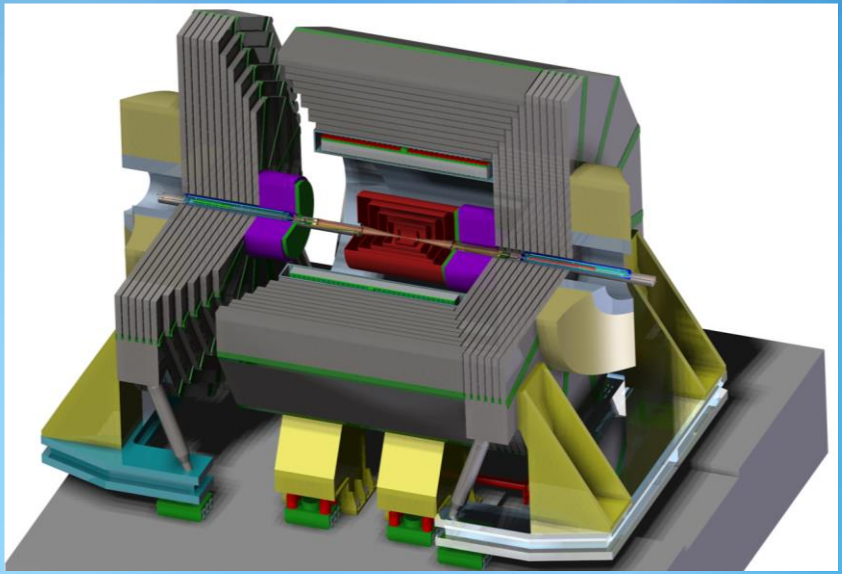
The SiD Detector – Status and Recent Work

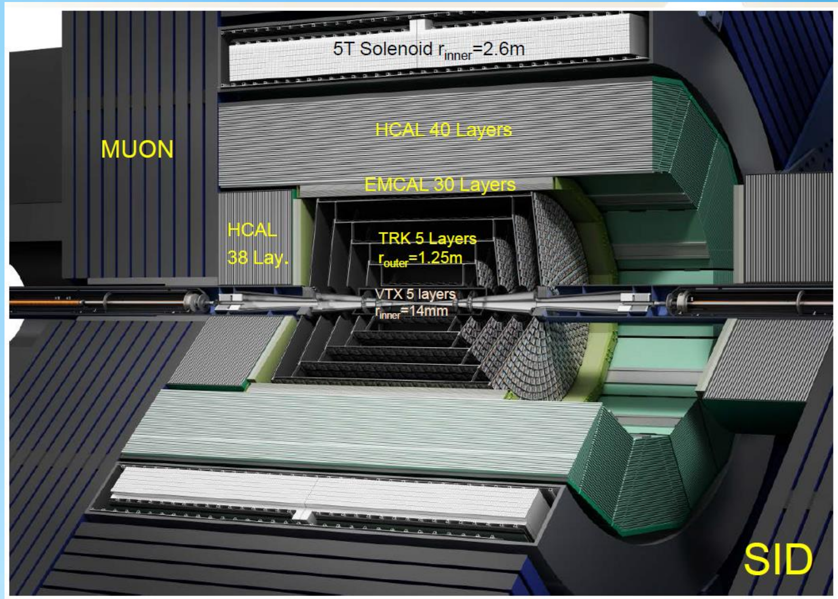
Andy White

UNIVERSITY OF TEXAS ARLINGTON

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

With thanks to SiD colleagues
for materials provided!





SiD Detector

- SiD design criteria

- Status of work on subsystems (VTX, tracker, ECal, HCal, FCal)
  Emphasis on work/updates since talk at LCWS2017

- Weekly optimization study meetings – many students involved!

- GOAL: be ready for a period of intensive/well-supported R&D as preparation for the writing of a full SiD Technical Design Report.

- While the SiD design has been stable for some time, we are always open to new ideas, new technologies, that could improve/maintain performance while reducing cost.

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.

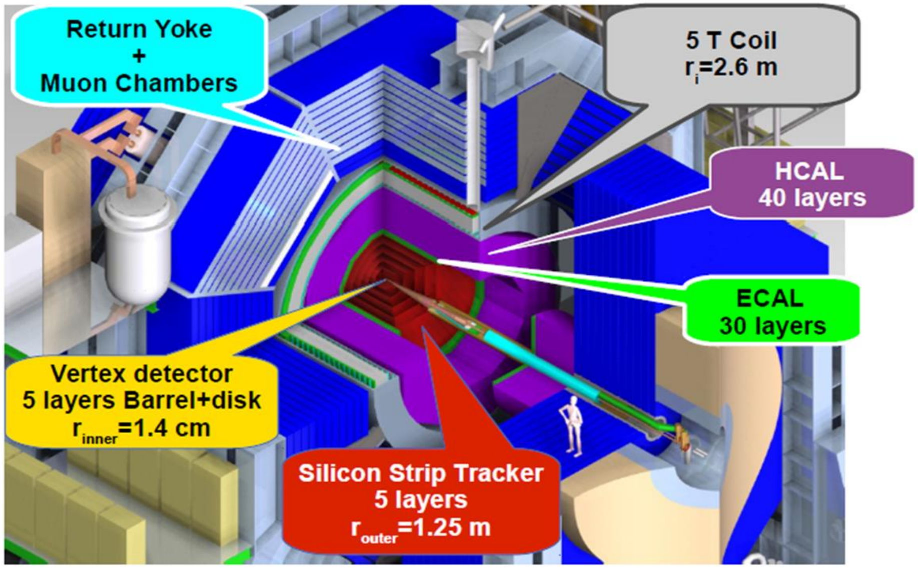
Highly segmented "tracking" calorimeters optimized for Particle Flow.

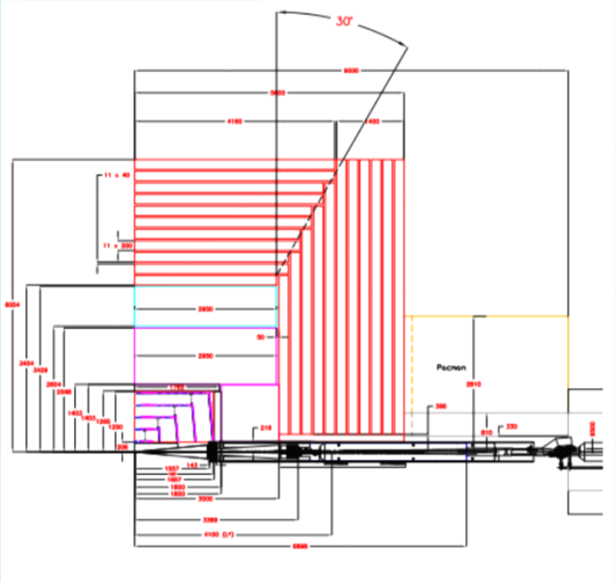
Compact design with 5T field.

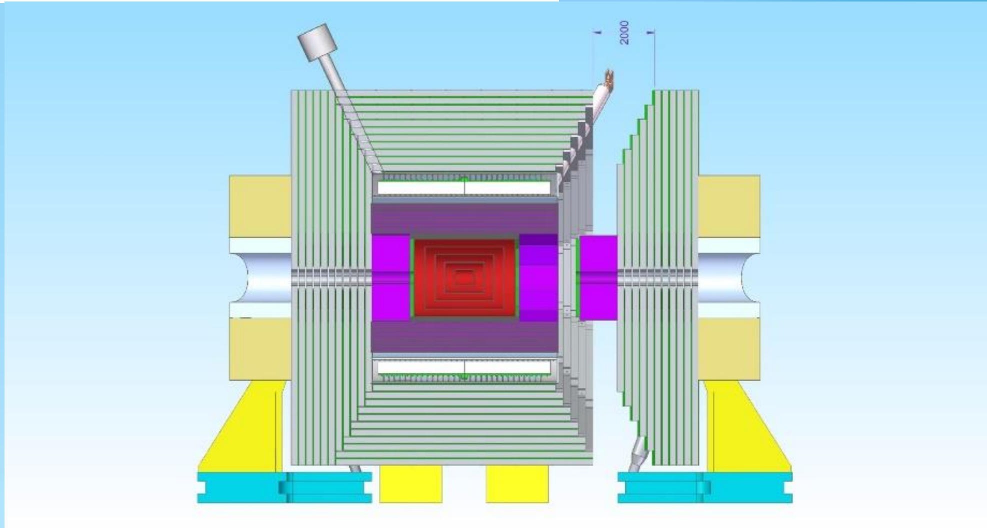
Iron flux return/muon identifier – component of SiD self-shielding.

Detector is designed for rapid push-pull operation.

SiD Detector Baseline

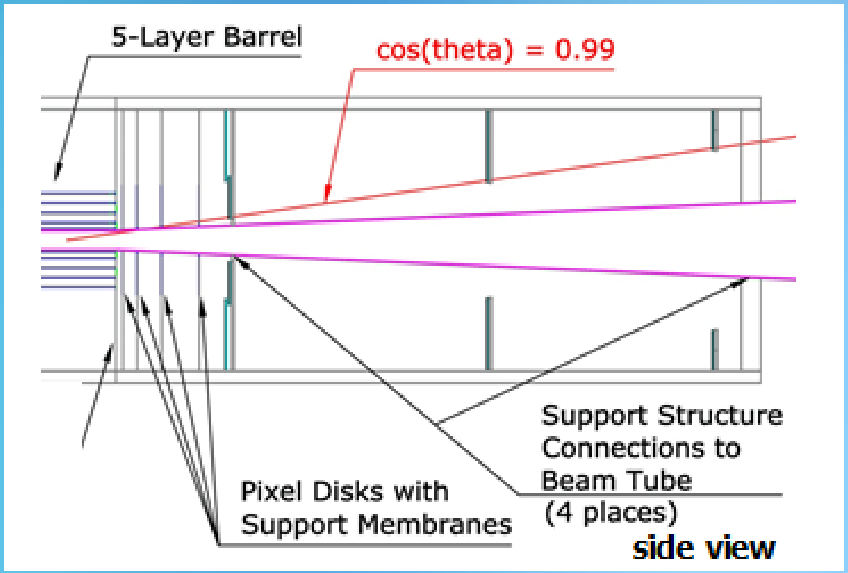


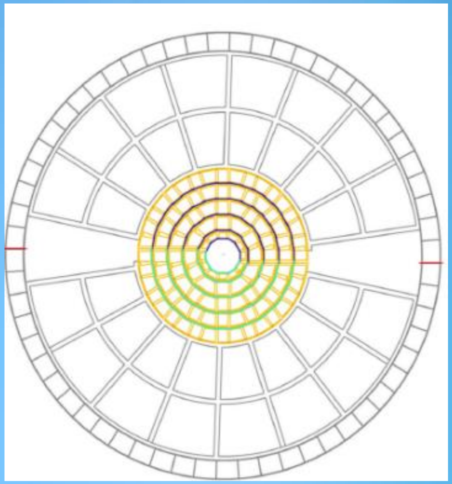




SiD Tracking: A Robust, Low Material, High Precision Silicon System

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

Preliminary ideas for mechanical design and support – awaiting engineering effort.

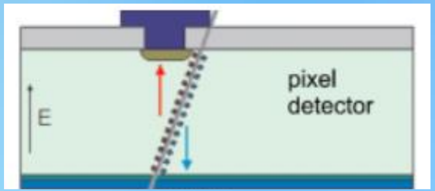
Power pulsing, forced air cooling

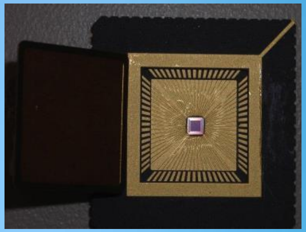
Needs R&D support to pursue
- somewhat independent of the choice of technology.

Options for the SiD Vertex Detector

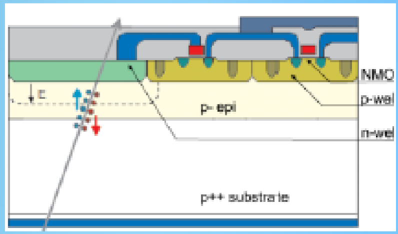
The Vertex Detector is small– late installation – no reason to choose implementation now – wait for R&D/advances in technology

- **Si diode pixels**
  ("standard" technology)

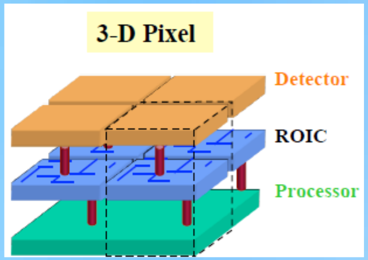


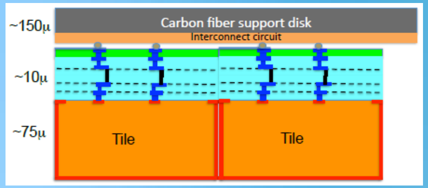


- Monolithic designs
  (**MAPS, Chronopixel**)

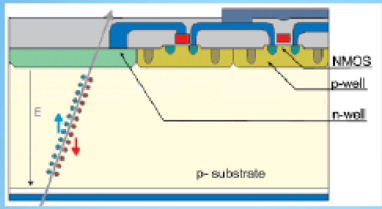


- Vertically Integrated ("3D")
  Approaches (VIP Chip)





- High Voltage CMOS
  (snappy timing)

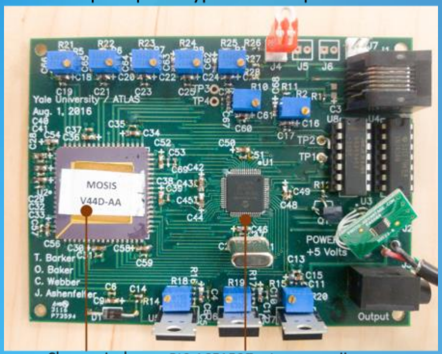


-> Monitor developing technologies – open to new ideas!

Chronopixel – baseline for SiD vertex detector

Working on Prototype #3:

Chronopixel prototype 3 development board

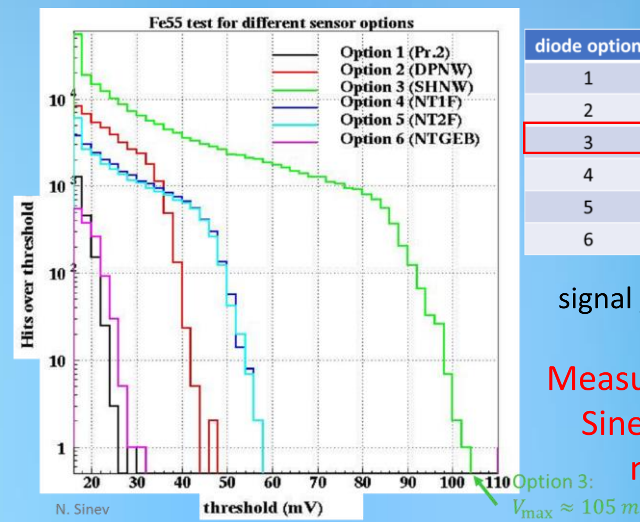


Chronopixel PIC 16F1527 microcontroller

- 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

Past and ongoing R&D:

James Brau, Nikolai Sinev, David Strom – U. Oregon
Charles Baltay, Keith Baker, Christian Weber – Yale
Thomas Barker – Tomtronics



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

signal / noise ~ 1/sqrt(C)

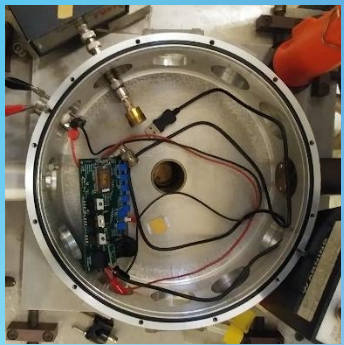
Measurements by Nick Sinev at SLAC over many years.

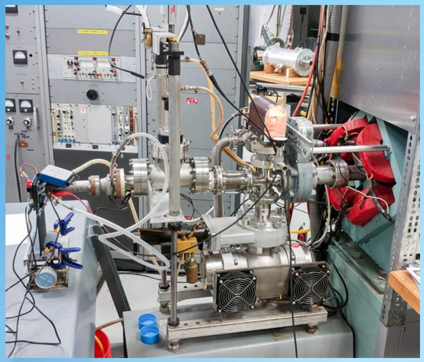
Many problems solved; concept proven valid

New - Irradiation tests at Yale

Neutron Irradiation

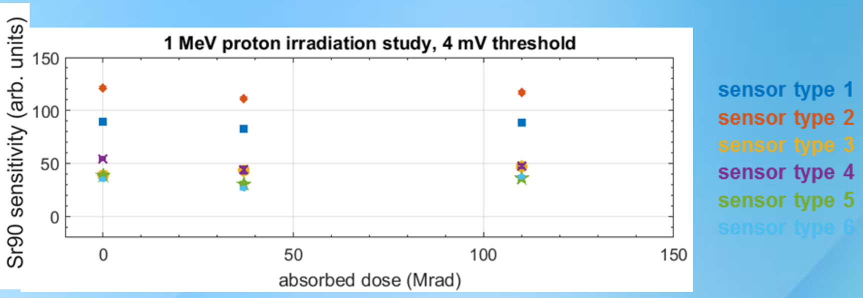
4 MeV proton incident on ^{7}Li target to produce neutrons
total number of neutrons created is eventually determined by radiation assay of target
Chronopixel still functional after $10^{13}\ n_{eq}/cm^2$





TID tests

1 MeV protons incident on Chonopixel
Multiple runs, track functionality by Sr90 count rate

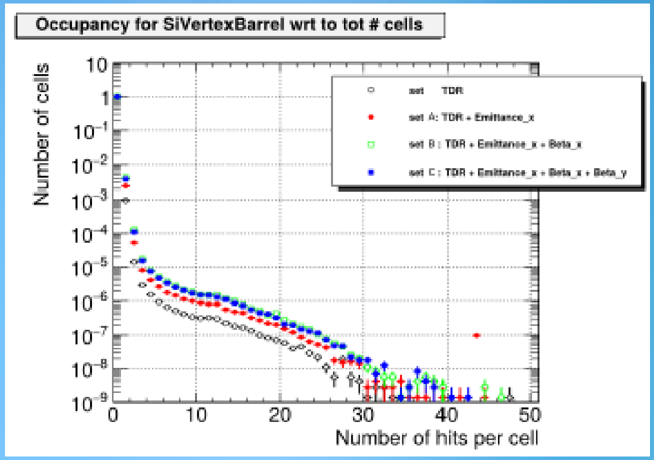


SiD pair background study

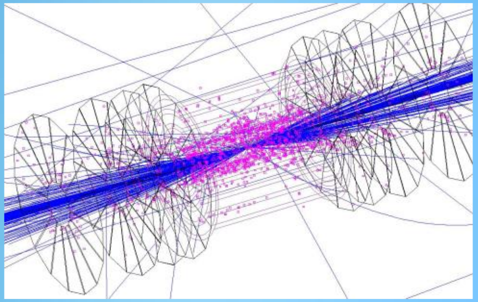
Previous study (LCWS2017) was made for new ILC250 parameter sets

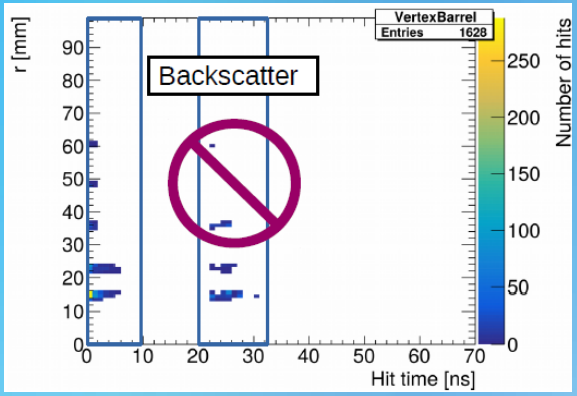
Set	ϵ_x [µm]	β_x [mm]	β_y [mm]
TDR	10	13.0	0.41
(A)	5	13.0	0.41
(B)	5	9.19	0.41
(C)	5	9.19	0.58

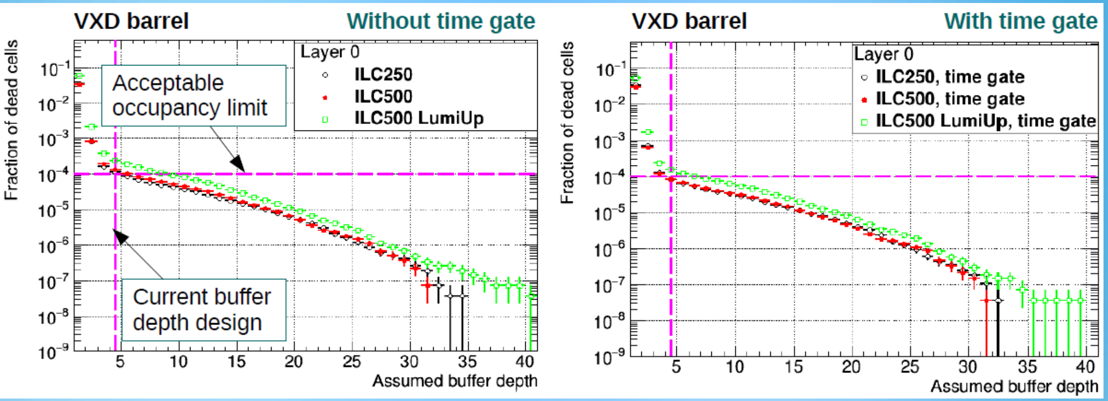
Anne Schuetz (DESY)



New hit time study revealed that pairs backscatter at BeamCal → backscatter pairs hit VXD 20ns after bunch crossing



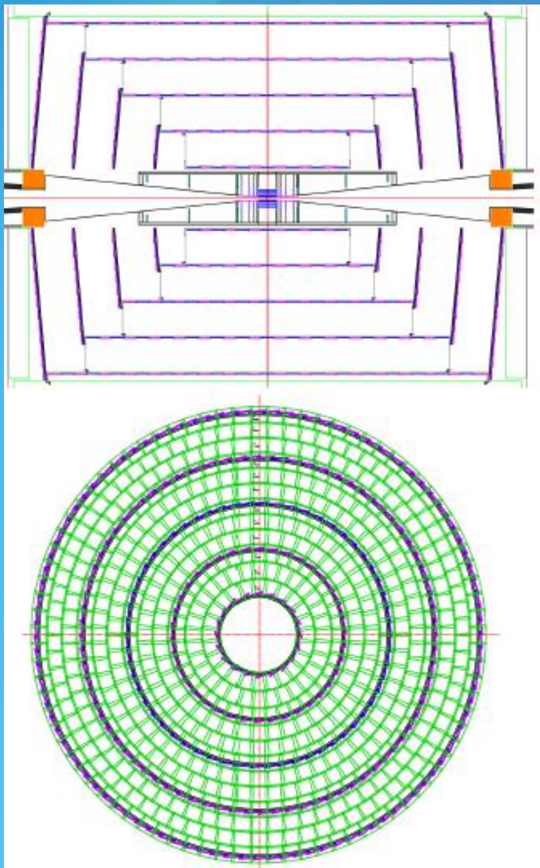


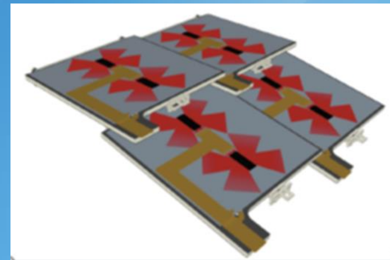


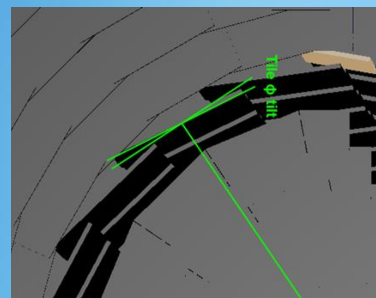
Time gate (<10 ns) reduces the occupancy by up to 36%.

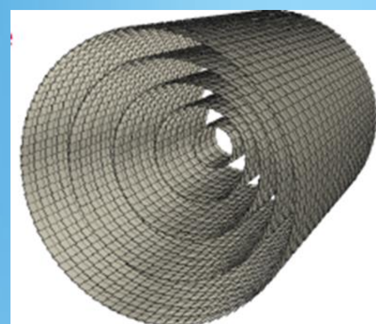
Even for ILC500 LumiUp, occupancy close to acceptable limit →increasing the buffer depth by only 2 would guarantee similar VXD performance throughout the first ILC stages!

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

kPixM – optimized for tracker, 40μm x 500μm pixels. Position resn. < 14μm, S/N >20

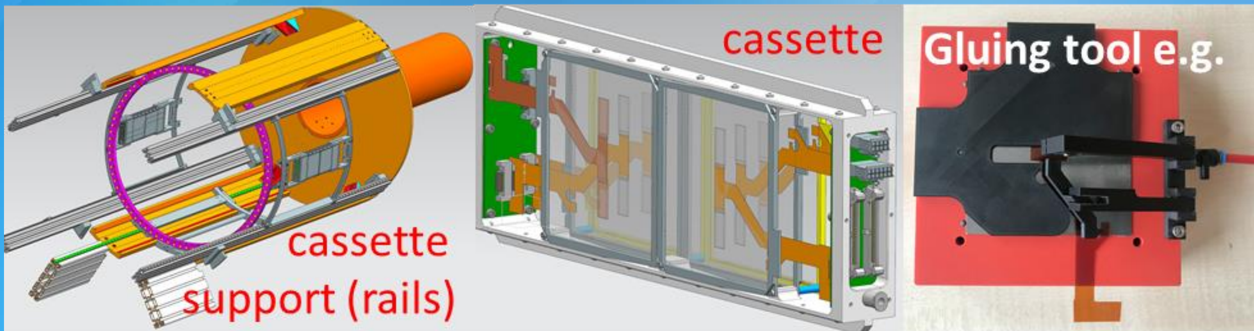
Goal – full prototype test: sensor + kPix + cables

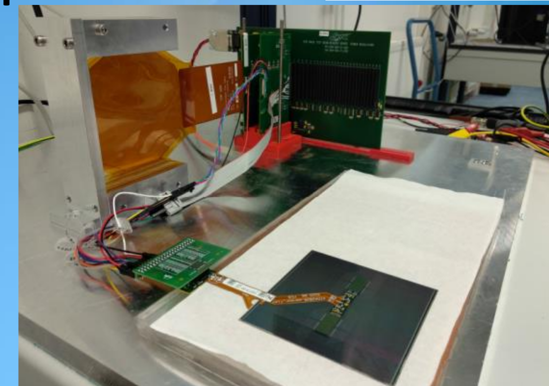
SLAC, UNM

- Pixel tracker option and alignment methods (Bristol)
- Carbon fiber structures for low material, integrated services (Oxford, Lancaster, Liverpool)

SiD Silicon (Strip) Tracker

SiD Strip Sensor in a beam telescope at DESY





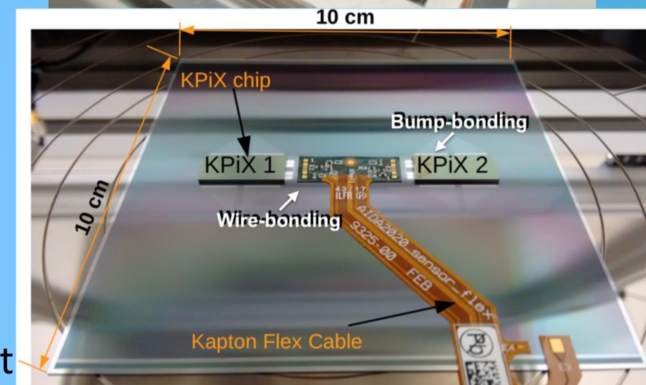
Goal: build a large active area telescope in a 1T solenoid (delivery Jan, 2019), providing resolution >10 μm at bending direction, and along magnetic field > 1 mm.

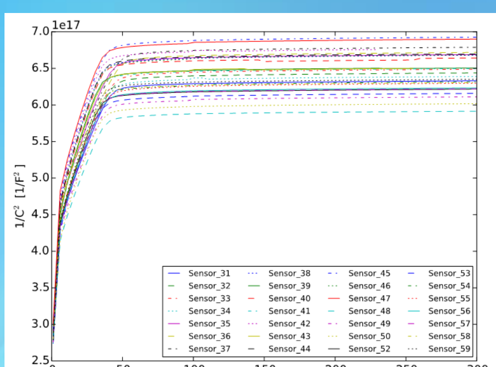
SiD strip sensor:

- Thickness of 320 μm → material budget 0.3% X0
- Pitch 25 μm -> resolution ~7.2 μm, Alternate strip readout

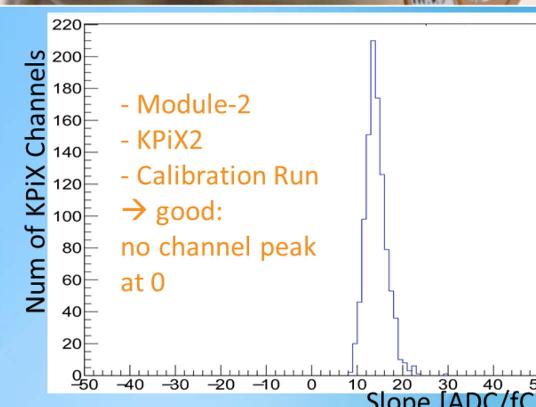
Readout system:

- KPiX chip: integrated pitch adapter and 1024-channel digital readout ASIC, 920 out of 1024 connected to strips (2*920)





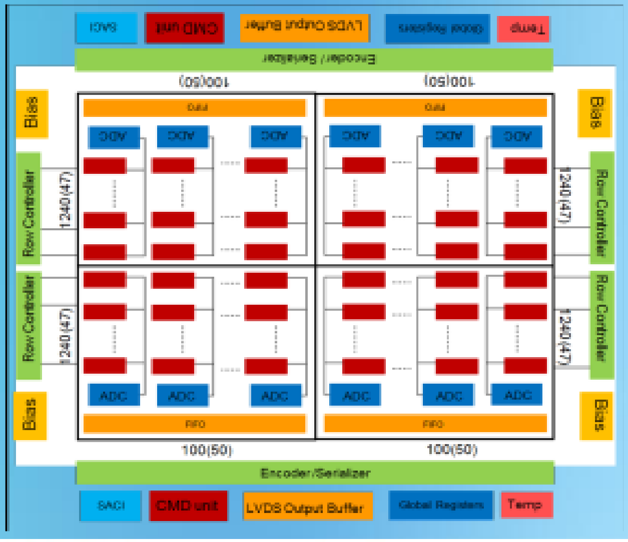
Good behavior in IV/CV: fully depleted @~50V, quite bare sensor (~100-200 nA).



2019 - kPixM (monolithic pixel sensor: MAPS)

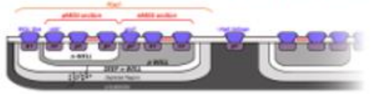
- Based on KPiX readout chip experiences
  - Beam-tested at SLAC (first generations of KPiX)
  - Design and fabricate two types of MAPS:
    - For ECAL (kPixM-Cal)
    - For tracking (kPixM-trk)

If funding available!



kPixM Test structure submission:

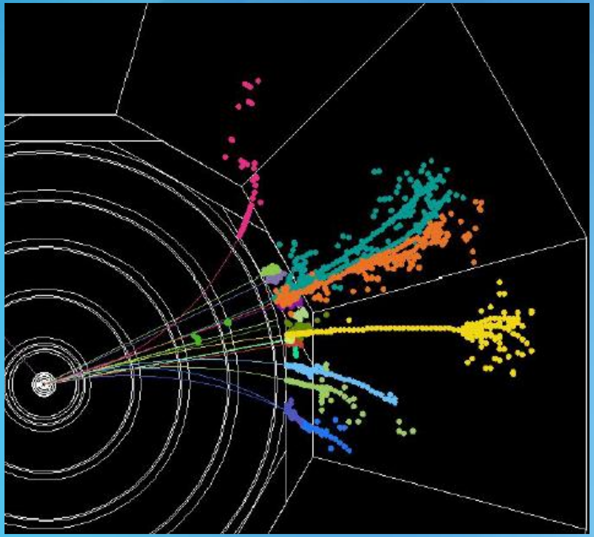
Technology LFoundry 150nm on high resistivity substrate (2kΩcm) thinned to 150μm (fully depleted with 80V)



kPixM architchture

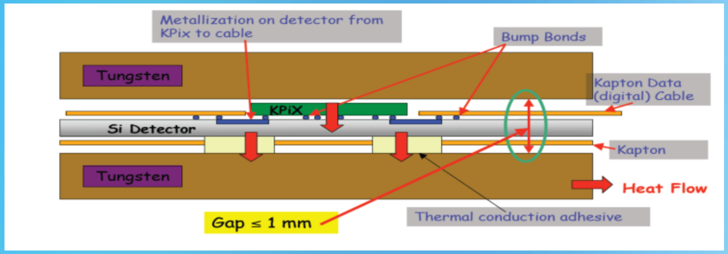
	kPixM-Trk	kPixM-Cal
Pixel size	50x500 μm^2	1000x1000 μm^2
Array	200x2400	100x94
Full Size	Stitched 5x5 reticles	Stitched 5x5 reticles
Max. Signal	1fC	1pC
Effective ENC	<200e^-	<1000e^-
Filtering	LP + CDS	LP + CDS
S/N	>20	>4
In pix mem. depth	1 bucket	16 buckets
ADC resolution	12 bits	12 bits
DC Power cons.	~ 20μW/pix	~ 20μW/pix
Power pulsing	Yes	Yes

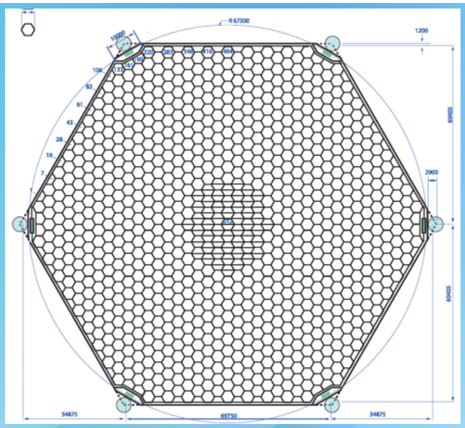
SiD Electromagnetic Calorimeter



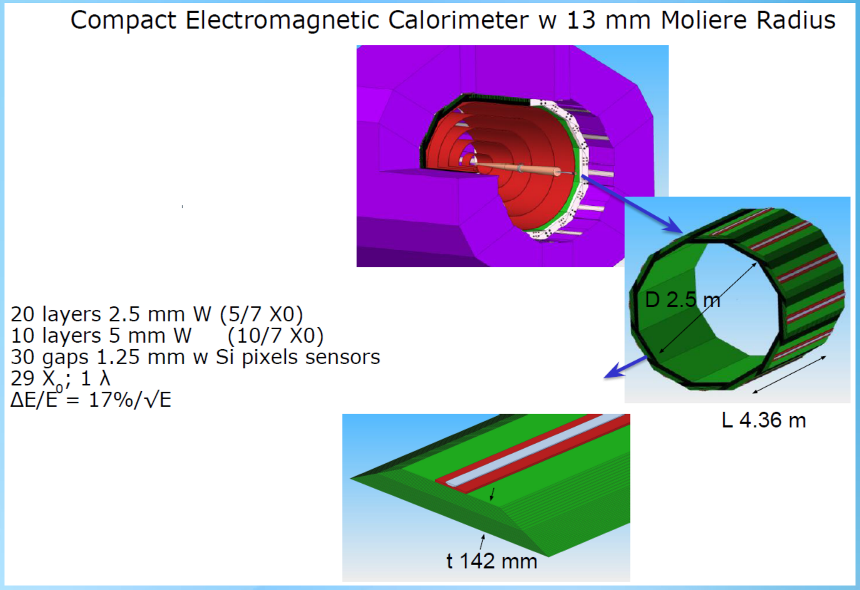
Highly granular "imaging" calorimetry essential for ILC physics program:

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





Baseline design: Silicon/Tungsten

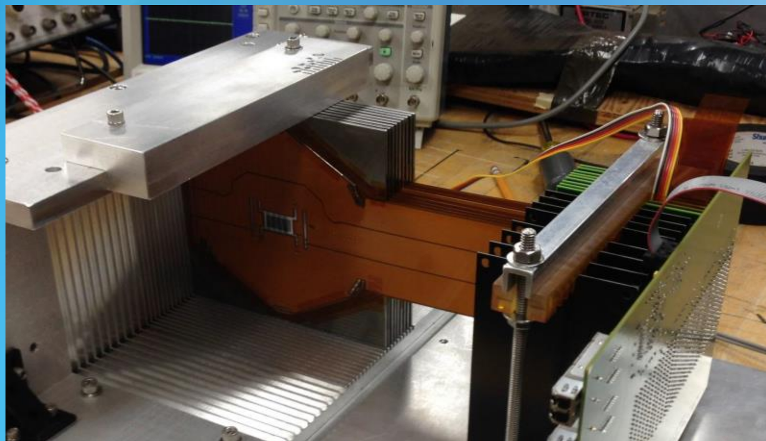


Oregon, SLAC, UC Davis

SiD SiW ECal Test Beam Analysis

A. Steinhebel, J. Barkeloo, J. Brau, D. Mead

U of Oregon, SLAC, UC Davis

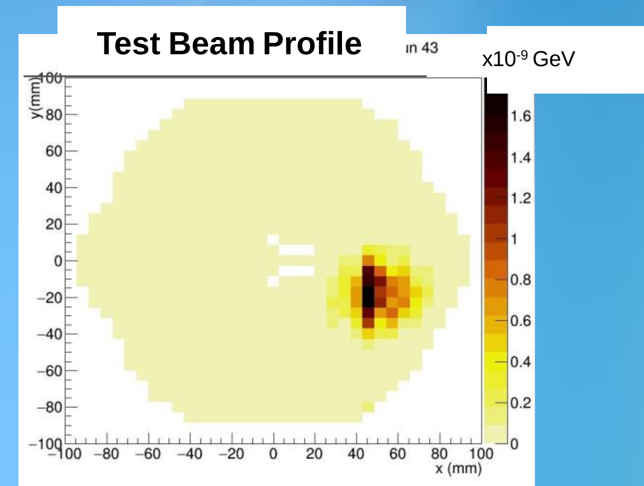


9 layer Si/W Calorimeter

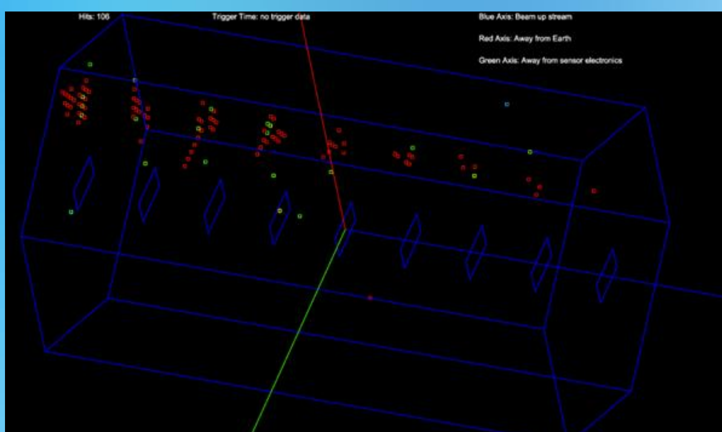
~ 6 X_0

13 mm^2 pixels

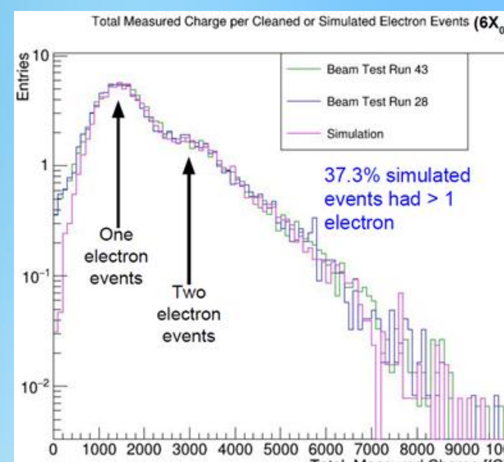
12.1 GeV electrons

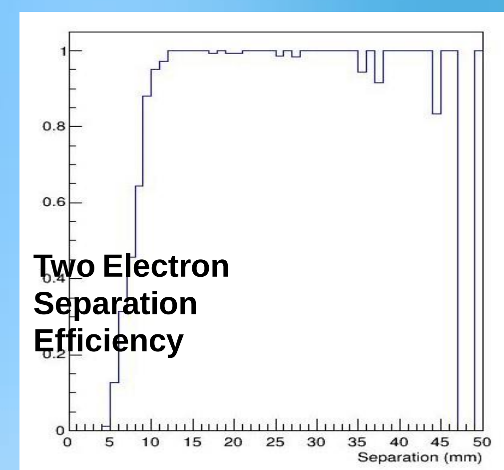


Single electron event



Simulation vs. data



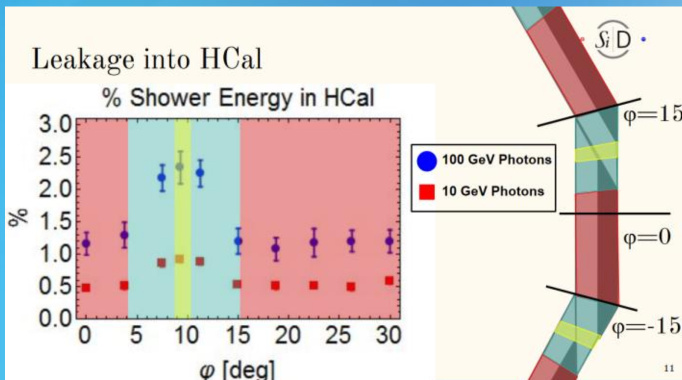


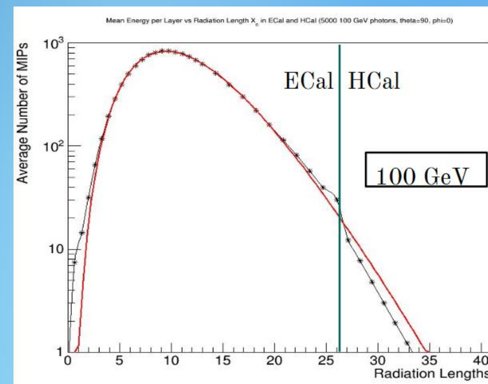
SiD Electromagnetic Calorimeter

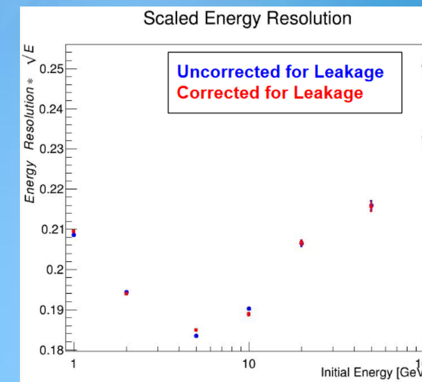
A. Steinhebel, J. Barkeloo, J. Brau

U of Oregon, SLAC, UC Davis

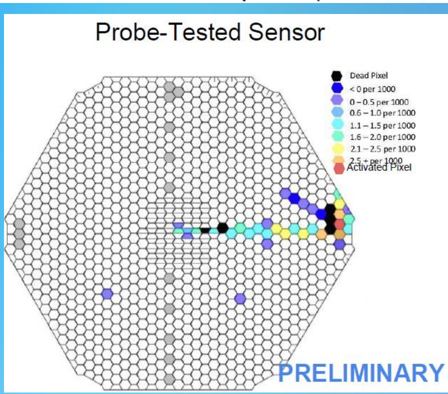
ECal – HCal interface – effects affecting calibration (A. Steinhebel – Oregon)



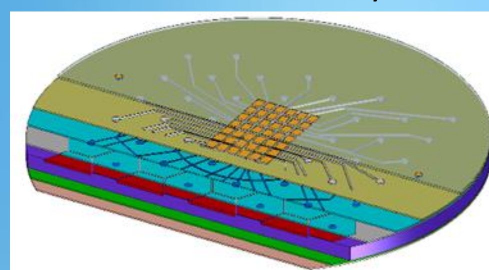




Additional signal detected in pixels along trace of activated pixel (cross talk)

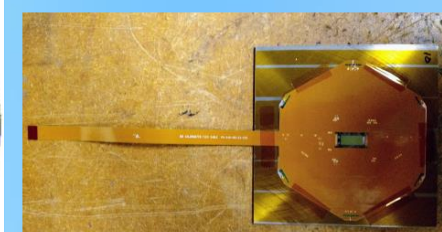


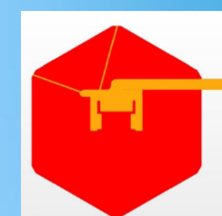
New sensor design – added shield layer

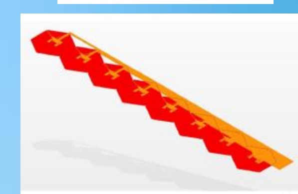


UBM built at fab; bump bonding of KPiX easy

New cable design: one cable/sensor, wire bonded





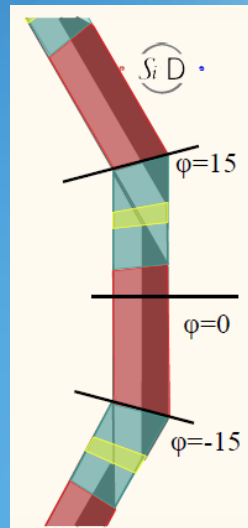


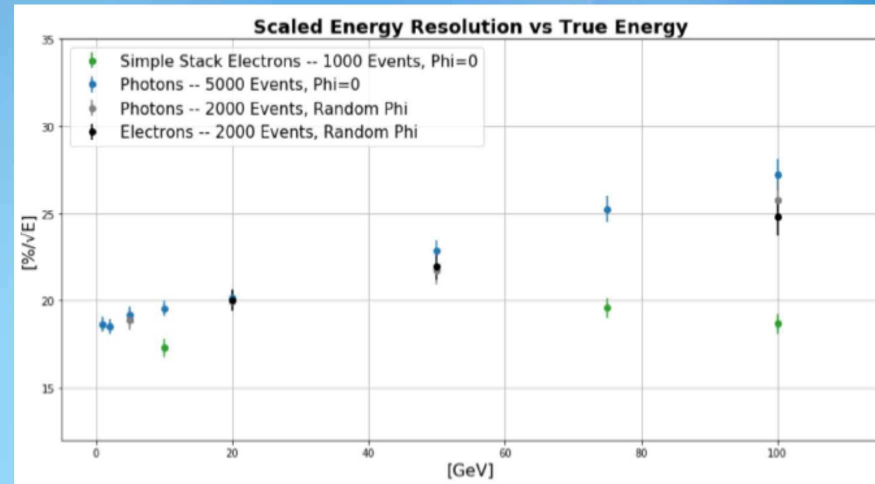
Status: testing beginning of *new* sensor bump-bonded to KPiX, new cable wire-bonded. Sensor and KPiX calibrate – all connections are good.

SiD Electromagnetic Calorimeter

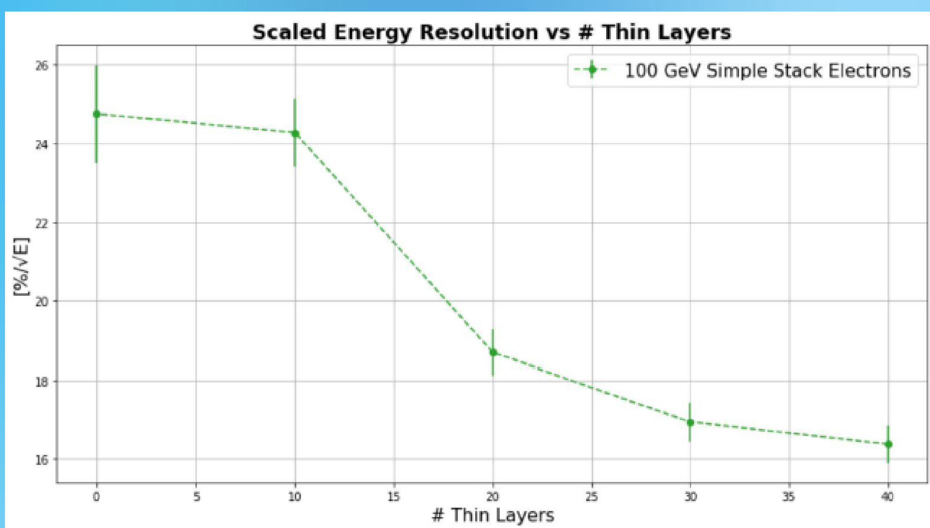
Study ECal resolution at various entry points:

- Center of module
- Overlap region





Work in progress…

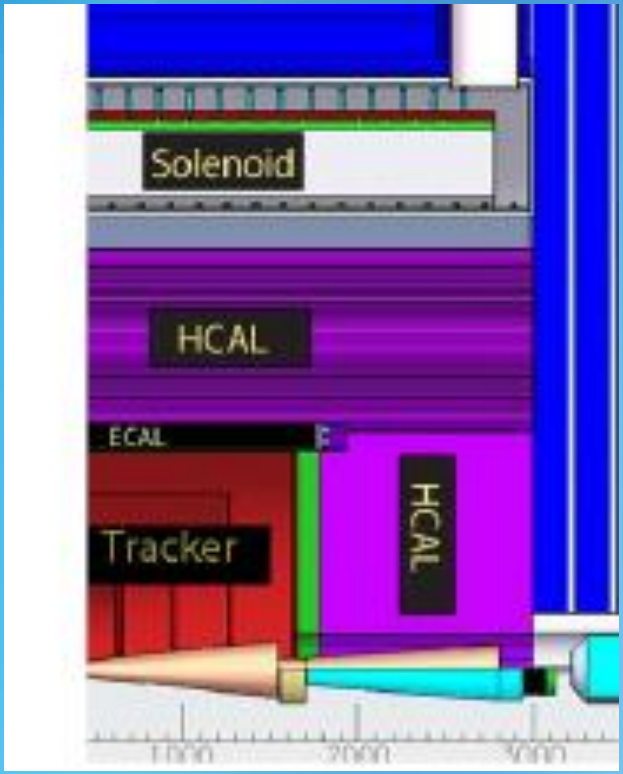


Also – comparison with "simple stack" implemented using GEANT4

A. Steinhebel, J. Barkeloo, J. Brau

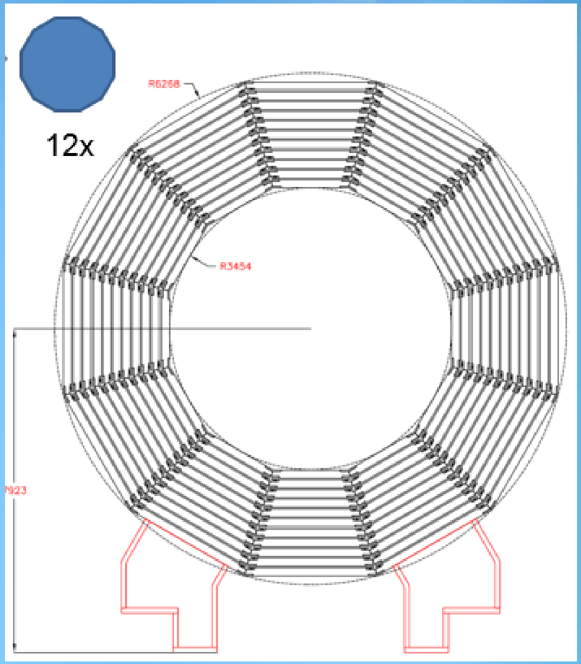
U of Oregon, SLAC, UC Davis

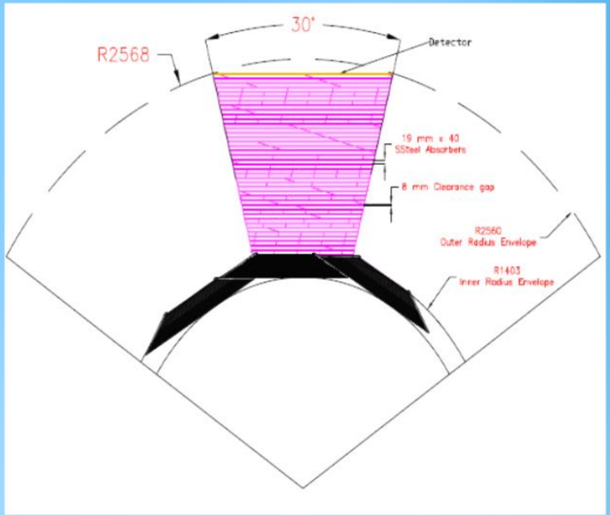
SiD Hadron Calorimeter



12-fold barrel geometry

Marco Oriunno (SLAC)



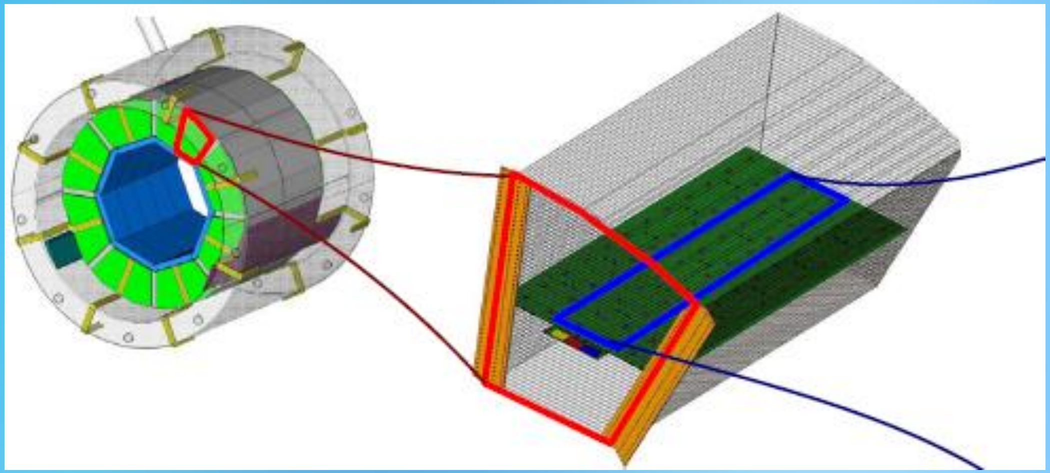


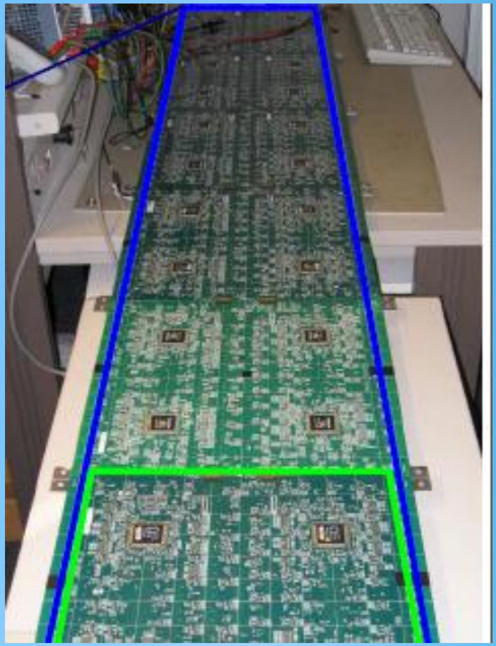
Baseline technology for the SiD HCal is Scintillator/SiPM/Steel

UTA, SLAC

SiD Hadron Calorimeter

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



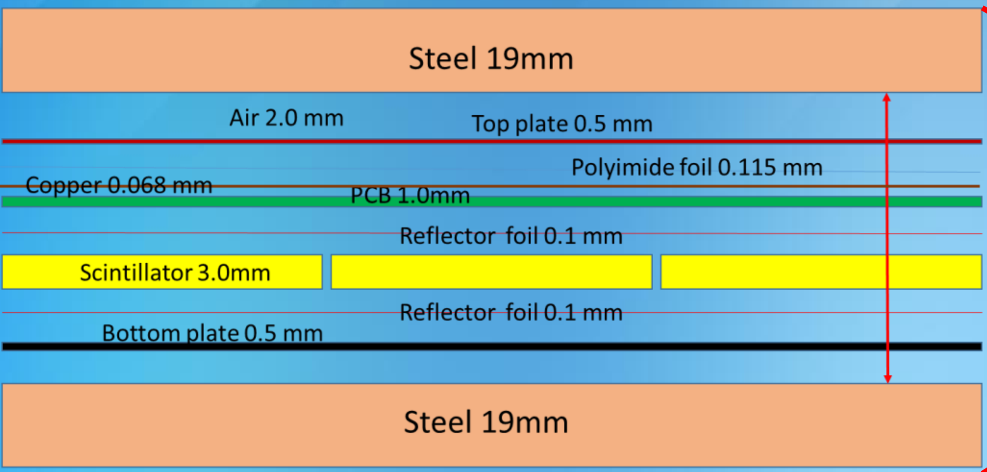


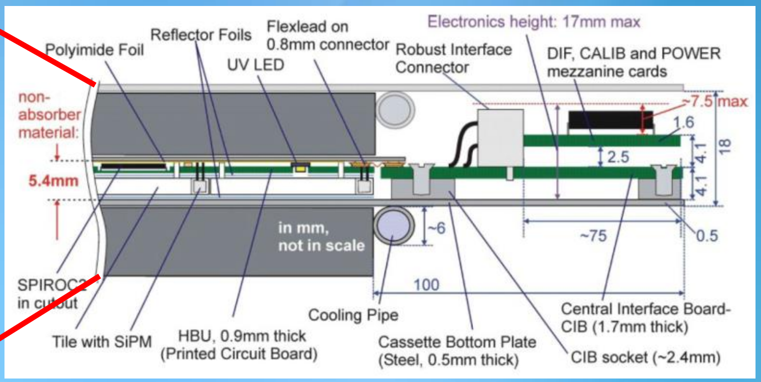
- Start to develop SiD-specific designs for barrel, endcaps (funding dependent).

UTA, SLAC

SiD Hadron Calorimeter

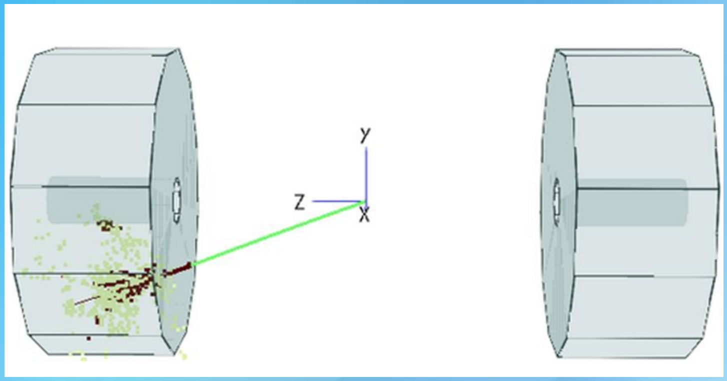
CALICE design

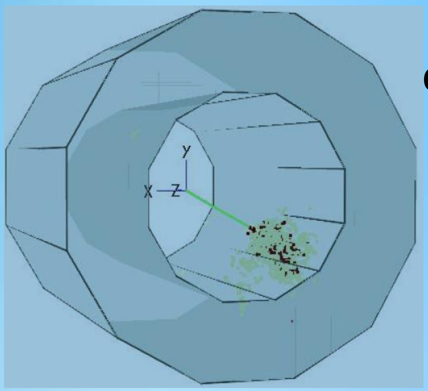




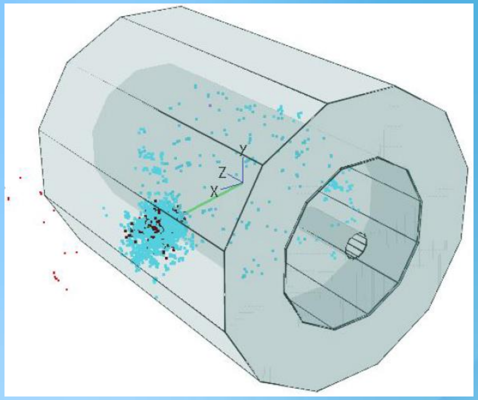
Active layer thickness = 7.383 mm

Ongoing: single particle studies.
Next: full event studies with PANDORA as prelude to next round of physics studies



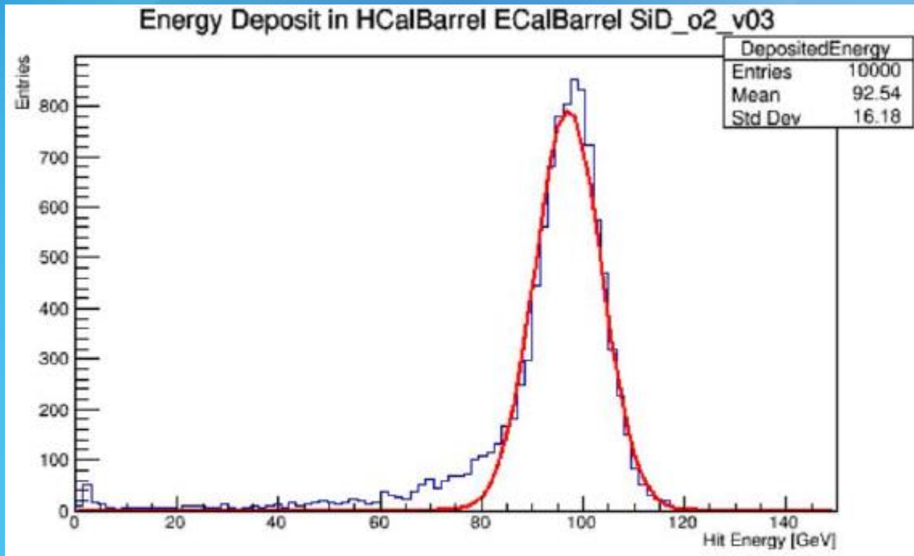


70 GeV charged π



UTA, SLAC

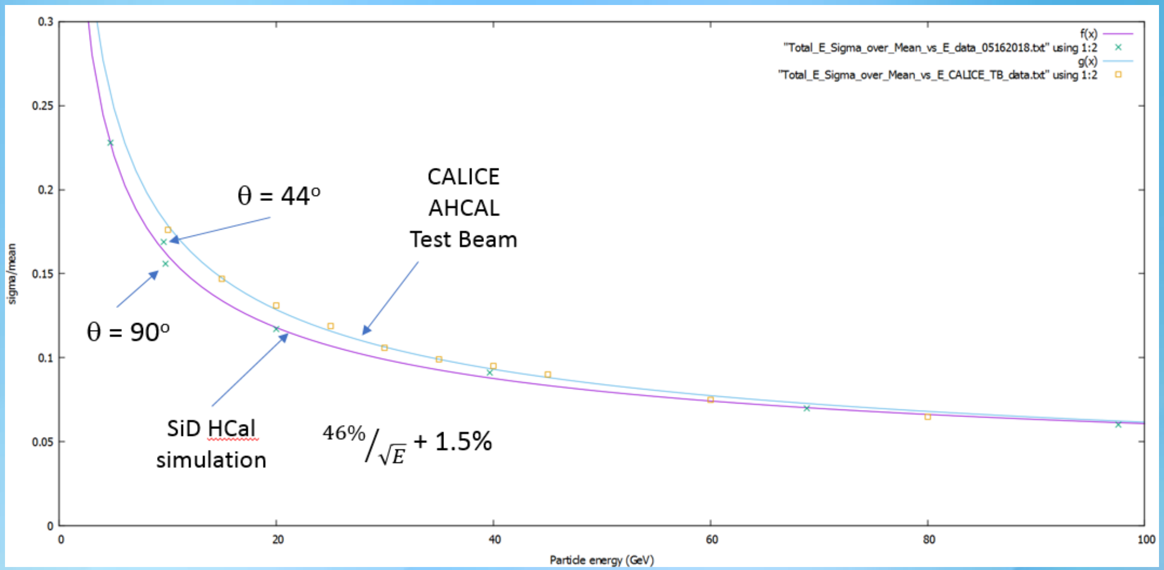
SiD Hadron Calorimeter



10,000 100 GeV charged pions

Sum of energies in the ECal + HCal.

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

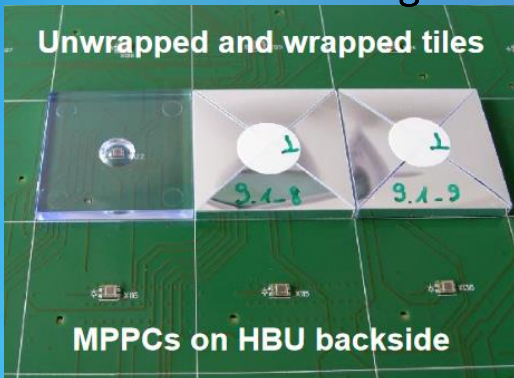


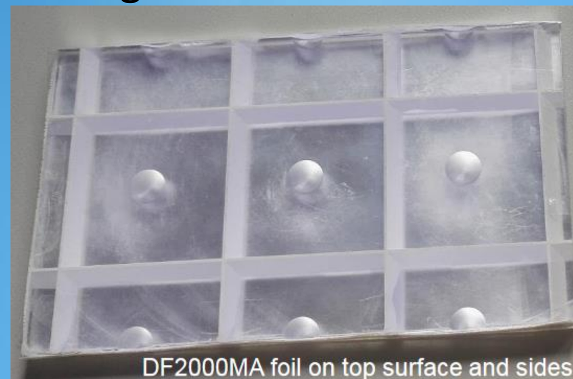
A. Myers, R. McCoy, S. Nag, D. Sharma, AW - UTA

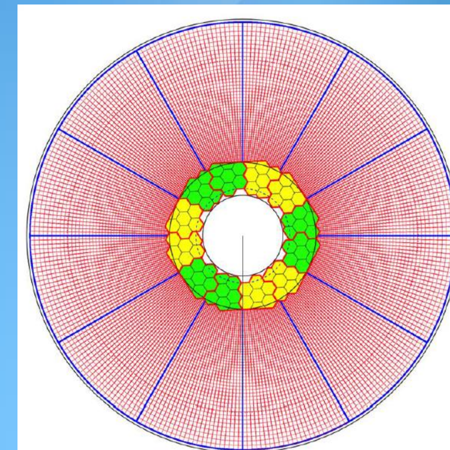
SiD Hadron Calorimeter

Following CALICE developments for AHCAL

Single tiles or mega-tiles?

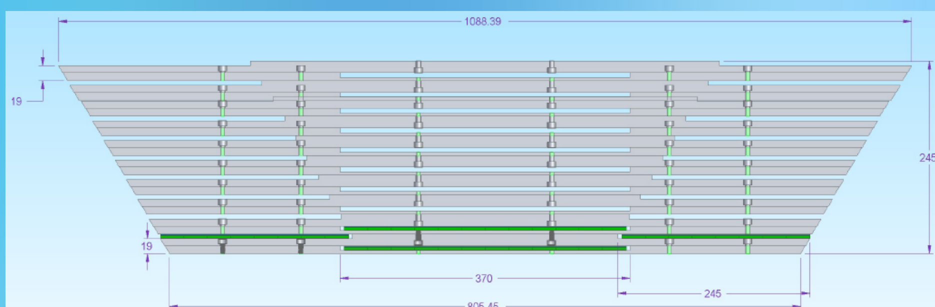


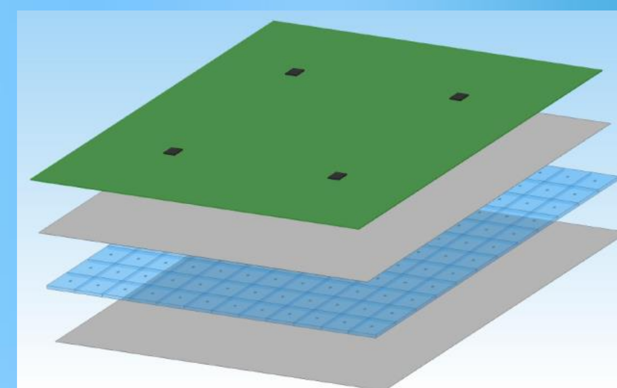




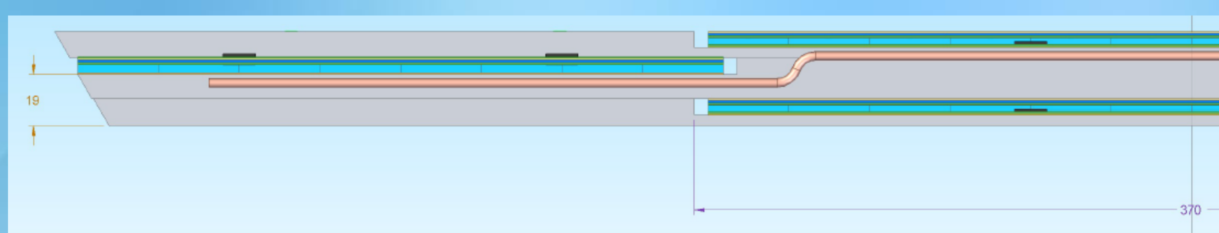
Same issue for CMS HGCAL

Initial SiD Hcal design ideas
(for barrel – endcaps next)

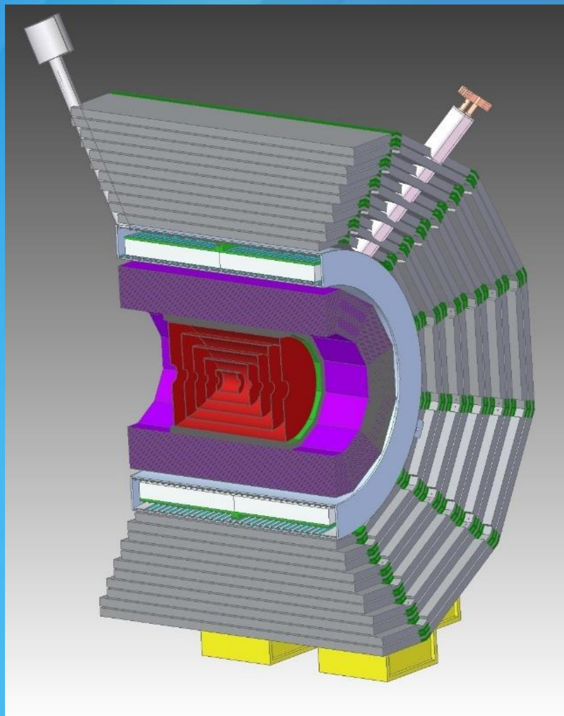




Marco Oriunno
(SLAC)

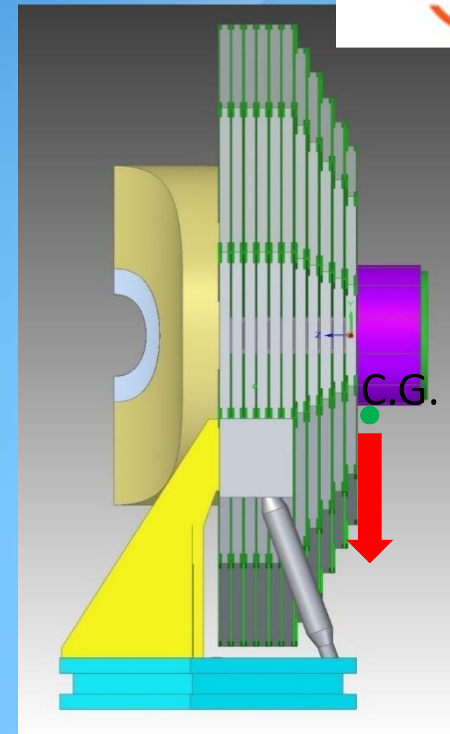


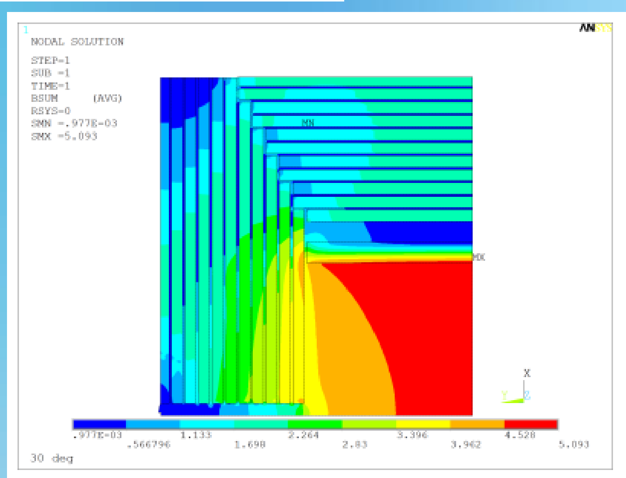
Muon identifier/Calorimeter Tail Catcher

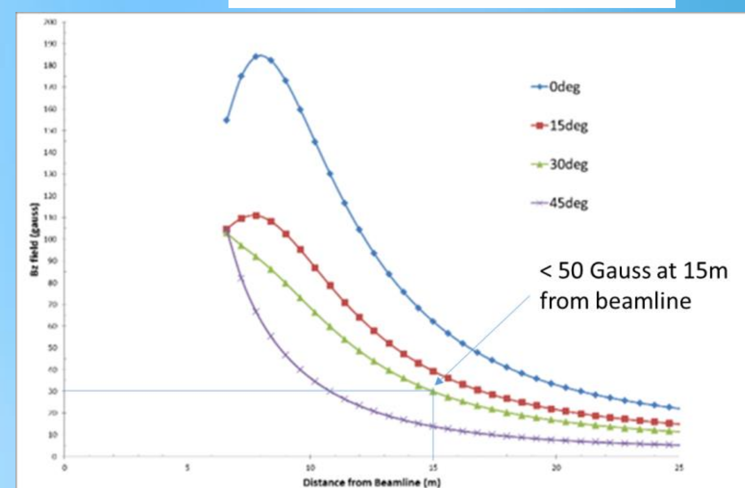


Redesign of barrel/door junction
More efficient flux return
Easier transport/handling

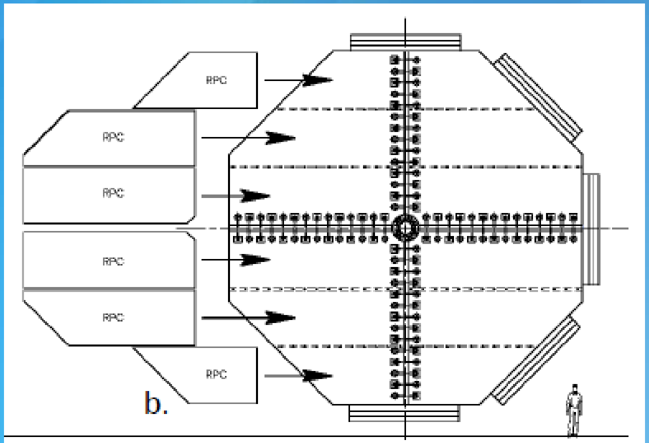
Marco Oriunno
(SLAC)

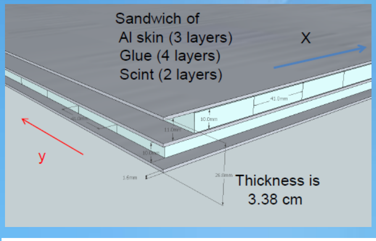


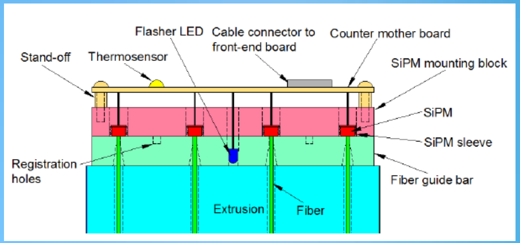




Muon identifier/Calorimeter Tail Catcher



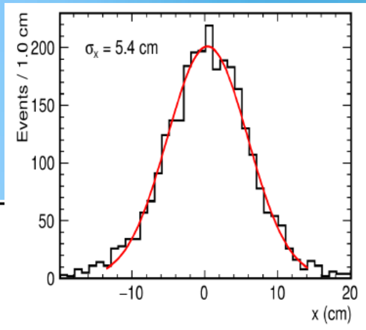




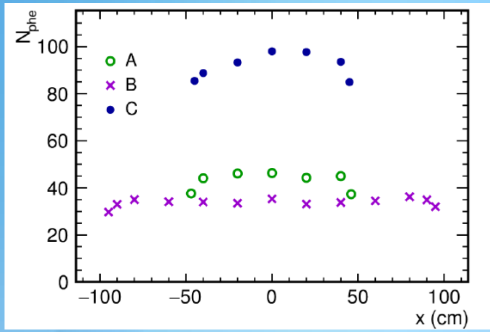
SiD Baseline – long scintillator strips with WLS fiber and SiPM readout

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

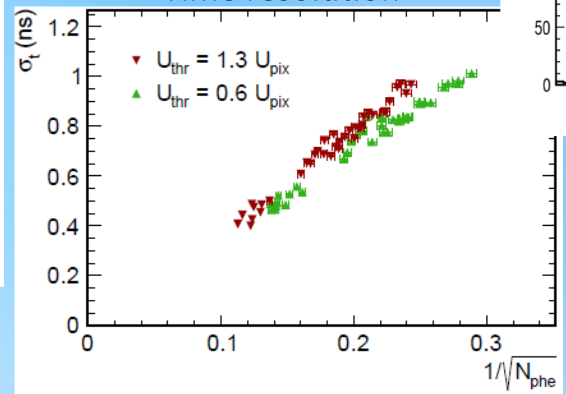
Development work at Fermilab:



Position resolution



Time resolution

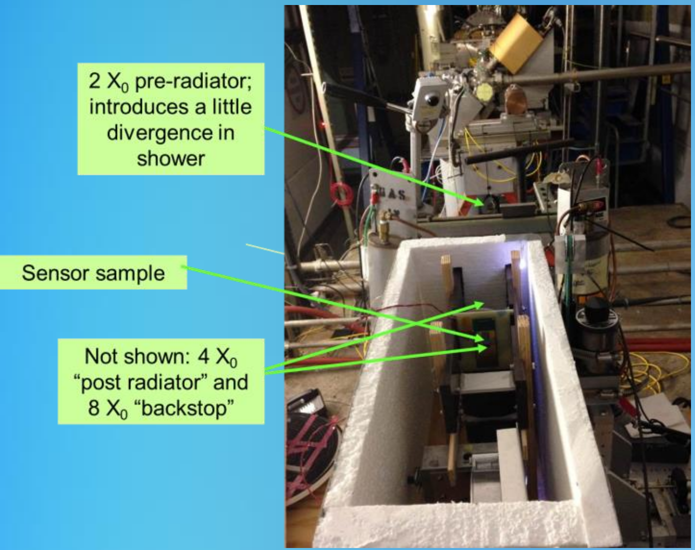


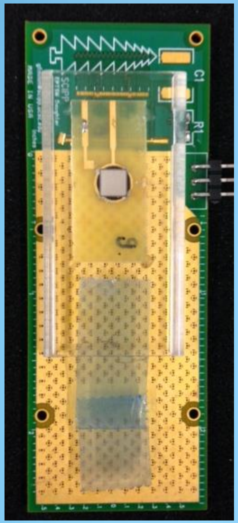
Paper published:
NIMA, **848**, 54-59, 2017

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



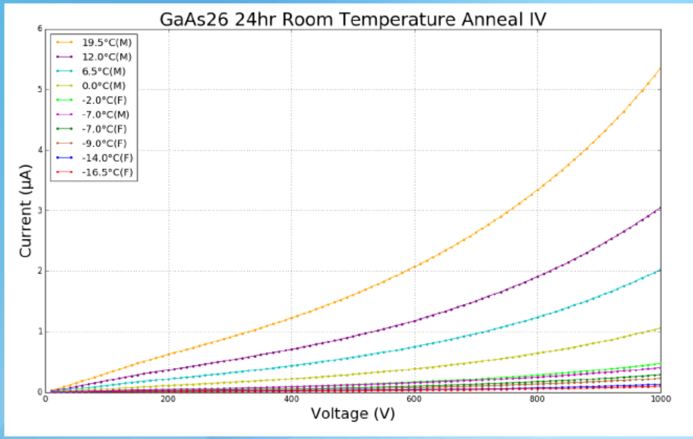


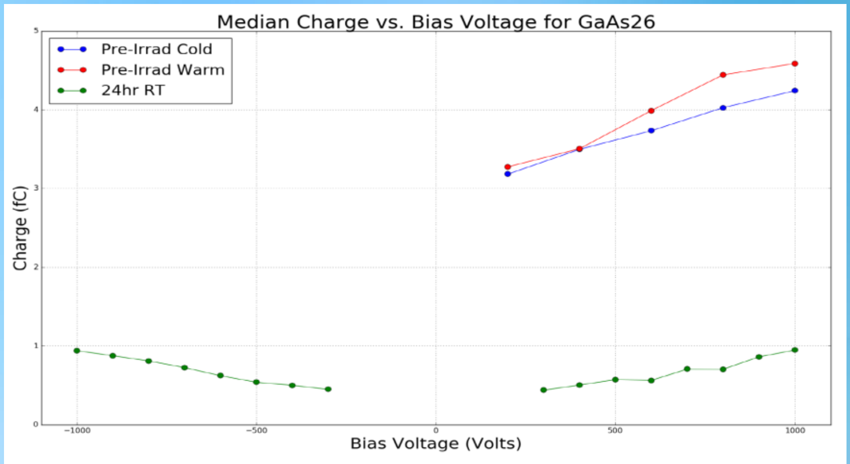
- Gallium Arsenide sensor provided by Georgy Shelkov, JINR
- Sn-doped Liquid-Encapsulated Czochralski fabrication
- 300 μm thick
- 0.16 cm^2 area

GaAs Charge Collection after 100 Mrad Exposure (new result)
(previously only for 21 Mrad)

GaAs Dark Current

Thermal runaway?

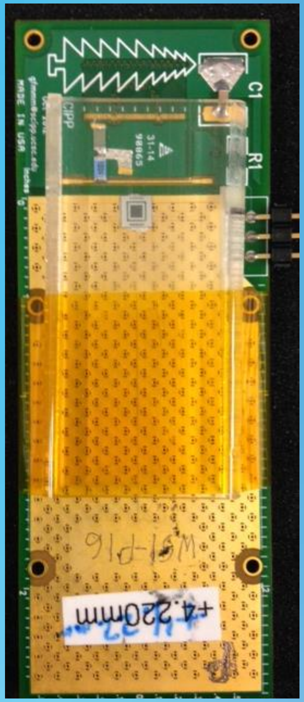


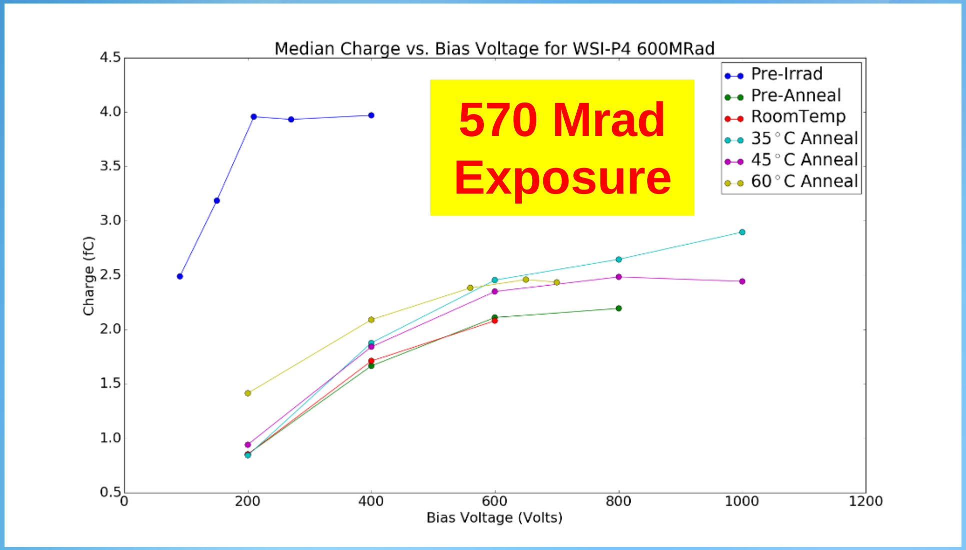


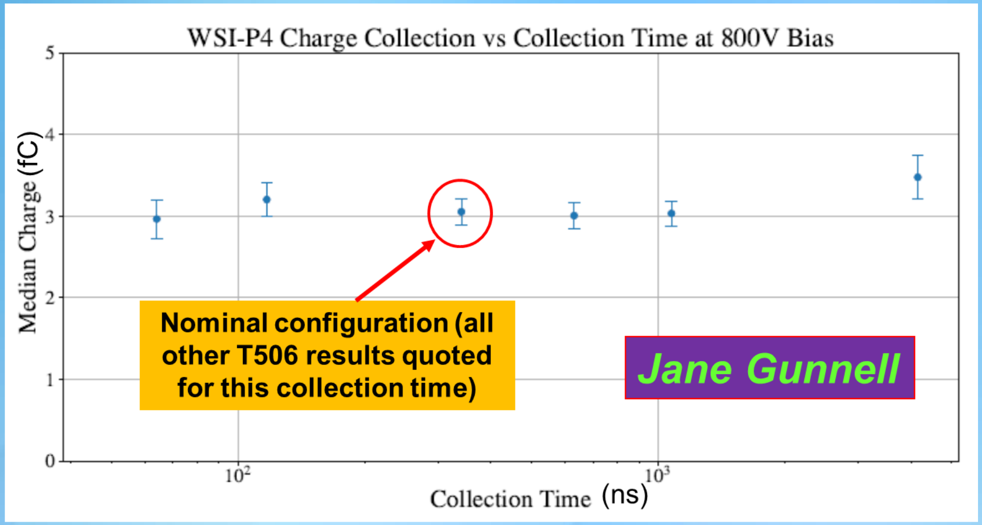
Sean Hyslop

Forward calorimetry

Micron
PF Si Diode
300μm
Area 0.025 cm²





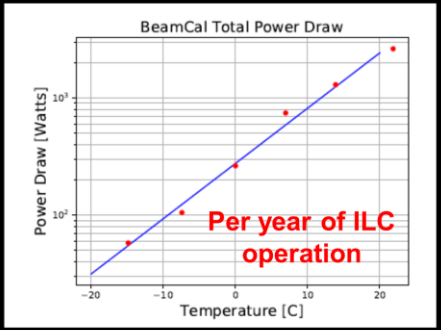


BeamCal Simulation in FLUKA

- BeamCal absorbs about 10 TeV per crossing, resulting in electromagnetic doses as high as **100 Mrad/year**
- Associated neutrons can damage sensors and generate backgrounds in the central detector
- GEANT not adequate for simulation of neutron field ➔ implement FLUKA simulation
- Design parameters from detailed baseline description (DBD)
- Primaries sourced from single Guinea Pig simulation of e^{+-} pairs associated with one bunch crossing

Ben Smithers

Overall Power Draw vs Temperature



- **Can limit accumulation to less than 100W per year by operating below -10° C**
- **At -30° C (standard for LHC sensor operation), accumulation would be of order 15 W per year**

Idea: Use FLUKA to extrapolate from UCSC radiation-damage studies (T506)

Peripheral Fluence Estimates

- **Front-end electronics will likely be mounted just outside BeamCal instrument**

Table 2: Neutron fluences at various positions 1 cm outside the BeamCal instrument, for 10^7 seconds of ILC operation, in cm^{-2}. The angle is measured relative to the axis defined by the center of the BeamCal and the centerline of the smaller circular cutout.

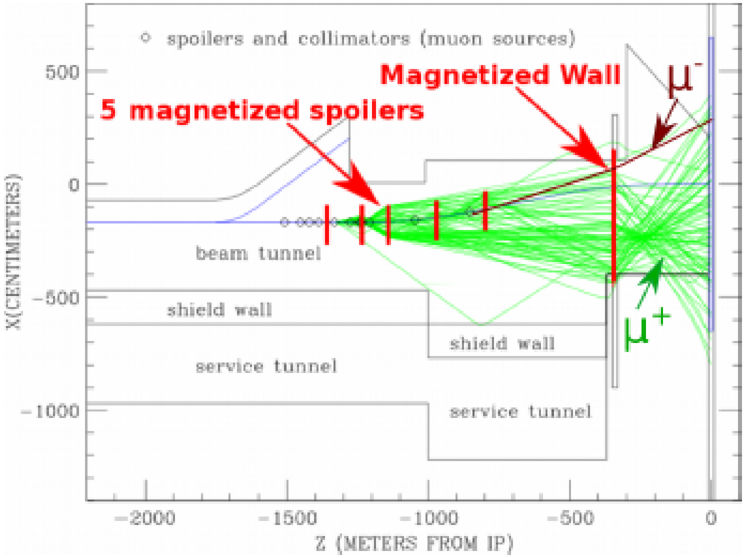
Angular position	0	$\pi/2$	π	$3\pi/2$
Layer 12 fluence (cm^{-2})	4.9×10^{11}	5.9×10^{11}	7.3×10^{11}	8.0×10^{11}
Layer 30 fluence (cm^{-2})	4.8×10^{11}	4.6×10^{11}	5.7×10^{11}	5.4×10^{11}

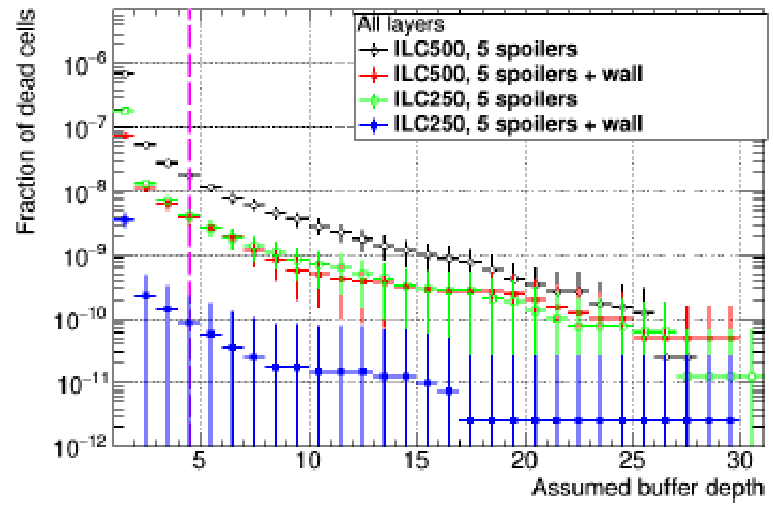
- **Electromagnetic fluence less than $10^{11}/cm^2$ (less than 2.5 krad) per year at any position**
- **These levels far below conventional levels of concern**

MDI Studies

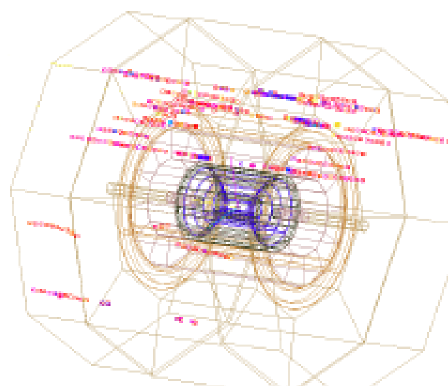
Anne Scheutz (DESY)

BDS muon study





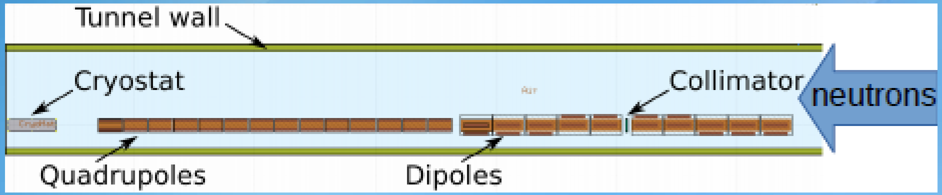
#muons / bunch crossing	ILC250	ILC500
No shielding	39.3	130.1
Magnetized spoilers	1.3	4.3
Magnetized spoilers + wall	0.03	0.6

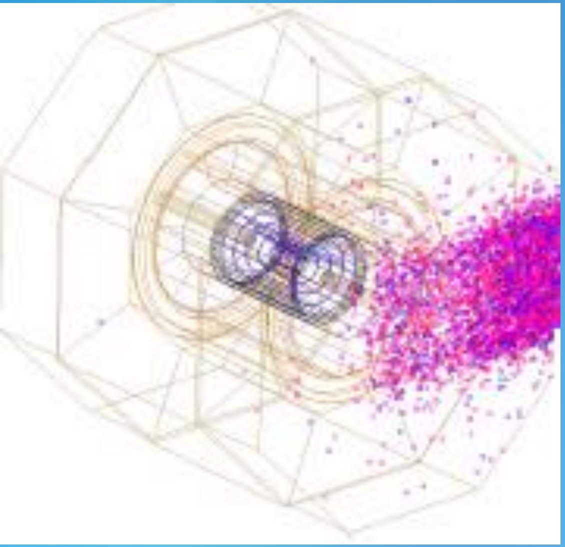


At ILC250, magnetized spoilers without wall are sufficient for occupancy mitigation.

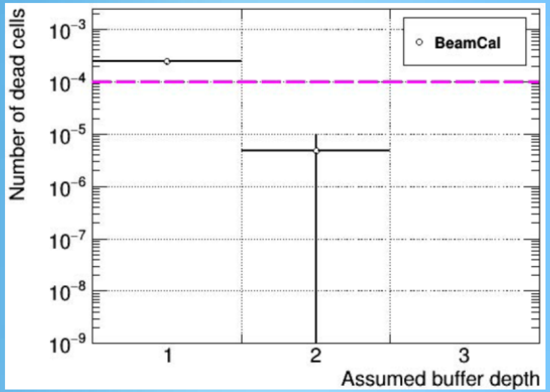
Wall might me neccessary at higher stages, and as a tertiary containment device.

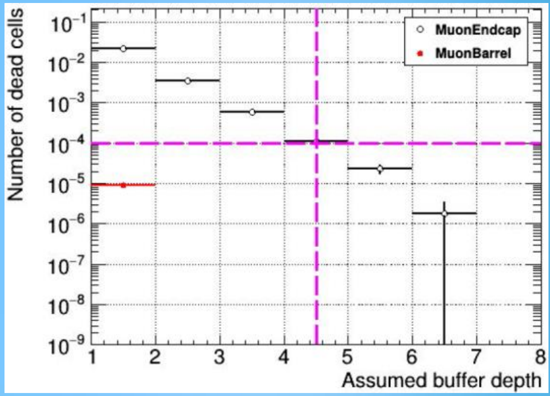
ILC main beam dump study





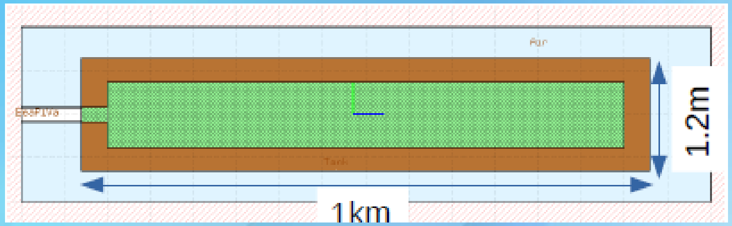
Neutron gas (of ~6 million neutrons per beam bunch → 12 million from positron and electron side) reaches the IR.
→ Neutron hits in muon system and BeamCal only
→ Inner subdetectors shielded by Pacman





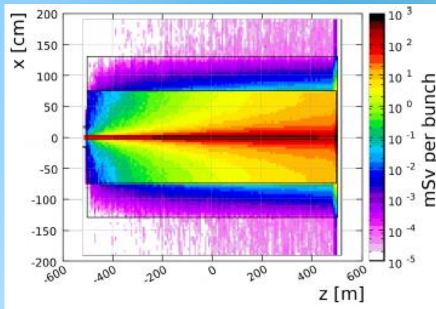
Anne Scheutz (DESY)

1km long gaseous beam dump (filled with Nitrogen)



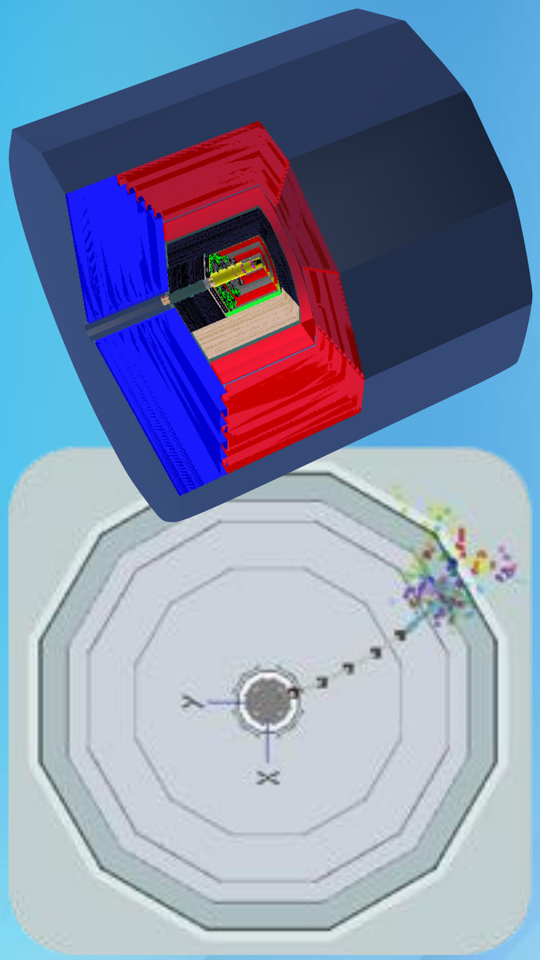
Alternative beam dump study

→ Dose equivalent average per bunch in proximity of beam dump:
10−4 mSv cm−3
up to 3 orders of magnitude smaller than for water beam dumps
→ no neutrons created that travel back to IR!



Computing/Software/Simulation

SiD is implemented in the common DD4hep framework, and undergoing various iterations to incorporate geometry changes and for compatibility with the latest DD4hep developments:



SiD_o2_v02	obsolete	• based on 2015 engineering drawings • includes a Scintillator AHCal • many custom drivers • includes Pandora extensions & det_type flags required for particle flow reconstruction • was used for ECal/HCal optimisation, and for tracking studies
SiD_o3_v02	test	• **same as SiD_o2_v02 but AHCal has Cu/brass instead of steel absorbers**
SiD_o2_v03	current	• **includes new stepped Muon detector with scintillators instead of RPCs** • **updated coding conventions** • **some new custom drivers** • **incorporates important changes in DDSim and DDRec** • **used for current detector optimisation and sensitivity studies**

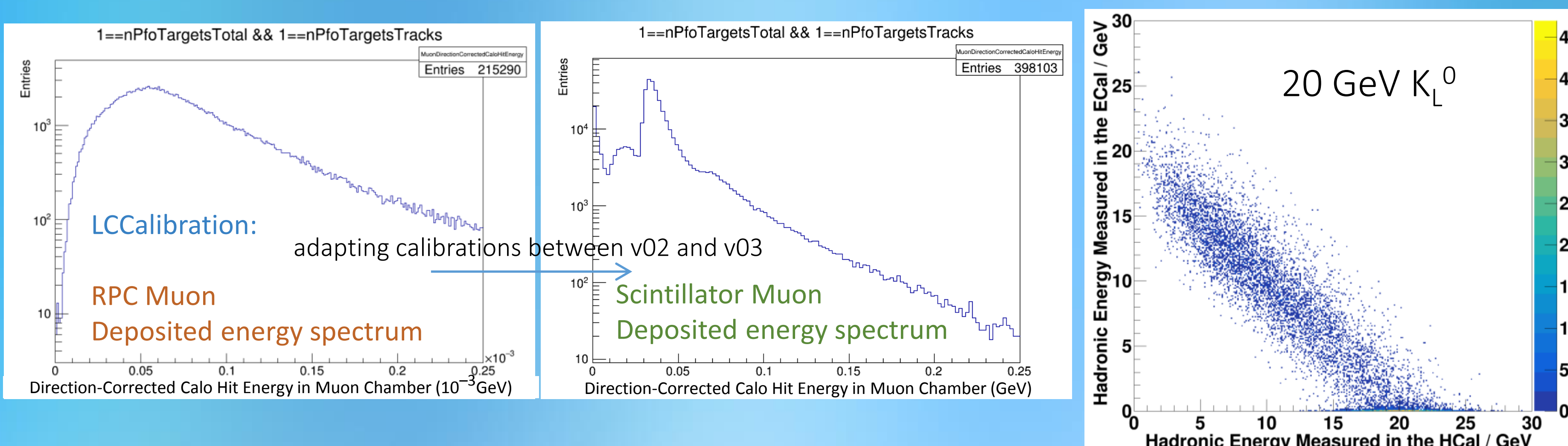
Work in progress: LumiCal in the full DD4HEP SiD simulation

Glasgow, PNNL, UTA, Oregon, UCSC

Computing/Software/Simulation

Complete simulation+reconstruction is in place using the SiD reconstruction chain, based on the CLICdet reconstruction:

- includes full pattern recognition tracking, and Pandora particle flow reconstruction via DDMarlinPandora
- calorimeter calibration is done via Ete Remi's LCCalibration (https://github.com/iLCSoft/LCCalibration) and the constants are used in the current reconstruction



- current focus is on **benchmarking calorimeter performance, tracking,** and **forward calorimetry optimisation**

Glasgow, PNNL, UTA, Oregon, UCSC

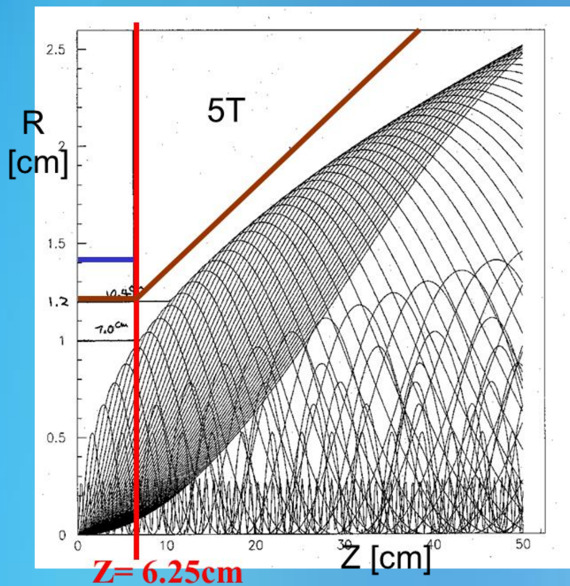
SiD going forward

- SiD has had a viable and validated design for many years.
- A limited amount of very valuable R&D has been carried out with highly constrained support.
- We have a new simulation in the DD4HEP framework – now verifying performance.
- Following simulation verification, we anticipate a new series of physics studies.
- Developing a plan for SiD support for R&D towards a TDR.
- We have many interesting opportunities for further hardware and software studies, and welcome new ideas!
- We also welcome new members of SiD !

EXTRA

VTX – Pair Background revisited for ILC250

Previous study
T. Murayama



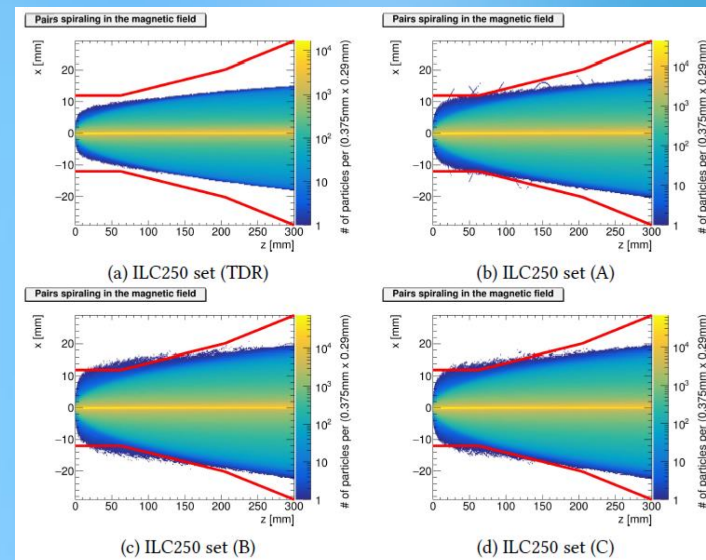
Increase luminosity by reducing ε_x and/or β_x

but…

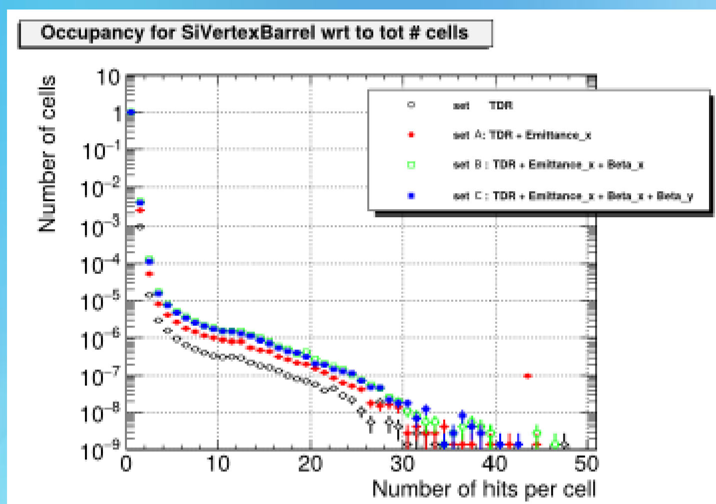
Larger beam-beam interactions -> increased pair bkgd

New ILC250 parameter sets

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



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



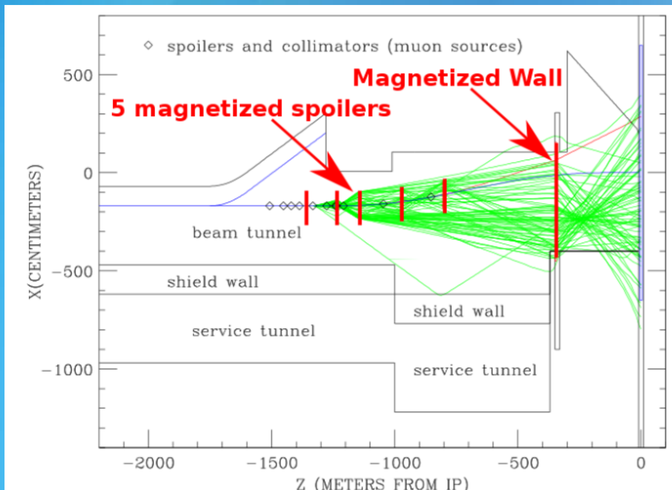
Occupancy in layer 0 for the new sets is significantly increased with respect to the TDR scheme…but can be accommodated in SiD VTX design

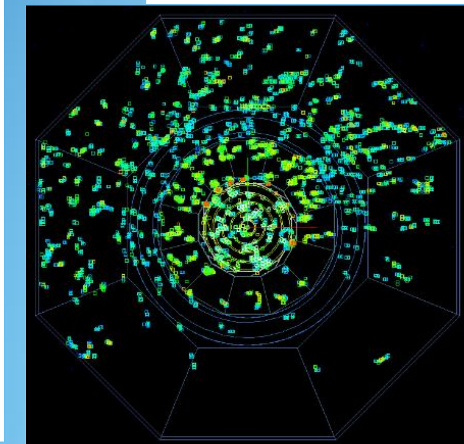
Anne Schuetz (DESY)

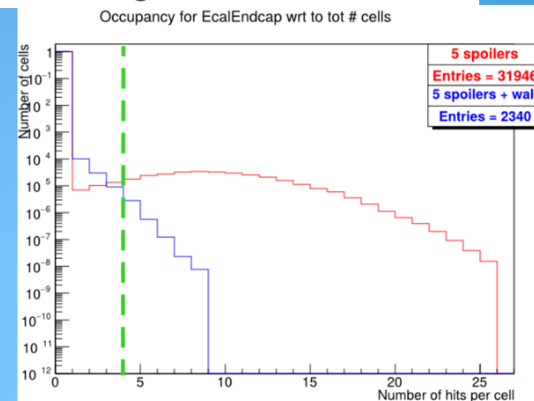
MDI Studies

Muons from the BDS system

Scenario	Number of muons in a detector with 6.5m radius
No Spoilers	130 muons/bunch crossing
5 Spoilers	4.3 muons/bunch crossing
5 Spoilers + Wall	0.6 muons/bunch crossing







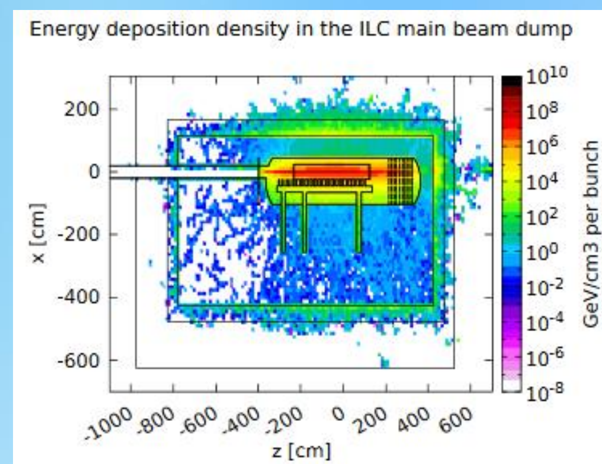
SiD would like to KEEP the Wall

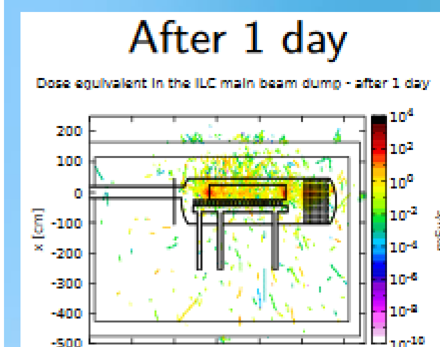
Neutrons from the beam dump:

- 17MW dumped into water vessel
- FLUKA – neutrons from model of dump

NEXT:

- Neutrons through the extraction line
- Neutrons reaching IP/detector
- **Neutrons occupancy in SiD**





? UCSC work

Anne Schuetz (DESY)