Perspectives on antideuteron search with AMS experiment

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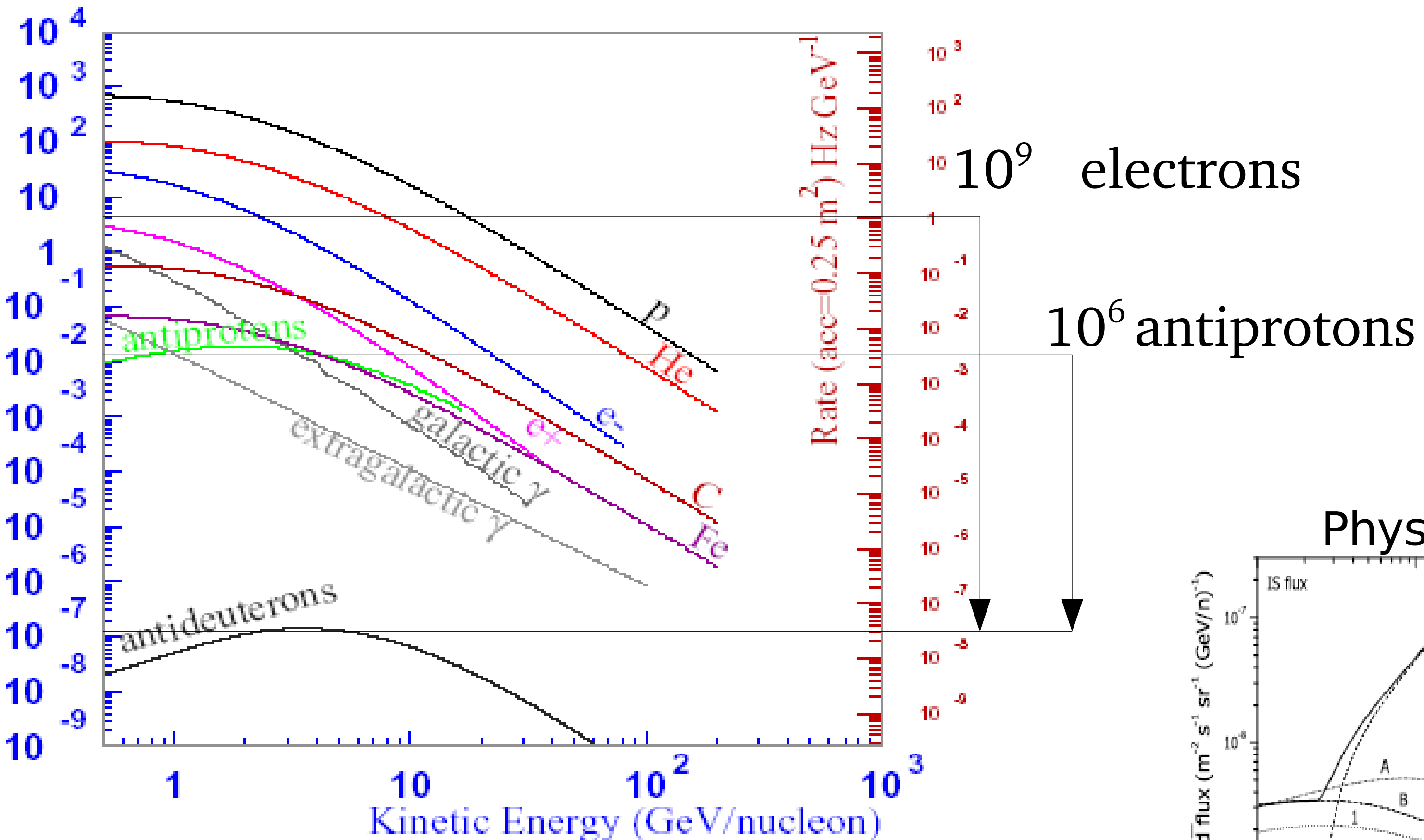
Outlook

1. **Antideuterons in Cosmic Rays**

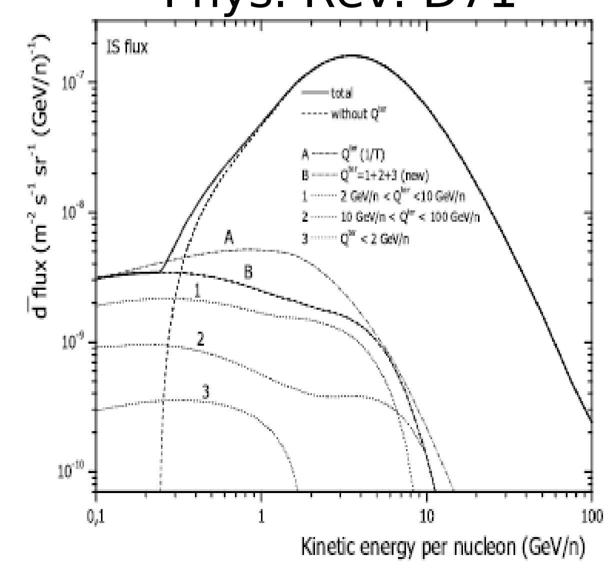
   standard and exotic production
2. **Present status of measurements** – BESS limit
3. **Future prospects**
4. **AMS-02**

   description of the experiment and highlights of the analysis
5. **GAPS** (General Antiparticle Spectrometer)
6. **Summary**

Antideuterons in Cosmic Rays



Phys. Rev. D71

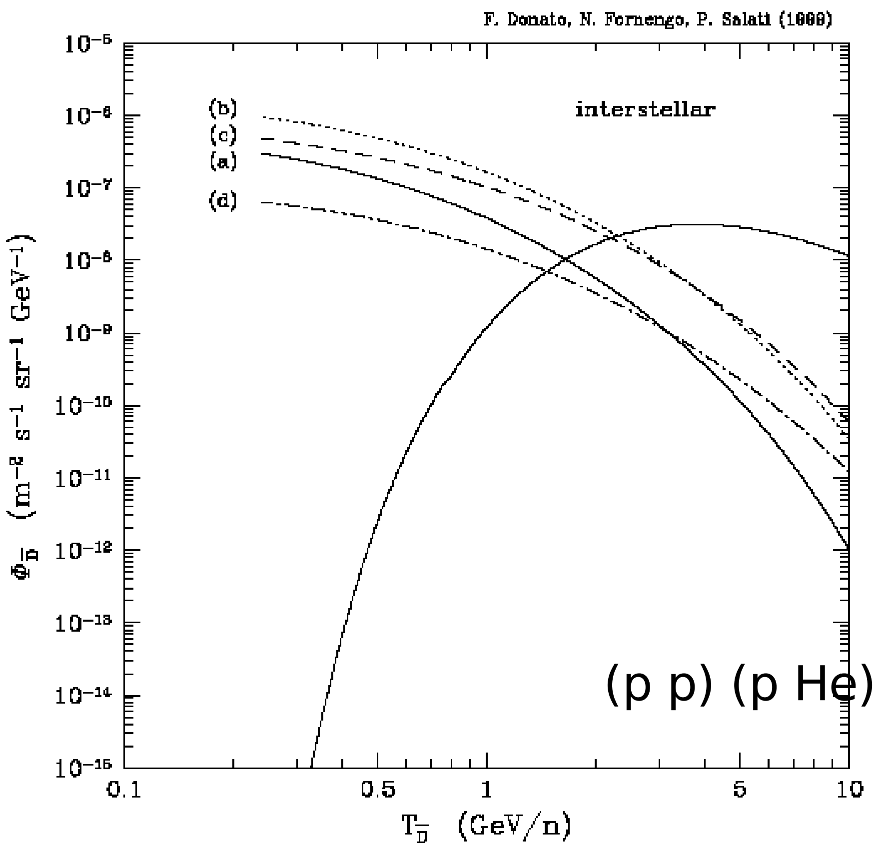


antideuterons – secondary flux only

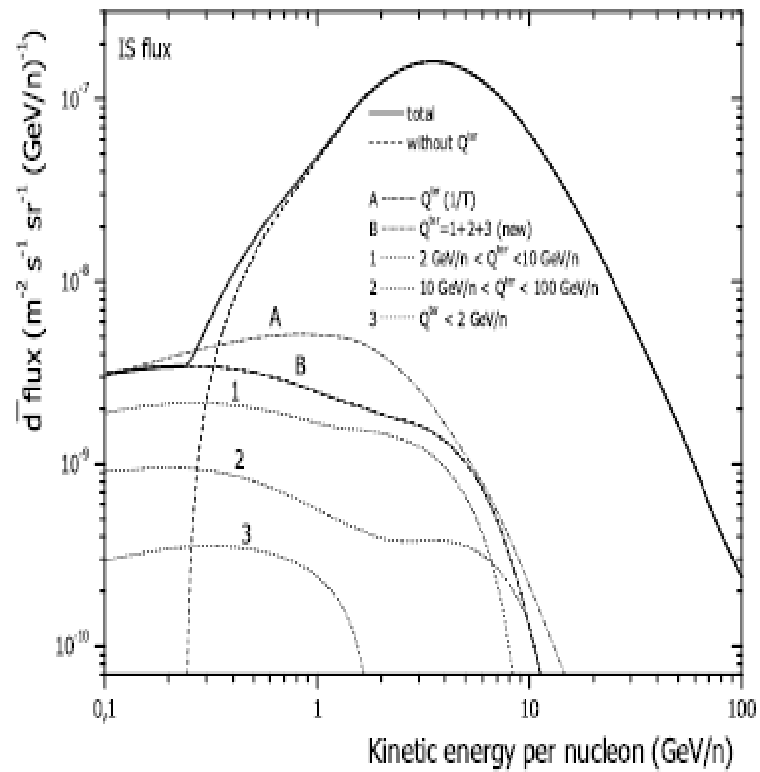
Antideuteron channel

- The way of production of antideuterons is not well understood, but…
- spectra of DM signal and secondary background very different:

astro-ph/0503544



(p p) (p He) (He p)

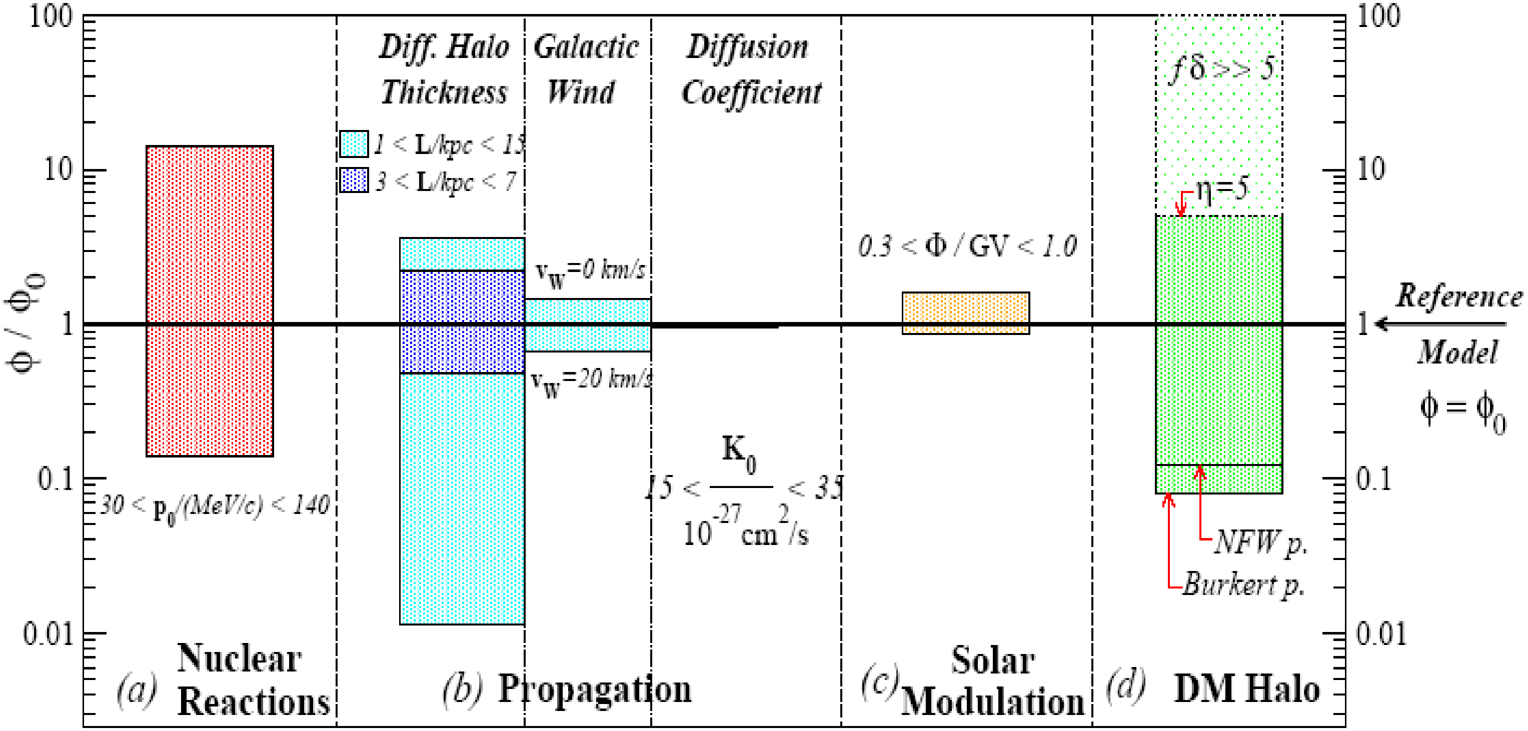


+ (antip p) (antip He)

The theoretical works continues…

Uncertainty of flux

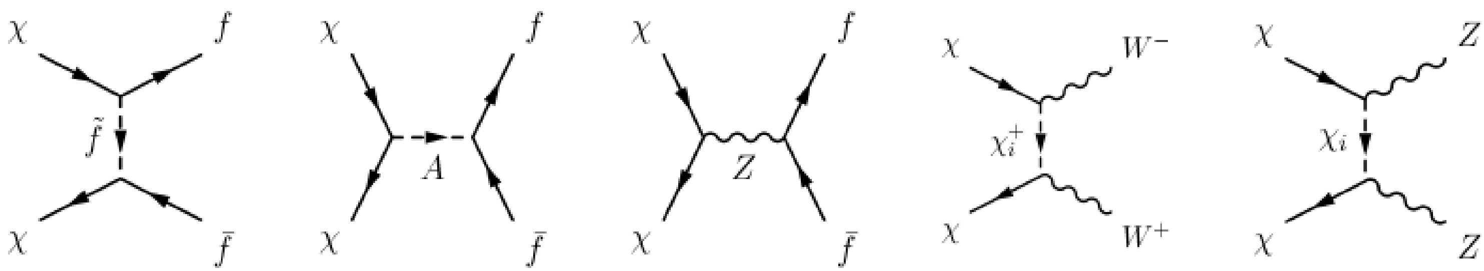
Uncertainties in Primary Antideuteron Flux



Baer & Profumo 2005

Antideuterons in Cosmic Rays

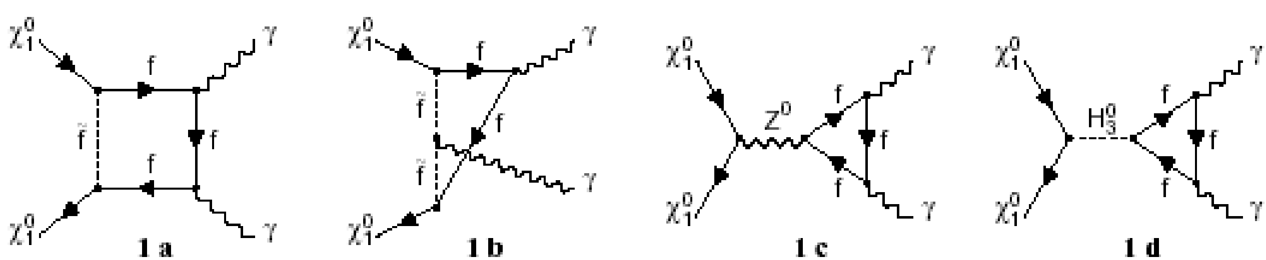
(Production in exotic processes)



$\chi^0_1\chi^0_1 \rightarrow q\ \bar{q}$, W^+W^-, ZZ, … hadronization, decays ….

$\rightarrow\ \bar{p}$, $\bar{D}$, γ (continuum), e^+, (also neutrinos-> km3, IceCube)

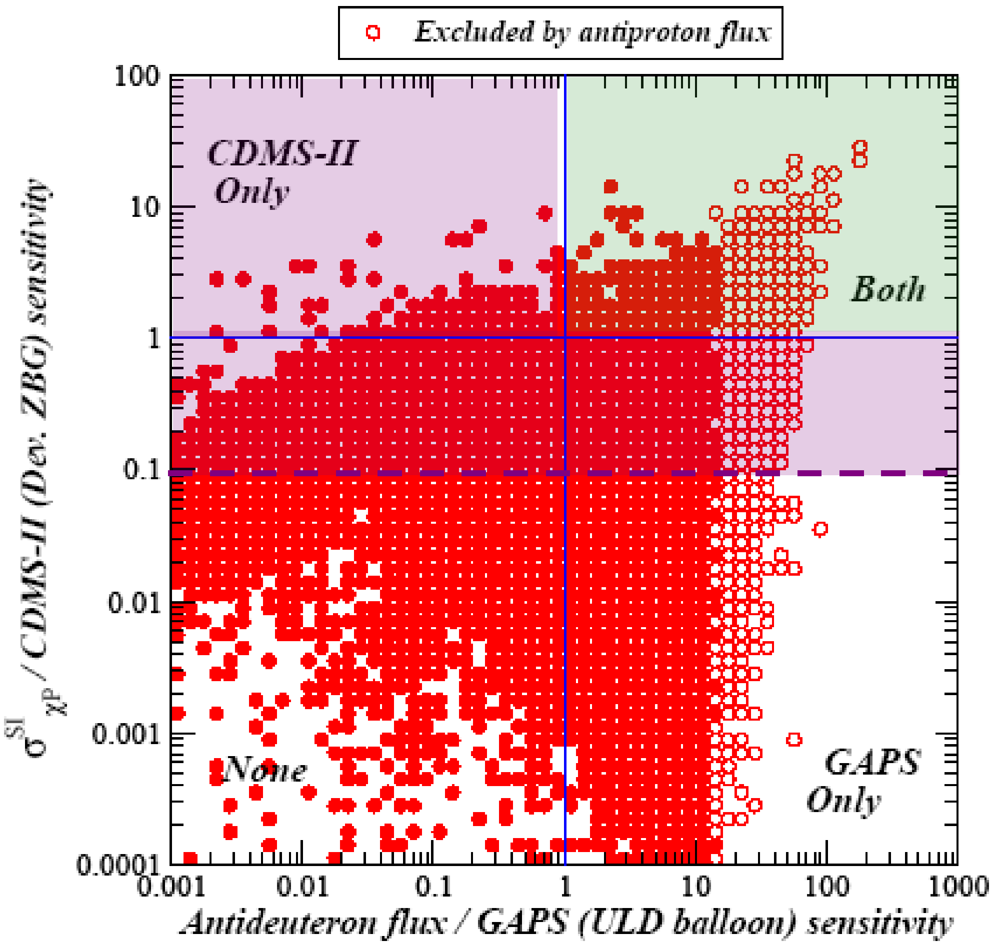
Channels observable in AMS (or other CR detectors) plus suppressed but very characteristic – gamma line:



Complementarity with other searches

In the part of the parameter space where direct searches does not give good potential – searches in antideuteron channel have strong potential.

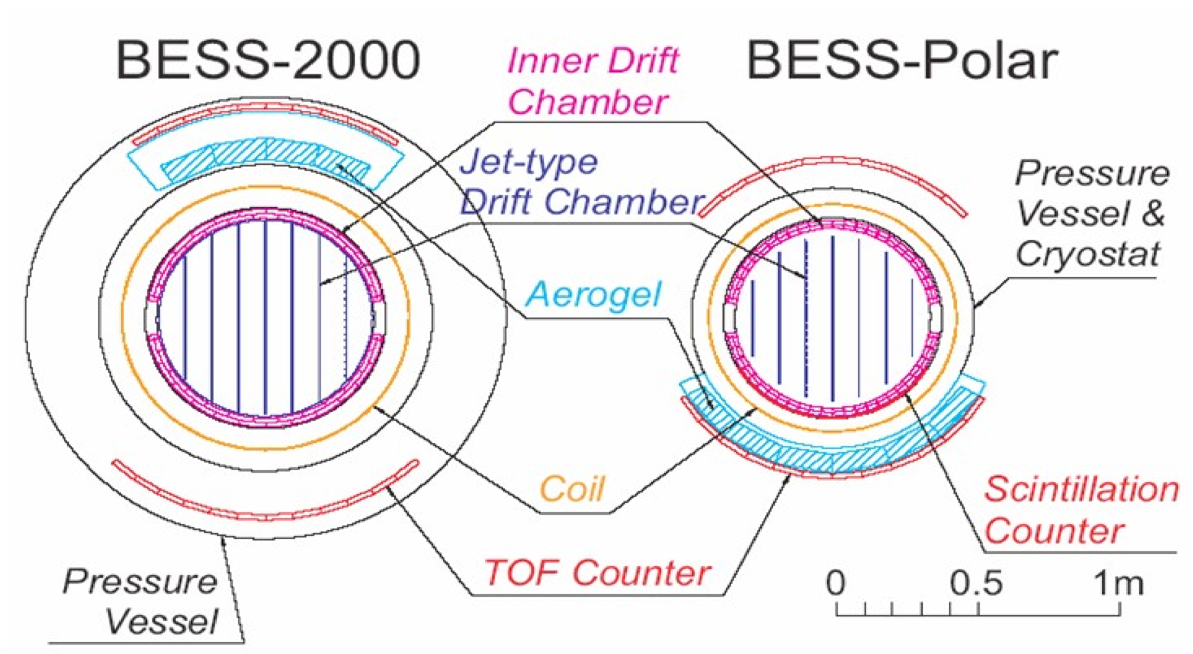
Antideuterons are also a sensitive probe for primodial black holes



Baer & Profumo 2005

Antideuterons – present status

- BESS collaboration upper limit on low enegy antideuteron flux (astro-ph/0504361) : $\Phi < 1.9 \cdot 10^{-4}\, m^{-2}\, s^{-1}\, sr^{-1}$ (GeV/n)$^{-}$
  (BESS energy range 0.17 – 1.15 GeV/n)
- From this no constraint on WIMPs (no model predicts so high fluxes), some constraint on primodial Black Holes

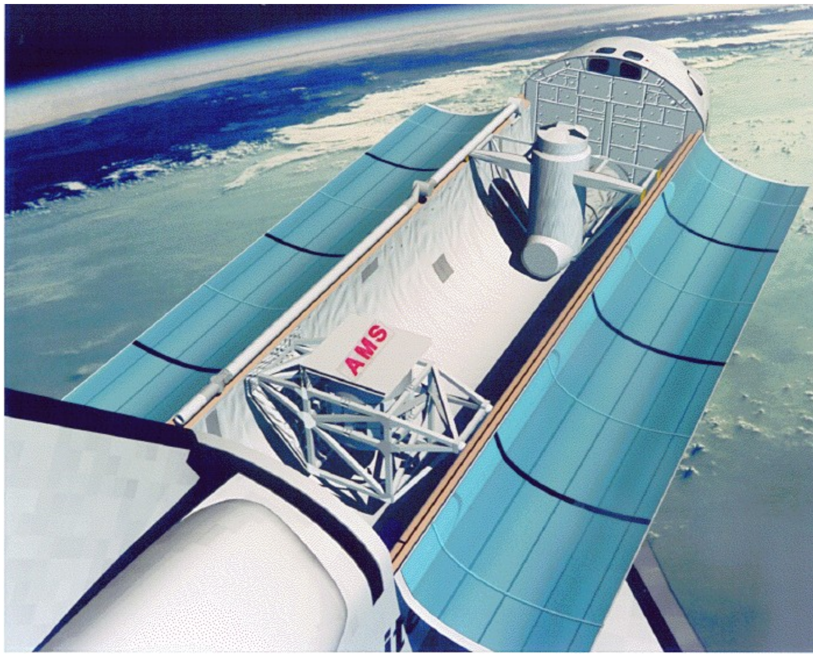


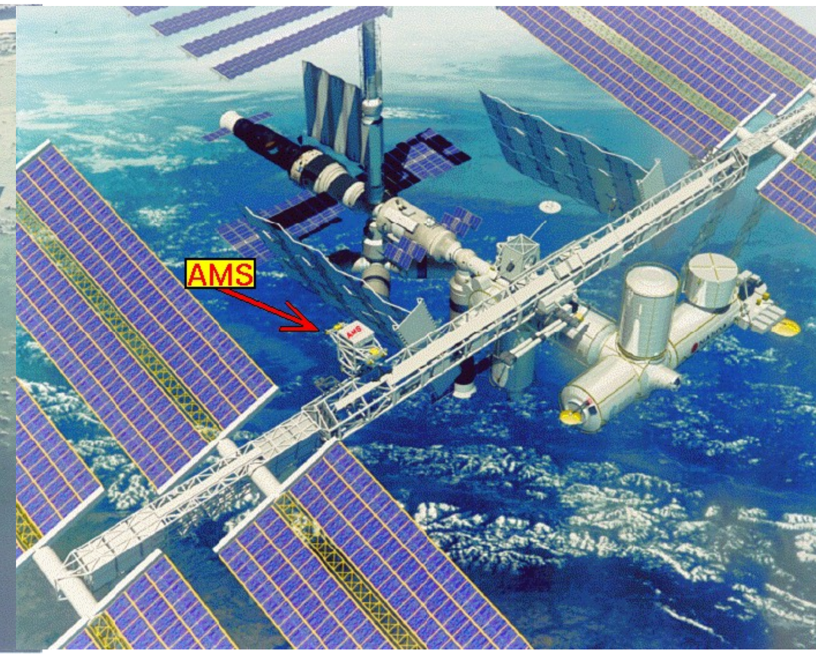
Future prospects

- Pamela – acceptance way too small to see any antideuterons but probably will be able improve upper limit on antideuteron flux
- AMS-02 – much larger acceptance, some antideuterons can be registered, however lower threshold on kinetic energy is quite high
- GAPS – interesting technology...
- Theoretical work and accelerator measurements are still needed to improve the accuracy of estimation of standard flux

AMS-01 and 02 Experiments

AMS-01





AMS-02

Launched on Space Shuttle Discovery in July 1998

(10-day flight)

AMS-02: Large acceptance cosmic-ray spectrometer to be located on the ISS for a period of at least three years (2009-...)

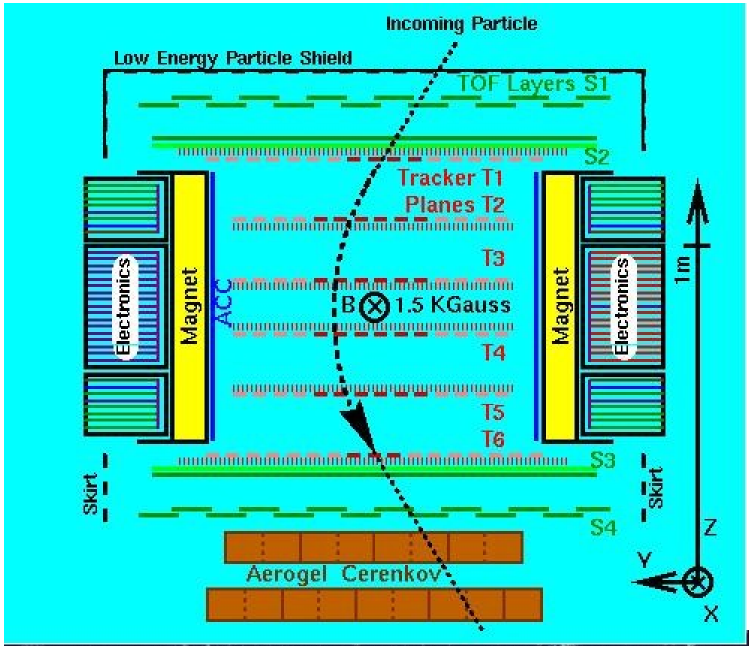
AMS-01

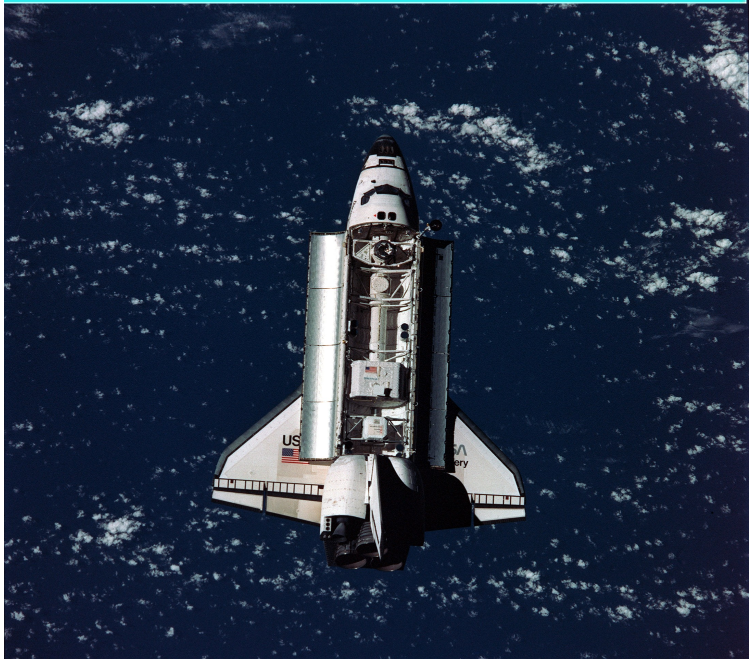
Very interesting physical results:

- Best present limit on antihelium
- One of the best measurement of proton/electron/positron fluxes
- New radiation belt (e,p,^{3}He, atmospheric origin, short-lived)
- Recently: confirmation of positron flux excess seen by HEAT (publication in preparation)

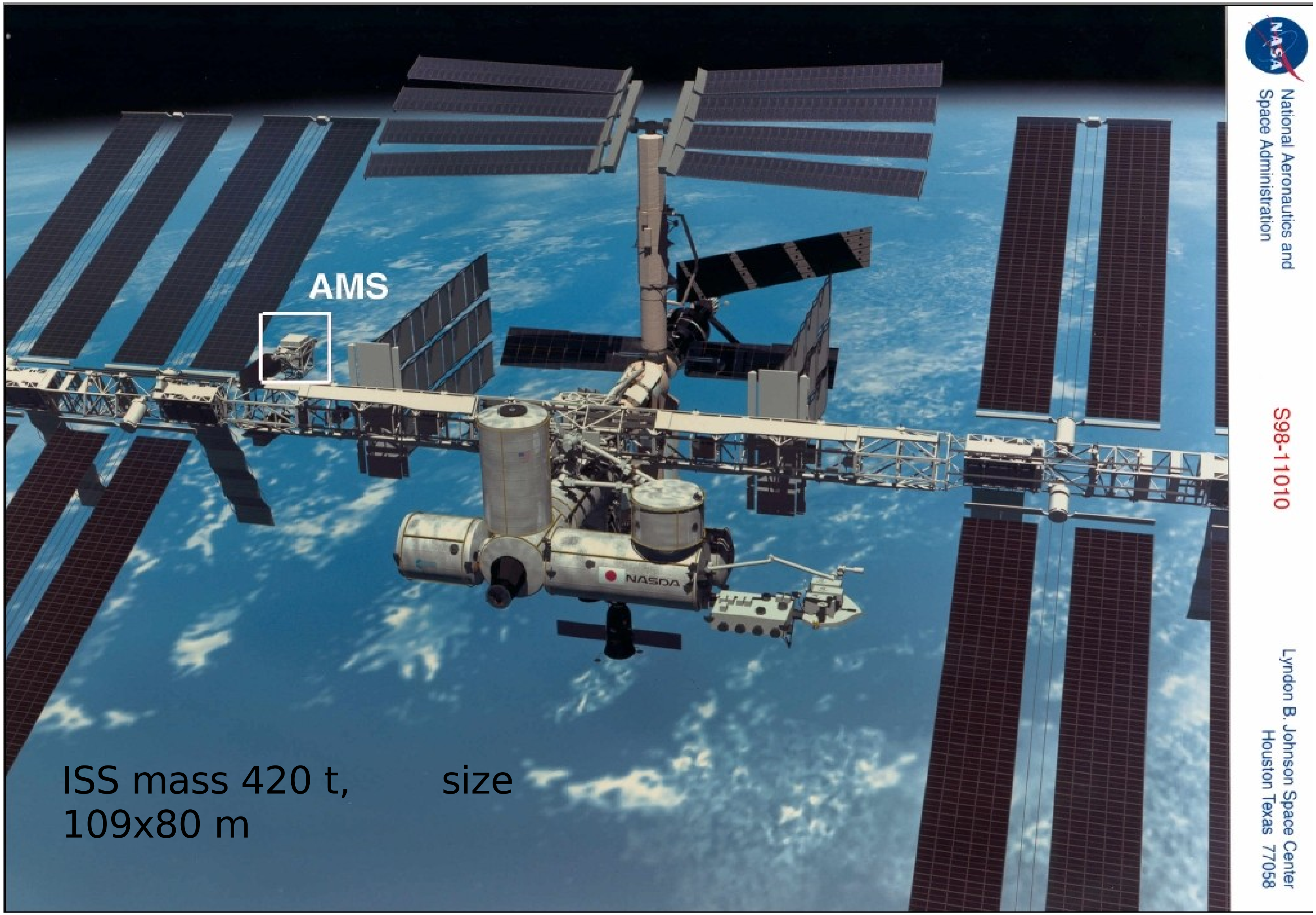
(Phys. Lett. B461, 387-396;

Phys. Lett. B472, 215-226 and other)





AMS-02 on ISS



ISS mass 420 t, size 109x80 m

AMS-02 general considerations

- Goal: CR measurement with large statistics
- Space requirements:
  - Weight 6700 kg
  - Power consumption 2 kW
  - Vibration: 17 G RMS
  - Reliability (3 years) – redundancy
  - Thermal environment ($\Delta T = 100$ C)
  - Radiation resistance
  - Orbital debris and micrometeorites (helium tank)
  - Small dipole moment (even smaller in case of free satellite)

AMS-02 Experiment

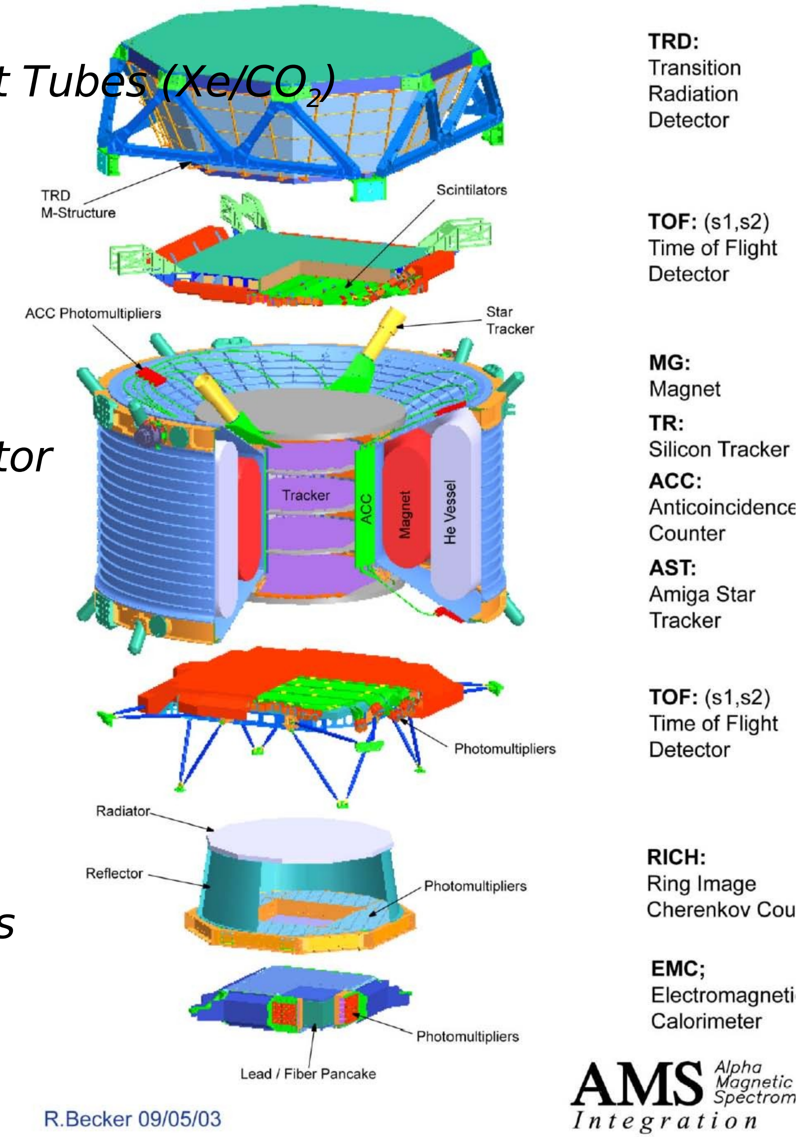
Transition Radiation Detector (TRD): *Foam + Straw Drift Tubes (Xe/CO_2)*
e/p separation, rejection power > 100 up to 300 GeV

Time of Flight (TOF): *scintillators, Δt =~160ps*
Main trigger, charge separation, β with few % precision

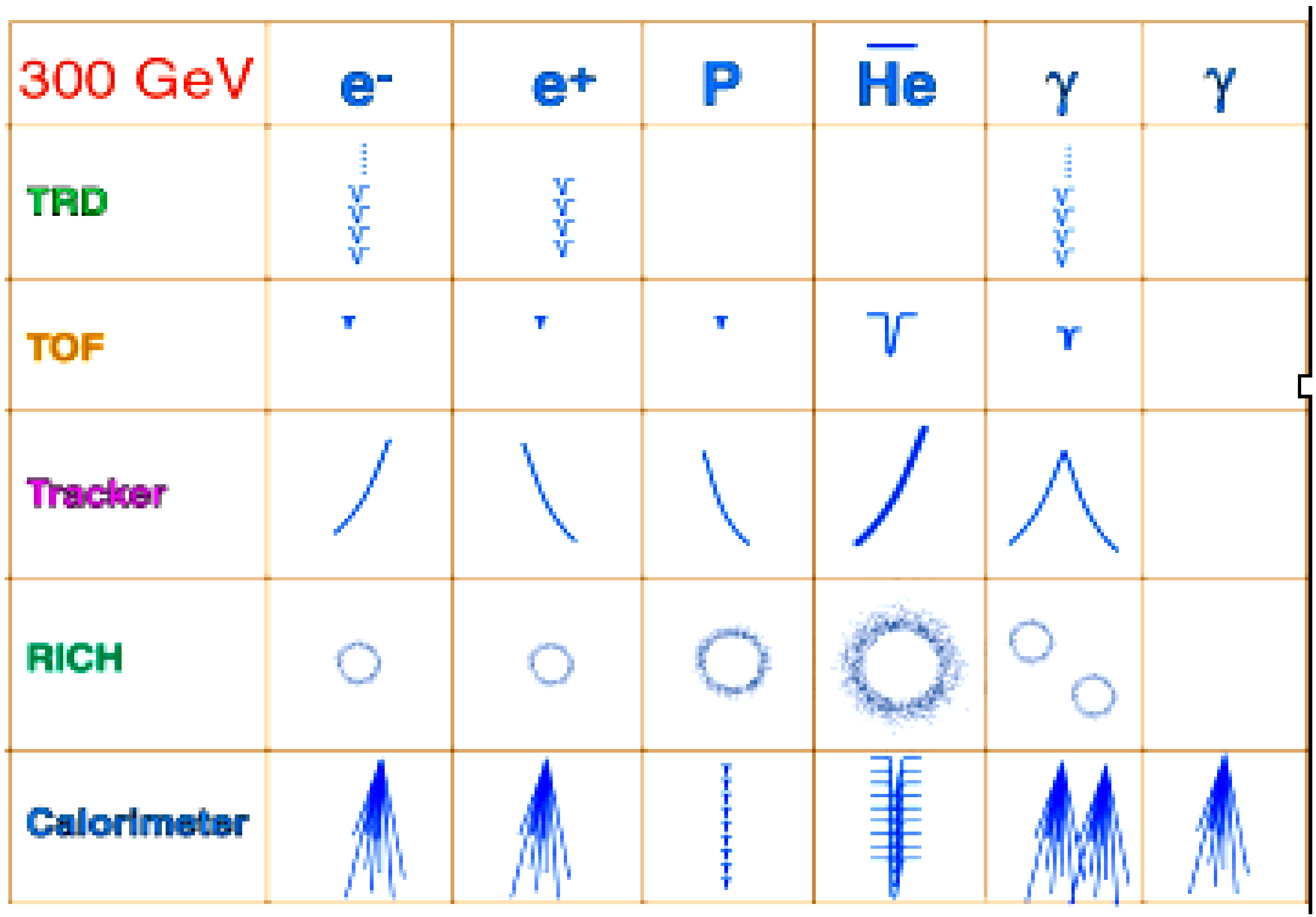
Superconducting Magnet : *BL^2 = 0.85 Tm^2*
Tracker (8 layers) : *double sided silicon microstrip detector*
<2% resolution below 10 GV, rigidity up to 2-3 TV, charge separation

RICH : *Radiator (Aerogel, NaF)*
β measurement with 0.1% precision, charge separation, isotope separation (2% precision on mass below 10 GeV/n)

Electromagnetic Calorimeter (ECAL): *Lead+scint. Fibers*
$e^{\pm}$,γ, detection, standalone trigger
<3% en. res. above 10 GeV, e/p separation >1000



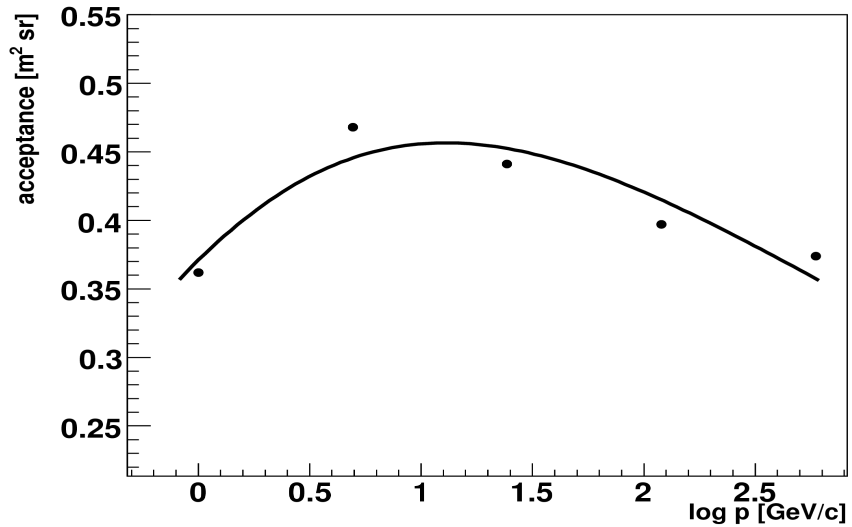
Strategies of measurements



AMS-02 – highlights of analysis

(S. Gentile, F. Giovacchini (Bologna), V.Choutko (MIT), MS)

- Deuterons and antideuterons interactions in Monte Carlo – lack of experimental data so high uncertainities in determination of the cross section (especially with carbon).
- To obtain (antid,A_t) BESS used scalling from (antip,A_t) [NIM A489, 170 (2002)]
- Geometrical acceptance: events with no activity in anticoincidence counters, with tracks in TRK and TRD, with velocity measurement.



Strategy

1. protons should not be a problem – very low charge confusion and mass resolution good enough (10^{11})
2. reject electrons in TRD plus mass resolution (10^{9})
3. deuterons – rejection only by sign of charge (10^{9})
4. antiprotons – rejection only by mass resolution (10^{6}) - the most dangerous background

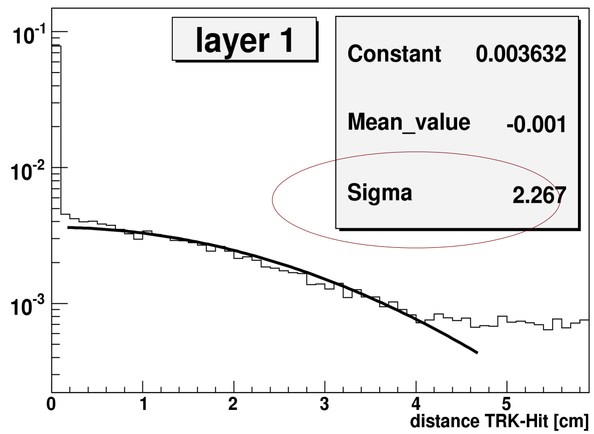
>> mass resolution is crucial:

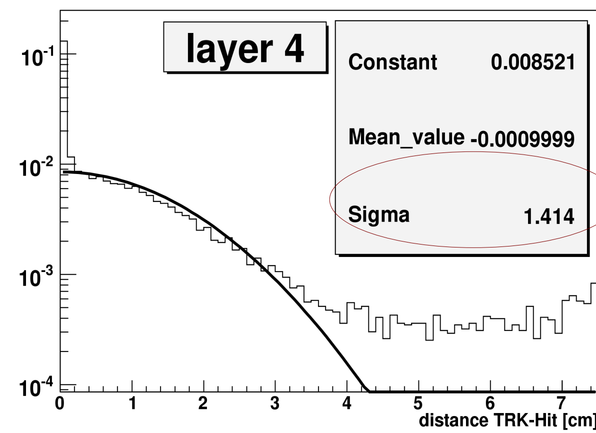
$$m = p\sqrt{\left(\frac{1}{\beta^2} - 1\right)} \qquad \Delta m = \Delta p \oplus \beta^2 \Delta\beta$$

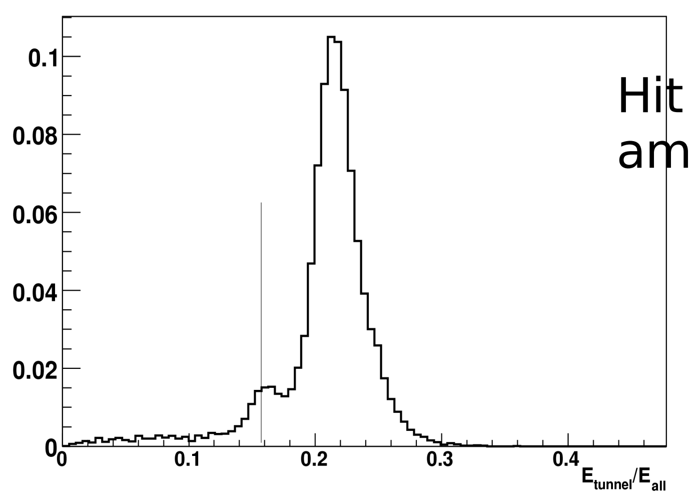
Therefore we need to optimize reconstruction of momentum and velocity

Example of cut for momentum reconstruction: energy in TRK tunnel

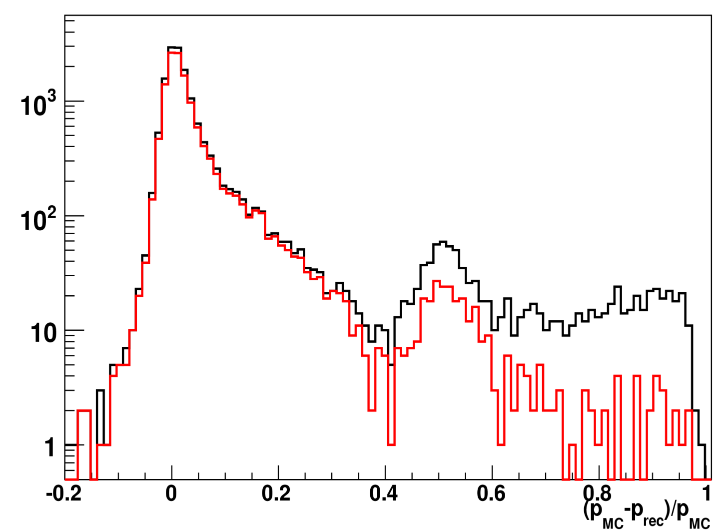
Ratio of energy in a tunnel around the track divided by energy of all clusters in the tracker. Due to clusters ambiguity it is not close to one. The diameter of the tunnel in every layer is chosen to be 2.5 .







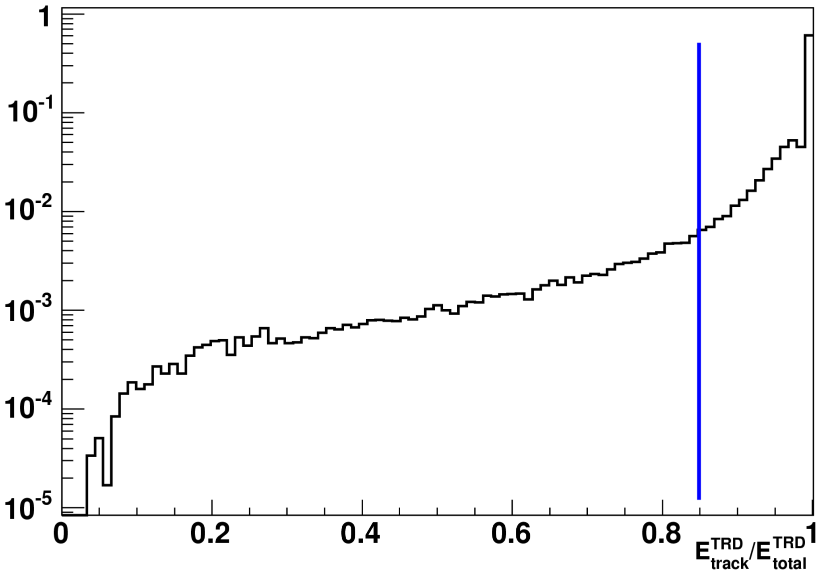
Hit ambiguity

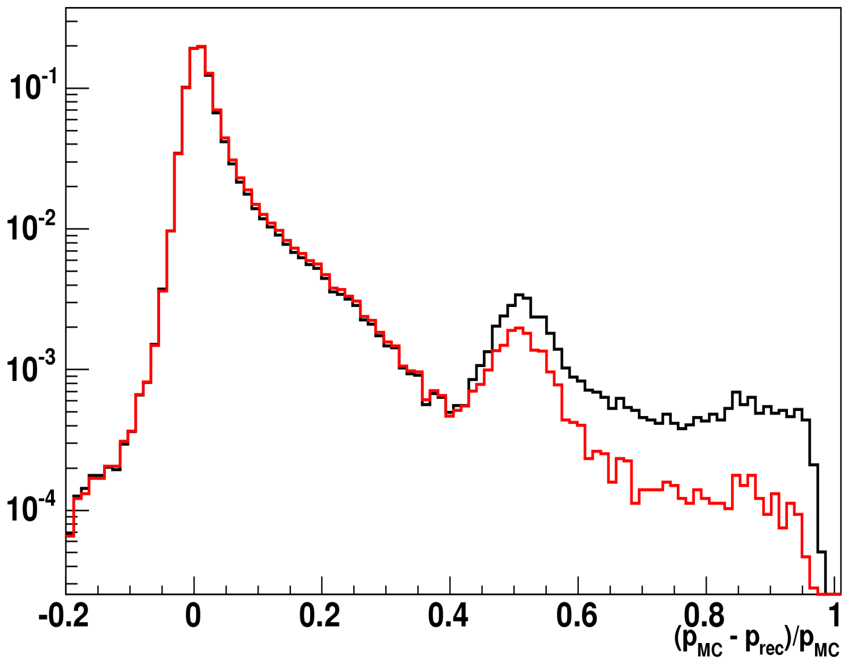


Other example: cut on activity in TRD (not only TRK)

Idea: events with too much energy off TRD track should be rejected as the ones where particle interacts strongly in TRD.

0.85

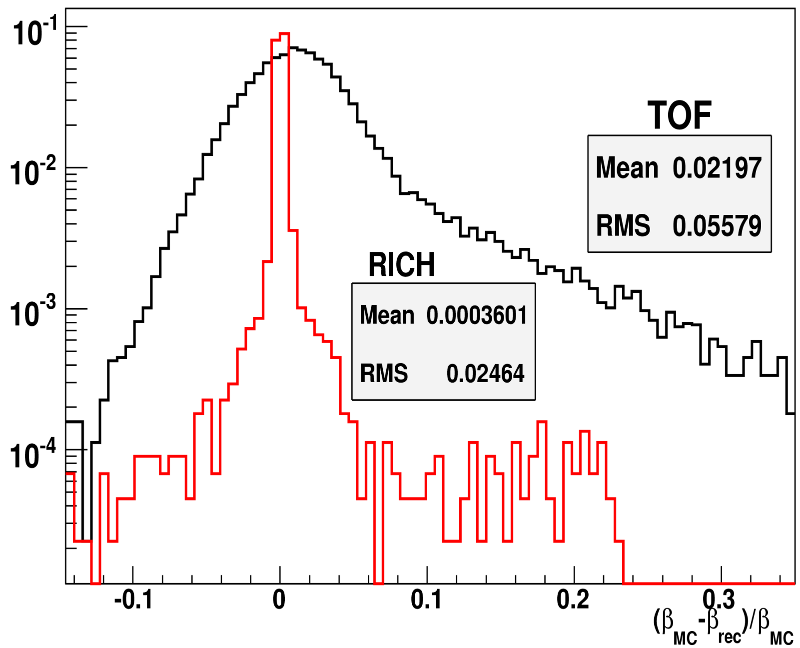




Velocity measurement

Two possibilities: TOF and RICH

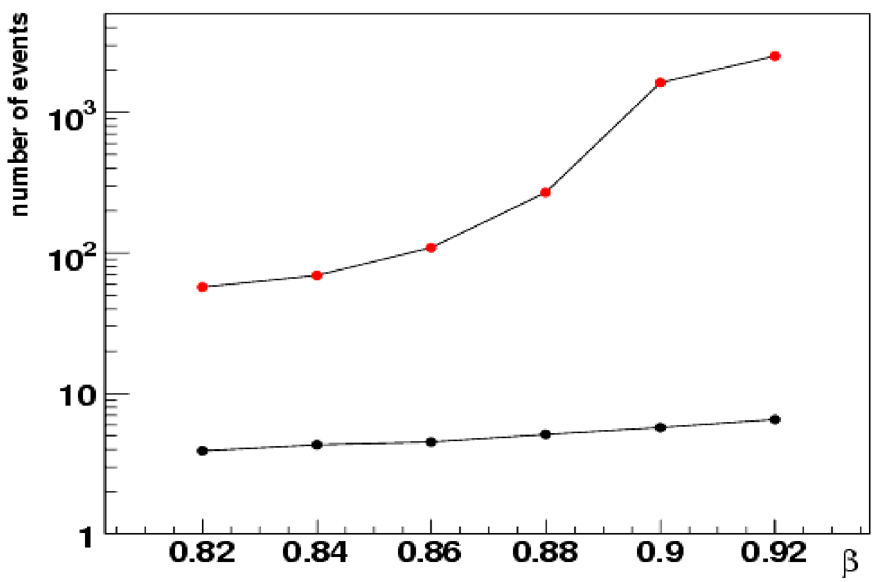
	TOF	RICH
kinetic energy:	0.2-0.7 [GeV/nucl]	0.8-10 [GeV/nucl] (NaF) 2.5-10 [GeV/nucl] (Aerogel)
	(low energies are interesting)	
final acceptance:	about 0.3 [m^2sr]	about 0.04 [m^2sr]
resolution $\delta\beta/\beta$:	about 5%	about 0.1 %



if RICH is accessible and passes cuts,
we take RICH velocity
otherwise we test TOF velocity

Cut on maximal velocity in TOF

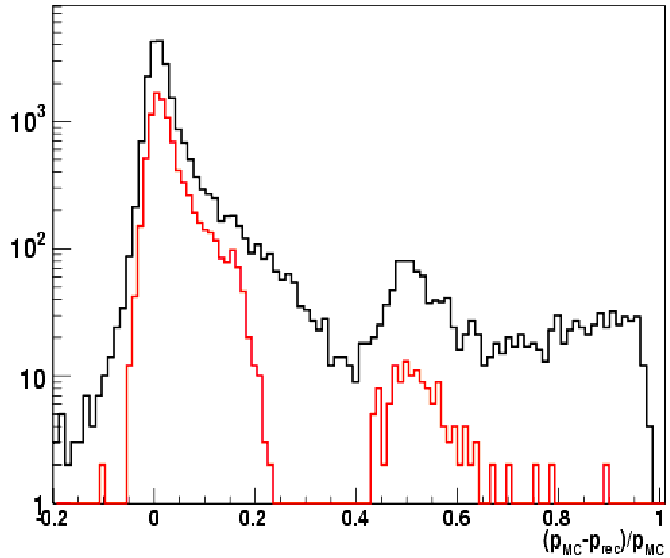
For high velocities the beta reconstruction in TOF becames less precise and antiprotons can fake antideuterons. Cut on maximal value of velocity measured in TOF is crucial for antiproton rejection.



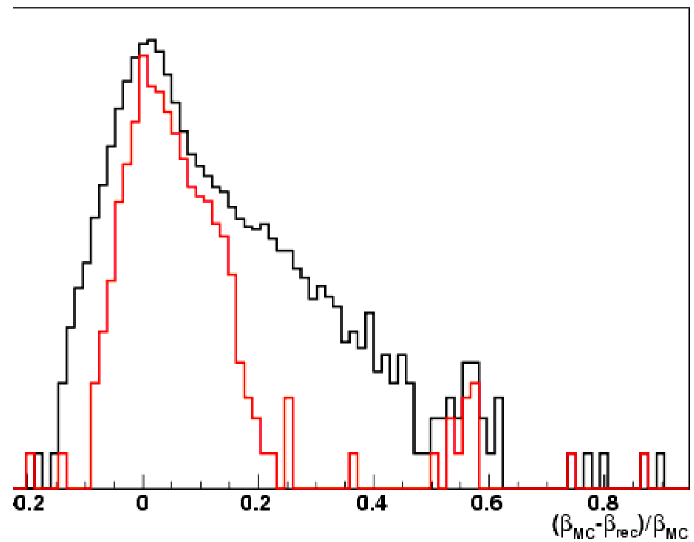
Using standard antideuteron and antiproton fluxes, including geomagnetic cutoff.

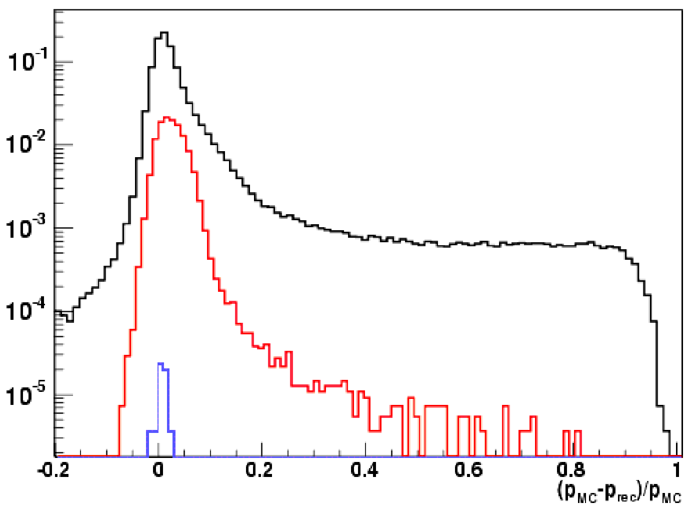
=> even using a severe cut on maximal velocity in TOF the antiproton background will prevent us from seeing the registered antideuterons

Final quality of momentum and velocity reconstructions

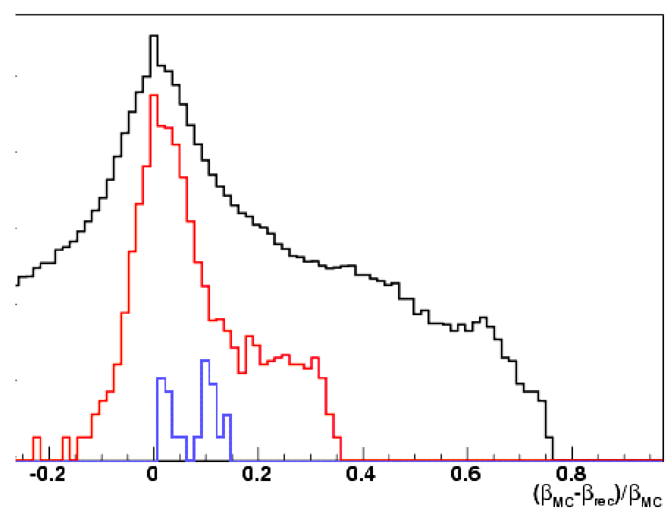


antid

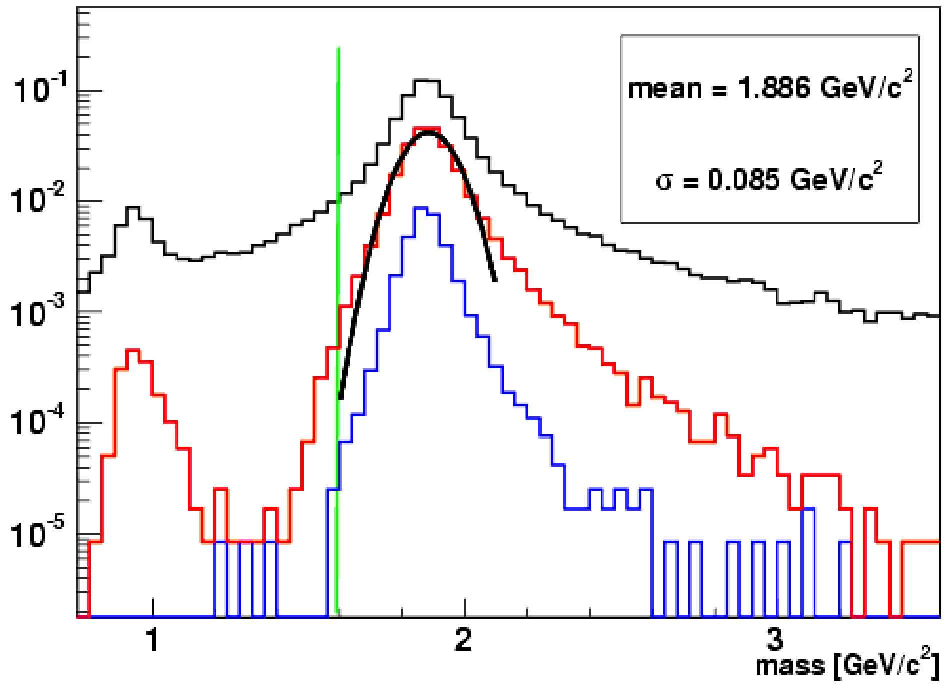




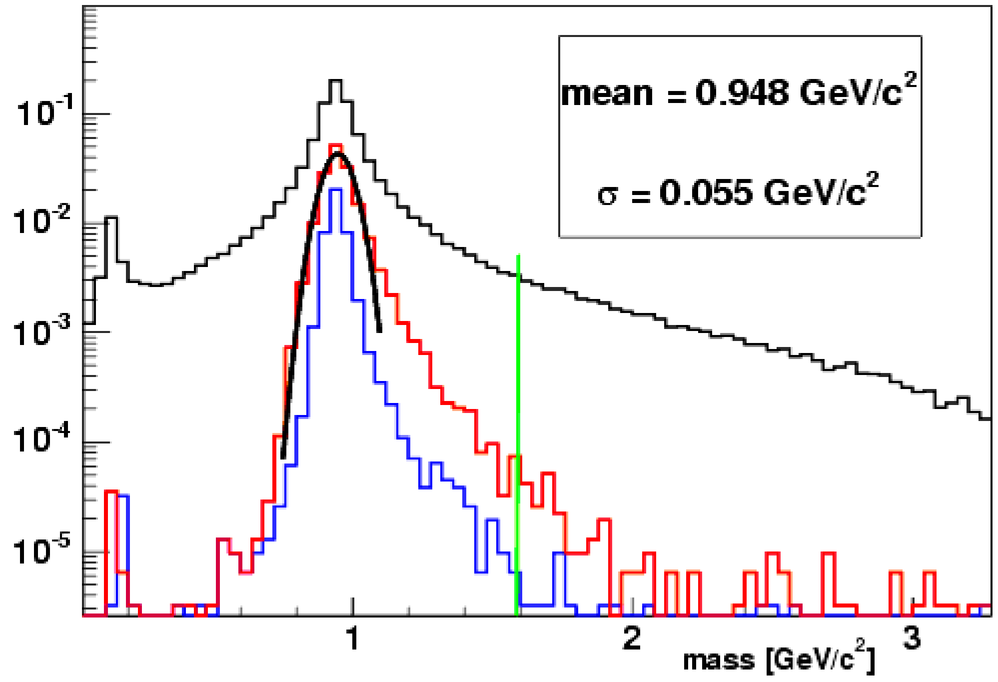
antip



Final quality of mass reconstruction



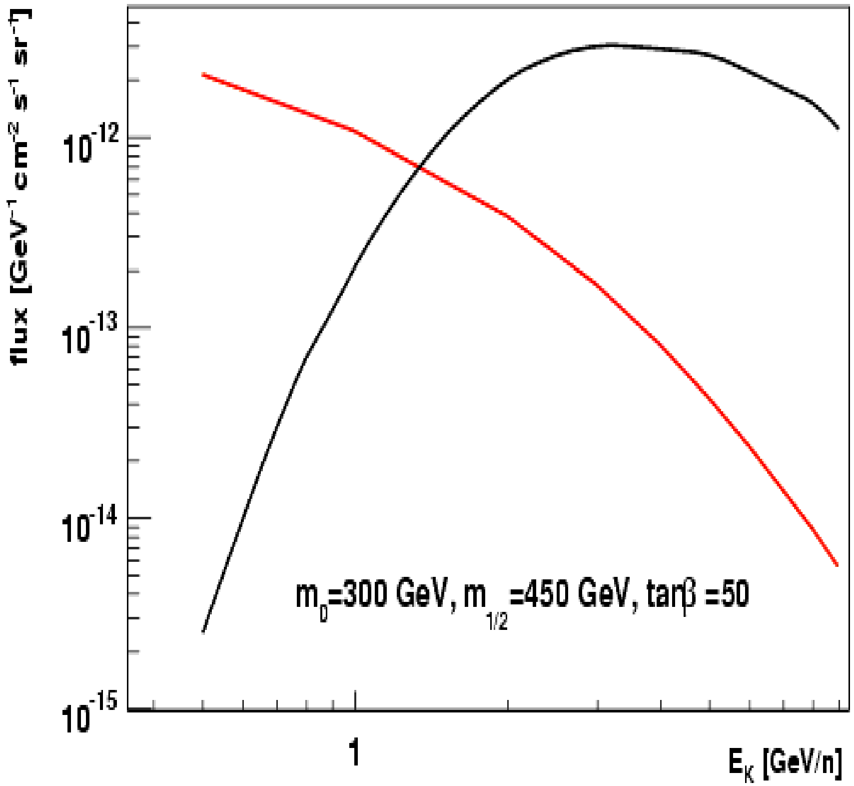
antid



antip

Sensitivity to SUSY fluxes

eg. benchmark model L:



Model L with Boots factor 100 detectable: 200 antideuterons registered (45 in RICH)

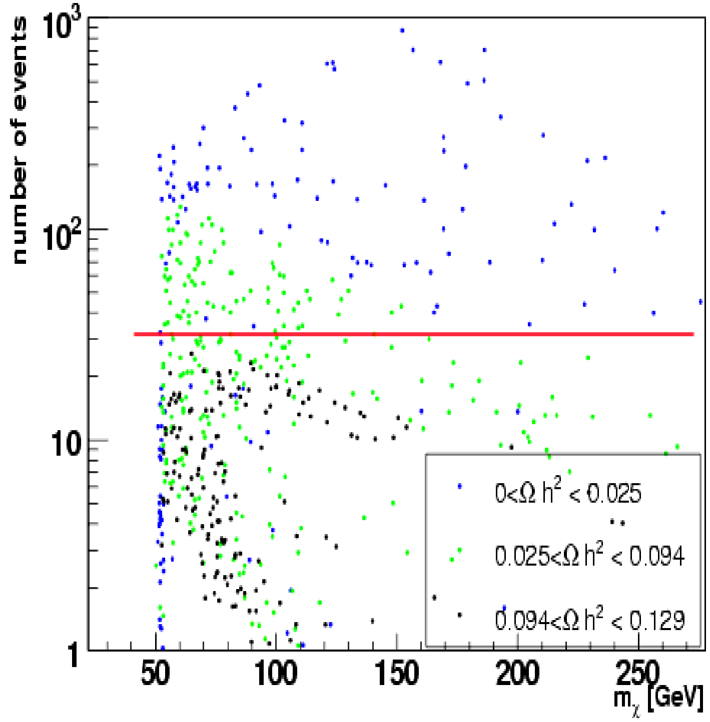
Sugra wild scan (5000 models), DarkSusy 4.1, NFW model with boost factor 1000:

m_0: 50-3000

$m_{1/2}$: 50-1600

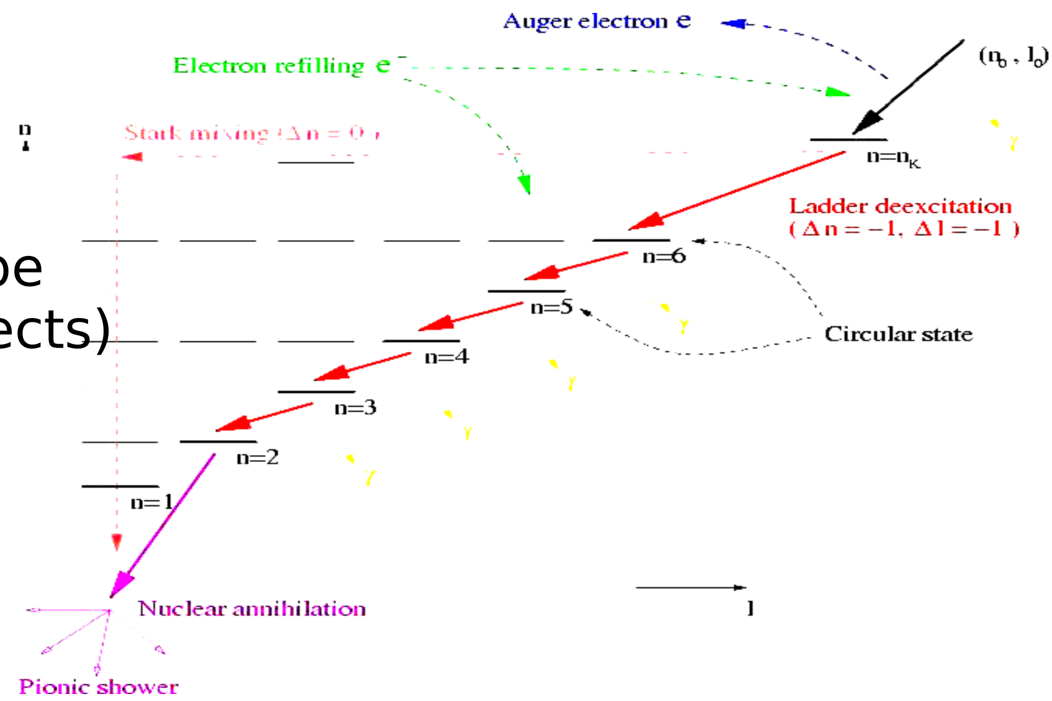
A_0 : 0.1 – 2000

tg β: 3 - 60



Can other experiment do better? GeneralAntiParticleSpectrometer

- Detection technique based on characteristic de-excitation signal from exotic atoms where electron is replaced by antideuteron nuclei plus annihilation hadronic cascade (Astrophys.J. 566,604 (2002))
- Discrimination against protons 10^{12}
- Kinetic energy range 0.05-0.4 GeV/n
- Planned balloon flight (2010) and than a satellite or a deep space probe (to avoid geomagnetic and solar effects)
- Deep space probe not good for galactic background and SUSY antideuteron production in WW final state (higher energies)
- Ongoing RND (KEK beamtests)



GAPS

team:

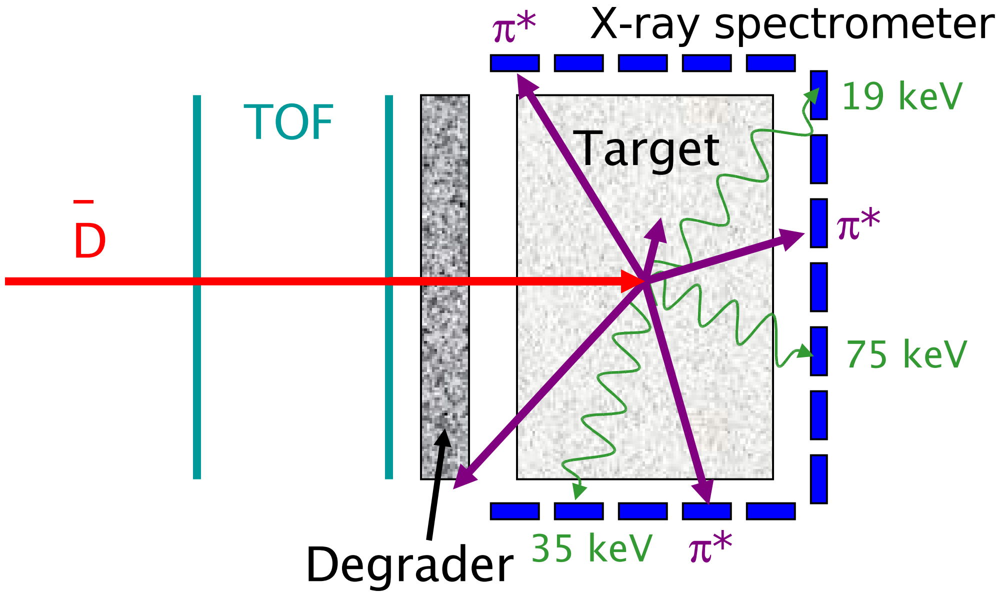
C. Hailey (P.I.), F. Gahbauer, H. Yu, J. Koglin (Columbia University)

W. Craig , K. Ziock (LLNL)

F. Harrison (CalTech)

J. Hong (Harvard)

detector:



goal:

conduct balloon-based GAPS antideuteron search by 2010 (ULDB)

satellite mission possible

GAPS – main background

- Coincidence of proton + 3 photon background is primary problem

- spallation and activation produce beta-particles, neutrons (n,gamma),(n,n’)

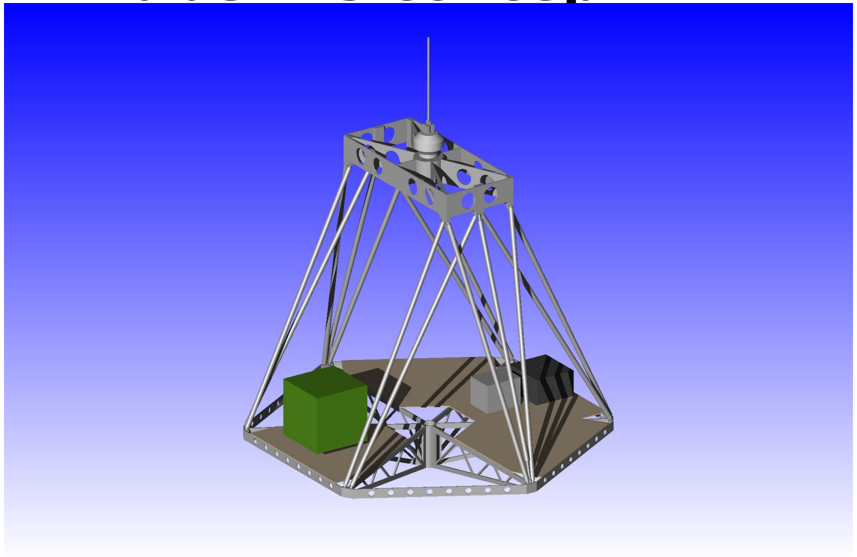
GAPS - sensitivity

1. GAPS will be sensitive in the region uncovered by AMS (0.05-02 GeV/nucl)
2. GAPS will not be sensitive to antideuterons from spallation

therefore GAPS will be SUSY DM detector...

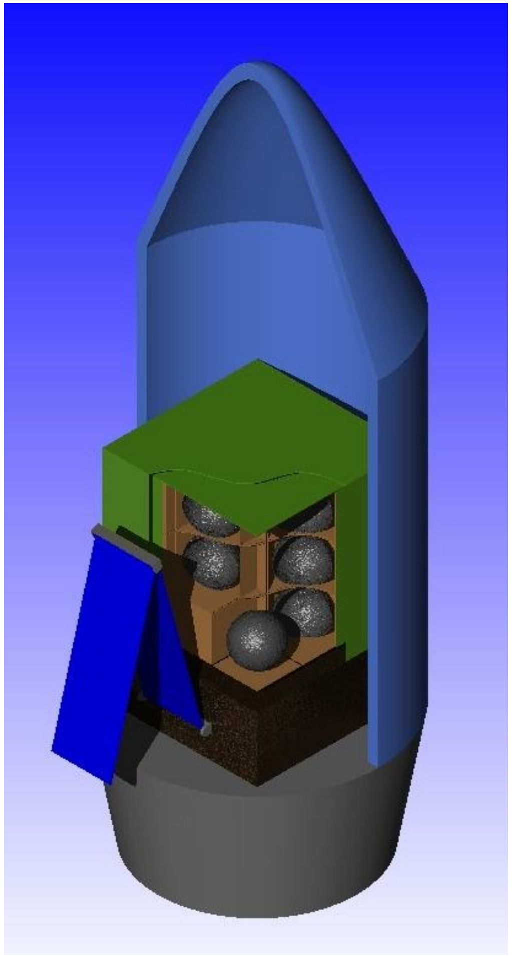
An ultralong balloon mission would cover about ½ of the searchable SUSY parameter space where the neutralino is likely to be

- **ubGAPS concept**



	ubGAPS
Energy band (GeV/n)	**0.125-0.36 NaI**
Pk. Eff. Grasp (m^2 sr)	**0.88 NaI**
Background rejection power	**10^{12}**
Mission life	**200 days**
Sensitivity (m^2 sr s GeV)$^{-1}$	**9.7 x 10^{-8}**

GAPS antideuteron search on Explorer class mission in low earth orbit



- Probe primary antideuterons at E < 0.2 GeV
- NASA Explorer mission (total cost = 199.6 M$)
- Delta II 2420-10 3m rocket
- High latitude orbit (L = 70°N)
- 3 year mission
- Total size = 5 m
- Total weight = 2200 kg
- 27 CZT cells with Nitrogen gas
- Total column density = 5 g/cm^2
- Energy band 0.1-0.2 GeV/n
- Peak eff. Grasp 45 m^2 sr
- Background rejection 10^{12}
- I_{min} 2.6 x $10^{-9} m^{-2} s^{-1} sr^{-1} GeV^{-1}$

  >> 20 times more sensitive than a magnetic spectrometer type mission

Summary

1. antideuterons have never been observed in CR – the only experiment which gave limit is BESS

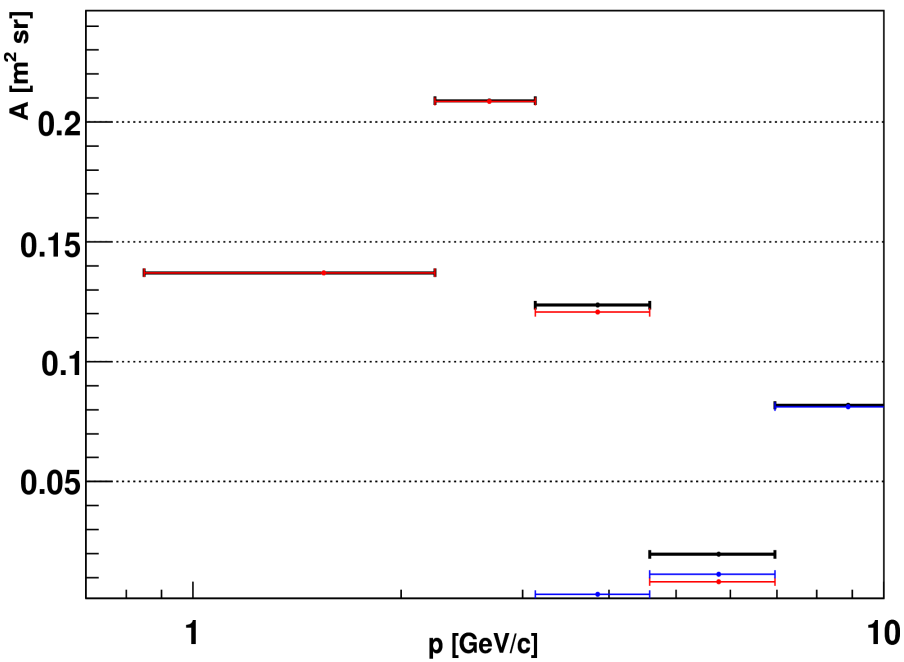
2. there are 8 expected antideuterons from spallation processes (5 in RICH)
these antideuterons probably will not be visible due to antiproton background
(there is still a hope for RICH)

3. there are SUSY models which give high antideuteron fluxes –
- can be detectable in AMS and in the same time these models are difficult in direct searches

4. a very interesting experiment is coming GAPS,
with interesting discovery potential

Additional slides

Final acceptance and efficiencies

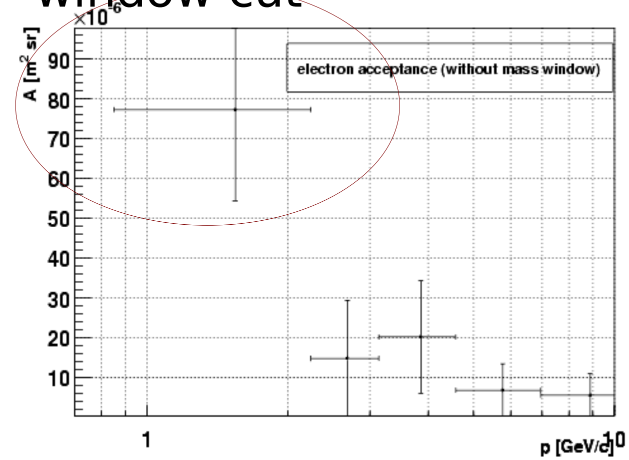


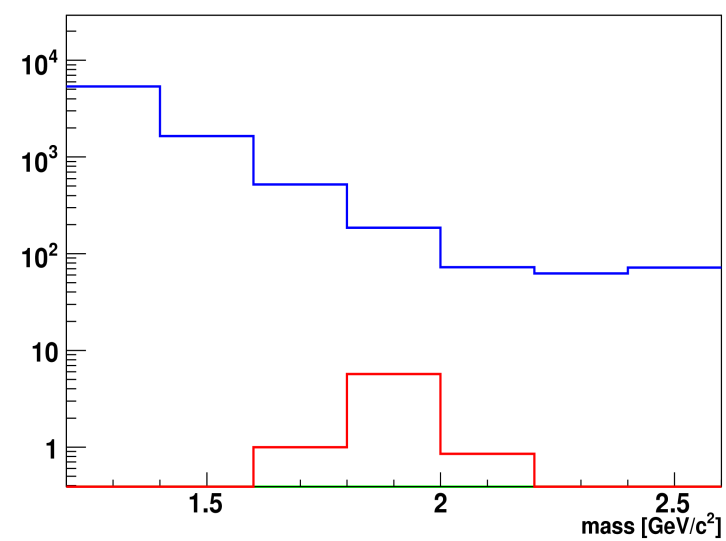
TOF

RICH

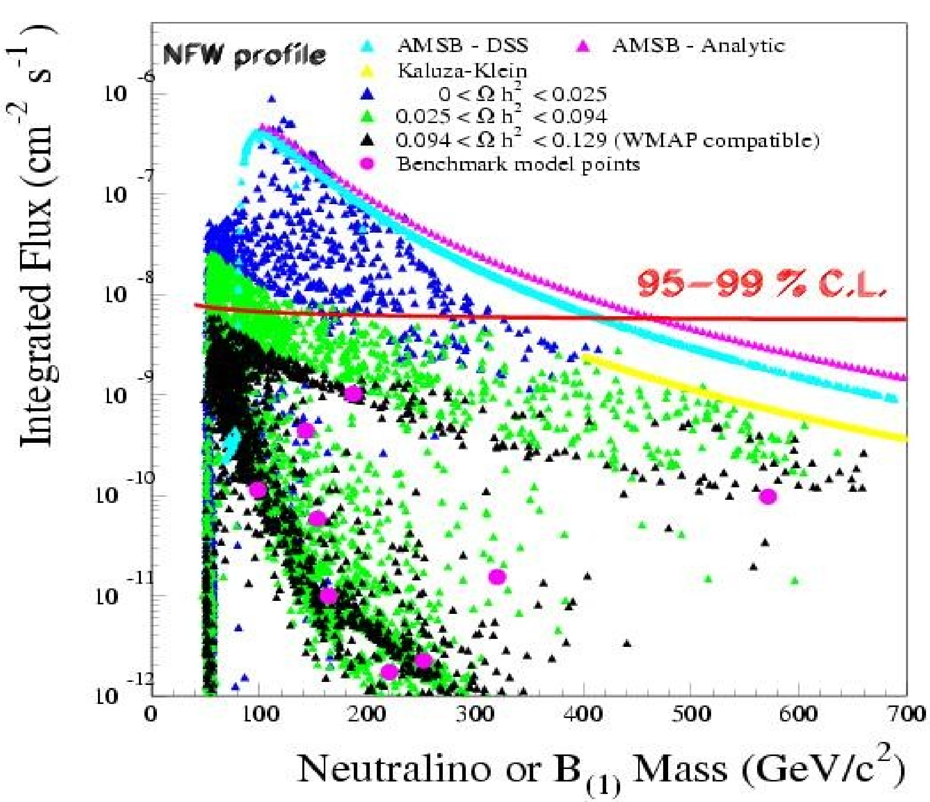
= 0.9 corresponds to p = 3.8 GeV/c

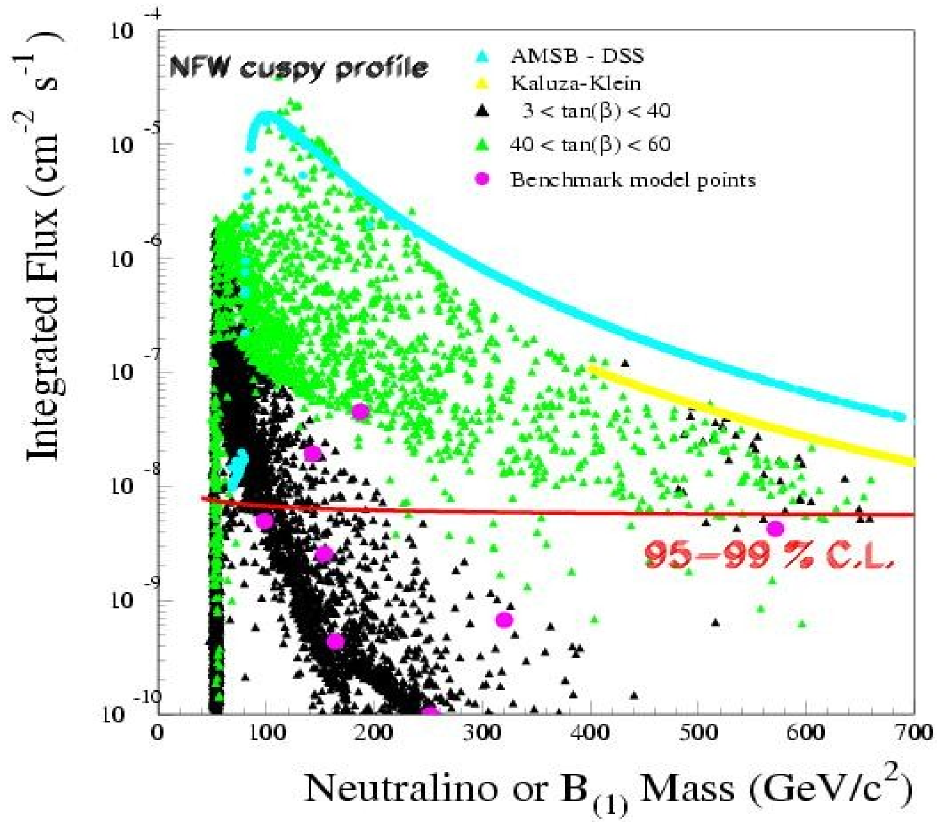
This momentum is disfavored by mass window cut





Gamma channel in AMS-02

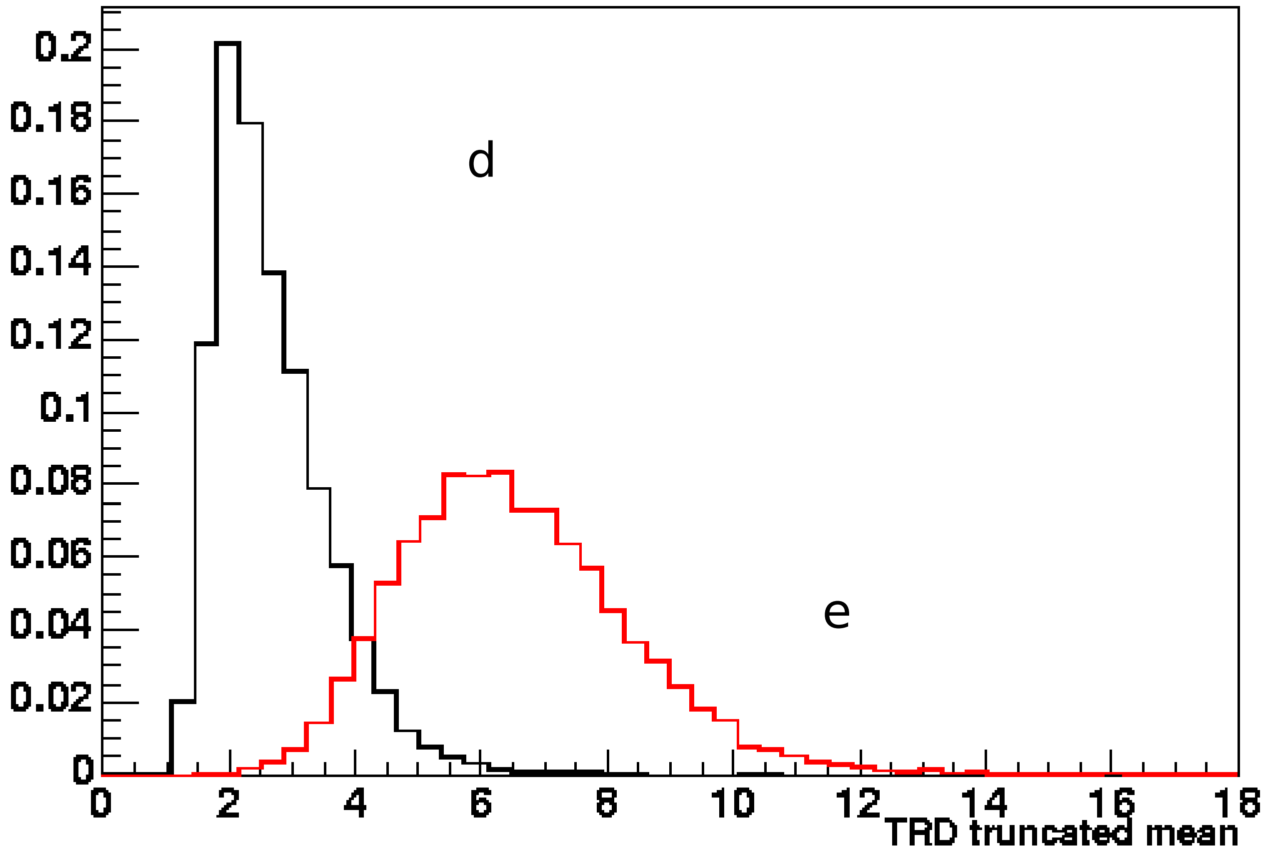




astro-ph/0508349

Assume cuspy profile in CG and treat it as a point source.

Electron rejection: truncated mean energy



Momentum-dependent cut:
0.85-2 GeV/c: 4.7 MeV
2-3 GeV/c : 4.1 MeV
3-5 GeV/c : 3.3 MeV
> 5 GeV/c : 3.1 MeV

efficiency:
antideuteron - 87%
electron - 4%
(with respect to preselection)

Fluxes on orbit

The geomagentic cutoff for deuterons is:

1. about 6 GeV/c for equatorial region (0<Theta<0.3)
2. about 4 GeV/c for 0.6<Theta<0.7
3. about 0.8 GeV/c for 0.9<Theta<1.0 (Quasi-polar region)

The fluxes in this analysis are taken from BESS measurements (antiprotons), AMS-01 (electrons). Geomagnetic cutoff is included in a approximative way (no flux below the cutoff).
Calculation is done in 5 momentum ranges defined by:
0.85, 2.24, 3.13, 4.58, 6.96,10.8

Numbers of events

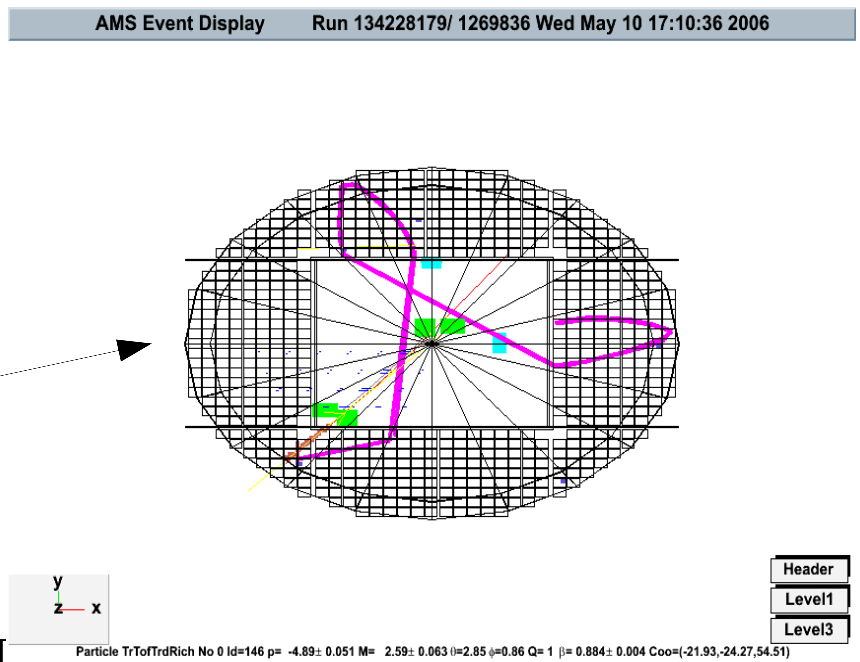
$$N=\sum N_i=\sum(\Phi_i A_i \epsilon_i t\, f_g)\ where\ A-acceptance,\ t=3\ years,\ f_g-correction\ for\ geomagnetic\ cutoff$$

Antideuterons (secondary): 8 (6) in RICH: 5 (5)

electrons: < 1000 in RICH: < 100 (lack of stat)

antiprotons: 1000 ± 400 (600) in RICH: 150 ± 50 (140)

Antiprotons are a subject of further amelioration, there are events which have problems with reconstruction in RICH, for example:



Cut on number of hits used in track

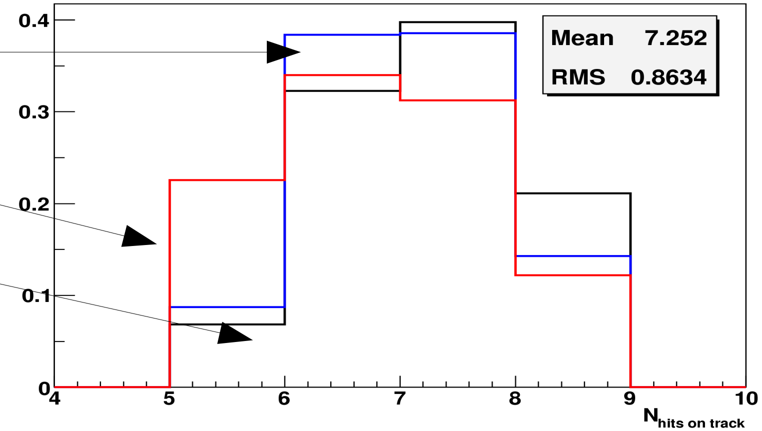
- $N_{\text{hits on track}} > 5$
- It does not improve momentum resolution
- But helps to reject electrons and antiprotons paying low price in efficiency

- 5 hits: 6.6% (and 21% of electr
- 6 hits: 32.8%
- 7 hits: 40.2 %
- 8 hits: 20.4 %

antiprotons

electrons

antideuterons

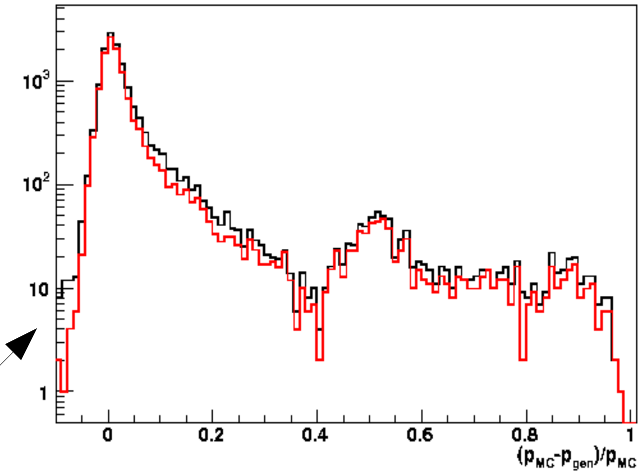


chi^2 cut

- chi2/ndf < 3.0: 86%

chosen value because efficiency grows slower after chi2/ndf = 3

Rejects events with overestimated momentum – helps to reject antiproton background

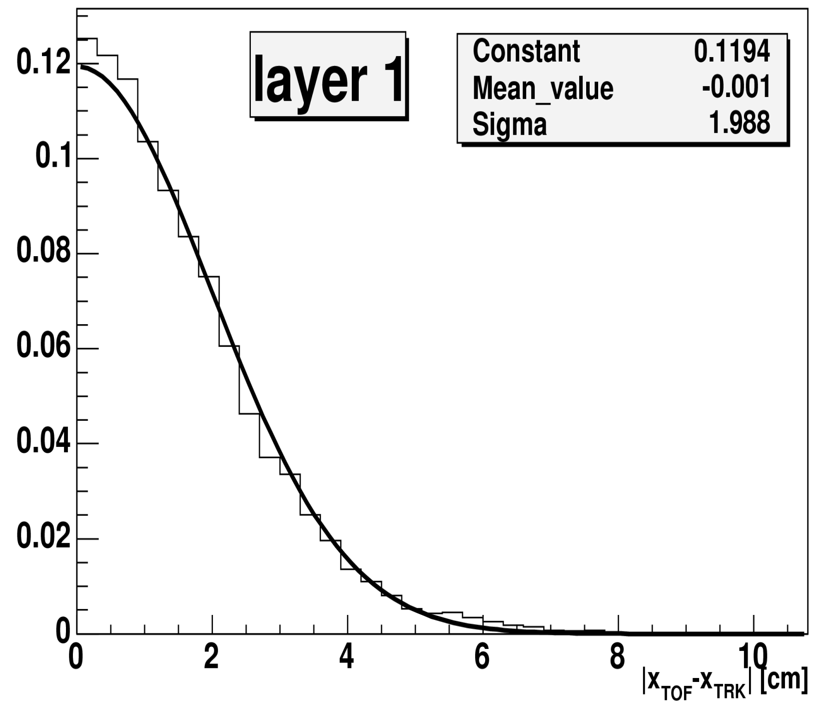


Optimization on TOF beta

1. TOF planes used for beta reconstruction = 4 ; efficiency= 0.75
2. extra TOF clusters < 2 ; efficiency=0.96
   (one extra cluster allowed because it can be low-energy cluster in TOF layer 1,2)
3. beta < 0.9 (0.87)
4. distance between TOF clusters and TRK extrapolation (2.5 sigma)
   efficiency=0.88

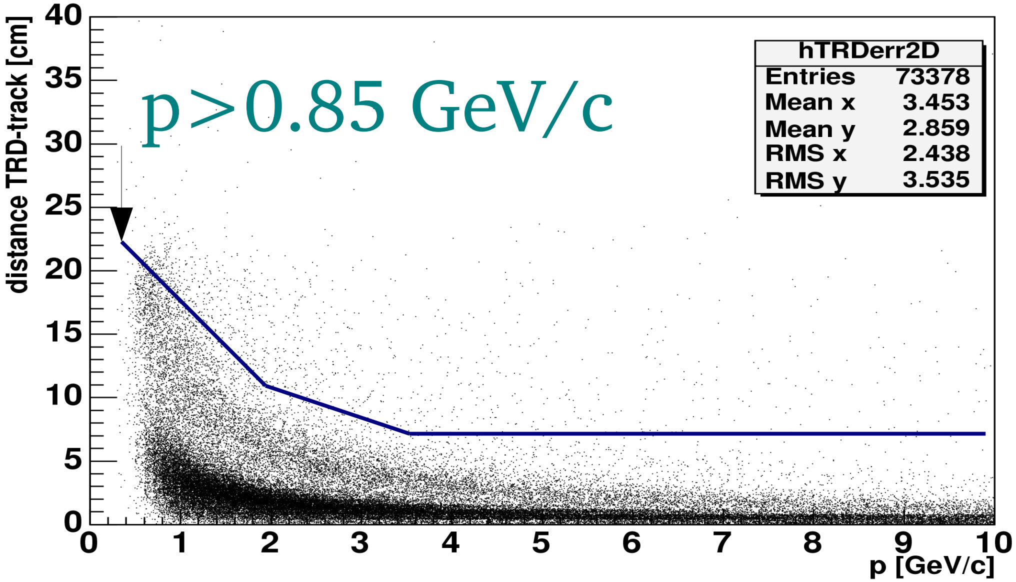
beta< 0.9 gives about:
2 antideuteron events
150 antiproton events

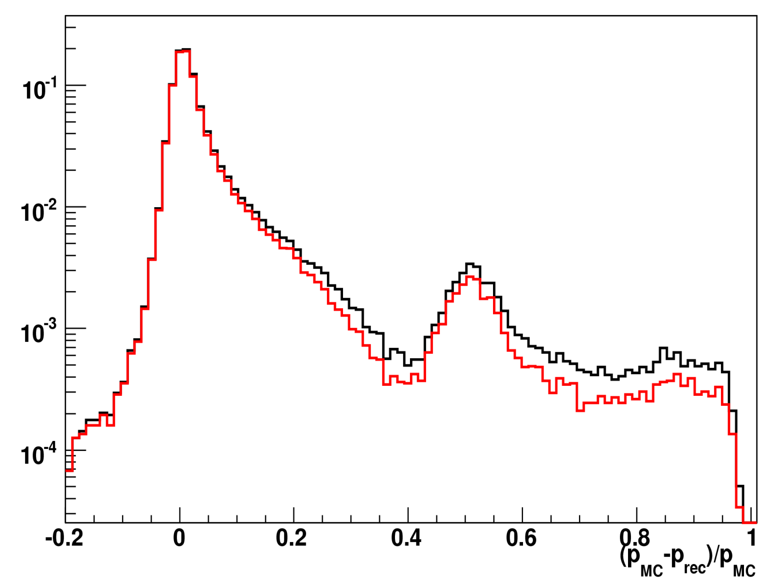
beta<0.87 gives about:
1 antideutron event
100 antiproton events



Distance between TRD track and extrapolation of Particle track

Idea: low momentum particles might loose significant fraction of energy with soft scattering in TRD – reject those which loose the most by cutting the ones which changed direction of motion (TRD vs TRK estimation).





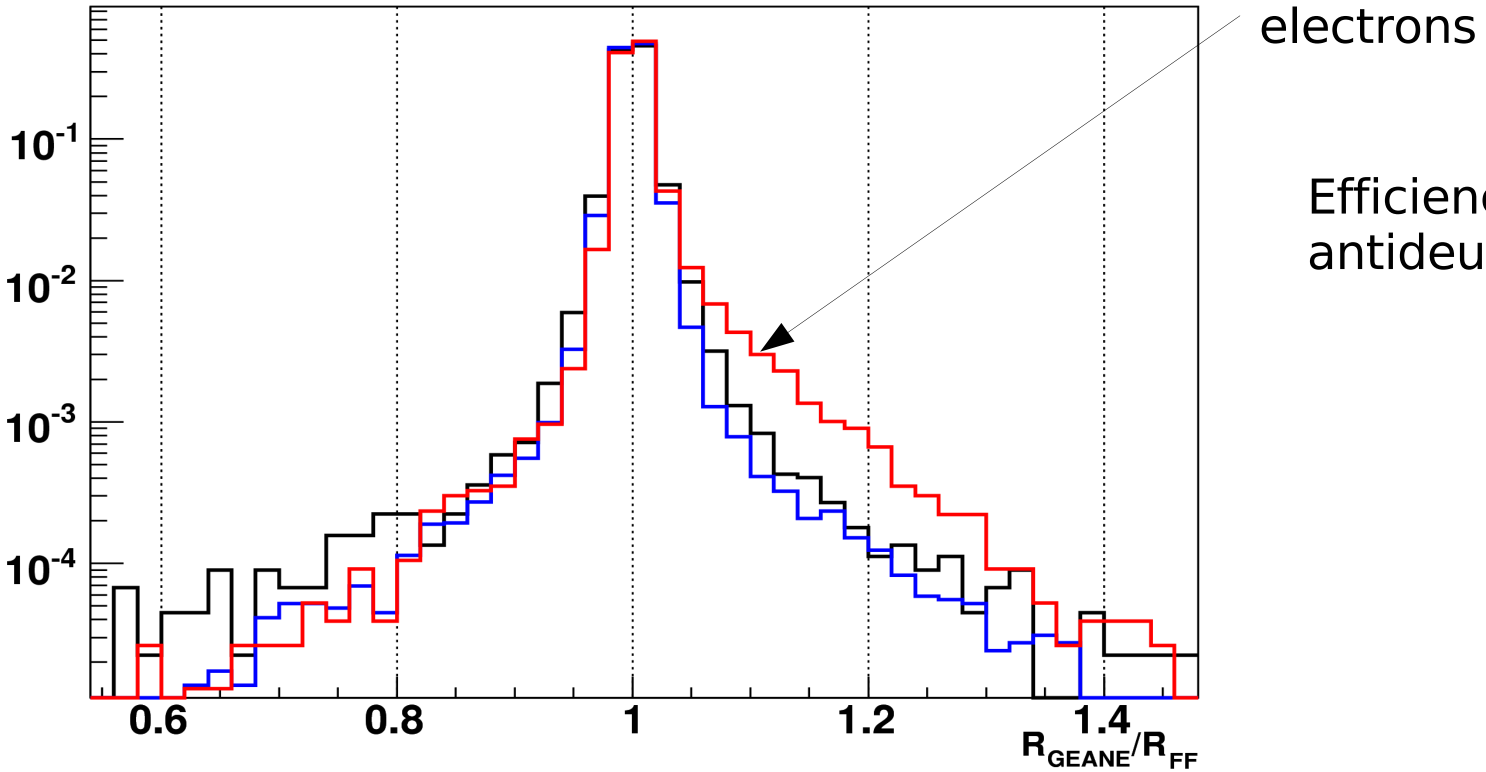
momentum-dependent cut because low-momentum antideuterons are important

efficiency=0.94

Geane/FastFit rigidity

We need a very precise measurement of momentum, so we ask to have the same momentum measurements from two independent algorithms.

$$0.97 < R_{GEANE}/R_{FF} < 1.03$$



Efficiency antideuterons = 0.95