ILD in DBD

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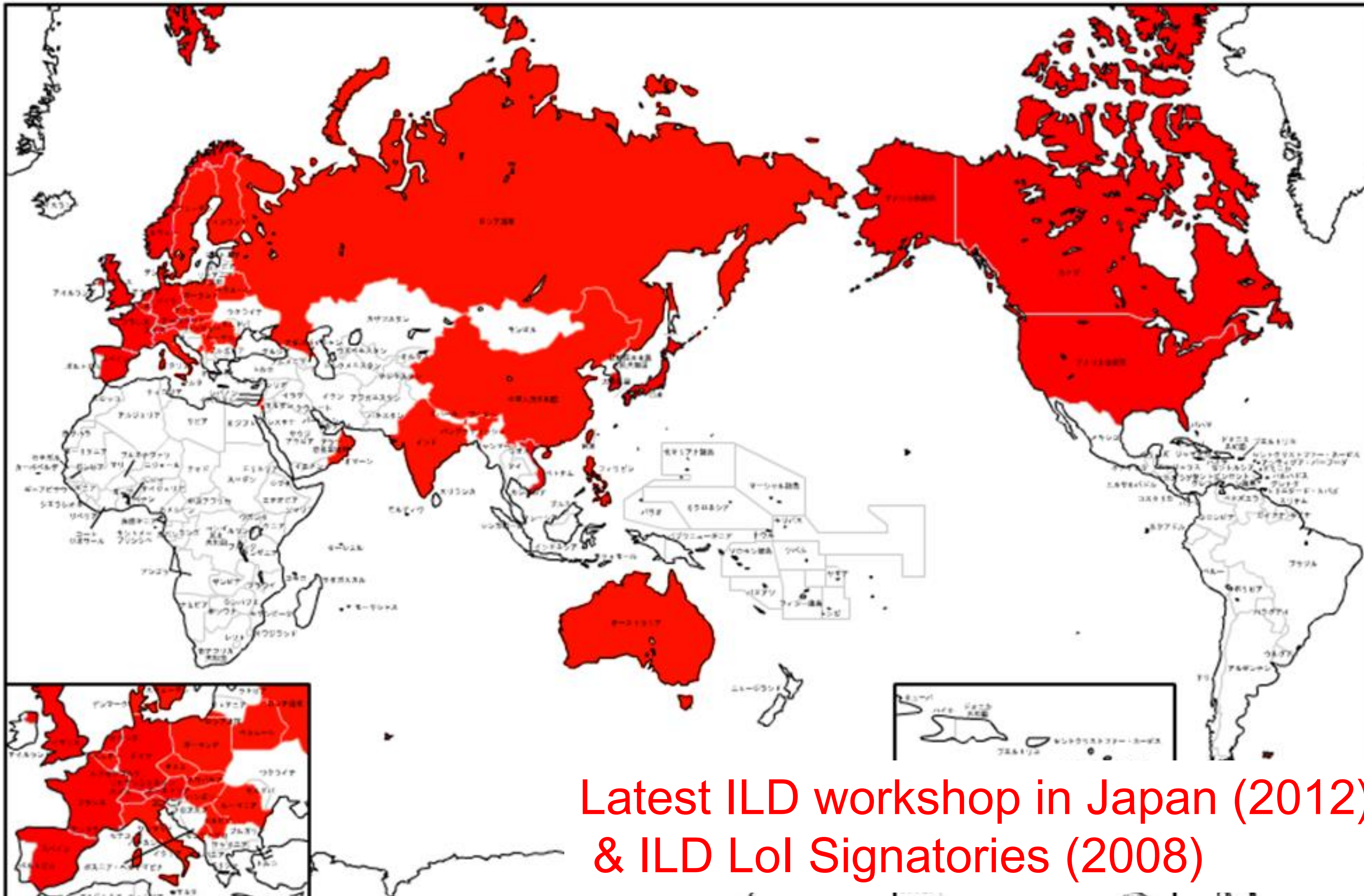
ILD: A detector for particle flow

ILD worldwide



Latest ILD workshop in Japan (2012)
& ILD LoI Signatories (2008)

ILD Timelines/Workshops

- 2007 Unification of GLD & LDC
  - 2008.1 ILDWS DESY
  - 2008.9 ILDWS Cambridge
  - 2009.2 ILDWS Seoul
- 2009.3 Letter of Intent
  - 2010.1 ILDWS Paris
  - 2011.5 ILDWS Orsay
  - 2012.4 ILDWS Kyushu
- 2012.12 DBD Report

Intensive physics studies for LoI

Intensive physics studies for DBD

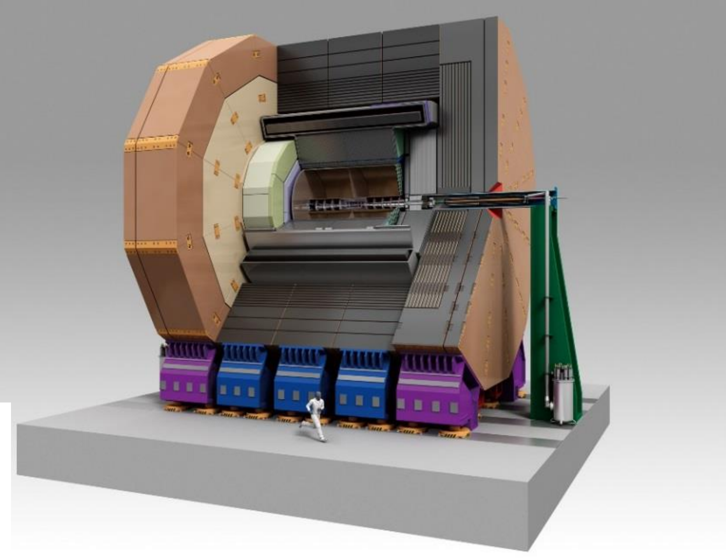
Detector R&D

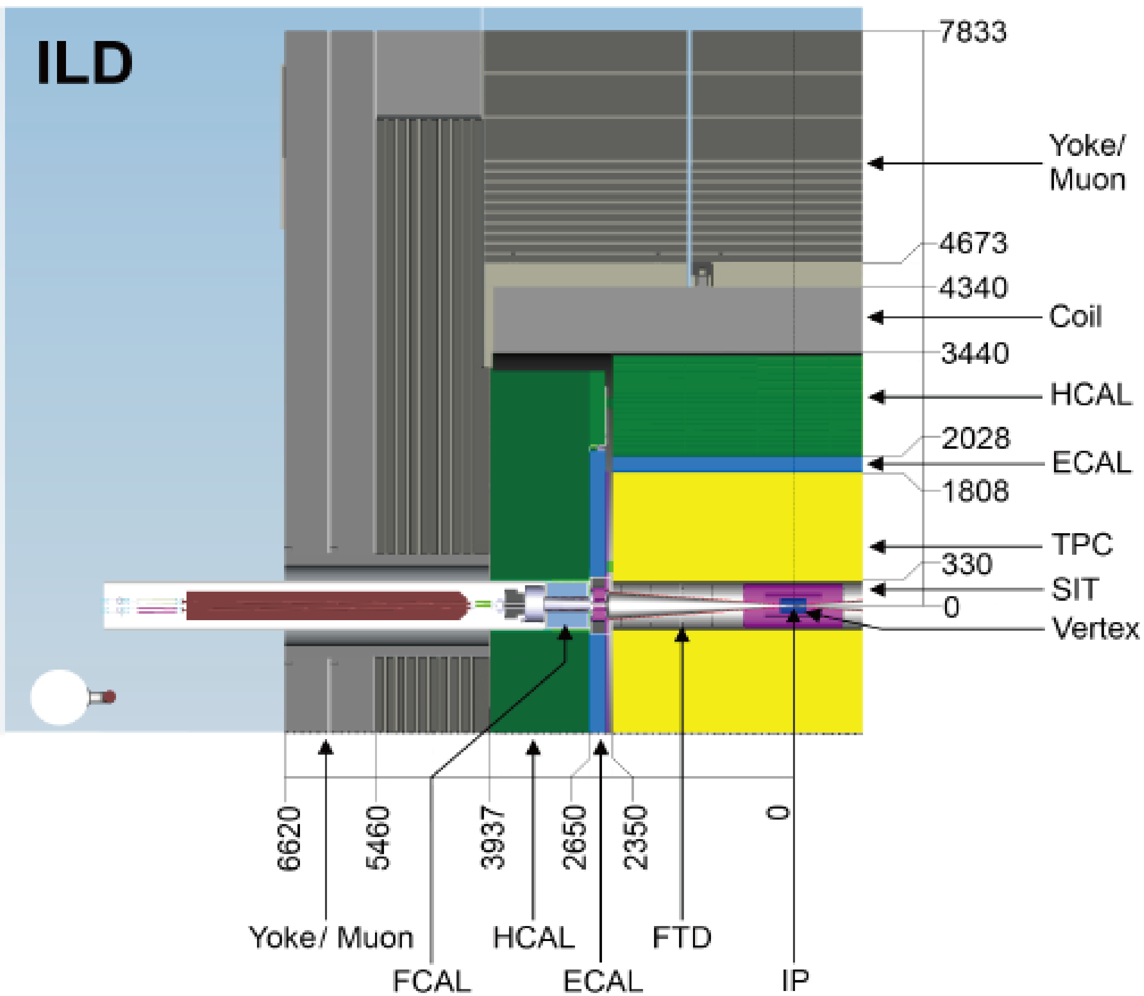
WORKSHOP

Kyushu University, Fukuoka, Japan

DBD ILD detector

Concept is not so changed from LoI,
but much more reality included
Optimized for not only 500 GeV but also 1 TeV

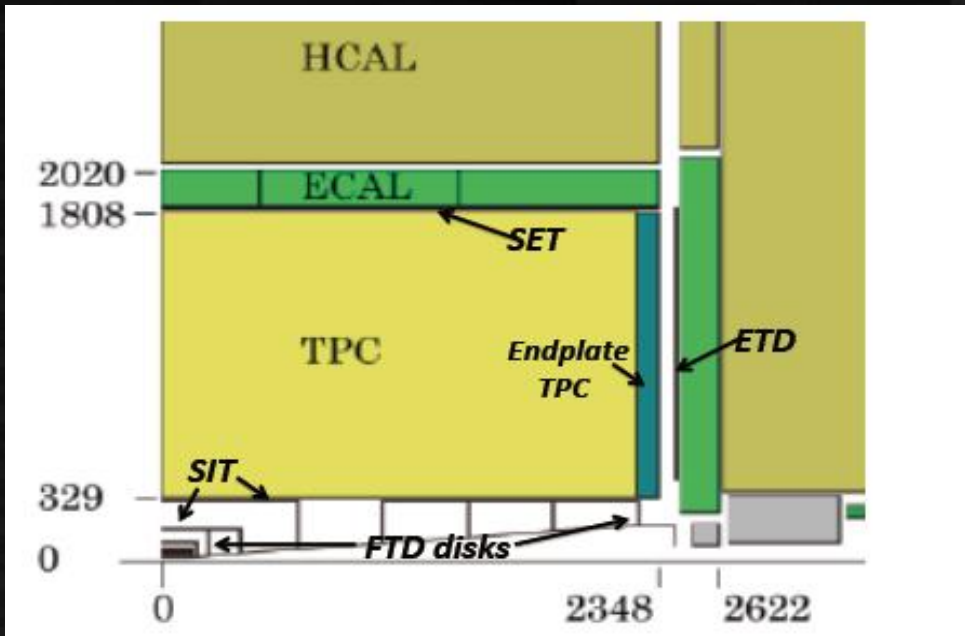


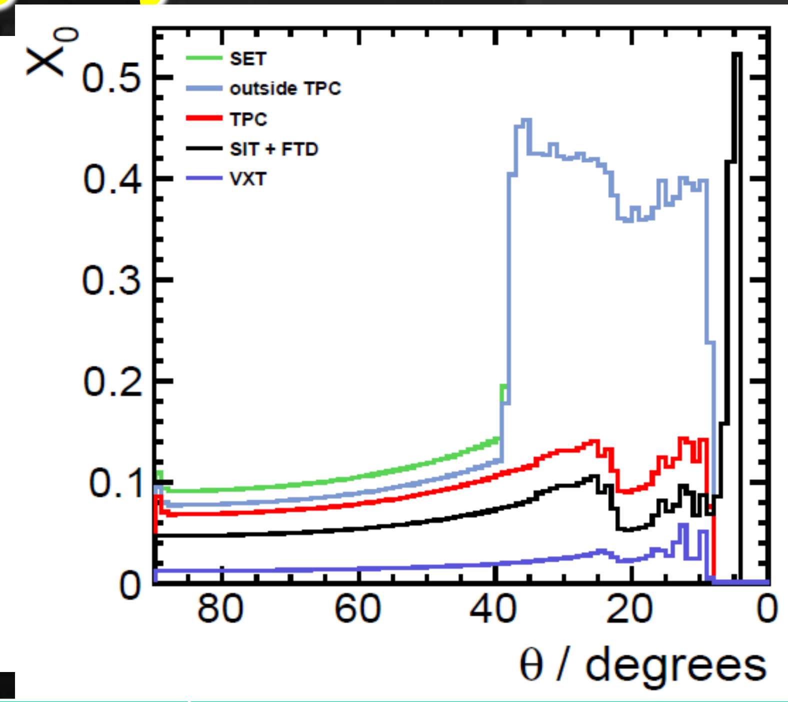


ILD is larger than SiD
Components:

- Vertex
- Silicon tracking (SIT/SET/ETD/FTD)
- Gas TPC
- ECAL/HCAL/FCAL
- SC Coil (3.5 Tesla)
- Muon in Iron Yoke

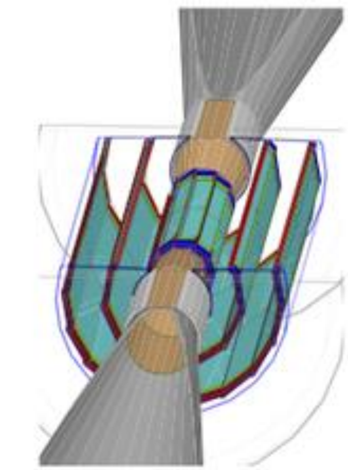
ILD Tracking System





Technology	Silicon Pixel	Silicon Strip	Time Projection Chamber
Detector	VTX / FTD (inner)	SIT/SET/ETD/ FTD (outer)	TPC
Point resolution	***	**	*
Time resolution	*	***	*
Occupancy	***	*	*
NDF of fits	*	*	***

1. Vertex Detector



Target: 5 μm IP resolution for high-p tracks within high background environment

3 x 2 layers: r = 16 & 18, 35 & 37, 58 & 60 mm
(option: equally spaced 5 layers at 15-60 mm)
Length: 125 mm (first 2 layers) & 250 mm (others)
cosθ up to 0.9-0.97 is covered

Technology	CMOS	FPCCD	DEPFET
Pixel size	17 / 34 μm	5 / 10 μm	20 μm
Readout time	50 / 100 μs	Slow (intra-train)	50 / 100 μs
Resolution	2.8 / 4 μm	1.4 / 2.9 μm	Similar to CMOS
Occupancy	OK	OK	OK
Temperature, heat	30 C, 10 W	-40 C, 35 W	30 C, 10 W
Cooling	Air or N_2	CO_2 (two phase)	Air or N_2
Radiation	Tested	Will be checked	Tested
Technology	Matured	Developing	Used in Belle2

2. Silicon Tracking

Detectors

- SIT – 2 double layers of strips between VTX & TPC
- SET, ETD – 1 layer strip after TPC (barrel, endcap)
- FTD – 7 discs
  - Inner 2 discs: pixel (similar to the vertex detector)
  - Outer 5 discs: strip (similar to SIT/SET/ETD)

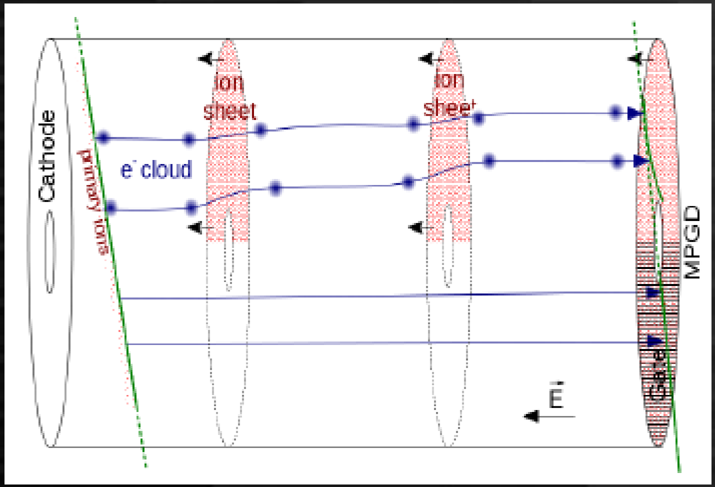
Functions / merits

- Time stamping (80 ns standalone, 2 ns with TPC)
- Precise points (7 μm) to connect VTX/TPC/ECAL
- Calibration of TPC

Close collaboration with SiLC / SiD / LHC groups

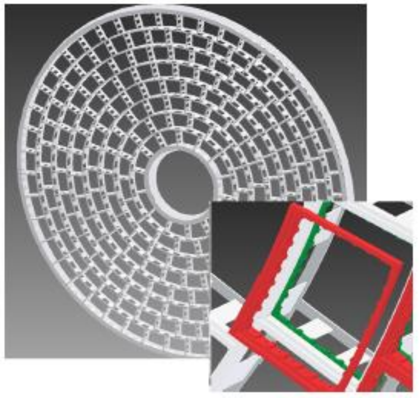
3. Time Projection Chamber

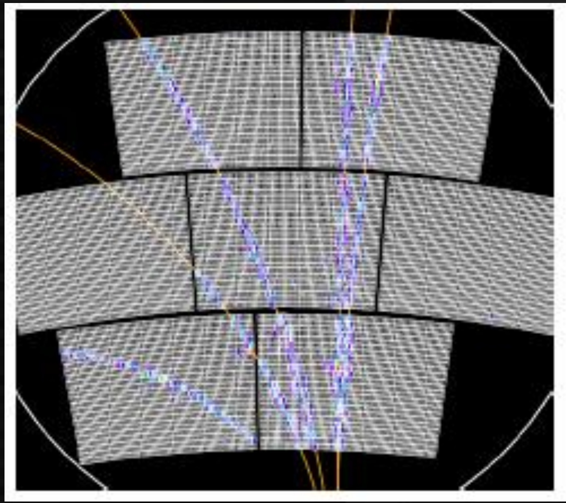
Target: $\delta(1/p_T) \sim 10^{-4}$ /GeV/c (TPC only)



TPC characteristics:
- Continuous tracks
  strong for off-axis tracks
- PID by dE/dx possible
- Low material in barrel region

TPC options/issues
- Field distortion by ions
  - Primary ion effect is not critical
  - ion-gate to avoid secondary ion
- Gas amplification
  - Micromegas
  - GEM
- Readout
  - Pad (1 x 6 mm^2)
  - Pixel



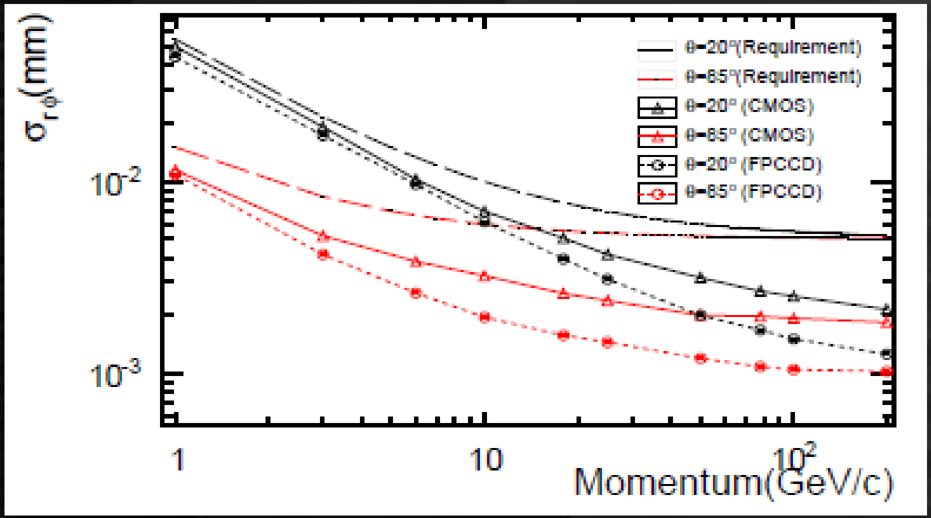


track at test beam

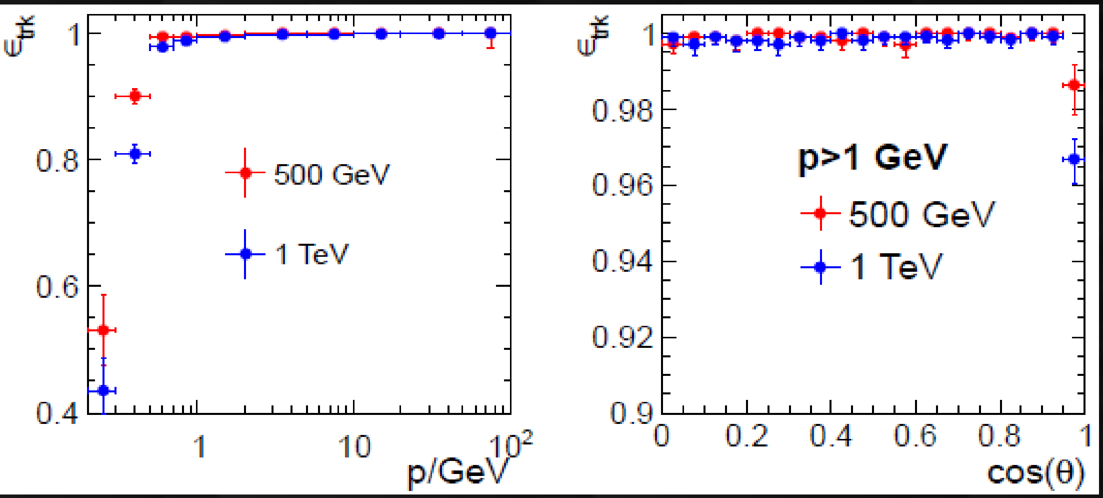
Tracking Software / Performance

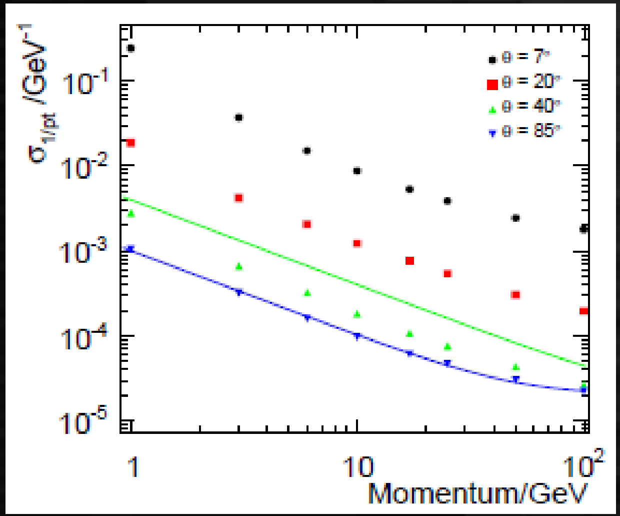
Current design of the tracking

- Silicon tracking (pattern rec. + Kalman) using VTX + SIT + FTD -> SiTracks
- Clupatra for TPC tracking
- Refitting SiTracks and TPC tracks



impact parameter resolution

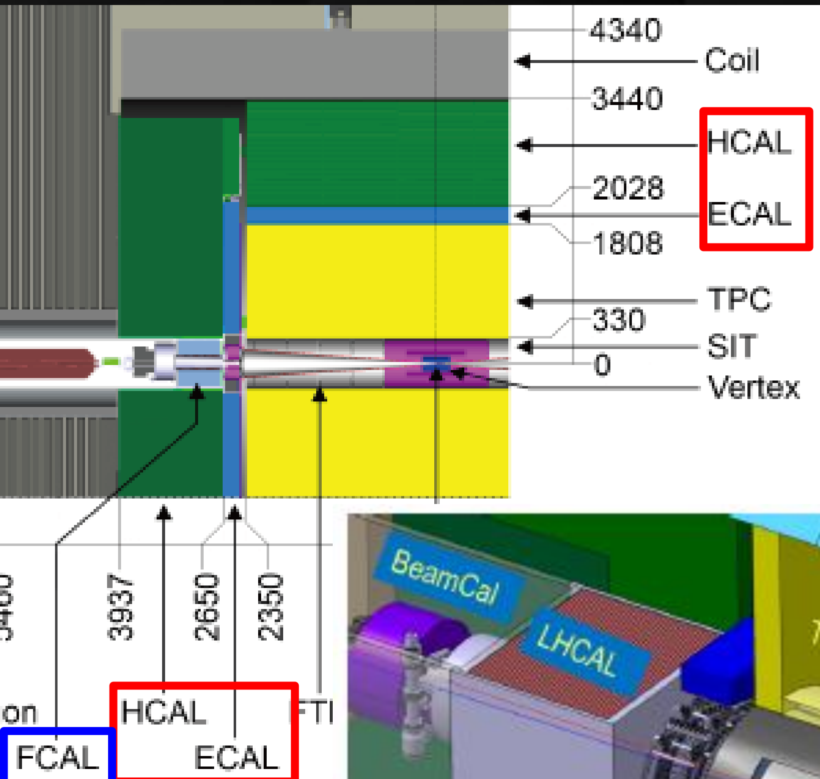


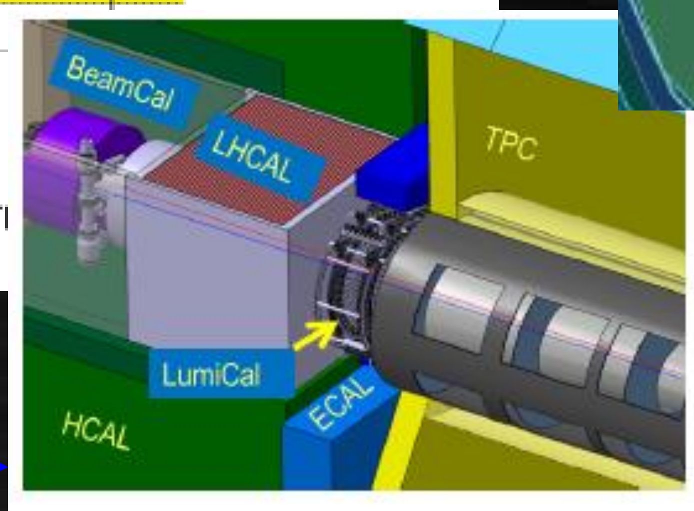


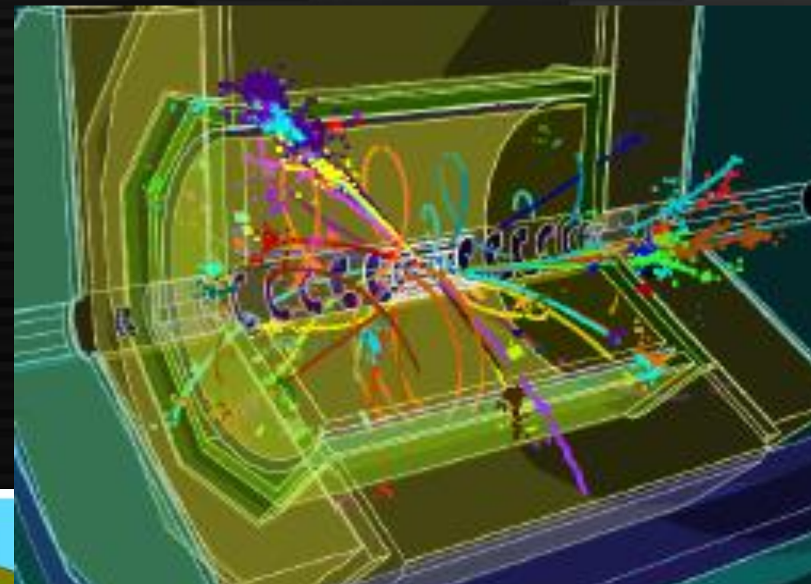
tracking efficiency on ttbar events with pair-bg overlayed

track momentum resolution

ILD Calorimeter System







Highly granular calorimetry is essential to Particle Flow.
Good coverage in forward region is also important.

ECAL, HCAL, FCAL(LumiCal, LHCAL, BeamCal)

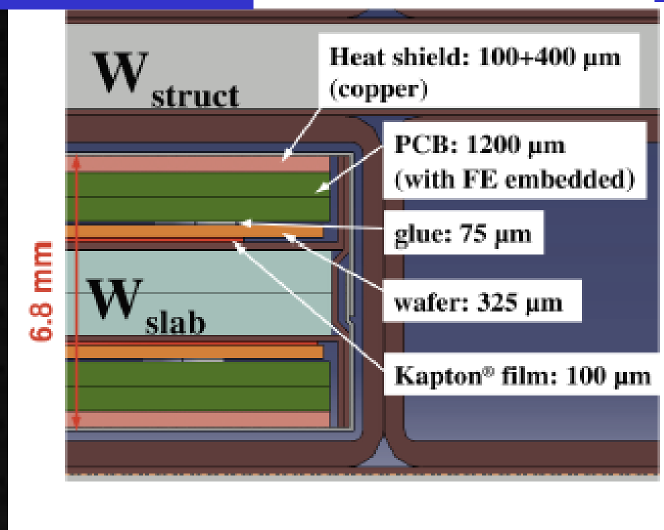
1. Electromagnetic Calorimeter

Granularity of ECAL
is critical for PFA
-> 5 mm “pixel” for ILD

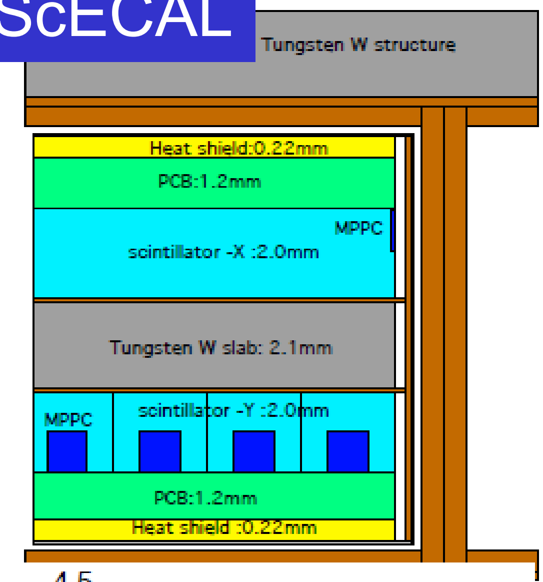
Two options
- Silicon tiles
- Scintillator strips

Beam test at larger tiles gives $\sigma \sim 15\,\% / \sqrt{E}$ with good linearity in both

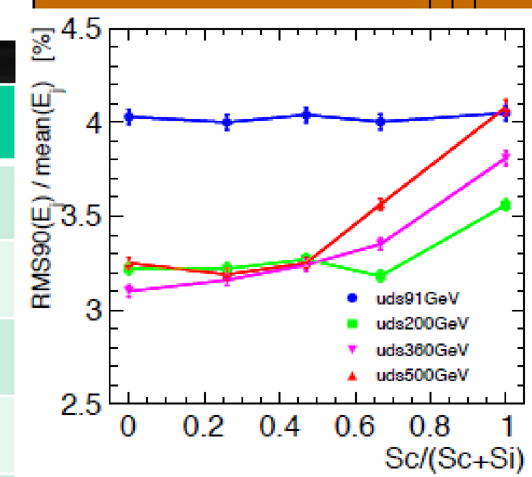
SiECAL



ScECAL



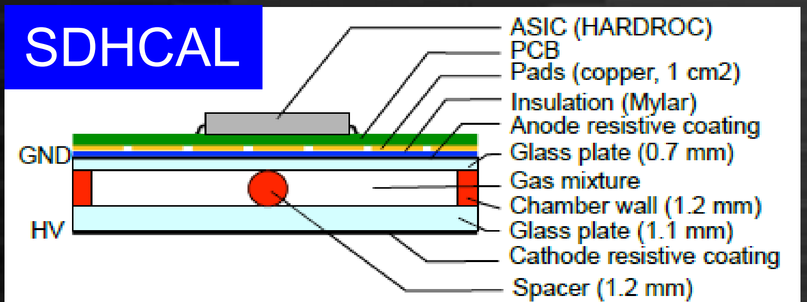
	SiECAL	ScECAL
Absorber	Tungsten	
Sensor	Si tile	Plastic sci. strip
Granularity	5 x 5 mm^2	5 x 45 mm^2
Perf. at Z pole qq	~4%	~4%
Perf. at high E qq	better	moderate (optimization needed)



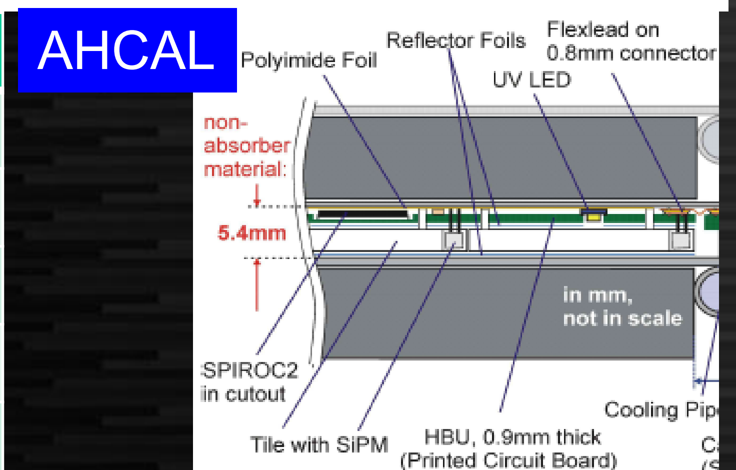
Hybrid option is being investigated

2. Hadron Calorimeter

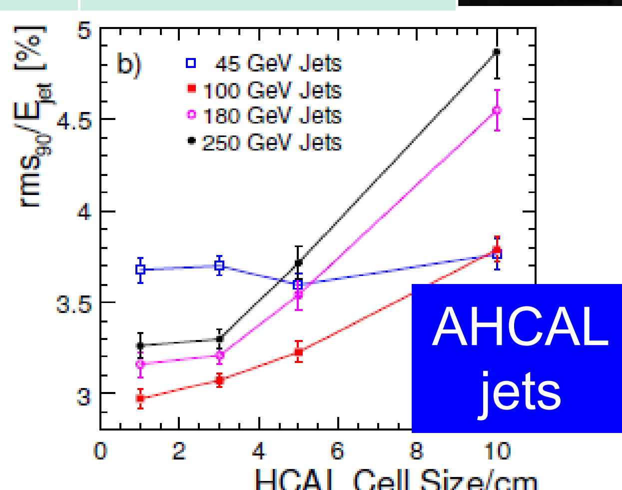
Particle separation at HCAL is also very important in PFA resolution
Two options:
Analog HCAL vs. Semi-Digital HCAL

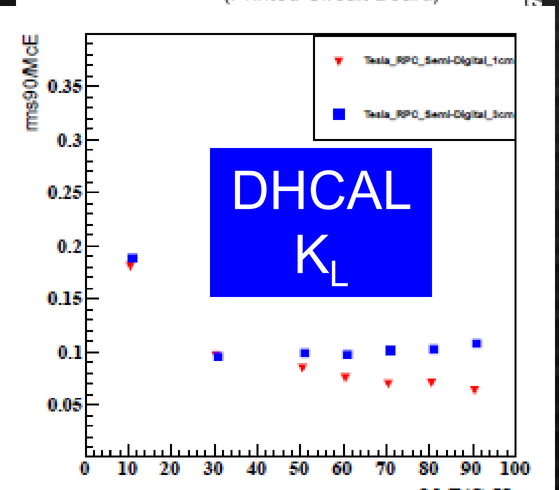


	AHCAL	SDHCAL
Absorber	Iron, 2 cm thick x 48 layers, 6 λ_0	
Sensor	Sci + SiPM	Glass RPC
Granularity	3 x 3 cm^2	1 x 1 cm^2
Readout	analog	2-bit
Cost	Moderate	Moderate



Cell sizes optimized for AHCAL as 3x3 by jets, and 1x1 by kaon for SDHCAL
Similar result shown in ttbar analysis at 500 GeV





Particle Flow Performance

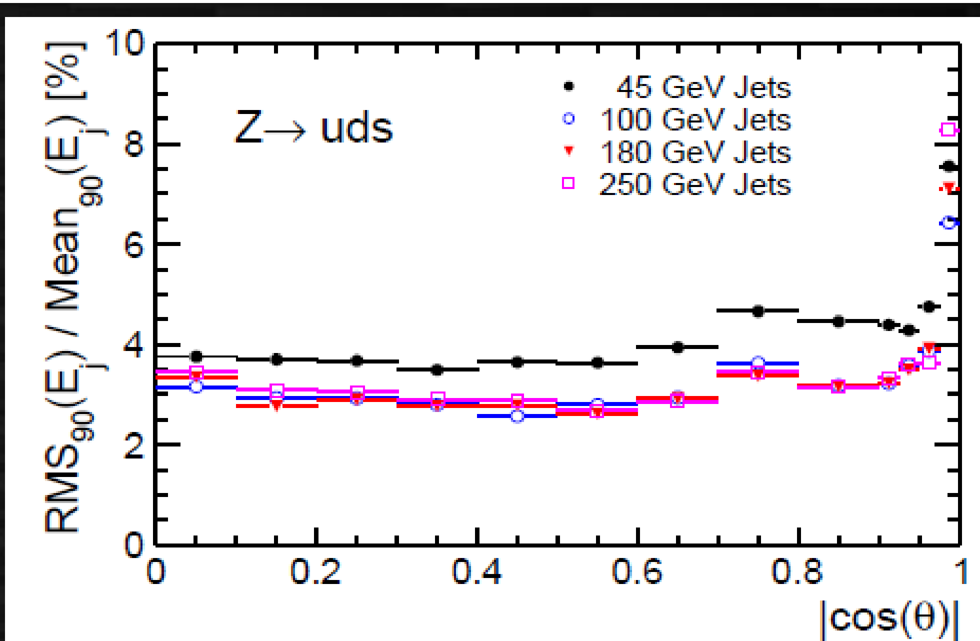
Particle flow (PandoraPFA) is updated from LoI, gives better performance esp. at higher energies

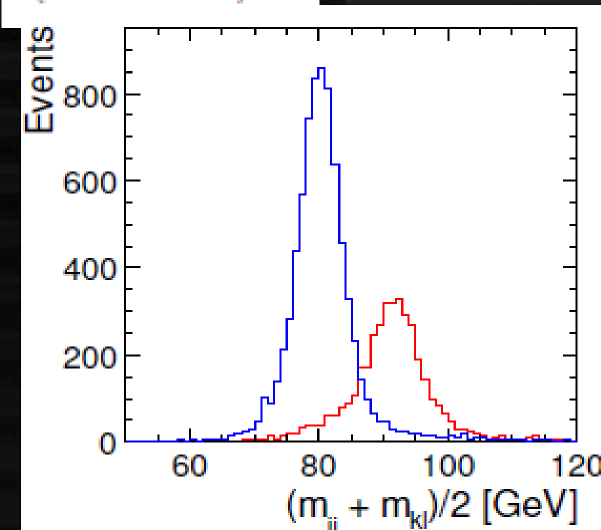
DBD, |cosθ| < 0.7

Jet Energy	rms_{90}	$rms_{90}/\sqrt{E_{jj}/\text{GeV}}$	σ_{E_j}/E_j
45 GeV	2.4 GeV	24.7 %	(3.66 ± 0.05) %
100 GeV	4.0 GeV	28.3 %	(2.83 ± 0.04) %
180 GeV	7.3 GeV	38.5 %	(2.86 ± 0.04) %
250 GeV	10.4 GeV	46.6 %	(2.95 ± 0.04) %

cf. LoI

σ_{E_j}/E_j
(3.71 ± 0.05) %
(2.95 ± 0.04) %
(2.99 ± 0.04) %
(3.17 ± 0.05) %

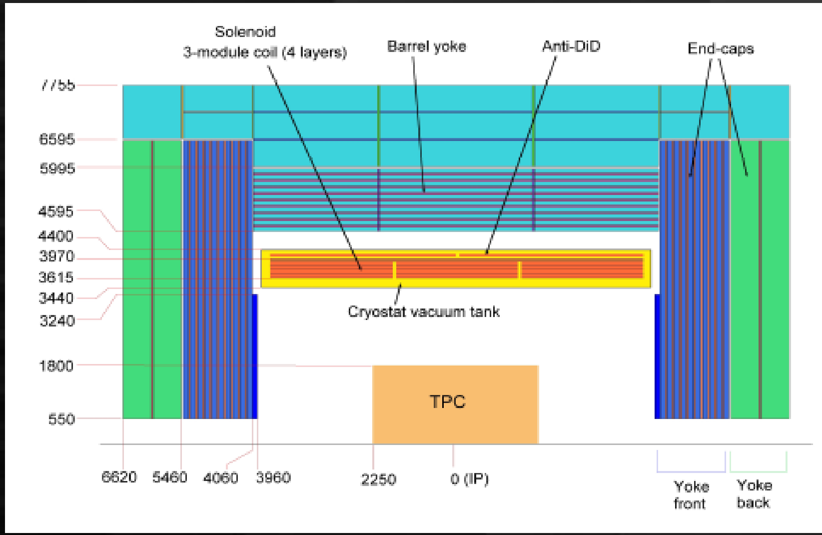




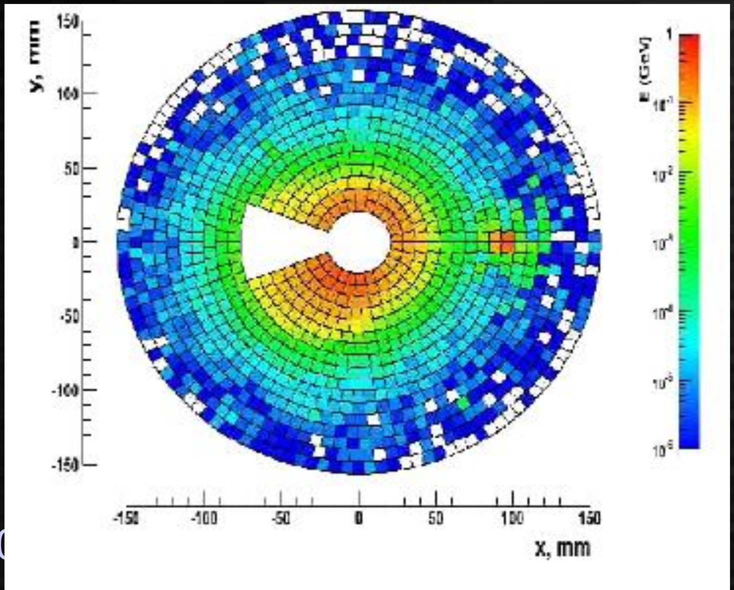
ννWW & ννZZ separation at 1 TeV, LoI detector

Other Components

- Coil/Yoke/Muon
  - Coil: 4 Tesla design (ILD nominal: 3.5 T) with integrated Anti-DID
  - Yoke: Fe + Muon sandwich
  - Muon: Sci (7-10 x 27-30 mm) or RPC (1 x 1 cm^2, 1-bit) worked also as tail catcher of HCAL

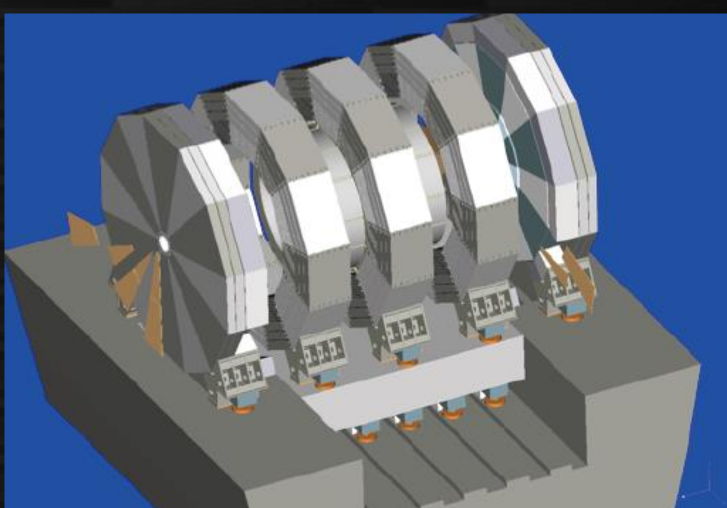


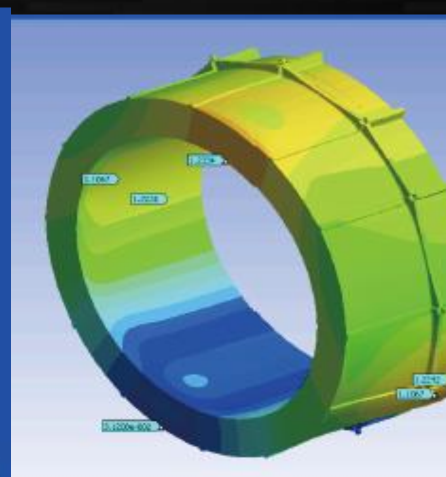
- FCAL (LumiCal/BeamCal) for e^+e^- pair and two-γ tag
  - LumiCal: Silicon pads with 10-bit readout
  - BeamCal: GaAs or CVD diamond

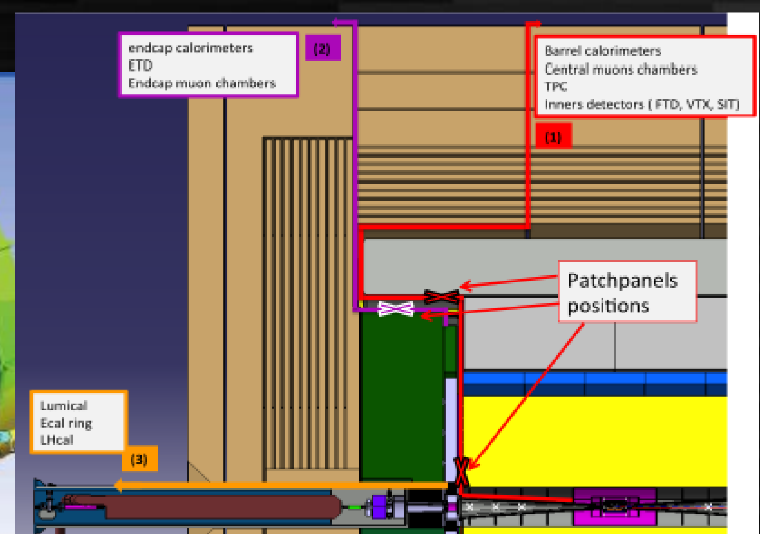


ILD Engineering Study

- “First engineering model” appeared after studies on
  - Mechanical Structure, Support Structure
  - Cabling, Cooling, Power pulsing
  - Detector Integration, Installation
  - Detector Alignment, Calibration, push-pull study
  - DAQ etc.
- Simulation model also gets much more reality







Software in DBD

DBD Condition

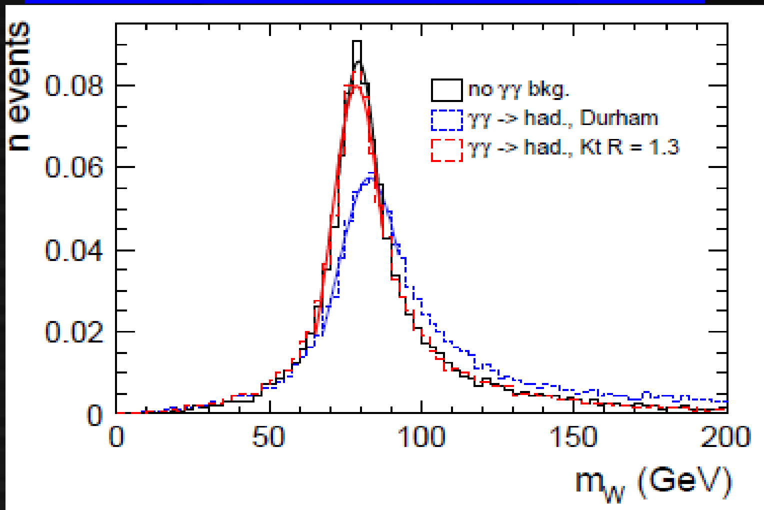
- Detector gets much reality (ladders, dead regions, etc.)
- Background included – $\gamma\gamma$->hadrons, pairs
- Requirement of more performance

Software Updates

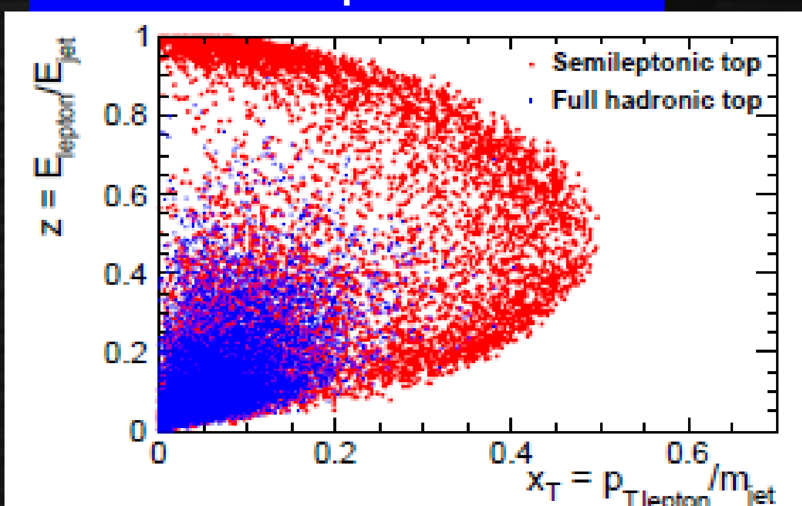
- Tracking rewritten from fortran to C++ for dense tracks
- PandoraPFA rewritten as modular framework
- kT jet clustering for $\gamma\gamma$->hadron removal
- Isolated lepton finder with lepton p_T/E after jet clustering
- Vertex clustering for better flavor tagging
- LCFIPlus (vertex finder rewritten with intensive tuning, TMVA BDT used, more input variables)

Some plots with new software

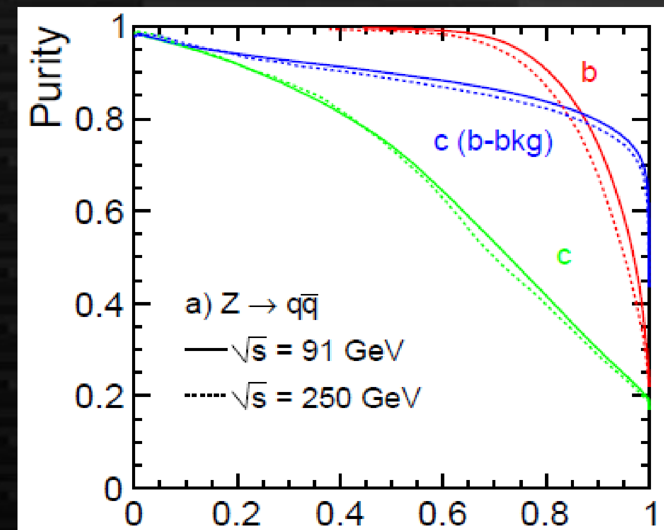
γγ->hadron with kT jet

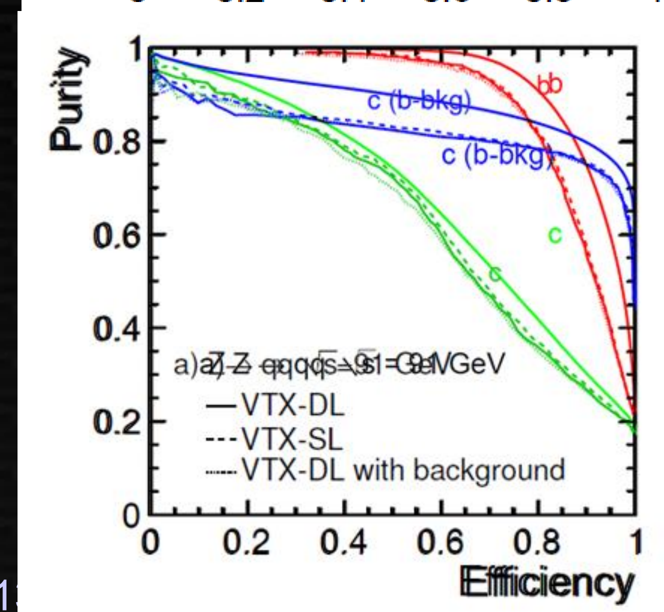


isolated lepton finder



Flavor tagging performance





DBD Physics Analyses

DBD detectors, γγ->hadron overlaid (except hhh analysis)

E/L	Process	Measure	Stat. error	Comments
$\sqrt{s}$ = 1 TeV L = 0.5 ab^{-1} for each P = (-80,+20) / (+80,-20)	νvh->ννbb	ΔσBR /σBR for each P	0.54 / 2.1 %	
	ννh->ννcc		5.7 / 36.8 %	
	ννh->ννgg		3.9 / 25.7 %	
	ννh->ννWW*(4j)		3.6 / 23.7 %	
	ννh->ννμμ		41% / -	
	ee->WW	ΔP/P for e-/e+	0.19 / 1.13 %	
	tth	$\Delta g_{tth}/g_{tth}$	4.3 %	6 + 8 jets
500 GeV P = (-80,+30) / (+80,-30)	tt->bbqqqq	A_{FB}	3.0 / 3.2 %	0.25 ab^{-1} at each pol, Consistent to LoI
	tt->bblνqq	A_{FB} λ_t	1.7 / 1.3 % 3.3 / 3.7 %	0.25 ab^{-1} at each pol
	Zhh + ννhh	Δλ/λ	44 %	$e^-_L e^+_R$ only, 2ab^{-1}
1 TeV	ννhh	Δλ/λ	18 %	

1 TeV Analysis: $\nu\nu h \to \nu\nu qq$

H.Ono

Higgs decay channels	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
Higgs BRs	57.8%	2.7%	8.6%	21.6%	0.02%	6.4%	2.7%	0.23%	0.16%

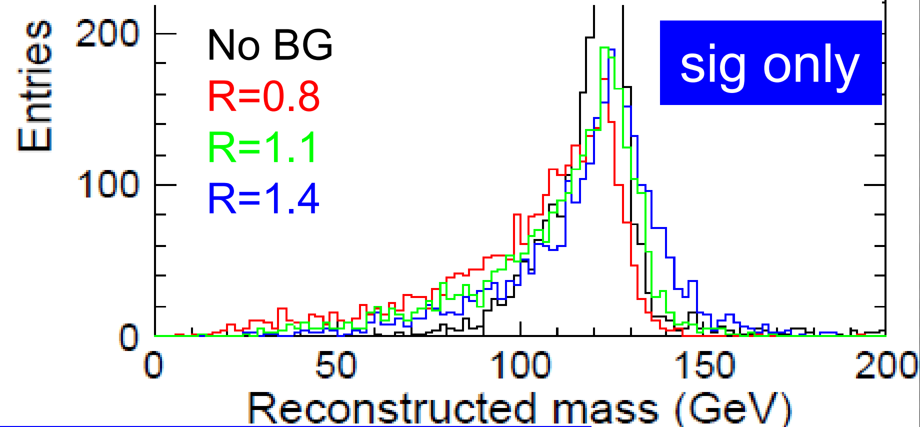
Conditions:

- DBD, m_H = 125 GeV
- $\gamma\gamma$->hadron overlayed
- k_T jet clustering 2j forced 2-jet, R = 1.1
- LCFIPlus re-JC & flavor tag

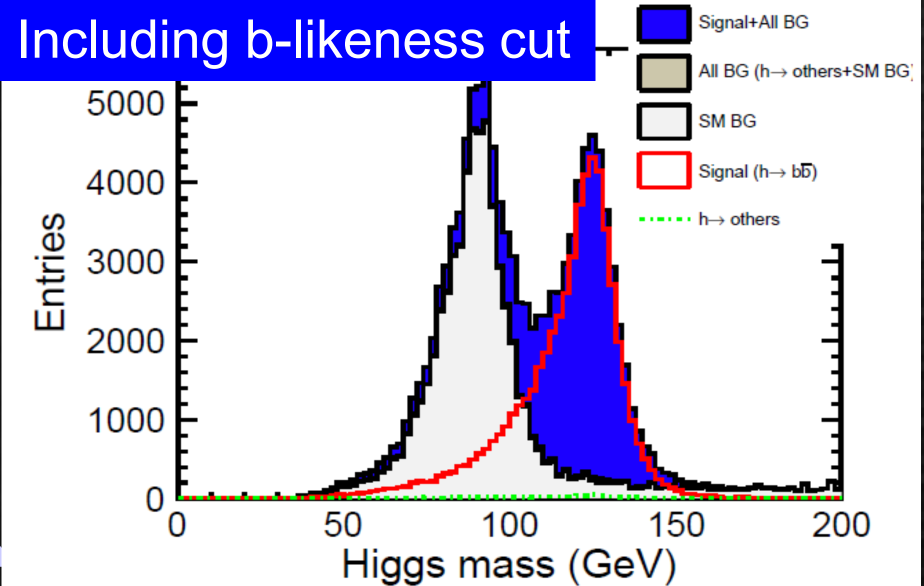
Cuts on:

- E_{BCAL} < 50 GeV
- Thrust < 0.95
- 100 < E_{vis} < 400 GeV
- P_T > 50 GeV
- $N_{chargedPFO}$ > 15
- $|\cos\theta_h|$ < 0.95
- 110 < M_{jj} < 150 GeV

Eff. ~ 35%
Pur. ~ 33%



Including b-likeness cut

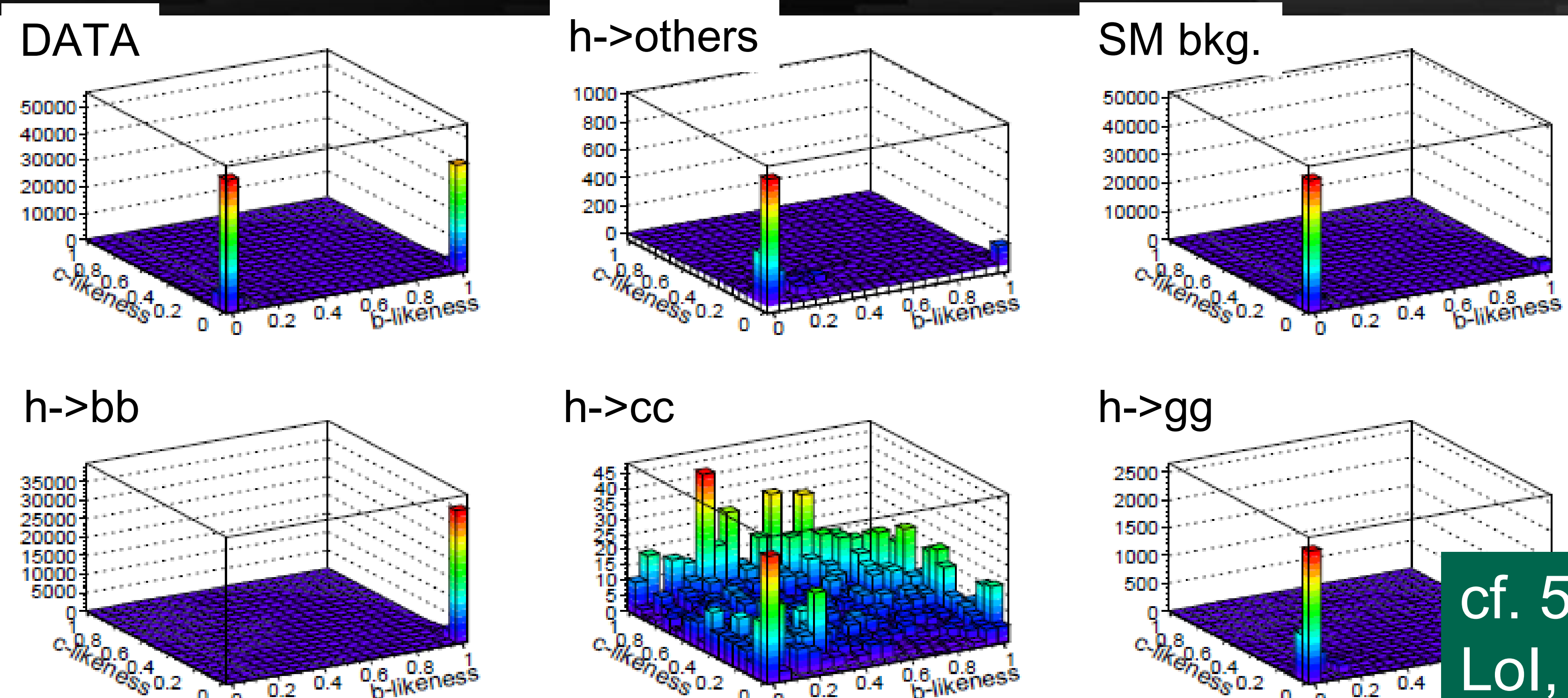


Taikan Suehara

1 TeV Analysis: νvh -> νvqq

H.Ono

Template fit with b-, c-, bc- likeness; Toy-MC with 5000 data sets



cf. 500 GeV LoI, m_H=120

1 TeV DBD
m_H = 125

inosity	500 fb^{-1}	500 fb^{-1}	1 ab^{-1}	500 fb^{-1}
$P(e^-, e^+)$	$P(-0.8, +0.2)$	$P(+0.8, -0.2)$	$P(-0.8, +0.2)$	$P(-0.8, +0.3)$
$\Delta\sigma BR/\sigma BR(h \to b\bar{b})$	0.54%	2.1%	0.39%	0.6%
$\Delta\sigma BR/\sigma BR(h \to c\bar{c})$	5.7%	36.8%	3.9%	5.2%
$\Delta\sigma BR/\sigma BR(h \to gg)$	3.9%	25.7%	2.8%	5.0%

1 TeV Analysis: $\nu\nu h \to \nu\nu WW^*$

H.Ono

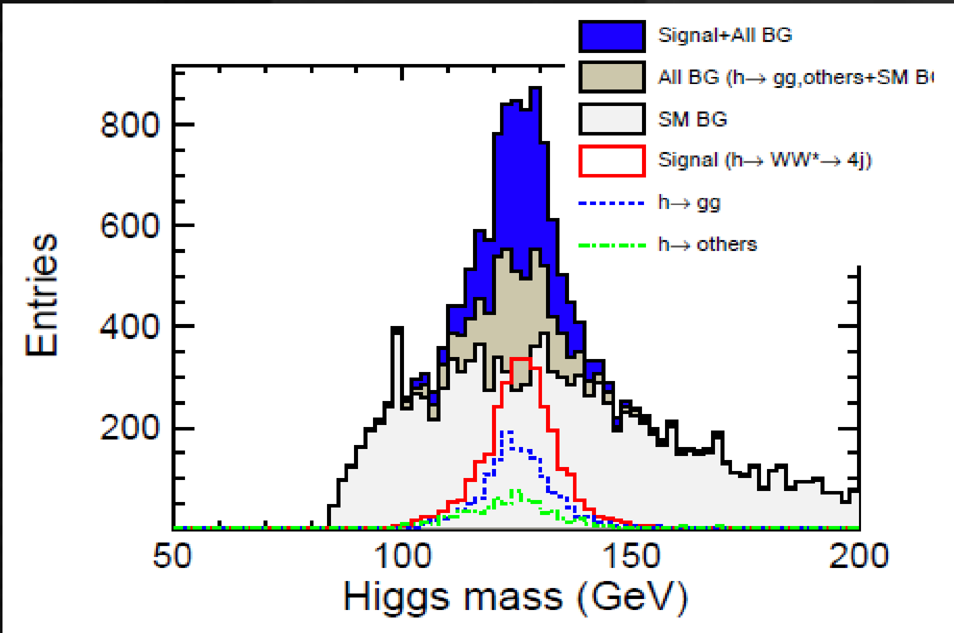
Higgs decay channels	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
Higgs BRs	57.8%	2.7%	8.6%	21.6%	0.02%	6.4%	2.7%	0.23%	0.16%

Conditions: Almost the same as qq

- 4-jet clustering instead of 2j

Cuts on:

- E_{BCAL} ,Thrust, E_{vis}, P_T, $N_{cPFO} > 25$
- $|\cos\theta_j| < 0.9$
- Y_{23} and Y_{34} (JC threshold)
- Anti-btag (sum b-like < 0.8)
- $60 < M_{W1} < 95$ GeV
- $15 < M_{W2} < 60$ GeV
- $110 < M_h < 140$ GeV



Just counting S & N after cuts

Integrated luminosity	500 fb^{-1}	500 fb^{-1}	1 ab^{-1}
Beam polarization P(e$^-$, e$^+$)	P(−0.8, +0.2)	P(+0.8, −0.2)	P(−0.8, +0.2)
Signal significance ($S/\sqrt{S+B}$)	27.9	4.2	39.7
$\Delta\sigma BR/\sigma BR(h \to WW^* \to 4j)$	3.6%	23.7%	2.5%

1 TeV Analysis: ννh -> ννμμ

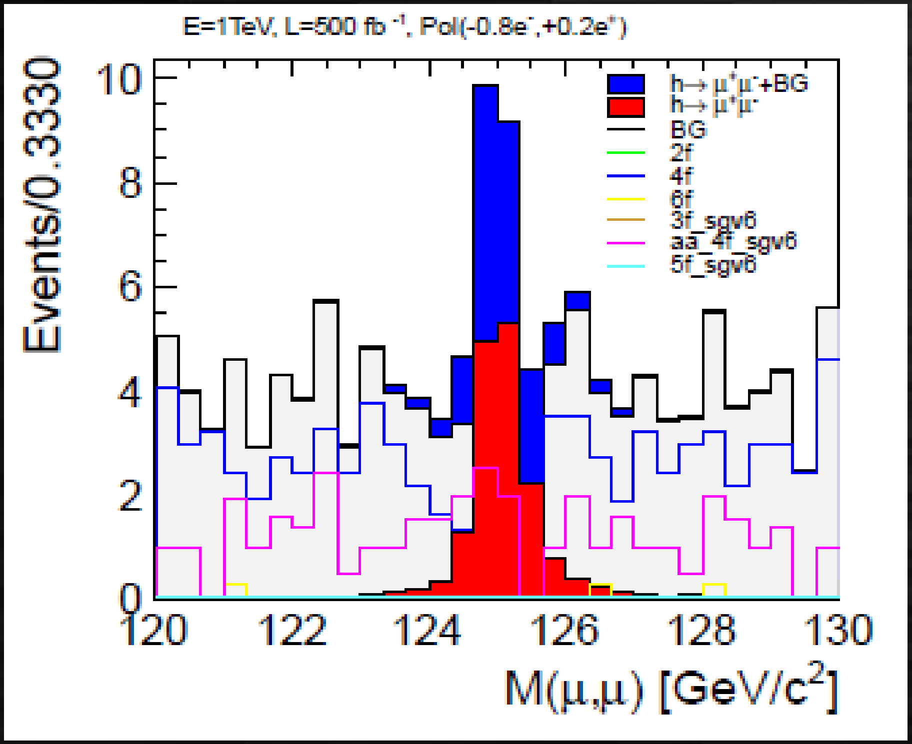
C.Calancha

Higgs decay channels	$b\bar{b}$	$c\bar{c}$	gg	WW*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ*	$\gamma\gamma$	$Z\gamma$
Higgs BRs	57.8%	2.7%	8.6%	21.6%	0.02%	6.4%	2.7%	0.23%	0.16%

preselection cuts

N = only 45 with 1 TeV, 500 fb^{-1} P(-0.8, 0.2)

Muons
charged PFO
$E > 15$ GeV
$E_{calE}/(E_{calE}+E_{calH}) < 0.5$
$(E_{calE}+E_{calH})/\lvert\vec{P}\rvert < 0.3$
$\lvert d_0/\Delta d_0\rvert < 5$
Dimuon system
Opposite sign charges
$E_{muon1}+E_{muon2} < 400$ GeV
$\lvert M(\mu^+,\mu^-)-125\rvert < 30$ GeV/c^2
$\not{E} > 300$ GeV
charged PFO's with $E > 15$ GeV < 4
charged leptons with $E > 15$ GeV < 3



optimized cuts for S/√S+B

Table 3: Result of the optimization.

$\not{E}_T > 40$ GeV
$\not{E} > 550$ GeV
$P_T(\mu^+)+P_T(\mu^-) > 130$ GeV/c
$cos(\mu^+,\mu^-) > -0.45$
BCal < 70 GeV

124 – 126 GeV window: S=14.95, B=21.96, ~2.3σ
S/√S+B = 0.444 ± 0.015, ΔσBr/σBr = 44 ± 3 %

1 TeV Analysis: WW

A.Rosca

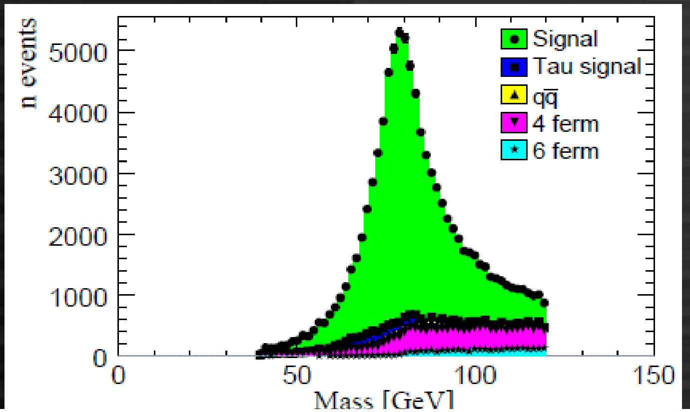
Target: luminosity-weighted polarization measurement

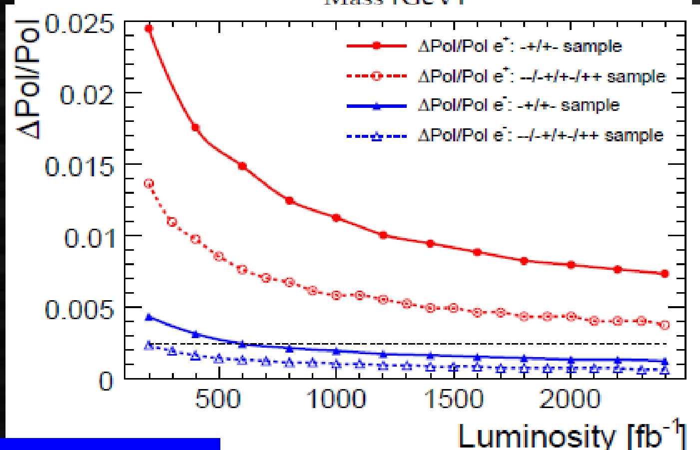
Procedure:

- Use only semileptonic WW (for charge/mass reconstruction)
- Preselection by N_{PFO}, P_T, E_{vis}, m_{vis}
- Isolated lepton selection
- kT jet clustering: R=1.3, 2-jet
- 2C kinematic fit
- Tau veto & Mass & $\cos\theta_W$ cut

Polarization calculation:

- Blondel scheme: use σ for (++),(+-),(-+),(--) = (1:1:1:1) data
- Angular fit: use $\cos\theta_W$ distribution to be compared with templates (++),(+-),(-+),(--) = (1:4:4:1) or (+-),(-+) only



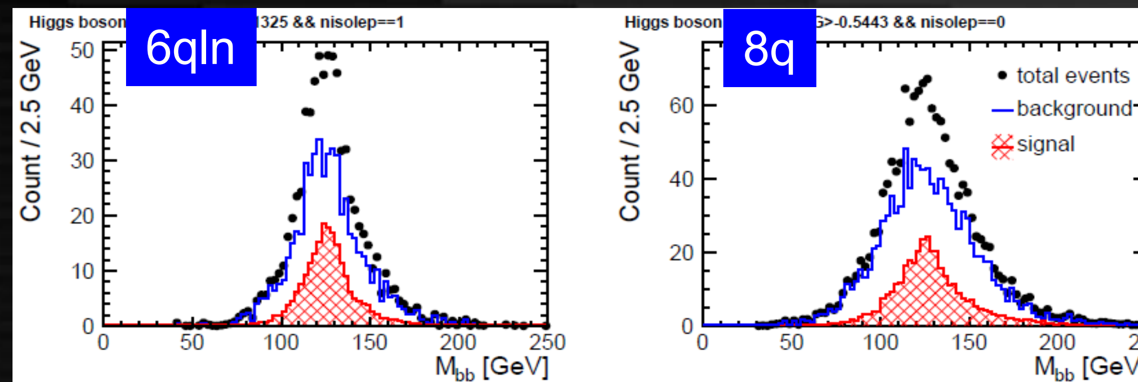


1ab^{-1} result	$\Delta P_{e^-}/P_{e^-}$	$\Delta P_{e^+}/P_{e^+}$
Blondel technique (25% $++/+-/-+/--$)	0.44%	1.19%
Fit method (10% $++/--$) (40% $+-/-+$)	0.11%	0.6%
Fit method (50% $+-/-+$)	0.19%	1.13%

1 TeV Analysis: tth

T.Price et al.

Direct measurement of top-Yukawa coupling
N_{tth} (6qlν) = 629, n_{tth} (8q) = 653 at 500 fb^{-1} each pol.



Procedure:

- Use 8q / 6qlν final states
- Isolated lepton search based on E_{lep}/E_{jet}
- 4-momentum cons. for p_ν
- k_T JC w/R=1.2 for $\gamma\gamma$->hadron
- χ^2-based jet-pair selection with b-tag value by LCFIPlus

Variables for cuts or TMVA:

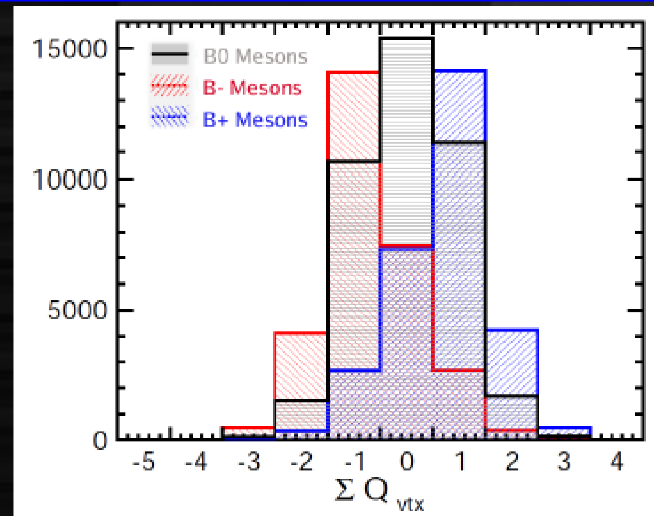
- N_{isolep}, E_{vis}, N_{PFO}, thrust
- Jet Clustering y_{ij}
- b-tag (3rd and 4th largest)
- Helicity of Higgs decay

	Efficiency	Purity	Significan
Semileptonic (Cut)	15.1%	30.6%	5.40
Hadronic (Cut)	39.1%	20.3%	7.20
Semileptonic (TMVA)	33.3%	28.0%	7.59
Hadronic (TMVA)	56.0%	25.2%	9.59

g_{tth} can be determined by 4.3% with TMVA BDT results

500 GeV: tt hadronic

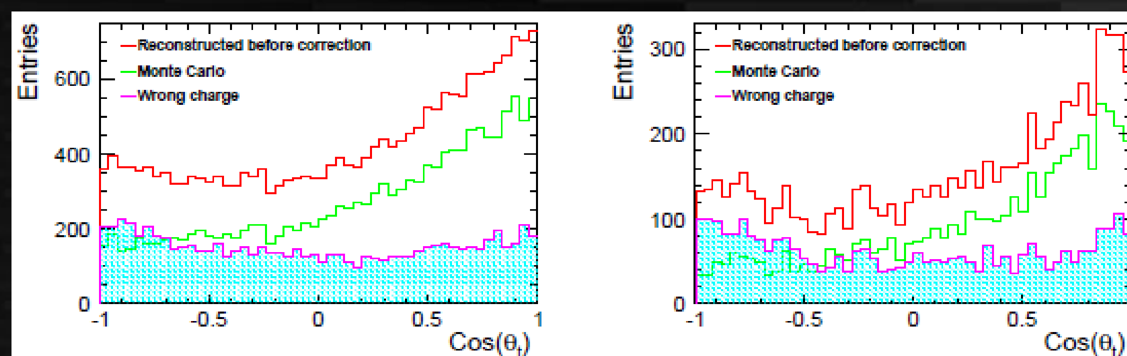
To repeat the LoI analysis with improved geometry and software



Procedure:

- Signal only (no process bkg.) $\gamma\gamma$ -> hadron is overlaid
- 6-jet clustering by LCFIPlus (Durham based)
- 2 b-tag by LCFIPlus -> 2 tops
- χ^2 based jet-pair selection
- χ^2 cut, mass cut
- Jet charge determination (LCFIPlus)
- Calculate A_{FB}

jet charge distribution - consistent with LoI

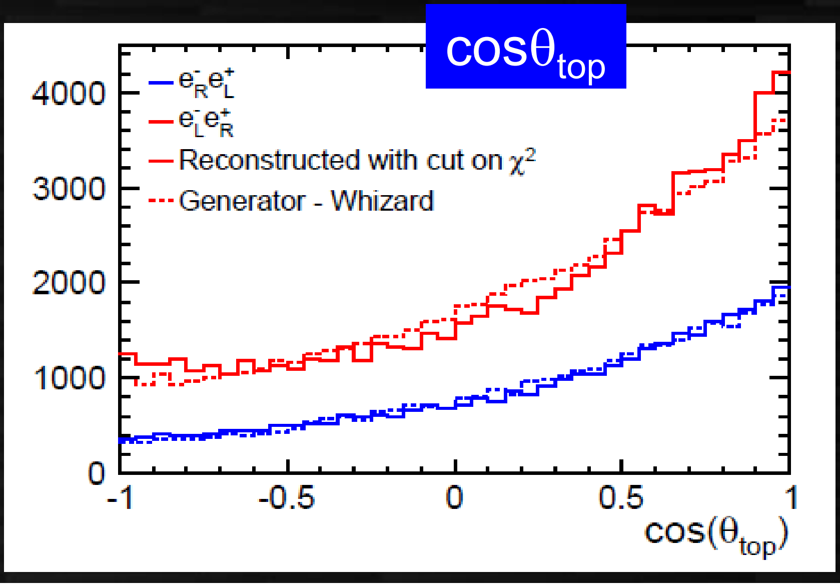


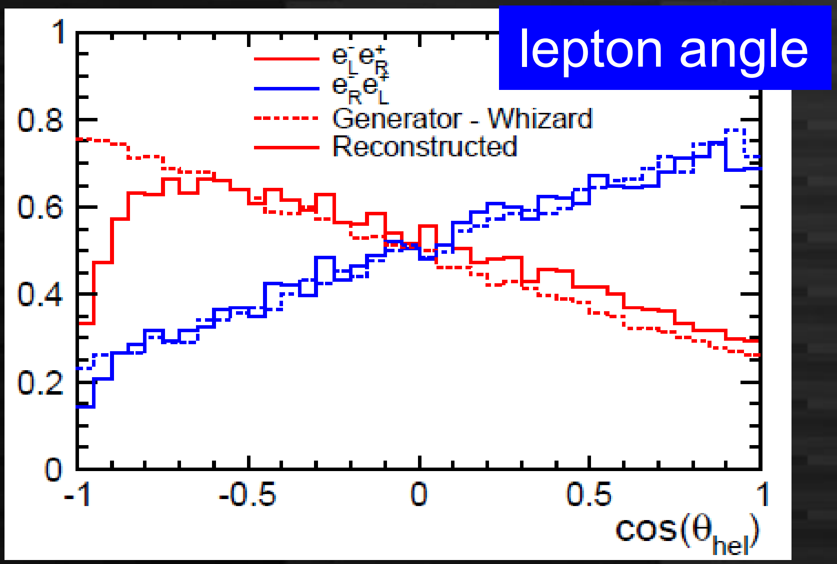
almost the same result as LoI is obtained

P, P'	$(A^t_{FB})_{gen.}$	A^t_{FB}	$(\delta_{A_{FB}}/A_{FB})_{stat.}$ [%]	$(\delta_{A_{FB}}/A_{FB})_{syst.}$ [%]
$-1, +1$	0.355	0.344	2.9 (corrected to $P, P' = -0.8, +0.3$)	0.8
$+1, -1$	0.438	0.443	3.2 (corrected to $P, P' = +0.8, -0.3$)	0.3

tt semileptonic at 500 GeV

Semileptonic is more suitable for A_{FB} because of easier charge determination





$\mathcal{P}, \mathcal{P}'$	$(A^t_{FB})_{gen.}$	A^t_{FB}	$(\delta_{A_{FB}}/A_{FB})_{stat.}$ [%]
$-1, +1$	0.360	0.359	1.7 (for $\mathcal{P}, \mathcal{P}' = -0.8, +0.3$)
$+1, -1$	0.433	0.410	1.3 (for $\mathcal{P}, \mathcal{P}' = +0.8, -0.3$)

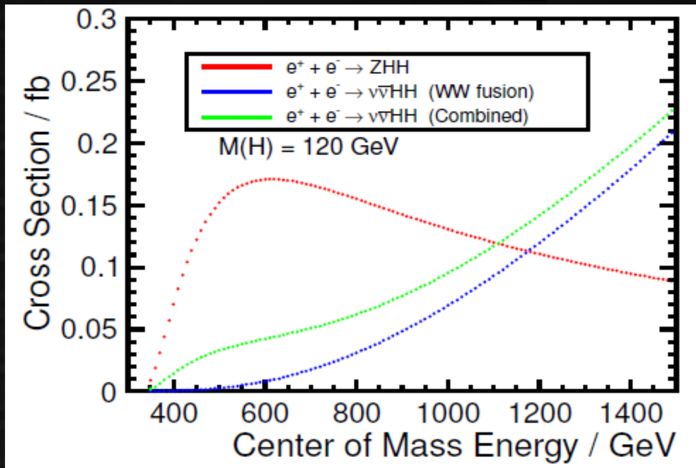
AFB (hadronic)
2.9%
3.2%

$\mathcal{P}, \mathcal{P}'$	$(\lambda_t)_{gen.}$	$(\lambda_t)_{rec.}$	$(\delta\lambda_t)_{stat.}$ for $\mathcal{P}, \mathcal{P}' = \mp 0.8, \pm 0.3$	$(\delta\lambda_t)_{syst.}$
$-1, +1$	-0.514	-0.476	0.011	0.011
$+1, -1$	0.546	0.510	0.016	0.010

usable for determining top form factors

Zhh and ννhh at 500 and 1000 GeV

J.Tian



500 GeV – Zhh dominant
(6f – heavy tt background)
1 TeV – ννhh dominant

Condition:

- m_H = 120 GeV, 2 ab^{-1}
- no γγ -> hadrons
- Zhh: 5 categories of Z bb, qq, νν, ee, μμ
- Durham JC, LCFIPlus
- Using TMVA MLPs for bkg. separation

500 GeV result

category	S	B	S/√B
bbbbbb	13.6	30.7	2.2
qqbbbb	18.8	90.6	1.9
ννbbbb	8.5	7.9	2.5
eebbbb	3.7	4.3	1.5
μμbbbb	4.5	6.0	1.5

Combined: σ = 0.22 ± 0.06 fb, 5.0 σ excess
$\Delta\lambda_{hhh} / \lambda_{hhh}$ = 44% (incl. event weighting)

cf. 57% in LoI

1 TeV result

S = 35.7, B = 33.7, 7.2 σ excess
$\Delta\lambda_{hhh} / \lambda_{hhh}$ = 18% (incl. event weighting)

better sensitivity on λ_{hhh} mainly comes from larger dependence of σ on λ_{hhh}

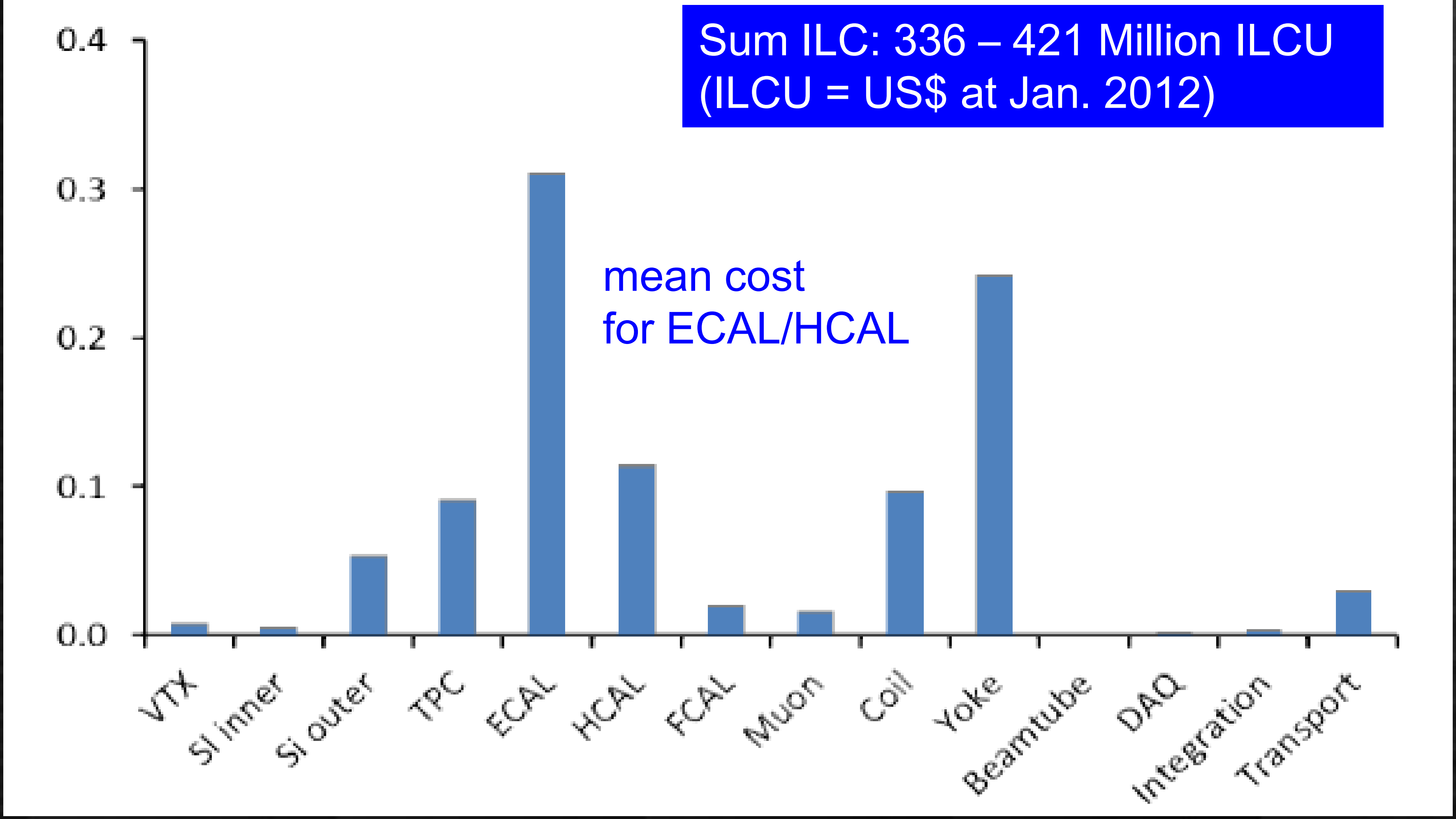
Much improvement of LoI thanks to new flavor tagging & intensive optimization of analysis
-> many ideas for improvement still under study

Reprocessing 250/350/500 GeV

- For staged construction of ILC, 250 GeV performance with latest software is critical.
- 250/350/500 GeV samples in DBD cfg. almost ready.
- Higgs recoil & Br. analysis will be redone for snowmass input
- Plenty of other physics programs still ongoing
  - tt threshold analysis at 350 GeV for top-Yukawa
  - h -> $\tau\tau$ analysis (3.5% obtained with LoI sample)

  (those two are also for snowmass)
  - Zhh with h->bbWW*
  - BSM searches (incl. SUSY), Exotic Higgs searches
  - more coming...

ILD Cost



- Manpower, R&D not included
- Uncertainty: about 20%

Summary / Comment

- Many achievements in ILD DBD
  - Feasibility and realism of the detector shown
  - First engineering design completed
  - All DBD benchmarks + α covered
- Post-DBD studies include
  - Engineering study of mass production, large prototype, infrastructure etc.
  - Physics with 125 GeV Higgs and more (mainly lower energy than 1 TeV)
  - Detector optimization by physics view