Status of the LHCf experimental apparatus at LHC

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LHCf: main Physics Topics

- **Experimental measurement:**
  - Precise measurement of $\gamma$ and $\pi^0$ spectra in the very forward region at LHC

- **$7\mathrm{TeV} + 7\mathrm{TeV}$ in the c.m. frame $\rightarrow 10^{17}\ \text{eV}$ in the laboratory frame:**
  - We can better simulate in the biggest’s world laboratory what happens in nature when a Very High Energy Cosmic Ray interacts in the atmosphere

- **Why in the very forward region?**
  - Because the dominant contribution to the energy flux in the atmospheric shower development is carried on by the very forward produced particles
A ‘practical’ approach

LHCf’s measurements will be used to calibrate the Monte Carlo codes heavily used in the Cosmic Ray analysis to study the atmospheric shower development

- VHECR energy spectra
- HECR Composition

AGASA $\times 0.9$
HiRes $\times 1.2$
Yakutsk $\times 0.75$
Auger $\times 1.2$ (not enough)
LHCf: location and detector layout

**Detector I**
- Tungsten
- Scintillator
- Scintillating fibers

**Detector II**
- Tungsten
- Scintillator
- Silicon μ strips

**INTERACTION POINT**
- IP1 (ATLAS)

**Beam line**
- 140 m

**Detectors should measure energy and impact point of γ from π⁰ decays**
- e.m. calorimeters with position sensitive layers

**Two independent detectors on both side of IP1**
- ✔ Redundancy
- ✔ Background rejection (especially beam-gas)
LHCf location

Detectors installed in the TAN region, 140 m away from the Interaction Point, in front of luminosity monitors.

- Here the beam pipe splits in 2 separate tubes.
- Charged particle are swept away by magnets!!!
- We will cover the rapidity range from $y = 8.5$ up to $y \rightarrow \infty$. 
Detector #1

2 towers 24 cm long stacked vertically with 5 mm gap
Lower: 2 cm x 2 cm area
Upper: 4 cm x 4 cm area

Absorber
22 tungsten layers
7mm - 14 mm thick
(W: X_0 = 3.5mm, R_M = 9mm)

Energy

4 pairs of scintillating fiber layers for tracking purpose
(6, 10, 30, 42 r.l.)

Impact point

16 scintillator layers
(3 mm thick)

Trigger and energy profile measurements
Detector # 2

We used LHC style electronics and readout

4 pairs of silicon microstrip layers (6, 12, 30, 42 r.l.) for tracking purpose (X and Y directions)

16 scintillator layers (3 mm thick)

Absorber
22 tungsten layers
7mm - 14 mm thick (2-4 r.l.)
(W : X₀ = 3.5mm, Rₚ = 9mm)

Trigger and energy profile measurements

Impact point

2 towers 24 cm long stacked on their edges and offset from one another

Lower: 2.5 cm x 2.5 cm
Upper: 3.2 cm x 3.2 cm

Energy
Double ARM Detectors

Arm# 1 Detector
Arm# 2 Detector

290mm
90mm
Detectors in place

Installation performed in two phases:

2. Pre-Installation (2007)
   Baking out of the beam pipe (200 °C)
4. Final Installation (Jan 2008)
An Update on the 2007 SPS Beam Test

- CERN : SPS T2 H4
- August/September 2007
- Incident Particles
  - Proton 150, 350 GeV/c
  - Electron 50, 100, 150, 200 GeV/c
  - Muon 150 GeV/c

Test was very successful!!!!
- Energy calibration of the calorimeters
- Spatial resolution of the tracking systems

Results were partially published on JINST: 2008 JINST 3 S08006
Energy Resolution - Leakage

Monte Carlo

Energy distribution is corrected for leakage!

MC predicts that the leakage is energy independent!
Energy resolution < 3% even for the smallest tower!
Simulation vs Data

Energy released in the 4° scintillation layer

Simulation is very well understood!

100 GeV e⁻

150 GeV µ
\[ \pi^0 \text{ reconstruction} \]

350 GeV Proton beam → Carbon target (3 cm) in the slot used for beam monitor → 9.15 m

\( \gamma \) (not in scale!)

Arm1

> \(10^7\) proton on target (special setting from the SPS people)

\(\checkmark\) Dedicated trigger on both towers of the calorimeter has been used

Calorimeters

\( E_{\gamma} = 18\text{GeV} \)

\( E_{\gamma} = 46\text{GeV} \)

Shower Profile @ First SciFi Layer

40 mm Calorimeter

20 mm Calorimeter

40 m m

20 m m

X

Y

X

Y
\( \pi^0 \) mass reconstruction

\( \approx 250 \pi^0 \) events triggered (in a quite big background) and on disk

- Low photon energy (\( \geq 20 \text{ GeV} \))
- Direct protons in the towers
- Multi hits in the same tower

\[ \Delta m \sim 8 \text{ MeV} \]
\[ \Delta m/m \sim 6\% \]
200 GeV electrons

\[ \sigma_x = 172 \ \mu m \]

\[ \sigma_y = 159 \ \mu m \]
ARM 2 Position Resolution
200 GeV electrons

\[ \sigma_x = 40 \mu m \]

\[ \sigma_y = 64 \mu m \]

Alignment has been taken into account
By looking only at the silicon energy measured, we have an energy resolution $\sim 12\%$ !!!!!

We can use it as a check for the radiation damage of the scintillators.
At least in the 50-200 GeV energy range the silicon energy measurement is linear.
Conclusions

- LHCf is an LHC experiment which is a strong link between the accelerator physics and the Cosmic-Ray physics.

- Detectors have been integrated in 2007 and installed at LHC during the first half of 2008.

- Detectors were tested at SPS before installation (Oct. 2007) and results are well in agreement with the simulations:
  - Energy resolution / calibration
  - Spatial resolution of scintillating fibers and silicon detectors

- LHCf is ready for data taking at the beginning of the LHC very-low-luminosity run (<10^{30} \text{ cm}^{-2} \text{ s}^{-1})

THANK YOU!
Spare slides
Front Counter

- 2 fixed Front Counters were installed in front of Arm1 and Arm2
- They will not move with Arm1 and Arm2
- They are segmented in 2 x and 2 y slices
- Very useful to check the beam quality and hence decide to move Arm1 and Arm2 in the operating position from the ‘garage’ position
Construction of silicon modules

- Al frame
- Scintillator
- W (absorber)
- Delrin frame
- Silicon
- Al layer 0.5 mm
- Kapton fanout
- Fiberglass fanout
- PACE3 chip
- Front-end PCBs
- \( \mu \)-bondings
- Samtec mini coaxial cable (to read-out PCB)
Y-side silicon layer with front-end

Dow Corning RTV 340 heat sink compound
Developed for the CMS ECAL silicon preshower

- 32 analog-in channels
- high dynamic range
- 25 ns peaking time
- CMOS sub-micron
- 600 mW consumption

DELTA chip: preamp. stage, shaping, and internal calib. sys

PACE-AM chip: analog pipeline (matrix 192x32 capacitors), control logic and output lines
Preparation for data taking

✓ A ‘control room’ ... has been prepared since there was no space for us in the Atlas buildings ... .
Communications with LHC

- Experimental status (On/Off, Gain, etc.)
- Detector position (Garage/Operating, position in mm, etc.)
- Luminosity rate (Single and Double Arm)
  - Front Counter rate (single Arm, double Arm coincidence)
  - Small tower rate (single Arm)
  - Big tower rate (single Arm)
  - Double Arm coincidence rate (FC.AND.Towers in opposite sides)
- Horizontal and Vertical position of the Beam (every 10000 events or in the whole RUN)
- Injection Inhibit
- Handshaking signals (Injection, Adjust, Beam Dump)

Link: Important for machine tuning!
We are in strict contact with them.

LHCf sends signals to LHC through the DIP system.

Link have been tested and it works fine!

Important for machine tuning!
We are in strict contact with them.
We are ready for data taking

- On September 10 we observed some signals on Front Counters, with Arm1 and Arm2 in garage position for safety reasons
  - That day the Atlas BPTX signal was still not available (no info on the real bunches in the Atlas zone)
- On September 11 Atlas gave us the synchronized BPTX signals, and we could take Front Counter data by using this signal (still in garage position)
- We are measuring Beam-Gas from the Beam2 on Arm1 side
While waiting for collisions…

A short comment on new models:
PICCO, EPOS

Very big interest in LHCf data and in this physics field

LHCf : Monte Carlo discrimination

Gamma Energy Spectrum of 20mm square at Beam Center

$10^6$ generated LHC interactions $\rightarrow$ 1 M inute exposure @ $10^{29}$ cm$^{-2}$s$^{-1}$ luminosity

Discrimination between various models is feasible in a very short time

Quantitative discrimination with the help of a properly defined $\chi^2$ discriminating variable based on the spectrum shape (see TDR for details)

5% Energy resolution

DPMJET3
QGSJET
QGSJETII
SIBYLL

Gamma Energy [GeV]
Radiation Damage Studies

Scintillating fibers and scintillators

- Expected dose: 100 Gy/day at $10^{30}$ cm$^{-2}$s$^{-1}$
- Few months @ $10^{30}$ cm$^{-2}$s$^{-1}$: 10 kGy
- 50% light output
- Continuous monitor and calibration with Laser system!!!
Estimate of the background

✓ beam-beam pipe
  ➔ E_\gamma (signal) > 200 GeV, OK
  background < 1%

✓ beam-gas
  ➔ It depends on the beam condition
  background < 1% (under 10^{-10} Torr)

✓ beam halo-beam pipe
  ➔ It has been newly estimated from the beam loss rate
  Background < 10% (conservative value)
Effect of LHCf on BRAN measurement

LUMI monitor (BRAN) inside TAN is beyond LHCf (replacing 4th copper bar)

The effect of LHCf on BRAN measurements has been studied by simulation:

- Reduction of shower particles at BRAN
- Position dependence on beam displacement

(question from machine peoples: if we shift by 1 mm the real beam, does the center of the measured neutral energy shifts by 1 mm?)
LHCf: model dependence of neutron energy distribution

Original n energy

Neutron Energy Distributions

Counts \([100\text{GeV}/\text{10}^7\text{inel}]\)

QGSJET
QGSJET II
DPMJET3
SIBYLL

30% energy resolution

Neutron Energy Spectrum of 20mm Calorimeter at beam center

particle/bin

0.0015
0.0010
0.0005
0.0000

0 5000 10000
Neutron Energy [GeV]
LHCf performances: energy spectrum of $\pi^0$

Typical energy resolution of $g$ is 3% at 1 TeV
Transverse projection in TAN slot

**ARM1:** Maximization of the acceptance for vertical beam displacement (crossing angle > 0)

**ARM2:** Maximization of the acceptance in R (distance from beam center)
\( \pi^0 \) geometrical acceptance

**Arm #1**

**Pi0 Energy**
- 1.0 TeV
- 2.0 TeV
- 5.0 TeV

**Arm #2**

**Pi0 Energy**
- 1.0 TeV
- 2.0 TeV
- 5.0 TeV