Antimatter and Dark Matter search in Space with AMS-02

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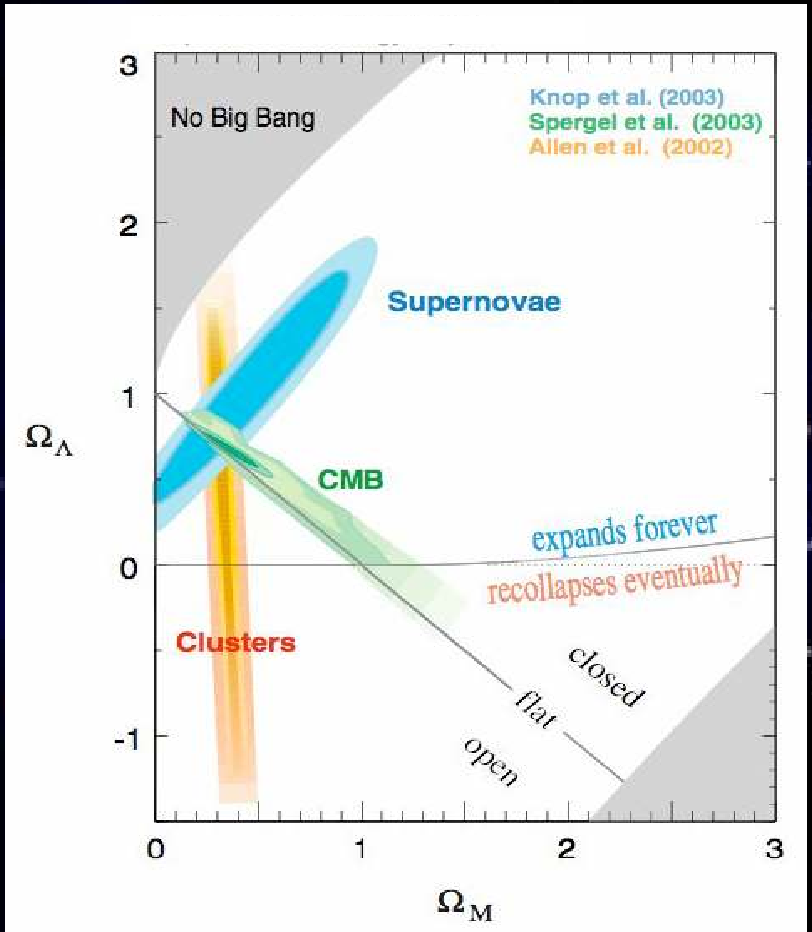
Precision cosmology...



Large scale structures
(SSDS, ...)
$\Omega_m = 0.25 - 0.3$

Cosmic MW backgoround
(WMAP, BOOMERanG)
Flat universe ($\Omega_{tot} = 1$)
$\Omega_m \approx 0.25 \rightarrow \Omega_\Lambda > 0$

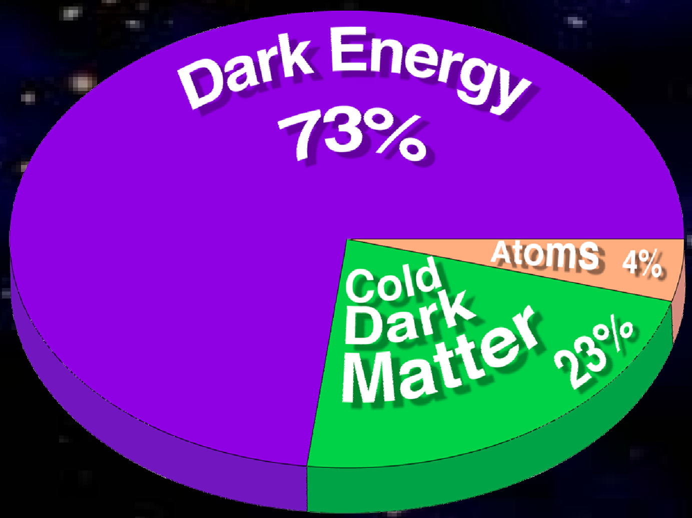
Type Ia SuperNovae
(HUBBLE)
Accelerated expansion
$\Omega_\Lambda > 0$

Precision cosmology…

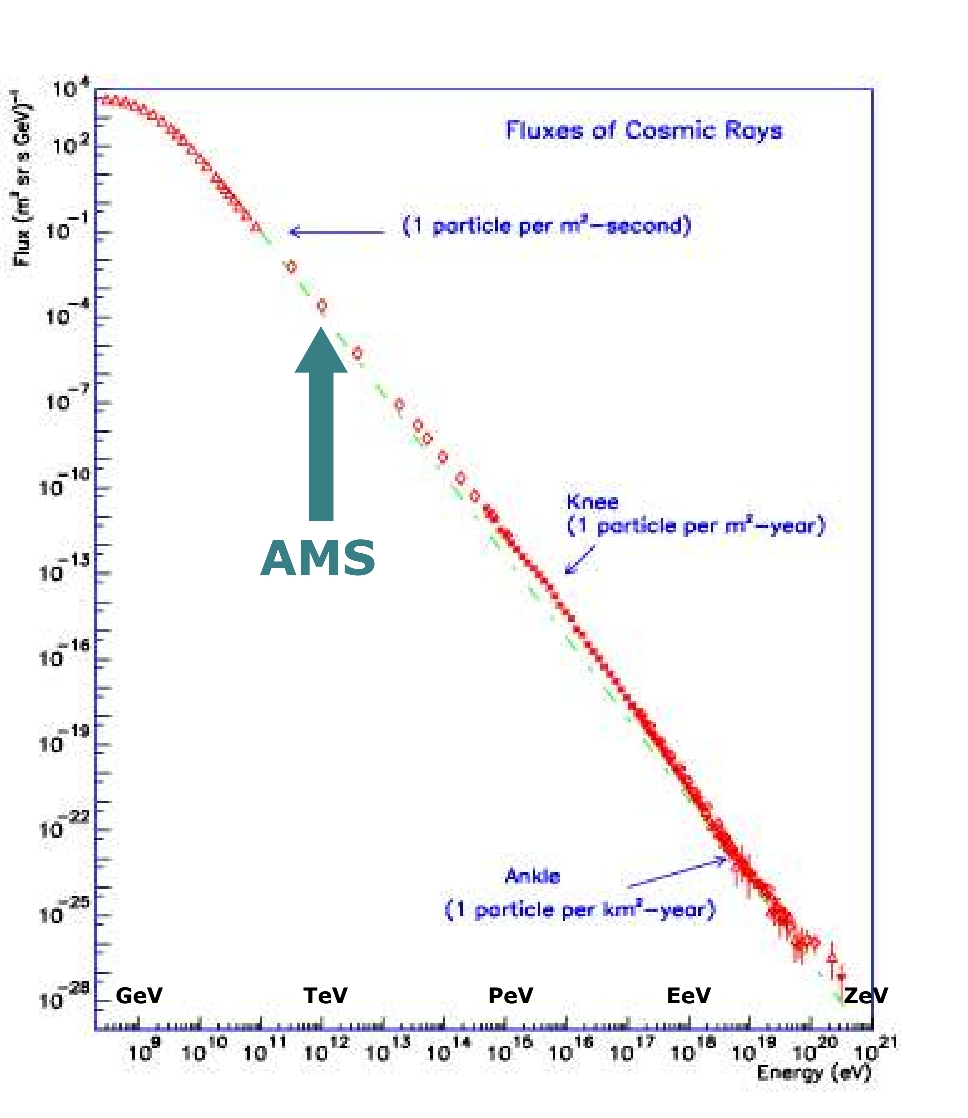
"Standard" cosmological model describes a Universe

- flat, homogeneous and isotropic on large scale
- composed of:

Ordinary matter and radiation	4.4%
Cold Dark matter	23 %
Dark energy	73 %
Antimatter	$< 10^{-6}$ matter



Precision cosmology in the spectrum of Cosmic Rays



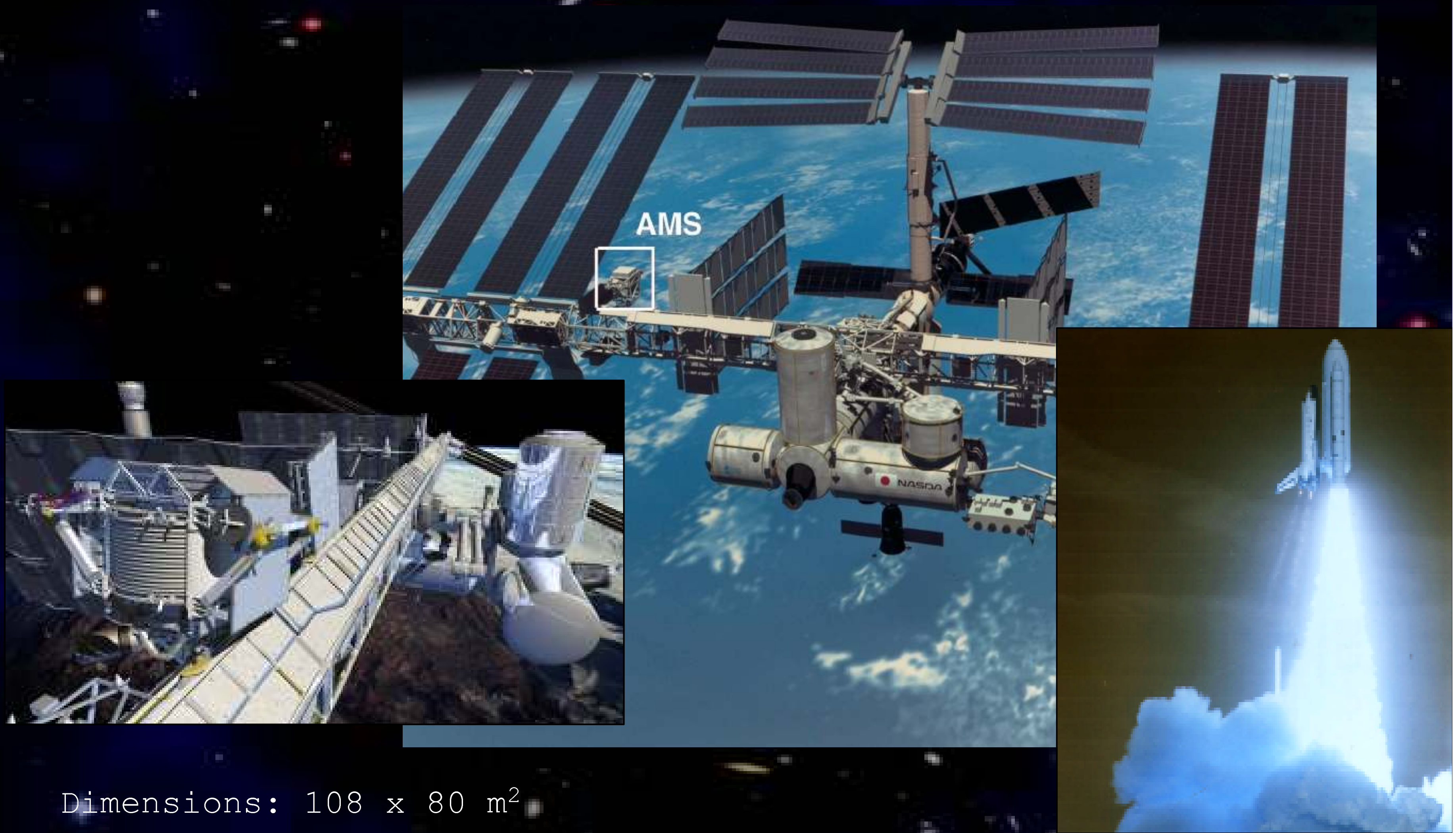
The presence of **dark matter annihilation products** provides a modification of the **Cosmic Rays spectrum** provided one has enough sensitivity to detect it

AMS-02:
a large acceptance magnetic spectrometer in space

Large acceptance & long exposure time -> high statistics

Space -> negligible environmental background

The International Space Station



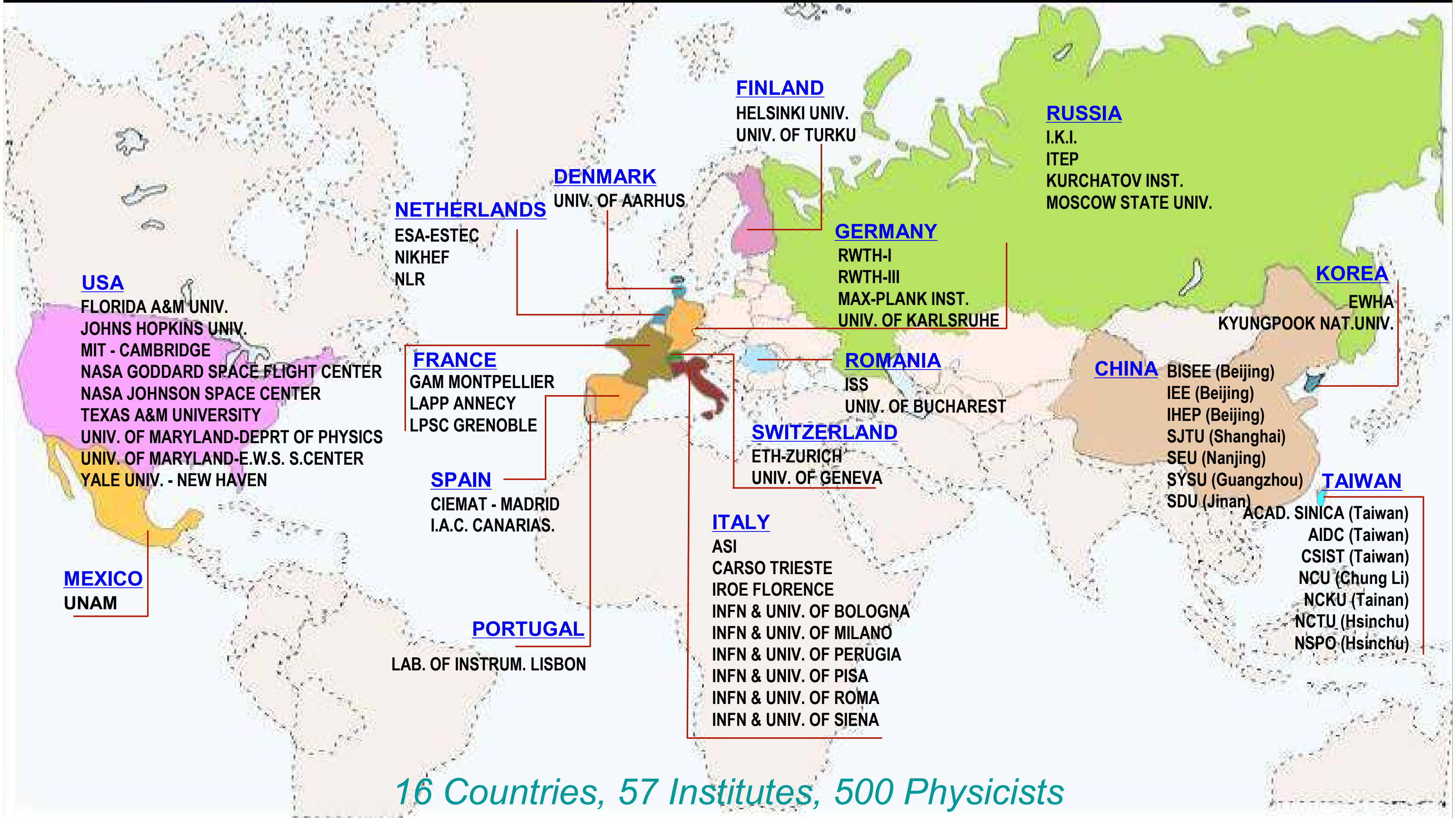
Dimensions: 108 x 80 m^2

Inclination: 51.57°, 15.62 revs/d

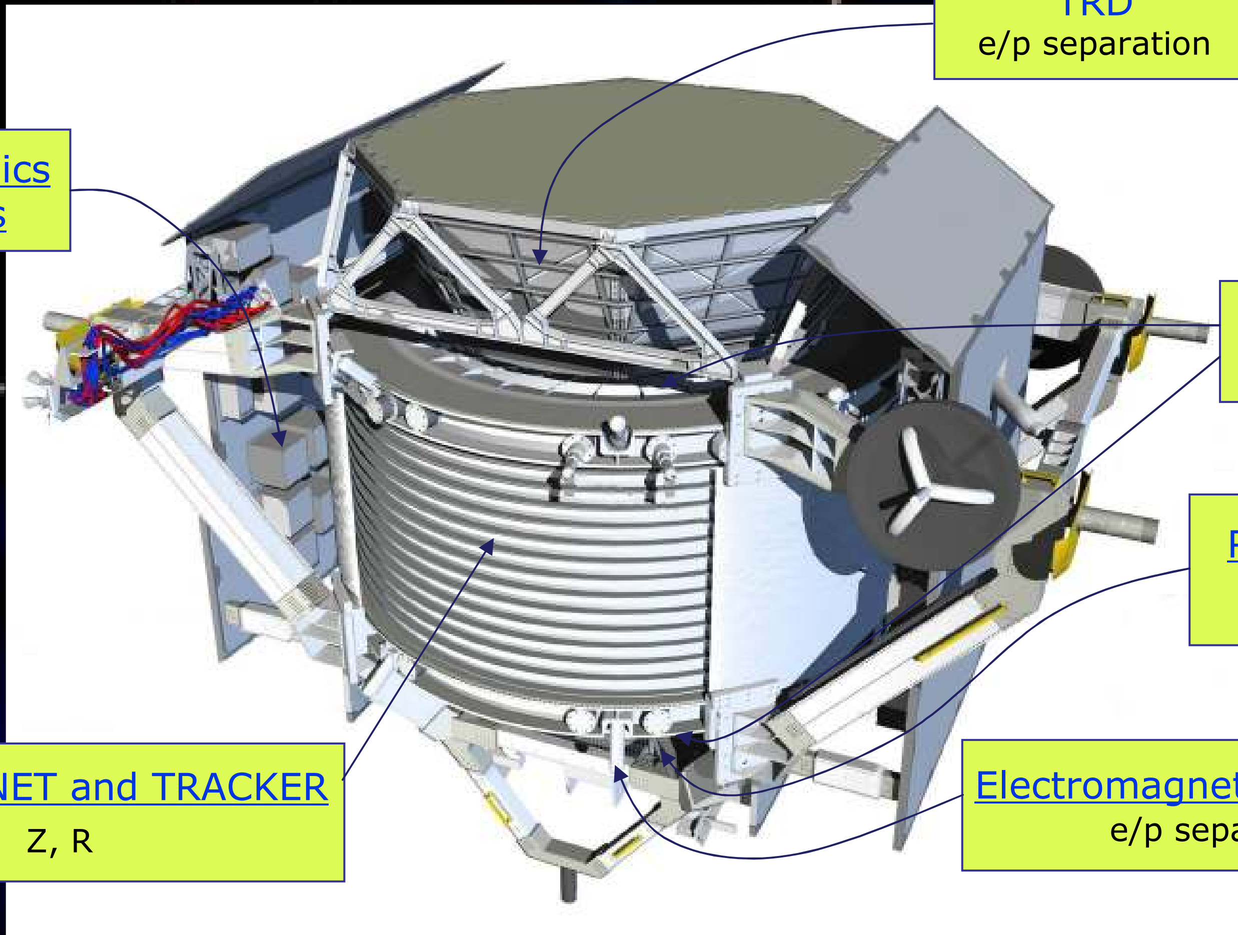
ΔT: -60 ÷ +40 °C

Orbit: ellyptic at 400 km

The AMS-02 Collaboration

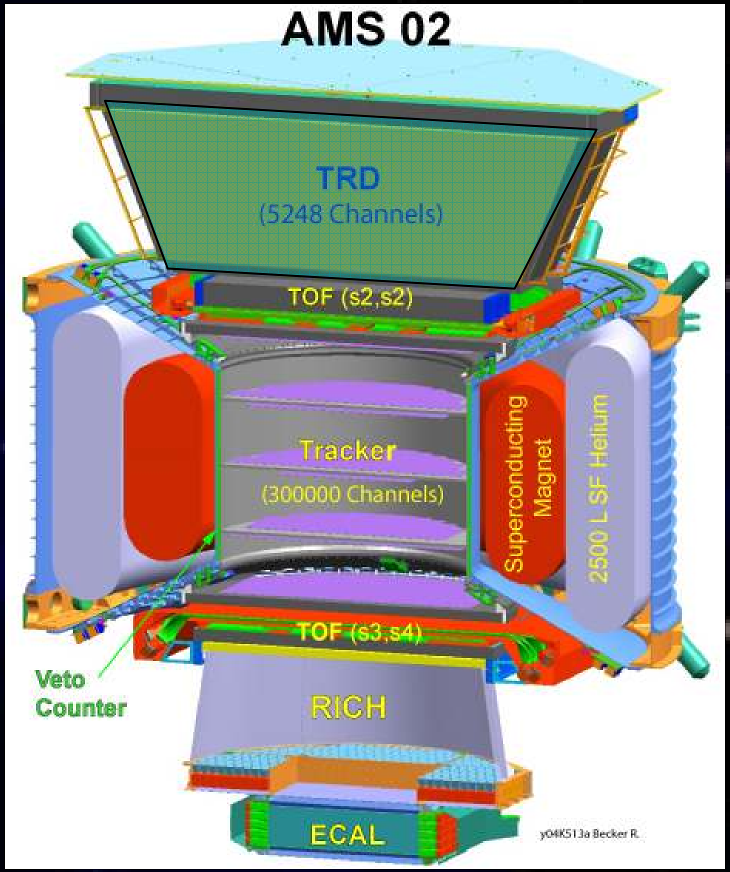


The AMS-02 detector



Geometrical acceptance: 0.45 m^2sr **Total weight » 7 T**

Transition Radiation Detector (TRD)

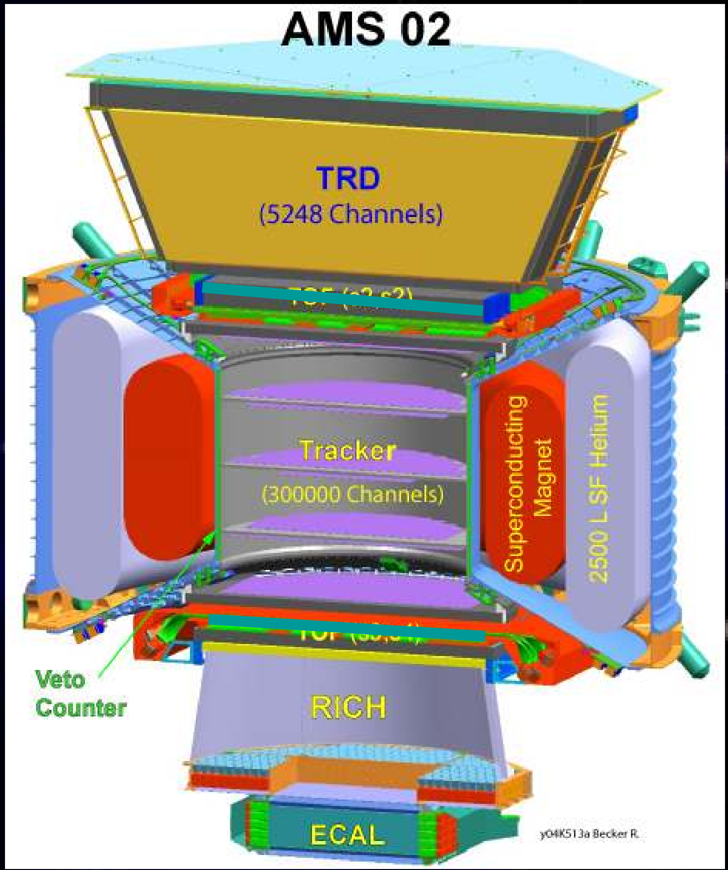


Fleece radiator + straw tubes (Xe:CO_2)

e/p separation > 10^2 up to 300 GeV

3D tracking

Time of Flight (TOF)



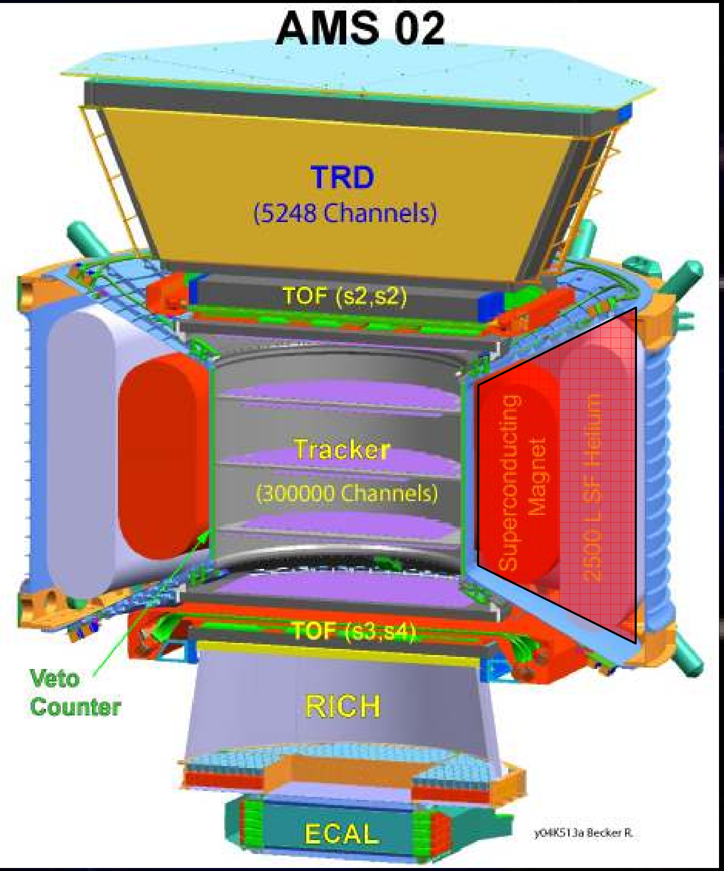
2+2 layers of scintillators, Δt ~160 ps

Main Trigger

Z **separation**

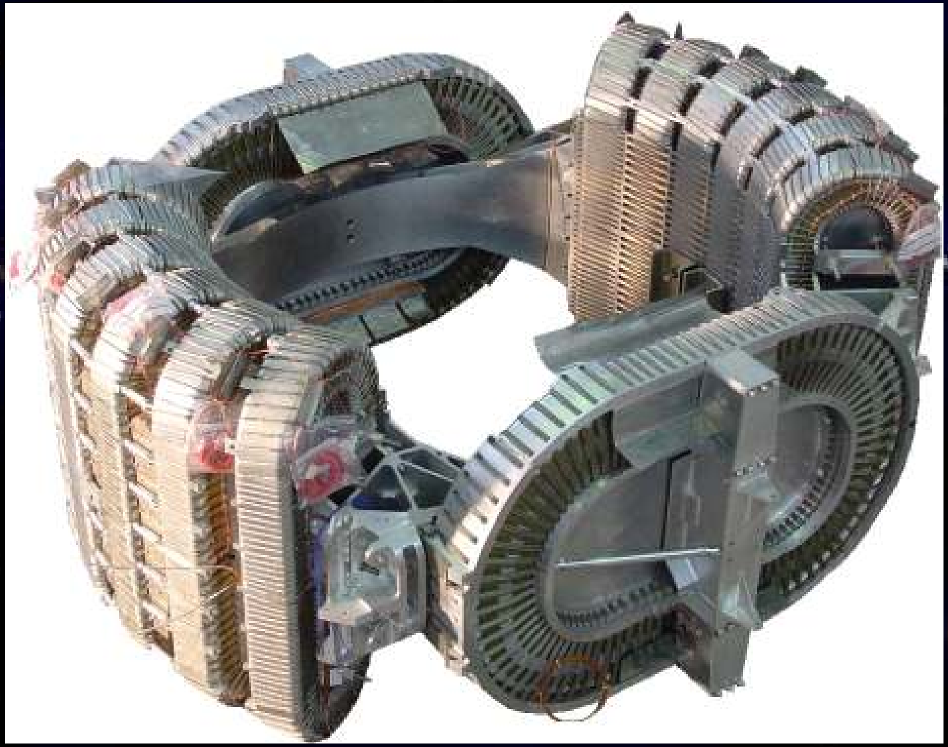
β with few % precision

Superconducting Magnet



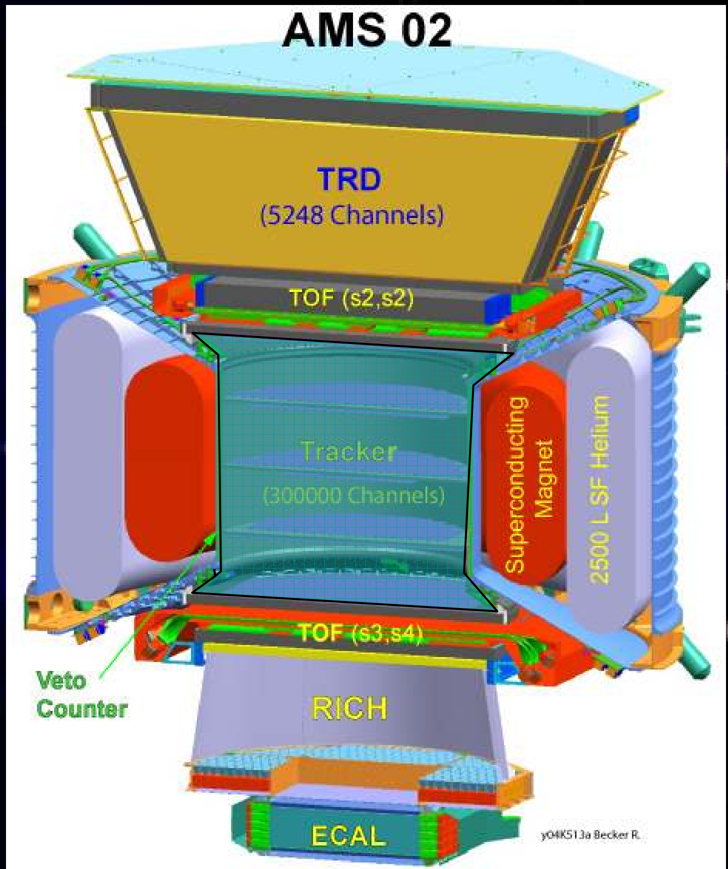
Coils cooled to 1.8 K by 2.5 m^3 of superfluid He

Contained dipolar field of $BL^2 = 0.85\ Tm^2$



First Superconducting Magnet ever operating in Space!

Silicon Tracker

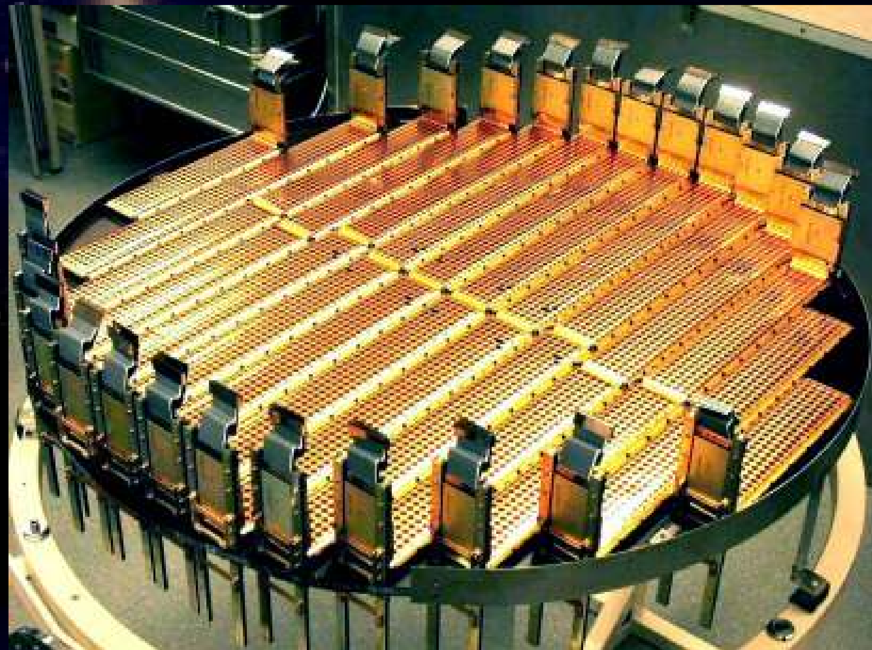


8 layers double sided silicon microstrip detector

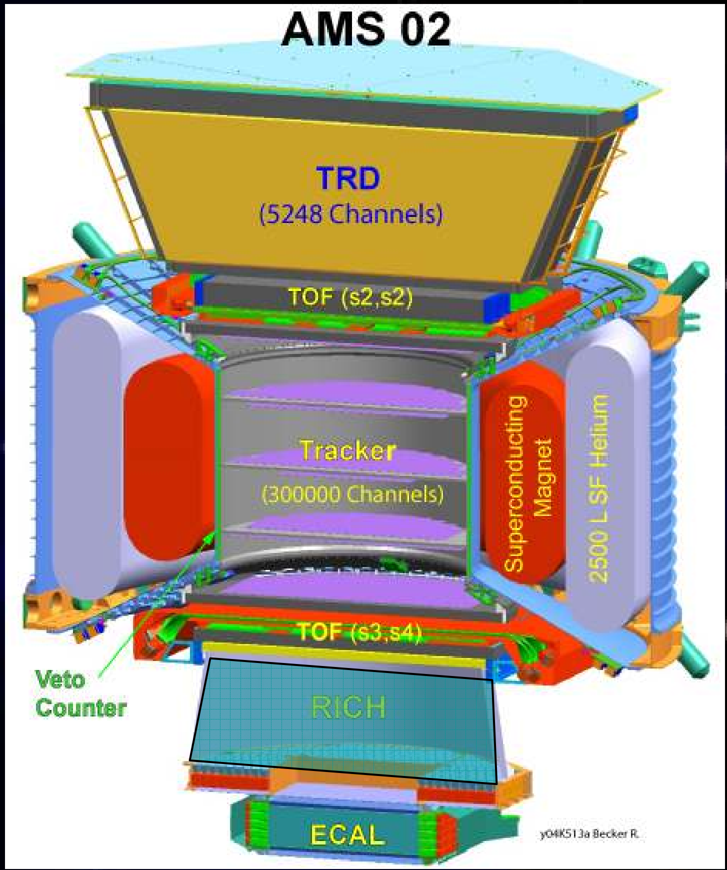
Z separation

***R* up to 2-3 TeV**

σ_R < 2% for *R* < 10 GeV



Ring Imaging Cherenkov (RICH)

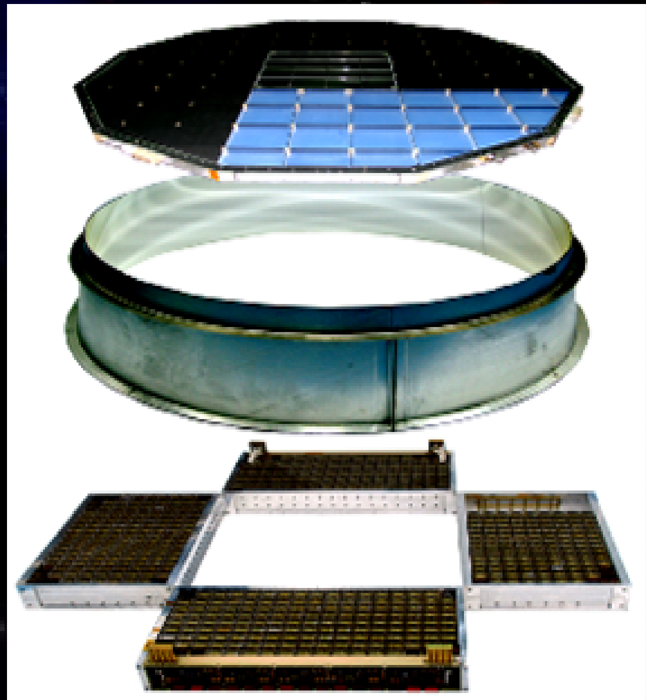


2 Radiators: NaF (center), Aerogel (elsewhere)

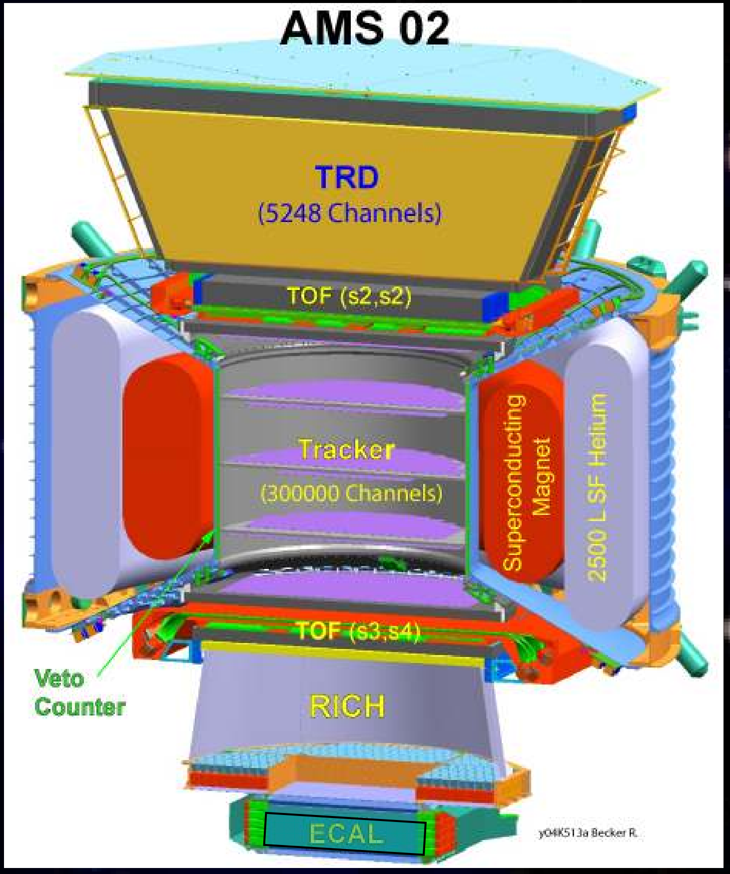
Z **and isotopes separation**

σ_{mass} **= 2% below 10 GeV/n**

β **with 0.1% precision**



Electromagnetic Calorimeter



9 superlayers of Lead + Scint. Fibers

Standalone Trigger

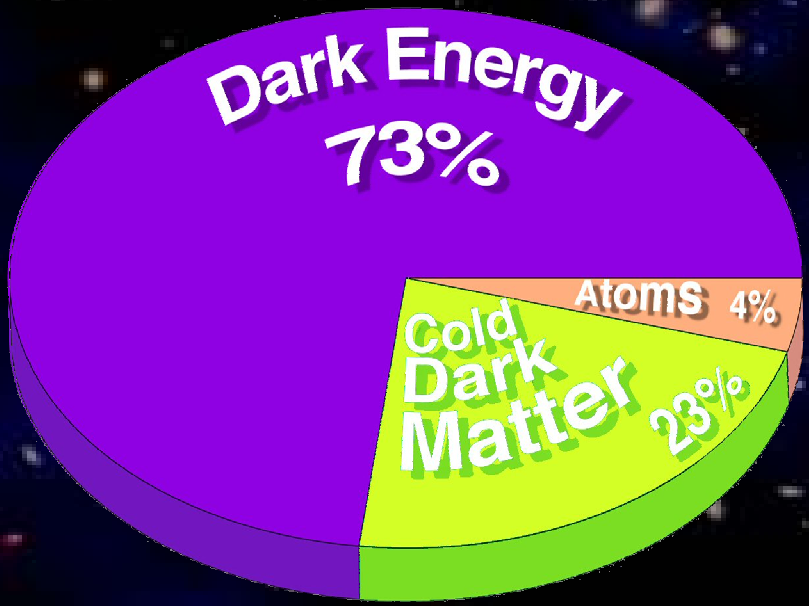
$e^{\pm}$, γ detection

σ_E <3% for E > 10 GeV

e/p separation > 10^3

3D imaging

Origin of Dark matter



Several models provide CDM candidates (WIMPS)

R-parity conserving Supersymmetric models
Lightest SUSY particle:
neutralino χ

Extra-dimensional models
Lightest Kaluza-Klein particle:
n=1 mode of U(1) gauge boson $B^{(1)}$

May be discovered at LCH?

- Difficult to correlate with CDM
- Part of the parameter space not accessible

→ **Astrophysical detection of relic WIMPs is needed**

Indirect search of CDM = detection of WIMP annihilation products

$\chi\chi$ annihilations can produce

Neutrinos

- direct production
- W decay
- Heavy Quarks decay
- charged Pions decay

e^+

- direct production (strongly suppressed): $E_e = m_X$
- W decay
- Heavy Quarks decay
- Leptons and charged Pions decay

Photons

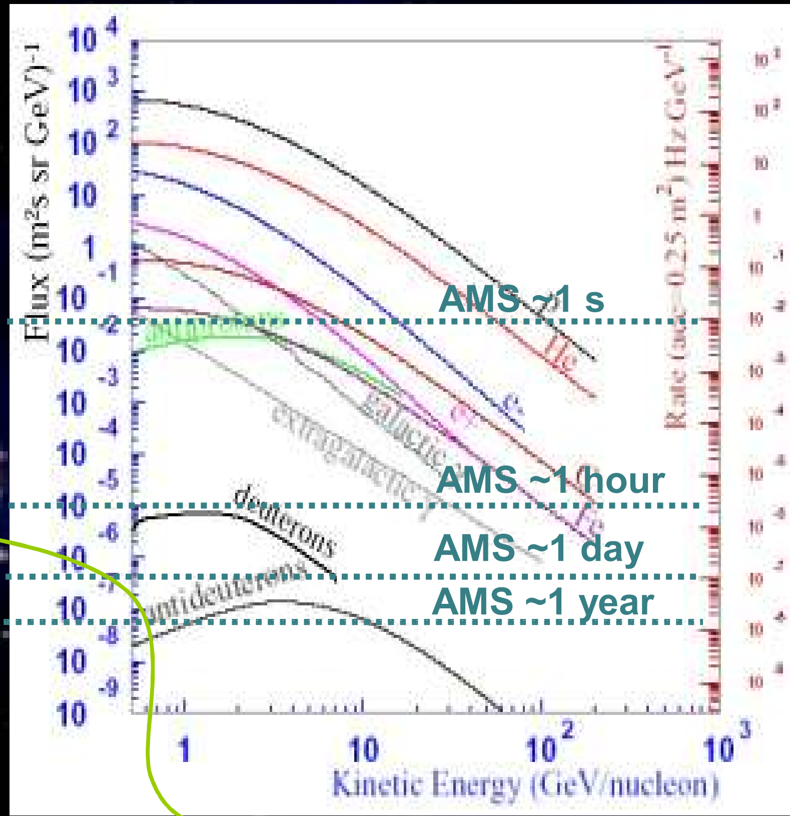
- direct production : $E_\gamma = m_X$
- decay of neutral Pions

$\bar{p}$

- indirect production dominant
- Hadronization : $E_h << m_X$

Antideuterons

- no direct production
- Hadronization + coalescence: $E_h << m_X$



Channels accessible to AMS

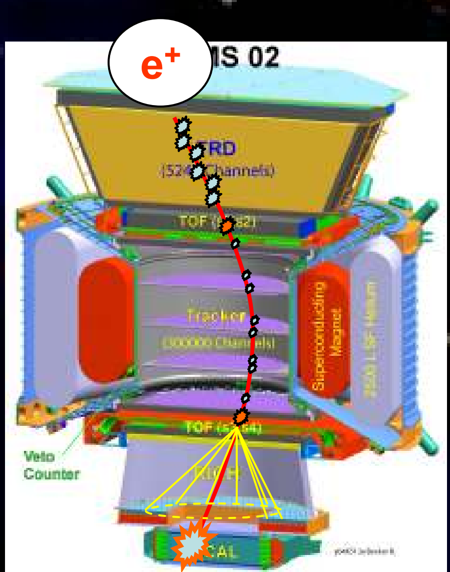
Dark matter search: Positrons

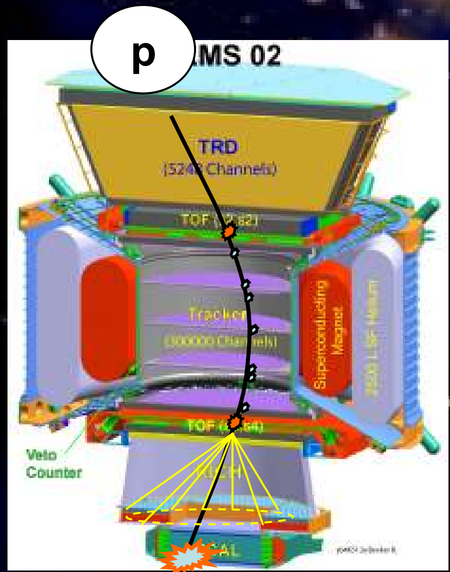
An excess in the 10 GeV region has been reported by HEAT based on a ~10^2 positrons sample

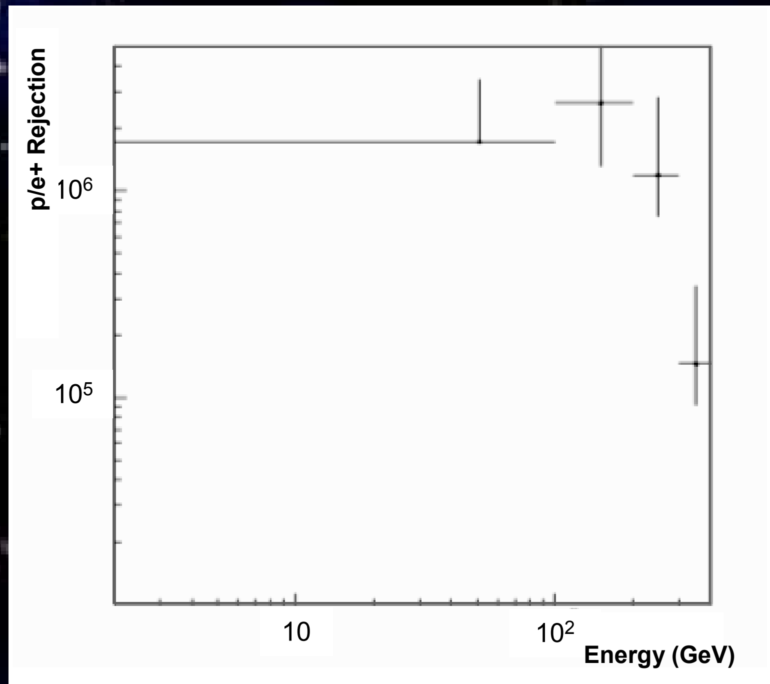
AMS will collect about 10^5 positrons in the $10 < E < 50$ GeV region, in 3 years

Main background sources:

	rel. abundance	rejection factor
protons	~ 10^4	10^2 - 10^3 [TRD] x 10^3 [ECAL] ≥ 10^5
electrons	~ 10	10^4 [TOF+Tracker]

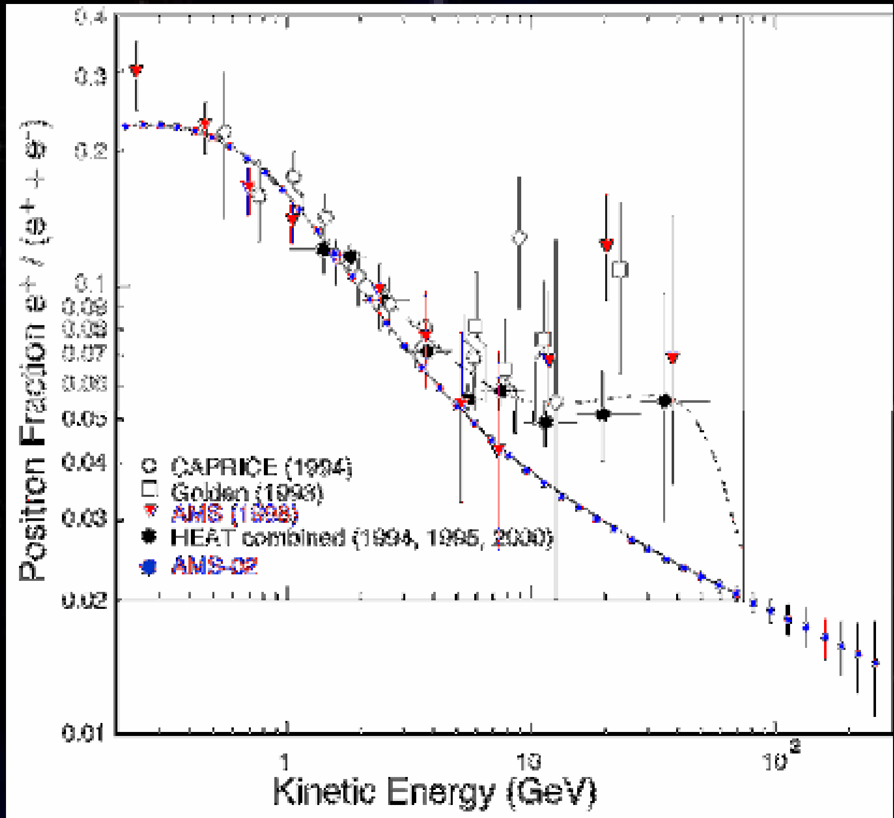






Dark matter search: Positrons

Example of **neutralino annihiliation signals** observed by AMS in the **positron spectrum** with the boost factors* that fit the HEAT data and motivated with a inhomogenous dark matter density (*clumpiness*)

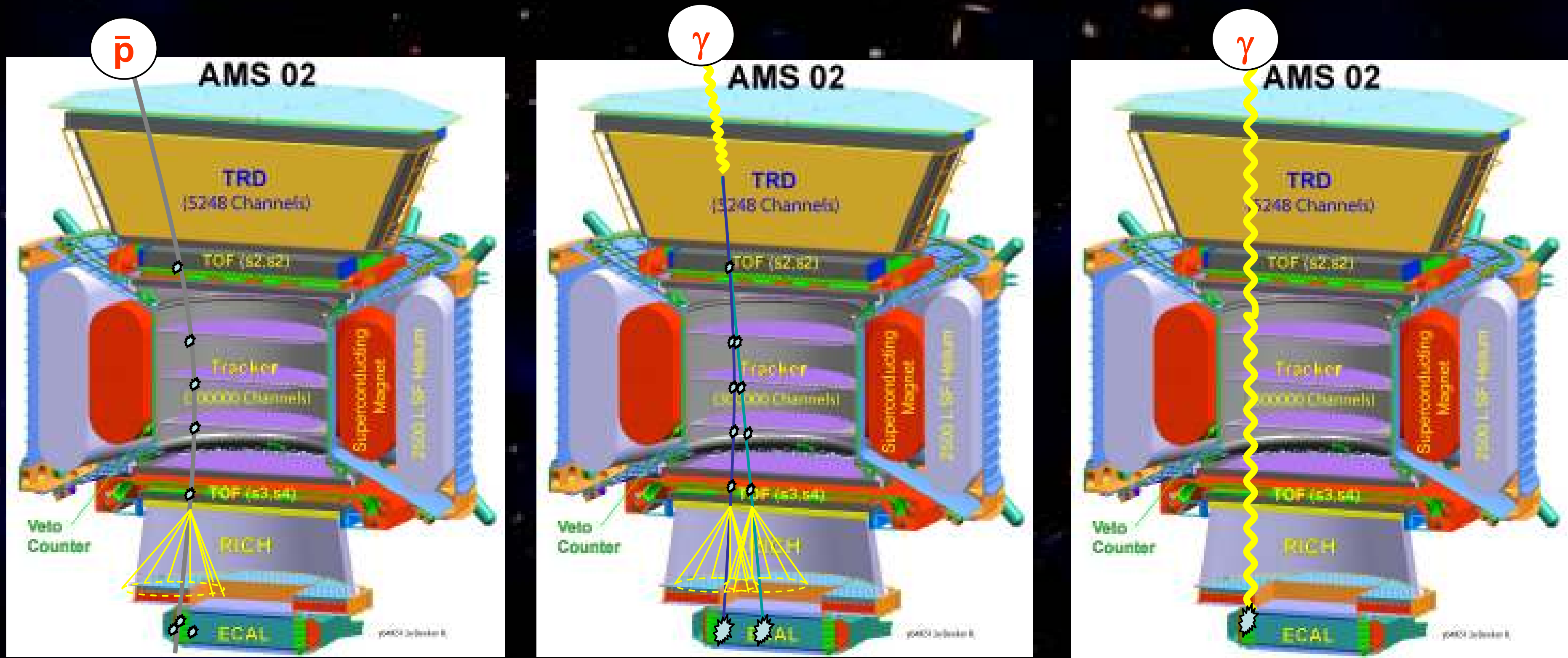


χ gaugino dominated

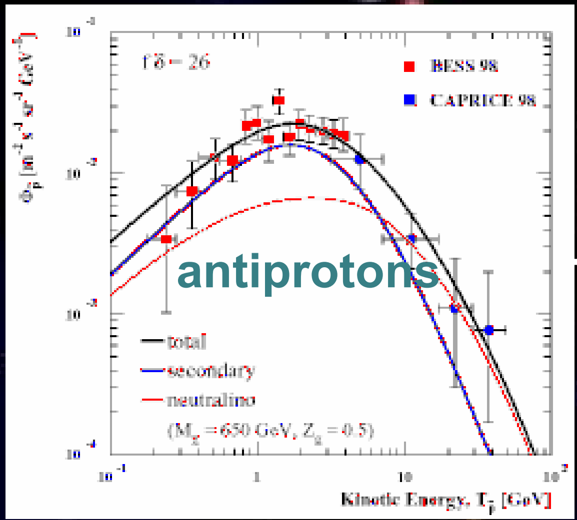
m_χ = 91 GeV

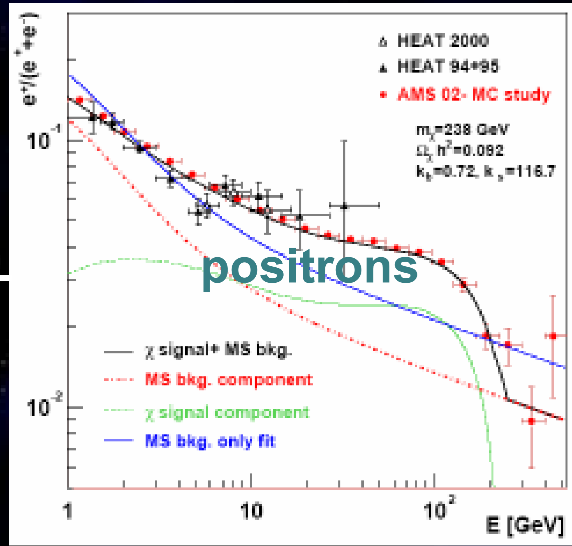
*Baltz et al., Ph.Rev D65, 063511

Dark matter search: Antiprotons & Photons

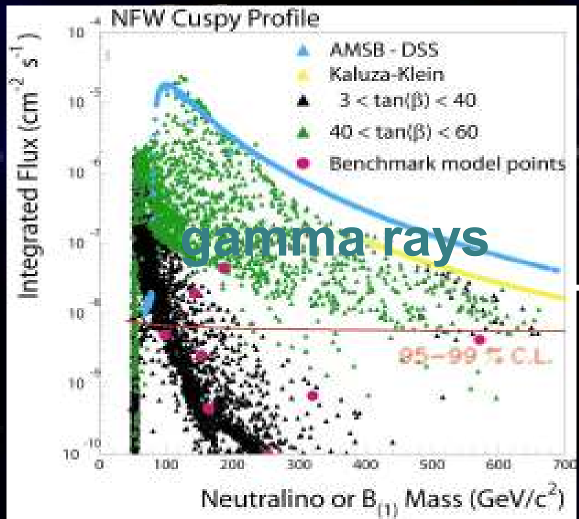


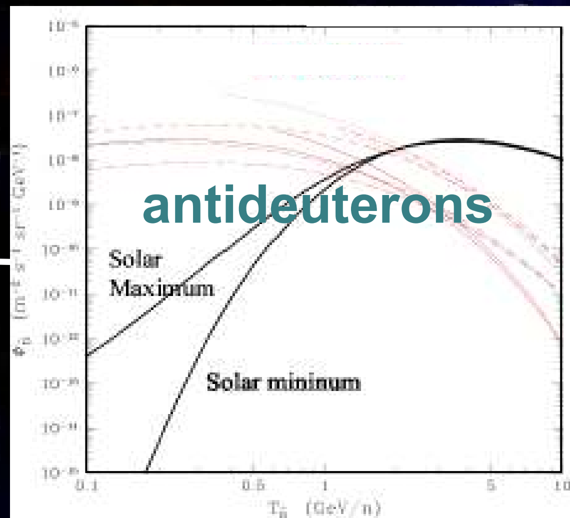
Dark matter search: unique feature of AMS-02





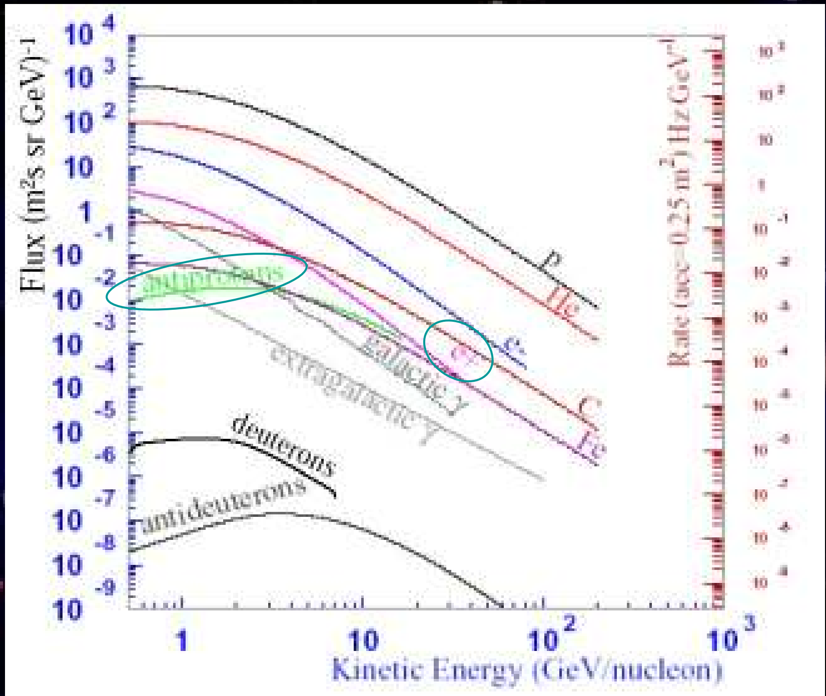
Combining searches in **different channels** increases confidence to **DM signals**





Origin of Antimatter

- In the Big Bang theory **matter** and **antimatter** are created with **equal abundances**
- The disappearance of antimatter requires **barion number** violation and **another source of CP violation**



Antiparticles are produced in collisions between high energy particles and are observed in the Cosmic Rays

$\varphi(e^+)/\ \varphi(e^-) \sim 10^{-1}$ at 10 GeV

$\varphi(\overline{p})\ /\ \varphi(p) \sim 10^{-5}$ at 10 GeV

An **antihelium nucleus** has very low probability of being produced in collisions: $n(\overline{He})/n(He) \approx 10^{-6} - 10^{-8}$

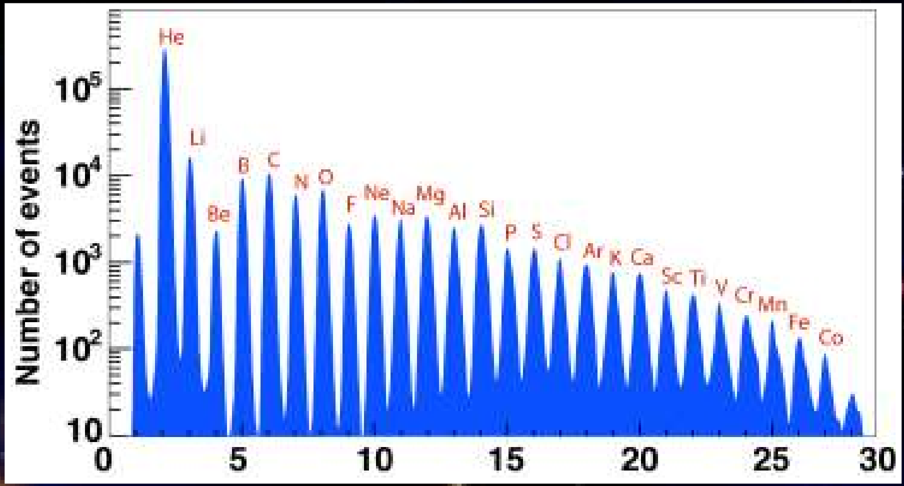
⟹ its detection indicates the existence of an **antimatter area** somewhere in the Universe

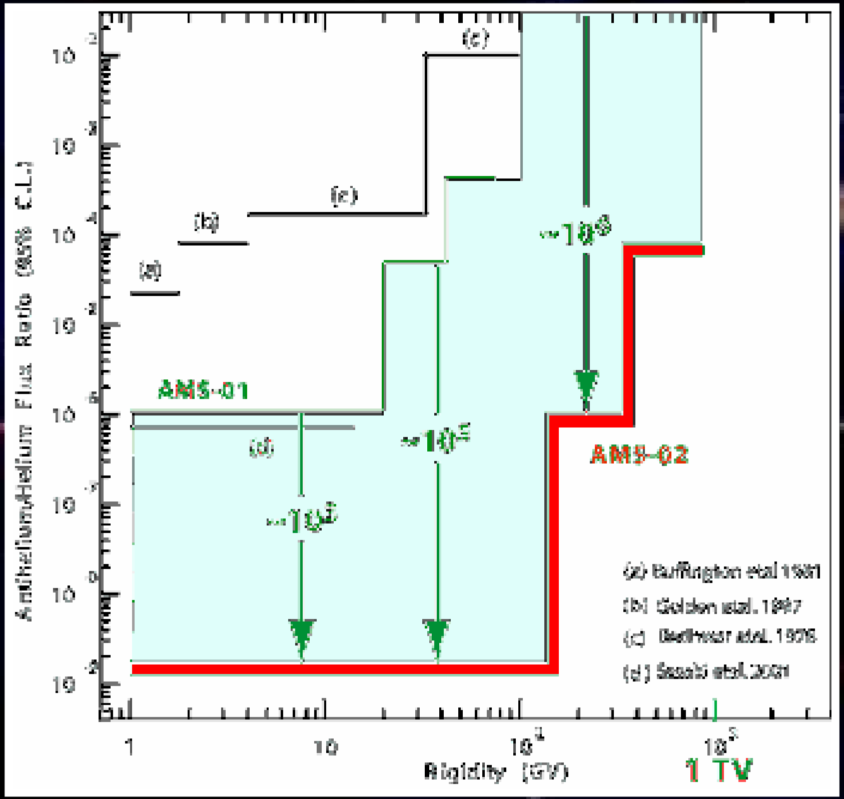
Expected limits on anti-He

AMS will collect in three years $2x10^9$ nuclei with energies up to 2 TeV

Sensitivity up to anti-Iron

The limit put by precursor flight AMS-01 will be increased of a factor 10^3





Sensitivity: if no antinucleus is observed -> there is no antimatter to the edge of the observable universe (~ 1000 Mpc)

Conclusions

- *The AMS experiment, during its 3 year mission, will be able to measure spectra of particles and nuclei up to Iron in the GeV-TeV range*

- ***Dark matter indirect search:***
- measure **simultaneously** and with unprecedented precision the rates and spectra of *positrons, photons, antiprotons, antideuteron*
  - *confirm or disprove with high accuracy the excess in HEAT positron data in the few GeV region*
  - *a γ signal from the galactic center will be visible in AMS in the case of cuspy halo profile or extra enhancements*
  - *very accurate measurement of the high energy tail of the antiproton spectrum*
- Several models for Dark Matter candidates can be constrained by the new AMS data

- ***Antimatter search:***
- If no antinucleus is observed the hypothesis of *barion asymmetry* will be strongly favoured as no antimatter areas are present in the observable universe

- ***Accurate study of CR composition and energy spectrum (H, He, B/C, $^{9}Be/^{10}Be$)***
- ***Search of new types of matter (strangelets)***

The integration of the detector is almost completed

In 2009, AMS-02 will be ready at NASA KSC for the launch to the ISS


Thank you!