ICD GUIDE

ANALYSIS BASED ON ROOT

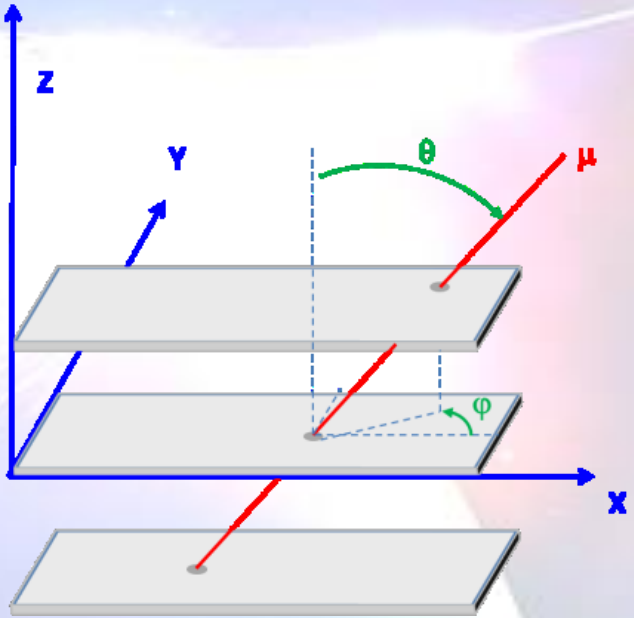
Extreme Energy Events
Science inside Schools

ANALYSIS FOR THE ICD

GOAL: MEARSURE THE ANGULAR DISTRIBUTIONS OF MUONS
HOW: ANALYZE THE EEE DATA USING ROOT
WHEN: ON NOVEMBER 6th

ZENITHAL DISTRIBUTION: Flux of muons as a function of the zenithal angle θ

AZIMUTHAL DISTRIBUTION: Flux of muons as a function of the azimuthal angle ϕ

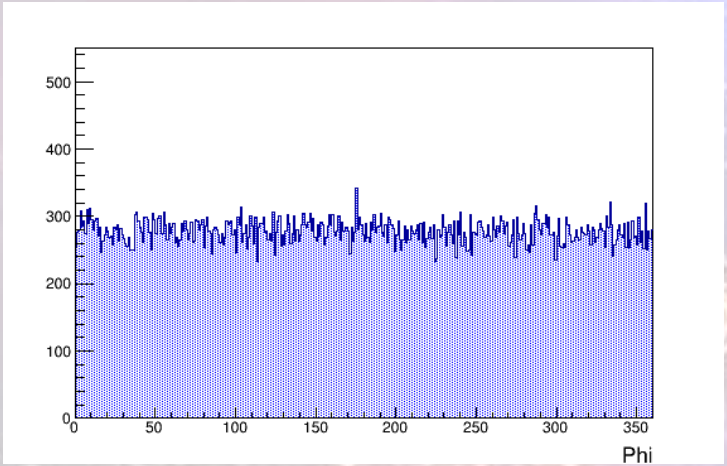


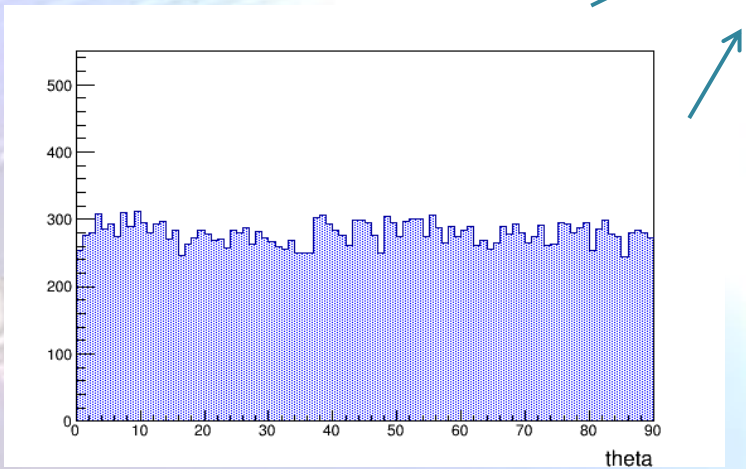
FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

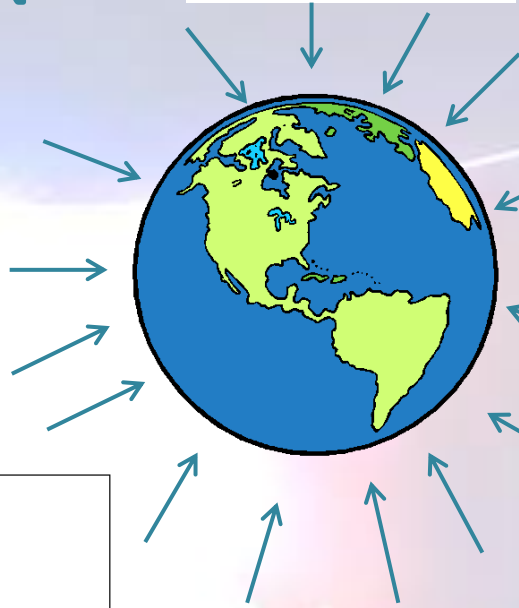
Ideally muons arrive from all direction with the same probability (isotropically)

ZENITHAL DISTRIBUTION : uniform (flat)
AZIMUTHAL DISTRIBUTION: uniform (flat)

is it true?







FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

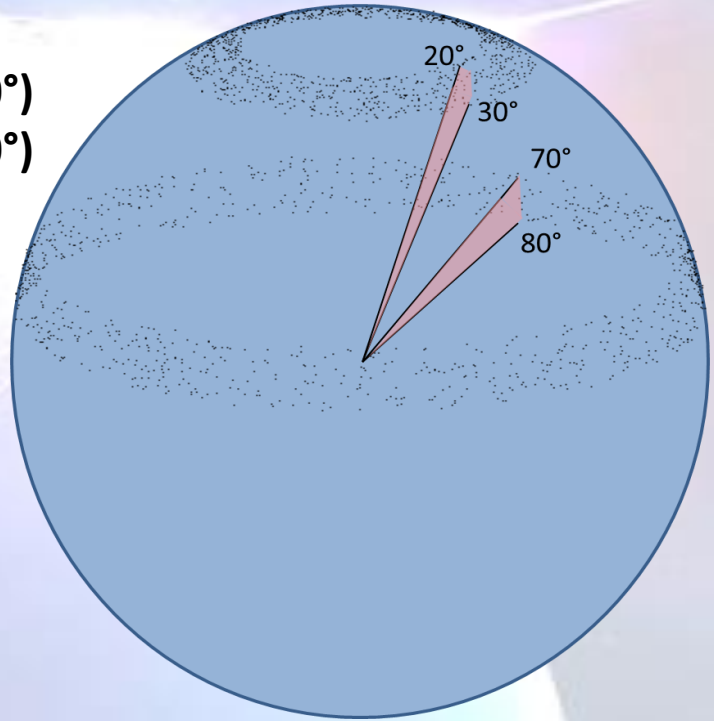
Due to geometrical reasons the zenithal distribution should be $\propto \sin(\theta)$

N1 = 1000 particles on A1 area (uniform in $d\theta$ = 20°-30°)
N2 = 1000 particles on A2 area (uniform in $d\theta$ = 70°-80°)

Rate1 = N1/A1
Rate2 = N2/A2

A2 > A1 → Rate1 > Rate2

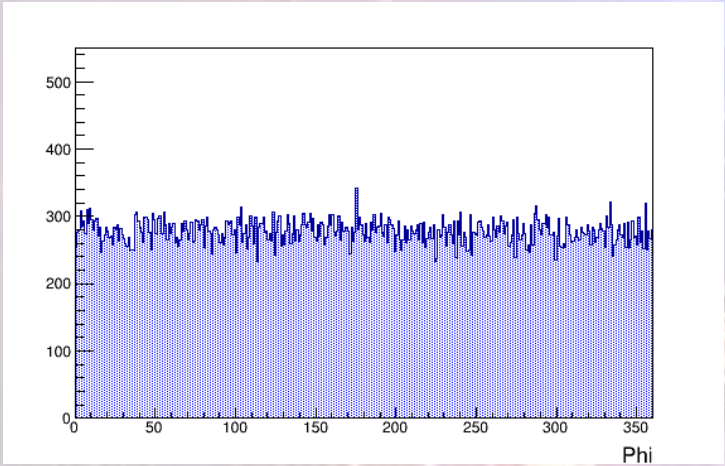
NOT ISOTROPIC!

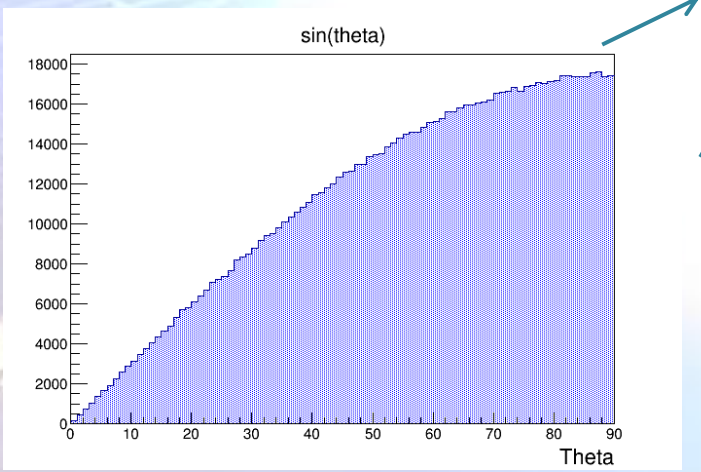


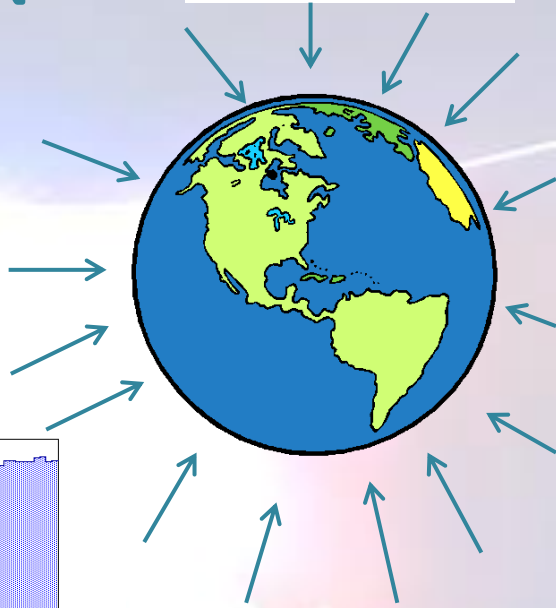
FIRST ASSUMPTION: ISOTROPIC DISTRIBUTION

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

AZIMUTHAL DISTRIBUTION: **uniform (flat)**



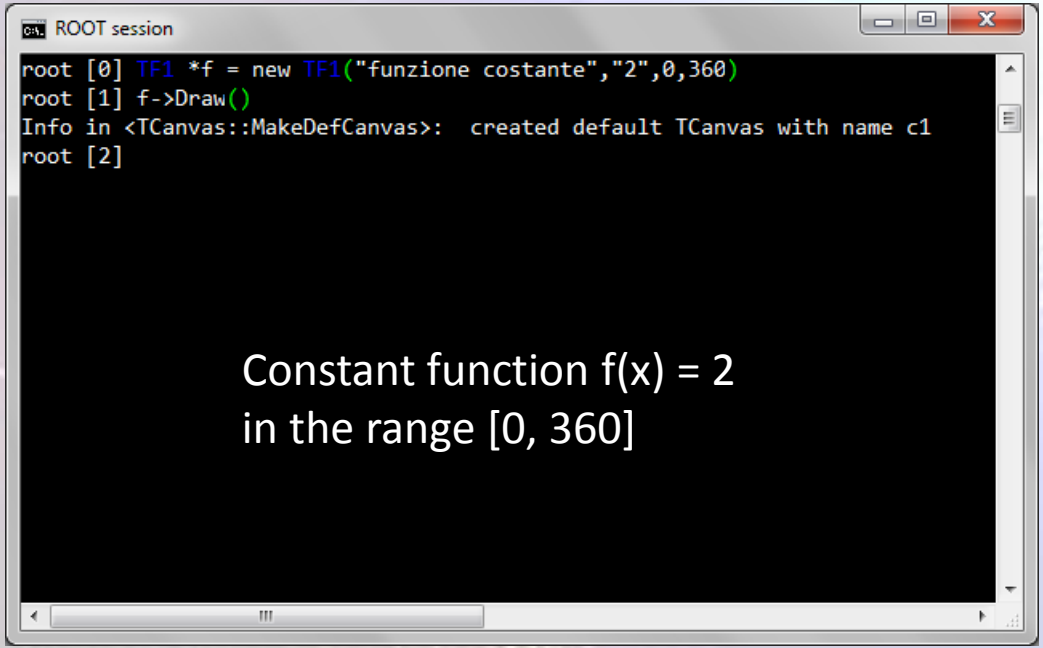




SIMPLE EXERCISE WITH ROOT

Define and draw a function

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



SIMPLE EXERCISE WITH ROOT

Define and draw a function

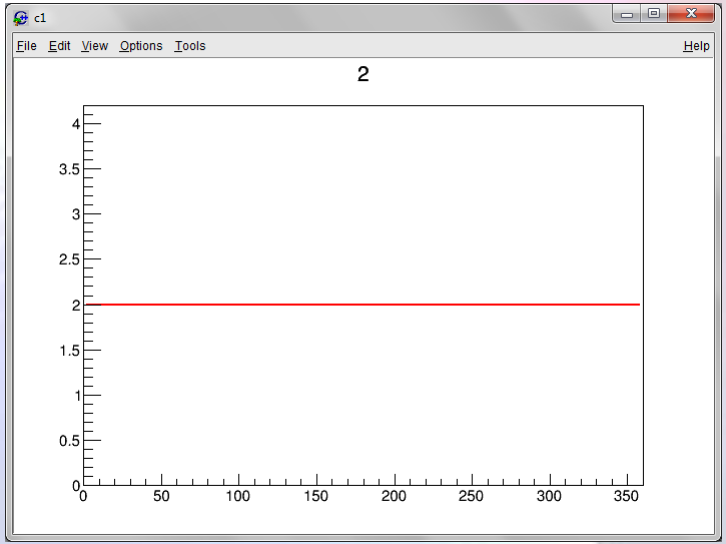
TF1 *f = new TF1("funzione costante", "2", 0, 360)

f-> Draw()

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]



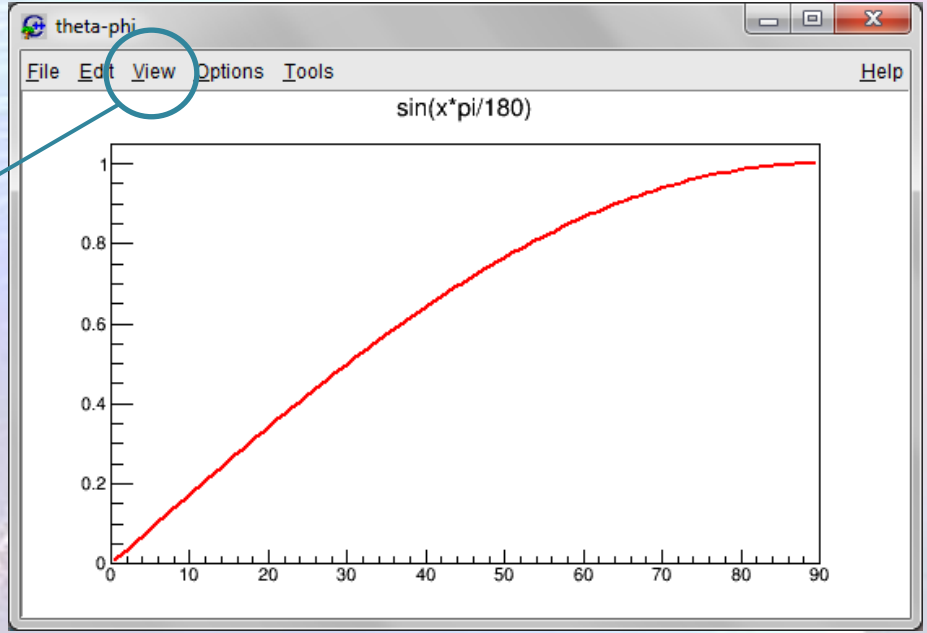
SIMPLE EXERCISE WITH ROOT

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

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

The sine function needs the argument in radiants
(pi = 3,14)

Play with the graphics
Menu View → Editor



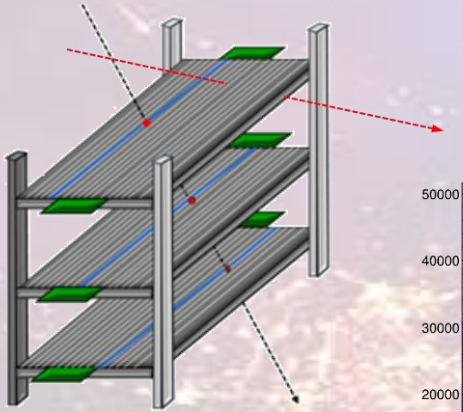
NOT SO EASY...

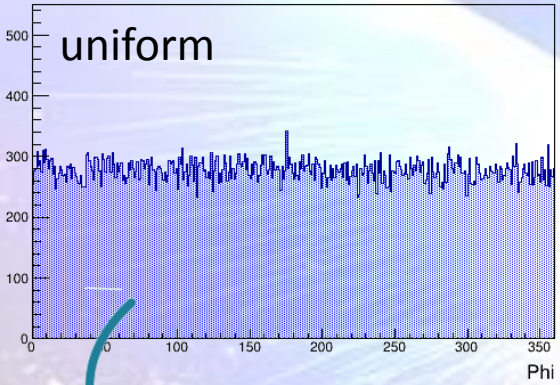
The angular distribution of the muons (ideally isotropic) is affected by 2 other factors:

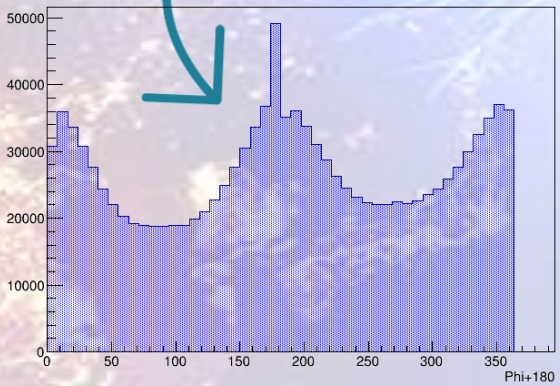
NOT SO EASY...

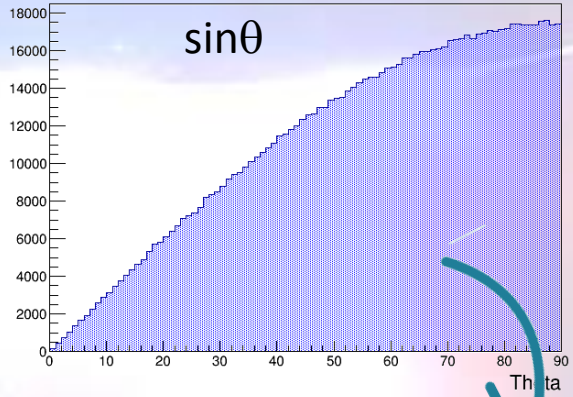
The angular distribution of the muons (ideally isotropic) is affected by 2 other factors:

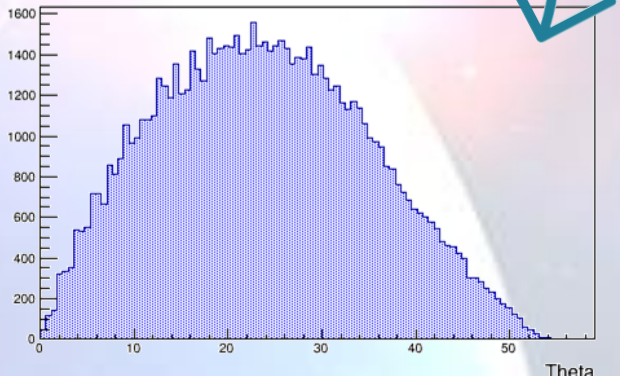
- **Detector acceptance**











NOT SO EASY...

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

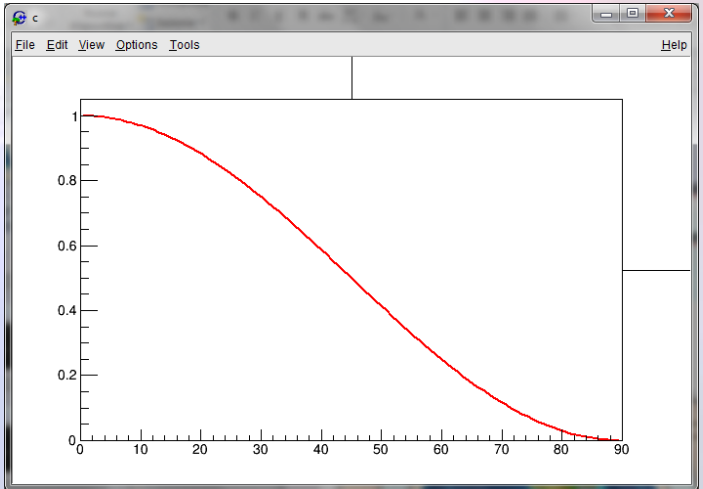
- **Detector acceptance**

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 → $\propto \cos^2\theta$ (vertical muons are more abundant)**

Draw this function using ROOT



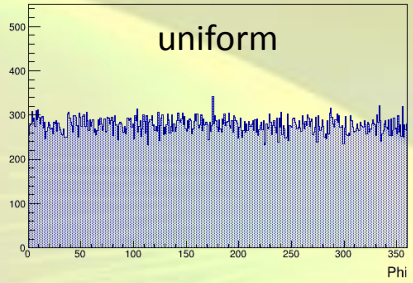
IN SUMMARY

AZIMUTHAL DISTRIBUTION

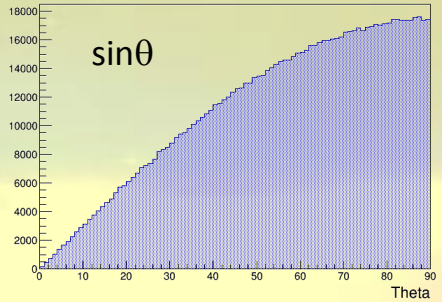
ZENITHAL DISTRIBUTION

- $\propto \sin\theta$

Azimuthal distribution



Zenithal distribution



Isotropic distribution

Extreme Energy Events
Science inside Schools

IN SUMMARY

AZIMUTHAL DISTRIBUTION

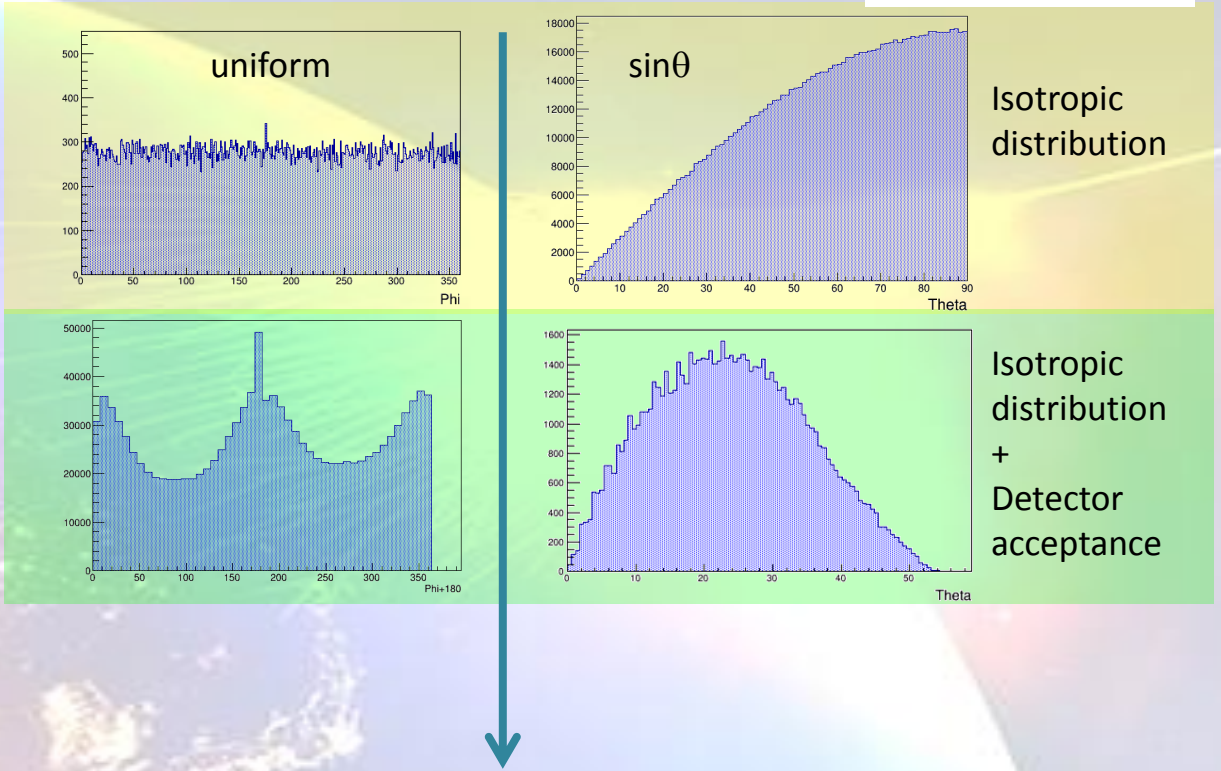
- **Detector acceptance**

ZENITHAL DISTRIBUTION

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

Azimuthal distribution

Zenithal distribution



IN SUMMARY

AZIMUTHAL DISTRIBUTION

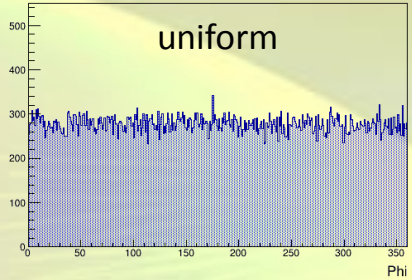
- **Detector acceptance**

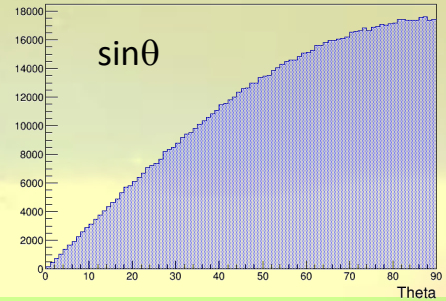
ZENITHAL DISTRIBUTION

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

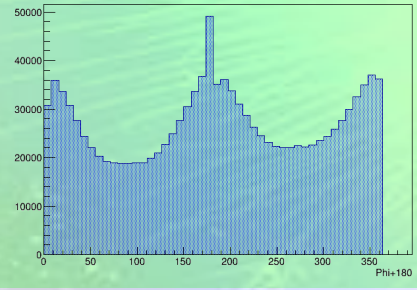
Azimuthal distribution

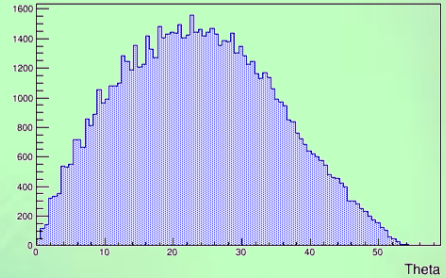
Zenithal distribution



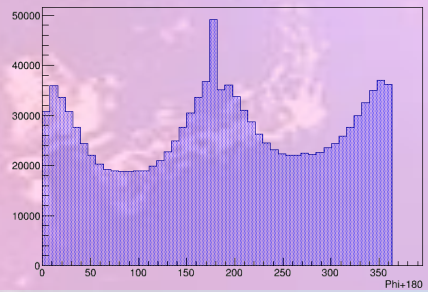


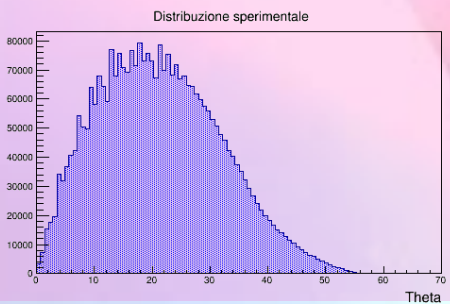
Isotropic distribution





Isotropic distribution + Detector acceptance





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

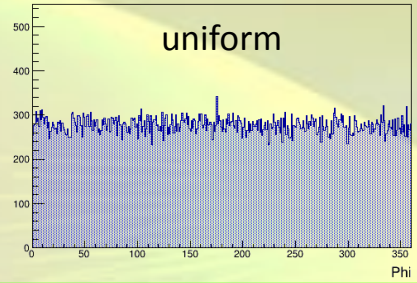
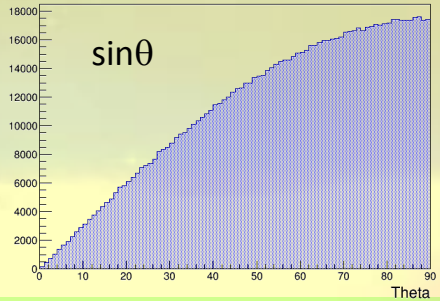
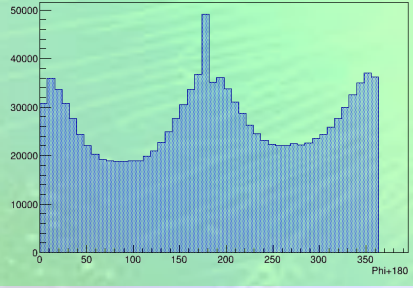
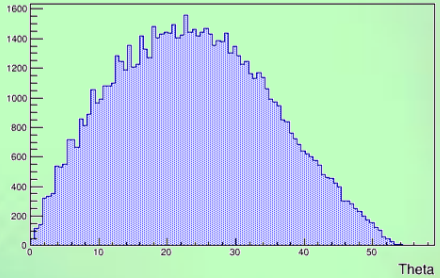
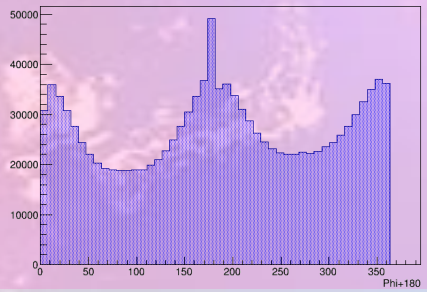
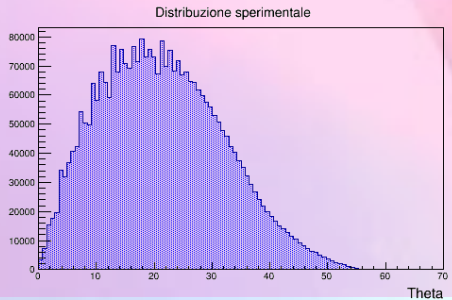
IN SUMMARY

AZIMUTHAL DISTRIBUTION

- **Detector acceptance**

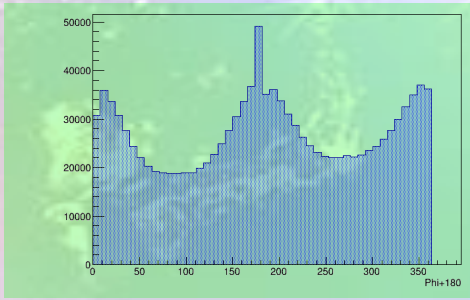
ZENITHAL DISTRIBUTION

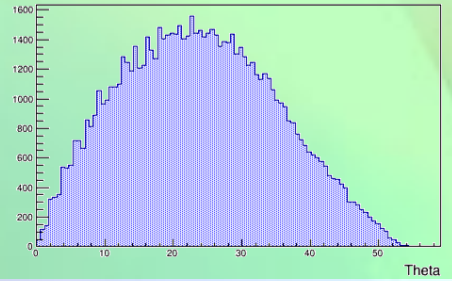
- **$\propto \sin\theta$**
- **Detector acceptance**
- **$\propto \cos^2\theta$**

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)**



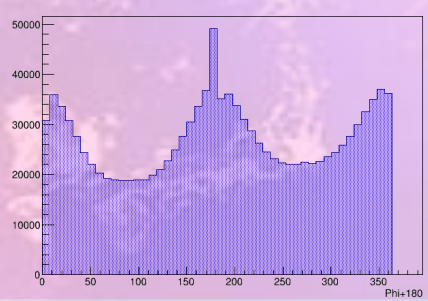


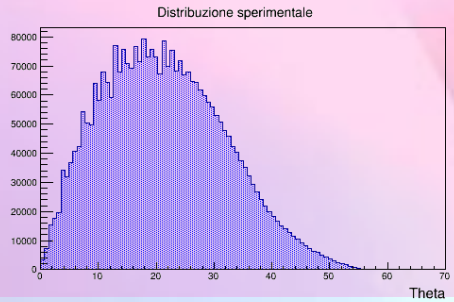
Isotropic distribution + Detector acceptance

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)**

2. Study of the experimental angular distribution (isotropic distribution + detector acceptance effects + $\cos^2\theta$ factor)

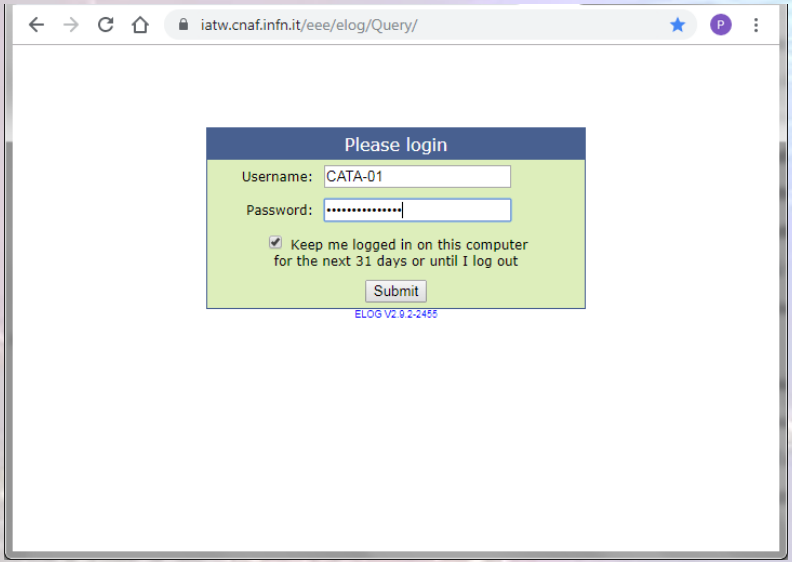
3. Ratio (distribution 2/ distribution 1) to isolate the $\cos^2\theta$ factor

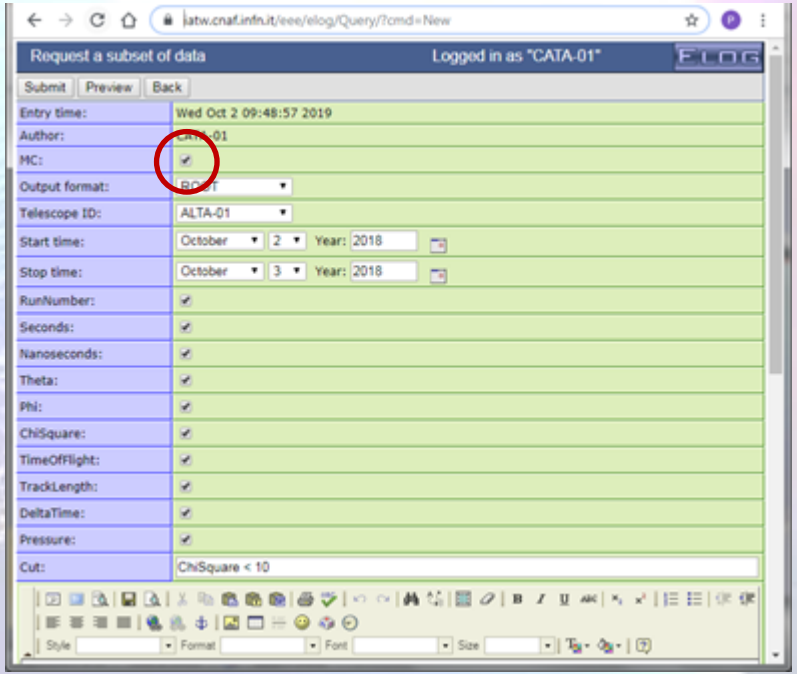
DATA analysis – step 1

Choose a telescope and submit a query to download MC data

iatw.cnaf.infn.it/eee/elog/Query

(check the data quality on the EEE DQM page)





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

Your ROOT code for MC data

ICD_analysis.txt - Blocco note

File Modifica Formato Visualizza ?

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hThetaMC->Draw();
cThetaMC->SaveAs("D:\\\EEE\\ICD\\2019\\ROOT\\MCTheta.png");

}
```

OPEN THE ROOT FILE AND GET THE TREE

DATA analysis – step 1

Your ROOT code for MC data

ICD_analysis.txt - Blocco note

File Modifica Formato Visualizza ?

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TCanvas *cThetaMC = new TCanvas();
eeeMC->Draw("Theta >> hThetaMC");
hThetaMC->Draw();
cThetaMC->SaveAs("D:\\\EEE\\ICD\\2019\\ROOT\\MCTheta.png");

}
```

CREATE THE HISTOS (EMPTY)

- Range
- nBins

DATA analysis – step 1

Your ROOT code for MC data

ICD_analysis.txt - Blocco note

File Modifica Formato Visualizza ?

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hPhiMC->Draw();
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//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");

}
```

FILL THE HISTO FOR PHI DISTRIBUTION, DRAW AND SAVE IT

DATA analysis – step 1

Your ROOT code for MC data

ICD_analysis.txt - Blocco note

File Modifica Formato Visualizza ?

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//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");

}
```
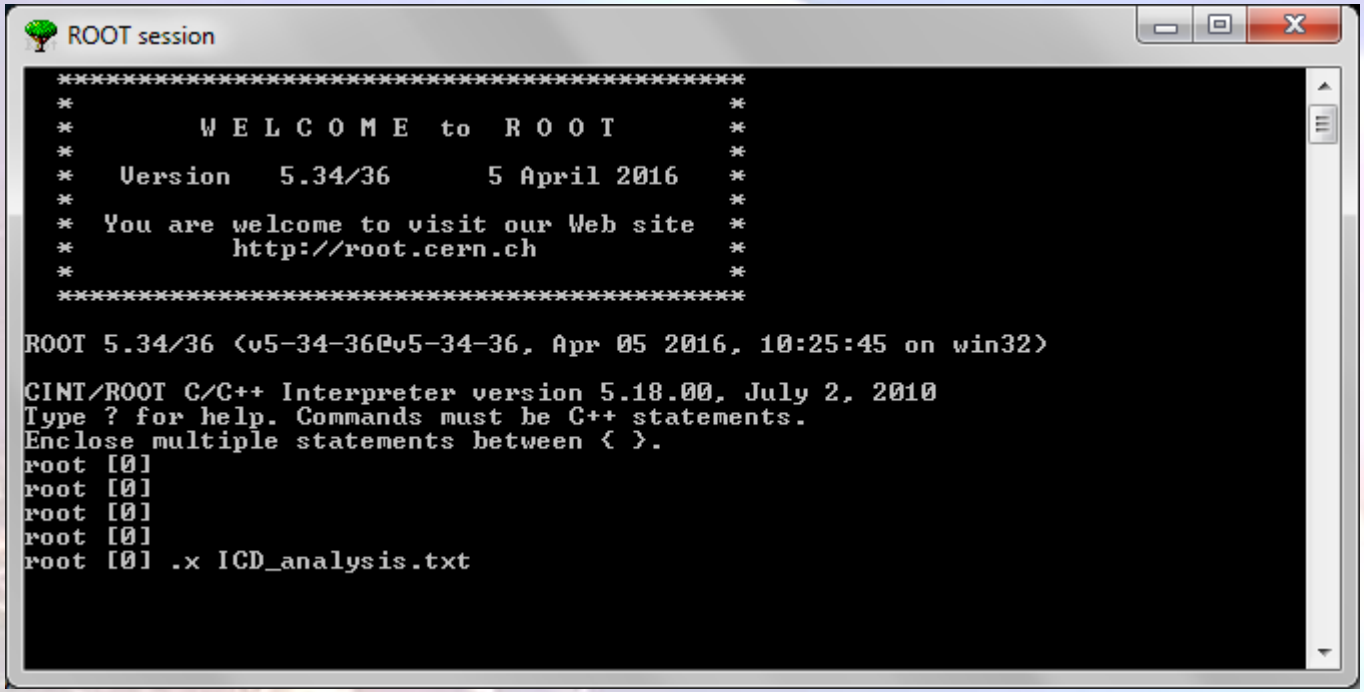

FILL THE HISTO FOR THETA DISTRIBUTION, DRAW AND SAVE IT

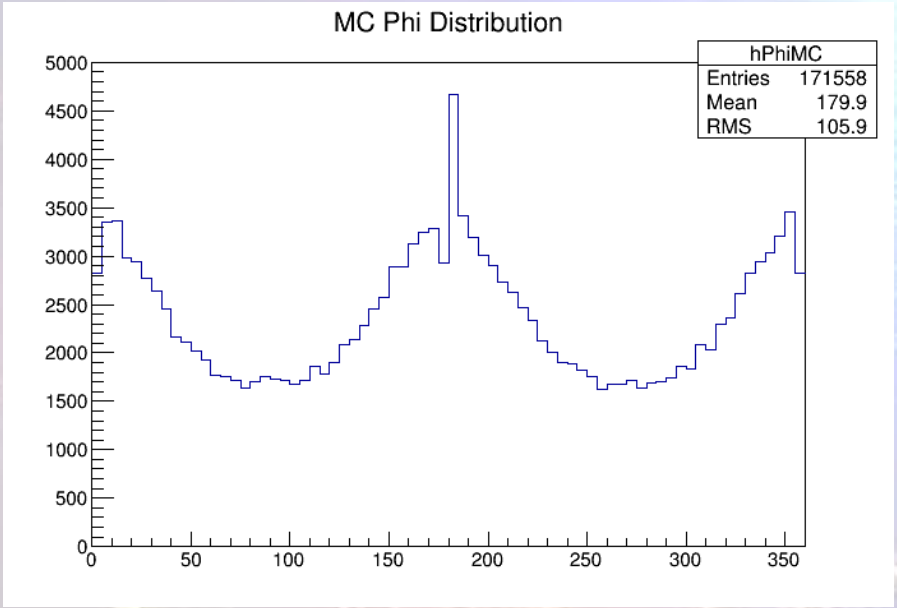
DATA analysis – step 1

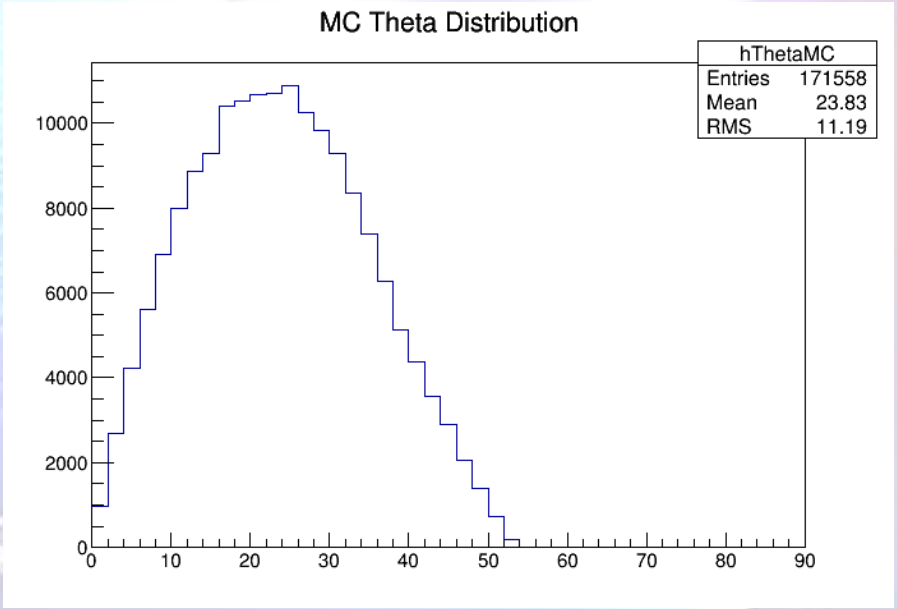
Your ROOT code for MC data



DATA analysis – step 1

Your ROOT code for MC data





DATA analysis – step 2

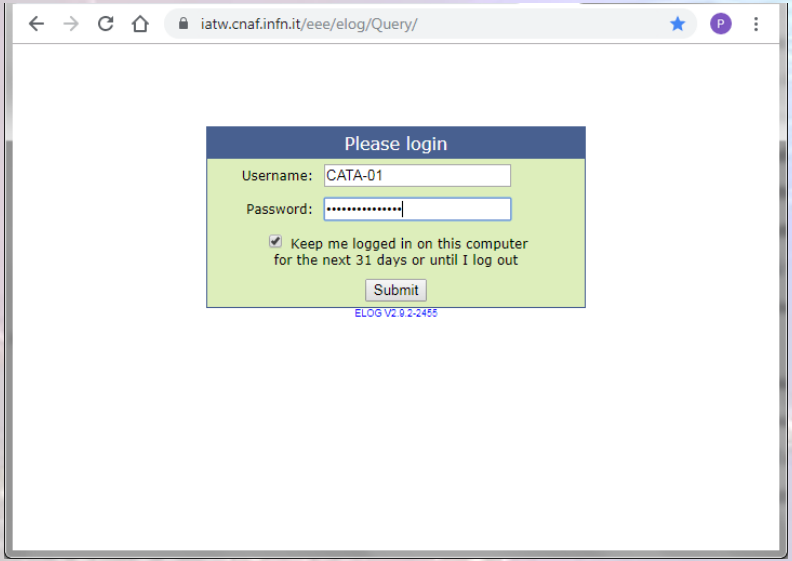
1. Study of the angular distribution in case of isotropic distribution + detector acceptance effects (Monte Carlo simulated data)

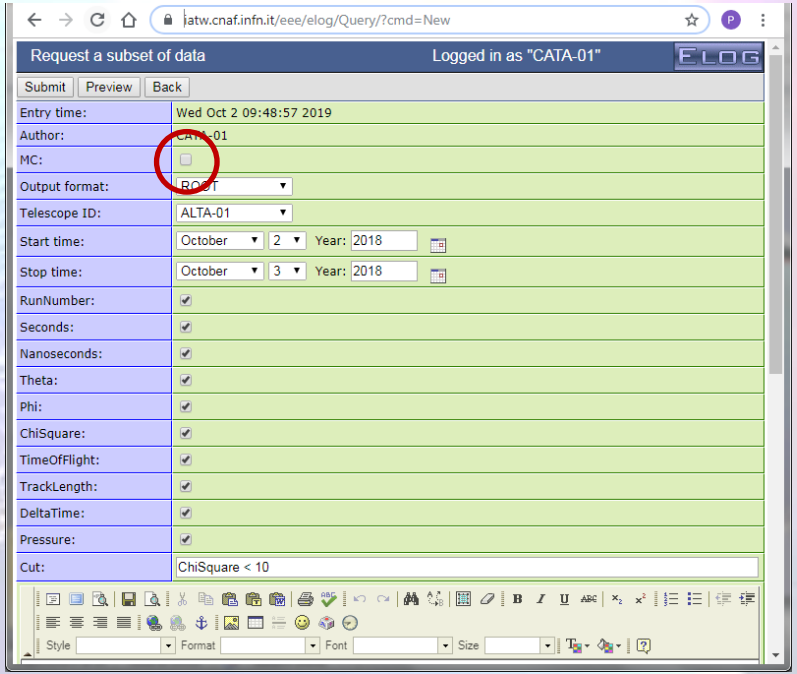
2. **Study of the experimental angular distribution (isotropic distribution + detector acceptance effects + $\cos^2\theta$ factor)**

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 (use Duplicate function, without MC flag)





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

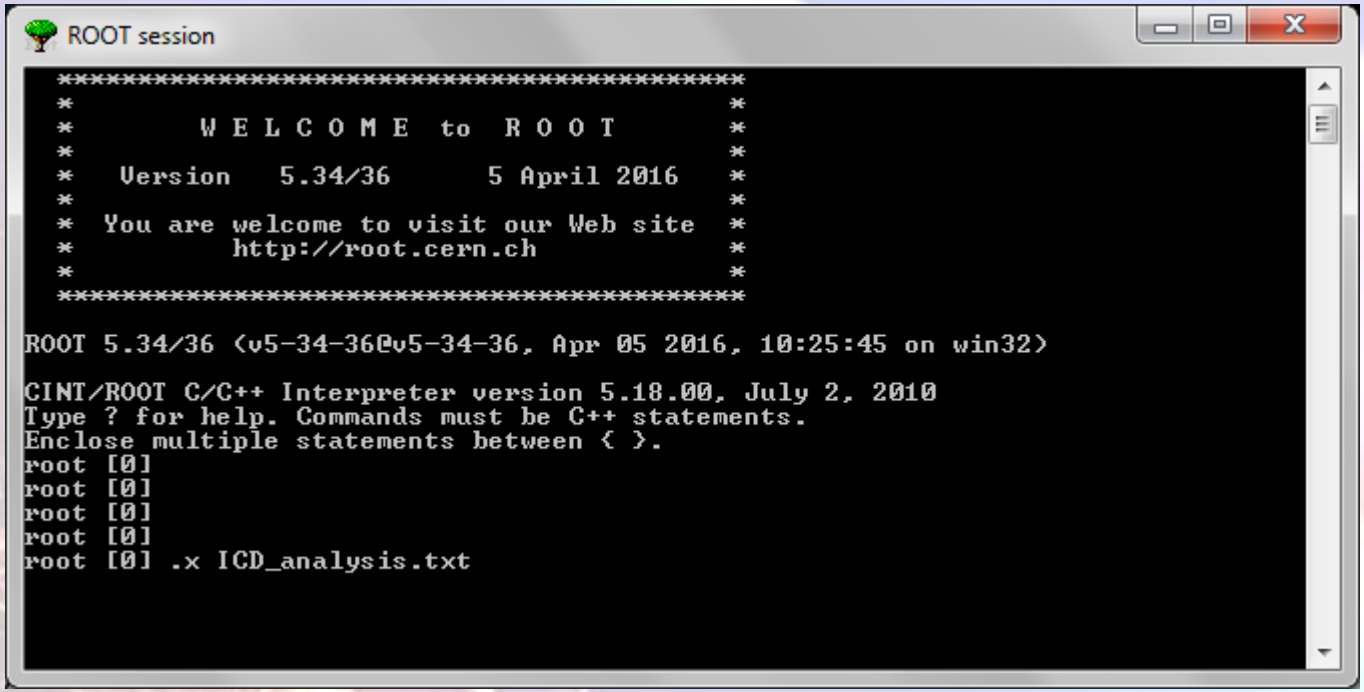
ICD_analysis.txt - Blocco note

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");


}
```

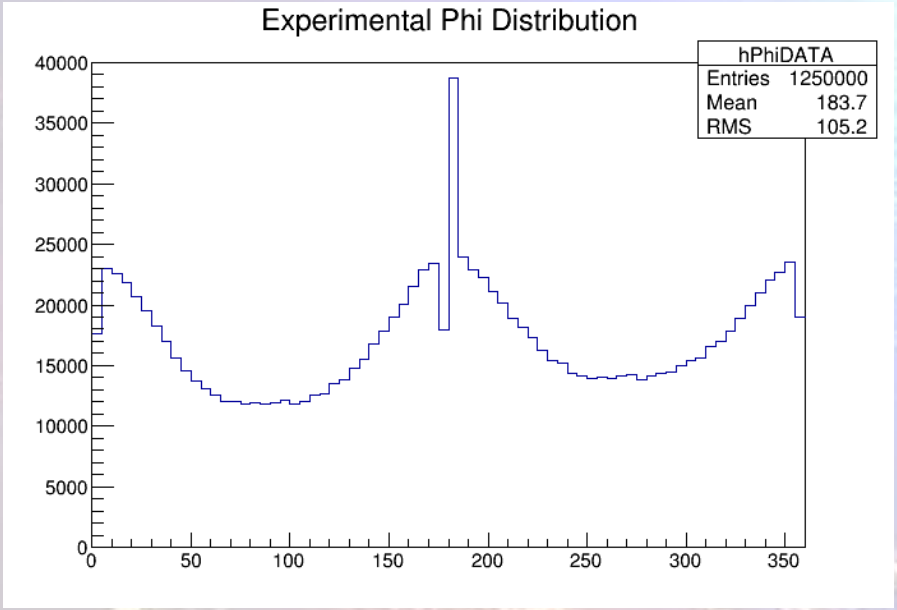
DATA analysis – step 2

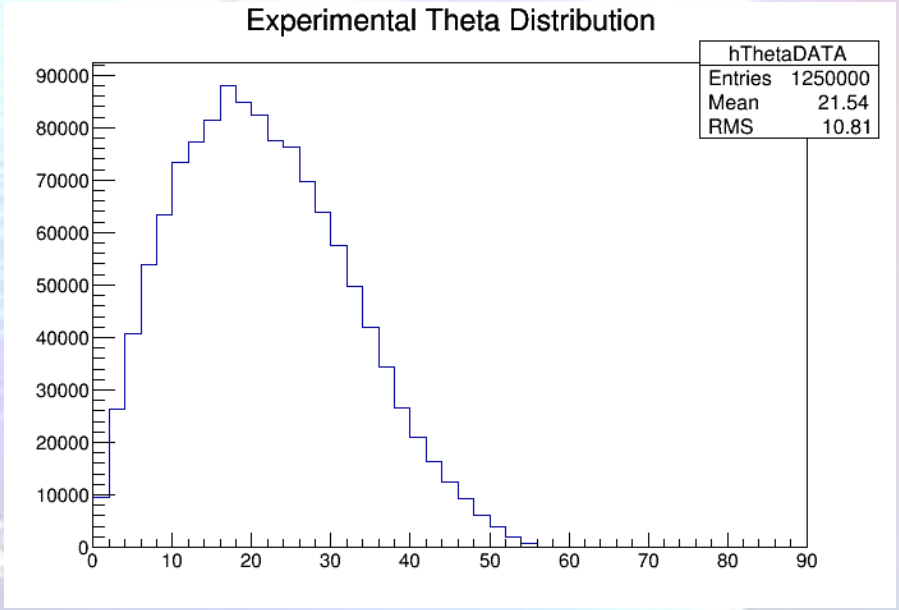
Your ROOT code for experimental data



DATA analysis – step 2

Your ROOT code for experimental data





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)

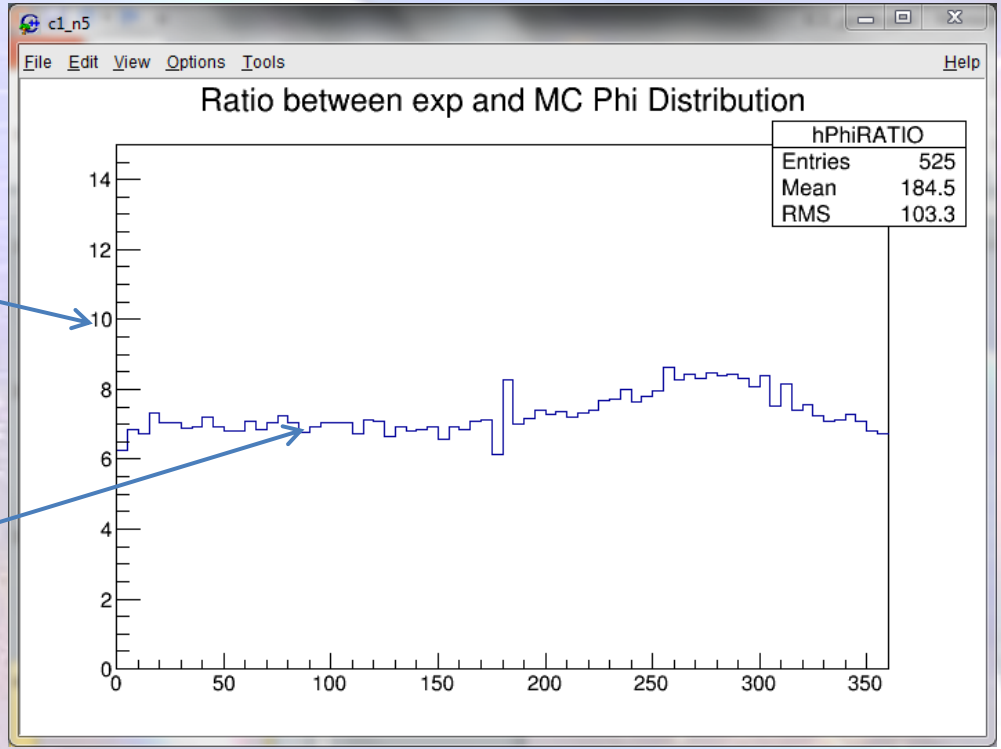
Compare the Phi Distribution with a constant function f(x) = pol0

DATA analysis – step 3

Compare data with expected trend (phi distribution)

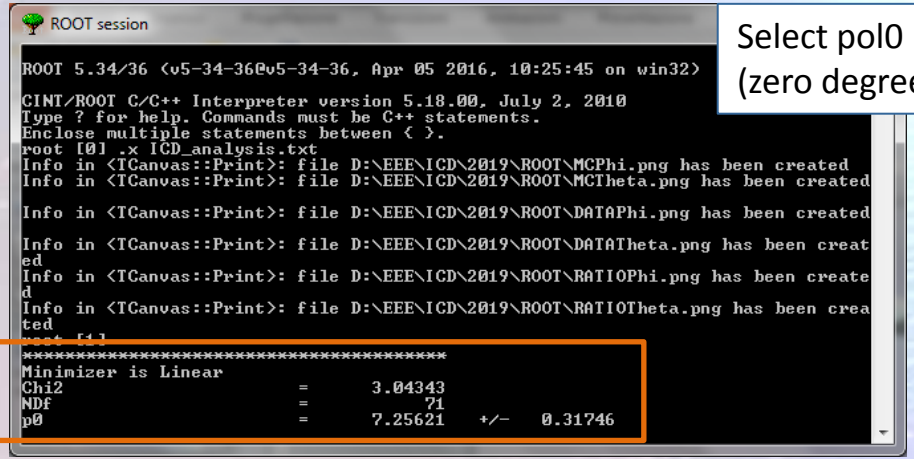
Right click on the vertical scale
→ SetRangeUser
→ [0, 15]

Right click on the histo line
→ FitPanel



DATA analysis – step 3

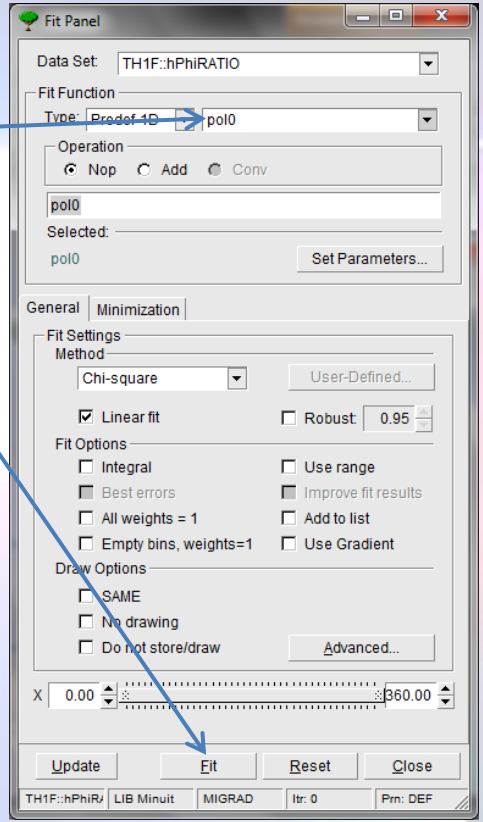
Compare data with expected trend (phi distribution)



Output of the fit procedure

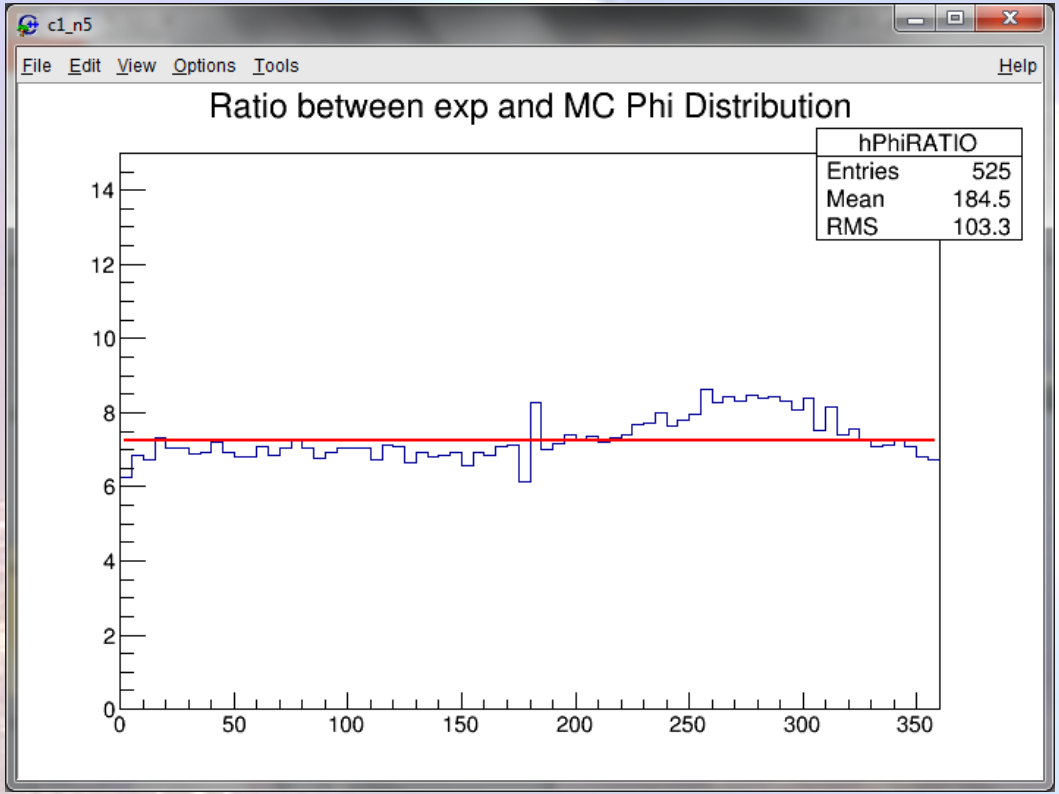
Select pol0
(zero degree polynomial)

Press Fit



DATA analysis – step 3

Compare data with expected trend (phi distribution)

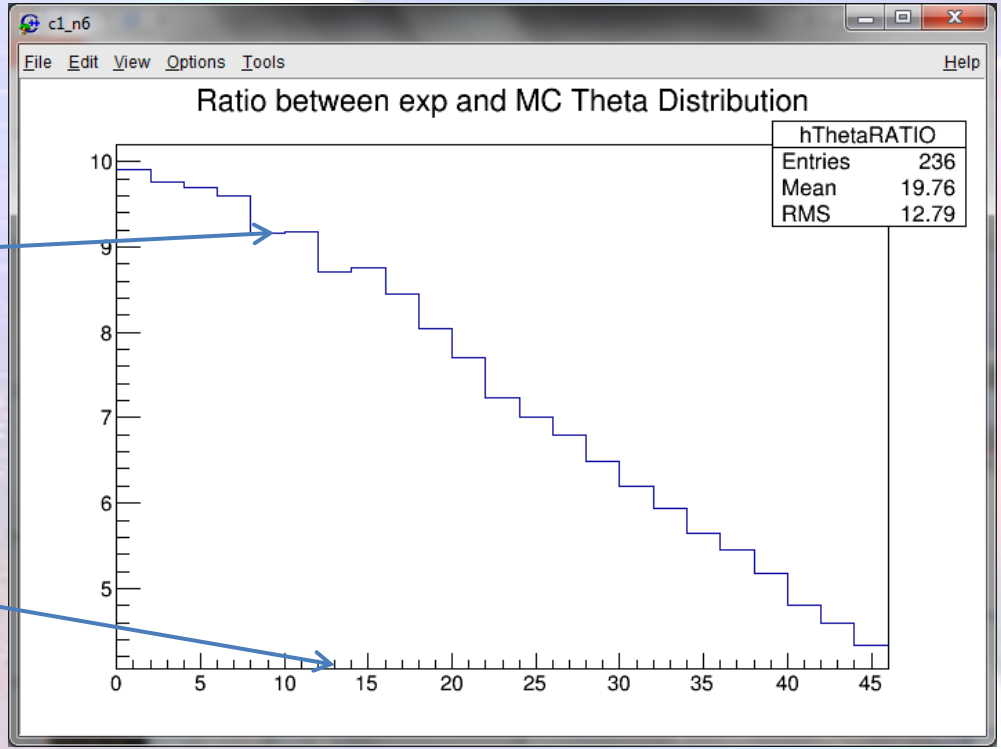


DATA analysis – step 3

Compare data with expected trend (theta distribution)

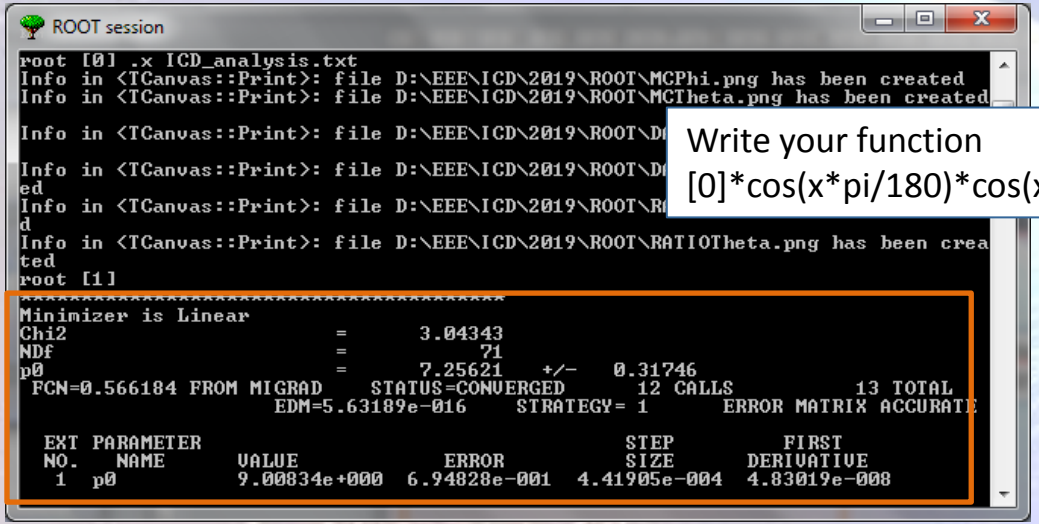
Right click on the histo line
→ FitPanel

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



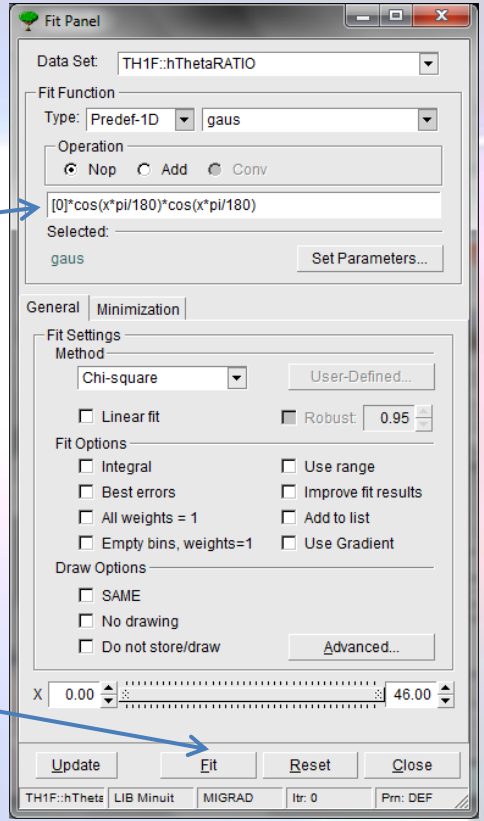
DATA analysis – step 3

Compare data with expected trend (theta distribution)



Output of the fit procedure

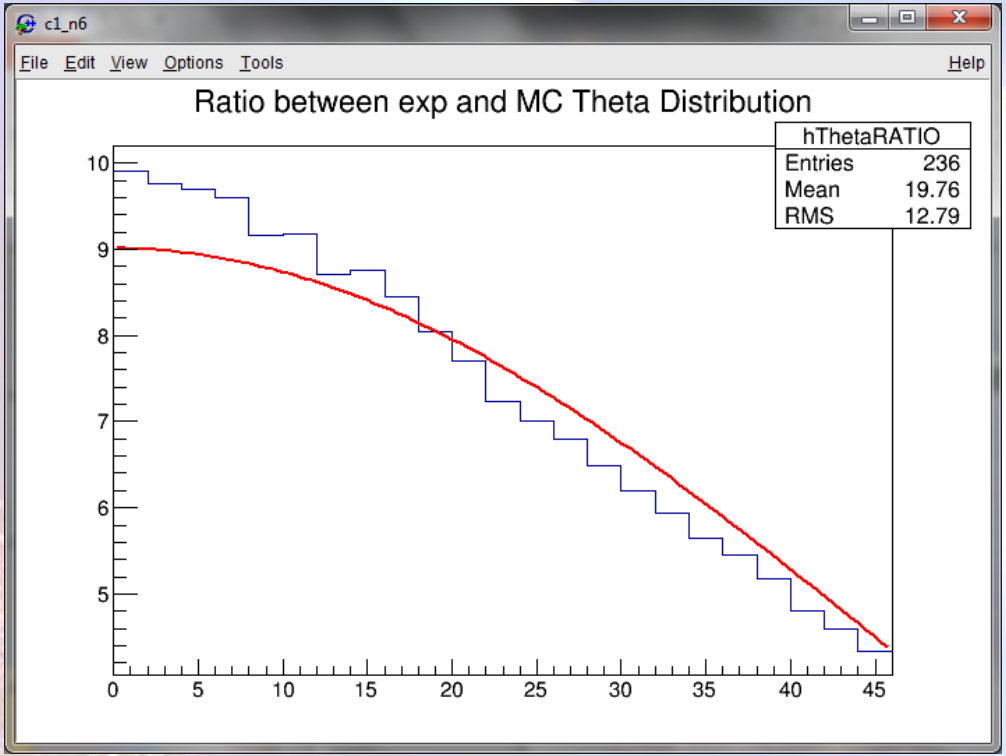
Write your function
[0]*cos(x*pi/180)*cos(x*pi/180)



Press Fit

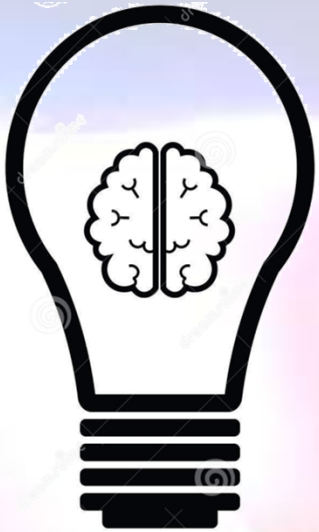
DATA analysis – step 3

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