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Signal+BIB event production and characterization

Muon Collider framework tutorial

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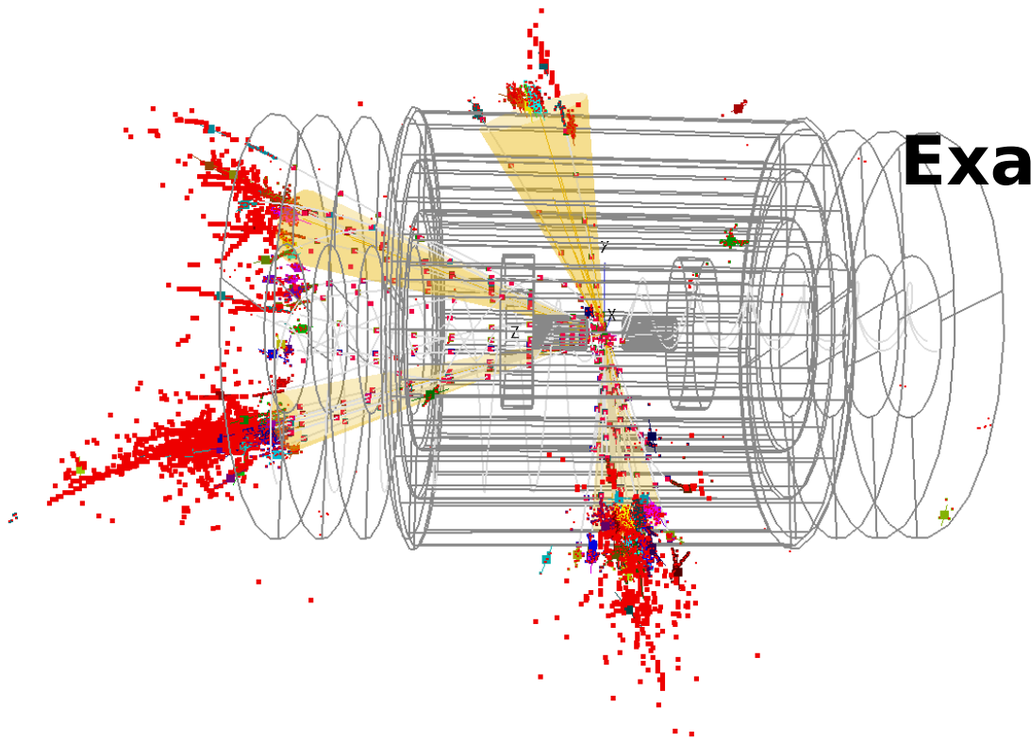
What you have learnt up to now

- This is the last part of the Muon Collider framework tutorial. Now you should be able to:
  - Simulate and reconstruct a signal;
  - Study the signal kinematics;
  - Simulate the beam-induced-background;
  - Study the BIB properties: occupancy, timing etc.

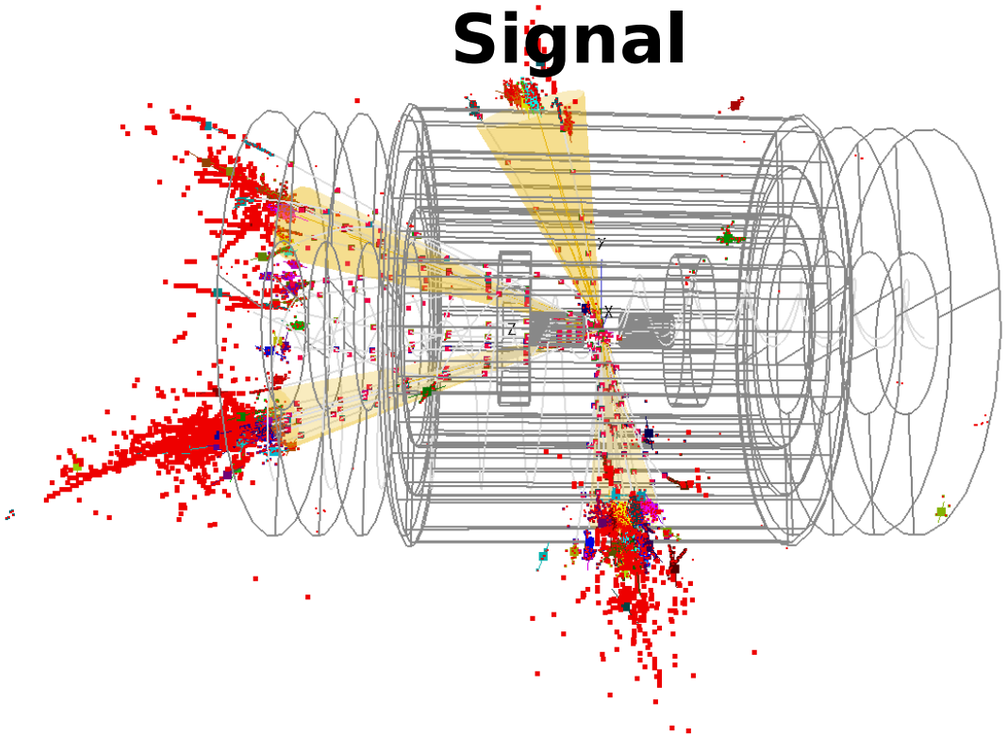


Example of signal event

What you will learn in this section

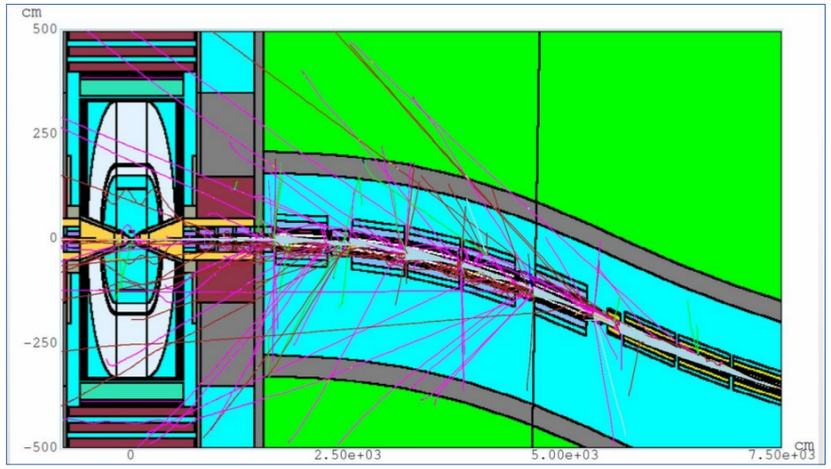
- In this exercise you are going to:
  - Overlay the signal and a fraction of the BIB at 1.5 TeV
  - Reconstruct the signal+BIB event
  - Compare the signal+BIB with the signal only reconstruction
  - Mitigate the BIB impact with reconstructed-level cuts
  - Measure the reconstruction performance

Signal



+

BIB



Prompt muons sample

- The HH → bbbb events are too complicated for this tutorial. You can try to reconstruct the HH + BIB events as exercise :-)

- To learn the basic concepts of the signal+BIB reconstruction it is better to study the muon reconstruction.

- For this reason a single event with **1000 prompt muons** (coming from the interaction points) have been generated for you with a ParticleGun processor. The reconstruction is on your hands!

- Muons are uniformly distributed in angle, and they have a uniform p_T between 0 and 10 GeV.

Exercise overview

The exercise is located in the **MuC-Tutorial/tutorial/3-mu_BIB** directory.

The directory contains the following:

- `reco_sig_only_steer.xml`: Marlin steering file for the reconstruction of the signal, without the BIB;
- `reco_sig_and_BIB_steer.xml`: Marlin steering file for the reconstruction of the signal overlayed with the BIB;
- `compare_sig_and_BIB.C`: ROOT macro to compare the track reconstruction in the two cases: with and without the BIB;
- `track_pt_resolution.C`: determination of the track p_T resolution, with and without the BIB.

Run the reconstruction → output

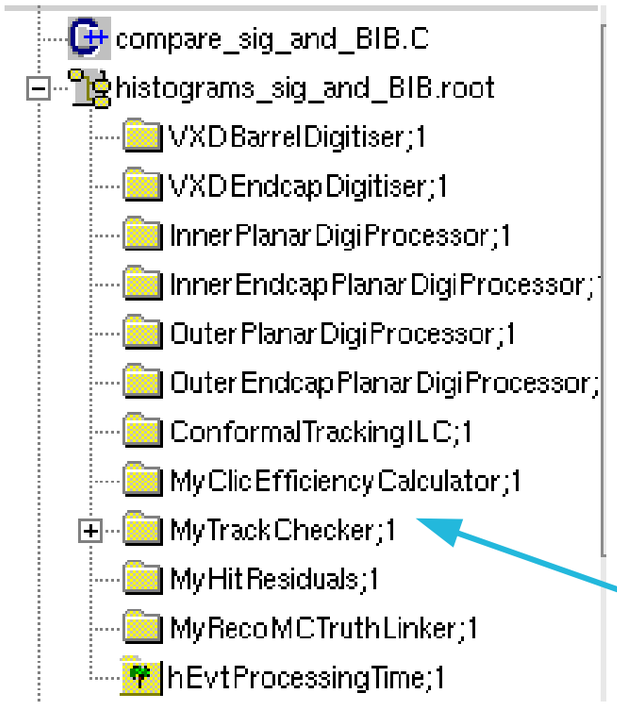
I assume that you are already in the tutorial environment.

In order to reconstruct the signal+BIB event:

- `Marlin reco_sig_and_BIB.xml > log_sig_and_BIB.log`

We want to reconstruct also the signal only event. This will be important for the comparison:

- `Marlin reco_sig_only_steer.xml > log_sig_only.log`



You are going to obtain two ROOT files (one for each reconstruction)
histograms_sig_and_BIB.root and
histograms_sig_only.root

The information saved inside depends on the Marlin configuration. Our analysis relies on **MyTrackChecker**.

The overlay processor

Overlay: simulated hits from the signal and from the BIB are put together **before** the digitization.

This business is performed by the overlay processor.

```
<!-- ============================================================================================== -->
<!-- ============================================================================================== -->
<!-- == Global setup                                                                           == -->
<!-- ============================================================================================== -->
<!-- ============================================================================================== -->
<processor name="Config" type="CLICRecoConfig" >
  <parameter name="Verbosity" options="DEBUG0-9,MESSAGE0-9,WARNING0-9,ERROR0-9,SILENT"> DEBUG7  </parameter>
  <!--Which option to use for Overlay: False, BIB. Then use, e.g., Config.OverlayFalse in the condition-->
  <parameter name="Overlay" type="string">BIB</parameter>
  <!--Possible values and conditions for option Overlay-->
  <parameter name="OverlayChoices" type="StringVec">False BIB</parameter>
  <!--Which option to use for Tracking: Truth, ConformalPlusExtrapolator, Conformal. Then use, e.g., Config.TrackingTruth in the condition-->
  <parameter name="Tracking" type="string">Conformal </parameter>
  <!--Possible values and conditions for option Tracking-->
  <parameter name="TrackingChoices" type="StringVec">Truth Conformal  </parameter>
  <!--Which option to use for VertexUnconstrained: ON, OFF. Then use, e.g., Config.VertexUnconstrainedOFF in the condition-->
  <parameter name="VertexUnconstrained" type="string">OFF </parameter>
  <!--Possible values and conditions for option Tracking-->
  <parameter name="VertexUnconstrainedChoices" type="StringVec">ON OFF  </parameter>
  <!--verbosity level of this processor ("DEBUG0-4,MESSAGE0-4,WARNING0-4,ERROR0-4,SILENT")-->
</processor>
```

Master switch to activate the BIB overlay

Overlay configuration-1

```
<!-- ================================================================================================================ -->
<!-- ================================================================================================================ -->
<!-- == Overlay configuration                                                                                      == -->
<!-- ================================================================================================================ -->
<!-- ================================================================================================================ -->

<group name="Overlay">
  <parameter name="MCParticleCollectionName" type="string">MCParticle </parameter>
  <!--The output MC Particle Collection Name for the physics event-->
  <parameter name="MCPhysicsParticleCollectionName" type="string"> MCPhysicsParticles </parameter>
  <!--Time difference between bunches in the bunch train in ns-->
  <parameter name="Delta_t" type="float" value="1"/>
  <!--Number of bunches in a bunch train-->
  <parameter name="NBunchtrain" type="int" value="1"/>

  <parameter name="Collection_IntegrationTimes" type="StringVec" >
    VertexBarrelCollection        0.3
    VertexEndcapCollection        0.3

    InnerTrackerBarrelCollection  0.6
    InnerTrackerEndcapCollection  0.6

    OuterTrackerBarrelCollection  0.6
    OuterTrackerEndcapCollection  0.6

    ECalBarrelCollection          10.
    ECalEndcapCollection          10.
    ECalPlugCollection            10.

    HCalBarrelCollection          10.
    HCalEndcapCollection          10.
    HCalRingCollection            10.

    YokeBarrelCollection          10.
    YokeEndcapCollection          10.

</parameter>
<!--Number of the Bunch crossing of the physics event-->
<parameter name="PhysicsBX" type="int" value="1"/>
<!--Draw random number of Events to overlay from Poisson distribution with  mean value NumberBackground-->
<parameter name="Poisson_random_NOverlay" type="bool" value="false"/>
<!--Place the physics event at an random position in the train - overrides PhysicsBX-->
<parameter name="RandomBx" type="bool" value="false"/>
<!--[mm/ns] (float) - default 5.0e-2 (5cm/us)-->
<parameter name="TPCDriftvelocity" type="float" value="0.05"/>
<parameter name="BackgroundFileNames" type="StringVec"> </parameter>
```

Integration time windows: [-0.25,+X] ns with respect to the time of arrival of a photon from the IP to the sensor

Only collections in the list are merged

Overlay configuration-2

```
<processor name="OverlayBIB" type="OverlayTimingGeneric">
  <parameter name="BackgroundFileNames" type="StringVec">
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j1.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j2.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j3.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j4.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j5.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j6.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j7.slcio
    /data/samples/BIB/sim_mumi-1e3x500-26m-lowth-excl_j8.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j1.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j2.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j3.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j4.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j5.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j6.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j7.slcio
    /data/samples/BIB/sim_mupl-1e3x500-26m-lowth-excl_j8.slcio
  </parameter>
  <parameter name="StartBackgroundFileIndex" type="int" value="0"/>
  <parameter name="AllowReusingBackgroundFiles" type="bool" value="false" />
  <parameter name="Verbosity" options="DEBUG0-4,MESSAGE0-4,WARNING0-4,ERROR0-4,SILENT">WARNING </parameter>
  <parameter name="NBunchtrain" type="int" value="1" />
  <!--<parameter name="NumberBackground" type="float" value="2993" />-->
  <parameter name="NumberBackground" type="float" value="10" />
</processor>

</group>
```

BIB files

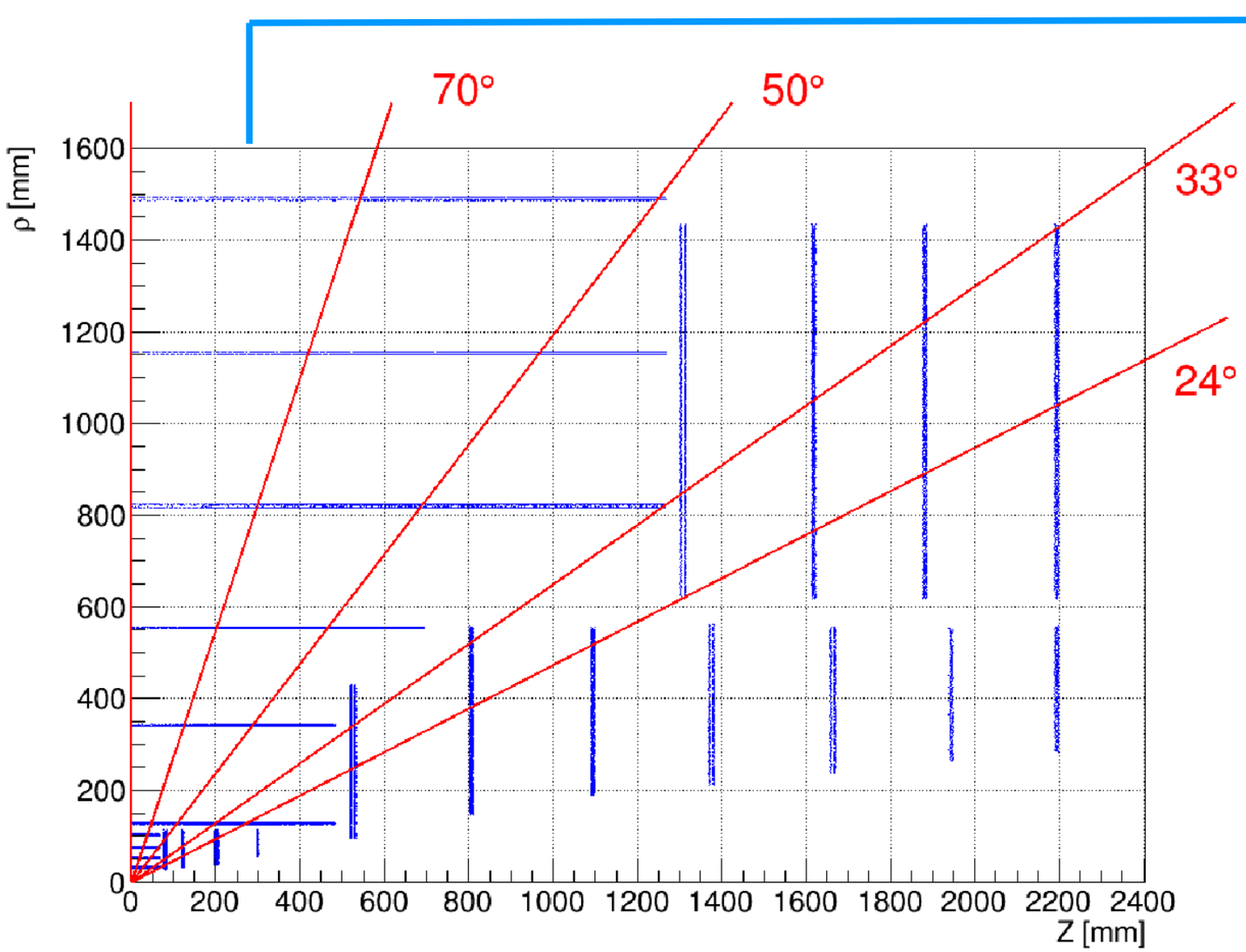
Number of BIB sub-events overlayed with the signal. The full bunch crossing is composed of 2993 BIB sub-events.

Hands on!

- We are reconstructing the signal with 10/2993 of the BIB: it takes about **5 minutes**.
- Try yourselves to increase the BIB fraction…today we don't have enough time!

Track reconstruction

- In the second part of the exercise we analyse the output of the track reconstruction.
- Don't worry if you haven't finished your job, we have prepared tuples reconstructed with the full BIB! **But with a trick:**



Only tracks with 70° < θ < 90° have been reconstructed. This technique is called **regional tracking**. Of about ~130 signal muons are in this region.

Regional tracking is not implemented in the framework, you need to modify the source code (out of the scope of the tutorial).

Track parameters

- The **conformal tracking algorithm** is used.
- After the pattern recognition, the hits are fitted with a helix.
- The track fit parameters are the following:

Parameter	Description
D_0	the distance between the helix and the reference point in the x-y plane
Φ	the azimuthal angle of the reference point with respect to the center of the helix
Ω	the signed curvature of the track, defined as $\Omega = \frac{p_T}{cBQ}$, where B is the magnetic field and Q is the charge of the particle
Z_0	the distance between the helix and the reference point in the z direction
$tan(\lambda)$	the dip angle, i.e., the angle of the helix to the x-y plane

- We are going to analyse D_0, Ω and Z_0

Track reconstruction

In order to compare the reconstruction with and without the BIB, you can use the following macro:

- `root -l`
- `.L compare_sig_and_BIB.C`
- `compare_sig_and_BIB(20,0,0)`

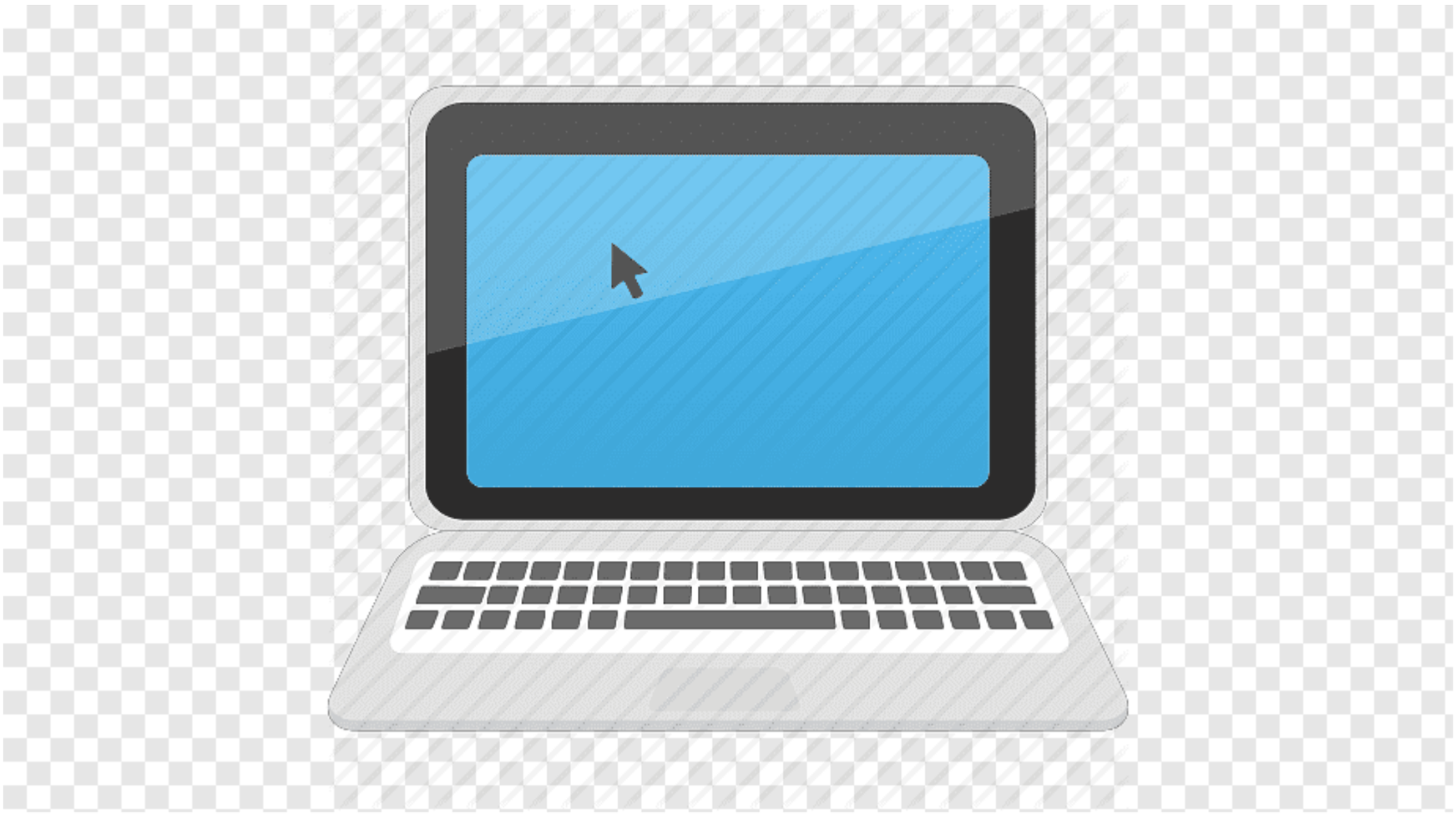
Usage: **compare_sig_and_BIB(Double_t chi2_max=20., Int_t nhits_min=0, Int_t plot_ID=0)**

You can modify the cut on the maximum χ^2/ndof, on the minimum number of hits, and you can chose the plot to show:

0: χ^2/ndof
1: number of hits
2: track p_T
3: D_0
4: Z_0
5: Ω

Hands on!

- Try to find the optimal cuts for the track selection.
- Check how the number of tracks changes with different cuts.
- Check how the distributions of fitted track parameters change with cuts.



Track p_T resolution

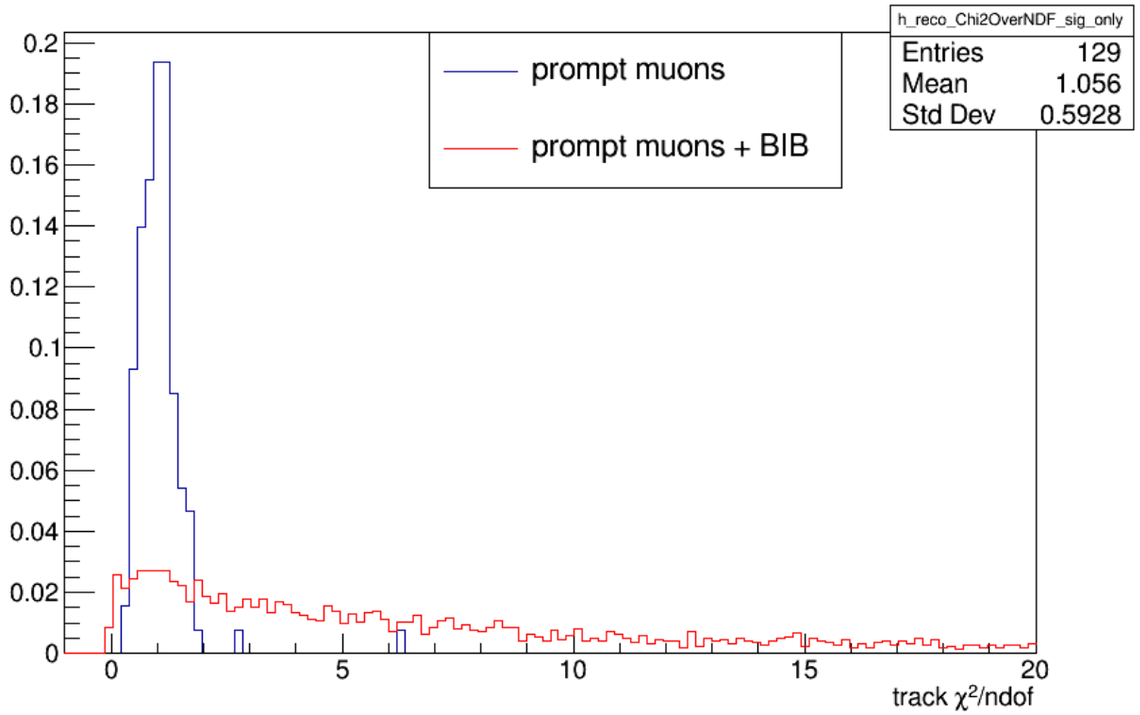
A macro for the determination of the track p_T resolution is available:

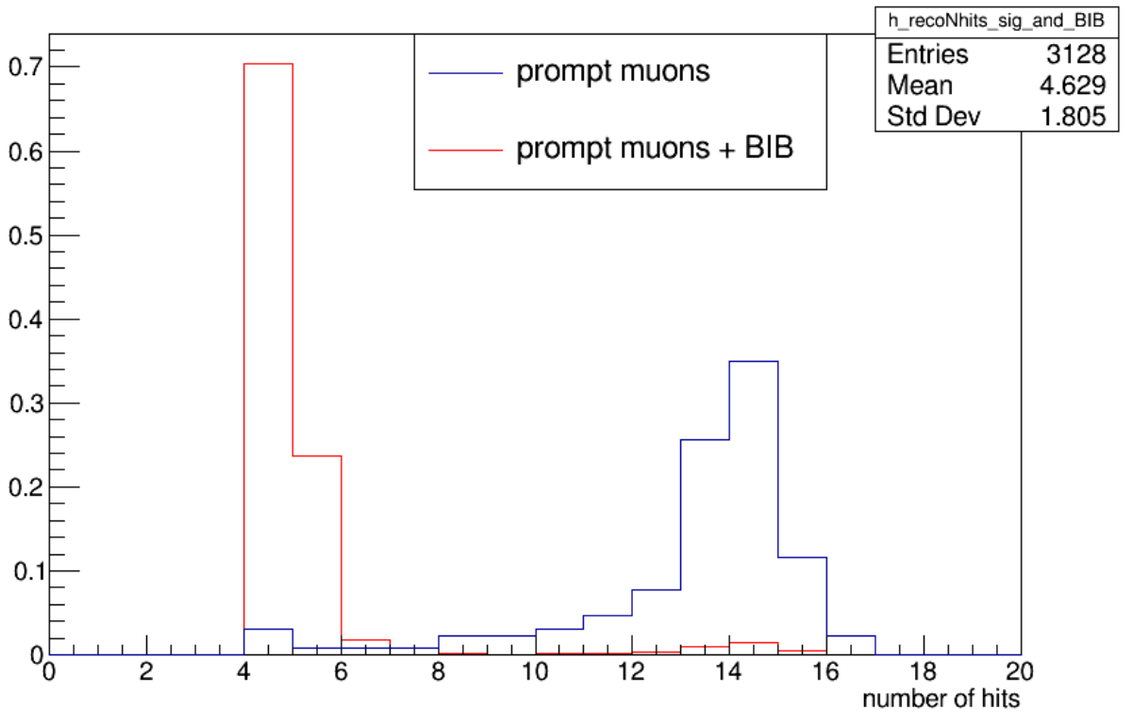
- `root -l`
- `.L track_pt_resolution.C`
- `track_pt_resolution()`

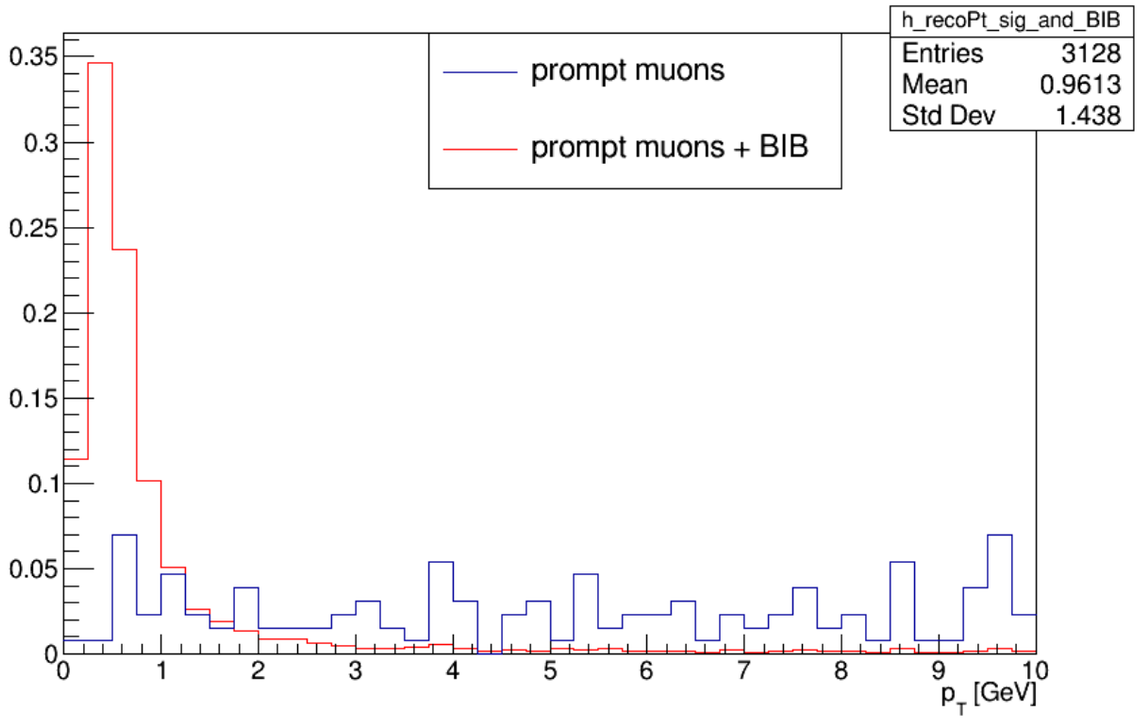
Cuts on the maximum χ^2/ndof and on the minimum number of hits are already implemented. Check how the resolution changes with and without the BIB!

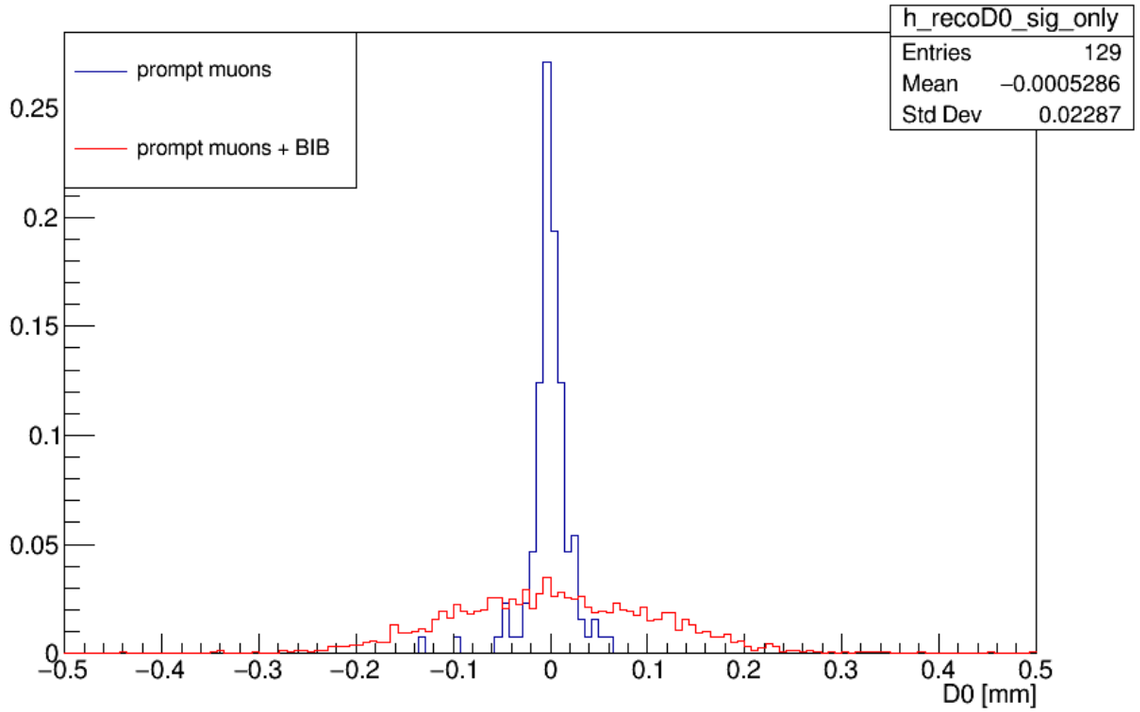
* * *

BACKUP

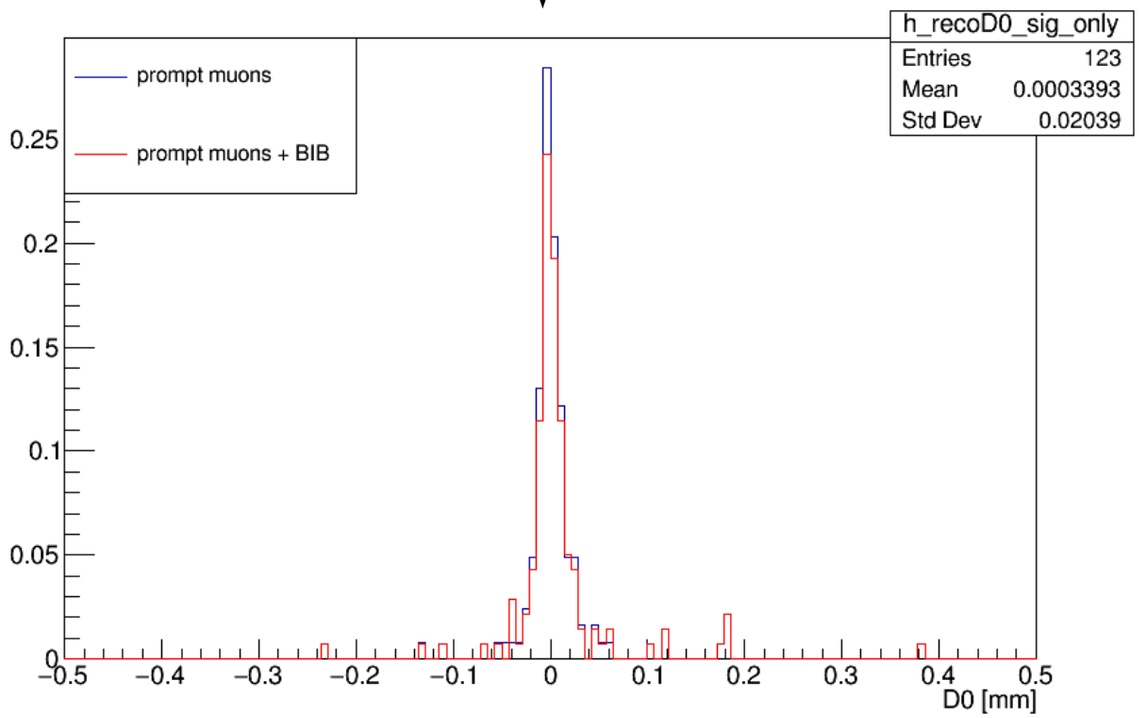

h_reco_Chi2OverNDF_sig_only
Entries 129
Mean 1.056
Std Dev 0.5928
prompt muons
prompt muons + BIB
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
track χ²/ndof

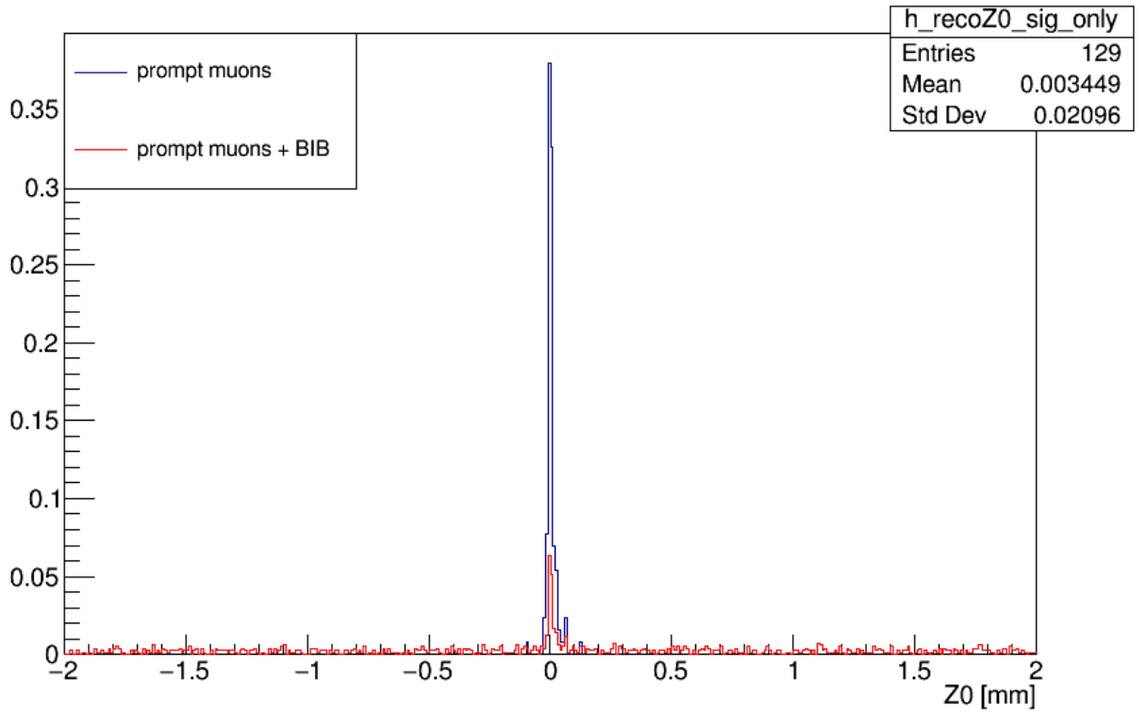

h_recoNhits_sig_and_BIB
Entries 3128
Mean 4.629
Std Dev 1.805
prompt muons
prompt muons + BIB
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
number of hits


h_recoPt_sig_and_BIB
Entries 3128
Mean 0.9613
Std Dev 1.438
prompt muons
prompt muons + BIB
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7 8 9 10
p_T [GeV]

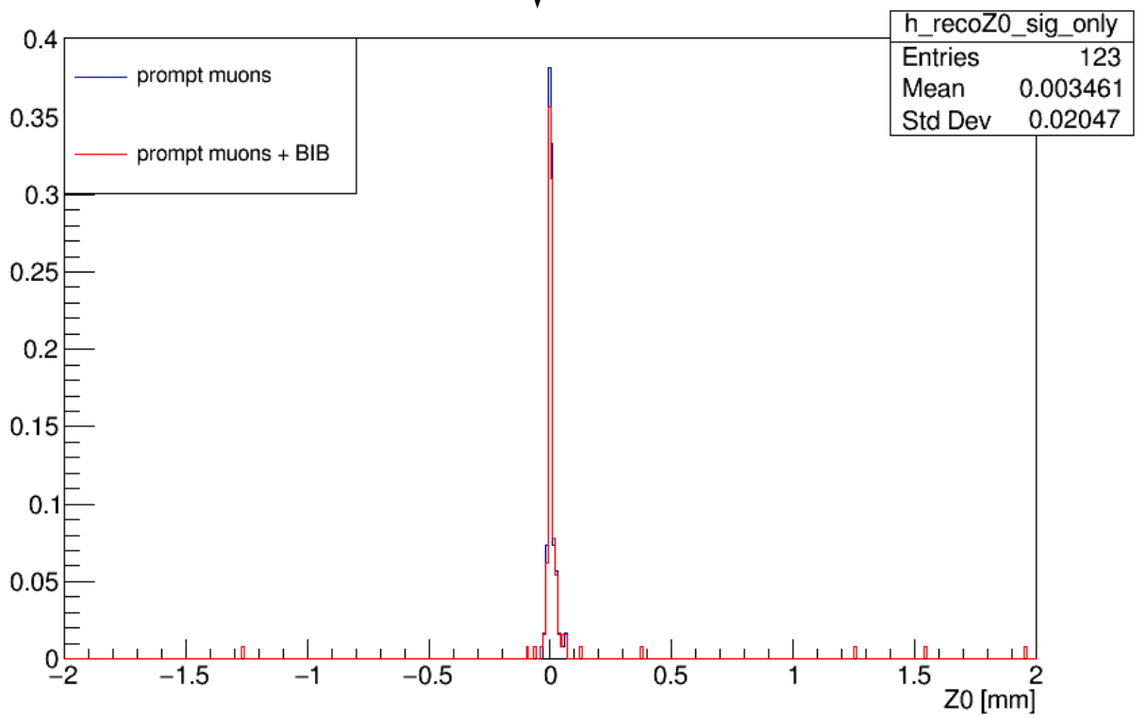

h_recoD0_sig_only
Entries 129
Mean −0.0005286
Std Dev 0.02287
prompt muons
prompt muons + BIB
0.25
0.2
0.15
0.1
0.05
0
−0.5
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
0.5
D0 [mm]

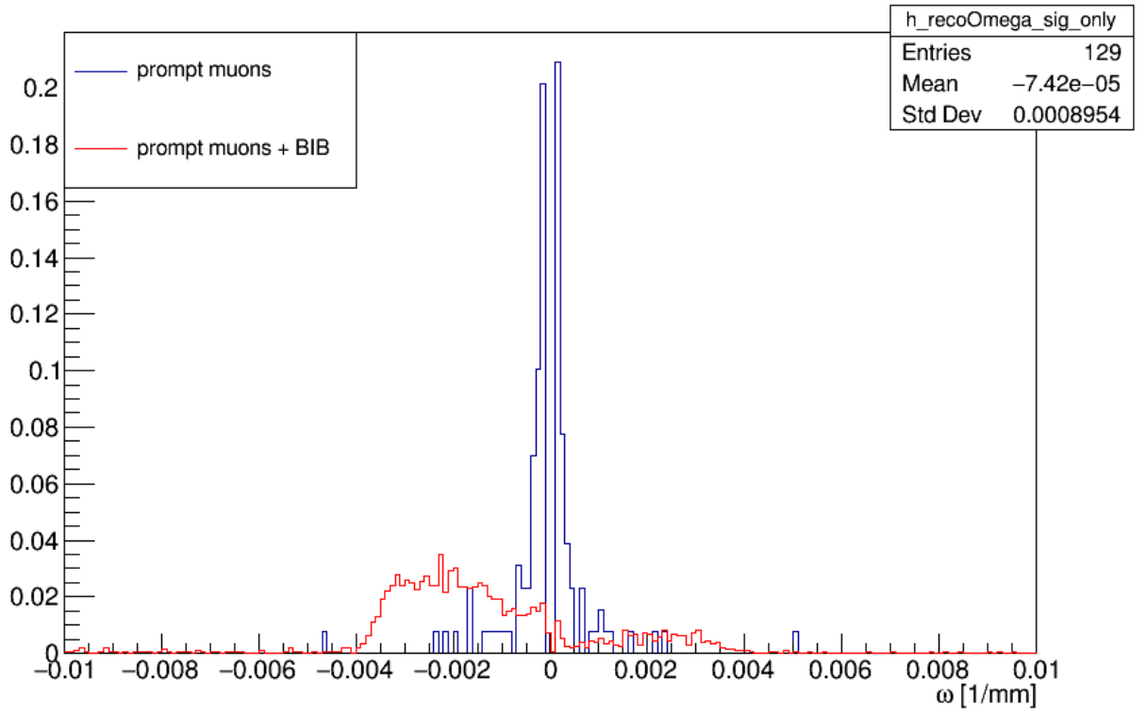
cuts


h_recoD0_sig_only
Entries 123
Mean 0.0003393
Std Dev 0.02039
prompt muons
prompt muons + BIB
0.25
0.2
0.15
0.1
0.05
0
−0.5
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
0.5
D0 [mm]

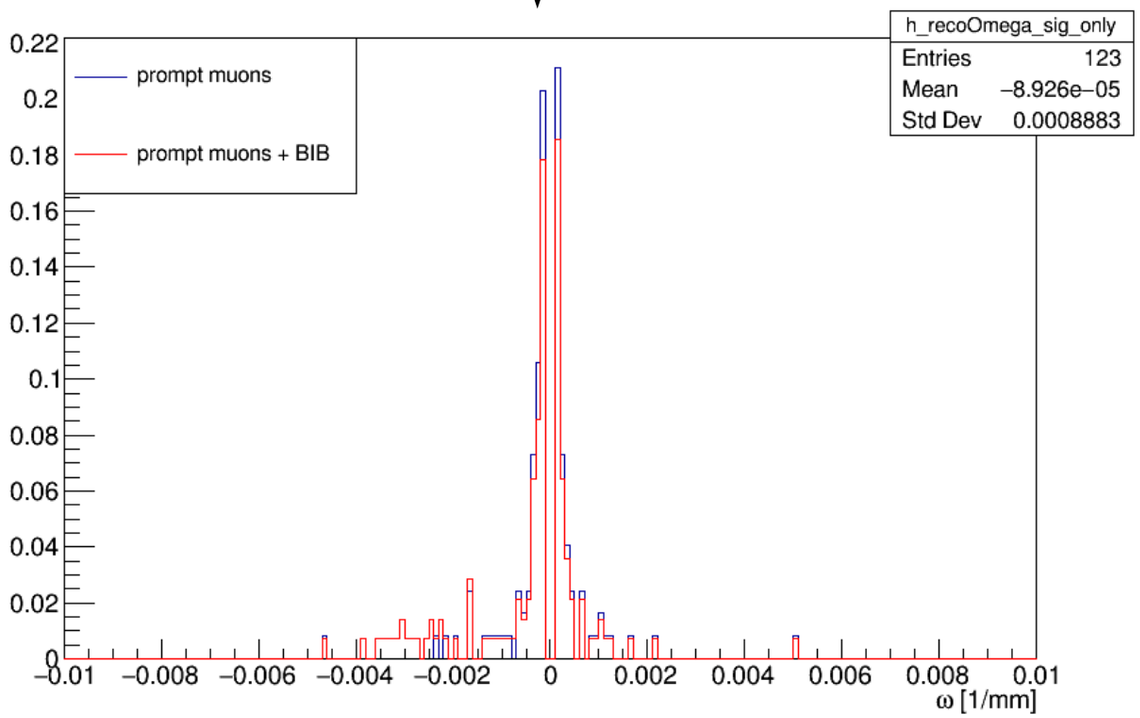

h_recoZ0_sig_only
Entries 129
Mean 0.003449
Std Dev 0.02096
prompt muons
prompt muons + BIB
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
Z0 [mm]

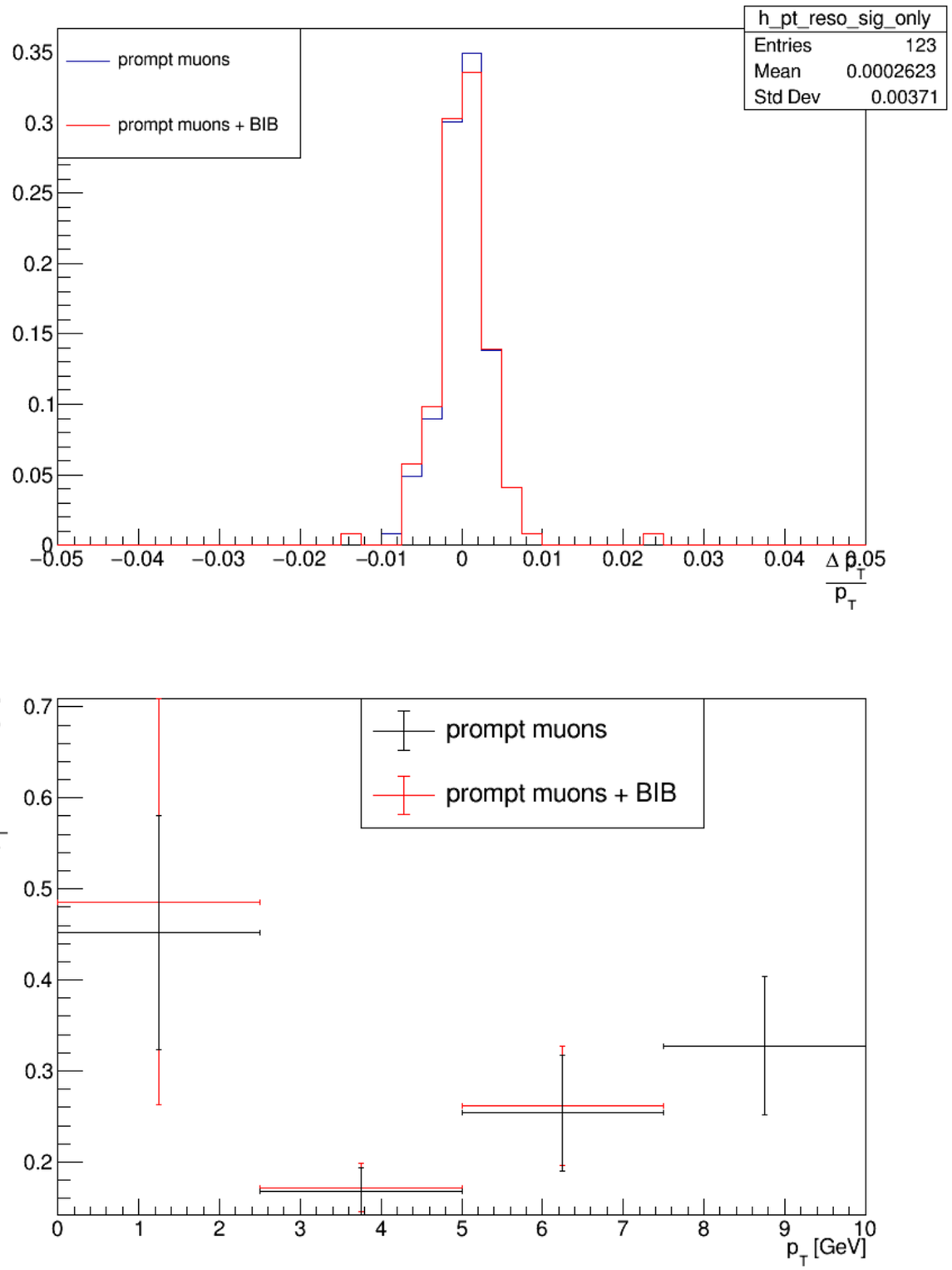
cuts


h_recoZ0_sig_only
Entries 123
Mean 0.003461
Std Dev 0.02047
prompt muons
prompt muons + BIB
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
Z0 [mm]


h_recoOmega_sig_only
Entries 129
Mean −7.42e−05
Std Dev 0.0008954
prompt muons
prompt muons + BIB
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.01 −0.008 −0.006 −0.004 −0.002 0 0.002 0.004 0.006 0.008 0.01
ω [1/mm]

cuts


h_recoOmega_sig_only
Entries 123
Mean −8.926e−05
Std Dev 0.0008883
prompt muons
prompt muons + BIB
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.01 −0.008 −0.006 −0.004 −0.002 0 0.002 0.004 0.006 0.008 0.01
ω [1/mm]


h_pt_reso_sig_only
Entries 123
Mean 0.0002623
Std Dev 0.00371
prompt muons
prompt muons + BIB
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05 −0.04 −0.03 −0.02 −0.01 0 0.01 0.02 0.03 0.04 0.05
Δ p_T / p_T
track p_T resolution [%]
0.7
0.6
0.5
0.4
0.3
0.2
prompt muons
prompt muons + BIB
0 1 2 3 4 5 6 7 8 9 10
p_T [GeV]