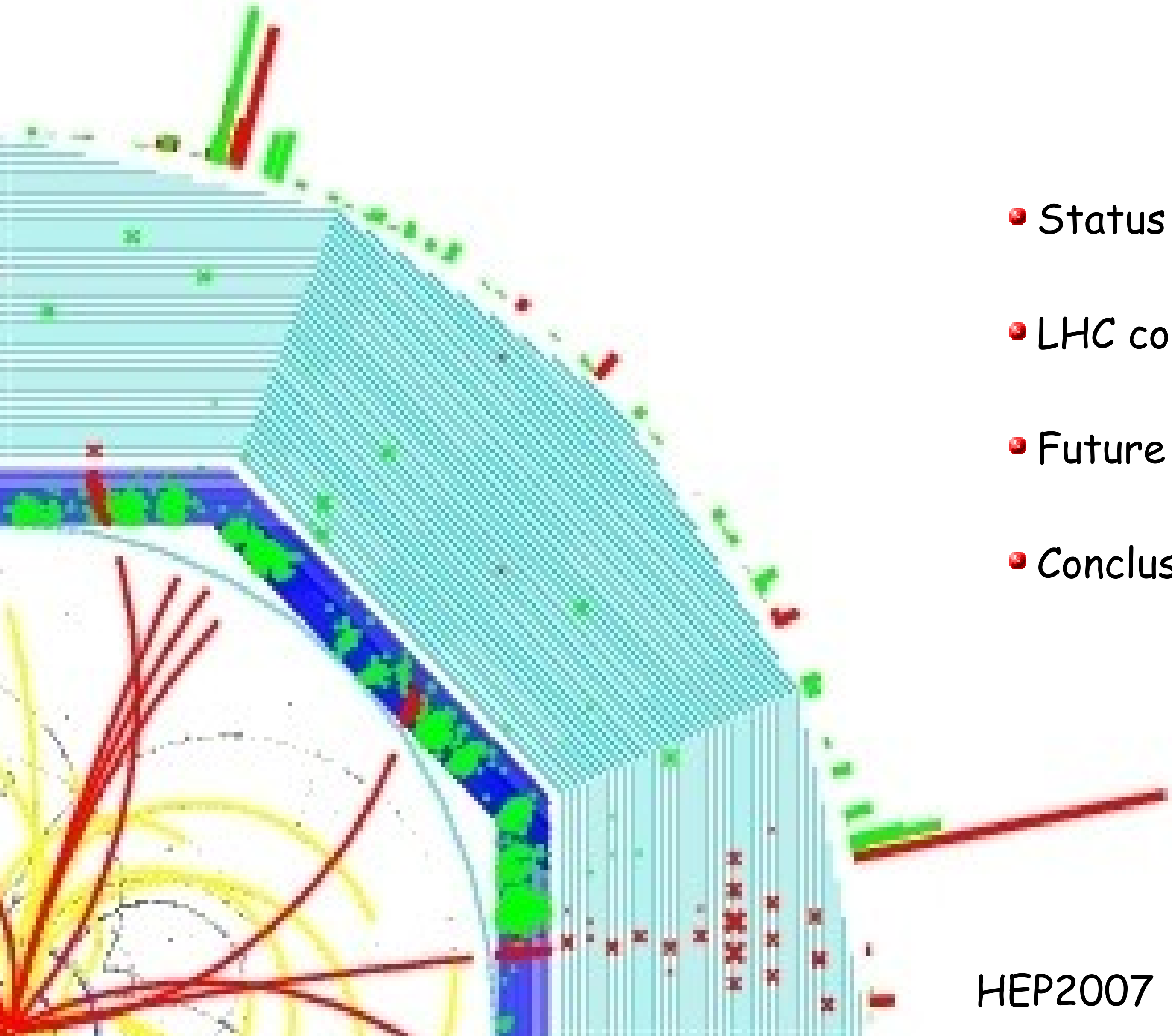
Detectors

Ties Behnke, DESY



- Status of the field
- LHC commissioning
- Future Projects and Directions
- Conclusions and Outlook

HEP2007 Manchester 19-25 July, 2007

Today

- LHC is “about” to start, but Detector development finished
- Major R&D projects are on the horizon: sLHC, ILC
- Physics prospects are exciting and challenging
- Both accelerator based and non-accelerator based experiments push the limits of what can be done

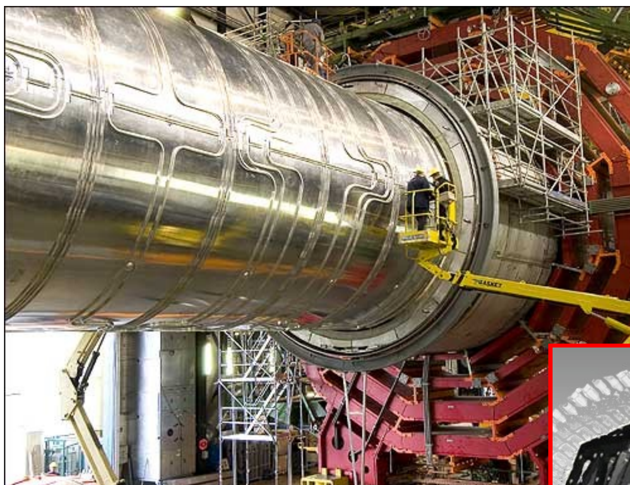
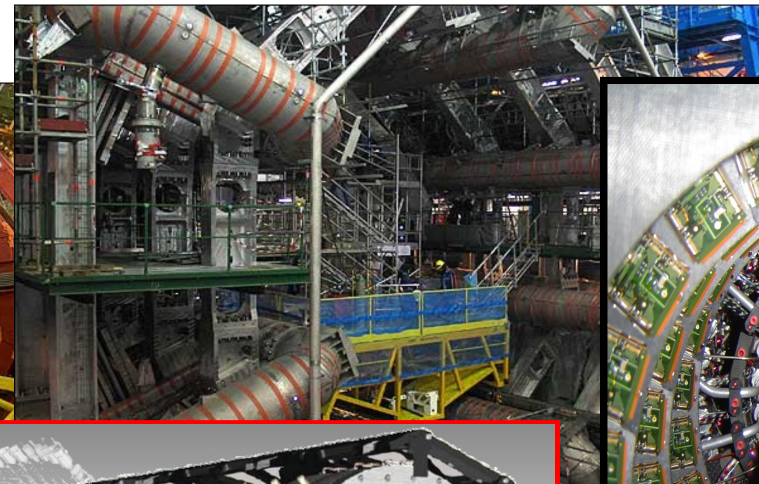
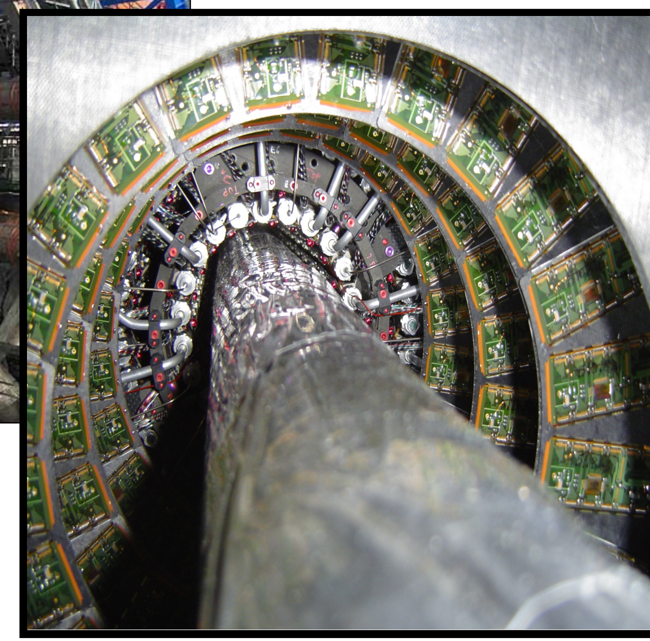
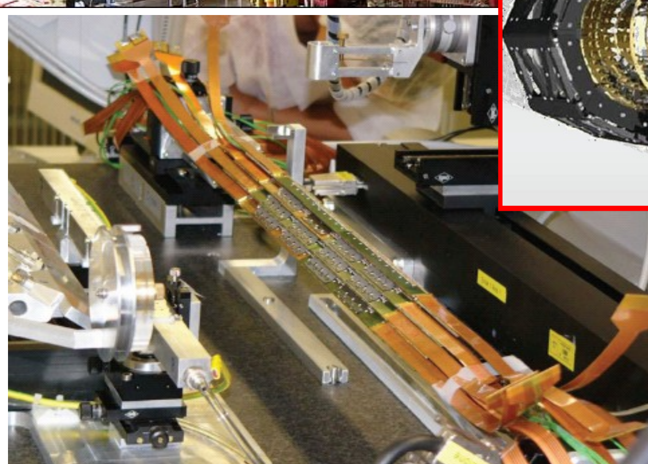
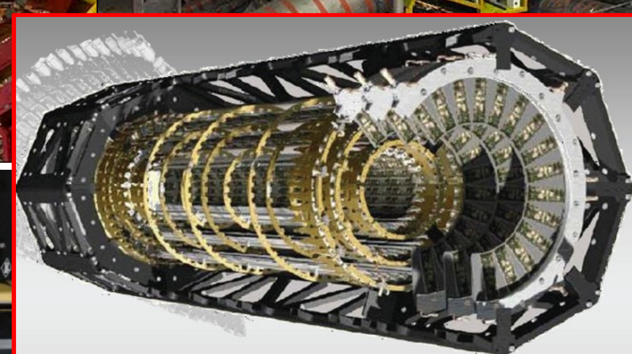
Accelerator technology is advancing rapidly

Detectors are critical if we are to fully utilize our capabilities

R&D is driven by the physics program and requirements

LHC: the near Future

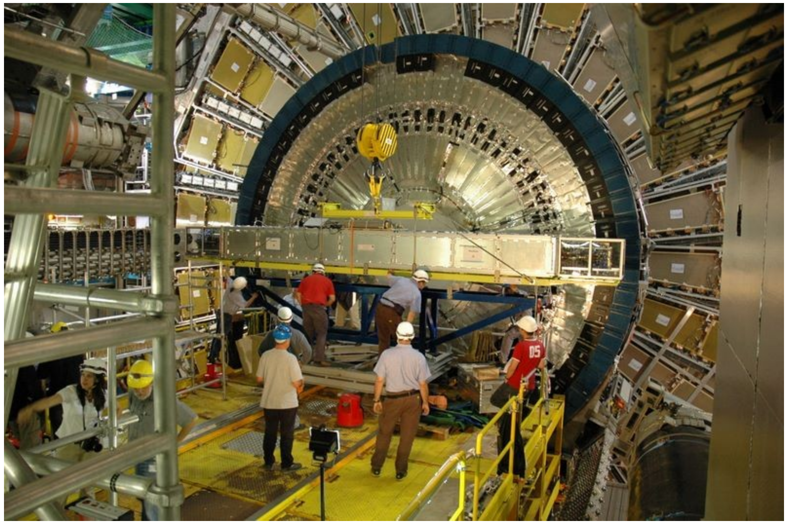
Detector Commissioning at the LHC is in full swing / close to finished

Major installation effort
Major alignment effort
Major integration effort
Major data handling effort

ATLAS Installation

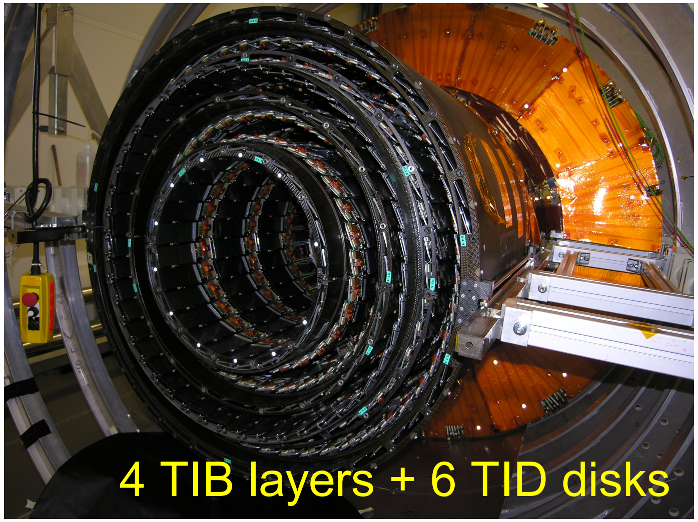
- Pixel Package Lowered; 25 June
- Pixel Package Installed; 29 June

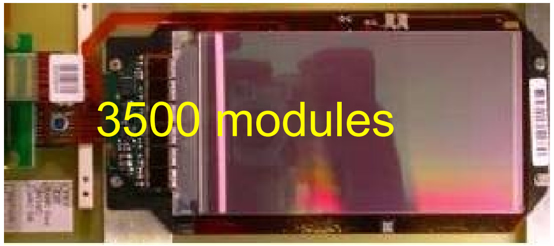


ATLAS installation is well advance
Integration and commissioning is proceeding
Intend to be ready when LHC turns on

A. Andreazza, F. Tarrade, D. Damazzio, C.Schmitt, T. Goettfert, F. Petrucci, P. Miyagawa, A. Nairz, T. Pauly, R. Gonzalo

CMS Installation



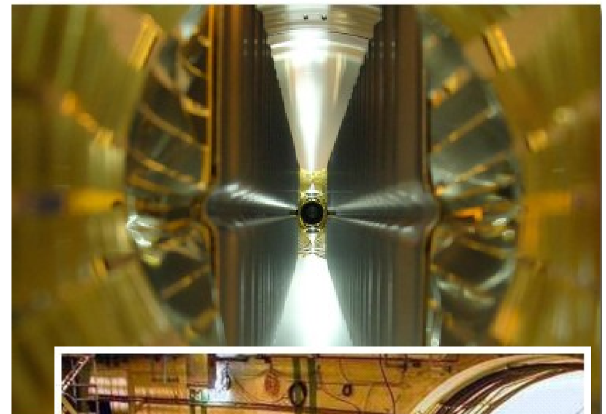


Detector successfully installed in cavern
Tracker, calorimeter barrel installed
Pixel soon to come
Endcap calorimeter under construction

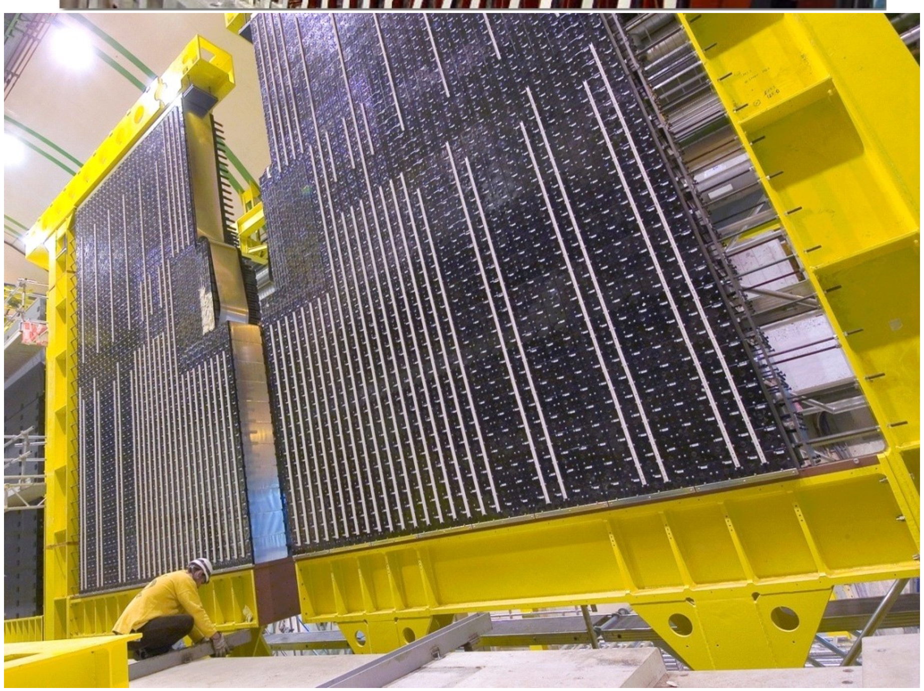
A. Satpathy, C. Wulz, RM Brown, W. Erdmann, S. Malik, M. Fernandez-Garcia, T. Boccali, A. Oh, P. Bargassa, H. Sakulin, I. Tomalin

LHCb Installation

VELO Installation/ Status



Rich in the cavern



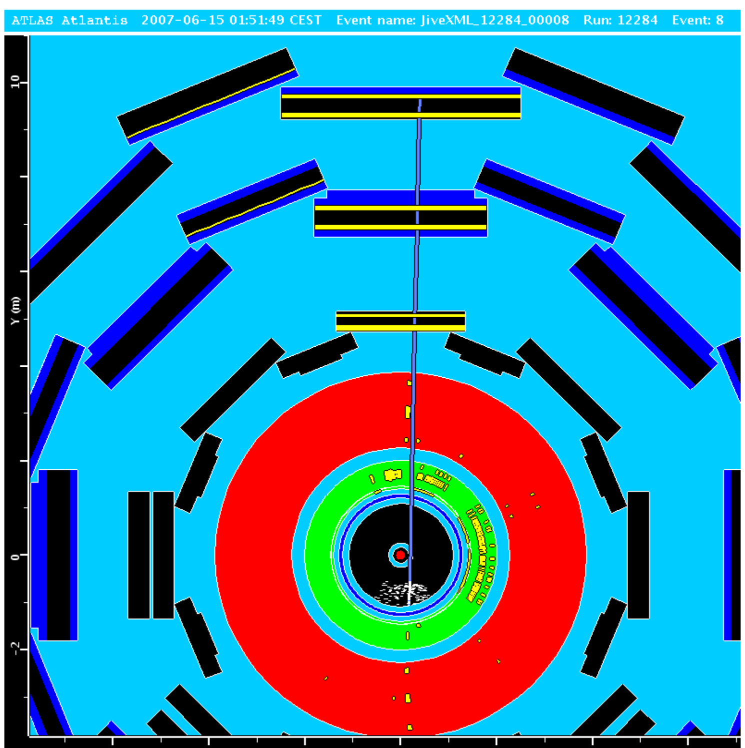
Calorimeter

H. Terrier, O. Behrendt, U. Kerzel, F. Macherfert, C. Parkes,

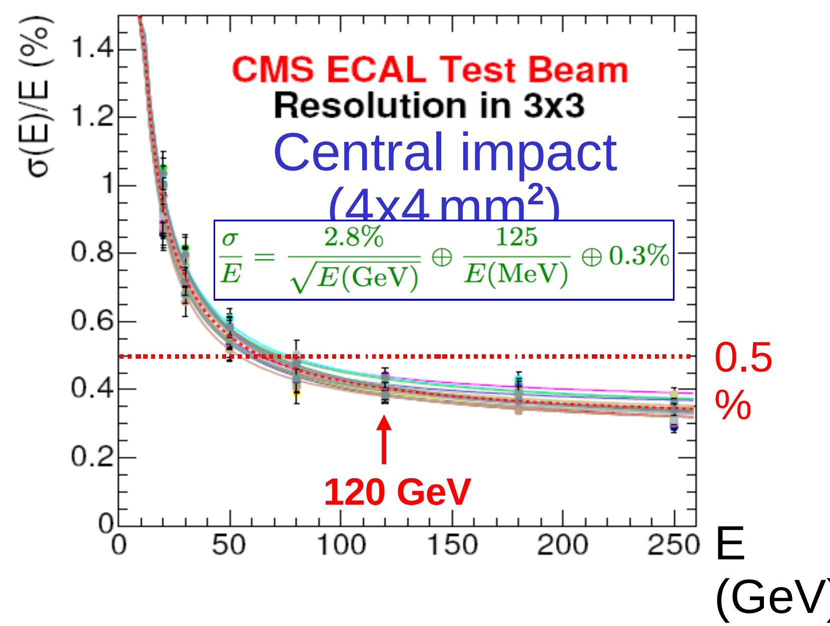
The Challenges now:

- Commissioning (integration of many systems, common DAQ, data handling...)
- Concerns hardware and software

Event display from cosmic run
with combined calorimeters in ATLAS



CMS barrel crystal calibration
(test beam)



Much more in parallel session talks

Future Projects

Accelerator based experiments:

LHC upgrade -> sLHC

ILC

Super - B

All pose challenges to the experiments

More immediate projects:

which are in many cases surprisingly similar

Neutrino beams (T2K, FNAL, ..)

Non – accelerator based experiments

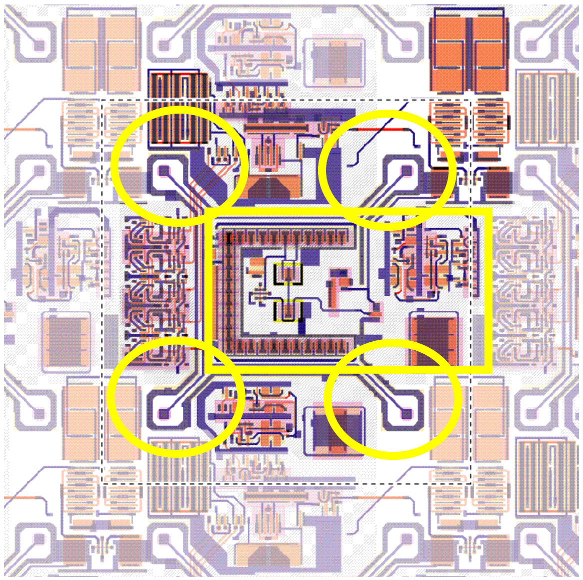
FROM TOKAI TO KAMIOKA

JHF ν long-baseline neutrino-oscillation experiment at J-PARC

NEXT GENERATION LONG-BASELINE NEUTRINO OSCILLATION EXPERIMENT

Technology trends

Technology enables advances in detectors



Pixel cell for SI-pixel based ECAL (N. Watson)

- Segmentation
  - Small pixel sizes
  - Small cell large volume calorimeters
  - Advanced gas detectors
- Speed
  - Faster, higher bandwidth
  - Low noise
  - Low power
- Feature size/ Integration
  - Cutting edge technologies
  - Functionality moves into the front end
- Materials
  - Novel materials: thin detectors
  - Optimized mechanical integration

Segmentation

A global trend: larger and larger segmentation

LHC/ sLHC: deal with large occupations and backgrounds

ILC:

- need extreme precision
- deal with backgrounds (Vertex Detector)
- do "tracking with a calorimeter"

Driven by technology:
price ~ area,
not # of channels

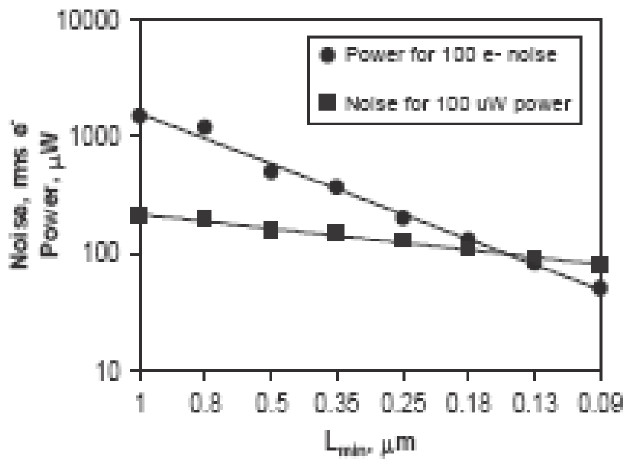
ILC examples of proposed granularity:

- Silicon Tungsten Calorimeter 9×10^7 cells (5x5 mm2)
- Vertex Detector 9×10^9 pixels (20x20 μm2)

Without the technology the physics will suffer

Speed/ Power

- Speed is often a critical parameter
  - SLHC: event pile-up, background rates
  - ILC: Background close to IP, bunch structure
  - Super B Factory: similar issue



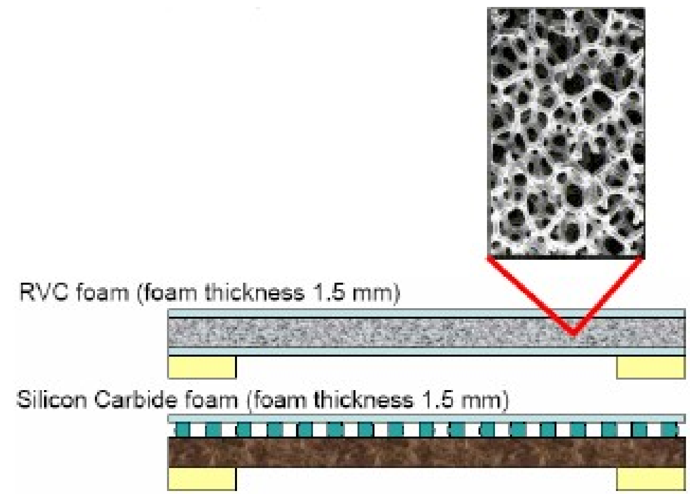
- Power is closely related to that

  - "Power in – Heat out"
  - Particularly important for large number of channel systems
  - Important design consideration with potentially large consequences

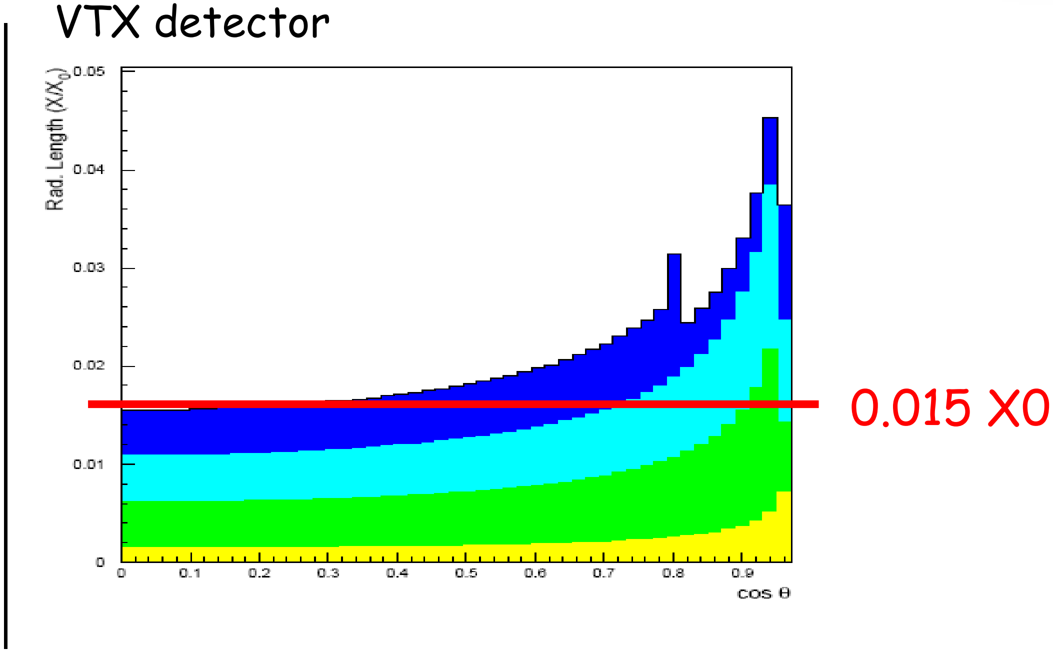
Material

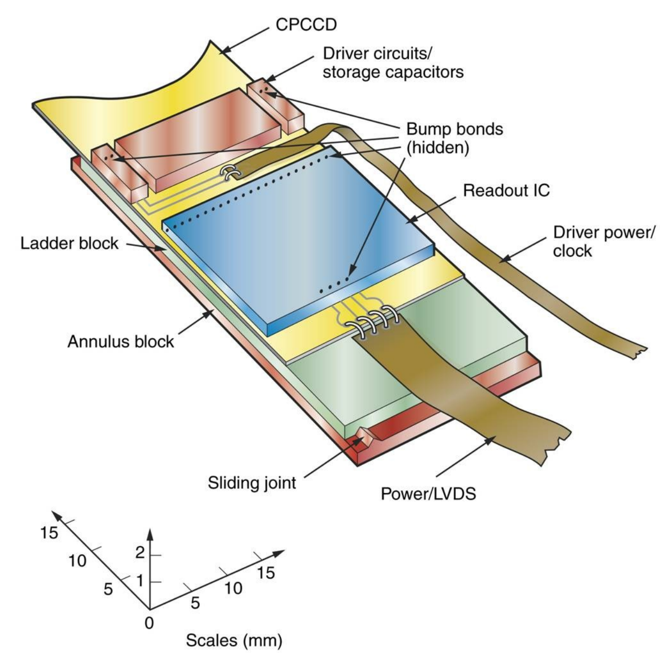
Low material detectors are of central importance for many applications

Skilled engineering becomes a major asset/ problem/ requirement



Estimated material budget for a ILC VTX detector

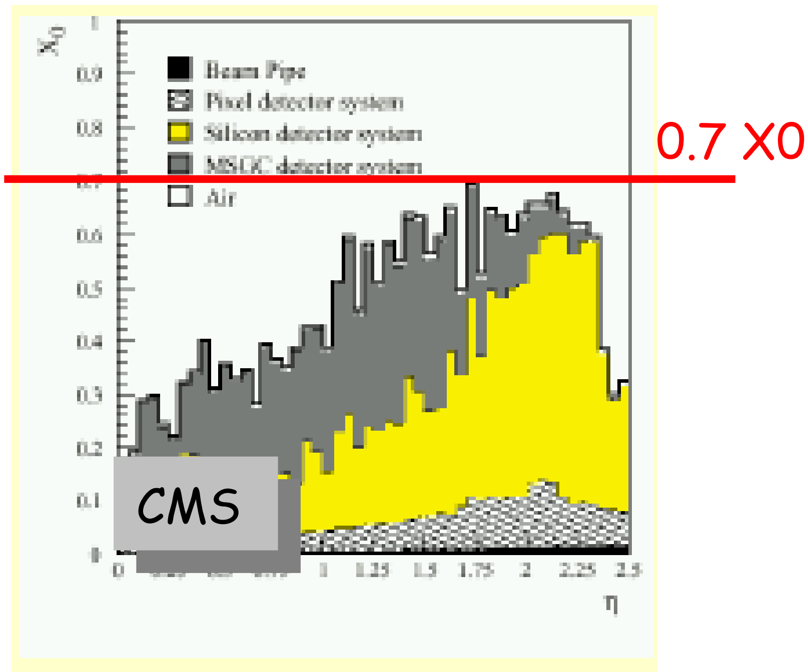




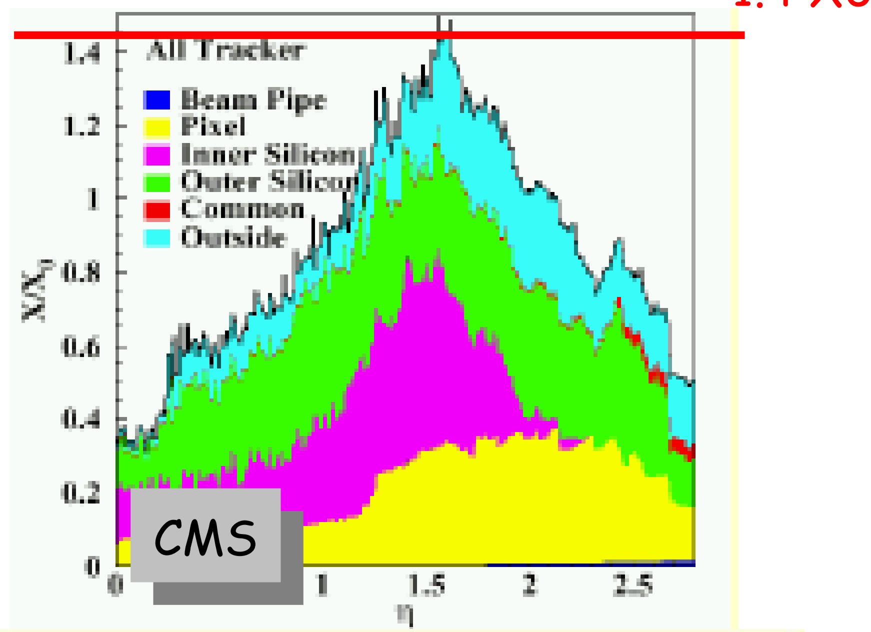
Materials: from Concept to Reality

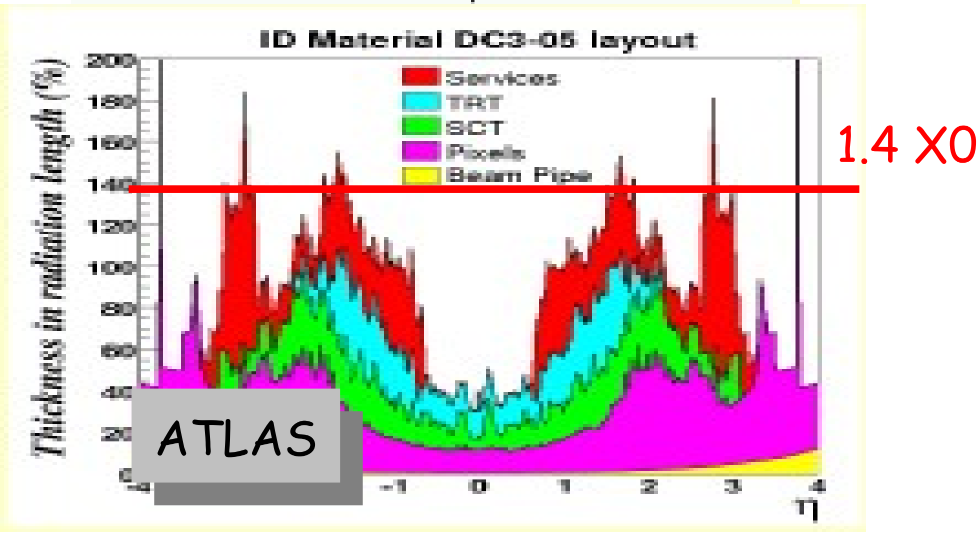
Major difference / advance to LHC detectors is needed:

The detector TDR 1996



... and the reality 10 years later





sLHC Detector Challenges

Radiation

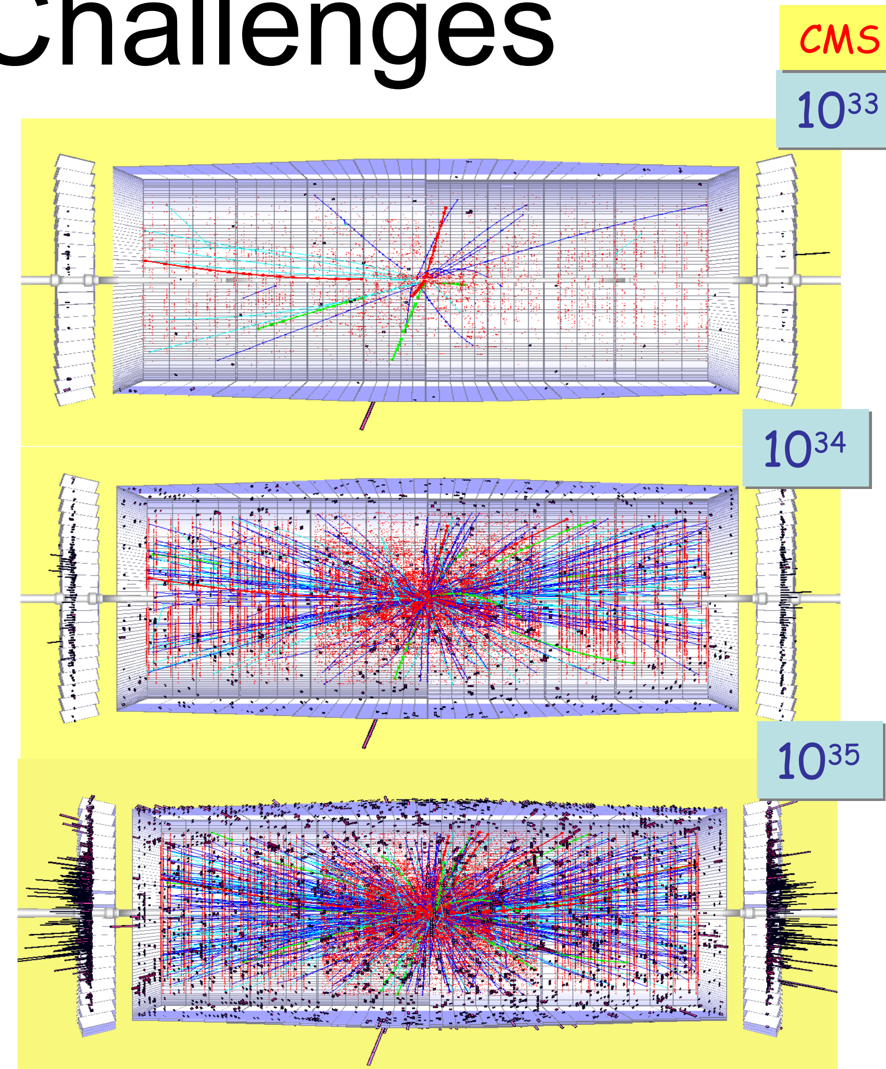
$-10^{16}/cm^2 @ r=5\,cm\;(\;400\,MRad\;)$
$-10^{15}/cm^2 @ r=20\,cm\;(\;40\,MRad\;)$
$-2\times10^{14}/cm^2 @ r=50\,cm\;(\;10\,MRad\;)$

-> Technology

Pileup

200 interactions / crossing
$dN_{ch}/d\,\eta(\eta=0)=1500$

-> Geometry



I. Dawson

Huge number of forward-going tracks, mostly low pt

The biggest challenge is for the tracker

SLHC Tracking issues

Radiation is main concern:

- radiation hardness
- occupancies

SI-strip detectors:

OK for r>60 cm,
pitch of 80-160μm
need to operate at 2xLHC tested fluences

“Standard” pixel detectors

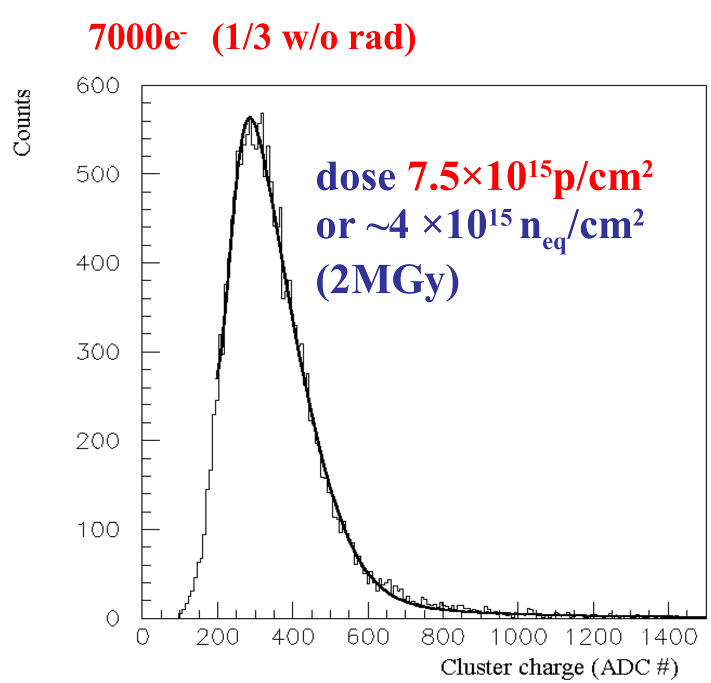
Can work between 20cm < r < 60 cm
through pixel size = 1/10 current strip cell,
10 times current pixel size

New technology pixel

Feature size 50μmx50μm
many ideas: CVD diamond, monolithic pixel, ...

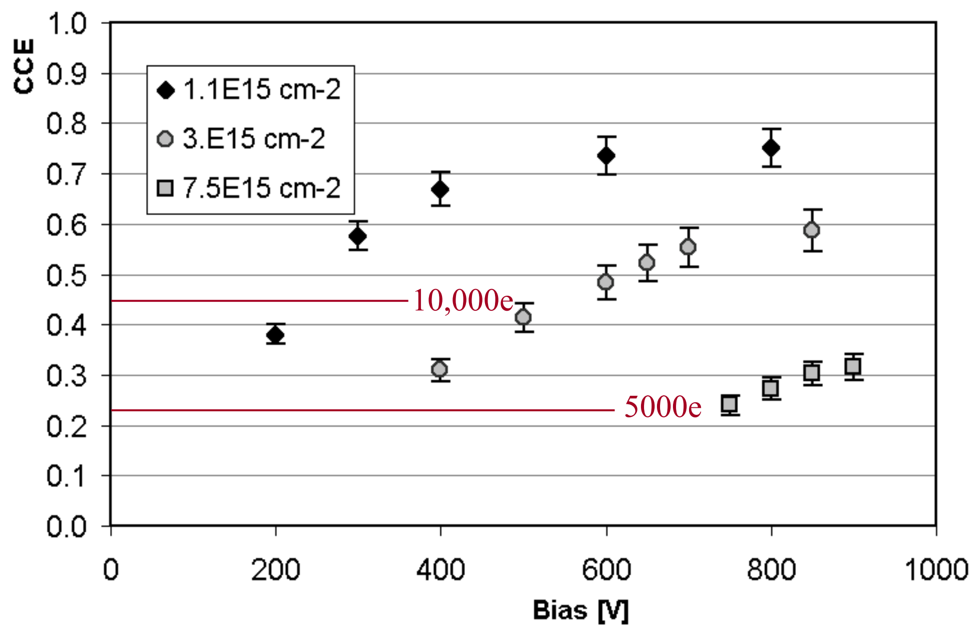
Silicon R&D for sLHC

Required:
Silicon sensors able to withstand up to six times the LHC radiation doses.
For pixels at $r \geq 10$cm: require survival to $\sim 6 \times 10^{15}\ n_{eq}/cm^2$ ($\sim 10^{16} p/cm^2$) with Signal/Noise > 10.
(RD50)



Short strip (1cm) prototype detector

Efficiency for different radiation doses



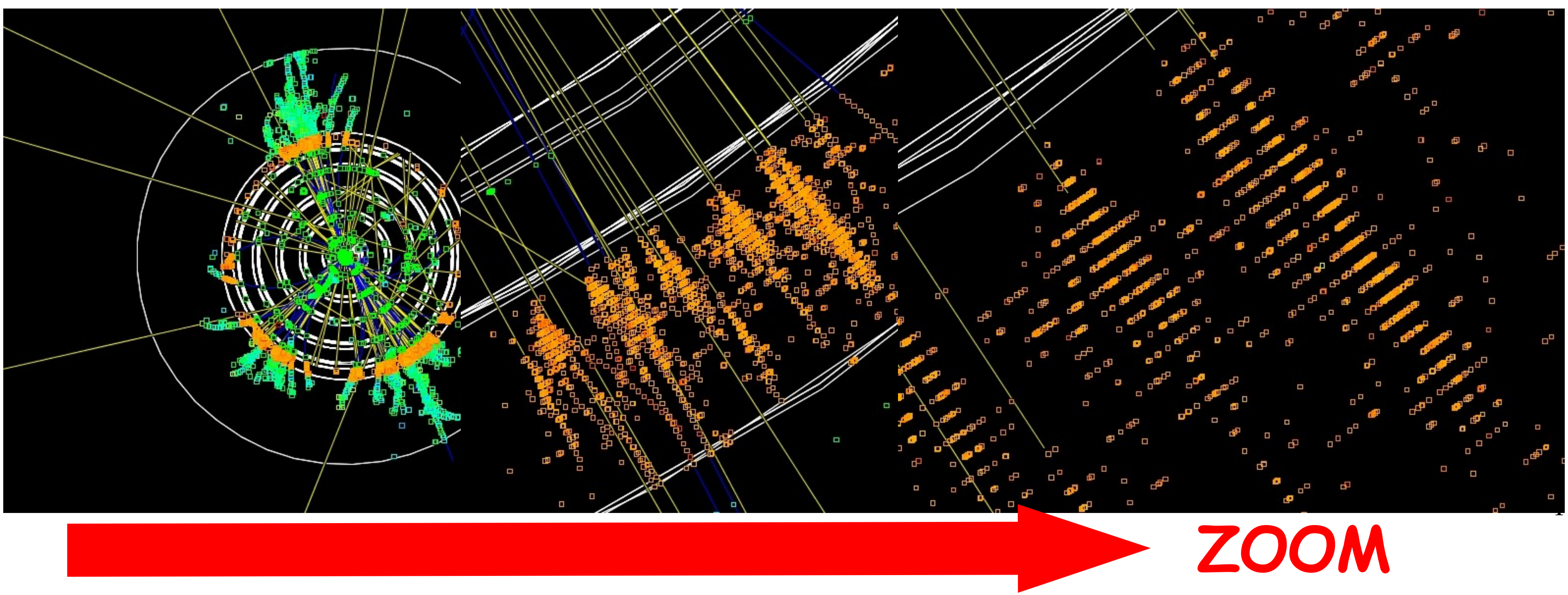
For the innermost layers:
CVD diamond? Maybe Gas (micromegas)?

ILC Detector Challenges

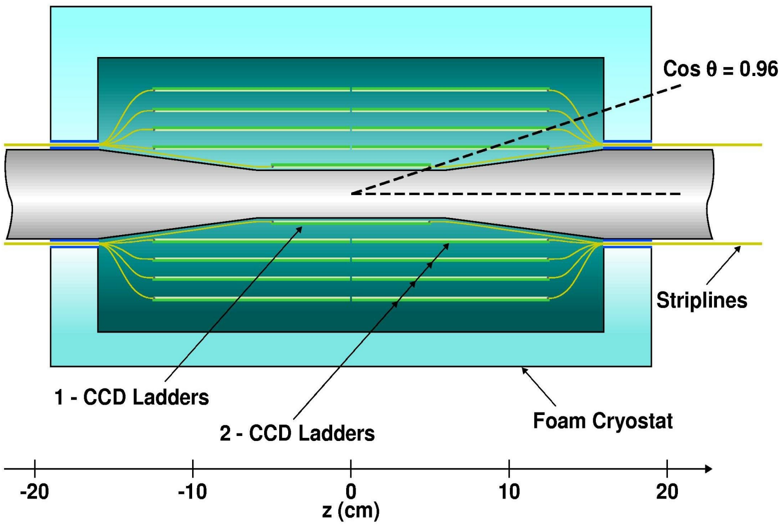
Precision physics in a "low" radiation environment

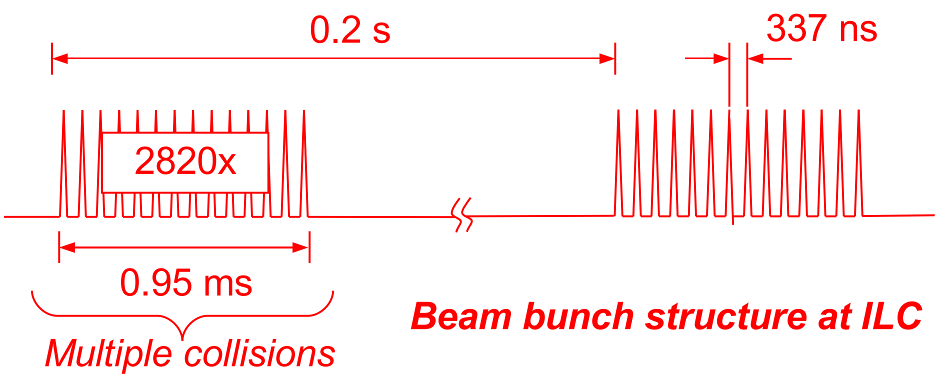
Pixel vertex detectors
high precision tracking
excellent jet mass resolution

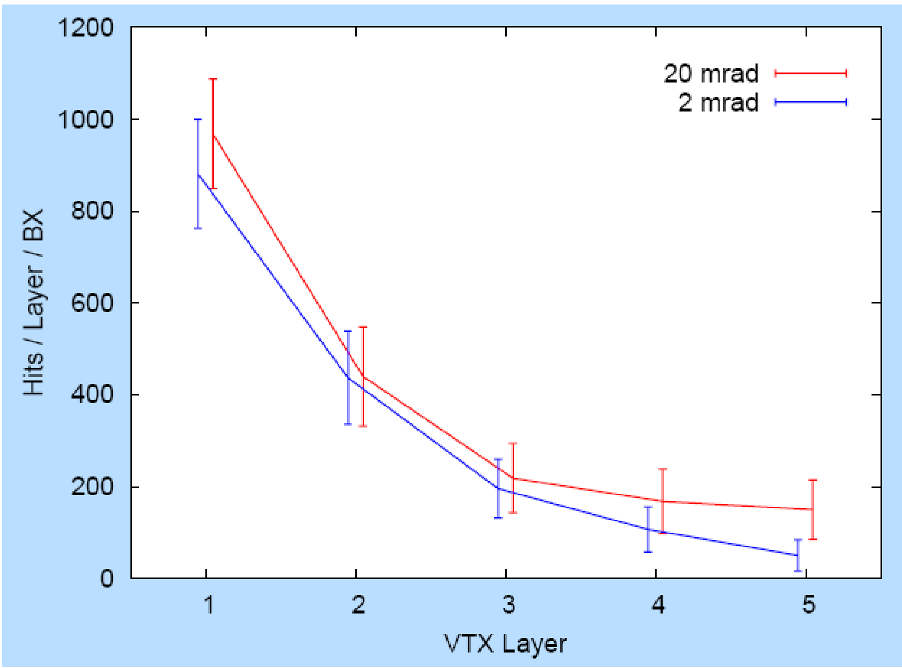
Detailed event reconstruction



ILC Vertex Detector Concepts







Challenges:

- Resolution
- handle the ILC bunch structure (accumulate many bunches in one picture)
- background occupancies
- Goal of < 0.1% X0 per layer

VTX Technologies

readout

- Column Parallel CCD: 50MHz (10cm inner layer read-out both ends)
- DEPFET: low noise deep depletion device 22.5×36μm
- CMOS MAPS: 20 columns of 5mm depth (256 20μm active pixels) at 10MHz

store

- FAPS: in-pixel memory (but compromise # cells and pixel area)
- CCD: in-pixel memory (ISIS) (limited vendors for 20×20μm pixels)
- SoI: deep depletion substrate with vias to CMOS circuitry
- 3D: industrial process multi-tier approach allows mix of technologies

size

- FPCCD: 5μm×5μm pixels read out between bunch trains
- CMOS: 5μm×5μm micro-pixels integrated with 50μm×50μm macro-pixels

Wide variety of technologies are under study

Very active field, lots of progress in the past years

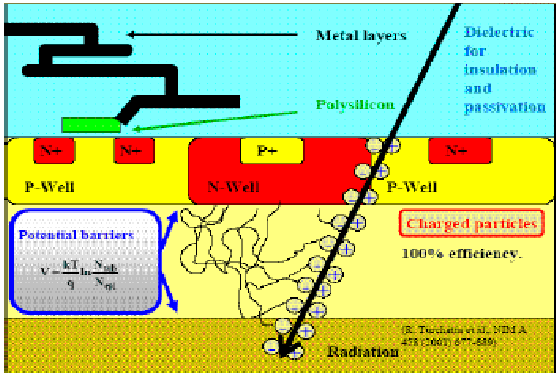
Large overlap with other projects: STAR upgrade, Super B, sLHC: room for common effort? European program under FP7?

Very incomplete list of projects

Vertexing Technologies

MAPS technology

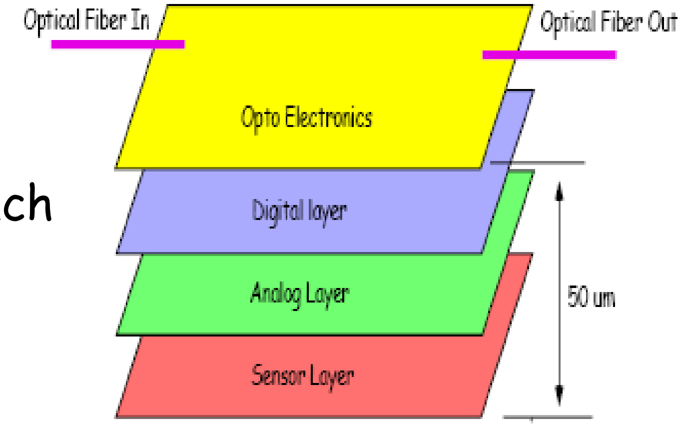
- Active pixel (on pixel electronics)
- Thin sensitive layer: back-thinning
- Radiation tolerant:
  - X-rays tested to few 100 kRad
  - Neutrons tested to 10^13 n(eq)/cm2



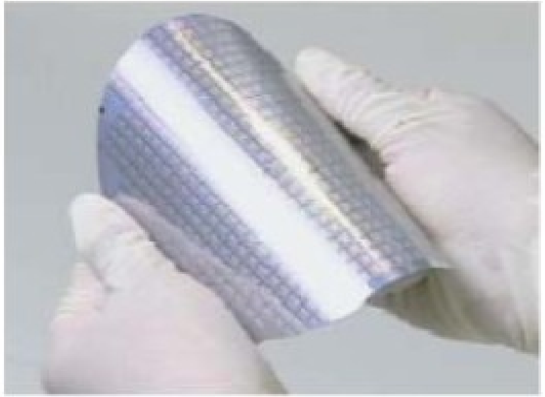
Application of MAPS technology in STAR upgrade, Belle upgrade

3D structures

multi-tier approach allows mixtures of technologies



Designer's Dream

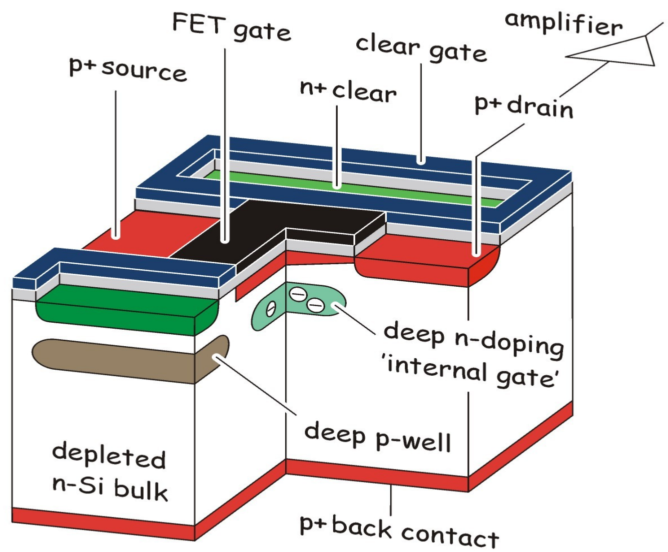


Wafer thinned to 50 microns (leti)

Very incomplete list of projects

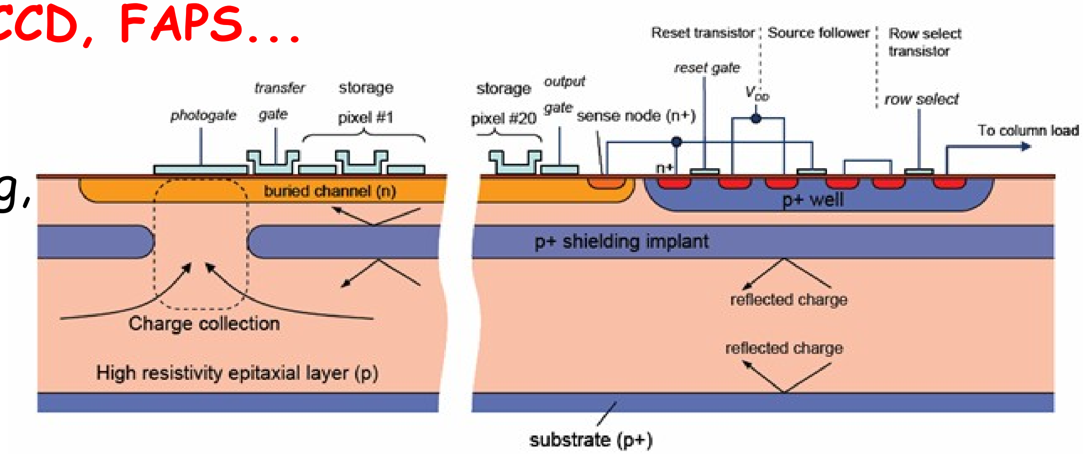
Vertexing Technologies

Low noise, low power technology: DEPFET



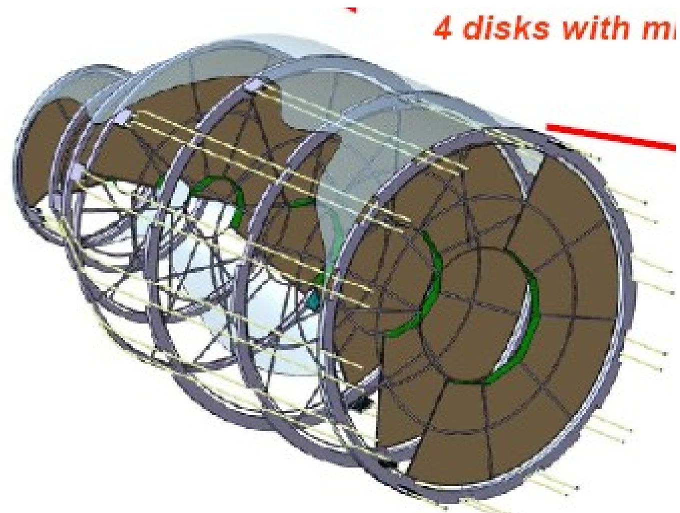
- Fully depleted sensitive layer
- Internal amplification
- Powered only during readout, not during charge collection

Charge storage in the pixel: ISIS, CCD, FAPS...



- Ideal for ILC: fast sensing, relaxed reading
- Little sensitivity to EMI

Tracking technologies: SI tracking



Proposed forward
SI tracking system for LDC

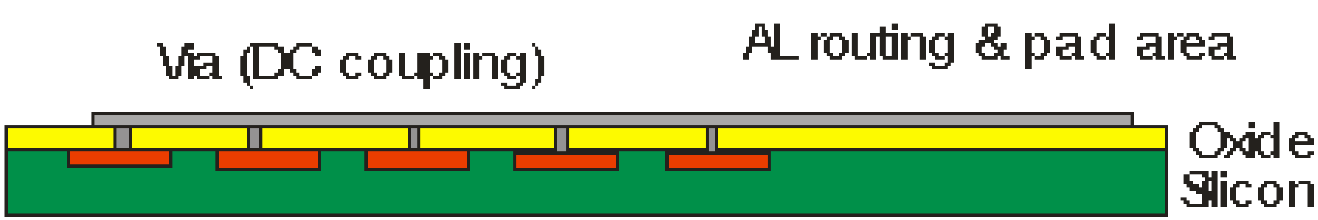
Silicon strip detector developments:

material budget

light support structures

control of thermal load

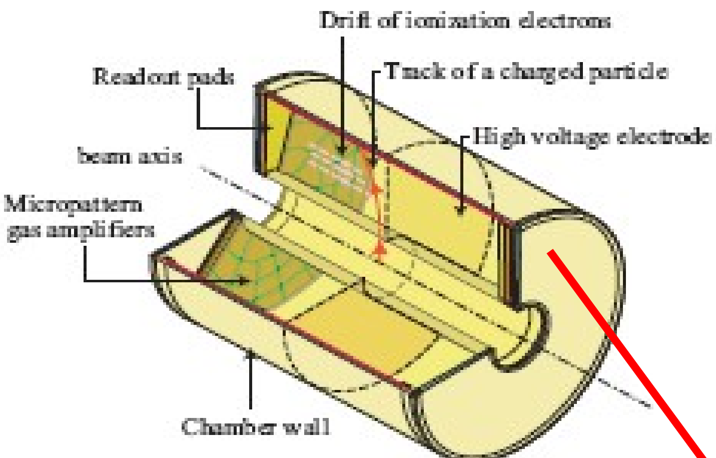
Large area
low mass systems

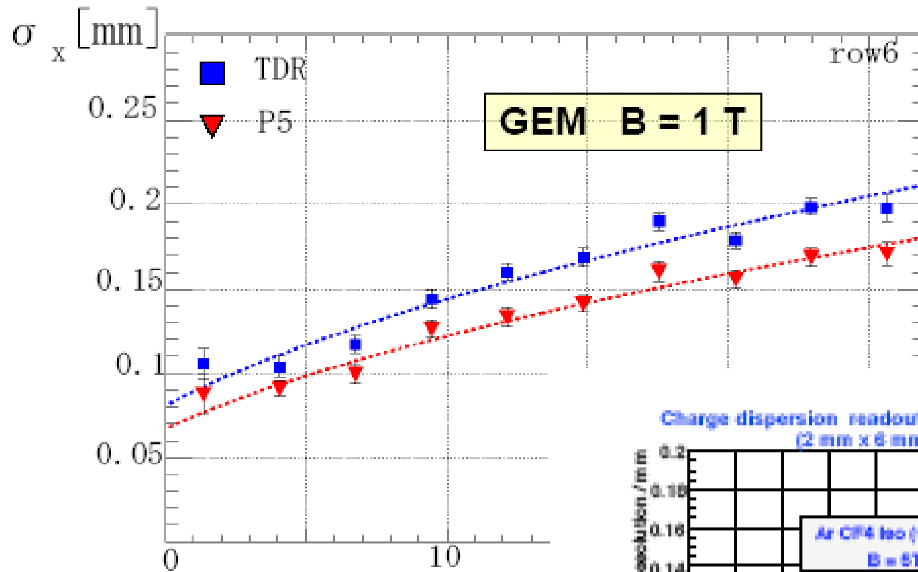


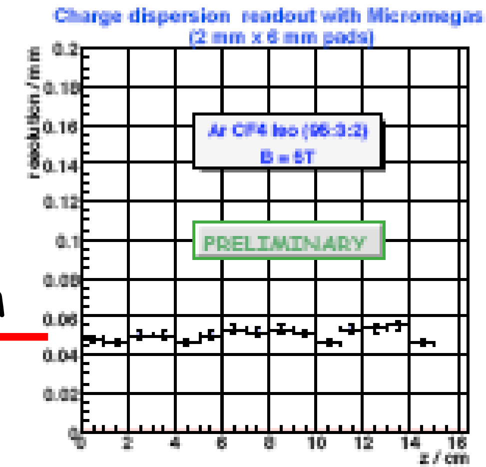
Integrate readout into detector to minimise material

Tracking technologies: TPC

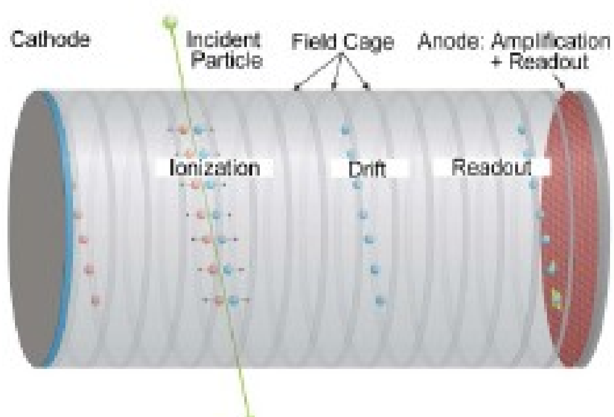
Gas amplification by
Micro Pattern Gas Detector

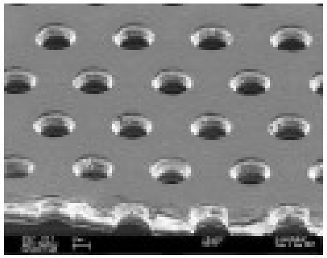


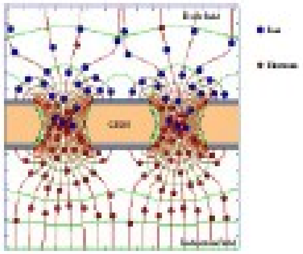




50µm





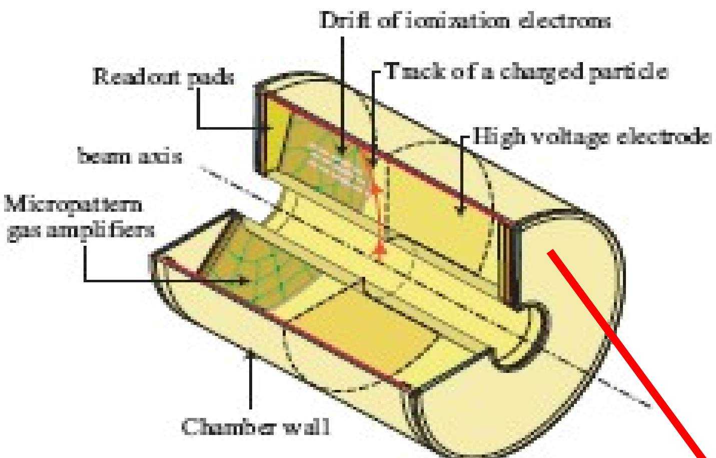


Micromegas

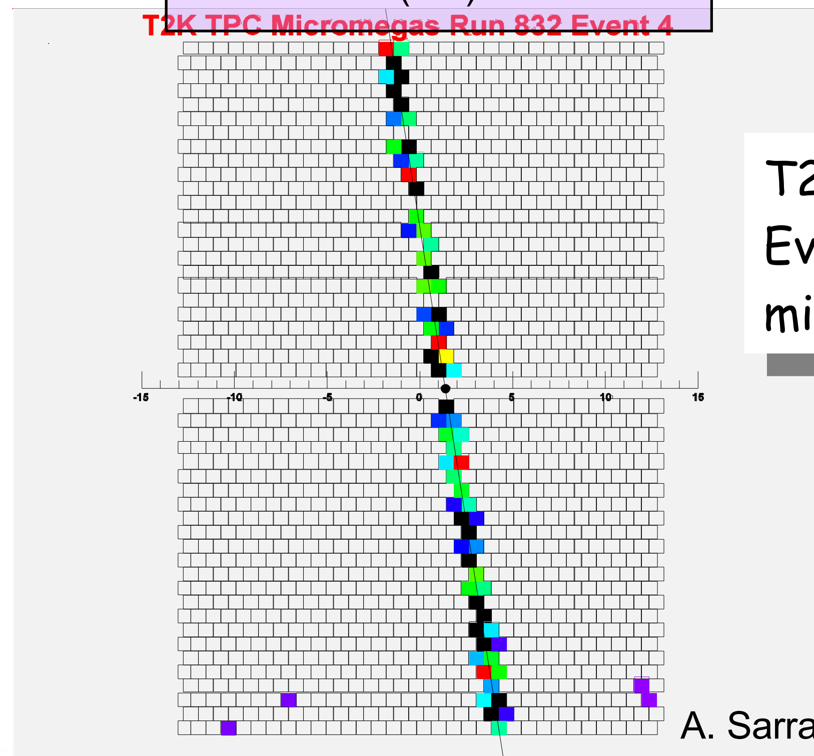
GEM

Tracking technologies: TPC

Gas amplification by
Micro Pattern Gas Detector



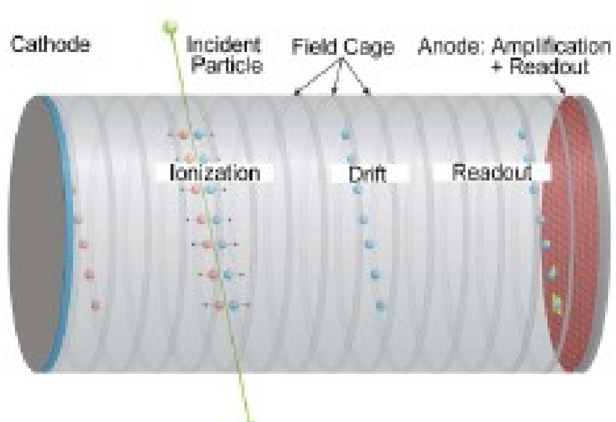
Event recorded at B = 0.2T in Ar (95%) iC_4H_{10} (2%) CF_4 (3%)

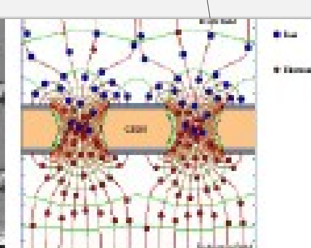


T2KTPC test Event with micromeagas

A. Sarrat

Micromegas

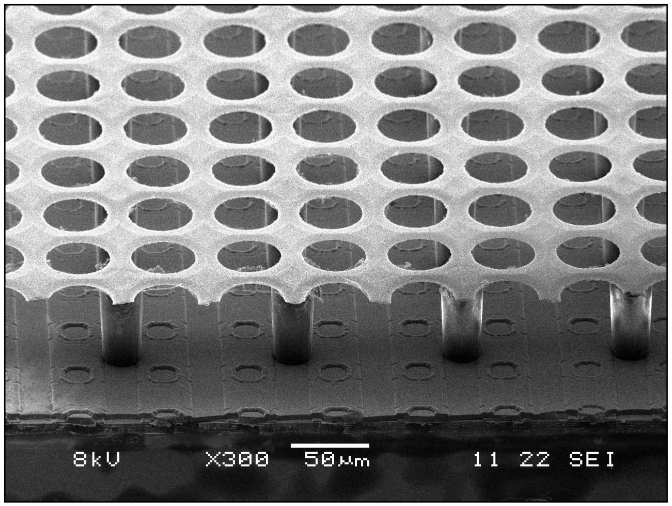




GEM

TPC goes Silicon

Amplification

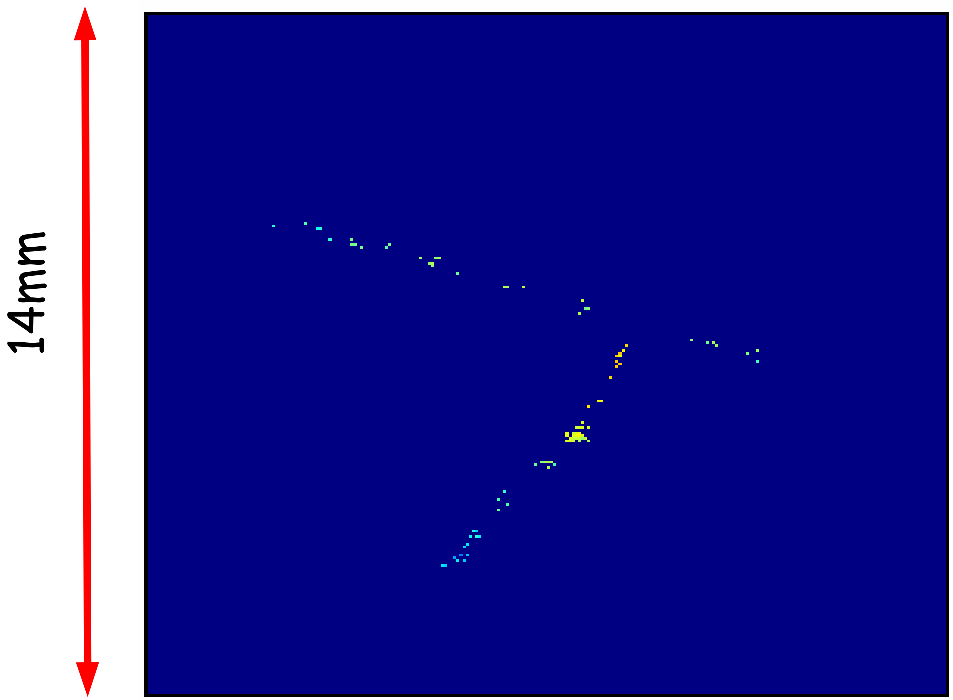


Bulk Micromegas:

SI fabrication techniques are used to create gas amplification structures

Readout

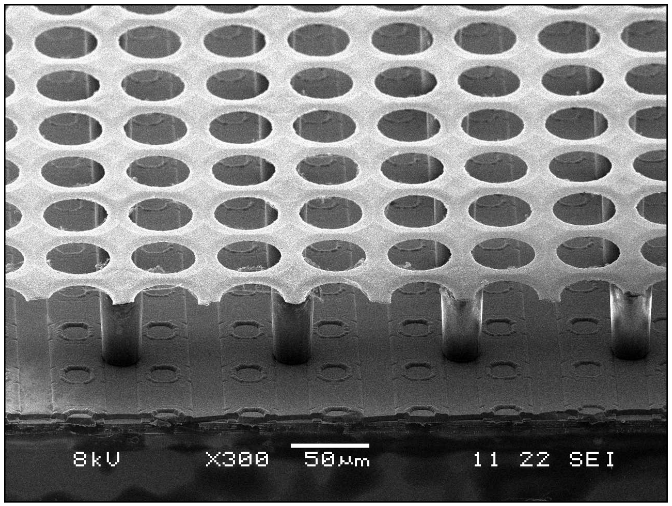
MediPix chip mounted in place of the pad plane:
pixel readout 50µm x 50µm



"electronic bubble chamber"

TPC goes Silicon

Amplification



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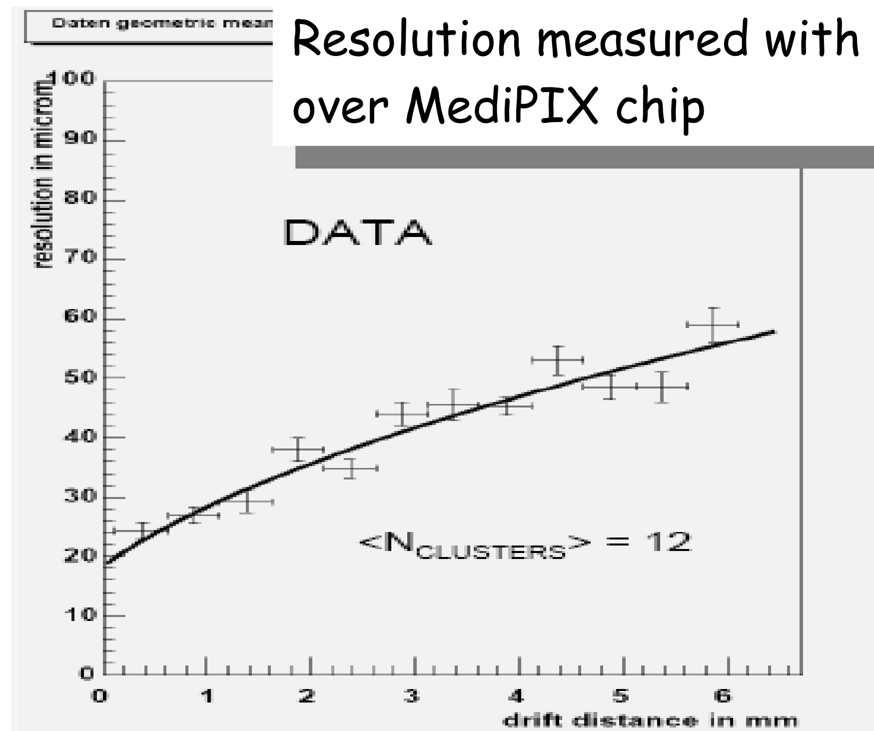


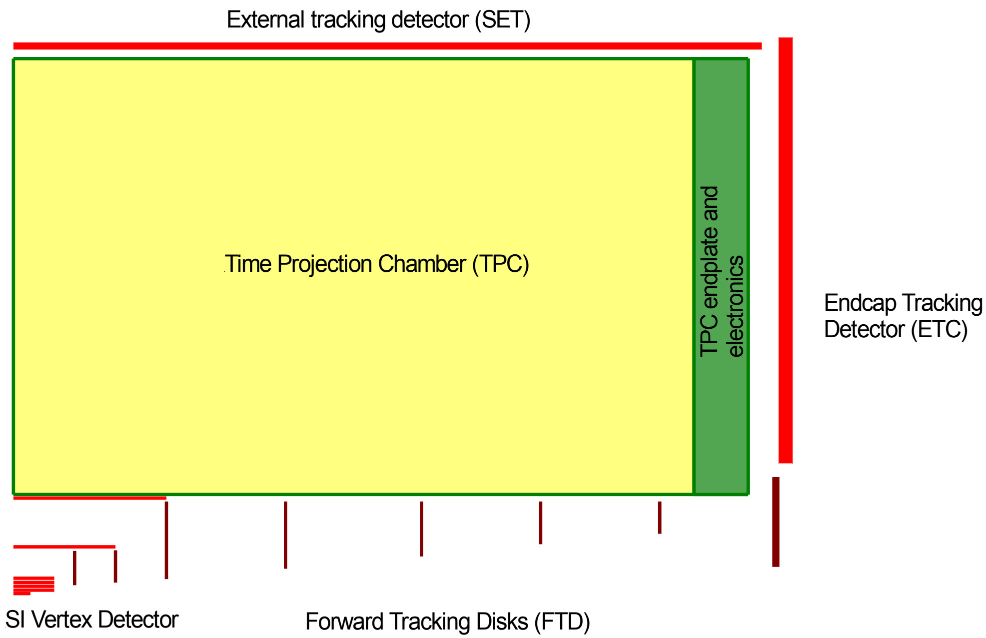
Resolution measured with GEM over MediPIX chip

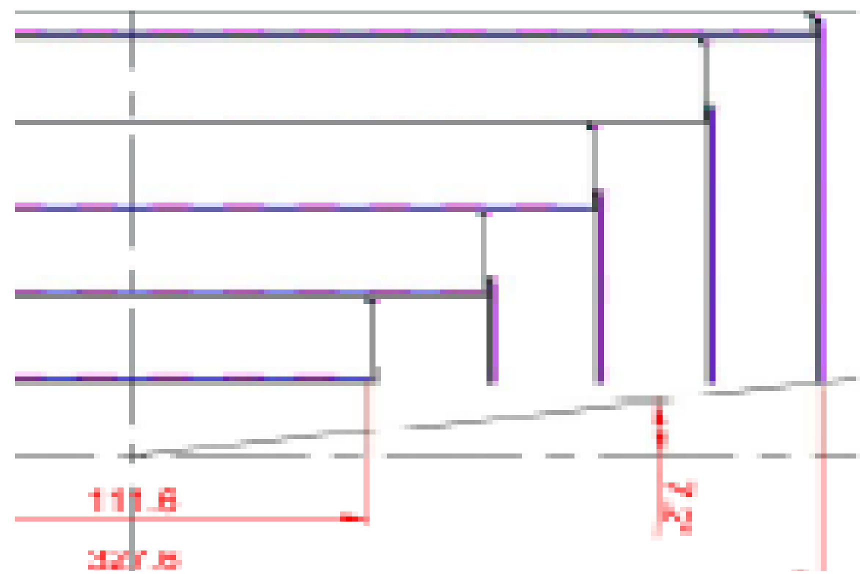
“electronic bubble chamber”

The Future of Tracking at the ILC

TPC based tracker with SI

All-SI tracker





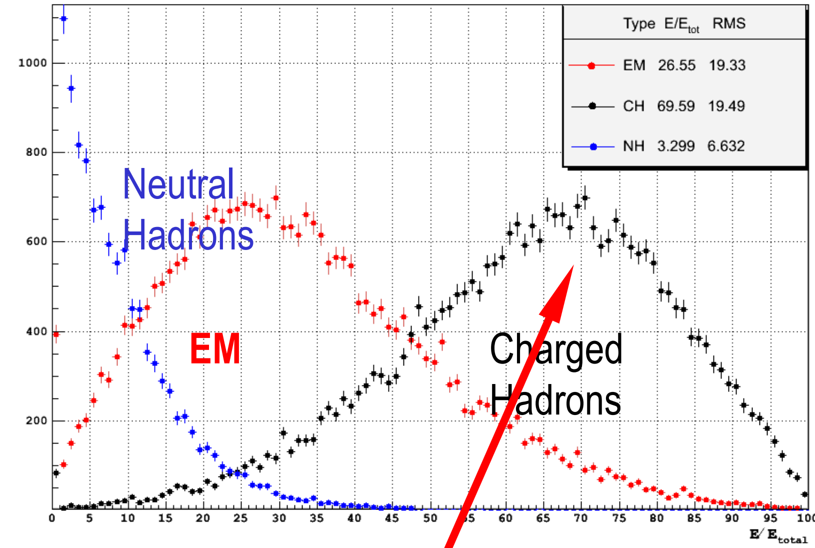
Robust, redundant
point resolution
gas + SI technology mixture
speed

Robust, few points
point resolution
single technology
speed

The discussion is ongoing, no clear favorite

Particle Flow

- Most precise event reconstruction (measured e.g. in the jet mass)
- Individual particles are reconstructed: charged and neutrals



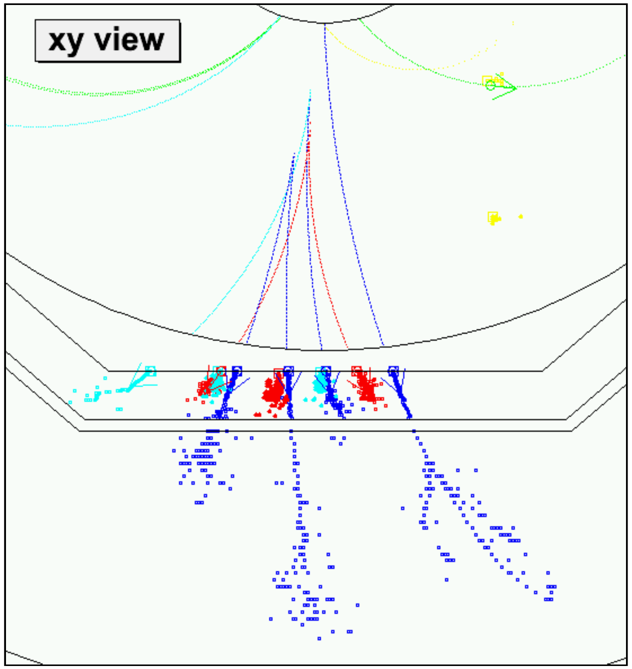
Fundamental problem: fluctuations in the calorimeter: <70%>

use tracker as much as possible
replace information in calo by tracker information
only use calo for neutral particles (photons, neutral hadrons)

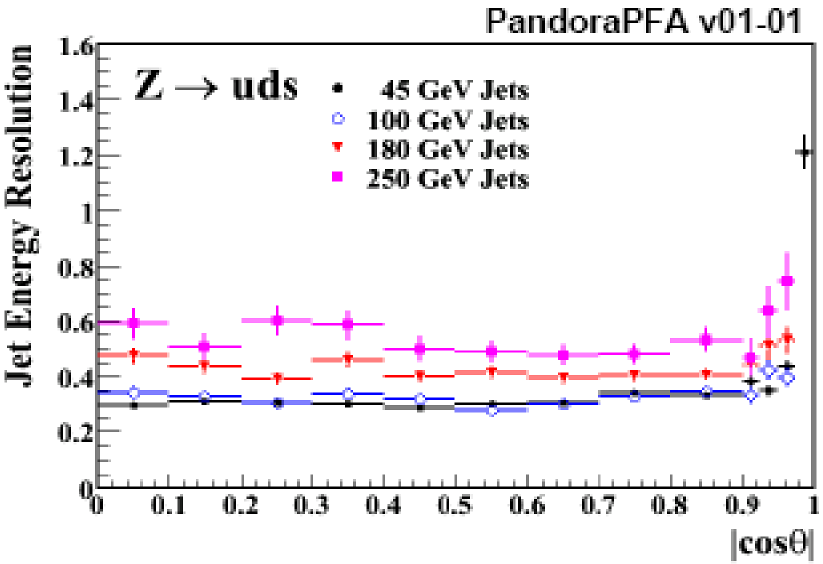
Pushes requirements for calorimeter:
excellent segmentation
energy resolution is of lesser importance

$30\%/\sqrt{E}$ (below 100 GeV) is the goal

Particle Flow in Simulation



Simulation of an event



M. Thomson

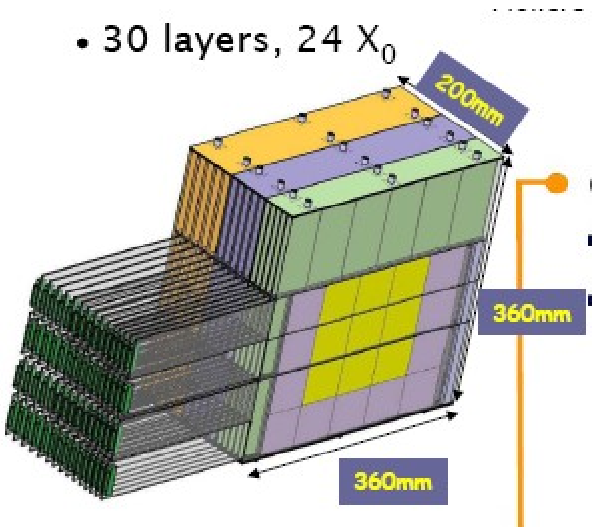
Resolution close to 30%/√E for jets below 100 GeV

Particle flow gives ~2x better performance than traditional approach (<100 GeV jets)

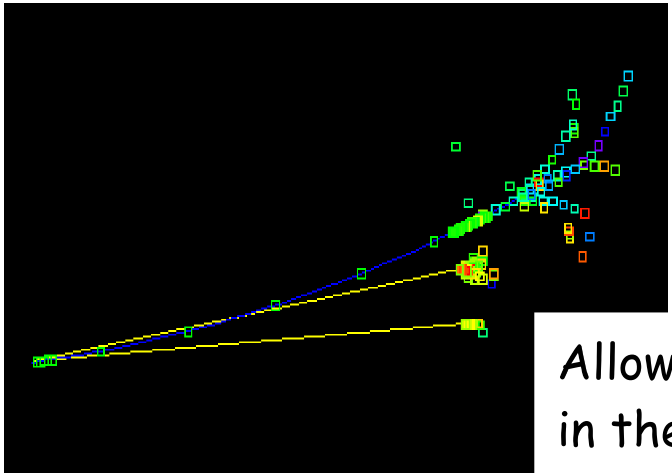
Software is an important part of the detector optimization and development

Si-W ECAL developments

Typical granularity for ECAL: 0.5cmx0.5cm to 1cmx1cm,
SI detectors, Tungsten absorbers

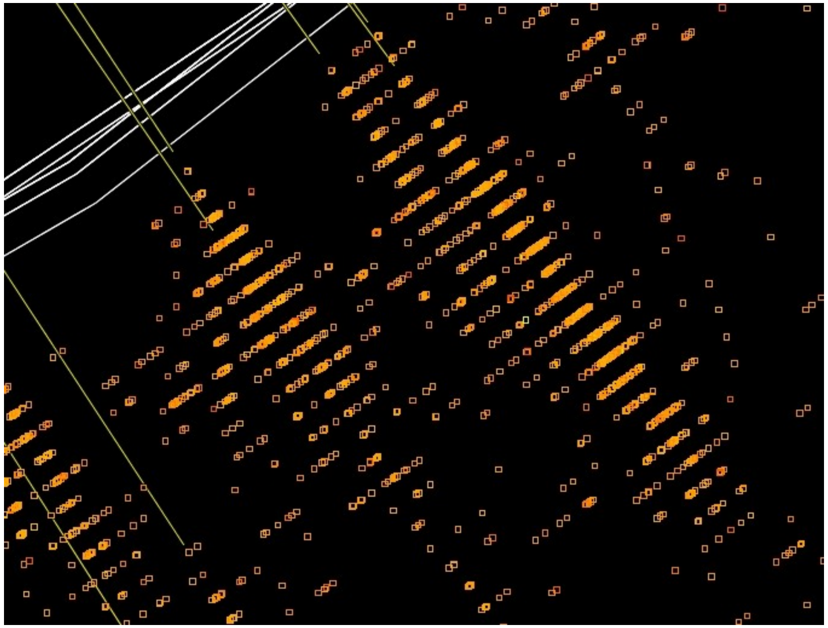


CALICE prototype



Allows “tracking”
in the calorimeter

Extreme direction:
MAPS sensors in the ECAL



Very detailed shower images

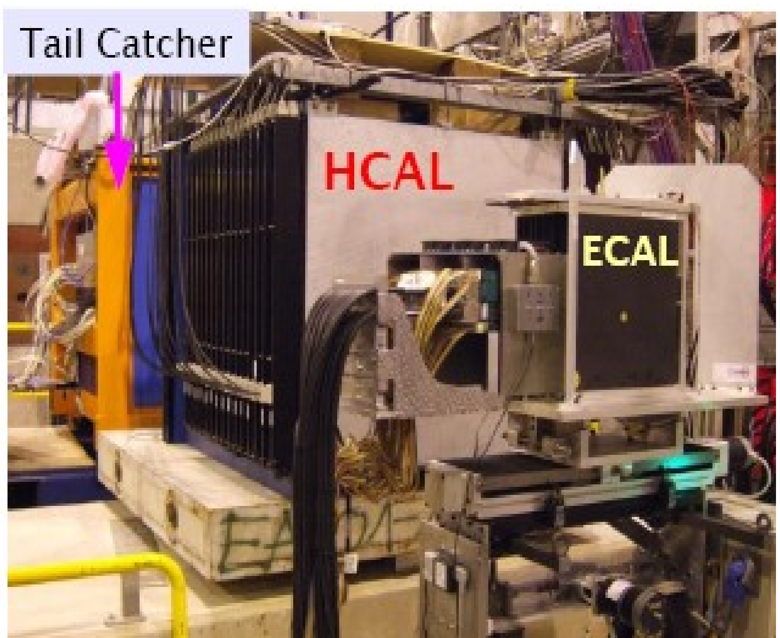
HCAL developments

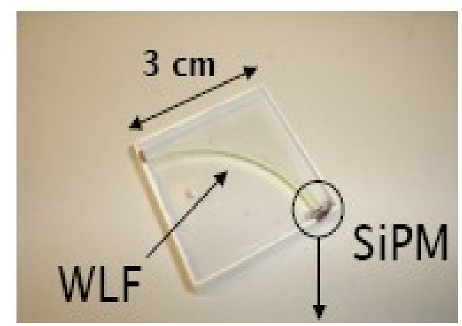
HCAL plays crucial role in a particle flow calorimeter

Simulation of hadronic shower is problematic

Typical cell sizes 3x3 cm^2 with analogue readout

Digital option investigated (smaller cells, 1bit readout)



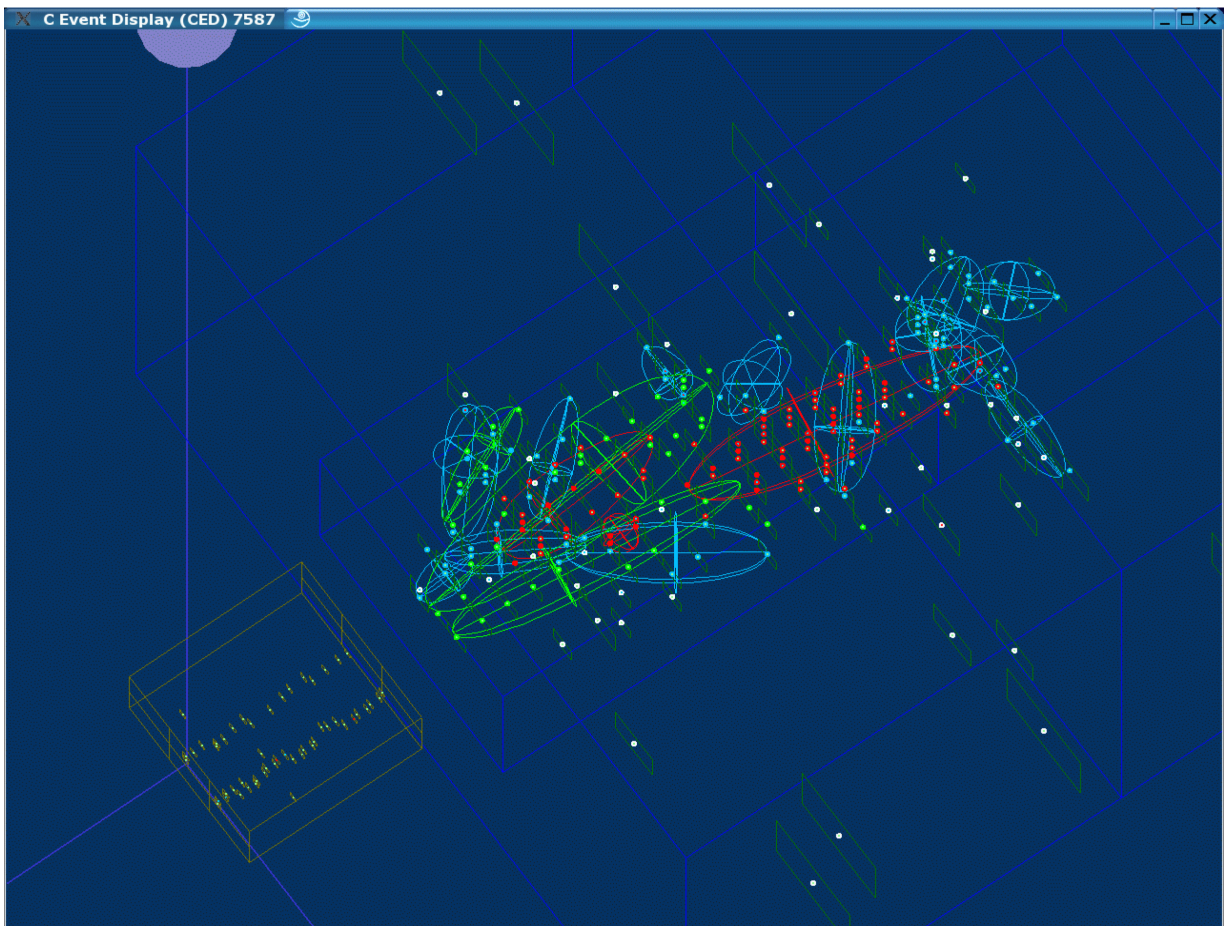


Major effort (CALICE) to protoype such a calorimeter for the ILC

ECAL/ HCAL Test Beam (CALICE)

Major effort to test
- Technologies
- Shower physics

Combined ECAL/ HCAL/ Tailcatcher
test beam at CERN (2006/7) FNAL (2007/8)



2 track event
recorded at the CERN
test beam

with reconstruction
run on the data

ECAL/ HCAL Test Beam (CALICE)

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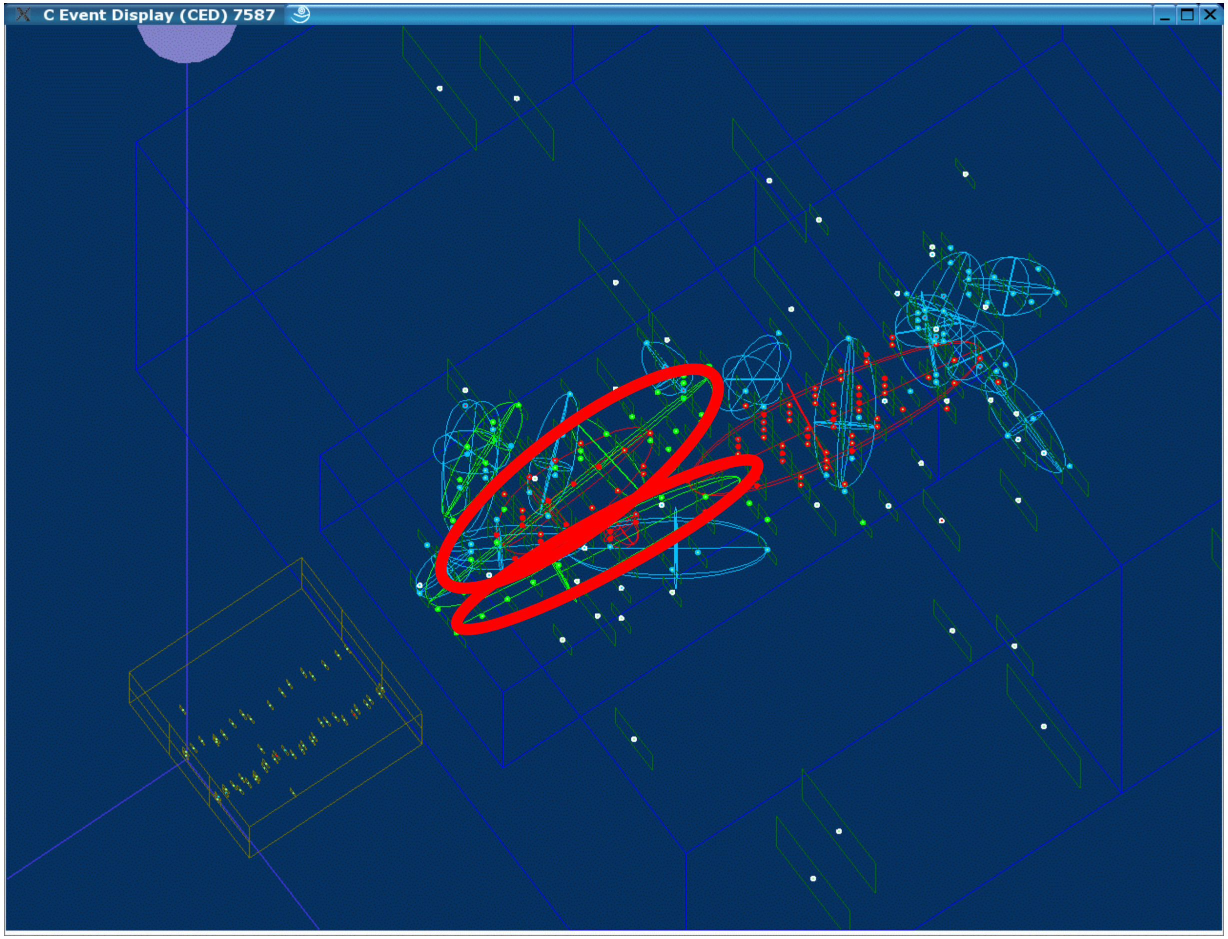


2 track event
recorded at the CERN
test beam

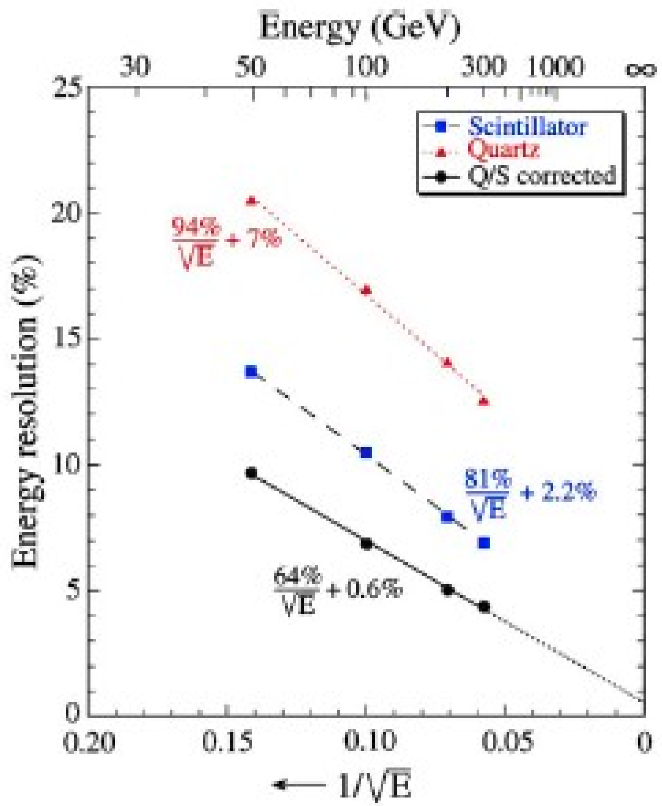
with reconstruction
run on the data

Several Tbyte of data
recorded at different E
for pion, electron, muon

DREAM technology

Dual readout calorimeter:

- Scintillator and Cerenkov fibers
- Sensitivities to EM and had part are different

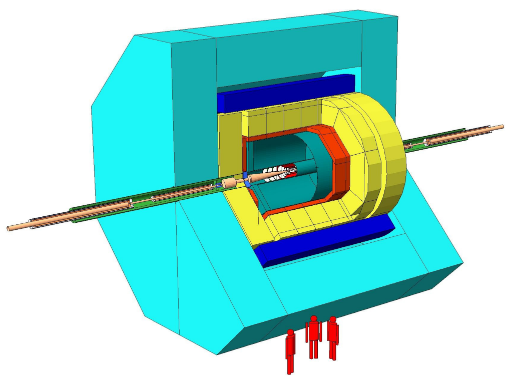


Good energy resolution possible
compensation by software "easy"
segmentation is difficult, in particular in depth

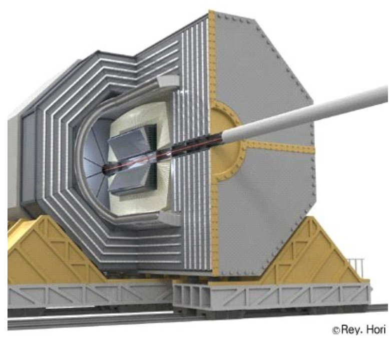
Is this an alternative to the "particle flow" calorimeters?

Detectors at the ILC

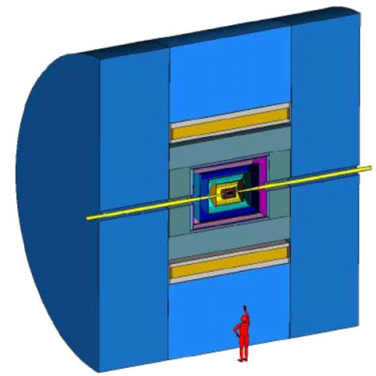
Four detector concepts at the ILC



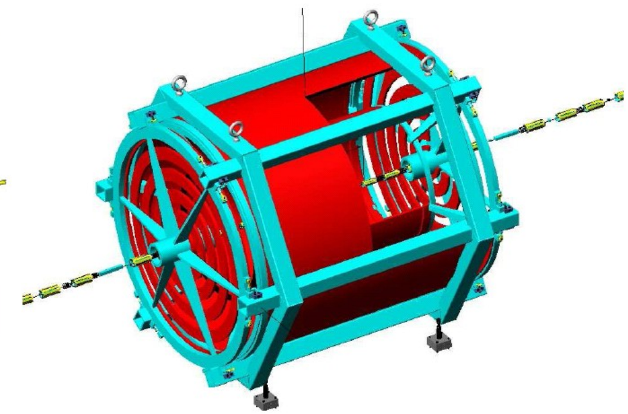
LDC



GLD



SiD



4th

2007

Today
R&D collaborations
concept groups

2008

Letter
of intent

Select
Two

2010

Light
engineering
report

Ensure two
complete
proposals

Outlook and Conclusion

Detector Developments is an active and fascinating field

40 talks in parallel session (D. Newbold, I. Winterer)
- LHC commissioning
- LHC data handling and computing
- R&D projects (ILC, sLHC, SuperB, STAR, MICE, ...)

apologies for those topics not covered in this talk

Continuing advances in detector technology are central to the continued vitality of out field

(remark: test beams are important!)

Technology makes new approach possible: SI-TPC, particle flow calorimeter, ...

Technology will be central to the success of the current and future projects