Track Reconstruction Upgrade Proposal

possible targets: STAR / eSTAR / EIC

Dmitry Arkhipkin and Yulia Zulkarneeva

Tracking Review Meeting, Apr 16th, 2013

Motivation

- STAR: tracking codes - **Sti, Stv**, KFParticle (?)
- **Sti tracker** – ported from ALICE@CERN
  - Kalman-based, modular, find'n'fit approach
  - Custom simplified TGeo geometry, constant field (?)
    - used to speedup tracking, requires subsystem-specific manpower
  - Has difficulties with tracking in forward direction (TBC?)
  - Validated Kalman codes
- **Stv tracker** – in-house STAR project
  - Kalman-based, monolithic, find'n'fit approach
  - Full TGeo geometry, 3D field (?)
  - Kalman codes not validated
  - Evergoing issues: hit errors, seed instabilities, questionable seed following, eta-phi distributions, (as discussed at weekly meetings)..
- **Is there any other possibilities out there?** Preferably:
  - Kalman-based (local fit vs global fit), modular
  - Full TGeo geometry and 3D magnetic field support
  - Validated codes for the track fitter / vertex reconstruction
  - Feature-enriched: multi-PID fitting, annealing fit to deal with outliers and overcorrections?
  - Not demanding in terms of code support

We think: YES

Track Reco: Proposed Setup, part I

disclaimer: developed off-hours, based on past experience, no STAR time spent on this..

Pattern Recognition: **Riemann** track finder

- Mapping of the hits to the Riemann sphere;
- suitable for TPC-like detectors in a solenoidal magnetic field;
- fast and robust, tolerant to TPC distortions;
- http://www-alt.gsi.de/informationen/wti/library/scientificreport2011/PAPERS/PHN-HSD-PANDA-04.pdf
- External Dependencies: none

Fitter: **Genfit** toolkit

- experiment-independent, modular toolkit with validated fitter code
  - includes Kalman Filter and Deterministic Annealing Filter (DAF)
- supports 1-d, 2-d (planar), 3-d (virtual plane perpendicular to track) hits;
- allows simultaneous fit with different mass hypothesis:
  - i.e. p/K/pi/e/mu with separate fit results and correct energy loss for each hypothesis
- includes Geane/RungeKutta track propagators, so could be used in track following too;
- Geane/RungeKutta track propagators use TGeo for geometry/material effects, and have B-field map adaptor, so same geometry and field to be used in Monte-Carlo and Reconstruction
  - any B-field is allowed, no constrains
- URL: http://genfit.sourceforge.net/Main.html
- URL: http://dx.doi.org/10.1016/j.nima.2010.03.136
- External Dependencies: none;

see next page for part II...

Track Reco: Proposed Setup, part II

Vertex Reconstruction finding and fitting: **Rave** toolkit

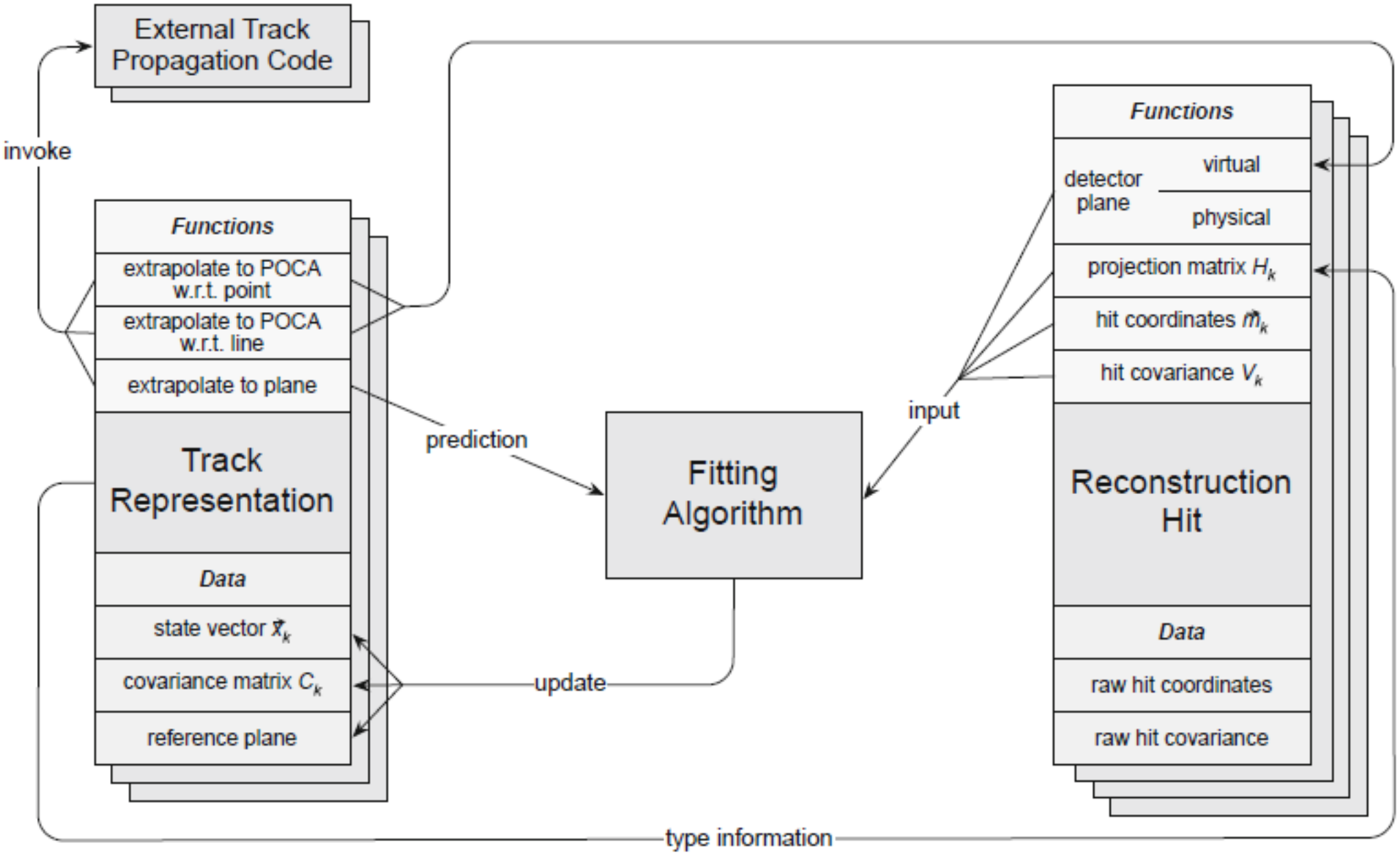
- detector-independent toolkit for vertex reconstruction
- includes adaptive vertex finder/fitter and kalman finder/fitter;
- note: Genfit includes Rave adaptor codes, so it is easy to push Genfit tracks into Rave and get vertex maid of Genfit tracks back;
- URL: https://rave.hepforge.org/
- URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4178956
- External Dependencies: CLHEP, boost

Web-based **Event Display** / Online Event Display

- browser-based Event Display, built using WebGL (true 3D in browser);
- supports Tracks and EMC hits;
- could be used as Run-time event display, using [data_format] -> JSON converter (there is one for STAR);
- not published anywhere yet, developed off-hours (so no direct dependency on STAR);
- URL: http://www.star.bnl.gov/~dmitry/eventdisplay/
- Browser Dependency: Google Chrome or Firefox
  - there is a flag to enable WebGL in Safari, see: https://discussions.apple.com/thread/3300585?start=0&tstart=0

Genfit, part I

C. Höppner et al. / Nuclear Instruments and Methods in Physics Research A 620 (2010) 518–525



Genfit: track representations

Currently available in GENFIT:

- **GeaneTrackRep2**:
  - Based on FORTRAN code GEANE from CERN's VMC package
  - [M. Innocente, et al., GEANE: ..., CERN Program Library, W5013-E (1991)]
- **RKTrackRep**:
  - Runge-Kutta track follower ported from GEANT3 to C++
  - extrapolate to: point, line, cylinder, detector plane
- Both track representations are validated

Parameterizaton: in detector plane spanned by vectors u and v:

- u, v, du/dw, dv/dw, q/p

Both classes include:

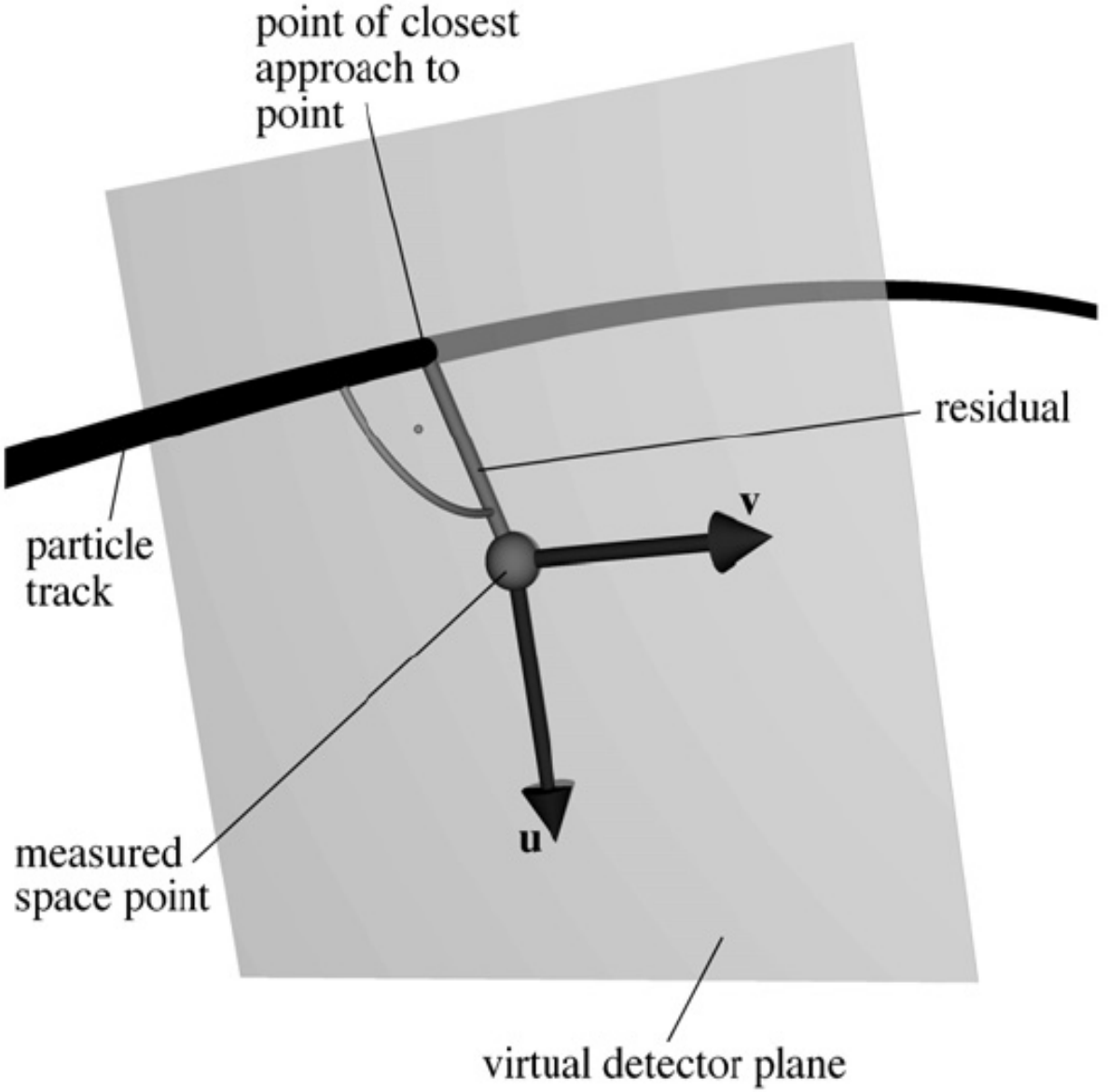
- Generic magnetic field interface
- Geometry / material implementation via ROOT's TGeo
- Material effects:
  - Bethe-Bloch, energy-loss straggling, multiple scattering, Bremsstrahlung

Genfit, part II

fit minimizes orthogonal distance to space point

Progressive Fittng Algorithm - Kalman Filter:

- include information of hits into track parameters / covariance one by one
- fittng step: inclusion of one hit k
- extrapolate parameters / covariance into detector plane
- update track parameters / covariance with weighted mean between track and hit parameters / covariances
- after inclusion of all hits:
- χ2-minimized track parameters in last detector plane



Rave

A detector-independent toolkit for vertex reconstruction
(RAVE = ”Reconstruction (of vertices) in Abstract, Versatile Environments”)

Representative robust algorithms

- `AdaptiveVertexFitter` (AVF):
  A robust generalization of the Kalman filter, iteratively downweighting the contribution of outlier tracks to the objective function (“soft assignment”). The extra weights w_i on the reduced residuals r_i are calculated by a Fermi function with cutoff parameter r_{cut}. In addition, a deterministic annealing schedule with decreasing “temperature” T is introduced in order to avoid falling into local minima:

$$w_i(r_i, T) = \frac{e^{-r_i^2/2T}}{e^{-r_i^2/2T} + e^{-r_{cut}^2/2T}} = \frac{1}{1 + e^{(r_i^2 - r_{cut}^2)/2T}}$$

  Iterations (index k, omitted above) start with $w_{i,1} = 1$ (least-squares). For $k > 1$, the $w_{i,k} = w_i(r_{i,k-1}, T_k)$, with $T_k \leq T_{k-1}$ defined by the annealing schedule. For $T \to 0$, the Fermi function approximates the Heaviside function, and the assignment turns into a “hard” one ($w_i = 1$ or 0).

- `MultiVertexFitter` (MVF):
  This robust estimator is a generalized AVF, simultaneously fitting n vertices by “soft assignment” of each track to more than one vertex. The extra weights w_{ij} on the reduced residuals r_{ij} w.r.t. vertex j are

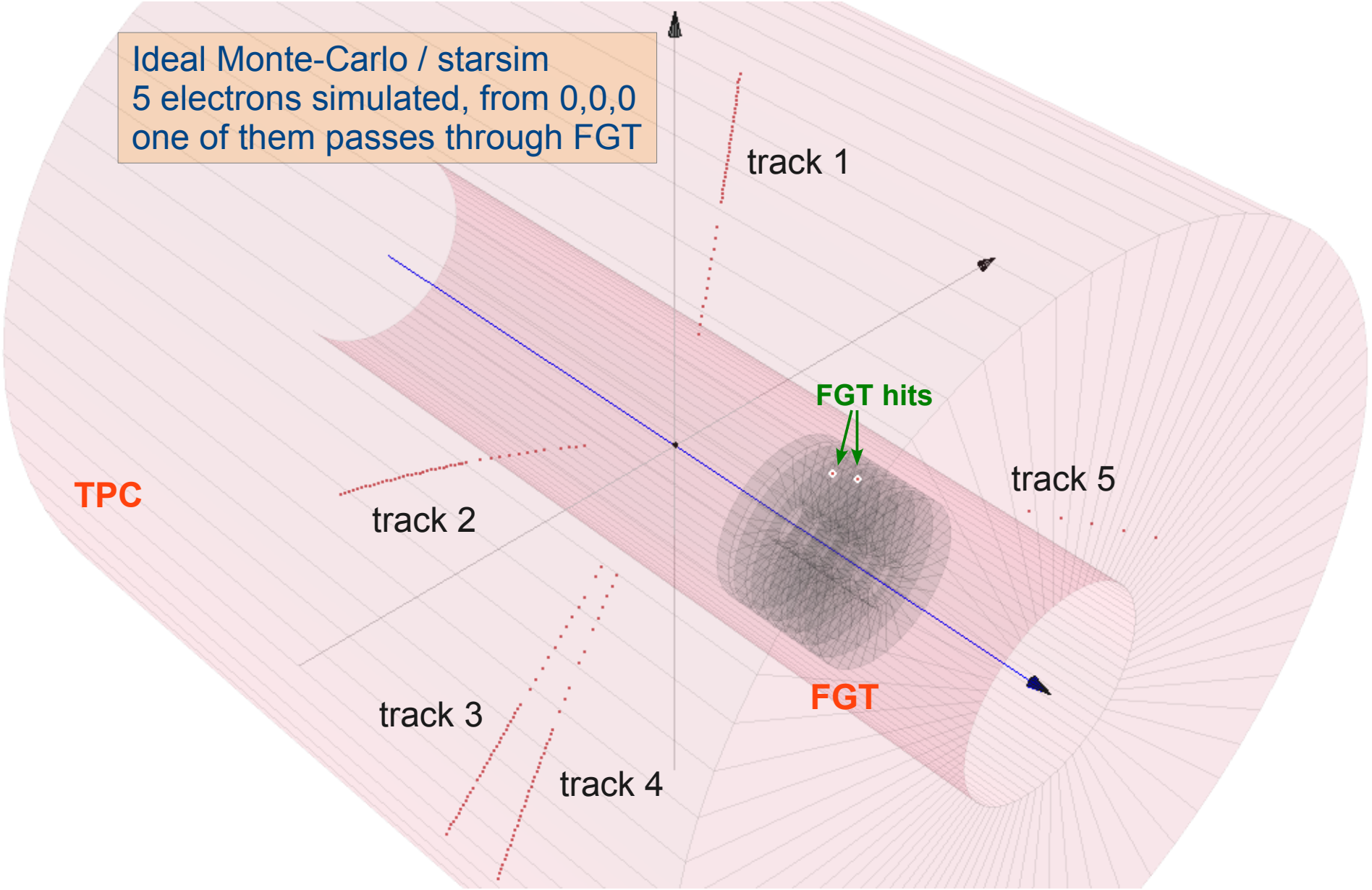
$$w_{ij}(r_{ij}, T) = \frac{e^{-r_{ij}^2/2T}}{\sum_{\ell=1}^{n} e^{-r_{i\ell}^2/2T} + e^{-r_{cut}^2/2T}}$$

Example: step by step walk through

see next four slides..

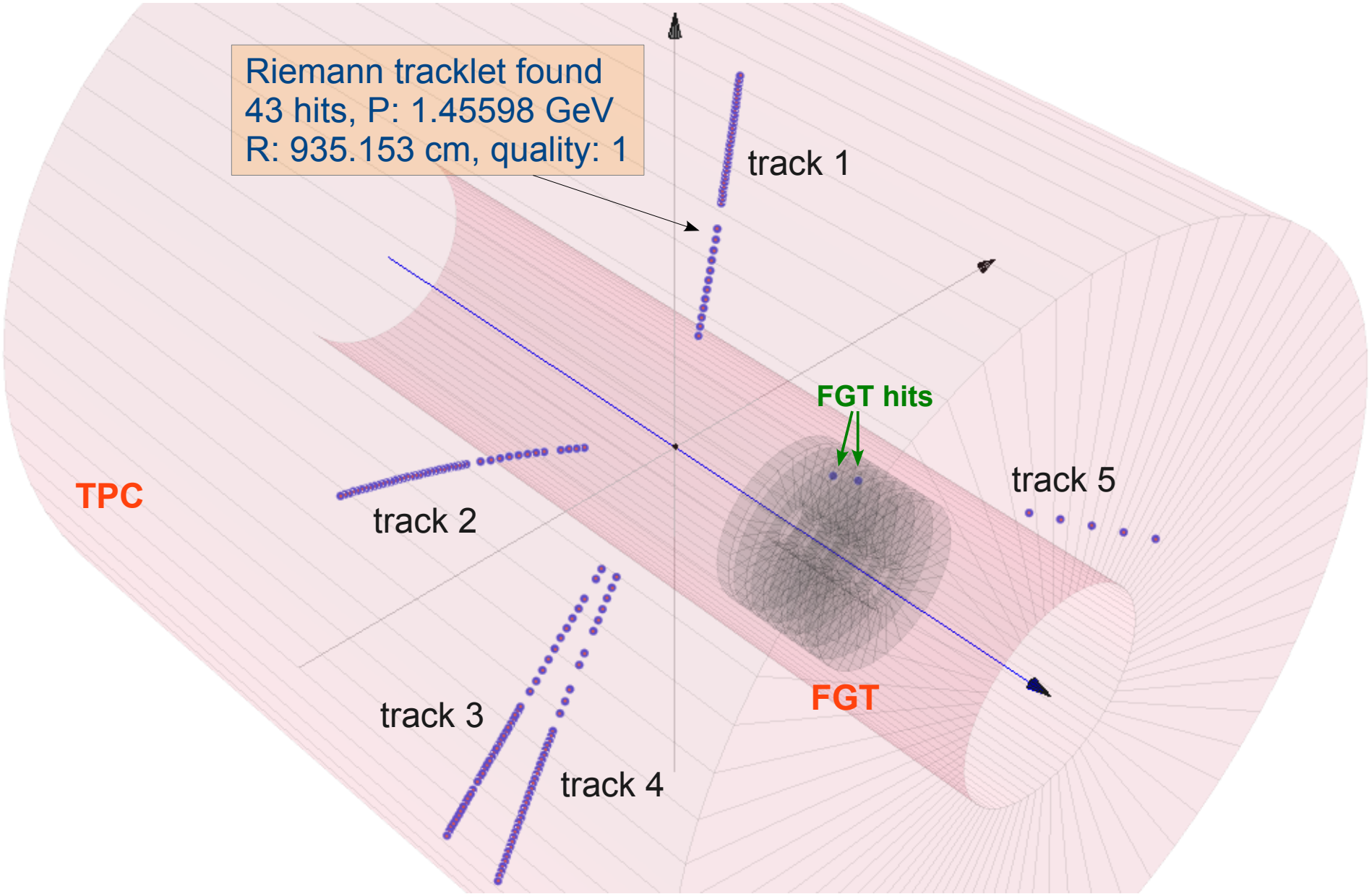
/ screenshots from simple TEve-based event display written in 15 minutes /

Raw Event: hits from **TPC** and **FGT**



red markers represent positions of TPC and FGT hits imported from StEvent

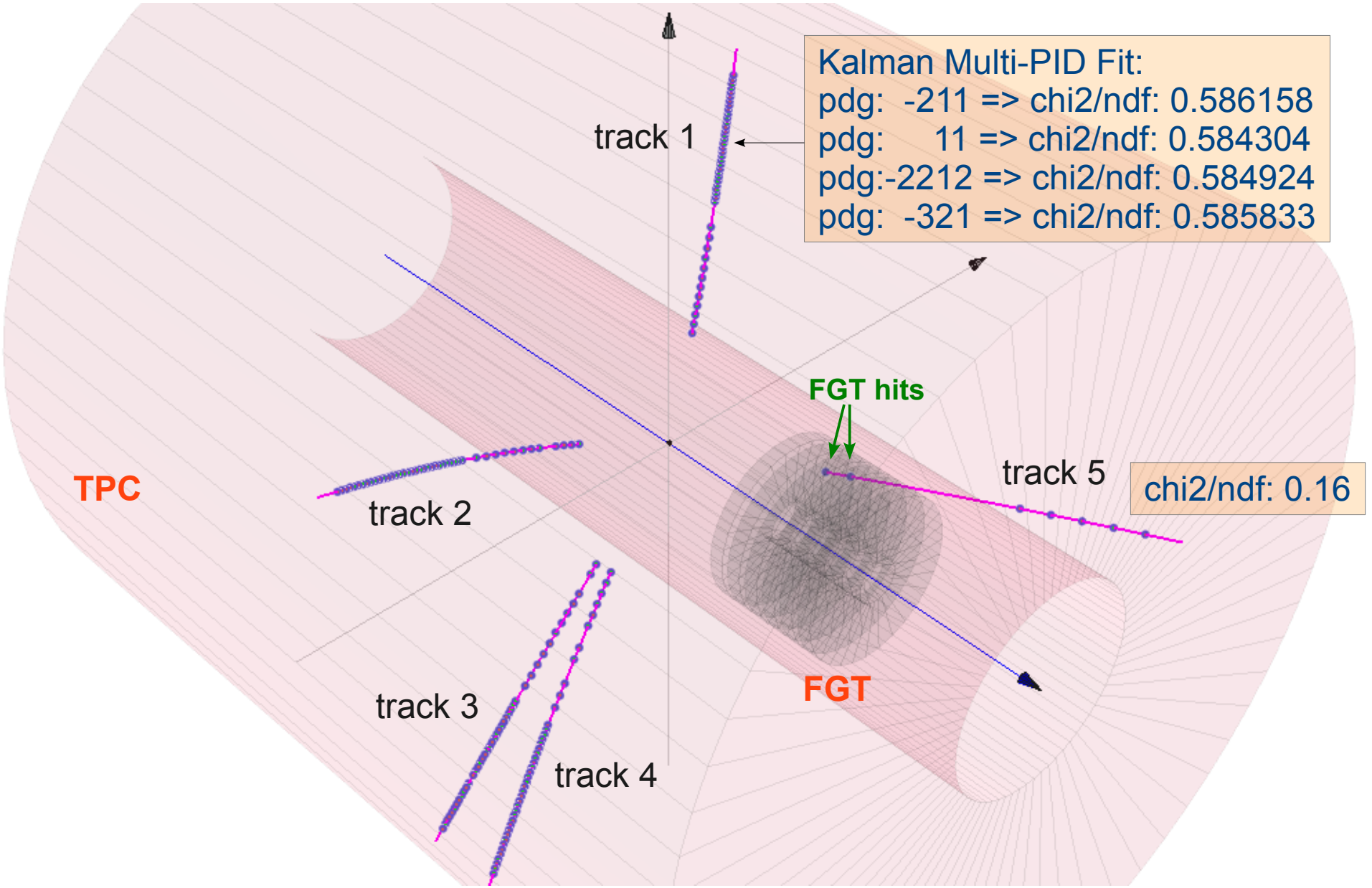
I. Pattern Recognition: **Riemann**



blue markers indicate positions of TPC and FGT hits, forming tracks found by Riemann algo.

Riemann: no material effects, constant field, simple fit..

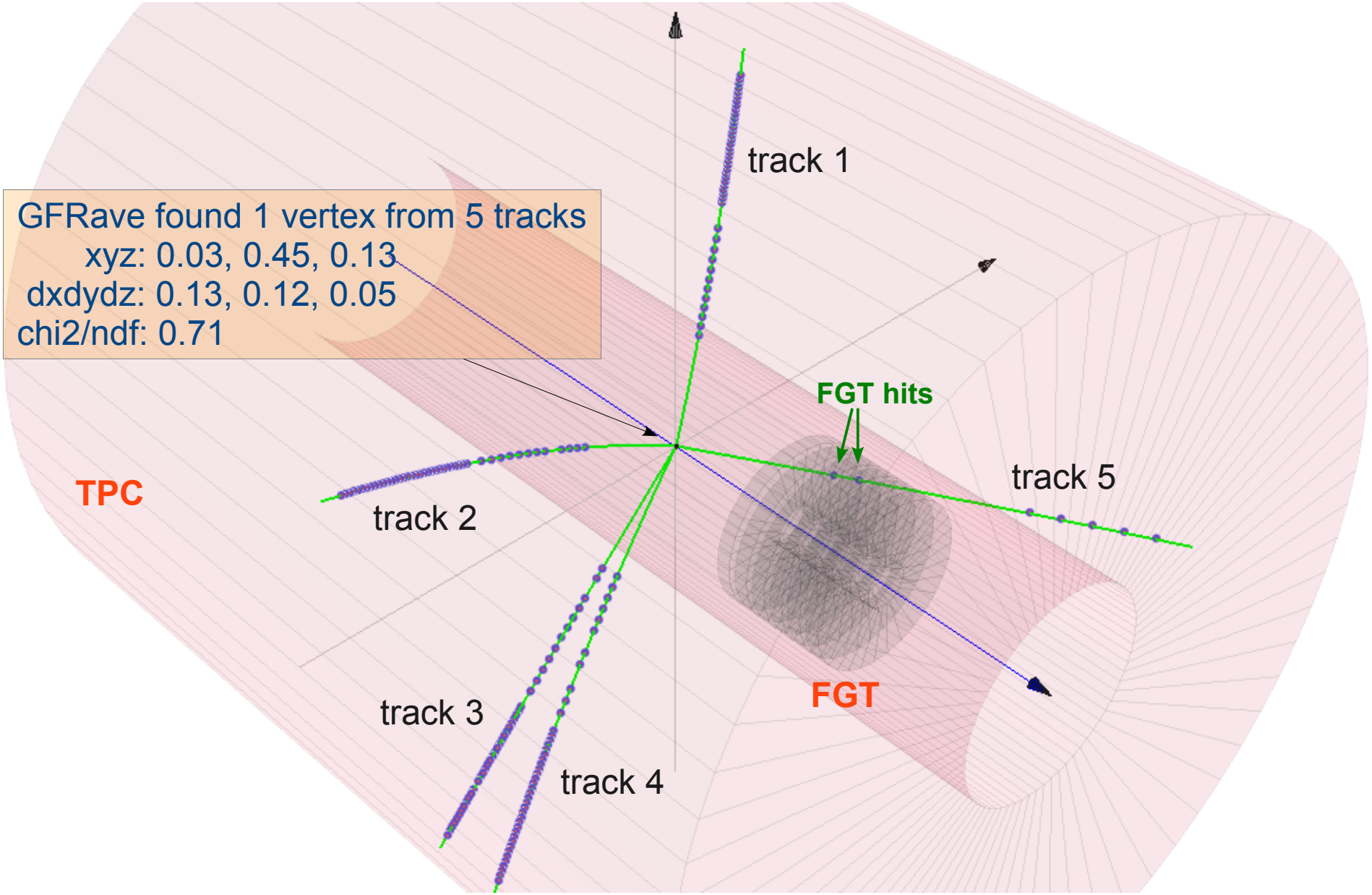
II. Track Fit: **Genfit** (Kalman/DAF)



purple lines show track fit results

Genfit: full material effects (TGeo), 3D Mag.Field, Kalman/DAF fit, multi-PID fitting

III. Vertex Finding and Fitting: **Rave**

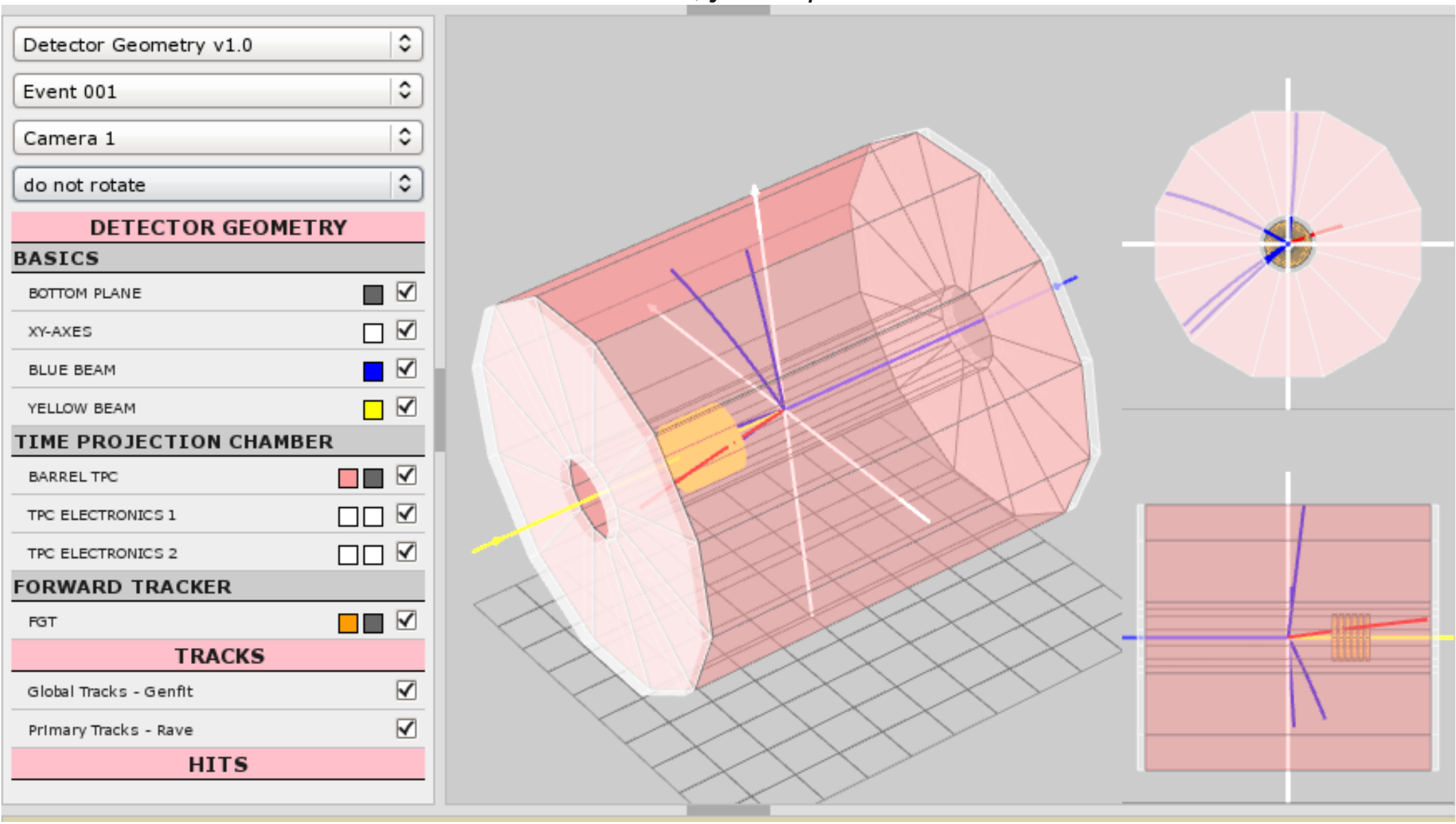


green lines show primary tracks and vertex, found by Rave

Rave: full material effects, 3D magnetic field, annealing vertex reco and fitting algorithms

IV: Web-based Event Display

same event of 5 electrons, just exported in JSON format

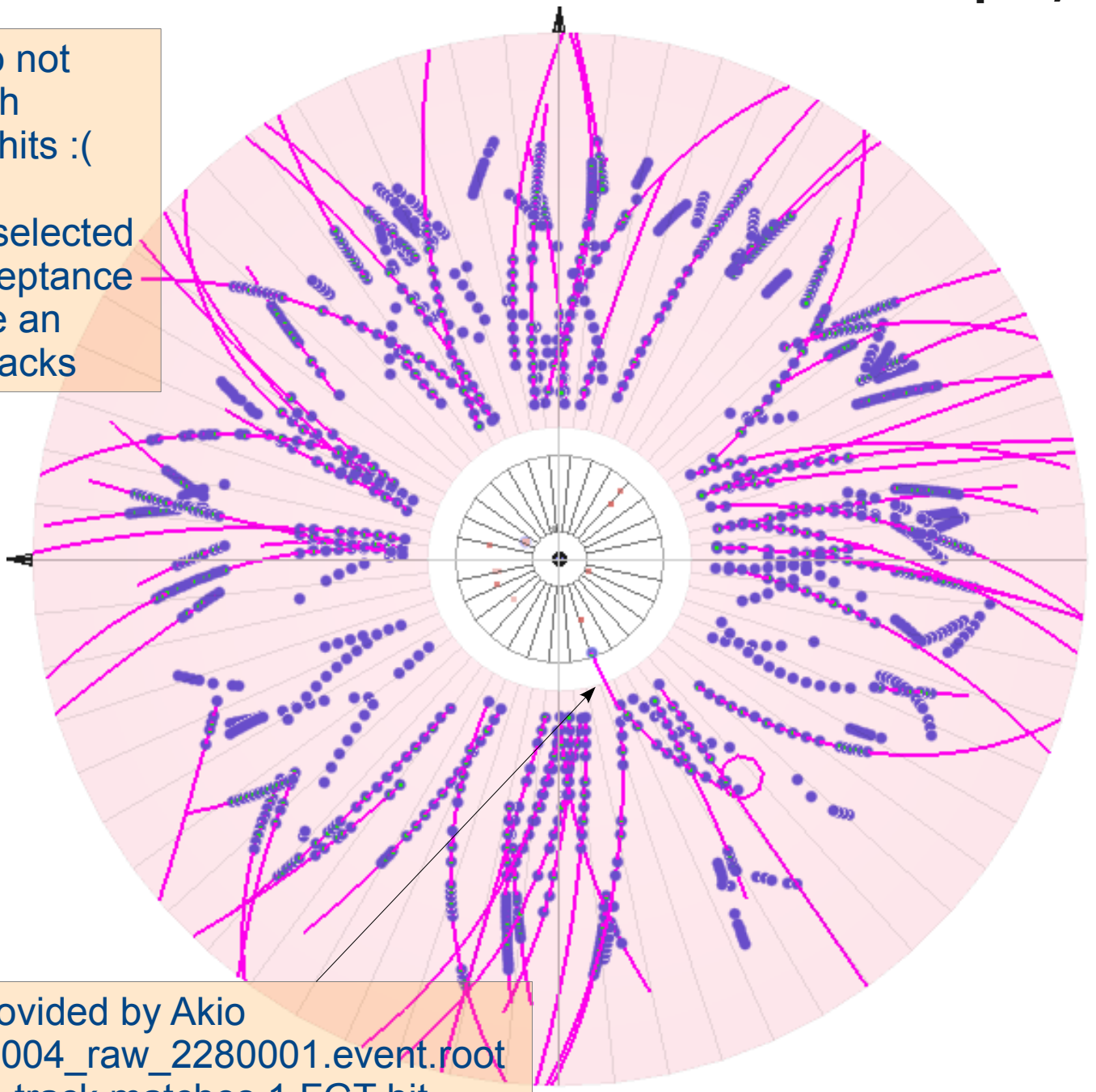


Convenient way to visualize online data, or some particular reco event

http://www.star.bnl.gov/~dmitry/eventdisplay/

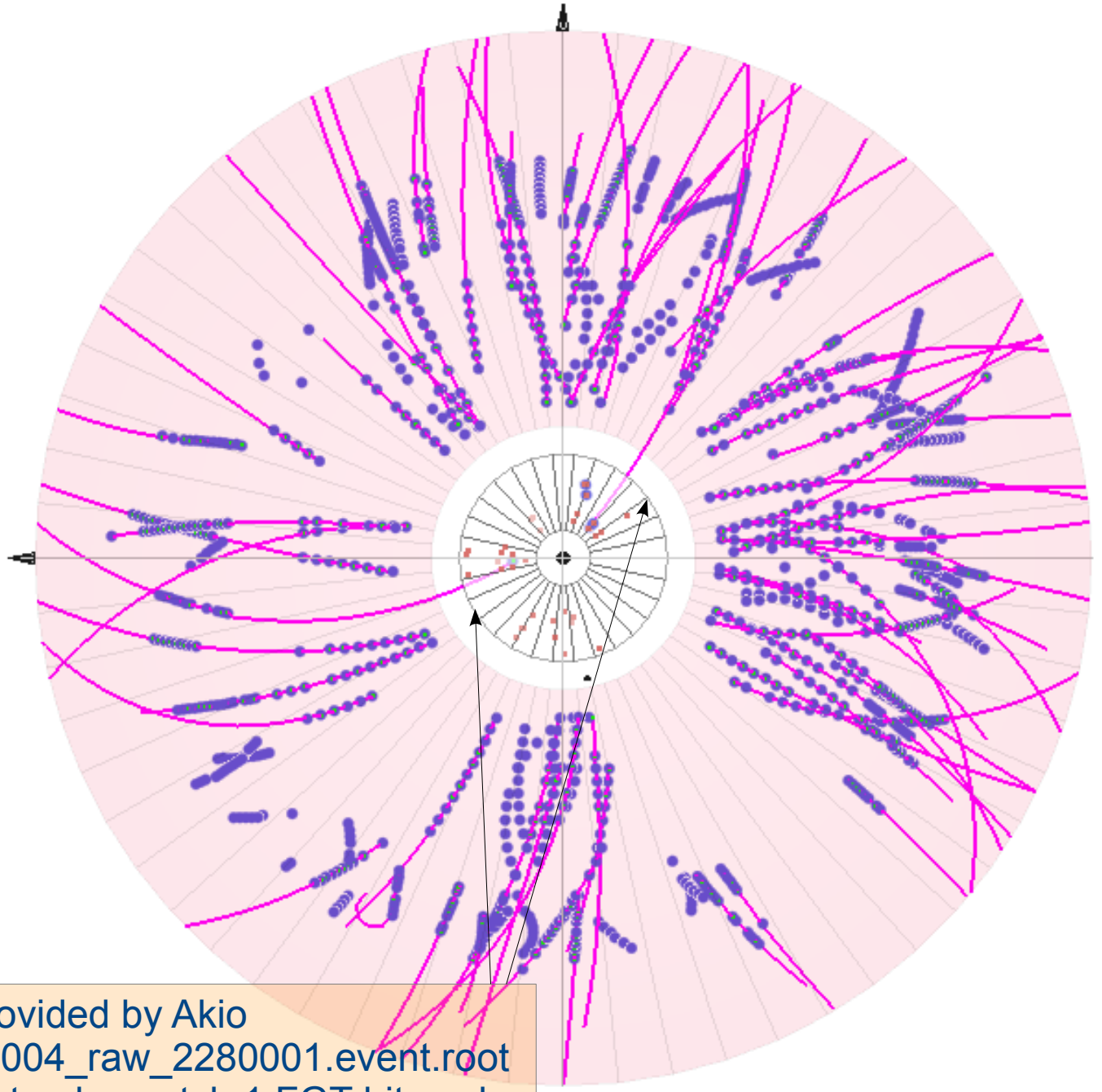
FGT: real data reco attempt, I

Most events do not have tracks with matching FGT hits :(
Some do :)
Event hits are selected in the FGT acceptance cone - could be an issue for soft tracks



Data kindly provided by Akio
st_WE_14094004_raw_2280001.event.root
Event N9, one track matches 1 FGT hit

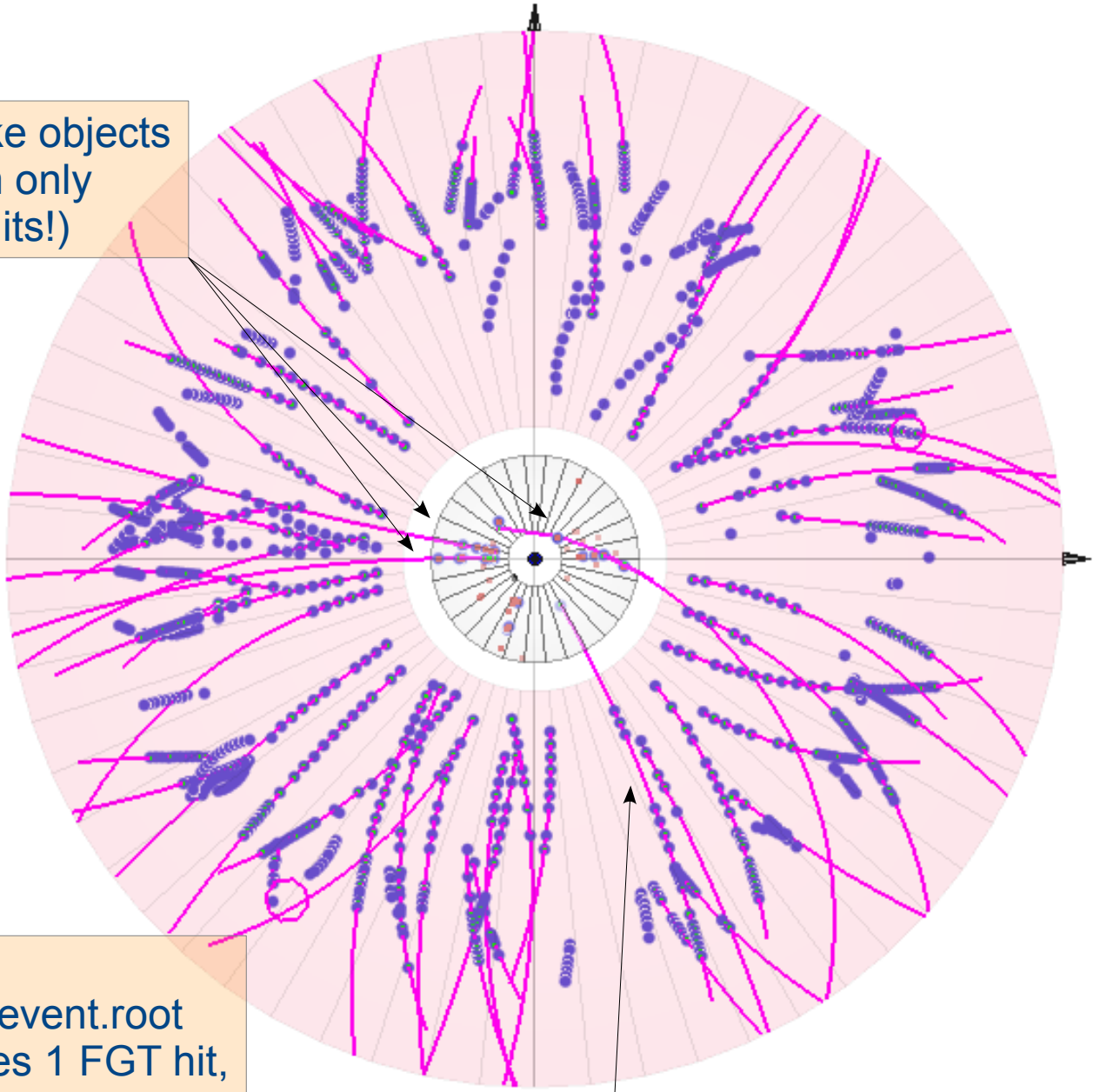
FGT: real data, reco attempt, II



Data kindly provided by Akio
st_WE_14094004_raw_2280001.event.root
Event N5, two tracks match 1 FGT hit each

FGT: real data, reco attempt, III

Suspicious track-like objects forming tracks from only one FGT disk (5+ hits!)



good track/match

Data kindly provided by Akio
st_WE_14094004_raw_2280001.event.root
Event N10, one TPC track matches 1 FGT hit, three FGT-only tracks,
composed of hits from just one FGT plane ?!

Summary & Outlook

- Track reconstruction setup, based on validated components was proposed
  - pattern reco: Riemann
  - fitter: Genfit, externally maintained
  - vertexing: Rave, externally maintained
  - event displays: simple TEve + web-based WebGL
- Prototype of the setup was written based on the existing STAR framework
  - includes all stages: pattern recognition, fitting, vertexing, web-based event display, implemented as STAR Makers
  - somewhat tested on both MC and Reco STAR data
  - includes simple built-in event display based on TEve
  - Includes export to web-based-event display
  - Fully VMC ready..
- May serve as a next-generation feature-rich track/vertex reconstruction package, with minimal maintenance and support
- Genfit and Rave are considered for/used in experiments like ILD@ILC, CBM/PANDA@FAIR, Belle II, g-2/EDM..