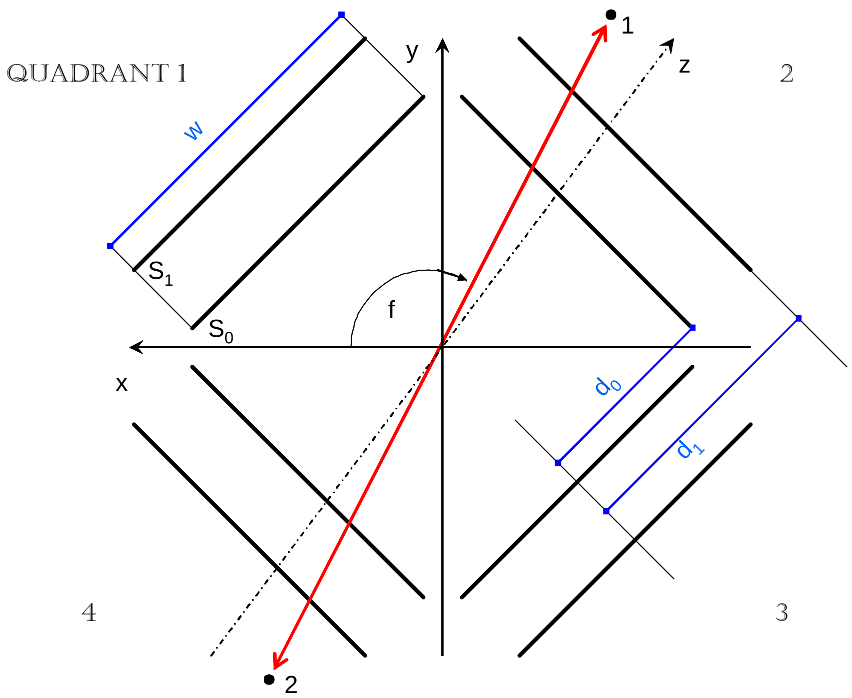
Event Simulation for pp or pbarp elastic scattering

A) The input is given by the following detector setup, which

1. For pp scattering a convenient choice to identify the two protons is to associate the smaller scattering angle θ with particle 1. No information is lost, the two protons are not distinguishable and the angular distributions of all observables extend to 90 degree in the cm.
2. In pbar-p scattering the two particles are distinguishable. The scattering angle θ is associated to the imping particle.



Silicon Detector Dimensions and Positions

$w := 100$ mm $\quad d := \begin{pmatrix} 60 \\ 80 \end{pmatrix}$ mm

Detectors are infinite along z coordinate with a strip pitch of

$ds := 0.8$ mm

and a thickness of $t := 0.03$ cm

which corresponds to $t \cdot 10^4 = 300$ μm

Phi Acceptance for the different detectors in the four quadrants

$$\varphi_{acc}(l,q) := \begin{bmatrix} \frac{\pi}{4}\cdot(2\cdot q-1) - \operatorname{acos}\left[\frac{d_l}{\sqrt{(d_l)^2+\left(\frac{w}{2}\right)^2}}\right] \\ \frac{\pi}{4}\cdot(2\cdot q-1) + \operatorname{acos}\left[\frac{d_l}{\sqrt{(d_l)^2+\left(\frac{w}{2}\right)^2}}\right] \end{bmatrix}$$

Phi Acceptance for hits in all four layers

$$\frac{\left(\varphi_{acc}(1,1)_1 - \varphi_{acc}(1,1)_0\right)\cdot 4}{2\cdot\pi} = 0.711$$

$$\varphi_{quad}(q) := \left[\frac{\pi}{4}\cdot(2\cdot q-1)\right]$$

	Inner Layer	Outer Layer
Quadrant 1	$\varphi_{acc}(0,1) = \begin{pmatrix} 5.194 \\ 84.806 \end{pmatrix}\cdot deg$	$\varphi_{acc}(1,1) = \begin{pmatrix} 12.995 \\ 77.005 \end{pmatrix}\cdot deg$
Quadrant 2	$\varphi_{acc}(0,2) = \begin{pmatrix} 95.194 \\ 174.806 \end{pmatrix}\cdot deg$	$\varphi_{acc}(1,2) = \begin{pmatrix} 102.995 \\ 167.005 \end{pmatrix}\cdot deg$
Quadrant 3	$\varphi_{acc}(0,3) = \begin{pmatrix} 185.194 \\ 264.806 \end{pmatrix}\cdot deg$	$\varphi_{acc}(1,3) = \begin{pmatrix} 192.995 \\ 257.005 \end{pmatrix}\cdot deg$
Quadrant 4	$\varphi_{acc}(0,4) = \begin{pmatrix} 275.194 \\ 354.806 \end{pmatrix}\cdot deg$	$\varphi_{acc}(1,4) = \begin{pmatrix} 282.995 \\ 347.005 \end{pmatrix}\cdot deg$

$\varphi_{quad}(1) = 45\cdot deg$

$\varphi_{quad}(2) = 135\cdot deg$

$\varphi_{quad}(3) = 225\cdot deg$

$\varphi_{quad}(4) = 315\cdot deg$

In total, nevents are generated in nbin bins

$nevent := 25000$ $i := 0..nevent-1$ $nbin := 40$

x0 and y0 offsets are ranging from

$x0_{min} := -5$ mm $x0_{max} := 5$ mm $x0_i := rnd(x0_{max} - x0_{min}) - x0_{max}$ $Hx0 := histogram(nbin, x0)$

$y0_{min} := -5$ mm $y0_{max} := 5$ mm $y0_i := rnd(y0_{max} - y0_{min}) - y0_{max}$ $Hy0 := histogram(nbin, y0)$

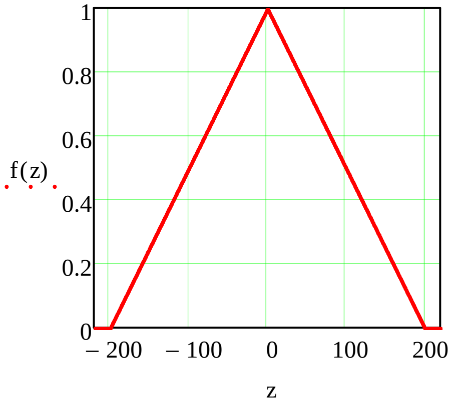
The vertex is located between $z0_{min} := -200$ mm $z0_{max} := 200$ mm.

normalized probability distribution
function for a triangular shape

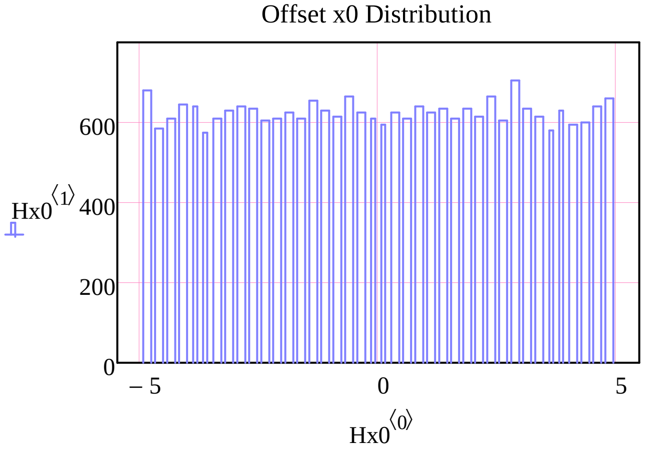
$$f(z) := if\left(z0_{min} \le z < z0_{max}, 1 - \frac{\sqrt{z^2}}{z0_{max}}, 0\right)$$

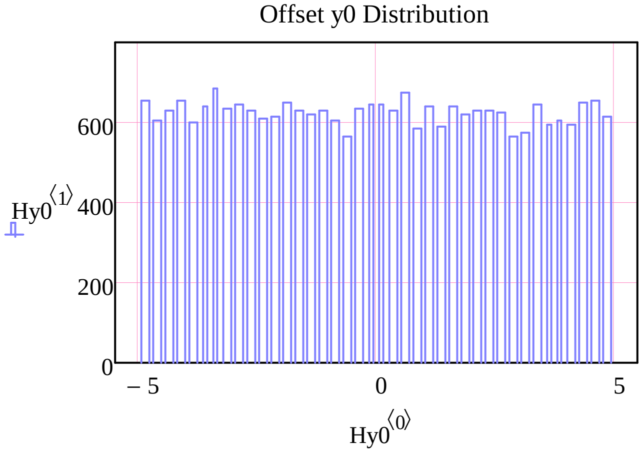
$$z0 := \begin{array}{|l} i \leftarrow 0 \\ \text{while } i < nevent \\ \quad \begin{array}{|l} random \leftarrow rnd(z0_{max} - z0_{min}) - z0_{max} \\ \text{if } f(random) \ge rnd(1) \\ \quad \begin{array}{|l} z0_i \leftarrow random \\ i \leftarrow i + 1 \end{array} \end{array} \\ z0 \end{array}$$

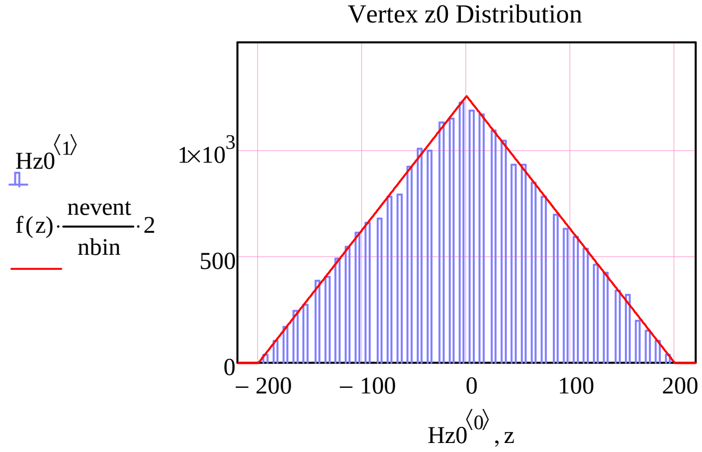
triangular distribution



$Hz0 := histogram(nbin, z0)$



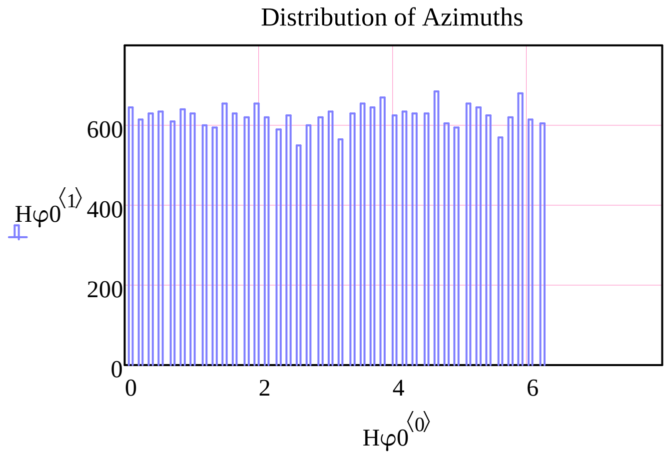




also uniformly distributed are the generated events in φ

$\varphi 0_i := rnd(2\pi)$

$H\varphi 0 := histogram(nbin, \varphi 0)$

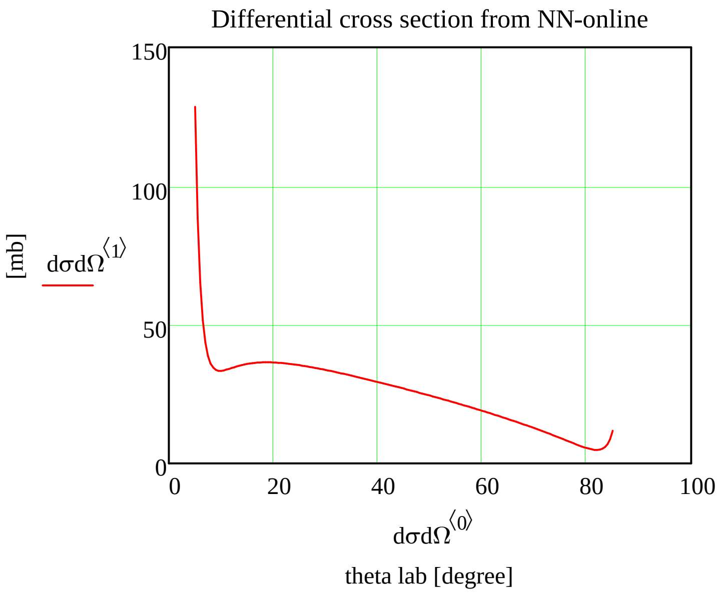


pick before implementation of a real cross section a simple distribution function

$d\sigma d\Omega 45 :=$ pp-45MeV_pwa93.txt

$d\sigma d\Omega 200 :=$ pp-200MeV_pwa93.txt

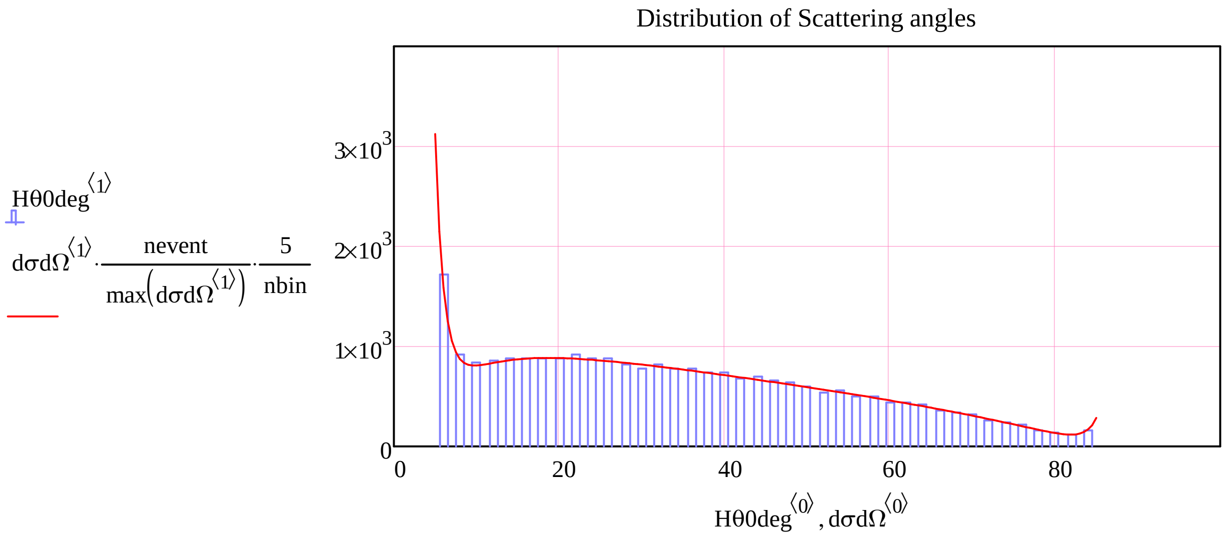
specify input data in use $d\sigma d\Omega := d\sigma d\Omega 45$



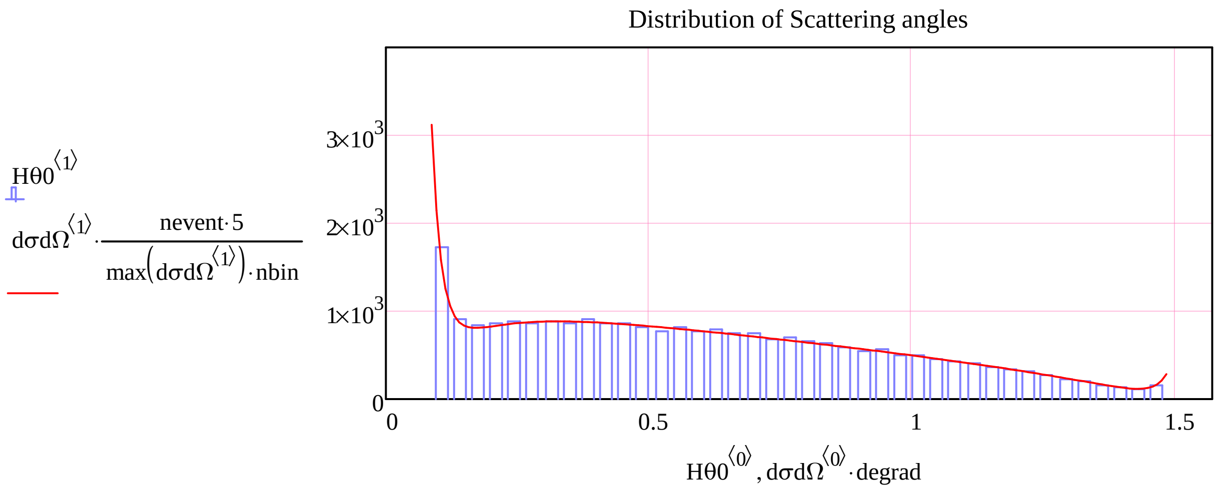
$\theta 0_{min} := 5$ degree $\theta 0_{max} := 85$ degree $degrad := \frac{\pi}{180}$ conversion from degree to radian $radeg := \frac{1}{degrad}$

$$\theta0 := \left| \begin{array}{l} i \leftarrow 0 \\ \text{while } i < nevent \\ \quad \left| \begin{array}{l} \theta out \leftarrow rnd(\theta0_{max}\cdot degrad - \theta0_{min}\cdot degrad) + \theta0_{min}\cdot degrad \\ j \leftarrow \dfrac{round\left[2\cdot\left(\dfrac{\theta out}{degrad}\right)\right]}{2}\cdot\dfrac{1}{0.5} - 10 \\ \text{if } \left(d\sigma d\Omega^{\langle 1\rangle}\right)_j \geq rnd\left(max\left(d\sigma d\Omega^{\langle 1\rangle}\right)\right) \\ \quad \left| \begin{array}{l} \theta0_i \leftarrow \theta out \\ i \leftarrow i + 1 \end{array} \right. \end{array} \right. \\ \theta0 \end{array} \right.$$

$$H\theta0deg := histogram(nbin, \theta0\cdot radeg)$$



$$H\theta0 := histogram(nbin, \theta0)$$



Now we can compose the input vector from the five parameters θ0, φ0, x0, y0, z0

$$X_i := \left(\theta0_i \quad \varphi0_i \quad x0_i \quad y0_i \quad z0_i\right)$$

$X := \mathrm{augment}(\theta 0, \varphi 0, x0, y0, z0)$

Kinematics for Forward and Recoil

kinetic energy $T_p := 45$ MeV

proton rest mass $m_p := 938.272$ MeV

$$\beta_{lab} := \frac{\sqrt{T_p^2 + 2 \cdot m_p \cdot T_p}}{m_p + T_p} \qquad \gamma_{lab} := \frac{1}{\sqrt{1 - \beta_{lab}^2}} \qquad fk := \frac{2}{1 + \gamma_{lab}} \qquad fk = 0.97658$$

Kinematics of pp elastic scattering

kineamtics calculations

$$\beta_{cm} := \frac{\beta_{lab} \cdot \gamma_{lab}}{1 + \gamma_{lab}} \qquad \gamma_{cm} := \frac{1}{\sqrt{1 - \beta_{cm}^2}} \qquad \beta_{cm} = 0.153 \qquad \gamma_{cm} = 1.012$$

Lab projectile energy and momentum

$$p_{lab} := \gamma_{lab} \cdot \beta_{lab} \cdot m_p \qquad E_{lab} := \gamma_{lab} \cdot m_p$$

CM energy s

$p_{lab} = 294.057$ MeV/c

$$s := m_p^2 + 2 \cdot E_{lab} \cdot m_p + m_p^2$$

$\sqrt{s} = 1898.911$ MeV^2

$$p_{cm} := \frac{p_{lab} \cdot m_p}{\sqrt{s}} \qquad p_{cm} = 145.297$$ MeV/c

$$\beta(T) := \frac{\sqrt{T^2 + 2 \cdot m_p \cdot T}}{m_p + T}$$

for speed calculation

For pp elastic scattering tg(theta_rec)=fk/tg(theta)

B) Event simulation

An event is defined by a straight line through a vertex point (x0,y0,z0) that has the general form (x-x0)/A=(y-y0)/B=(z-z0)/C. The recoil prong also originates from the vertex and has a direction given by kinematics. Here, we assume values for the five independent parameters that describe an event (θ,φ,x0,y0,z0) and calculate the appropriate **four** silicon detector coordinates.

$\theta 0_0 = 16.895 \cdot deg$ $\quad \varphi 0_0 = 351.094 \cdot deg$

$\varphi 0_{r_i} := \varphi 0_i + \pi$

$\varphi 0_{r_0} = 531.094 \cdot deg$

x $\quad A1_i := \cos(\varphi 0_i) \cdot \sin(\theta 0_i)$ $\quad A1_0 = 0.287$ $\quad x0_0 = -1.668$ mm

y $\quad B1_i := \sin(\varphi 0_i) \cdot \sin(\theta 0_i)$ $\quad B1_0 = -0.045$ $\quad y0_0 = 1.775$ mm

z $\quad C1_i := \cos(\theta 0_i)$ $\quad C1_0 = 0.957$ $\quad z0_0 = -153.218$ mm

Note:

- θ and ϕ can be converted into A and B, **and** C (C is not an independent quantity)

check $\quad \text{angle}(A1_0, B1_0) = 351.094 \cdot deg$

$$\text{atan}\left[\frac{\sqrt{(A1_0)^2 + (B1_0)^2}}{\sqrt{1 - \left(\frac{A1_0}{\cos(\varphi 0_0)}\right)^2}}\right] = 16.895 \cdot deg$$

straight line of first track

straight line of second track

$$\theta 0_{r_i} := \text{atan}\left(\frac{fk}{\tan(\theta 0_i)}\right) \qquad \theta 0_{r_0} = 72.723 \cdot deg$$

$$\text{first}(\gamma, i) := \begin{pmatrix} x0_i \\ y0_i \\ z0_i \end{pmatrix} + \gamma \cdot \begin{pmatrix} A1_i \\ B1_i \\ C1_i \end{pmatrix}$$

x $\quad A2_i := \cos(\varphi 0_{r_i}) \cdot \sin(\theta 0_{r_i})$ $\quad A2_0 = -0.943$

y $\quad B2_i := \sin(\varphi 0_{r_i}) \cdot \sin(\theta 0_{r_i})$ $\quad B2_0 = 0.148$

z $\quad C2_i := \cos(\theta 0_{r_i})$ $\quad C2_0 = 0.297$

$$\text{second}(\delta, i) := \begin{pmatrix} x0_i \\ y0_i \\ z0_i \end{pmatrix} + \delta \cdot \begin{pmatrix} A2_i \\ B2_i \\ C2_i \end{pmatrix}$$

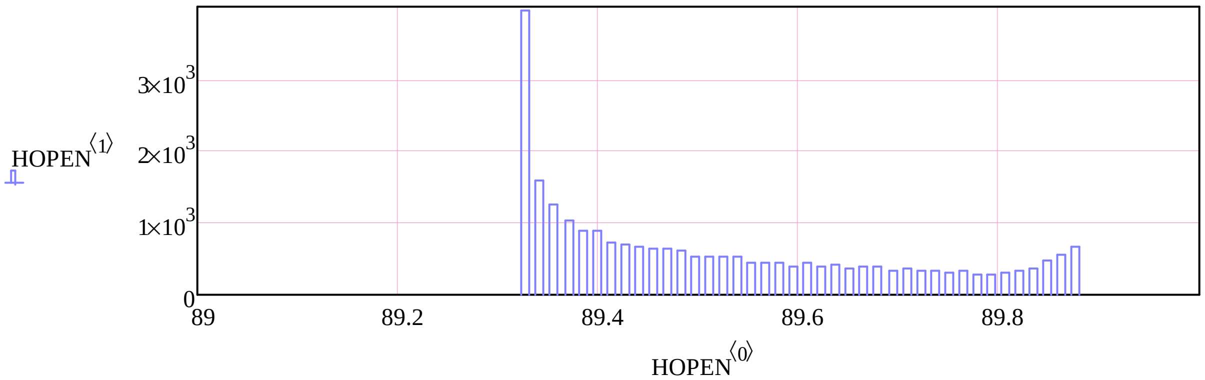
Opening angle

$$OPEN_i := \text{atan}\left(\frac{fk}{\tan(\theta 0_i)}\right) + \text{atan}\left[\frac{\sqrt{(A1_i)^2 + (B1_i)^2}}{\sqrt{1 - \left(\frac{A1_i}{\cos(\varphi 0_i)}\right)^2}}\right]$$

$OPEN_0 = 89.619 \cdot deg$

$HOPEN := \text{histogram}(nbin, OPEN \cdot radeg)$

Distribution of Opening angles



Express the angle θ_rec in terms of θ (lab system), the angle of the forward scattered proton (based on *Particle Kinematics* by E. Byckling and K. Kajantie, pp.74.

for Definition: $\quad \theta := \theta 0_0 \qquad \theta_r := \theta 0_{r_0}$

Lab momentum of the particles as function of the emission angle

$$P_{lab}(\theta) := \left[p_{lab}\cdot\left[m_p\cdot E_{lab} + 0.5\cdot\left(m_p^{\,2} + m_p^{\,2} + m_p^{\,2} - m_p^{\,2}\right)\right]\cdot\cos(\theta) + \left(E_{lab} + m_p\right)\cdot\left[\left(m_p\cdot E_{lab}\right)^2 - m_p^{\,2}\cdot m_p^{\,2} - m_p^{\,2}\cdot p_{lab}^{\,2}\cdot\sin(\theta)^2\right]^{0.5}\right]\cdot\left[\left(E_{lab} + m_p\right)^2 - p_{lab}^{\,2}\cdot\cos(\theta)^2\right]^{-1}$$

$P_{lab}(\theta) = 280.796$ MeV/c $\quad P_{lab}(\theta_r) = 85.462$ MeV/c

Lab kinetic energy of the particles as function of the proton scattering angle

$$TT_p(\theta) := \left[\left(E_{lab} + m_p\right)\cdot\left[m_p\cdot E_{lab} + 0.5\cdot\left(m_p^{\,2} + m_p^{\,2} + m_p^{\,2} - m_p^{\,2}\right)\right] + p_{lab}\cdot\cos(\theta)\cdot\left[\left(m_p\cdot E_{lab}\right)^2 - m_p^{\,2}\cdot m_p^{\,2} - m_p^{\,2}\cdot p_{lab}^{\,2}\cdot\sin(\theta)^2\right]^{0.5}\right]\cdot\left[\left(E_{lab} + m_p\right)^2 - p_{lab}^{\,2}\cdot\cos(\theta)^2\right]^{-1} - m_p$$

$TT_p(\theta) = 41.116$ MeV $\quad TT_p(\theta_r) = 3.884$ MeV $\quad TT_p(\theta) + TT_p(\theta_r) = 45$ MeV $\quad$ aha, correct!

With the given geometry, hits appear in the following detector layers

$$\text{hitq}(l,\varphi) := \begin{array}{|l} 1 \text{ if } \left(\varphi_{acc}(l,1)_0 < \varphi < \varphi_{acc}(l,1)_1\right) \\ 2 \text{ if } \left(\varphi_{acc}(l,2)_0 < \varphi < \varphi_{acc}(l,2)_1\right) \\ 3 \text{ if } \left(\varphi_{acc}(l,3)_0 < \varphi < \varphi_{acc}(l,3)_1\right) \\ 4 \text{ if } \left(\varphi_{acc}(l,4)_0 < \varphi < \varphi_{acc}(l,4)_1\right) \\ 1 \text{ if } \varphi_{acc}(l,1)_0 + 2\cdot\pi < \varphi < \varphi_{acc}(l,1)_1 + 2\cdot\pi \\ 2 \text{ if } \varphi_{acc}(l,2)_0 + 2\cdot\pi < \varphi < \varphi_{acc}(l,2)_1 + 2\cdot\pi \\ 3 \text{ if } \varphi_{acc}(l,3)_0 + 2\cdot\pi < \varphi < \varphi_{acc}(l,3)_1 + 2\cdot\pi \\ 4 \text{ if } \varphi_{acc}(l,4)_0 + 2\cdot\pi < \varphi < \varphi_{acc}(l,4)_1 + 2\cdot\pi \\ 0 \text{ otherwise} \end{array}$$

Define equations for the eight detector planes

$$Si(\alpha,\beta,l,q) := \begin{pmatrix} \cos(\varphi_{quad}(q))\cdot d_l \\ \sin(\varphi_{quad}(q))\cdot d_l \\ 0 \end{pmatrix} + \alpha\cdot\begin{pmatrix} -\cos(\varphi_{quad}(q)) \\ \sin(\varphi_{quad}(q)) \\ 0 \end{pmatrix} + \beta\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

Determine intercept of first prong and detectors

$$M1(l,i) := \begin{pmatrix} -\cos(\varphi_{quad}(hitq(l,\varphi0_i))) & 0 & -A1_i \\ \sin(\varphi_{quad}(hitq(l,\varphi0_i))) & 0 & -B1_i \\ 0 & 1 & -C1_i \end{pmatrix} \quad v1(l,i) := \begin{pmatrix} x0_i \\ y0_i \\ z0_i \end{pmatrix} - \begin{pmatrix} \cos(\varphi_{quad}(hitq(l,\varphi0_i)))\cdot d_l \\ \sin(\varphi_{quad}(hitq(l,\varphi0_i)))\cdot d_l \\ 0 \end{pmatrix}$$

Coordinates in 3D in the Silicon layers

$$Si1\_3D(l,i) := first(lsolve(M1(l,i),v1(l,i))_2, i)$$

1st Layer (0) 2nd Layer (1)

$$Si1\_3D(0,19) = \begin{pmatrix} 8.631 \\ -76.222 \\ 45.5 \end{pmatrix} \begin{matrix} x \\ y \\ z \end{matrix} \qquad Si1\_3D(1,19) = \begin{pmatrix} 11.694 \\ -101.443 \\ 111.886 \end{pmatrix}$$

Determine intercept of second prong and detectors

$$M2(l,i) := \begin{pmatrix} -\cos(\varphi_{quad}(hitq(l,\varphi0_{r_i}))) & 0 & -A2_i \\ \sin(\varphi_{quad}(hitq(l,\varphi0_{r_i}))) & 0 & -B2_i \\ 0 & 1 & -C2_i \end{pmatrix} \quad v2(l,i) := \begin{pmatrix} x0_i \\ y0_i \\ z0_i \end{pmatrix} - \begin{pmatrix} \cos(\varphi_{quad}(hitq(l,\varphi0_{r_i})))\cdot d_l \\ \sin(\varphi_{quad}(hitq(l,\varphi0_{r_i})))\cdot d_l \\ 0 \end{pmatrix}$$

Coordinates in 3D in the Silicon layers

$$Si2\_3D(l,i) := second(lsolve(M2(l,i),v2(l,i))_2, i)$$

1st Layer (0) 2nd Layer (1)

$$Si2\_3D(0,19) = \begin{pmatrix} -9.743 \\ 75.109 \\ -133.031 \end{pmatrix} \begin{matrix} x \\ y \\ z \end{matrix} \qquad Si2\_3D(1,19) = \begin{pmatrix} 11.694 \\ -101.443 \\ -202.73 \end{pmatrix}$$

Function to convert the 3D coordinates of the first track into silicon wires along **sw** and **sz.** We start counting the strips along w from smaller values of φ.

$$Si1\_2D(l,i) := \left[\sqrt{\left(\frac{d_l}{\cos(\varphi_{quad}(hitq(l,\varphi0_i)) - \varphi_{acc}(l,hitq(l,\varphi0_i))_0)}\cdot\cos(\varphi_{acc}(l,hitq(l,\varphi0_i))_0) - Si1\_3D(l,i)_0 \right)^2 + \left(\frac{d_l}{\cos(\varphi_{quad}(hitq(l,\varphi0_i)) - \varphi_{acc}(l,hitq(l,\varphi0_i))_0)}\cdot\sin(\varphi_{acc}(l,hitq(l,\varphi0_i))_0 \right.} \atop Si1\_3D(l,i)_2 + |z0_{min}| \right.$$

$$Si1\_2D(0,5) = \begin{pmatrix} 57.469 \\ 303.863 \end{pmatrix} \qquad Si1\_2D(1,5) = \begin{pmatrix} 59.863 \\ 380.683 \end{pmatrix}$$

Function to convert the 3D coordinates of the recoil track into silicon wires along **sw** and **sz**.

$$Si2\_2D(l,i) := \left[\sqrt{\left(\frac{d_l}{\cos\left(\varphi_{quad}\left(hitq\left(l,\varphi0_{r_i}\right)\right) - \varphi_{acc}\left(l,hitq\left(l,\varphi0_{r_i}\right)\right)_0\right)}\cdot\cos\left(\varphi_{acc}\left(l,hitq\left(l,\varphi0_{r_i}\right)\right)_0\right) - Si2\_3D(l,i)_0\right)^2 + \left(\frac{d_l}{\cos\left(\varphi_{quad}\left(hitq\left(l,\varphi0_{r_i}\right)\right) - \varphi_{acc}\left(l,hitq\left(l,\varphi0_{r_i}\right)\right)_0\right)}\cdot\sin\left(\varphi_{acc}\left(l,hi\right.\right.\right.}\right.$$

$$Si2\_3D(l,i)_2 + \left|z0_{min}\right|$$

$$Si2\_2D(0,0) = \begin{pmatrix} 91.892 \\ 68.939 \end{pmatrix} \quad Si2\_2D(1,0) = \begin{pmatrix} 110.175 \\ 15.053 \end{pmatrix}$$

X =

	0	1	2	3	4	5
0	0.295	6.128	-1.668	1.775	-153.218	
1	0.55	0.794	-3.946	1.792	50.103	
2	1.064	4.594	-3.296	-2.364	-36.239	
3	0.12	3.637	0.033	1.087	-128.419	
4	0.738	4.533	0.907	-4.008	55.571	
5	0.256	2.475	-0.287	-0.135	-126.184	
6	0.498	5.465	1.679	-0.953	19.844	
7	1.475	1.845	2.102	1.422	...	

quad #, layer 0 — quad #, layer 1

first track

$hit10_i := hitq\left(0,\varphi0_i\right)$ $\quad hit11_i := hitq\left(1,\varphi0_i\right)$

3D positions

$hit10x_i := Si1\_3D(0,i)_0$ $\quad hit11x_i := Si1\_3D(1,i)_0$

$hit10y_i := Si1\_3D(0,i)_1$ $\quad hit11y_i := Si1\_3D(1,i)_1$

$hit10z_i := Si1\_3D(0,i)_2$ $\quad hit11z_i := Si1\_3D(1,i)_2$

quad #, layer 0 — quad #, layer 1

second track

$hit20_i := hitq\left(0,\varphi0_{r_i}\right)$ $\quad hit21_i := hitq\left(1,\varphi0_{r_i}\right)$

$hit20x_i := Si2\_3D(0,i)_0$ $\quad hit21x_i := Si2\_3D(1,i)_0$

$hit20y_i := Si2\_3D(0,i)_1$ $\quad hit21y_i := Si2\_3D(1,i)_1$

$hit20z_i := Si2\_3D(0,i)_2$ $\quad hit21z_i := Si2\_3D(1,i)_2$

Append hits to event parameter vector $X := \text{augment}(X, hit10, hit11, hit20, hit21, hit10x, hit10y, hit10z, hit11x, hit11y, hit11z, hit20x, hit20y, hit20z, hit21x, hit21y, hit21z)$

Include energy of both particles $TT1_i := TT_p(\theta 0_i)$ $TT2_i := TT_p(\theta 0r_i)$ in MeV $X := \text{augment}(X, TT1, TT2)$

Velocities of both particles $beta1_i := \beta(TT1_i)$ $beta2_i := \beta(TT2_i)$ $clight := 3\cdot 10^8 \cdot 1000$ mm/s

calculate time of impact in layers with respect to collision

for particle 1

$$t10_i := \frac{\sqrt{(X_{i,2}-X_{i,9})^2+(X_{i,3}-X_{i,10})^2+(X_{i,4}-X_{i,11})^2}}{beta1_i \cdot clight}$$

$$t11_i := \frac{\sqrt{(X_{i,2}-X_{i,12})^2+(X_{i,3}-X_{i,13})^2+(X_{i,4}-X_{i,14})^2}}{beta1_i \cdot clight}$$

for particle 2

$$t20_i := \frac{\sqrt{(X_{i,2}-X_{i,15})^2+(X_{i,3}-X_{i,16})^2+(X_{i,4}-X_{i,17})^2}}{beta1_i \cdot clight}$$

$$t21_i := \frac{\sqrt{(X_{i,2}-X_{i,18})^2+(X_{i,3}-X_{i,19})^2+(X_{i,4}-X_{i,20})^2}}{beta1_i \cdot clight}$$

Include time of impact into array $X := \text{augment}(X, t10, t11, t20, t21)$

X =

	0	1	2	3	4	5	6	7	8	9
0	0.295	6.128	-1.668	1.775	-153.218	4	0	2	0	74.666
1	0.55	0.794	-3.946	1.792	50.103	1	1	3	3	39.168
2	1.064	4.594	-3.296	-2.364	-36.239	3	0	1	0	-11.744
3	0.12	3.637	0.033	1.087	-128.419	3	3	1	1	-55.788
4	0.738	4.533	0.907	-4.008	55.571	3	0	1	0	-11.639
5	0.256	2.475	-0.287	-0.135	-126.184	2	2	4	4	-47.707
6	0.498	5.465	1.679	-0.953	19.844	4	4	2	2	41.434
7	1.475	1.845	2.102	1.422	83.998	2	2	4	4	...

$$\text{Extract}\varphi(A) := \begin{array}{|l} i \leftarrow 0 \\ U \leftarrow 0 \\ \text{for } j \in 0..\text{rows}(A)-1 \\ \quad \text{if } \left(A_{j,5} = A_{j,6} \neq 0\right) \wedge \left(A_{j,7} = A_{j,8} \neq 0\right) \\ \qquad \begin{array}{|l} \text{for } k \in 0..26 \\ \quad U_{i,k} \leftarrow A_{j,k} \\ i \leftarrow i+1 \end{array} \\ U \end{array}$$

$X\varphi := \text{Extract}\varphi(X)$ $\frac{\text{rows}(X\varphi)}{\text{rows}(X)} = 0.713$

$X\varphi =$

	0	1	2	3	4	5	6	7	8
0	0.55	0.794	-3.946	1.792	50.103	1	1	3	3
1	0.12	3.637	0.033	1.087	-128.419	3	3	1	1
2	0.256	2.475	-0.287	-0.135	-126.184	2	2	4	4
3	0.498	5.465	1.679	-0.953	19.844	4	4	2	2
4	1.475	1.845	2.102	1.422	83.998	2	2	4	4
5	0.66	2.335	-4.658	-2.15	12.473	2	2	4	4
6	1.211	2.135	3.363	-2.39	35.11	2	2	4	4
7	1.183	2.801	4.08	-3.945	3.241	2	2	4	...

The detectors shall extend in z to +- 150 mm, remove events outside the phi acceptance and outside this range

$zdet_{min} := -50$ mm $zdet_{max} := 250$ mm

$$\text{Extractz}(A) := \begin{array}{|l} i \leftarrow 0 \\ U \leftarrow 0 \\ \text{for } j \in 0..\text{rows}(A)-1 \\ \quad \text{if } \left(zdet_{min} \le A_{j,11} \le zdet_{max}\right) \wedge \left(zdet_{min} \le A_{j,14} \le zdet_{max}\right) \wedge \left(zdet_{min} \le A_{j,17} \le zdet_{max}\right) \wedge \left(zdet_{min} \le A_{j,20} \le zdet_{max}\right) \\ \qquad \begin{array}{|l} \text{for } k \in 0..26 \\ \quad U_{i,k} \leftarrow A_{j,k} \\ i \leftarrow i+1 \end{array} \\ U \end{array}$$

Now throw away those events that do not hit the detector in z

$Xz := Extractz(X\varphi)$

Xz =

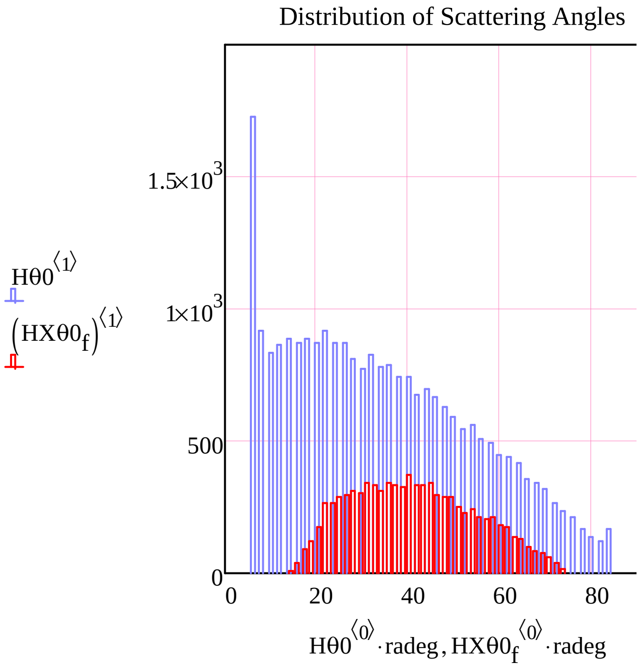
	0	1	2	3	4	5
0	0.55	0.794	-3.946	1.792	50.103	1
1	0.498	5.465	1.679	-0.953	19.844	4
2	0.66	2.335	-4.658	-2.15	12.473	2
3	1.211	2.135	3.363	-2.39	35.11	2
4	1.183	2.801	4.08	-3.945	3.241	2
5	0.776	3.439	0.28	3.289	-104.627	3
6	0.637	2.7	0.277	0.216	-77.369	2
7	0.733	5.27	-3.46	-4.786	55.601	4
8	0.872	5.058	-1.473	-3.865	28.459	4
9	0.405	4.38	-3.016	4.302	7.96	3
10	0.642	3.87	-4.323	4.648	-55.693	3
11	0.385	5.74	-3.198	-1.923	17.46	...

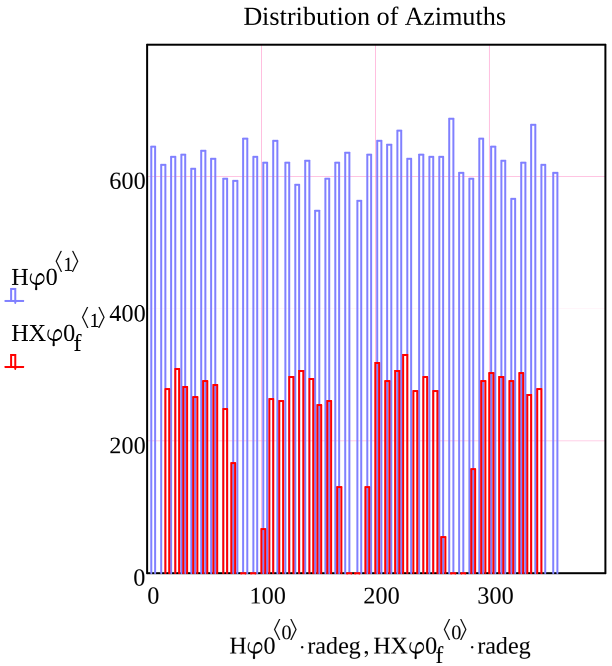
Histogram the final result:

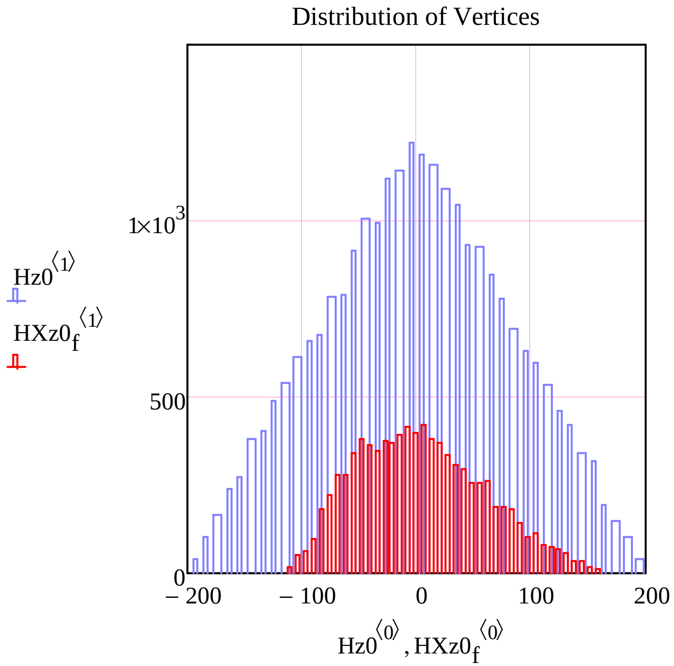
$HX\theta 0_f := histogram\left(nbin, Xz^{\langle 0\rangle}\right)$

$HX\varphi 0_f := histogram\left(nbin, Xz^{\langle 1\rangle}\right)$

$HXz0_f := histogram\left(nbin, Xz^{\langle 4\rangle}\right)$

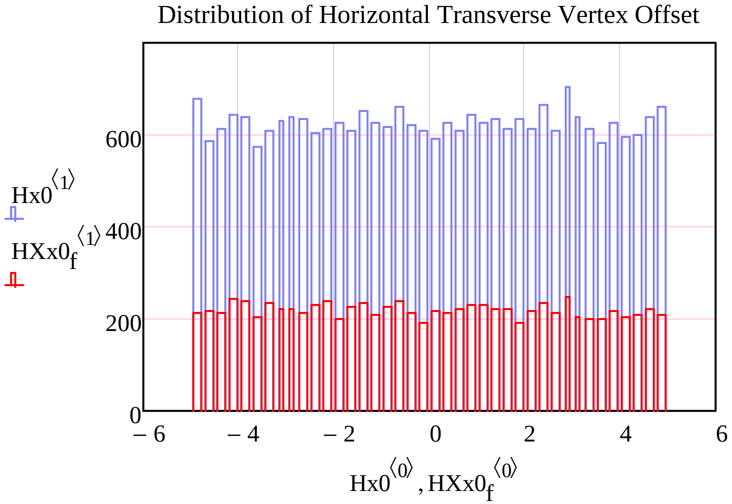


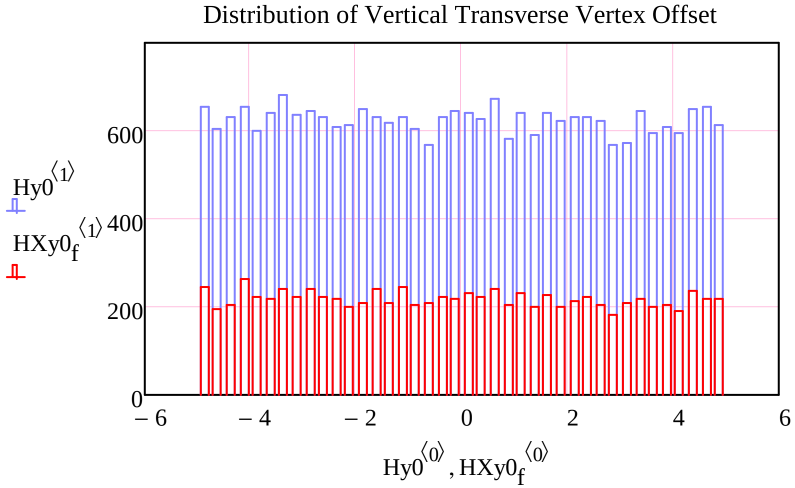




$HXx0_f := \text{histogram}\left(nbin, Xz^{\langle 2 \rangle}\right)$

$HXy0_f := \text{histogram}\left(nbin, Xz^{\langle 3 \rangle}\right)$





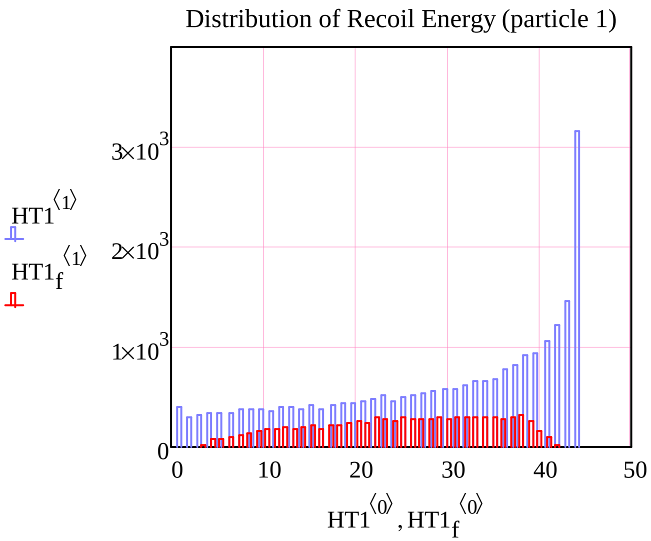
$HT1 := \text{histogram}\left(nbin, X^{\langle 21 \rangle}\right)$

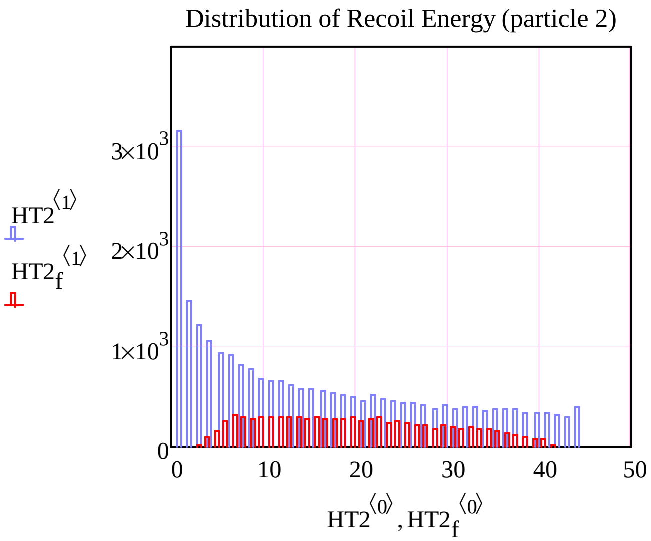
$HT1_f := \text{histogram}\left(nbin, Xz^{\langle 21 \rangle}\right)$

$HT2 := \text{histogram}\left(nbin, X^{\langle 22 \rangle}\right)$

$HT2_f := \text{histogram}\left(nbin, Xz^{\langle 22 \rangle}\right)$

Total acceptance $\frac{\text{rows}(Xz)}{\text{rows}(X)} = 0.349$



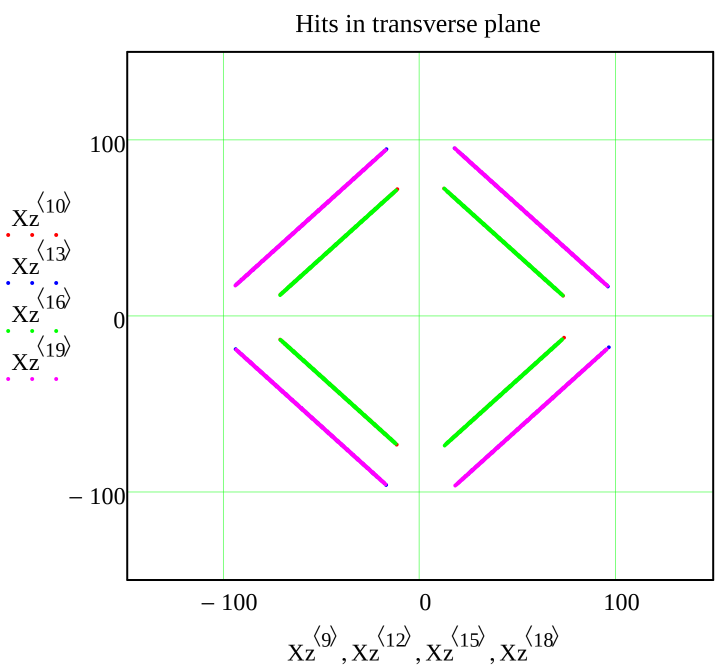


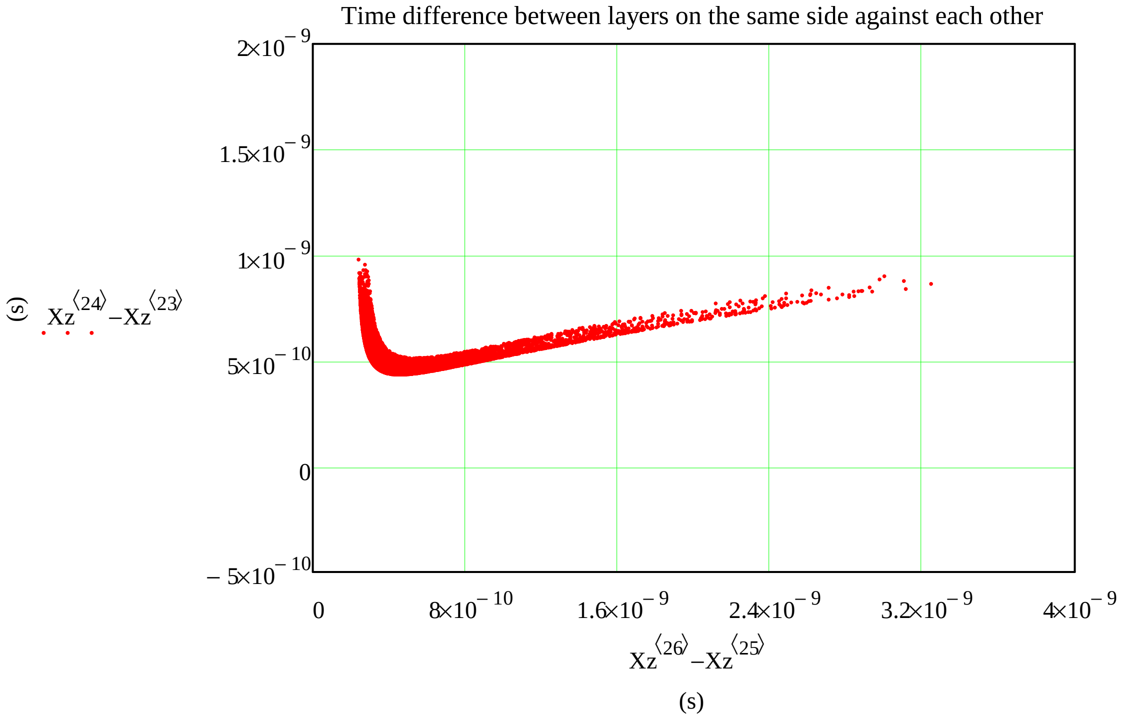
$\max\left(Xz^{\langle 21 \rangle}\right) = 42.517$ MeV

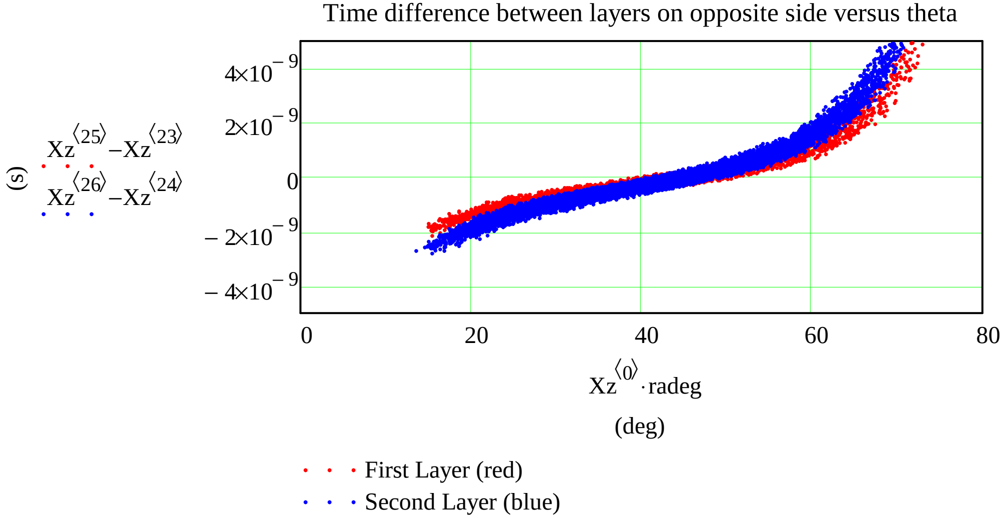
$\min\left(Xz^{\langle 21 \rangle}\right) = 3.078$ MeV

$Hl0x_f := \text{histogram}\left(nbin, Xz^{\langle 9 \rangle}\right)$ $Hl0y_f := \text{histogram}\left(nbin, Xz^{\langle 10 \rangle}\right)$

Plot distribution of time difference between layers







$$\left.\overline{\left.\right) - \text{Si1\_3D}(l,i)_1\Big)^2}\right]$$

$$\left.\left.\left.\mathrm{tq}\left(1,\varphi 0_{r_i}\right)\right)_0\right) - \mathrm{Si2\_3D}(1,i)_1\right)^2\Bigg]$$