LHCf plans for pA data taking

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pA@LHC workshop @CERN
Introduction ~Physics motivation of LHCf~

- UHE cosmic-ray air-shower is initiated by \( pA \) or \( AA \) interaction
- Its development is to be understood by the HE particle physics

\[ \sqrt{s} = 14 \text{TeV} \Leftrightarrow E_{\text{lab}} = 10^{17} \text{eV} \]

1. Inelastic cross section (ex. by TOTEM)
2. \textbf{Forward energy spectrum}
3. Inelasticity

\[
\begin{align*}
\text{}\frac{dE}{d\eta} \text{[TeV]} & \geq \text{Energy flux} \\
\text{at LHC 14TeV pp} & \\
\text{Most of the} & \\
\text{energy flows into} & \\
\text{very forward} &
\end{align*}
\]
LHCf experiment

Two independent detectors at either side of IP1 (Arm1, Arm2)

neutral particles, such as $\gamma$, $\pi^0$, n, with $\eta > 8.4$ enter into the detector slot
LHCf detectors

Sampling and imaging EM calorimeter

- Absorber: W (44 r.l, 1.55λ₁)
- Energy measurement: plastic scintillator tiles
- 4 tracking layers for imaging: XY-SciFi (Arm1) and XY-Silicon strip (Arm2)
- Each detector has two calorimeter towers, which allow to reconstruct π⁰

Front Counters

- thin scintillators 80x80 mm
- monitors beam condition
- Van der Meer scan

Performances

- Energy resolution (> 100 GeV): < 3% for 1 TeV γ & ~ 30% for n
- Position resolution for photons: ~ 40 μm (Arm2)
## Operations & status

<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>2009/2010</td>
<td>p - p</td>
<td>450+450 GeV</td>
<td>4.3 $10^{14}$</td>
<td>Arm1+Arm2</td>
</tr>
<tr>
<td>2010</td>
<td>p - p</td>
<td>3.5+3.5 TeV</td>
<td>2.6 $10^{16}$</td>
<td>Arm1+Arm2</td>
</tr>
<tr>
<td>now</td>
<td></td>
<td></td>
<td></td>
<td>detectors were detached from the tunnel</td>
</tr>
<tr>
<td>Nov 2012</td>
<td>p - Pb</td>
<td>3.5 (4.0) TeV proton E</td>
<td>10^{16}</td>
<td>Arm2</td>
</tr>
<tr>
<td>2014-2015</td>
<td>p - p</td>
<td>6.5+6.5 TeV</td>
<td>9.0 $10^{16}$</td>
<td>Arm1+Arm2 upgraded</td>
</tr>
</tbody>
</table>
Results: photons

- 7 TeV: PLB 703, 128, 2011
- 900 GeV: submitted, quite similar tendency to the 7 TeV. Compared with 7 TeV (Arm1, the same $p_T$ region selected) Spectral shape is common
Results: neutral pions

- Submitted (arXiv:1205.4578)
- EPOS shows the best agreement in the $p_T$ distribution
- Next: neutron, $\gamma$ full paper ($p_T$)
LHCf in pA runs: Letter of Intent

CERN-LHCC-2011-015 / LHCC-I-021

- Physics goals
  - model discrimination with a cosmic-ray point of view, by photons, neutral pions & neutrons
  - nuclear modification factor
  - inelasticity and others?

*How much data will be required?*

- Also, 1 detector has only 2 calorimeter pads, so the particle *multiplicity* should be checked

=> Monte Carlo simulation study
MC setups

- Protons with energy $E_p = 3.5$ TeV, and Pb with
  $$E_N = \frac{Z}{A} E_p = 1.38 \text{ TeV/nucleon} \quad \Rightarrow \quad \sqrt{s_{NN}} = 4.4 \text{ TeV}$$
- Detector responses are not introduced, but the geometrical config. and a realistic E-smearing of Arm2 are considered
- $10^7$ collisions (~ $2 \times 10^5$ photon events in total)

<about hadronic models>
- Results are shown for DPMJET 3.0-5 and EPOS 1.99
- EPOS 1.99 does not consider Fermi motion and Nuclear Fragmentation. Be careful for the Pb-remnant side results
- QGSJET2 can be used for p-Pb collisions. Works in progress.
- Public version of other models (Sybill, HIJING, Pythia etc.) cannot be used for p-Pb collisions
multiplicity: p-remnant side

small tower

$\gamma$-rays, small tower
EPOS
DPMJET III

Fraction of events

$\gamma$

n

neutrons, small tower
EPOS
DPMJET III

Fraction of events

$\gamma$-rays, big tower
EPOS
DPMJET III

Fraction of events

neutrons, big tower
EPOS
DPMJET III

Fraction of events

• multi-hit events are $<\sim1\%$ of single events
multiplicity: Pb-remnant side

small tower

large tower

\[ \gamma \]

\[ n \]

possibility of “(too) many neutrons” =>

- Arm2, which has the finer Si \( \mu \)-strip detectors
- First p-remnant side, then Pb-side by swapped beam (no strong need to install both of the two detectors)
Expected spectra: p-remnant side

- \(\gamma\): \(10^7\) collisions is enough for the model discrimination
- \(n\): introduced \(\Delta E=35\%\) is dominant, but still has a certain power for the model discrimination
\( \gamma \) invariant cross section: p-remnant side

- Smooth enough with the same stat
- If the \( \gamma \) spectrum in 4.4 TeV pp collisions is measured (or estimated), we can derive the nuclear modification factor for \( \eta > 8.4 \)
- A big suppression reported for \( \eta = 4 \)

cf.) NMF by STAR@RHIC (PRL97, 152302, 2006)
Neutral pions

- We can detect neutral pions
- Complementary for the model discrimination
- Important info to check the detector performance
Expected spectra: Pb-remnant side

Small tower

Large tower

Large difference among models.
Interesting if we can solve the large multiplicity.
Plans for DAQ

1. Only Arm2 will be installed in a short TS in Oct. Radiation, transportation, cabling, etc. are all ok.
2. DAQ first in p-remnant side, then in Pb side. Arm2 was installed in this side in 2010. No big change.
3. Required min. # events: $10^8$ collisions ($2\times10^6 \gamma$)
   Beam parameters : #bunch=590, Luminosity<$10^{28}$cm$^{-2}$s$^{-1}$, $\sigma=2b$
   (pile-up is negligible for the max. luminosity)
   Assuming that the luminosity is only $10^{26}$cm$^{-2}$s$^{-1}$,
   the min. running time for physics is **140 hours (6 days)**

Presented in LPCC (10/2011),
then approved in LHCC (12/2011 & 03/2012)

*We will be back in this autumn!*
Discussions ~physics with ATLAS?~

- In hardware level a common trigger with ATLAS is hard to be implemented in this pA run.
- **An ATLAS event ID is recorded in our data. Event reconstruction with ATLAS can be done in offline.**

- Thus, the point is the # fraction of common events, i.e., the trigger efficiencies of each experiments. If the beam luminosity is not high, they would be similar.
- Which detector of ATLAS? It would be relatively easy to combine the ZDC data with our data, compared with data of the central detectors.
- Max. trigger rate?
Summary

• LHCf: experiment for measurement of very forward neutral particles ($\gamma$, $\pi^0$, n), for the cosmic-ray physics
• Analyses show smooth spectra and the capability of discrimination of the models used in the CR MCs
• For pA runs, we will be back to take data:
  ▫ for the model discrimination, and also for the other physics, such as NMF, inelasticity, etc.
  ▫ by one detector (Arm2)
  ▫ First in the p-remnant side, then in the Pb-side
• A possibility of the offline analysis combined with the ATLAS information is also discussed
backup
pPb is still useful for CR

- γ spectrum (p-remnant) in different η 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
Comparison between Models

DPMJET 3.04  SIBYLL 2.1  EPOS 1.99  PYTHIA 8.145  QGSJET II-03

- None of the models nicely describe the LHCf data in the whole energy range (100 GeV – 3.5 TeV).
- Very big discrepancy in the high energy region
- Significant improvement of the models is possible by model developers
900 GeV - 7 TeV comparison

\[ X_F = \frac{2E}{\sqrt{s}} \]

7 TeV: only small tower

900 GeV: (large \(\rightarrow\) region2) + (small \(\rightarrow\) region1)

\[ 5\text{mm} \times 7\text{TeV}/900\text{GeV} = 38.9\text{mm} \]

\[ r=5\text{mm} \]

\[ \Rightarrow \text{the same } P_t \text{ region@900GeV} \]
Ratio plots: p-remnant

\( \gamma \)-rays, small tower
p-remnant side

\( \gamma \)-rays, big tower
p-remnant side

Neutrons, small tower
p-remnant side

Neutrons, big tower
p-remnant side
Ratio plots: Pb-remnant

\[
\text{\(\gamma\)-rays, small tower}
\]
\[
\text{\(\gamma\)-rays, big tower}
\]
\[
\text{neutrons, small tower}
\]
\[
\text{neutrons, big tower}
\]
misc

- 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

- Radiation: $< 175 \mu$Sv per person (LTEX meeting, confId=188469 on the CERN indico)
- Max. Trigger rate: LHCf ~1KHz
- formula of NMF

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