Highlights from the 9th Pisa Meeting on Advanced Detectors
Calorimetry Session

Riccardo Paramatti
University of Rome “La Sapienza” and INFN Rome

Detector Seminar - CERN
18/07/2003
| Sunday  
| May 25 | Monday  
| May 26 | Wednesday  
| May 28 | Thursday  
| May 29 | Friday  
| May 30 | Saturday  
| May 31 |
| --- | --- | --- | --- | --- | --- |
| **A.** | 9:00 Welcome addresses & Opening talks | **Gravitational Waves**  
**Fundamental Physics**  
convener: Gary Sanders | **Front End E Trigger**  
**DAQ Data Management**  
convener: Katsuo Tokushuku | **9:00**  
Bus departure to airports |
| **R.** | **11:00 End of session** |
| **I.** | **Cadmium**  
**conveners:** Tourin, E. Lorenz | **12:00 Bus departure Excursion** |
| **V.** | **Welcome cocktails**  
7:30 p.m.  
Welcome at Hotel Hermitage Hotel del Golfo Park Hotel Napoleone |
| **A.** | **Concert:** 9:30 p.m. |
| **L.** | **Gala dinner:** 9:00 p.m. |

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**Tracking Sessions: talk by Silvia Schuh (4th July)**
9th Pisa Meeting: calorimetry session

Jim FREEMAN (FNAL)
CMS Hadron Calorimeter Status

Fabrice HUJAUT (CPPM - IN2P3)
Performance of the ATLAS EM Calorimeter Modules

Volker KORBEL (DESY - Hamburg)
The TESLA-CALICE Tile HCAL, Concept, Status,

Satoshi MIHARA (ICEPP - University of Tokyo)
R&D Work on a Liquid-Xenon Photon Detector for...

Jose REPOUND (ANL)
A Digital Hardon Calorimeter for the Linear Collider

Ann VAN LYESEBETTEN (CEA - Saclay)
Performance of the Light Monitoring System for CM...

Sebastian WHITE (BNL)
Very Forward Calorimetry at RHIC and LHC

POSTERS

Yuriy BASHMAKOV (P.N.Lebedev Physical Institute)
Electromagnetic Calorimeter with Transversal Orientation of Scintillating Fibers

Philippe BOURGEOIS (CEA - Saclay)
Performances of the CsI(Tl) Detector Element of the GLAST CALorimeter

Cristina CARLOGANU (CNRS - LPC Clermont Ferrand)
MAPMTs and FE Electronics for the LHCb Preshower Readout

Andrea JEREZONIE (LAPP - Amecy)
The ATLAS Liquid Argon Electromagnetic Calorimeter Construction Status

Stefano LAMI (INFN - Pisa)
The CDF Calorimetry Upgrade for Run IIb

Stefano LAMI (INFN - Pisa)
The CDF MiniPlug Calorimeters

Riccardo PARAMATTI (INFN - Roma 1)
Calibration Strategy of CMS Electromagnetic Calorimeter

Giulio USAI (INFN - Pisa)
Trigger of Low pT Muons with the ATLAS Hadronic Calorimeter
Liquid-Xenon photon detector for $\mu \rightarrow e\gamma$

Physics motivations: in the Standard Model this decay is forbidden; in the SM + Neutrino Oscillation this decay is strongly suppressed; in SUSY framework the Branching Ratio could be just below the current limit by MEGA ($BR \approx 10^{-11}$). MEG sensitivity down to $10^{-14}$

- $\mu \rightarrow e\gamma$ in...
  - **SM+Neutrino Oscillation**
    * Suppressed as $\sim (m_\nu/m_\mu)^4$

- **SUSY**
  * Large top Yukawa coupling

- Continuous beam @ PSI ($10^8 \mu/s$) on a stopping target
- Positron and photon back-to-back and in time
- Photon detected by Liquid Xe Photon Detector
- Positron detected by the Solenoidal Magnetic Spectrometer with a graded magnetic field

![Diagram of muon decay into electron and gamma](image)
**Liquid-Xenon photon detector for µ-> eγ (2)**

**Signal:** a positron and a photon back-to-back with $E = 52.8 \text{ MeV}$

**Background:**
- Radiative $\mu^+$ decay (if neutrinos carry small amount of energy)
- Positron from usual decay with $E = m_\mu/2$ and photon from radiative muon decay or from annihilation in flight of positron (not in time)

**Requirements:** fast response, good energy, position and time resolution -> Liquid Xenon

**Absorption of scintillation light**

The emission reaction can't happen in the reverse way; only impurity (water, oxygen) could absorb the light.

Absorption length increased, 7cm -> >1 m by Xenon purification.
Liquid-Xenon photon detector for $\mu \rightarrow e \gamma$ (3)

Small prototype:
- 32 PMT surrounding 2.34 litres of active volume
- without purification system
- gamma-rays sources of different elements
- $\alpha$ source for PMT calibration

Energy, position and time resolution measurements in agreement with Montecarlo simulation.

Results published in 2002.
Liquid-Xenon photon detector for $\mu \rightarrow e\gamma$ (4)

Large prototype:
- 228 PMT surrounding 68.6 liters of active volume (120 liters of liquid xenon in total)
- Development and test of purification system for Xenon
- PMT long term operation at low temp.
- Gamma beam test up to 40 MeV
- 60 MeV electron beam
- Absorption length measurement
GLAST Calorimeter

- High energy gamma rays: 20 MeV - 300 GeV
- GLAST will be launched in September 2006
- The CDE have to operate in space at $\approx -10^\circ C$
- 2 of 4 long side depolished to increase the tapering

GLAST Large Area Telescope:
- 4×4 Towers (Silicon Tracker + Csl(Tl) Calorimeter)

Incoming gamma ray

Anti
Coincidence
detector

electron-positron pair

GLAST LAT Calorimeter:
- 8 hodoscopic layers of 12 CDE

CsI(Tl) detector Element:
- CsI(Tl) Crystal
- 2 glued Dual PIN photoDiodes
- VM2000 wrap (Multilayer Mylar)
- 2 Endcap (Delrin)

1536 CsI(Tl) detector Elements
GLAST Calorimeter (2)

- 14 CDE have been assembled and tested with cosmic muons
- The CsI LY decrease with temperature: test -20 °C -> 30 °C

Main CDE Performances:
- Light Yield: electrons per MeV deposit in 2cm CsI(Tl)
- Energy resolution (for 11.2MeV deposit)
- Tapering: Ratio of Left-Right crossing particles

<table>
<thead>
<tr>
<th></th>
<th>Small PIN (25mm²)</th>
<th>Large PIN (152mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Yield (e/MeV)</td>
<td>1300</td>
<td>8200</td>
</tr>
<tr>
<td>Energy Resolution (%)</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>Tapering (%)</td>
<td>75</td>
<td>74</td>
</tr>
</tbody>
</table>

Wrapping Material Comparison:
- VM2000 1.00 (CDE Baseline)
- Tyvek+Alu 0.71 (Xtal packaging)
- Milipore+Alu 0.62
- Aluminium 0.33
- Tedlar (black) 0.18 (max light lost)
ATLAS Electromagnetic Calorimeter

- Lead - liquid Argon sampling calorimeter
- Accordion geometry
- 2 half-barrels: \(|\eta| < 1.475\)
- 2 endcaps: \(1.375 < |\eta| < 3.2\)
- Outside the solenoid

The ATLAS calorimeter is built in 8 construction sites: Annecy, Saclay, CERN, Grenoble, Stockholm (barrel) and Marseille, Madrid, Novosibirsk (endcap)
Longitudinal segmentation will provide good particle ID.

- Full azimuthal coverage (accordion)
- Good rapidity coverage ($|\eta| < 3.2$)
- High granularity (almost 200 000 channels)
- Longitudinal segmentation
  - STRIPS: position measurement, $\gamma/\pi^0$ separation
  - MIDDLE: main energy deposit
  - BACK: high energy showers, had./em separation
  - For $|\eta| < 1.8$ a presampler is added to correct for energy losses before the calorimeter

Barrel: constant gap thickness (2.1 mm), uniform HV (2 kV)
End-cap: gap varying from 3.1 to 0.9 mm, HV set by steps on 9 sectors
CMS Electromagnetic Calorimeter

- Crystal calorimeter
- \( \approx 75000 \) lead tungstate PbWO\(_4\) crystals
- Magnetic field: \( B = 4 \) T
- Endcap preshower: \( 1.65 < |\eta| < 2.6 \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Barrel</th>
<th>Endcap</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta ) coverage</td>
<td>(</td>
<td>\eta</td>
</tr>
<tr>
<td>Granularity (( \Delta \eta \times \Delta \phi ))</td>
<td>( 0.0175 \times 0.0175 )</td>
<td>varies in ( \eta )</td>
</tr>
<tr>
<td>Crystal Dims. (cm(^3))</td>
<td>( 2.18 \times 2.18 \times 23 )</td>
<td>( 2.85 \times 2.85 \times 22 )</td>
</tr>
<tr>
<td>Depth in ( X_0 )</td>
<td>25.8</td>
<td>24.7 (+3( X_0 ))</td>
</tr>
<tr>
<td>No. of crystals</td>
<td>61,200</td>
<td>14,950</td>
</tr>
<tr>
<td>Crystal Volume (m(^3))</td>
<td>8.14</td>
<td>3.04</td>
</tr>
<tr>
<td>Photodetector</td>
<td>APDs</td>
<td>VPTs</td>
</tr>
<tr>
<td>Modularity</td>
<td>36 supermodules</td>
<td>4 Dees</td>
</tr>
</tbody>
</table>

Two barrel
Regional Centers: CERN (lab 27) and INFN/ENEA - Rome

Endcap construction: UK, CERN
• Fast scintillation
• Small $X_0$ and $R_m$
• Intrinsic radiation hardness
• Relatively easy to grow
• Massive production capability

• Low Light Yield
• High index of refraction
• Strong LY dependance on $T$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation length</td>
<td>cm</td>
</tr>
<tr>
<td>Moliere radius</td>
<td>cm</td>
</tr>
<tr>
<td>Hardness</td>
<td>Moh</td>
</tr>
<tr>
<td>Refractive index</td>
<td></td>
</tr>
<tr>
<td>Peak emission</td>
<td>nm</td>
</tr>
<tr>
<td>% of light in 25 ns</td>
<td></td>
</tr>
<tr>
<td>Light yield (23 cm)</td>
<td>$\gamma$/MeV</td>
</tr>
</tbody>
</table>
Module assembly
• Geometrical measurements
• Gap thickness measurements
• Electrical test during assembly
  - HV performance (2200 V)
• Module cabling
• Tests in final configuration
ATLAS: construction status (2)

Production module stacking

Completed: 10/16 modules

η = 0

η = 1.5

Completed: 32/32 modules

η = 1.4

η = 3.2

End-cap

Barrel
Production module integration

First half-barrel completed
4 dead channels (over 55,000) after test at warm of complete half-barrel

Second one under assembly

First wheel under assembly
End-cap wheel
Insertion in cryostats

- Second half-barrel inserted: 08/03
- Barrel cryostat down in the pit: 07/04
- End-cap wheels inserted: 09/03, 07/04
- End-cap cryostats down in the pit: 12/04 and 06/05
CMS: construction status

- 6000 crystal preproduction (1998-2000)
- Crystal production (2001-): 2-in-one crystal production is starting now

Further increase of the PbWO ingot diameter is foreseen: 2Endcap or 4Barrel crystals in one ingot are in test phase
CMS: construction status (2)

CERN (lab 27) and INFN/ENEA (Casaccia) Regional Centers:
- Automatic measurements of:
  crystal dimensions, transmission, light yield and uniformity
- Submodule assembly (10 crystals)
- Module assembly (40-50 submodules)
### CMS: construction status (3)

#### Modules from Rome RC

#### Supermodule assembly at CERN

#### Modules production

|   | SM 0 | SM 1 | SM 2 | SM 3 | SM 4 | SM 5 | SM 6 | SM 7 | SM 8 | SM 9 | SM 10 | SM 11 | SM 12 | SM 13 | SM 14 | SM 15 | SM 16 | SM 17 | SM 18 |
|---|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|
| M1 | CERN |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |
| M2 | Rome |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |
| M3 | Rome |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |
| M4 | CERN |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |
The discovery potential of an intermediate mass Higgs boson via the two photon decay channel depends on the energy resolution.

\[
\sigma = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c
\]

- **a**: stochastic term from Poisson-like fluctuations
  - sampling contribution
    (natural advantage of homogeneous calorimeters)
- **b**: noise term from electronic and pile-up
  - relevant at low energy
- **c**: constant term
  - dangerous limitation to high energy resolution
  - important contribution from intercalibration constants
the stochastic term

CMS

- photostatistics contribution:
  - light yield
  - light collection efficiency
  - geometrical efficiency of the photodetector
  - photocathode quantum efficiency

- electron current multiplication in APD

- lateral containment of the shower

Total stochastic term: \( a = 2.7\% \)

ATLAS

- pure sampling fluctuations
- deterioration for increasing \( \eta \):
  - increase of amount of material
  - decrease of sampling frequency

Total stochastic term: \( a \approx 10\% \)
CMS: the constant term

- leakage (front, rear, dead material)
  CMS full shower simulation < 0.2 %
- temperature stabilization < 0.1 °C
  \(\frac{dL_Y}{dT} = -2.0\%/°C\) @ 18°C; \(\frac{dM}{dT} \sim -2.3 \%/°C\)
- APD bias stabilization (±20 mV / 400 V)
  \(\frac{dM}{dV} = 3\%/V\)
- light collection uniformity (next slide)
- intercalibration by monitor and physics signals

Total constant term \(c = 0.5\%\)
CMS: the constant term (2)

- A non uniformity of the light collection in the shower max region may significantly contribute to the constant term in the energy resolution.
- Uniformity can be controlled by depolishing one lateral face with a given roughness.

Lab measurement

- $C_{\text{fnuf}} < 0.3\%$
- $\Delta (\text{LY})/\Delta X_0 = \pm 0.35\%/X_0$
ATLAS: the constant term

- Absorber and gap thickness
- Ionization signal dependence with temperature
  (argon density vs $T = -0.45 \%/{}^\circ C$
  drift velocity vs $T = -1.55 \%/{}^\circ C$)
- High Voltage stabilization
- Leakage, material in front of calorimeter

Local constant term $c = 0.5 \%$

over a small area ($\Delta \eta \times \Delta \phi = 0.2 \times 0.4 \rightarrow 128$ cells in the middle sector) with independent cell to cell electronics calibration

Global constant term $c = 0.7 \%$

in situ-calibration with $Z \rightarrow e^+ e^-$ decays to correct long-range non-uniformity
Performance: $H \rightarrow \gamma \gamma$

**ATLAS - 100 fb$^{-1}$**

$M_H = 120$ GeV

$S/\sqrt{B} \approx 6.5 \rightarrow 4.3$ with $M_H = 120 \rightarrow 150$ GeV

**CMS - 100 fb$^{-1}$**

$M_H = 130$ GeV

$S/\sqrt{B} \approx 13 \rightarrow 8$ with $M_H = 120 \rightarrow 150$ GeV
ATLAS: Test beam

For every tested point:

- 1999-2000: barrel and endcap full-size prototype
- 2001-2002: 7 (4 barrel and 3 endcap) production modules
- 2002: combined endcap run with hadronic

Barrel

Data (η=0.48)
- a = 8.95%
- c = 0.33%

End-cap

η=1.9
- Data
- MC
- a = 10.35%±0.05
- c = 0.27%±0.02

For every tested point:
- stochastic term
- a < 10 % (barrel)
- a < 12.5% (endcap)
Global non-uniformity $\approx 0.6\%$ for whole module

Global non-uniformity $\approx 0.5\%$ for whole module

Global constant term $\approx 0.7\%$ within specifications
ATLAS: Future test beam

Combined Tests in 2004:
(with whole final ATLAS set-up)

- **Barrel**: Trackers (Pixels, SCT, TRT), EM Calo., Hadronic Calo., Muons
- **End-cap**: EM, Hadronic, Forward

→ last beam test program before LHC

- Solid motivations for physics: good complement to simulation
- Tuning of ATLAS online hardware and software
- Understanding/tuning of the most advanced offline software tools (simulations, reconstruction,...)
- Test of calibration procedure
- Identification of problems and solutions before commissioning
Only few Supermodules will be calibrated at the Cern Test Beam facilities (intercalibration \(\approx 2\%\))

All crystals are intercalibrated in the lab. module assembly phase by Light Yield measurements \(\approx 4\%\)

LY meas. of reference crystals in INFN/ENEA Regional Center

(with PMT and tyvek wrapping at 18 °C)
CMS: Test Beam 2002

Principal Goals

- Validation of SM architecture and electronics chain
- System Test: noise, capsules, HV (final concept)
- Monitoring with laser (final system) and stability
- Slope S vs R: comparison of XL responses to laser and electrons under irradiation

Intercalibration: lab. measurements vs test beam

\[ \sigma = 4.7\% \]
Total dose after 10 years of running (5x10^5 pb^-1)

→ Only e.m. radiation produces a damage
→ Scintillation mechanism is not affected
→ Only crystal transparency is reduced
→ Creation of color centers
→ Damage level depends on dose rate
→ Creation and annealing of color centers at room temperature
→ Damage level reaches an equilibrium after a small administered dose
→ Partial damage recovery in few hours
→ Loss in extracted light of few % is tolerable and can be followed with a monitor system

Dose rates [Gy/h] in ECAL at luminosity L=10^{34} cm^{-2}s^{-1}
• The relation between XL response to e (S/S₀) and response to laser (R/R₀) varies in the same way during recovery and irradiation phases.

• Crystals irradiated 2-3 times produce same slope α

• Light monitoring system operational and stable
High luminosity simulation at $\eta=0$, based on data taken in test beam

- Laser OK for correction of electron response
- 2003 test beam with other modules (different pseudorapidity) and more statistics

Time scale for absolute calibration with Z events
**In-situ calibration with physics events**: this is the main tool to reduce the constant term to the design goal of 0.5%.

- At the beginning of detector operation -> fast intercalibration method based on the $\phi$ symmetry in minimum bias events.
- Energetic electrons from $Z \rightarrow e^+ e^-$ decay -> intercalibration of different regions and absolute energy scale setting.
- Once the Tracker fully functional -> intercalibration of individual crystals with $E/p$ measurement ($W \rightarrow ev$ events).

**TRACKER MATERIAL**: the amount of material (~ 1 $X_0$) between interaction point and ECAL is the main difficulty in performing calibration.
CMS: In situ calibration (2)

φ symmetry

Assumption: the total transverse energy deposited from a large number of events should be the same for all crystals at fixed $\eta$.

Aim: reduce the number of intercalibration constants at the startup: from 61200 (crystals) to 170 (rings) in the barrel.

Studies with fully simulated Montecarlo give a precision of 1.3% - 3.5%, in case of limited knowledge of $\phi$ inhomogeneity.
CMS: In situ calibration (3)

\[ Z \rightarrow e^+ e^- \]

- The rings can rapidly be intercalibrated using \( Z \rightarrow e^+ e^- \) without tracker momentum measurements, using reconstruction of the invariant mass
- A large fraction of events allows to intercalibrate the endcaps with respect to the barrel
- The \( Z \rightarrow e^+ e^- \) rate is \( \sim 1 \text{ Hz} \) (almost flat in \( \eta \))

\[ W \rightarrow e^+ \nu \]

- The electron shower involves many crystals \( \rightarrow \) algorithm to unscramble individually the calibration constants.
- The \( W \rightarrow e^- \nu \) rate is \( \sim 10 \text{ Hz} \).

In few weeks at \( 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \), exploiting the full tracker information, this high statistics channel will allow to reach 0.5% resolution
ATLAS: In-situ calibration

Calibration with $Z \to e^+e^-$ decays

- Expected event rate: 1 Hz at low luminosity
- 0.3 % accuracy possible over the 400 $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$ regions within a few days
- By convoluting this result with a local constant term of 0.5%, we achieve a global constant term of 0.6%
(not only) Tracker Material

• Complex tracking system + frames + cooling + cables and services
• Some radiation lengths between the interaction point and the electromagnetic calorimeter
• Bremsstrahlung and photon conversion (big non-gaussian tails in physical distributions)
Bremsstrahlung

The electron cluster is spread by Bremsstrahlung (mainly in $\phi$)

- Too little reconstructed cluster: not full containment of brem. photons
- Too big reconstructed cluster: noise, pile-up

ATLAS Energy recovery: cluster with fixed and optimized dimension.

CMS Energy recovery: SuperCluster = clustering with dynamic algos.
✓ Measure in a cluster of cells (shower not contained in one read-out cell)

✓ Compensate for energy losses before and leakage beyond the calorimeter

✓ Correct for finite cluster size along $\eta$

✓ Correct for $\phi$ modulation (accordion geometry)

✓ Correct for L1/clock phase (specific to testbeam data)

✓ Correct for discrete HV setting in the end-cap sectors (gap is varying continuously)
SUPERCLUSTERs

- Hybrid Algorithm: Used in the barrel
- Island Algorithm: Used in the endcaps

To be compared with intrinsic calorimeter resolution < 0.9%
Resolution at 245 GeV (in $\eta$ units x 1000):

Front (S1): $\sim 0.15$ ($\sim 0.25$ mm at $\eta=0$)

Middle (S2): $\sim 0.35$ ($\sim 0.55$ mm at $\eta=0$)
### A brief ECAL comparison

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
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<tbody>
<tr>
<td>Barrel construction status</td>
<td>☺</td>
<td>☹</td>
</tr>
<tr>
<td>Endcaps construction status</td>
<td>☺</td>
<td>☹</td>
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<tr>
<td>Energy resolution: stocastic term</td>
<td>☹</td>
<td>☺</td>
</tr>
<tr>
<td>Energy resolution: constant term</td>
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<td></td>
<td>ATLAS</td>
<td>CMS</td>
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<tr>
<td>Intercalibration in situ with physics events</td>
<td>😞</td>
<td>😊</td>
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<tr>
<td>Electron reconstruction</td>
<td>😞</td>
<td>😊</td>
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<tr>
<td>$\gamma/\pi^0$ separation</td>
<td>😊</td>
<td>😞</td>
</tr>
<tr>
<td>Tracker material, (bremsstrahlung and photon conv.)</td>
<td>😞  😞</td>
<td>😞  😞</td>
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