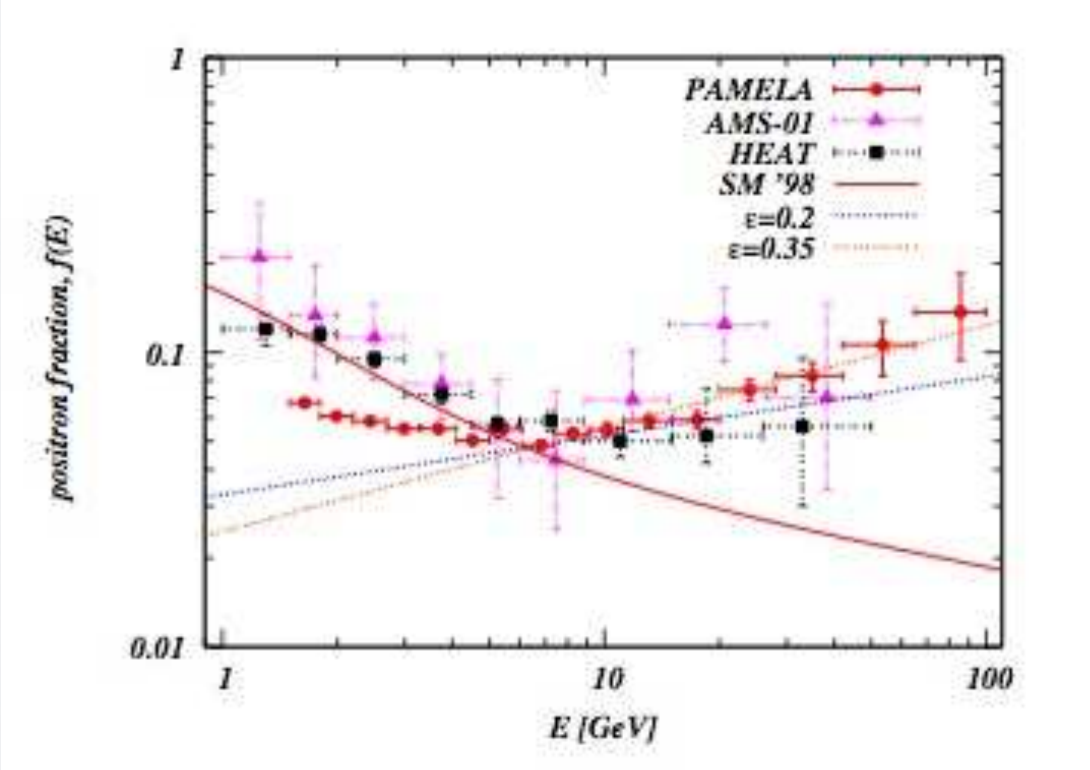
ASTROPARTICLE PHYSICS WITH AMS02

Marco Incagli - INFN Pisa
SCINEGHE - 7 oct 2009

Primary Component in $e^{\pm}$

- PAMELA has observed an increase in the positron fraction, confirming previous hints from other experiments like HEAT and AMS01; Fermi has confirmed the excess in $e^{+}+e^{-}$ spectrum



- The most likely interpretation is that an additional primary source of high energy $e^{\pm}$ exists or a secondary acceleration mechanism is at work

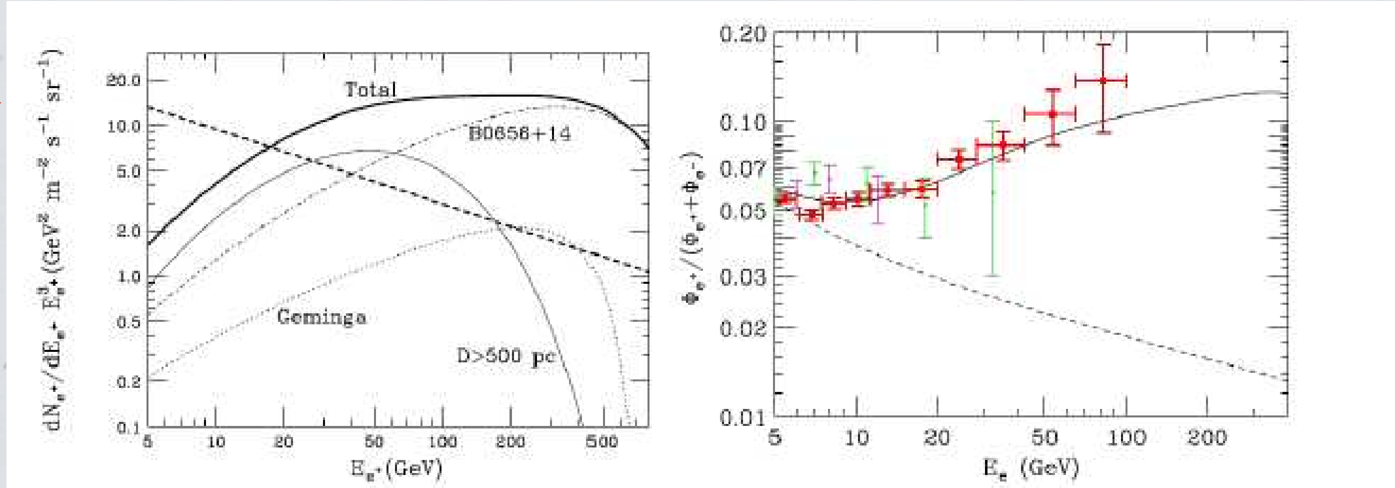
- For a discussion on alternatives see Serpico arXiv:0810.4846

What is this "primary" component?

1. Conventional sources:
    1. pulsar emission
    2. cosmic rays reacceleration (I will use "primary" also for this, although it really is an acceleration of secondaries)
2. Non conventional sources:
    1. dark matter annihilation/decay
3. A combination of the above

Pulsar emission

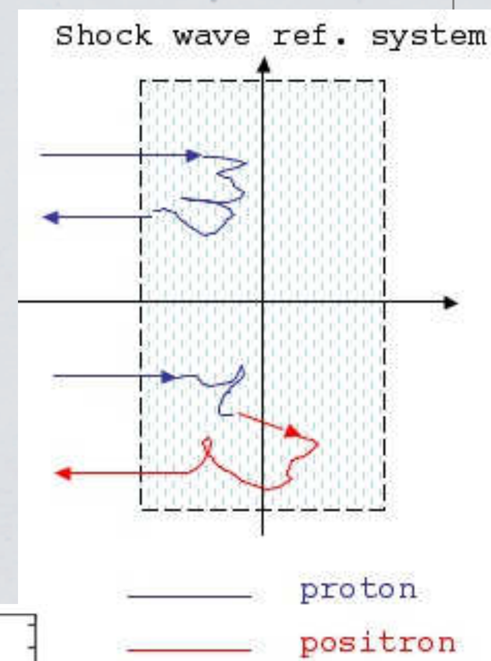
- Neutron stars with magnetic axis forming an angle with rotation axis
- Dipole emission with photons converted in e^+e^- pairs (no pp pairs produced!)
- Data are reproduced assuming a cutoff at ~600GeV and a production efficiency of 5-10%
- Pulsar age is ~10^5 years : only few in our vicinity (~kpc)

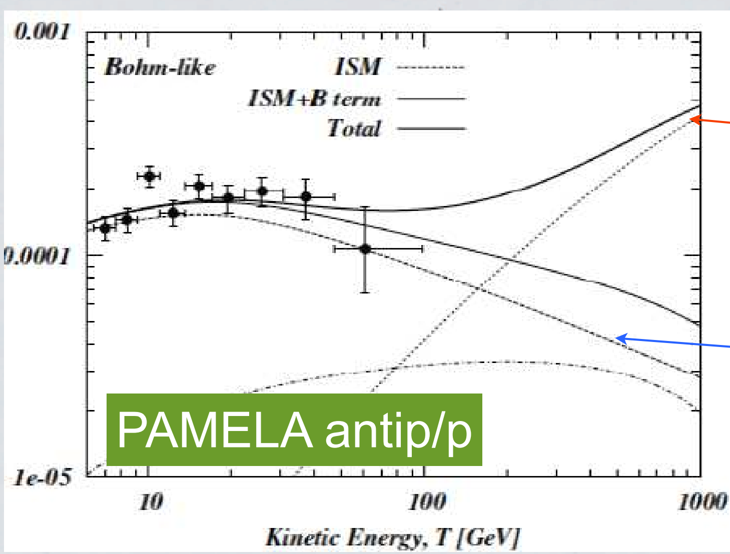


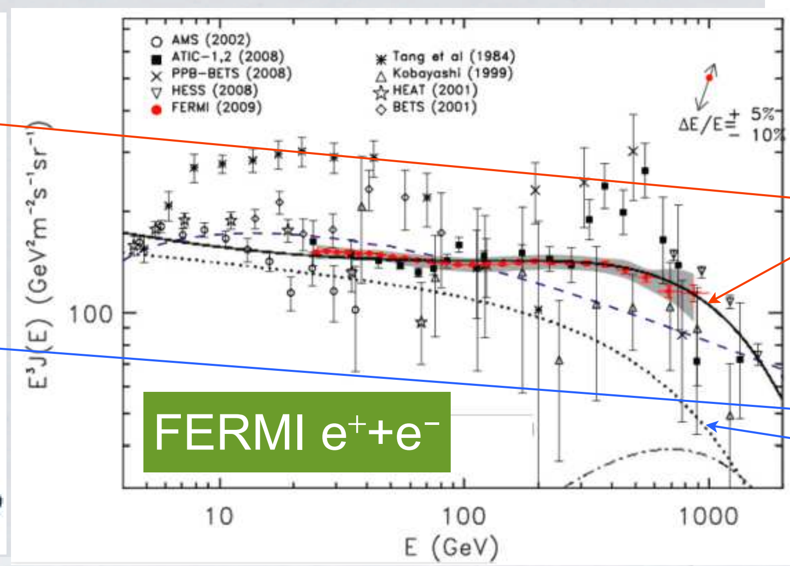
Left: Contributions to the positron spectrum from B0656+14, Geminga and pulsars with $D > 400\,\mathrm{pc}$ and positron fraction (right) for a Galactic pulsar birthrate of $1/25\,\mathrm{yr}^{-1}$, injection spectrum $\propto E^{-1.5} exp(-E/600\mathrm{GeV})$ and 3×10^{47} erg in pairs.

Cosmic Rays reacceleration

- **Fermi mechanism**: cosmic rays are accelerated in interactions with supernovae shock waves
- **Reacceleration** `(Blasi PRL 103,051104(2009))`: when secondaries are produced inside the acceleration region
- The same mechanism produces an excess in antiprotons

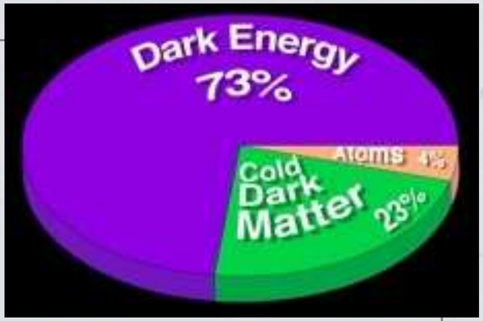






reacceleration

standard spectrum



Dark Matter

WMAP: $\Omega_M h^2 = 0.135 \pm 0.008$; $\Omega_b h^2 = 0.0224 \pm 0.0009$

* Dark Matter makes up ~85% of existing matter in the universe
* Many candidates for Dark Matter exist, with cross sections and masses spanning a wide range of values

Table 1. Properties of various Dark Matter Candidates

Type	Particle Spin	Approximate Mass Scale
Axion	0	μeV-meV
Inert Higgs Doublet	0	50 GeV
Sterile Neutrino	1/2	keV
Neutralino	1/2	10 GeV - 10 TeV
Kaluza-Klein UED	1	TeV

Bergstrom

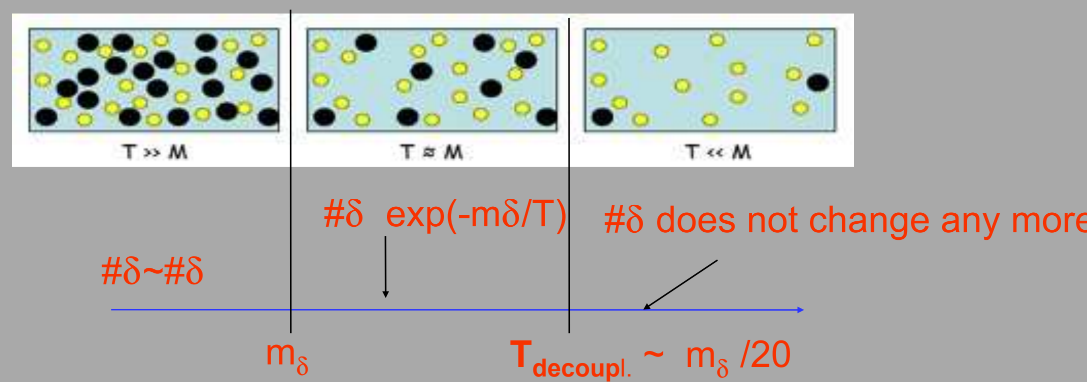
WIMPs (Weakly Interacting Massive Particles)

- however WIMPs have some special characteristics:

  1. singular coincidence between Particle Standard Model and Cosmological Model to provide valid candidates at the TeV scale

“Stolen” from A.Masiero SIF09 - see his talk for details

Ex: a particle √, in thermal equilibrium with photons, annihilates with a cross section $\delta_A \sim \surd / m_{\surd}^2$



It’s relic density depends on particle physics (δ_A) and on cosmological quantities (T_0, G, ...)

$$\Omega_\chi h^2 \simeq const. \cdot \frac{T_0^3}{M_{\rm Pl}^3 \langle \sigma_A v \rangle} \simeq \frac{0.1 \text{ pb} \cdot c}{\langle \sigma_A v \rangle}$$

If $m_{\surd} \sim 10^2 - 10^3$GeV => $\surd_{\surd} h^2 \sim 10^{-2} - 10^{-1}$!!!

WIMPs (Weakly Interacting Massive Particles)

* however WIMPs have some special characteristics:

1. singular coincidence between Particle Standard Model and Cosmological Model to provide valid candidates at the TeV scale

2. DM candidates "naturally" exist in theories built non ad hoc: *neutralinos (SUSY), KK particles (Extra Dimensions), inert Higgs (to cancel Λ^2 terms at 1 loop)*

"Stolen" from A.Masiero SIF09 - see his talk for details

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) ENLARGEMENT OF THE SM	(x^μ, θ) Anticomm. Coord.	(x^μ, j^i) New bosonic Coord.	SM part + new part to cancel Λ^2 at 1-Loop
2) SELECTION RULE •DISCRETE SYMM. •STABLE NEW PART.	R-PARITY LSP Neutralino spin 1/2	KK-PARITY LKP spin1	T-PARITY LTP spin0
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

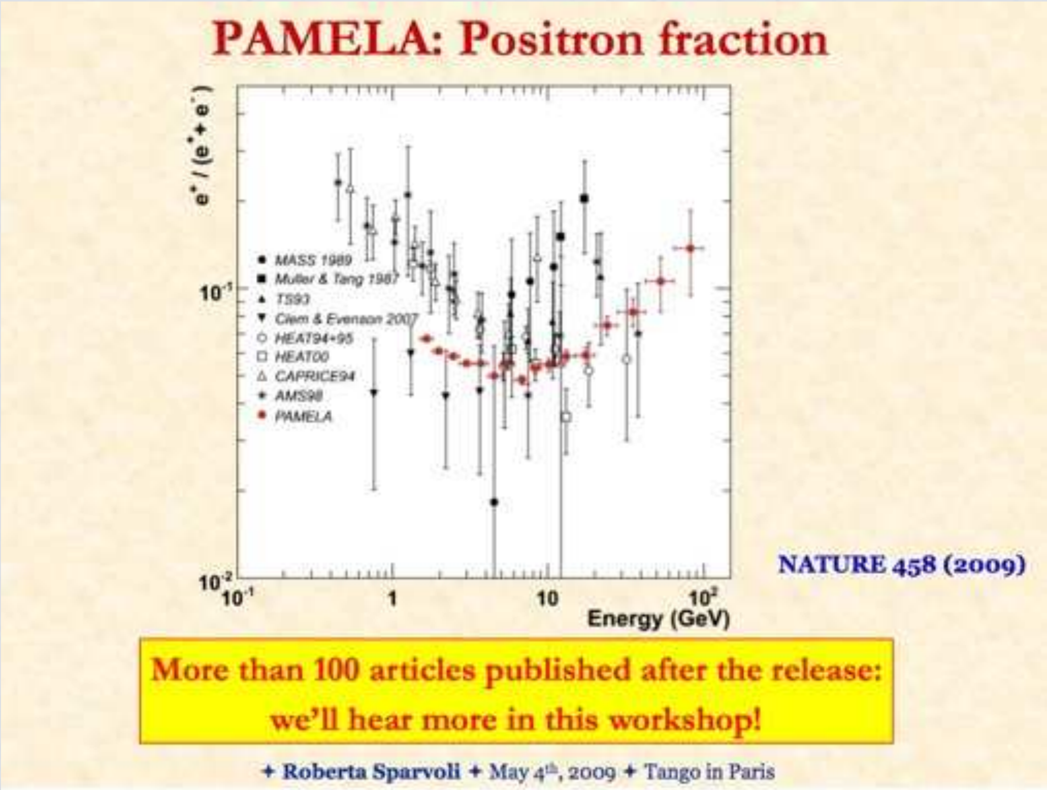
example in SUSY therory: *neutralino annihilation* and production of *positrons, photons, antiprotons and antideuterons*

$$\chi\chi \to W^+W^- \to e^+ + \nu_e + W^-$$
$$\chi\chi \to b\bar{b} \to e^+ + X$$
$$\chi\chi \to \gamma\gamma \quad (via\ loops)$$
$$\chi\chi \to hadrons \to \pi^0 + X \to \gamma\gamma + X$$
$$\chi\chi \to hadrons \to \bar{p} + Y$$
$$\chi\chi \to hadrons \to \bar{D} + Y$$

How is it possible to discriminate among different solutions?

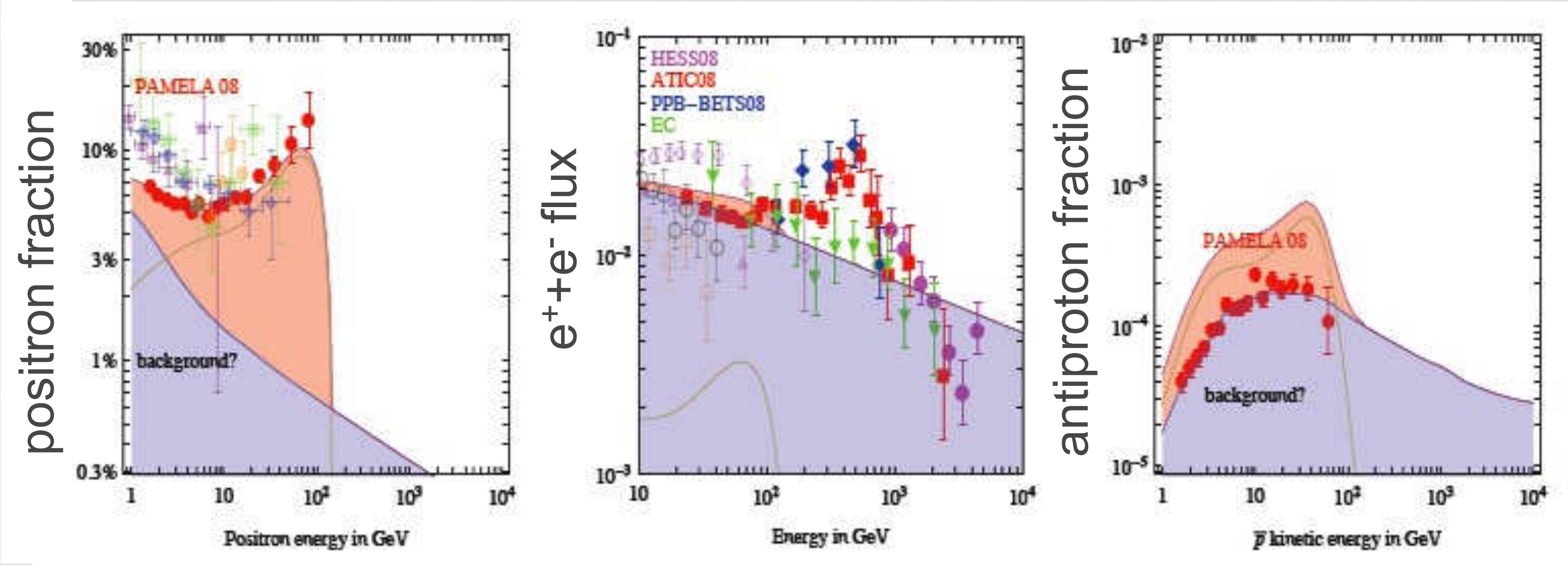
1. Collect high statistics with improved resolution in a larger energy window (= *more and better* approach): example prePAMELA vs postPAMELA

2. Compare different channels and constraint the theory (= *biodiversity* approach): *more later*



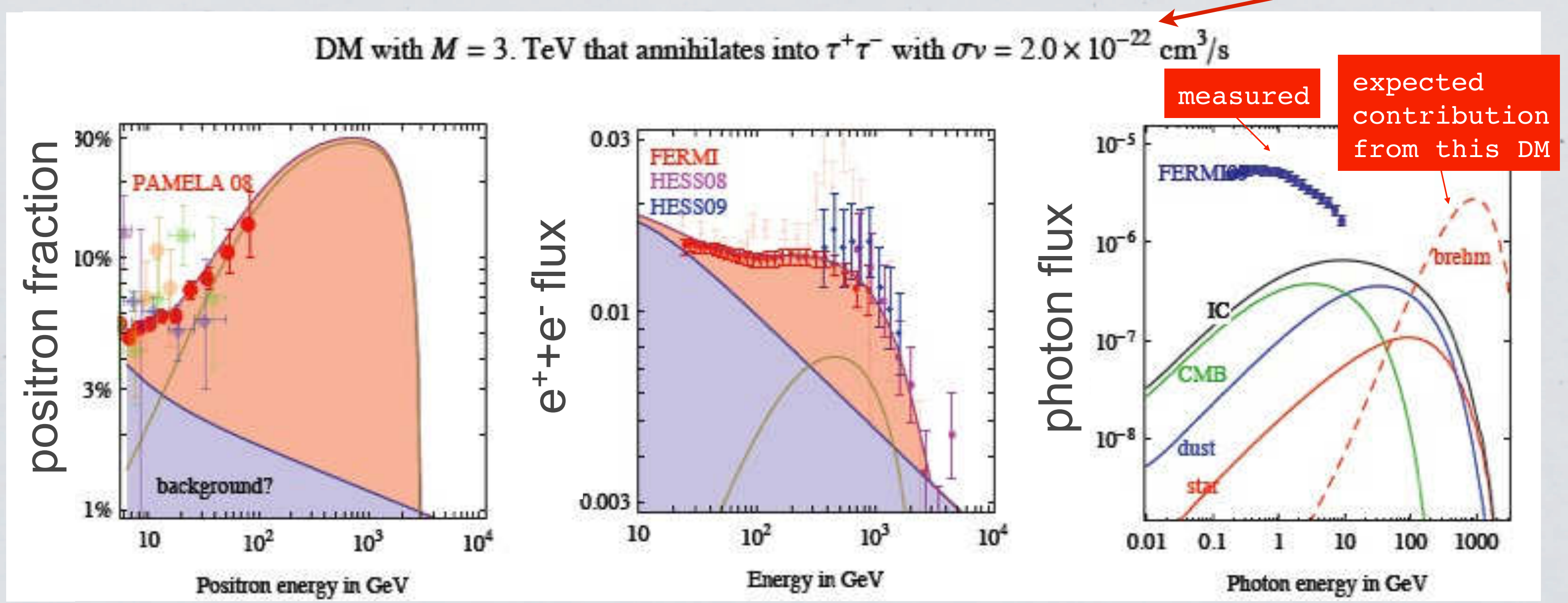
The richness of *biodiversity*

- A Dark Matter candidate of M_τ=150GeV which decays in W^+W^- well explains *positrons data*, but it fails in describing *e^++e^- flux*, as measured by ATIC and FERMI, and *antiproton/proton ratio*, measured by PAMELA



DM discovered?

- A different hypothesis: M_τ=3TeV, decay in $\tau^+\tau^-$, BF=10^4



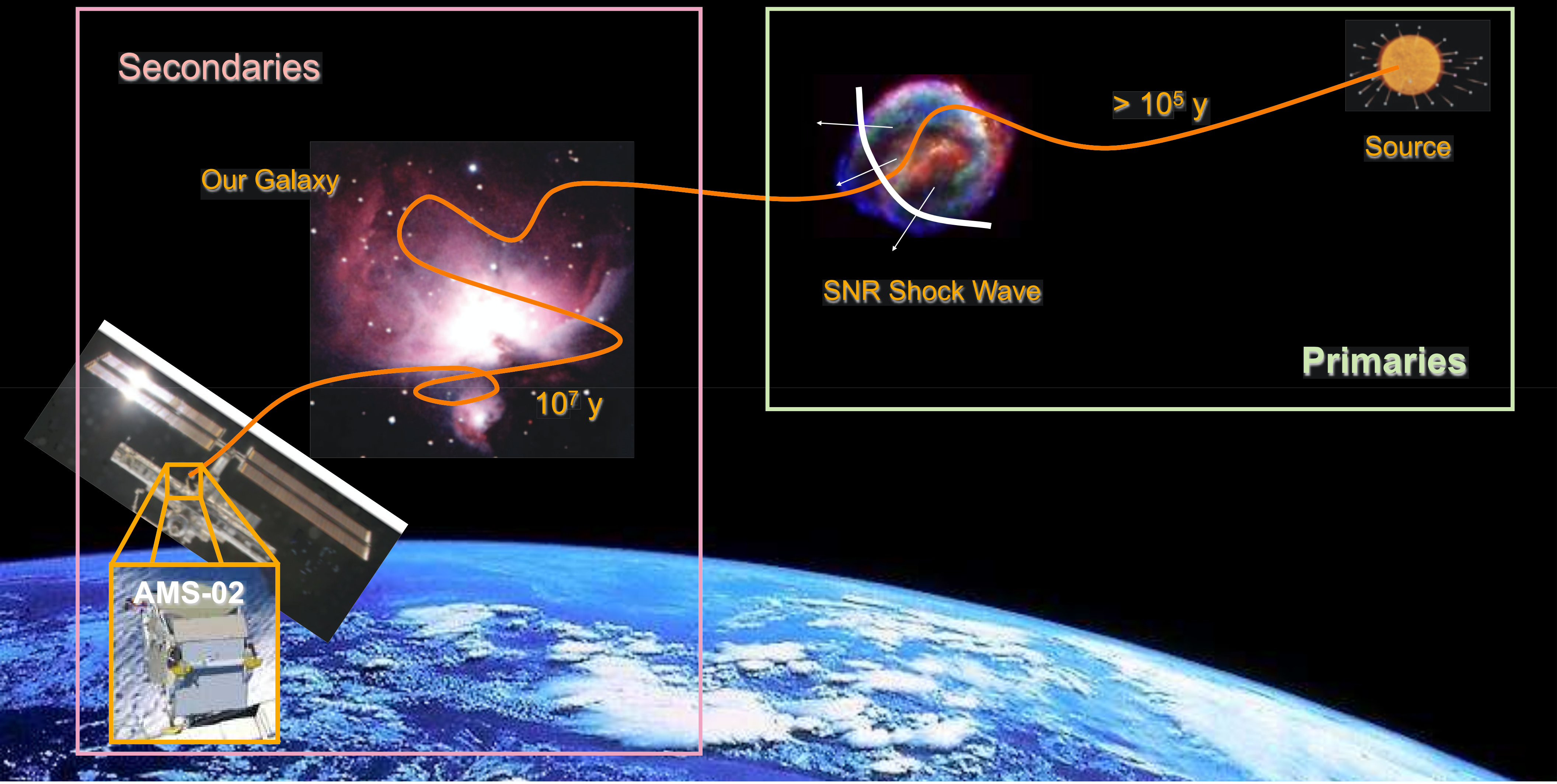
- ...maybe not! Rather unnatural (mostly $\tau^+\tau^-$) and large boost required

Other ingredients to make predictions

- The flux measured on the earth has many contributions:
  - *background due to "standard" cosmic rays*: depends on production mechanism, propagation, acceleration, confinement in our galaxy, interactions with InterStellar Medium, ...
  - *"signal" due to eventual DM*: depends on DM density (squared!), on propagation, ...
- **A new generation experiment should be able to constraint, as much as possible, all these additional sources of incertitude**

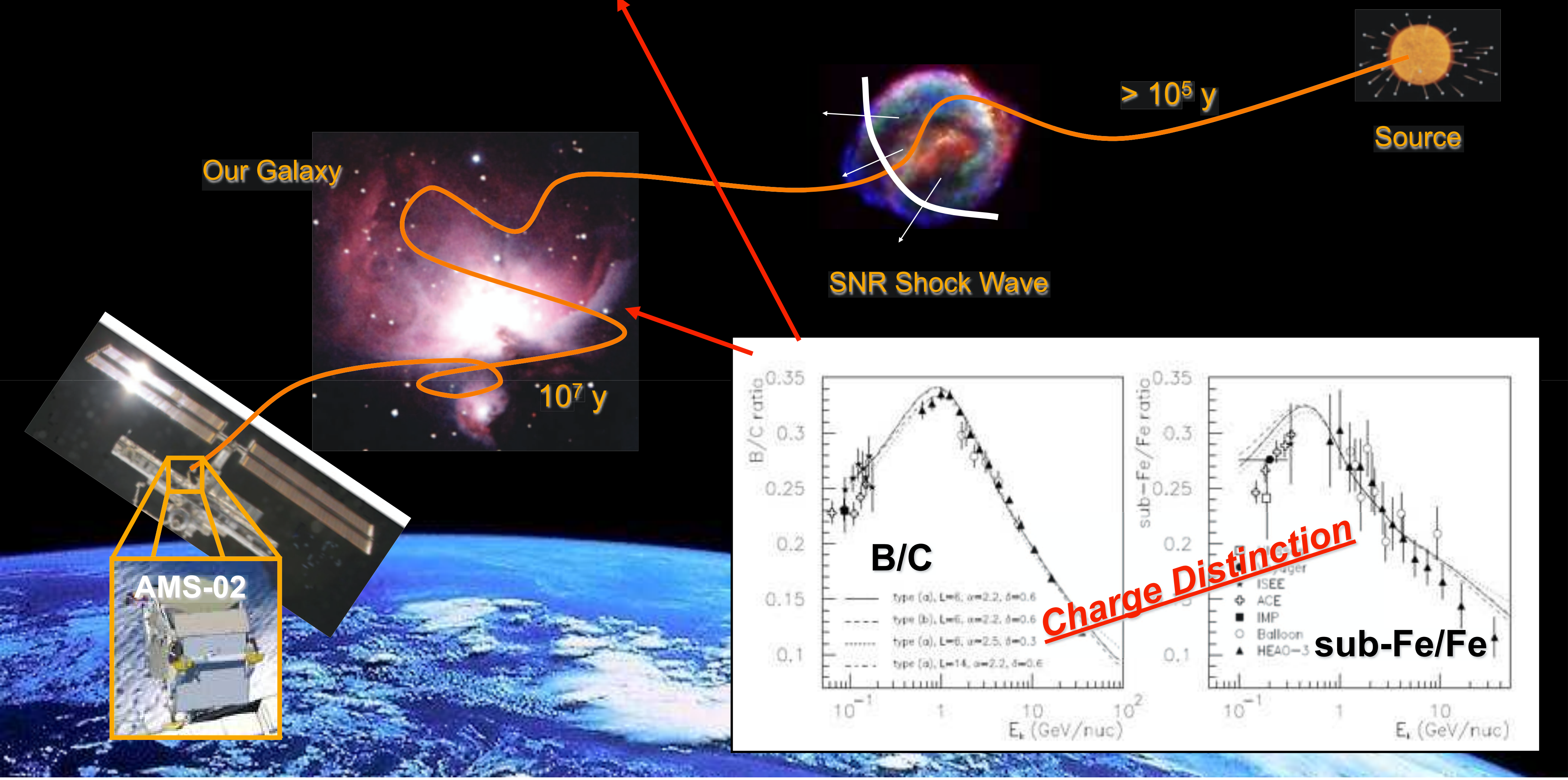
COSMIC RAYS: many incertitudes in production and propagation mechanisms

- These incertitudes affect both the background prediction and the signal propagation from production to detection, in particular for charged particles



COSMIC RAYS: production and propagation

	stable	**δ decay**	**K capture**
primary CR	*big bang and stellar nucleosynthesis*	*age of the origin material (U, Pu, Cm, …)*	*Delay between synthesis and acceleration (^{56}Ni, ^{57}Co)*
secondary CR (dependent from ISM)	*diffusion process (B/C, sub-Fe/Fe)*	*galaxy confinement time (^{10}Be, ^{26}Al, ^{36}Cl, ^{54}Mn)*	*Energy changes (decelerations)*



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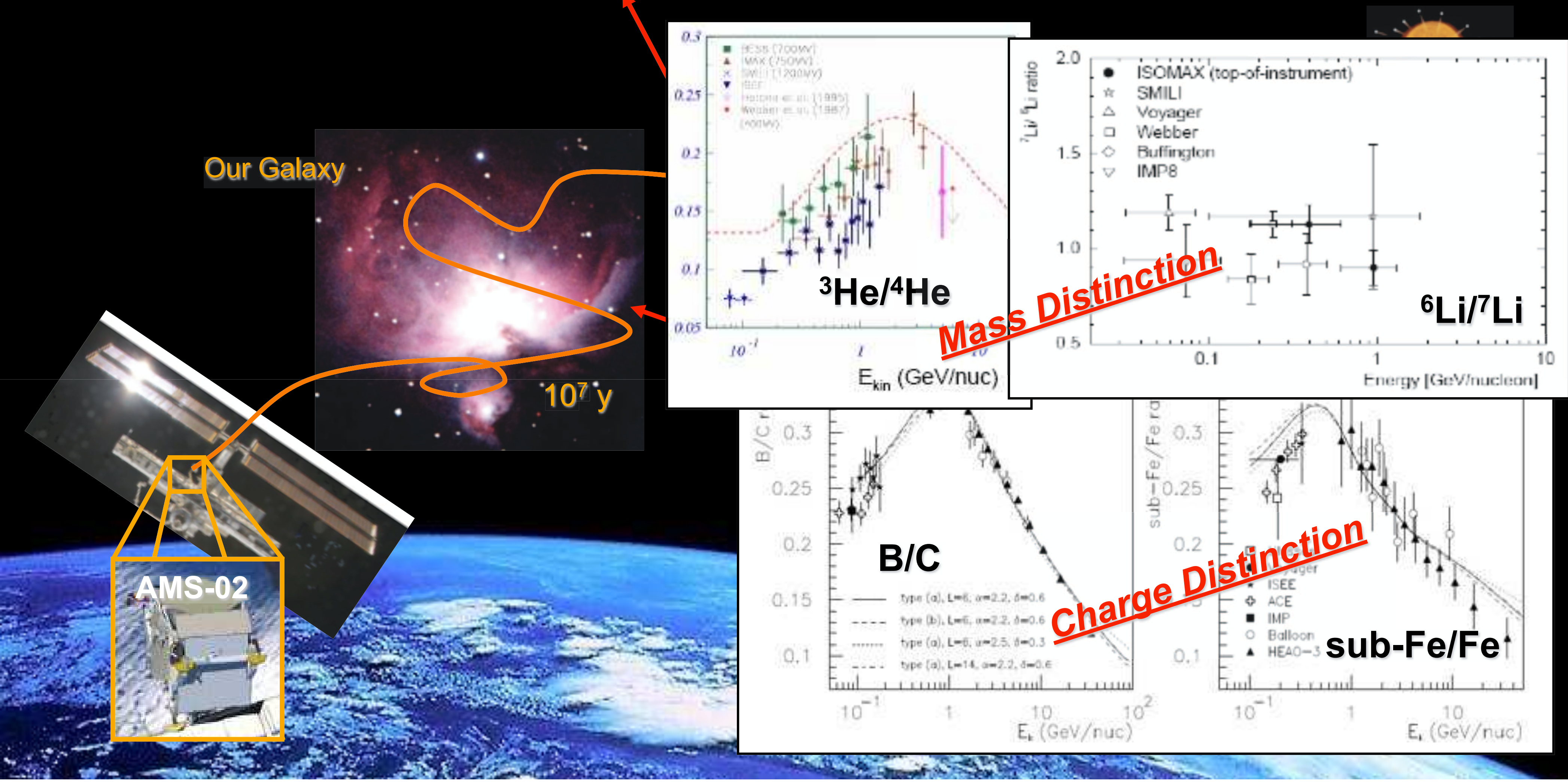

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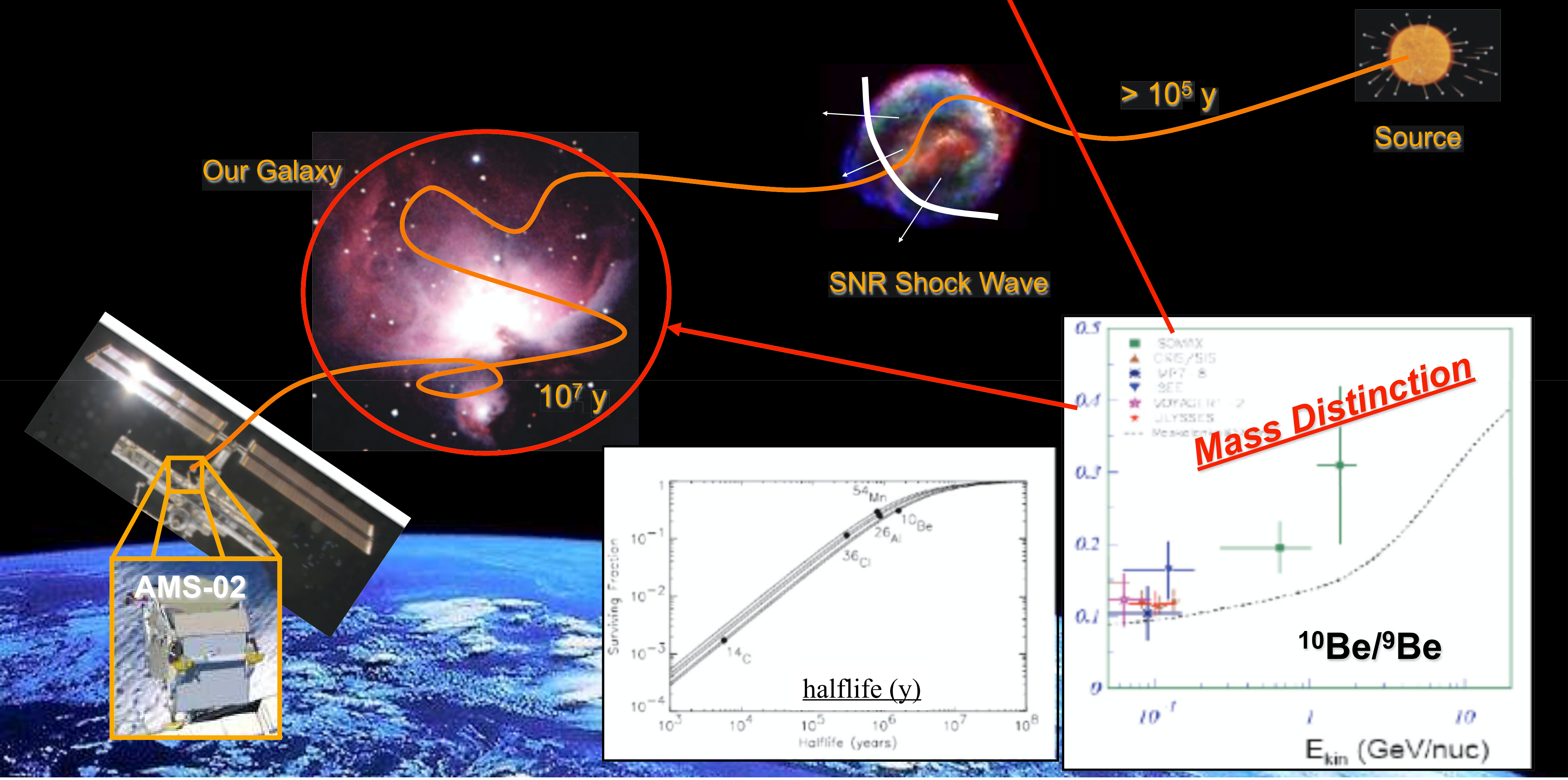
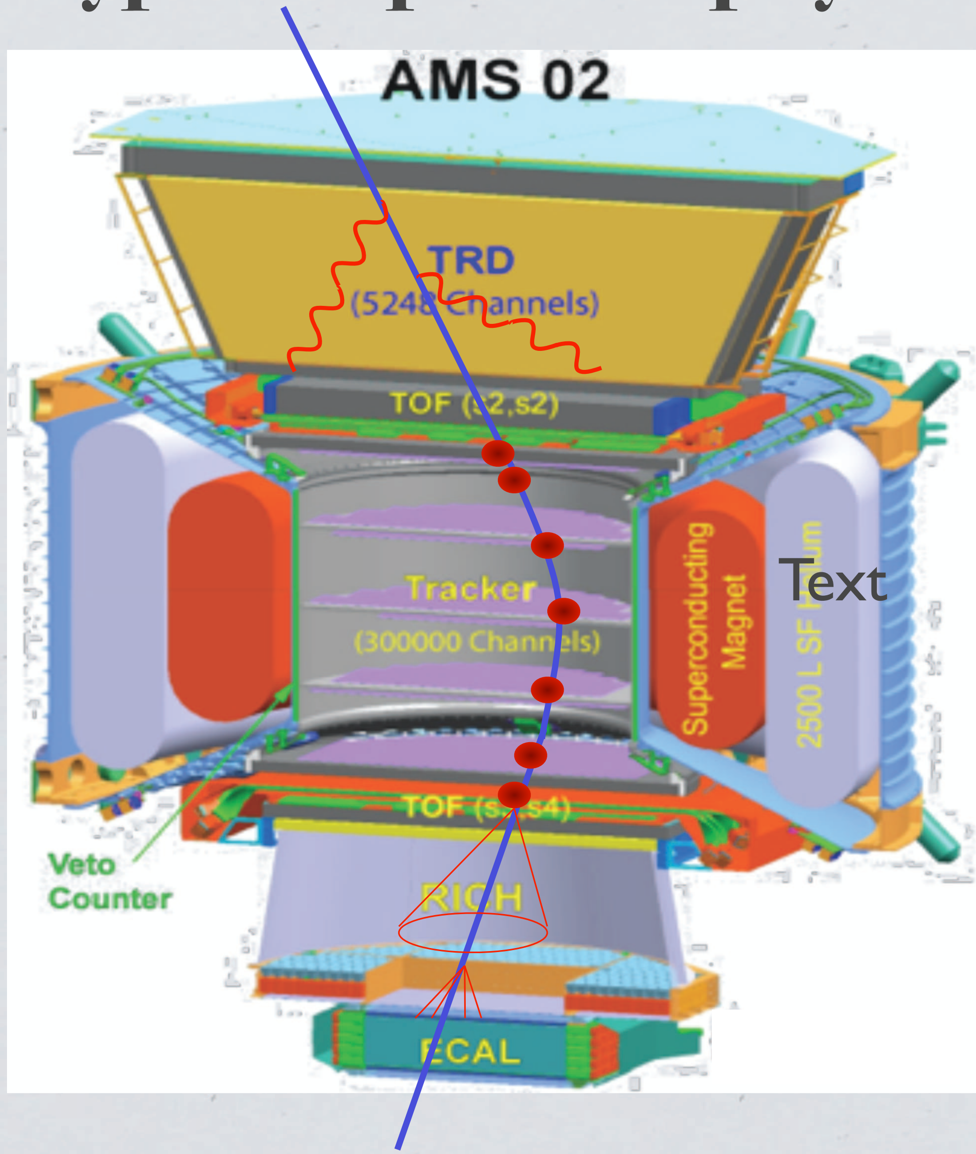


A general purpose experiment

* In summary, an experiment aiming to settle these issues needs:
  * **Magnetic field:** *positive vs negative* charge
  * **Good calorimeter:** e^+ *vs p* (easier for negative charge)
  * **Way to distinguish Z and A:** background predictions and signal propagation
  * **Large statistics:** flux $\sim E(GeV)^{-3}$ so large geometrical acceptance and long integration time necessary to reach E~1TeV
  * **Optimal localization:** outside atmosphere to see primaries

AMS02:
a "typical" particle physics apparatus in space



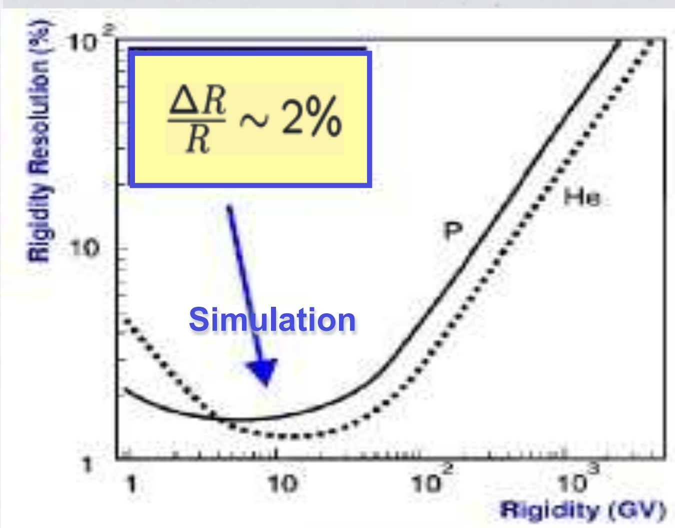
TRD	Xe/CO_2 Straws e/h rej. $>10^2$ 1-300 GeV $0.5m^2sr$
TOF	Trigger (2up+2low) $\delta_{t:}$ = 120ps: δ dE/dX: Z
Superconducting Magnet (0.8 T)	3500liters superfluid He
Silicon Strip Tracker	$6m^2$ p up to 1TV and Z(dE/dX)
RICH	Aerogel/NaF 3δ Sep. A~26 1-12 GeV + Z
ECAL	3D lead/scint-fibre e/h rej. $>10^3$ 1-1000GeV $0.05m^2sr$

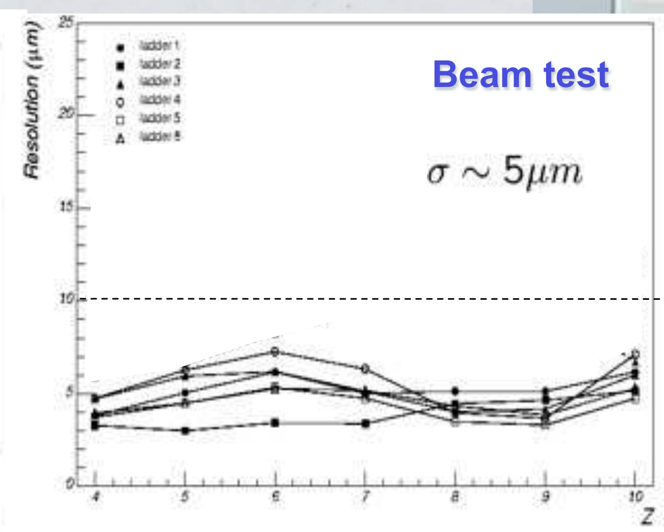
AMS02 performances: rigidity

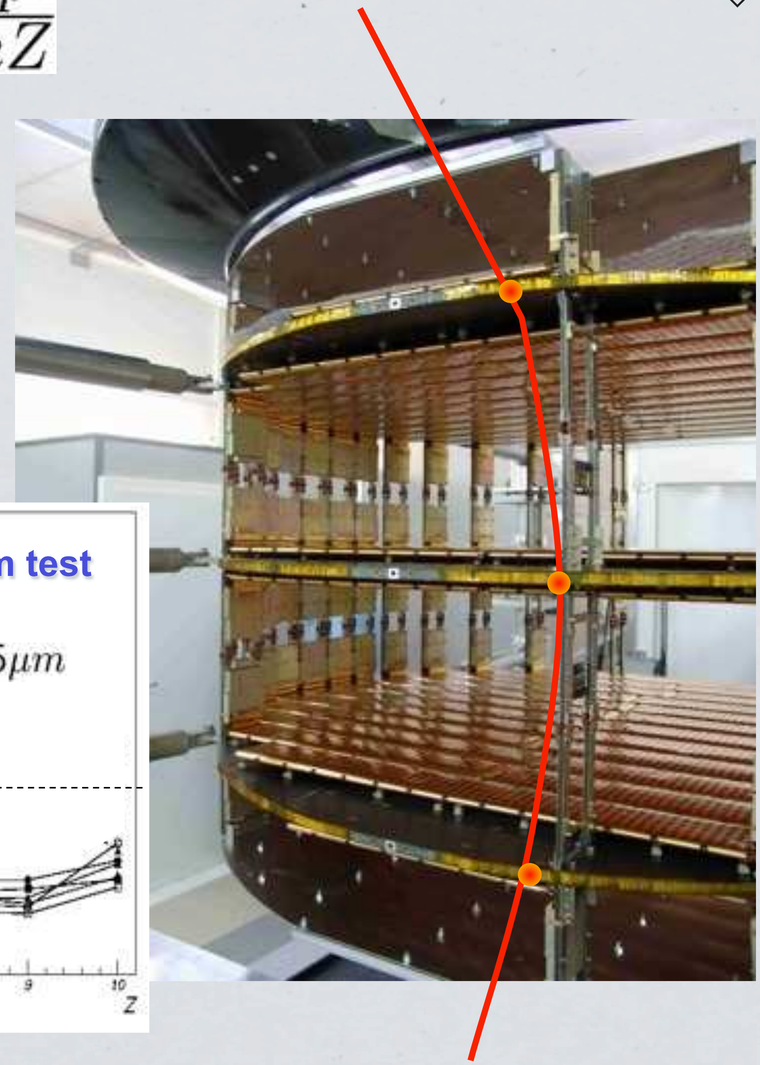
$$R = B\rho = \frac{p}{eZ}$$

The AMS-02 Si Tracker + magnet:

- Permanent dipole magnet B=0.8T
- Silicon double-sided sensors
- 8 layers arranged in 5 planes
- Resolution < 10 μm in the bending direction
- A rigidity determination of 2% at 10 GV

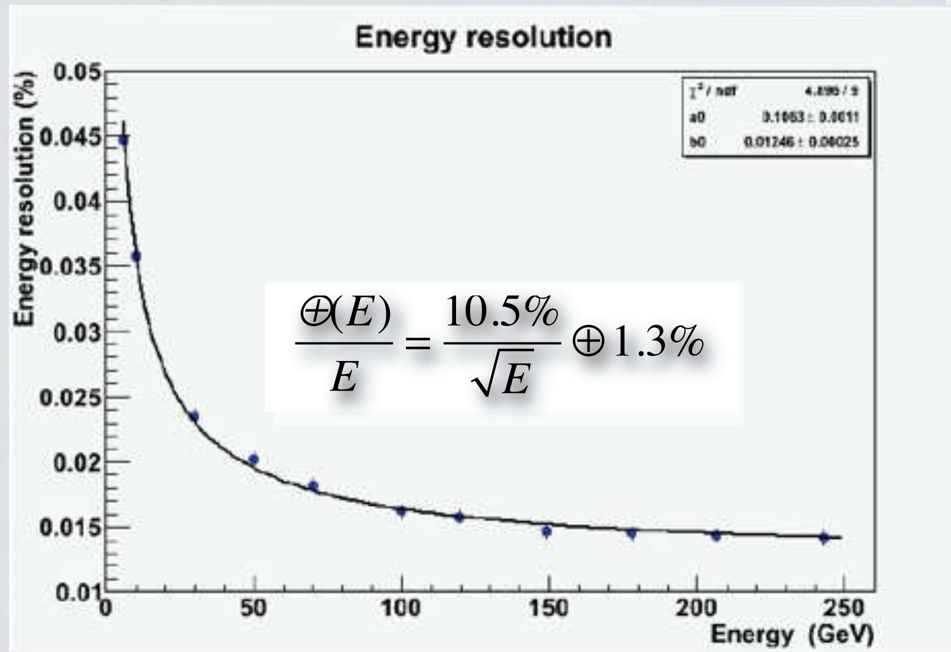




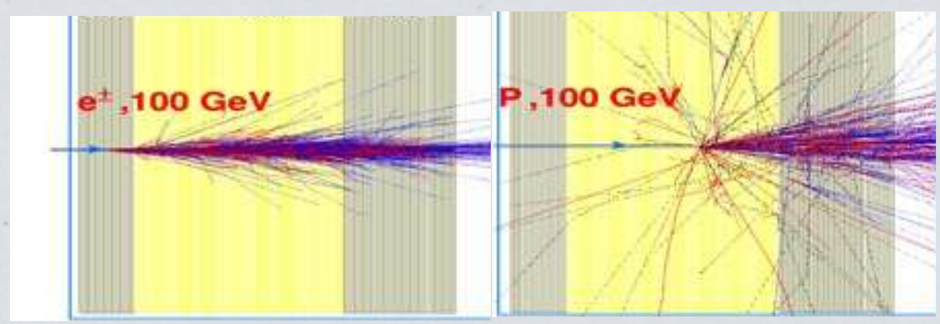


AMS02 performances:
e/p separation with ECAL

TEST BEAM DATA

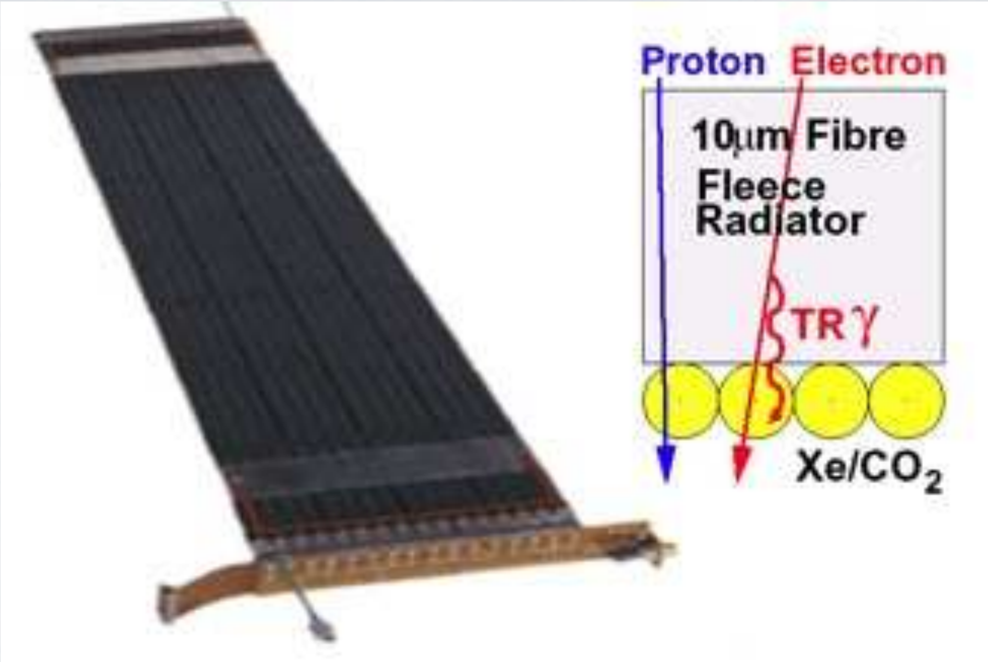


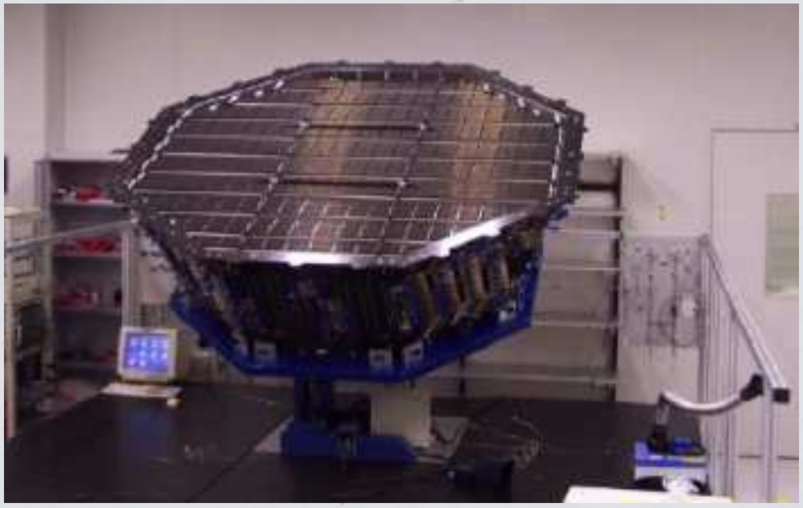
- ✓ Lead-SciFi calorimeter with $17.2\ \mathbf{X_0}$ & $0.8\ \delta_i$
- ✓ Energy resolution with ECAL <2% at E>50GeV
- ✓ Discriminant variables used to characterize electromagnetic behavior: electron efficiency >95%, proton reduction $\sim 10^3$

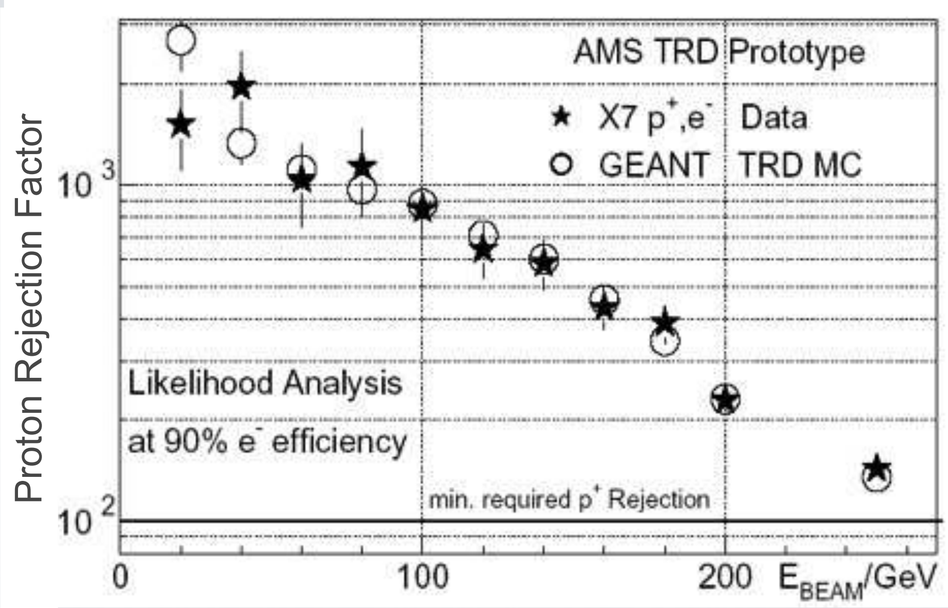


AMS02 performances: e/p separation with TRD

20 layers of Xe/CO2 filled straw tubes for dE/dx Transition Radiation x-ray detection



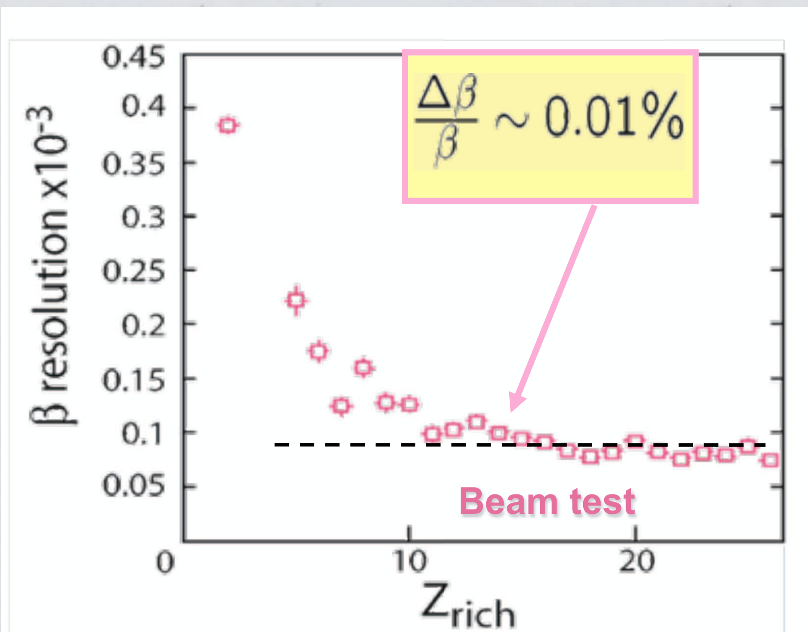


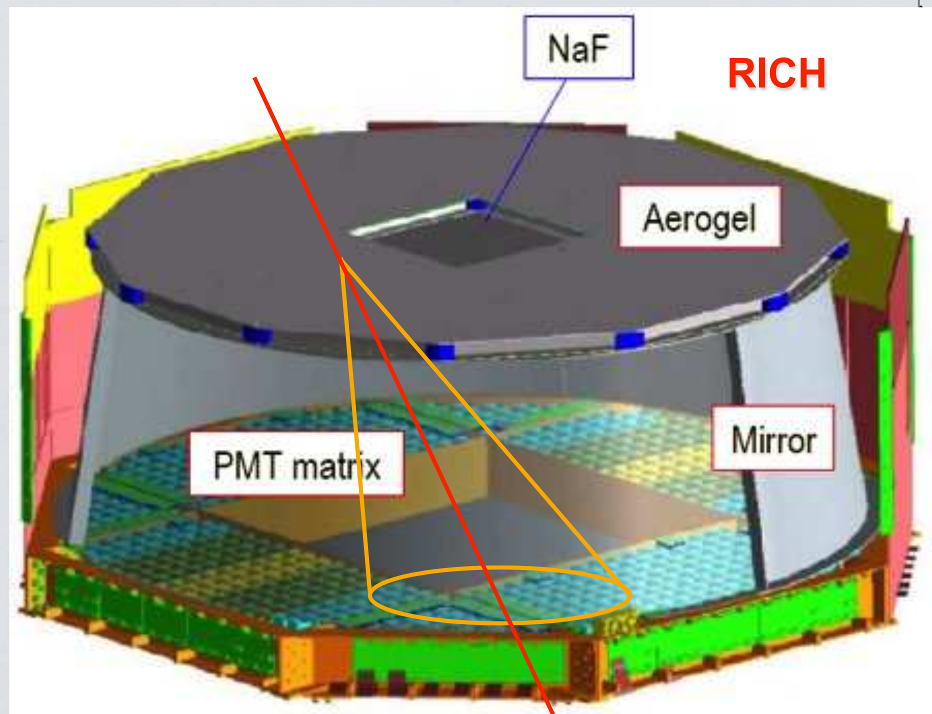


AMS02 performances: velocity measurement in RICH and TOF

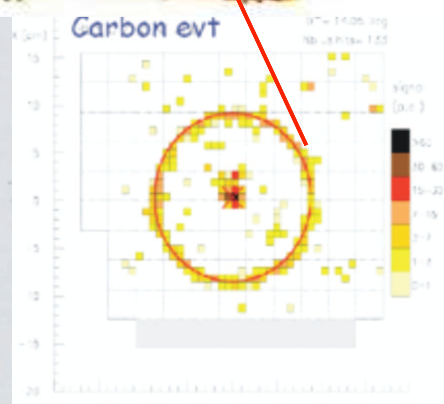
Redundant measurements

- **RICH**: δ with δδ/δ = 0.01%
- TOF: δ = δL/δt with δδ/δ = 1%





$$\boxed{\cos\theta_c = \frac{1}{\beta n}}$$



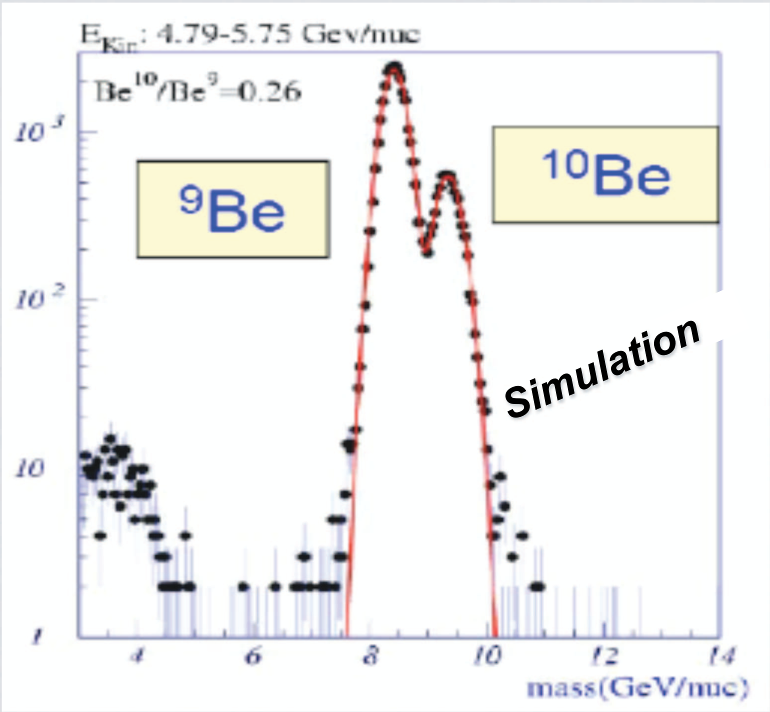
AMS02 performances: mass measurement

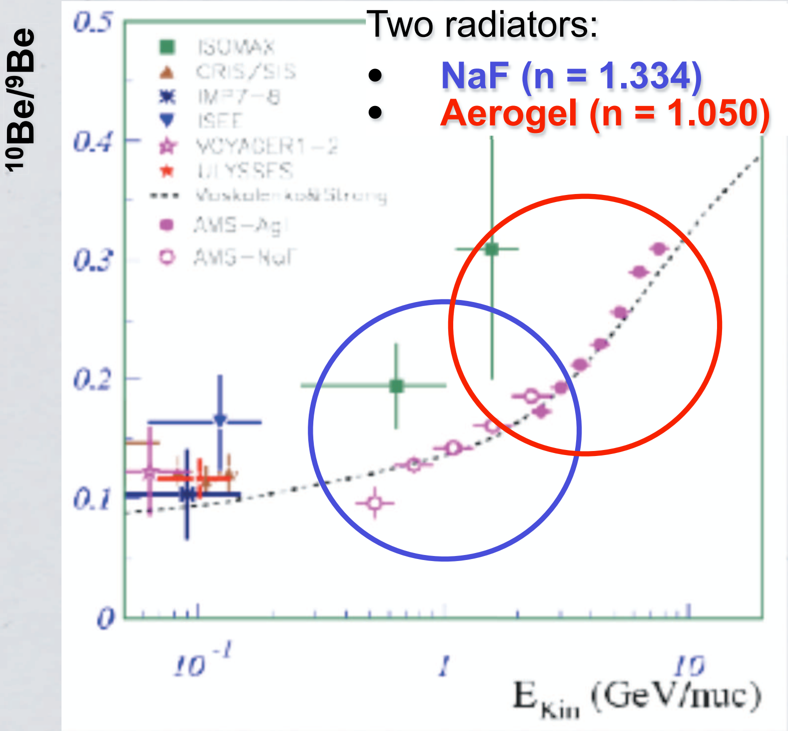
The AMS-02 spectrometry

- Tracker for rigidity and charge
- RICH for velocity and charge
- Isotopic distinction up to 10 GeV/n

$$m = \frac{e}{c} \cdot \frac{RZ}{\beta\gamma}$$

$$\left(\frac{\Delta m}{m}\right)^2 = \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2 + \left(\frac{\Delta R}{R}\right)^2$$





Two radiators:

- NaF (n = 1.334)
- Aerogel (n = 1.050)

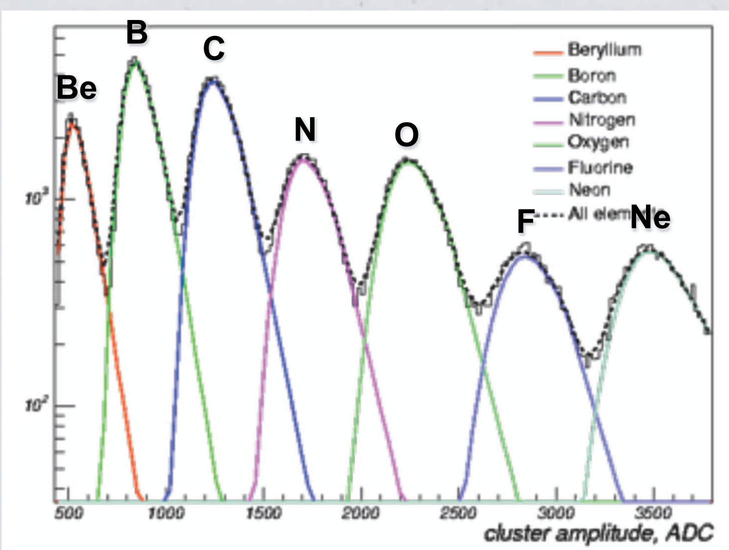
AMS02 performances: charge measurement

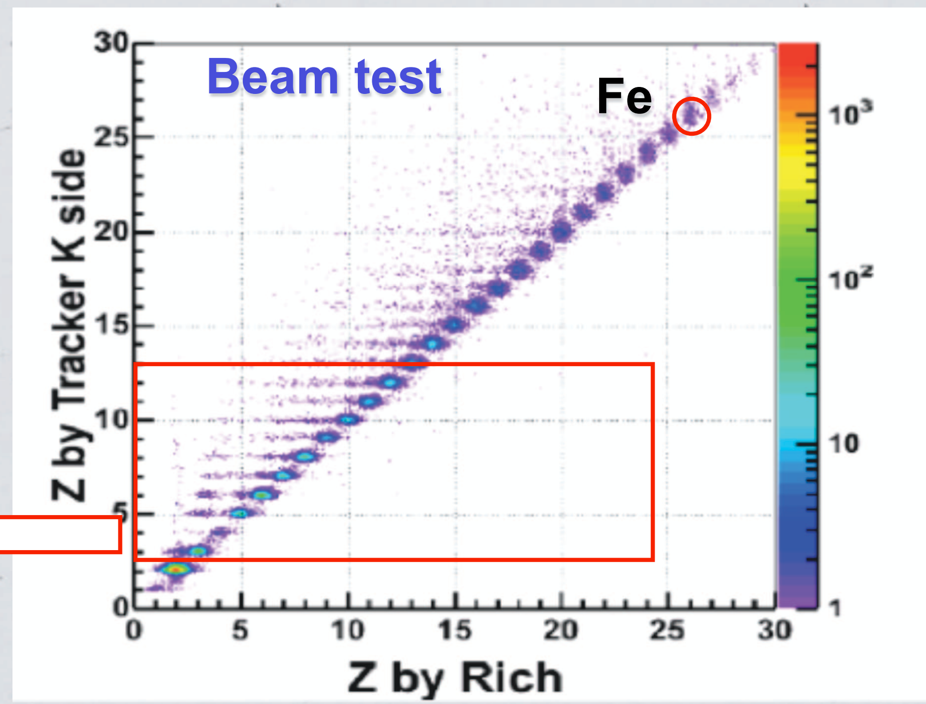
The charge evaluation is redundant

- Tracker, TOF, ECAL: energy deposition by ionization
- RICH: number of photons in the Cherenkov ring

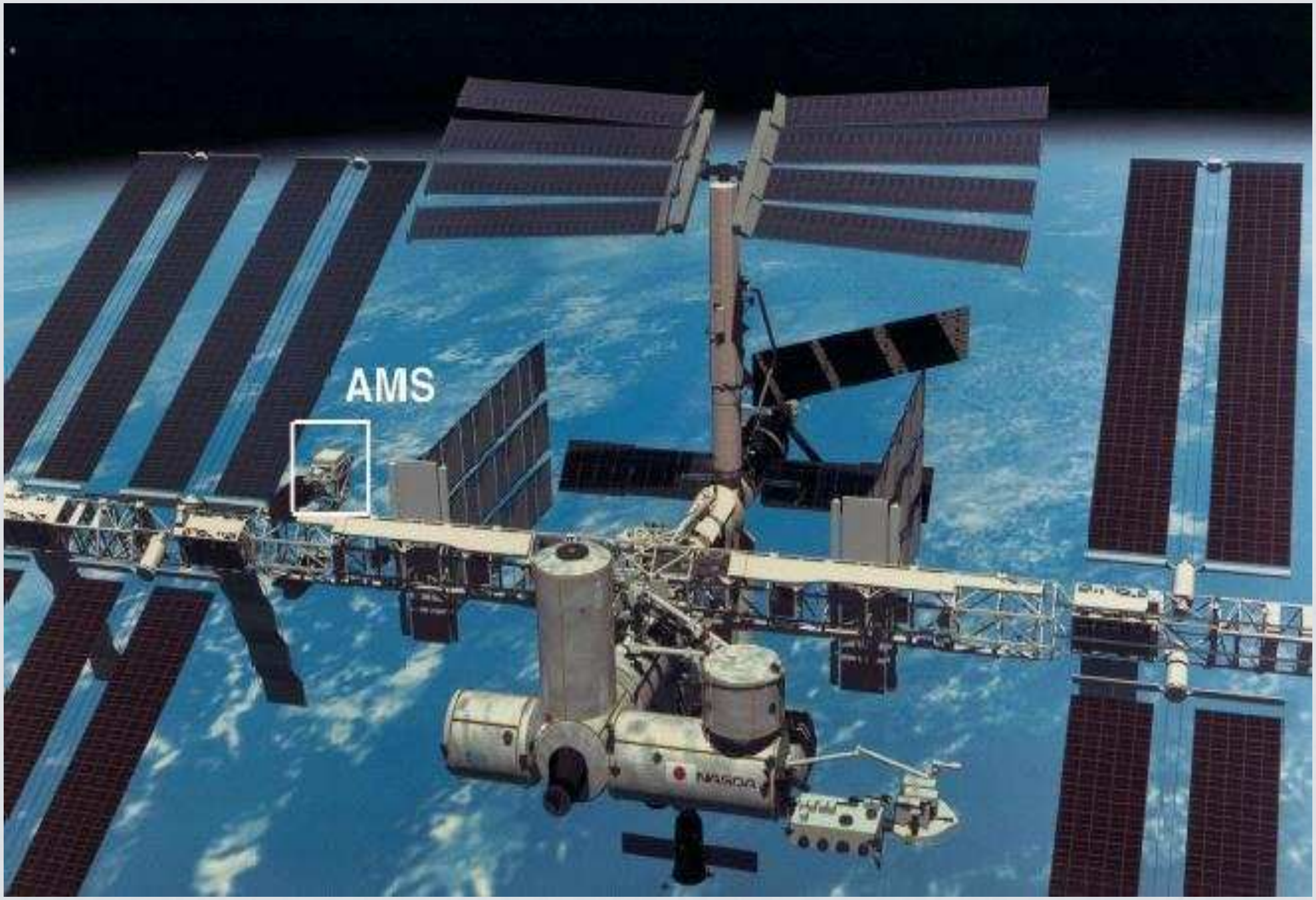
$$\left(\frac{dE}{dX}\right)_{\text{bethe}} \propto Z^2$$

$$N_\gamma \propto Z^2 \Delta L \left[1 - \frac{1}{\beta^2 n^2}\right]$$



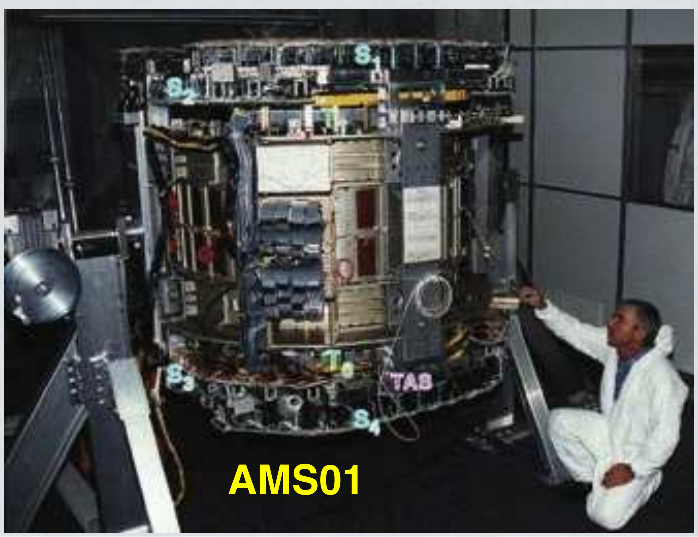


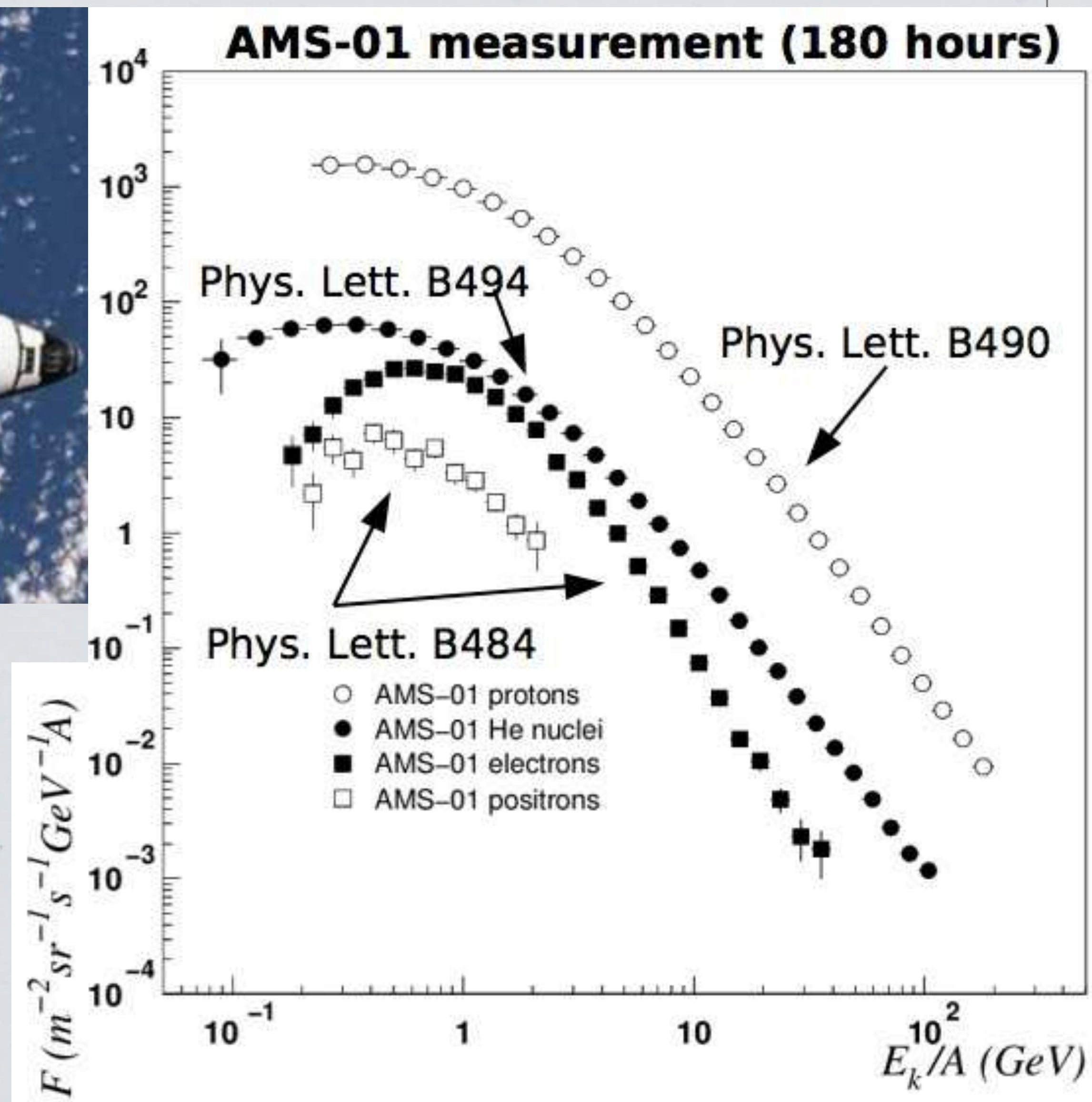
AMS02 on the ISS



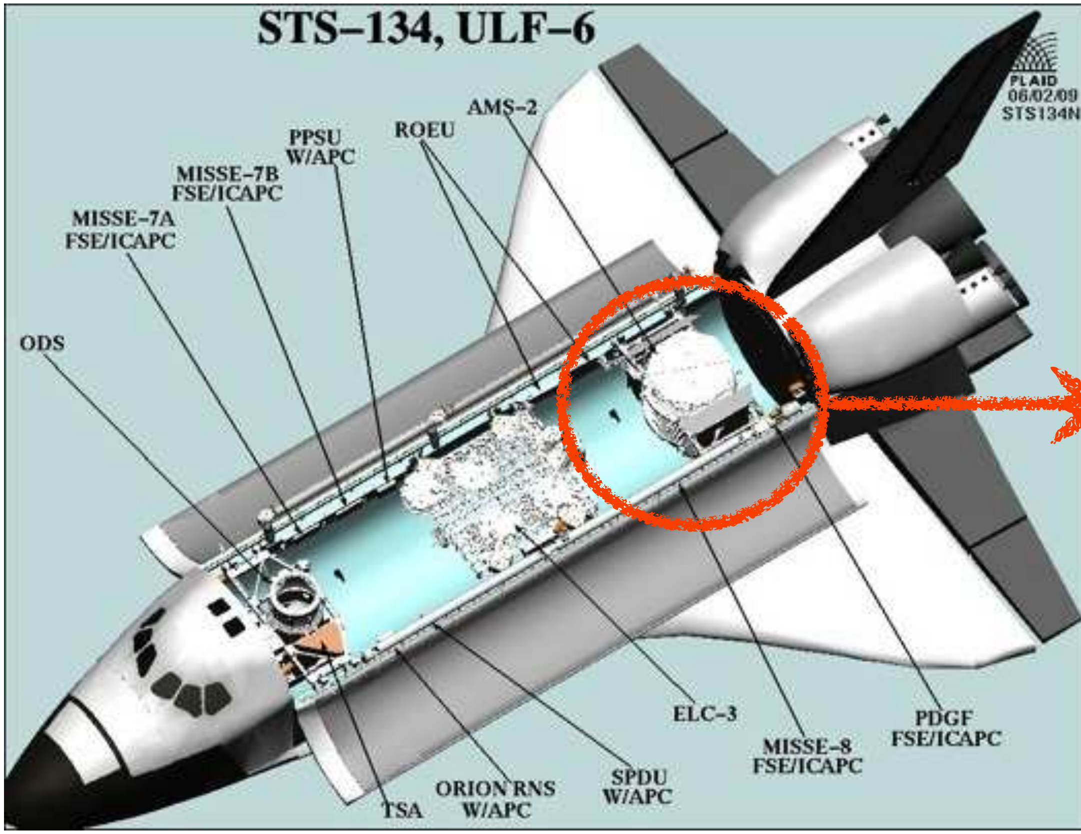
- The experiment will be installed on the ISS
- >3 years mission with magnetic field
- acceptance = **0.24m^{2}sr** (**0.08m^{2}sr** with ECAL)

Precursor flight: AMS01





SPACE SHUTTLE PROGRAM
Space Shuttle Flight Operations and Integration Office
NASA Johnson Space Center, Houston, Texas



AMS-2 will fly on board of STS-134

AMS-2 takes ~1/4 of shuttle cargo bay

Colonel Roberto Vittori will be part of the crew which will fly on STS-134 in this 13 days mission

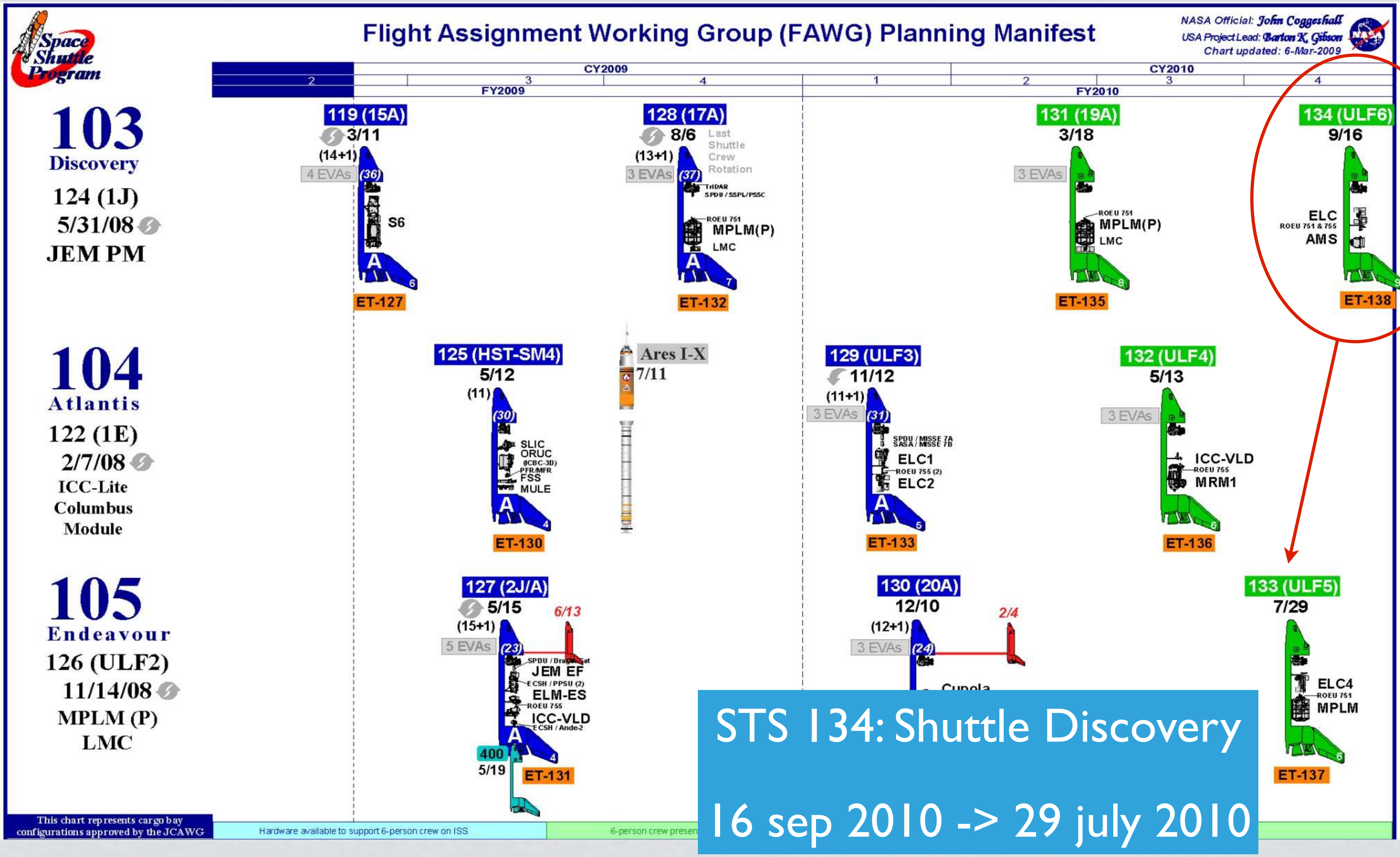
CR# S072134

Baseline STS-134 in the Flight Definition and Requirements Document (FDRD)

June 25, 2009 – PRCB

MO3/Shelby Lawson
Mission Integration Mgr.

Shuttle manifest



STS 134: Shuttle Discovery

16 sep 2010 -> 29 july 2010

Presenter Shelby Lawson

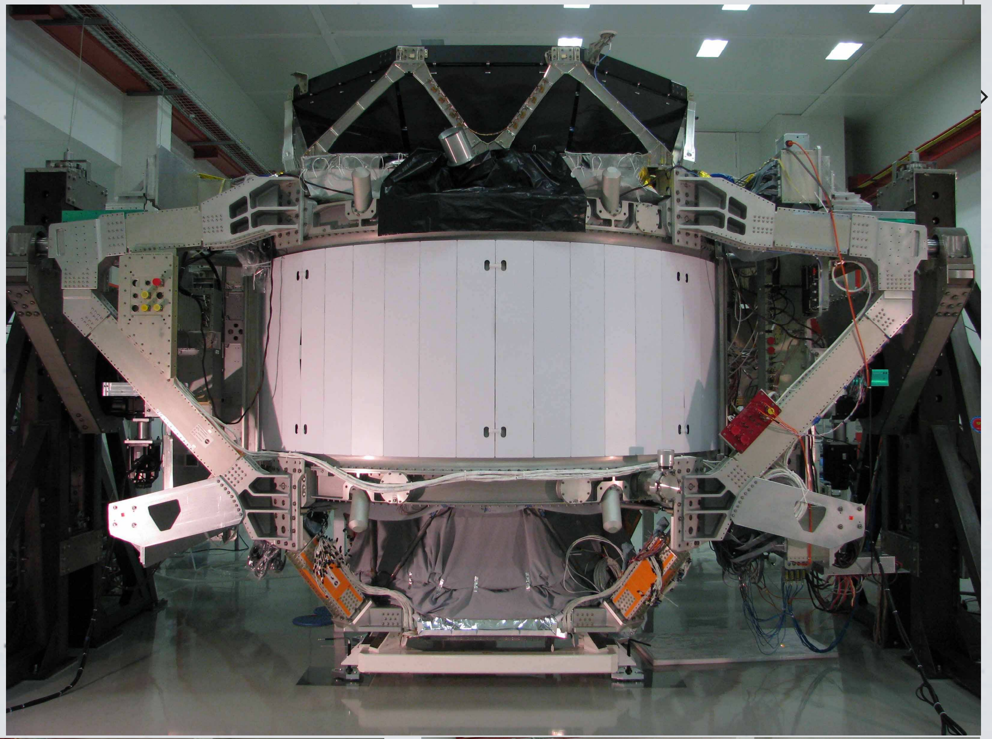
STS-134 (ISS-ULF6) Timeline Overview

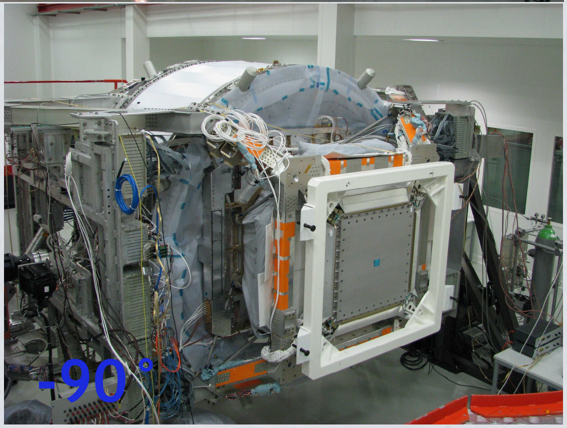
FD1	Launch
FD2	SRMS Checkout; OBSS Survey; EMU Checkout; EVA Tool Config
FD3	RPM, Rendezvous w/ Station & dock to PMA2 (on Node 2 forward port); Orion RNS DTO-703; Ingress Station; Middeck transfers; Deploy ELC3 from Shuttle PLB to ISS P3 Upper Outer CAS
FD4	Deploy AMS-02 from Shuttle PLB to ISS S3 Upper Inboard CAS, EVA Prep
FD5	EVA 1 – Transfer MISSE 8 from PLB to ISS, Return MISSE 7a & 7b from ELC2 to PLB sidewalls
FD6	Focused Inspection (if required), Water Dump, EVA Prep
FD7	EVA 2 – Clean/lubricate Starboard and Port SARJ
FD8	Late Inspection, Off Duty, EVA Prep
FD9	EVA 3 – Transfer and stow Integrated Boom Assembly from PLB to S1 Truss OSE; Install PDGF on ISS; Middeck Transfers
FD10	Off duty, Crew Conference, GLACIER stow, Hatch Close
FD11	Undock from ISS; Flyaround; Re-rendezvous for Orion RNS DTO-703
FD12	Cabin Stow, Water Dump, FCS C/O
FD13	Deorbit Prep, Landing

AMS deployment foreseen on 4th mission day: 1 aug 2010

AMS status

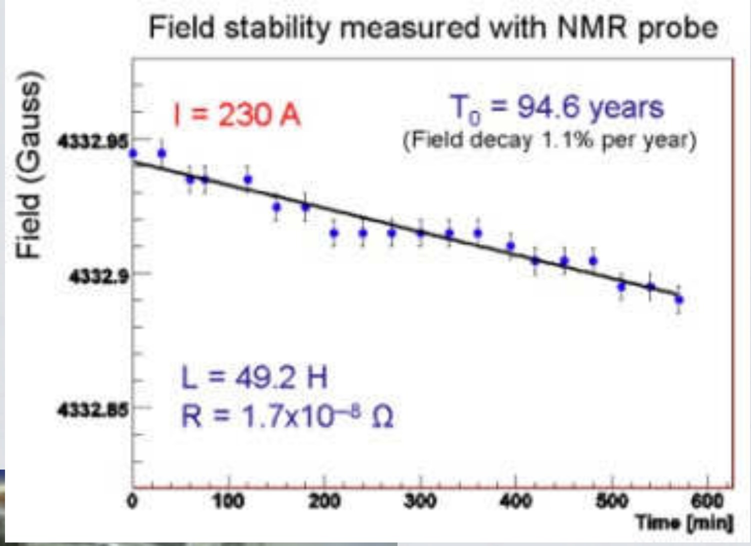
- AMS has been pre-integrated without the solenoid to check mechanical interferences and to test the DAQ system
- Several months of cosmic ray runs with the detector in different configurations

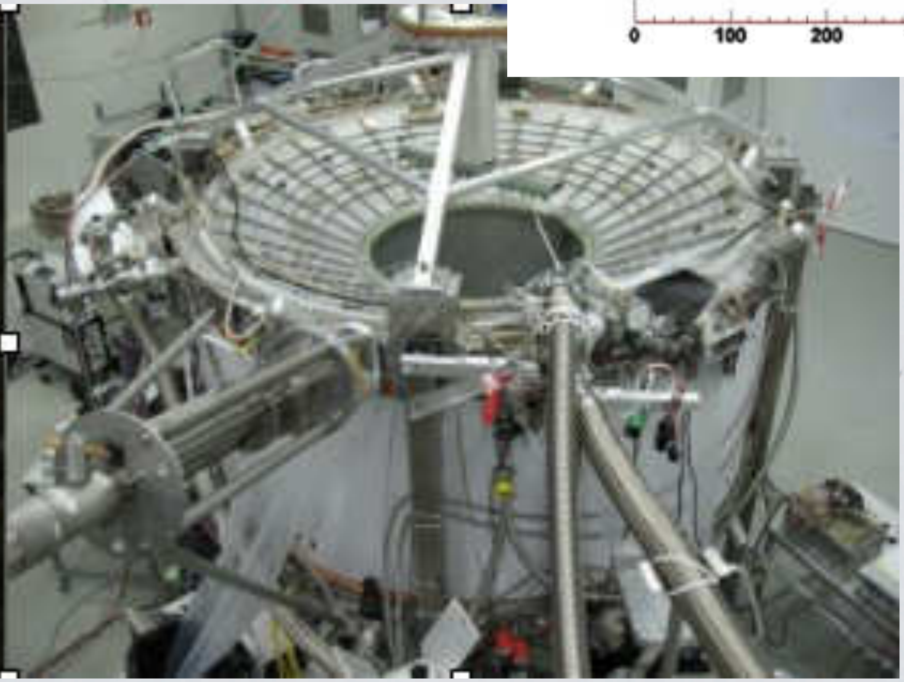




Magnetic field map

- Then the detector has been disassembled, the magnet switched on and the field mapped: field decay at 1.1% per year





AMS02 schedule

- October-november 2009: flight integration and magnet cool down

- At the end of november AMS02 will leave (forever) the clean room in CERN Prevessin site for the following operations:

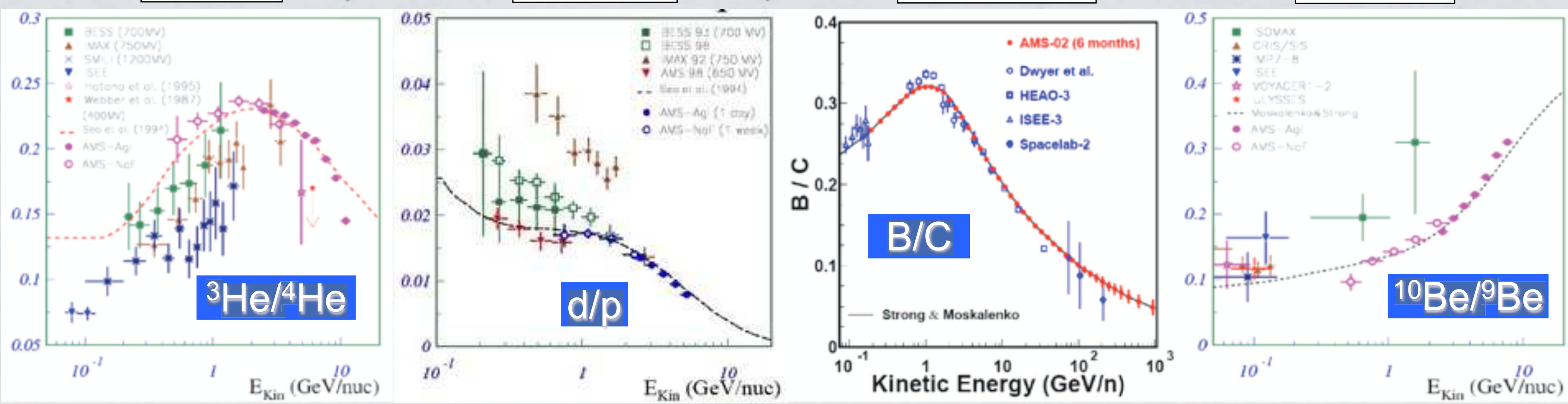
Major tasks after leaving CERN				
Task	Start date	Offset from previous task	Duration (Elapsed Days)	End date
Beam Test operations	27-nov-09	0	20	17-dic-09
ESTEC operations (TVT & EMI)	17-dic-09	0	87	14-mar-10
KSC operations	14-mar-10	0	122	14-lug-10

- ready for the flight of july 29!

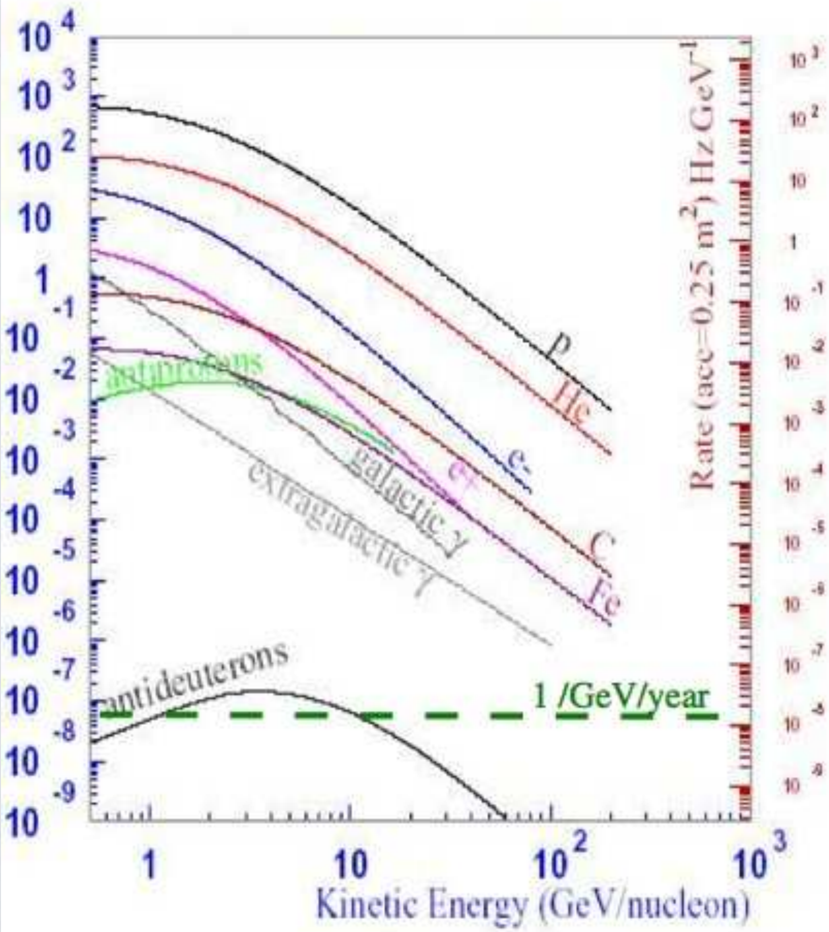
Physics in AMS: Cosmic Rays propagation

* AMS02 can collect **>10^6 particles** in each of the channel described below in order to constraint with good precision CR propagation and confinement properties

1 day | 1 week | 6 months | 1 year



Physics in AMS: DM indirect search



- **Positrons, gammas, antiprotons and antideuterons are optimal channels for the indirect detection of dark matter. Examples:**

$$\chi\chi \rightarrow W^+ W^- \rightarrow e^+ + \nu_e + W^-$$

$$\chi\chi \rightarrow b\bar{b} \rightarrow e^+ + X$$

$$\chi\chi \rightarrow \gamma\gamma \quad \text{(via loops)}$$

$$\chi\chi \rightarrow hadrons \rightarrow \pi^0 + X \rightarrow \gamma\gamma + X$$

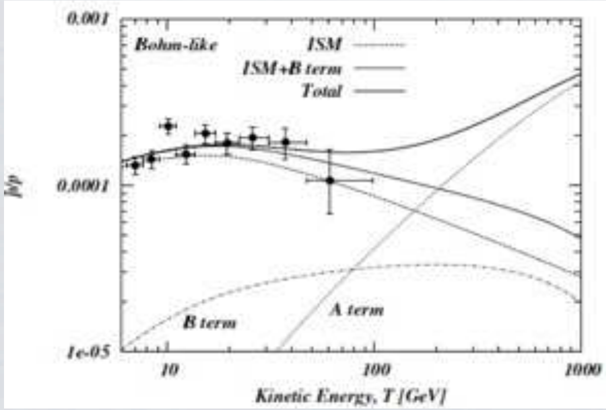
$$\chi\chi \rightarrow hadrons \rightarrow \bar{p} + Y$$

$$\chi\chi \rightarrow hadrons \rightarrow \bar{D} + Y$$

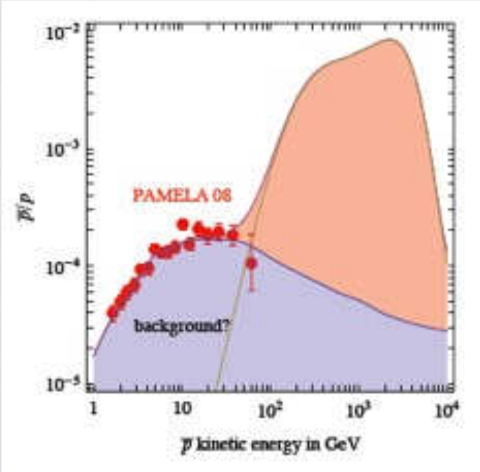
Antiprotons

* Main background: protons from charge misreconstruction
* Antiprotons can discriminate among different contributions: pulsars (no antip), cosmic ray reacceleration, DM

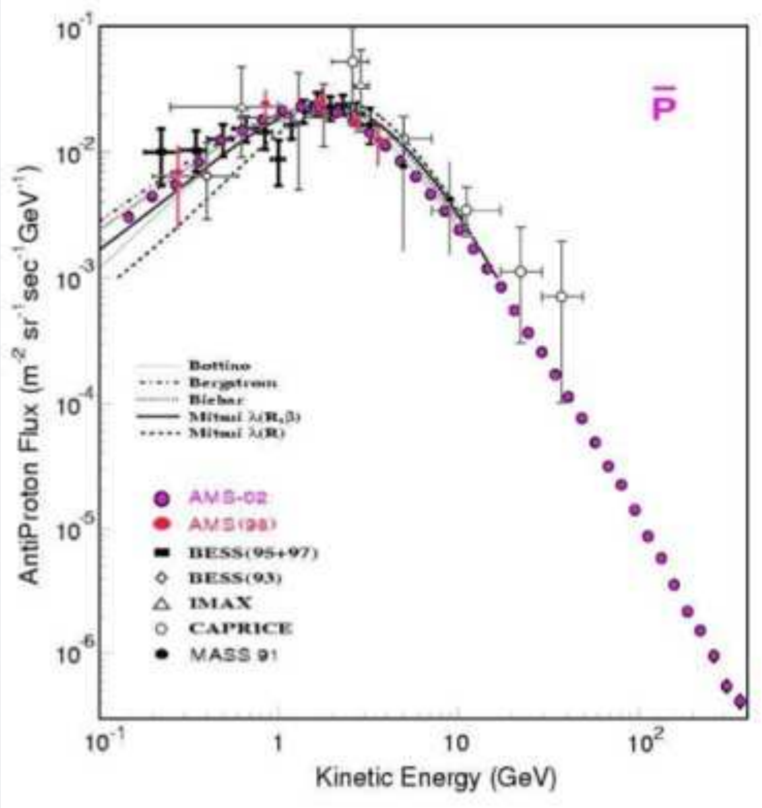
CR reacceleration: Blasi, 09



DM 10TeV into WW: Cirelli et al, 08



AMS: statistical error only



What about antideuterons?

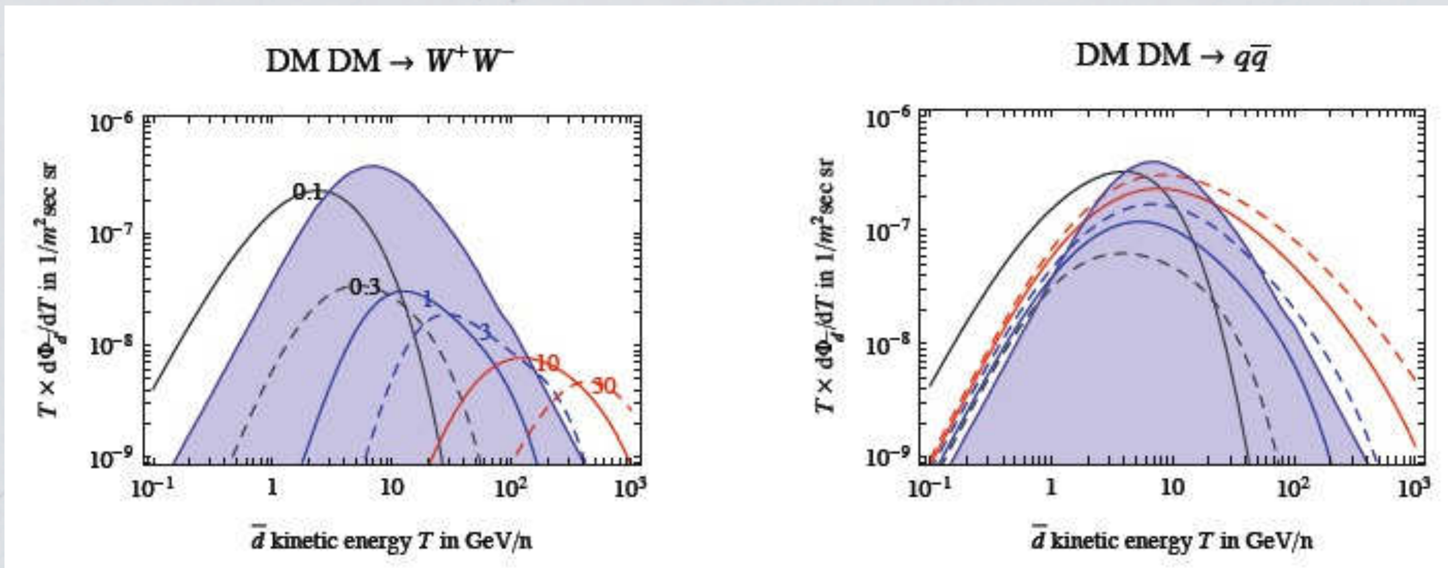
* Antideuterons are produced by antip, antid coalescence after qq hadronization

* A new recent calculation (`CERN-PH-TH/2009-149`) has increased the coalescence probability due to the jet-like structure of the high mass DM-DM interactions

* AMS sensitivity is below $10^{-7}(\mathrm{m}^2\,\mathrm{s}\,\mathrm{sr})^{-1}$, so few antid events could be observed

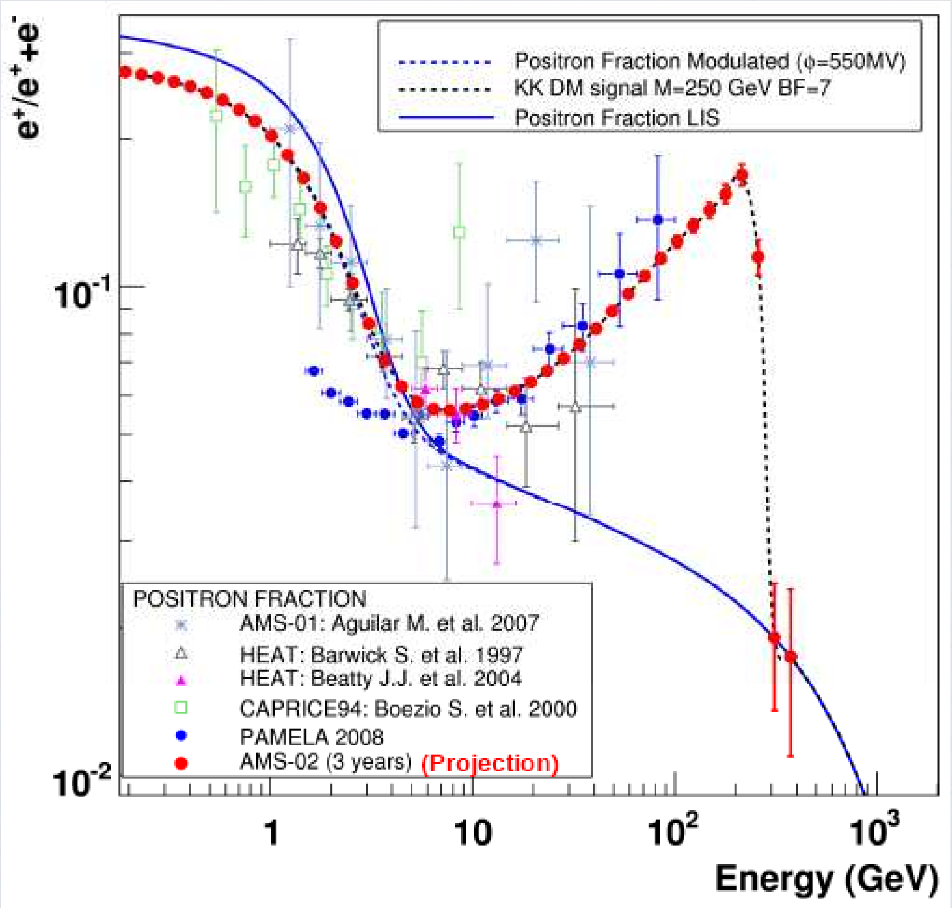
➡ Antid production for DM mass 0.1-30TeV

➡ filled histogram: secondary antid production



electrons/positrons

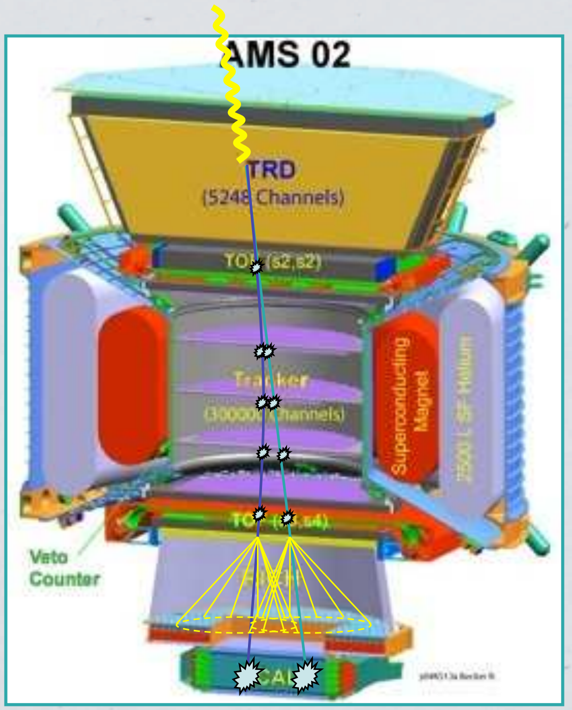
- ECAL standalone rejection at ~10^3
- Combined with Tracker (E/p matching) and TRD a p suppression of ~10^6 is achieved
- e+,e- spectra free from background from hadrons
- Positron absolute spectrum can be measured up to ~500GeV or more (depending on spectral shape)



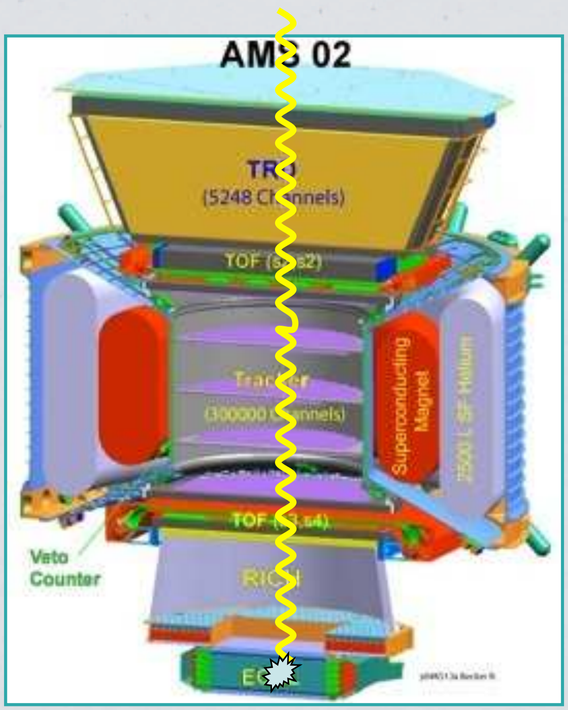
Photons in AMS02

Two δ detection modes in AMS-02

- **Photon conversion** direction from Tracker, energy from Tracker+ECAL
- **Single photon** direction and angle from ECAL

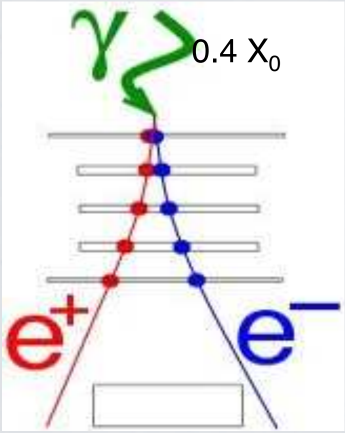


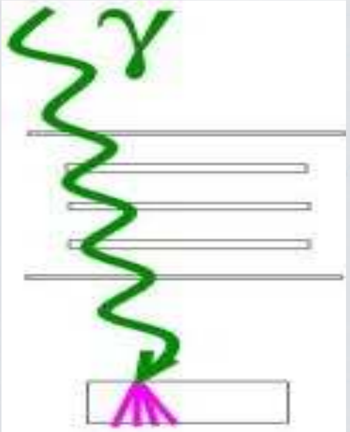
Main bg: δ rays
Rejection factor: >10^5(p), $4\cdot10^4$(e)
[TRD veto, invariant mass]

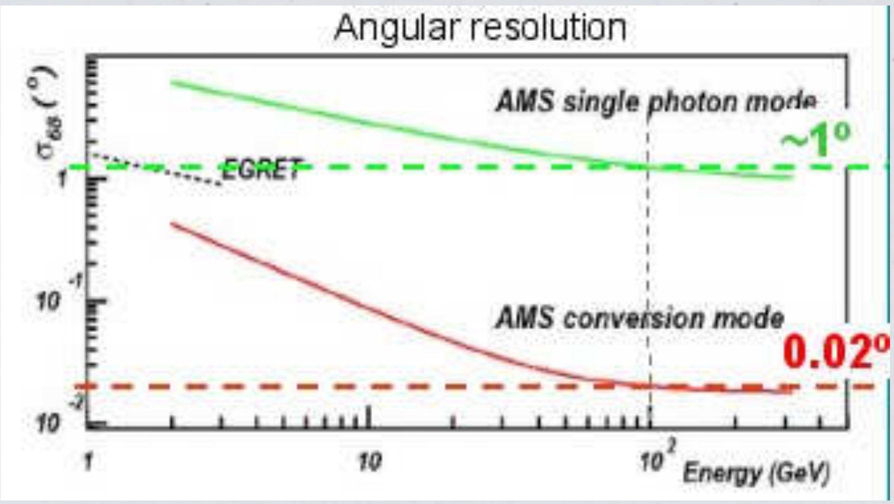


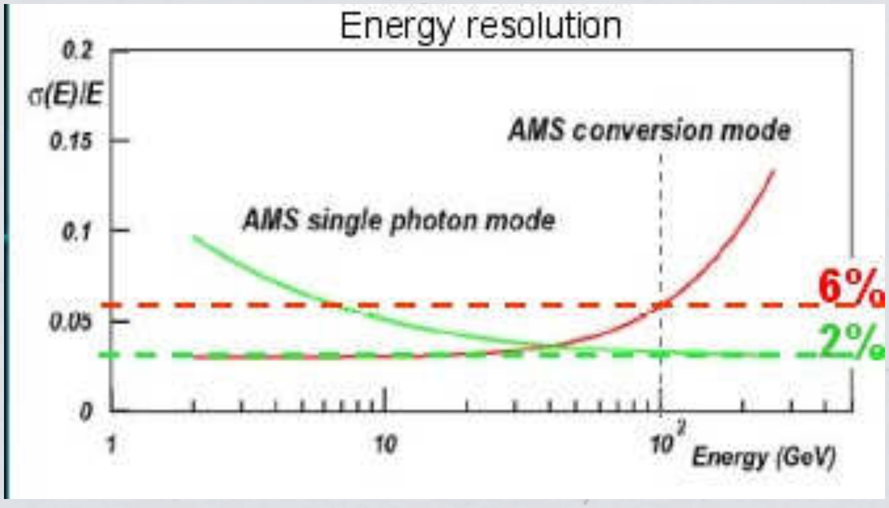
Main bg: secondaries: δ from p interactions
Rejection power: $5\cdot10^6$ [veto on hits, δ direction]

Photons in AMS02









In spite of the smaller (with respect to FERMI) field of view, the good angular and energy resolutions make AMS a competitive actor also for photon physics

Summary

* PAMELA, Fermi and other previous experiments have shown the presence of a "primary" component in the electron/positron spectrum in the region 10-1000GeV
* This energy region is of particular interest for Dark Matter search
* The contemporary measurement of positron+antiproton+antid +photon fluxes, together with the measurement of nuclei with Z>1, is the best tool to establish the nature of this component
* The AMS02 experiment, which will start taking data on august 2010, has the capabilities of performing all these measurements