Realistic simulation and hit reconstruction for the Straw Tracker

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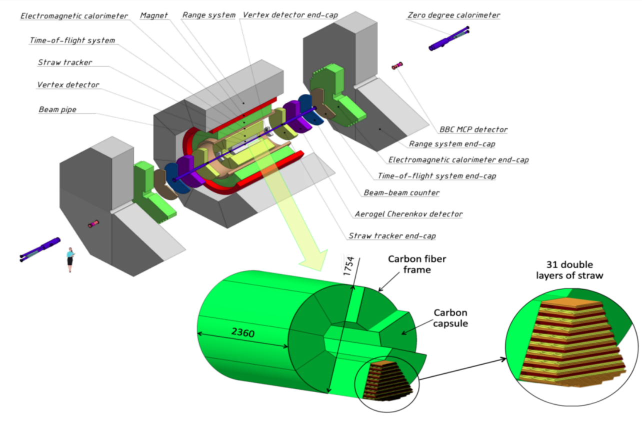
PNPI | SPD Physics & MC Meeting

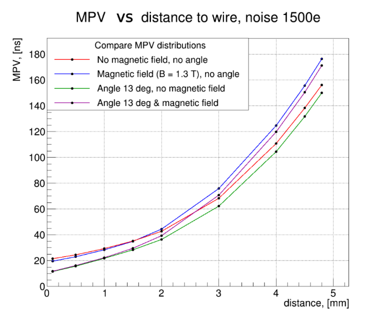
Straw Tracker – the main tracking system of SPD

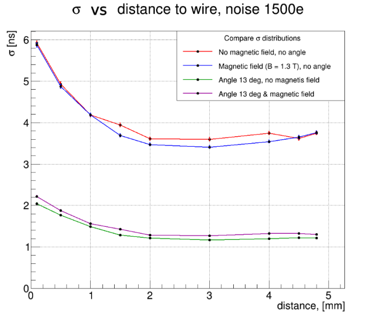


Straw diameter: 10mm thickness 36μm PET

Barrel is made of 8 modules with up to 31 double-layers, with the ZUV orientation $(0^{\circ}, +3^{\circ}, -3^{\circ})$

2023| Sonya B. & Vitalii B. parameterized mode and variance of the straw signal registration time distribution by Garfiled++/LTSpice





Straw diameter: 10 mm

Anode diameter: 30 mkm

Gas mixture: Ar+CO2 / 70:30 [%]

Gas gain = 4.5E4

Peaking time 25 ns

Signal amplification 3 mV/fC

Noise is implemented

Threshold 10 mV

VMM3-based readout model

Source: Diploma by Sonya B.

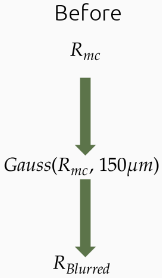
Two versions of SPDROOT are used.

1. Geometry-update-spring 2023: $\sigma(R_{MC})$ is const $= 150\mu$m
2. Development 2024: $\sigma(R_{MC})$ is $0.06506 * exp(-3.26 * R_{MC})$

Before the SPDROOT blurred the MC point

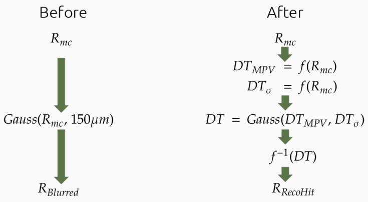
`File: spddata/hits/vnt/SpdMCStrawHit1D.cxx`

- Initially, there was no simulation of the real signal.
- Monte Carlo Point was blurred in an almost infinite while loop with a fixed variance of 150 μm



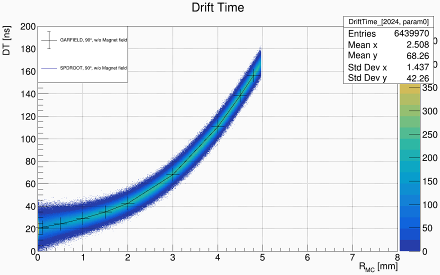
We introduced the realistic signal parameterization (Hit Reconstruction) to SPDROOT

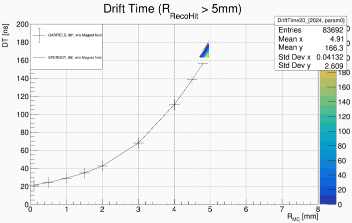
File: `spddata/hits/vnt/SpdMCStrawHit1D.cxx`

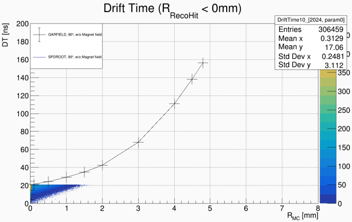


- The distribution of the drift time (DT) is provided by Sonya B.
- The DT is calculated for each Monte Carlo point
- Afterward, DT is smeared by $\sigma(DT) = f(R_{MC})$
- Roots of the inverse function (parabola) provide $R_{RecoHit}$

4% of hits are lost near the anode
Less than 1% is reconstructed outside the tube



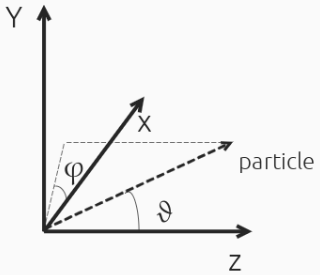




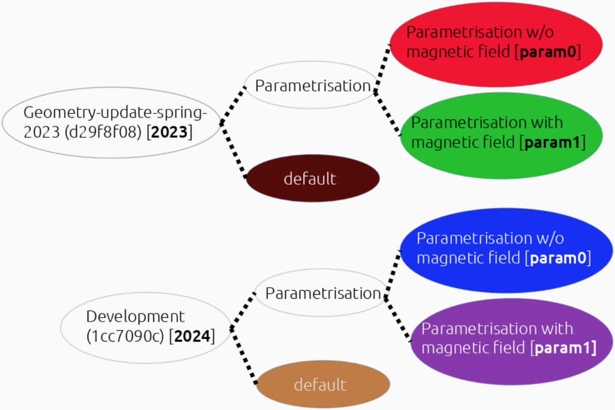
Therefore, the accuracy of hits position estimation is an object of utter importance.

Simulation settings

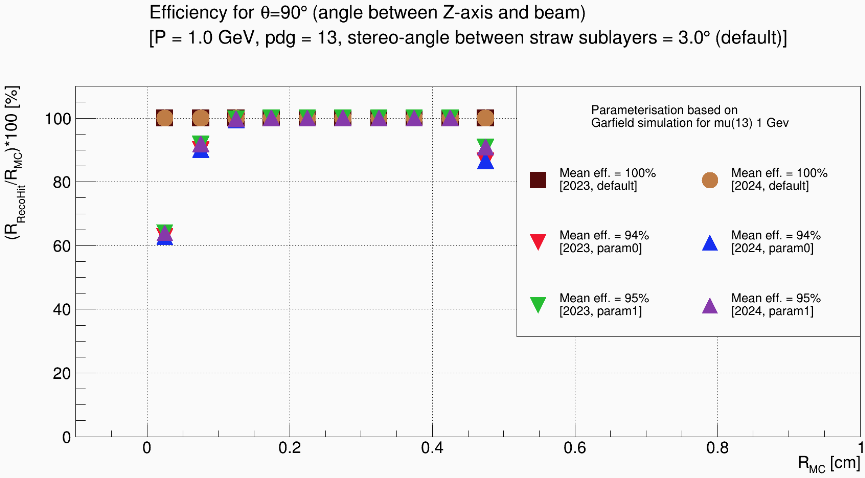
- **Patricle:** muon (μ, pdg = 13)
- **Energy:** 1GeV
- **Generator:** SpdIsotropicGenerator
  - θ**:** is angle between Z-axis and beam (**now we used** $\theta = 90^\circ$)
  - ϕ**:** From 0° to 360°
- **Detectors:** Only Straw Barrel
- **Vertex:** Off
- **Magnet:** field_full1_8.bin
- **Events:** 100k (for $\theta = 90^\circ$)



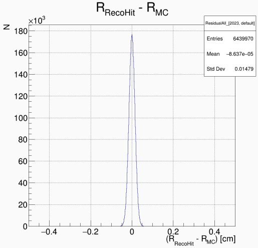
The comparision includes simuls by two versions of SPDROOT w/o magnetic field (param0) and w/ magnetic field 1.3T (param1)

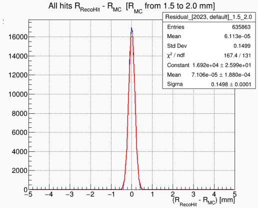


Reconstruction efficiencies for param0/1 difference are the same

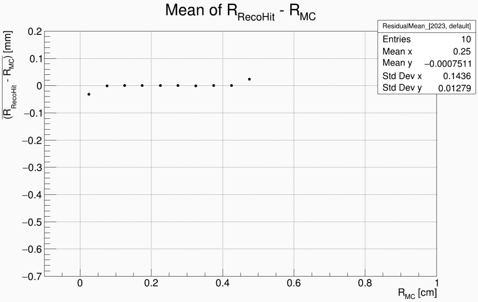


Distributions of residuals over areas R_{mc} We are considering 10 ranges [mm]: [0.0–0.5), [0.5–1.0), [1.5–2.0), etc.

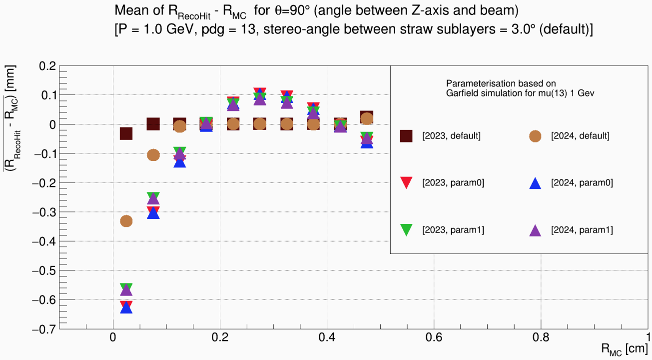




This is default version 2023



Bias Analysis of hit reconstruction: Default vs. Parametric Versions.

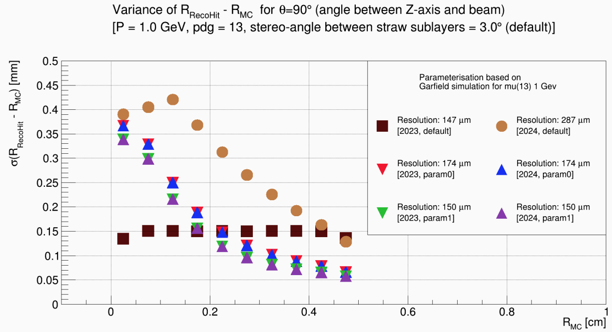


$R_{RecoHit}$ for defaul version is $gRandom \to Gaus(R_{MC}, \sigma(R_{MC}))$

$R_{RecoHit}$ for param version is calculated from smearing function

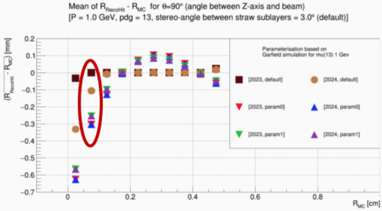
In Development2024 version (default) toy parameterization was added

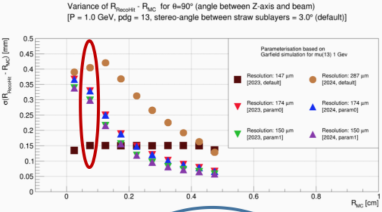
Variance of $R_{MC} - R_{RecoHit}$

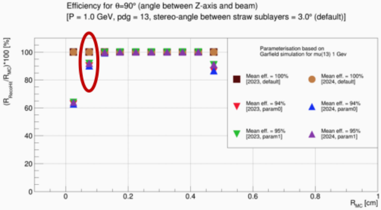


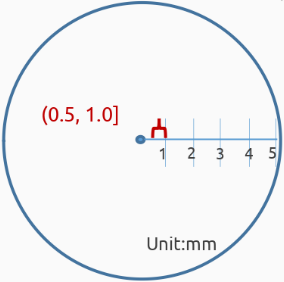
1. $\sigma(R_{MC})$ for 2023 defaul version is const $= 150\mu m$
2. $\sigma(R_{MC})$ for 2024 defaul version is $0.06506 * exp(-3.26 * R_{MC})$
3. $\sigma(R_{MC})$ for 2023/4 param0/1 calculated with SmearHit func.

Let’s look at interesting areas: from 0.5 to 1.0;

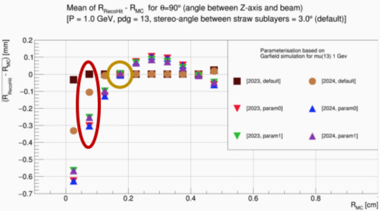


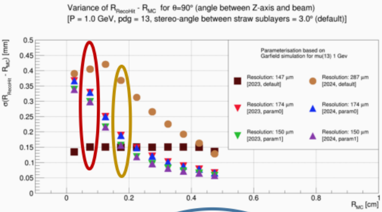


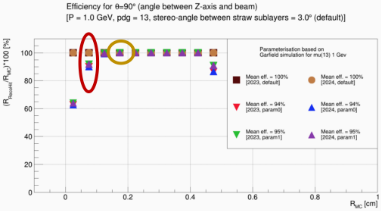


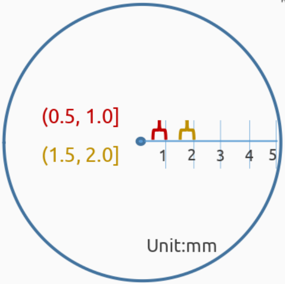


Let’s look at interesting areas: from 0.5 to 1.0; from 1.5 to 2.0

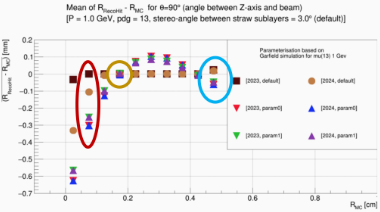


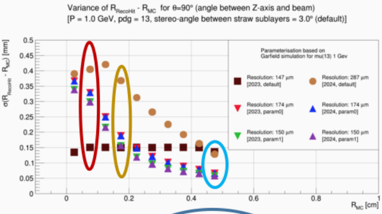


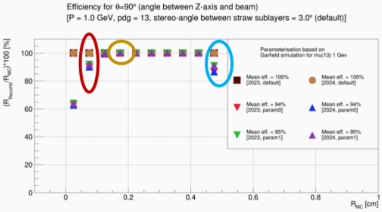


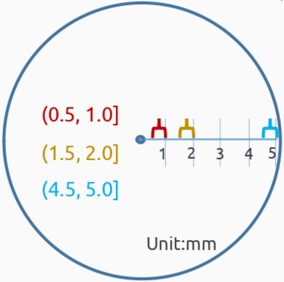


Let's look at interesting areas: from 0.5 to 1.0; from 1.5 to 2.0 and from 4.5 to 5.0 mm



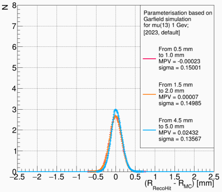




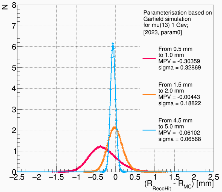


Residual for three selected point

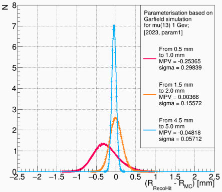
$R_{RecoHit}$ - R_{MC} for θ=90°
[2023, default]



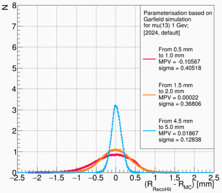
$R_{RecoHit}$ - R_{MC} for θ=90°
[2023, param0]



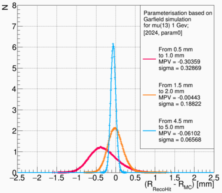
$R_{RecoHit}$ - R_{MC} for θ=90°
[2023, param1]



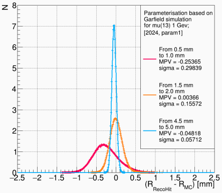
$R_{RecoHit}$ - R_{MC} for θ=90°
[2024, default]



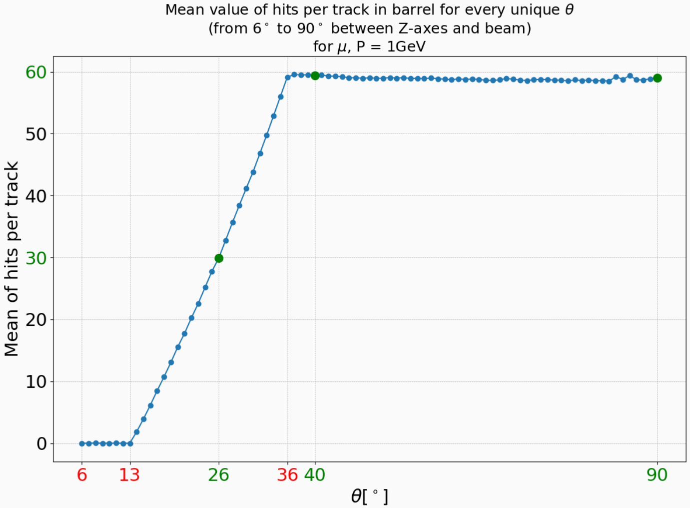
$R_{RecoHit}$ - R_{MC} for θ=90°
[2024, param0]



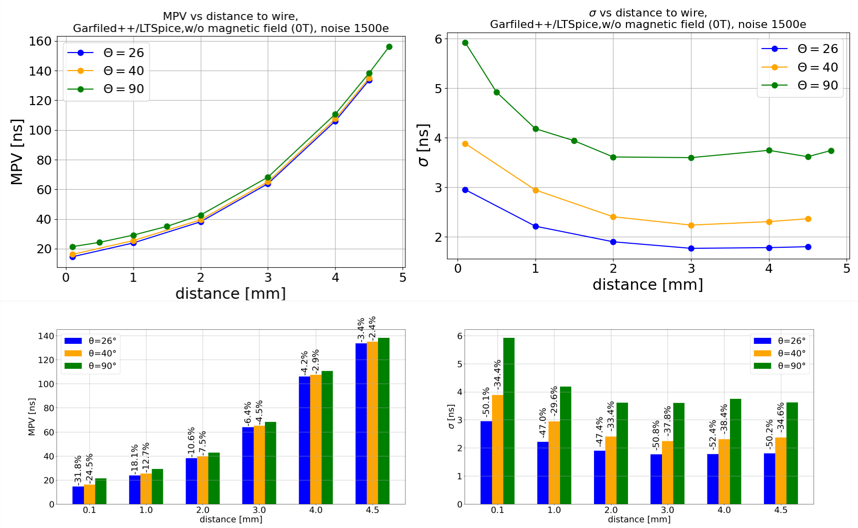
$R_{RecoHit}$ - R_{MC} for θ=90°
[2024, param1]



Next, we'll analyze the behavior at an angle with 30 hits per track (26°) and at the left edge of the saturation plateau (40°).

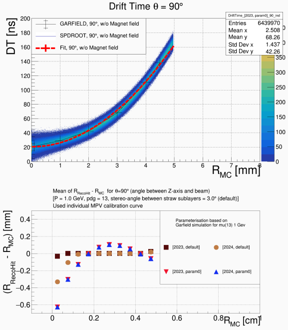


Difference near anode $> 20\% \rightarrow$ switch to individual calibration curves

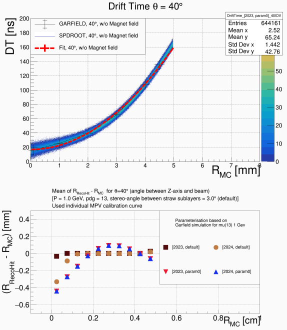


Individual calibration curve: less bias

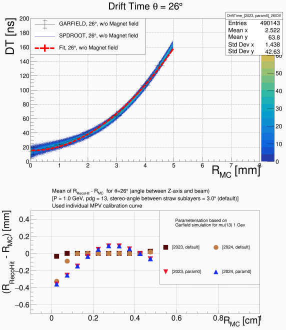
$DT = 20.72 R_{MC}^2 + 5.7$



$DT = 16.88 R_{MC}^2 + 5.7$

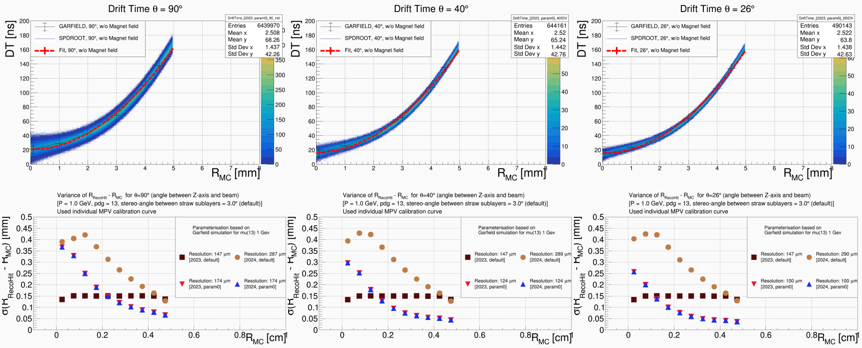


$DT = 15.39 R_{MC}^2 + 5.7$

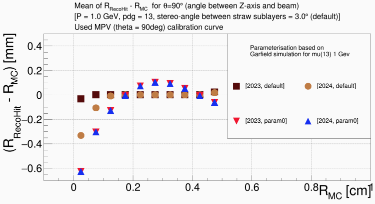


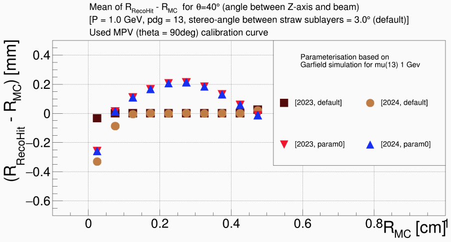
Individual calibration curve: less bias, higher resolution.

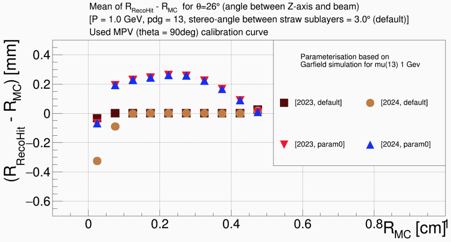
$DT = 20.72R_{MC}^2 + 5.7$ $\quad$ $DT = 16.88R_{MC}^2 + 5.7$ $\quad$ $DT = 15.39R_{MC}^2 + 5.7$



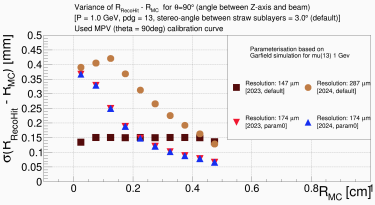
Bias increases with the same calibration curve (90°).

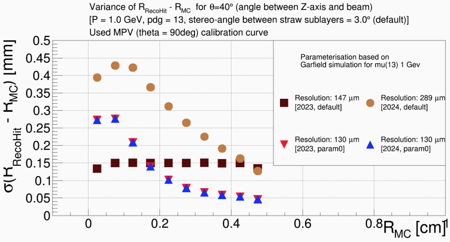


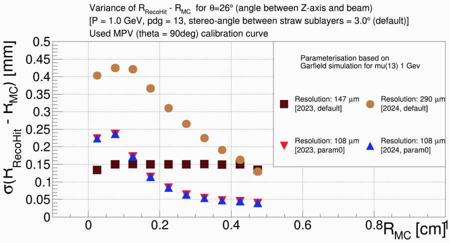




Reduced variance: ineffective with high bias







Summary

- **Signal Parameterization:** Straw signal parameterization by Sonya B. and Vitalii B. was implemented in SPDROOT for several angles.
- **SPDROOT:**
  - **Parameterization:** A comparison of different parameterization approaches, considering with and without the magnetic field, was conducted.
  - **Hit Reconstruction:** A straw hit reconstruction procedure has been introduced into SPDROOT.
- https://git.jinr.ru/nica/spdroot/-/tree/Straw-Signal-Parameterisation

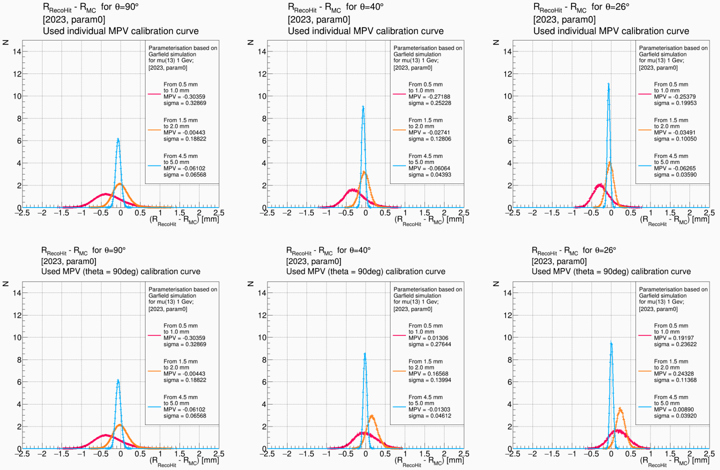
Result:

- Initially, both parameterization approaches seem to work similarly, so we'll use the parameterization without considering the magnetic field for future work.
- The initial version developed shows a bias at the level of 100 as a function of the radius.
- For the current realistic simulation of VVMM3-based readout model, the average resolution for 90° is 150μm.
- Using a single calibration curve results in high bias and reduced variance, making it ineffective.

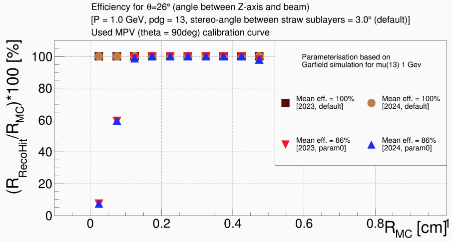
Thank you for your attention!

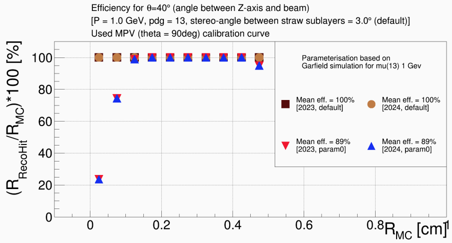
bckp

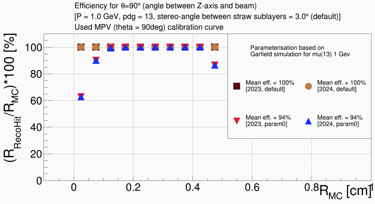
2023 param0 | Residual for three selected point | Bias issues with a single calibration curve



Efficiency


Efficiency for θ=26° (angle between Z-axis and beam)
[P = 1.0 GeV, pdg = 13, stereo-angle between straw sublayers = 3.0° (default)]
Used MPV (theta = 90deg) calibration curve
(R_RecoHit/R_MC)*100 [%]
R_MC [cm]
Parameterisation based on
Garfield simulation for mu(13) 1 Gev
Mean eff. = 100%
[2023, default]
Mean eff. = 100%
[2024, default]
Mean eff. = 86%
[2023, param0]
Mean eff. = 86%
[2024, param0]


Efficiency for θ=40° (angle between Z-axis and beam)
[P = 1.0 GeV, pdg = 13, stereo-angle between straw sublayers = 3.0° (default)]
Used MPV (theta = 90deg) calibration curve
(R_RecoHit/R_MC)*100 [%]
R_MC [cm]
Parameterisation based on
Garfield simulation for mu(13) 1 Gev
Mean eff. = 100%
[2023, default]
Mean eff. = 100%
[2024, default]
Mean eff. = 89%
[2023, param0]
Mean eff. = 89%
[2024, param0]


Efficiency for θ=90° (angle between Z-axis and beam)
[P = 1.0 GeV, pdg = 13, stereo-angle between straw sublayers = 3.0° (default)]
Used MPV (theta = 90deg) calibration curve
(R_RecoHit/R_MC)*100 [%]
R_MC [cm]
Parameterisation based on
Garfield simulation for mu(13) 1 Gev
Mean eff. = 100%
[2023, default]
Mean eff. = 100%
[2024, default]
Mean eff. = 94%
[2023, param0]
Mean eff. = 94%
[2024, param0]

Efficiency: details

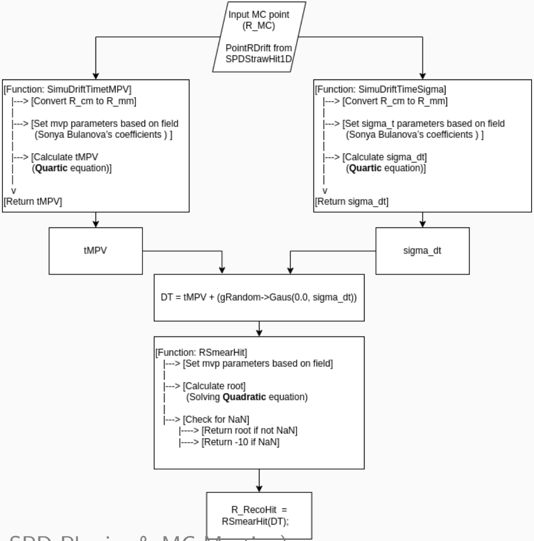
To calculate the efficiency in the range of R_{mc} from 0.0 to 0.5 cm, the total number of R_{mc} was counted, then it was calculated how many of these R_{mc} were reconstructed:

$Eff = \frac{N_{RecoHit}}{N_{totalOfHits}}$

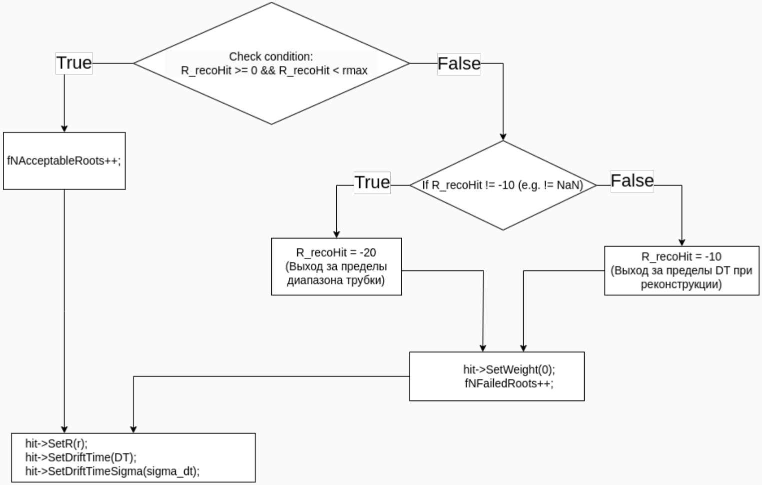
The efficiency of the parameterized version is lower than in the default version.

No reco in default.

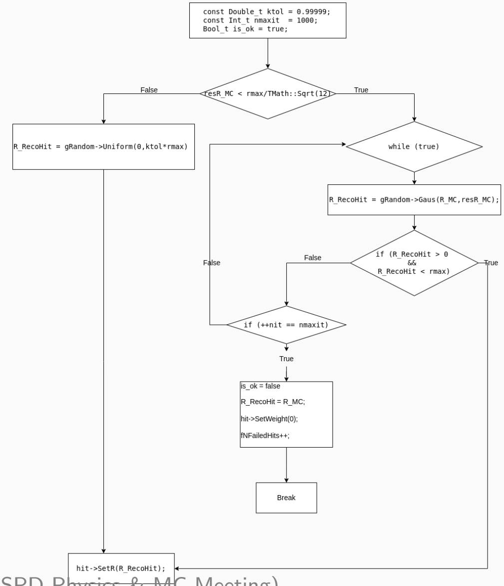
1. Drift time (DT) from R_{mc} and Garfield's simulations
2. $R_{RecoHit}$ from DT



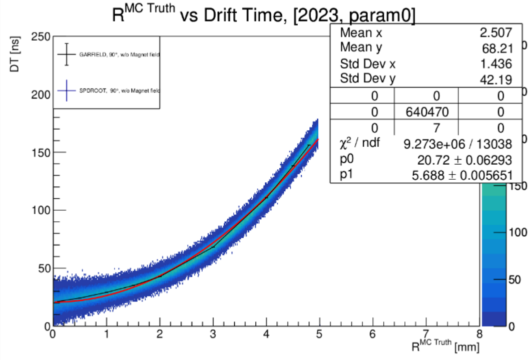
Create hit position in param0/1

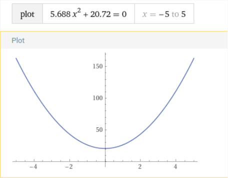


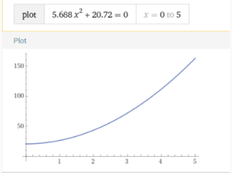
Create hit position in default



Coeff for quadratic equation (param0)



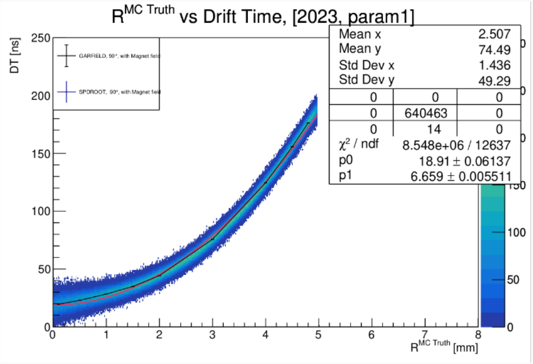




Derivative

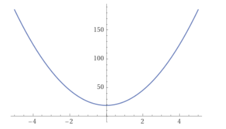
$$\frac{d}{dx}\left(5.688\,x^2 + 20.72\right) = 11.376\,x$$

Coeff for quadratic equation (param1)



plot $6.659\,x^2 + 18.91 = 0\,x$ $x = -5$ to 5

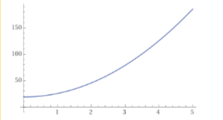
Plot



Input interpretation

plot $6.659\,x^2 + 18.91 = 0$ $x = 0$ to 5

Plot



Derivative

$$\frac{d}{dx}\left(6.659\,x^2 + 18.91\right) = 13.318\,x$$