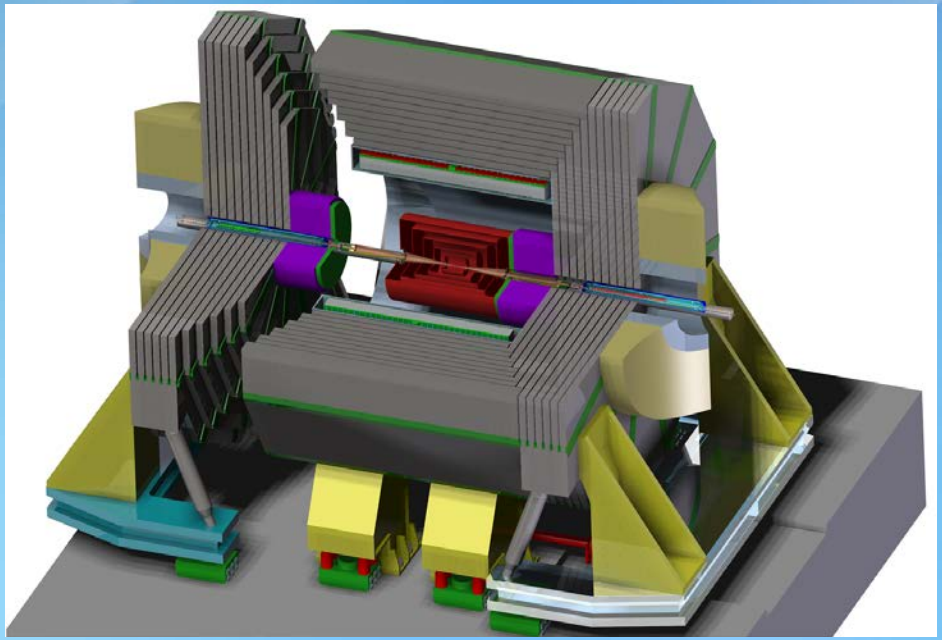
The SiD Detector – for the International Linear Collider

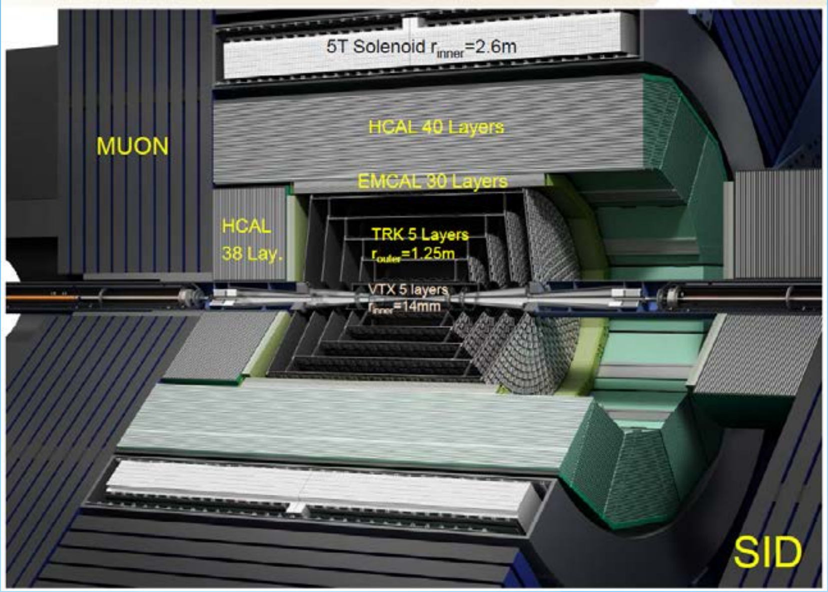
Andy White

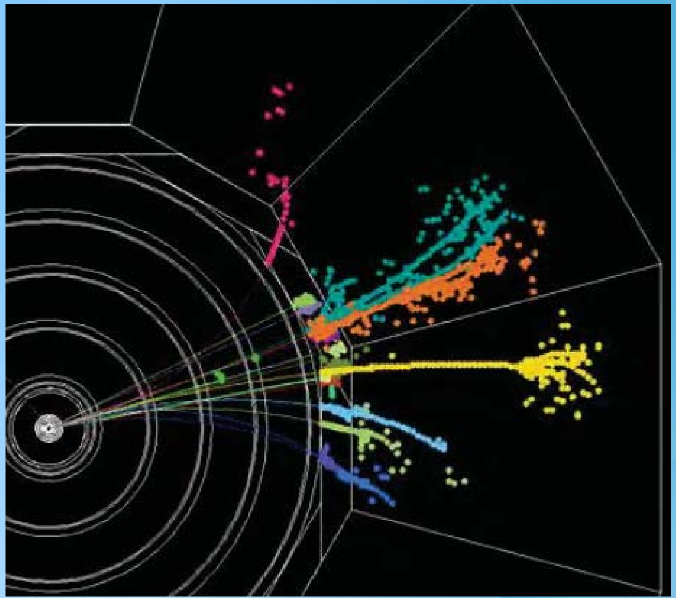
UNIVERSITY OF TEXAS ARLINGTON



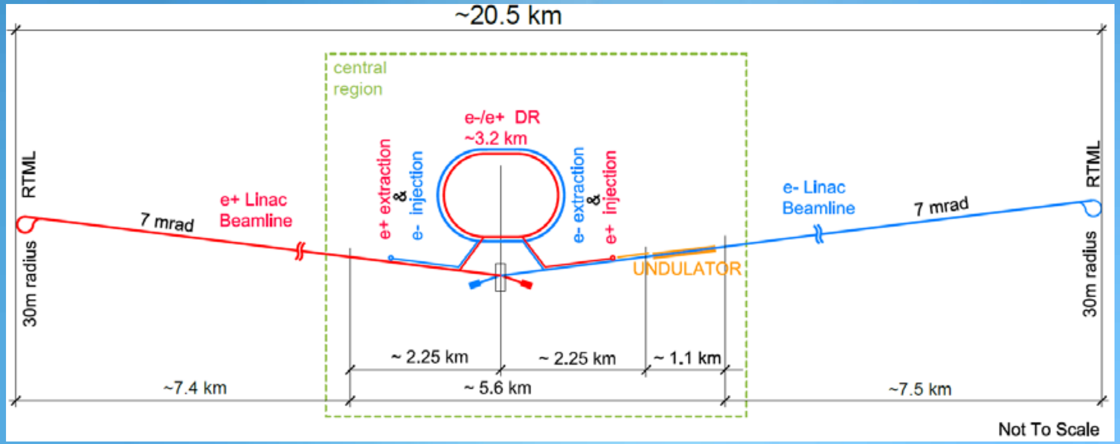
On behalf of the
SiD Consortium
(M. Stanitzki, A.White
Spokespersons)

With thanks to SiD colleagues
for materials provided!

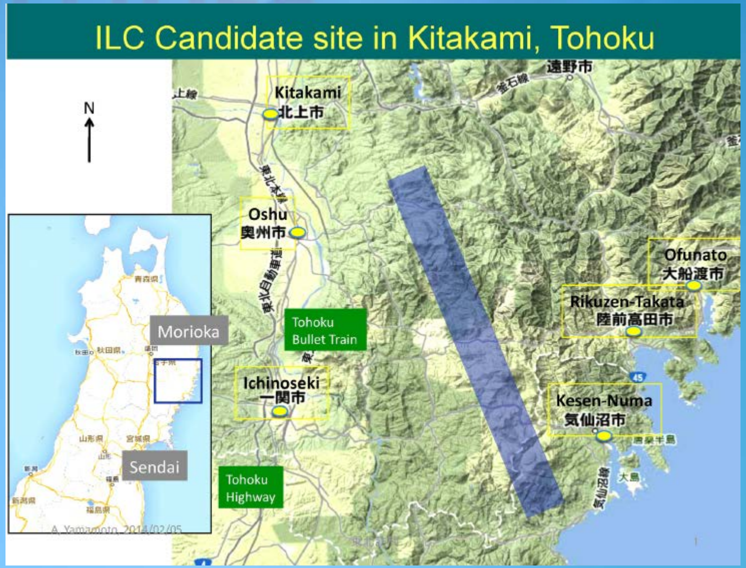




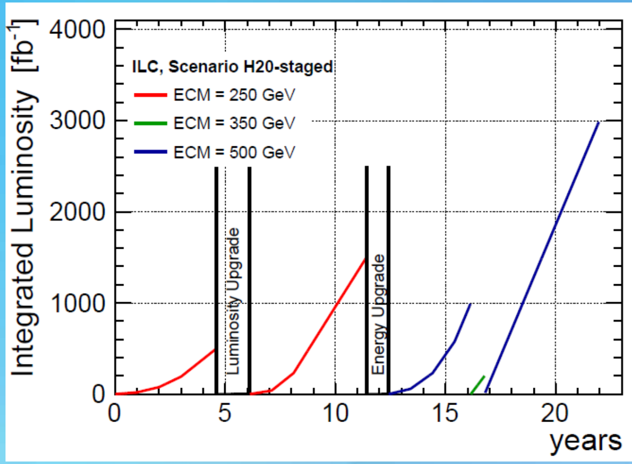
THE INTERNATIONAL LINEAR COLLIDER

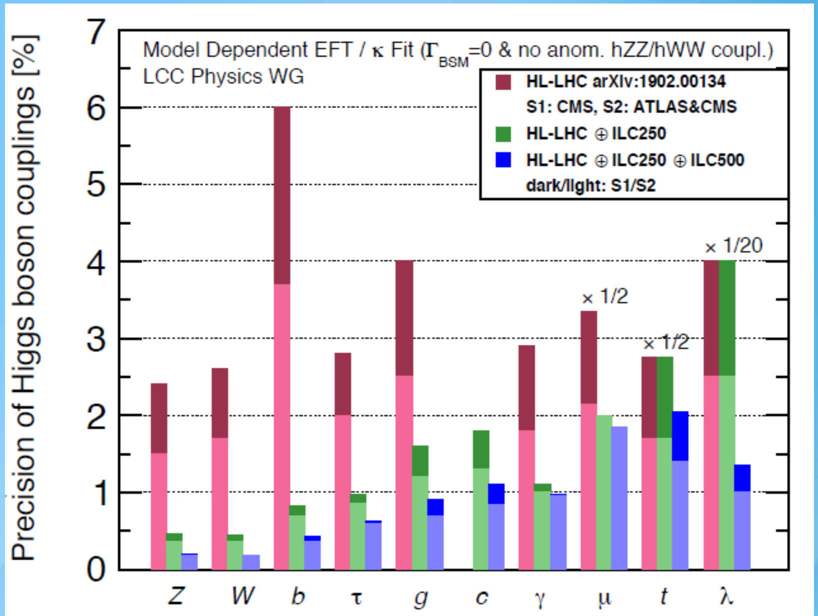


ILC Schematic for 250 GeV staged configuration



Parameter	Initial stage	TDR
C.M. Energy (GeV)	250	500
Length (km)	20	31
Luminosity (x10^{34})	1.35 (2.7, 5.4)	1.8
Repetition (Hz)	5 (10)	5
Beam Pulse Period (ms)	0.73	0.73
Beam Current (mA in pulse)	5.8	5.8
Beam size (y) at FF (nm)	**7.7**	**5.9**
SRF Cavity Gr (MV/m), Q_0	**31.5,** 1x10 ^{10}	**31.5,** 1x10 ^{10}
Site Power (MW)	**129**	**163**





International Linear Collider

European Particle Physics Strategy Update

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

Chris Fall/Director – DoE/Office of Science – HEPAP meeting:

ILC in Japan as an example of US participation in global science

Jim Siegrist/DoE-OHEP - HEPAP meeting:

- Current support from the U.S. to enable Japan move forward with the ILC
  - To strengthen the long-standing U.S.-Japan cooperation in science and technology, concerted effort during last 12-15 months by the U.S. Government — DOE, U.S. State Department, The White House Office of Science & Technology Policy, and the National Security Council — to support a Japanese initiative to move forward to the proposed ILC "Pre-Laboratory" phase of the project

* Expect International Development Team (to setup ILC Pre-Lab) to be in place by August *

The SiD Detector and the SiD Consortium

SiD Detector

SiD Design Study started 2004 (Victoria ALCPG)
Validated by International Detector Advisory Group
Can deliver for the ILC Physics Program as configured

SiD Consortium

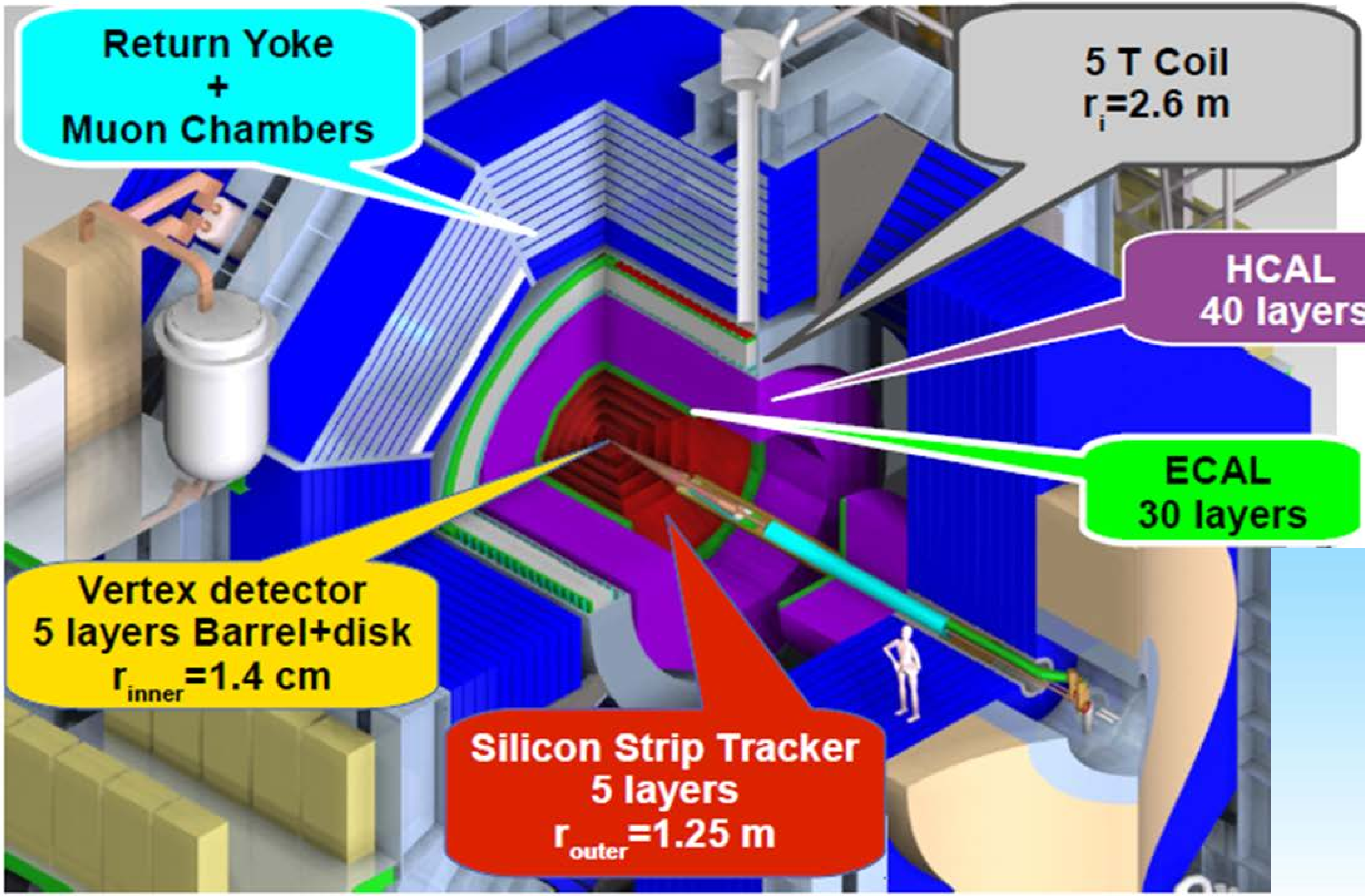
- since 2013
- Byelaws
- Individual and institutional memberships (Guest membership available for Snowmass studies!
- IB Chair – Phil Burrows (U. Oxford)

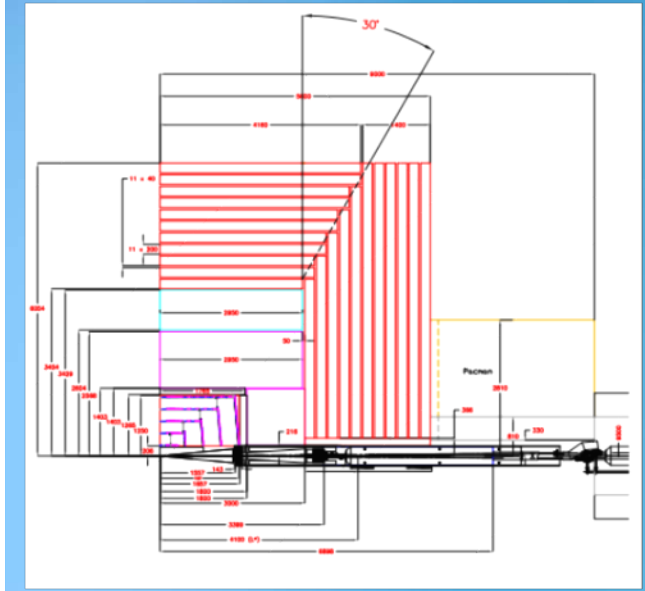
Very open and welcoming of new colleagues to join SiD to make it better by contributing new ideas, upgrades/alternatives– particularly by the younger generation!

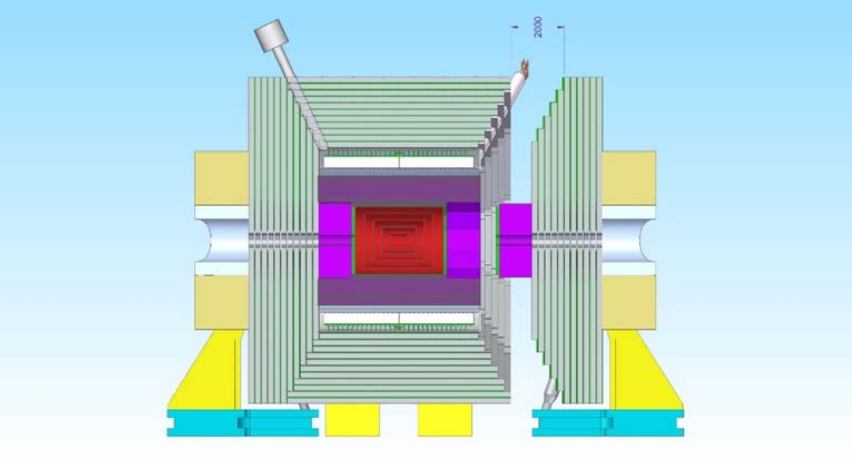
SiD – Required Physics Performance

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

SiD Detector Baseline







The SiD Design Rationale

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

Design basics:

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

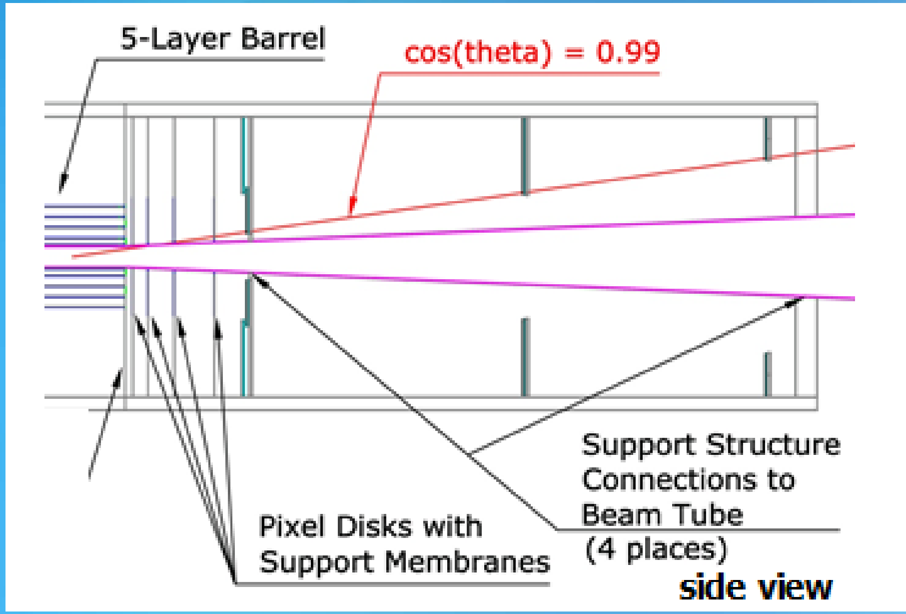
Highly segmented “tracking” calorimeters optimized for Particle Flow.

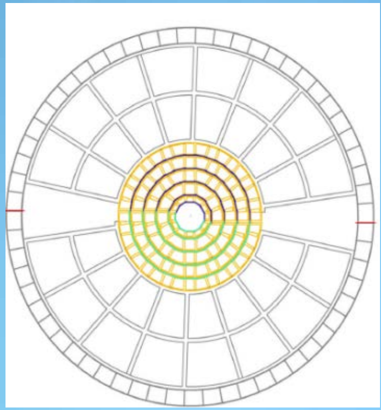
Compact design with 5T field.

Iron flux return/muon identifier – component of SiD self-shielding.

Detector is designed for rapid push-pull operation.

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





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

ILC Beam environment:

Bunch crossing rate (Collisions rate) ~3 MHz
Number of bunches in bunch train up to ~3000
(first 250 GeV stage 1312)
Bunch trains interval – 200 ms. (5 Hertz)

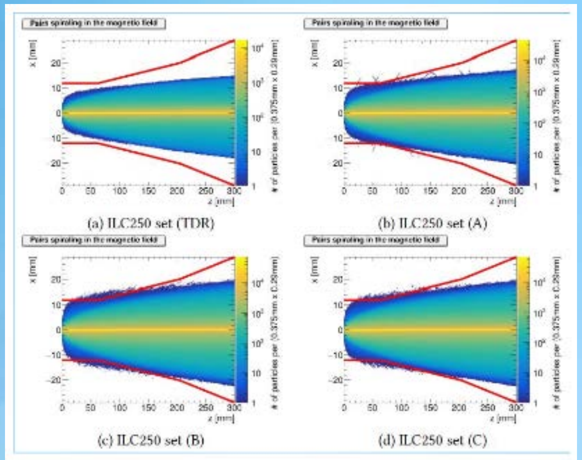
5T field allows first layer to be very close to the beam.

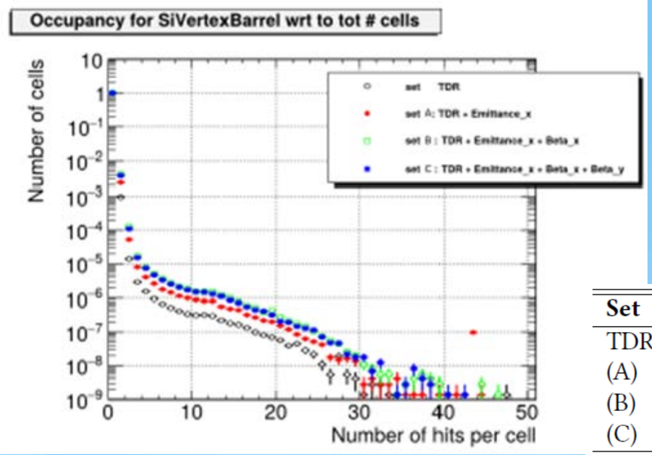
R_{min} = 14mm.

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 / mm²
- Single bunch time resolution





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

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

Three prototypes studied

Chronopixel - Oregon, Yale

Chronopixel prototype 3 development board

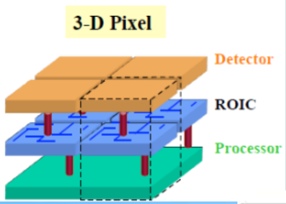
Chronopixel   PIC 16F1527 microcontroller

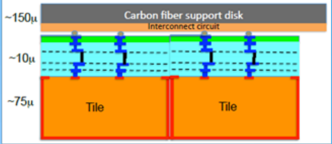
- monolithic CMOS design
  90 nm feature size,
  7 µm epitaxial layer
  280 µm thick chip
  10 ohm·cm
  manufactured by TSMC
- store up to 2 hits per pixel, 12 bit per timestamps
- 25 µm pixel pitch
- implements 6 sensor diode options

Following a multi-year R&D effort, Chronopixel prototype 3 demonstrated a working ILC CMOS vertex sensor that satisfies the ILC design requirements.

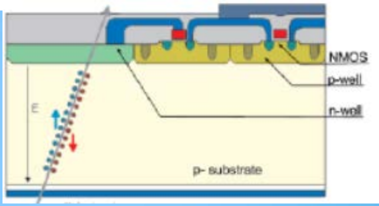
Possible alternatives

Vertically Integrated ("3D")



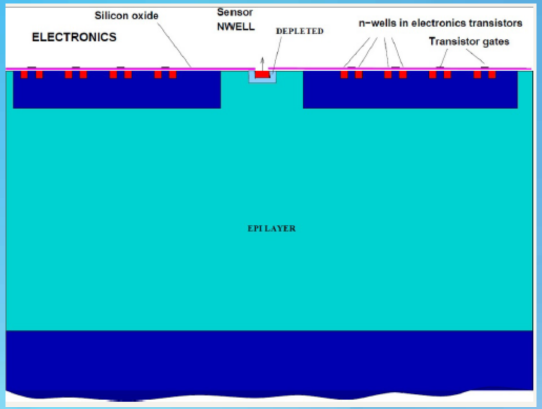


HV CMOS

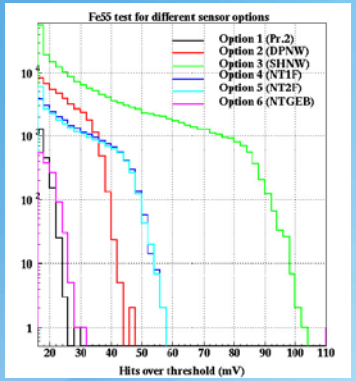


OPPORTUNITY FOR COLLABORATION!

Option 3 – shallow N-WELL



Best option, but more studies needed



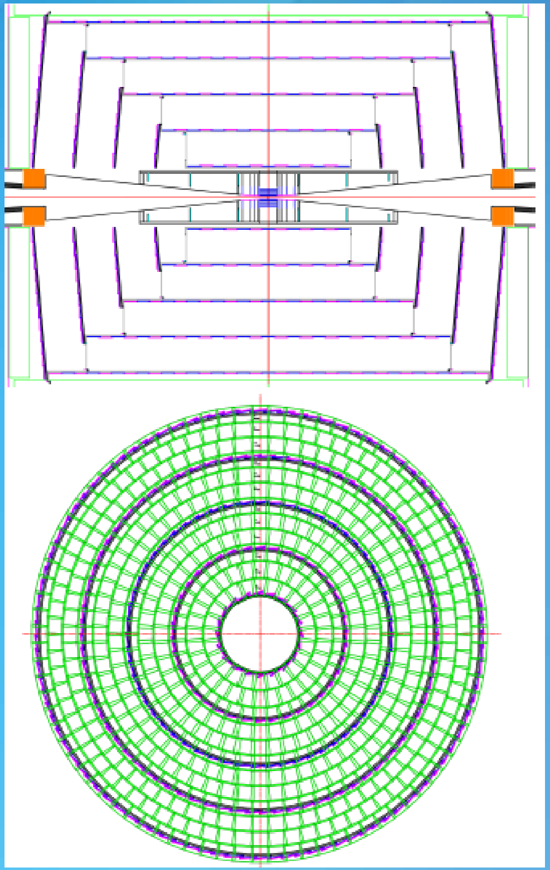
diode option	Capacitance (fF)	µV/e
1	9.0	18
2	6.2	26
3	2.7	59
4	4.9	33
5	4.9	33
6	8.9	18

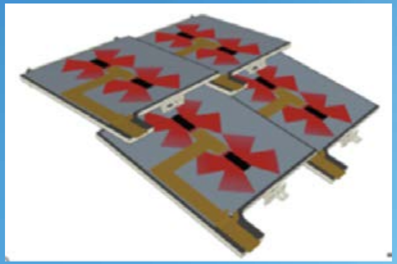
Option #	Noise r.m.s (mV)	Noise r.m.s (# electrons)
1	1.12	63
2	1.08	42
3	1.7	29
4	1.21	37
5	1.23	38
6	0.98	54

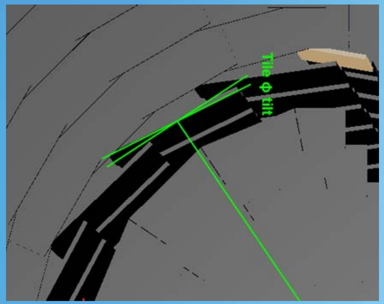
Parameter	ILC Requirement	Prototype Tests
Detector Sensitivity	10 µV/electron	59 µV/electron
Detector Noise	25 electrons	29 electrons
Comparator Accuracy	0.2 mV RMS	0.2 mV RMS
Sensor Capacitance	10 fF	2.7 fF
Clocking Speed	3.3 MHz	7.3 MHz
Charge collection time	300 nsec	20 nsec
Readout Rate	25 Mbits/sec	25 Mbits/sec
Power Consumption	0.13 mW/mm^2	OK by estimate
Radiation Hardness	10^{11} neutrons/cm^2/yr	10^{13}neutrons/cm^2 or 110 Mrad

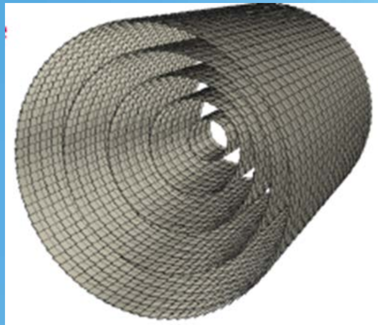
J. Brau – CPAD Workshop Dec '19

SiD Silicon (Strip) Tracker



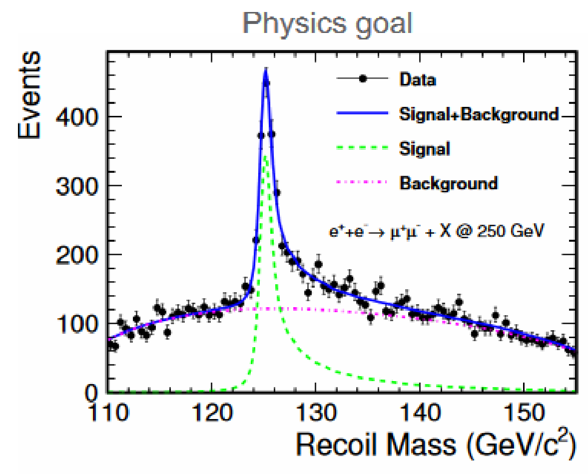




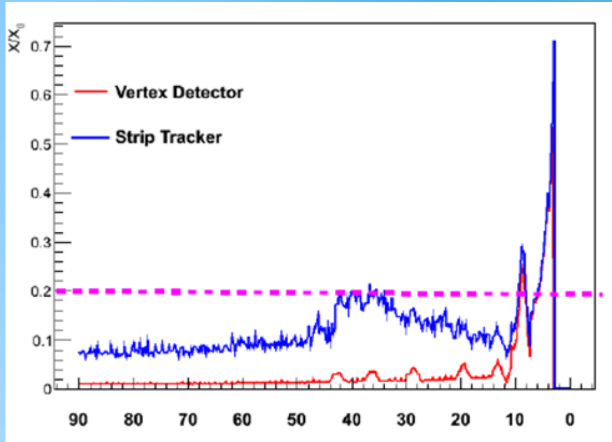


Baseline

- 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



Excellent momentum resolution to obtain the best possible recoil mass measurement



MAPS/Pixel tracker option

kPixM – optimized for tracker, 25µm x 500µm pixels. Position resn. < 10µm, S/N >20

Future initiative: SLAC/DESY for MAPS tracker development.

OPPORTUNITY FOR COLLABORATION !

Goal – full prototype test: sensor + kPix + cables

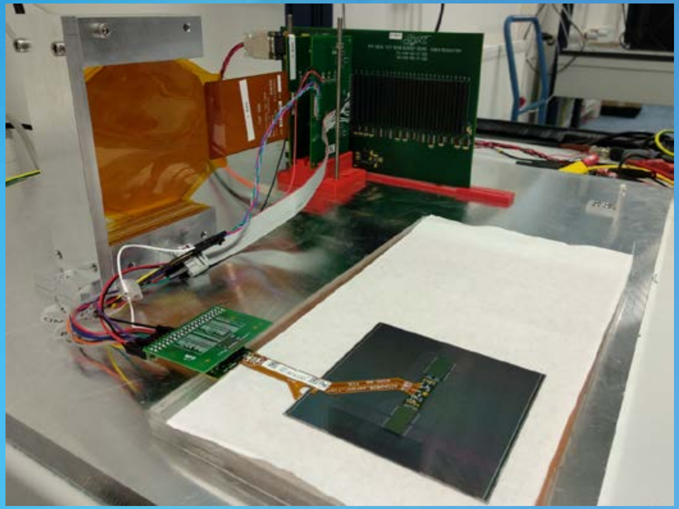
Pixel tracker option and alignment methods (Bristol)

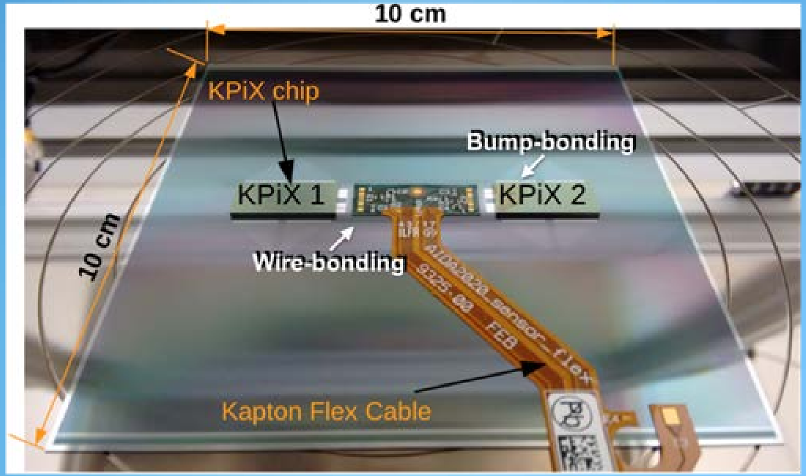
Carbon fiber structures for low material, integrated services (Oxford, Lancaster, Liverpool)

SiD Silicon (Strip) Tracker

DESY Test Beam results

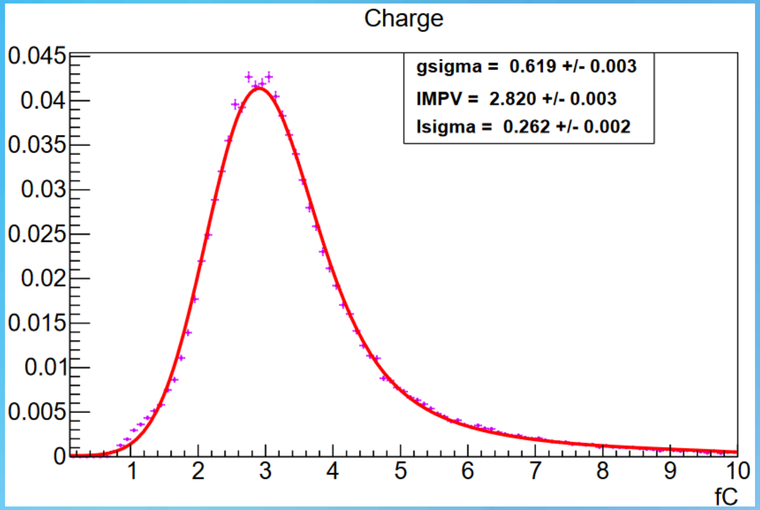
M. Stanitzki, U. Kraemer DESY
M. Breidenbach SLAC



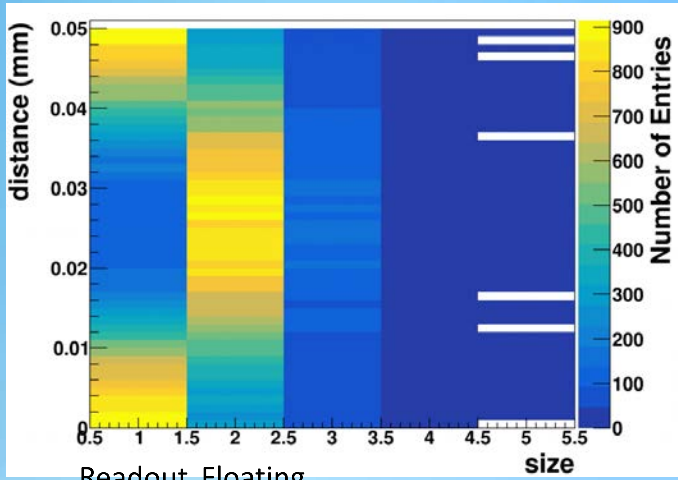


Residuals of sensor measurement
External telescope

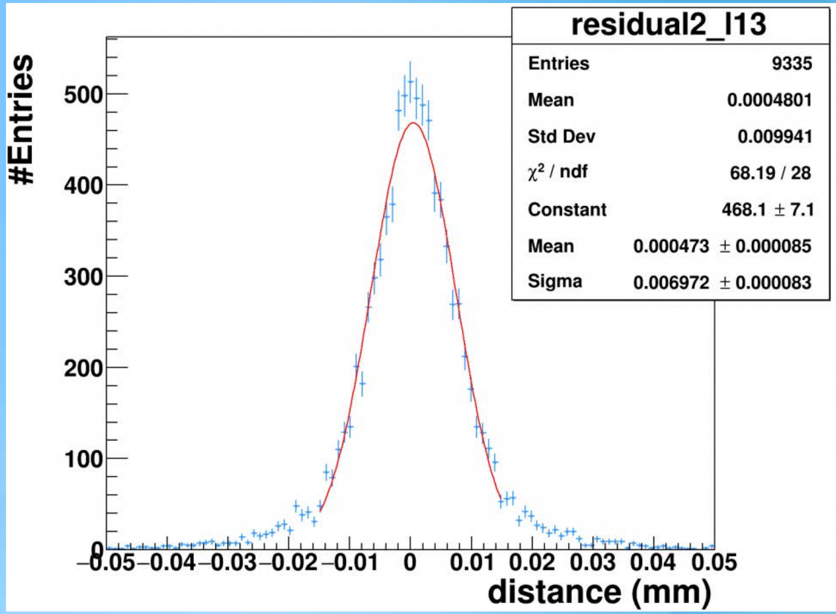
Single point resolution 7μm



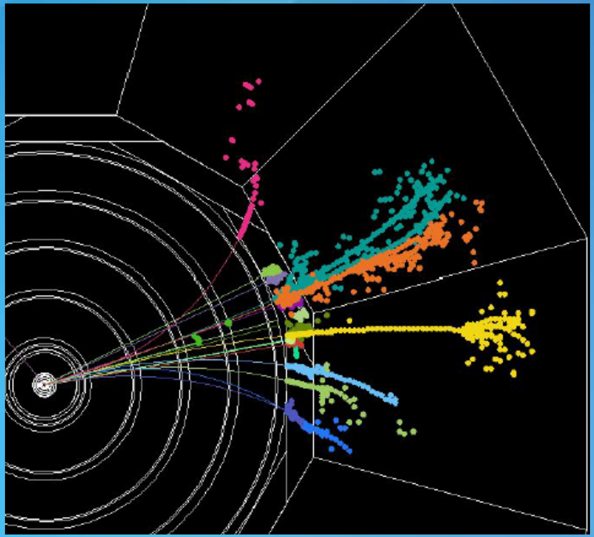
Charge distribution – hits on track
MPV of charge of 2.8 fC



Readout strip   Floating strip



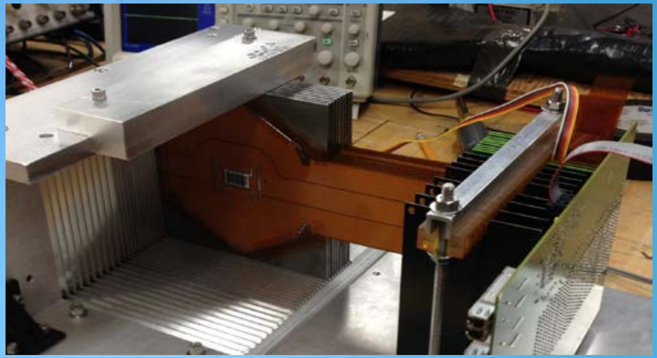
SiD Electromagnetic Calorimeter

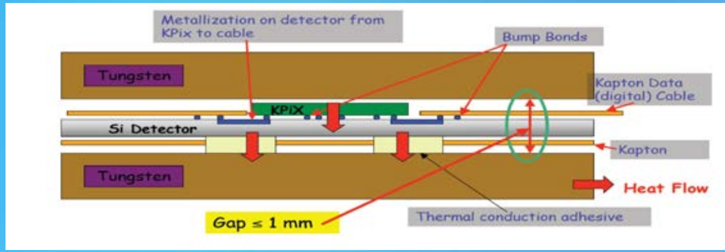


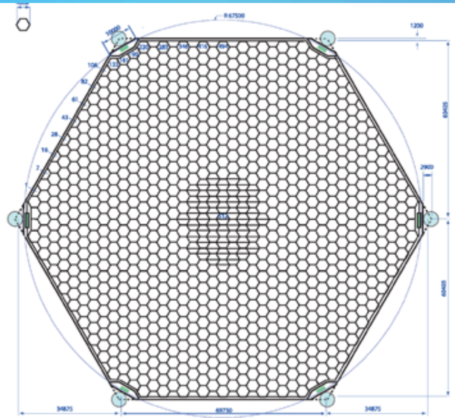
Highly granular "imaging" calorimetry essential for ILC physics program:

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

Beam tests,9-layers, SLAC

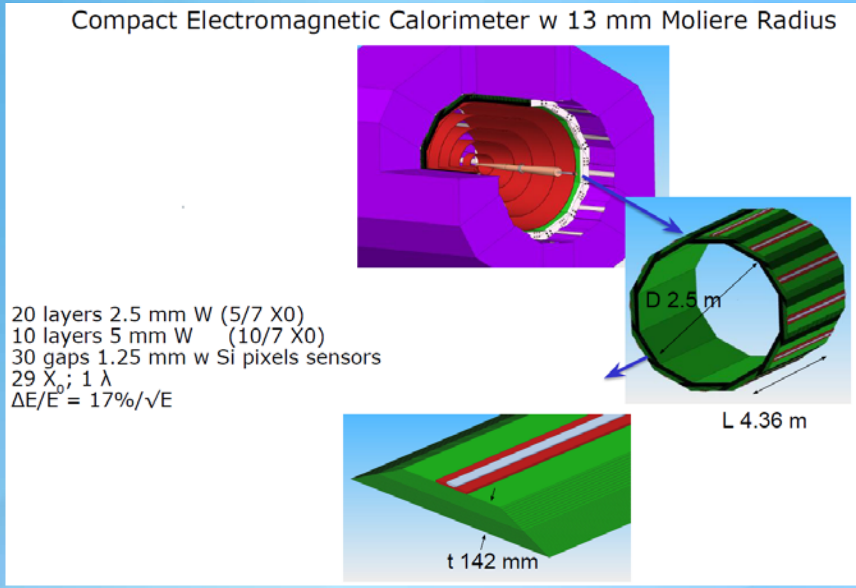






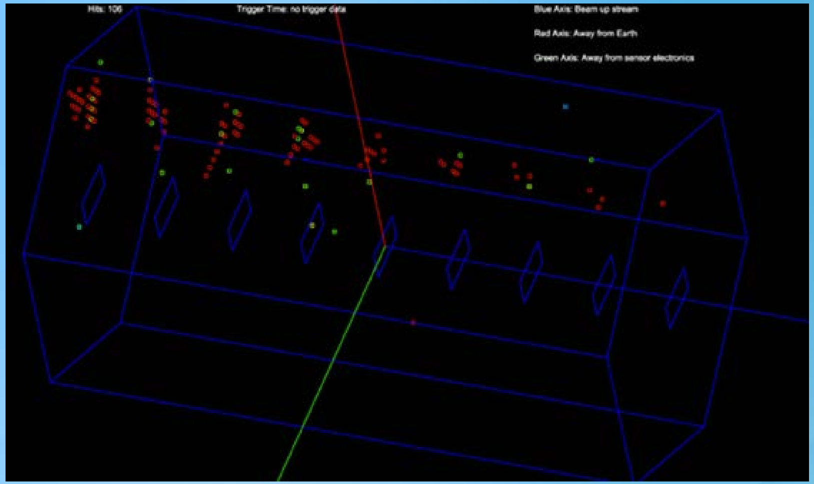
1024 pixels
13 mm^2

Baseline design: Silicon/Tungsten



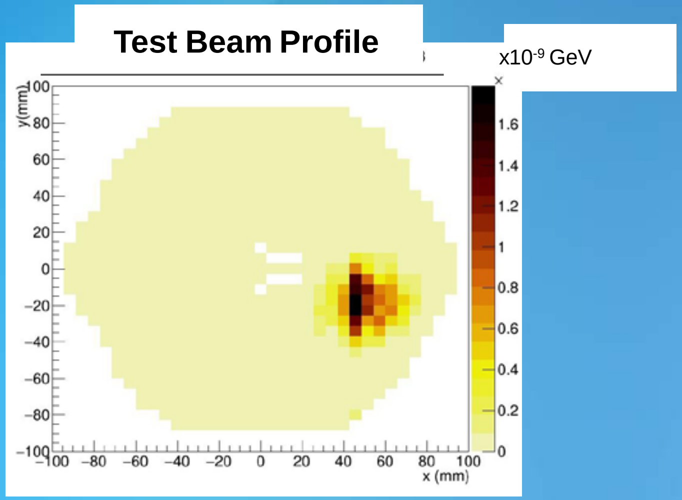
Oregon, SLAC, UC Davis

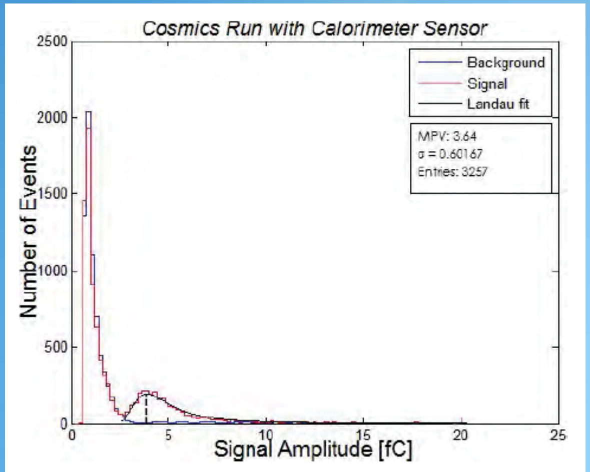
Single electron event

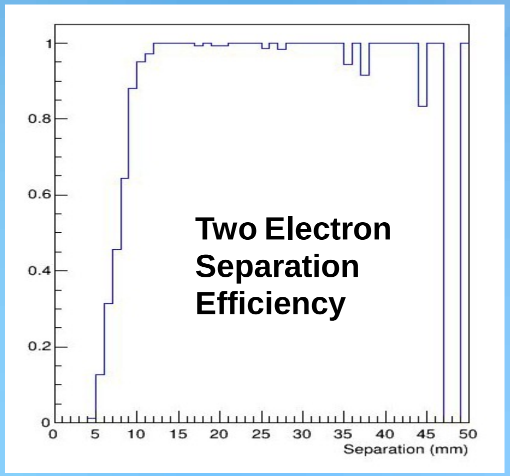


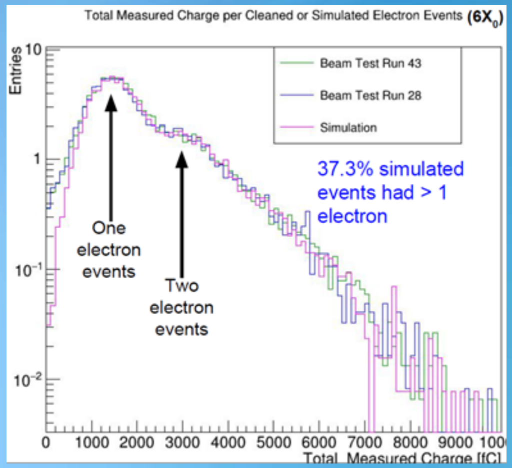
SiD Electromagnetic Calorimeter

J Barkeloo et al 2019 J. Phys.: Conf. Ser. 1162 012016

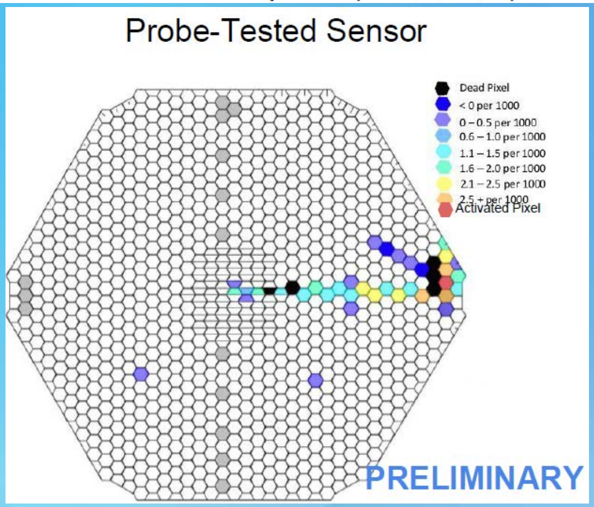




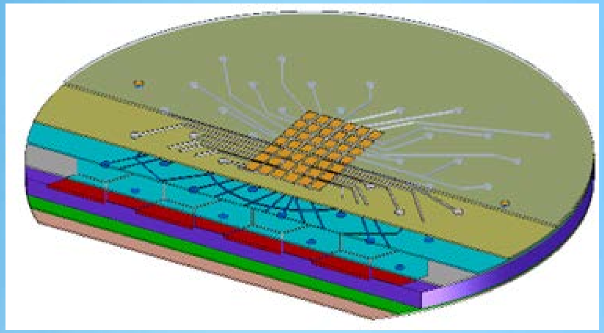




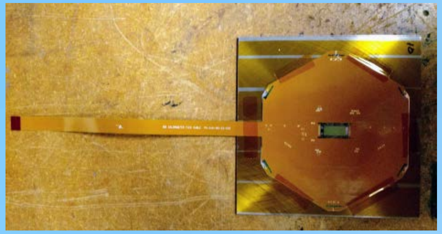
Additional signal detected in pixels along trace of activated pixel (cross talk)



New sensor design – added shield layer



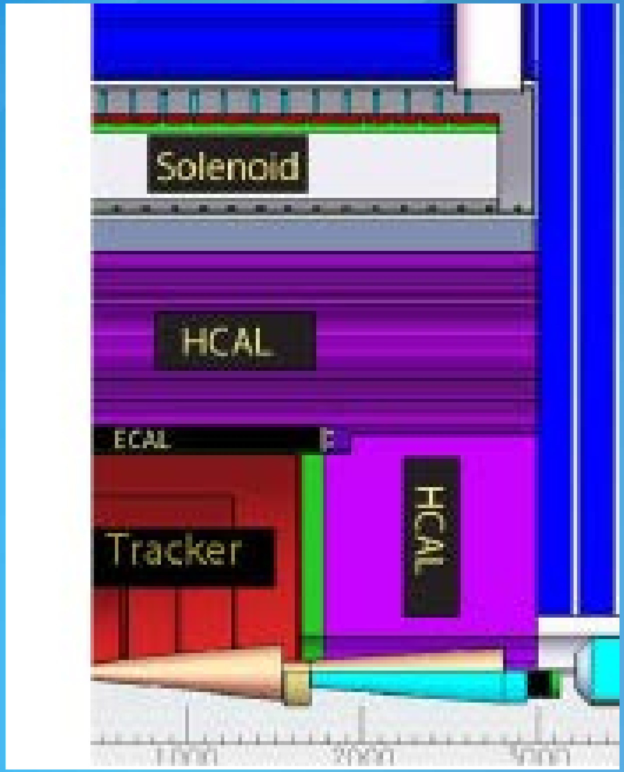
New cable design: one cable/sensor, wire bonded

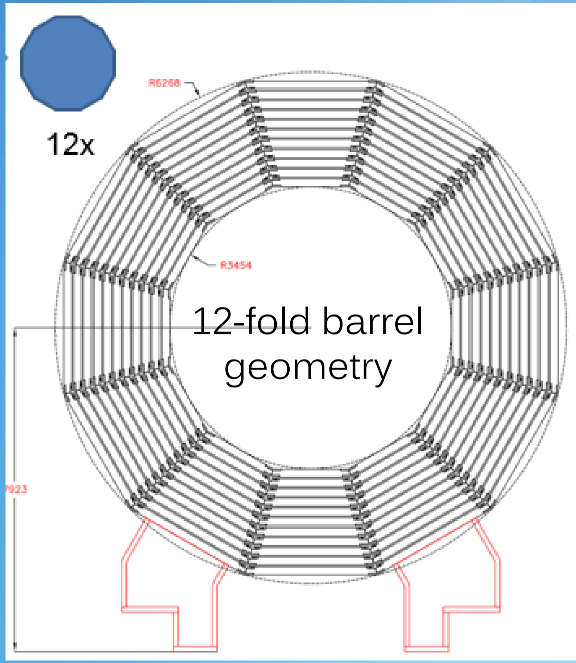


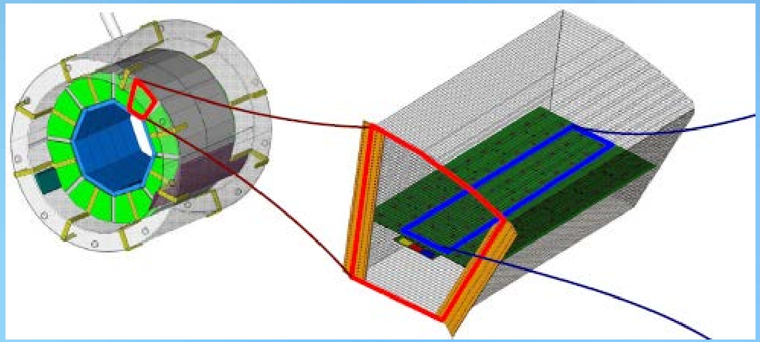
OPPORTUNITY FOR COLLABORATION!

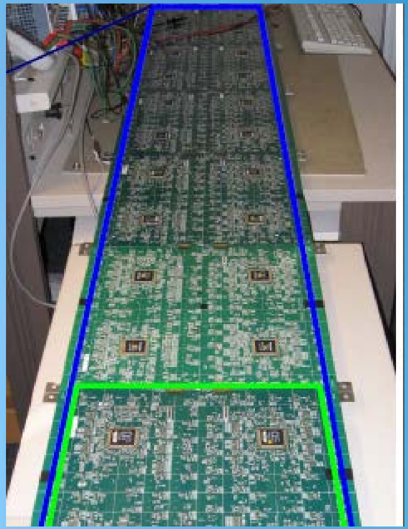
Status: testing beginning of *new* sensor bump-bonded to KPiX, new cable wire-bonded. Sensor and KPiX calibrate – all connections are good.

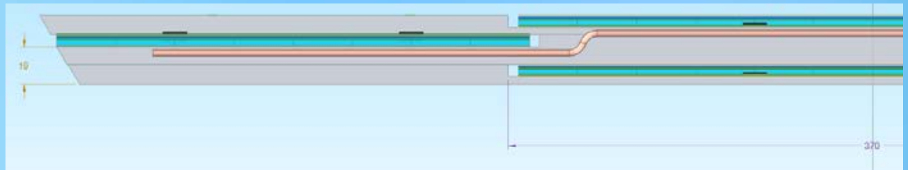
SiD Hadron Calorimeter







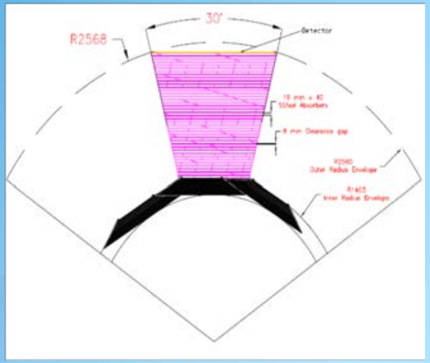




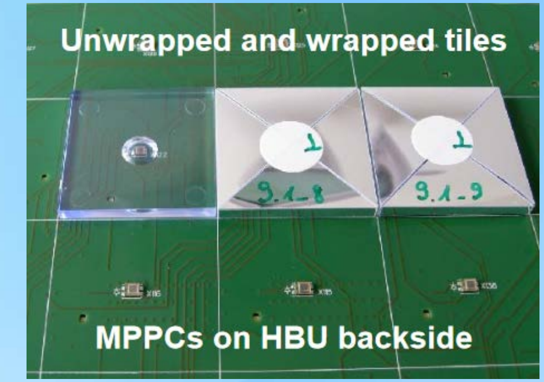
Baseline technology for the SiD HCal is Scintillator/SiPM/Steel

Marco Oriunno (SLAC)

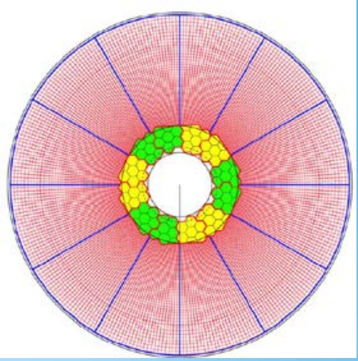
OPPORTUNITY FOR COLLABORATION !



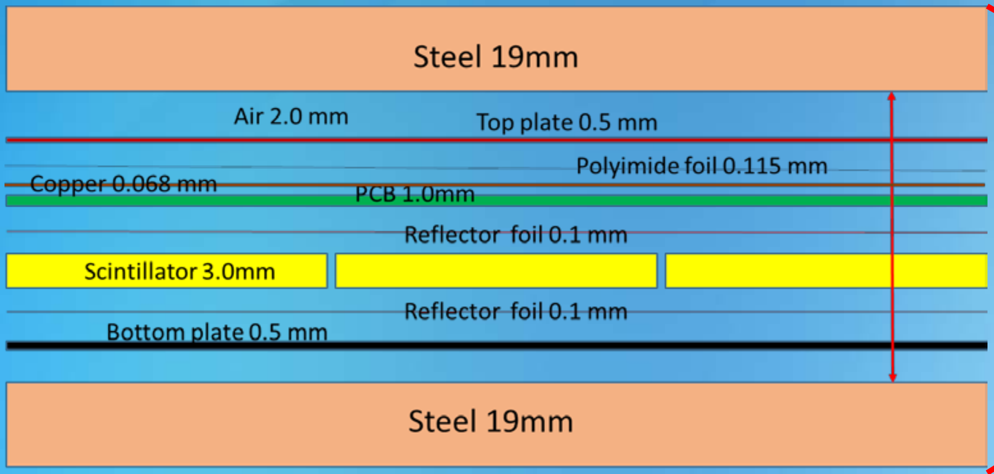
UTA, SLAC



Same issues for CMS HGCAL

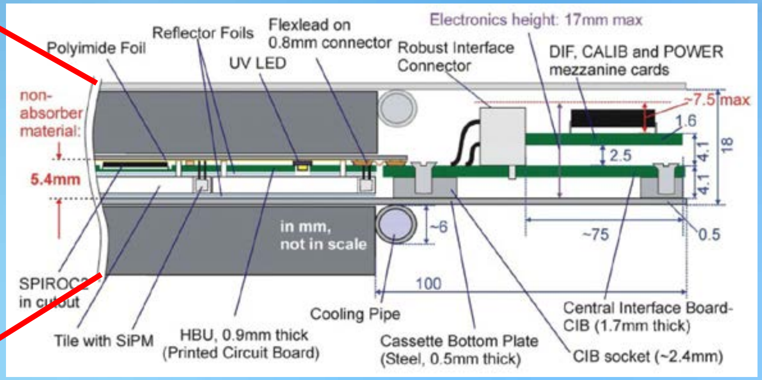


SiD Hadron Calorimeter



Active layer thickness = 7.383 mm

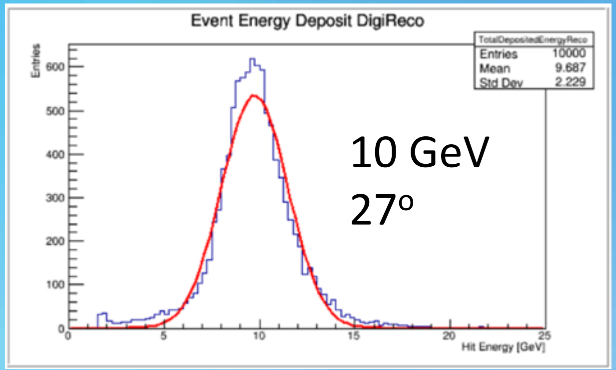
CALICE design

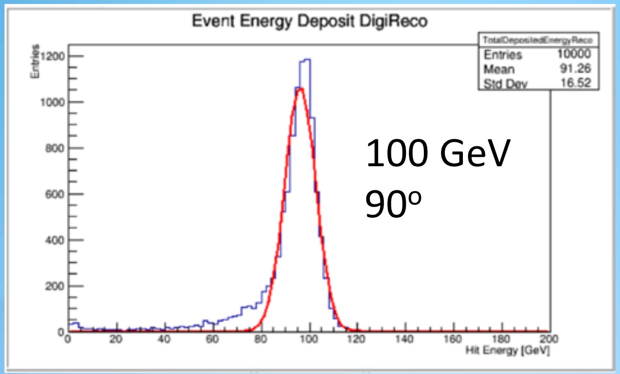


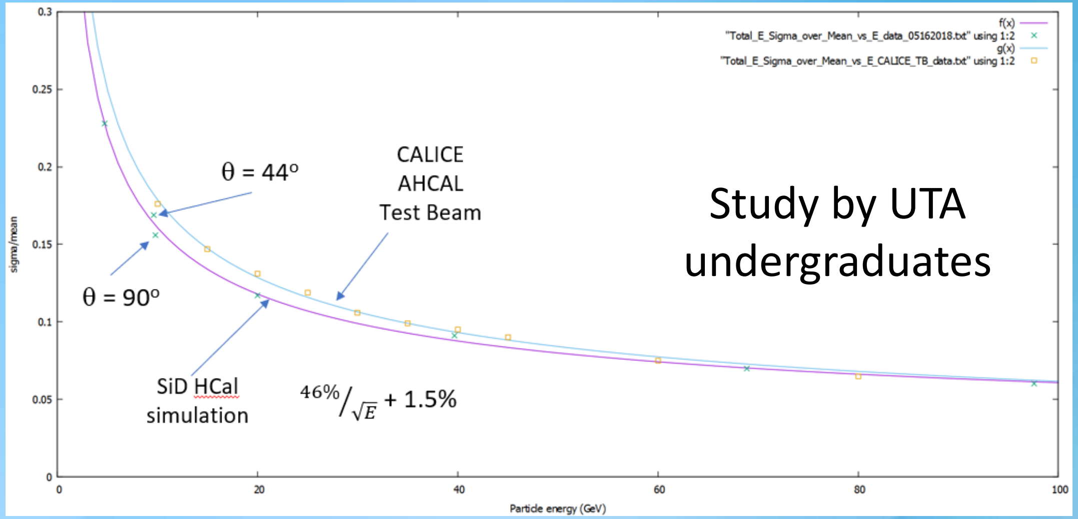
Checking new SiD simulation: compare simulated single particle energy resolution with actual CALICE test beam results

Ongoing: single particle studies.

Next: full event studies with PANDORA as prelude to next round of physics studies

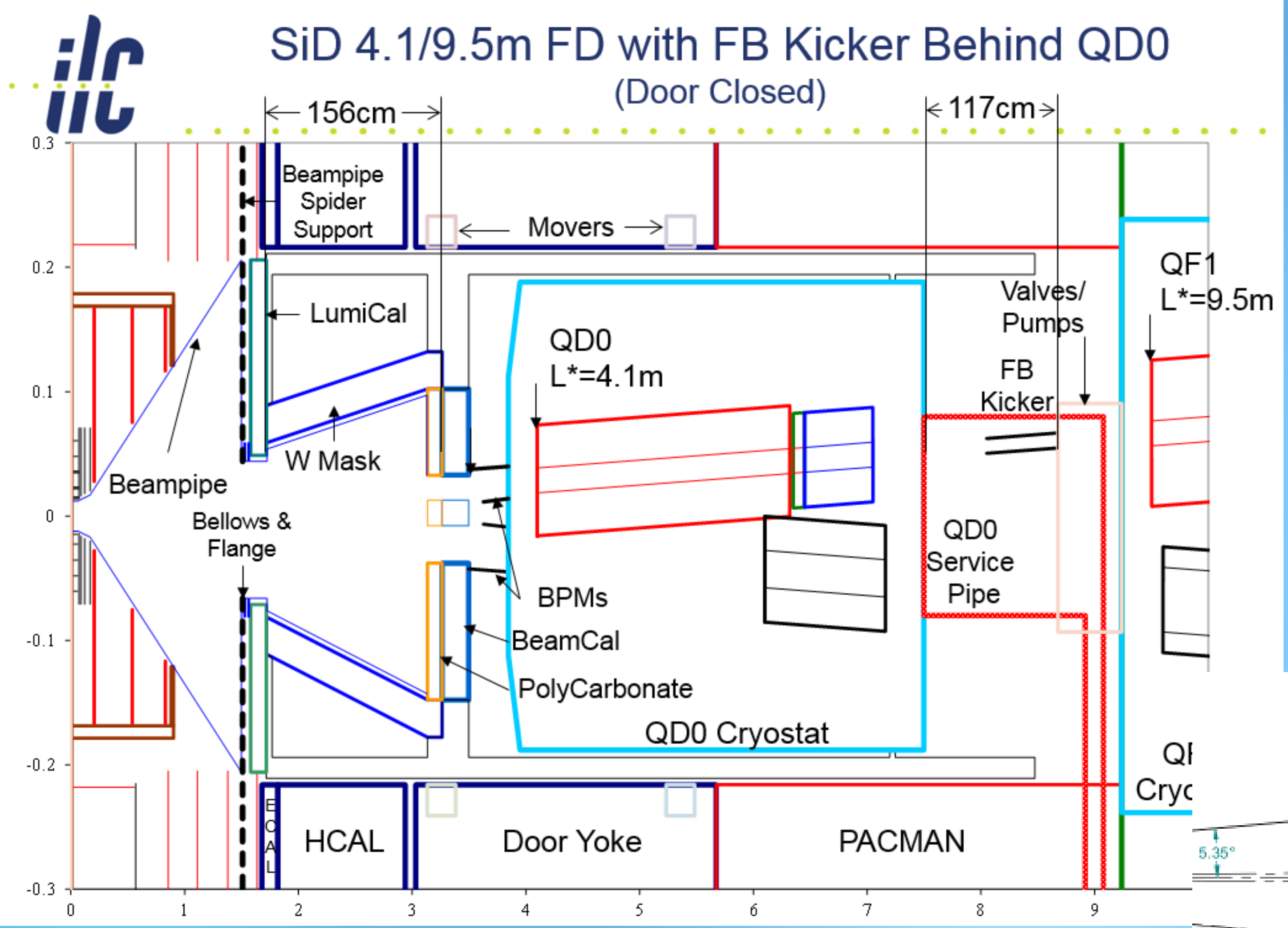






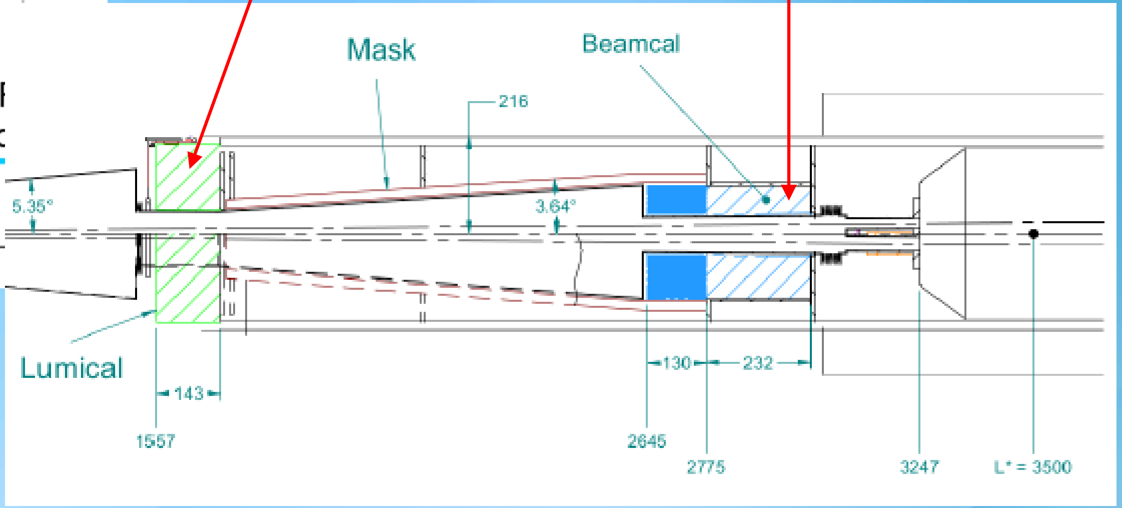
UTA, SLAC

Forward calorimetry



Lumi Cal

Beam Cal



Forward calorimetry

- **Sensor irradiation studies for Forward Calorimetry**

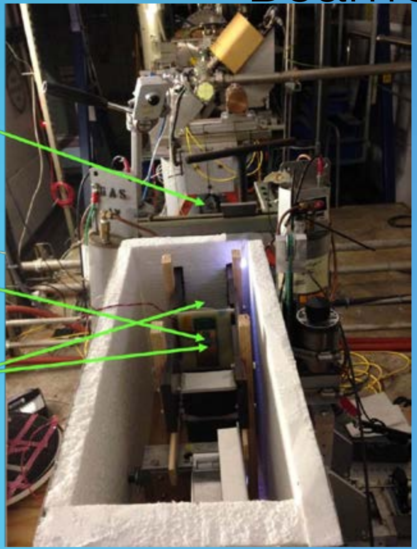
(B. Schumm et al. UCSC – SLAC Expt. T-506)

BeamCal radiation dose at inner radius ~100 Mrad/year

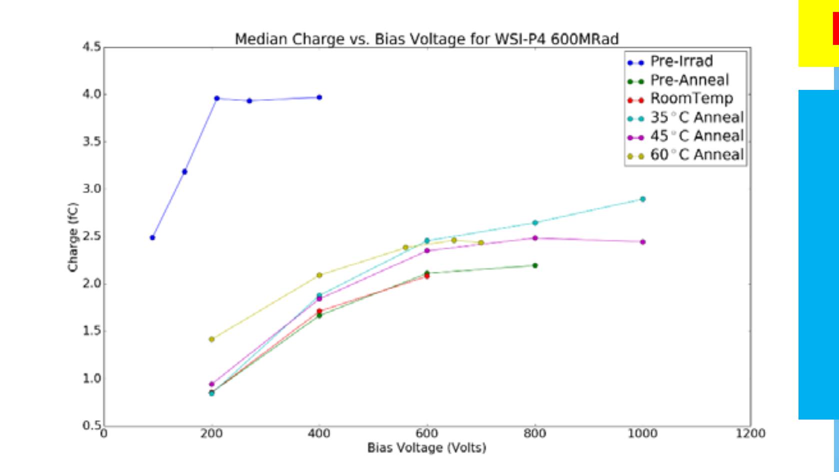
2 X_0 pre-radiator; introduces a little divergence in shower

Sensor sample

Not shown: 4 X_0 "post radiator" and 8 X_0 "backstop"



Ongoing electromagnetic radiation damage studies (Si diode, GaAs…) within FCAL Collaboration umbrella

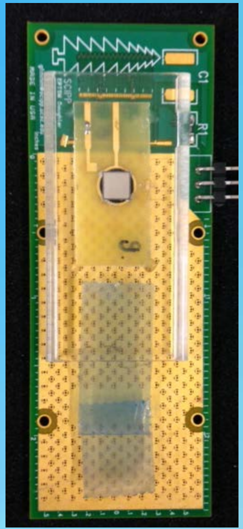


570 Mrad Exposure

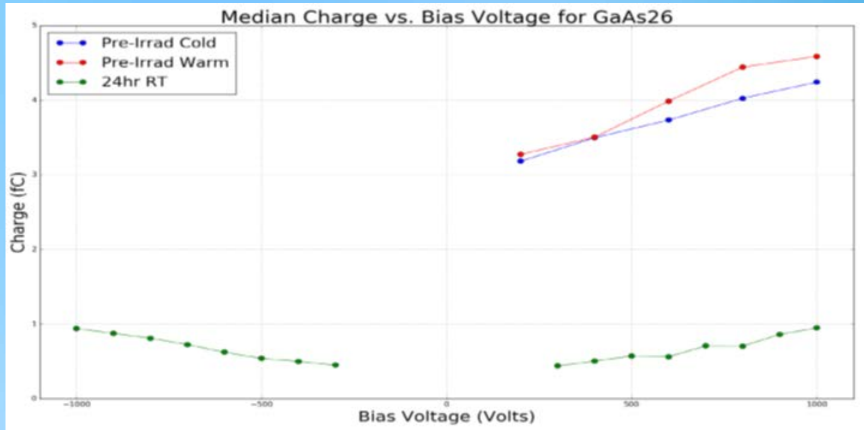
PF Si Diode Sensor

300μm

Area 0.025 cm^2



- Gallium Arsenide sensor provided by Georgy Shelkov, JINR
- Sn-doped Liquid-Encapsulated Czochralski fabrication
- 300 μm thick
- 0.16 cm^2 area



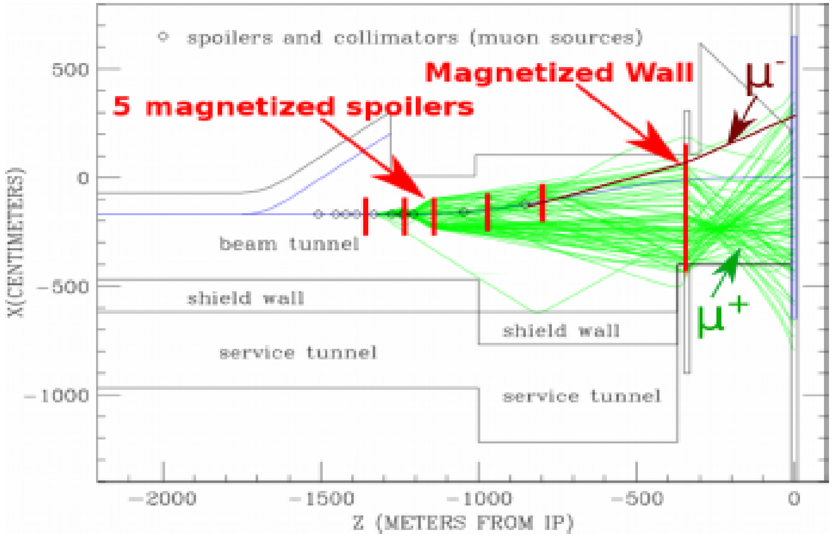
GaAs Charge Collection after 100 Mrad Exposure

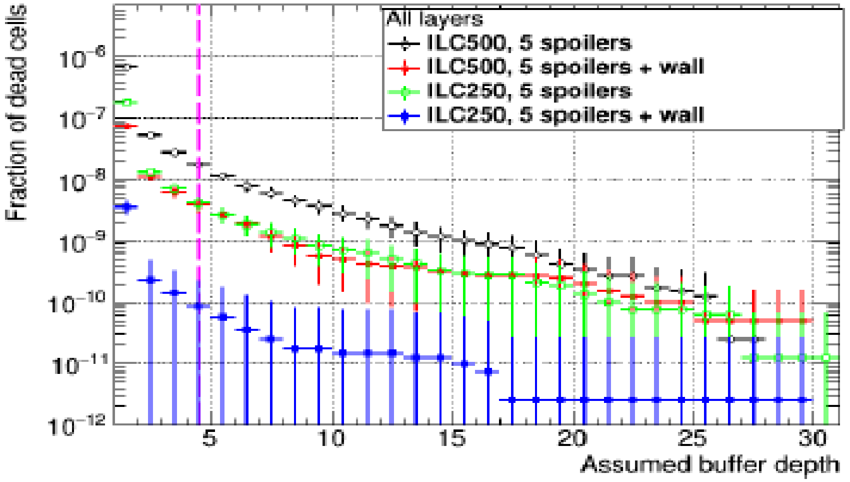
(previously only for 21 Mrad)

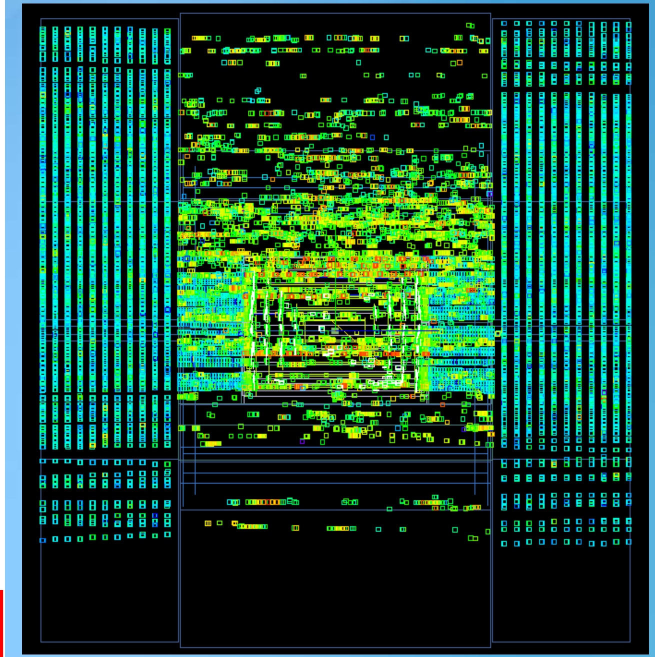
Sean Hyslop

MDI Studies

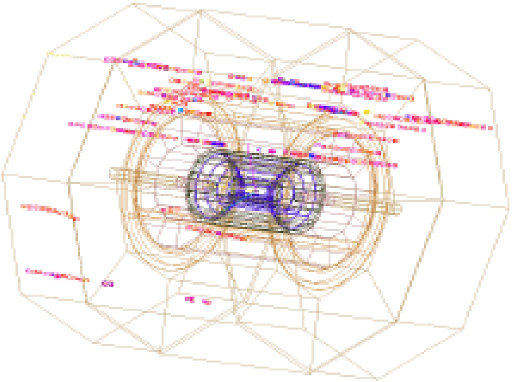
BDS muon study







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

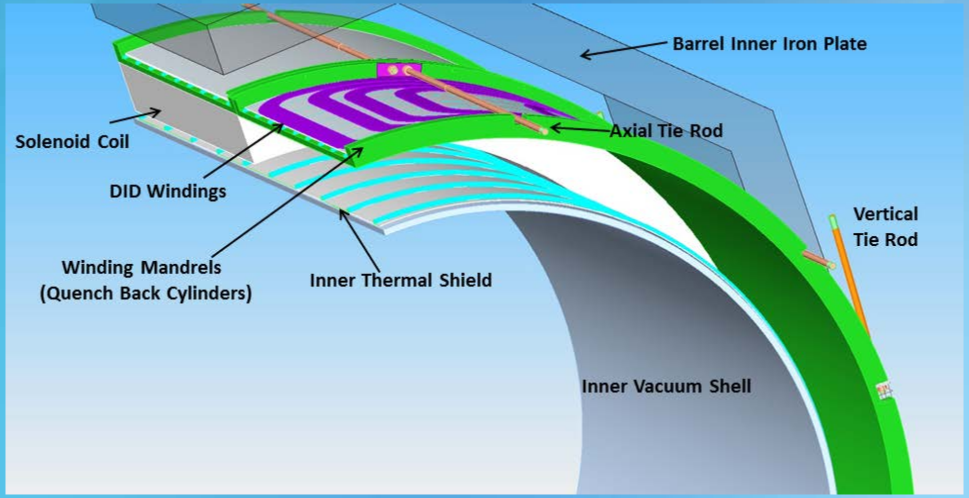


At ILC250, magnetized spoilers without wall are sufficient for occupancy mitigation.

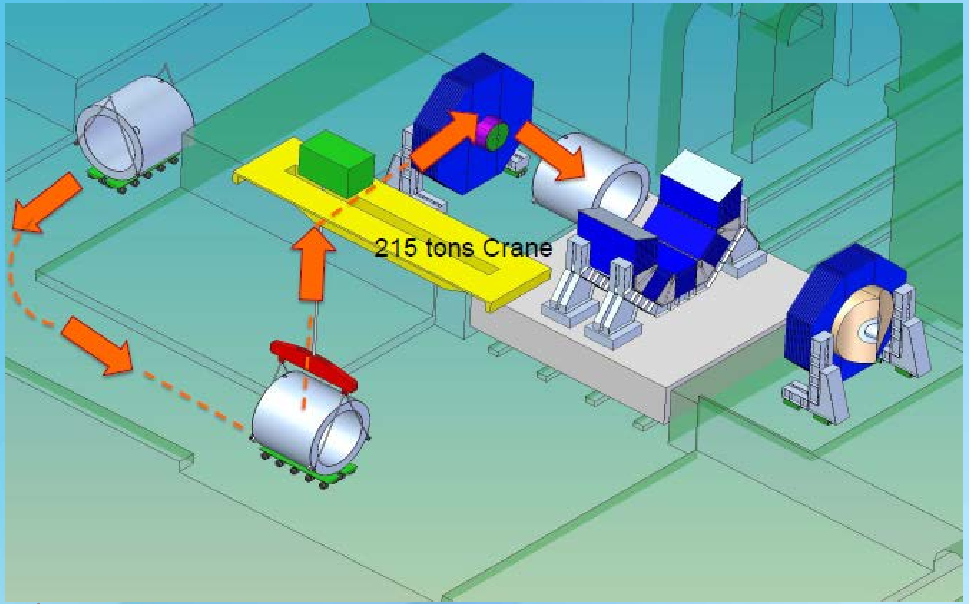
Wall might me neccessary at higher stages, and as a tertiary containment device.

Anne Schuetz (DESY)

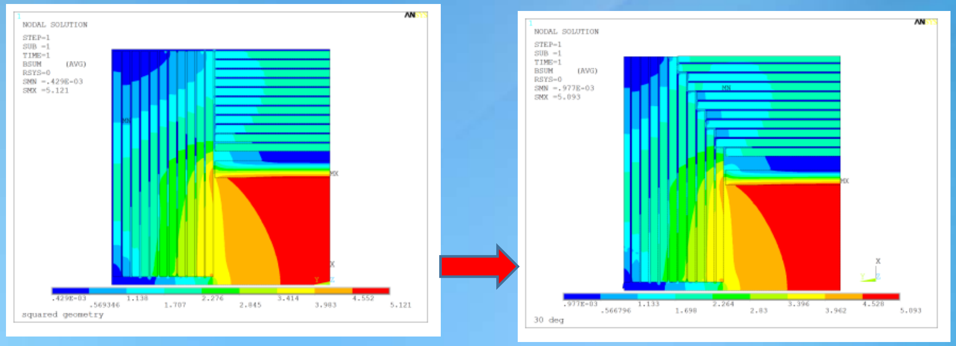
SiD Solenoid



Baseline CMS conductor

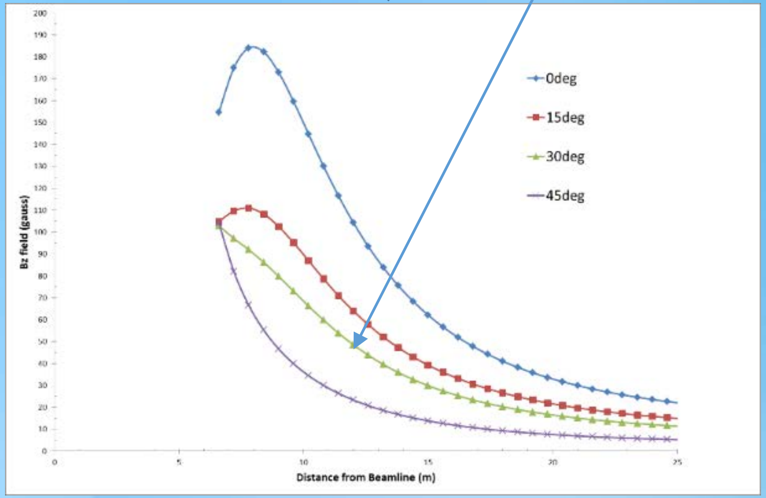


30° design



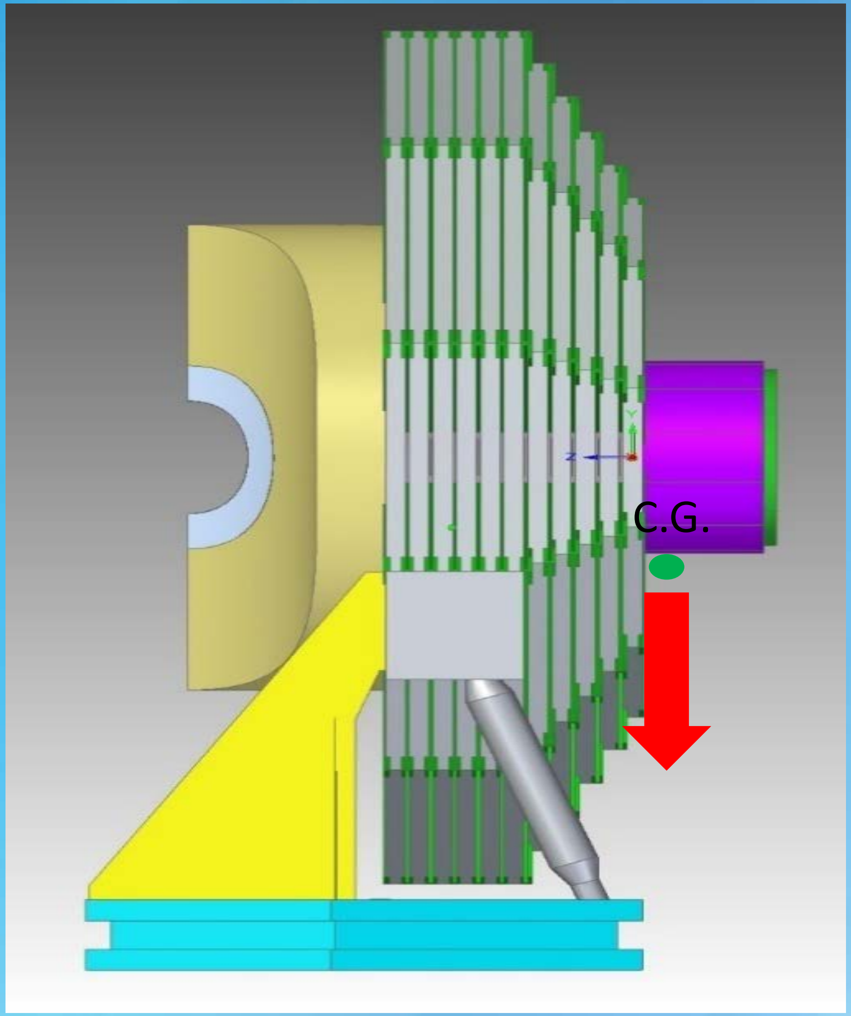
Redesign of barrel/door junction
More efficient flux return
Easier transport/handling

< 50 Gauss at 15m/30 deg cut

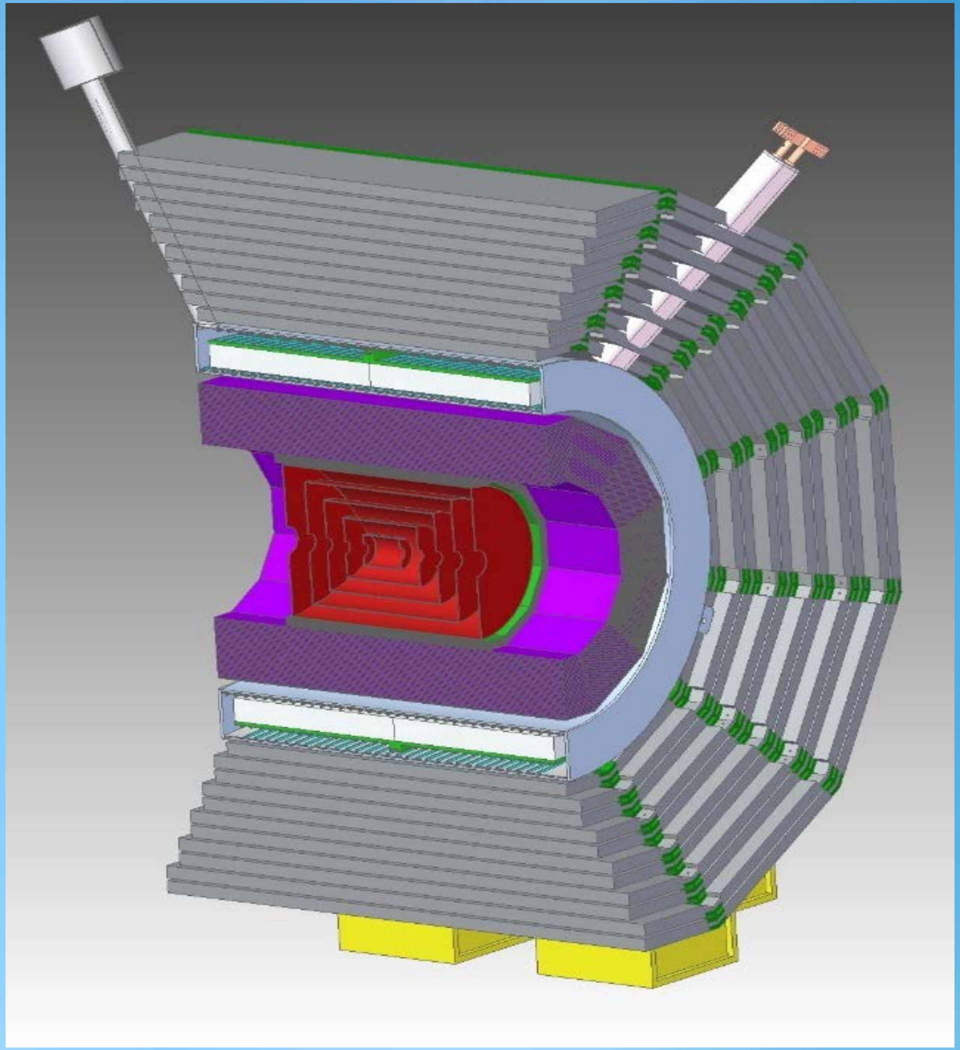


M. Oriunno (SLAC)

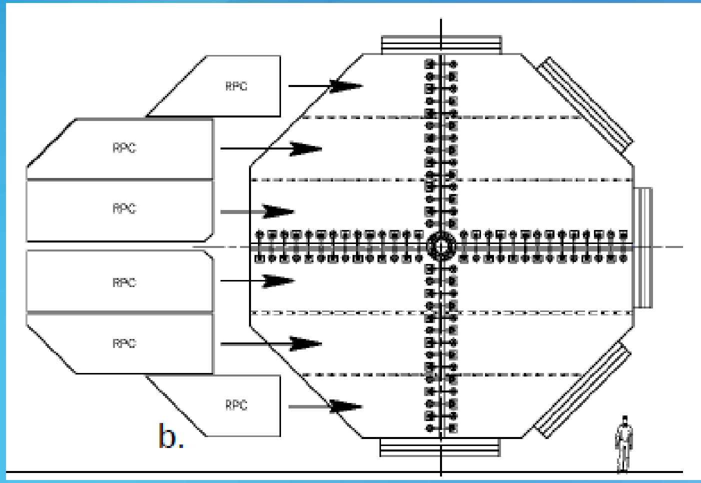
Muon identifier/Calorimeter Tail Catcher

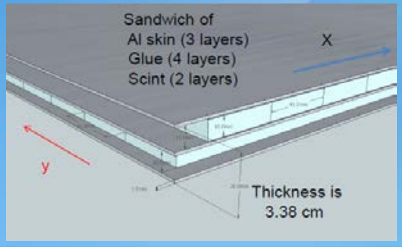


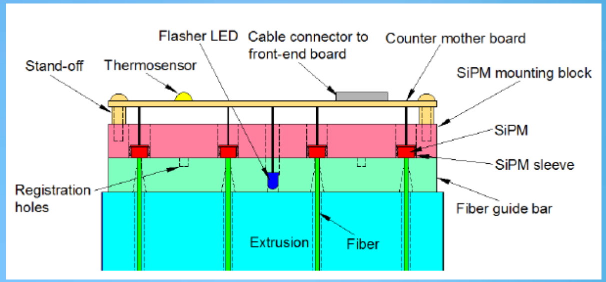
Marco Oriunno
(SLAC)



Muon identifier/Calorimeter Tail Catcher



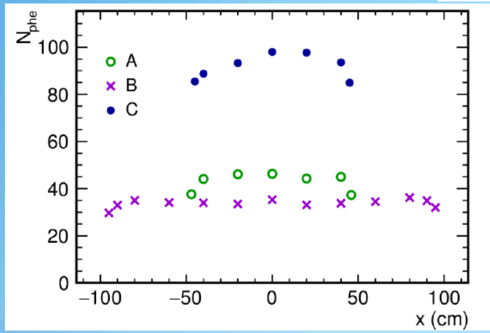




SiD Baseline – long scintillator strips with WLS fiber and SiPM readout

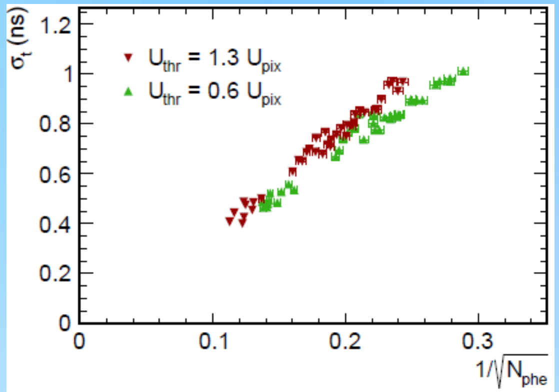
- Consistent extension of the baseline HCal scintillator technology
- Need to optimize number of layers, strip dimensions.

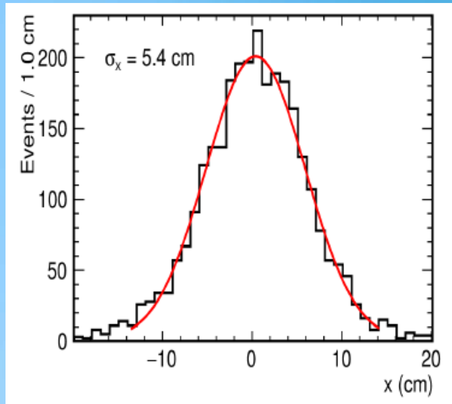
Development work at Fermilab:



Paper published:
NIMA, **848**, 54-59, 2017

Time resolution





Position resolution

ILC, SiD and Snowmass 2021

DESY 20-122,
KEK Preprint 2020-8,
IFIC/20-34, LCTP-20-14
SLAC-PUB-17543
July, 2020

ILC Study Questions for Snowmass 2021

LCC Physics Working Group

Eur. Phys. J. Plus (2020) 135:525
https://doi.org/10.1140/epjp/s13360-020-00528-z

The European Physical Journal Plus

Regular Article

Check for updates

Primer on ILC physics and SiD software tools

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Received: 26 May 2020 / Accepted: 11 June 2020

Abstract We first outline the standard model of particle physics, particle production and decay, and the expected signal and background at a Higgs factory like the international linear collider (ILC). We then introduce high-energy colliders and collider detectors and briefly detail the ILC and the silicon detector (SiD), one of the two detectors proposed for the ILC. Next, we review the available software tools for ILC event generation, SiD detector simulation, and event reconstruction. Finally, we suggest open avenues in research for detector optimization and physics analysis. The pedagogical level is suitable for advanced undergraduate and beginning graduate students in physics and research scientists in related fields.

SiD Snowmass 2021 Monte Carlo

Documentation

- Primer on ILC Physics and SiD Software Tools (2002.02399)
- Delphes Fast Detector Simulation (Delphes)
- Delphes SiD on Hepforge (DSiD)
- Example Root Macro for Analysis (macro.cc)

Generated Signal

- Higgs to Invisible: e+e- -> ZH, H->invisible (250 GeV CME, P=80/30)
  - Z->qqbar Whizard StdHep Delphes Root
  - Z->l+l- Whizard StdHep Delphes Root
- Higgs to Tau Pairs (250 GeV CME)
- Double Higgstrahlung (500 GeV CME)
- Double WW Fusion (1000 GeV CME)

DBD Backgrounds*

- 250GeV CME, L=250fb-1, P=80/30 Whizard StdHep Delphes Root
- 350GeV CME, L=350fb-1, P=80/30 Whizard StdHep Delphes Root
- 500GeV CME, L=500fb-1, P=80/30 Whizard StdHep Delphes Root
- 1000GeV CME, L=1000fb-1, P=80/20 Whizard StdHep Delphes Root

The ILC and SiD going forward

- The ILC is moving towards realization!
- The International Development Team starts work next week.

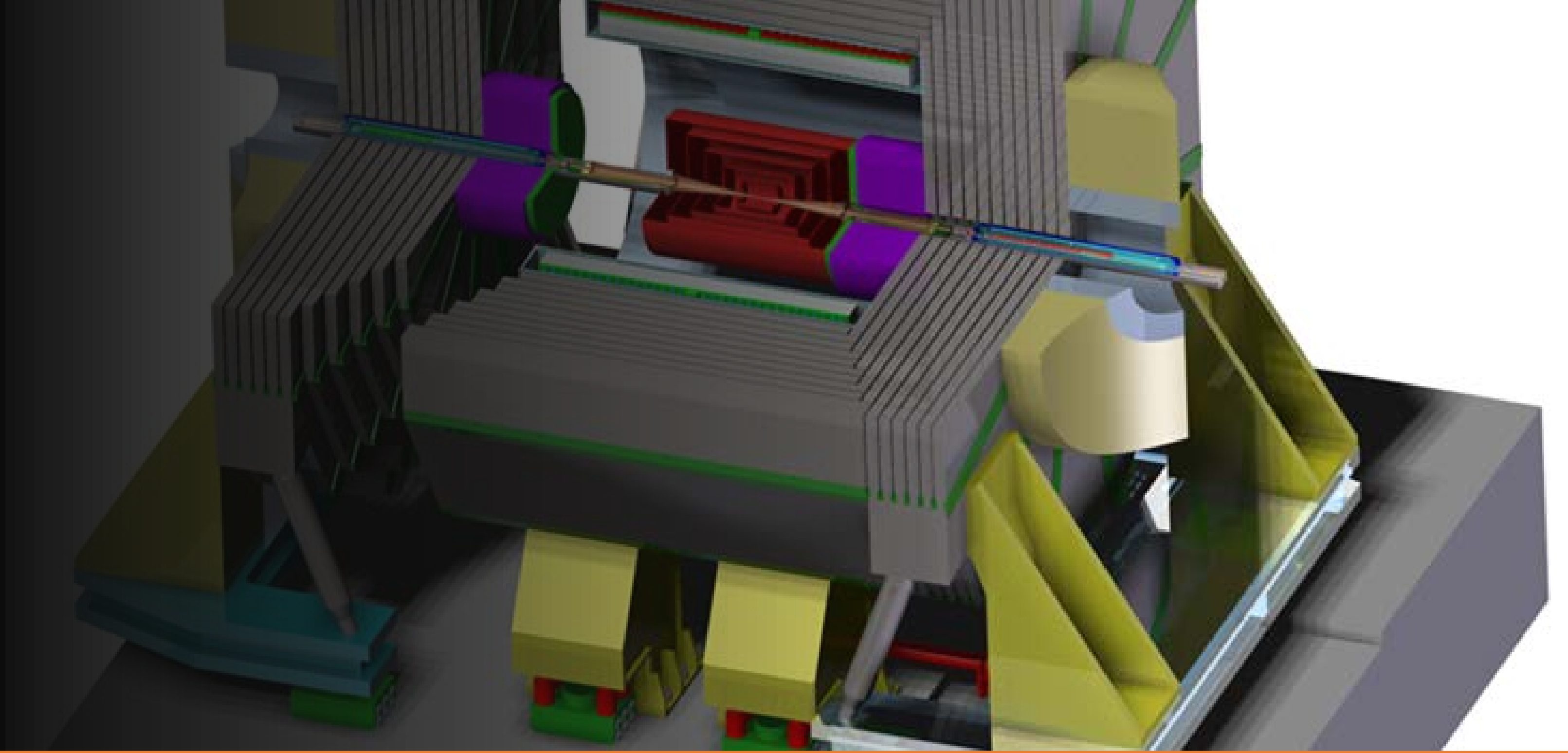
- SiD has a validated detector design that can deliver the ILC Physics Program.

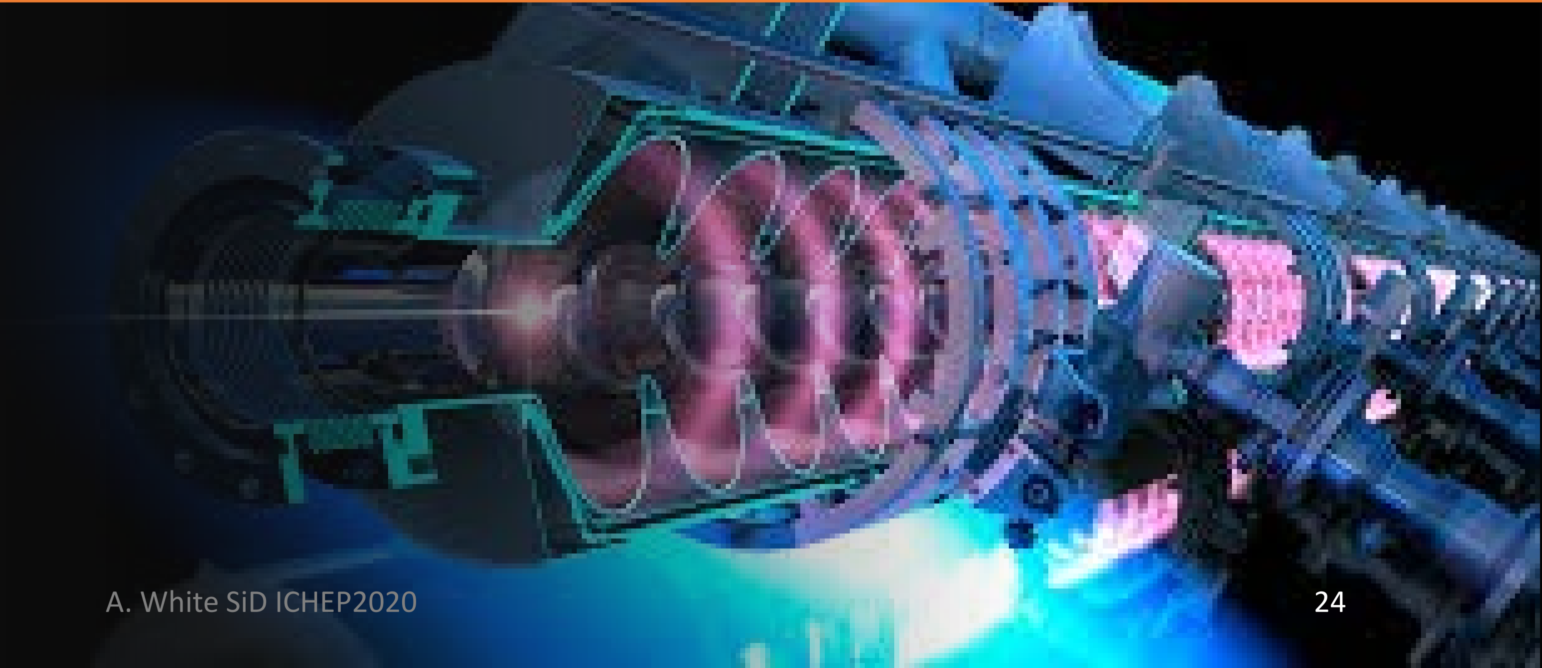
- There are many opportunities for new ideas and optimization.

- SiD welcomes new members – join us for Snowmass and beyond - especially young physicists!

Marcel Stanitzki (DESY) marcel.stanitzki@desy.de
Andy White (UTA) awhite@uta.edu

Thank you





ILC Parameters

Quantity	Symbol	Unit	Initial	TDR	Upgrades	
Centre of mass energy	$\sqrt{s}$	GeV	250	250	500	1000
Luminosity	$\mathcal{L}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.35	0.75	1.8	4.9
Polarisation for $e^-(e^+)$	$P_-(P_+)$		80 %(30 %)	80 %(30 %)	80 %(30 %)	80 %(20 %)
Repetition frequency	f_{rep}	Hz	5	5	5	4
Bunches per pulse	n_{bunch}	1	1312	1312	1312	2450
Bunch population	N_{e}	10^{10}	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	554	554	366
Beam current in pulse	I_{pulse}	mA	5.8	5.8	5.8	7.6
Beam pulse duration	t_{pulse}	μs	727	727	727	897
Average beam power	P_{ave}	MW	5.3	5.3	10.5	27.2
Norm. hor. emitt. at IP	$\gamma\epsilon_{\text{x}}$	μm	5	10	10	10
Norm. vert. emitt. at IP	$\gamma\epsilon_{\text{y}}$	nm	35	35	35	35
RMS hor. beam size at IP	σ^*_{x}	nm	516	729	474	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	7.7	5.9	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$			87.1 %	58.3 %	44.5 %
Energy loss from beamstrahlung	δ_{BS}		2.6 %	0.97 %	4.5 %	10.5 %
Site AC power	P_{site}	MW	129	122	163	300
Site length	L_{site}	km	20.5	31	31	40

SiD Detector Parameters

Vertex Detector

Barrel	R	z_{max}	
Layer 1	14	63	
Layer 2	22	63	
Layer 3	35	63	
Layer 4	48	63	
Layer 5	60	63	
Disk	R_{inner}	R_{outer}	z_{center}
Disk 1	14	71	72
Disk 2	16	71	92
Disk 3	18	71	123
Disk 4	20	71	172
Forward Disk	R_{inner}	R_{outer}	z_{center}
Disk 1	28	166	207
Disk 2	76	166	541
Disk 3	117	166	832

Main tracker

Barrel Region	R (cm)	Length of sensor coverage (cm)	Number of modules in ϕ	Number of modules in z
Barrel 1	21.95	111.6	20	13
Barrel 2	46.95	147.3	38	17
Barrel 3	71.95	200.1	58	23
Barrel 4	96.95	251.8	80	29
Barrel 5	121.95	304.5	102	35
Disk Region	z_{inner} (cm)	R_{inner} (cm)	R_{outer} (cm)	Number of modules per end
Disk 1	78.89	20.89	49.80	96
Disk 2	107.50	20.89	75.14	238
Disk 3	135.55	20.89	100.31	438
Disk 4	164.09	20.89	125.36	662

Electromagnetic Calorimeter

inner radius of ECAL barrel	1.27 m
maximum z of barrel	1.76 m
longitudinal profile	20 layers $\times$ 0.64 X_0
	10 layers $\times$ 1.30 X_0
EM energy resolution	$0.17/\sqrt{E} \oplus 1\%$
readout gap	1.25 mm (or less)
effective Molière radius ($\mathcal{R}$)	14 mm