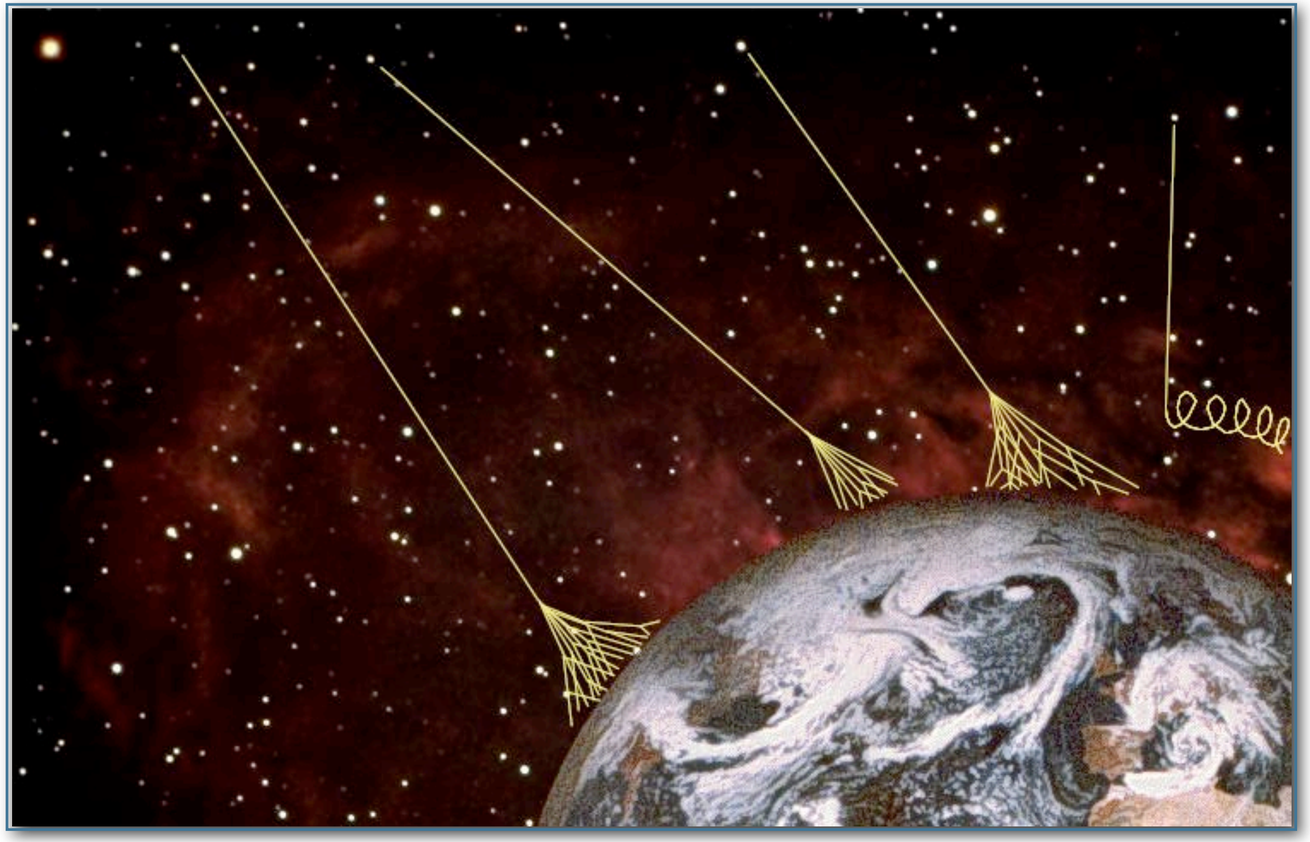
"Using the magnetic distortion of horizontal showers of cosmic rays in Pierre Auger Observatory"

Miguel Blanco - LPNHE Paris

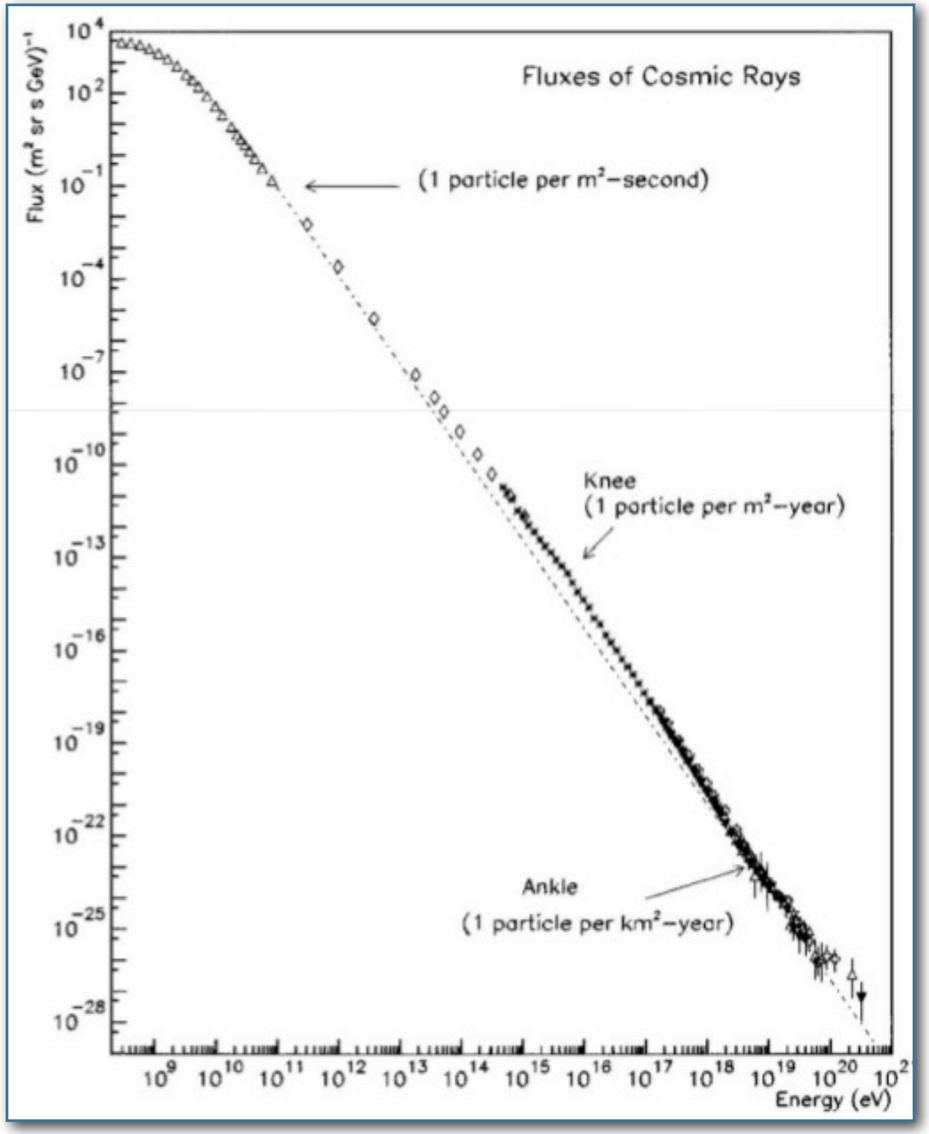
Warming up

- Horizontal air showers.
- Auger experiment.
- Motivation and proposal.
- Simulations.
- Results.
- Conclusions.



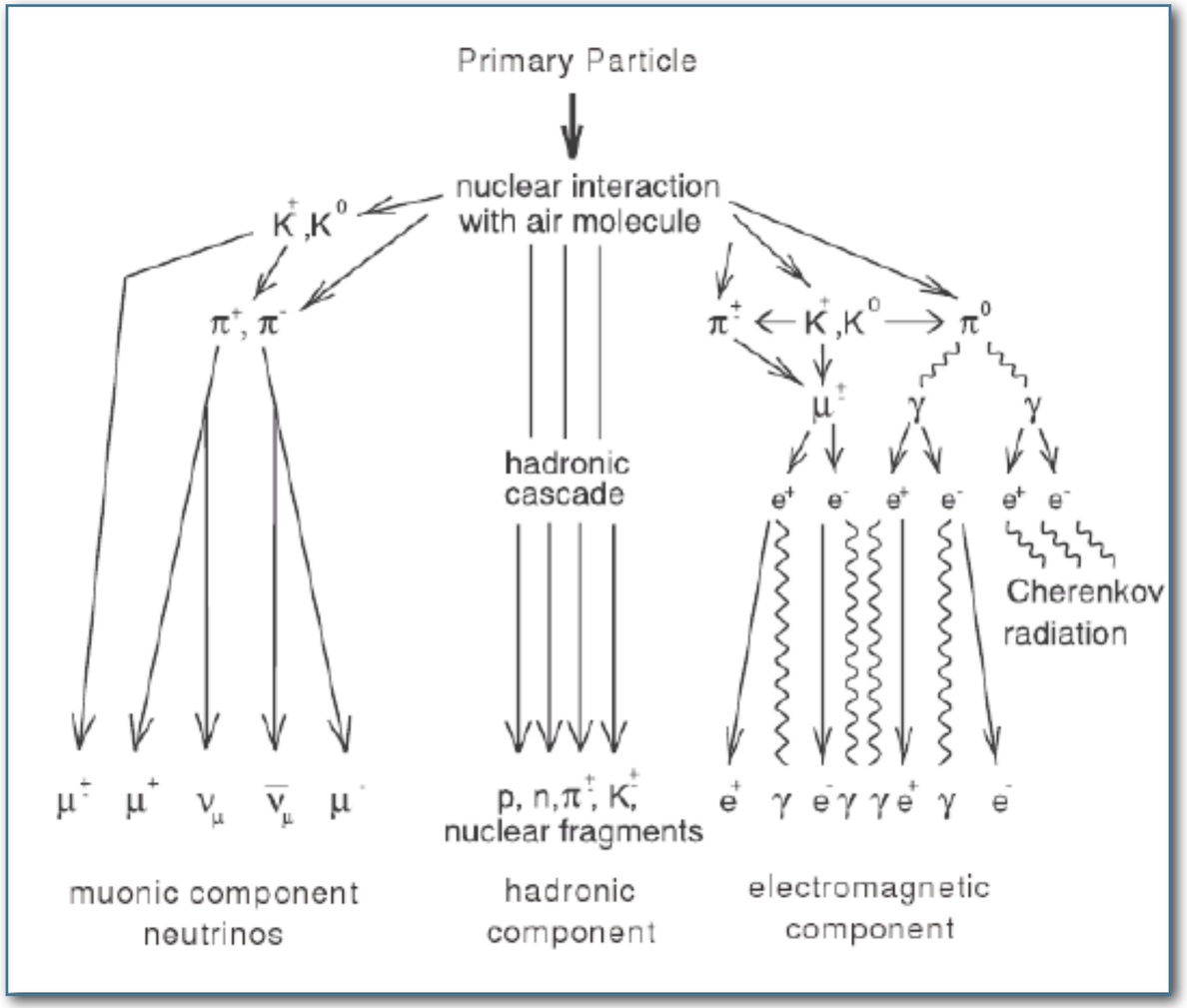
From cosmic rays to EAS

- Ultra High Energy Cosmic Rays. (EeV)
- Very low flux: Imposible to detect directly the primary particle.
- EAS: Extensive Air Shower.
- The atmosphere as calorimeter.



Horizontal Air Showers

- A primary particle coming from space into the atmostphere creates a shower.
- Muonic component, electromagnetic component, hadronic component.
- Horizontal showers travel longer distances: only muons remain.



Pierre Auger Observatory

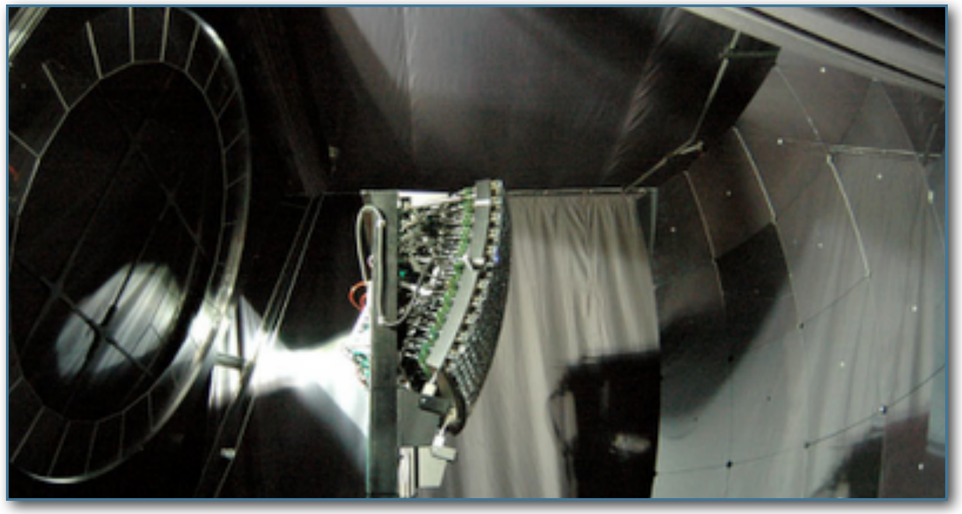
- Pampa Amarilla. Argentina.
- Ultra High Energy Cosmic Rays.
- High energy -> Few arrivals -> Large surface.
- Cherenkov surface detectors and fluorescence telescopes.

Mendoza
Pampa Amarilla
San Rafael -
Malargüe

Pierre Auger Observatory

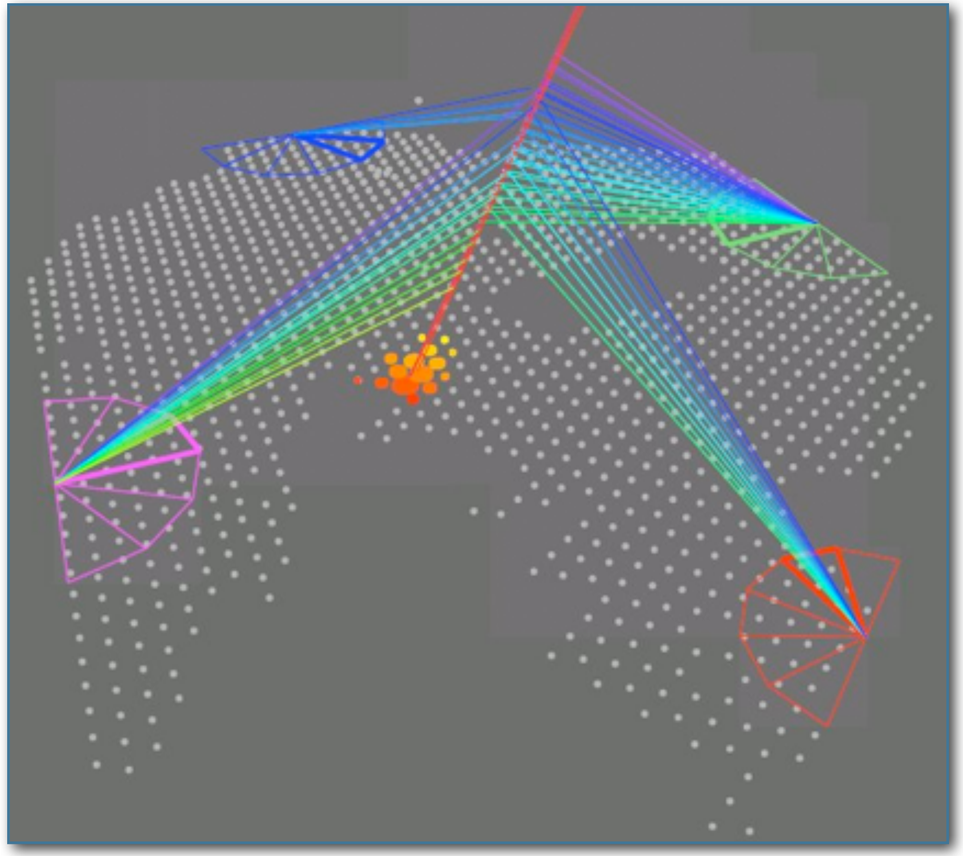
- **Surface detectors**
  - Cherenkov light in pure water.
  - 1600 tanks array.
  - 3000 km^2

- **Fluorescence detectors**
  - Fluorescence light directly from the shower.
  - 6 telescopes in each of 4 stations.



Motivation

- Horizontal showers are purely muonic.
- Muons come from far away, having a large magnetic deviation, depending on the path. Sensitivity to X^{μ}_{max}
- Complementary to other studies. Systematic errors are different.



What do we measure?

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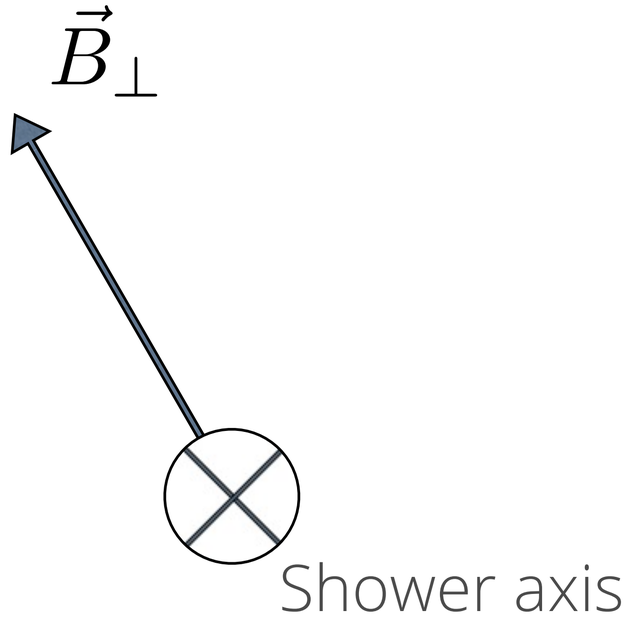
- In the projection of the shower plane (perpendicular to axis).



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- The spot is distorted:

$$F(r, \zeta - \zeta_B)$$

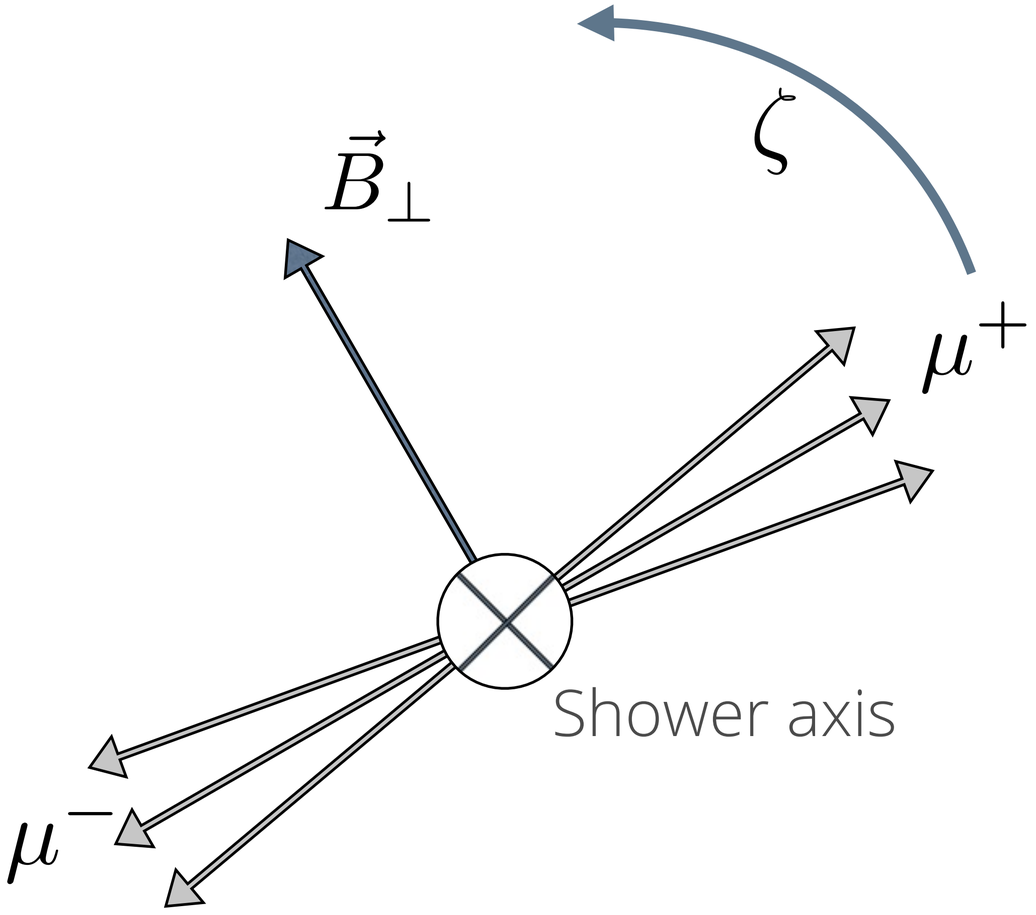

Fig. 1: Magnetic distortion.

What do we measure?

- In the projection of the shower plane (perpendicular to axis).
- The spot is distorted:

$$F(r, \zeta - \zeta_B)$$

- Deviation from isotropy carry information on the muon path: X^{μ}_{max}.

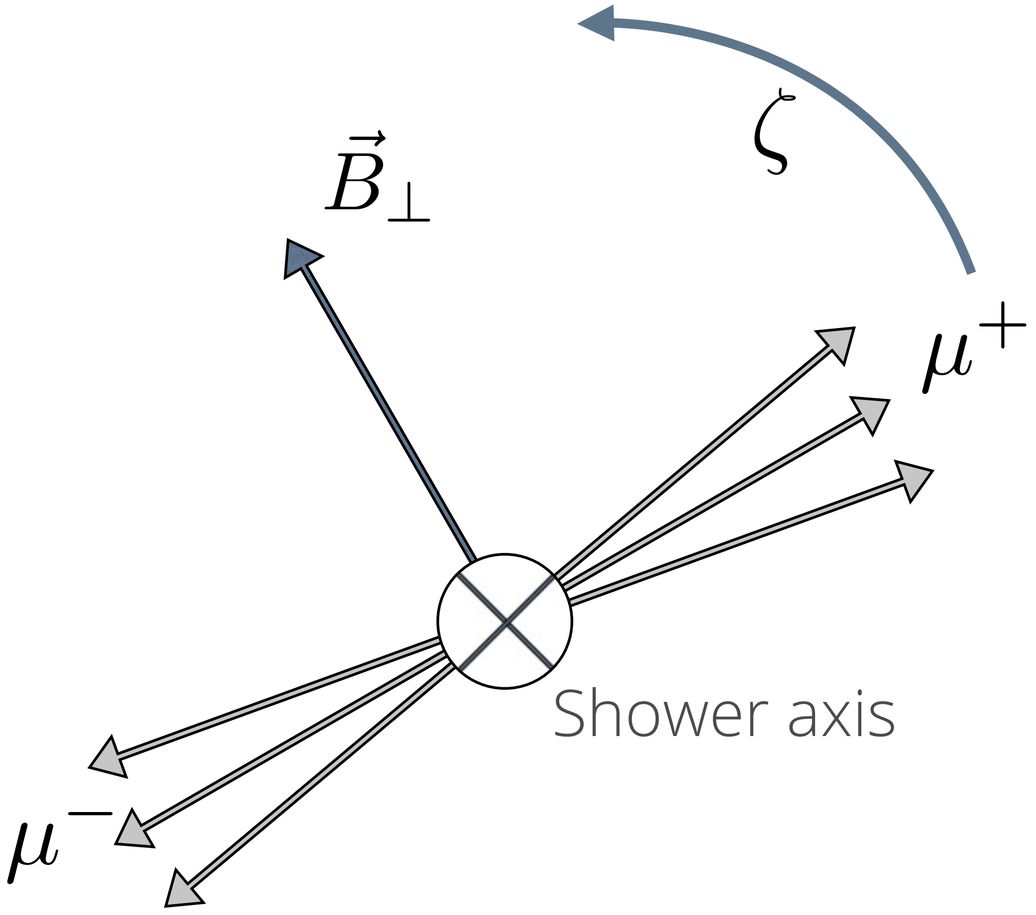

Fig. 1: Magnetic distortion.

Tools for a fast simulation

- **AIRES** with large $\mathbf{E_{cut}}$ (500 MeV) for photons, electrons and positrons (no chance to produce muons).
- Code modified to extract all **muons** at their **production point**. Negigible dependance on magnetic field.
- Further step: home-made **propagation to the ground** of muons accounting for magnetic deviation, multiple scattering, energy loss, decay.
- With **one shower** at (E,θ): produce **many muonic showers** at (E,θ,φ). Simplified simulation of tank response.

Tools for analsysis

Parameters to analyse: W/L, α and λ

- **With / Length:**
  - Ideal detector. Computing with all muons.
  - Real detector. Computing with signal in tanks.

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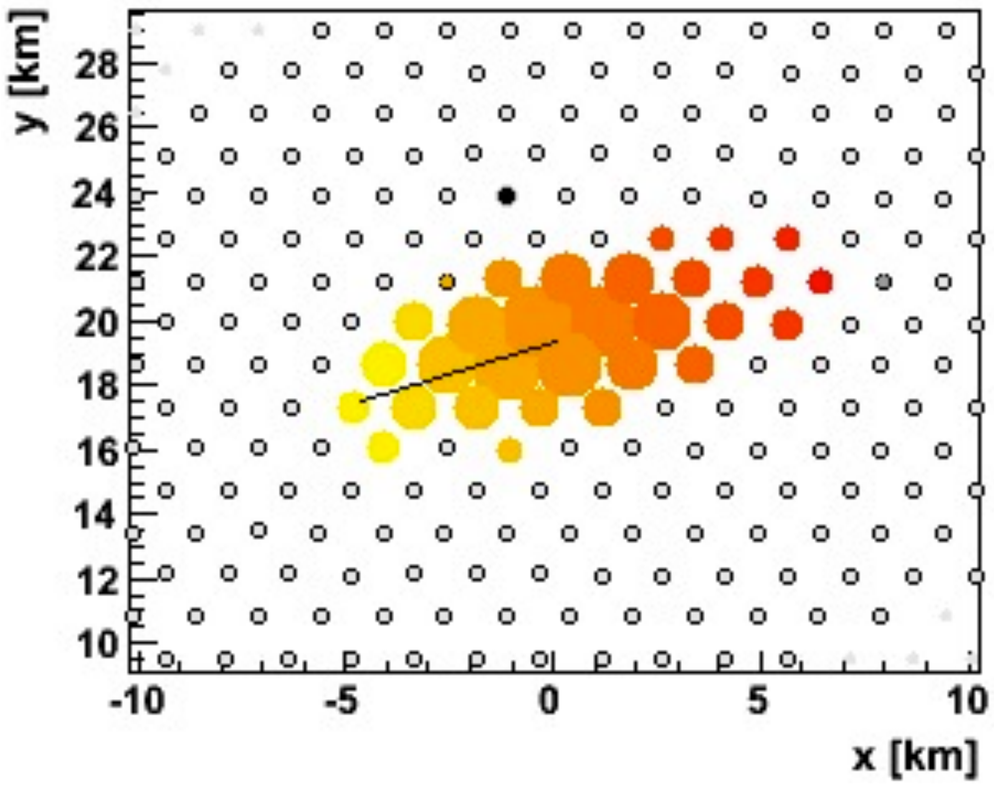

Fig. 2: Event browser display

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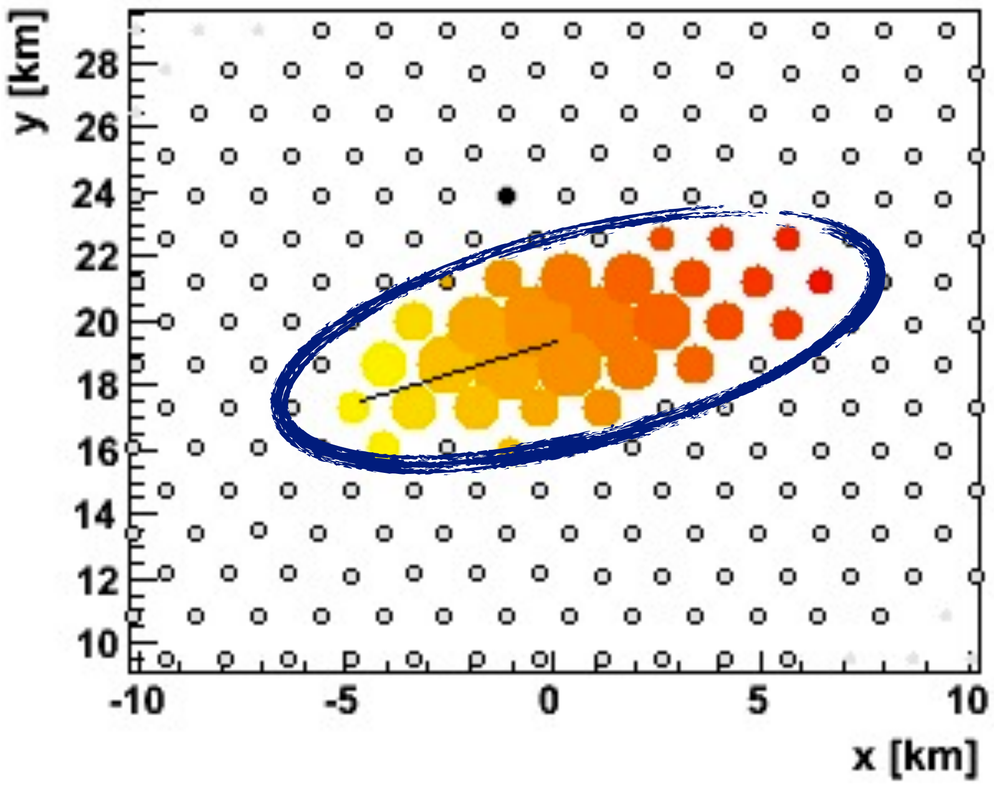

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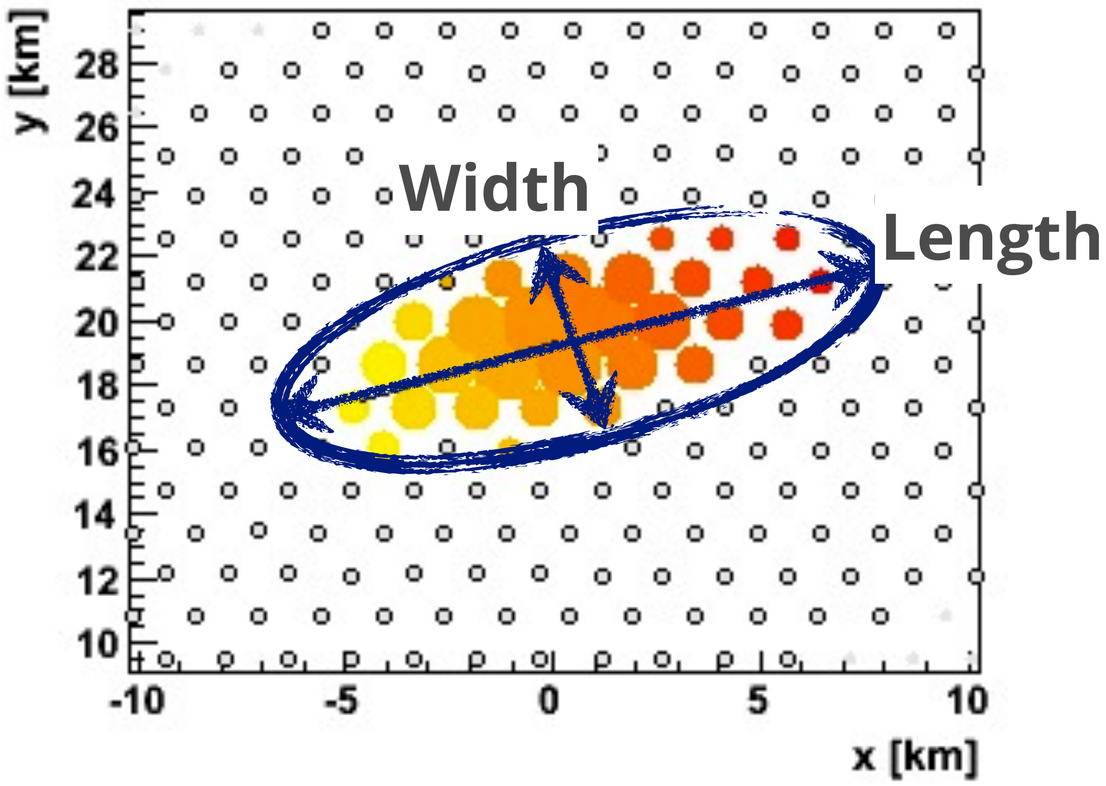

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Tools for analysis

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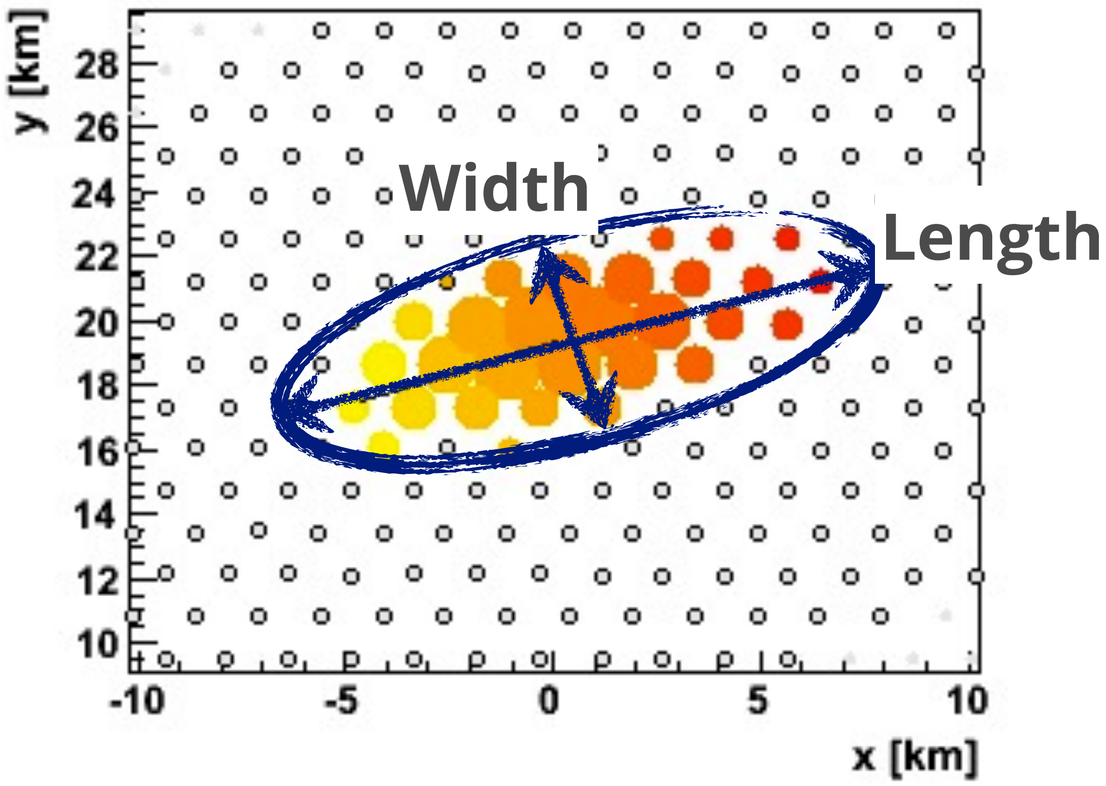

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- 5 parameters are fitted: X_c, Y_c (for the core position), S_{1000}, λ, α.

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  - 5 parameters are fitted: X_c, Y_c (for the core position), S_{1000}, λ, α.

$$S(r,\zeta) = S_{1000} * e^{-\lambda(\sqrt{\frac{r}{1000}}-1)} * (1 + \alpha \cos[2(\zeta - \zeta_B)])$$

Tools for analysis

Parameters to analyse: W/L, α and λ

- **LDF distortion.**
  - θ and φ obtained from arrival times.
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Lateral distribution

Angular distortion

$$S(r,\zeta) = S_{1000} * e^{-\lambda(\sqrt{\frac{r}{1000}}-1)} * (1 + \alpha \cos[2(\zeta - \zeta_B)])$$

Tools for analsysis

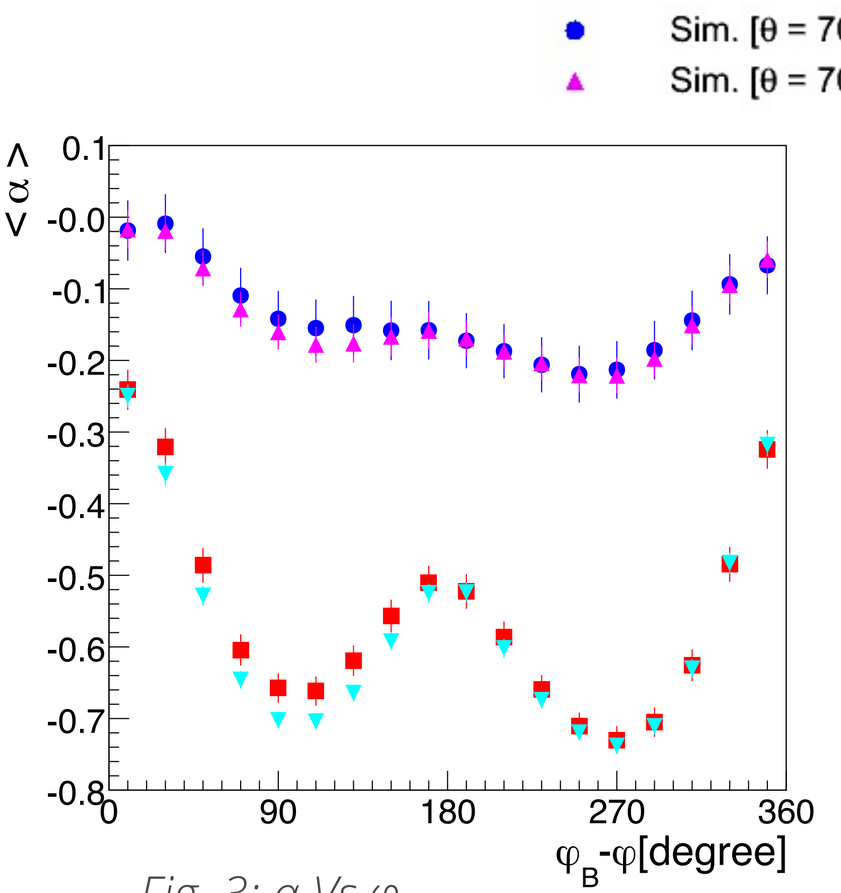

Fig. 3: α Vs φ

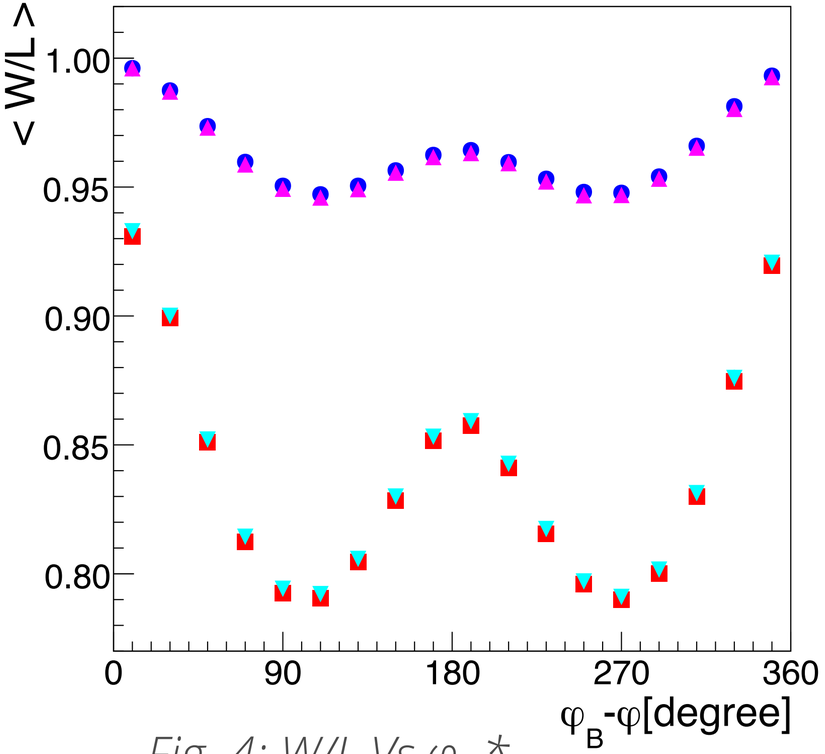

*Fig. 4: W/L Vs φ **

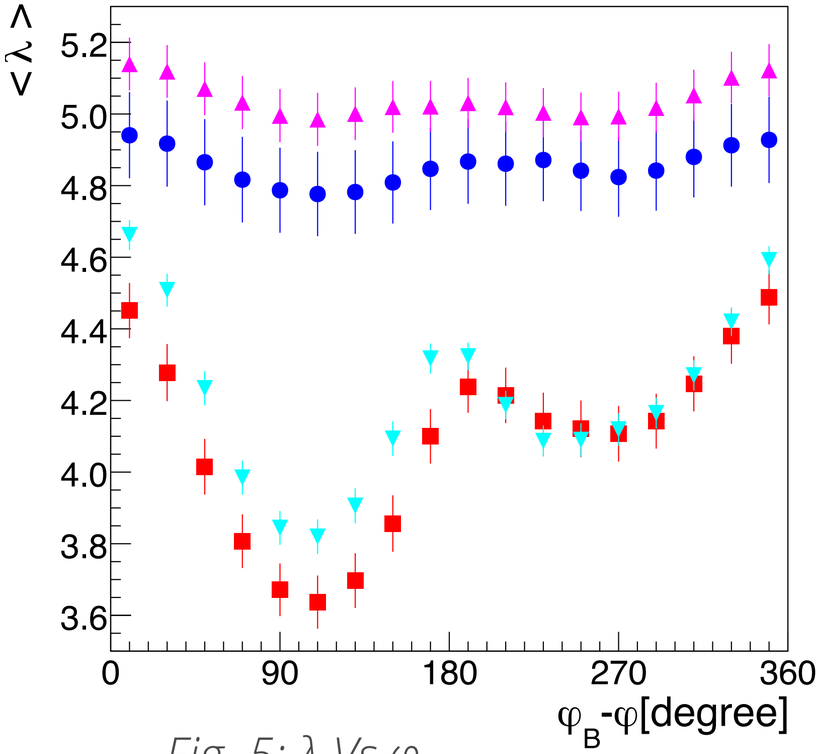

Fig. 5: λ Vs φ

Two parameters are analysed: α and W/L. And a check: λ.

** Only statistical errors in Y axis*

Tools for analsysis

100 protons
E = 10 EeV, θ = 74°

- If θ and φ are known (they are), sensitivity on X^{μ}_{max} appears.

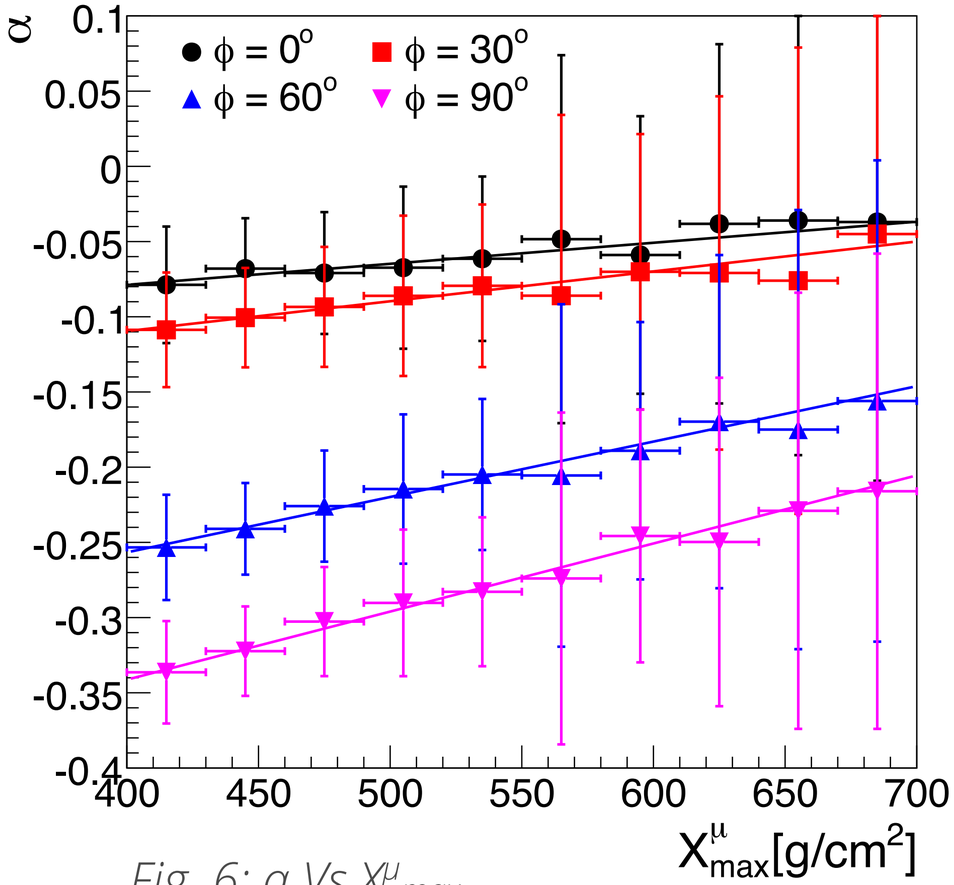

Fig. 6: α Vs X^{μ}_{max}

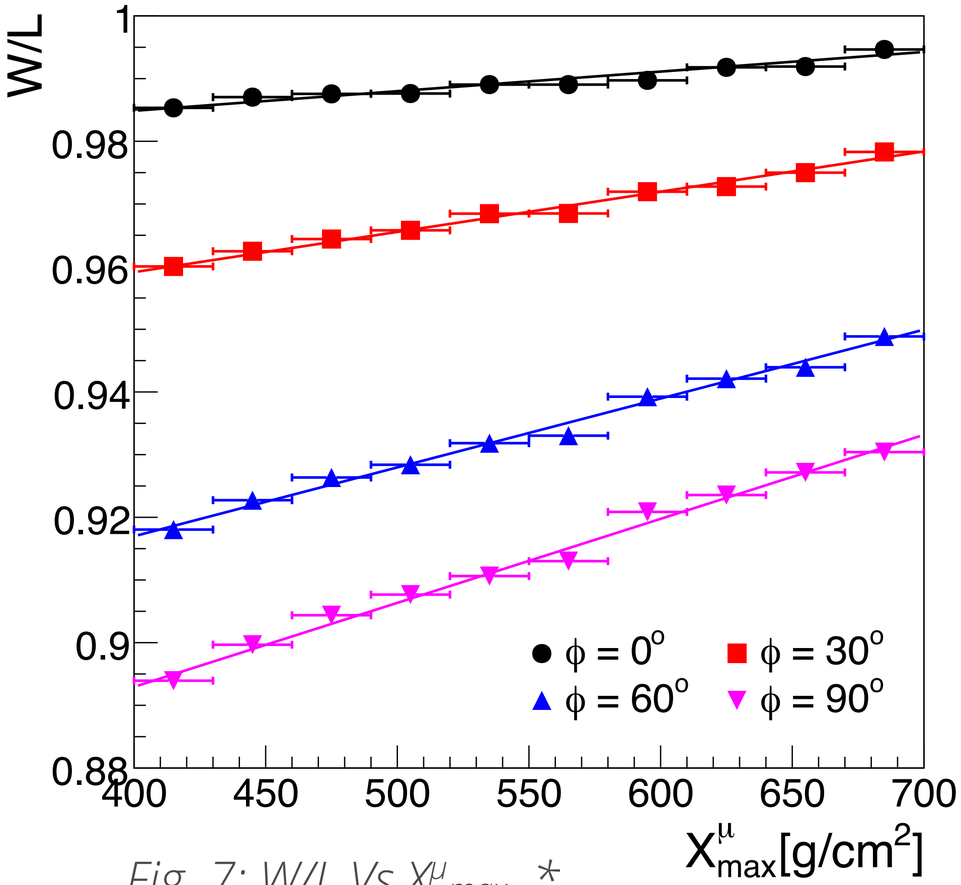

*Fig. 7: W/L Vs X^{μ}_{max} **

- For statistical basis: for 1 event, σ(α) > difference p-Fe.

** Only statistical errors in Y axis*

1st comparison with data

The data are from years 2007-2010.

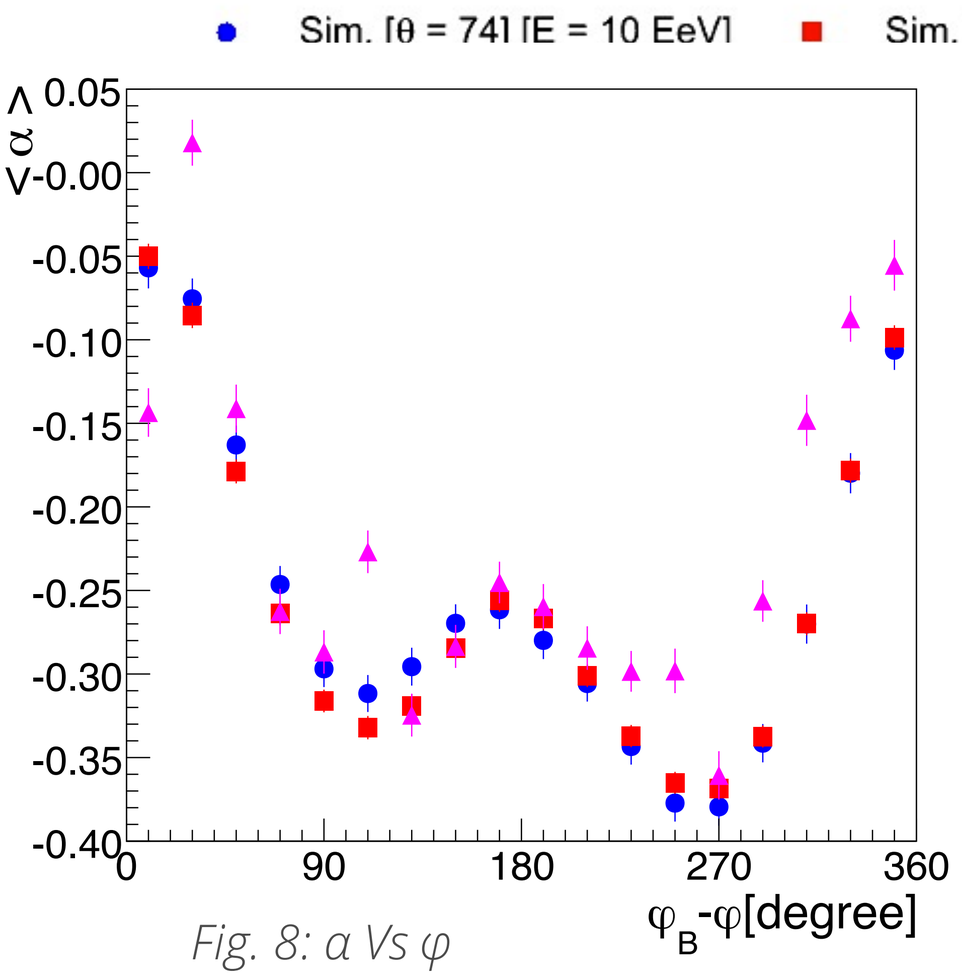

Fig. 8: α Vs φ

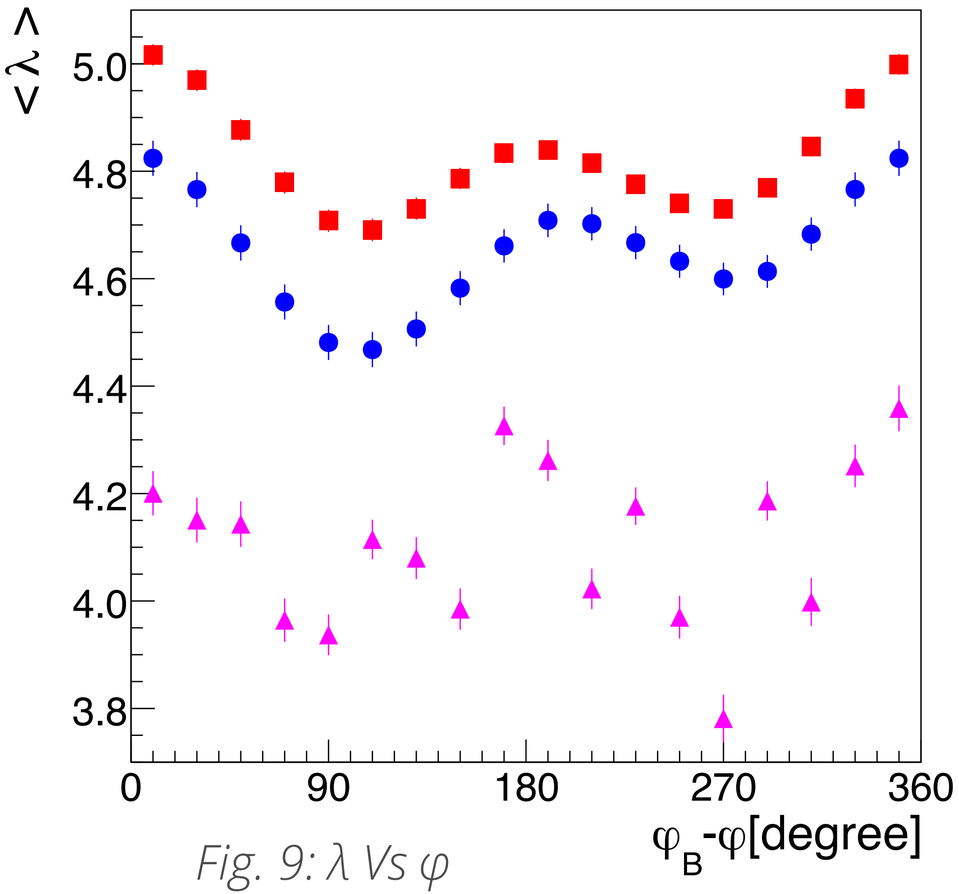

Fig. 9: λ Vs φ

$$S(r,\zeta) = S_{1000} * e^{-\lambda(\sqrt{\frac{r}{1000}}-1)} * (1 + \alpha\cos[2(\zeta - \zeta_B)])$$

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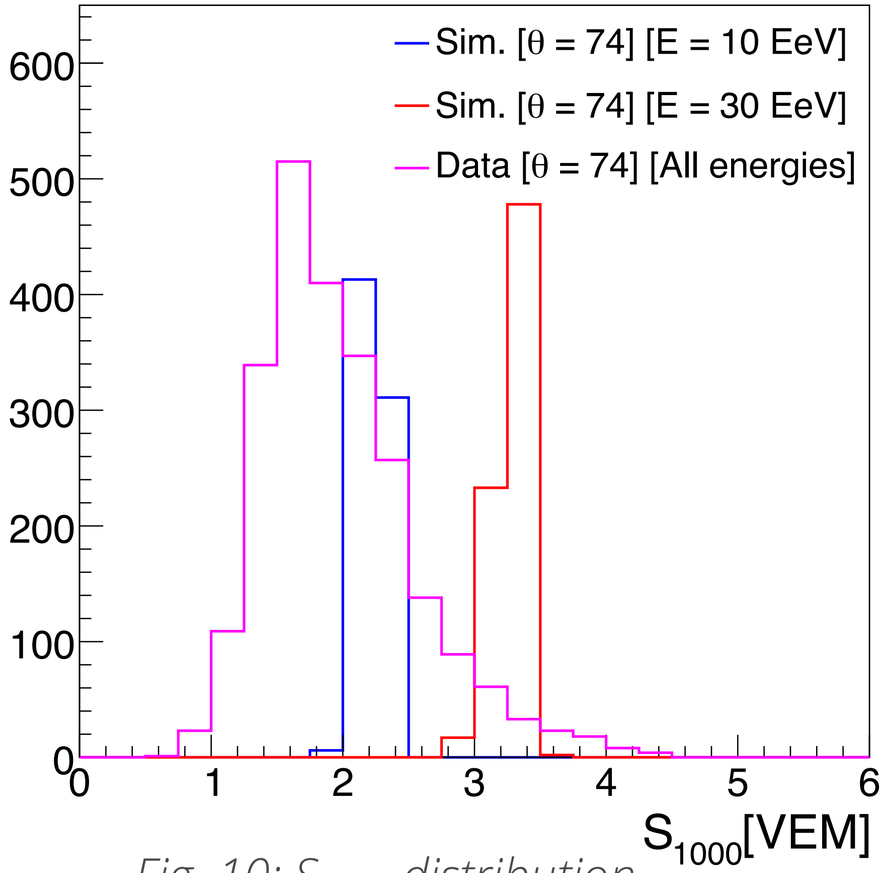

Fig. 10: S_{1000} distribution

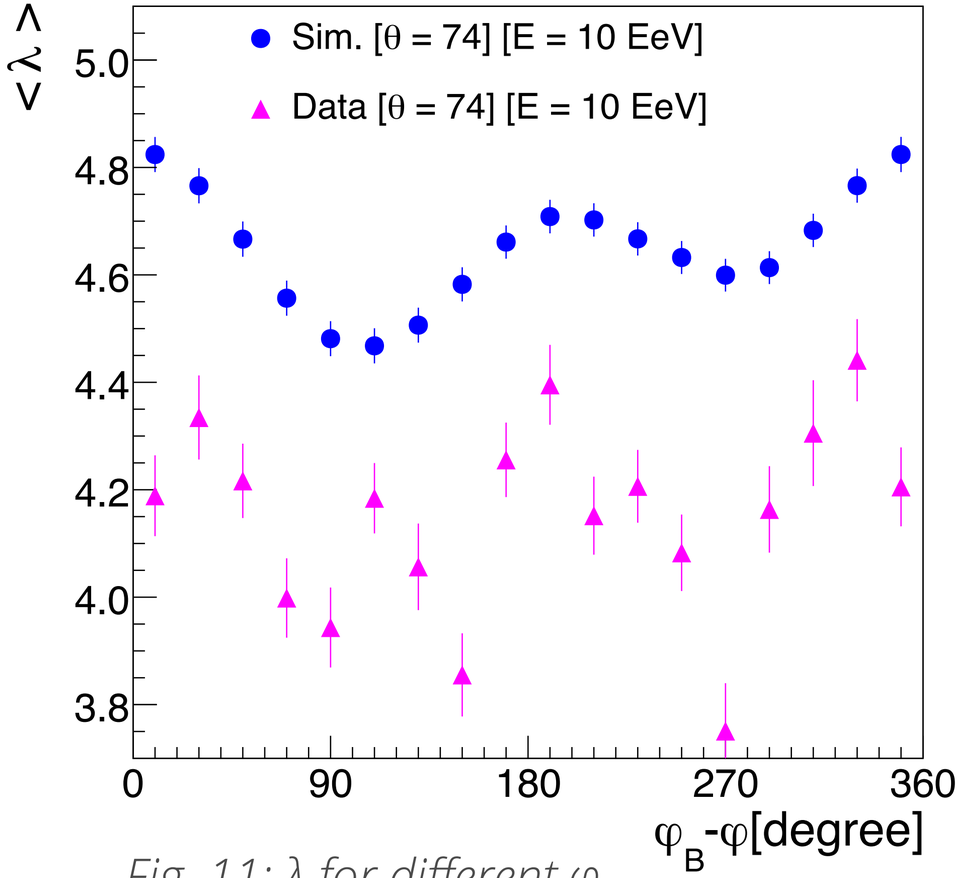

Fig. 11: λ for different φ

Applying cuts in S_{1000} to select in energy.

$$S(r,\zeta) = S_{1000} * e^{-\lambda(\sqrt{\frac{r}{1000}}-1)} * (1 + \alpha\cos[2(\zeta - \zeta_B)])$$

Checking the model

- λ is not very sensitive to X^{μ}_{max}, but it is sensitive to the **energy** and the **lateral shape**.
- It is a way to **check** the model.

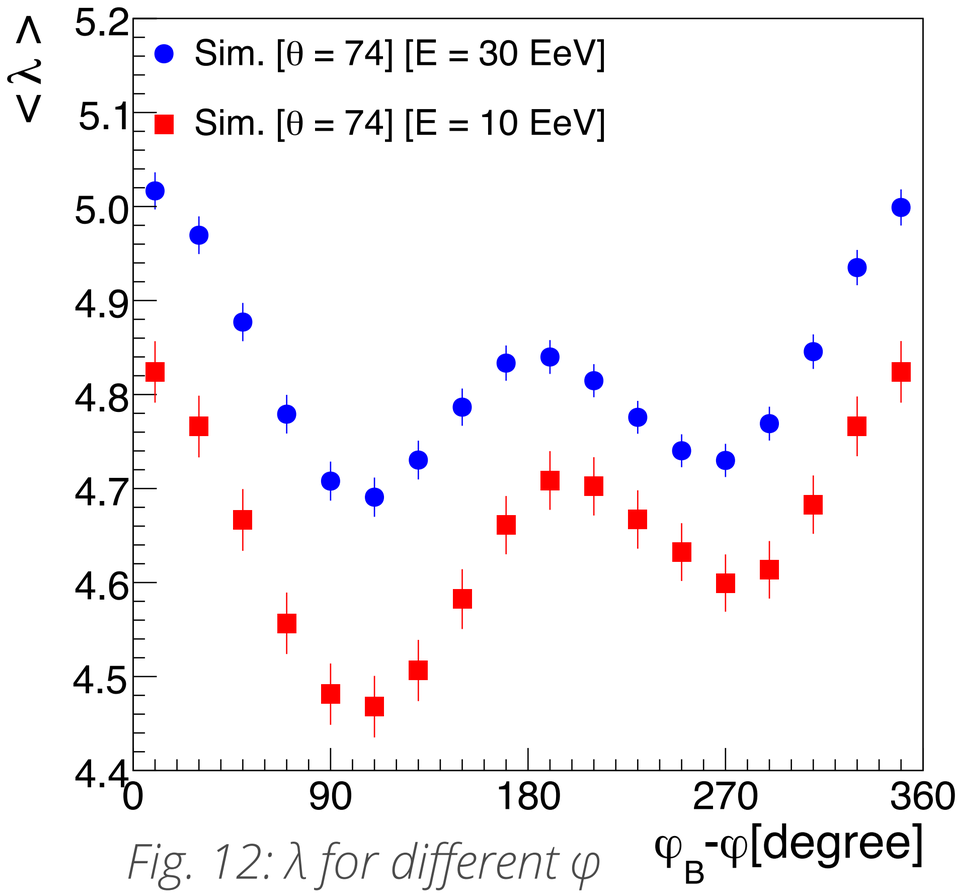

Fig. 12: λ for different φ

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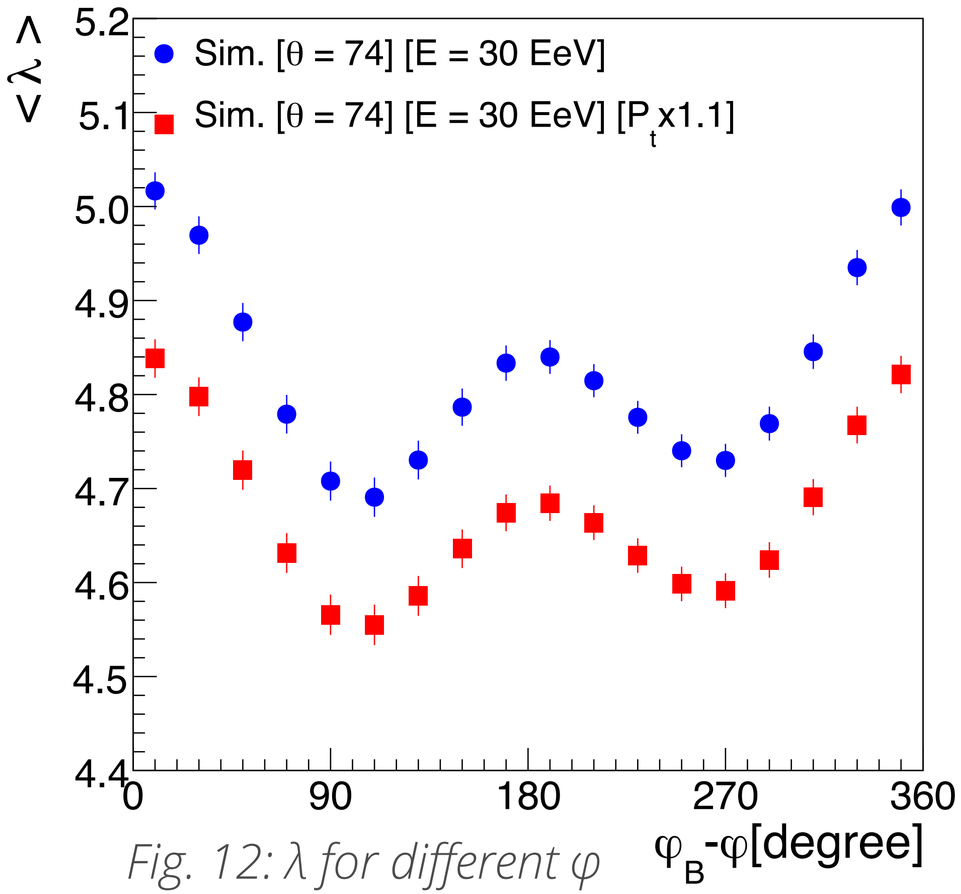

Fig. 12: λ for different φ

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To be done

- Selection criteria for real events.
- Improvement in the fit: account for silent stations, higher order terms in ζ for very large θ.
- Effects of missing stations, edge effects, ...
- Matching energy SIM-DATA: using S_{1000}?, number of stations?

Conclusions

- An estimation for an statistical basis analysis.
- Relation between spot shape & X^{μ}_{max}. In simulations.
- Sensitivity to lateral distribution.
- The larger θ, the higher effect, the fewer events.
- Many and more to be

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Magnetic deviation gives us information.

Thank you, questions?

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LPNHE, Paris

Conclusions

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- *Sensitivity to lateral distribution.*
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Magnetic deviation gives us information.

Bonus tracks

Pierre Billoir, Miguel Blanco
LPNHE Paris

Bonus tracks

Analysis with different energies and different θ angles. Data and simulations

A set of different $\theta = [70°, 74°, 80°]$, and protons at $E = [6\,\text{EeV}, 10\,\text{EeV}, 30\,\text{EeV}$. The data has been selected, not according to the energy, but the S_{1000}. Following the table 1, and justified by the figure 22.

Energy[EeV]	S_{1000}[VEM]
6	1.5 - 2.0
10	2.0 - 2.5
30	3.0 - 3.5

Table 1 Assignement to energy according to S_{1000} value.

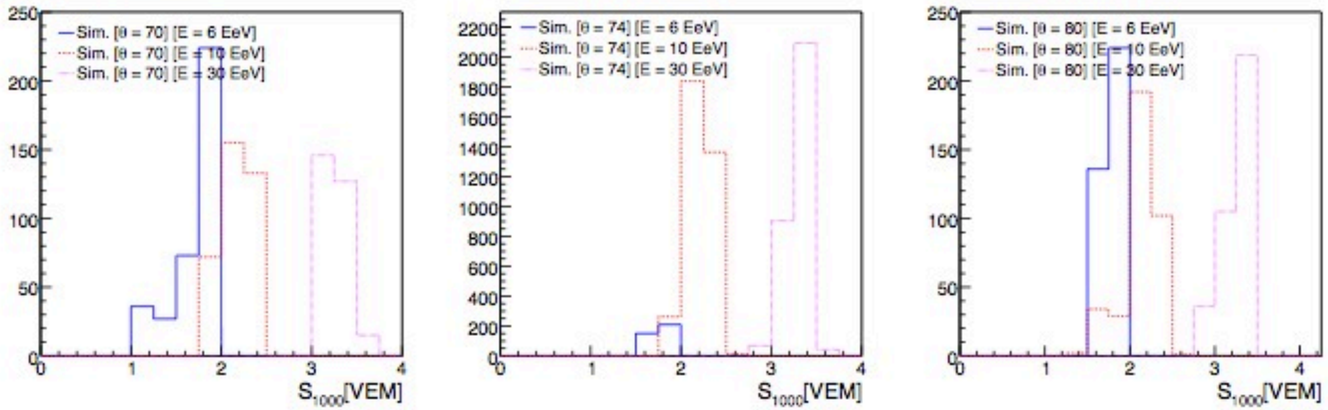
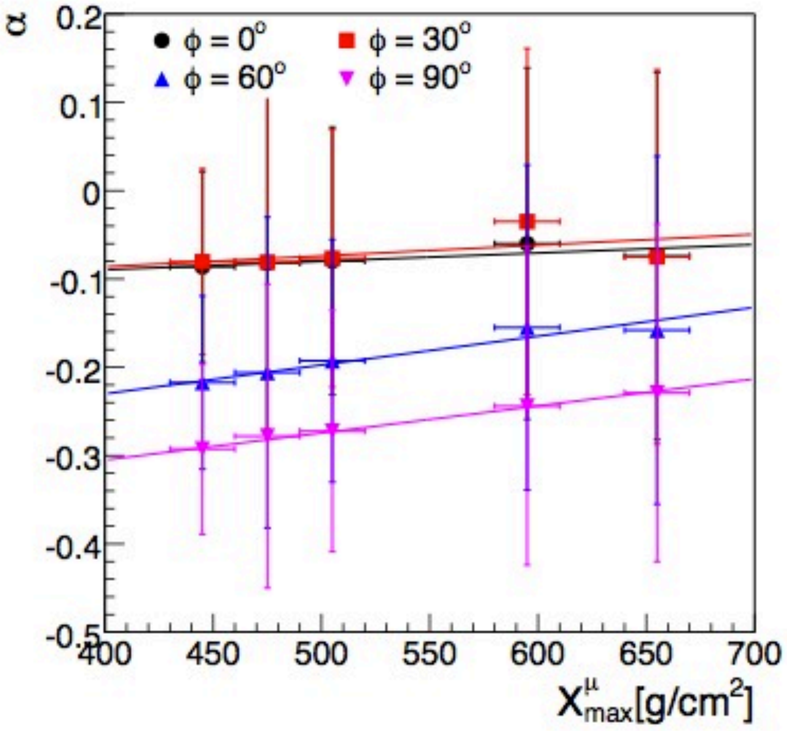
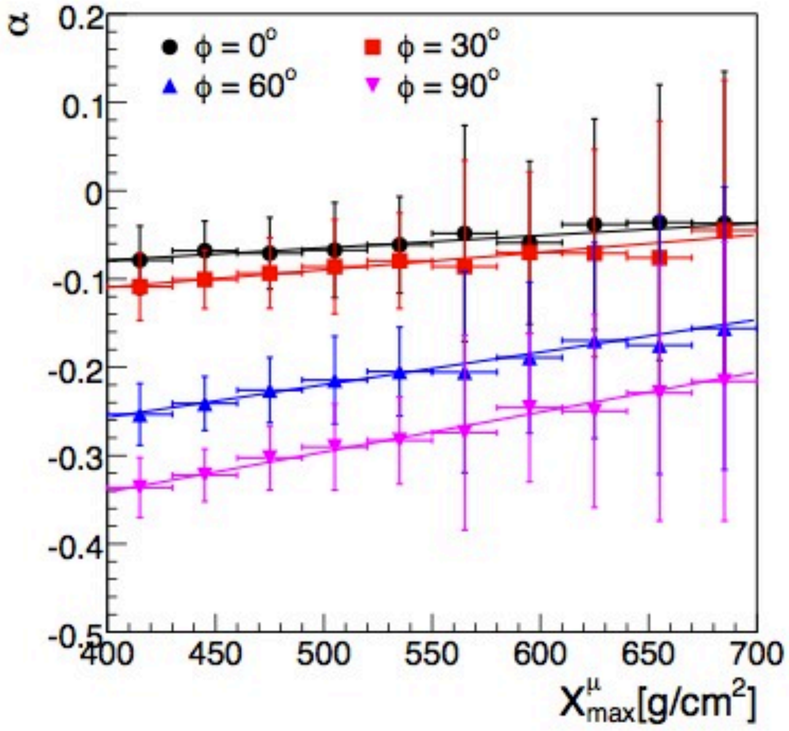


Figure 22 Distributions of S_{1000} for different energies and angles.

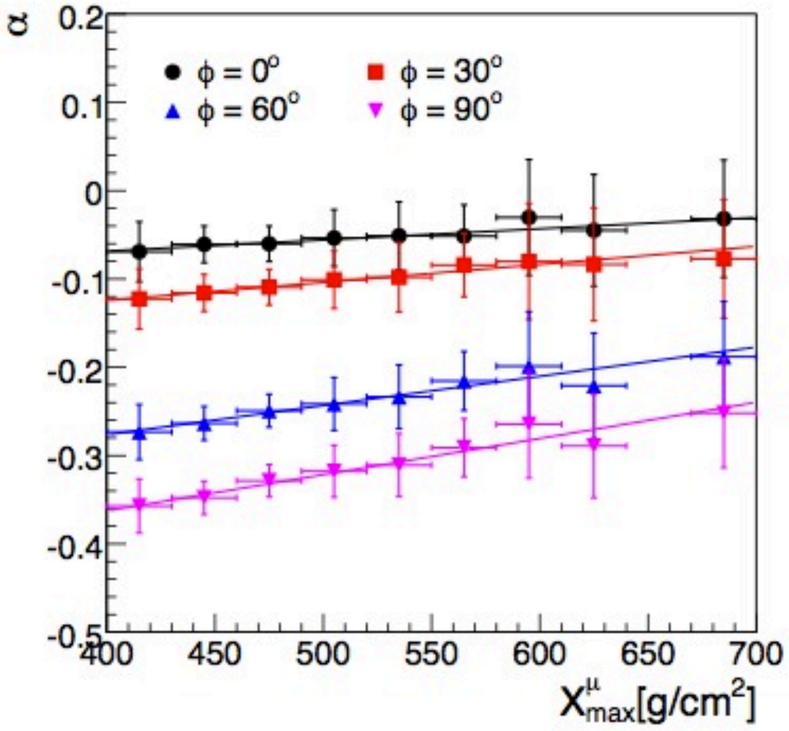
Bonus tracks



E = 10 EeV, θ = 70°



E = 10 EeV, θ = 74°



E = 10 EeV, θ = 80°

Bonus tracks

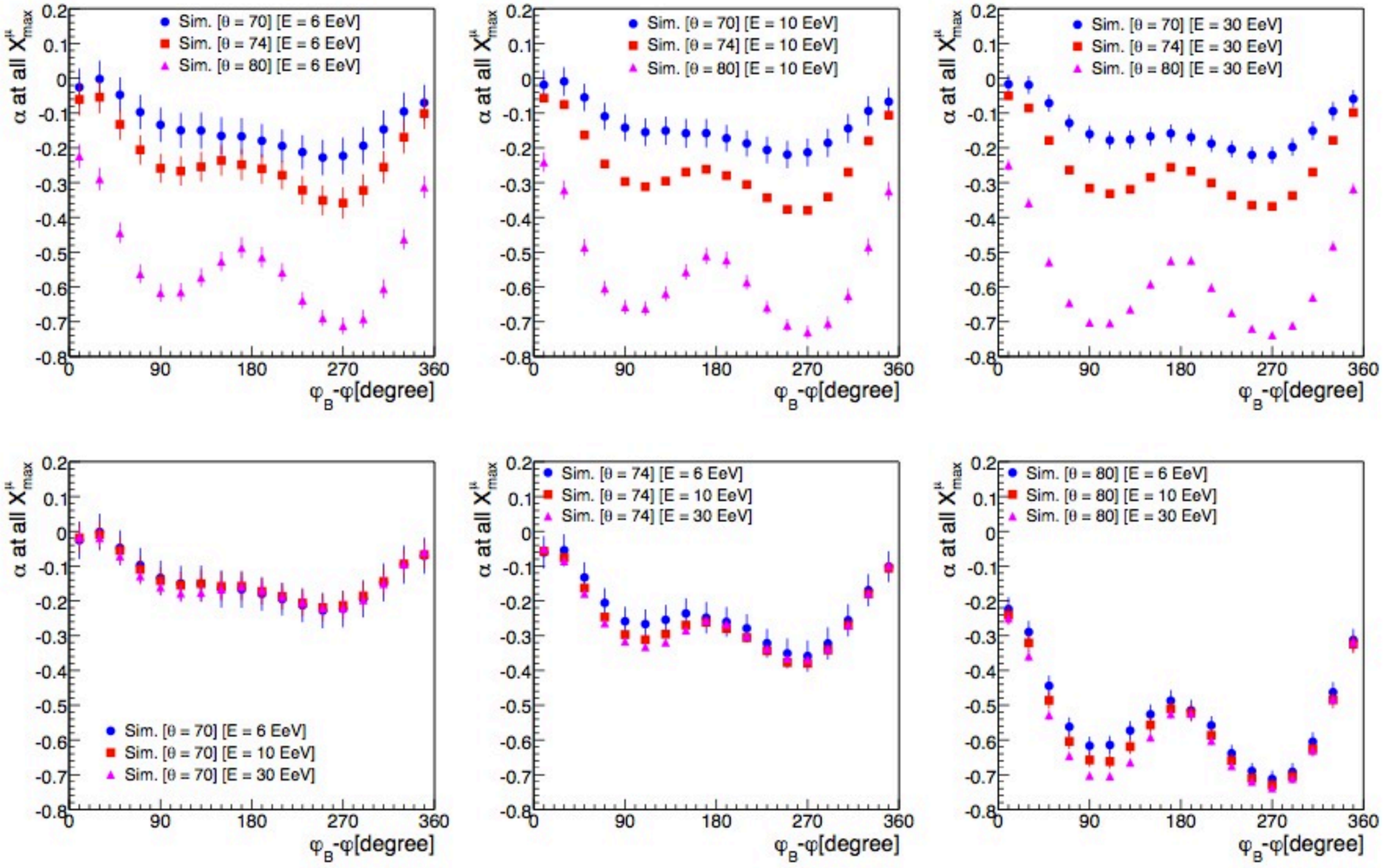


Figure 24 The mean values of α according with ϕ. Same energy for different θs (above). And same θ for different energies (bellow).

Bonus tracks

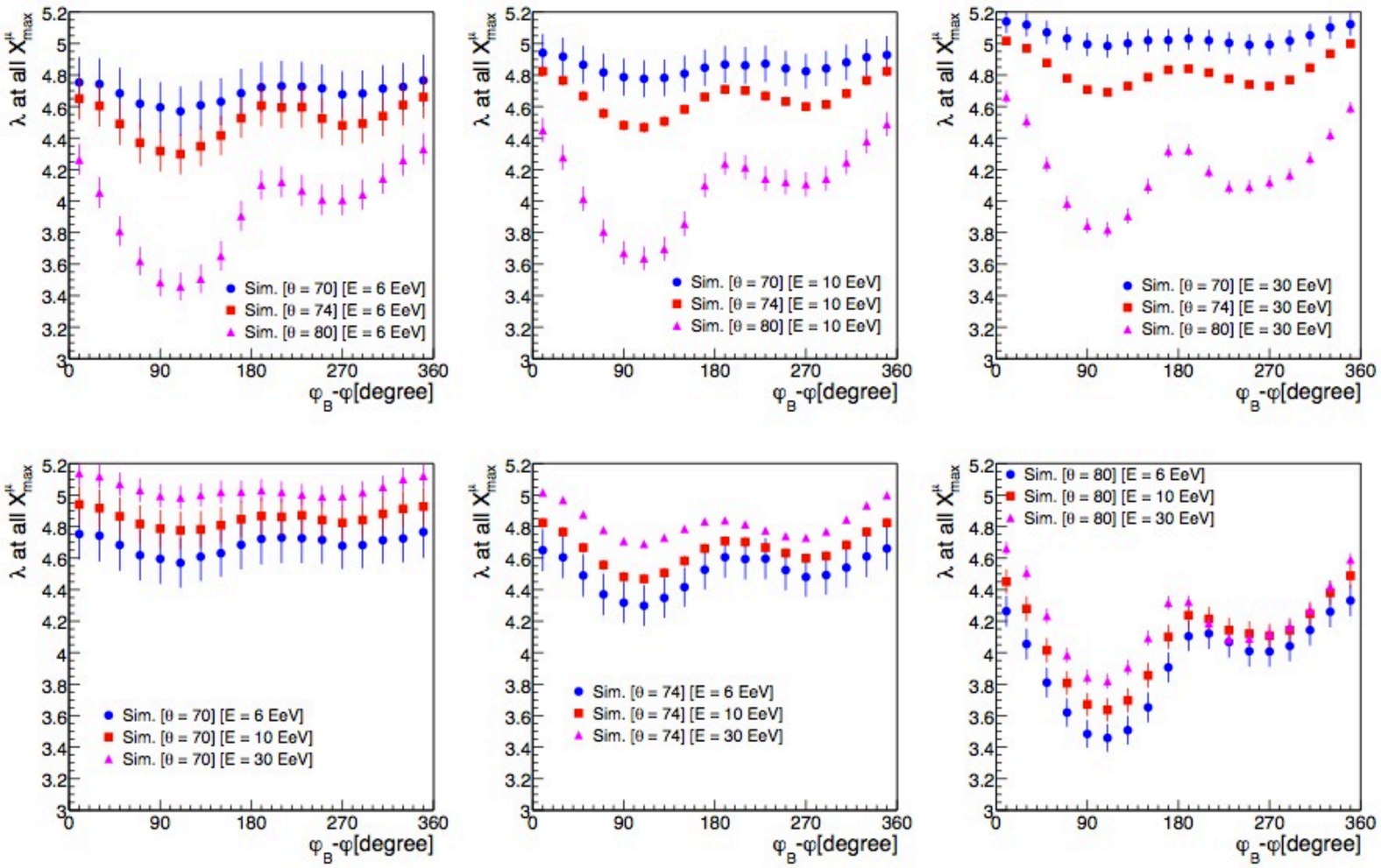


Figure 25 The mean values of λ according with ϕ. Same energy for different θs (above). And same θ for different energies (bellow).

Bonus tracks

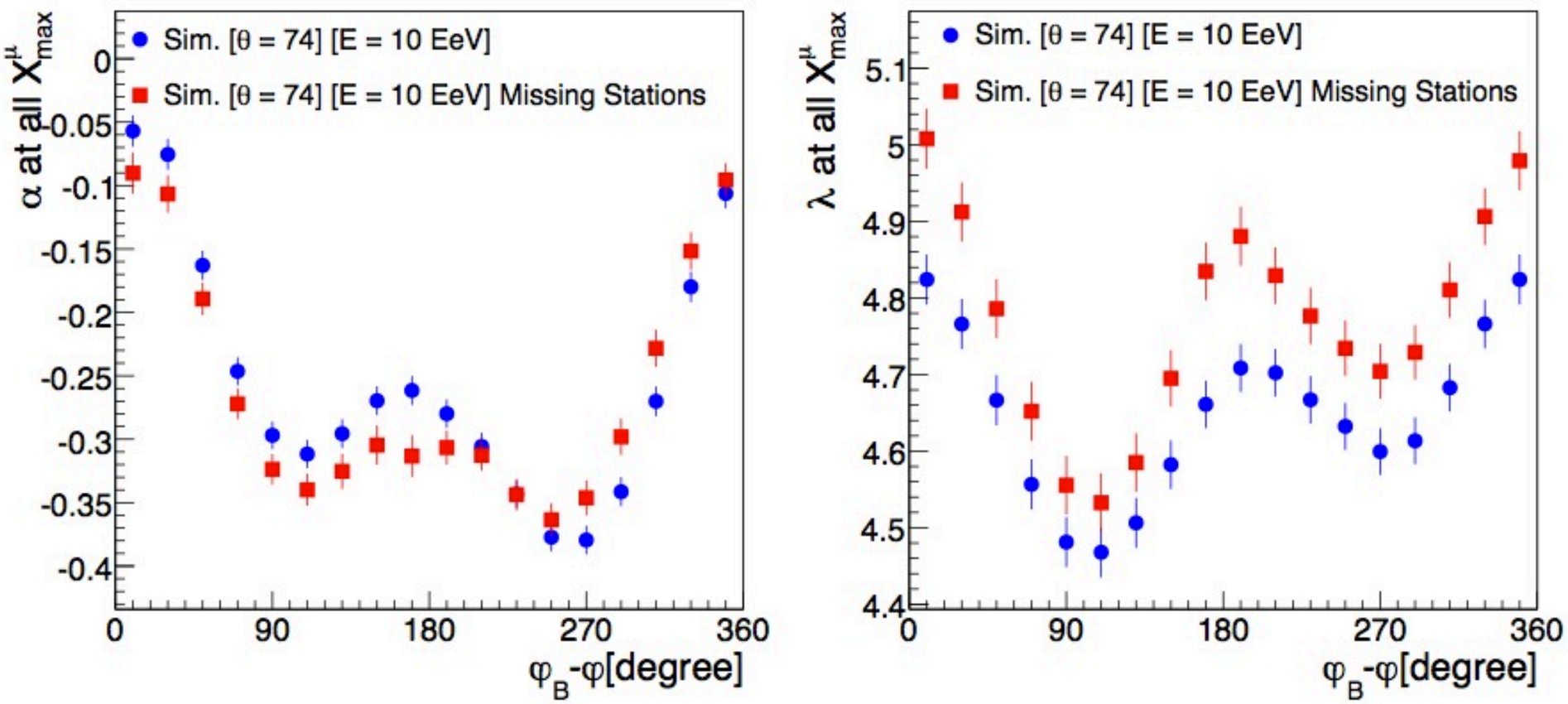
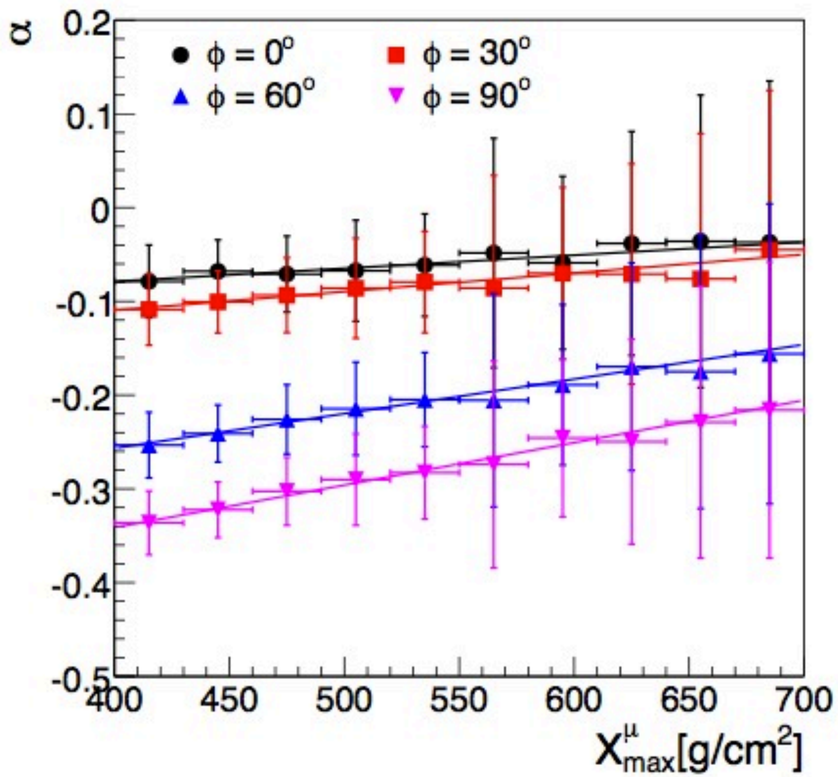
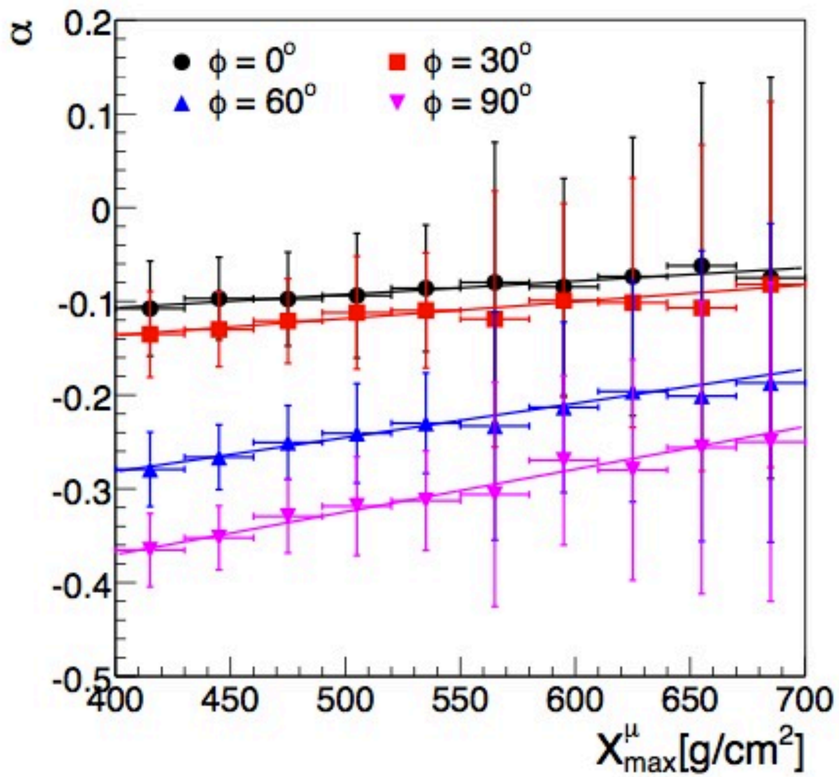


Figure 26 General analysis done again with the asimulation in wich we assume a limited detector. Some part of the ground spot is always missing. Above case with a perfect detector (left) and the limited one (right).

Bonus tracks



Perfect detector



With missing stations

Bonus tracks

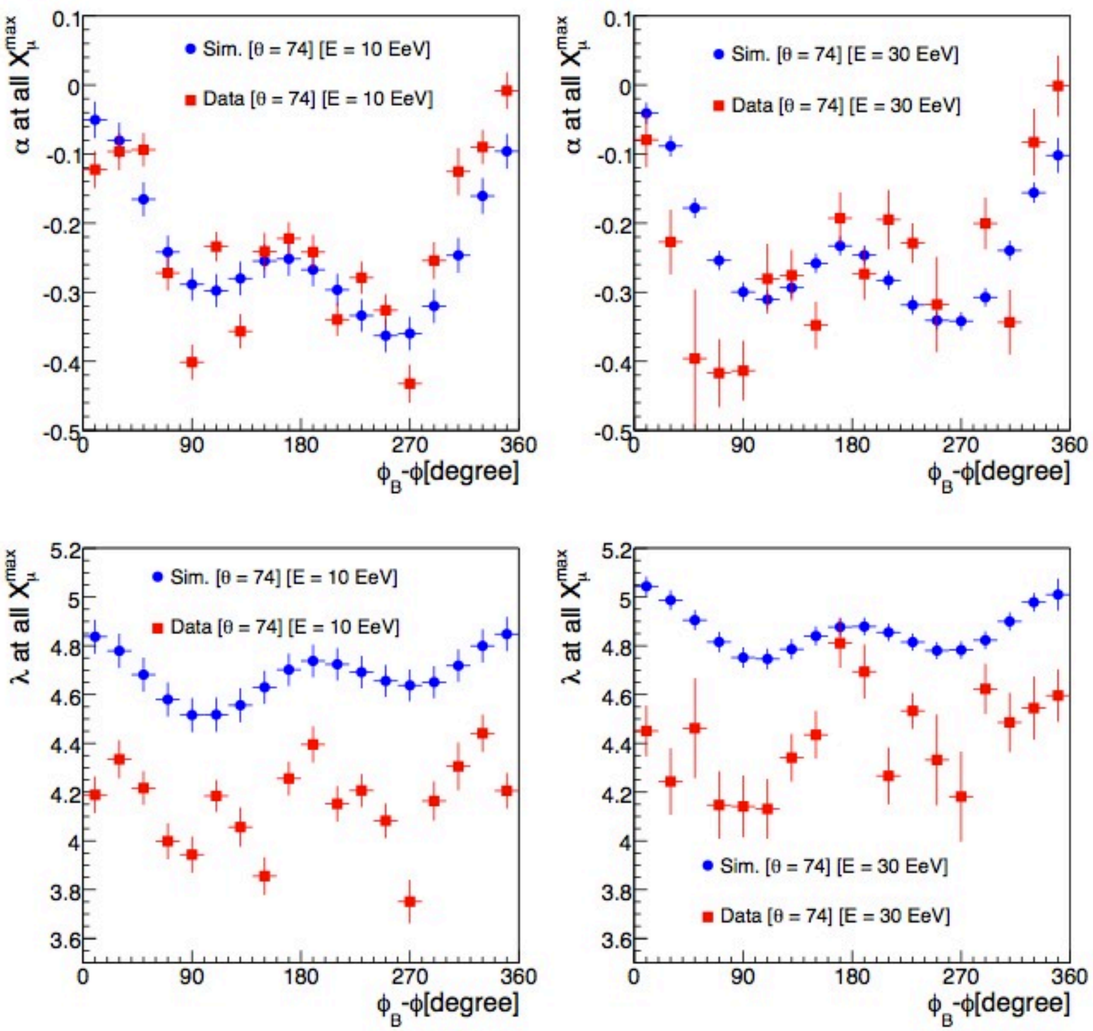
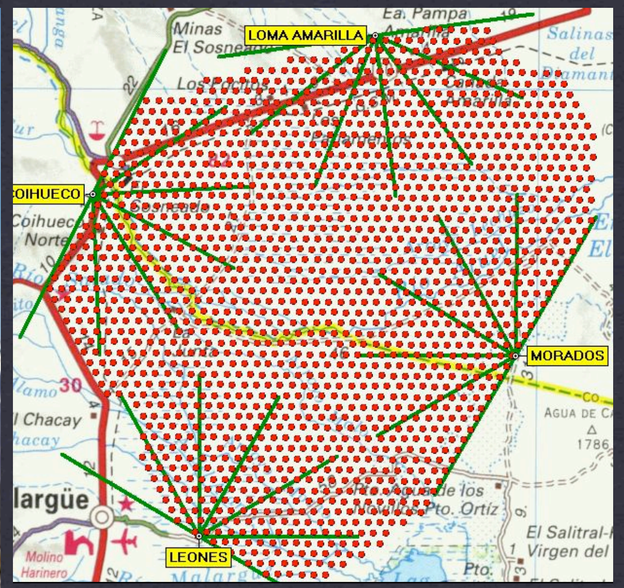


Figure 28 All the values of α and λ according with ϕ for all the values of X^{μ}_{max}. Analysis for different energies.



DETECTORES DE SUPERFICIE

1500 TANQUES

Detectores de superficie

- Efecto Cherenkov: ¡Más rápido que la luz!
- 1500 tanques en 3000 km^2.
- Operativos todo el día.

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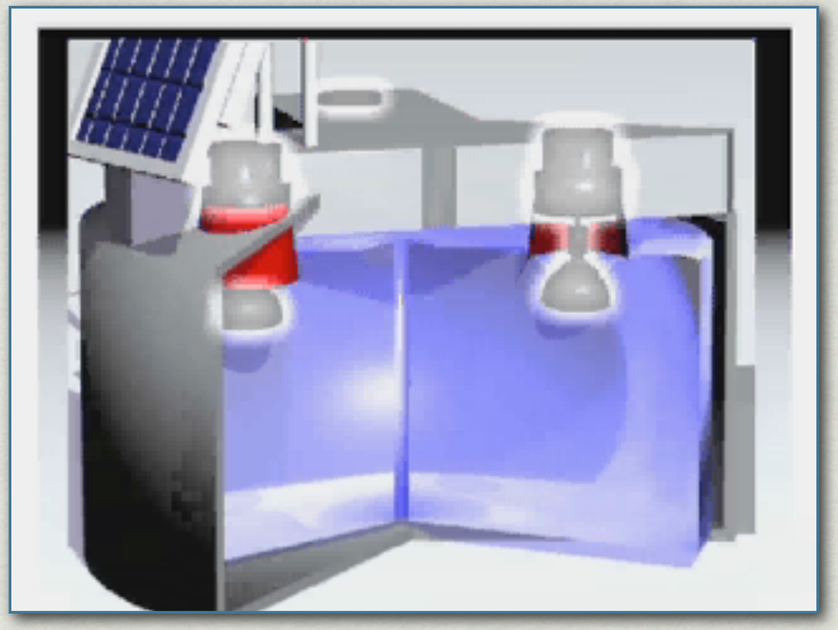

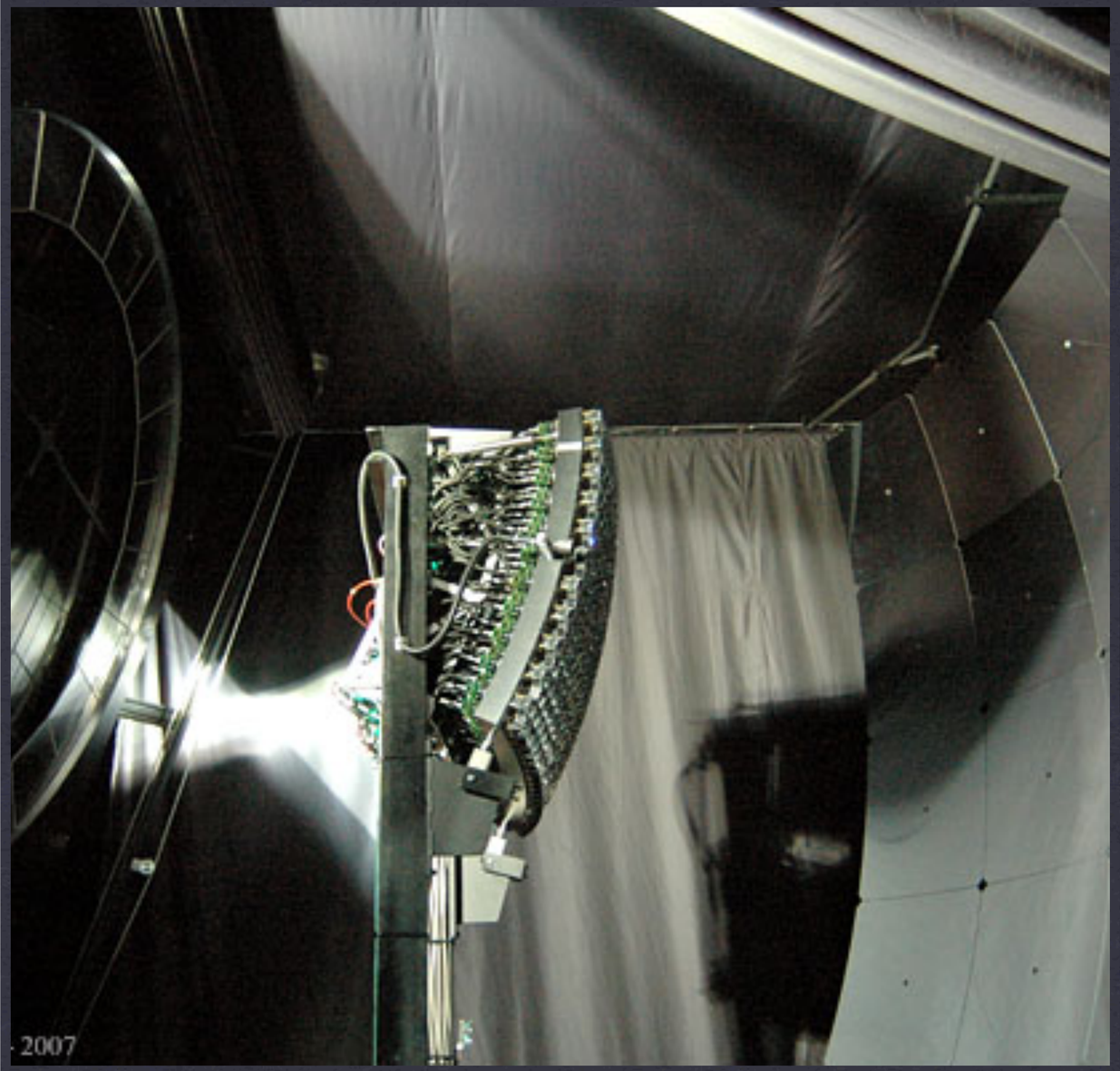

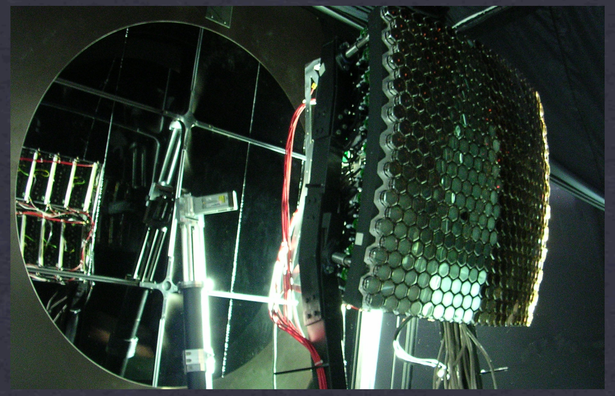

DETECTORES DE FLUORESCENCIA

CUATRO ESTACIONES CON 6 TELESCOPIOS

Detectores de fluorescencia

- Fluorescencia.
- Atrapar energía para emitirla después.
- Luz muy débil.
- 13% del tiempo.