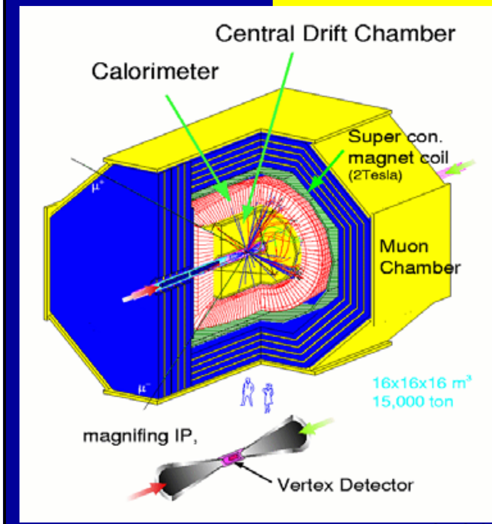
Detector R&D

W. Lohmann, DESY



R&D on the following Subdetectors:

- Lumi Calorimeter and Forward Region Instrumentation
- Vertexing
- Tracking
- Calorimetry
- Muon Detectors

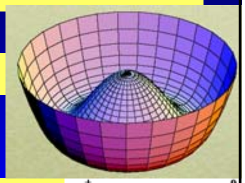
A New Detector 'Scale'

Impact Parameter: (secondary vertices)	1/3 x SLD 1/5-10 x LEP	• Small beampipe • Low material budget • 4-5 layer structure
Momentum resolution	1/10 x LEP	• Single hit resolution • Number of hits • High B field
Jet energy resolution	1/3 x LEP, HERA	• Fine granularity compact calorimeters • single particle shower reconstruction and particle flow approach
Hermeticity	> 5 mrad	

Dedicated Detector R&D needed

Physics Requirements for a Detector

Major Goal: Explore Elektroweak Symmetry Breaking

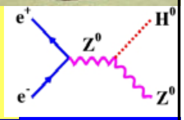


A light Higgs Boson:

Identification of the Higgs (Mass, Spin, Parity), Couplings

$e^+e^- \longrightarrow ZH \longrightarrow l^+ l^- X$

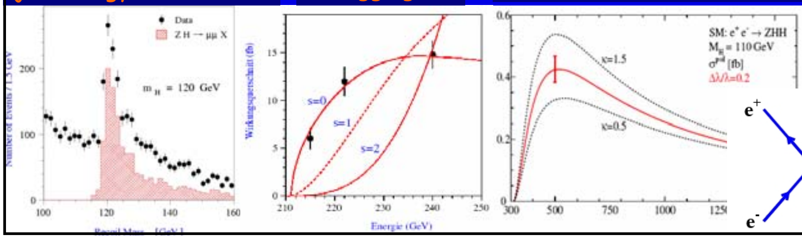
('golden physics channel'), with $\delta(m_{l^+l^-}) \ll \Gamma_Z$

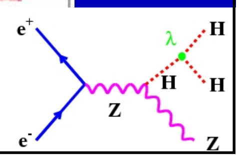


Mass
accuracy ~40 MeV
Momentum and
jet energy resolution

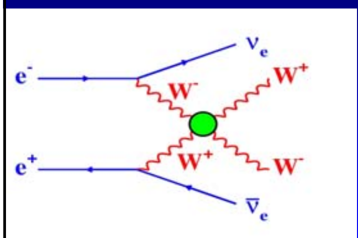
Spin, Parity
CP
b-tagging,
τ -tagging

Higgs Field Potential, λ
Jet energy resolution,
b-tagging, vertex charge





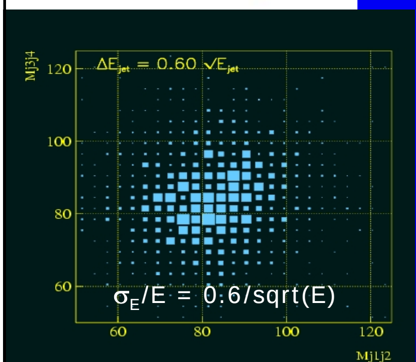
Or, no Higgs Boson:

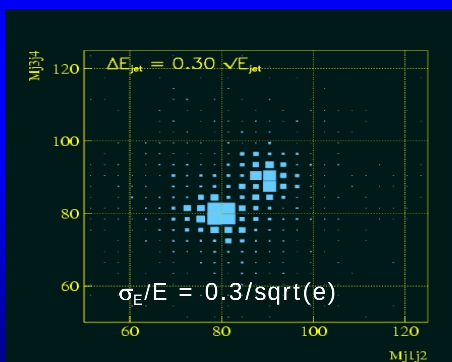


Strong Interactions of Gauge Bosons

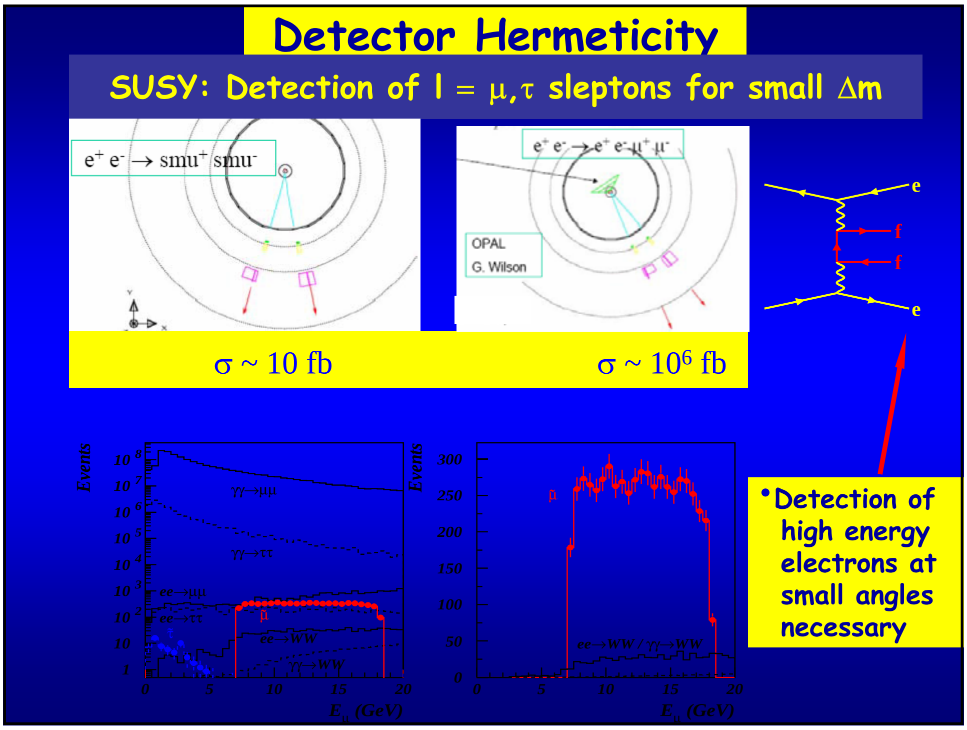
-Reconstruction of the W's from the measured Jet energies and directions

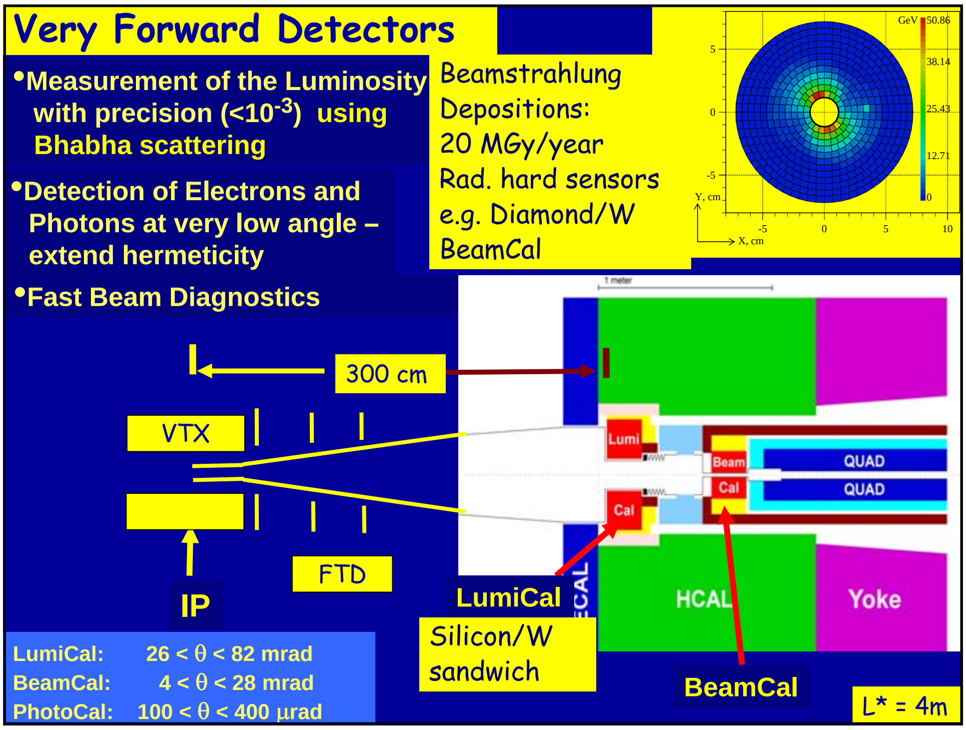
Separation of WW and ZZ final states!

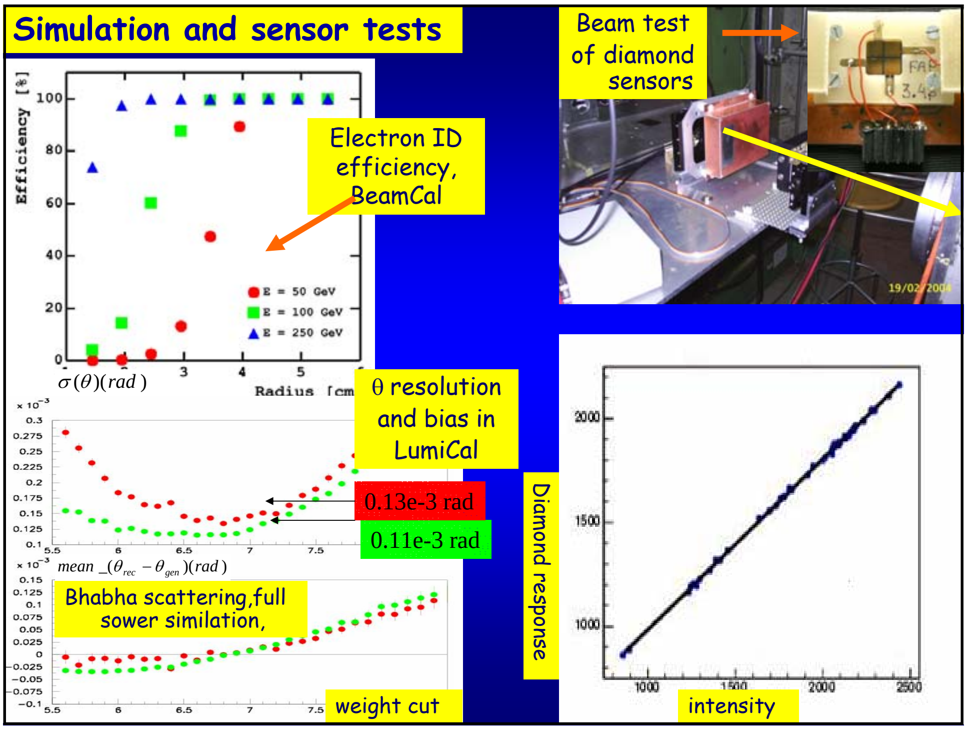


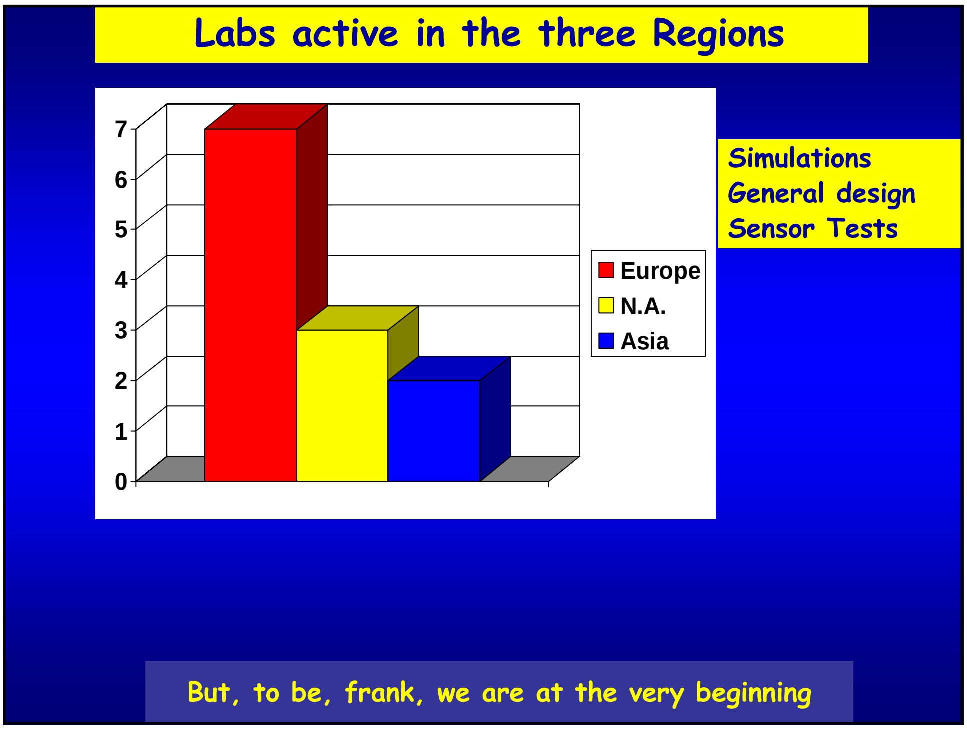


and then search for technicolor

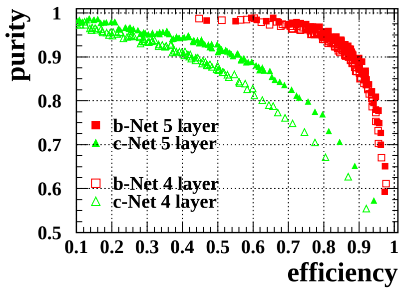

Detector Hermeticity
SUSY: Detection of l = μ,τ sleptons for small Δm
e+ e- → smu+ smu-
e+ e- → e+ e- μ+ μ-
OPAL
G. Wilson
σ ~ 10 fb
σ ~ 10^6 fb
e
f
f
e
•Detection of high energy electrons at small angles necessary
Events
γγ→μμ
γγ→ττ
ee→μμ
ee→ττ
ee→WW
γγ→WW
μ
E_μ (GeV)
ee→WW / γγ→WW

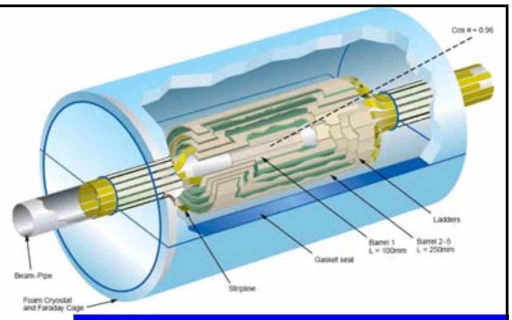

Very Forward Detectors
•Measurement of the Luminosity with precision (<10^-3) using Bhabha scattering
•Detection of Electrons and Photons at very low angle – extend hermeticity
•Fast Beam Diagnostics
Beamstrahlung
Depositions:
20 MGy/year
Rad. hard sensors
e.g. Diamond/W
BeamCal
GeV
Y, cm
X, cm
300 cm
1 meter
VTX
FTD
IP
Lumi
Cal
Beam
Cal
QUAD
QUAD
HCAL
Yoke
ECAL
LumiCal
Silicon/W
sandwich
BeamCal
L* = 4m
LumiCal: 26 < θ < 82 mrad
BeamCal: 4 < θ < 28 mrad
PhotoCal: 100 < θ < 400 μrad


Simulation and sensor tests
Electron ID efficiency, BeamCal
Efficiency [%]
Radius [cm]
E = 50 GeV
E = 100 GeV
E = 250 GeV
θ resolution and bias in LumiCal
0.13e-3 rad
0.11e-3 rad
Bhabha scattering,full sower similation,
weight cut
Beam test of diamond sensors
Diamond response
intensity


Labs active in the three Regions
Europe
N.A.
Asia
Simulations
General design
Sensor Tests
But, to be, frank, we are at the very beginning

Vertex Detector





- Space Point Resolution < 4μm
- Impact Parameter Resolution ($\delta(IP) = 5 \otimes 10/p \sin^{3/2}\theta$) μm
- Vertex Charge Measurement
  Transparent, < 0.1 % X_0 per layer
  Small beam pipe Radius, < 15 mm
  thin walled beam pipe

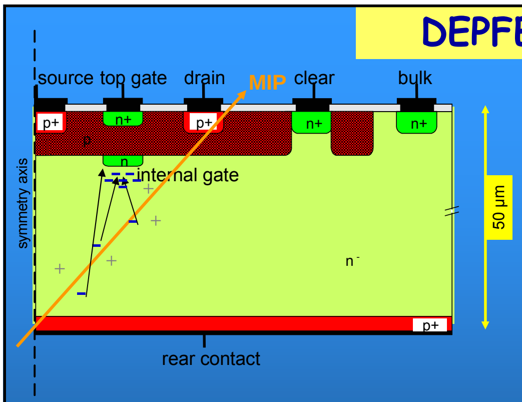
Vertex Detectors

Concepts under Development:

- Charge Coupled Devices, CCD (demonstrated at SLD)
- Fine Pixel CCD, FPCCD
- DEpleted P-channel Field Effect Transistor (DEPFET)
- Monolithic Active Pixel (CMOS), MAPS
- Silicon on Insulator, SoI
- Image Sensor with In-Situ Storage (ISIS)
- Hybrid Pixel Sensors (HAPS)
- …….

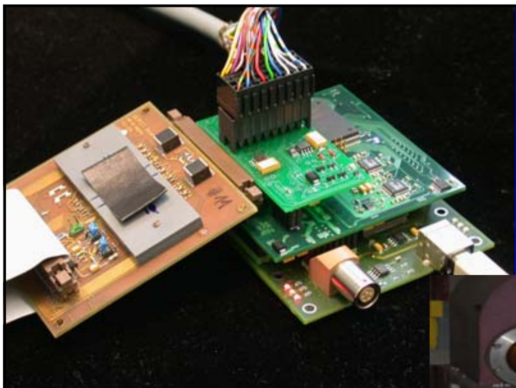
11 technologies, 26 Groups around the world

DEPFET

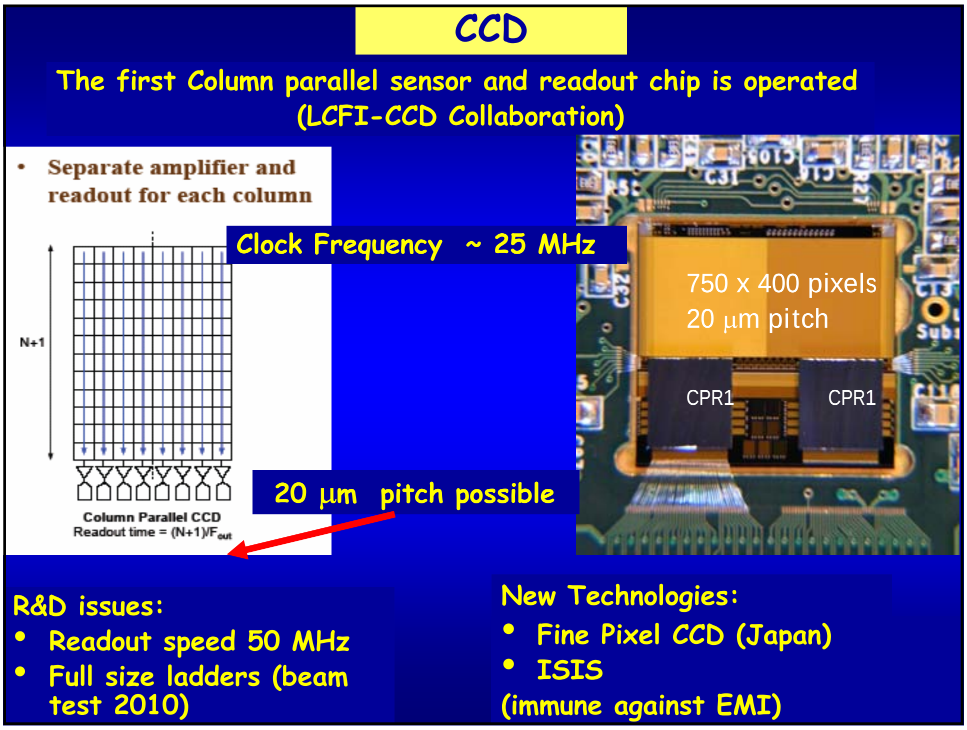


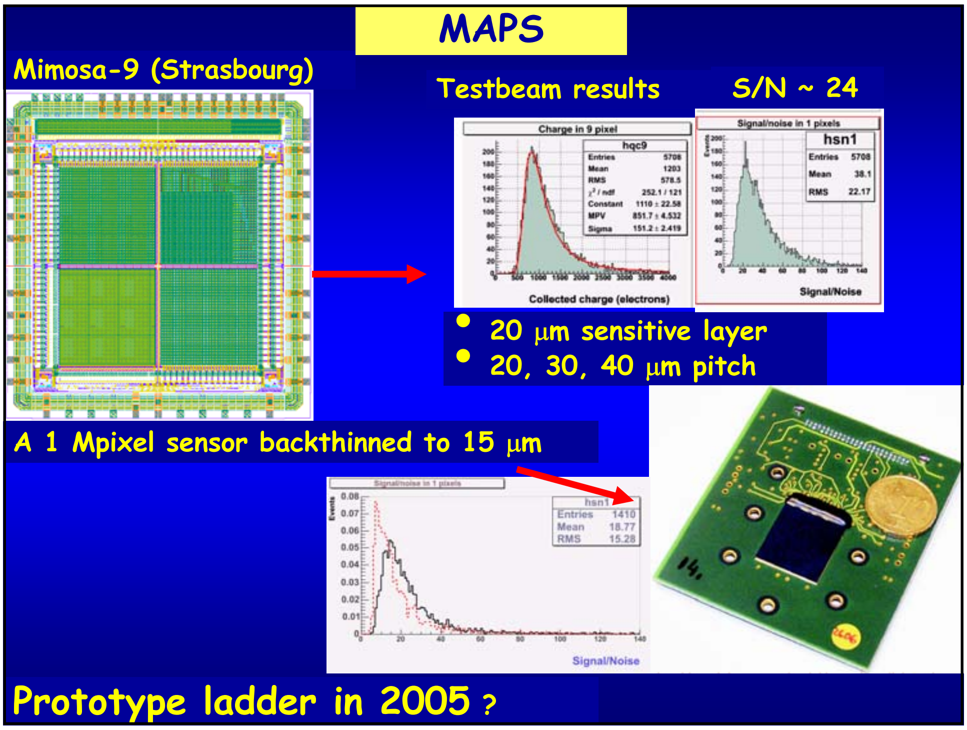
Bonn, Mannheim, Munich

- Full Prototype System built, tested in the Lab and Testbeam
  Pixel size 20 x 30 μm^2, 64 x 128 pixel
- Thinning to 50 μm demonstrated
- Rad. Hardness tested to 1 Mrad (^{60}Co)
- Readout with 100 MHz, Noise tolerable
- Low Power Consumption (5W for a five Layer Detector)

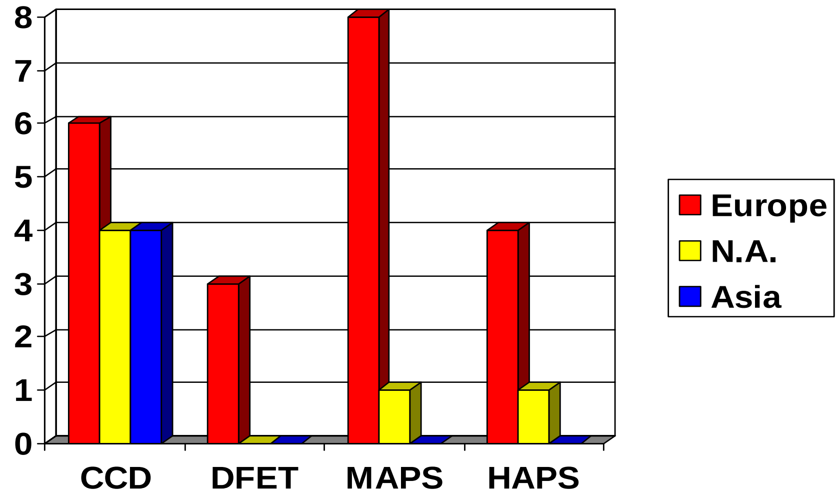


Next Step: Design and produce a 512 x256 Pixel matrix


CCD
The first Column parallel sensor and readout chip is operated
(LCFI-CCD Collaboration)
Separate amplifier and readout for each column
N+1
Column Parallel CCD
Readout time = (N+1)/F_out
Clock Frequency ~ 25 MHz
750 x 400 pixels
20 μm pitch
CPR1
CPR1
20 μm pitch possible
R&D issues:
Readout speed 50 MHz
Full size ladders (beam test 2010)
New Technologies:
Fine Pixel CCD (Japan)
ISIS
(immune against EMI)

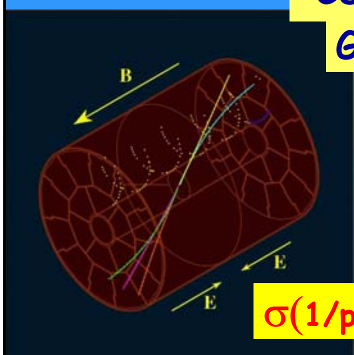

MAPS
Mimosa-9 (Strasbourg)
Testbeam results
S/N ~ 24
Charge in 9 pixel
Collected charge (electrons)
Signal/noise in 1 pixels
Signal/Noise
20 μm sensitive layer
20, 30, 40 μm pitch
A 1 Mpixel sensor backthinned to 15 μm
Prototype ladder in 2005 ?

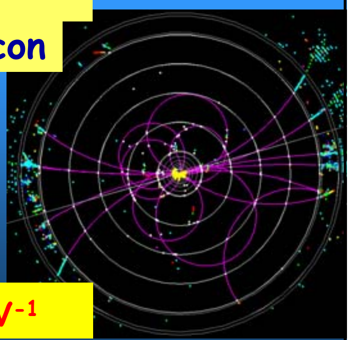
Labs involved from the three Regions



Exchange of informations between the groups (phone meetings)

Central Tracker
Gaseous or Silicon

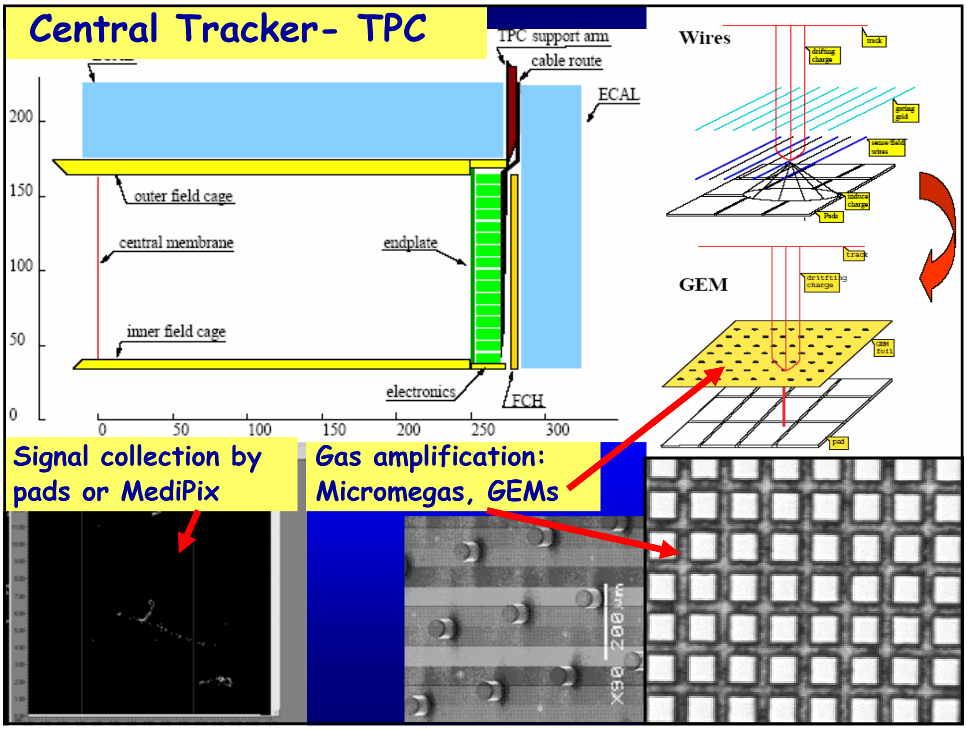




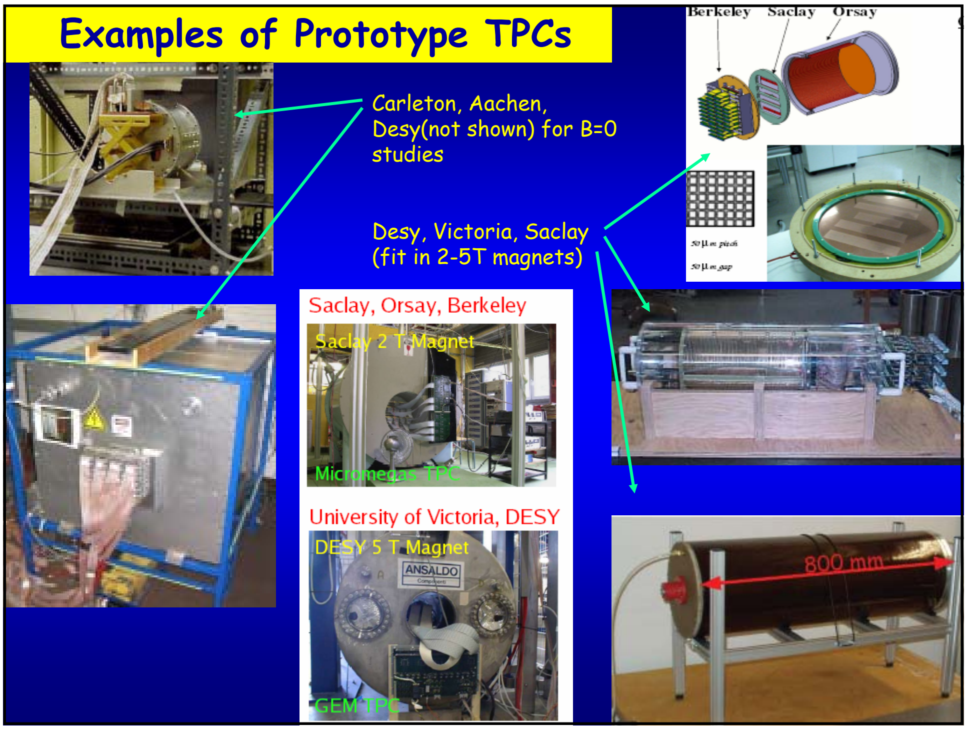
$\sigma(1/p) = 6 \times 10^{-5}\ GeV^{-1}$

- Field Cage- homogeneous E field
- Mechanical Frame (< 3% X_0)
- Novel Gas Amplification System
- Gas Mixture
- Performance at High B –Field (100μm (Rϕ) Resolution)

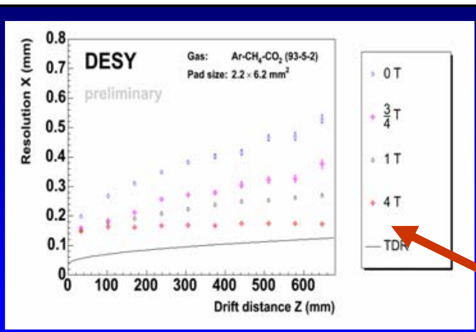
- Design Studies (GossamerTracker) (Resolution, Track Efficiency)
- Long Silicon Strip sensors (Barrel)
- Si Drift sensors (Forward)
- Mechanical Support (<1% X_0 per layer
- FE Electronics (low noise, digitisation)

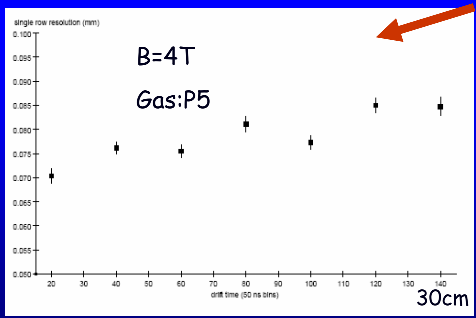


Central Tracker- TPC
TPC support arm
cable route
ECAL
outer field cage
central membrane
endplate
inner field cage
electronics
FCH
Wires
GEM
Signal collection by pads or MediPix
Gas amplification: Micromegas, GEMs



Examples of Prototype TPCs
Berkeley
Saclay
Orsay
Carleton, Aachen, Desy(not shown) for B=0 studies
Desy, Victoria, Saclay (fit in 2-5T magnets)
Saclay, Orsay, Berkeley
Saclay 2 T Magnet
Micromegas TPC
University of Victoria, DESY
DESY 5 T Magnet
GEM TPC
800 mm



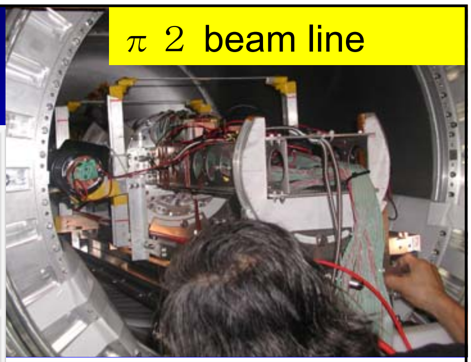


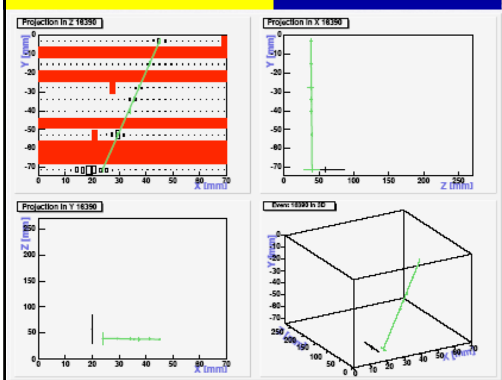
Point resolution, GEM

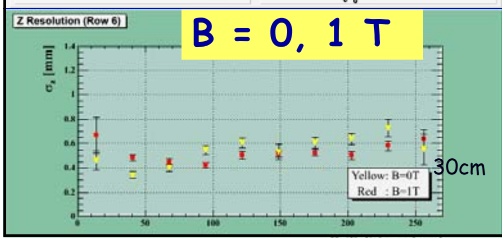
- 2x6mm^2 pads.
- In Desy chamber triple GEM is used
- In Victoria chamber a double GEM
- In general (also for Micromegas) the resolution is not as good as expected from simulations
- we are searching for why (electronics, noise, method).

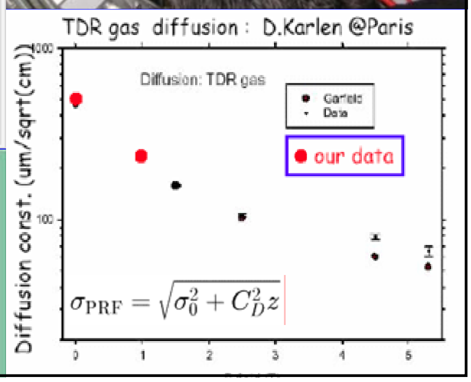
Beam Test @ KEK

π 2 beam line









TPC, status and next steps:

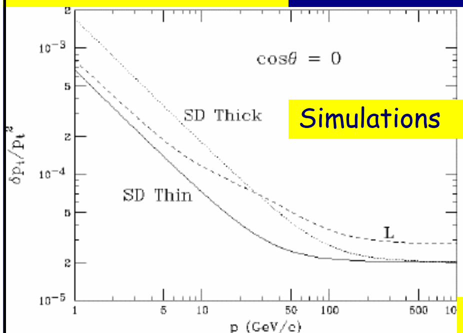
- A large international Community is engaged in TPC R&D
- Both GEMs and MICROMEGAS seem to work
- Construction of a 'Large Prototype'
- Full System Test with the 'Large Prototype' in a beam

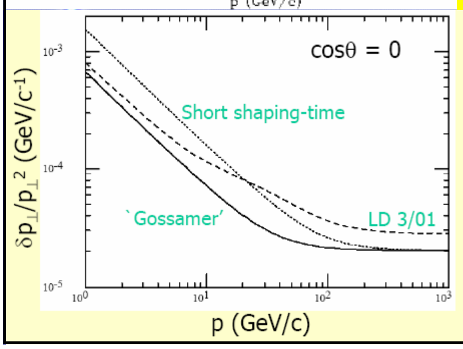
A Collection of ongoing R&D topics:

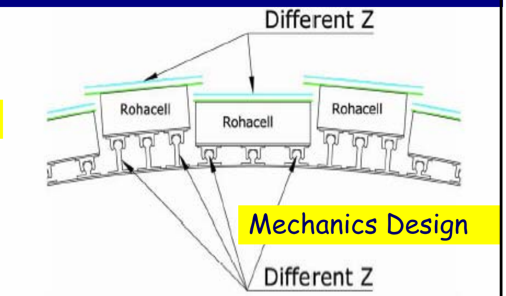
- Choice of gas mixture (Diffusion, D-velocity)
- Ion feedback

- Readout electronics (pad density)
- neutron background

SID/SiLC



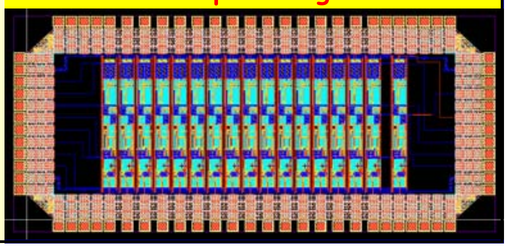




FE and readout chip prototype (.18μm UMC)

16 channel pream, shaper. ADC)

Lab. Tests are promising



SID/SiLC

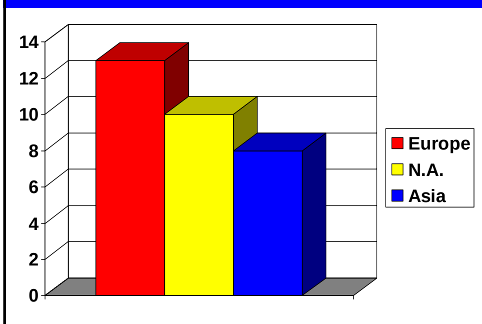
SiLC plans testbeam measurements
with a prototype ladder in the fall of 2006

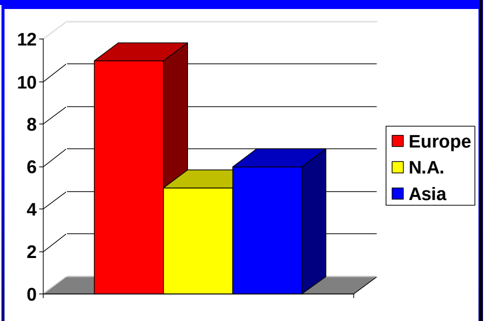
- Close contacts between N.A. and European groups
- Exchange of designs for detector and electronics
- Joint effort in simulations
- Common testbeam measurement

Labs involved from the three Regions

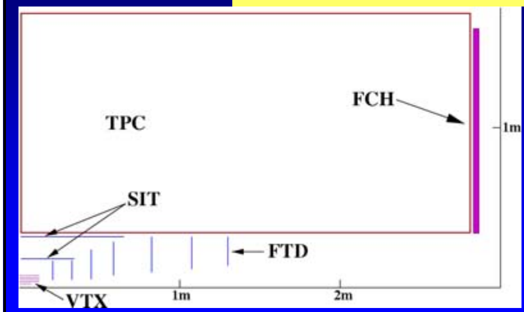
TPC

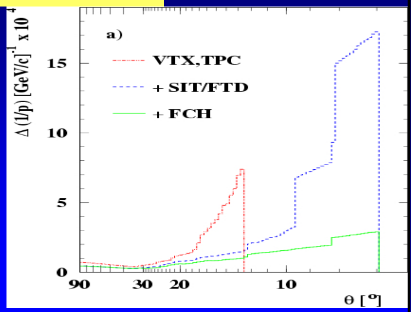
SID/SiLC





FORWARD TRACKING

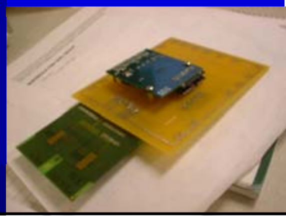


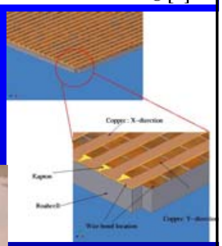


+SIT : $\sigma(1/p) = 0.5 \times 10^{-4}$ GeV^{-1}

- SIT: Silicon strips
- FTD: Silicon disks
- FTC: Straw tubes, GEMs

Design studies in DESY/JINR
R&D in Louisiana Tech. Univ.,
10 x 10 cm^2 prototypes,
Tests with Cosmics





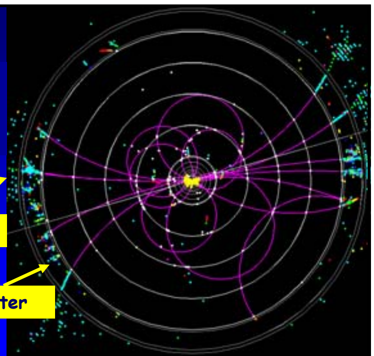
or: SiLC Components

Calorimetry

'Particle' flow concept requires to identify showers of individual particles in a jet

Separation of 'neutral' and 'charged' depositions

Charged particles in a jet are most precisely measured in the tracker



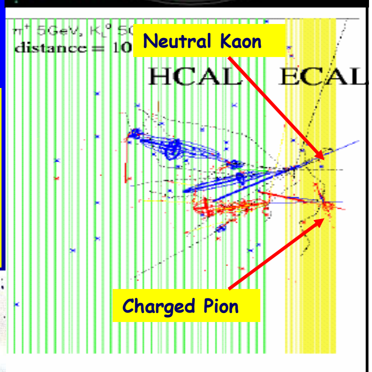
Charged cluster

Neutral cluster

Summing up the the energy measurement from tracking (charged), ECAL and HCAL(neutrals) :

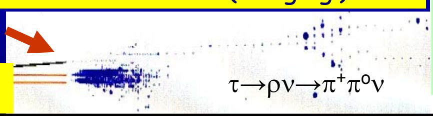
$\Delta E/E$ = 30%/ sqrt(E) for jets!

Granularity (longitudinal and transversal) (1x1 cm^2)
Compactness (small X_0, R_M)
Mip detection (charged particle tracking)
Photon direction measurement ('imaging')

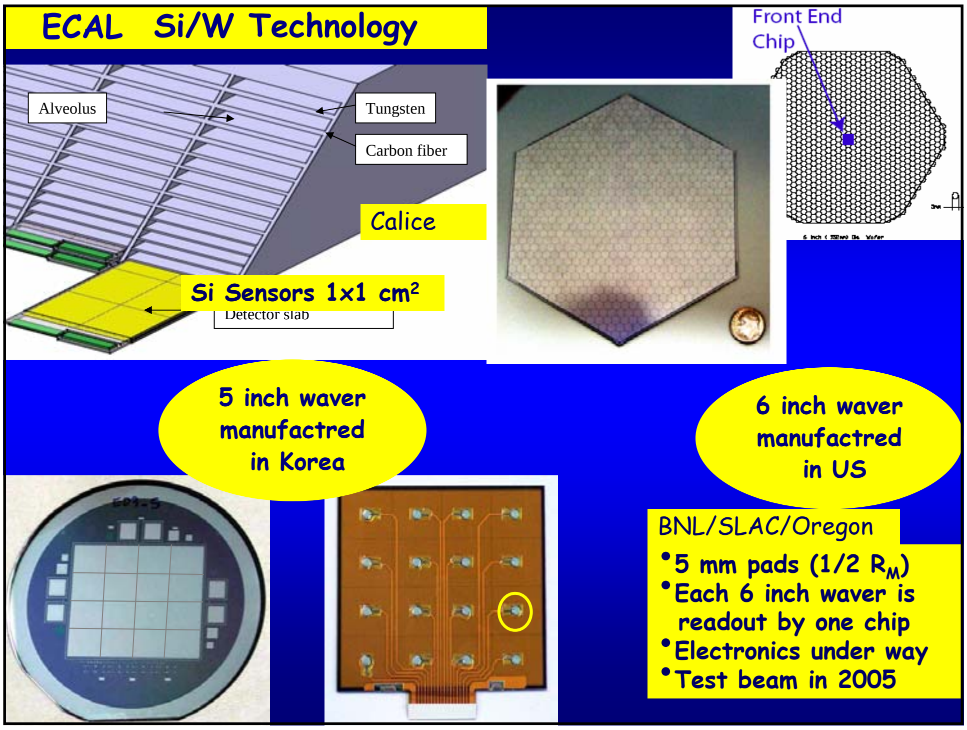


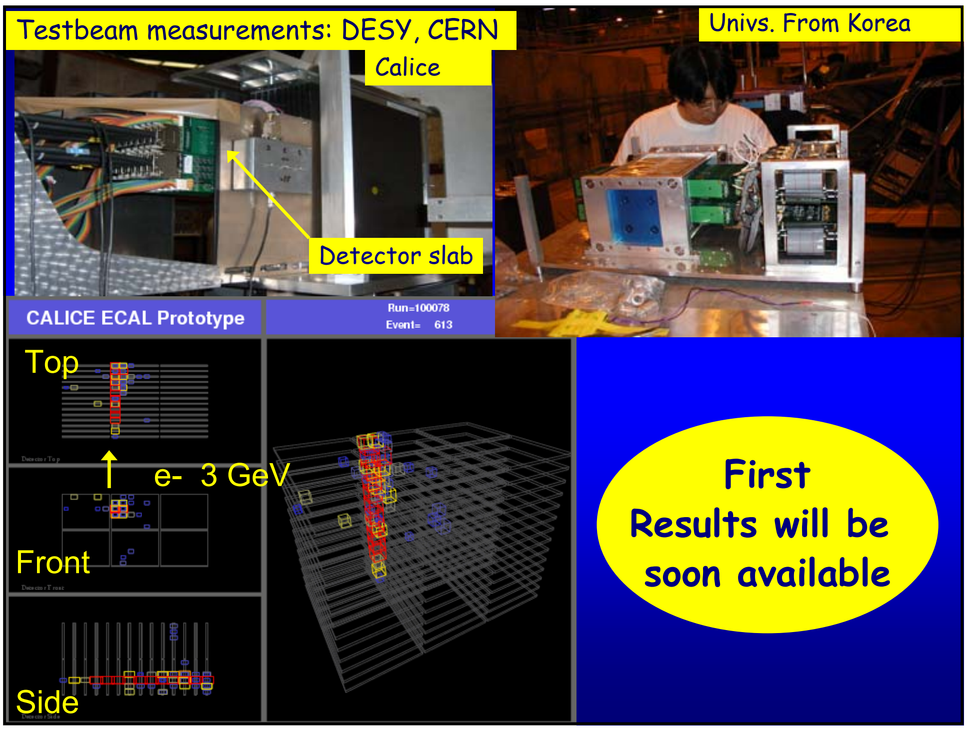
Neutral Kaon

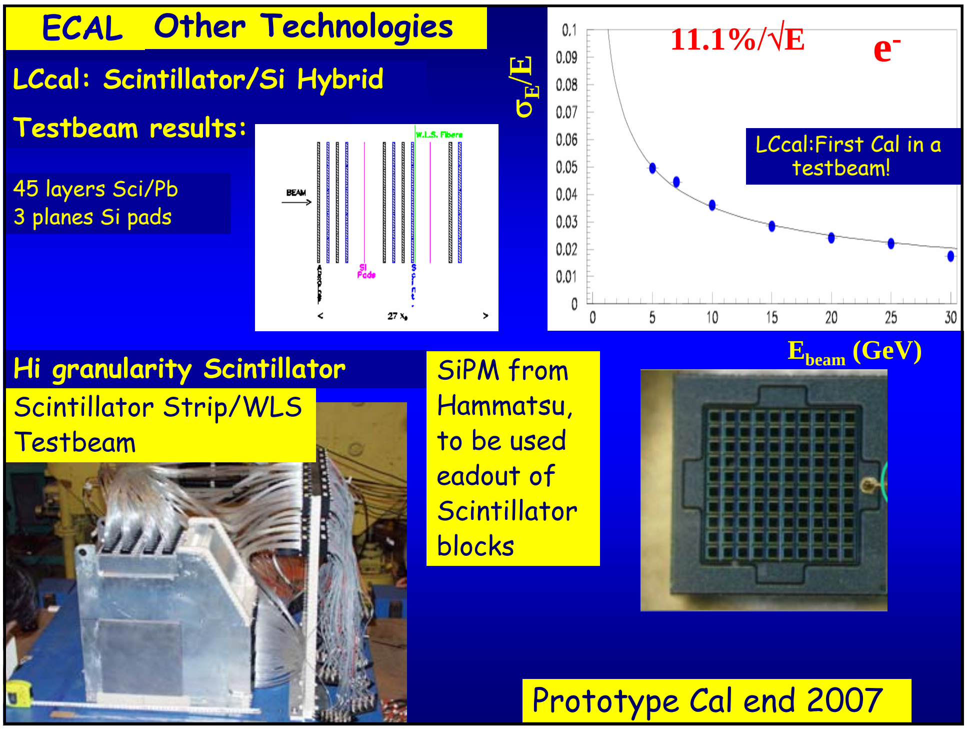
Charged Pion

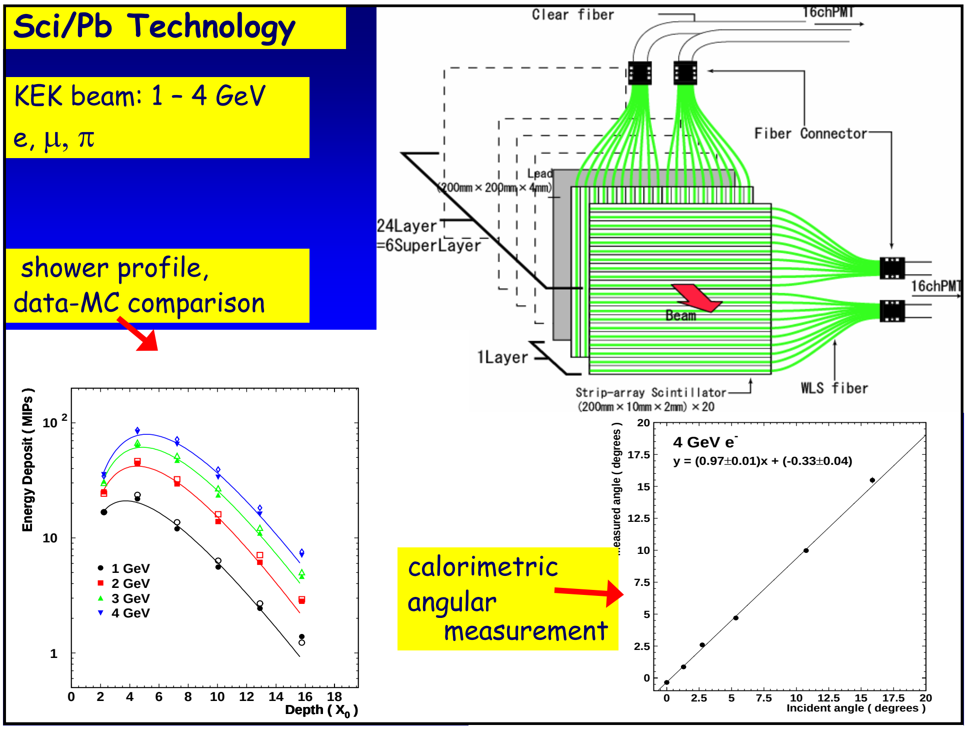


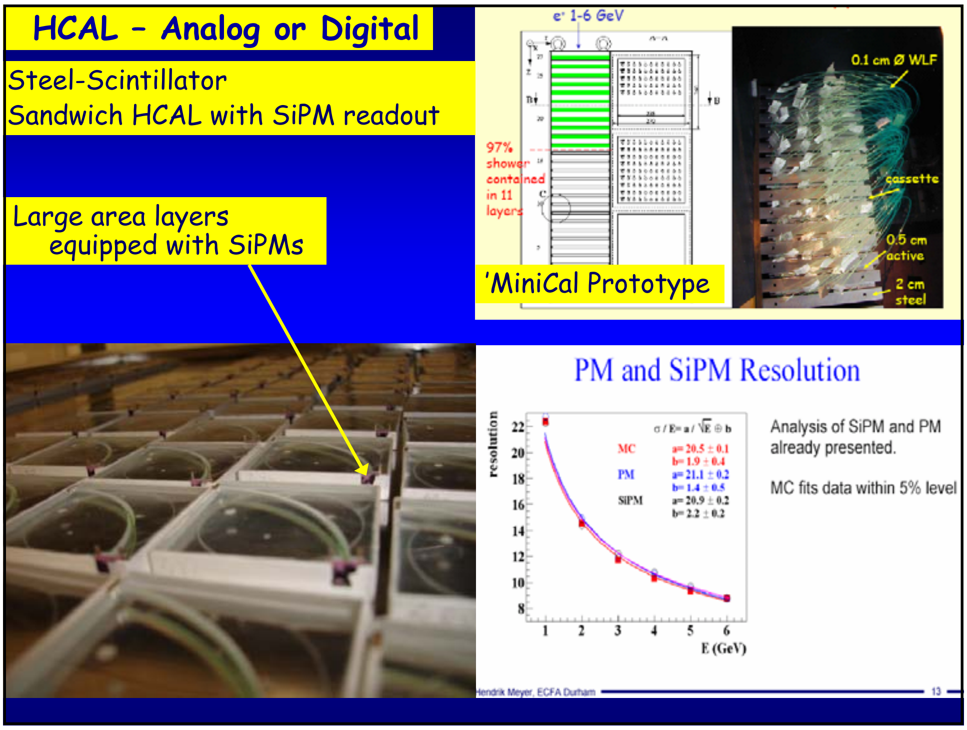
Showers of the neutral Pion

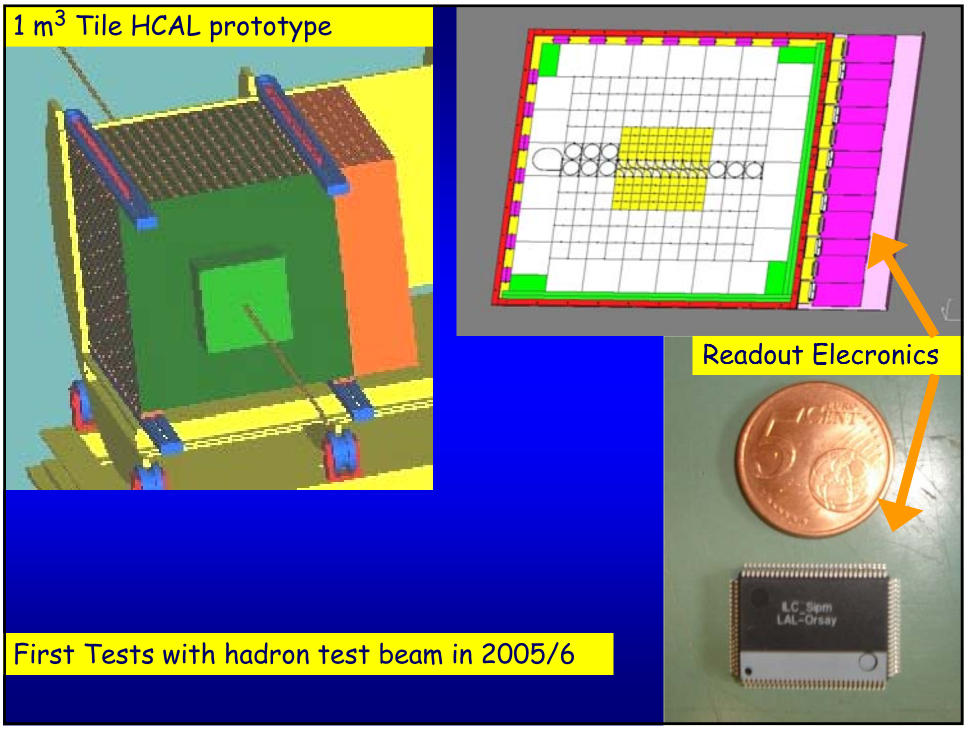

ECAL Si/W Technology
Front End
Chip
Alveolus
Tungsten
Carbon fiber
Calice
Si Sensors 1x1 cm²
Detector slab
5 inch waver
manufactred
in Korea
6 inch waver
manufactred
in US
BNL/SLAC/Oregon
•5 mm pads (1/2 R$_M$)
•Each 6 inch waver is
readout by one chip
•Electronics under way
•Test beam in 2005

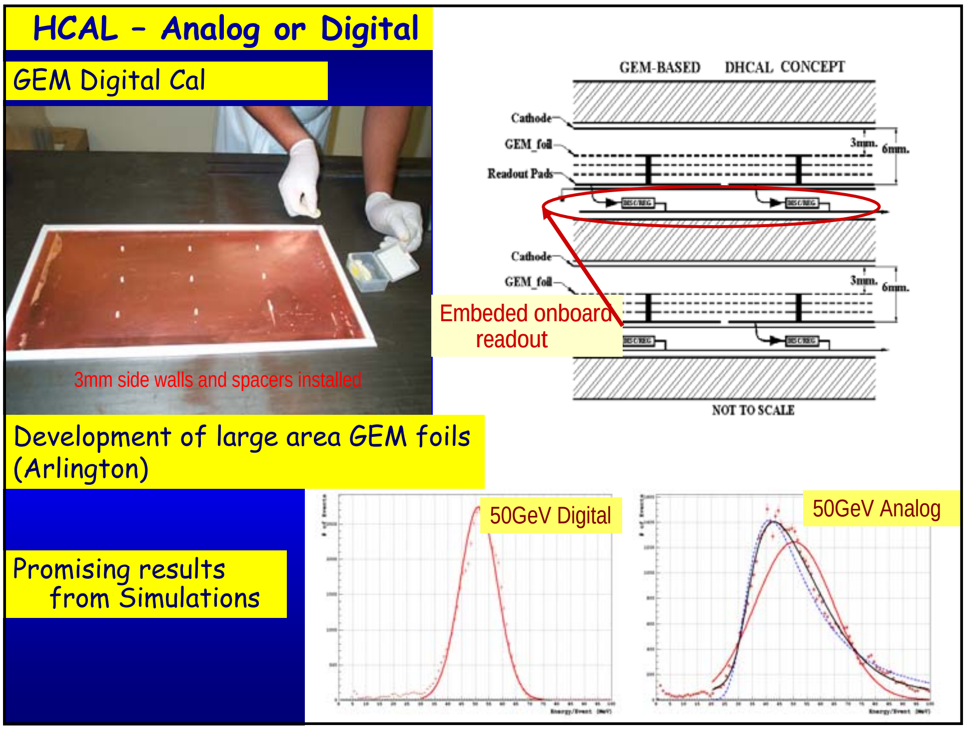

Testbeam measurements: DESY, CERN
Univs. From Korea
Calice
Detector slab
CALICE ECAL Prototype
Run=100078
Event= 613
Top
e- 3 GeV
Front
Side
First
Results will be
soon available

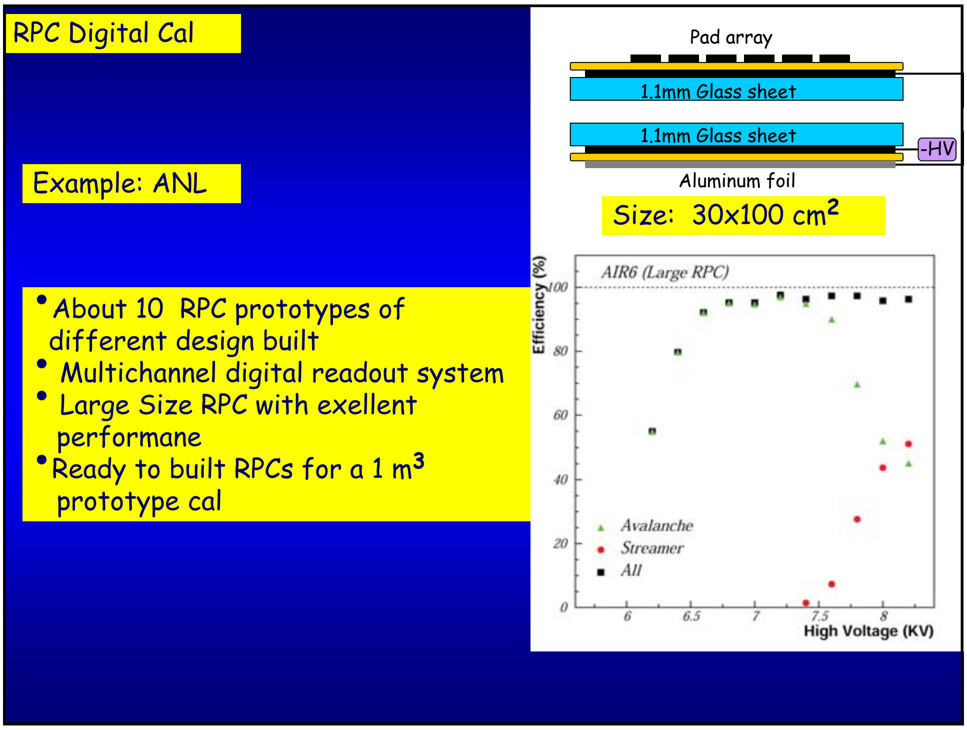

ECAL Other Technologies
LCcal: Scintillator/Si Hybrid
Testbeam results:
45 layers Sci/Pb
3 planes Si pads
BEAM
27 X₀
σE/E
11.1%/√E
e-
LCcal:First Cal in a testbeam!
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0 5 10 15 20 25 30
Ebeam (GeV)
Hi granularity Scintillator
Scintillator Strip/WLS Testbeam
SiPM from Hammatsu, to be used eadout of Scintillator blocks
Prototype Cal end 2007


Sci/Pb Technology
KEK beam: 1 – 4 GeV
e, μ, π
shower profile,
data-MC comparison
Clear fiber
16chPMT
Fiber Connector
Lead (200mm × 200mm × 4mm)
24Layer =6SuperLayer
Beam
1Layer
Strip-array Scintillator (200mm × 10mm × 2mm) × 20
WLS fiber
16chPMT
Energy Deposit (MIPs)
10²
10
1
1 GeV
2 GeV
3 GeV
4 GeV
0 2 4 6 8 10 12 14 16 18
Depth (X₀)
calorimetric angular measurement
4 GeV e-
y = (0.97±0.01)x + (-0.33±0.04)
20
17.5
15
12.5
10
7.5
5
2.5
0
0 2.5 5 7.5 10 12.5 15 17.5 20
Incident angle (degrees)

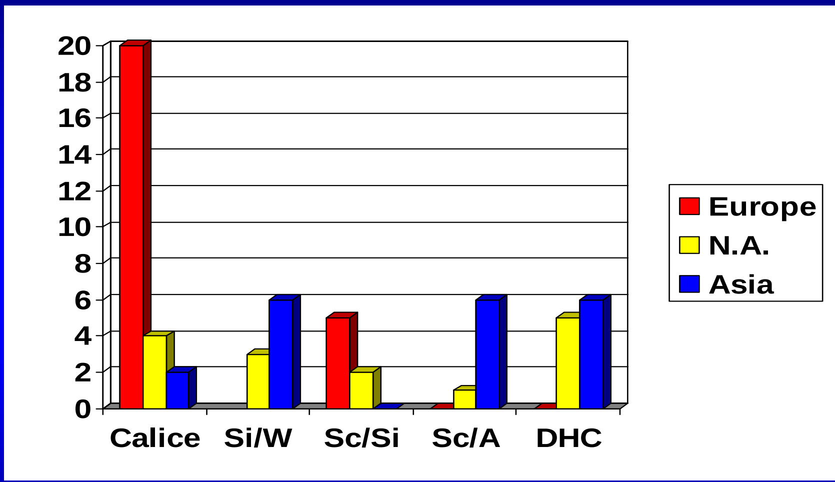

HCAL – Analog or Digital
Steel-Scintillator
Sandwich HCAL with SiPM readout
Large area layers
equipped with SiPMs
e⁺ 1-6 GeV
97% shower contained in 11 layers
'MiniCal Prototype
0.1 cm Ø WLF
cassette
0.5 cm active
2 cm steel
PM and SiPM Resolution
Analysis of SiPM and PM already presented.
MC fits data within 5% level
resolution
E (GeV)
MC
PM
SiPM
Hendrik Meyer, ECFA Durham


1 m³ Tile HCAL prototype
Readout Elecronics
ILC_Sipm
LAL-Orsay
First Tests with hadron test beam in 2005/6


HCAL – Analog or Digital
GEM Digital Cal
3mm side walls and spacers installed
GEM-BASED DHCAL CONCEPT
Cathode
GEM_foil
Readout Pads
3mm.
6mm.
Embeded onboard readout
NOT TO SCALE
Development of large area GEM foils (Arlington)
Promising results from Simulations
50GeV Digital
50GeV Analog


RPC Digital Cal
Example: ANL
• About 10 RPC prototypes of different design built
• Multichannel digital readout system
• Large Size RPC with exellent performane
• Ready to built RPCs for a 1 m3 prototype cal
Pad array
1.1mm Glass sheet
1.1mm Glass sheet
-HV
Aluminum foil
Size: 30x100 cm2
AIR6 (Large RPC)
Efficiency (%)
Avalanche
Streamer
All
High Voltage (KV)

Labs involved from the three Regions



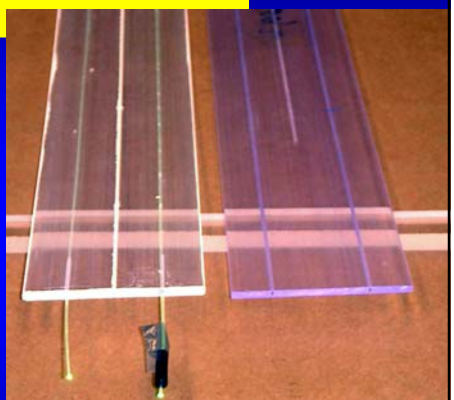
- CALICE includes institutes from all regions
- N.A. groups and CALICE plan a joint testbeam program at FNAL

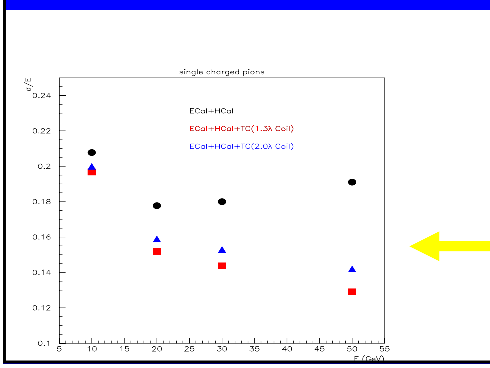
Muon Detection

Instrumentation of the Iron of the Magnet – Large area detectors

Technologies:

- RPCs
- Scintillation counter strips





Improves
The resolution of the
HCAL

Status in R&D

The nice things:

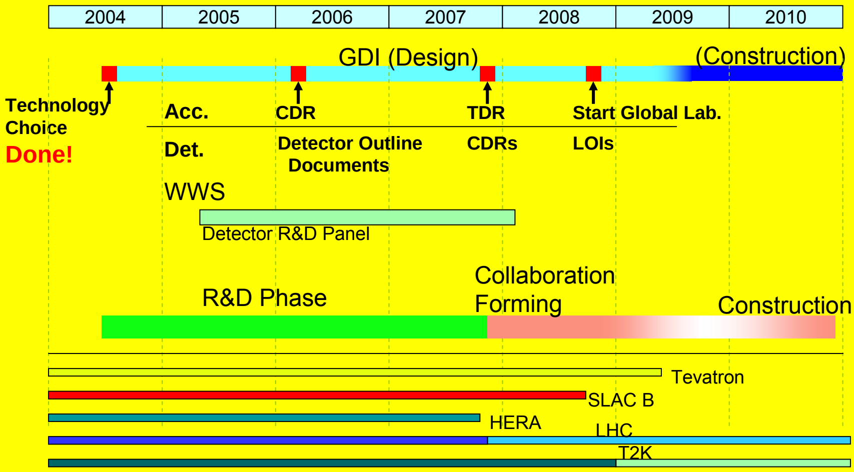
- Lots of activities in all subdetectors
- Simulations to optimise the design of all components are ongoing
- Mechanics design studies under way
- Readout concepts are designed and under test
- Testbeam studies are done for many sensors, but not yet all
- A few prototype detectors started studies with testbeams

Status in R&D

The challenges left:

- There are essential parameters to be better understood
- Testbeam studies must be extended to all sensor types
- Testbeam studies for prototypes of all subdetectors are the Major Topic for the next years- the only way to proove of performance goals
- Testbeam results are input for refined simulations- improved designs or redesigns
- 'Full system' tests must be done
- Prototypes and testbeams need a new level of funding
- I am sure I forgot something

Time Schedule



Taken from Y. Sugimoto

Conclusion

Its timely to organise our community world wide to strengthen and structure the efforts in ILC Detector R&D

Charge of the LC Detector R&D Panel:

- creation of a register of ongoing R&D programs
- Survey the R&D relevant for LC experiments
- Critically review the status of R&D
- Facilitate the review of R&D proposals

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