

# ICD GUIDE

ANALYSIS BASED ON ROOT

# ANALYSIS FOR THE ICD

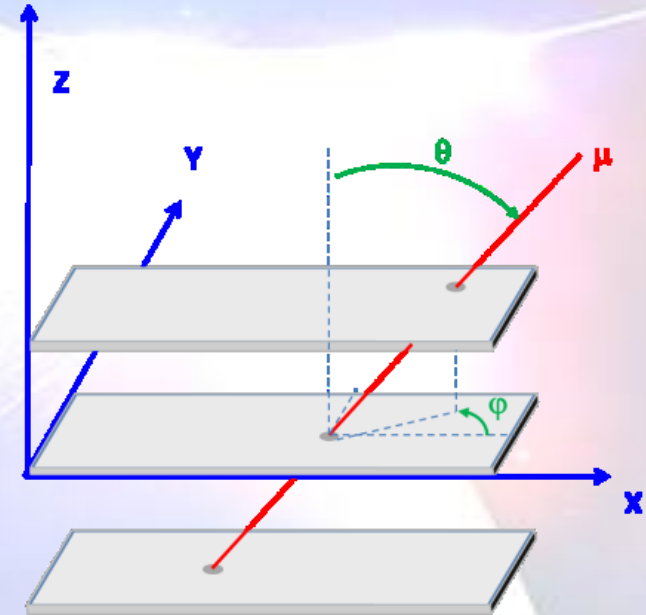
**GOAL:** MEASURE THE ANGULAR DISTRIBUTIONS OF MUONS

**HOW:** ANALYZE THE EEE DATA USING ROOT

**WHEN:** ON NOVEMBER 6<sup>th</sup>

**ZENITHAL DISTRIBUTION:** Flux of muons as a function of the zenithal angle  $\theta$

**AZIMUTHAL DISTRIBUTION:** Flux of muons as a function of the azimuthal angle  $\phi$



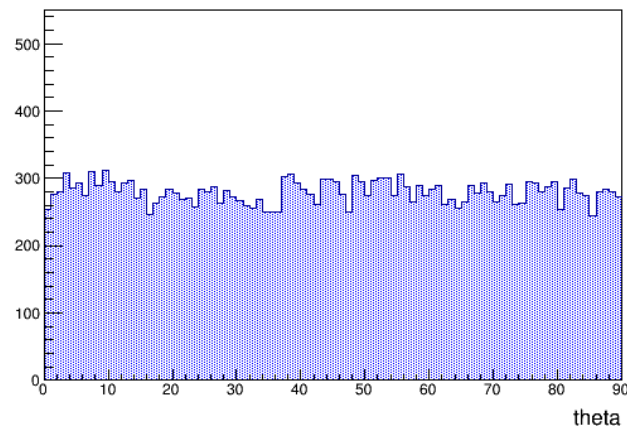
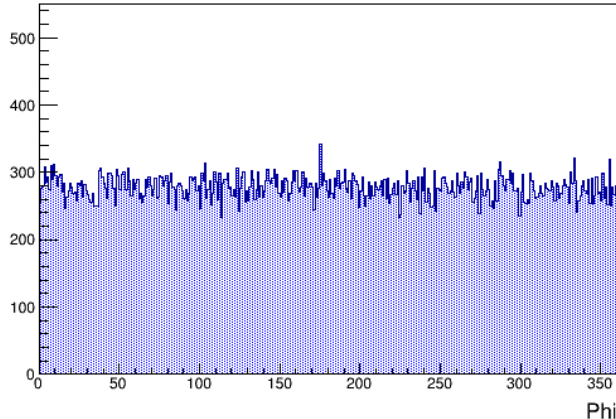
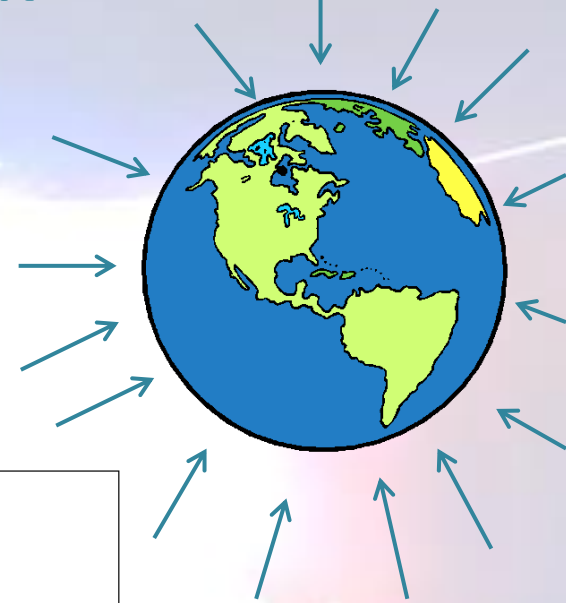
# FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

Ideally muons arrive from all direction with the same probability (isotropically)

**ZENITHAL DISTRIBUTION :** uniform (flat)

**AZIMUTHAL DISTRIBUTION:** uniform (flat)

is it true?



## FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

Due to geometrical reasons the zenithal distribution should be  $\propto \sin(\theta)$

$N_1 = 1000$  particles on  $A_1$  area (uniform in  $d\theta = 20^\circ\text{-}30^\circ$ )

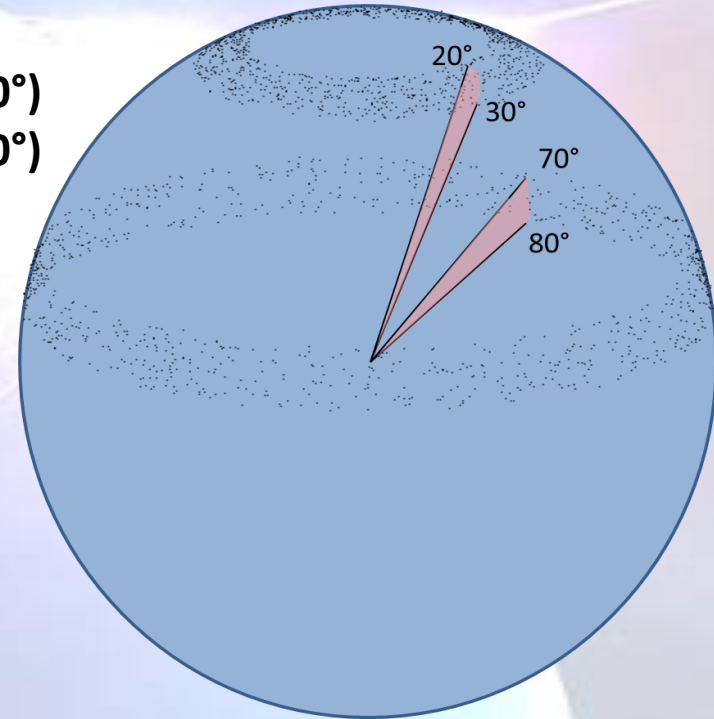
$N_2 = 1000$  particles on  $A_2$  area (uniform in  $d\theta = 70^\circ\text{-}80^\circ$ )

$\text{Rate}_1 = N_1/A_1$

$\text{Rate}_2 = N_2/A_2$

$A_2 > A_1 \rightarrow \text{Rate}_1 > \text{Rate}_2$

**NOT ISOTROPIC!**

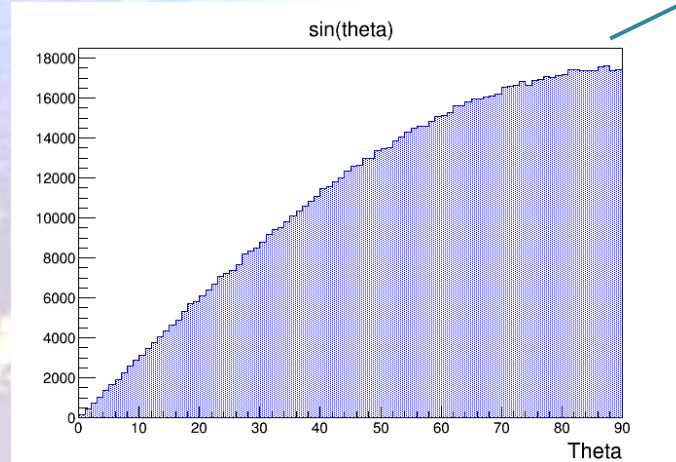
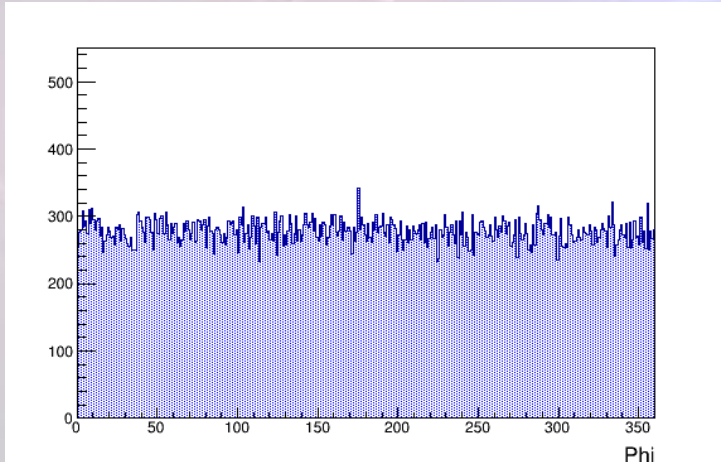
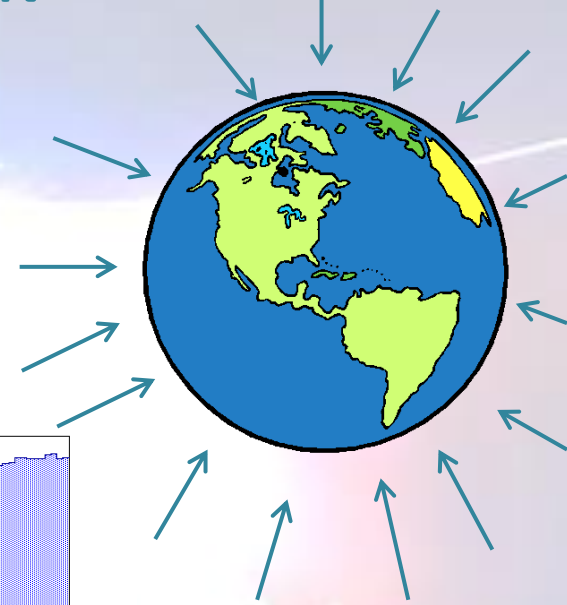




# FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

ZENITHAL DISTRIBUTION :  $\propto \sin(\theta)$

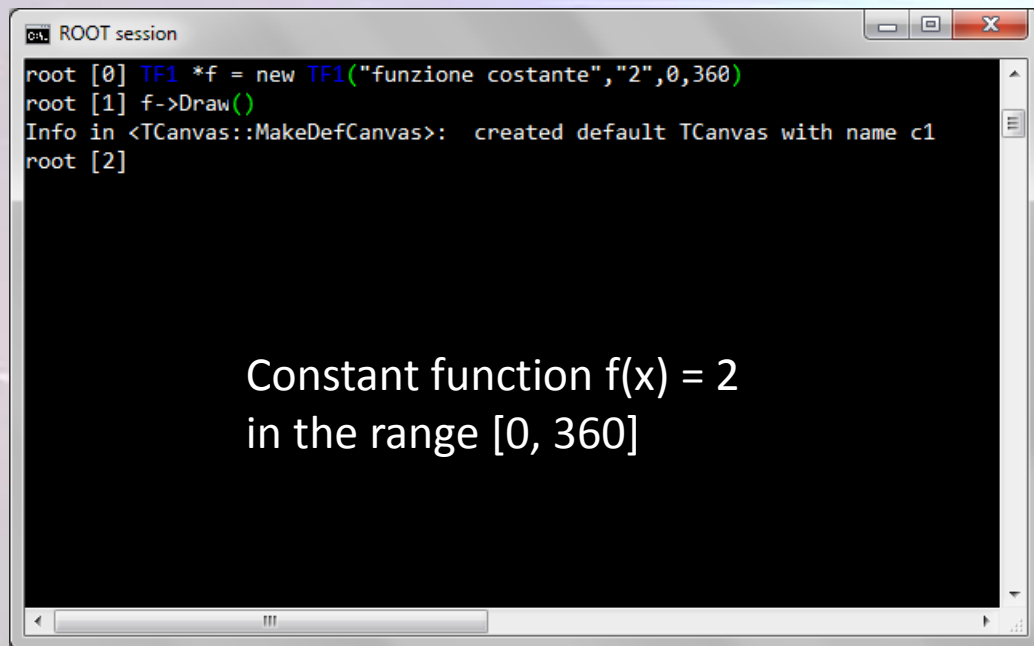
AZIMUTHAL DISTRIBUTION: uniform (flat)



# SIMPLE EXERCISE WITH ROOT

Define and draw a function

**TF1 \*f = new TF1("funzione costante", "2", 0, 360)**



```
ROOT session
root [0] TF1 *f = new TF1("funzione costante","2",0,360)
root [1] f->Draw()
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [2]
```

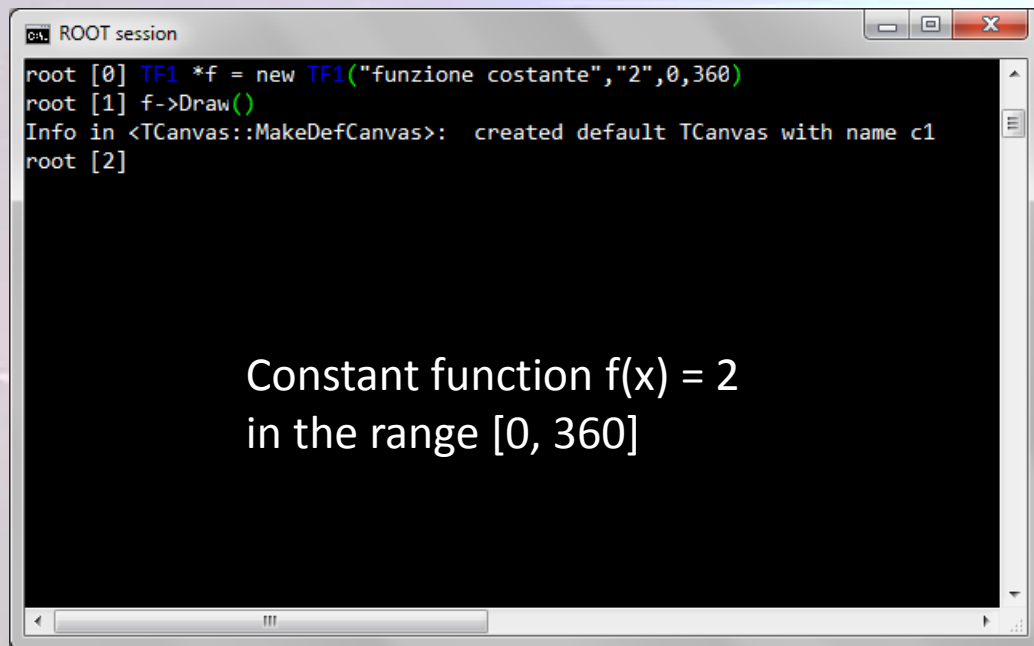
Constant function  $f(x) = 2$   
in the range  $[0, 360]$

# SIMPLE EXERCISE WITH ROOT

Define and draw a function

```
TF1 *f = new TF1("funzione costante", "2", 0, 360)
```

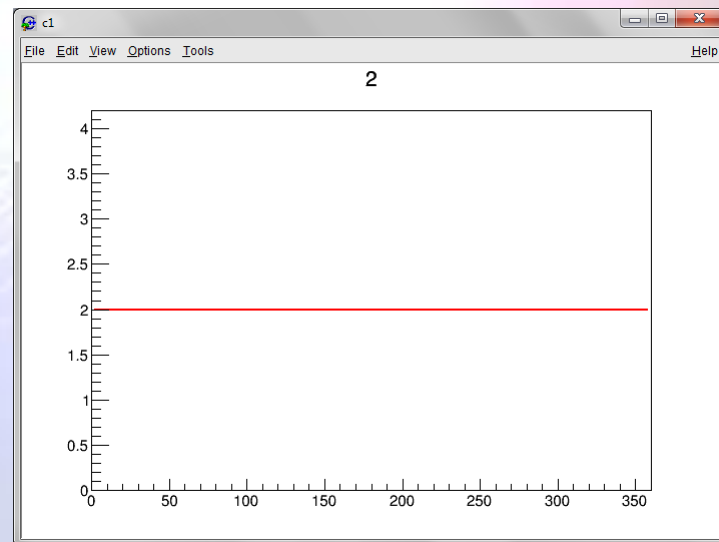
```
f->Draw()
```



A screenshot of a ROOT session window titled "ROOT session". The window has a black background with white text. The text shows the execution of two commands: `root [0] TF1 *f = new TF1("funzione costante", "2", 0, 360)` and `root [1] f->Draw()`. Below the commands, an information message states: `Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1`. The prompt `root [2]` is visible at the bottom. A large white text overlay is positioned in the lower right area of the window, reading: "Constant function  $f(x) = 2$  in the range  $[0, 360]$ ".

```
root [0] TF1 *f = new TF1("funzione costante", "2", 0, 360)
root [1] f->Draw()
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [2]
```

Constant function  $f(x) = 2$   
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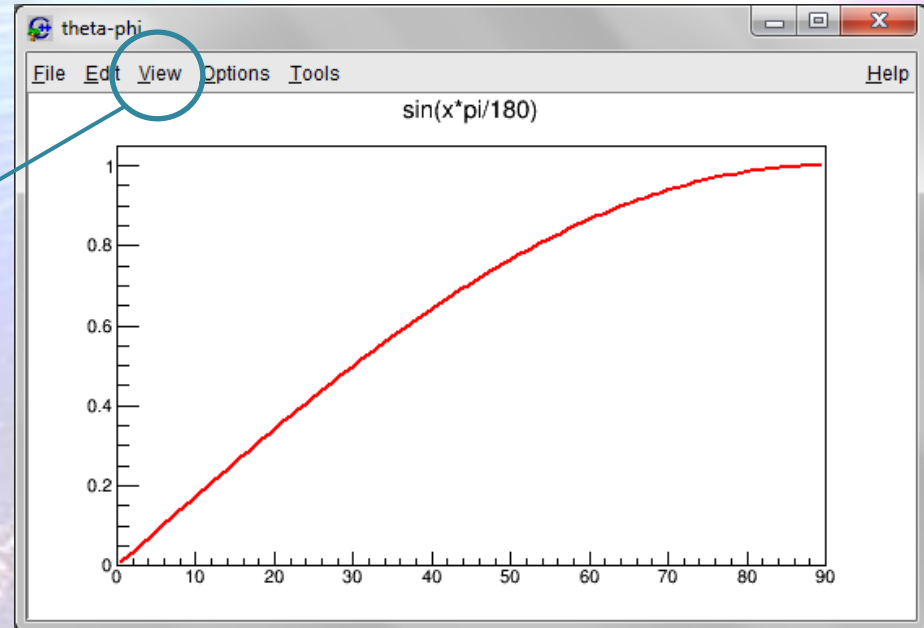
## SIMPLE EXERCISE WITH ROOT

Define and draw a function  $f(x) = \sin\theta$

```
TF1 *f = new TF1("funzione seno", "sin(x * pi / 180)", 0, 90)
```

The sine function needs the argument  
in radians  
( $\pi = 3,14$ )

Play with the graphics  
Menu View → Editor





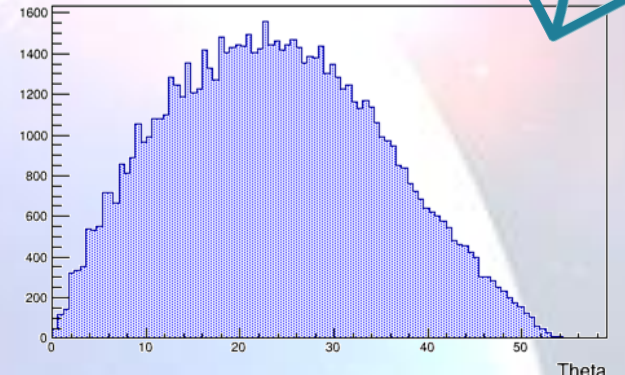
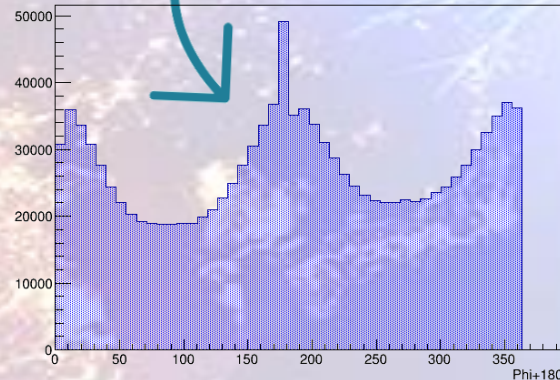
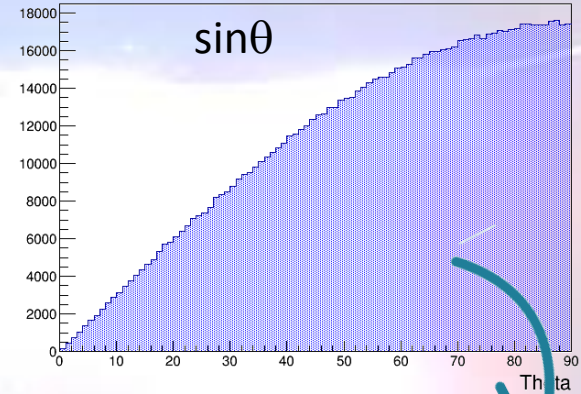
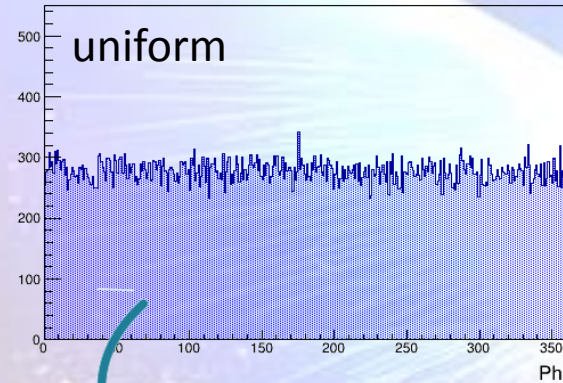
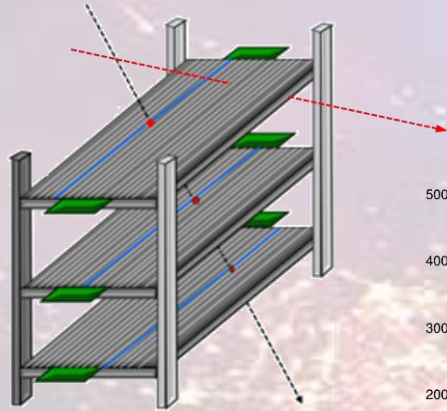
## NOT SO EASY...

The angular distribution of the muons (ideally isotropic) is affected by 2 other factors:

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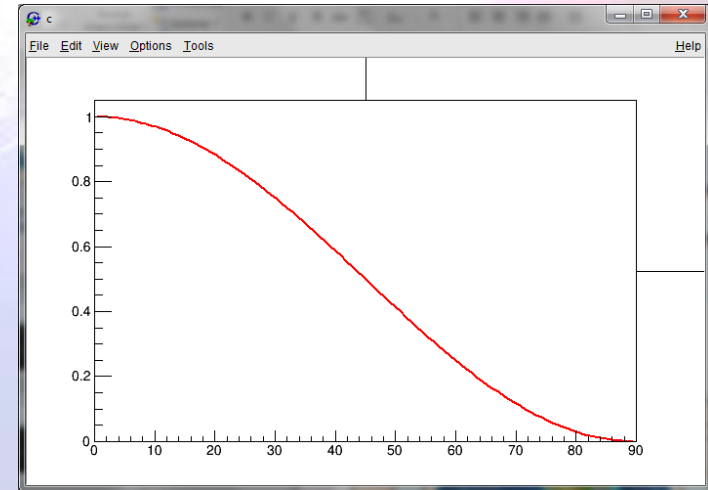
## NOT SO EASY...

The angular distribution of the muons (ideally isotropic) is affected by 2 other factors:

- Detector acceptance
- Absorption due to the Earth's atmosphere  $\rightarrow \propto \cos^2\theta$   
(vertical muons are more abundant)



Draw this function using ROOT





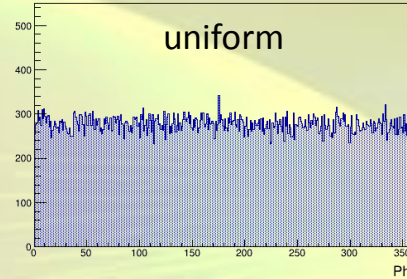
# IN SUMMARY

## AZIMUTHAL DISTRIBUTION

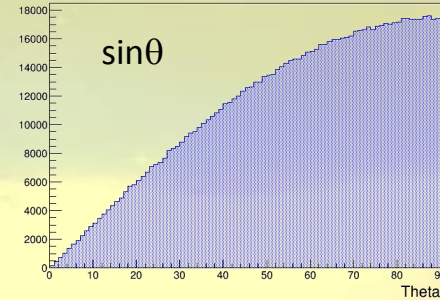
## ZENITHAL DISTRIBUTION

- $\propto \sin\theta$

Azimuthal  
distribution



Zenithal  
distribution



Isotropic  
distribution



# IN SUMMARY

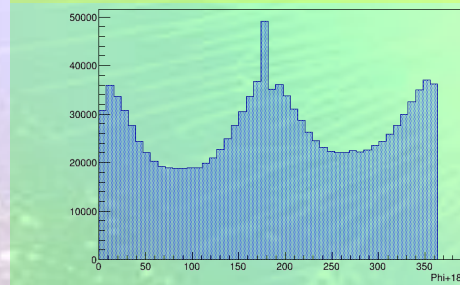
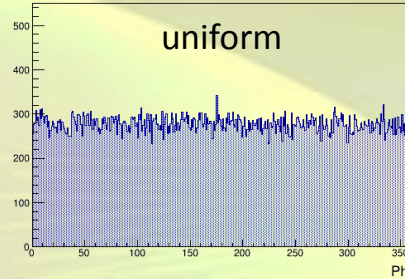
## AZIMUTHAL DISTRIBUTION

- Detector acceptance

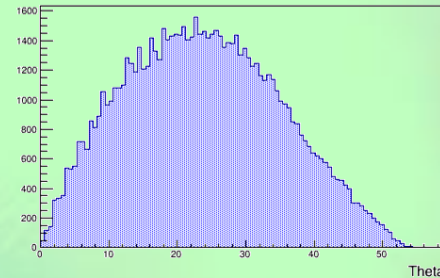
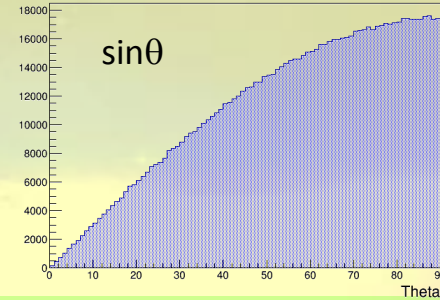
## ZENITHAL DISTRIBUTION

- $\propto \sin\theta$
- Detector acceptance

Azimuthal  
distribution



Zenithal  
distribution



Isotropic  
distribution

Isotropic  
distribution  
+  
Detector  
acceptance

# IN SUMMARY

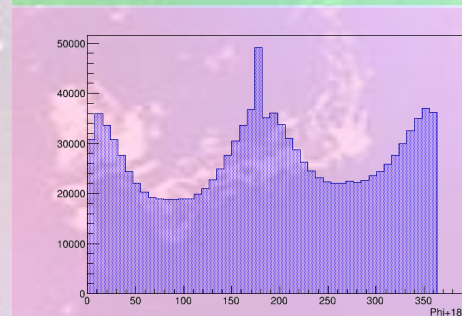
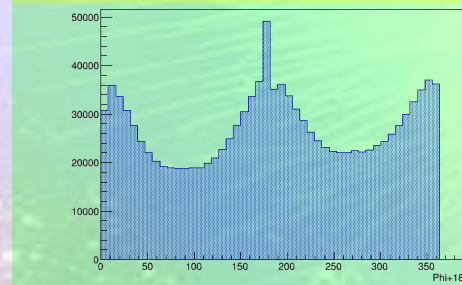
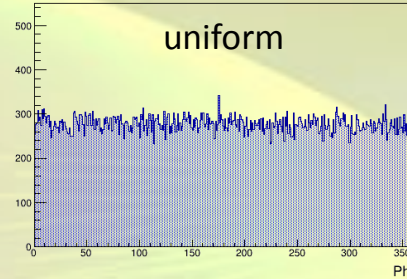
## AZIMUTHAL DISTRIBUTION

- Detector acceptance

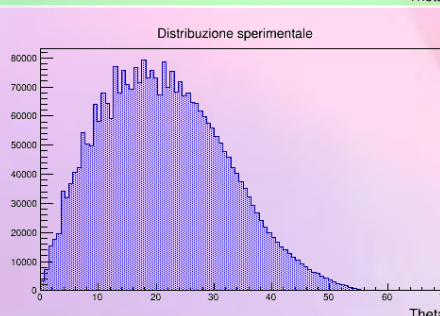
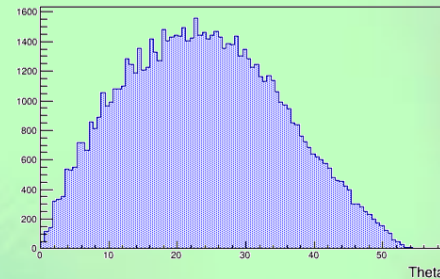
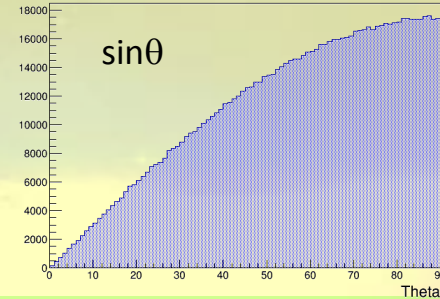
## ZENITHAL DISTRIBUTION

- $\propto \sin\theta$
- Detector acceptance
- $\propto \cos^2\theta$

### Azimuthal distribution



### Zenithal distribution



Isotropic distribution

Isotropic distribution + Detector acceptance

Isotropic distribution + Detector acceptance +  $\cos^2\theta$

# IN SUMMARY

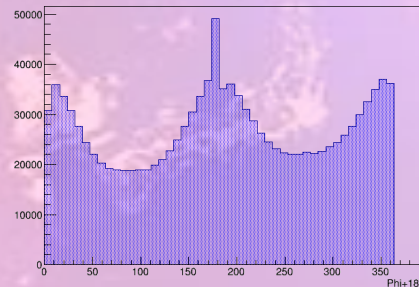
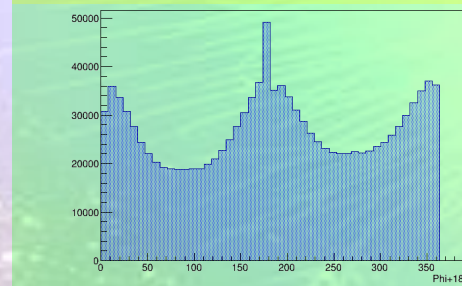
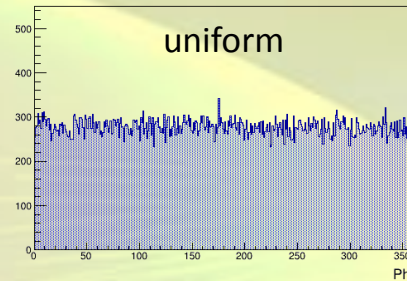
## AZIMUTHAL DISTRIBUTION

- Detector acceptance

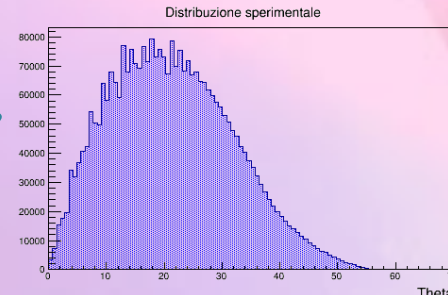
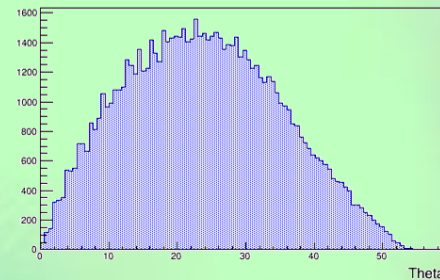
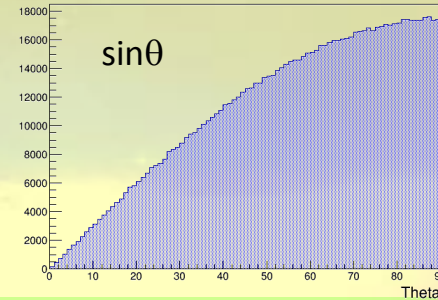
## ZENITHAL DISTRIBUTION

- $\propto \sin\theta$
- Detector acceptance
- $\propto \cos^2\theta$

### Azimuthal distribution



### Zenithal distribution



Isotropic distribution

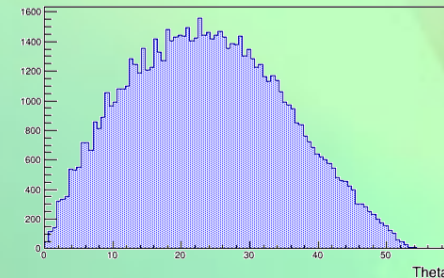
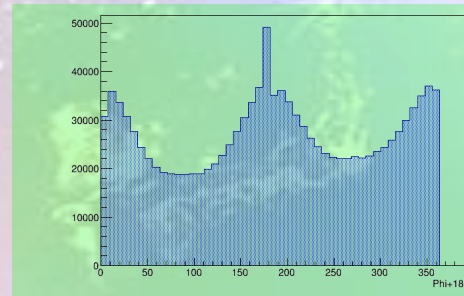
Isotropic distribution + Detector acceptance

Isotropic distribution + Detector acceptance +  $\cos^2\theta$



# DATA analysis

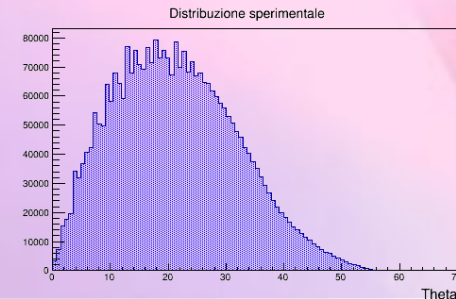
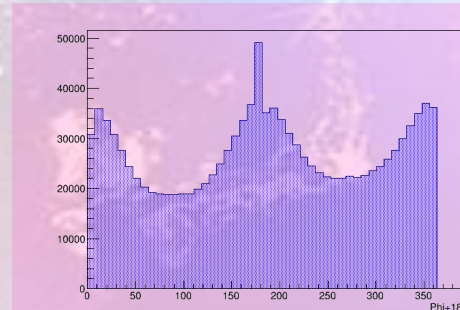
1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)



Isotropic  
distribution  
+  
Detector  
acceptance

# DATA analysis

1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)
2. Study of the experimental angular distribution (isotropic distribution + detector acceptance effects +  $\cos^2\theta$  factor)



Isotropic  
distribution  
+  
Detector  
acceptance  
+  
 $\cos^2\theta$



# DATA analysis

1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)
2. Study of the experimental angular distribution (isotropic distribution + detector acceptance effects +  $\cos^2\theta$  factor)
3. Ratio (distribution 2/ distribution 1) to isolate the  $\cos^2\theta$  factor

# DATA analysis – step 1

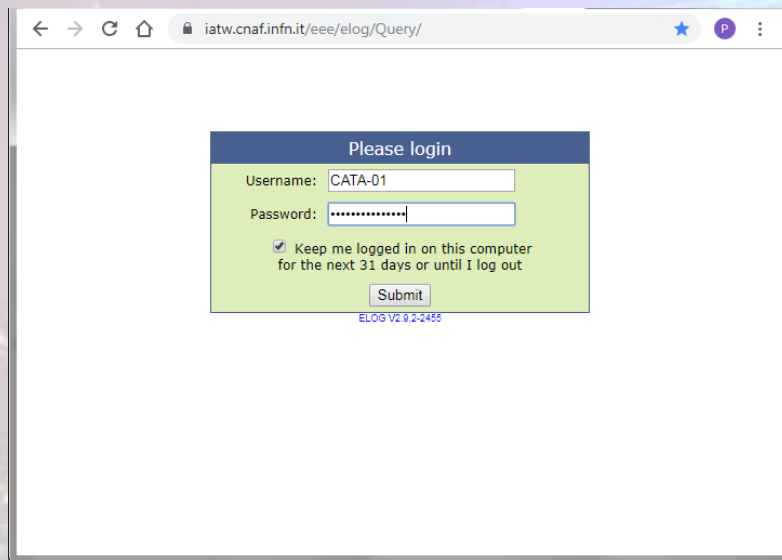
1. **Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)**
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3. Ratio (distribution 2/ distribution 1) to isolate the  $\cos^2\theta$  factor

# DATA analysis – step 1

Choose a telescope and submit a query to download MC data

[iatw.cnaf.infn.it/eee/elog/Query](http://iatw.cnaf.infn.it/eee/elog/Query)

(check the data quality on the EEE DQM page)



← → ↻ 🏠 iatw.cnaf.infn.it/eee/elog/Query/ ★ ⓘ

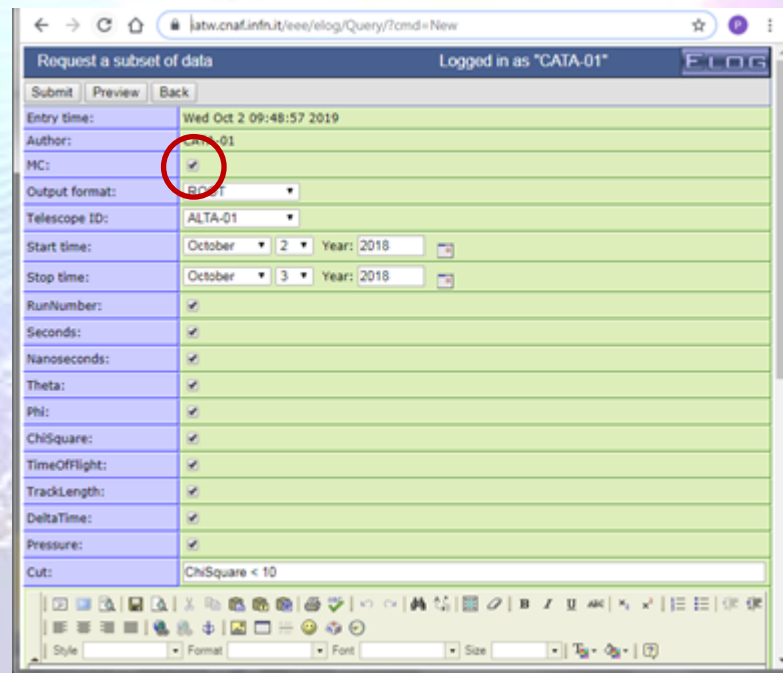
Please login

Username:

Password:

☒ Keep me logged in on this computer for the next 31 days or until I log out

ELOG V2.0.2-2466



← → ↻ 🏠 iatw.cnaf.infn.it/eee/elog/Query/?cmd=New ★ ⓘ

Request a subset of data Logged in as "CATA-01" ELOG

Entry time:	Wed Oct 2 09:48:57 2019
Author:	CATA-01
MC:	<input checked="" type="checkbox"/>
Output format:	ROOT
Telescope ID:	ALTA-01
Start time:	October 2 Year: 2018
Stop time:	October 3 Year: 2018
RunNumber:	<input checked="" type="checkbox"/>
Seconds:	<input checked="" type="checkbox"/>
Nanoseconds:	<input checked="" type="checkbox"/>
Theta:	<input checked="" type="checkbox"/>
Phi:	<input checked="" type="checkbox"/>
ChiSquare:	<input checked="" type="checkbox"/>
TimeOfFlight:	<input checked="" type="checkbox"/>
TrackLength:	<input checked="" type="checkbox"/>
DeltaTime:	<input checked="" type="checkbox"/>
Pressure:	<input checked="" type="checkbox"/>
Cut:	ChiSquare < 10

# DATA analysis – step 1

**Write your ROOT code in a .txt file (ICD\_analysis.txt):**

- To open the ROOT file
- To create and draw histograms for MC Phi and Theta distributions

**Save your code file (ICD\_analysis.txt) in C:\root\_v5.34.38\macros**

**Open ROOT (desktop icon)**

**Execute your code: *.x ICD\_analysis.txt***

# DATA analysis – step 1

## Your ROOT code for MC data

```
ICD_analysis.txt - Blocco note
File Modifica Formato Visualizza ?

{

//OPEN ROOT FILE WITH MC DATA
TFile *fMC = new TFile("D:\\\\EEE\\ICD\\2019\\ROOT\\ALTA-01from2018-10-02to2018-10-03-MC.root");
TTree *eeeMC = (TTree*)fMC->Get("eee");

//CREATE HISTOS FOR MC THETA AND PHI DISTRIBUTIONS
TH1F *hPhiMC = new TH1F("hPhiMC", "MC Phi Distribution", 72, 0, 360);
TH1F *hThetaMC = new TH1F("hThetaMC", "MC Theta Distribution", 45, 0, 90);

//FILL AND DRAW MC PHI DISTRIBUTION
TCanvas *cPhiMC = new TCanvas();
eeeMC->Draw("(Phi+180) >> hPhiMC");
hPhiMC->Draw();
cPhiMC->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\MCPhi.png");

//FILL AND DRAW MC THETA DISTRIBUTION
TCanvas *cThetaMC = new TCanvas();
eeeMC->Draw("Theta >> hThetaMC");
hThetaMC->Draw();
cThetaMC->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\MCTheta.png");

}
```



# DATA analysis – step 1

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File Modifica Formato Visualizza ?
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TFile *fMC = new TFile("D:\\\\EEE\\ICD\\2019\\ROOT\\ALTA-01from2018-10-02to2018-10-03-MC.root");
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}
```

**OPEN THE ROOT FILE  
AND GET THE TREE**

# DATA analysis – step 1

## Your ROOT code for MC data

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}
```

**CREATE THE HISTOS  
(EMPTY)**

- Range
- nBins

# DATA analysis – step 1

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//FILL AND DRAW MC THETA DISTRIBUTION
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hThetaMC->Draw();
cThetaMC->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\MCTheta.png");

}
```

**FILL THE HISTO FOR  
PHI DISTRIBUTION,  
DRAW AND SAVE IT**

# DATA analysis – step 1

## Your ROOT code for MC data

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File Modifica Formato Visualizza ?
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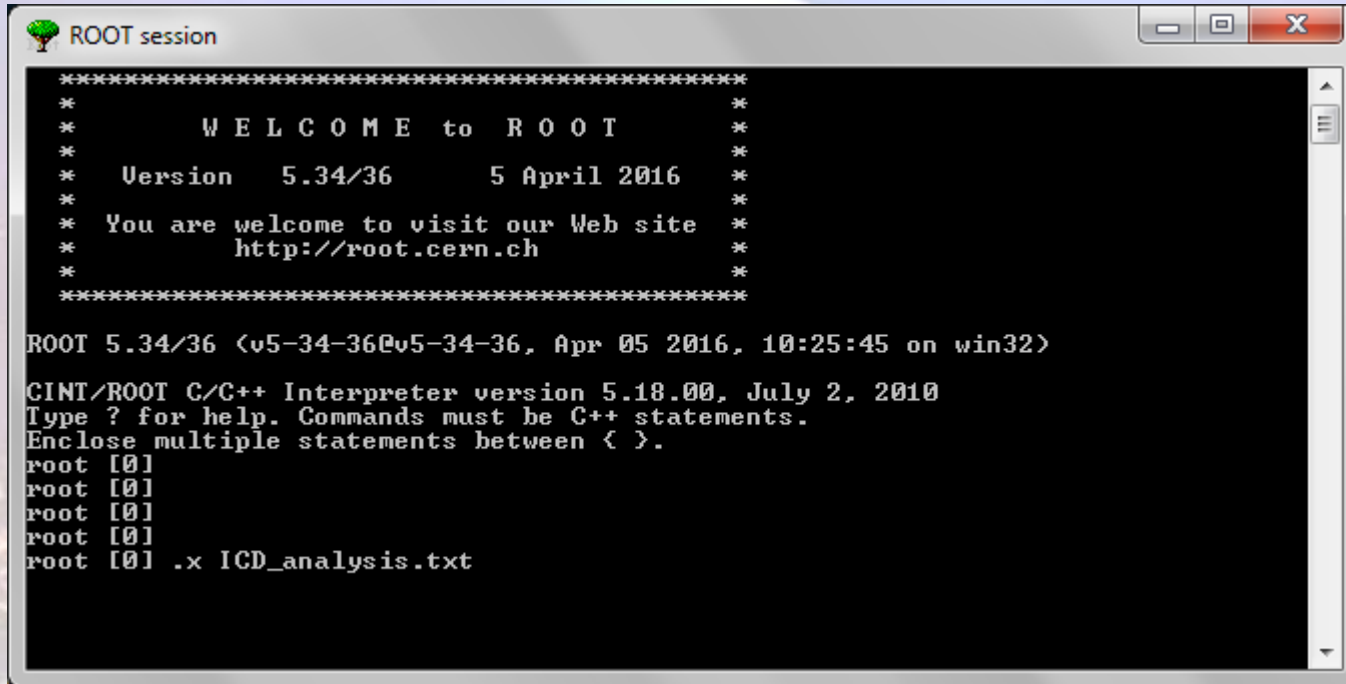
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eeeMC->Draw("Theta >> hThetaMC");
hThetaMC->Draw();
cThetaMC->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\MCTheta.png");
}
```

**FILL THE HISTO FOR  
THETA DISTRIBUTION,  
DRAW AND SAVE IT**

# DATA analysis – step 1

## Your ROOT code for MC data



```
ROOT session
*****
*                               *
*      W E L C O M E  t o  R O O T      *
*                               *
*   Version   5.34/36           5 April 2016   *
*                               *
*   You are welcome to visit our Web site   *
*      http://root.cern.ch                *
*                               *
*****

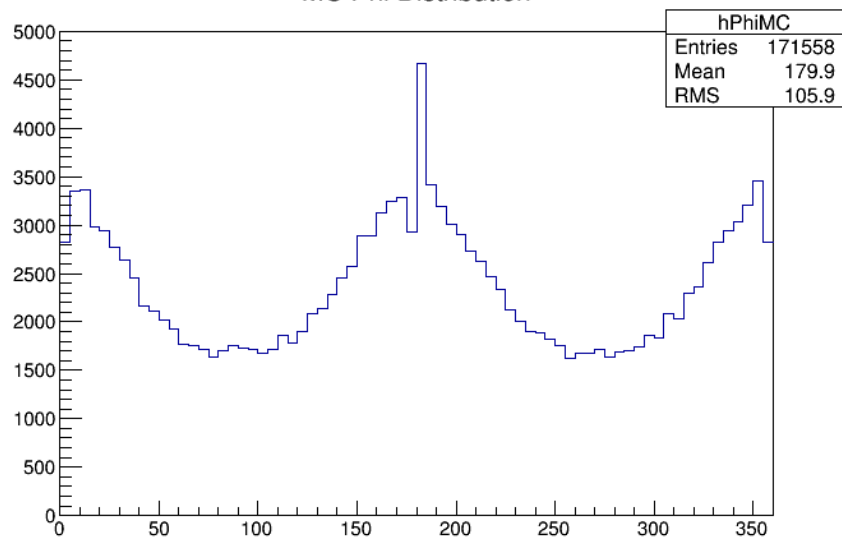
ROOT 5.34/36 (v5-34-36@v5-34-36, Apr 05 2016, 10:25:45 on win32)
CINT/ROOT C/C++ Interpreter version 5.18.00, July 2, 2010
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0]
root [0]
root [0]
root [0]
root [0] .x ICD_analysis.txt
```



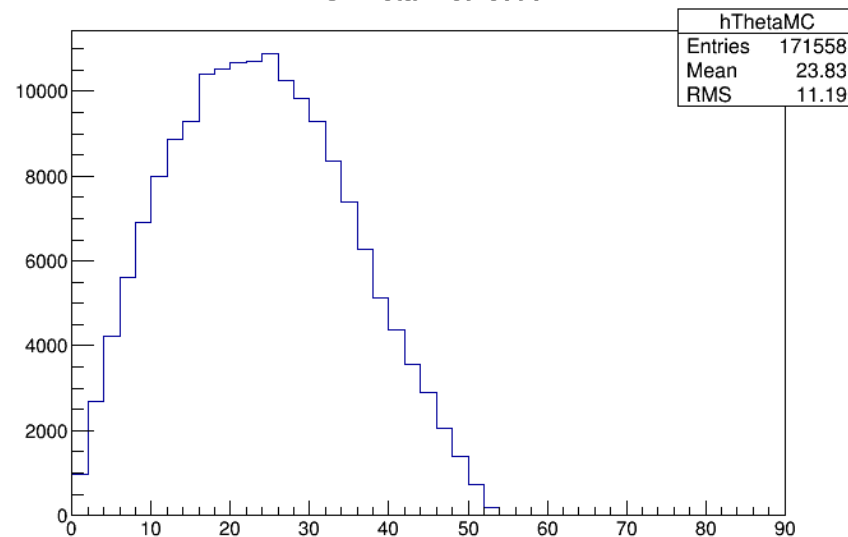
# DATA analysis – step 1

## Your ROOT code for MC data

MC Phi Distribution



MC Theta Distribution

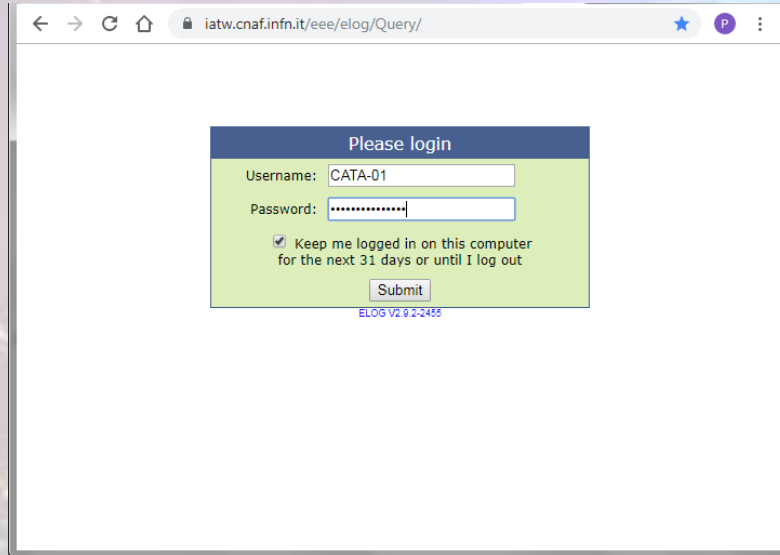


## DATA analysis – step 2

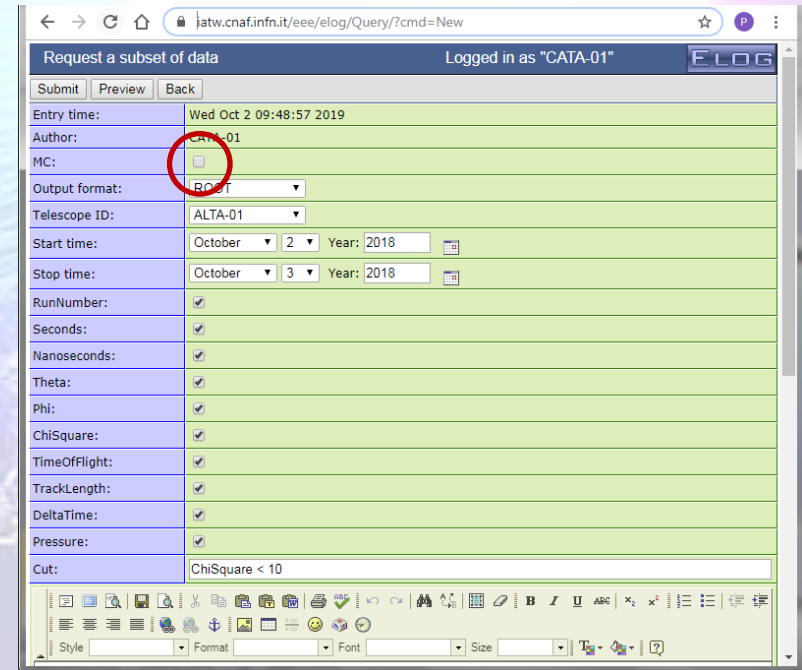
1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)
2. **Study of the experimental angular distribution (isotropic distribution + detector acceptance effects +  $\cos^2\theta$  factor)**
3. Ratio (distribution 2/ distribution 1) to isolate the  $\cos^2\theta$  factor

# DATA analysis – step 2

Submit a query to download experimental data [iatw.cnaf.infn.it/eee/elog/Query](http://iatw.cnaf.infn.it/eee/elog/Query)  
(use Duplicate function, without MC flag)



A screenshot of a web browser showing the login page for the ELOG system. The browser's address bar displays 'iatw.cnaf.infn.it/eee/elog/Query/'. The page has a light green background. A dark blue header bar contains the text 'Please login'. Below this, there are two input fields: 'Username:' with the value 'CATA-01' and 'Password:' with a masked password '.....'. A checkbox labeled 'Keep me logged in on this computer for the next 31 days or until I log out' is checked. A 'Submit' button is located below the password field. At the bottom of the login box, the text 'ELOG V2.9.2-2455' is visible.



A screenshot of the ELOG query interface. The browser's address bar shows 'iatw.cnaf.infn.it/eee/elog/Query/?cmd=New'. The page is titled 'Request a subset of data' and shows 'Logged in as "CATA-01"'. There are three buttons: 'Submit', 'Preview', and 'Back'. The interface displays a list of data fields and their values. The 'MC' field is highlighted with a red circle and contains a checkbox that is currently unchecked. The 'Output format' is set to 'ROOT'. The 'Telescope ID' is 'ALTA-01'. The 'Start time' is 'October 2, 2018' and the 'Stop time' is 'October 3, 2018'. The 'RunNumber' is '1'. The 'Seconds' field is checked. The 'Nanoseconds' field is checked. The 'Theta' field is checked. The 'Phi' field is checked. The 'ChiSquare' field is checked. The 'TimeOfFlight' field is checked. The 'TrackLength' field is checked. The 'DeltaTime' field is checked. The 'Pressure' field is checked. The 'Cut' field is 'ChiSquare < 10'.

## DATA analysis – step 2

**Write and append your ROOT code in the .txt file (ICD\_analysis.txt):**

- To open the ROOT file
- To create and draw histograms for experimental Phi and Theta distributions

**Open ROOT (desktop icon)**

**Execute your code: `.x ICD_analysis.txt`**

# DATA analysis – step 2

## Your ROOT code for experimental data

```
ICD_analysis.txt - Blocco note
File Modifica Formato Visualizza ?

//OPEN ROOT FILE WITH EXPERIMENTAL DATA
TFile *fDATA = new TFile("D:\\\\EEE\\ICD\\2019\\ROOT\\ALTA-01from2018-10-02to2018-10-03.root");
TTree *eeeDATA = (TTree*)fDATA->Get("eee");

//CREATE HISTOS FOR EXPERIMENTAL THETA AND PHI DISTRIBUTIONS
TH1F *hPhiDATA = new TH1F("hPhiDATA", "Experimental Phi Distribution", 72, 0, 360);
TH1F *hThetaDATA = new TH1F("hThetaDATA", "Experimental Theta Distribution", 45, 0, 90);

//FILL AND DRAW EXPERIMENTAL PHI DISTRIBUTION
TCanvas *cPhiDATA = new TCanvas();
eeeDATA->Draw("(Phi+180) >> hPhiDATA");
hPhiDATA->Draw();
cPhiDATA->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\DATAPhi.png");

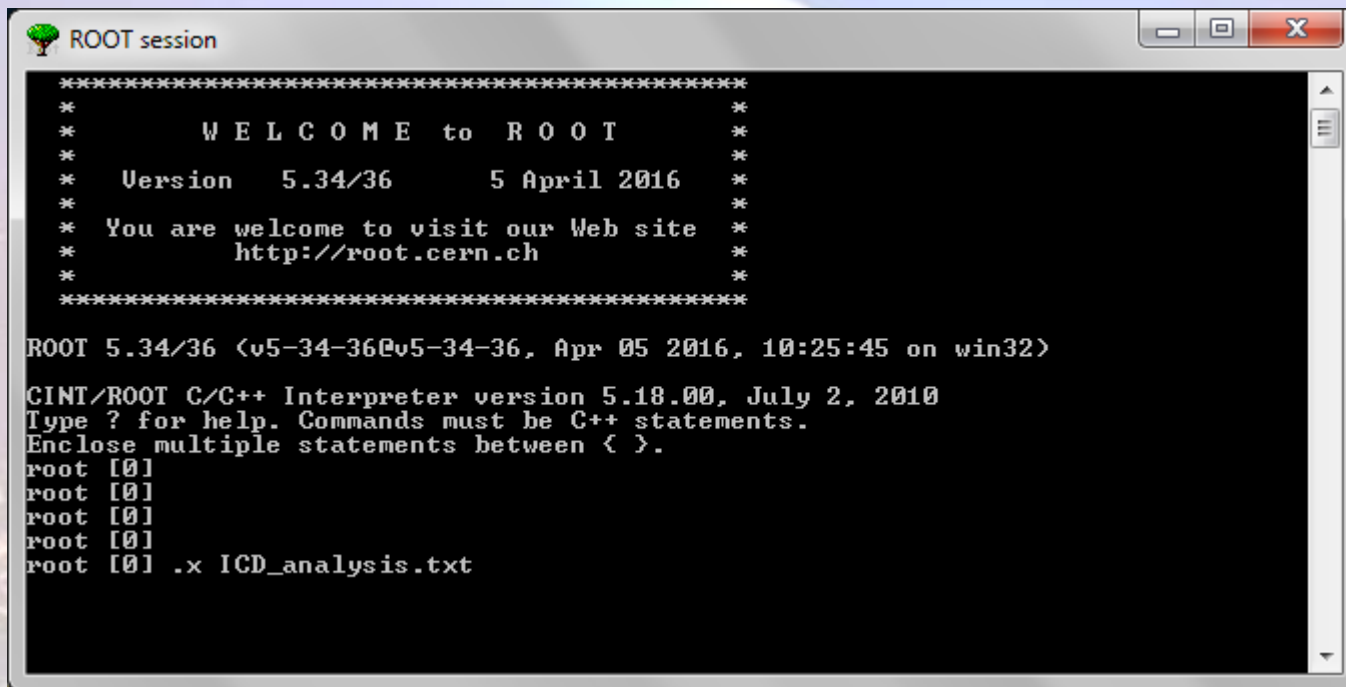
//FILL AND DRAW EXPERIMENTAL THETA DISTRIBUTION
TCanvas *cThetaDATA = new TCanvas();
eeeDATA->Draw("Theta >> hThetaDATA");
hThetaDATA->Draw();
cThetaDATA->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\DATATheta.png");

}
```



# DATA analysis – step 2

## Your ROOT code for experimental data



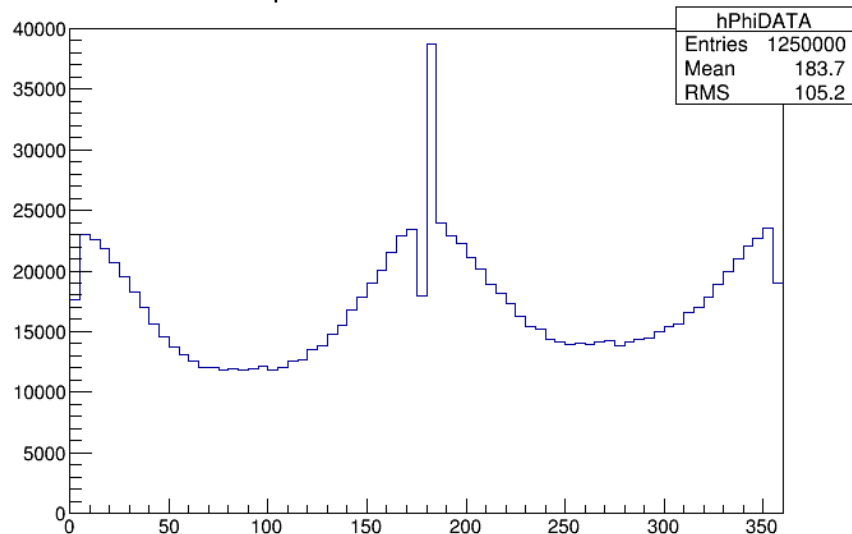
```
ROOT session
*****
*                                     *
*      W E L C O M E  t o  R O O T      *
*                                     *
*   Version   5.34/36           5 April 2016   *
*                                     *
*   You are welcome to visit our Web site   *
*      http://root.cern.ch                *
*                                     *
*****

ROOT 5.34/36 (v5-34-36@v5-34-36, Apr 05 2016, 10:25:45 on win32)
CINT/ROOT C/C++ Interpreter version 5.18.00, July 2, 2010
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0]
root [0]
root [0]
root [0]
root [0] .x ICD_analysis.txt
```

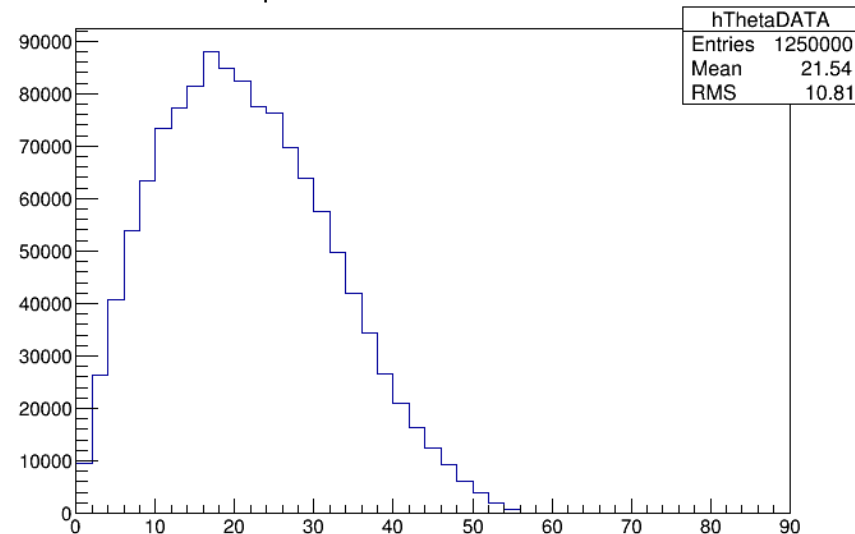
# DATA analysis – step 2

## Your ROOT code for experimental data

Experimental Phi Distribution



Experimental Theta Distribution



## DATA analysis – step 3

1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)
2. Study of the experimental angular distribution (isotropic distribution + detector acceptance effects +  $\cos^2\theta$  factor)
3. **Ratio (distribution 2/ distribution 1) to isolate the  $\cos^2\theta$  factor**

## DATA analysis – step 3

**Write and append your ROOT code in the .txt file (ICD\_analysis.txt):**

- **To create, fill and draw histos (for the ratio)**

**Open ROOT (desktop icon)**

**Execute your code: `.x ICD_analysis.txt`**

# DATA analysis – step 3

## Your ROOT code to calculate the ratio

```
ICD_analysis.txt - Blocco note
File Modifica Formato Visualizza ?

// CREATE HISTOS FOR THE RATIOS
TH1F *hPhiRATIO = new TH1F("hPhiRATIO", "Ratio between exp and MC Phi Distribution", 72, 0, 360);
TH1F *hThetaRATIO = new TH1F("hThetaRATIO", "Ratio between exp and MC Theta Distribution", 45, 0, 90);

hPhiRATIO->Divide(hPhiDATA,hPhiMC);
TCanvas *cPhiRATIO = new TCanvas();
hPhiRATIO->Draw();
cPhiRATIO->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\RATIOPhi.png");

hThetaRATIO->Divide(hThetaDATA,hThetaMC);
TCanvas *cThetaRATIO = new TCanvas();
hThetaRATIO->Draw();
cThetaRATIO->SaveAs("D:\\\\EEE\\ICD\\2019\\ROOT\\RATIOTheta.png");

}
```



## DATA analysis – step 3

Your ROOT code to calculate the ratio

Compare the Theta Distribution with a  $\cos^2\theta$  function

$$[0] * \cos(x * \pi / 180) * \cos(x * \pi / 180)$$

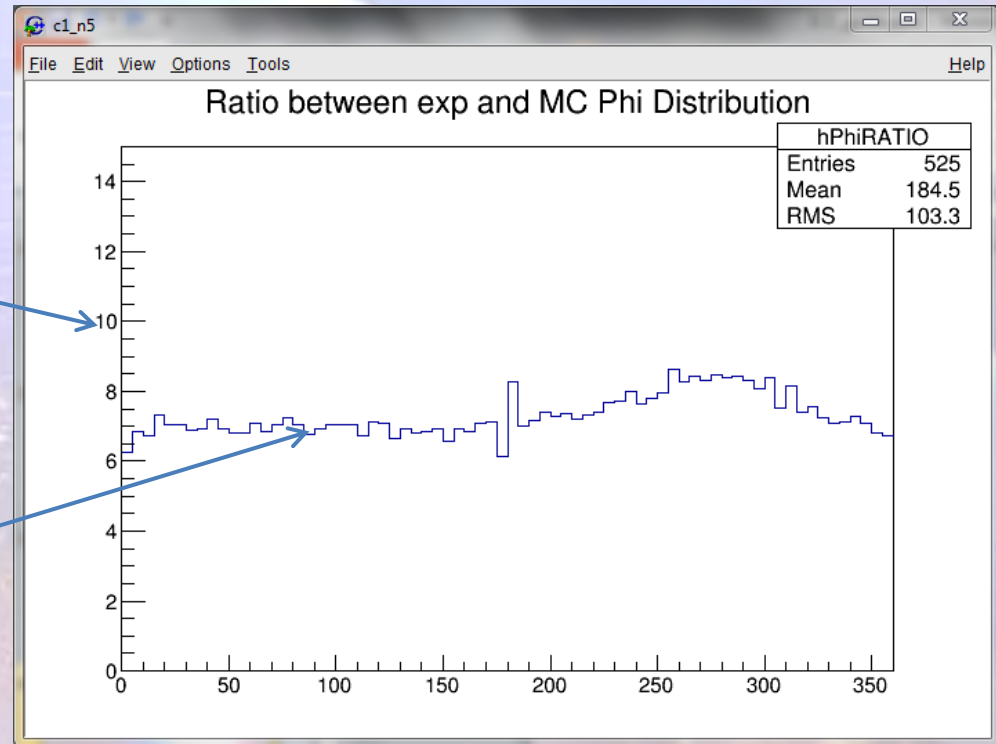
Compare the Phi Distribution with a constant function  $f(x) = \text{pol0}$

# DATA analysis – step 3

## Compare data with expected trend (phi distribution)

Right click on the vertical scale  
 → SetRangeUser  
 → [0, 15]

Right click on the histo line  
 → FitPanel



# DATA analysis – step 3

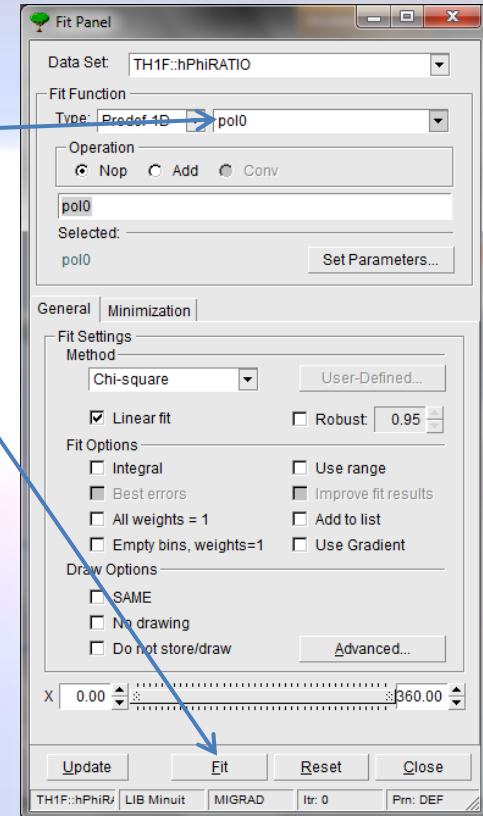
## Compare data with expected trend (phi distribution)

```
ROOT session
ROOT 5.34/36 <v5-34-36v5-34-36, Apr 05 2016, 10:25:45 on win32>
CINT/ROOT C/C++ Interpreter version 5.18.00, July 2, 2010
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between < >.
root [0] .x ICD_analysis.txt
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\MCPHi.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\MCTheta.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\DATAPhi.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\DATATheta.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\RATIOPhi.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\RATIOTheta.png has been created
root [1]
*****
Minimizer is Linear
Chi2      =      3.04343
NDF       =      71
p0        =      7.25621 +/- 0.31746
```

Select pol0  
(zero degree polynomial)

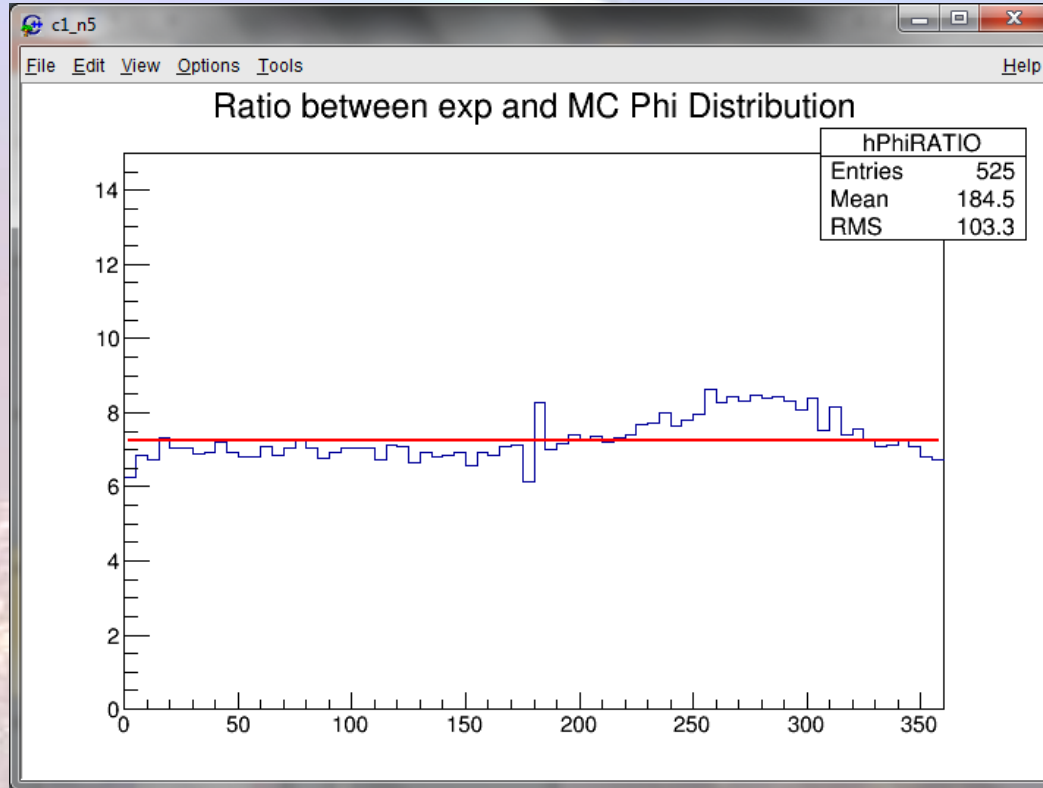
Press Fit

Output of the fit procedure



# DATA analysis – step 3

## Compare data with expected trend (phi distribution)

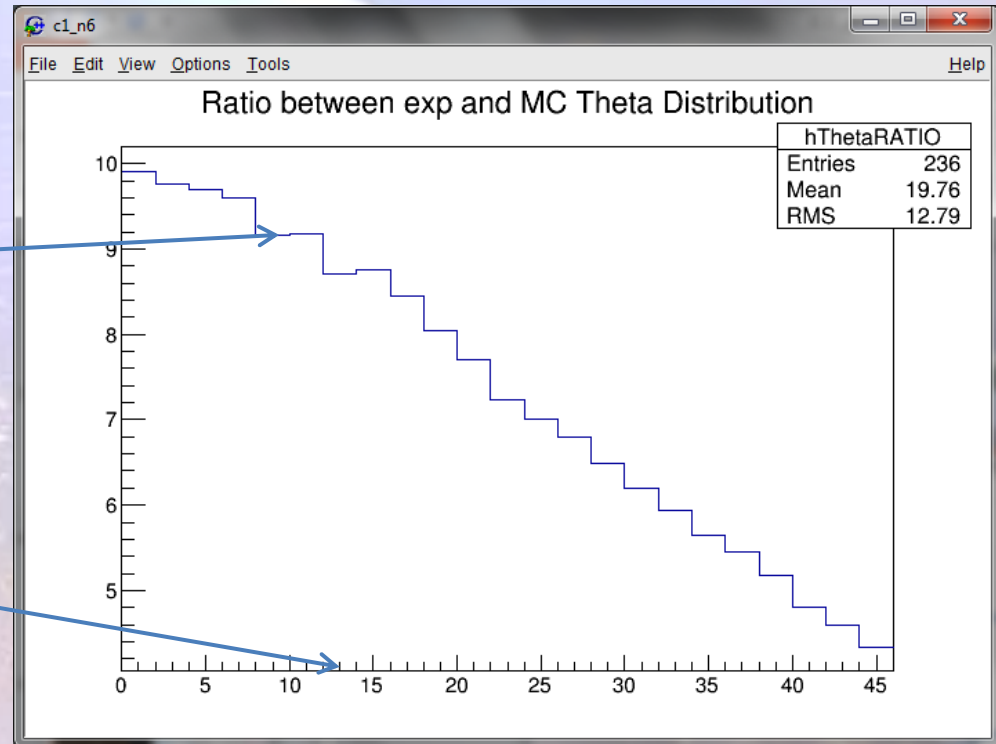


# DATA analysis – step 3

## Compare data with expected trend (theta distribution)

Right click on the histo line  
 → FitPanel

Right click on the horizontal scale  
 → SetRangeUser  
 → [0, 45]





# DATA analysis – step 3

## Compare data with expected trend (theta distribution)

```
ROOT session
root [0] .x ICD_analysis.txt
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\MCPHi.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\MCTheta.png has been created
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\
Info in <TCanvas::Print>: file D:\EEE\ICD\2019\ROOT\RATIOTheta.png has been created
root [1]

*****
Minimizer is Linear
Chi2          =      3.04343
Ndf           =      71
p0            =      7.25621 +/- 0.31746
FCN=0.566184 FROM MIGRAD STATUS=CONVERGED 12 CALLS 13 TOTAL
EDM=5.63189e-016 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER
NO.  NAME      VALUE      ERROR      STEP      FIRST
1    p0      9.00834e+000  6.94828e-001  4.41905e-004  4.83019e-008
```

Write your function  
 $[0] * \cos(x * \pi / 180) * \cos(x * \pi / 180)$

Output of the fit procedure

Press Fit

Fit Panel

Data Set: TH1F::hThetaRATIO

Fit Function  
 Type: Predef-1D gaus

Operation  
☒ Nop ☐ Add ☐ Conv

$[0] * \cos(x * \pi / 180) * \cos(x * \pi / 180)$

Selected: gaus Set Parameters...

General | Minimization

Fit Settings  
 Method: Chi-square User-Defined...

☐ Linear fit ☒ Robust: 0.95

Fit Options  
☐ Integral ☐ Use range  
☐ Best errors ☐ Improve fit results  
☐ All weights = 1 ☐ Add to list  
☐ Empty bins, weights=1 ☐ Use Gradient

Draw Options  
☐ SAME ☐ No drawing ☐ Do not store/draw Advanced...

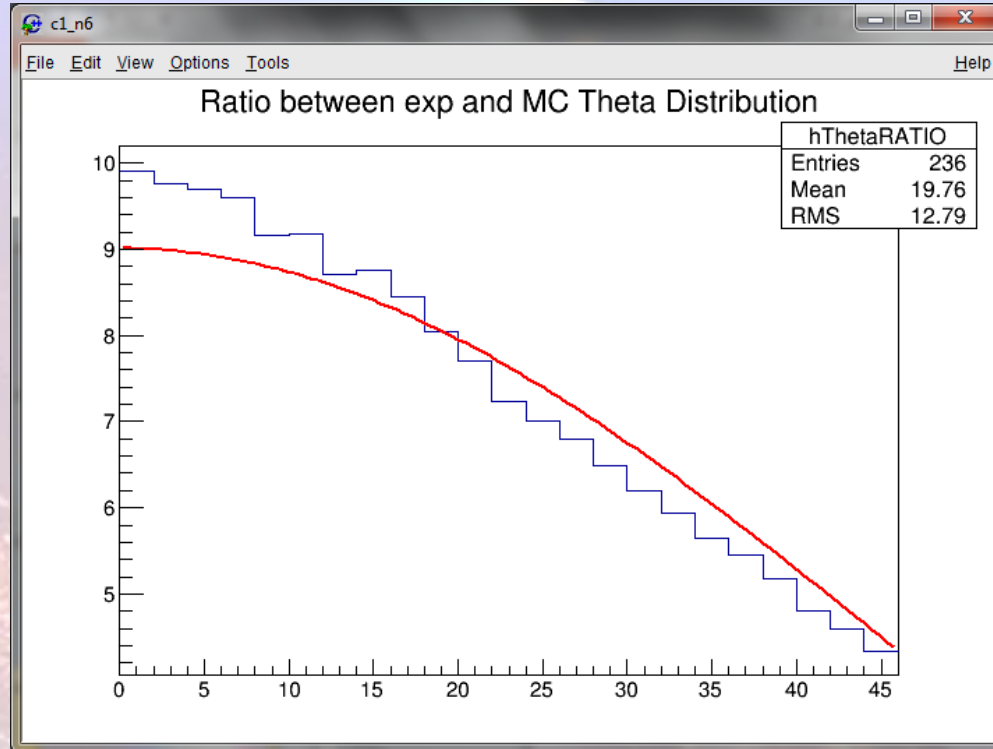
X: 0.00 46.00

Update Fit Reset Close

TH1F::hTheta LIB Minuit MIGRAD ltr: 0 Pm: DEF

# DATA analysis – step 3

## Compare data with expected trend (theta distribution)



## Possible improvements

- Study the zenithal distribution in ranges of  $\Phi$
- Study the azimuthal distribution in ranges of  $\Theta$
- Apply cuts on ChiSquare, TOF, Tracklength...
- Improve the graphycs
- ...
- And use your imagination and creativity

For any question please contact your EEE referent

