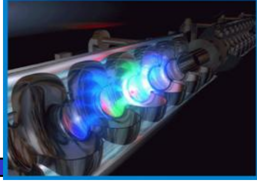
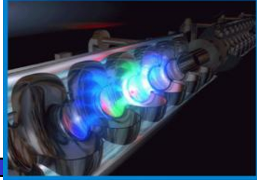


A CALORIMETER FOR THE FUTURE LINEAR COLLIDER

Stéphane MONTEIL

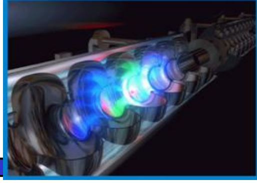
Laboratoire de Physique Corpusculaire de Clermont-Ferrand,
Université Blaise Pascal / IN2P3-CNRS



OUTLINE

- ✓THE MACHINE : PERFORMANCE AND STRATEGIES
- ✓THE PHYSICS CASE
- ✓GUIDELINES FOR THE DESIGN OF THE DETECTOR
- ✓THE CALORIMETRIC SYSTEM
- ✓CONCLUSION AND PERSPECTIVES FOR ITS R&D

THE MACHINE : PERFORMANCE AND STRATEGIES

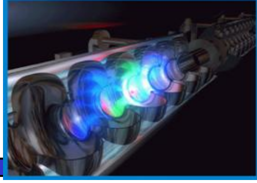


There were two machine technologies and basically three projects supported by the Europe (TESLA), the US (NLC) and the Japan (JLC). At the end, ONE machine in the world; the convergence between the projects and the choice of the technology has been made by a dedicated committee: it will be COLD. YET,

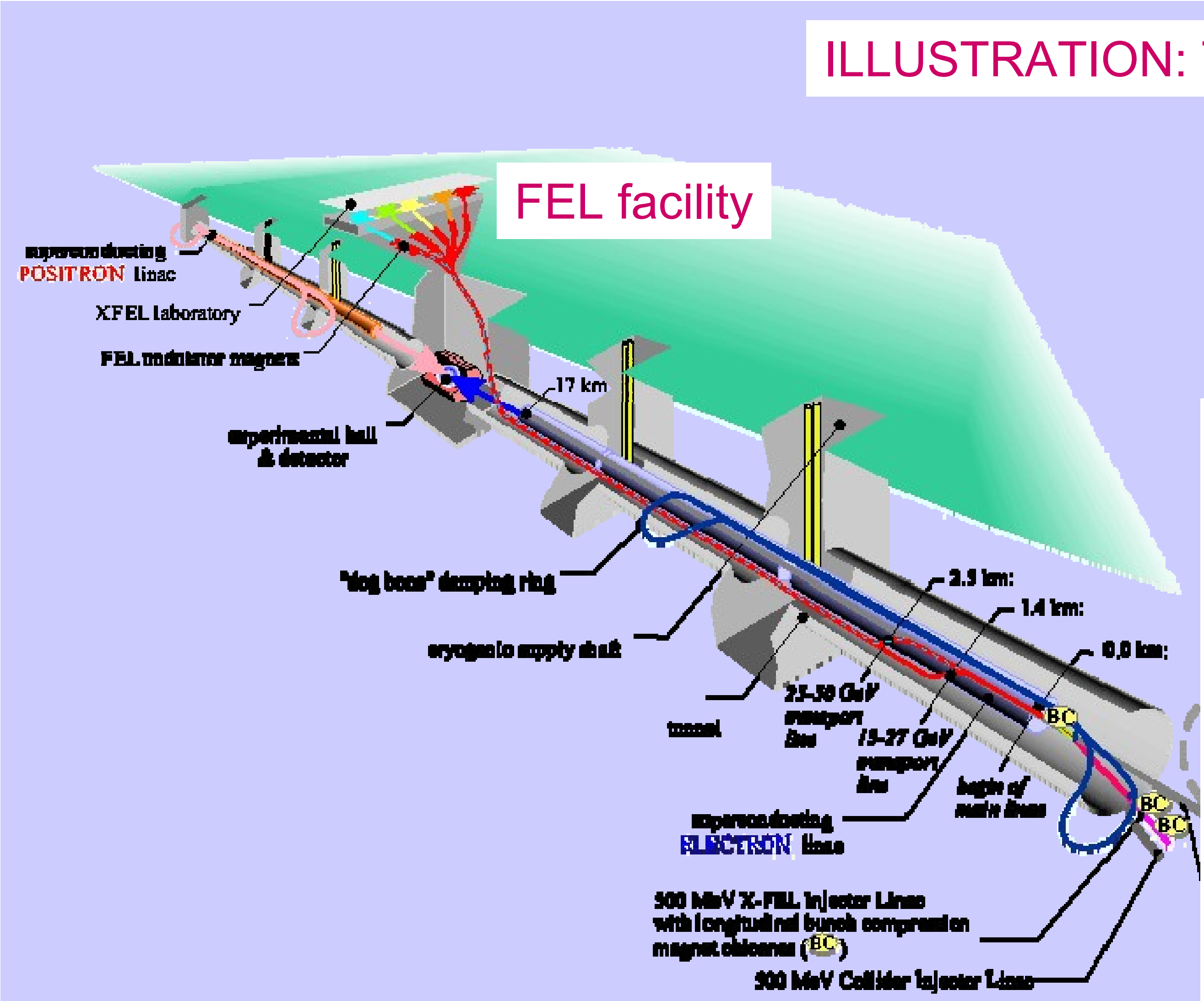
✓OVERALL LOOK THE MACHINE

✓THE HOT vs COLD TECHNOLOGIES

✓THE PERFORMANCE OF THE TESLA CAVITIES



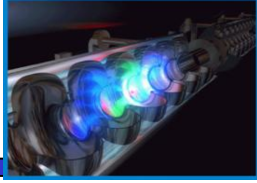
THE MACHINE : PERFORMANCE AND STRATEGIES



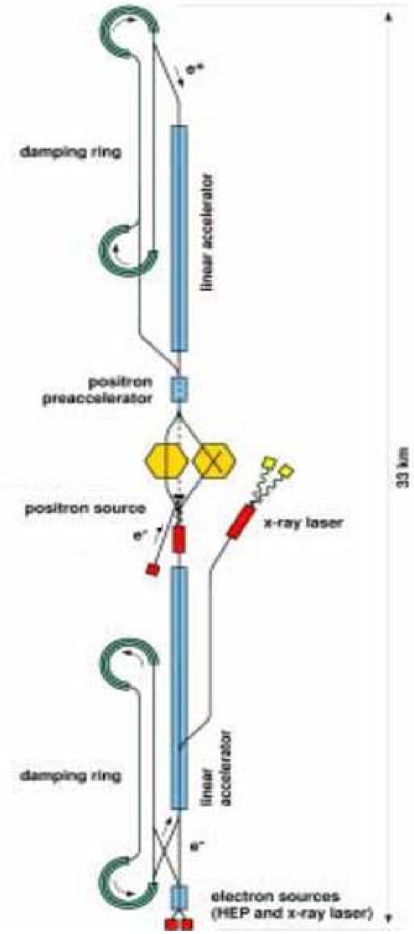
Electron/positron collider at a centre-of-mass energy from 90 GeV to 1 TeV

Study by energy
GigaZ,
W, top,
Higgs,
BSM …

THE MACHINE : PERFORMANCE AND STRATEGIES



TESLA



NLC JLC

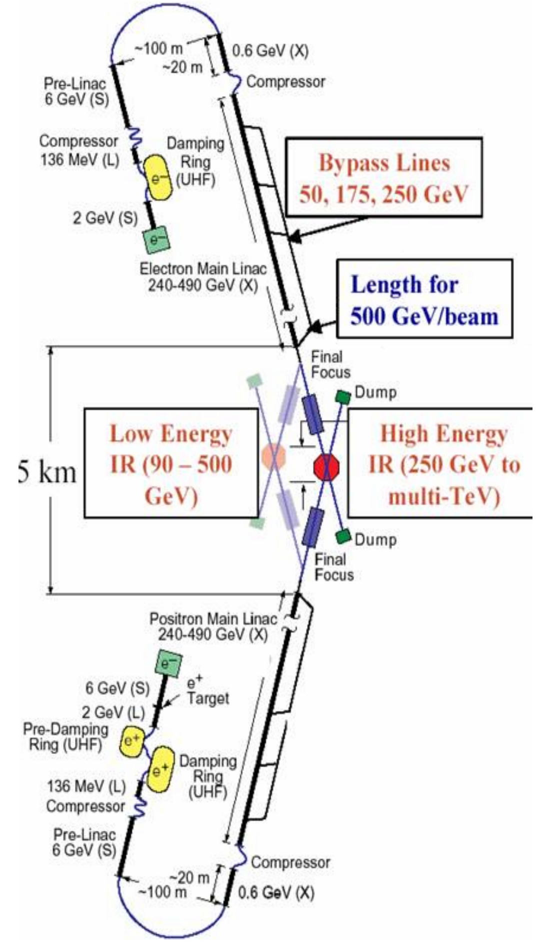
	TESLA	NLC /JLC-X +
$\mathcal{L}$ (10^{34} cm^{-2}s^{-1})	3.4 → 5.8	2.0 → 3.4
$\sqrt{s}$ (GeV)	500 → 800	500 → 1000
Frequency RF (GHz)	1.3	11.4
Beamsstrahlung (%)	3.2 → 4.3	4.6 → 10.2
Gradient (MV/m)	23.4 → 35	70
Nbr bunch/train	2820 → 4886	196
Δt bunch (ns)	337 → 176	1.4

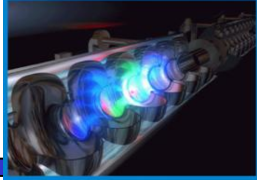
+ US and japanese are slightly different

$\mathcal{L} = 5.10^{34}$cm^{-2}s^{-1} 10^7s/year → 500 fb^{-1}/year

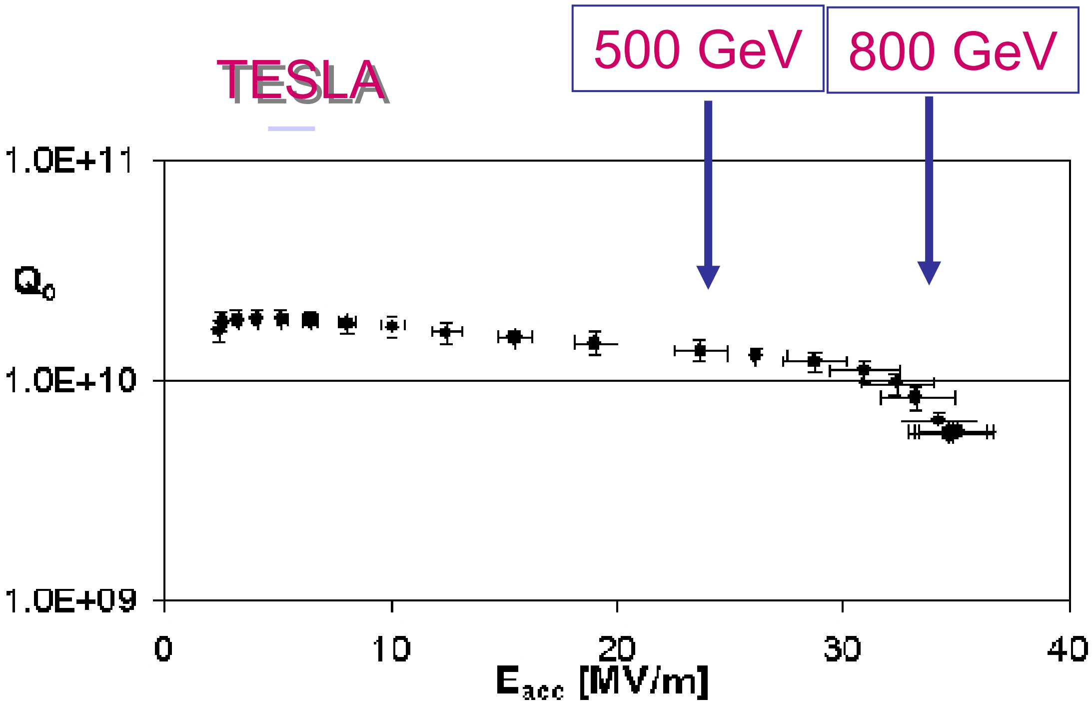
FUTURE FUTURE : CLIC multi TeV machine

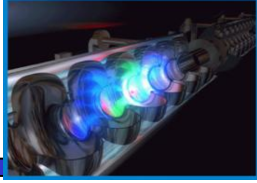
30 GHz , electric field 150 MV/m beam driven power source





ACCELARATING GRADIENT ACHIEVED FOR NINE-CELLS CAVITIES

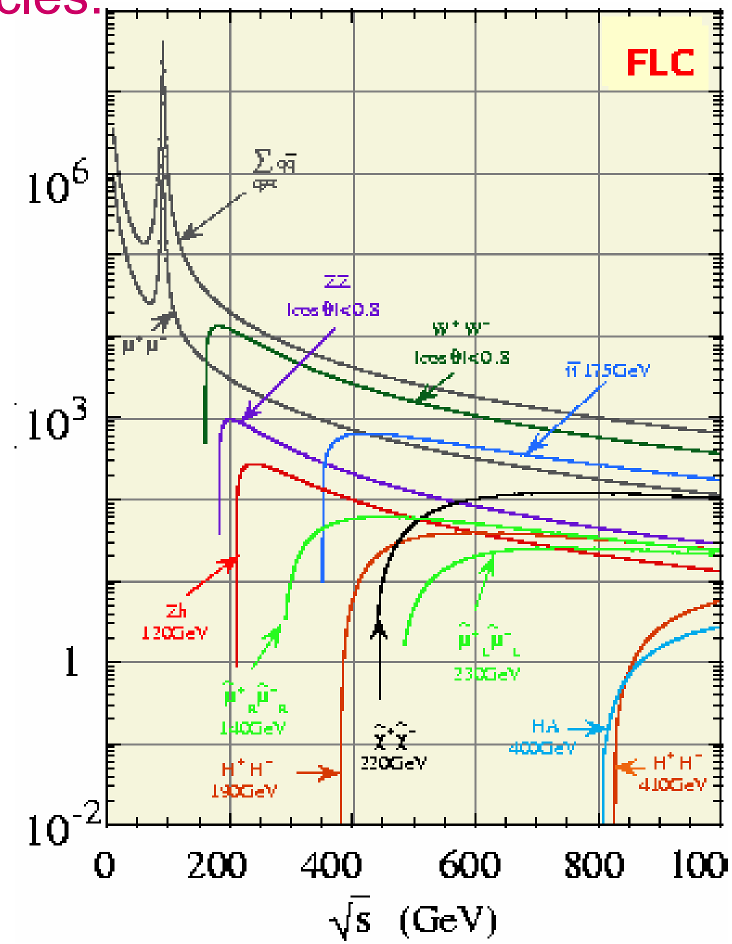




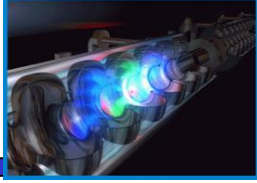
MAIN ITEMS

Basically all the physics of the elementary particles.

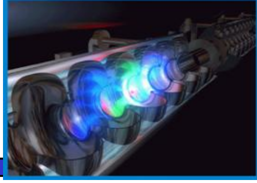
- ✓ KEY POINTS FROM THE MACHINE
- ✓ SUPER-LEP, W and top THRESHOLDS
- ✓ ELECTROWEAK SYMMETRY BREAKING
- ✓A RUNNING SCENARIO



KEY POINTS OF THE MACHINE FOR THE PHYSICS

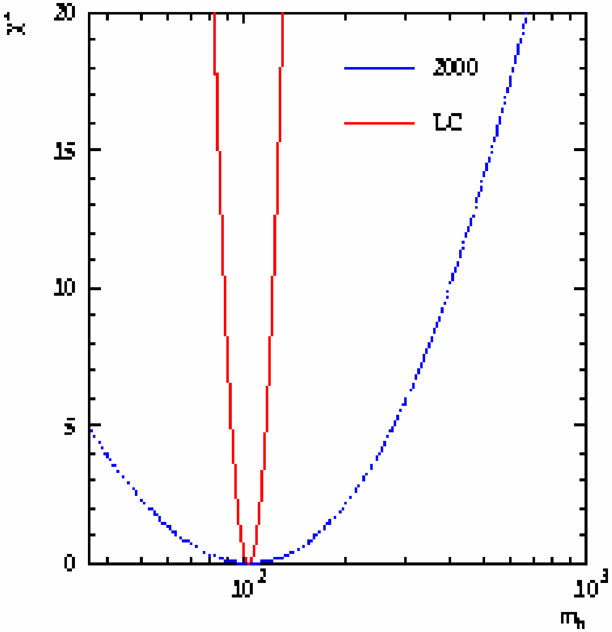


- ✓Point-like particles @ a known centre_of_mass energy.
- ✓Clear (if the detector clever enough) experimental environment.
- ✓High luminosity for precision measurements.
- ✓Satellite modes for the machine running: $\gamma\gamma$,eγ,ee .
- ✓Triggerless : all final states and angular distributions can be examined.
- ✓Centre-of-mass energy adjusted to the physical purpose (90 to 800 GeV).
- ✓Beams are polarised.



SUPER-LEP, W and top pair thresholds

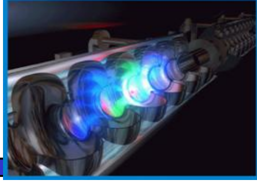
	LEP/SLC/Tev [19]	TESLA
$\sin^2\theta^l_{eff}$	0.23146 ± 0.00017	± 0.000013
lineshape observables:		
M_Z	91.1875 ± 0.0021 GeV	± 0.0021 GeV
$\alpha_s(M_Z^2)$	0.1183 ± 0.0027	± 0.0009
$\Delta\rho_l$	$(0.55 \pm 0.10) \cdot 10^{-2}$	$\pm 0.05 \cdot 10^{-2}$
N_ν	2.984 ± 0.008	± 0.004
heavy flavours:		
A_b	0.898 ± 0.015	± 0.001
R_b^0	0.21653 ± 0.00069	± 0.00014
M_W	80.436 ± 0.036 GeV	± 0.006 GeV



$\Delta m_h/m_h \sim 5\%$

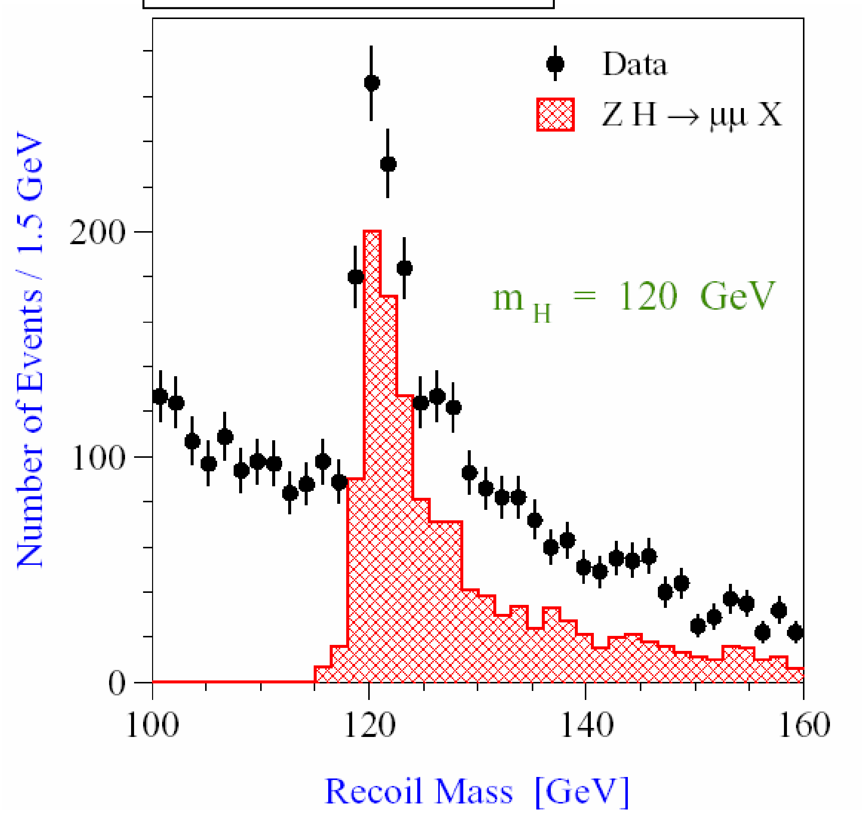
M_{top} expected to be measured with 100 MeV/c^2 uncertainty *(CDR TESLA)*
M_W expected to be measured with 10 MeV/c^2 uncertainty

YIELDING EXTREMELY PRECISE CONSISTENCY CHECKS OF THE SM
GIVES A TASTE OF THE PRECISION OF THE MACHINE.



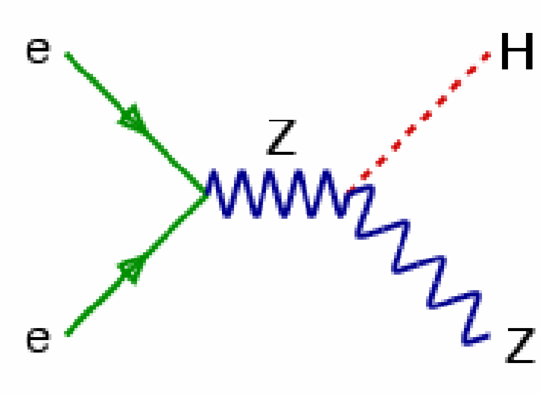
ELECTROWEAK SYMMETRY BREAKING: HIGGS?

Mass and width

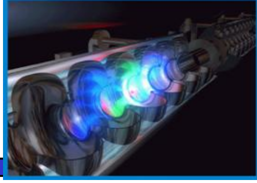


WHAT TO LEARN ?

- ✓Mass, width, branching ratios
- ✓Spin/parity
- ✓Fermion and boson couplings
- ✓Self-interactions

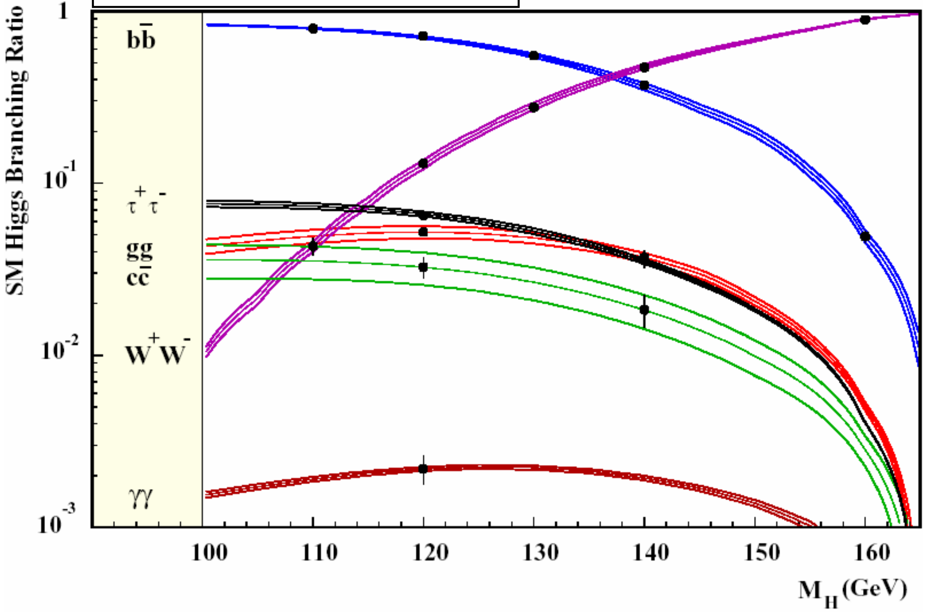


Mass determination independantly of the higgs decay ; beam energy constraint



HIGGS PHYSICS

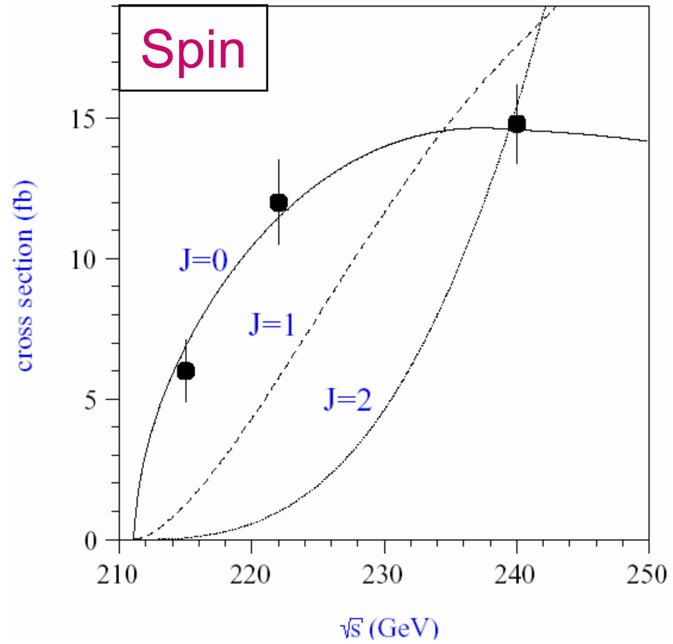
Branching ratios



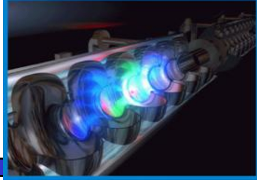
ΔBR/BR~3%

ΔBR/BR(h→WW,ZZ)=6%

Spin



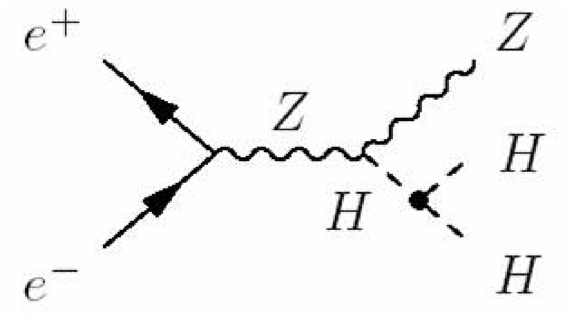
THE PHYSICS CASE



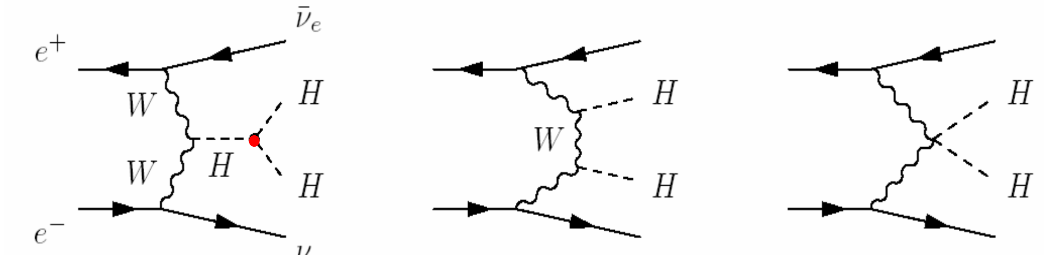
HIGGS PHYSICS

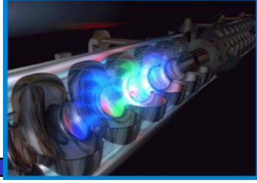
Higgs potential

The self-interaction of the Higgs boson determines the Higgs potential(λ)



$\Delta\lambda/\lambda$=20% (10%) m_h @ 140 GeV $\sqrt{s}$=500 (800) GeV 1ab^{-1}





LC starts few years after LHC

A RUNNING SCENARIO

run between 200 and 500 GeV, Go to E_{cm} max according to observations

A ‘higgs’ at LHC
- Nature of the higgs, MSSM ou MS
- Characteristics

EWSB origin

A ‘SUSY’ signal
- measure precisely masses, mixings, etc.

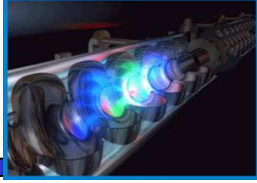
SUSY origin

No clear signal from LHC
- HZ with Z->charged leptons
- Precision measurements from Z to top

Standard Model or New Physics

And a lot more from CP violation to QCD …

GUIDELINES FOR THE DESIGN OF THE DETECTOR

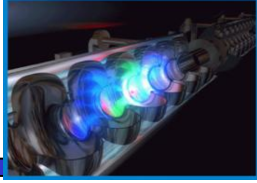


OUTLINE

✓TRACKING AND RELATED DETECTORS; THE b/c TAGGING:

✓THE MEASUREMENT OF THE JETS

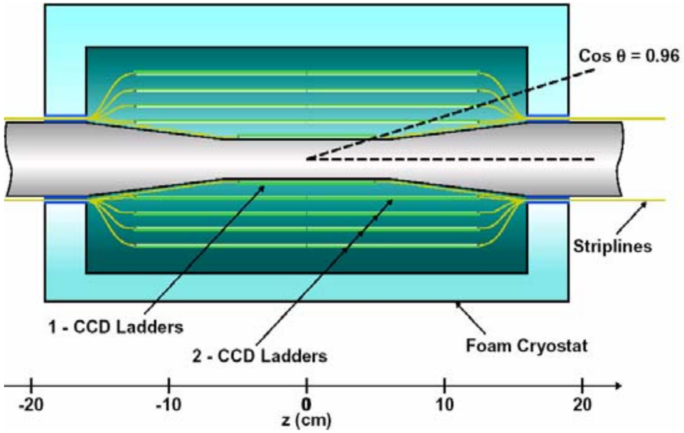
✓THE PARTICLE FLOW MEASUREMENT



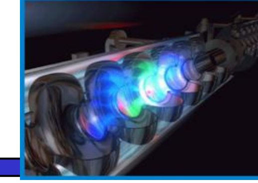
THE b/c TAGGING: THE VERTEX DETECTOR

A triviality: the physics programme is based for an important part upon the identification of heavy fermions, i.e it is mandatory to have excellent performance (better than LEP/SLD because of the highest multiplicity) of the b,c and τ decay vertices.

There is a consensus, at least in the ECFA-DESY community: internal radius < 1.5 cm and more than 4 read-out layers



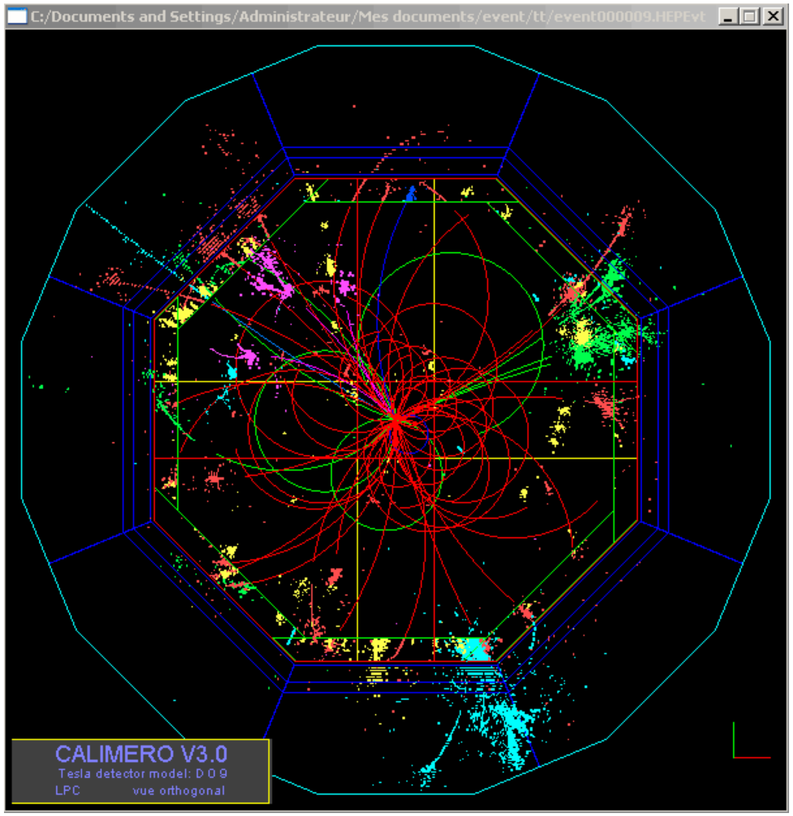
Most advanced R&D are
- ✓CCD
- ✓CMOS
- ✓DEPFET



GUIDELINES FOR THE DESIGN OF THE DETECTOR

THE CENTRAL TRACKER

Top pair production @ 500 GeV



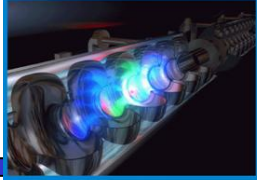
CONSTRAINTS DRIVEN BY:

✓Good separation between tracks even in high multiplicity for boson mass meas. in di-jets; find the V0.

✓Good momentum resolution for dilepton masses.
(+Machine background sensitivity)

THE CANDIDATES ARE:

✓A TPC
✓Silicium tracker



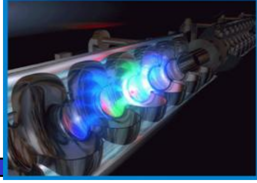
GUIDELINES FOR THE DESIGN OF THE DETECTOR

THE TRACKING WE WANT IS EASY TO IMAGINE EVEN IF THE R&D PROJECTS ARE AMBITIOUS BUT …

WHICH CALORIMETRY ?

… GO BACK TO PHYSICS

GUIDELINES FOR THE DESIGN OF THE DETECTOR

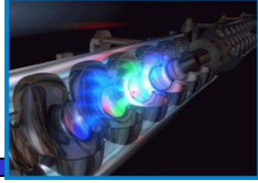


PHYSICS PROCESS	FINAL STATES
Zγ	2l, 2 jets
W+W-	1l+2jets, 4 jets
tt	l+jets, 6jets
tth	8 jets
hZ	2l+2 jets, 4 jets
hhZ	2l+4 jets, 8jets
stopstop	6 jets + missing energy

CAN'T AVOID THE NEED OF MEASURING W AND Z DECAYS IN JETS
(Trivial for GigaZ programme, still true for most of the LC physics progamme)

RECONSTRUCTION OF THE JETS IS OF MAJOR IMPORTANCE AND SHALL GUIDE THE DESIGN. ONCE SAID, IT WILL RAPIDLY APPEAR THAT LEPTON AND PHOTON RECONSTRUCTION WILL TAKE BENEFIT OF THAT PHILOSOPHY.

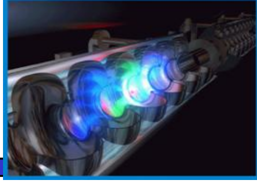
GUIDELINES FOR THE DESIGN OF THE DETECTOR



TWO APPROACHES FOR THE MEASUREMENT OF THE JETS

1) A global energy flow measurement : use only the calorimetry adequately compensated and segmented to fit the jet size (or the hadronic shower one). As an illustration, take the excellent H1 calorimeter -> Ejet @ 100 GeV is measured at 4.2%.

2) An analytical particle flow measurement : following the basic idea of the LEP energy flow measurement. Each component is identified and measured with the dedicated detector. Can we get better than the first option ?



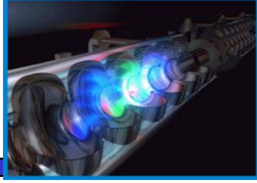
THE ANALYTIC ENERGY FLOW MEASUREMENT

Each particle of the jet or di-jet is reconstructed and identified and the jet energy flow is the sum of the three components:

$$E_{JET} = \Sigma \left(E_{EM} + E_{HAD^0} + E_{CH}\right)$$

- ✓Photons (hence π^0…) measured by ECAL
- ✓Other neutral hadrons measured by ECAL and HCAL
- ✓Charged tracks measured by the tracking system

This approach is supported by the argument : 65% of the energy is brought by charged tracks much more well measured by the tracker even at large centre-of-mass energies (multi-jets environment implies high multiplicities of low-energy particles).



TO GO FURTHER … A TYPICAL JET CONTAINS

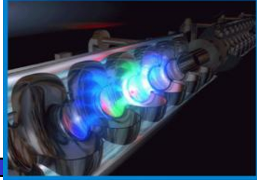
$$E_{JET} = \Sigma\ (E_{EM}\ (25\ \%) + E_{HAD^0}\ (10\ \%) + E_{CH}\ (65\ \%))$$

With a high multiplicity of somehow low energy particles that we would like all to be reconstructed, yet to be complete and deal with a non-asymptotic detector,

$$\sigma^2\ jet = \sigma^2 ch. + \sigma^2\ \gamma\ + \sigma^2\ h^0 + \sigma^2 misassignment + \sigma^2 threshold$$

Assuming typical resolution of 10^{-5} for the charged tracks, 12% stochastic term for photons and 40% stochastic term for neutral hadrons, IT COMES THAT $\sigma^2\ jet = (0.14)^2\ E_{jet}$.

THE RATE OF PARTICLE MISASSIGNMENT DETERMINES THE JET RECONSTRUCTION QUALITY

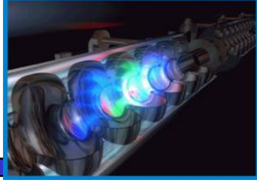


INPUTS FROM THE ANALYTIC ENERGY FLOW

- ✓Energy and angular resolution should be good
- ✓Particle reconstruction should be excellent:
  - ✓Small moliere radius
  - ✓Fine longitudinal segmentation for 3D

HERMETICITY ← → **GRANULARITY**

GUIDELINES FOR THE DESIGN OF THE DETECTOR



INPUTS FROM THE MACHINE

✓Machine background requires a 3-4 T magnetic field

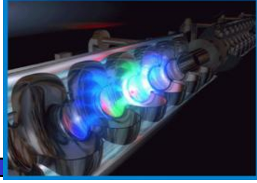
✓The corresponding coil thickness in the state of the art is about 2 nuclear interaction lengthes.

ECAL ***and*** HCAL SHALL BE INSIDE THE COIL

In addition, the calorimetric system must be far away from the interaction point to get the jet components well separated (large tracker (and field) are preferred –fits well with a TPC) but then the constraint for the calorimetry is

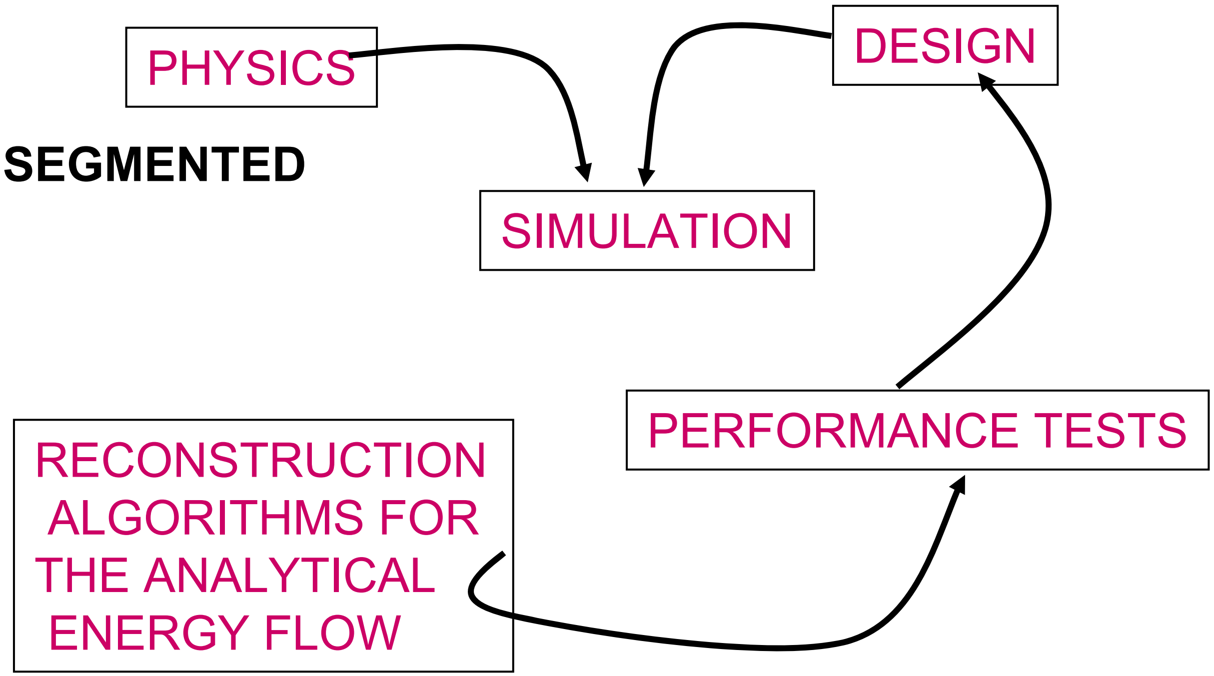
COMPACTNESS

GUIDELINES FOR THE DESIGN OF THE DETECTOR

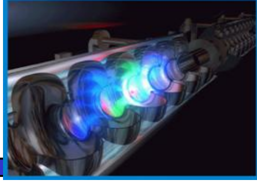


TO SUMMARIZE : the calorimetric system must be:

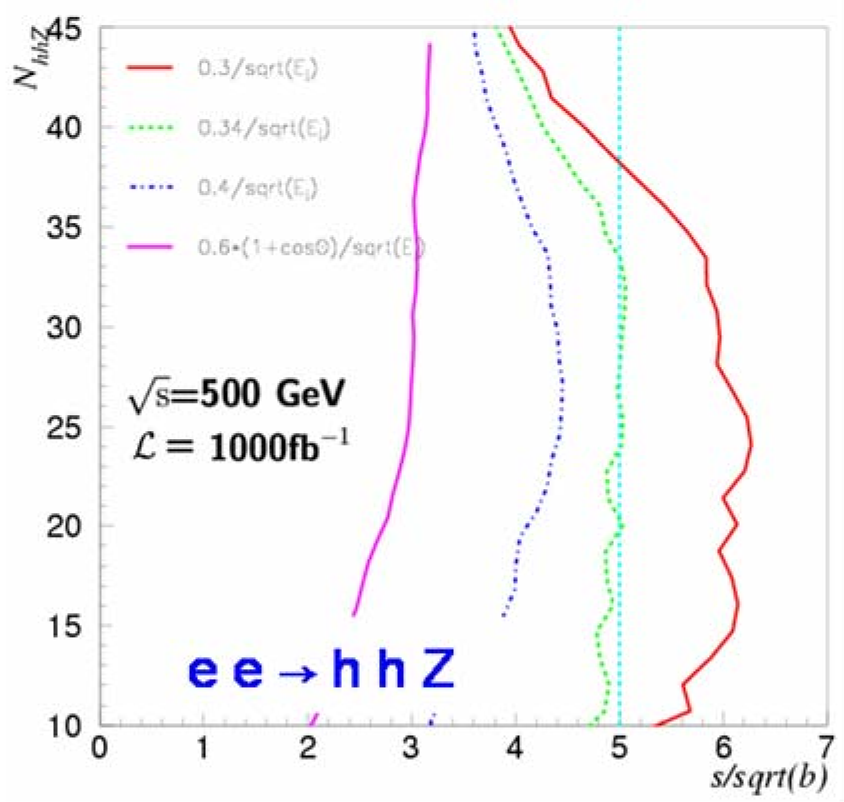
1) **COMPACT**
2) **HERMETIC**
3) **GRANULAR**
4) **LONGITUDINALLY SEGMENTED**



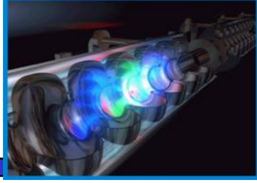
5) **THE OPTIMISATION OF THE DESIGN MUST INCLUDE THE ENERGY FLOW RECONSTRUCTION ALGORITHM ACCORDING TO THE ITERATIVE SKETCH**



A FURTHER ARGUMENT OF THE ENERGY FLOW PRIORITY …
A PHYSICS EXAMPLE OF WHAT WE COULD NOT DO WITH A NON-EXCELLENT (LEP-like) ENERGY FLOW :



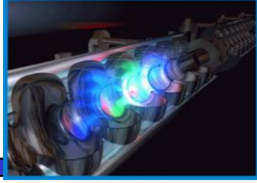
THE MEASUREMENT OF THE SELF-INTERACTIONS OF THE HIGGS BOSON REQUIRES A RESOLUTION AS GOOD AS 0.35/sqrt(E)



OUTLINE

- ✓THE CALICE COLLABORATION
- ✓ KEY POINTS FOR THE ECAL
- ✓ KEY POINTS FOR THE HCAL
- ✓ RECONSTRUCTION ALGORITHMS

THE CALICE COLLABORATION

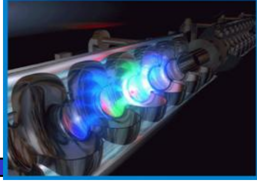


THE *CALICE* COLLABORATION :
27 laboratories, 170 members.
Spokeperson : Jean-Claude Brient.

FOR WHICH DETECTORS ?

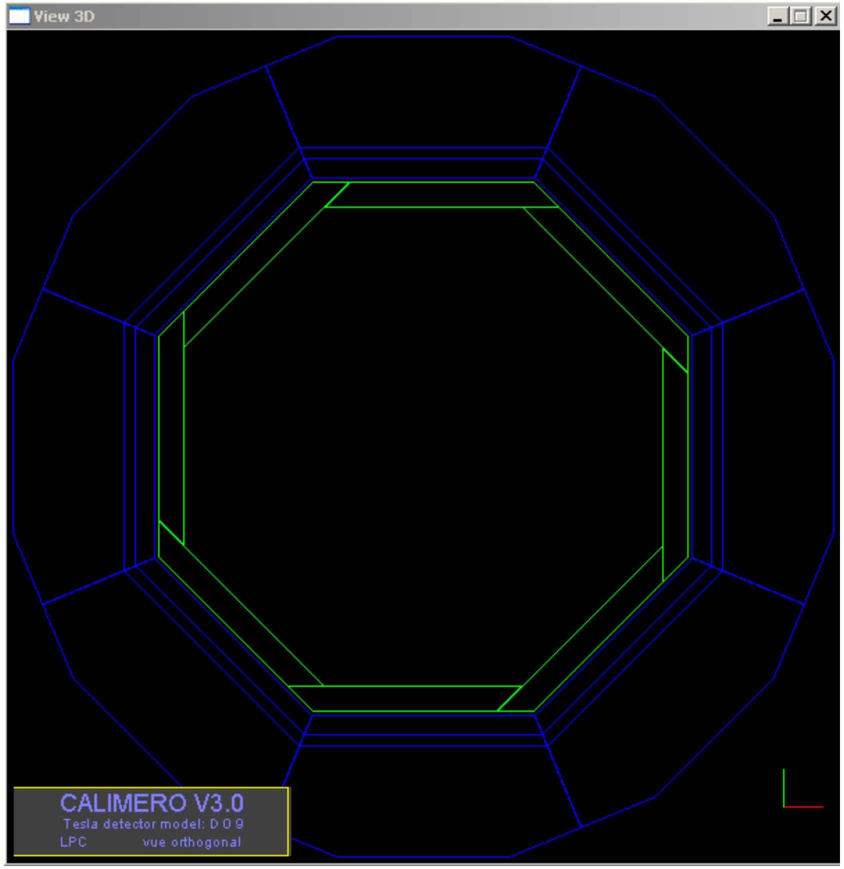
✓ECAL: TUNGSTEN/SILICIUM W/Si WITH LARGE SAMPLING

✓HCAL: TWO OPTIONS
- ✓Gas detector/radiator sampling
- ✓Scintillator tile/ radiator sampling



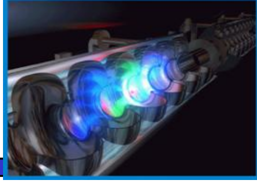
THE SIMULATION

MOKKA: A GEANT4-BASED FULL SIMULATION OF THE DETECTOR DEVELOPPED AT LLR-ECOLE POLYTECHNIQUE FOR ECAL, HCAL … AND MORE …

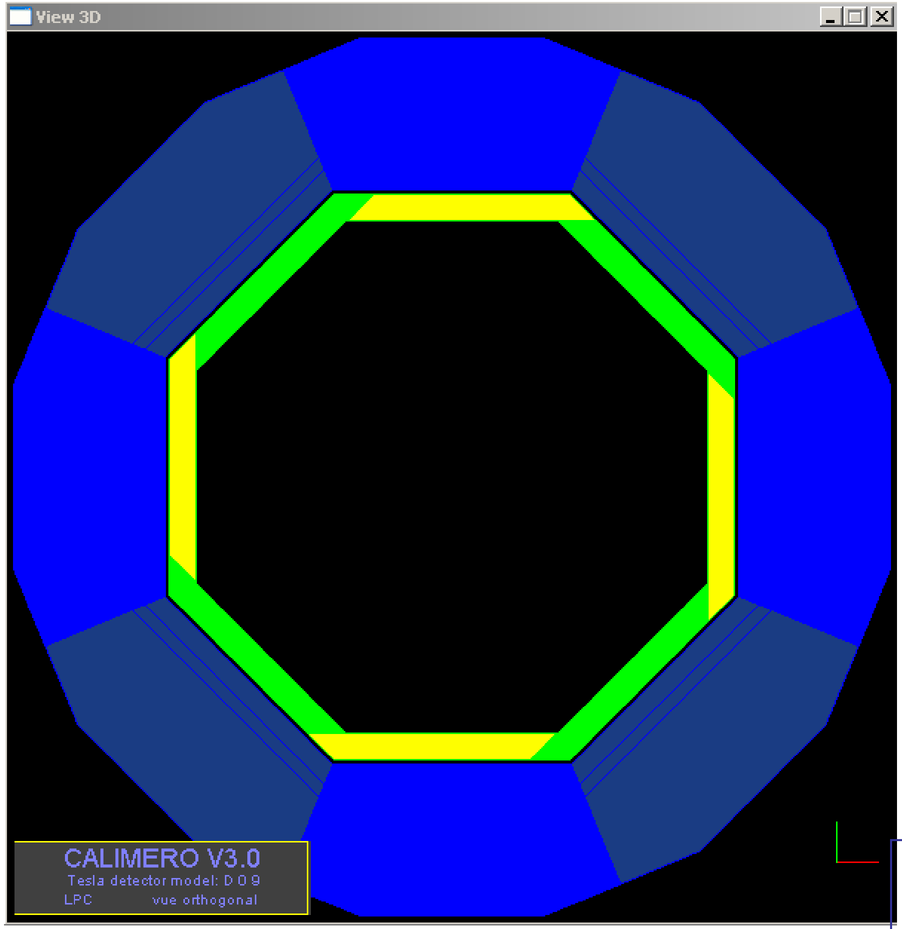


VERY POWERFUL TOOL USED TO BUILD THE ENERGY FLOW AND TO DESIGN THE PROTOTYPES

THE IMAGES I SHOW ARE FROM AN EVENT DISPLAY DEVELOPPED AT CLERMONT: CALIMERO (CALorimeter IMage RecOnstruction)

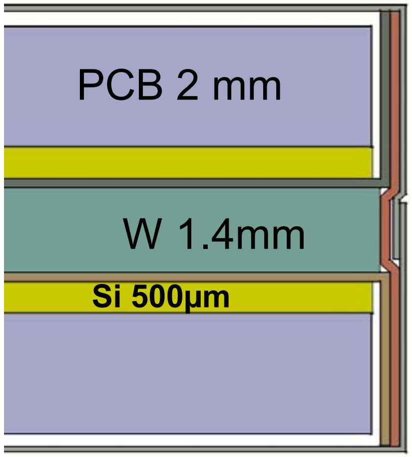


HERMETICITY: NO CRACK



- ✓Octogonal geometry
- ✓40 Silicium layers
- ✓Detection element : 1x1 cm2
- ✓High integration level
- ✓24 X0 for 20 cm thickness

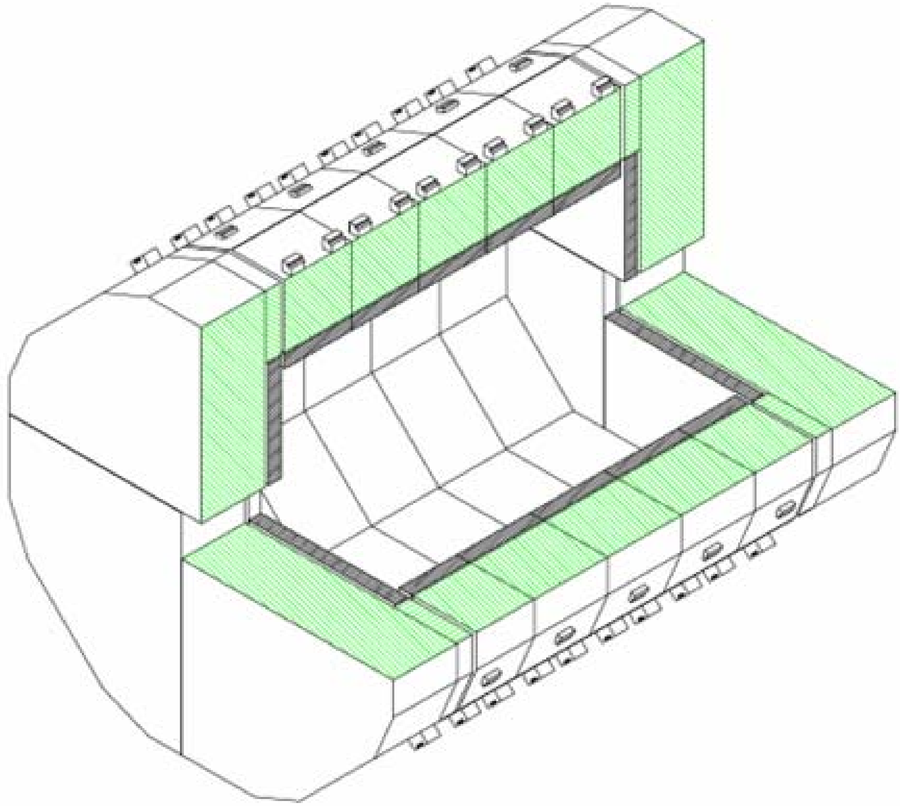
A TYPICAL LAYER

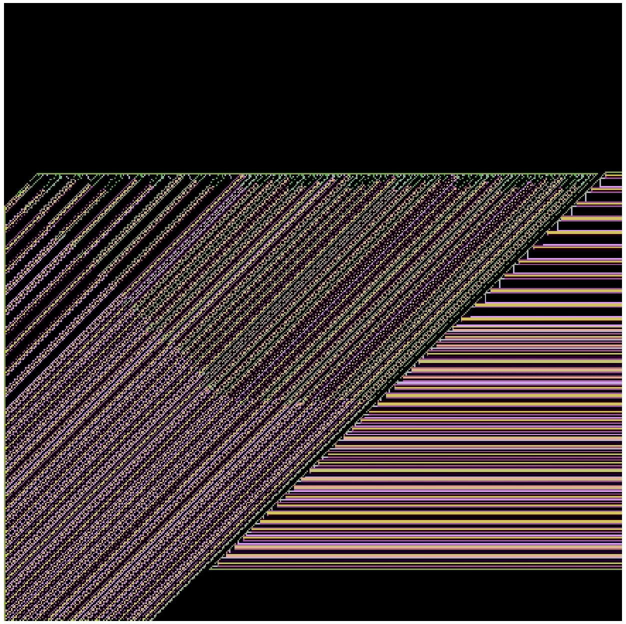


COMPACTNESS

HERMITICITY: NO CRACK

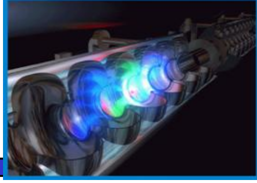
END-CAP GEOMETRY



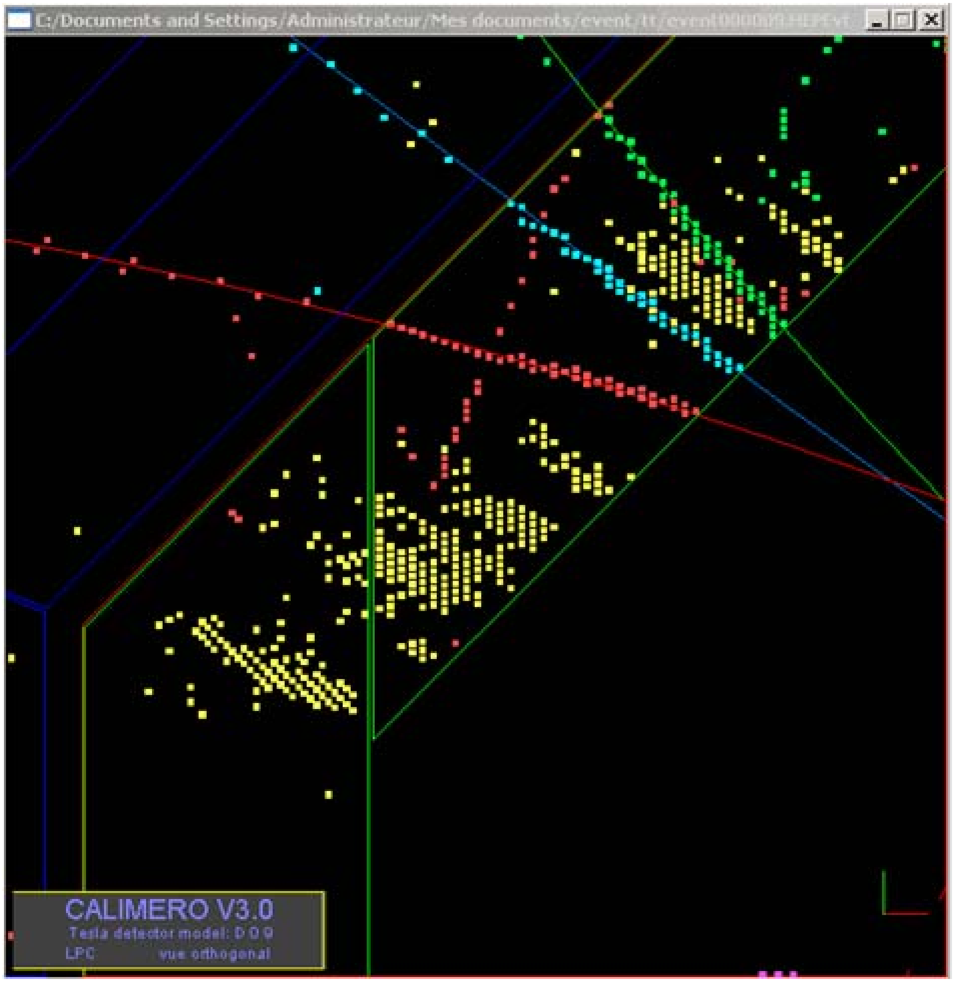


CREDITS LLR

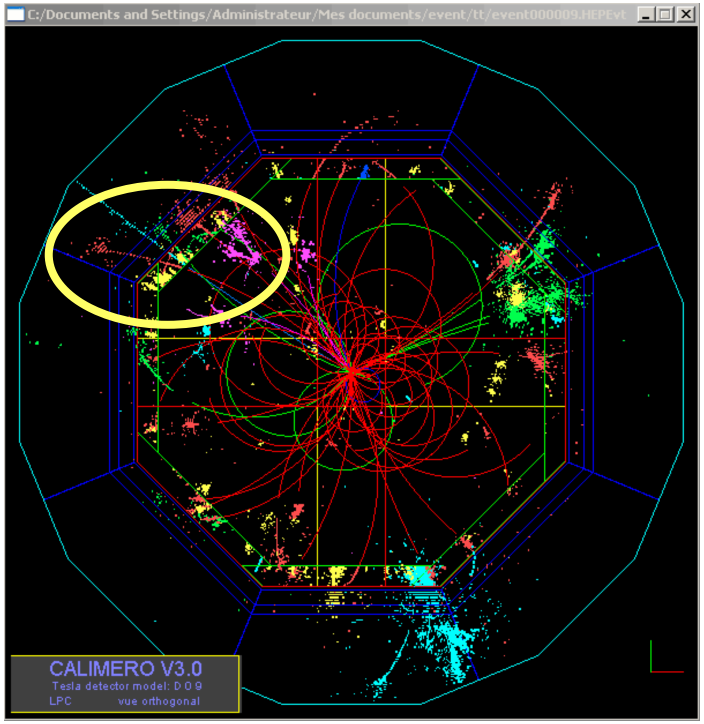
OVERLAP FOR THE BARREL OCTOGONES



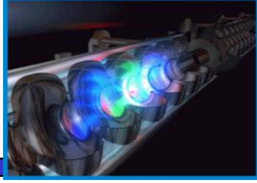
GRANULARITY3D: 30 MILLIONS OF CHANNELS



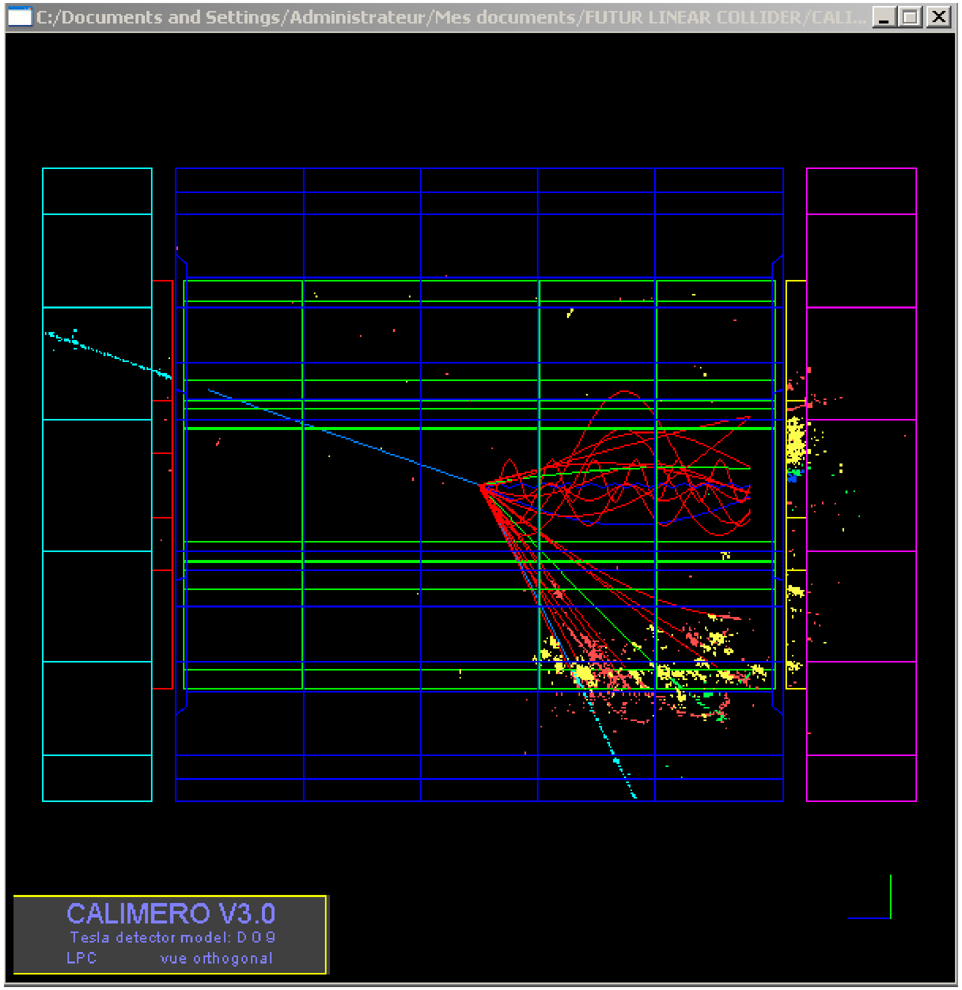
Top pair production @ 500 GeV



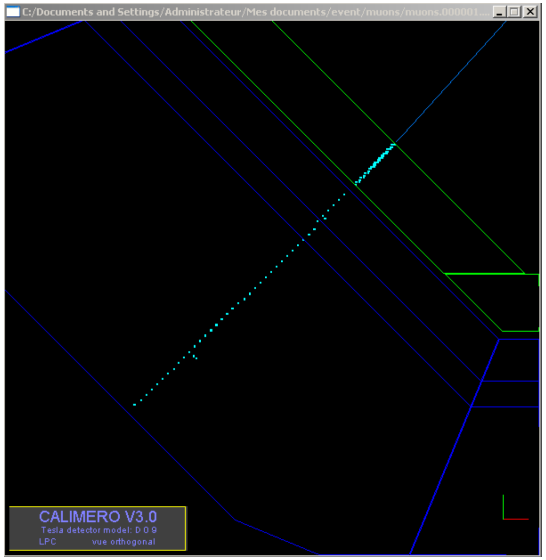
3 HECTARES OF SILICIUM !



GRANULARITY3D: 30 MILLIONS OF CHANNELS

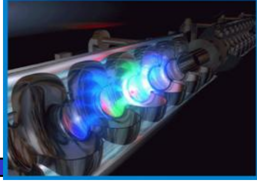


W pair production @ 500 GeV
One W decays leptonically



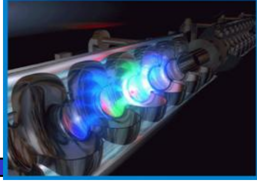
Calorimeters make the μid !

THE CALORIMETRIC SYSTEM / ECAL



PERFORMANCE OF THE DESIGN MUST BE REGARDED ACCORDING TO THE ANALYTICAL ENERGY/PARTICLE FLOW AND HENCE RELIES ON THE RECONSTRUCTION ALGORITHMS

LET'S LOOK TO A DEDICATED ONE FOR PHOTON RECONSTRUCTION AND MEASUREMENT …



PHOTON RECONSTRUCTION: EMILE

Energy Measurement Intended for Low Energy em showers

- Two pads (i and j) are connected according a link strength d_{ij} defined by terms which reflects the basic process ($e \rightarrow \gamma$, $\gamma \rightarrow e$)

Long distance interaction	$e^{-\rho_{ij}/X_o}$
Energy relation	E_i/E_j
Angular dependence	$1/(1-\beta\cos\theta_{ij})$

where

ρ_{ij} is the 3D distance between the pads i and j,
X_o is the interaction length,
θ_{ij} is the angle between the pad i and j
β=.99

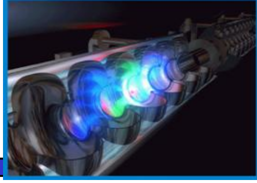
Thus d_{ij} is defined as

$$d_{ij} = e^{-\rho_{ij}/X_o} \times E_i/E_j \times 1/(1-\beta\cos\theta_{ij})$$

Virtues:

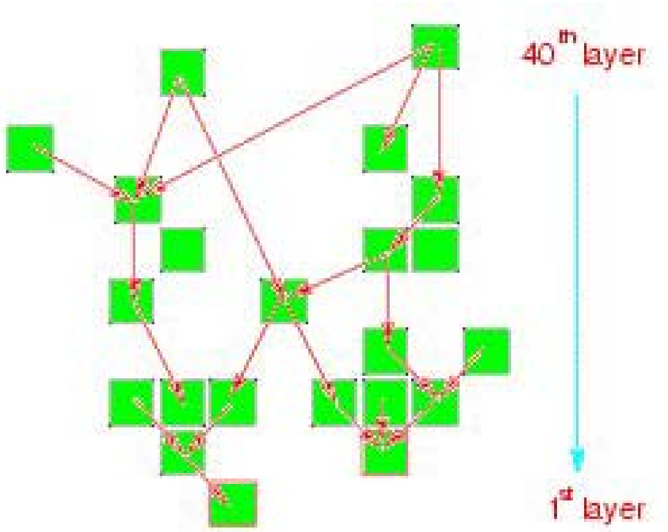
✓3-Dimensionnal
✓Physical insight
✓No seed
✓Democratic
✓Long range

Treat the overlap of two showers in the ECAL up to very low energies.



PHOTON RECONSTRUCTION: EMILE

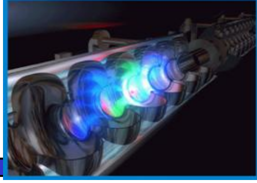
Energy Measurement Intended for Low Energy em showers



✓The d_{ij} are determined between every pair of pads in the event *(j>i)*

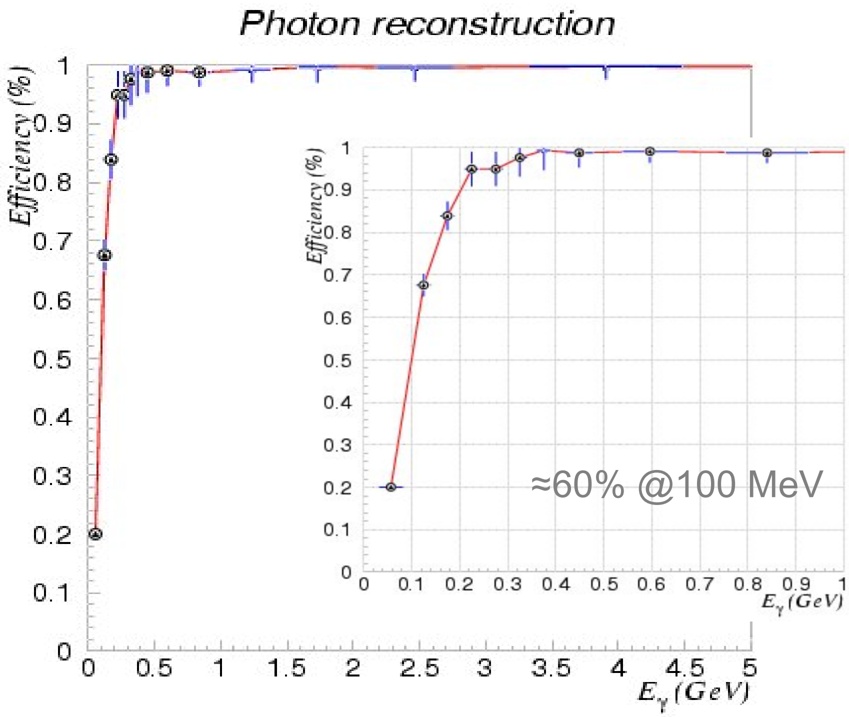
✓Pad energy is projected on the layer according to their d_{ij}
ie reverting the e.m. shower development

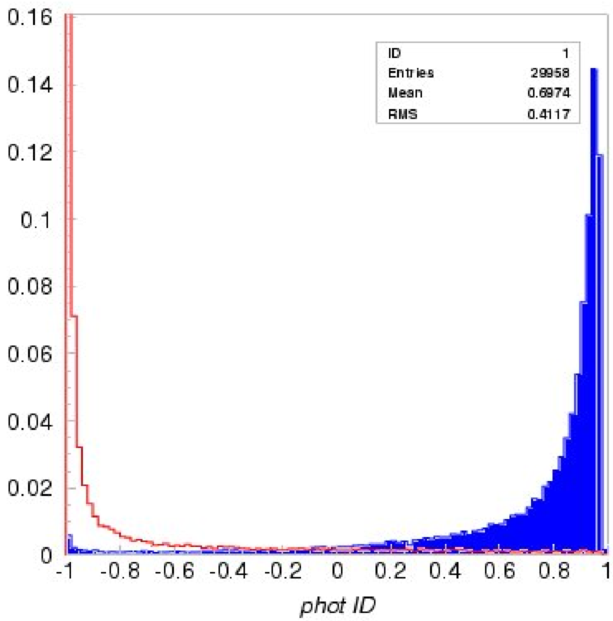
✓A terminal pad defines an EMILE object
✓Characteristics of the cluster are built through the d_{ij} weighing matrix
✓The information from a pad is shared by many objects



PHOTON RECONSTRUCTION: EMILE

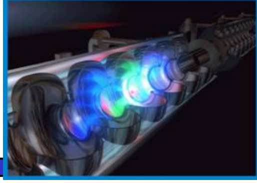
PERFORMANCE



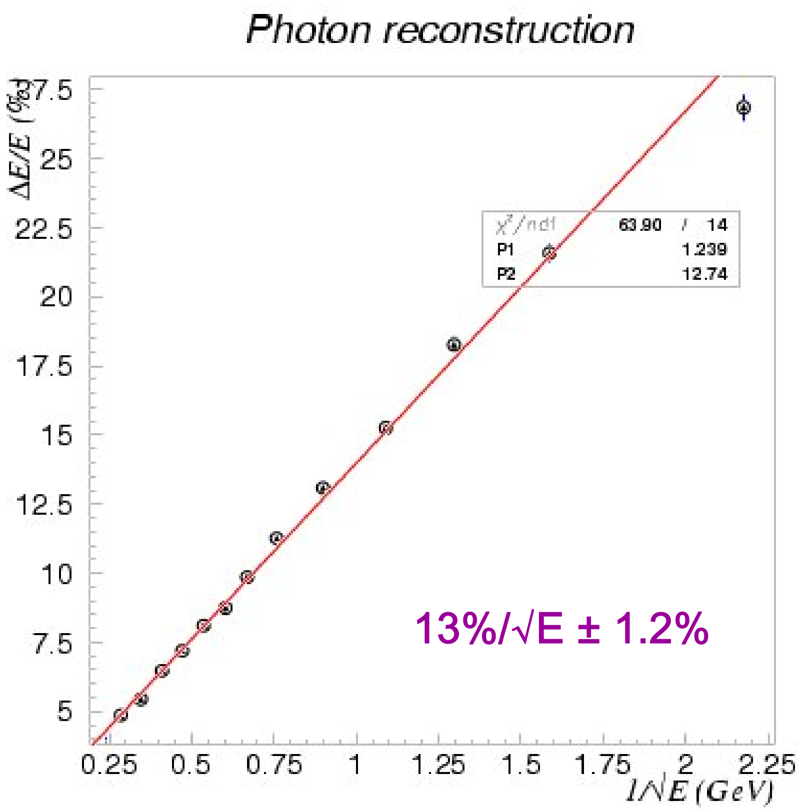


Photon ID

- ✓ Longitudinal and transverse profiles
- ✓ Pad multiplicity
- ✓ Centre-of-gravity position



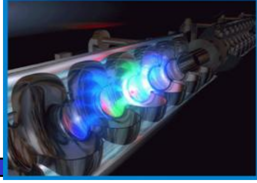
PHOTON RECONSTRUCTION: EMILE



EMILE TREATS BOTH:

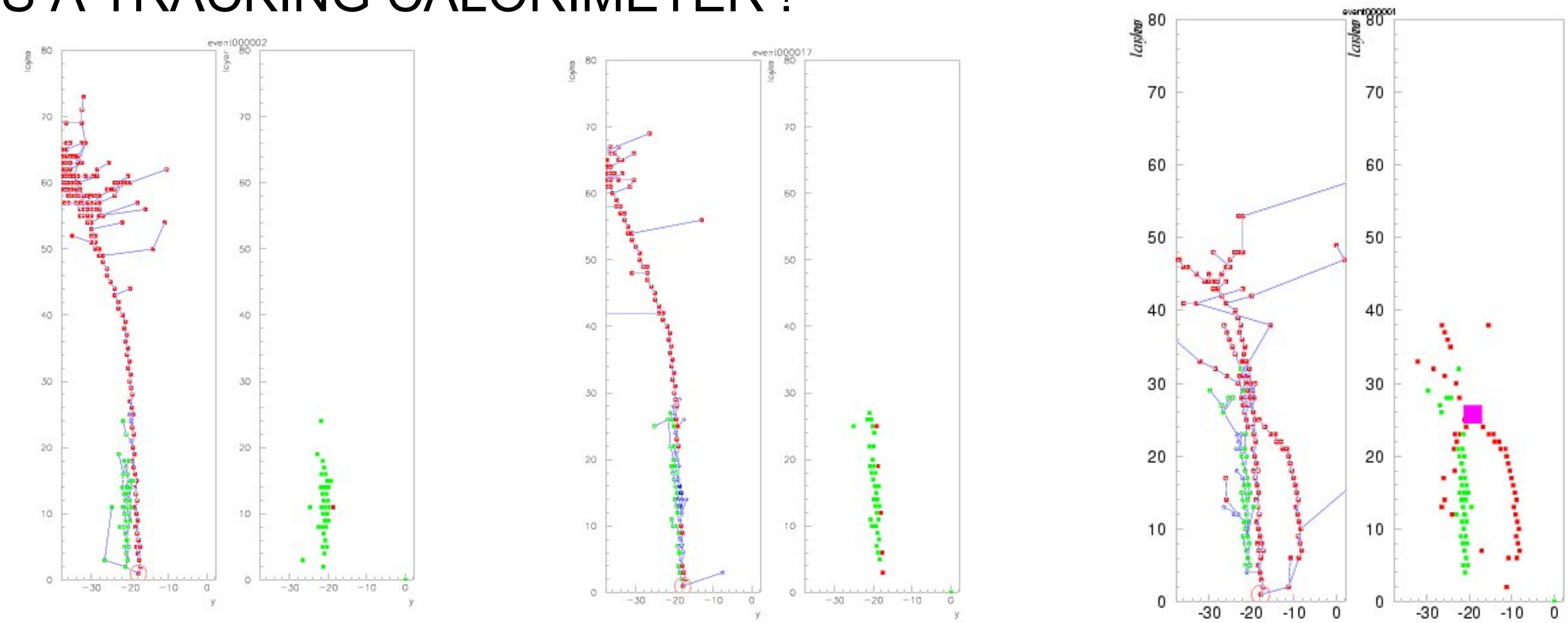
✓THE OVERLAP BETWEEN THE PHOTON AND ITS NEIGHBOURS IF ANY (MISSASSIGNMENT)

✓THE THRESHOLD PROBLEM: IDENTIFIES PHOTONS TILL 100 MeV

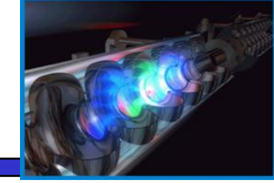


ANOTHER EXAMPLE OF RECONSTRUCTION TAKING BENEFIT OF THE LONGITUDINALLY SEGMENTED ECAL:

Separation of the photon: method based on pattern recognition with minimum ionizing particle identification and vertexing (if any).
IT'S A TRACKING CALORIMETER !



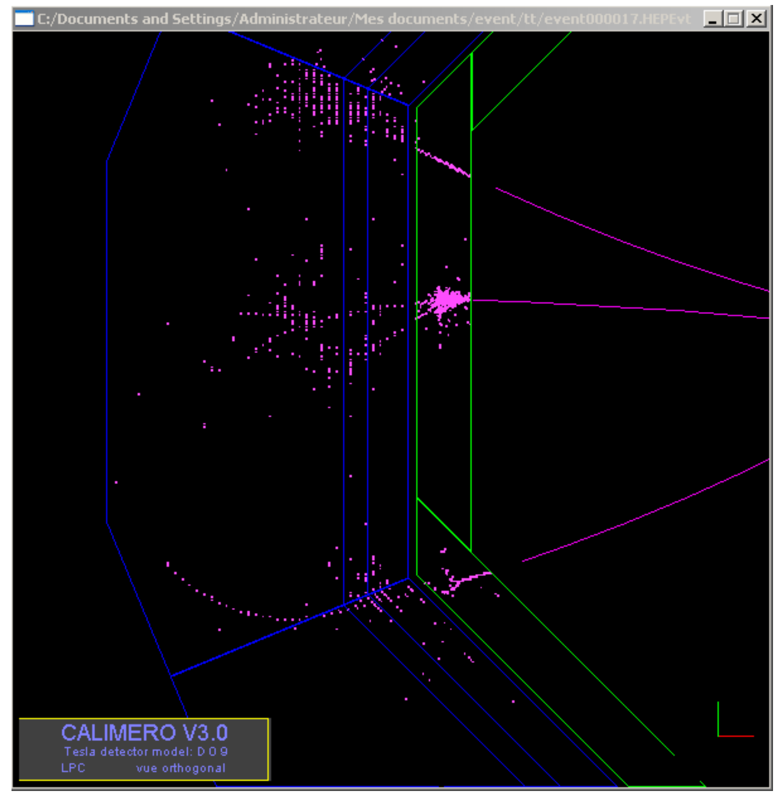
Few examples w/ $\gamma_{\text{1 GeV}} / \pi^{\pm}_{\text{10 GeV}}$ separated by less than few centimeters at the ECAL entrance



HADRONIC CALORIMETER WITH DIGITAL READOUT

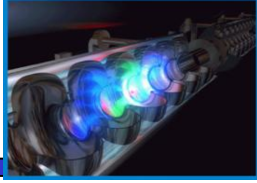
MAIN FEATURES:

- ✓SAMPLING CALORIMETER – GAS RADIATOR
- ✓40 layers (RPC, GEM …)
- ✓Active detection element : 1x1 cm2 pad
- ✓50 Millions of channels with digital readout
- ✓The energy is measured by counting the hit multiplicity



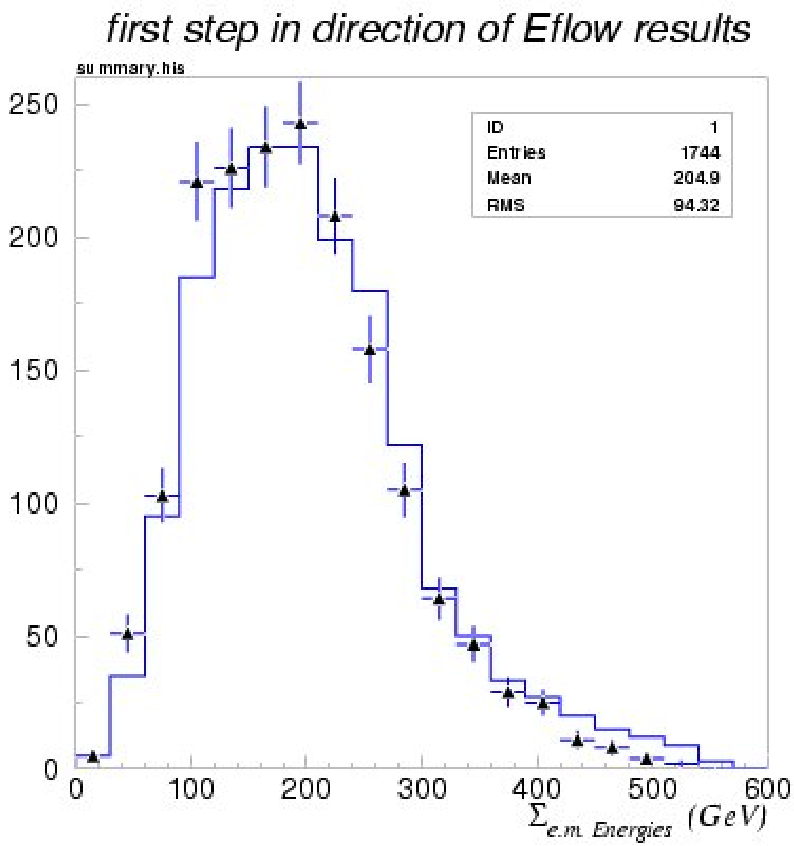
ADVANTAGES – GEANT BASED

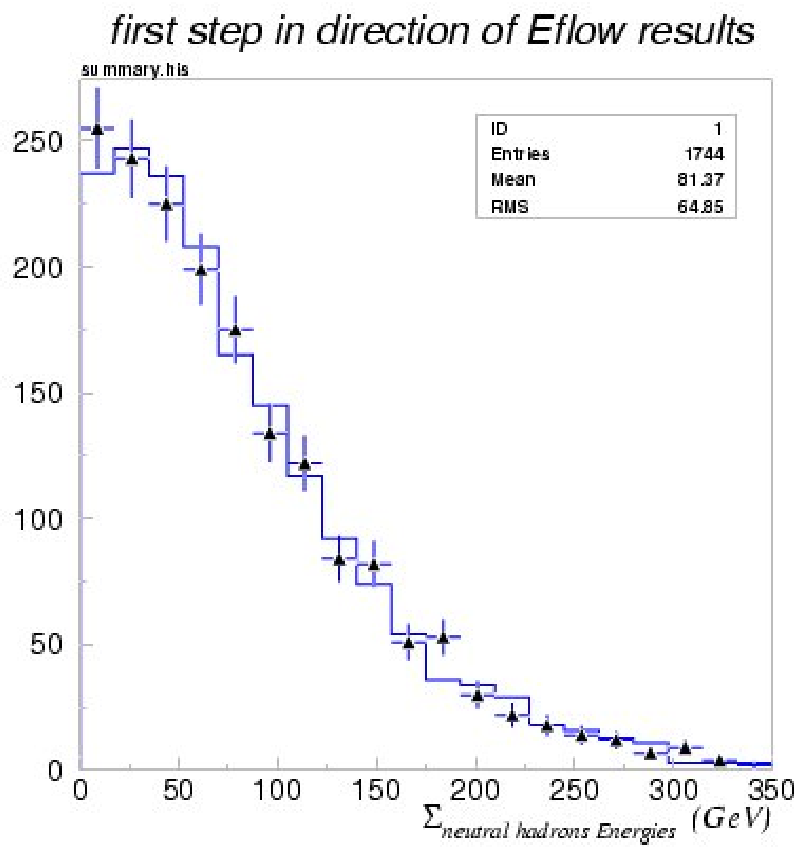
- ✓Separate and Reconstruct individually neutral hadrons
- ✓Identify muons
- ✓Energy resolution is not a problem



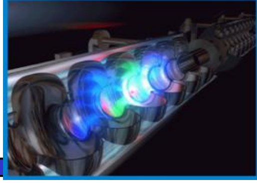
STUDYING A BENCHMARK PHYSICS PROCESS: WW pairs @ 800 GeV/c2

Most difficult channel to test the energy flow



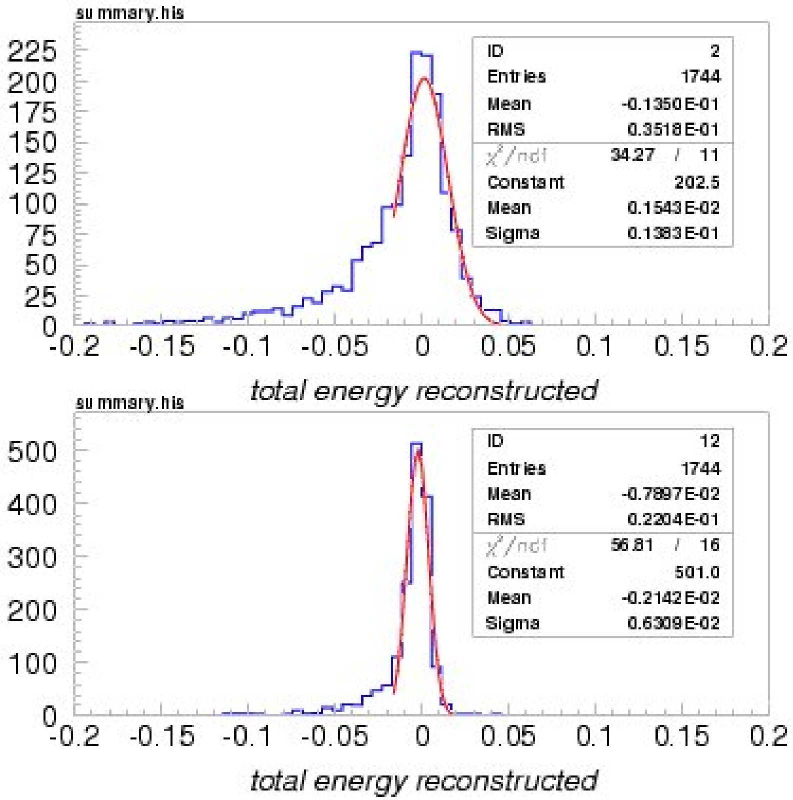


THE CALORIMETRIC SYSTEM – ENERGY FLOW

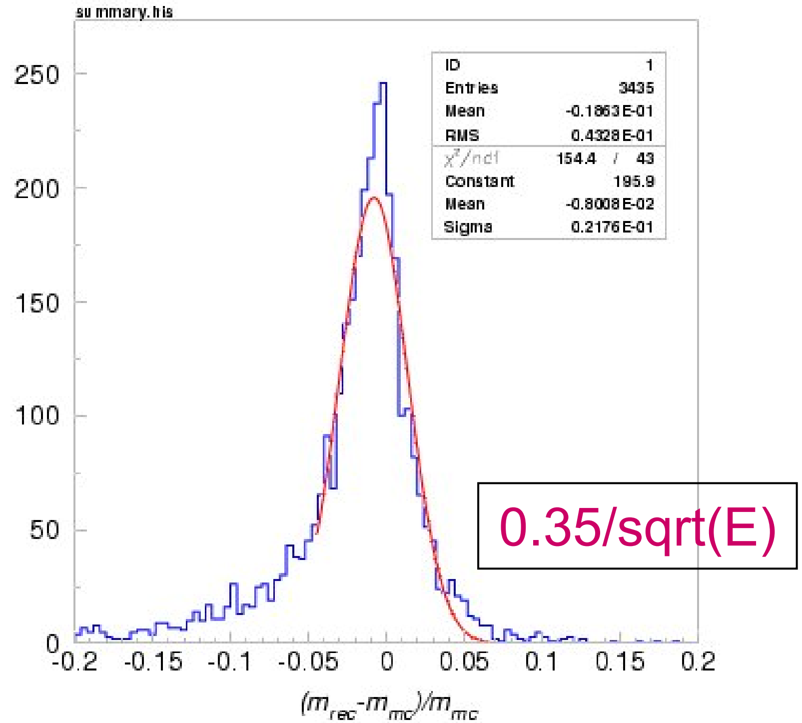


STUDYING A BENCHMARK PHYSICS PROCESS: WW pairs @ 800 GeV/c2

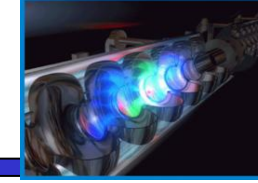
first step in direction of Eflow results



ass reconstruction from WW pair production



HCAL RECONSTRUCTION IS AN IMPORTANT ISSUE



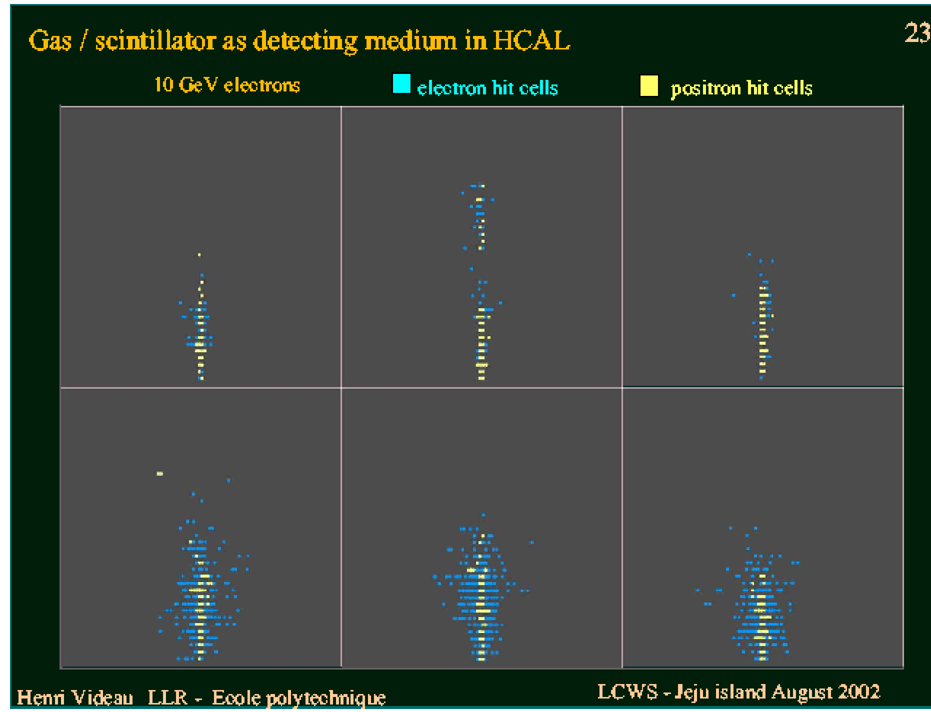
THE CALORIMETRIC SYSTEM

FUTURE STEP IN R&D FOR THE CALORIMETRY IN CALICE

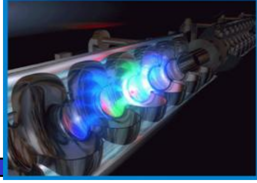
Prototype for ECAL/HCAL is to be tested in test beams in the years from 2005 with the two main purposes:

✓checking the GEANT4 simulation for the HCAL

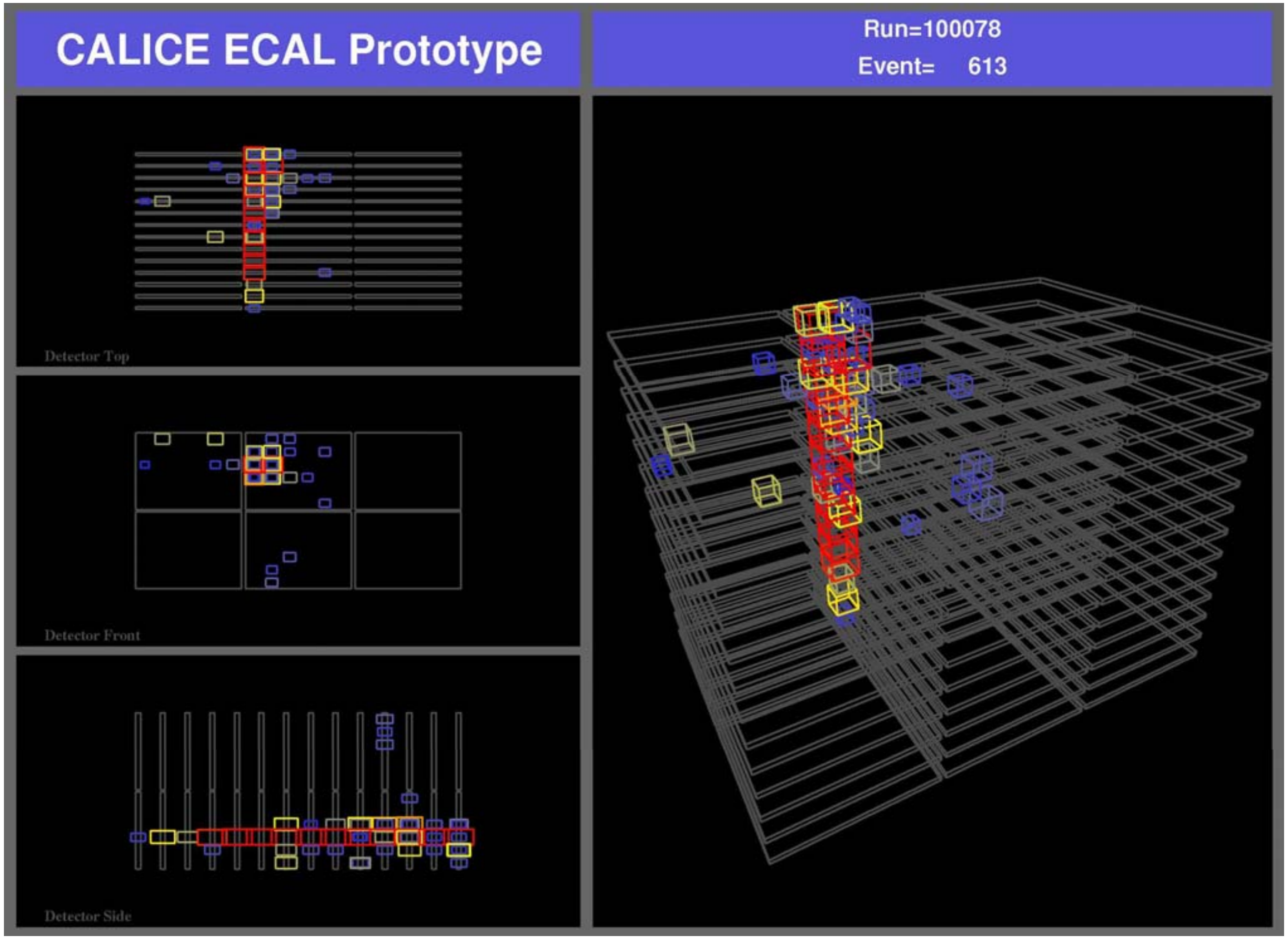
✓ test the high level of integration for the ECAL

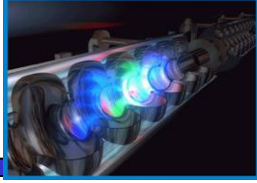


CREDIT Henri Videau



ECAL PROTOTYPE IN ELECTRON BEAMS AT DESY





CONCLUSIONS

✓The design of the detector/calorimetry inspired by the analytical energy flow

✓Iterations between the software (reconstruction algorithms) and the design provided that …

✓The simulation has to be tested; this is the next step.

The physics case of the LC is very appealing …
The CALICE calorimeter project is fascinating !

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