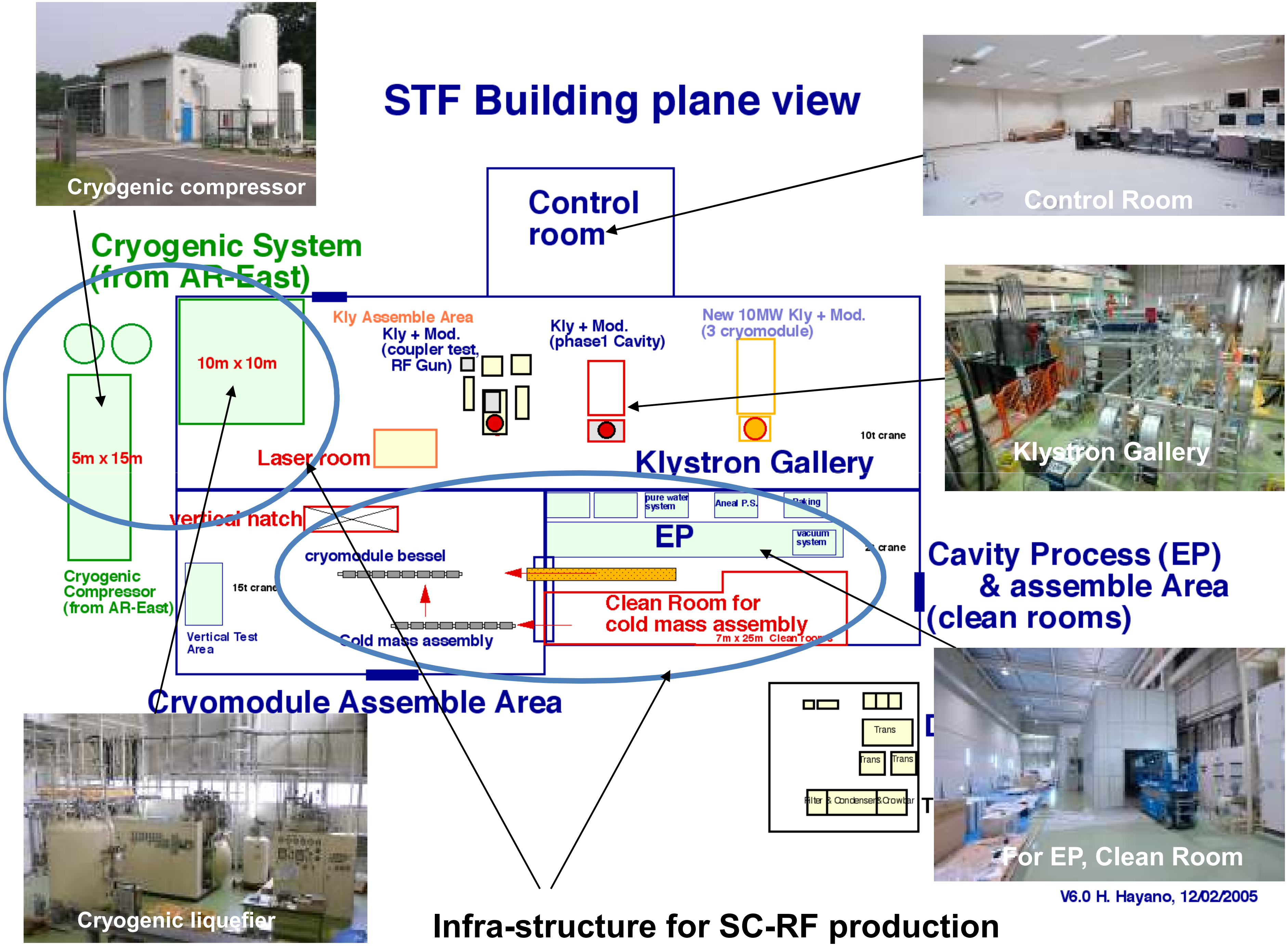
DESY EP

Chemical Polish



Electro Polish

STF Building plane view



Infra-structure for SC-RF production

V6.0 H. Hayano, 12/02/2005

SUSY Particles @ ILC

- ILC can pair-create SUSY particles

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

$$\text{etc.}\quad e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-,\ \tilde{\chi}_1^+ \to W^+\tilde{\chi}_1^0$$

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

CAlorimeter for the LInear Collider Experiment

330 physicists/engineers from 57 institutes and 17 countries coming from 4 continents

Main Task : Develop fine granular calorimeter for Particle Flow Algorithm at the ILC experiment.

Electromagnetic CAL:

- Scintillator-Tungsten

(Kobe / Shinshu / Tsukuba / Niigata / Tokyo / Kyungpook universities)

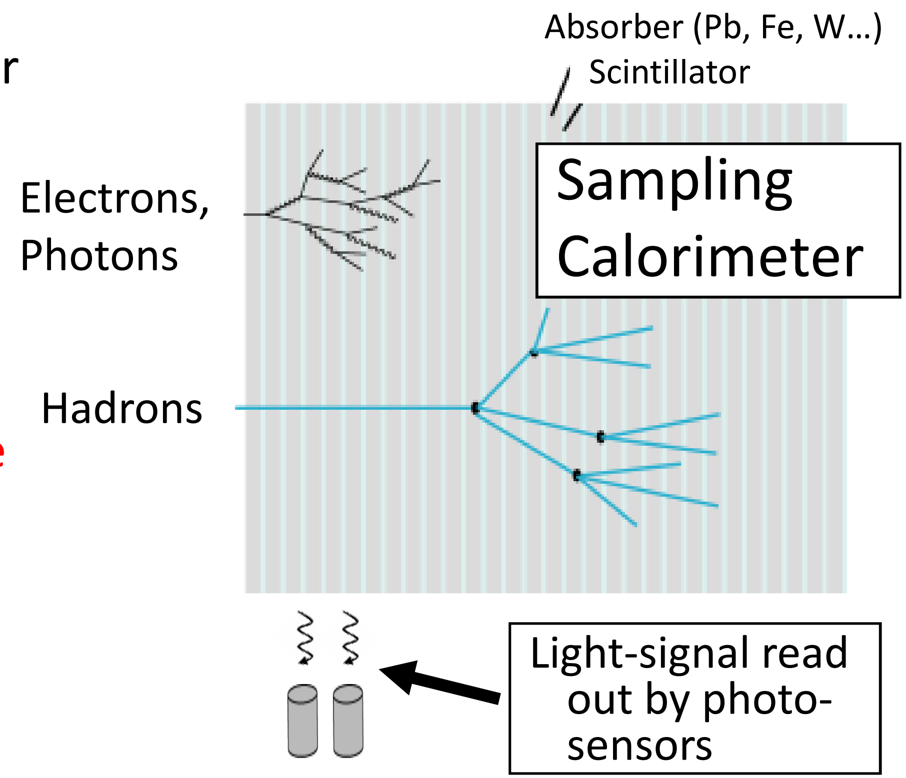
- Silicon-Tungsten
- Digital SiW ECAL (MAPS)

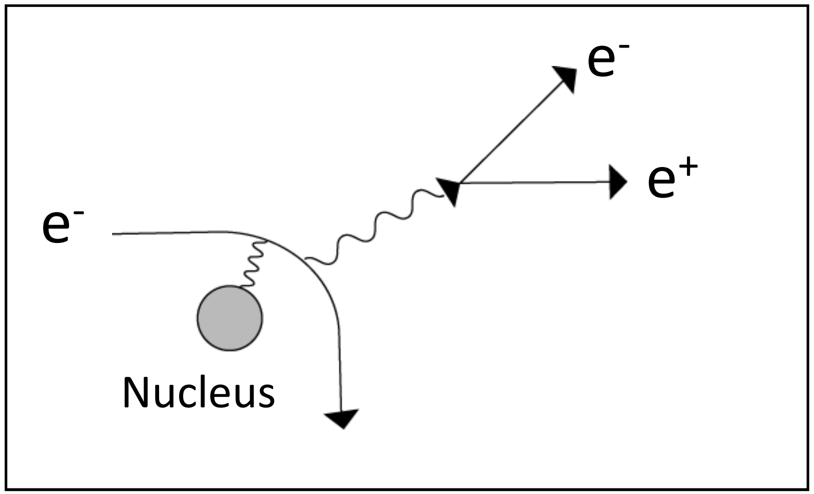
Hadron CAL:

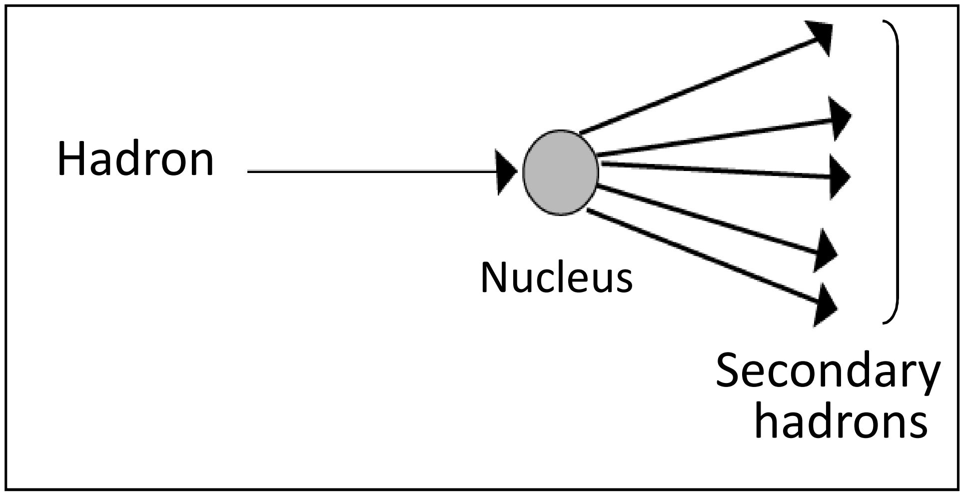
- Analog (Scintillator) HCAL
- Digital HCAL

Calorimetry of high energy particles

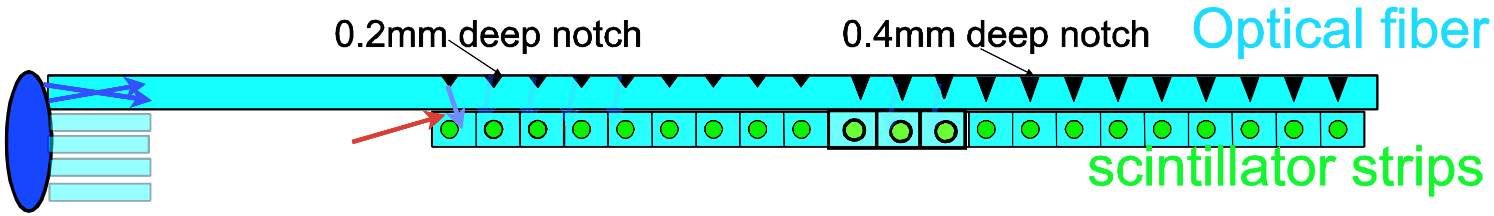
- High energy particles cause cascade shower inside the calorimeter
  - Electromagnetic shower
  - Hadron shower
- Num. of particles in the shower ~ proportional to energy of original particle
- Count num. of particles by active material in the calorimeter (sampling calorimeter)

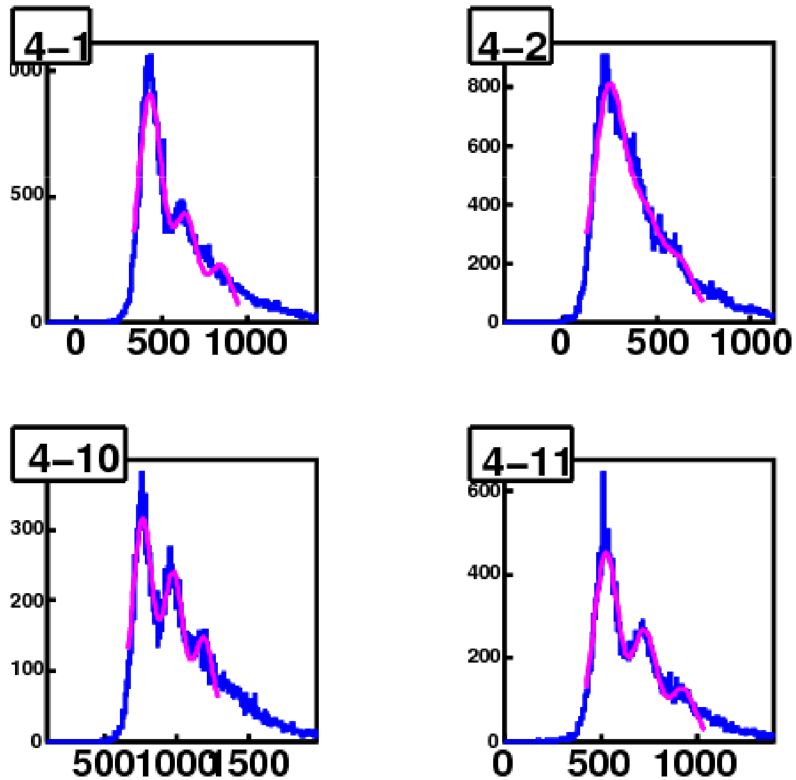






Gain monitoring by LED and notched fiber





- Nice pedestal-1pe peak separation has been observed on ~70% of all channels.
- For other channels, electrical noise on readout board was too large to perform the gain measurement. Investigation is underway.