Detectors for e^+e^- Linear Colliders

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(On behalf of the Americas Linear Collider Committee)

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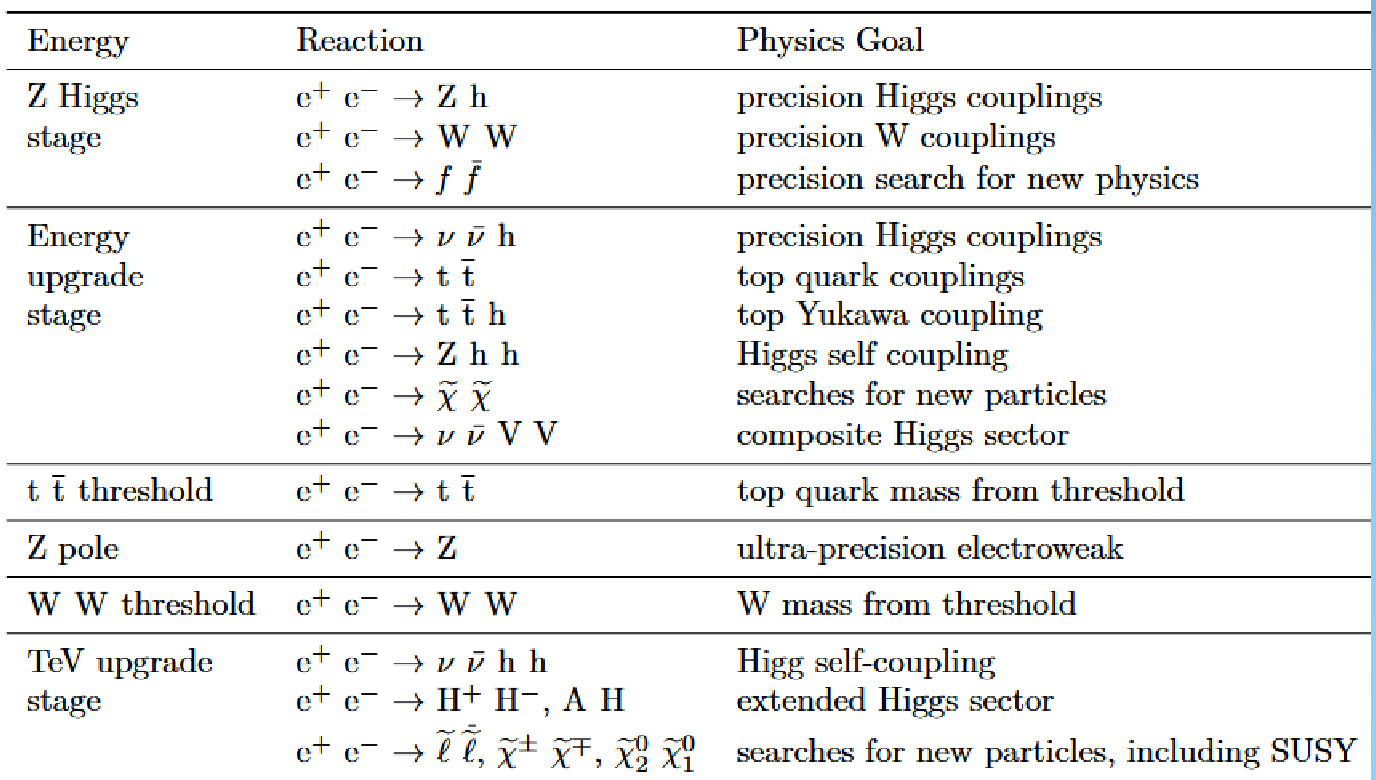
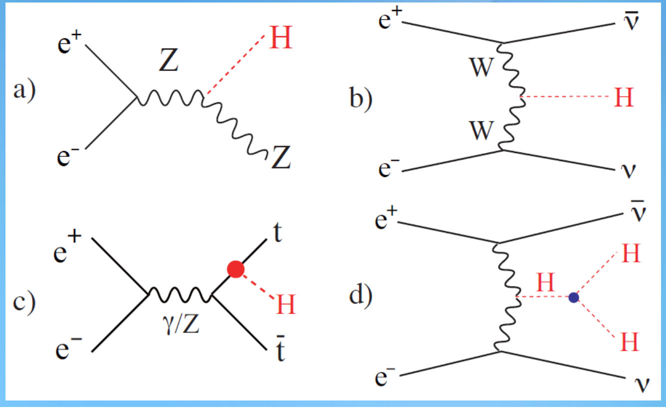
P5 Meeting, BNL, April 13, 2023

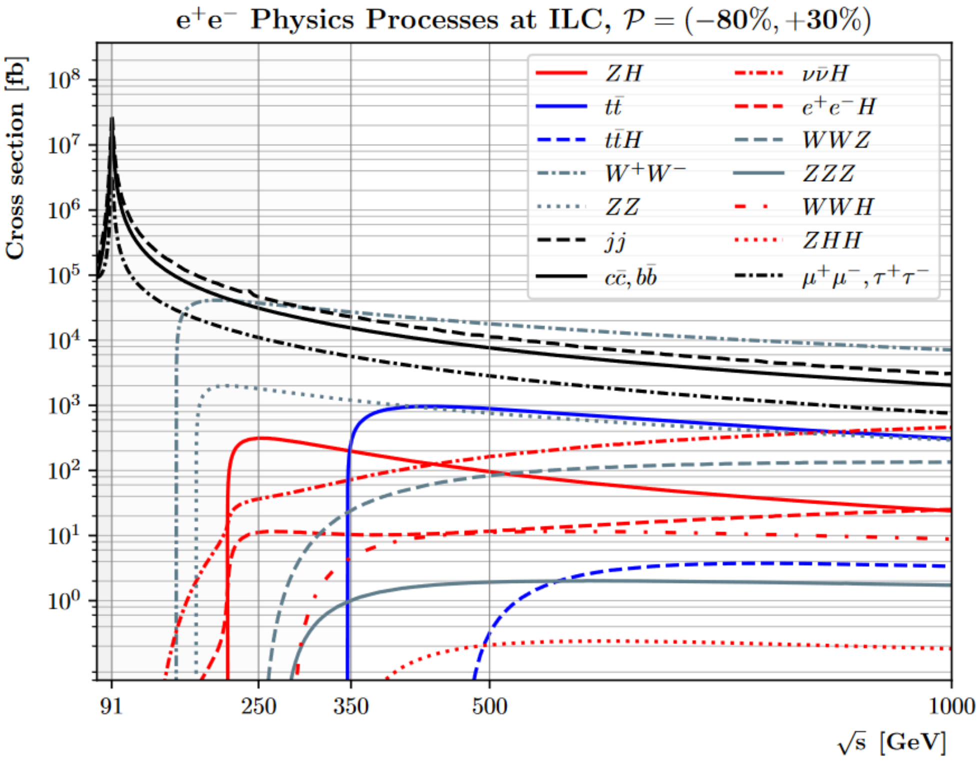
With thanks to ILD, SiD and C^3 colleagues for materials provided!

ILC Physics – major processes to be studied



Energy	Reaction	Physics Goal
Z Higgs stage	$e^+ e^- \to Z\ h$	precision Higgs couplings
	$e^+ e^- \to W\ W$	precision W couplings
	$e^+ e^- \to f\ \bar{f}$	precision search for new physics
Energy upgrade stage	$e^+ e^- \to \nu\ \bar{\nu}\ h$	precision Higgs couplings
	$e^+ e^- \to t\ \bar{t}$	top quark couplings
	$e^+ e^- \to t\ \bar{t}\ h$	top Yukawa coupling
	$e^+ e^- \to Z\ h\ h$	Higgs self coupling
	$e^+ e^- \to \tilde{\chi}\ \tilde{\chi}$	searches for new particles
	$e^+ e^- \to \nu\ \bar{\nu}\ V\ V$	composite Higgs sector
t t̄ threshold	$e^+ e^- \to t\ \bar{t}$	top quark mass from threshold
Z pole	$e^+ e^- \to Z$	ultra-precision electroweak
W W threshold	$e^+ e^- \to W\ W$	W mass from threshold
TeV upgrade stage	$e^+ e^- \to \nu\ \bar{\nu}\ h\ h$	Higg self-coupling
	$e^+ e^- \to H^+\ H^-,\ A\ H$	extended Higgs sector
	$e^+ e^- \to \tilde{\ell}\ \bar{\tilde{\ell}},\ \tilde{\chi}^{\pm}\ \tilde{\chi}^{\mp},\ \tilde{\chi}^0_2\ \tilde{\chi}^0_1$	searches for new particles, including SUSY

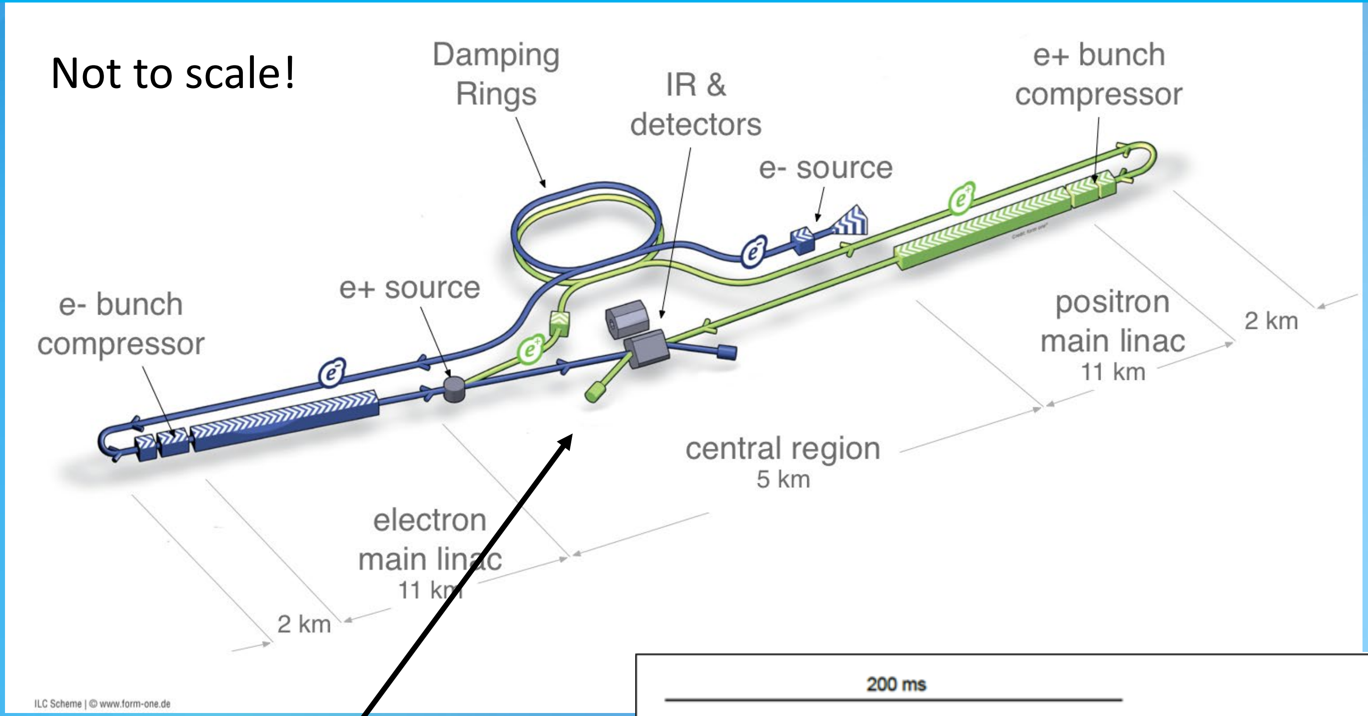




ILC covers the entire range of Higgs physics,
as well as top, new physics searches, and Z and W.

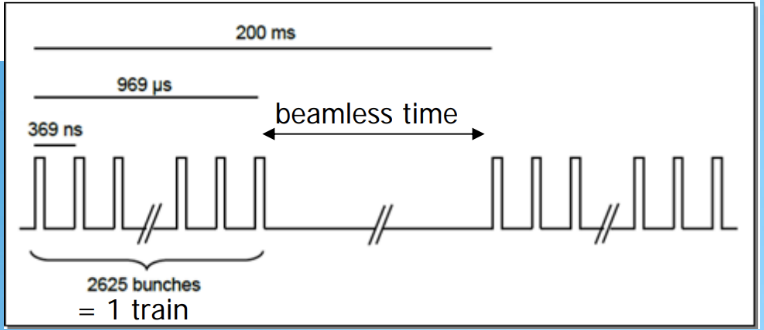
ILC Snowmass report:arXiv:2203.07622

The ILC Accelerator



ILC Scheme | © www.form-one.de

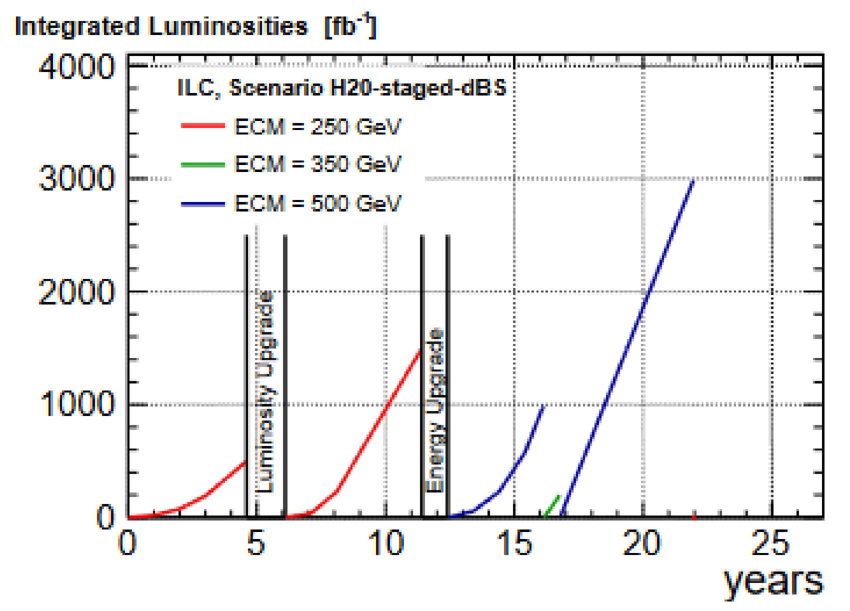
ILC is designed for two Detectors in Push-Pull arrangement



Power pulsing allows for minimal material for cooling

"H20" ILC running scenario

Begin at 250/ZH for Higgs physics



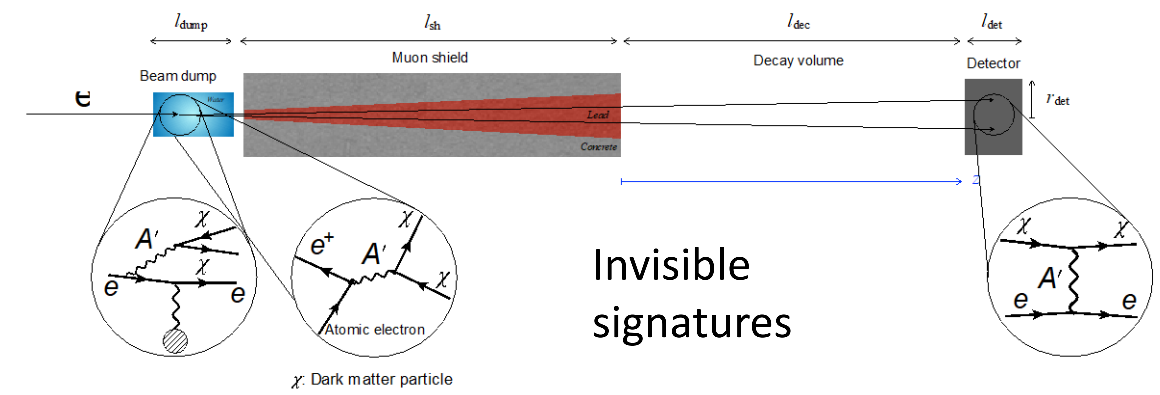
ILC parameters

COM energy Z-pole – 1000 GeV (and maybe higher)
Polarization e$^-$ 80%, e$^+$ 30%
Repetition frequency 5 Hz
Bunches per train 1312/2625
Linac bunch interval 554 ns (initial)
Interaction rate ~1 Hz for e+e- → $f\bar{f}$
Site AC Power 111 MW (250 GeV)

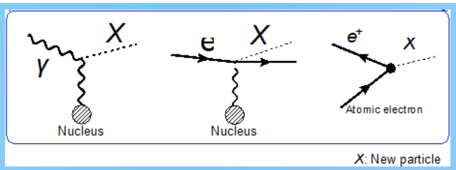
ILC Experiments away from the IP

See also: ILCX workshop

Electron and *positron* beam dumps: $N_{EOT} = 4 \times 10^{21}$ /year



Invisible signatures



Visible signatures

Secondary beam lines:

Light-shining-through-wall
Requires 1-10 MeV photon beam
10^{17} ɣ/s

Strong QED, using laser on beam, astrophysics, pathway to ɣ-ɣ collider

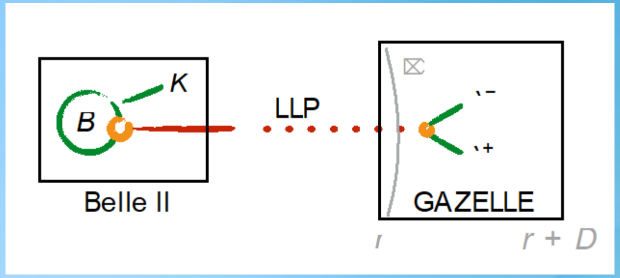
LUXE-like, optical dumps for ALP searches

Far forward detectors:

Off-axis detector to capture long-lived particles

Belle II study found little gain, as acceptance drops with distance.

ILC has increased boost compared to Belle II → larger rate in FD
Beam structure allows direct correlation of events in ND <-> FD



Why Experiments at an e^+e^- Linear Collider?

Clean collisions of elementary particles at precise energies.

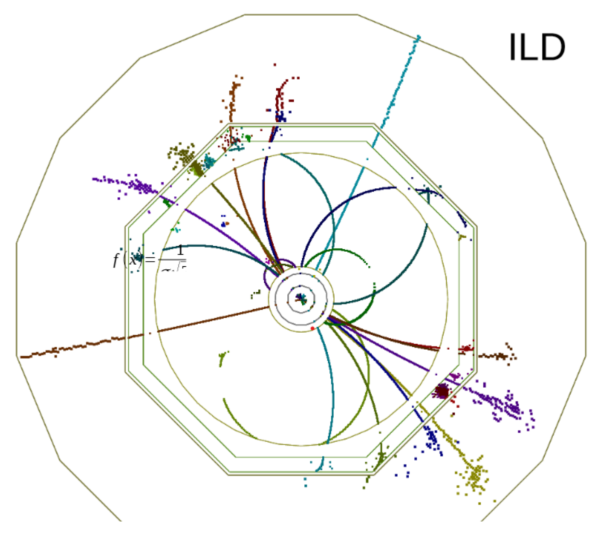
Energy range extendable – full Higgs physics coverage

Polarization for e^- and e^+ to optimize signal rates and background suppression

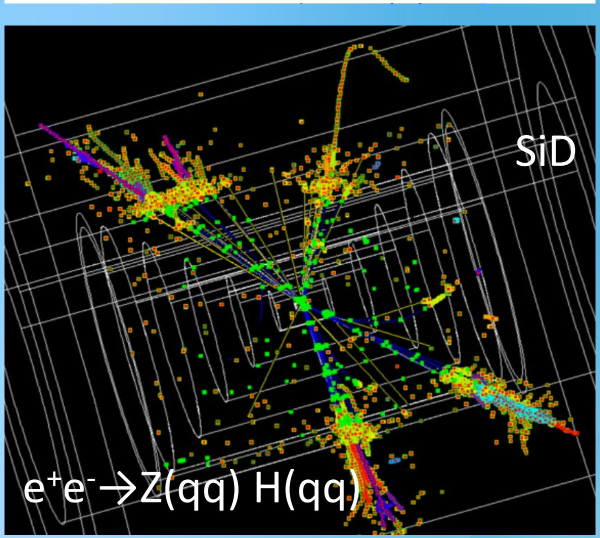
No pile-up as in hadron collider experiments
(Expect ~1 hadronic interaction per bunch train)
No trigger needed – record all events

Power pulsing possible – reduced material budget

Potential detector upgrade paths using new technologies



$e^+e^- \rightarrow Z(\mu^+\mu^-)\ H(qq)$



$e^+e^- \rightarrow Z(qq)\ H(qq)$

Brief history of ILC Detectors

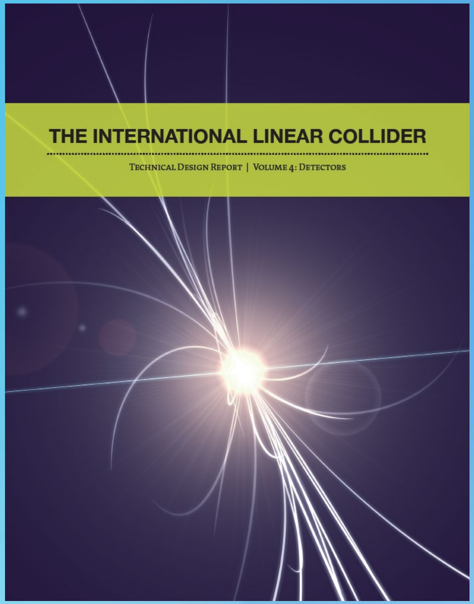
Initial concepts – early ‘90s

LOIs 2009 (3 Concepts)

ILD and SiD validated by International Detector Advisory Group

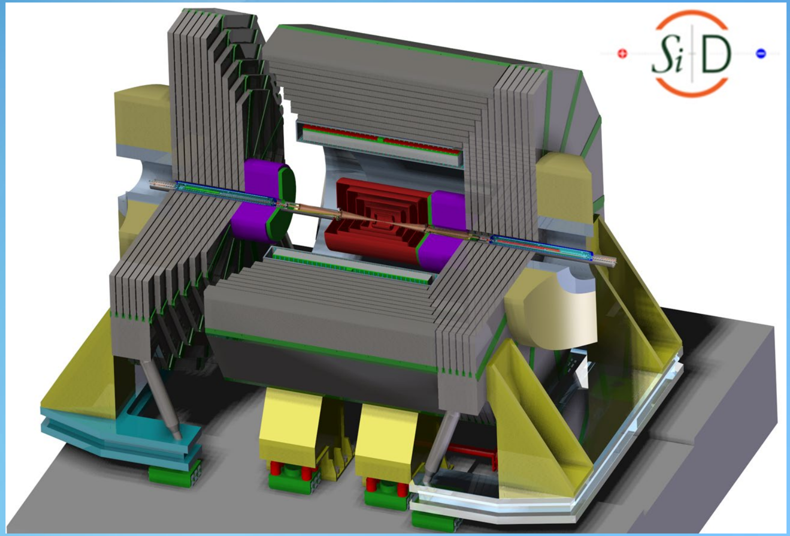
ILC TDR 2013 – inc. ILD and SiD DBDs

2013



THE INTERNATIONAL LINEAR COLLIDER

Technical Design Report | Volume 4: Detectors



SiD and ILD are typical collider detectors

SiD Design update 2021

October 20, 2021

Updating the SiD Detector concept

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The SiD Detector is one of two detector designs for the future International Linear Collider (ILC) that were validated in 2012 SiD features a compact, cost-constrained design for precision Higgs and other measurements, and sensitivity to a wide range of possible new phenomena. A robust silicon vertex and tracking system, combined with a five Tesla central solenoidal field, provides excellent momentum resolution. The highly granular calorimeter system is optimized for Particle Flow application to achieve very good jet energy resolution over a wide range of energies. With a potential construction date of the ILC moving closer, it is now the time to review the design and technology decision that have been made during the DBD phase and reconsider them in the light of the recent technological advances. For each area of SiD development R&D topics and opportunities for participation will be discussed.

arXiv:2110.09965v1 [physics.ins-det] 19 Oct 2021

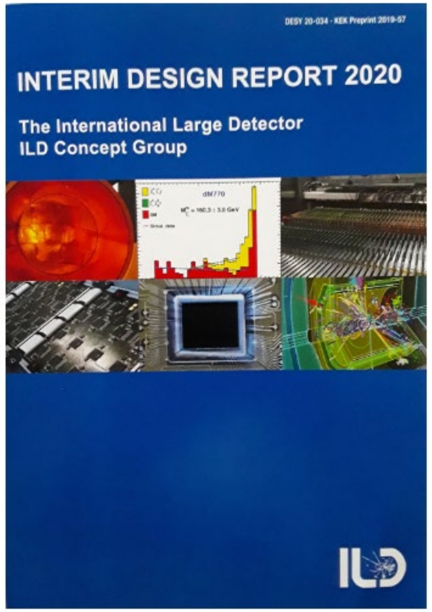
I. INTRODUCTION

The International Linear Collider (ILC) [1] is a proposed e^+e^- collider at the energy frontier. The ILC is a 20 km long linear accelerator using superconducting cavities with a initial baseline center-of-mass energy of 250 GeV. The ILC will provide polarized beams for both electrons (80%) and positrons (30%), which is a unique capability of linear colliders. The ILC project includes a clear upgrade path to center-of-mass energies of 1 TeV, or even slightly beyond. The ILC has a mature baseline design which has been summarized in the Technical Design Report (TDR), which was presented in 2012 [2, 3].

The ILC environment is unique and very different than at synchrotrons. The ILC accelerates a bunch train with 1300 bunches roughly 550 ns apart roughly every 200 ms, so collisions only happen during 1 ms followed by a quiet time of 199 ms. This allows to buffer the data on the front-ends, read out at the end of the bunch train and then to power down the front-ends (power-pulsing). This reduces the average power consumption by roughly a factor of 100.

SiD started as a detector concept for linear colliders almost twenty years ago [4, 5]. It was well documented in the ILC TDR Detailed Baseline Document (DBD) [6] in 2012. This note will first give a brief review on the current design and layout of SiD and then identify and highlight the improvements appropriate for a construction start in the late 2020s, and the new opportunities for R&D contributions. This note will not recapitulate the DBD in great details, and the reader should refer to the ILC TDR for a complete summary of the physics motivations [7], the ILC accelerator [3] and the conceptual detector designs[6]. For a review of the R&D activities in the Linear Collider Community, the Detector R&D Report [8] is an excellent summary.

2020

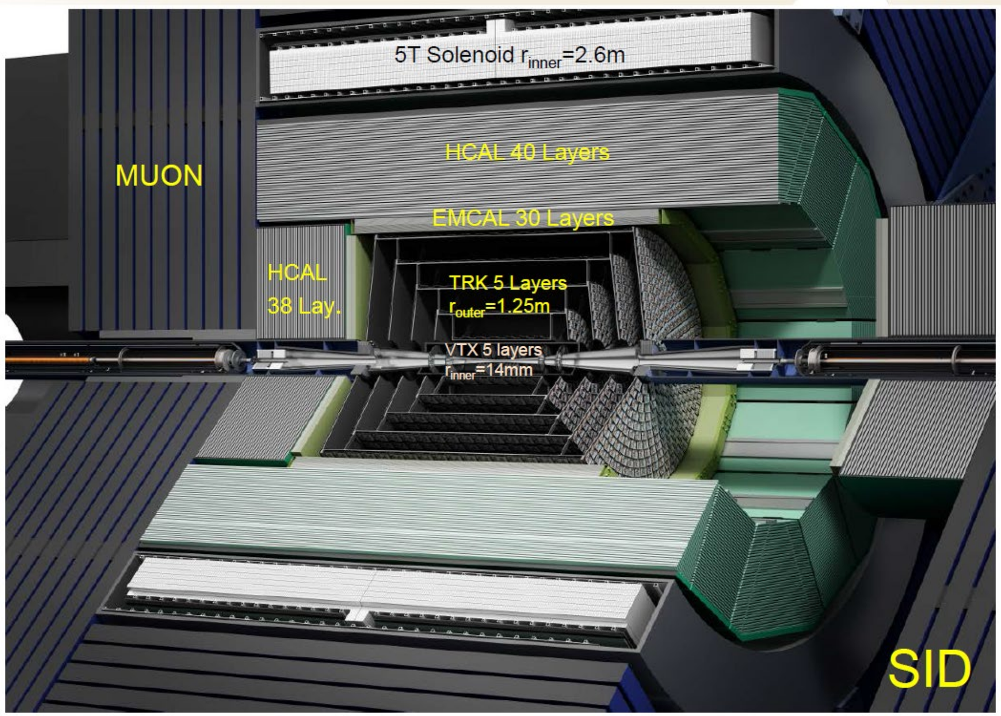


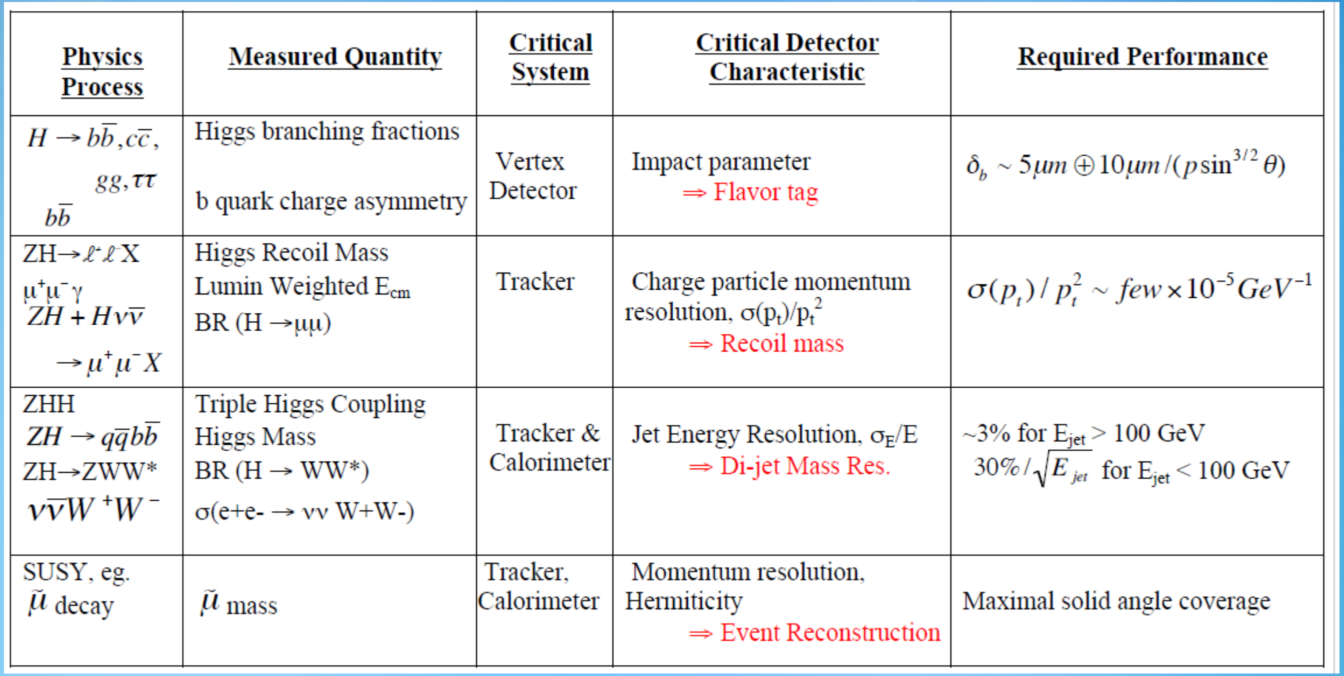
DESY 20-034 · KEK Preprint 2019-57

INTERIM DESIGN REPORT 2020

The International Large Detector
ILD Concept Group

SiD Detector Baseline





Physics Process	**Measured Quantity**	**Critical System**	**Critical Detector Characteristic**	**Required Performance**
$H \to b\bar{b}, c\bar{c}, gg, \tau\tau$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impact parameter ⇒ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$
ZH→$\ell^+\ell^-$X $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu} \to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR (H →μμ)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ ⇒ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$
ZHH $ZH \to q\bar{q}b\bar{b}$ ZH→ZWW* $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass BR (H → WW*) σ(e+e- → νν W+W-)	Tracker & Calorimeter	Jet Energy Resolution, σ_E/E ⇒ Di-jet Mass Res.	~3% for E_{jet} > 100 GeV $30\%/\sqrt{E_{jet}}$ for E_{jet} < 100 GeV
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum resolution, Hermiticity ⇒ Event Reconstruction	Maximal solid angle coverage

*A **compact, cost-constrained detector** designed to make precision measurements and be sensitive to a wide range of new phenomena.*

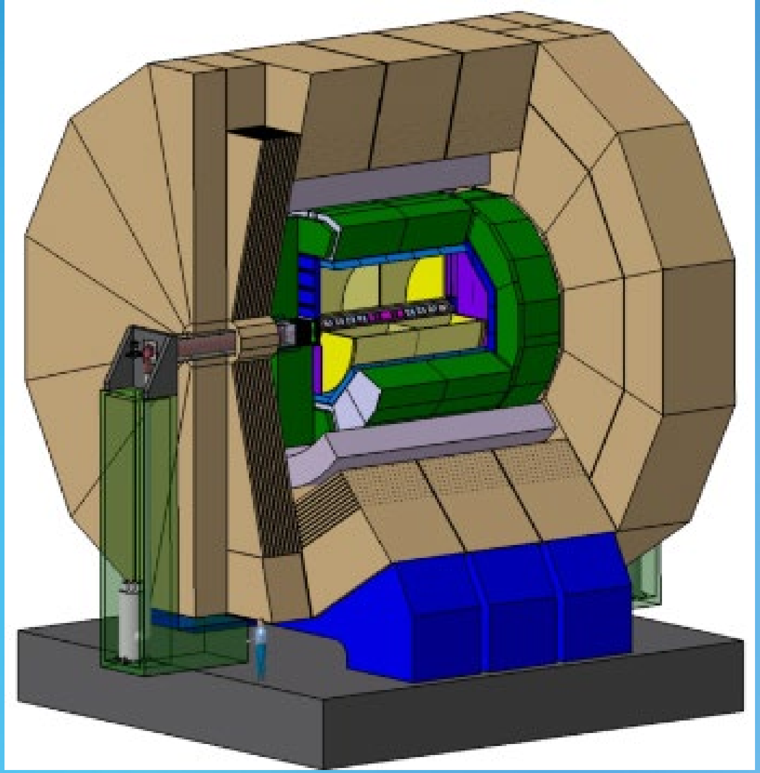
Robust **silicon vertexing and tracking** system – excellent momentum resolution, live for single bunch crossings.

Highly segmented “tracking” **calorimeters optimized for Particle Flow.**

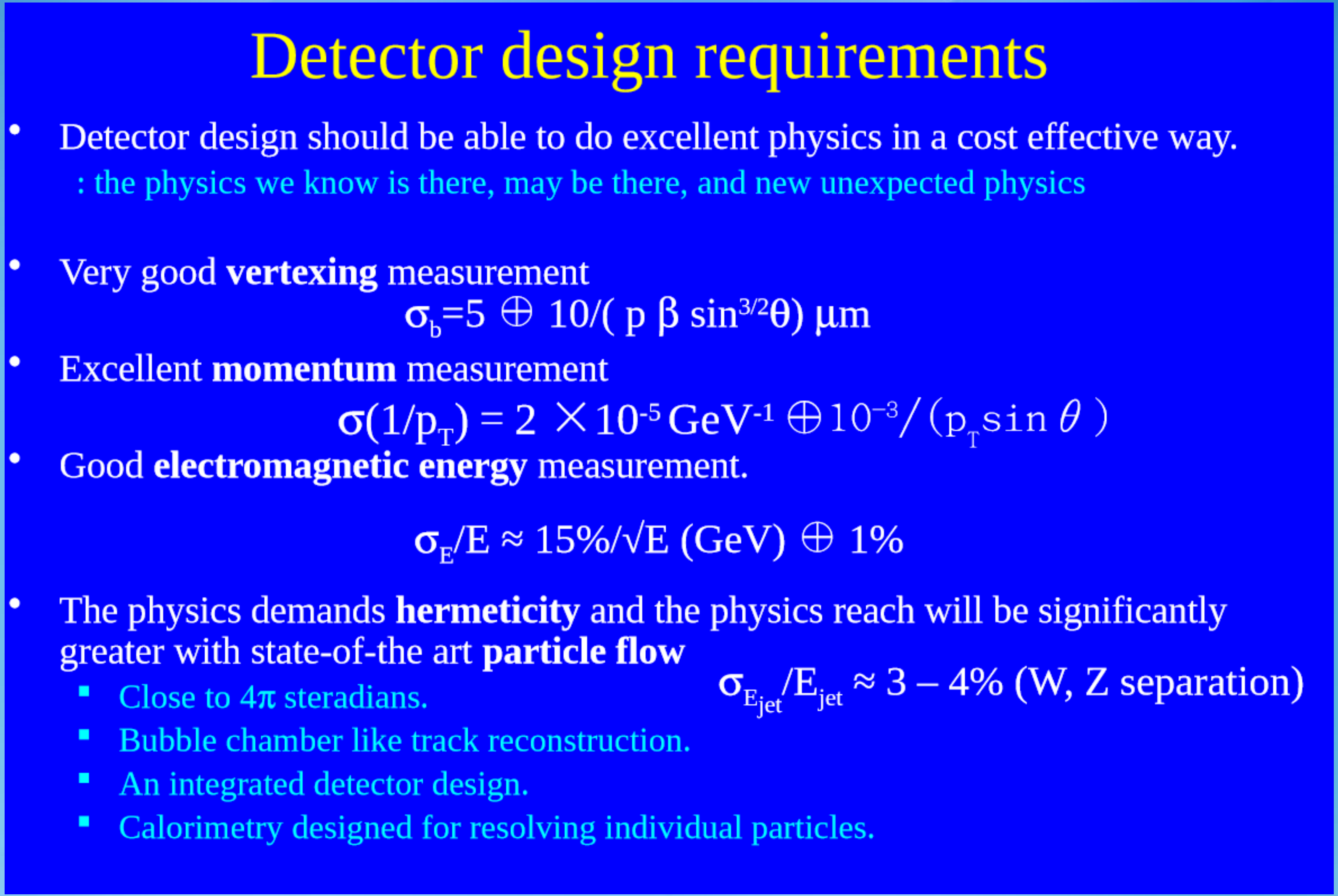
Compact design with **5T field**.

Detector is designed for rapid push-pull operation.

ILD Detector Design



B field 3.5T
TPC for Main Tracking
Overall detector concept optimized for Particle Flow



Detector design requirements

- Detector design should be able to do excellent physics in a cost effective way.
  : the physics we know is there, may be there, and new unexpected physics
- Very good **vertexing** measurement

$$\sigma_b = 5 \oplus 10/(p\,\beta\,\sin^{3/2}\theta)\ \mu m$$

- Excellent **momentum** measurement

$$\sigma(1/p_T) = 2 \times 10^{-5}\,\mathrm{GeV}^{-1} \oplus 10^{-3}/(p_T \sin\theta)$$

- Good **electromagnetic energy** measurement.

$$\sigma_E/E \approx 15\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 1\%$$

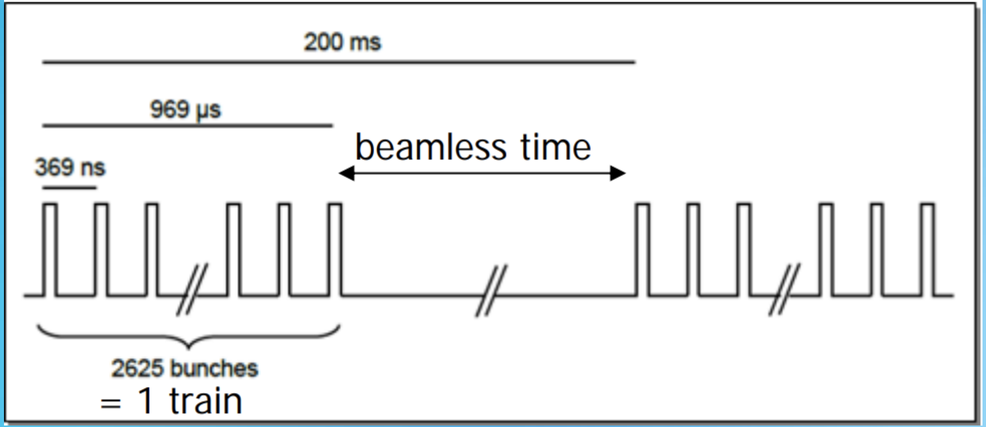
- The physics demands **hermeticity** and the physics reach will be significantly greater with state-of-the art **particle flow**
  - Close to 4π steradians.
  - Bubble chamber like track reconstruction.
  - An integrated detector design.
  - Calorimetry designed for resolving individual particles.

$$\sigma_{E_{jet}}/E_{jet} \approx 3 - 4\%\ (W, Z\ \text{separation})$$

Both ILD and SiD designs have been simulated in detail – ILC physics studies are based on full simulation data.

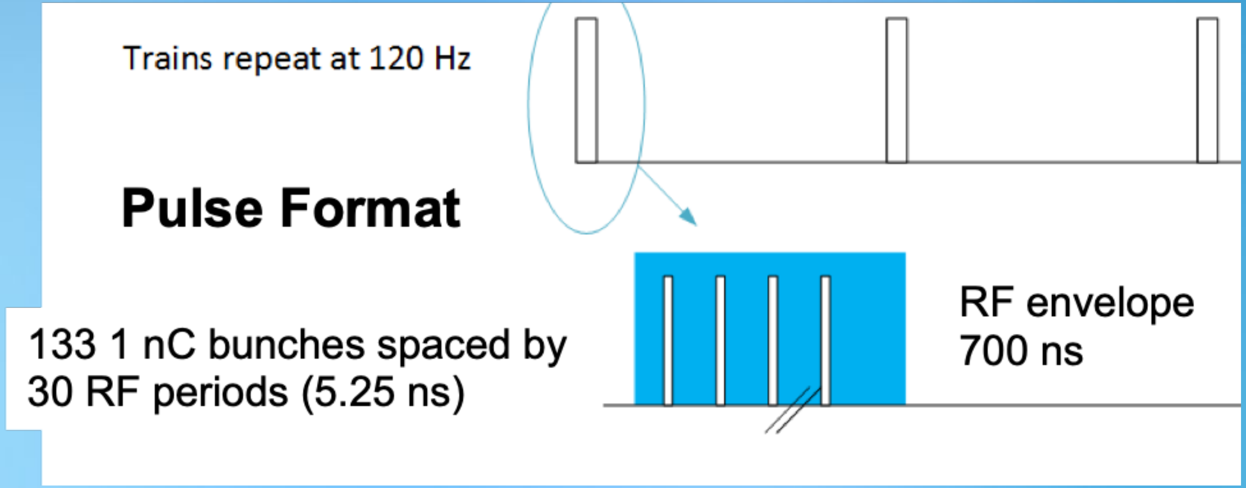
Design Considerations for C^3 (Cool Copper Collider)

ILC timing structure



1 ms long bunch trains at 5 Hz
308ns spacing

C^3 timing structure



ILC/C^3 timing structure: Fraction of a percent duty cycle

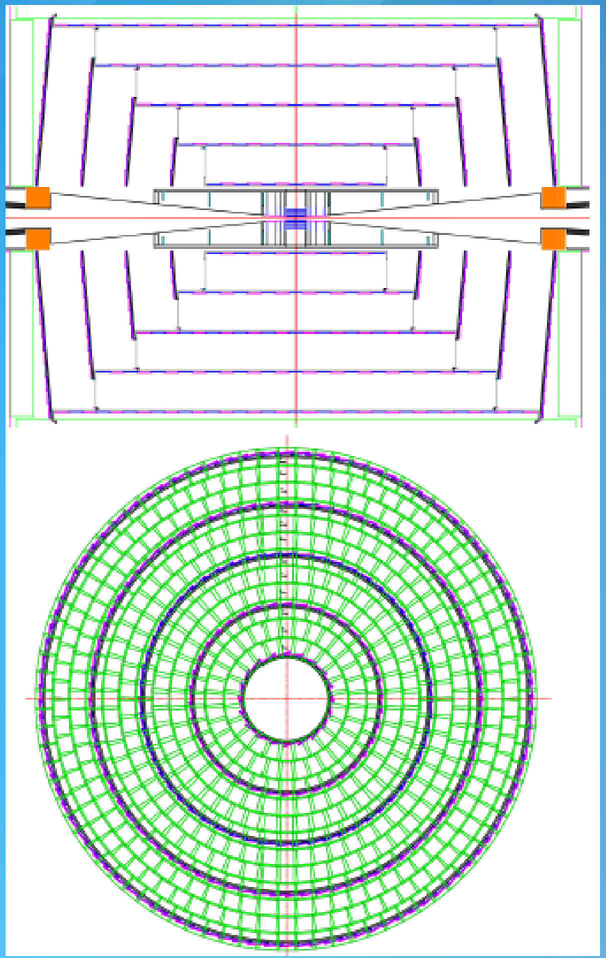
- **Power pulsing possible**, significantly reduce heat load
  - Factor of 50-100 power saving for FE analog power
  - Significantly reduction for the material budget

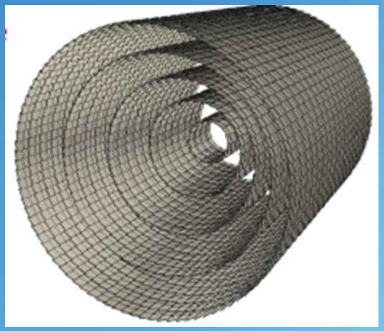
Experience from CLIC shows that SiD will be able to deliver C^3 physics with only incremental changes.

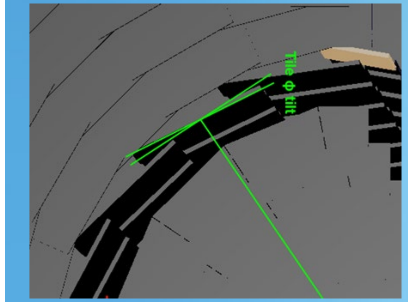
Detector requirements for C^3 are essentially the same as for ILC

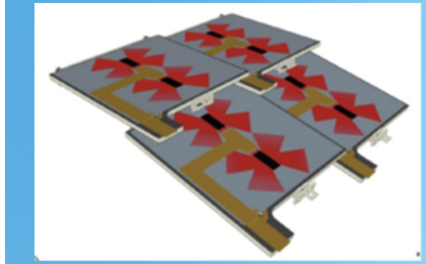
An ILC-like detector overall design and ongoing optimizations are viable for operation at C^3.

SiD Silicon (Strip) Tracker





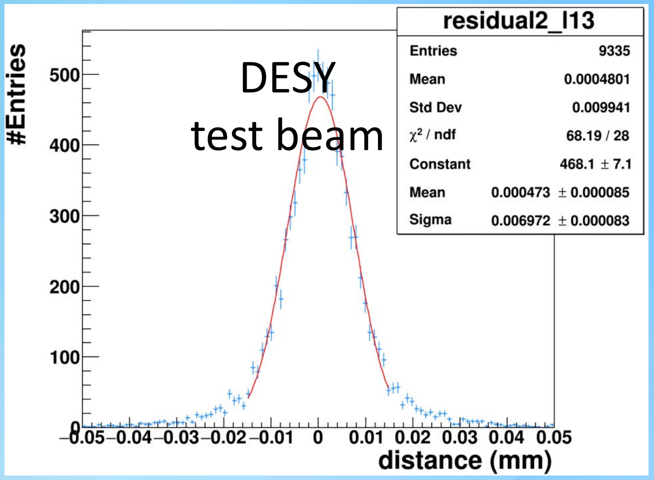




Baseline

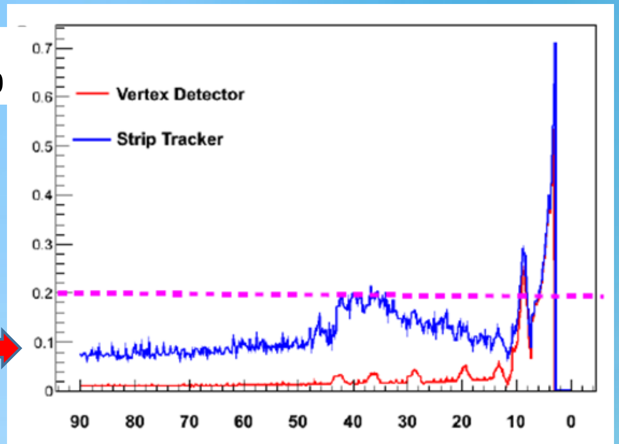
- All Silicon Tracker
  - Using Silicon micro-strips
    - 25 µm pitch / 50 µm readout
    - v2 sensor prototype July 2017*
- 5 barrel layers / 4 disks
- Tracking unified with vertex detector
  - 10 layers in barrel
- Gas-cooled
- Material budget < 20% X_0 in the active region
- Readout using KPiX ASIC
  - Same readout as ECAL
  - Bump-bonded directly to the module

Single point resolution 7µm



X/X_0

Note:
< 10% X_0

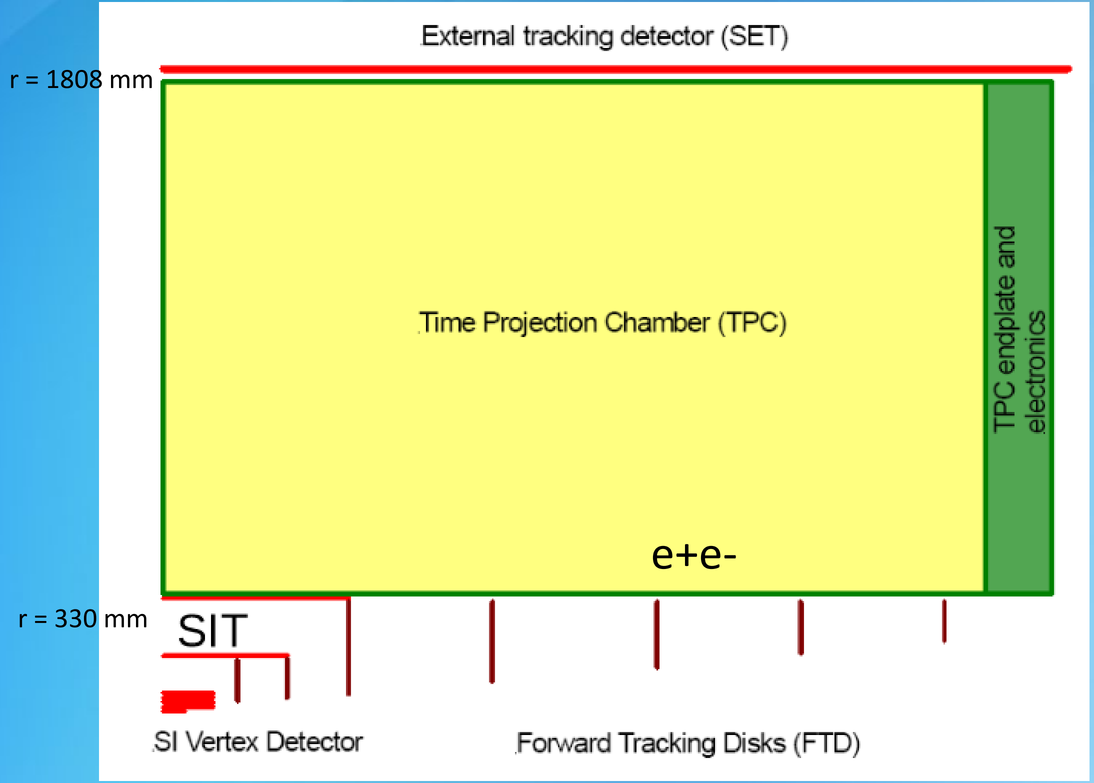


Polar angle (deg.)

Now exploring MAPS for the main SiD tracker

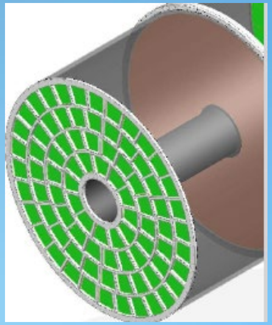
ILD Tracking

Main Tracker: TPC

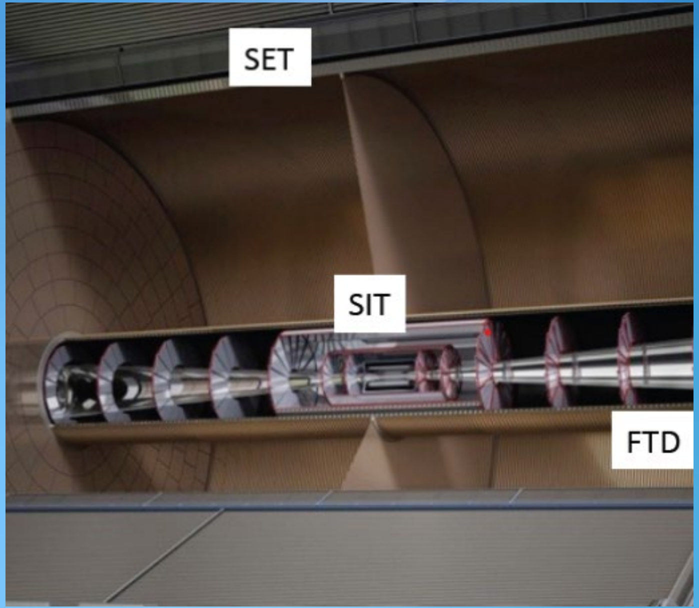


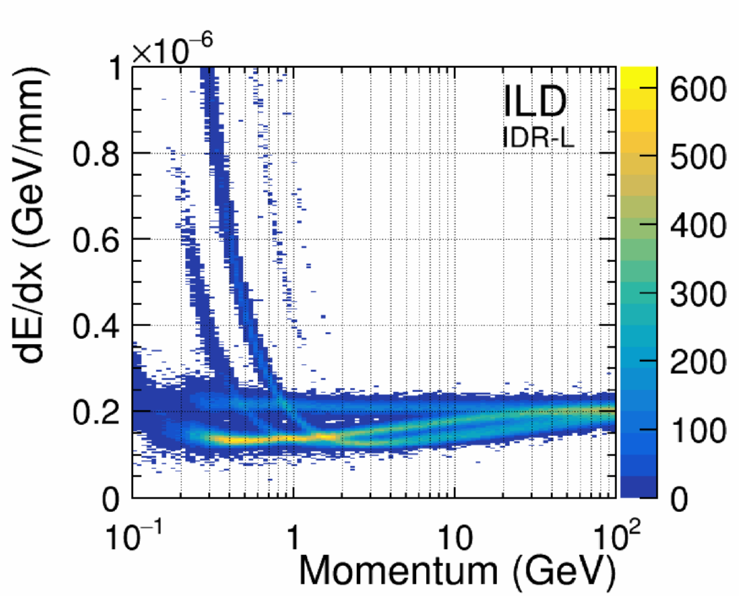
TPC Readout options:
GEM, Micromegas, Pixel

Pixel readout for the TPC is a promising research area for ILD that needs targeted R&D support



3 x10^9 volume pixels.
224 points per track.
Single-point resolution
50 - 100 μm r-phi,
400 μm r-z





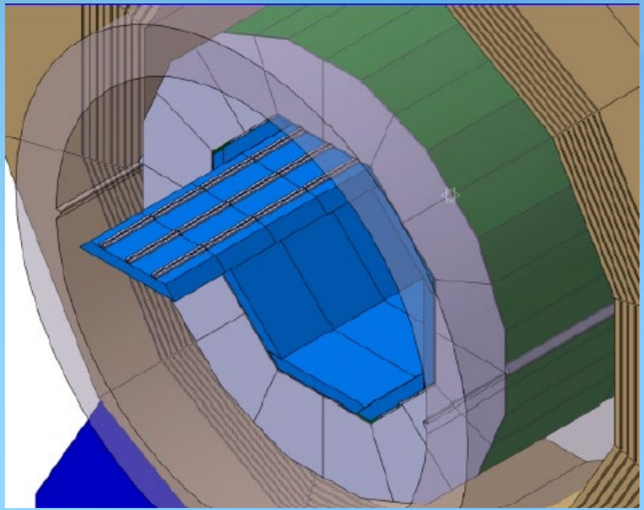
TPC offers dE/dx for particle ID and measurement of in-flight decays

ILD Calorimetry Technologies

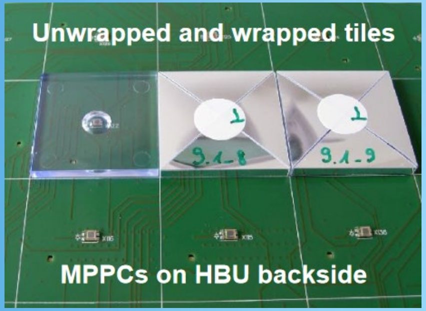
Build on studies by CALICE

- ECAL (24 X_0: 20 x 0.6 X_0+ 10 x 1.2 X_0)

- Silicon-W
- transverse cell-size 5mm X 5mm
- Scintillator-W with SiPM readout
- 5mm X 45 mm X 2mm strips
- (Digital: MAPS)

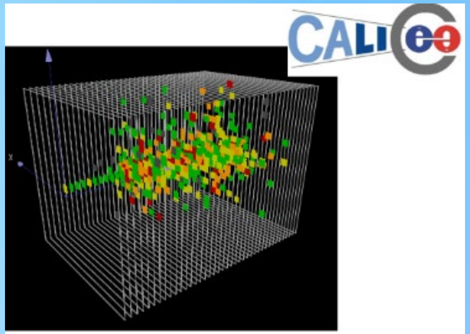


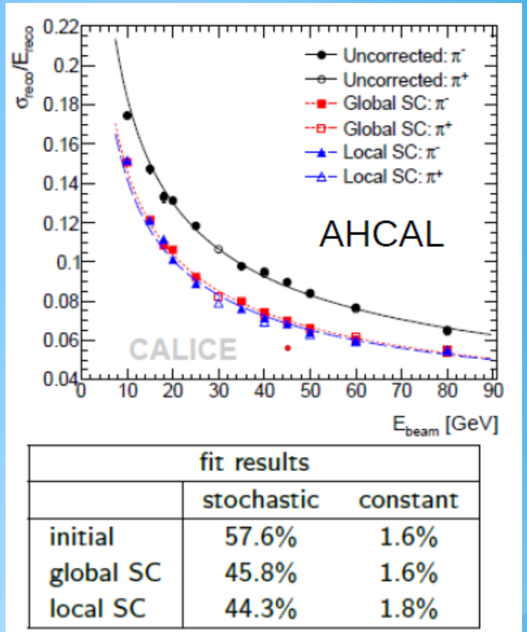
2m Prototype for SiW-ECAL (LLR)



- HCAL

- Analog : Scintillator + Stainless Steel.
- Tiles with Si-PM readout
- 3mm Sc, 3cm X 3cm.
- Digital/Semi-Digital : Gas + Stainless Steel.
- Glass RPCs or MPGDs, 1cm X 1cm

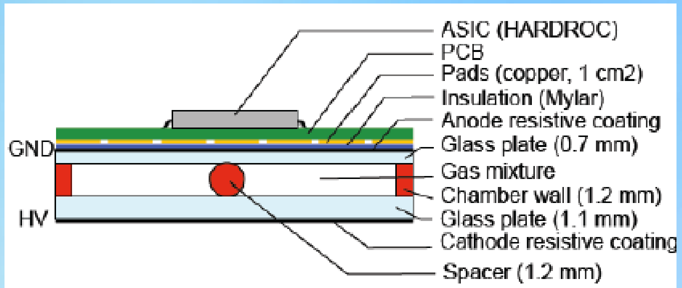




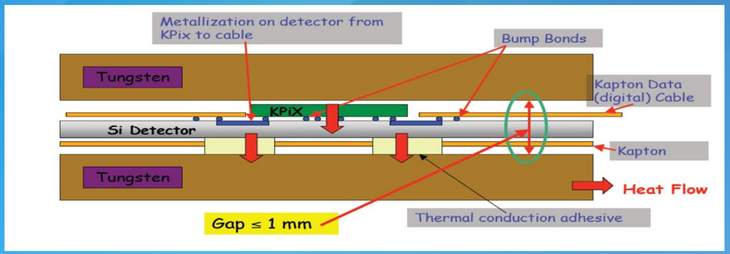
fit results		
	stochastic	constant
initial	57.6%	1.6%
global SC	45.8%	1.6%
local SC	44.3%	1.8%

ILC TDR Vol. 4

SDHCAL

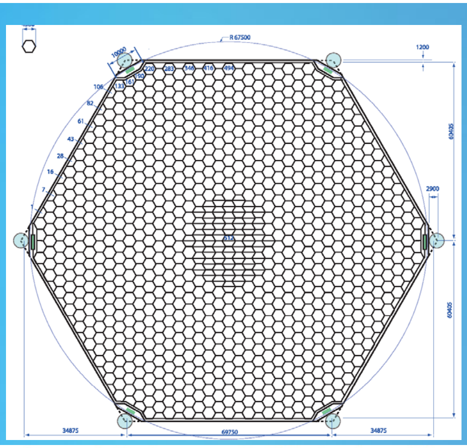


SiD Electromagnetic Calorimeter



Highly granular “imaging” calorimetry essential for ILC physics program:

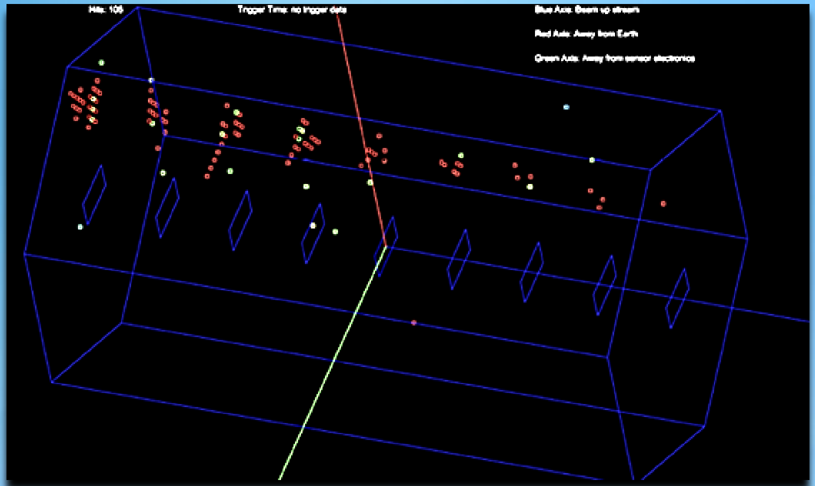
- Particle id/reconstruction
- Tracking charged particles
- Integral part of Particle Flow detector design

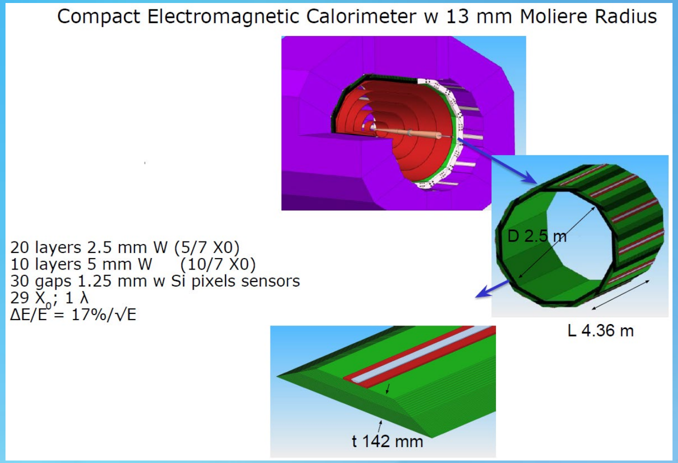


1024 pixels
13 mm²

Baseline design: Silicon/Tungsten

Single electron event

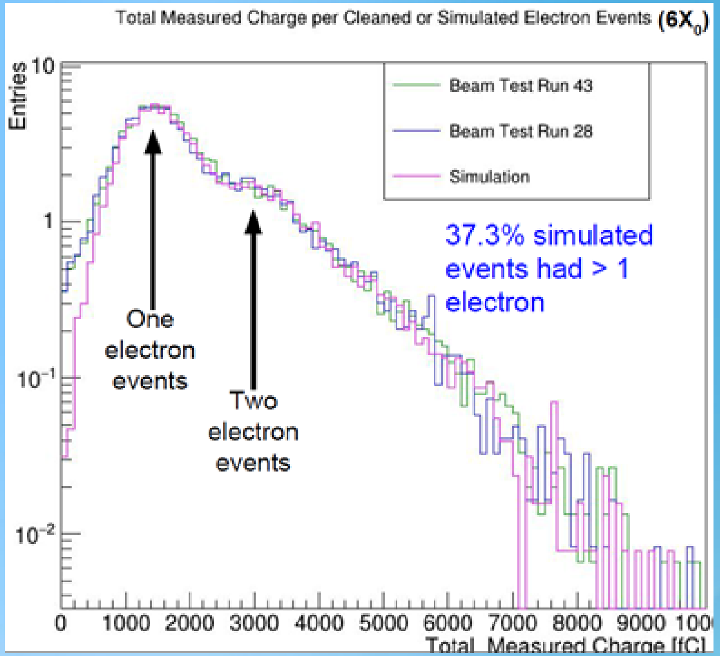




Compact Electromagnetic Calorimeter w 13 mm Moliere Radius

20 layers 2.5 mm W (5/7 X0)
10 layers 5 mm W   (10/7 X0)
30 gaps 1.25 mm w Si pixels sensors
29 X_0; 1 λ
ΔE/E = 17%/√E

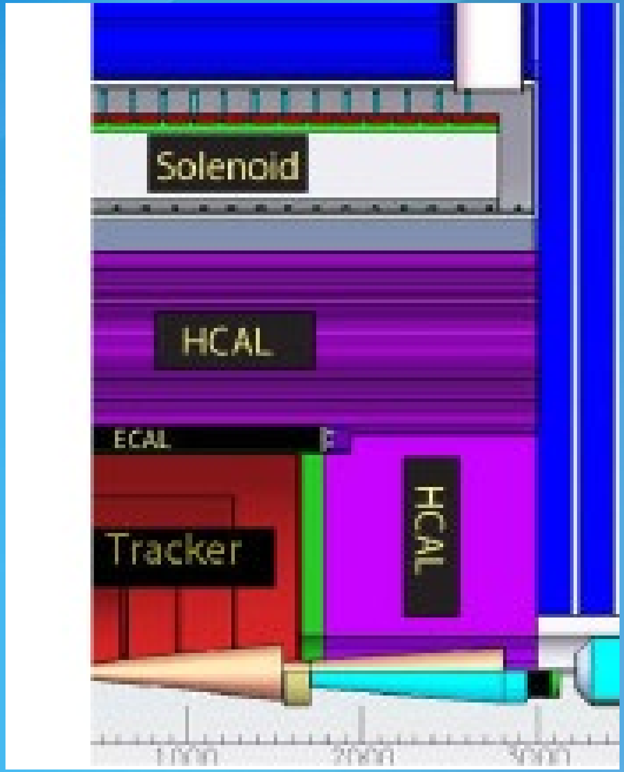
Beam tests,9-layers, SLAC

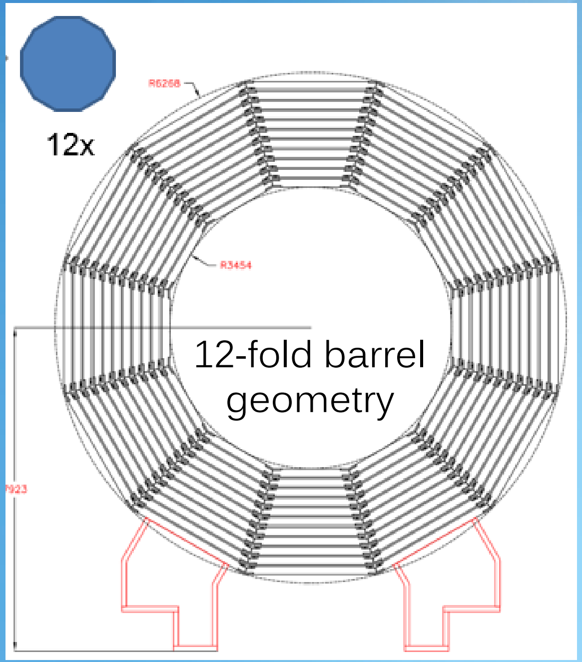


Total Measured Charge per Cleaned or Simulated Electron Events (6X_0)

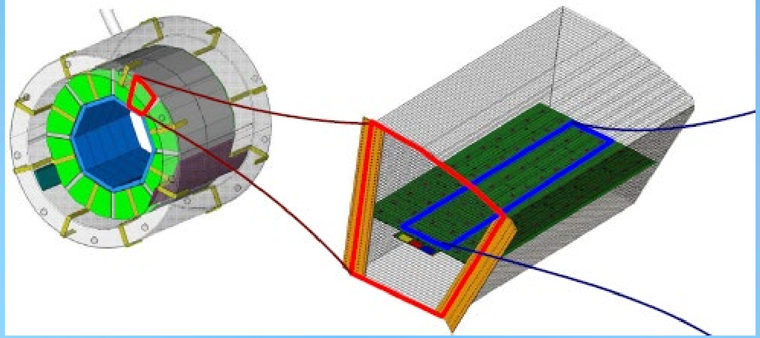
37.3% simulated events had > 1 electron

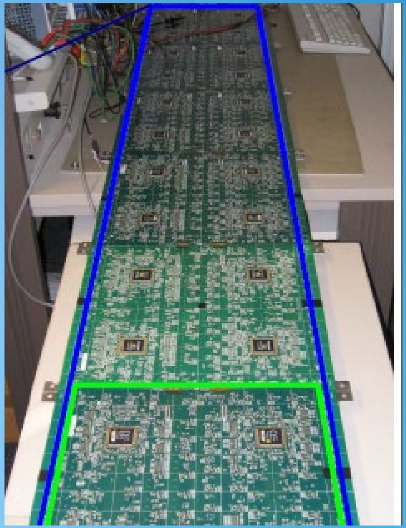
SiD Hadron Calorimeter





12-fold barrel geometry

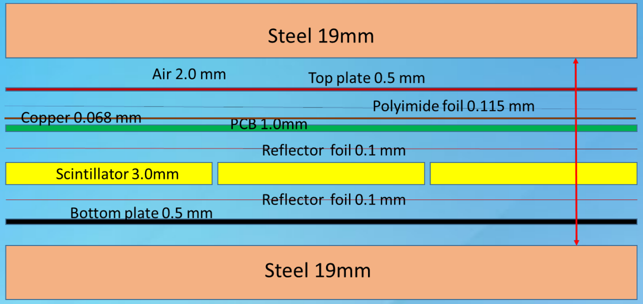




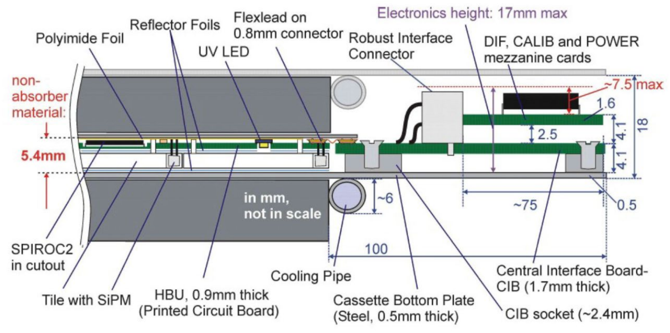
CALICE design

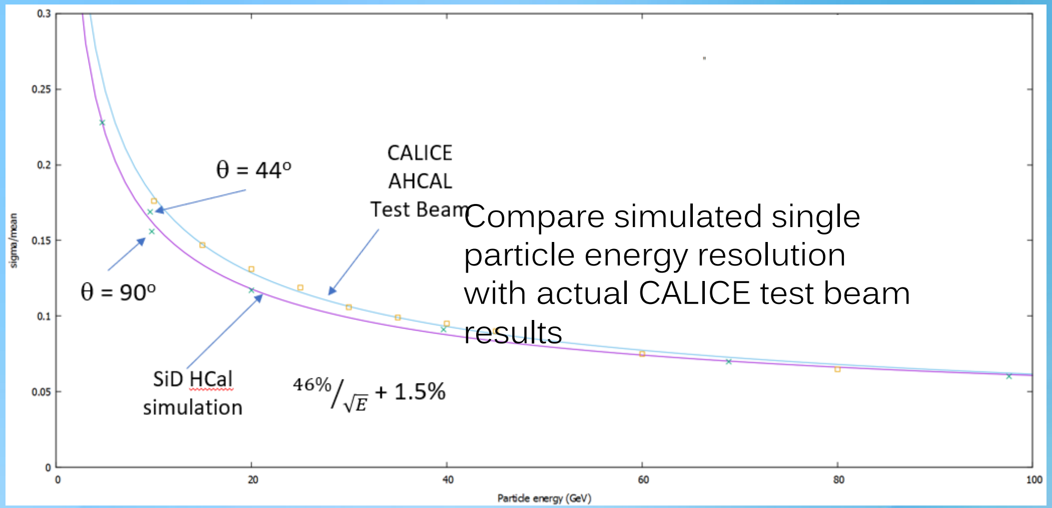
Baseline technology for the SiD HCal is Scintillator/SiPM/Steel

Similar issues for CMS HGCAL



Active layer thickness = 7.383 mm

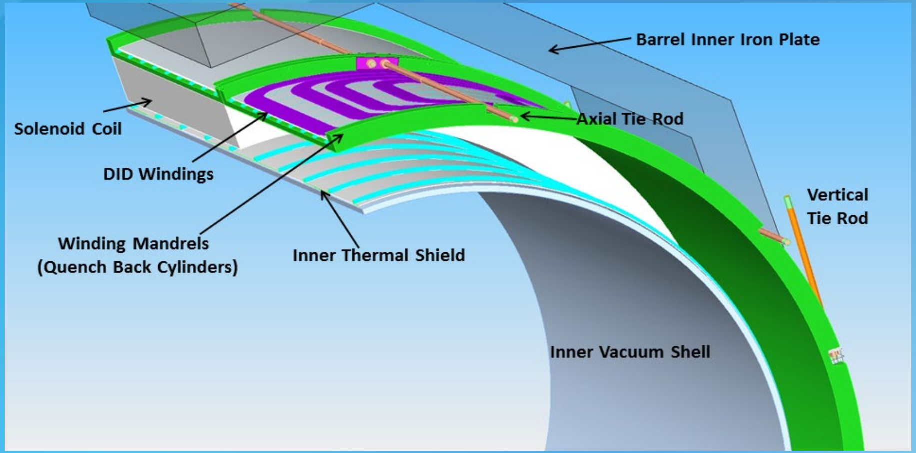




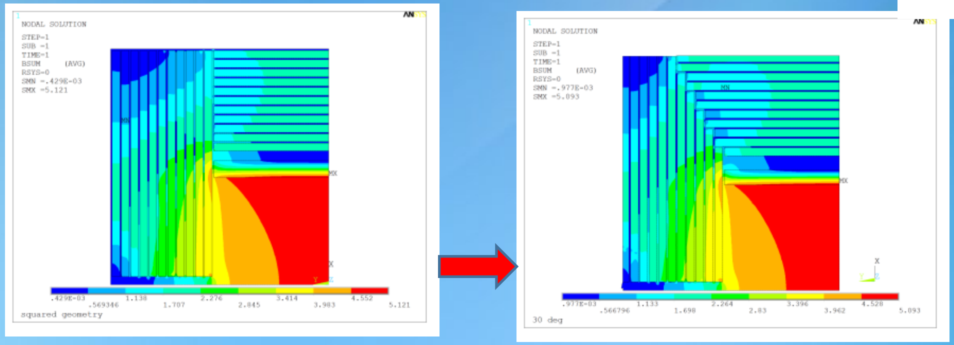
Compare simulated single particle energy resolution with actual CALICE test beam results

SiD Solenoid

Baseline CMS conductor

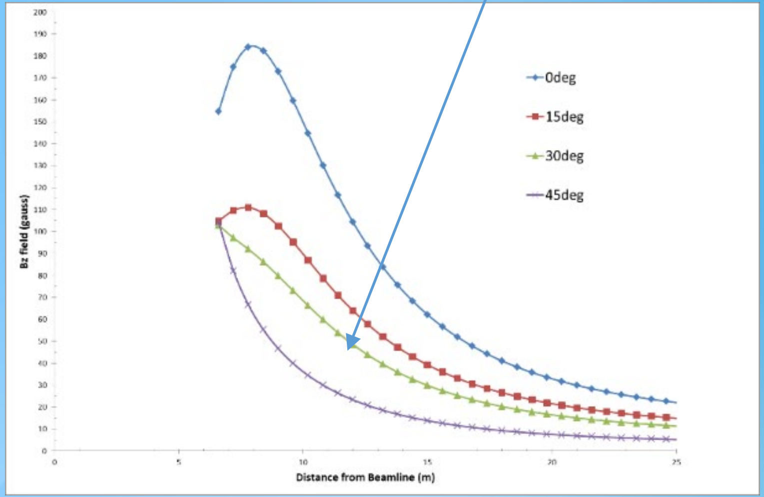


30^{o} design



Redesign of barrel/door junction
More efficient flux return
Easier transport/handling

< 50 Gauss at 15m/30 deg cut



Early start on coil development is critical for both SiD and ILD – no current producer of CMS-style conductor - potential showstopper!

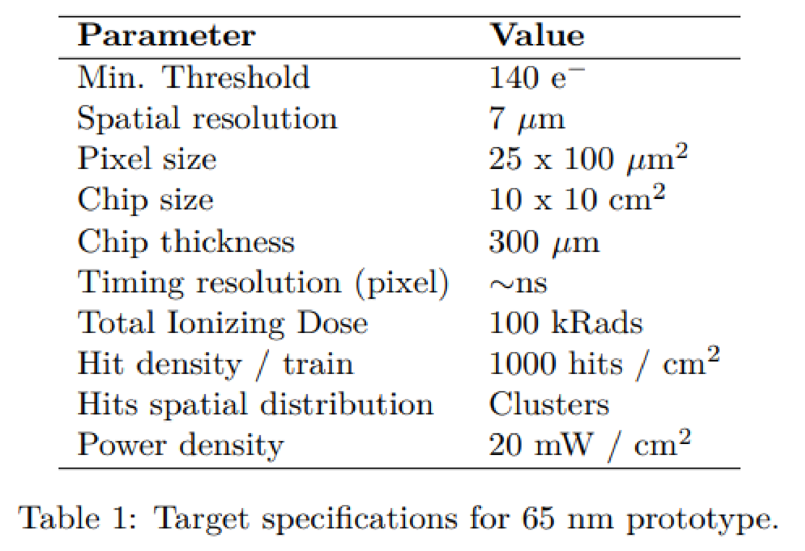
Conclusions from recent CERN Magnet Workshop

- Al-stabilized superconductor technology is appropriate for HEP detector magnet technology.

- CICC (Cable-in-conduit conductor) approach may also be a solution

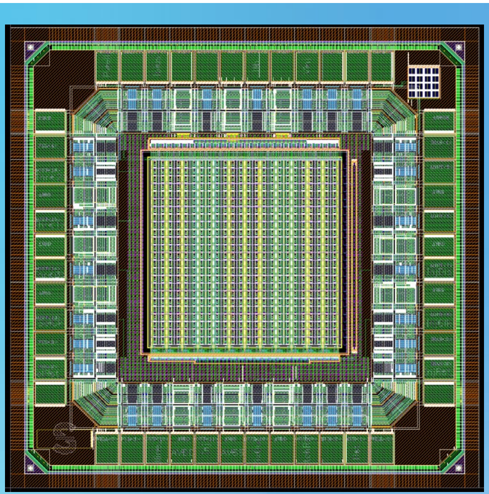
(see also: arxiv.org/2203.07799)

Monolithic Active Pixels for Tracking



Parameter	Value
Min. Threshold	140 e^-
Spatial resolution	7 μm
Pixel size	25 x 100 μm^2
Chip size	10 x 10 cm^2
Chip thickness	300 μm
Timing resolution (pixel)	$\sim$ns
Total Ionizing Dose	100 kRads
Hit density / train	1000 hits / cm^2
Hits spatial distribution	Clusters
Power density	20 mW / cm^2

Table 1: Target specifications for 65 nm prototype.



- Potential for providing higher granularity, thinner, intelligent detectors at lower overall cost.

- Stitching – large scale sensors, reduced dead areas

- Lower power, lower cost, less material.

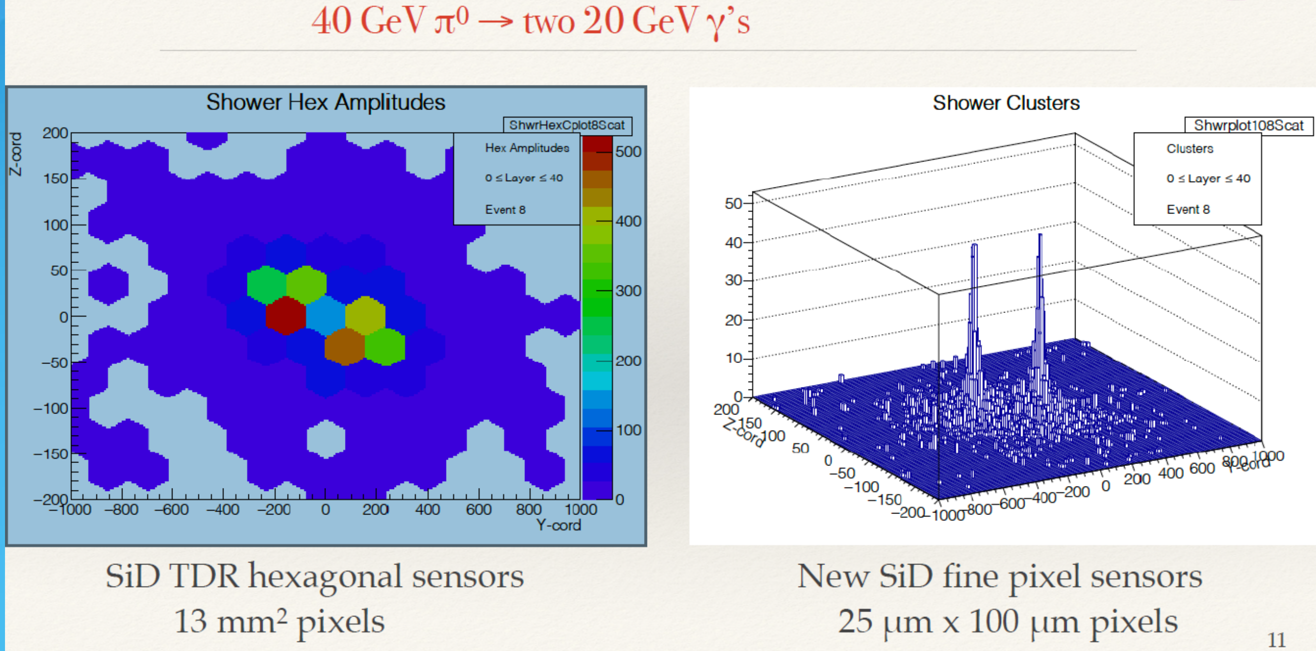
- Fully-depleted MAPS/CMOS: faster charge collection, higher efficiency, less cross-pixel charge sharing

- SLAC working in WP1.2 collaboration at CERN
- ALICE ITS3 upgrade main driver
- Design 1.5x1.5 mm^2 prototype with few pixels to test sensor + front-end
- Submission of first prototype in 2022

- Study sensor performance on TowerSemi 65 nm process
- Feedback from WP 1.2 measurements at CERN

This is a major research area that needs urgent, targeted R&D support.

MAPS-based Electromagnetic Calorimetry



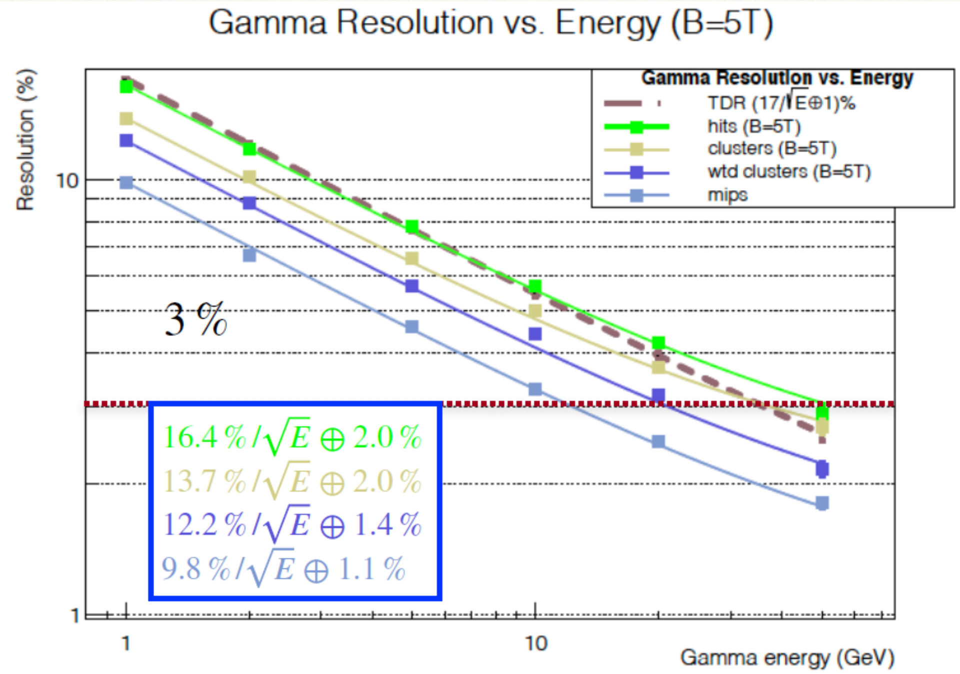
40 GeV $\pi^0 \rightarrow$ two 20 GeV γ's

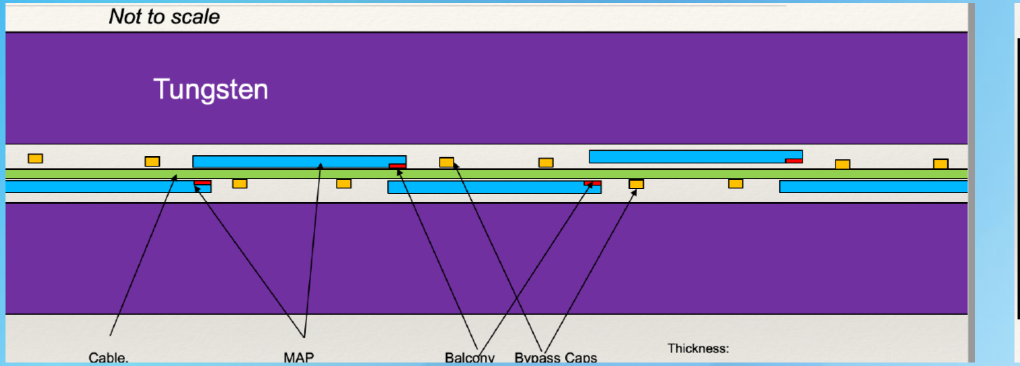
SiD TDR hexagonal sensors
13 mm² pixels

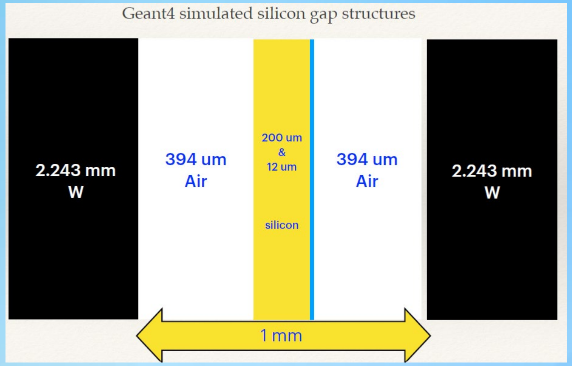
New SiD fine pixel sensors
25 μm x 100 μm pixels

11

Instruments 2022, 6(4), 51







Geant4 simulated silicon gap structures

High Priority, Critical R&D Needed

Technology R&D

Superconducting Coil(s) - wire and winding techniques, project with industry

MAPS for Tracking and ECal – stitching, large scale sensors, reduced dead areas

Pixel readout for TPC – GridPix dE/dx from cluster counting

Fast timing/power requirements – explore benefits for tracking/calorimetry

Detector Concept development

Concept major parameters: overall dimensions, magnet field strength, MDI, services

Major subsystems: main calorimeters, magnet return yoke, tracker and their interplay

Strategy for assembly and installation of detectors

ILC Timeline

Developed to match success-oriented ILC timeline from IDT

The significant work already done on ILC detectors makes this aggressive timeline achievable.

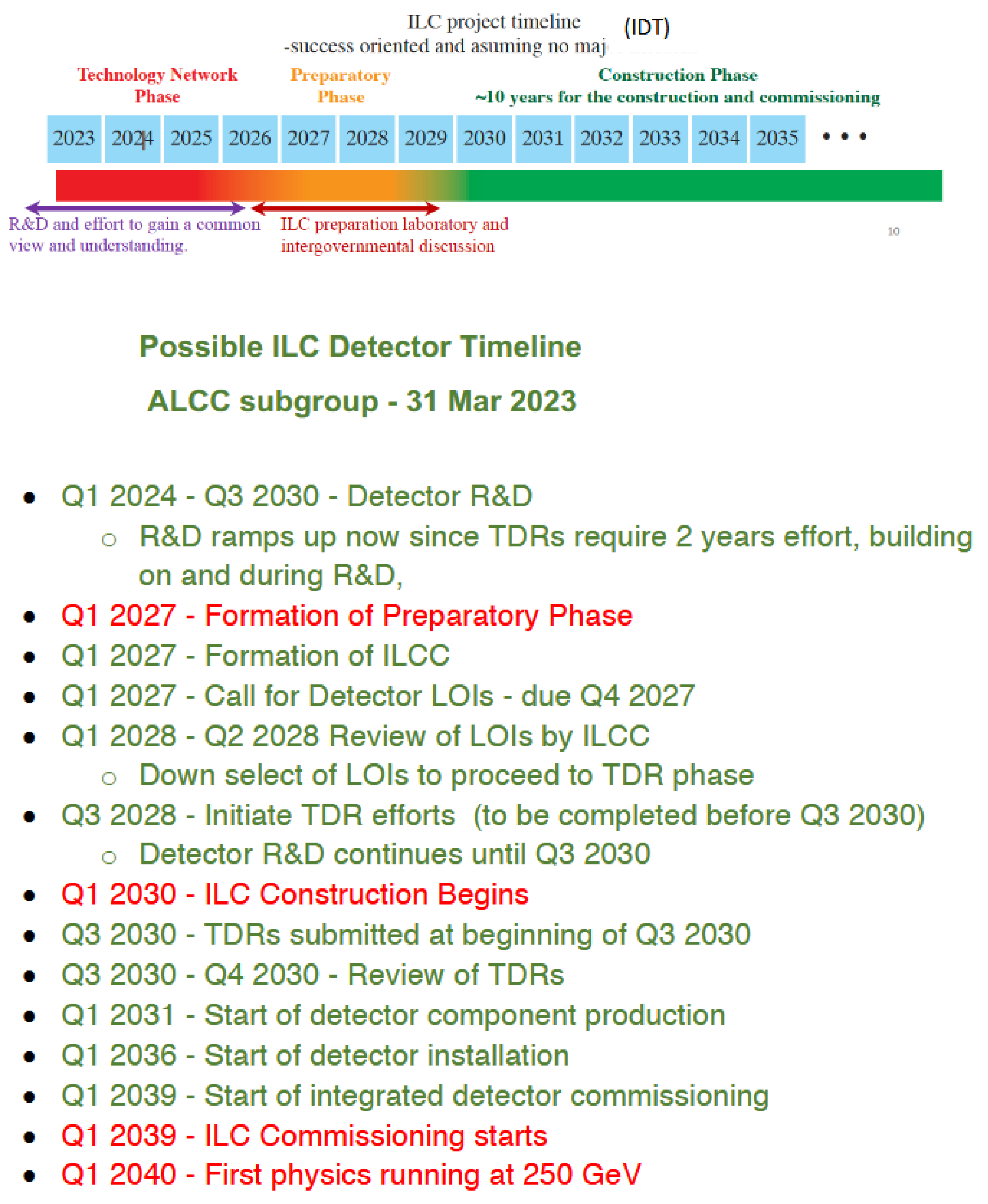
To respond to this timeline two development lines are needed:

- Detector R&D on specific technologies.

- Development of Detector Concepts towards the TDR stage

For both these lines new ideas are always welcome for new technologies

…and/or new detector concepts.



ILC project timeline (IDT)
-success oriented and asuming no maj

Technology Network Phase | **Preparatory Phase** | **Construction Phase**
~10 years for the construction and commissioning

2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 • • •

R&D and effort to gain a common view and understanding.

ILC preparation laboratory and intergovernmental discussion

10

Possible ILC Detector Timeline

ALCC subgroup - 31 Mar 2023

- Q1 2024 - Q3 2030 - Detector R&D
    - R&D ramps up now since TDRs require 2 years effort, building on and during R&D,
- Q1 2027 - Formation of Preparatory Phase
- Q1 2027 - Formation of ILCC
- Q1 2027 - Call for Detector LOIs - due Q4 2027
- Q1 2028 - Q2 2028 Review of LOIs by ILCC
    - Down select of LOIs to proceed to TDR phase
- Q3 2028 - Initiate TDR efforts (to be completed before Q3 2030)
    - Detector R&D continues until Q3 2030
- Q1 2030 - ILC Construction Begins
- Q3 2030 - TDRs submitted at beginning of Q3 2030
- Q3 2030 - Q4 2030 - Review of TDRs
- Q1 2031 - Start of detector component production
- Q1 2036 - Start of detector installation
- Q1 2039 - Start of integrated detector commissioning
- Q1 2039 - ILC Commissioning starts
- Q1 2040 - First physics running at 250 GeV

Conclusions

- A Higgs Factory has been identified via the Snowmass process as the highest HEP priority after HL-LHC upgrades construction – also consistent with European Strategy and JAHEP statement.

- A Linear Collider offers unique features, such as polarization and extensibility of energy range, that will fully map the Higgs Physics Program, including self-interaction, in a timely manner.

- Development over an extended period has resulted in two validated e^+e^- detector concepts.

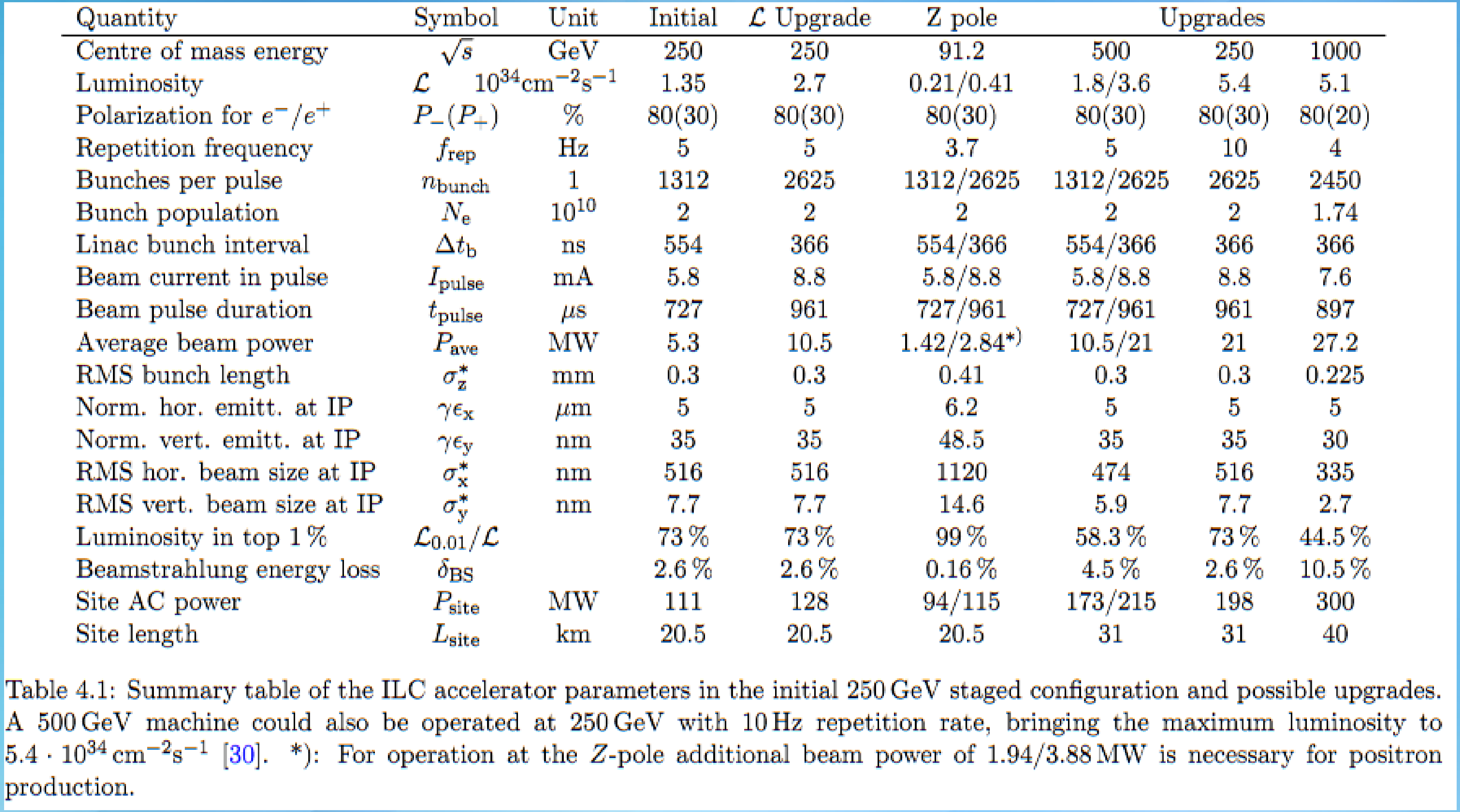
- R&D is needed for technologies beyond the original designs

- Support is needed to bring ILC detectors to the TDR stage.

- In order for the US to play a major role in a Higgs Factory an **"immediate, vigorous and targeted detector R&D program" (Snowmass EF report) is needed.**

Extra

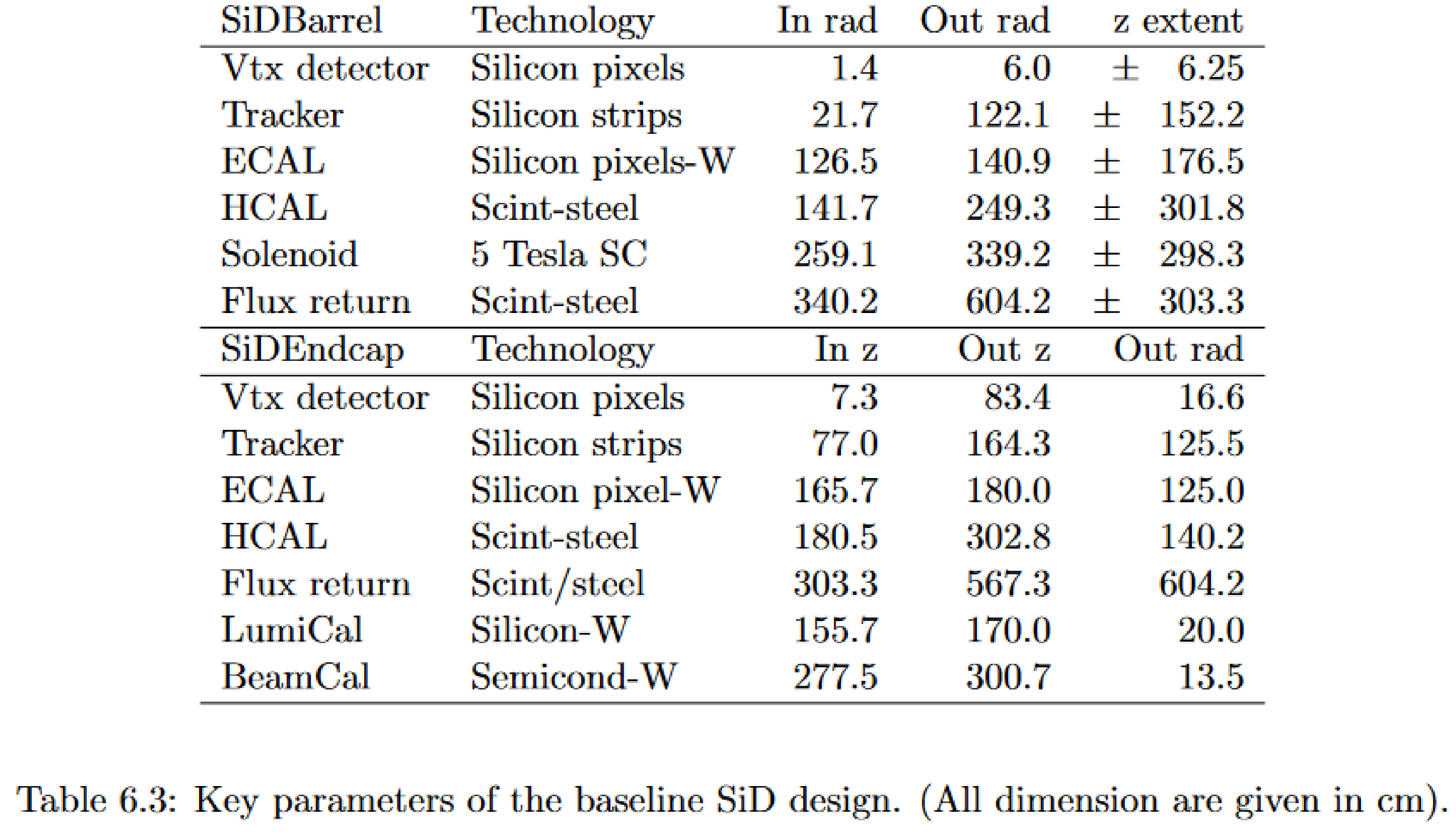
ILC Parameters



Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ^*_{z}	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	6.2	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	48.5	35	35	30
RMS hor. beam size at IP	σ^*_{x}	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	128	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [30]. *): For operation at the Z-pole additional beam power of 1.94/3.88 MW is necessary for positron production.

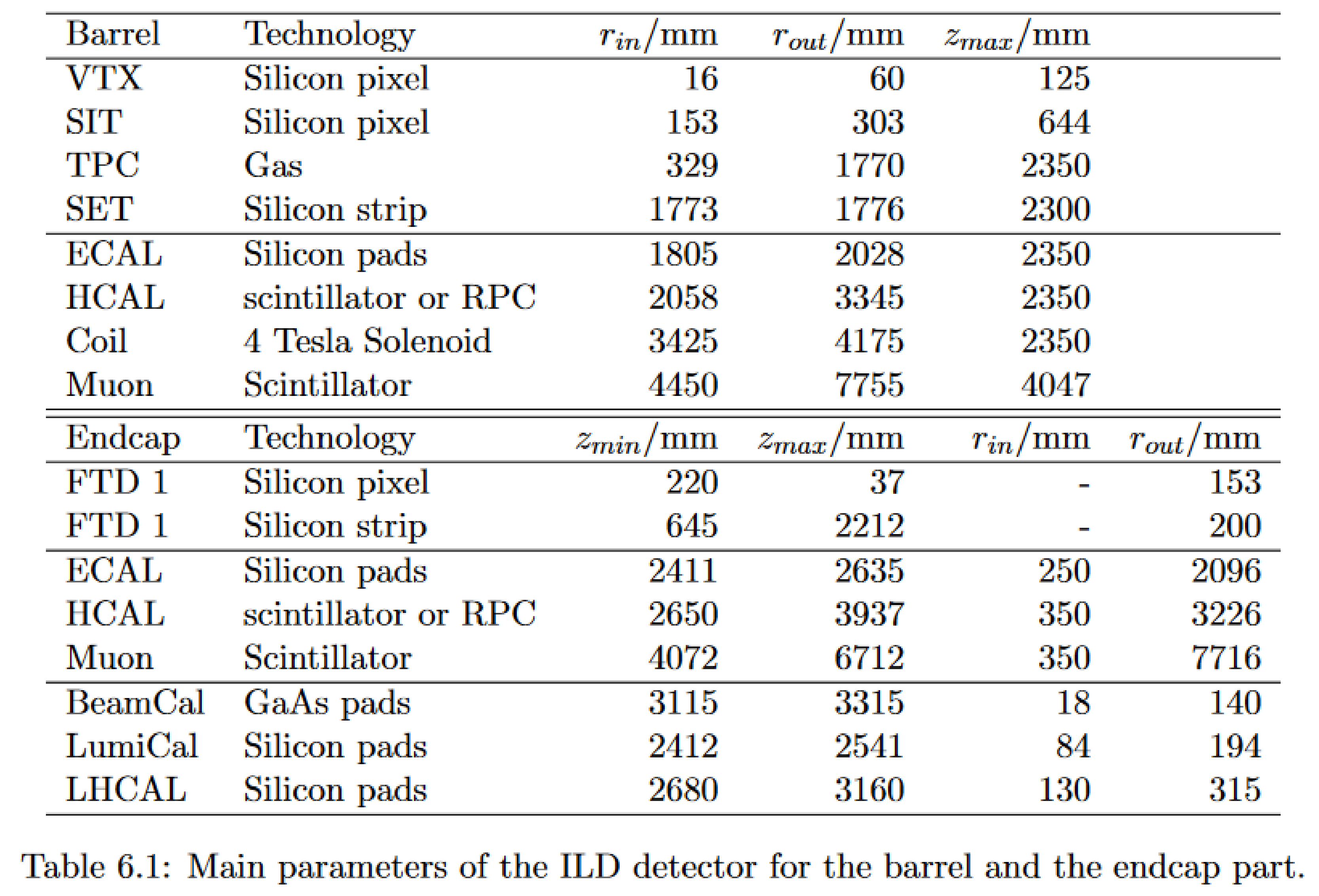
SiD Parameters



SiDBarrel	Technology	In rad	Out rad	z extent
Vtx detector	Silicon pixels	1.4	6.0	± 6.25
Tracker	Silicon strips	21.7	122.1	± 152.2
ECAL	Silicon pixels-W	126.5	140.9	± 176.5
HCAL	Scint-steel	141.7	249.3	± 301.8
Solenoid	5 Tesla SC	259.1	339.2	± 298.3
Flux return	Scint-steel	340.2	604.2	± 303.3
SiDEndcap	**Technology**	**In z**	**Out z**	**Out rad**
Vtx detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	Scint-steel	180.5	302.8	140.2
Flux return	Scint/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semicond-W	277.5	300.7	13.5

Table 6.3: Key parameters of the baseline SiD design. (All dimension are given in cm).

ILD Parameters

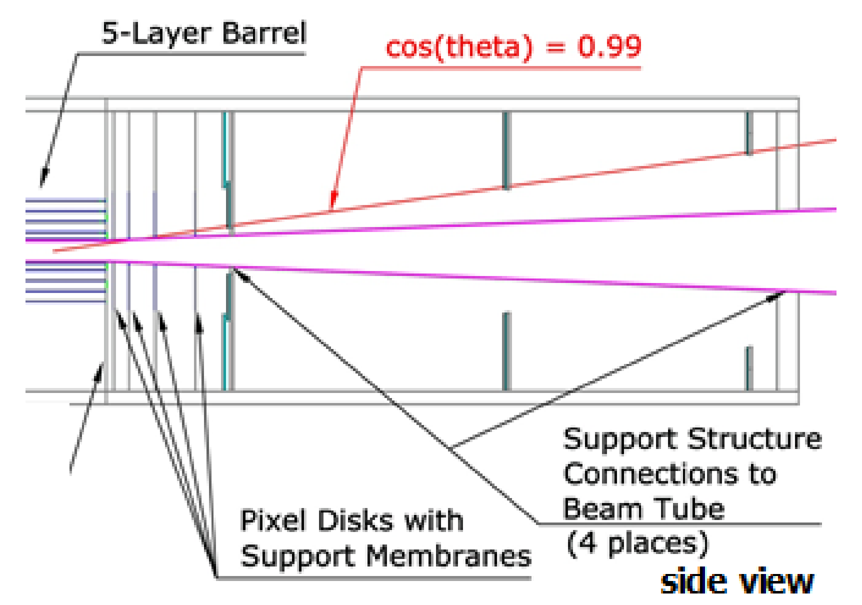


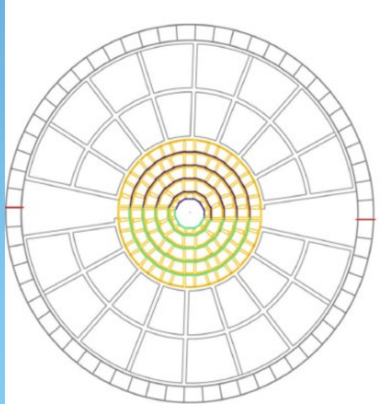
Barrel	Technology	r_{in}/mm	r_{out}/mm	z_{max}/mm
VTX	Silicon pixel	16	60	125
SIT	Silicon pixel	153	303	644
TPC	Gas	329	1770	2350
SET	Silicon strip	1773	1776	2300
ECAL	Silicon pads	1805	2028	2350
HCAL	scintillator or RPC	2058	3345	2350
Coil	4 Tesla Solenoid	3425	4175	2350
Muon	Scintillator	4450	7755	4047

Endcap	Technology	z_{min}/mm	z_{max}/mm	r_{in}/mm	r_{out}/mm
FTD 1	Silicon pixel	220	37	-	153
FTD 1	Silicon strip	645	2212	-	200
ECAL	Silicon pads	2411	2635	250	2096
HCAL	scintillator or RPC	2650	3937	350	3226
Muon	Scintillator	4072	6712	350	7716
BeamCal	GaAs pads	3115	3315	18	140
LumiCal	Silicon pads	2412	2541	84	194
LHCAL	Silicon pads	2680	3160	130	315

Table 6.1: Main parameters of the ILD detector for the barrel and the endcap part.

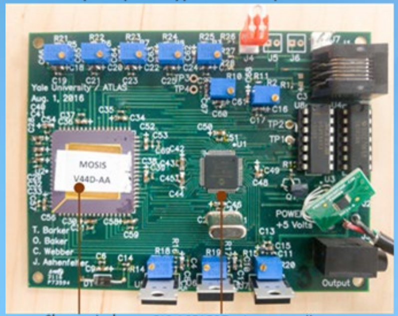
SiD Tracking: A Robust, Low Material, High Precision Silicon System Vertex Detector





Chronopixel - Oregon, Yale

Chronopixel prototype 3 development board



- monolithic CMOS design
  90 nm feature size,
  7 μm epitaxial layer
  280 μm thick chip
  10 ohm·cm
  manufactured by TSMC
- store up to 2 hits per pixel, 12 bit per timestamps
- 25 μm pixel pitch
- implements 6 sensor diode options

Prototype 3 satisfies ILC design Requirements
Also considering 3D pixels, HV CMOS,…

Preliminary ideas for mechanical design.
Power pulsing, forced air cooling

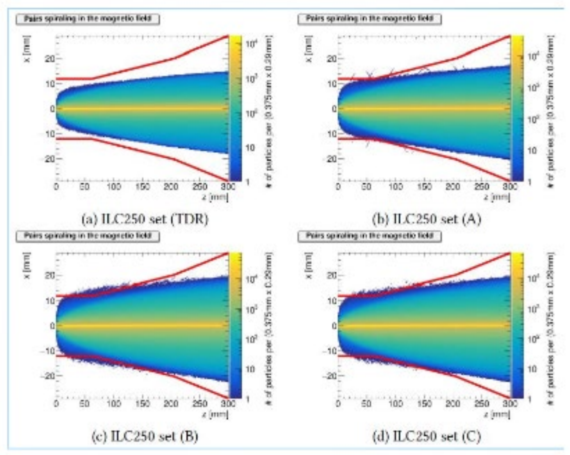
5T field allows first layer to be very close to the beam.

R_{min} = 14mm.

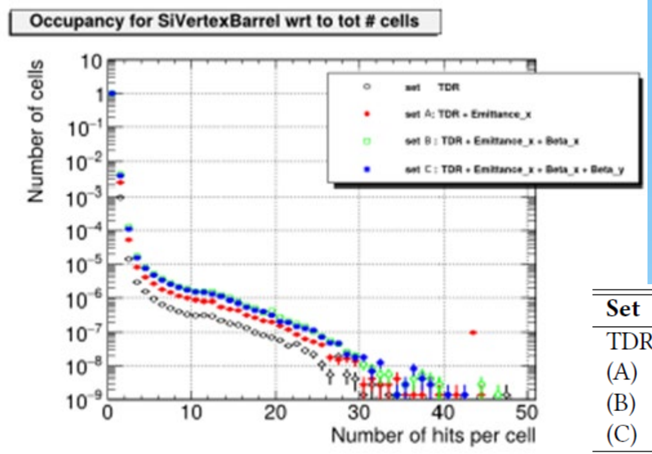
Pair background/Occupancy study

Very challenging requirements

- < 3 μm hit resolution
- Feature size ~20 μm
- ~0.1% X_0 per layer material budget
- < 130 μW / mm^2
- Single bunch time resolution



(a) ILC250 set (TDR)
(b) ILC250 set (A)
(c) ILC250 set (B)
(d) ILC250 set (C)

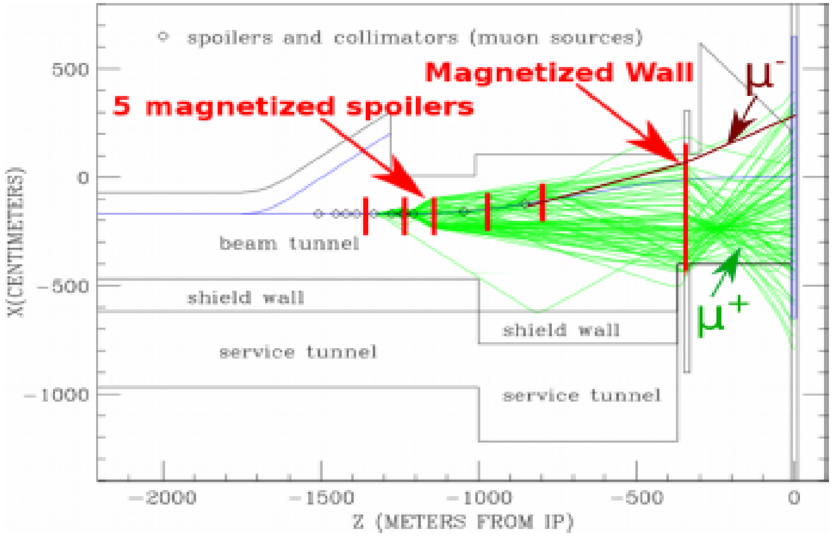


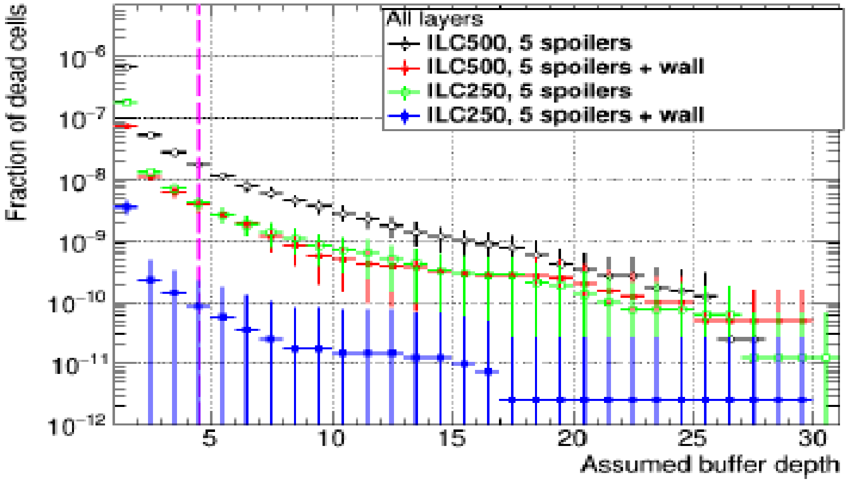
Anne Schuetz
(DESY)

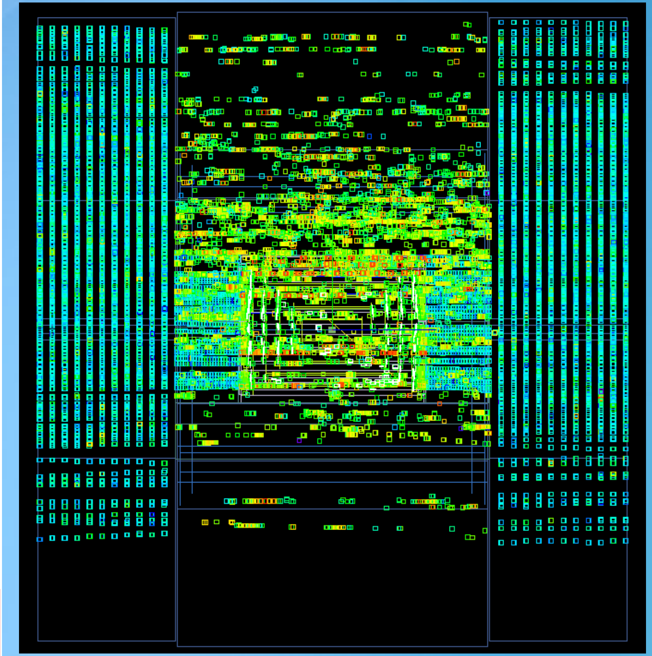
Set	ϵ_x [μm]	β_x [mm]	β_y [mm]
TDR	10	13.0	0.41
(A)	5	13.0	0.41
(B)	5	9.19	0.41
(C)	5	9.19	0.58

MDI Studies

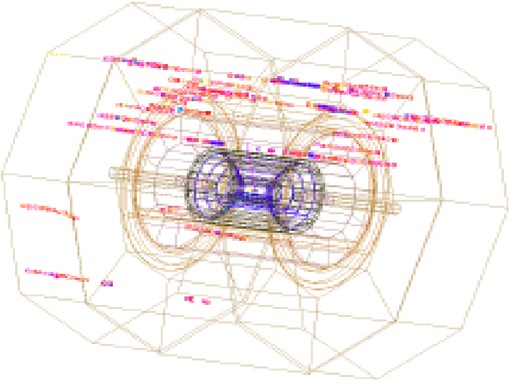
BDS muon study







#muons / bunch crossing	ILC250	ILC500
No shielding	39.3	130.1
Magnetized spoilers	1.3	4.3
Magnetized spoilers + wall	0.03	0.6

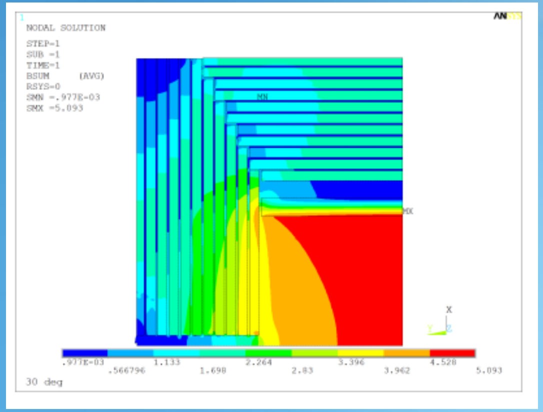


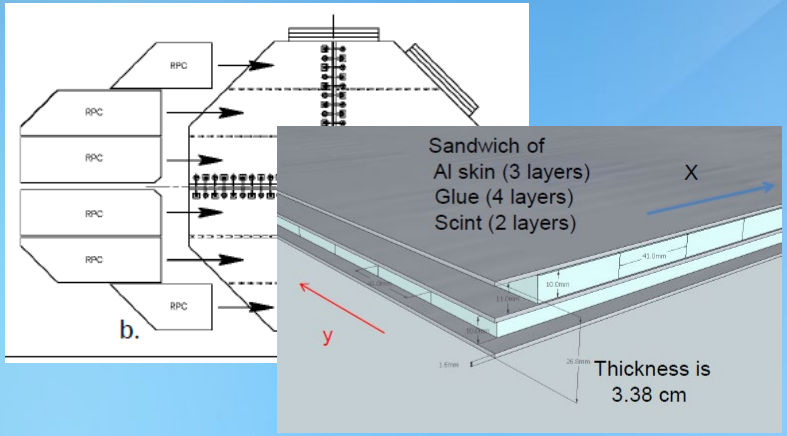
At ILC250, magnetized spoilers without wall are sufficient for occupancy mitigation.

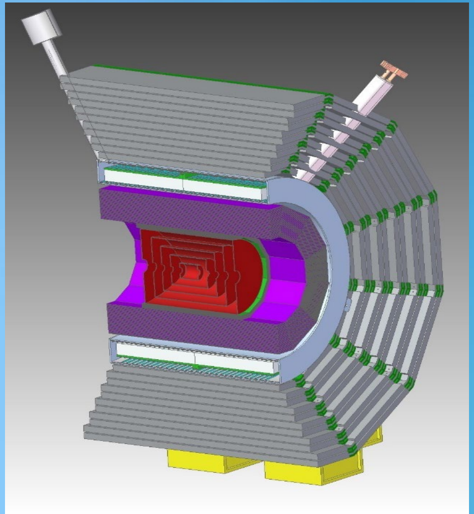
Wall might me neccessary at higher stages, and as a tertiary containment device.

Anne Schuetz
(DESY)

SiD Muon identifier/Calorimeter Tail Catcher





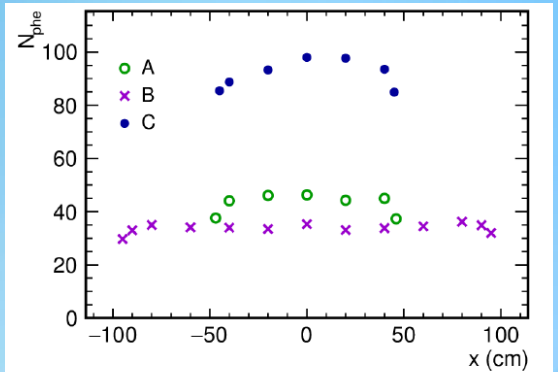


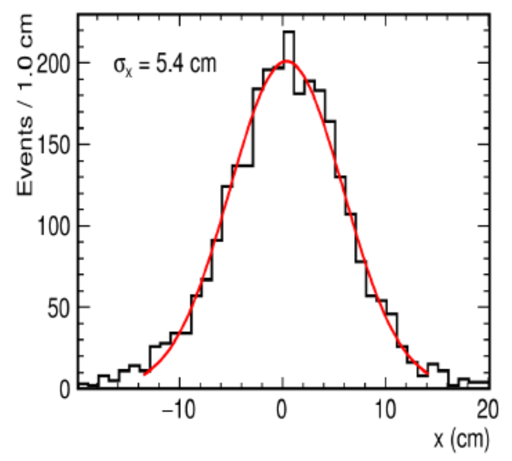
SiD Baseline – long scintillator strips with WLS fiber and SiPM readout

- Consistent extension of the baseline HCal scintillator technology
- Need to optimize number of layers, strip dimensions.

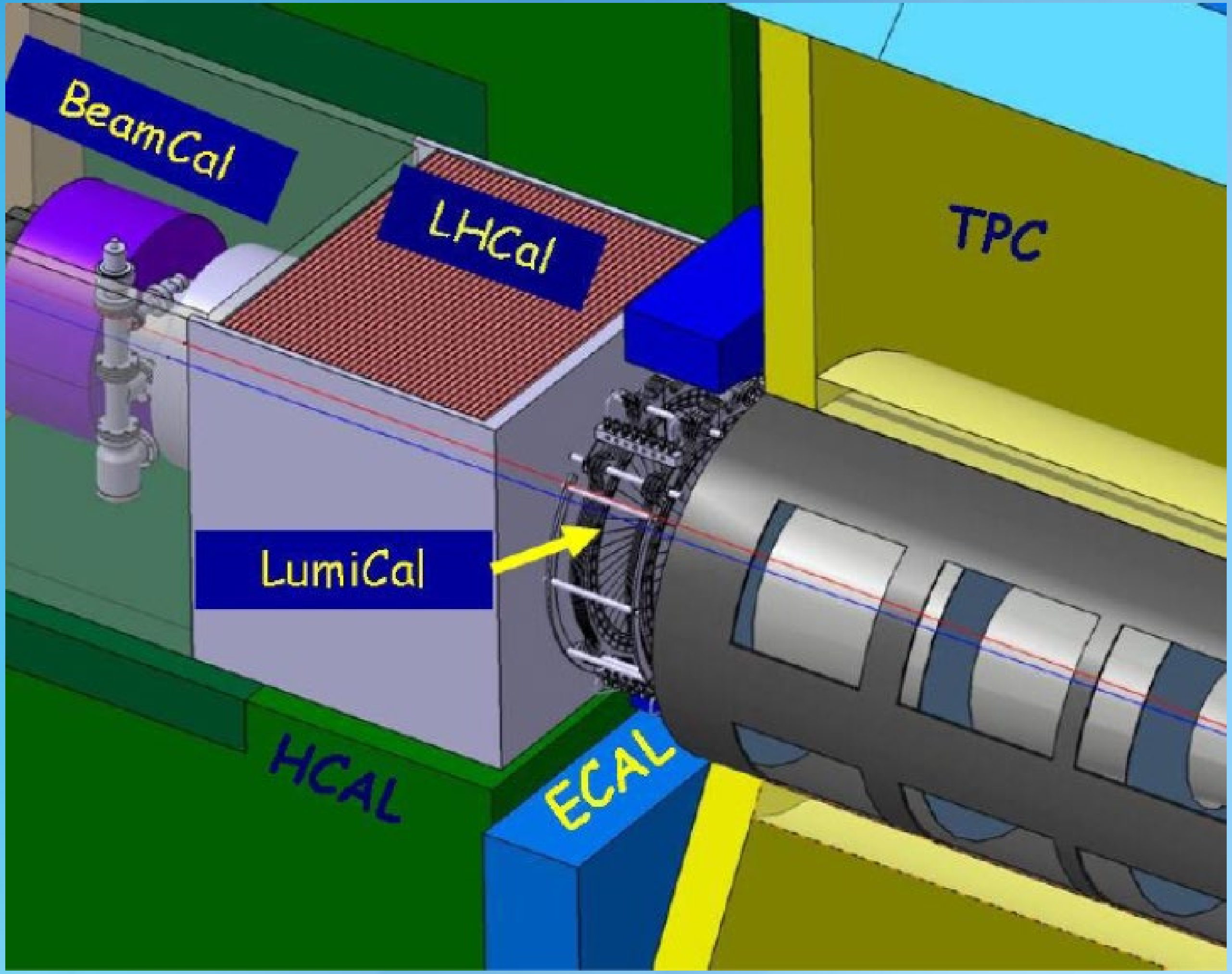
Marco Oriunno
(SLAC)

Development work at Fermilab:





ILD Forward Calorimetry



Goals: Measure precision luminosity (with Bhabhas) and provide hermeticity down to around 5 mrad.

LumiCal (32-74 mr)
LHCal (4l plug)
BeamCal (5-40 mr)

Hermeticity is a strength of linear colliders