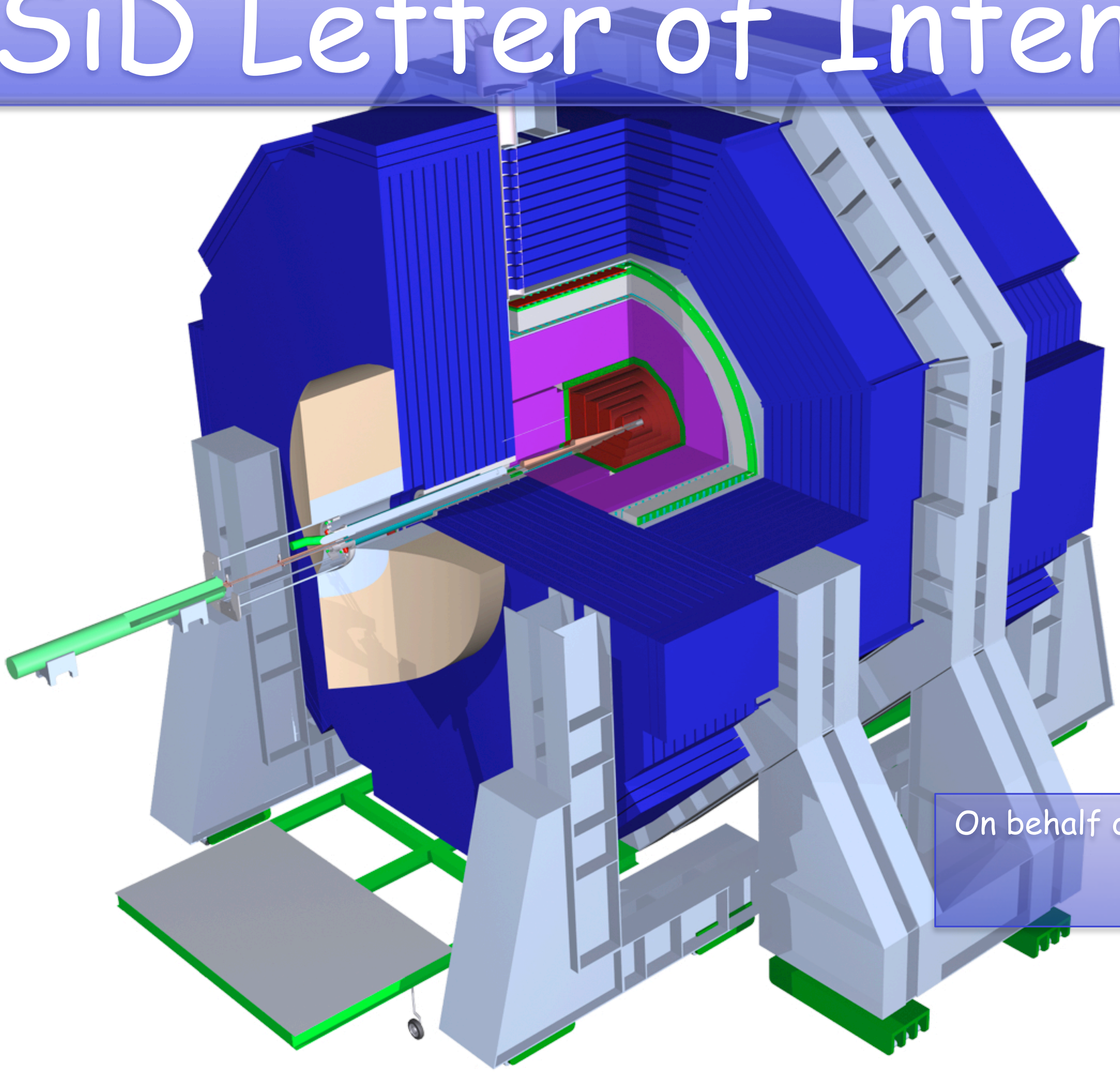
SiD Letter of Intent



On behalf of SiD concept group
Hiro Aihara
Univ. of Tokyo

Joint ACFA physics and detector workshop and the GDE meeting on
the International Linear Collider (TILC09), Tsukuba, Japan, April 17-21, 2009

SiD project definition

- Design an ILC general purpose detector that enables precision measurements on
  - Higgs boson properties,
  - Gauge boson scattering,
  - Effects resulting form extra dimensions,
  - Supersymmetric particles, and
  - Top quark properties.
- Challenges
  - Excellent mass resolution to measure recoil masses, kinematic edges and spectra
  - Flavor tagging capability based on a precision vertexing
  - Excellent hadronic (or jet) energy resolution capable of separating W(jj) from Z(jj)
  - Excellent hermeticity for missing-energy final states
  - Works in the ILC environment
- Who are we ? 234 authors, 77 institutes, 18 countries and up.

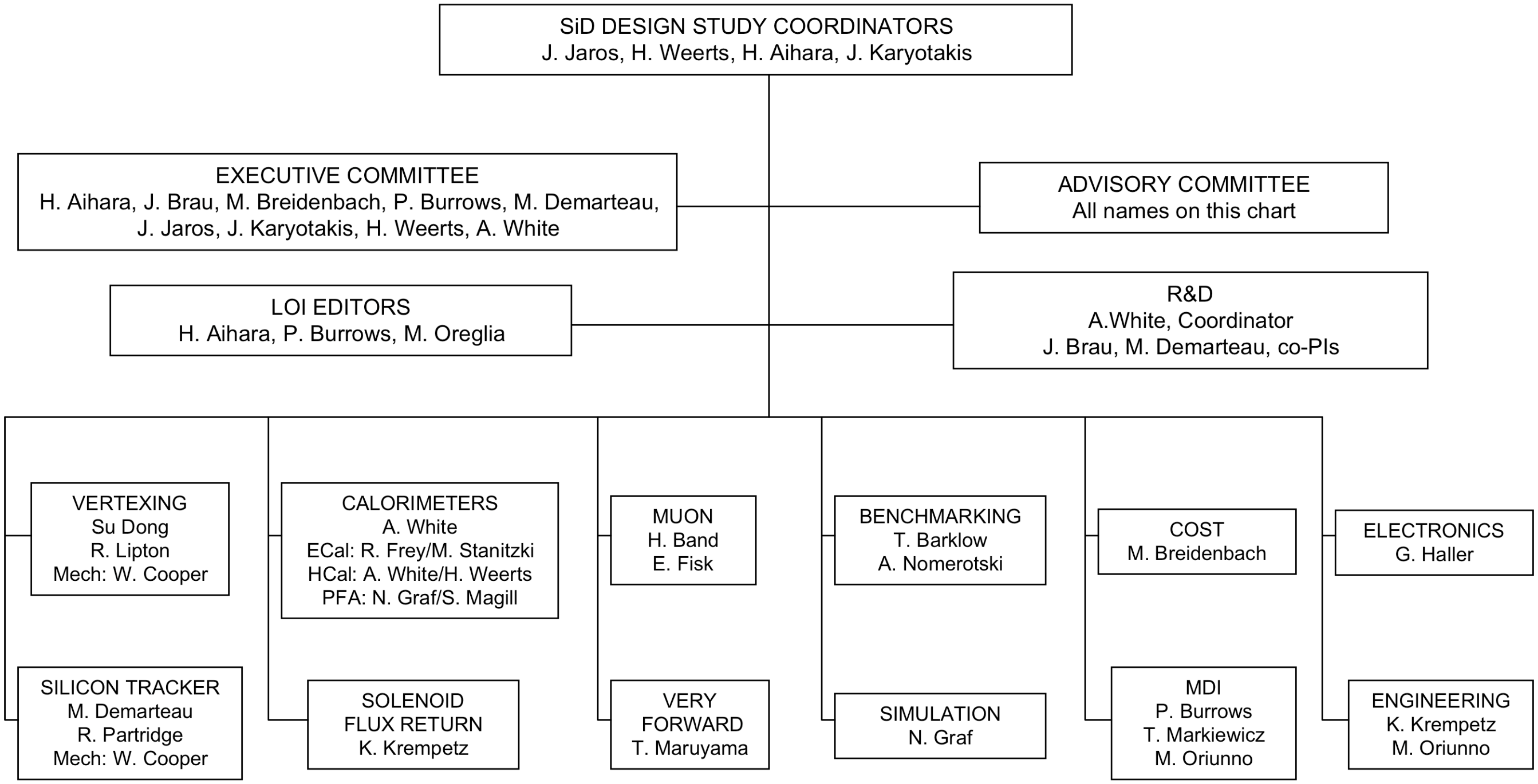
Universities

U. of Barcelona, Spain
U. of Bonn, Germany
Boston U.
Bristol U., UK
Brown U.
U. of California, Davis
U. of California, Santa Cruz
Caltech
Charles U., Prague, Czech
U. of Chicago
Chonbuk National U., Korea
U. of Colorado, Boulder
Colorado State U.
Cornell U.
U. of Delhi, India
Imperial College, London, UK
Ewha Woman's U. Korea
Ghent U., Belgium
Gomel State Tech. U., Belarus
U. of Hawaii
U. of Helsinki, Finland
Indiana U.
U. of Iowa
Kansas State U.
Kyungpook National U., Korea
Louisiana Tech University
Massachusetts Institute of Technology
U. of Massachusetts
U. of Melbourne, Australia
U. of Michigan
U. of Minnesota
U. of Mississippi
U. of Montenegro, Montenegro
Moscow State U. ,Russia
Nanjing U. ,China
U. of New Mexico
Northern Illinois U.
U. of Notre Dame
Obninsk State U. for Nucl. Power Eng., Russia
U. of Oregon
Oxford U., UK
U. of Pierre and Marie Curie LPNHE, France
Princeton U.
Purdue U.
Universitat Ramon Llull, Spain
U. of Rochester
Seoul National U., Korea
State U. of New York, Stony Brook
U. of Santiago de Compostela, Spain
U. of Science and Technology, China
U. of Texas, Arlington
U. of Texas, Dallas
U. of Tokyo, Japan
U. of Washington
Wayne State U.
U. of Wisconsin
Yale U.
Yonsei U. Korea

Laboratories and Institutes

Argonne National Laboratory
Institute of Microelectronics of Barcelona, Spain
Birla Institute for Technology and Science, India
Brookhaven National Laboratory
CEA-Saclay, France
CERN, Switzerland
Fermi National Accelerator Laboratory
GSI, Germany
IHEP, China
Institute of Nuclear Research, Hungary
Instituto de Fisica Corpuscular, Spain
Institute de Fisica de Cantabria, Spain
IPHC-IN2P3/CNRS, France
Institute of Physics, Prague, Czech
Irfu, CEA/Saclay< France
LAPP, CNRS/IN2P3 Université de Savoie, France
LPNHE, CNRS/IN2P3 Universites Paris VI et Paris VII, France
IPPP, UK
Lawrence Livermore National Laboratory
Max Planck Institute, Munich, Germany
Molecular Biology Consortium
Physical Sciences Laboratory, Wisconsin
Rutherford Appleton Laboratory, UK
SLAC National Accelerator Laboratory

SiD Organization Chart



SiD DESIGN STUDY COORDINATORS
J. Jaros, H. Weerts, H. Aihara, J. Karyotakis

EXECUTIVE COMMITTEE
H. Aihara, J. Brau, M. Breidenbach, P. Burrows, M. Demarteau,
J. Jaros, J. Karyotakis, H. Weerts, A. White

ADVISORY COMMITTEE
All names on this chart

LOI EDITORS
H. Aihara, P. Burrows, M. Oreglia

R&D
A.White, Coordinator
J. Brau, M. Demarteau, co-PIs

VERTEXING
Su Dong
R. Lipton
Mech: W. Cooper

SILICON TRACKER
M. Demarteau
R. Partridge
Mech: W. Cooper

CALORIMETERS
A. White
ECal: R. Frey/M. Stanitzki
HCal: A. White/H. Weerts
PFA: N. Graf/S. Magill

SOLENOID
FLUX RETURN
K. Krempetz

MUON
H. Band
E. Fisk

VERY
FORWARD
T. Maruyama

BENCHMARKING
T. Barklow
A. Nomerotski

SIMULATION
N. Graf

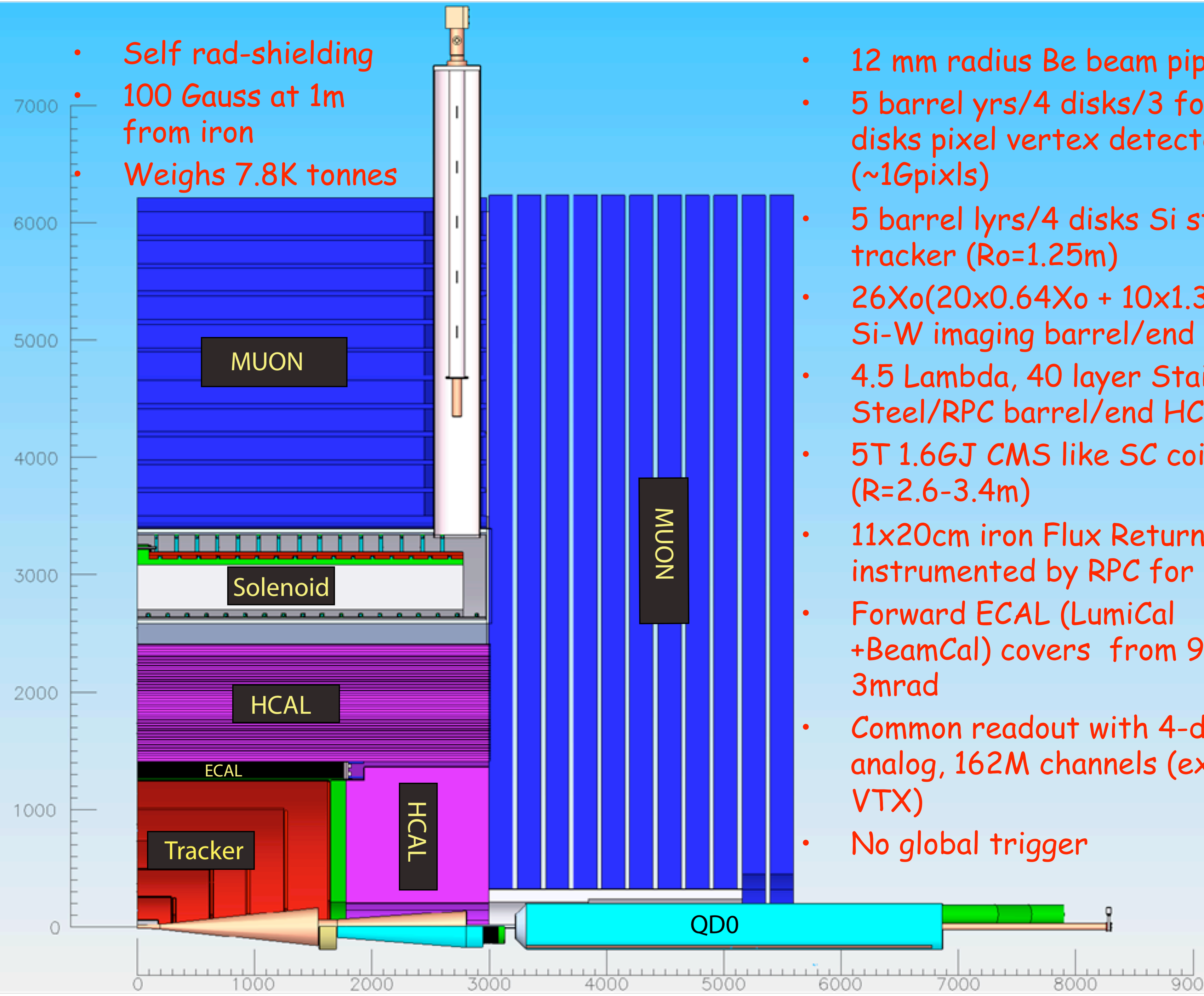
COST
M. Breidenbach

MDI
P. Burrows
T. Markiewicz
M. Oriunno

ELECTRONICS
G. Haller

ENGINEERING
K. Krempetz
M. Oriunno

SiD was initiated in 2004 at Victoria LCWS, produced DOD in 2006 and was reviewed in 2007 by WWS.



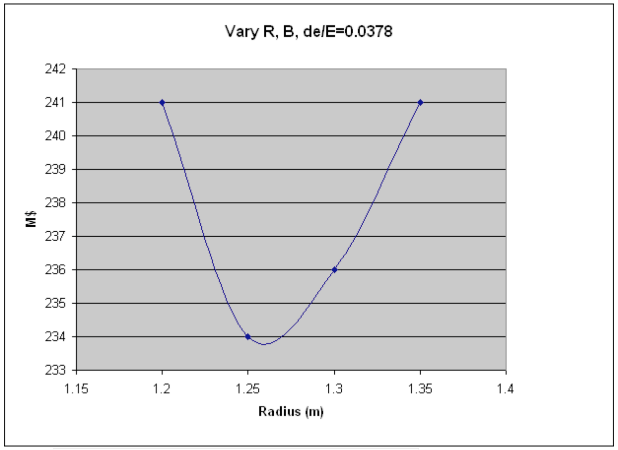
- Self rad-shielding
- 100 Gauss at 1m from iron
- Weighs 7.8K tonnes

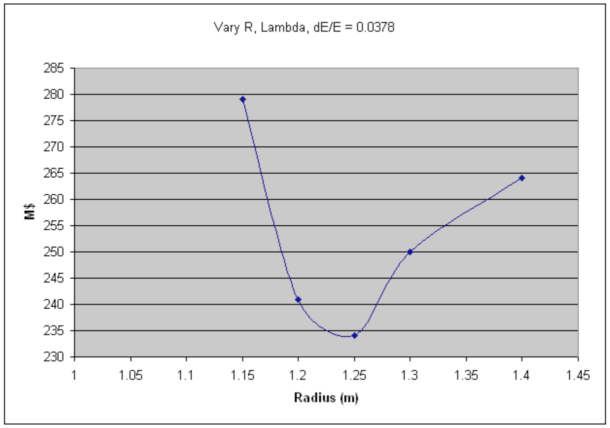
- 12 mm radius Be beam pipe
- 5 barrel yrs/4 disks/3 foward disks pixel vertex detector (~1Gpixls)
- 5 barrel lyrs/4 disks Si strip tracker (Ro=1.25m)
- 26Xo(20x0.64Xo + 10x1.3Xo) Si-W imaging barrel/end ECAL
- 4.5 Lambda, 40 layer Stainless Steel/RPC barrel/end HCAL
- 5T 1.6GJ CMS like SC coil (R=2.6-3.4m)
- 11x20cm iron Flux Return instrumented by RPC for muons
- Forward ECAL (LumiCal +BeamCal) covers from 90 to 3mrad
- Common readout with 4-deep analog, 162M channels (excl. VTX)
- No global trigger

Detector optimization

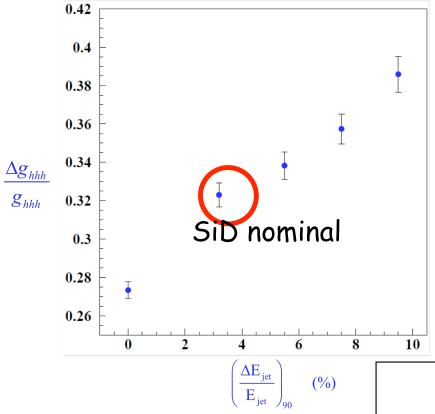
- Calorimeters (and a solenoid) is costly and their design determines the global parameter of the detector.
- The cal performance/cost critically depend on how far they are placed from the IP and how thick they must be.
- Therefore, to a large degree, the system optimization reduces to optimization of the parameters of the calorimeters (and a solenoid).
- SiD uses a parametric model for cost vs global parameters and a model to estimate the jet energy/momentum/impact parameter resolutions as a function of global parameters (derived from a full simulation). Based on these tools, for each jet resolution, we find the global parameters that give the lowest cost.
- Using a fast MC simulation we physics performance vs jet energy resolution, and therefore, we find physics performance vs minimum cost.

Detector optimization (example plots) via PFA jet energy





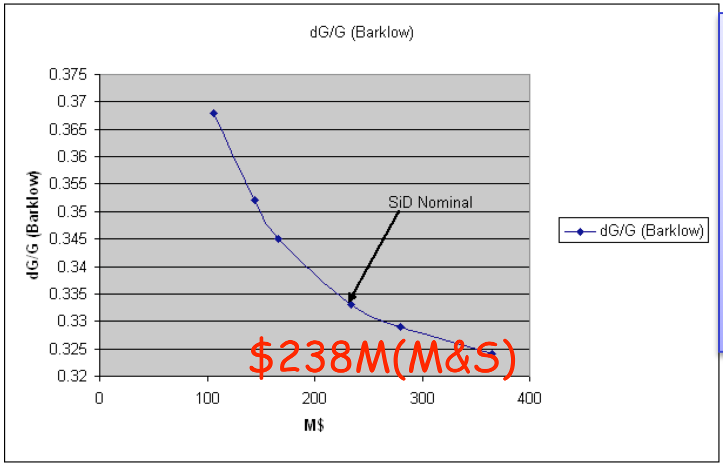
For a fixed jet energy resolution of 4%



SiD nominal

Physics performance vs jet energy resolution

Fractional error of triple Higgs coupling measured from sqrt(s)=500 GeV ZHH(qqqqbb)



$238M(M&S)

R=1.25m,
ECAL=26Xo (1lambda)
HCAL=4.5 lambda deep
B=5T
Flux return iron=2.2m thick

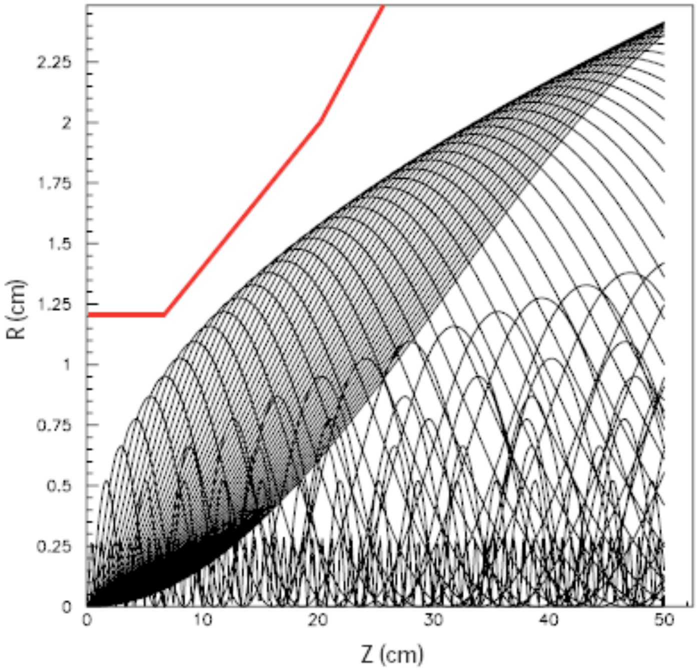
Detector Optimization via vertex/tracker

- ILC environment
  - 5 Hz bunch trains, each containing 2625 bunches, separated by 369.2ns
  - Severe beam-related background anticipated

Background sources for the nominal ILC 500 GeV beam parameters.

Source	#particles/bunch	< E> (GeV)
Disrupted primary beam	2×10^{10}	244
Beamstrahlung photons	25×10^{10}	4.4
e^+e^-pairs from beam-beam interactions	75K	2.5
Radiative Bhabhas	320K	195
$\gamma\gamma \rightarrow$ hadrons/muons	0.5 events/1.3 events	-

To be immune to backgrounds/pileups,
make the tracking/Ecal only
sensitive to single bunch crossings.
+SLC experience
"Silicon sensors in a high solenoid field"
Hits are recorded in 4-deep channel-by-
channel buffers.
(The vertex detector may not need single
bunch time stamps.)

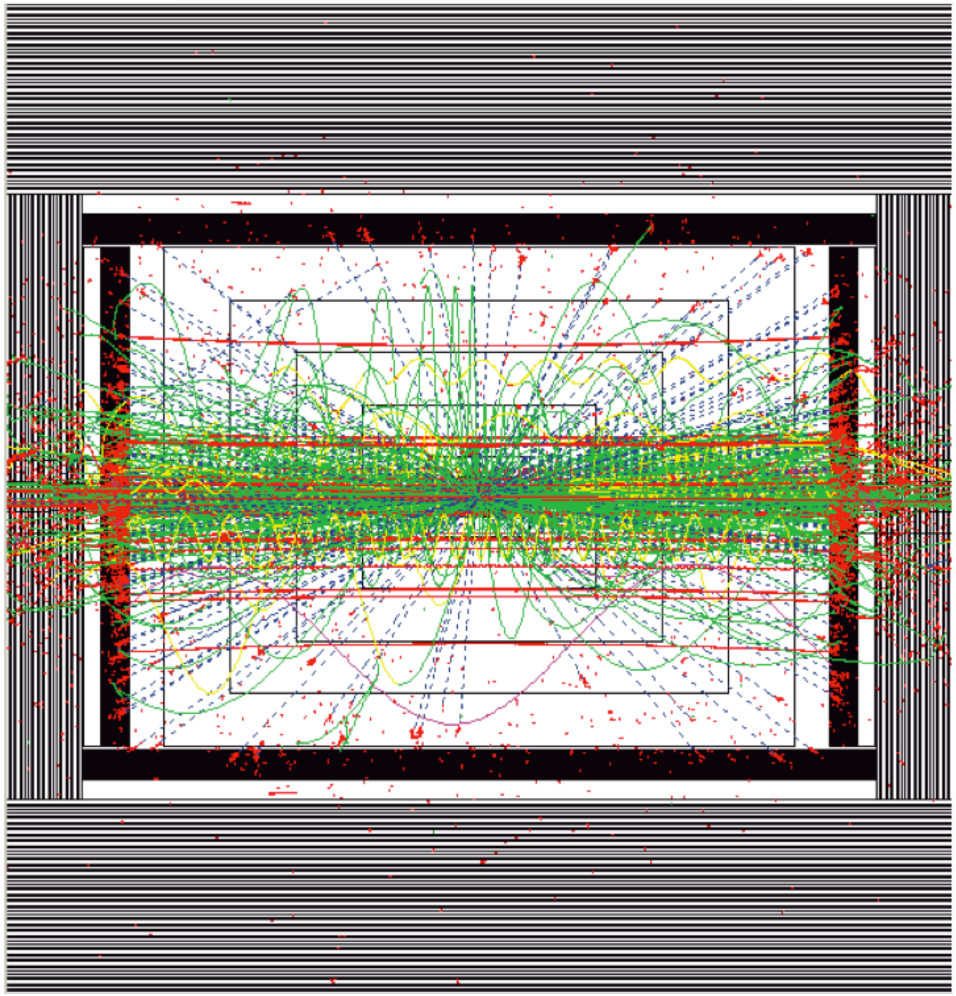


Envelope of pair backgrounds
in 5T for ILC "nominal" parameters.

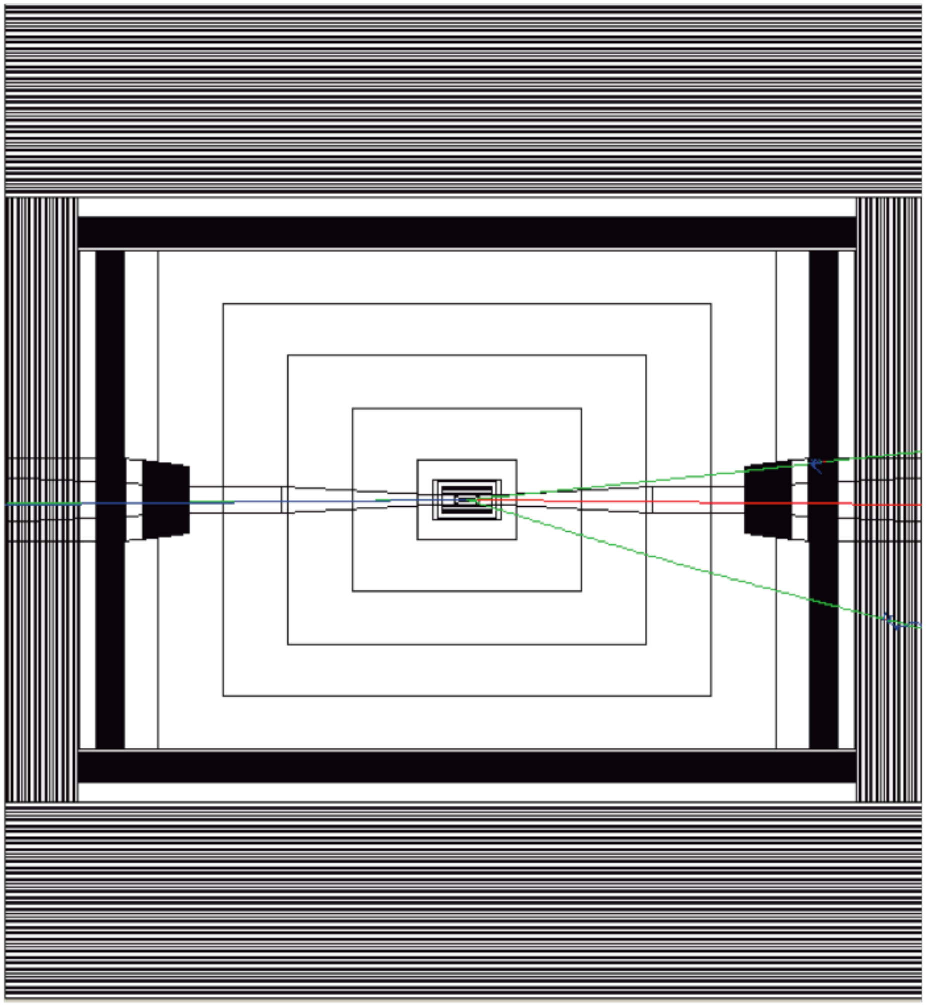
Low-P (low beam power option) is
not compatible with our baseline
parameters.

Detector optimization

150 bunches integrated



Time-stamped single bunch crossing

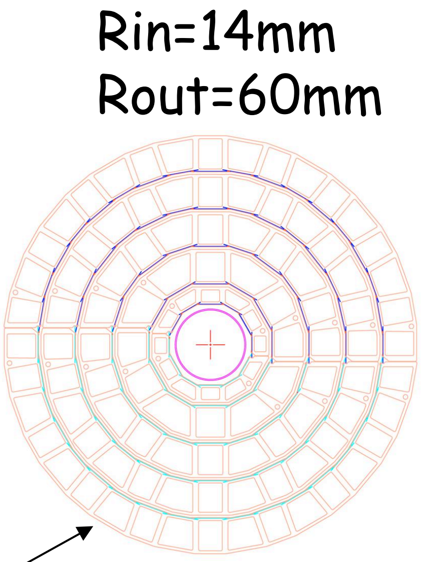


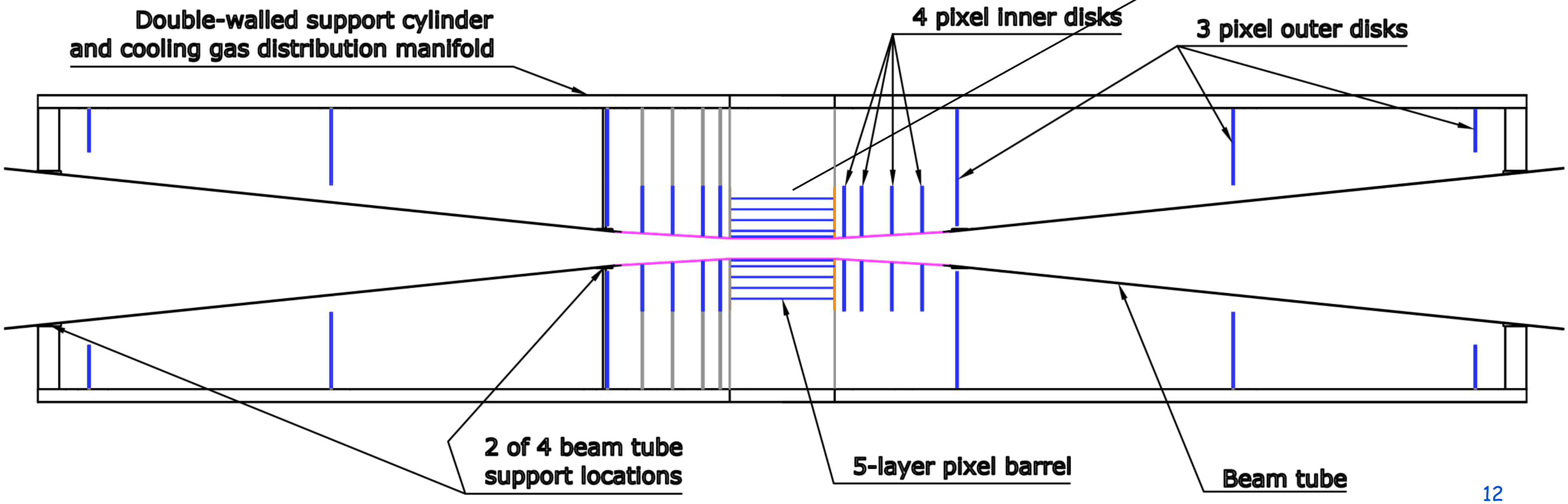
SiD

Highlights of Subsystem and R&D issues

Vertex Detector

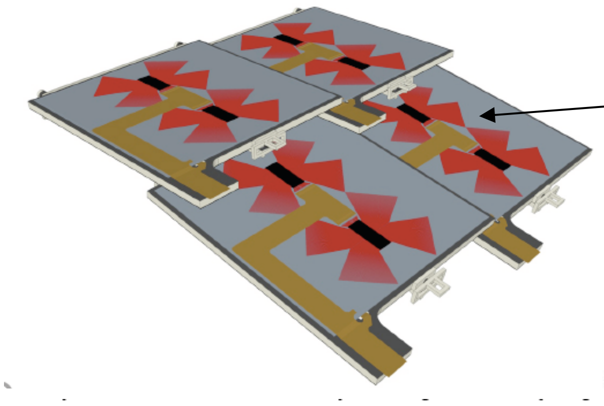
- Gas cooled (Barrel 20Watts)
- Power pulsed (Barrel:100:1 duty factor, 2000Watt peak load =1.5Vx1333A)=> a serial powering/DC-DC(HV->LV) conversion
- low mass system (0.1% X_0 / layer)
- Sensor technology : SiD directly working on 3D, Chronopix, and DEPFET sensors. Cronopix and 3D options have full single bunch crossing time stamping capability.
- Support structure: Sensors themselves form a support structure; sensors of each barrel layer are glued along their edges to form a cylinder. How to replace it if a sensor(s) failed ?



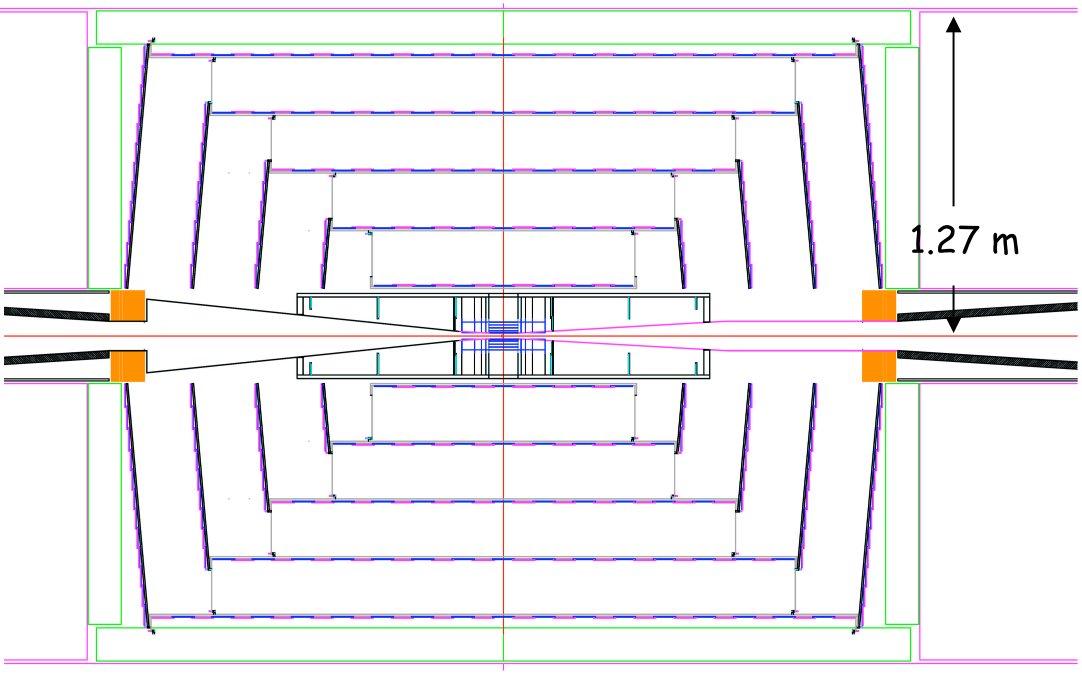


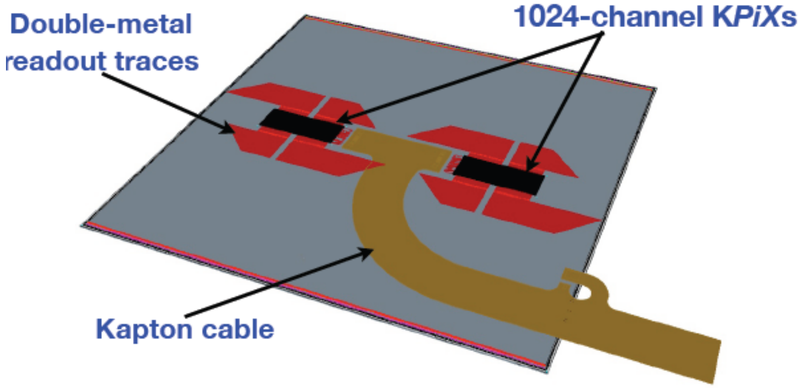
Si-strip Tracker

~100 m² Si Strips: Barrel single sided (r-φ); endcaps double sided



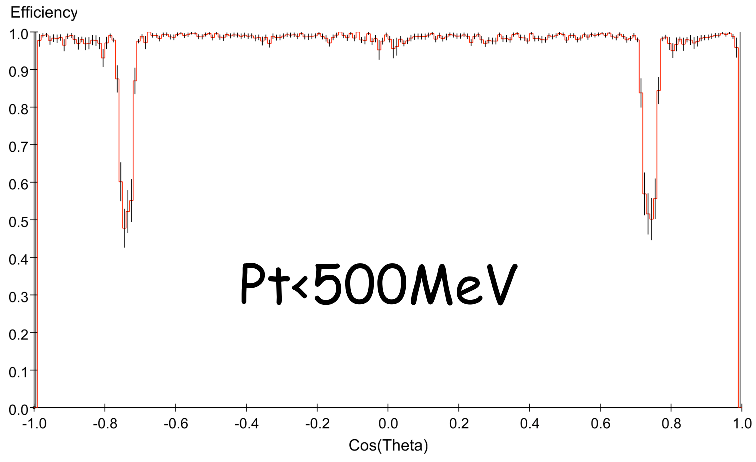
Modular low mass sensors tile CF cylinders



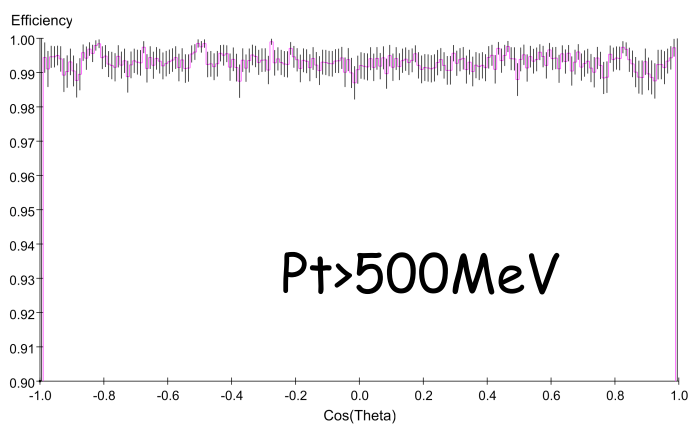


~10 cm x 10 cm; 320 μm thick; 25 μm sense pitch; 50 μm readout (prototype fabricated);
S/N > 20; <5 μm hit resolution
Bump bonded readout with 2 KPiX chip; no hybrid
KPiX measures amplitude and bunch # in ILC train, up to 4 measurements per train
Pulsed Power: 20 μW/channel avg; ~600 W for 30 M channels; gas cooling

Performance forecast : Integrated Vertex+Tracker tracking



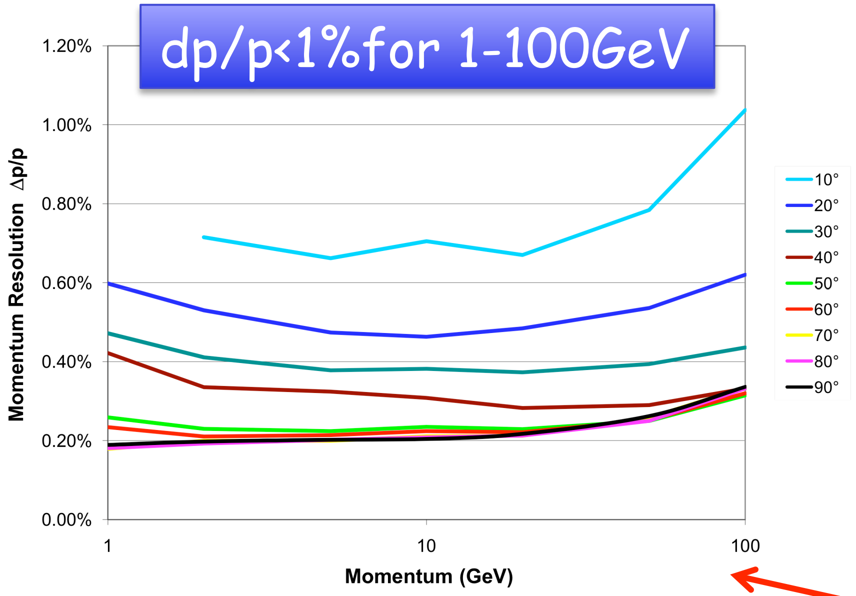
Pt<500MeV



Pt>500MeV

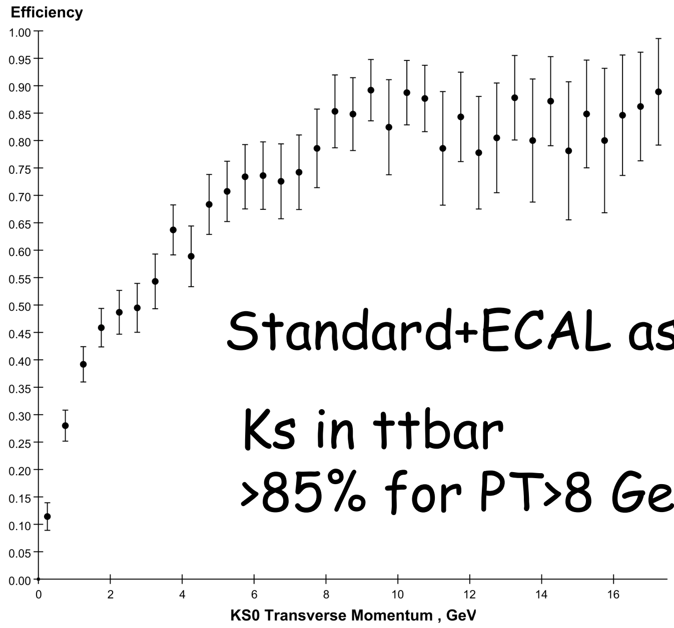
>99%

Track finding eff. ttbar @500GeV CMS



dp/p<1%for 1-100GeV

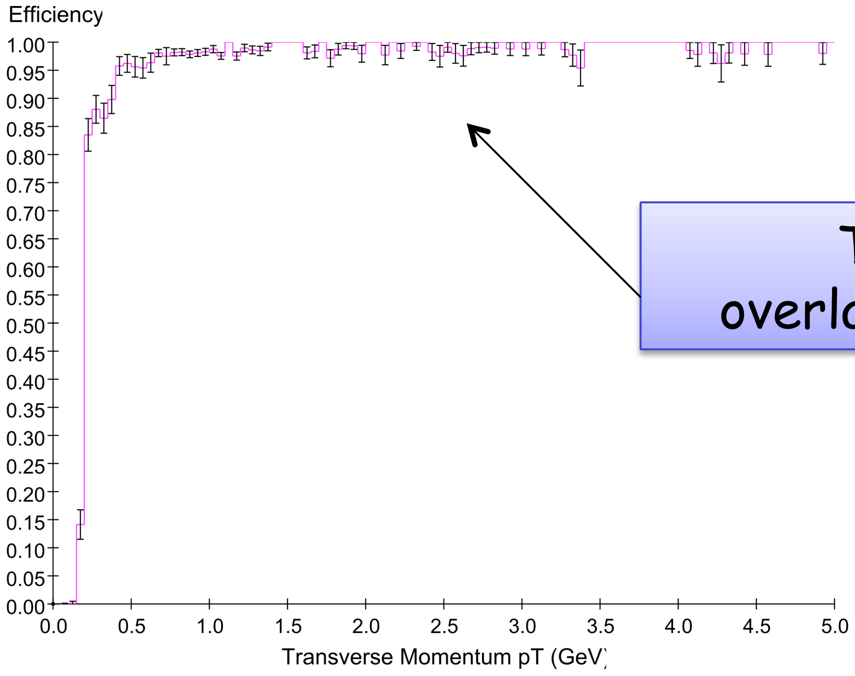
Impact parameter resolution ~4micron



Standard+ECAL assisted

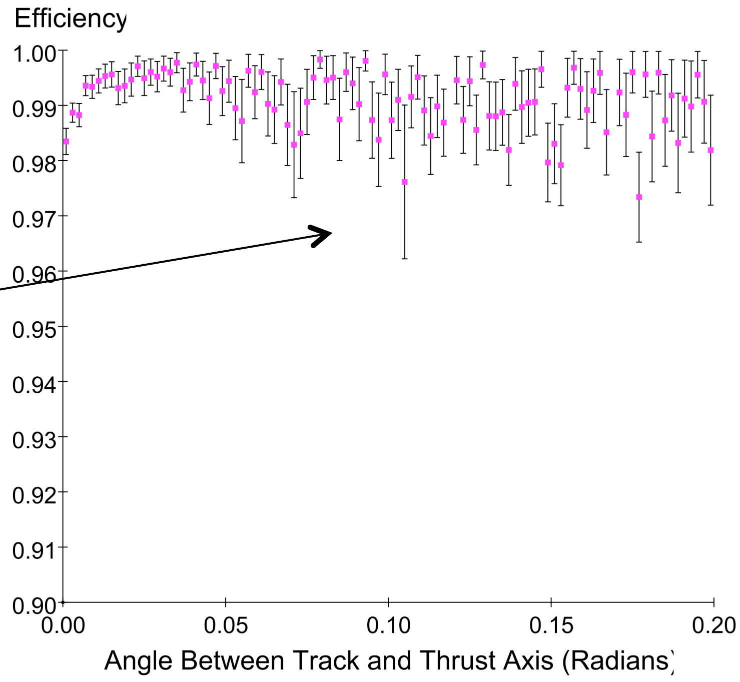
Ks in ttbar
>85% for PT>8 GeV

Further Performance forecast : Vertex+Tracker tracking



Tracking eff. for bbbar@500GeV
overlaid with 10 bunch crossing background

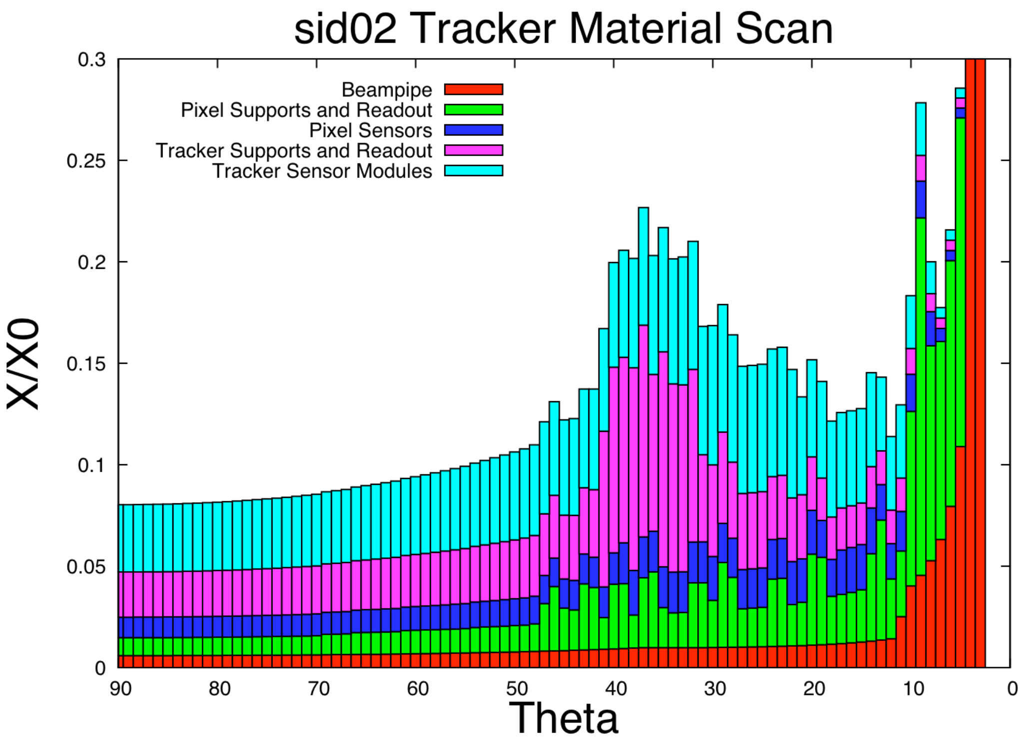
98%



Tracking efficiency vs angle from
the thrust axis for qqbar @1TeV

R&D issues

- Engineering low-mass vertex tracking system
- cooling
- pulsed power operation
    - vibration due to Lorentz force in 5T
- More detailed tracking performance studies
    - Effect of non-uniform B (6% Bz drop at the end)
    - failure mode analysis



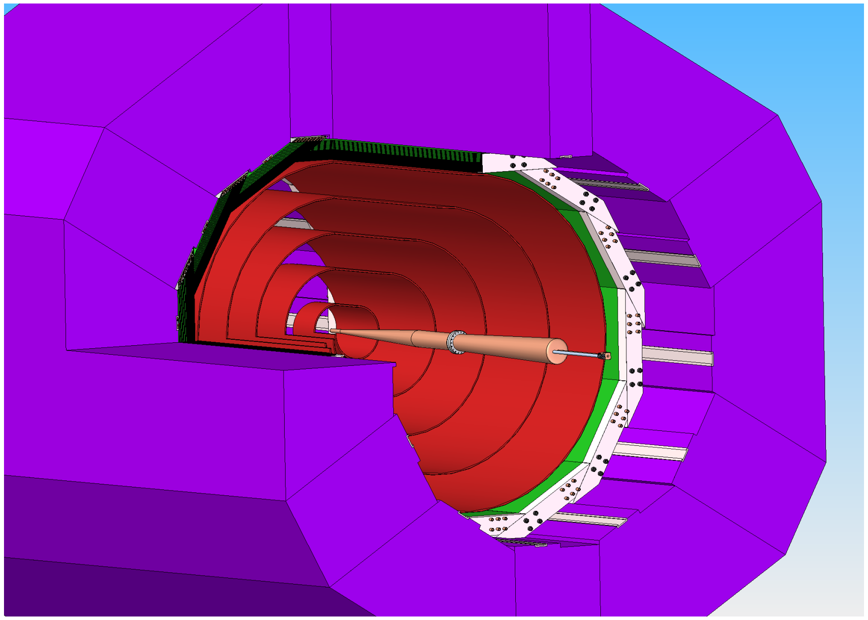
Tracking algorithm requires 7 hits out of 10. So, one hit less will not degrade the performance very much. More study necessary for low pT tracks or those that have fewer than 10 "true" hits because of decays, secondary interactions, or V tracks.

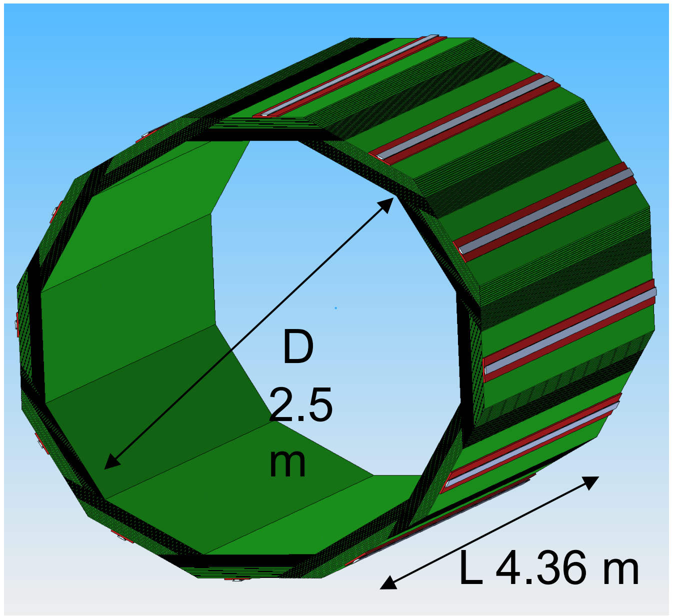
- in-situ alignment via Frequency scanning interferometry and/or Infrared Transparent Silicon Sensors

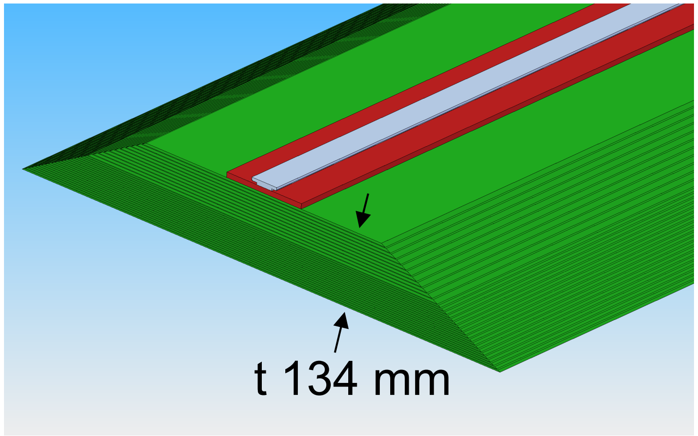
Would probably require an engineering prototype in 5T magnet as the 2007 ILC Tracking R&D Review Committee pointed out.

Si-W sampling/imaging ECAL

- 20 layers 2.5 mm W (5/7 X_0)
- 10 layers 5 mm W (10/7 X_0)
- 30 gaps 1.25 mm Si pixels sensors
- 26 X_0; 1 lambda
- $\Delta E/E = 17\%/\mathrm{sqrt}(E)$;
- Effective Moliere radius = 14 mm (Key for imaging)



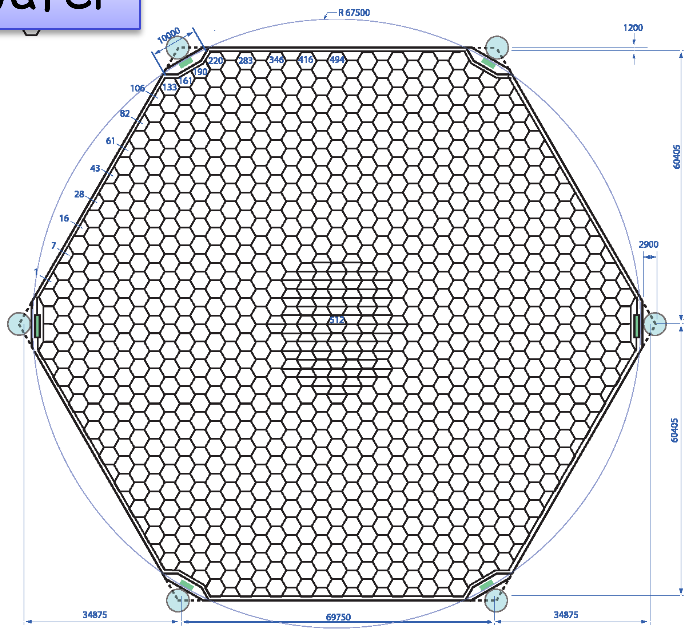


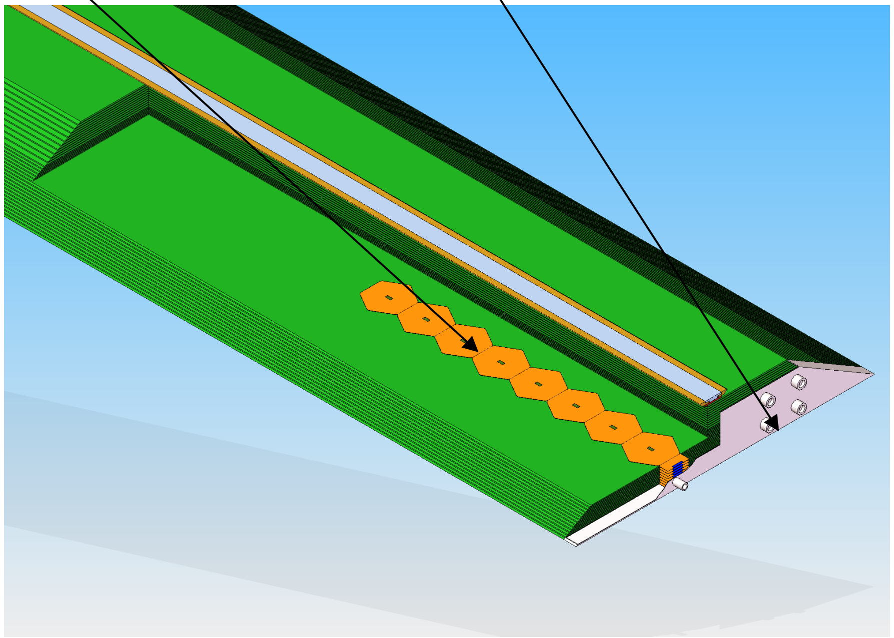


Baseline ECAL active layer

- Layers are tiled with hexagonal sensors, 1024 13 mm^2 pixels/sensor.
- Kapton bus cables take digital data; power; bias; and control to/from end concentrators.
- ~100M readout channels
- Pulsed power; 115 W / barrel module; fluid cooled from edge

6inch wafer

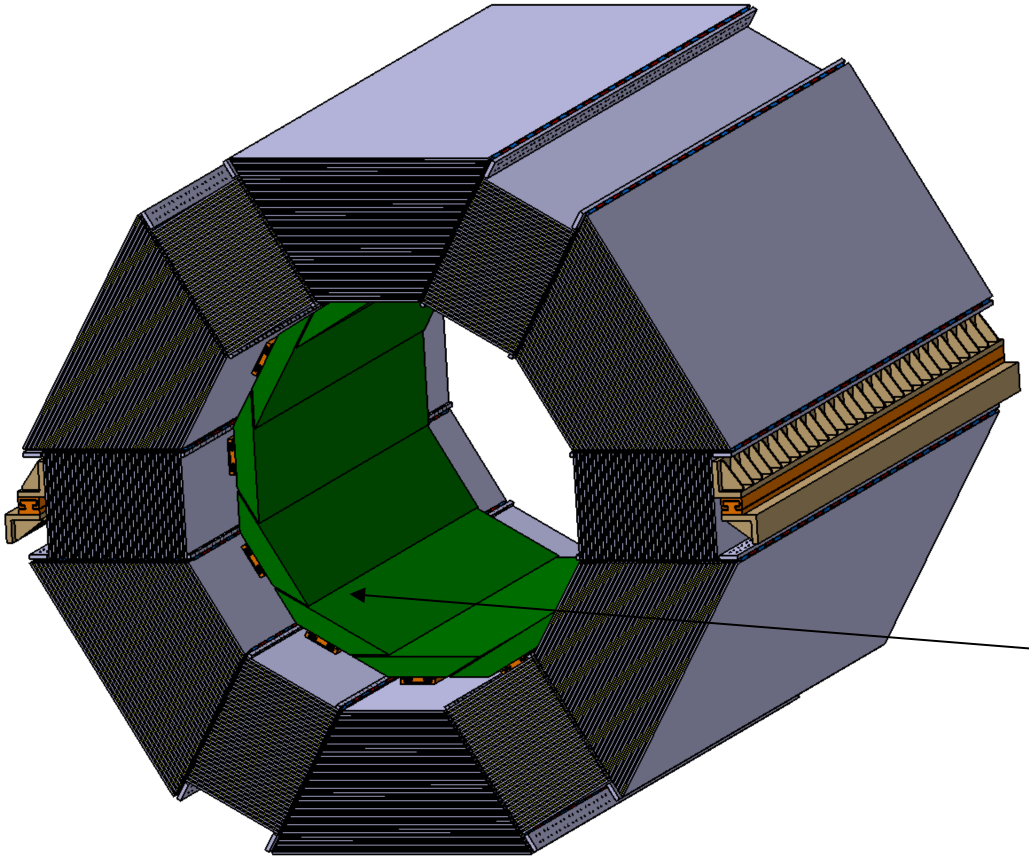




Digital ECAL based on the CMOS-based Monolithic Active Pixel Sensors (MAPS) with 50micron x 50 micron pixels has also been pursued.

Stainless Steel-RPC sampling HCAL

- 4.5 lambda Stainless Steel Absorber
- 40 Layers Glass RPC's w 1 cm^2 pixels (~35M readout channels)



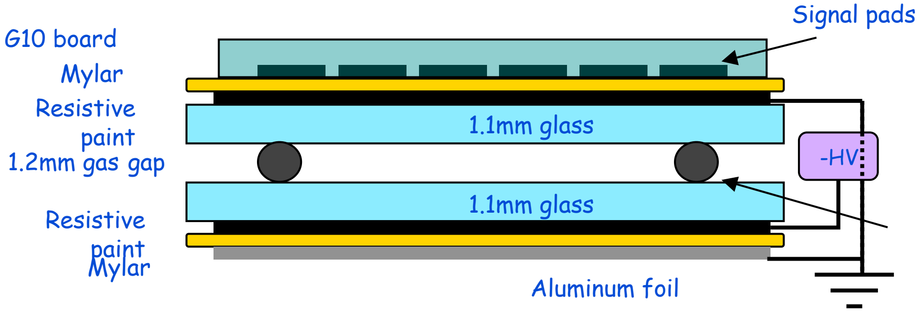
12 non-projective crack modules

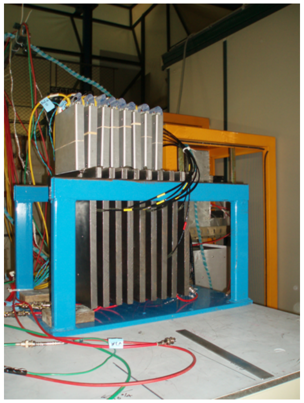
Support from inner cryostat

Electromagnetic Calorimeter

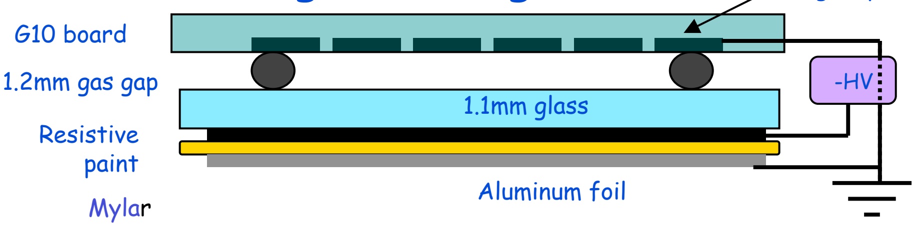
Baseline HCAL active layer : Glass Resistive Plate Chambers

Two-glass design





One-glass design



Vertical Slice Test

Cosmics, FNAL Test Beam

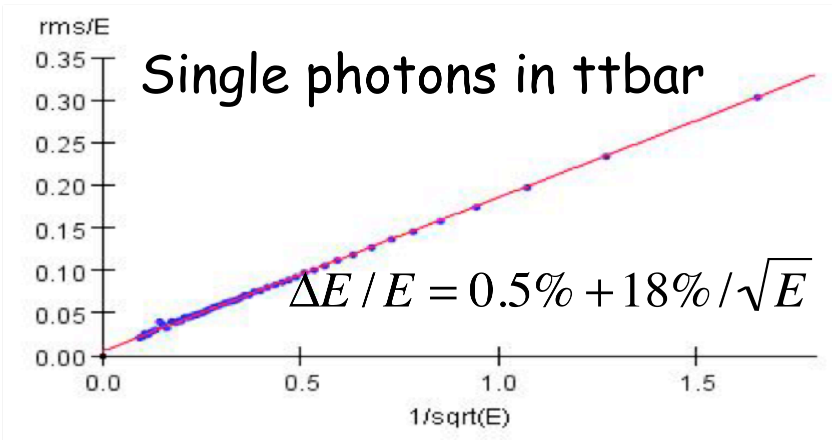
No long term degradation with either design

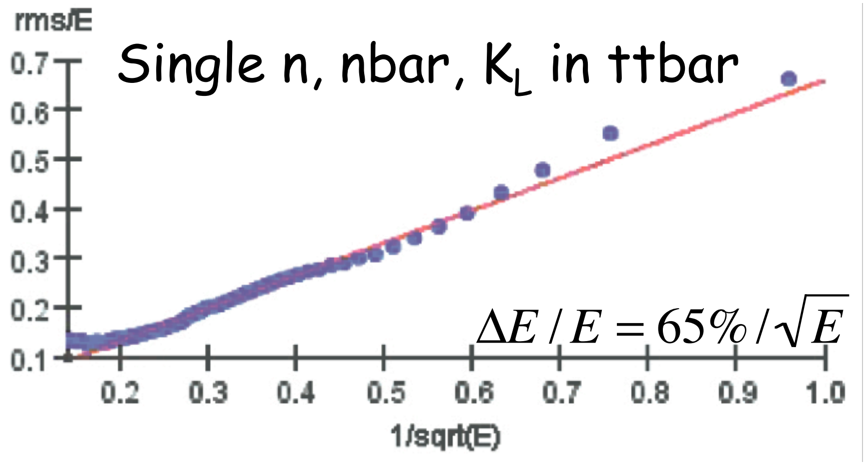
Large RPC's: 32 x 96 cm^2 corresponding to 3072 channels

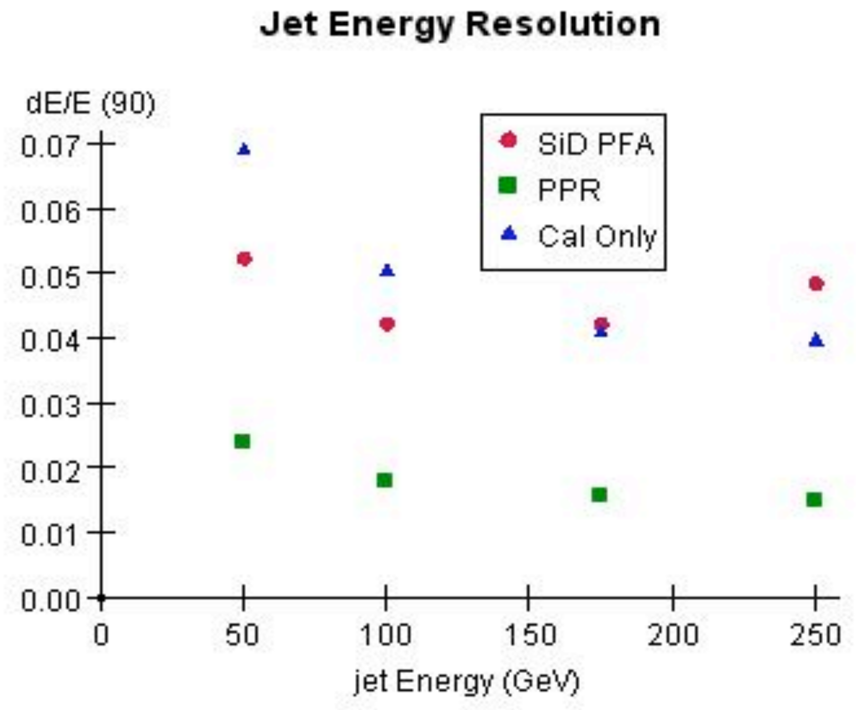
1st prototype assembled and being tested

GEM, MICROMEGAS and scintillator as active layer have been pursued.

ECAL+HCAL PFA performance forecast

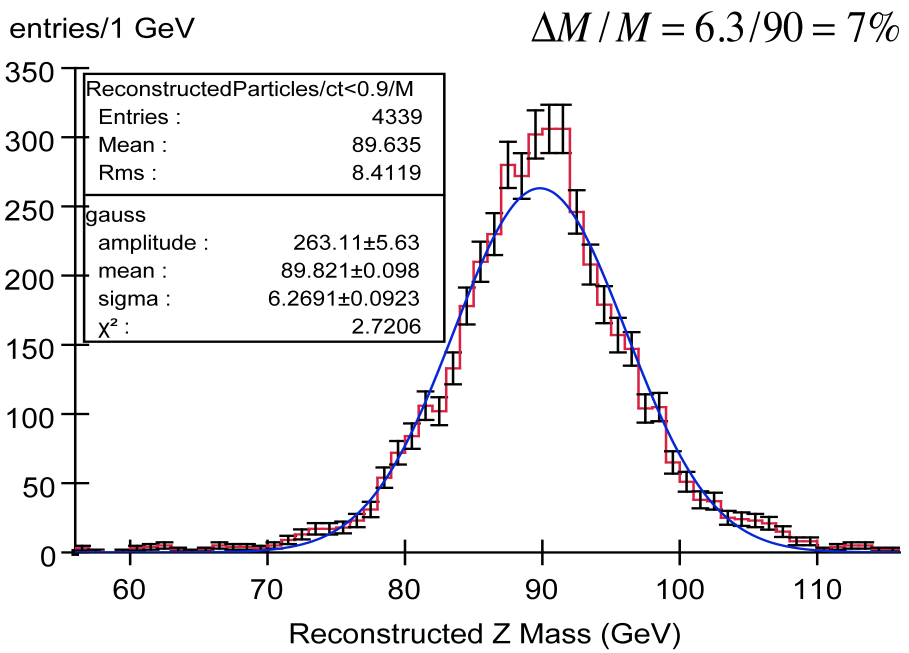






Dijets at 100-500GeV CMS

500 GeV e+e- -> ZZ -> nunuqq, q = uds



- Our PFA performance is still limited by pattern recognition (i.e. confusion between neutrals and track ionizations in CAL).

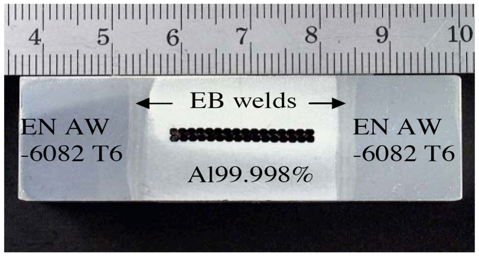
- Leakage from the back can be compensated by muon detectors in forward regions (not in barrel) if required.

- Further improvement on PFA is expected.

- A non-PFA CAL, based on the dual readout, is under investigation for the beyond-500 GeV ILC.

SiD Magnet

Magnet is a cost driver. >$100M
R&D to make it less costly.

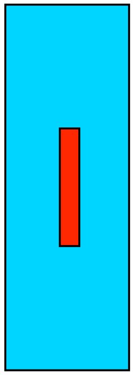


The CMS conductor is the baseline.
Proven, but difficult and expensive because of on site e-beam welding.

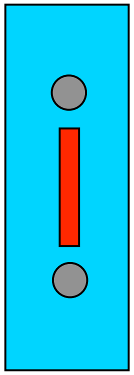
GOAL: Develop a different conductor that is easier and cheaper.

Two Possible Advanced Conductors

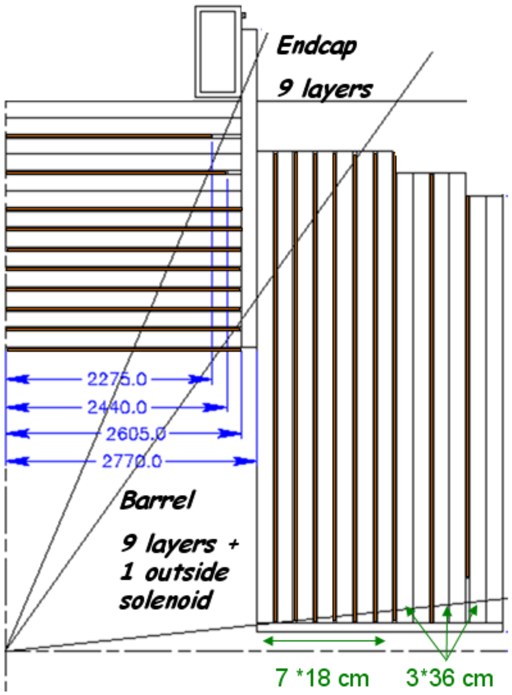
Use a uniform dilute aluminum alloy or a high purity aluminum matrix composite.



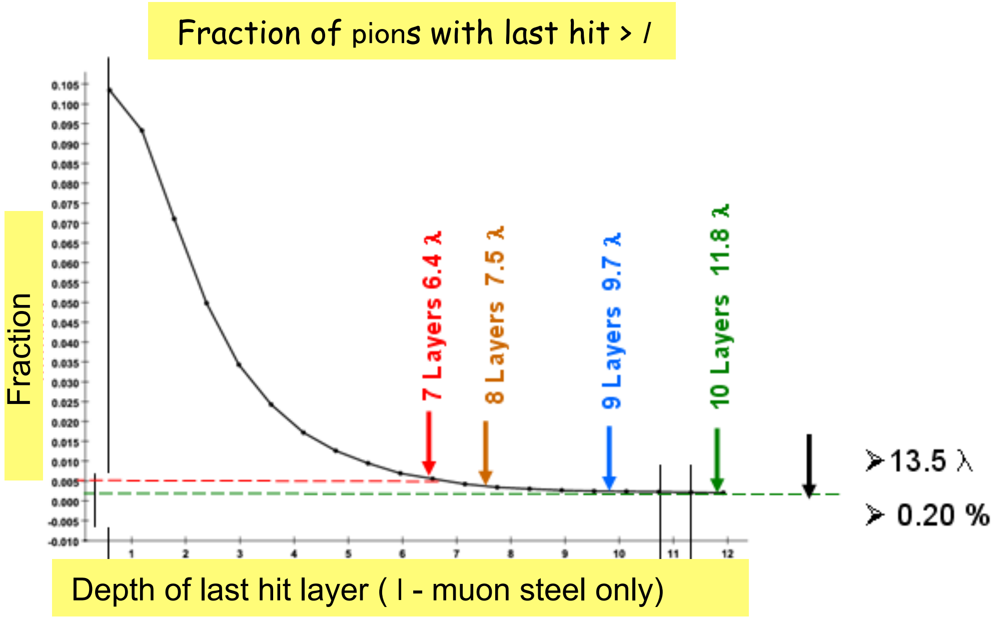
Add reinforcing Inconel cables to the stabilizer.



Muon /Flux Return

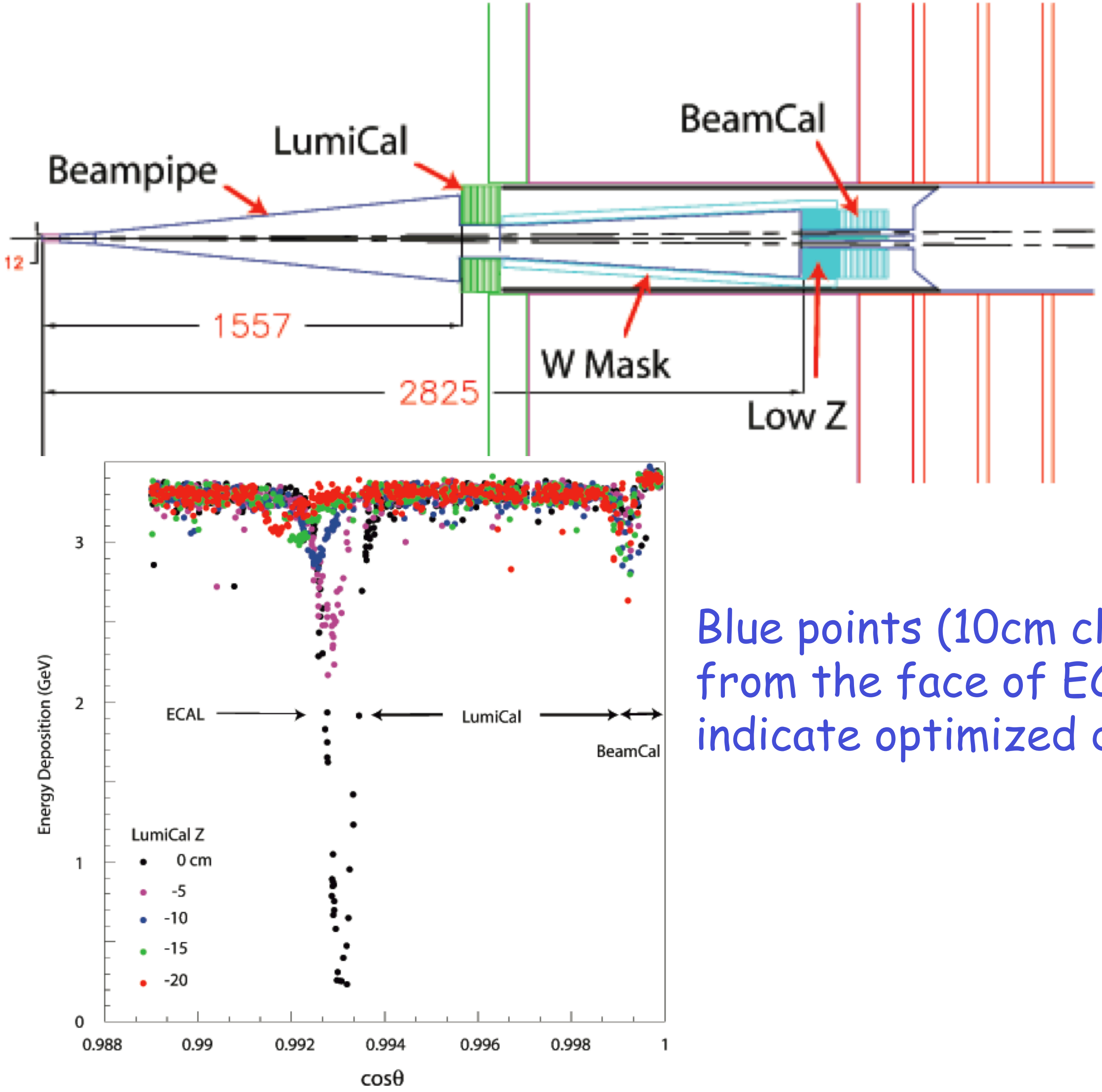


- 11 layers
- ECAL + HCAL + Solenoid = 5.5 lambda
- Muon = 13 lambda
- Study of pion misidentification vs cut on penetration depth in steel flux return, 10<p<50 GeV/c - flat distribution

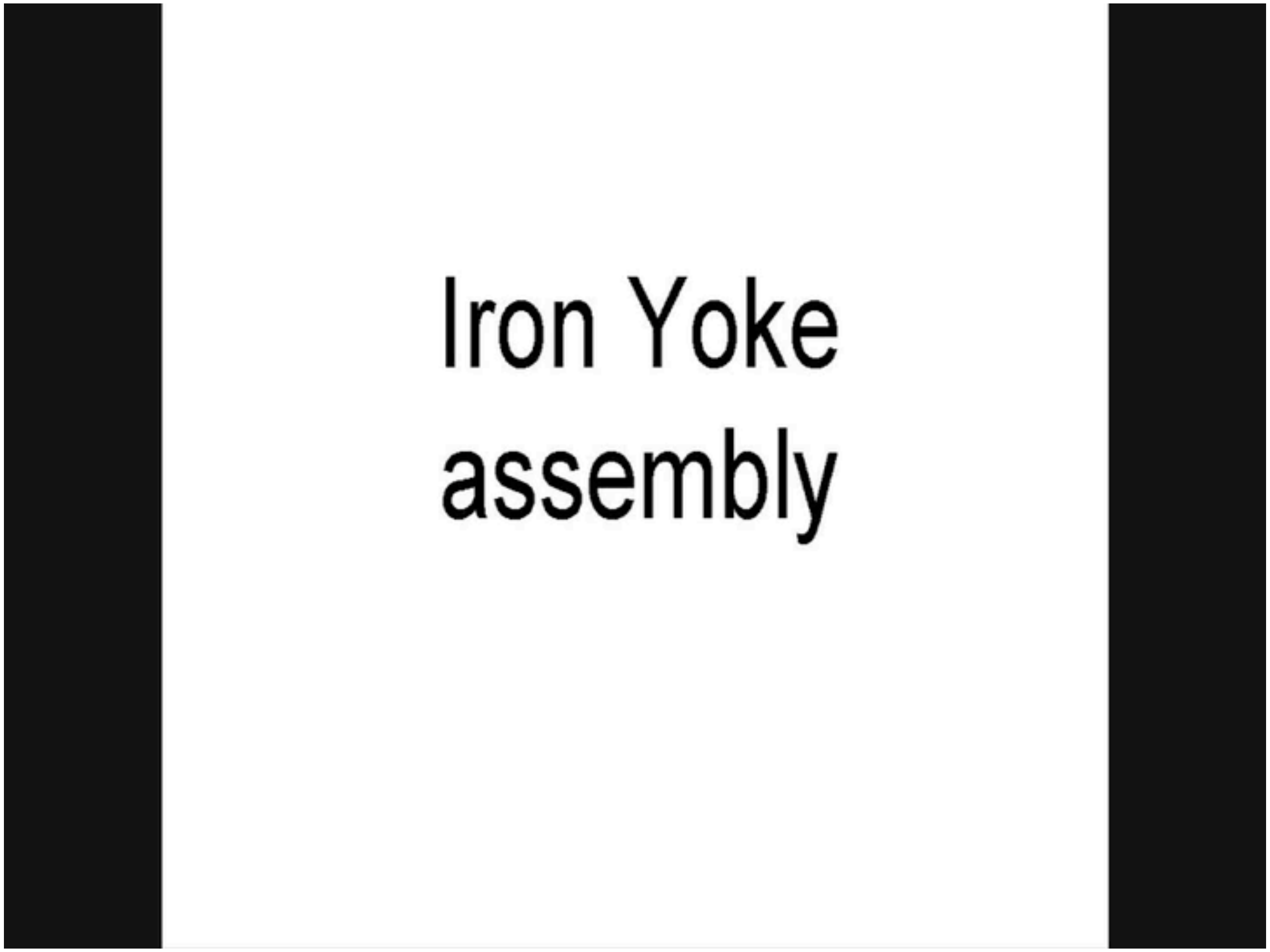


- Steel thickness determined by flux return requirements
- Modest detector resolution needs can be met by scintillator strips or RPCs

Forward Detector

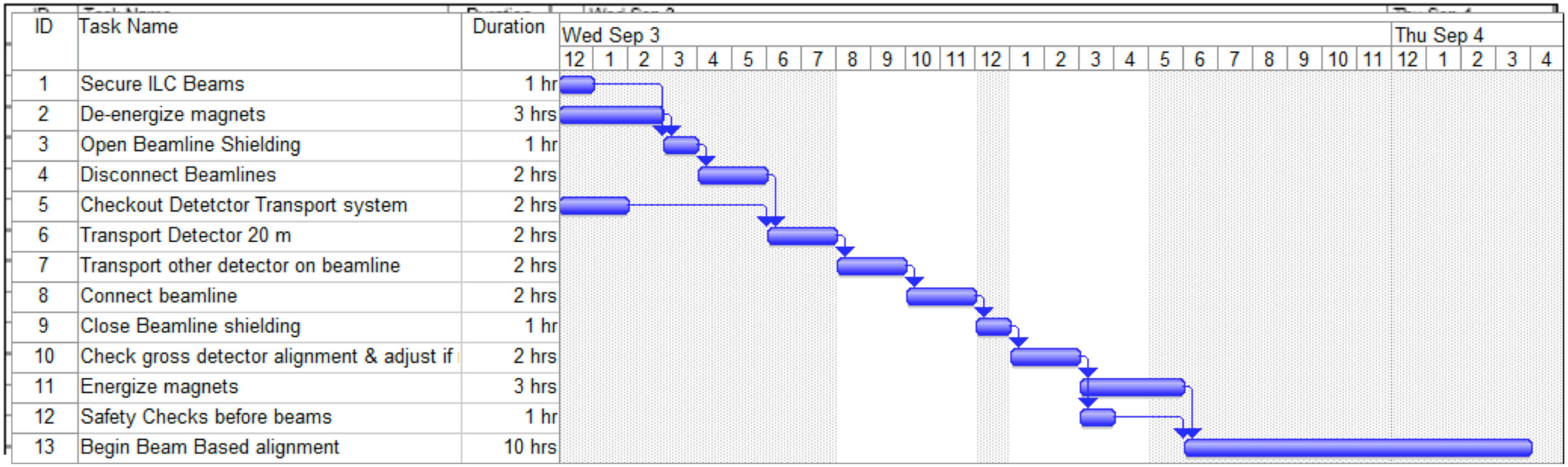


Blue points (10cm closer to IP from the face of ECAL) indicate optimized design.



Iron Yoke assembly

One-day Push-Pull Operation



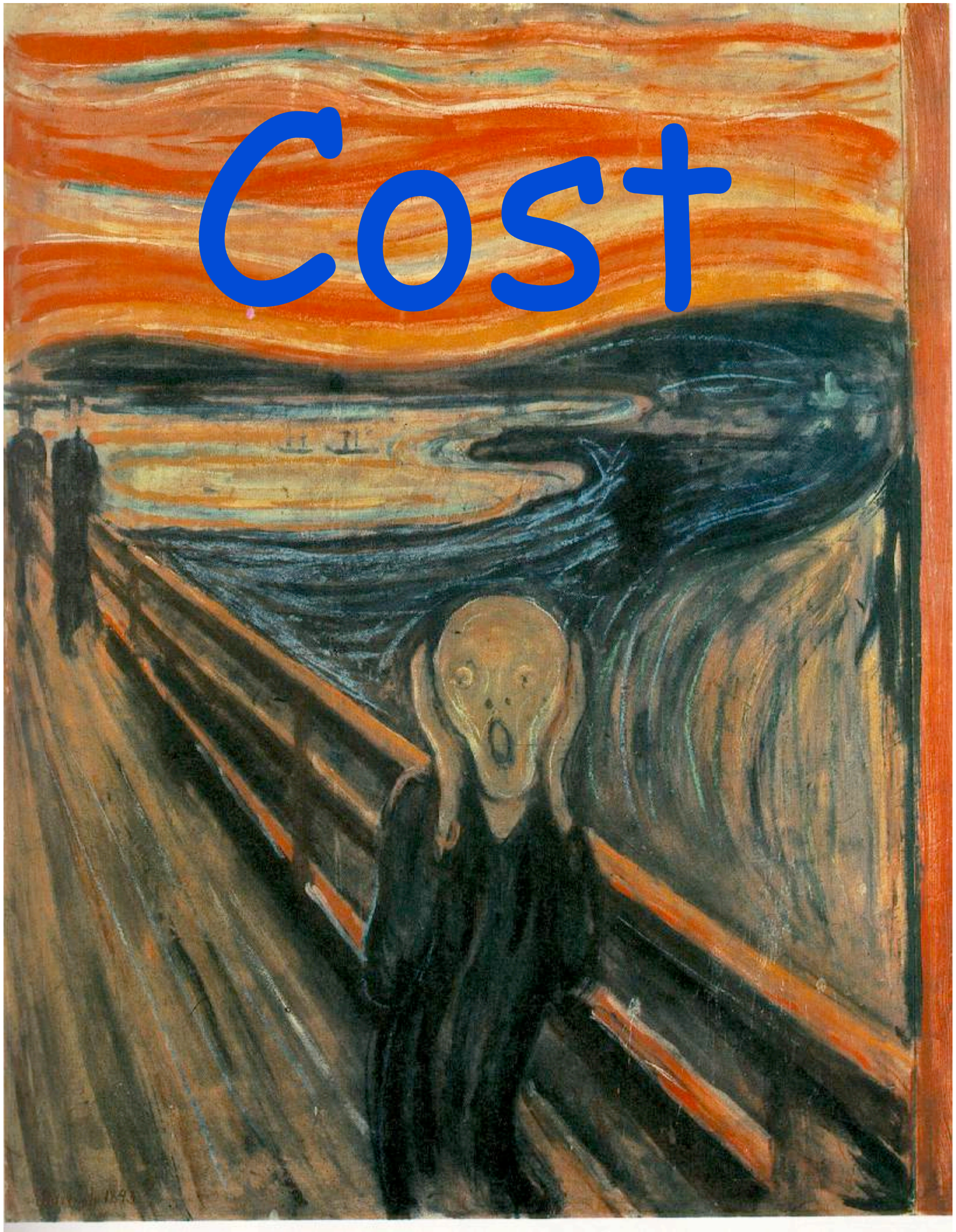
ID	Task Name	Duration
1	Secure ILC Beams	1 hr
2	De-energize magnets	3 hrs
3	Open Beamline Shielding	1 hr
4	Disconnect Beamlines	2 hrs
5	Checkout Detetctor Transport system	2 hrs
6	Transport Detector 20 m	2 hrs
7	Transport other detector on beamline	2 hrs
8	Connect beamline	2 hrs
9	Close Beamline shielding	1 hr
10	Check gross detector alignment & adjust if	2 hrs
11	Energize magnets	3 hrs
12	Safety Checks before beams	1 hr
13	Begin Beam Based alignment	10 hrs

SiD moves into the beam position as a single unit (barrel+ends) on Hilman rollers to a precision of +- 1mm.

SiD carries all of SC magnet services/utilities except He liquifier.

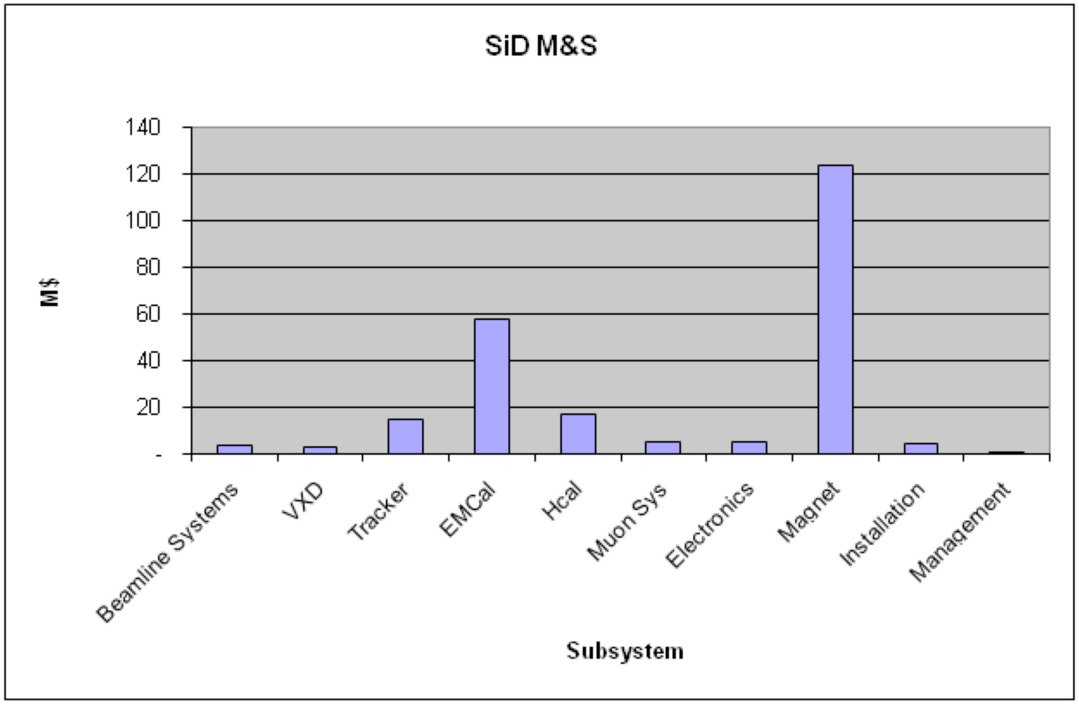
All utility lines (~350KW power, water, chilled water and compressed air) remain connected all the time.

Cost



	M&S Base (M$)	M&S Contingency (M$)	Engineering (MY)	Technical (MY)	Administrative (MY)
LumCal and BeamCal	3.68	1.42	4.0	10.0	0.0
VXD	2.80	2.04	8.0	17.7	0.0
Tracker	14.45	5.71	24.0	53.2	0.0
ECAL	57.74	23.02	13.0	287.8	0.0
HCAL	16.72	6.15	13.0	28.2	0.0
Muon System	5.35	1.65	5.0	20.1	0.0
Electronics	4.90	1.65	44.1	41.7	0.0
Magnet	123.74	42.58	29.2	25.0	0.0
Installation	4.10	1.08	4.5	46.0	0.0
Management	0.92	0.17	42.0	18.0	30.0
Totals	234	85	187	548	30

Subsystem summary of costs. Labor contingency is not shown.



Future Year Muon Developments

The muon detector effort will work toward a technology choice during 2011. RPC efforts include cost-effective readouts and aging studies. The scintillator SiPM work is expected to include evaluation of SiPM manufacturers, mounting, temperature control, and monitoring, as well as development or acquisition of an SiPM compatible ASIC, possibly a modified KPiX. Planning for construction of a larger-scale prototype of the selected technology would begin, with simulation studies of overall detector performance for muons. The simulation model of the muon system would be derived from measurements with prototypes.

Forward Calorimetry

Two photon processes present a major background to searches for certain supersymmetric particles. These processes can be identified by detecting a high energy electron or positron in the beamcal, above the beamstrahlung background. Developing highly efficient techniques for tagging electrons and suppressing background is being done with full GEANT simulation.

Through its participation in the CERN-based RD50 R&D collaboration, SiD collaborators are working on the development of Czochralski-process silicon diode sensors for application to high-radiation environments. Due to the relatively high oxygen content, it is expected that Czochralski sensors will be much more resistant to damage than standard sensors produced from float-zone process silicon. Studies are investigating the suitability of Czochralski sensors for forward calorimetry.

Future Year Forward Calorimeter Developments

The outcomes of these studies of two photon backgrounds will lead to refined designs of the beamcal. Radiation hard detectors and readout electronics for the beamcal must be developed.

Beamline Instrumentation

SiD is interested in beamline instrumentation, particularly work on energy spectrometry and polarimetry. This area of needed R&D can be followed jointly with other detector groups, as well as machine groups.

Schedule and Milestones

2009

- **Simulation/Reconstruction:** PFA improvements; tracking simulation and reconstruction improvements and background studies; simulation of dual readout concept; optimization of SiD design.
- **Electronics:** Full KPiX chip; develop beamcal readout.
- **Tracker:** Sensor test; sensor with readout test; develop alignment concept.
- **ECAL:** Sensor test; sensor with readout test.
- **Beamcal:** Evaluation of beamcal sensor technologies.
- **HCAL:** RPC and GEM with readout tests; GEM slice test; Micromegas slice test; RPC construct 1 m^3; engineering design of HCAL module; dual readout crystal candidate selection and photon detection studies.

- **Vertex:** Develop sensors; continue mechanical and power distribution designs.
- **Muon:** Test RPCs, scintillating fiber, and RPC longevity.

2010

- **Simulation/Reconstruction:** Update physics studies; dual readout full simulation and physics performance.
- **Electronics:** Test beamcal sensor readout; develop SiPM readout (if needed).
- **Tracker:** Test alignment concept; beam test sensors with readout and support system in B field; test Lorentz forces and mechanical stability with pulsed power.
- **ECAL:** Build and test ECAL tower; build mechanical prototype for ECAL module.
- **HCAL:** Produce engineering design of module with integrated readout; dual readout beam test of concept; continue beam tests and analysis; ready 1 m^2 modules of GEM and Micromegas; continue development of suitable crystals.
- **Vertex:** Develop sensors; continue mechanical and power distribution designs.
- **Muon:** Prototype muon chambers; longevity test; study costs.
- **MDI:** Develop push pull designs; vibration studies; study alignment issues.
- **Magnet:** Develop new conductor jointly with others.
- **Beamcal:** Design sensors.

2011

- **Technology Selections:** ECAL, HCAL, Muon.
- **Engineering:** Complete engineering designs for ECAL, HCAL and Muons for chosen technologies and forward systems; plan preproduction and detailed design phase.
- **Simulation/Reconstruction:** Complete detector optimization; realistic GEANT4 detector description based on technology choices; generate MC data.
- **Complete beam testing:** SiW ECAL, RPC, GEM, Micromegas, Scint & SiPM HCAL; proof of principle development of suitable crystals and photodetectors.
- **Tracker:** Test large scale system.
- **Vertex:** Test sensors; continue mechanical and power distribution designs.
- **Benchmarking:** Studies with final detector choices and optimized design.
- **Magnet:** Continue new conductor development.

2012

- Complete optimized SiD detector design.
- Begin tests of magnet material.
- Begin full scale prototyping.
- Write SiD proposal.

Conclusion

The SiD R&D Plan has been evolving for several years, and the definition of SiD's critical needs has sharpened through the LoI process. The SiD R&D Plan is designed to deliver the results needed to provide a solid technical basis of an optimized SiD detector design in 2012.

End

Backups

Expected LOI contents:
final wording of IDAG additional requests

✓(1) Detector optimization: identification of the major parameters which drive the total detector cost and its sensitivity to variations of these parameters.

✓(2) Plans for getting the necessary R&D results to transform the design concept into a well-defined detector proposal.

✓(3) Conceptual design and implementation of the support structures and the dead zones in the detector simulation.

✓(4) Sensitivity of different detector components to machine background in the context of the beam parameter space considered in the RDR.

✓(5) Calibration and alignment schemes.

✓(6) Estimates of overall size, weight, and requirements for crane coverage and shielding.

✓(7) Push-pull ability with respect to technical aspects (assembly areas needed, detector transport and connections, time scale) and maintaining the detector performance for a stable and time-efficient operation.

✓(8) A statement about energy coverage, identifying the deterioration of the performance at energies up to 1 TeV and the consequent detector upgrades.

Questions:

a) The choice of beam pipe radius and vertex detector inner radius
are driven by machine background
(mainly incoherent pairs from the IP).
Can you provide additional information on your assumptions
on background rates, on safety margins and on impact on performance
if the background would be higher?

b) The detector is expected to be read-out separating
each bunch crossing (mainly by means of the KPiX circuit).
Is this assumption going to be valid also for the vertex detector?

c) How extensive a study has been made of the robustness of
the tracking against failure of one or more detector planes?
The vertex detector is glued, replacement of parts seems unlikely.
Similarly how much impact does the loss of one or more planes
make on PFA performance..

d) Can you provide more details concerning the choice of 4.5 interaction
lengths for the depth of the HCal? How sensitive is it to assumptions on PFA algorithm?
How much can be obtained from the Muon system used as a tail catcher
for the hadronic showers, which is mentioned as an option?

e) Current PFA analysis provides rms90 = 4.0 GeV in M(Z->qq) from ZZ at 500 GeV,
with most of the uncertainty due error in tracks/clusters matching.
The Gaussian width of the Z(jj) appears significantly wider
in the studies of benchmark channels.
The LoI mentions that the performance of the algorithm is expected to be improved,
can you provide some more details about it?

http://silicondetector.org/display/SiD/LOI

Silicon Detector Letter of Intent and Supporting Materials

Letter of Intent

Supporting Materials:

Tracking and Vertexing

Tracking and Vertexing

Calorimetry

GEM Digital Hadron Calorimetry

MICROMEGAS Digital Hadron Calorimetry

Dual Readout Calorimetry

Muon System

Muon R&D Overview

Simulation and Reconstruction

Detector Simulation

Particle Flow Reconstruction

Polarization and Beam Energy Measurement

Polarimeters and Energy Spectrometers for the ILC Beam Delivery System

Detector Assumptions

- The detectors are self-shielded.
- The beamline has portable shielding (Pacmen) that have a section meeting the tunnel mouth that is common with the other detector.
- Liquid He (4K) is delivered by a permanently connected flex line to the detector. 2K He is made by a system that moves with the detector, and all the QD0 plumbing moves with the detector.
- All detector power and data cables are permanently connected to the detector.
- The detector is designed so that small distortions of the steel do not change stresses on the cryostat, which in turn isolates the support of the calorimeters and tracker.
- The wavelength scanning interferometer system checks alignment for the barrel and relates the endcap positions.
- The full detector position is adjustable in X and Y to 1 mm. The Y range will need to be determined to accommodate floor motion.
- Roller and drive system designed for 1-5 mm/s.