

dRICH 2026 beam test

first analysis of SPS data with SiPM readout

Roberto Preghenella
INFN Bologna

Basic information

- data collected on the last night of the extended **SPS** run period
- this presentation focuses on a single **SiPM** run: 20260604-231255
- dRICH was in **C₂F₆ gas** configuration: Marco/Fulvio for more details
- according to notes, dRICH was rotated in **$\eta = 3.2$** configuration
- did not focus too much on timing calibration, it is decent but not ideal
- events tagged with the **timing-scintillator** system
- **finger-scintillator trigger** tagging is available, but not used in this analysis

the processed data used for this analysis is **available to anyone** interested

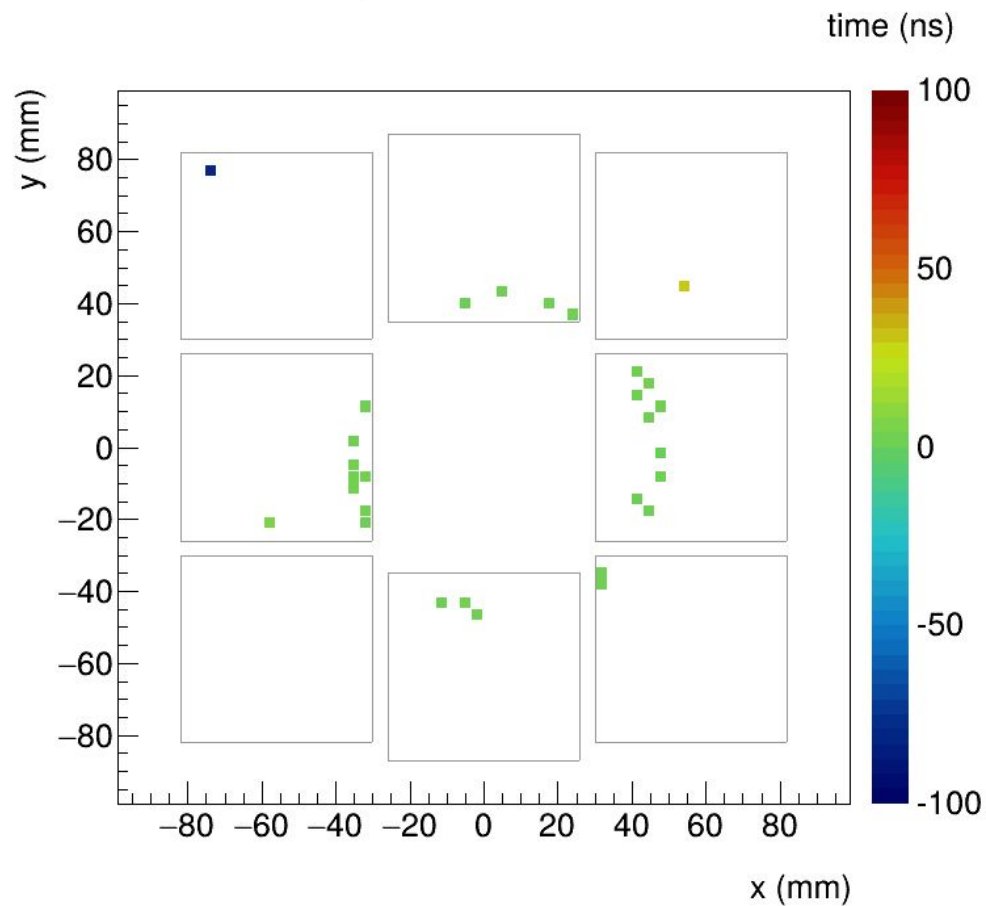
<https://cernbox.cern.ch/s/ea4m1fRrJq94Jn7>

a trivial ROOT TTree of POD types containing the recorded hits

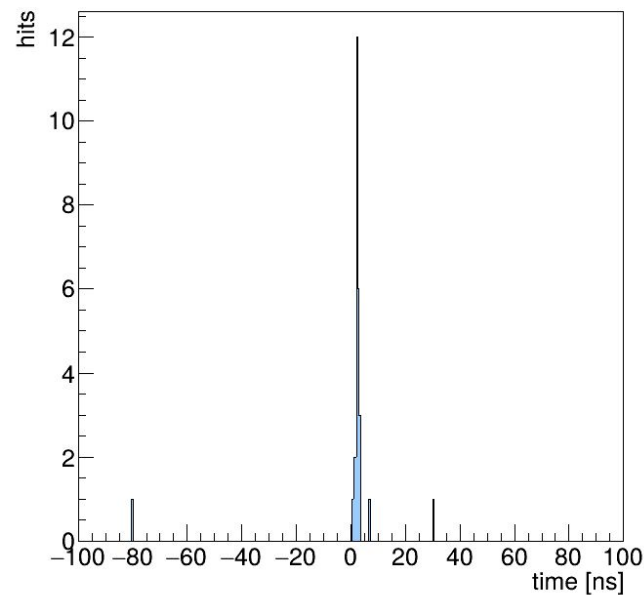
nhits, x[nhits], y[nhits], time[nhits]

some event-display
images

spill 0 frame 0

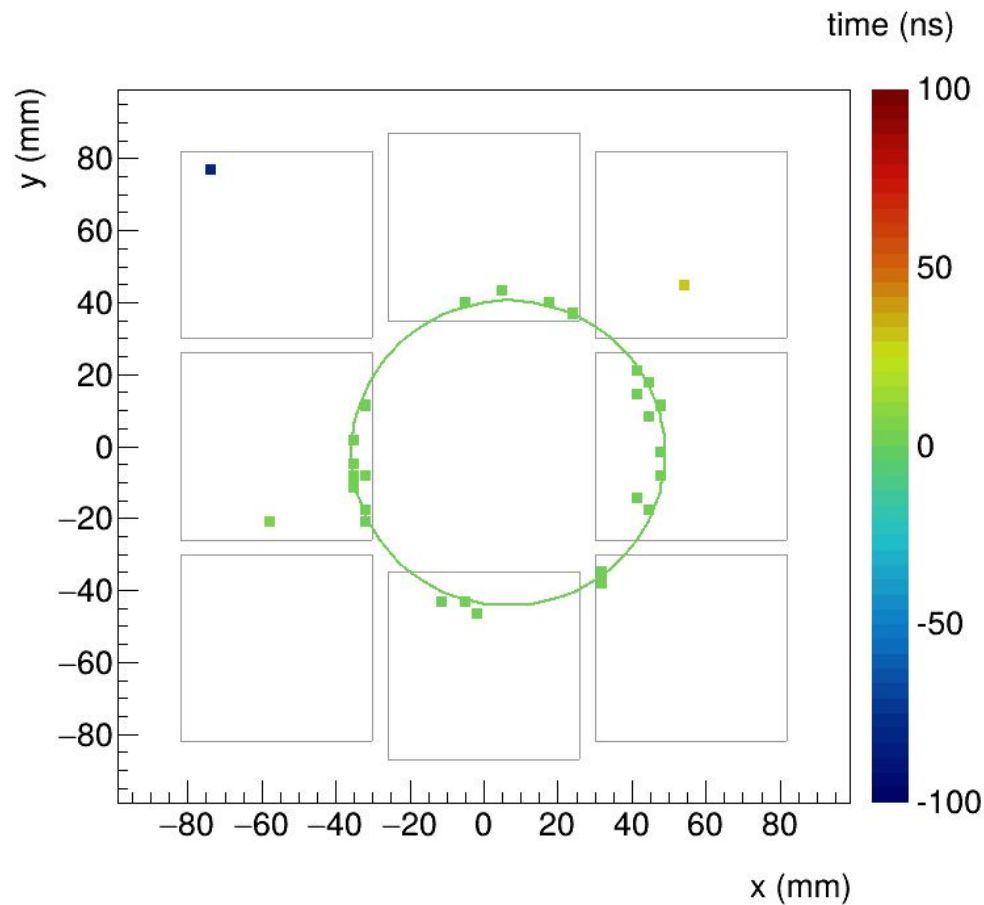


spill 0 frame 0 Cherenkov timing

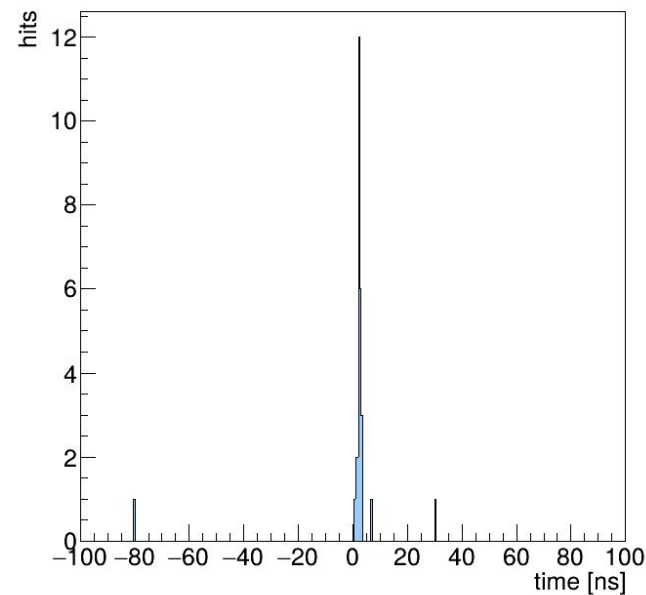


hit times represented with colour coding, hits clustered in time forming a circular pattern

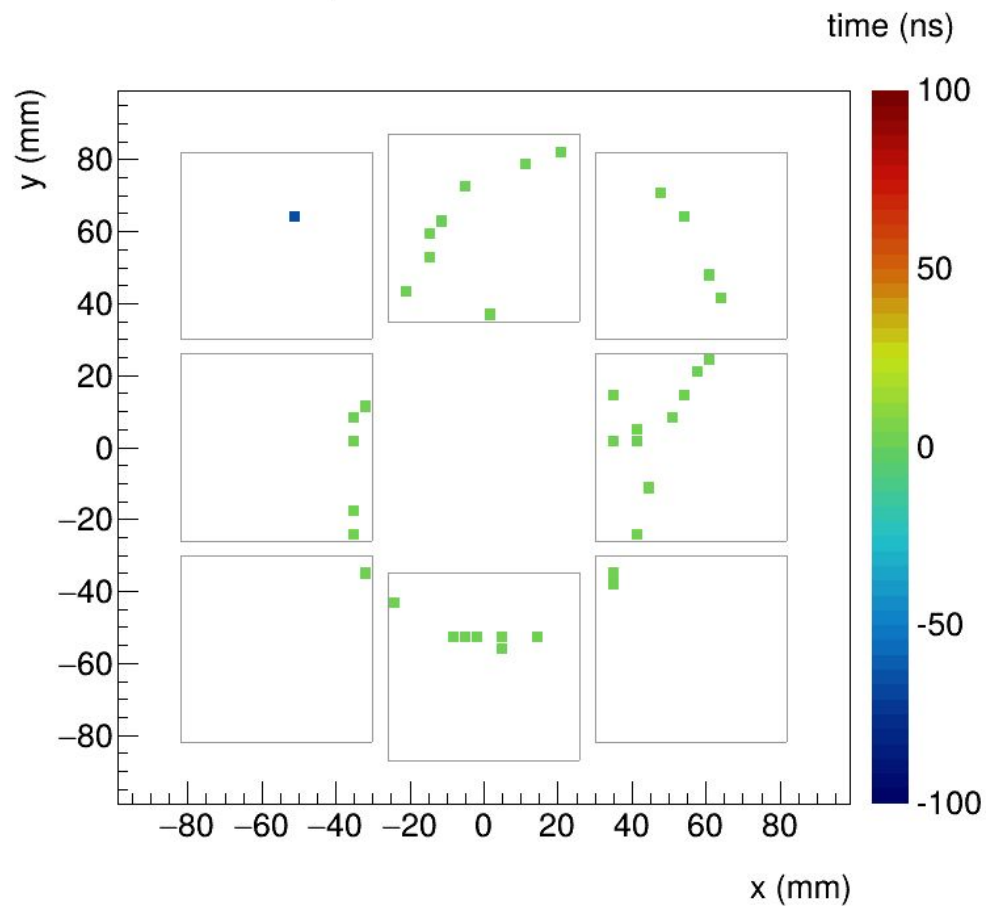
spill 0 frame 0



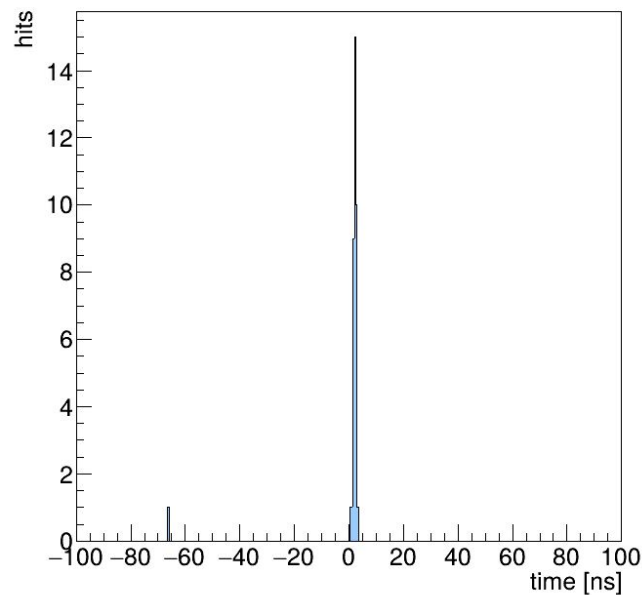
spill 0 frame 0 Cherenkov timing



spill 0 frame 239

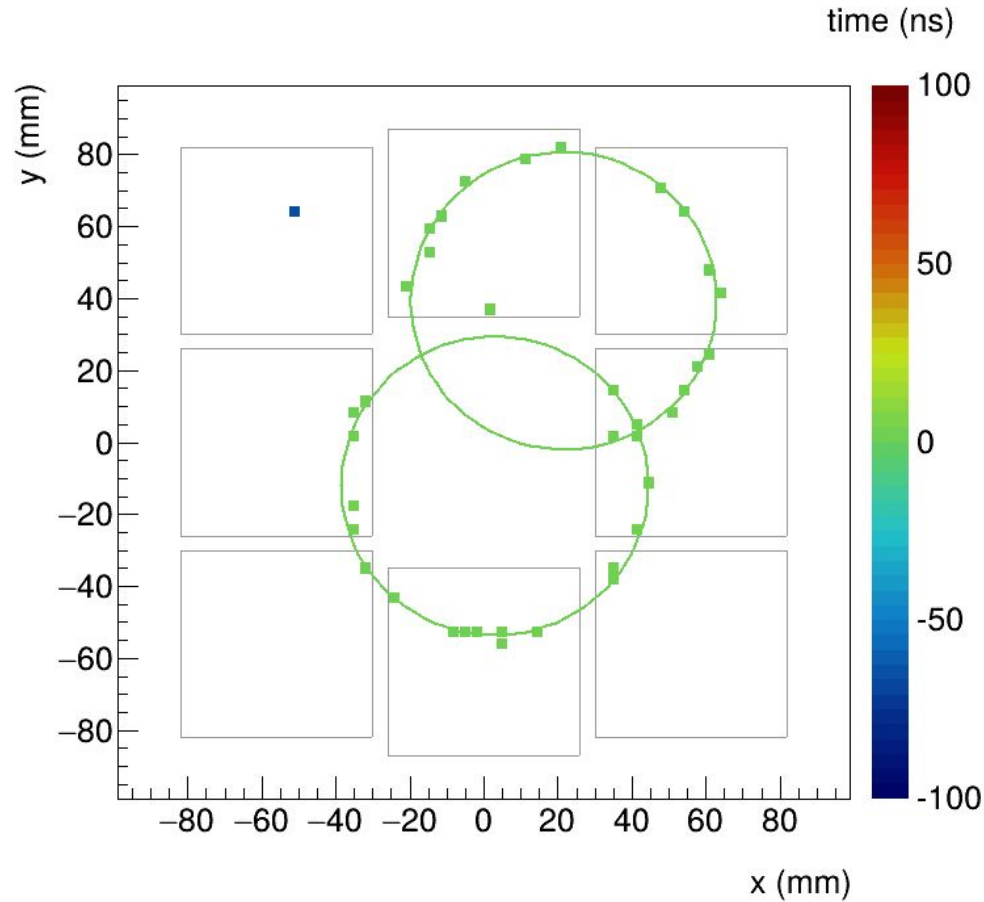


spill 0 frame 239 Cherenkov timing

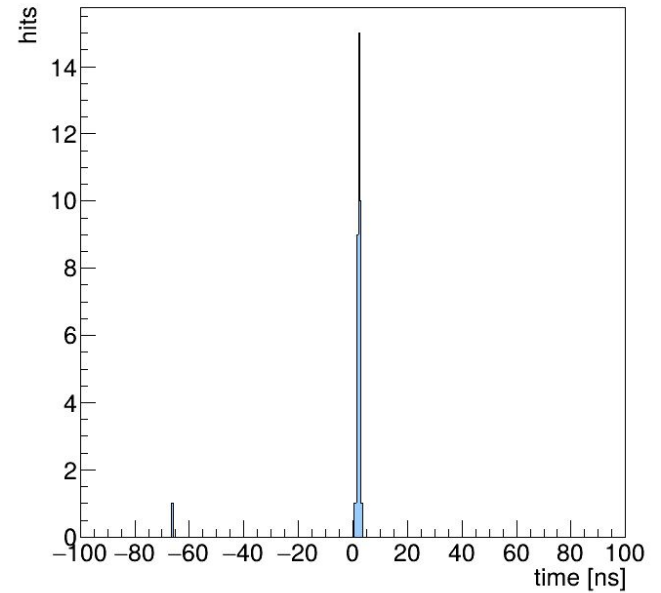


two almost simultaneous particles producing displaced "rings"

spill 0 frame 239

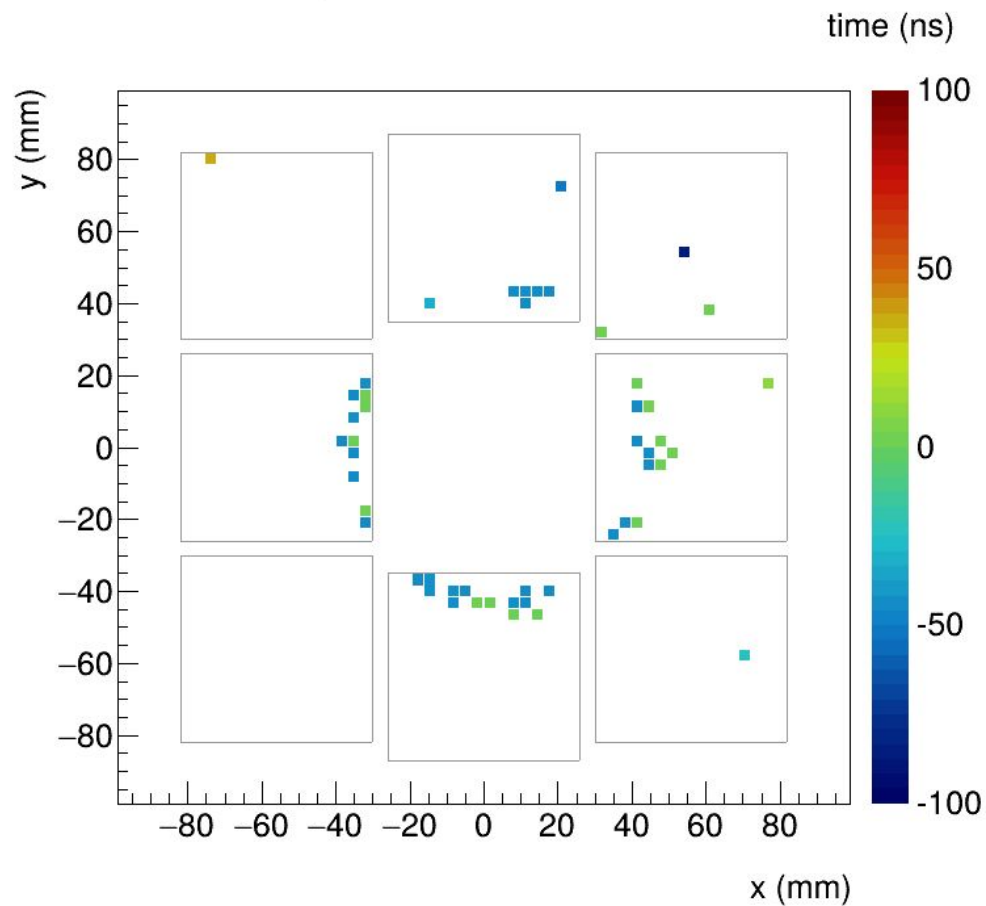


spill 0 frame 239 Cherenkov timing

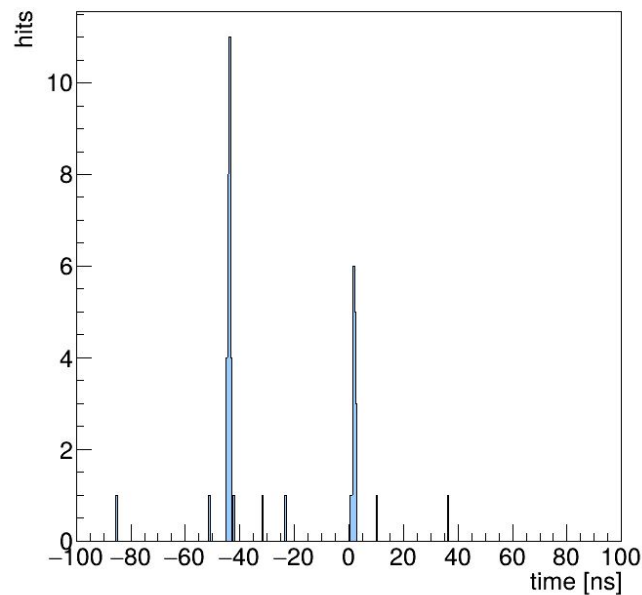


two almost simultaneous particles producing displaced "rings"

spill 0 frame 1065

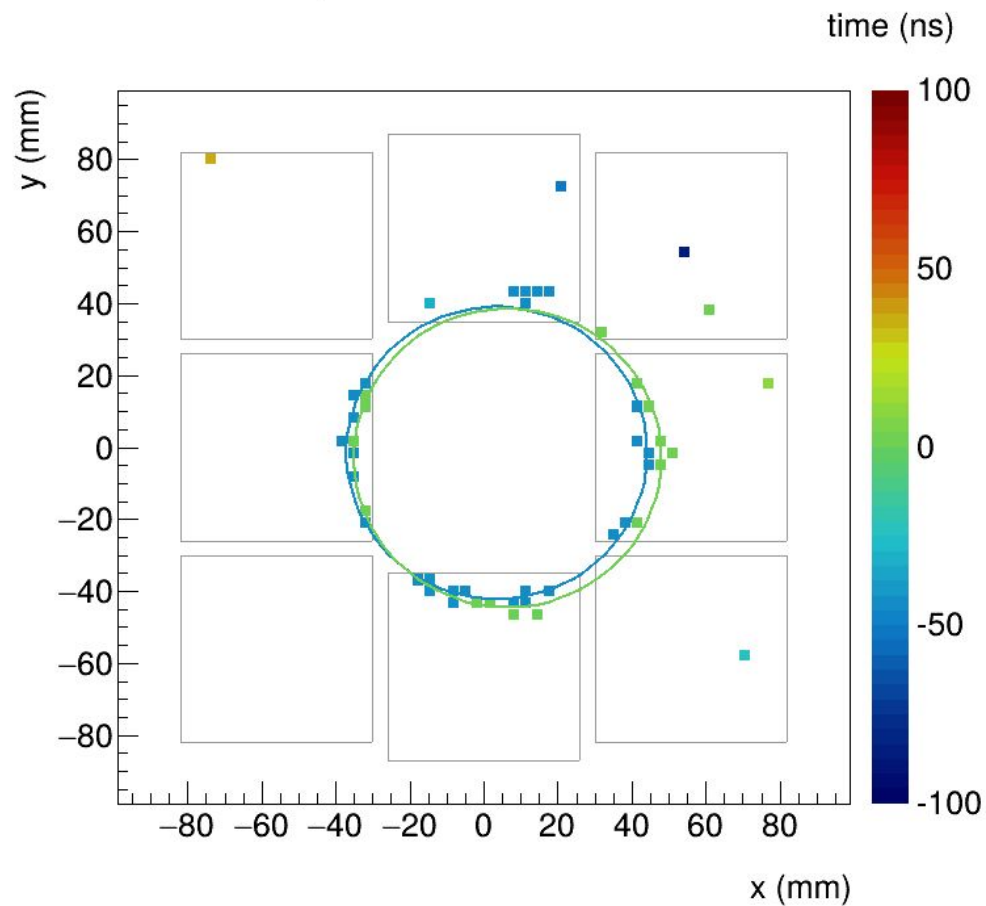


spill 0 frame 1065 Cherenkov timing

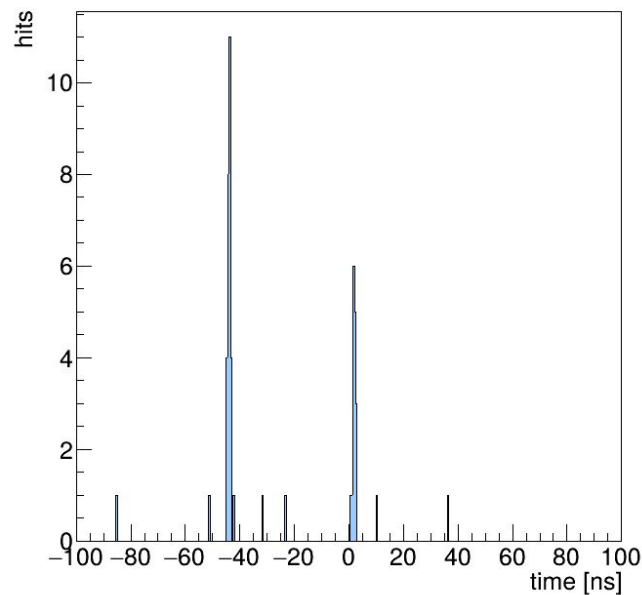


two successive particles producing almost overlapping rings

spill 0 frame 1065

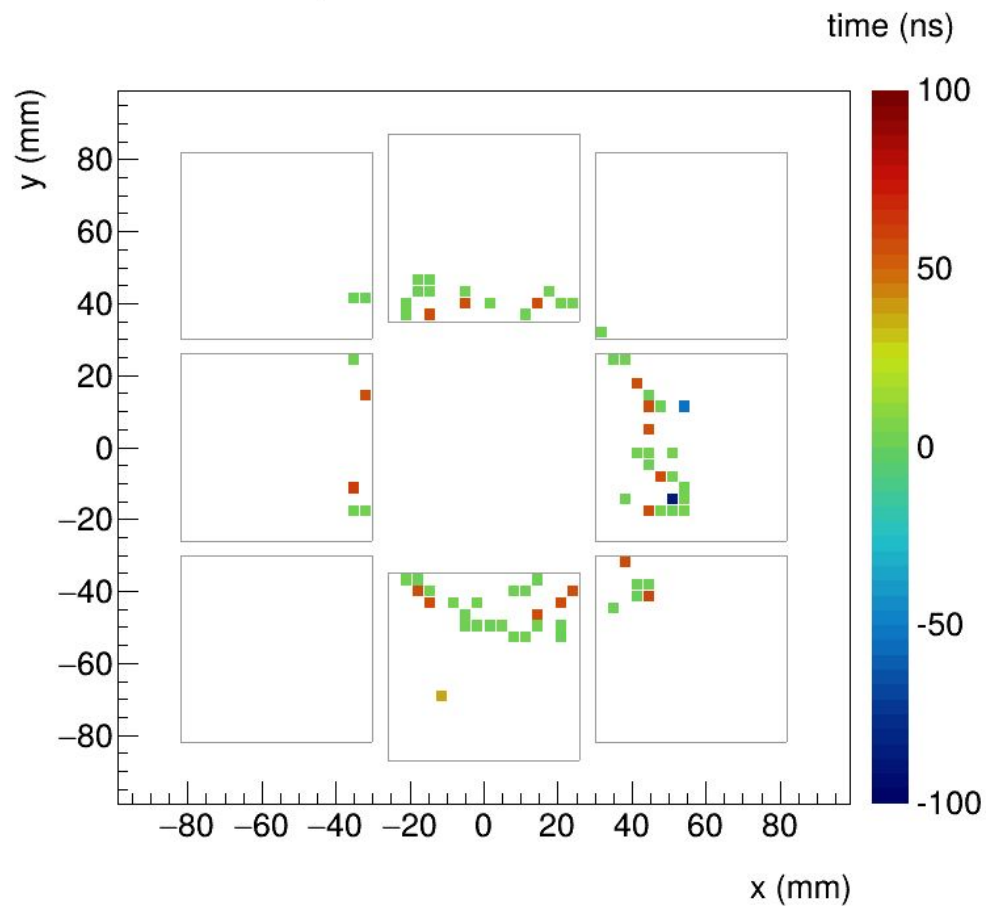


spill 0 frame 1065 Cherenkov timing

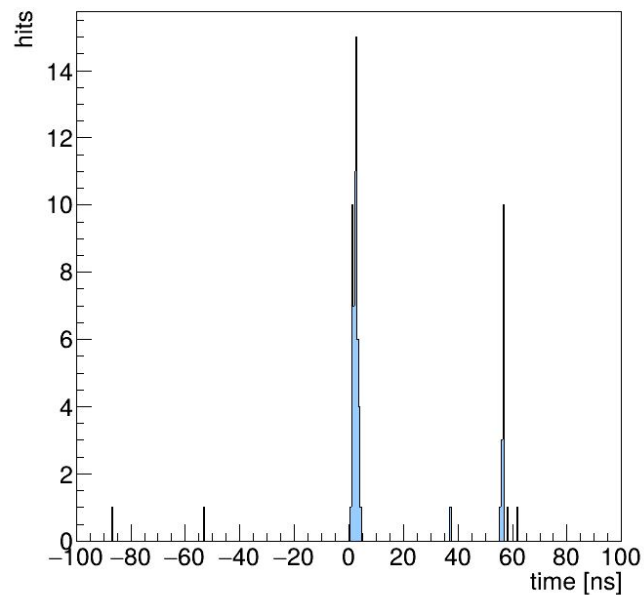


two successive particles producing almost overlapping rings

spill 0 frame 2215

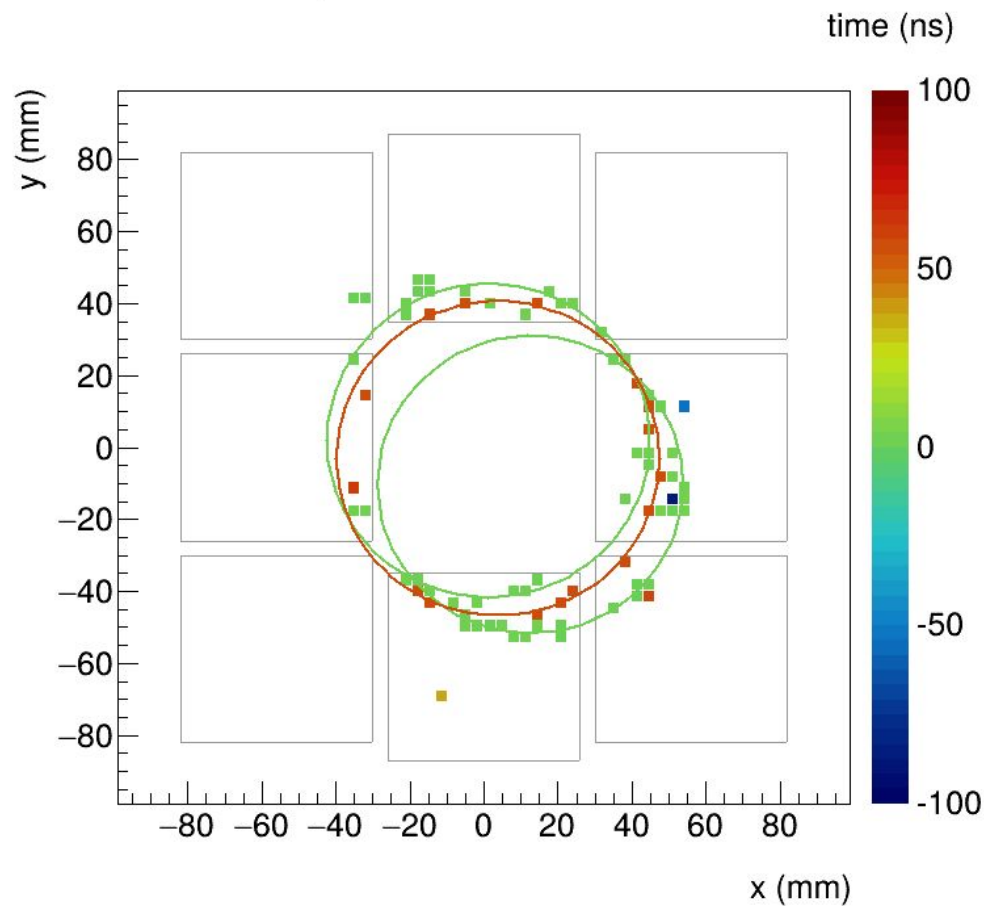


spill 0 frame 2215 Cherenkov timing

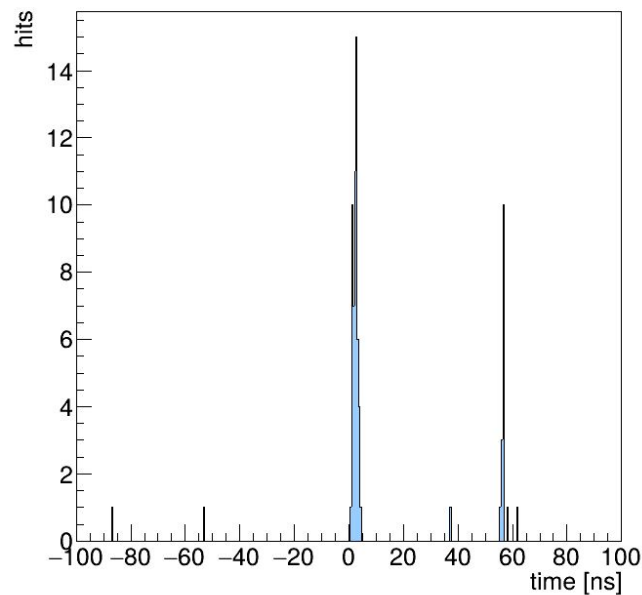


something looking a bit more messy

spill 0 frame 2215

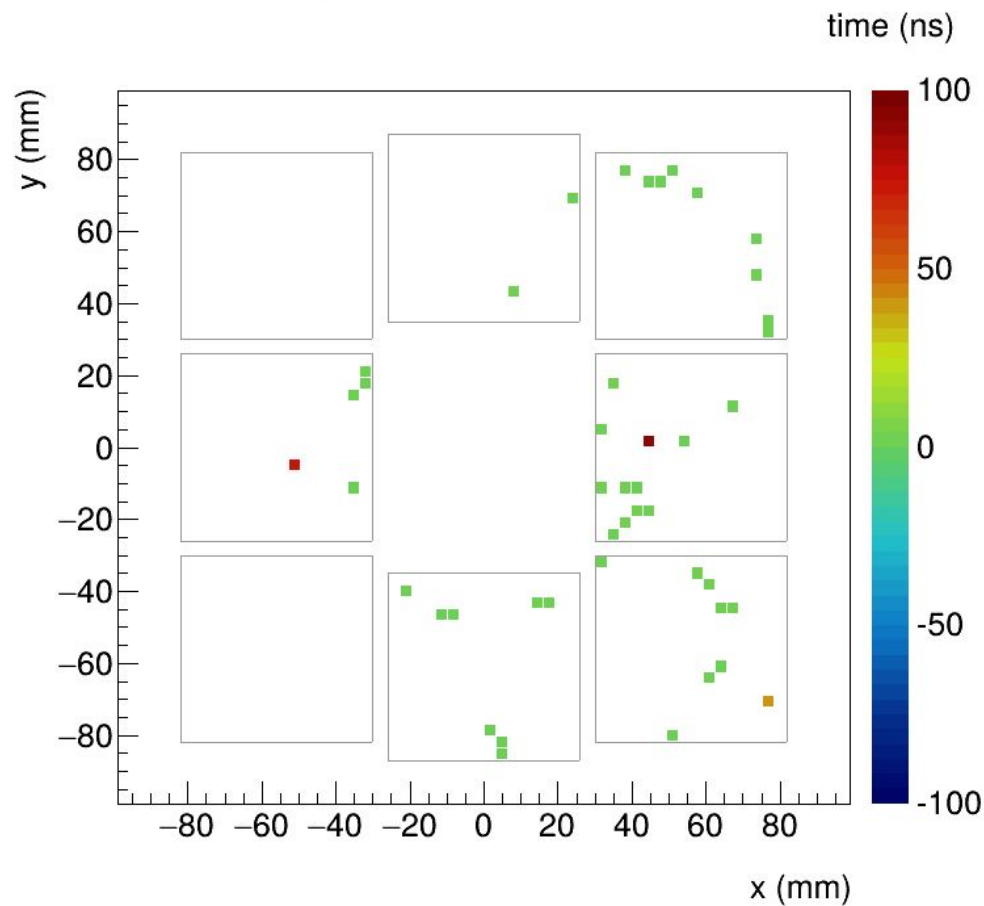


spill 0 frame 2215 Cherenkov timing

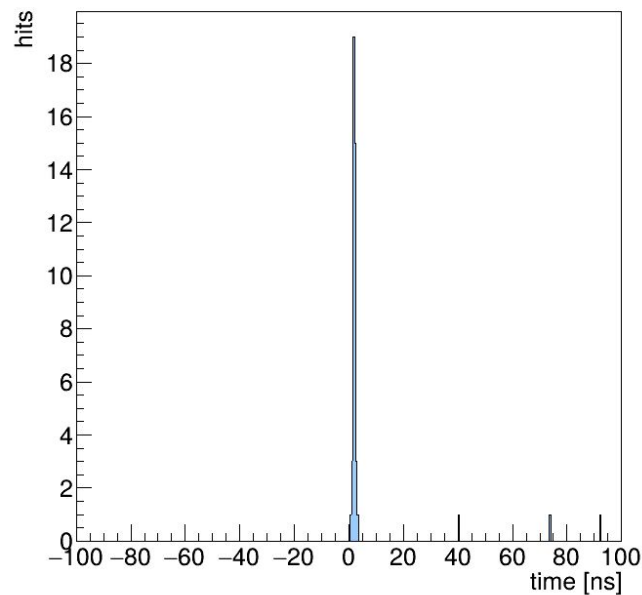


but eventually reconstructible likely as a three-particles event

spill 0 frame 4479

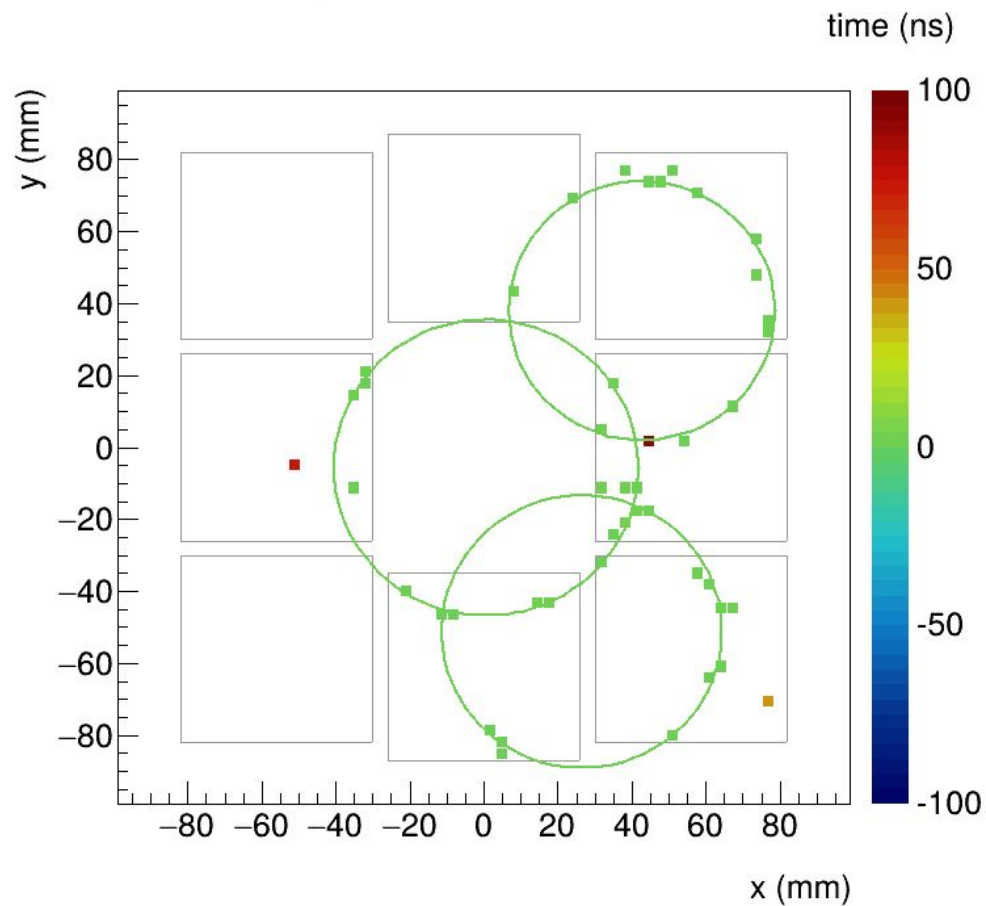


spill 0 frame 4479 Cherenkov timing

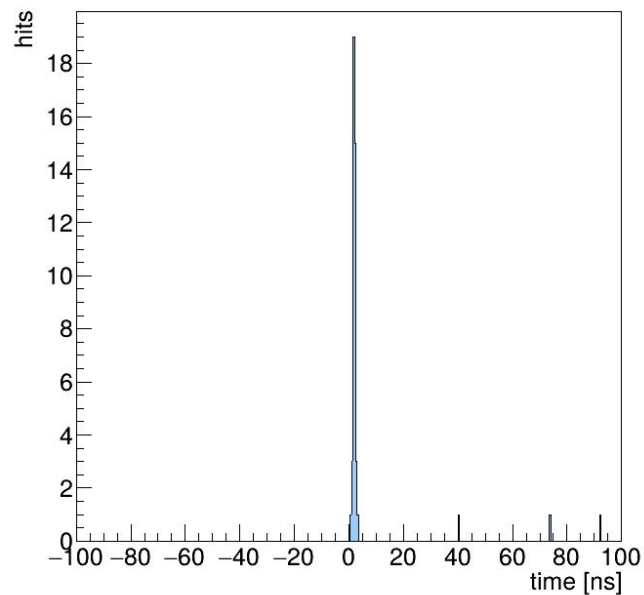


and this one already looks like a three-particles event

spill 0 frame 4479

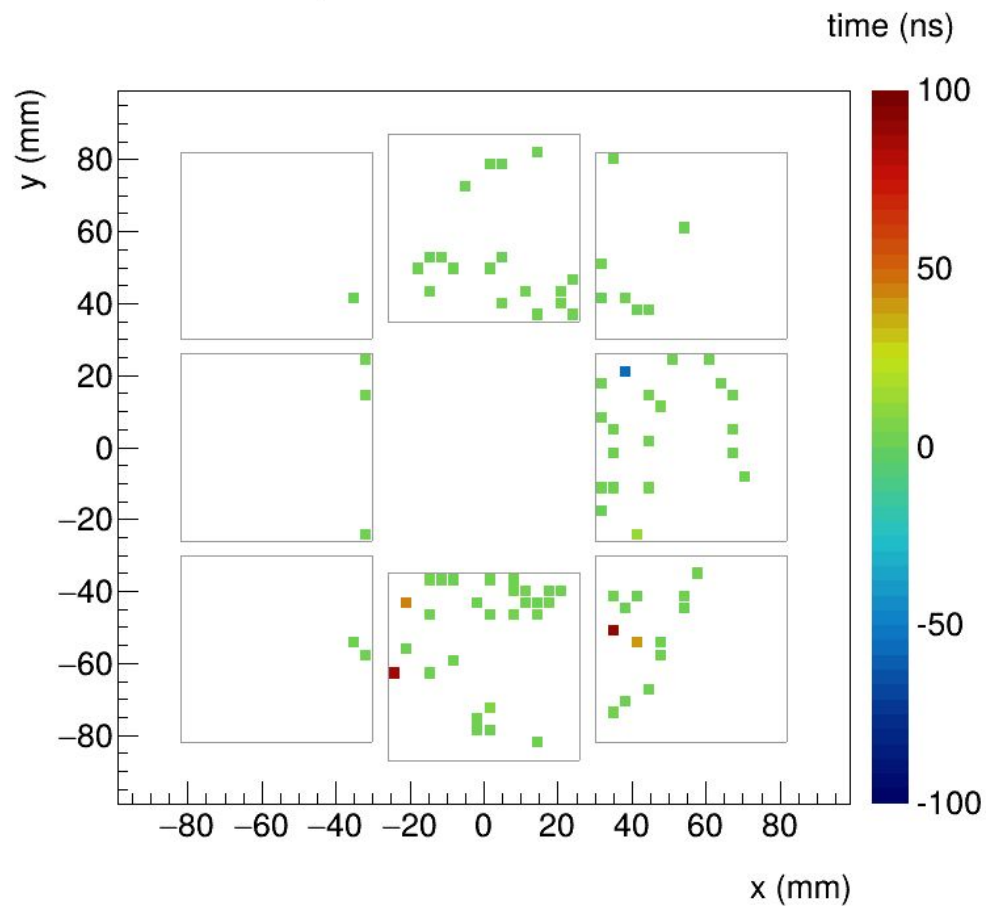


spill 0 frame 4479 Cherenkov timing

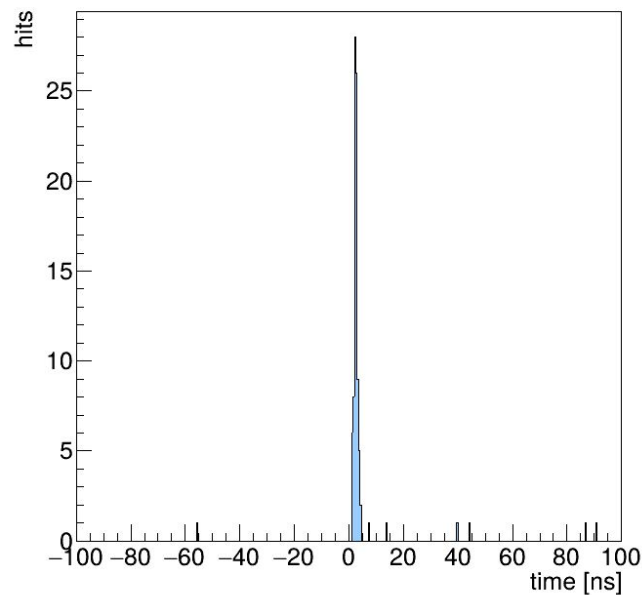


and indeed it is reconstructed as such

spill 0 frame 1320

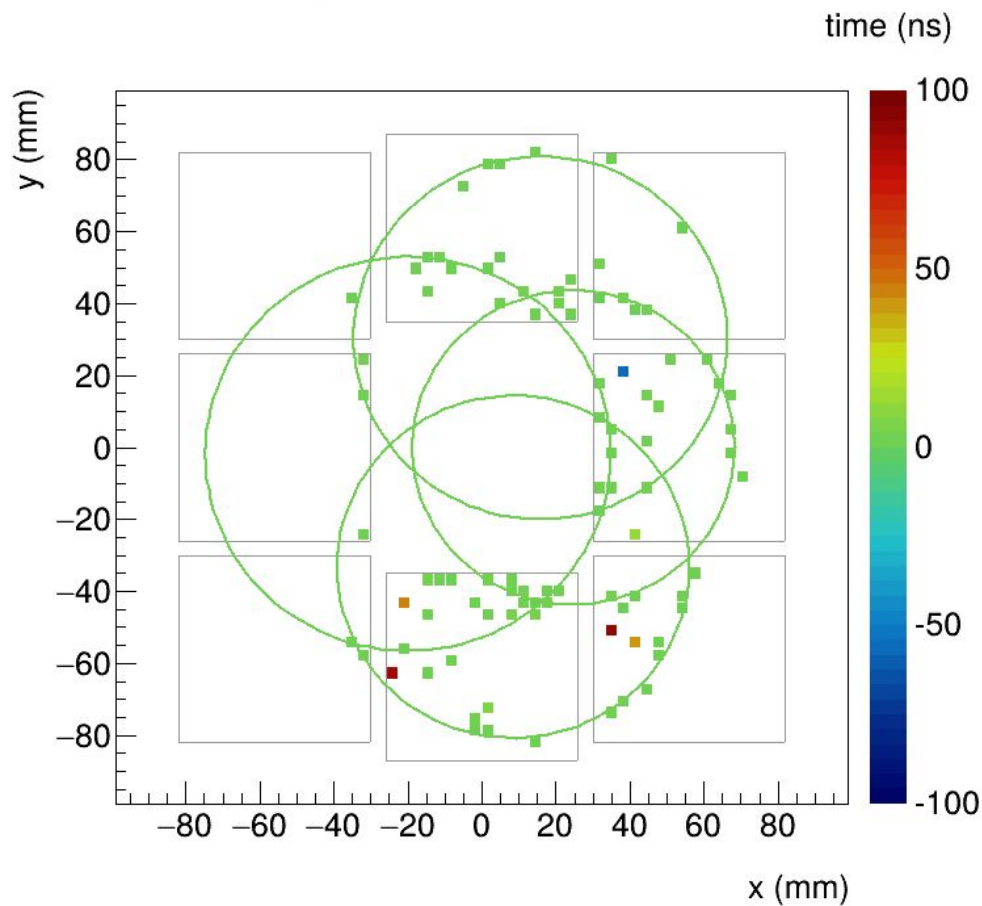


spill 0 frame 1320 Cherenkov timing

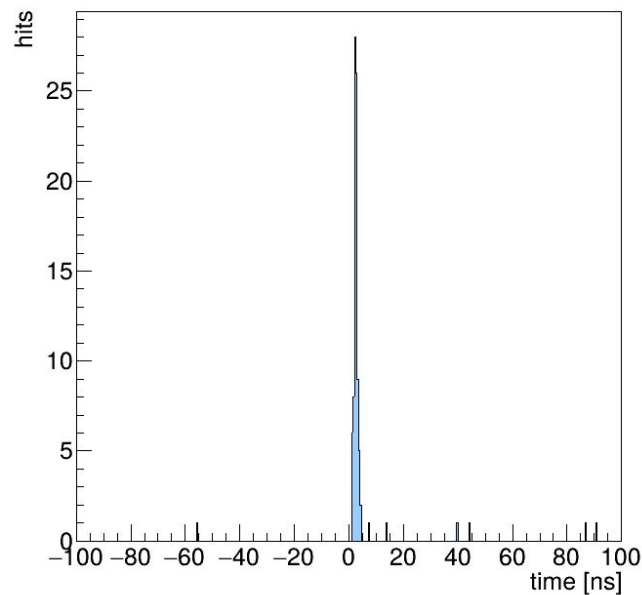


there are also complex topologies, like this one, which are in coincidence with the triggered-particle time

spill 0 frame 1320

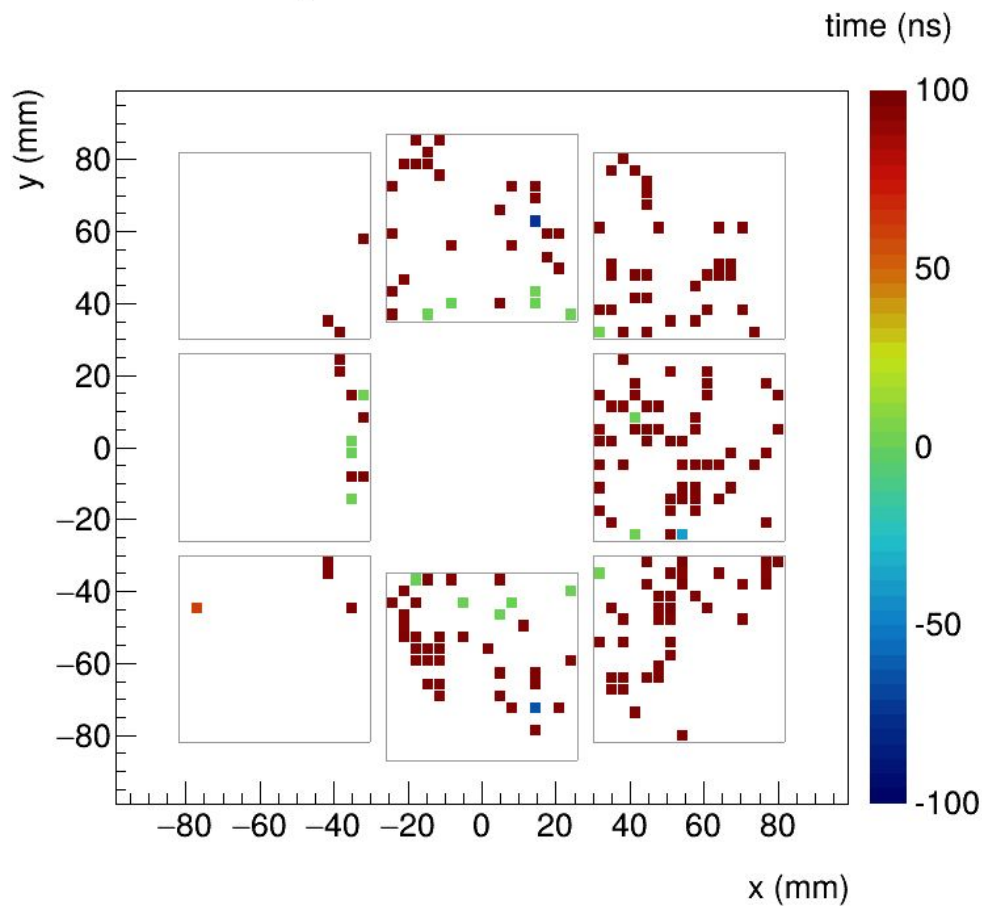


spill 0 frame 1320 Cherenkov timing

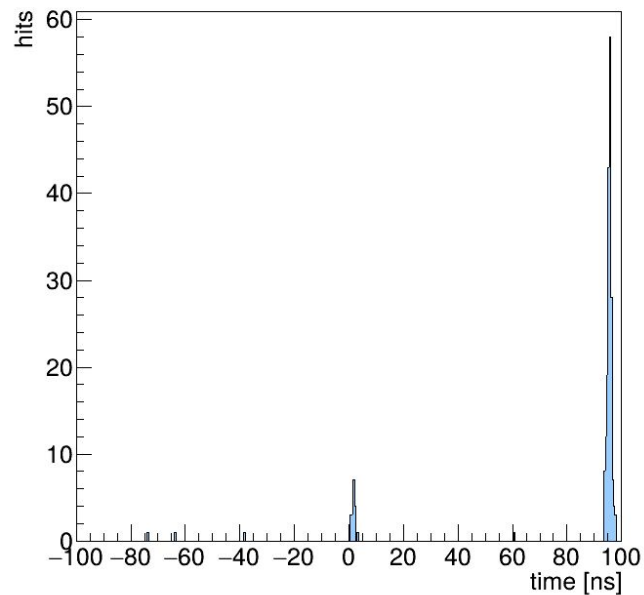


that might look like as multiple-ring events, but at I would not bet what this is (rings are too large for C_2F_6)

spill 0 frame 21960

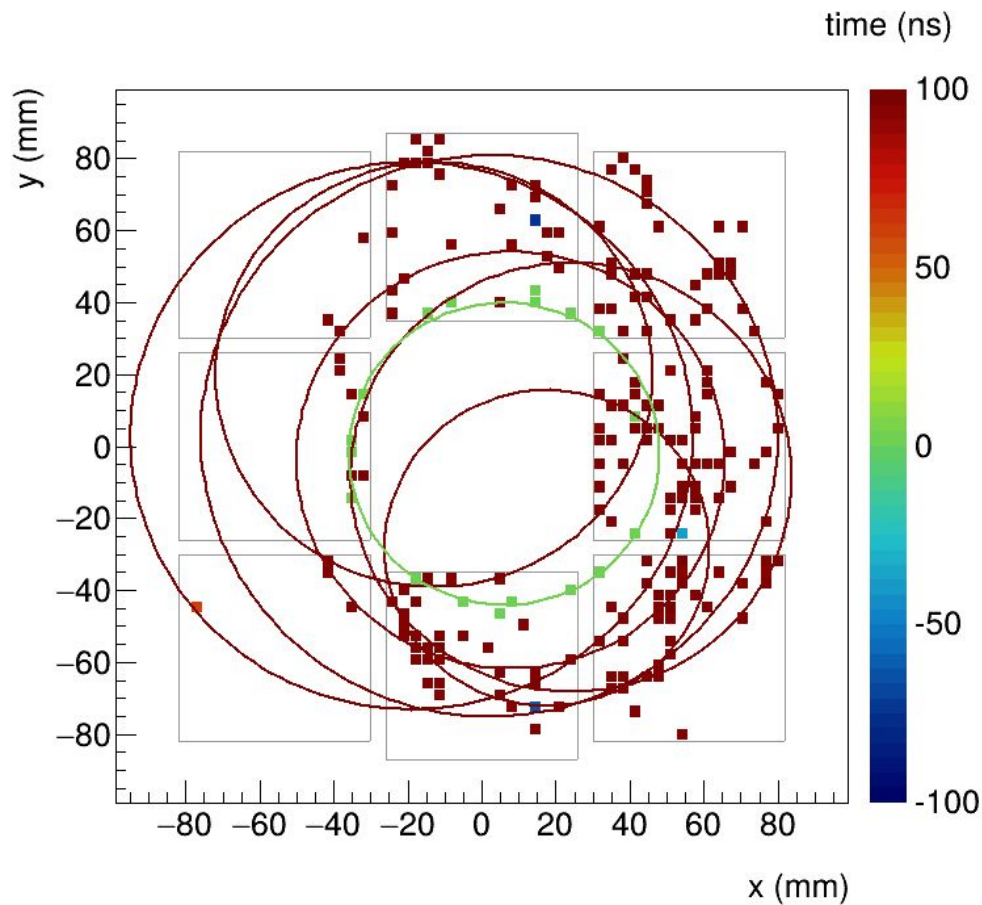


spill 0 frame 21960 Cherenkov timing

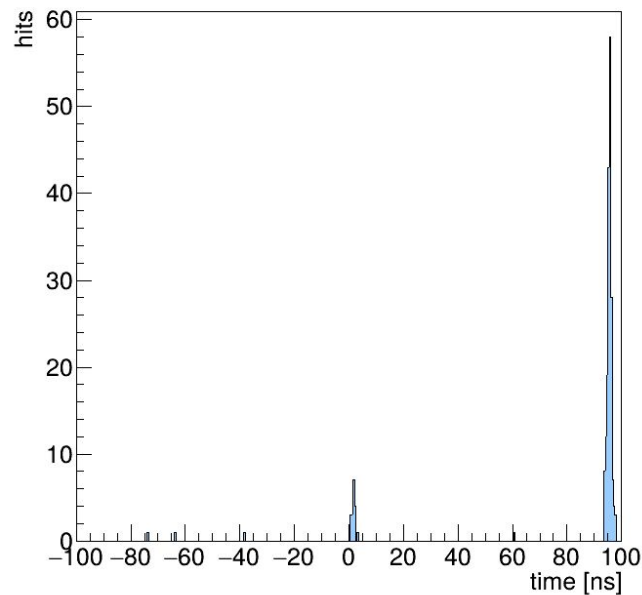


some events look like a total mess, but timing reveals a clean ring underneath

spill 0 frame 21960

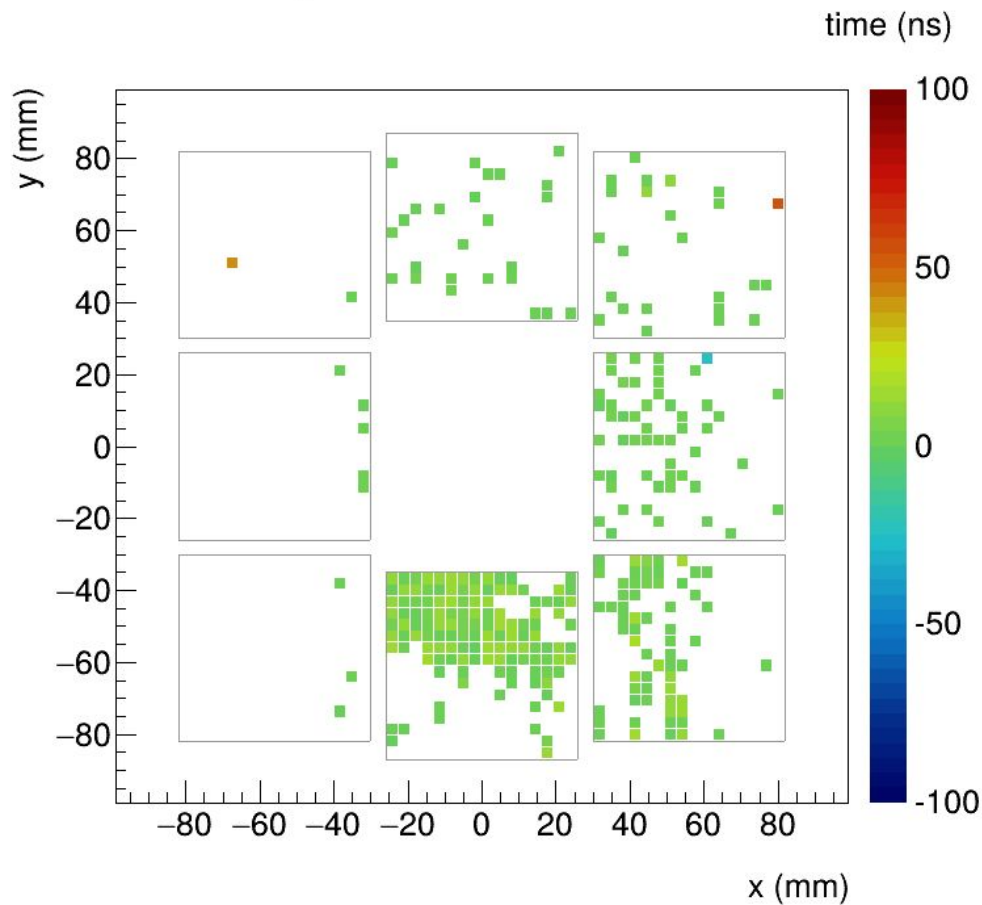


spill 0 frame 21960 Cherenkov timing

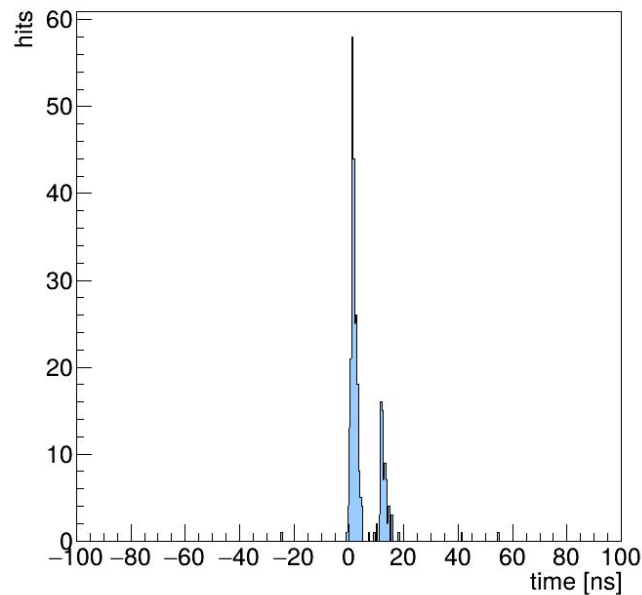


some events look like a total mess, but timing reveals a clean ring underneath

spill 0 frame 60415



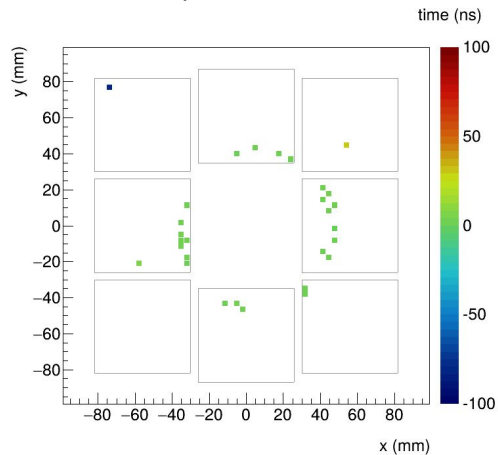
spill 0 frame 60415 Cherenkov timing



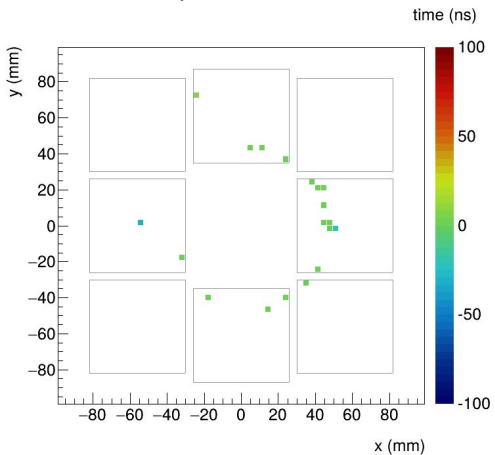
some events seem to be gone wild, maybe something was not properly tuned in electronics settings

focus on one-ring
events

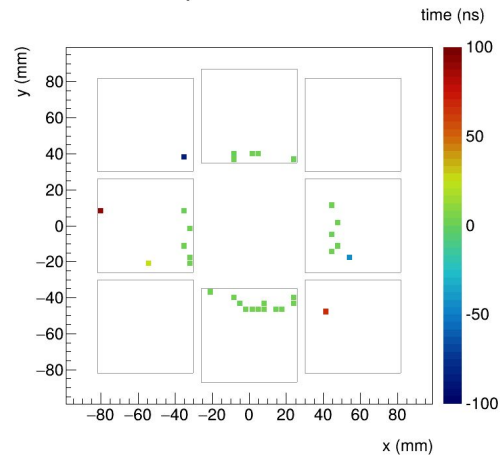
spill 0 frame 0



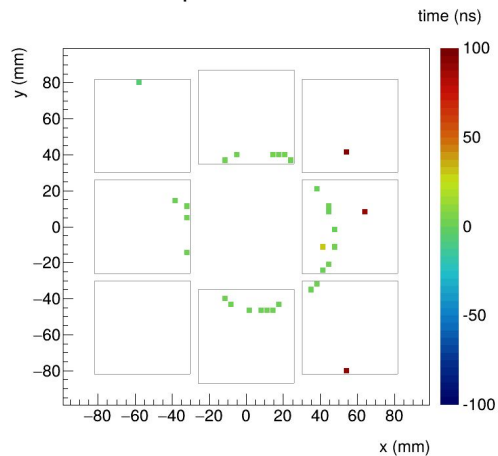
spill 0 frame 1



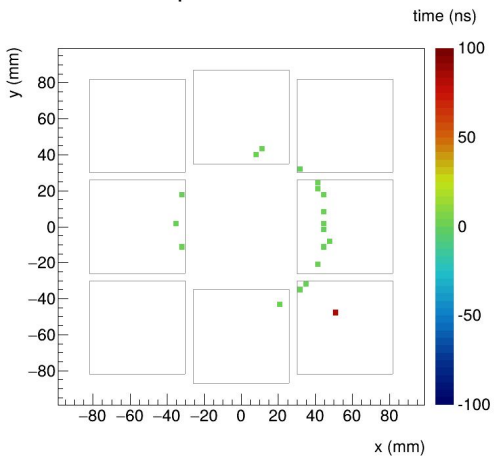
spill 0 frame 2



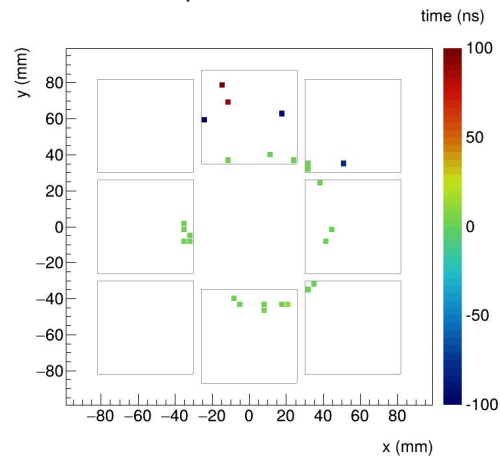
spill 0 frame 3



spill 0 frame 4

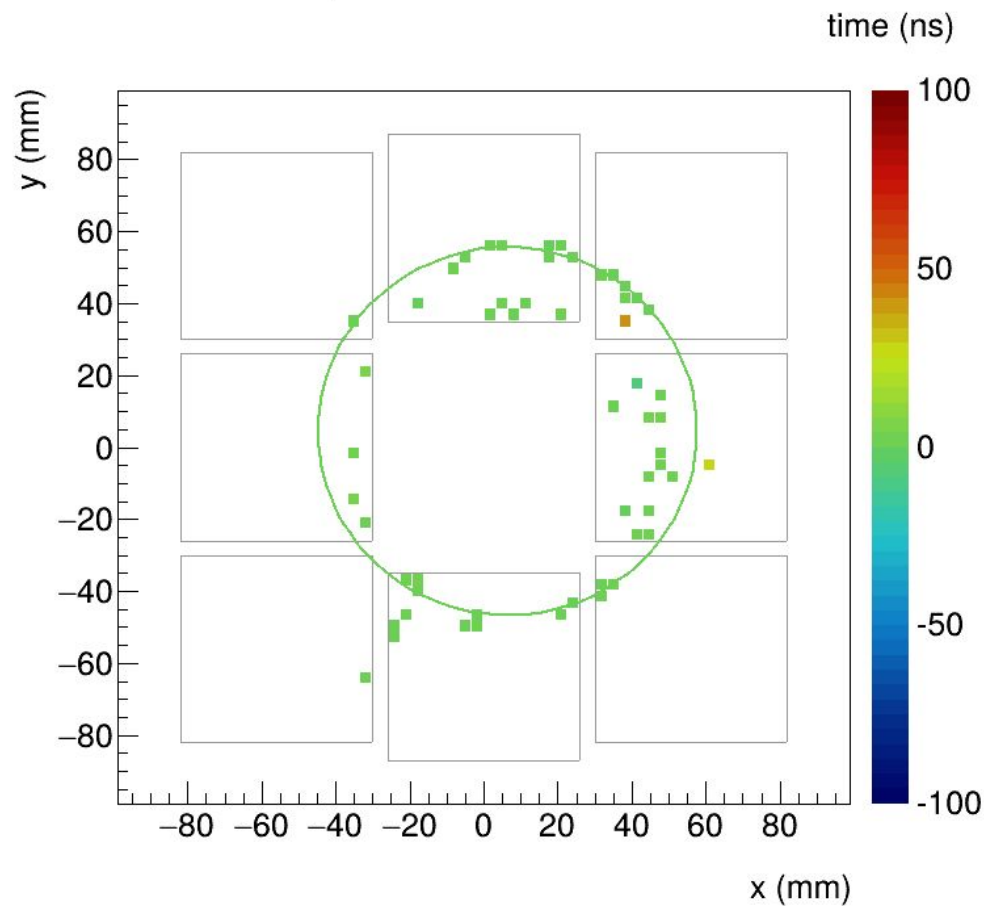


spill 0 frame 5

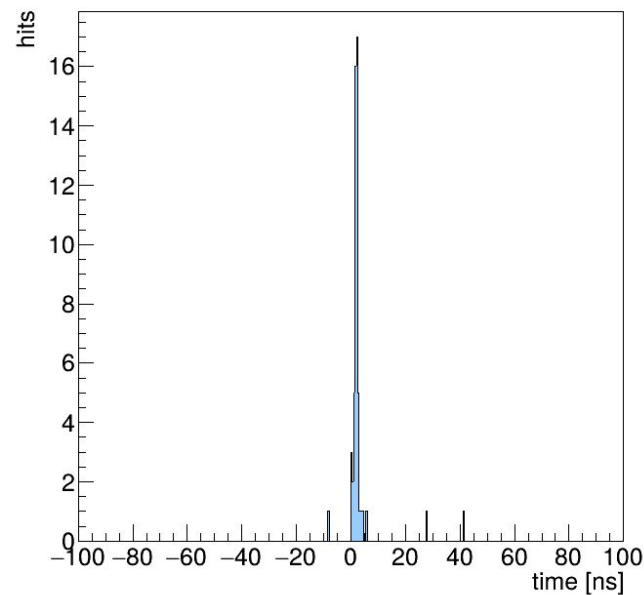


which are the majority

spill 0 frame 750

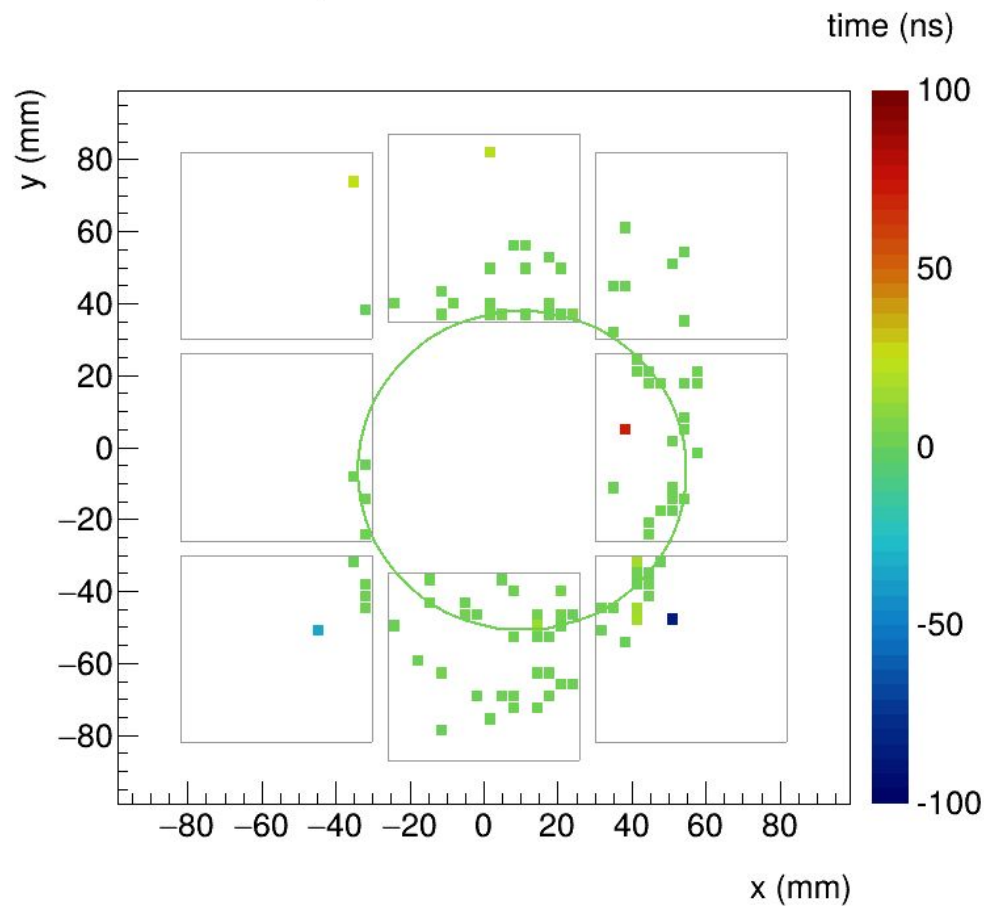


spill 0 frame 750 Cherenkov timing

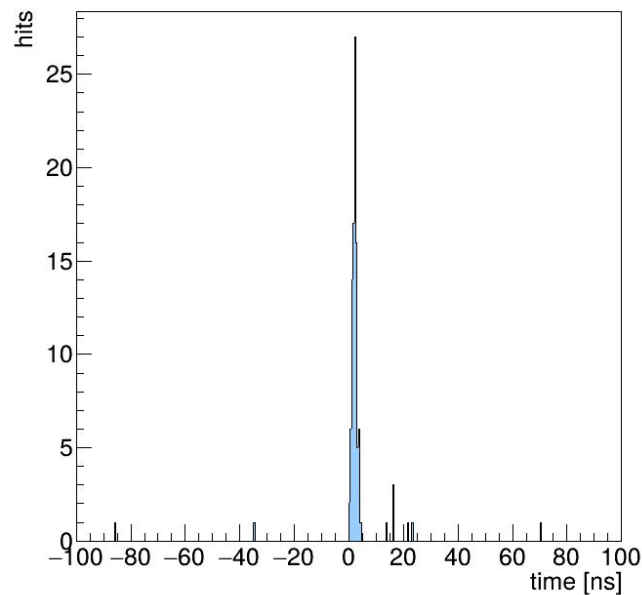


but the pattern-recognition algorithm is not perfect and sometime it flags a messier event as a one-ring event

spill 0 frame 6177

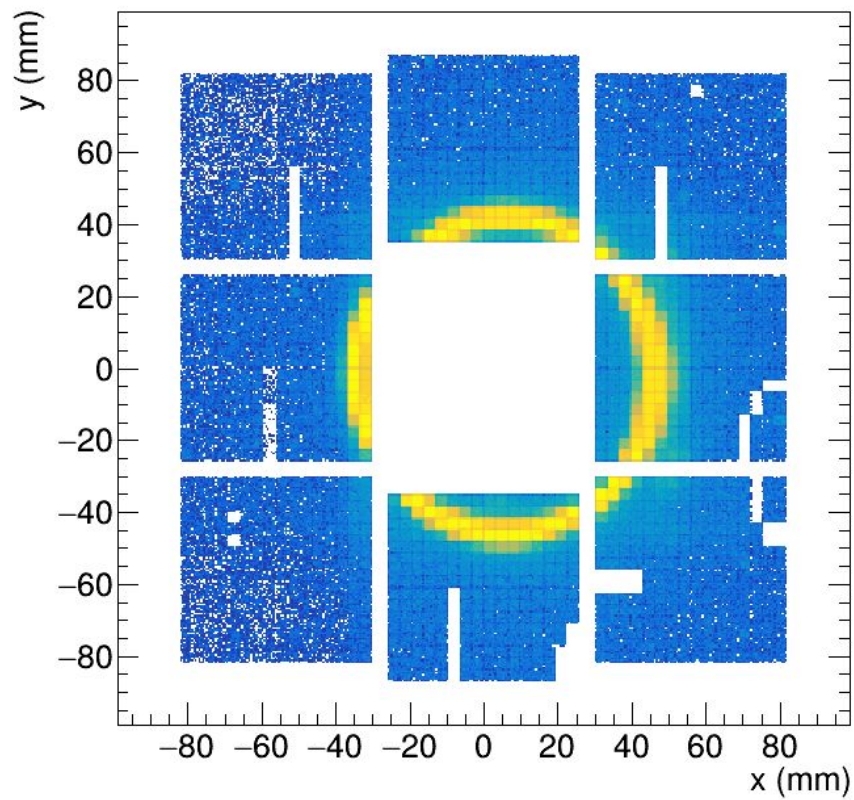


spill 0 frame 6177 Cherenkov timing

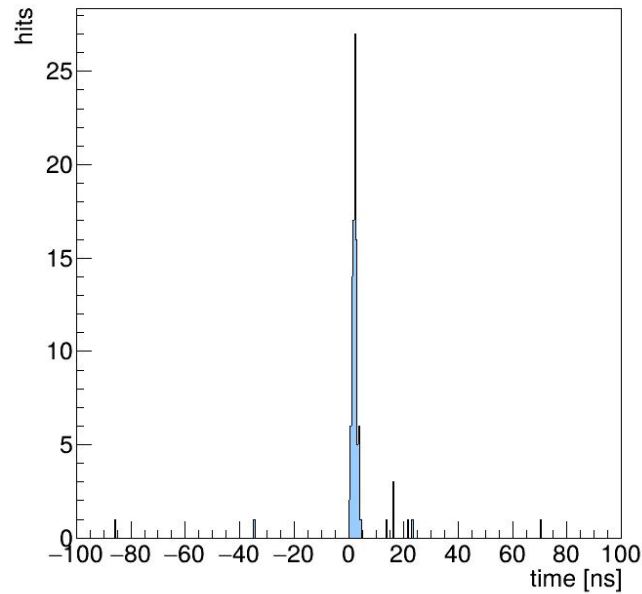


one might try to do pattern recognition and event selection better, but for the moment this analysis remains a bit contaminated

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



spill 0 frame 6177 Cherenkov timing



representation of the accumulated hits in selected one-ring events (hit position is smeared to enhance visualisation)

inverse ray-tracing
reconstruction

```

# All coordinates and radii are in millimetres, angles are in radians.
# These values describe the nominal optical geometry.
# Data-derived alignment corrections belong in a separate configuration.

[mirror]
center = (1150.08, 0.0, 939.0)
radius = 2203.01
pivot_center = (327.9, 0.0, 3110.6)      # Mechanical rotation pivot of the mirror, in millimetres.
rotation_vector = (0.0, 0.0, 0.0)        # Mirror rotation about the mechanical pivot.

[detector]
sphere_center = (1834.0, 0.0, 1414.0)    # The photodetector is a tangent plane located on a nominal sphere.
sphere_radius = 1100.0
theta = -0.66041320                      # Direction from the sphere centre to the tangent-plane centre
phi = 0.0                                # plane centre = (1163.3, 0.0, 2282.6) mm.
rotation_vector = (0.0, 0.0, 0.0)        # Rotation of the detector plane about its fixed plane centre.

[track]
origin = (0.0, 0.0, 0.0)
direction = (0.0, 0.0, 1.0)              # The track goes along the z axis.
emission_z = 2534.0                      # The pseudorapidity is defined by a rotation of the whole dRICH assembly.

[assembly]
rotation_x_pivot = (0.0, 0.0, 2500.0)    # Rotation pivots and angles of the whole dRICH assembly.
rotation_x = 0.0
rotation_y_pivot = (0.0, 0.0, 0.0)
rotation_y = -0.081479300                # This corresponds to eta = 3.2

```

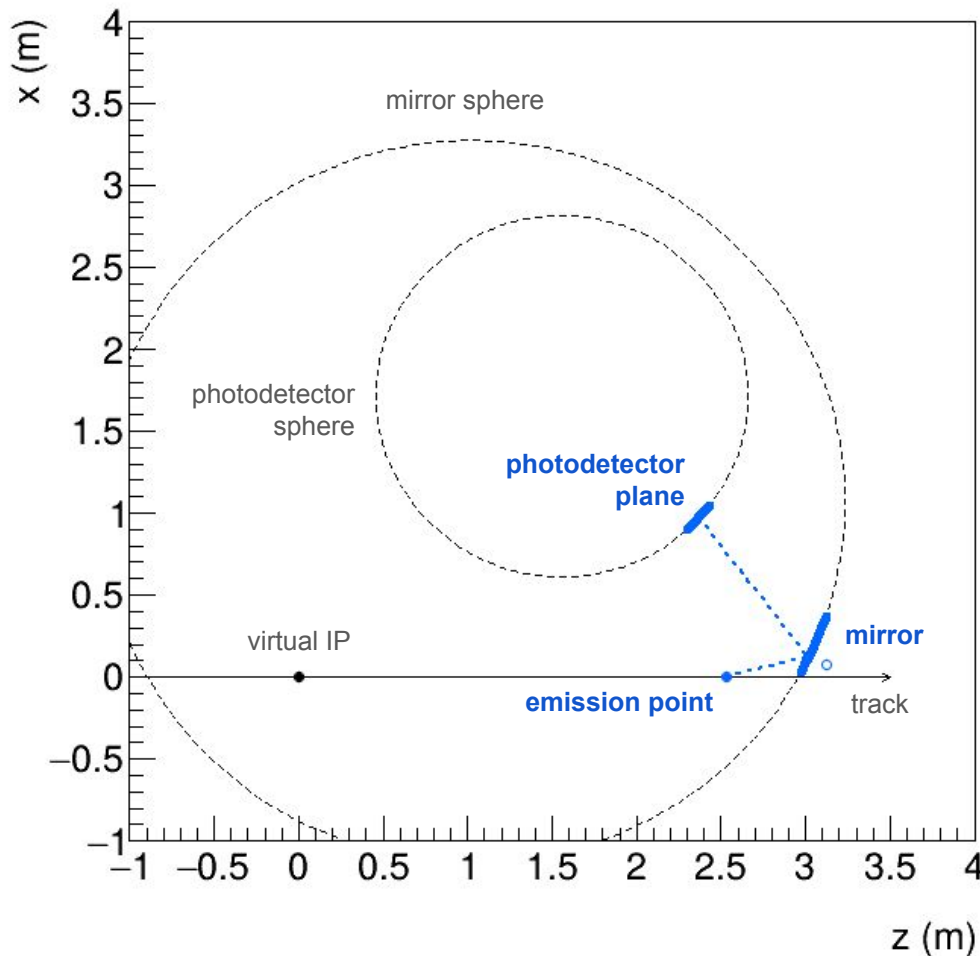
All coordinates and radii are in millin
These values describe the nominal optic
Data-derived alignment corrections belc

[mirror]
center = (1150.08, 0.0, 939.0)
radius = 2203.01
pivot_center = (327.9, 0.0, 3110.6)
rotation_vector = (0.0, 0.0, 0.0)

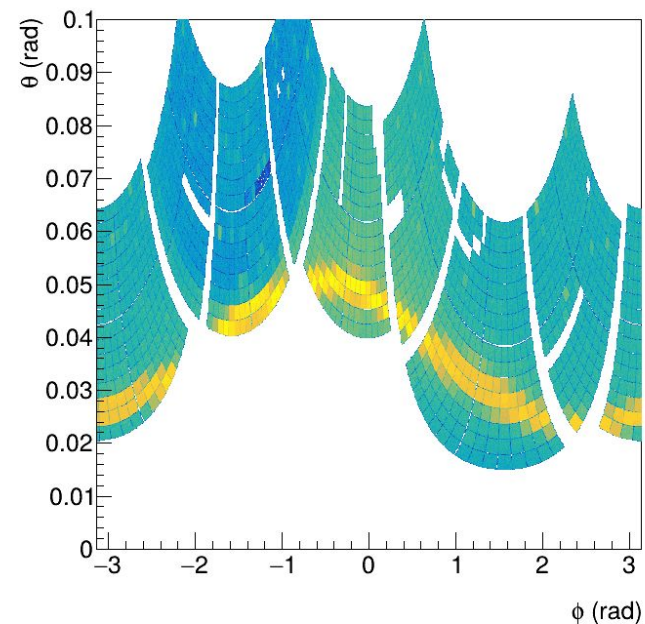
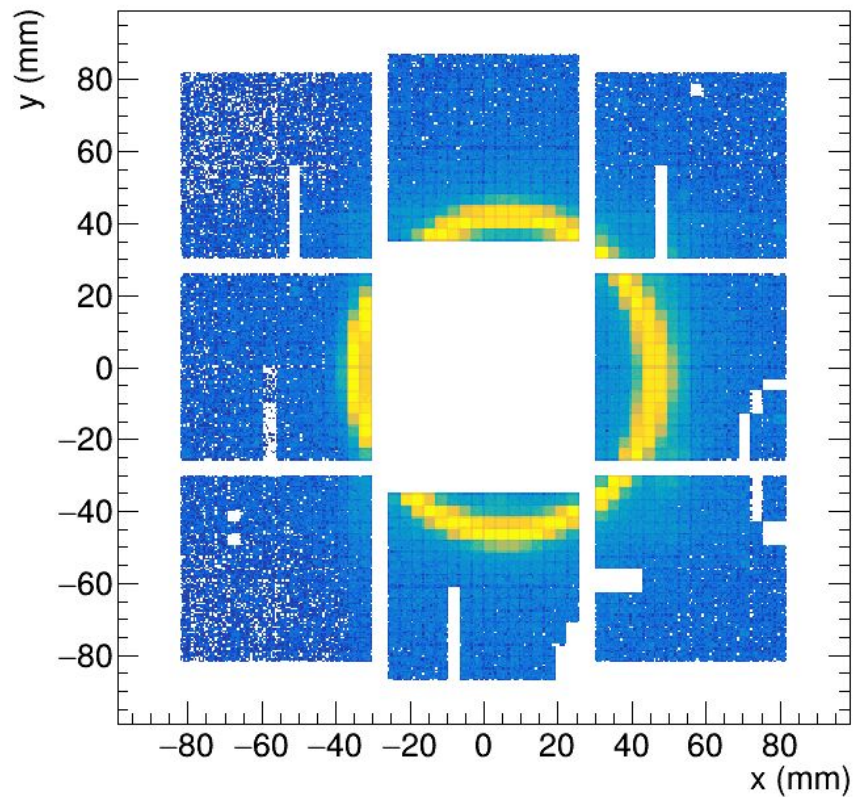
[detector]
sphere_center = (1834.0, 0.0, 1414.0)
sphere_radius = 1100.0
theta = -0.66041320
phi = 0.0
rotation_vector = (0.0, 0.0, 0.0)

[track]
origin = (0.0, 0.0, 0.0)
direction = (0.0, 0.0, 1.0)
emission_z = 2534.0

[assembly]
rotation_x_pivot = (0.0, 0.0, 2500.0)
rotation_x = 0.0
rotation_y_pivot = (0.0, 0.0, 0.0)
rotation_y = -0.081479300



events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



fitting geometry
parameters

Best SPS geometry fit found with eta = 3.2 fixed.

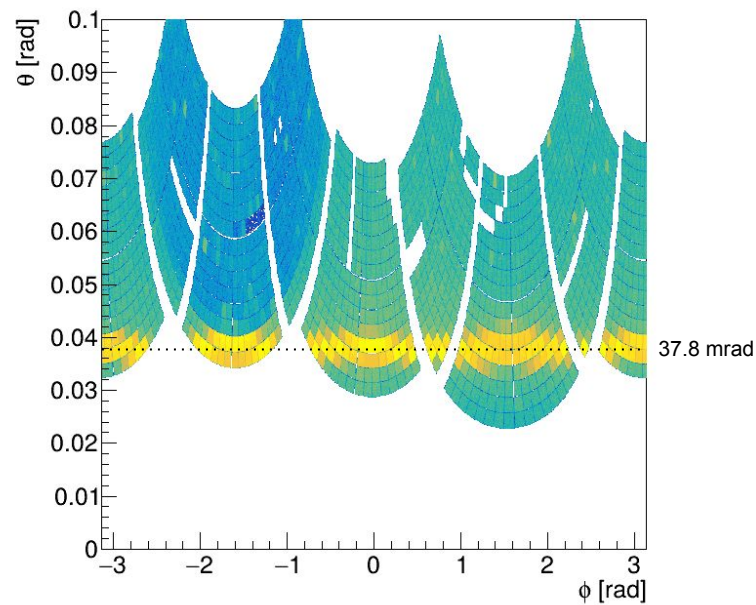
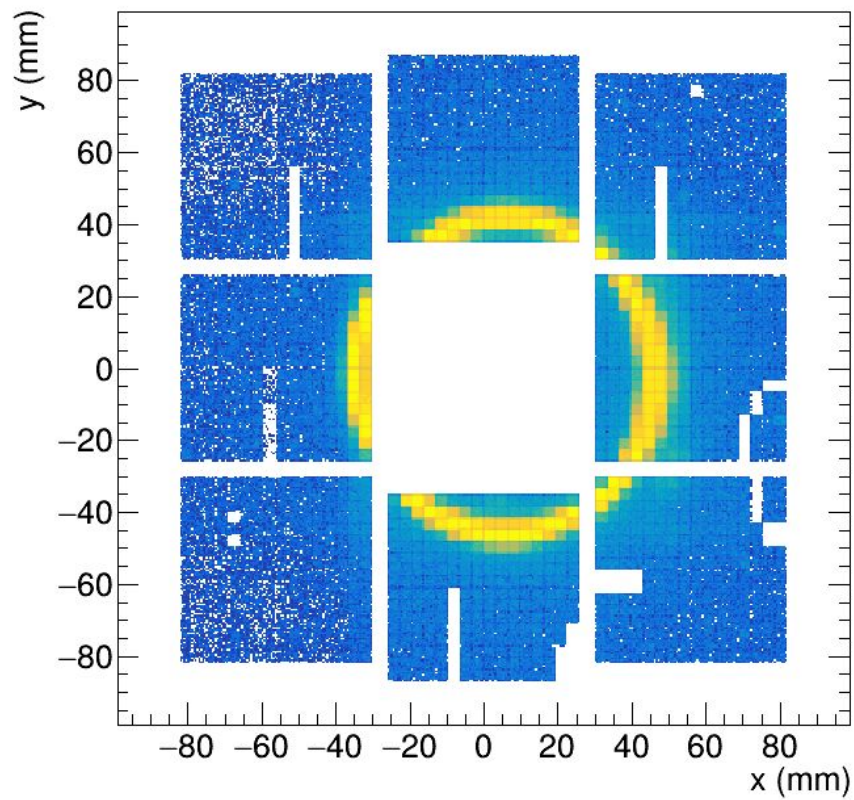
# name	start	min	max	status
assembly_rotation_x	0.0	-0.1	0.1	fixed
assembly_rotation_y	-0.081479300	-0.2	0.2	fixed
assembly_rotation_x_pivot_y	0.0	-500.0	500.0	fixed
assembly_rotation_x_pivot_z	2500.0	1500.0	3500.0	fixed
emission_z	2534.0	2300.0	2700.0	fixed
mirror_delta_x	0.0	-100.0	100.0	fixed
mirror_delta_y	0.0	-100.0	100.0	fixed
mirror_delta_z	0.0	-100.0	100.0	fixed
mirror_delta_r	0.0	-100.0	100.0	fixed
mirror_rotation_x	0.0314381	-0.1	0.1	free
mirror_rotation_y	0.0563053	-0.1	0.1	free
mirror_rotation_z	0.0	-0.01	0.01	fixed
detector_delta_x	0.0	-100.0	100.0	fixed
detector_delta_y	0.0	-100.0	100.0	fixed
detector_delta_z	0.0	-100.0	100.0	fixed
detector_delta_theta	-0.126726	-0.2	0.2	free
detector_delta_phi	-0.0632111	-0.2	0.2	free
detector_rotation_x	0.0	-0.1	0.1	fixed
detector_rotation_y	0.0	-0.1	0.1	fixed
detector_rotation_z	0.0	-0.1	0.1	fixed
expected_cherenkov_angle	0.0378242	0.03	0.05	free

fitted detector geometry parameters, forced $\eta = 3.2 \rightarrow$ best fitted cherenkov $\theta = 37.82$ mrad (is $n = 1.000716$ realistic?)

Best SPS geometry fit found with theta = 39.979159 mrad fixed.

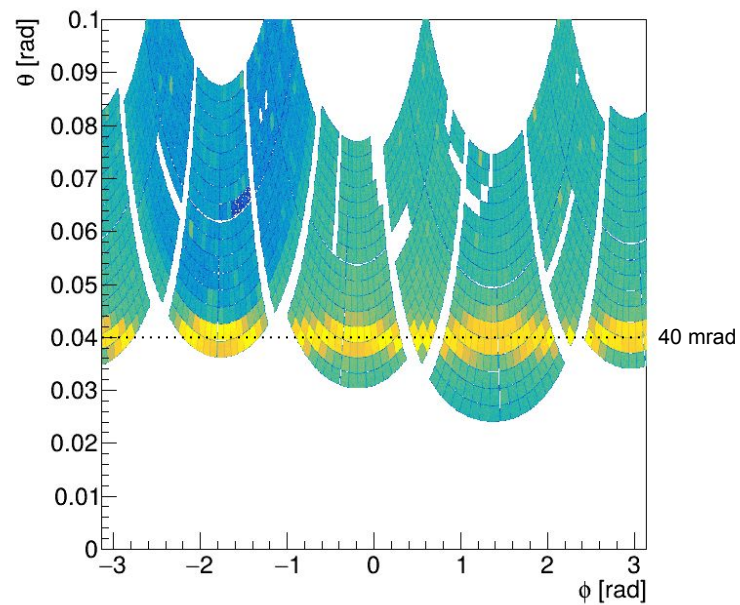
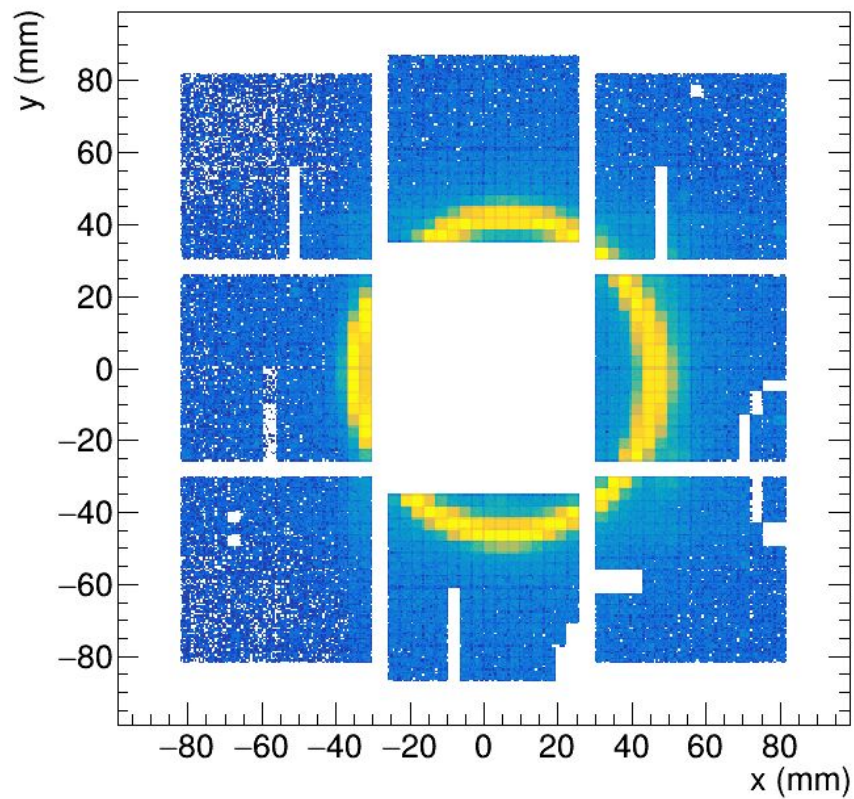
# name	start	min	max	status
assembly_rotation_x	0.00354026	-0.1	0.1	free
assembly_rotation_y	-0.174760	-0.2	0.2	free
assembly_rotation_x_pivot_y	0.0	-500.0	500.0	fixed
assembly_rotation_x_pivot_z	2500.0	1500.0	3500.0	fixed
emission_z	2534.0	2300.0	2700.0	fixed
mirror_delta_x	0.0	-100.0	100.0	fixed
mirror_delta_y	0.0	-100.0	100.0	fixed
mirror_delta_z	0.0	-100.0	100.0	fixed
mirror_delta_r	0.0	-100.0	100.0	fixed
mirror_rotation_x	0.00617343	-0.1	0.1	free
mirror_rotation_y	0.0175609	-0.1	0.1	free
mirror_rotation_z	-0.00216257	-0.01	0.01	free
detector_delta_x	0.0	-100.0	100.0	fixed
detector_delta_y	0.0	-100.0	100.0	fixed
detector_delta_z	0.0	-100.0	100.0	fixed
detector_delta_theta	0.0264554	-0.1	0.1	free
detector_delta_phi	0.000127001	-0.1	0.1	free
detector_rotation_x	-0.0803536	-0.1	0.1	free
detector_rotation_y	0.108421	-0.2	0.2	free
detector_rotation_z	-0.0873099	-0.1	0.1	free
expected_cherenkov_angle	0.039979159	0.03	0.05	fixed

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



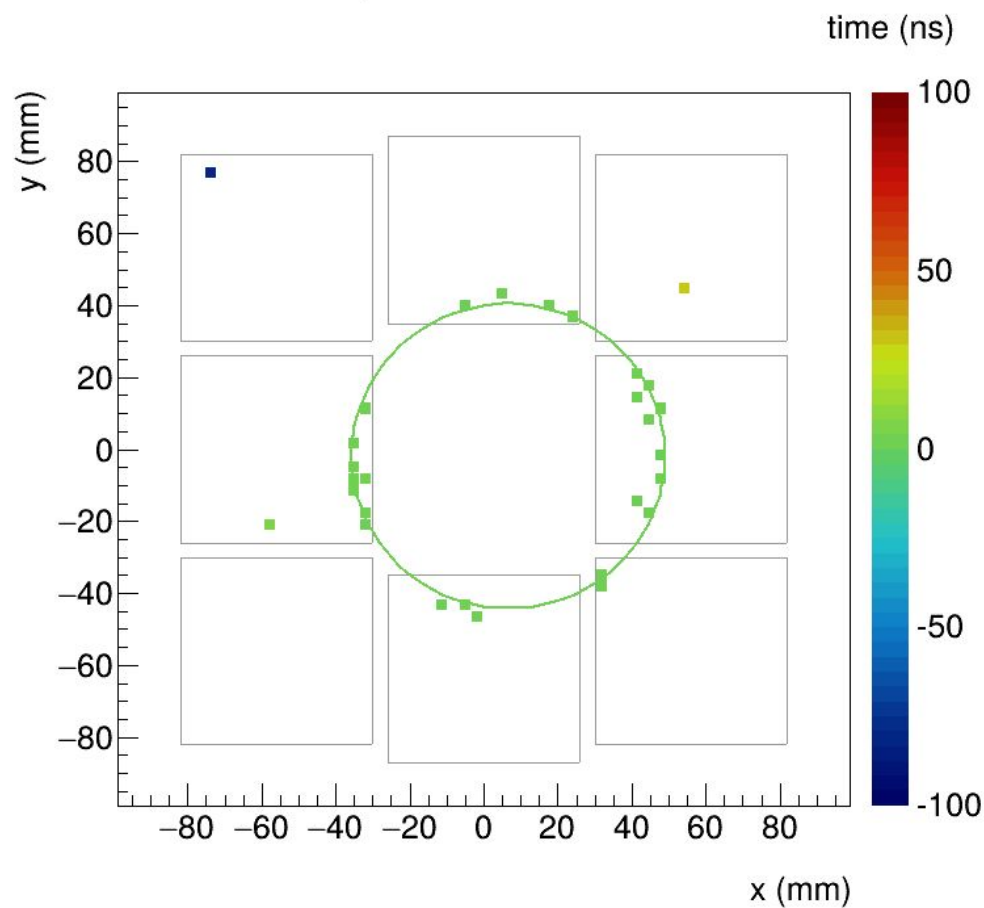
IRT reconstruction using fitted geometry parameters, forced $\eta = 3.2$

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$

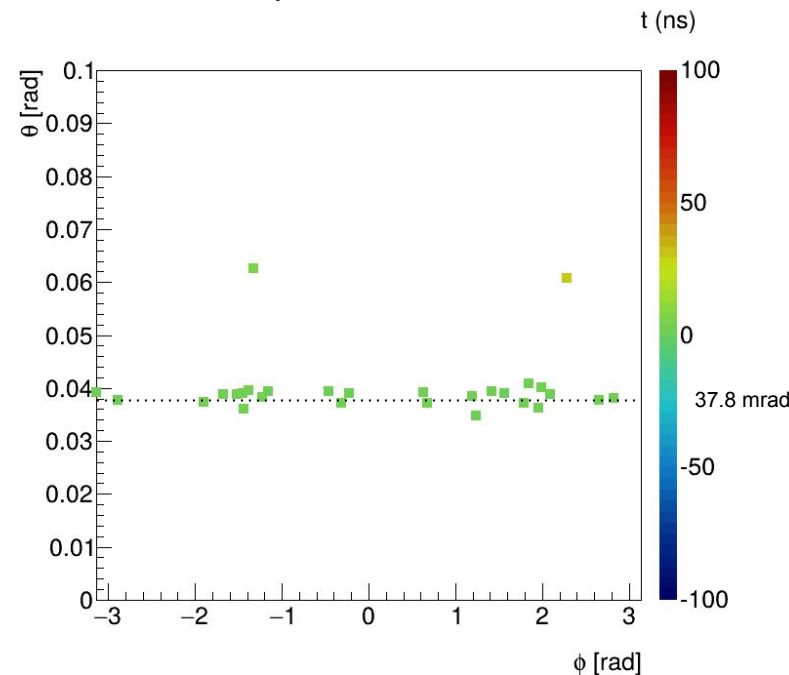


some event-display
images with IRT

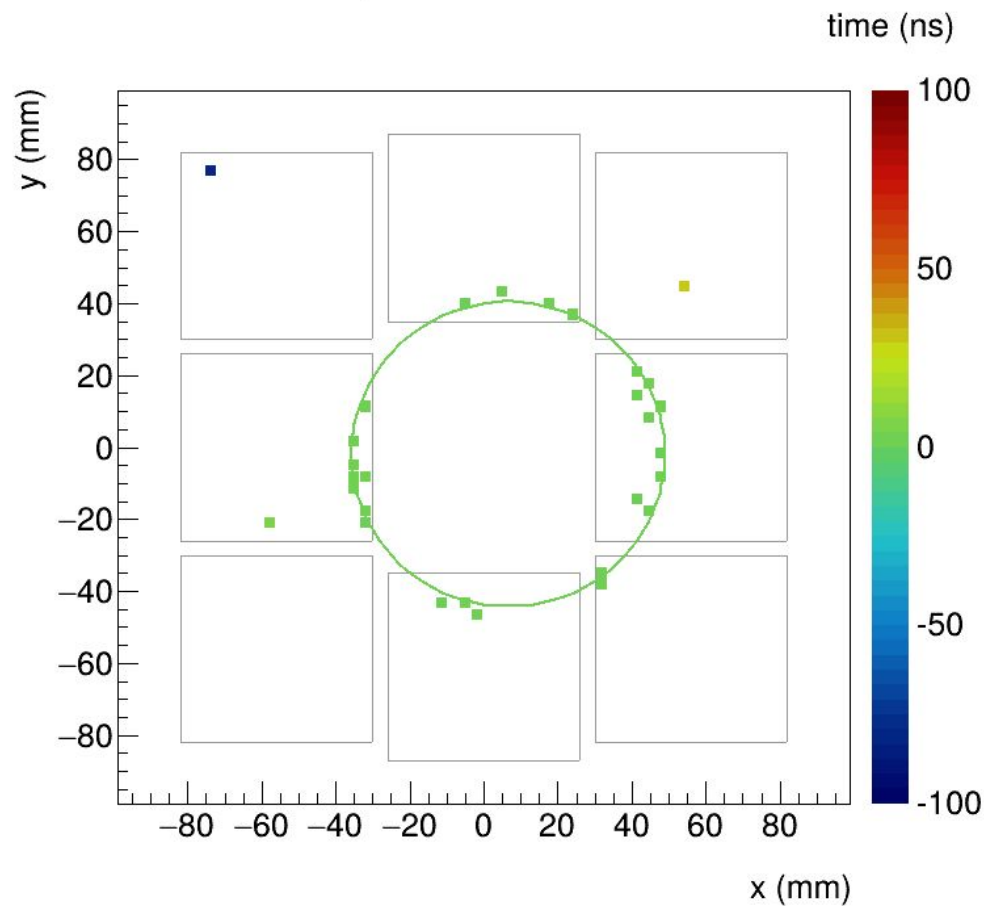
spill 0 frame 0



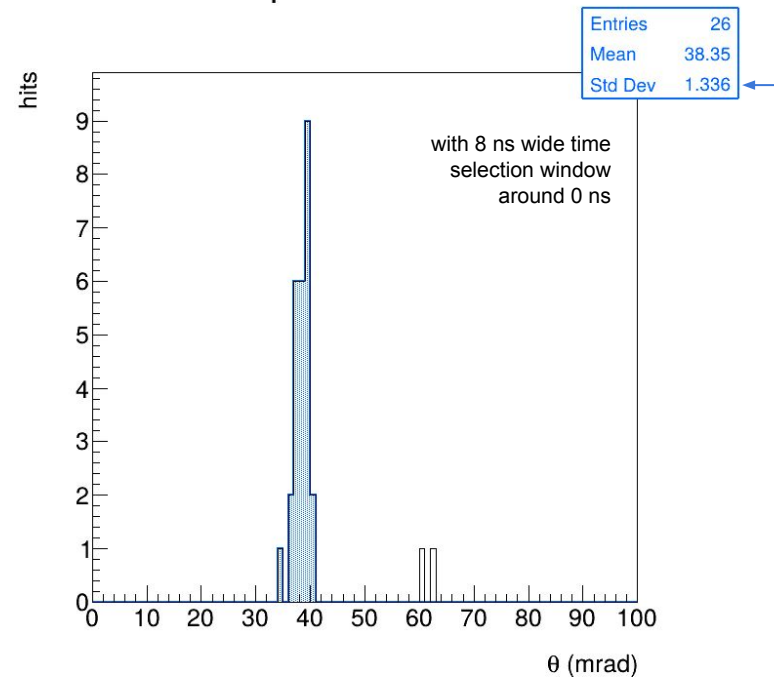
spill 0 frame 0



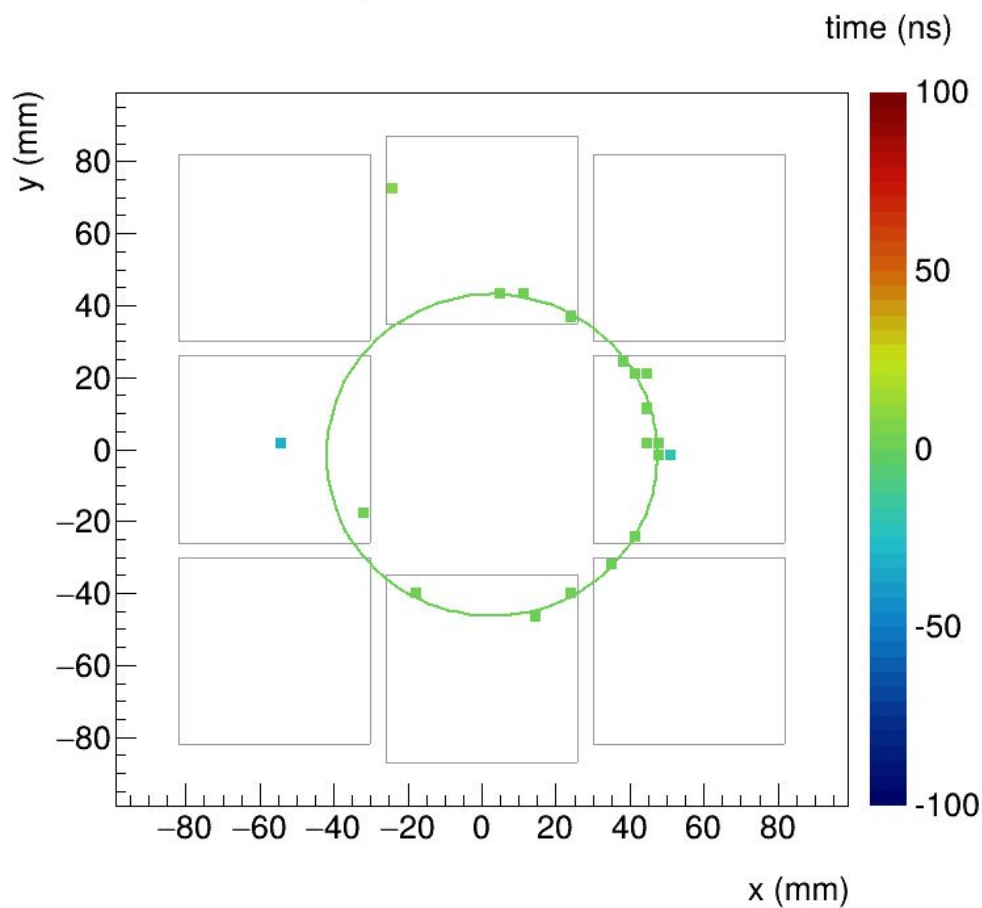
spill 0 frame 0



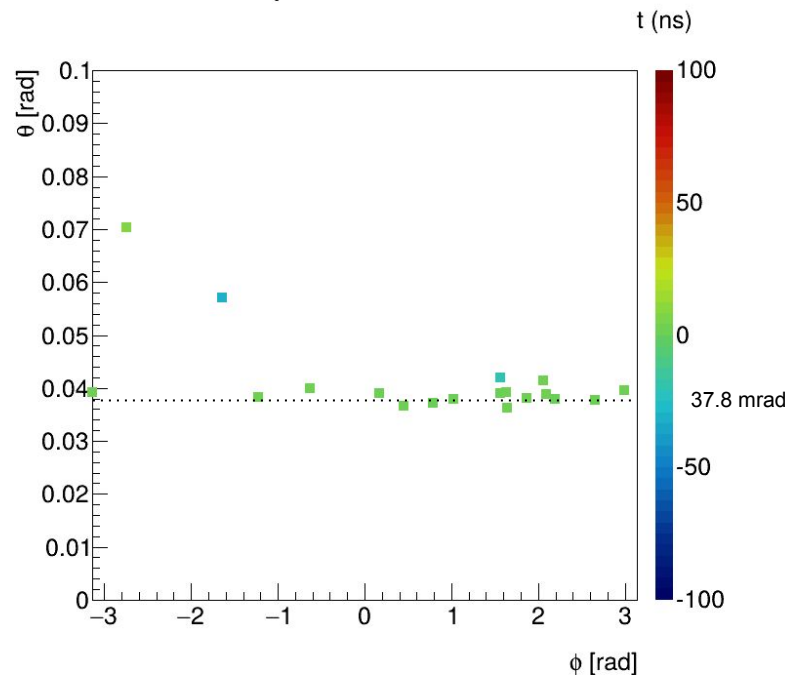
spill 0 frame 0



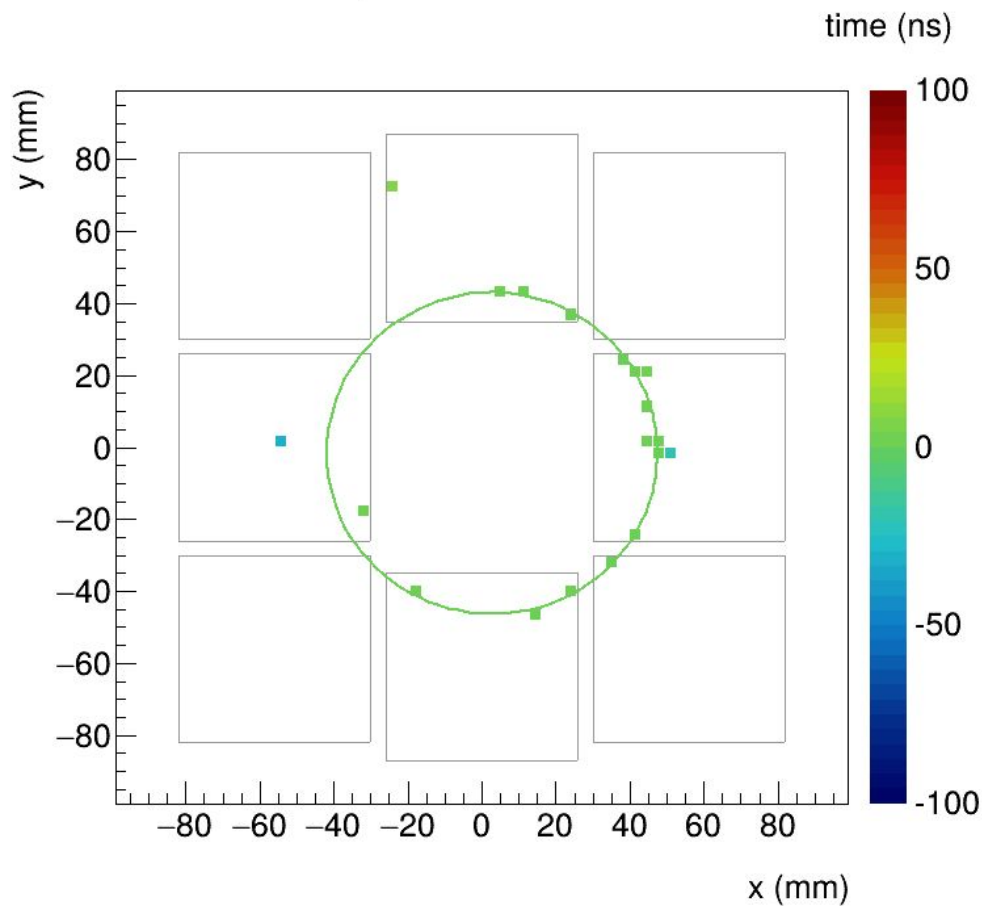
spill 0 frame 1



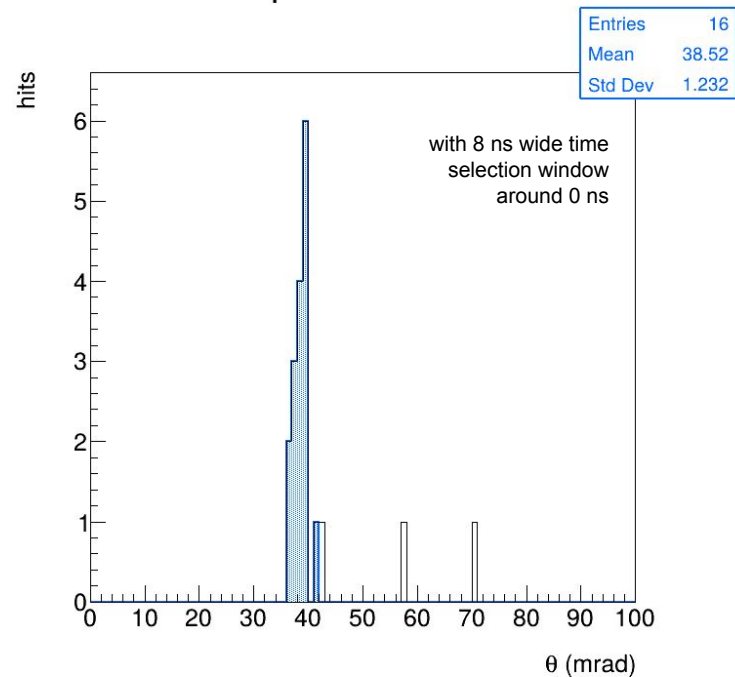
spill 0 frame 1



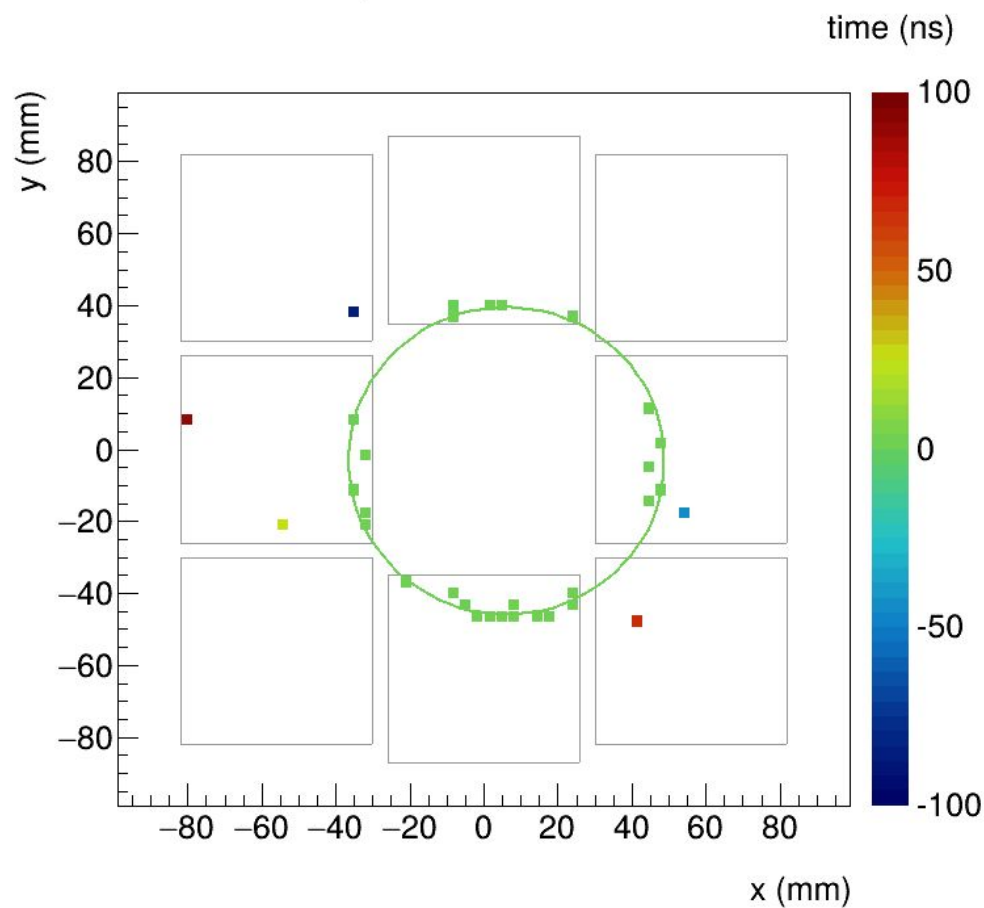
spill 0 frame 1



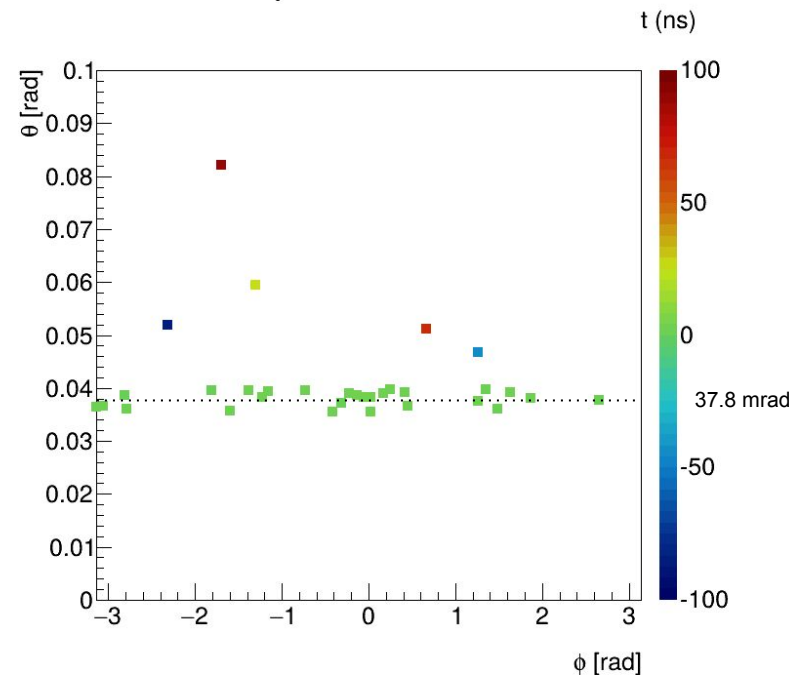
spill 0 frame 1



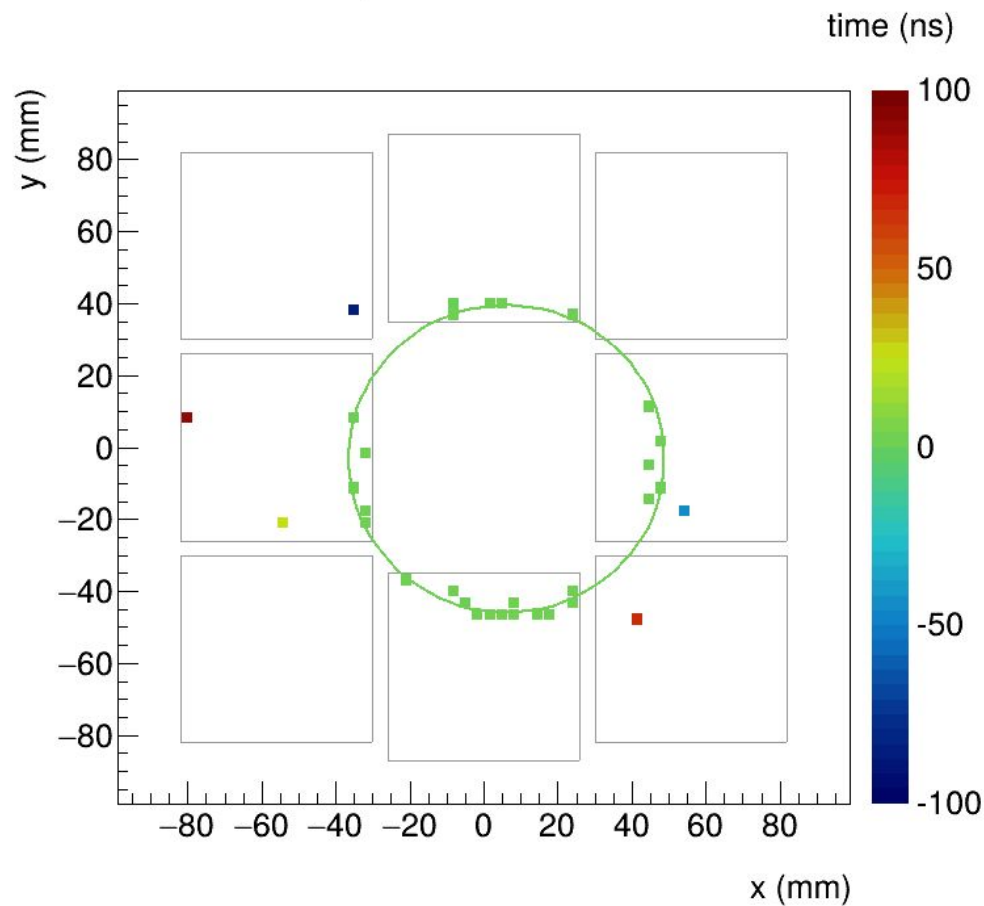
spill 0 frame 2



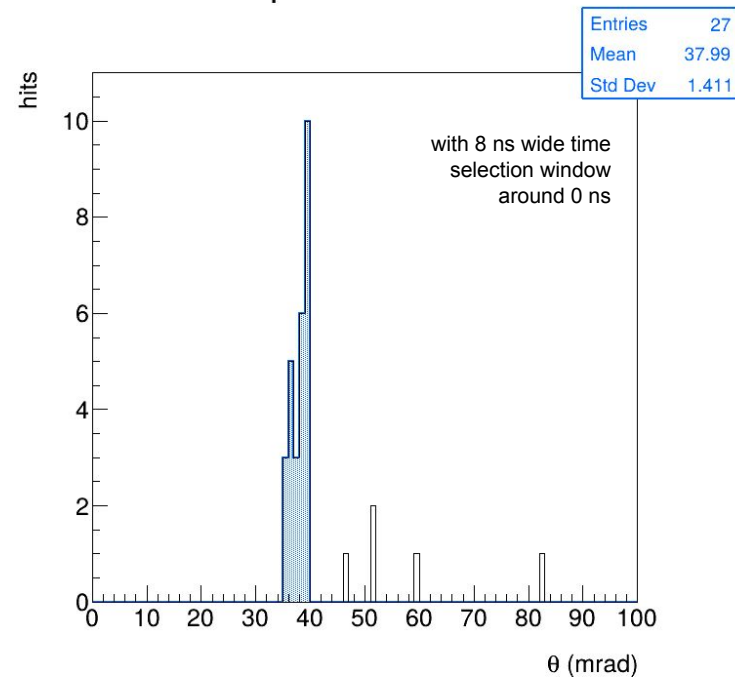
spill 0 frame 2



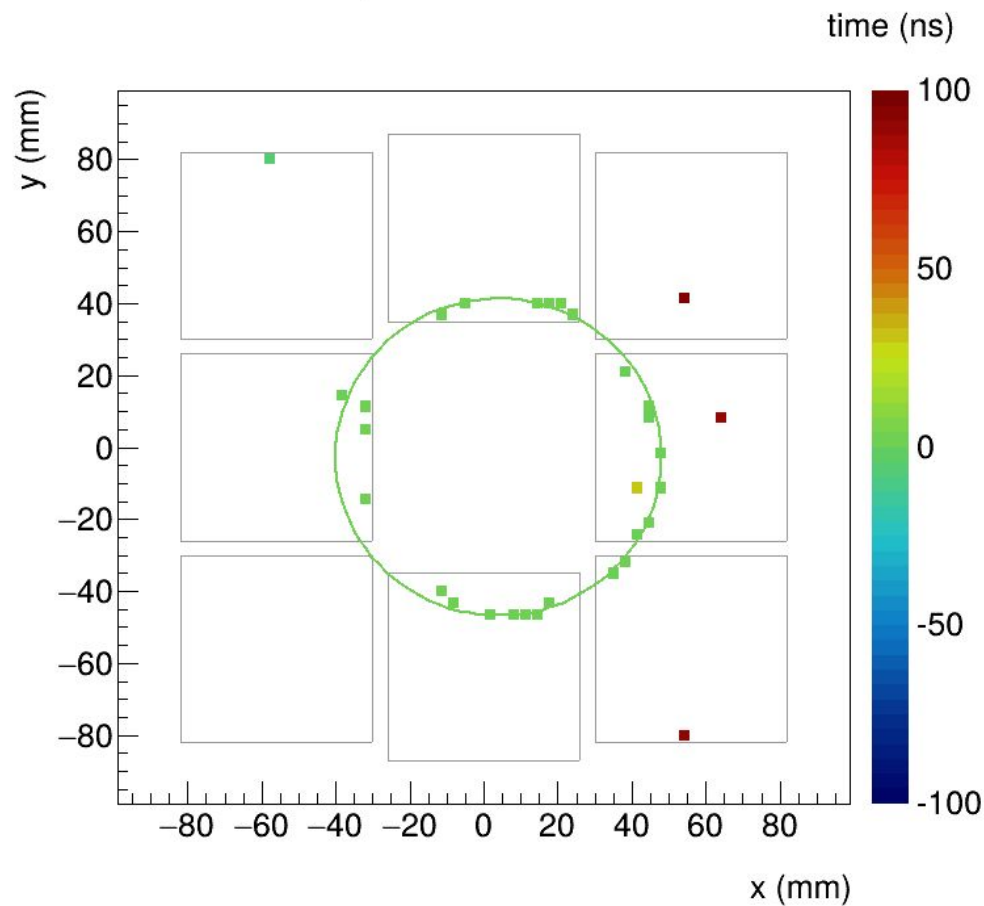
spill 0 frame 2



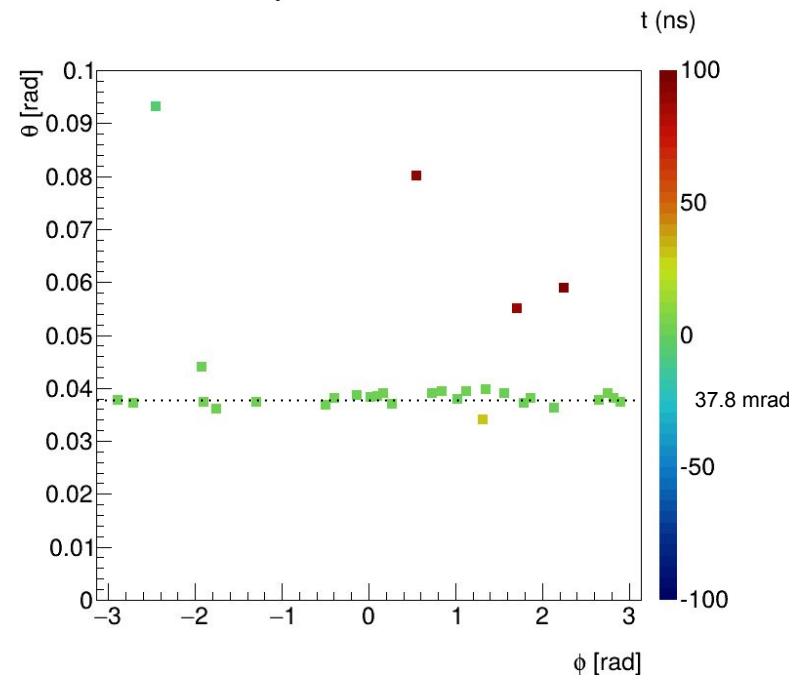
spill 0 frame 2



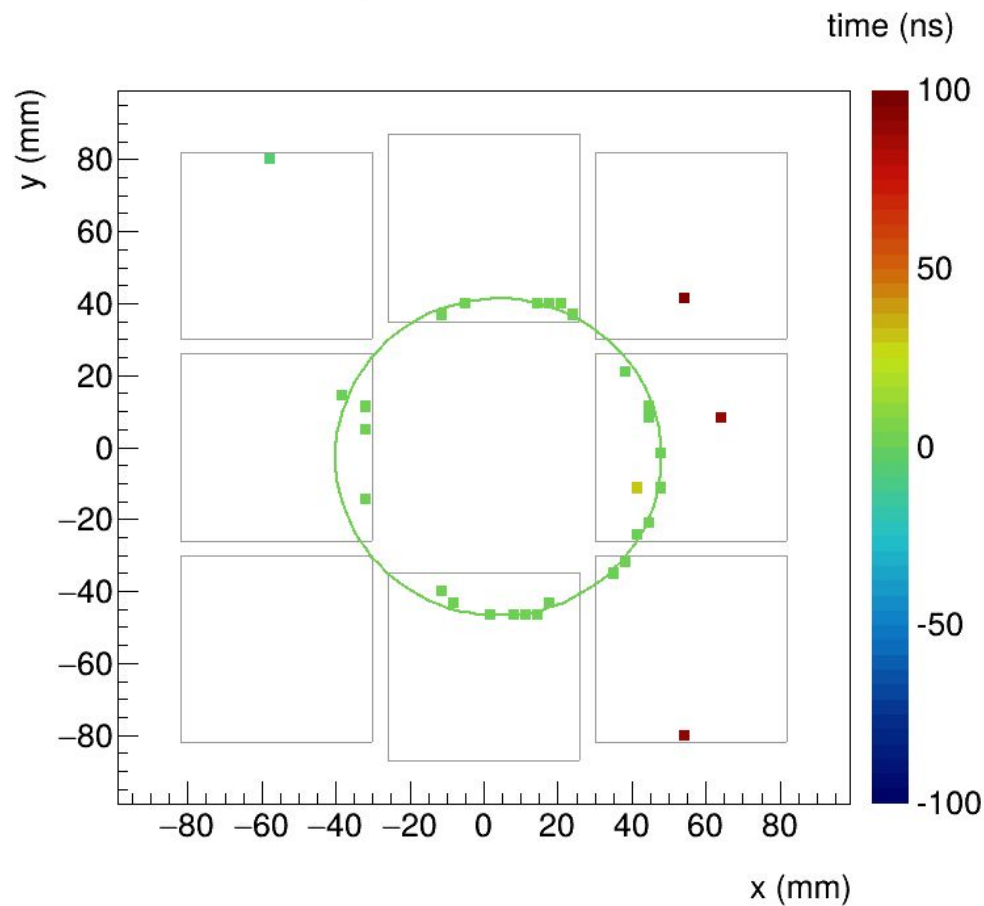
spill 0 frame 3



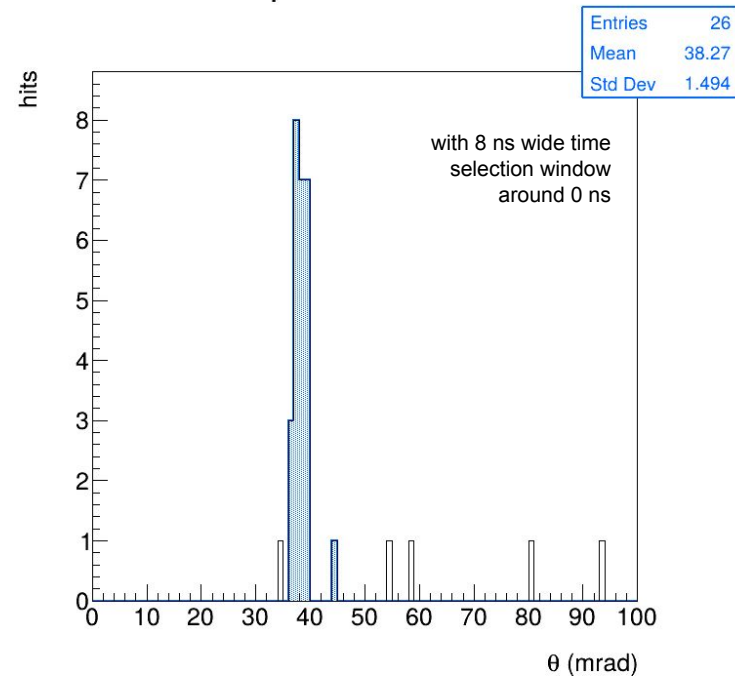
spill 0 frame 3



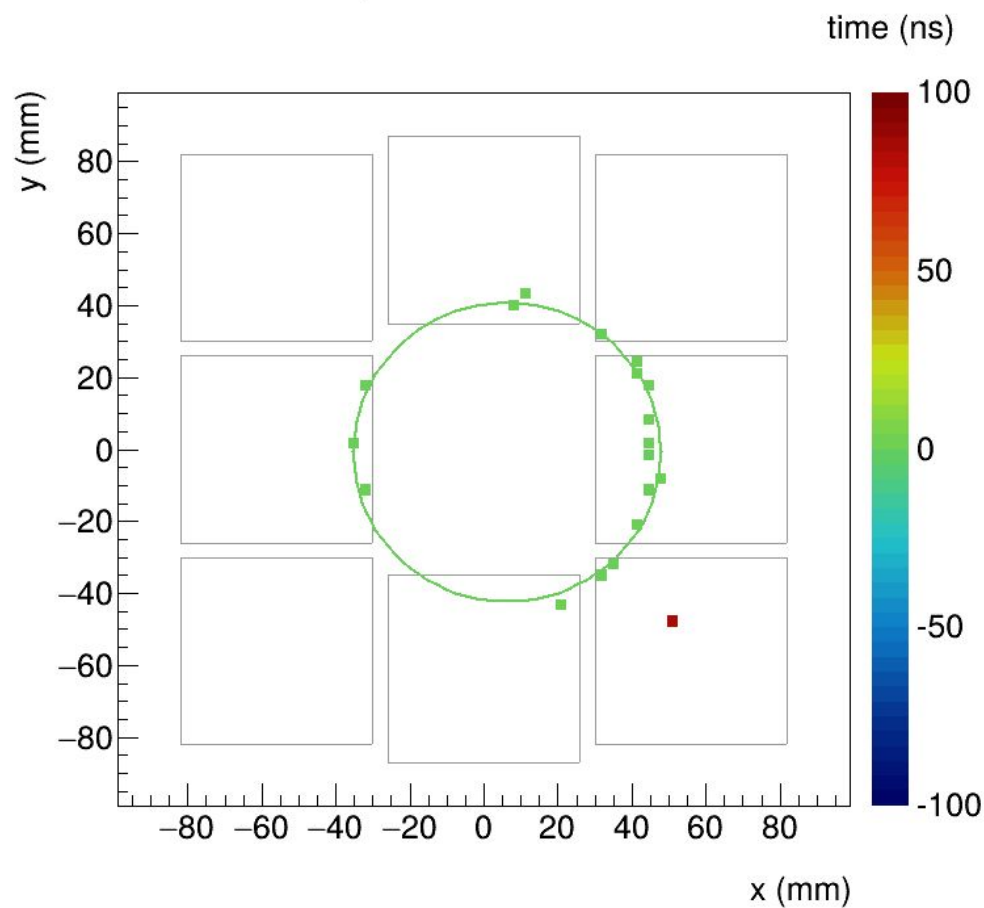
spill 0 frame 3



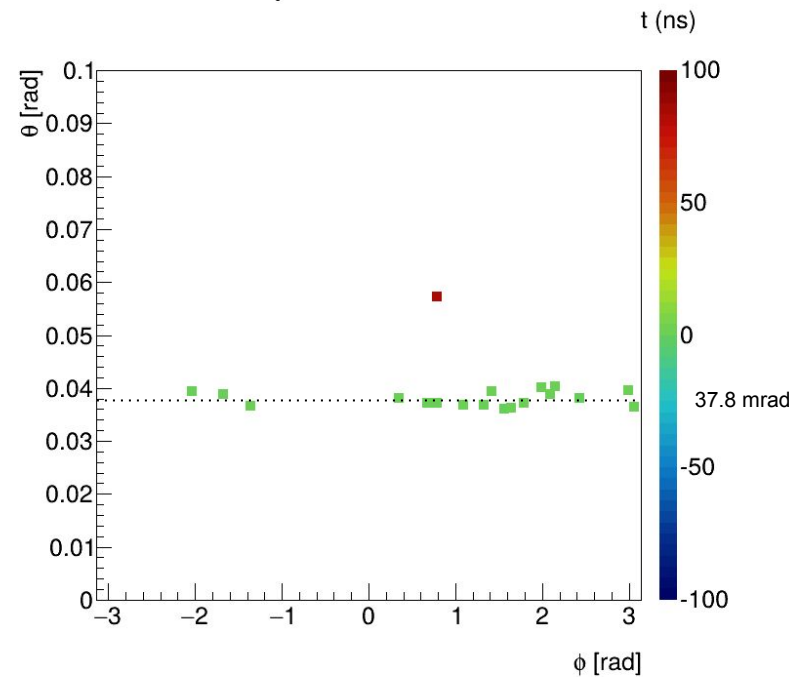
spill 0 frame 3



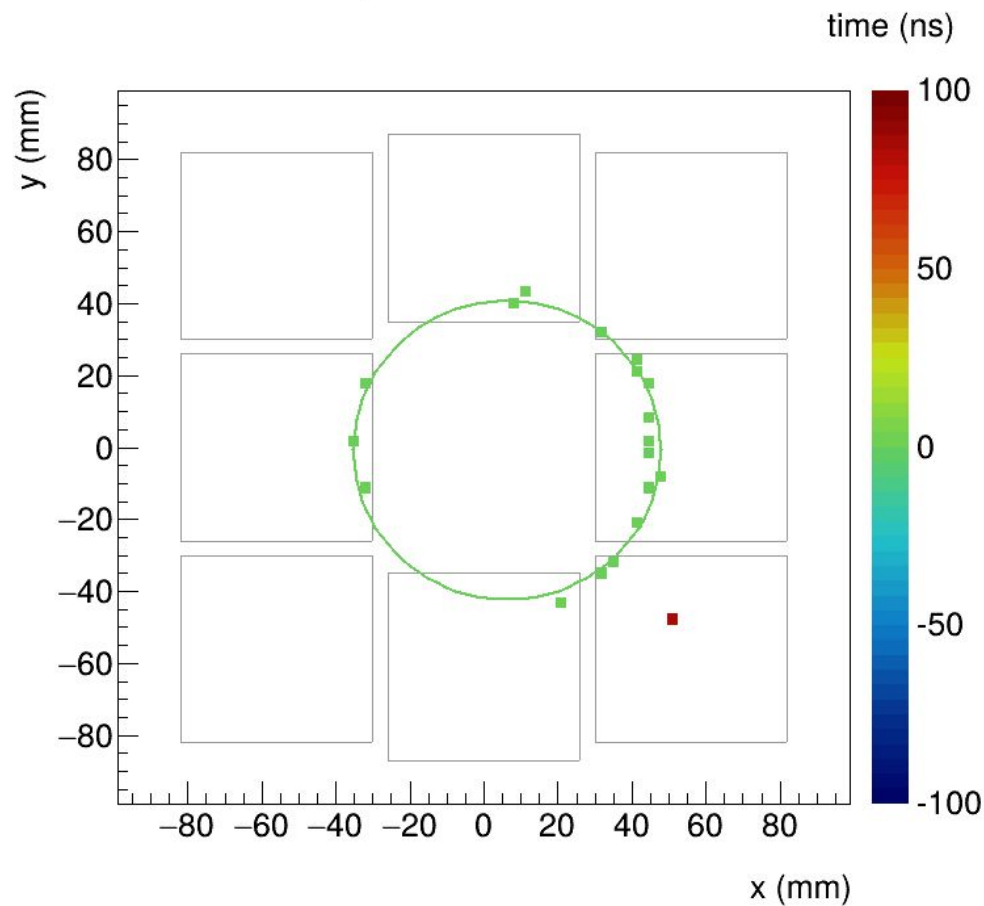
spill 0 frame 4



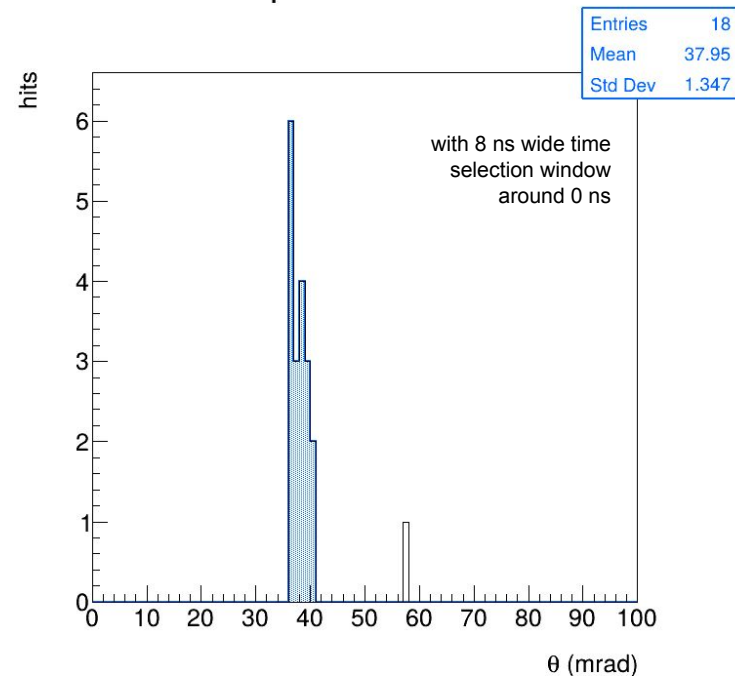
spill 0 frame 4



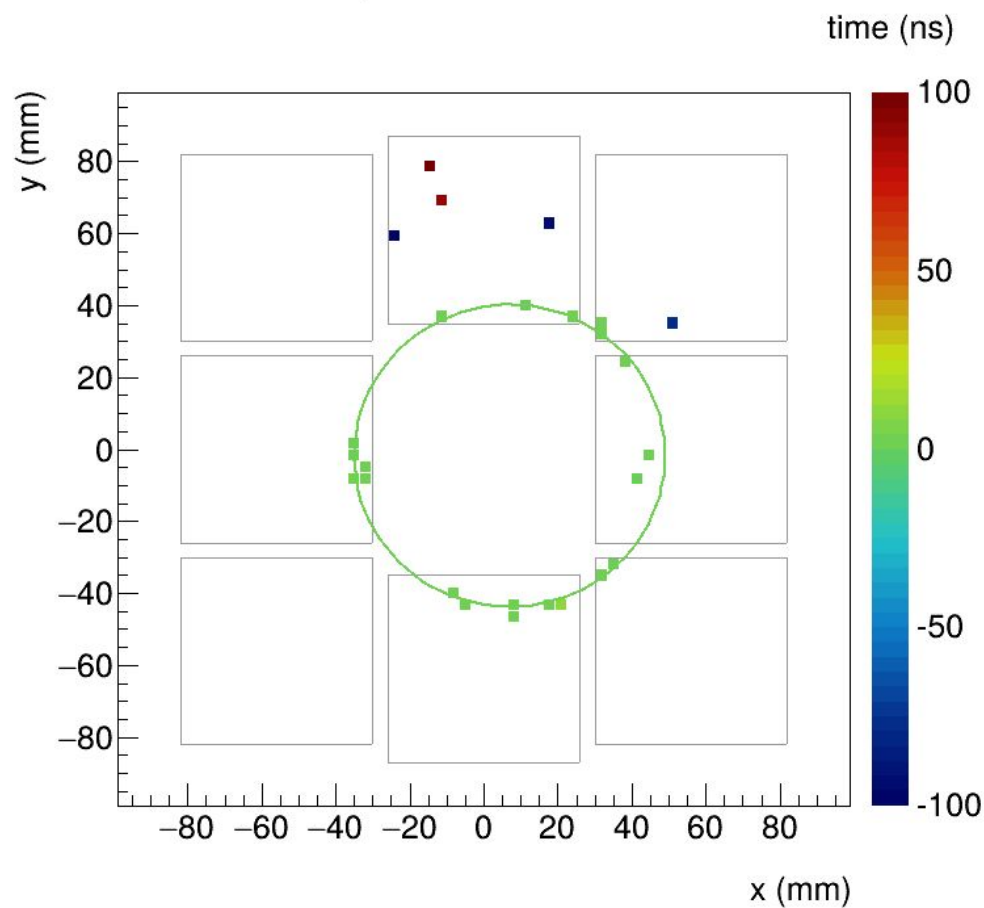
spill 0 frame 4



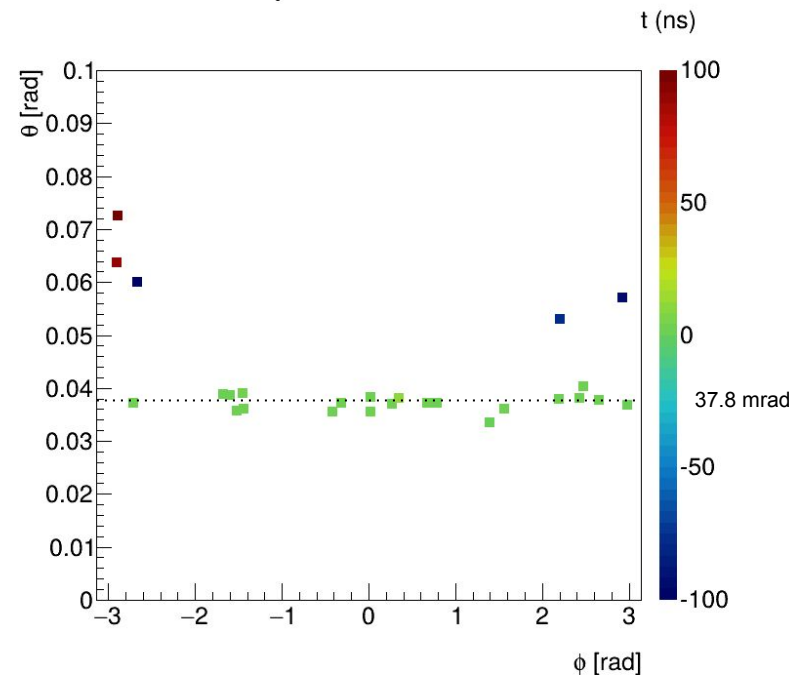
spill 0 frame 4



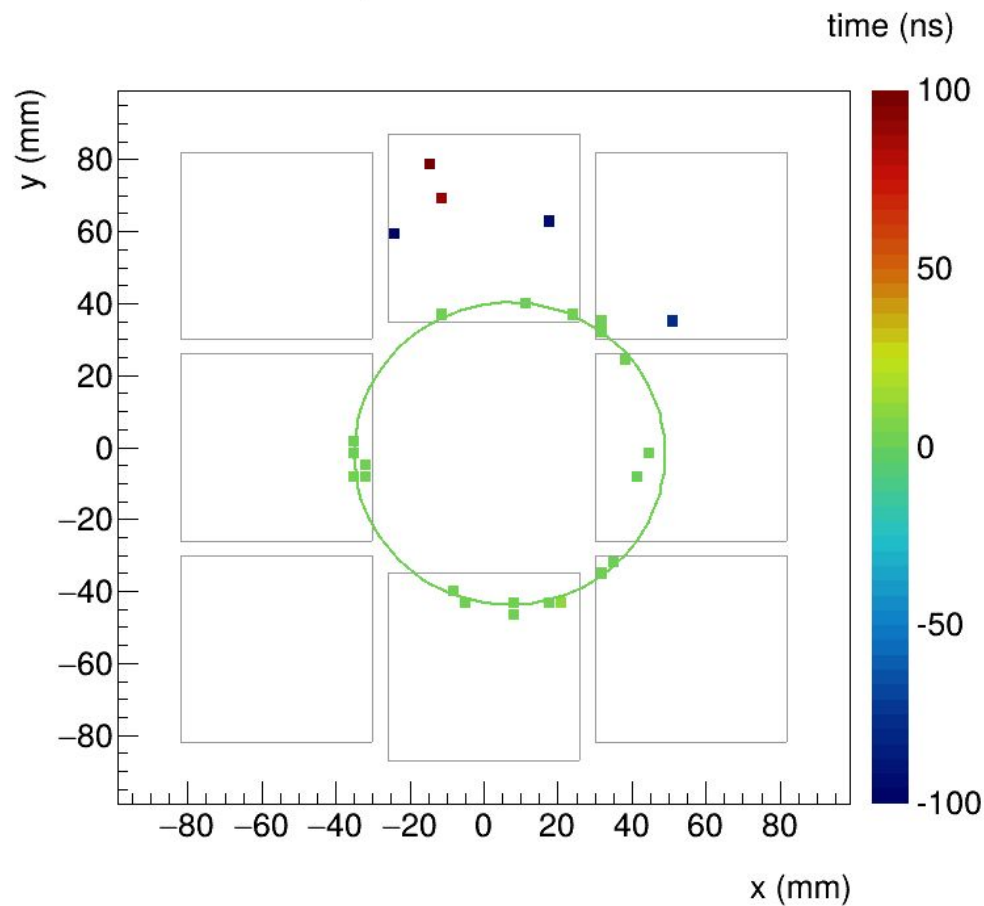
spill 0 frame 5



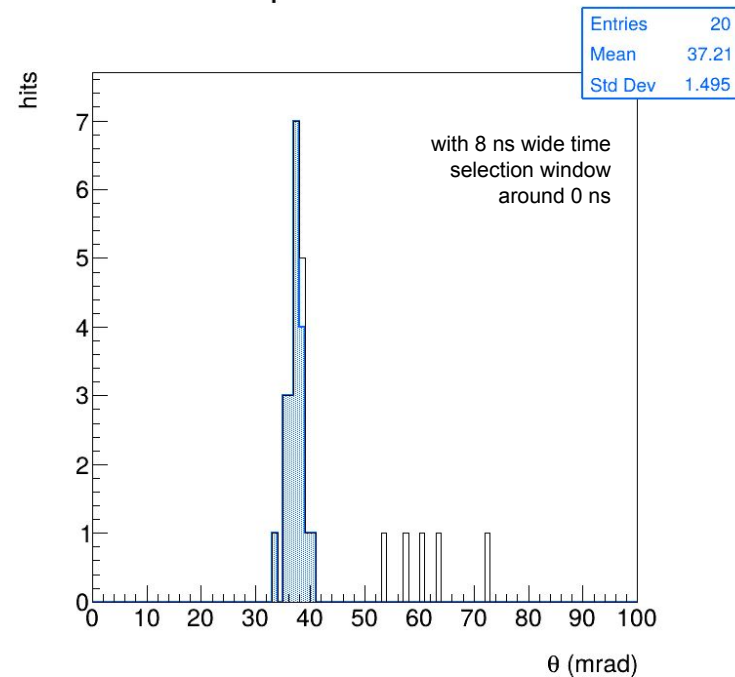
spill 0 frame 5



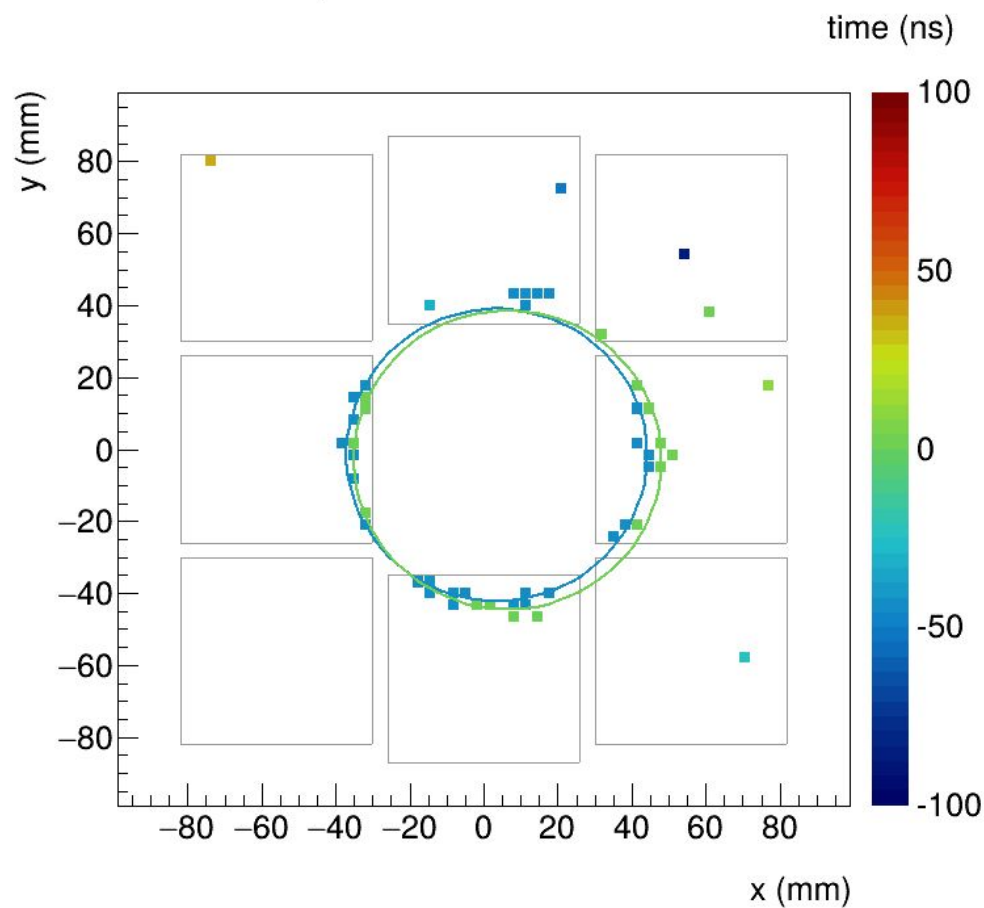
spill 0 frame 5



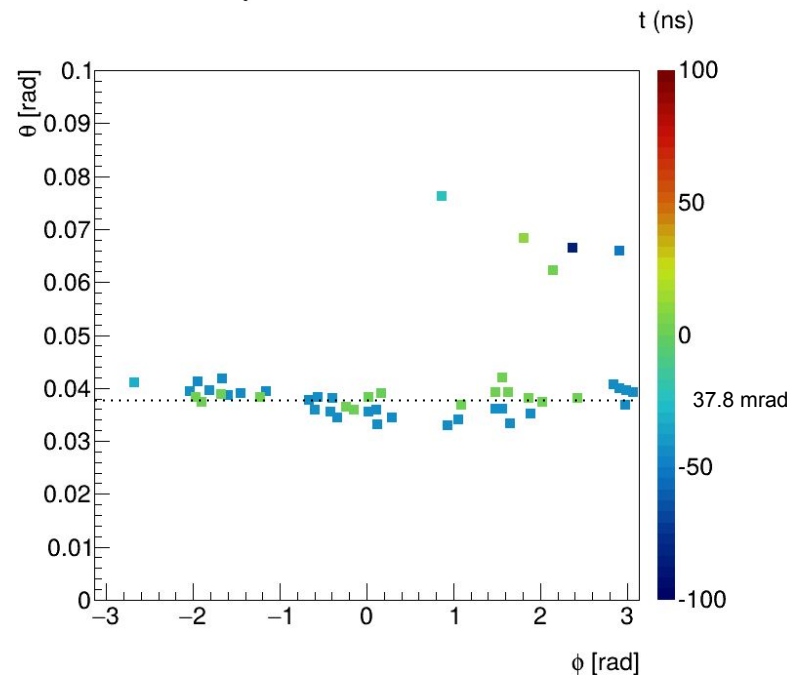
spill 0 frame 5



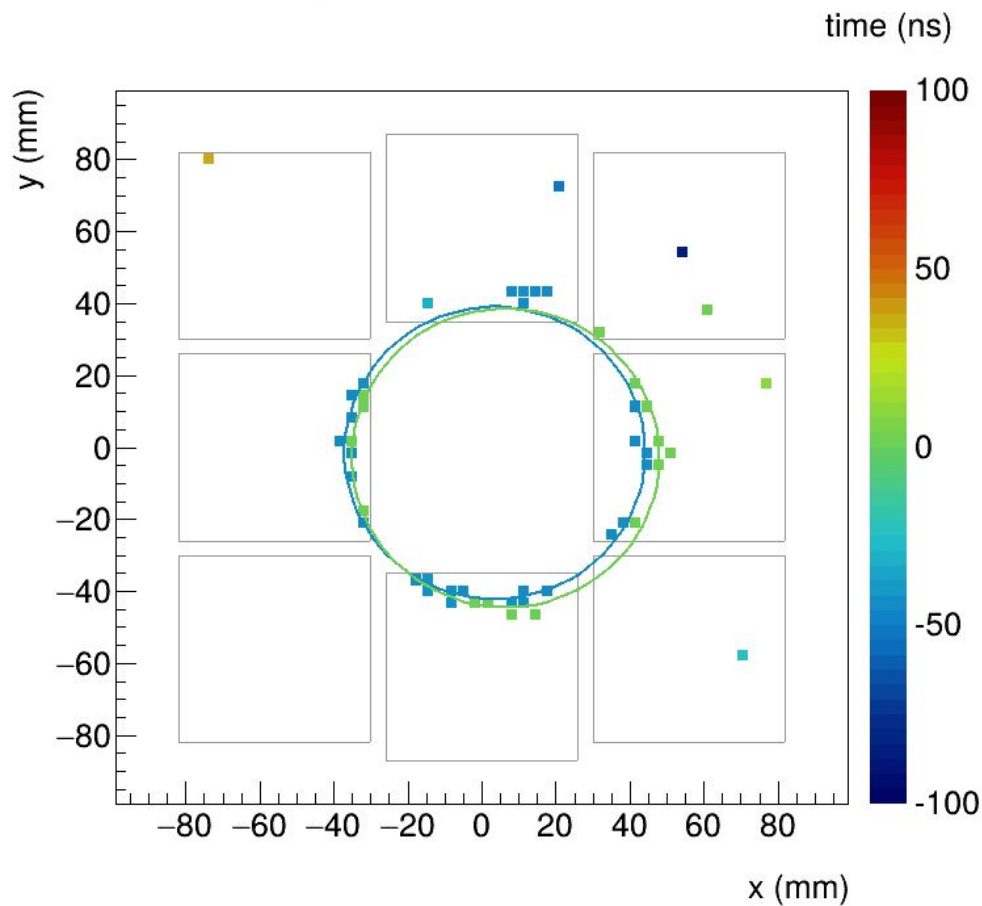
spill 0 frame 1065



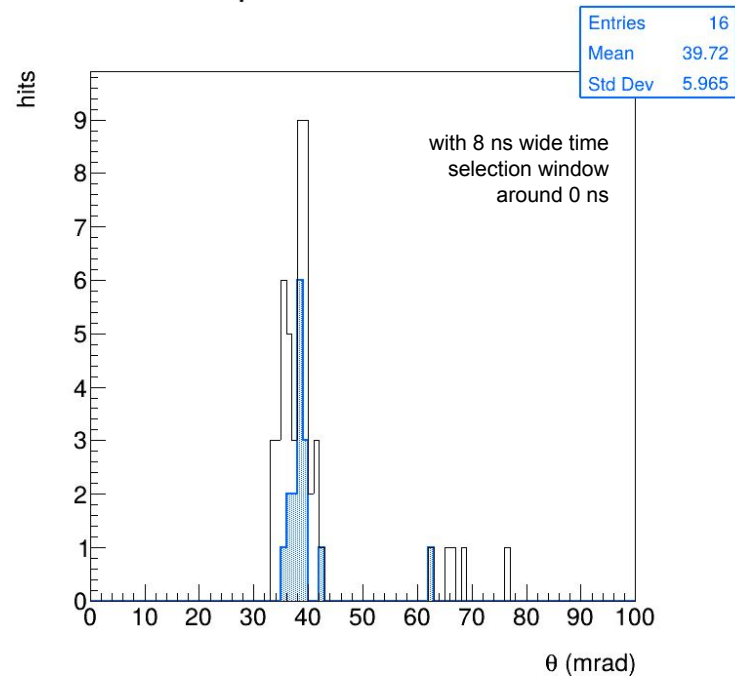
spill 0 frame 1065



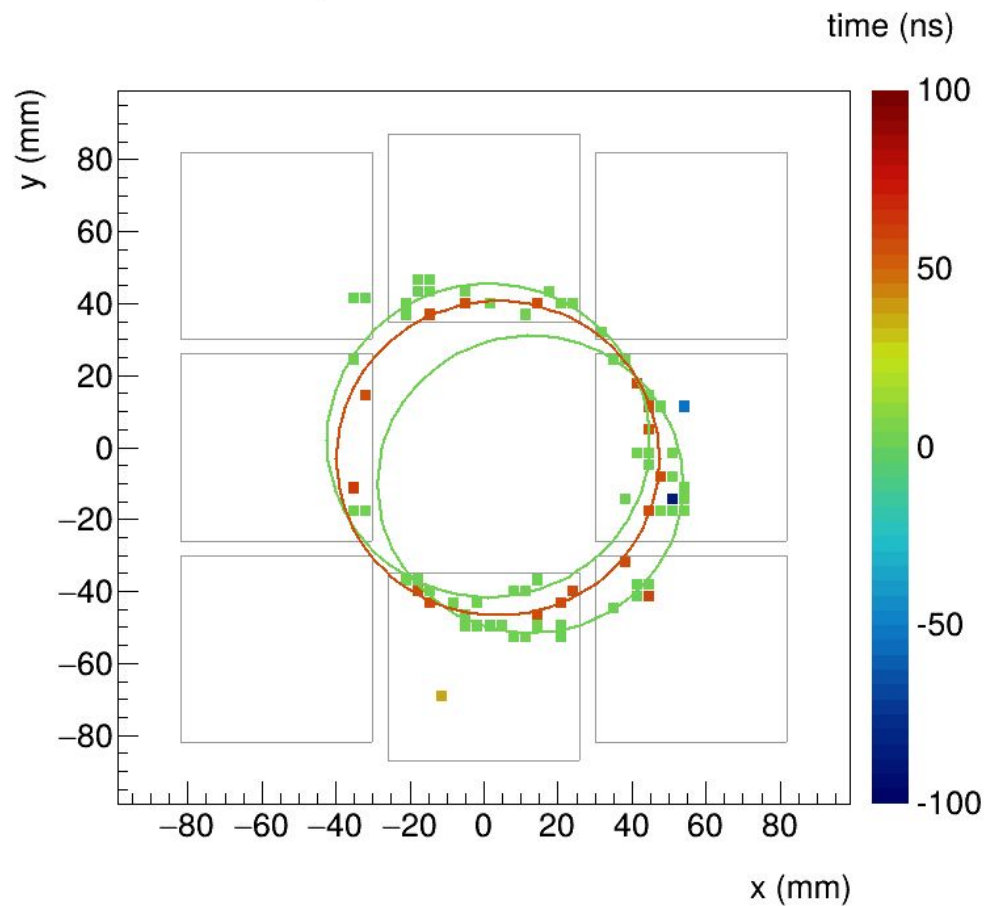
spill 0 frame 1065



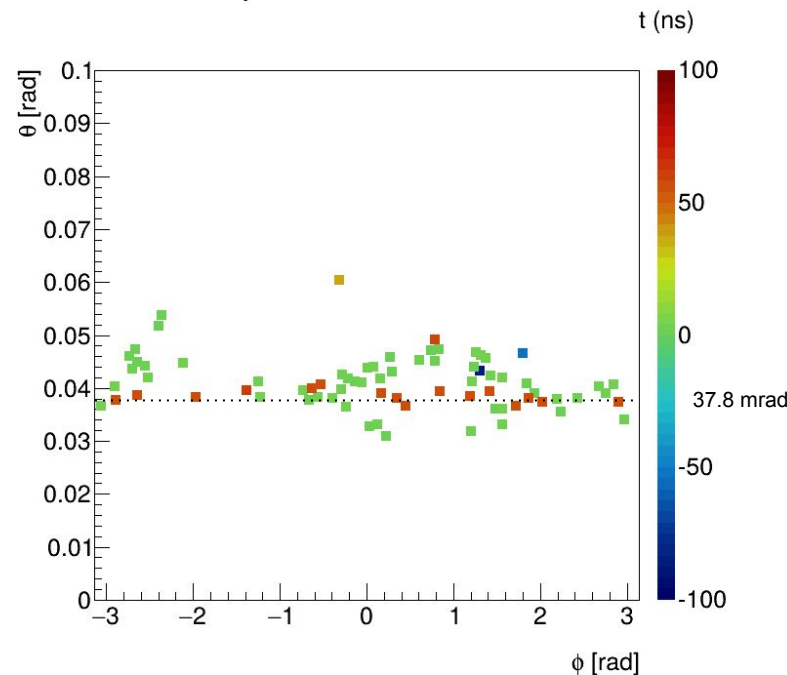
spill 0 frame 1065



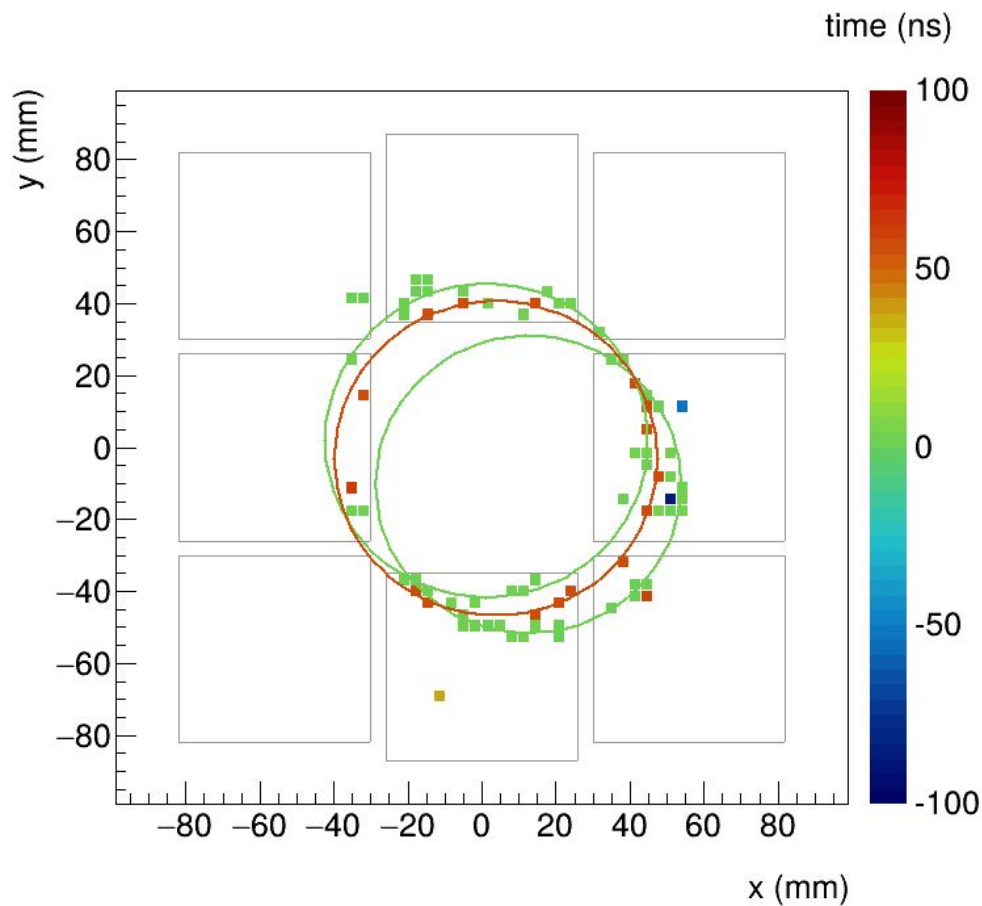
spill 0 frame 2215



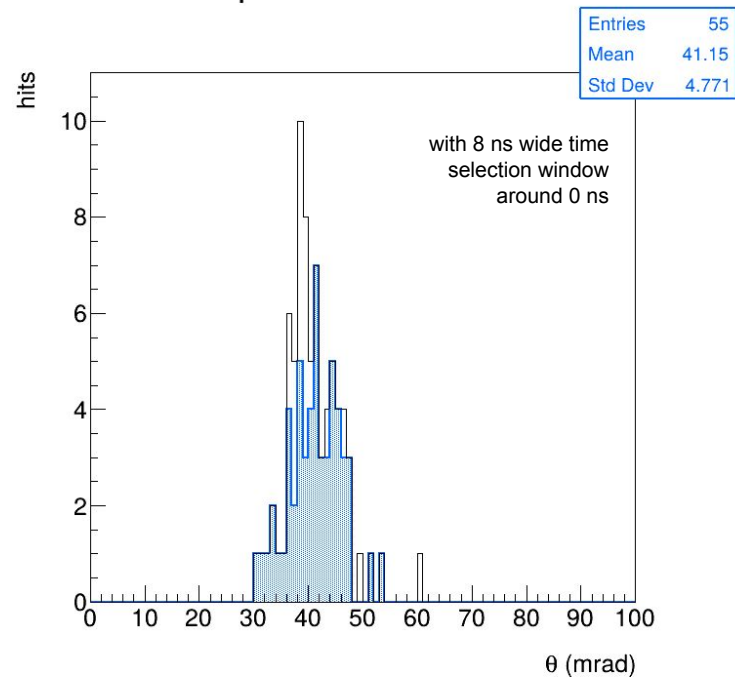
spill 0 frame 2215



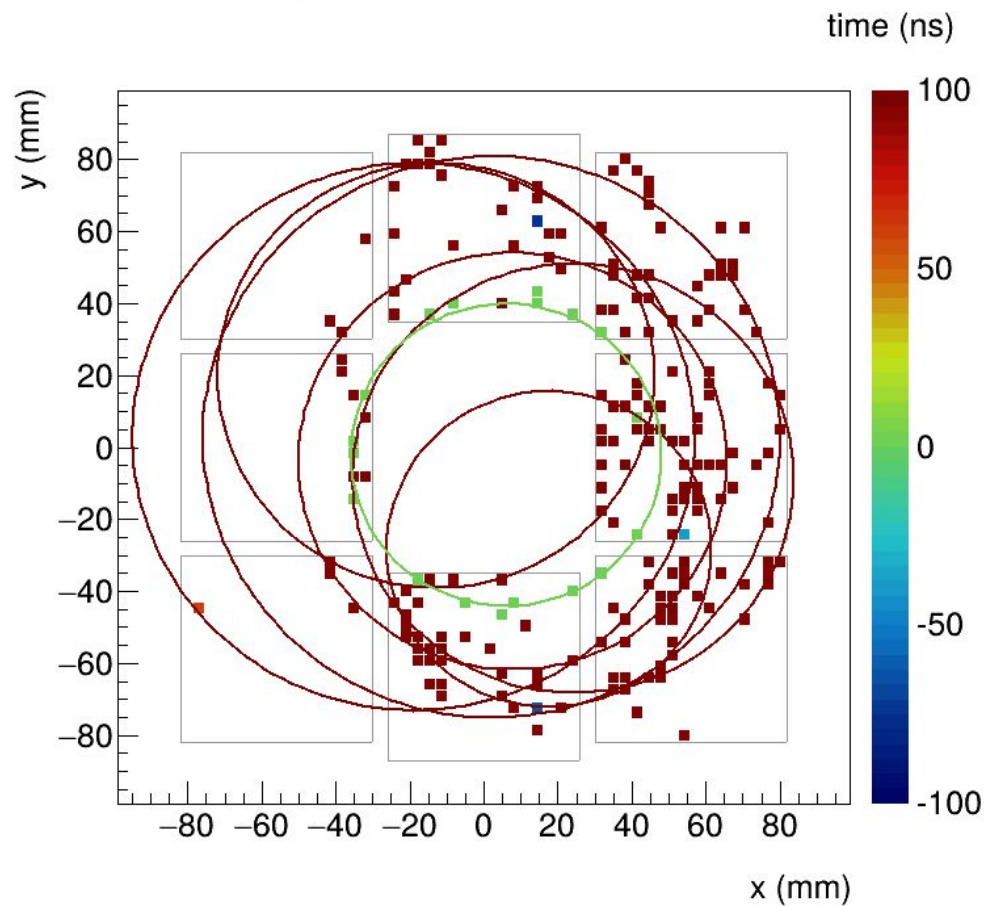
spill 0 frame 2215



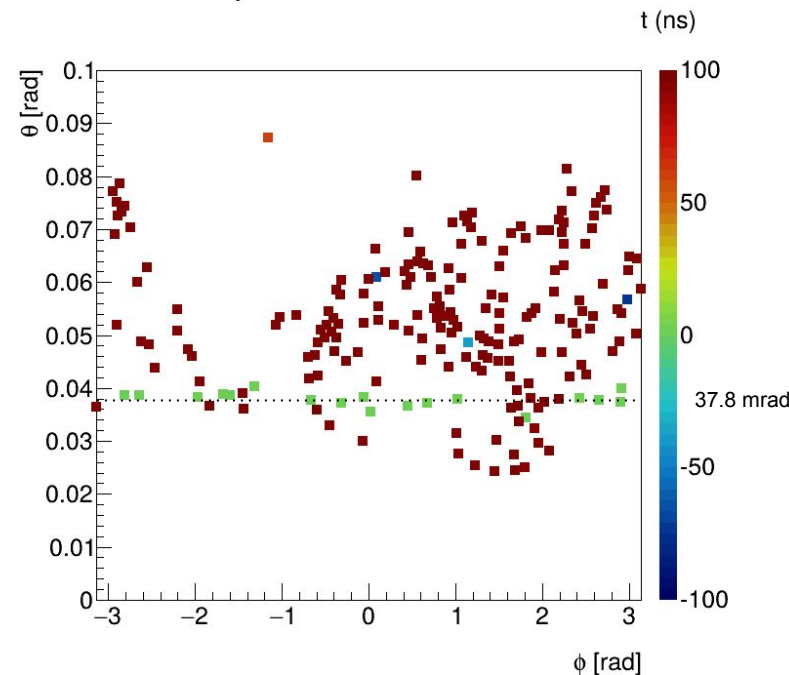
spill 0 frame 2215



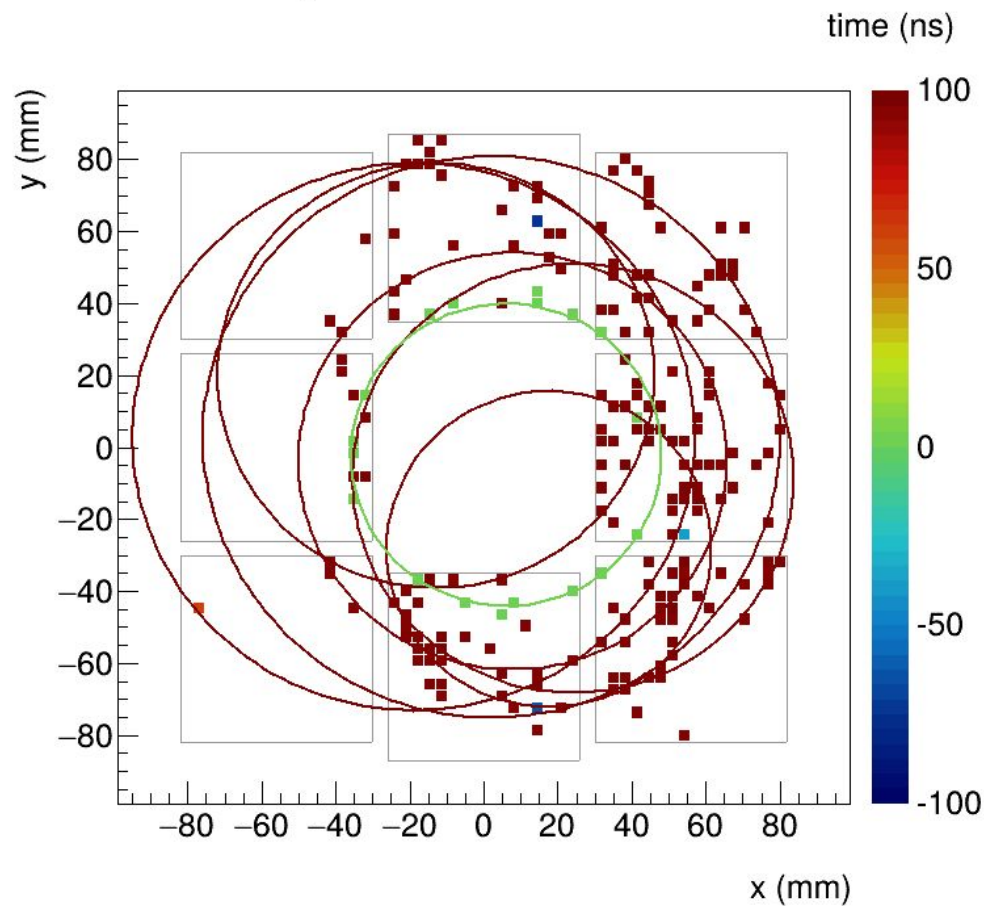
spill 0 frame 21960



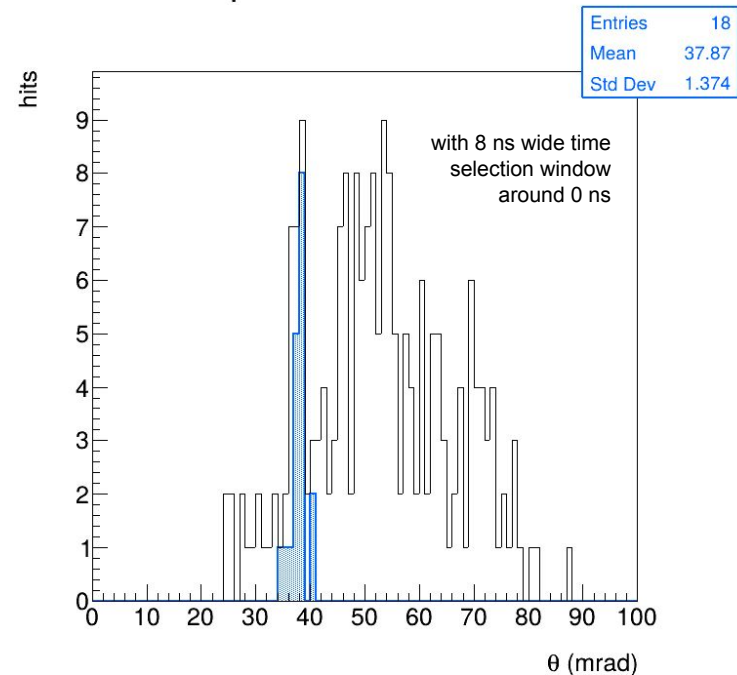
spill 0 frame 21960



spill 0 frame 21960

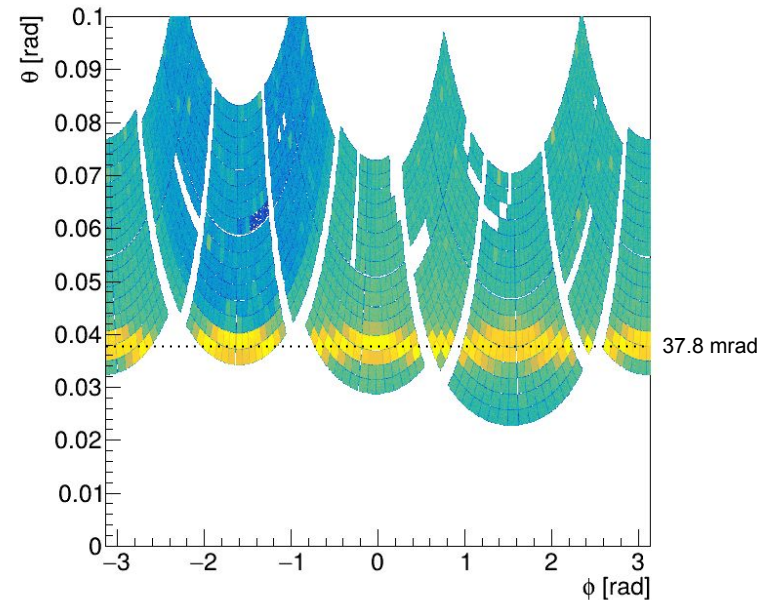
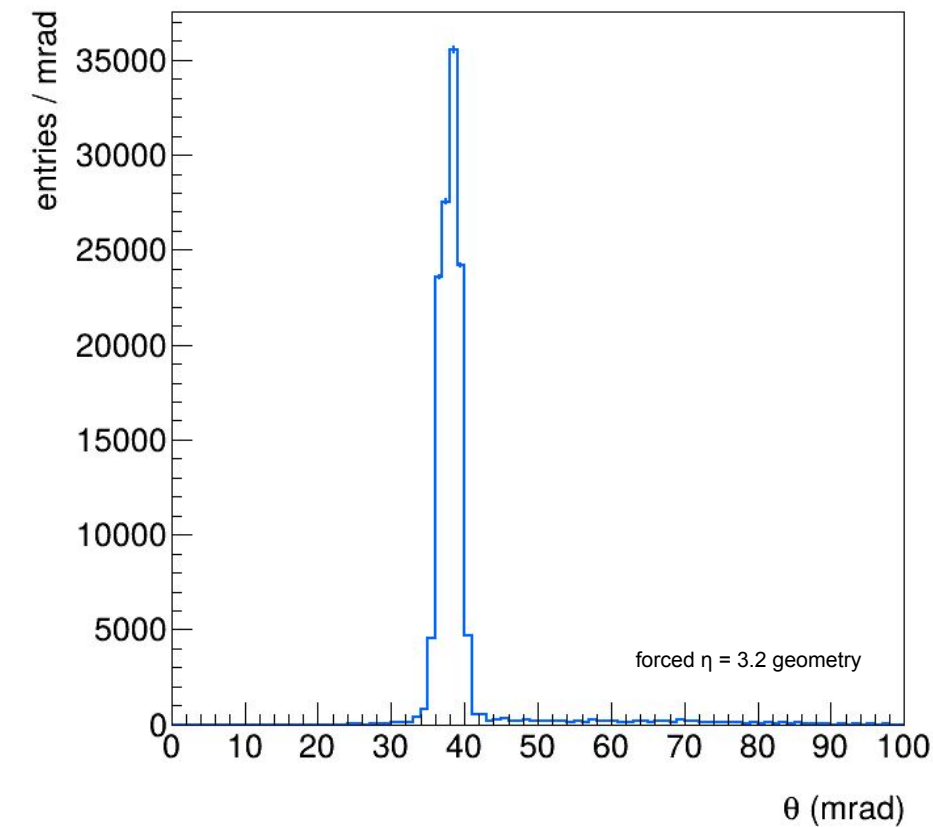


spill 0 frame 21960



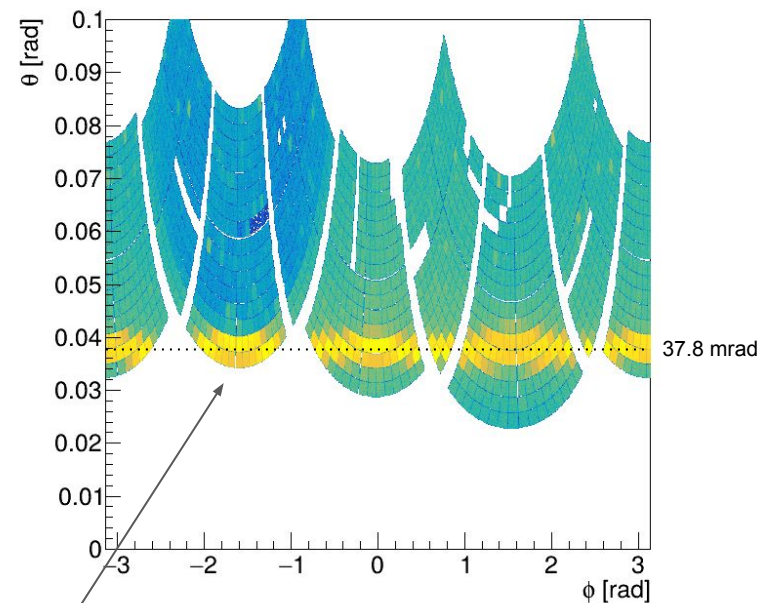
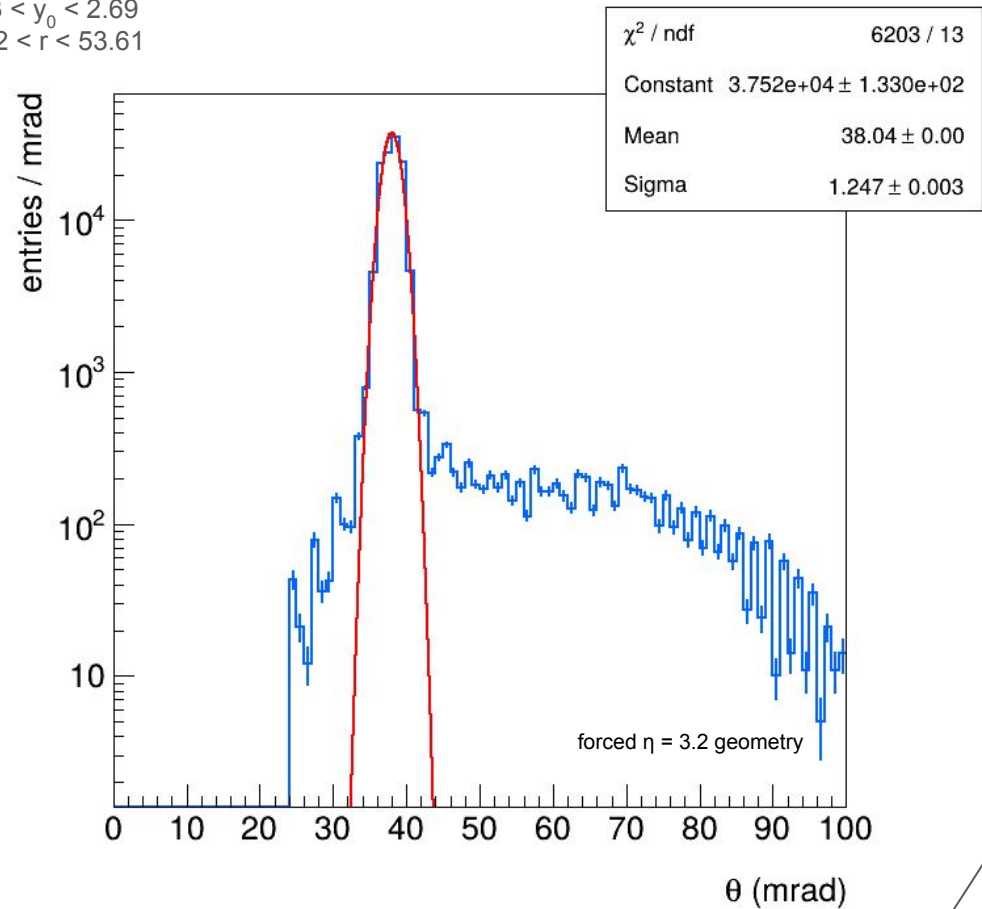
IRT-reconstructed
photon angles

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



distribution of the IRT reconstructed single-photon cherenkov angle of all hits (within expected timing) in selected one-ring events

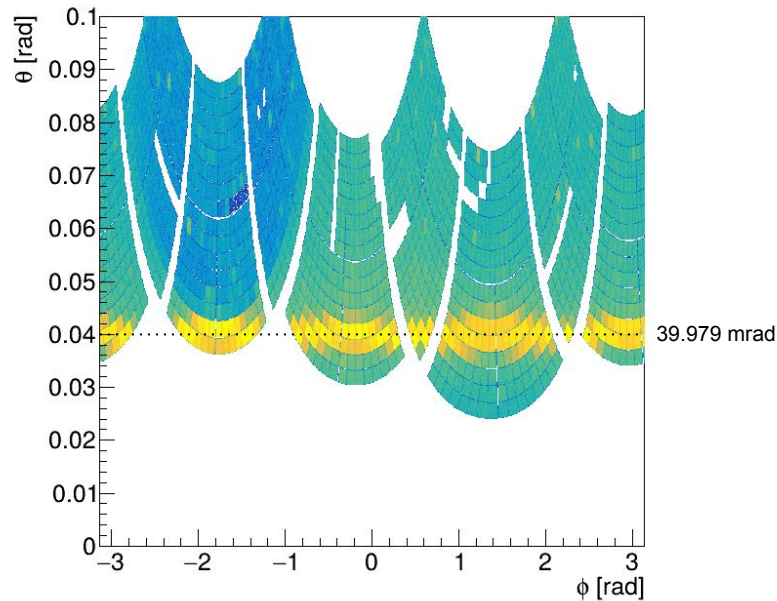
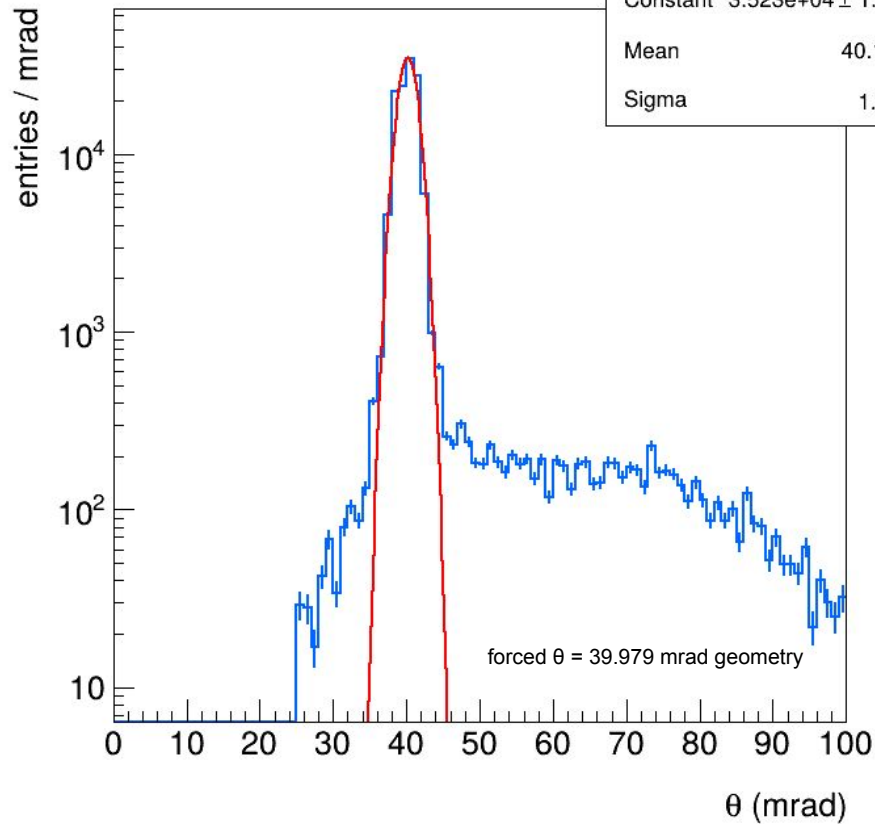
events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



gaussian fit yields single-photon $\sigma = 1.25$ mrad (but incomplete acceptance might bias it a bit)

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$

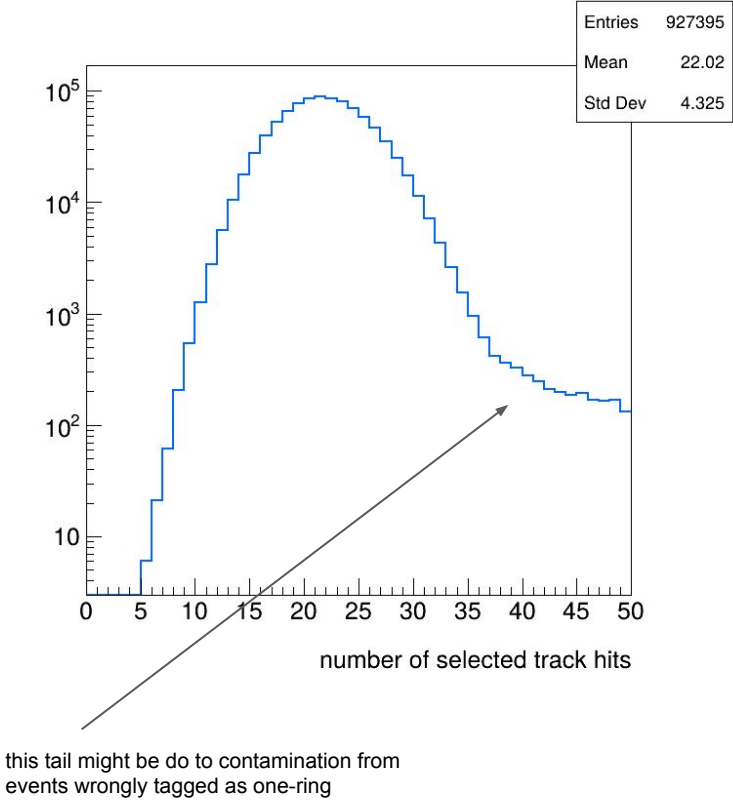
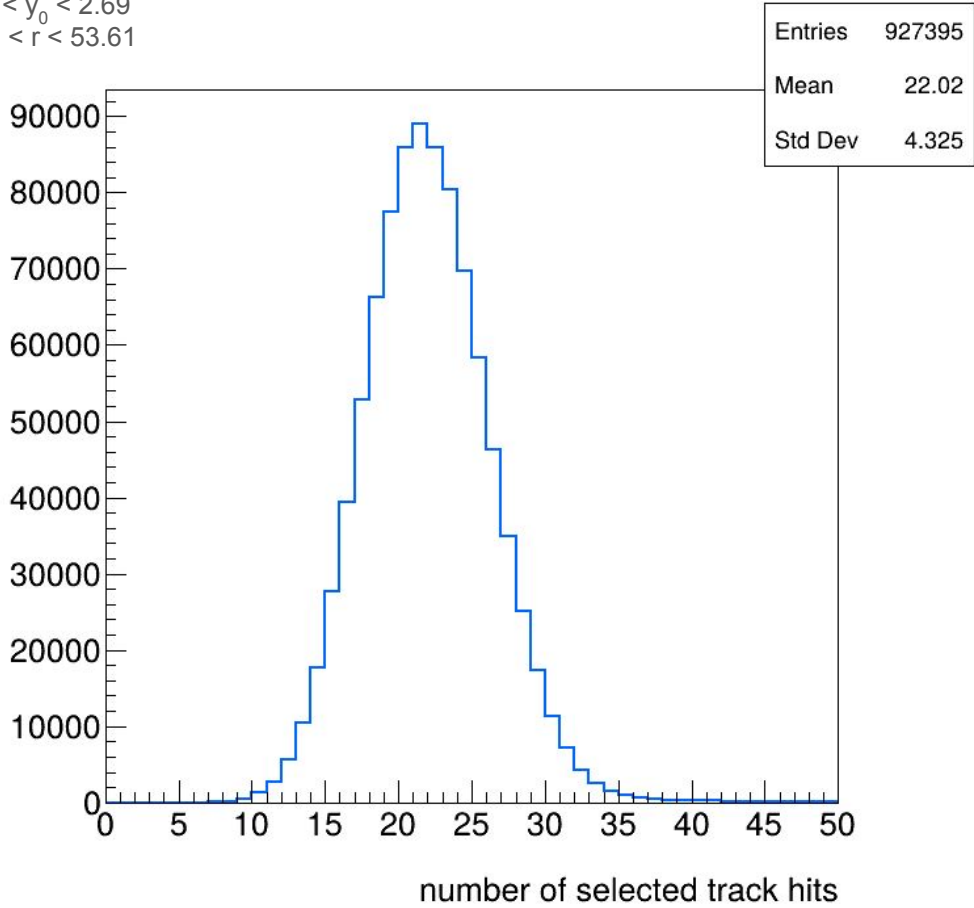
χ^2 / ndf	7640 / 13
Constant	$3.523\text{e}+04 \pm 1.267\text{e}+02$
Mean	40.15 ± 0.00
Sigma	1.31 ± 0.00



in the other geometry fit configuration gaussian fit yields single-photon $\sigma = 1.31$ mrad

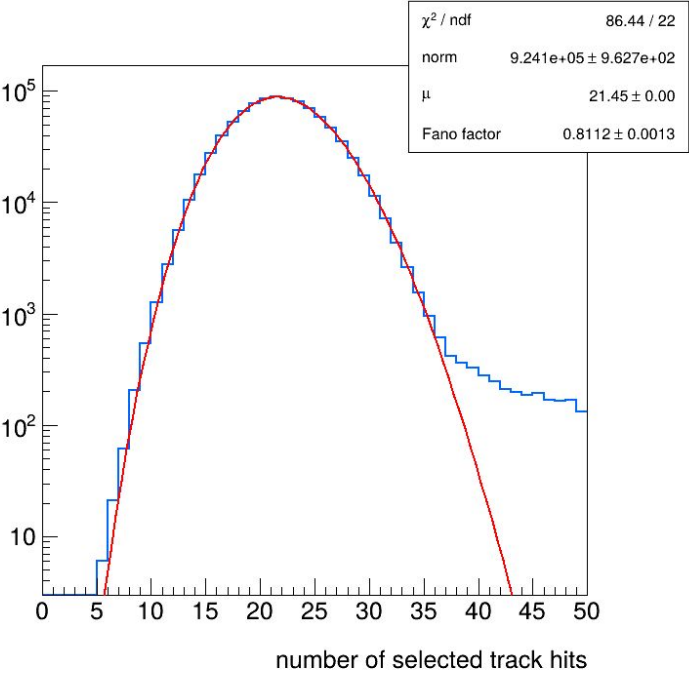
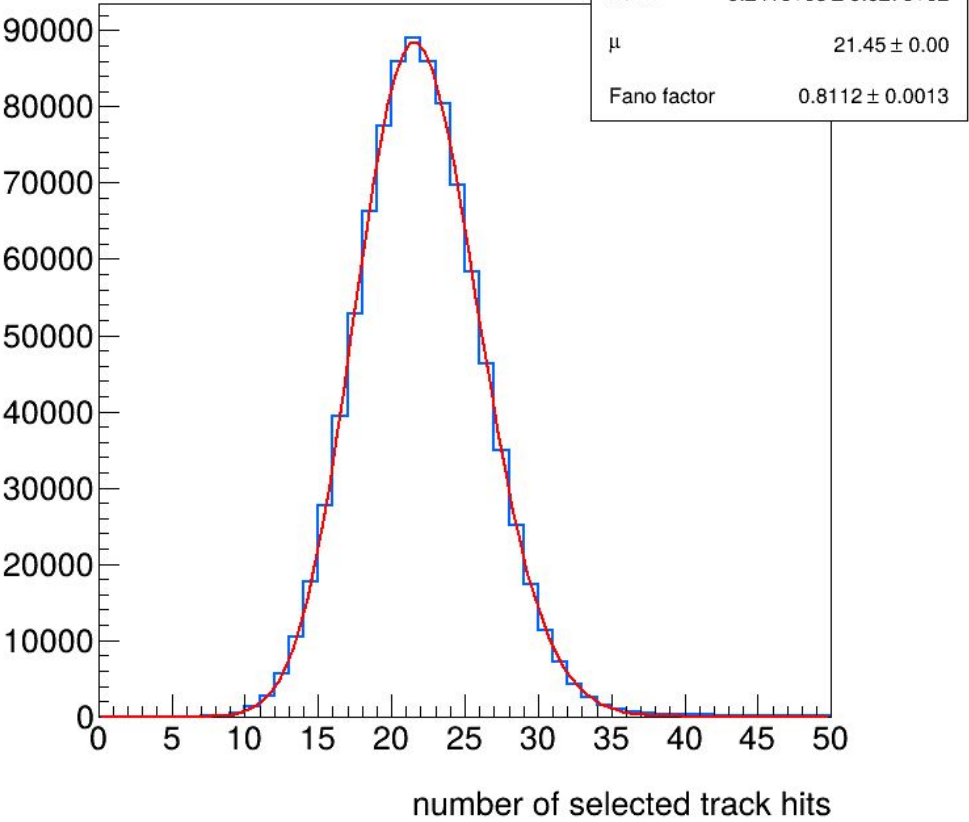
IRT-reconstructed
track angles

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



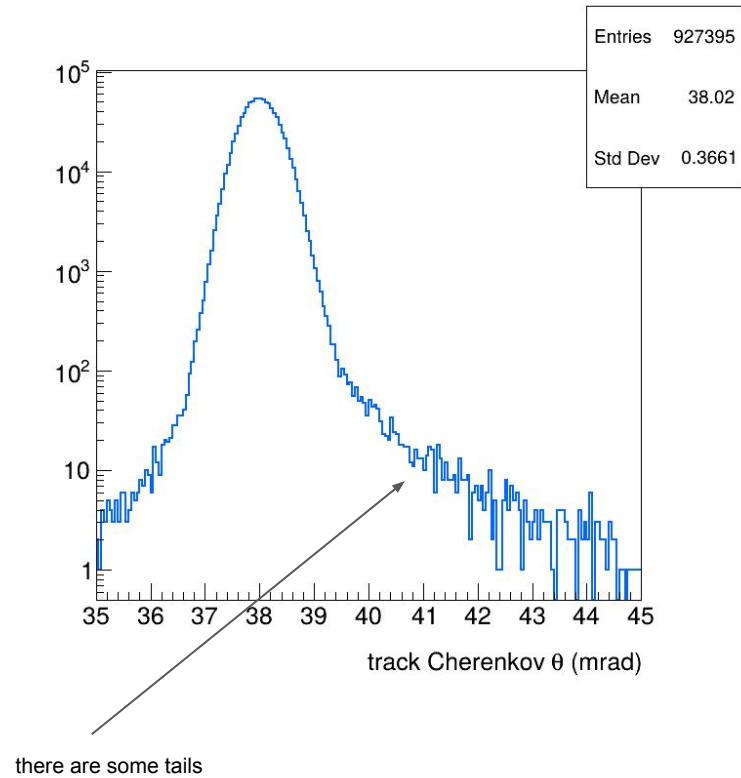
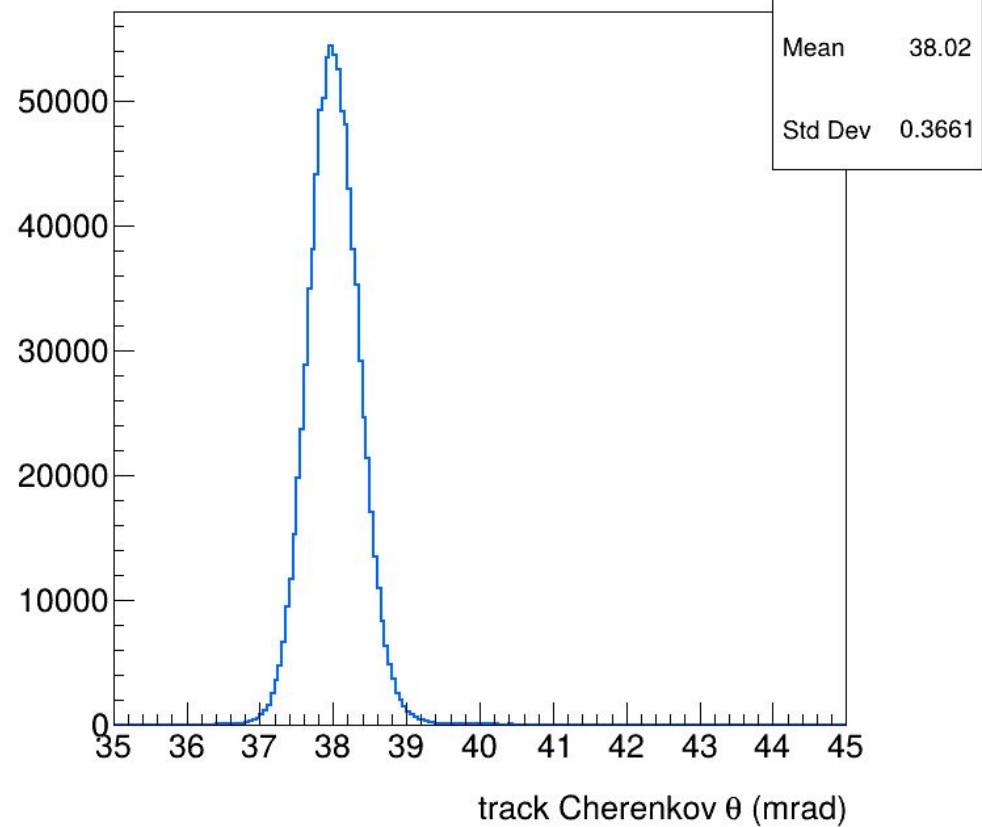
event-by-event distribution of the number of selected hits, mean is large: 22 hits / track

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



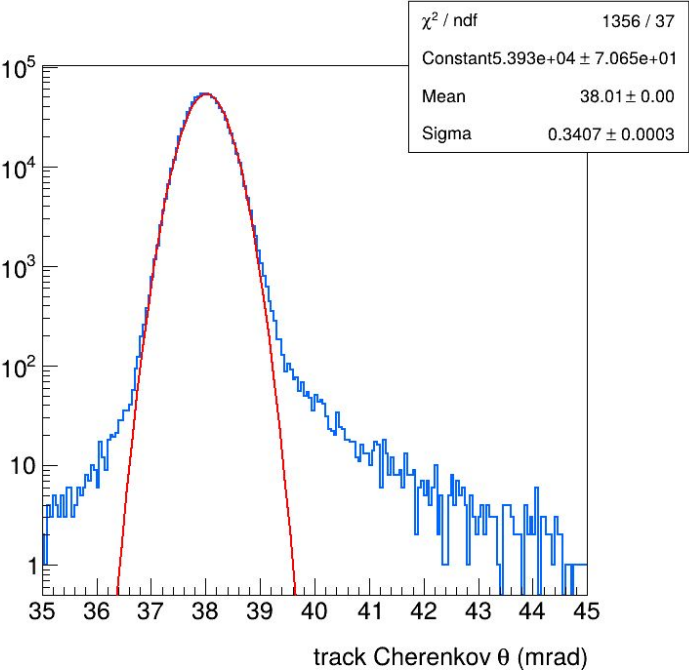
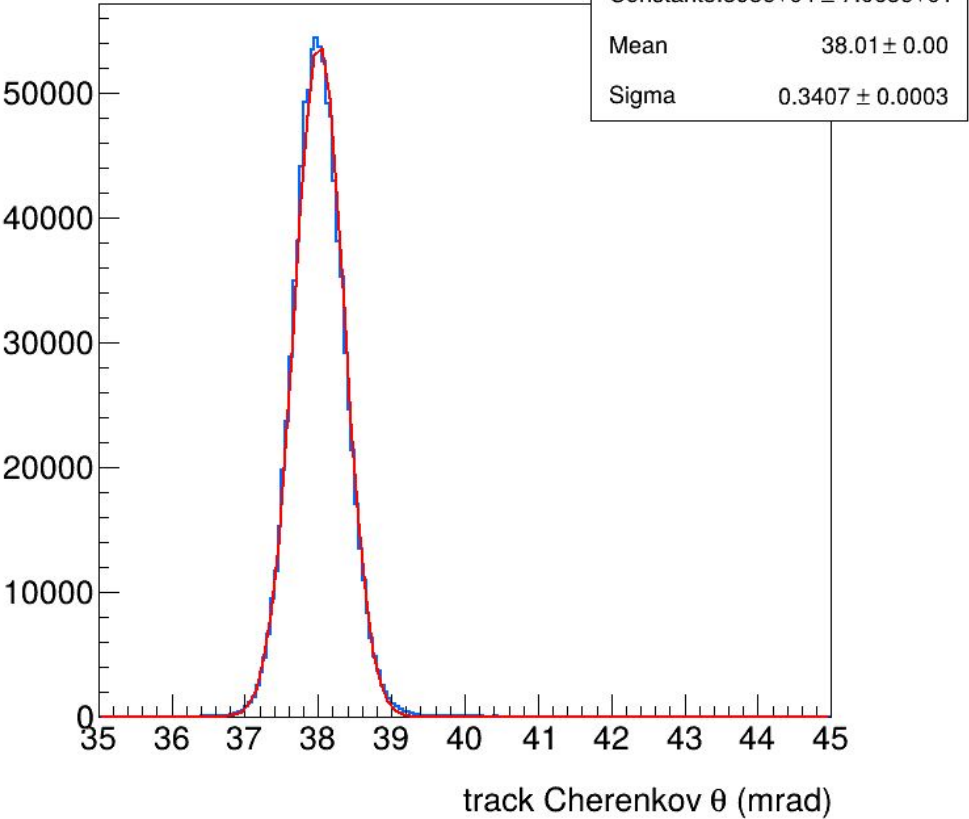
Poisson fit shows undercorrelations (Fano factor is 0.81), likely due to impossibility of having > 1 photon on same channel

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



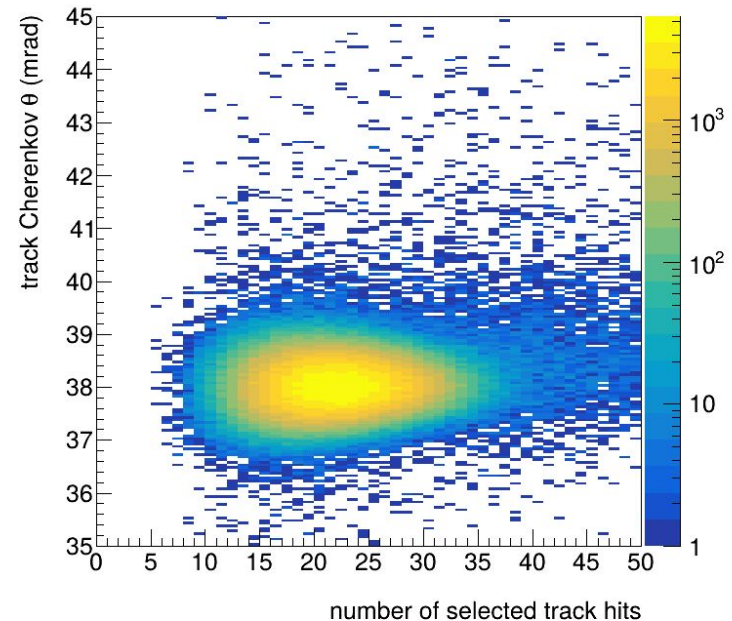
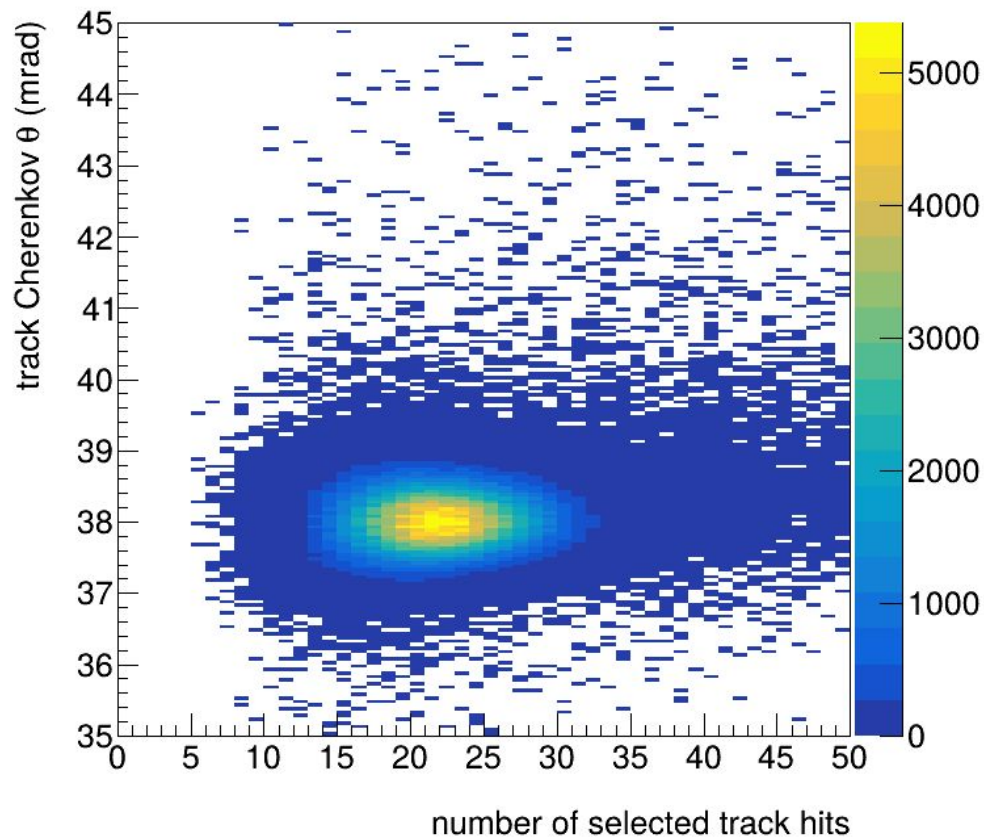
event-by-event distribution of the reconstructed track Cherenkov angle

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



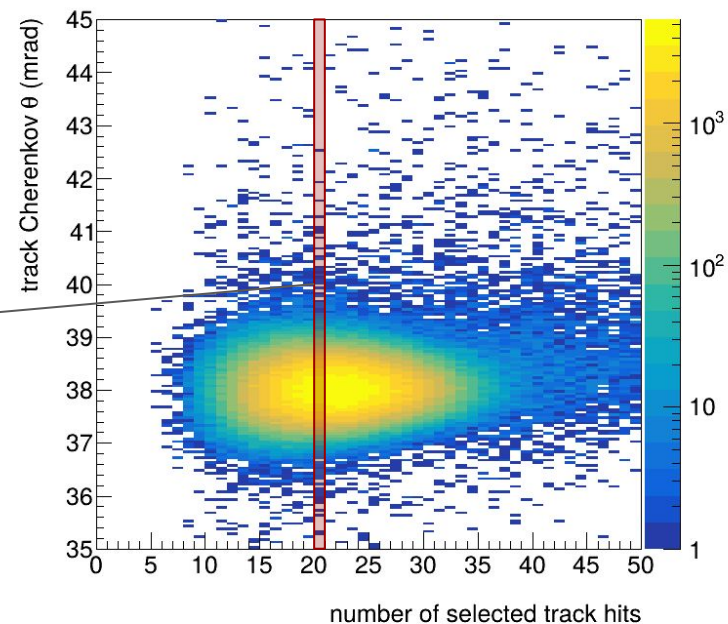
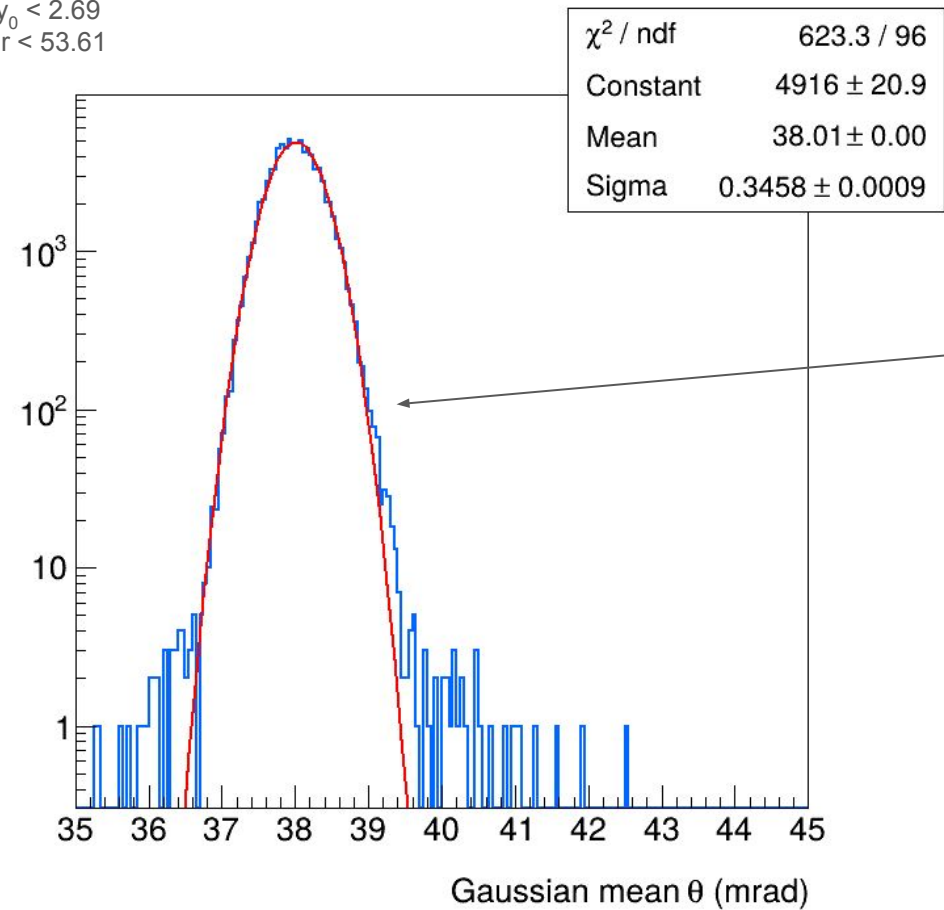
average track Cherenkov resolution is 0.34 mrad

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



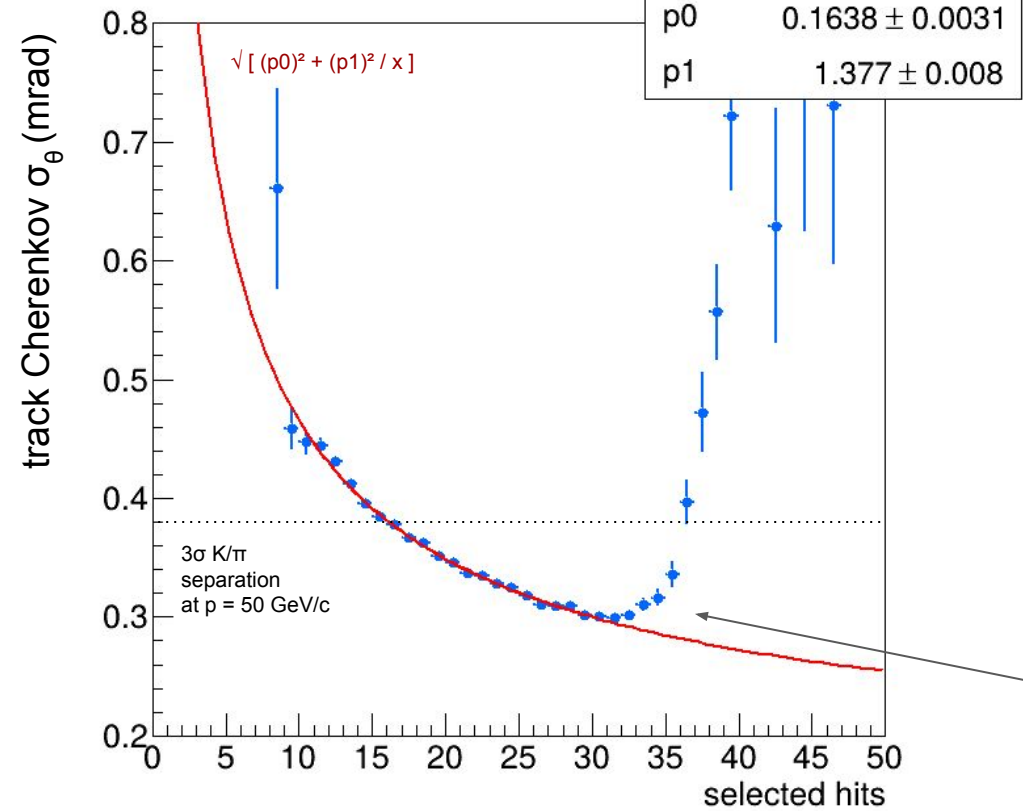
extract single-photon angular resolution from the gaussian fits in slices of the track hit multiplicity

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$

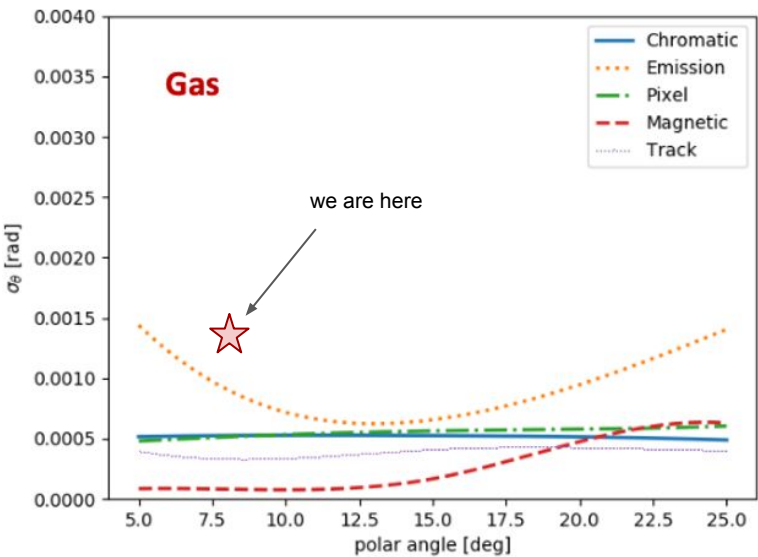


extract single-photon angular resolution from the gaussian fits in slices of the track hit multiplicity (here shown N = 20 slice)

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



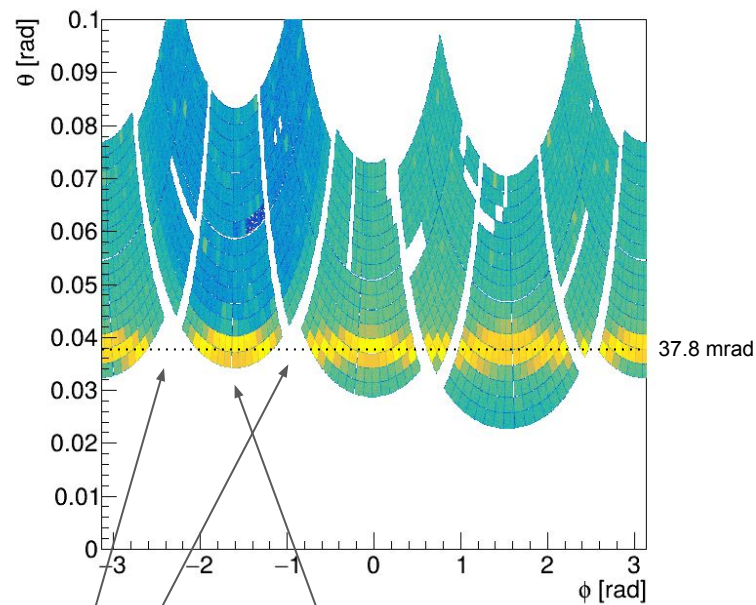
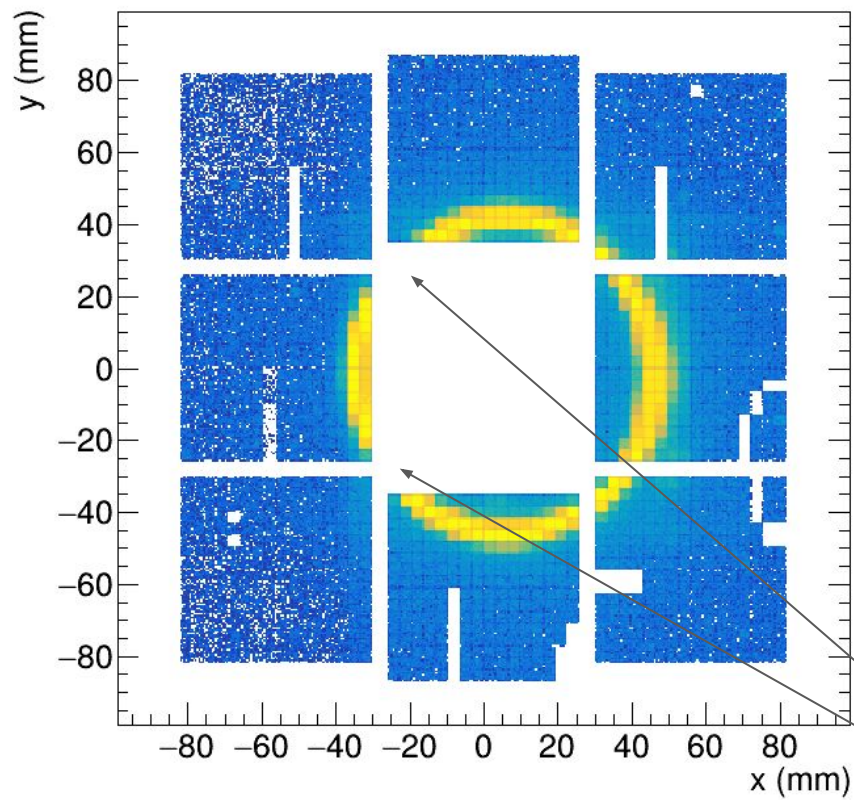
on the Yellow Report plot



from reconstructed track rings, single-photon angular resolution is 1.38 mrad, with a constant term of 0.16 mrad

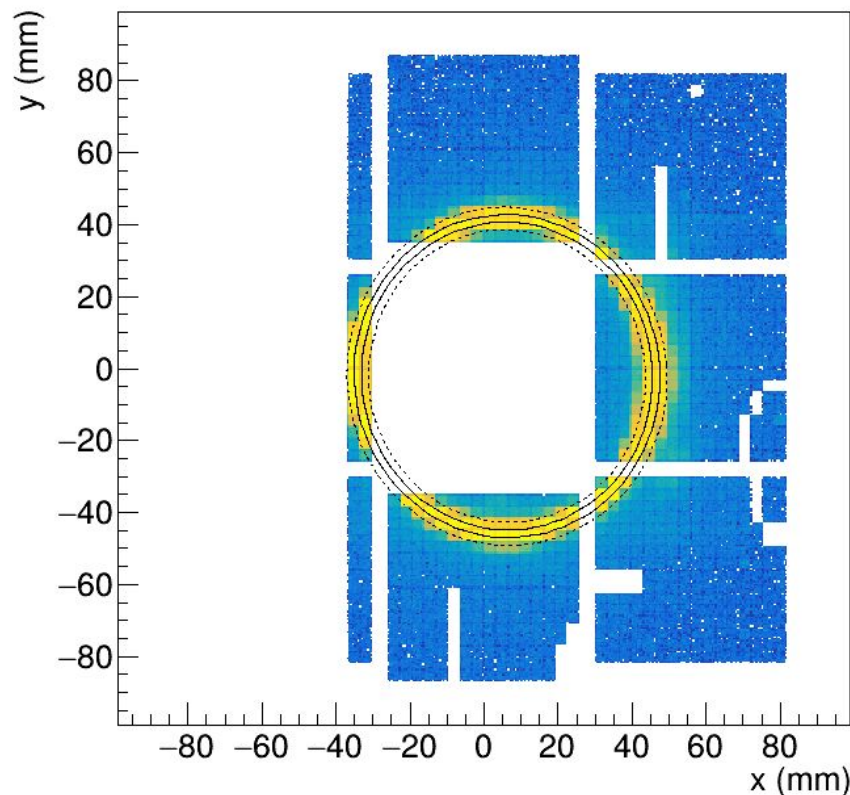
acceptance

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



the average 22 hits / track should be corrected by the acceptance, as we have large holes in Φ and incomplete coverages

events with one ring
 $1.68 < x_0 < 10.53$
 $-6.93 < y_0 < 2.69$
 $30.52 < r < 53.61$



calculations based on the fitted ellipse model

- **continuous ring**
 - 33.08 hits
- **ideal full-area pixel array**
 - with $3 \times 3 \text{ mm}^2$ pixels
 - 3.2 mm pitch
 - 29.07 hits
- **realistic full-area PDU array**
 - with 3 mm gaps between PDUs
 - 26.02 hits
- **real eight-PDU geometry**
 - 21.73 hits
 - the model matches the data

relative to the ideal full-area pixel array, the real geometry intercepts an **acceptance of ~75%**

relative to the realistic full-area PDU array, the real geometry intercepts an **acceptance of ~83.5%**

robust fit of the hit map with an ellipse model, estimated acceptance: ~83.5% → average 26 photons/track (~17 in the YR)



That's all Folks!