ILD

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for ILD concept group
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ILC PAC @KEK

Outline

- Introduction
- Sub-systems
- ILD system
- ILD performance
- Cost
- Summary

Introduction

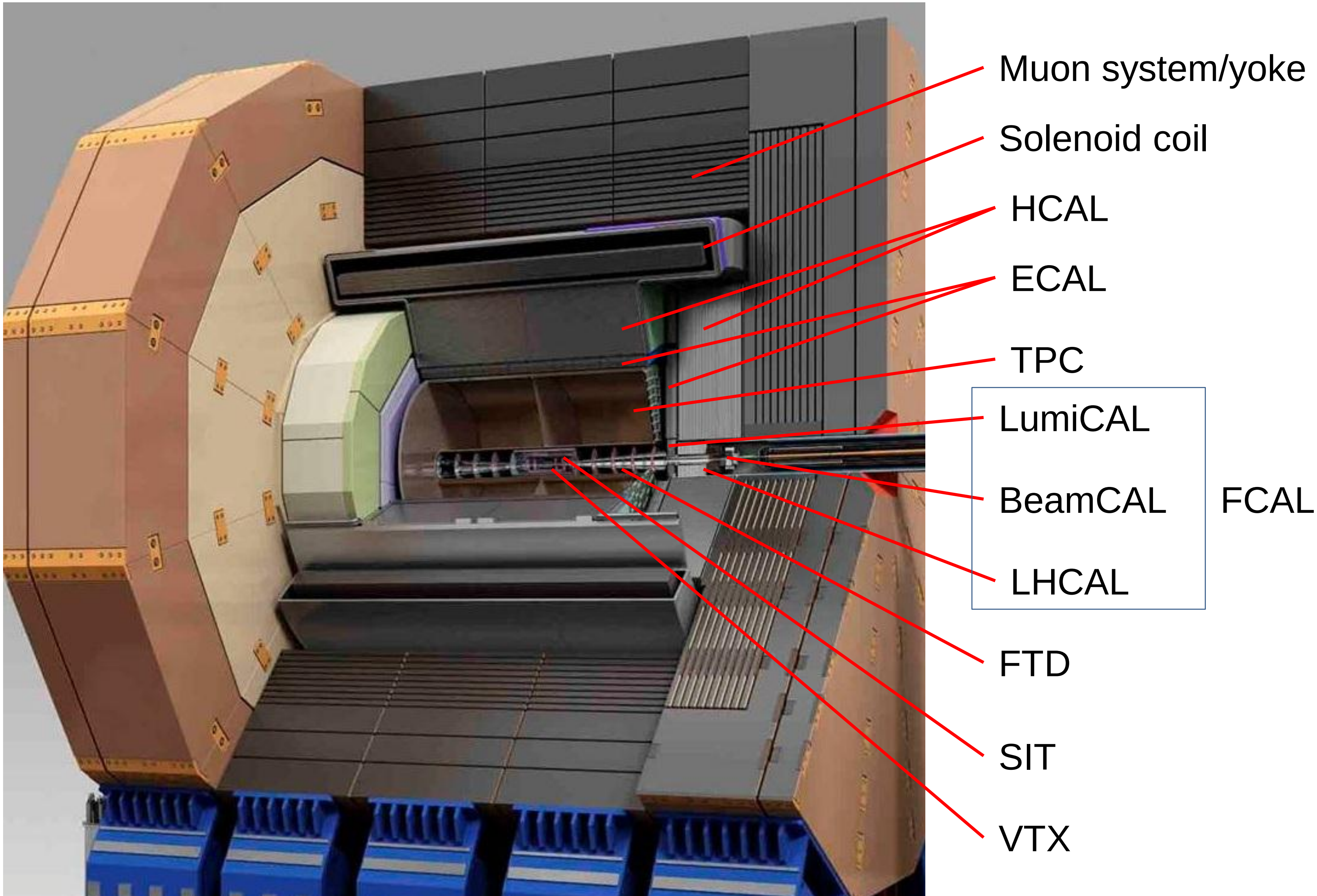
Events on ILD since last PAC

- May 15-16: ILC PAC @Fermilab
  - ILD status report by Graham Wilson
- May 23-25: ILD Workshop @Kyushu Univ.
- Sep.28: ILD DBD 0th draft sent to IDAG
  - Many holes, particularly in physics analysis section
- Oct. 22-26: LCWS2012 @UTA
  - IDAG review
  - ILD meeting (discussed mainly physics analysis)
- Nov. 30: Submission of ILD DBD draft
  - Draft is quite complete
  - Results of benchmark analysis is still preliminary
  - Delay in finalization of the numbers of costing

ILD philosophy

- Detector for precision measurement
- Excellent jet energy resolution by PFA
  - Calorimeters inside the solenoid of 3.5T
  - High granularity calorimeters (ECAL + HCAL +FCAL)
  - Large size detector for particle separation in space and excellent momentum resolution
- Powerful tracking system (micro-pixel vertex detector + Si trackers + TPC) for high momentum resolution, efficient track reconstruction and flavor tagging
- Hermetic coverage down to 5mrad

ILD


Muon system/yoke
Solenoid coil
HCAL
ECAL
TPC
LumiCAL
BeamCAL
LHCAL
FCAL
FTD
SIT
VTX

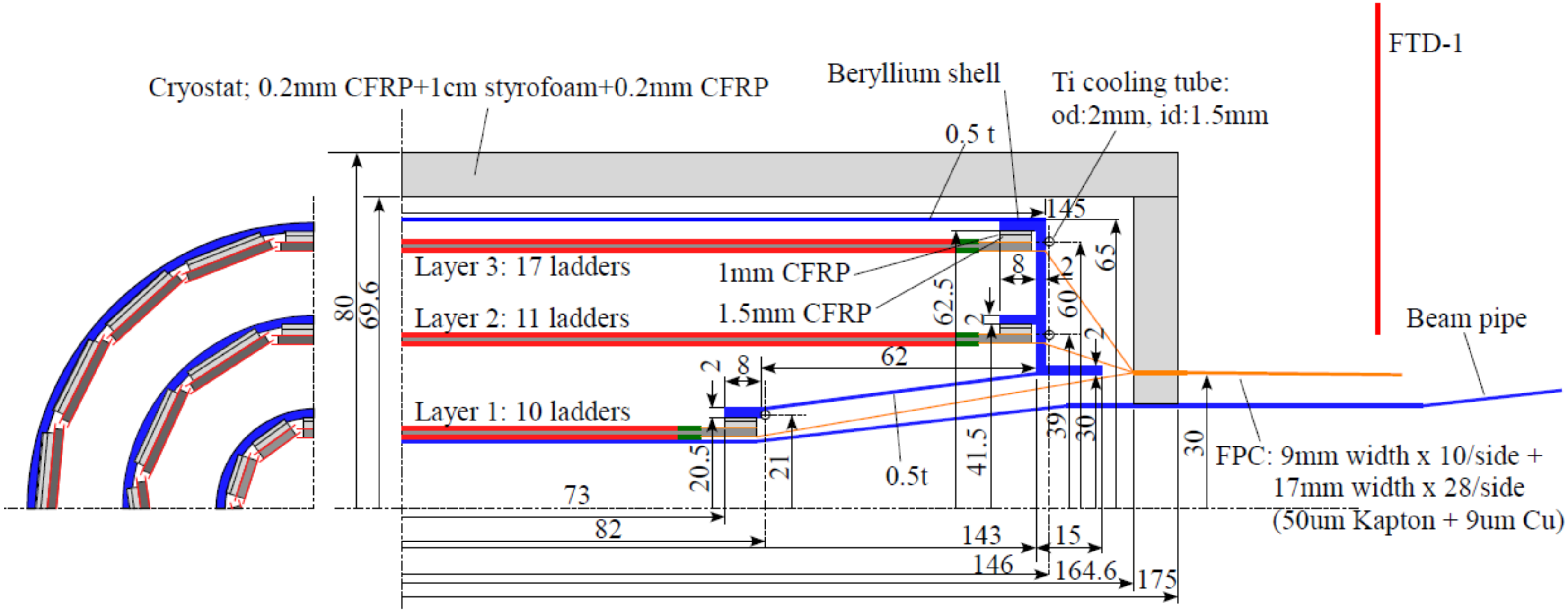
ILD baseline

	Sensor options for baseline design			Alternative
VTX	CMOS	FPCCD	DEPFET	
SIT	False double-sided strip			Double-sided strip
FTD 1-2	CMOS	FPCCD	DEPFET	
FTD 3-7	False double-sided strip			
TPC	GEM	MicroMEGAS		Pixel readout
ECAL	W-Si pad	W-Scintillator strip		W-Pixel
HCAL	Analog (Scintillator)	Semi digital (RPC)	← Mechanical structure is also different	
FCAL	W-Si / GaAs	W-Si / Diamond		
Muon	Scintillator strip			RPC

Sub-systems

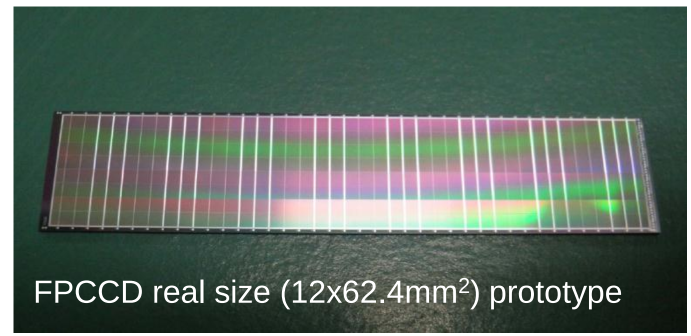
Vertex detector

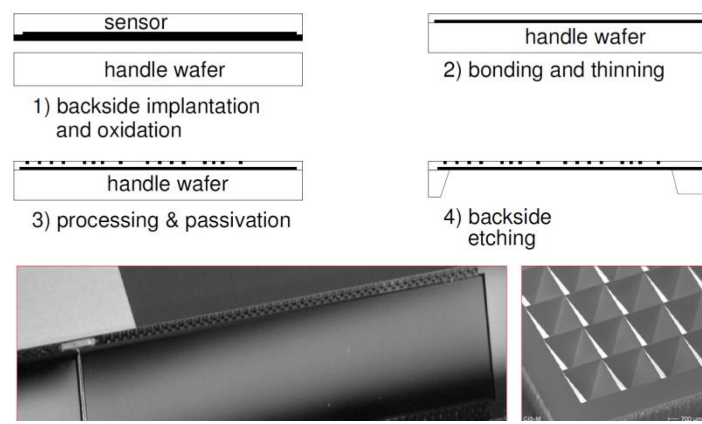
- Excellent impact parameter resolution better than $5\oplus10/p\beta\sin^{3/2}\theta$ is required for efficient flavor tagging
- 3 layers of double-sided ladders (6 pixel layers)
  - Effect on pair-background rejection is expected, but not demonstrated yet
- Barrel only: $|\cos\theta|<0.97$ for inner layer and $|\cos\theta|<0.9$ for outer layer
- Point resolution <3um for innermost layer
- Material budget: $0.3\%X_0$/ladder=$0.15\%X_0$/layer
- Sensor options: CMOS, FPCCD, DEPFET



Vertex detector

- CMOS option
  - Pixel size: 17x17(L1), 17x85(L2), 34x34(L3-6)
  - Frame readout time: 10us~100us
  - Power consumption: 600W → 10W by power pulsing
- FPCCD option
  - Pixel size: 5x5 (L1-2), 10x10(L3-6)
  - Readout between trains
  - Power consumption: ~40W (no power pulsing)
- DEPFET option
  - Experience at Belle-II
  - Frame readout time: 50us~100us
  - 5-single layer of all-Si ladder option
- Cooling
  - CO2 cooling for FPCCD
  - Additional material budget is small: 0.3%X_0 in end-plate 0.1%X_0 in cryostat
  - Air cooling for CMOS/DEPFET

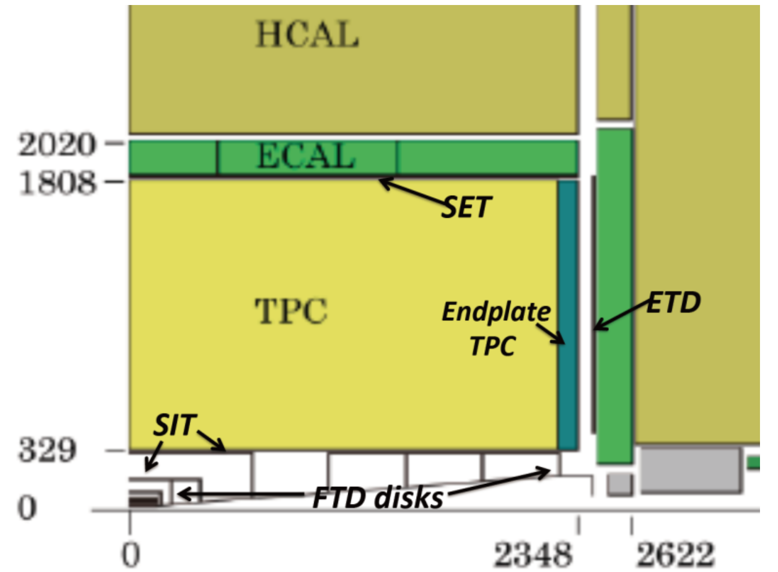

FPCCD real size (12x62.4mm^2) prototype



DEPFET all Si ladder

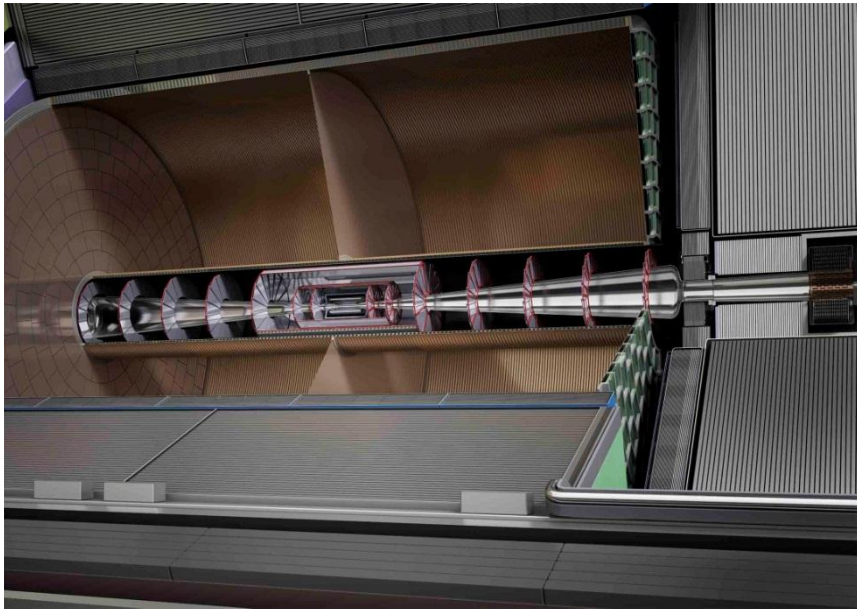
Silicon tracking system

- Silicon tracking system
  - SIT (Silicon Inner Tracker)
  - SET (Silicon External Tracker)
  - ETD (Endcap Tracking Detector)
  - FTD (Forward Tracking Detector)
- Role of Silicon tracking system
  - Additional precise space points
  - Improvement of forward coverage
  - Alignment of overall tracking system
  - Time stamping
- SIT/SET/ETD
  - Two/one/one false double-sided layers of Si strip
  - Material budget: 0.65%X_0/layer
  - Same silicon strip tiles of 10cmx10cm with 50um pitch, 200um thick, edgeless sensors will be used
  - Point resolution of ~7um



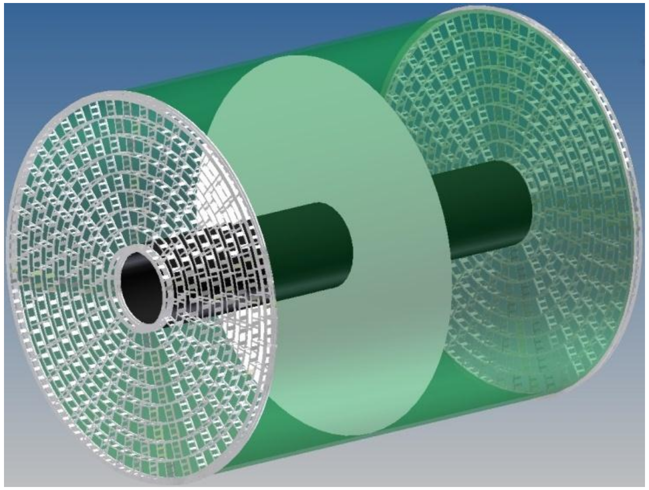
Silicon tracking system

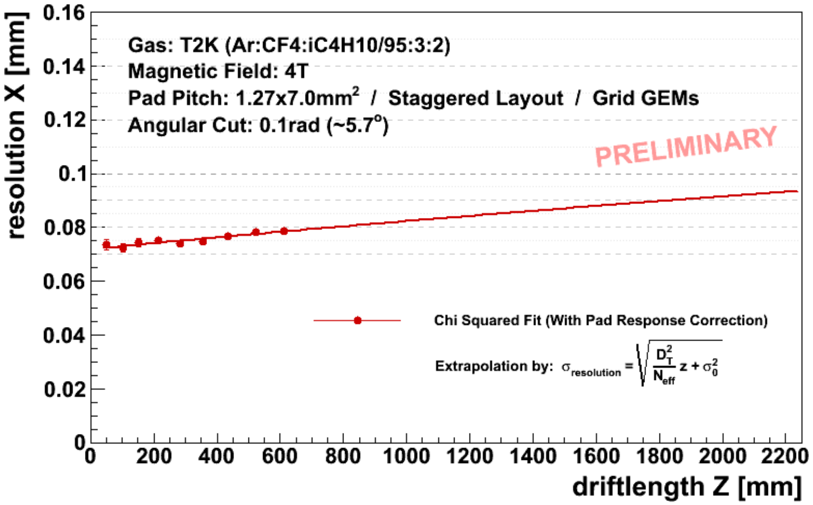
- FTD
  - Two pixel discs and five false double-sided strip disks
  - Pixel sensor options: CMOS, FPCCD, DEPFET
  - Power consumption: 2kW/disk → 100W/disk by power pulsing
  - Supercapacitor-based power distribution system
    - Low current from outside and high pulse current on the readout electronics board
    - Radiation hardness and lifetime to be studied



TPC

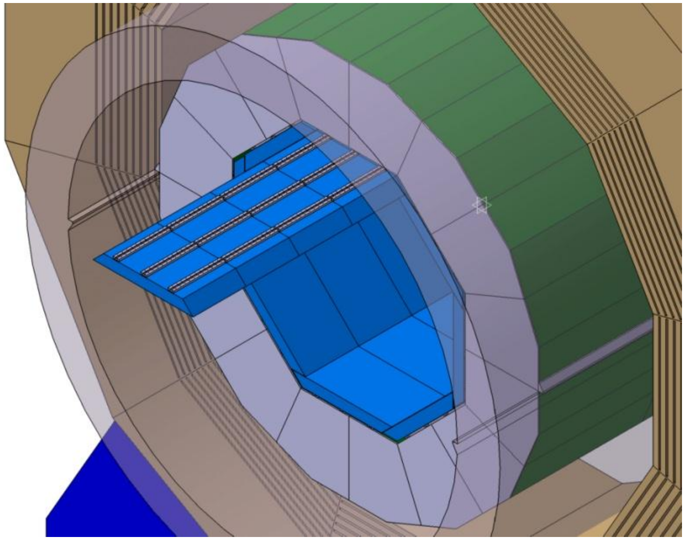
- Time Projection Chamber: The central tracker of ILD
- Tracks can be measured with many (~200/track) 3-dimensional r-ϕ-z space points
- $\sigma_{r\phi}$<100um is expected
- dE/dx information for particle identification
- Two main options for gas amplification: GEM or Micromegas
- Readout pad size ~ 1x6mm^2 → 10^6 pads/side
- Pixel readout R&D as a future alternative
- Material budget: 5%X_0 in barrel region and <25%X_0 in endplate region
- Cooling by 2-phase CO2

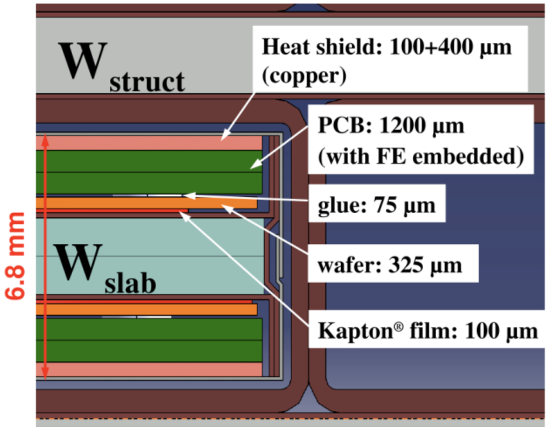


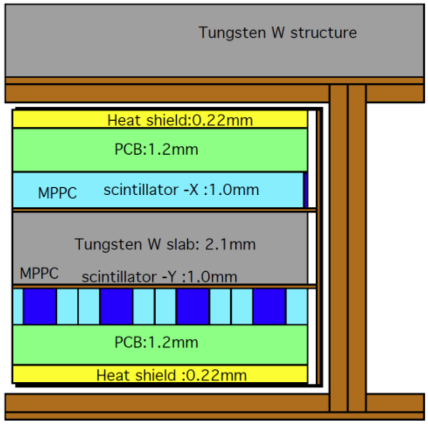


ECAL

- Sampling calorimeter of tungsten absorber / Si or scintillator-strip sensitive layer sandwich
- 30 layers / $24X_0$
- Si sensor: $5x5mm^2$ pixel size
- Scintillator strip: $5x45mm^2$, read out by MPPC
- Leak-less water cooling → Other methods are also investigated

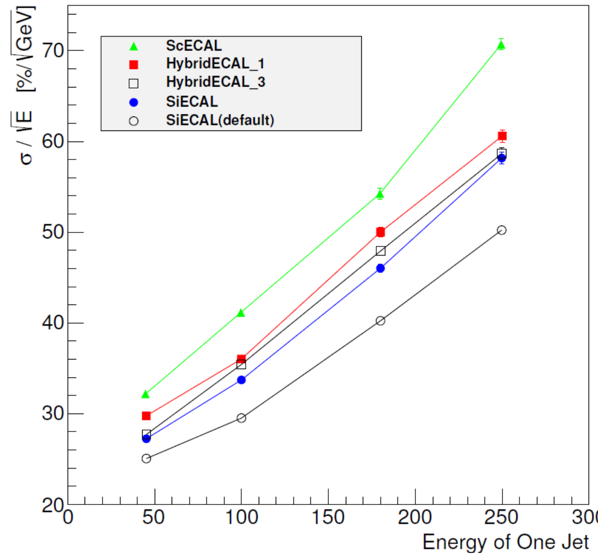


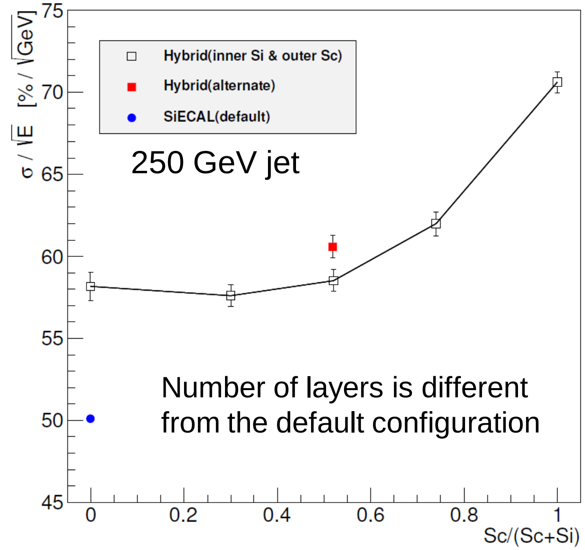




ECAL

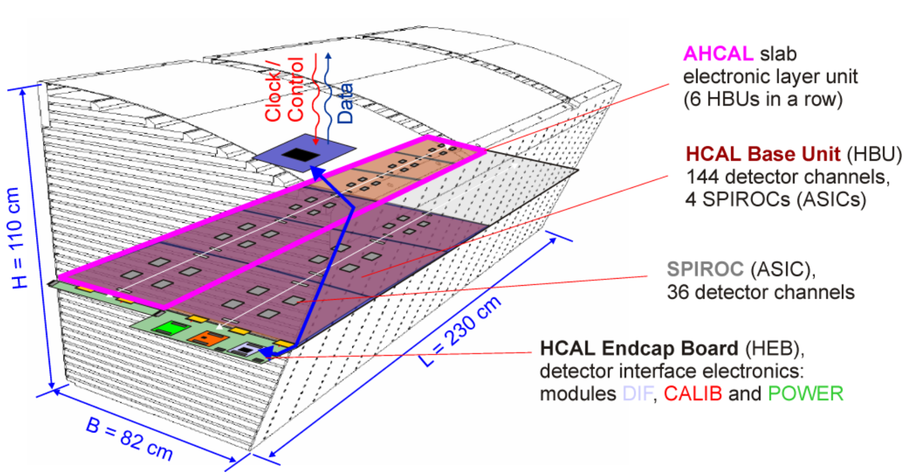
- Detector optimization
  - Si sensor is one of the cost drivers of ILD
  - How to reduce the cost
    - Reduce inner radius ?
    - Reduce number of layers ?
    - Si-Scintillator hybrid →Performance is not degraded up to 50%



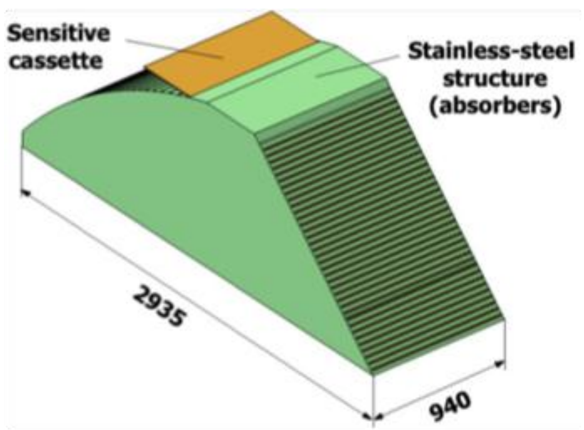


HCAL

- Sampling calorimeter with steel absorber (48 layers, $6\lambda_I$)
- Two options for the active layer
  - Scintillator tiles with analog readout → AHCAL
  - Glass RPC with semi digital (2-bits) readout → SDHCAL
- Different mechanical structure is proposed by the two groups



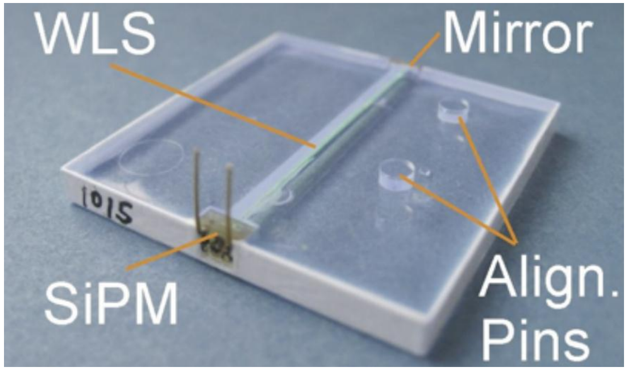
AHCAL module

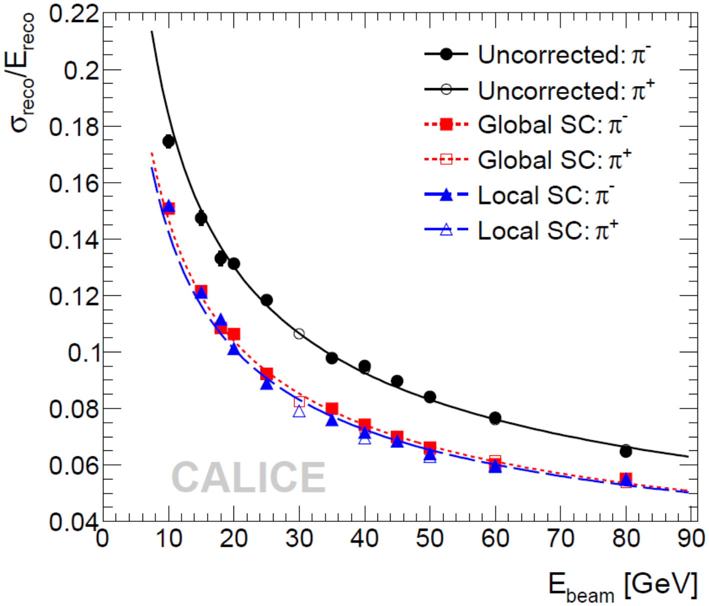


SDHCAL module

AHCAL

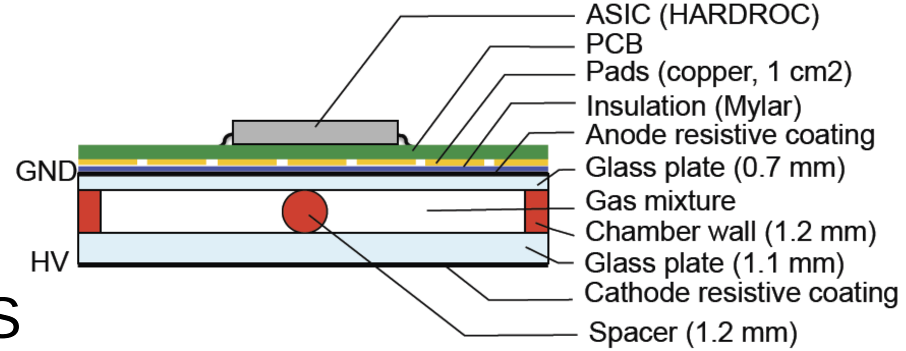
- $3x3cm^2$ segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/π ~1.2) technique was shown to work well through beam tests: $58\%/E^{1/2}$ → $45\%/E^{1/2}$
- Test beam results are also used for evaluation of GEANT4 physics list

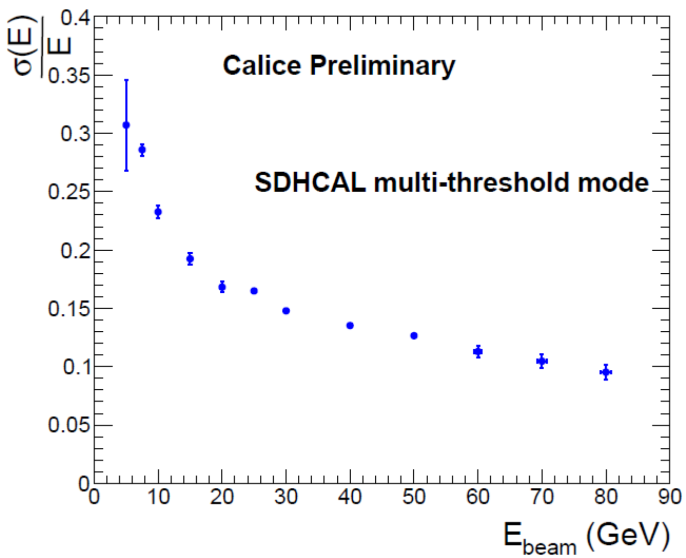


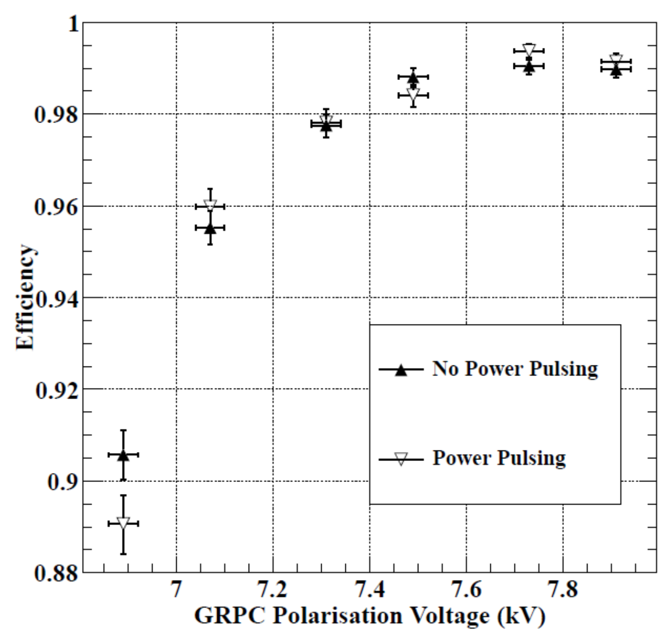


SDHCAL

- Active layer: GRPC with 1.2mm gap with 1x1cm^2 signal pick-up pads
- Demonstrated to work with power-pulsing in 3T B-field
- Test beam at CERN PS and SPS
  - Still better resolution is expected using more detailed analyses

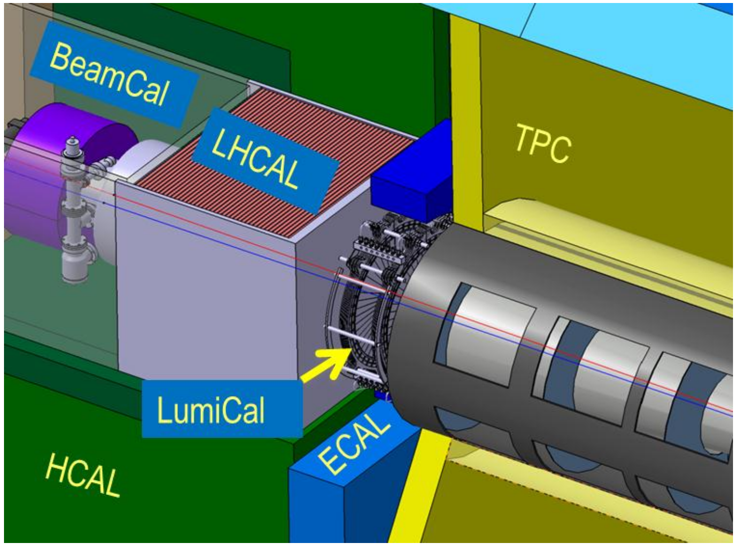






Forward calorimeters

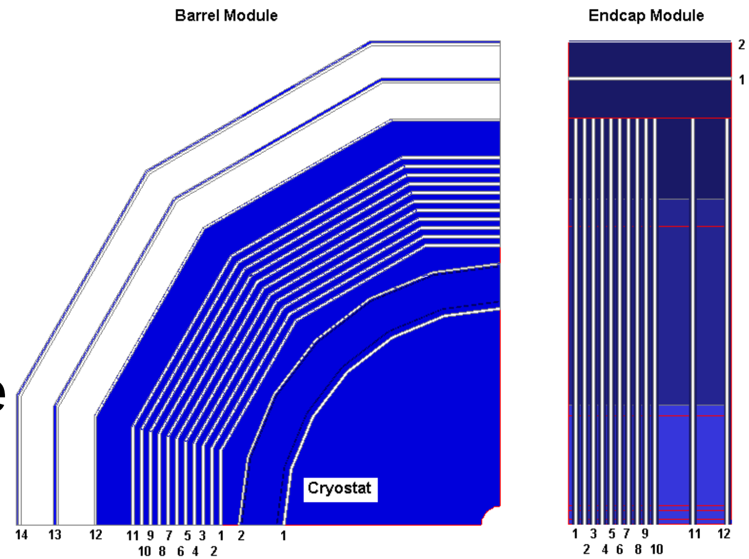
- LumiCal
  - Precise (<10^{-3}) luminosity measurement
- BeamCal
  - Better hermeticity
  - Bunch-by-bunch luminosity and other beam parameter measurements (~10%)
- LHCAL
  - Better hermeticity for hadrons

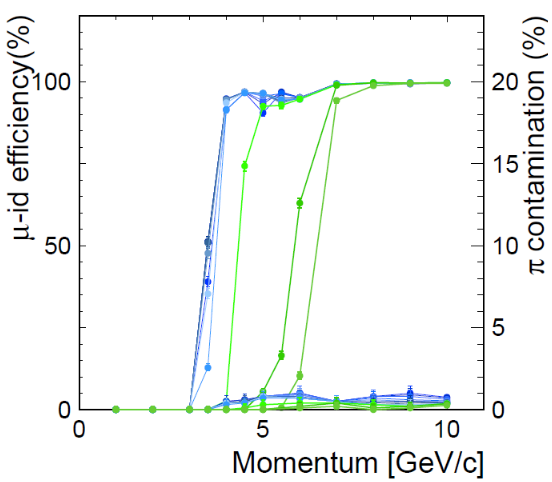


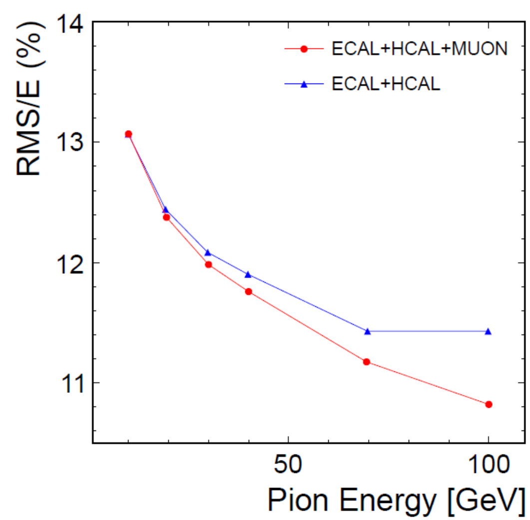
	Technology	Coverage
LumiCal	W-Si	31 – 77 mrad
LHCAL	W-Si	
BeamCal	W-GaAs / Diamond	5 – 40 mrad

Muon system

- Active layers (14 for barrel, 12 for endcap) interleaved with iron slabs of return yoke
- Baseline design adopts scintillator strips + WLS fiber + SiPM readout as the active layer
- RPC is considered as an alternative
- Used for muon identification and as a tail catcher of the HCAL

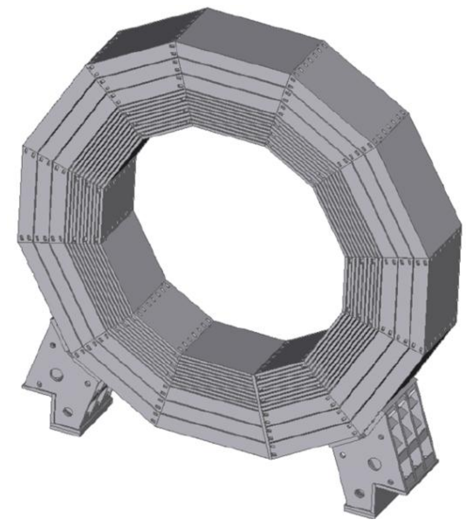


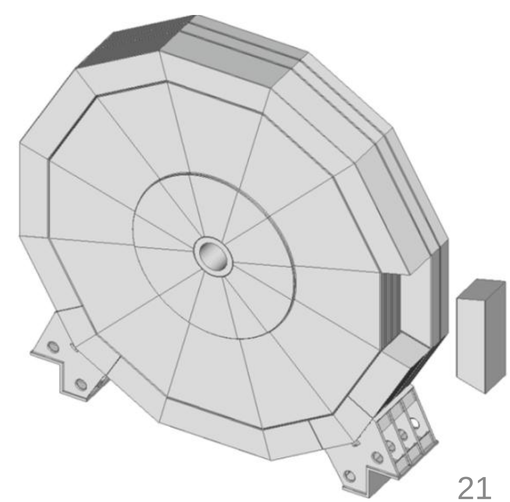




Coil and yoke

- B field: Nominal 3.5T, maximum 4T
- Anti-DID in the same cryostat
- Self shielding in terms of radiation protection
- Leakage field < 50G at 15m from IP
- Magnet design
  - Similar to CMS: 3 barrel rings + 2 endcaps
  - Cryostat size: ϕ=8.8m, L=7.8m
  - Coil is divided into 3 modules in z
  - Cold mass = 168t
  - Total weight = 13400t
  - Stored energy ~2.3GJ
- Yoke design
  - Each barrel ring consists of 12 trapezoidal blocks of ~190t: 2300t for a ring
  - Endcap yoke consists of 12 sectors: total weight~3250t/side

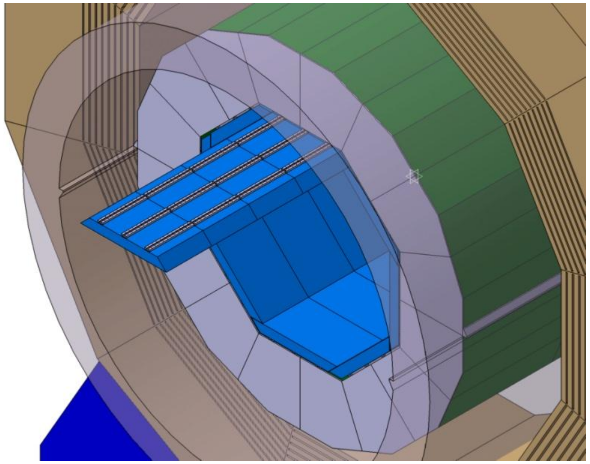


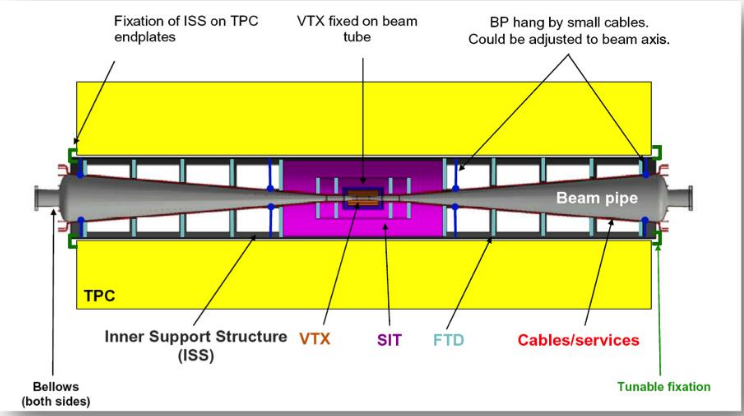


ILD system

Detector integration

- Yoke and magnet
  - Solenoid cryostat, which supports all of the central detectors, is supported from central barrel yoke ring
  - Maximum deformation of the cryostat <2.5mm
- Barrel HCAL (~600t) is supported by 2 rails inside the cryostat
- Barrel ECAL modules are supported by rails attached to barrel HCAL
- Endcap calorimeters are supported from the endcap yoke
- TPC is supported from the cryostat
- Inner trackers (SIT, FTD, VTX) are housed in a inner support structure (ISS), and the ISS is supported from TPC end-plate
- Forward detectors (LumiCal, BeamCal, LHCA) are supported together with QD0 from a support tube extended from the external pillar

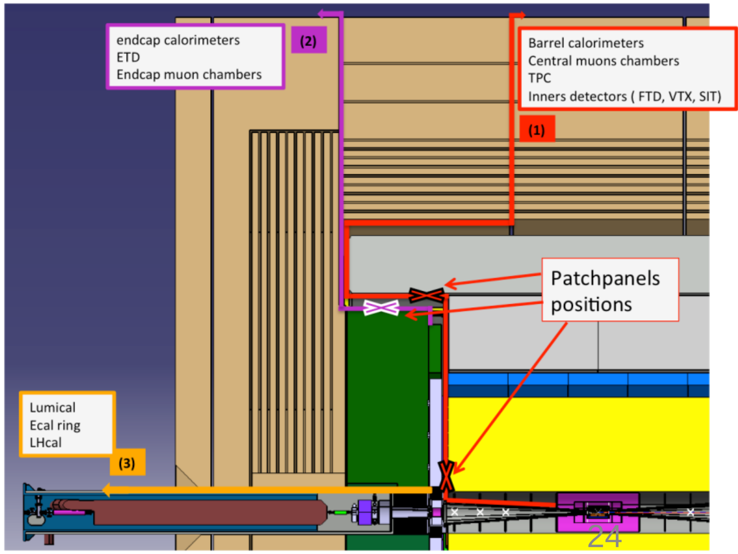




Detector integration

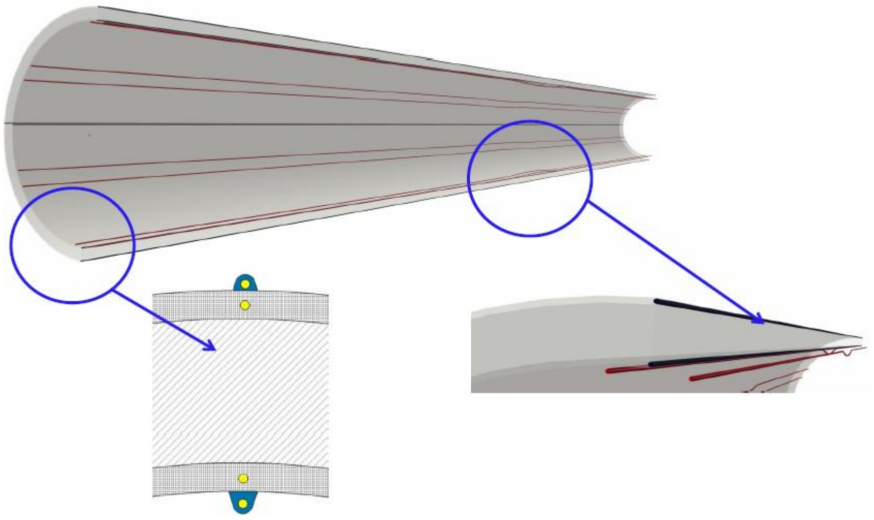
- Detector assembly: site-dependent
  - Non-mountain site: CMS style
    - Pre-assembled and tested on surface
    - Large pieces (3 barrel rings + 2 endcaps) are lowered through vertical shaft
    - 3500t crane for the vertical shaft
  - Mountain site: Access through horizontal tunnel
    - Yoke rings are assembled underground
    - 250t crane(/detector) in the underground experimental hall

- Detector service path
  - Detector services (cables and tubes) are considered seriously for ILD
  - Barrel detectors
    - services go through gap of central yoke rings
  - Endcap detectors
    - gap between endcap yoke and barrel yoke
  - Forward detectors
    - along the QD0 support structure



Calibration/alignment

- Alignment procedure
  - Accurate positioning during construction of sub-detectors by coordinate measuring machine
  - Alignment at the installation phase by standard survey technique
  - Hardware alignment system during operation
  - Ultimate micro-meter order alignment by “track-based alignment”
- Alignment techniques under R&D
  - IR laser alignment for Si strip detectors
  - Fiber Bragg Grating (FBG) sensors for mechanical structure alignment → Smart support structure



Data acquisition

- ILD DAQ: Trigger-less
- Compared to LHC, ILD DAQ is less demanding in throughput, but the number of readout channels is >x10 larger → Data suppression at detector level (digitization in front-end electronics)
- Most of the data volume (99%) come from beam background
- Design of the DAQ system is still at the conceptual design level

Software tools

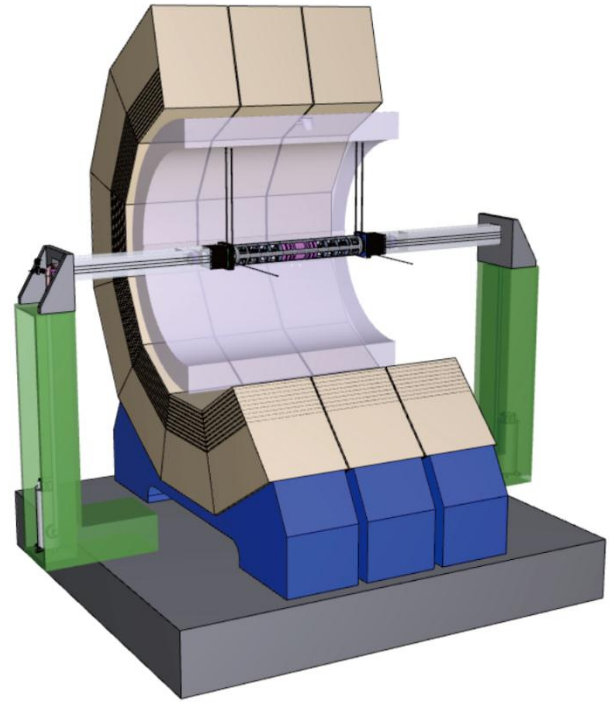
- Core tools
  - LCIO
    - Provides a hierarchical event data
    - Commonly used by ILD, SiD, CLIC
  - Gear: API for detector geometry
  - Mokka: GEANT4 based full simulation
  - Marlin: Framework for further processing of the simulated data
- Detector models in Mokka
  - Realistic model: Mechanical support structures, electronics, cables, dead materials, and cracks are also implemented
  - Three models created
    - ILD_o1_v05: AHCAL and SiECAL
    - ILD_o2_v05: SDHCAL and SiECAL
    - ILD_o3_v05: AHCAL and ScECAL

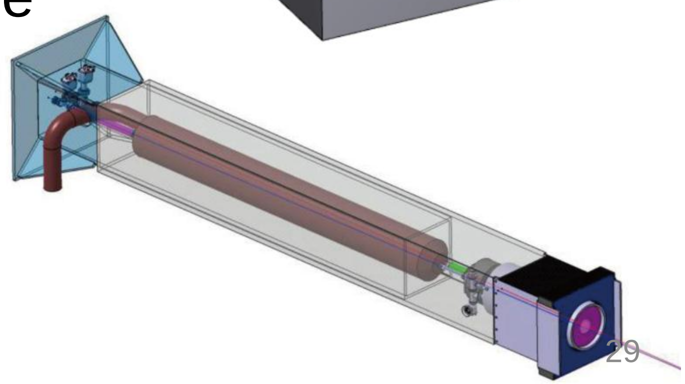
Software tools

- Marlin
  - Reconstruction and analysis system
  - Some new/updated packages have been developed for DBD analysis
    - Track reconstruction: Kaltest, IMarlinTrK, Clupatra, FwdTracking – replacing old Fortran code with C++ code
    - Particle flow: PandoraPFA
    - Secondary vertex tagging: LCFIVertex, LCFIPlus
  - Background overlay
    - Pair background is not overlaid in MC study
    - Two-photon background events are overlaid before reconstruction

MDI and experimental area

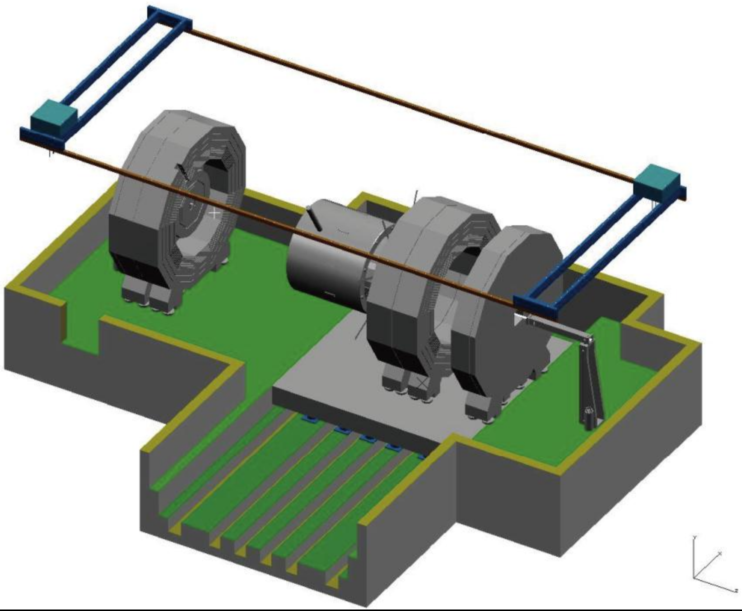
- Push-pull
  - ILD (~14kt) is place on a platform (20x20x2.2m^3) for push-pull operation
  - ILD has its own moving system (air pads and grease pads) on the platform
  - Alignment accuracy after movement should be <1mm
- QD0
  - QD0 is supported by a support tube which is supported from a pillar standing on the platform
  - Vibration of QD0 has to be less than 50nm above 1Hz

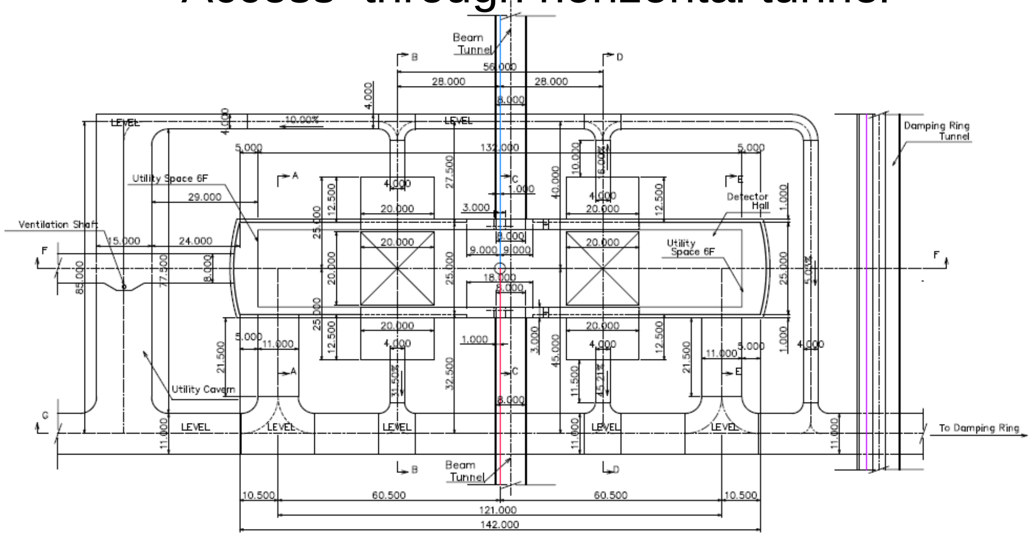


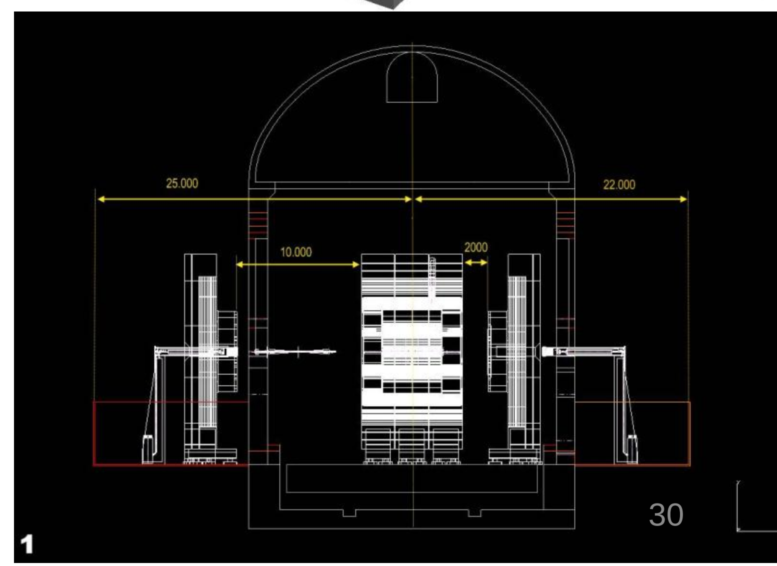


MDI and experimental area

- Experimental area for flat surface
  - Z-shape experimental hall
  - ϕ18m vertical shaft above IP
  - ϕ10m vertical shaft in ILD garage (ϕ8m for SiD)
  - Two ϕ5m shafts for elevator/services
- Experimental area for mountain site
  - I-shape experimental hall with garage alcoves for detector maintenance
  - Access through horizontal tunnel





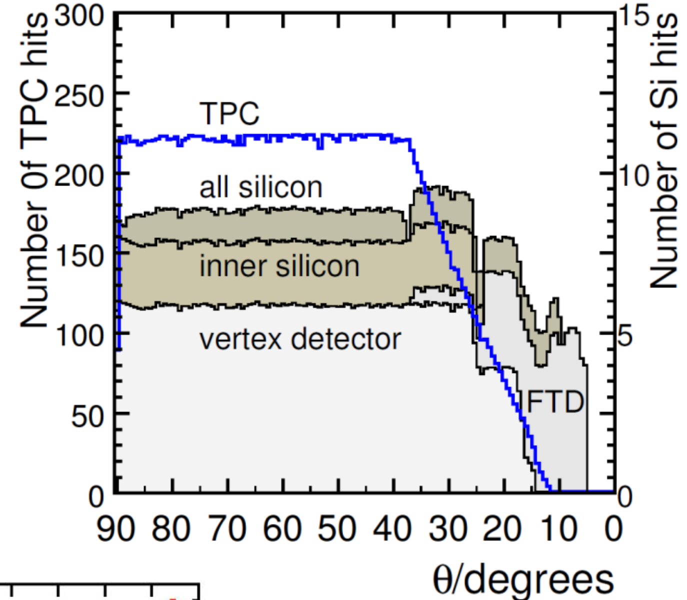


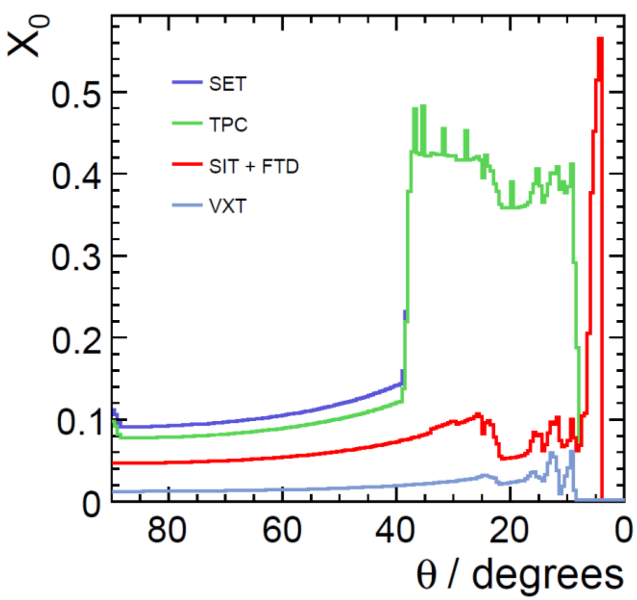
ILD performance

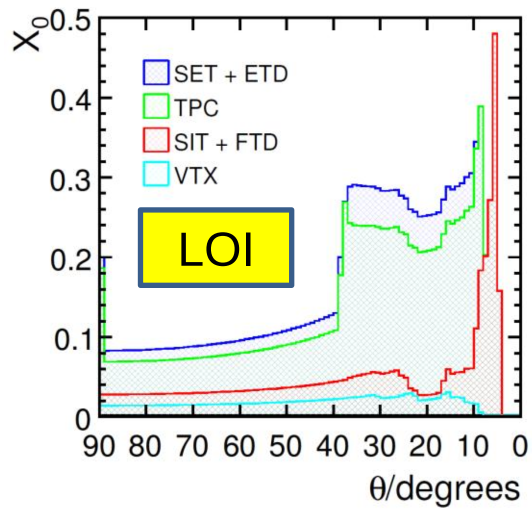
- ILD benchmark analysis is still on-going
- All the numbers may change by the end of January 2013

Tracking performance

- Detector coverage and material budget
  - More material budget than LOI because of more realistic detector implementation

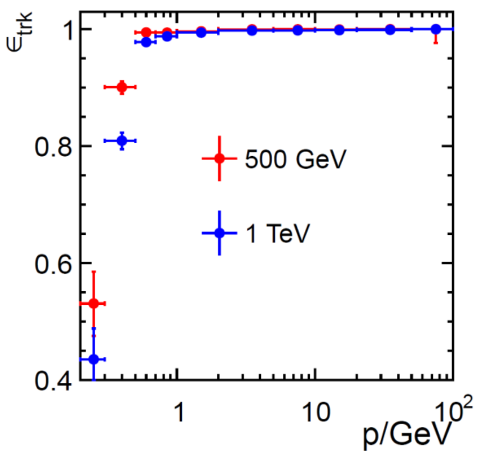




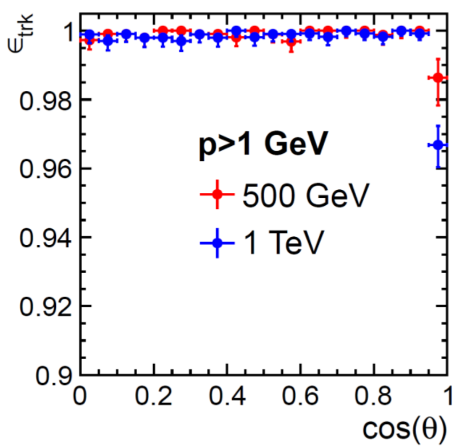


Tracking performance

- Performance goal
  - $\sigma_{1/p_T} \sim 2\mathrm{x}10^{-5} \mathrm{GeV}^{-1}$
  - $\sigma_{r\phi} = 5 \oplus 10/p\sin^{3/2}\theta$ [um]

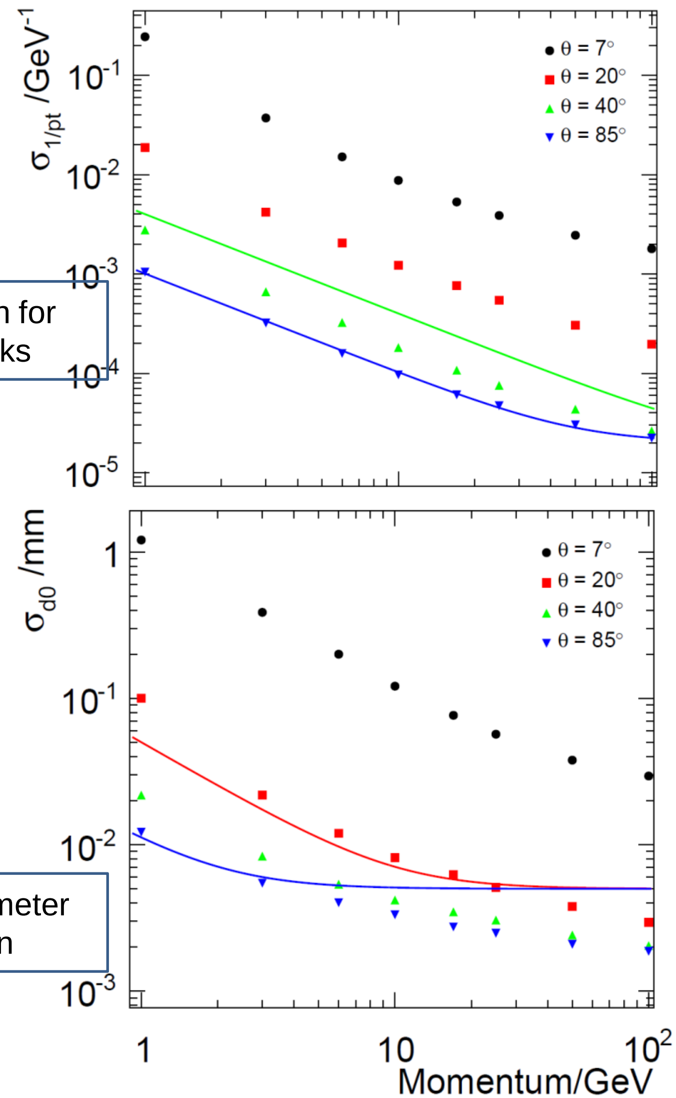


Tracking efficiency for t t events



Pt resolution for muon tracks

Impact parameter resolution

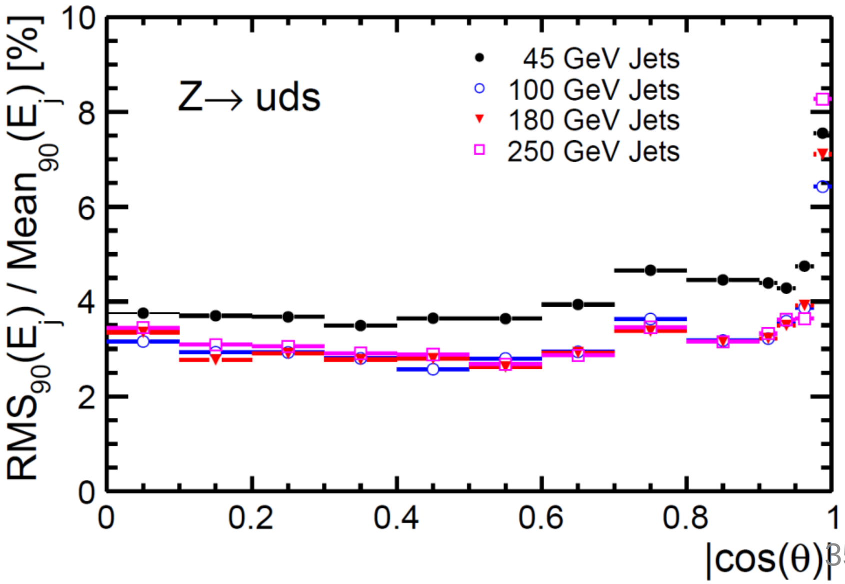


PFA performance

- Performance goal
  - Jet energy resolution < 3.5% for efficient separation of W, Z, and Higgs in hadronic mode
  - $\sigma_E/E = \alpha/\mathrm{sqrt}(E)$ is not applicable because particle density depends on Ejet
  - Jet energy resolution is slightly better than LOI due to improvement of reconstruction software

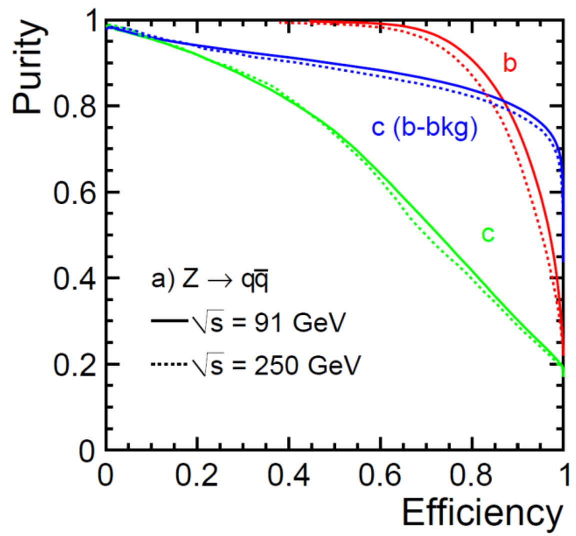
Jet energy	σ_E/E
45 GeV	3.66%
100 GeV	2.83%
180 GeV	2.86%
250 GeV	2.95%

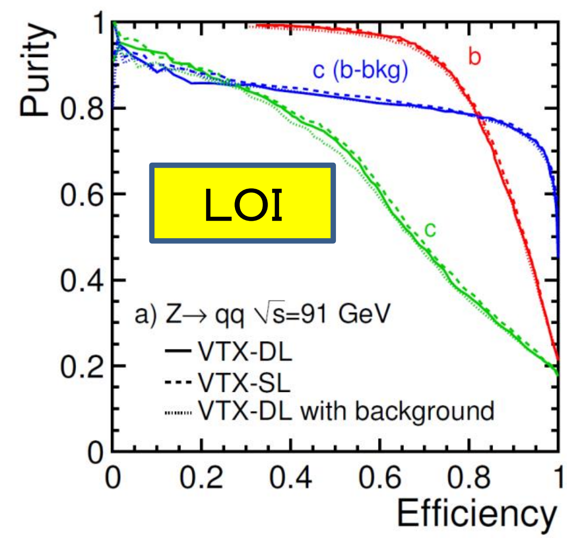
Z→u,d,s events
|cosθ|<0.7

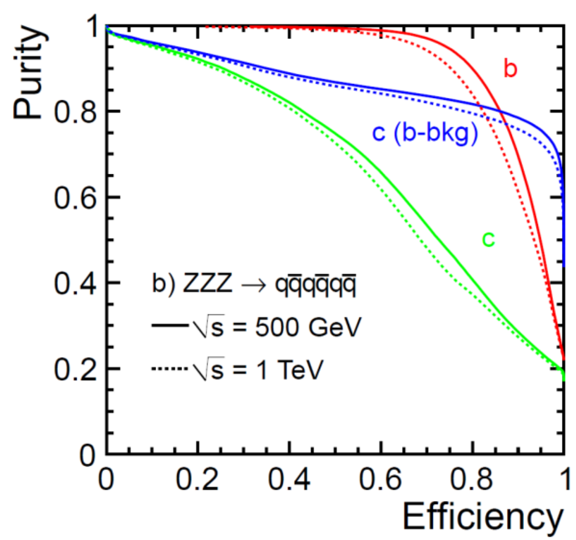


Flavor-tag performance

- New software LCFIPlus is used
- Improvement from LOI can be seen although VTX point resolution is worse in DBD







LOI benchmark

ECM (GeV)	Observable	Precision	Comments	Post LOI analysis
250	$\sigma(e^+e^- \rightarrow Zh)$	2.5%	Model independent	
	m_h	32 MeV	Model independent	
	m_h	27 MeV	Model dependent	
250	$Br(h \rightarrow bb)$	2.7%	Includes 2.5% of $\sigma(Zh)$	2.7%*
	$Br(h \rightarrow cc)$	12%		7.3%*
	$Br(h \rightarrow gg)$	29%		8.9%*
	$Br(h \rightarrow \tau\tau)$			4.9%
	$Br(h \rightarrow WW^*)$			8.6%
500	$\sigma(e^+e^- \rightarrow \chi_1^+\chi_1^-)$	0.6%		
	$\sigma(e^+e^- \rightarrow \chi_2^0\chi_2^0)$	2.1%		
	$m(\chi_1^+)$	2.4 GeV	From kinematical edges Two masses (LSP and χ_1^+/χ_2^0) are fitted simultaneously	
	$m(\chi_2^0)$	0.9 GeV		
	$m(\chi_1^0)$	0.8 GeV		

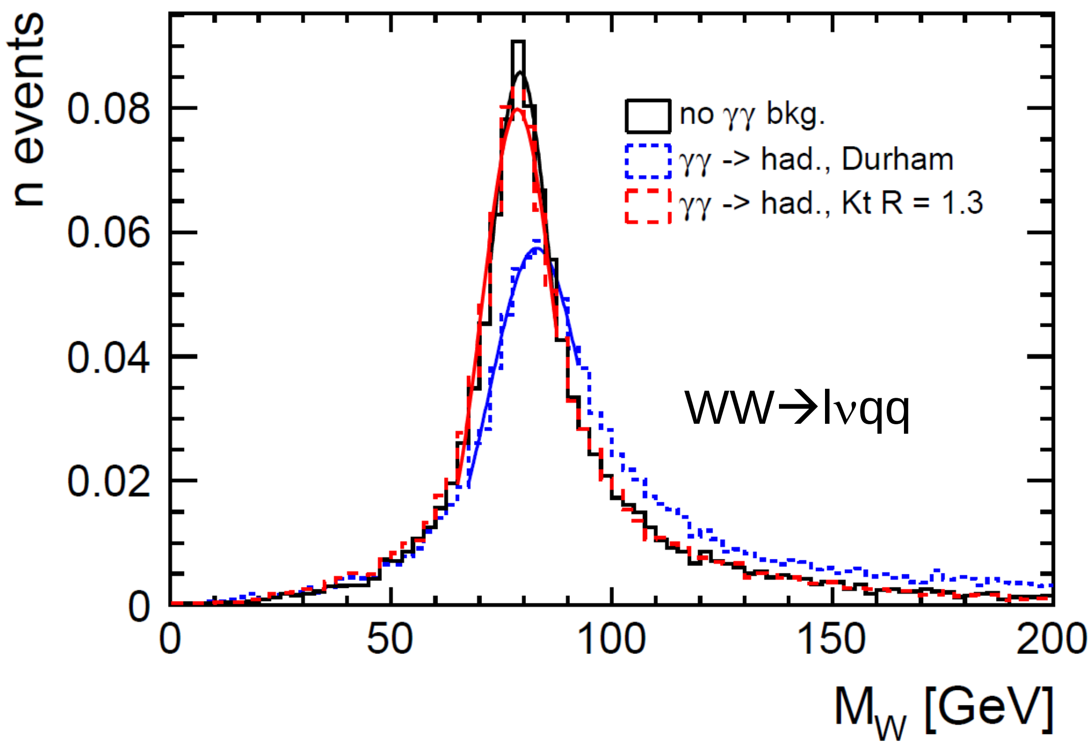
* http://arxiv.org/abs/arXiv:1207.0300
H.Ono, Akiya Miaymoto

LOI benchmark

ECM (GeV)	Observable	Precision	Comments
500	$\sigma(e^+e^- \rightarrow \tau\tau)$	0.29%	$\theta\tau\tau$>178degree
	A^{τ}_{FB}	0.0025	$\theta\tau\tau$>178degree
	$P\tau$	0.007	Excluding $a_1\nu$
500	$\sigma(e^+e^- \rightarrow tt)$	0.4%	(bqq)(bqq) only
	m_t	40 MeV	Fully hadronic only
	m_t	30 MeV	+ semi-hadronic
	Γ_t	27 MeV	Fully hadronic only
	Γ_t	22 MeV	+ semi-hadronic
	A_{FB}	0.0079	Fully hadronic only
500	$\sigma(e^+e^- \rightarrow \mu_L^+\mu_L^-)$	2.5%	SPS1a' (smuon)
	$m(\mu_L)$	0.5 GeV	
500	$m(\tau_1)$	$0.1\text{GeV} \oplus 1.3\sigma_{LSP}$	SPS1a' (stau)
1000	α_4	$-1.4 < \alpha_4 < 1.1$	Strong EWSB in WW scattering
	α_5	$-0.9 < \alpha_5 < 0.8$	

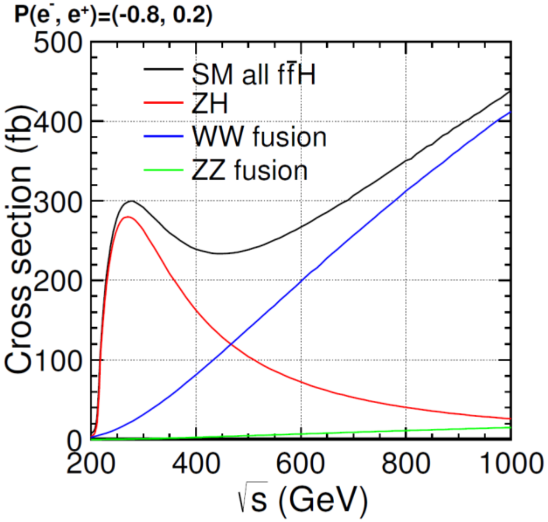
1TeV benchmark

- Jet clustering algorithm
  - k_t algorithm is used for jet clustering to reject low p_t and small θ particles from $\gamma\gamma$ background pile-up



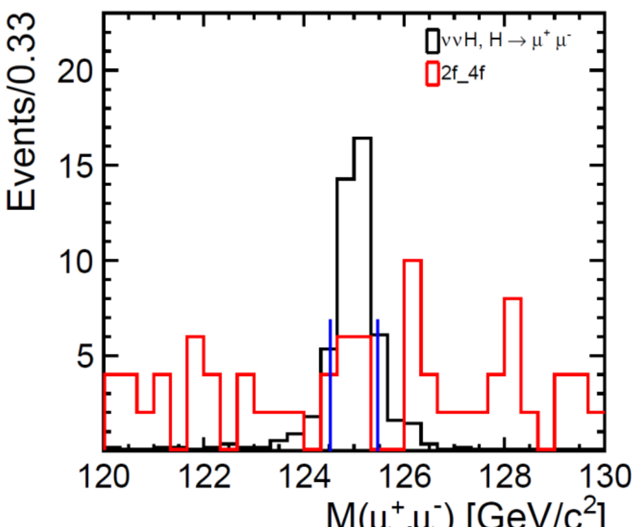
1TeV benchmark

- $e^+e^- \rightarrow \nu\nu h$
  - Higgs production cross section is larger than 250 GeV
  - Luminosity is larger than 250 GeV
  - Higgs → $\mu\mu$ channel can be measured



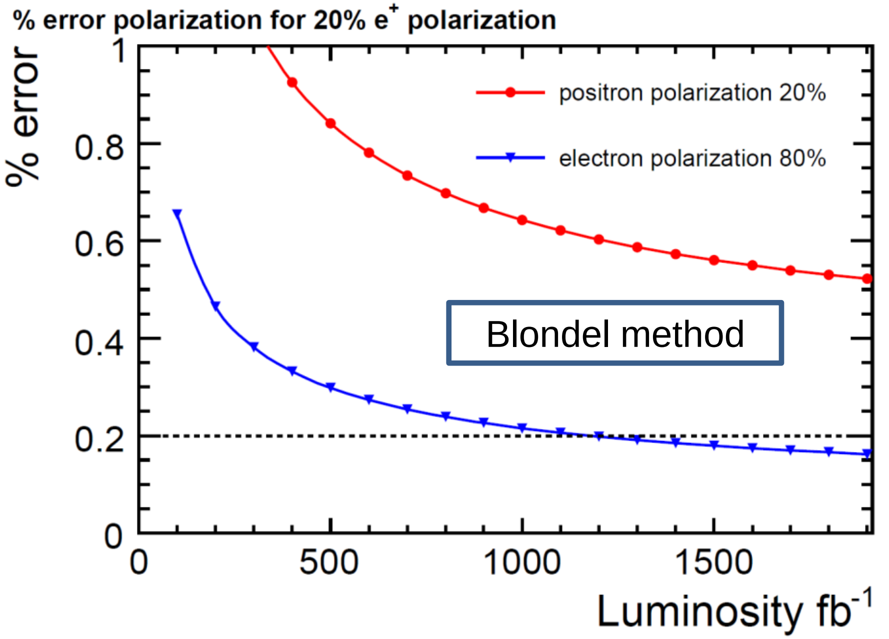
Decay mode	σBr accuracy ($500fb^{-1}$, -0.8,+0.2)	Comments
bb	0.4%	
cc	5%	
gg	4%	
WW*	3%	Fully hadronic mode only
μμ	??	

Preliminary



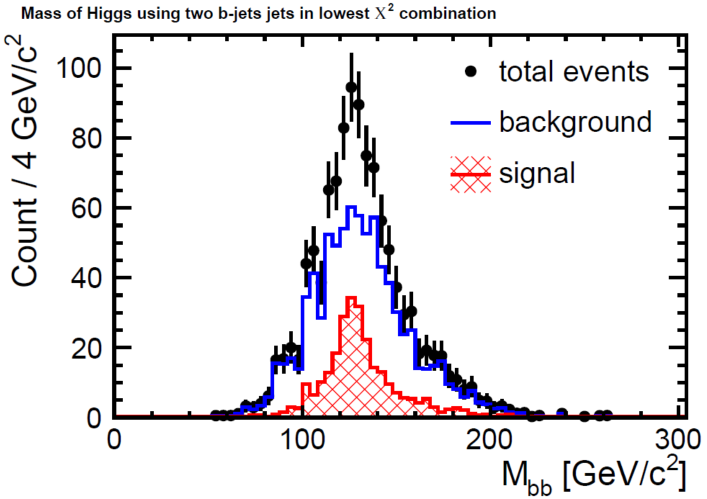
1TeV benchmark

- $e^+ e^- \rightarrow W^+ W^-$
  - Precise measurement of beam polarization
  - Two methods
    - Modified Blondel scheme: (+,+),(+,-),(-,+),(-.-) data required
    - Angular distribution of W → Analysis not finished yet



1TeV benchmark

- $e^+ e^- \rightarrow t\ t\ h$
  - Fully hadronic mode (8 jets, no isolated lepton) and semi-leptonic mode (6 jets + 1 isolated lepton) were used
  - Main background: ttbb, ttZ, and tt
  - Multivariable analysis technique is effective to reduce the background
  - Preliminary result on accuracy of top Yukawa coupling with 500fb^{-1} (+0.8,-0.2) and 500fb^{-1} (-0.8,+0.2)
    - 7.0% for semi-leptonic mode
    - 6.5% for hadronic mode
    - **4.8% for combined data**

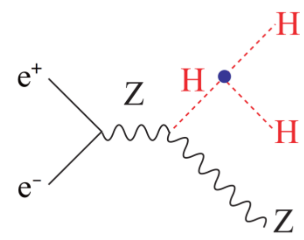


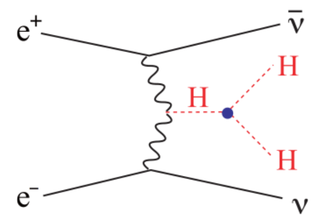
LOI-DBD common benchmark

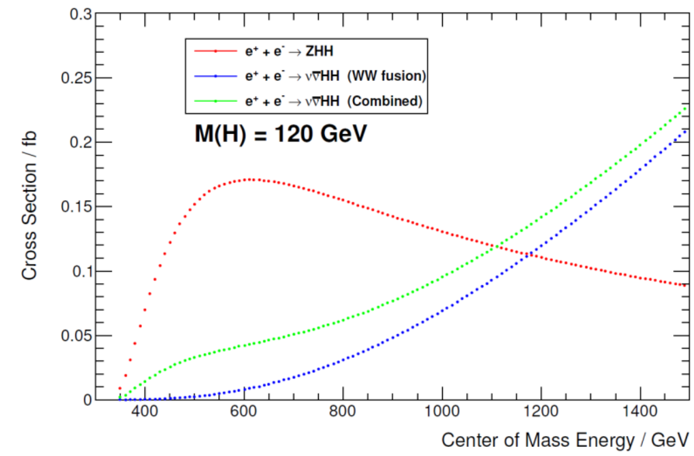
- We used $e^+e^- \rightarrow t\,t$ channel for the comparison between LOI and DBD analysis @500 GeV
- Forward-backward asymmetry is determined by hadronic decay mode
- Vertex charge determination is needed → good benchmark for vertex detector/finding
- Results with $500 fb^{-1}$, $P(e^-, e^+)=(-0.8, +0.3)$:
  - A^t_{FB} = Coming soon (DBD)
  - $A^t_{FB} = 0.334 \pm 0.0079$ (LOI)

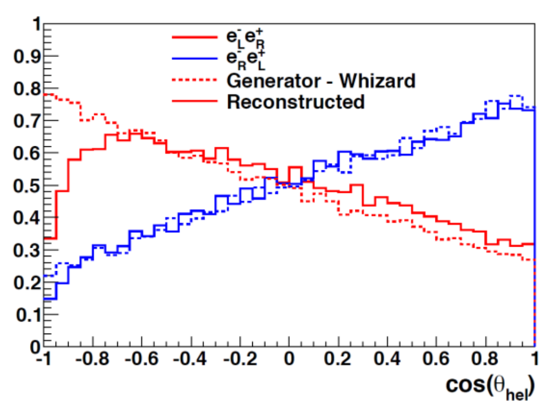
Other physics processes

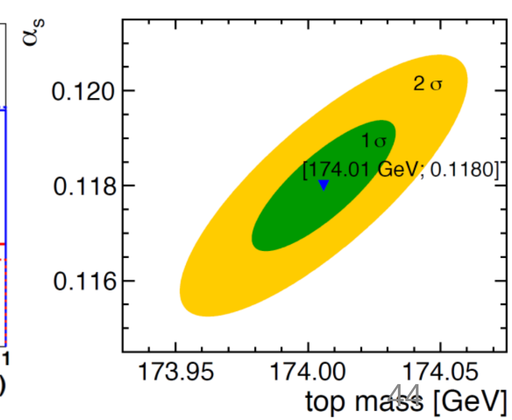
- Higgs self coupling
  - Zhh final state at 500 GeV
    - 27% accuracy in Zhh cross section = 44% accuracy in λ with $2ab^{-1}$
  - $\nu\nu$hh final state at 1TeV
    - 17% accuracy in λ with $2ab^{-1}$ (Fast simulation)
    - Full simulation study on going
- Further t t study
  - A^{t}_{FB} by semi-leptonic decay mode
    - 1% measurement can be done
  - A^{t}_{hel} (helicity asymmetry) measurement
  - t t at threshold: measurement of m_t and α_s





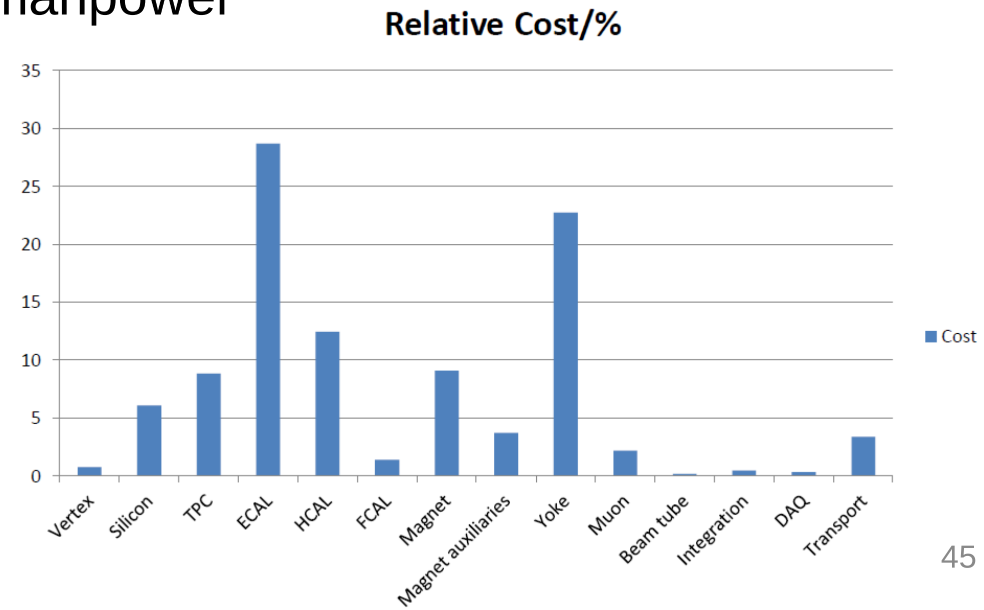






Cost

- Progress since LOI
  - Development of technological prototypes close to final design → Information on costs
  - Integration of whole detector has been studied
  - New agreement on methodology and unit costs of cost drivers
- ILD current cost evaluation
  - Study is on-going
  - ~500 MILCU including manpower



Summary

- Detailed baseline design of ILD based on validated detector technologies has been presented
- Compared with LOI, more realistic design including support structure, cables, other services, and dead material has been made
- Although the material budget has been increased, better detector performance than LOI has been obtained thanks to the improvement of software tools and analysis methods
- New benchmark processes at 1 TeV have been studied with 2-photon process background overlaid (We still need few weeks to finalize the results, though)
- We still need detector R&D, particularly in the engineering aspect, after completion of DBD