MIPP
hadron-hadron and hadron-nucleus Cross Section Measurements:

a small first-step,
a theoretical primer
and how-to guide

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Status

- I wanted to develop code that uses pass 3 DST to:
  - exercise the data to see what works and find problems
  - push the development of preliminary code forward to see if all the variables one would need for getting physics out of the pass 3 DST are available
  - develop code that would eventually become a Bin-Wise Cross Section measurement, i.e. uses each bin of a histogram distribution of produced particle momentum and angle like a single channel analyzer cross section measurement as historically done in the olden days of nuclear physics.
- Get some prelimanary plots to show for internal Fermilab use.

Theory behind Cross Section:

The elastic scattering amplitude $F(q,s)$, where s is total hadron-nucleon center of mass energy squared and q is the momentum transfer vector, gives us a possibility to calculate total cross section through the optical theorem.

$$\sigma(s) = 4\pi/k \text{ Im } F(0,s)$$

where k is the hadron projectile momentum in the target nucleus rest frame. Using this amplitude we are also able to calculate differential elastic cross section

$$d\sigma_{elast.}(s)/d\Omega = |F(q,s)|^2$$

$$d\sigma_{elast.}(s)/dt = \pi/k^2 \, |F(q,s)|^2$$

and total elastic cross section

$$\sigma_{elastic.}(s) = \int d\Omega \, |F(q,s)|^2 = 1/k^2 \int dq \, |F(q,s)|^2$$

The elastic scattering amplitude can be expressed through the profile function:

$$\Gamma(B,s) = 1\text{-}S(B,s)$$

$$F(q,s)=ik/2\pi \int d^2 B\, e^{iq\Gamma(B,s)}$$

where S(B,s) is the S-matrix and B is the impact parameter vector perpendicular to the incident momentum k. The total and elastic cross sections can be obtained from the profile function Γ(B,s):

$$\sigma_{tot}(s)= 2 \int d^2 B\, \mathrm{Real}[\Gamma(B,s)]$$

$$\sigma_{elast.}(s) = \int d^2 B\, |\Gamma(B,s)|^2$$

Thus to calculate the total, elastic and differential cross sections we need to know S-matrix S(B,s).

To obtain total and elastic hadron-hadron or hadron-nucleus cross section at given initial energy we have to integrate the profile function $\Gamma(B,s) = 1-S(B,s)$. This can be done with help of the Monte Carlo averaging procedure often used to obtain the S-matrix values if we need to correct for a slope within a bin because the bin width was large due to a lack of statistics. These values depend on the squared total c.m. energy and the particle 4-momenta.

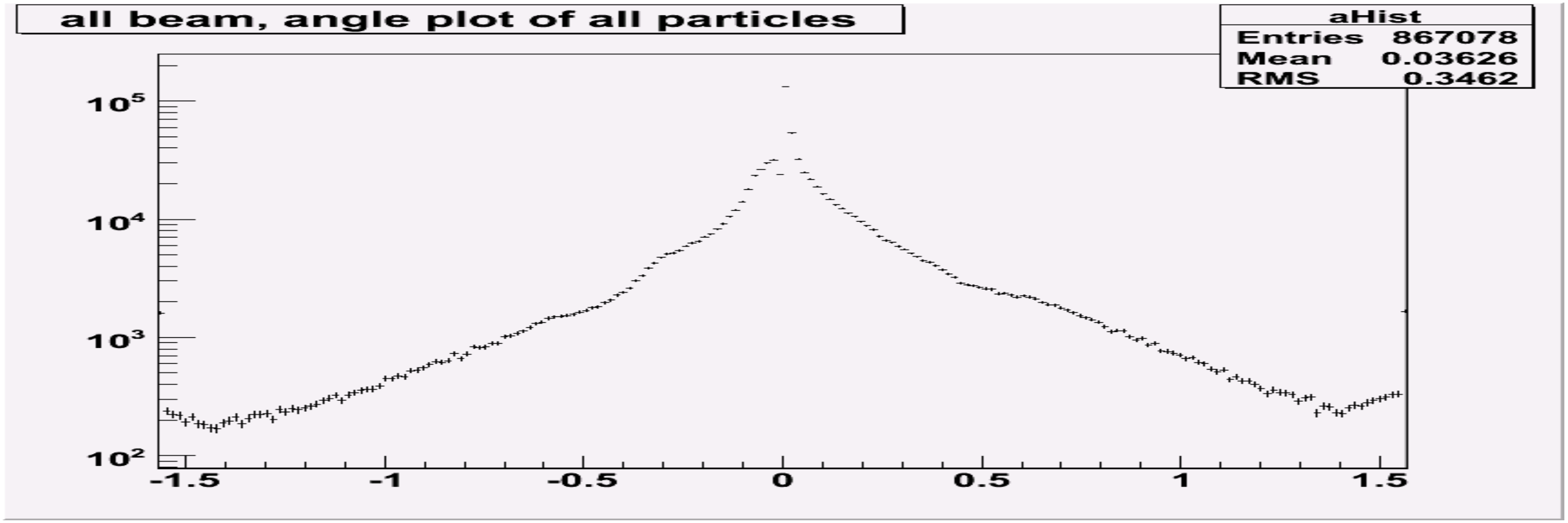
Then by integration over B we find the total and elastic cross sections. To obtain the elastic differential cross section, Equations 2 and 3, we have at first to perform the back Fourier transform of the profile function.

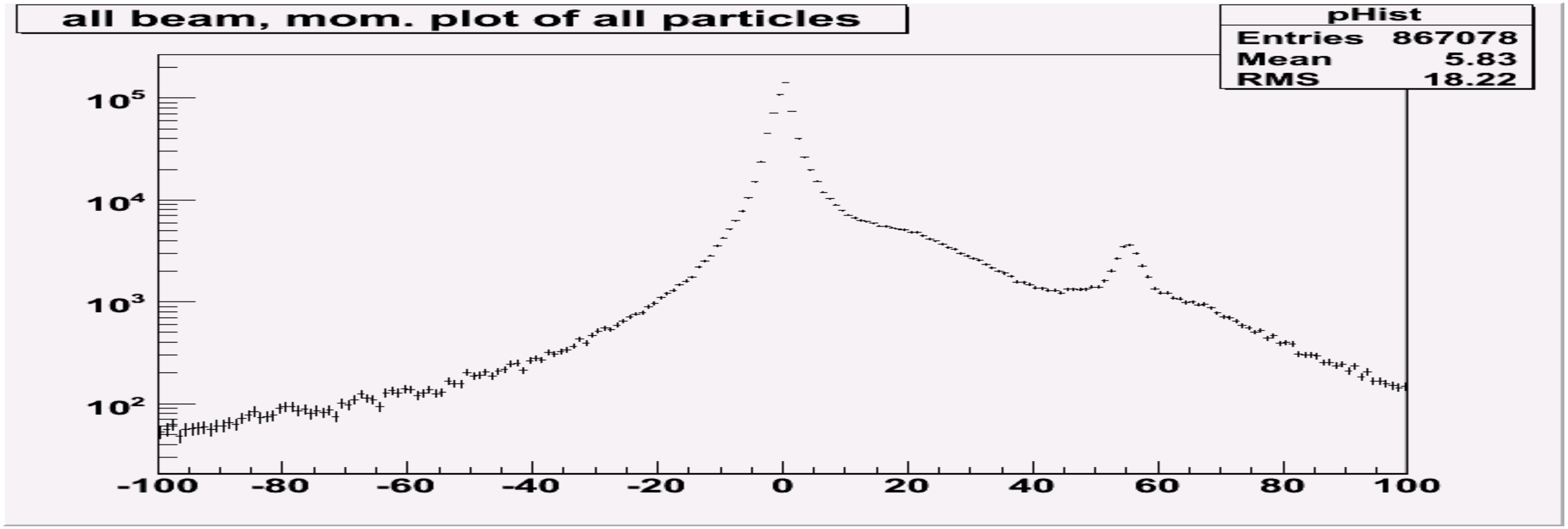
Don't Panic

- To the expert who has done this before then I hope I got everything correct and all looks very straight forward.
- To the newcomer in this physics topic, my first word of advice is don't panic, it is all just a lot of counting and histogram manipulation.

- Now on to the details:

For +59 GeV/c beam hitting Liquid Hydrogen target,
all the particles produced have the following distribution:

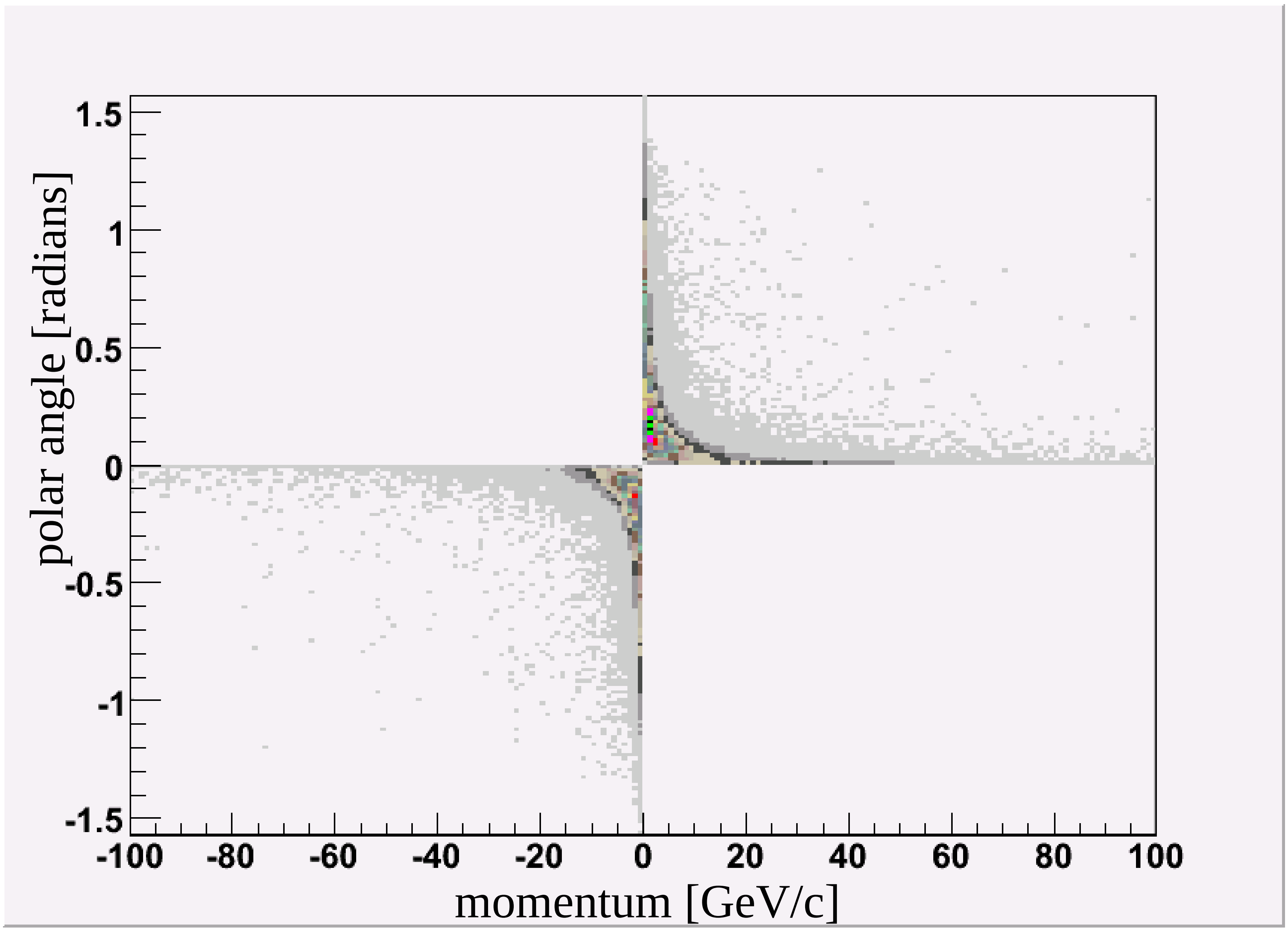




- These plots are essentially dσ/dt because they do not contain k^2, in the hadron-target center of mass system .
  - The momentum plot integrates over all angles so would have the y-axis:

    #particles/st.-radian/momentum bin
  - The angle plot integrates over all momentums and its y-axis as:

    #particles/momentum-bit/angle bin
- The more important plot is the 2-d plot these projection histograms come from and is the main way we will store the information for manipulation.



polar angle [radians]
1.5
1
0.5
0
-0.5
-1
-1.5
-100
-80
-60
-40
-20
0
20
40
60
80
100
momentum [GeV/c]

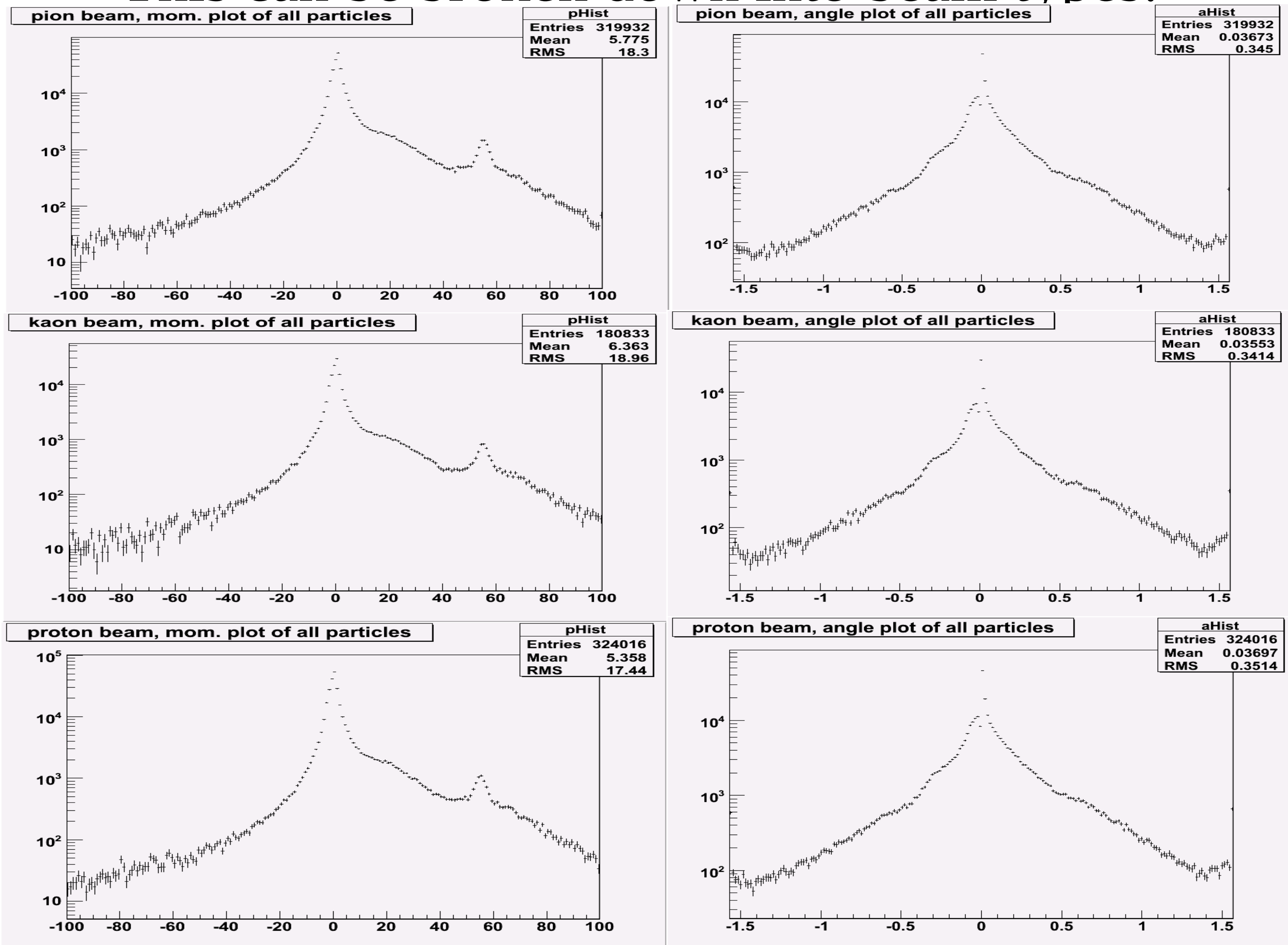
Variables needed:

- Beam:
  - beam particle type
  - impact vector
  - momentum
  - momentum transfer using: beam particle, target nuclei produced particles.

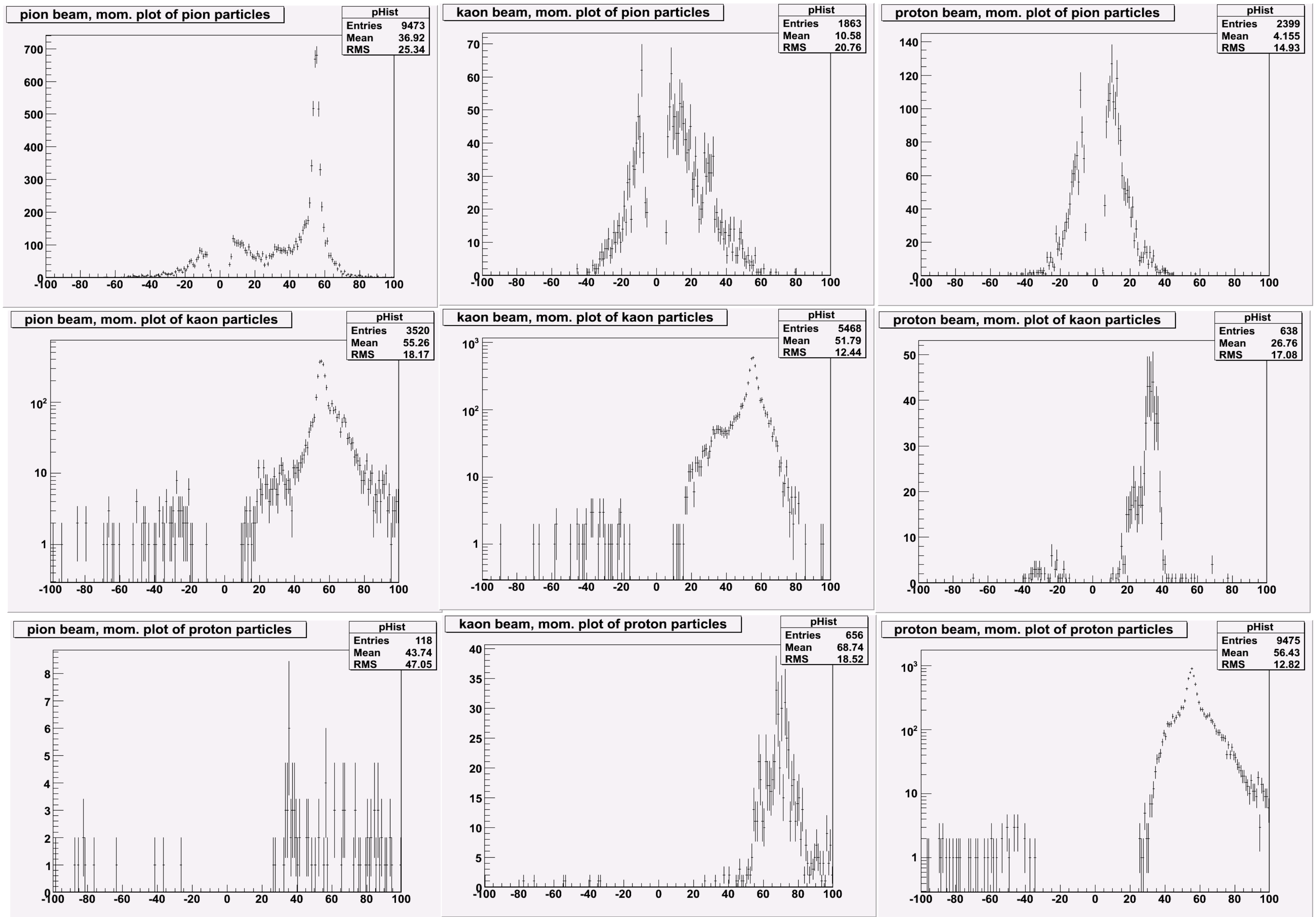
- Produced particle:
  - PID information
  - 4-vector
  - vertex

- Interaction type
  - elastic
  - inelastic
  - associate production
  - 1-particle inclusive
  - 2-particle inclusive

This can be broken down into beam types:



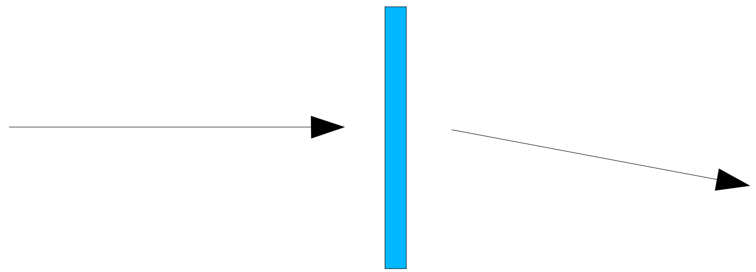
Using PID of produced particle, only RICH working right now, we have:

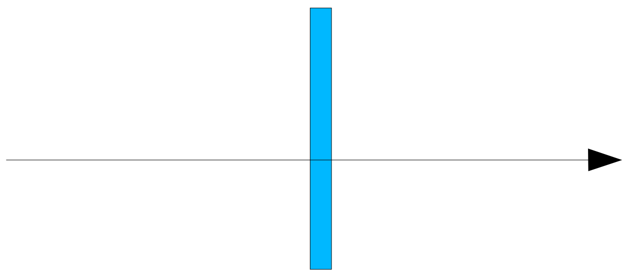


How to select interaction type:

<u>elastic</u>: no interaction

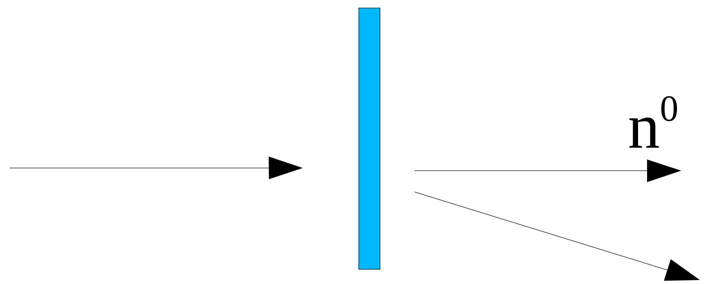
is just scattering:

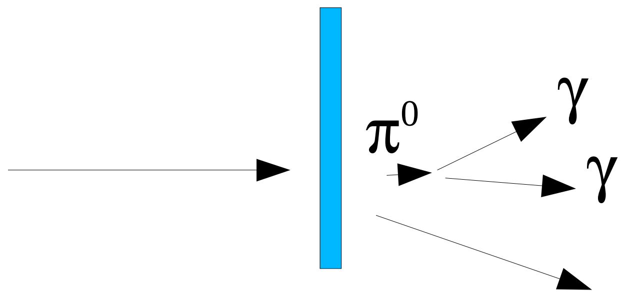




our target is only 1% I.L.
so a straight track is a
good sign of no interaction.

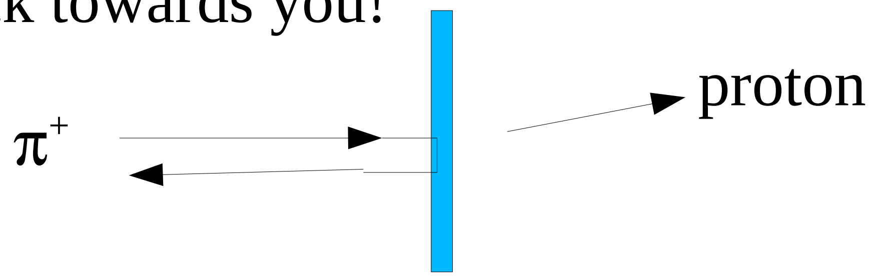
But, there are some elastic
that will look like inelastic
interaction:





use hadron or EM caloremeter
to reject events and MC to help.

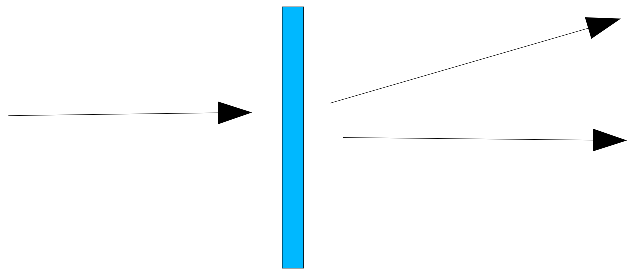
The most famous of all elastic scattering is backward scattering, Rutherford's comment that it is as shocking as your cannon ball flying back towards you!



Use meson beam data on Liquid Hydrogen target and look for events with a single proton in the MIPP detector.

inelastic:

a hard interaction, our trigger enhances this so we will have a lot.



will benefit from vertexing
and momentum balance cuts.

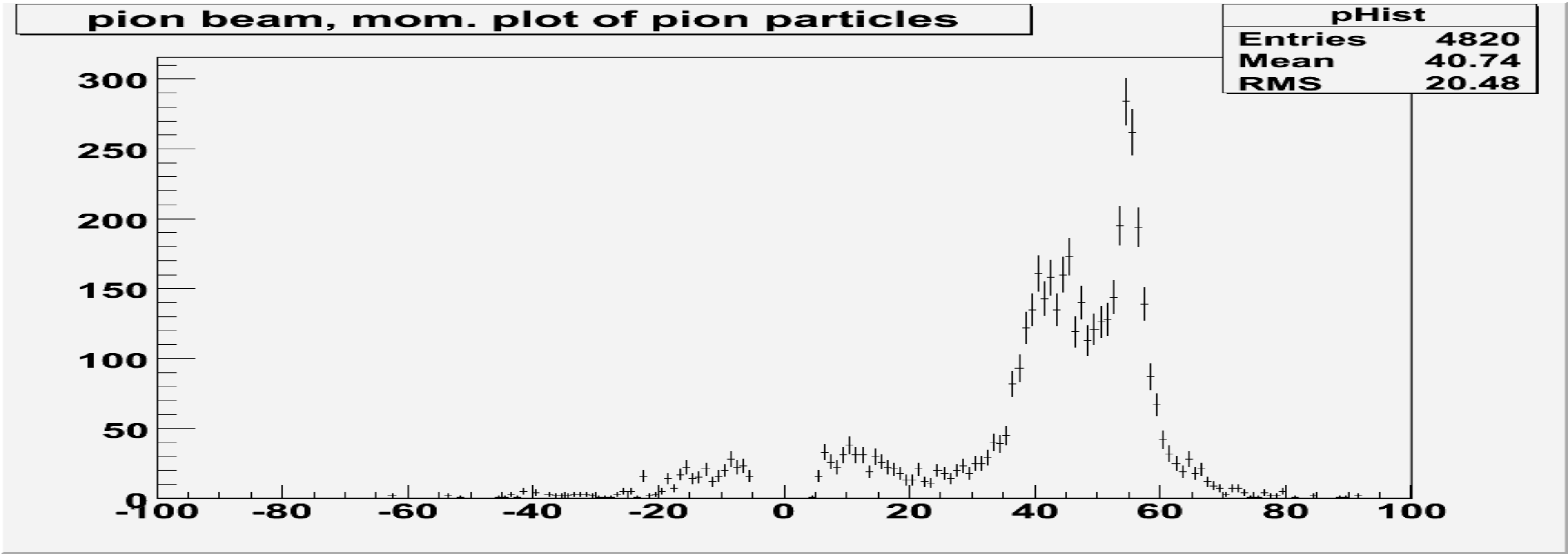
Just like elastic had backgrounds from inelastic
so do does inelastic have background from elastic events.

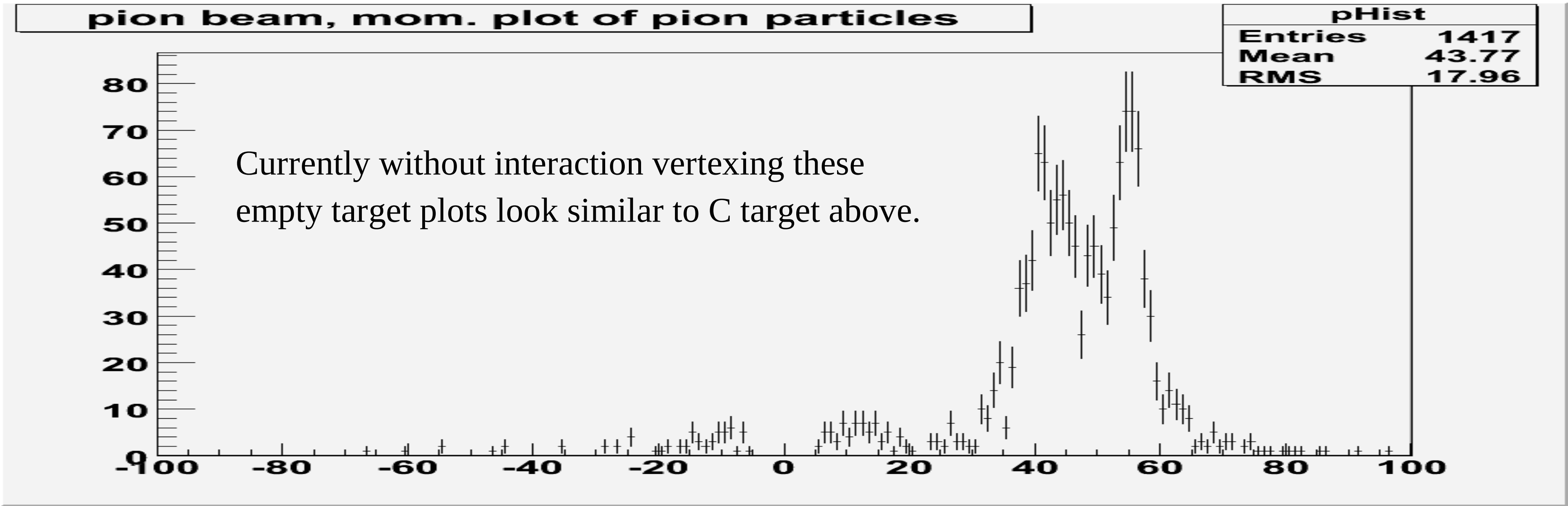
Plus, there are the added problems of multiple beam
particles, accompanying neutrals that can make fake events.

Associate production where the K^0_{short} or Λ^0 escape and
decay outside of our reconstruction volume are another problem.

- Use vertexing, momentum balancing cuts and in the c.m. of hadron-nucleus system plot of $d\sigma/d\Omega$.
- Scales plots for prescale and interaction trigger.
- Combined with empty target runs, scaled for prescales and trigger efficiencies, subtracted off.
- MC acceptance adjustment which is due to the detector not being infinate and dead channels, this is a bin-by-bin multiplication.
- This would then give our first preliminary physics plots that would need systematic errors understood well enough to defend.

Thin Carbon target data top, and Empty target bottom for +59 GeV/c:

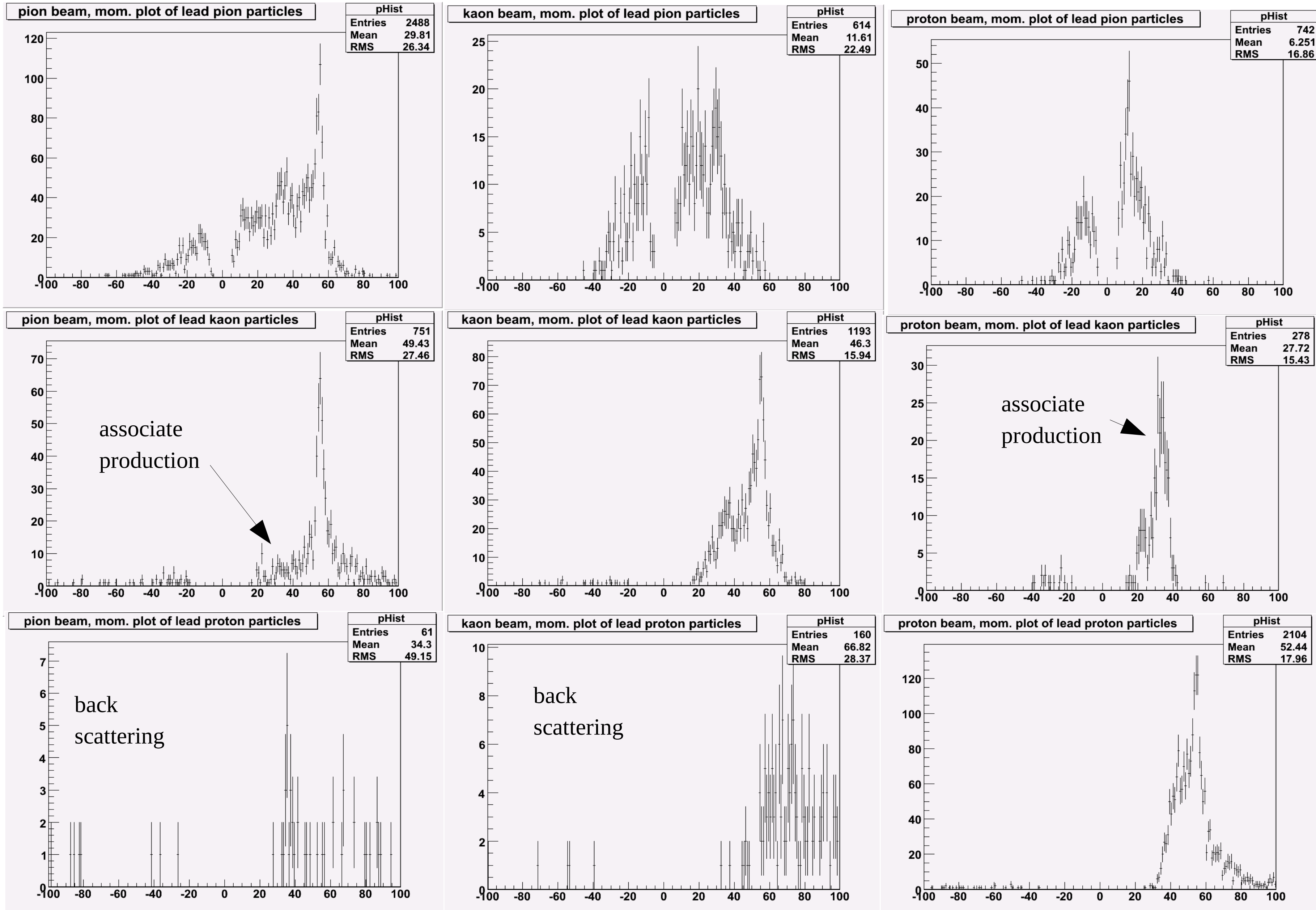




Root C++ code being developed for Physics tree branches to:

- All produced particles
- Leading particle
- Elastic Scattering
- Inelastic Scattering
- Associate Production Cross Section
- ....   etc.....

Leading particle as ID by RICH in an event for different beams:



Conclusion:

- Working with data to see physics plots started, but still a long way to go to preliminary physics.
- It was nice that we could see some peaks attributable to physics process, but at the same time see some problems in the distributions
- All problems will be improved or even eliminated once vertexing, improved tracking, full PID comes online, especially momentum balancing cuts.

Invariant Mass studies in MIPP

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E907 Collaboration Meeting

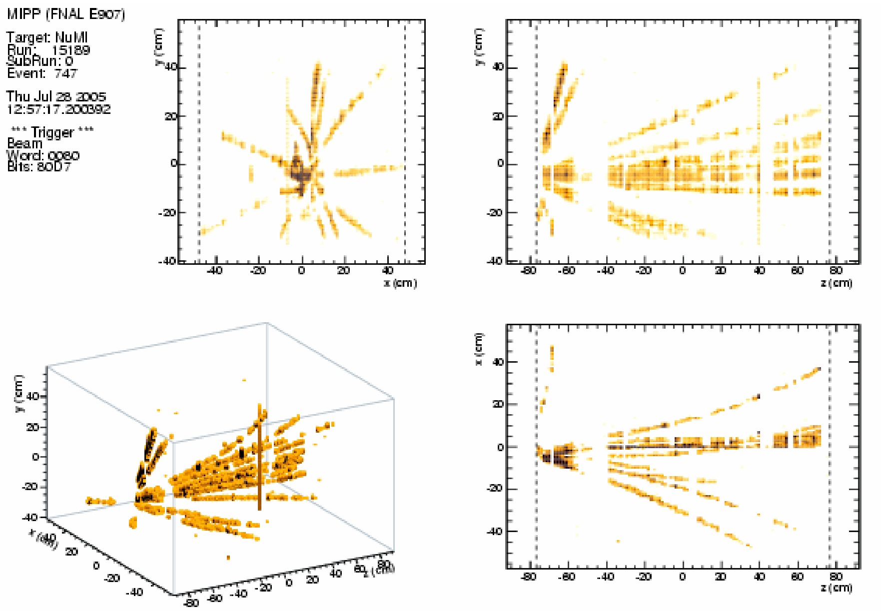
April 8, 2006

Why study invariant mass?

- Calibration:
  - A large well selected sample of charged pions from K_{short}^0 decay are needed to calibrate Particle Identification in various detectors.
    - for example Ckov
  - All experiments use the K_{short}^0 and Λ^0 invariant mass peaks to check and finalize:
    - Magnetic field
    - Tracking chamber locations
    - Analysis code performance
- Public Relations: to show our detector components, analysis code and data are working and that the PID is doing a good job.

Events used:

- We used events with at least one negative and positive track but not more than 10 total tracks.
- Beam particles species were able to be selected from a set of 60 subruns of +59 GeV on LH2 target.



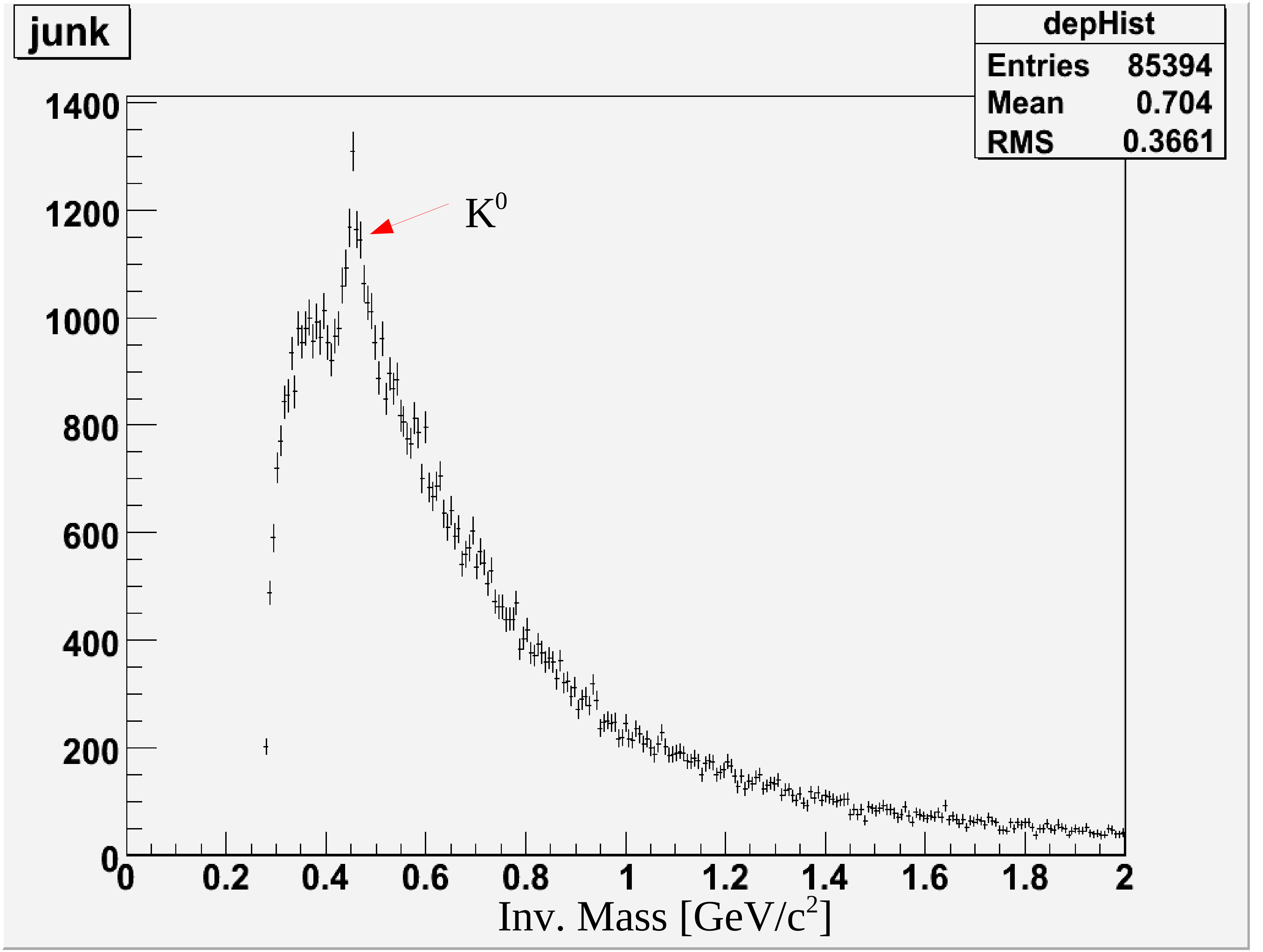
Calculations:

- Using the relativistic mass formula and known proton and pion PDG masses:

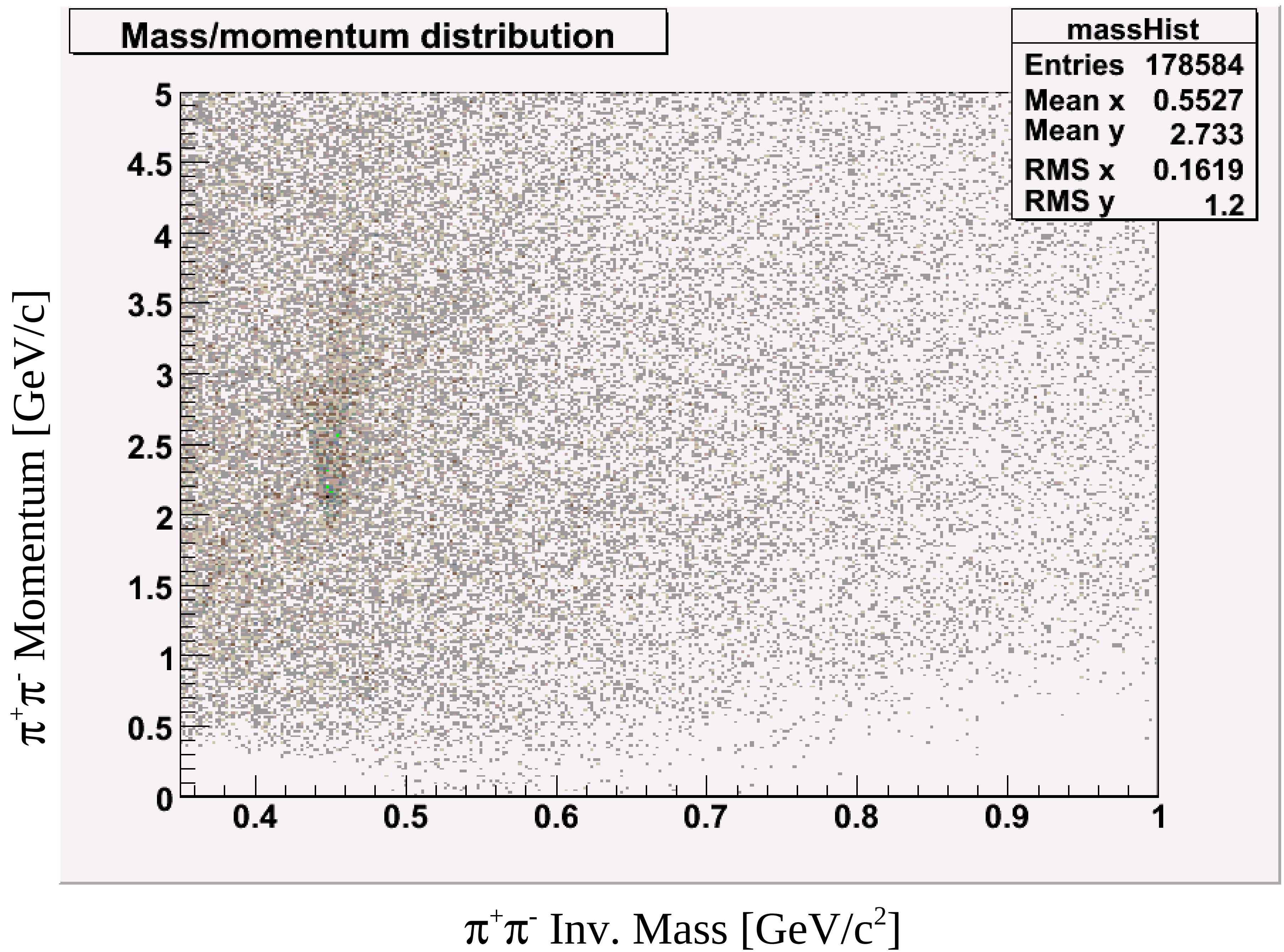
  Energy(pπ) = $\sqrt{(m_{PDG}^2+p^2)_1} + \sqrt{(m_{PDG}^2+p^2)_2}$

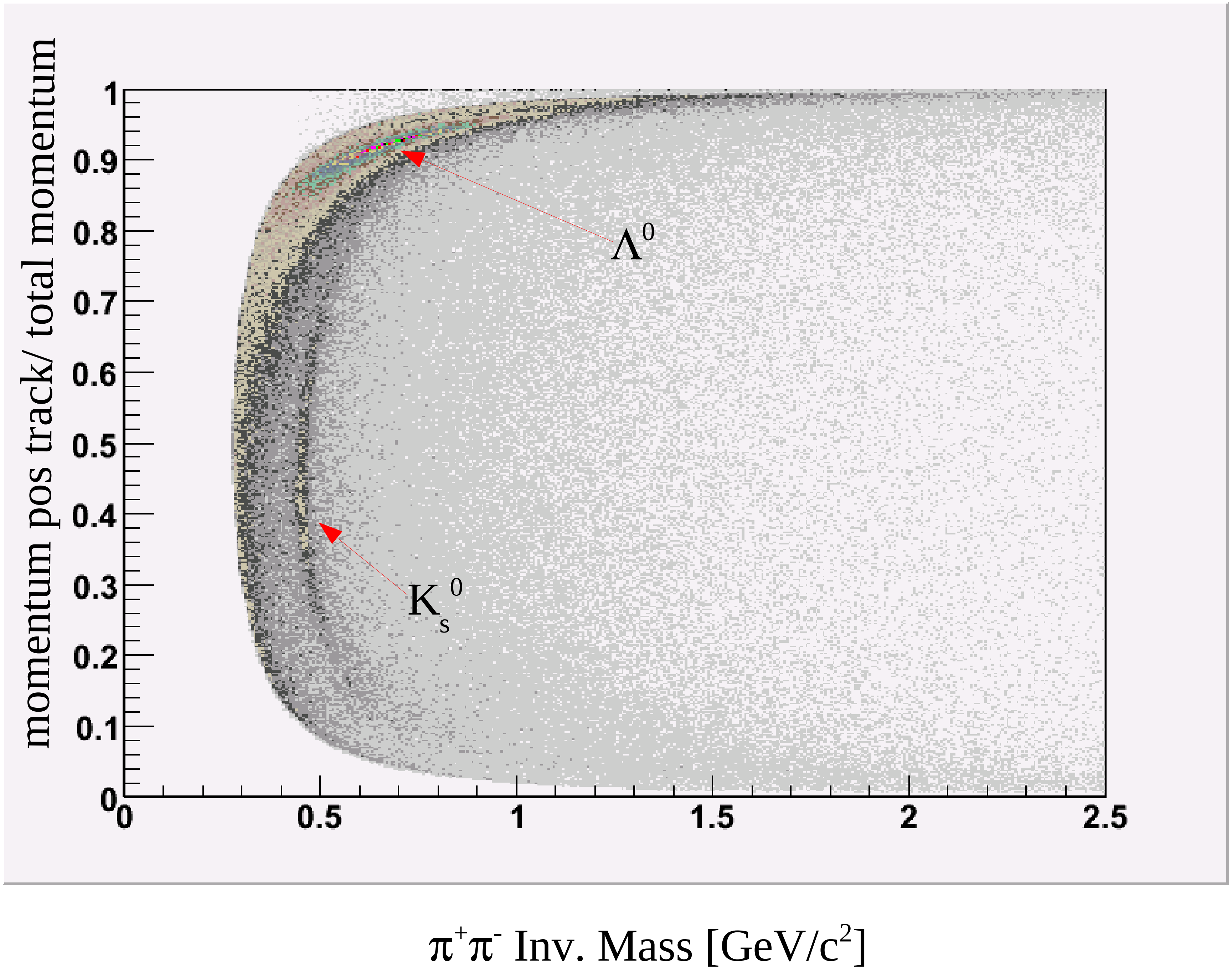
  InvMass(pπ) = $\sqrt{\text{Energy}(p\pi)^2 - (px_1+px_2)^2 - (py_1+py_2)^2 - (pz_1+pz_2)^2}$

  - 1) All combinatoric pairs of negative and positive tracks in a single event searched and plotted.
  - 2) For K^0 mass used $\pi^+\pi^-$ mass combination, and for Λ^0 mass used p π^- masses.
- This method relies only upon track momentum reconstruction, not vertexing.



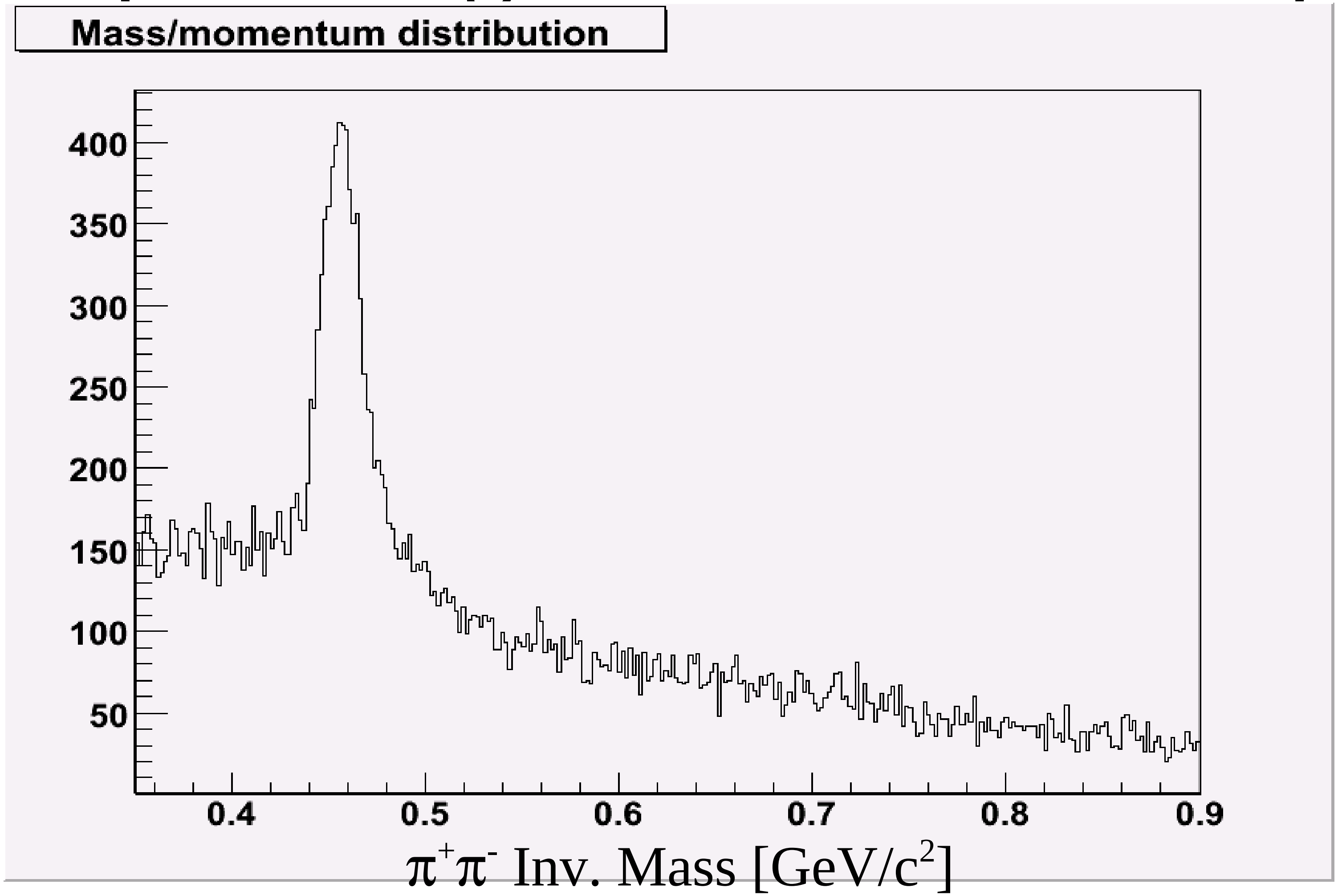
junk
depHist
Entries 85394
Mean 0.704
RMS 0.3661
K0
1400
1200
1000
800
600
400
200
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Inv. Mass [GeV/c2]


Mass/momentum distribution
massHist
Entries 178584
Mean x 0.5527
Mean y 2.733
RMS x 0.1619
RMS y 1.2
π⁺π⁻ Momentum [GeV/c]
π⁺π⁻ Inv. Mass [GeV/c²]
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.4
0.5
0.6
0.7
0.8
0.9
1

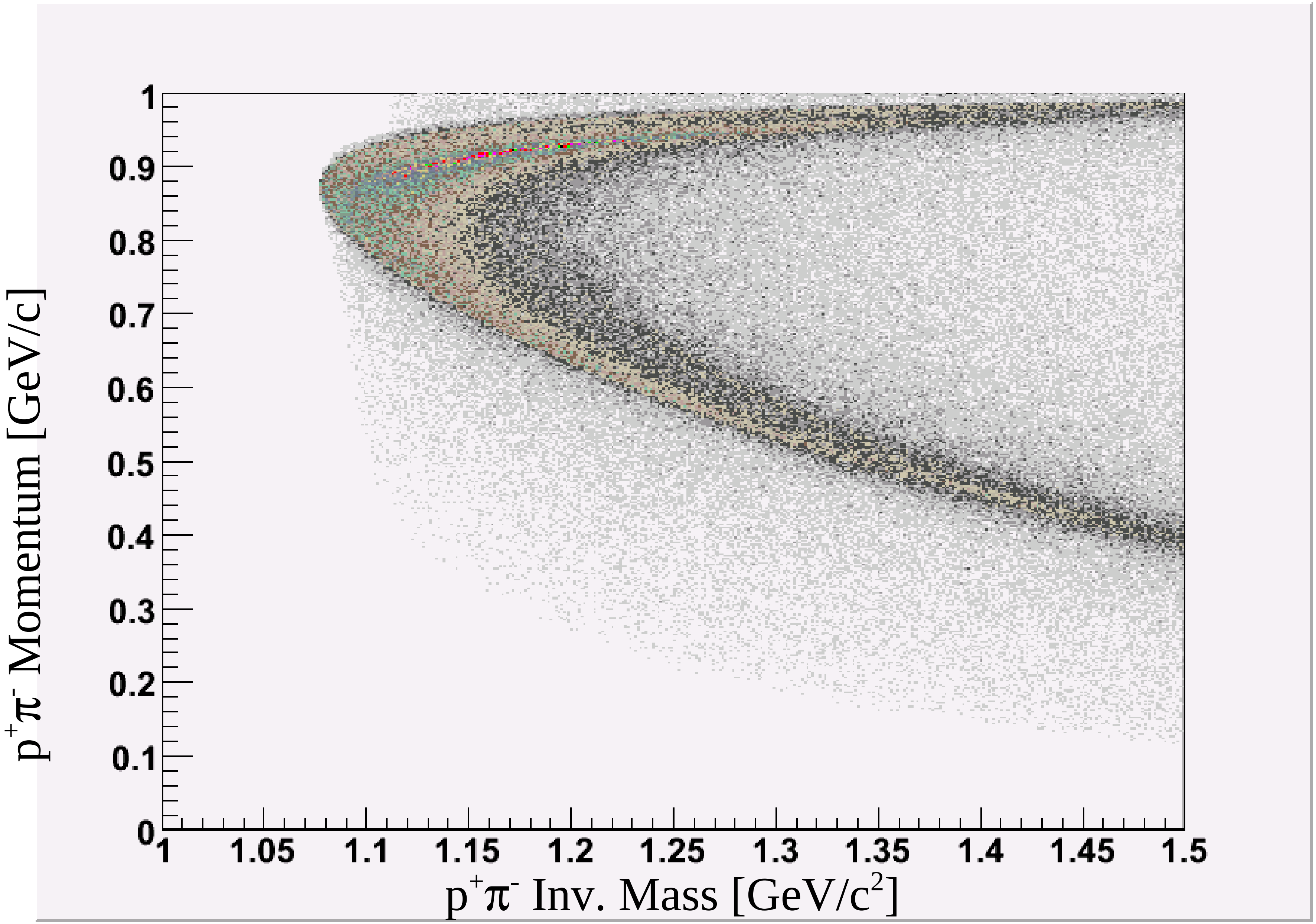


momentum pos track/ total momentum
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
Λ0
Ks0
π+π- Inv. Mass [GeV/c2]

Simple cuts give a clean K^0 sample

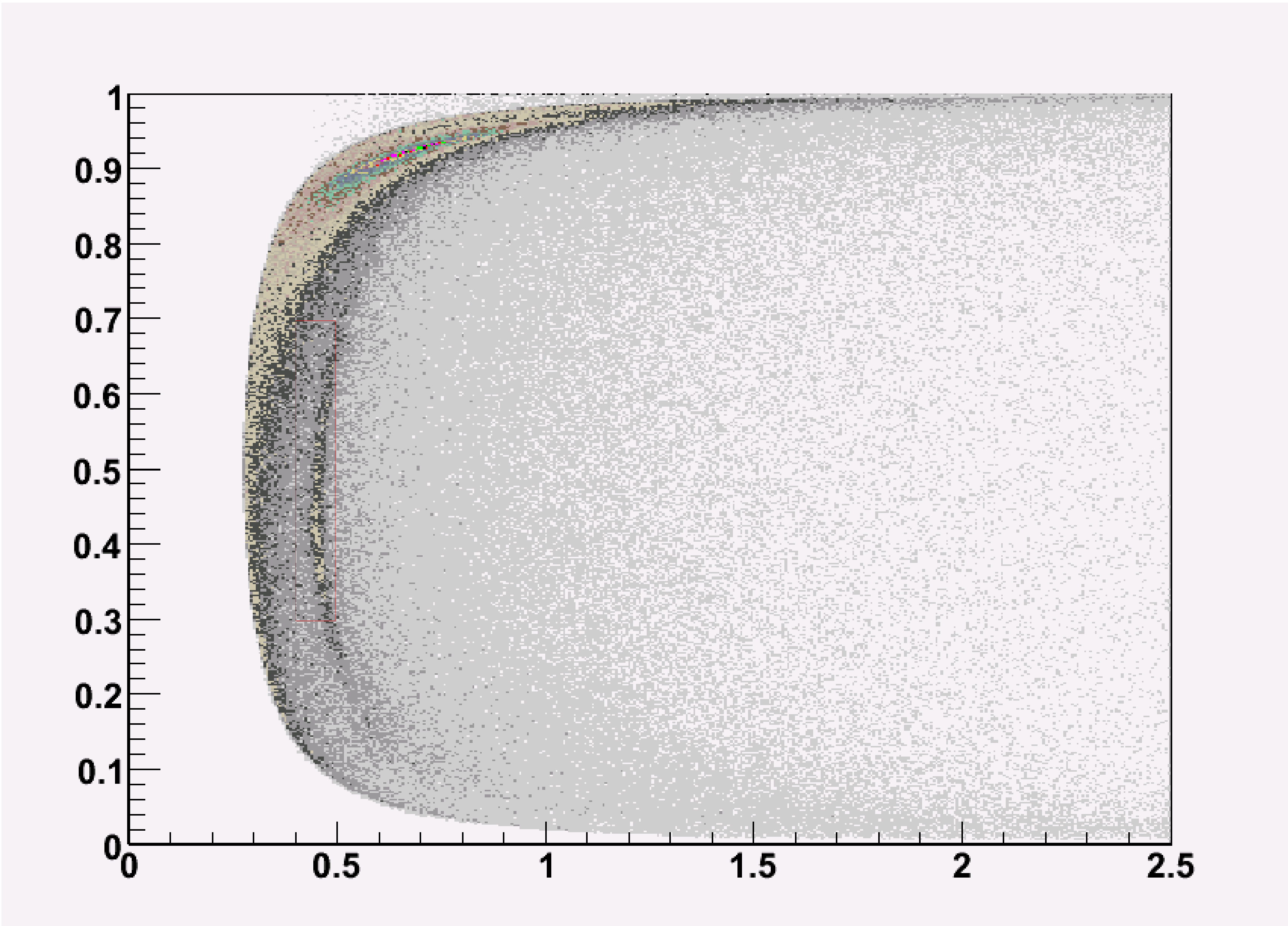


$\pi^+\pi^-$ Inv. Mass [GeV/c^2]

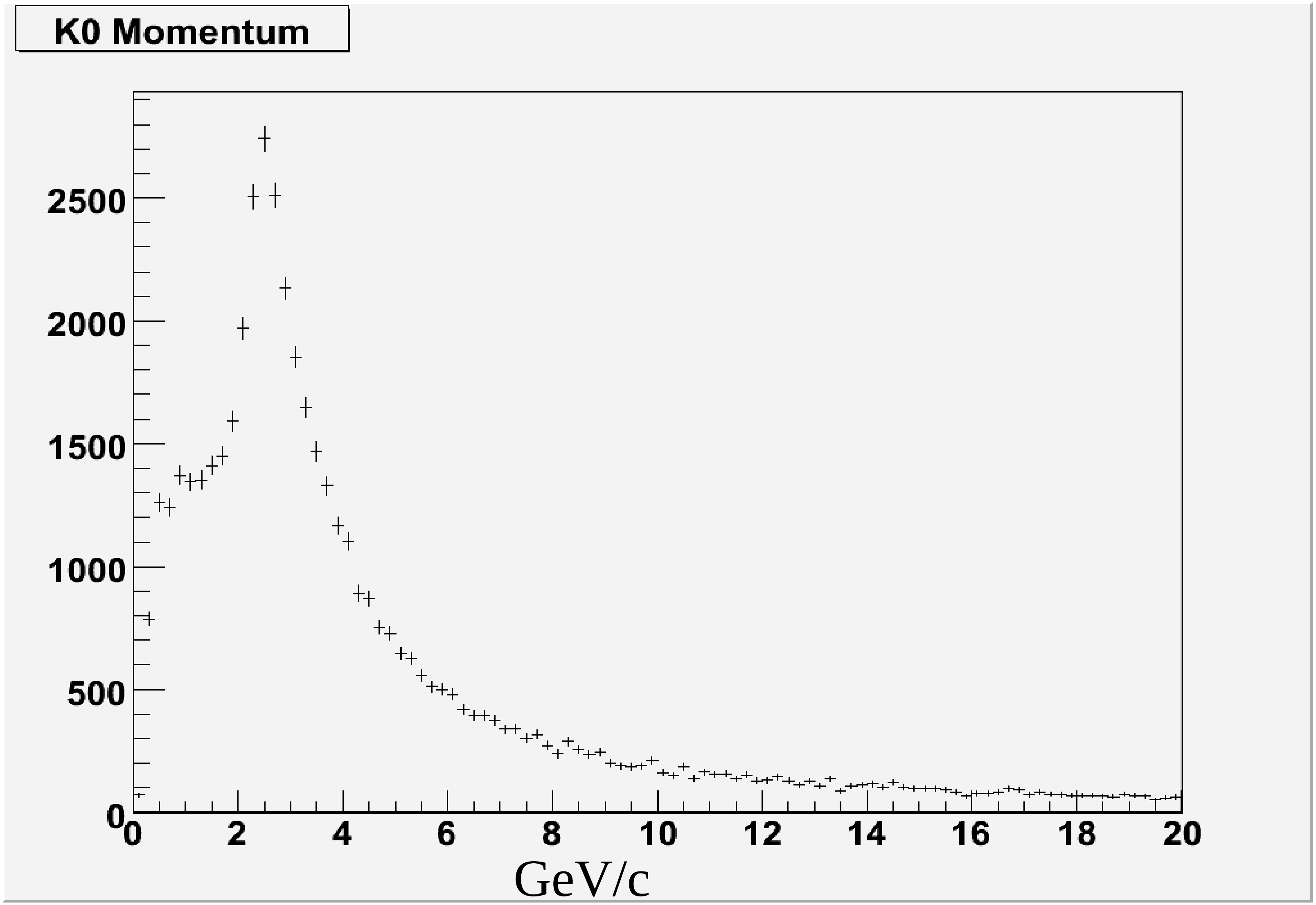


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
p+π- Momentum [GeV/c]
p+π- Inv. Mass [GeV/c2]

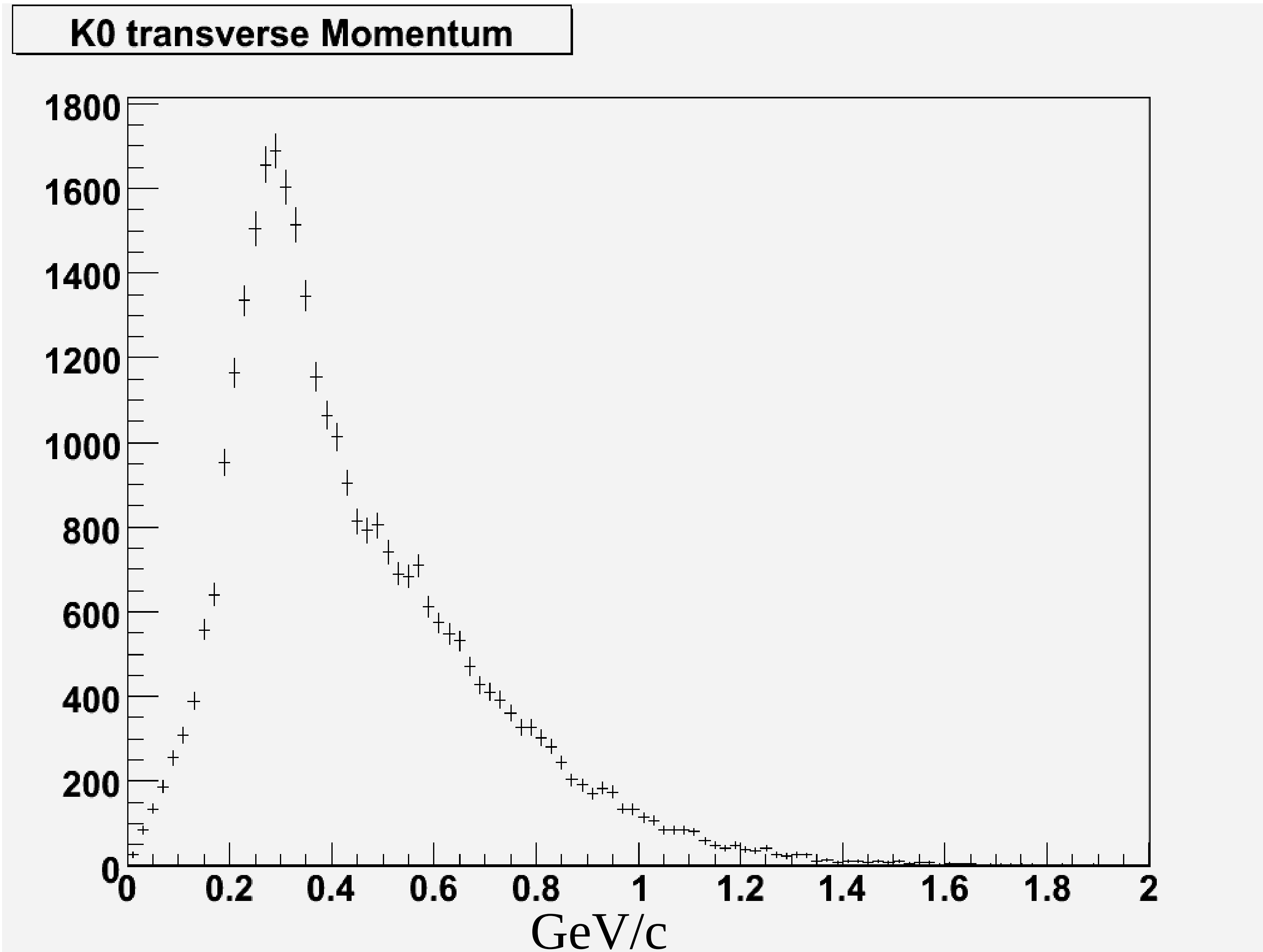
Selecting K^0 from Box



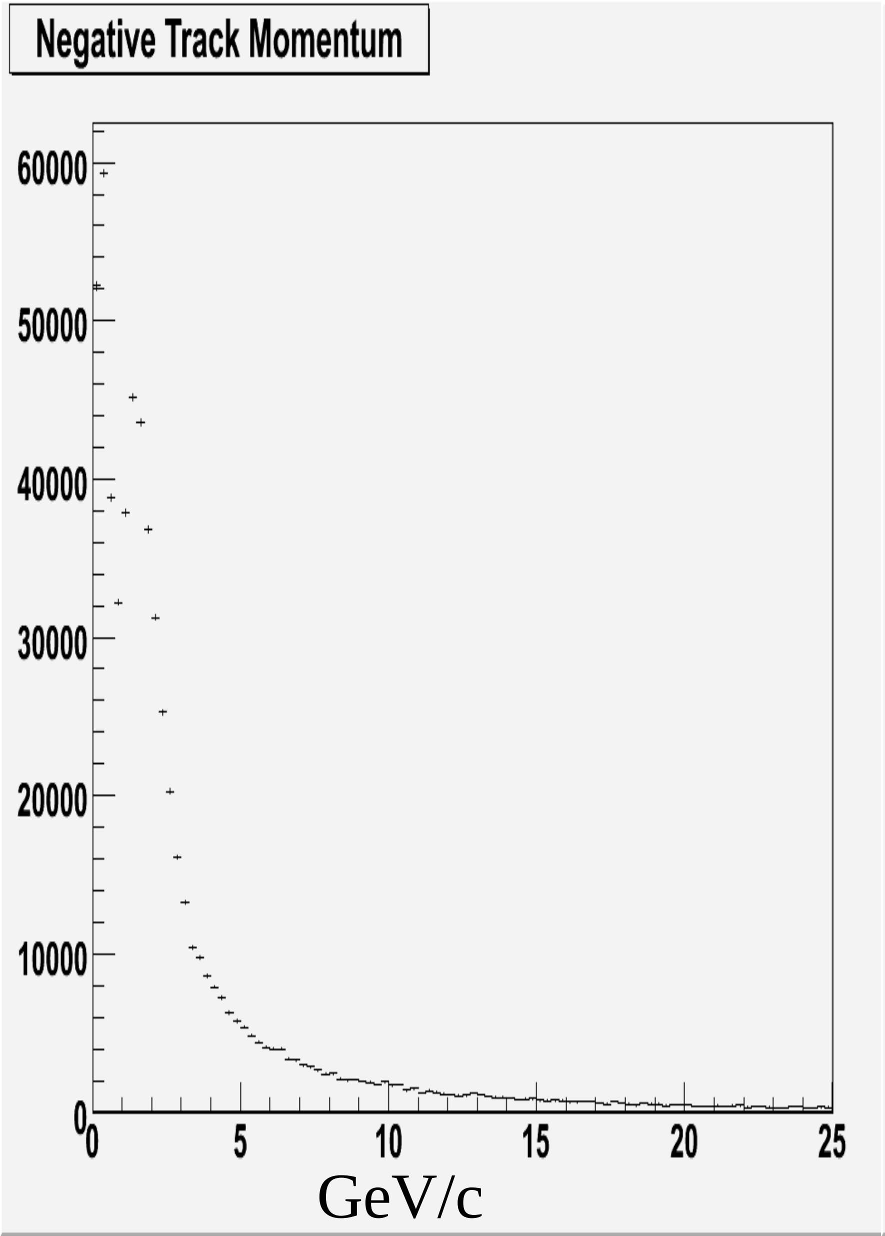
K^0 momentum, i.e. sum of pair.

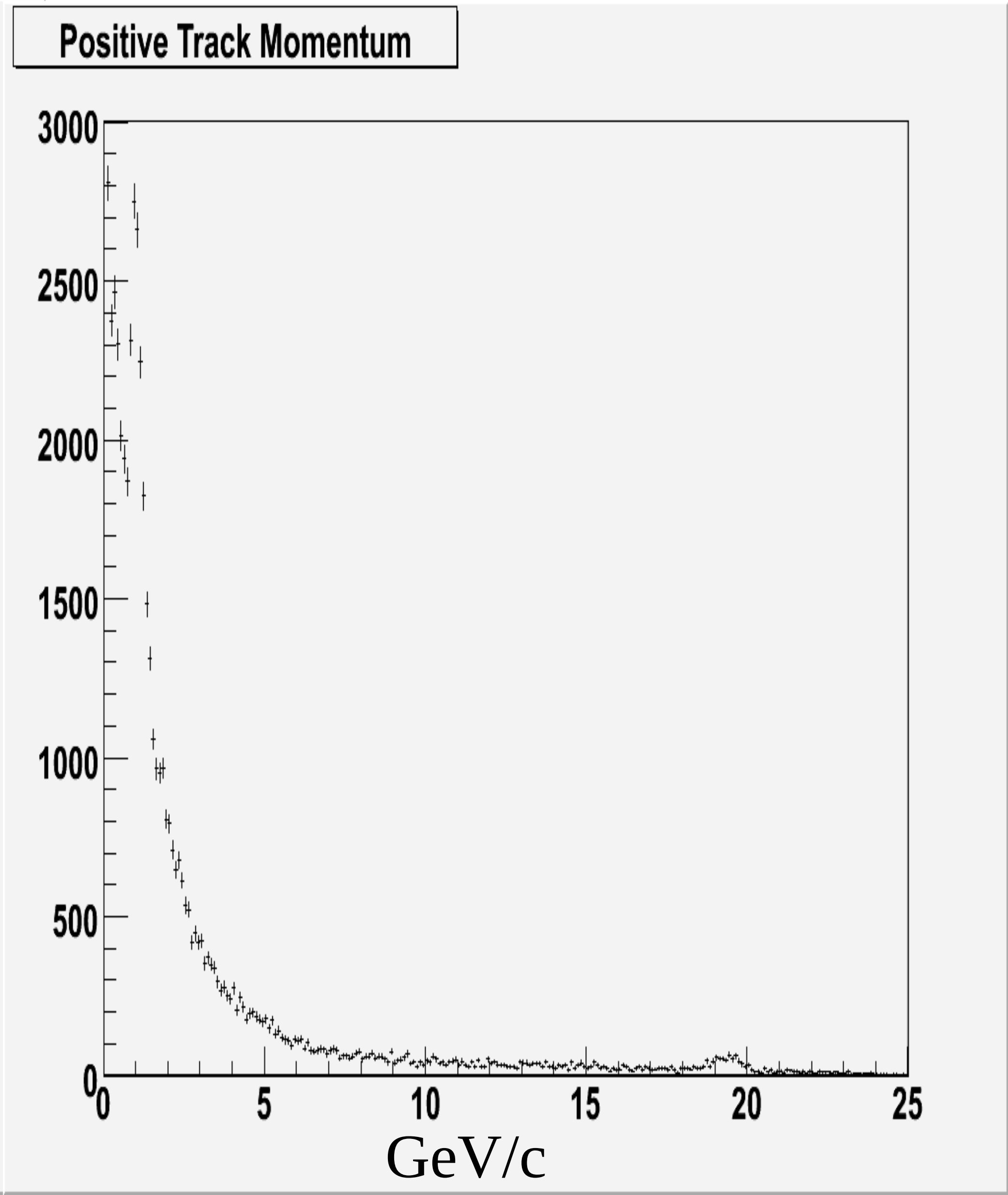


K^0 transverse momentum

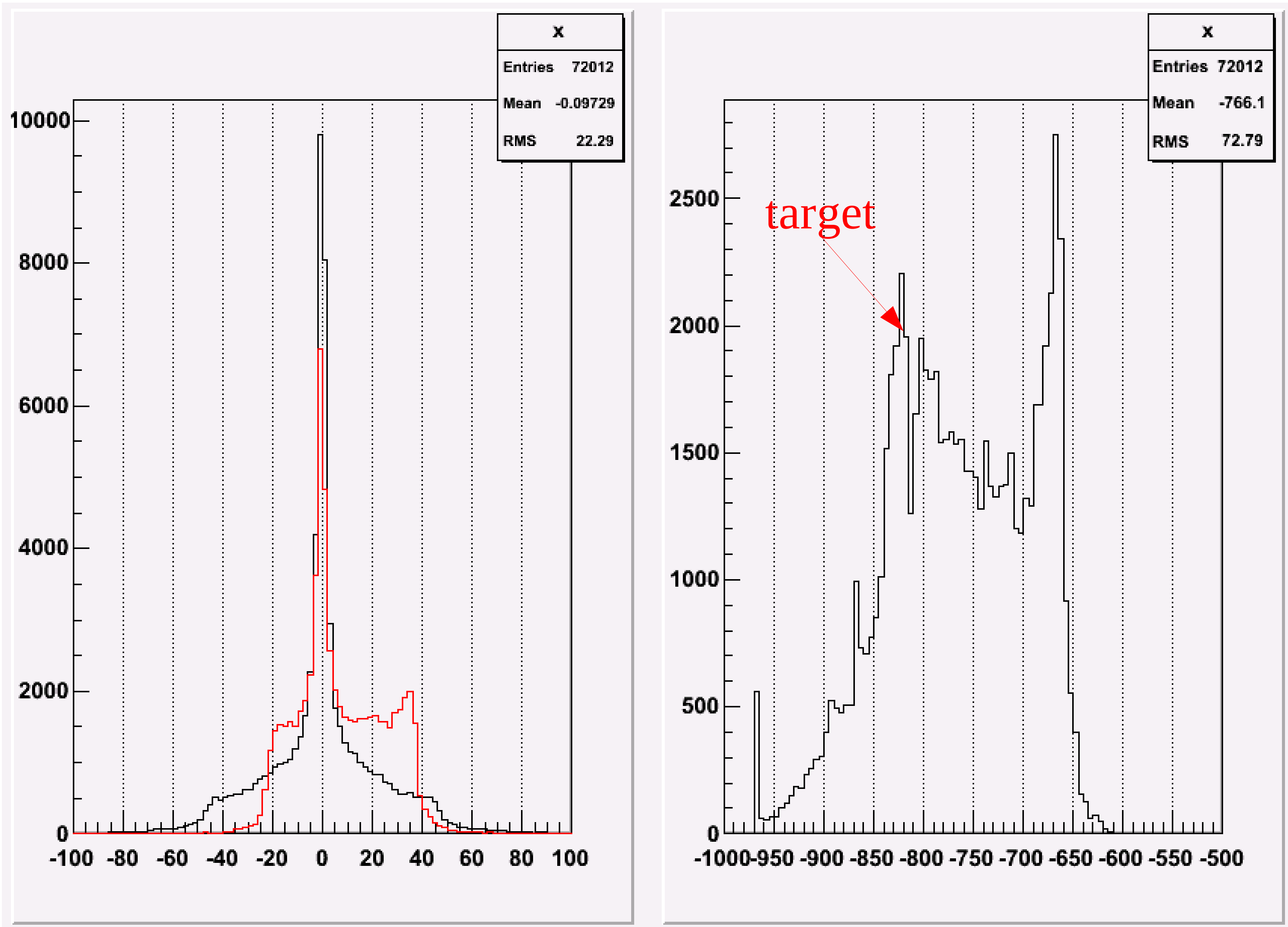


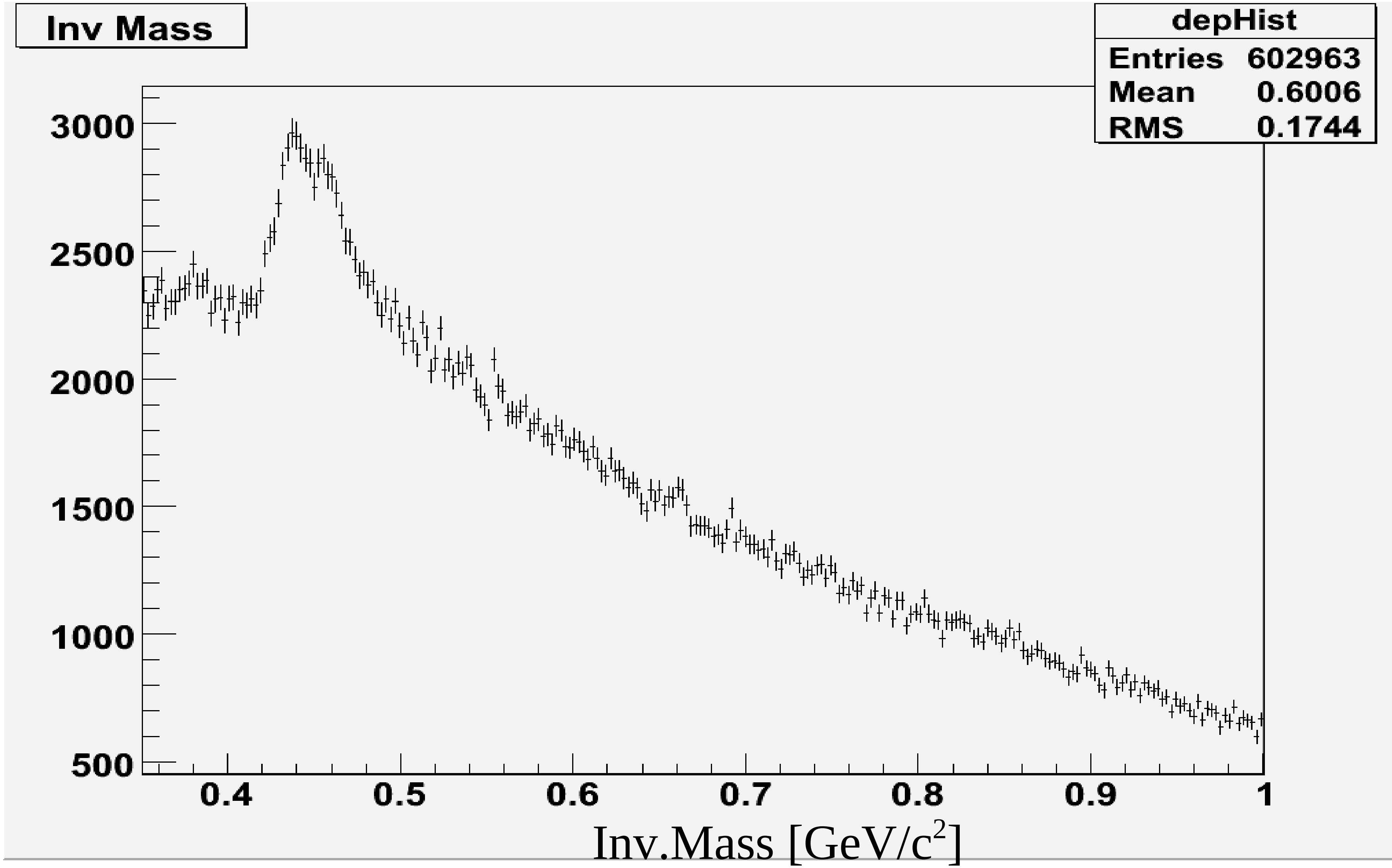
Positive and Negative Track momentum





Vertexes of the tracks, needs more work





Problem: Adding more data from end of run after the JGG magnet short, noticed the K^0 mass peak shifted upwards. Have to study correction to magnetic field to correct.

Conclusion:

- We see both K^0 and Λ^0 decays.
- Magnetic field needs some improvements
- These K^0 decaying into $\pi^+\pi^-$ can be used for DCkov calibration.
- Need to get the vertexing working to be completely useful plus want the p_x,p_y,p_z of each track inbetween the two magnet and downstream in field free regions.