About the possibility of observation of antideuterons in AMS02 - **summary of the efforts**

Mariusz Sapinski,
INFN Roma1
CERN, April 27, 2006

Actually there are a lot of people interested in antideuterons

- Vitaly Choutko
- Francesca Giovancchini

CERN/MIT/INFN Bologna

- Fernando Barao
- Rui Pereira

LIP Lisbon
Presentation in february

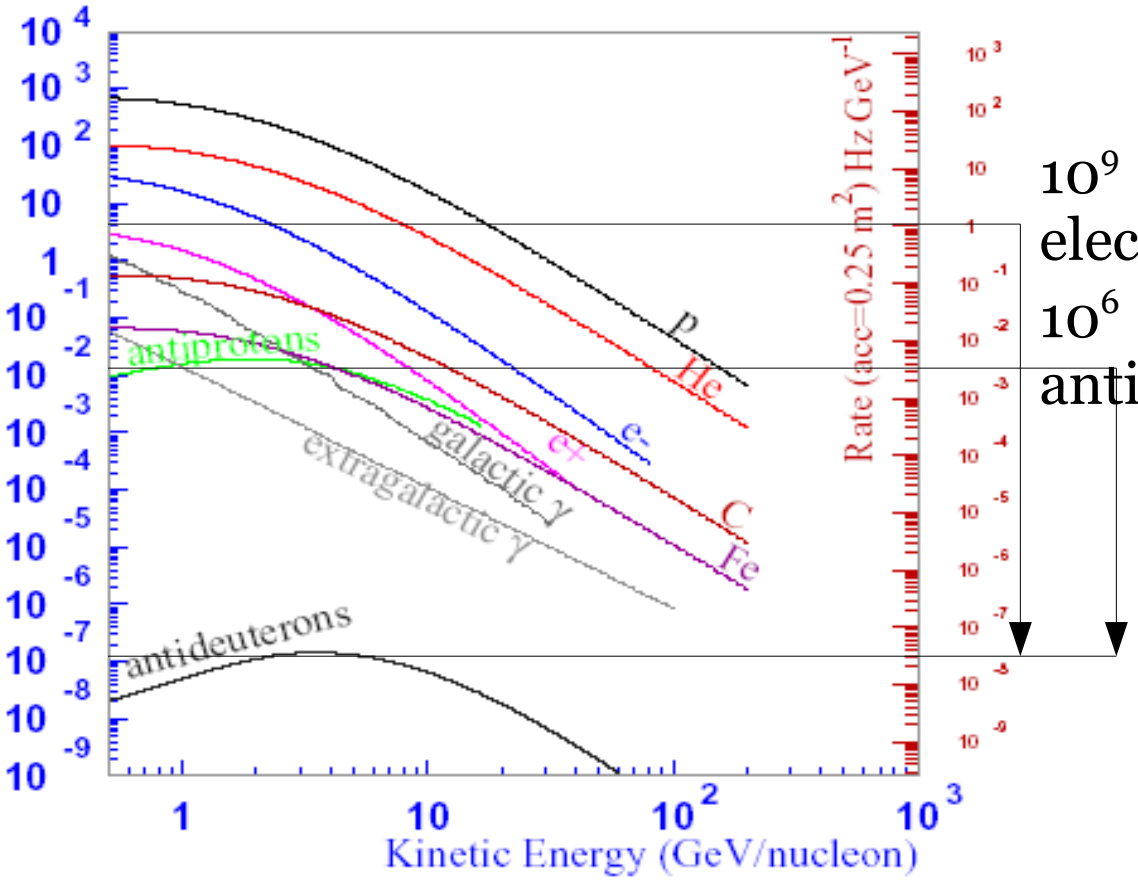
- Mariusz Sapinski
- Simonetta Gentile

INFN/Roma1

Presentations yesterday

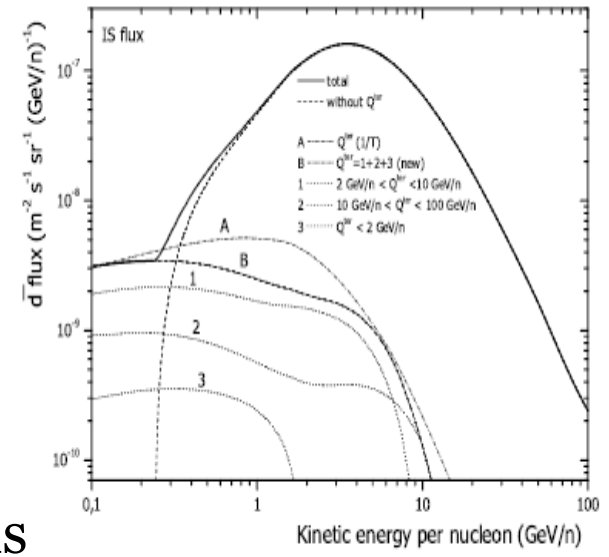
Groups have different approaches what might end in a very interesting results.

Situation



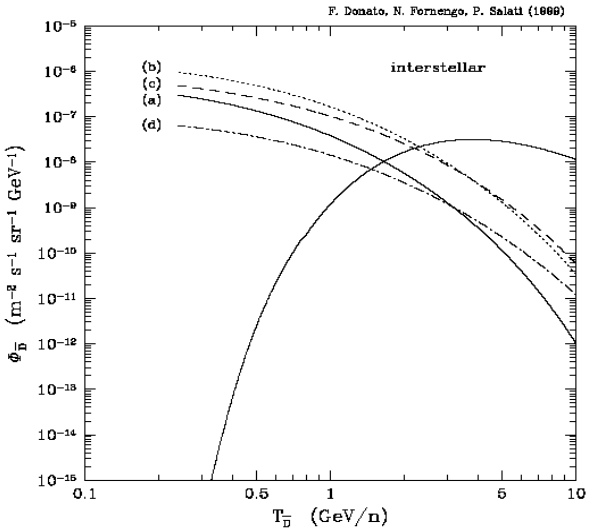
10^9 electrons

10^6 antiprotons



Phys. Rev. D71

PROMISING: Dark Matter signature



Protons > 10^{11}, but charge confusion for low momenta gives 10^8 (or 10^6) and the rest is like antiprotons, so we are safe. Antiprotons rejected by mass measurement only.

2 approaches

1. focused on background-free measurement (rejection of all background)

2. focused on keeping acceptance for antideuterons high enough to see signal

→ **Comparable results**

In both cases there are 2 analysis branches with:
- velocity measurement in TOF
- velocity measurement in RICH

And 4 types of cuts:
- Reject events with interactions
- Momentum quality cuts
- Velocity quality cuts (TOF and RICH)
- Electron rejection cuts

AntiDeuteron Selection with AMS02 Detector

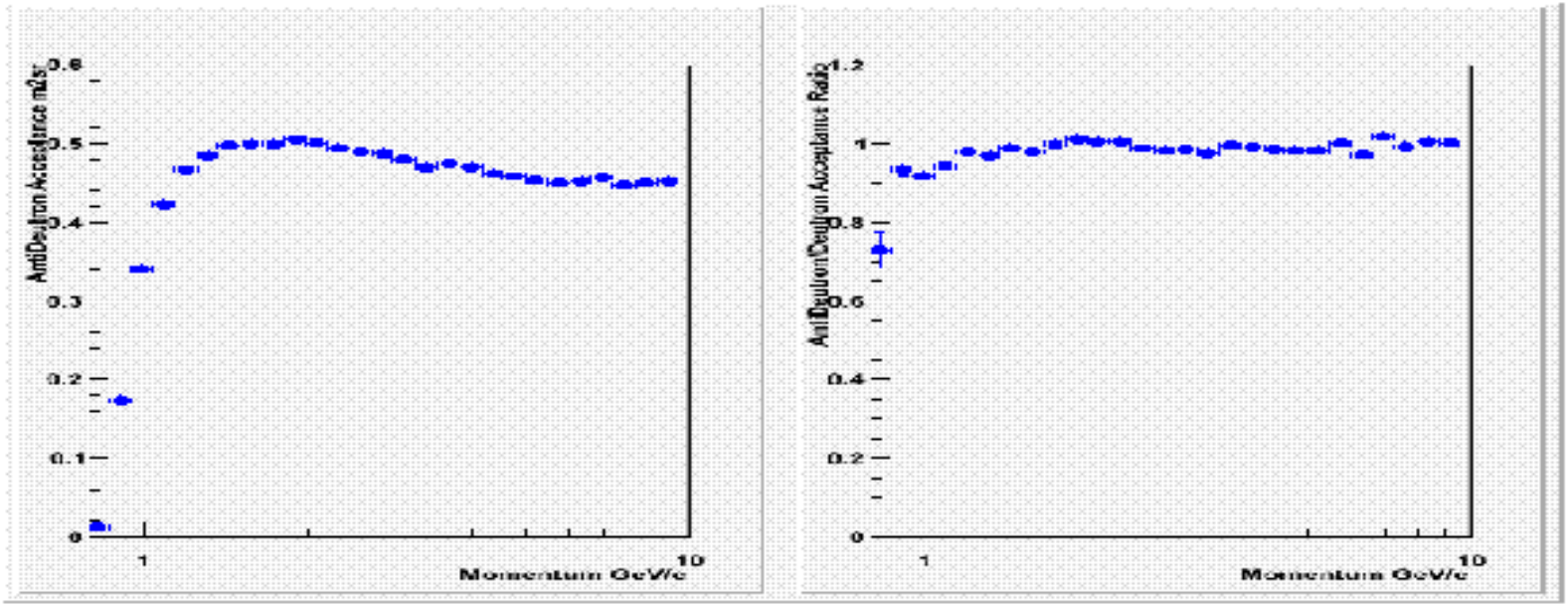
Vitali Choutko (M.I.T.)
Francesca Giovacchini (INFN Bologna)

AMS Analysis Meeting, April, 2006

Available at:
http://ams.cern.ch/AMS/Analysis/hpl3itp1/ams02_ad.pdf

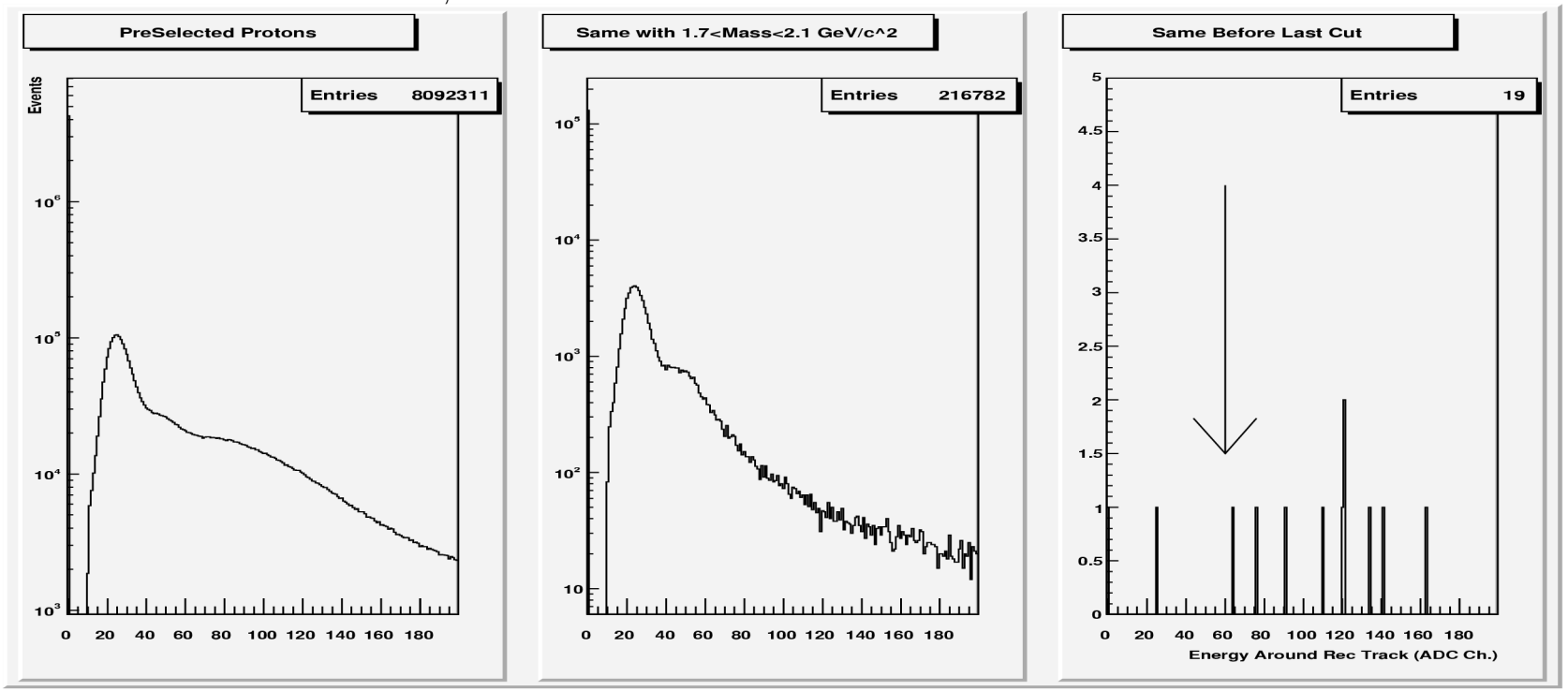
Preselection

- At Least one TRD and one Tracker track reconstructed & matched with each other and TOF hits;
- $\|Z\|$=1 reconstructed particle;



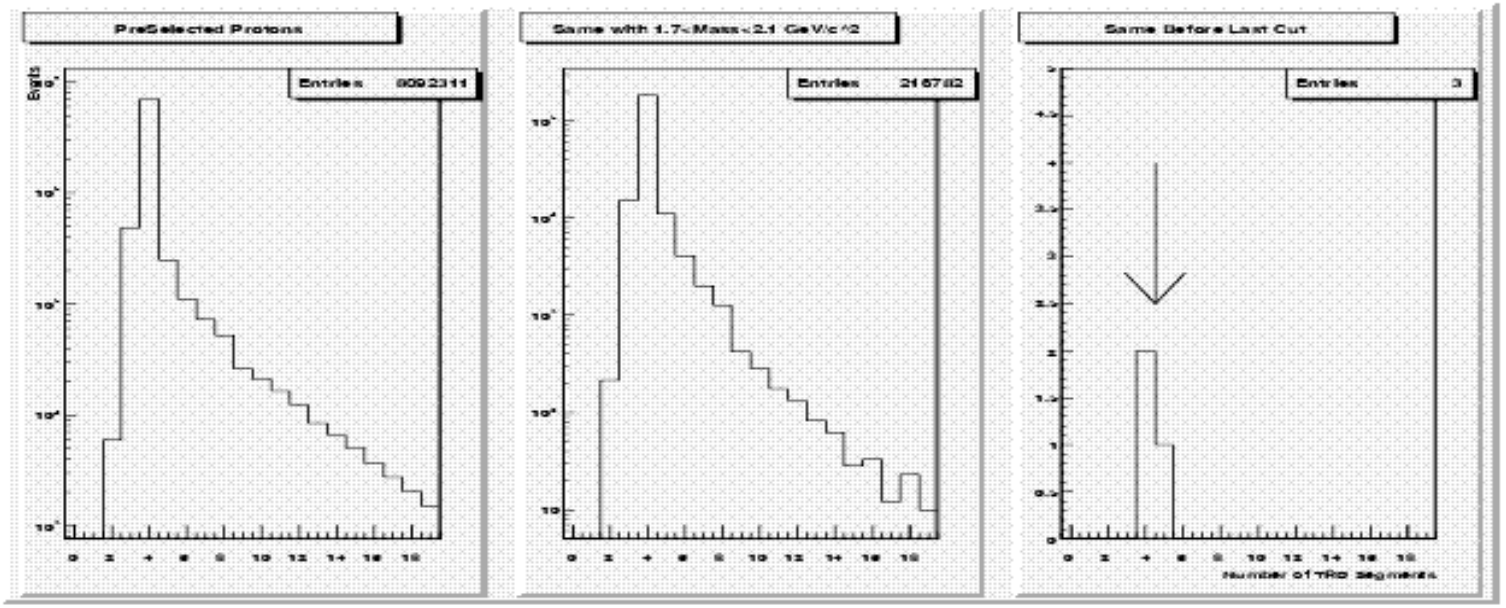
Selection: Suppression Events With Interactions

- Number Of ToF Clusters < 5;
- Number Of AntiClusters According Trigger (< 1 if no Ecal activity, < 2 otherwise);
- Sum of Tracker Hits Amplitudes in the Vicinity of Reconstructed Track < 60;



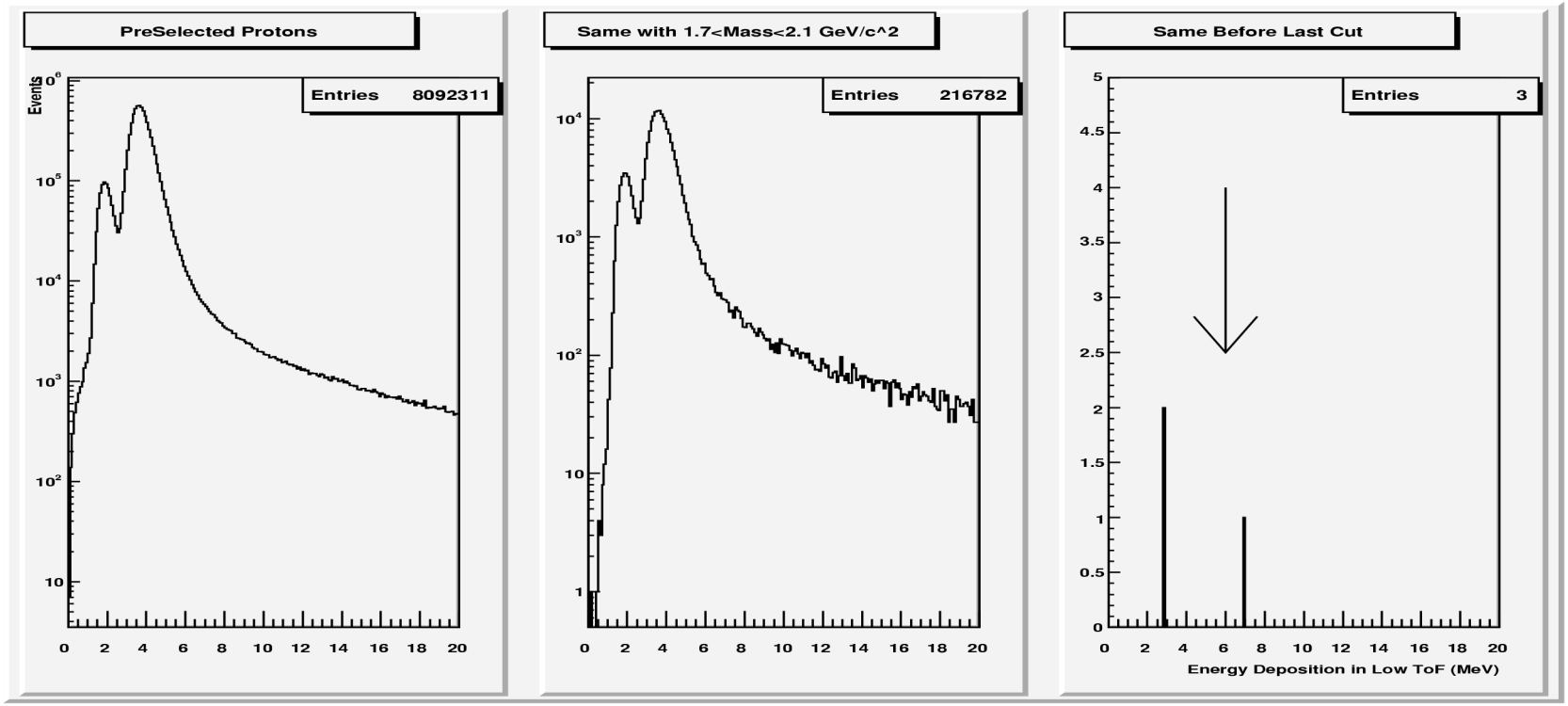
Selection: Suppression Events With Interactions

- Number of TRD Segments <5;



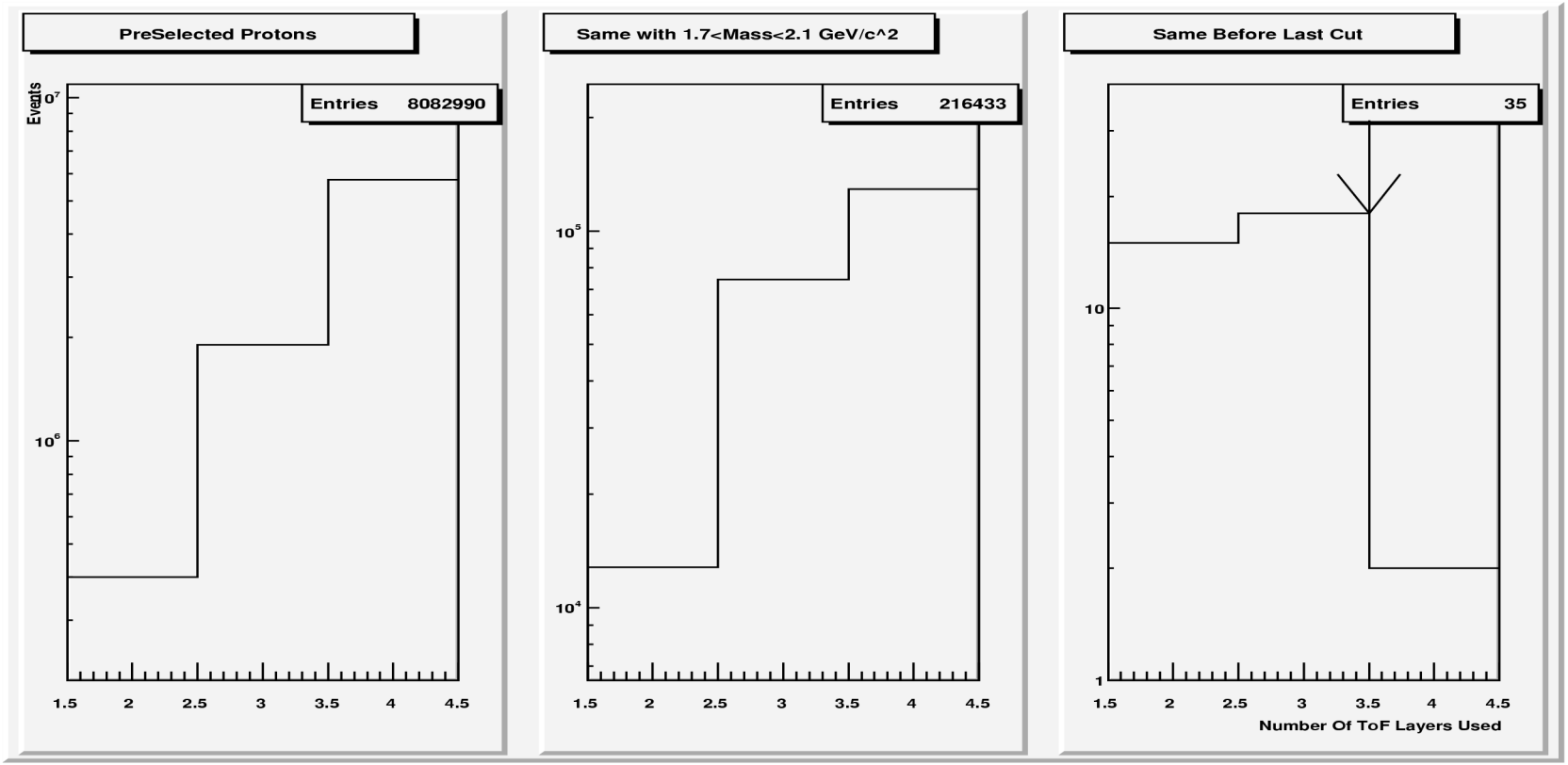
Selection: Suppression Events With Interactions

- $\text{Energy}_{\text{TOF}_{\text{upper}}} < 6$ MeV;
- $\text{Energy}_{\text{TOF}_{\text{lower}}} < 6$ MeV;



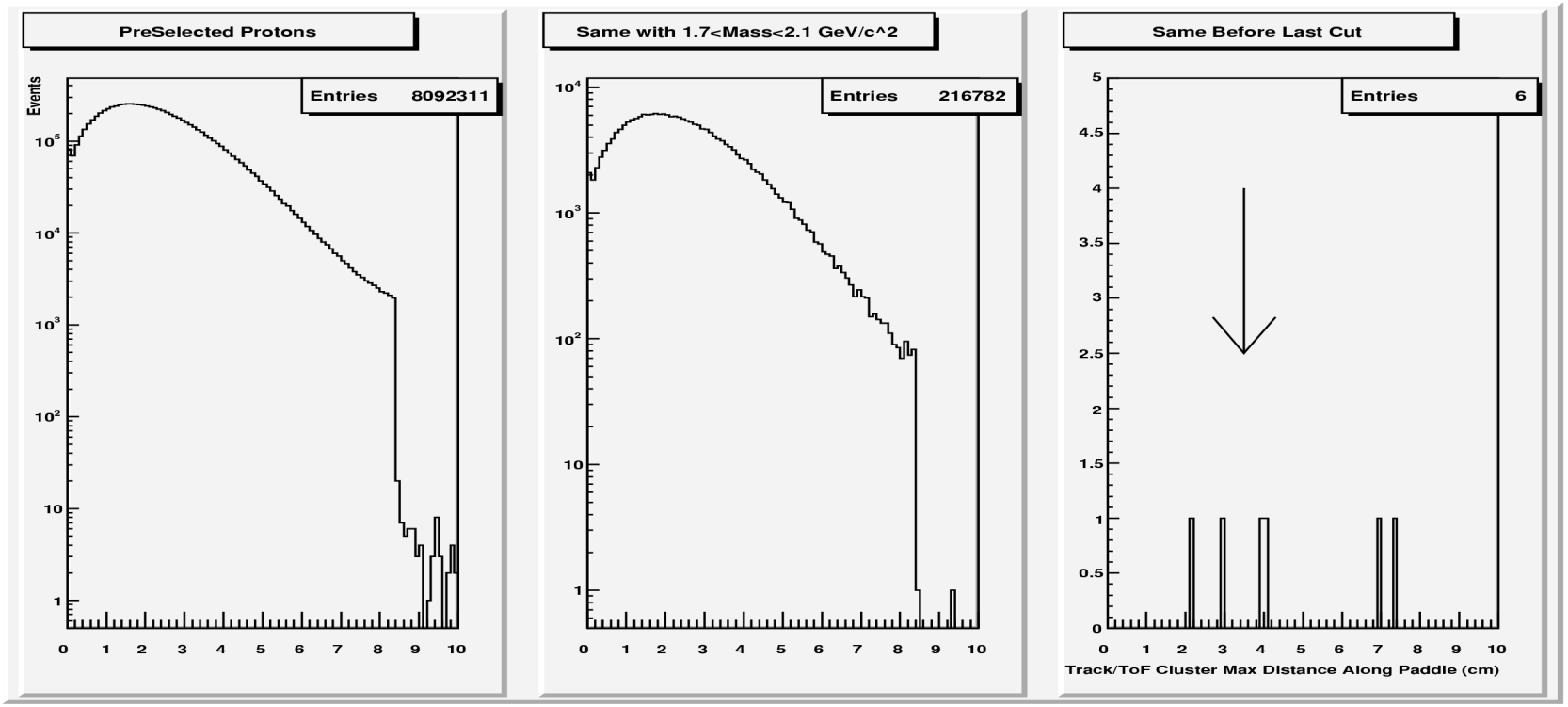
Selection: $\bar{p}, e^-$ Background (TOF Based)

- Number of ToF Layers Used for Velocity Calculation = 4;



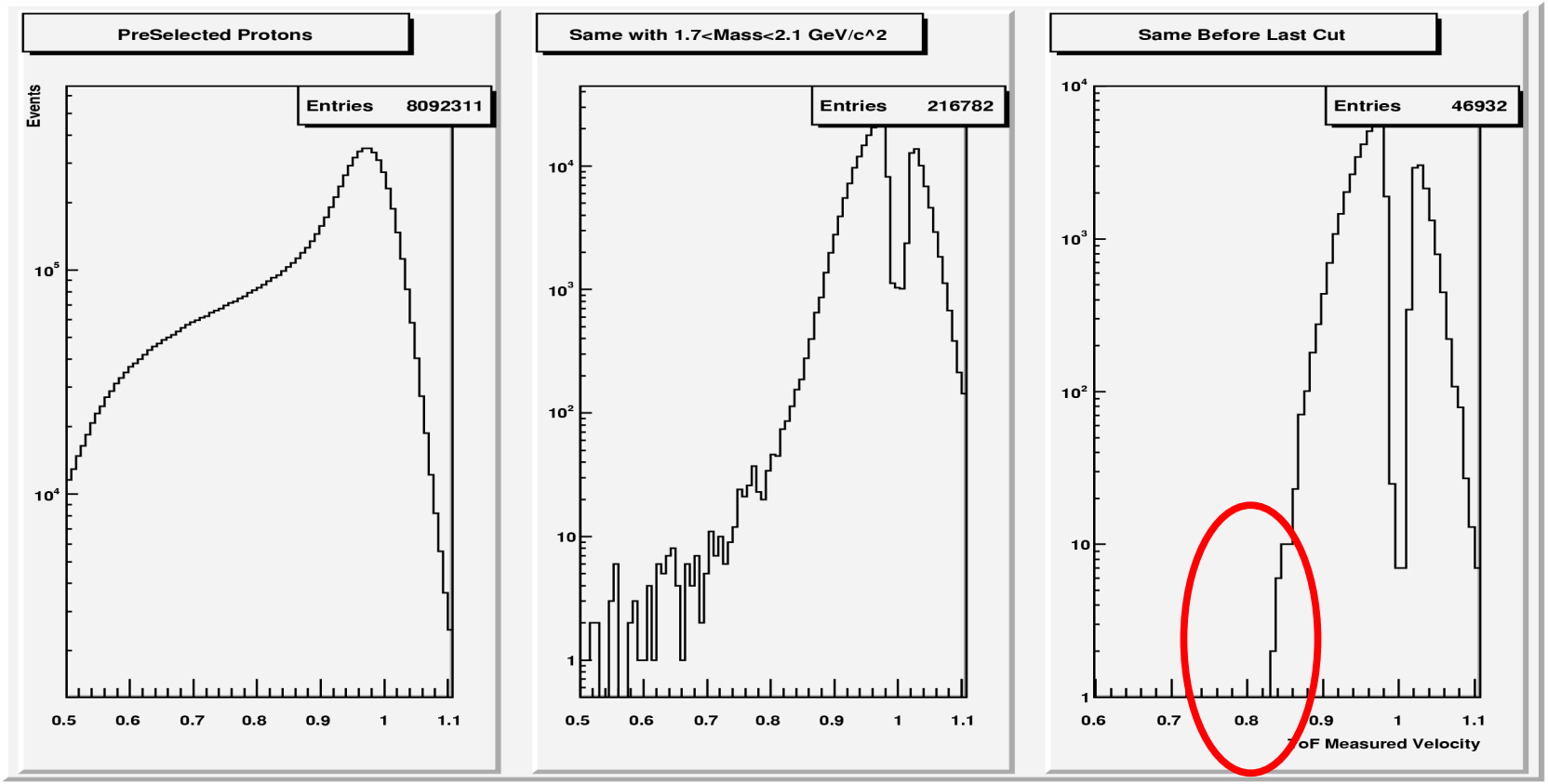
Selection: $\bar{p}, e^-$ Background (TOF Based)

- $\chi^2_\beta < 12$;
- Max Distance Between Track and ToF Cluster Along ToF Paddle < 3.5 cm;



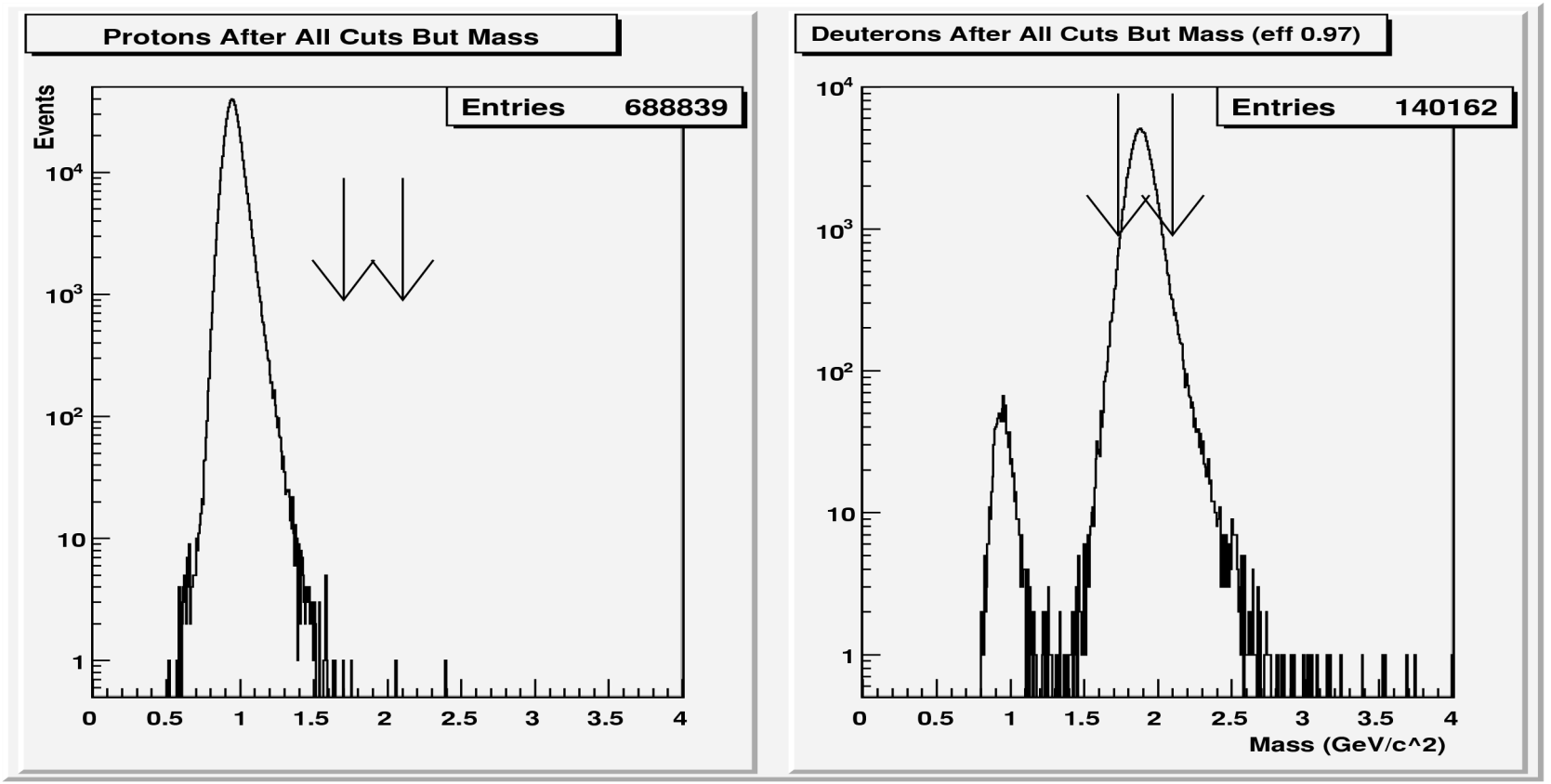
Selection: $\bar{p}, e^-$ Background (TOF Based)

- Velocity < 0.835 (To Obtain No Events; 0.84 Gives 2);

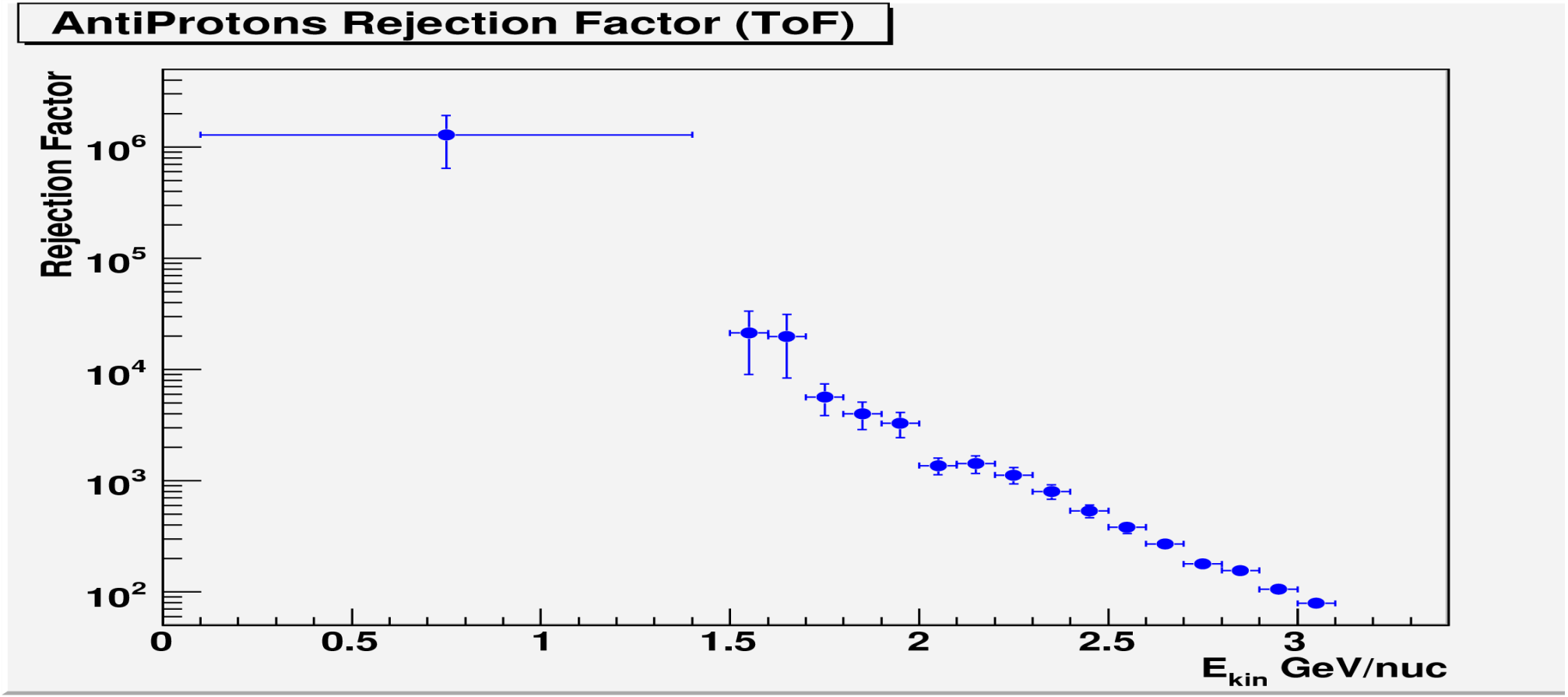


Selection: $\bar{p}, e^-$ Background (TOF Based)

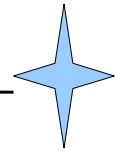
- $1.7 < \text{Mass} < 2.1$ GeV/c^2;



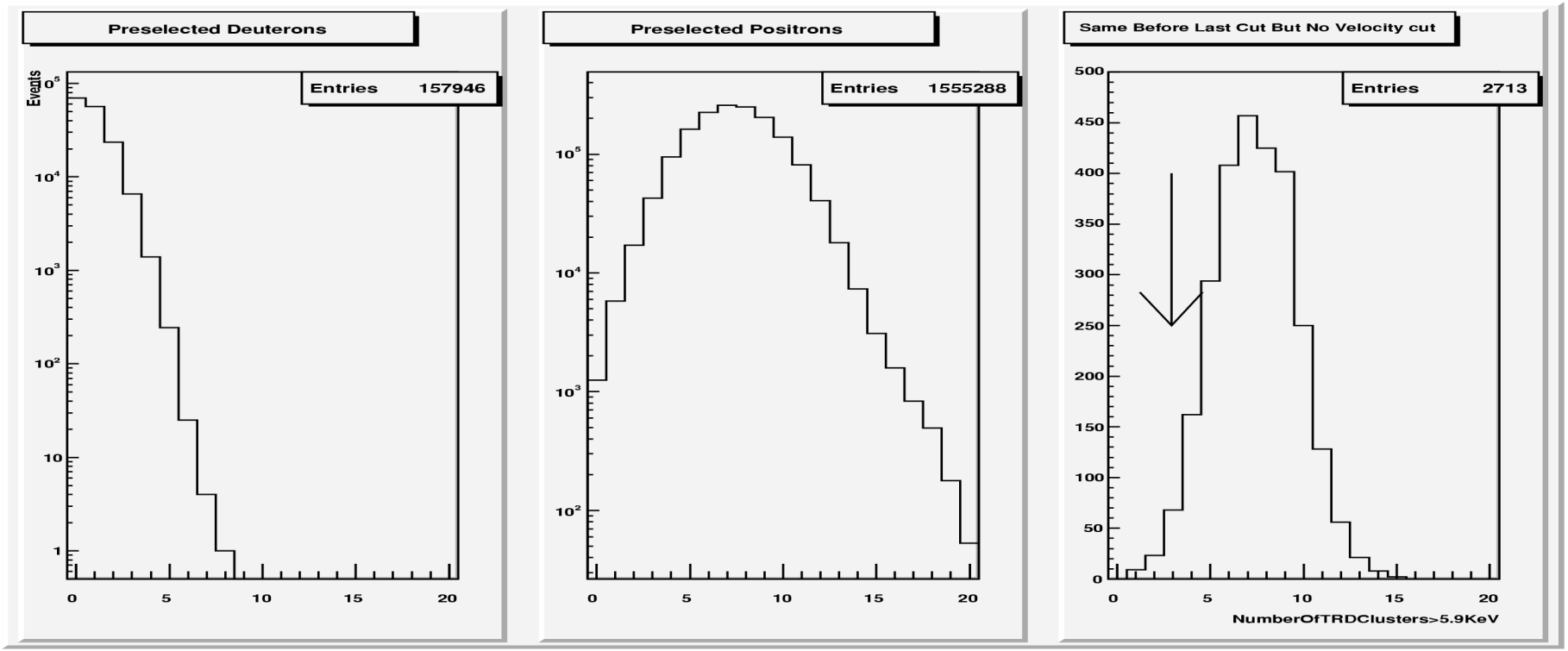
Rejection Factor Antiprotons (TOF Based)



Selection: Electron Background

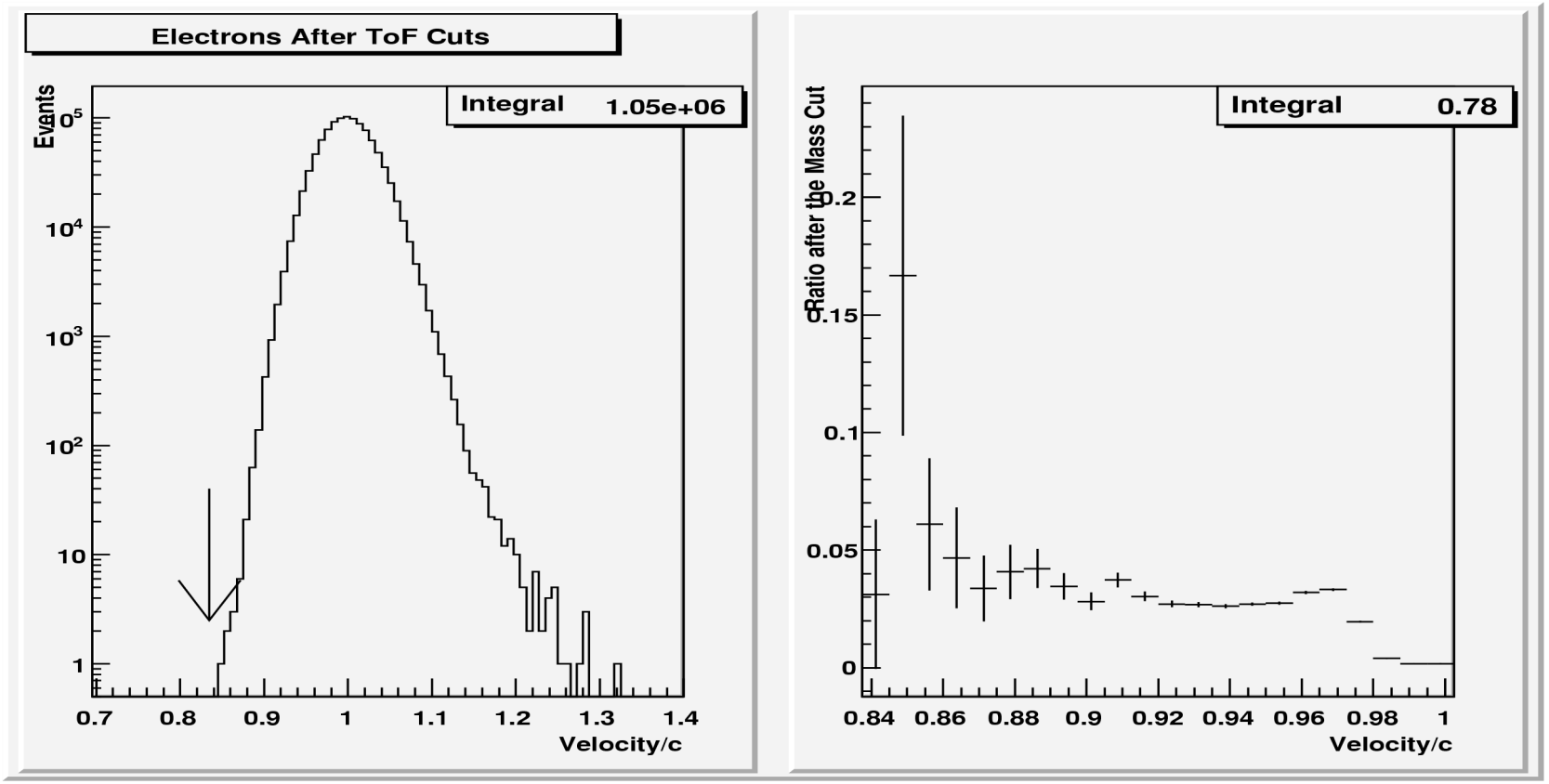


- $\frac{\text{Energy}_{\text{ECAL}}}{\text{Momentum}_{\text{Tracker}}} < 1;$
- Number Of TRD Hits in Track $> 11;$
- $\text{Number}_{\text{TRDClusters}>(5.7+0.3*\log(\text{Momentum}))/\beta^{5/3}\text{KeV}} < 3;$



Rejection Factor Electrons (ToF Range)

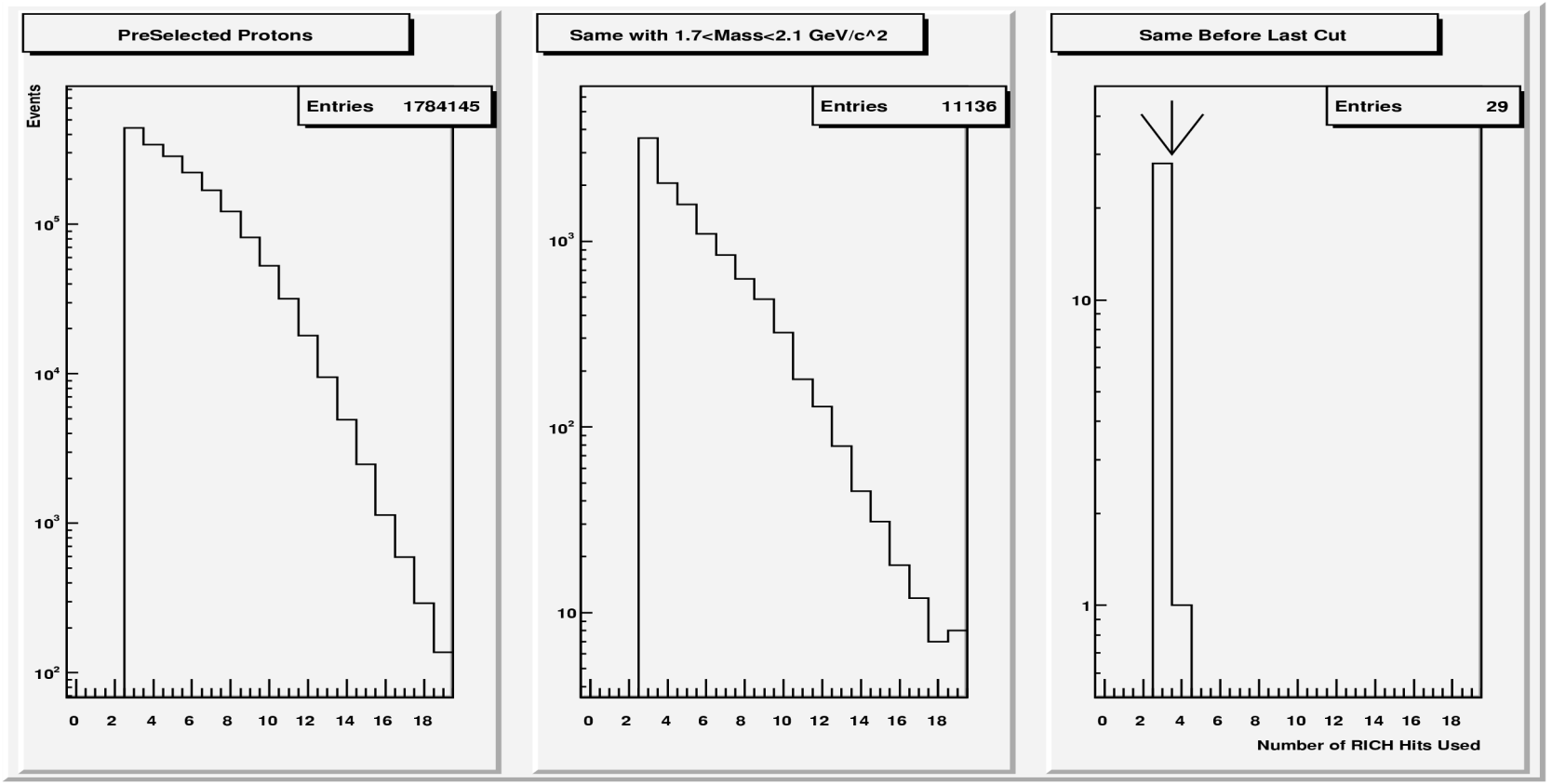
- For All ToF Range $> 10^6 \times 20(\text{MassCut}) \times 90(\text{TRD}) = 1.8 \cdot 10^9$



Selection: $\bar{p}, e^-$ Background (RICH$_{Agl}$ Based)

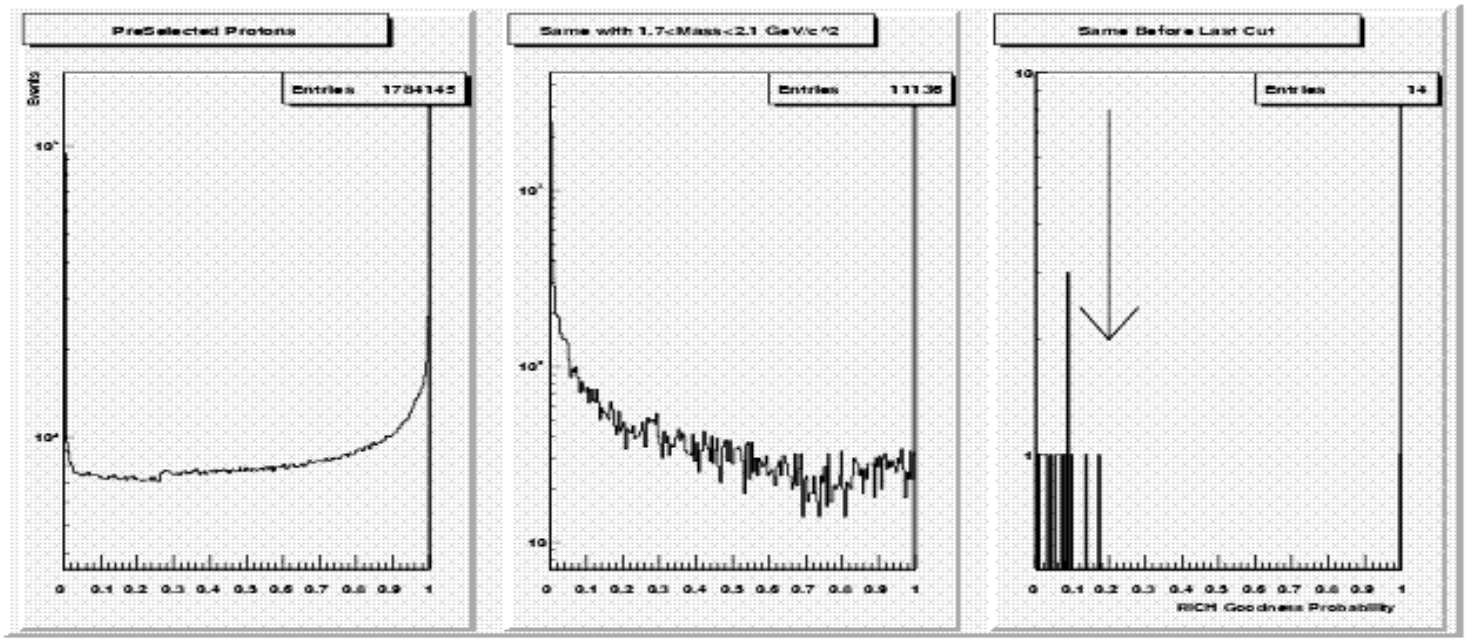
Aerogel only

- Number of RICH Hits Used >3;



Selection: $\bar{p}, e^-$ Background (RICH_{Agl} Based)

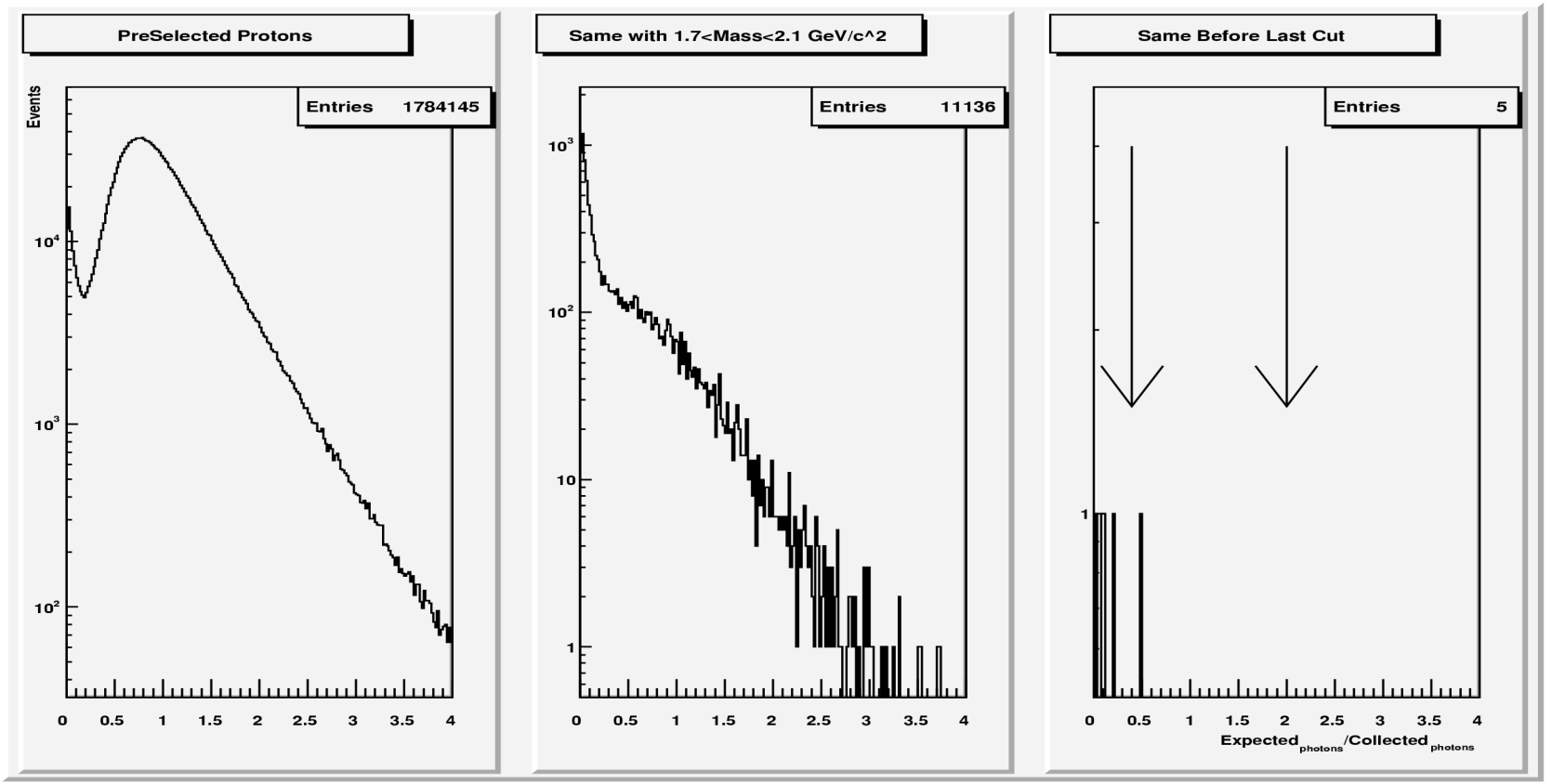
- Probability to Be a Good Ring >0.2;



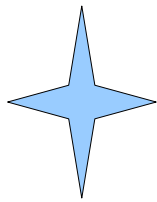
Selection: $\bar{p}, e^-$ Background (RICH$_{Agl}$ Based)

- $2 > \frac{\gamma \text{Expected}}{\gamma \text{Collected}} > 0.4;$

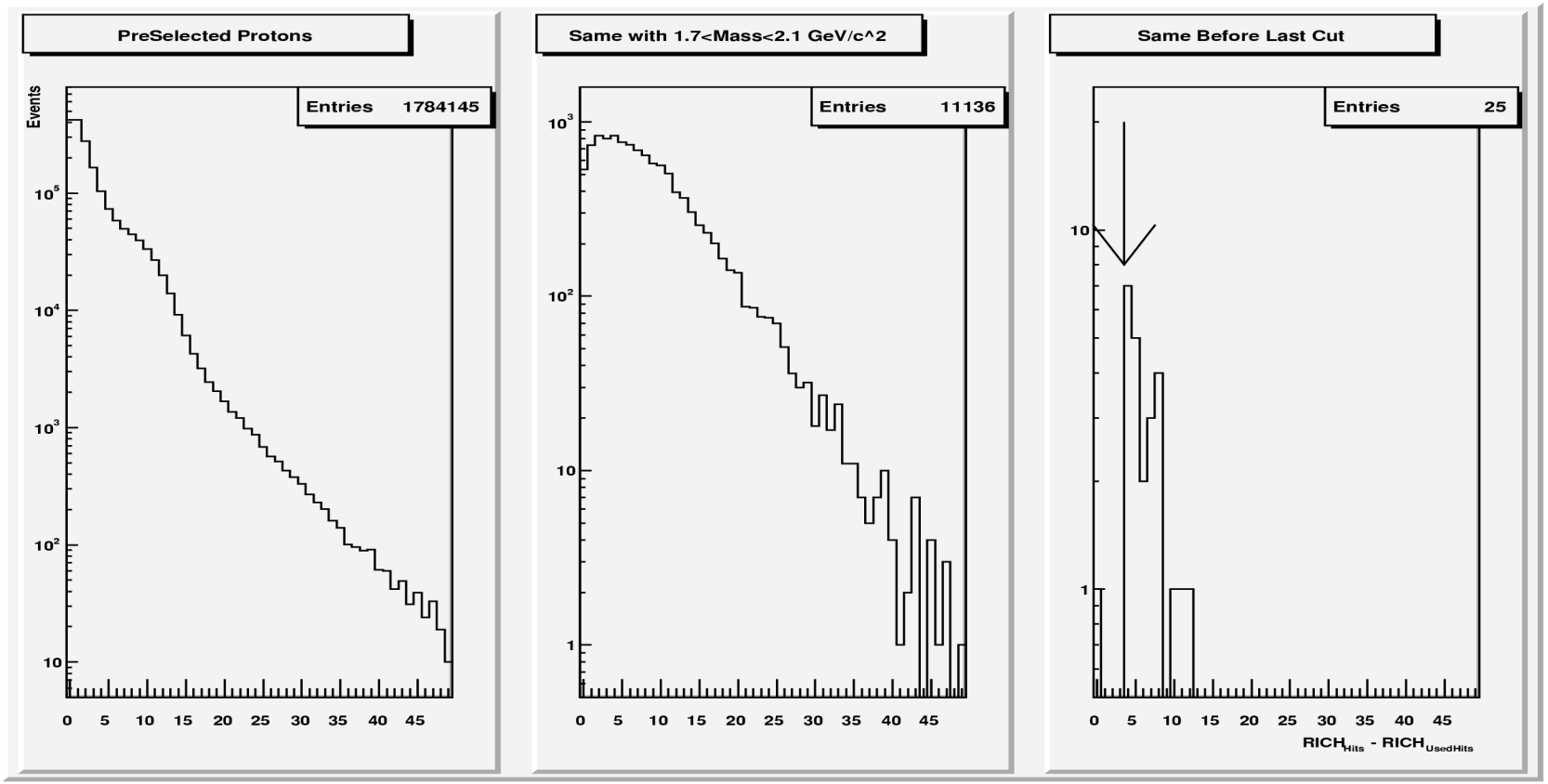
Z=1 compatible Ring



Selection: $\bar{p}, e^-$ Background ($\mathbf{RICH}_{Agl}$ Based)

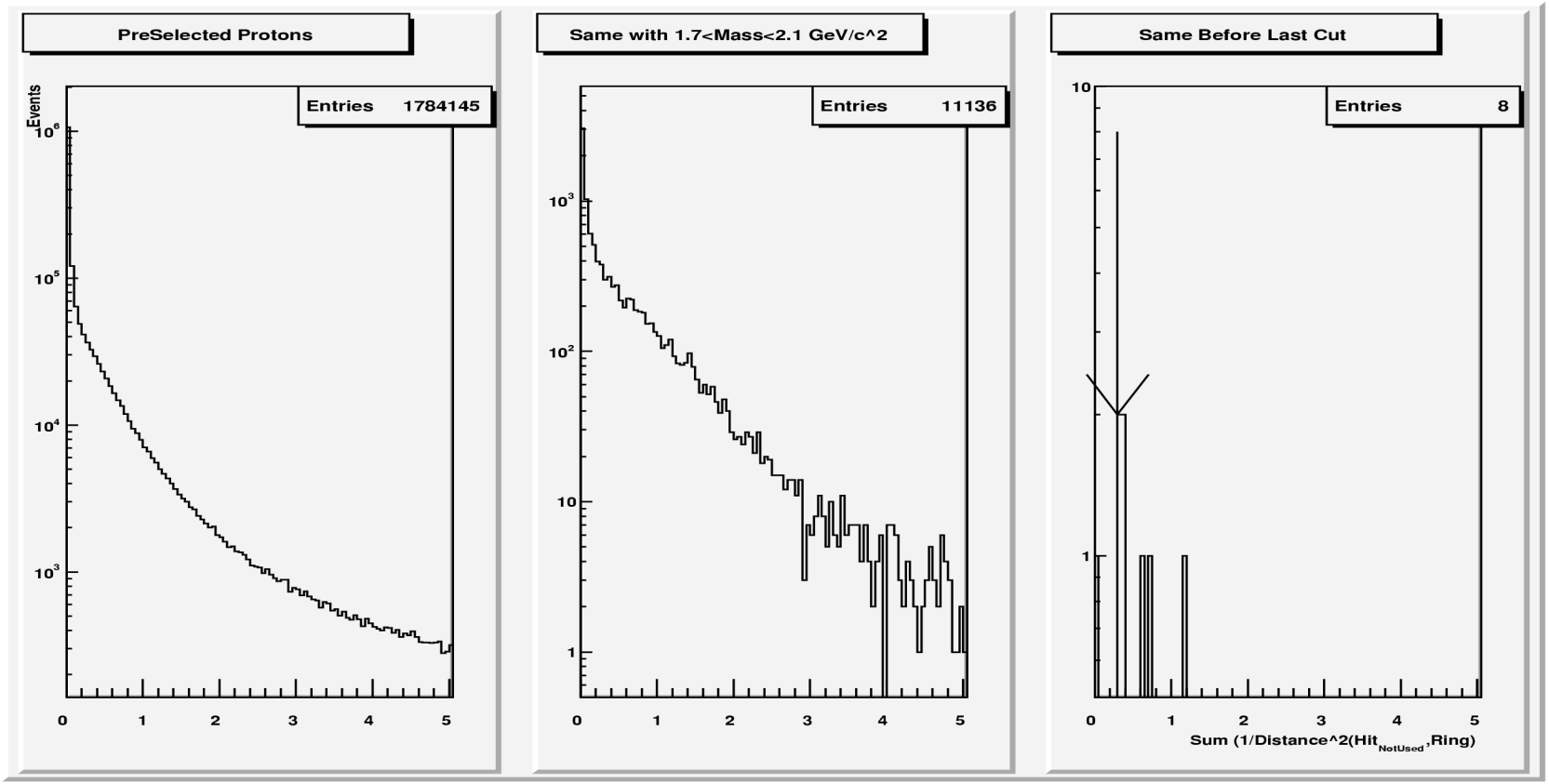


- Number of Unused Hits Except "Hot Spots" < 4;



Selection: $\bar{p}, e^-$ Background ($\mathbf{RICH}_{Agl}$ Based)

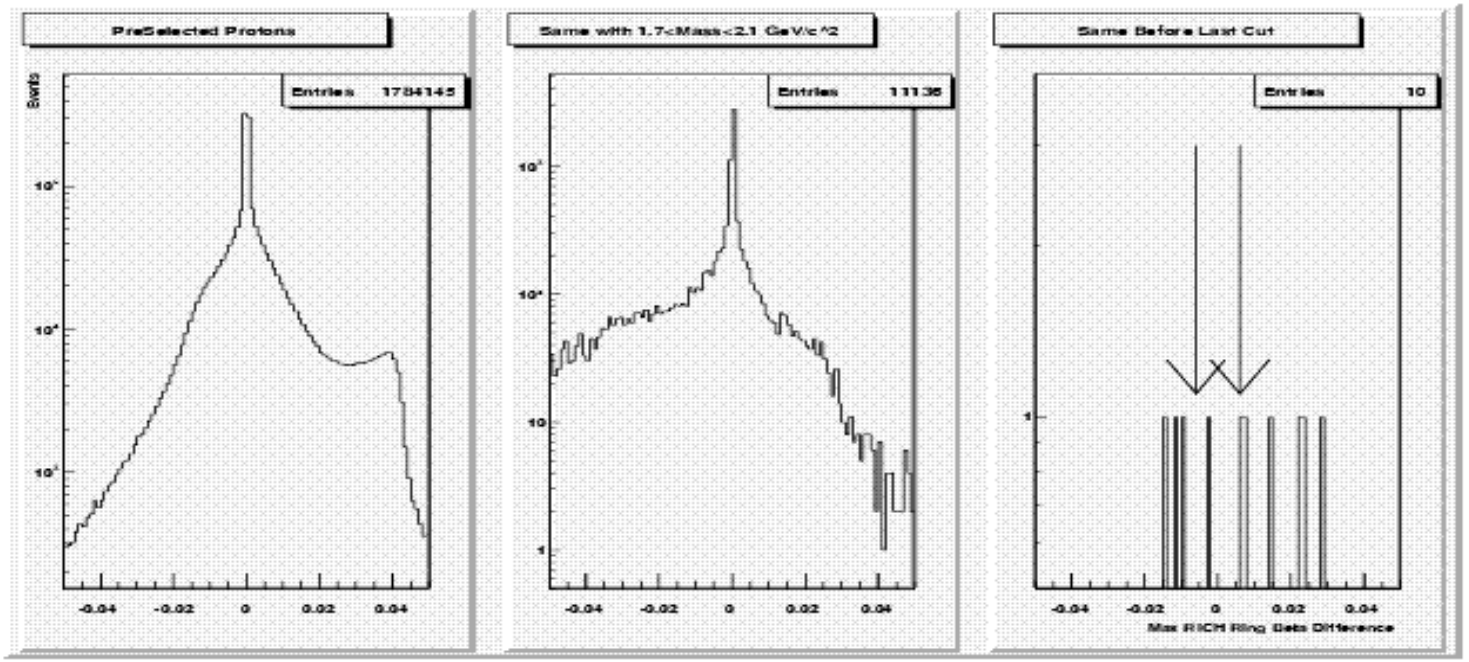
- $\Sigma\,\mathrm{Distance}^{-2}_{(\mathrm{UnusedHit,Ring})} < 0.3\ \mathrm{cm}^{-2}$;



Selection: $\bar{p}, e^-$ Background (RICH_{Agl} Based)

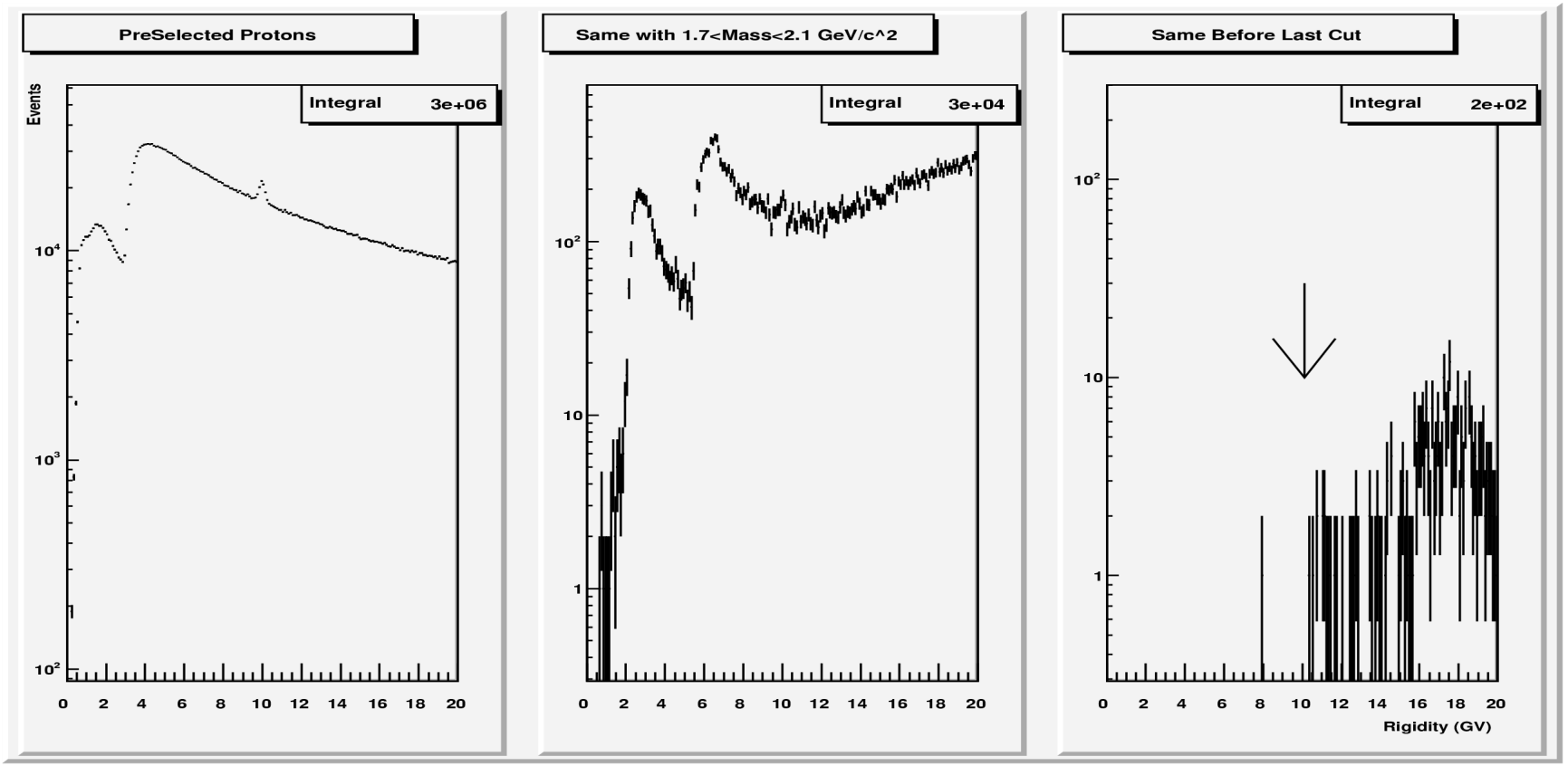
- Max Difference Between RICH Rings Velocities < 0.006;

Normally there are 2 Rings
associated with 2 tracks



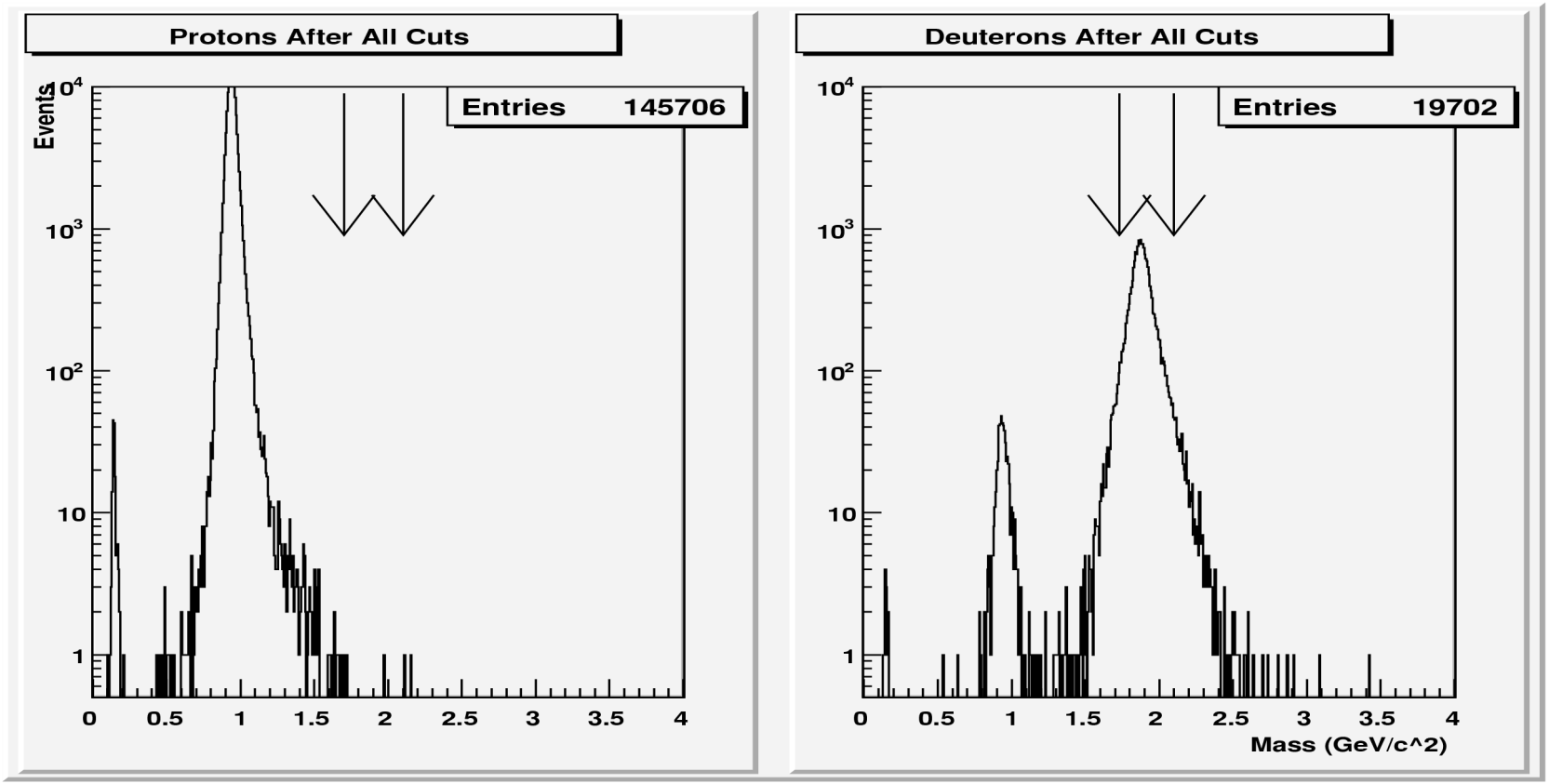
Selection: $\bar{p}, e^-$ Background ($\mathbf{RICH}_{Agl}$ Based)

- Rigidity < 10 GV;

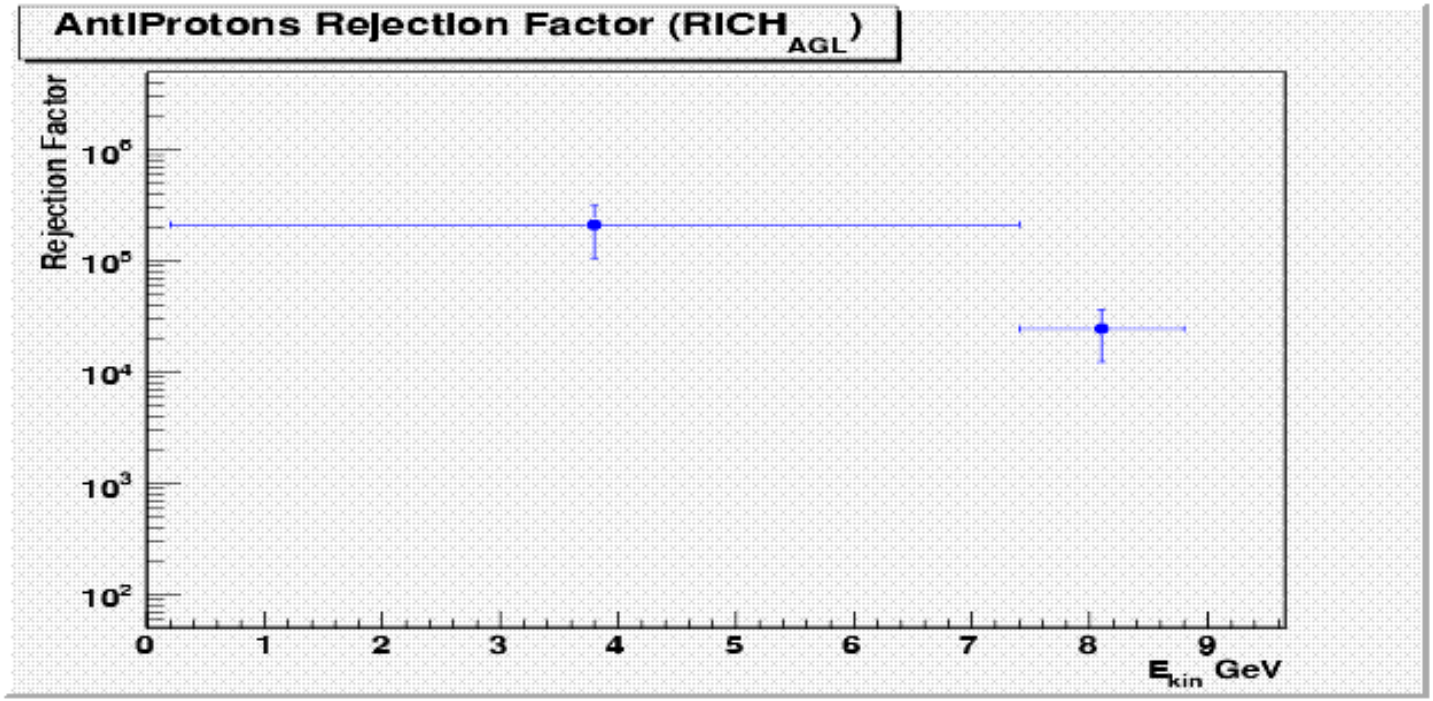


Selection: $\bar{p}, e^-$ Background (RICH$_{Agl}$ Based)

- $1.73 < \mathrm{Mass} < 2.1\ \mathrm{GeV/c^2}$;

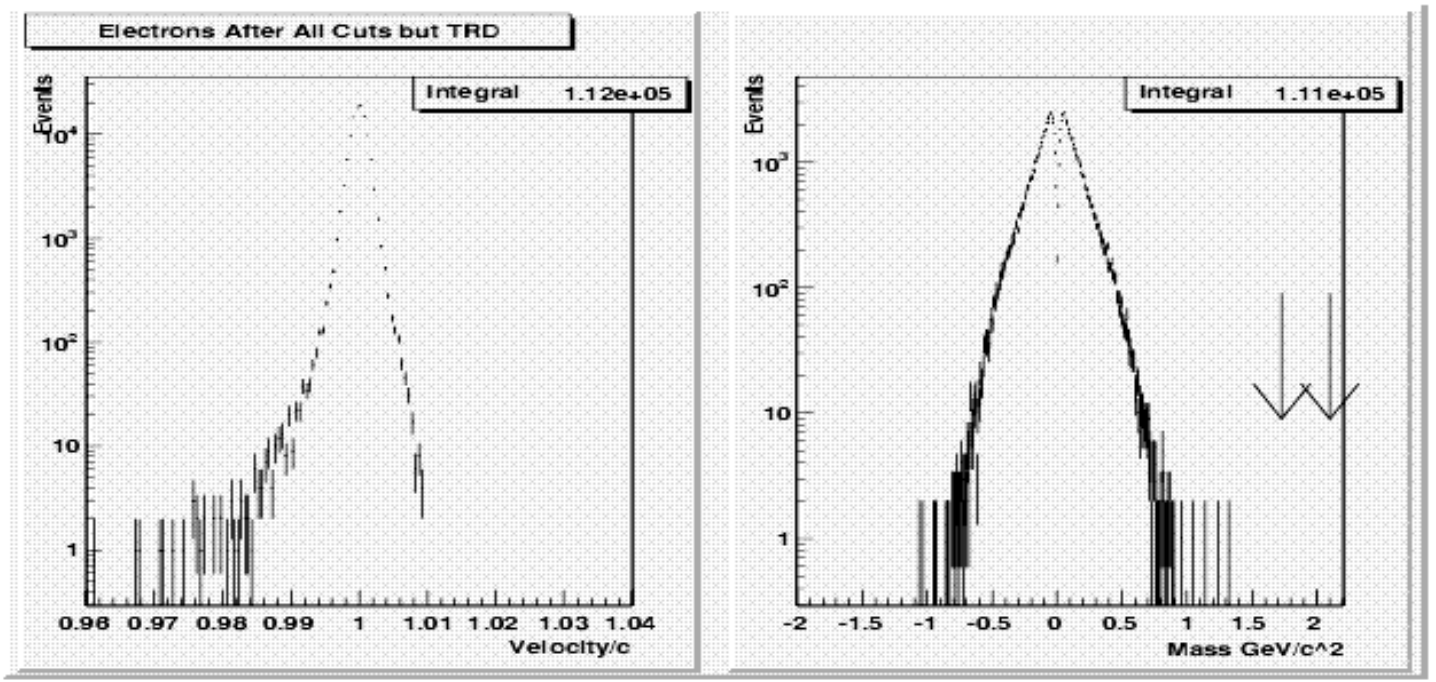


Rejection Factor AntiProtons (RICH$_{AGL}$ Range)

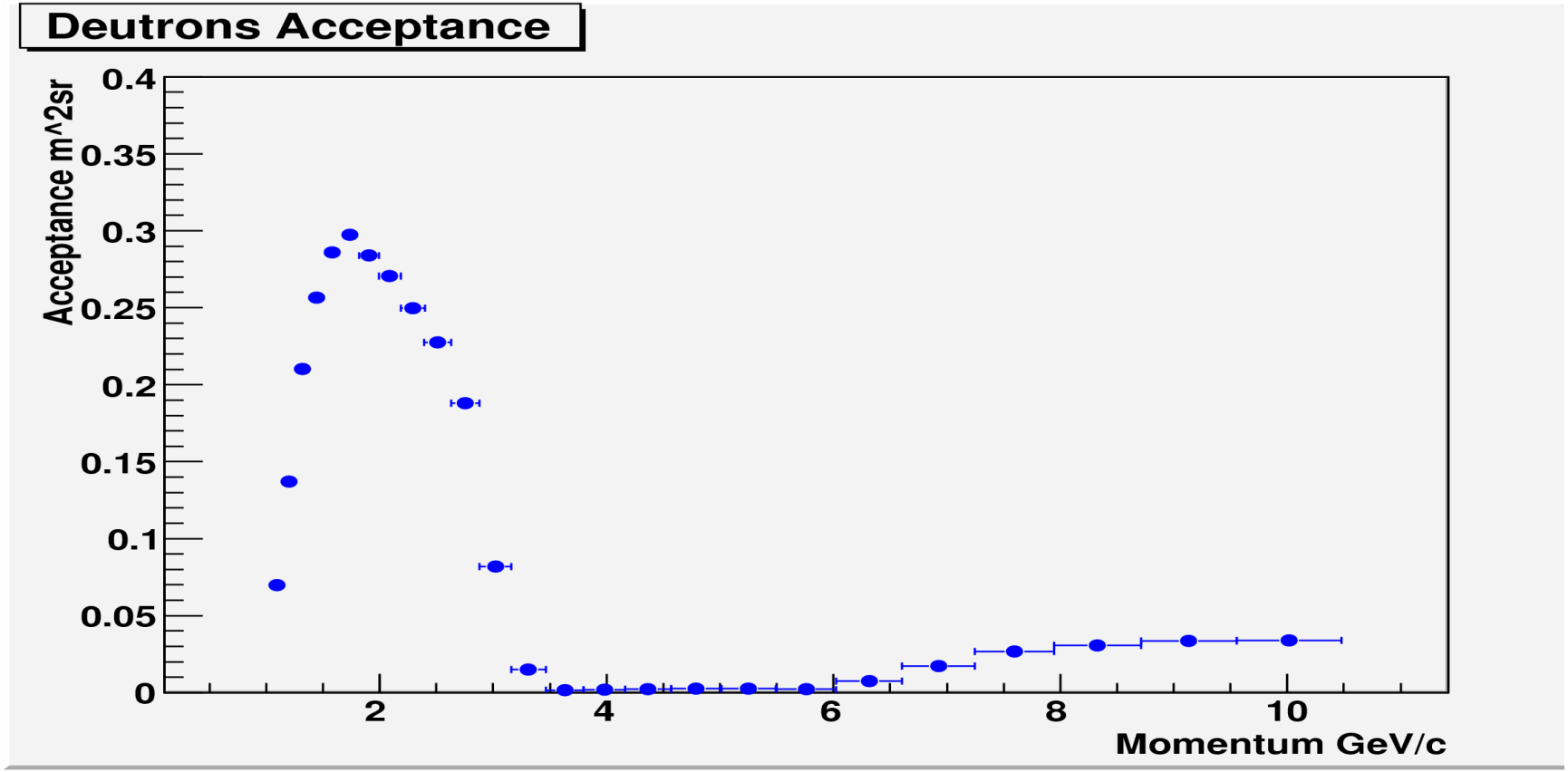


Rejection Factor Electrons (RICH_{AGL} Range)

- For All RICH/Agl Range $> 10^5 \times 6(\text{Wild Guess}) \times 90(\text{TRD}) = 5 \cdot 10^7$



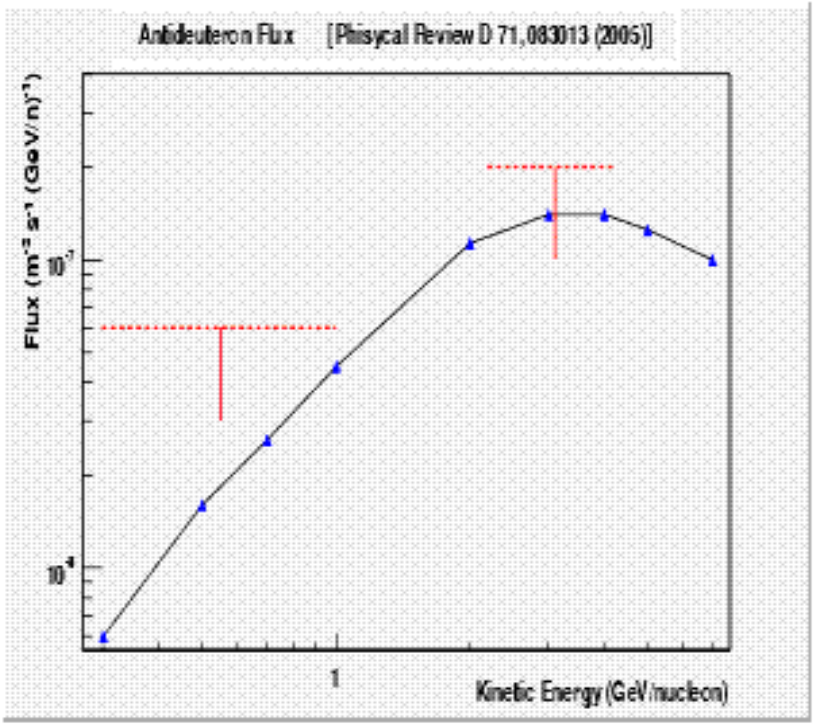
Acceptance

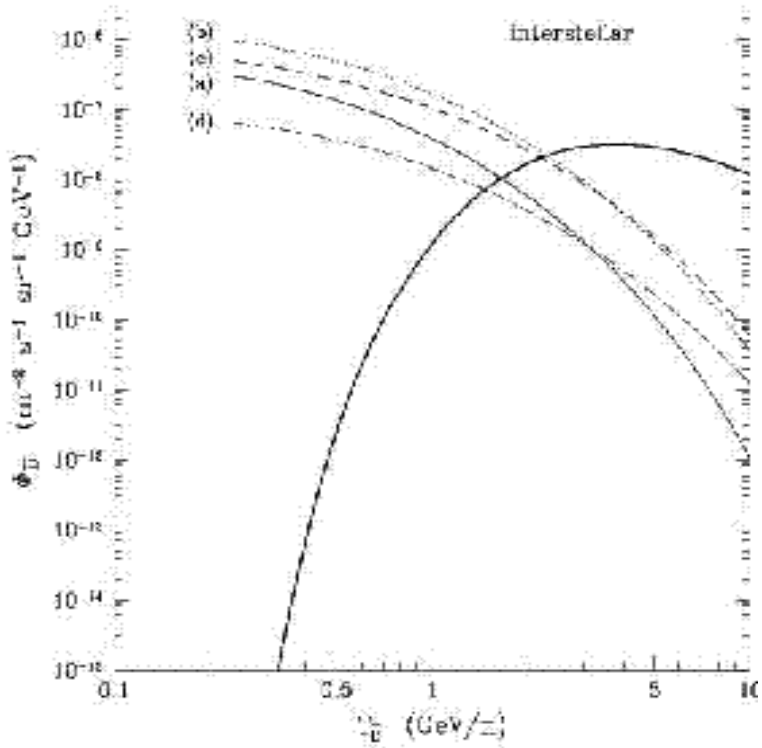

Deutrons Acceptance
Acceptance m^2sr
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
Momentum GeV/c

Estimated Signal To Background Ratios

Particle	S/B Ratio (ToF)	S/B Ratio (RICH$_{AGL}$)
$\bar{p}$	1.4	1.3
e^-	> 1.3	>3.3
p	15-30	100-200

AntiDeuteron Spectrum Measurement Example





Summary

- An antideuteron selection based on the latest MC samples been presented;
- The obtained antideuteron acceptance and background s pression allows nearly background free measurement of tideuteron flux in some supersymmetric models;
- However, the expected secondary antideuteron flux seems t too low to be directly measured by AMS02;
- In addition, antideuterons in the energy region covered RICH NAF radiator have very small acceptance and the b ground rejection power largely insufficient to obtain backgro free measurement.

Let me add that Francesca and Vitaly have also prepared antideuteron Monte Carlo

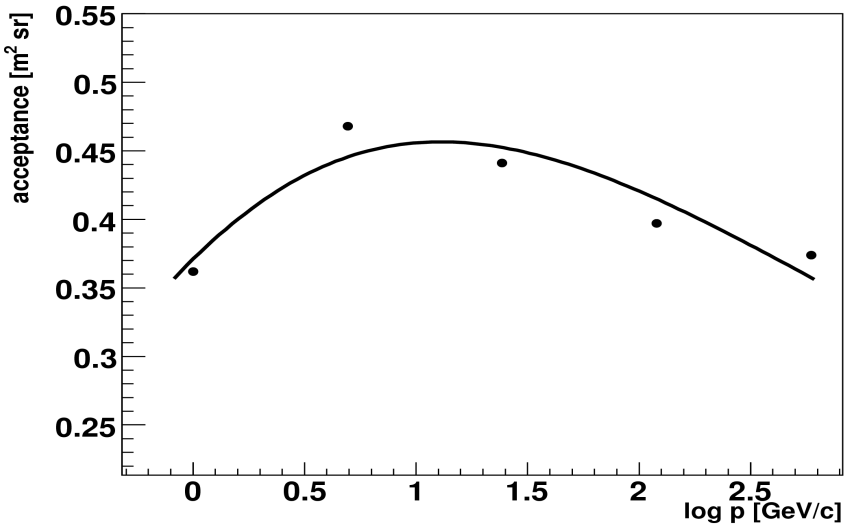
– originally in GEANT antideuteron particle is not described.

The other approach

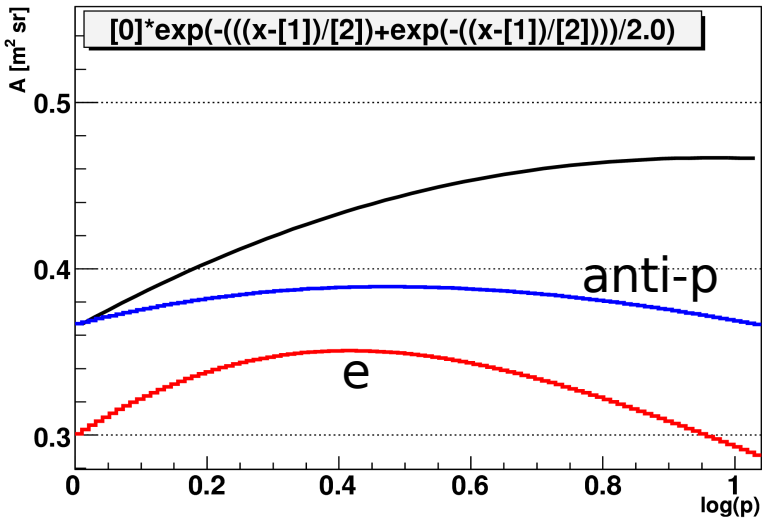
- No rejection of NaF rings
- Less sophisticated cuts in RICH
- Looser cut on velocity in TOF
- Accept more background events but try to control background (try to determine what fraction of measured antideuterons are antiprotons)

Antideuteron acceptance

Preselection cuts: events with no activity in anticoincidence counters, with one AMS-Particle with tracks in TRK and TRD, with Beta measurement with |Z|=1.
Acceptance calculated separately for electrons and antiprotons.



events generated on the top plane



Acceptance formula:

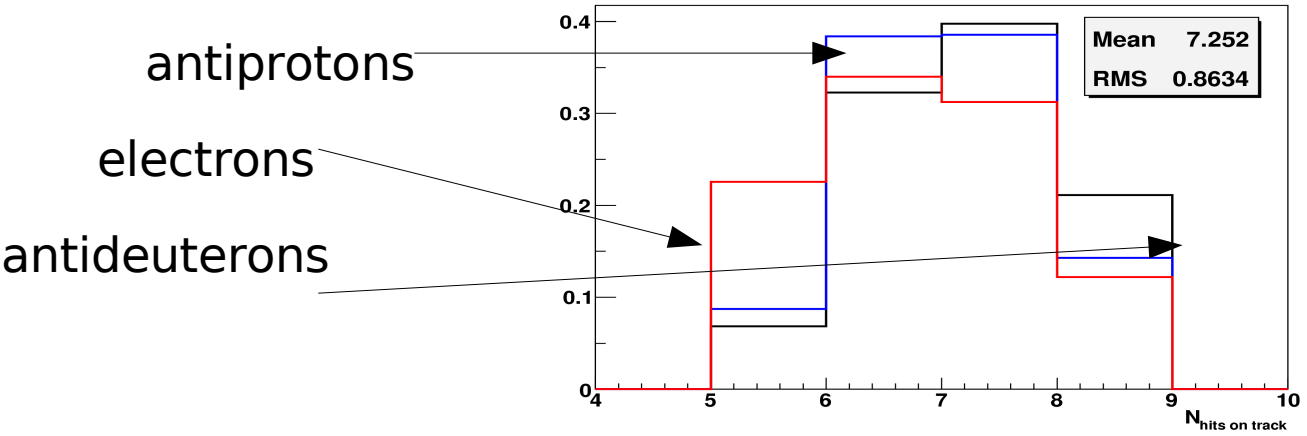
$$\mathrm{Acc}(p) = p_0 \exp \frac{\frac{-x-p_1}{p_2} + \exp\left(\frac{-x-p_1}{p_2}\right)}{2}$$

p_0=0.77
p_1=0.97
p_2=1.14 m² sr

CUTS ON MOMENTUM RECONSTRUCTION

Cut on number of hits used in track

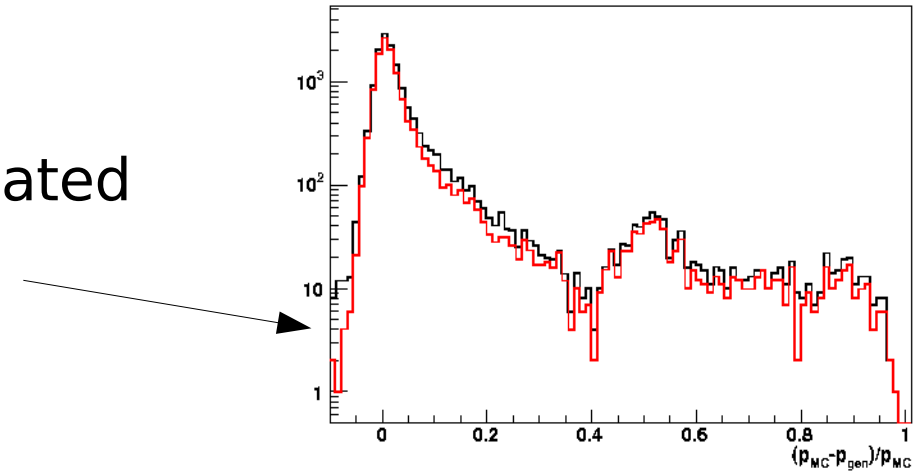
- $N_{hits\ on\ track}>5$
  - 5 hits: 6.6% (and 21% of electrons)
- But helps to reject electrons and antiprotons paying low price in efficiency



chi² cut

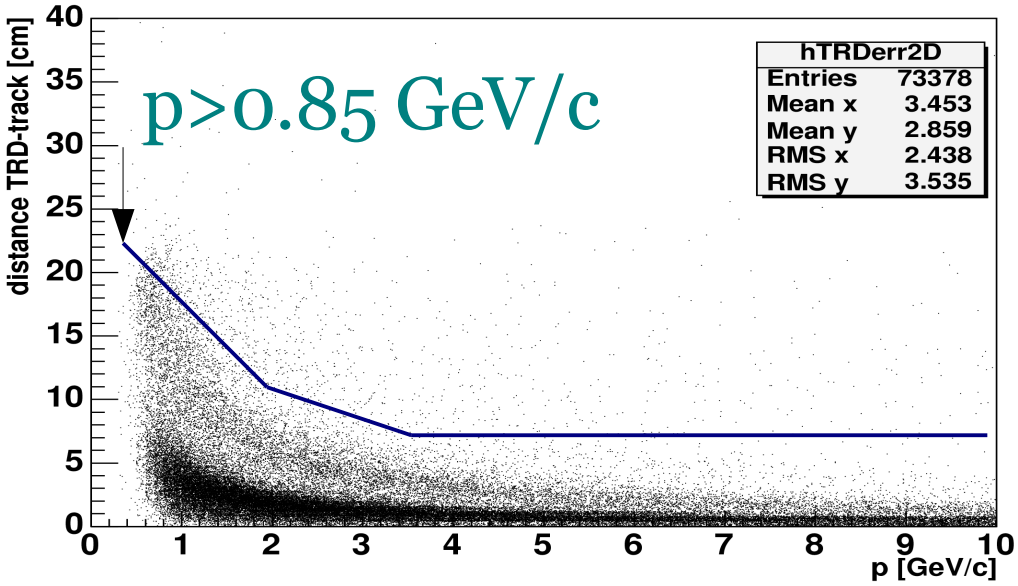
- chi2/ndf < 3.0: 86%

Rejects events with overestimated momentum – helps to reject antiproton background

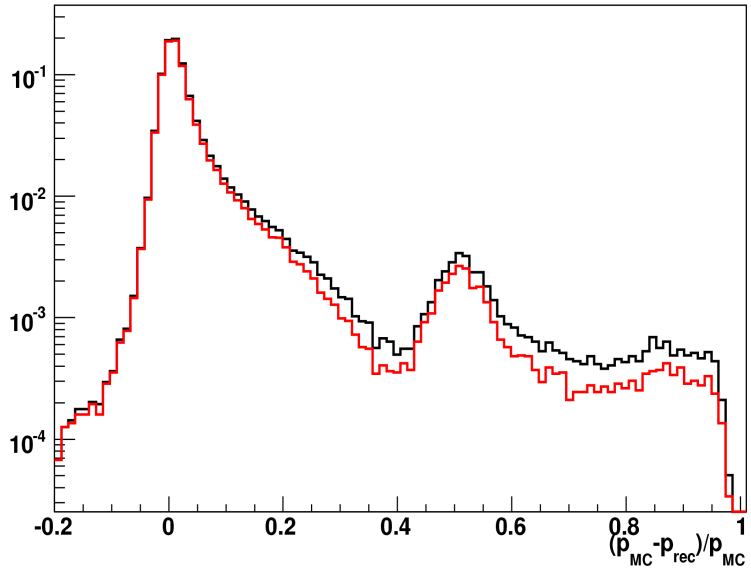


Distance between TRD track and extrapolation of Particle track

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).



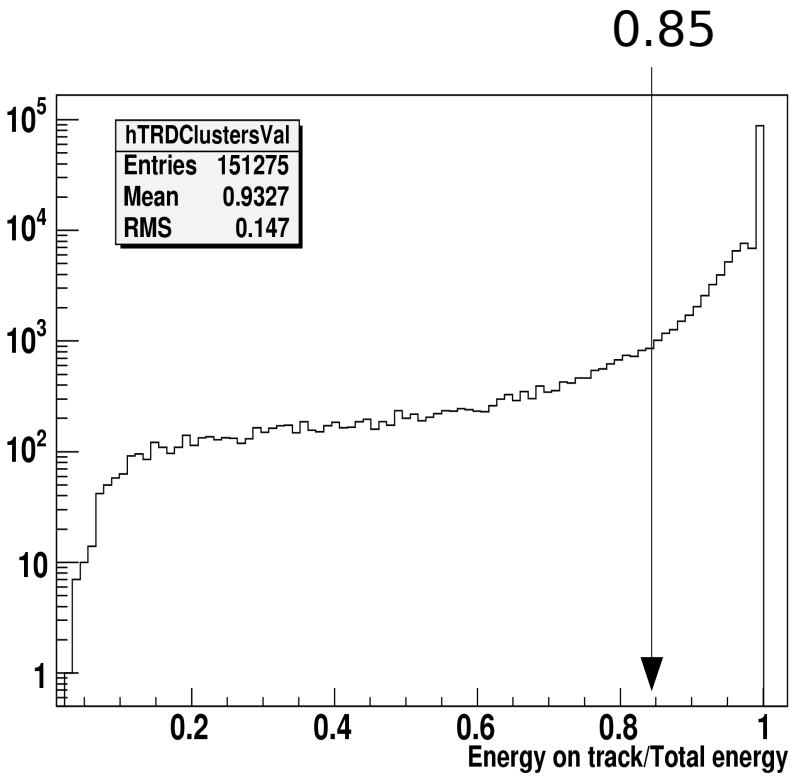
momentum-dependent cut because low-momentum antideuterons are important

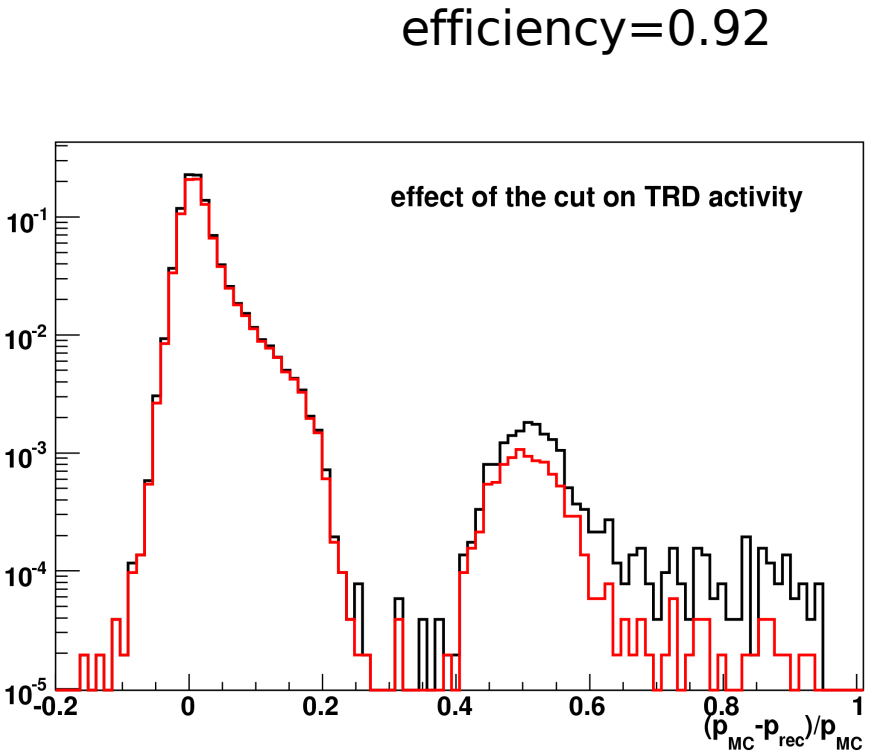


efficiency=0.94

Cut on activity in TRD

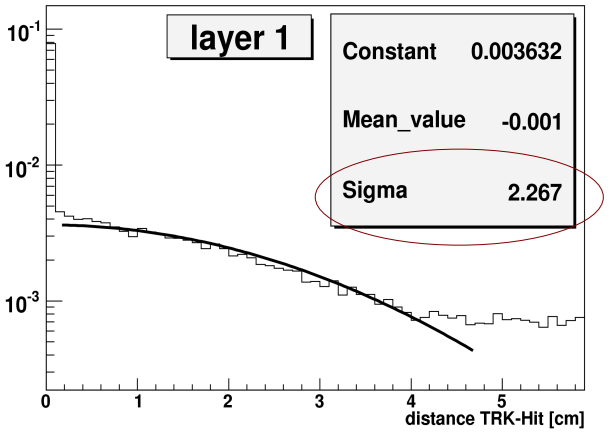
Idea: events with too much energy off TRD track should be rejected as the ones where particle interacts strongly in TRD.

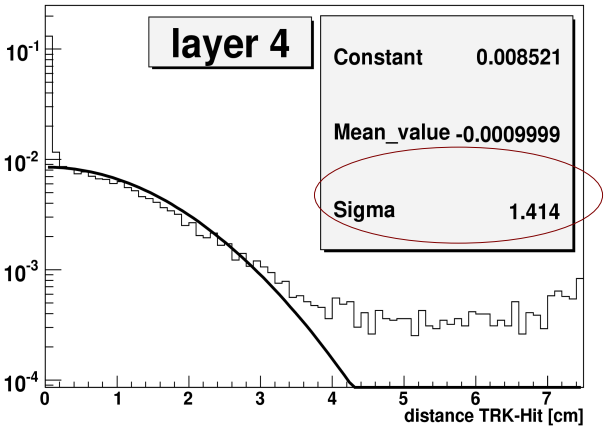


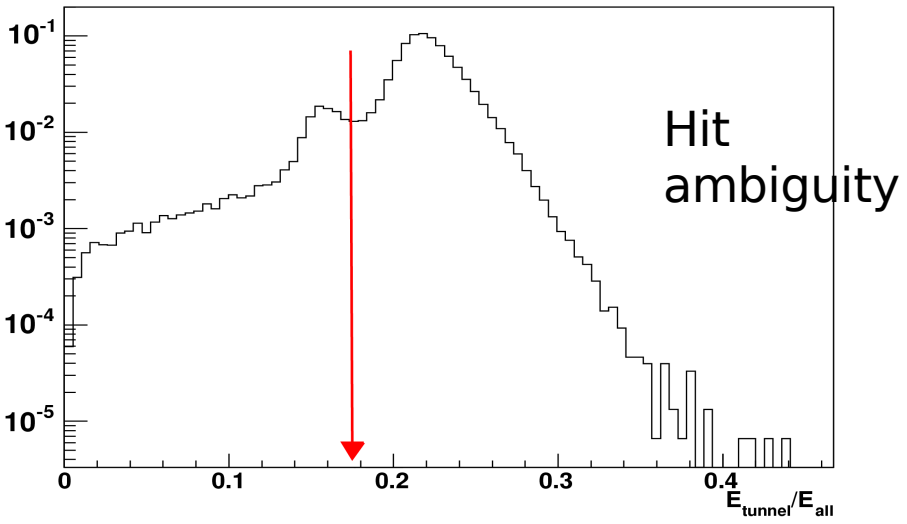


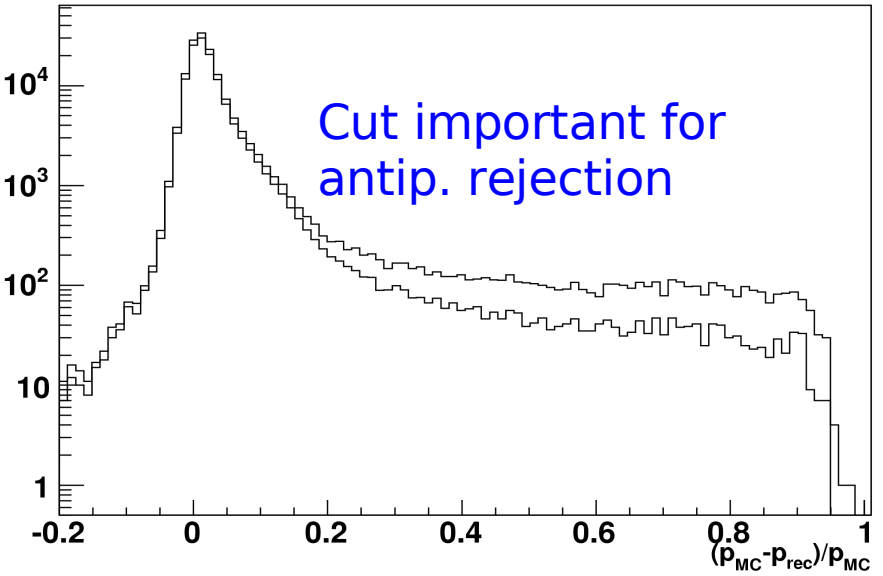
Energy in TRK tunnel

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 2.5σ.





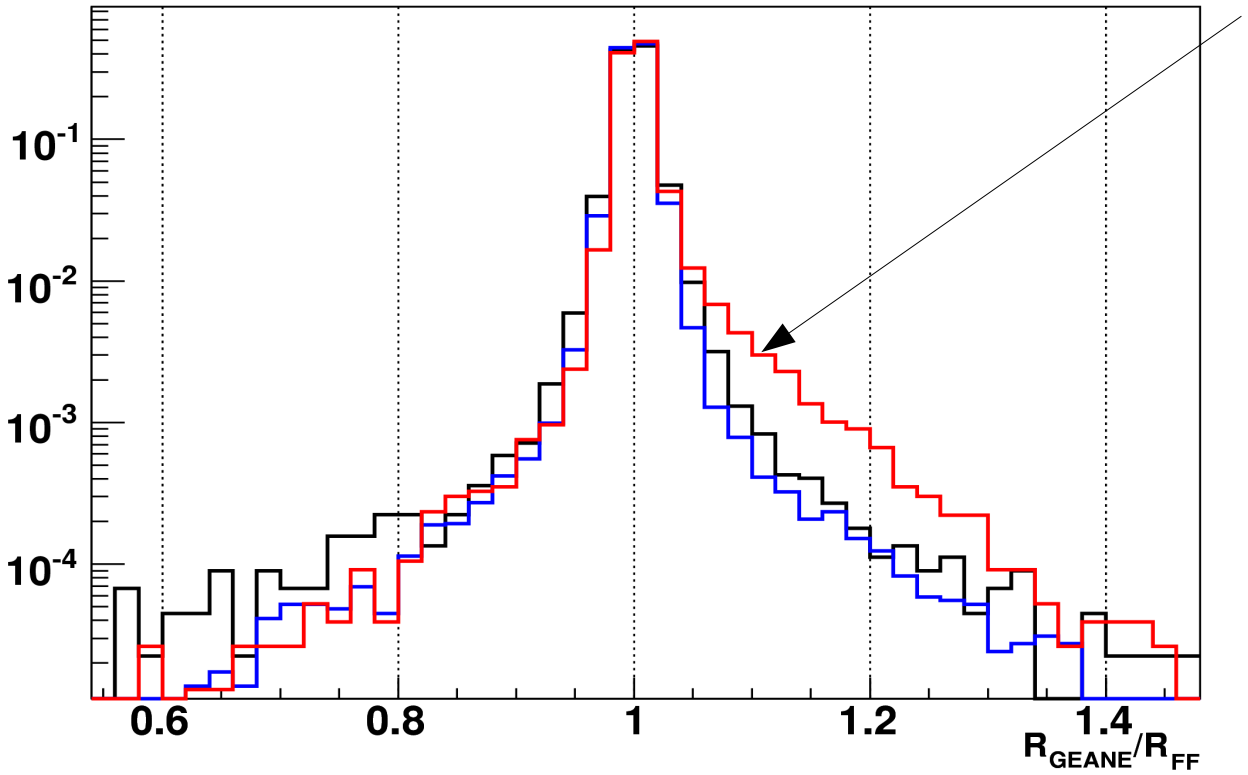




Geane/FastFit rigidity

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

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



electrons

Efficiency
antideuterons = 0.95

Velocity measurement

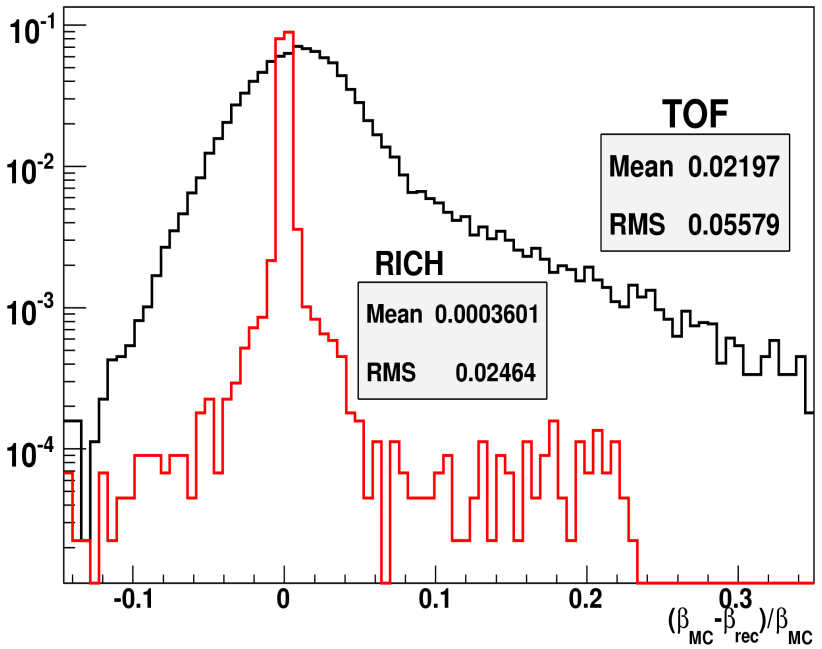
Two possibilities: RICH and TOF

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

optimization cuts:

TOF – strong cut $\beta < 0.90$ or lower (0.9 allows to "glue" TOF and RICH branches of analysis)

RICH – cuts suggested by Carlos Delgado + cuts cleaning sample from events interacting in the upstream detectors



26% of events have a RICH Ring

A comparison of beta reconstruction if TOF and in RICH:
TOF has large tail with under-estimated beta while for RICH we must deal with overestimated beta

Optimization on RICH beta

All cuts on RICH together

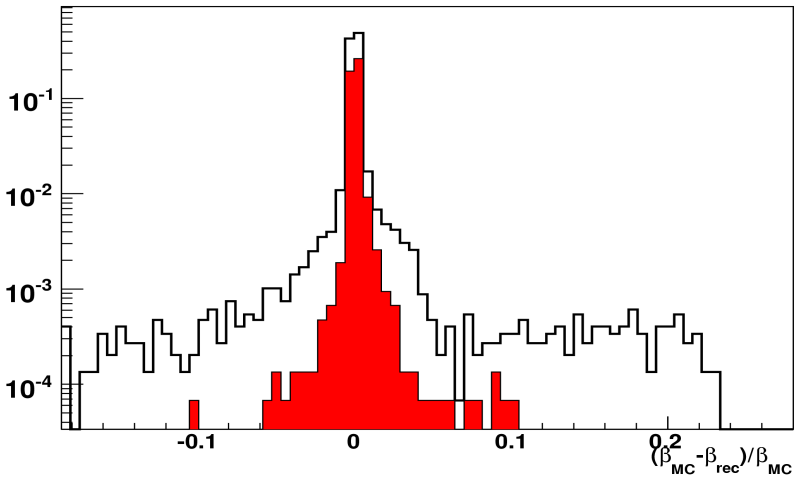
efficiency=0.841

Carlos Delgado proposition:

1. ring without overlapping particle
   (effic = 0.996)
2. Z=1 - compatible ring
   (NpCol/NpExp <2, effic=0.87)

3. good-shape ring
   (probability > 0.003, effic=0.93)

4. only one particle crossing the plane with PMTs
   (effic=0.999)



Efficiencies with respect to events after preselection and with Ring

Optimization on RICH beta

Additional cuts:

1. particle entrance point to RICH r<55-60 cm

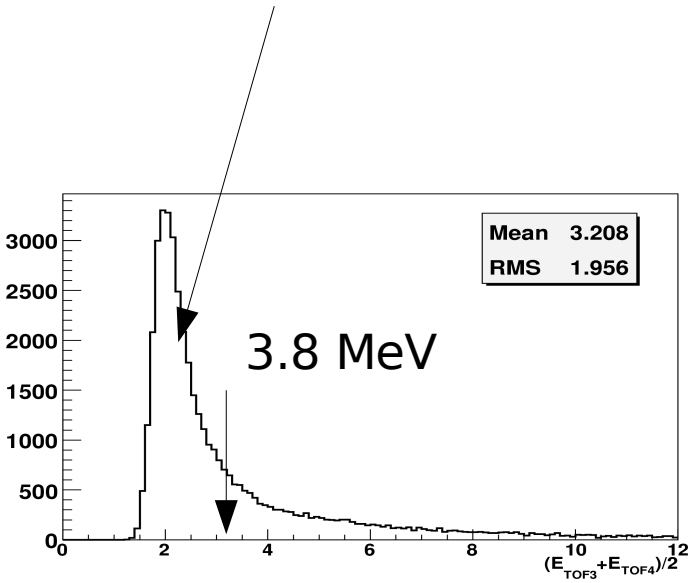
2. number of reconstructed rings < 3

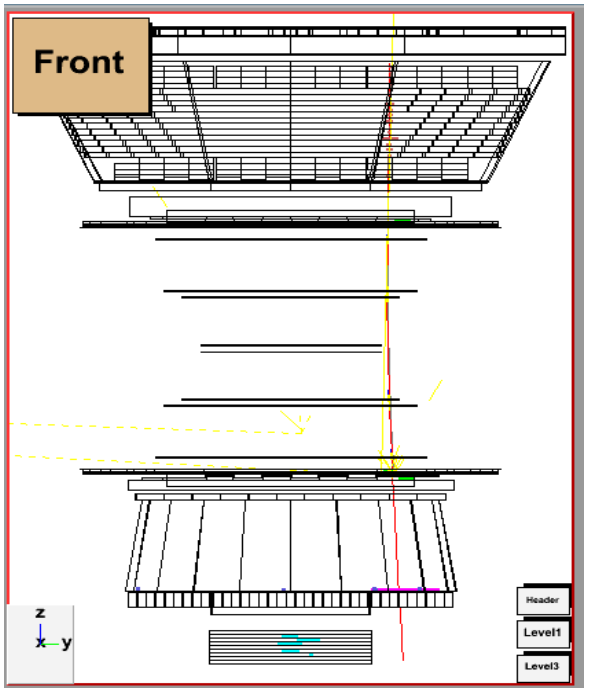
3. extra TOF cluster not in layers 3/4

4. cut on energy deposit in layers 3/4

5. beta<0.99

Effic=0.958
(with respect to events after Carlos' cuts)





MC: antiproton
with p=4.2, beta=0.976

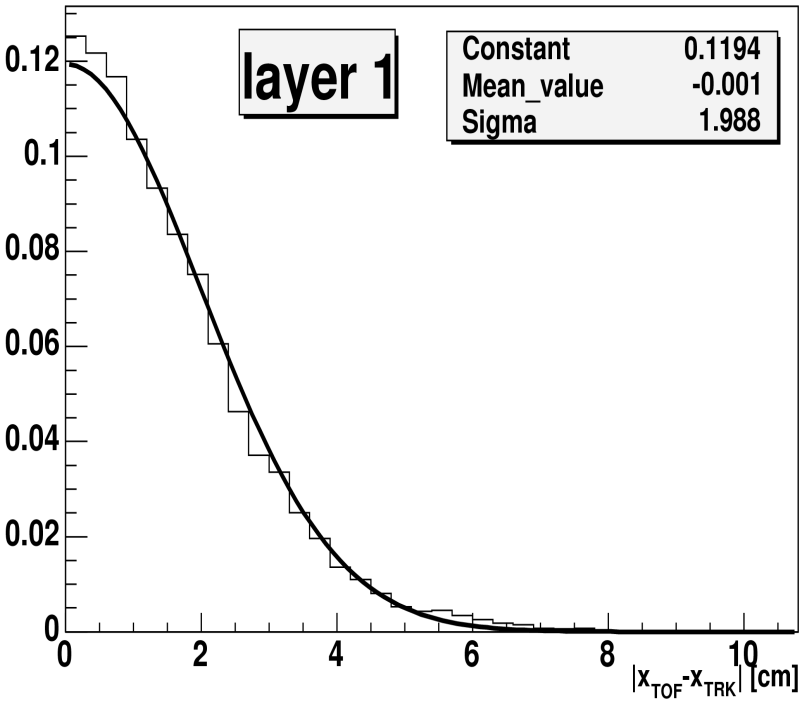
rec: antideuteron(?)
with p=4.2, beta=0.998
M=2.66

Optimization on TOF beta

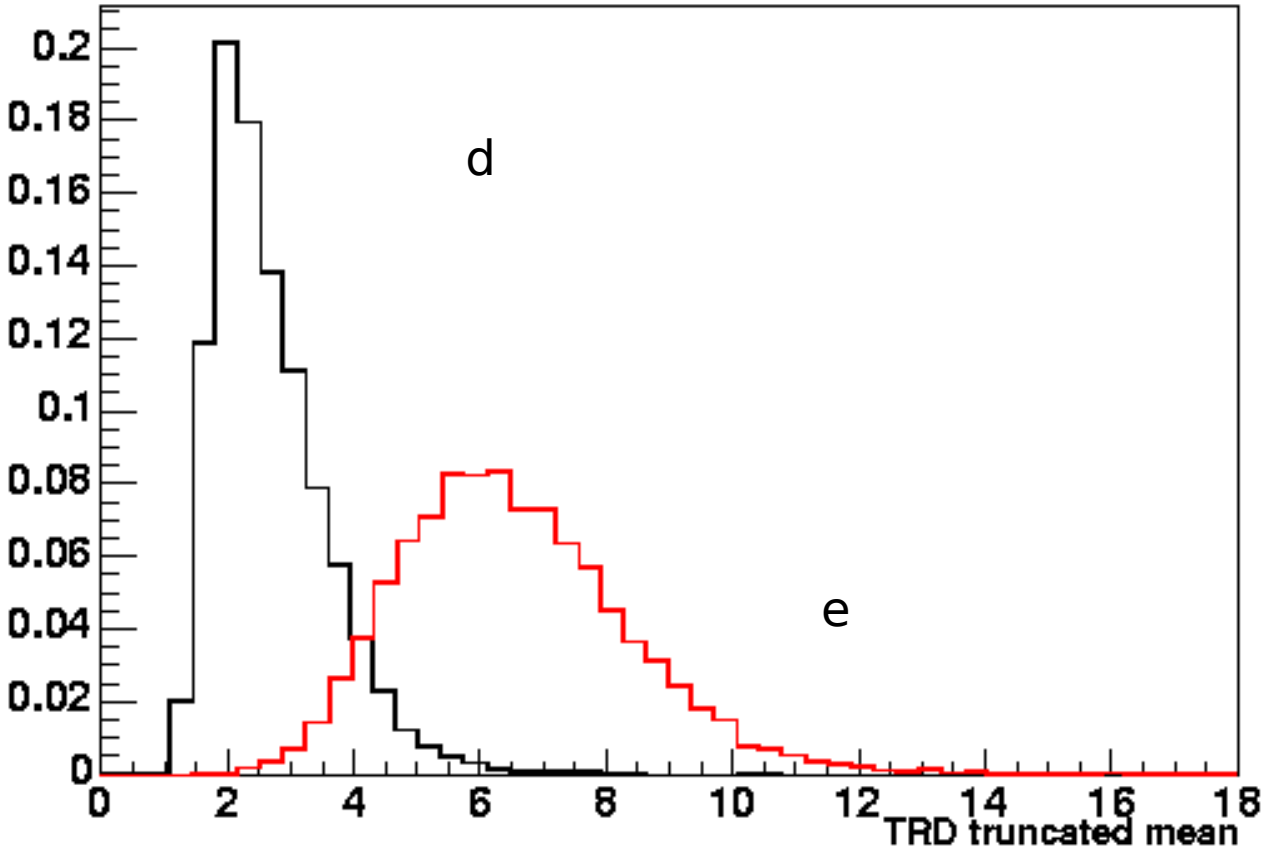
1. TOF planes used for beta reconstruction = 4 ; efficiency= 0.75
2. extra TOF clusters < 2 ; efficiency=0.96
   (one extra cluster allowed because it can be low-energy cluster in TOF layer 1,2)
3. beta < 0.9 (0.87)
4. distance between TOF clusters and TRK extrapolation (2.5 sigma)
   efficiency=0.88

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

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



Electron rejection: truncated mean energy

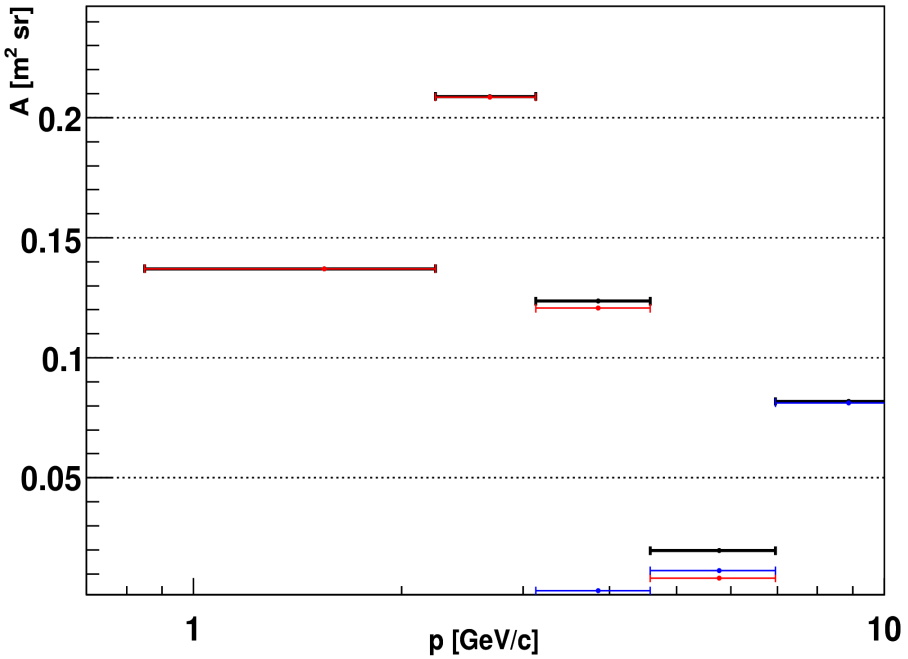


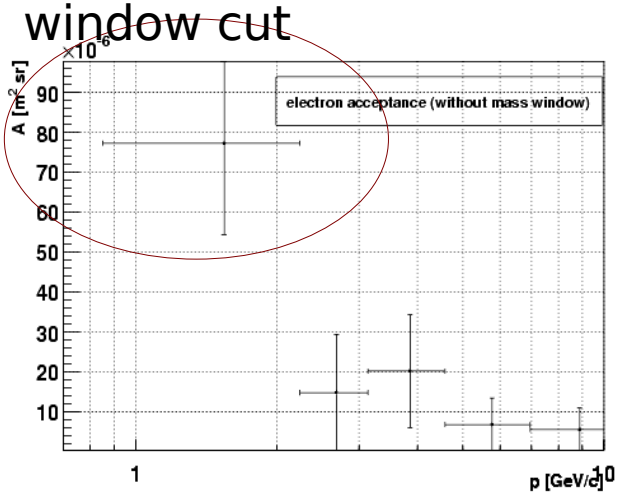
Momentum-dependent cut:
0.85-2 GeV/c: 4.7 MeV
2-3 GeV/c : 4.1 MeV
3-5 GeV/c : 3.3 MeV
> 5 GeV/c : 3.1 MeV

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

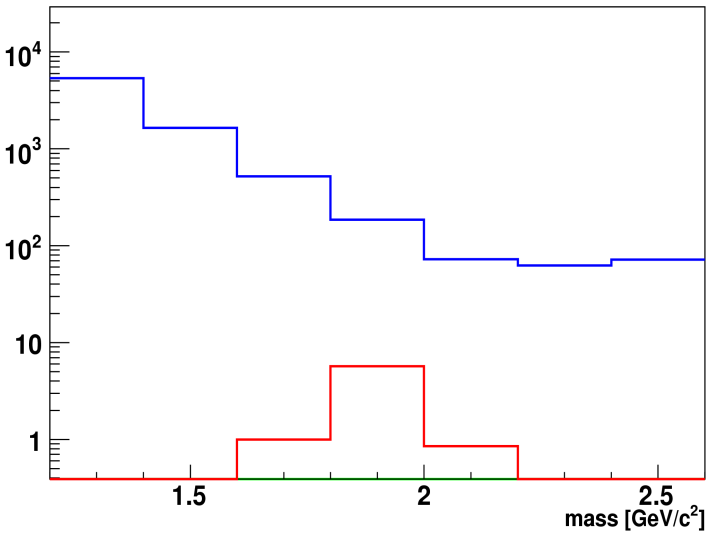
Final acceptance and efficiencies

This momentum is disfavored by mass window cut





TOF RICH



$\beta = 0.9$ corresponds to $p = 3.8$ GeV/c

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 an 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 GeV

Numbers of events

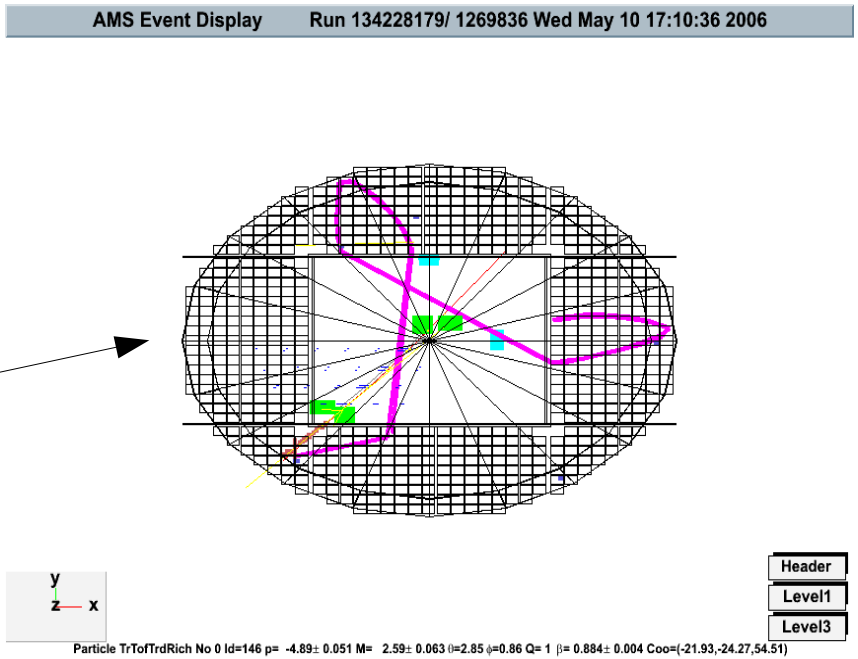
$$N = \Sigma N_i = \Sigma \left(\Phi_i A_i \epsilon_i t f_g \right) \text{ where } A - \text{acceptance}, t = 3 \text{ years}, f_g - \text{correction for geomagnetic cutoff}$$

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

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

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

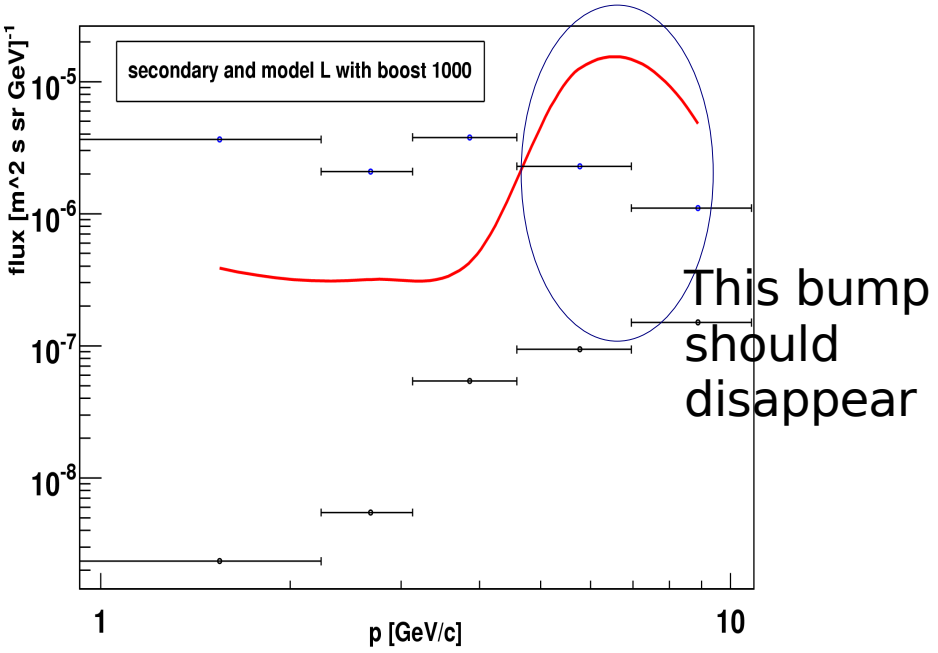
Antiprotons are a subject of further amelioration, there are events which have problems with reconstruction in RICH, for example:



Sensitivity

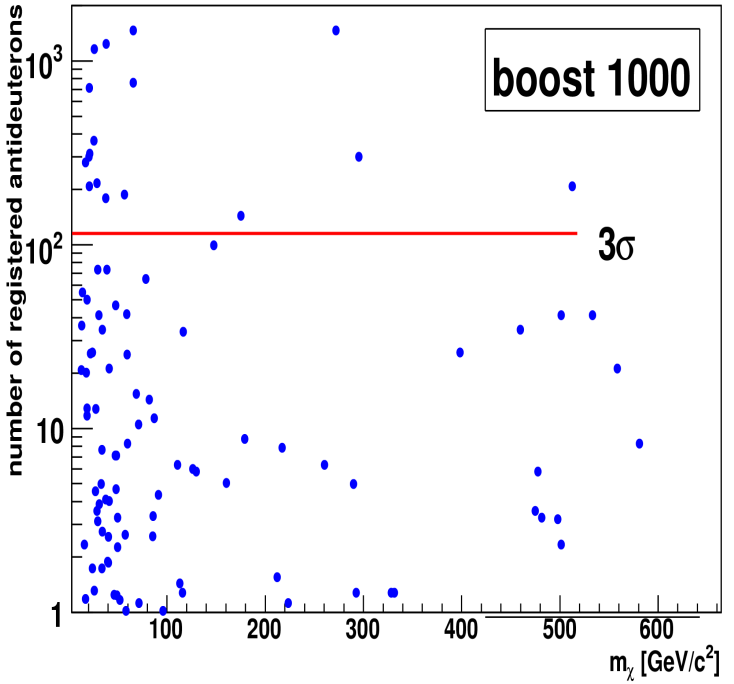
Sensitivity: $\mathrm{Sens} = max(3\frac{\sqrt{B}}{A\epsilon t}, \frac{5}{A\epsilon t})$

model L: m_0=300, $m_{1/2}$ = 450, A_0=0, sign(μ)=1, tgβ=50



This bump should disappear

Simple Sugra wild scan (500 models), DarkSusy 4.1,
m_0: 50-3000 $m_{1/2}$: 50-1600
A_0 : 0.1 – 2000 tgβ: 2 - 60



Model L detectable: 200 deuterons registered (45 in RICH)

Choice of the cut on beta

We will not be able to see secondary antideuterons with low momentum.
Q: how much flux from neutralino annihilation should be higher
than secondary flux to have S/sq(B) = 3?

Let's assume first bin of momentum only.

$$S = \Phi_{sec} A \epsilon t \qquad S_{dm} = \Phi_{dm} A \epsilon t \qquad B = \Phi_B A_B \epsilon_B t$$

$$\frac{S_{dm}}{\sqrt{B}} = 3 \qquad therefore \qquad \frac{\Phi_{dm}}{\Phi_{sec}} = \frac{S_{dm}}{S} = \frac{3\sqrt{B}}{S}$$

$$if\ \beta < 0.9 \qquad \frac{\Phi_{dm}}{\Phi_{sec}} = 17 \qquad\qquad if\ \beta < 0.87 \qquad \frac{\Phi_{dm}}{\Phi_{sec}} = 30$$

If we know well the systematic effects of antiproton measurement the optimal cut on beta might be not the lowest one

Conclusions

1. there are 8 expected antideuterons from spallation processes and 5 of them will be in RICH channel

these antideuterons probably will not be visible due to antiproton background (there is still a hope for RICH)

2. electron background is below 1000 events (100 in RICH) – we need much more statistics to estimate it better, but there is room for extra/more efficient cuts

3. antiproton background in TOF is about 450 and in RICH 150 events. In addition many of these events have badly reconstructed rings in RICH so it is a reducible backgoround. Also further reduction in TOF possible with stronger cut on β, but this cut should be tuned to get the best sensitivity.

4. antideuterons from neutralino annihilation will not be visible unless there is a large boost factor (> 100).

Common conclusions

1. Antideuterons from spallation are behind AMS sensitivity
(but not so far)

2. There is a hole in sensitivity between 3 and 6 GeV/c
(NaF region of RICH)

3. The eventual flux from DM annihilation could be visible if it is a 10-100 times higher than flux from spallation.
(clumpy DM halo helps)