A detailed 3D cutaway rendering of the SiD detector. The central feature is a large, purple, barrel-shaped calorimeter. Inside it is a red, multi-layered structure representing the inner detector. The entire assembly is surrounded by a thick, blue, multi-layered structure representing the shielding. Various pipes, cables, and mechanical components are visible throughout the structure. A small human figure is placed near the bottom right for scale.

# **SiD**

## **Detailed Baseline Design**

**Marcel Stanitzki**  
for the SiD Detector Concept

**LCWS 2012 Arlington, TX**





# SiD Detector overview

- SiD Rationale

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

- Design choices

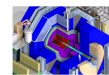
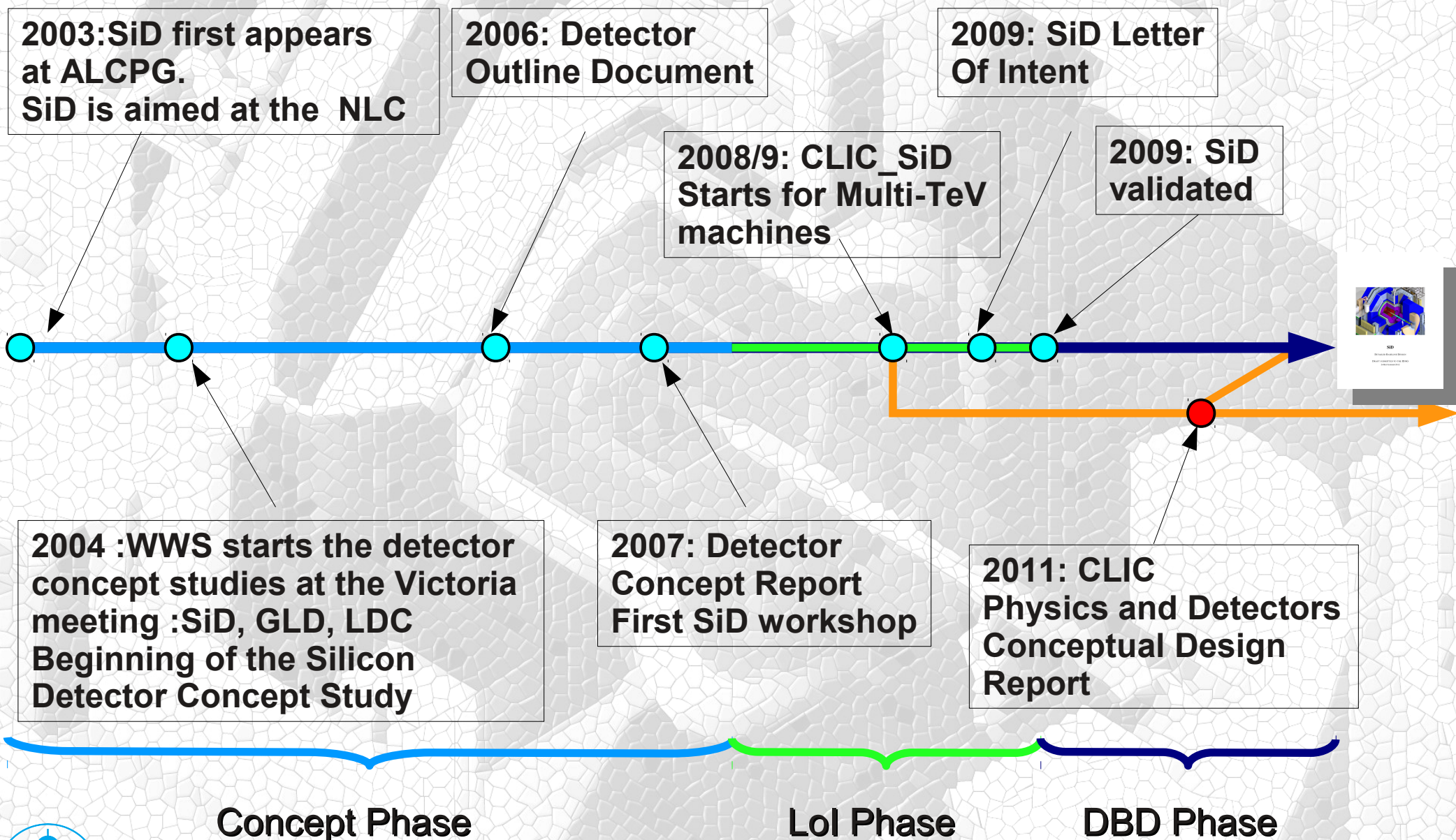
- Compact design with 5T field.
- Robust silicon vertexing and tracking system with excellent momentum resolution
- Time-stamping for single bunch crossings.
- Highly granular Calorimetry optimized for Particle Flow
- Iron flux return/muon identifier is part of the SiD self-shielding
- Detector is designed for rapid push-pull operation







# Moving towards the DBD



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# And many reports...

SLAC-PUB-11413

## The SILICON DETECTOR (SiD) and LINEAR COLLIDER DETECTOR R&D in ASIA and NORTH AMERICA\*

James E. Brau, University of Oregon, USA  
Martin Breidenbach, SLAC, USA  
Yoshiaki Fujii, KEK, Japan

### Abstract

In Asia and North America research and development on a linear collider detector has followed complementary paths to that in Europe. Among the developments in the US has been the conception of a detector built around silicon tracking, which relies heavily on a pixel (CCD) vertex detector, and employs a silicon tungsten calorimeter. Since this detector is quite different from the TESLA detector, we describe it here, along with some of the sub-system specific R&D in these regions.

### INTRODUCTION

The TESLA detector, which has been developed by the ECFA-DESY studies over the past several years, optimizes the design of the detector around a specific set of assumptions. Alternative assumptions exist, and to a varying degree, have been applied to the design of other possible linear collider detectors, such as the JLC<sup>1</sup> Detector, the North American Large Detector, and the North American Silicon Detector (so-called SiD). Table 1 summarizes the properties of these differing choices. This table shows a number of similarities between the detectors.

- both TESLA and the Large Detector use TPC trackers.
- both TESLA and the Silicon Detector use silicon strip detectors for the EM calorimeter.
- The Large Detector and the JLC Detector choose scintillator tile with lead for EM and hadron calorimetry.

Other details vary, including the choice of magnetic field, which ranges from 3 up to 5 Tesla. Each of these designs is guided by the physics goals, which lead to the following principal detector goals:

- Two-jet mass resolution, comparable to the natural widths of the W and Z for an unambiguous identification of the final states.
- Excellent flavor-tagging efficiency and purity.

- Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-stopping with resolution better than the beam energy spread.

\*The authors acknowledge the help of the following people in preparing this overview: Greg Fisk, Ray Bey, John Jans, Tom Markiewicz, Bruce Schumm, Eric Tjornheim, and Ian Yu.

\*The name JLC was changed to GLC in April, 2003.  
Presented at 4th ECFA / DESY Workshop on Physics and Detectors for a 90 GeV to 500 GeV Linear e+e- Collider, Amsterdam, The Netherlands, 1-4 Apr 2003.  
Work supported in part by Department of Energy contract DE-AC02-76SF00515

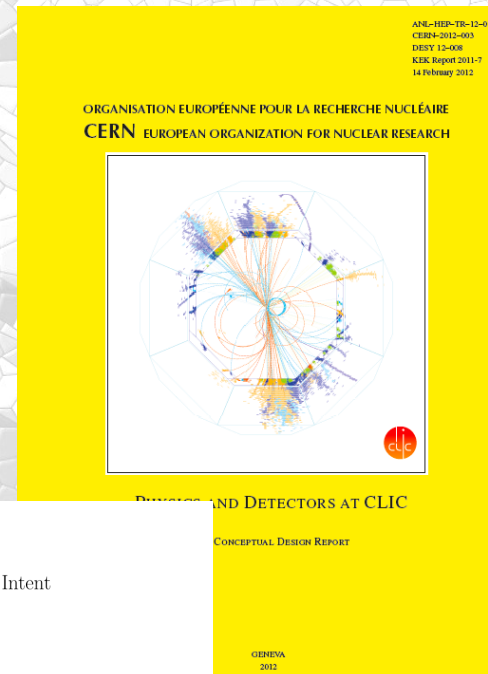
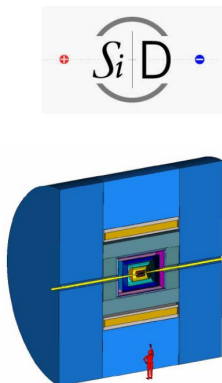


Figure 1: The Silicon Detector.

The strategy of energy-flow calorimetry leads directly to a reasonably large value of  $B/E$  to provide charged neutral separation in a jet, and to an electromagnetic calorimeter (EMCAL) design with a small Moliere radius and small pixel size. Additionally, it is desirable to read out each layer of the EMCAL to provide maximal information on shower development. This leads to the same neutral solution as TESLA, a series of layers of about 0.5 X<sub>0</sub> Tungsten sheets alternating with arrays of silicon diodes. Such

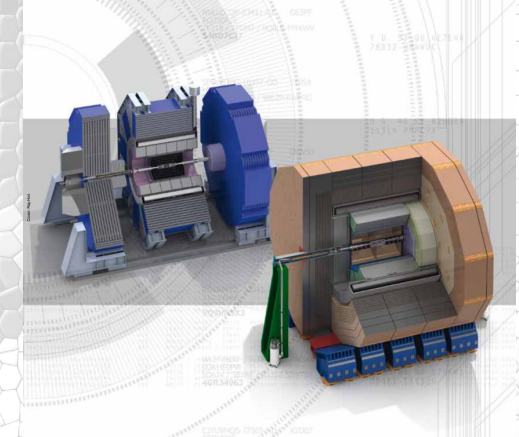
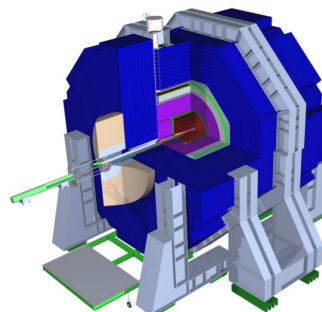
## SID Detector Outline Document

Version of: 19 May 2006 1:11:36 PM CST



## SiD Letter of Intent

31 March 2009



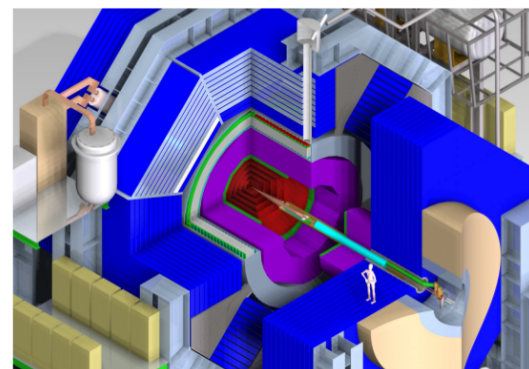


- The DBD describes a baseline of SiD for the ILC
  - Choices have been made for all subsystems besides the Vertex detector, however options have been kept
  - The detector is fully costed
- The DBD is not a TDR (M. Breidenbach)
  - Engineering effort not sufficient
  - Not all R&D has been completed
- In SiD's view the subsystem options offer
  - Improved performance or lower cost
  - Not as mature as the baseline choices yet



# Writing the DBD

- Started planning in 2011
- Appointed four main editors
  - P. Burrows (Oxford), L. Linssen (CERN), M. Stanitzki (DESY), A. White (UTA)
- Outline presented at KILC 2012
- SiD Workshop in August 2012 at SLAC
- Draft submitted to the IDAG on 23<sup>rd</sup> of September



**SiD**

DETAILED BASELINE DESIGN

DRAFT SUBMITTED TO THE IDAG  
24/SEPTEMBER/2012



- As promised to the IDAG, we delivered a “rather complete” draft on 23<sup>rd</sup> of September 2012
- Known “features” at the time of submission
  - Simulation & Reconstruction wasn't completed
  - Performance plots were preliminary
  - No Benchmarking results were available
- Page limits
  - in the right ball park
- Incorporating the common section
  - This came too late for the “IDAG” draft

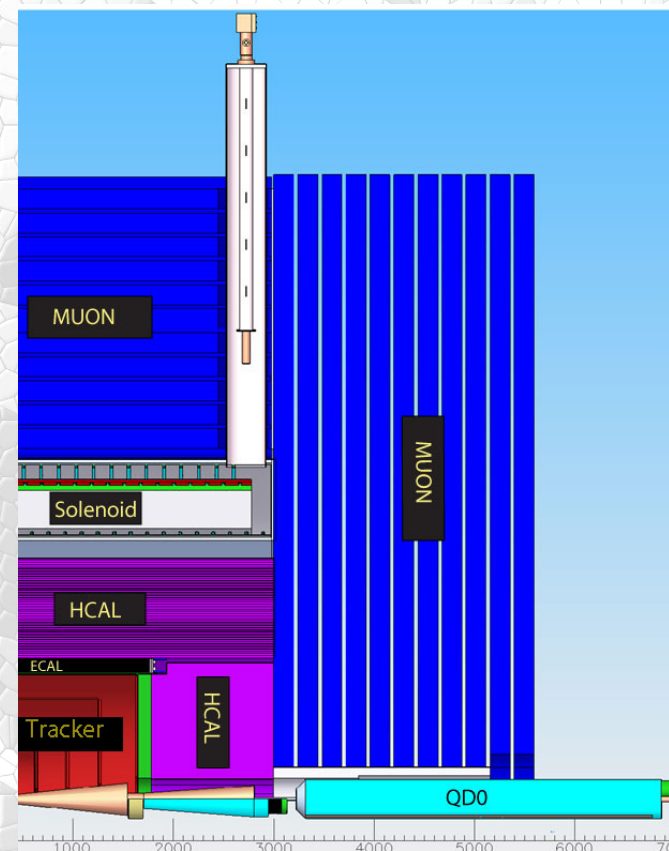
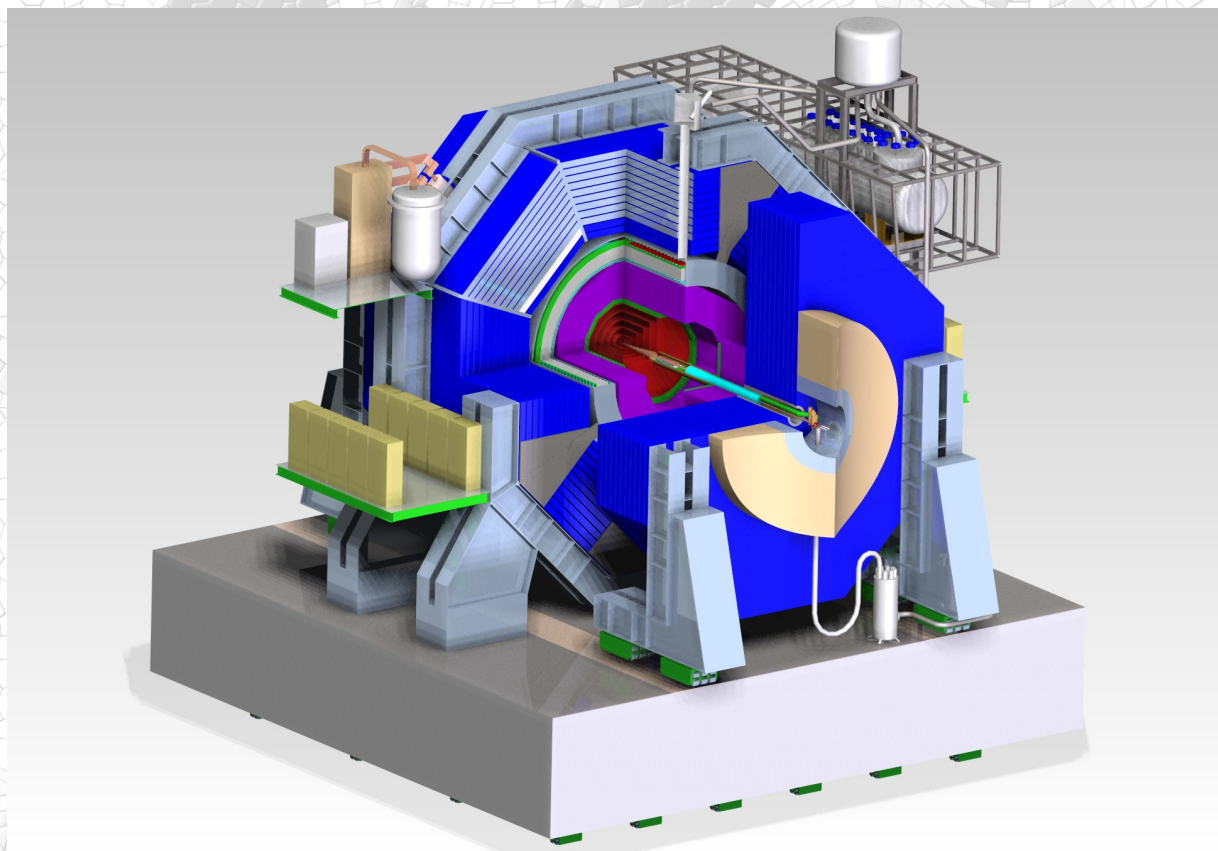


# Highlights from the DBD

- The DBD is a write-up of three years of activity
  - Lots of things have been achieved
- Will give a few selected highlights
  - Focus on new things since the LoI
  - R&D Highlights from the subsystems
  - Simulation & Reconstruction
  - Engineering
  - Costing
- 25 min is way too short to cover 150+ pages
  - Can't cover it all



# The DBD detector



- SiD is fully designed for push-pull (using a platform)
- PFA paradigm has driven design choices





# Detector parameters

SiD BARREL	Technology	Inner radius	Outer radius	z max
Vertex detector	Silicon pixels	1.4	6.0	$\pm$ 6.25
Tracker	Silicon strips	21.7	122.1	$\pm$ 152.2
ECAL	Silicon pixels-W	126.5	140.9	$\pm$ 176.5
HCAL	RPC-steel	141.7	249.3	$\pm$ 301.8
Solenoid	5 Tesla	259.1	339.2	$\pm$ 298.3
Flux return	Scintillator/steel	340.2	604.2	$\pm$ 303.3

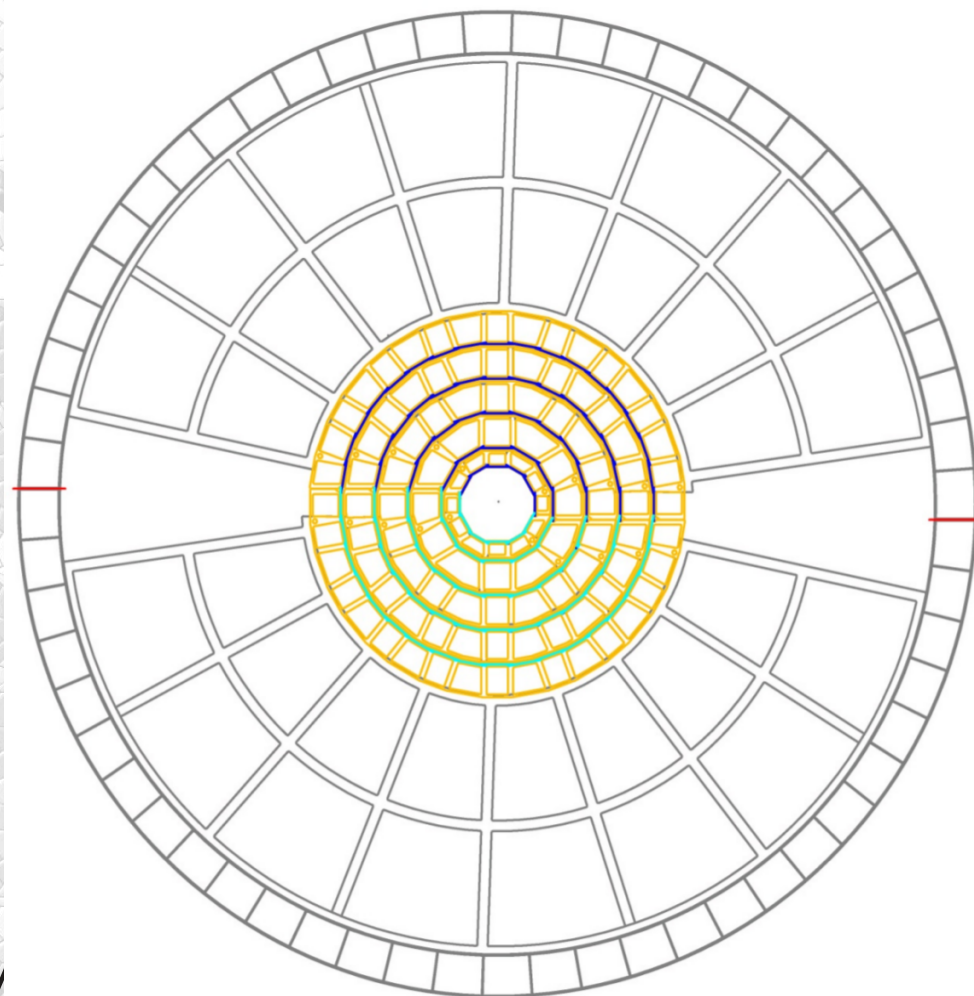
  

SiD ENDCAP	Technology	Inner z	Outer z	Outer radius
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5



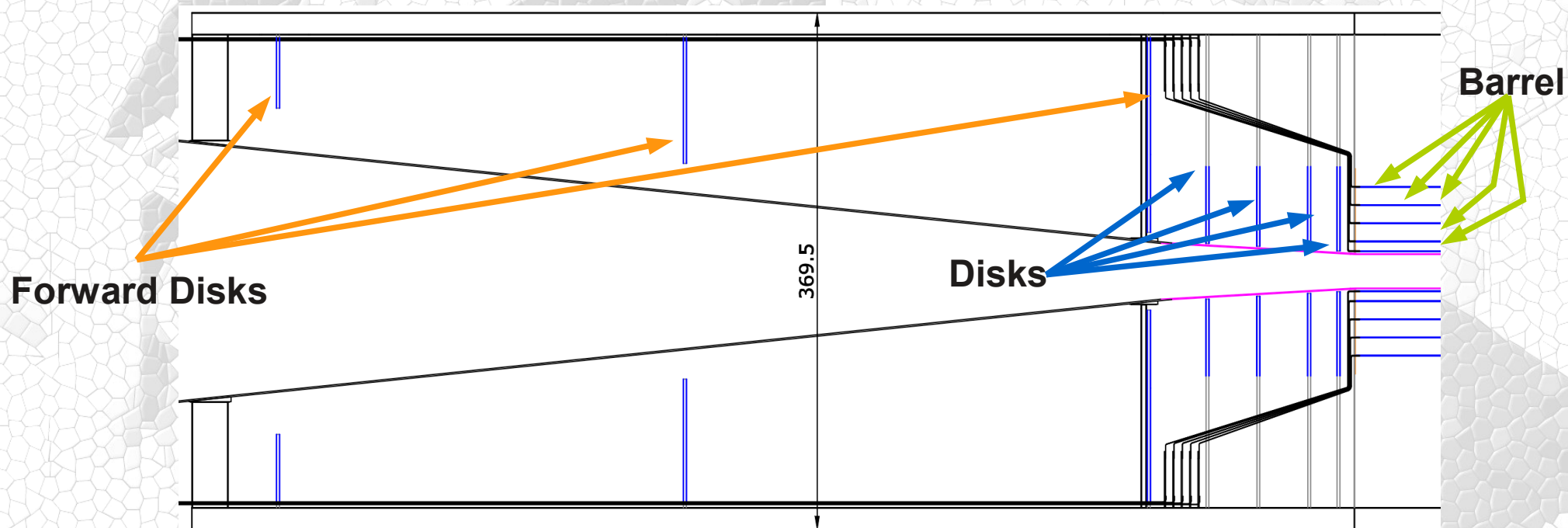


- Many potential technology choices
  - No baseline selected yet
- Requirements
  - $< 5 \mu\text{m}$  hit resolution
  - $\sim 0.1 \% X_0$  per layer
  - $< 130 \mu\text{W}/\text{mm}^2$
  - Single bunch timing resolution
- Insertion of Vertex straightforward
  - Allows to make late technology choice





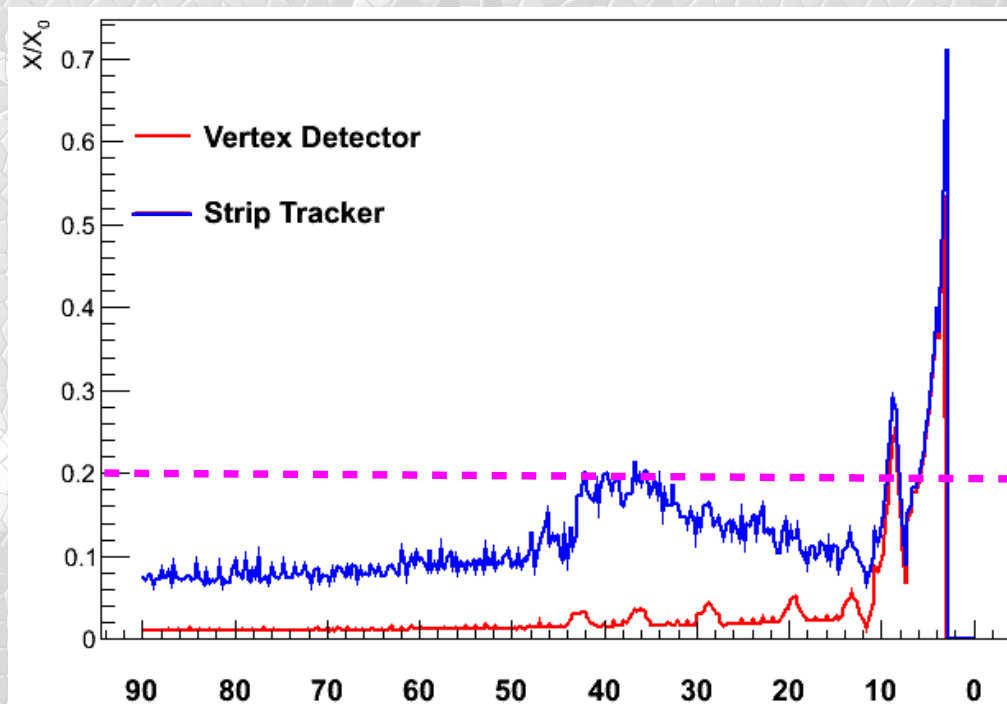
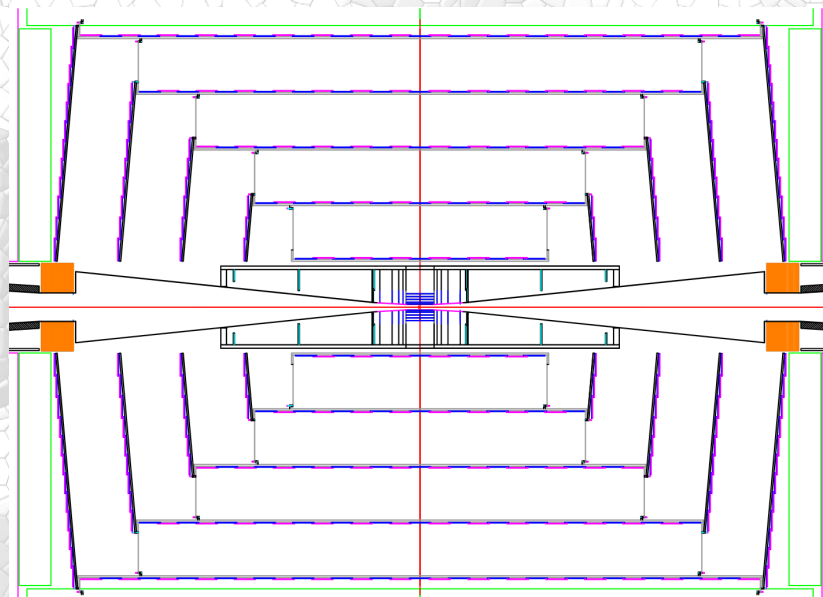
# Vertex Mechanics



- 5 Barrel Layers, 4 Disks, 3 Forward Disks
- Total power consumption  $\sim 20$  W
- Air-cooled
- Powering using DC-DC or serial powering
  - Learn from LHC upgrade experiences

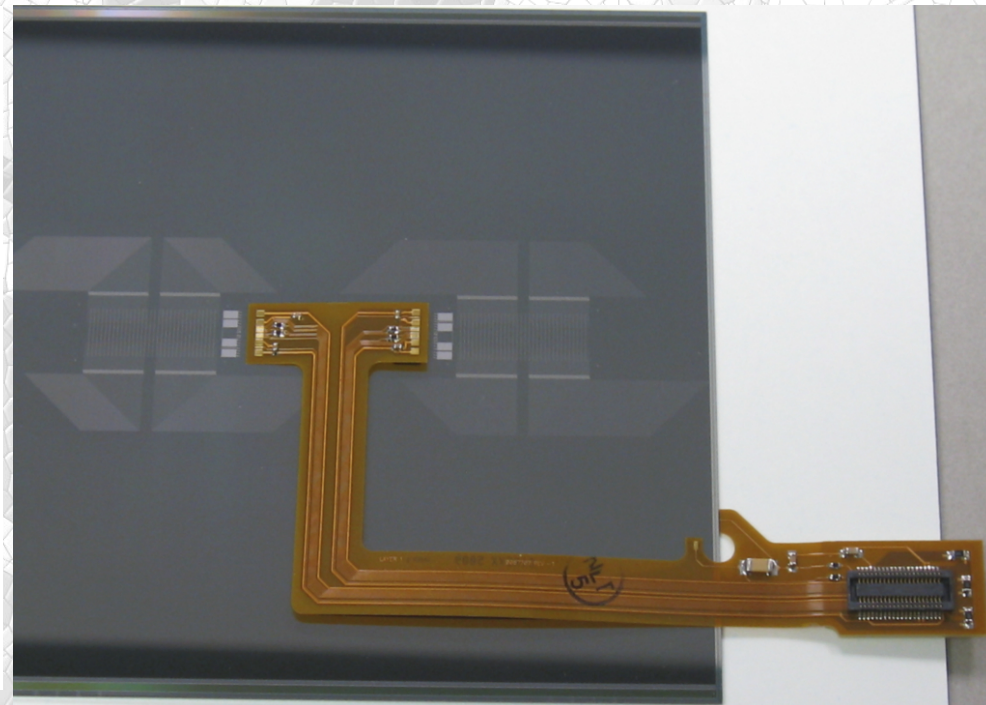
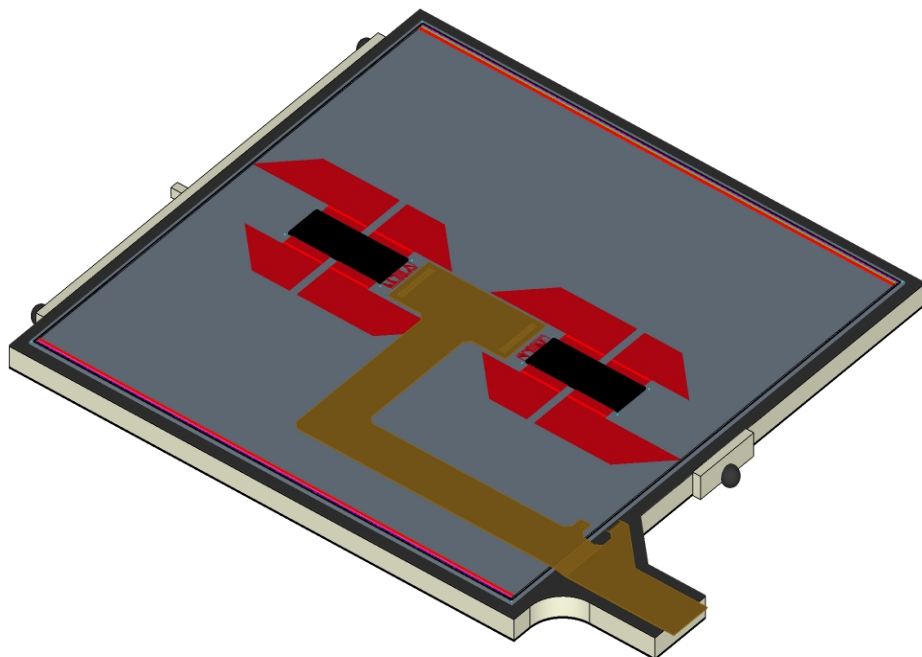


- All silicon tracker
  - Using silicon micro-strips
- 5 barrel layers and 4 disks
- Cooling
  - Gas-cooled
- Material budget
  - less than 20 %  $X_0$  in the active area
- Readout using KPiX
  - Bump-bonded directly to the modules





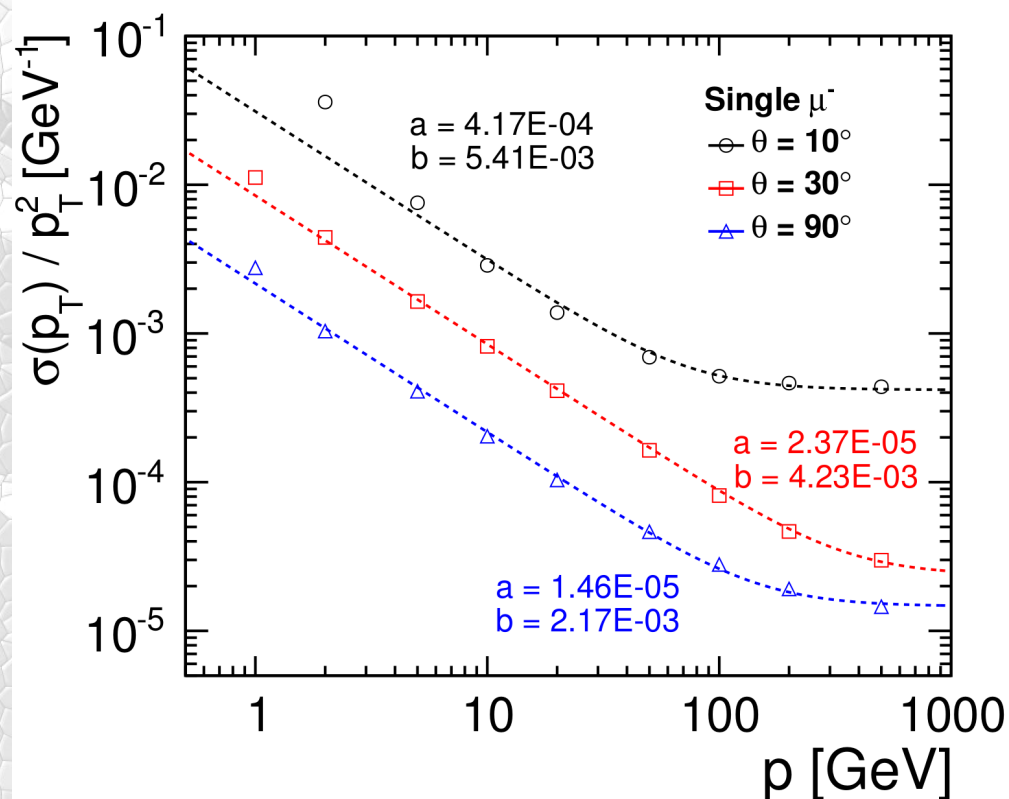
# Tracker Module



- Tracker modules from drawing to reality ...
- Sensors uses double metal layers
- Awaiting KPix bump-bonding



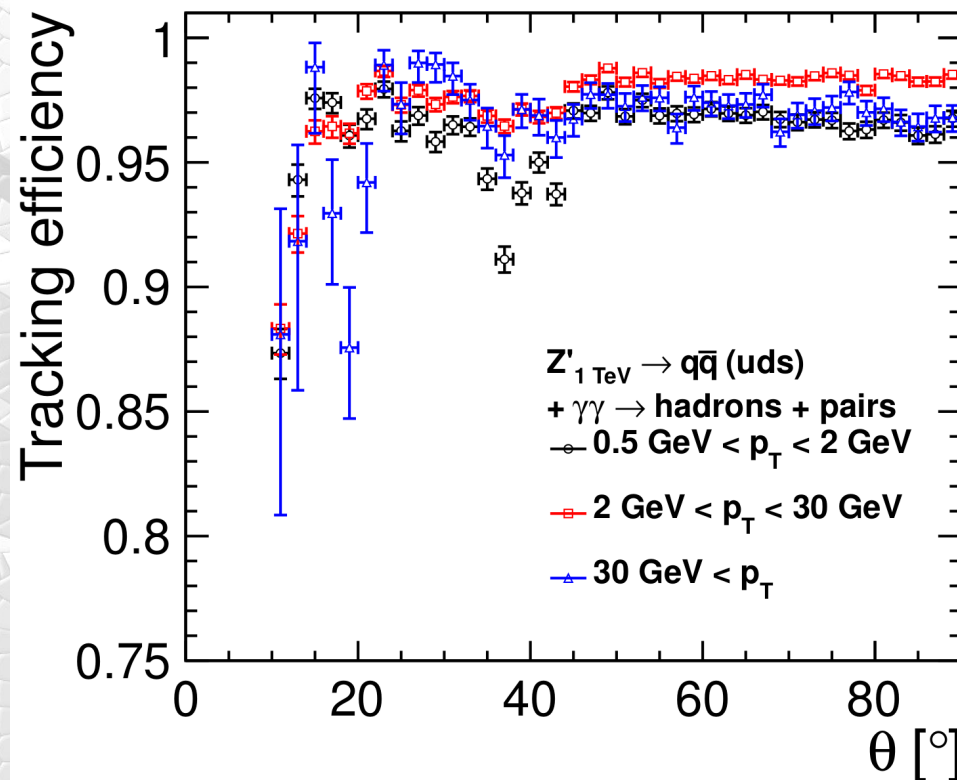
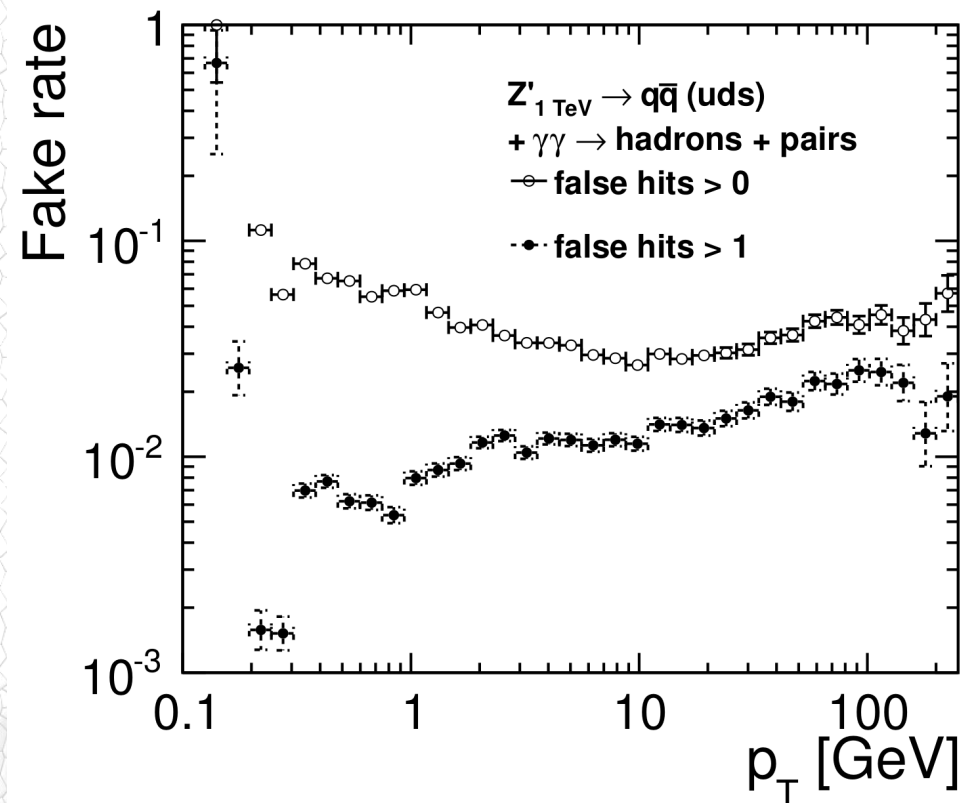
- SiD tracking is integrated
  - Vertex and Tracker
  - 10 Hits/track coverage for almost entire polar angle
- Tracking system
  - Achieves desired  $\Delta p_T/p_T$  resolution of  $1.46 \cdot 10^{-5}$
  - >99 % efficiency over most of the phase space
  - Impact parameter resolution of  $\sim 2 \mu\text{m}$  demonstrated







# Robustness vs. backgrounds



- $Z' \rightarrow \text{uds}$  at 1 TeV with 1 bunch crossing of background overlaid
- Demonstrates robustness of SiD Tracking





- SiD ECAL
  - Tungsten absorber
  - 20+10 layers
  - $20 \times 0.64 + 10 \times 1.30 X_0$
- SiD HCAL
  - Steel Absorber
  - 40 layers
  - $4.5 \Lambda_i$
- Baseline Readout using
  - 5x5 mm<sup>2</sup> silicon pads
- Baseline readout
  - 1x1 cm<sup>2</sup> RPCs
- SiD has selected baseline choices for its Calorimeter
  - Options are being considered
- Lots of test beam activities (past, present and future)
  - Parts of the program done as part of the CALICE effort



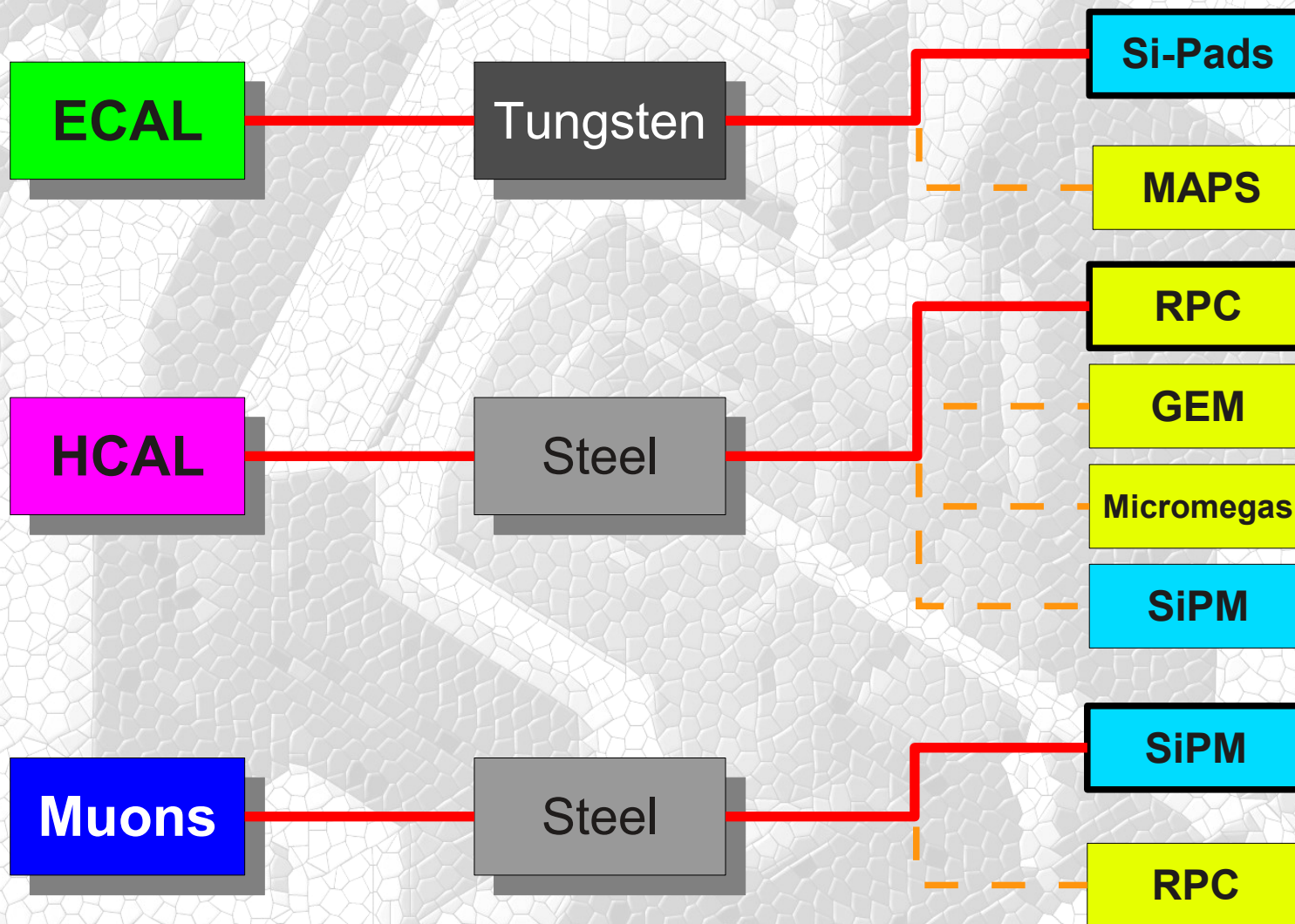


# Calorimetry Tree

Subsystem

Absorber

Readout



*Analog Readout*

*Digital Readout*

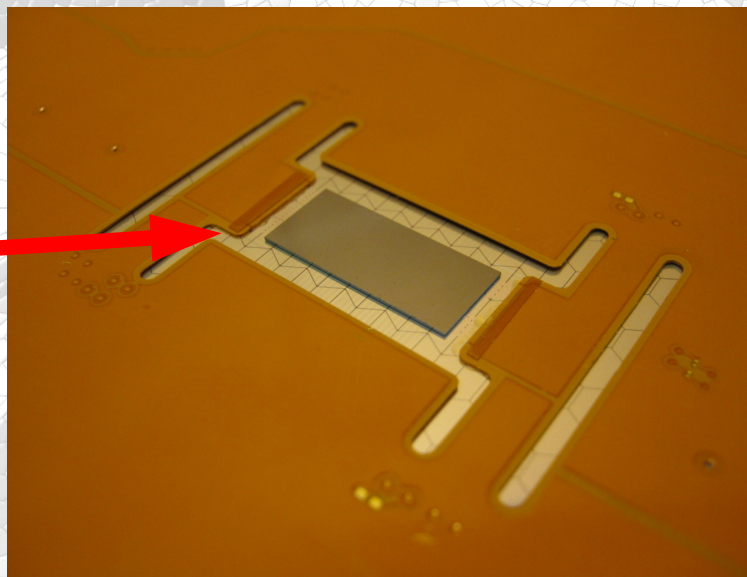
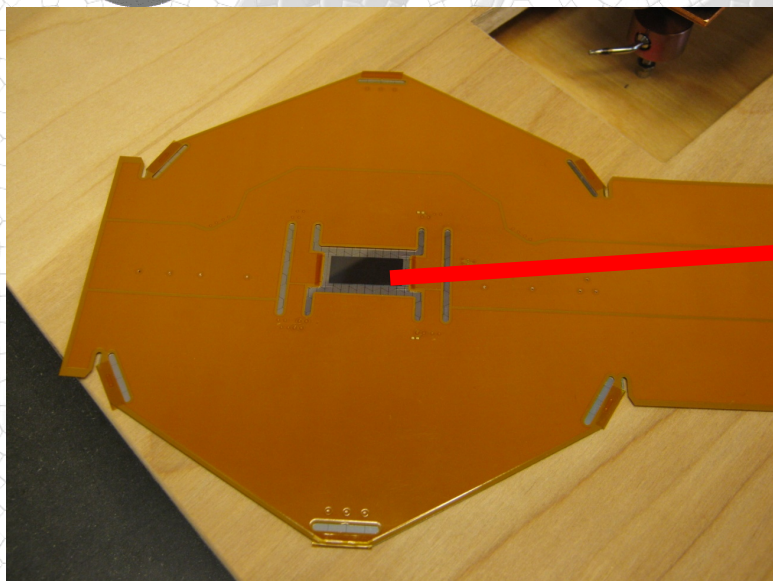


*Baseline*

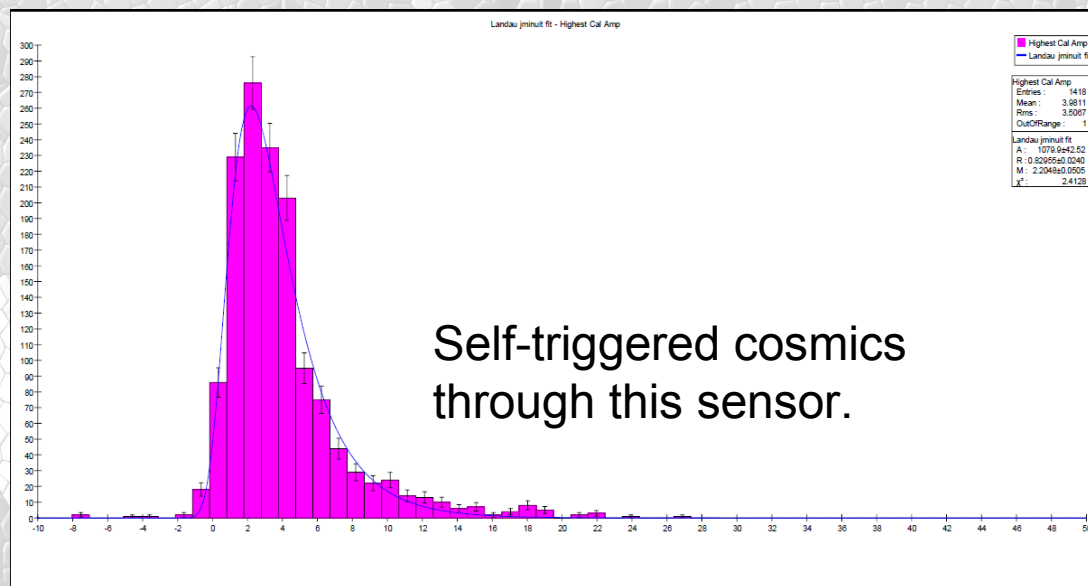
*Option*



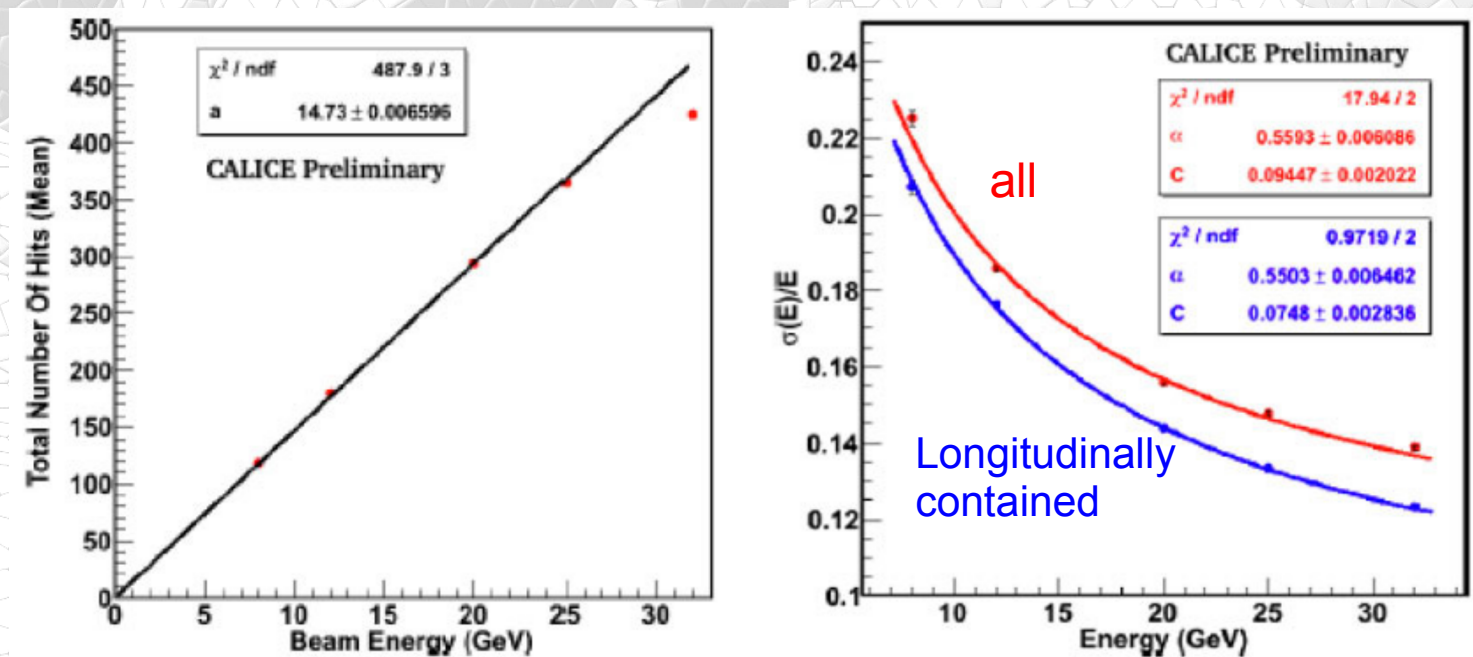




- KPiX bump bonded to 1024 pixel sensor
- Cable bump bonded to sensor
- Assembly is 1 mm high



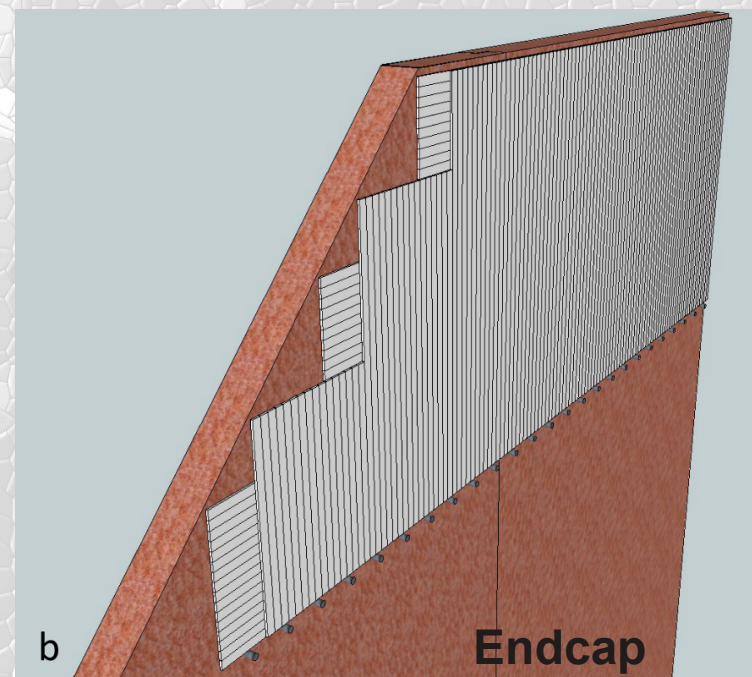
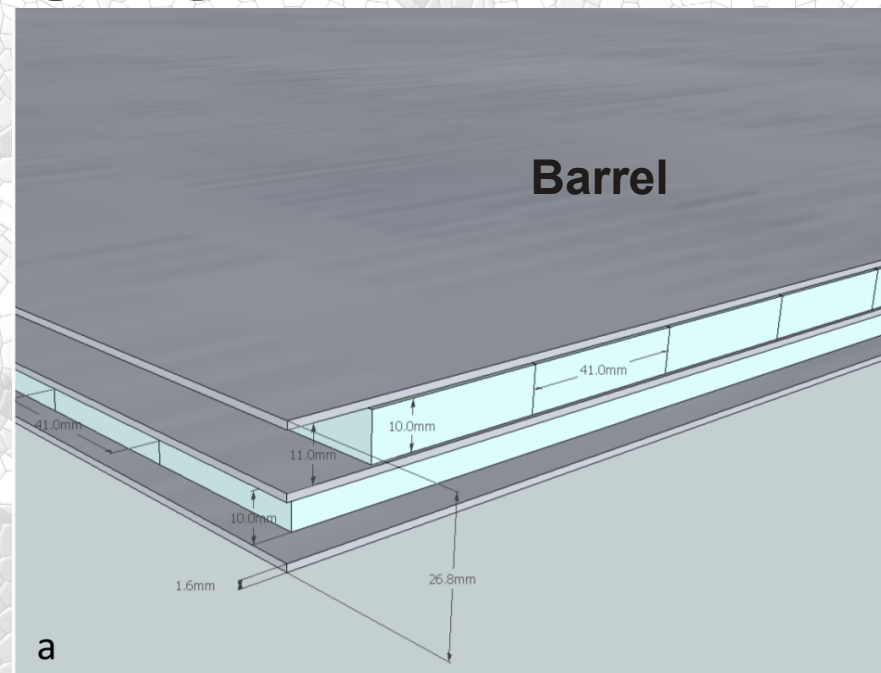




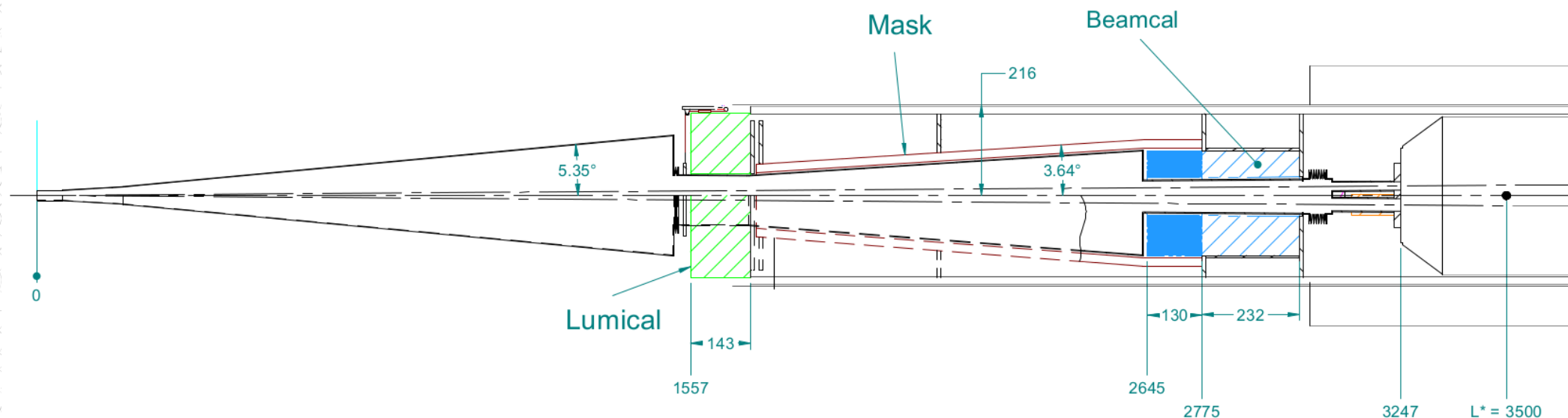
- After an extensive Test beam campaign
  - The RPC technology is a great candidate for the readout of a highly segmented calorimeter.
  - The dark rate in the DHCAL is very low
  - The response is linear up to about 30 GeV/c.



- Major change in baseline option
  - Readout technology
- New baseline option
  - Scintillator bars
  - SiPM readout
  - First engineering desing of the muon layers
- RPC remains an option
  - Still actively being pursued





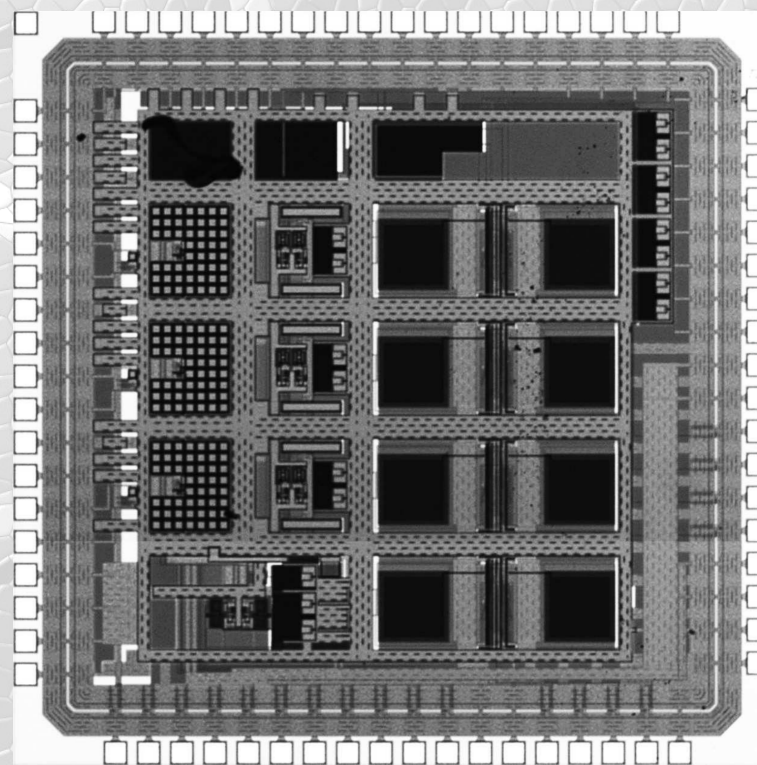
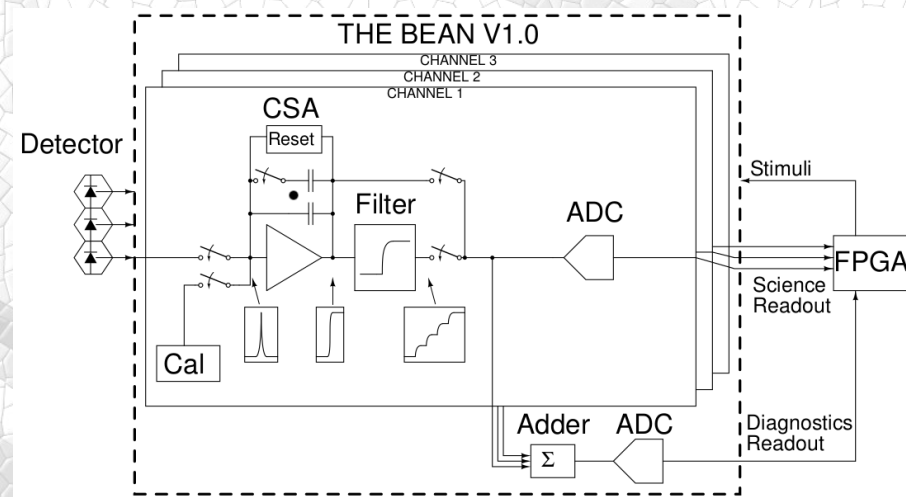


- SiD has two detectors in its forward region
  - LumiCal and BeamCal
  - SiD R&D is part of the worldwide FCAL effort.
  - Close interactions with MDI group
- A dedicated chip for BeamCal (Bean) has been developed

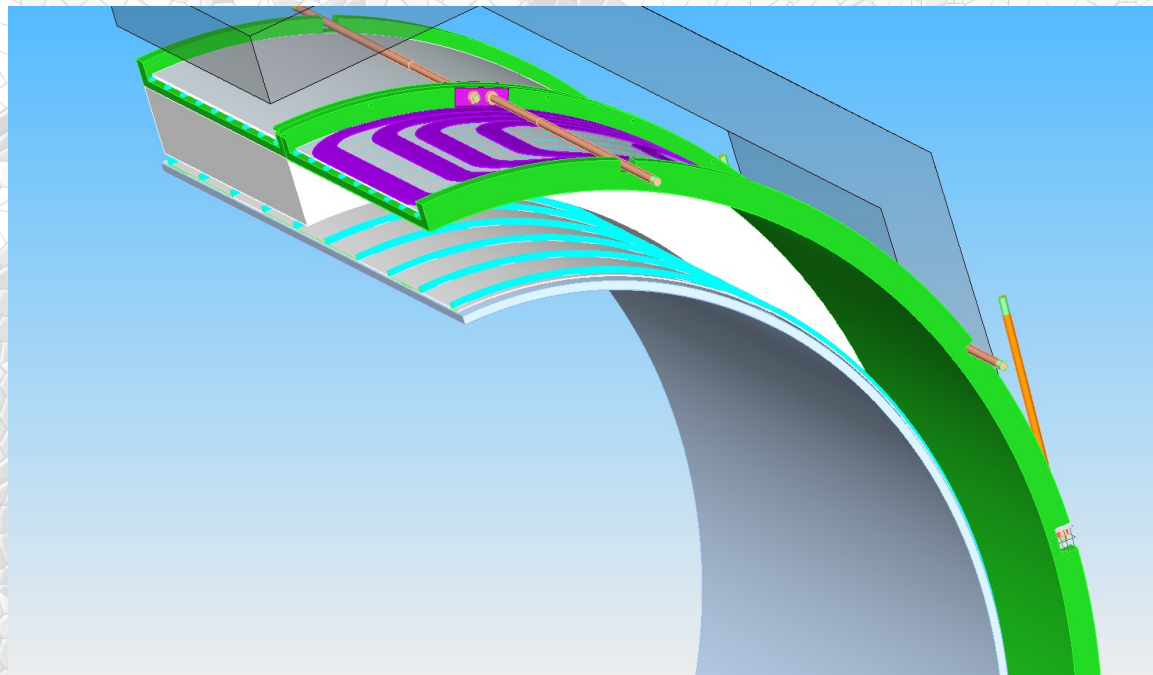
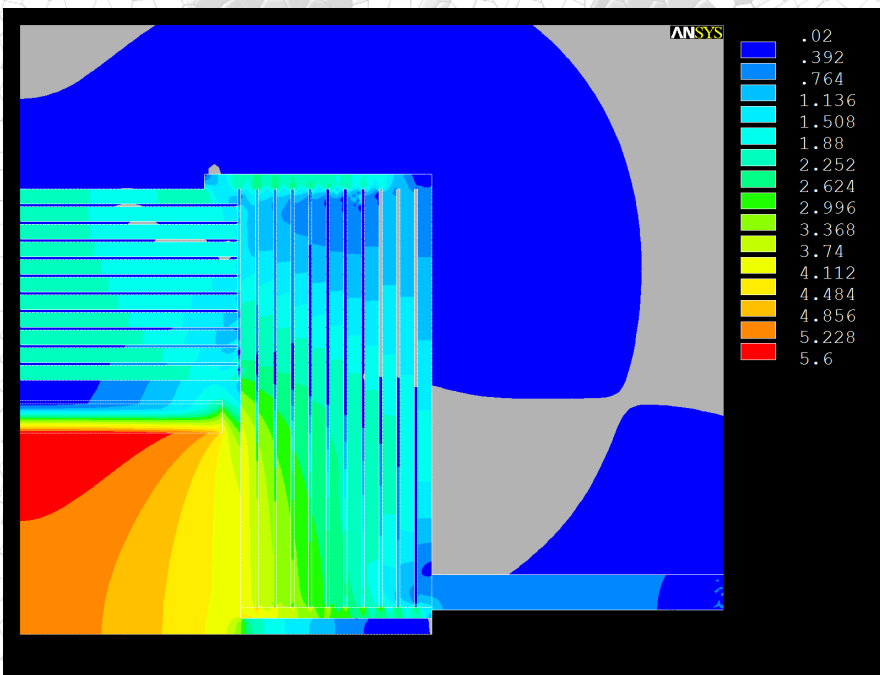


# The Bean Chip

- Bean V1.0
  - Dedicated chip for the high-occupancy environment
- Specs
  - 32 channel
  - 2820 Buffers
  - 10 bit ADC/ channel
  - Fast analog adding
- Successful Test phase just finished





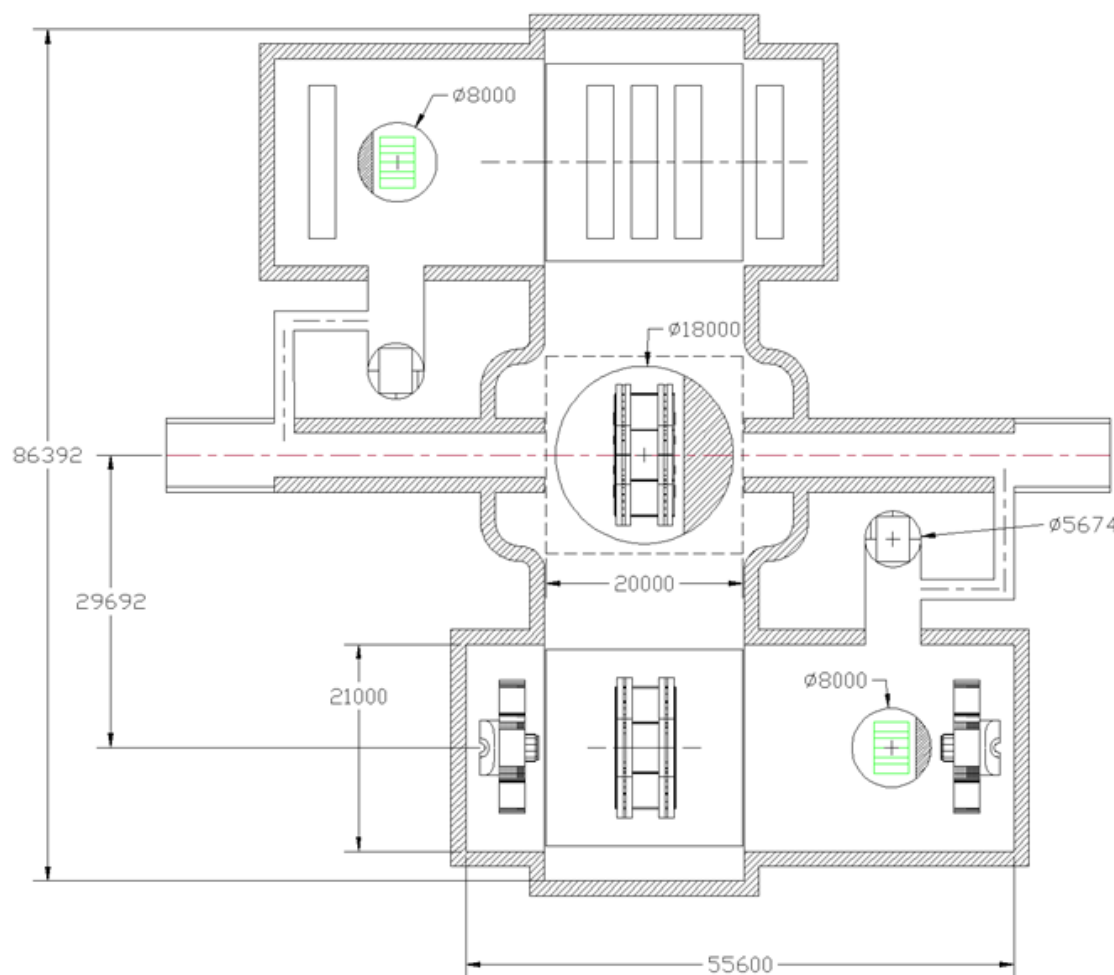


- The 5 T coil builds on the CMS experience
  - Especially on the CMS Conductor
- Engineering challenges are well understood
  - Advances in computing ease the design

Summary: Feasibility of SiD design demonstrated

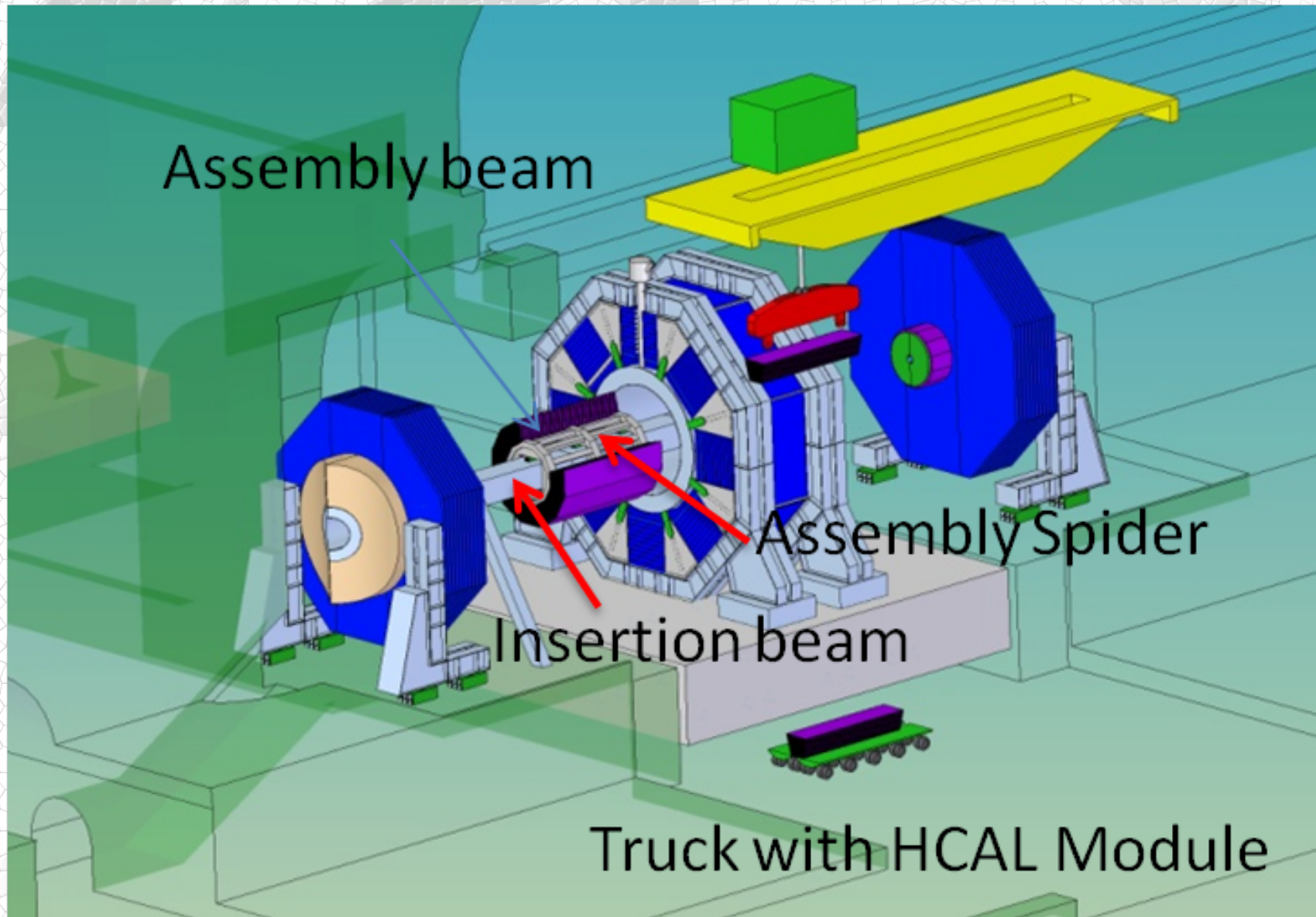


# Push-Pull Concept



- Push-Pull using concrete platform
- SiD is optimistic to do Push-pull in a few days
  - Minimum estimate is 32 hours



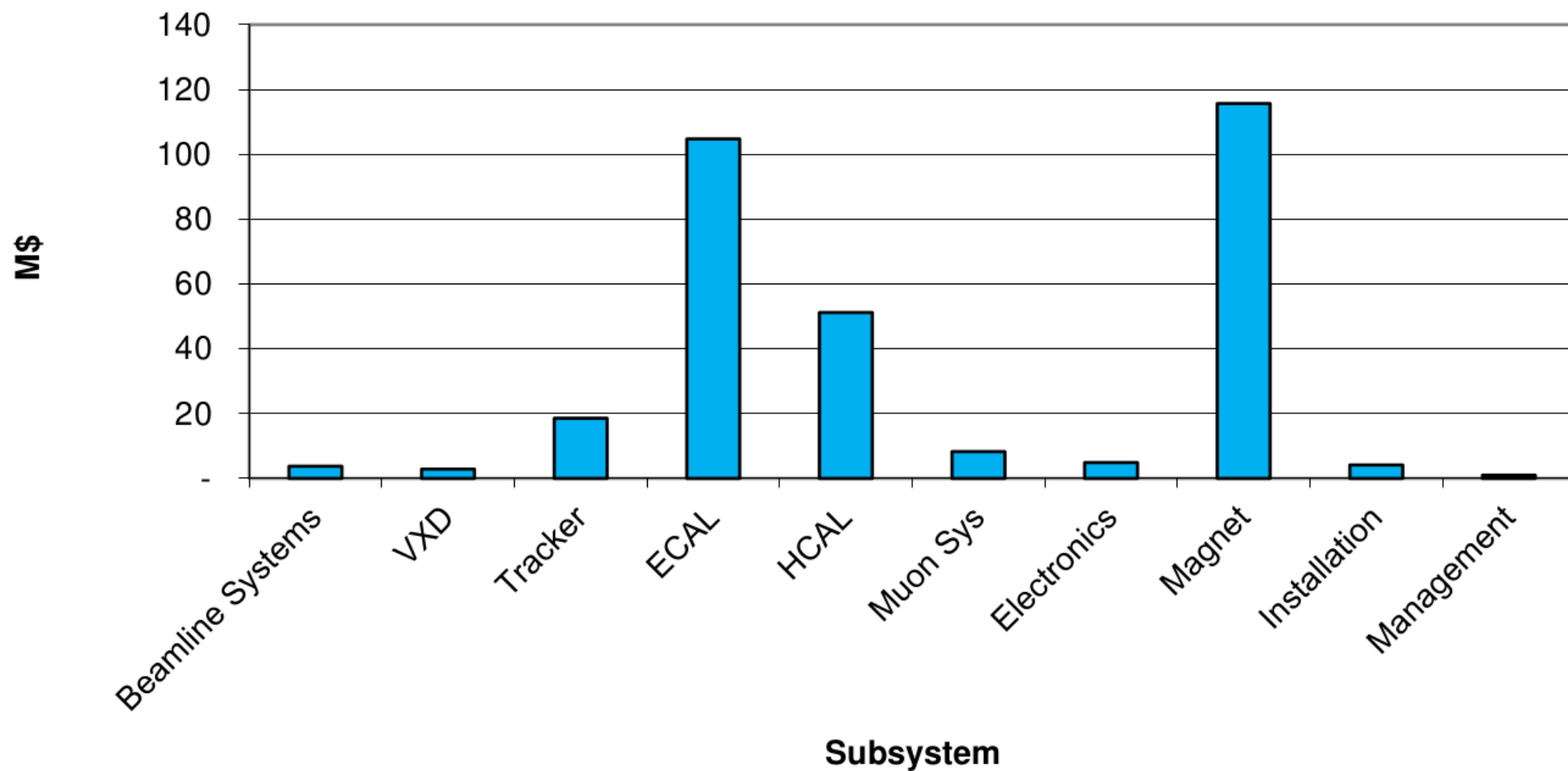




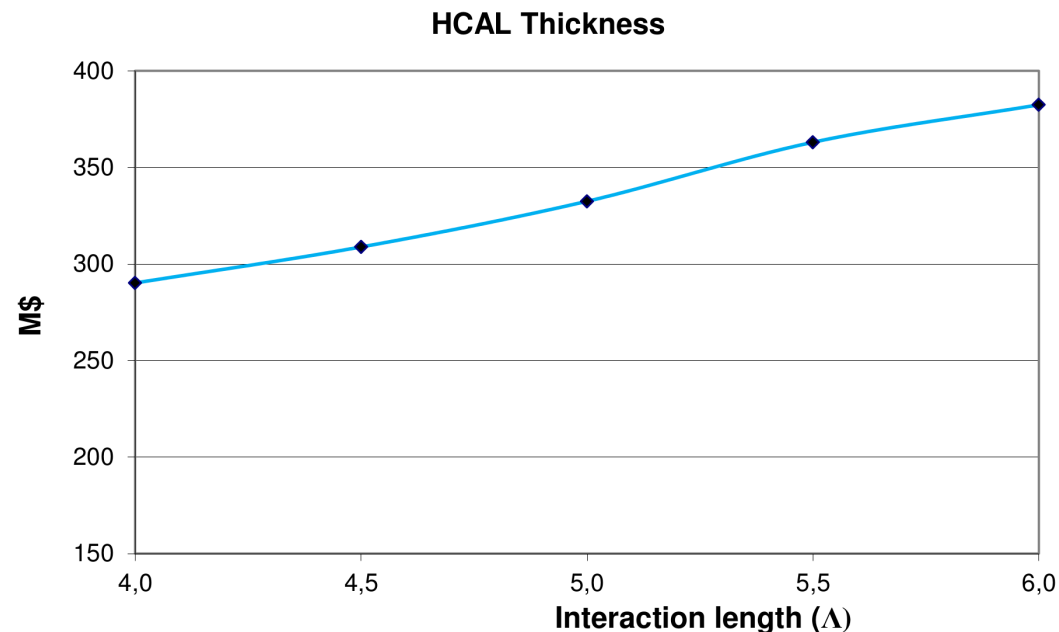
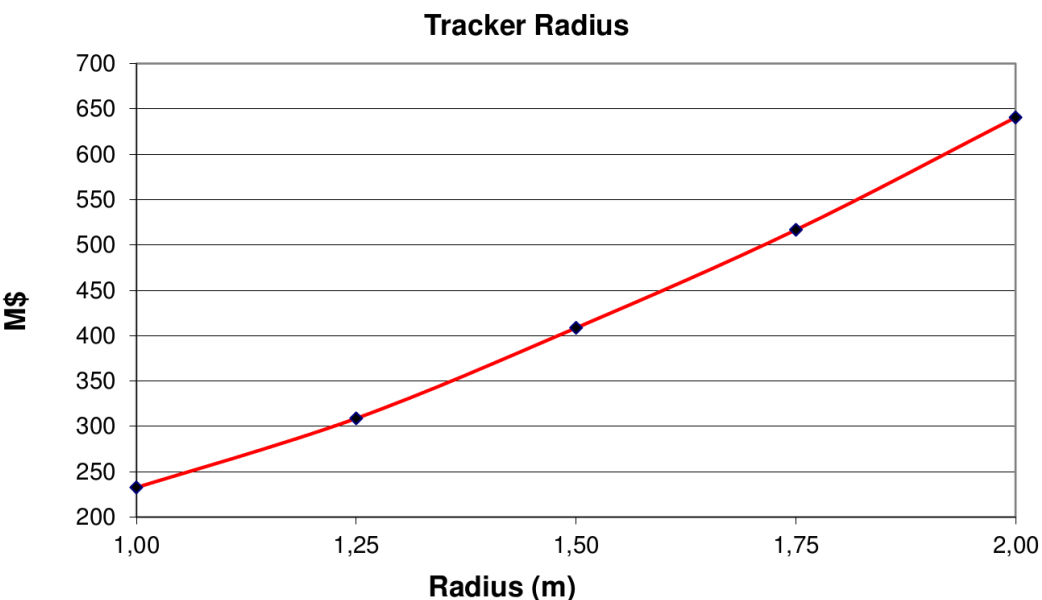
- SiD is using the agreed-upon unit costs
  - As agreed by SiD,ILD and CLIC
- Assuming “almost everything beyond the platform” is machine cost
- Costs in 2008 US-\$
  - M&S : 315 M\$
  - Contingency: 127 M\$
  - Effort: 748 MY
- Cost Sensitivity analysis (double unit costs)
  - Silicon sensors and magnet have largest impact
  - 26 and 14 % cost increase respectively
  -



## SiD M&S



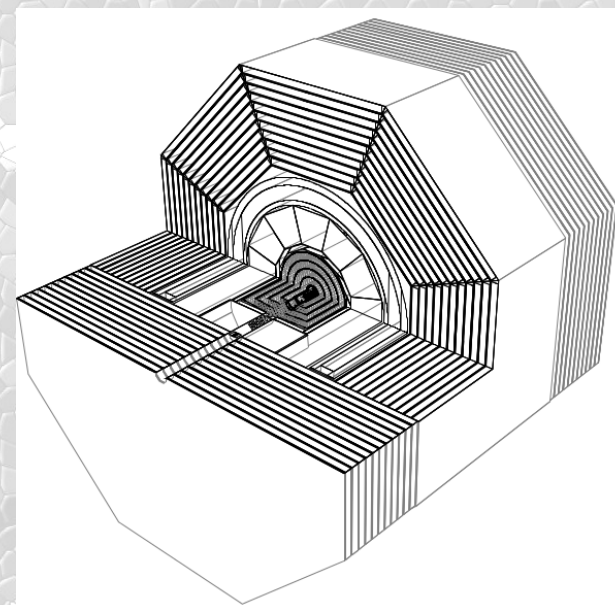
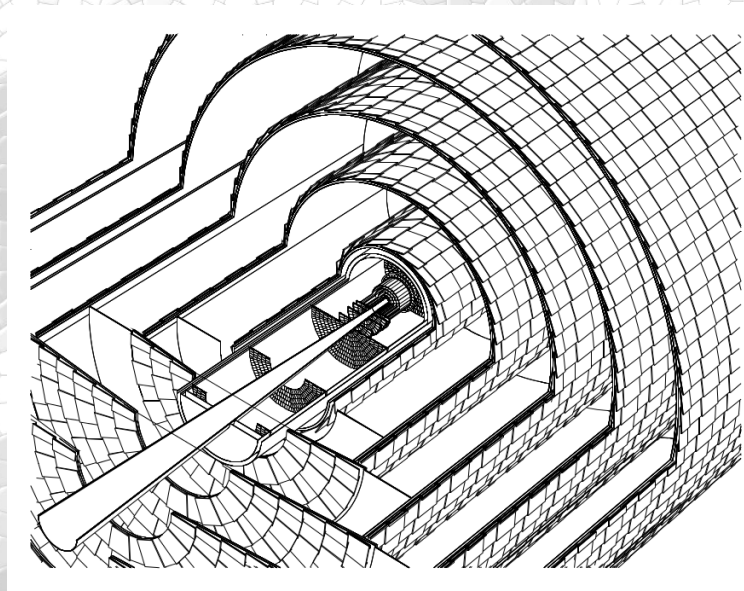




- Parametric Detector costing model allows study of main parameter dependencies
- Shown is Base M&S cost
  - Labor and Contingency excluded



- Many updates since LoI
- Simulation
  - Tracker modules and calorimeter segments now simulated
  - Background Overlay
- Reconstruction
  - Improved Tracking
  - Usage of SLICPandora
  - Reconstruction with full backgrounds
- Successfully tested during the CLIC-CDR.



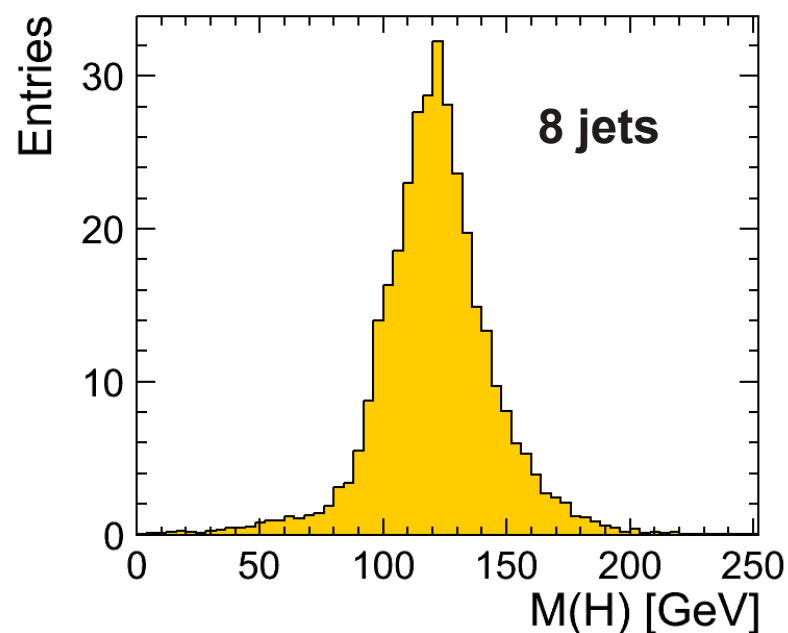
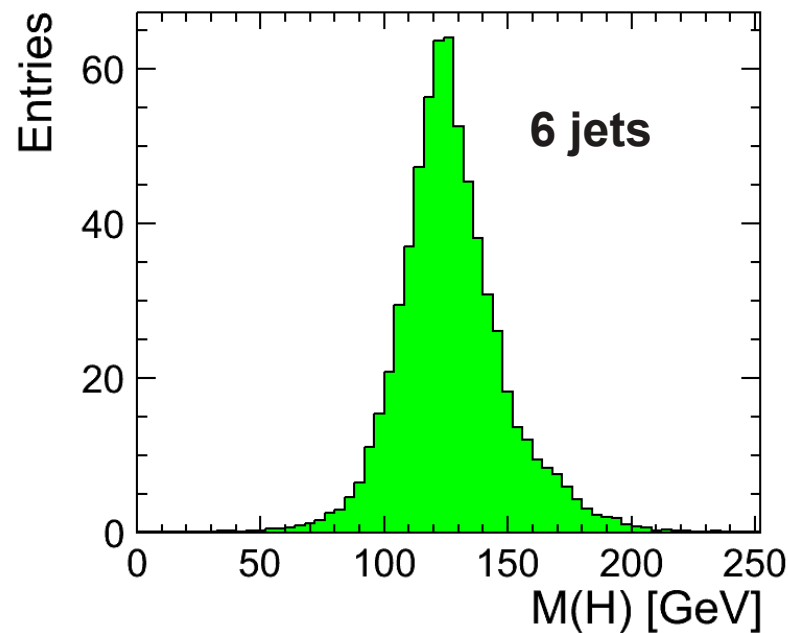


# Updates since submission

- SiD MC event sample corresponds roughly to  $2000 \text{ fb}^{-1}$  at  $E_{\text{cm}}=1\text{TeV}$  and  $250 \text{ fb}^{-1}$  at  $E_{\text{cm}}=500 \text{ GeV}$ .
- Background from incoherent  $e^+e^-$  pairs and  $\gamma\gamma\rightarrow\text{hadrons}$  are included.
- 66,421,842 events in 60 categories have been simulated and reconstructed; currently in the middle of 2<sup>nd</sup> iteration of reconstruction following identification of some bugs
- Benchmark analysis tools - flavor tagging, handling of background from incoherent  $e^+e^-$  pairs and  $\gamma\gamma\rightarrow\text{hadrons}$ , etc.– have been developed and tested.
- Individual benchmark analyses are at various levels of completion

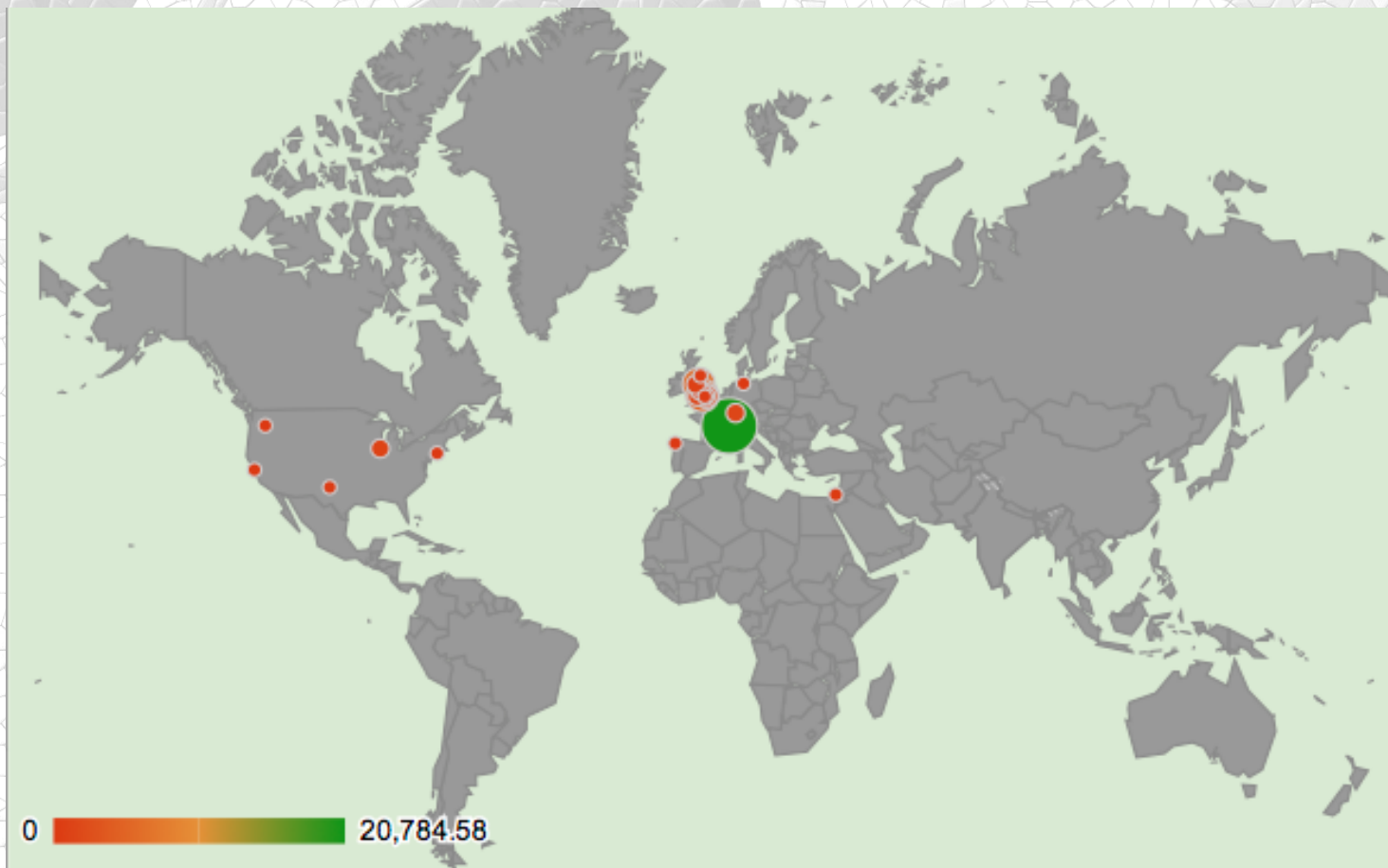


- Studying ttH at 1 TeV
  - 6 jet and 8 jet final states
  - Full reconstruction
- The physics events were overlaid with beam-related backgrounds corresponding to 1 BX:
  - incoherent pairs (450.000 particles)
  - $4.1 \text{ } \gamma\gamma \rightarrow \text{hadrons}$  interactions
- $\chi^2$  for jet pairing





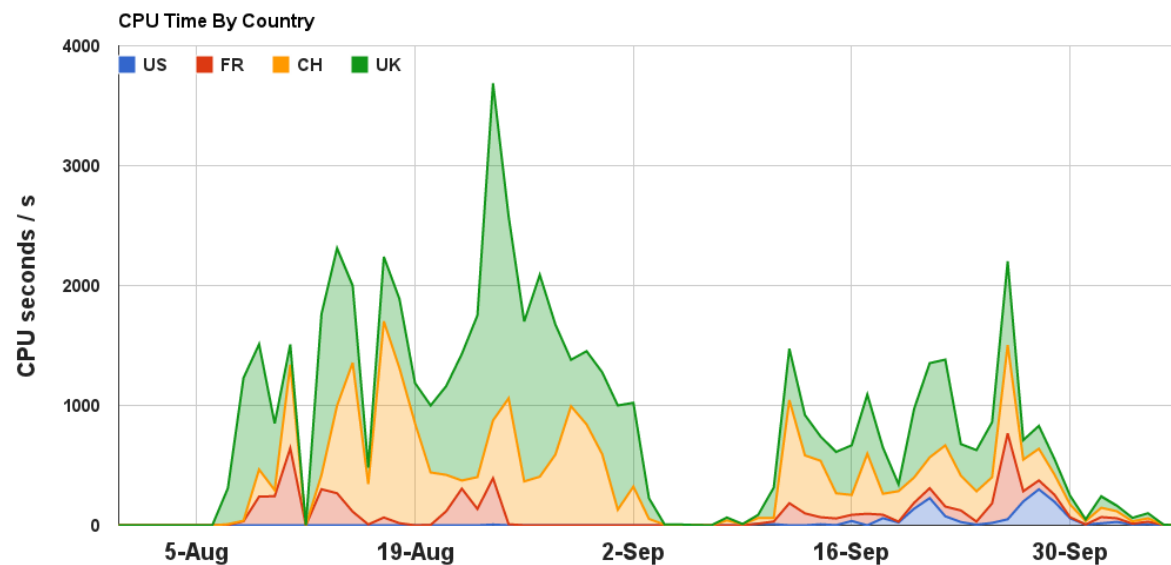
# Production update



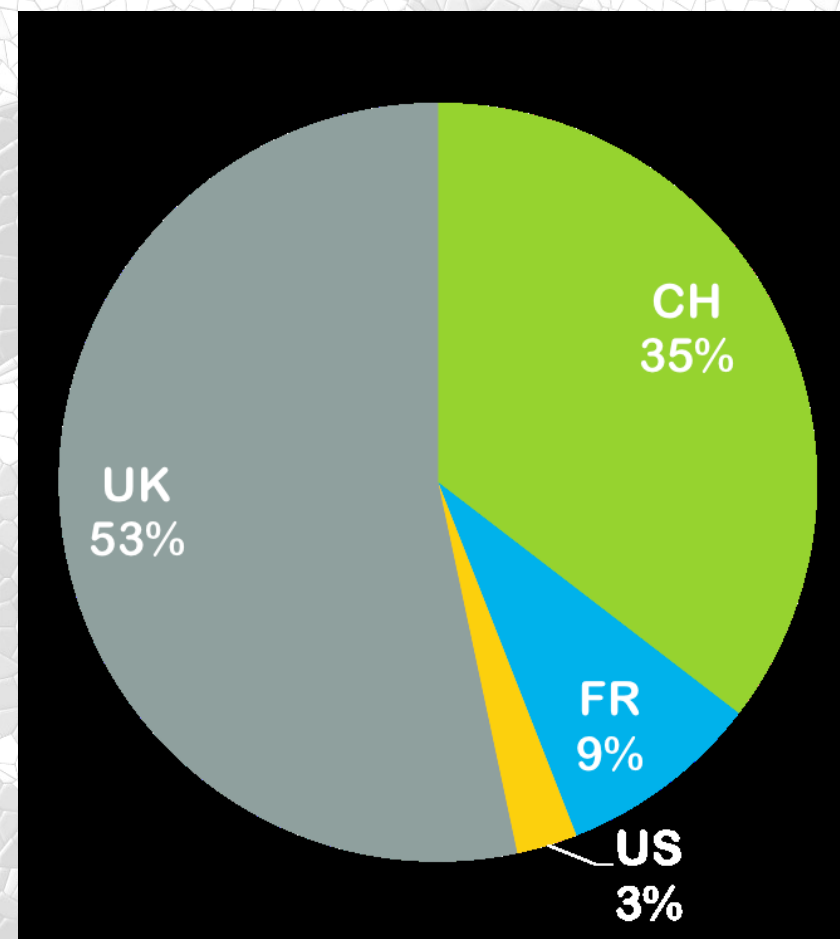
- Production is an worldwide effort
  - Success at the side, merging the two ILC VOs
- Using ILCDIRAC, already used for the CLIC CDR
  - Well tested system



# CPU time per Country



Total Storage: 127 TB in 2,681,083 Files



More details in Jan Strube's Talk





# SiD-related Talks at LCWS

- Tuesday 10/23

- 0900 MDI Update from SiD Marco Oriunno
- 1118 slic and lcsim Jeremy McCormick
- 1136 ALCPG software: status and future plans Norman Graf
- 1212 SiD DBD production (DIRAC) Jan Strube
- 1400 First results from Tungsten-DHCAL tests Jose Repond
- 1420 Micromegas/SDHCAL Andy White (for the LAPP group)

- Wednesday 10/24

- 0940 Measurement of the top Yukawa coupling at  $\sqrt{s} = 1$  TeV using the SiD Detector Philipp Roloff
- 1100 GEM/DHCAL status Seongtae Park





- Wednesday 10/24
  - 1440 SiD silicon-tungsten ECal and KPiX efforts Marty Breidenbach
  - 1500 DECAL using MAPS technology Tony Price
- Thursday 10/25
  - 0930 Current progress on SiD muon detection Gene Fisk
  - 1100 Combined detector performance in the SiD DBD Jan Strube
  - 1120 Occupancies from beam-related backgrounds in SiD at ILC and CLIC Christian Grefe
  - 1600 SiD DBD Tracking Performance Christian Grefe



- SiD DBD gives a detailed description of the current status
  - Just an overview given
- Significant progress since the LoI
  - Despite difficult funding climate
- Production is well under way
  - Updates are keep coming in
- SiD looks forward to the discussion with IDAG
- SiD is ready for the next phase