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The HIP Alignment Method

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Outline

Introduction

- Develop an algorithm that can be used for detector alignment esp. planar sensors (MVD, LMD,...)
- Find the correct position of the detector (or its individual component) by calculating the 6 parameters (3 for the translation and 3 the rotation) of the transformation from the GCS to LCS.
- This can be achieved by using the **"Hits and Impact Points (HIP) Alignment Method".**

Basic Formalism of the HIP Alignment Method

It is consisting on finding the correct transformation by minimizing of the hit residuals $q_m(u_m, v_m, 0)$ of the measured point and $q_x(u_x, v_x, 0)$ of the track impact point in LCS ($\hat{w}$, the 3^{rd} component unit vector, is perpendicular to the detector plane).

$$\chi^2 = \sum_{j}^{Ntrack} \varepsilon_j^T V_j^{-1} \varepsilon_j$$

where: $$\varepsilon = \begin{pmatrix} \varepsilon_u \\ \varepsilon_v \end{pmatrix} = \begin{pmatrix} u_x - u_m \\ v_x - v_m \end{pmatrix}$$

V_j is the sum of measured and impact point positions covariance matrices of track j.

The Alignment Parameters

The correct total transformation from the GCS to the LCS:

$$q = \Delta R R \left(r - r_0 \right) - \Delta q$$

where: $q\left(u,v,w\right)$: point coordinates in LCS,

$r\left(x,y,z\right)$: point coordinates in GCS,

$r_0\left(x_0,y_0,z_0\right)$: origin coordinates of LCS in GCS,

$R = R_\alpha R_\beta R_\gamma$: (ideal) rotation matrix,

$\Delta R = R_{\Delta\alpha} R_{\Delta\beta} R_{\Delta\gamma}$:corrective rotation matrix,

$\Delta q = \Delta R R \Delta r = \left(\Delta u, \Delta v, \Delta w \right)$:corrective translation.

***p* = (Δu,Δv,Δw,Δα,Δβ, Δγ)** is the alignment parameter.

The alignment corrections are expected to be small, the fitted trajectories can be approximated with a straight line in a vicinity of the detector plane. The line equation is :

$$r_s = r_x + h\hat{s}$$

As a consequence, $q_s(h) = \Delta RR(r_x + h\hat{s} - r_0) - \Delta q$

r_x is the trajectory impact point on the detector,

$\hat{s}$ is the unit vector parallel to the line,

h is a parameter which satisfies $q_s(h_x).\hat{w} = 0$

Finally: $$q_x^c = \Delta Rq_x + (\Delta w - [\Delta Rq_x]_3).\frac{\Delta R\hat{t}}{[\Delta R\hat{t}]_3} - \Delta q$$

"c" indicates the corrected position after the alignment,
"3" indicates the 3rd component,
$\hat{t} = R\hat{s}$ is the uncorrected trajectory direction in LCS

Residuals Expressions

The matrix rotation following the zxz convention van be written as :

$$\Delta R = \begin{pmatrix} 1 & \Delta\gamma + \Delta\alpha & 0 \\ -\Delta\gamma - \Delta\alpha & 1 & \Delta\beta \\ 0 & -\Delta\beta & 1 \end{pmatrix}$$

Therefore :

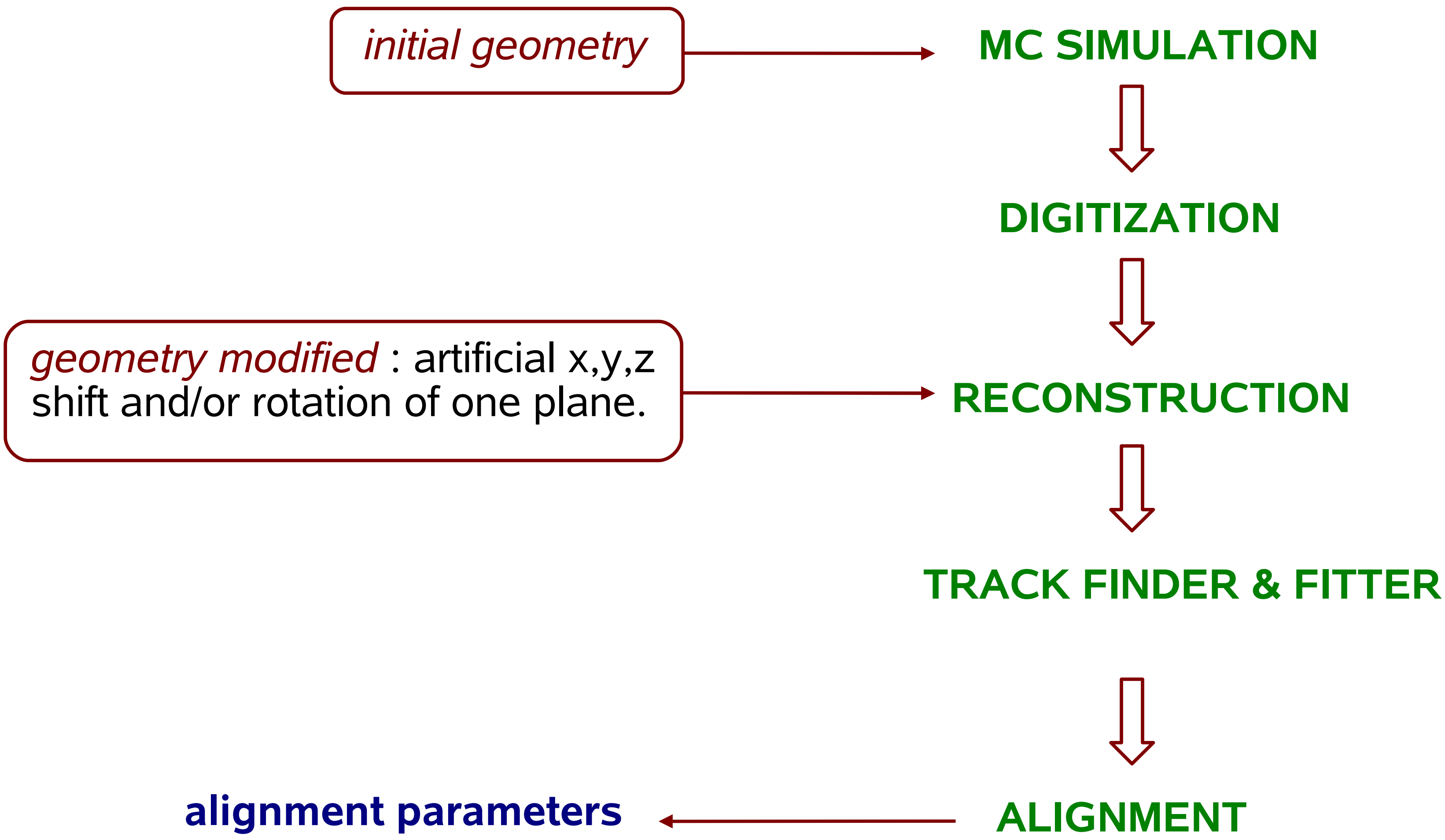
$$\varepsilon_u = u_x - \Delta u + (\Delta\gamma + \Delta\alpha) v_x + (\Delta w + \Delta\beta v_x) \tan\psi - u_m$$

$$\varepsilon_v = v_x - \Delta v - (\Delta\gamma + \Delta\alpha) u_x + (\Delta w + \Delta\beta v_x) \tan\theta - v_m$$

where : $\tan\theta = \hat{t}_2 / \hat{t}_3$ (θ is the angle between uw-plane and the track)

$\tan\psi = \hat{t}_1 / \hat{t}_3$ (ψ is the angle between vw-plane and the track)

Simulation Studies



Initial geometry: 4 layers of Silicon Strip Sensors parallel to xy-plane and have axis the z-axis

geometry modified : at the 4th plane

- x-shift : -0.0284 cm
- y-shift : 0.0279 cm
- z-shift : 0.0 cm
- ϕ = 50 mrad
- θ = 20 mrad
- ψ = 25 mrad

100000 proton tracks at 1000GeV/c (to minimize the effect of scattering) are generated. So,

$$V_j = V = \begin{pmatrix} \sigma_x^2 + \sigma_m^2 & 0 \\ 0 & \sigma_x^2 + \sigma_m^2 \end{pmatrix} = \begin{pmatrix} \sigma_m^2 & 0 \\ 0 & \sigma_m^2 \end{pmatrix}$$

$\sigma_m = pitch/\sqrt{12}$: error from the digitization

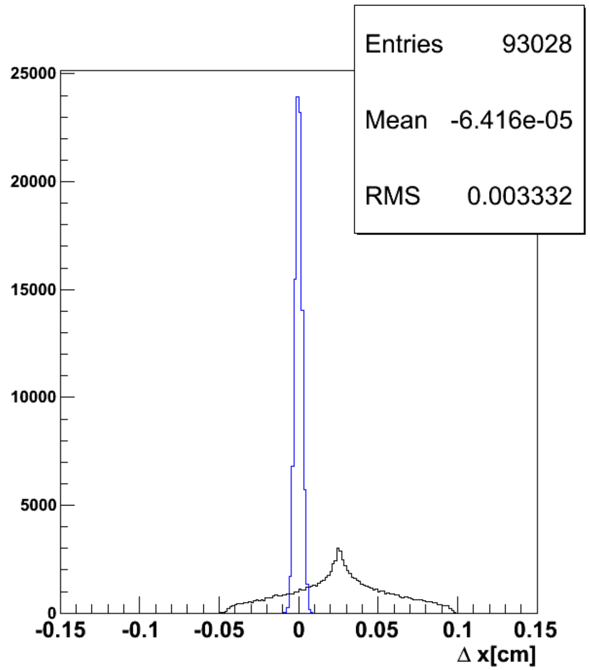
Result

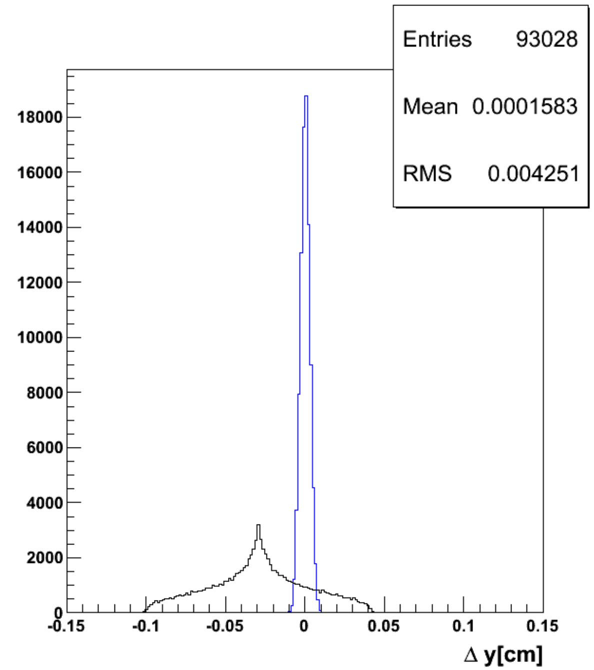
	Displacement
Δx(cm)	-0.0284
Δy(cm)	0.0279
ϕ(mrad)	50
θ(mrad)	20
ψ(mrad)	25

Params	Values
Δu(cm)	0.0277(6.87e-06)
Δv(cm)	- 0.0274 (6.80e-06)
Δα(mrad)	- 49.99 (3.63e-04)
Δβ(mrad)	- 19.32 (1.37e-03)
Δγ(mrad)	- 22.62 (1.54e-04)

Residuals

black: before alignment
blue: after alignment





Outlook

- Use the algorithm for experimental data (Bonn TS beam test at COSY) : test algorithm for more than one plane.
- Calcul of the covariante matrix for relative lower beam momenta