Optimization of detectors for the ILC

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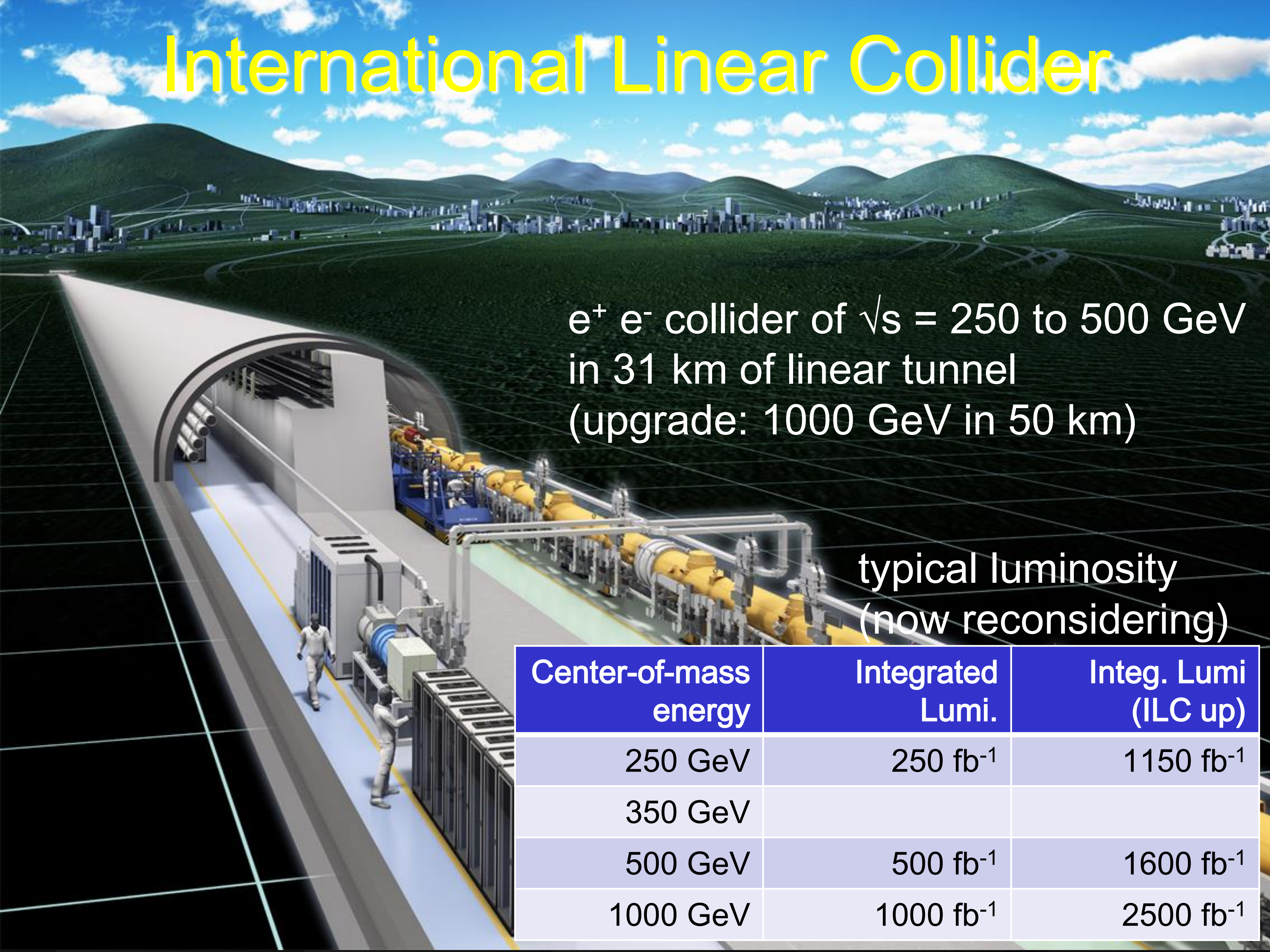
(Kyushu University, Japan)
on behalf of ILD and SiD group

International Linear Collider



$e^+ e^-$ collider of $\sqrt{s}$ = 250 to 500 GeV
in 31 km of linear tunnel
(upgrade: 1000 GeV in 50 km)

typical luminosity
(now reconsidering)

Center-of-mass energy	Integrated Lumi.	Integ. Lumi (ILC up)
250 GeV	250 fb^{-1}	1150 fb^{-1}
350 GeV		
500 GeV	500 fb^{-1}	1600 fb^{-1}
1000 GeV	1000 fb^{-1}	2500 fb^{-1}

ILC History & Status

1980's-2001: Studies and proposals of TESLA, NLC & JLC

2005: Efforts unified to ILC based on the cold technology

2007: ILC Reference Design Report

2009: Letter of Intent of ILC detectors

- First optimization done here

2012: ILC Accelerator TDR & Detector DBD

- Realistic detector report with cost estimation

2012: Higgs Discovery

~2013: Interest of Japanese government raised

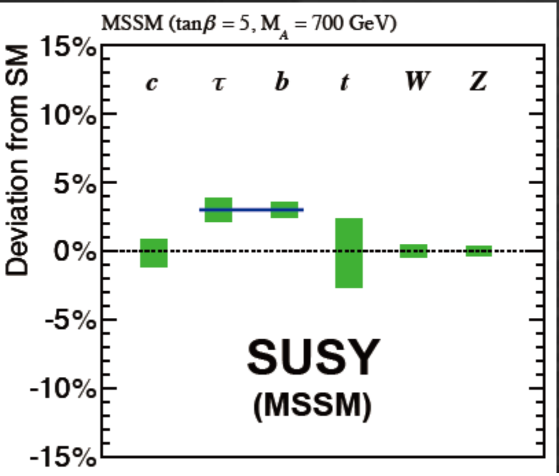
- Japanese site candidate endorsed to Kitakami (Tohoku)

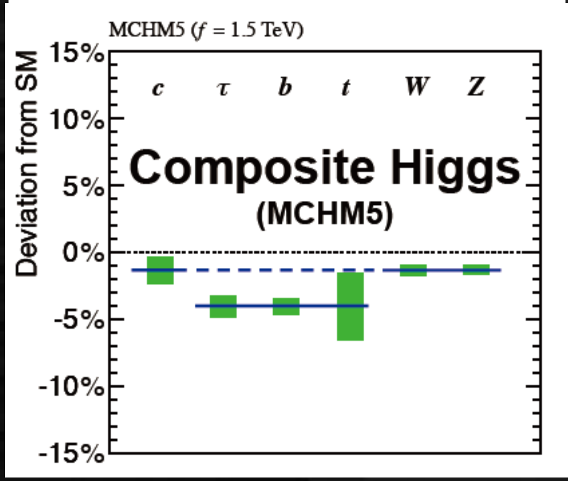
Physics targets and site/political conditions clearer now
- re-optimization towards "Green sign" expected in a few years!

What will ILC be built for?

1. Higgs as a probe for New Physics

- Higgs discovery phase has been over
  → precise measurements!
- New physics shift Higgs properties
- O(1%) Higgs coupling measurements
  is critical for new physics search
  and model identification





2. Various direct/indirect searches

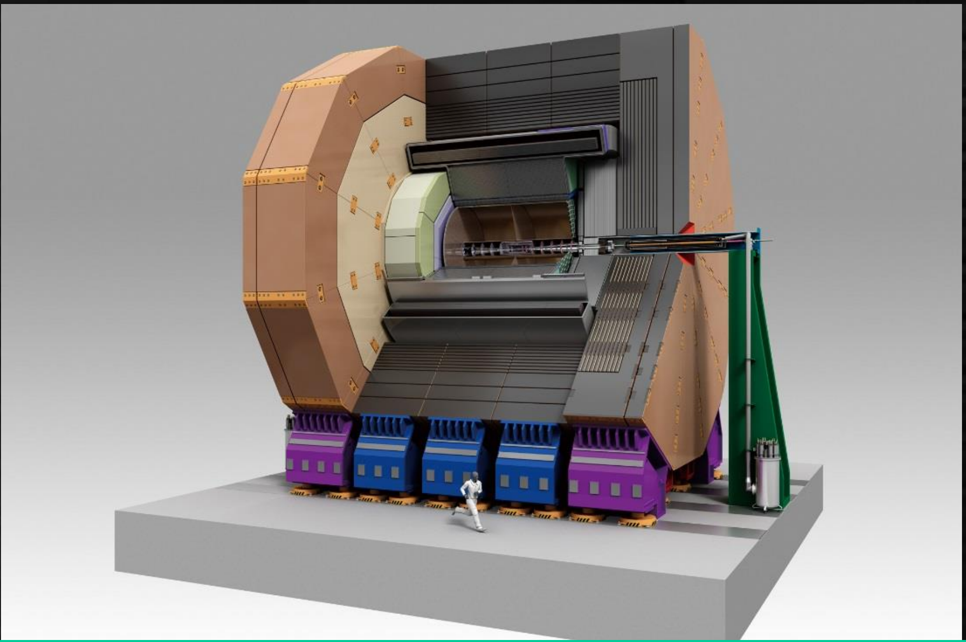
- Electroweakino search (eg. Higgsino)
  ILC is sensitive to LHC blind spots
- DM direct search
- top & electroweak precise measurements
- Exotic search

ILC & LHC: difference

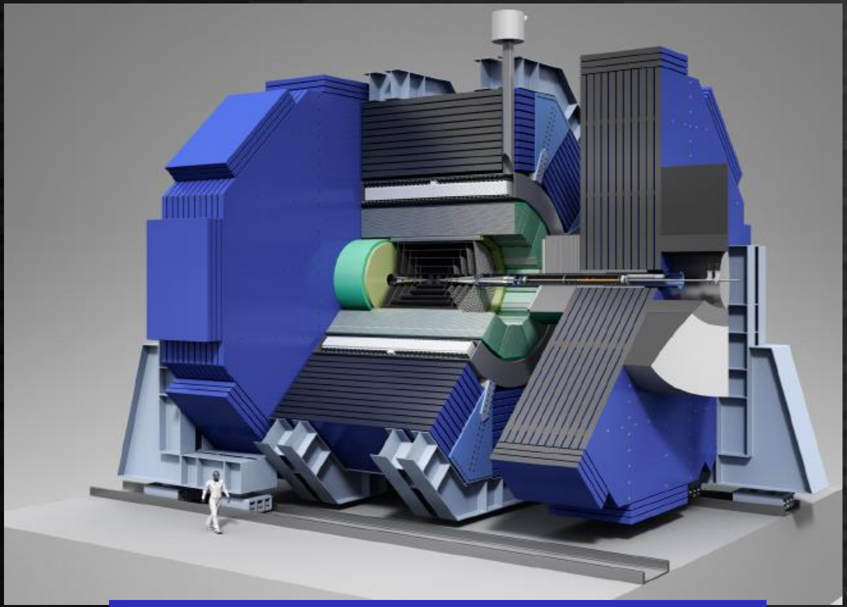
- No QCD production & monochromatic energy
  - LHC: ‘One Higgs per 10^{10} collision’ (collision: qq inelastic)
  - ILC: ‘One Higgs per 100 collision’ (collision: qq production)
- Pileup
  - LHC: O(10-100) per bunch
  - ILC: 1.2 forward low energy jets in 500 GeV
- Radiation
  - LHC: ~ 30 kGy, 5 x 10^{13} n_{eq} / year at 50 mm from IP
  - ILC: ~ 1 kGy, 10^{11} n_{eq} / year at 16 mm from IP
- Trigger
  - ILC: triggerless

Radiation & rate tolerance is less important in ILC
→ emphasis on resolution

ILC detectors



International Large Detector (ILD)

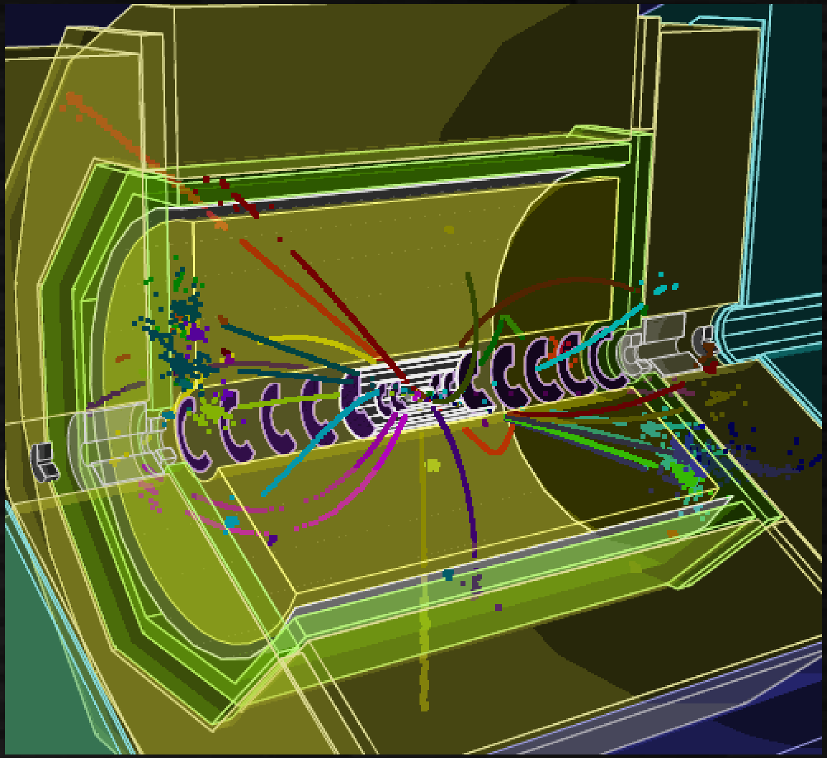


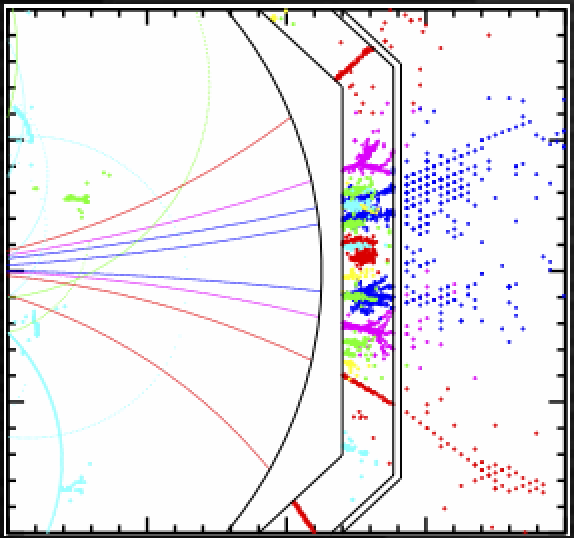
Silicon Detector (SiD)

Common features:
- Low-mass small pixel vertex detector
- Low-mass silicon tracking
- Fine-granular ECAL/HCAL inside coil
- Muon detector
- Forward tracker/calorimeter

Different features:
- Size (SiD: smaller)
- Magnetic field (3.5T/5T)
- Main tracker
TPC(ILD) Silicon only(SiD)

Detector for Particle Flow





Track-cluster matching 1 by 1
→ Particle flow

Advantages: ~60% of particles in jet are charged hadrons (π/K):
use track momentum for them instead of HCAL
Neutral hadrons (K^0/n) are only ~10%

Requirements: Finely granular calorimeter to separate each
→ very precise cells (O(1 cm)) in calorimeters

ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

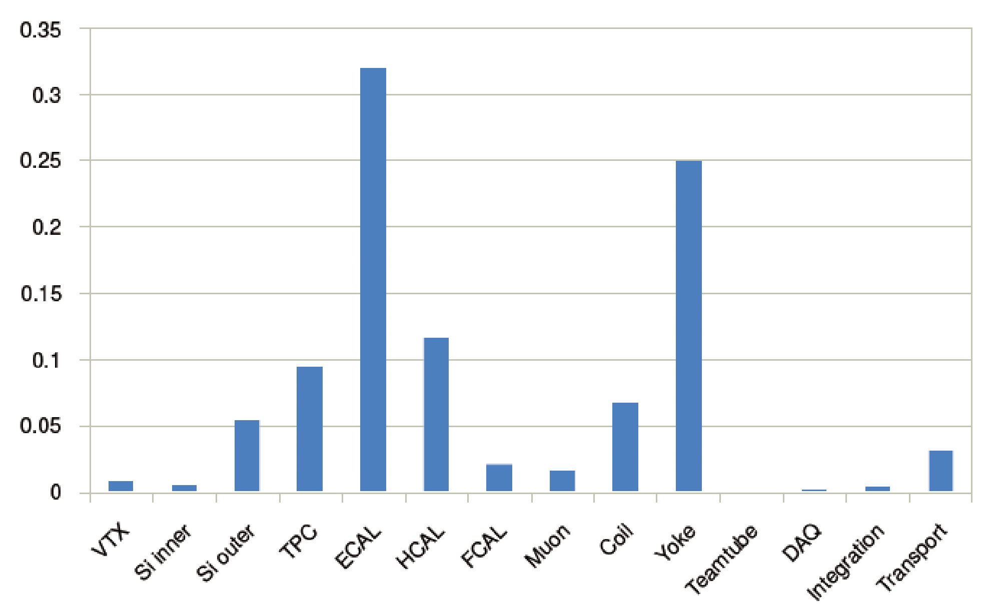
Physics requirements should drive the optimization

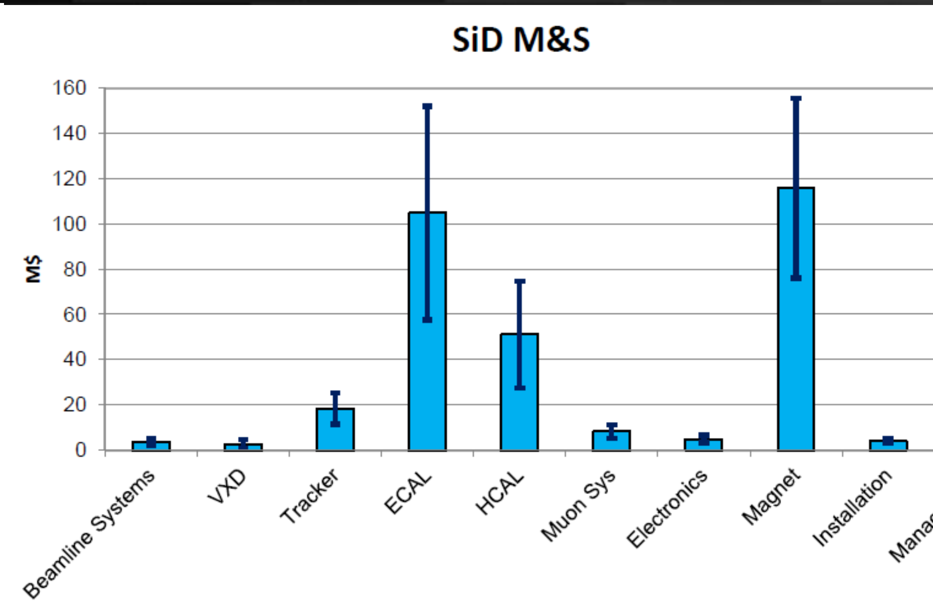
Detector costs

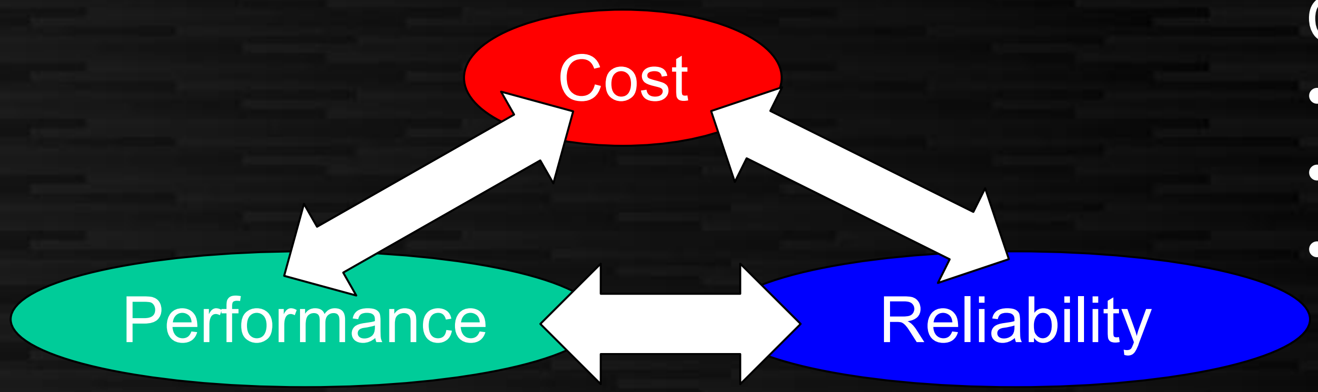
ILD: 391 M ILCU (US$ Jan.2012)

ILC Acc.: 7800 M ILCU

SiD: 314 M US$
(wo/ contingency & inflation)







Cost concerns:
- Size
- B field
- ECAL

ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
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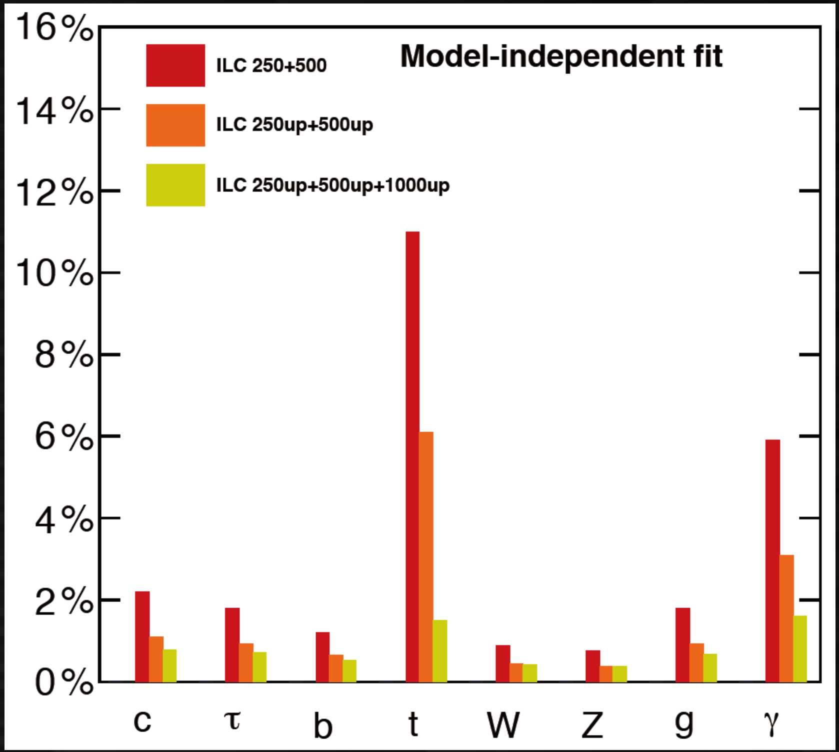
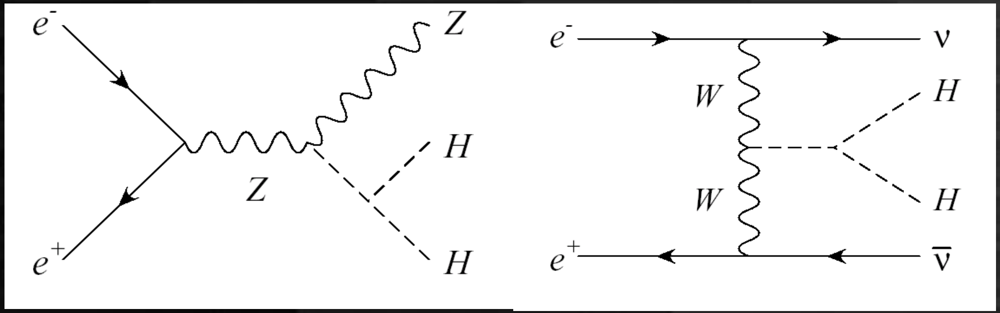
Physics with track pointing

Hbb, Hcc, Hgg coupling



- H → cc heavily depends on c-tagging performance

Higgs self coupling



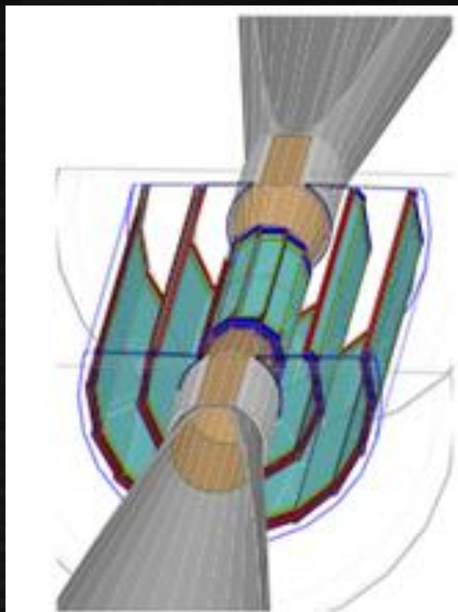
500 GeV (ZHH) 1 TeV (ννHH)

- 4b/2b separation is critical to suppress background
- High purity b-tag

Tau & metastable BSM

Physics case is very clear
Flavor tagging heavily depends on software – optimization not easy

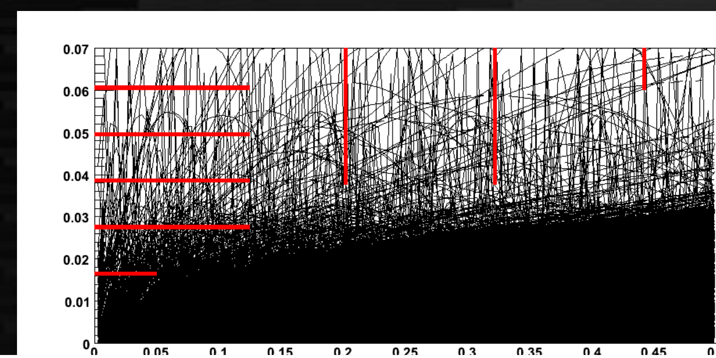
ILC Vertex Detector

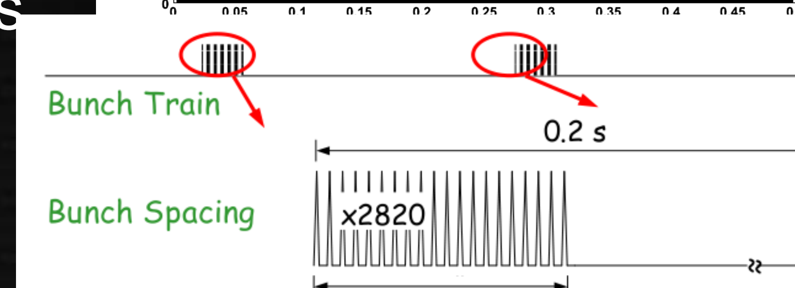


5-6 layers at r ~ 15 to 60 mm
(cf. CMS at 44 to 102 mm)
All pixels (5-25 μm, depending on technology)

- Good point resolution (esp. for c-tagging)
- Low material budget
- Pair background

(overlaid low energy e^+e^- pairs by beam)





Fast readout or BX tagging

Readout between trains or # BX added to hits → reduce/separate pairs

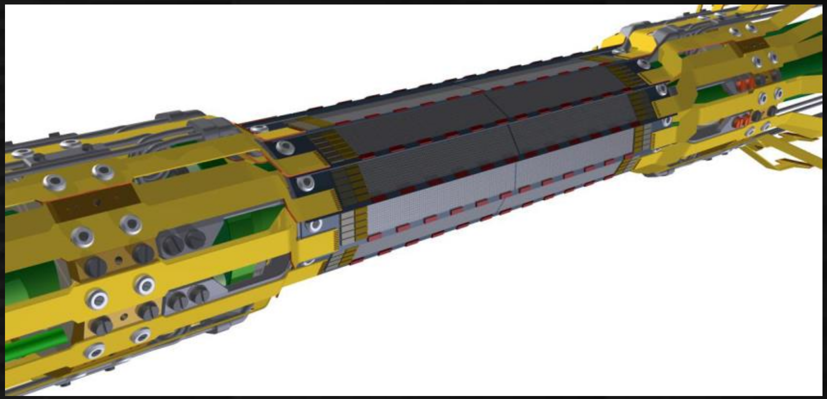
Granular technology

Smaller pixels to reduce occupancy
Slow readout between trains

Vertex detector: ILC technologies

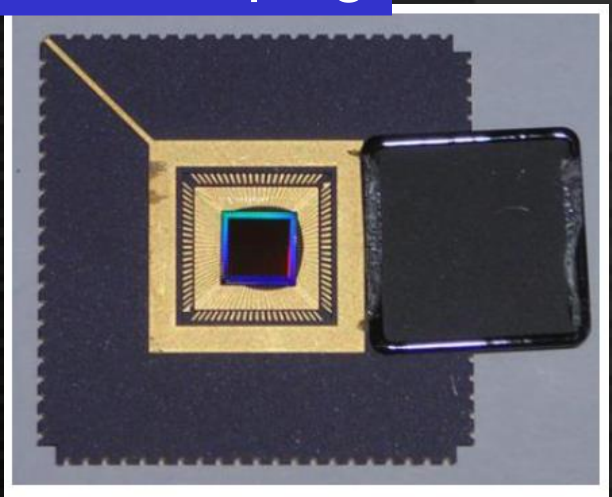
Fast readout technologies

20 μm CMOS



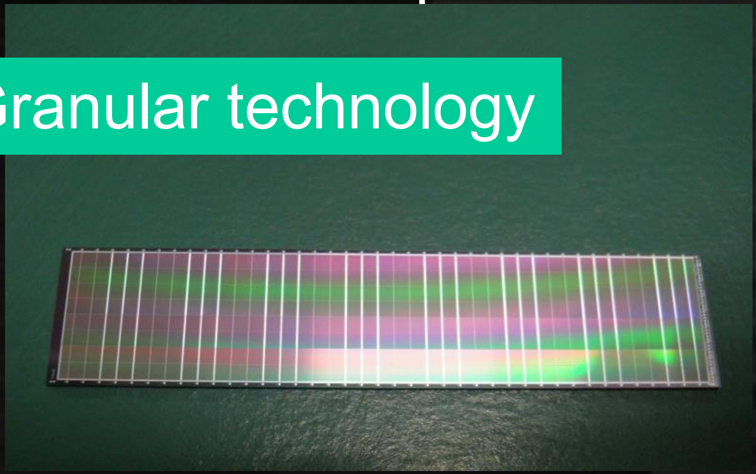
DEPFET

Time stamping



Chronopixel

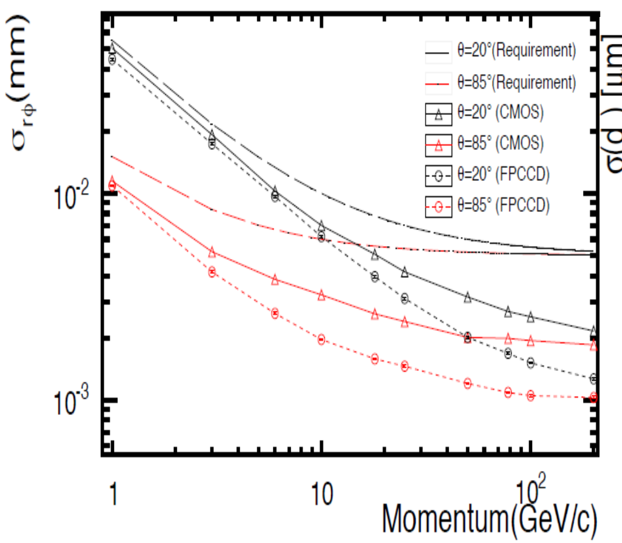
Granular technology

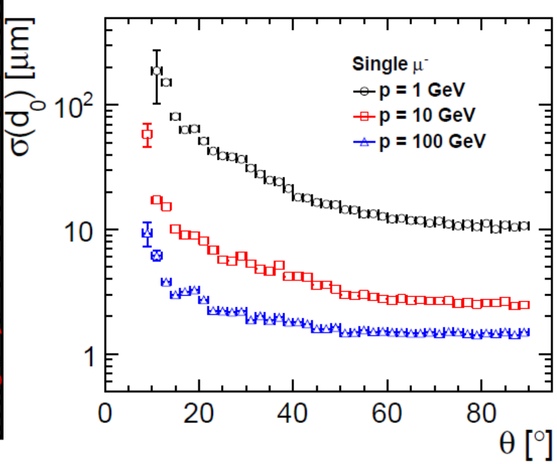


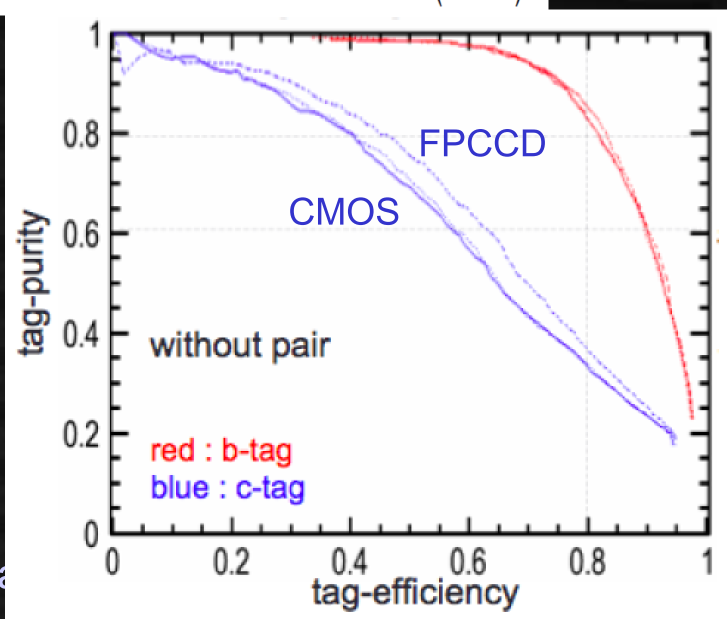
Fine Pixel CCD

Performance comparison

Good d_0/z_0 resolution

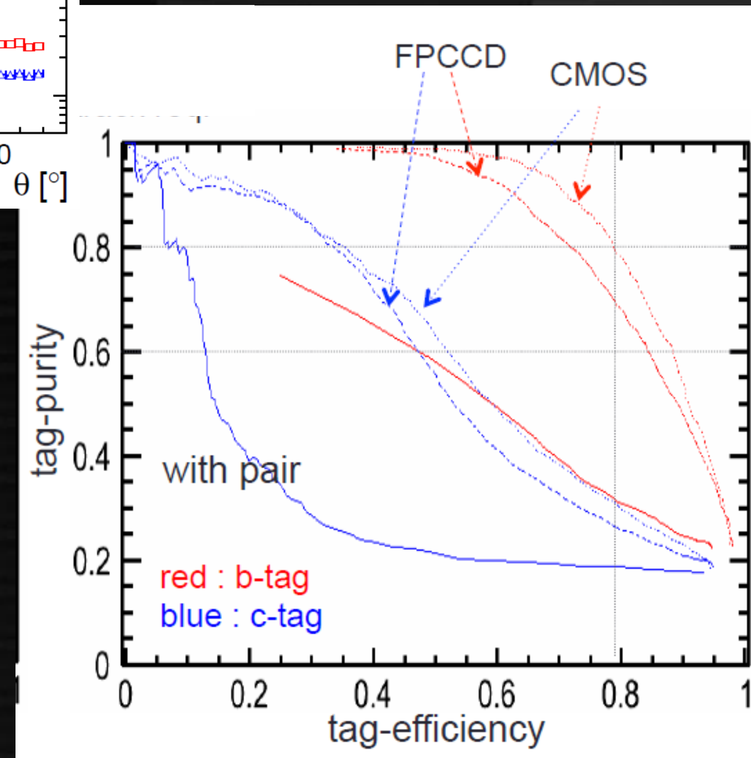






Pair background

Pair reduction software should be optimized

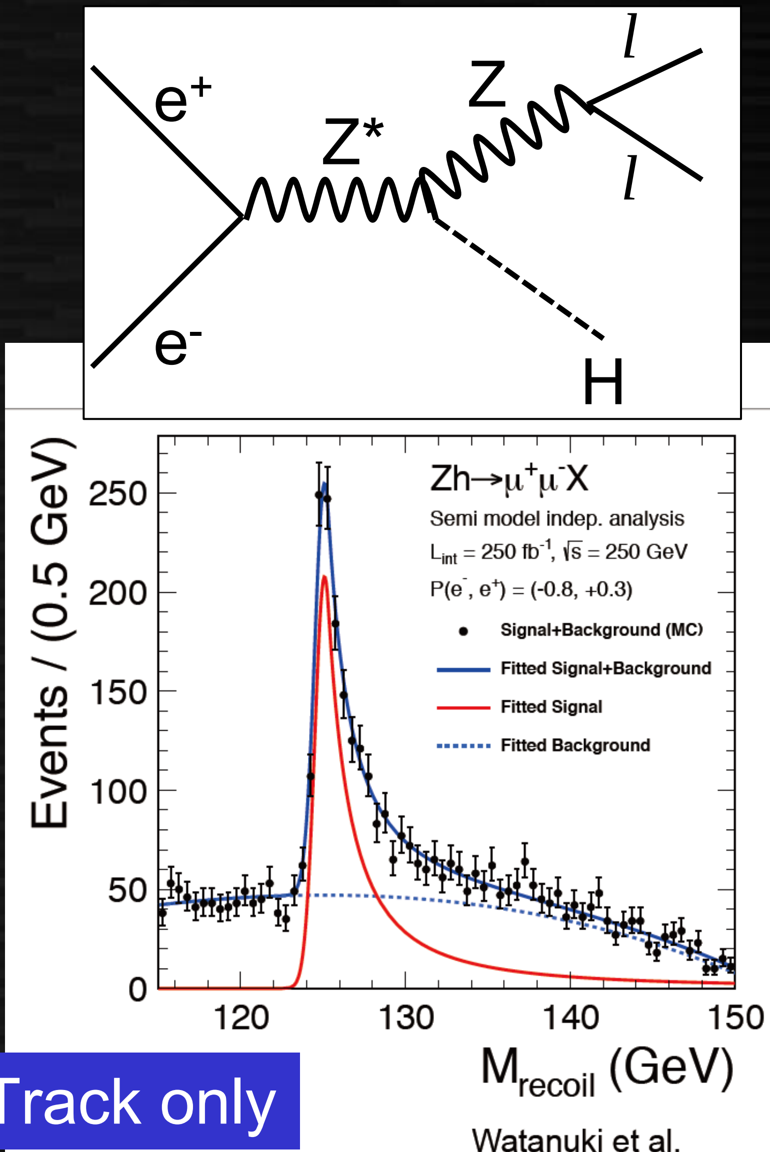


ILC detector challenges

1. Precise determination of track origin
   - Vertex detector
2. Momentum resolution of tracks
   - Main tracker
3. Jet energy resolution
   - Calorimeter

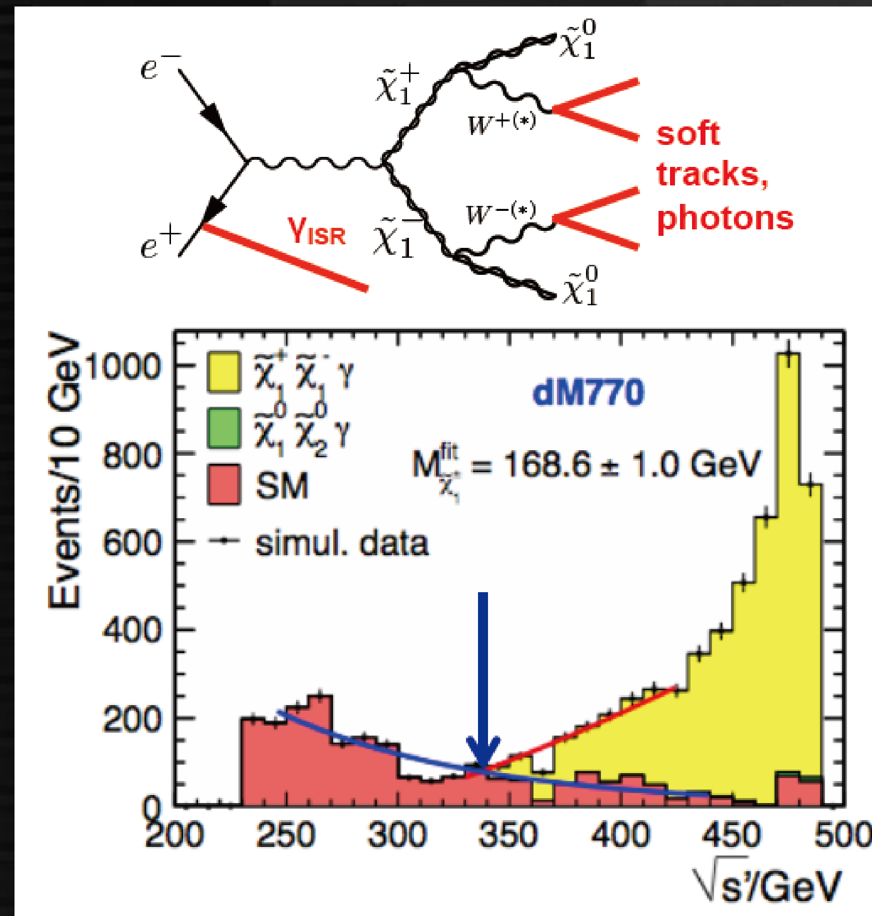
Main tracker – physics case

Higgs recoil measurements



Track only

SUSY: NLSP/LSP degenerated

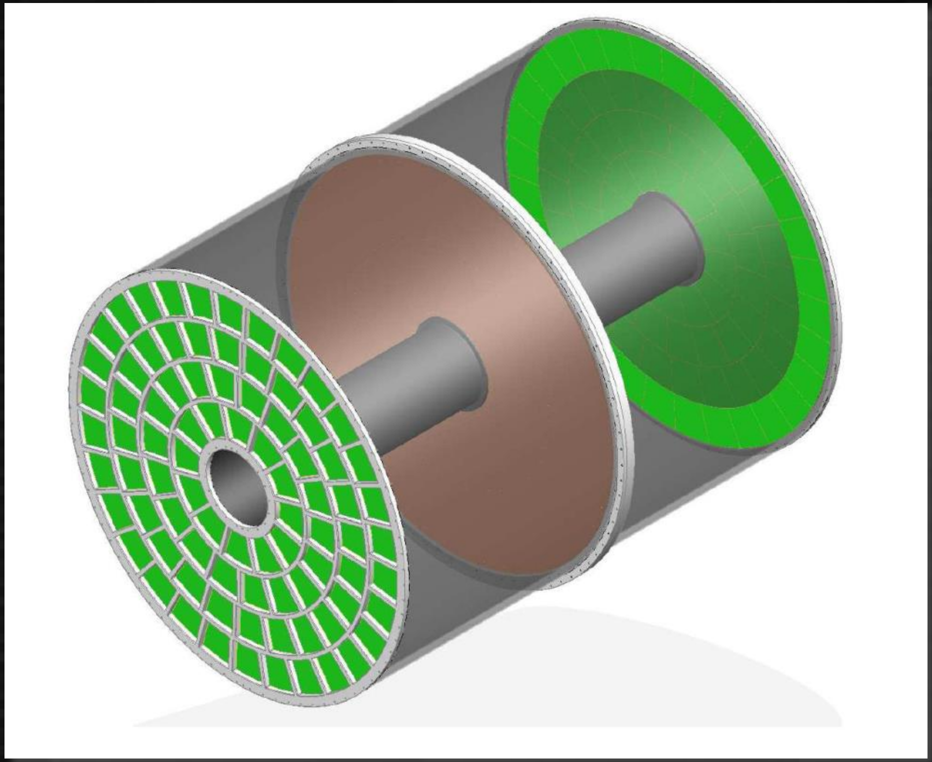


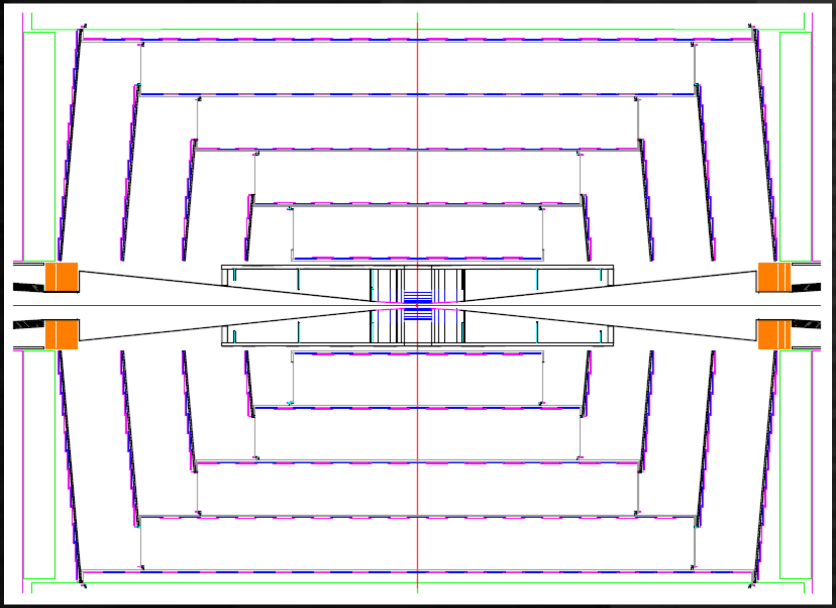
Main tracker – TPC vs silicon only

ILD: Time Projection Chamber
+ inner silicon (2 layers)
+ outer silicon (2 layers)

SiD: Silicon strip only (5 layers)

(+ 5-6 layers of vertex detector for both ILD & SiD)



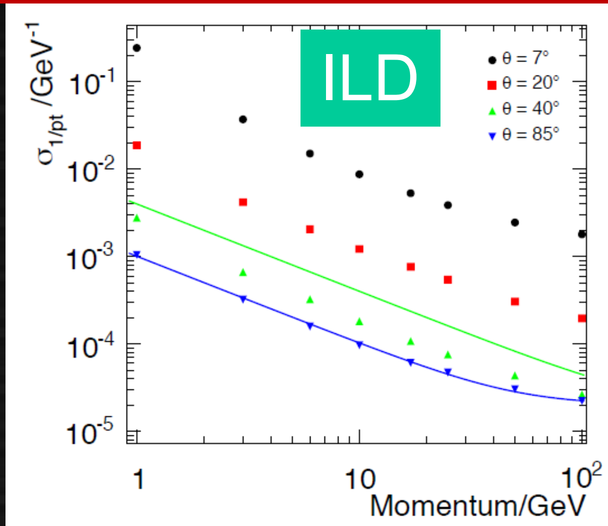


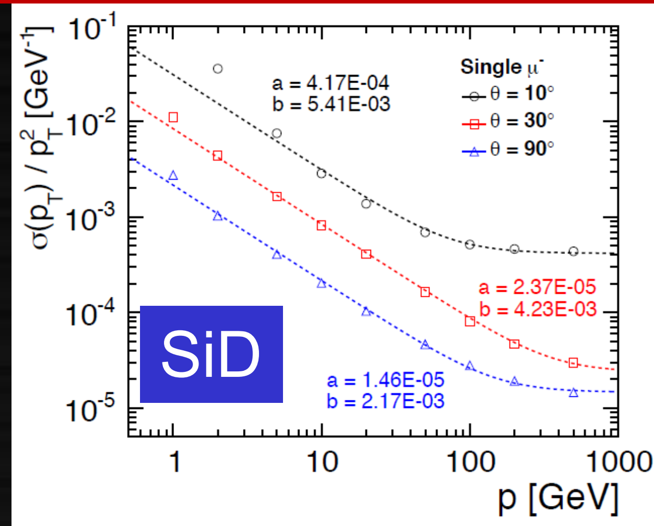
3.5 Tesla, r_{max} ~ 1800 mm

5 Tesla, r_{max} ~ 1220 mm

Main tracker – resolution & material

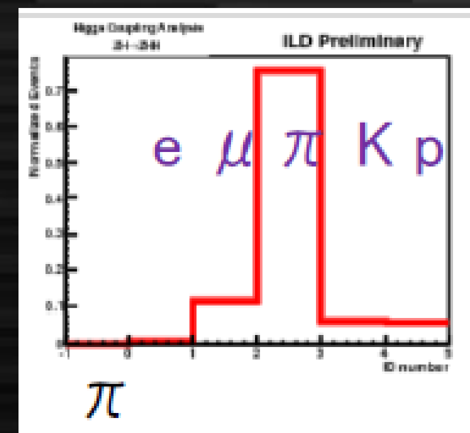
p_T resolution: ILD better in low pT, SiD high pT



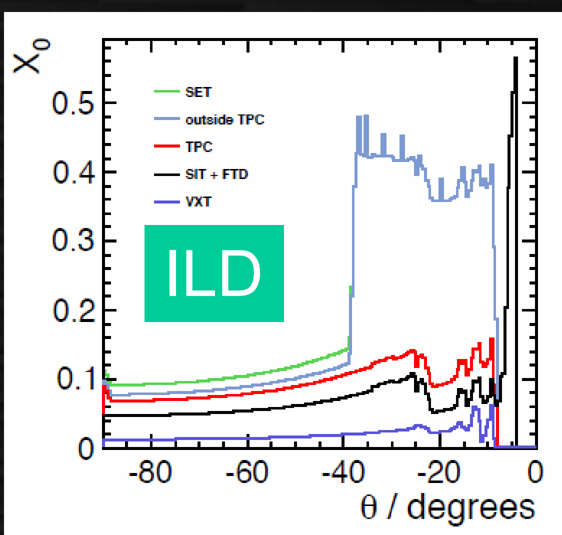


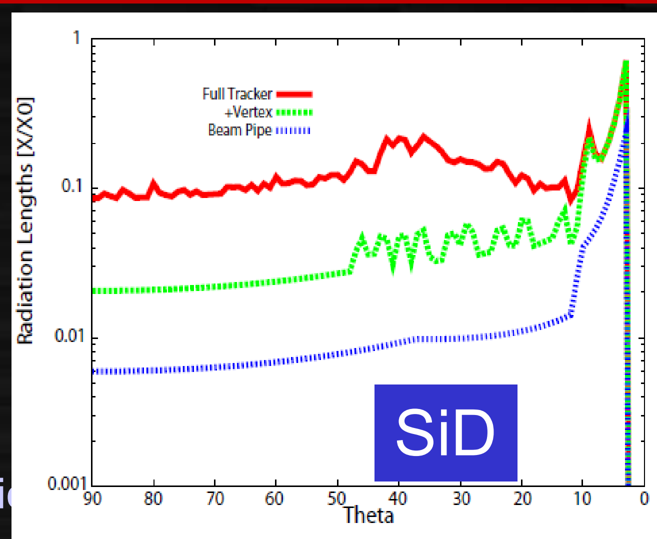
TPC (ILD):

- dE/dx for K/π separation



material: similar in barrel, SiD better in endcap

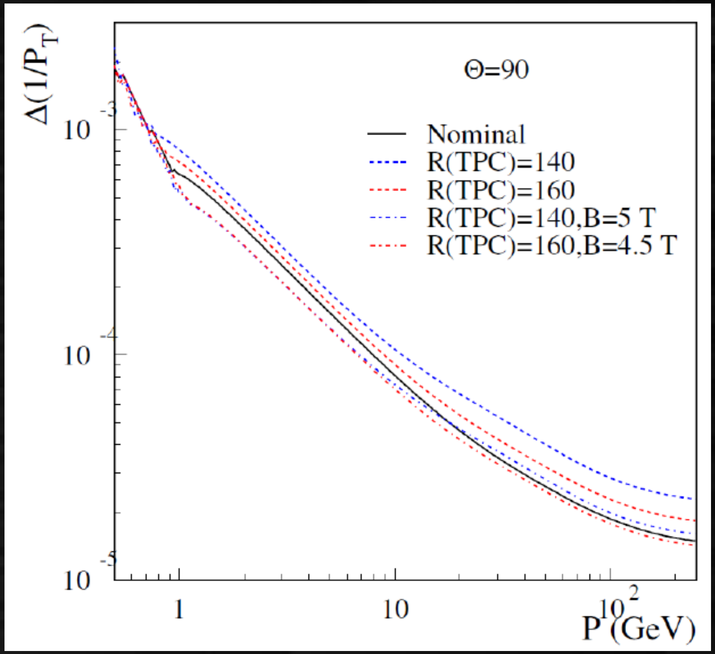


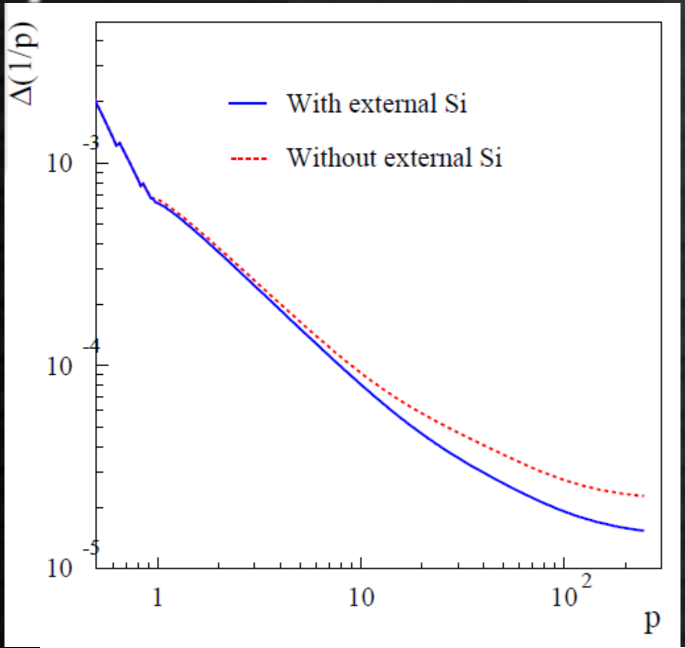


Silicon only (SiD):

- More robust for dense-track reconstruction

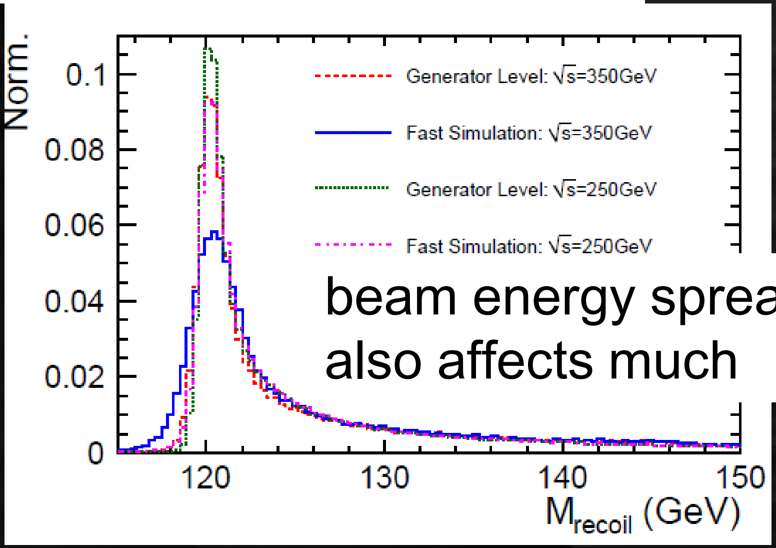
Optimization of parameters





μμH performance (preliminary)

	N_{sig}	N_{BG}	δ_σ	δ_m
nominal	1596	4584	3.55%	32.5 MeV
DBD			~3.7%	~37 MeV
160, 3.5	1590	4583	3.60%	35.6 MeV
160, 4.5	1592	4662	3.66%	33.7 MeV
140, 3.5	1595	4654	3.64%	39.3 MeV
140, 5.0	1586	4640	3.66%	34.0 MeV



beam energy spread also affects much

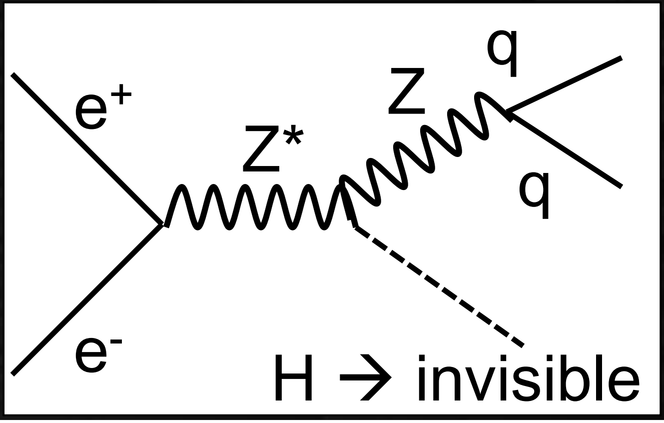
Mass resolution is affected by B & r, for cross section not clear

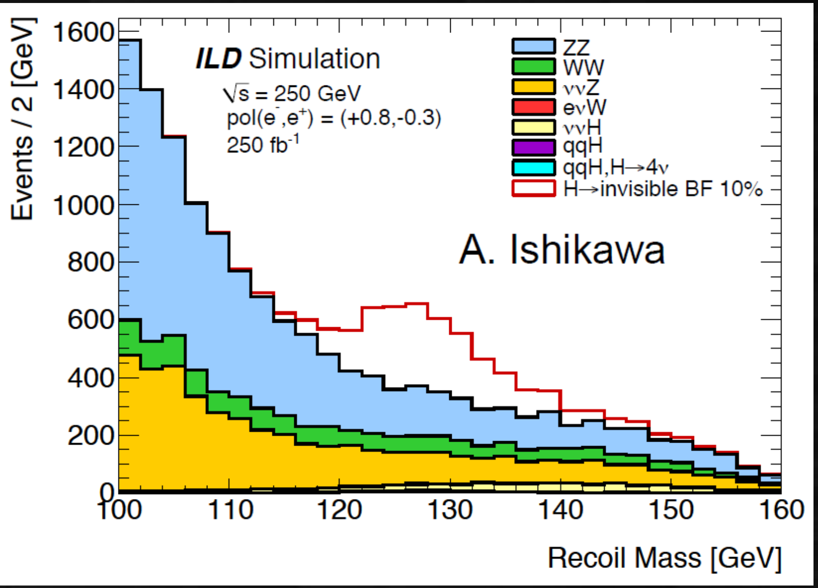
ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

Calorimeter: physics

Invisible Higgs decay





Others: jet resolution

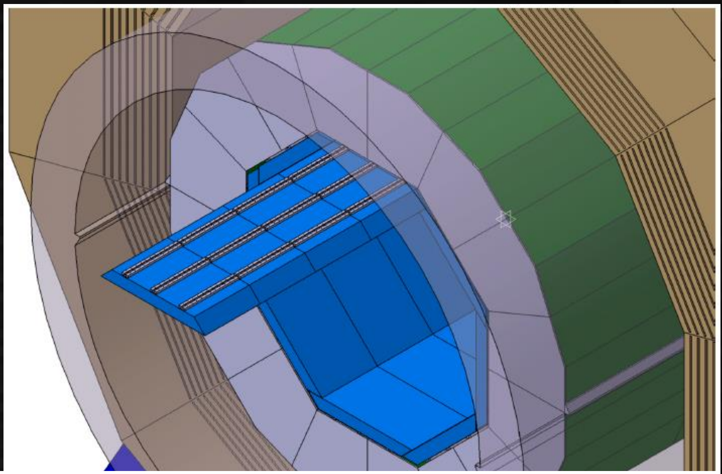
- qqH, total cross section
- precise W/Z coupling by eνW/ννZ
- ZHH/ννHH and other multi-jet physics: (jet clustering dominates)

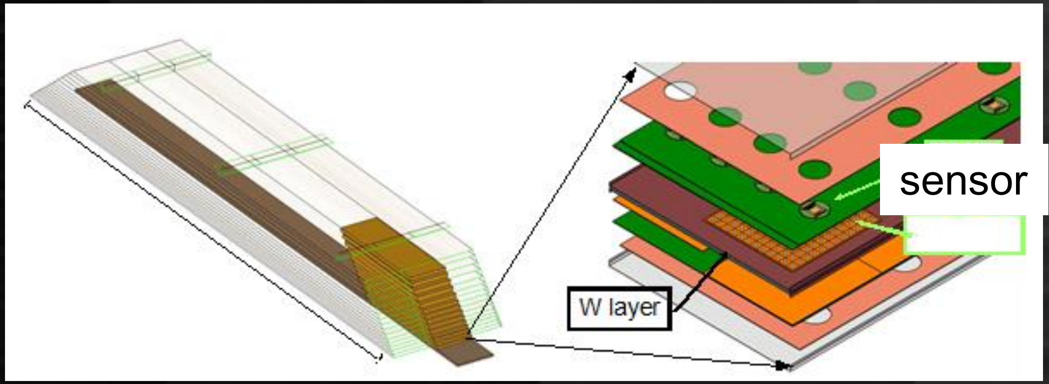
Others: non-jet states, (less considered)

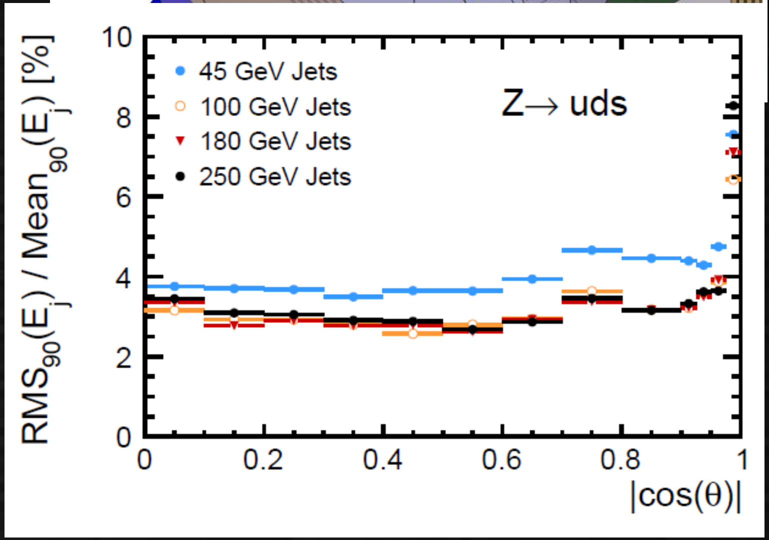
- Higgs CP by H→ττ
- H → γγ
- new physics, non-pointing photons etc.

Important, but we need a trade-off with cost

ILC Calorimeter





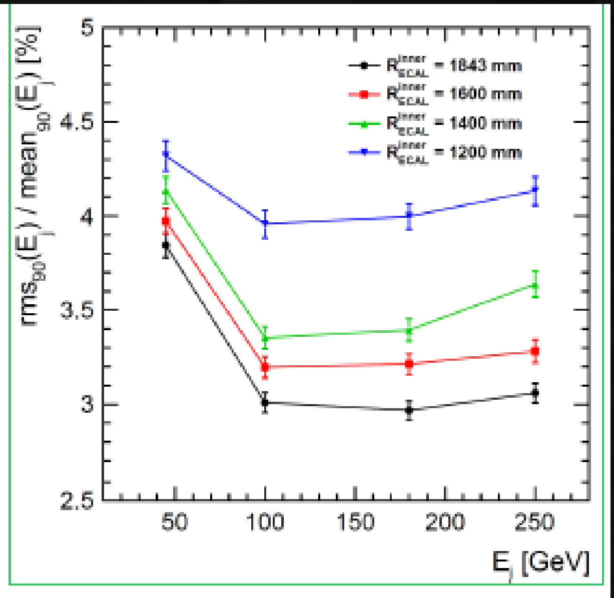


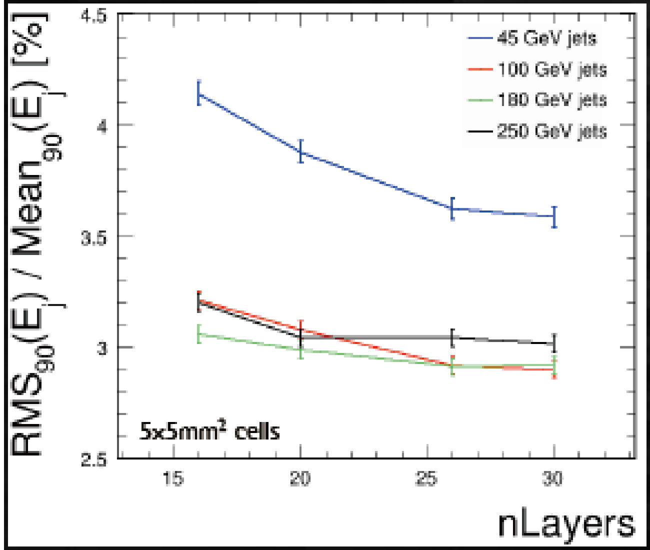
$30\ \%/\sqrt{E_j}$ obtained for $E_j < 100$ GeV
($50\ \%/\sqrt{E_j}$ expected without PFA)

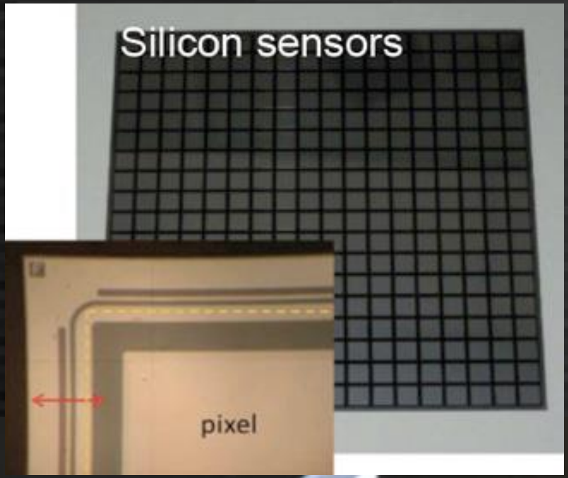
- Sandwich calorimeter
  ECAL: ~ 30 layers, W absorber
  (baseline: Silicon sensor for both ILD/SiD)
  HCAL: 40-50 layers, Fe absorber
  (baseline: Scintillator(ILD) or RPC(SiD))
- Highly granular cells
  ECAL: ~ 5 mm HCAL: 1-3 cm cells
  (in baseline options)
  ASICs/electronics between layers

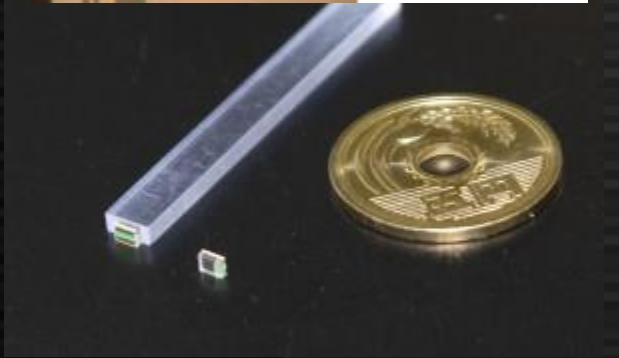
Calorimeter: tuning parameters

ECAL: cost concern is BIG









ECAL inner radius

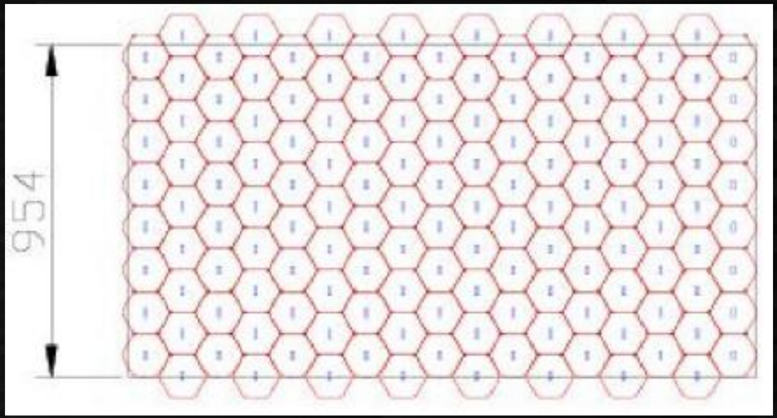
ECAL # layers

Smaller radius, fewer layers
→ big cost advantage,
but performance degraded
How much is allowed – physics

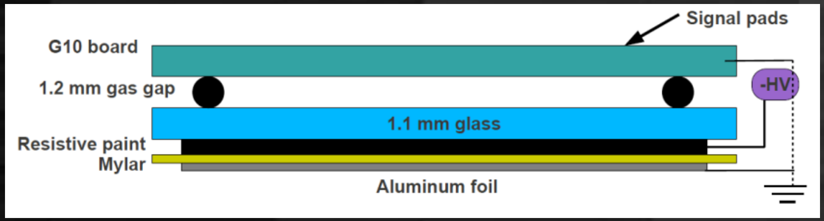
Scintillator strip + SiPM
or Si/Sc hybrid option
big cost advantage
energy resolution similar,
but more complexity

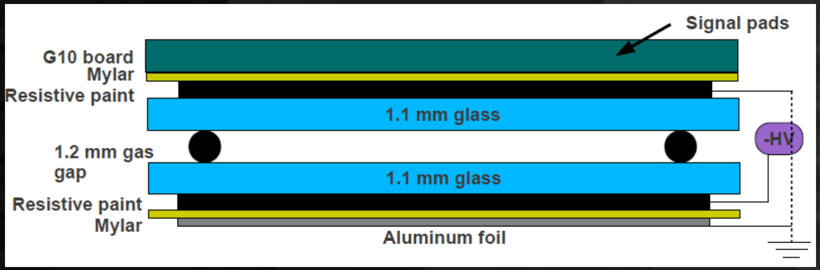
Many parameters: difficult to optimize

Sensor & readout technologies

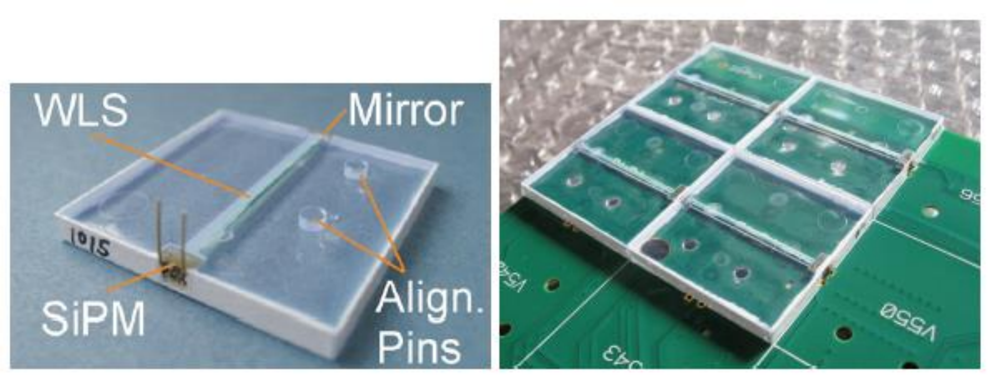


Hexagonal design for Si-ECAL





RPC digital-HCAL (1- and 2-glass)



Scintillator-tile analog HCAL

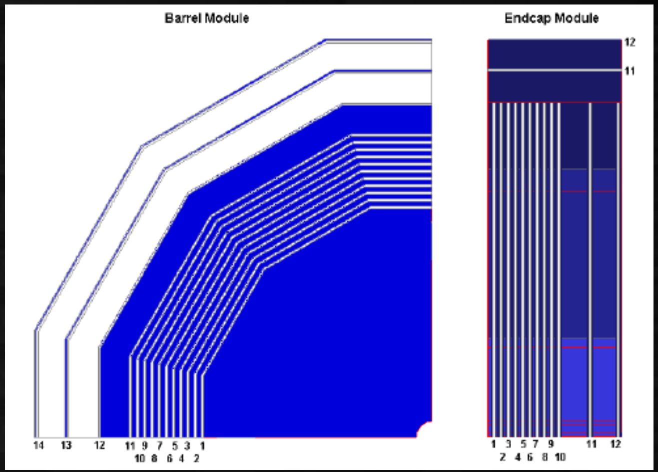
Readout of HCAL

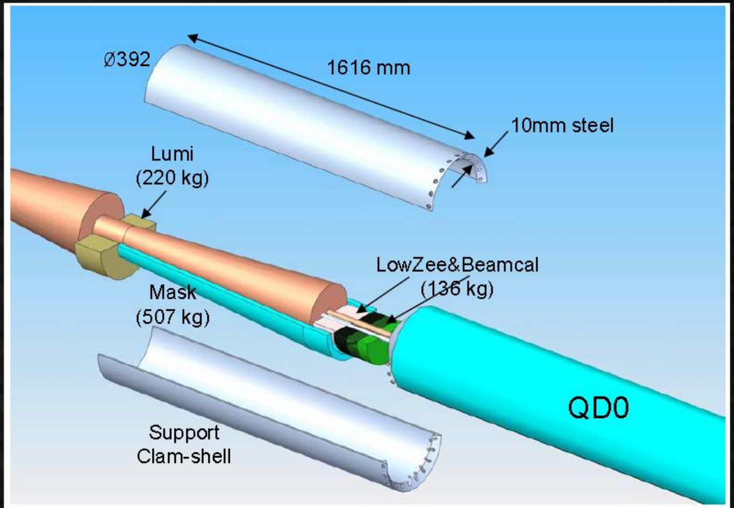
- Analog with 3 x 3 cm^2
- Semi-digital (2-bit) or Digital with 1 x 1 cm^2

→ similar performance? need detailed study

Muon & forward detectors

Muon detector: sandwiched in return yoke (outside of coil)





Forward tracking
ILD: cosθ < 0.996 (outer discs)
SiD: cosθ < 0.990 (forward discs)

LumiCal (W/Silicon) / LHCal (?)
ILD: 31-77 mrad
SiD: 40-90 mrad

BeamCal (GaAs or CVD)
ILD/SiD: 7-40 mrad

Powerful for rejecting beam backgrounds (two-photon, beamstrahlung)

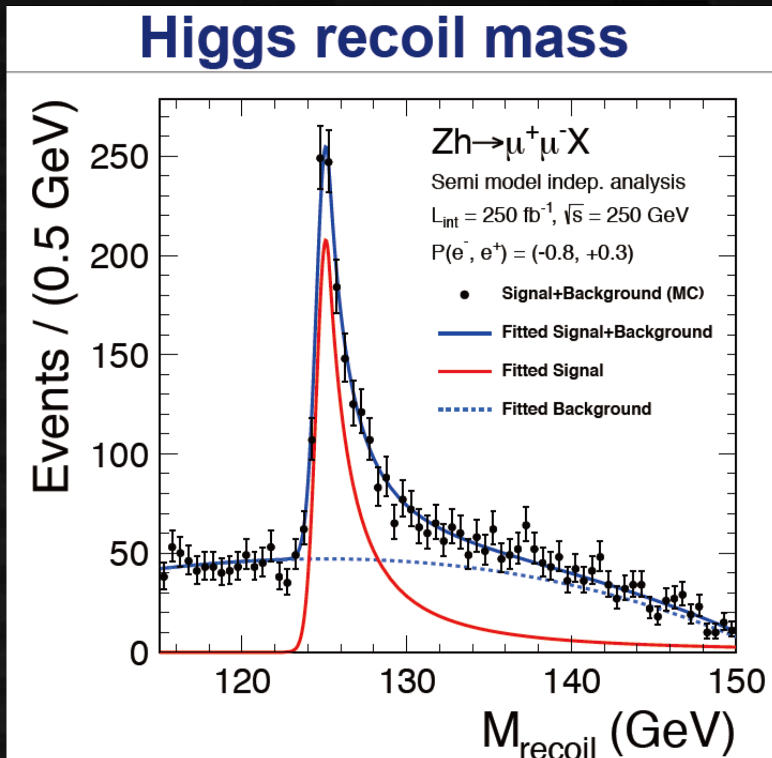
Summary, towards optimal ILD/SiD

- Vertex: Critical. Must maximize performance. Pair background should be competed.
- Tracker: moderate requirements on resolution, should keep low momentum tracking to maximize new physics reach.
- Calorimeter: Cost driver. consider slightly weaker performance. options available.

Careful treatment of software and physics necessary to assure reliability of estimation.
Optimization based on physics performance ongoing, to be concluded towards detector TDR(s) in a few years.

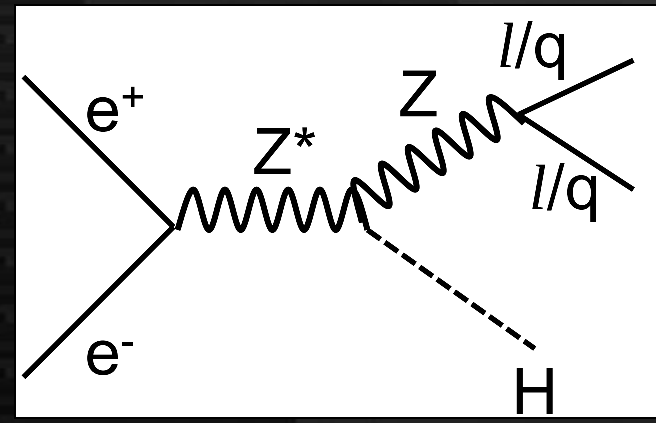
ILC Physics Program

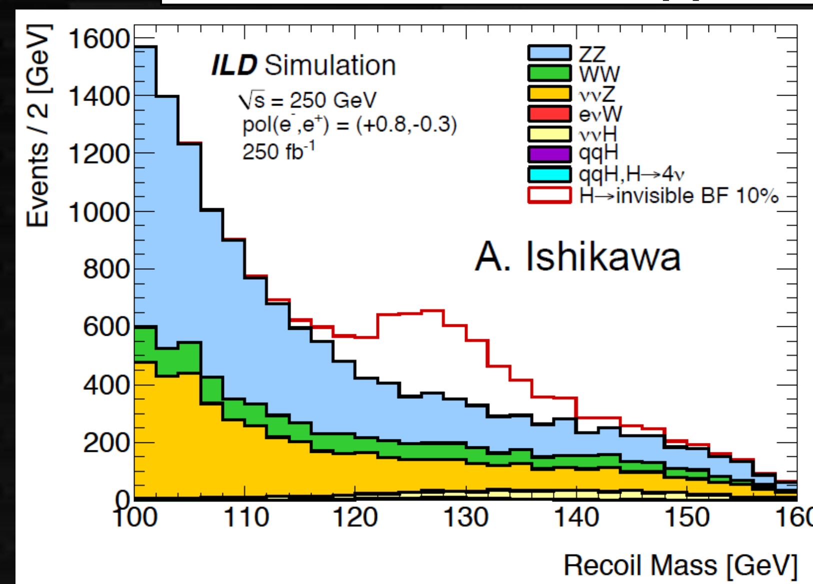
Higgs recoil measurements



Key for model-independent Higgs coupling & precise m_H determination

Momentum resolution of tracks (e/μ) essential

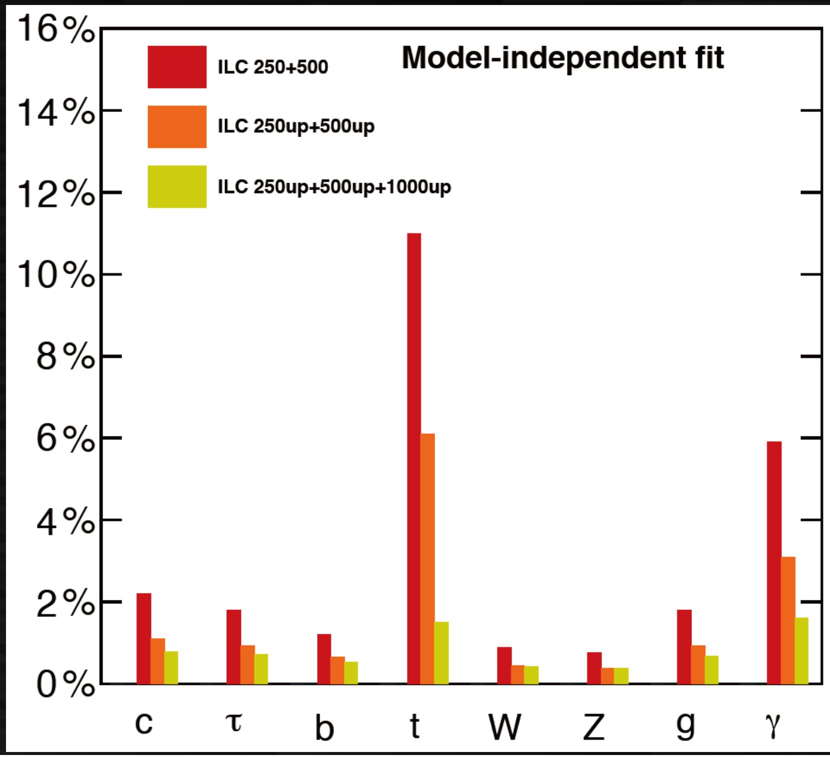




qqH, H → invisible:

Jet energy resolution essential

Higgs as a probe for New Physics



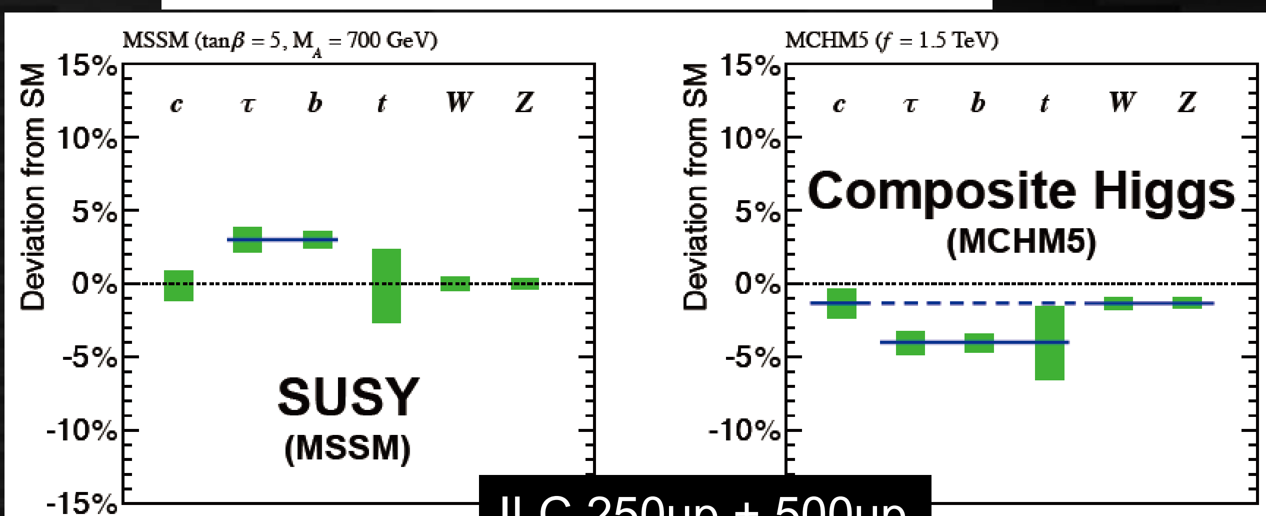
ILC 250:
Lumi 417 fb-1, sqrt(s) = 250 GeV

ILC 500:
Lumi 833 fb-1, sqrt(s) = 500 GeV

ILC 250up:
Lumi 1920 fb-1, sqrt(s) = 250 GeV

ILC 500up:
Lumi 2670 fb-1, sqrt(s) = 500 GeV

ILC 1000up:
Lumi 4170 fb-1, sqrt(s) = 1 TeV



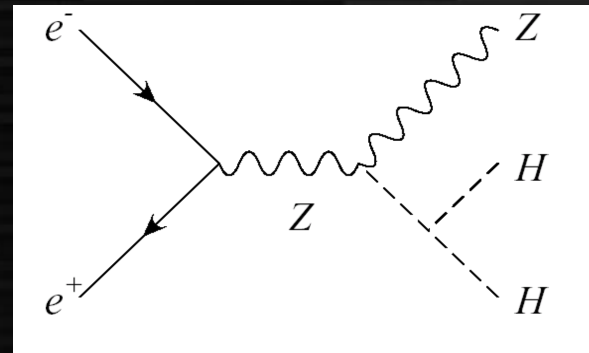
ILC 250up + 500up

< 1% coupling meas.
very sensitive to NP
Jet reconstruction &
b/c tagging essential

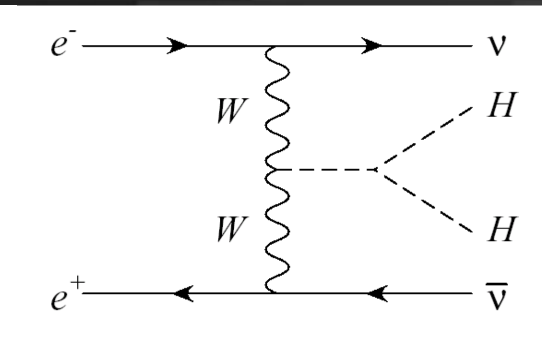
Higgs CP via H → ττ

Need full reconstruction of energetic tau
→ particle separation at ECAL essential

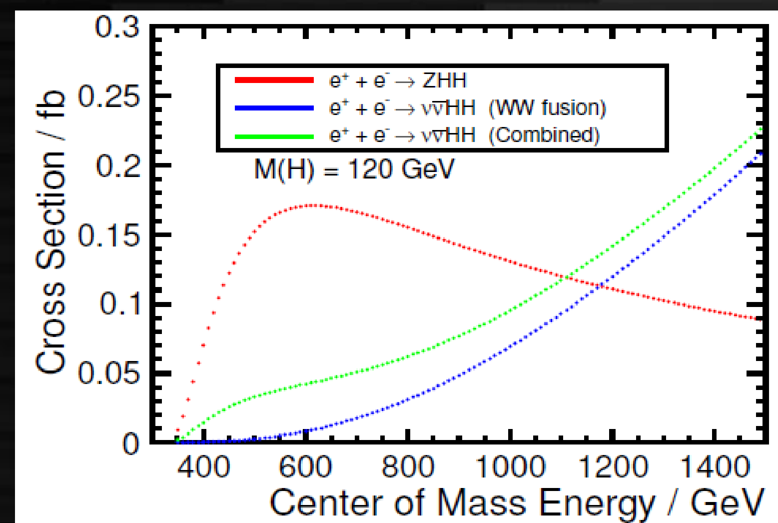
Higgs self coupling



500 GeV (ZHH)

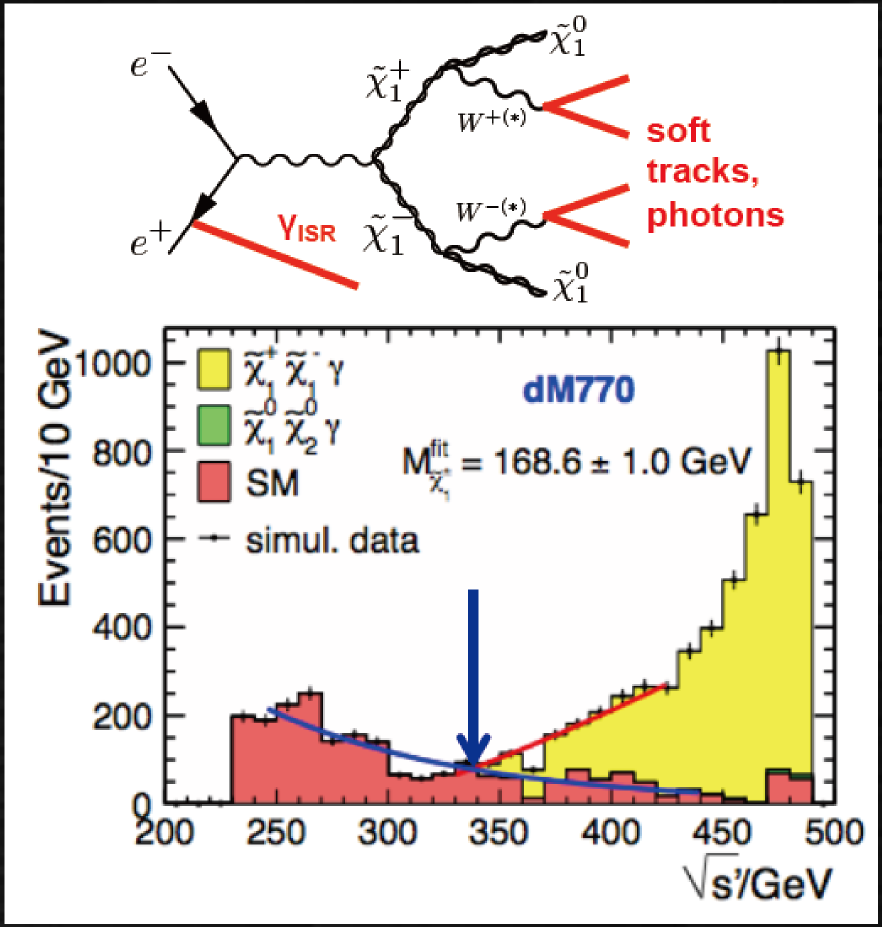


1 TeV (ννHH)



HH → 4b: golden mode
b-tagging performance essential
jet clustering more important than jet energy resolution

Soft SUSY: NLSP/LSP degenerated



Natural for Higgsino LSP

Low momentum tracking

+ forward coverage for ISR

Others

Exotic searches:

- Non-pointing photons
- metastable particles

Precise measurements:

- Gauge 3-point /4-point coupling

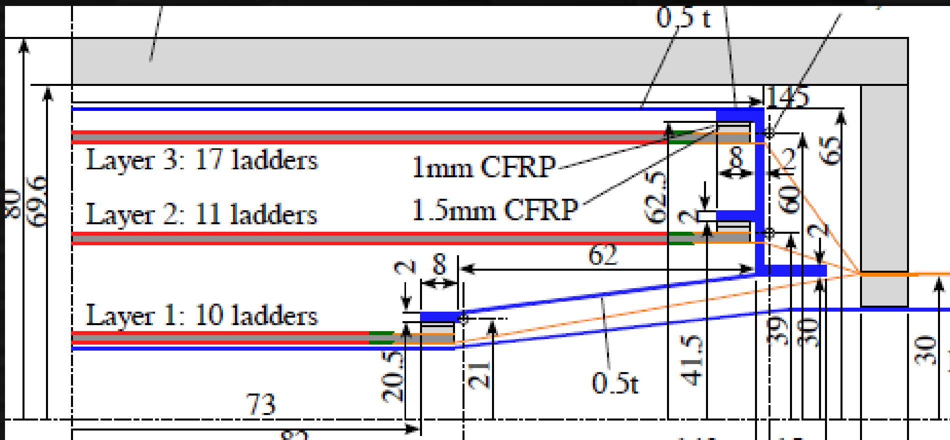
Performance Requirements

1. Point resolution by vertex detector
   – Flavor tagging for Higgs BR, self coupling etc.
   – Tau reconstruction, metastables etc.
2. Momentum resolution of tracks
   – Higgs recoil mass
   – Low momentum tracking for new physics
3. Jet energy resolution by PFA
   – Higgs invisible, precise measurements
4. Forward tagging
   – New physics

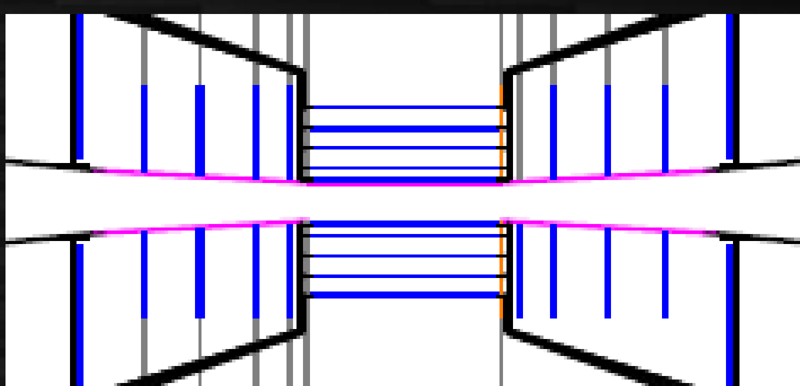
Backup

Vertex detector: geometry

ILD: 3 double layers (reference)



SiD: 5 single layers



3 double layers:
- Mechanically rigid
- discrimination of pairs by hit shape of two layers

5 single layers:
- More space points

radius of layers
- SiD: 14-60 mm
- ILD: 15-60 mm

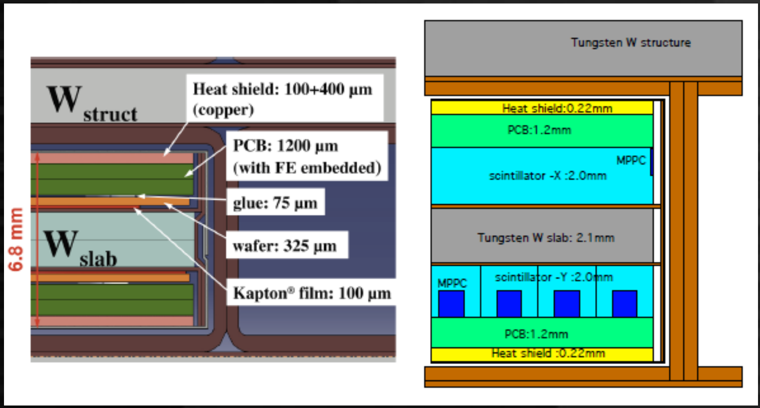
Inner → better resolution but more pairs (esp. in higher E)

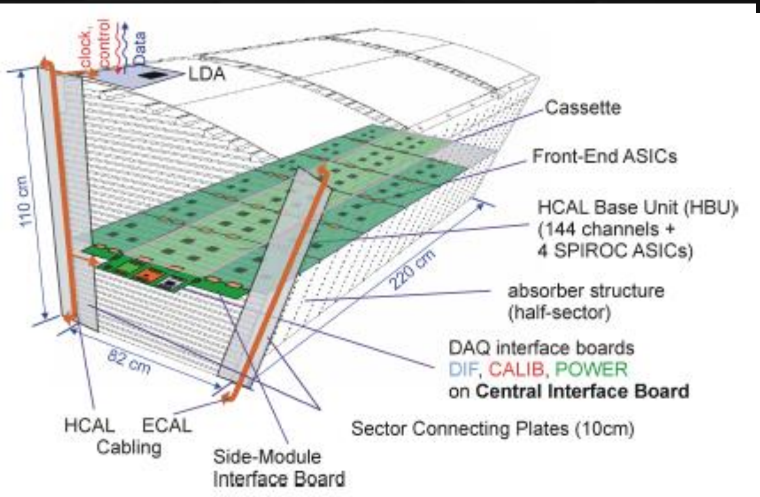
Different setup in 250/500?

Readout, analog, semi- or digital

ECAL
- Silicon (ILD/SiD, baseline) – Analog, 13 or 25 mm^2
- Scintillator (ILD, option) – Analog, 5 x 45 mm^2
- ILD/SiD MAPS (premature option) – Digital, 50 x 50 μm^2

HCAL
- ILD Scintillator – Analog, 3 x 3 cm^2
- ILD GRPC – 2bit, 1 x 1 cm^2
- SiD RPC – Digital, 1 x 1 cm^2





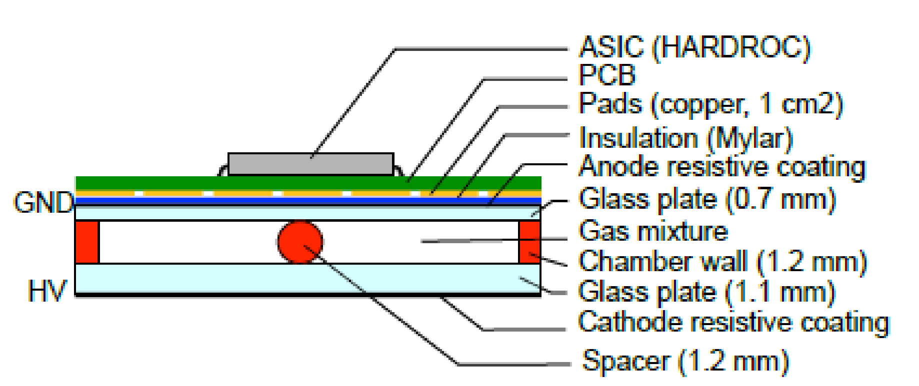


Figure 2.4.16: Structure of the GRPC.