R&D on Calorimetry for the ILC inside the CALICE Collaboration

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26/05/08

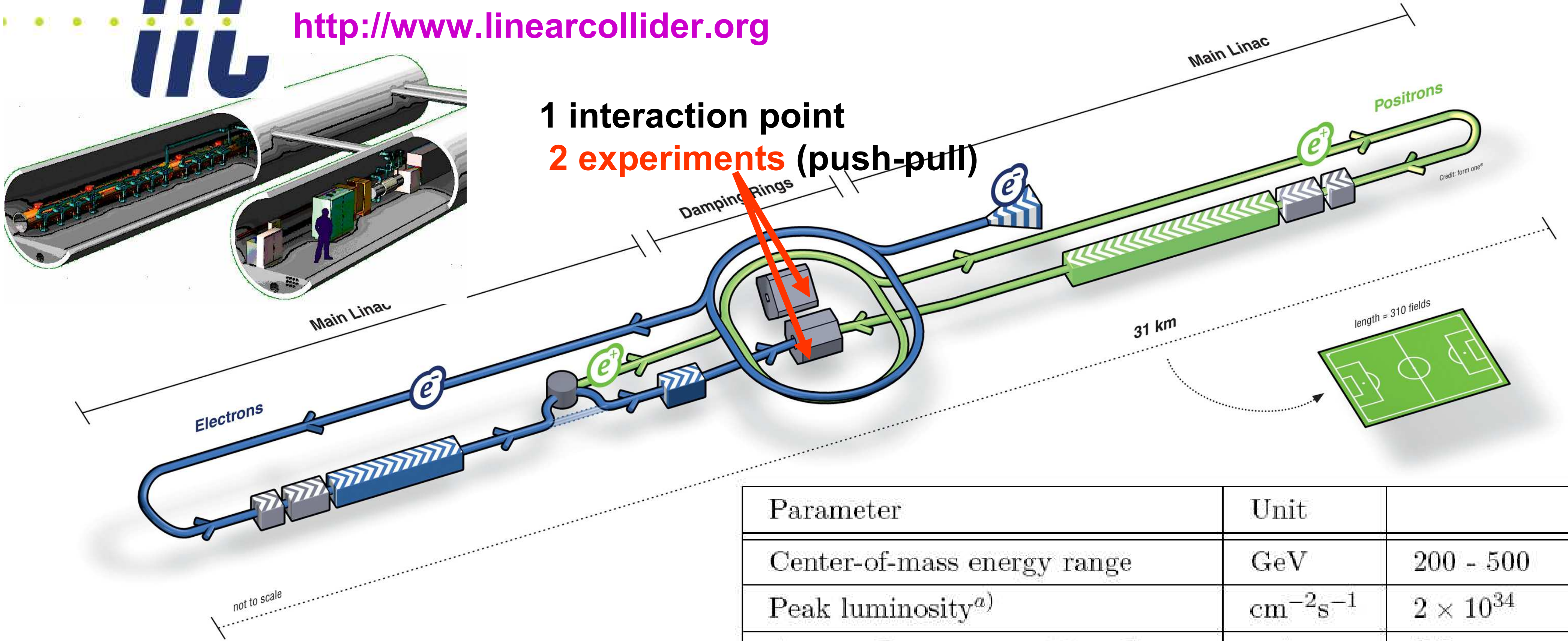
OUTLINE

- The ILC.
- ILC Detector requirements➔ Calorimeters
- The CALICE Collaboration. CIEMAT @ CALICE
- The European DHCAL project @ CALICE
  - Description, working plan, CIEMAT work for DHCAL
- People involved in the project & Budget request

International Linear Collider

http://www.linearcollider.org

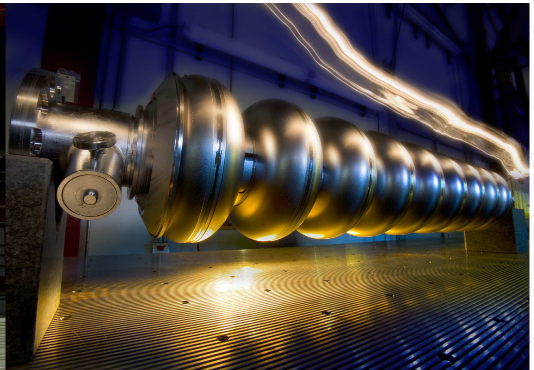
e^+e^- Linear Collider



1 interaction point

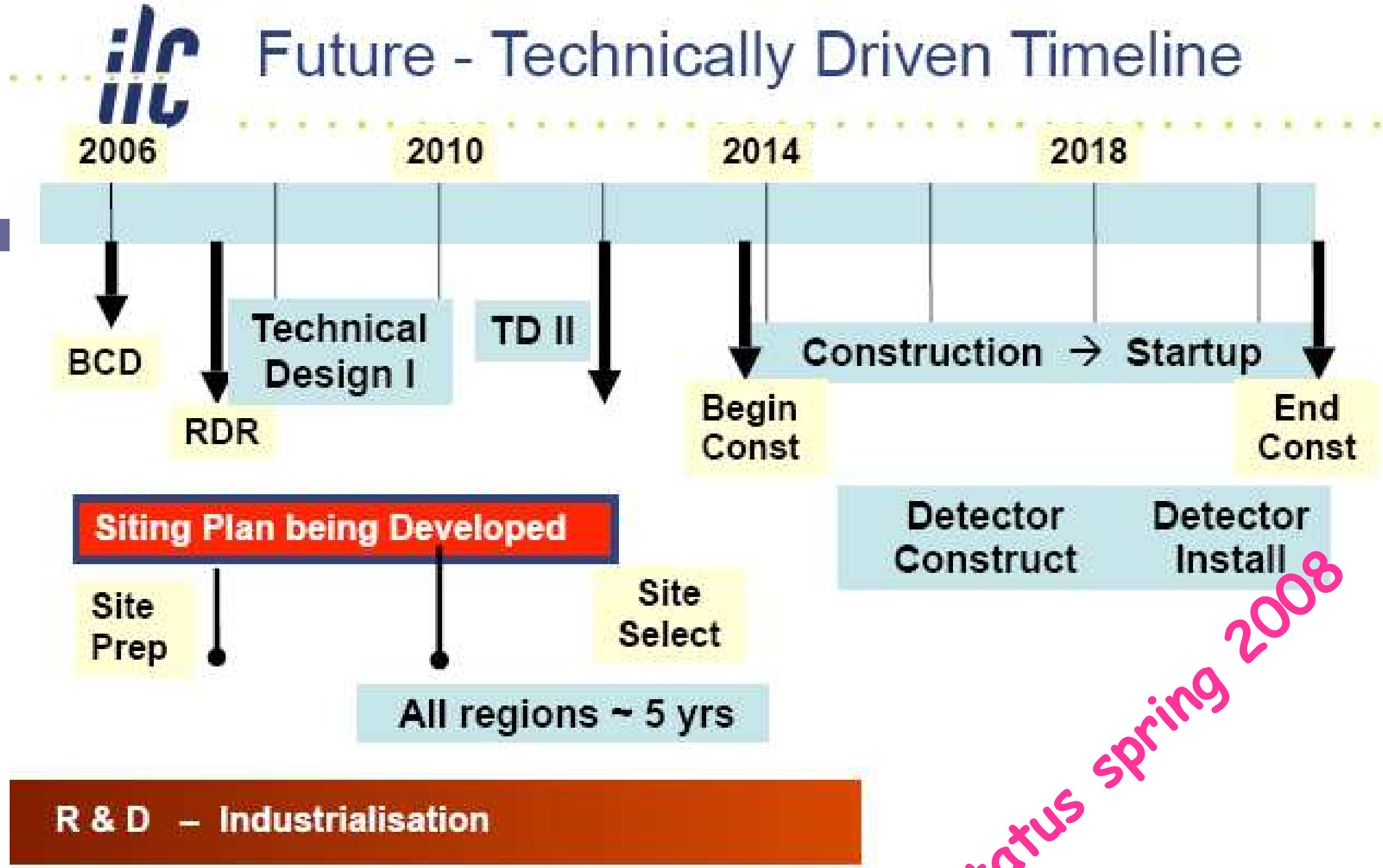
2 experiments (push-pull)

Parameter	Unit	
Center-of-mass energy range	GeV	200 - 500
Peak luminosity$^{a)}$	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	2×10^{34}
Average beam current in pulse	mA	9.0
Pulse rate	Hz	5.0
Pulse length (beam)	ms	~ 1
Number of bunches per pulse		1000 - 5400
Charge per bunch	nC	1.6 - 3.2
Accelerating gradient$^{a)}$	MV/m	31.5
RF pulse length	ms	1.6
Beam power (per beam)$^{a)}$	MW	10.8
Typical beam size at IP$^{a)}$ ($h \times v$)	nm	640×5.7
Total AC Power consumption$^{a)}$	MW	230



2x11km (~170000) superconducting cavities

Time schedules



Status spring 2008

Detector RoadMap

2007 | 2009 | 2012

Call for letters of intent

Letters of intent

collect groups willing to contribute to a EDR for the concept

Research Director

Prepare an engineering design report (light) in step with the collider

A complete concept
some engineering support of the concept
a reliable costing
demonstration: we can start if we may

Detectors at ILC

The ILC environment is more "*friendly*" than LHC: detectors will have lower rates, lower radiation and less background

BUT

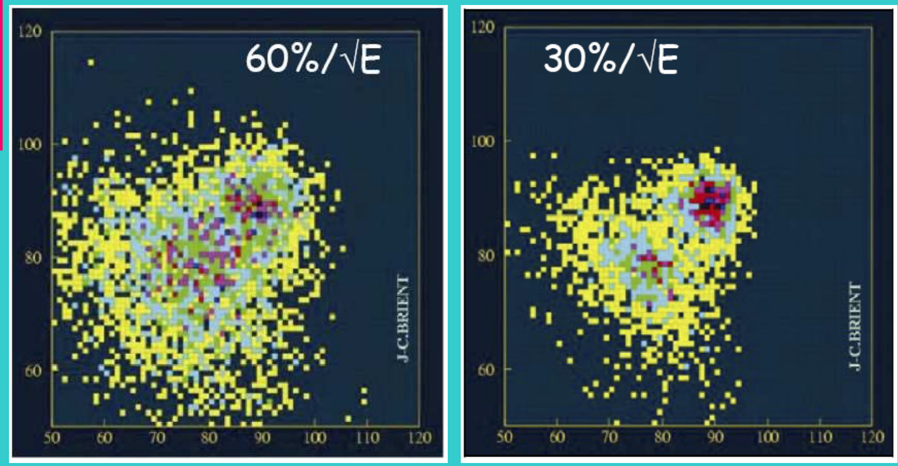
ILC physics requires **high precision measurements**: jet energy resolution, tracker momentum resolution, vertex impact parameter resolution and particle ID

Sub-Detector Performance Needed for Key ILC Physics Measurements.

Physics Process	Measured Quantity	Critical System	Critical Detector Characterstic	Required Performance
ZHH $HZ \to q\bar{q}b\bar{b}$ $ZH \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass $B(H \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution, $\Delta E/E$	3to4%
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-(\gamma)$ $ZH + H\nu\nu \to \mu^+\mu^- X$	Higgs Recoil Mass Luminosity Weighted Ecm $B(H \to \mu^+\mu^-)$	Tracker	Charged Particle Momentum Res., $\Delta p_t/p_t^2$	5×10^{-5}
$HZ, H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs Branching Fractions b quark charge asymmetry	Vertex Detector	Impact Parameter, δ_b	$5\mu m \oplus 10\mu m/p(GeV/c)\sin^{3/2}\theta$
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum Res., hermeticity	

ILC Calorimeters requirements

Many interesting processes with heavy bosons W,Z,H. We need to reconstruct their hadronic decay modes → multi-jet final states

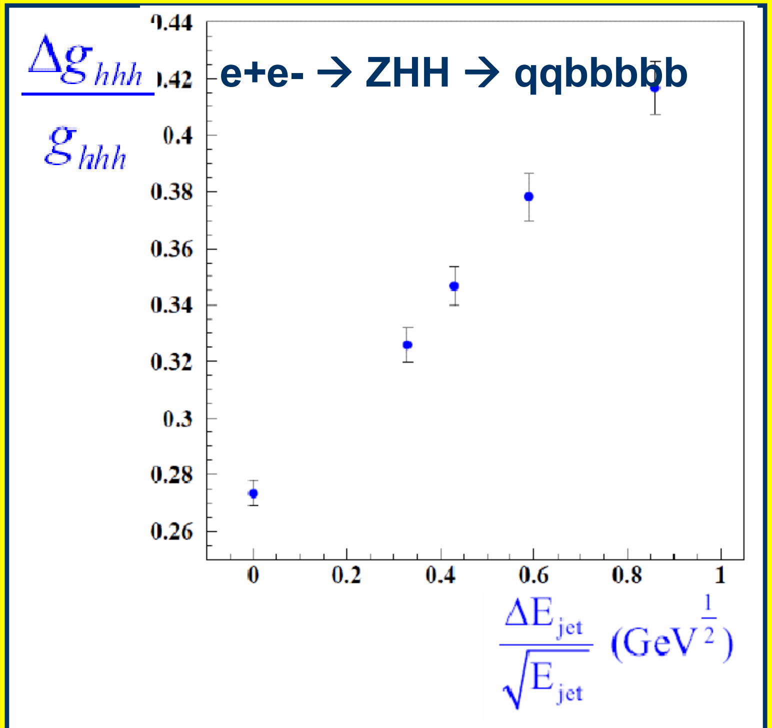


We need

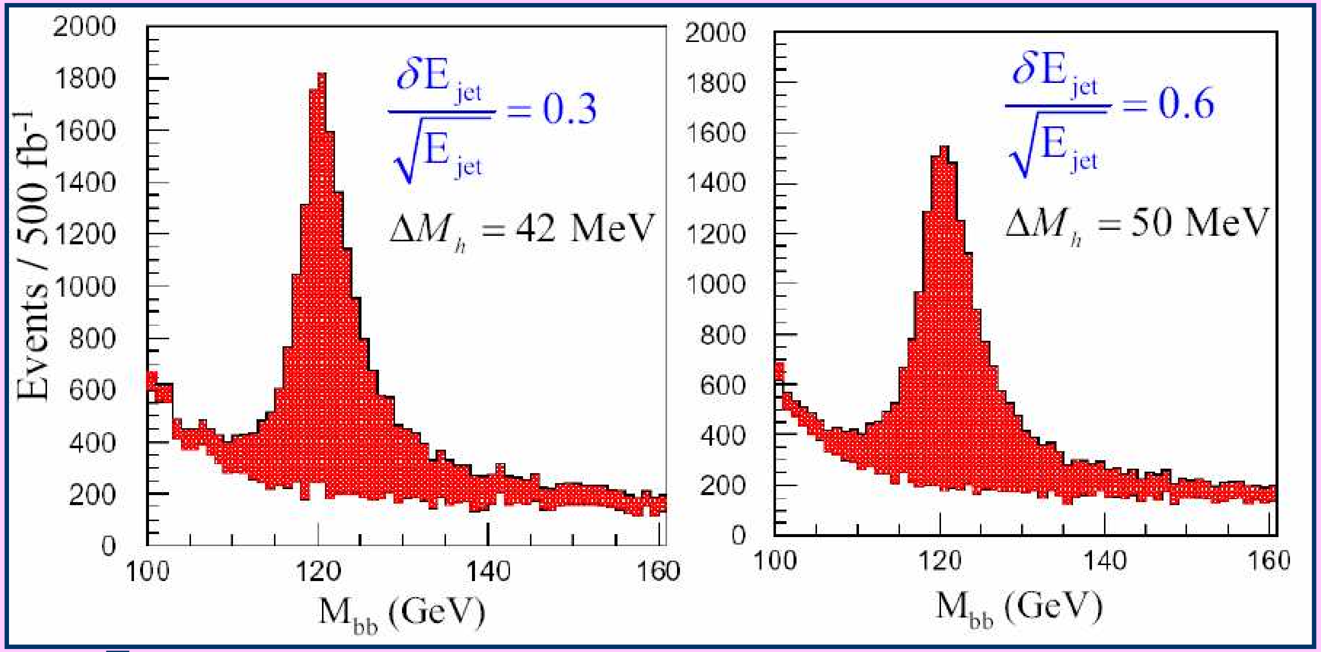
Excellent jet energy & di-jet mass resolution.

Discrimination of W and Z similar to their natural widths ➜ $\sigma(E) \approx 30\%\sqrt{E(\mathrm{GeV})}$

Higgs self coupling measurement λ_{hhh}

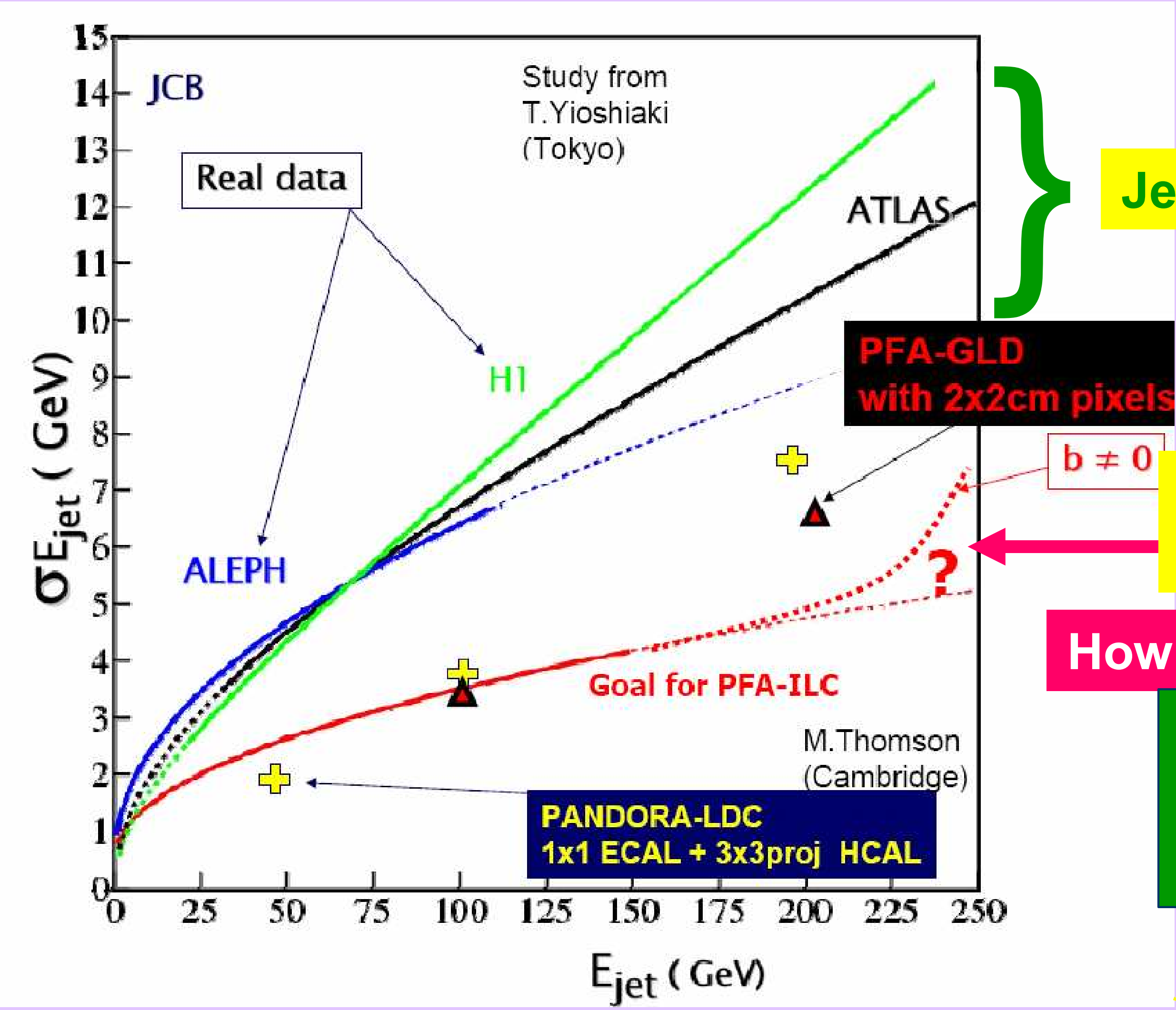


Higgs mass in 4-jet channel   e+e- → ZH qqbb @ 350GeV, 500fb-1



ΔE/√E=60% → 30% equivalent to ~40% luminosity gain

ILC Calorimeters requirements (II)



Jet resolution nowadays

ILC Goal,
A factor 2 better!!

How we can achieve it?

PFA
Particle Flow Algorithm

Particle Flow Algorithm

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		$\leq 0.04^2$ (goal)

18%/√E

"Perfect" PFA

Particle Flow Approach: ➔ Reconstruct each particle individually

Measure charged particles ONLY in the tracker
(➔ remove main part of hadronic energy fluctuations)
Photon energy measured by the Electromagnetic Calorimeter
Neutral hadrons measured by the Electromagnetic & Hadronic calorimeters

Charged particles should be separated from neutral hadrons in the calorimeters

Associate charged particles with calorimeter clusters
Separate from nearby cluster

→ Pattern recognition on the Calorimeters

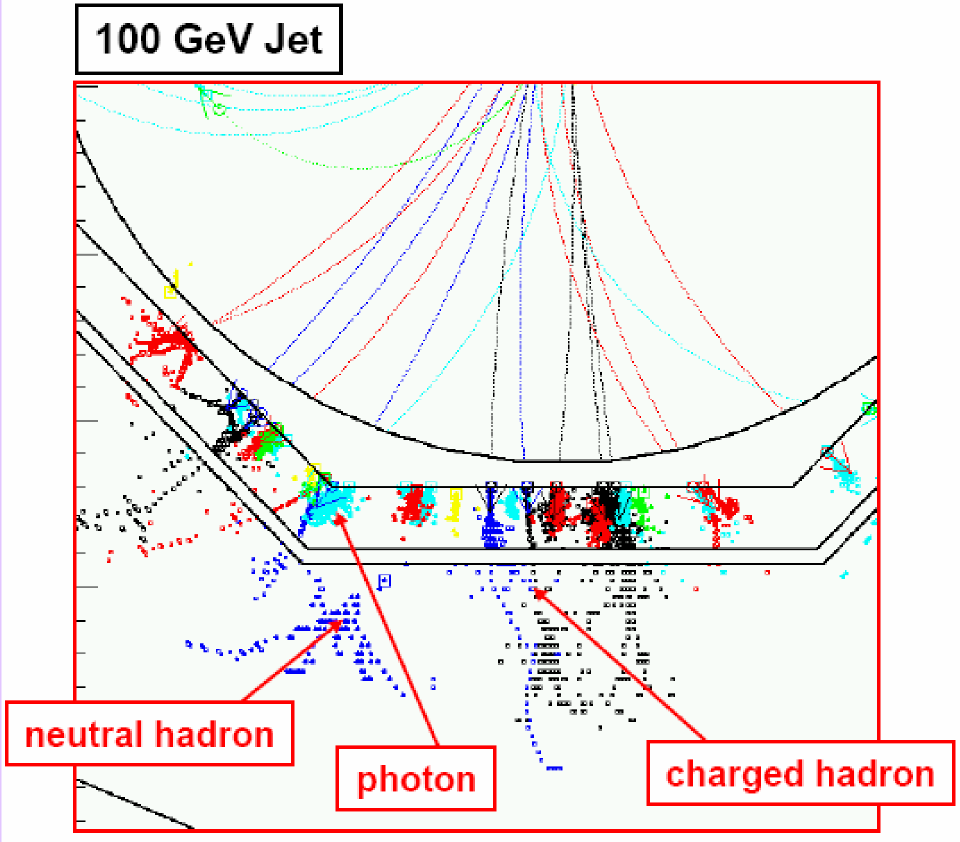
$$\sigma_{jet} = \sigma_{charg} \oplus \sigma_{phot} \oplus \sigma_{neut} \oplus \sigma_{confusion}$$

Jet resolution depends on detector resolution + software

Calorimeter requirements for PFA

Unprecedented granularity
Calorimeter readout in three dimensions

- **Highly granular calorimeter**
  ➔ True and efficient separation and association of closely spaced energy clusters with the correct tracks.
- **Shower reconstruction is needed**
- **Many longitudinal samplings**
  ➔ To avoid jet energy resolution degradation via the sampling term.
- **Excellent linkage to tracker is needed**



A new calorimeter concept !!!
The Calorimeter becomes a tracking device
Segmentation more important than energy resolution

Many readout channels
➔ High cost

The CALICE Colaboration

CALICE (CAlorimeter for the LInear Collider Experiment)

More than 200 people, 45 institutes, all 3 ILC regions

R&D on high granularity calorimetry optimised for PFA
The aim is to find the "best" calorimeter to deliver the ILC physics requirements

	Absorber	#layers	Pad size	Sensor
ECAL	Tungsten	20-30	$0.5 \times 0.5 mm^2$	Silicon Pad
ECAL	Tungsten	20-30	$0.04 \times 0.04 mm^2$	MAPS
ECAL	Lead	20-30	$1 \times 1 cm^2$	Scintillator
AHCAL	Steel	~50	$3 \times 3 cm^2$	Scintillator
DHCAL	Steel	~50	$1 \times 1 cm^2$	GRPC/GEM/μMEGAS

MAPS= Monolothic Active Pixel Sensors, CMOS technology

R&D technologies

Benefits from the colaboration

Shared hardware (electronic readout system, mechanical structures)

Shared software: All projects use the same DAQ & software (Reco & MC)

Shared test beams ➔ Combined tests e.g. Si-ECAL+Scint-HCAL+TCMT at CERN in 2006/2007
ECALs+HCALs+TCMT at FNAL in 2008/2010

Shared knowledge: CALICE meetings (3/year) are an excellent forum to report/discuss progress/ideas

Goals of CALICE Collaboration

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

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

-tune reconstruction algorithms
-validate existing MC models

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

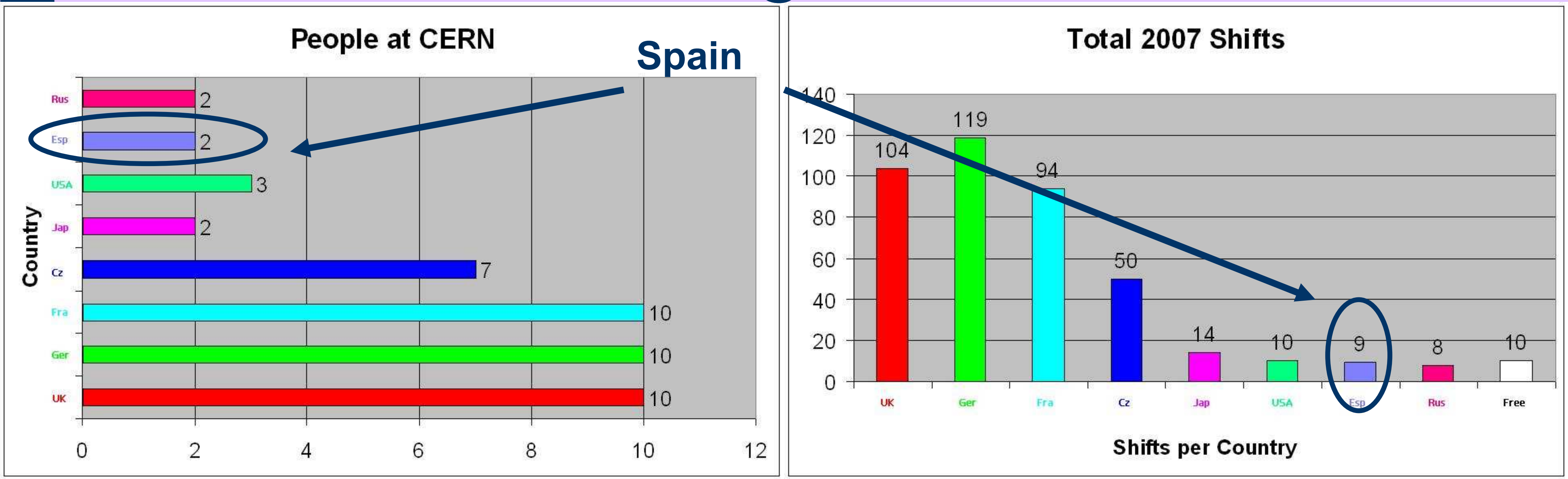
To design, build and test **ILC calorimeter prototypes**

CIEMAT at CALICE

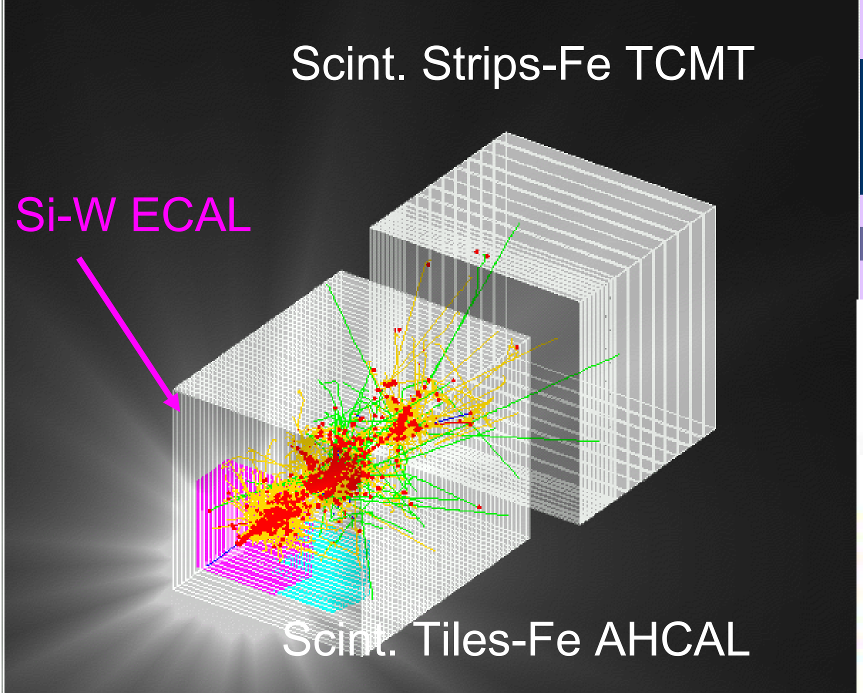
CIEMAT is member of CALICE since 2007 with representation in the Steering Board

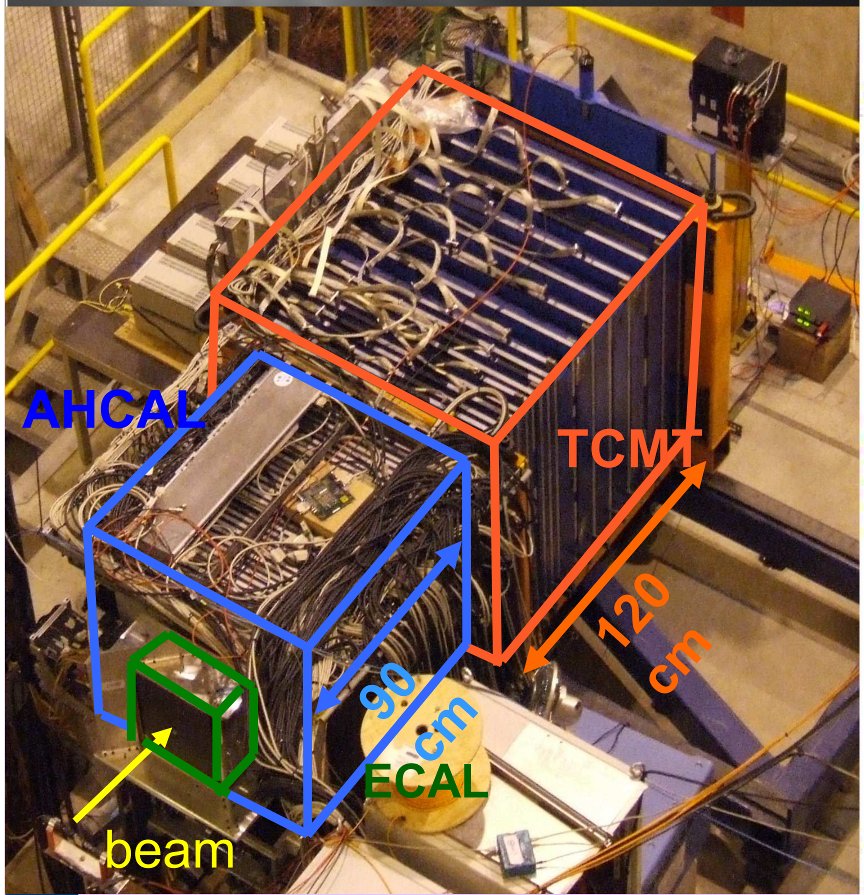
- ✓ **Participation in common activities as Test Beams (2007 at CERN, 2008 at FNAL).**
- ✓ **Some GRID computing infrastructure at CIEMAT for CALICE**
- ✓ **Participation in the DHCAL**

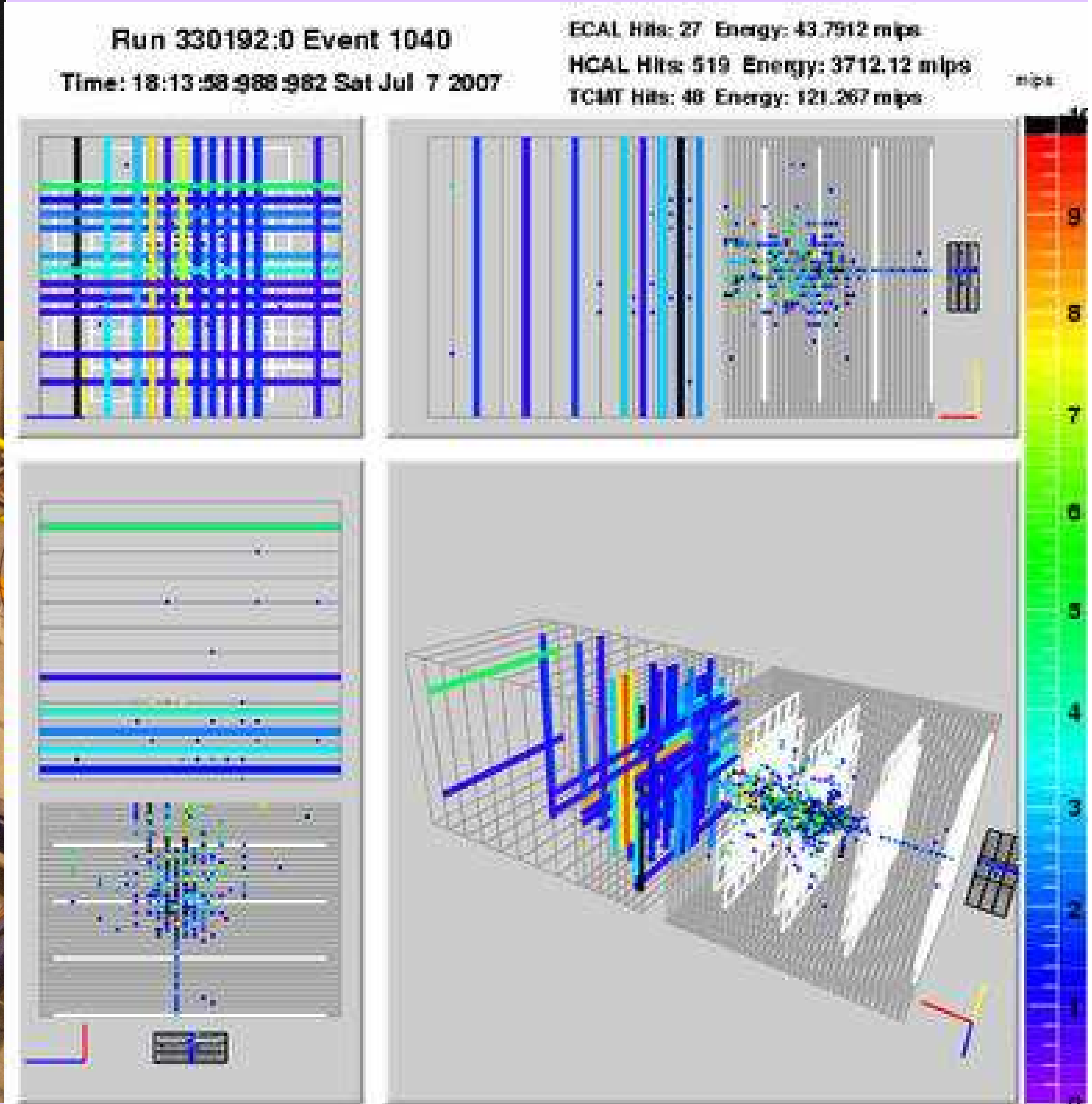
Test beam @ CERN 2007



Calice Testbeam@CERN







Europe DHCAL project

Several European Groups:

CIEMAT (Centro de Investigaciones Energéticas Medioambientales y Tecnológicas)
IHEP (Institute of High Energy Physics – Protvino).
IPNL (Institut de Physique Nucléaire de Lyon)
LAL (Laboratory de l´Accélérateur Linéaire-Orsay)
LLR (Ecole Politechnique – Palaiseau)
LAP (Laboratoire d´Annecy de Physique des Particles)

Goals:

Design and construction of a digital hadronic calorimeter prototype (CALICE technical prototype ~ 1m^3- active) to be tested during 2009-2011 in a test beam together with the others ECAL & HCAL CALICE prototypes

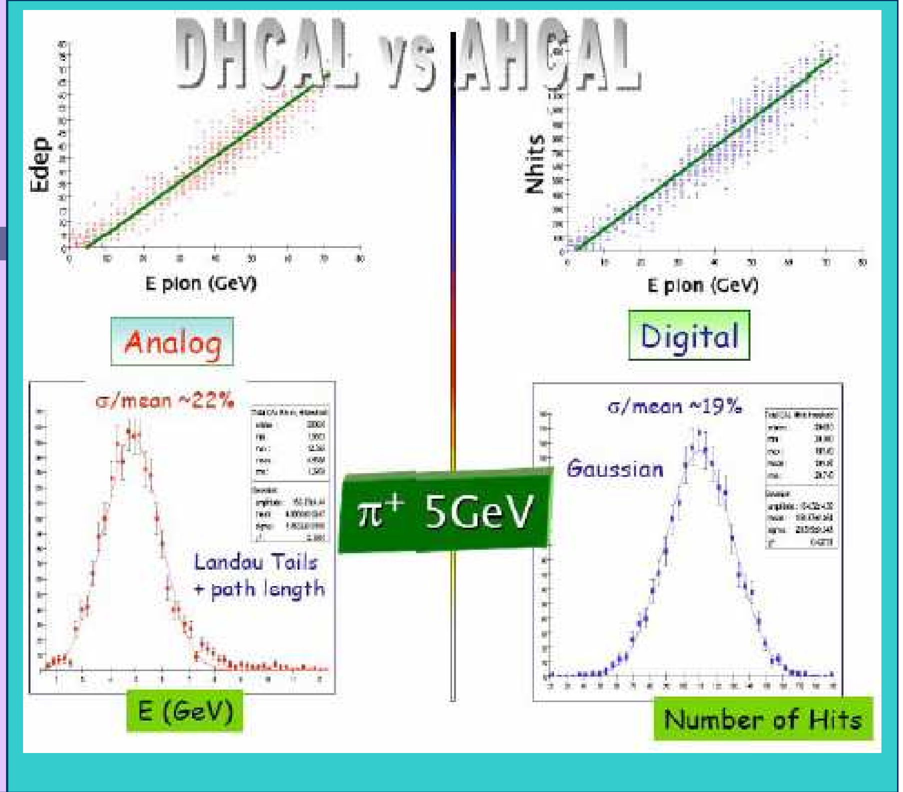
Prototype Characteristics:

Absorber: 40 – 50 steel plates
Active: Gaseous detector pads 1x1 cm^2 (**GRPC o MICROMEGAS**)
➔ Digital (Semidigital) readout
~200K channels

Digital calorimeter

New concept

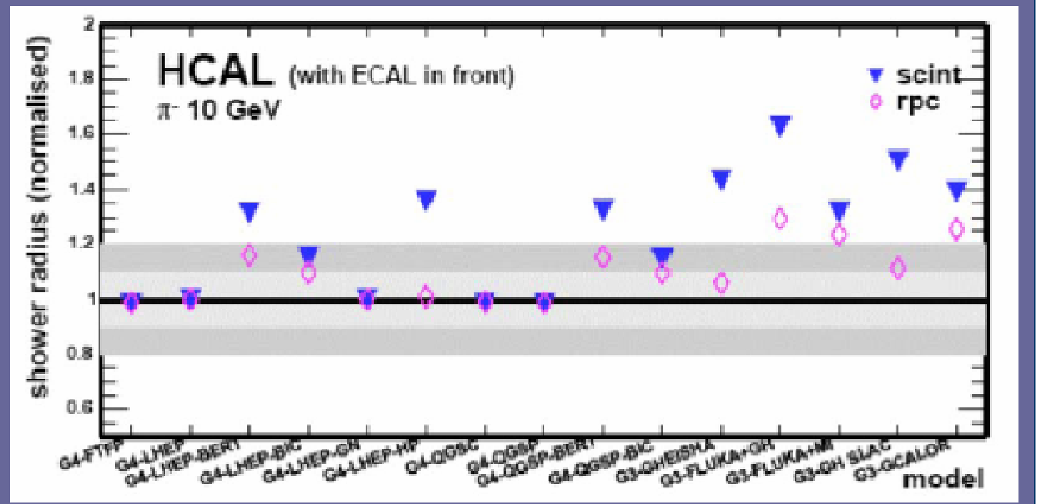
Use **number of hits instead of deposited energy**
➔ **How many & which pads over a threshold**
(a 2-threshold solution is being considered
➔ improves the performance for high energy)



Simpler electronics (just a comparator)
Simplifies requirements on uniformity of the active medium, reduces costs of electronics

but **higher granularity** 1x1cm^2
➔ **70-80 millions of channels**

Large uncertainties between hadronic simulations models



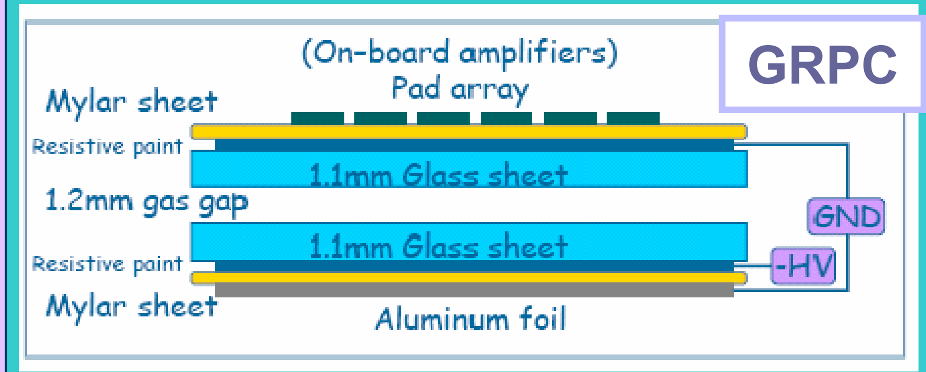
According to the simulation, it provides

Better separation between close showers
Better energy resolution, smaller tails
Better identification of muons

BUT It should be tested!!
MonteCarlo is not real life!!
With a **realistic prototype** large enough
- to contain the hadronic shower
- to check the viability of operating with such a huge number of channels
- to compare with the other HCAL CALICE prototypes

Glass Resistive Plate Chambers- GRPC

IHEP-IPNL

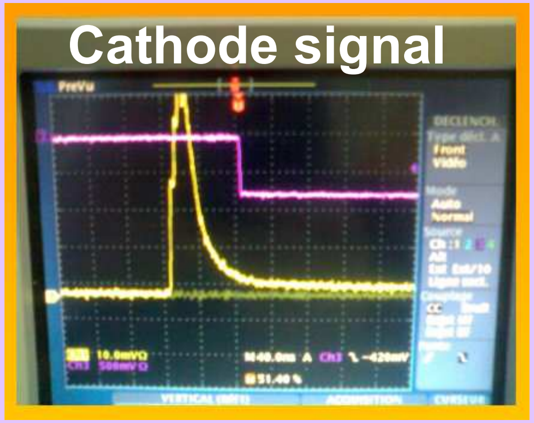


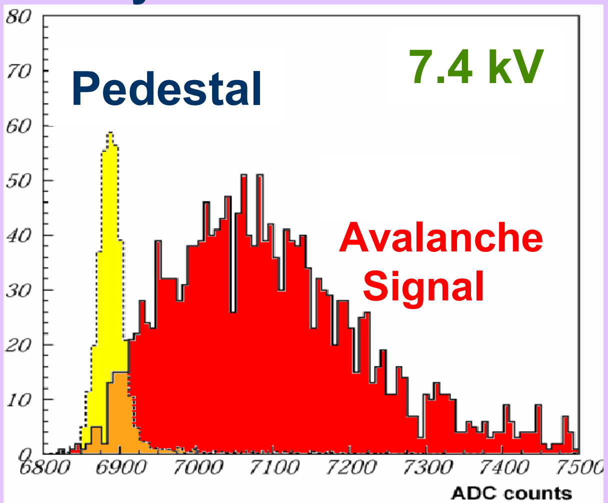
Gas: TFE/i-C4H10/SF6 93/5/2

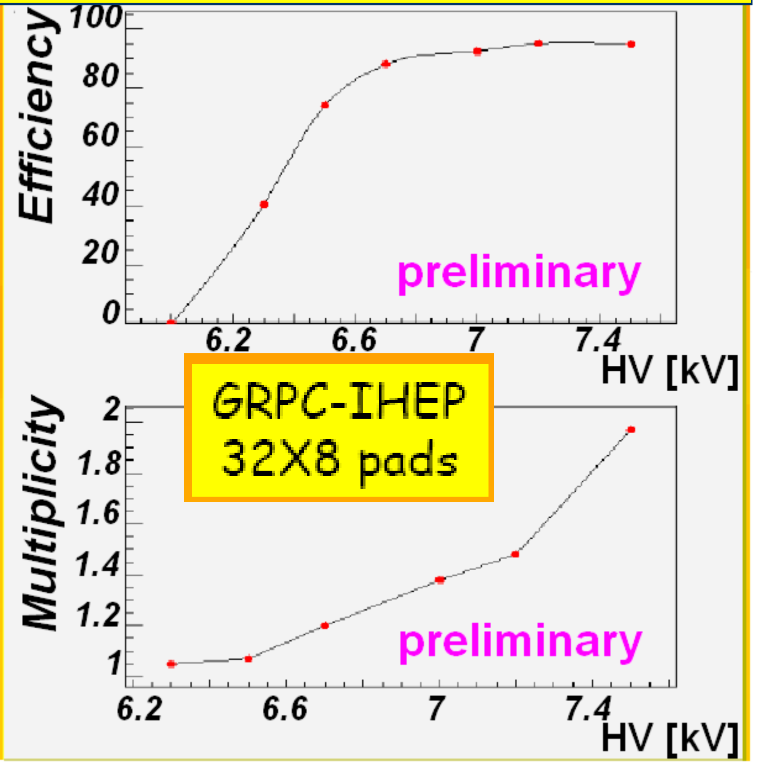
Two operational modes

Avalanche Mode	Streamer Mode
2 – 10+ mV,	> 100 mV,
0.2 – 10+ pC	> 20 pC
Very high efficiency (>95%)	High efficiency (~ 90%)
Low noise	Low noise
Smaller lateral size	Larger lateral size
Higher rate capability (~100Hz/cm²)	Lower capability (~1Hz/cm²)

Avalanche in the gas produce a very fast charge in the pick-up pads



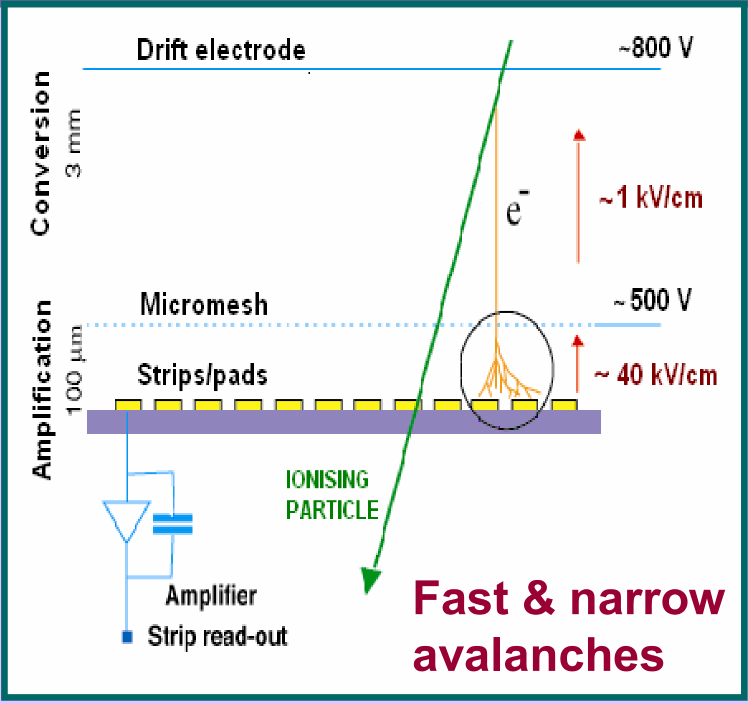


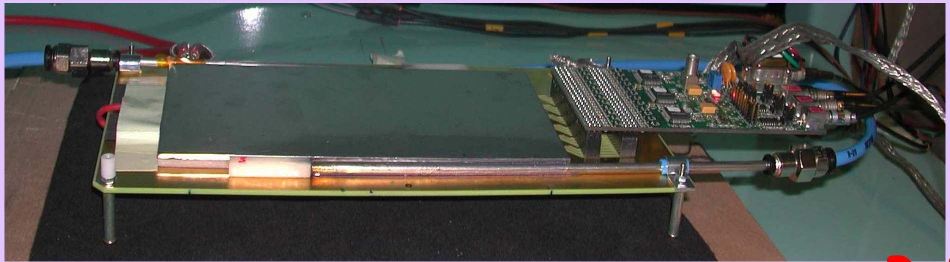


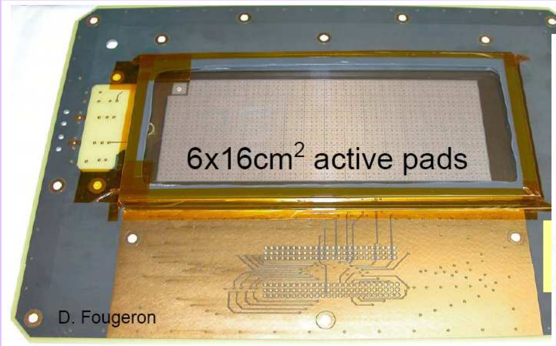
GRPC: Easy to build, robust but "physical" crosstalk (Broader avalanches)

➔ RPC Gap=1.2mm vs 100 micron MICROMEGAS

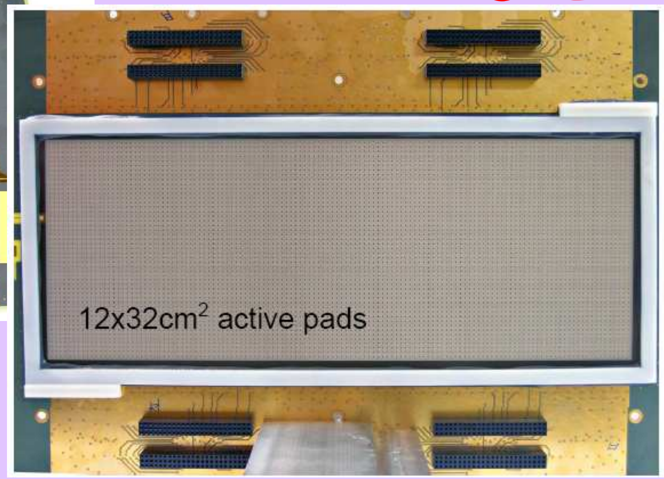
MICROMEsh GAseous Structure -MICROMEGAS



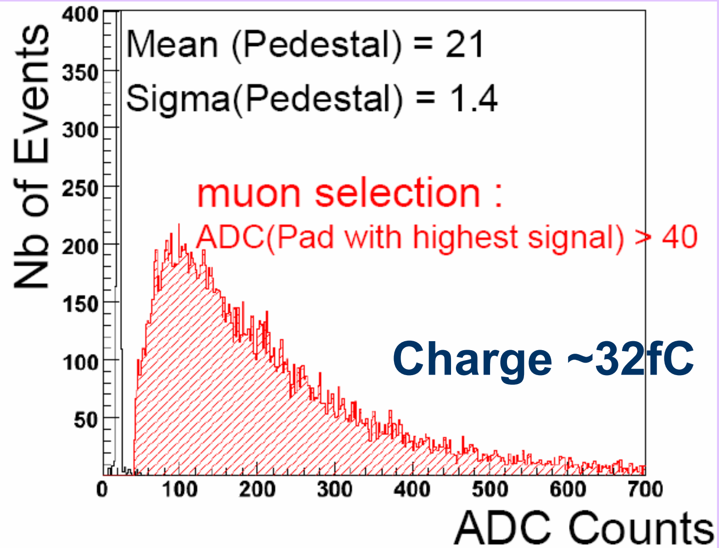


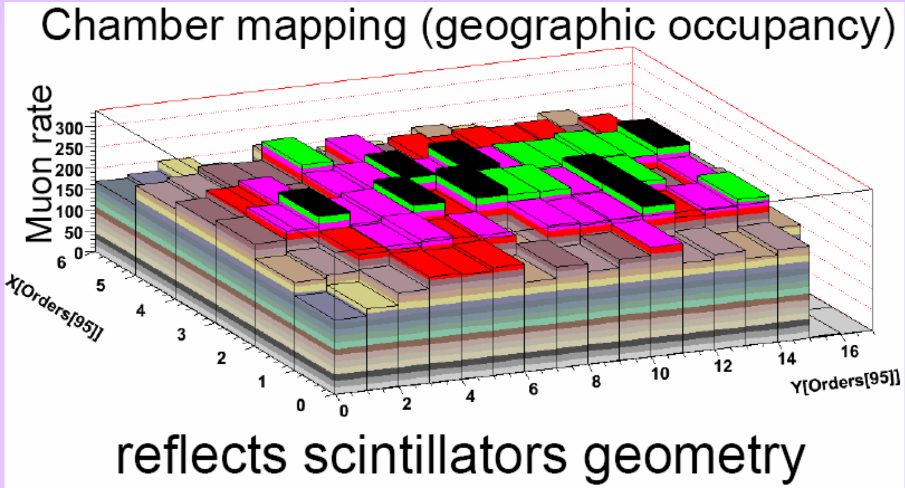


Built@CERN



Gas: Ar/i-C4H10 95/5

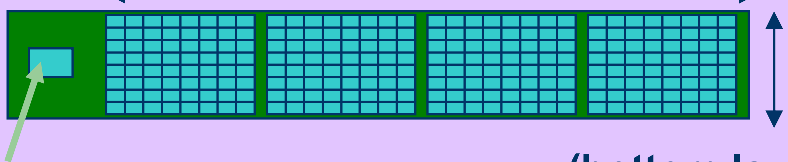


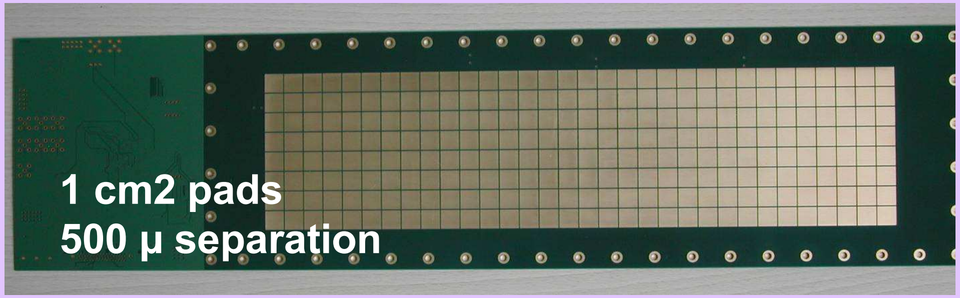


Readout Electronics

FE Board Prototype (HARDROC)

8-layer PCB
4 chips HARDROC (top layer)
8X32 pads (1cm²) ➔ 256 ch
(bottom layer)
Readout: 1 FPGA +USB





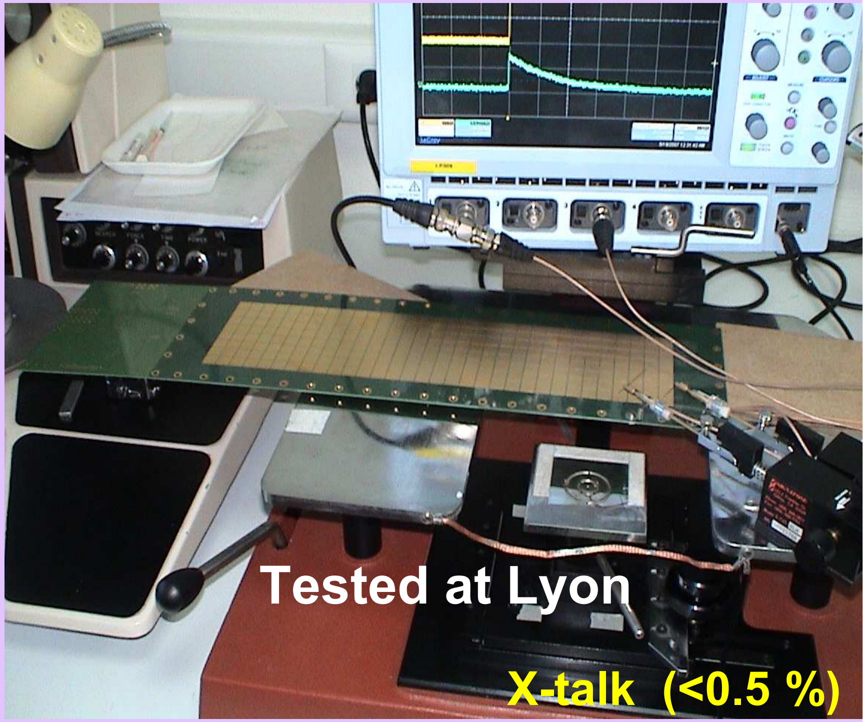
HARDROC chip has a large dynamic range

➔Needed for adapting to the GRPC & MICROMEGAS differences:

	GRPC	Micromégas
Charge	0.1∼10 pC	1∼100 fC
C_{det} (1 cm^2)	80 pF	80 pF
t_r	2 ns	<2 ns
largeur	20 ns	<10 ns

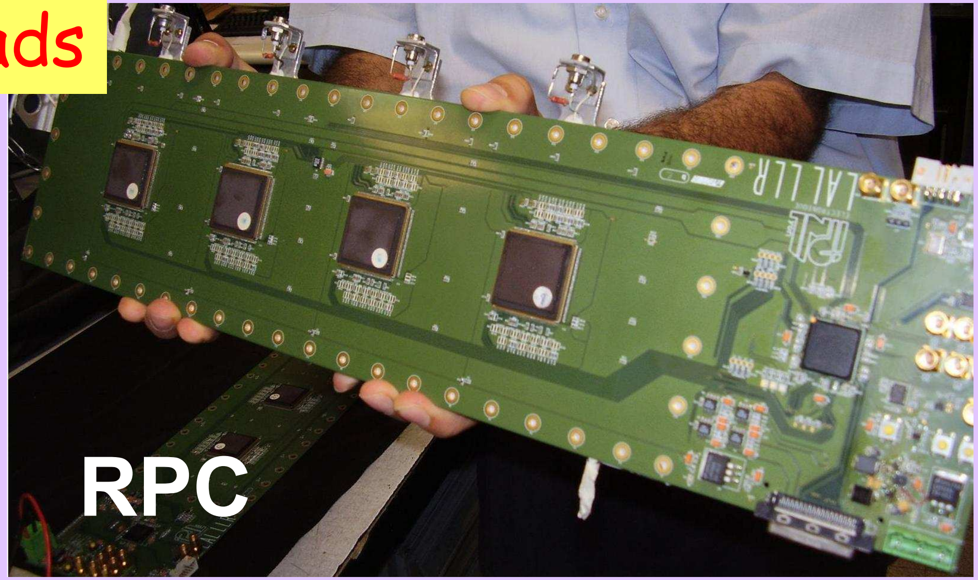
Present version have several outputs:
- Analogical
- Digital with 2 thresholds

Allow
comparative studies & threshold optimization



Integration of Chamber + Electronics

256 Pads



Till now the detectors have been tested mainly with "private" readout electronics

Absorber plates

Electronic & Detectors tested till now at lab

A Test Beam at CERN is foreseen for 10-17 July & 3-11 August

CIEMAT participation

DHCAL working plan for next years: Gaseous detectors

- **2008-2009**
  - **Design & Construction** of
    - **70X70 cm2 GRPC plane fully equipped**
    - **70X70 cm2 µMEGAS plane fully equipped**

  Each single module should be closed with PCBs containing the readout pads & FE electronics.

  Many factors in favor of using rather small PCB

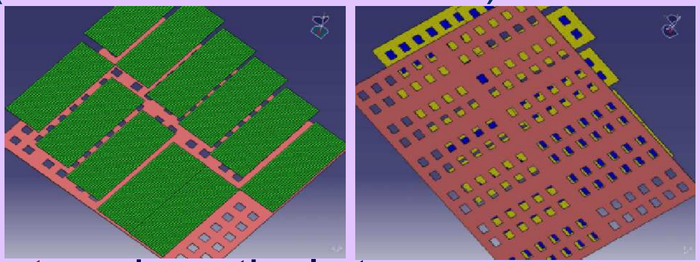
  ➔ What is the optimized PCB size?

  ➔ How to connect different PCBs on one detector? (mechanical & electrical)

  CIEMAT participation

  12 PCB with 12 Hardrocs could be a good compromise

  The mechanical problem could be solved by using a support made of low density rigid material (Epoxy/FR4/Carbon fiber) with holes to host the chips boxes

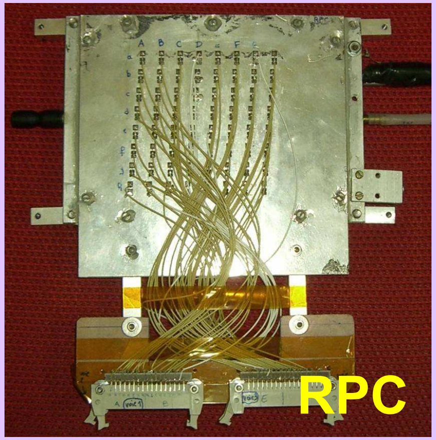


  - Those modules should be **tested on the lab & beam tests** exhaustively to **measure their performance & take a decision on the technology**
    - Efficiency vs HV
    - Check of response uniformity along the pads
    - electronics & physical crosstalk
    - optimization of threshold levels

  CIEMAT participation

- **2009**
  - Construction & tests of 40-50 detector planes for the 1m^3 calorimeter prototype

Testing of Detectors at CIEMAT



A small RPC prototype waiting to be tested

A cosmic test bench being assembled at CIEMAT

- ➔ Recycling some electronics used on other experiments (old in some cases, not very appropriate in others) + some modules borrowed from our French collaborators

Some money needed for electronics modules & gas

DHCAL working plan for next years: Mechanical Structure

CALICE Calorimeter for ILC
Ciemat

CIEMAT participation

- **2008**

  Design of the prototype

  (Coordinated by the CIEMAT mechanical engineer)

  Following the CALICE philosophy the aim is to design a "**Technical prototype" (ILC-Like)** that can be considered as a module-0 for a "real" experiment.

  ➔ It is intended to provide crucial information on integration issues and constraints for a full-scale calorimeter.

  Close collaboration with ECAL CALICE groups to be integrated together on test beams

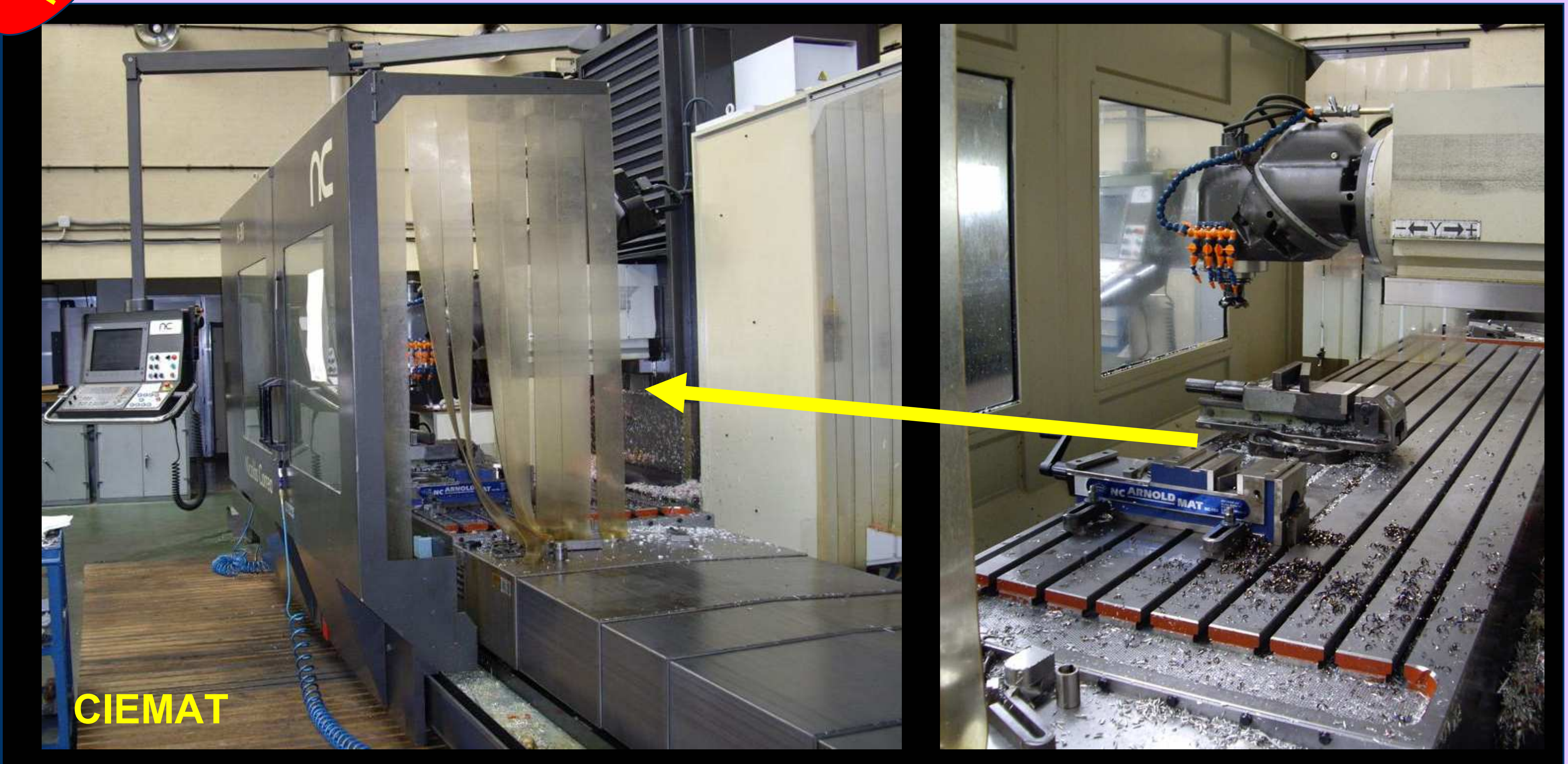
  For the test beam a structure larger than 1m^3 could be built but equipped only partially (1m^3)

DHCAL working plan for next years: Mechanical Structure

CIEMAT participation

- **2008-09 Construction at CIEMAT**
  - We intend to build the mechanical structure at the CIEMAT Workshops (machining the plates & build ancillary tooling)

    ➔ This will save an important amount of money



DHCAL working plan for next years: Final Assembly

- **2009**

  The final assembly of the calorimeter will be done probably at Lyon

  - Assembly

    Qualified CIEMAT technicians under the engineer supervision will participate on the assembly

  - Quality tests

    Participation of CIEMAT physicists

CIEMAT participation

DHCAL working plan for next years: Beam Tests

- **2009-2011**

  Extensive Beam tests program, **probably at FNAL**

  The prototype will be tested together with other CALICE calorimeters using common electronics & DAQ ➔ Allow realistic comparisons

  Those tests will serve to obtain expertise in operating extremely segmented calorimeters under real conditions and they are mandatory to validate the required performance with a "real" digital readout calorimeter

We plan to be involved on all the test beam activities:

Preparation, data taking, data analysis & MC

Some of the studies to be performed:

CIEMAT participation

- Crosstalk & noise rates in realistic operating conditions
- Linearity with the hadron energies
- Energy resolution
- Longitudinal & Transversal development of hadron showers to understand the tracking capabilities essential to develop the PFA reconstruction.
- Development of prototype simulation in the frame of the simulation tools available in the collaboration (MOKKA) based in GEANT4
- Dedicated studies to compare real data and MC
- Studies to compare the performance with the one obtained with the AHCAL option

People & Experience

Dr Mary-Cruz Fouz
Dr Jesús Marín (Electronics)
Dr Jesus Puerta
Enrique Calvo (Mechanical Engineer)

Technicians (Mechanics & Electronics)

All the members of the project have a large experience on R&D on Particle Physics detectors and they have/had important responsibilities on previous projects.

In particular on **calorimetry** & **gaseous detectors** (Parallel Plate Chambers & Drift Tubes) for the Very forward calorimeter and the Barrel muon detector of CMS

Personal requirements

We consider that the project offers an **excellent possibility to make PhD Theses.**

A PhD Student could follow the different stages of the project:

- Tests on the laboratory
- Calorimeter assembly
- Test beam data analysis and MonteCarlo studies, including the work on PFA.

At the same time **a PhD student will be very beneficial for the project**

Budget

Previous budget at CIEMAT: 12Keuros from an "Acción Complementaria" FPA2007-29117-E

Budget for the 1m^3 prototype

- Detector & electronics

The French groups have received funding (420000 euros) from the *Agence National de la Recherche (ARN)* through the *"Program blanc" BLAN07-2_193809* dedicated to build the gas detectors and the front end electronics

- **Absorber – Mechanical structure (➔ Pending!)**

Our intention with this project is to complete the not funded part by requesting the **money needed to order the raw material** that will be machined at the CIEMAT workshops (thus saving a very significant amount of money)

Other budget required

- Infrastructure tests & Gas
- Computing
- Travel expenses (test beam & meetings)

Table 1: Total Funding required in Kiloeuros

	1st year	2nd year	3rd year	Total
Calorimeter Absorber	81			81
Micromegas/RPC	6			6
Front-End Electronics	12			12
Trigger & DAQ & Gas for cosmic tests	54	5.5		59.5
Computing GRID resources	7	13	9	29
Participation on Tests	13	22	13.8	48.8
Participation on meetings	13.3	13.3	13.3	39.9
TOTAL	186.3	53.8	36.1	276.2

BACKUP

Travel Expenses

Travel expenses:

Concept	Expenses	Travel	Total
Collaboration Meetings			
~ 3 Weeks per year (at least one outside Europe) 2 persons	3x(3x5x160)x2 = 14400	3x(2x400+800)x2 = 9600	24000
Technical Meetings			
~3 per year	3x(3x3x160)x2 = 8640	3x(3x400)x2 = 7200	15840
Participation on TestBeams			
1 month (15+15) per person and year	2x(30x160)x3= 28800	2x(2x800)x3 = 9600	38400
Assembly and tests at Lyon			
1 month 2 persons	(30x160)x2= 9600	400x2=800	10400
		TOTAL	88640

Computing & Electronics equipment

Computing:

Concept	Total
Disk – 20 TB	17000
50 Ksi2k	12000
TOTAL	29000

Equipment for cosmic tests:

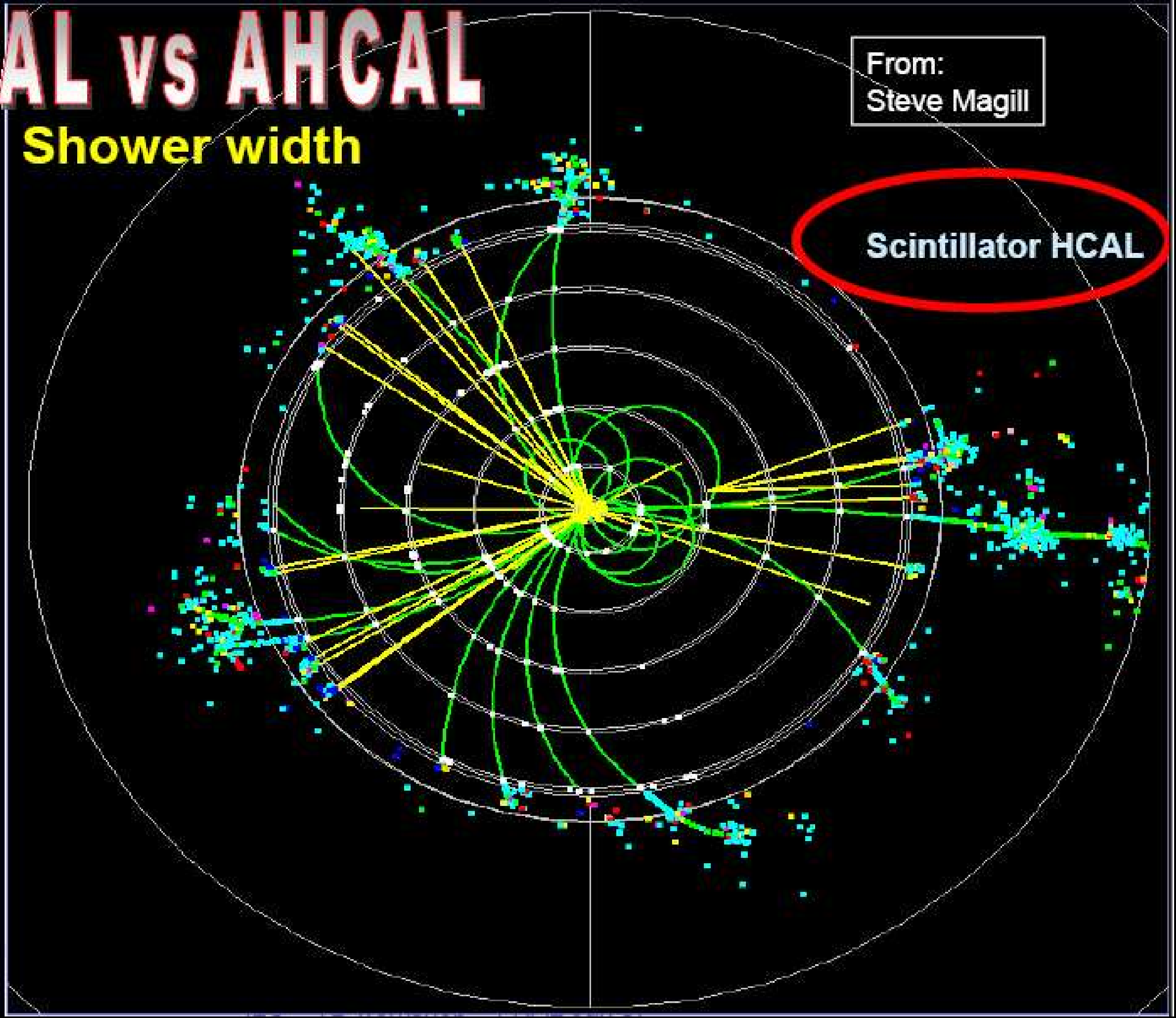
Concept	Total
VME Crate	3000
Crate Controller	6000
ADC, TDC	7000
NIM modules for Trigger	9000
HV modules	6000
Scintillators and Photomultipliers	11000
Gas	16000
Dedicated PC for tests	1500
TOTAL	59500

Chronogram

Tasks	Centre	Persons	First Year (*)	Second Year (*)	Third Year (*)
Desing and Construction of the mechanical structure	CIEMAT	Enrique Calvo Technical Staff	X X X X X X X X		
Tests of Prototypes at CIEMAT with cosmics	CIEMAT	MªCruz Fouz Jesús Marín Jesús Puerta	X X X X X X X X X X X	X X X X X X	
Assembly and tests at Lyon	CIEMAT	Enrique Calvo Jesús Puerta Jesús Marín Technical Staff	X X		
Tests on a Test Beam	CIEMAT	Jesús Puerta Enrique Calvo Mª Cruz Fouz Jesús Marín	X X X	X X X X X X X X X X X	X X X X
Test beam data Analysis and Simulation	CIEMAT	Mª Cruz Fouz Jesús Puerta	X X X	X X X X X X X X X X X X	X X X X X X X X X X X X

(*) Mark an X inside the corresponding boxes (months)

DHCAL vs AHCAL



DHCAL vs AHCAL

Shower width