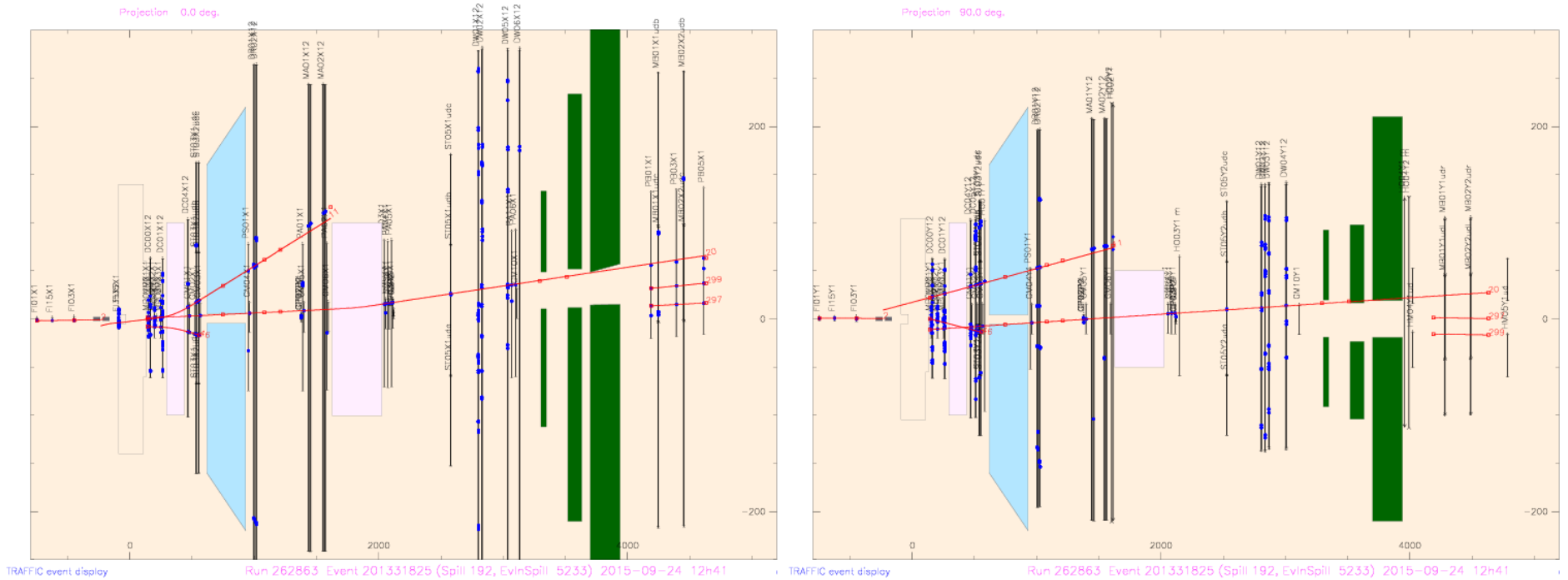
Detector Alignment

September 24, 2015

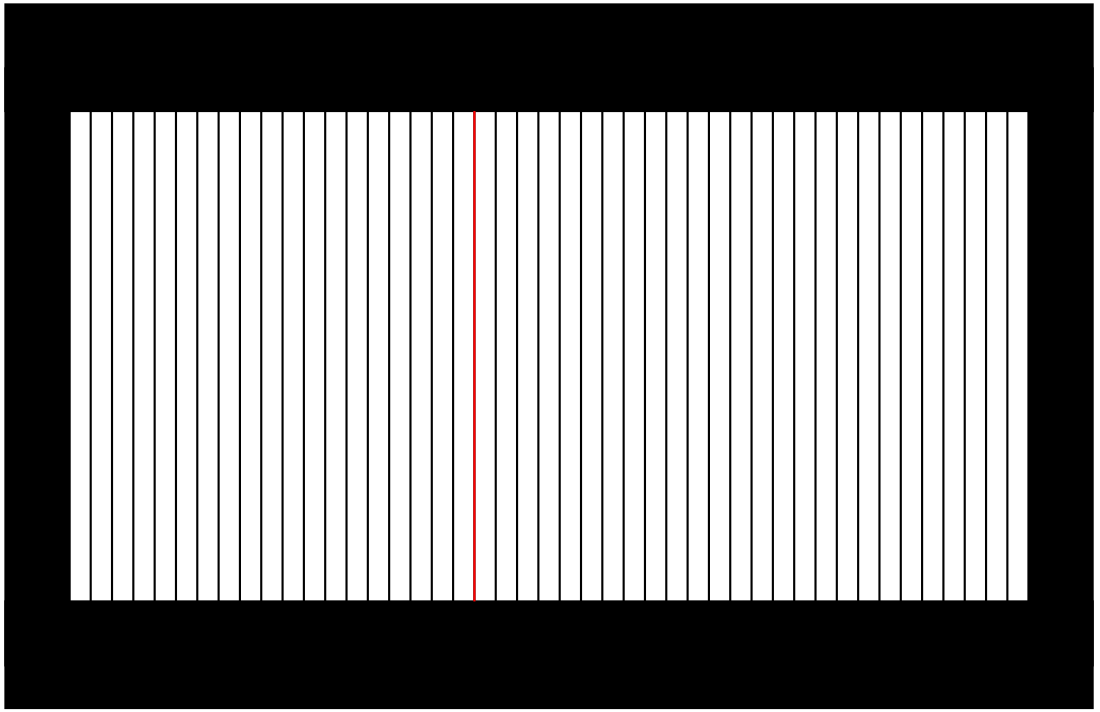
Introduction

You have seen an event display with some tracks reconstructed...



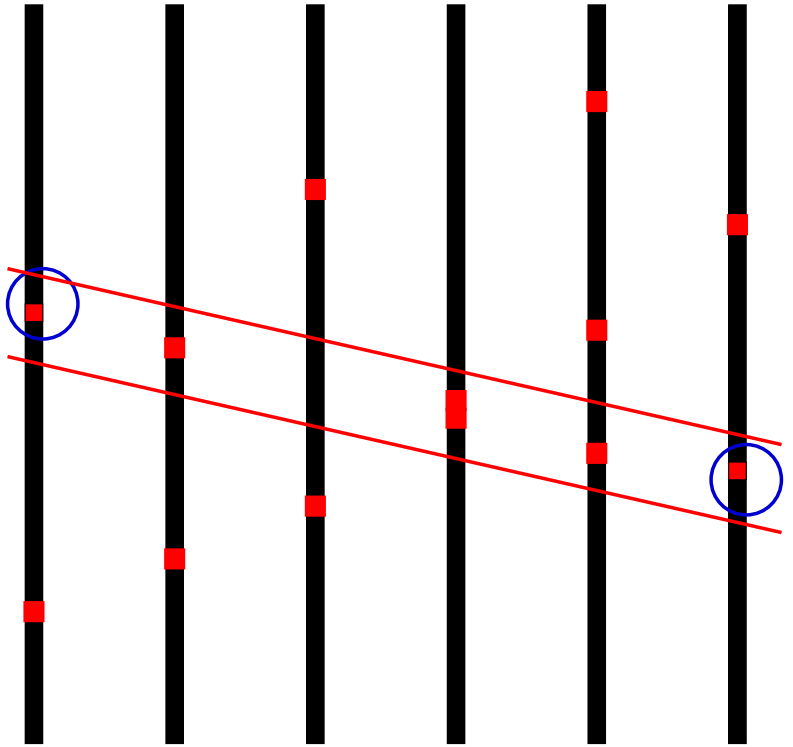
But how to make track?!

The Simplest Detector



- Passing charged particle will 'fire a wire'
- There is also a noise and a wire can be fired randomly with some probability
- Basically, based on the wire numbers at different position along the beam line one must decide if the track can be build...

Tracking...



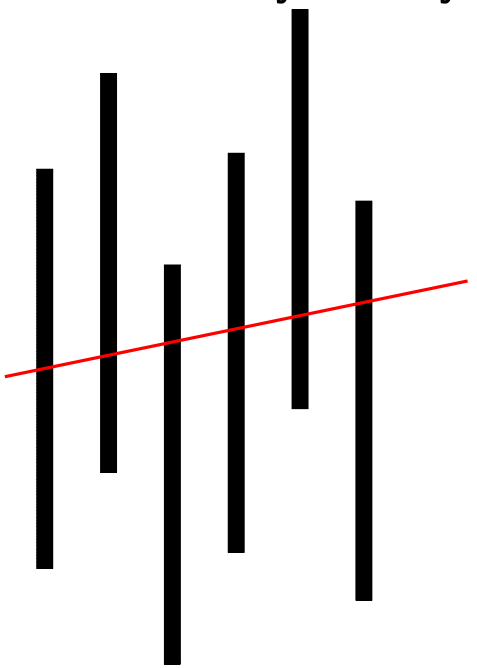
- Select 'pivot points', select route, add hits to a track...
- Sounds simple, but:
  - usually 10x hits than on the figure
  - tracks are not necessary straight lines (magnetic field)
  - one needs to bridge tracks segments through the magnet
  - detectors are not aligned perfectly ...

Detector Alignment

- Detector size 5mx3m
- Detector weight 400kg
- You have to hang it: 1.5m above the ground 20m in the N direction away from edge of the white board.
- Question: How precisely can you do it?!

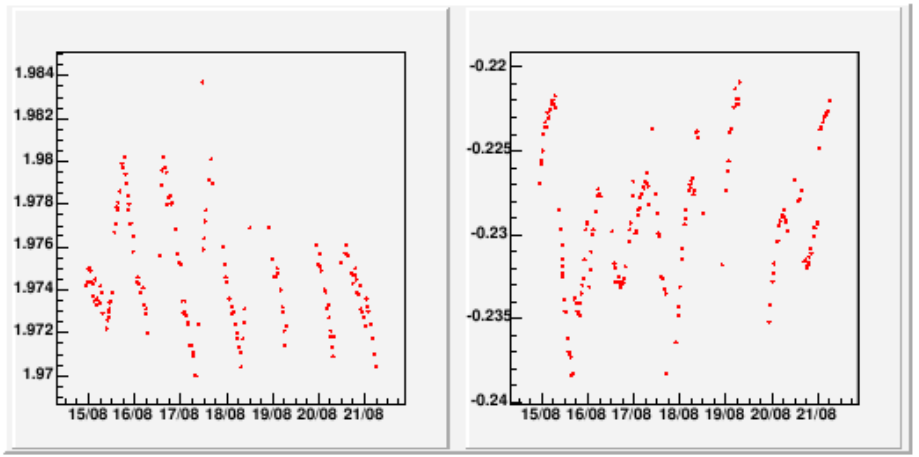
Detector Alignment cont.

- More often than not, detectors are misalignment by 1-2mm
- Best COMPASS detectors have resolution of $5\mu m$.
- If such detector is shifted by 1mm, it means that for a given track instead of signal in a wire 97-103 one of 297-303 will fire!
- In such condition there is no chance to assign correct hit to a track!
- Mechanically it would be extremely costly to improve the situation...



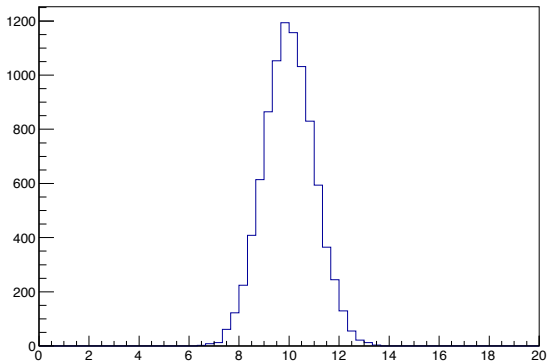
Thermal Expansion...

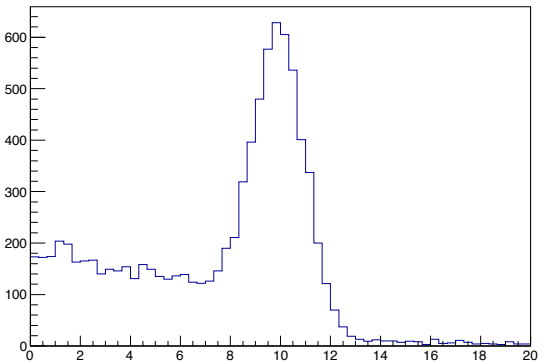
- Suppose that you somehow managed to put your detector withing a few μm from the desired place...
- Aluminum is relatively 'low cost' and 'low weight' material,
- Detector frames are often build from aluminum
- Its thermal expansion coefficient is $2.3 \cdot 10^{-5}$ 1/K
- There is about 10 degree difference between day and night
- A 5m long detector can shrink more than a 1 mm!
- Basically one is almost at the starting point...
- As a results alignment is done software-wise
- Sometimes a new alignment is needed every 30min-1h

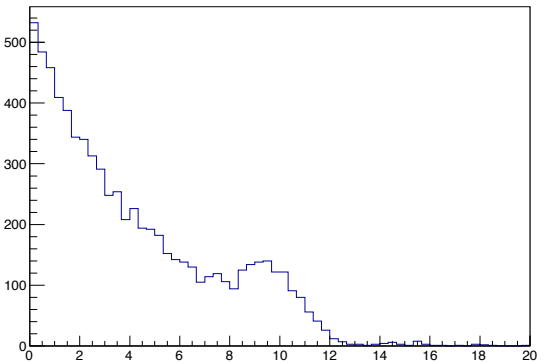


The Simplest Method...

- Low intensity run - one track in the spectrometer
- Two detectors are assumed as pivot points (they will not move)
- Hits in these detectors are used to make a track
- For any other detector one checks the distance is measured between the expected track position and the closest fired wire
- Some spectra for detector miss-aligned by 10 wires and having 0%, 3%, and 10% of a noise



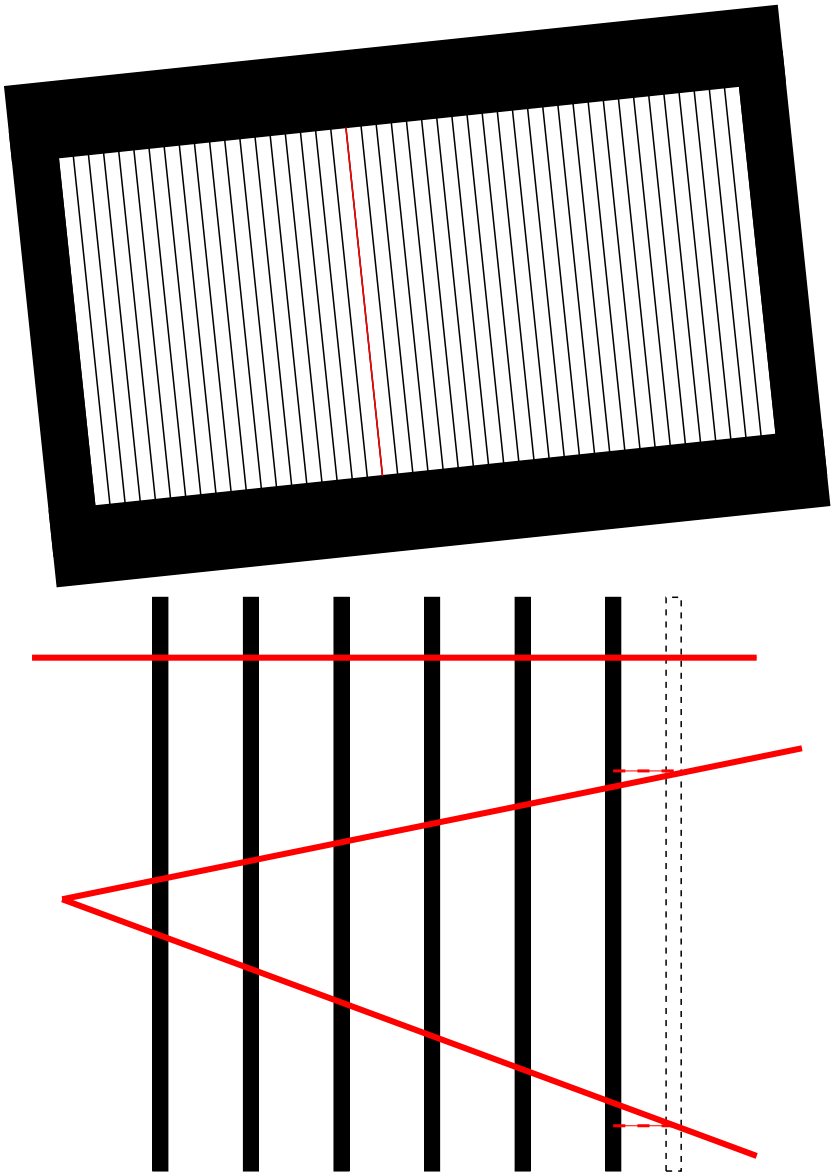




The Simplest Method - limitations

- The method is simple, but:
- Detector may not only be miss-aligned in only one coordinate
  - can be shifted perpendicularly to the wires
  - can be rotated by any of the 3 projections (only 1 rotation is really important)
  - can be shifted along the beam
  - or distance between the wires is different than it is expected

Possible Miss-alignments



How the True Alignment Is Done...

- One tries to simultaneously fit x,y,z rotation and pitch of the detectors.
- To have analytical solution problem has to be linearized e.g. $sin(\theta) \approx \theta$
- One builds set of equations to compare model with real measurement

$$x_1 + \Delta x_1 + y_1 \Delta\theta_1 + ... - A_1 z - B_1 = u_{11}$$
$$x_2 + \Delta x_2 + y_2 \Delta\theta_2 + ... - A_1 z - B_1 = u_{21} \ .$$
$$\vdots$$
$$x_n + \Delta x_n + y_n \Delta\theta_n + ... - A_1 z - B_1 = u_{n1}$$
$$x_1 + \Delta x_1 + y_1 \Delta\theta_1 + ... - A_2 z - B_2 = u_{12} \ .$$
$$\vdots$$
$$x_n + \Delta x_n + y_n \Delta\theta_n + ... - A_m z - B_m = u_{nm}$$

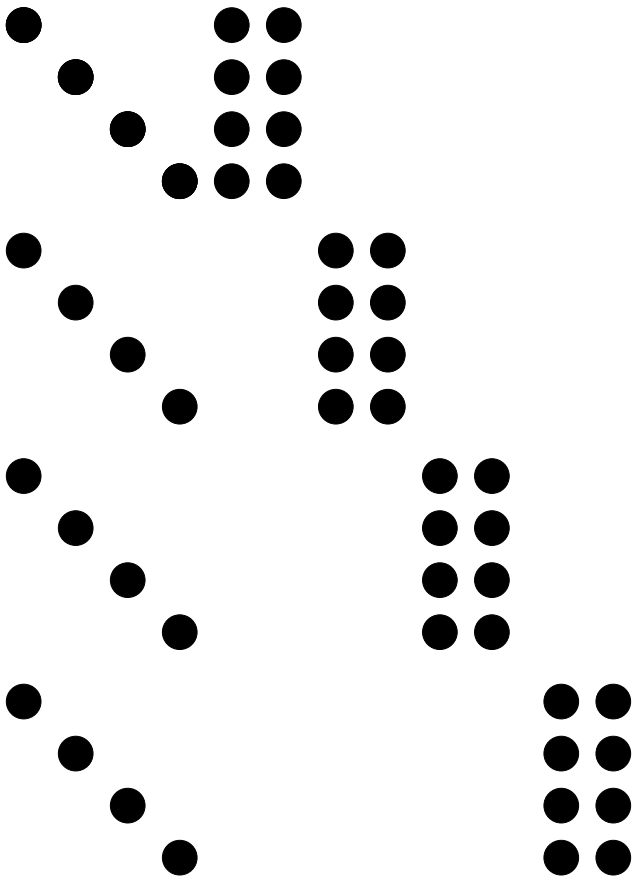
- This linear algebra problem has an analytical solution.
- There is only one small detail...

Matrix Inversion

- To solve a linear equation system certain matrix has to be inverted
- We have 300 detectors planes and want align 5 parameters and we use 100000 tracks...
- The matrix we should invert can easily have a few million rows
- In general the matrix inversion is $O(N^3)$ process, and this means that the matrix inversion on normal PC would take a few weeks...
- BTW. There are faster algorithms to invert matrices...

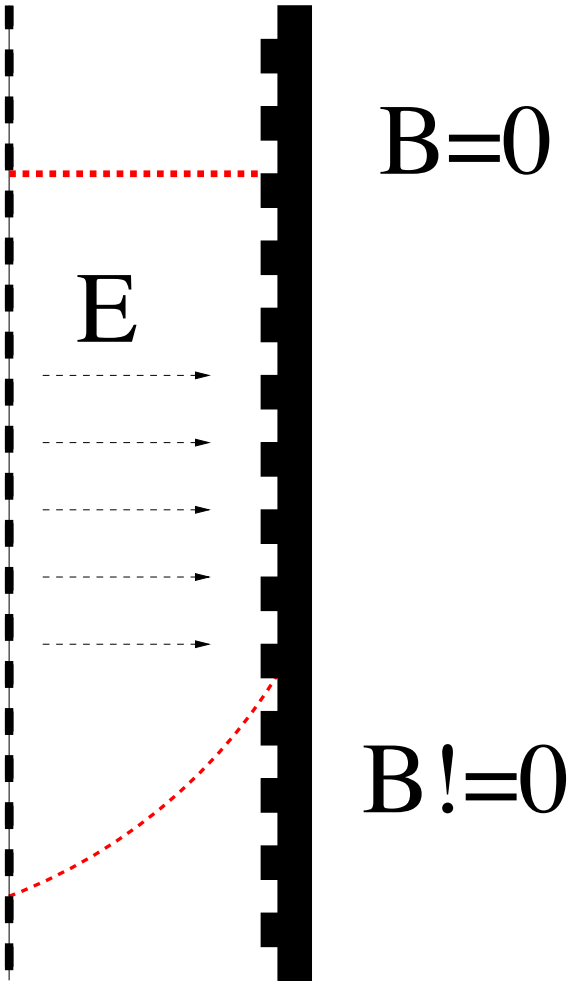
Mathematical Trick...

- The matrix has a special structure
- V. Blobel has shown how to invert it much faster
- In reality only matrix of the size (300x5)*(300*5) and 100000 (2x2) matrices has to be inverted. This take a few seconds.



You Think You Are Done...

- ... and then you switch on magnetic field...
- Different detectors types behave differently in the magnetic field...



Instead of Summary

- Gain due to presented alignment method vs. the simplest one

	OLD	NEW	RATIO
tracks/events	1.71	3.09	1.8
χ^2/ndf	8.0	3.1	2.6
Interaction vertex (%)	36%	45%	1.25
μ, μ'(%)	14	33	2.3