ILC

Accelerator
Physics
Detectors
Calorimeters

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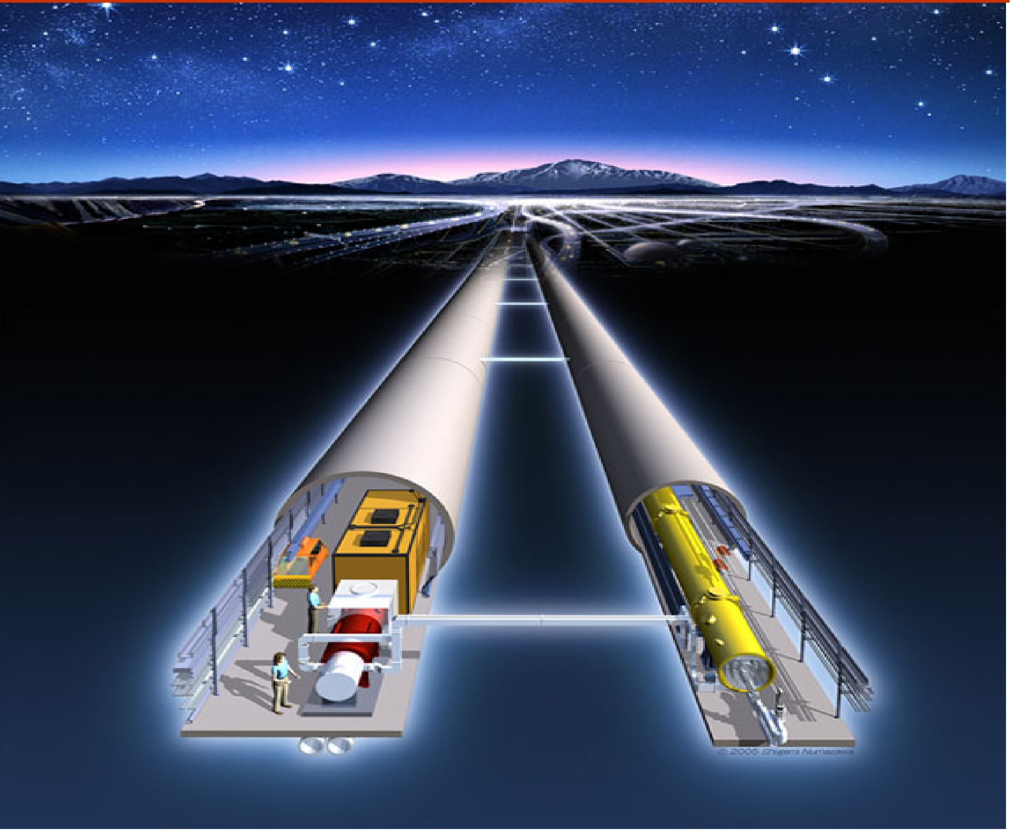
FZU AV CR

I. Accelerator

International Linear Collider (ILC)

A Vision of the Future

RDR to ILC



CMS Energy 500 GeV

Foreseen Upgrade to 1 TeV

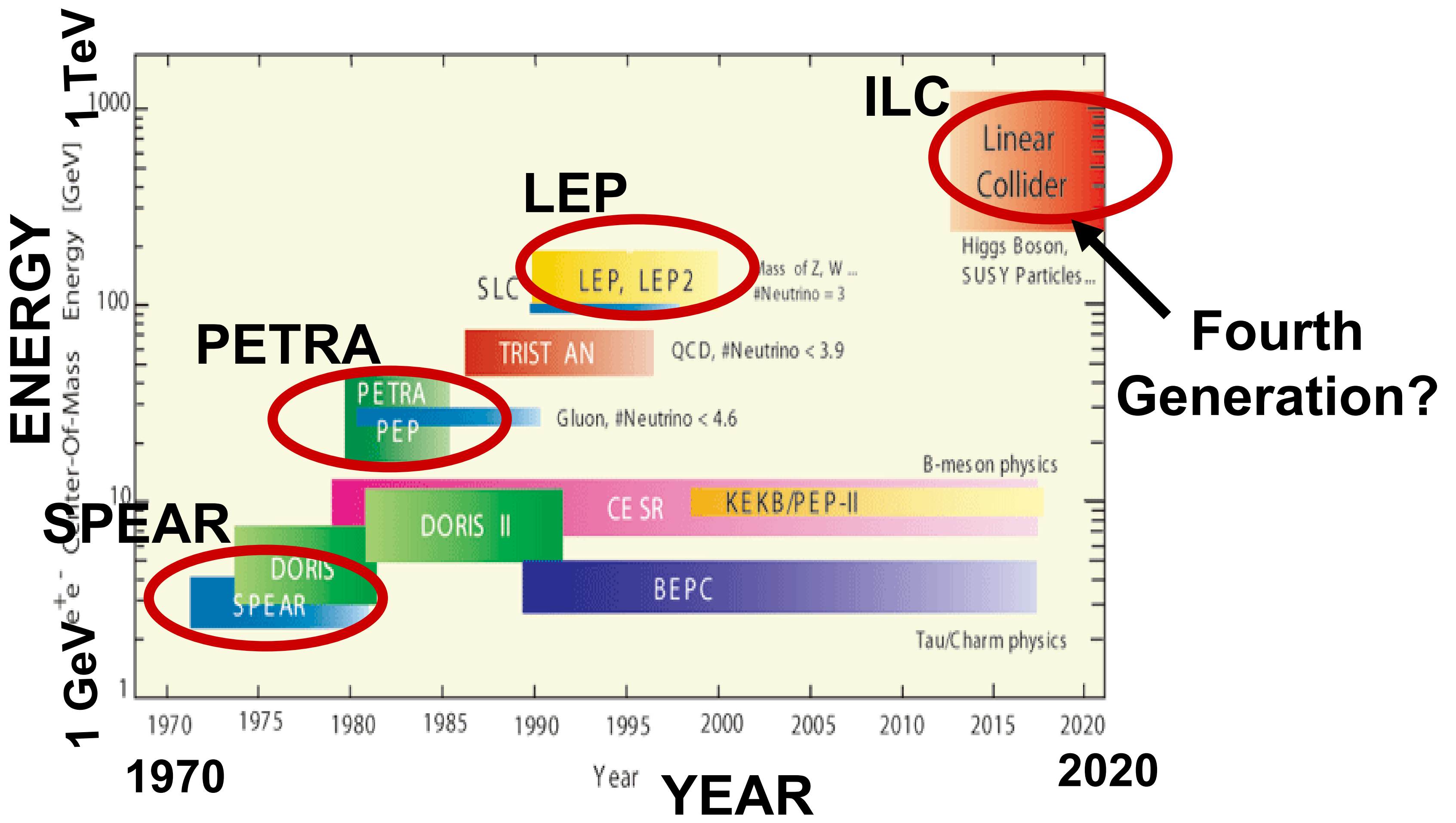
Acc. Gradient 31.5 MV/m

Overall Length 31 km

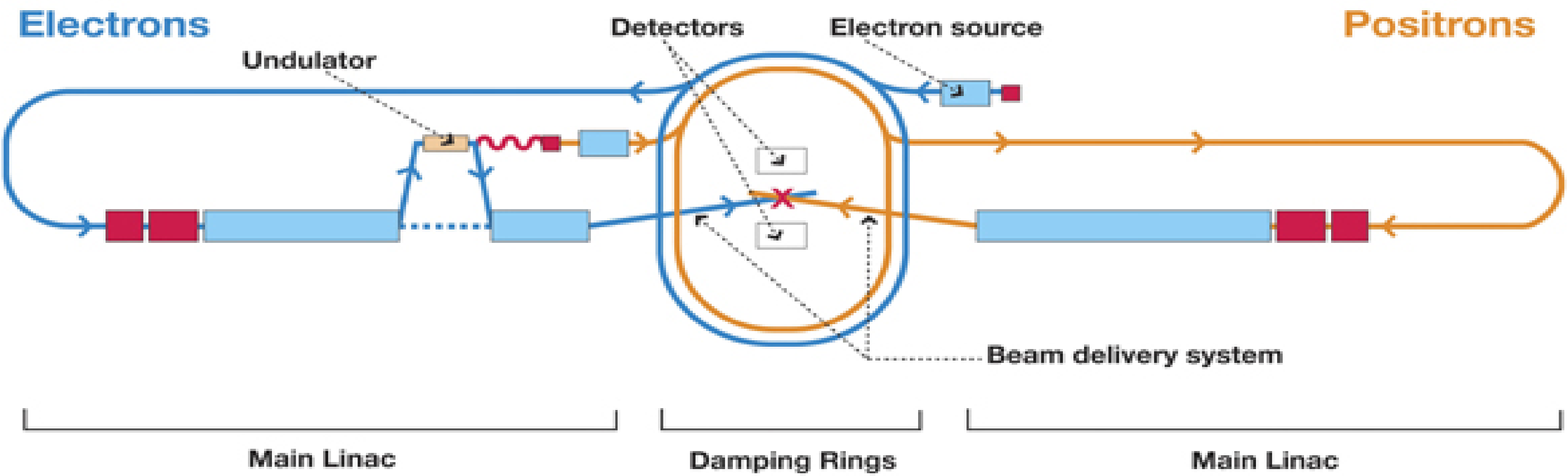
Luminosity 2x10^34 1/cm^2s

Three Generations of e^+e^- Colliders

The Energy Frontier

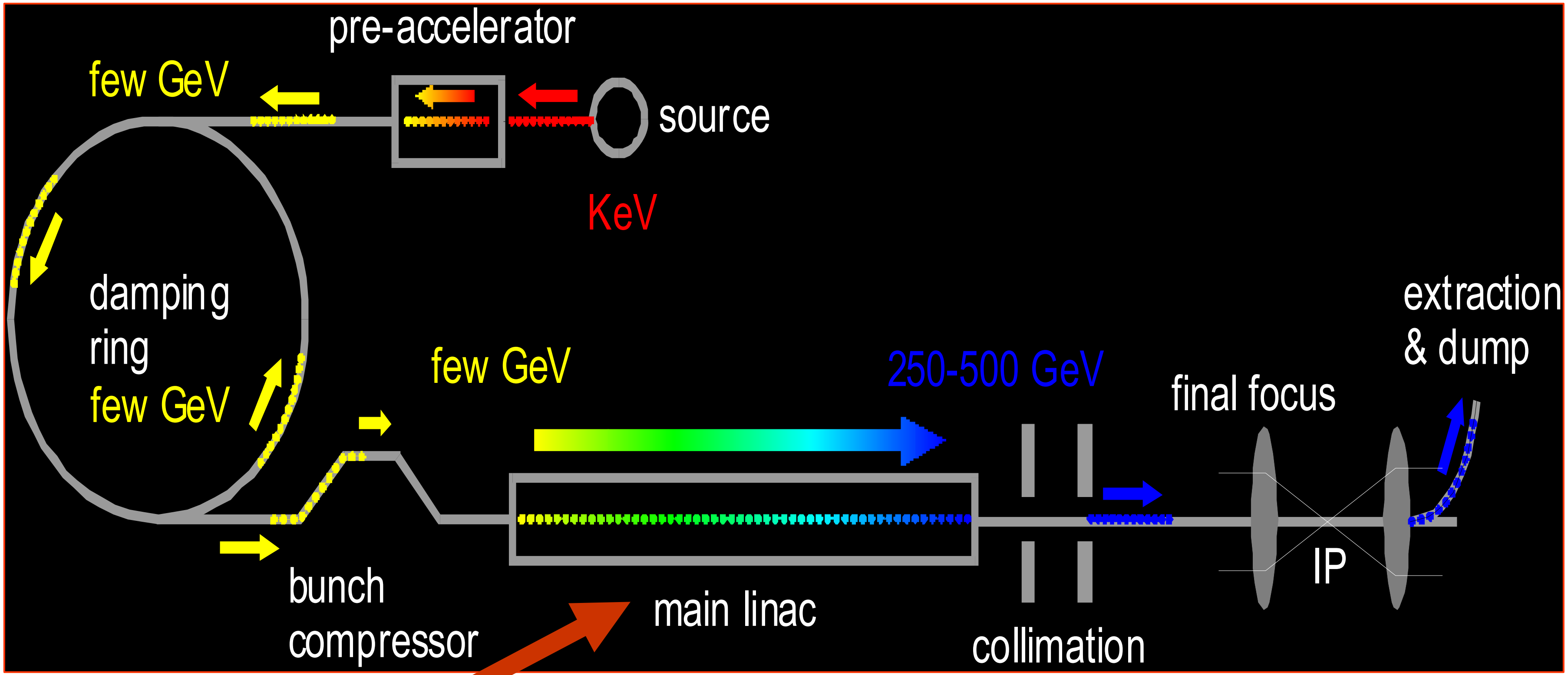


ILC Components



- Electron Source (polarization 80%)
- Positron Source (polarization 30 to 60%)
- Damping Rings, 5 Gev
- Main Linacs 50-250 GeV
- Beam Delivery System
- Detectors (push-pull configuration)

GDE -- Designing a Linear Collider



Superconducting RF Main Linac

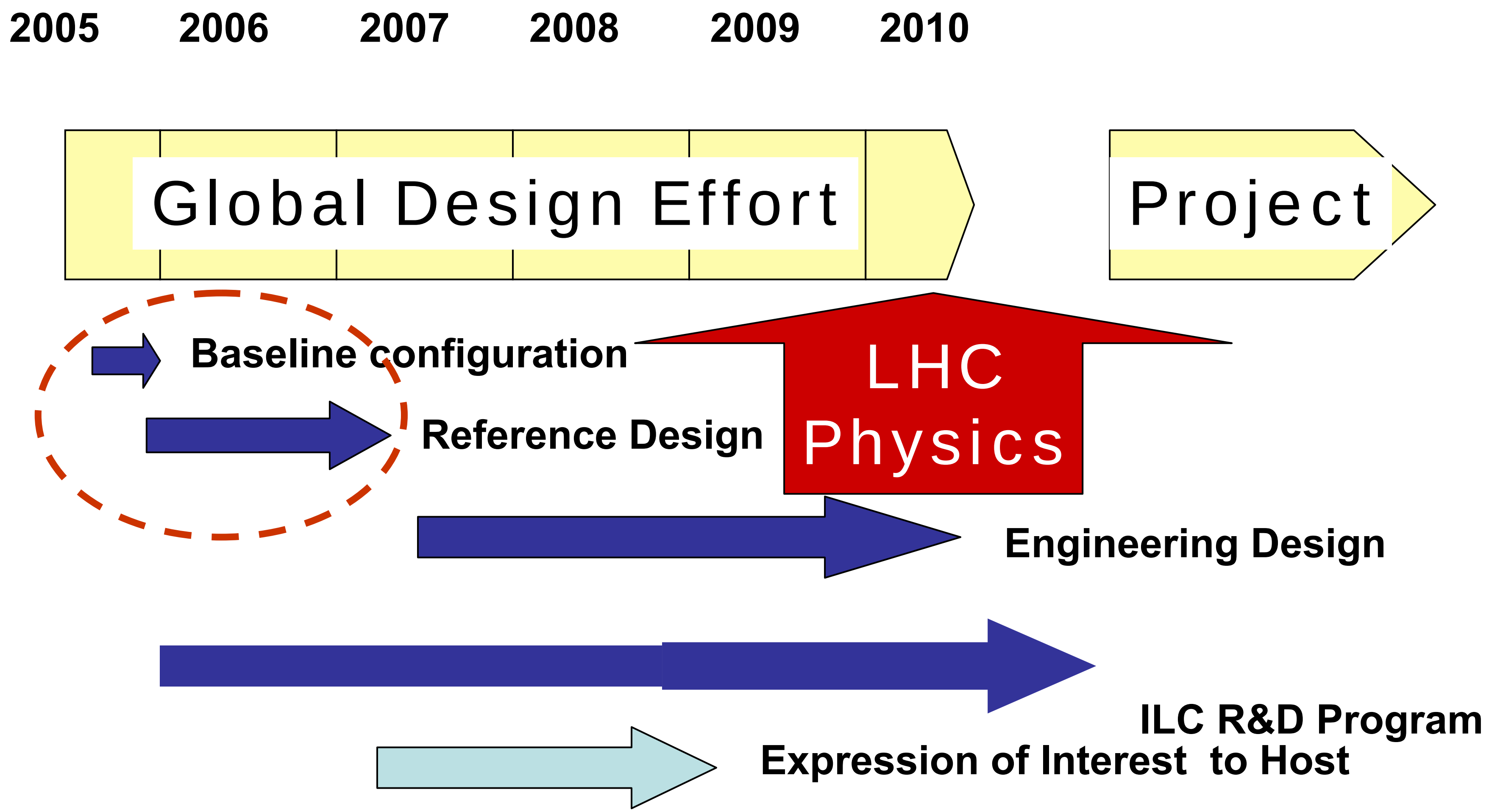
Superconductive Cavities

Niobium, 1.3 GHz, He - 2K, 35MV/m

RDR Design Parameters

Max. Center-of-mass energy	500	GeV
Peak Luminosity	$\sim 2\times10^{34}$	$1/cm^2s$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Number of bunches	~2500	
Total AC Power Consumption	~230	MW

ILC – Global Design Phase



- **Our technically driven time-scale is**
  - Construction proposal in 2010
  - Construction start in 2012 → Construction complete in 2019

II. Physics

ILC Physics Goals

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%
- The machine must be upgradeable to 1 TeV

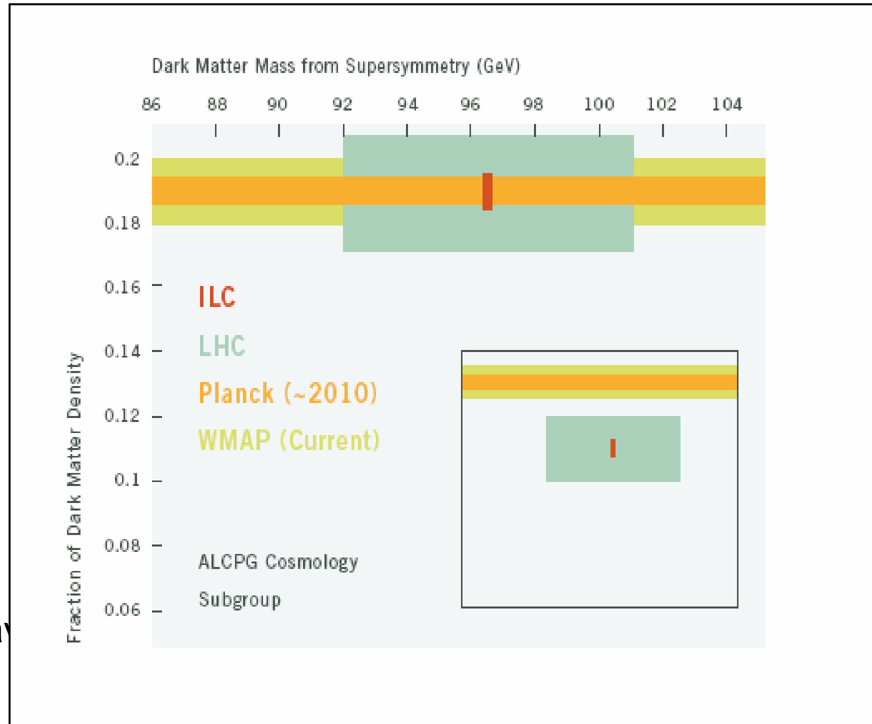
Physics

LHC will open Terascale physics

- Deep significance to fundamental physics
- What is nature of EWSB?
- Are there hidden extra dimensions?
- Are there new symmetries of space and time?
- Dark matter particles

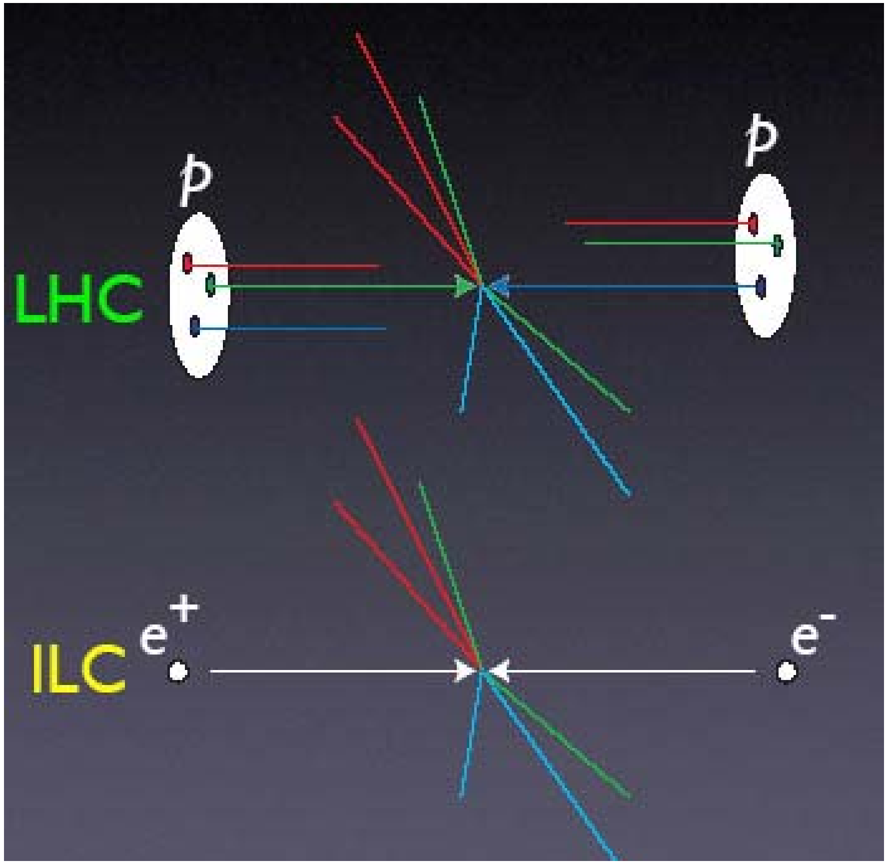
ILC is needed to explore and

- elucidate nature of Terascale
- Deeper look into Terascale questions
- Precision exploration of new physics



Precision Physics at the Terascale

- **elementary particles**
- **well-defined**
  - **energy,**
  - **angular momentum**
- **uses full COM energy**
- **produces particles democratically**
- **can mostly fully reconstruct events**

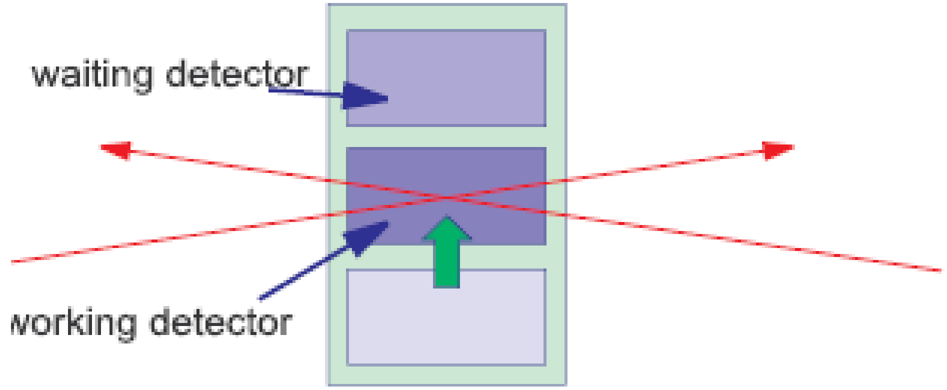


III. Detectors

Single IR with Push-Pull Detectors

- Large cost saving compared with 2 IR
  - ~200 M$ compared with 2 IR with crossing angles 14/14 mrad
- Push-pull detectors
  - Task force from WWS and GDE formed
    - But need careful design and R&D
      - For exam, need quick switch-over
    - 2 IR should be kept as an 'Alternative'

End of 2008 –
Two detector designs recognized for development to the engineering design phase



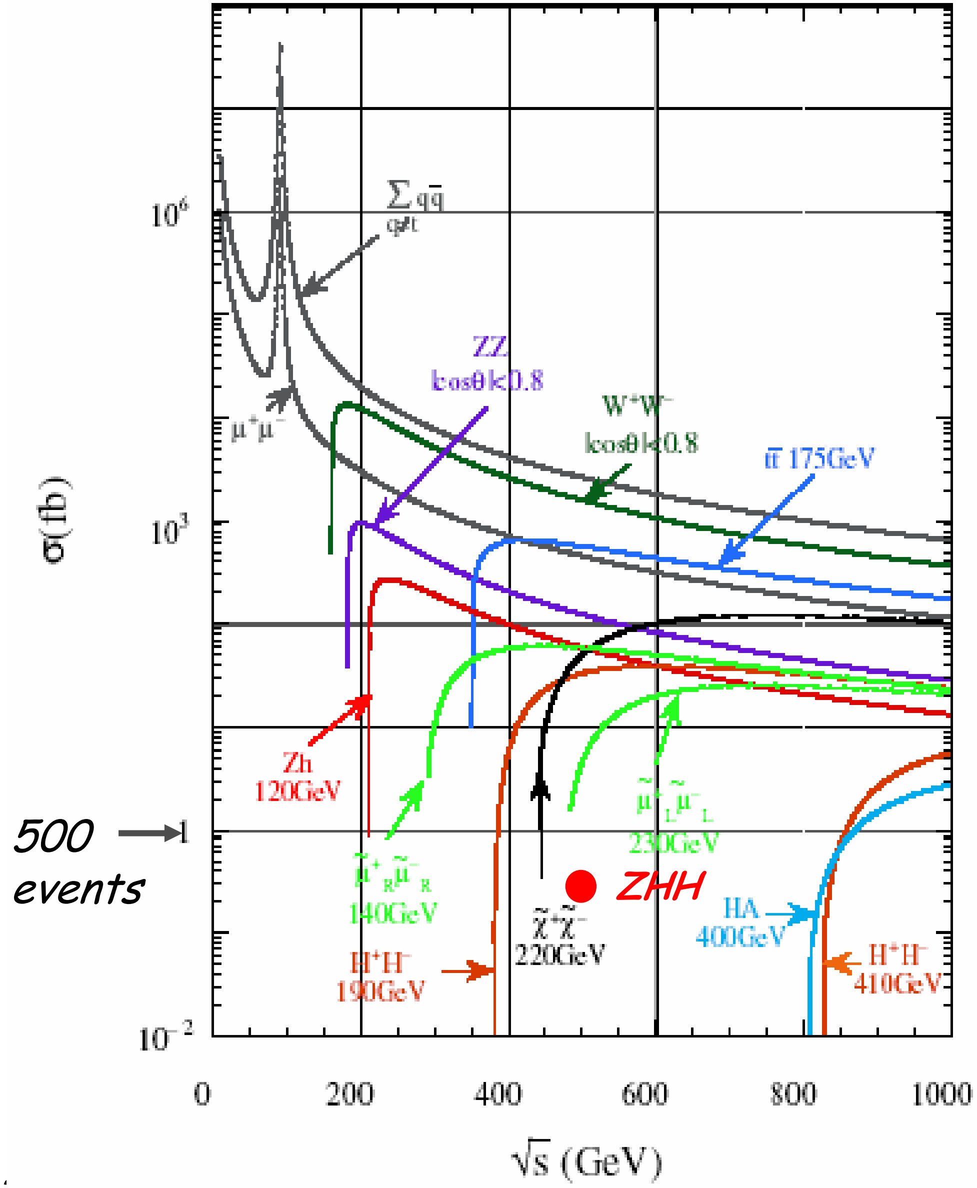
Goal of ILC Physics and Detector

- ILC Physics is described in Physics chapter of DCR
- Opportunities of ILC experiments
  - Clean, well-defined initial state,
  - Trigger-less readout
  - Low radiation field

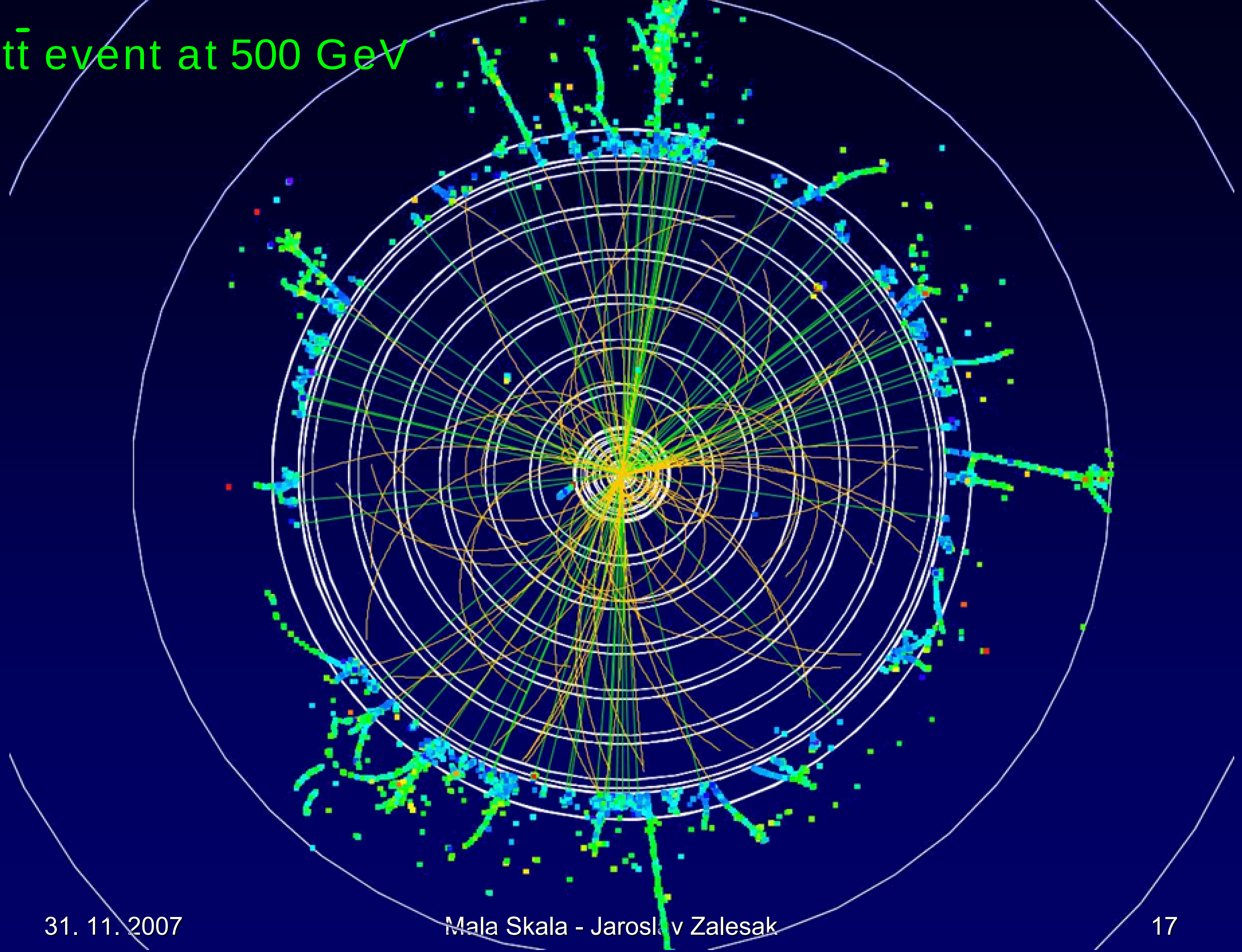
  ➔ ideal environment for precision studies and sensitive searches for faint new physics
- ILC detector design concentrate on measuring partons with high precision
  - Quarks/ gamma → Good jet energy measurement
  - Leptons (e/m) → tracking
  - b/c quarks ID → Vertexing

Precision Physics at the ILC

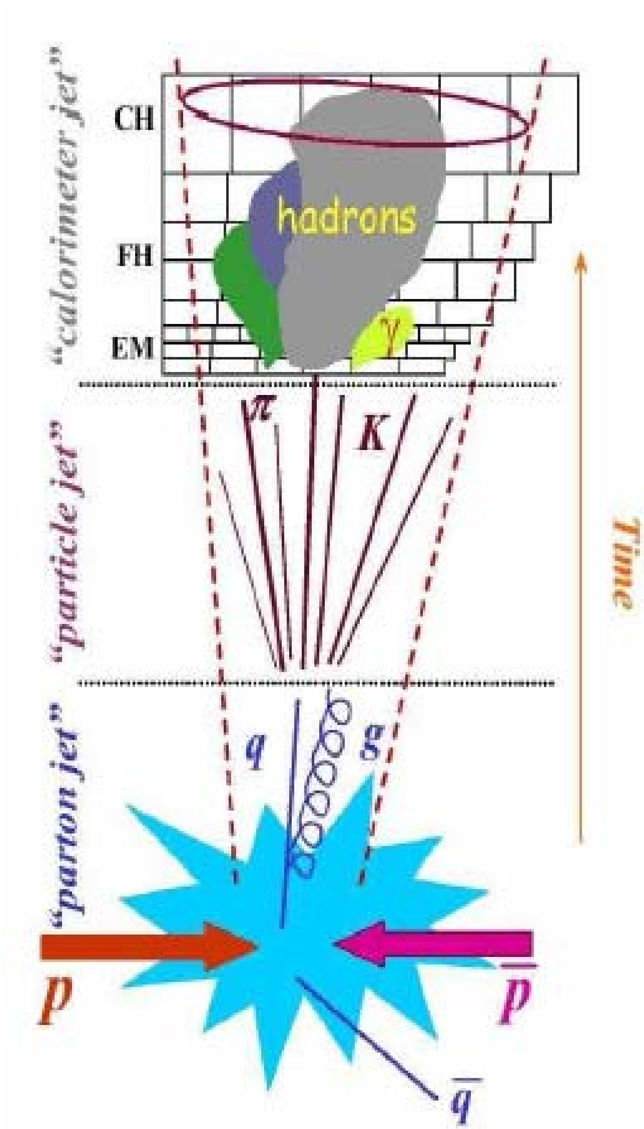
- e^+e^- : background-free but can be complex multi-jet events
- Includes final states with heavy bosons *W, Z, H*
- But, statistics limited so must include hadronic decay modes (~80% BR) -> *multi-jet events*
- In general no kinematic fits -> full event reconstruction



$t\bar{t}$ event at 500 GeV



Parton Measurement via Jet Recon



- Calorimeter jet
  - Interaction of hadrons with calorimeter.
  - Collection of calorimeter cell energies.
- Particle jet
  - After hadronization and fragmentation.
  - Effect of hadronization is soft $\Rightarrow$ allows comparison between particle and parton jets.
- Parton jet
  - Hard scattering.
  - Additional showers.

The Particle Flow Approach to Jet Reconstruction

PFA Aim : *1 to 1 correspondence between measured detector objects and particle 4-vectors*

-> Detector Jet == Particle Jet

-> combines ***tracking*** and ***3-D imaging calorimetry*** :

- good tracking for charged particles (~60% of jet E)
  - -> σ_p (tracking) <<< σ_E for photons or hadrons in CAL
- good EM Calorimetry for photon measurement (~25% of jet E)
  - -> σ_E for photons < σ_E for neutral hadrons
- good separation of neutral and charged showers in E/HCAL
  - -> CAL objects == particles
  - -> 1 particle : 1 object -> small CAL cells
- adequate E resolution for neutrals in HCAL (~13% of jet E)
  - -> σ_E < minimum mass difference, e.g. $M_Z - M_W$
  - -> still largest contribution to jet E resolution

The PFA Approach and Detector Design

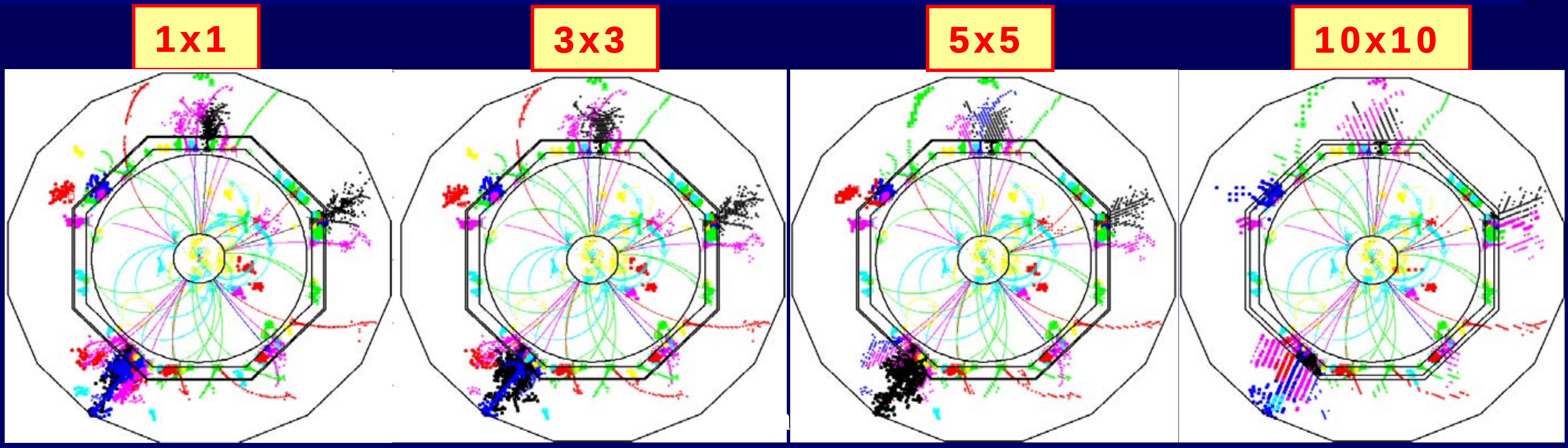
PFA key -> complete separation of charged and neutral hadron showers

$$\Delta E_{jet}/E_{jet} = \delta(Tracker) \oplus \delta(EMCAL) \oplus \delta(HDCAL)$$
$$\oplus\, \delta(Acceptance) \oplus \delta(Confusion)$$

Requires a calorimeter designed for optimal 3-D hadron (and photon) shower reconstruction :

- -> granularity << shower transverse size (number of "hits")
- -> segmentation << shower longitudinal size ("hits")
- -> digital or analog readout?
- -> dependence on inner R, B-field, etc.

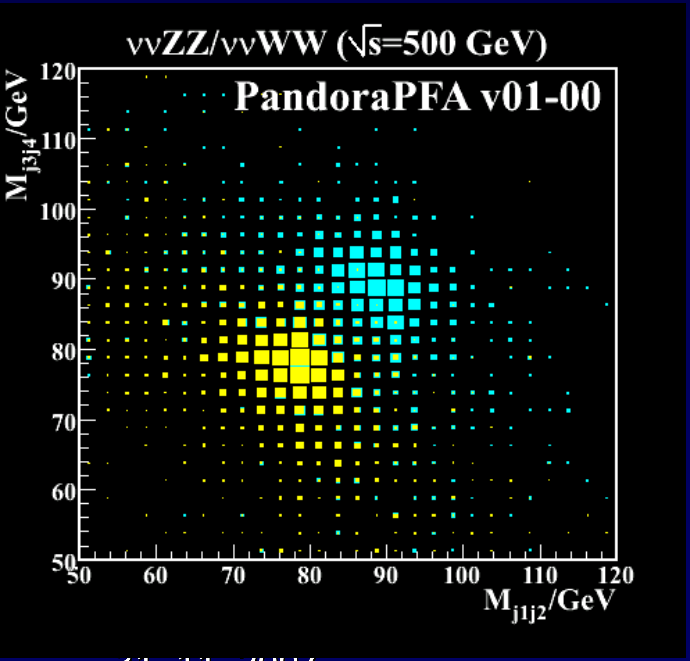
uses optimized PFA to test detector model variations

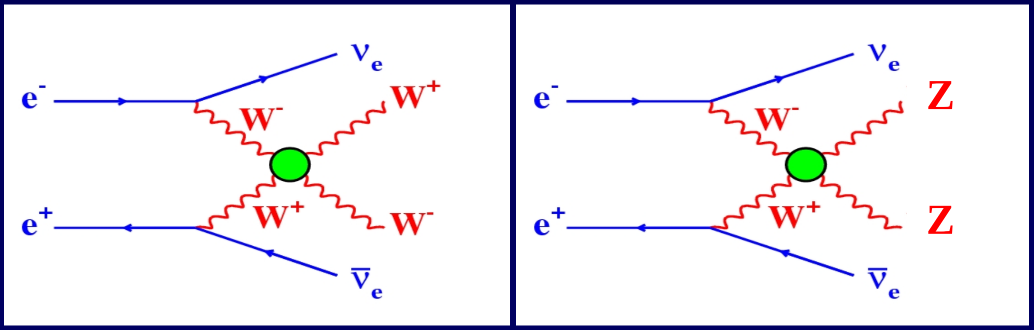


Jet reconstruction will be crucial to our understanding of physics at the ILC.

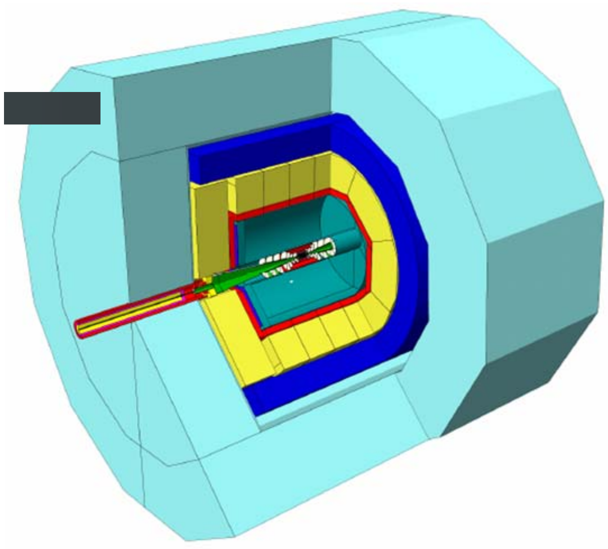
-> The PFA approach to jet reconstruction is seen as a way to use the components of an ILC detector in an optimal way, achieving unprecedented mass resolution from dijet reconstruction.

Dependencies on various detector parameters are now being studied, which will ultimately influence our choice of technologies for ILC detector component design – in particular the calorimeters.

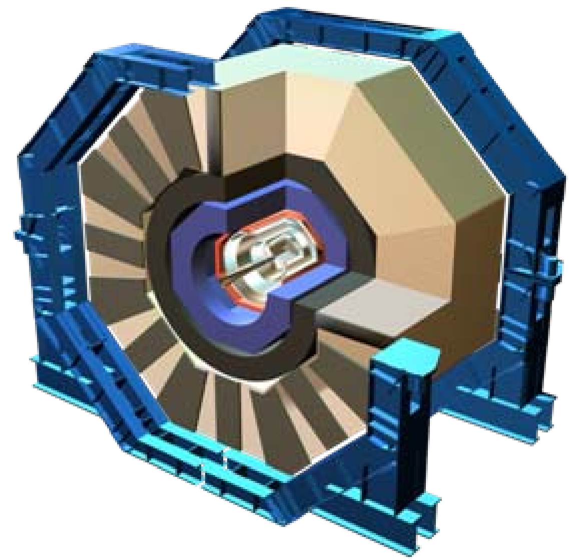




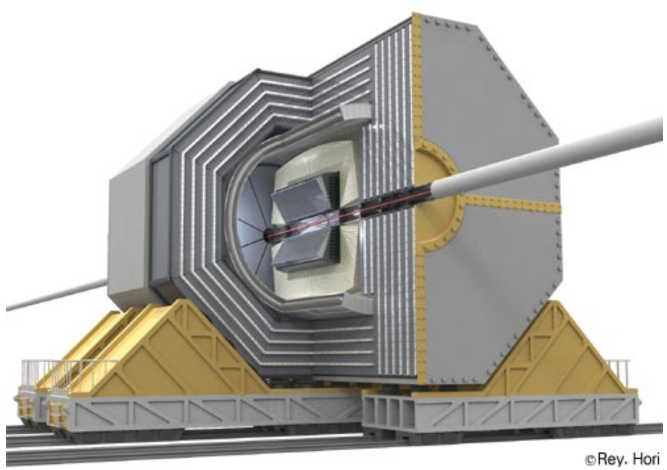
The Detector Concepts



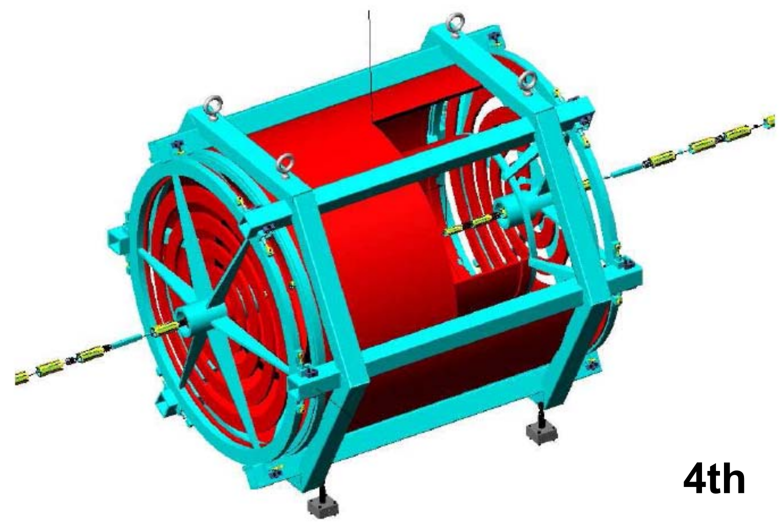
LDC



SiD



GLD



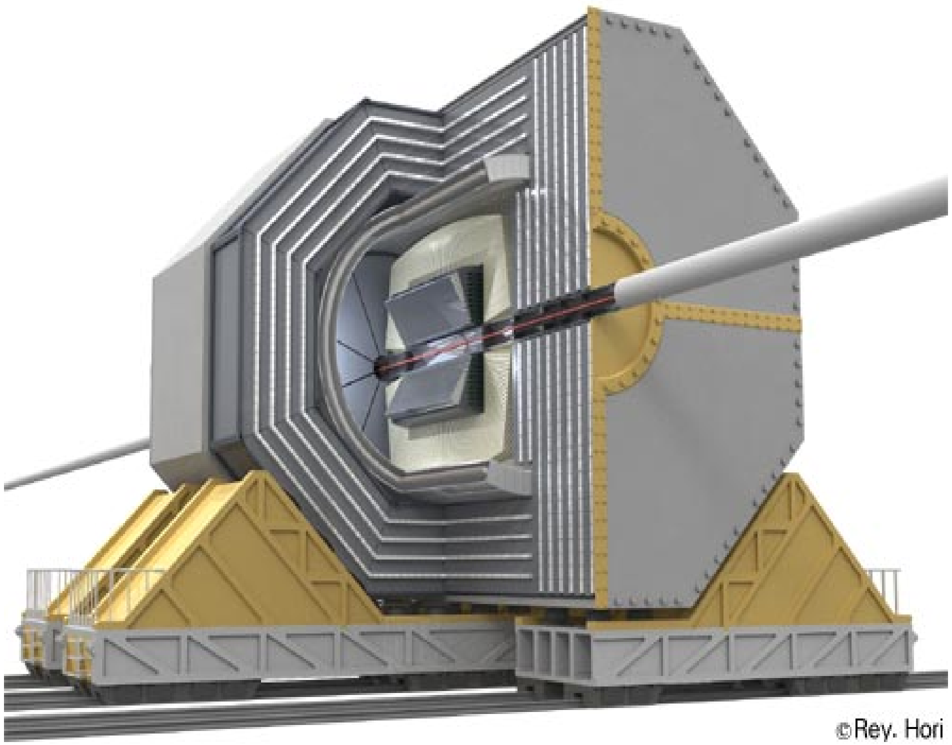
4th

The Concepts

	Tracking	ECal Inner Radius	Solenoid	EM Cal	Hadron Cal	Other
SiD	silicon	1.27 m	5 Tesla	Si/W	Digital (RPC..)	Had cal inside coil
LCD	TPC gaseous	1.68 m	4 Tesla	Si/W	Digital or Analog	Had cal inside coil
GLD	TPC gaseous	2.1 m	3 Tesla	W/ Scin.	Pb/ Scin.	Had cal inside coil
4th	TPC gaseous	1.4 m	3.5/1.5	crystal	Multi-fiber readout	Double Solenoid

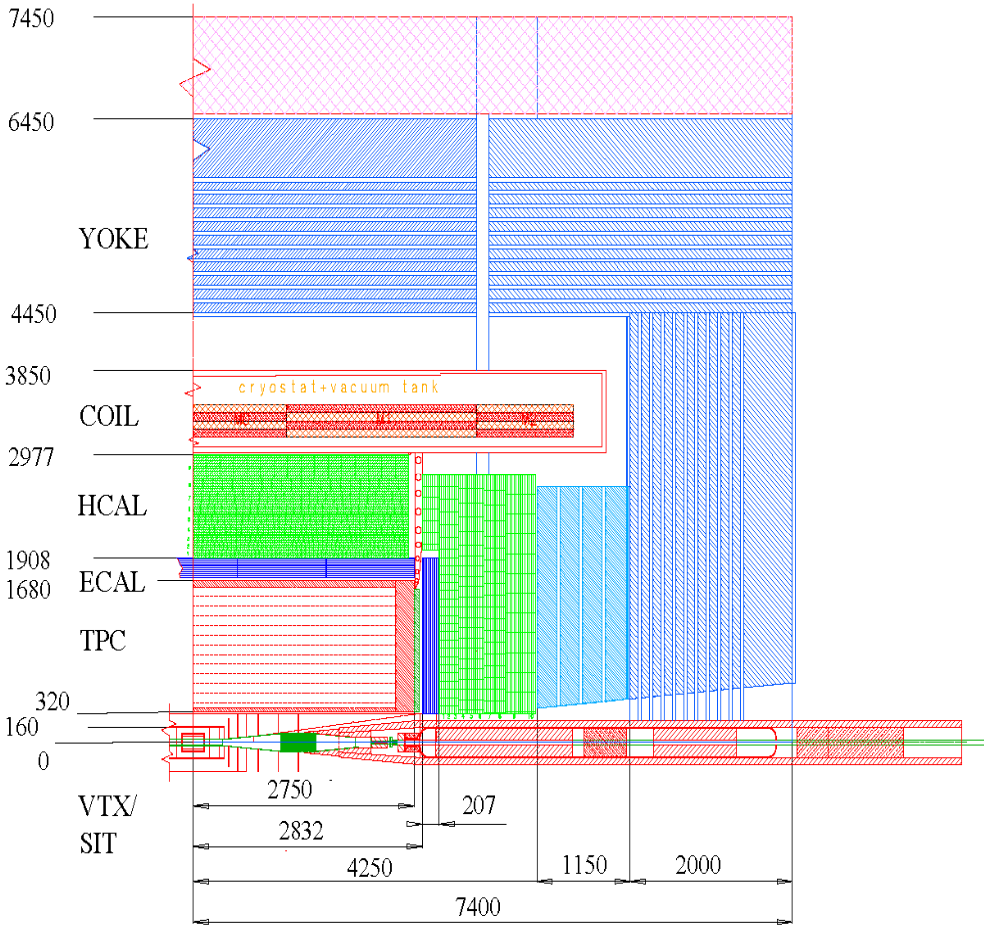
IV. LDC detedtor

Detector Concept for the ILC



- Four different detector design concepts differing in B-field, radius, tracking systems
- Large detector Design Concept (LDC)
- High B-field (4T), small radius (6m), TPC

LDC Layout



- Tracking Systems (VTX detector, central tracker, large TPC)
- Calorimeter (ECAL, HCAL, forward cal.)
- Magnet System (large 4T coil)
- Muon System (outside coil)

V. Calorimeters

&

CALICE

Calorimeter for ILC

Goals of the Collaboration

To provide a basis for choosing a **calorimeter technology** for the ILC detectors

To **measure** electromagnetic and hadronic showers with unprecedented granularity

Physics prototypes

Various technologies (silicon, scintillator, gas)
Large cubes (1 m^3 HCALs)
Not necessarily optimized for an ILC calorimeter
Detailed test program in particle beams

Technical prototypes

Various technologies
Can be only partially equipped
Appropriate shapes (wedges) for ILC detectors
All bells and whistles (cooling, integrated supplies…)
Detailed test program in particle beams

To **advance** calorimeter technologies and our **understanding** of calorimetry in general

To design, build and test **ILC calorimeter prototypes**

PFAs and Calorimetry

Fact

Particle Flow Algorithms improve energy resolution compared to calorimeter measurement alone (see ALEPH, CDF, ZEUS…)

How do they work?

Particles in jets	**Fraction of energy**	**Measured with**	**Resolution** [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion	The real challenge		**≤ $\mathbf{0.04^2}$** (goal)

} 18%/√E

Minimize confusion term

Maximize segmentation of the calorimeter readout

High segmentation

O(<1 cm²) in the ECAL
O(~1 cm²) in the HCAL
→ O(10^7 – 10^8) channels for entire ILC calorimter

Can PFAs achieve the ILC goal?

YES!!

CALICE Test Beam Activities

2006 – Fall 2007

DESY electrons 1 – 6 GeV

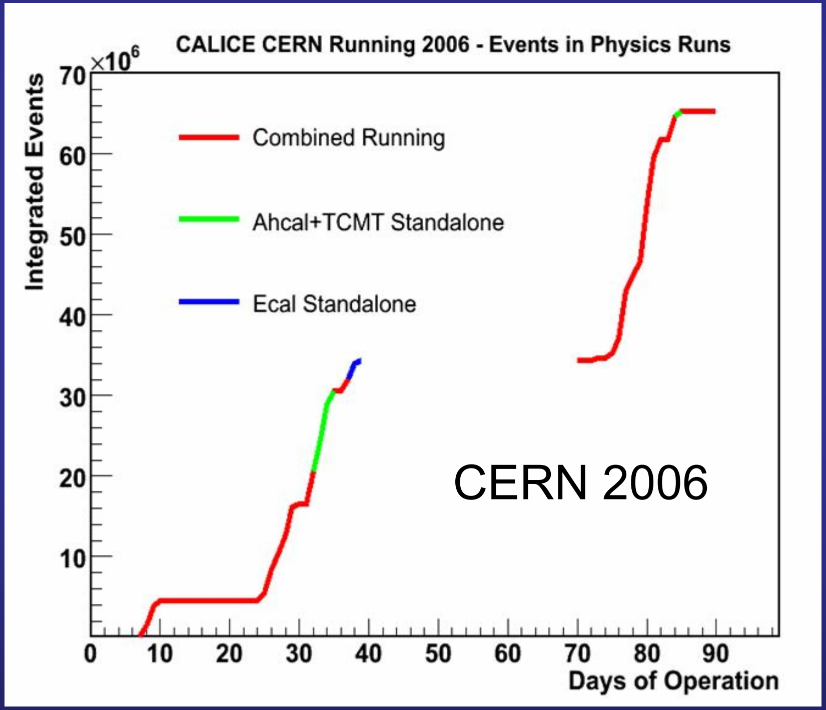
Silicon-ECAL
Scintillator ECAL
Scintillator HCAL
TCMT

CERN electrons and pions 6 – 120 GeV

Silicon-ECAL
Scintillator HCAL
TCMT (complete)

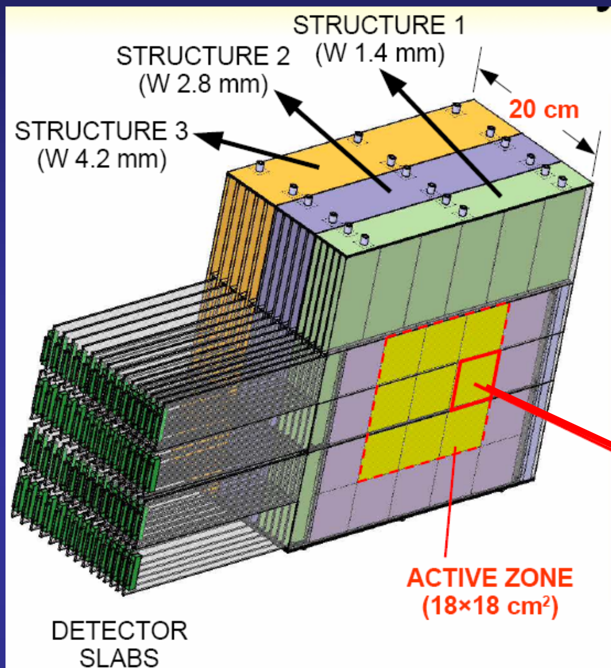
FNAL protons at 120 GeV

3 RPCs
1 GEM
10 RPCs+4 GEMs



Silicon-Tungsten ECAL

Physics prototype

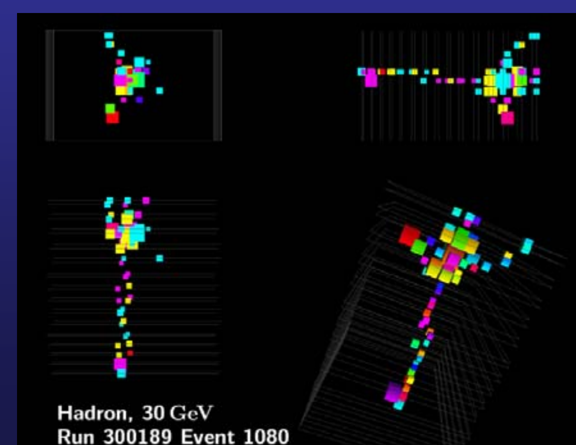


1 X_0(W) = 3.5 mm

3 structures with different W thicknesses
30 layers; 1 x 1 cm^2 pads
12 x 18 cm^2 instrumented in 2006 CERN tests
→ 6480 readout channels

Tests at DESY/CERN in 2006

Electrons 1 – 45 GeV
Pions 6 – 120 GeV

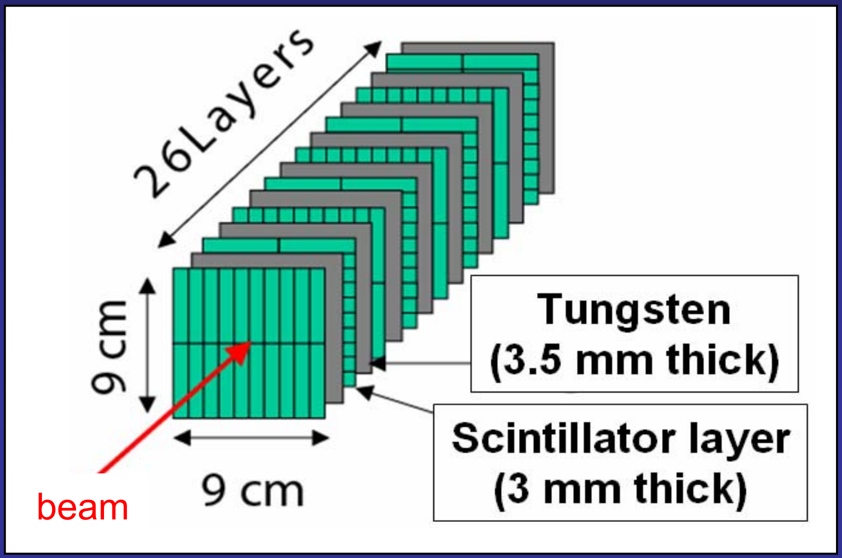


Electronic Readout

Front-end boards located outside of module
Digitization with VME – based system (off detector)

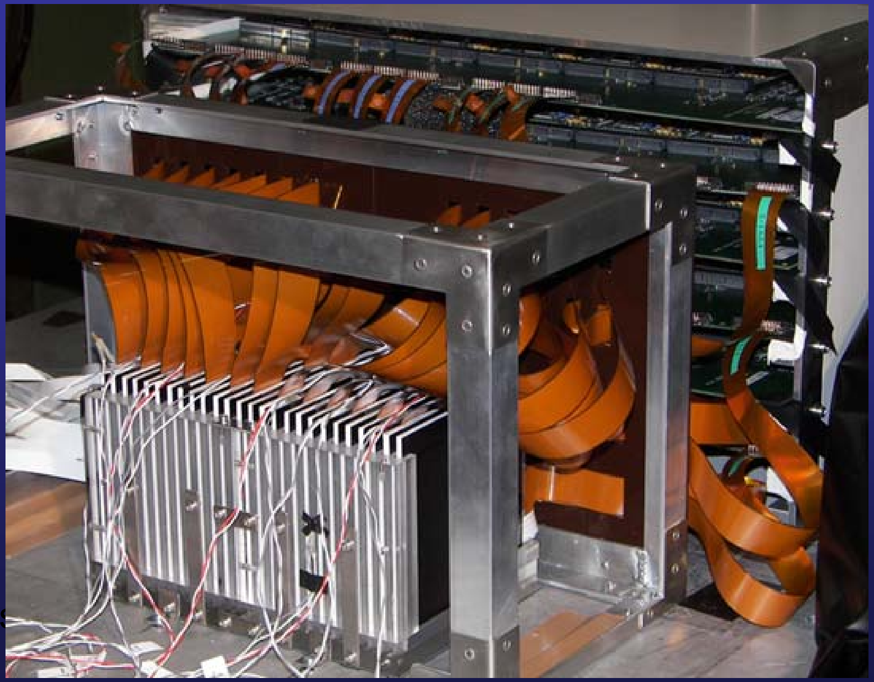
Scintillator-Tungsten ECAL

Offers the possibility of hardware compensation



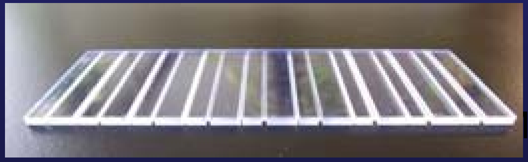
Physics prototype

26 layers
1 x 4.5 x 0.3 cm^3 scintillator strips
Read out with Hamamatsu MPPCs
+ Scintillator-HCAL electronics

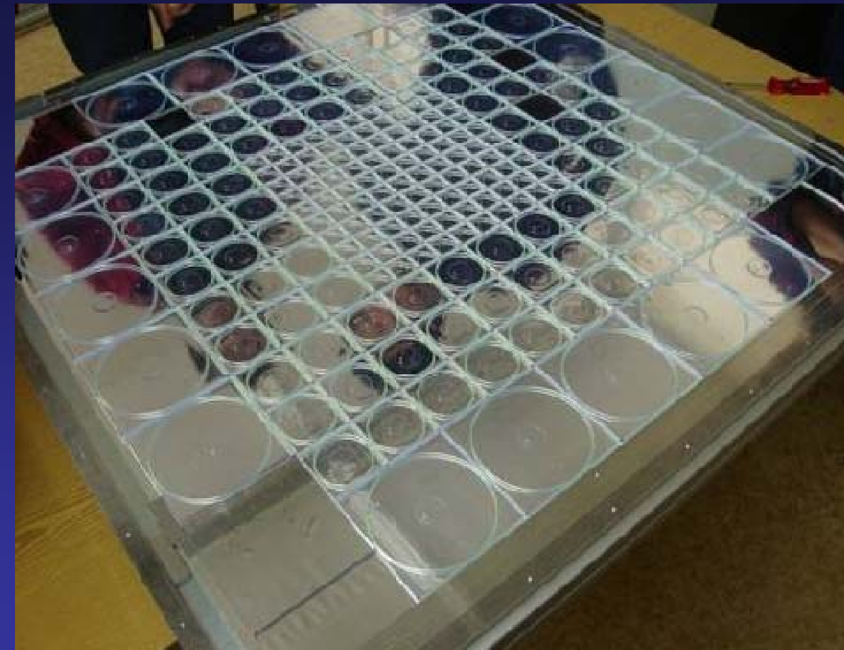


Tested different set-ups

WLSF and groves
No WLSF (direct coupling)
WLSF in extruded scintillator



Scintillator HCAL



First calorimeter to use SiPMs

Physics prototype

38 steel plates with a thickness of 1 X_0 each
Scintillator pads of 3 x 3 → 12 x 12 cm^2
→ ~8,000 readout channels

Electronic readout

Silicon Photomultipliers (SiPMs)
Digitization with VME-based system (off detector)

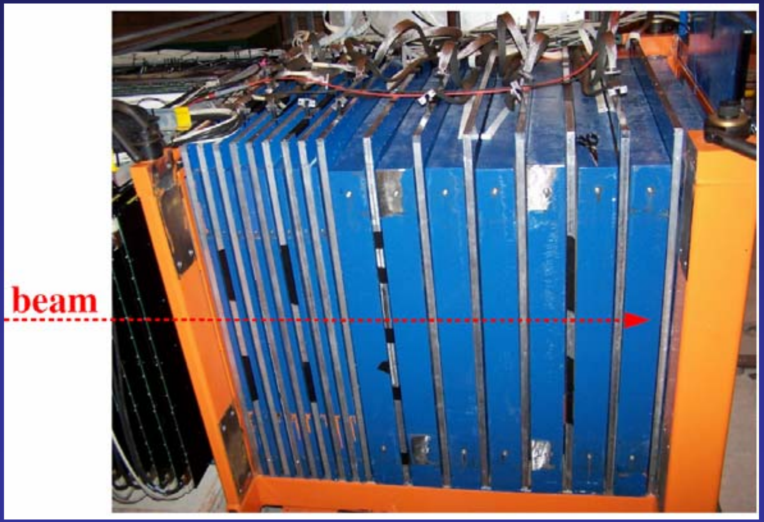
Tests at DESY/CERN in 2006

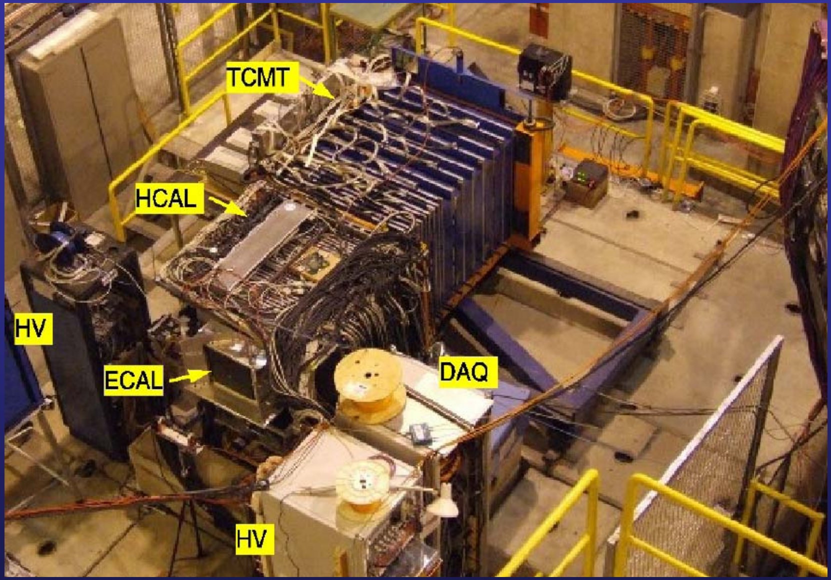
23/38 readout planes
Electrons 1 – 45 GeV
Pions 6 – 50 GeV

Tail Catcher Muon Tracker (TCMT)

TCMT

Steel absorber: layers 1 – 8: t = 2 cm
9 – 16: t = 10 cm
Scintillator strips of 5 x 100 x 0.5 cm^3
Alternate x, y orientations
Complete TMCT in October 2006 CERN run

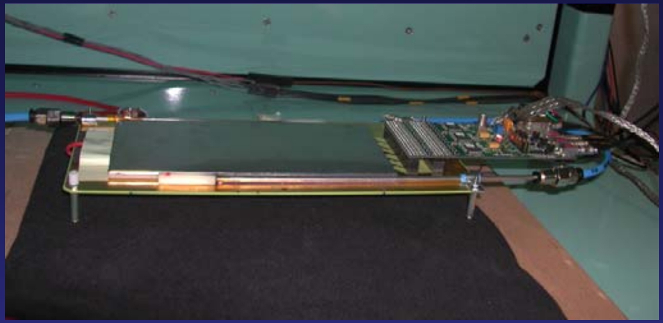




Electronic readout

SiPMs as for scintillator HCAL
Same electronic system as scintillator HCAL

Digital HCAL



Active elements considered

Resistive Plate Chambers (RPCs): R&D (virtually) complete
Gas Electron Multipliers (GEMs): R&D ongoing
MicroMegas: R&D initiated

RPCs and GEMs were tested in FNAL test beam

Physics prototype

{16 mm steel plates + 4 mm copper (cooling) } x 38
Re-use stack from scintillator-HCAL

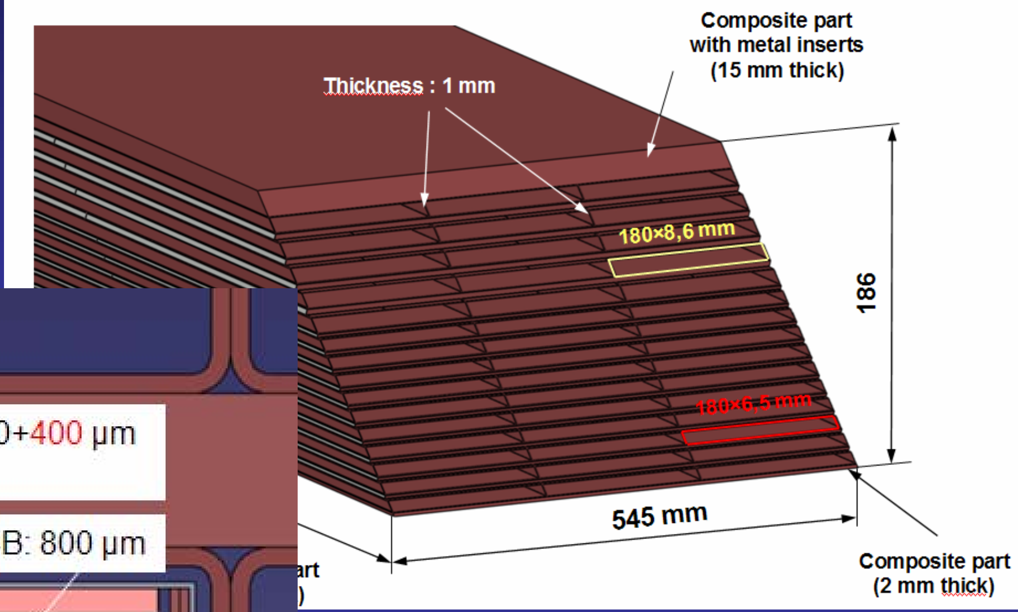
Electronic readout system

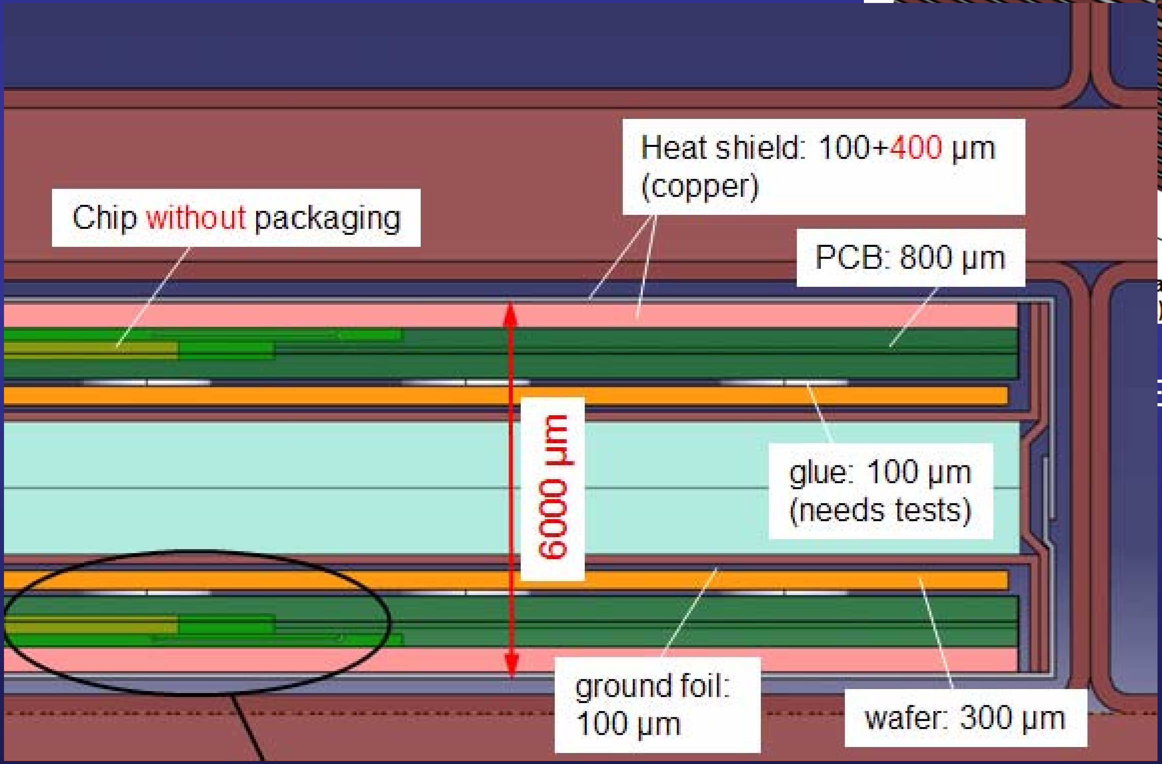
1 x 1 cm^2 pads with digital (single-bit) readout
→ Large number of channels (400,000 for physics prototype)
One-bit (digital) resolution with on-detector ASIC
Currently preparing Vertical Slice Test
→ if successful initiate construction of physics prototype

Towards Technical Prototypes

Silicon – Tungsten ECAL Module

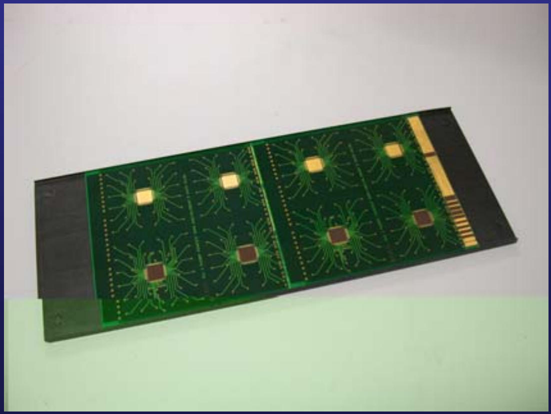
Designing the alveolar structure
Many studies: cooling, gluing, production…





Chips and bonded wires
inside the PCB

Effective active gap thickness ~ 2,200 μm

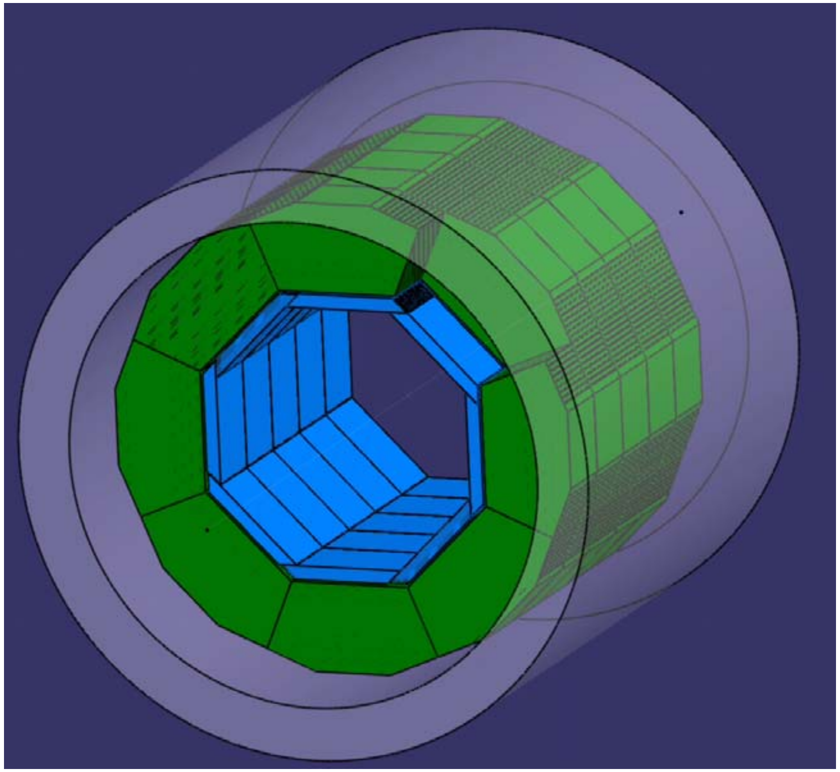


Conclusions

Test beam activities with physics prototypes

	Project	2007b	2008a	2008b	2009a	2009b
ECAL	**Si-W**	CERN test beam	FNAL test beam			
	MAPS	1st prototype chip		2nd prototype chip	DESY test beam	
	Scintillator			FNAL test beam		
HCAL	**Scintillator**	CERN test beam	FNAL test beam			
	RPC	Vertical slice test in FNAL test beam	Physics prototype construction	FNAL test beam		
	GEM	Vertical slice test In FNAL test beam	Further R&D on GEMs		Physics prototype construction	FNAL test beam
	MicroMegas		1 plane			
TCMT	**Scintllator**	CERN test beam	FNAL test beam			

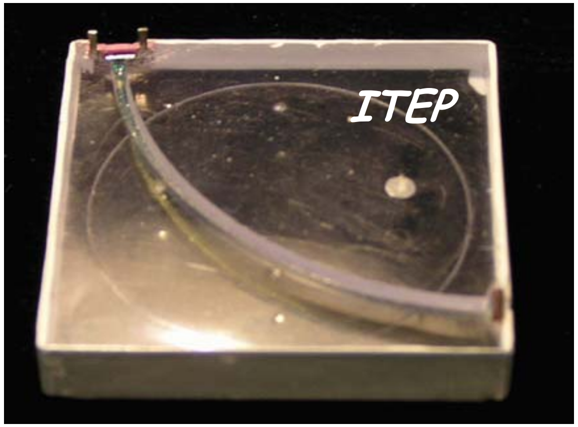
+ further R&D, technical prototype designs, construction & testing…



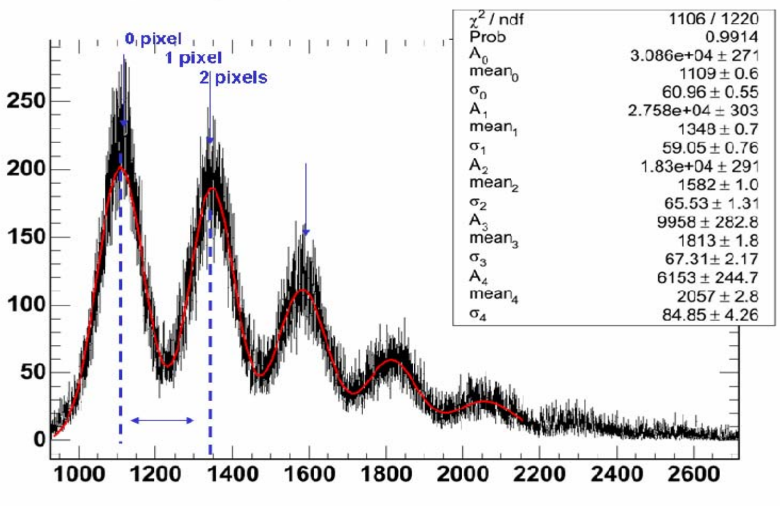
VI. AHCAL

SiPMs for calorimetry

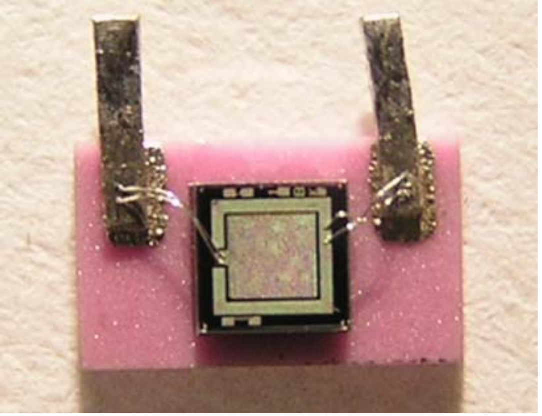
- Multipixel Geiger Mode Photodiodes
  - Gain 10^6, bias ~ 50 V, size 1 mm^2
  - Insensitive to magnetic fields



3x3 cm scintillator tile with WLS fibre

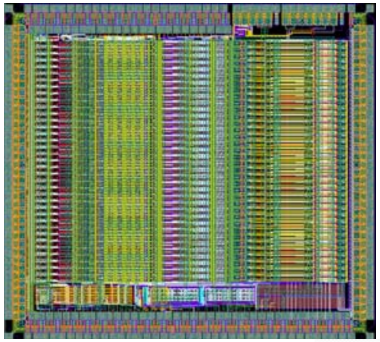


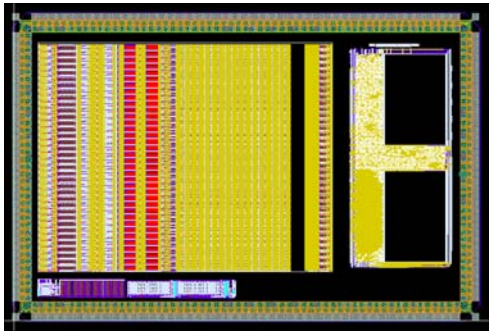
1156 pixels with individual quenching resistor on common substrate



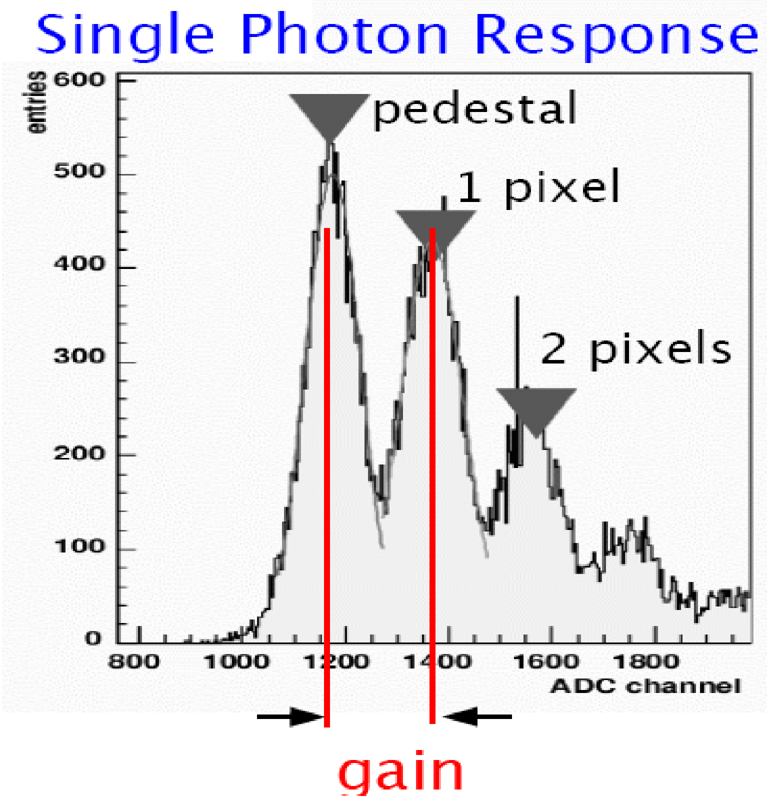
Readout and calibration

- Readout: follow integrated apporach for ECAL and HCAL
  - Synergies in ASIC development
  - Standardized system downstream





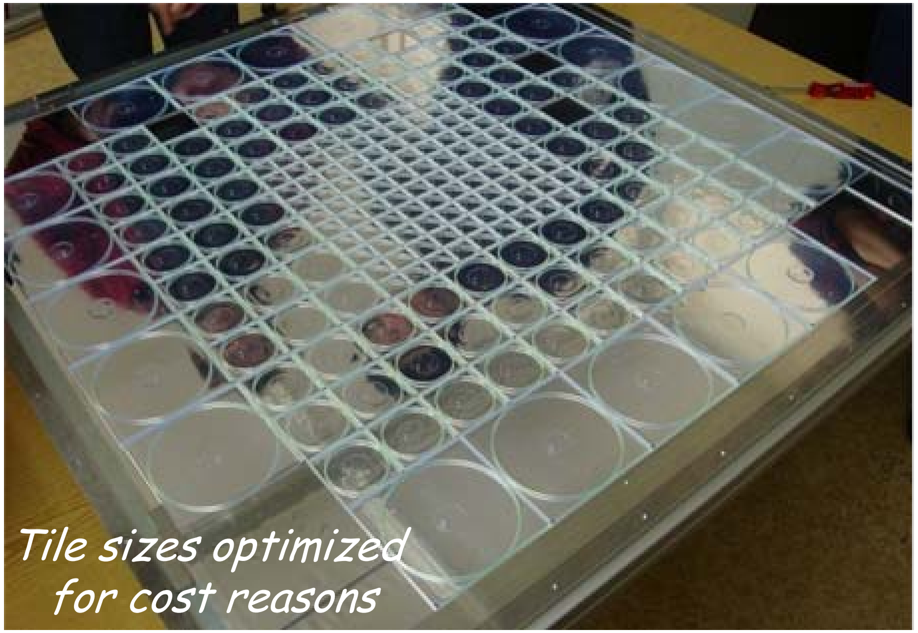
- Calibration: use MIP scale
  - inter-calibration and long-term variations

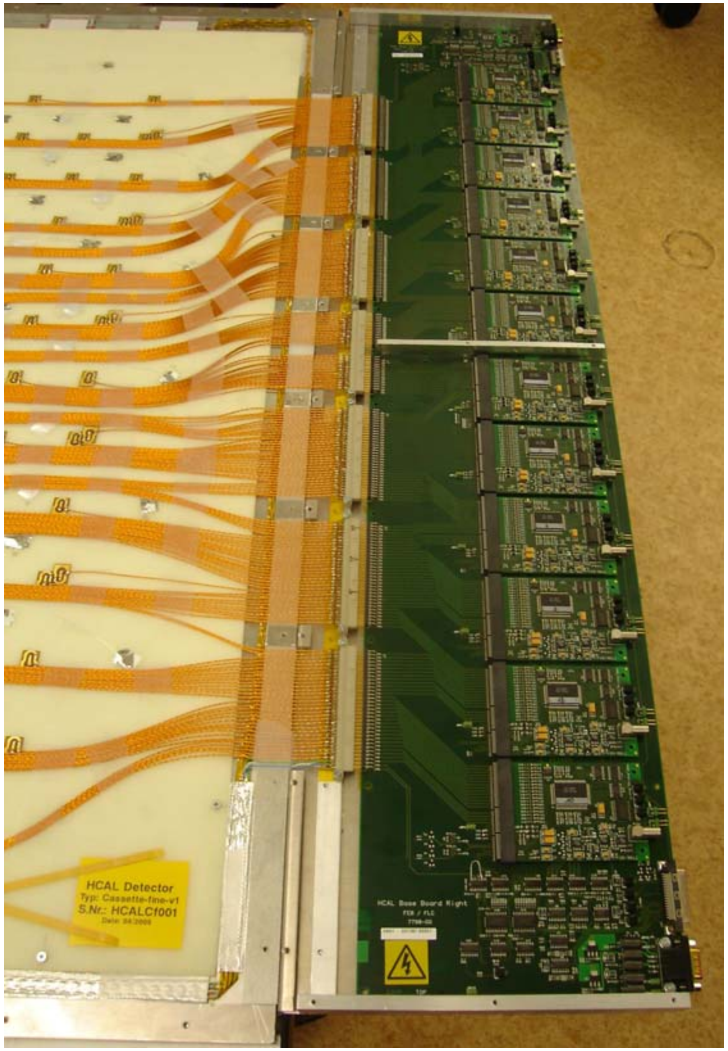


- Monitoring: auto-calibration
  - SiPM gain variations directly observable (~2%/K)
  - Also needed for non-linearity corrections

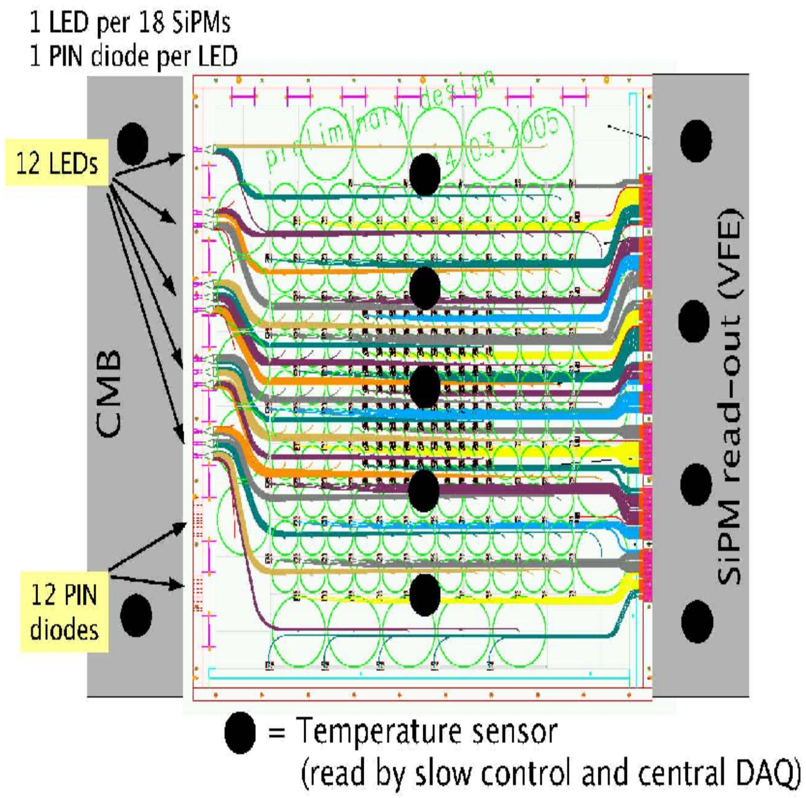
Tile HCAL testbeam prototype

- 1 cubic metre
- 38 layers, 2cm steel plates
- 8000 tiles with SiPMs
- Electronics based on CALICE ECAL design, common back-end and DAQ





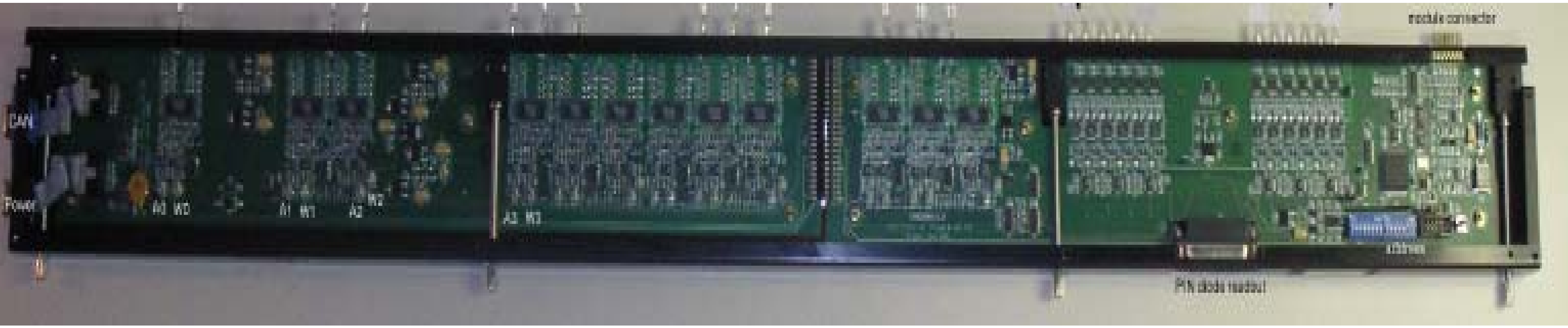
Physics Prototype (PPT)



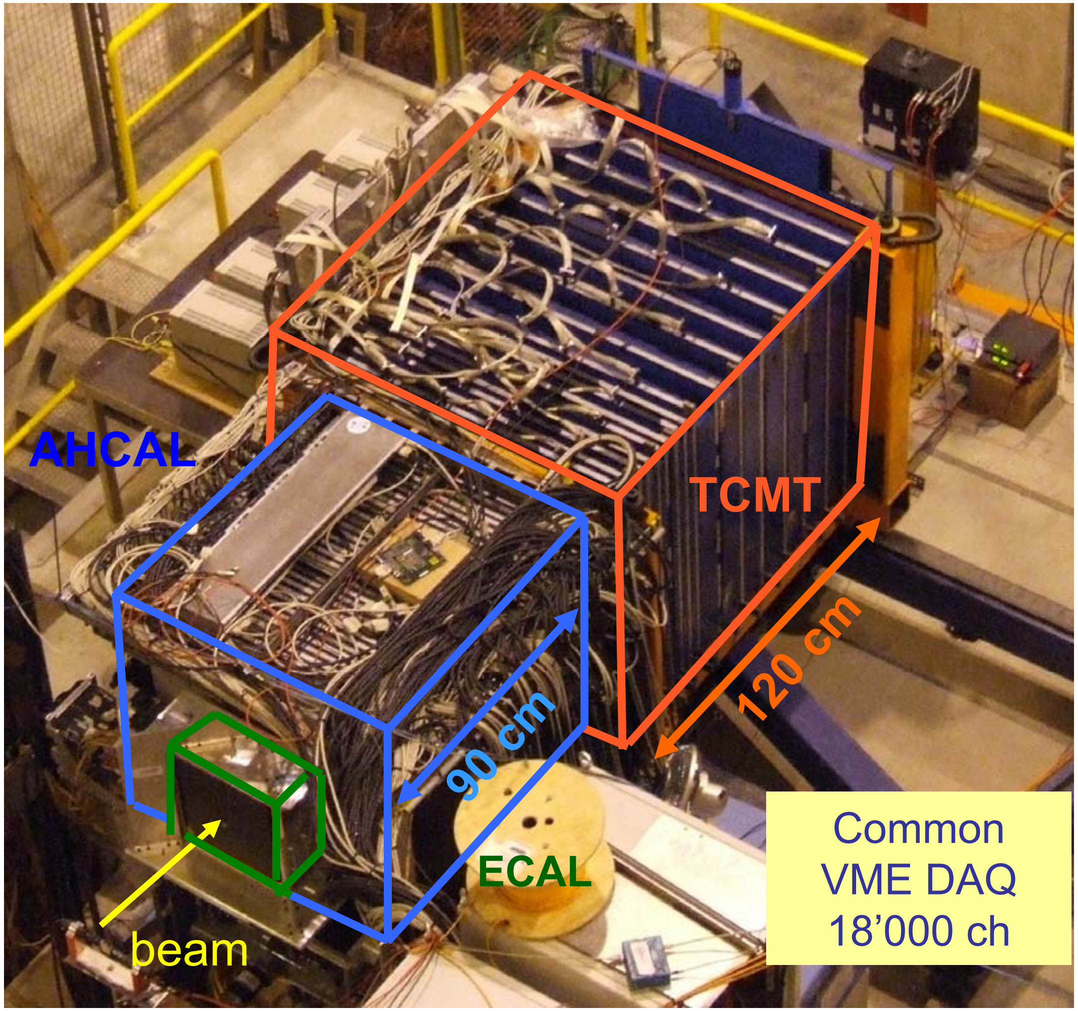
- 1 m^3 device consisting of 38 planes of scintillating tiles
- SiPM readout, altogether about 8000 channels
- Each plane equipped with LEDs and appropriate light distribution system

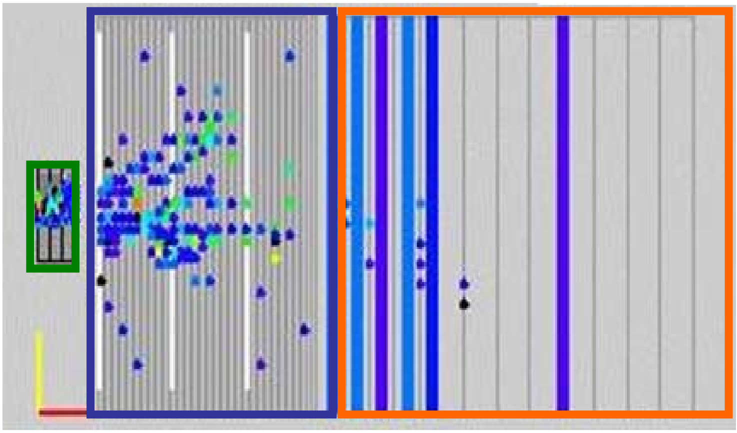
Calibration and monitoring

- SiPM response varies by ~ 5% / K (depending on ΔV)
- The test beam prototype has a highly versatile and redundant LED based monitoring system (electronics: Prague)
  - 1 LED illuminates 18 tiles via fibre bundle
  - PIN-diode controled LED reference signals
  - Low light intensity for gain measurements (single p.e. peaks)
  - Large dynamic range for long-term test of saturation
  - Temperature sensors



CALICE installation at CERN SPS





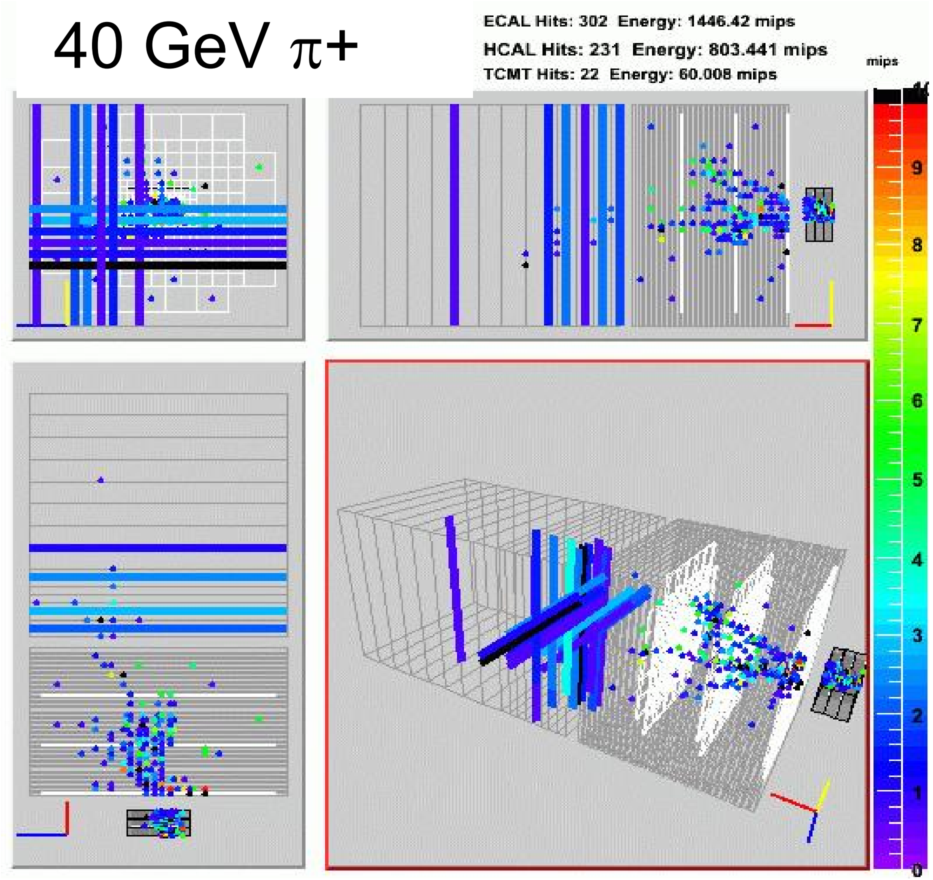
July - Nov. 2006
CALICE detectors installed in the H6b experimental hall at the CERN SPS

successful commissioning

Hadron (electron) beam
6 - 100 (50) GeV

pion runs

combined system needed to study hadronic showers



data collected at 0° incident angle only

from 50 GeV secondary beam:

E [GeV]	Pion	E [GeV]	Electron
80	~1.2M	45	~600 k
60	~1.2M	40	~600 k
50	~1.2M	30	~600 k
40	~1.2M	20	~600 k
30	~1.2M	10	~600 k

from 10 GeV secondary beam:

E [GeV]	Pion	E [GeV]	Electron
20	~120k	20	~50k
15	~300k	15	~200k
10	~100k	10	~120k
6	~250k	6	~50k