International e^+e^- Linear Collider Detector R&D and Fermilab

Slawek Tkaczyk, Fermilab

Fermilab PAC - 11-12 November 2004

- World LC Detector Activities
- North American R&D Projects
- LC Detector R&D at Fermilab
  - Interaction Region
  - Vertexing and Tracking
  - Calorimetry
  - Muons
  - Solenoid
  - Test Beams
- Summary and Outlook

Studies of Physics and Detectors for LC

- Understanding of EWSB requires precision measurements.
- Large group of physicists worldwide wants to build a TeV class Linear Collider starting at 0.5 TeV as the next international accelerator facility.
- ITRP recommended the International Linear Collider to be based on SuperConducting RF technology.
- Global Design Initiative is being formed to lead and coordinate ILC activities.
- World Wide Study asked to organize Global Experimental Program, parallel to GDI for the ILC.

World Wide Study of Physics and Detectors for ILC

- The World Wide Study fosters working relations between participants of the regional studies by organizing regularly the International Linear Collider Workshops.
- Expanded roles of the WWS after the technology decision:
  - Coordinate studies on regional detector concepts, and work toward inter-regional detector TDRs;
  - Interface closely with GDI, especially to address the most important Machine-Detector Interface issues;
  - Identify R&D efforts relevant to the ILC experimental program, catalog existing work, encourage activities on the important but still missing aspects, establish peer review process of the proposals;
  - Panels set up on: Costing, Detector R&D and MDI.

GDI Proposed Milestones

- **2004 - ITRP Technology Recommendation($\surd$)**
- **2005 - Accelerator CDR**
- **2005 - Detector CDRs (preliminary)**
- **2007 - Accelerator TDR/Detector CDR**
- **2008 - ILC Site Selection**

Physics and Detector Requirements

- Provide precision measurements in the energy range from M_Z to 1 TeV of small signals in the presence of backgrounds.
  - ▷ EWSB - Higgs, Susy, Strong WW scattering
  - ▷ Top physics
  - ▷ New or Unknown Physics
- Contributions from M. Carena, B. Dobrescu, A. Freitas, J.Lykken.
- Two-jet mass resolution adequate to distinguish W from Z
- High efficiency and purity heavy flavor b and c tagging
- Momentum resolution for precision reconstruction of the recoil mass in Higgs-strahlung events (better than beam energy spread)
- Precise determination of the missing energy -τ

ILC Detector R&D

- **Define performance of individual detector subsystems necessary to implement all elements of the physics program at LC, and when needed explore new technologies in a R&D program.**
- **R&D programs launched in Asia, Europe and America, coordinated internationally** **(J.Brau, Ch.Damerell, H.E.Fisk, Y.Fujii, R.Heuer, H.Park, K.Riles, R.Settles, H.Yamamoto - members of the panel)**

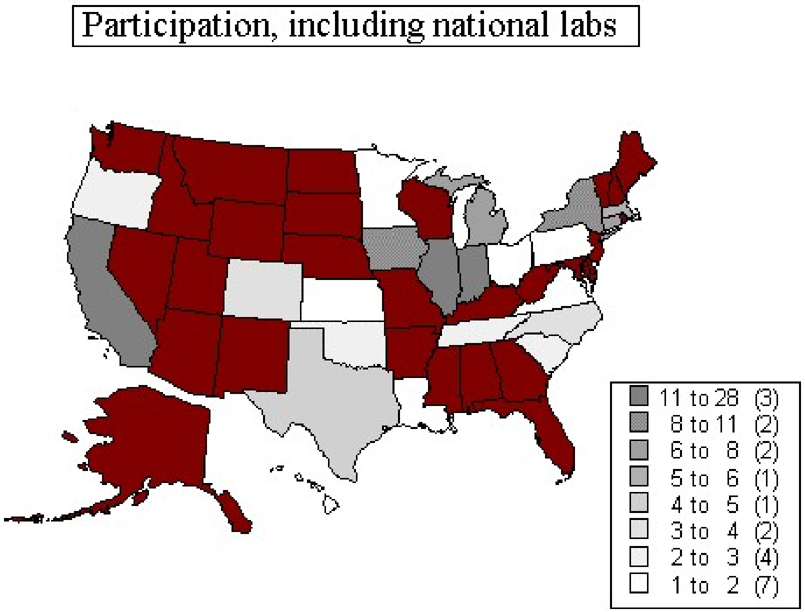
  $http://blueox.uoregon.edu/\sim lc/randd.html$
- **Studies of essential physics benchmarks of concept detectors;**
- **Many open issues for LC detectors;**
- **Detector R&D devoted to the LHC helpful, but not sufficient.**

Detector Performance Goals

- ILC detector studies aim at development and optimizations in the following areas:
  - ▷ finely segmented calorimetry for particle flow measurement
  - ▷ very thin pixel vertex detector
  - ▷ integrated, low power readout
  - ▷ development of cost reduction strategies
- Understand beamline-detector interaction
  - ▷ IR layout -masks, Final Focus
  - ▷ beam-beam interactions, Lumi spectrum, polarization, backgrounds, bunch structure

LC R&D in the US in FY03-06

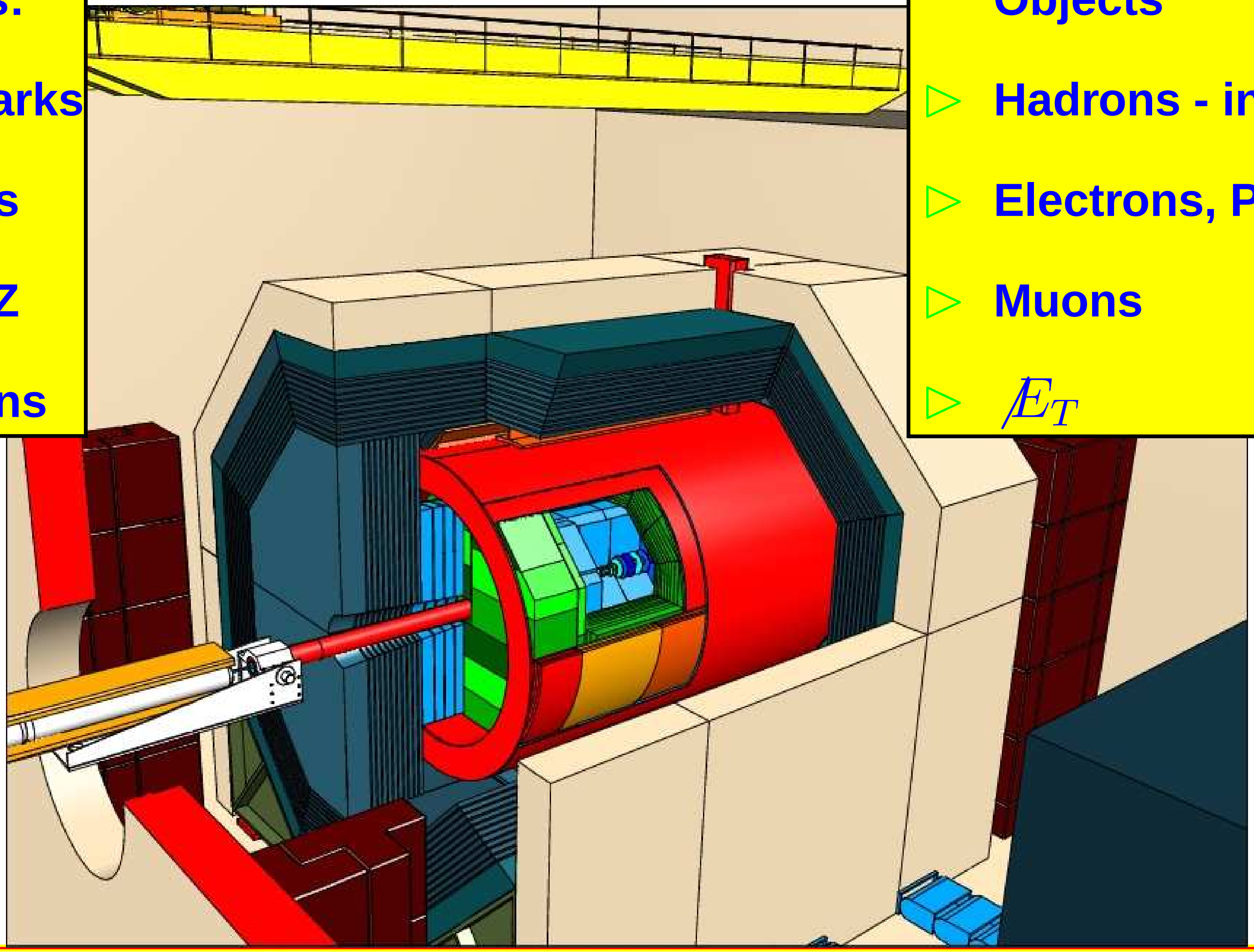
- **Physicists at universities and national labs prepared a number of proposals describing a nation-wide program of R&D activities leading to the design and construction of the LC.**
- **University Program of Accelerator and Detector Research for the Linear Collider - a proposal written by Linear Collider R&D Working Group (DOE) and University Consortium for the LC (NSF).** **(Coordination by physicists at FNAL, SLAC, Cornell and Universities)**
- **The proposal covered both accelerator and detector projects and was prepared in coordination with other efforts world-wide to avoid unnecessary duplication of efforts.**



- **The groups represent a broad cross section of institutions: 71 projects, 47 universities in 22 states, 5 national labs, 11 foreign institutions.**
- **Lumi (9), VTX&Tracking (14), Calo (13), Muon (3).**
- **Fermilab involved in both accelerator (7) and detector proposals: (4).**

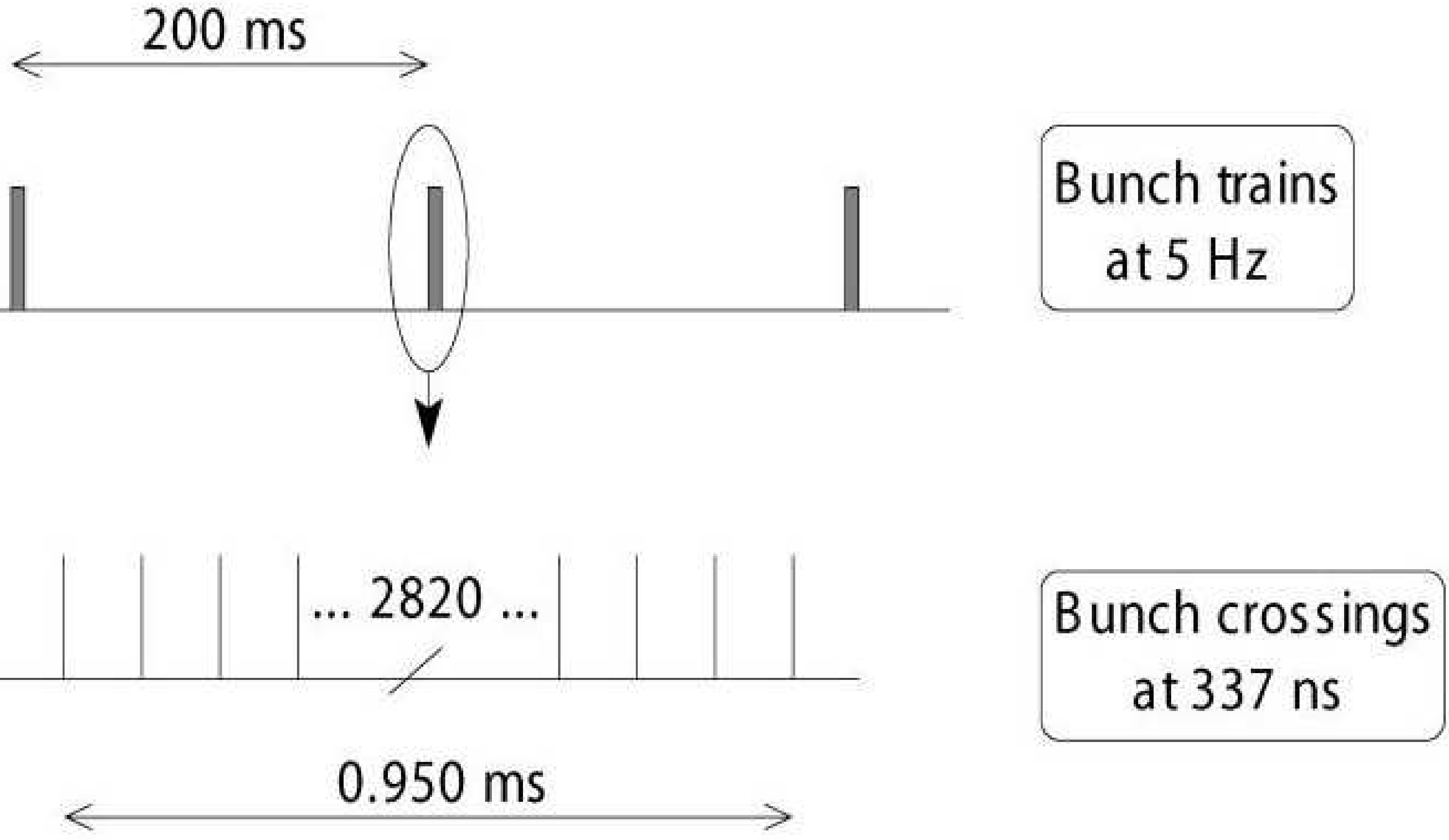
Object Oriented Detector Design

- **Physics Objects:**
  - b, c quarks
  - t quarks
  - W and Z
  - τ leptons



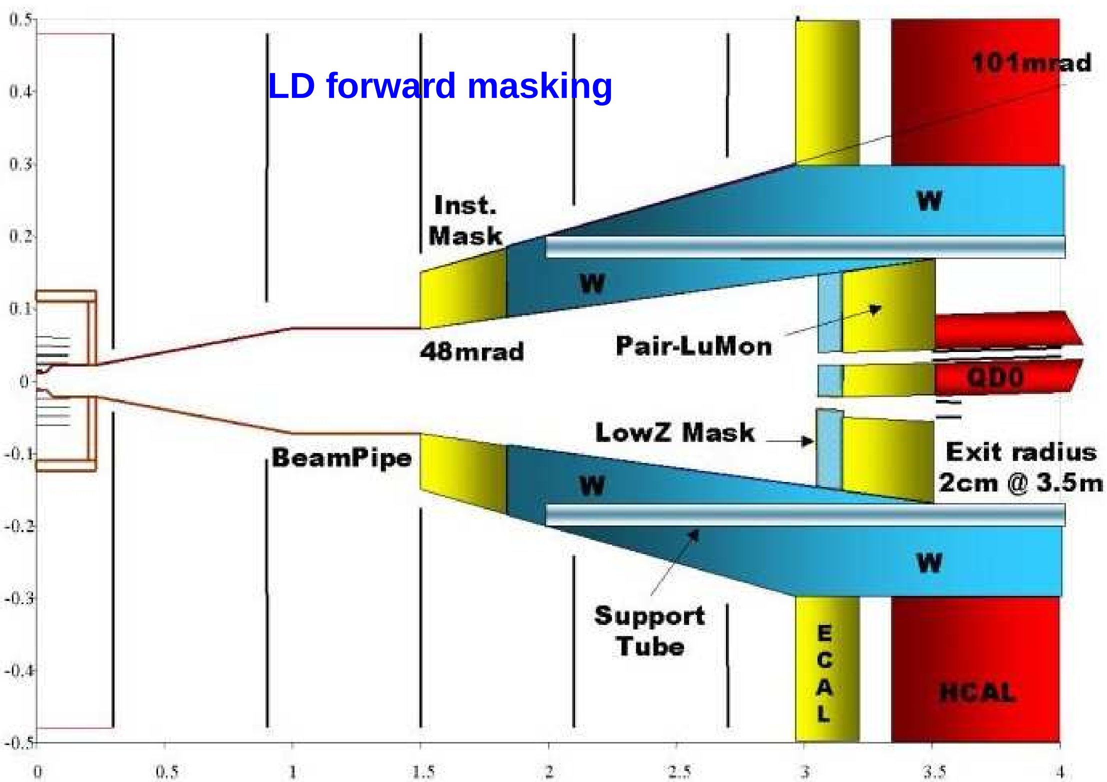
- **Detected Objects**
  - Hadrons - in Jets
  - Electrons, Photons
  - Muons
  - $\not{E}_T$

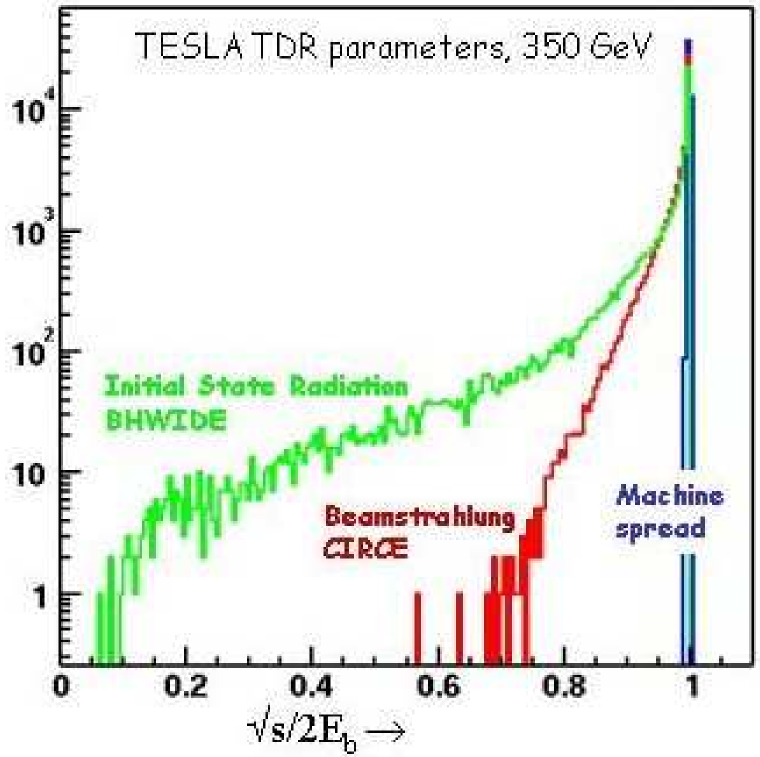
Beam Time Structure



Luminosity Spectrum

- Lumi spectrum essential for many precision measurements: m$_H$, m$_t$ $<$100 MeV, m$_W$, new physics.
- Combination of acollinearity of Bhabhas and beamline spectroscopy to get the full spectrum;
- Masks shield from direct and backscattered beam induced bkg;
- Provide instrumentation for luminosity spectrum measurement, hermeticity;



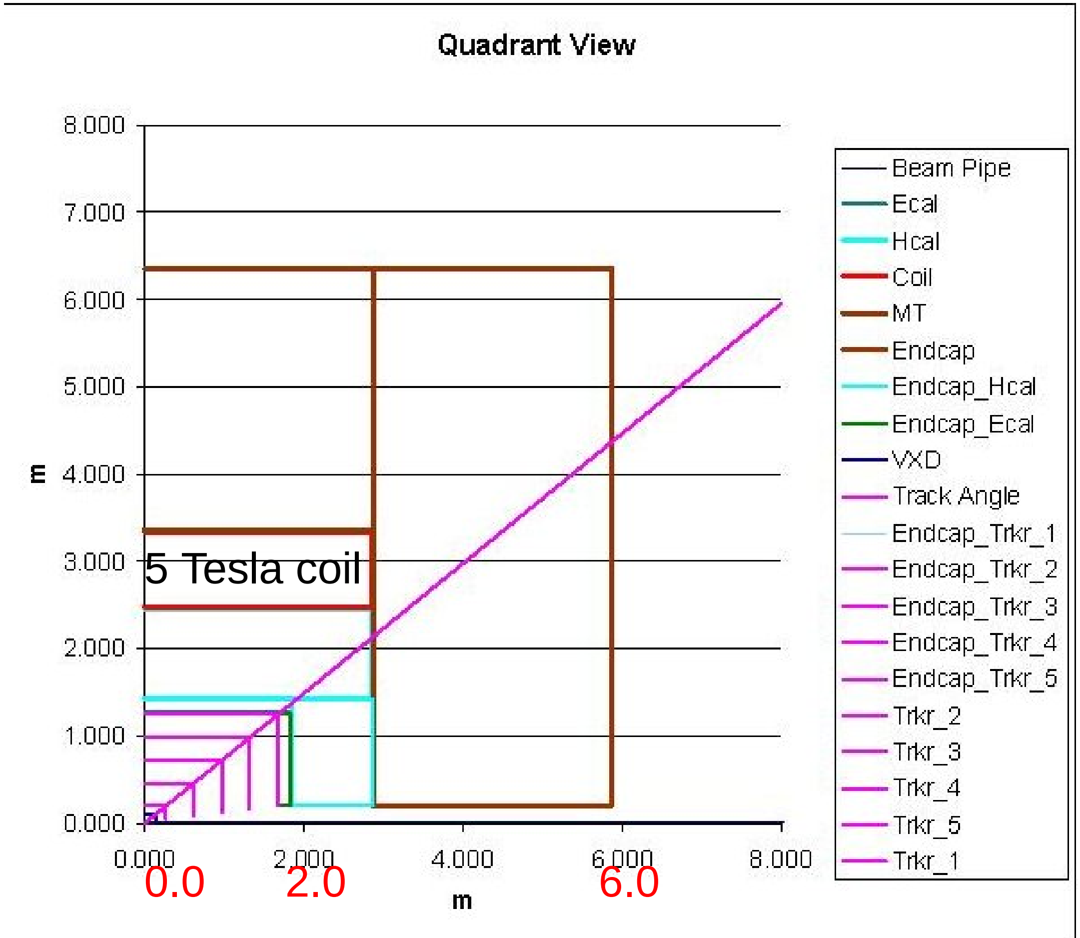


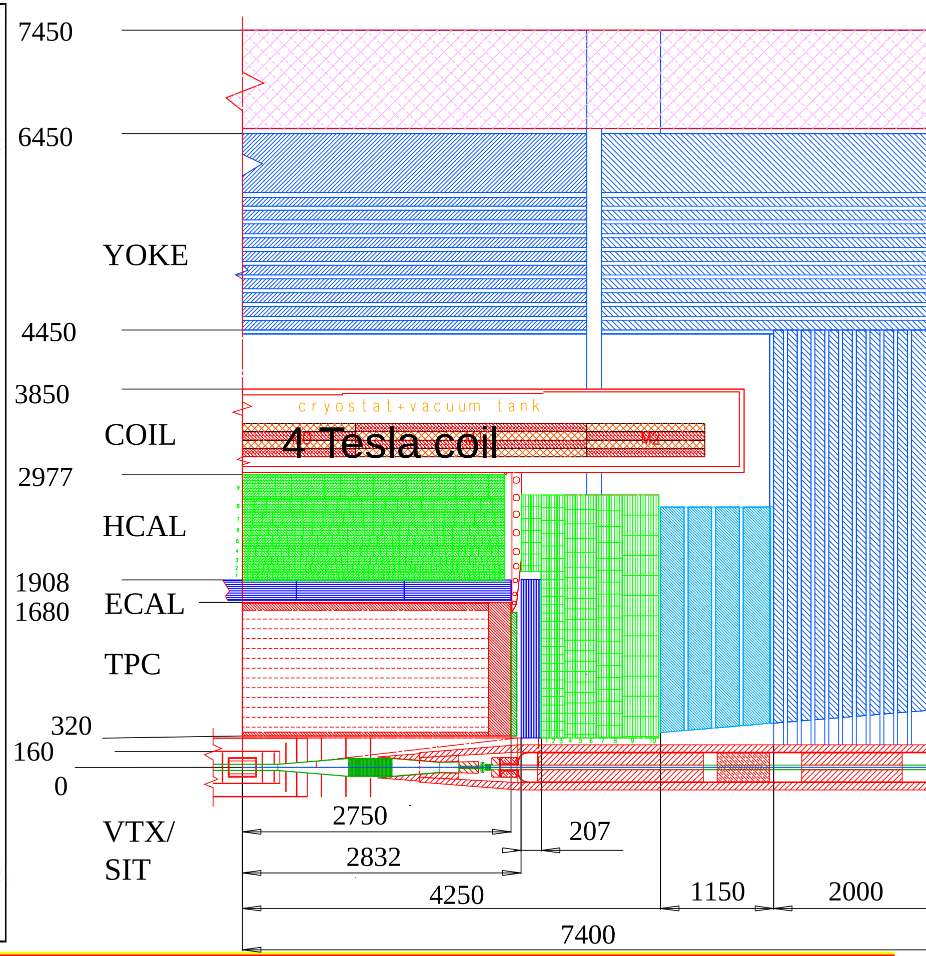
N. Mokhov (FNAL)

Detector Conceptual Designs

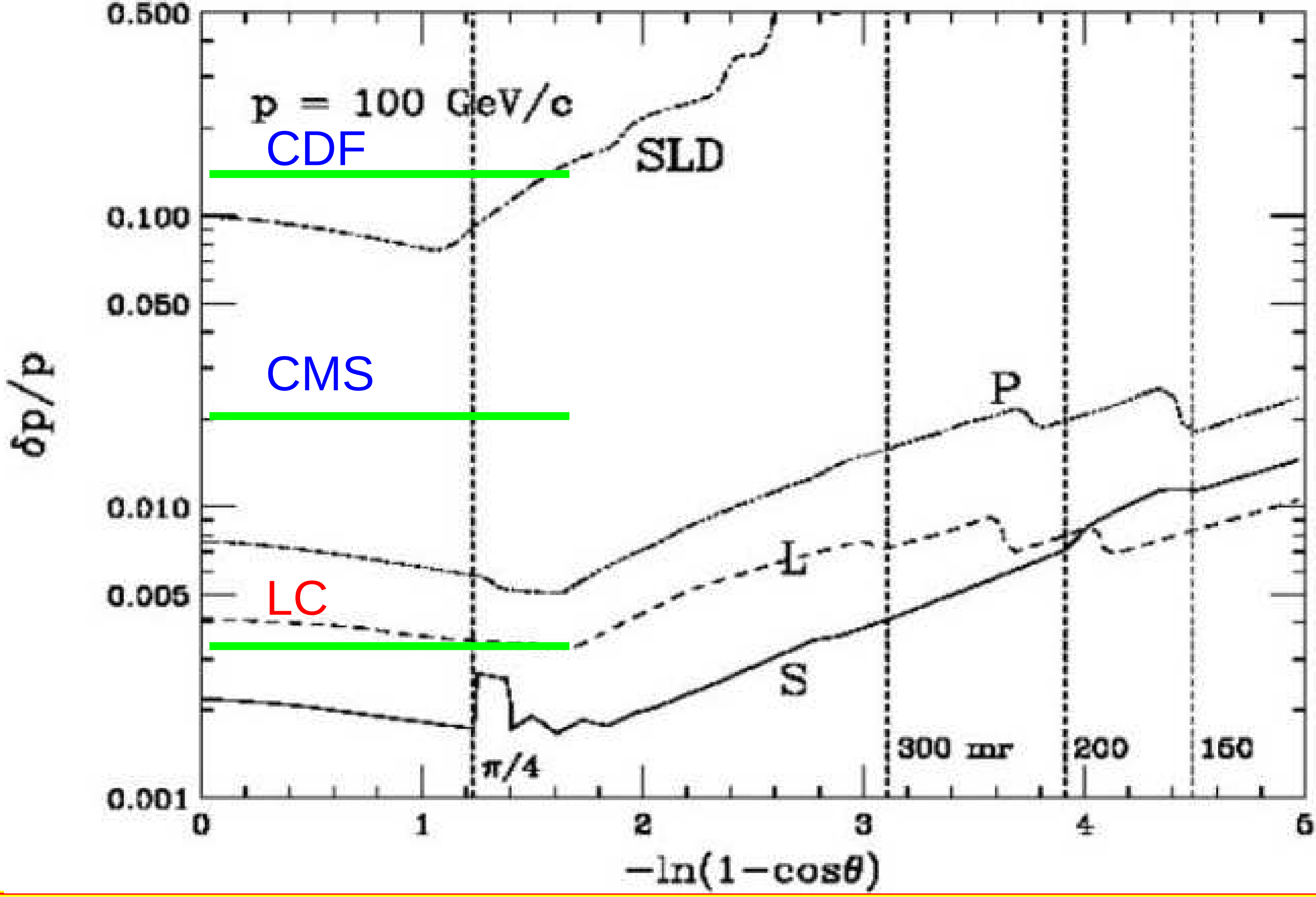
SiliconDetector

Large Detector

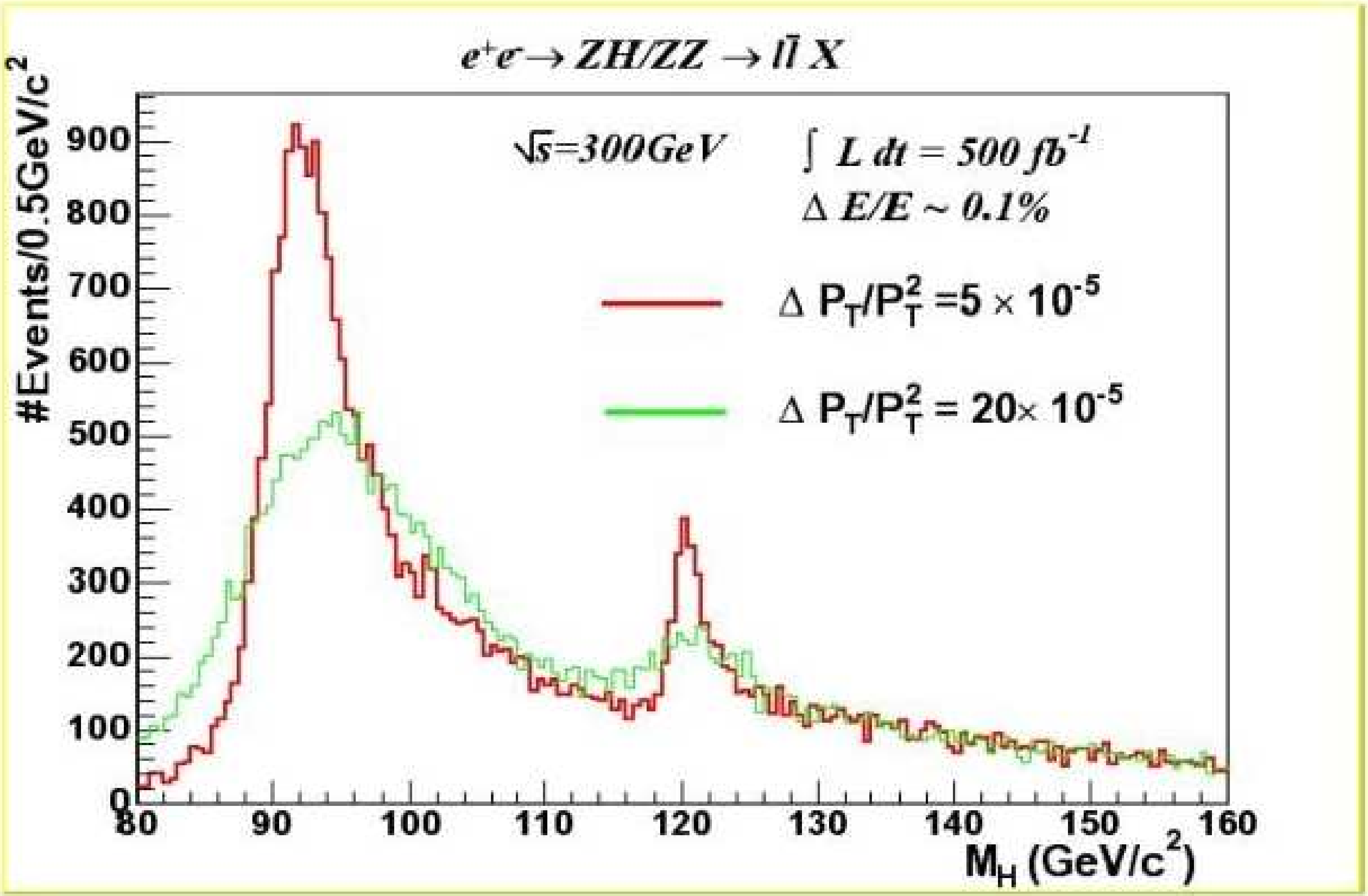




Momentum Resolution

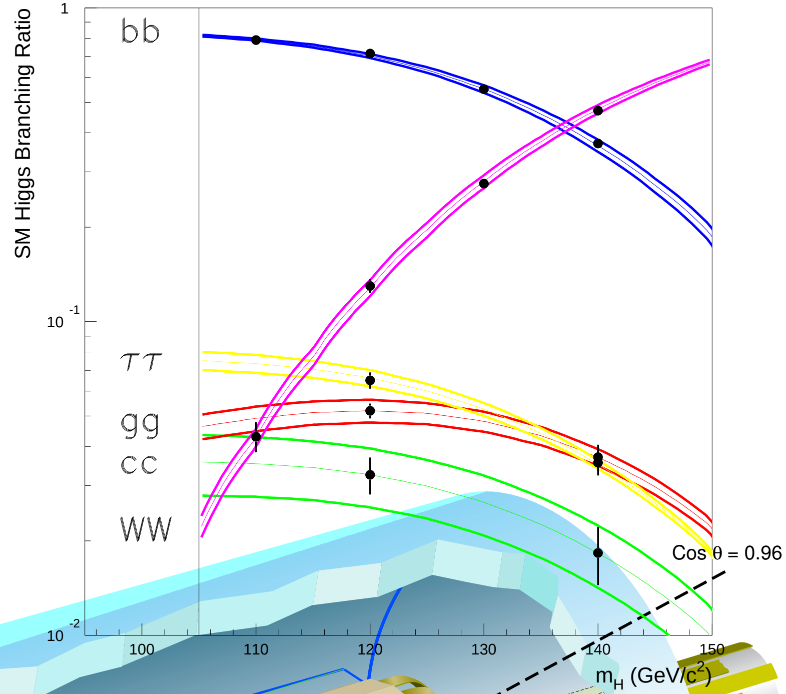


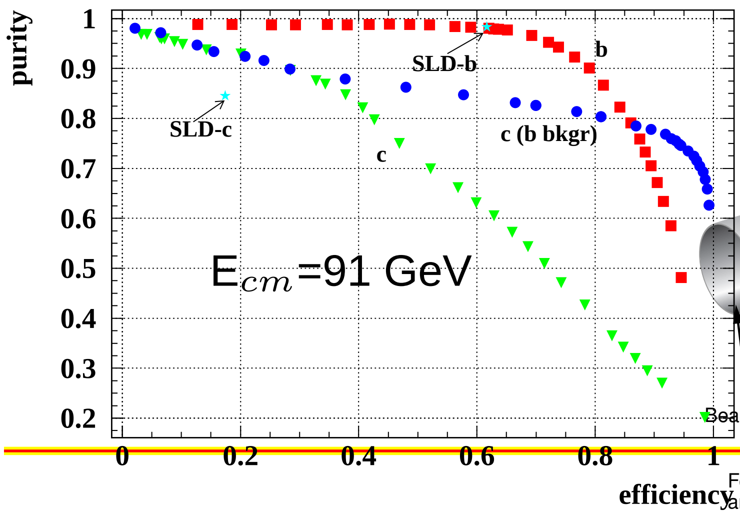
Momentum Resolution

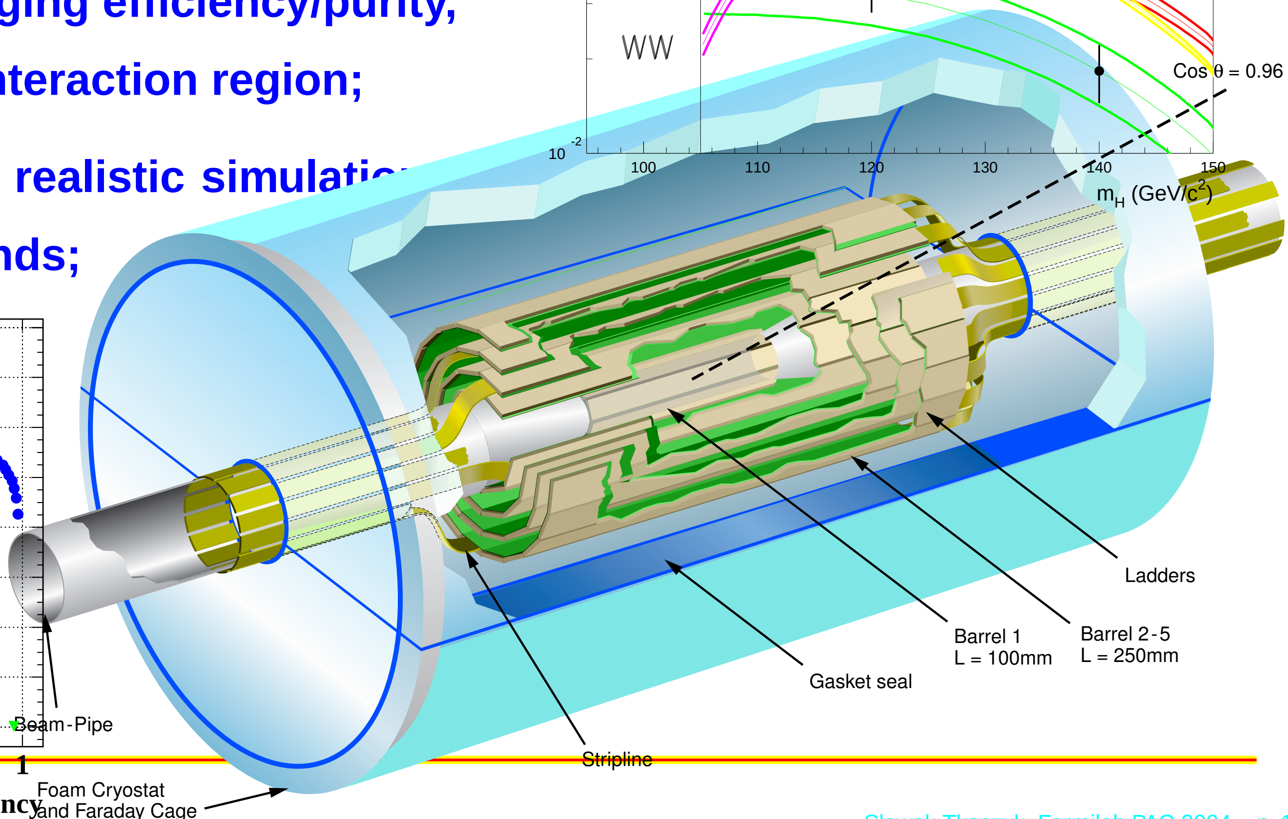


Vertex Detection

- **Performance issues to be studied:**
  - **Optimization of the detector geometry and pixel sizes;**
  - **5-layer device for excellent pattern recognition;**
  - **Importance of the radius of the Inner Layer (1cm ?) and its impact on the b,c tagging efficiency/purity, and instrumentation of the interaction region;**
  - **Higgs BR studies with more realistic simulatio[…] in the presence of backgrounds;**

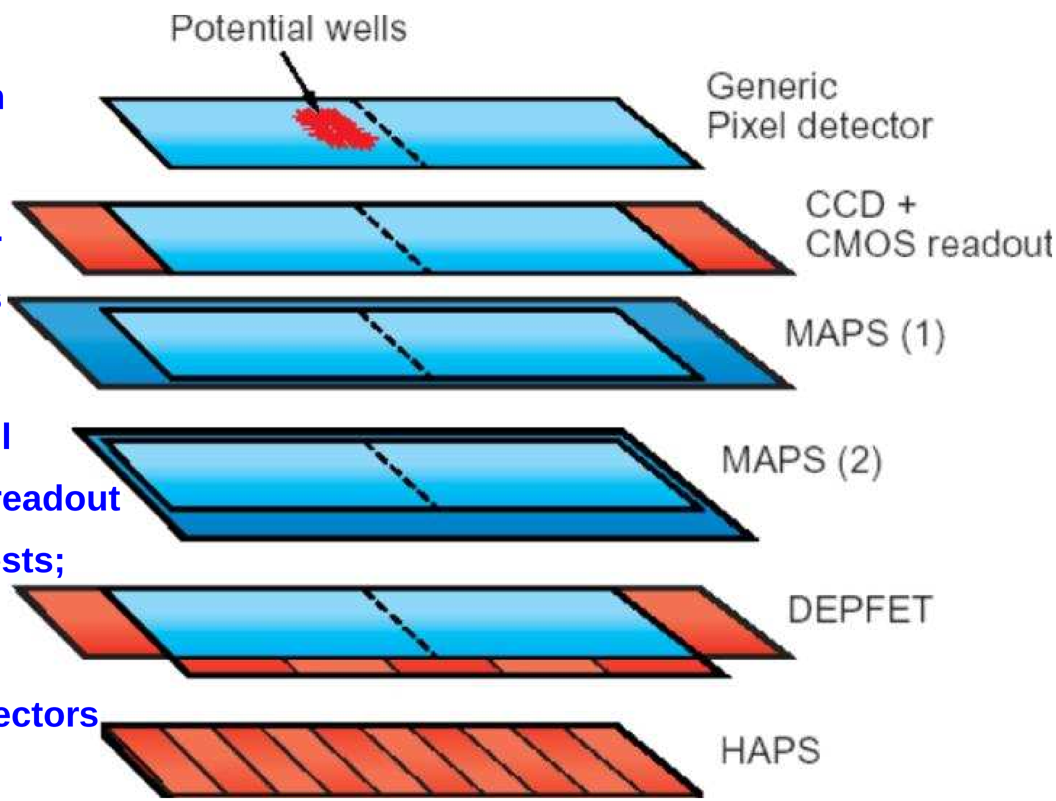






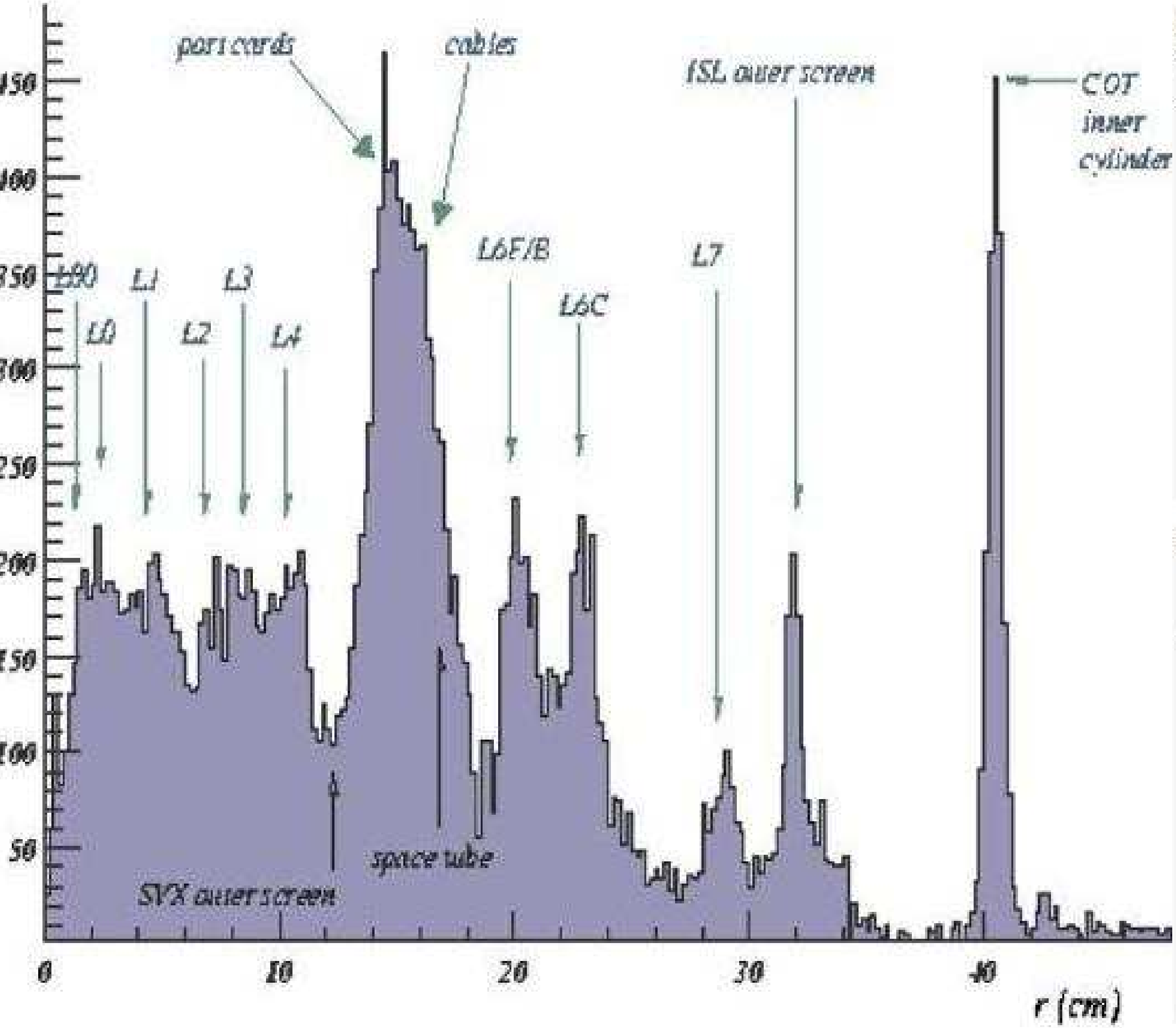
Vertex Detector Technologies

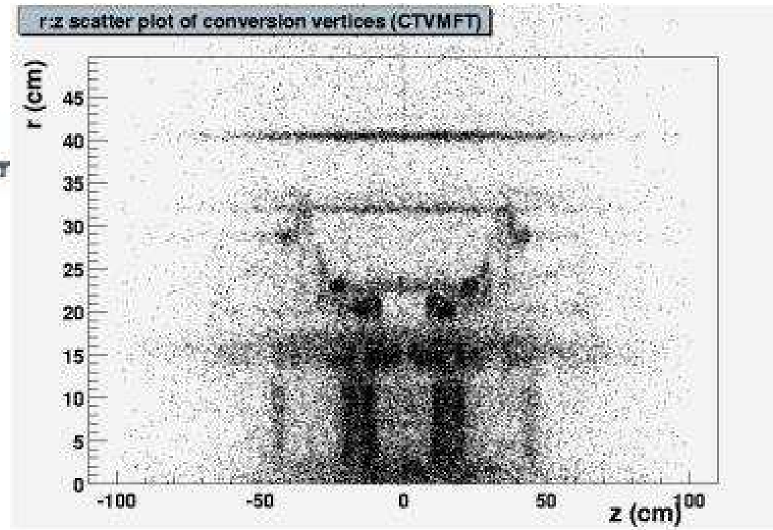
- **CCD based VTX detector**
  - **R&D to improve the limitations: readout speed, radiation tolerance, material budget;**
  - **development of fast column parallel CCD with readout electronics, 50 MHz;**
  - **thin ladder - unsupported version - 0.06%X_0- problematic; or semi/fully supported versions 0.1%X_0 under study;**
- **Monolithic Active Pixel Sensor (CMOS) - small prototypes (MIMOSA-n) with column parallel readout and zero suppression fabricated and under tests;**
- **DEPFET - first structures under tests**
- **Rich experience in construction of vertex detectors at FNAL...**
- **Interest in development of MAPS and study of new DSM processes by W. Wester, R. Yarema's group.**

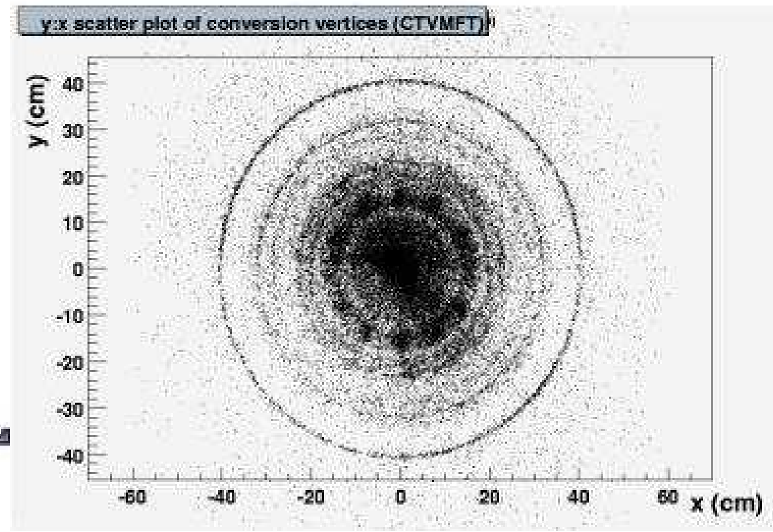


Vertex Detection

- **Material distribution in a typical vertex system.**

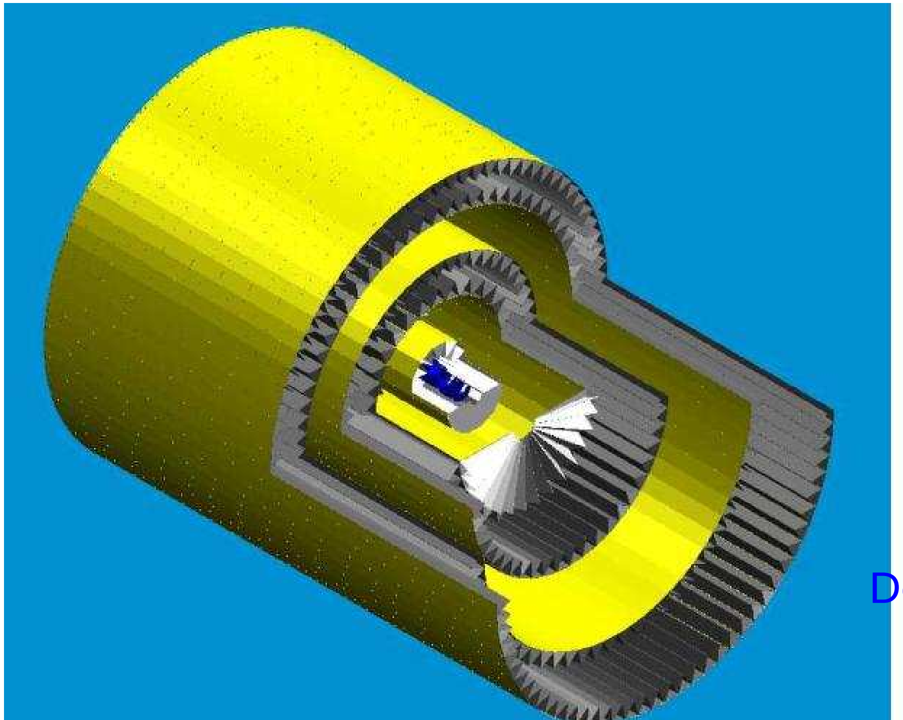




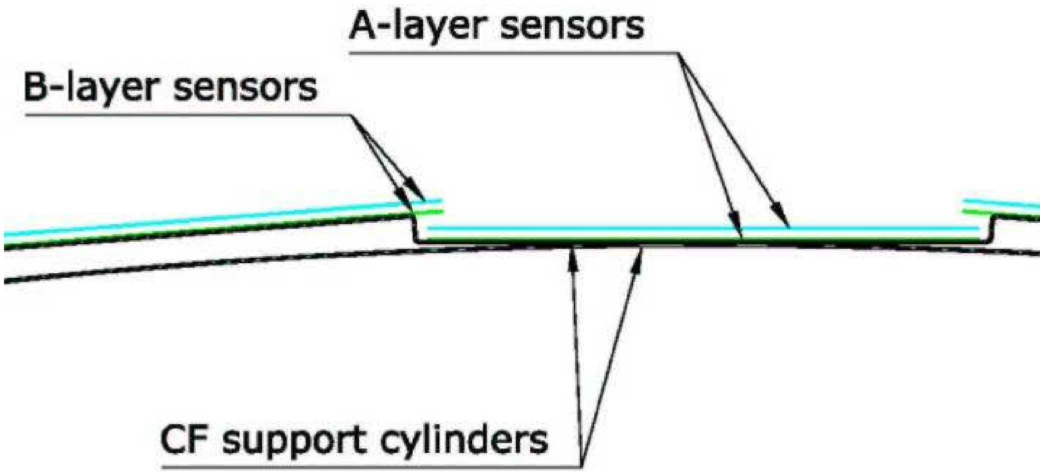


Si Tracker Work @FNAL

- **Layout and Support Structure design by W.Cooper, M.Demarteau, M.Hrycyk**
- **Ladder configuration under study**
- **Minimal electronics and power pulsing make gas cooling possible for mass reduction**



5 layers at radii 20-125cm

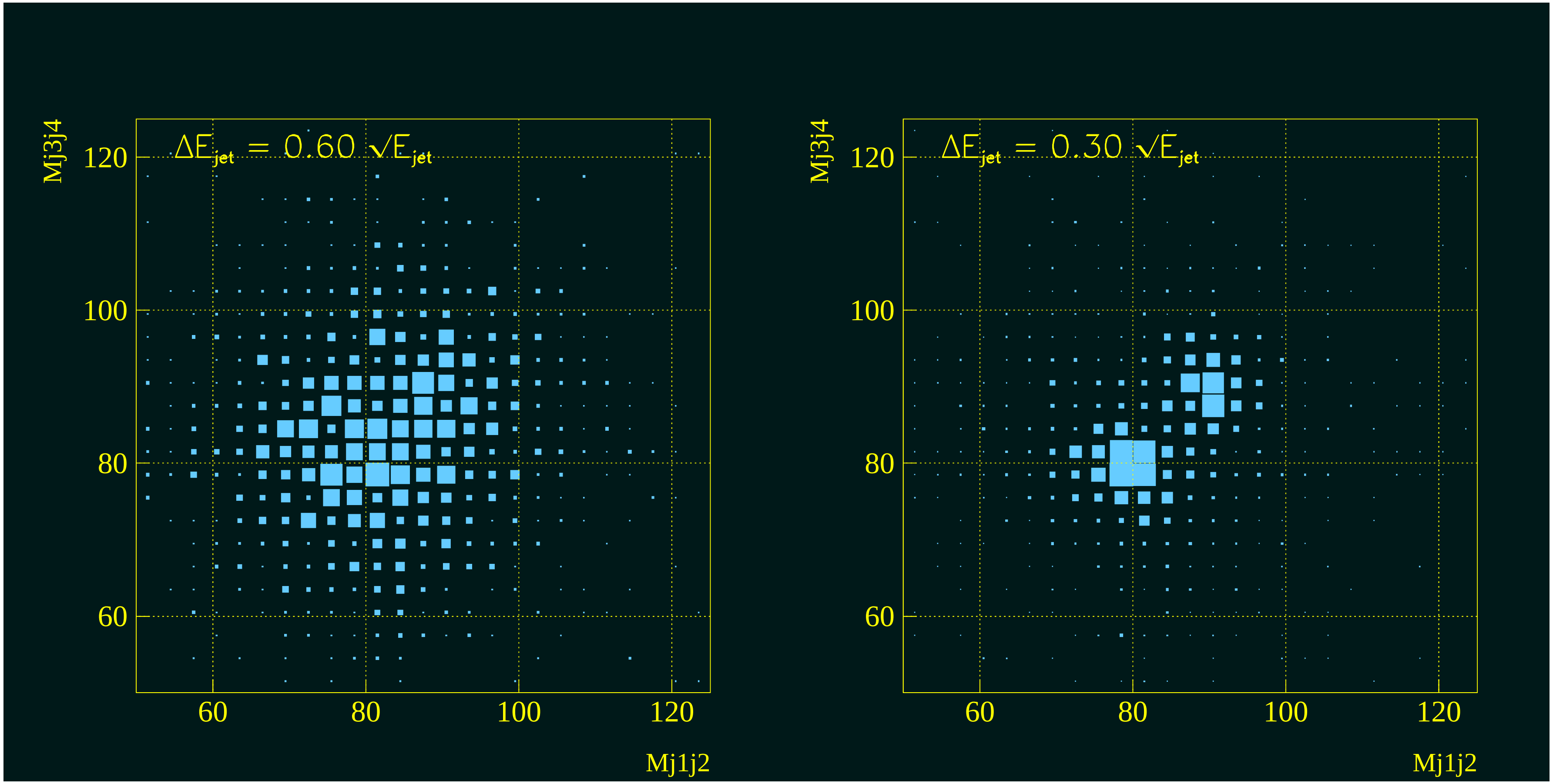


Double carbon fibre support cylinders for each barrel

Calorimeter Performance Goal

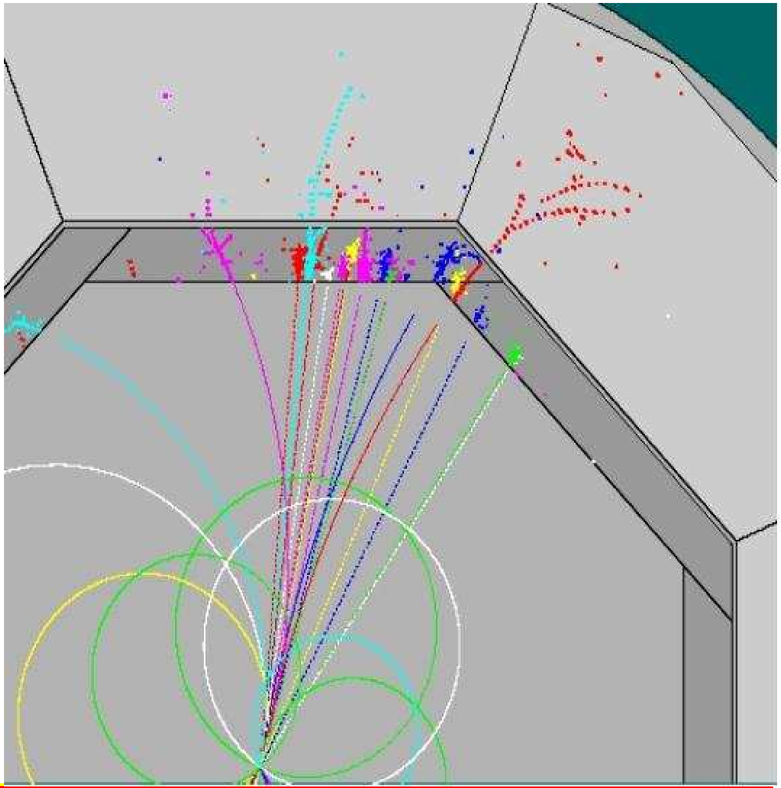
- **Precision measurement of jet energy to separate Ws and Zs in hadronic decays on an event by event basis:**

$e^+e^- \rightarrow HZ$, $e^+e^- \rightarrow \nu\bar{\nu}WW(ZZ)$, $e^+e^- \rightarrow HHZ$



Particle Flow Concept

- **Combination of two methods of particle energy measurement**
  - ▷ **charged particles in jets more precisely measured in a tracking detector;**
  - ▷ **for a typical multijet event: 60% charged energy; 20% photons, 10% neutral hadrons;**
  - ▷ **photons and electrons measured in calorimeter (ECAL).**



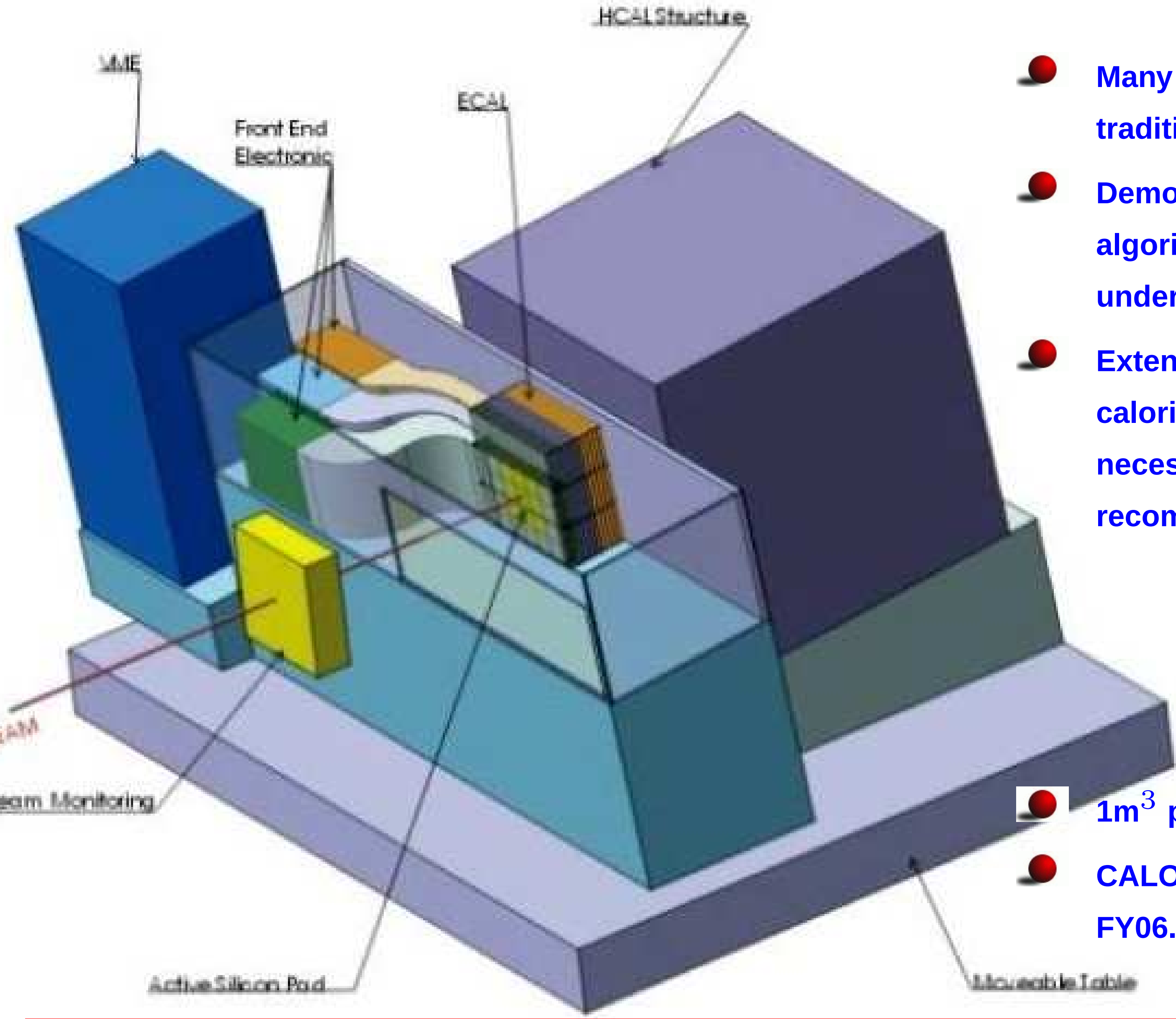
- **Particle Flow Algorithm requires separating charged from neutral energies in Imaging Calorimeter system.**
- **The main lines of design of the calorimeter system:**
  - ▷ **high 3D granularity and hermeticity;**
  - ▷ **minimal re-interactions, separate particles in the tracker;**
  - ▷ **dense material for compact showers;**
- **Active interplay between simulation and detector designs to identify and measure each jet energy component as well as possible.**

Calorimeter Technology Options

- **Electromagnetic-ECAL**
  - ▷ **Silicon-Tungsten;**
  - ▷ **Crystal $PbWO_4$;**
  - ▷ **Silicon-Scintillator**
- **Hadronic - HCAL**
  - **Analog Readout:**
    - ▷ **Tiles**
  - **Digital Readout:**
    - ▷ **Gas Electron Multipliers -GEM**
    - ▷ **Resistive Plate Chamber -RPC**
    - ▷ **Scintillator**
    - ▷ **Short Drift Tubes -SDT**

Recent summary by A. White at Jan'04 ALCPG at SLAC

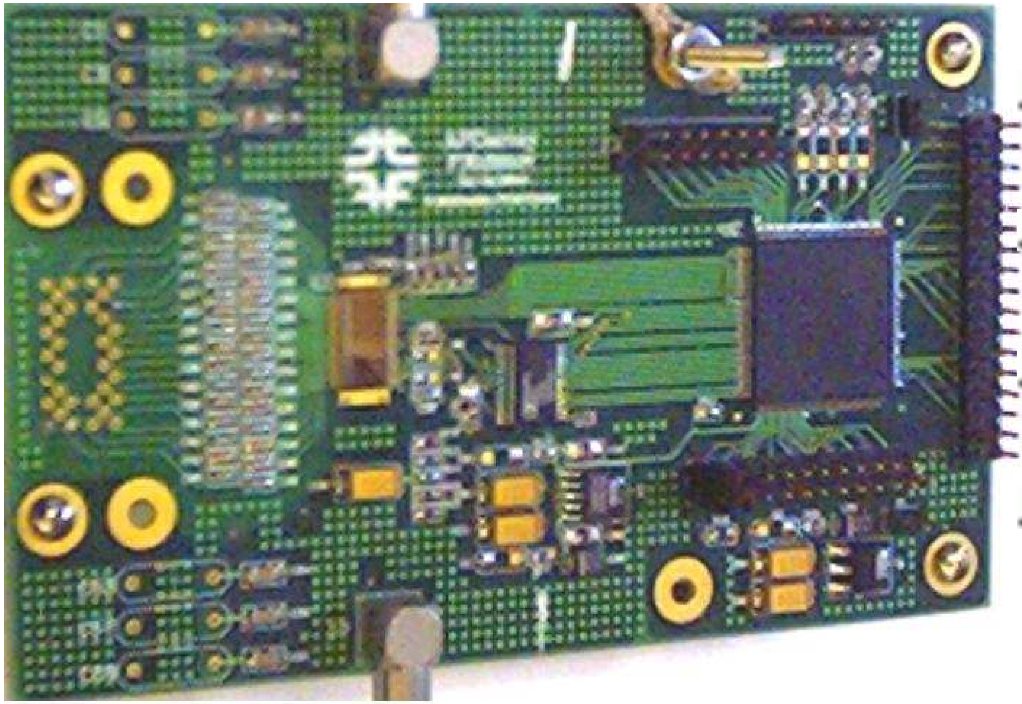
CALORIMETER Prototype R&D



- Many CALO options discussed: traditional, particle flow, digital HCAL.
- Demonstration of full particle flow algorithm with pattern recognition underway.
- Extensive tests of high granularity calorimeters (data, simulations) necessary to precede any technology recommendations.
- 1m^3 prototype: 400,000 channels
- CALO structures in the test beam by FY06.

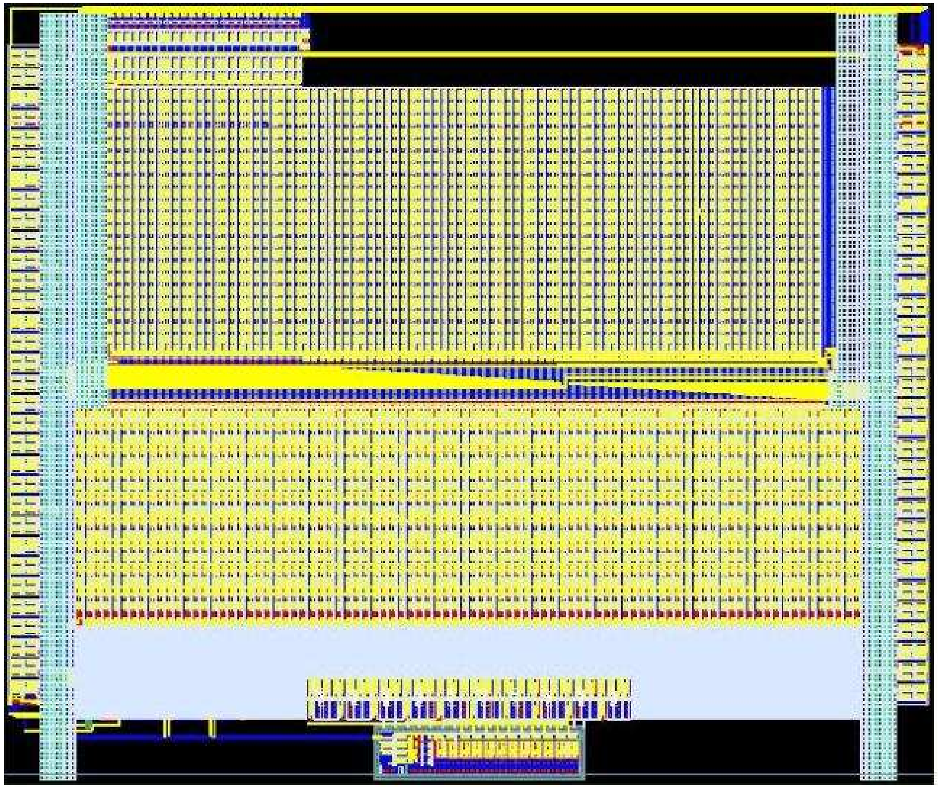
CALORIMETER R&D @FNAL

- **Experience in the FNAL ASIC group in calorimeter electronics: KTeV, CDF, BTeV, CMS and overlap with new initiatives (LC, NOνA)**



- **Large channel counts require the low cost and power designs.**
- **Avalanche Photodiodes (APD) readout using FNAL ASICs.**
- **Prototype board for LC DCAL R&D using scintillator (U.Colorado proposal)**
- **Silicon Photomultipliers new readout for scintillator based tail-catcher (NIU proposal).**

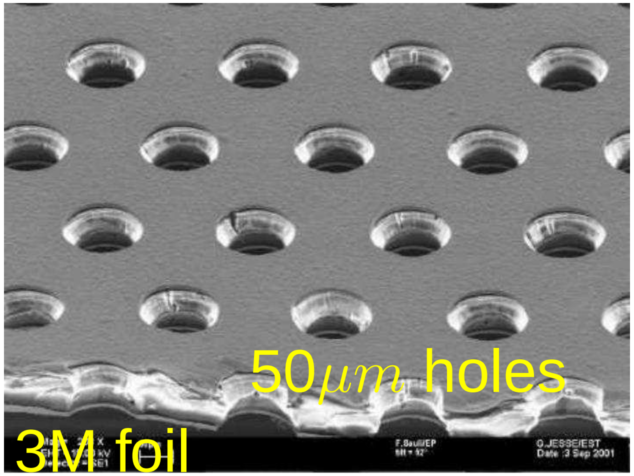
CALORIMETER R&D @FNAL



- New ASIC development effort under way for the Digital Calo chip (submission planned for FY05)
- 64-channel chip designed for two gains, time stamping and triggering capabilities
- Readout for:
  - RPC (ANL proposal)
  - GEM (UTArlington proposal)

Muon Detector Work @FNAL

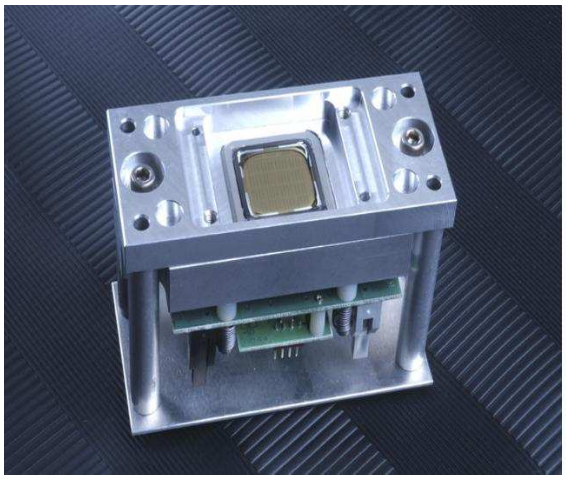
- **Gaseous Electron Multiplication - UTA**



- **Resistive Plate Chambers - INFN Frascatti**

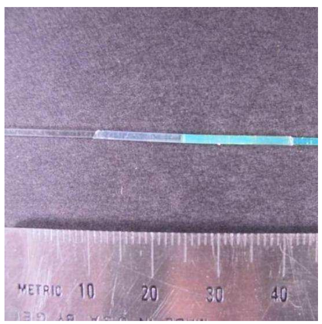
Screen printed resistive coating

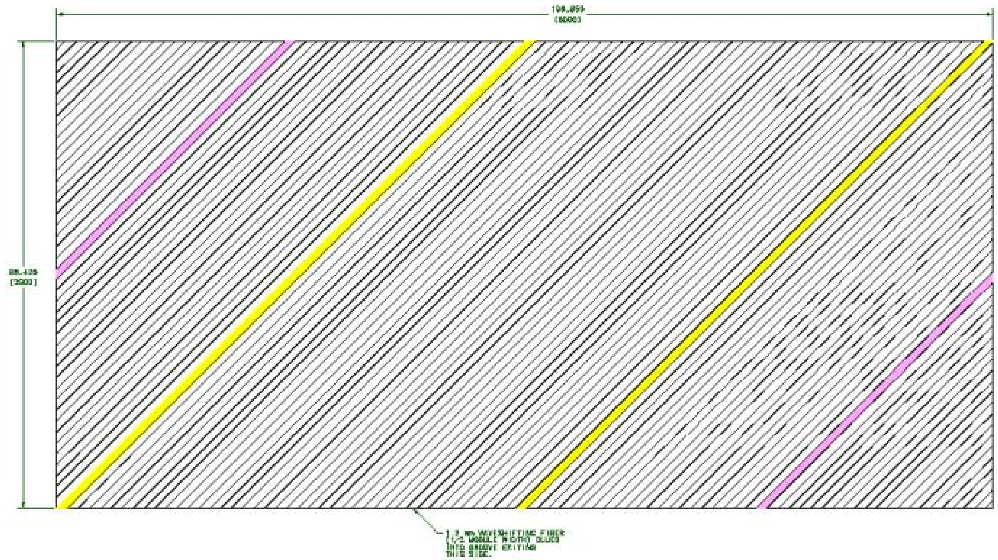
MAPMT 16/64ch



- **Scintillator based -Davis/NIU/Notre Dame/Wayne St./FNAL H.E.Fisk**

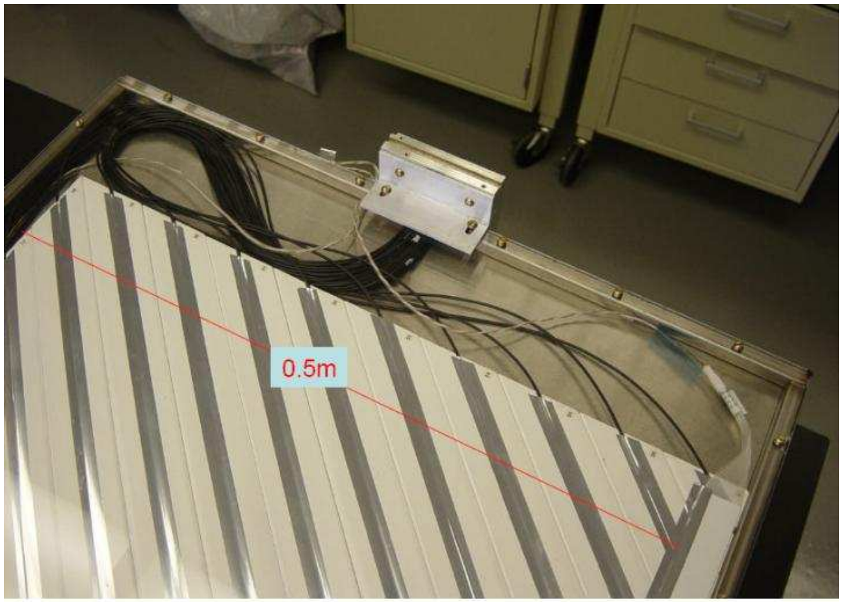
1.2 mm fibre thermally fused



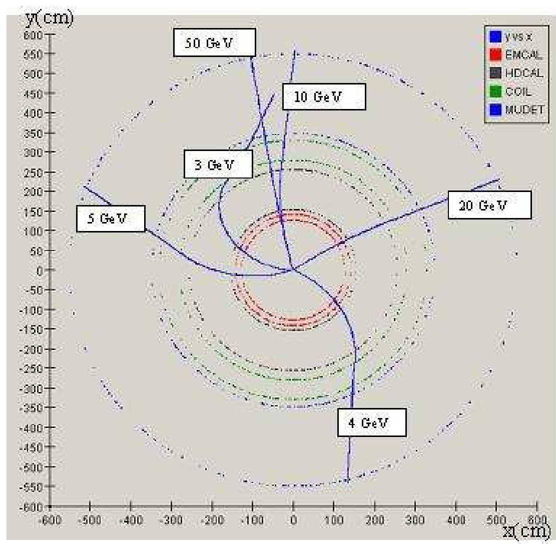


Muon Detector Work @FNAL

- **1/16 plane from Notre Dame**
- **Testing to begin now**



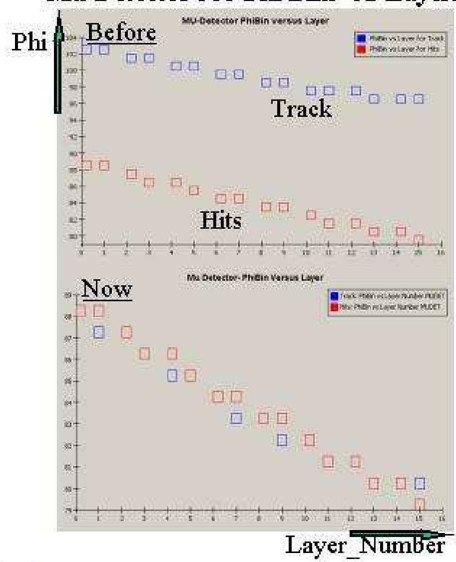
- **Simulation studies of single muons in the detector.**
- **MIP tracks reconstructed in 5T magnetic field.**



EMCAL -2 RED Rings
HDCAL -2 BLACK Rings
COIL -2 GREEN Rings
MUDET -2 BLUE Rings

C. Milstene

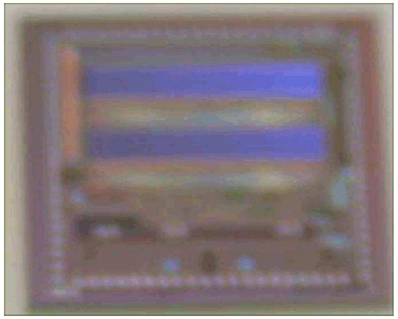
Mu-Detector 300 Phi Bins- 32 Layers



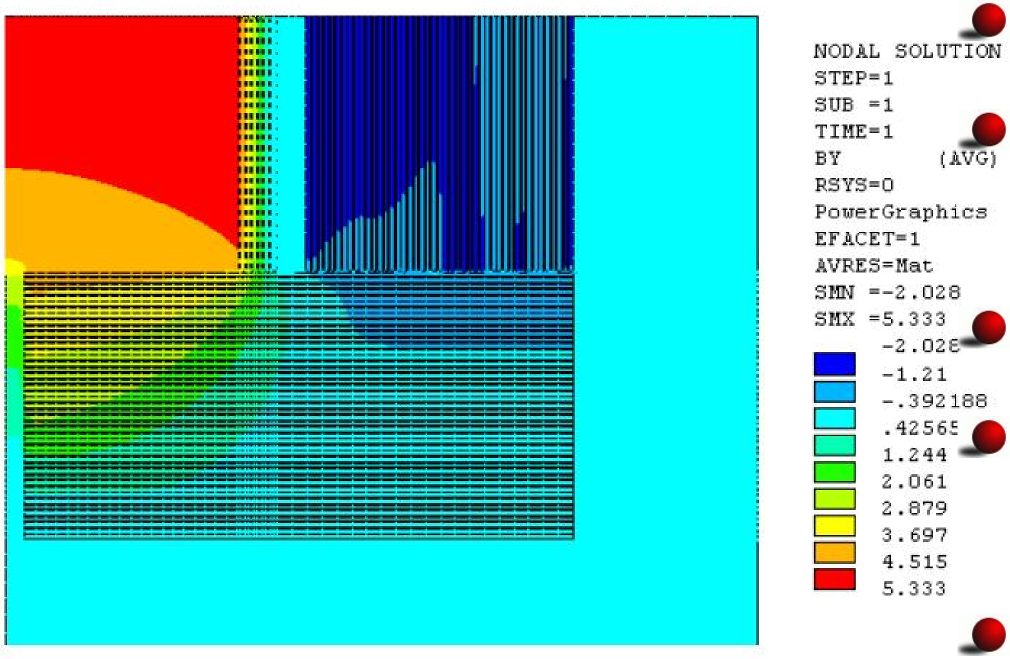
High Voltage Control ASIC @FNAL

- The Resonant Mode Controller Chip (RMCC) is a long standing FNAL circuit design now implemented in an ASIC.
- High Voltage/Low current applications such as phototubes, bias voltage supplies are ideal place for use.
- Detectors with many HV channels will benefit from this low cost HV sources with the RMCC ASIC.

- Chip used for PM supply.
- Plan to build a demonstrator PCB for bias voltage.
- LC Proposals: RPC (ANL) and Scintillator Calorimeter (U.Colorado) plan to use this device.



5 Tesla Solenoid Studies @FNAL

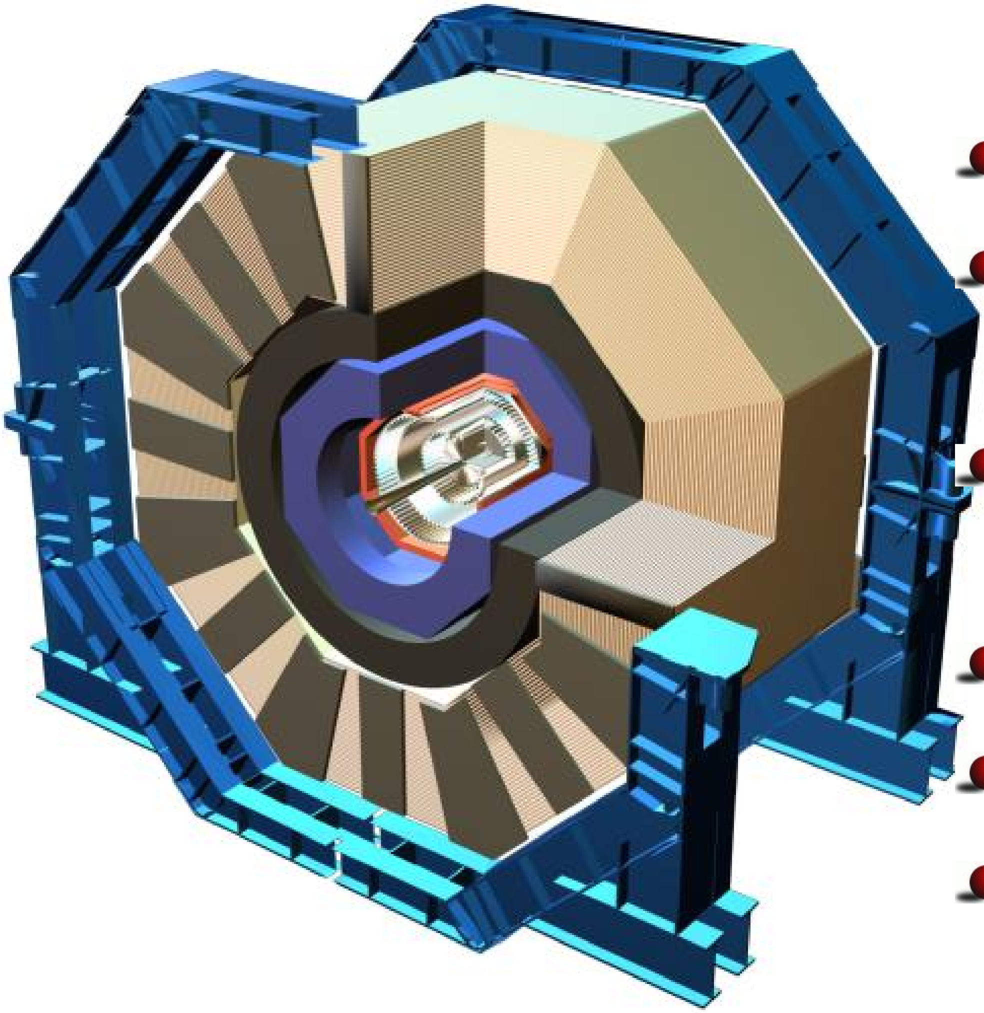


- SiD: w/5T; technical feasibility?
- FNAL expertise: R.P.Smith, R.Wands, K.Krempetz
- Collaboration with Saclay
- Use 4T CMS solenoid as a starting point
- First results shown, stress analysis to follow

Test Beam Facility @FNAL

- **ILC groups are designing and building prototype detectors to be tested in electron and hadron test beams.**
- **Specific proposals to laboratories are being created.**
- **Needs of calorimeter R&D groups are most demanding and FNAL TB coordinator E. Ramberg is developing a plan how to address them at Fermilab.**

ILC Detector Concept Study@FNAL



- Vertex Detector Pixel and Silicon Front End Readout;
- Tracker layout and design;
- Calorimetry FE Electronics and readout ASIC;
- Scintillator studies applied to Calorimeter and Muon subsystems;
- Superconducting solenoid - 5 T;
- Prototype Detector tests in the beam;
- Physics and Detector simulation studies;

ILC Efforts @FNAL

- Fermilab assists WWS in managing the LC physics and detector studies:
  - A. Kronfeld member of the International Organizing Committee WWS;
  - D. Finley, G. Gollin, S. Tkaczyk R&D Proposal Coordinators;
  - H. Weerts(FNAL) and J. Jaros (SLAC) leaders of the SiDetector concept study;
  - M. Carena, H. Fisk, A. Juste, S. Tkaczyk WG leaders;
- E. Ramberg coordinates the Test Beam Facility at FNAL;
- E. Fisk and S. Tkaczyk lead the LC Physics and Detector work in EPP-PPD; G.P. Yeh liaison in CD for LC simulation support.

ILC Detector R&D

- R&D on Front-End electronics for LC detectors is a very important element of this program.
- Big unknown with longest lead times (as experience of present detectors shows)
- Requires concentrated efforts and continuous attention
- Embedded with active detectors
- Impacts the designs in earliest stages:
  - power dissipation and cooling requirements;
  - material budget;
  - evaluation of production risks and cost;
- Large laboratories usually lead those efforts! (e.g. CERN, DESY, RAL)

Summary

- FNAL involved in many aspects of the ILC detector R&D.
- FNAL efforts are increasing.
- FNAL well prepared to lead front-end electronics R&D activities.
- Collaboration with Universities and other labs essential element of concept detectors studies.
- Many contacts established between FNAL and SLAC, ANL, NIU, U.Colorado, UC. Davis, Wayne State, U. Notre Dame, U. Texas Arlington,...

Outlook

- More Fermilab staff need to get involved at any level in the LC physics and detector studies.
- Eventually the ILC detector activities have to become an approved R&D project.
- It is not too early to start thinking about how to get there and when it should be.