Opportunity to contribute in the search of the Dark Matter - II

Michela Chiosso, University of Torino and INFN

COMPASS Workshop “Beyond 2020” - CERN
21-22 March 2016
Dark Matter searches related measurements:
p-He cross section measurements → pbar production in ISM

High Energy Cosmic Rays composition related searches:
particle production in atmospheric showers
Cosmic rays antiprotons

Cosmic ray antiprotons are a remarkable diagnostic tool for astroparticle physics.

The bulk of the measured flux consistent with a purely secondary origin in CR collisions onto interstellar medium gas (ISM)

but additional primary components are not excluded, either of astrophysical origin or of exotic nature, such as dark matter annihilation or decay

More precise measurements of secondary components are needed

Secondary components mainly come from: \( p-p; p-He; He-p; He-He \)

Reactions involving helium represent a sizable fraction of the total yield, easily reaching 40\% at low energies and no data are available

\( p \ p: 56\%; \ p \ He: 24 \% ; \ He \ p: 12 \% ; \ He \ He: 6 \% ; \ p \ N \ (C, N, O): 2\% \)
Why not at LHC?

The energy scale relevant for cosmic ray experiments is considerably below the energy scale of operating colliders:

AMS-02 is expected to detect antiprotons up to kinetic energies of several 100 GeV, which descend from primary cosmic rays with energies $E \approx 10$ to $10000$ GeV.

This corresponds to CM energies $\sqrt{s} \approx 4$-100 GeV
Most recent data on inclusive $p+p \rightarrow \bar{p} + X$ from NA49 experiment (2010)

NA49: $p$ beam momentum = 158 GeV/c, wide range in $P_T$ (0.10, 1.50) and $X_R$ (0.11, 0.44), Lab antiprotons energy from 8 GeV up to 70 GeV

In older experiments critical subtraction of the antiprotons fraction coming from strange hyperons decay ($\Lambda, \Sigma$) → needed precise vertex detection and tracking reconstruction

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$p_T$ (GeV)</th>
<th>$x_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dekkers et al, CERN 1965 [18]</td>
<td>6.1, 6.7</td>
<td>(0.10, 0.79)</td>
<td>(0.34, 0.65)</td>
</tr>
<tr>
<td>Allaby et al, CERN 1970 [19]</td>
<td></td>
<td>(0.05, 0.90)</td>
<td>(0.40, 0.94)</td>
</tr>
<tr>
<td>Capiluppi et al, CERN 1974 [20]</td>
<td>23.3, 30.6, 44.6, 53.0, 62.7</td>
<td>(0.18, 1.29)</td>
<td>(0.06, 0.43)</td>
</tr>
<tr>
<td>Guettler et al, CERN 1976 [21]</td>
<td>23.0, 31.0, 45.0, 53.0, 63.0</td>
<td>(0.12, 0.47)</td>
<td>(0.036, 0.092)</td>
</tr>
<tr>
<td>Johnson et al, FNAL 1978 [22]</td>
<td>13.8, 19.4, 27.4</td>
<td>(0.25, 0.75)</td>
<td>(0.31, 0.55)</td>
</tr>
<tr>
<td>Antreasyan et al, FNAL 1979 [23]</td>
<td>19.4, 23.8, 27.4</td>
<td>(0.77, 6.15)</td>
<td>(0.08, 0.58)</td>
</tr>
<tr>
<td>BRAHMS, BNL 2008 [13]</td>
<td>200</td>
<td>(0.82, 3.97)</td>
<td>(0.11, 0.39)</td>
</tr>
<tr>
<td>NA49, CERN 2010 [14]</td>
<td>17.3</td>
<td>(0.10, 1.50)</td>
<td>(0.11, 0.44)</td>
</tr>
</tbody>
</table>
These experiments require:

- a state-of-the-art spectrometer with high acceptance and high resolution for charged and neutral particles in order to perform measurements of multi-particle final states over a wide kinematic range

- Proton beam, variable energy in the range 10 GeV – 1 TeV

- Liquid He target

- micro vertex detection and precise tracking

- Particles identification detectors: antiprotons, positrons, gammas in the final state

**Data needed also on:**

- \( p+p \text{ and } p+\text{He} \rightarrow e^+ + X \) at \( E_{e} < 50 \text{ GeV} \)

- \( p+\text{He} \rightarrow \pi^0 \rightarrow \gamma\gamma \) at \( E_{\gamma} \) from 500 MeV up to 500 GeV

**The goal:**
- absolute cross-section measurement (with precision better than 10%)
**COMPASS facility at CERN**

**Most important features:**

- Muon, electron or **hadron secondary beams**
- Solid state polarised targets (NH3 or 6LiD) as well as **liquid hydrogen target and nuclear targets**
- Powerful tracking system – 350 planes
- PiD – **Calorimeters, RICH, Muon walls**

A high momentum resolution for charged particles provided by a two-stage magnetic spectrometer.

**Accessible final states**

π, κ, p, pbar, gammas

**2009 data**

190 GeV/c proton beam
40 cm long Liquid H2 target
Trigger on recoil proton

**measurements with nuclear targets:**
a target holder can house up to 16 target disks
COMPASS facility at CERN: hadron beam

**50-280 GeV/c hadron beam**

Liquid H2 target

<table>
<thead>
<tr>
<th>Momentum (GeV/c)</th>
<th>Positive beams</th>
<th>Negative beams</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>π⁺</td>
<td>K⁺</td>
</tr>
<tr>
<td>100</td>
<td>0.618</td>
<td>0.015</td>
</tr>
<tr>
<td>160</td>
<td>0.360</td>
<td>0.017</td>
</tr>
<tr>
<td>190</td>
<td>0.240</td>
<td>0.014</td>
</tr>
<tr>
<td>200</td>
<td>0.205</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Maximum beam momentum (high-energy mode) 280 GeV/c
Maximum beam momentum (normal mode) 250 GeV/c

Two CEDARs designed to provide fast beam particle identification at high rates for particle momenta up to 300 GeV/c

A particle identification efficiency of almost 90% for protons is estimated using a multiplicity of 4 with a high purity of larger than 95% for the chosen working point of the CEDAR.
Antiproton Identification

The RICH Detector

3m long vessel filled with C4F10 gas as a radiator

The refractive index of the radiator material ($n \approx 1.0015$) corresponds to Cherenkov thresholds of about 2.5, 9, and 17 GeV/c for pions, kaons, and protons, respectively.
pion-kaon separation at 95% confidence level for momenta up to 45\,GeV/c.

Average number of photons per ring at saturation, i.e. for $\beta=1$ is 56 in the central and 14 in the peripheral region.
Precise vertex reconstruction and tracking

Precise tracking immediately upstream and downstream of the target is performed by silicon microstrip detectors:

three stations upstream of the target, which are used as a beam telescope, and two stations downstream of the target, which are used for vertex reconstruction

Spatial resolution: along the beam axis varies from 0.75 to 4.7mm, across the beam axis lies in the 13 to 16 $\mu$m

For the tracking in the beam region: pixelised Gas Electron Multiplier (GEM) detectors with a minimised material budget along the beam

For the tracking at small angles: Micromegas trackers
Electromagnetic calorimetry

ECAL1: the dynamic range is set to detect energies of up to 60 GeV in GAMS cells, 30 GeV in MAINZ cells and 20 GeV in OLGA cells.

ECAL2: the dynamic range of the central cells is set to a maximum energy of 150 GeV and to 60 GeV for the outermost two rows and lines for diffractive data taking.

\[
\gamma, e^+, e^-; \pi^0 \text{ separation capability in the final state}
\]
**Table 5: Overview of trigger subsystems, vetos and physics triggers used for data taking.**

<table>
<thead>
<tr>
<th>Trigger subsystem</th>
<th>Logical composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam trigger (BT)</td>
<td>SciFi1 $\land$ beam counter</td>
</tr>
<tr>
<td>Beam killer veto</td>
<td>beam killer 1 $\land$ beam killer 2</td>
</tr>
<tr>
<td>Veto</td>
<td>Sandwich $\lor$ veto hodoscopes $\lor$ beam killer</td>
</tr>
<tr>
<td>Proton trigger</td>
<td>see Eq. 3</td>
</tr>
<tr>
<td>Multiplicity trigger MT1</td>
<td>1 (later 2) el. of outer ring counter</td>
</tr>
<tr>
<td>Multiplicity trigger MT2</td>
<td>amp. inner disk $&gt;$ 1.6 MIPs (later 2.5 MIPs)</td>
</tr>
<tr>
<td>Calorimeter trigger</td>
<td>$\sum_{12 \times 12}^{}$ cell amplitude $&gt;$ threshold</td>
</tr>
<tr>
<td>CEDAR trigger</td>
<td>CEDAR1 multiplicity $\land$ CEDAR2 multiplicity</td>
</tr>
<tr>
<td><strong>Physics trigger</strong></td>
<td><strong>Logical composition</strong></td>
</tr>
<tr>
<td>Diffractive trigger DT0</td>
<td>BT $\land$ proton trigger $\land$ veto</td>
</tr>
<tr>
<td>Low-$t$ trigger LT1</td>
<td>BT $\land$ MT1 $\land$ veto</td>
</tr>
<tr>
<td>Low-$t$ trigger LT2</td>
<td>BT $\land$ MT2 $\land$ veto</td>
</tr>
<tr>
<td>Primakoff trigger Prim1</td>
<td>BT $\land$ calorimeter trigger ($&gt; 60$ GeV) $\land$ veto</td>
</tr>
<tr>
<td>Primakoff trigger Prim2</td>
<td>BT $\land$ calorimeter trigger ($&gt; 40$ GeV) $\land$ veto</td>
</tr>
<tr>
<td>Kaon trigger KT</td>
<td>BT $\land$ CEDAR trigger $\land$ veto</td>
</tr>
</tbody>
</table>

**Rate / 10 s spill**

- 180k
- 370k (140k)
- 620k (260k)
- 260k
- 450k
- 30k

**Figure 3.1:** DT0 trigger scheme: Trigger (blue) and Veto (purple) components [59]. In the spectromter, a non-interacting beam track (red) and an event with three charged tracks (green) is drawn for illustration.
Feasibility studies

**NA49** (2001: 13 days of data taking)
p+p at 160 GeV/c: 1 100 000 events → 550 000 events on DST (special spill)

42,000 events/day

Beam Intensity: $1 \times 10^4$ p/s
LH target: 20.29 cm long

**COMPASS:**
Beam Intensity: $5 \times 10^6$ p/s
LH target: 40 cm long

$\approx$ Factor 1000 more events/day
Cosmic rays studies

Elemental composition at high energy is still unknown → essential to:
solve finally the puzzle of high energy cosmic rays sources

understand the transition from galactic to extra-galactic cosmic rays

understand change in the power-law of the cosmic rays fluxes, like the “knee”,
at 3x10^6 GeV

Cosmic rays measurements above 10^5 GeV are based on detection at ground
of secondary particle showers (EAS) which they produce in the Earth
Atmosphere

The uncertainty of the extrapolation of the hadronic production cross section in
extensive air shower is a major problem for the interpretation of existing
cosmic ray data for example in terms of the primary mass composition

Relevant measurements for cosmic rays physics: pion-carbon and proton-
carbon from 50 GeV beam energy up to a few hundreds of GeV

Uncertainty of hadron interaction models

Uncertainty in the interpretation of the observables
Hadron Physics and NPQCD
20 - 22 aprile 2015
Centro Convegni Sant'Agostino
Cortona, Via Guelfa 40
http://npqcd15.to.infn.it/
e-mail: npqcd15@to.infn.it

FUTURE DIRECTIONS

Direct measurements:
The next challenge will be to extend direct measurements up to 1000 TeV with the
same level of accuracy reached so far.
✓ New “ideas” on Calorimetry: increase acceptance, good resolution with reasonable
size/weight (e.g. Calocube).
✓ Gain one energy decade in anti-matter detection: warm superconducting magnets,
μm tracking on large surface with low-consumption electronics

Opportunities are around the corner: e.g. China space programs (HERD)

Indirect measurements:
Next challenges: better determination of chemical composition and higher exposures
with, at the highest energies, a full sky coverage (north/south observations)
✓ LHAASO - Cosmic rays in the region of the transition galactic extra-galactic.
✓ Auger Prime - Muon content to better address composition at the highest energies.
✓ Ground based detection of ultra high energy cosmic rays with full sky coverage.
✓ Spatial based detection of ultra high energy cosmic rays (EUSO concept).

Not only CR:
✓ p-He cross section measurements → pbar production in ISM (LHCb-SMOG?
COMPASS?)
✓ particle production in atmospheric showers → TOTEM, LHCF,.....SAS?

Cosmic rays and accelerator physics
(Alessia Tricomi, Paolo Lipari)

Overview on cosmic rays and accelerators: Ralph Engel
Cosmic ray phenomenology - low energy: Fiorenza Donato
Cosmic ray phenomenology - high energy: Andrea Chiavassa
Cosmic ray and accelerators, experiment: Lorenzo Bonechi
Cosmic ray, future: Oscar Adriani

A new idea!
- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
- Injection of noble gas atoms inside the beam pipe to:
  - Measure the beam profile
  - Measure the luminosity
- Why don’t use SMOG to measure cross section relevant for Cosmic Ray Physics???
- F-He→Antiprotons+X
- We could make use of ‘perfect’ Particle Identification Detectors
- We could make use of the highest possible energies
- Direct access to protons in the most interesting energy region
Spare Slides

Michela Chiosso, University of Torino and INFN
These experiments require:

The bulk of antiprotons is produced by proton with kinetic energy 10-20 times larger. AMS energies ~ 1-500 GeV in $E_{p\bar{p}}$ → beam proton energies with ~ few GeV – 10 TeV

$Z_i = \frac{E_{p\bar{p}}}{E_p}$ or $\frac{E_\gamma}{E_p}$

$E_{p\bar{p}} = 1, 3, 10$ GeV

$E_\gamma = 10$ GeV
Figure 1: Average transverse momentum of $\bar{p}$

Figure 2: Cross section against momentum.

Figure 3: Cross section against rapidity.

Figure 4: Cross section against $p_T$. 
Nominal Beam intensity: of $5 \times 10^6 \text{ s}^{-1}$ (2009)
If one assume 70% efficiency of the CEDARs proton tagging
we can expect up to $\approx 2.5 \times 10^6 \text{ p s}^{-1}$
Caprice RICH Detector

Superconductive magnet with tracking system, RICH with C4F10 gas radiator, imaging silicon-tungsten calorimeter
**Tracking**

**Pixel-GEMs detectors** with pixel readout in the central region for precise tracking in the beam region, able to cope with the high particle fluxes in the beam centre, and to separate individual hits close to the beam.
Cosmic rays studies
AMS
mattoni di aerogel con un indice di rifrazione $n$ di 1.05 e mattoni fluoruro di sodio (NaF) nella parte centrale, con indice di rifrazione 1.33, per estendere in basso il range di velocità misurabili e garantire che i fotoni siano raccolti nel piano di rivelazione

$\text{Sigma}_{\beta/\beta} = 0.1\%/Z$
M2 beam line secondary beams

Particle production at 0 mrad

![Graph showing particle production rates vs. momentum for different particles (p, K^+, K^-, pbar) at 0 mrad.](image-url)
For each event the RICH-1 data are decoded, the MAPMT hits are selected on the basis of the time information and the MWPCs hits are selected on the basis of the time and amplitude information and clustered; all accepted particles, namely tracks within the RICH angular acceptance and having a momentum between 1.8 and 180 GeV/c, are then correlated to the RICH reconstructed coordinates. These resolutions allow pion-kaon separation at 95% confidence level for momenta up to 45 GeV/c. The average number of photons per ring at saturation, i.e. for $\beta=1$ is 56 in the central and 14 in the peripheral region.