

Tracking Simulation & Reconstruction

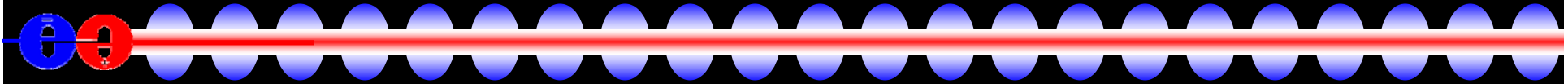
Norman A. Graf

(including work by Jeremy McCormick)

April 4, 2006

Geant4: MCS Fix

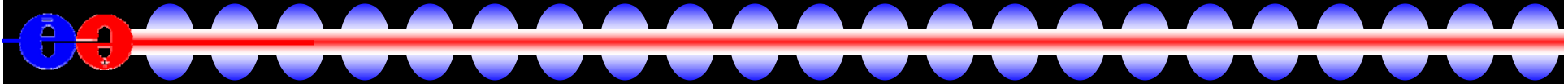
2



- Geant4 versions prior to version 8 had ~30% variation in energy deposition in thin layers depending on the production cut for secondaries.
- The version 8 stepping model changed this.
- Now a series of steps of decreasing size is taken as the particle approaches a volume boundary.
 - Seemed to fix or at least drastically reduce problems with varying energy deposition.
- It may have also introduced bugs / problems ...
- Number of steps per layer seems to scale
 - e.g. 40-50 micron steps in tracker layer and 4-5 micron steps in vertex layer

SLIC: SimTrackerHit Updates

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- Momentum added to SimTrackerHit
 - For single step, current particle momentum.
 - For multiple steps, average of particle momenta.
 - Implemented in org.lcsim interface / implementation and Event Browser.
- Path length added to SimTrackerHit
 - For single step, distance from pre to post step point
 - For multiple steps, distance from entry to exit point
 - Or in case of interaction, multiple tracks are produced, so it is start of new track to exit point
 - Also implemented in org.lcsim
- Entry and exit point from path length and momentum
 - Not yet in org.lcsim interfaces (but trivial)
- Released with LCIO version 1.7 (Cambridge)

LCSim Event



Run:0 Event: 0

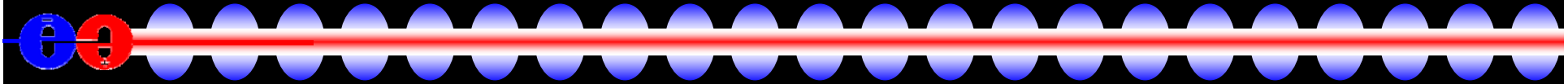
- Event
 - EcalBarrHits
 - EcalEndcapHits
 - ForwardEcalEndcap
 - HcalBarrHits
 - HcalEndcapHits
 - LuminosityMonitorH
 - MCParticle
 - MCParticleEndPoin
 - MuonBarrHits
 - MuonEndcapHits
 - TkrBarrHits**
 - TkrEndcapHits
 - VxBarrHits
 - VxEndcapHits
 - MCParticleTree

Collection: TkrBarrHits size:377 flags:c0000000

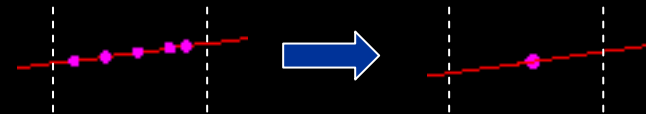
id: syst...	id: layer	id: barr...	x (mm)	y (mm)	z (mm)	dEdx (GeV)	time (ns)	px (GeV)	py (GeV)	pz (GeV)	pathLength (mm)
13	3	0	-516.62	-819.72	866.59	1.0882E-4	8.0703	3.5049E-4	-6.4218E-5	-.0010064	.13482
13	4	0	-517.28	-819.35	862.99	1.5041E-4	10.507	-6.3473E-5	-1.9939E-4	-1.7364E-5	.098904
13	4	0	-215.77	-1205.8	1423.8	9.2928E-5	8.2888	5.6848E-5	2.1151E-4	-2.3349E-4	.18280
13	0	0	-202.07	2.4258	-18.814	8.4814E-5	9.5180	-.11.697	.29396	-1.0905	.30133
13	1	0	-457.90	13.054	-42.673	1.6052E-4	1.5360	-.11.680	.67765	-1.0907	.30143
13	2	0	-712.37	32.008	-66.471	8.7739E-5	2.3916	-.11.652	1.0592	-1.0902	.30161
13	3	0	-967.26	59.408	-90.353	8.7814E-5	3.2513	-.11.610	1.4406	-1.0911	.30188
13	4	0	-1221.4	95.182	-114.29	1.0079E-4	4.1118	-.11.556	1.8205	-1.0914	.30223
13	0	0	-201.74	-11.778	-62.498	1.2659E-4	100.66	-1.5041	-.23680	-.47600	.31585
13	1	0	-450.28	-84.197	-143.62	9.6445E-5	1.6173	-1.3959	-.60743	-.47540	.32244
13	2	0	-677.93	-221.13	-226.98	9.0348E-5	2.5505	-1.1889	-.94994	-.47503	.33569
13	3	0	-870.86	-425.13	-314.66	1.6222E-4	3.5367	-.88361	-1.2387	-.47394	.35747
13	4	0	-1008.3	-695.87	-409.72	1.2459E-4	4.6038	-.47876	-1.4434	-.47492	.39374
13	0	0	14.209	201.44	245.25	4.1456E-5	.67684	-1.6908E-4	-1.3521E-4	1.6649E-4	.055816
13	3	0	-502.00	-829.09	-411.88	7.2626E-6	5.3418	-4.4560E-4	-4.8823E-4	1.7634E-4	.026753
13	3	0	-501.99	-829.11	-411.98	1.3489E-4	11.637	-1.1307E-4	2.4991E-4	-1.8961E-4	.15763
13	4	0	-502.01	-829.07	-412.08	9.5562E-5	11.638	-8.0698E-5	1.4025E-4	-2.2725E-5	.059711
13	4	0	-522.72	-1107.8	308.98	1.6136E-5	5.3875	-1.6609E-4	-1.3280E-7	-7.7428E-5	.012591
13	1	0	450.39	-83.670	-277.66	1.1618E-4	5.4579	.60880	-.11152	-.37334	.31528
13	2	0	711.64	-45.324	-439.01	1.4746E-4	2.8322	.55160	.28038	-.37190	.40679
13	3	0	932.81	262.66	-676.38	3.1136E-4	4.3661	.089296	.61067	-.37179	.86054
13	3	0	656.72	712.63	-1021.3	2.9856E-4	6.5973	-.58402	.19678	-.37198	.86028
13	2	0	710.23	-62.015	297.64	8.8848E-5	16.662	-6.0126E-5	-1.0705E-4	1.8854E-4	.11730
13	3	0	284.65	1191.7	-707.28	2.2920E-4	15.751	-1.2470E-4	1.5541E-4	1.7885E-4	.13612
13	2	0	-620.81	350.84	678.55	.0046407	6.5994	-.081992	.021597	.063570	.39588
13	4	0	-552.72	-795.84	-709.98	3.8797E-5	7.6193	-.0088544	-.018904	.0083445	3.8274E-5
13	4	0	1202.9	-231.75	-1038.4	3.6846E-5	42.817	-.020545	.0095953	2.5424E-4	3.5348E-5
13	4	0	969.75	748.85	74.800	2.6749E-4	196.57	.0017414	-.0019064	-.0011791	.76857
13	4	0	969.38	749.34	75.657	3.3350E-4	56.105	8.5247E-4	-.0010166	.0016451	.96327
13	4	0	968.38	750.63	79.249	1.9381E-4	56.131	.0010754	-.0016248	8.6281E-4	.72866
13	4	0	967.98	750.90	78.103	2.6077E-4	56.160	2.7965E-5	-.0017679	-5.1162E-4	.61755
13	4	0	968.83	749.80	77.435	1.1268E-4	56.167	7.2861E-4	7.2312E-4	-6.6238E-4	.34782
13	4	0	968.84	749.94	76.883	6.5261E-4	56.170	-4.2154E-4	1.2642E-5	-3.0880E-4	.38377
13	4	0	959.08	139.48	400.38	3.0113E-5	111.85	-5.6859E-5	6.7751E-5	-9.8716E-6	.0032125
13	3	0	1016.4	-683.83	411.76	4.9751E-5	13.180	9.7038E-5	-6.2164E-5	-7.0181E-6	.0077151

SLIC: Combining Hits

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- Used to consistently have $O(1)$ hit per track crossing per layer in silicon tracker
 - Except in case of interactions (fairly rare)
- Geant4 MCS fix changed this to $O(4)$ hits / layer.
- Always possible to combine hits in SLIC (TPCS)
 - `combine_hits` flag
- Now an option to combine hits in the compact description
 - This will become the default in MC production runs.
 - Can still turn on for high precision studies, debugging, accuracy checks, etc.
- Sim code is a lot more complicated than single hits per step so bugs potentially exist.
 - We need to study new SLIC output thoroughly.



```
<detector id="11" name="VertexBarrel" type="MultiLayerTracker" readout="VtxBarrHits" combineHits="true">
```

(compact)

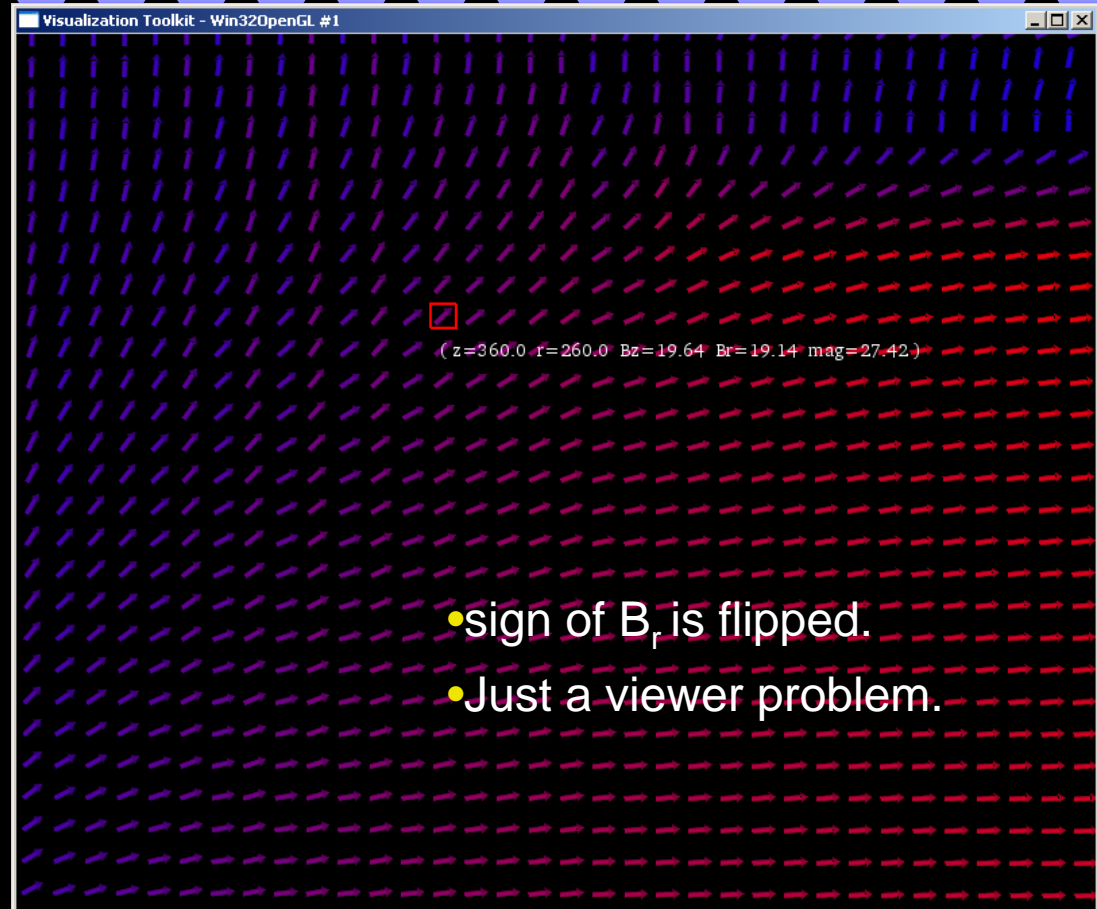


```
<tracker name="TrackerBarrel" hits_collection="TkrBarrHits" combine_hits="true"> (lcmd)
```

SLIC: Magnetic Field Map

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- SLIC and org.lcsim support an RZB field map
 - format from Takashi Maruyama's FORTRAN code
 - C++ interpolation code from Norman
- data is single quadrant
- symmetric in phi
- visualization with VTK (python)
- Working on implementation of DID/DIDn't
- Working on arbitrary field map.

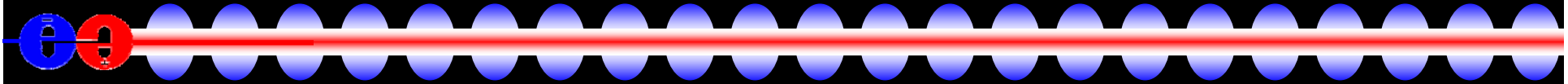


- sign of B_r is flipped.
- Just a viewer problem.

- To study effect of non-uniform field, do not need to include in reco (yet).
- Put field in simulation, analyze with perfect field. Difference gives maximum bound on the size of the effect. (Have Runge-Kutta propagators, but very slow.)

Compact: Regions and Limits

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- Regions can be used to set production cuts in compact

- limits production of secondaries (e[±], gamma)
 - potential distance < cut → not produced
 - particle dEdX - E(secondary)
- also called “range cut”
- different from setting physics limits

```
<regions>
  <region name="EcalRegion" cut="0.5" lunit="mm" />
</regions>

...

<slice region="EcalRegion" ... />
```

- physics limits

- set minimums and maximums
 - step length max
 - track length max
 - time max
 - kE min
 - range min (not same as production cut)
- step length useful for calorimeters
 - particle goes across > 1 pad

```
<limits>
  <limitset name="TrackerLimits">
    <limit name="step_length_max"
      value="1.0" unit="micrometer"
      particles="**"
    </limitset>
  </limits>

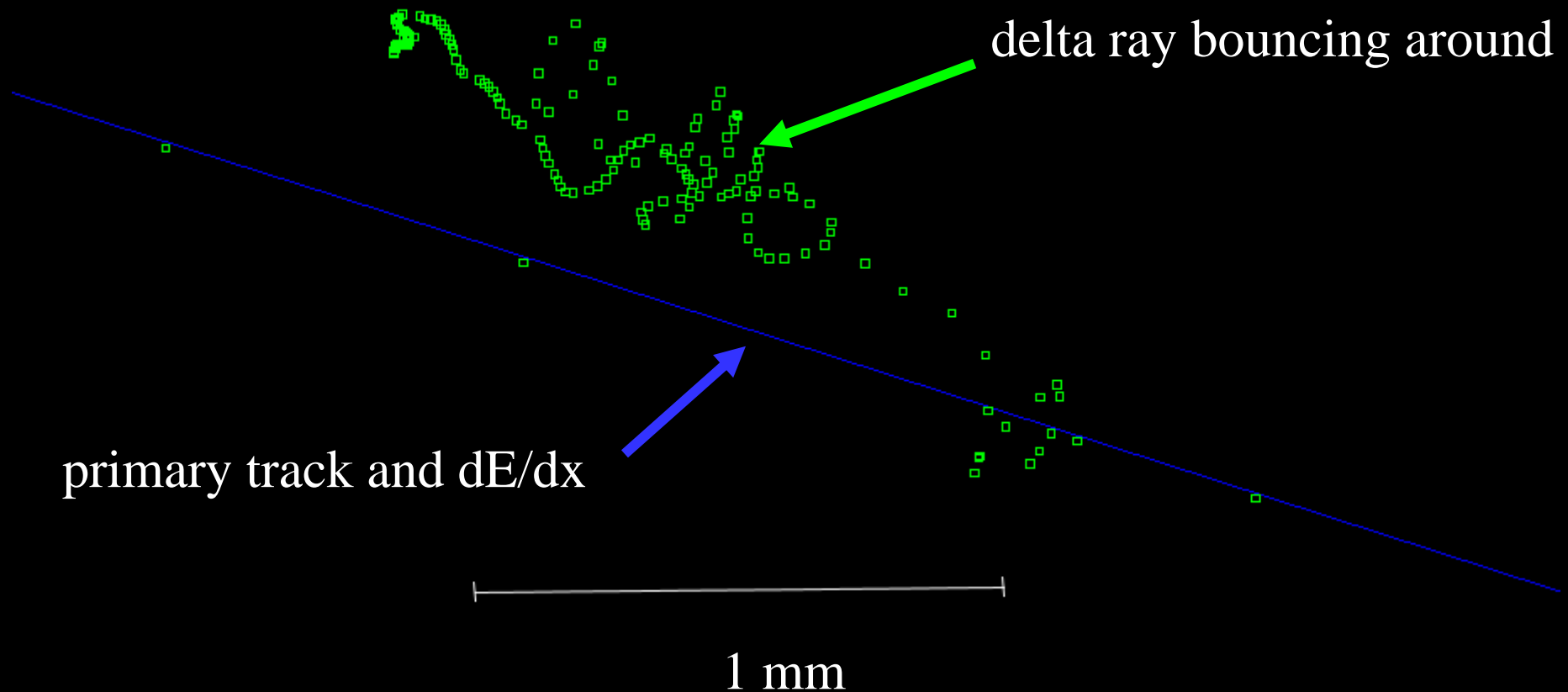
...

<slice limits="EcalLimits" ... />
```

Step and Energy limit example

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- delta ray hits in TPC with small step size



Infrastructure components

❖ Hit

- Defined at a surface.
- Provides a measurement and associated error
- Provides a mechanism to predict the measurement from a track fit
- Provides access to underlying cluster and/or digits

❖ Surface

- Generally correspond to geometric shapes representing detector devices.
- Provide basis for tracks, and constrain one of the track parameters.
- The track vector at a surface is expressed in parameters which are “natural” for that surface.

Hits

❖ Cylinder

- 1D Axial: ϕ (for convenience)
- 1D Stereo: $\phi + \kappa z$
- 2D Combined: (ϕ, z)

❖ XY Plane

- 1D Stereo: $w_v * v + w_z * z$
- 2D Combined: (v, z)

❖ Z Plane

- 1D Stereo: $w_x * x + w_y * y$
- 2D Combined: (x, y)

Hit Interface

Hit

HitVector measuredVector();

HitError measuredError();

TrackerHit

double[] getPosition();

double[] getCovMatrix();

❖ **Biggest difference is how measurements are treated. Hit only returns what is expressly being measured.**

- **e.g. Axial strips on cylindrical surface only measure φ , so return φ and $\delta\varphi$, instead of (x, y, z) with covariance matrix, faking z with very large δz .**

Track Finding

- ❖ Implemented a conformal mapping technique
 - Maps curved trajectories onto straight lines
 - Simple link-and-tree type of following approach associates hits.
 - Once enough hits are linked, do a simple helix fit
 - circle in rPhi
 - straight line in s-z
 - Use track parameters to predict track and pick up hits.
 - Finding strategy is runtime controlled by specifying parameters such as starting/ending layer, beam constraint, minimum # of hits, max. χ^2 , etc.

Track Finding

- ❖ Currently using TPC hits, vertex detector hits and forward tracker disk hits.
 - TPC hits are φ, z measurements at fixed r .
 - VTX hits are pixels, so give 2D hits:
 - φ, z measurements at fixed r in barrel
 - x, y measurements at fixed z on disks.
 - FWD hits are assumed to be double layer of stereo strips, giving 2D (x, y) hits (+ ghosts) at fixed z .
 - Currently not handling ghosts, coming soon.
 - Currently not extrapolating into axial-only barrel silicon tracker (coming soon).

Data Samples

❖ Single muons

- simple sanity check

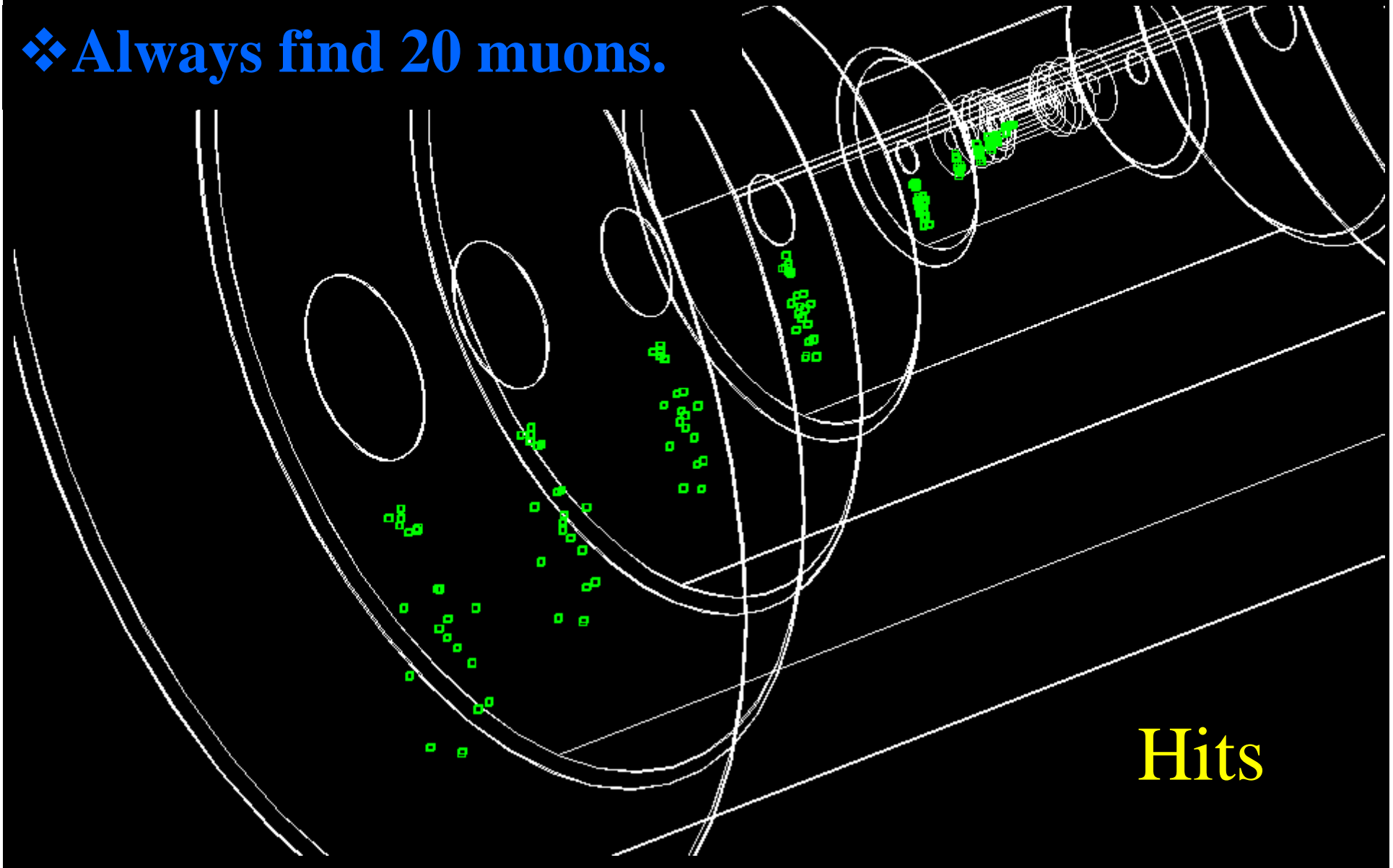
❖ Multiple muons

- next step in complexity, known momentum, acceptance and number of tracks to find.

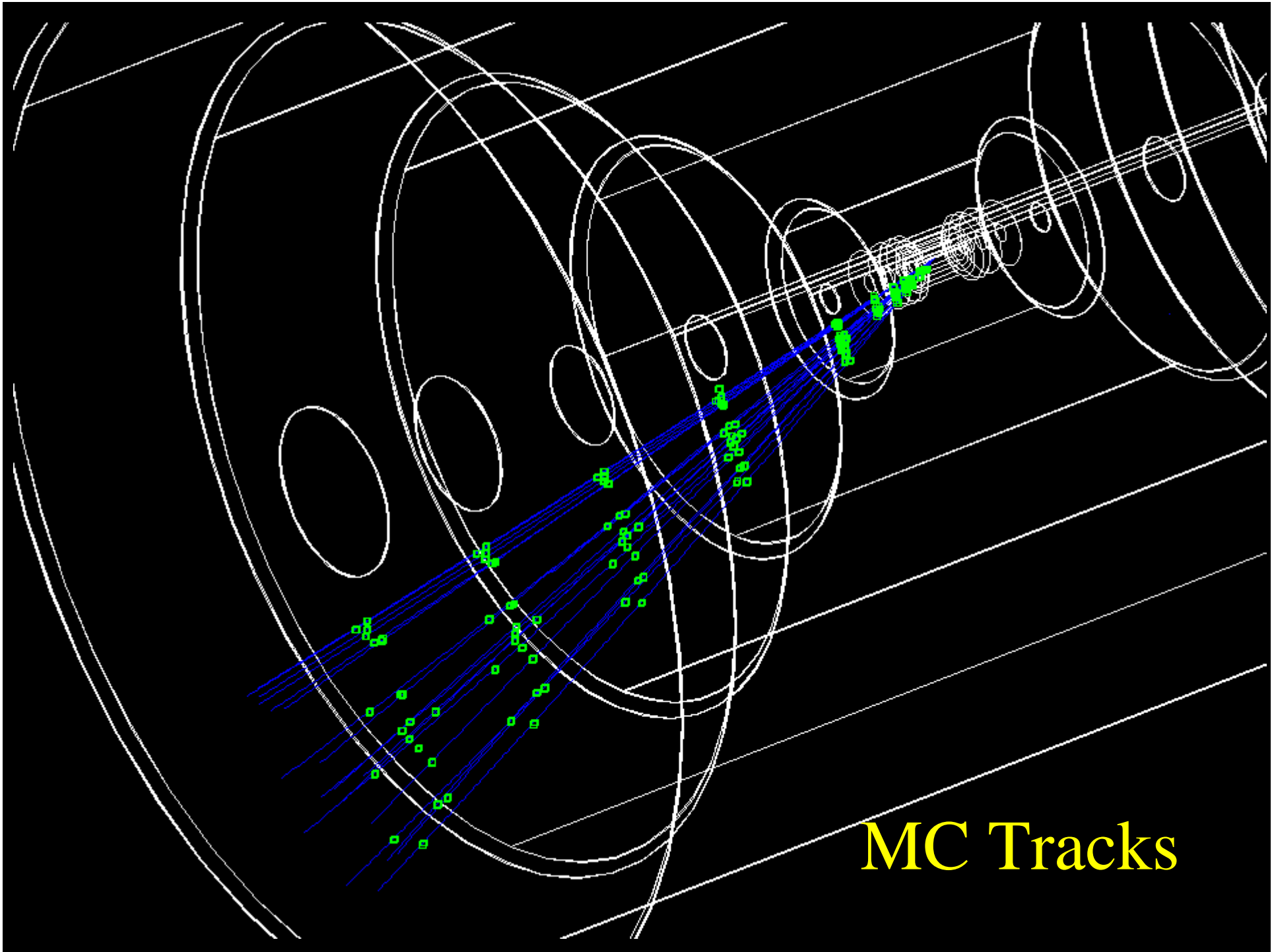
❖ $t\bar{t} \rightarrow$ six jets

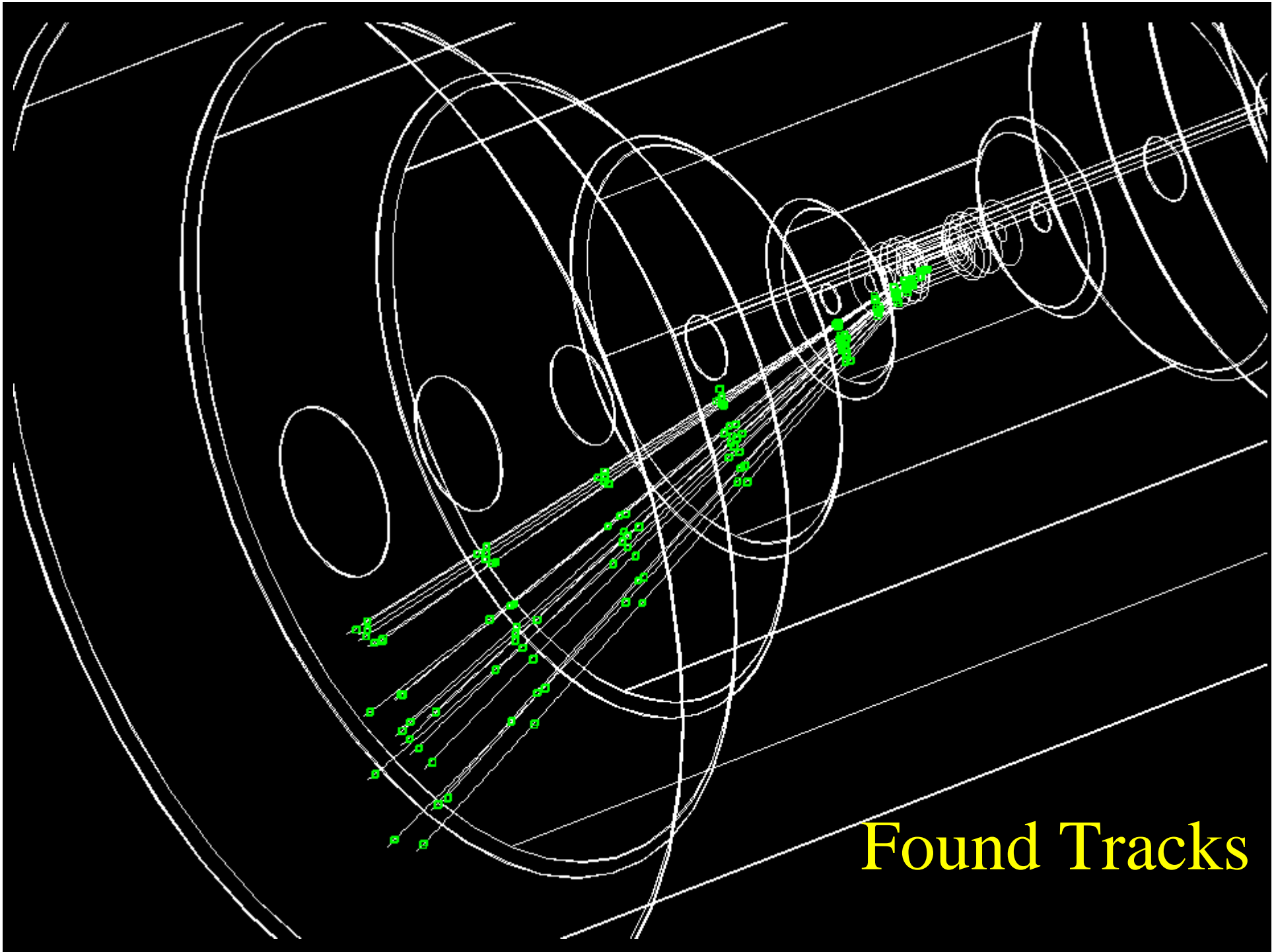
- reasonably tough real physics environment.
Challenge is to define the denominator, i.e. which tracks should have been found.

- ❖ **Generate 20 muons into the forward tracking region.**
- ❖ **Always find 20 muons.**



Hits

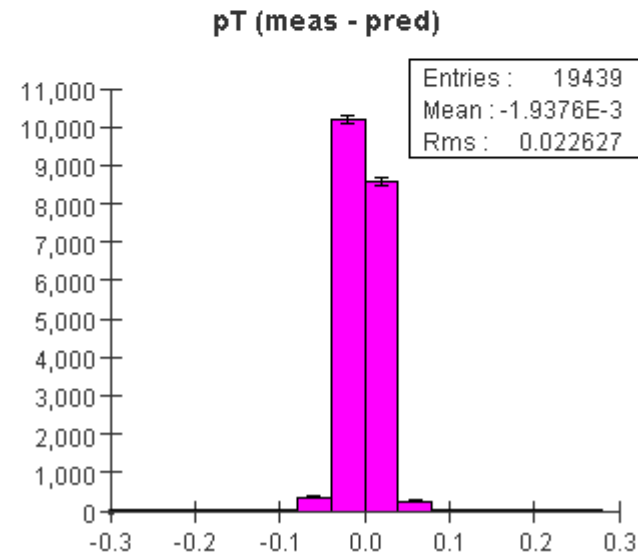
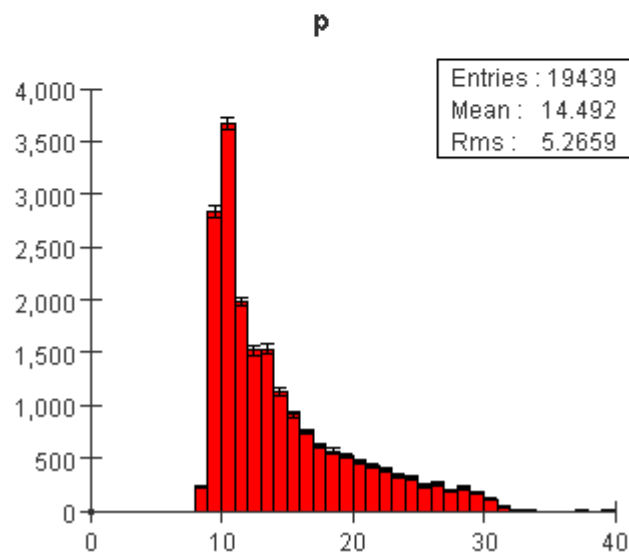
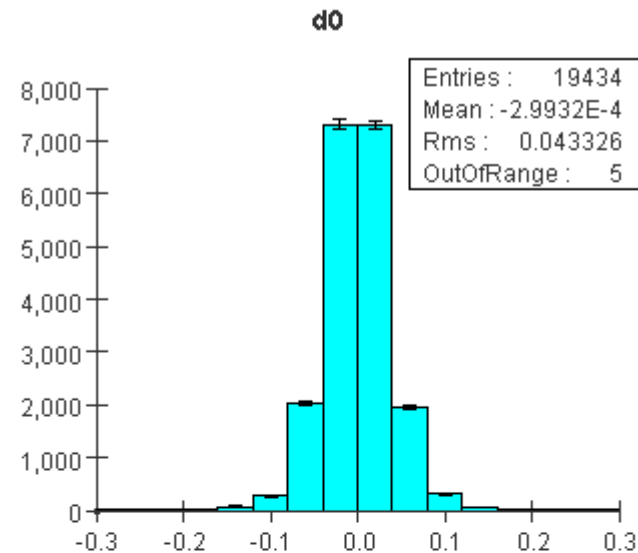
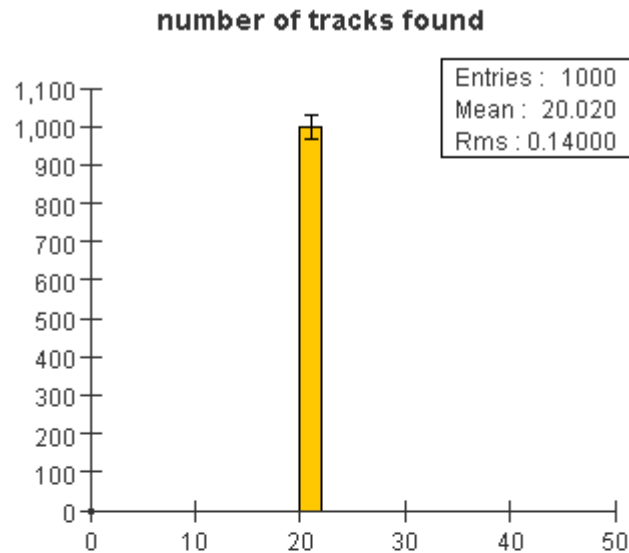




Found Tracks

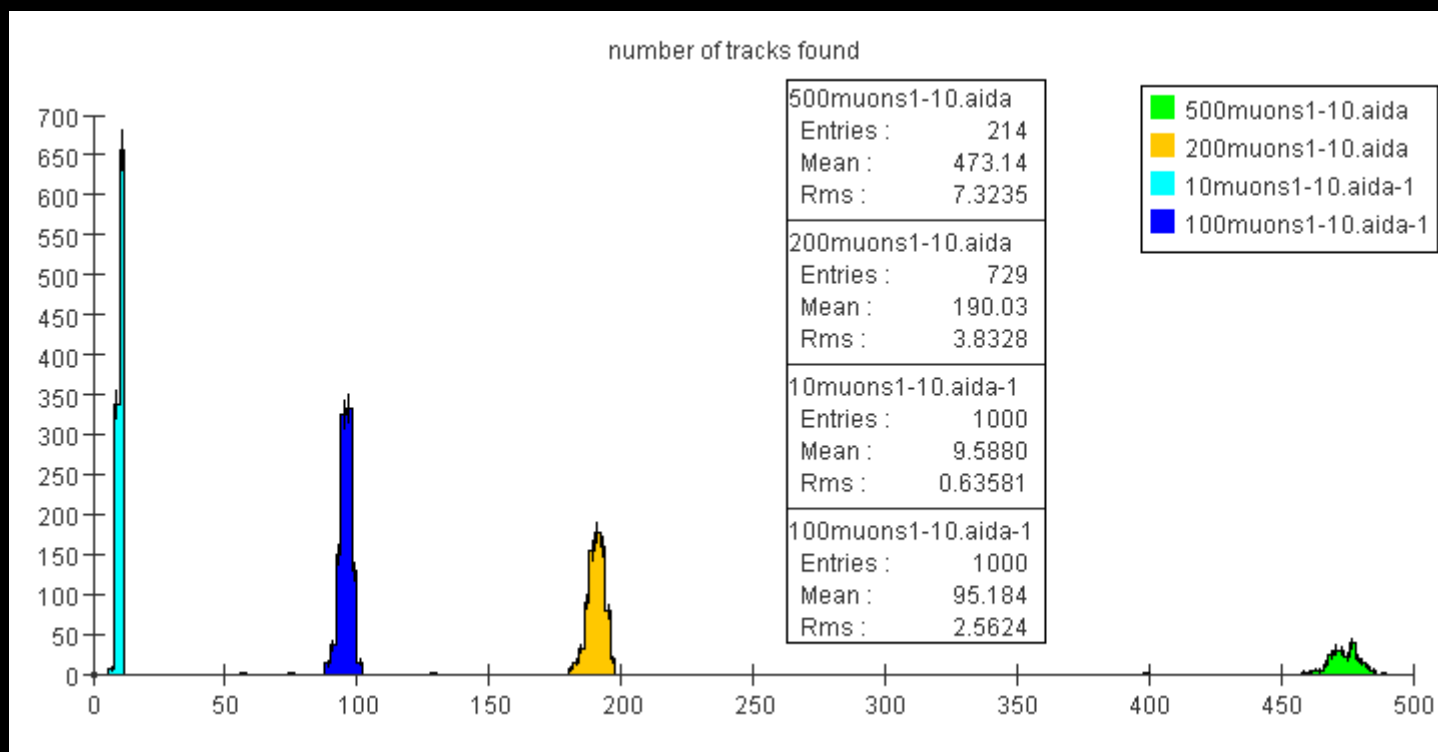
Multiple Forward Muons

Gene



Multiple Isotropic Tracks

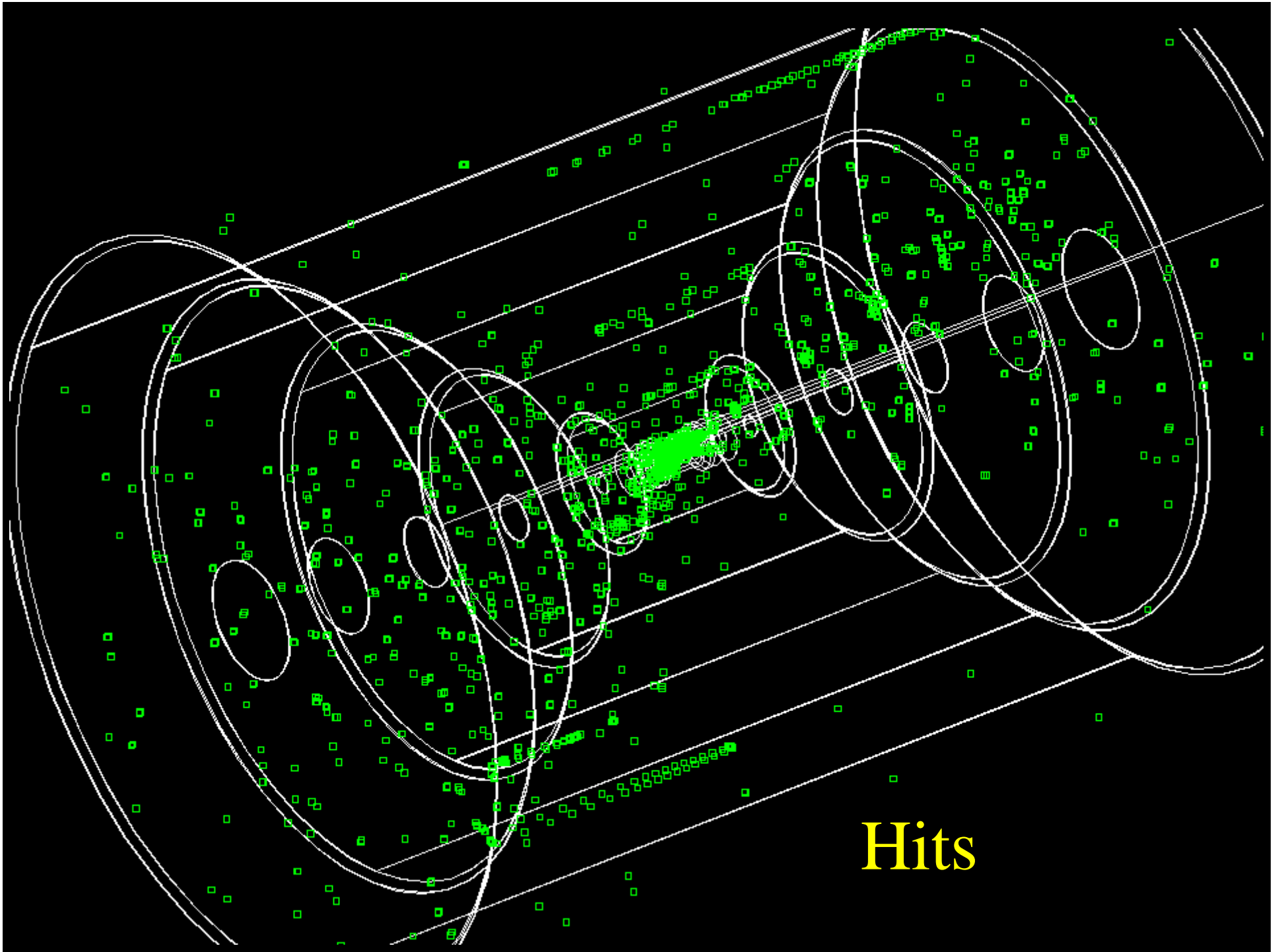
- ❖ Generate multiple (10, 100, 200, 500) muons per event isotropically between 1 and 10 GeV down to 4 degrees of the beam. Find ~95% out of the box.

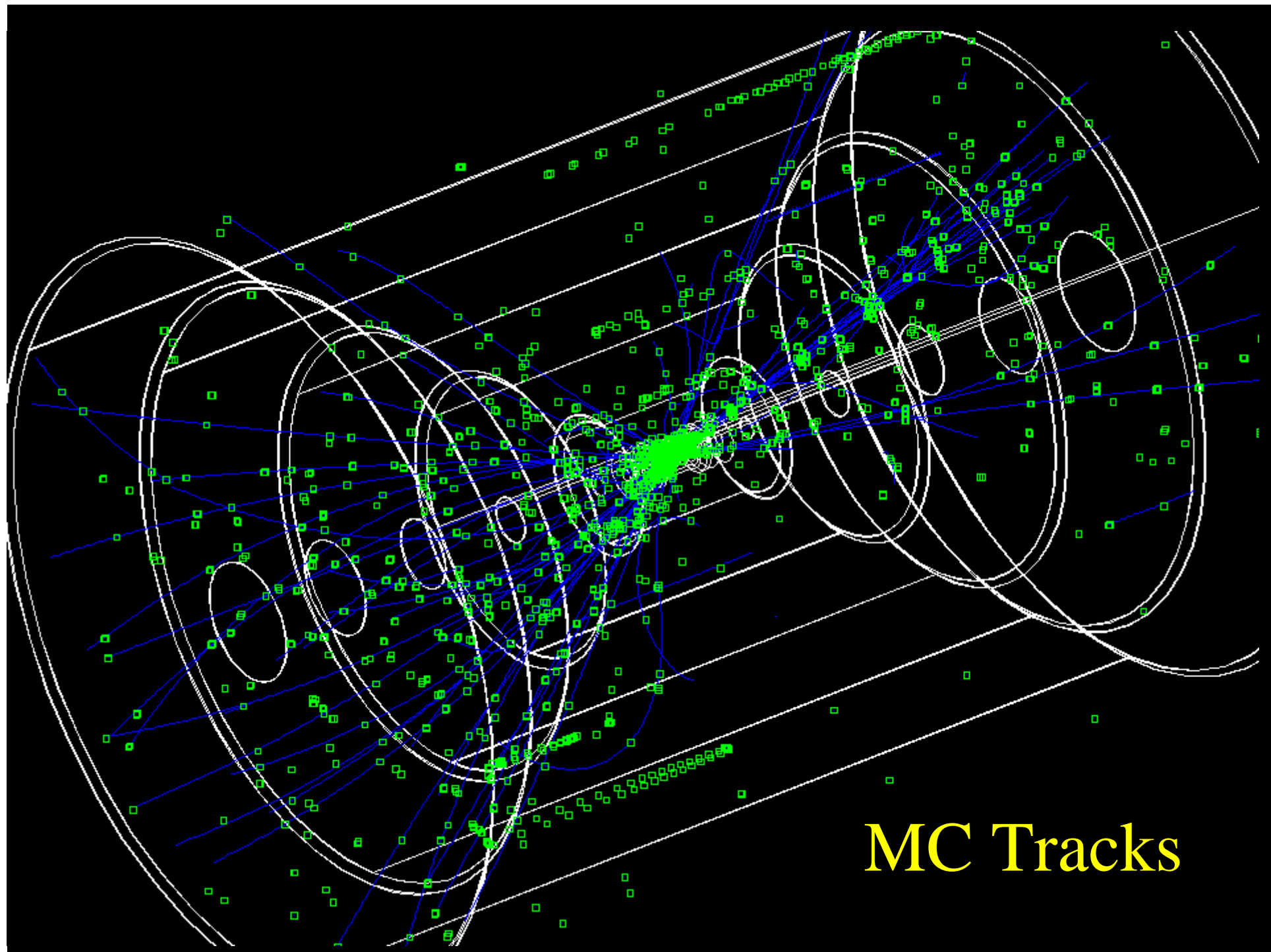


- ❖ n.b. some tracks are actually outside tracker acceptance.

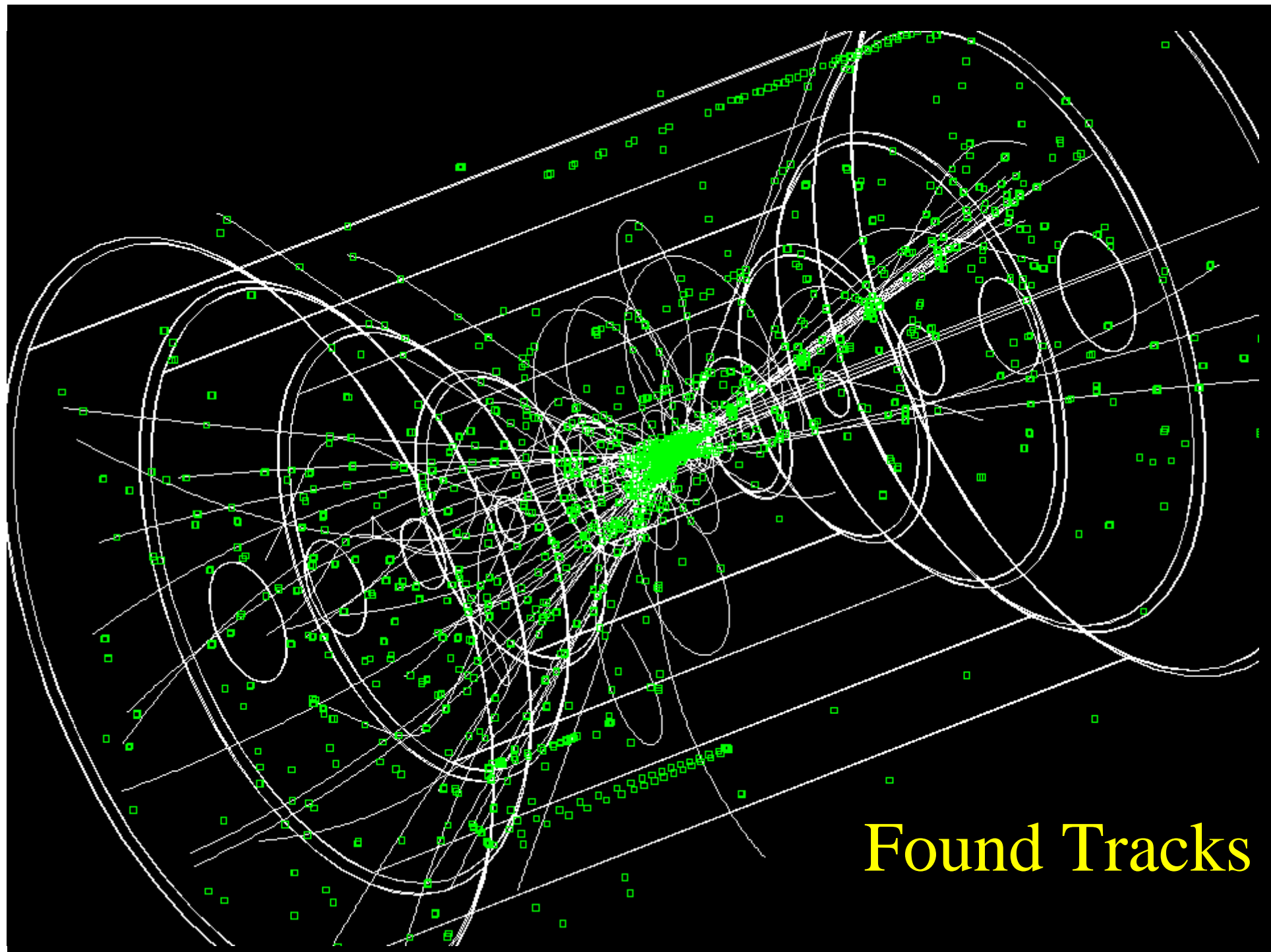
$t\bar{t} \rightarrow \text{six jets}$

- ❖ Generate $e^+ e^- \rightarrow t\bar{t}$, $t\bar{t} \rightarrow \text{six jets}$.
- ❖ Takes 3min to fully analyze 900 events on 1.7GHz laptop.
 - Open event, read in data.
 - Create tracker hits.
 - Find tracks.
 - Fit tracks.
 - Analyze tracks.
 - Write out histograms.

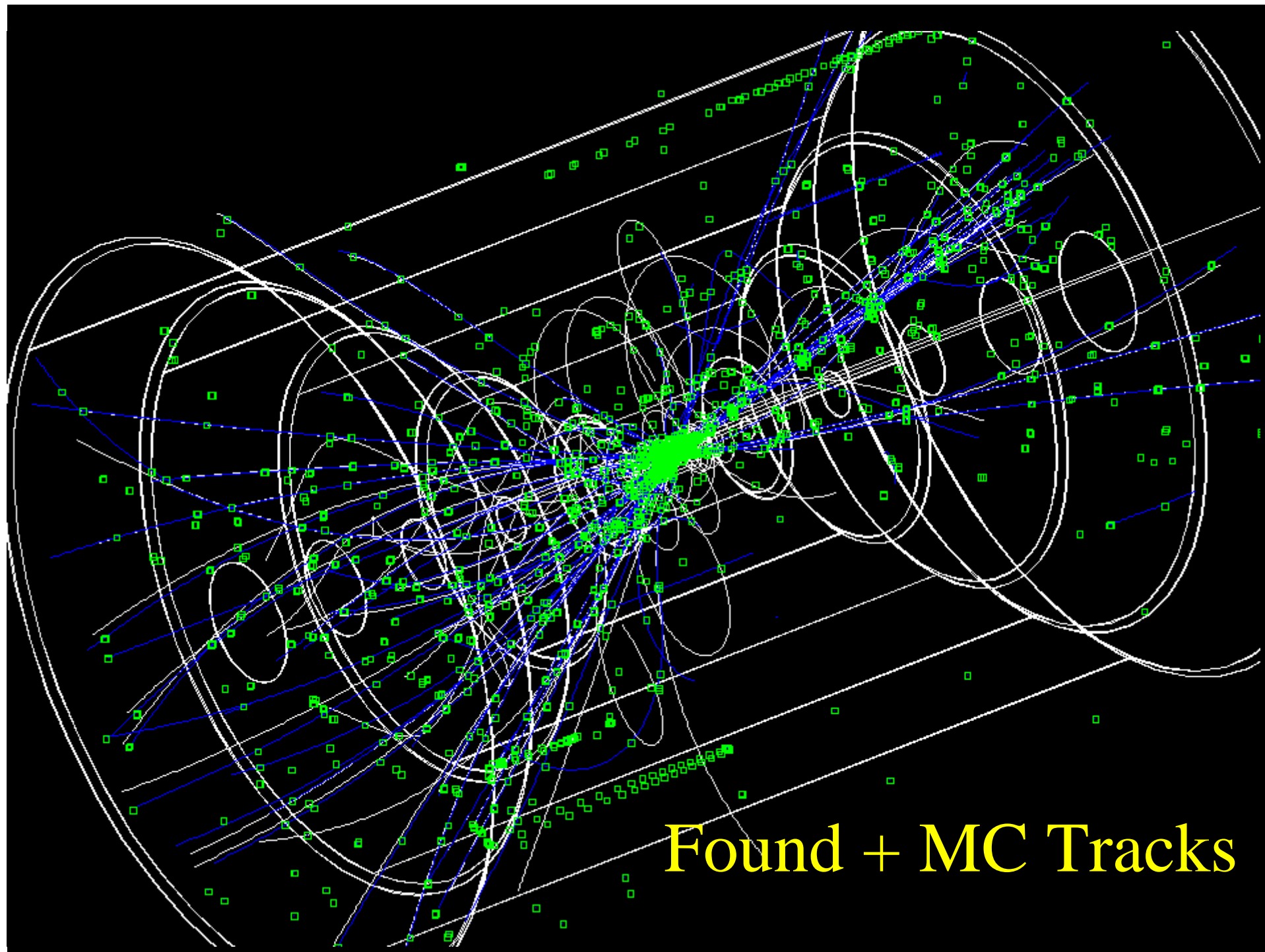




MC Tracks

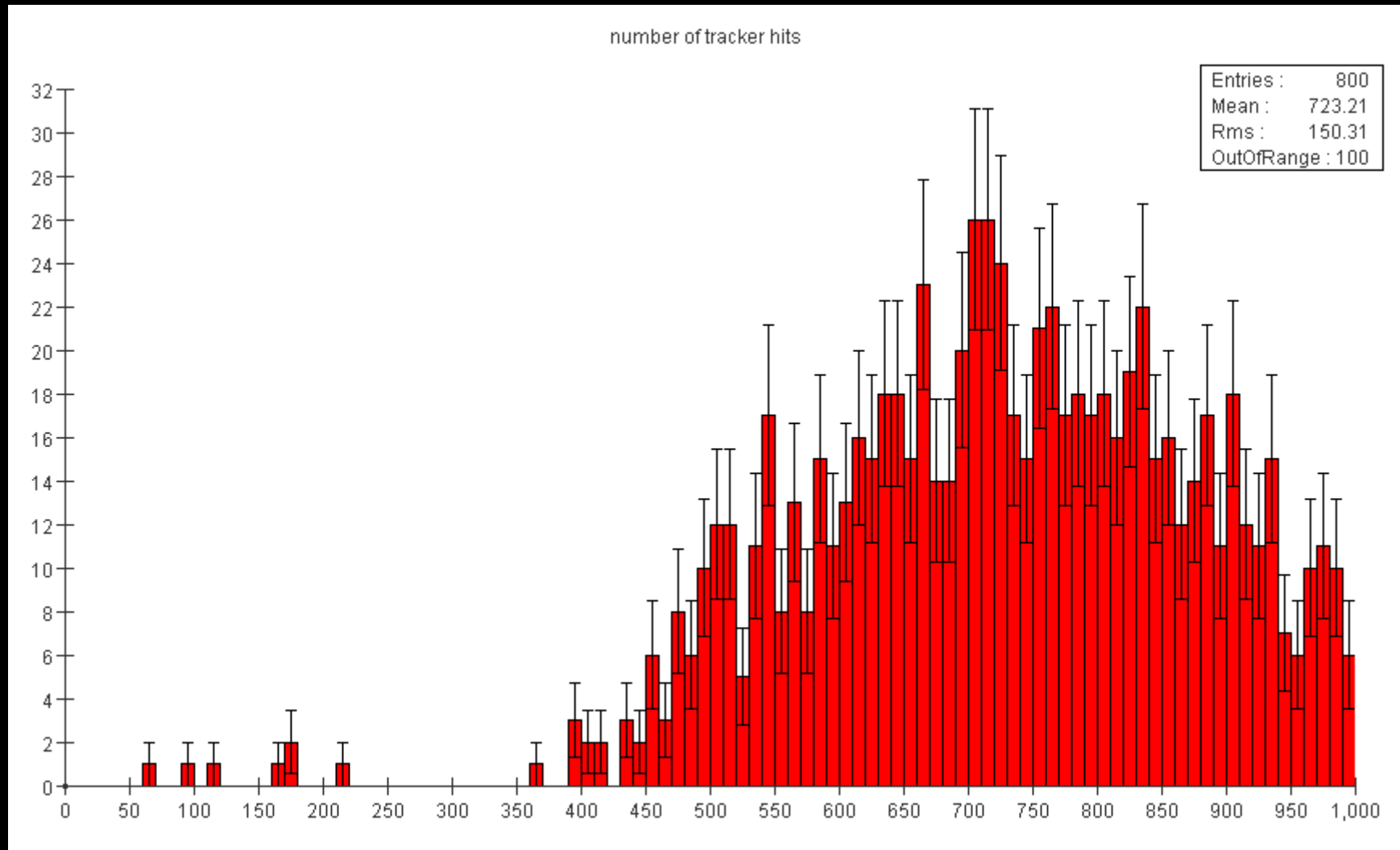


Found Tracks

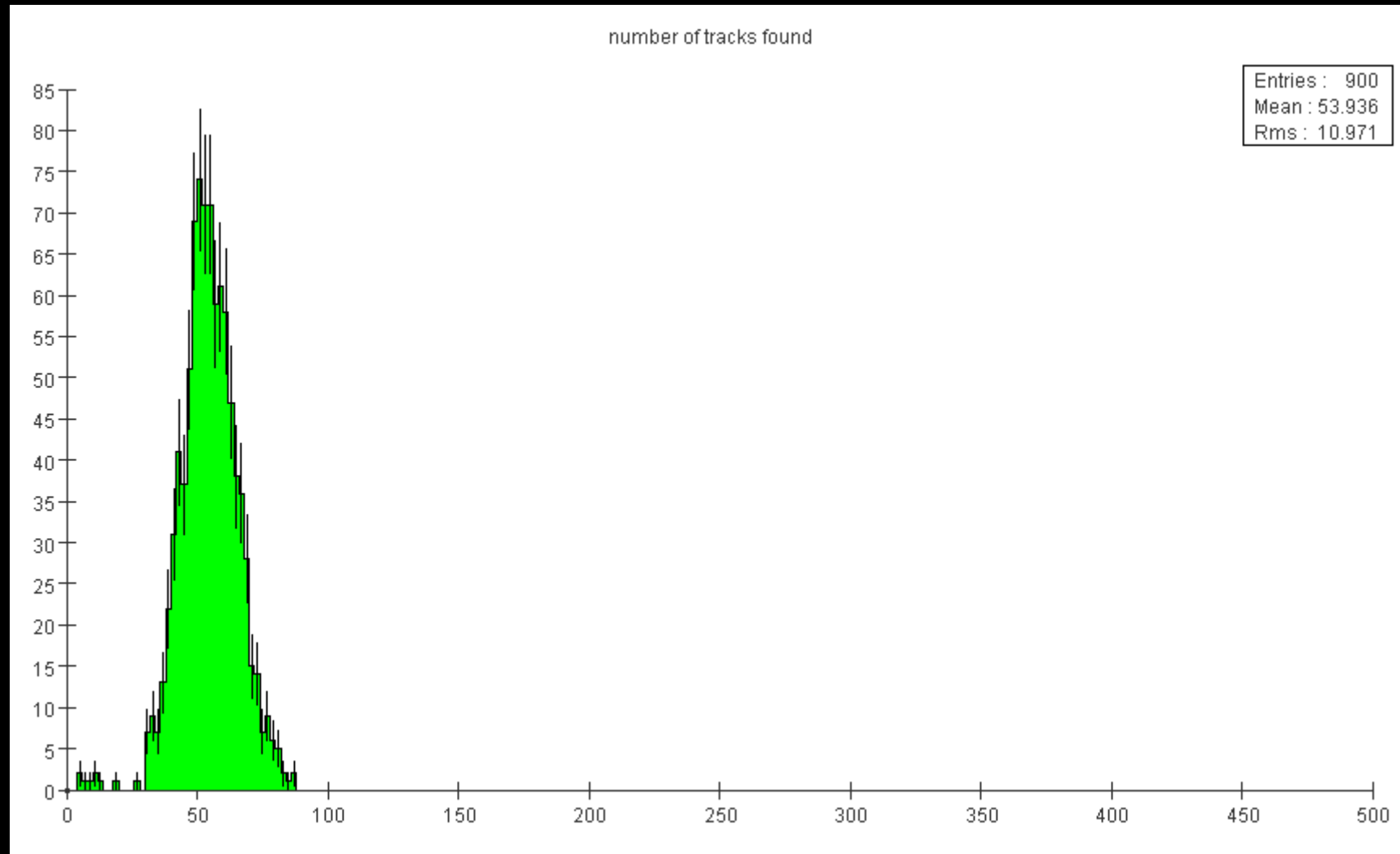


Found + MC Tracks

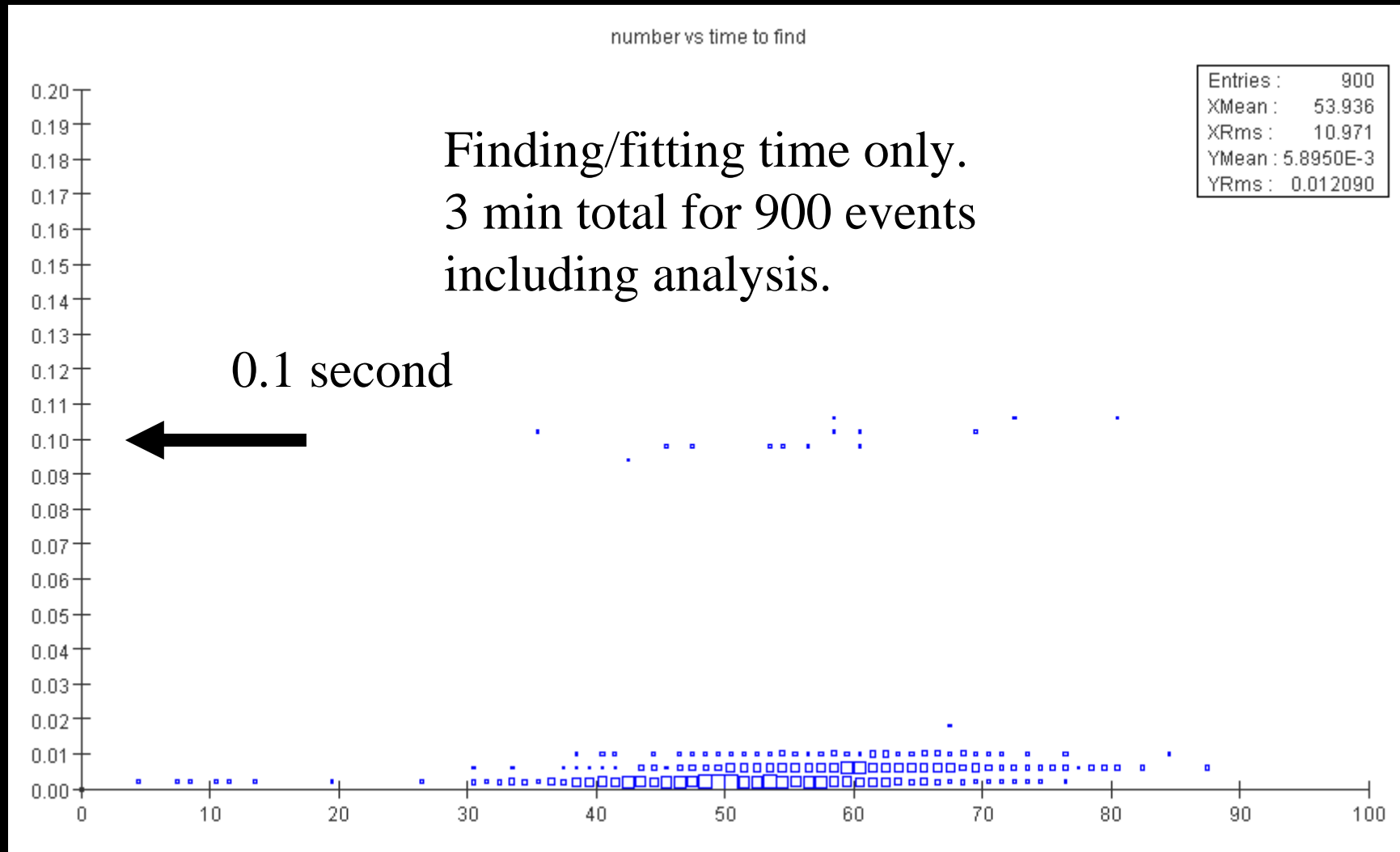
$t\bar{t} \rightarrow \text{six jets}$ # of Hits



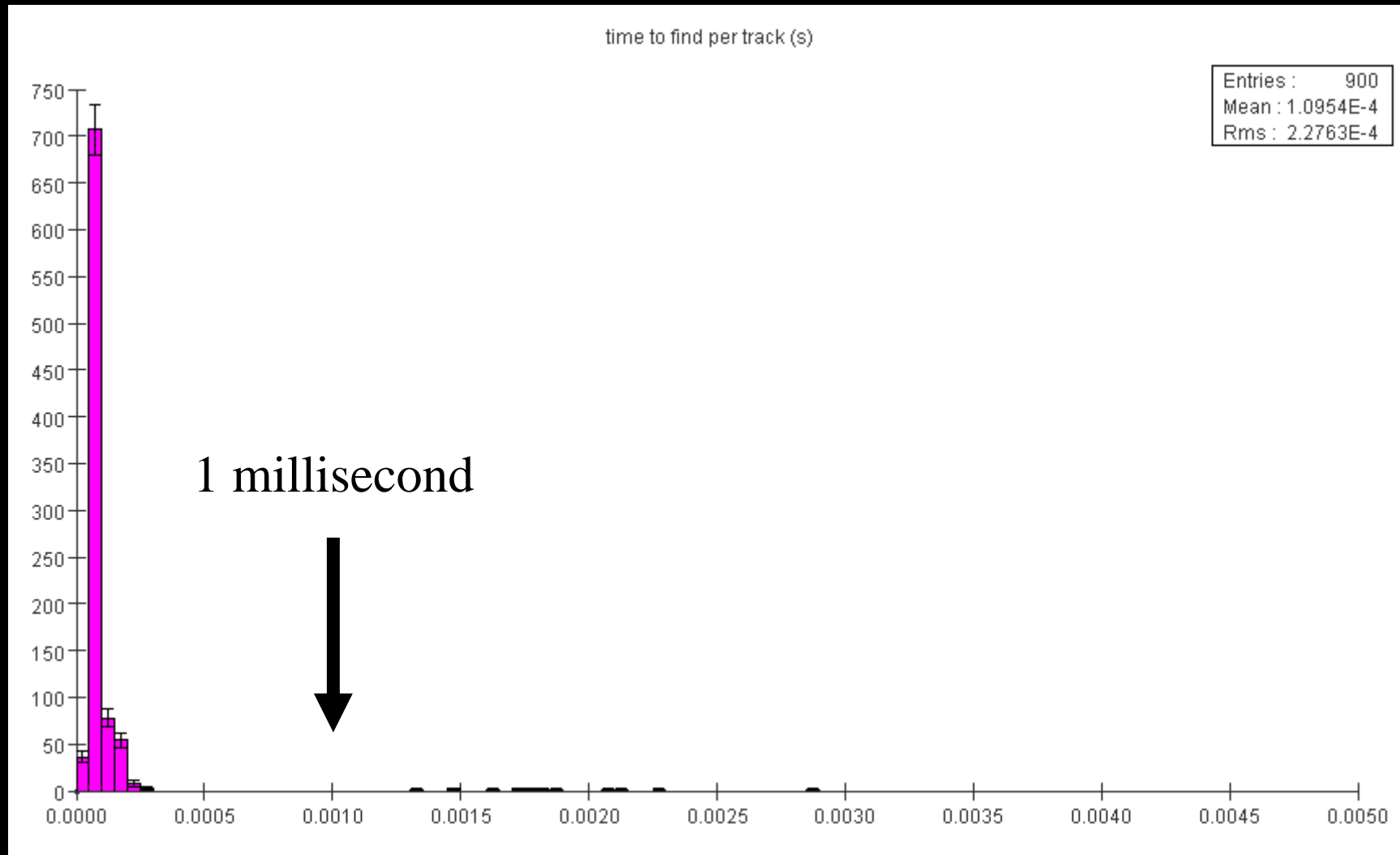
of tracks found



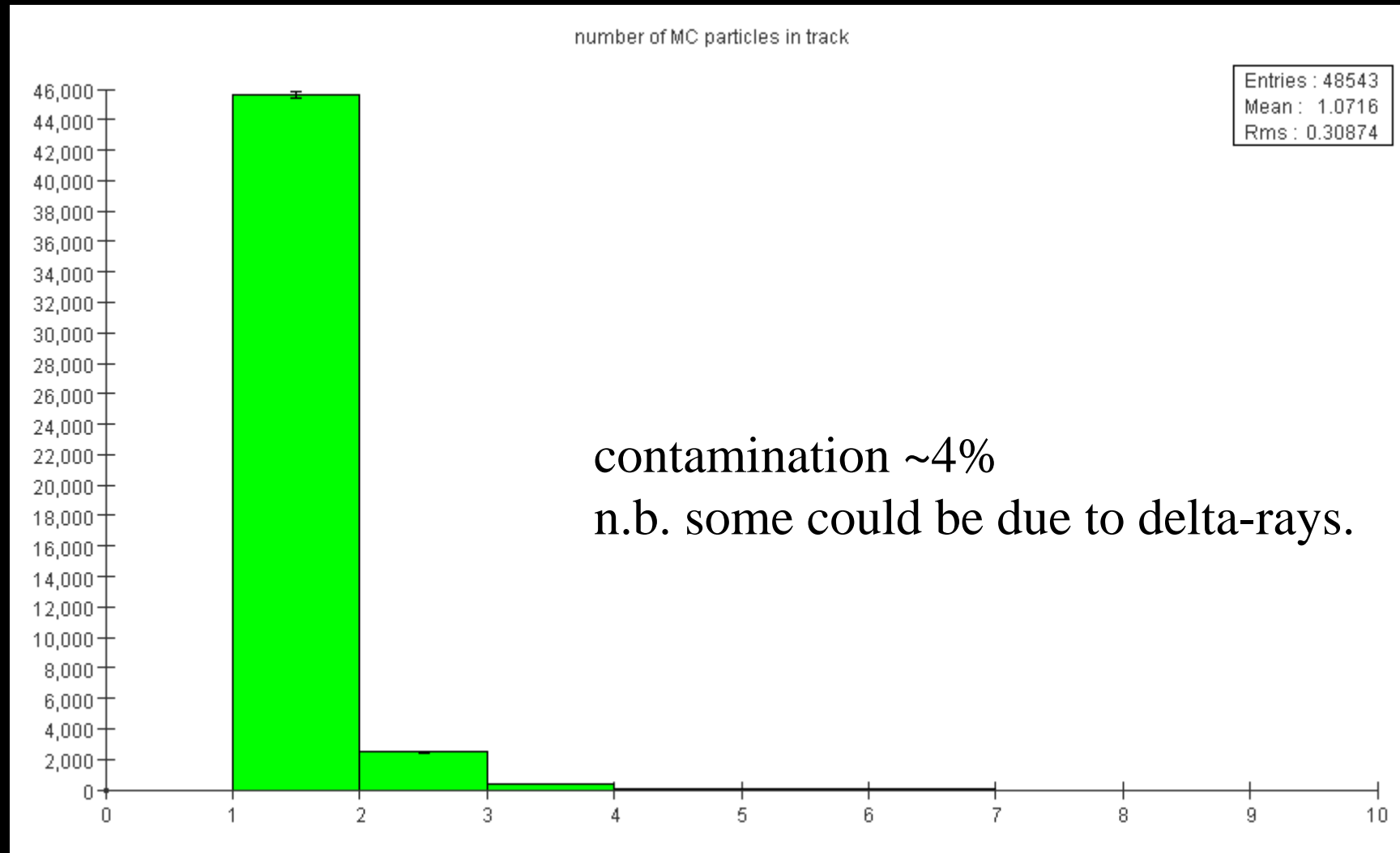
time (s) vs # tracks (1.7GHz)



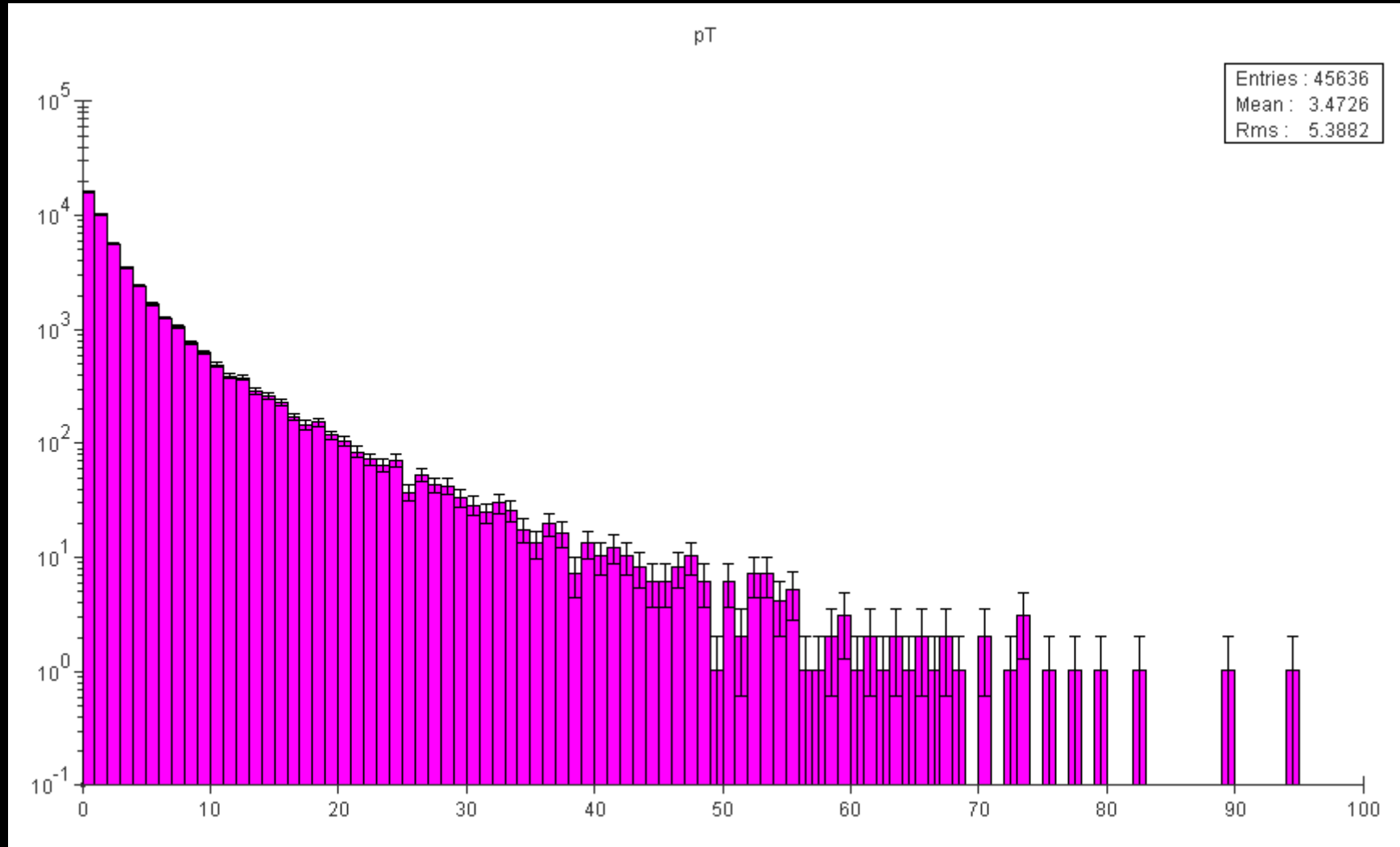
time(s) per track (1.7GHz)



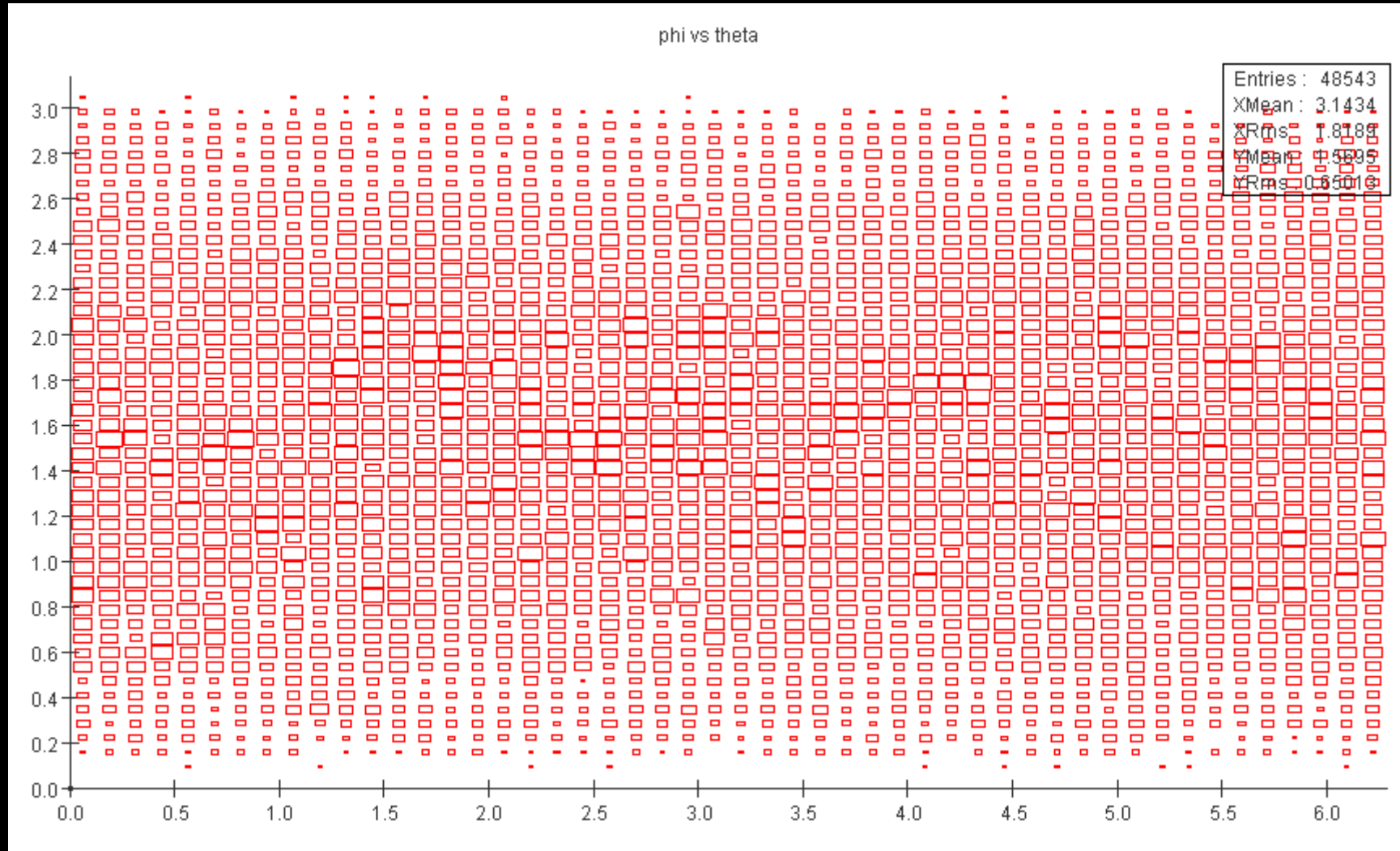
of MCParticles/track



$t\bar{t} \rightarrow \text{six jets } p_T$

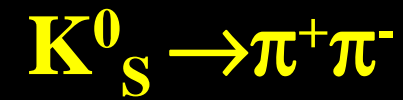


ϕ vs θ



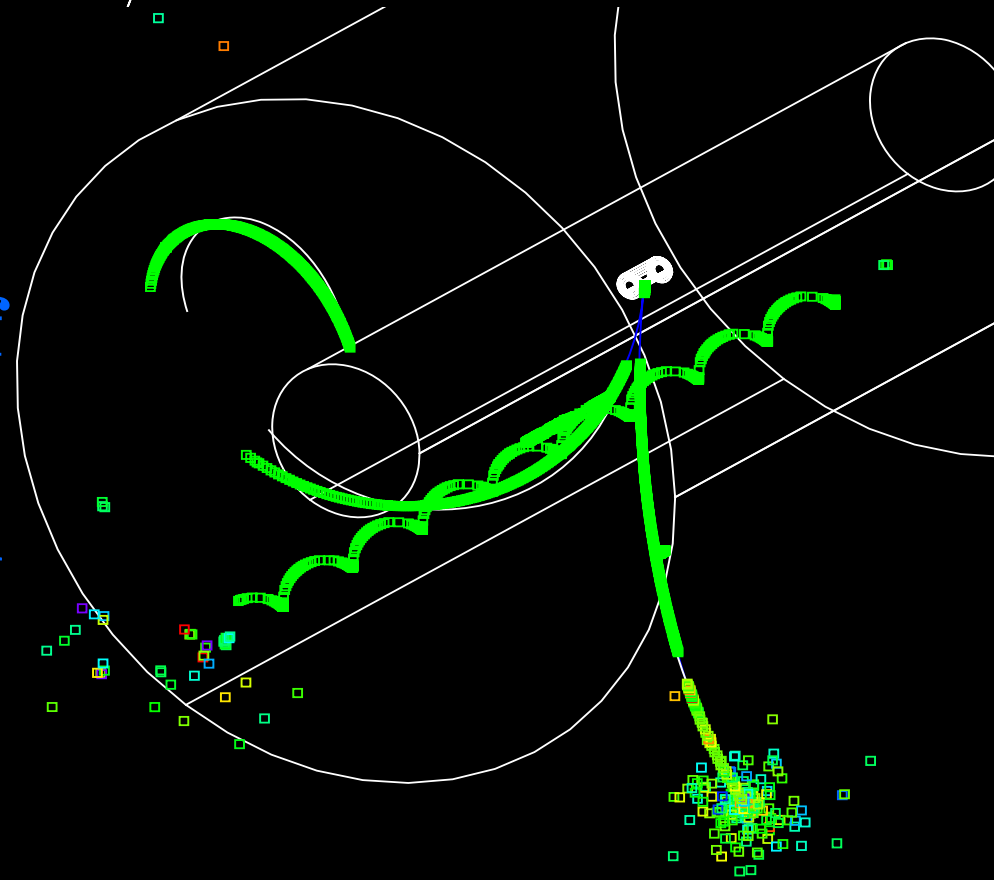
Application to TPC

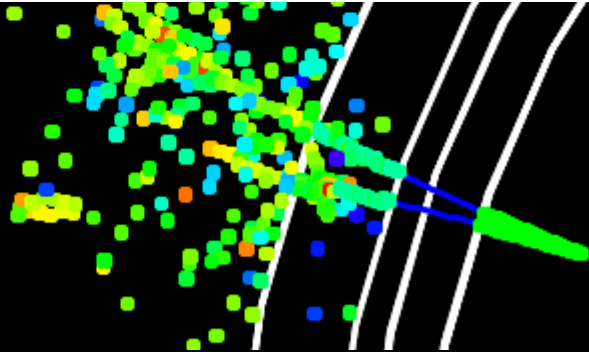
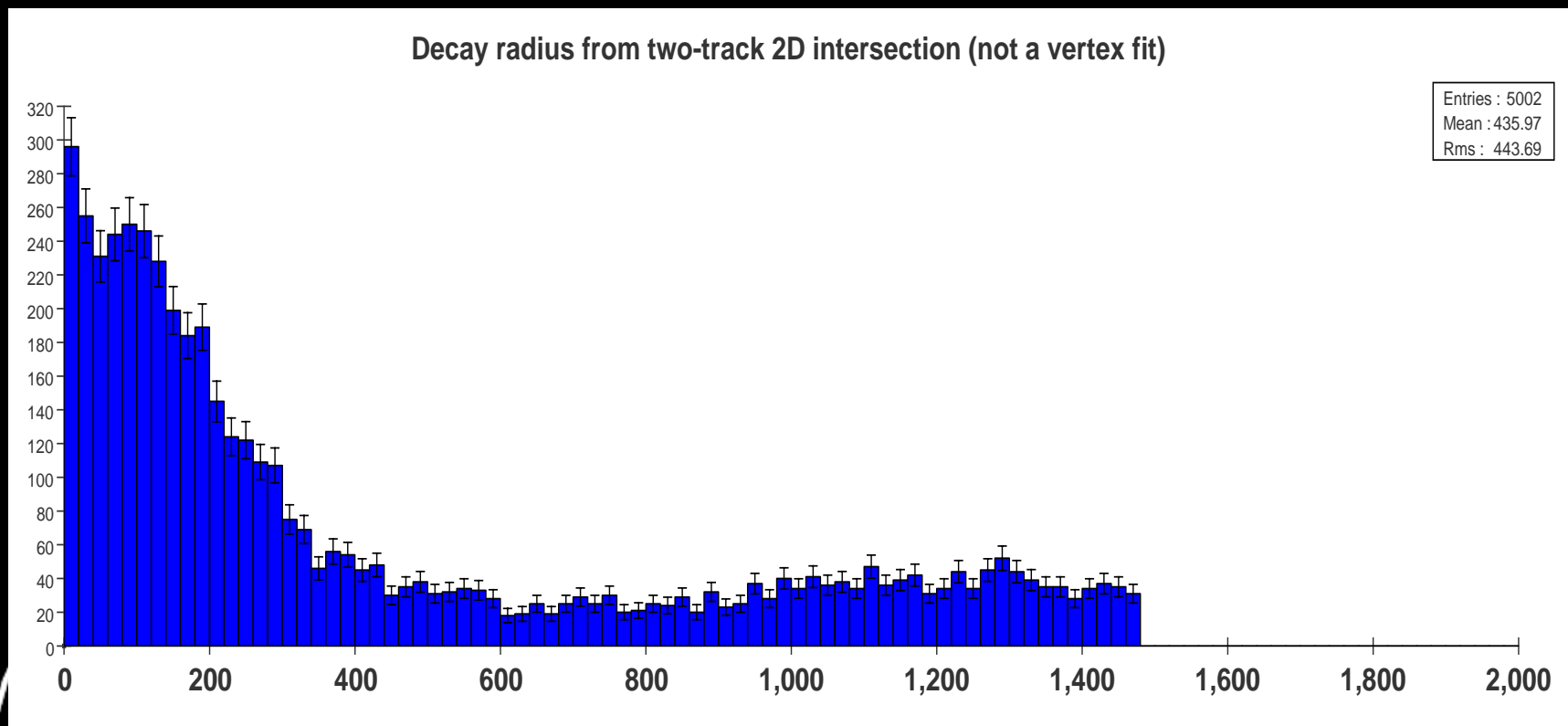
- ❖ Apply pattern recognition package to events generated with `ldcaug05`.
- ❖ 200 layers of 6.28 mm P10 (+ 5 VTX layers).
- ❖ Single hit per track per crossing of pad layer.
- ❖ Start from outermost layer, proceed inwards.
- ❖ First impressions quite favorable:
 - high efficiency
 - finds high-impact parameter tracks
 - finds low momentum tracks
 - will need to stitch together looper segments



❖ Finds both segments of the low momentum looper. Two tracks will have to be stitched.

- n.b. my problem with setting display





- ❖ Finds high-impact parameter tracks.
- ❖ V's even at large radii.



Summary

- ❖ A number of improvements has been made to the Geant simulation package slic.
- ❖ Pattern recognition based on 2-D measurements on surfaces is implemented.
- ❖ Fast, with high efficiency.
- ❖ Finding strategy depends only on layer topology of tracker (can mix and match barrel & disk).
- ❖ Fitting with full Kalman filter soon.
- ❖ Lots of work ahead to characterize and improve.

backup

Cylinder

- ❖ Surface defined coaxial with z , therefore specified by a single parameter r .
- ❖ Track Parameters: $(\phi, z, \alpha, \tan\lambda, q/p_T)$
- ❖ Bounded surface adds z_{\min} and z_{\max} .
- ❖ Supports 1D and 2D hits:
 - 1D Axial: ϕ
 - 1D Stereo: $\phi + \kappa z$
 - 2D Combined: (ϕ, z)

XY Plane

- ❖ Surface defined parallel with z , therefore specified by distance u from the z axis and an angle ϕ of the normal with respect to x axis.
- ❖ Track Parameters: $(v, z, dv/du, dz/du, q/p)$
- ❖ Bounded surface adds polygonal boundaries.
- ❖ Supports 1D and 2D hits:
 - 1D Stereo: $w_v * v + w_z * z$
 - 2D Combined: (v, z)

Z Plane

- ❖ Surface defined perpendicular to z, therefore specified by single parameter z.
- ❖ Track Parameters: $(x, y, dx/dz, dy/dz, q/p)$
- ❖ Bounded surface adds polygonal boundaries.
- ❖ Supports 1D and 2D hits:
 - 1D Stereo: $w_x * x + w_y * y$
 - 2D Combined: (x, y)