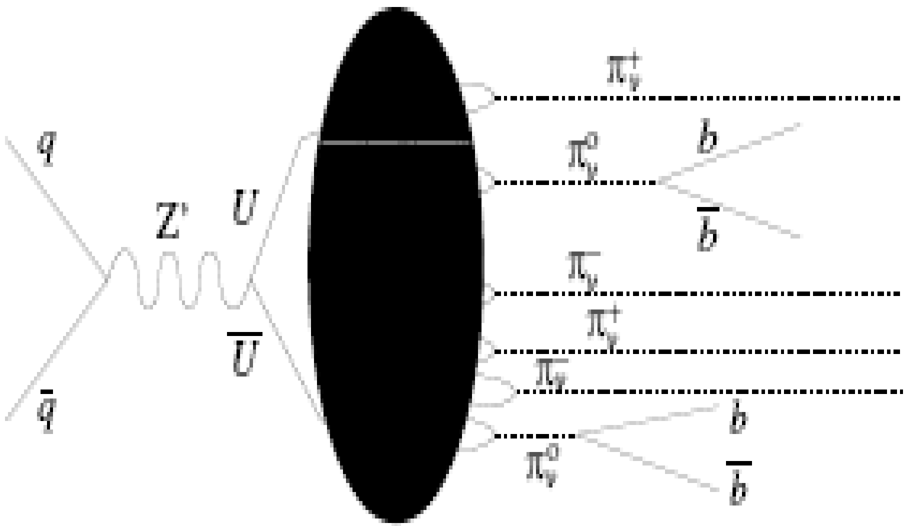
Search for NLLP->bb

- Several models predict long-lived neutral particles that decay with a "weak-scale or above" lifetime
- These particles are often scalars, and so would couple preferentially to massive particles (where kinematically allowed)
- M. Strassler, from the University of Washington, has been pushing these models heavily lately
  - "Hidden Valley" models, a strongly coupled gauge group, weakly-coupled to the SM: hep-ph/0604261
  - Higgs which mix with a stable scalar: hep-ph/0605193
  - NMSSM SUSY Models
- Signature:
  - A "mega" secondary vertex
  - Either another "mega" vertex on the other side, or mET from the escape of a particle past the calorimeter
    - Depends on the NLLP lifetime
- A "mega" secondary vertex is a bbbar vertex pair, far from the PV
  - Either one vertex with many tracks (>=6?) or two nearby vertices with a few tracks each
  - Muons, from the b's (good for triggering)
- An interesting "final-state" which has not been carefully explored before experimentally!



This is a "v-hadron" event, with a long-lived v-pion.

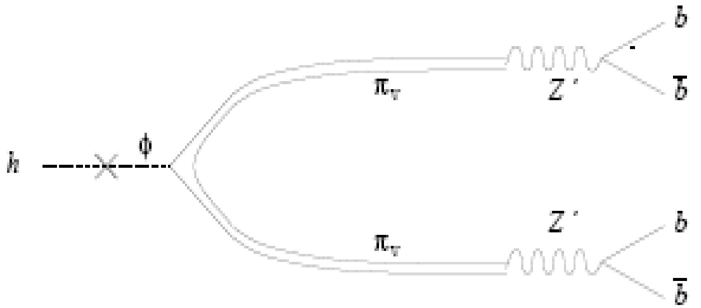


FIG. 1: Higgs decay to v-hadrons, each of which decays to $b\bar{b}$.

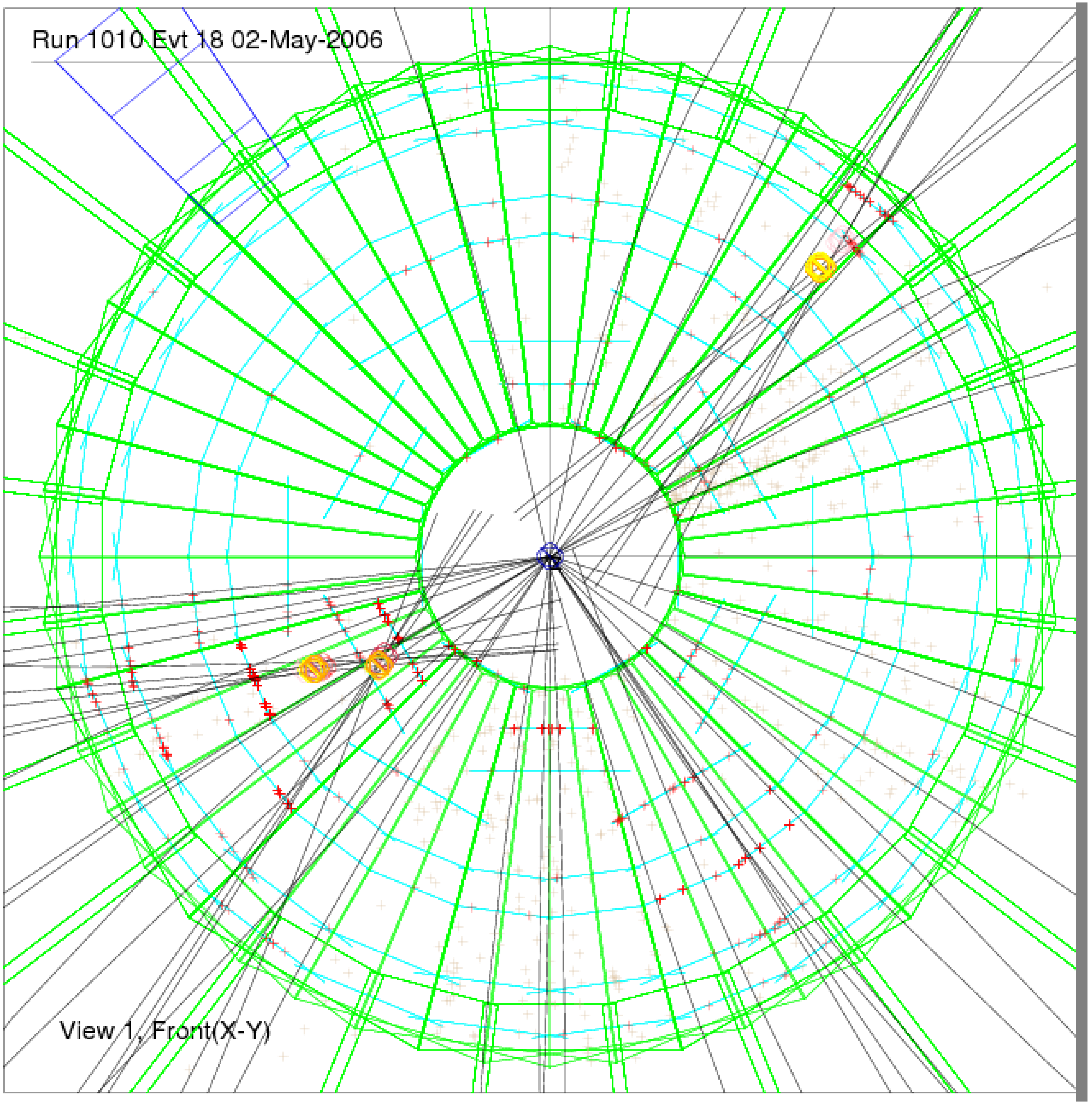
NLLP->bb MC

First, I made some MC events, to get a feel for what these things would look like at D0

I made H->Z(->bb)Z(->bb), and adjusted mH, mZ, and the Z lifetime

This is an example of mH=200 GeV, mZ=40 GeV and ctau_Z=50mm

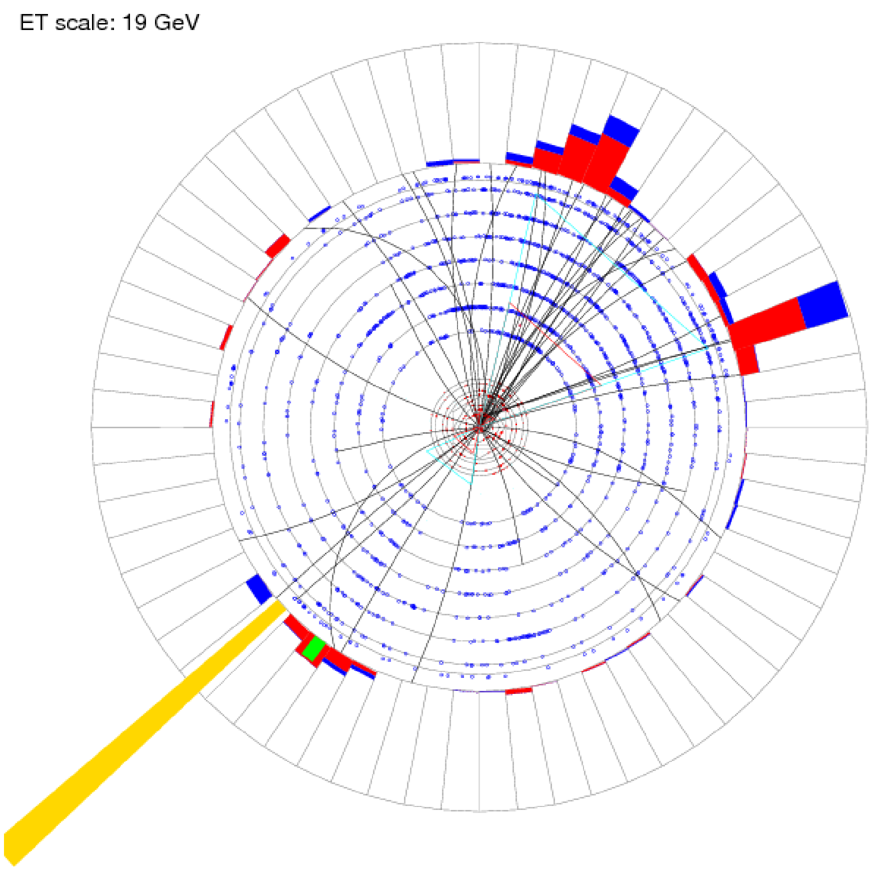
Note the one mega vertex, and the opposite side nearby vertex pair

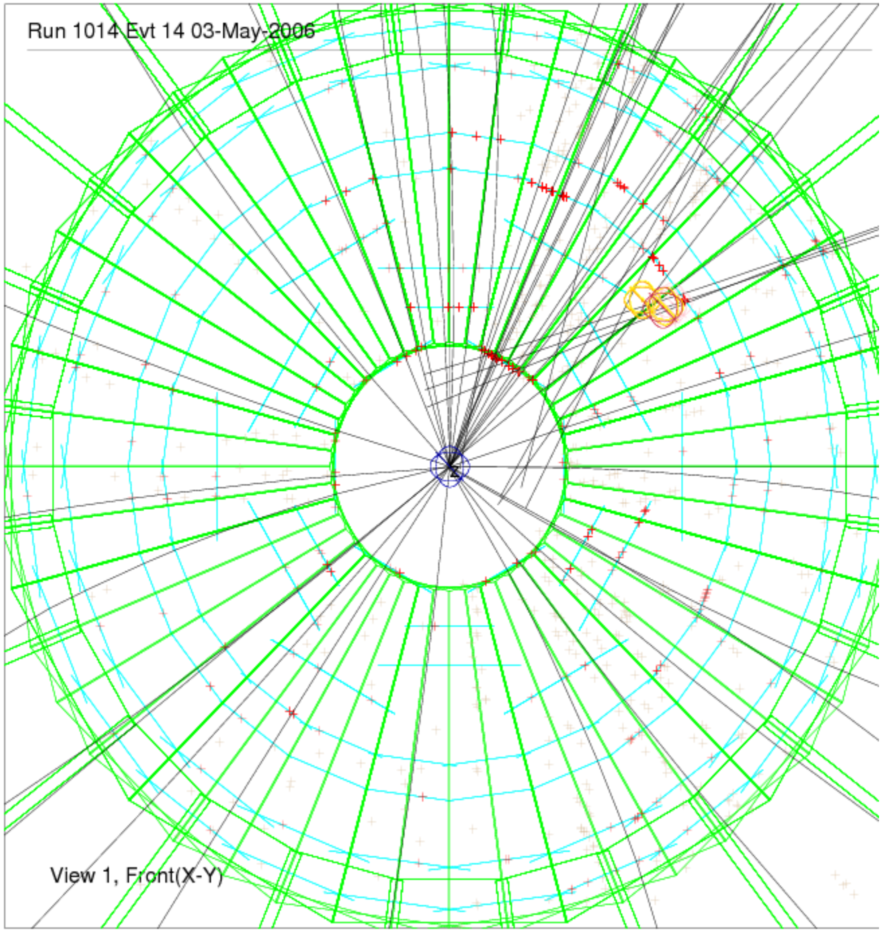


Columbia University
In the City of New York

This is with H=200 GeV, *Z*=40 GeV and ctau_*Z*=*500* mm

There's some chance of having one mega vertex in the tracker, and another decay outside the tracker, giving large mET in the opposite direction (as measured possibly in the Cal, the track-mET, or both)





Data / Reconstruction

I adjusted the vertexing parameters, from dxy<0.15 cm to 3cm and dz<0.4cm to 10cm

Also had to remove a hard cut I discovered (in a .cpp file!!!) that only considered seed vertices in Lxy<2.6 and Lz<5

We can reconstruct these types of "mega-ip" vertices with decent efficiency

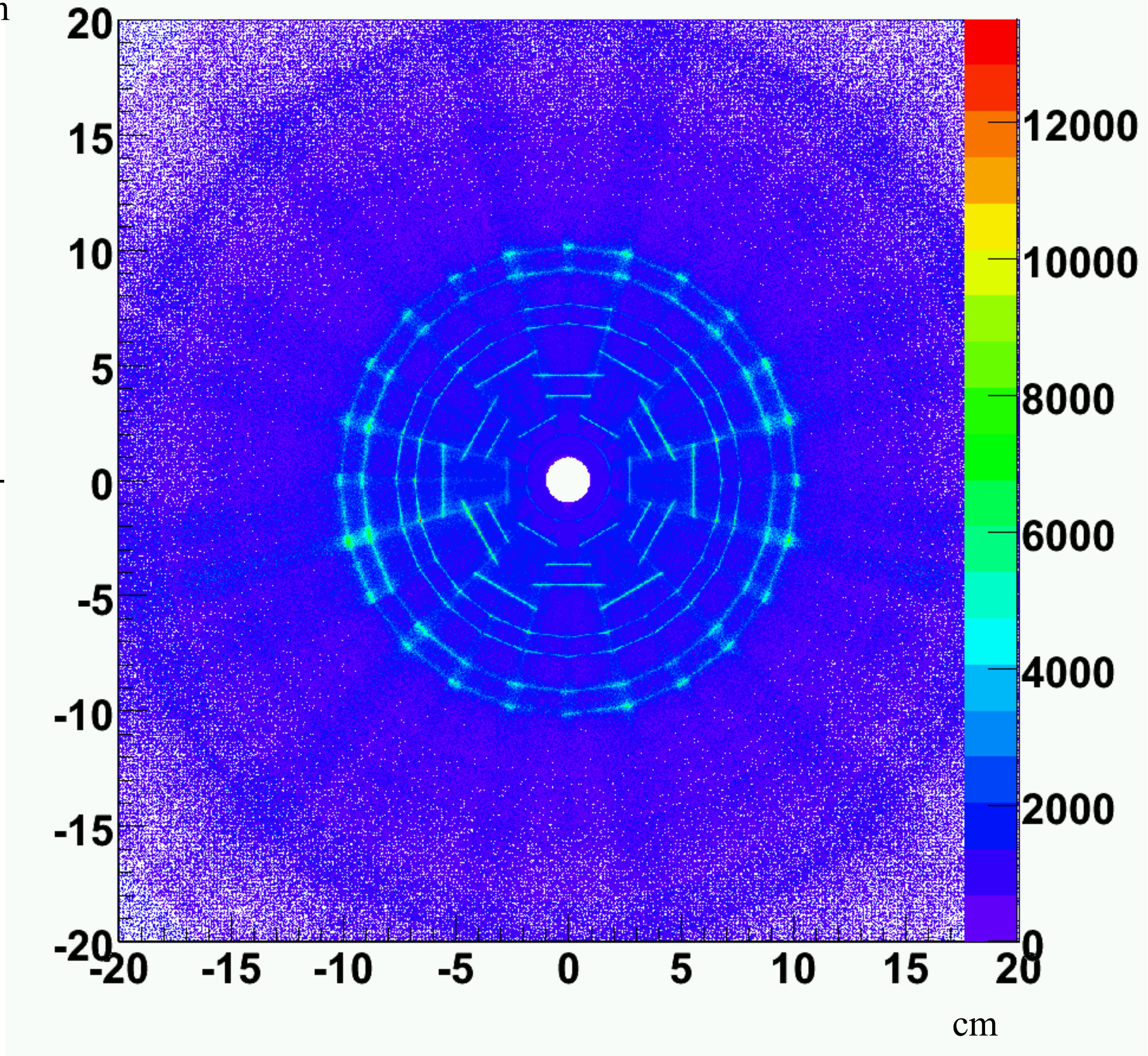
Muons are available for triggering (from the 4b's)
- Plenty of triggers are available which require a non-track-matched muon and jets -> in place for Z->bb

I've processed the p17 1/fb "BID_SKIM" dataset with this "loosened" vertexing

Here's where the "far" vertices are in the data...

Obviously, interaction of outgoing particles with material is a dominant effect at large radius

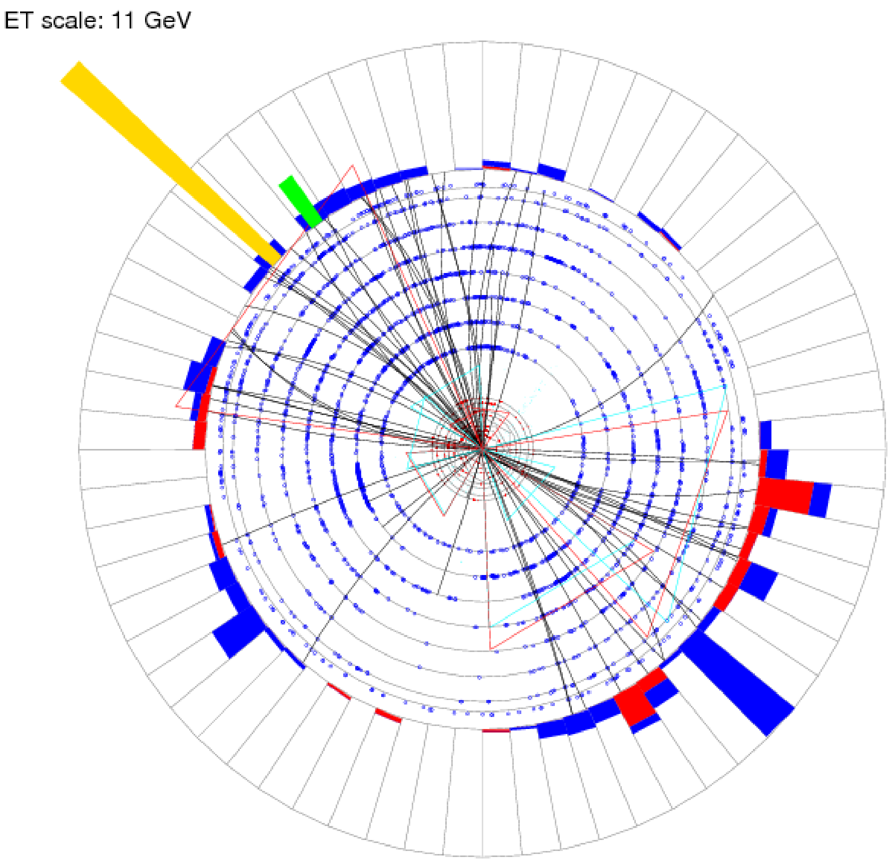
It's not just photon conversions, there's also vertices with >6 tracks!
- inelastic nuclear scattering?

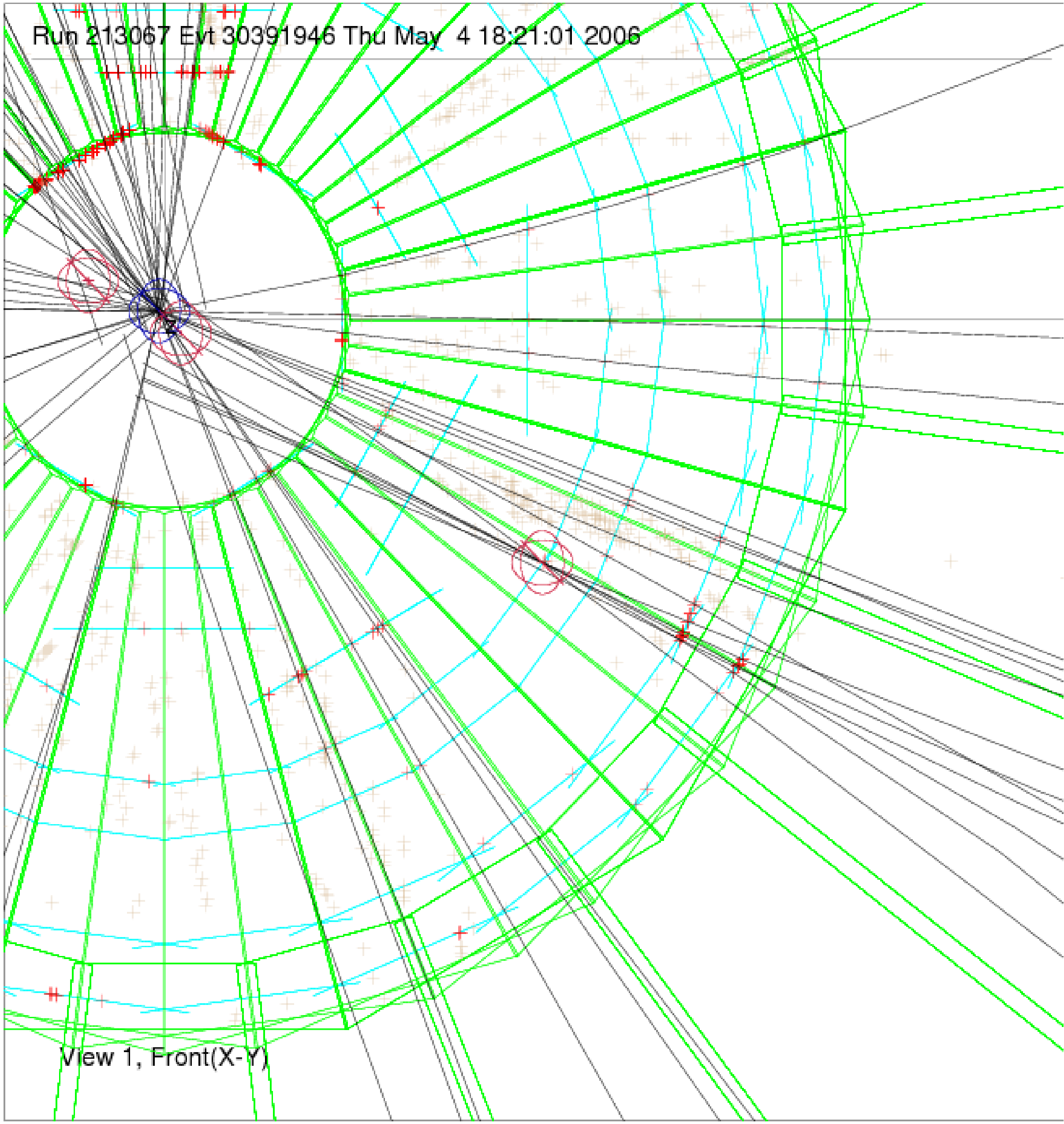


XY vertex density * radius^2

A data event

Plenty of "interesting" events, a "mega-ip" vertex:
- multiplicity >=6 tracks
- radius (2d decay length) > 5cm
- chi2/ndof < 25
- mass > 5 GeV



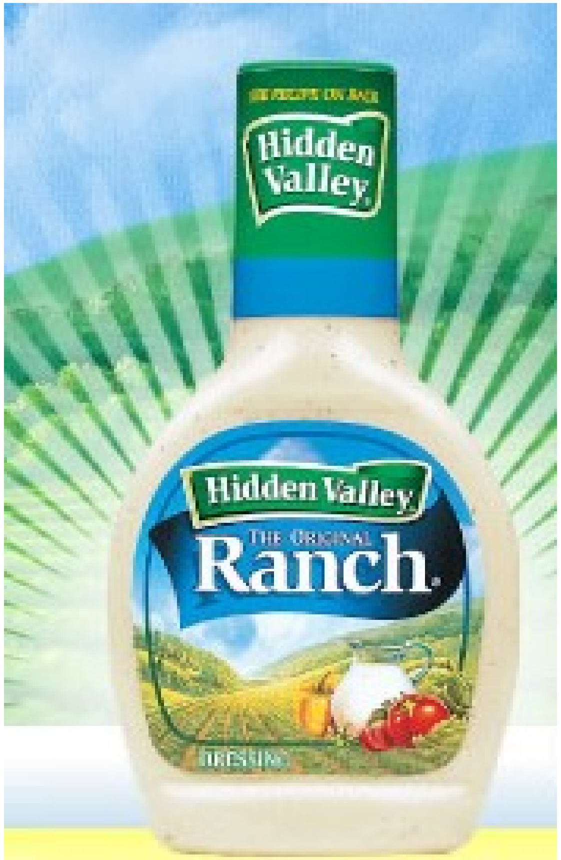


Analysis Plan

- 1) Measure the rate to have a vertex-type
- 2) See how the rate changes after requiring
  an (opposite-side?) mega vertex
  or large (opposite-side?) missing ET
- These two branches are sensitive to different NLLP lifetimes
- Optimize the vertex requirements (by studying signal MC vs. background from data)
- Determine signal efficiency from MC
  - Difficult part of course is correcting the simulation to match the performance in data, measure uncertainties, etc.
- See if we really live in a world with Hidden Valley

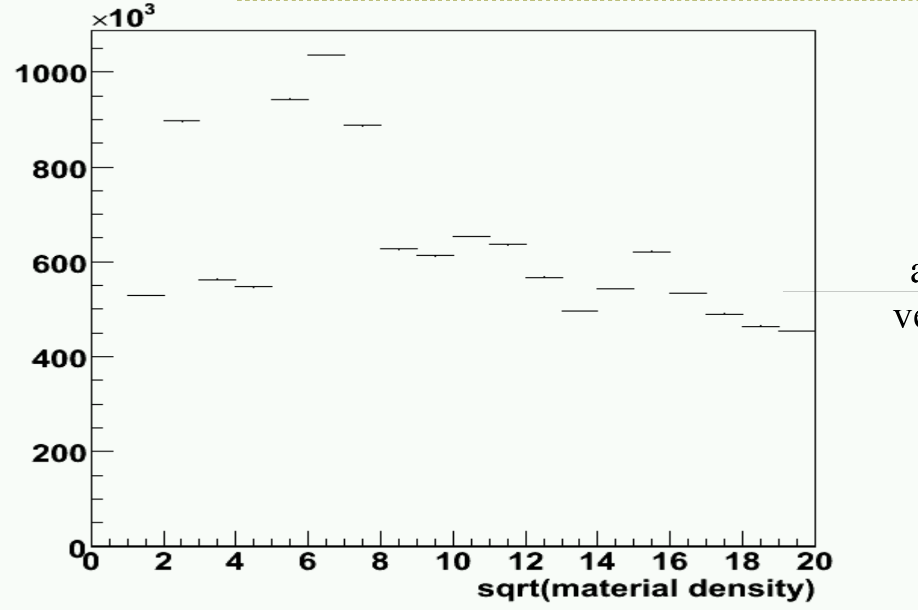
Extra way to increase S/B:

- Determine the material distribution -> the x-ray plot
- Separate the vertices by the probability to have a material interaction at that location (as measured using the x-ray plot)
  - material interactions (background) occur in material
  - signal vertices don't know where the material is

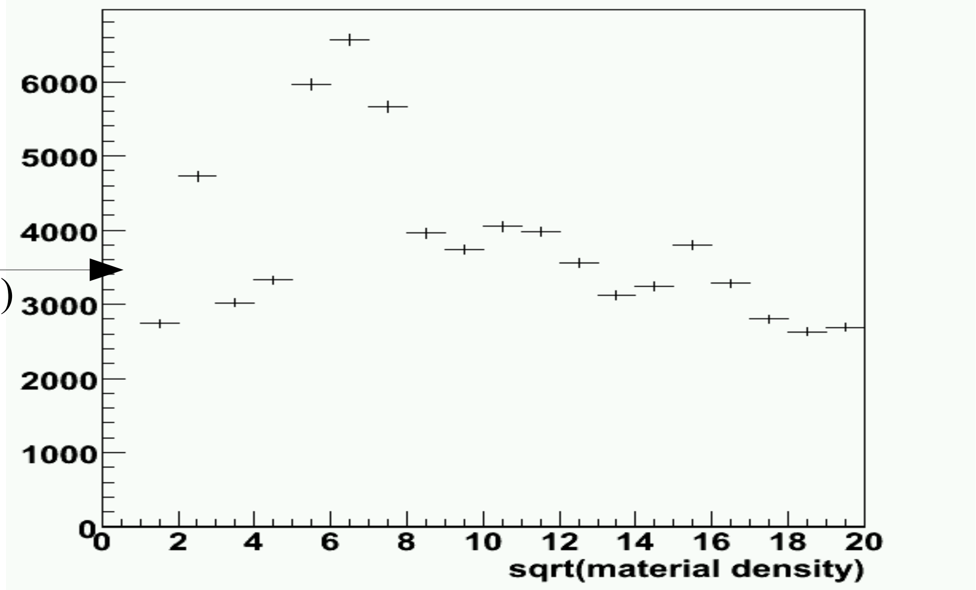


?

2-track vertices



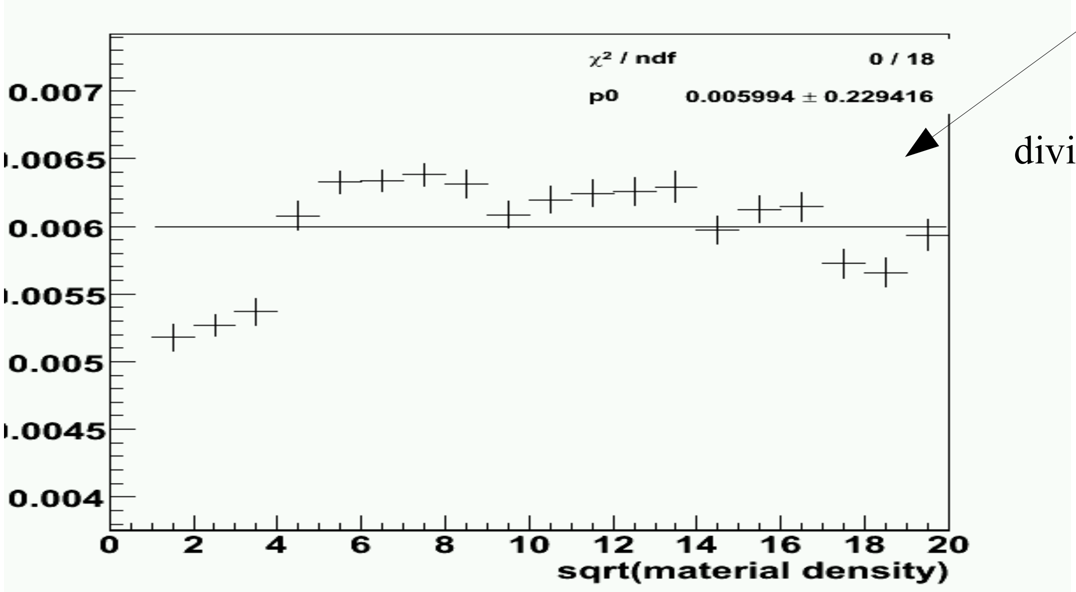
after a “mille” vertex (3 tracks)



About 0.5% of events with a distant vertex have an additional “mille” vertex.

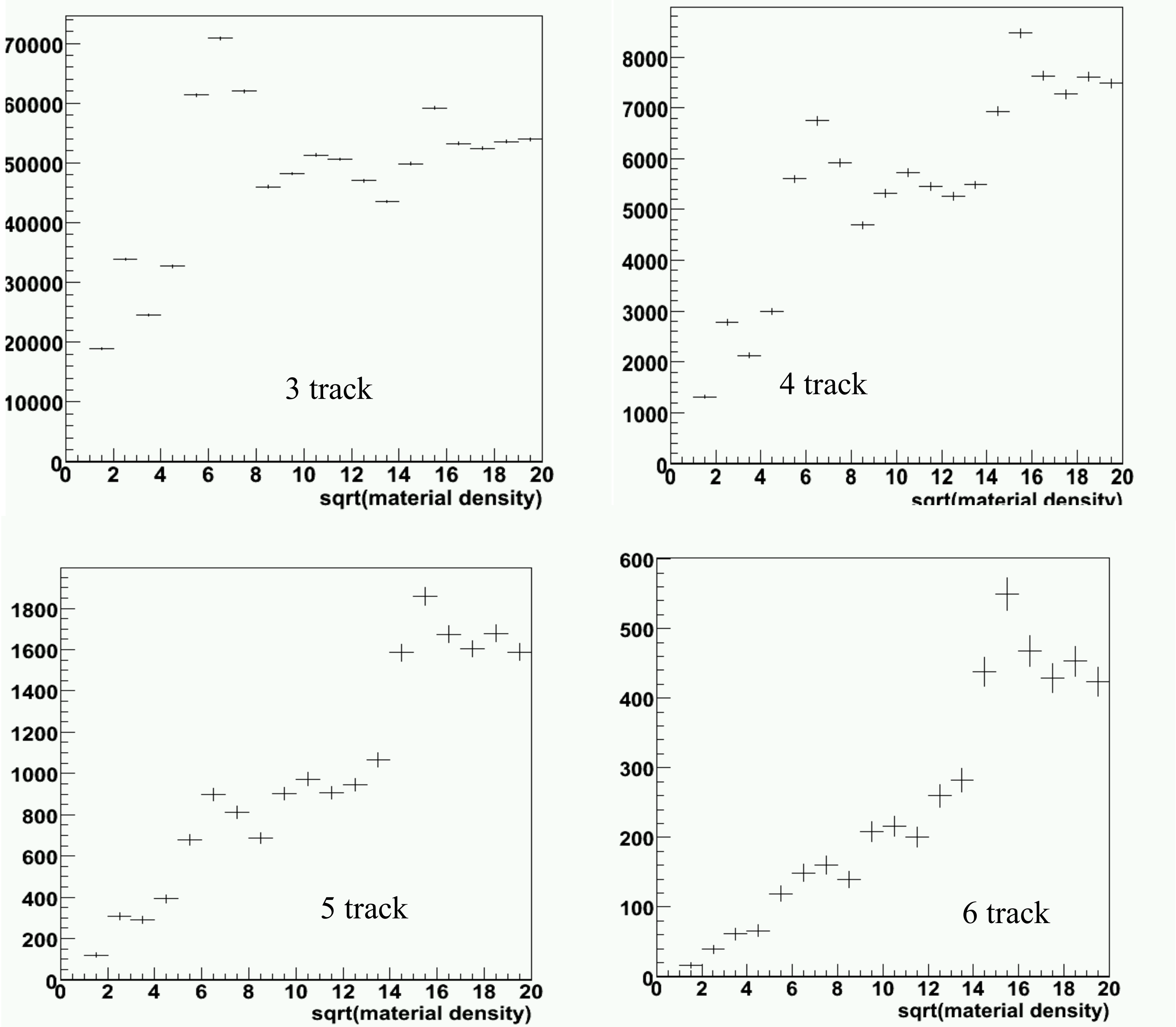
This is a measure of the “random background”.

Background level is roughly independent of material density region, as expected.



divided...

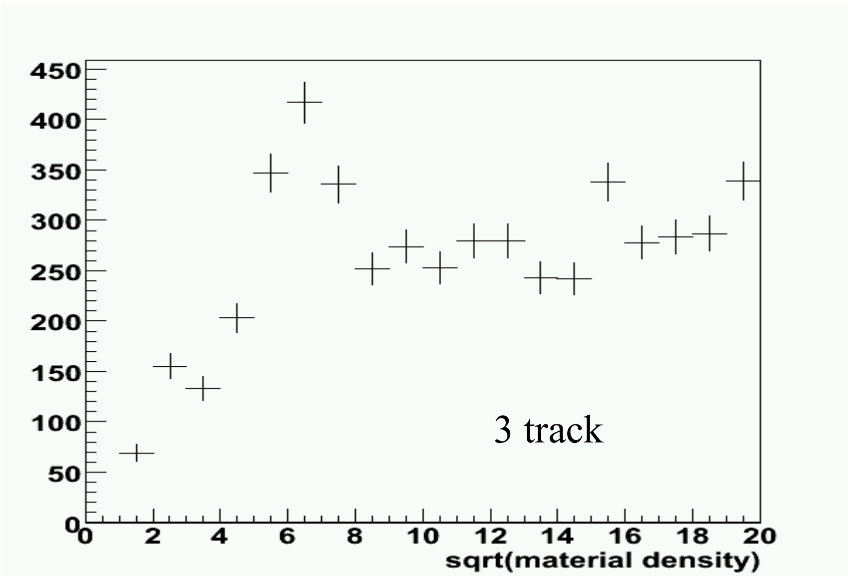
Data Vertices

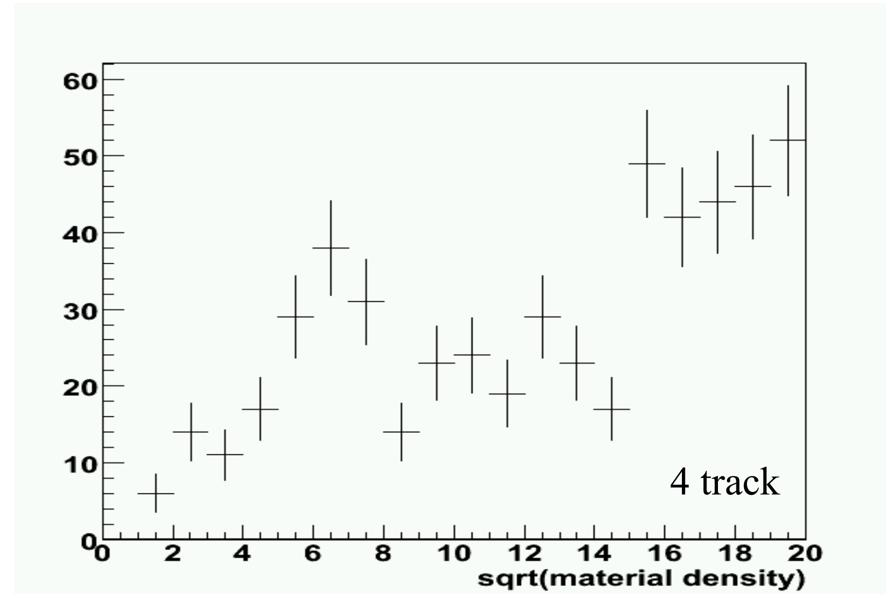


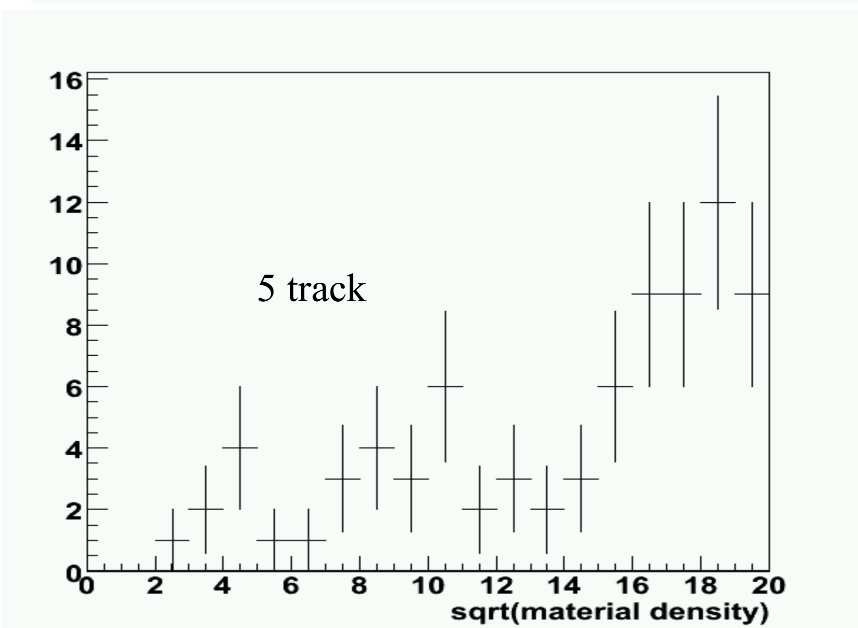
Bigger vertices tend to be in denser material.

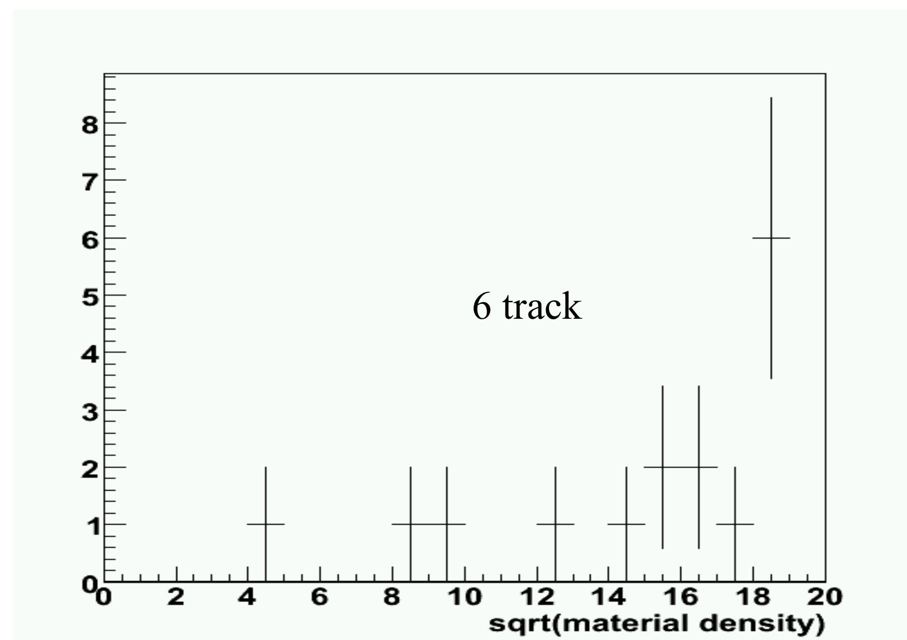
Less fakes?
Less decays in flight?

Data Vertices after a “mille”

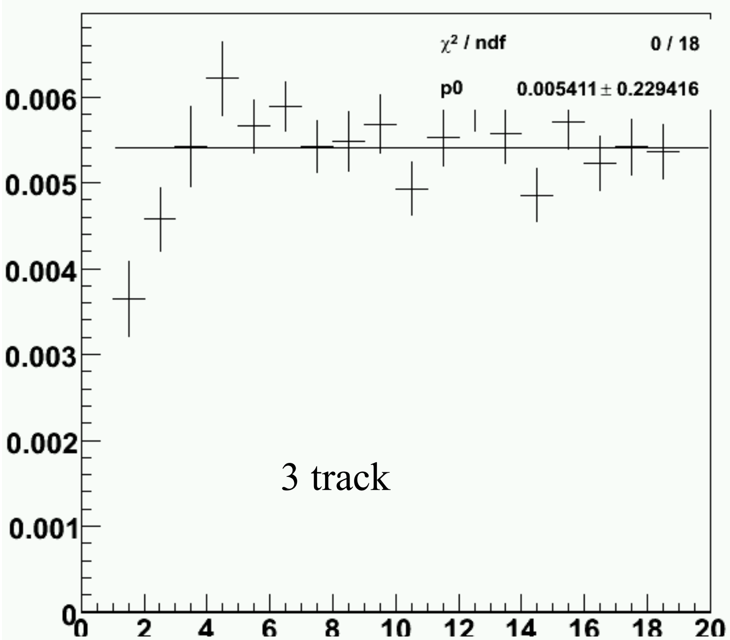


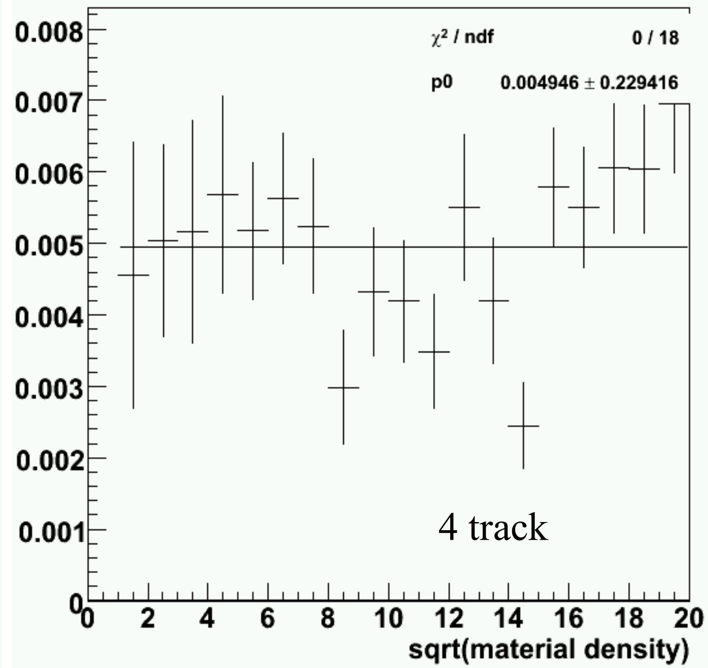




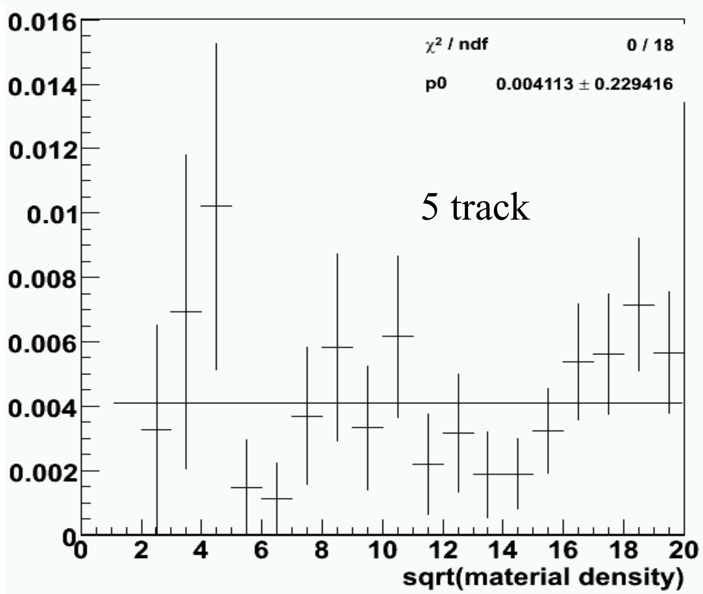


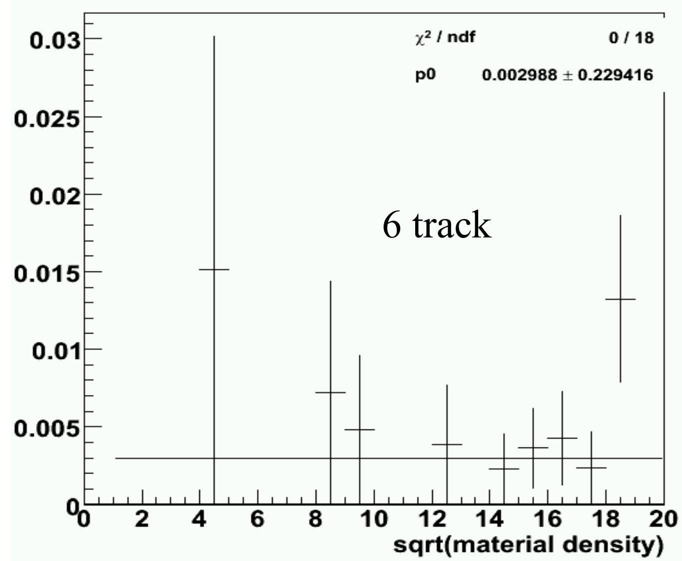
Background levels in data



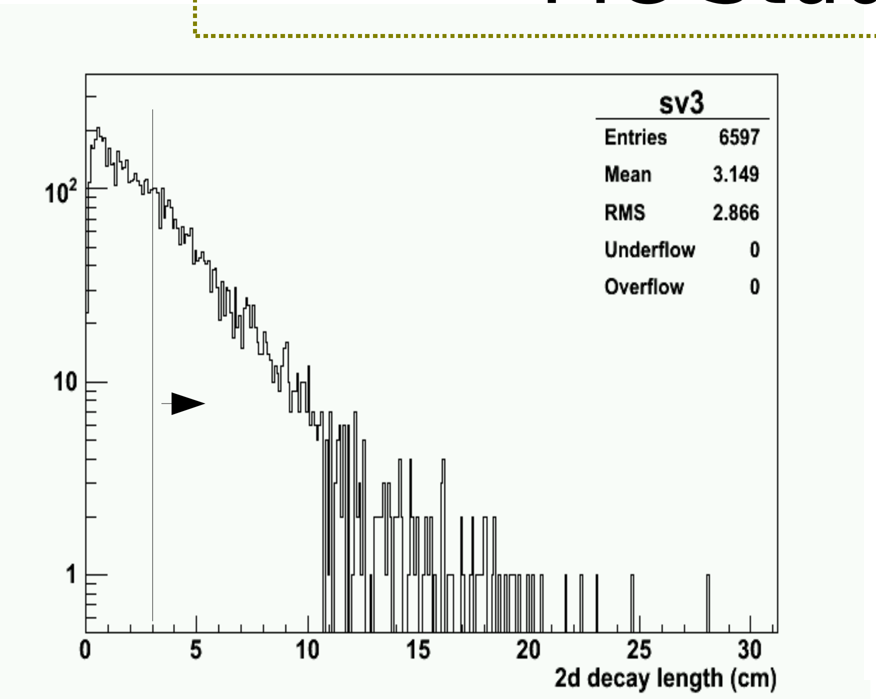


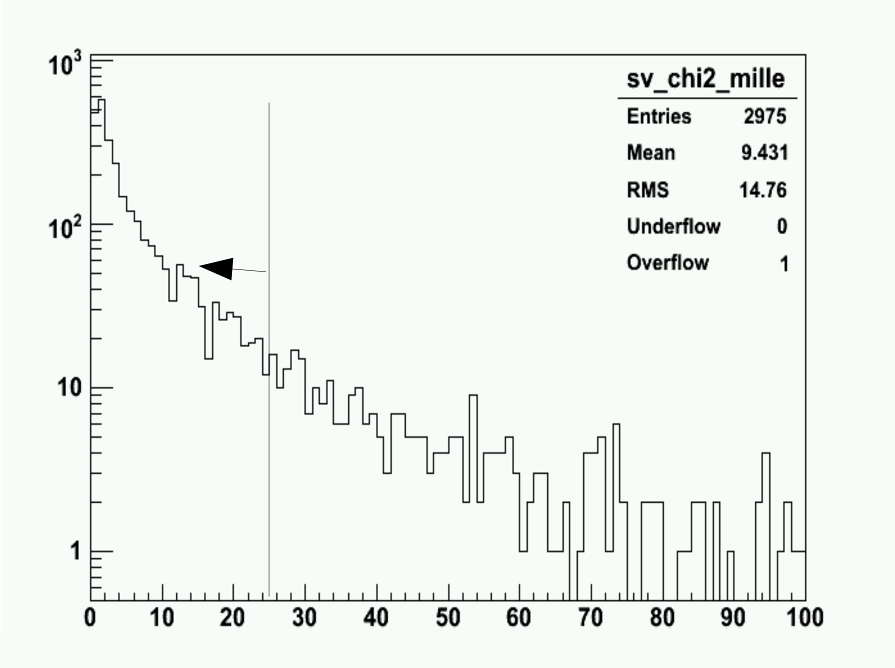
Slight decrease in fraction of events which have an additional "mille" vertex as the vertex track multiplicity increases...

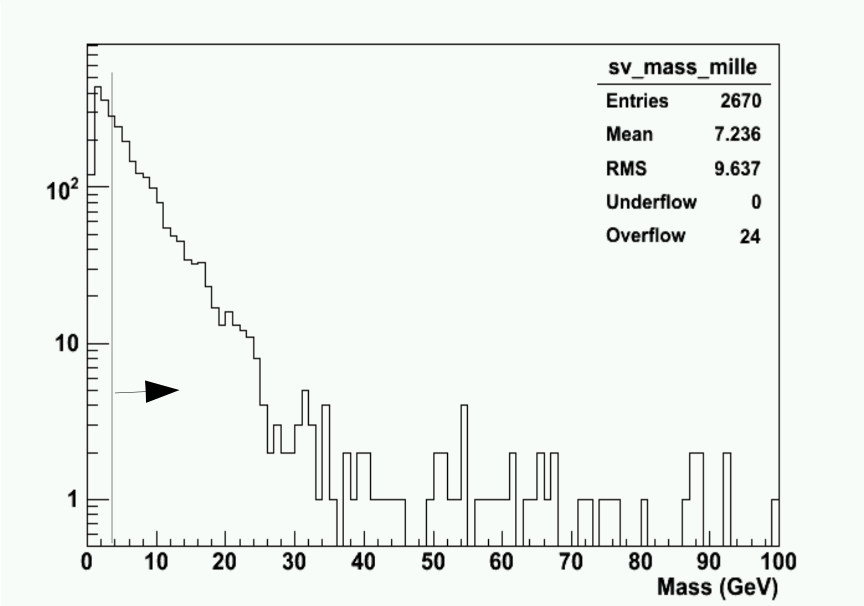


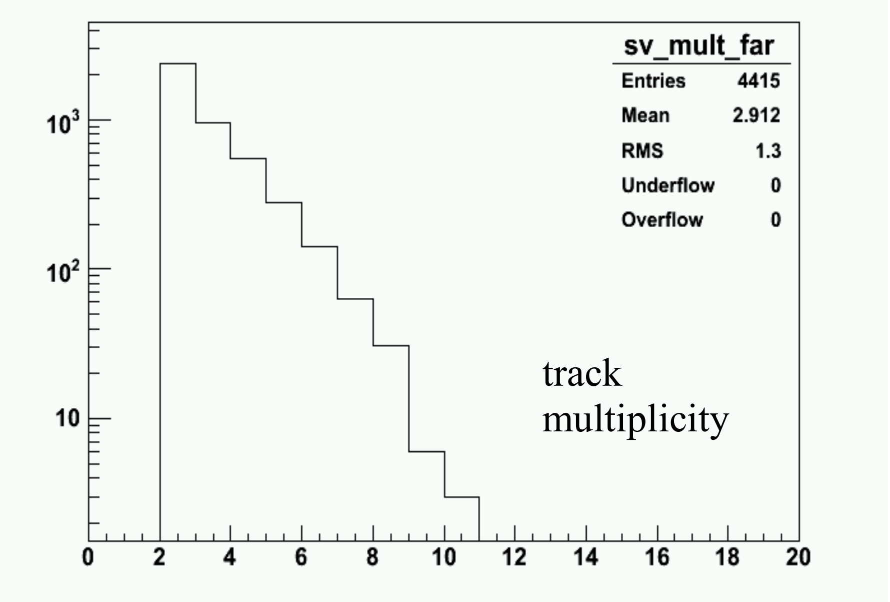


MC Studies of Distributions





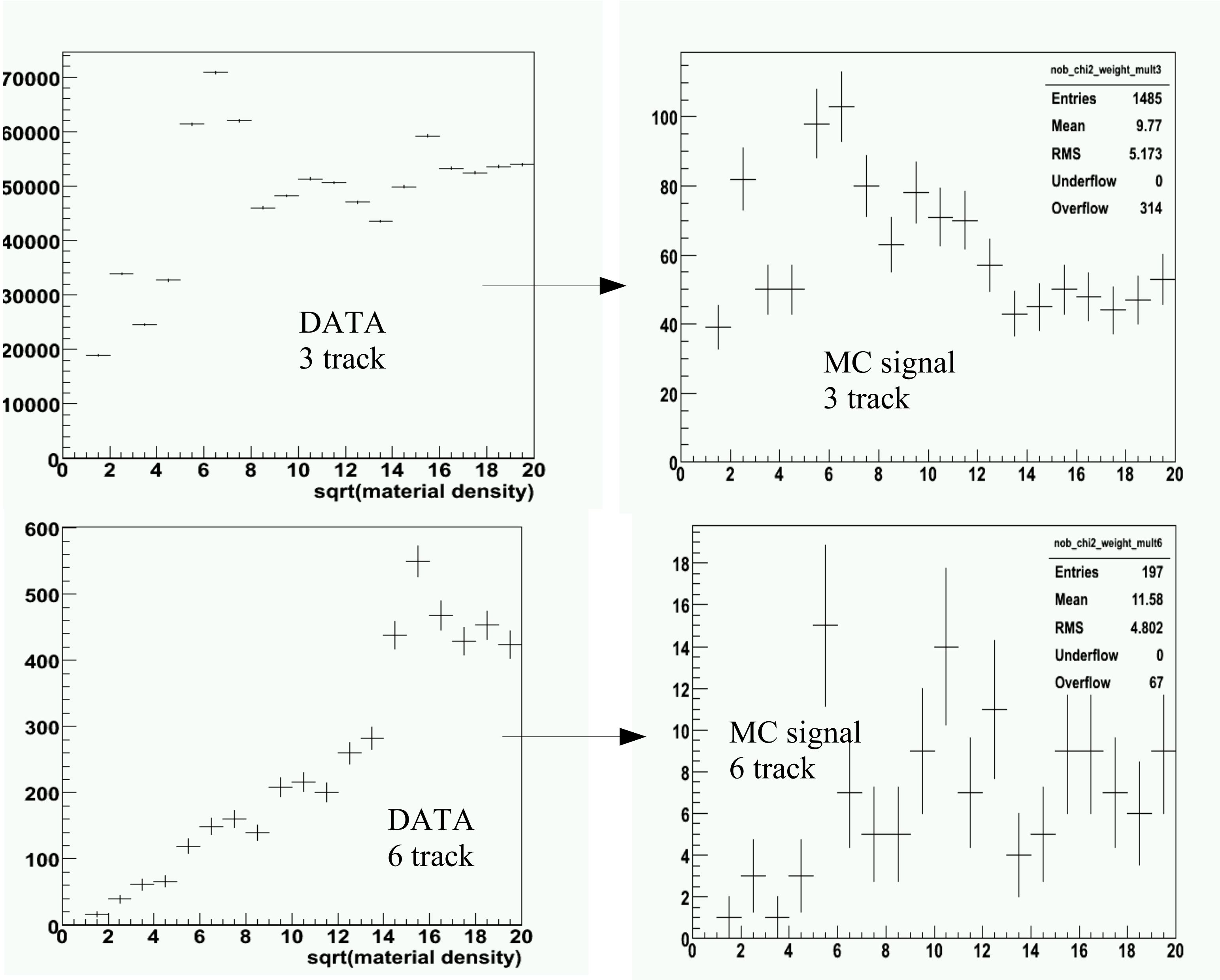




MC Signal Vertices

More signal vertices in low material density regions, as expected...

especially for large vertices.

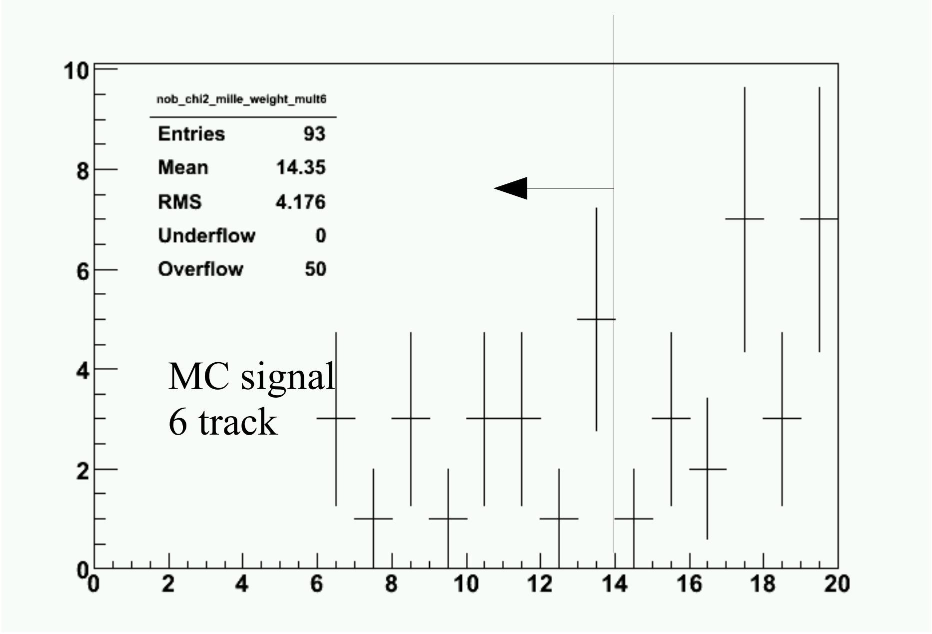


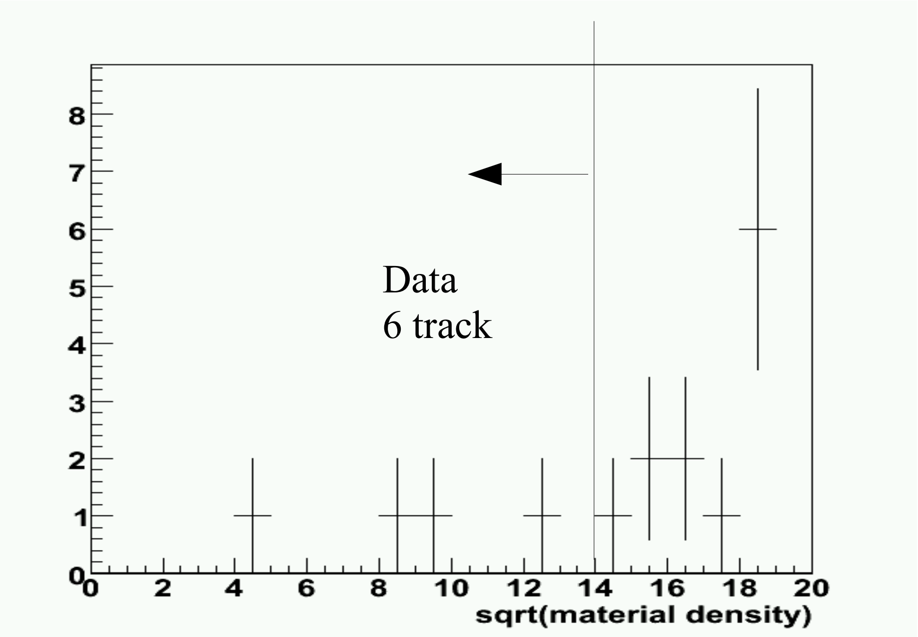
Data to MC Signal Comparison

Signal would show up as an excess of events with a large vertex and a “mega” vertex.

Cuts are still very non-optimal!

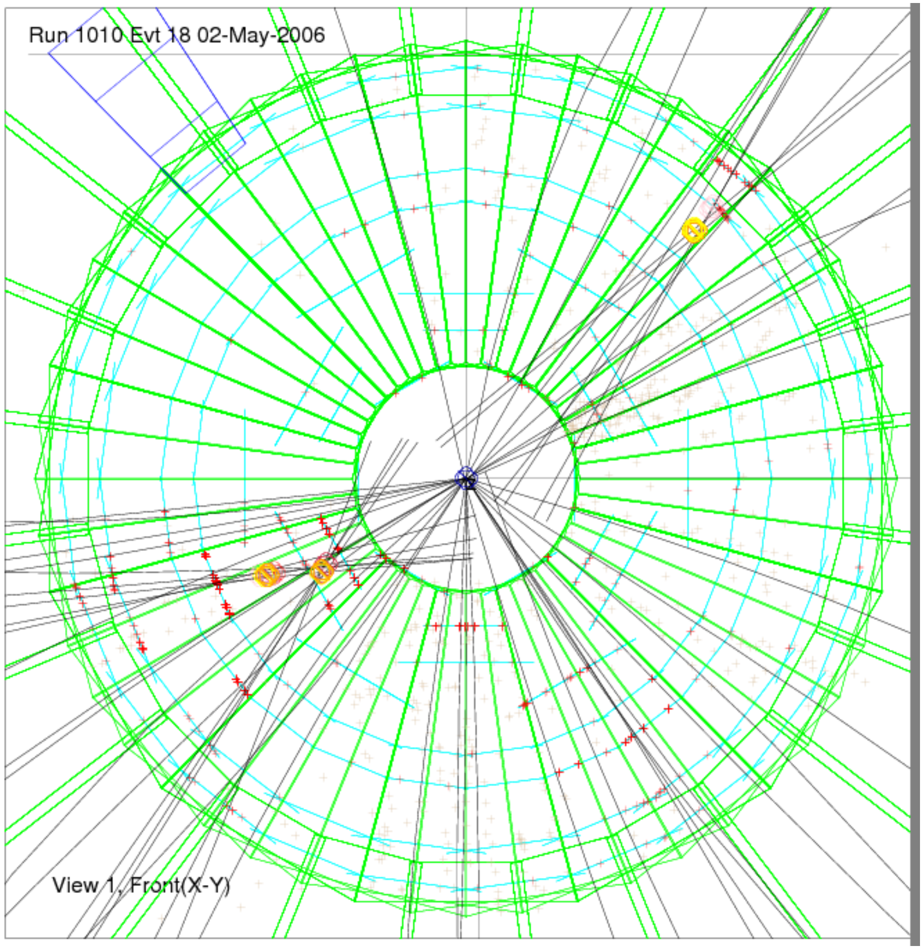
We are sensitive to a signal of 10,000 h->LL->bb,bb events already.





Conclusions

- Long-lived neutral particles decaying to bbbar are a plausible new phenomena that have never been searched for
- We can reconstruct bbbar vertex pairs at large radius (up to ~20cm) *after some fixes*
- Have processed the full p17 muon+jet dataset
- Have generated ~20,000 events of signal MC
- Many properties of the backgrounds have been understood in data (shown previously, in backup slides)
- An analysis strategy is in place, based on correlations between large vertices or a large vertex and large mET
- Material locations have been measured, and can be down-weighted to increase S/B
- Analysis is roughly sensitive to a signal of 10,000 events, depending on lifetime
- Still highly unoptimized!

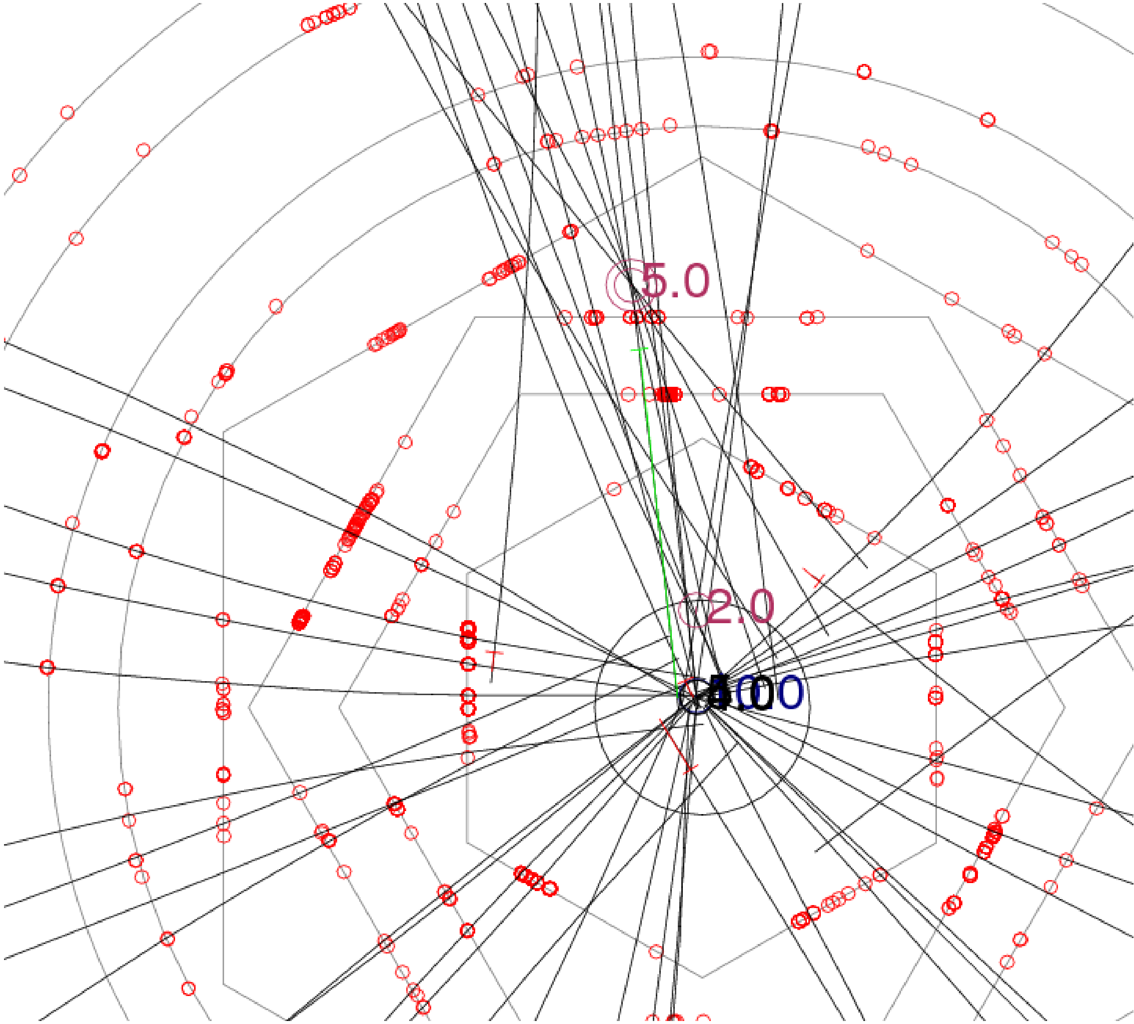


Backup

Muon Matching

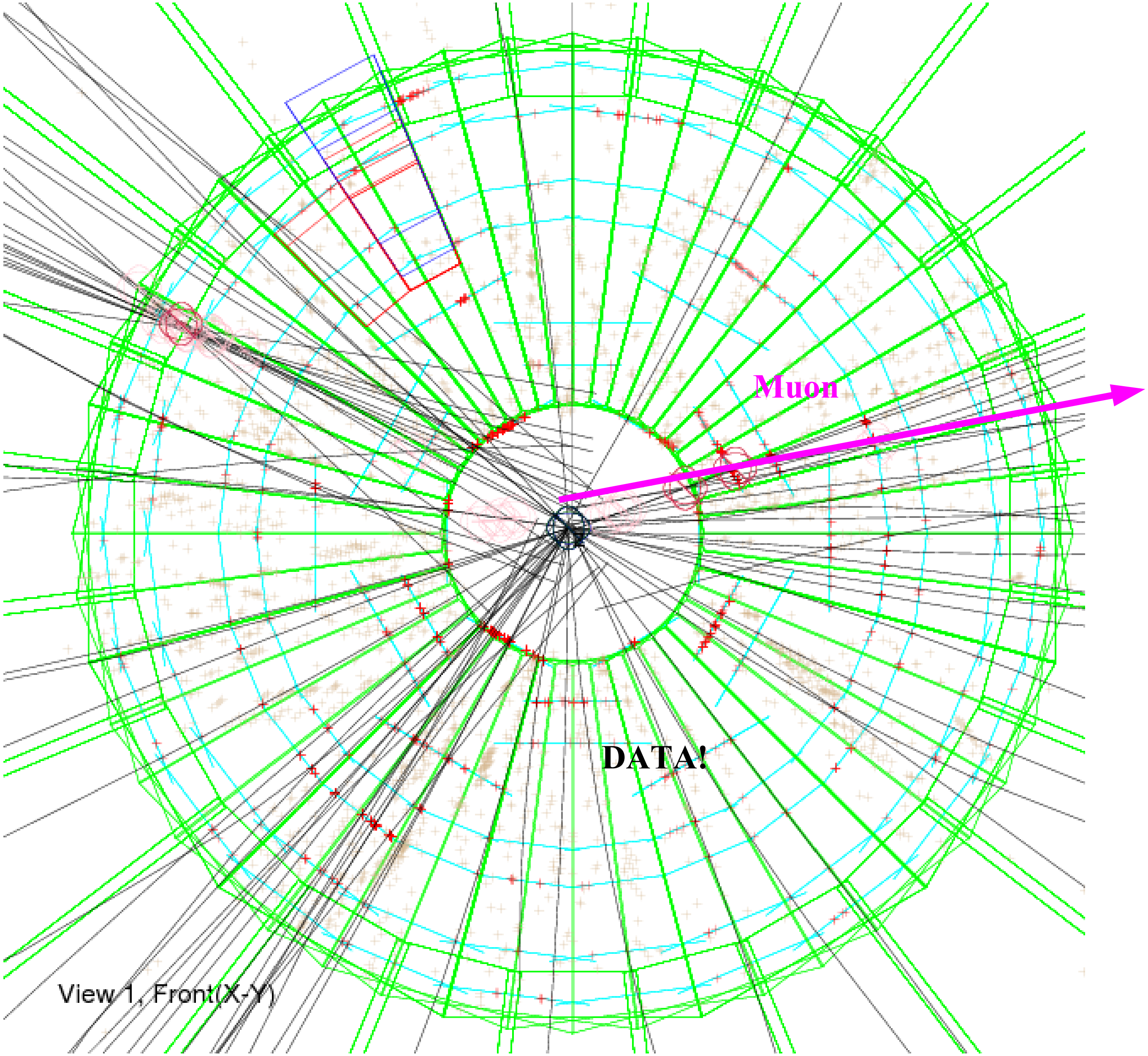
Look for the muon (used for triggering and good evidence for bbbar) to be <u>matched</u> to the mega vertex

- The background (inelastic collisions of outgoing particles with detector material) should not produce muons very often. Initial studies confirm this hypothesis...
  - I had to write some code to do this vertex-muon matching, and have reprocessed the data
    - Draw the muon-matched vertex in d0ve with a double-circle around it
    - Muon track is colored in green at the start



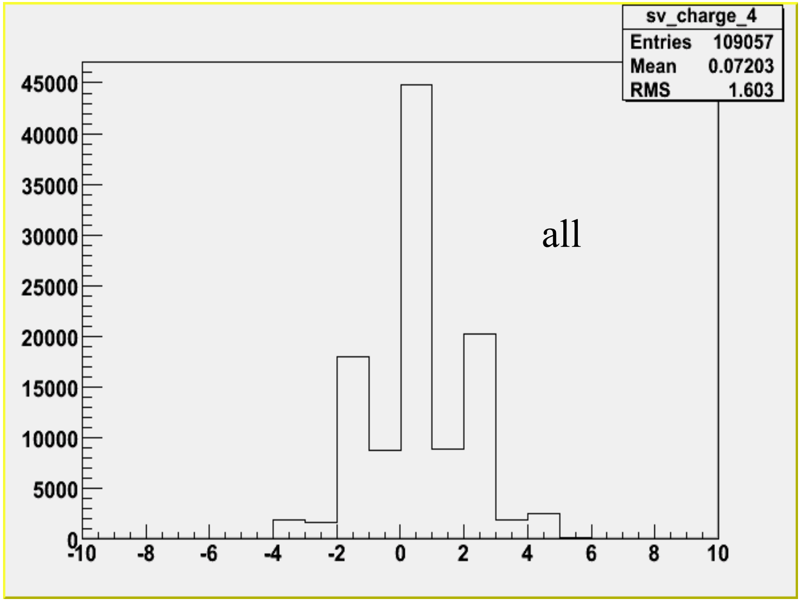
- I was happy to see that my favorite event from data thus far indeed has the muon matched to a secondary vertex at ~30mm! ...

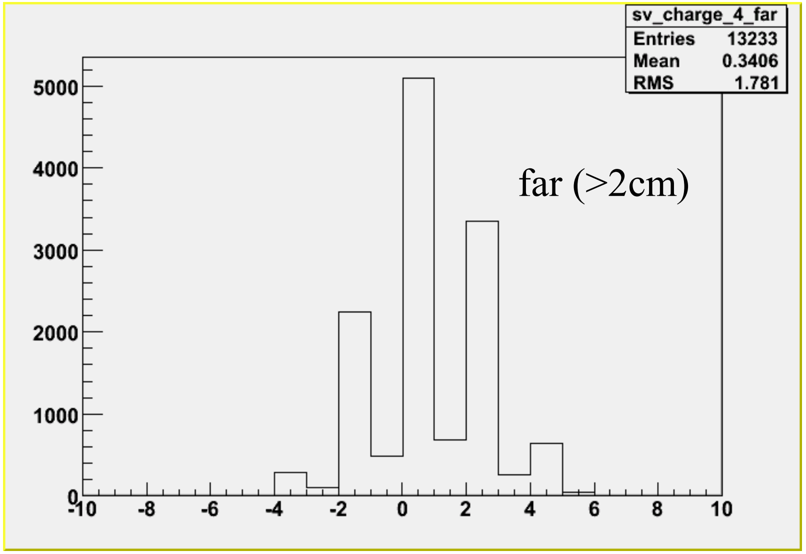
Candidate?



Vertex Charge

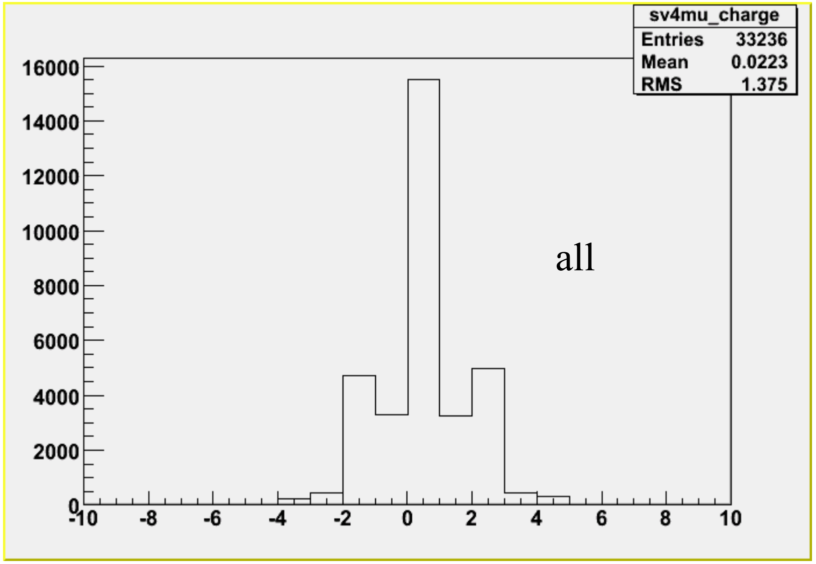
- The dominant background at large decay length is supposedly "inelastic scattering":
  - pion + nucleus (in material or air)
- Since the nucleus is positively charged, we expect the resulting vertex reconstructed to have a bias towards positive charge
  - This is what we see!

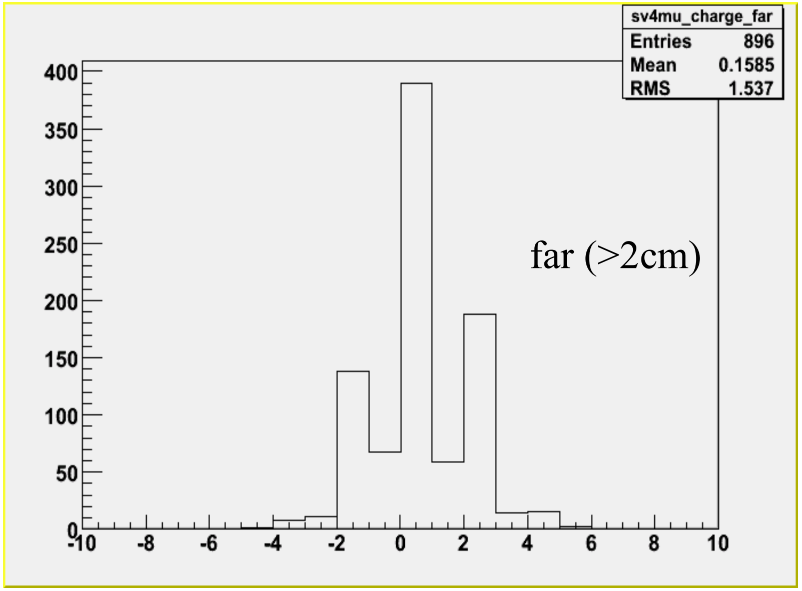




Muon Vertex Charge

- Muon vertices also have some positive charge?
  - About half the amount that non-muon vertices have





Follow-up

- \- Triggers? Look out for L1 track-matched muon triggers, these have a major inefficiency at high IP. Fortunately, there are non-L1-track muon+jet triggers that can be used.
- \- How to deal with the pairs of b / bbar vertices? Have to look for these pairs and/or combine them. Sometimes they are combined automatically due to resolution effects.
- \- Can you search for a resonance in the di-jet mass or in the bbbar (vertex) mass?
  - Yes, worth a try.
- \- Problem using a vector boson (Z) to simulate the scalar NLLP production and decay to bbbar?
  - Maybe... will switch to H->hh->bbbb
-