Particle physics detector conceived for high precision study of CRs at TV energy

Physics goals

- Antimatter search (|Z|>1 anti-nuclei)
- Dark Matter (light anti-matter & γ-rays)
- Exotic signals?
- GCR & γ-rays astrophysics
- Solar Physics (modulation & SEP)
- Magnetospheric physics

How it will fulfill these goals?

- Large collaboration: 16 Countries, 60 Institutes and ~500+ Physicists
- Same concept (precision & capability) as the large state-of-the-art HEP detectors [but: fitting into the space shuttle & no human intervention after installation]
- Operation in space, ISS, at 400km, no backgrounds from atmospheric interactions [extensive multi-step space qualification tests]
- Collection power: geometrical factor (≈ 0.5 m2sr) X exposure time ( = ISS lifetime) [extensive calibration campaigns on ground]
The AMS Project

AMS Collaboration
- 16 countries
- 60 institutes
- 500+ physicists
- 20 years

Project timeline
1994 CONCEPT
1997 AMS-01 PROTOTYPE
1998: STS-91
2000 @CERN AMS-02 CONSTRUCTION
2008 @CERN SC MAGNET BEAM TEST
2010 @CERN SC -> PM NEW BEAM TEST
2010 TVT @ ESA (NL)
2011 @KSC INTEGRATION & CR-μ RUN

MAY 2011 STS-134 FLIGHT
ON THE ISS

→ Steadily taking data on the ISS since May 19th 2011

NICOLA TOMASSETTI - LPSC - IN2P3/CNRS GRENOBLE

L-TPC SYMPOSIUM - PARIS 15 / 12 / 2014
May 16th 1011: launch!

May 16, 2011 @ KSC, US
STS-134 / Endeavour on launchpad
May 19th 2011: activation!

ISS - May 19, 2011
AMS installation completed
Full time monitored

The Payload Operation Control Center (POCC)

Since the 27th June, 2011, 5:00 am GMT, AMS-02 is controlled 24/7 from the new POCC building at CERN, Prevesin site.

Shifts are organized to monitor the AMS-02 conditions, operations, and the continuous flow of data to ground.

Since July 2012, a second control room (the Asia POCC) is running at the CSIST facility in Taiwan.
The AMS-02 instrument

Particles and nuclei are defined by their charge ($Z$) and energy ($E \sim P$).

Z, P are measured independently from Tracker, RICH, TOF and ECAL.
Multiple measurements of energy

- **Tracker**, $R = \frac{p}{Z}$
  - $\Delta R/R \approx 2TV$

- **TOF**, $\beta$
  - $\Delta \beta/\beta \approx 1\%$

- **ECAL**, $E$
  - $\Delta E/E$ (TeV $e^\pm$) $\sim 2\%$
  - $\Delta E/E$ (TeV $p$) $\sim 50\%$

- **RICH**, $\beta$
  - $\Delta \beta/\beta \approx 0.05\%$

- **Geomagnetic cutoff**
  - $\Delta R/R \approx 10\%$ up $\sim 25$ GV
Multiple measurements of charge

Tracker Plane 1 (L1)

TRD

Upper TOF (1 counter)

Inner Tracker (L2-L8)

Lower TOF (1 counter)

RICH

Tracker Plane 9 (L9)

$\Delta Z$ (carbon)

0.30

0.33

0.16

0.12

0.16

0.32

0.30
Multiple measurements of charge

Nuclei Identification in AMS
Multiple measurement of interactions

MATERIAL RECONSTRUCTION USING INTERACTION VERTICES RECONSTRUCTED BY TRD

AMS ON ISS - PHOTO

TOP COVER TOMOGRAPHY

TRD MATRERIAL FINE STRUCTURE
Multiple lepton/hadron separation

\[ P_e = \prod_{i=1}^{n} P_e^{(i)}(A) \]

TRD emission in 22 layers

Rigidity + \( \beta + Z \) = particle’s mass

ECAL/BDT DISCRIMINATION ON SHOWER TOPOLOGY

ECAL/TRACKER ESTIMATOR

ECAL/BDT ESTIMATOR

TRD ESTIMATOR
No redundancy for particle sign

Matter-antimatter distinction: only from the track curvature

Charge confusion: probability to get the wrong particle sign

Sources of charge confusion:
- Interactions & sec production
- Track mis-reconstruction
- Finite momentum resolution

Charge confusion probability estimators have been developed for leptons and hadrons, with the help of beam test data and MC simulation
Positron fraction results

Positron fraction measured between 0.5 to 350 GeV of energy

✓ 1.5 years of data. 74,000 events.
✓ 72 events in the last energy bin
✓ No fine structure in the spectra.
✓ Persistent rise up ~ 200 GeV

The $e^+$ secondary production is expected to decrease monotonically, while results indicate a persistent rise. The positron fraction increases steadily from 10 to 250 GeV.
October 2014 – New publication: positron fraction up ~500 GeV w/ 3yrs data

- New high-energy data (3 yrs statistics) released. 0.5 GeV – 500 GeV
- The Positron fraction above ~200 GeV does not increase anymore
Lepton fluxes: \( e^+ \), \( e^- \), and “all electron”

*September 2014 – New publication: positron fraction in 0.5 - 500 GeV*

*October 2014 – New publication: electron and positron fluxes up to 700 GeV*

*November 2014 – New publication: electron + positron total flux up to 1 TeV*

**Electron spectrum \( x E^3 \)**

Above 10 GeV: smooth, slowly falling curve. Fairly good agreement with the PAMELA data. Different solar modulation at low energies.

**Positron spectrum \( x E^3 \)**

Flat spectrum from \(~10\) to 30 GeV. Change of slope above 30 GeV, harder than \( E^{-3} \), completely different from the \( e^- \) spectrum.
Search for dark matter

**Annihilation**  \( \chi + \chi \rightarrow (...) \rightarrow e^+, \bar{p}, \bar{d}, \gamma \)

**Production**  \( p + p \rightarrow (...) \rightarrow \chi + \chi \)

**Scattering**  \( \chi + N \rightarrow \chi + N \)

**IN SPACE: AMS**

**IN ACCELERATORS:** LHC

**UNDERGROUND:** XENON, CDMS, LUX

NICOLA TOMASSETTI - LPSC - IN2P3/CNRS GRENOBLE
L-TPC SYMPOSIUM - PARIS 15 / 12 / 2014
Dark matter and CR propagation physics

- **Background** from cosmic-ray sources (SNR) - No anti-matter expected
- **Background** from p+ISM collisions on disc: from propagation models
- **Signal** from DM annihilation $\chi + \chi \rightarrow (...) \rightarrow$ antimatter

**DISC**
- Sources (SNRs)
- Intestellar matter (ISM)

**MAGNETIC HALO**
- Energy dependent CR diffusion
Positron excess: sources of HE positrons

Standard prediction: of $e^+$ from $p$+ISM collisions
→ Cannot account for the observed positron data
→ Background for new physics/astrophysical signals

- Dark Matter particles
- Astrophysical sources (SNR/PWN)
- CR collisions with ISM

**Background for new physics/astrophysical signals**

\[ \text{positron flux } \times E^3 \]

\[ E^3 \phi_{e^+} \, / \, (\text{GeV}^2 \, m^{-2} \, s^{-1} \, sr^{-1}) \]

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NICOLA TOMASSETTI - LPSC - IN2P3/CNRS GRENOBLE
L-TPC SYMPOSIUM - PARIS 15 / 12 / 2014
Pure Dark-Matter scenarios

DM fits more challenging w/i precision of data. But many unknowns from DM particles

Bosonic or hadronic channels (bb,WW): large masses ($M_\chi \sim 10$ TeV). Large $<\sigma v> \sim 10^{-21}$ cm$^3$/sec

Leptonic channels (e+e- ... 2 x $\tau+\tau$-): $\sim$ TeV mass, $<\sigma v>\sim 10^{-23}$ cm$^3$/sec

New data: hints of flattening above $\sim 300$ GeV
Pure DM scenario: TeV-scale DM, into leptonic states, with enhanced annihilation rates.

✓ Search for signal in hadronic data: pbar/p ratio
✓ Uncertainty in background and signal propagation: CR nuclear data
Astrophysical Interpretations: nearby source

**Nearby Pulsar scenario**

- SNRs: electron, hadrons
- hadrons+ ISM collisions: secondary e+ and e-
- PWN: primary e+ and e-

- Additional contribution to SNRs
- Astrophysically plausible
- Many parameters unknown
- No signal in hadronic channels

**Old Supernova Remnant scenario**

- SNRs: electron, hadrons, e+ from p-p collisions
- hadrons+ ISM collisions: secondary e+ and e-

- No additional source required
- Astrophysically plausible
- Atypical SNR properties. Model dependent.
- Signals in hadronic & nuclear channels

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**Di Mauro et al (Torino) 2014**

![Positrons graph](image1)

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**Mertsch & Sarkar 2014**

![Positron fraction graph](image2)
Perspective for the DM search

**Lepton data at TeV energy**
- Discrimination DM/Astro scenarios
- Long observation time
- Model unknown, parameter degeneracy

**Anti-proton/proton ratio above ~100 GeV**
- Expected signature from DM
- Present data consistent with background
- BG uncertainty (propagation & cross-sections)
Conclusions

AMS fundamental science experiment in the International Space Station

Dark Matter search is central to the AMS Physics Program

- Potential to shed a light on the nature of the Dark Matter
- Positron fraction up to 500 GeV with ~3 years of time exposure
- Search for anomalies in the anti-proton spectrum at high energy
- CR spectra measurements of proton and light nuclei

Data taking ongoing. Extensive data analysis ongoing.

~1300 days of mission. 60 Giga-particles collected

2014: lepton data released
- Positron fraction at high energy
- Electron & Positron spectra
- All-electron energy spectrum

2015: hadrons and nuclei
- Proton and Helium spectra at TeV
- Nuclei: B/C ratio and C/O ratio
- Antimatter: antiproton/proton ratio
Operating in the International Space Station since May 2011, AMS is performing very accurate measurements of cosmic ray (e.g. Proton and Helium nuclei) with unprecedented sensitivity. This picture represents a “tomographic” reconstruction of the AMS top-of-instrument material obtained using the Proton-to-Helium flux ratio. Tiny changes of the interaction probabilities of these nuclei with different materials are used to trace the material inhomogeneities. Detector elements such as screws, electronics boards, and mechanical interfaces are clearly recognizable.
AMS-02: Evidence of fragmentation

Carbon $\rightarrow$ Boron in Upper TOF

Optimized for high-Z measurements
- Large dynamical range: $Z \sim 1 - 30$
- Many layers of active material.
- Many independent evaluations of $Z$.

Dedicated Trigger for $Z > 1$:
- 4/4 TOF planes fired
- Multiple TOF hits allowed
- NACC < 5

Minimum bias trigger:
- 1/100 prescaling!!
- 3/4 TOF fired
- No conditions on NACC