The SiD Consortium and Detector – Status and Plans

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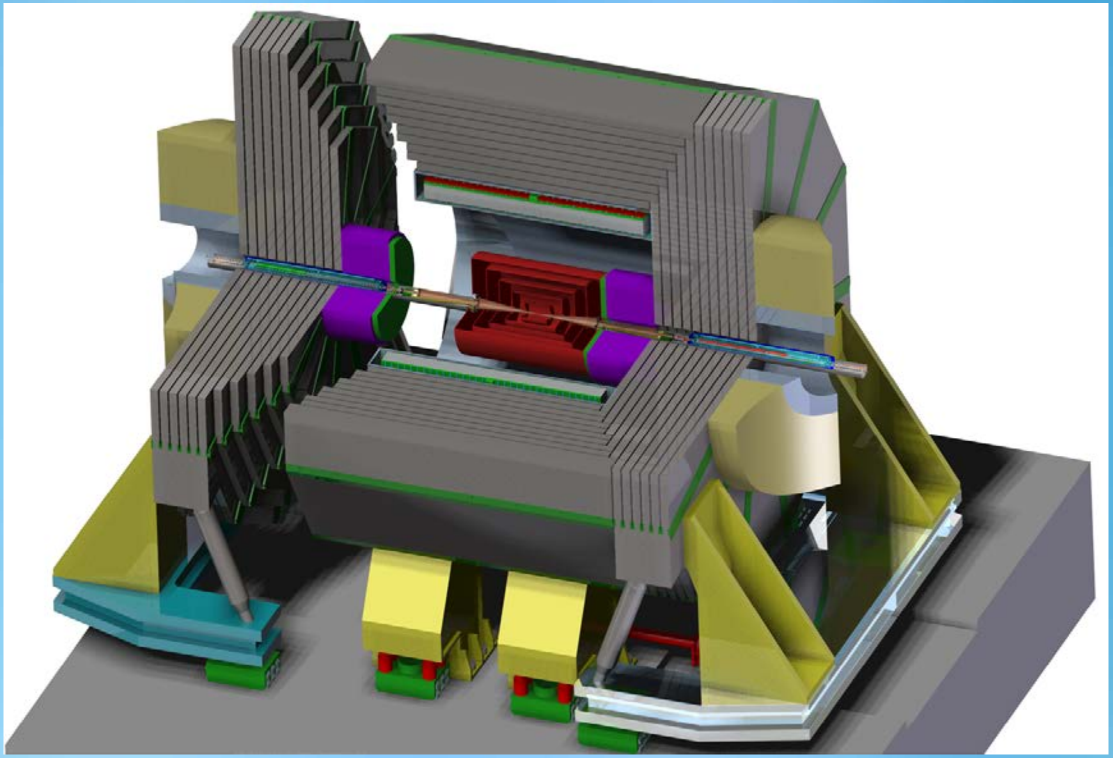
UNIVERSITY OF TEXAS ARLINGTON



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

With thanks to SiD colleagues
for materials provided!

SiD PDAP Review – Outline

- Review of SiD Detector Design Status and Accomplishments

- Plans, R&D Studies for 2017

- Funding, SiD path forward

SiD Consortium

- Consortium has been in existence since 2014

- Recent significant additions:

  1) Tohoku University (Hitoshi Yamamoto) – with interests in Semiconductor R&D, Physics Analyses, and Detector Optimization.

  2) Glasgow University (Aidan Robson) – with interests in Silicon Tracking and a implementation of the DD4HEP-based SiD simulation.

- We now have a established formal, but lightweight, organization with procedures for adding new members, making significant changes to the detector design, etc.

Recent SiD Activities

- The basic SiD design has been in place for an extended period, but we are always open to:
    - New technologies
    - Design optimization
    - Performance improvements
    - Cost reduction

- Design optimization and performance studies (co-lead by Jan Strube and Aidan Robson) have seen significant and sustained efforts during the past year. Regular weekly meetings with many contributing institutions and high level of student participation.

- Design variations, simulation development, background studies, subsystem performance studies are all activities that SiD can pursue in the present situation of minimal funding. However, it continues to be challenging to go further, e.g. building and testing significant prototypes in a pre-TDR phase.
- There is hope that the new U.S. – Japan funding will alleviate this situation somewhat.

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.

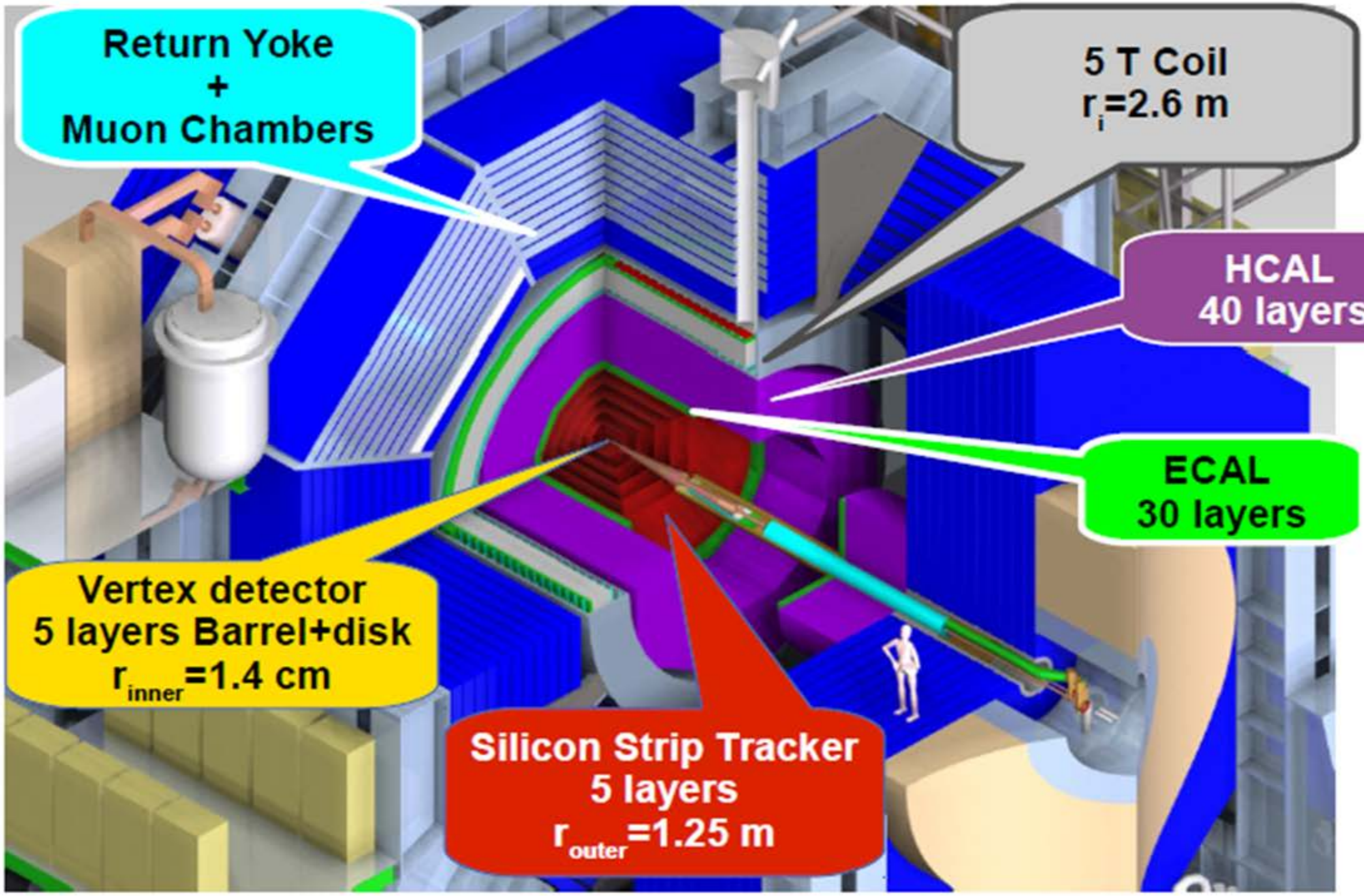
Highly segmented “tracking” calorimeters optimized for Particle Flow.

Compact design with 5T field.

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

Detector is designed for rapid push-pull operation.

SiD Detector Baseline

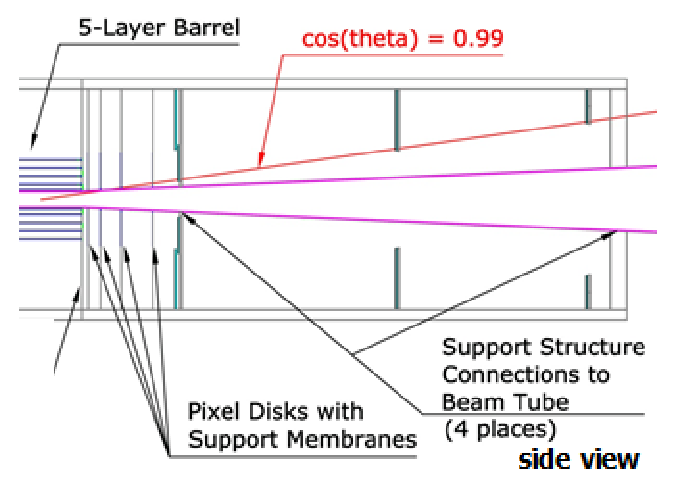


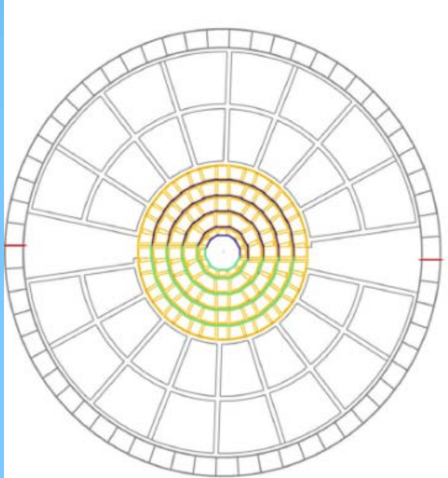
Review of Activities by Subsystem

Subsystem description
Summary of activities for this year

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

Vertex Detector

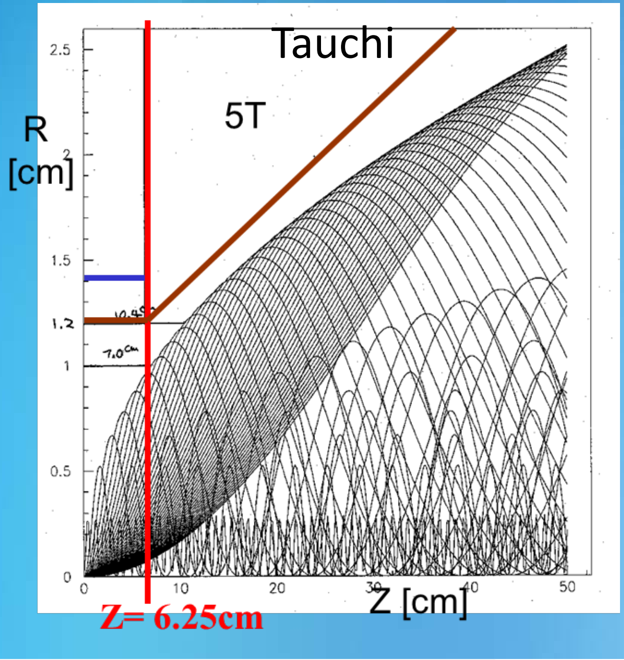


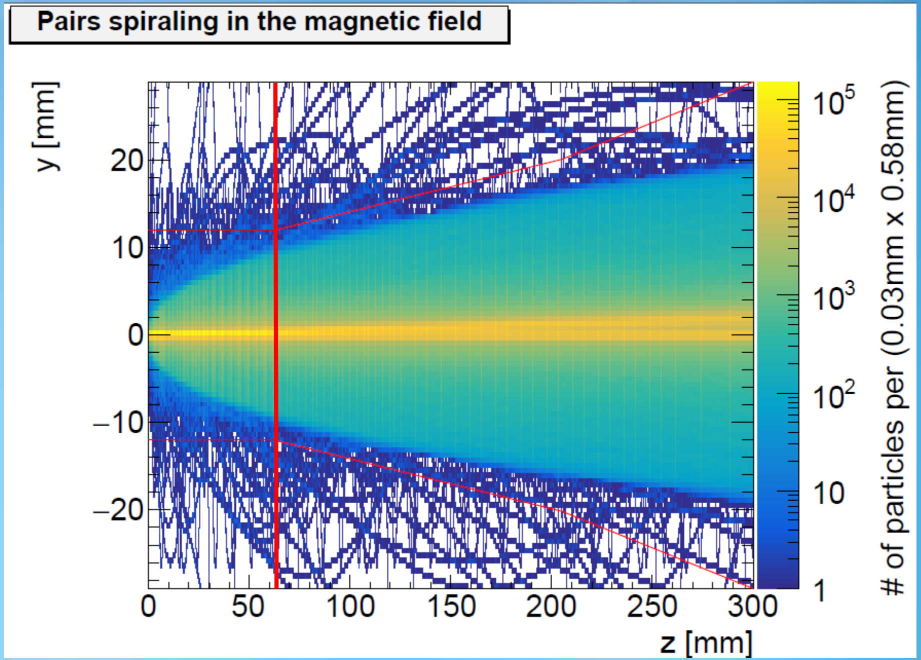


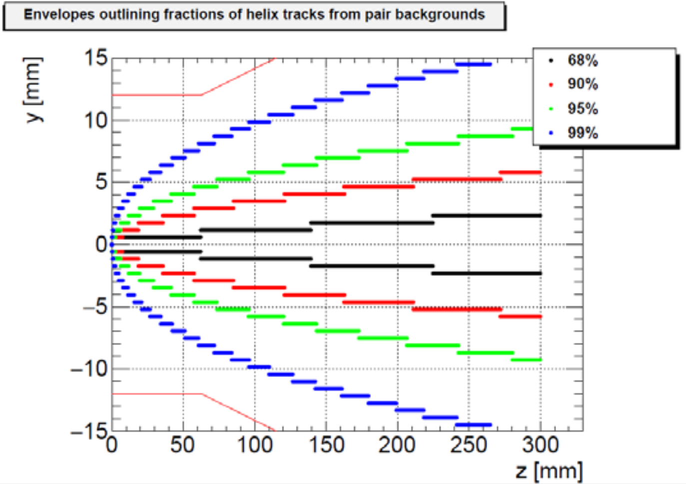
Very challenging requirements

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

VTX – Pair Background revisited







With the current beam pipe design, about 0.45% of all particles leave tracks outside the beam pipe.

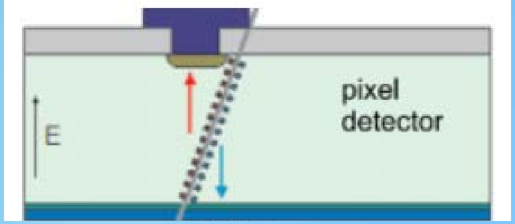
Consider reducing the beam pipe radius by 2 mm.?
Additional vertex detector layer at a radius of 7mm and a length of (2*30mm=) 60mm.?n
Physics benefits?

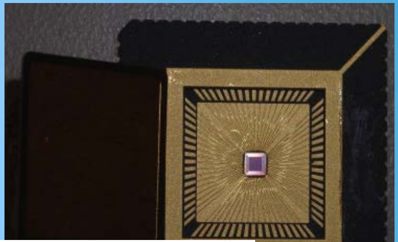
A. Schuetz (DESY)

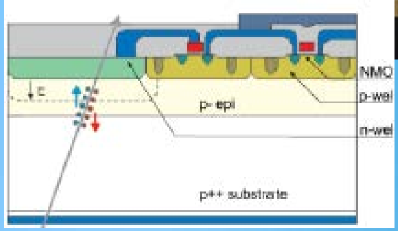
What options are considered for the SiD Vertex Detector?

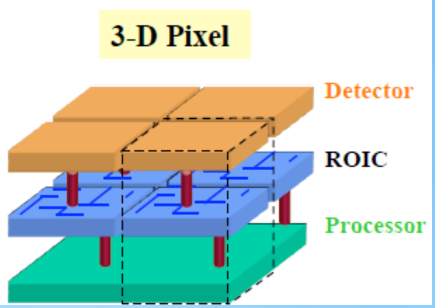
The Vertex Detector is the size of a Coke can – late installation – no reason to choose implementation now – wait for advances in technology

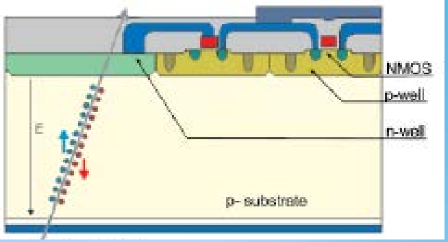
- Si diode pixels (“standard” technology)
- Monolithic designs (MAPS, Chronopix)
- Vertically Integrated (“3D”) Approaches (VIP Chip)
- High Voltage CMOS (snappy timing)









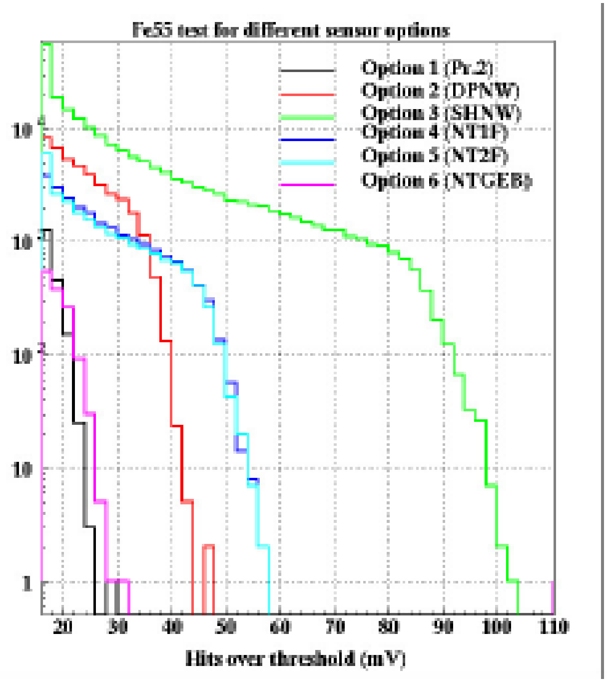


SiD Vertex Detector

Status of Chronopixel R&D

N. Sinev et al, Oregon/Yale Collaboration

- A series of three Chronopixel prototypes yielded conclusions:
  - Pixels can record time stamps with 300 ns period.
  - All hit pixels can be read out between bunch trains (sparse readout).
  - Pulsed power will not ruin comparator performance.
  - All NMOS electronics works with acceptable power consumption – Question remains: how does it compare to deep P-well option?
  - Comparator offset calibration works.
  - Sensor diode capacitance an issue for 90 nm process.
- Prototype 3 had six sensor options to study sensor diode capacitance.



Signal from Fe55 - 5.9 keV X-rays.

Derived cpacitances:

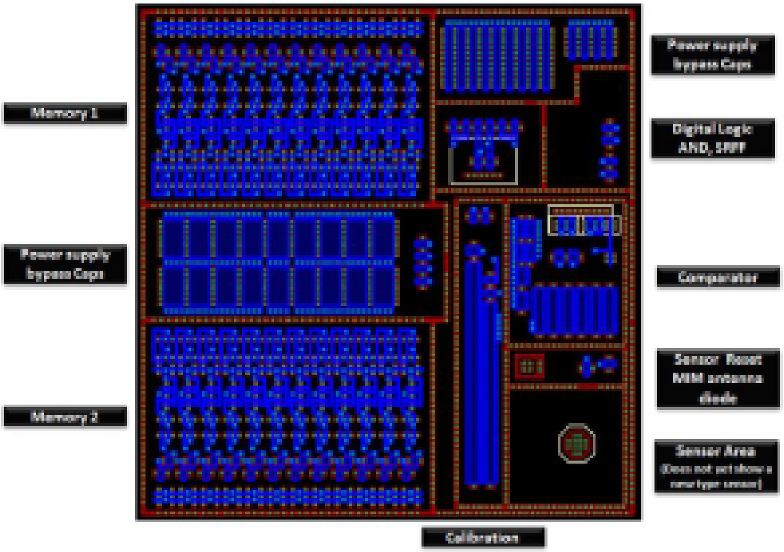
Opt 1 – 9.04 fF, Opt 2 – 6.2 fF,
Opt 3 – 2.73 fF, Opt 4 & 5 4.9 fF,
Opt 6 – 8.9 fF

SiD Vertex Detector

Chronopixel R&D - Summary and plans

N. Sinev et al, Oregon/Yale Collaboration

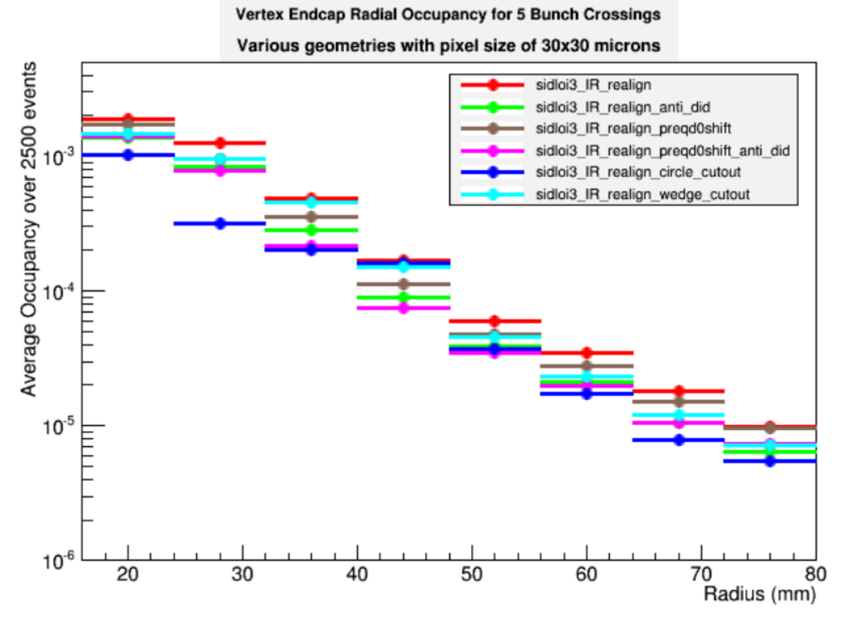
- Many problems solved – concept proven to be valid.
- Large sensor capacitance in 90 nm technology appears solved!
- Need to fully understand sensor operations details. We absolutely need to measure sensor efficiency for minimum ionizing particles.
- Cross talk issues have been addressed by separating analog and digital power and adding small decoupling capacitor. Some minor cross talk persists. Will try to minimize more.
- Currently (2016) Yale University group doing measurements with prototype 3 chips, including measurement of minimum ionizing particles (beta-source) and radiation hardness tests.



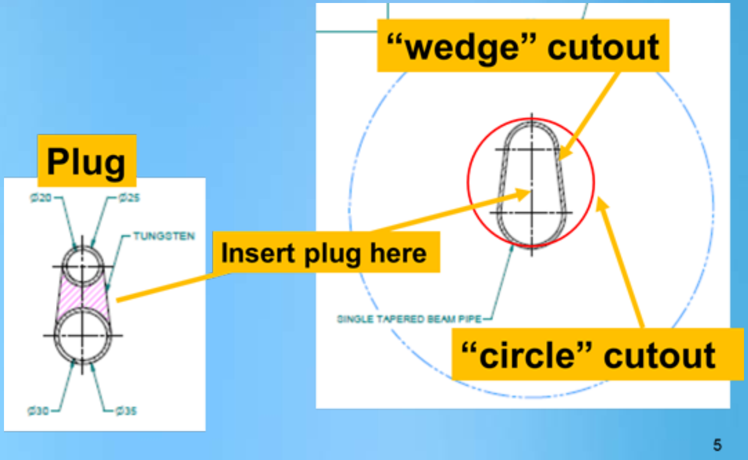
Ongoing work in the SiD Consortium

- Dependence of vertex detector occupancy on shape of hole in forward calorimeter
(B. Schuum, C.Milke – UCSC)

VXD endcap occupancy : 30x30 um pixels, integrating over 5 bunch crossings.

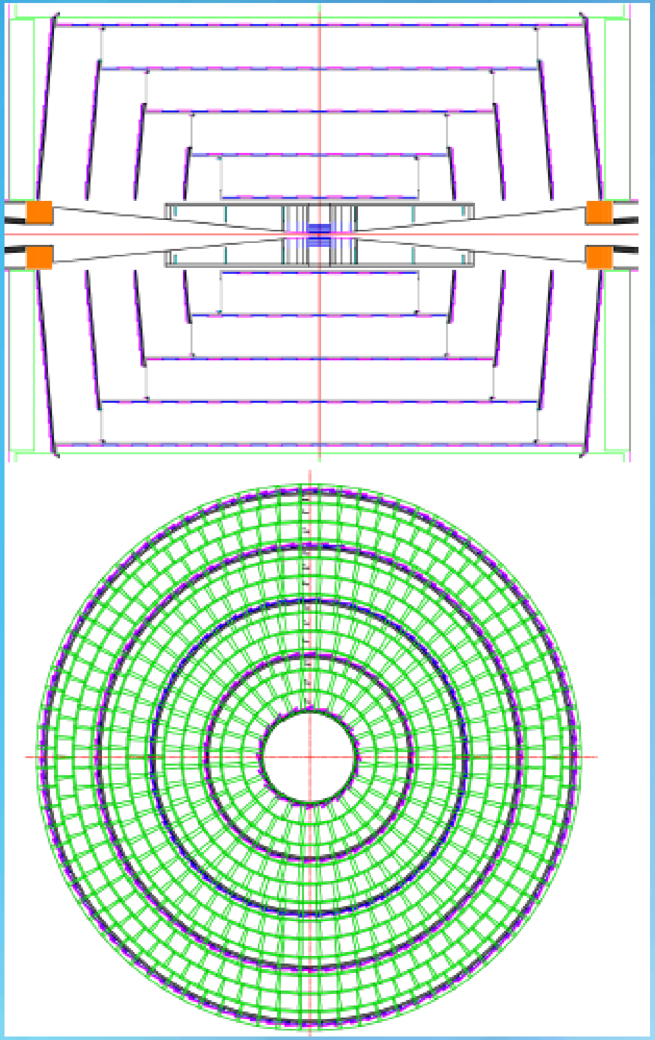


Incoherent pairs



Occupancy varies drammatically with radius; dominated by inner radii

SiD Silicon (Strip) Tracker



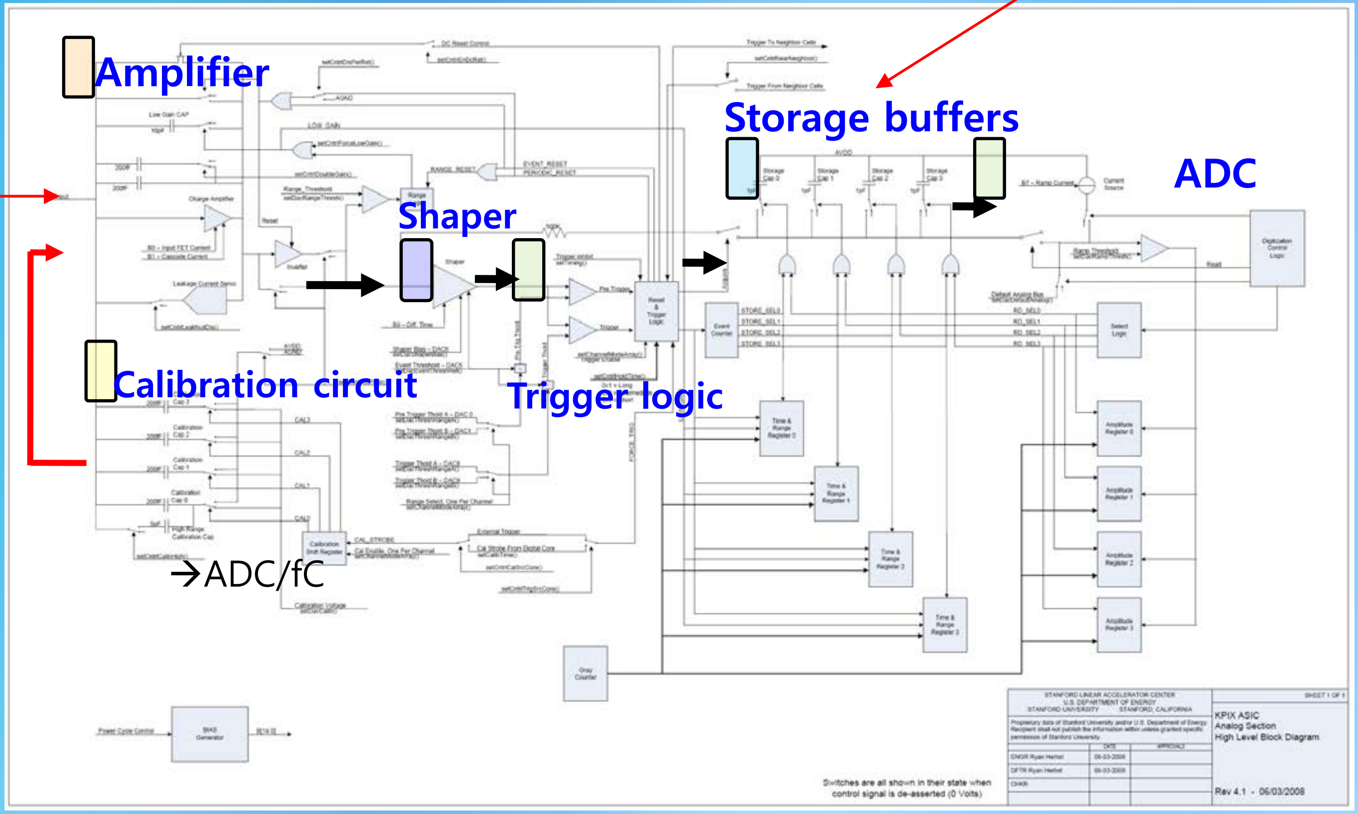
- All Silicon Tracker
  - Using Silicon micro-strips
    - 25 µm pitch / 50 µm readout
- 5 barrel layers / 4 disks
- Tracking unified with vertex detector
  - 10 layers in barrel
- Gas-cooled
- Material budget < 20% X_0 in the active region
- Readout using KPiX ASIC
  - Same readout as ECAL
  - Bump-bonded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

KPiX Readout scheme (SLAC)

Sensor element

4-deep

“pipeline”



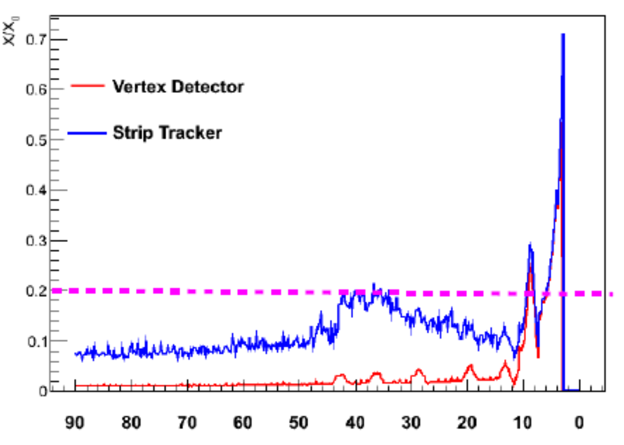
KPiX

1024 – channel chip

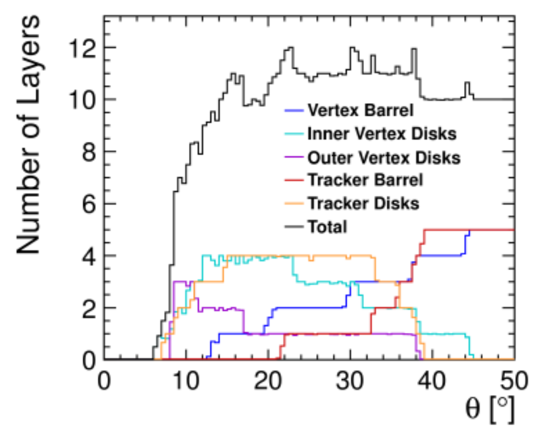
Intended as basic readout for all SiD detector elements except the vertex detector.

SiD Silicon Tracking System – Characteristics and Performance

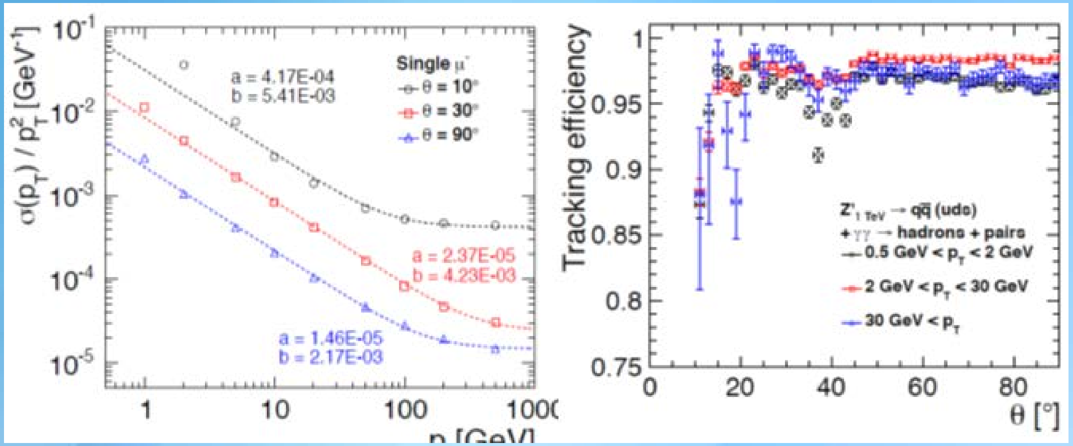
Material profile



Layers/coverage



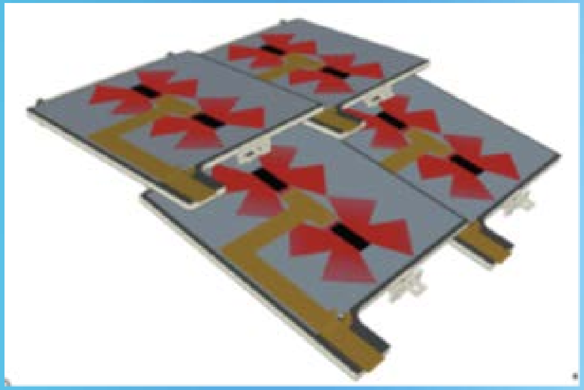
Tracking performance

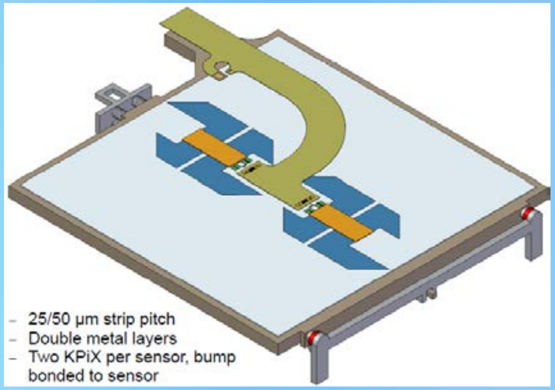


Ongoing work in the SiD Consortium

- **Silicon Tracker** (SLAC, Davis, UNM):

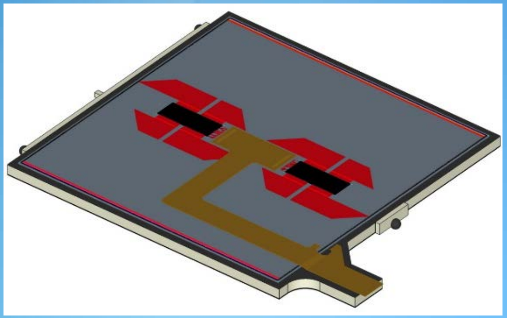
Working towards full prototype test - sensor + KPiX + cables





- 25/50 µm strip pitch
- Double metal layers
- Two KPiX per sensor, bump bonded to sensor

SiD Tracker Sensors



- In 2008, SiD completed a design for Tracker Sensors and ordered 20 prototypes from Hamamatsu.
- The prototypes and test structures were received in 2008, and we soon found that wirebonds to the sensor caused damage to the sensors, presumably due to the oxide layer between Metal 1 and 2 being inadequate.
- At that time, Hamamatsu was told about the problem, but negotiations were unsatisfactory and the matter was dropped for several years.
- In 2016, there was renewed interest in these sensors from both ILD and SiD, and the subject was re-opened with Hamamatsu. The negotiations this time seem quite favorable. Hamamatsu will increase the oxide layer thickness which should fix the wirebonding problem, and they will provide Under Bump Metallization (UBM) which we have learned is much more cost effective for the sensor vendor to provide. We are proceeding with Hamamatsu.

SiD Pixel Tracker Study

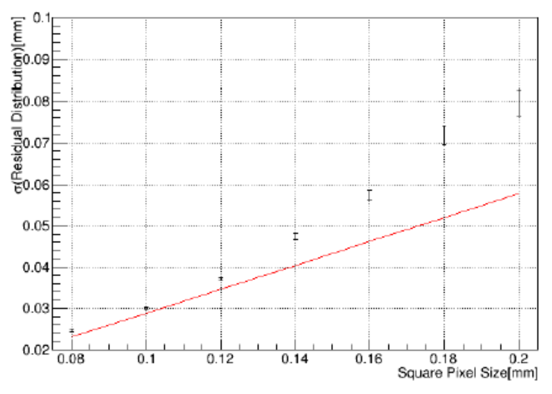
Compare pixel tracker with baseline Si strip tracker.

Pixel Tracker

(J. Goldstein(Bristol))

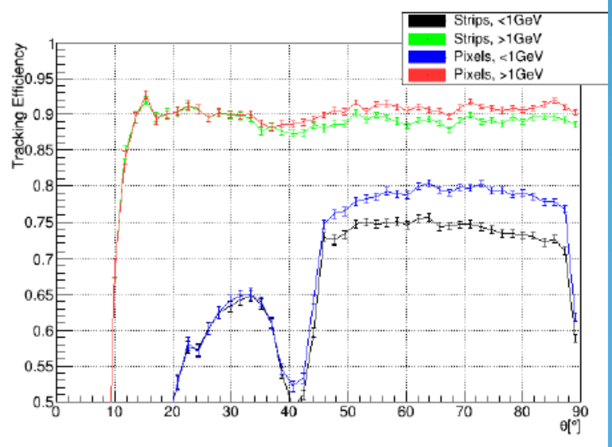
- Robust pattern recognition
- Thinner – less mass
- Standard CMOS – cheaper?
- Power consumption??

Tracking residuals, 100 GeV μ, 60°



Tracking efficiency

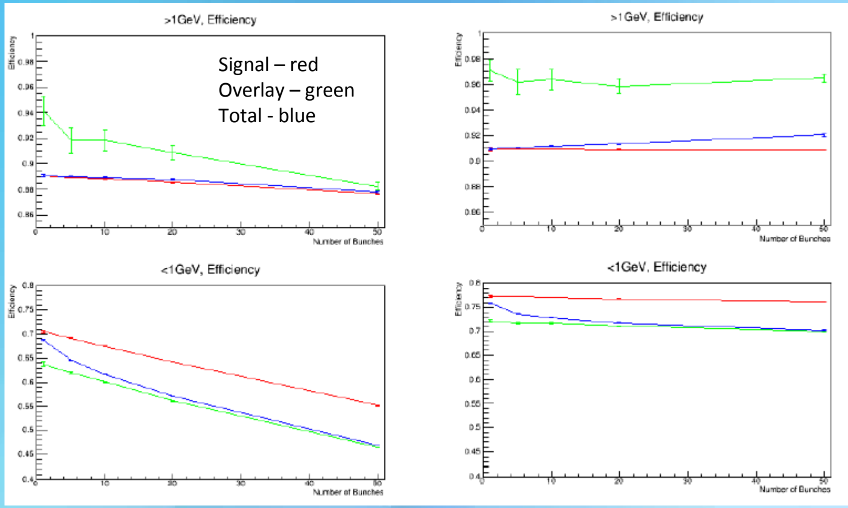
Charged π from 500 GeV ttbar events

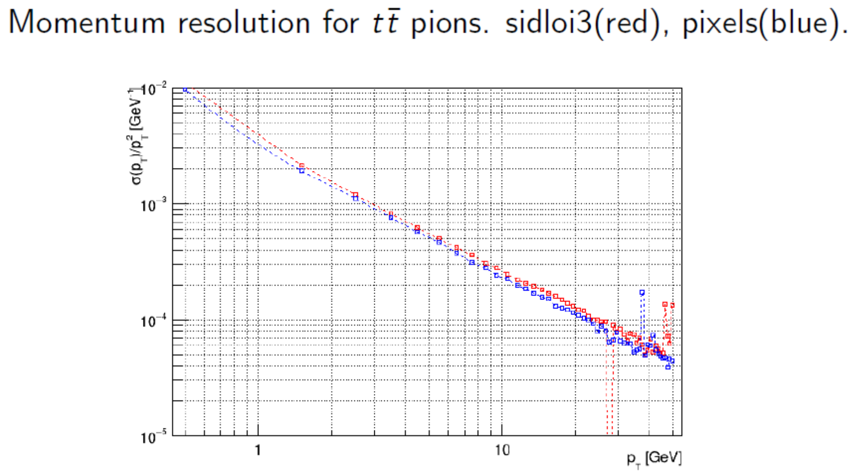


Efficiency with overlay ($\gamma\gamma$ -> h only)

Strips

Pixels



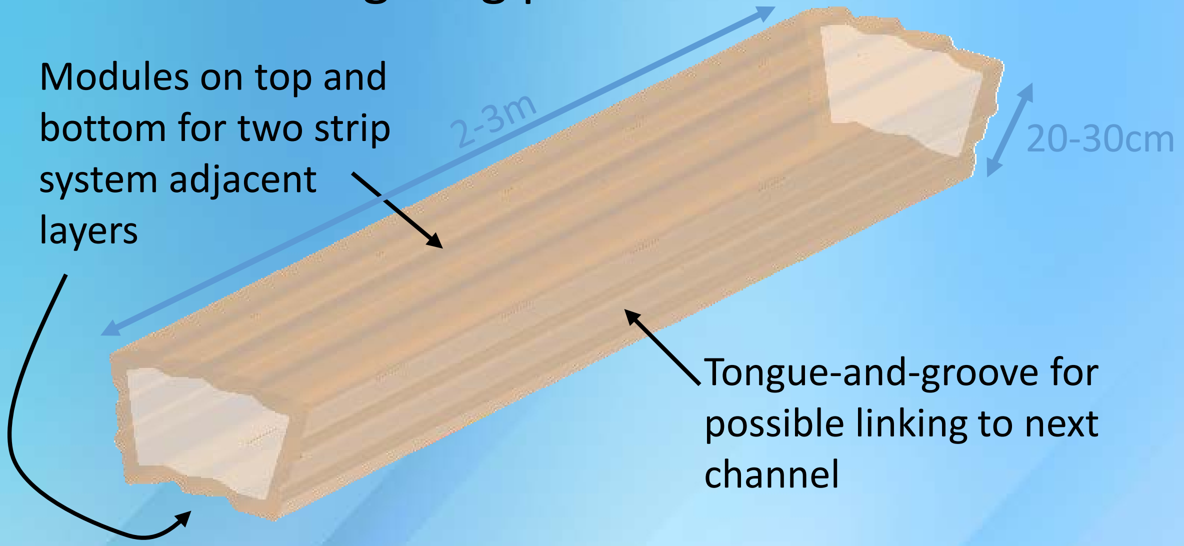


Momentum resolution for $t\bar{t}$ pions. sidloi3(red), pixels(blue).

Support structures

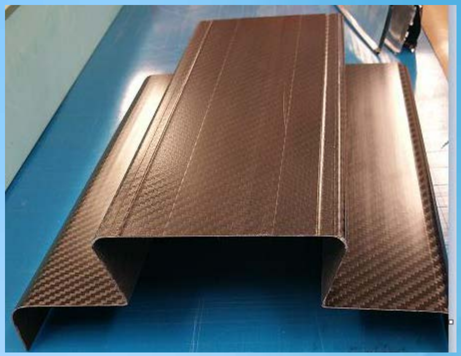
U. Oxford/U. Liverpool
Georg Viehhauser; Joost Vossebeld

- The goal is to build structures (including services and cooling) with less than 1% X_0 with lengths of several metres
- The idea is for local supports consisting of CFRP box channels, which combine ultra-high modulus skins, high moment of inertia and manageable dimensions
  - Services are co-cured into the structure
  - Also investigating possibilities to link the box channels



Modules on top and bottom for two strip system adjacent layers

Tongue-and-groove for possible linking to next channel



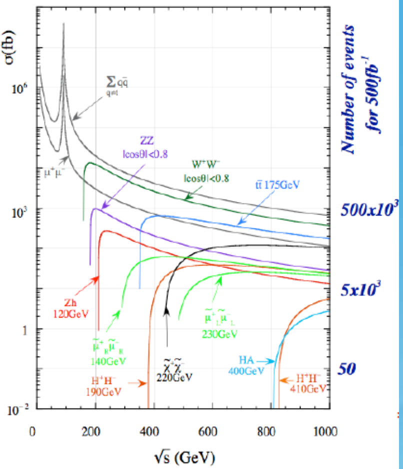
Ongoing work in the SiD Consortium

Alignment (J. Goldstein (Bristol))

- Requirements for tracking elements: Few μm for vertex detector, 10-20 μm for tracker
  - Survey of individual modules
  - Real-time monitoring systems
  - Track-based methods - ~10^4 high P_T tracks/month
  - Need studies as function of √s, theta, momentum

Z-pole running ??

- SiD and ILD have been asked to make statements on the need for Z-pole running
  - Significant potential impact on accelerator design/operation
  - Cross-sections higher at Z, but luminosity lower
  - Impact on detector (push-pull) running schedule
  - SiD makes no assumption on Z-pole running for calibration purposes.



Low Energy/Z-pole note

Z-Pole Running for SiD

The SiD Consortium

DRAFT
November 7, 2016

Abstract

The ILC detectors will need extensive calibration and alignment, much of which will rely on physics data. The ultimate statistical precision achievable is likely to depend primarily on the number of well-measured charged tracks incident on specific detector elements. It has been suggested that it will be advantageous (or even necessary) to have significant ILC running at $\sqrt{s} = 91$ GeV to take advantage of the Z-pole cross section enhancement, even if the accelerator can only provide a much-reduced luminosity.

This preliminary study examines the expected charged particle fluxes from all processes at $\sqrt{s} = 91$ GeV and 500 GeV as a function of polar angle and momentum in the transverse plane. It is found that the ratio of the 500 GeV flux to that at the Z-pole has only a weak dependence on transverse momentum and is smallest when perpendicular to the beamline, rapidly rising in the forward regions. Even in the most central region, however, the lower cross section at high energies will be largely compensated by the expected higher luminosity. It therefore appears that there is no advantage in taking data at the Z-pole unless the luminosity is significantly higher than that currently forseen.

1 Introduction

The physics reach of the SiD detector at the ILC depends critically on the calibration and alignment of the different subdetectors. In particular, tracking elements will need to be aligned to an accuracy of microns (vertex detector), tens of microns (tracker) or hundreds of microns (muon detectors), and calorimeters will need calibrating to achieve a jet energy resolution at the few percent level.

The detailed calibration and alignment strategies for SiD will depend on the final detector technologies, and studies have just barely started. They will inevitably require a combination of detailed survey data, real-time monitoring and physics data from collisions (and possibly even cosmic rays and beam backgrounds).

The physics collision data available for these purposes will depend on the integrated luminosity delivered, the cross sections of the physics processes, and the kinematic distributions of the particles produced.

The ILC will deliver physics collisions at an energy of 250 GeV and above, with luminosities of the order of 10^{34} cm^{-2}s^{-1}. As described in the March 2016 paper from the ILC Parameters Joint Working Group, it should also be possible

Preliminary study – all relevant physics processes included.

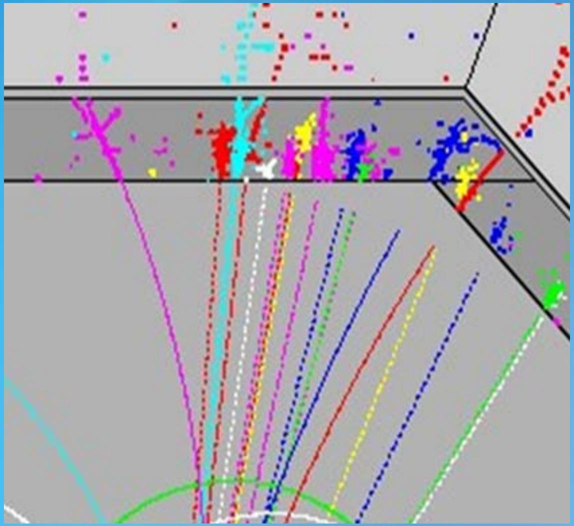
Examine flux of charged particles above min(Pt) per tracker module.

Sufficient fluxes at higher energies

Conclusion:
“SiD requests only running at higher energies”

This result should be taken as part of a comprehensive alignment and calibration scheme.

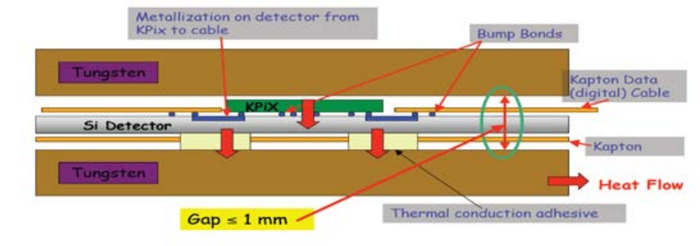
Electromagnetic Calorimeter

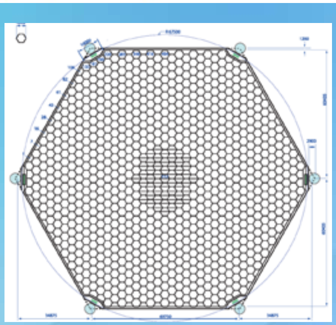


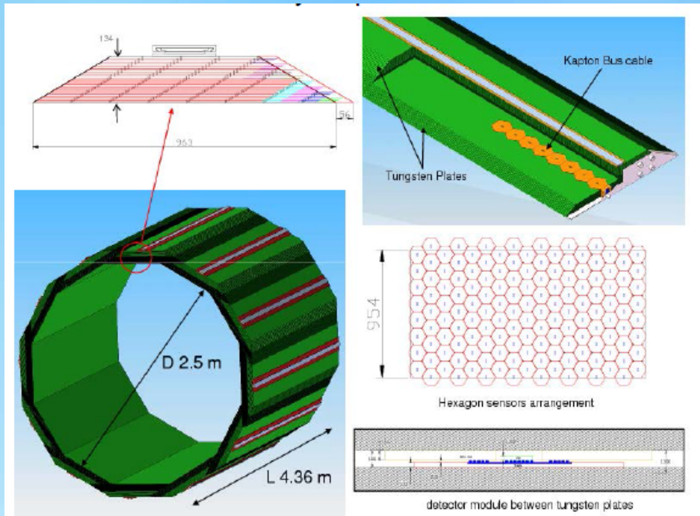
Highly granular “imaging” calorimetry essential for ILC physics program:

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

Baseline design: Silicon/Tungsten





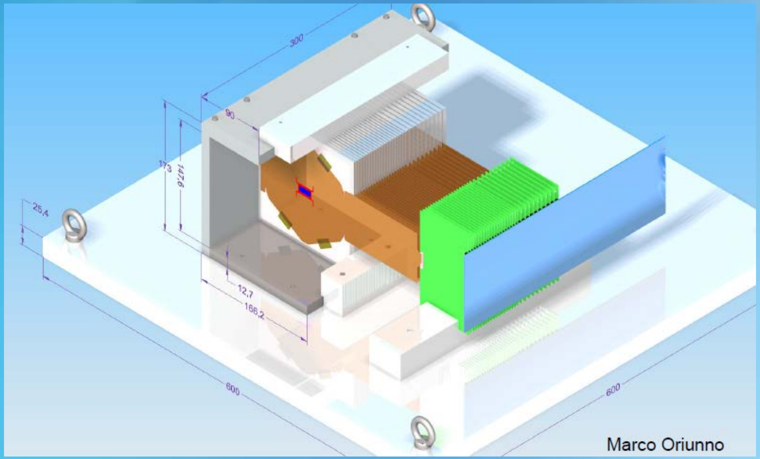


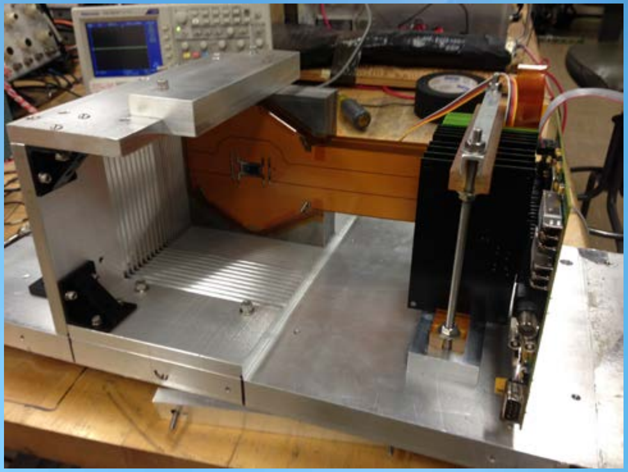
Baseline configuration:

- transverse: 12 mm^2 pixels
- longitudinal: $(20 \times 5/7\ X_0)$ + $(10 \times 10/7\ X_0)$ $\Rightarrow$ 17%/sqrt(E)
- 1 mm readout gaps $\Rightarrow$ 13 mm effective Moliere radius

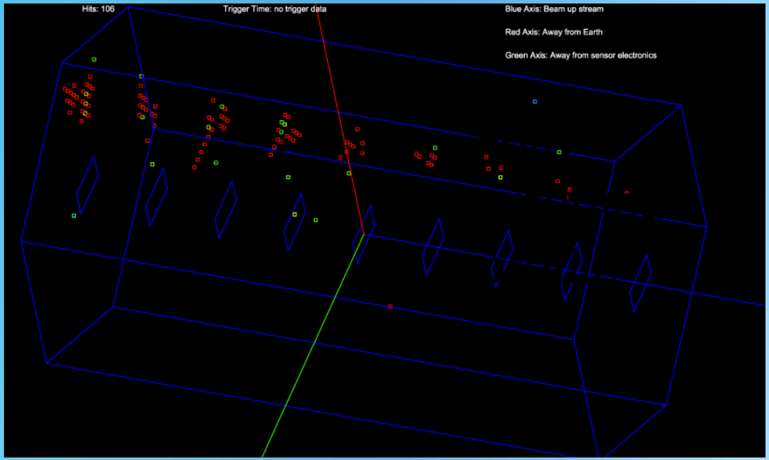
E.M. Calorimeter – beam tests

U of Oregon, SLAC, UC Davis

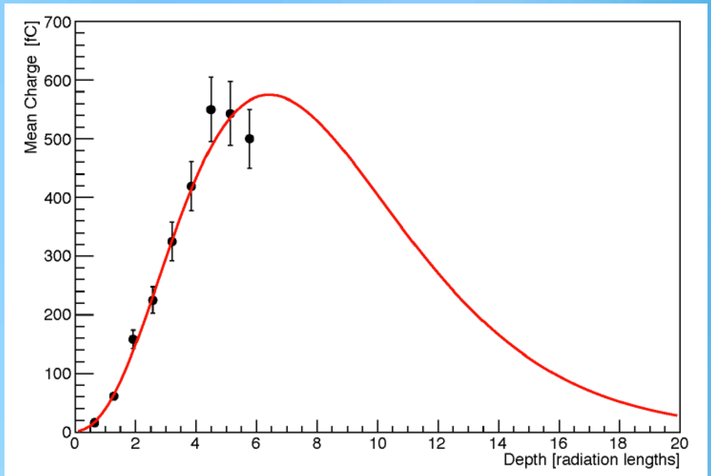




Single electron in 9-layer prototype



Longitudinal charge deposition

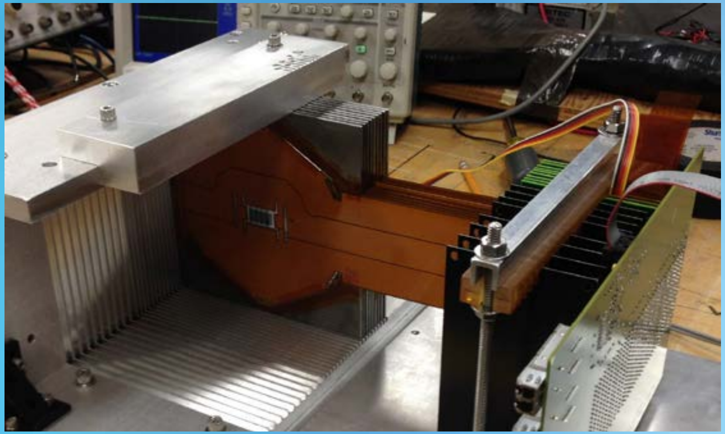


- Parasitic crosstalk – new design has additional shield layer
- Issue with KPiX resets causing “monster events” – understood/small change
- Move from aluminum bond pads to gold for next sensors

SiD SiW ECal Test Beam Analysis

A. Steinhebel, J. Barkeloo, J. Brau

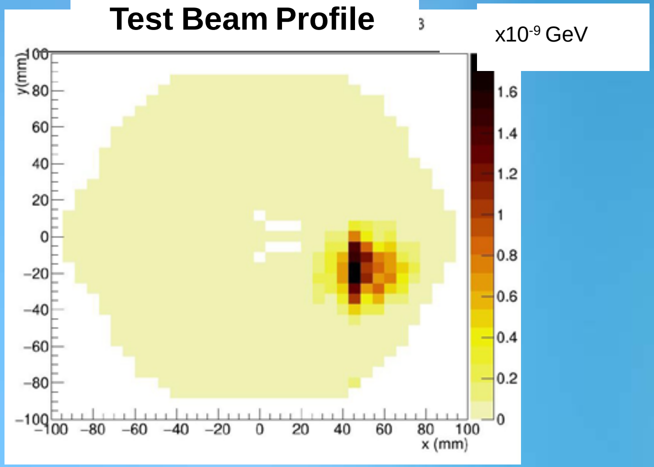
U of Oregon, SLAC, UC Davis

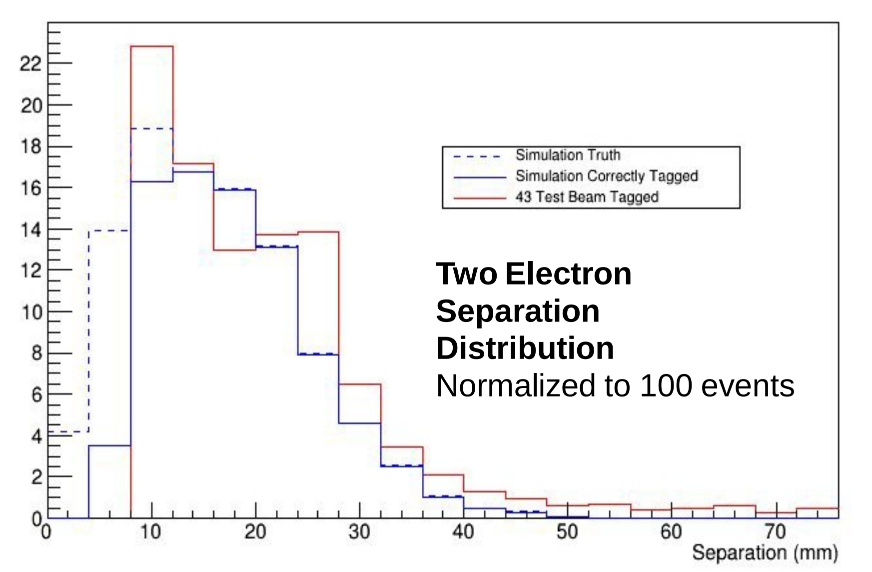


9 layer Si/W Calorimeter
~ 6 X_0
13 mm^2 pixels

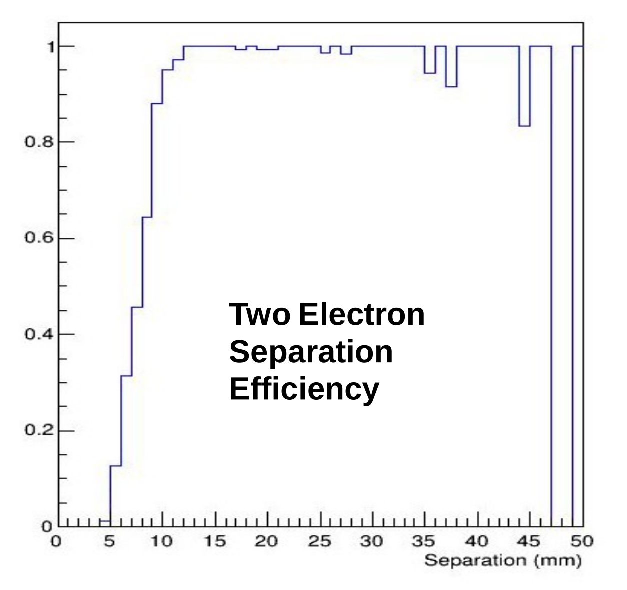
12.1 GeV electrons

Test Beam Profile





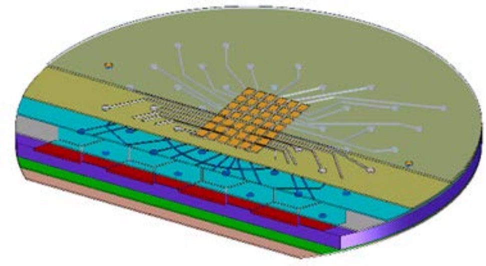
Two Electron Separation Distribution
Normalized to 100 events



Two Electron Separation Efficiency

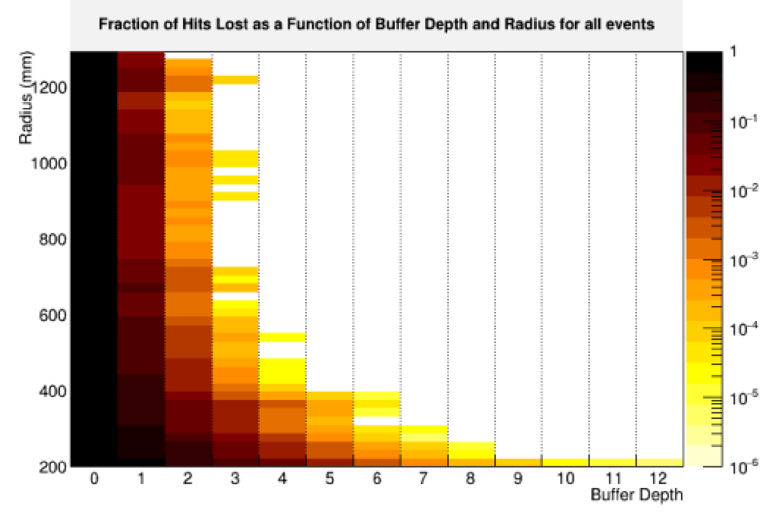
Ongoing work in the SiD Consortium

- **Electromagnetic Calorimeter** (U. Oregon)
  - New sensors w/gold bond pads and additional shielding layer received –> next round of beam tests

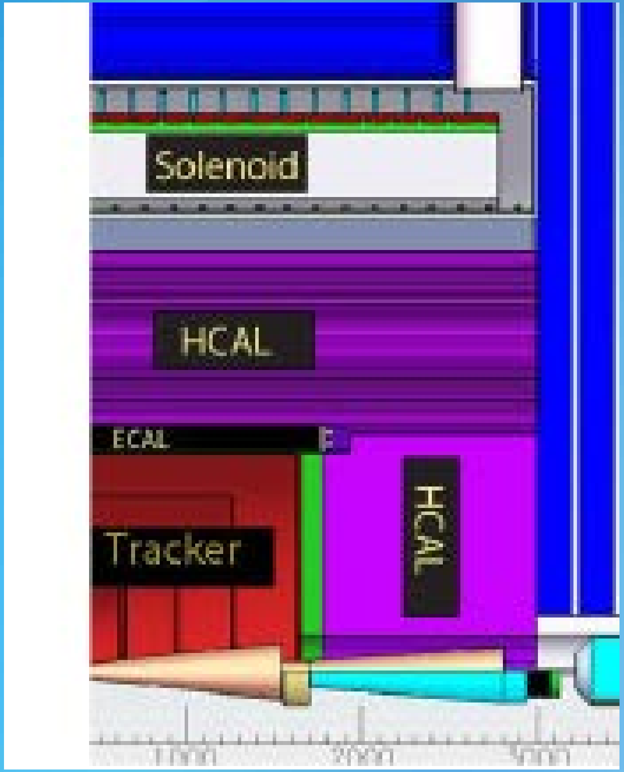


- Study of required KPiX buffer depth (B. Schumm – UCSC) for the endcap calorimeter.

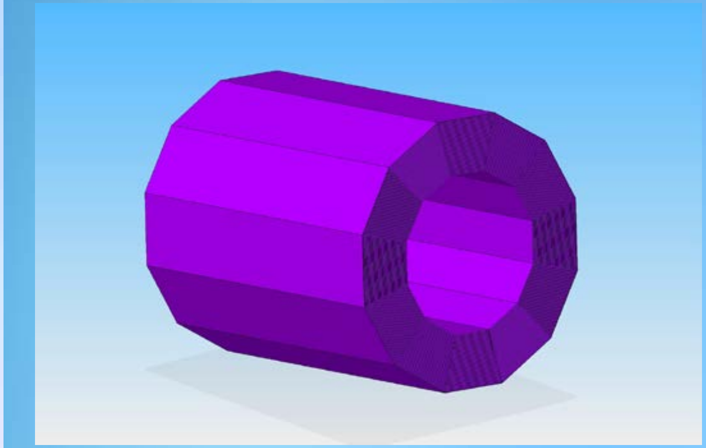
KPiX fractional hit loss as a function of buffer depth and radius

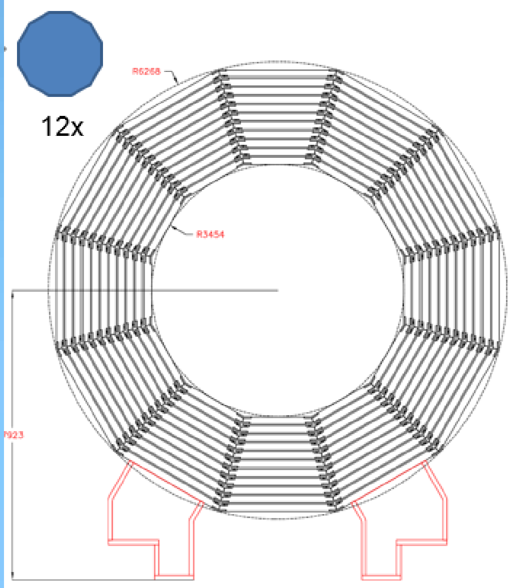


SiD Hadron Calorimeter

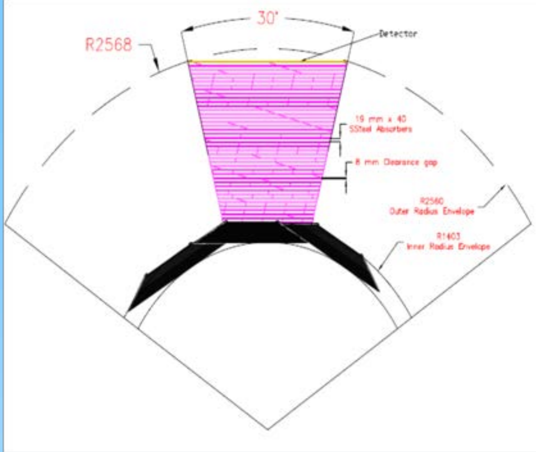


12-fold barrel geometry

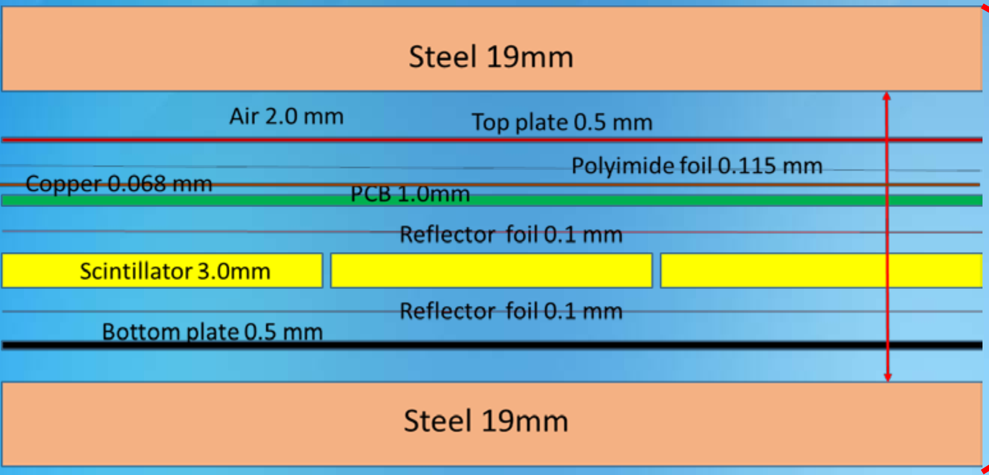




Following a review – new baseline technology for the SiD HCal is Scintillator/SiPM/Steel



SiD Hadron Calorimeter



Steel 19mm

Air 2.0 mm

Top plate 0.5 mm

Polyimide foil 0.115 mm

Copper 0.068 mm

PCB 1.0mm

Reflector foil 0.1 mm

Scintillator 3.0mm

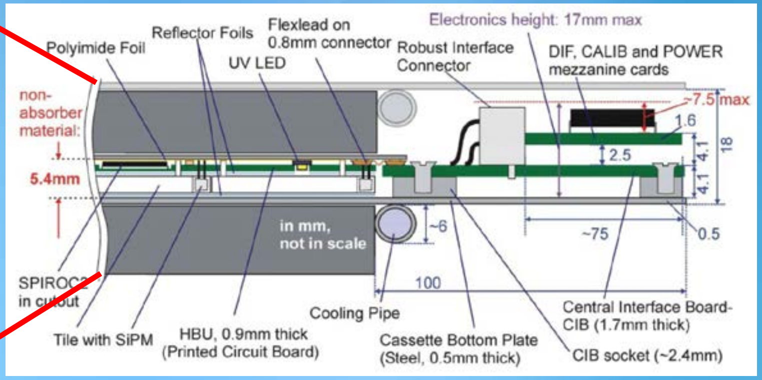
Reflector foil 0.1 mm

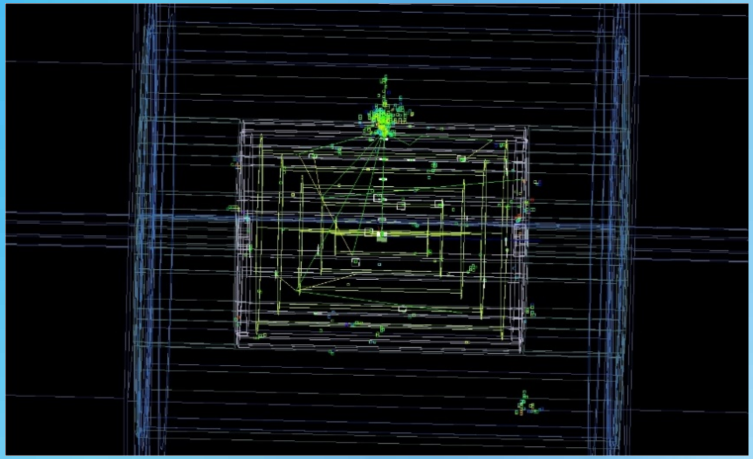
Bottom plate 0.5 mm

Steel 19mm

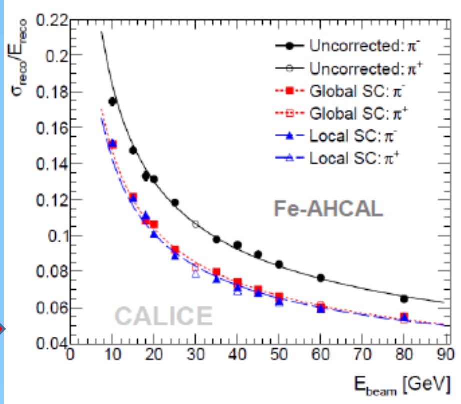
Active layer thickness = 7.383 mm

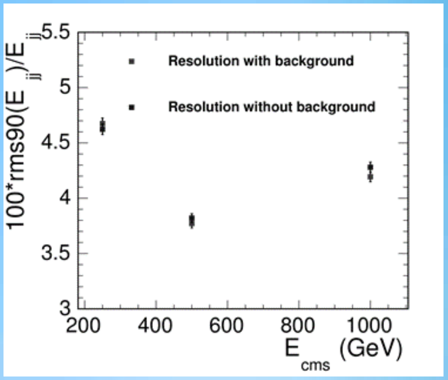
CALICE design





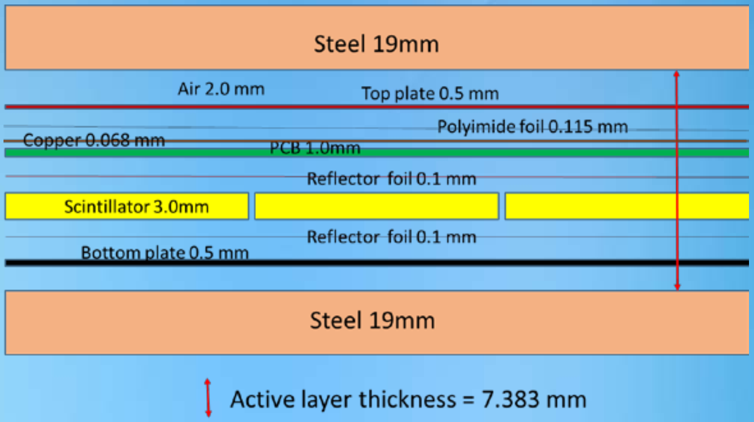
Initial goal: compare simulated single particle energy resolution with actual CALICE test beam results





SiD Hadron Calorimeter

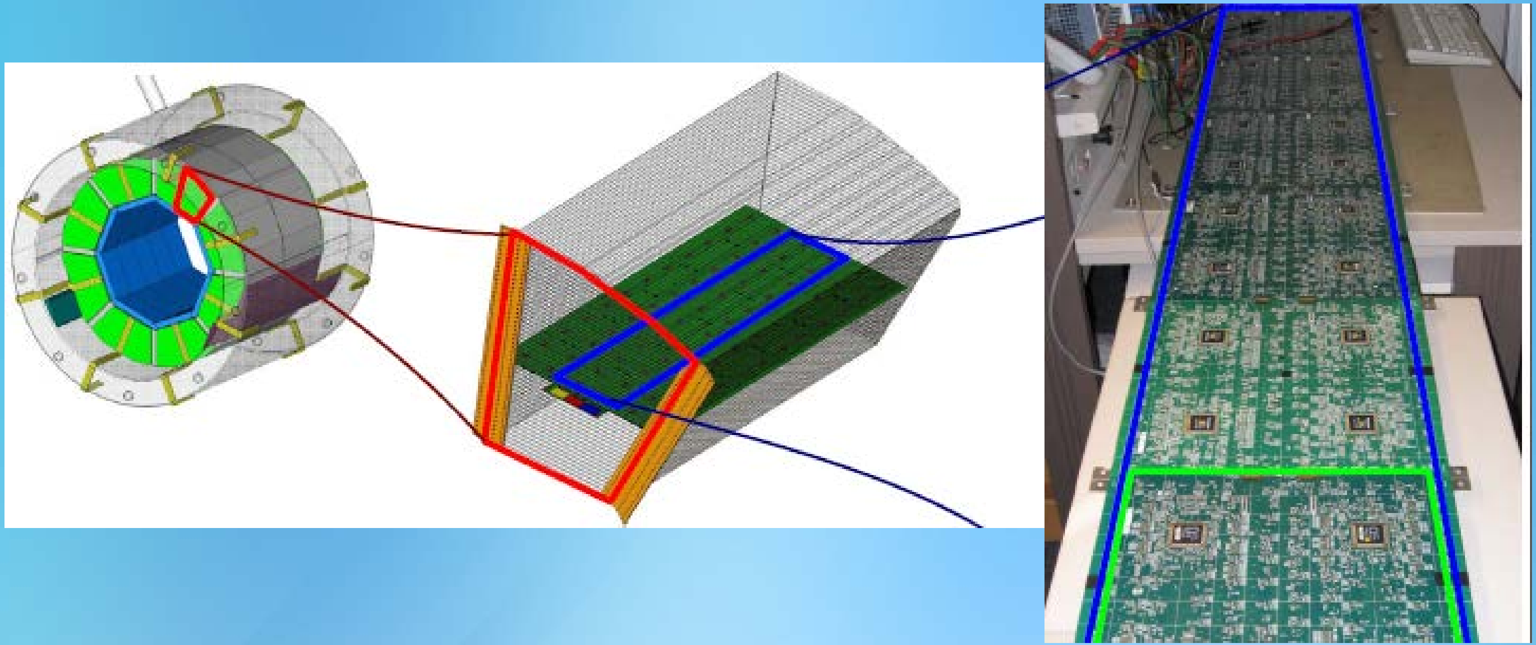
Simulation: DD4HEP geometry
implementation by
UTA (undergraduate students:
Andrew Myers, Ross McCoy)



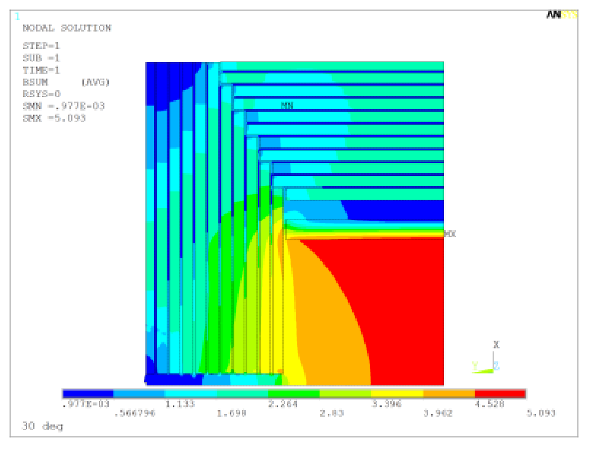
Latest UTA AHCAL Simulation results

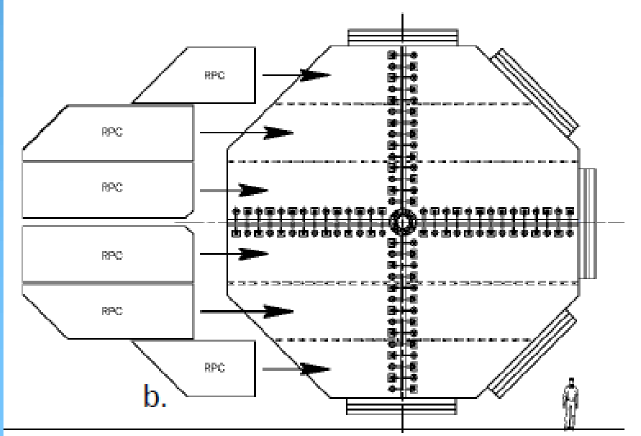
Ongoing work in the SiD Consortium

- **Hadron Calorimeter**
  - Mechanical design following re-baselining to Scintillator/Steel
  - Follow CALICE developments



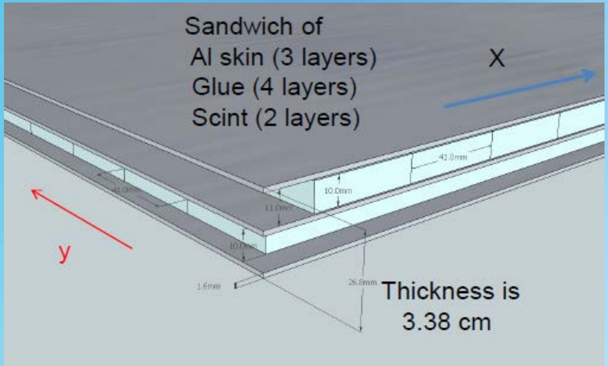
Muon identifier/Calorimeter Tail Catcher

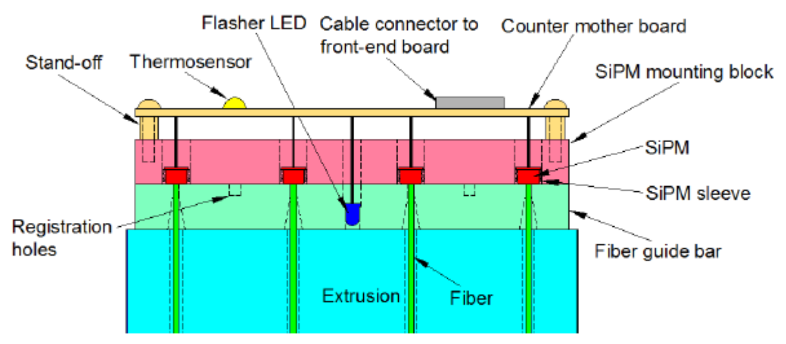




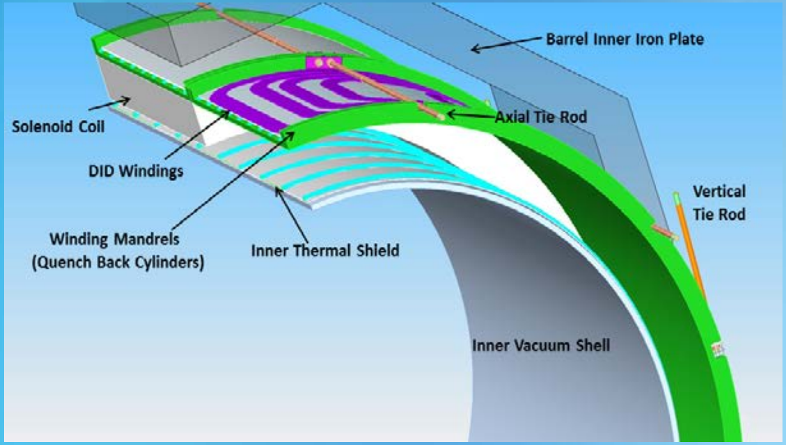
SiD Baseline – long scintillator strips with WLS fiber and SiPM readout

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

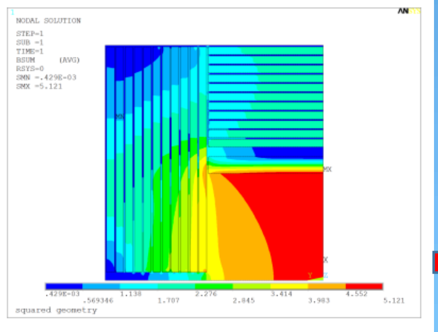




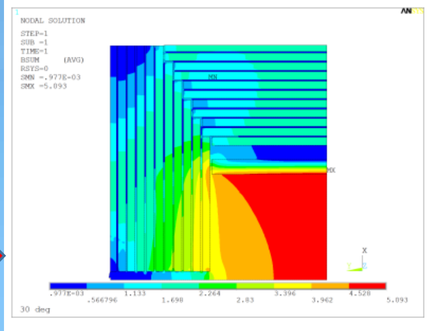
SiD Solenoid



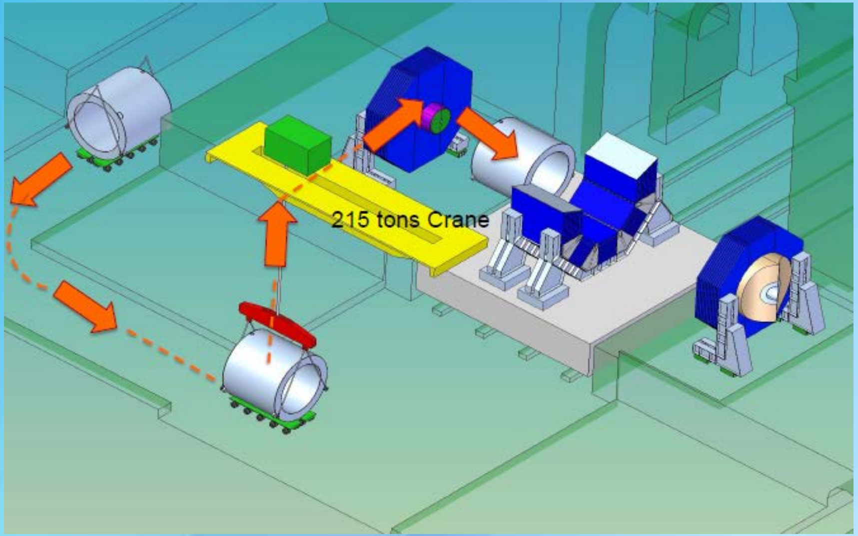
Baseline CMS conductor

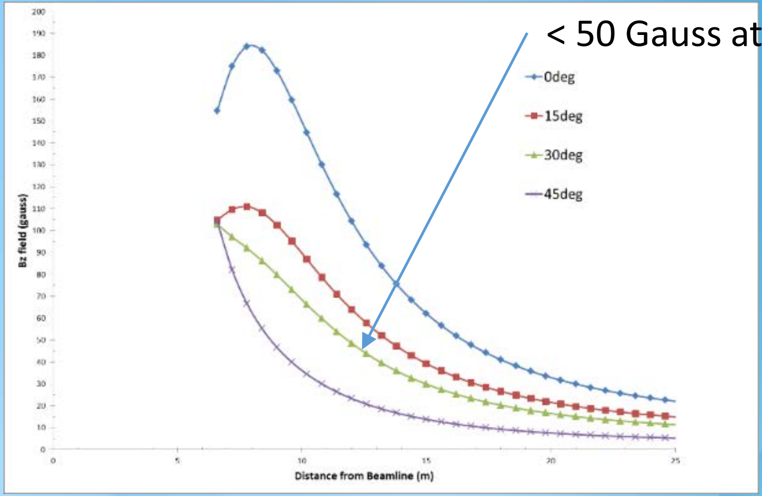


30° design



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





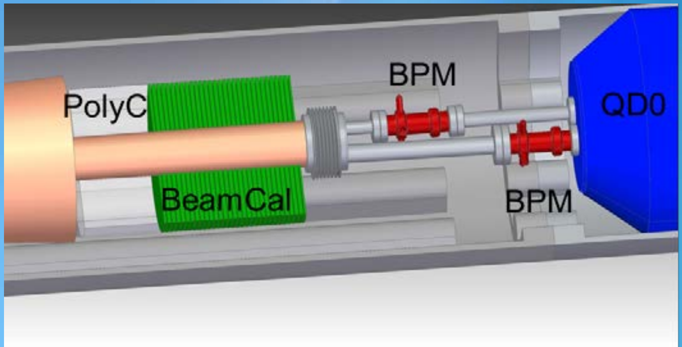
< 50 Gauss at 15m

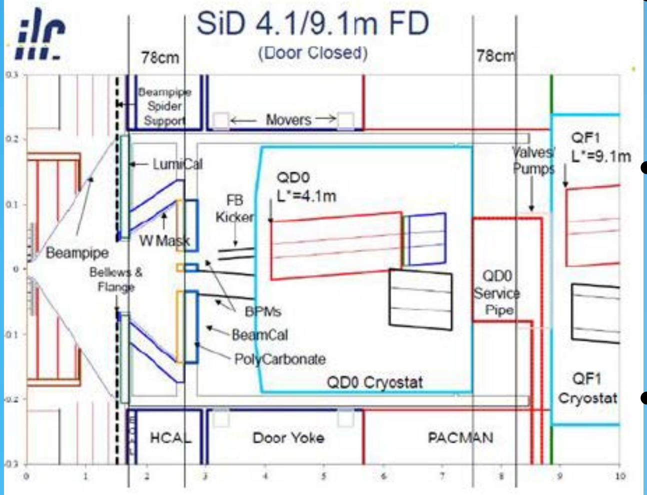
M. Oriunno (SLAC)

Ongoing work in the SiD Consortium

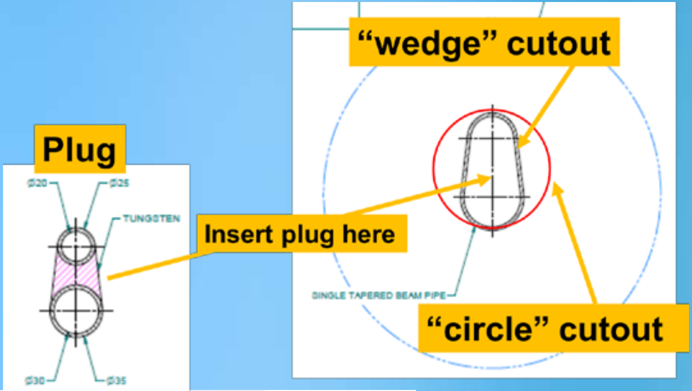
- **Forward region (**B. Schumm UCSC)
  - New layout with new L* = 4.1m

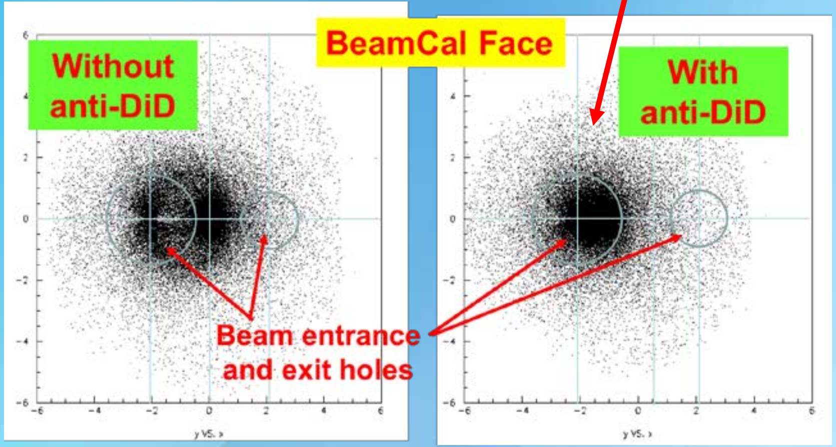
T. Markiewicz (SLAC)

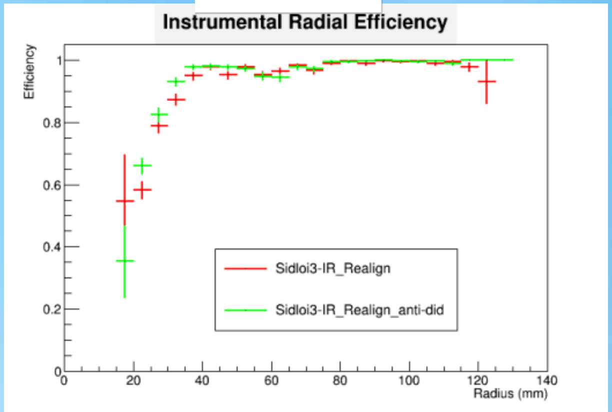




- **BeamCal** design – around outgoing beam pipe
- Anti-DID sweeps the incoherent pairs into outgoing beamline – less background
- Eliminate Anti-DID ?







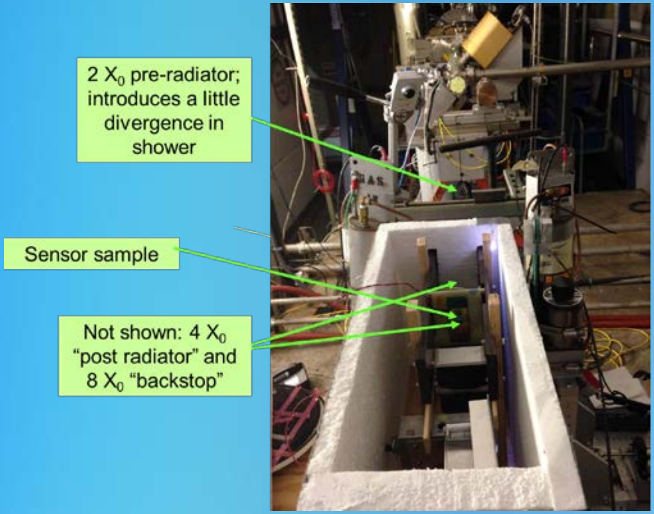
50 GeV electrons from the IP

Ongoing work in the SiD Consortium

- **Sensor irradiation studies for Forward Calorimetry**

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

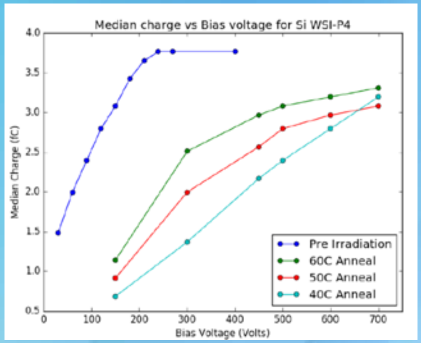
BeamCal radiation dose at inner radius ~100 Mrad/year

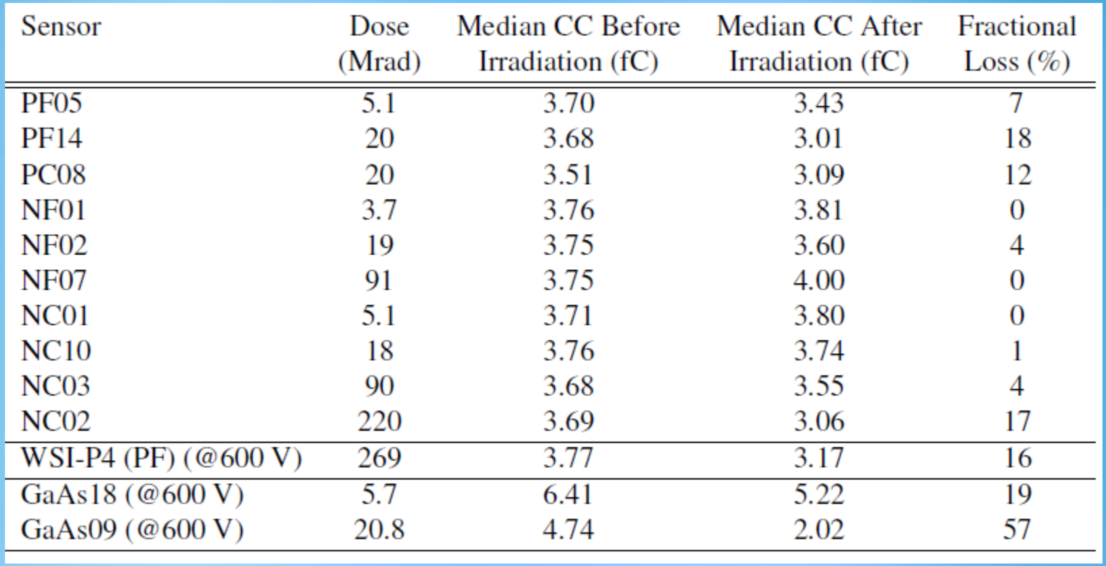


2 X_0 pre-radiator; introduces a little divergence in shower

Sensor sample

Not shown: 4 X_0 “post radiator” and 8 X_0 “backstop”





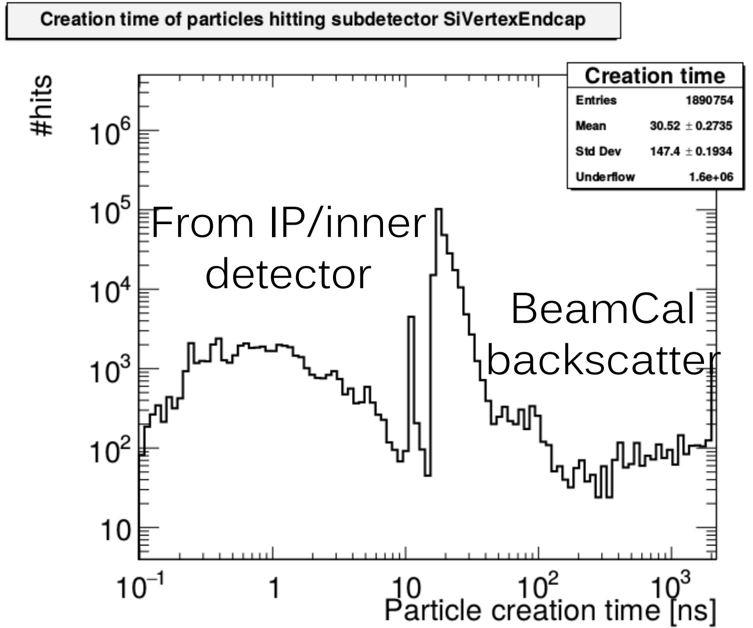
Sensor	Dose (Mrad)	Median CC Before Irradiation (fC)	Median CC After Irradiation (fC)	Fractional Loss (%)
PF05	5.1	3.70	3.43	7
PF14	20	3.68	3.01	18
PC08	20	3.51	3.09	12
NF01	3.7	3.76	3.81	0
NF02	19	3.75	3.60	4
NF07	91	3.75	4.00	0
NC01	5.1	3.71	3.80	0
NC10	18	3.76	3.74	1
NC03	90	3.68	3.55	4
NC02	220	3.69	3.06	17
WSI-P4 (PF) (@600 V)	269	3.77	3.17	16
GaAs18 (@600 V)	5.7	6.41	5.22	19
GaAs09 (@600 V)	20.8	4.74	2.02	57

PF, PC, NF, NC. "P" or "N" refers to p-type or n-type bulk; "F" is float-zone and "C" is magnetic Czochralski.

Ongoing work in the SiD Consortium

Study - can timing be used to cut background?
(A. Schuetz – DESY)

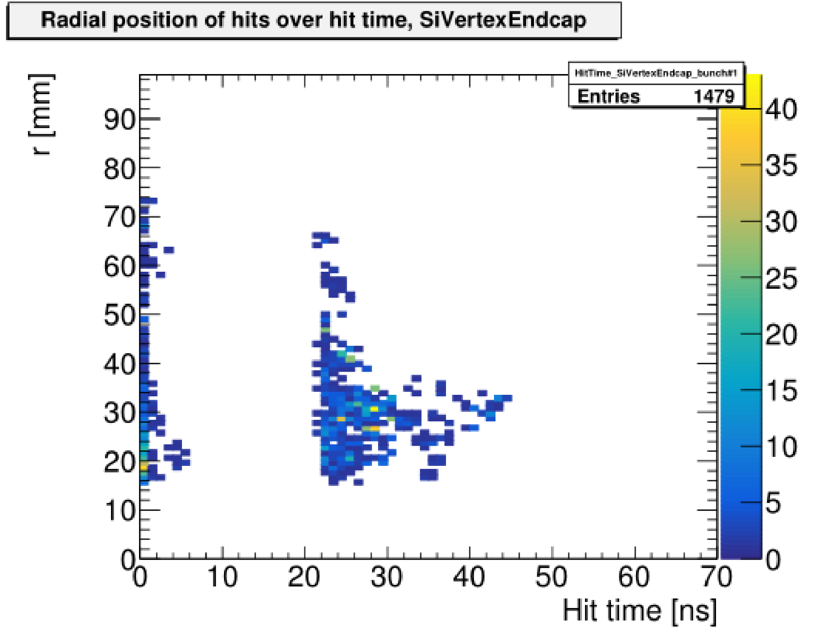
Pairs – creation time
1 train = 1312 bunches



From IP/inner detector

BeamCal backscatter

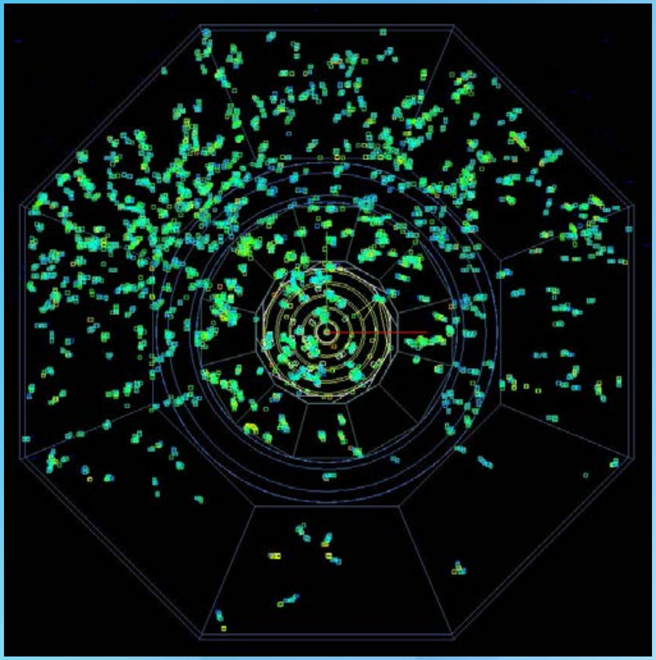
Time at VTX endcap
1 bunch

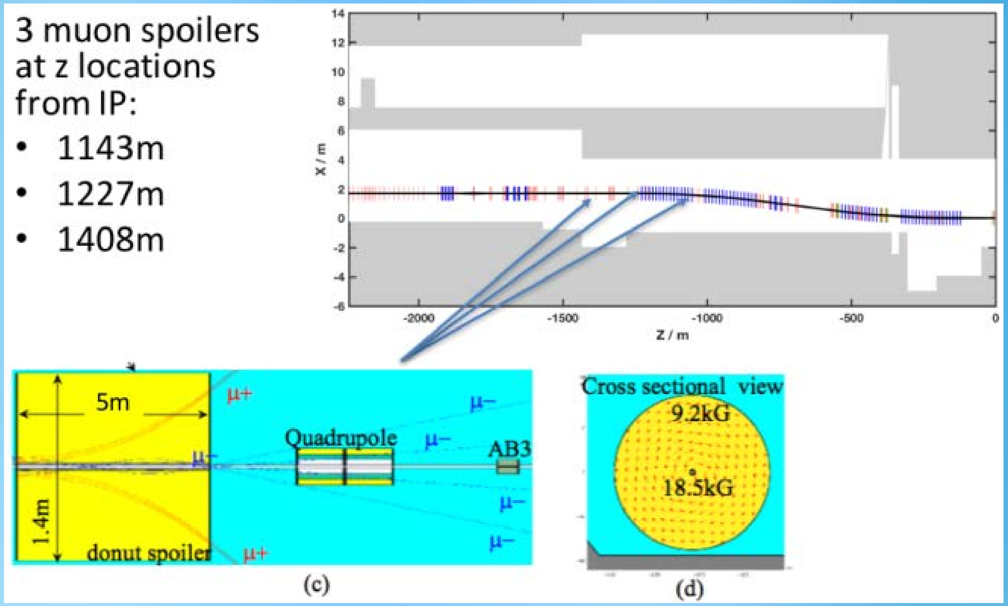


Ongoing work in the SiD Consortium

- Beam-related muon background – study started
- (A. Schuetz – DESY), L. Keller (SLAC)

Beam muon hits in SiD:
1 bunch



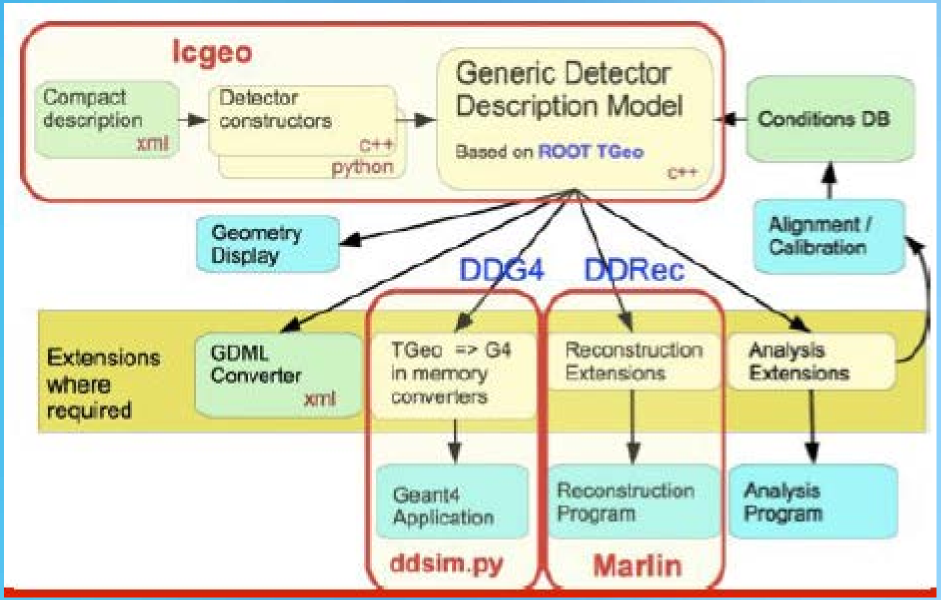


3 muon spoilers at z locations from IP:

- 1143m
- 1227m
- 1408m

Ongoing work in the SiD Consortium

- Software Development (A. Robson et al (Glasgow))
  - Switch to **DD4HEP** for alignment with ILD and CLICdp



These were a few examples of the studies being made by SiD to optimize the detector design – plenty of room for **new ideas**, **opportunities** to make contributions!

More details of DD4HEP simulation

SiD Plans for 2017 (1)

VTX – Oregon/Yale – continue studies with prototype #3, minimum ionizing particles,
radiation hardness

- Follow development of various technologies: 3-D, HV CMOS,…

TRK - SLAC, UNM - next generation of tracker sensors (Hamamatsu)

- SLAC – kPixM development, test structure
- U. Bristol – Continue development of Pixel tracker option, develop alignment procedures
- Follow CF structures development in UK (Oxford, Liverpool)
- Glasgow – tracking software development

ECal – Oregon/SLAC/UC Davis – new sensors (shielding layer), new prototype module
next round of beam tests

- SLAC – kPixM development, test structure

HCal – UTA – continue Scintillator/SiPM/Steel technology implementation in new simulation framework. Start SiD-specific HCal module design – follow CALICE activities. Work towards SiD HCal prototype modules (barrel, endcap).

SiD Plans for 2017 (2)

FCal – UCSC – continue radiation hardness studies (more beam tests?)

- Finish collision parameters study/beam cal geometry
- BeamCal reconstruction/new framework/fast MC
- FLUKA study of neutron production from BeamCal

Computing/Software – Glasgow - DD4HEP simulation commissioning - (with many SiD groups contributing subsystem implementations).

MDI – SLAC – Interface to ILC/MDI

- DESY/SLAC – Muon background/spoilers, FLUKA beam dump study

Physics studies planned – SLAC (T. Barklow) – general ILC physics studies, backgrounds

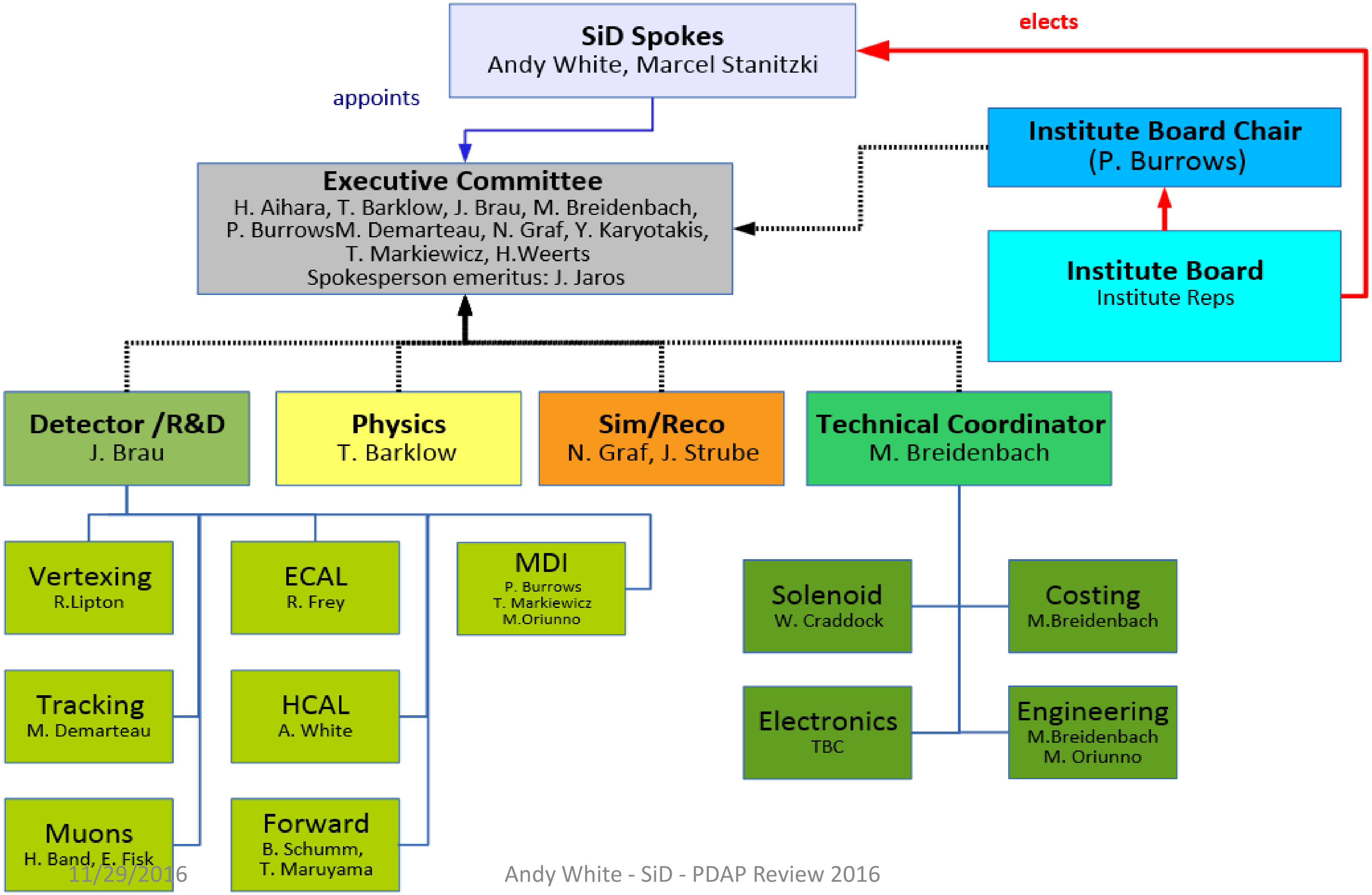
- Students: A. Schuetz(DESY), Bogdan(Glasgow), A. Steinhebel (UO, h ->$\tau\tau$), UCSC (degenerate stau), C. Potter (UO, light MSSM)

General – Engineering (Mechanical, electronics) ?? As support allows.

Moving forward in the climate of uncertainty

- U.S. University groups waiting for the outcome of the comparative review process (~January).
- Collaborative proposal will be submitted to the recently announced U.S. – Japan Science and Technology Cooperation Program in HEP.
- Essentially no support for ILC activity at U.S. Labs.
- Ongoing support in UK/Europe for ILC work (SiD and Detector R&D groups)
- Continue to work with/for the Detector R&D groups (e.g. CALICE for SiD HCal, FCAL for SiD Forward Region).
- U.S. will hold the 2017 regional meeting at SLAC – "keep a hand in the ILC…"

SiD Consortium Organization



SiD Spokes
Andy White, Marcel Stanitzki

appoints

elects

Executive Committee
H. Aihara, T. Barklow, J. Brau, M. Breidenbach,
P. BurrowsM. Demarteau, N. Graf, Y. Karyotakis,
T. Markiewicz, H.Weerts
Spokesperson emeritus: J. Jaros

Institute Board Chair
(P. Burrows)

Institute Board
Institute Reps

Detector /R&D
J. Brau

Physics
T. Barklow

Sim/Reco
N. Graf, J. Strube

Technical Coordinator
M. Breidenbach

Vertexing
R.Lipton

ECAL
R. Frey

MDI
P. Burrows
T. Markiewicz
M.Oriunno

Tracking
M. Demarteau

HCAL
A. White

Muons
H. Band, E. Fisk

Forward
B. Schumm,
T. Maruyama

Solenoid
W. Craddock

Costing
M.Breidenbach

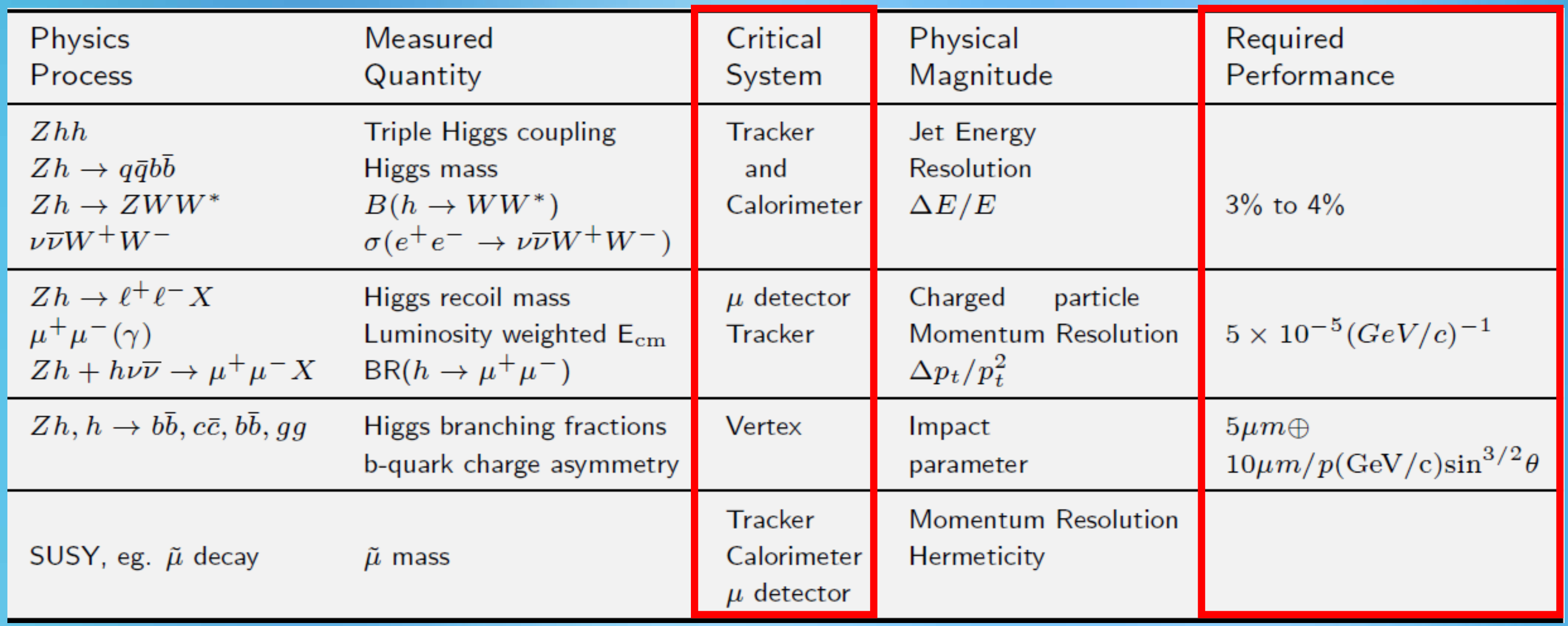
Electronics
TBC

Engineering
M.Breidenbach
M. Oriunno

Thank you

Extra material

What are the demands on the detector performance from the ILC physics program?



Physics Process	Measured Quantity	Critical System	Physical Magnitude	Required Performance
Zhh $Zh \to q\bar{q}b\bar{b}$ $Zh \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs coupling Higgs mass $B(h \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution $\Delta E/E$	3% to 4%
$Zh \to \ell^+\ell^-X$ $\mu^+\mu^-(\gamma)$ $Zh + h\nu\bar{\nu} \to \mu^+\mu^-X$	Higgs recoil mass Luminosity weighted E_{cm} $\mathrm{BR}(h \to \mu^+\mu^-)$	μ detector Tracker	Charged particle Momentum Resolution $\Delta p_t/p_t^2$	$5 \times 10^{-5}(GeV/c)^{-1}$
$Zh, h \to b\bar{b}, c\bar{c}, b\bar{b}, gg$	Higgs branching fractions b-quark charge asymmetry	Vertex	Impact parameter	$5\mu m \oplus$ $10\mu m/p(\mathrm{GeV}/c)\sin^{3/2}\theta$
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker Calorimeter μ detector	Momentum Resolution Hermeticity	

The International Linear Collider, Technical Design Report:
Volume 4, Detectors
https://www.linearcollider.org/ILC/Publications/Technical-Design-Report