Detector R&D Opportunities for the Future e^+e^- Linear Collider

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Interaction Meeting on Linear Collider and Neutrino Physics
10-12 November 2003, Indian National Science Academy, Delhi, India

- World Wide Study of Physics and Detectors for LC
- Linear Collider Detector R&D
  - Vertexing
  - Calorimetry
- North American R&D Projects
- Fermilab Activities

World Wide Study of the Physics and Detectors for Future Linear Colliders

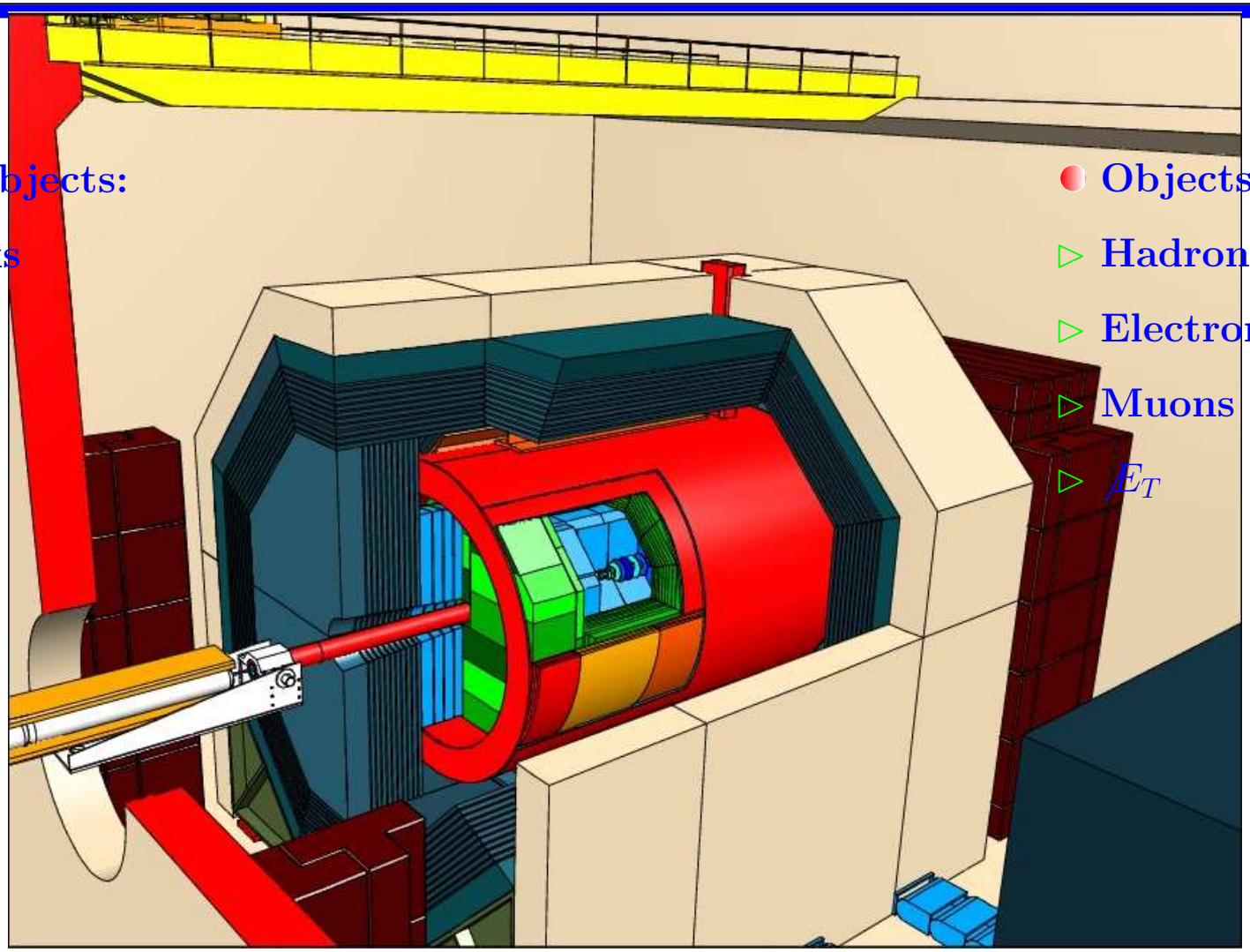
- Ongoing studies of physics and detectors carried in Europe, America and Asia with $\approx$ 2 regional meetings to report progress and coordinate local efforts. (Additional organization for the accelerator activities.)
- The World Wide Study fosters working relations between participants of the regional studies by organizing regularly the Linear Collider Workshops (the LCWS series, next Paris 2004).
- Many new theoretical ideas explored and large number of final states in the e^+e^- collisions and other beam options simulated.
- Physics case for high energy Linear Collider has been well developed and articulated in many written documents or reports: LCWS proceedings, ECFA-DESY Workshops and TESLA TDR, ACFA Workshops and JLC Roadmap, North American LC Workshops, Snowmass2001, White, Orange,... papers.
- LCWS Series of international meetings with inputs from regional studies have been vital to making the case.
- **Large group of physicists worldwide wants to build a TeV class Linear Collider starting at 0.5 TeV as the next international accelerator facility.**
- The idea endorsed by Asian, European, International - Committees for Future Accelerators, HEPAP, German Science Council, also reviewed by Global Science Forum (OECD).
- Become a signatory of the document "Understanding Matter, Energy, Space and Time: The Case for e^+e^- Linear Collider". http://ww-flc.desy.de/lcsurvey/

Physics and Detector Goals

- Physics goals involve 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 Unexpected Physics
- Many open issues for LC detectors and accelerator.
- Detector R&D devoted to the LHC helpful, but not sufficient.
- Goals of LC detector studies aim at development and optimizations in the following areas:
  - ▷ finely segmented calorimetry for energy flow measurement
  - ▷ very thin pixel vertex detector
  - ▷ integrated readout
  - ▷ development of cost reduction strategies
- Understand beamline-detector interaction
  - ▷ IR layout -masks, Final Focus
  - ▷ beam-beam interactions, Lumi spectrum, polarization, backgrounds, bunch structure

Object Oriented Detector Design

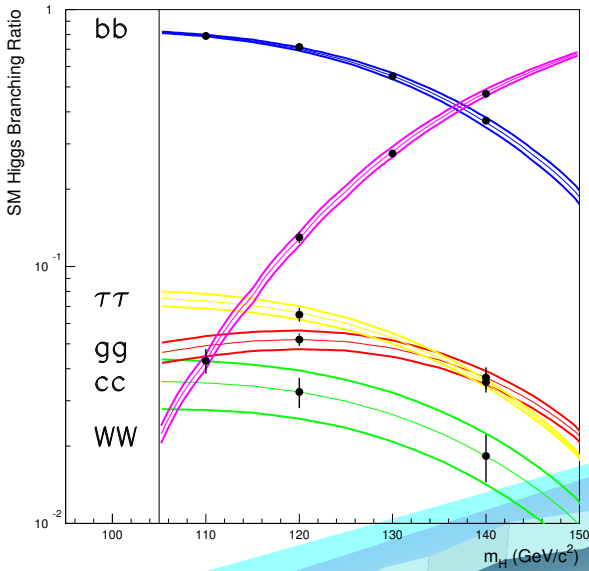
- **Physics Objects:**
  - ▷ b, c quarks
  - ▷ t quarks
  - ▷ W and Z
  - ▷ τ leptons

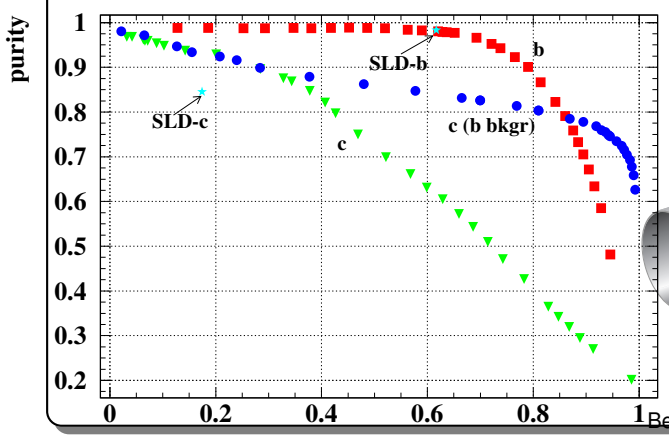


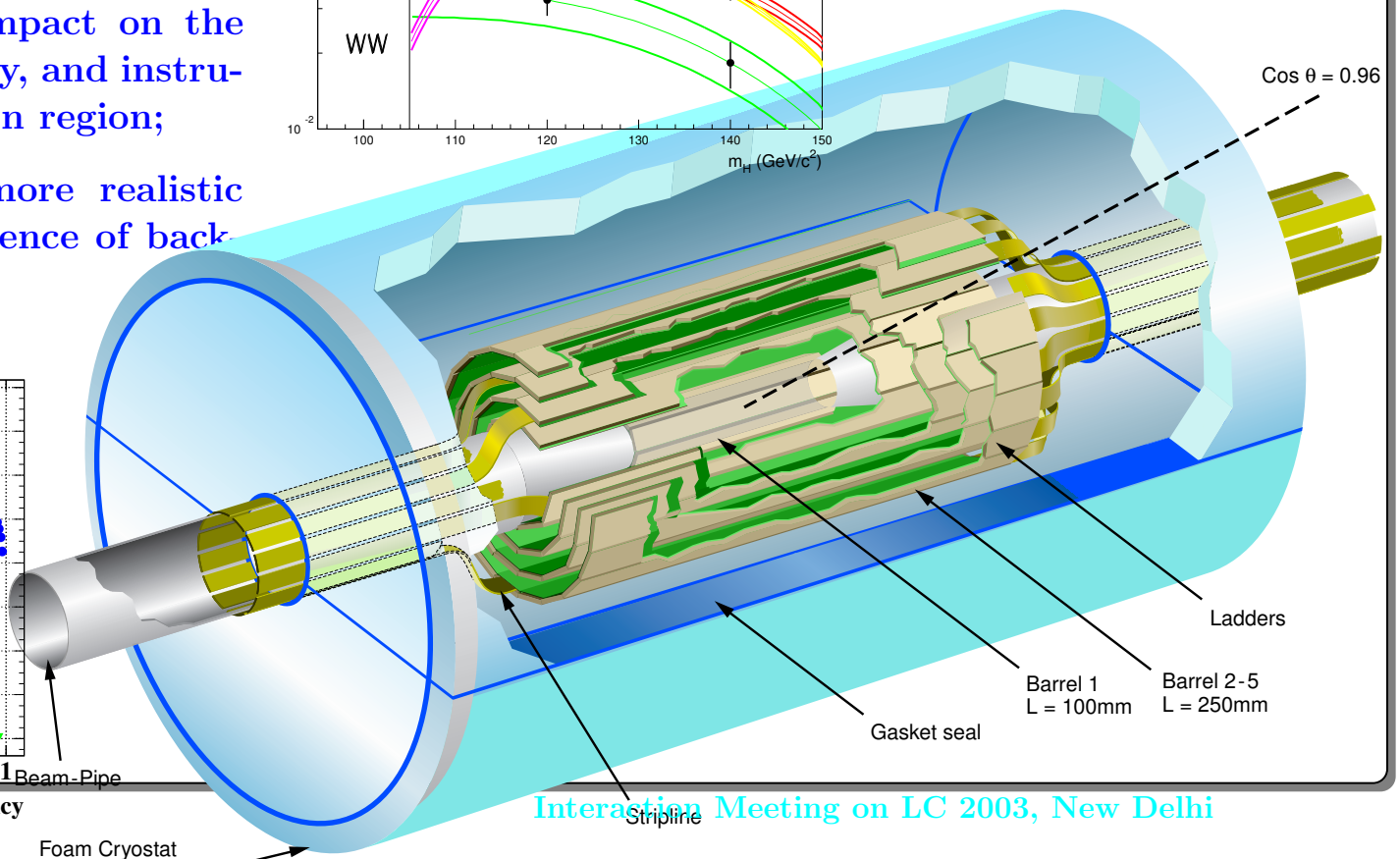
- **Objects Observed**
  - ▷ Hadrons - in Jets
  - ▷ Electrons, Photons
  - ▷ Muons
  - ▷ $\not{E}_T$

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 position 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 simulation and in the presence of backgrounds;

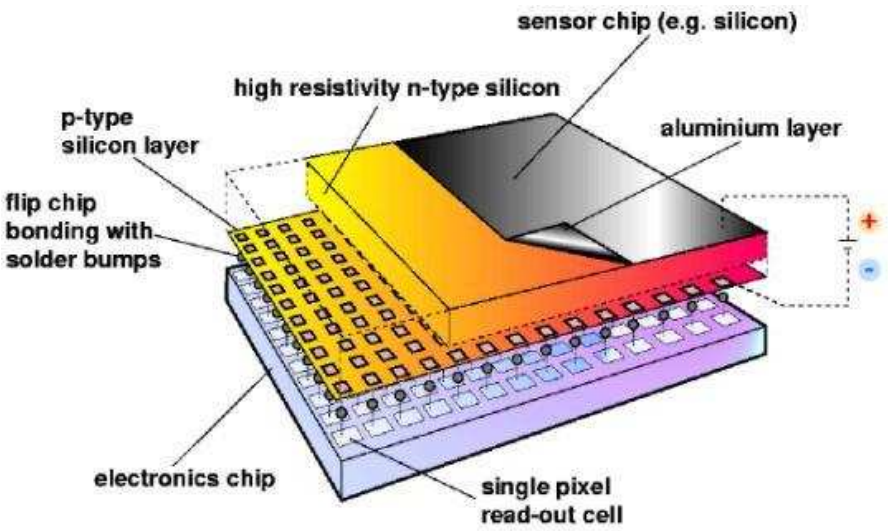


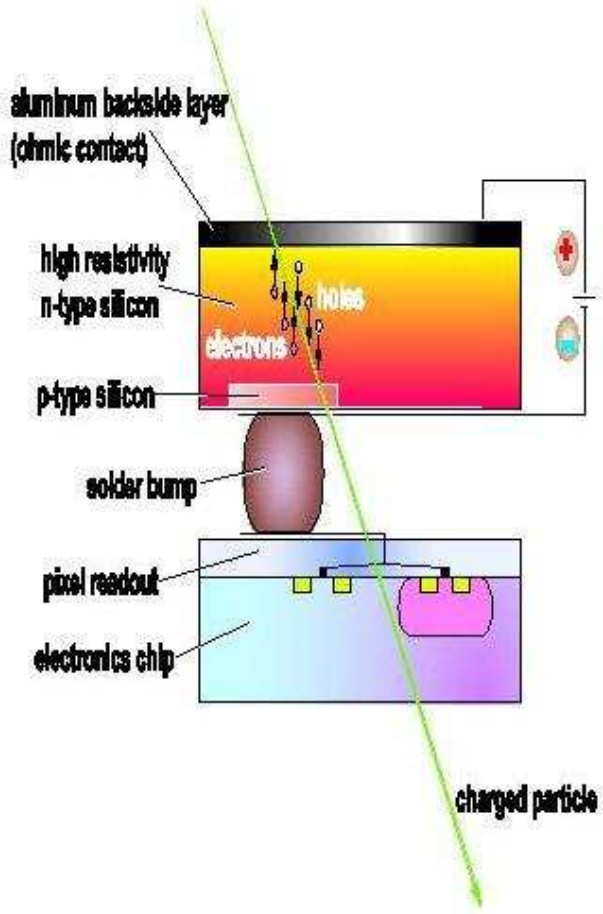




Vertex Detection

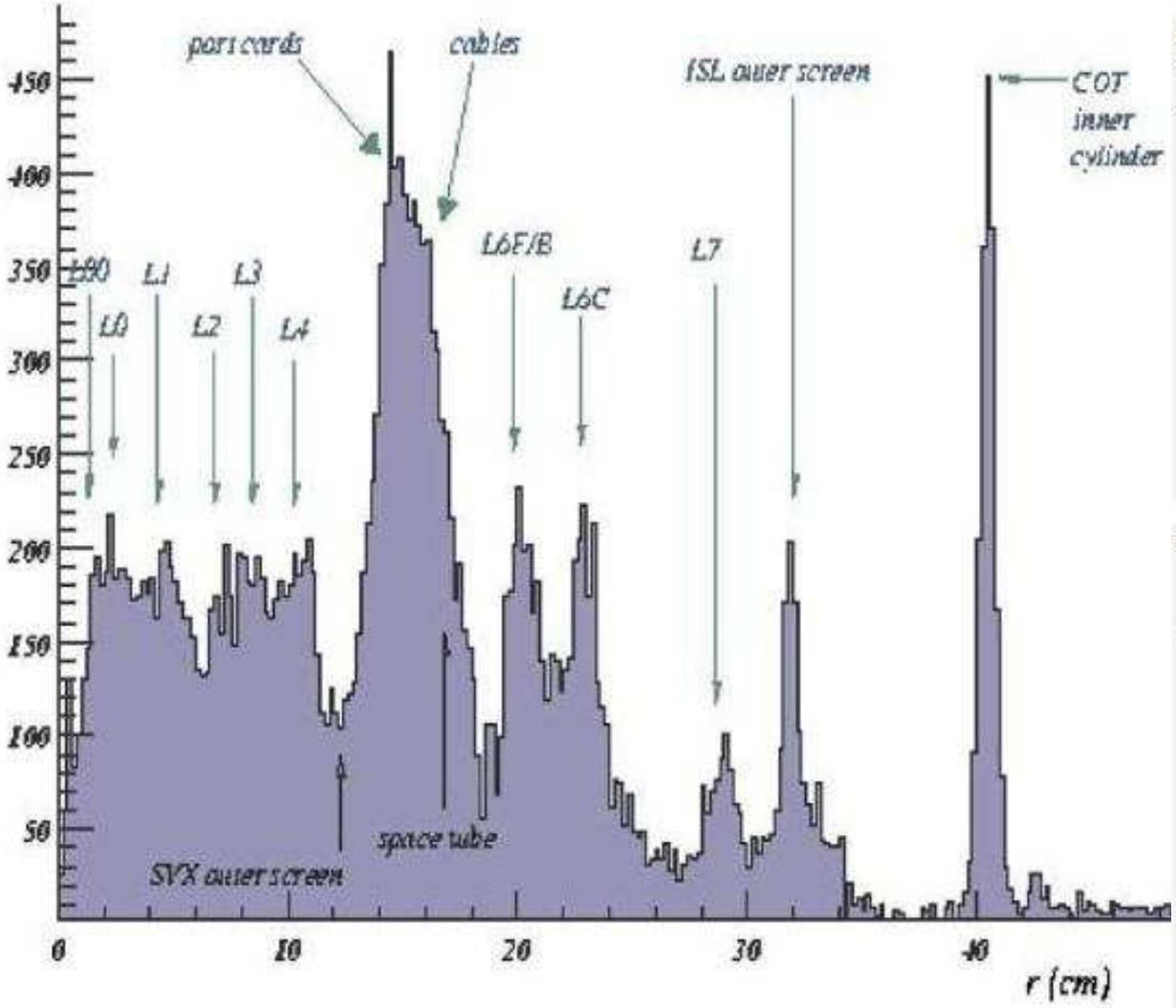
- Develop very thin, radiation hardened sensors, and fast readout to match the time structure of the accelerator.

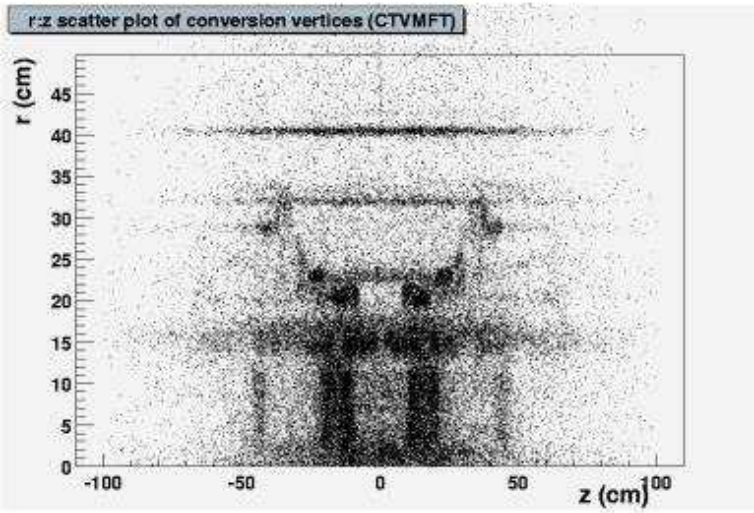


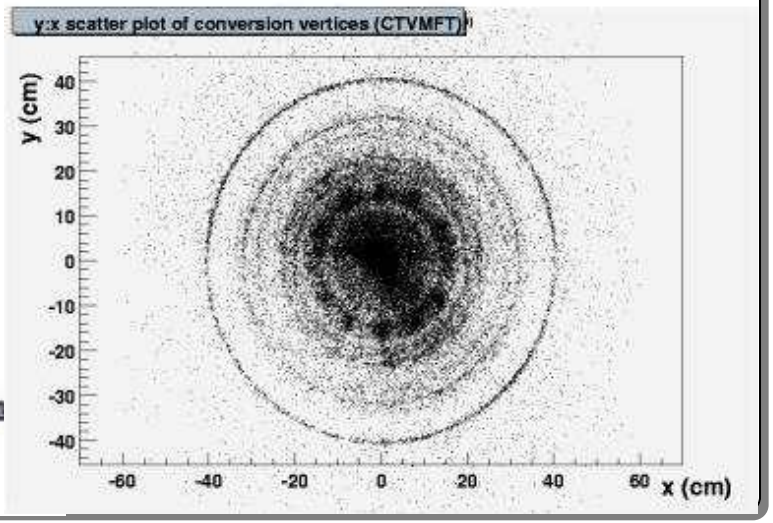


Vertex Detection

- What is the vertex detector mass distribution like?







Vertex Detection

- **Technologies for a Vertex Detector: CCD, MAPS, HAPS, DEPFET,...**

- CCD based VTX detector

  - R&D to improve the limitations: readout speed, radiation tolerance, material budget;

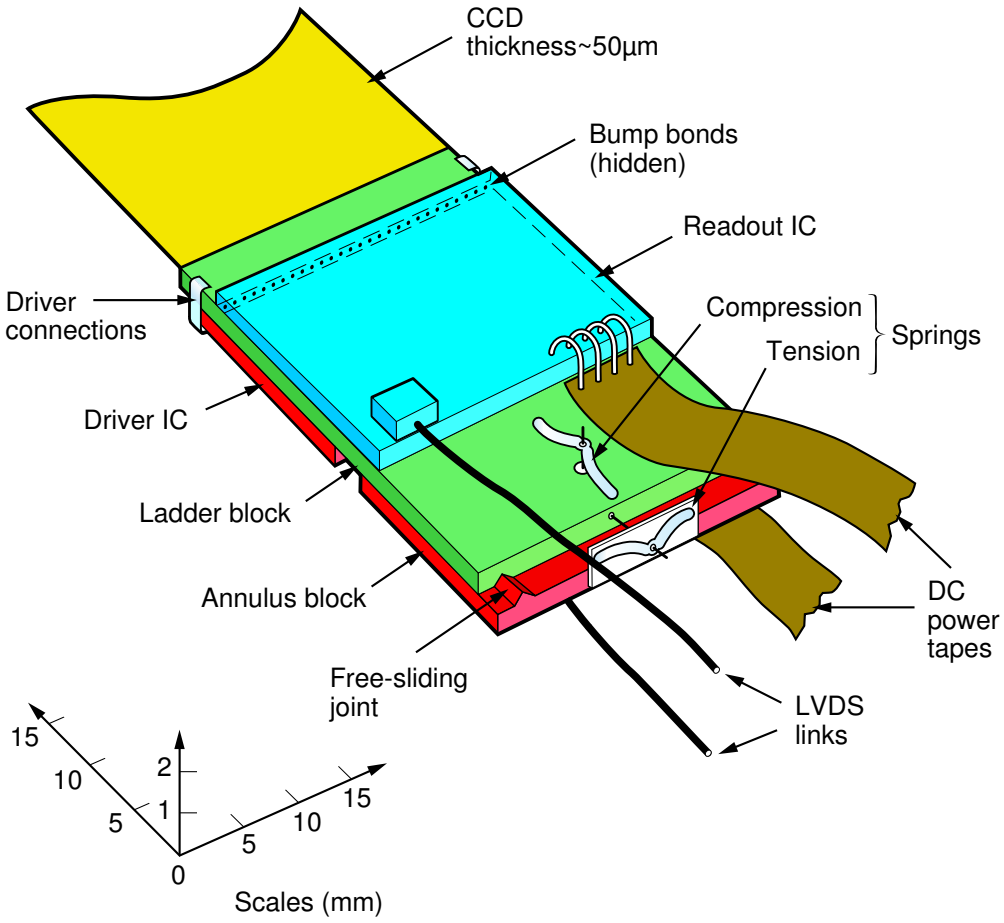
  - development of fast column parallel CCD with readout electronics;

  - 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

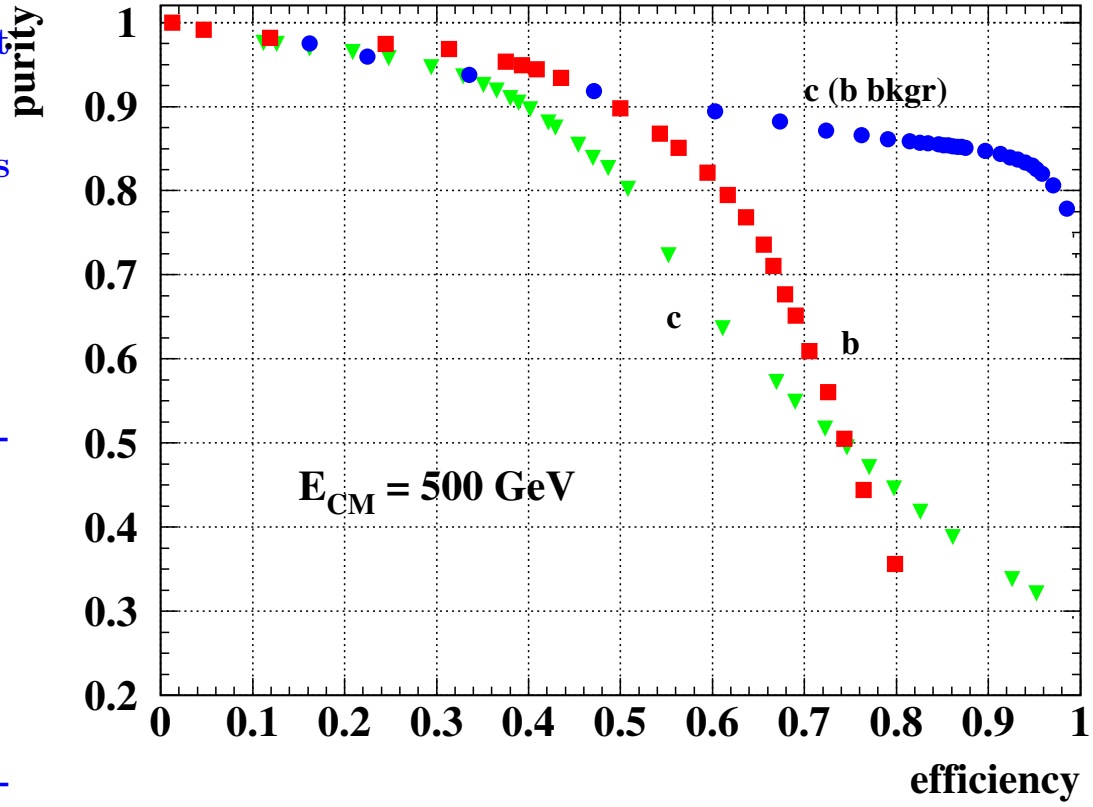
- For all options there is much scope for development, but it is important to push hard for the immense physics prizes.



Performance of a Vertex Detector at 500 GeV

- Simulated tagging performance of a 5-layer CCD vertex detector, LC-PHSM-2003-61 C. Damerell et al.

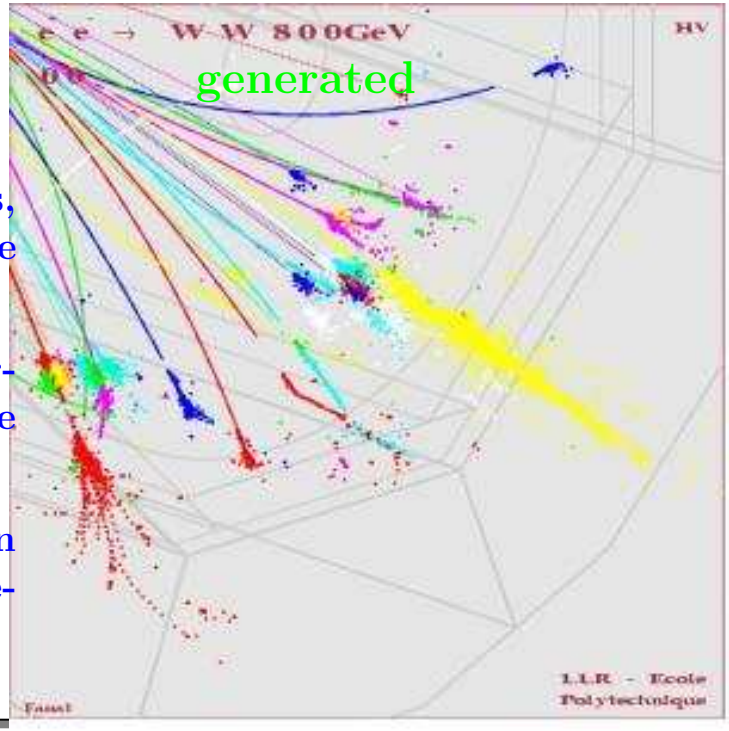
- $e^+e^- \to q\bar{q}$ process considered using Pythia at 91 and 500 GeV in a Tesla detector.
  - 20 x 20 μm pixels, with first layer at a radius of 1.5cm;
  - simplified vertex detector geometry;
  - thin ladder - 0.06%X_0;
- b,c flavours tagged in jets using a NN algorithm;
- Preliminary results of this simplified study:
  - b-tagging worse at higher energy;
  - c-tagging improved at higher energy;
- differences arise from different quark composition and increased fraction of gluon splitting at high energies;

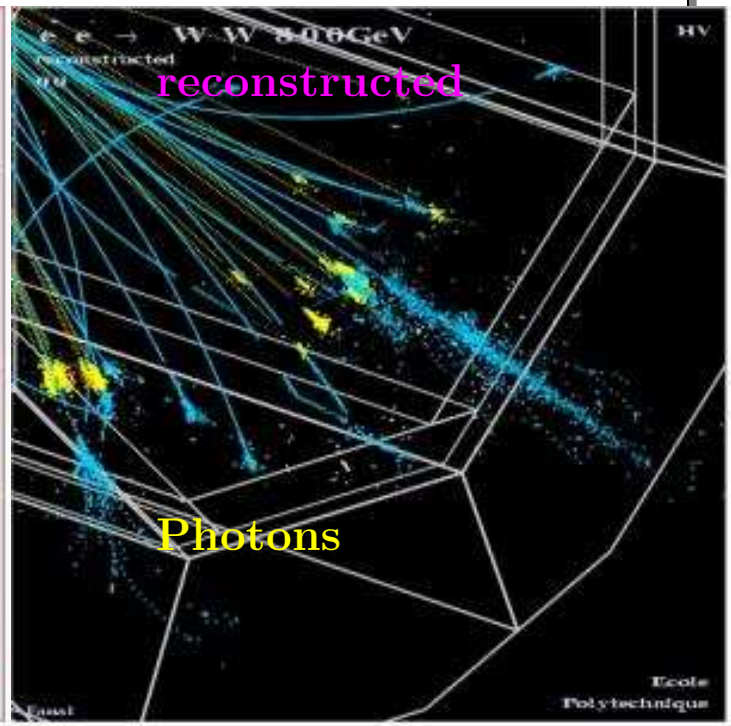


Calorimetry

- At LC environment, energy of isolated charged calorimeter cluster may be replaced by better measured matching tracker momentum.
- Energy flow - combination of two methods of particle energy measurement by tracker and by calorimeter, since charged particles in jets more precisely measured in a tracking detector.
  - ▷ for a typical multijet event: 60% charged energy; 20% photons, 10% neutral hadrons;
- Implementing Energy Flow requires separating charge from neutral energies in Imaging Calorimeter, dense, highly segmented in 3D calorimeter with $\sigma_E/E \sim 30\%/\sqrt{E_{jet}}$ or better.

- The main lines of design:
  - ▷ minimal re-interactions, separate particles in the tracker;
  - ▷ dense, granular and hermetic calorimeter at large distances
- Active interplay between simulation and detector designs.





Calorimeter R&D

- Many calorimeter R&D efforts ongoing or being planned worldwide: CALICE,...

- Current thinking will guide the future calorimeter designs:
  - ▷ new ideas, designs, technologies possible;
  - ▷ development of new reconstruction algorithms;
  - ▷ optimization of designs.

- The future implementation of calorimeters will also depend on the designs and performance of other detector subsystems (tracking...).

Calorimetry

- How to test the Energy Flow or what drives the choice of a detector design?
- Physics limitations, tracking resolution and shower overlaps at high energies have to be addressed.
- In ideal case, if simulation accuracy is in doubts, then build a detector, make an experiment, analyze data, redesign the detector, redo the experiment,...
- Is test beam an option?
  - ▷ Do we need jets or only different particles to validate the calorimeters?
  - ▷ can one make an equivalent of a jet in a test beam; poorly, no W's or Z's.
- Full simulation and verification with the data, or test beams are required to understand limitations to the jet energy measurements.

Simulation Activities

- Several simulation packages available with specific detector geometries and used in regional studies: (Simdet, Brahms, Gismo, Geant3, etc.)
- They played an important role in preparation of various design reports on physics and detector studies, eg. Tesla TDR.
- Longer term goal to move towards modern tools: Object Oriented Software. Huge task!
- Develop a common simulation framework for all LC related studies, shared between regional collaborations.(Java Analysis Studio, root, Geant4, Mokka, ...)
- Need to apply the old and new tools to address specific detector and physics related questions.

General Purpose R&D

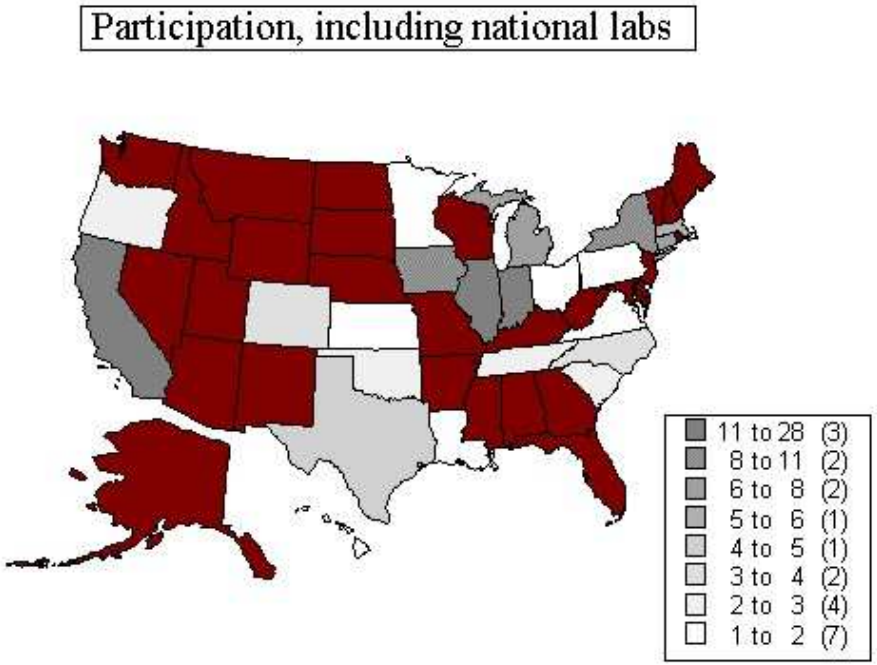
- In response to physics, technological and financial challenges new approaches must be searched for innovative accelerator and detector concepts well before they may be needed.
- Continued, diverse and vigorous R&D programs accompanied by investment are needed for near and far future projects.
- For the near future, define performance of individual detector subsystems indispensable to implement all elements of the physics program at LC, and when necessary explore new technologies in a newly launched international R&D program.
- Such R&D programs were launched in Asia, Europe and America, are 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/∼lc/randd.html

LC R&D in the US in FY03

- 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.
- Fermilab involved in both accelerator (7) and detector proposals: (4).

LC R&D in the US in FY03

- **The US LC Steering Group set up a review of proposals separate for detector and accelerator and submitted the proposal to DOE and NSF on October 15th 2002.**

- *http://www.hep.uiuc.edu/LCRD/html_files/proposal.html*

- **Work on other topics possible - US contacts: Brau, Chakraborty, Finley, Jaros, Mallik, or Tkaczyk.**
  http://www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm
  http://blueox.uoregon.edu/ ~ jimbrau/LC/ALCPG/

- **The program will be funded in FY2004 and beyond!**

LC R&D at Fermilab

- Dedicated group of people identified, with modest budget and access to technical help: (Engineering groups, Scintillator Extrusion Facility (w/NIU), Detector R&D and Assembly Facilities, ASIC Design Group, Silicon Detector Facility, Test Beam Group, Computing and Simulation Group, Physics Research Equipment Pool,...).

- Collaborating with wider LC community, national and worldwide, and involved in LCRD/UCLC proposals.

- Projects of interests related to Muon Detection, Prototyping of Vertex and Tracking Detectors, and Calorimetry, with additional participation of ASIC and Scintillator Development Groups.

- Meson Test Beam Facility - versatile beamline to test detectors in a beam of energies 5-120GeV at moderate intensities (<1MHz).

LC R&D Projects at Fermilab in FY2003

- Muon R&D projects, jointly w/ Wayne State, UC Davis, NIU, Notre Dame, address studies of properties of scintillators and fibers, development of the prototype readout for test modules, development of the related software.

- Calorimetry projects, jointly with UTA, ANL and ASIC group, address designs of prototype readout of a multi-cell GEM device and RPC.

- Vertex projects (w/ Purdue, BU, U. Oklahoma) study the mechanical behaviour of thinned Silicon, and development of an LC ASIC for CCD readout and data reduction.

LC R&D Projects at Fermilab in FY2004 and beyond

- Continue with projects started in FY2003.
- Begin development of detector and physics simulation software. NIU already involved in international efforts to develop Geant4 based software for physics simulations and detector response studies.
- Development of Monolithic Active Pixels chips in new CMOS processes, and associated readout control chips.
- Design of ASIC readout electronics for GEM/RPC detectors.

Conclusions

- Large, international group of enthusiastic and vibrant physicists working on the Linear Collider project.
- Fermilab is an active member of this group.
- Linear Collider R&D efforts around the world are progressing toward affordable machine and detector designs meeting the energy, luminosity and precision goals.
- We invite you to get involved in Linear Collider R&D while the international effort ramps up. Your expertise is valuable!