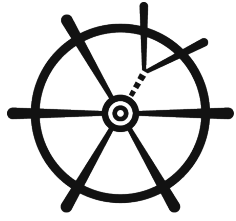

Tracker calibration studies in FairShip

Kevin Sedlaczek

July to September 2017

Summer Student Programme

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2. data sets
3. reconstructed distance to target
4. particle flux in strawtubes
5. summary
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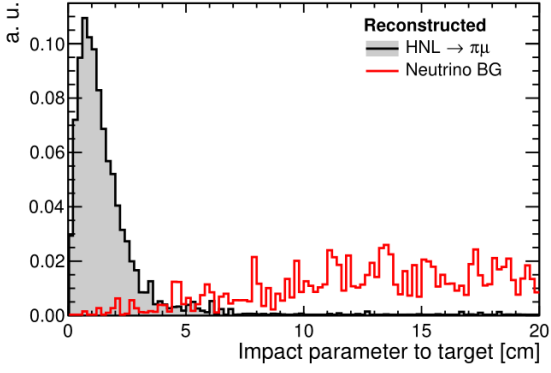
motivation



1. check for reconstruction effects on MC truth
2. reconstruct target position from measured tracks?
3. how accurate is the IP?
4. calibration of strawtubes
5. → what is the expected flux at tracker?

Used data sets

- Working with different samples that vary in the **magnetic field of the muon shield**
- Constructed via the FairShip framework
  - `run_SimScript.py` with flags `--MuonBack --FollowMuon` and `--Field` customized to change the field of the muon shield.
  - `ShipReco.py` to simulate the reconstruction and detector
  - files with different magnetic fields `muShield.B` of the muon shield
  - And also without any magnetic field in all detector components before T1 (`c.tauMS.B`= 1,5 T/`c.EmuMagnet.B`= 1 T)
  - samples with 100 000 events

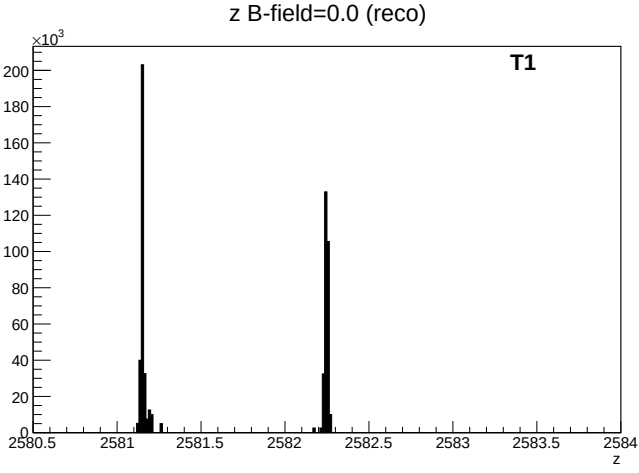
Calculated distance to target (impact parameter)

Calculation of impact parameter

The reconstructed tracks (namely the fitted states) are accessed via:

```
523 for event in t00:
524     for track in event.FitTracks:
525         state = track.getFittedState()
526         mom = state.getMom()
527         pos = state.getPos()
528         pdg = state.getPDG()
529
```

They yield a spatial vector $\vec{r}_{\text{track}} = (x, y, z)$ and a momentum vector $\vec{p} = (p_x, p_y, p_z)$. The spatial vector is used as a starting point, while the momentum vector defines the direction. The so defined straight line in 3D space can then be extrapolated to the z-component of the target centre.


z B-field=0.0 (reco)
×10^3
T1
200
180
160
140
120
100
80
60
40
20
0
2580.5
2581
2581.5
2582
2582.5
2583
2583.5
2584
z

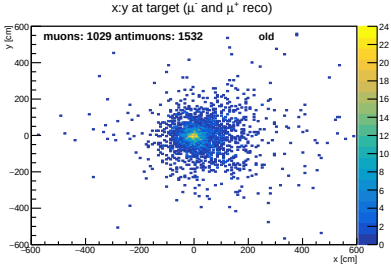
Calculation of impact parameter

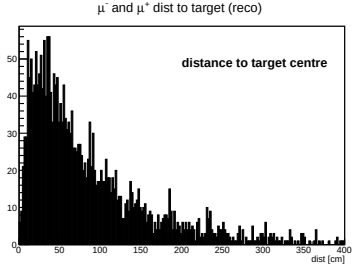
- The target centre is located at $z_t = -7067.0$, so that the x and y coordinates of the fitted tracks can be calculated.
- So the track is described by

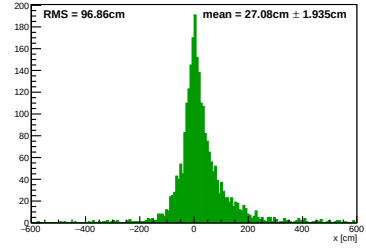
$$\vec{r}(t) = \vec{p} \cdot t + \vec{r}_{\text{track}} \tag{1}$$

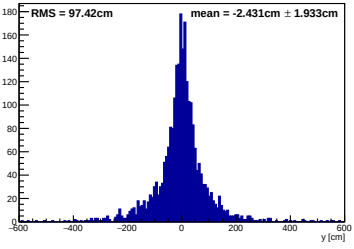
Thus one only needs to calculate the t for the z-component and apply it to x and y.

- $t = \frac{z_{\text{target}} - z}{p_z}$
- $x_{\text{target}} = p_x \cdot t + x$
- $y_{\text{target}} = p_y \cdot t + y$
- this then gives the distance in the x-y-plane: $d = \sqrt{x_{\text{target}}^2 + y_{\text{target}}^2}$


x:y at target (μ⁻ and μ⁺ reco)
muons: 1029 antimuons: 1532
old
y [cm]
x [cm]


μ⁻ and μ⁺ dist to target (reco)
distance to target centre
dist [cm]


x projection of μ⁻ and μ⁺ positions at target
RMS = 96.86cm
mean = 27.08cm ± 1.935cm
x [cm]

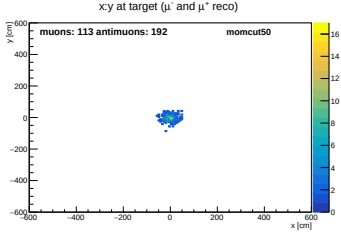

y projection of μ⁻ and μ⁺ positions at target
RMS = 97.42cm
mean = -2.431cm ± 1.933cm
y [cm]

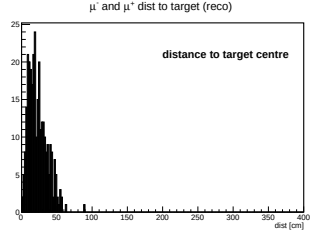
μ^+	all momenta	$p > 10$ GeV	$p < 10$ GeV
mean x /cm	$23{,}84 \pm 2{,}38$	$9{,}4 \pm 1{,}5$	$53{,}37 \pm 6{,}39$
mean y /cm	$-0{,}733 \pm 2{,}356$	$-0{,}12 \pm 1{,}56$	$-1{,}93 \pm 6{,}26$
RMS x /cm	92,28	46,73	142,1
RMS y /cm	92,27	49,6	142,7
μ^-	all momenta	$p > 10$ GeV	$p < 10$ GeV
mean x /cm	$29{,}31 \pm 3{,}17$	$8{,}13 \pm 1{,}95$	$64{,}38 \pm 7{,}45$
mean y /cm	$9{,}931 \pm 3{,}128$	$1{,}725 \pm 1{,}902$	$22{,}95 \pm 7{,}46$
RMS x /cm	102,3	49,74	147,4
RMS y /cm	102	48,58	151,3

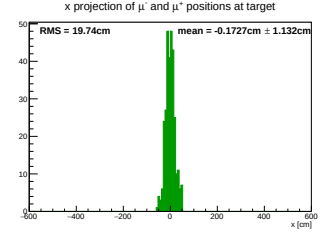
Table: Means and RMS of the x- and y-projections of the reconstructed IP.

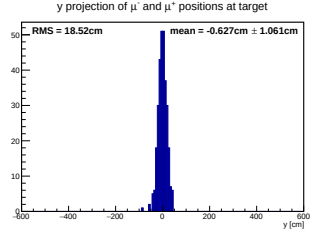
Dependence of asymmetry

- asymmetry in x-projection: mean shifted to one side
- mostly independent of charge of the muon
- momentum dependence: x- distribution moves to the same direction for both charges when setting momentum cuts


x:y at target (μ⁻ and μ⁺ reco)
muons: 113 antimuons: 192
momcut50
y [cm]
x [cm]


μ⁻ and μ⁺ dist to target (reco)
distance to target centre
dist [cm]


x projection of μ⁻ and μ⁺ positions at target
RMS = 19.74cm
mean = -0.1727cm ± 1.132cm
x [cm]

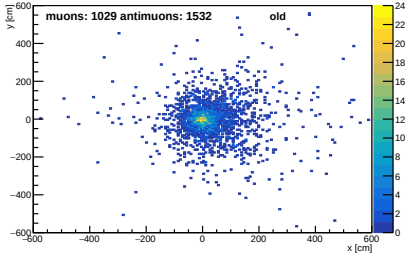

y projection of μ⁻ and μ⁺ positions at target
RMS = 18.52cm
mean = -0.627cm ± 1.061cm
y [cm]

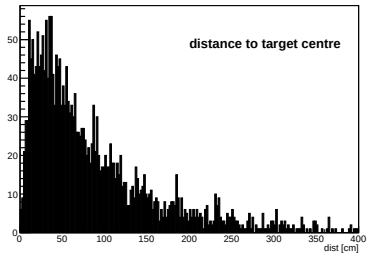
Dependence of asymmetry

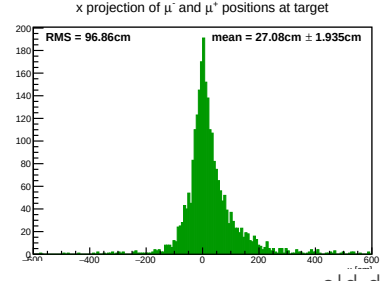
- asymmetry in x-projection: mean shifted to one side
- mostly independent of charge of the muon
- momentum dependence: x- distribution moves to the same direction for both charges when setting momentum cuts
- almost gone for momentum-cut above 50 GeV

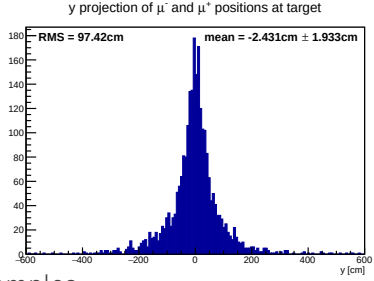
Also occured when using the extrapolator to go to $z = 0$ and using a linear fit to go to the target.
Looking at the slopes of the true MC muon tracks, there were only muons with px>0 and py==0.

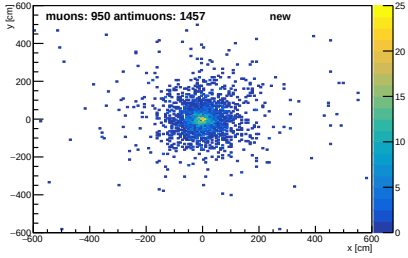
fix **bug** in MuonBackGenerator: phi=0 was used if phismearing was off instead of true phi

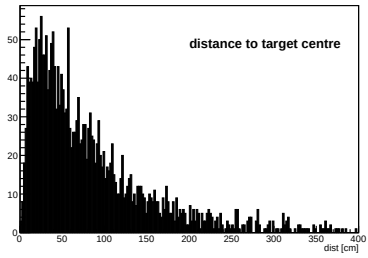

x:y at target (μ⁻ and μ⁺ reco)
muons: 1029 antimuons: 1532
old
y [cm]
x [cm]

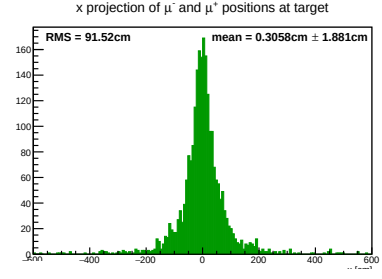

μ⁻ and μ⁺ dist to target (reco)
distance to target centre
dist [cm]

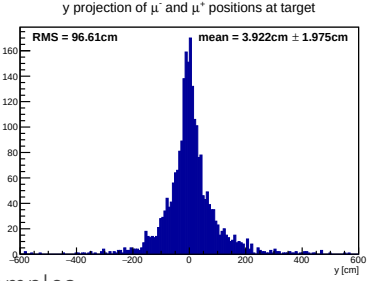

x projection of μ⁻ and μ⁺ positions at target
RMS = 96.86cm
mean = 27.08cm ± 1.935cm

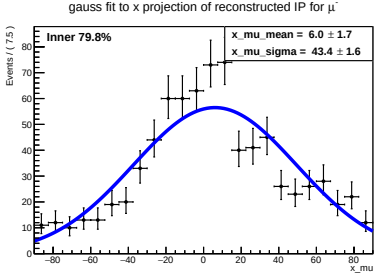

y projection of μ⁻ and μ⁺ positions at target
RMS = 97.42cm
mean = -2.431cm ± 1.933cm
y [cm]

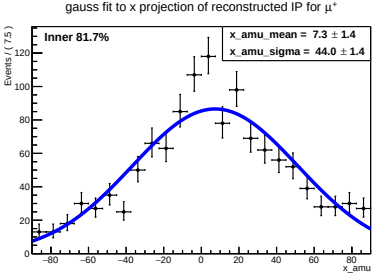

x:y at target (μ⁻ and μ⁺ reco)
muons: 950 antimuons: 1457
new
y [cm]
x [cm]

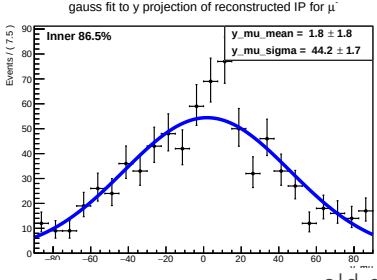

μ⁻ and μ⁺ dist to target (reco)
distance to target centre
dist [cm]

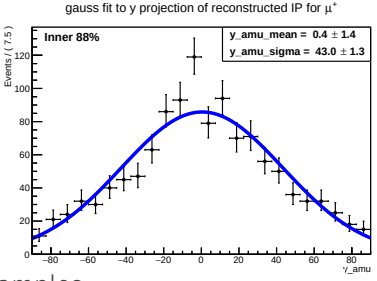

x projection of μ⁻ and μ⁺ positions at target
RMS = 91.52cm
mean = 0.3058cm ± 1.881cm


y projection of μ⁻ and μ⁺ positions at target
RMS = 96.61cm
mean = 3.922cm ± 1.975cm
y [cm]

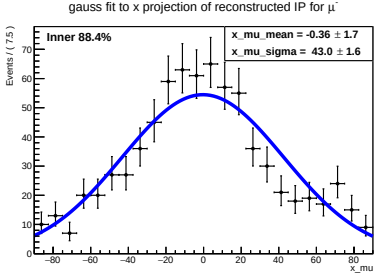


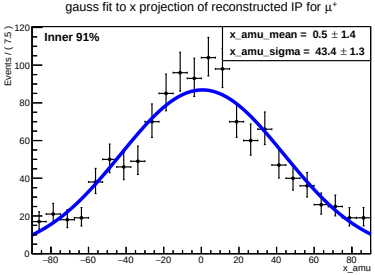


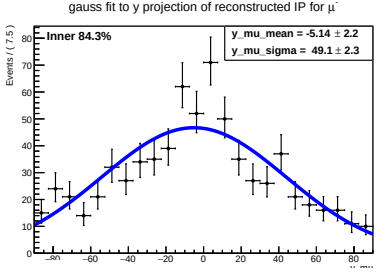


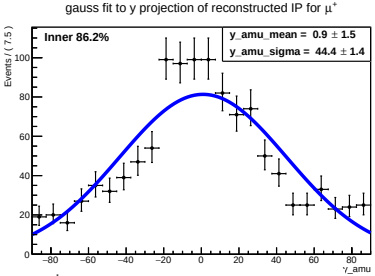


old data samples

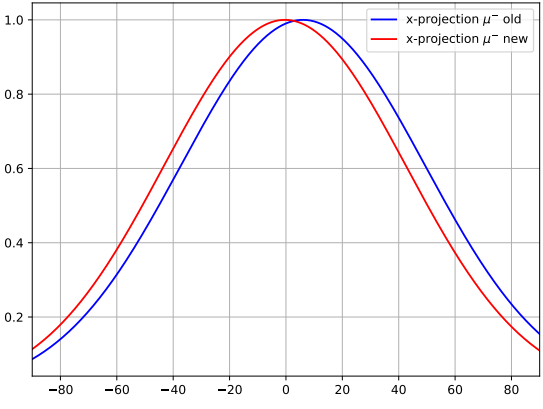

gauss fit to x projection of reconstructed IP for μ⁻
Inner 88.4%
x_mu_mean = -0.36 ± 1.7
x_mu_sigma = 43.0 ± 1.6
Events / (7.5)
x_mu

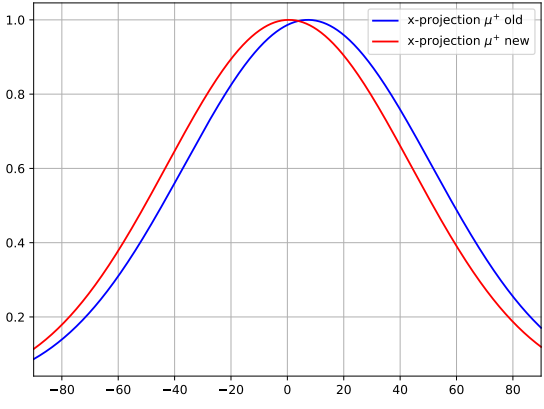

gauss fit to x projection of reconstructed IP for μ⁺
Inner 91%
x_amu_mean = 0.5 ± 1.4
x_amu_sigma = 43.4 ± 1.3
Events / (7.5)
x_amu


gauss fit to y projection of reconstructed IP for μ⁻
Inner 84.3%
y_mu_mean = -5.14 ± 2.2
y_mu_sigma = 49.1 ± 2.3
Events / (7.5)

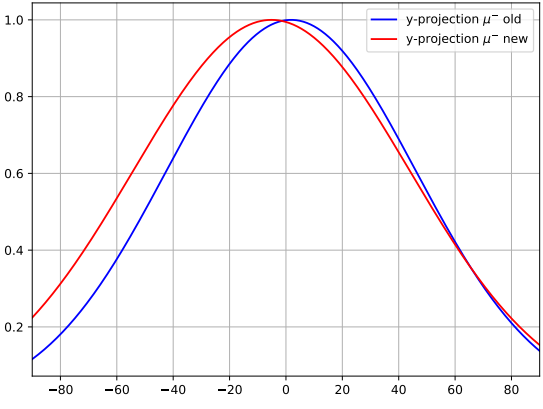

gauss fit to y projection of reconstructed IP for μ⁺
Inner 86.2%
y_amu_mean = 0.9 ± 1.5
y_amu_sigma = 44.4 ± 1.4
Events / (7.5)
y_amu

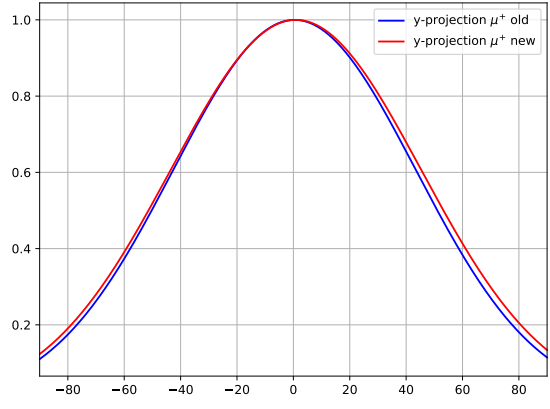
comparison of old and new files

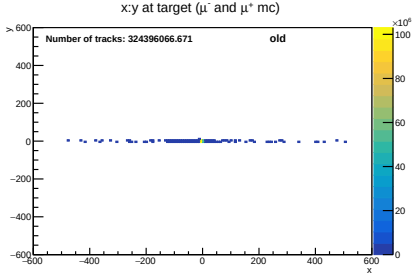


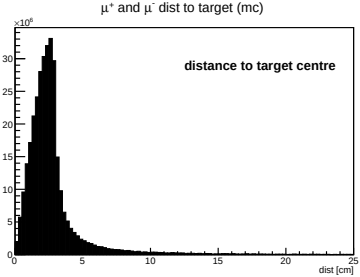


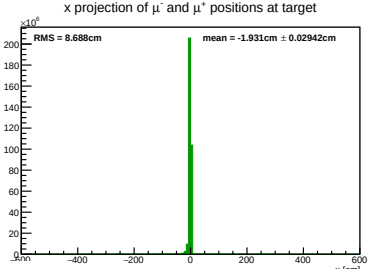
comparison of old and new files

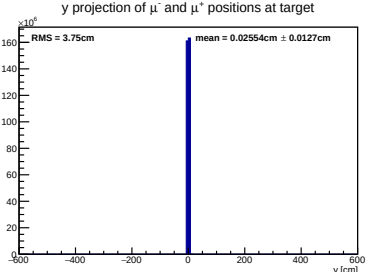




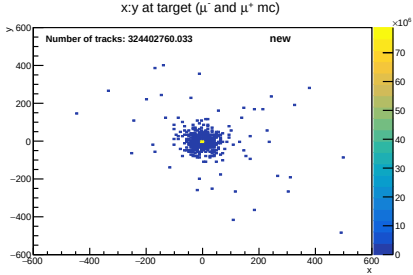


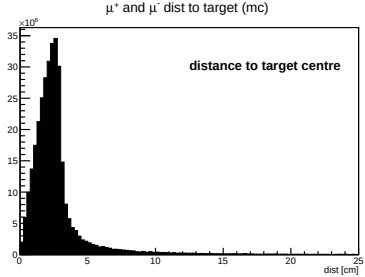


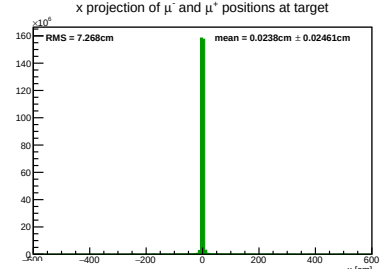


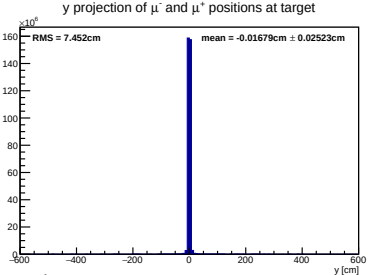


old data samples

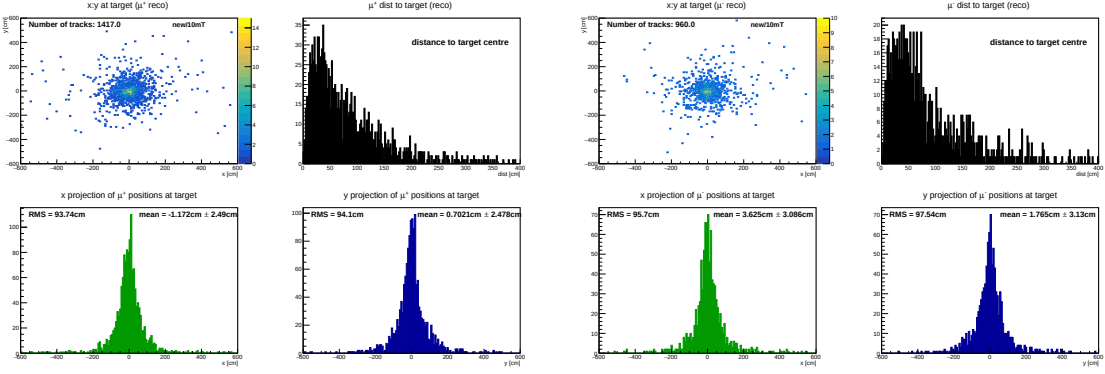

x:y at target (μ⁻ and μ⁺ mc)
Number of tracks: 324402760.033
new
y
x
×10⁶


μ⁺ and μ⁻ dist to target (mc)
distance to target centre
dist [cm]
×10⁶

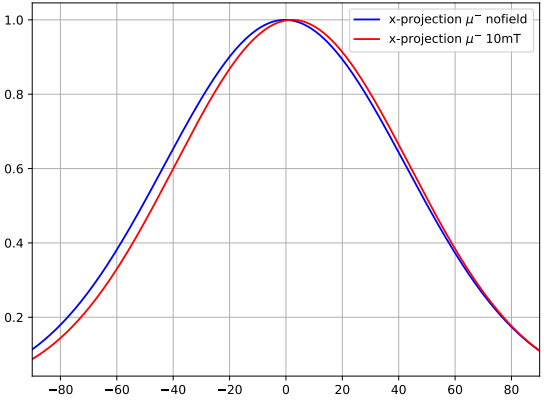

x projection of μ⁻ and μ⁺ positions at target
RMS = 7.268cm
mean = 0.0238cm ± 0.02461cm
×10⁶

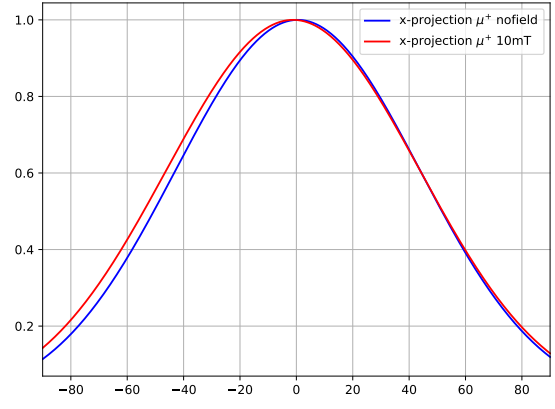

y projection of μ⁻ and μ⁺ positions at target
RMS = 7.452cm
mean = -0.01679cm ± 0.02523cm
y [cm]
×10⁶

Divided for μ^+ and μ^- all momenta but muon shield field = 10mT

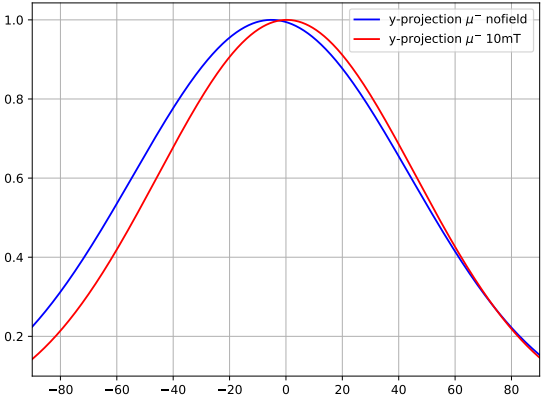


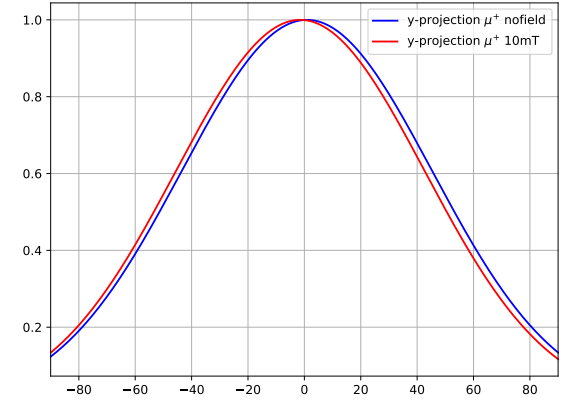
comparison of no field and 10mT in Muon shield





comparison of no field and 10mT in Muon shield





μ^+	$B_{\text{mu shield}} = 10\,\text{mT}$	$B_{\text{mu shield}} = 0\,\text{T}$
mean x /cm	$-1{,}16 \pm 1{,}50$	$0{,}512 \pm 1{,}394$
mean y /cm	$-1{,}45 \pm 1{,}47$	$0{,}911 \pm 1{,}477$
σ_x /cm	$45{,}03 \pm 1{,}46$	$43{,}40 \pm 1{,}32$
σ_y /cm	$44{,}13 \pm 1{,}41$	$44{,}43 \pm 1{,}42$
μ^-	$B_{\text{mu shield}} = 10\,\text{mT}$	$B_{\text{mu shield}} = 0\,\text{T}$
mean x /cm	$2{,}215 \pm 1{,}658$	$-0{,}363 \pm 1{,}741$
mean y /cm	$0{,}281 \pm 1{,}908$	$-5{,}136 \pm 2{,}199$
σ_x /cm	$41{,}76 \pm 1{,}52$	$42{,}965 \pm 1{,}630$
σ_y /cm	$45{,}72 \pm 1{,}88$	$49{,}077 \pm 2{,}296$

Table: Means and sigmas of the reconstructed IP for no magnetic field and a 10 mT field in the muon shield.

Investigation of particle flux in T1

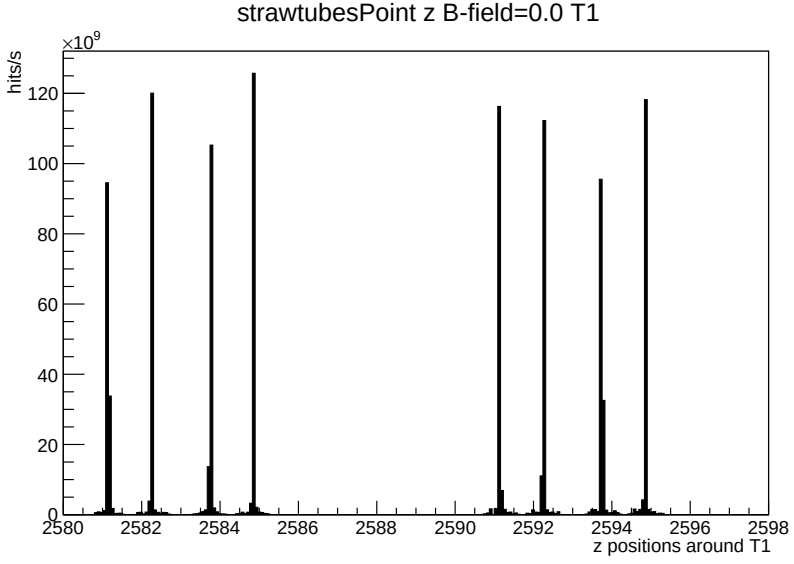
Investigation of particle flux in T1

- 4 strawtube stations in SHiP
- each one consists of 8 planes that are made of 2 layers of strawtubes
- 568 straws per layer $\rightarrow$ 1136 straws per plane $\rightarrow$ 9088 straws per station
- data samples with `--MuonBack` but without `--FollowMuon` to get total flux
- turned **off** the magnet of τ-station (1,5 T) and the `EMuMagnet` (1,0 T)

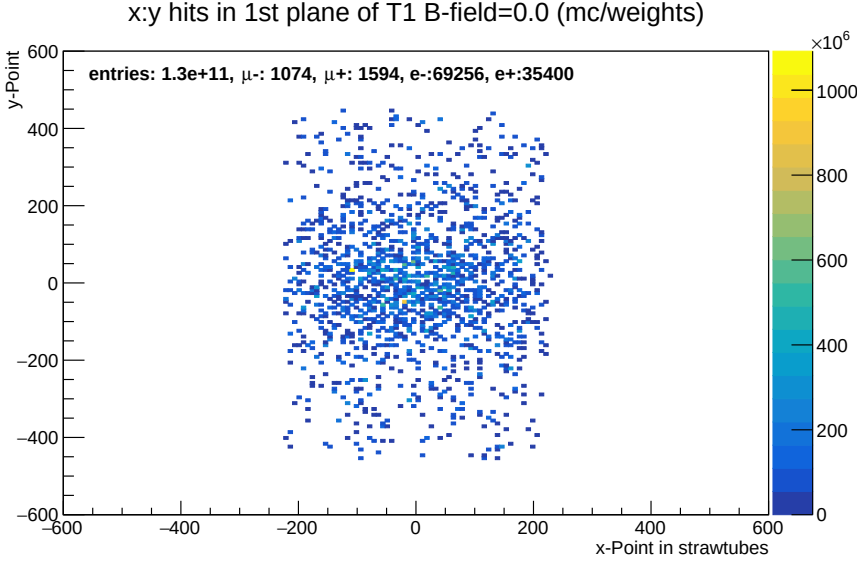
Investigation of particle flux in T1

To get the total flux per spill:

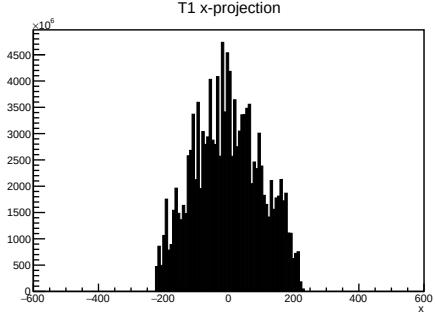
- apply Monte Carlo **weights** (2571 or 4975) on the events.
- only 100 000 events, so additional factor $\frac{17\,786\,274}{100\,000}$ to get to the 17 786 274 events of the used file `/eos/ship/data/Mbias/pythia8_Geant4-withCharm_onlyMuons_4magTarget.root`.
- count `strawtubesPoint` hits in range of first plane (arbitrary choice) so between $z = 2580$ and $z = 2581.5$.

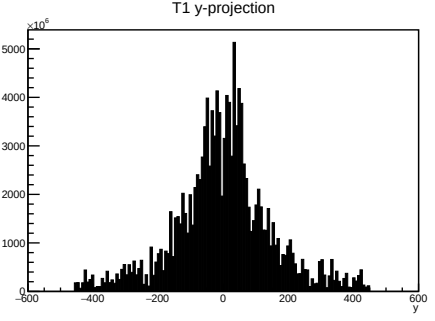


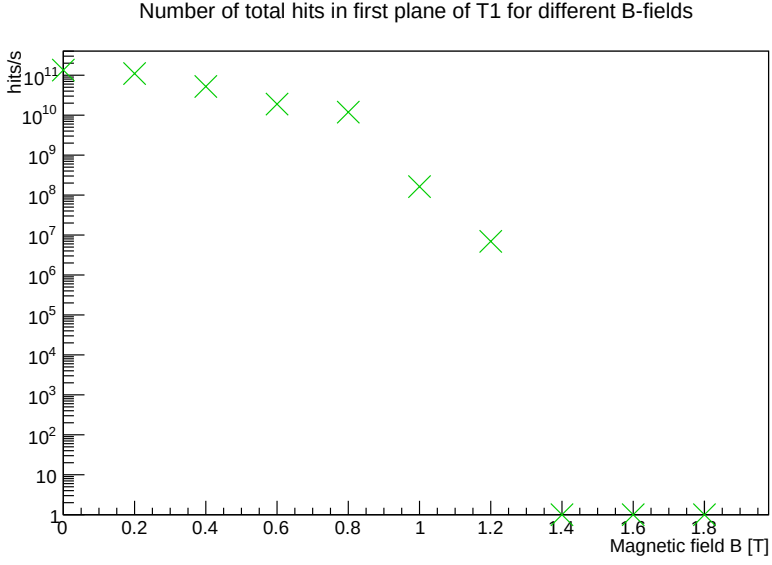
Particle flux in T1

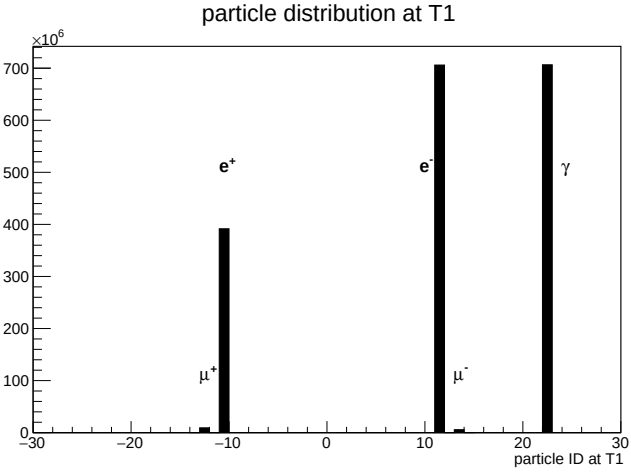


Particle flux in T1


T1 x-projection
×10^6
4500
4000
3500
3000
2500
2000
1500
1000
500
0
−600
−400
−200
0
200
400
600
x


T1 y-projection
×10^6
5000
4000
3000
2000
1000
0
−600
−400
−200
0
200
400
600
y


Number of total hits in first plane of T1 for different B-fields
hits/s
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Magnetic field B [T]


particle distribution at T1
×10^6
700
600
500
400
300
200
100
0
e+
e-
γ
μ+
μ-
−30
−20
−10
0
10
20
30
particle ID at T1

b-field [T]	hits/s in T1	hits/plane/s	hits/layer/s	hits/straw/s
0,0	$1{,}058 \cdot 10^{12}$	$1{,}344 \cdot 10^{11}$	$6{,}724 \cdot 10^{10}$	$1{,}183 \cdot 10^{8}$
0,2	$8{,}848 \cdot 10^{11}$	$1{,}101 \cdot 10^{11}$	$5{,}506 \cdot 10^{10}$	$9{,}694 \cdot 10^{7}$
0,4	$4{,}037 \cdot 10^{11}$	$5{,}229 \cdot 10^{10}$	$2{,}614 \cdot 10^{10}$	$4{,}603 \cdot 10^{7}$
0,6	$1{,}657 \cdot 10^{11}$	$1{,}895 \cdot 10^{10}$	$9{,}474 \cdot 10^{9}$	$1{,}668 \cdot 10^{7}$
0,8	$8{,}816 \cdot 10^{10}$	$1{,}191 \cdot 10^{10}$	$5{,}952 \cdot 10^{9}$	$1{,}048 \cdot 10^{7}$
1,0	$7{,}971 \cdot 10^{8}$	$1{,}629 \cdot 10^{8}$	$8{,}145 \cdot 10^{7}$	$1{,}434 \cdot 10^{5}$
1,2	$2{,}081 \cdot 10^{7}$	$6{,}936 \cdot 10^{6}$	$3{,}468 \cdot 10^{6}$	$6{,}106 \cdot 10^{3}$

Table: Particle flux at T1 for different magnetic fields of the muon shield (all other fields turned off). Average calculated from hits in one plane, so the maximum rate varies locally.

summary

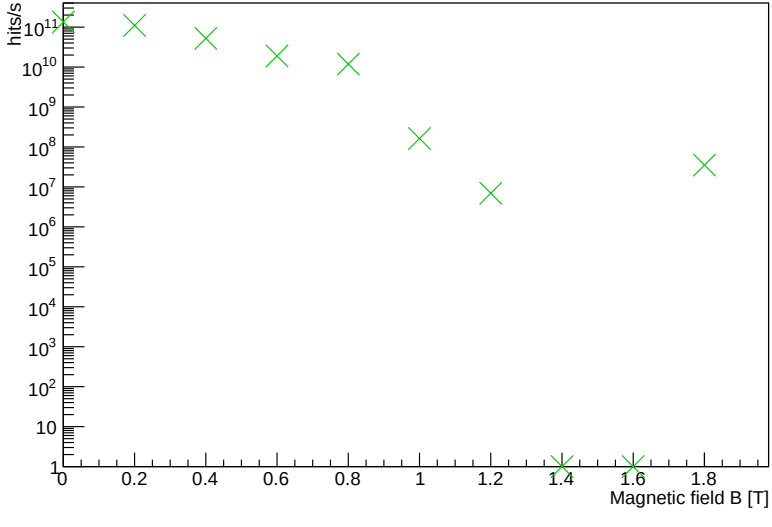
- At first: unexpectedly large asymmetry in x (no apparent physical reason)
- found a bug in MuonBackGenerator ($\rightarrow$ Thomas fixed it)
- new projection of IP looks as expected
- even 10 mT remnant field in muon shield doesn't shift the mean of the distribution much (x_{μ^+} : $(0{,}50 \pm 1{,}39)$ cm $\quad\rightarrow\quad$ $(-1{,}16 \pm 1{,}50)$ cm)
- particle flux can be regulated by the magnetic field of the muon shield over at least 5 orders of magnitude
- rates at certain fields seem to be managable with tracker $\rightarrow$ further more precise studies.

outlook

Of course, this can be improved. A few fields for further studies would be:

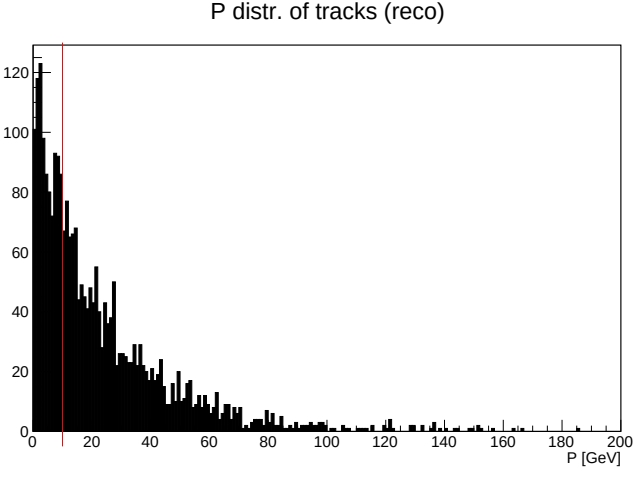
- examine bigger data samples
- investigate flux distribution within planes (not only average)
- use more exact extrapolation
- quantitatively compare accuracy of reconstructed IP to MC truth

Number of total hits in first plane of T1 for different B-fields

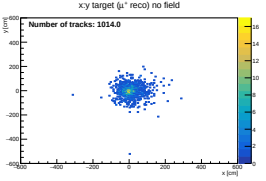


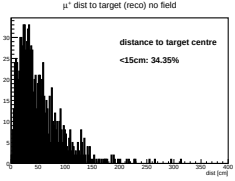
Back Up

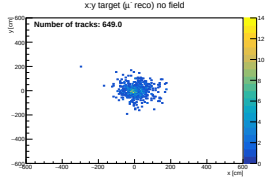
Momentum distribution of the tracks

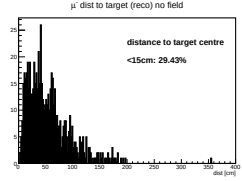


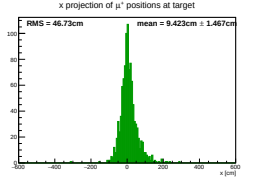
Divided for μ^+ and μ^- only momenta $>$ 10 GeV

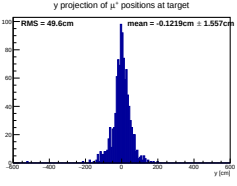


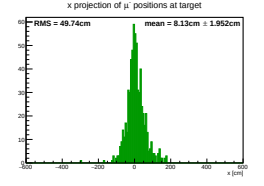


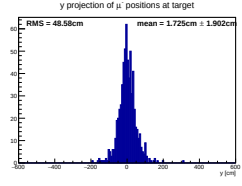












Divided for μ^+ and μ^- only momenta < 10 GeV