Timeslices simulation status update

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Motivation

1. The development of methods and software to model the response of SPD tracker in the trigger free regime.
2. Study of the temporal structure of signals.
3. The development of the events reconstruction algorithms in the trigger free regime.
4. Investigation of reconstruction efficiency and purity on MC simulation data.
5. Development of prototype software for event reconstruction at the stage of online data filtering.

Schematic representation of the SPD Straw Tracker

Figure 1: The Straw Tracker generated by neural network.

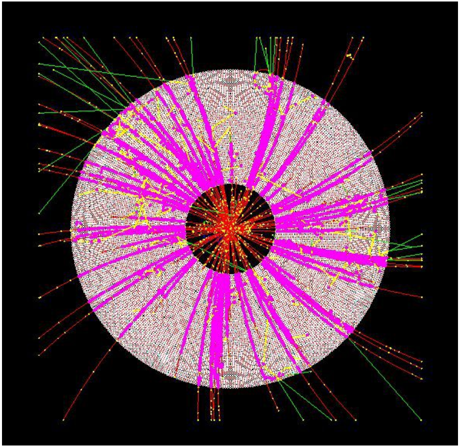
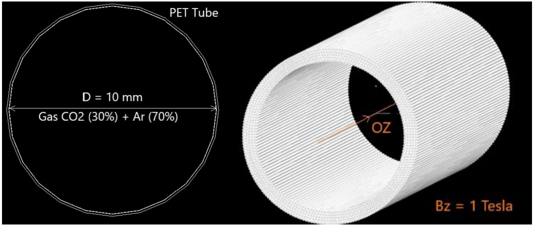


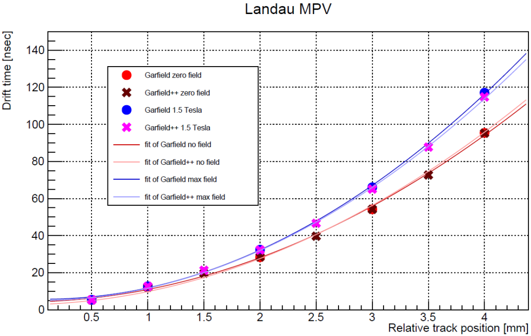
Figure 2: The toy model of the SPD Straw Tracker generated by authors.

Simulated events generation

1. The timeslice of $10\mu s$
2. The proton-proton beam crossing occurs every 76 ns.
3. The probability of proton-proton hard interaction at beam crossing
$$f(k) = \frac{\lambda^k}{k!} e^{-\lambda},\ \lambda = 0.3.$$
4. The interaction vertex position
$$f(z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{z-z_0}{\sigma}\right)^2},\ \sigma = 30\ \text{cm},\ z_0 = 0.$$
5. The number of muons produced in a one *pp* collision
$$f(k) = \frac{\lambda^k}{k!} e^{-\lambda},\ \lambda = 7.$$
6. Energy of primary muons E = 1 GeV.
7. The uniform distribution of the muon 3-momentum direction in 4π space.
8. Hit – energy loss point in the sensitive volume.

Modeling parameters





- Sensitive volumes: inner parts of straw tubes, gas-filled by $30\%\ CO_2 + 70\%$ Ar.
- Magnetic field: $\vec{B} = (0, 0, B_z)$, $B_z = 1$ T.
- First cluster drift time: $t(r) = 2.7101 + 1.2156r + 6.8287r^2$, r – shortest distance from the hit to the anode.

Drift time

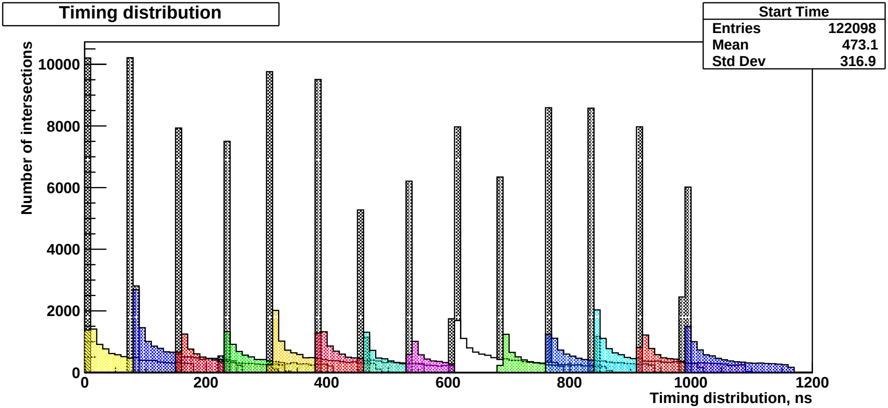


Figure 3: Timing distribution averaged by 100 time slices. Grey area – time of the intersection of the sensitive volume by the sample particle without taking into account the electron avalanche. Coloured area – ST response time distribution.

Schematic representation of the SPD Straw Tracker

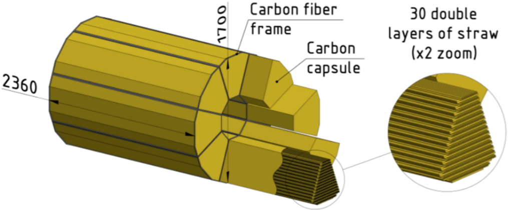


Figure 4: Schematic representation of the ST.

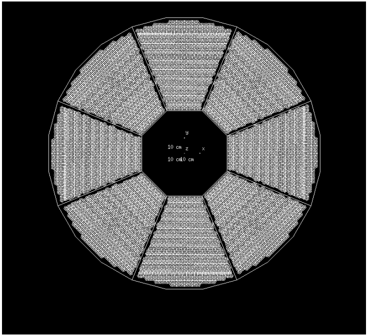


Figure 5: ST in GeoModel.

Timing distribution in full detector model

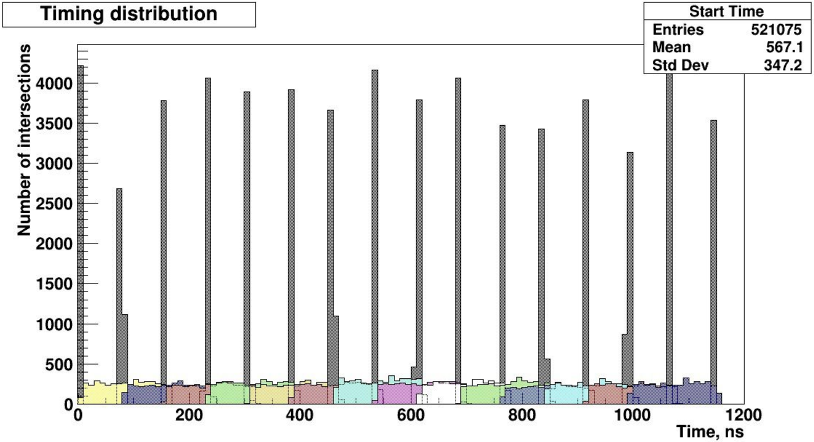


Figure 6: Timing distribution averaged by 400 time slices. Grey area – time of the intersection of the sensitive volume by the sample particle. without taking into account the electronic avalanche. Coloured area – ST response time distribution.

Track approximation 1

The set of hits $\{x_i, y_i\}_N$ in the XOY plane for the each track numbered N is approximated by the function $\tilde{y} = a_{2,N}\tilde{x}^2 + a_{1,N}\tilde{x} + a_{0,N} = f(\tilde{x})$.

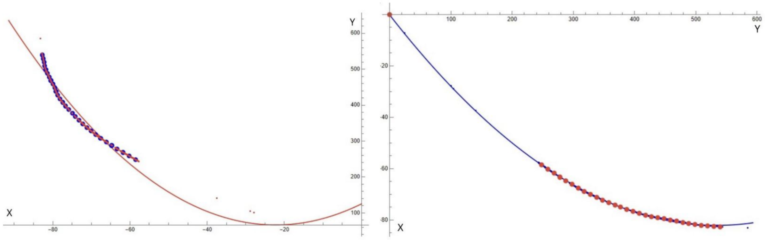
1. If any of sets $\{x_i\}_N$, $\{y_i\}_N$ is not ordered by ascending or descending, its elements correspond to function values $\tilde{y}(\tilde{x})$ while the elements of another to argument values $\tilde{x}$.
2. In case of both sets $\{x_i\}_N$, $\{y_i\}_N$ are ordered the adjusted R values

$$R_{adj} = 1 - \frac{(1 - R^2)(k - 1)}{k - n - 1}, \; R^2 = 1 - \frac{\sum_{i=1}^{k} (y_i - f(x_i))^2}{\sum_{i}^{k} (y_i - \bar{y})^2}$$

for $\{x_i, y_i\}_N \rightarrow (\tilde{x}, \tilde{y})$ and $\{x_i, y_i\}_N \rightarrow (\tilde{y}, \tilde{x})$ are compared.

Track approximation 2

$$R_{adj,Y(X)} > R_{adj,X(Y)}$$



Linear approximation $z_N = b_{1,N} L_N + b_{0,N}$, where the parabola arc length

$$L_N(\tilde{x}_{i,N}) = \int_0^{\tilde{x}_{i,N}} \sqrt{1 + (f'(\tilde{x}))^2} d\tilde{x}$$

$$= \frac{1}{4a_{1,N}} \left[\ln \left| \sqrt{(f'(\tilde{x}))^2 + 1} + f'(\tilde{x}) \right| + f'(\tilde{x}) \sqrt{(f'(\tilde{x}))^2 + 1} \right]$$

Track selection criteria

1. Residual sum of squares (RSS) criteria:

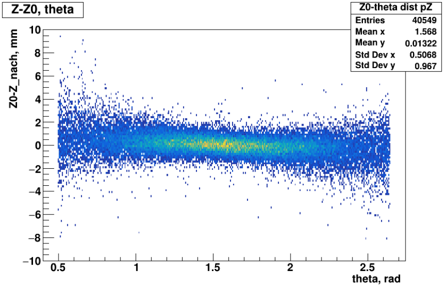
$$RSS = \sum_{i=1}^{n} (z_{i,N} - (b_{1,N} L_N(\tilde{x}_{i,N}) + b_{0,N}))^2$$

   The tracks with $RSS > 1.5$ are excluded from the analysis.

2. Polar angle cuts: $0.5 < \theta < \pi - 0.5$

Δz distribution

For the each track: $\Delta z_N = z_{0,N} - z_{nach,N}$
$z_{0,N} = b_{0,N}$ – the z-axis intersection coordinate with track approximation;
$z_{nach,N}$ – the initial z-coordinate of primary particle.



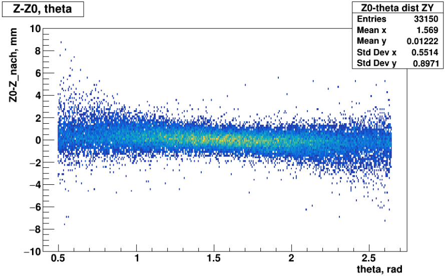


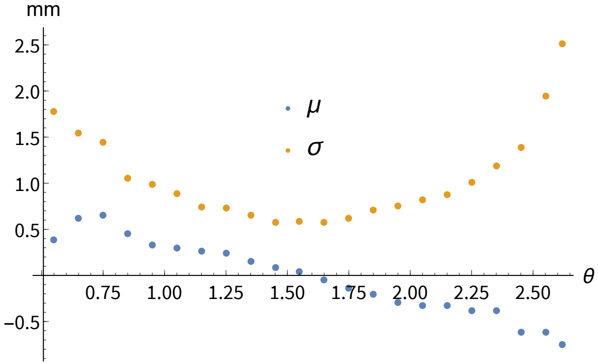
Figure 7: The exact value of θ (left), the direction to the first hit (right).

Δz distribution

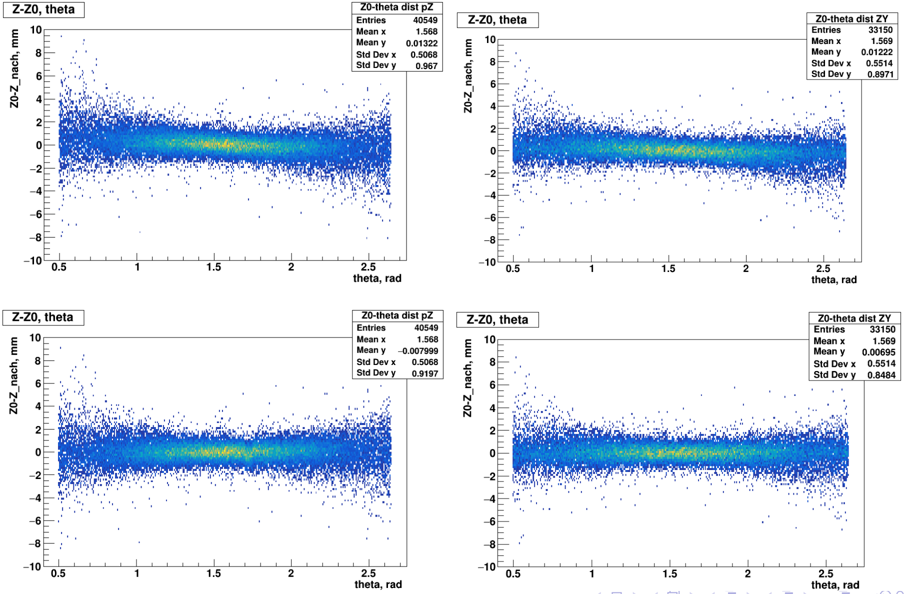
Suppose the normal distribution of all $z_{0,N}$ for the each value of θ

$$f(z_0, \theta) = \frac{1}{\sigma(\theta)\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{z_0 - \mu(\theta)}{\sigma(\theta)}\right)^2}$$

and extract $\sigma(\theta)$ and $\mu(\theta)$ from the fit.



Δz distribution corrected



Primary vertex finding procedure

1. Sort the $\{z_{0,N}\}$ in the ascending order.
2. Collect all the $\{z_{0,k}\}$ with overlapping intervals $\{z_{0,k} \pm \sigma_k\}$ into one cluster C and find its $z_{0,C} = \dfrac{1}{K} \sum_{k=1}^{K} z_{0,k}$
3. Find all the clusters and compare all the discovered cluster areas with true primary vertices.

Results

The obtained reconstruction efficiency $\frac{N_{reco}}{N_{all}} = 93\%$,
N_{reco} – number of correctly reconstructed vertices,
N_{all} – number of all primary vertices.

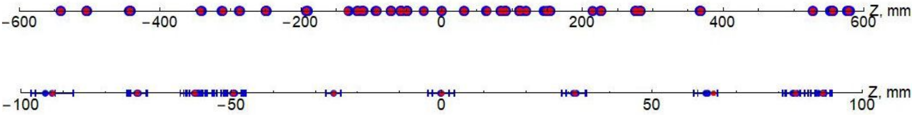


Figure 8: Reconstructed primary vertices within uncertainties (blue), true primary vertices (red).

Sources of errors

1. Indistinguishability of reconstructed vertices: 96% from all errors

Figure 9: Indistinguishable vertices.

2. Uncertainties of hits coordinates
3. Tracks curvature
4. The actual primary vertex displacement from the z-axis.

Conclusions and Acknowledgements

1. We obtained the temporal structure of the ST response and found a big overlap in straw tubes response times both in toy and realistic detector models.
2. We performed a test of the simple algorithm for primary vertex reconstruction and obtained a good success at the "ideal" simulated data.
3. The results show the possibility to separate the particles from the different primary vertices using a simple scheme, nevertheless the overlap of ST response times.
4. The next step of the presented study will be a performance test of the vertex finding algorithm using more complicated track approximation functions, using the input data with a lower purity, etc.
5. The authors are cordially grateful to the A. Zhemchugov for the fruitful discussions and suggestions and to the A. Allakhverdieva for the help in software installation and GeoModel detector model.

Thank you for your attention!