The origin, evolution and observational signature of macroscopically large antimatter regions in the Universe

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contributed talks: 280 ; 130 ; 265

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OUTLINE

- **Antimatter in the modern Universe**
- **Inhomogeneous baryogenesis**
- **Evolution and experimental signature of antimatter regions. AMS detector.**
- **Included talks:**
  130 M.Pearce: about the antimatter with the PAMELA
  265 F.Toyoda: about baryogenesis at the preheating

The baryon symmetric Universe?

How do we observe that our Universe is matter-antimatter asymmetric as a whole?

What is, if the dominance of matter over antimatter is only local up to a certain scale L_B

- **Direct observations exclude the macroscopic amount of antimatter within the distance up to 20Mpc, because the reaction of annihilation** $p\bar{p} \to \pi^0 \to \gamma$ (*G.Steigman 1976, F.M.Stecker et all 1971, 1985*)

- **Annihilation is unavoidable. The larger then 20Mpc matter and antimatter regions must be in contact, because of uniformity of CMBR.** (*W.H.Kinney, E.W.Kolb, M.S.Turner 1997*)

- **The annihilation, which would take place at the border between matter and antimatter region, during the early stages, disturbs the observable diffuse $\gamma -$ ray background. It does not happen if $L_B > 10^3$Mpc.** (*A.G.Cohen, A.De Rujula, S.L.Glashow 1998*)

We are living in the Universe, which does not contain any significant amount of antimatter.

$$\boxed{\frac{V_{\text{matter}}}{V_{\text{antimatter}}} >> 1}$$

Inhomogeneous baryogenesis

All three Sakharovs general prinsiple of bariogenesis: non-conservation of baryonic charge, breaking of C and CP symmetry and deviation from thermal equilibrium need phase transition.

The Universe with inhomogeneous baryon content can be created if a certain phase transition occurred at inflationary stage leaving behind astronomically large regions with different physical conditions.

The primordial antimatter domains to be formed in the early Universe, must be astronomically large but not too large and sufficiently rare to setisfy

$$\boxed{\frac{V_{\rm matter}}{V_{\rm antimatter}} >> 1}$$

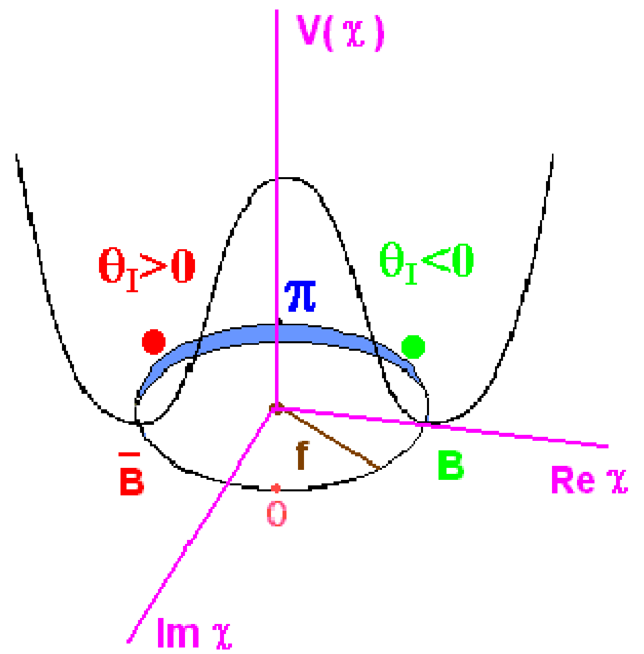
Astronomicaly large antimatter regions get formed out of primordial antimatter region which are not eaten up by diffusion of surrounding matter.

A primordial antimatter region which grows up to 1pc or more at the end of RD epoch remains unaffected by the diffusion (*M.Yu.Khlopov, R.V.Konoplich, R.Mignani, S.G.Rubin, A.Sakharov 1999*)

The critical surviving size of antimatter region at the present epoch

$$\boxed{L_{antimatter} > l_c = 8h^2 kpc}$$

Spontaneous baryogenesis



Complex, baryon charged scalar field $\chi = \frac{f}{\sqrt{2}} \exp(i\theta)$

$$V(\chi) = -m^2_{\chi^2}\chi^*\chi + \lambda_\chi(\chi^*\chi)^2 + V(\theta) + V_0$$

$$V(\theta) = \Lambda^4(1 - \cos\theta)$$

The lepton number violation (*A.D.Dolgov et all 1996*)

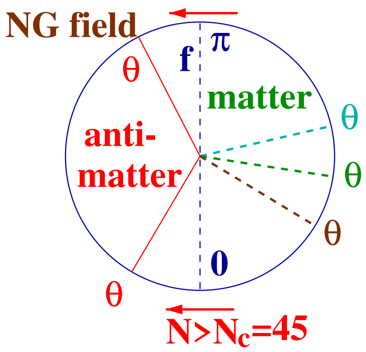
$$\mathcal{L}_{\Delta L} = g\chi\bar{Q}L + \text{h.c.}$$

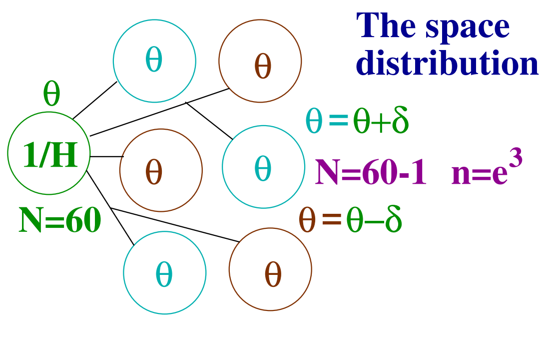
$$\text{U}(1): \qquad \chi; Q \to \exp(i\beta)\chi; Q \qquad L \to L$$

The number density of produced
$\theta_I < 0 \to$ baryons/$\theta_I > 0 \to$ antibaryons

$$n_{B(\bar{B})} = \frac{g^2 f^2 m_\theta}{4\pi^2}\theta_I \int_{\mp\frac{\theta_I}{2}}^{\infty} d\omega \frac{\sin^2\omega}{\omega^2}$$

Quantum fluctuations





During inflation the bottom is flat $m_\theta = \frac{\Lambda^2}{f} << H$

Since θ field is effectively massless, every e-fold it makes a quantum step with the lenght $\delta\theta = \frac{H}{2\pi f}$

During the time interval Δt the number of steps is $N = H\Delta t$ **(e-fold)**

$N_{max} \approx 60 \to 3000 h^{-1}\mathrm{Mpc}$ **(size of the Universe)**

$N_c = 45 \to l_c$ **(critical surviving size)**

Astronomically large antimatter regions get formed before the 45th e-fold

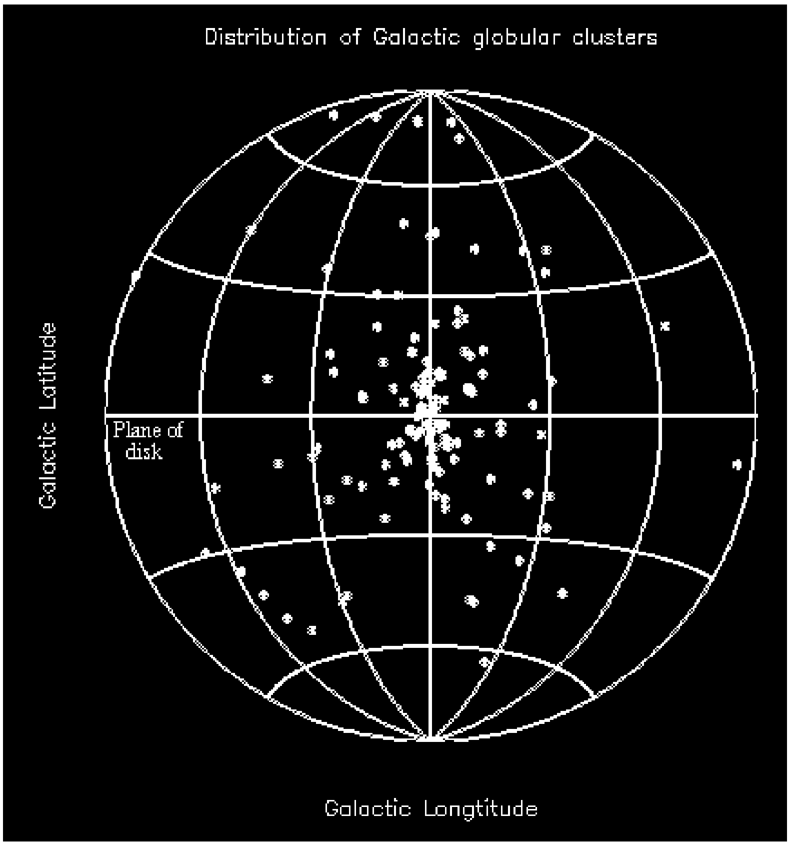
$\theta_{60} = \frac{\pi}{6}$; $\delta\theta = 0.026$

e-fold	n_{anti}	**Size**$\cdot h^{-1}$
50	74	**255 kpc**
49	$9 \cdot 10^3$	**94 kpc**
48	$8 \cdot 10^5$	**35 kpc**
47	$5.6 \cdot 10^7$	**12 kpc**
46	$3.34 \cdot 10^9$	**4.7 kpc**
45	$1.7 \cdot 10^{11}$	**1.7 kpc**

The total number of galaxies $\approx 10^{11}$

$$\boxed{\frac{V_{\mathrm{antimatter}}}{V_{\mathrm{matter}}} = 7.6 \cdot 10^{-9} << 1}$$

Globular clusters

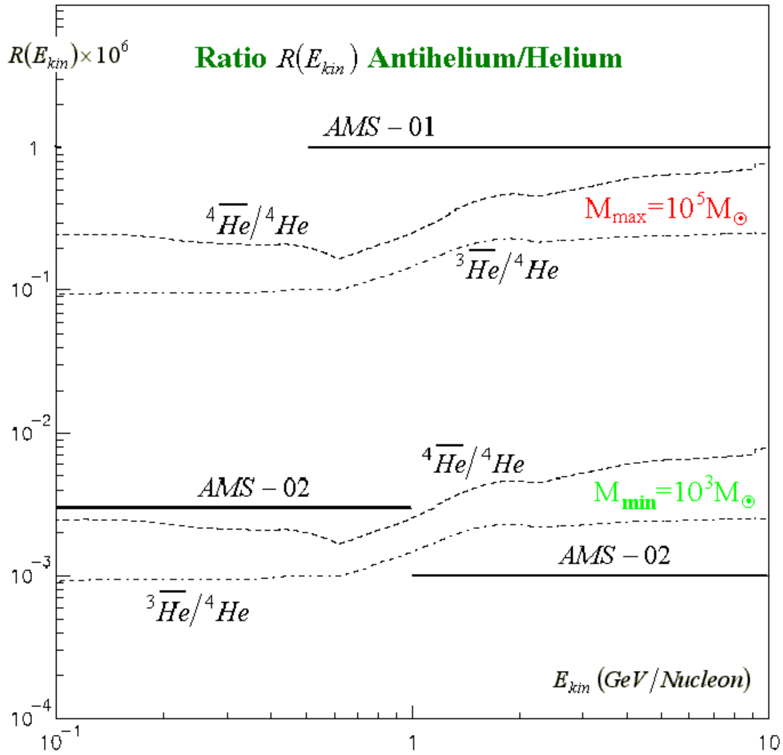


- l_c at the recombination epoch coincide with the scale of protoglobular clusters
- The volume box coming with every galaxy can contain up to 10 antimatter regions
- In a half of regions the density of the antimatter can be several times higher then the density of sorrounding matter. What makes them gravitationaly unstable.

If the high – density antimatter region has been formed in our Galaxy, it survives in the form of globular cluster at large galactocentric distance.

Globular cluster population in our Galaxy consists of 147 confirmed globular clusters. One of them could be made out of antistars.

Experimental signature



The integral effect of "anticluster" in our galaxy is estimated by the analysis of antimatter pollution.

The main source is the stelar wind.

The main content of pollution is $\bar{p}$ and $^4\bar{He}$

$\bar{p}$'s are collecting in the galaxy$\rightarrow$ γ flux.

EGRET normalization$\rightarrow$ $M_{max} = 10^5 M_\odot$

$l_c \rightarrow M_{min} = 10^3 M_\odot$

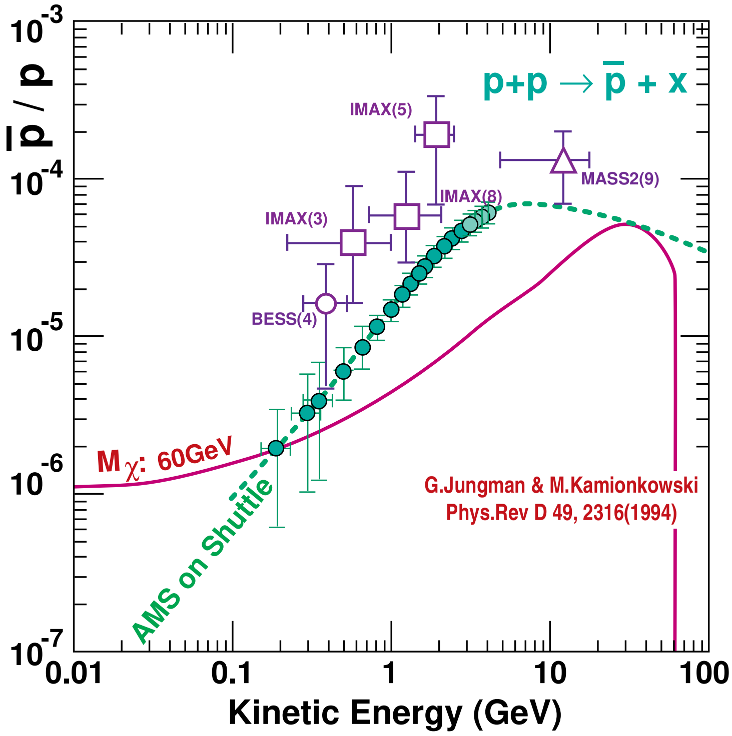
Expected flux of $^4\bar{He}$ in cosmic rays

$$\frac{N_{\bar{He}}}{N_{He}} \approx 10^{-8} - 10^{-6} \qquad E > 0.5 \ \text{GeV/nucleon}$$

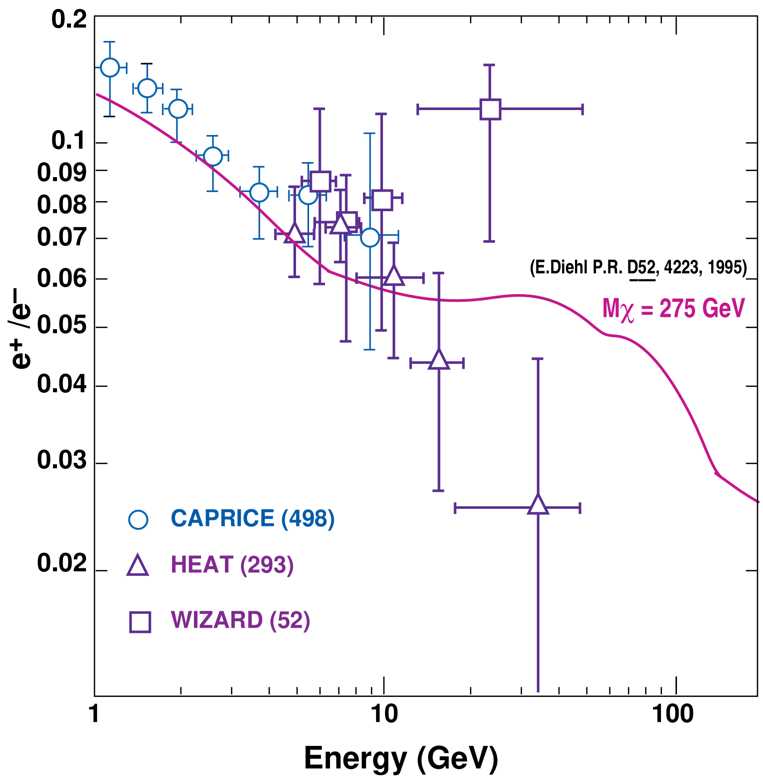
$^4\bar{He} + p \rightarrow {}^3\bar{He} + \text{all}$, **inelastic nuclei destruction, ionization and excitation of H atoms**

Dark matter signal

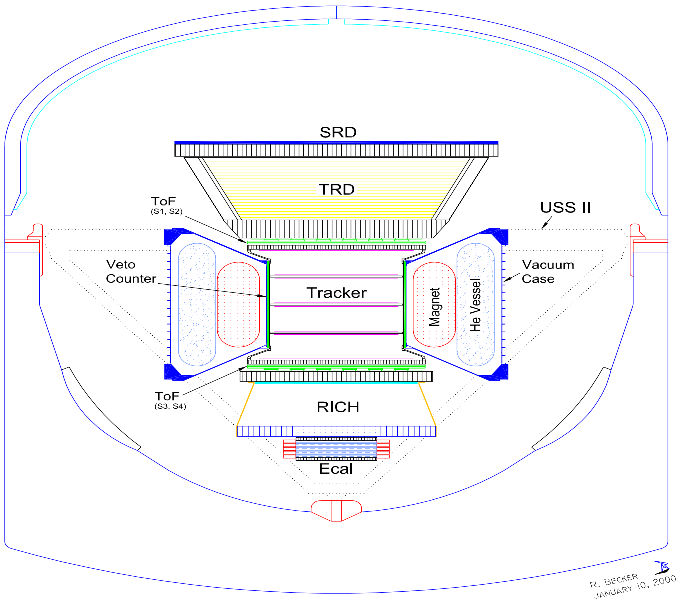
Antiprotons



Anomalos positron fraction in $\chi\bar{\chi}$ annihilation



AMS detector



AMS

Elements	Yield (or sensitivity)	(Now)	Energy Range (GV)	Physics
e^+	$\sim 10^8$	$(\sim 1.5\times10^3)$	0.5 - 100	Dark Matter (SUSY)
$\bar{p}$	5×10^5	(~ 75)	0.5 - 100	
γ			$\sim$ 1 - 300	
$\bar{H}_e/H_e$	$\frac{1}{10^9}$	$(\sim \frac{1}{10^5})$	0.5 - 20	Anti Matter Grand Unified Thoery Electroweak Theory (CP Violation)
$\bar{C}/C$	$\frac{1}{10^8}$	$(\sim \frac{1}{10^4})$	0.5 - 20	
D, H_2	10^9		1 - 3.0	Astrophysics (By Product)
^3H_e, ^4H_e	10^9		1 - 3.0	
B_e^9/B_e^{10}	2%		1 - 3.0	

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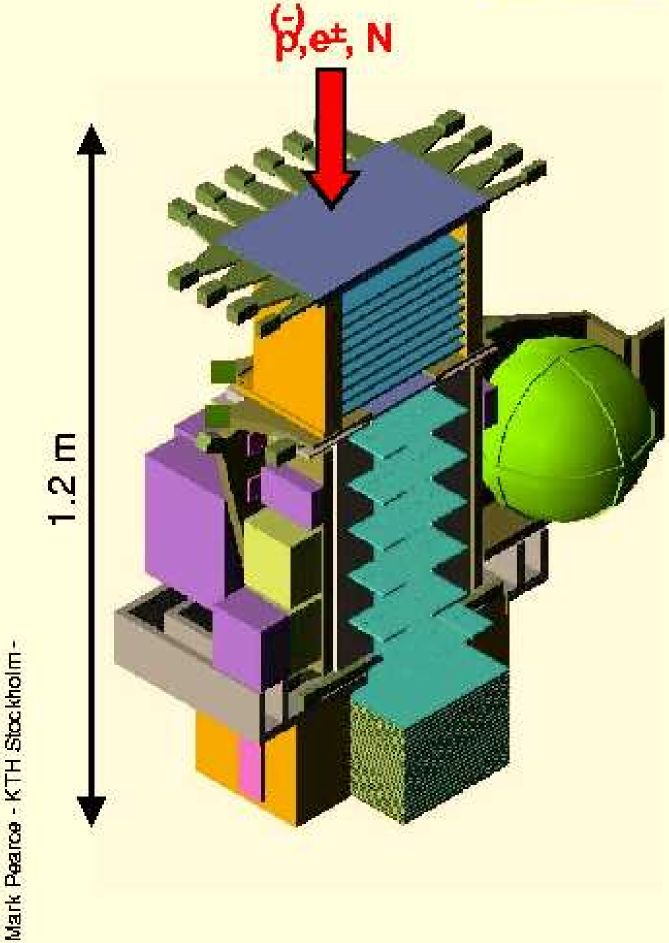
The PAMELA detector

Pamela Overview



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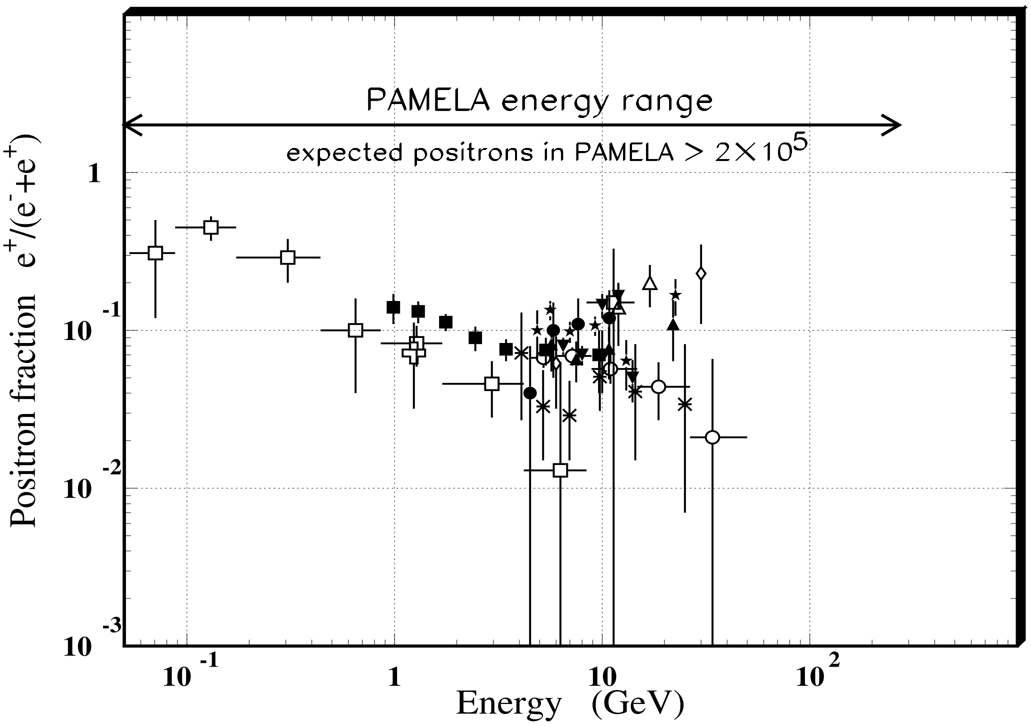
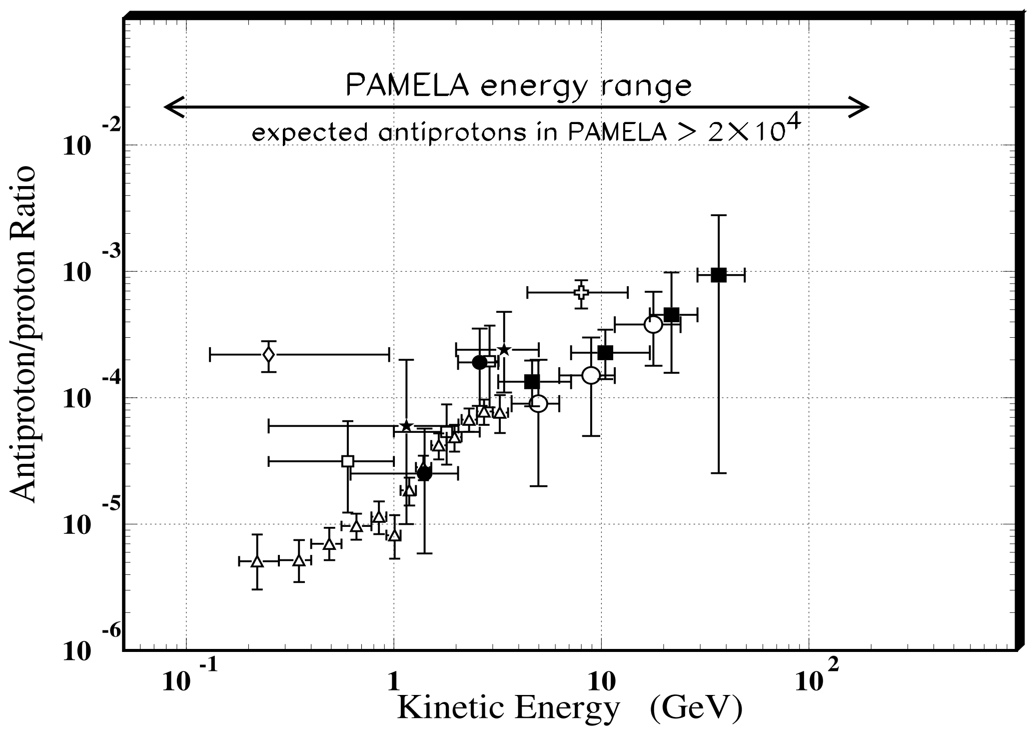
- Next step in the 'Russian Italian Mission' (RIM) founded in 90's to study cosmic rays in space [Si-eye-1 ('95) / Si-eye-2 ('97) / NINA-1 ('98)]
- Pamela is a collaboration between institutes in: Bari, Florence, **Stockholm (KTH)**, Moscow, NASA/GSFC, NMSU, Rome, Siegen and Trieste
- General purpose experiment:
  - $e^{\pm}$ energy spectrum
  - (Anti-) proton energy spectrum
  - H $\rightarrow$ C energy spectrum
  - Search for anti-helium
- 'Polar' orbit allows the study of low energy particles

Sensitivity





Baryogenesis at preheating

- **The reheating stage of the Universe after the inflationary period is divided into two parts. Preheating and thermalization.**

- **The preaheating stage of quantum particle production on a classical time depending background provides a state far from thermal equilibrium (*L.Kofmal, A.Linde, A.starobinsky 1997*).**

- *F.Toyoda et all, hep-ph/0010266 (talk 265)* **consider the system of complex scalar fields coupled to inflaton.**

- **At least two fields are needed to have 2 decay channels, since the effects of CP violation appears as the interference of two decay amplitudes.**

  Conclusion

  By this way, it is possible to generate the excess of baryon charge during the preaheating.

Conclusions

- **The existence of a small number of primordial antimatter regions in the matter/antimatter asymmetric Universe does not contradict to direct and indirect observations of diffuse γ–ray background**

- **The appropriate number of antimatter domains is found in the inflationary model with spontaneous baryogenesis. SUSY generalization of this scenarion is natural.**

- **The comming up AMS–02 experiment provides the test of the hypothesis of the existence of antimatter globular cluster in our galaxy, in the whole mass range** $10^5 M_\odot - 10^3 M_\odot$