Measurement of Photons and Neutral Pions in the Very Forward Region of LHC


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1. Review of experimental purpose
2. The results of the test experiment
3. Trigger, Beam condition, Schedule, Concluding remarks
1. Scientific purpose

The main purpose is to establish proton-proton interactions at the highest energy region with use of the highest energy accelerator in the world. It has been a long dream for cosmic ray physicists.

2. Experimental proposal

The proposal describes that a small calorimeter will be installed in front of the collision point at 140m away. It would be the smallest experiment using the largest accelerator in the world.

3. The beam condition

We require rather low luminosity operation, say 10 bunches(43) in the ring with $1 \times 10^{10}$ protons in a bunch. The machine people will enjoy a very special run of the accelerator for only a few hours.

4. Summary

We will be able to establish very important data point by this experiment, which will be very useful for not only cosmic ray people but also the GEANT 4 people.
Cosmic Ray Flux

Fluxes of Cosmic Rays

(1 particle per m²-second)

Knee
(1 particle per m²-year)

Ankle
(1 particle per km²-year)

$10^9$ eV  to  $10^{20}$ eV
New AUGER and Stereo Hi Res data (preliminary)
5x10^{19} eV proton initiated showers

Zenith angle 60 deg.

- $\gamma : x < 0.05$
- $\pi, K : x < 0.1$
- $x_F < 0.05$
- $x_F < 0.1$
The position of shower maximum
Knapp et al, Astroparticle Physics, 19(2003) 77
Additional statement on the L.O.I.

Within a year (2004-2005), two new data have been presented in the 29th ICRC by the AUGER and Hi-Res groups, but the riddle on the highest energy cosmic rays has been left. It has been cleared that the forthcoming results by the LHCf experiment will become more and more important.
Y Chamber

THE VACUUM TUBE CONTAINS TWO COUNTER-ROTATING BEAMS. THE BEAMS TRANSITION FROM ONE BEAM IN EACH TUBE TO TWO BEAM IN THE SAME TUBE.

Detector location

THE TWO COUNTER-ROTATING BEAMS INTERSECT 140 METERS

I. P (140 m away)

Beam pipe

Detector

projected Co thickness ~ 1 rJ

94 mm
TAN Nomenclature

Copper bars

Upper shielding

Junction box

Absorber box

Through bolt

Lower base plate

Upper base plate

Beam tube/ vacuum chamber

Marble

Beam tube support bracket

Side shielding
The TAN for the luminosity monitor

Photos taken
On April 25\textsuperscript{th}, 2005
At CERN
Detector #1: transverse projection

- **Scintillating fibers**
- **WLS fibers to readout plastic scintillators**
- **Hamamatsu MA-PMT for scintillating fibers**
- **PMTs for WLS fibers**

- BEAM AXIS
- 130 mm
- 90 mm

Rapidity range:

- $y \approx 7.8$
- $y \approx 8.5$
- $y \approx 9.9$
- $y \approx \infty$
Energy resolution

$< \Sigma_e(> 6) >$ (ptcl's)

- No scifi saturation and fit to it
- With scifi saturation at 1000 ptcs

$4.2 \times 10^3 \frac{E_{\gamma}}{100}$

Root mean square energy resolution (%)

- No scifi saturation and fit to it
- With scifi saturation at 1000 ptcs

$\frac{5}{\sqrt{E_{\gamma}}} + 1.2$

100 GeV

1 TeV

6 %

2 %
Cross-section derivation

By standard config. we need another config.

With two config., we can reconstruct cross-section of standard model (lines: dpmjet3) by observing $10^6$ events (dots)

Acceptance corrected
What we have done in a year

1. Monte Carlo calculations using DPMJET3, QGSJET and SYBILL models (popular in cosmic rays).

2. We have made the same detector that we have proposed and made an exposure at the CERN NA H4 beam line.
→ e, μ, p to measure ΔE/E and edge effect

3. We have investigated the calibration of the absolute value of shower particles in a range from 1000 – 100,000 by using a nitrogen laser system.

We would like to report mainly those results today.
Monte Carlo $\gamma$ ray energy spectrum

$10^6$ generated LHC interactions $\rightarrow$ 1 minute exposure
γ ray energy spectrum for different positions

Gamma Energy Spectrum of 20mm calorimeter at Center

Gamma Energy Spectrum of 20mm calorimeter at 30mm shift
Examples of simulated events for $\gamma$ and $n$
Additional statement on the L.O.I.

Within a year, two new data have been presented at the 29th ICRC by the AUGER and Hi-Res groups, but still the riddle on the highest energy cosmic rays has been left and furthermore the forthcoming results from the LHCf experiment has been important.

Summary 1 (on physics)

The particle production cross-section in the very forward region that will be obtained by the LHCf experiment will be very useful for various Monte Carlo generators.
The calorimeter in the test experiment

Size: 9.6 cm x 29 cm x 55 cm
The CERN test experiment on August 2004 (H4 Beam Line)

Detector Setup
LHCf CERN 2004
(side view)

1 cm x 1 cm
2 cm x 2 cm
trigger scintl

Silicon Calorimeter

Before correction

After correction

2 mm

200 GeV/c electron, 2 cm

Number of particles vs. Distance from edge (cm)
Energy resolution

- **Resolution**

  - **Energy Resolution (%)**
  - **Electron Energy (GeV/c)**

  - **Solid Line:** Monte Carlo (2cm)
  - **Dashed Line:** Monte Carlo (4cm)

- **Experiment (2cm)**
- **Experiment (4cm)**
We successfully developed high dynamic range photomultiplier system (R7400U modified).

Before Modification
GAIN: 5000 HV: -400 V

After Modification
GAIN: 260 HV: -450 V
HV – GAIN at R7400U Modified

Gain

2.3\times10^5 [-1500V]
Detector Calibration by Muon

0.9\times10^3

2.5\times10^2 [-450V]
LHC Experiment

300

1000

450 V

HV [V]
Multiple events/energy contamination

![Graph showing energy contamination of 19.3% for a 2cm x 2cm tower at beam center.](image)
Tower 3 x3 + 2x2 + 4x4

$\pi^0$ Invariant mass distribution

$\Delta m/m \sim 4\%$

$10^6$ LHC interactions
$\sim 1$ minute exposure
Summary 2

By the actual experiments, we have demonstrated that the experiment proposed in the L.O.I. and Technical Report of the LHCf experiment CAN measure the production cross-section of photons with $X_F \geq 0.1$ with an accuracy of $\Delta E/E \sim 4\%$. The mass of neutral pions will be obtained with an accuracy about $\Delta m/m \sim 4\%$.

Hopefully we will be able to get the absolute value of the mass of neutral pions without any systematic adjustment of the energy scale of shower particles.
Geometrical acceptance

The axis of the beam pipe

2 $\gamma$ from $\pi^0$: 1%
2 independent detectors on both sides of IPX

Detector I
- Tungsten
- Scintillator
  - Scintillating fibers

INTERACTION POINT

Detector II
- Tungsten
- Scintillator
  - Silicon μstrips

1. Redundancy
2. Background rejection (especially beam-gas)
3. Physics single diffractive/double diffractive
Detector #2

SciFi are replaced by silicon μstrips
70x70 mm²
Pitch 80 μm
3 double layers (x-y)
1 double layer in front of the calorimeter
RESIDUAL GAS DENSITY ESTIMATIONS
IN THE LHC EXPERIMENTAL INTERACTION REGIONS

A. Rossi and N. Hilleret

Abstract
The residual gas density for proton-proton runs in the LHC interaction regions IR1, IR2, IR5 and IR8 has been estimated using the VACuum Stability CODE (VASCO) [1] for the two scenarios of machine start-up and after electron scrubbing [2]. The results can be used for estimation of background noise to the LHC experiments for those operation phases.

Accelerator Technology Division

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Geneva, 18 September 2003
Figure 3: Residual gas density (molecules/m³) profile in the interaction region IR1, for the “machine start-up” period, at 1/3 of nominal beam current and top energy. The sections of the beam pipe at CT are underlined with a light blue marker. The interaction point is indicated with a star. The arrows represent the bumped pumps. The data are presented for one side of the experimental region, since the geometry is symmetrical with respect to the interaction point.

Figure 4: Residual gas density (molecules/m³) profile in the interaction region IR1, for the “after machine conditioning” period, at nominal beam current and top energy.
Summary 3 (on trigger)

The trigger pulse will be made by

1) arm #1 * arm#2 * machine signal

2) (arm#1 * machine signal) OR (arm#2 * machine signal)

3) arm#1* machine signal * ATLAS trigger signal
   (to be discussed with the ATLAS people)
The beam gas contamination

We estimate beam-beam: beam-gas = 2 : 1 @ L= $10^{29}$ and early stage
but at the later stage = 1: 0.01 @ L= $10^{29}$ and later stage

At the beginning, taking account of the acceptance for the beam-gas event by the M.C. calculation, we found that the ratio between beam-beam : beam-gas = 10 : 1 (contamination is ~10%)

However if we will take arm#1*arm#2 trigger, it will be reduced to 1000:1.

Unfortunately a that time we may loose pure single diffractive event.

Therefore we must repeat the data-taking after machine conditioning.

However the above value is estimated for the high luminosity case and in fact in the early low luminosity case, the gas in the beam pipe would be not so much. We must ask a calculation to the CERN vacuum group.
Concluding Remarks

★ A very important data will be obtained without change of present LHC projects.
★ The data will become extremely useful not only for cosmic ray physics, but also for high energy physics.
★ The data will be used for a long time.

• Other remarks
  ✤ We also want to measure N-N or p-N or or N-Fe collisions. (N= N₂ and O₂)
  ✤ We also get another important data on neutrons and K⁰s and the inelasticity.
Schedule

• We will write the Technical Design Report as soon as possible and come to present it in the early 2006.
• We will start the construction of the detector to make the beam test in the summer of 2006.
• During that time, we will discuss with the vacuum group of the LHC and the operation group of the LHC.
• Our detector will be also useful to know the collision rate between the beam-beam and beam-gas collisions at the beginning.
Coverage of $P_{T\gamma}$ and $E_\gamma$ range

Accessible region

Photons in the $P_{T\gamma}$-$E_\gamma$ plot
Red line corresponds to the beam pipe

The number of $\gamma$ detected depends on the geometrical acceptance
How to calibrate the absolute number of particles like $10^5$

1) The maximum current 100pC is determined from the ADC. The maximum countable value of the ADC is 100pC.

2) For the shower particles $10^5$, 25 photo-electrons x $10^5$ particles x 1.6 x $10^{-19}$ Coulomb x 250 (gain) = 100 pC. So the gain of the photomultipliers must be set at 250. We searched corresponding voltage to the gain 250 from the catalogue and found that it should be around 450V.

3) Then we have searched the Minimum Ionizing Particle (MIP) peak by using $\beta$-rays. For the HV -1500 Volts, we have seen the peak. At that voltage, the gain of the photomultiplier is $2.3\times10^5$. The peak of the 1 MIP corresponds to 25 photo-electrons and 0.9 pc.

4) So in actual experiment, we expose our calorimeter at the muon beam at first, under HV=-1500V. Then reduce it to -450V. Then the muon single peak corresponds to 900 particles @-450V.

5) The minimum resolution of the number of particles is estimated as to be 25 particles. But this value depends on the electric noise and pedestal. Thus we can say by using the modified photomultiplier, the number of particles in a range of $\sim100 - 100,000$ MIPs can be measured, using almost linear range of the gain of the photomultiplier.
Peak of Beta Ray @ -1500V

pedestal peak of beta ray = 3.7 ADC counts

MC simulation

dE peak of beta = 0.52 ~ 0.57 MeV
dE peak of 150GeV/c Muon = 0.45 MeV

Beta Ray Source

90Y :: Emax = 2.282 MeV
Neutron energy resolution

Neutron spectrum by different model
Beam pipe effect

+ particles from the collision point
■ particles from the beam pipe

3000 interactions: all particles

**Photons**

**Neutrons**