AMS-02 is an excellent experiment on the Space Station. It is now operational since 7 years. We plan to operate it till the end of the lifetime of the ISS in 2024. Is is now time to think about the next step!
Recent AMS Results

AMS 2016

AMS 2018

May 2011 – Nov. 2017

AMS 2015

AMS 2018
Discussion at this conference:

„We need to measure He/Proton to higher energies.“, Pasquale Blasi

„We need to measure photons in the energy range 300 GeV-3000 GeV with high precision.“, Ilias Cholis.

„To have the rigidity distribution for anti He would be great. “, Igor Moskalenko

As hosts we try to fulfill the wishes of our guests ...

Electron  Positron

AMS 2018
May 2011 – Nov. 2017
Similar to COBE and WMAP or the Hubble- and the James Webb Space Telescope the only option for significant improvements compared to AMS-02 is a large magnetic spectrometer operated at Lagrange Point 2.

A factor 10 in energy reach requires a factor 1000 in acceptance. AMS-02 has an acceptance of 0.1 m² sr at high energies and weights 7 tons.
The concept of AMS-100 is inspired by the design of the successfull BESS Polar Experiment.
ATLAS Central Solenoid Magnet

- only 0.66 radiation lengths X0 thick
- made from aluminium enforced Nb/Ti conductor
- operation temperature 4.5 K

- 5.3 long, 2.4 m diameter, 4.5 cm thick
- 5 tonne weight
- 2 tesla (T) magnetic field with a stored energy of 38 megajoules (MJ)
- 9 km of superconducting wire
- Nominal current: 7.73 kiloampere (kA)
AMS-100: Operation at Lagrange Point 2

Due to earth magnetic field a cryogenic solenoid magnet can only be operated at L2.

Space Experiments at L2:
• WMAP: Arrived at L$_2$ in 2001. Mission ended 2010
• Herschel: Arrived at L$_2$ July 2009. Ceased operation on 29 April 2013
• Chang'e 2: Arrived in August 2011 after completing a lunar mission before departing en route to asteroid 4179 Toutatis in April 2012.
Planck's cooling systems allow it to maintain a temperature of −273.05 °C. From August 2009, Planck was the coldest known object in space.

**Mission duration**

Planned: >15 months
Final: 4 years, 5 months, 8 days

**Spacecraft properties**

- **Manufacturer**: Thales Alenia Space
- **Launch mass**: 1,950 kg (4,300 lb)[1]
- **Payload mass**: 205 kg (452 lb)
- **Dimensions**: Body: 4.20 m × 4.22 m (13.8 ft × 13.8 ft)

**Start of mission**

- **Launch date**: 14 May 2009, 13:12:02 UTC
- **Rocket**: Ariane 5 ECA
- **Launch site**: Guiana Space Centre, French Guiana
- **Contractor**: Arianespace
- **Entered service**: 3 July 2009

**End of mission**

- **Disposal**: Decommissioned
- **Deactivated**: 23 October 2013, 12:10:27 UTC

**Orbital parameters**

- **Reference system**: L₂ point (1,500,000 km / 930,000 mi)
- **Regime**: Lissajous
The science phase of the mission is expected to start in 2018 and to last for 10.5 years.
This sunshield support structure is very strong, yet quite light, weighing only 63 kilograms (139 pounds), while supporting the sunshield itself, which weighs 700 kilograms (1,543 pounds).
# Current and upcoming rockets

<table>
<thead>
<tr>
<th>Name</th>
<th>LEO [kg]</th>
<th>other [kg]</th>
<th>First flight</th>
<th>ESA</th>
<th>SpaceX</th>
<th>CALT</th>
<th>NASA</th>
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<tbody>
<tr>
<td>Ariane 5</td>
<td>21,000</td>
<td>10,730 GTO</td>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Falcon Heavy</td>
<td>63,800</td>
<td>26,700 GTO</td>
<td>2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Long March 5</td>
<td>25,000</td>
<td>8,000 TLI</td>
<td>2016</td>
<td></td>
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<td>Long March 9</td>
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<tr>
<td>SLS Block 1B</td>
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<td>39,100 TLI</td>
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</tbody>
</table>

**Operational**

**Under development**

- **LEO**: Low Earth orbit
- **GTO**: Geostationary transfer orbit
- **TLI**: Trans-lunar injection
AMS-100 is rotational symmetric around the z-Axis.

Sun Shield

4 m

Spacecraft Bus

Sun

Thin Solenoid 1 Tesla,
3.5 m inner diameter, Length 5 m

Tracker
12 Layers
MDR 100 TeV

ECAL/HCAL: 86 X₀, 3 NIL

He – Vessel
20 m³

AMS-100

Spacecraft Bus:
(Electrical Power, Attitude Control, Communication, Command & Data Handling, Propulsion, Thermal Control)

AMS-100 is rotational symmetric around the z-Axis.
stopped in the ECAL.
Acceptance

At 10 TeV:
- Tracker: 81 [m^2 sr]
- ECAL: 26 [m^2 sr]
- Total: 107 [m^2 sr]

At 100 TeV:
- Tracker: 10 [m^2 sr]
- ECAL: 0 [m^2 sr]
- Total: 10 [m^2 sr]

Acceptance [m^2 sr]

- AMS-100
- AMS-100: ECAL

Accept all tracks with:
- at least 6 good hits
- a track length in the bending plane > 0.5m
- at least one barrel ToF trigger
AMS-100: A Magnetic Spectrometer at LP-2

- Weight: 43 t
- Readout-Channels: $4 \times 10^6$
- Power: 40 kW
- Trigger Rate: 1 MHz
- MDR: 100 TeV
- Acceptance: 100 m$^2$ sr
- B-Field: 1 Tesla
Measurements of proton spectrum before AMS

1. Protons are the most abundant charged cosmic rays.
2. These were the best data over the last hundred years.
3. Nonetheless, the data have large errors and are inconsistent.
4. These data limit the understanding of the production, acceleration and propagation of all cosmic rays.
AMS Measurement of the proton spectrum
We don’t know what we would find in this energy region with an instrument with 1% accuracy and an MDR of 100 TV.

Proton Flux
We don’t know what we would find in this energy region with an instrument with 1% accuracy and an MDR of 100 TV.
Anti-Deuteron

F. Donato, Fornengo, Korsmeier, 1711.08465 subm. PRD

\[ P_{\text{coal}} = 124 \pm 62 \text{ MeV} \]

\[ \phi \left[ \text{(GeV/n)}^{-1} \text{m}^{-2} \text{s}^{-1} \text{sr}^{-1} \right] \]

- DM CuKrKo
- MED-MAX
- Secondary CuKrKo
- MED-MAX
- Tertiary CuKrKo
- MED-MAX

AMS-100

BESS limit
GAPS sensitivity
AMS-02 sensitivity
Due to the rotational symmetry of the instrument one would expect the same number of anti-He particles going upwards or going downwards. This is equivalent to a change of the polarity of the magnetic field.
AMS-100: Charged Cosmic Rays

- Proton and Helium Spectra in the rigidity range R=500 GV - 100 TV.
- Carbon and Oxygen Spectra in the rigidity range R=100 GV - 50 TV.
- Lithium, Beryllium and Boron Spectra in the rigidity range R=100 GV-30 TV.
- Electron and Positron Spectra in the energy range E=100 GeV - 10 TeV.
- Anti-Proton Spectrum in the rigidity range R=100 GV - 10 TV.

If AMS-02 identifies Anti-Deuterium, Anti-Helium 3 and Anti-Helium 4 in primary cosmic rays, AMS-100 would be able to measure the spectra with >1000 Events for each species.
AMS-100 will monitor the whole sky continuously.

The acceptance for photons is up to 65 m² sr compared to FERMI 2.5 m² sr.

The angular Resolution for converted photons is $0.005 \text{ mm}/3.5\text{m} = 1 \times 10^{-4} \text{ deg}$ and will be $\sim 1,000$ better than the FERMI resolution.
The 3. FERMI catalog includes 3033 sources above 4 sigma significance.

AMS-100: Expected counts for 5 years for E=50 MeV – 1 TeV

- For every source in the 3. FERMI catalog we expect at least 1000 events in AMS-100.
- We expect to see 10000 new sources in AMS-100.
AMS-100: A Magnetic Spectrometer at LP-2

- The scale of this project is the scale of a LEP Experiment ⇔ inner part of (ATLAS,CMS) ⇔ 250 Million (€,$,CHF) but for space application i.e. 500 Million - 1000 Million (€,$,CHF).
- It requires a collaboration of 500 physicists, it is time to start the R&D now.
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<table>
<thead>
<tr>
<th>Year</th>
<th>Space Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Hubble</td>
</tr>
<tr>
<td>2008</td>
<td>FERMI</td>
</tr>
<tr>
<td>2011</td>
<td>AMS-02</td>
</tr>
<tr>
<td>2020</td>
<td>James Webb</td>
</tr>
<tr>
<td>2030</td>
<td>AMS-100</td>
</tr>
</tbody>
</table>
AMS-100: A Magnetic Spectrometer at LP-2

- A large scale superconducting magnet in space has large implications for human space exploration.
- To get a large scale superconducting magnet into space was even for S. Ting a challenge.
- We need a precursor flight with AMS-10, i.e. Acceptance 10 m² sr, MDR 10 TeV, to LP-2 in 2025 to prove the technical concept.
AMS-100: A Magnetic Spectrometer at LP-2

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Second Nobel Prize for Samuel C. C. Ting from MIT for the discovery of anti-matter in space.

AMS-10 first data confirmed the AMS-2 discoveries of anti-helium in space.

AMS-10 is the first space experiment with a large superconducting magnet and was launched in 2025.
Backup Slides
Magnet

- Thinn superconducting solenoid, $B=1$ Tesla, $T=4.5$ Kelvin
  made from aluminium enforced Nb/Ti conductor
- Inner diameter 3.5 m, Length 5 m, Material $0.48 \times 0$
- Weight 7,400 kg (11,500 kg
  extrapolated from BESS,
  3,500 kg extrapolated
  from ATLAS)
- $20 \text{ m}^3$ liquid He (2400 kg)
  should cool the magnet for
  $>6$ years. Vessel weight
  estimated to be 1700 kg.
\[
\begin{align*}
\text{n} & := 140 \text{ Unit}(m) \quad \text{# turns/m} \\
\text{Ix} & := 7.73 \text{ Unit}(kA) \quad \text{# from ATLAS solenoid} \\
\text{Magnet Wire Length} & := \text{simplify}(n*\text{Magnet LenY}*2*\text{Pi}*r\text{Magnet in}) \\
\text{Magnet Wire Length} & := 7696.902002 \text{ [m]} \quad (3.1) \\
\text{x1} & := -0.5*\text{Magnet LenY} \\
\text{x2} & := 0.5*\text{Magnet LenY} \\
\text{R} & := r\text{Magnet in} \\
\text{mu_0} & := \text{evalf(Constant(mu[0], units))} \\
\text{fB} & := x\rightarrow \text{simplify}(\text{mu_0}*n*\text{Ix}/2^*((x-x1)/\text{sqrt}((x-x1)^2+R^2)-(x-x2)/\text{sqrt}((x-x2)^2+R^2))) \\
\text{B TrackerCenter} & := \text{fB}(0 \text{ Unit}(m)) \\
\text{B TrackerEdge} & := \text{fB}(0.5 \text{ Unit}(\text{SiTrk LenY})) \\
\text{B Mean} & := \text{int} (\text{fB}(x \text{ OneM}), x=-0.5*\text{SiTrk LenY}/\text{OneM..0.5*SiTrk LenY}/\text{OneM})*\text{OneM}/\text{SiTrk LenY} \\
\text{B TrackerCenter} & := 1.114100220 \text{ [T]} \\
\text{B TrackerEdge} & := 0.8205328942 \text{ [T]} \\
\text{B Mean} & := 1.022762664 \text{ [T]} \quad (3.3) \\
\text{plot}(\text{fB}(x \text{ OneM})*\text{OneT}, x=\text{simplify}(1.5*x1/\text{OneM}..\text{simplify}(1.5*x2/\text{OneM})), \text{gridlines=true, y=0..1.5, labels=[]["z [m]","B [Tesla]"]])
\end{align*}
\]
Time of Flight (ToF)

- Provides the Trigger and measures the flight time
- Scintillator Tiles with wavelength shifting fibers and SiPMT readout.
- Two layers of 10 mm thick tiles on a CF-honeycomb support structure.
- Time resolution: < 120 ps
DIRC: Detection of Internally Reflected Cherenkov light

- First implemented in the BaBar Experiment (Stanford 1999-2008) to measure particle masses (Pion/Kaon separation).
- Allows isotope separation in cosmic rays ($^{9}$Be/$^{10}$Be, $^{3}$He/$^{4}$He, p/d, ...)

BaBar used fused silica radiator bars, 4.9 m (length) x 17.25 mm (thickness) x 35 mm (width).
AMS-100 DIRC

- Focal Plane instrumented with SiPM arrays.
- $^9\text{Be}/^{10}\text{Be}$ at 25 GeV/c momentum from P.S. Marrocchesi, 14$^{th}$ VCI, Feb. 2016
## Outer Detector

<table>
<thead>
<tr>
<th>Name</th>
<th>Weight [kg]</th>
<th>X0</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEPS</td>
<td>1,390</td>
<td>0.05</td>
</tr>
<tr>
<td>ACC</td>
<td>1,640</td>
<td>0.05</td>
</tr>
<tr>
<td>Magnet</td>
<td>11,430</td>
<td>0.48</td>
</tr>
<tr>
<td>ToF</td>
<td>1,560</td>
<td>0.05</td>
</tr>
<tr>
<td>DIRC</td>
<td>1,950</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17,970</strong></td>
<td><strong>0.78</strong></td>
</tr>
</tbody>
</table>

(19 g/cm$^2$)
Silicon Tracker

• Measures the particle track in the bending plane with up to 24 points.
• Readout pitch 0.1 mm, single point resolution 5 μm.
• Single sided Si-detectors (10cm x 10cm) form a ladder of 1m length. In total 3300 ladders are needed.
• Total area 330 m², 3.3 $10^6$ readout channels, Power consumption Front-End 1 mW/Channel ⇔ 3300 W total.
SciFi Tracker

- Measures the particle track in the non-bending plane with up to 24 points.
- Readout pitch 0.25 mm, single point resolution 50 μm.
- Constructed from 0.25 mm diameter scintillating fibers, arranged in 6 layers to form a up to 2.5m long fiber mat.
- 0.576 Million SIPM readout channels, 8000 km fibers.
Calorimeter System
ECAL/HCAL

It is a fine grained tungsten-scintillating fiber sampling calorimeter with SiPM readout that allows precise, 3-dimensional imaging of the longitudinal and lateral shower development, providing high electron/hadron discrimination and good energy resolution.

- Diameter 73 cm, Length 4 m, Weight 14,550 kg, depth 86 $X_0$/3 NIL, 100,000 readout channels
- The maximum of hadron showers will be contained up to 100 TeV.

A non interacting proton passing through ECAL. The electron produces an electromagnetic shower.