LHCf Status

Letter of Intent for p/Pb run

Oscar Adriani
University of Florence & INFN Firenze
On behalf of the LHCf Collaboration

December 7th, 2011
Introduction and Contents

- LHCf expression of interest for proton/Lead 2012 run
  - Presentation at the LPCC meeting on October 17th, 2011
  - Contact with Atlas management

- Letter of Intent submitted to LHCC on December 4th, 2011

In this presentation:
- Expected performances and physics results
- Short summary on the status of the LHCf upgrade
Few details about the LHCf Arm2 detector

**Sampling and imaging**

**E.M. calorimeter**

- Absorber: W (44 r.l, 1.55λ)
- Energy measurement: plastic scintillator tiles
- 4 tracking layers for imaging:
  - XY-Silicon strip (Arm#2)
- Each detector has two calorimeter towers, which allow to reconstruct π⁰

**Performances**

- Energy resolution (> 100 GeV):
  - < 3% for 1 TeV photons and ~30% for neutrons
- Position resolution for photons:
  - ~40μm (Arm#2)

**Front Counters**

- Thin scintillators 80x80 mm²
- Monitoring of beam condition
- Van der Meer scan

---

Arm2

Oscar Adriani

LHCf LOI for p/Pb run

December 7th, 2011
LHCf physics program for p-Pb run

Important information for the study of the interaction of UHECR in the Earth atmosphere

- Comparison with hadronic interaction models
- Study of the Nuclear Modification Factor
- Inelasticity

Precise measurement of $E$, $\eta$ and $p_T$ distributions for pseudo-rapidity $\eta > 8.4$ both for $p$ and Pb remnant

- Single $\gamma$
- Neutral pions
- Neutrons
Global LHCf physics program

LHCf measurement for p-Pb interactions at 3.5 TeV proton energy could be easily and finely integrated in the LHCf global campaign.

<table>
<thead>
<tr>
<th>Period</th>
<th>Type</th>
<th>Beam energy</th>
<th>LAB proton Energy (eV)</th>
<th>Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>p - p</td>
<td>450+450 GeV</td>
<td>4.3 \times 10^{14}</td>
<td>Arm1+Arm2</td>
</tr>
<tr>
<td>2009/2010</td>
<td>p - p</td>
<td>3.5+3.5 TeV</td>
<td>2.6 \times 10^{16}</td>
<td>Arm1+Arm2</td>
</tr>
<tr>
<td>2012</td>
<td>p – Pb</td>
<td>3.5 TeV</td>
<td>\text{proton E}</td>
<td>Arm2</td>
</tr>
<tr>
<td>2014</td>
<td>p - p</td>
<td>7+7 TeV</td>
<td>10^{17}</td>
<td>Arm1+Arm2 upgraded</td>
</tr>
</tbody>
</table>
What LHCf can measure in the p+Pb run (1)

E, p_T, η spectra of neutral particles

- We are simulating protons with energy \( E_p = 3.5 \text{ TeV} \)
  - Energy per nucleon for ion is \( E_N = \frac{Z}{A} E_p = 1.38 \text{ TeV/nucleon} \)
  - \( \sqrt{s_{NN}} = 4.4 \text{ TeV} \)

- “Arm2” geometry considered on both sides of IP1 to study both p-remnant side and Pb-remnant side

- No detector response introduced yet (only geometrical considerations and energy smearing)

- \( \sigma_{\text{ine}} = 2 \text{ barn}, \) following Michelangelo suggestion

"Pb-remnant side"  "p-remnant side"
Models used in the p/Pb simulations

- Results are shown for **DPMJET 3.0-5** and **EPOS 1.99**
  - 10⁷ events each
- **EPOS 1.99** does not consider Fermi motion and Nuclear Fragmentation
  - Some caveat for the Pb remnant side results.....
- **QGSJET2** can be used for p/Pb collisions
  - Work in progress, coming soon....
- Public version of other models (Sybill, HIJING, Pythia etc.) can not be used for p/Pb collisions at TeV scale!
Proton-remnant side - multiplicity

Small tower

- $\gamma$-rays, small tower
- Neutrons, small tower

Big tower

- $\gamma$-rays, big tower
- Neutrons, big tower
Proton-remnant side – photon spectrum

Small tower

Big tower

$\gamma$-rays, small tower

$\gamma$-rays, big tower

$\left(\frac{1}{N_{\text{ine}}} \frac{dN}{dE}\right)$ (GeV$^{-1}$)

$p$-remnant side

$p$-remnant side

$\left(\frac{\text{DPMJET-III}}{\text{EPOS}}\right)$ ratio

$\left(\frac{\text{DPMJET-III}}{\text{EPOS}}\right)$ ratio

Oscar Adriani

LHCf LOI for p/Pb run

December 7th, 2011
Proton-remnant side – neutron spectrum

Small tower

Big tower

35% ENERGY RESOLUTION IS CONSIDERED IN THESE PLOTS
Proton remnant side –
Invariant cross section for isolated $\gamma$-rays

---

**Diagram Description:**

- **DPMJET III**
  - Single $\gamma$
  - Legend:
    - $10.06 < Y < 11.80$
    - $9.45 < Y < 10.06$
    - $9.08 < Y < 9.45$
    - $8.81 < Y < 9.08$
    - $8.60 < Y < 8.81$
    - $8.42 < Y < 8.60$

- **EPOS**
  - Single $\gamma$
  - Legend:
    - $10.06 < Y < 11.80$
    - $9.45 < Y < 10.06$
    - $9.08 < Y < 9.45$
    - $8.81 < Y < 9.08$
    - $8.60 < Y < 8.81$
    - $8.42 < Y < 8.60$

---

**Axes:**

- $p_t$ (GeV/c)
- $E \, d^3\sigma/dp^3$ (b c$^3$/GeV$^2$)

---

Oscar Adriani
LHCf LOI for p/Pb run
December 7th, 2011
What LHCf can measure in the p+Pb run (2)
Study of the Nuclear Modification Factor

Nuclear Modification Factor measured at RHIC (production of \(\pi^0\)): strong suppression for small \(p_t\) at \(<\eta>=4\).

\[ R_{dAu}^Y = \frac{\sigma_{\text{inel}}^{pp}}{\langle N_{\text{bin}} \rangle \sigma_{\text{hadr}}^{dAu}} \frac{E d^3\sigma/dp^3(d + Au \rightarrow Y + X)}{E d^3\sigma/dp^3(p + p \rightarrow Y + X)} \]

LHCf can extend the measurement at higher energy and for \(\eta>8.4\)

Very important for CR Physics


Oscar Adriani

LHCf LOI for p/Pb run

December 7th, 2011
We can detect $\pi^0$!
Important tool for energy scale
And also for models check.....
Lead-remnant side – multiplicity

Please remind that EPOS does not consider Fermi motion and Nuclear Fragmentation
Lead-remnant side – photon spectrum

Small tower

Big tower

\[ \frac{1}{N_{\text{rem}}} \frac{dN}{dE} \text{ (GeV}^{-1}) \]

\[ \gamma\text{-rays, small tower} \]

\[ \gamma\text{-rays, big tower} \]

\[ \frac{(\text{DPMJET-III})}{(\text{EPOS})} \text{ ratio} \]
LHCf plans for the p/Pb run

- We require to run with **only one detector**
  - **Arm2** (W/scint. e.m. calorimeter + µ-strip silicon)
  - **Only on one side of IP1** (on IP2 side, compatible with the preferred machine setup: Beam1=p, Beam2=Pb)

- Minimal interference with Atlas
- Installation during the technical shutdown at the end of the p/p 2012 run
- Technical details to be agreed with Atlas, LHC, Radio-protection etc.
Some estimations based on reasonable machine parameters....

- Considering machine/physics parameters:
  - Number of bunches, \( n = 590 \) (150 ns spacing)
  - Luminosity up to \( 10^{28} \text{ cm}^{-2} \text{s}^{-1} \)
  - Interaction cross section 2 barn

- PILE-UP effect
  - Around \( 3 \times 10^{-3} \) interactions per bunch crossing
  - 1% probability for one interaction in 500 ns (typical time for the development of signals from LHCf scintillators after 200 m cables from TAN to USA15)
  - Some not interacting bunches required for beam-gas subtraction

- Beam gas first estimation indicate no problem
  - Beam Gas/Beam Beam = 3.10^{-4}
... and required statistics to complete the p/Pb physics run

+ Minimum required number of collision: $N_{\text{coll}} = 10^8$
  (factor 10 more statistics wrt shown plots)
  + Integrated luminosity $L^\text{int} = 50 \, \mu b^{-1}$
  + $2 \times 10^6$ single photons expected on p-remnant side
  + 35000 $\pi^0$ expected on same side

+ Assuming a pessimistic scenario with luminosity $L = 10^{26} \, \text{cm}^{-2}\text{s}^{-1}$:
  + Minimum running time for physics $t = 140 \, \text{h} (6 \, \text{days})$
Status of the LHCf upgrade
LHCf Upgrade for the 14 TeV p-p run

- Calorimeter radiation hardening by replacing plastic scintillator with GSO
  - Scintillator plates
    - 3 mm → 1mm thick scintillators
    - Acrylic → quartz light guides
      → construction and light yield uniformity test carried out in Japan
  - SciFi
    - 1 mm square fibers → 1 mm GSO square bars
    - No clad-core structure (GSO bar)
      → Attenuation and cross talk test carried out
    - Acrylic light guide fiber → quartz light guide fibers
      → Construction and light yield test carried out

- Fast install and uninstall of the detectors from TAN region under study

- Upgrade of the silicon positioning measurement system
  - Rearranging Silicon layers for independent precise energy measurement
  - Increase the dynamic range to reduce saturation effects
Radiation hardness of GSO

- No decrease up to 1 MGy
- +20% increase over 1 kGy ($\tau=4.2$ h recovery)
- 2 kGy is expected for 350nb$^{-1}$ @ 14TeV pp

**Figure 9.** Irradiated sample

**Figure 10.** Not irradiated ref. sample

**Figure 7.** Variation of intensity of the Xe lamp and the GSO-R response to Xe’s UV.

**Relative Light Yield**

Dose rate=2 kGy/hour

($\approx10^{3}$ cm$^{-2}$s$^{-1}$)

Irradiated sample

Not irradiated ref. sample

$\tau\approx4.2$ h recovery
Fast install/uninstall

- Silicon strip FE electronics
- LHCf main detector
- Calorimeters amplifier

Now 35 BNC connections in the tunnel
To be packed in 2-3 Harting multipoles connectors
To be assembled in a single structure

Now 3 main structures installed separately

Oscar Adriani

December 7th, 2011
LHCf on going analysis of the p-p data

- 900 GeV single photon spectrum
  - Analysis completed, paper submitted soon

- $\pi^0$ energy and $P_T$ spectra for
  Type I and II $\pi^0$
  - Analysis almost finished, draft circulating

- Hadron spectra

- $\eta$, $K^0$, $\Lambda$?
Conclusions

- Letter of Intent for the p/Pb run submitted to LHCC
- Interesting physics case can be investigated by LHCf
  - Most clean measurement on proton remnant side, but we can work also on Pb remnant side
  - Photon and neutron spectra and invariant cross section can be precisely measured in the $\eta>8.4$ rapidity range
- Operating conditions look promising
  - The machine expected conditions well fit the LHCf characteristics and good statistics can be collected in few days of data taking
  - Technical details for the installation/removal, radioprotection, radiation dose etc. will be addressed in the near future
- Meanwhile the upgrade program for 14 TeV run and the 900 GeV+7 TeV p-p analyses are on-going

Oscar Adriani
LHCf LOI for p/Pb run
December 7th, 2011
Spares slides
Photons on the proton remnant side

- Photon energy distribution in different $\eta$ intervals at $\sqrt{s_{NN}} = 7$ TeV
- Comparison of p-p / p-N / p-Pb
- Enhancement of suppression for heavier nuclei case

Courtesy of S. Ostapchenko
Lead-remnant side – neutron spectrum

Small tower

Big tower

35% ENERGY RESOLUTION IS CONSIDERED IN THESE PLOTS
CERN CPU

- Due to the East Japan spring earthquake and subsequent electrical power reduction, CPU service at ICRR, Univ. of Tokyo was strongly reduced, and is still reduced.

- During the last LHCC meeting, LHCf required to use CERN CPU service.

- We now routinely produce MC dataset with 200 job limitation by help of Bernd Panzer-Steindel (we will ask to increase job limit 😊)

MANY TANKS FOR THE SUPPORT!!!!!!
# GSO property

(EJ260: plastic scintillator used in the current LHCf detectors)

<table>
<thead>
<tr>
<th>Property</th>
<th>GSO</th>
<th>EJ-260</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>6.71</td>
<td>1.023</td>
</tr>
<tr>
<td>R.l. (cm)</td>
<td>1.38</td>
<td>14.2</td>
</tr>
<tr>
<td>Decay time (ns)</td>
<td>30-60</td>
<td>9.6</td>
</tr>
<tr>
<td>Fluorescence (NaI=100)</td>
<td>20</td>
<td>19.6</td>
</tr>
<tr>
<td>λ em (nm)</td>
<td>430</td>
<td>490</td>
</tr>
<tr>
<td>Refractive (@ λ em)</td>
<td>1.85</td>
<td>1.58</td>
</tr>
<tr>
<td>Tolerance (Gy)</td>
<td>10⁶</td>
<td>100</td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>1950</td>
<td>—</td>
</tr>
</tbody>
</table>

- **Heavy; reason to reduce 3->1mm**
- **Fast among inorganic scintillators**
- **Identical to the current scintillators**
- **Similar to the current scintillators**
- **Light collection may differ**
- **Best in the known scintillators**

Oscar Adriani

LHCf LOI for p/Pb run

December 7th, 2011
Uniformity test using C beam at HIMAC (preliminary results from quick analysis)

Scan examples for a 20mmx20mm and a 40mmx40mm GSO plates
All scintillators of Arm1 were mapped by C beam
Similar uniformity to the current detector is obtained

PMT via fiber bundle

No particle due to the beam pipe

PMT via fiber bundle
New structure

GSO bar bundle and quartz fiber light guide

GSO plate and light guide packed in a new holder

GSO plates and bars as calorimeters, but without Tungsten absorber layers

December 7th, 2011
GSO bars cross talk and attenuation

- Attenuation and cross talk are acceptable to determine the position of single particle shower and multihit identification

- For multihit analysis, further study is necessary

- Paint between the bars reduces cross talk, but worsens attenuation and its bar-to-bar variation
Estimation of Beam Gas background

- Input from p-p collisions (Data set used for the photon paper).
  - Luminosity per bunch \((L/n)\) : \(2 \times 10^{28} \text{ cm}^{-2}\text{s}^{-1}\)/bunch
  - Intensity per bunch \((I/n)\) : \(2 \times 10^{10}\) protons/bunch
  - Total detected events in 25mm tower at non-bunch crossing : 101 photon events (for non crossing bunches)
  - DAQ live time : \(~8 \times 10^3\) sec
  - -> Event rate of beam gas per bunch = \(\frac{101}{8000}/3 = 0.004\) Hz

- Inputs from p-Pb (assumptions)
  - Luminosity per bunches \((L/n)\) : \(1.7 \times 10^{25} \text{ cm}^{-2}\text{s}^{-1}\)/bunch \((L=10^{28}, n=590)\)
  - Inelastic cross section : 2 barn
  - Expected collision rate : 34 Hz
  - Expected photon detection rate in 25mm : 0.34 Hz \((\text{assuming acceptance}=0.01)\)

- Estimation of beam-gas background for p-Pb
  - Assuming as the optics for p-Pb is same as one for p-p (same beta, same emittance), the relative intensity is estimated by using \(L/n\).
  - \((I/n)_{pPb} / (I/n)_{pp} \sim 0.03\)
  - The beam-gas background rate should be proportional to the intensity per bunch, so it is estimated as \(0.03 \times 0.004\) Hz = \(10^{-4}\) Hz

- As conclusion, the N/S in p-Pb is estimated as \(10^{-4} / 0.34 = 3 \times 10^{-4}\) \(\rightarrow\) Negligible!!!