



Parameterization-based tracking for the P2 experiment

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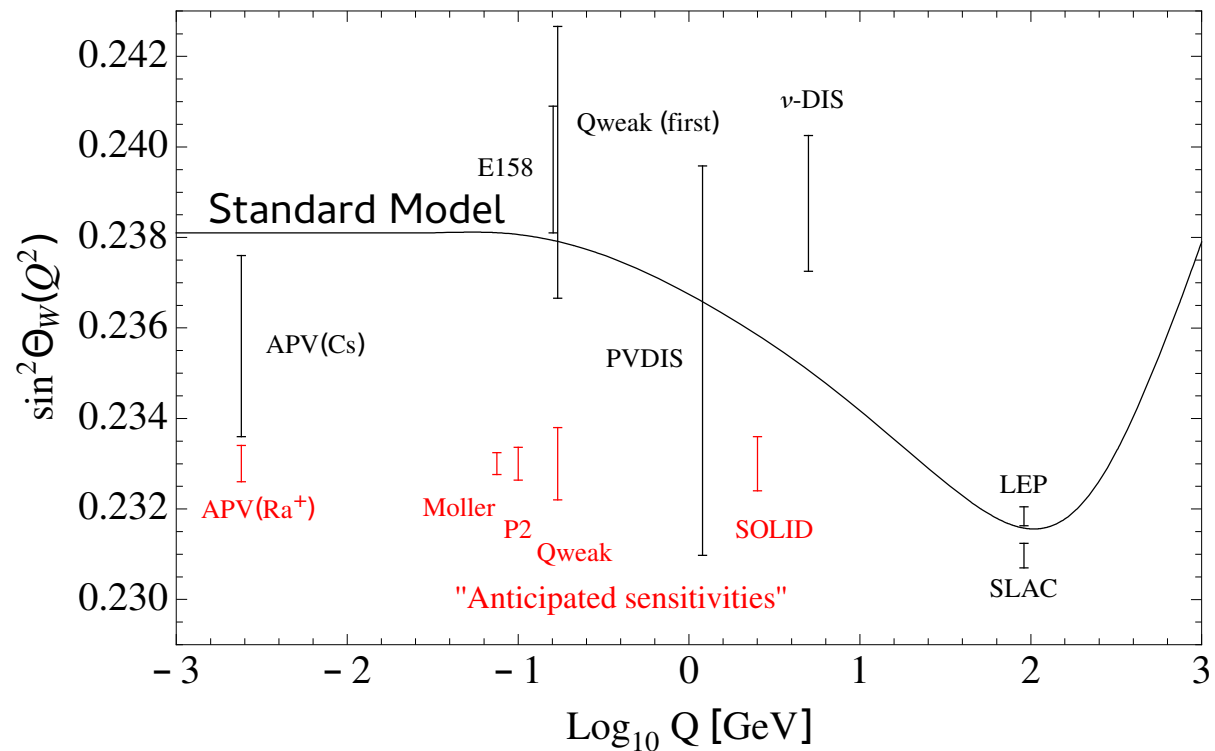
CTD/WIT 2017, LAL (Orsay)

The Weak Mixing Angle θ_w

defines the **relative strength** of **electromagnetic** and **weak** interactions

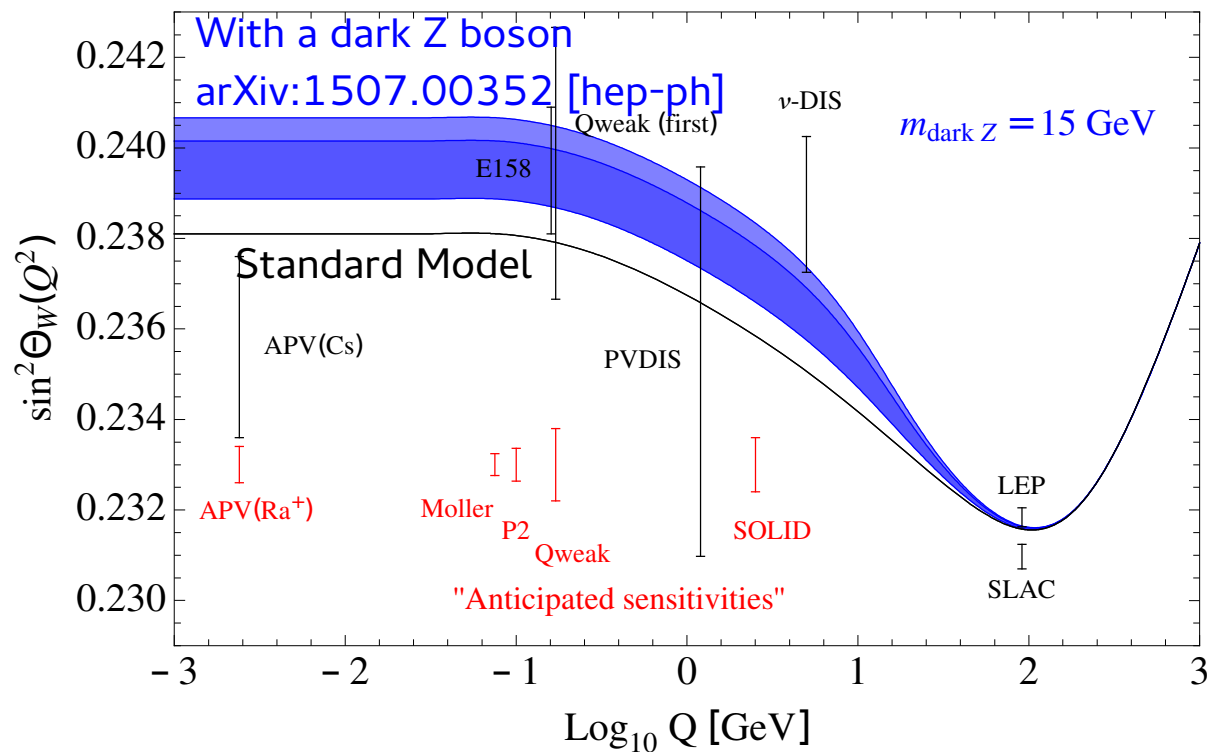
The Weak Mixing Angle θ_W

defines the **relative strength** of **electromagnetic** and **weak** interactions

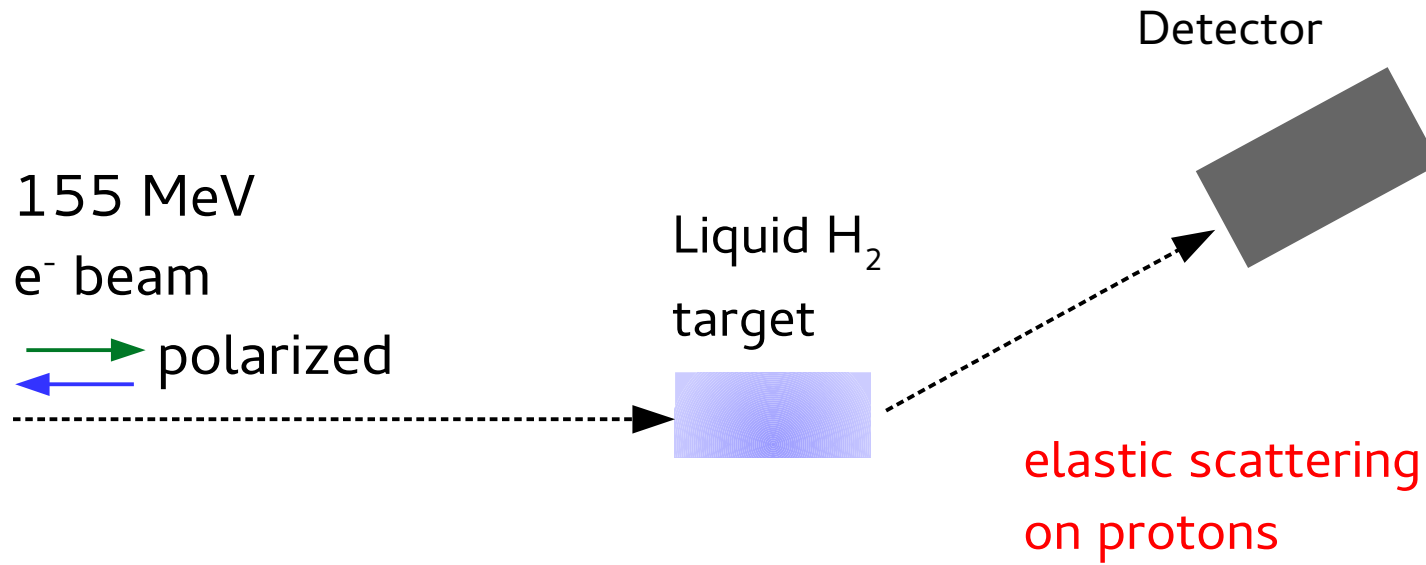


The Weak Mixing Angle θ_w

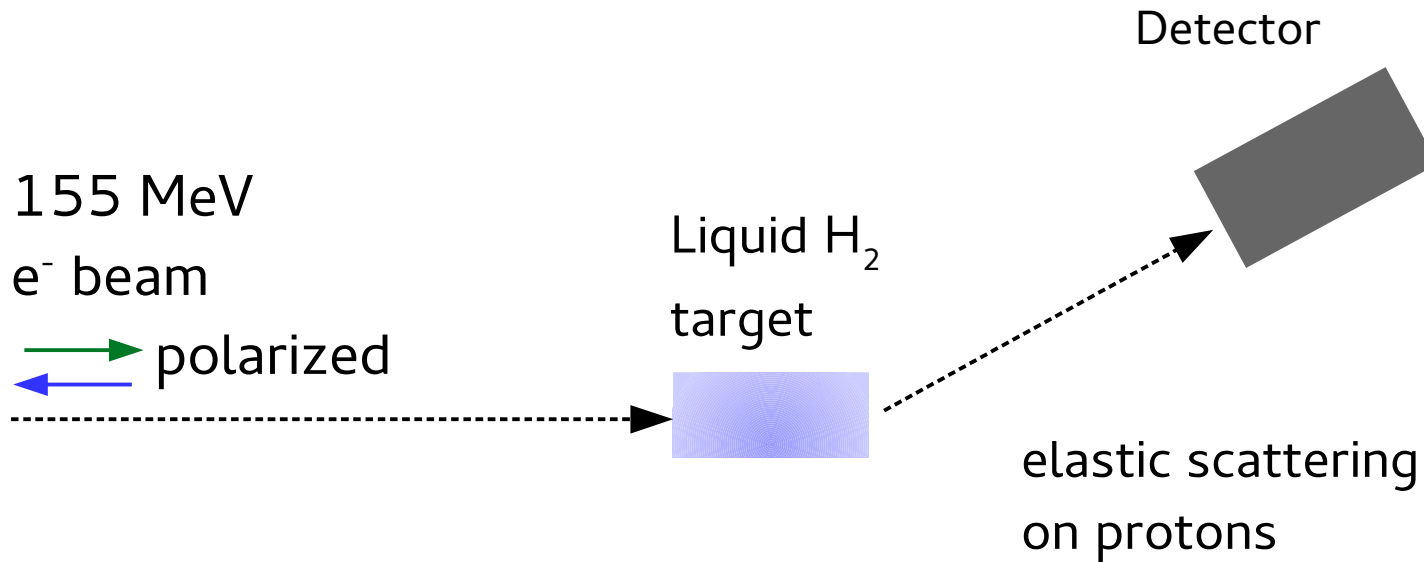
defines the relative strength of electromagnetic and weak interactions



θ_W measurement



θ_w measurement



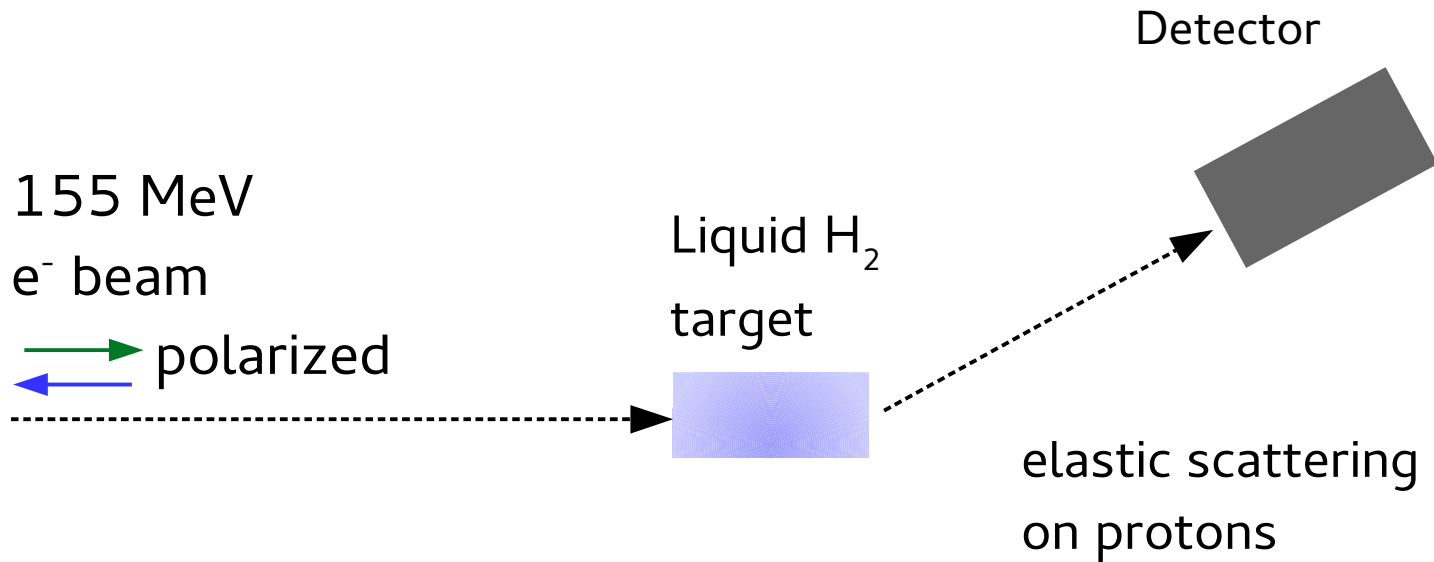
$$A_{PV} = \frac{N_{\downarrow} - N_{\uparrow}}{N_{\downarrow} + N_{\uparrow}} = \frac{\sigma_{\downarrow} - \sigma_{\uparrow}}{\sigma_{\downarrow} + \sigma_{\uparrow}} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha} (Q_w - F(Q^2))$$

$$Q_w = 1 - 4 \cdot \sin^2(\theta_w)$$

proton weak charge

Weak mixing angle

θ_W measurement



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

$$\Delta A_{PV} = \frac{1}{\sqrt{N_{\downarrow} + N_{\uparrow}}} < 6 \cdot 10^{-10} \text{ (2\% relative)}$$

$$\Rightarrow N_{\downarrow} + N_{\uparrow} \approx 3 \cdot 10^{18}$$

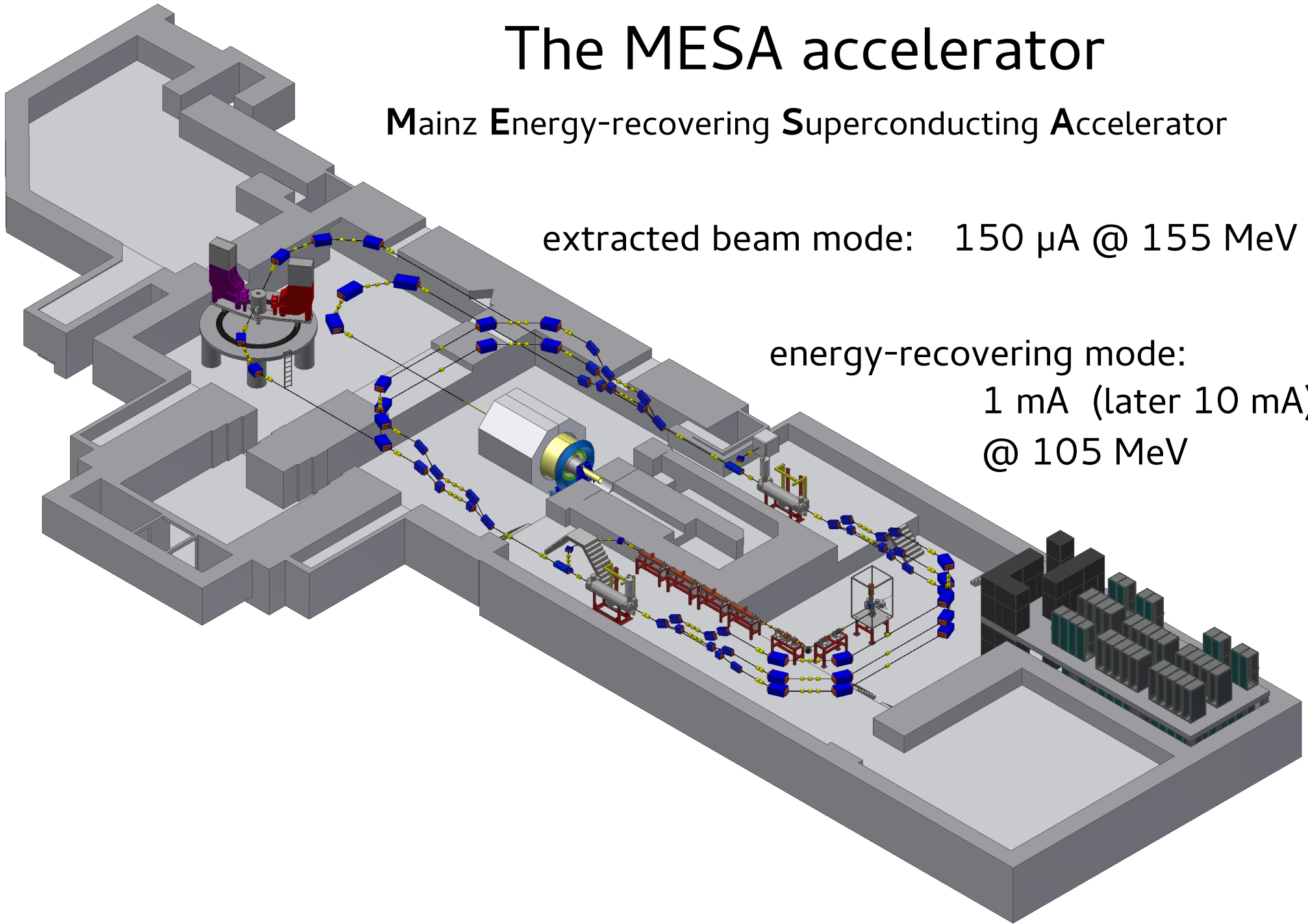
10 000 hours at
 10^{11} events/s

The MESA accelerator

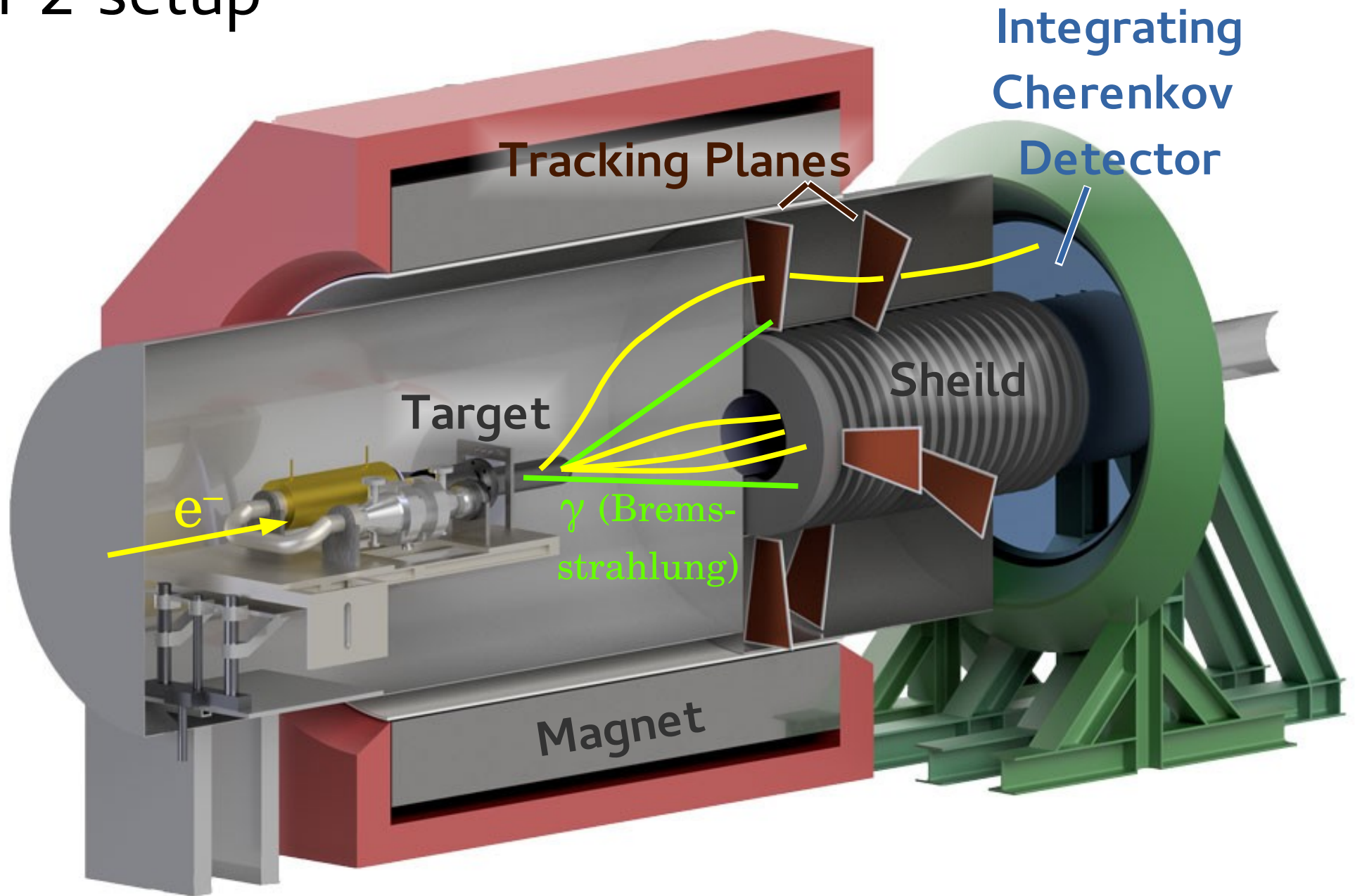
Mainz **E**nergy-recovering **S**uperconducting **A**ccelerator

extracted beam mode: 150 μA @ 155 MeV

energy-recovering mode:
1 mA (later 10 mA)
@ 105 MeV

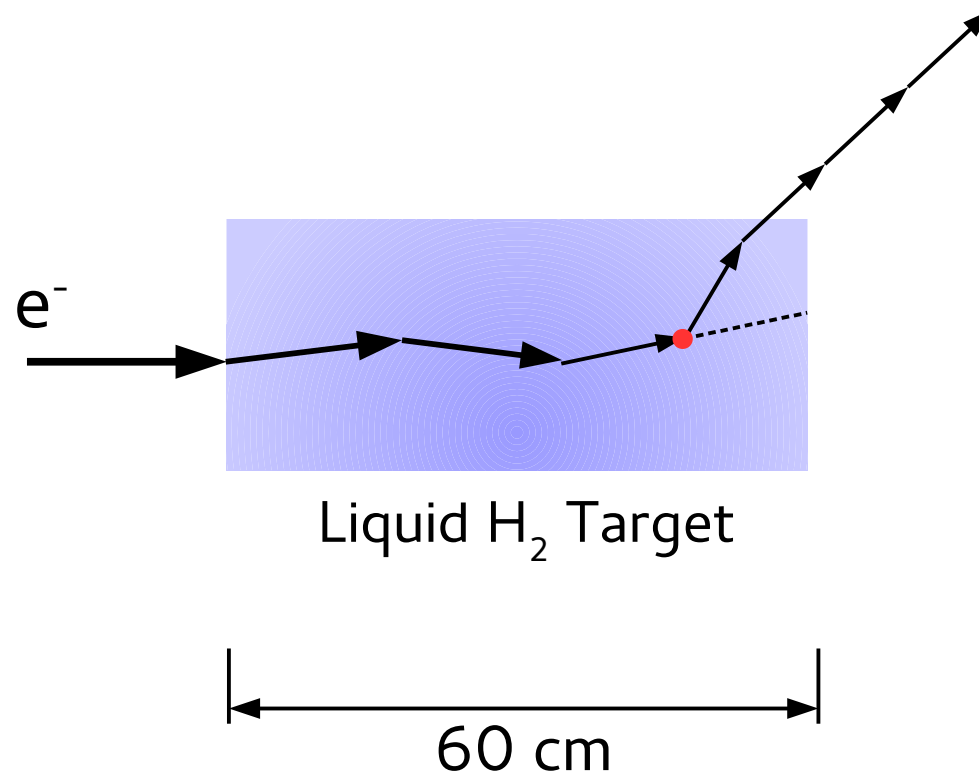


P2 setup



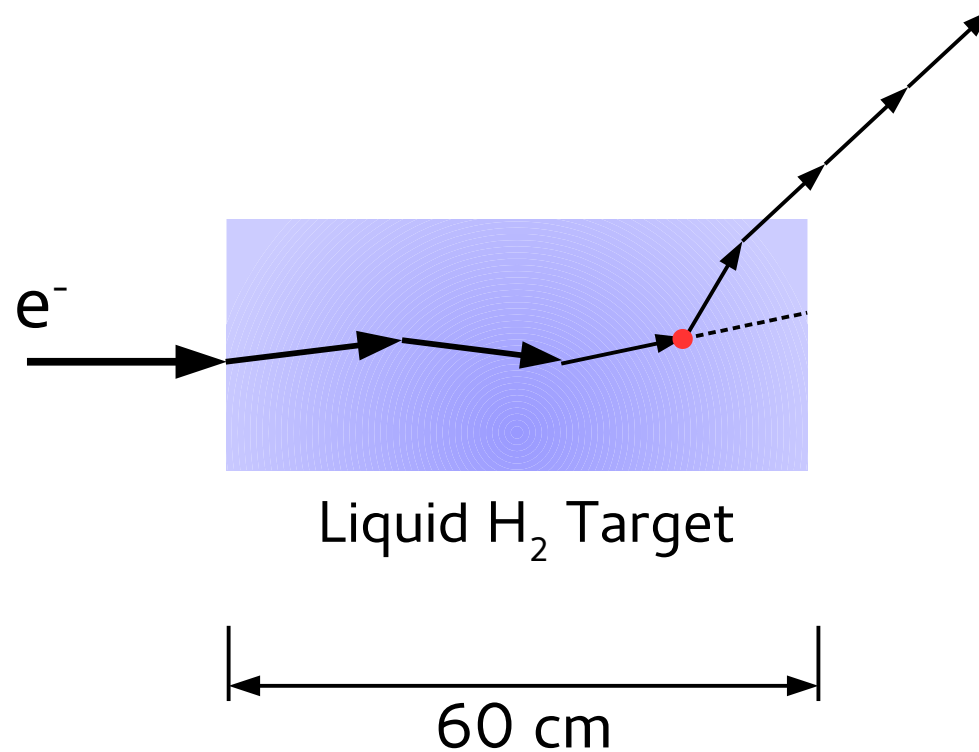
Why is tracking necessary?

"Measure" actual Q^2 distribution



Why is tracking necessary?

"Measure" actual Q^2 distribution

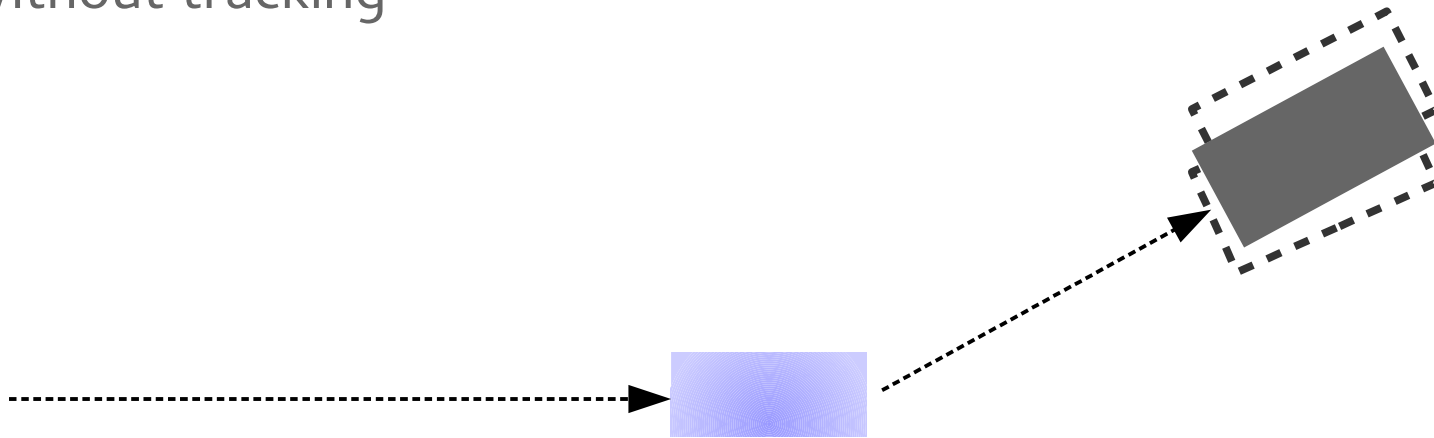


$$A_{PV} = \frac{N_{\downarrow} - N_{\uparrow}}{N_{\downarrow} + N_{\uparrow}} = \frac{\sigma_{\downarrow} - \sigma_{\uparrow}}{\sigma_{\downarrow} + \sigma_{\uparrow}} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha} (Q_W - F(Q^2))$$

Why is tracking necessary?

Validate the acceptance, alignment, and magnetic filed map

The magnetic field is anyways necessary,
even without tracking

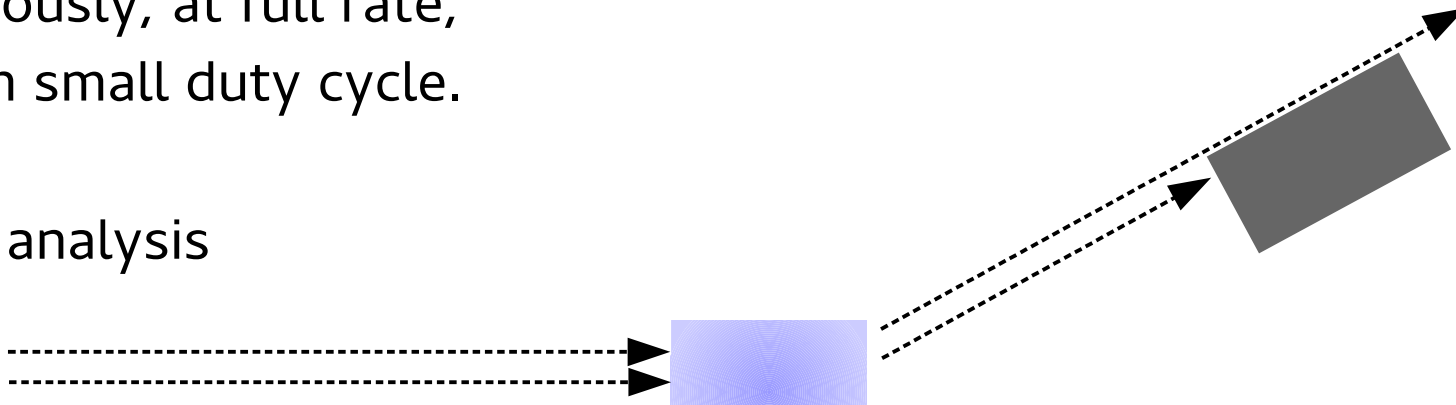


Why is tracking necessary?

Monitor the beam and the target conditions (e.g. boiling)

Continuously, at full rate,
but with small duty cycle.

On-line analysis



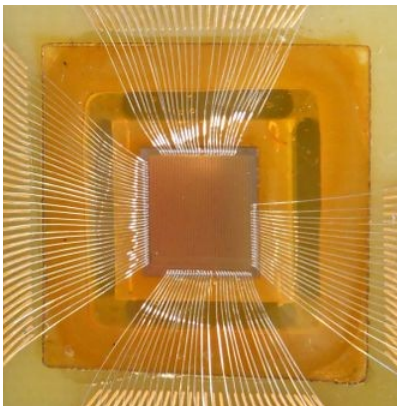
MuPix HV-MAPS

Originally developed for the Mu3e experiment, MuPix fits excellent to the needs of P2.

Peric, Ivan Nucl.Instrum.Meth. A582
(2007) 876-885

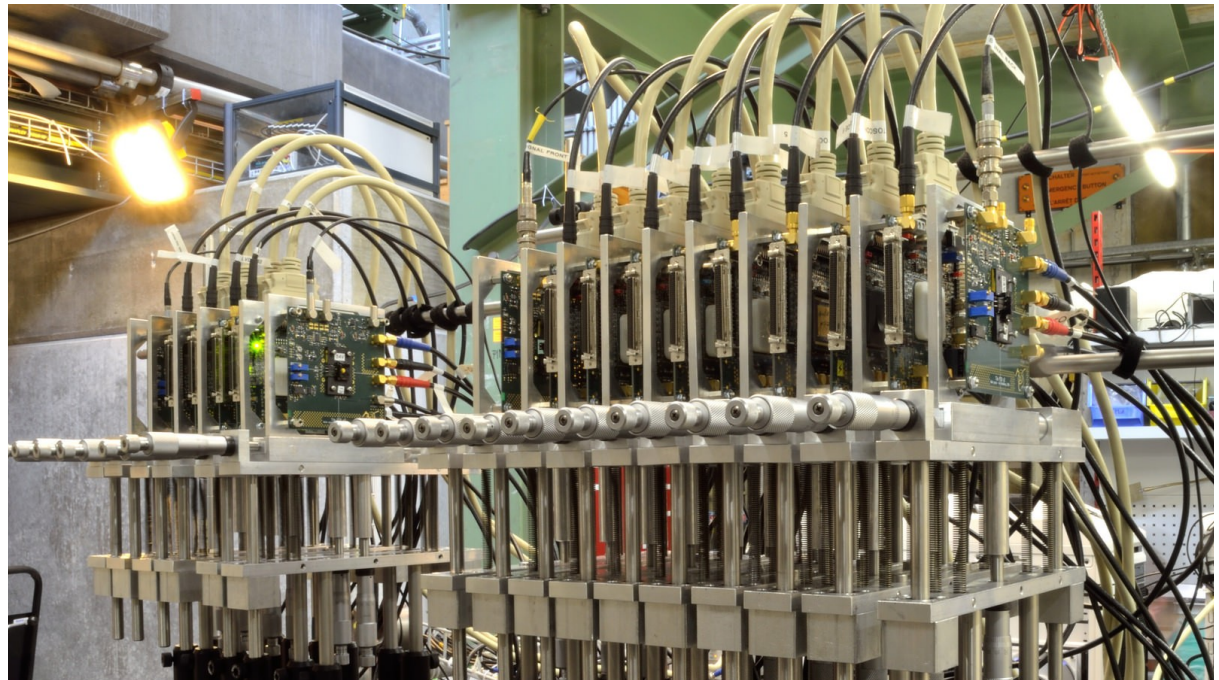
Augustin, Heiko et al. Nucl.Instrum.Meth.
A845 (2017) 194-198

- ▶ pixel size $80 \times 80 \mu\text{m}^2$ (latest version)
- ▶ digital readout
- ▶ time resolution 11 ns (measured)
- ▶ rate capability:
 - 2.5 MHz/chip tested (DAQ limited)
 - 30 MHz/chip
 - or 280 MHz/cm^2 } theoretical
- ▶ efficiency $> 99\%$ demonstrated

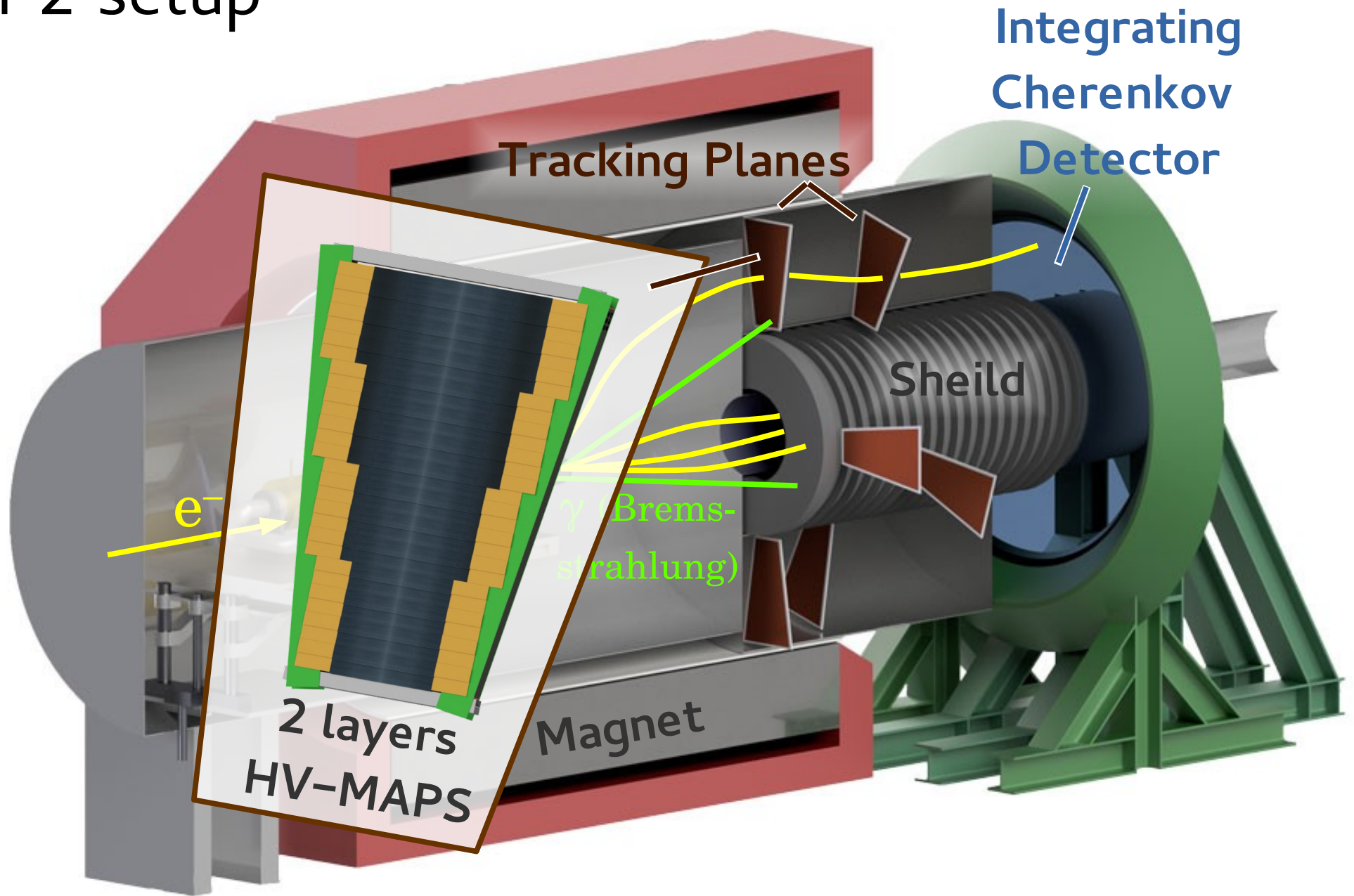


MuPix7
on a
readout
board

Beam test of
4- and 8-plane
MuPix telescopes
at PSI (2016)

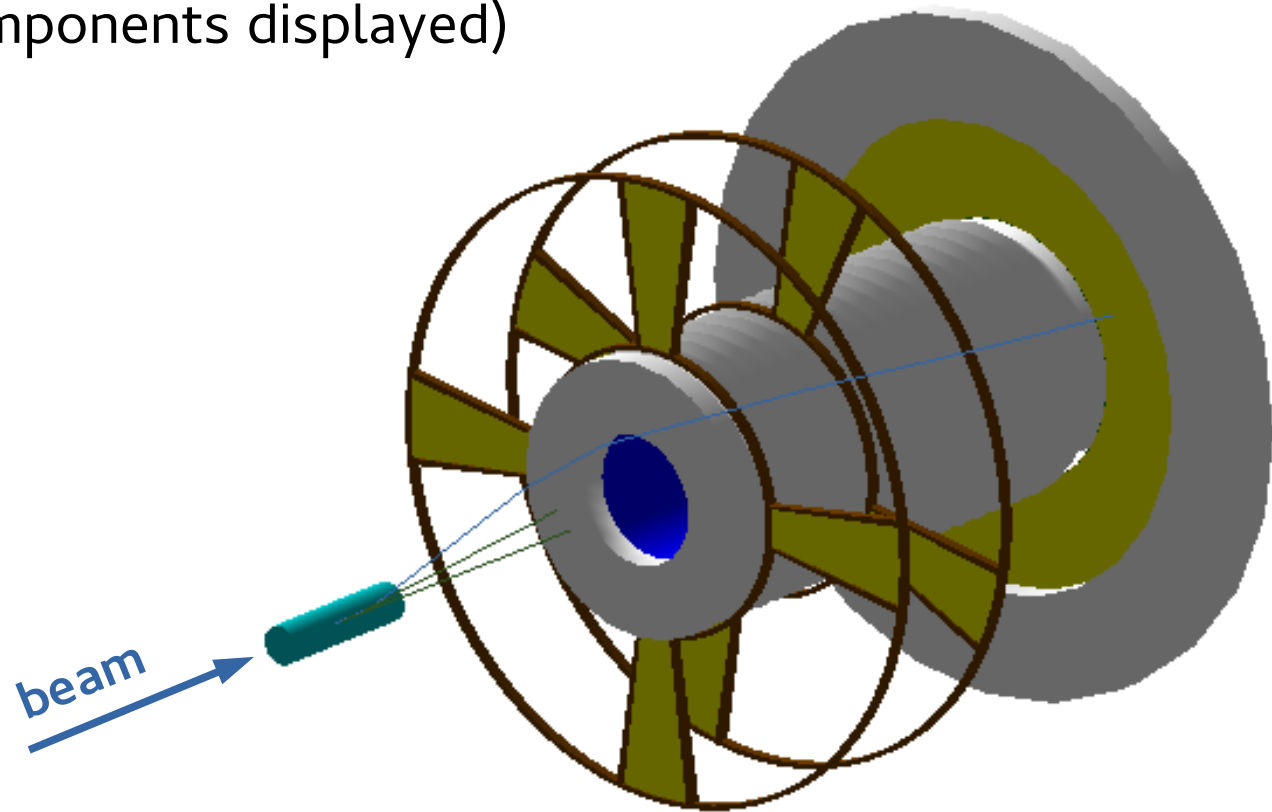


P2 setup



GEANT4 simulation

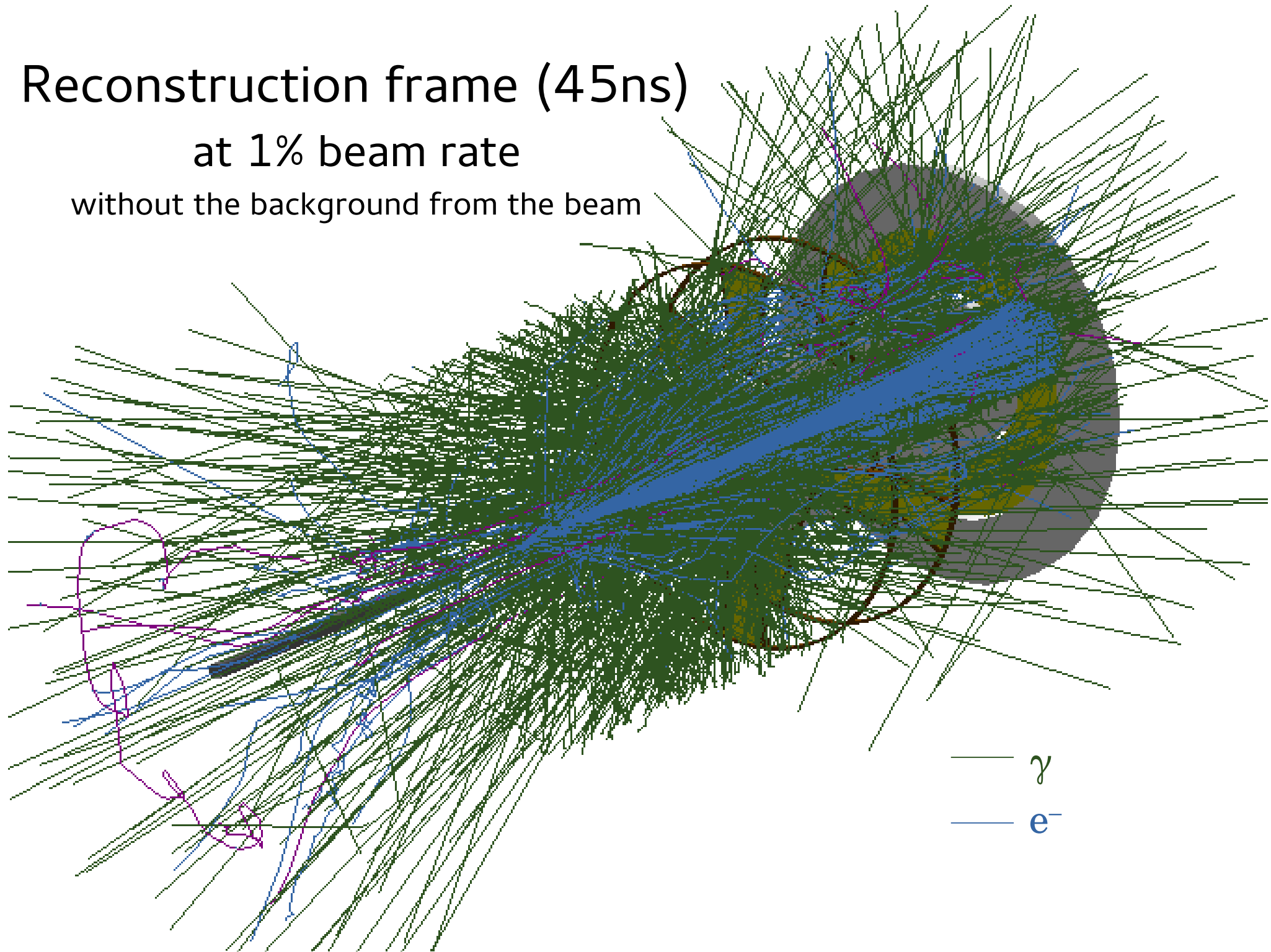
(only relevant components displayed)



Reconstruction frame (45ns)

at 1% beam rate

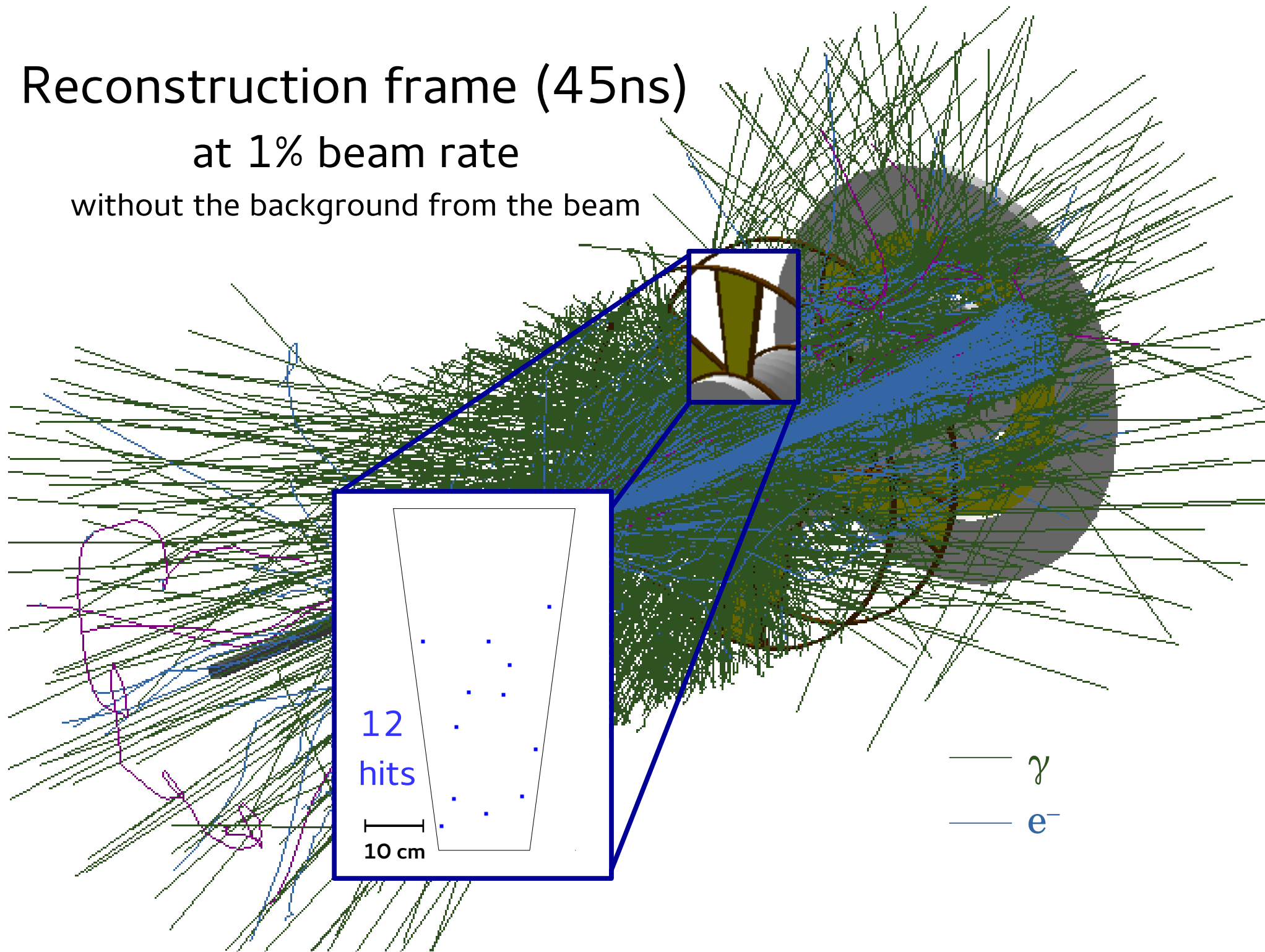
without the background from the beam



Reconstruction frame (45ns)

at 1% beam rate

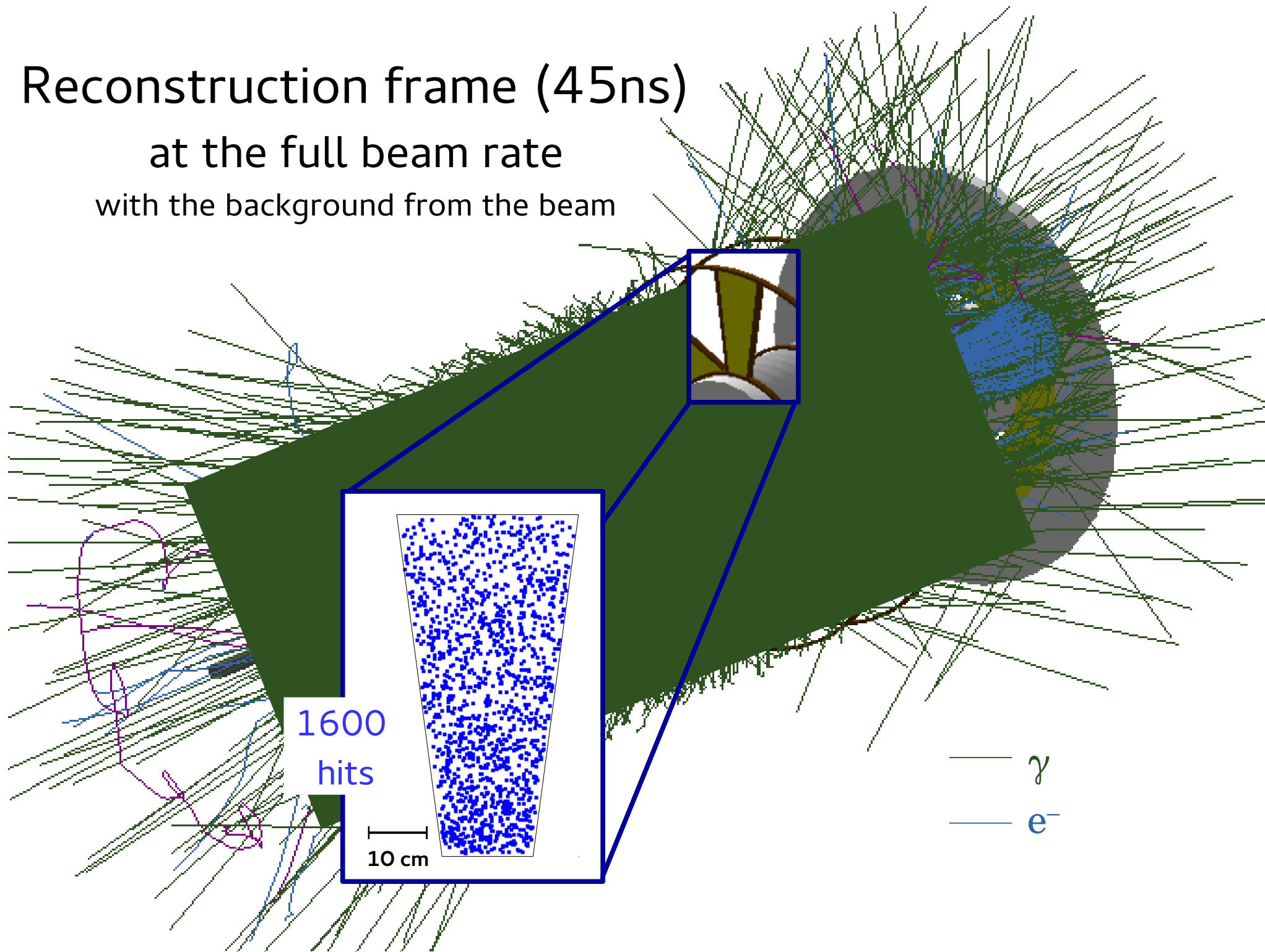
without the background from the beam



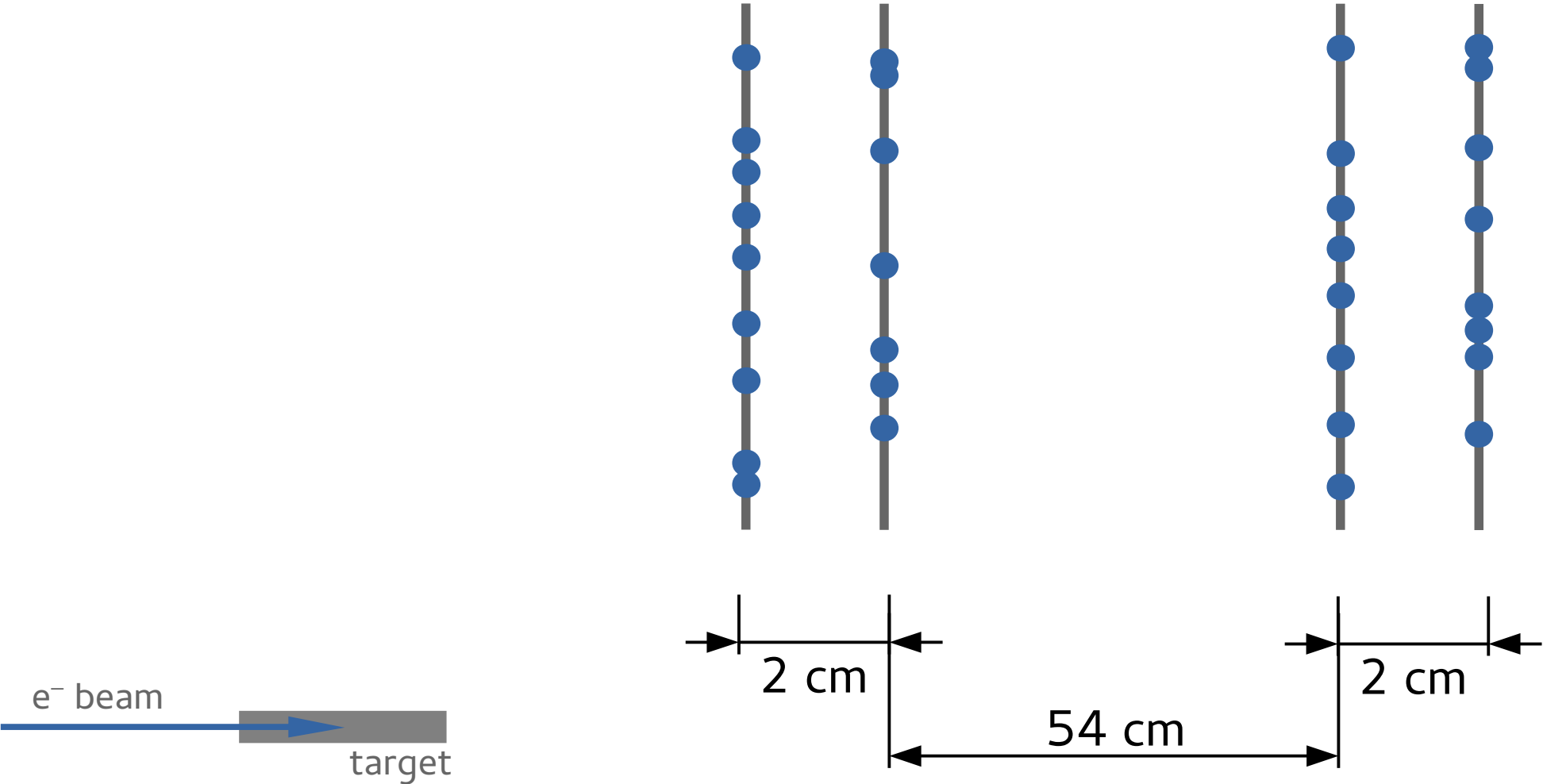
Reconstruction frame (45ns)

at the full beam rate

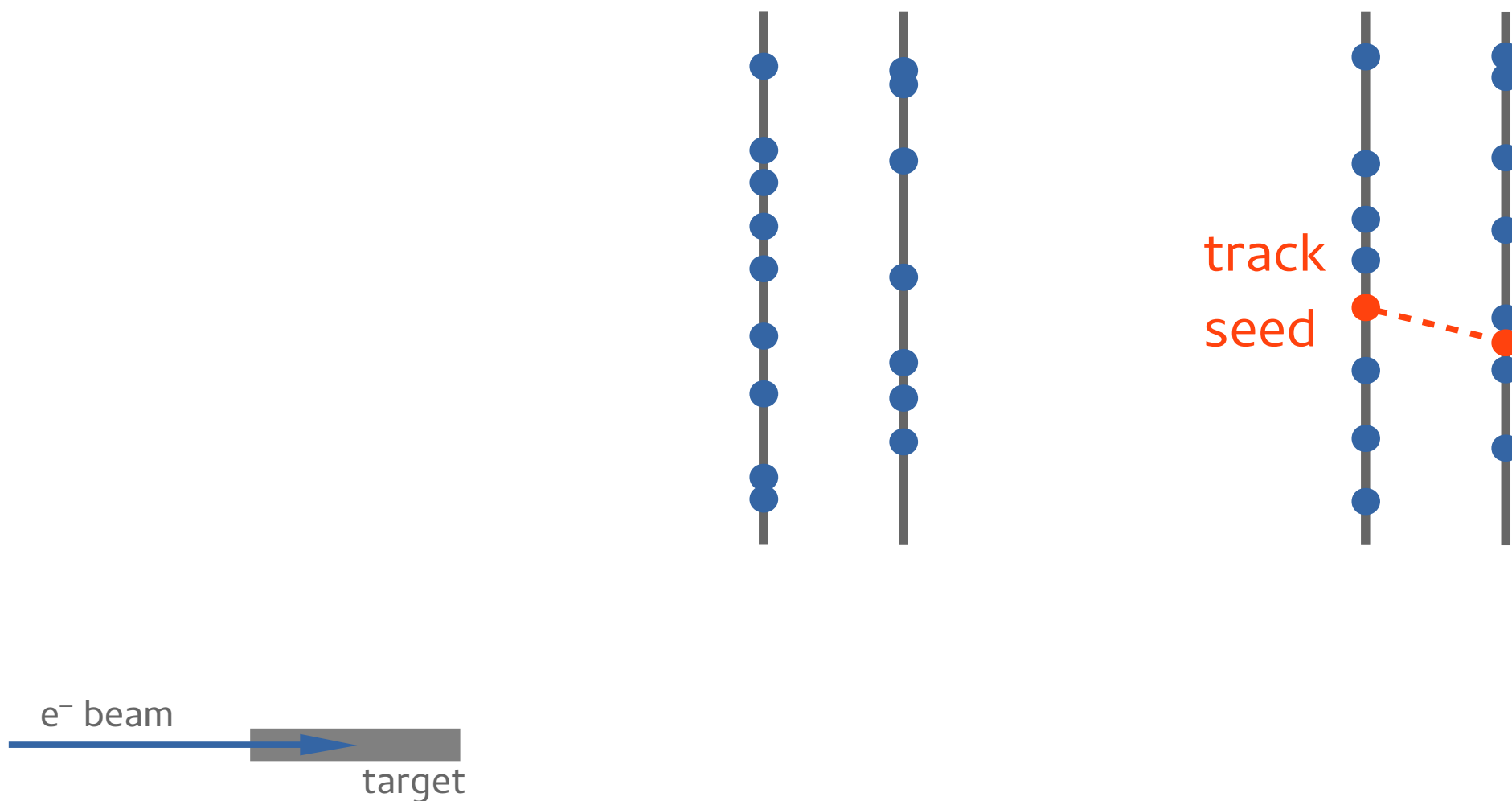
with the background from the beam



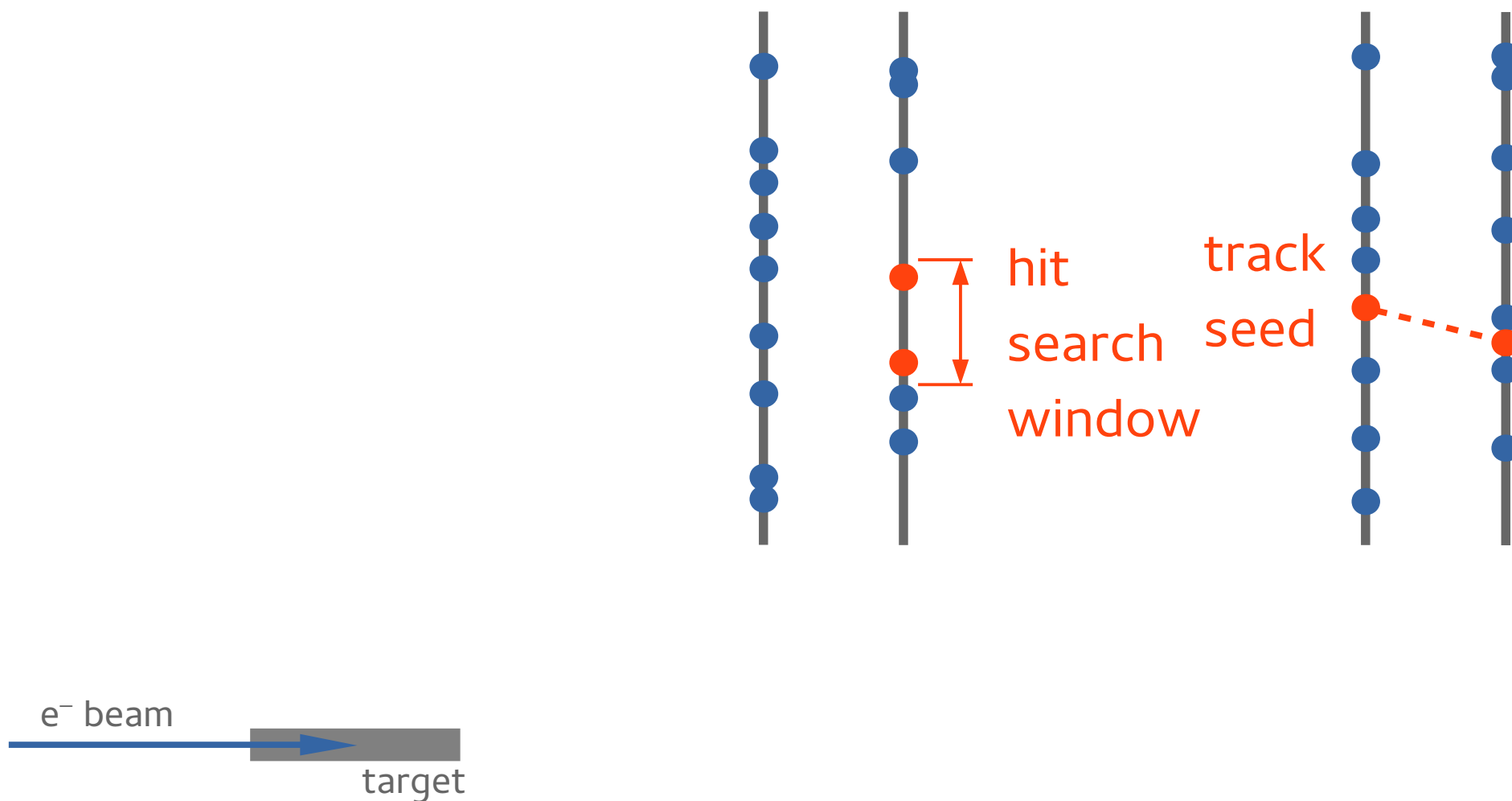
y-z view



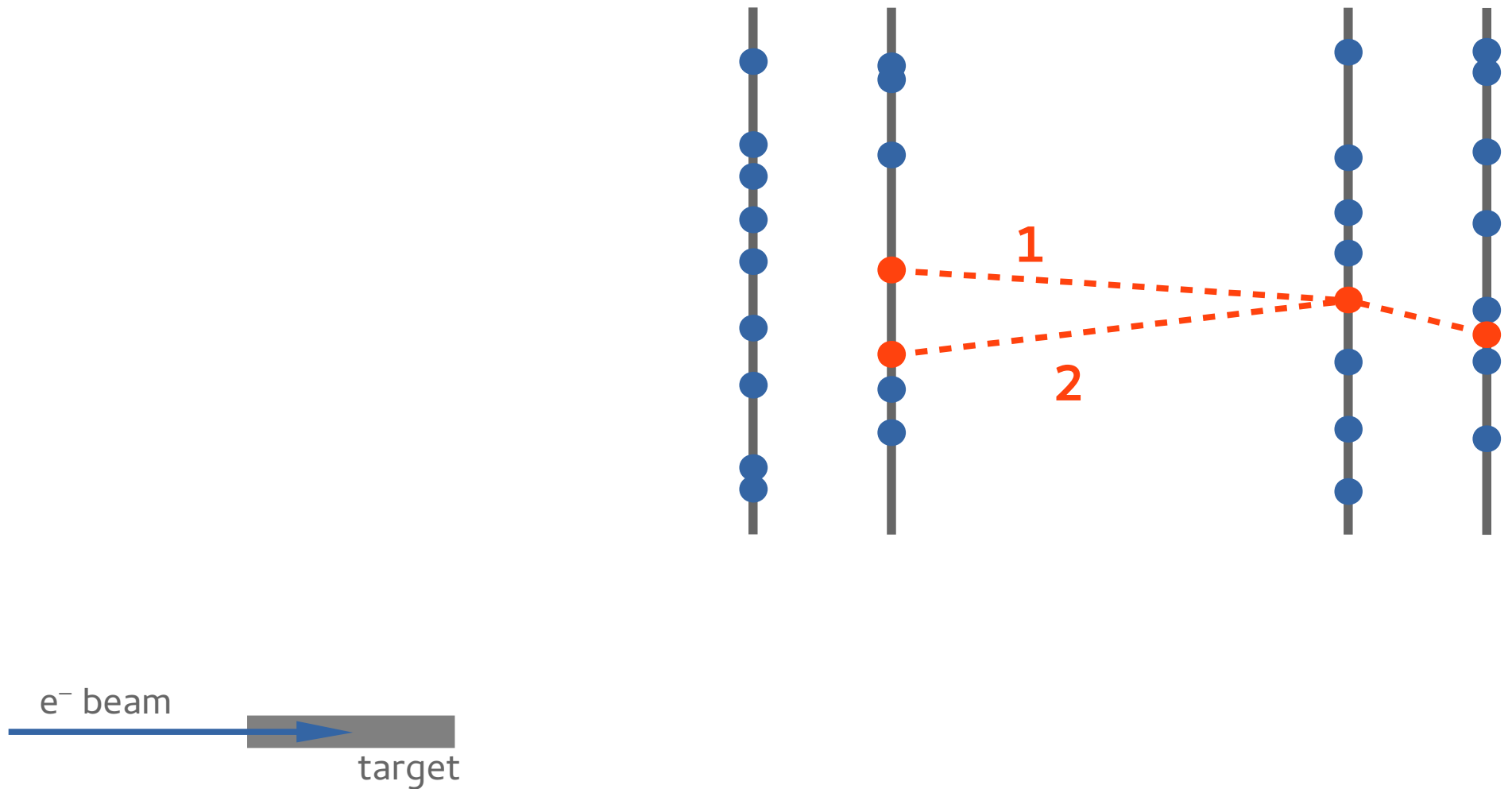
Conventional track following



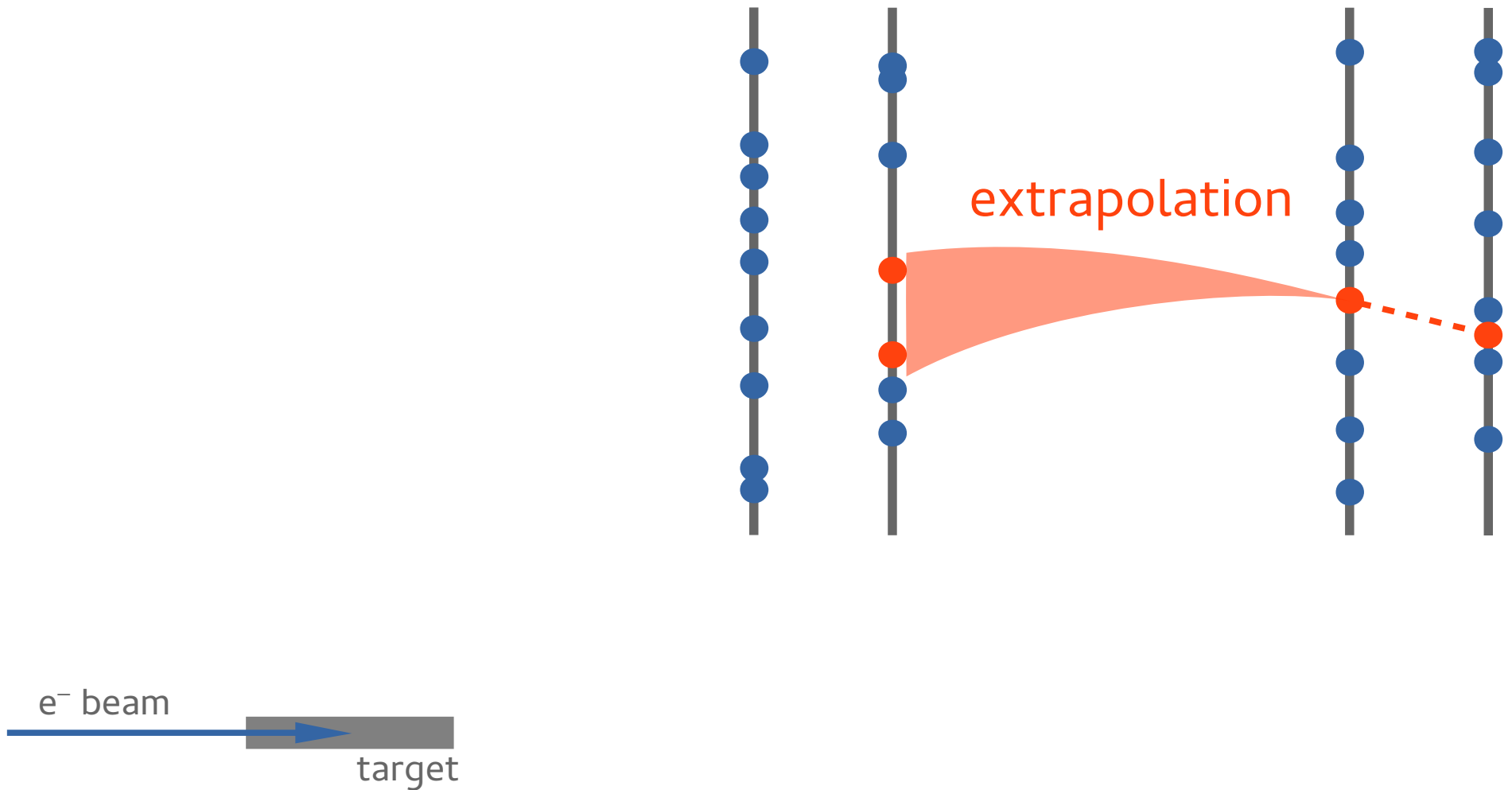
Conventional track following



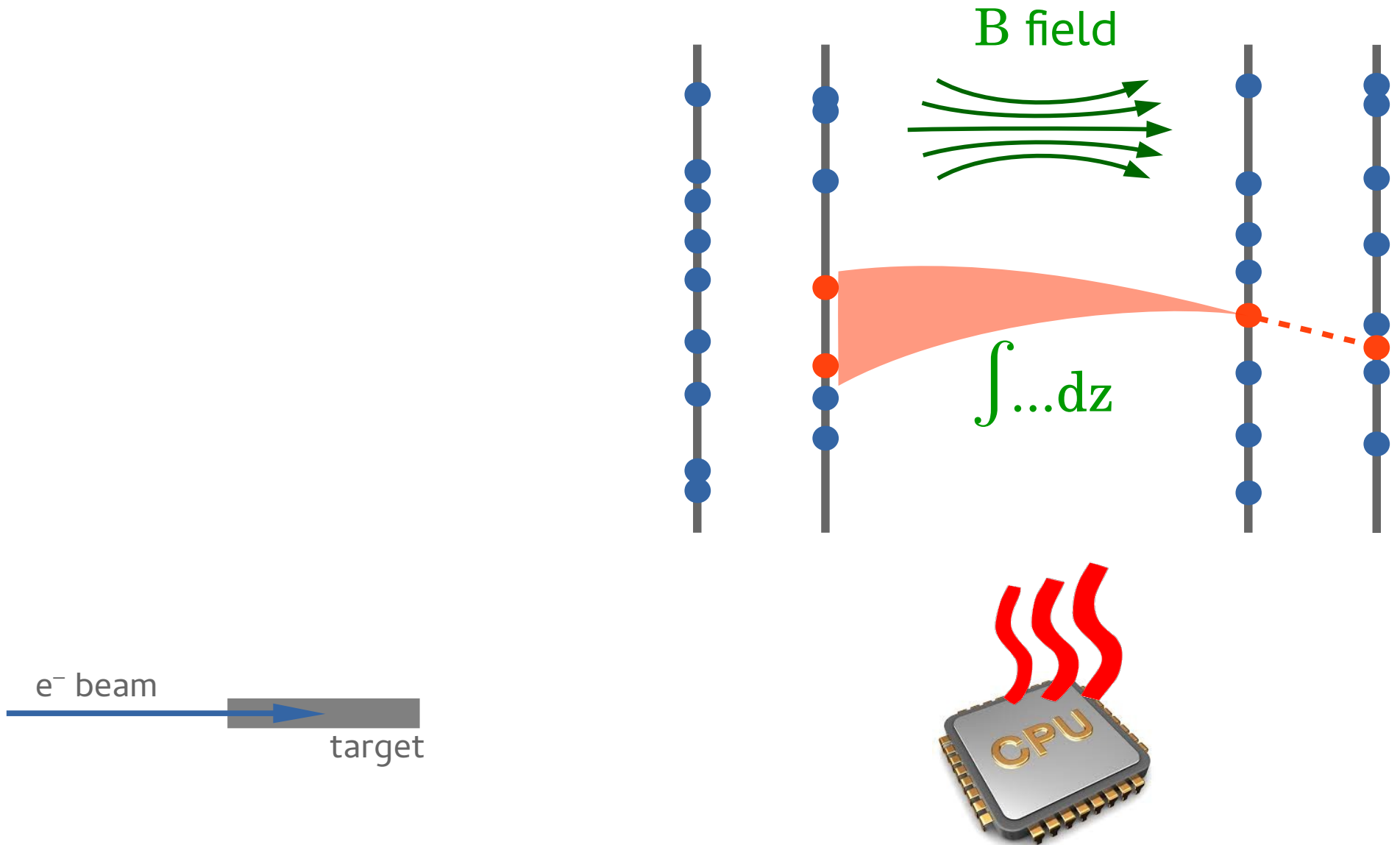
Conventional track following



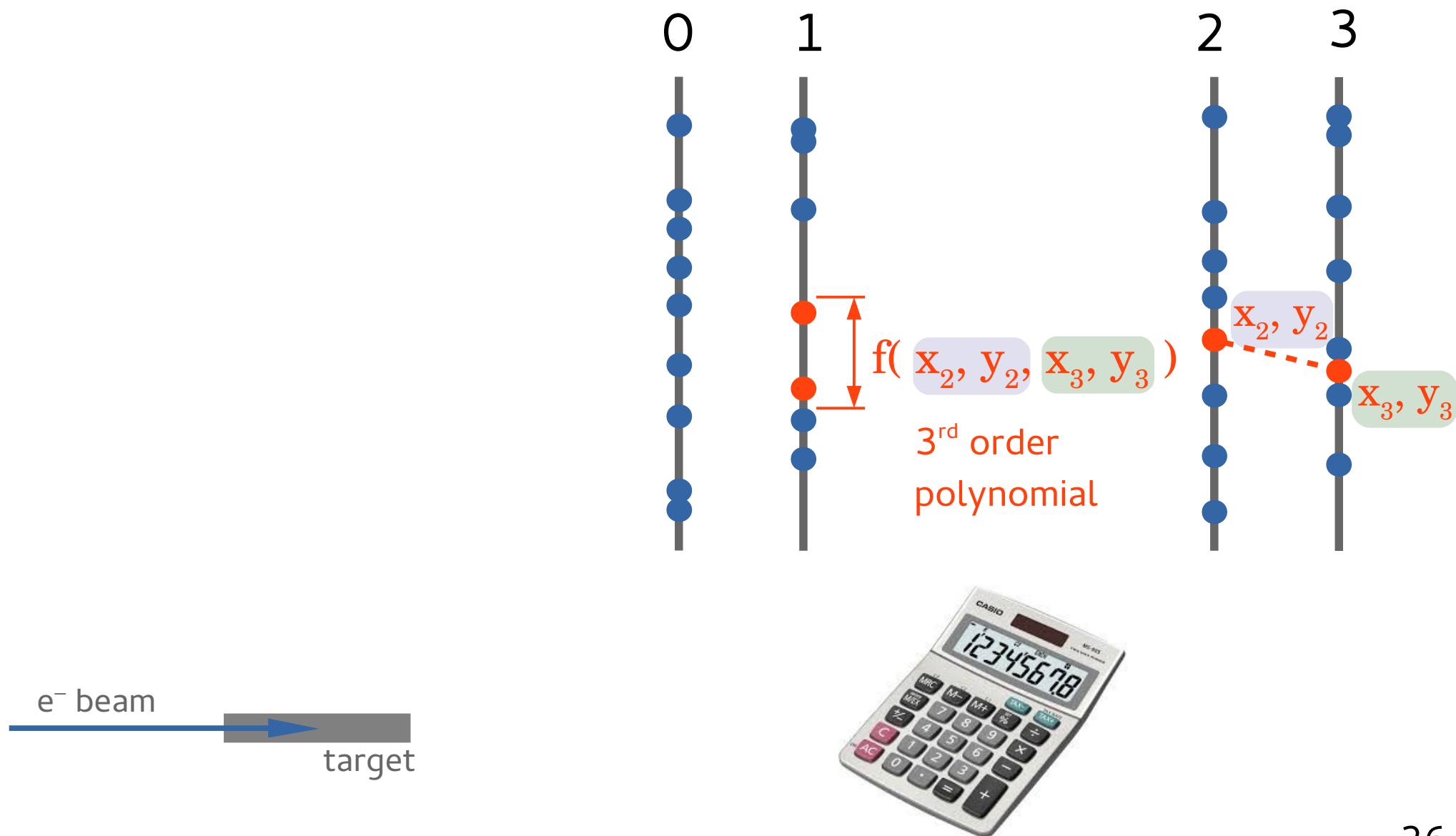
Conventional track following



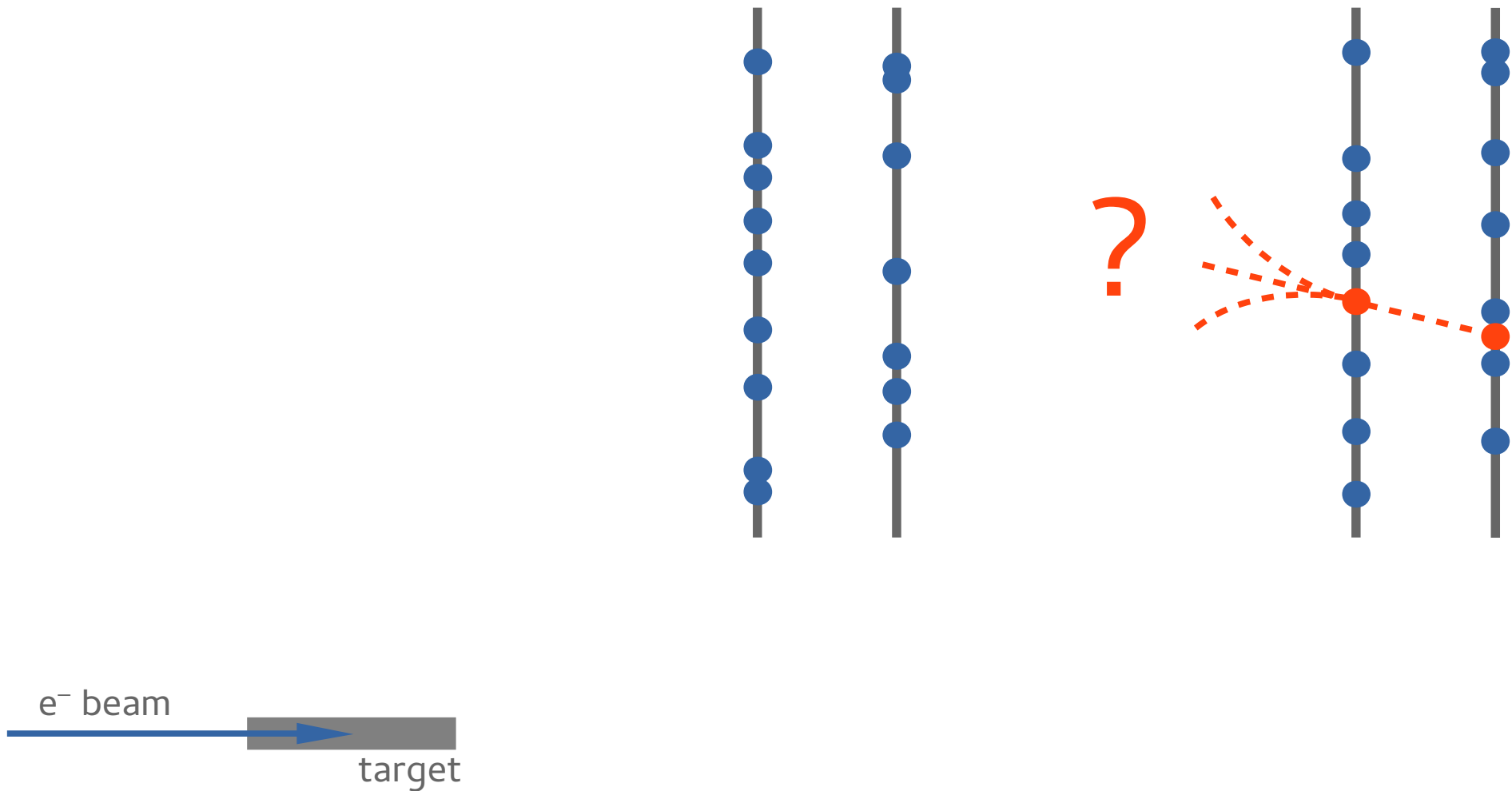
Conventional track following



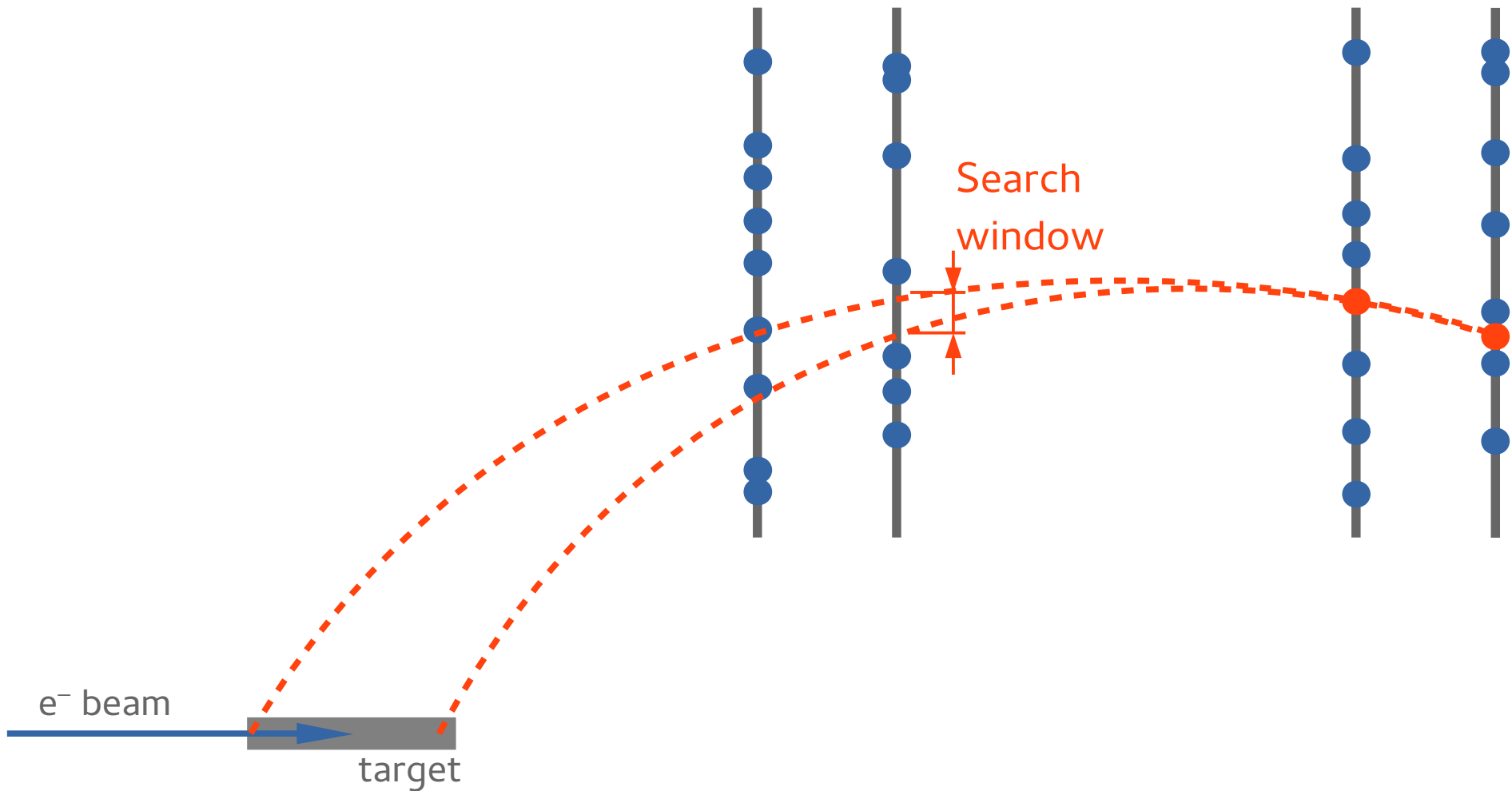
Parameterization-based track finding



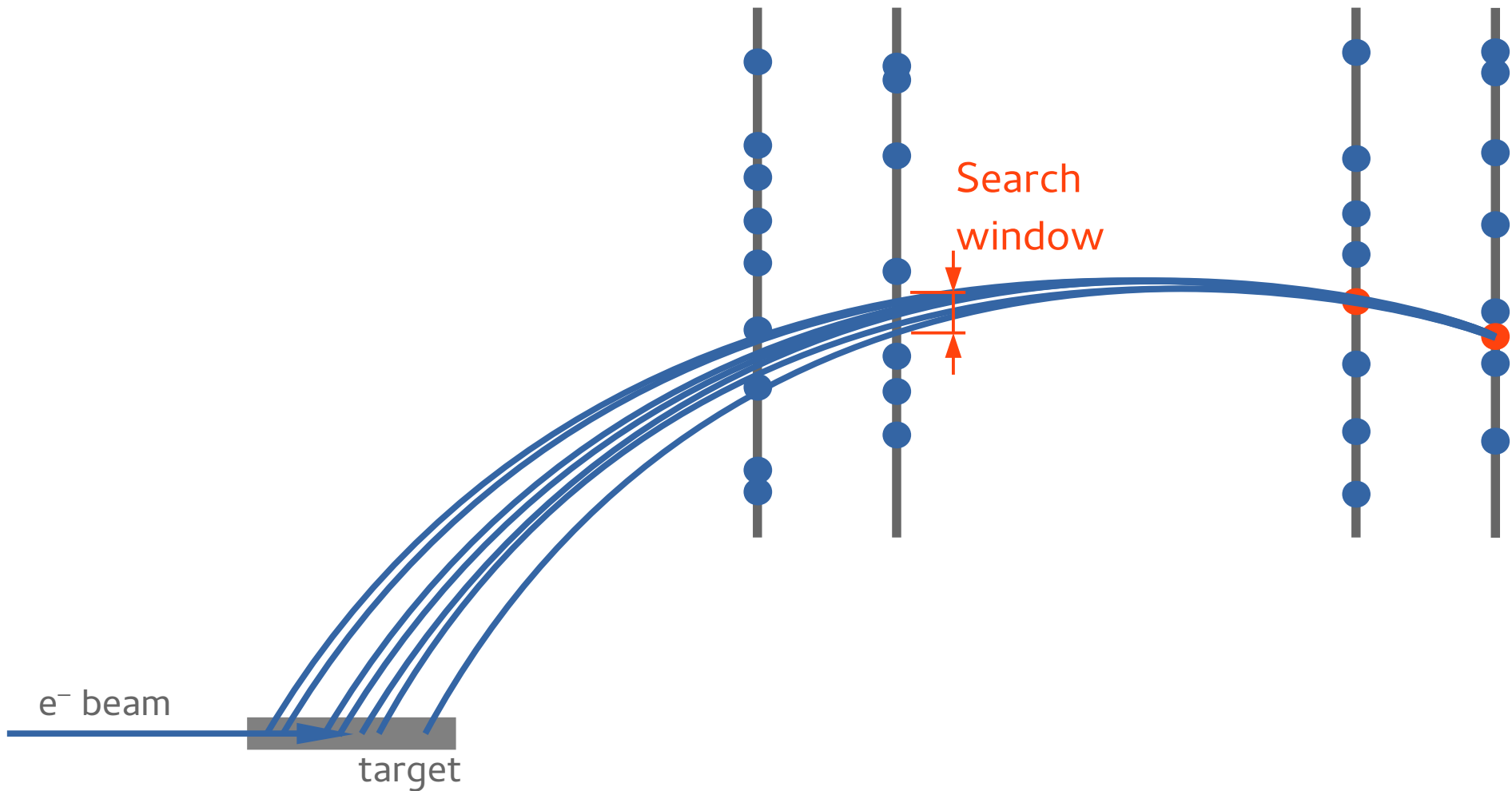
Extrapolation



Extrapolation with constraints

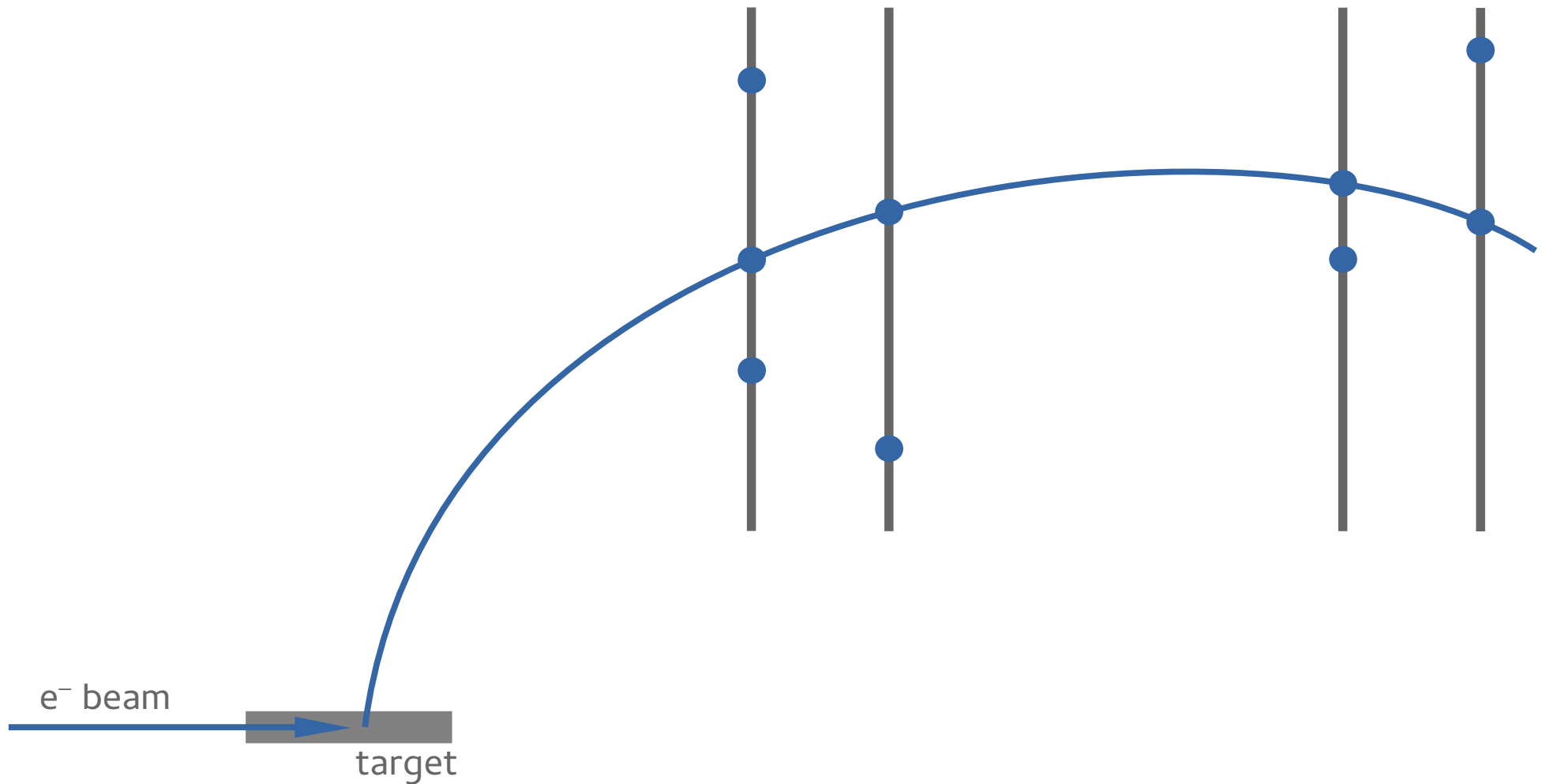


Using reference tracks instead of extrapolation



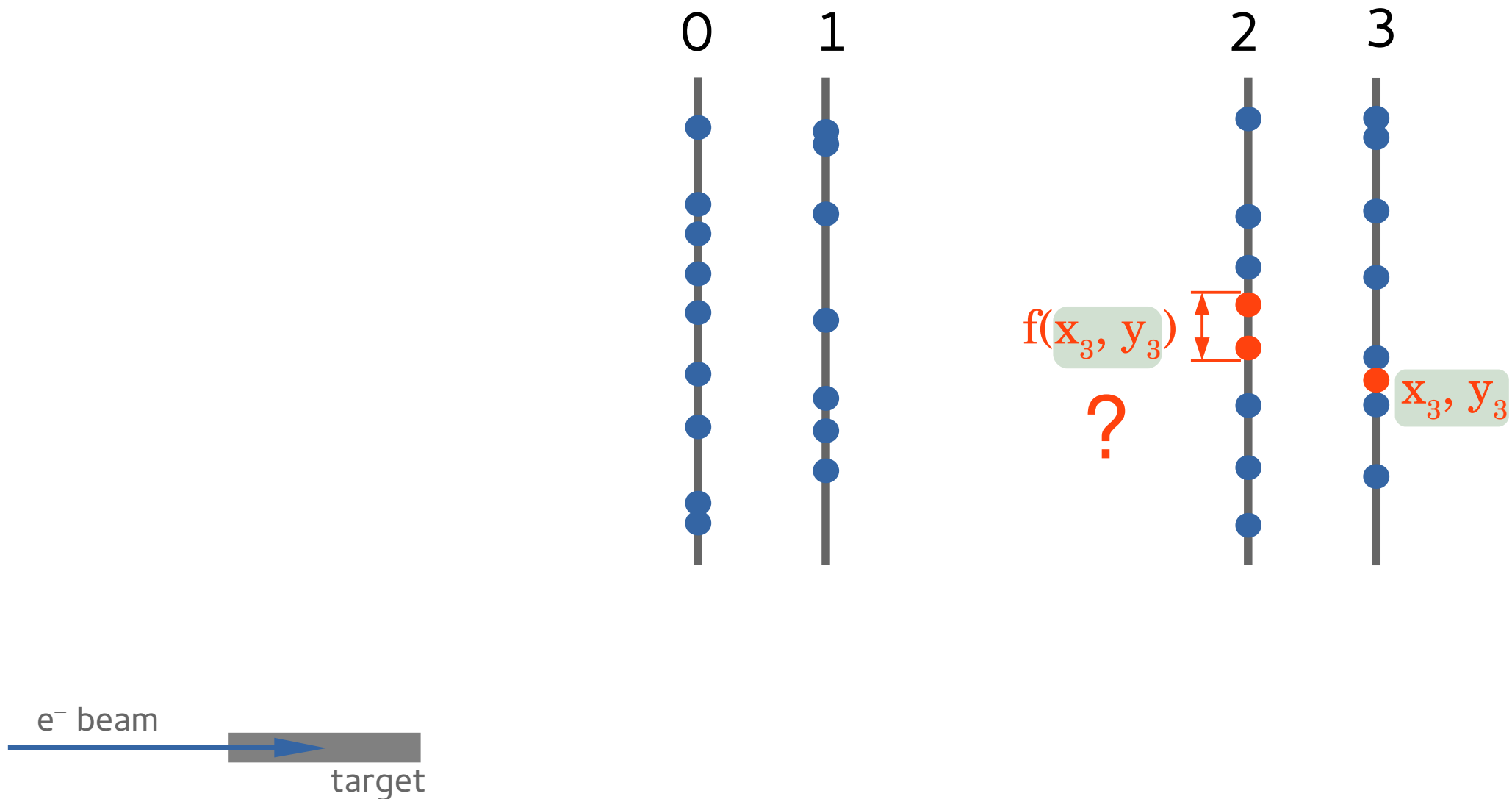
Reference tracks:

- ▶ from MC
- ▶ brute-force reconstruction at low rate; select by χ^2 .

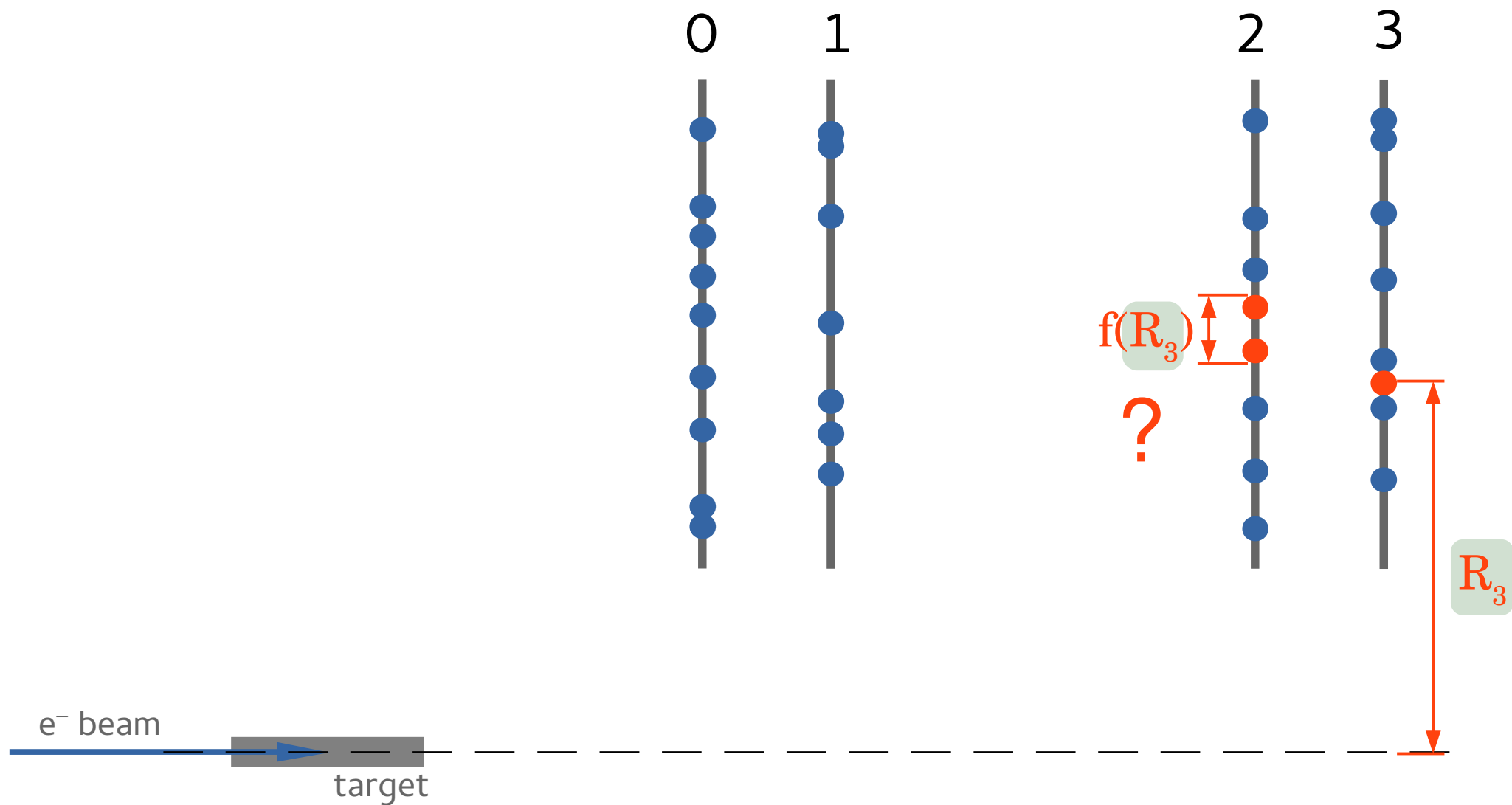


How to construct the parameterizations?

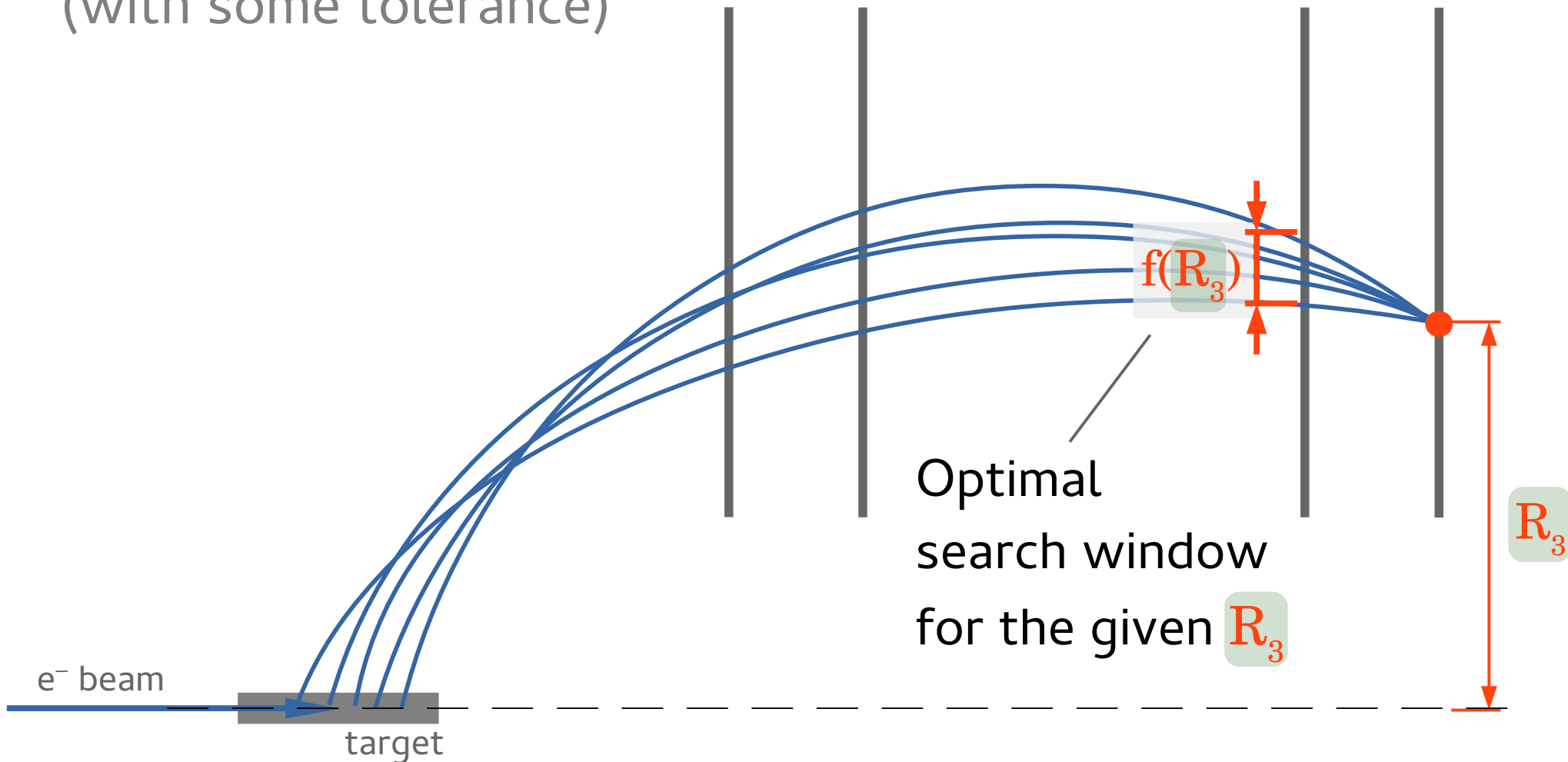
Search window for plane 2



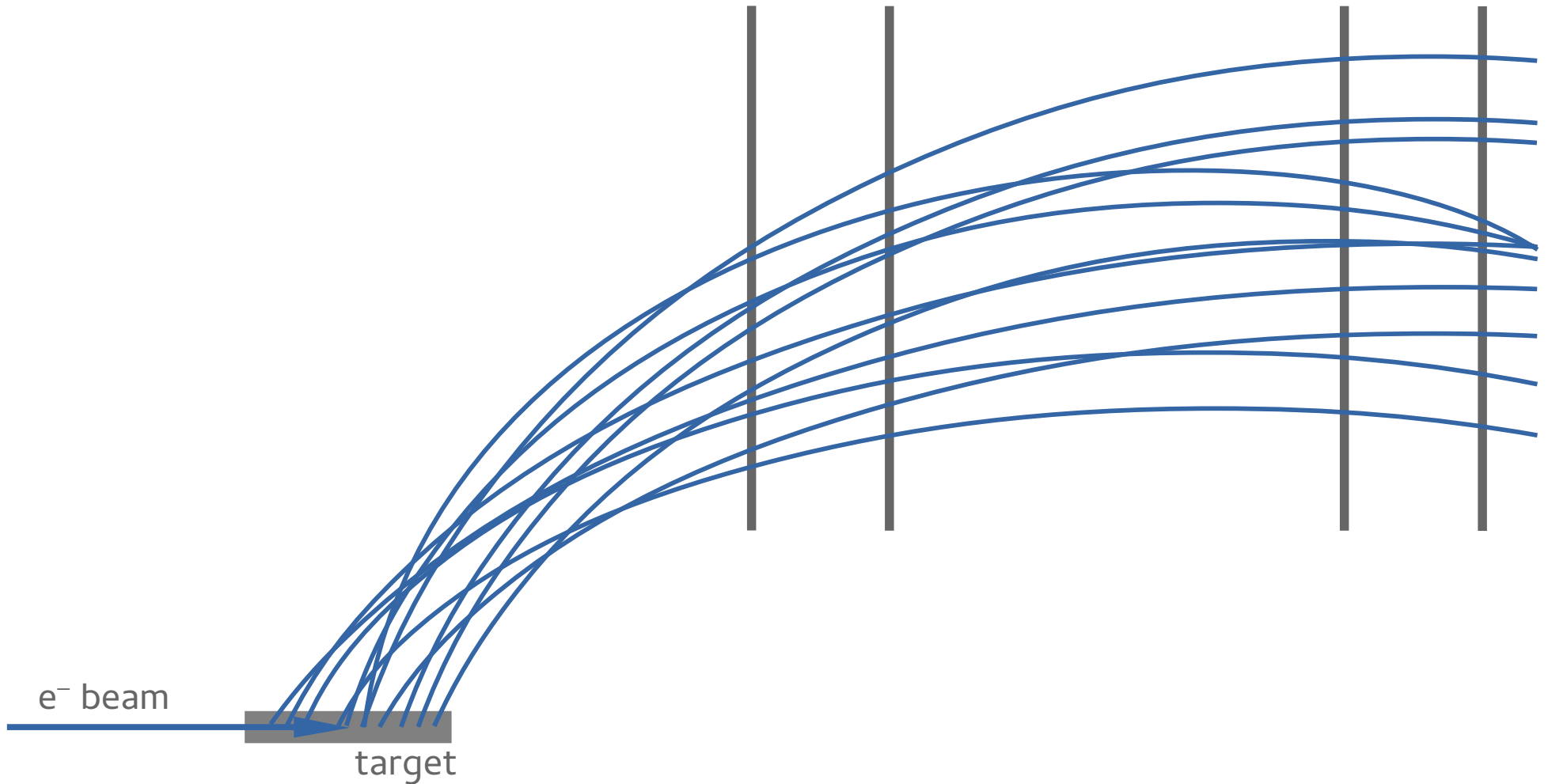
Search window for plane 2



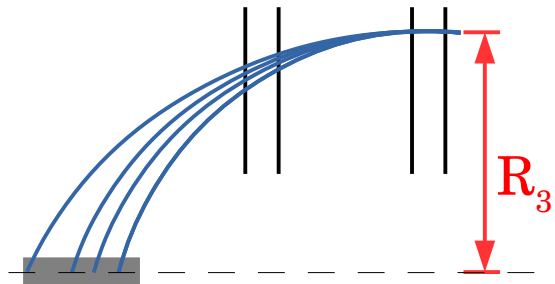
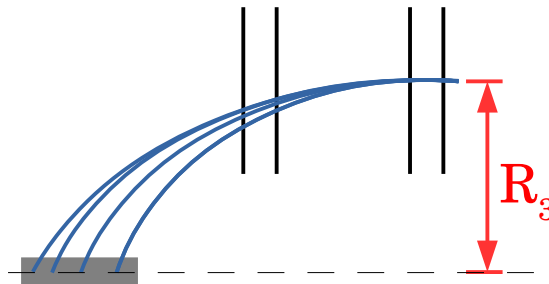
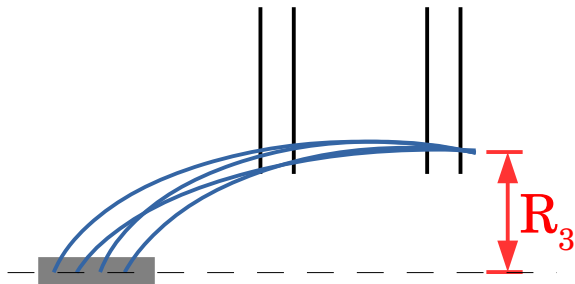
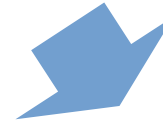
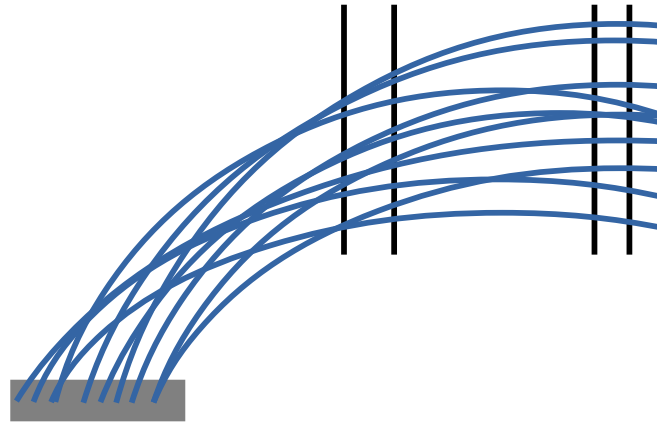
Take reference tracks
with the given R_3
(with some tolerance)

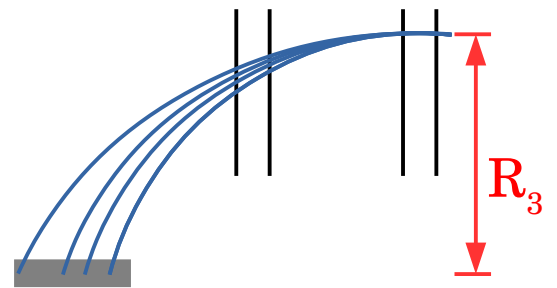
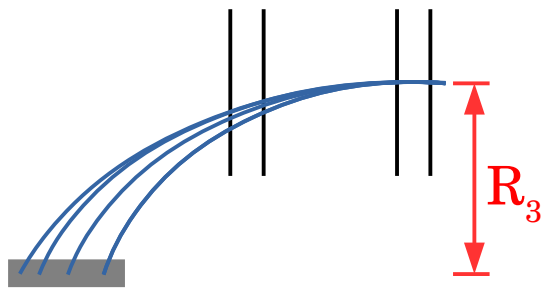
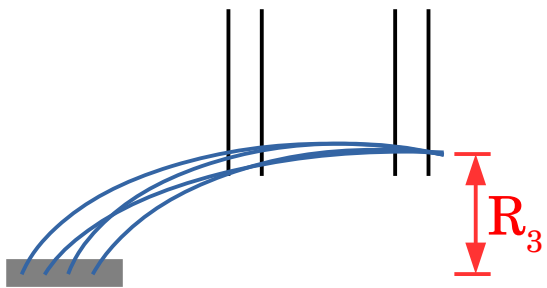


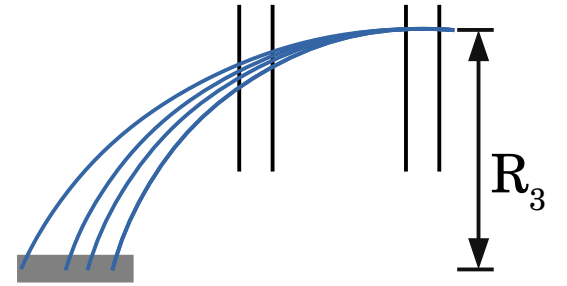
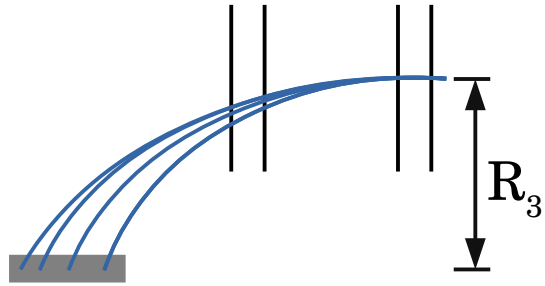
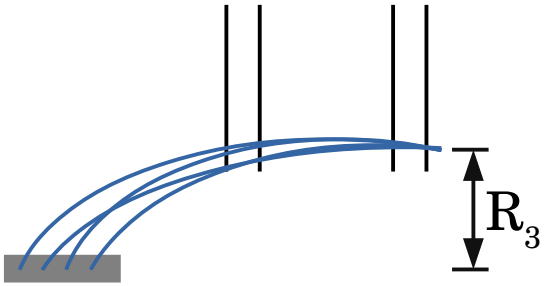
Collect large number of
reference tracks



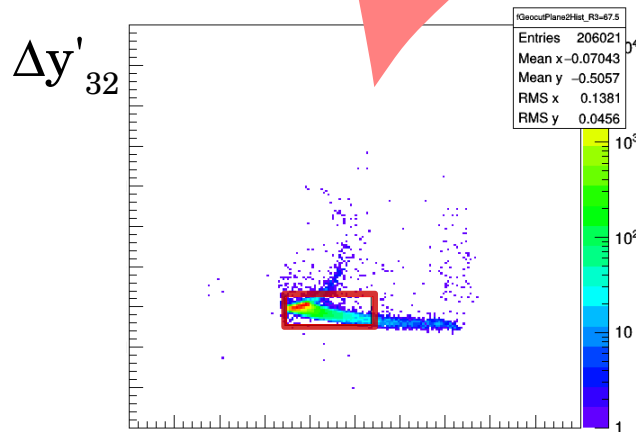
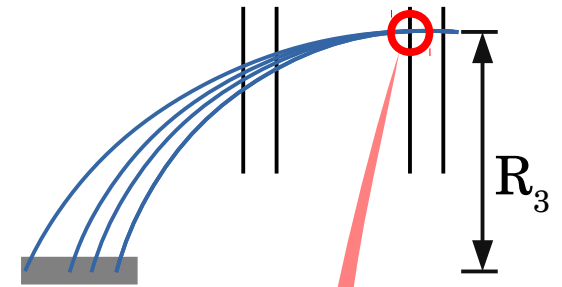
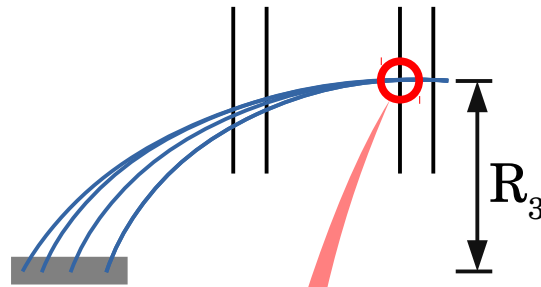
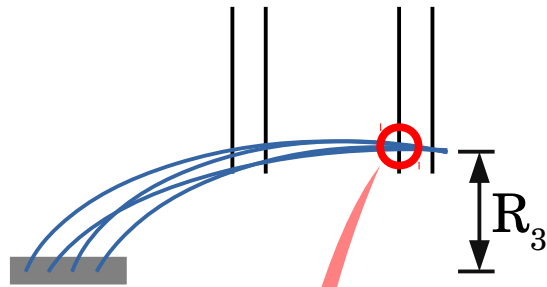
Group tracks
in R_3 bins



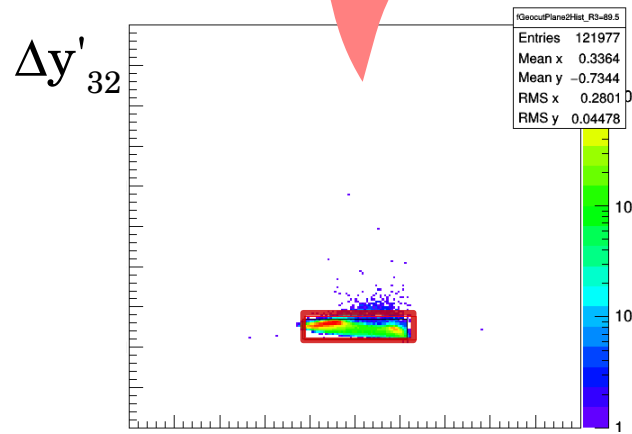




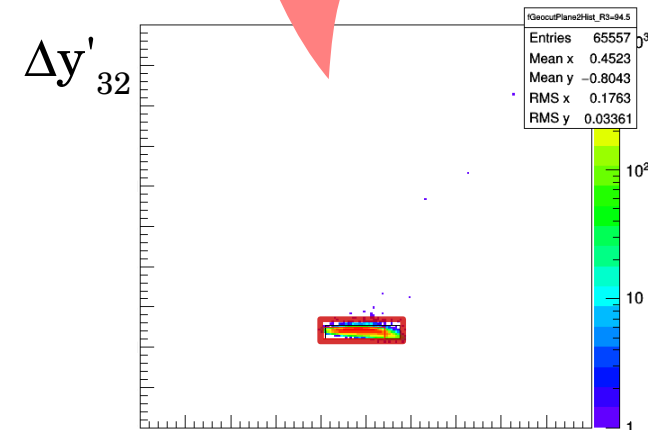
Search window for every R_3 bin:



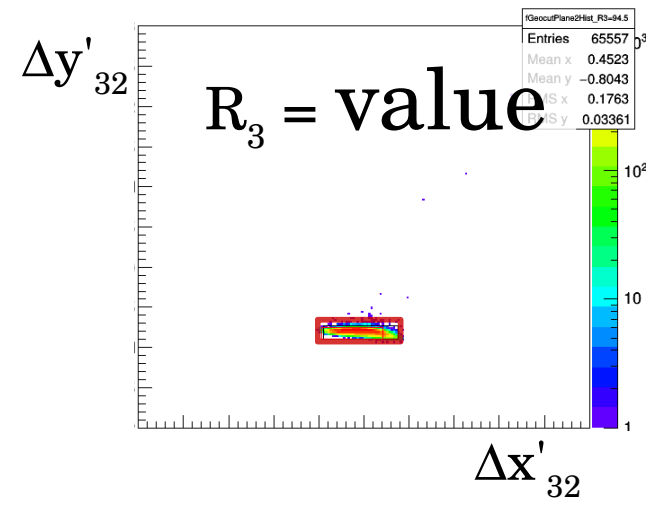
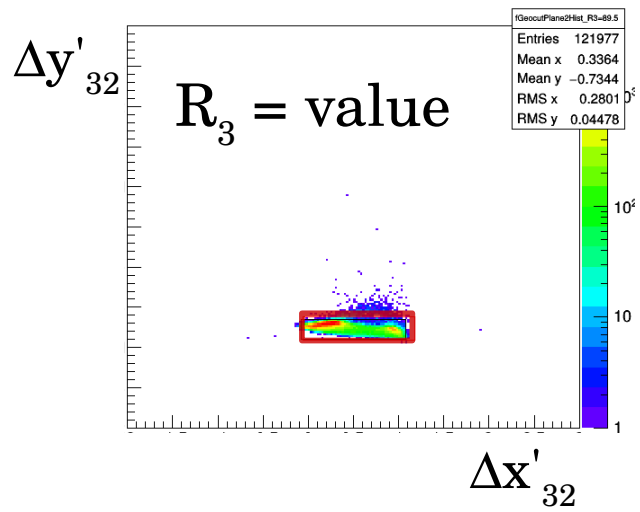
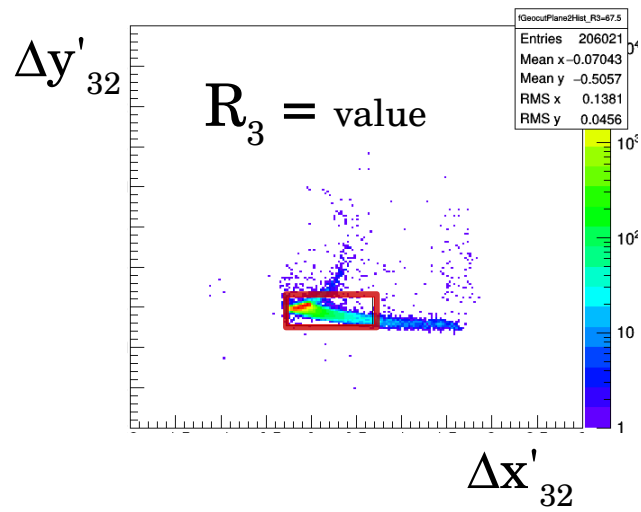
position of hit 2
relative to hit 3



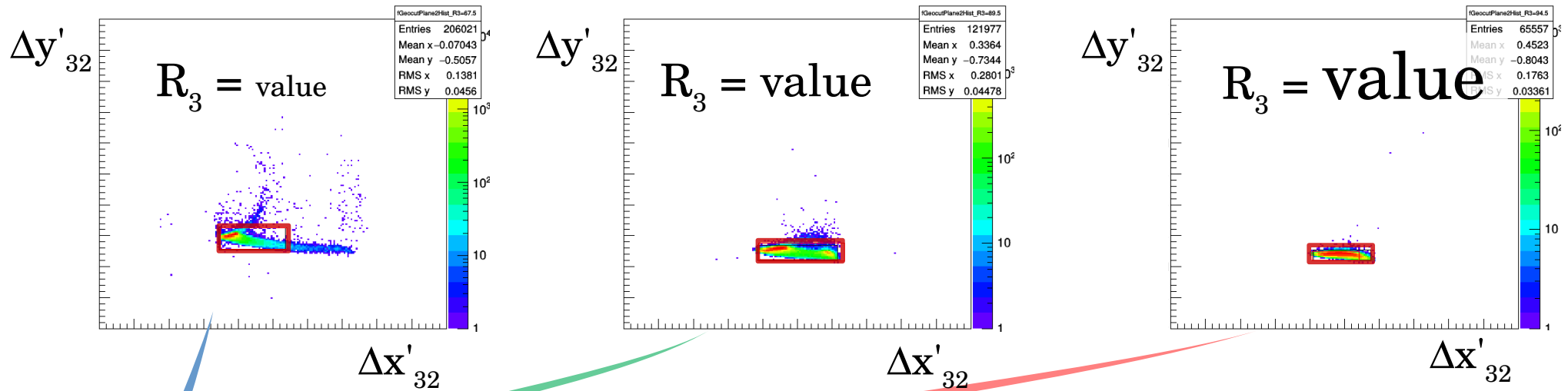
position of hit 2
relative to hit 3



position of hit 2
relative to hit 3



Extract window position and size:

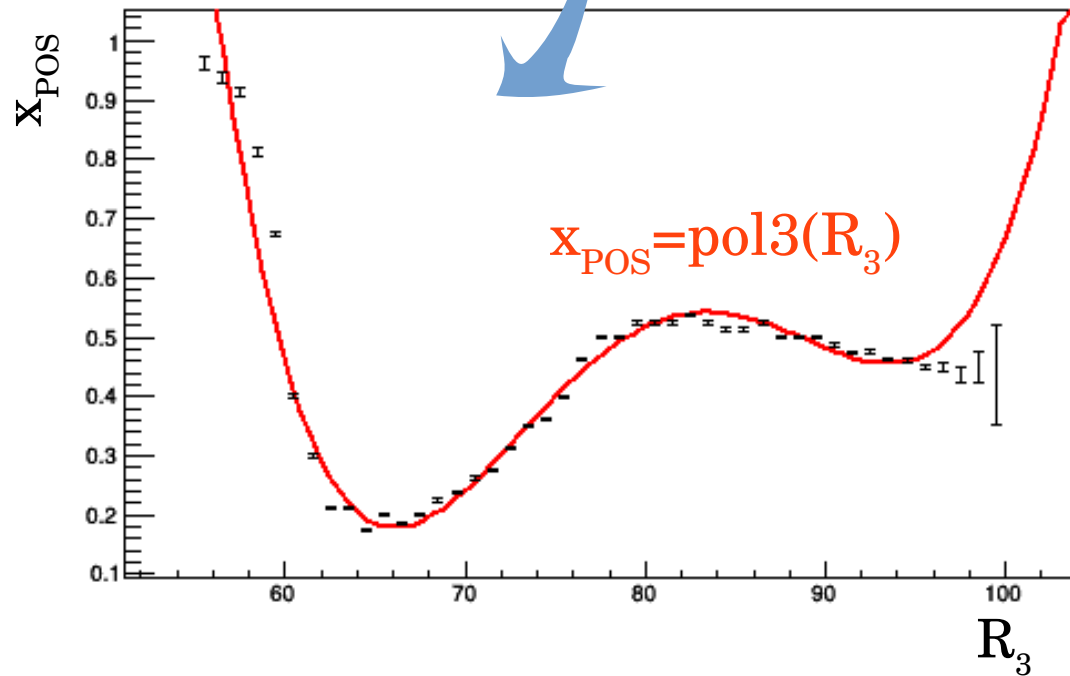


R_3	x_{POS}	y_{POS}	x_{SIZE}	y_{SIZE}	φ_{ROT}
...
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
...

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

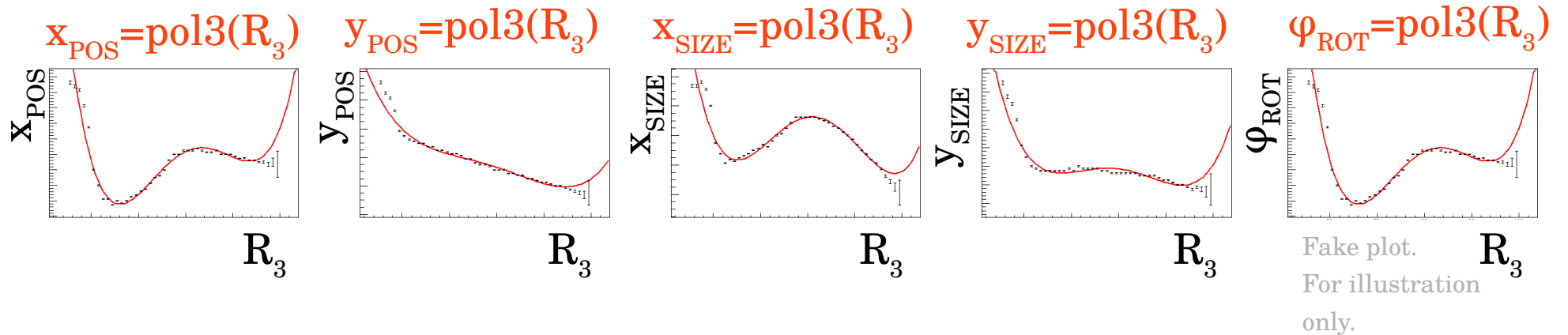
Fit

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

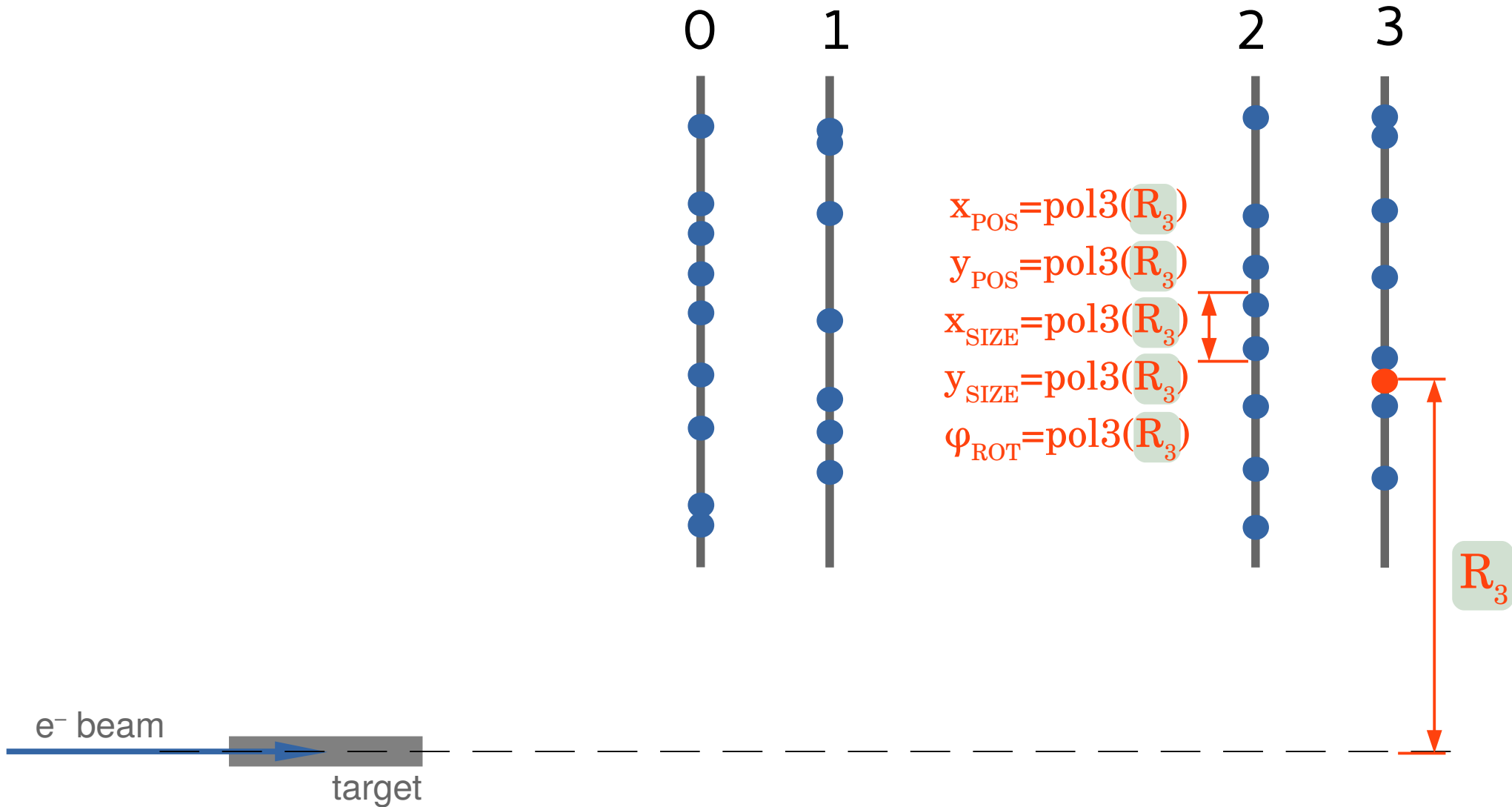


Fit

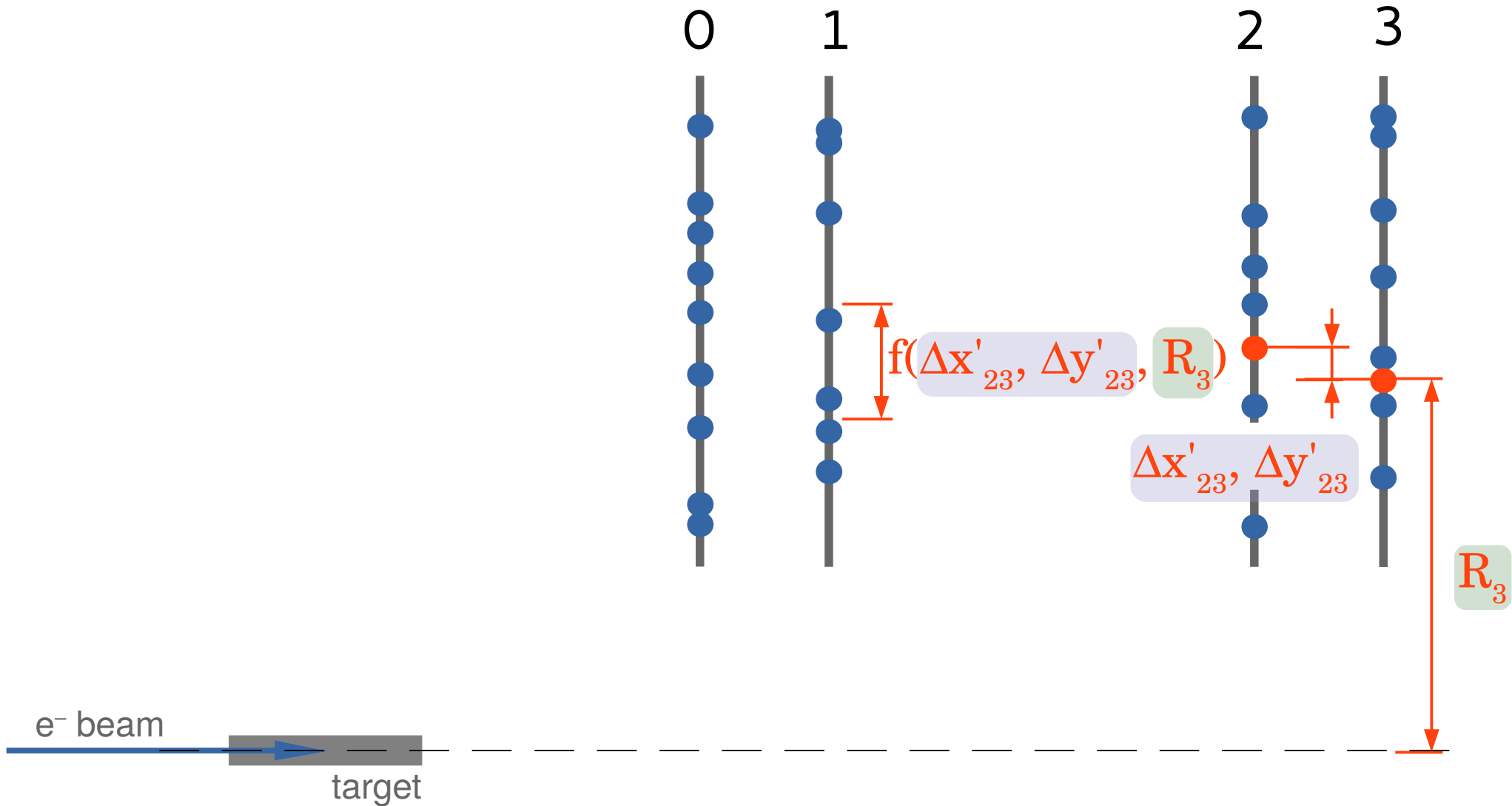
R_3	x_{POS}	y_{POS}	x_{SIZE}	y_{SIZE}	φ_{ROT}
...
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
value	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
...

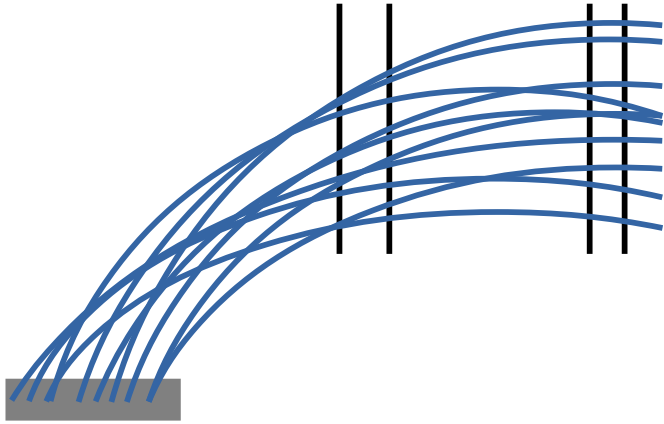


Search window for plane 2



Search window for plane 1





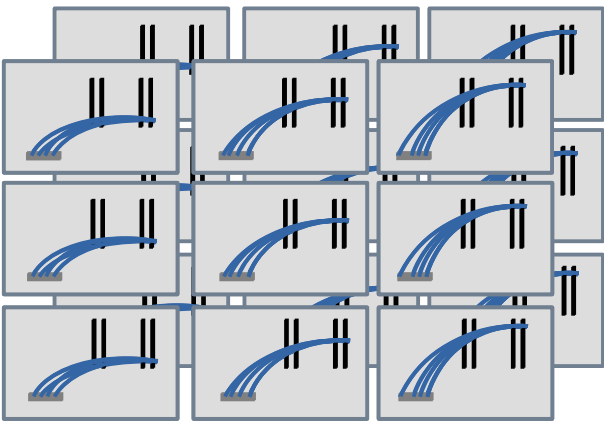
R_3	$\Delta x'_{23}$	$\Delta y'_{23}$	x_{POS}	y_{POS}	x_{SIZE}	y_{SIZE}	φ_{ROT}
...
...
...

bin by
 $\{R_3, \Delta x'_{23}, \Delta y'_{23}\}$



Fit (in 3D)

determine
the search
windows



$$x_{\text{SIZE}} = \text{pol3}(R_3, \Delta x'_{23}, \Delta y'_{23})$$

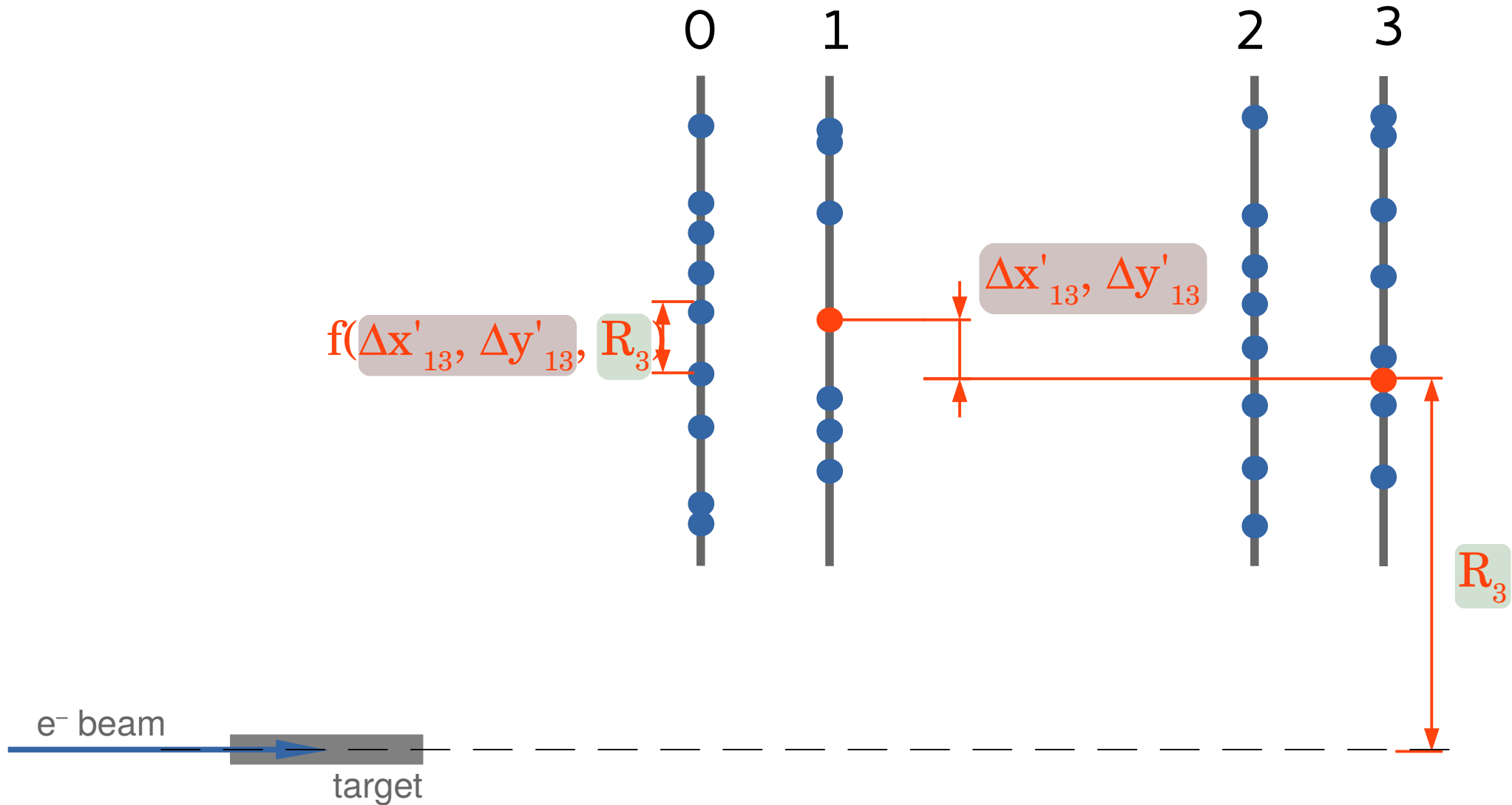
$$y_{\text{SIZE}} = \text{pol3}(R_3, \Delta x'_{23}, \Delta y'_{23})$$

$$x_{\text{POS}} = \text{pol3}(R_3, \Delta x'_{23}, \Delta y'_{23})$$

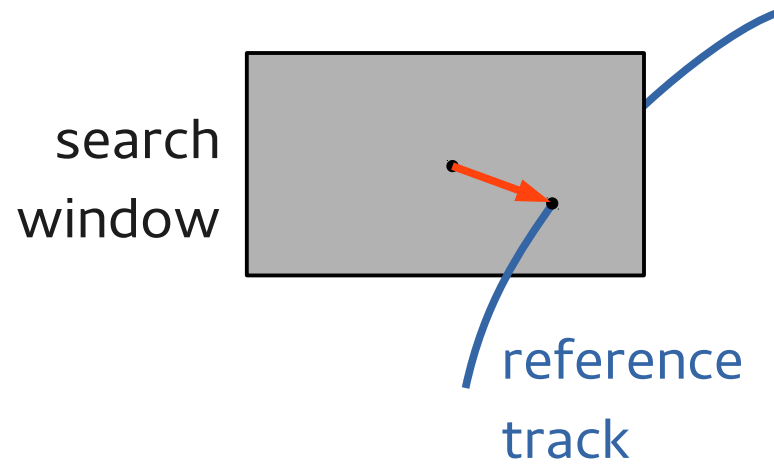
$$y_{\text{POS}} = \text{pol3}(R_3, \Delta x'_{23}, \Delta y'_{23})$$

$$\varphi_{\text{ROT}} = \text{pol3}(R_3, \Delta x'_{23}, \Delta y'_{23})$$

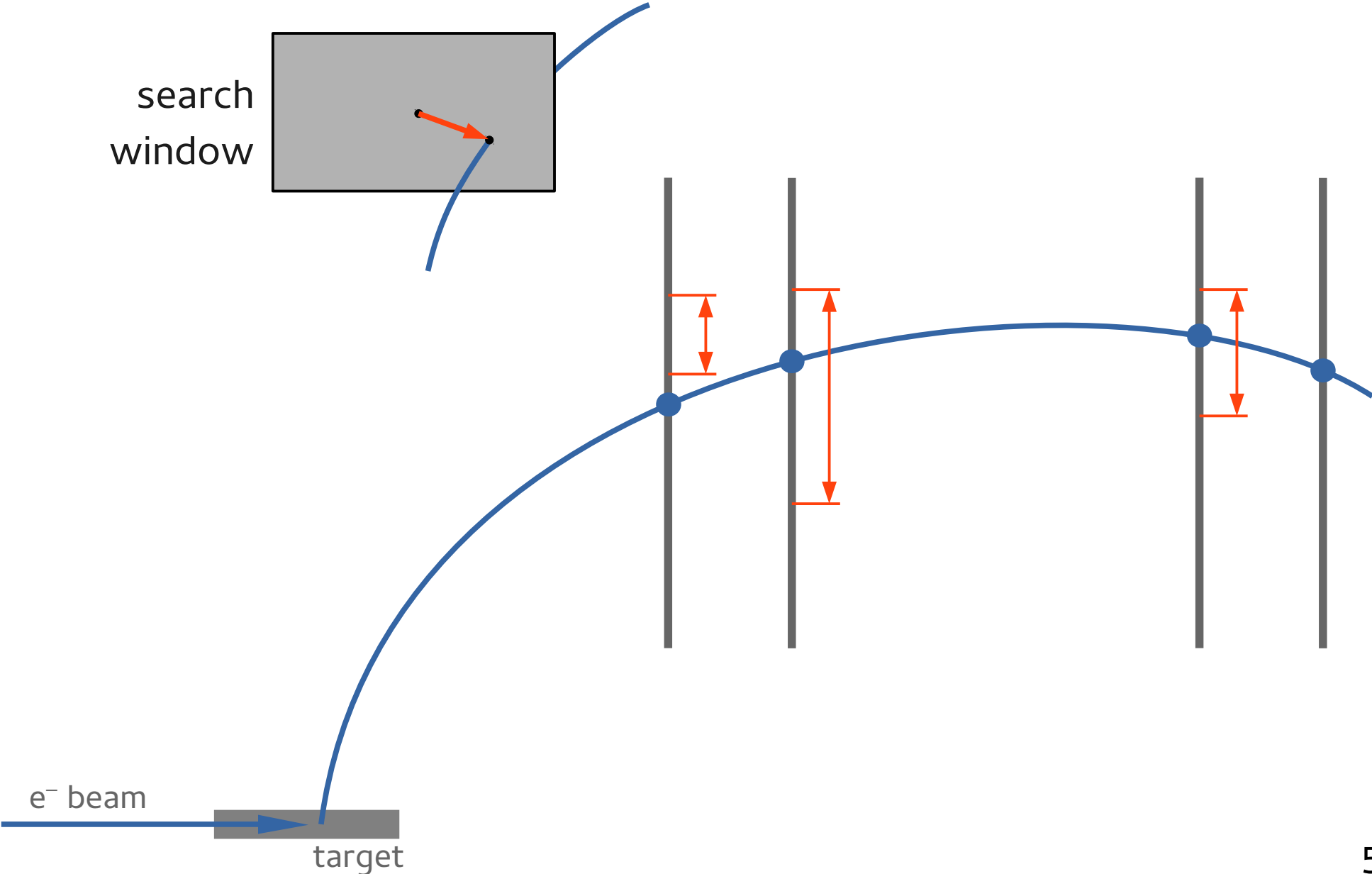
Search window for plane 0



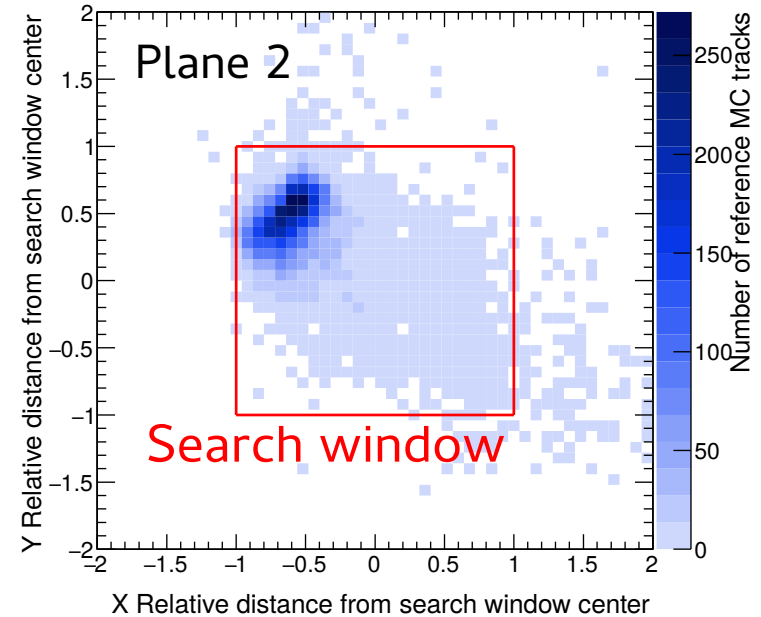
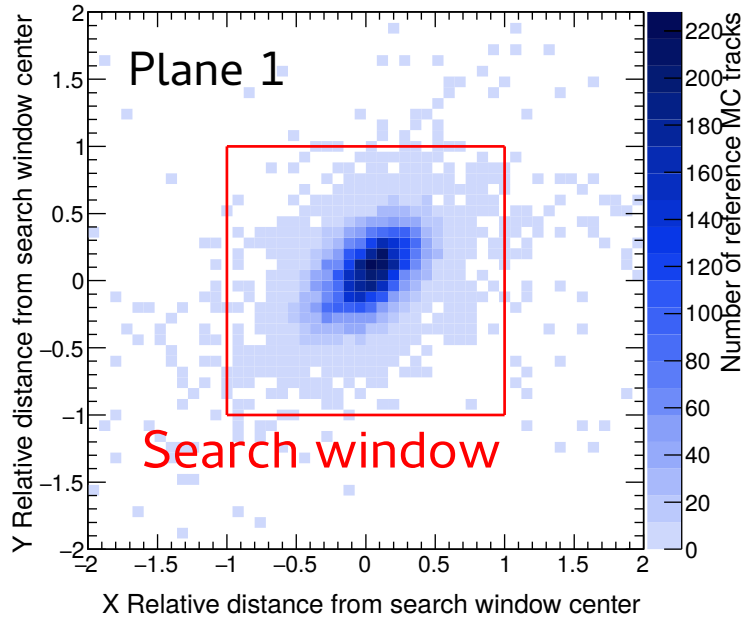
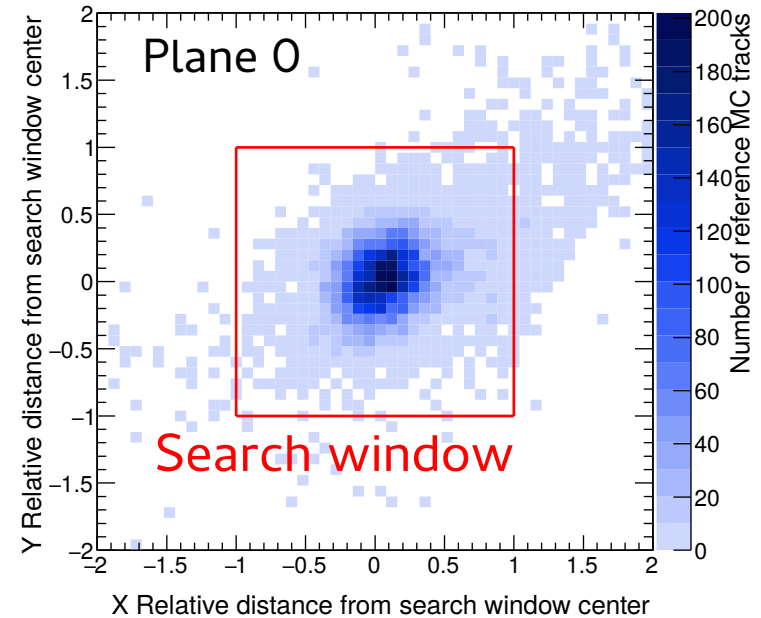
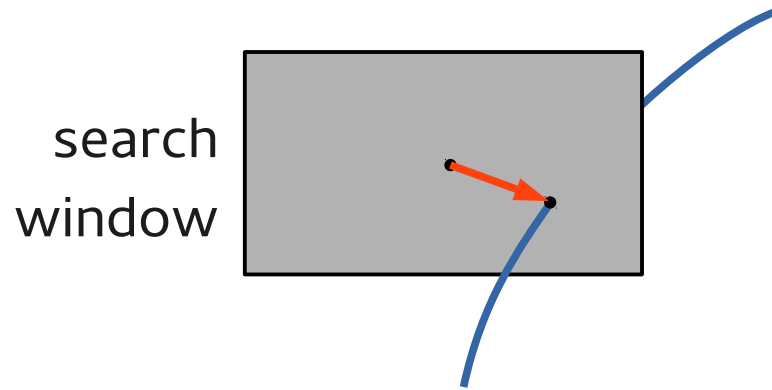
Relative distance from the center of the search window



Relative distance from the center of the search window



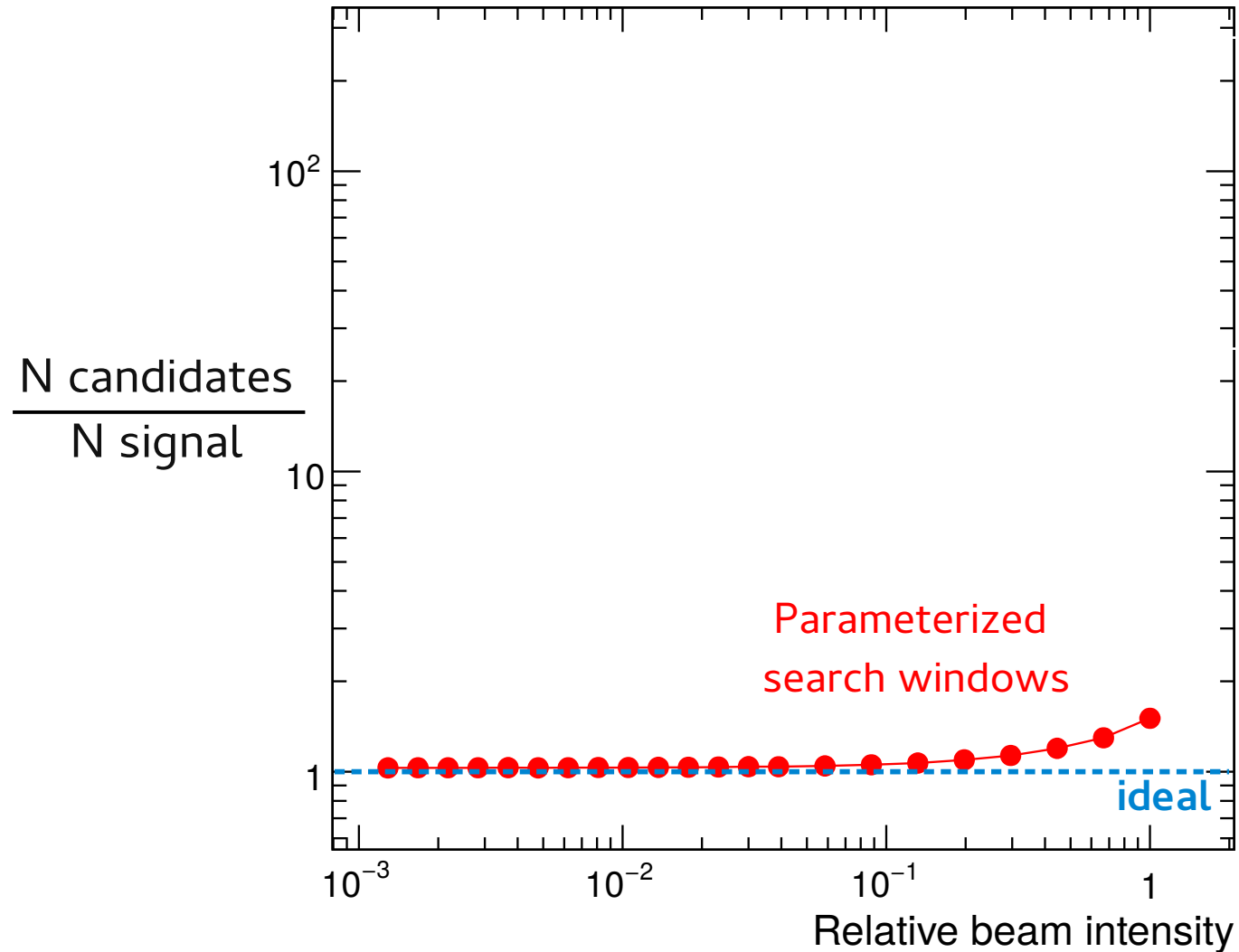
Relative distance from the center of the search window



Overall about 90% efficiency (depending on settings). 51

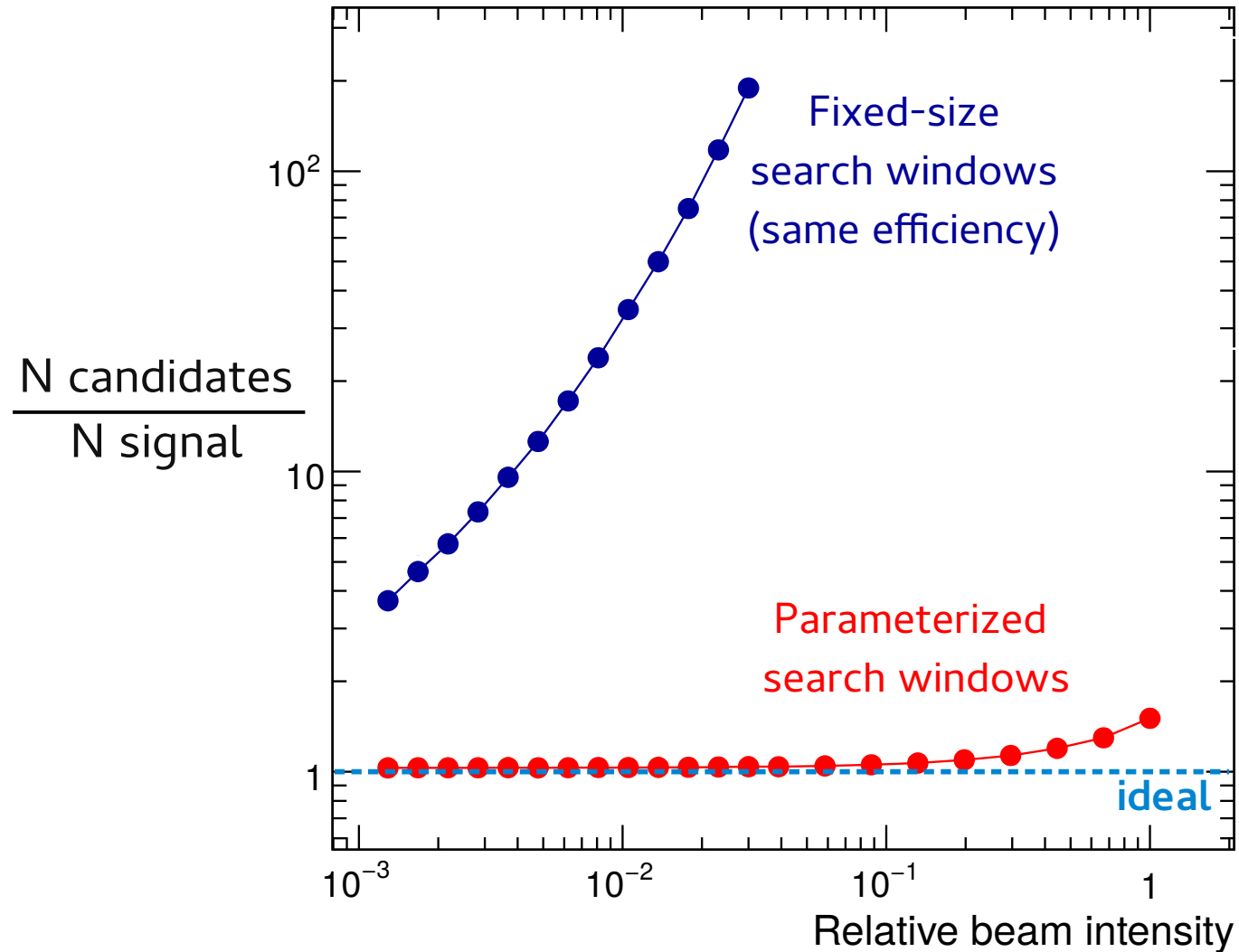
Performance

Number of candidates per signal track



Performance

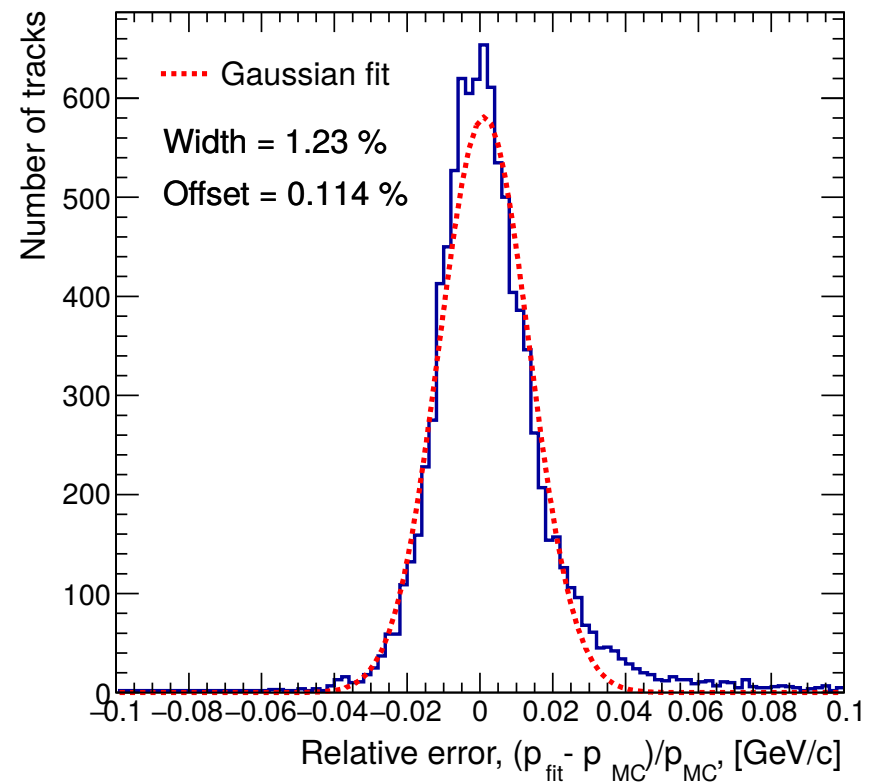
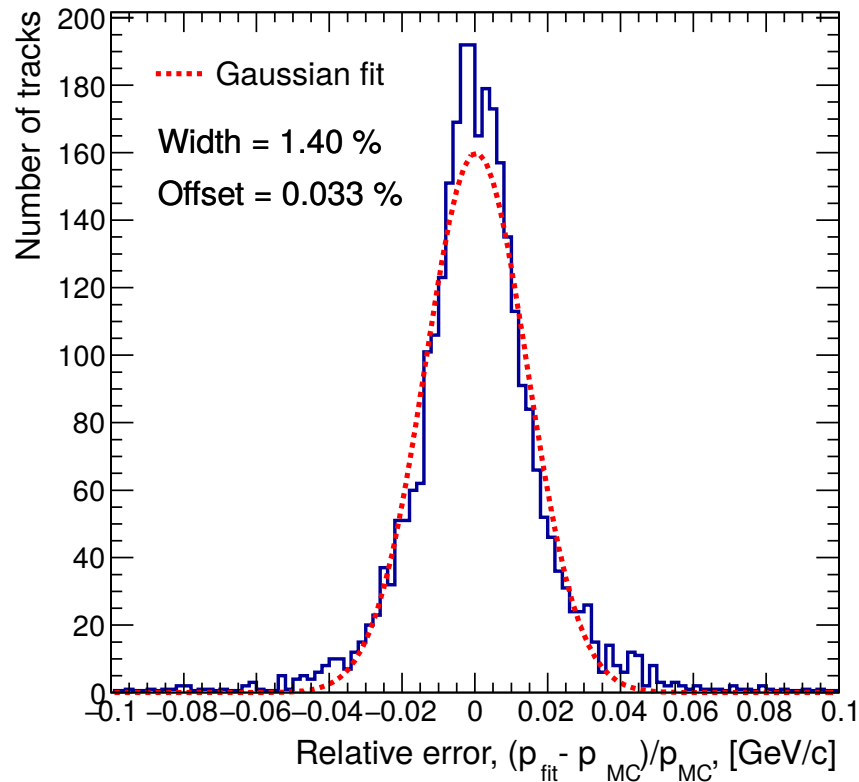
Number of candidates per signal track



Parameterization instead of fitting

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

Rigorous fit



Using GBL fit within the GENFIT framework

GBL: Kleinwort C. General Broken Lines as advanced track fitting method
<http://dx.doi.org/10.1016/j.nima.2012.01.024>

GENFIT: Rauch J., Schlüter T. GENFIT — a Generic Track-Fitting Toolkit
<https://doi.org/10.1088/1742-6596/608/1/012042>

Summary

Parameterization-based tracking:

- replaces rigorous model calculations by simple analytical parametric functions
- parameters can be tuned based on real data or model (MC or deterministic with covariance)
- enables accurate, efficient, and very fast track finding
- can be used to estimate the kinematic parameters
- works well in P2 due to narrow momentum range