Covariance error matrix

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```
Particle generated: negative muon
       Eta range : -4 to 4
    P range: 0.5 to 20 GeV/c
       # of events: 10000
       Vertex: (0,0,0) mm
```

Topic of study:

```
trackparam.setLocError({0.1,0.1}); //covariance of location
trackparam.setMomentumError({0.05,0.05,0.05}); // covariance on theta/phi/q/p
trackparam.setTimeError(0.1); // error on time
```

These are the errors we currently set on the initial track parameters that go into the CKF from the seeder.

These values should be guided by the parameter resolutions *at the seed level*, and the effects of adjusting these parameters should be studied. We want to find the 'sweet spot' for these values.

Ongoing work: how does initial error matrix affect our tracking?

Parameters Covariance matrix

$$C = \begin{bmatrix} \sigma^2(l_0) & \mathrm{cov}(l_0,l_1) & \mathrm{cov}(l_0,\phi) & \mathrm{cov}(l_0,\theta) & \mathrm{cov}(l_0,q/p) \\ . & \sigma^2(l_1) & \mathrm{cov}(l_1,\phi) & \mathrm{cov}(l_1,\theta) & \mathrm{cov}(l_1,q/p) \\ . & . & \sigma^2(\phi) & \mathrm{cov}(\phi,\theta) & \mathrm{cov}(\phi,q/p) \\ . & . & . & \sigma^2(\theta) & \mathrm{cov}(\theta,q/p) \\ . & . & . & . & \sigma^2(q/p) \end{bmatrix}$$

Hit residual and chi-square

$$\mathrm{Res} = \vec{\mathrm{x}}_{\mathrm{calibrated}} - \mathrm{H}\vec{\mathrm{x}}_{\mathrm{predicted}}$$

$$\chi^2 = \mathrm{Res}^{\mathrm{T}}(\mathrm{C}_{\mathrm{calibrated}} + \mathrm{HC}_{\mathrm{predicted}}\mathrm{H}^{\mathrm{T}})^{-1}\mathrm{Res}$$

Evolution of parameters covariance

$$C^f = J \cdot C^i \cdot J^T,$$

$$J = \begin{bmatrix} \frac{\partial l_0^f}{\partial l_0^i} & \cdots & \frac{\partial l_0^f}{\partial (q/p)^i} \\ \vdots & \ddots & \vdots \\ \frac{\partial (q/p)^f}{\partial l_0^i} & \cdots & \frac{\partial (q/p)^f}{\partial (q/p)^i} \end{bmatrix},$$

H is observation matrix

$C_{calibrated}$ is measurement covariance

$C_{predicted}$ is predicted estimate covariance

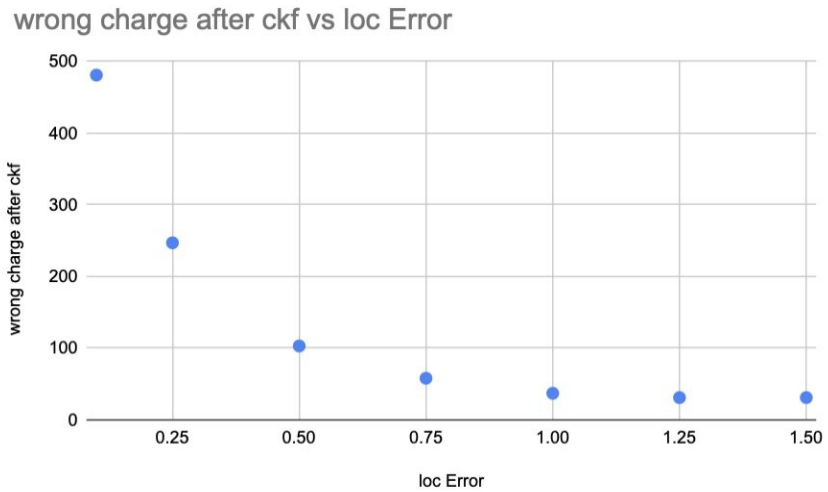
Loc Error

```
trackparam.setLocError({0.1,0.1}); //covariance of location
trackparam.setMomentumError({0.05,0.05,0.05}); // covariance on theta/phi/q/p
trackparam.setTimeError(0.1); // error on time
```

Wrong charge after CKF

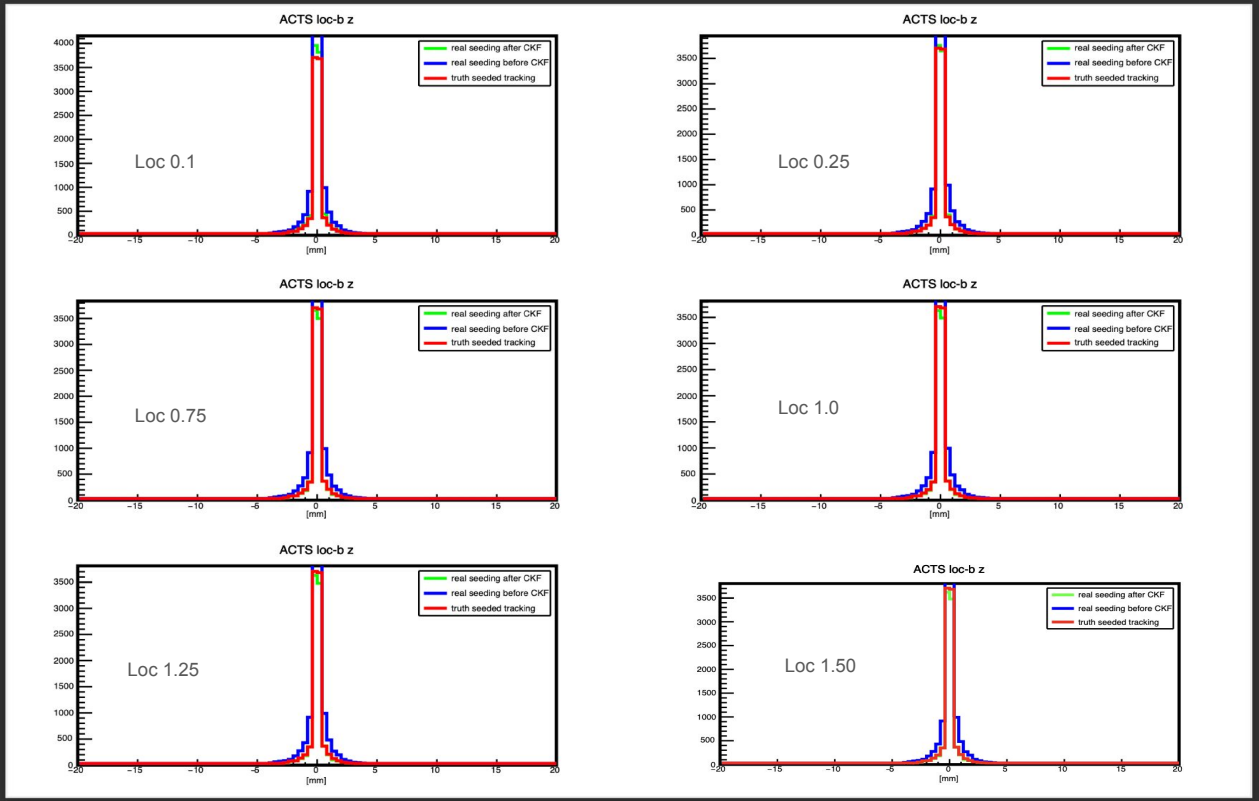
of wrong charge for unique real seeding after CKF decreases exponentially as we increase loc Error

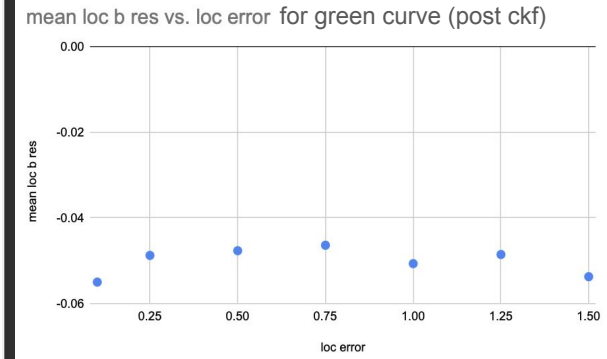
Total real seed after ckf = 27734
Unique real seed after ck ~ (9000,10000)
-Unique if two seeds' phi and theta difference is more than 2 mrad



Loc b resolution

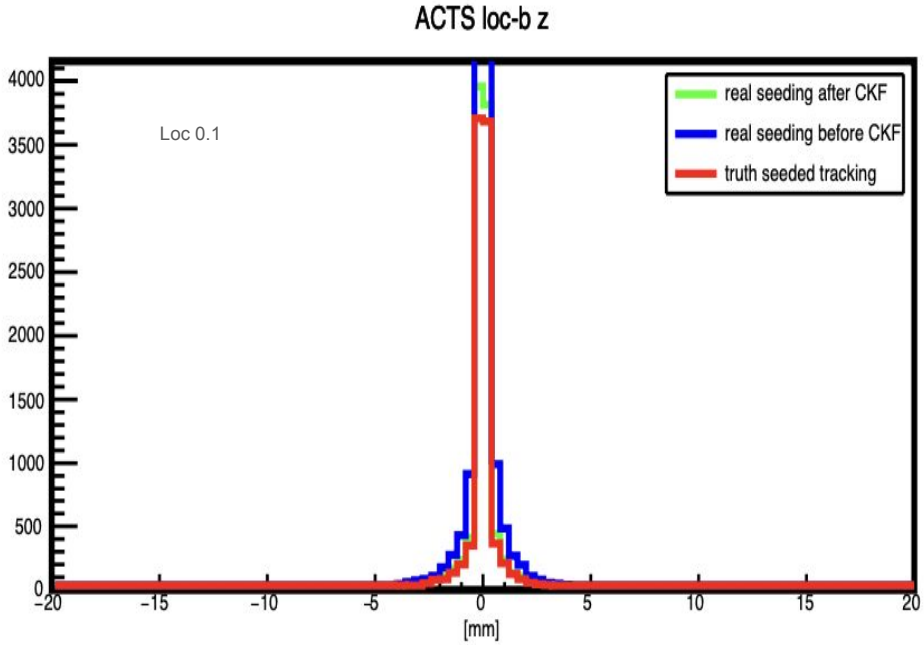
Loc b resolution is almost the same as we increase loc Error

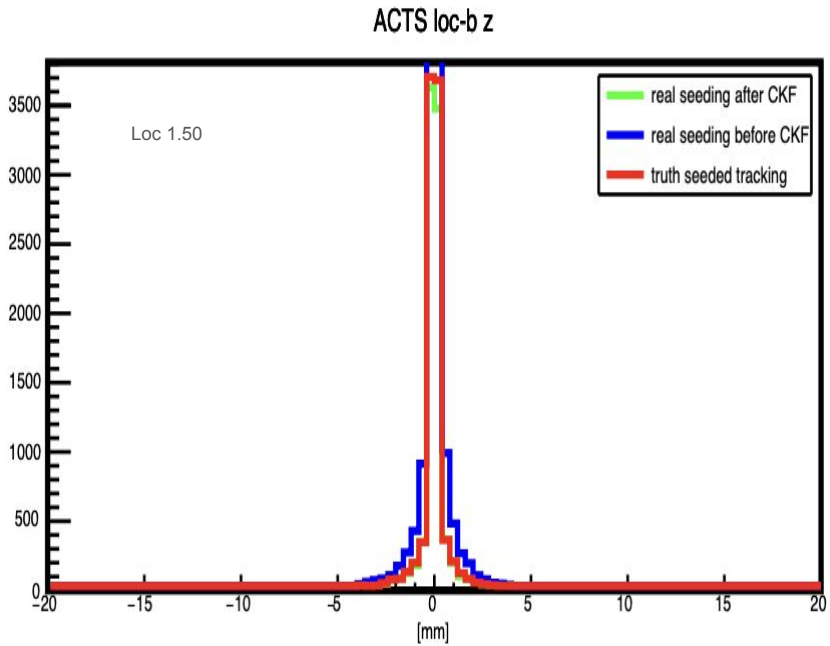




Revisiting Loc b resolution for loc 0.1 and 1.50 for a better view

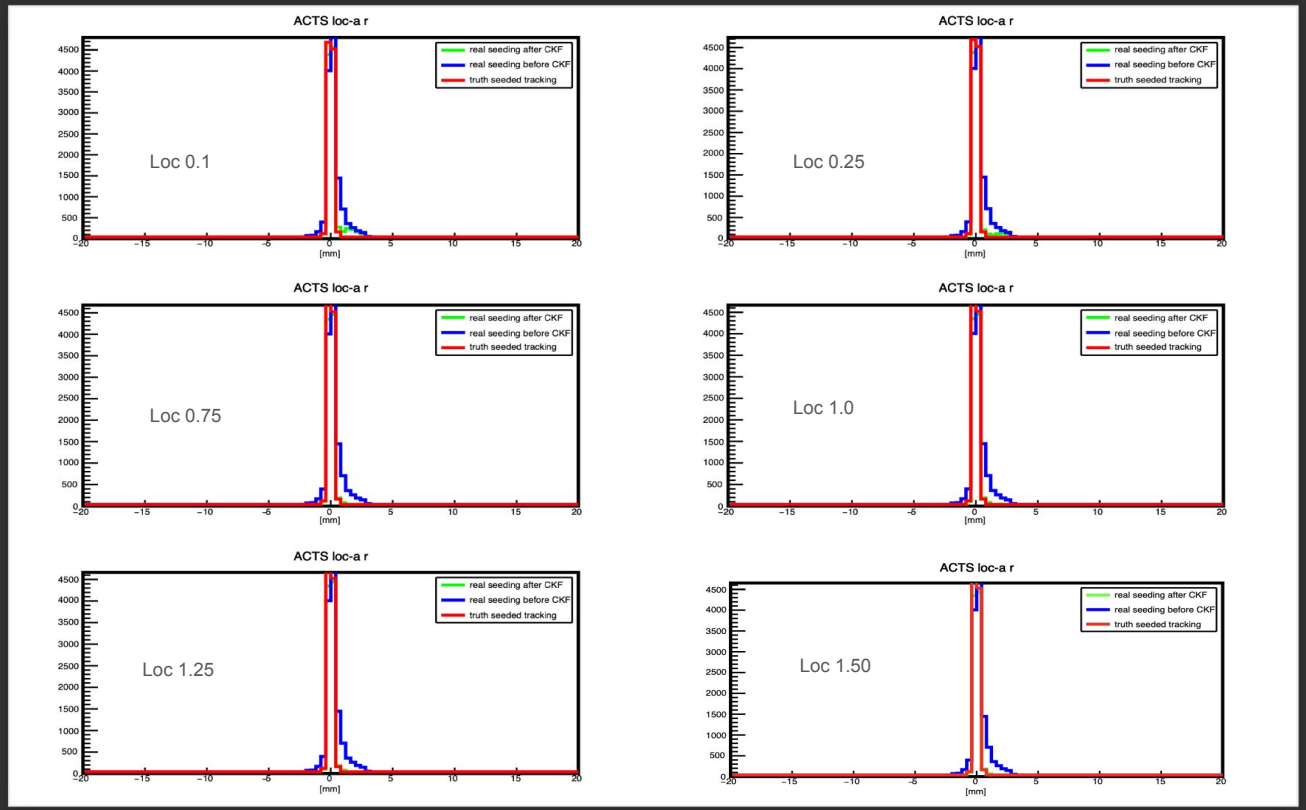
Loc b for real seeding after ckf remains symmetric for both loc 0.1 and 1.5



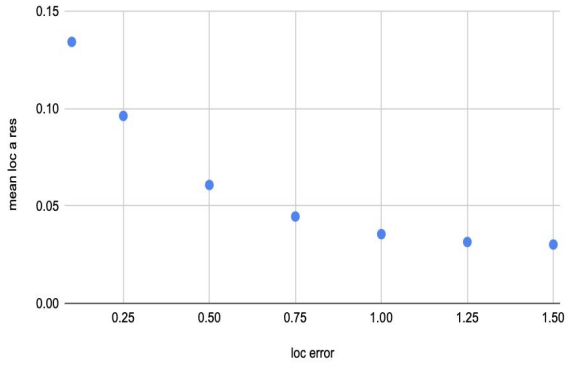


Loc a resolution

Loc a resolution becomes more symmetric as we increase loc Error

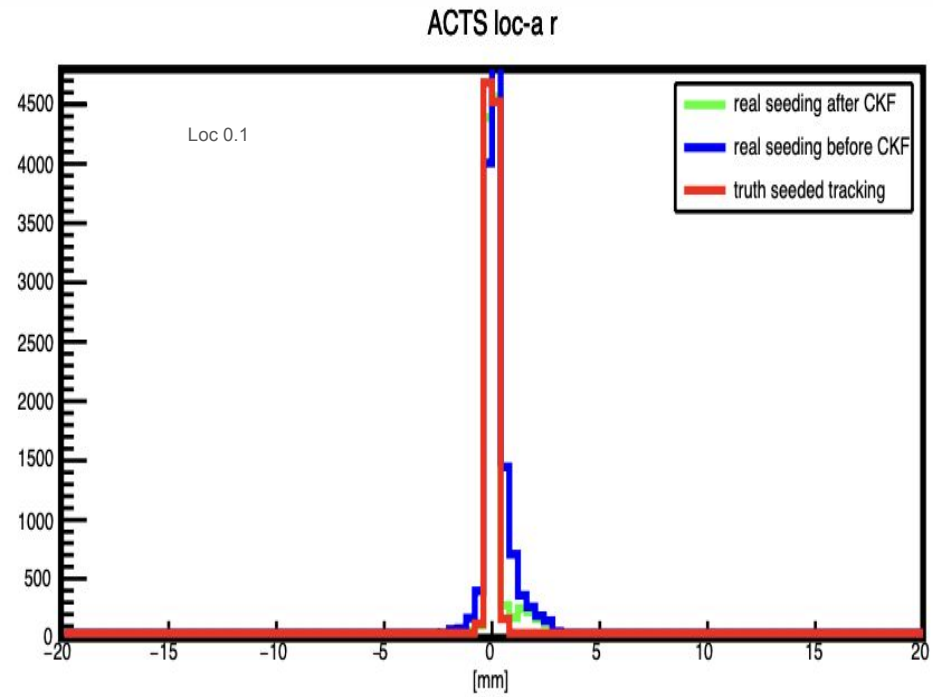


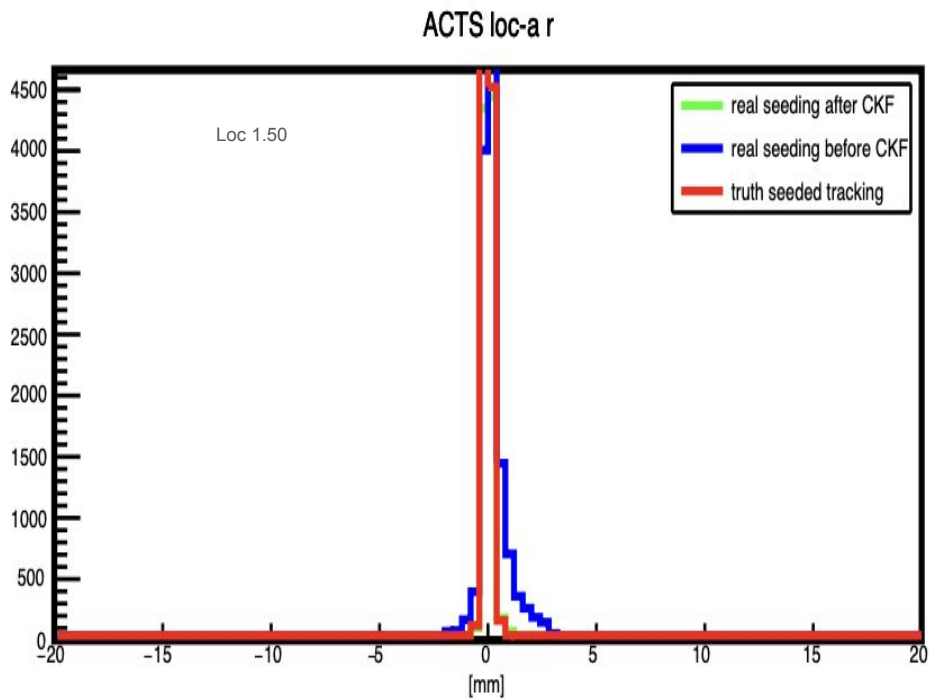
mean loc a res vs. loc error for green curve (post ckf)



Revisiting Loc a resolution for loc 0.1 and 1.5 for a better view

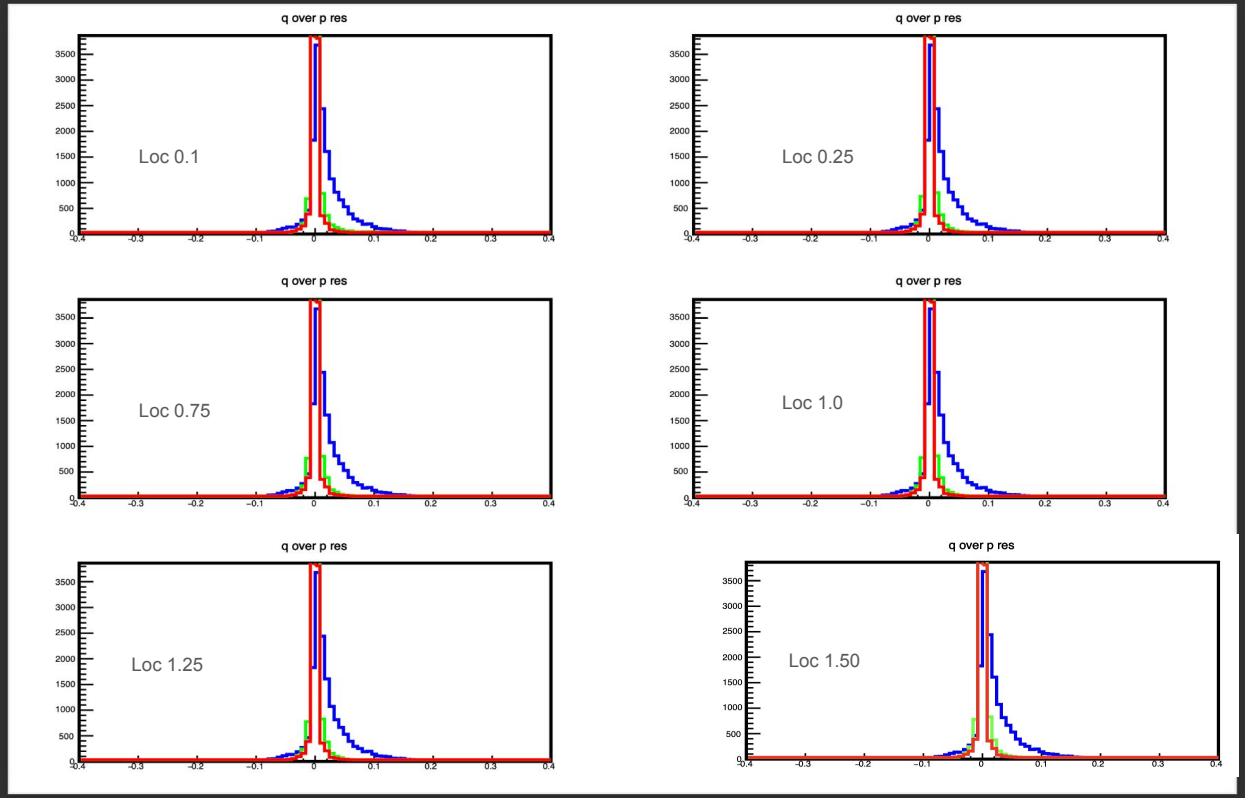
We observe an asymmetry in real seeding after ckf (green curve) for loc 0.1

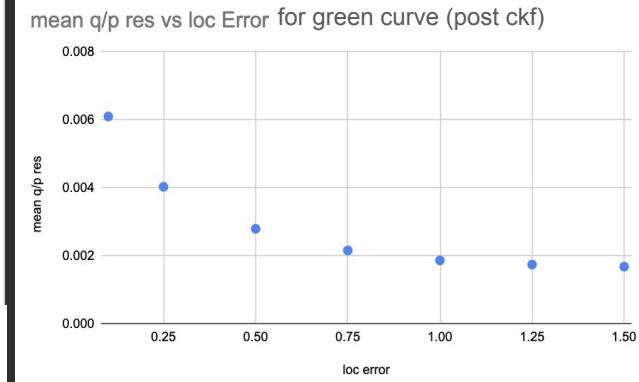




q/p resolution

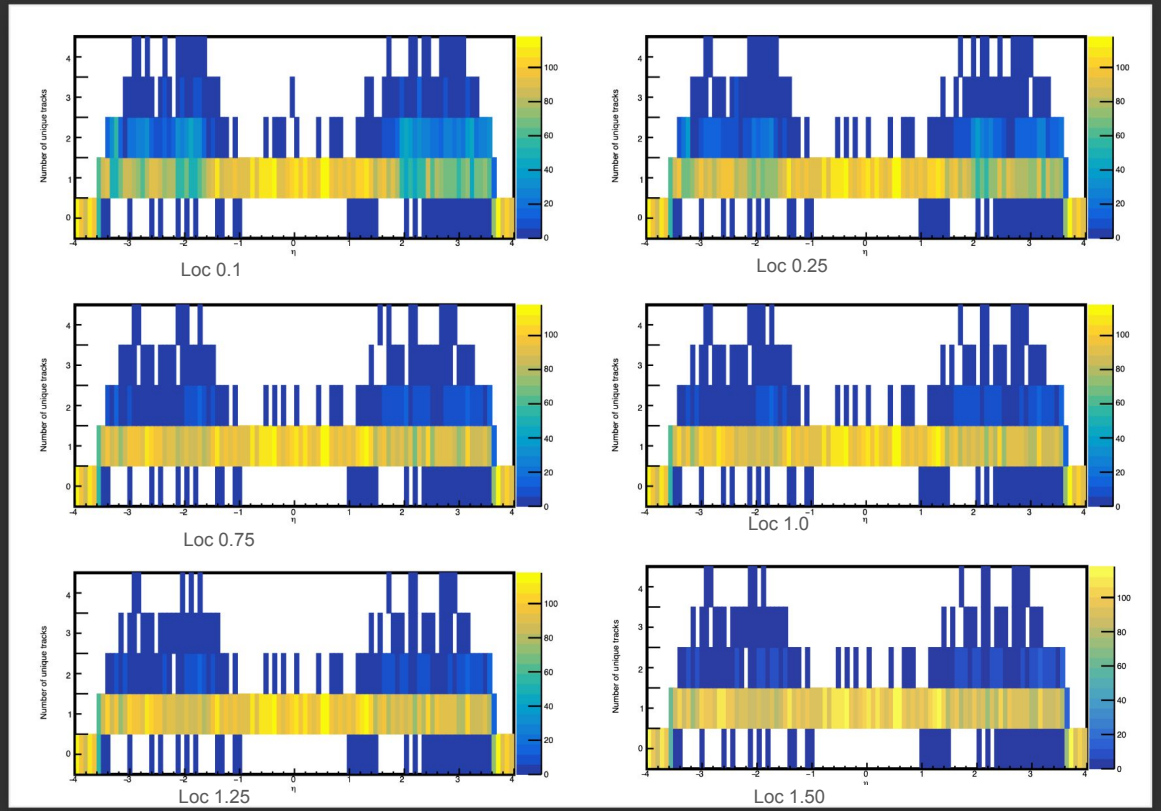
q/p resolution becomes more symmetric as we increase loc a error



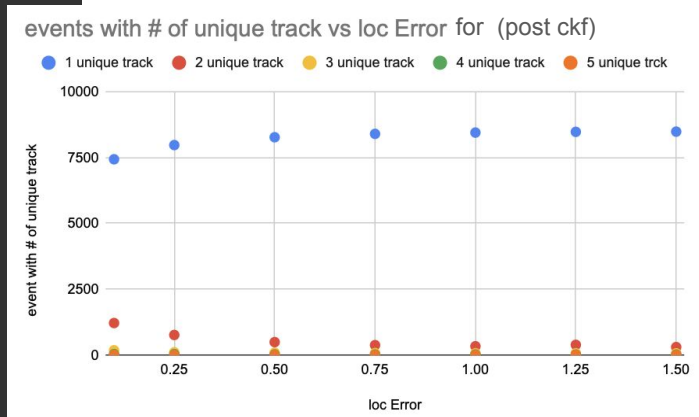


of unique tracks (angle cut 2 mrad)

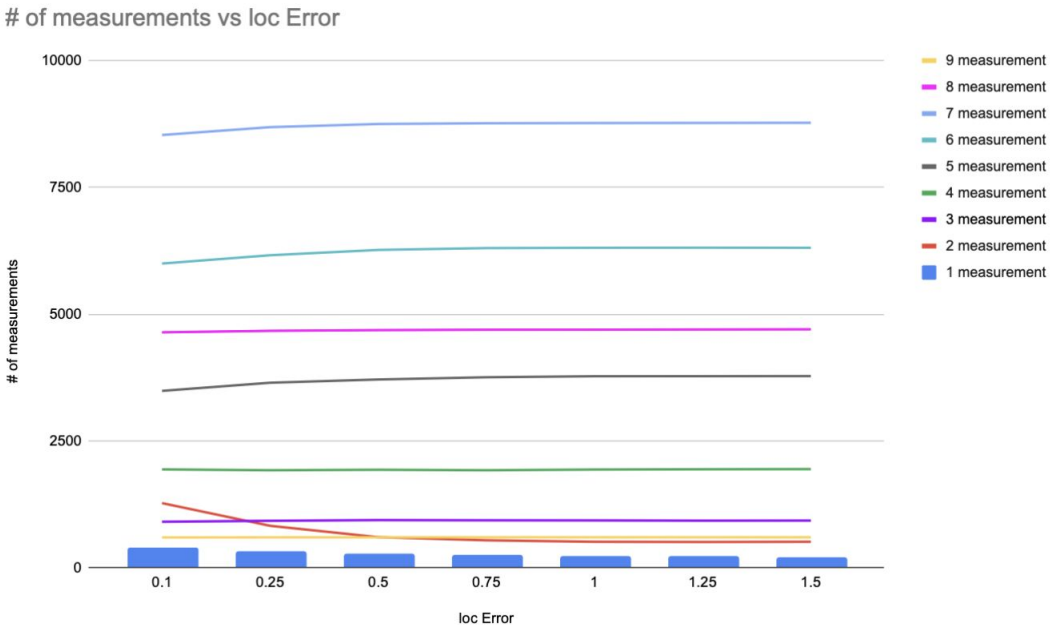
of 1 unique track increases as we increase loc error for real seeding after ckf

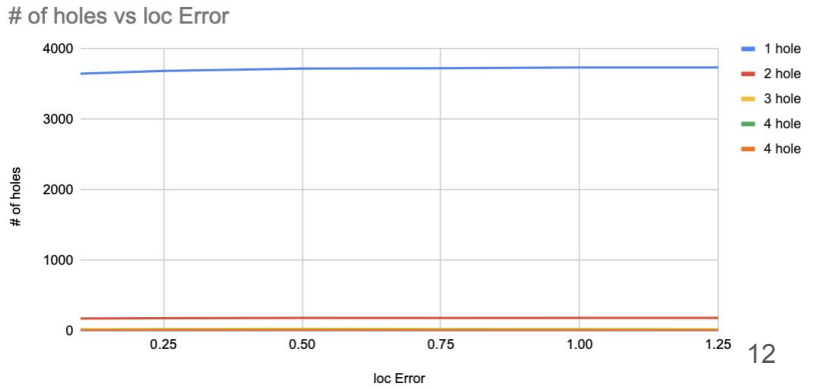


-Unique if two seeds' phi and theta difference is more than 2 mrad
-We throw away duplicate tracks
-increasing the loc (a,b) error reconstructs the duplicate tracks closer, so that we find more of one unique track instead of two unique tracks



of measurements, outliers, holes for real seeding after ckf

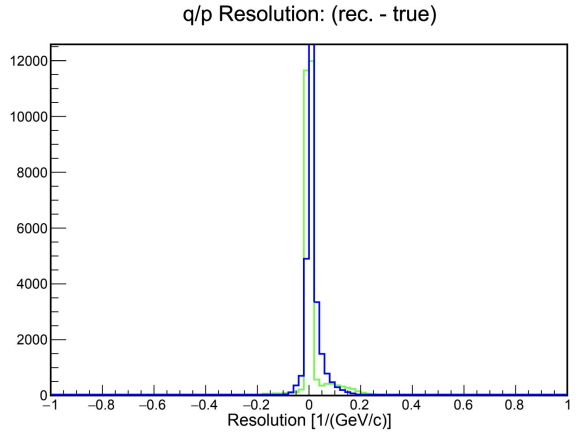


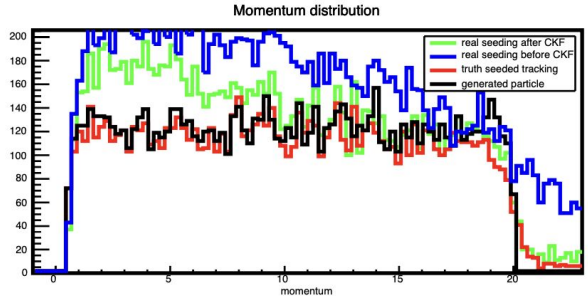


qOverp Error

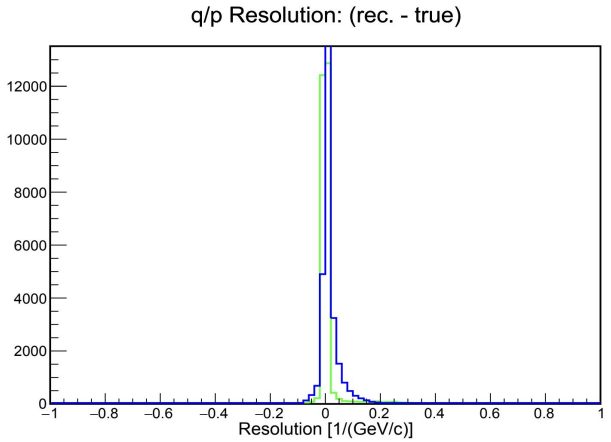
```
trackparam.setLocError({0.1,0.1}); //covariance of location
trackparam.setMomentumError({0.05,0.05,0.05}); // covariance on theta/phi/q/p
trackparam.setTimeError(0.1); // error on time
```

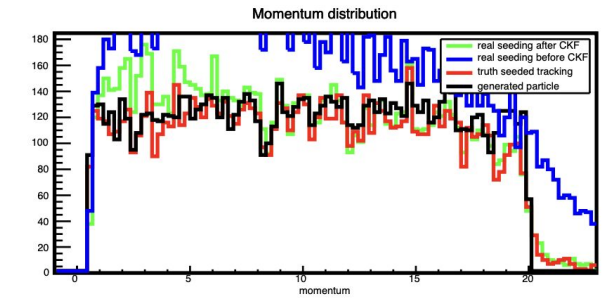
q/p res and p distribution (default parameter)





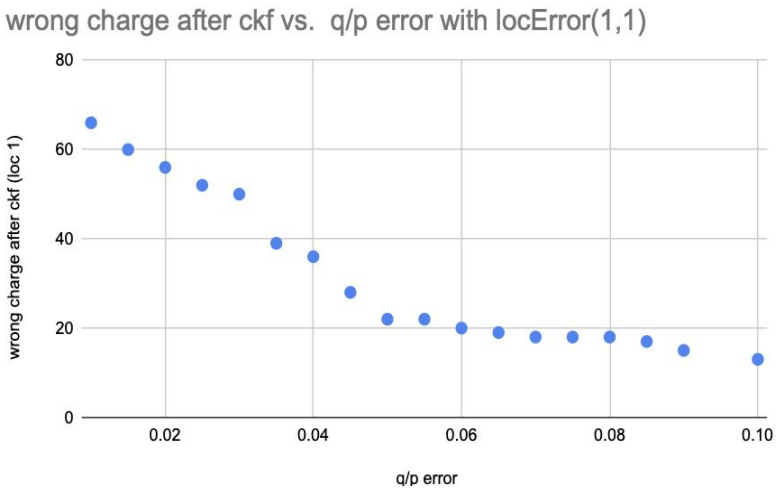
Previous ACTS/ePIC version



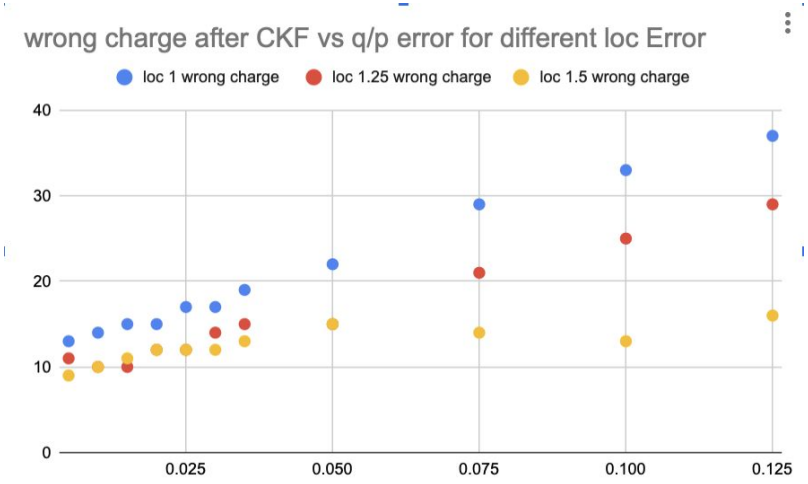


Current version

Wrong charge after CKF vs q/p error

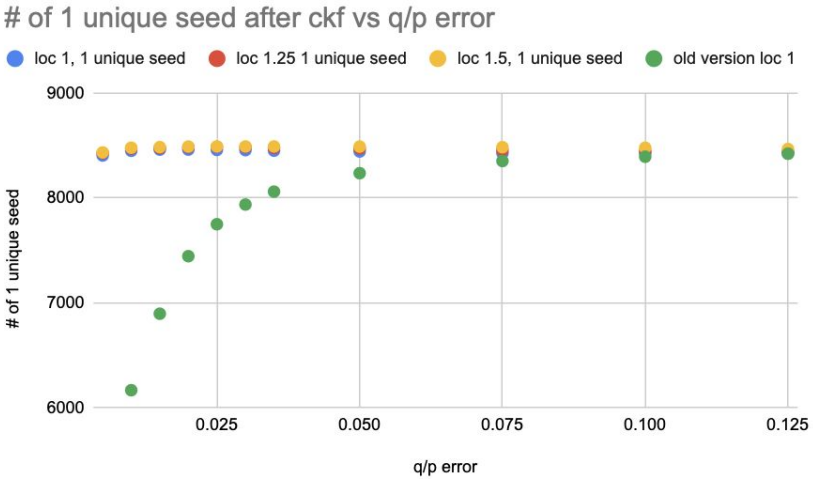


Previous ACTS/ePIC version

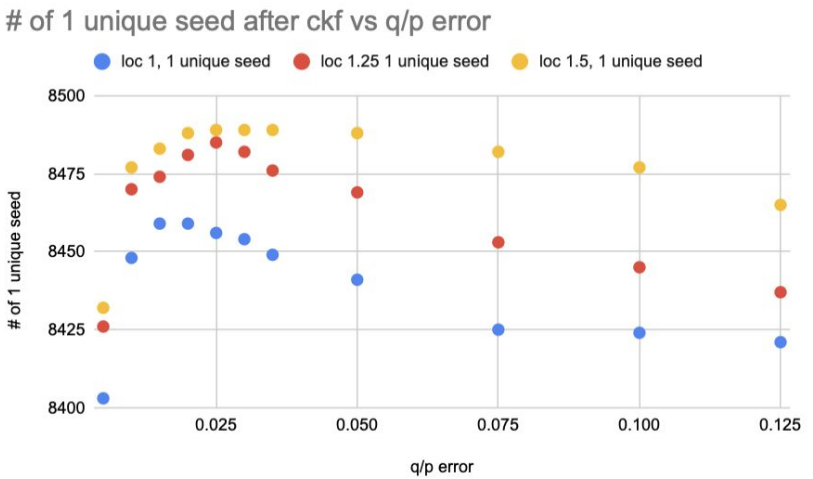


Current version

of 1 unique seed after ckf vs q/p error

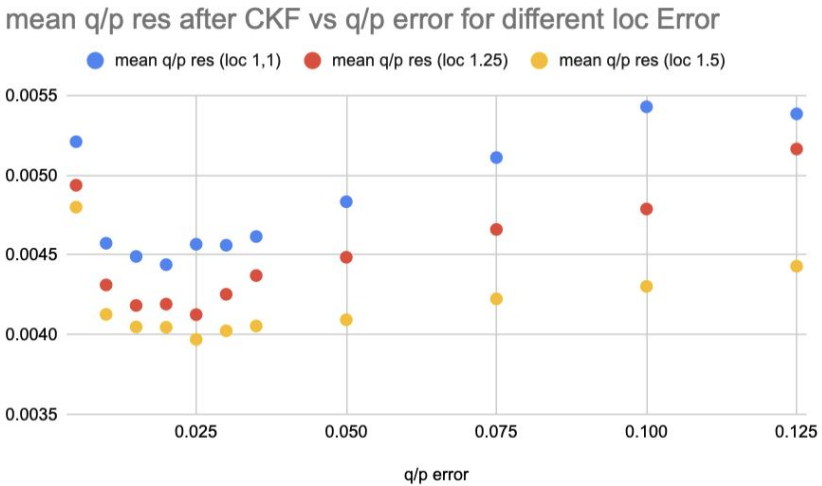


Current version



Current version

Mean q/p res vs q/p error



Current version

Summary

We observe better results as we increase loc (a,b) Errors

- We think a value between 1.0 to 1.5 would be good

We do not observe a huge change as we change q/p error, however there are some subtle differences

- We see improvement in data as we increase q/p error from 0.005 to 0.025, and after that, we see a very slow degradation in data
- A value around 0.025 looks good

As of now:

We have a new branch on EICrecon #1300 dedicated to the study of this cov error matrix

https://github.com/eic/EICrecon/issues/1300

These error values are hardcoded as of now. We propose to put them in a configuration file, so that we can change it on terminal and do more study!

EICrecon/src/algorithms/tracking/TrackSeeding.cc

Current Implementation:

```
edm4eic::Cov6f cov;
cov(0,0) = 0.1; // loc0
cov(1,1) = 0.1; // loc1
cov(2,2) = 0.05; // theta
cov(3,3) = 0.05; // phi
cov(4,4) = 0.05; // qOverP
cov(5,5) = 0.1; // time
trackparam.setCovariance(cov);
```

Our proposal:

```
edm4eic::Cov6f cov;
cov(0,0) = m_cfg.m_Loc_a_Error;
cov(1,1) = m_cfg.m_Loc_b_Error;
cov(2,2) = m_cfg.m_theta_Error;
cov(3,3) = m_cfg.m_phi_Error; //
cov(4,4) = m_cfg.m_qOverp_Error;
cov(5,5) = m_cfg.m_time_Error; /
trackparam.setCovariance(cov);
```

EICrecon/src/algorithms/tracking/OrthogonalTrackSeedingConfig.h

```
//// Error calculations
float m_Loc_a_Error = 0.1; //Error on Loc a
float m_Loc_b_Error = 0.1; //Error on Loc b
float m_theta_Error = 0.05; //Error on theta
float m_phi_Error = 0.05; //Error on phi
float m_qOverp_Error = 0.05; //Error on q over p
float m_time_Error = 0.1; //Error on time
```

Next: We also need to add these configurations in TrackSeeding_Factory.h

EICrecon/src/global/tracking/TrackSeeding_Factory.h

```
ParameterRef<float> m_Loc_a_Error {this, "Loc_a_Error", config().m_Loc_a_Error, "Error on Loc a for Acts::OrthogonalSeedFinder"};
 ParameterRef<float> m_Loc_b_Error {this, "Loc_b_Error", config().m_Loc_b_Error, "Error on Loc b for Acts::OrthogonalSeedFinder"};
 ParameterRef<float> m_theta_Error {this, "theta_Error", config().m_theta_Error, "Error on theta for Acts::OrthogonalSeedFinder"};
 ParameterRef<float> m_phi_Error {this, "phi_Error", config().m_phi_Error, "Error on phi for Acts::OrthogonalSeedFinder"};
 ParameterRef<float> m_qOverp_Error {this, "qOverp_Error", config().m_qOverp_Error, "Error on q over p for Acts::OrthogonalSeedFinder"};
 ParameterRef<float> m_time_Error {this, "time_Error", config().m_time_Error, "Error on time for Acts::OrthogonalSeedFinder"};
```

An example of how we can change these numbers on terminal and do our study

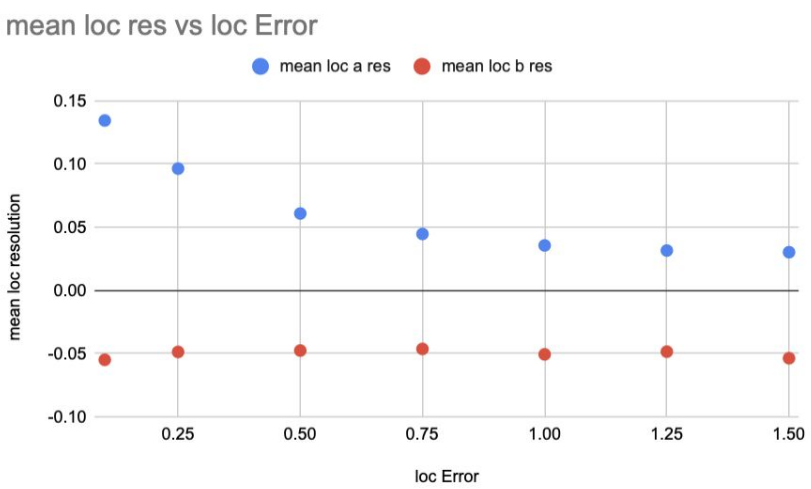
eicrecon -Ppodio:output_file=eicrecon_out_0_0_0testing.root -Pdd4hep:xml_files=epic_craterlake.xml -Pjana:nevents=10
-Ptracking:CentralTrackSeedingResults:qOverp_Error=0.03 -Ptracking:CentralTrackSeedingResults:Loc_a_Error=1
-Ptracking:CentralTrackSeedingResults:Loc_b_Error=1 output_0_0_0_10events.edm4hep.root

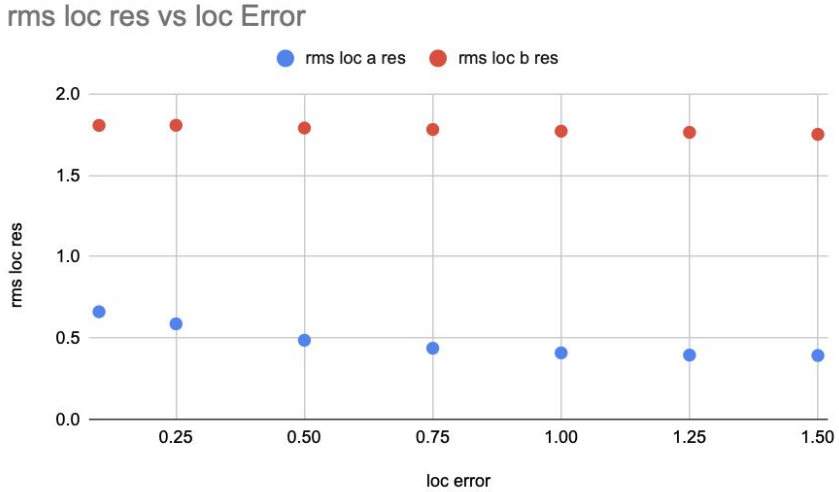
Next step:

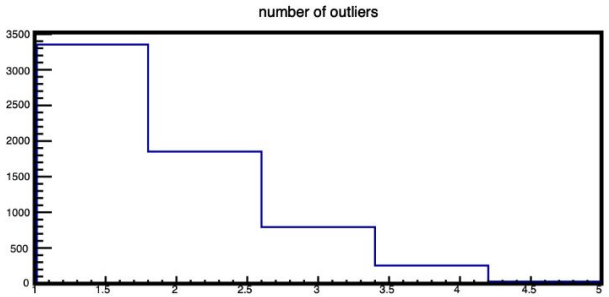
to study phi error and theta error

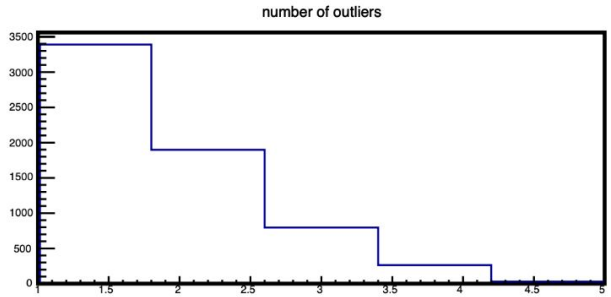
Thank you!

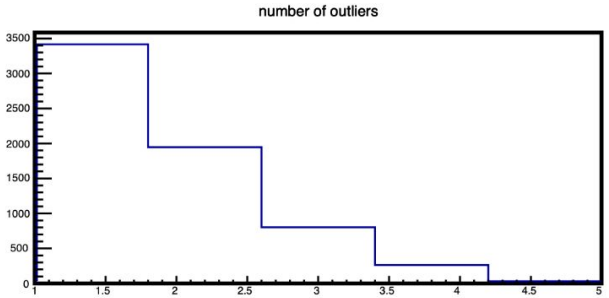
backup

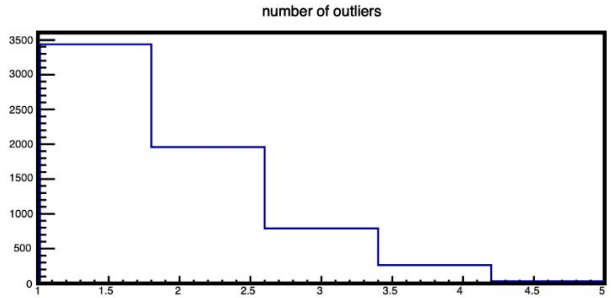

mean loc res vs loc Error
mean loc a res
mean loc b res
0.15
0.10
0.05
0.00
-0.05
-0.10
mean loc resolution
0.25
0.50
0.75
1.00
1.25
1.50
loc Error

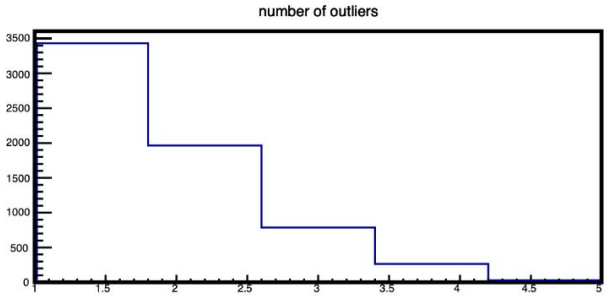

rms loc res vs loc Error
rms loc a res
rms loc b res
2.0
1.5
1.0
0.5
0.0
rms loc res
0.25
0.50
0.75
1.00
1.25
1.50
loc error

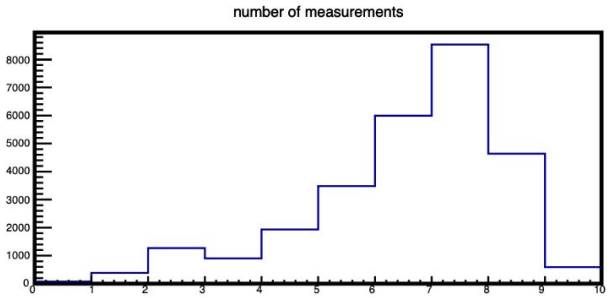

number of outliers
3500
3000
2500
2000
1500
1000
500
0
1
1.5
2
2.5
3
3.5
4
4.5
5


number of outliers
3500
3000
2500
2000
1500
1000
500
0
1
1.5
2
2.5
3
3.5
4
4.5
5


number of outliers
3500
3000
2500
2000
1500
1000
500
0
1
1.5
2
2.5
3
3.5
4
4.5
5


number of outliers
3500
3000
2500
2000
1500
1000
500
0
1
1.5
2
2.5
3
3.5
4
4.5
5


number of outliers
3500
3000
2500
2000
1500
1000
500
0
1
1.5
2
2.5
3
3.5
4
4.5
5


number of measurements
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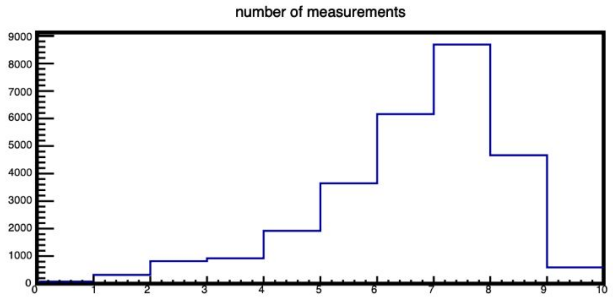
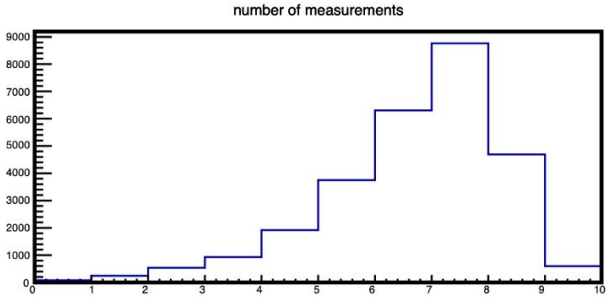
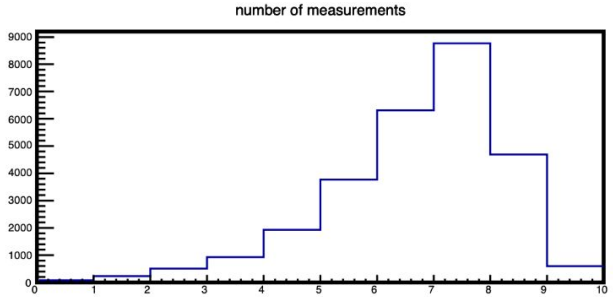
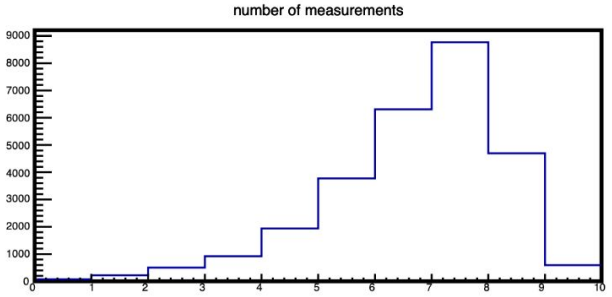
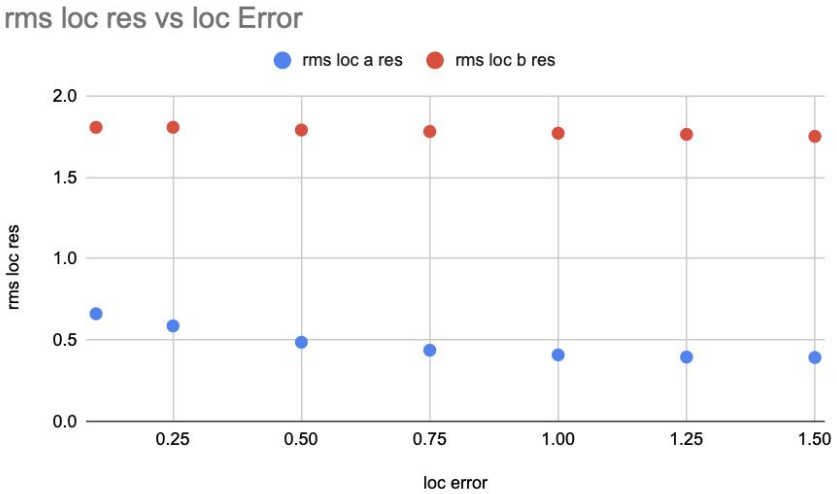
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10


number of measurements
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10


number of measurements
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10


number of measurements
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10


number of measurements
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10


rms loc res vs loc Error
rms loc a res
rms loc b res
2.0
1.5
1.0
0.5
0.0
rms loc res
0.25
0.50
0.75
1.00
1.25
1.50
loc error