Primary Vertex Reconstruction in the ATLAS Experiment at LHC

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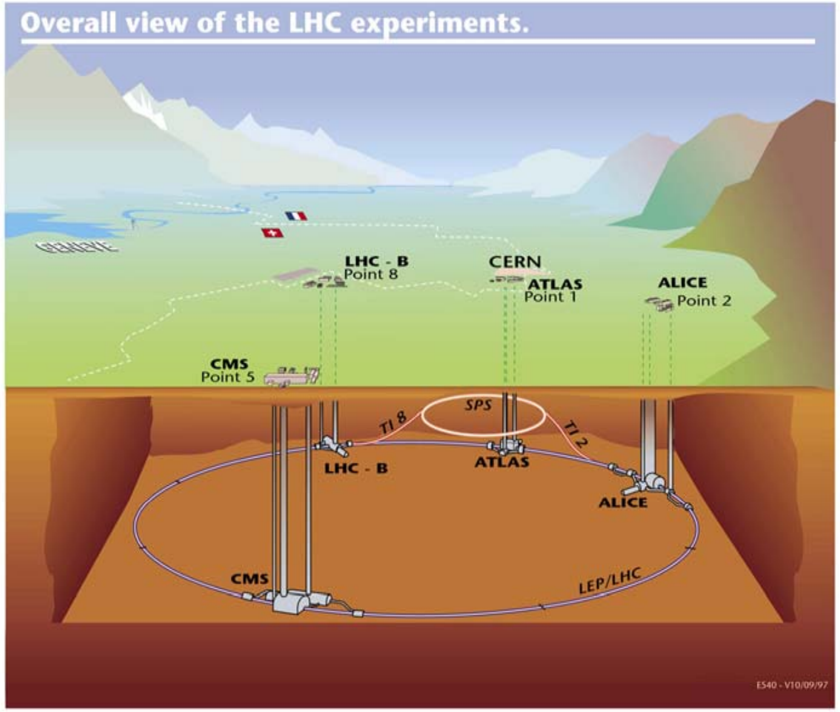
ATLAS and the LHC Environment

- LHC Environment:
  - 14 TeV pp collisions at 40 MHz
- Design Luminosity
  - 4.6 pile up events at $L=2\cdot10^{33}cm^{-2}s^{-1}$
  - about 24 pile up events at $L=10^{34}cm^{-2}s^{-1}$
- The beam spot is described by Gaussian parameters:
  - $\sigma_X=\sigma_Y=15\mu m$
  - $\sigma_Z=5.6cm$



- For many physics analyses, a better knowledge of the primary vertex is required.
  - Channels like $H\rightarrow 4l, H\rightarrow\gamma\gamma$, etc..
  - b- and τ-tagging
  - reconstruction of exclusive b-decays
  - measurement of lifetimes: b-flavoured hadrons, τ's, etc...

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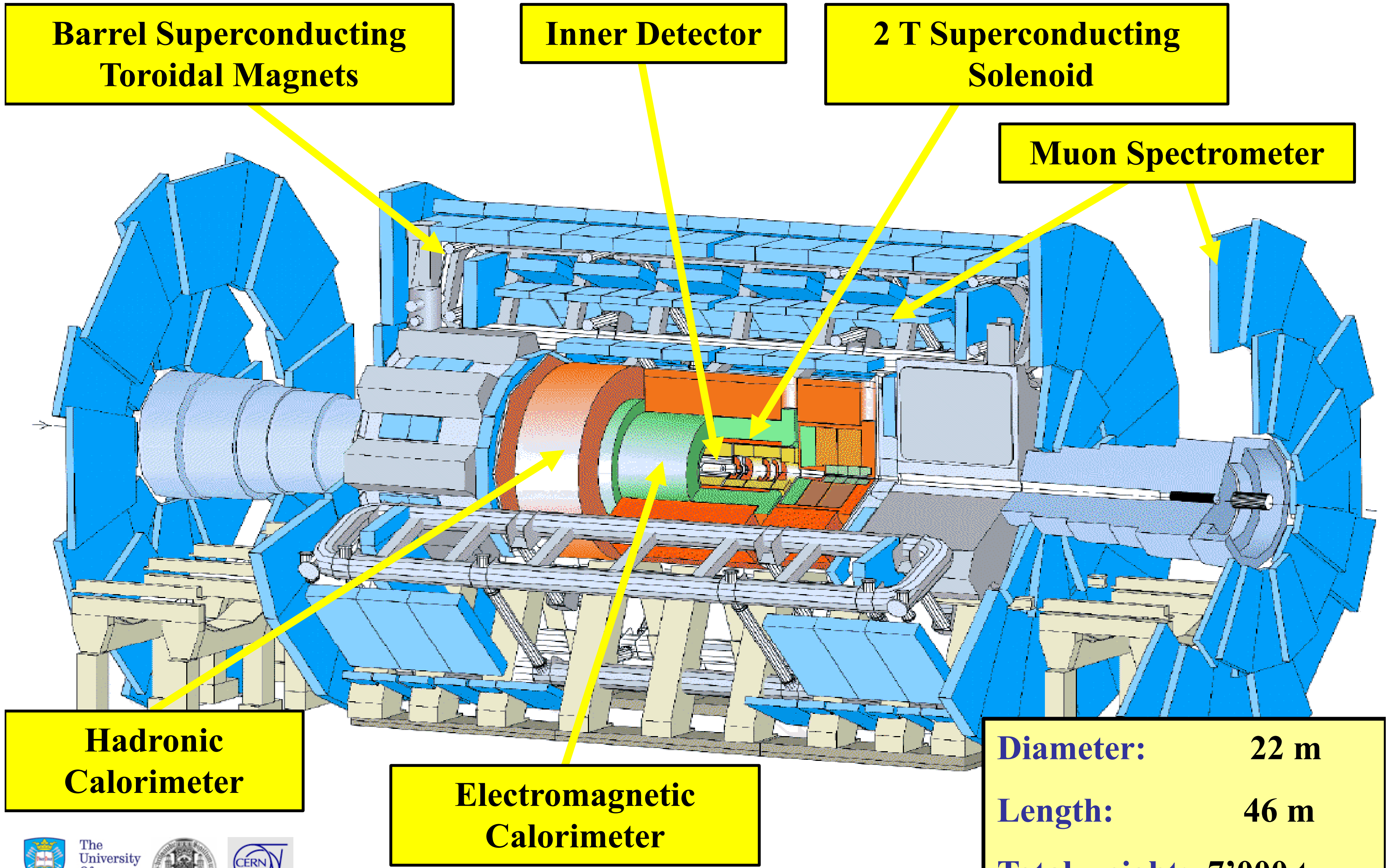
The ATLAS Experiment



Diameter:	**22 m**
Length:	**46 m**
Total weight:	**7'000 t**

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ATLAS Inner Detector

Transition Radiation Tracker

Based on the use of straw detectors separated by layers of a plastic radiator. Straws are 4 mm in diameter and up to 150 cm in length. 50’000 straws in barrell and 320’000 radial straws in the endcaps. About 36 measurements per trajectory.

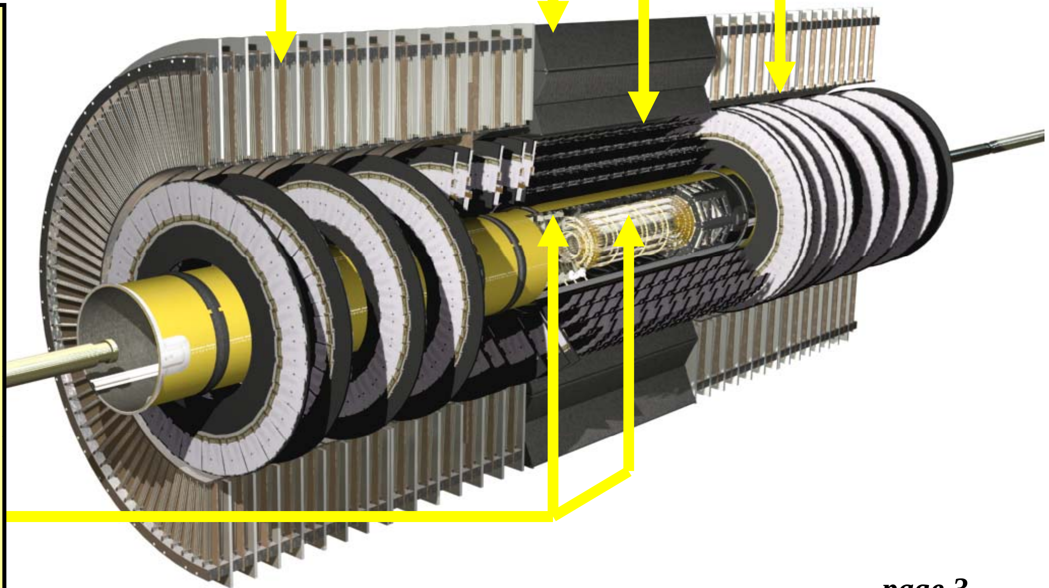
Semiconductor Tracker

4 barrel layers of silicon microstrip detectors. 9 endcap wheels (each side). Provide measurements in both Rφ and z.

Pixel Detector

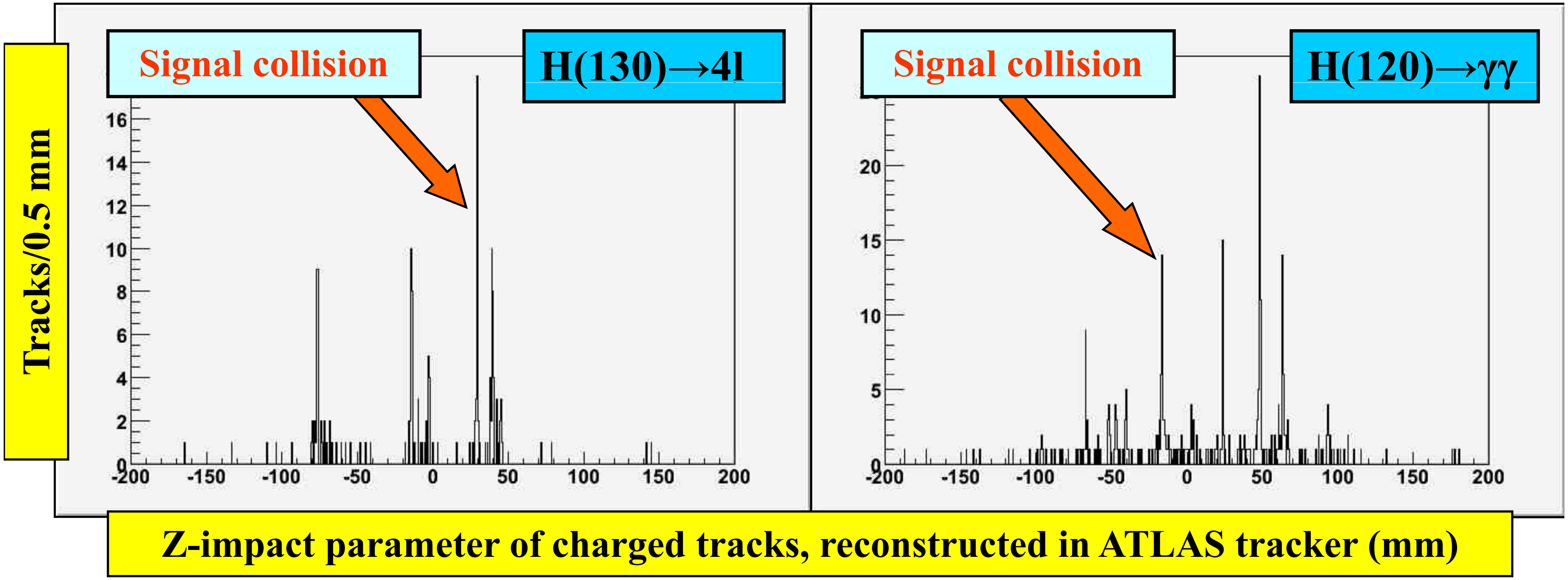
High precision and granularity measurements close to the interaction point, early separation of particle trajectories.

3 barrel layers at radii of 5, 8.8 and 12.2 cm and 3 endcap disks (each side). Rφ resolution ~12μm.



Identification of Primary vertices

- Comparing to minimum bias events, signal events usually have a higher track multiplicity and transverse momentum.
- In some analyses however, it is not true and this selection may not be optimal or introduce biases.
  - In such case, it is desirable to reconstruct all primary vertices and select the signal one using some additional information: leptons, photons, jet pointing etc ...



Primary Vertex Reconstruction

- Can generally be subdivided in two stages
  - Primary vertex finding: association of reconstructed tracks to a particular vertex candidate.
  - Vertex fitting: reconstruction of the actual vertex position and its covariance matrix, refit of incident tracks.

- Often, these two stages are not distinguishable
  - Algorithms exhibiting both "Fitting after finding" and "Finding through fitting" are implemented in ATLAS software.

- Whatever the internal differences of algorithms are, they should
  - ...be implemented in a common user-friendly interface
  - ...use the same Event Data Model

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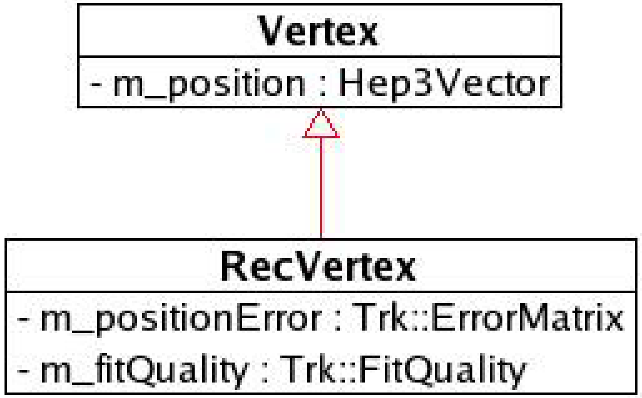
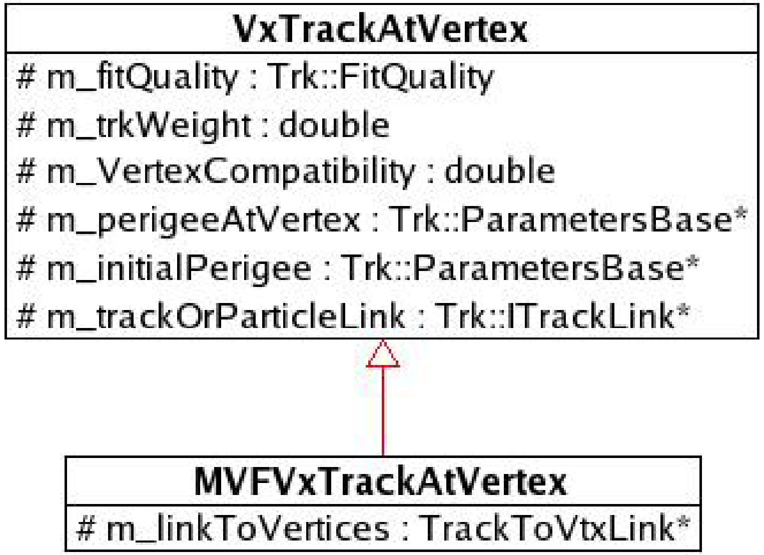
Event Data Model

Core classes..

Classes storing the position, covariance matrix and a fit quality of the reconstructed vertex.



A class describing a track used in a vertex fit. Stores the link to initial track objects, the trajectory state refitted with the knowledge of the vertex, the track weight and compatibility with respect to the vertex.

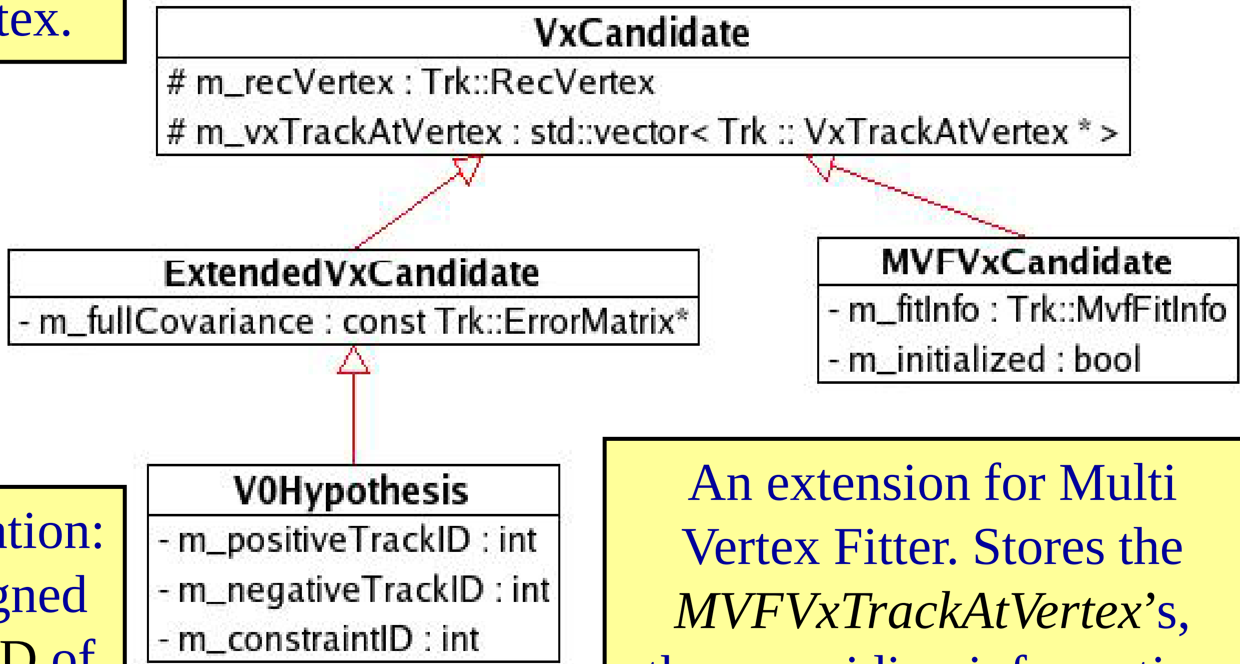


An extension for Multi Vertex Fitter, storing the information about the association of track to a set of vertices.

Event Data Model contd.

A base class, storing the reconstructed vertex position, covariance matrix and a vector of tracks fitted to the vertex.

Representations of reconstructed vertex ...



In addition, the full covariance matrix, including track-to-track and track-to-vertex correlations is stored.

Constrained fitting application: a mass hypothesis is assigned to incoming tracks. The ID of the constraint hypothesis is stored.

An extension for Multi Vertex Fitter. Stores the *MVFVxTrackAtVertex*'s, thus providing information about association of tracks to multiple vertices.

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Common interfaces

IVertexFinder

```
+ findVertex(trackTES : TrackCollection) : VxContainer
```

A base class for the primary vertex finders. A primary vertex finder analyses a provided track collection, returning the a collection of reconstructed vertices.

A base class for vertex fitters. Input of the fit method: a set of tracks and (optionally) a starting point of the fit. A possibility to use a beam constraint is provided. Output: a reconstructed *VxCandidate*.

IVertexFitter

```
+ fit(tracks : std::vector<const Trk::Track*>) : VxCandidate
+ fit(tracks : std::vector<const Trk::Track*>, startingPoint : Vertex) : VxCandidate
+ fit(tracks : std::vector<const Trk::Track*>, constraint : RecVertex) : VxCandidate
```

IVertexSeedFinder

```
+ findSeed(tracks : std::vector<const Trk::Track*>) : Vertex
```

A base class for algorithms estimating the starting point of the vertex fit.

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Common interfaces contd.

IVertexLinearizedTrackFactory
+ linearize(theTrack : VxTrackAtVertex, linPoint : Vertex) : void

A base class for calculation of parameters of linearization of measurement equation: dependence of the track parameters on the vertex position and track momentum at the vertex.

A base class for implementation of iterative vertex updators. Concrete implementations allow to add or remove a single track to or from a vertex candidate.

IVertexUpdator
+ add(vertex : VxCandidate, track : VxTrackAtVertex) : void
+ remove(vertex : VxCandidate, track : VxTrackAtVertex) : void

IVertexTrackUpdator
+ update(track : VxTrackAtVertex, vertex : RecVertex) : void

A base class for implementation of iterative track updators. Concrete implementations allow to refit a trajectory with the knowledge of the reconstructed vertex position.

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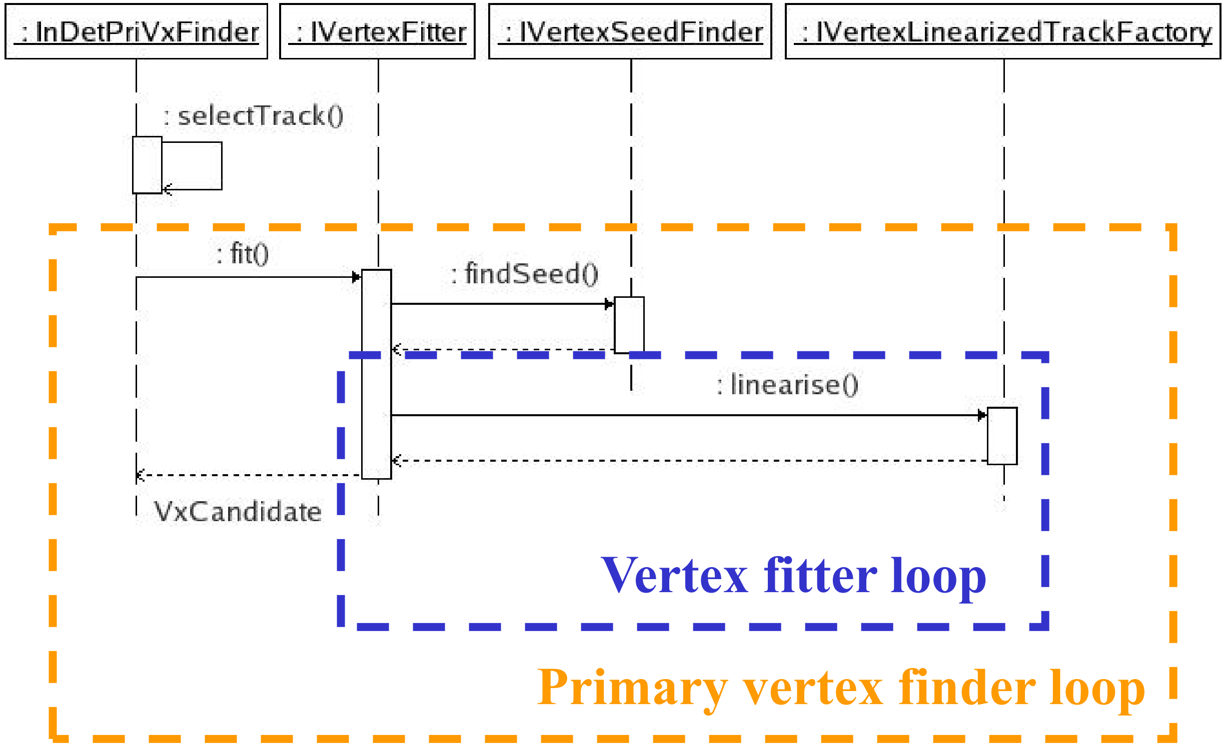
InDetPriVxFinderTool

(fitting after finding approach)

Clustering: Selects well reconstructed charged tracks, compatible with the bunch crossing region.

Searches for track clusters in Z using a sliding window method.

Clusters are considered to be independent vertex candidates.



Vertex fitting: Vertex candidates are fitted with one of the fitters provided.

The tracks least compatible with a given candidate are removed and the candidate refitted. Iterations continue until convergence.

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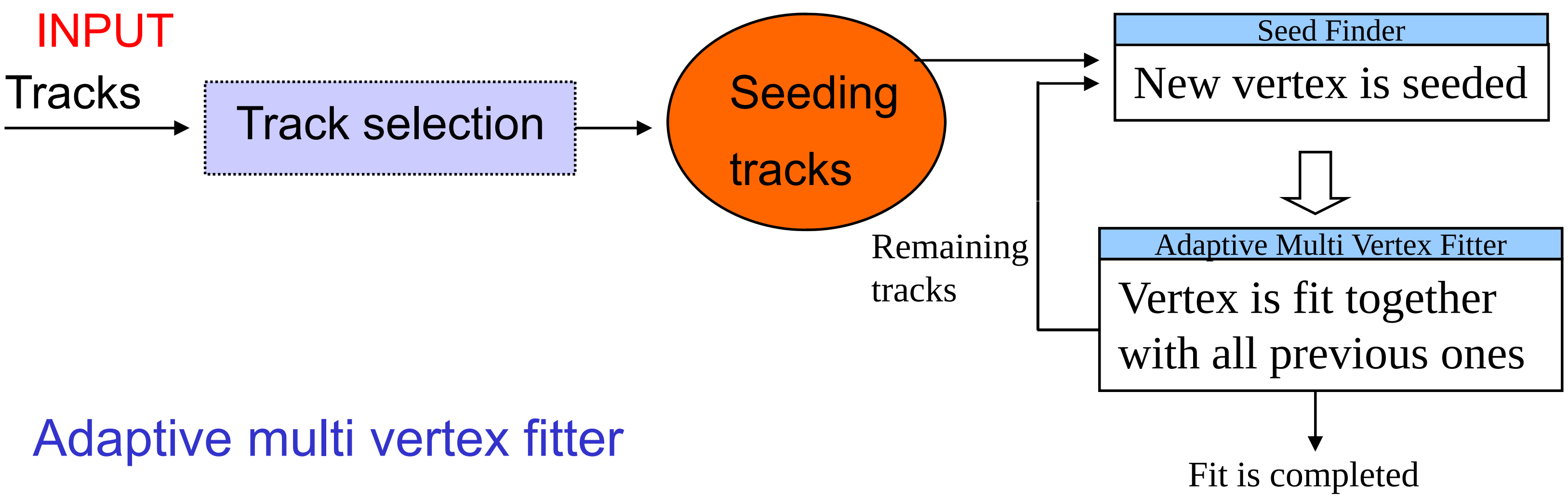
InDetAdaptiveMultiPriVxFinder

(Finding through fitting approach)

- Adaptive multi vertex finder



- Adaptive multi vertex fitter

  (R.Frühwirth, W. Waltenberger – CMS Conference Report 2004/062)

  – More vertices are fit simultaneously.

  – The vertices compete each against the other in order to get a certain track assigned to them.

  – An annealing procedure is used: the assignement of tracks to vertices gets harder as the fit iteration number increases and the vertex position is known with more precision.

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Vertex Fitters

- Billoir Tools package (*P.Billoir, S.Qian Nucl. Ins. and Meth. in Phys. Res. A311(1992) 139-150*)
  - The equations of motion of a charged particle in the magnetic field are approximated with their Taylor expansion in the vicinity of the vertex.
  - FastVertexFitter: the trajectories are approximated with straight lines in the vicinity of the vertex. No refit of the incident tracks is performed.
  - FullVertexFitter: The full parametrization of tracks is used, the refit of incident tracks is performed.

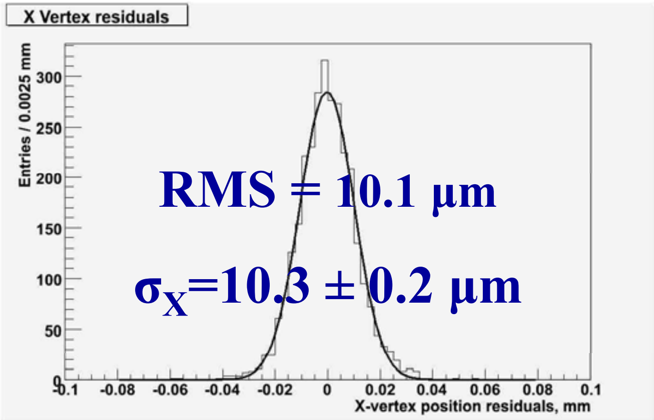
- Sequential vertex fitter (*R.Frühwirth Nucl. Ins. and Meth. 225(1984) 352*)
  - Implements a conventional Kalman filter for the vertex fitting.
  - A full analytical derivation of equation of motion is used.

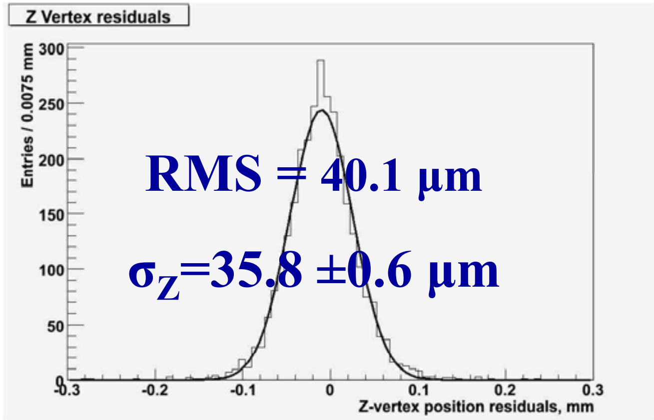
- Adaptive vertex fitter (*R.Frühwirth et al. Nucl. Ins. and Meth. in Phys Res A 502 (2003) 699*)
  - An iterative re-weighted least square algorithm.
  - Down-weights tracks according to their compatibility to the vertex candidate.
  - The outliers are thus efficiently discarded.

ATLAS Preliminary

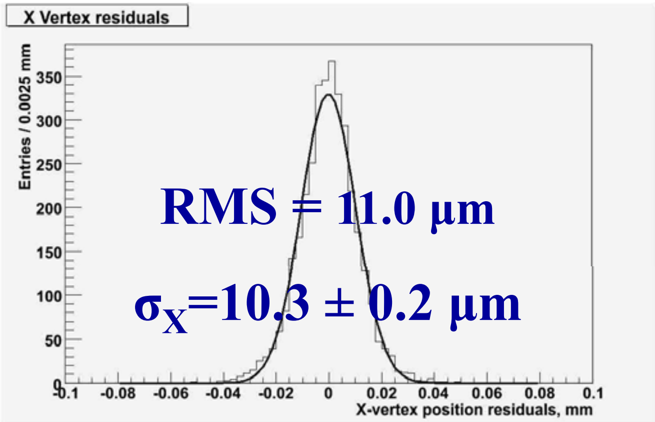
Performance

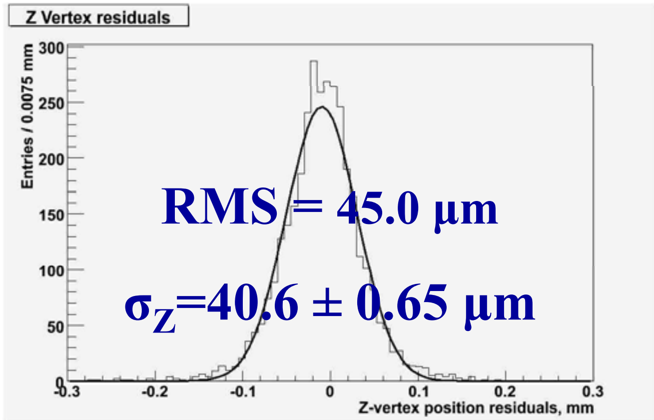
ATHENA rel. 12.0.6 Adaptive Multi Vertex Finder





ttbar
Finding efficiency
(100 µm criterion)
ε= 96.9 ± 1.8 %





H(130)→4l
Finding efficiency
(100 µm criterion)
ε=94.1 ± 1.6 %

Realistic conditions: misaligned geometry with material distortion

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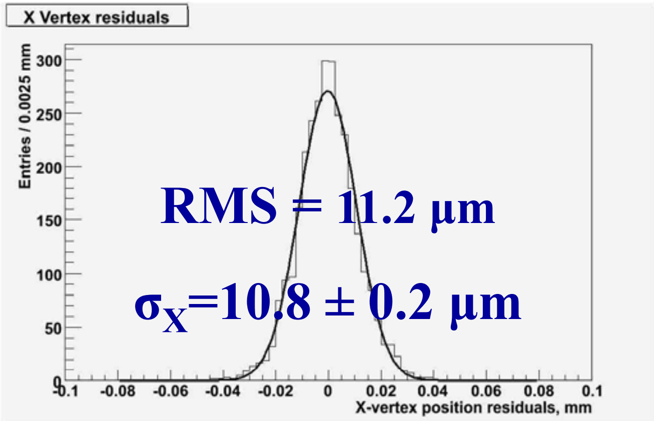
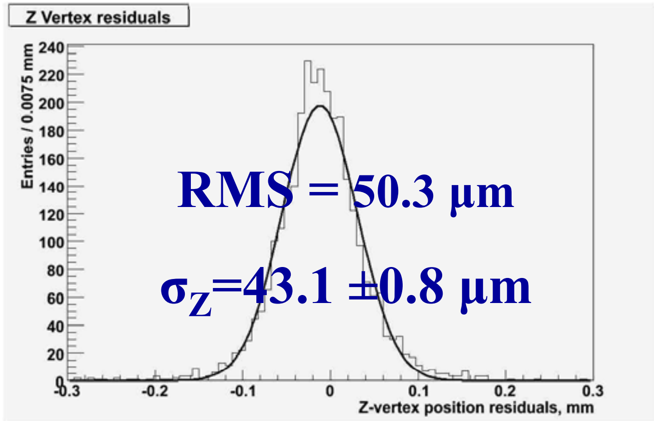
Performance contd.

ATLAS Preliminary

ATHENA rel. 12.0.6 InDetPriVxFinder + FastVertexFitter



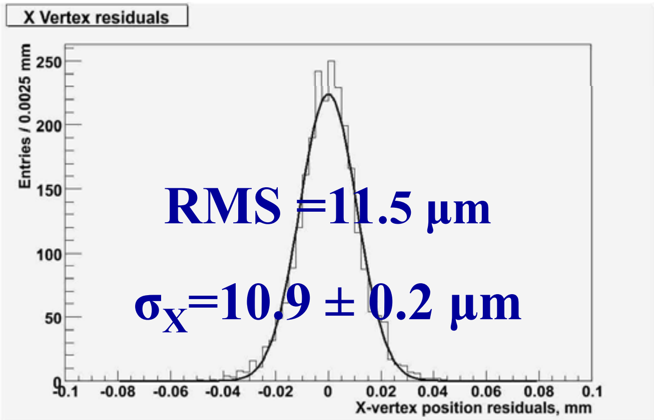


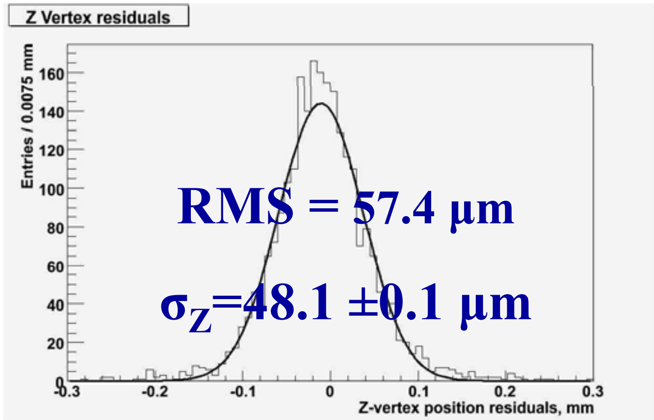
ttbar

Finding efficiency

(100 μm criterion)

ε =92.6 ± 1.8 %





H(130)→4l

Finding efficiency

(100 μm criterion)

ε=88.2 ± 1.8 %

Realistic conditions: misaligned geometry with material distortion

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Conclusion

- A primary vertex finding framework is implemented in ATLAS Athena environment.
- The Event Data Model and Common Interfaces are implemented in an object-oriented way, using the C++ language.
- Design of these components is made general enough to be used for different approaches to the vertex reconstruction.
- A set of different primary vertex finders and vertex fitters was designed and implemented to operate in the LHC pile up conditions.
- The Monte Carlo tests of the framework are performed, showing an excellent position resolution and a high reconstruction efficiency of primary vertices in pile up conditions.

We would like to express our gratitude to Gareth Brown from the University of Manchester for producing resolution plots and efficiency numbers.

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