Programme Matter and Technologies

Parameterization-based Tracking for the P2 Experiment

DTS-ST3: Detector Systems

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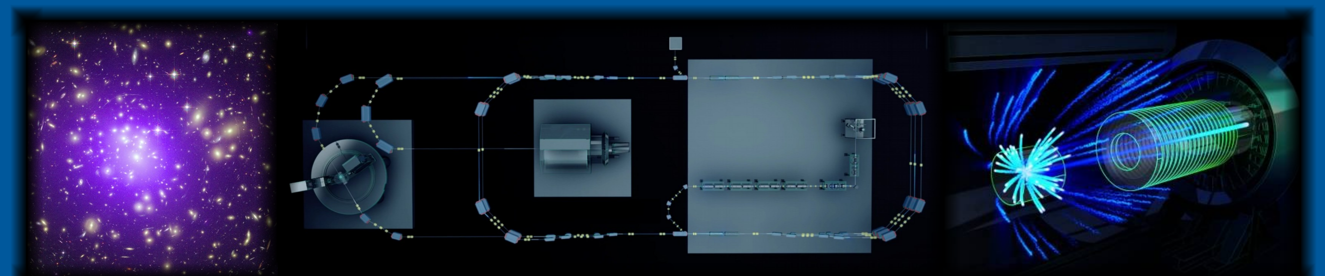
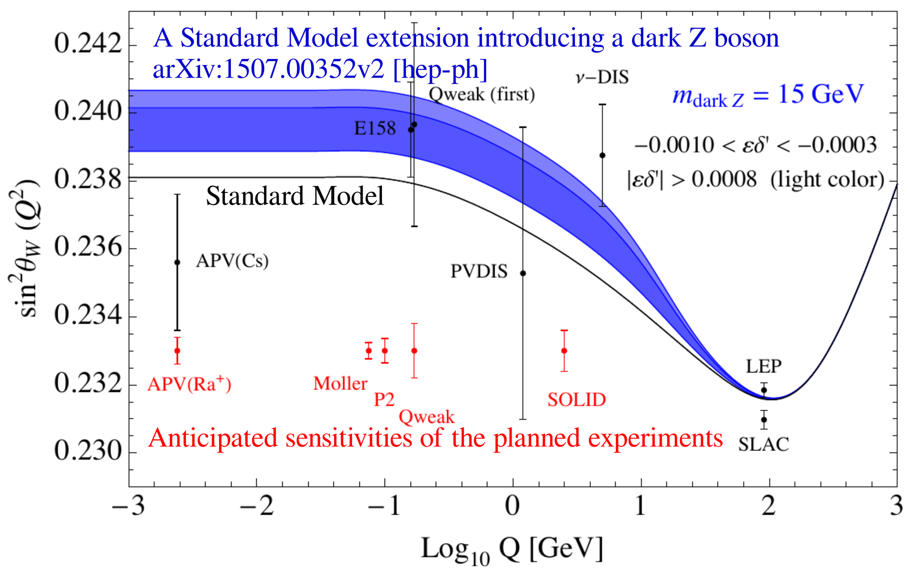
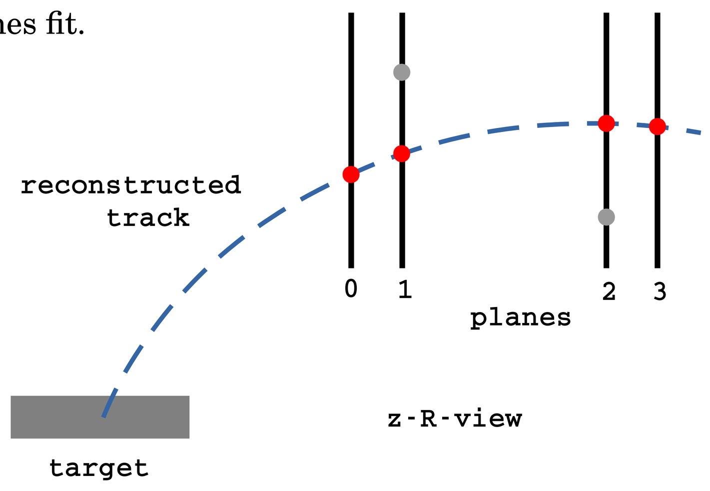


Motivation. A class of Standard Model extensions necessarily imply a modification of the running of the Weak Mixing Angle θ_W. The existing measurements of θ_W do not allow to discriminate between the Standard Model and the extensions. A precise measurement of the Weak Mixing Angle is therefore an indirect search for a new physics.

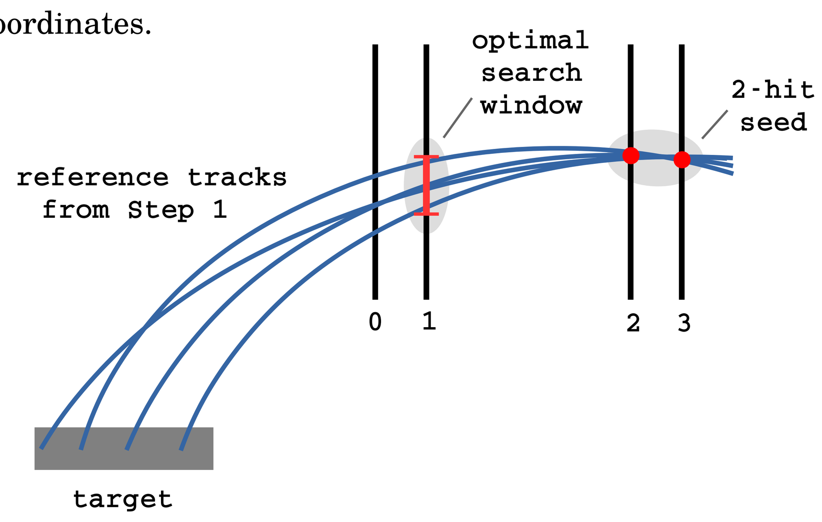


Parameterization-based tracking.

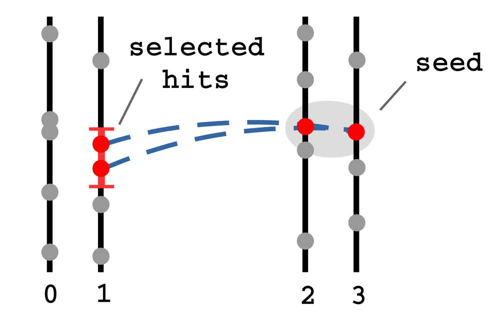
Step 1: Brute-force reconstruction at low rate.
Do a rigorous fit of all (reasonable) hit combinations. Use tracks with the best χ^2 as a reference in the Step 2. Currently, we use the GENFIT implementation of the General Broken Lines fit.



Step 2: Create parameterizations
For every possible track seed (consisting of one, two or three hits) look where the reference tracks cross the next plane. This is the optimal window for searching the hits matching to a similar seed at the reconstruction stage (Step 3). Store the search windows as a set of analytical functions of hit coordinates.



Step 3. Reconstruction
Take every hit in plane 3 as a seed. Extend the seeds with the hits within the optimal search windows. Also the fitting can be replaced by a parameterization.



Idea. A longitudinally-polarized electron beam is scattered on a proton target. The parity-violating asymmetry A_{PV} of the elastic scattering cross-section is measured. The latter can be related to weak charge of the proton Q_W, or to the Weak Mixing Angle θ_W as follows:

The electron flux (not individual particles) is measrued with a fused silica Cherenkov detector. The Tracking System is necessary to:
– measure the momentum transfer (Q^2) *distribution* of the scattered electrons (not Q^2 of each individual particle).
– validate the acceptance of the detector
– control the systematic uncertainties

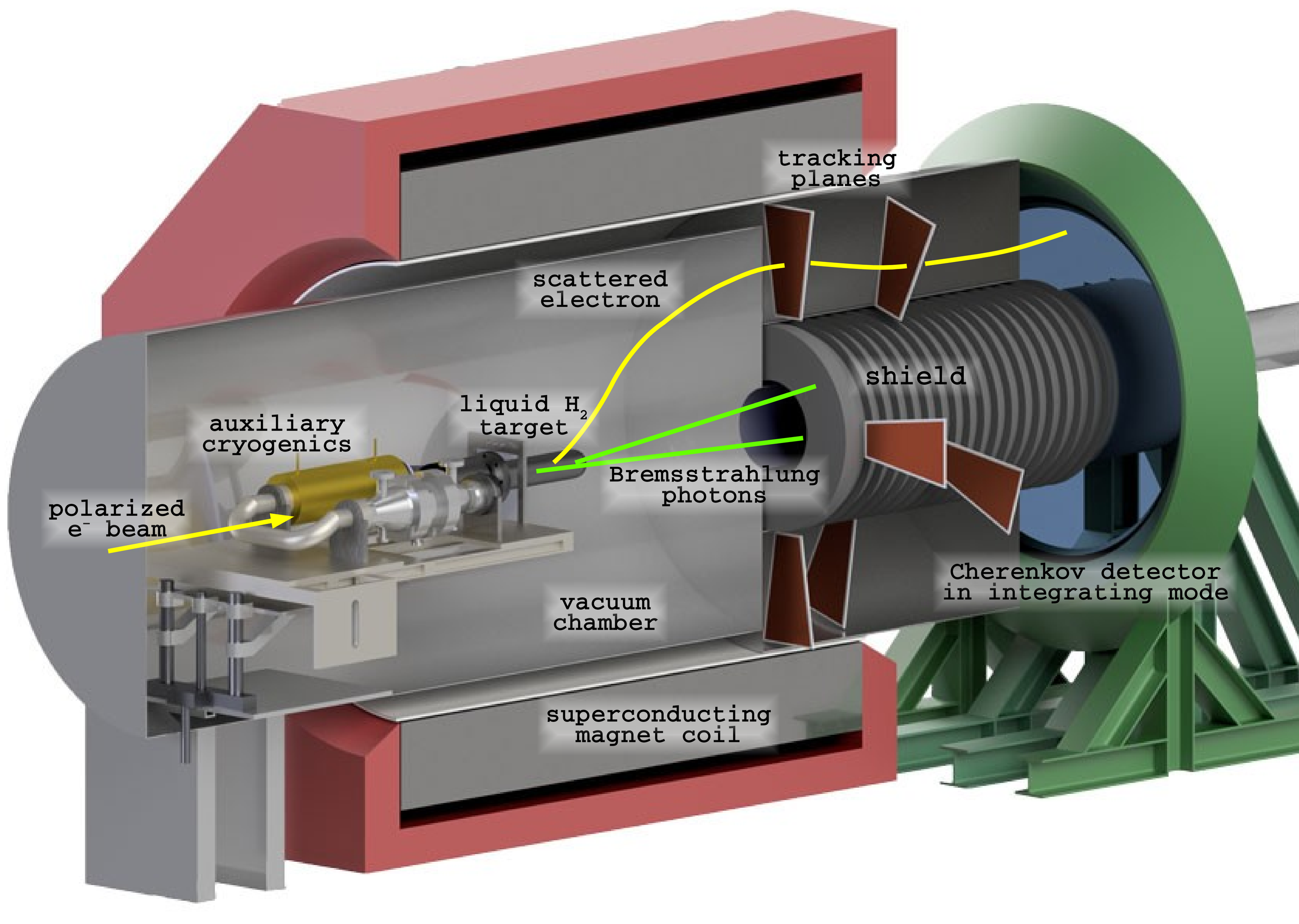
$$A_{PV}=\frac{N\downarrow - N\uparrow}{N\downarrow + N\uparrow}=\frac{\sigma\downarrow-\sigma\uparrow}{\sigma\downarrow+\sigma\uparrow}=\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W(Q^2)-F(Q^2)\right)\sim O(10^{-8})$$

$$Q_W(Q^2)=1-4\cdot\sin^2(\theta_W(Q^2))$$

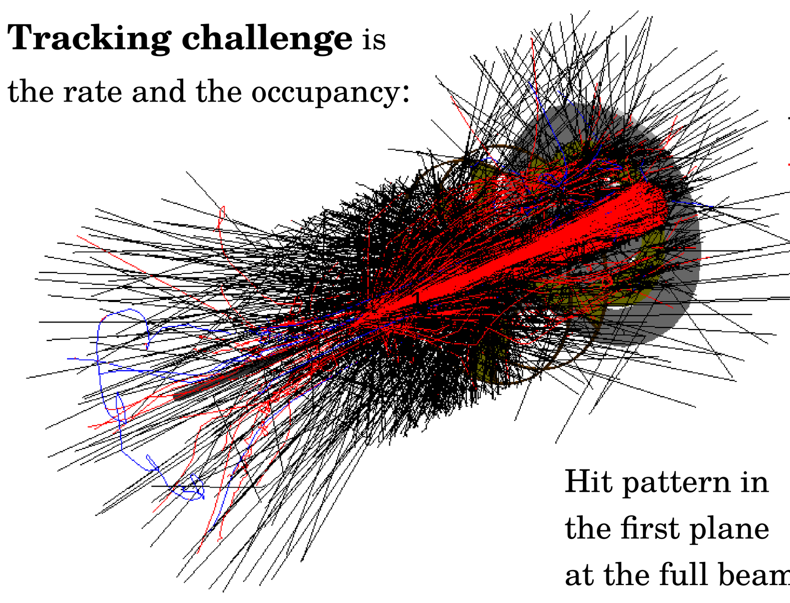
As A_{PV} is so tiny, an immense statistics is required.

The design goal is to collect $3\cdot 10^{18}$ electrons in 10 000 running hours (1 year non-stop)

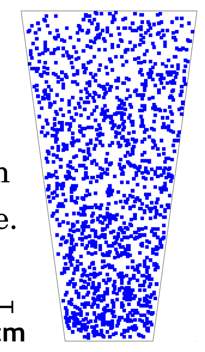
This corresponds to 10^{11} electrons/s.



Tracking challenge is the rate and the occupancy:

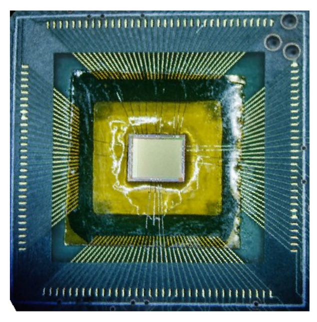


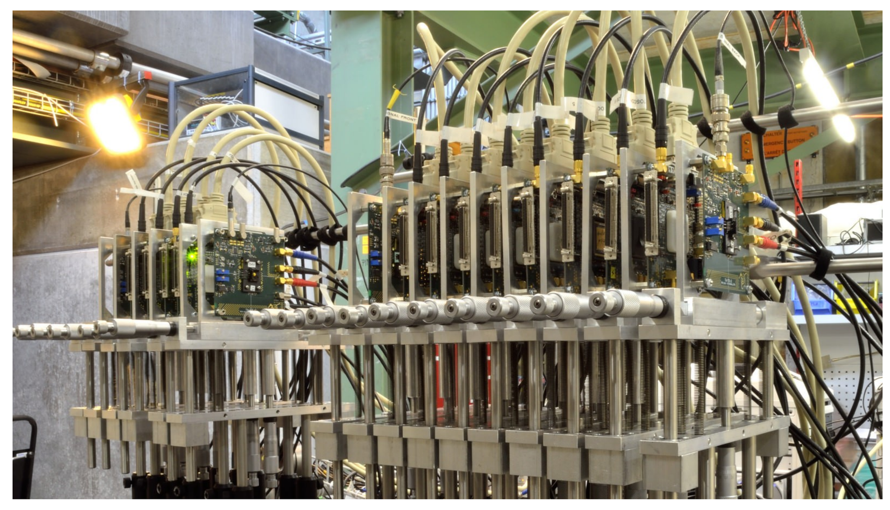
GEANT4 Simulation of 1/100 of a reconstruction frame (45 ns) at the full rate.



Hit pattern in the first plane at the full beam rate. One frame. 1600 hits.

MuPix HV-MAPS. Originally developed for the Mu3e experiment, MuPix fits excellent to the needs of P2:
– pixel size 80 x 80 µm²
– digital readout
– time resolution 11 ns (measured)
– rate capability: 2.5 MHz/chip tested
30 MHz/chip or 280 MHz/cm² expected
– efficiency > 99% demonstrated



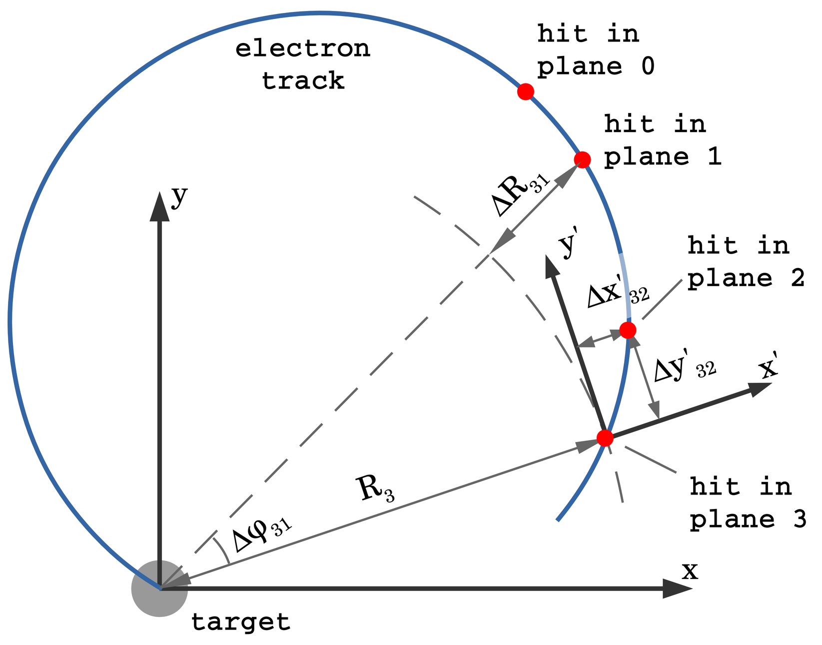


Test of a 4- and an 8-plane MuPix telescopes in a mixed e^+, μ^+, π^+ beam at Paul Scherrer Institute (Switzerland), 2016.

Parameterization functions

In the current implementation the search windows are rectangular, and they are parameterized with 3rd order polynomials as follows.

x_{POS}, y_{POS} – position of the window w.r.t. the last hit in the seed
x_{SIZE}, y_{SIZE} – size of the search window
φ_{ROT} – rotation of the search window



In plane 3 no search window is needed: we loop over all hits, and take each hit as a track seed.

In plane 2 the search window depends only on the position of hit 3. Due to the φ-symmetry of the setup only its R-coordinate is important:

x_{SIZE} = pol3(R_3)
y_{SIZE} = pol3(R_3)
x_{POS} = pol3(R_3)
y_{POS} = pol3(R_3)
φ_{ROT} = pol3(R_3)

In plane 1 the search window depends on the position of hits 3 and 2. Only their radial position (defined by R_3), and their position w.r.t. each other are important:

x_{SIZE} = pol3(R_3, $\Delta x'_{32}$, $\Delta y'_{32}$)
y_{SIZE} = pol3(R_3, $\Delta x'_{32}$, $\Delta y'_{32}$)
x_{POS} = pol3(R_3, $\Delta x'_{32}$, $\Delta y'_{32}$)
y_{POS} = pol3(R_3, $\Delta x'_{32}$, $\Delta y'_{32}$)
φ_{ROT} = pol3(R_3, $\Delta x'_{32}$, $\Delta y'_{32}$)

In plane 0 the search window depends on positions of hits 3, 2, and 1, but they are correlated, so the positions of hits 3 and 1 are sufficient:

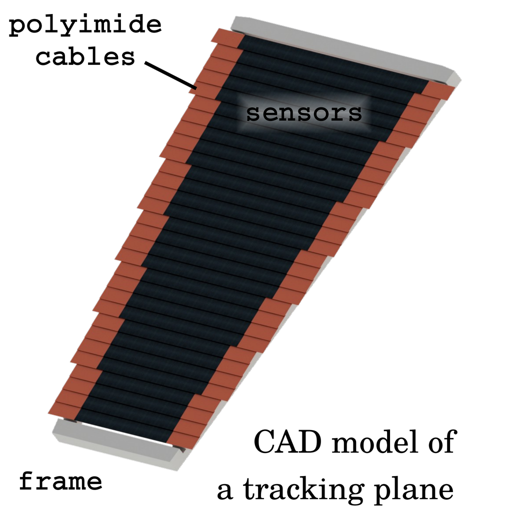
x_{SIZE} = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)
y_{SIZE} = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)
x_{POS} = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)
y_{POS} = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)
φ_{ROT} = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)

Tracking detector

Two pairs of HV-MAPS layers in 0.5 T·m inhomogenious field

Material (within acceptance)
50 µm Si (HV-MAPS)
+ 100 µm polyimide
+ 20 µm Al (signal traces)
0.1 % X_0 / plane

Cooling with He, blown from within the frame

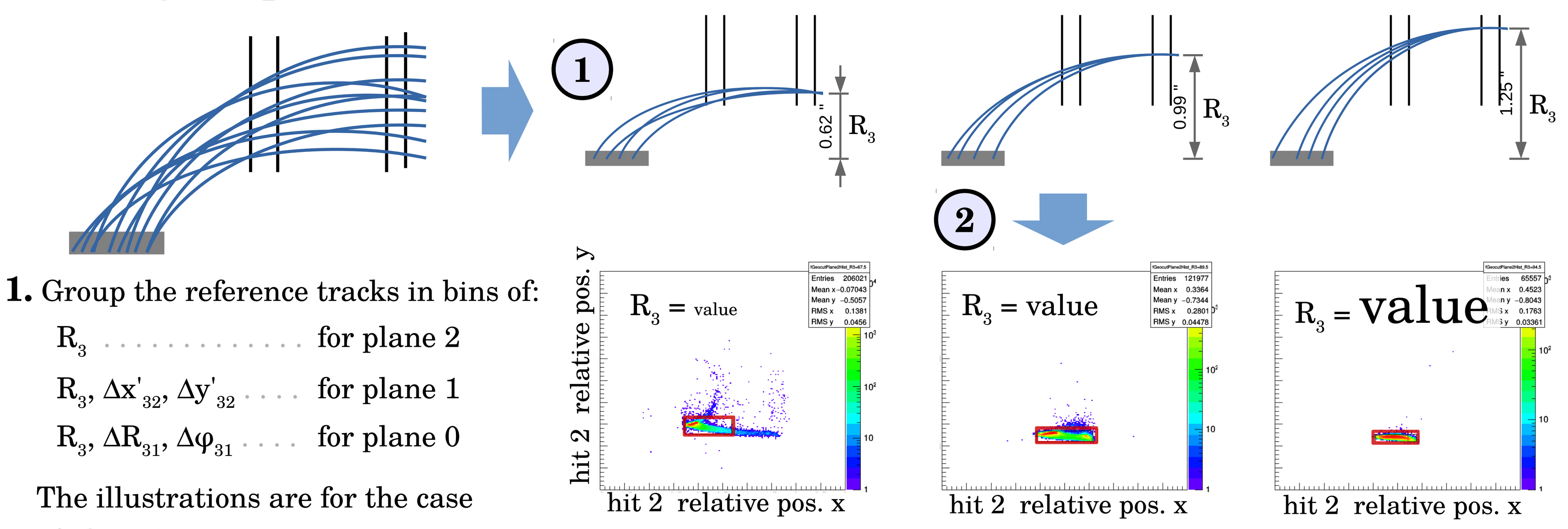


CAD model of a tracking plane

A 50 µm silicon wafer, as used for MuPix fabrication

A self-supporting structure made of 100 µm polyimide film. (Mu3e prototype)

Creating the parameterizations



1. Group the reference tracks in bins of:
R_3 . . . . for plane 2
R_3, $\Delta x'_{32}$, $\Delta y'_{32}$ . . . . for plane 1
R_3, ΔR_{31}, $\Delta\varphi_{31}$ . . . . for plane 0

The illustrations are for the case of plane 2.

2 and **3.** Find the optimal search window in every bin.

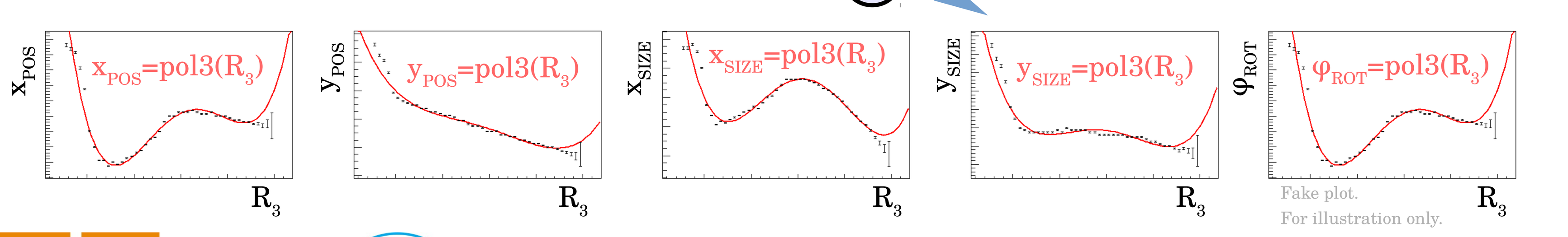
3

R_3	x_{POS}	y_{POS}	x_{SIZE}	y_{SIZE}	φ_{ROT}
...	...	...	...	...	...
value	■■■■	■■■■	■■■■	■■■■	■■■■
value	■■■■	■■■■	■■■■	■■■■	■■■■
value	■■■■	■■■■	■■■■	■■■■	■■■■
...	...	...	...	...	...

4. Fit x_{SIZE}, y_{SIZE}, x_{POS}, y_{POS}, φ_{ROT} as a function of the bin variables. The fitted functions are the required parameterizations!

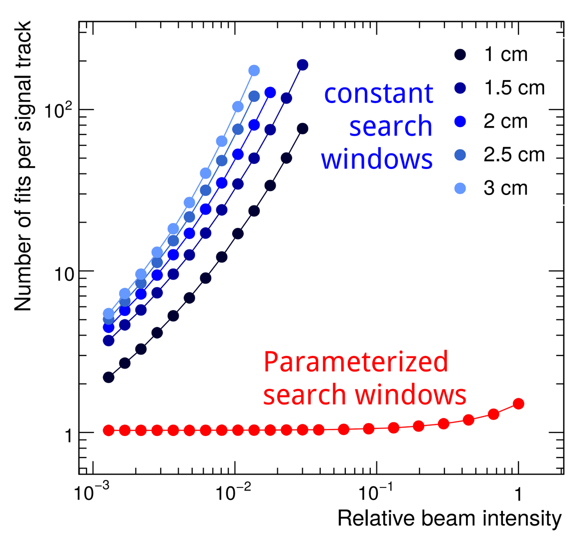
The momentum parameterization is created similarly.

4

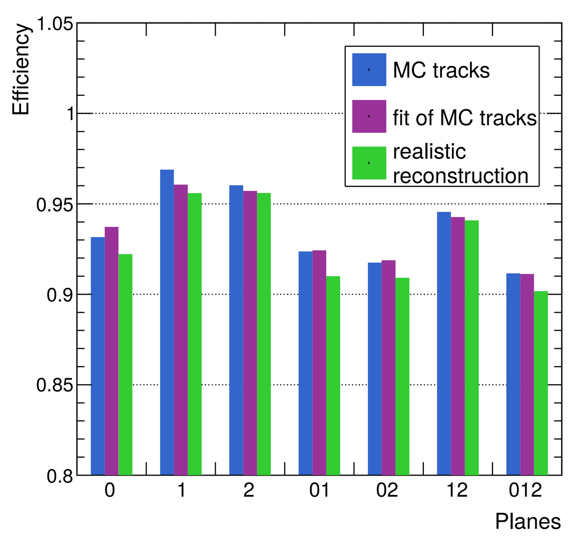


Performance

Suppression of combinatorics

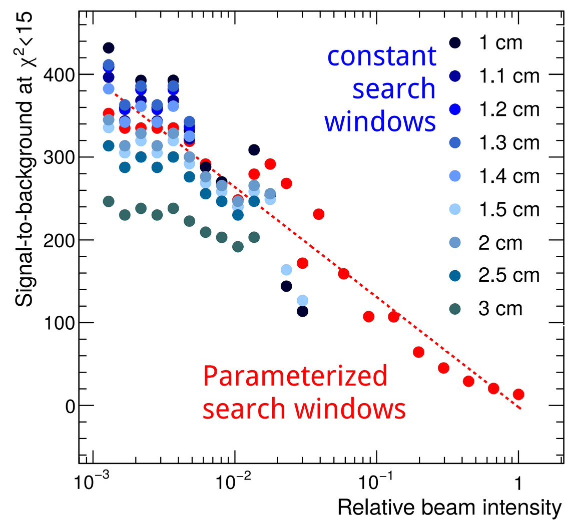


Efficiency



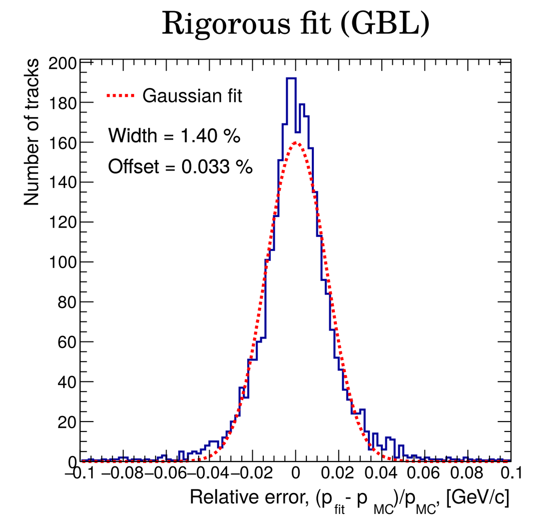
Search windows were created using different samples of reference tracks. Efficiency was evaluated on another sample of MC tracks with only "reconstructible" tracks selected. The plot shows the fraction of tracks accepted by the search windows in each of the planes or plane combinations. The inefficiency is caused mostly by the multiple scattering and the χ^2 cut.

Signal / Background

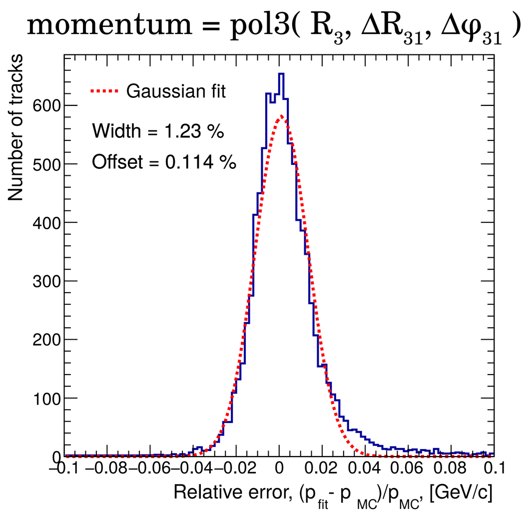


Momentum resolution

Rigorous fit (GBL)



Fit replaced by parameterization:
momentum = pol3(R_3, ΔR_{31}, $\Delta\varphi_{31}$)



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