The impact of the Fluorescence Yield on the reconstructed shower parameters

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Outline

- Introduction

- Fluorescence Yield Datasets

- Analytical Method.

- Results
  - Datasets
  - T, h effects
  - Uncertainties

-Comparison with detailed reconstruction

INTRODUCTION

Fluorescence yield

Y_λ is defined as the number of λ photons emmited per unit of deposited energy (ph/MeV)

$$Y_\lambda = \frac{Y_\lambda^0}{1 + P/P'_\lambda}$$

P' values determine the dependence of the fluorescence yield with atmospheric properties

$$\frac{1}{P'} = \frac{f_{N_2}}{P'_{N_2}} + \frac{f_{O_2}}{P'_{O_2}} + \frac{f_w}{P'_w}$$

P' contains contributions from all possible quenchers

$$P'_i = \frac{\sqrt{\pi \mu_{Ni} k T}}{\sqrt{8}\tau_0 \sigma_{Ni}} \qquad \sigma_{Ni} \propto T^\alpha \qquad P'_i \propto T^{\frac{1}{2}-\alpha}$$

P' depends on temperature

FY Dataset

The reconstruction of the shower parameters requires:

1.- Absolute values in dry air for all wavelengths, Y_λ (P_0, T_0). Or, alternatively $Y_{ref}(P_0,T_0)$ and $I_\lambda(P_0,T_0)$.

2.- $P'_\lambda(T_0)$ for dry air

3.- T dependence of collisional cross section, α_λ

4.- P'_w for all wavelengths (and its α_w values if possible).

Y_λ at any given P, T conditions can be obtained from:

$$Y_\lambda(P,T) = Y_\lambda(P_0,T_0)\frac{1 + P_0 / P'_\lambda(T_0)}{1 + P / P'_\lambda(T)}$$

Datasets in fluorescence telescopes

Three datasets have been used in cosmic rays experiments:

1.- Kakimoto-Bunner (K-B): used by HiRes in 2001.
- Kakimoto et al.: ϕ and P' values for 337, 351, 391 nm at (T_0=288 K, P_0=1013 hPa)
- Remaining bands contribute 30% and are distributed according to Bunner.

2.- Nagano:
- ϕ and P' values for 15 bands (T_0=293 K, P_0=1013 hPa)

3.- Nagano-Airfly (N-A): presently used by the Auger Collaboration
- Nagano et al. Y for 337 band (T_0=293 K, P_0=800 hPa)
- P' at T_0=293 K and relative intensities for 34 bands from Airfly Collaboration

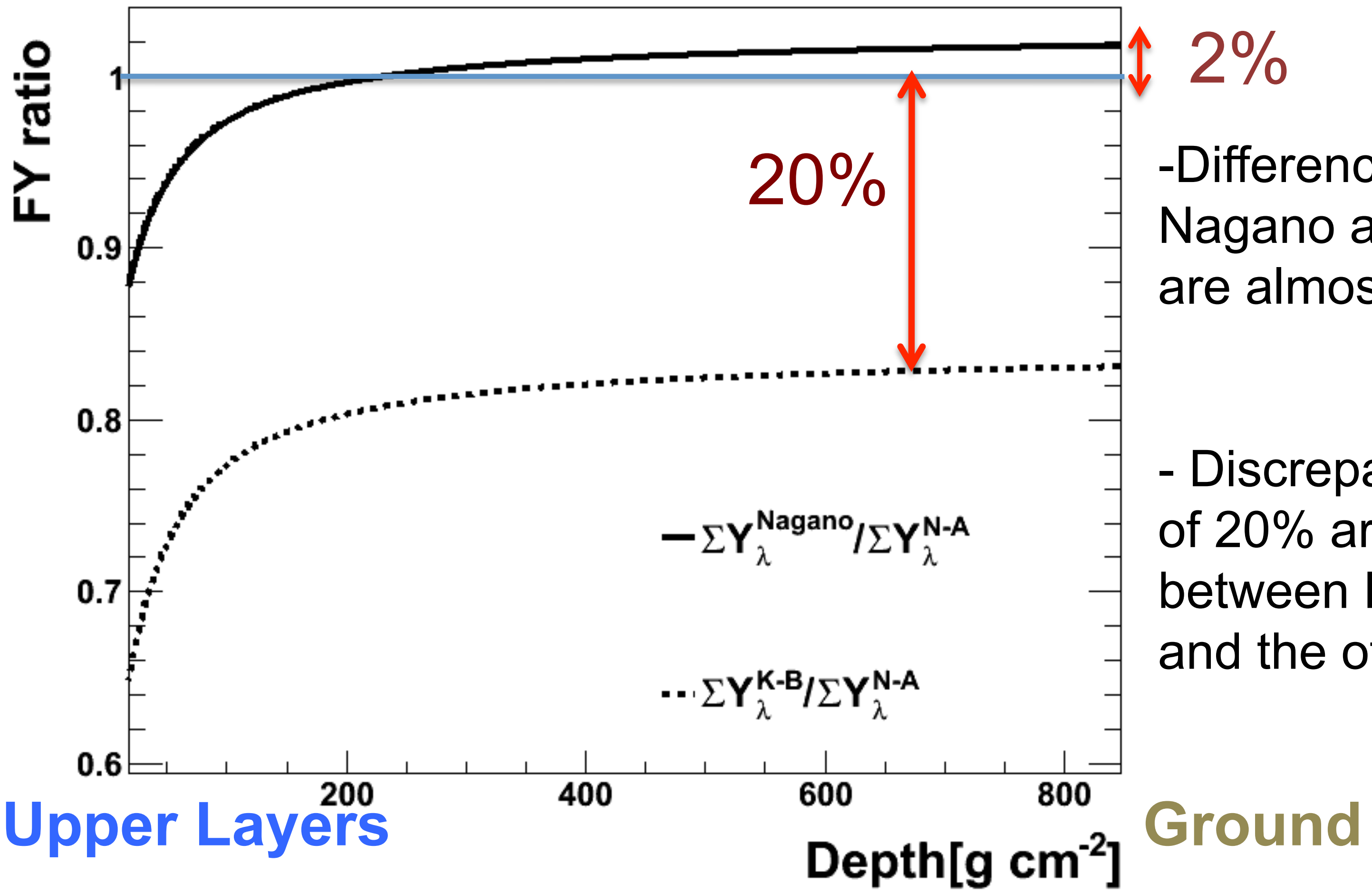
N-A will be the reference dataset in this work

COMPARISON OF DATASETS

Comparison of Datasets

$Y^{N\text{-}A}$ = fluorescence yield from the Nagano-Airfly dataset
$Y^{K\text{-}B}$ = fluorescence yield from the Kakimoto-Bunner dataset
Y^{Nagano} = fluorescence yield from the Nagano dataset

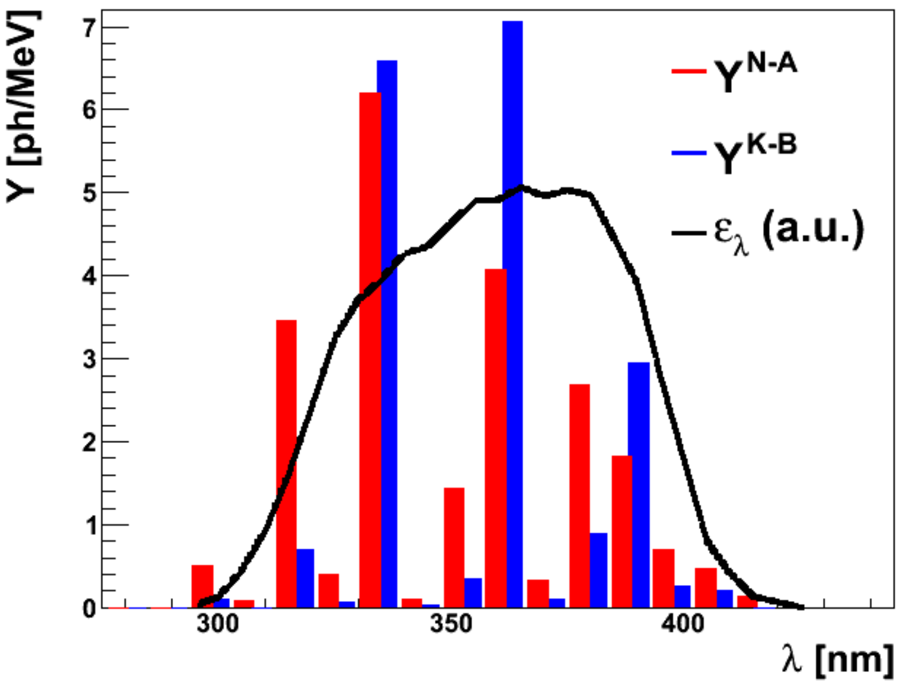
$$\text{FY Ratio} = \frac{Y^{Dataset}}{Y^{N-A}}$$

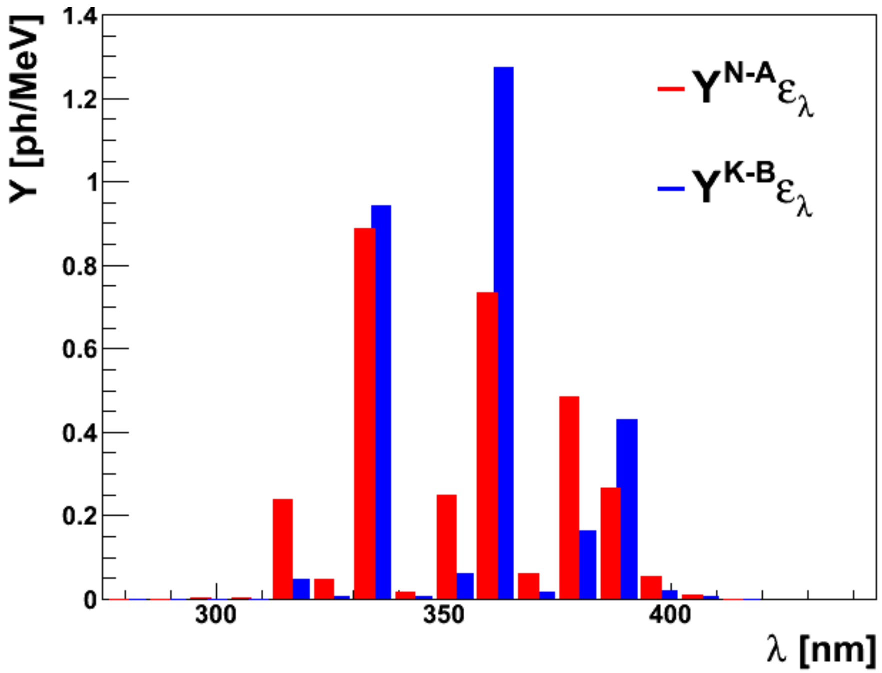


-Differences between Nagano and Nagano-Airfly are almost negligible (~2%)

- Discrepancies at the level of 20% are observed between Kakimoto-Bunner and the other datasets

Comparison of Datasets (K-B vs N-A)



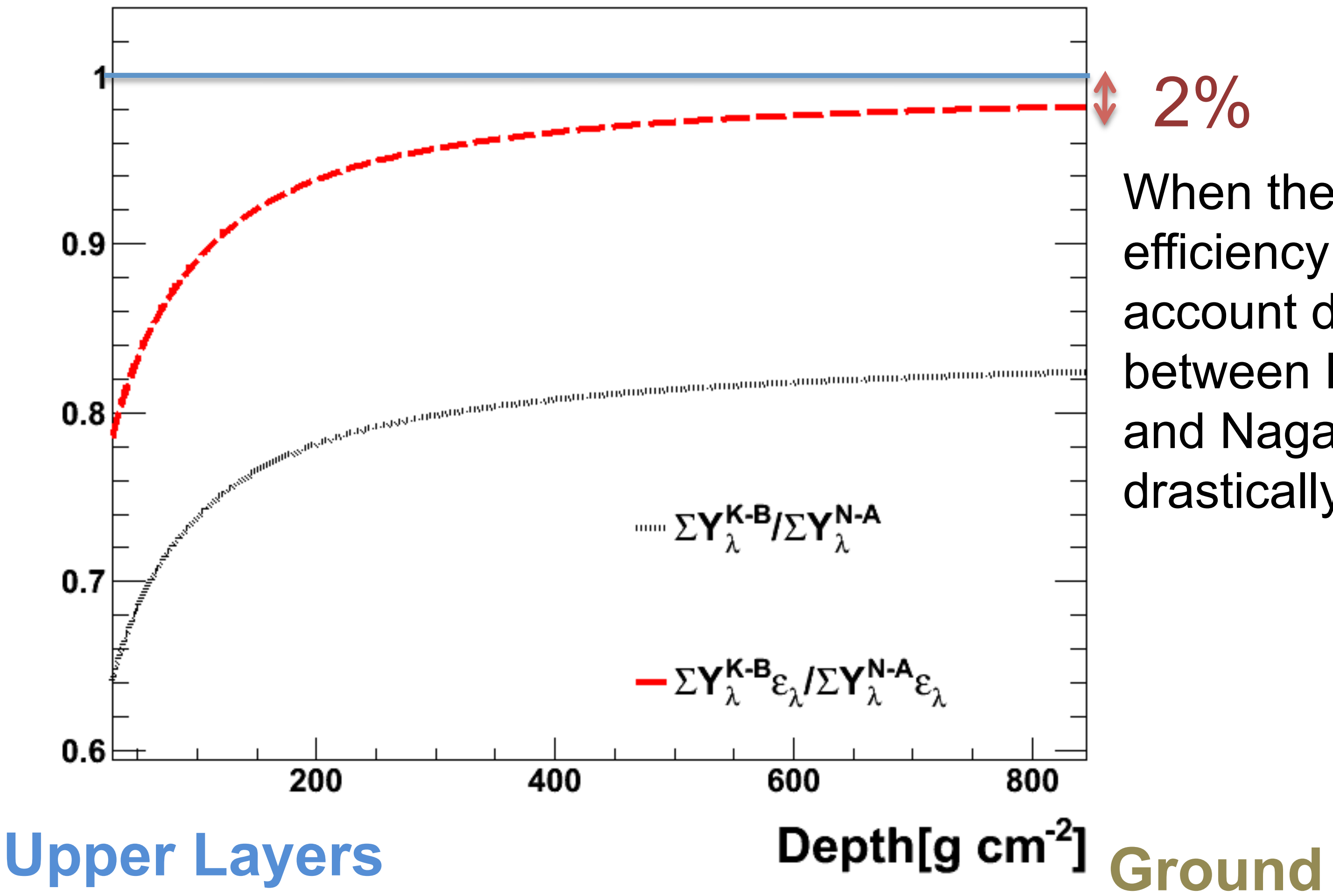


Fluorescence photons are detected with optical systems that have λ-dependent response (black line). When this efficiency is taken into account the relative intensities of the molecular bands are modified (right picture).

Comparison of Datasets (K-B vs N-A)

Y^{NA} = fluorescence yield from the Nagano-Airfly dataset
Y^{K-B} = fluorescence yield from the Kakimoto-Bunner dataset

$$\text{FY Ratio} = \frac{Y^{Dataset}}{Y^{N-A}}$$



When the detector efficiency is taken into account discrepancies between Kakimoto-Bunner and Nagano-Airfly are drastically reduced.

T AND H EFFECTS

Temperature and humidity effect

Temperature and humidity effect in the N-A dataset have been studied

- **Temperature:**

  AIRFLY Collaboration values for all the 34 bands*

$$\frac{1}{P'_{air}(\lambda)} \propto \left(\frac{T}{T_0}\right)^{1/2-\alpha_\lambda} \qquad \alpha_{\mathrm{NN}} = \alpha_{NO} = \alpha_{\mathrm{Airfly}}$$

- **Humidity:**

  P'_w from AIRFLY*

Atmospheric profile at Auger Site (Malargüe, Argentina)**

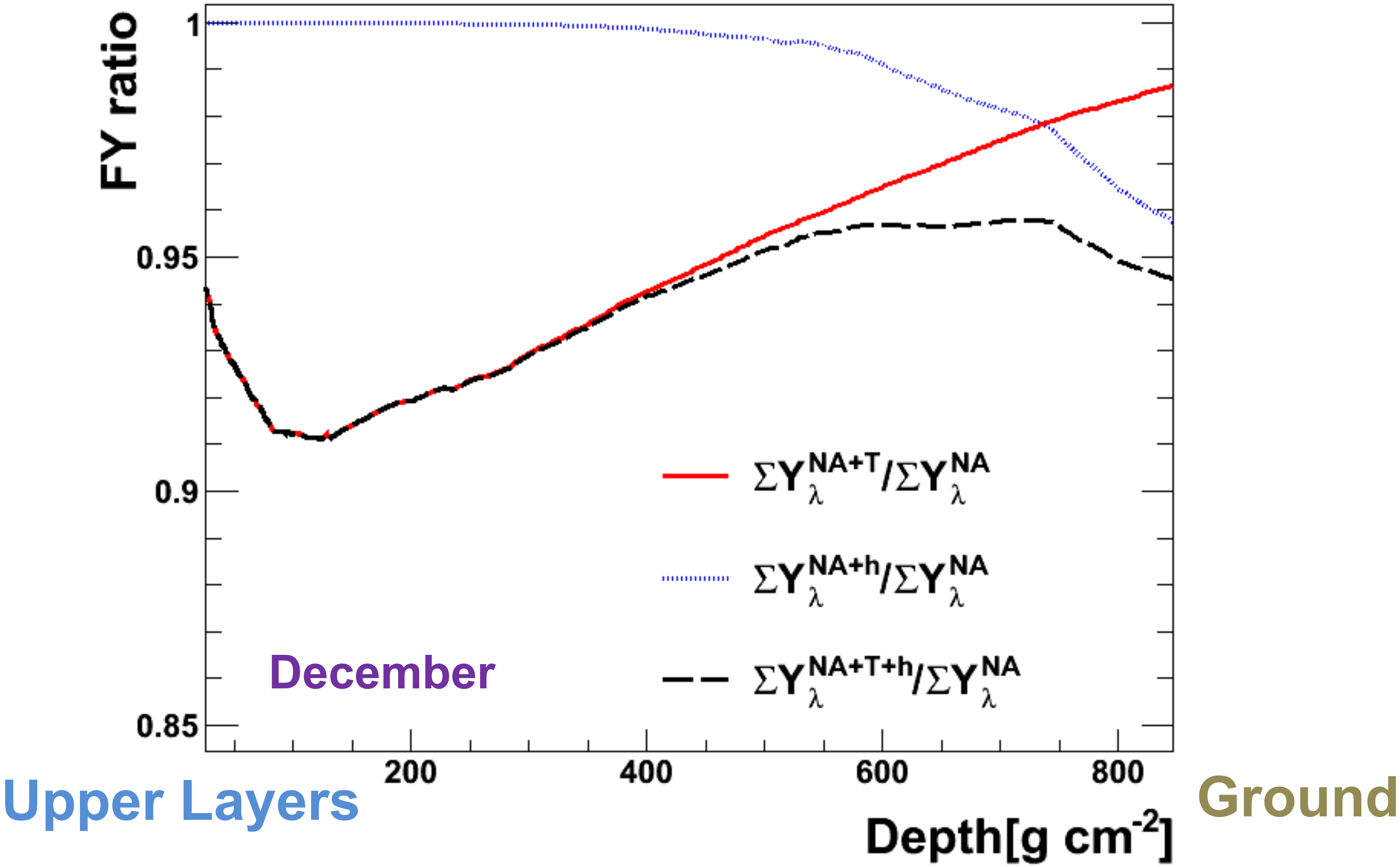
* Ave et al. Nucl. Instrum. and Meth. A **597** (2008) 50-54

** The Pierre Auger Coll. Astroparticle Physics **33** (2010) 108

FY(T,h) vs Depth

Y^{NA} = fluorescence yield from the Nagano-Airfly dataset

Y^{NA+T+h} = fluorescence yield including T and/or h contributions



ANALYTICAL METHOD

Simple analytical procedure to evaluate T,h effect

Longitudinal profile of fluorescence emission

Fluorescence yield

photons g^{-1} cm^2

$$\frac{dn_\gamma(X)}{dX} = \left(\frac{\mathrm{d}E}{dX}\right) Y(X)$$

profile of deposited energy described by a **Gaisser-Hillas function**

$Y \rightarrow Y'$ with a given fluorescence profile, a different FY assumption leads to a change in reconstructed energy

$$\frac{dE'}{dX} = \frac{Y(X)}{Y'(X)} \frac{dE}{dX} \qquad E' = \int \frac{Y(X)}{Y'(X)} \frac{dE}{dX} dX \qquad \text{FY Ratio} = \frac{Y'}{Y}$$

Simple analytical procedure to evaluate T,h effect

Longitudinal profile of fluorescence emission

Fluorescence yield

photons g^{-1} cm^2

$$\frac{dn_\gamma(X)}{dX} = \left(\frac{\mathrm{d}E}{dX}\right) Y(X)$$

profile of deposited energy described by a **Gaisser-Hillas function**

$Y \rightarrow Y'$ taking into account optical efficiency and atmospheric transmission:

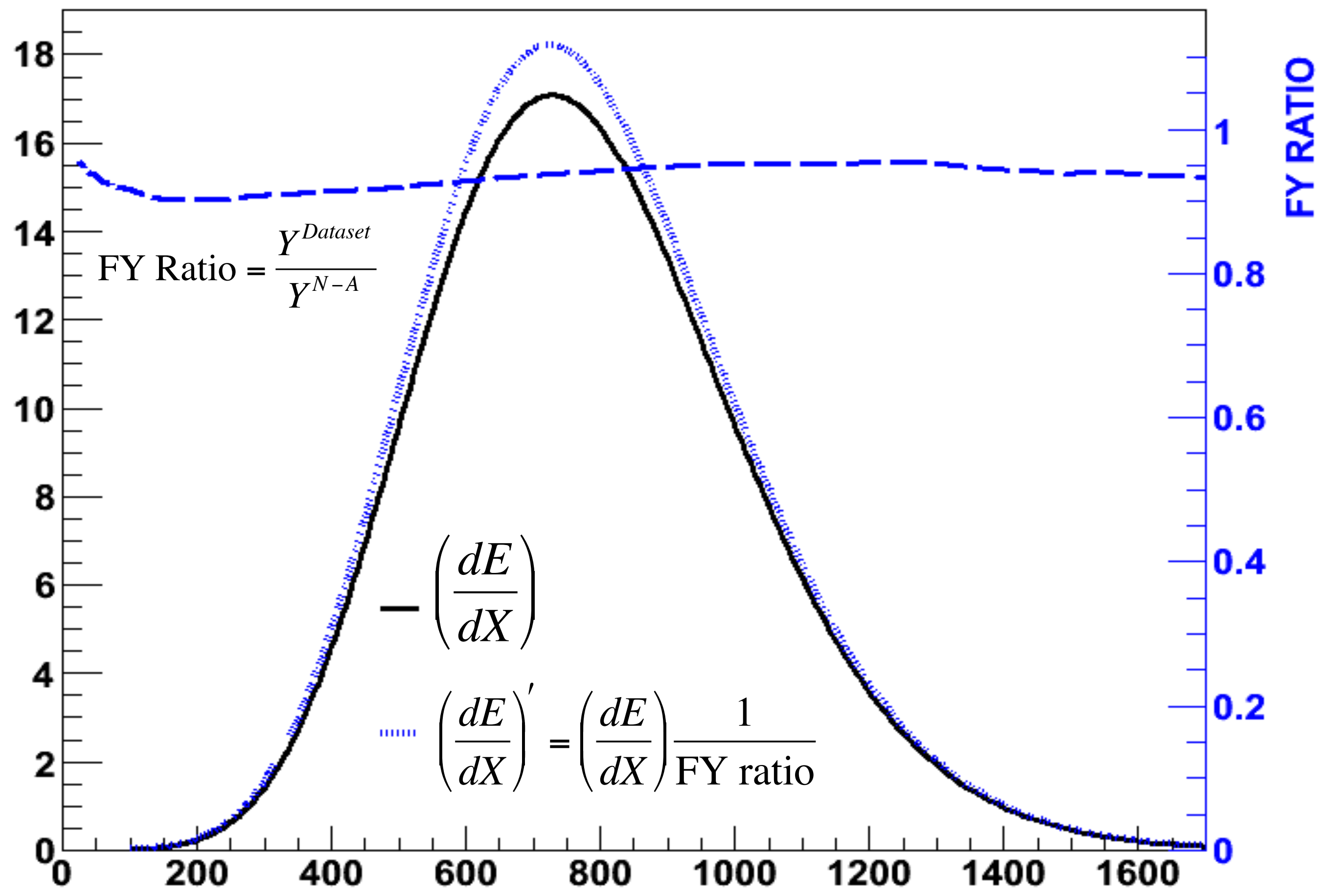
Atmospheric transmission

$$E' = \int_0^\infty \frac{\mathrm{d}E}{\mathrm{d}X} \frac{\sum_\lambda Y_\lambda(X)\varepsilon_\lambda T_\lambda(X)}{\sum_\lambda Y'_\lambda(X)\varepsilon_\lambda T_\lambda(X)} \mathrm{d}X$$

Optical efficiency of telescope

Method

$$E' = \int_0^\infty \frac{dE}{dX} \frac{\sum_\lambda Y_\lambda(X)\varepsilon_\lambda T_\lambda(X)}{\sum_\lambda Y'_\lambda(X)\varepsilon_\lambda T_\lambda(X)} dX = \int_0^\infty \frac{\mathrm{dE}}{\mathrm{dX}} \frac{1}{\mathrm{FY\ ratio}} dX$$



This method has been applied to different cases

Typical Gaisser-Hillas profiles for 6 types of showers:

1.- Primary energy: 10^{19} eV, 10^{20} eV

2.- Composition: p, Fe

3.- Geometry: 30º, 60º

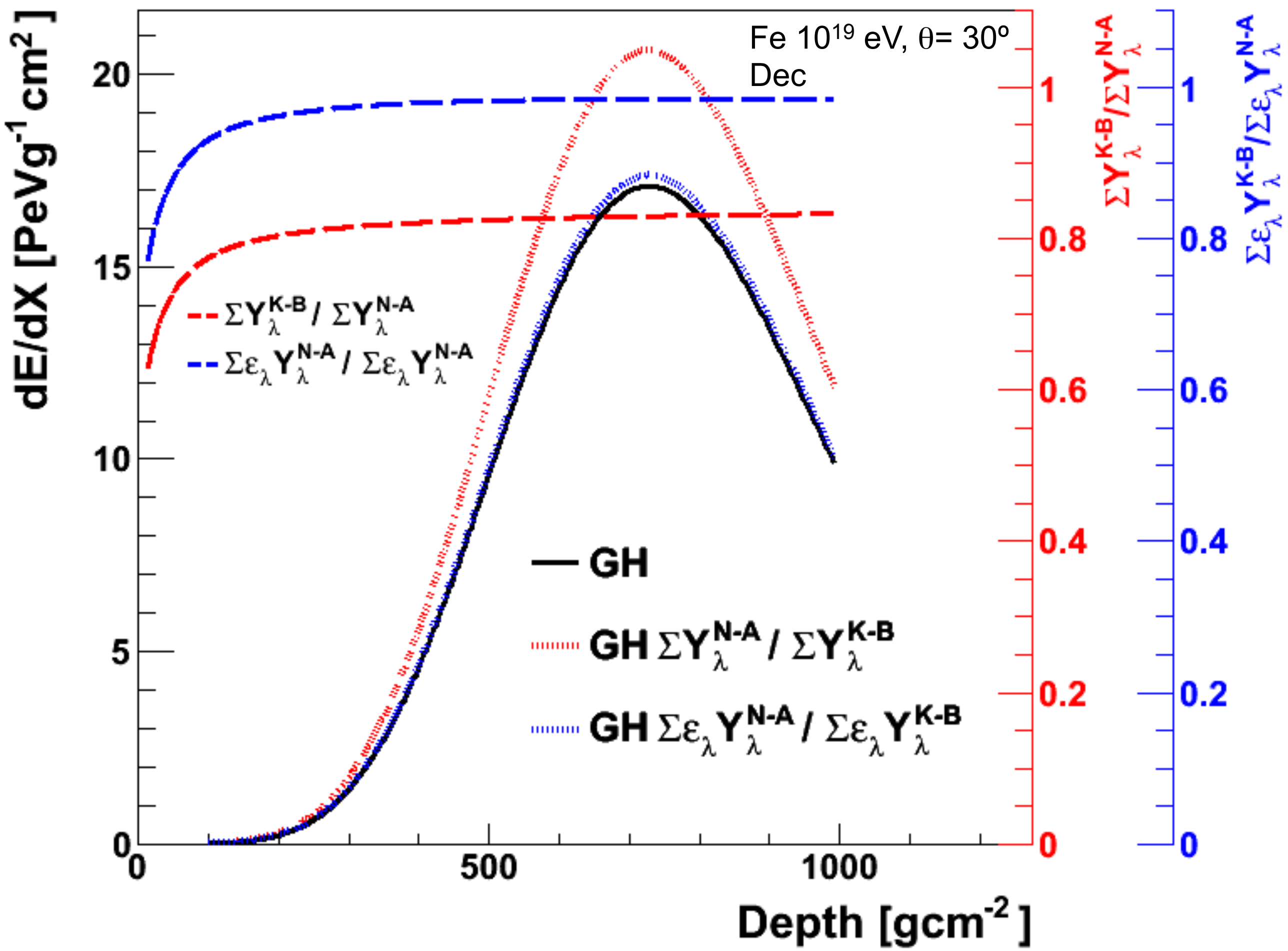
FY assumptions:

1.- Datasets (K-B, N-A, Nagano)

2.- T and h effects

RESULTS: COMPARISON OF DATASETS

Effect of dataset choice (N-A vs K-B)



$\delta E = (E'-E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

δE = 20.6 %

ΔX_{max} = -1 g·cm^{-2}

δE = 1.7 %

$\Delta X_{max} \approx$ 0 g·cm^{-2}

Effect of dataset choice (Nagano & K-B vs N-A)

1.- Average effect on energy

	$\delta E=(E'-E)/E$	
	Nagano/N-A	K-B / N-A
Y_λ	- 1 %	19 %
$Y_\lambda \cdot \varepsilon_\lambda$	- 2 %	2 %
$Y_\lambda \cdot \varepsilon_\lambda \cdot T_\lambda$ (30 km)	- 2 %	0 %

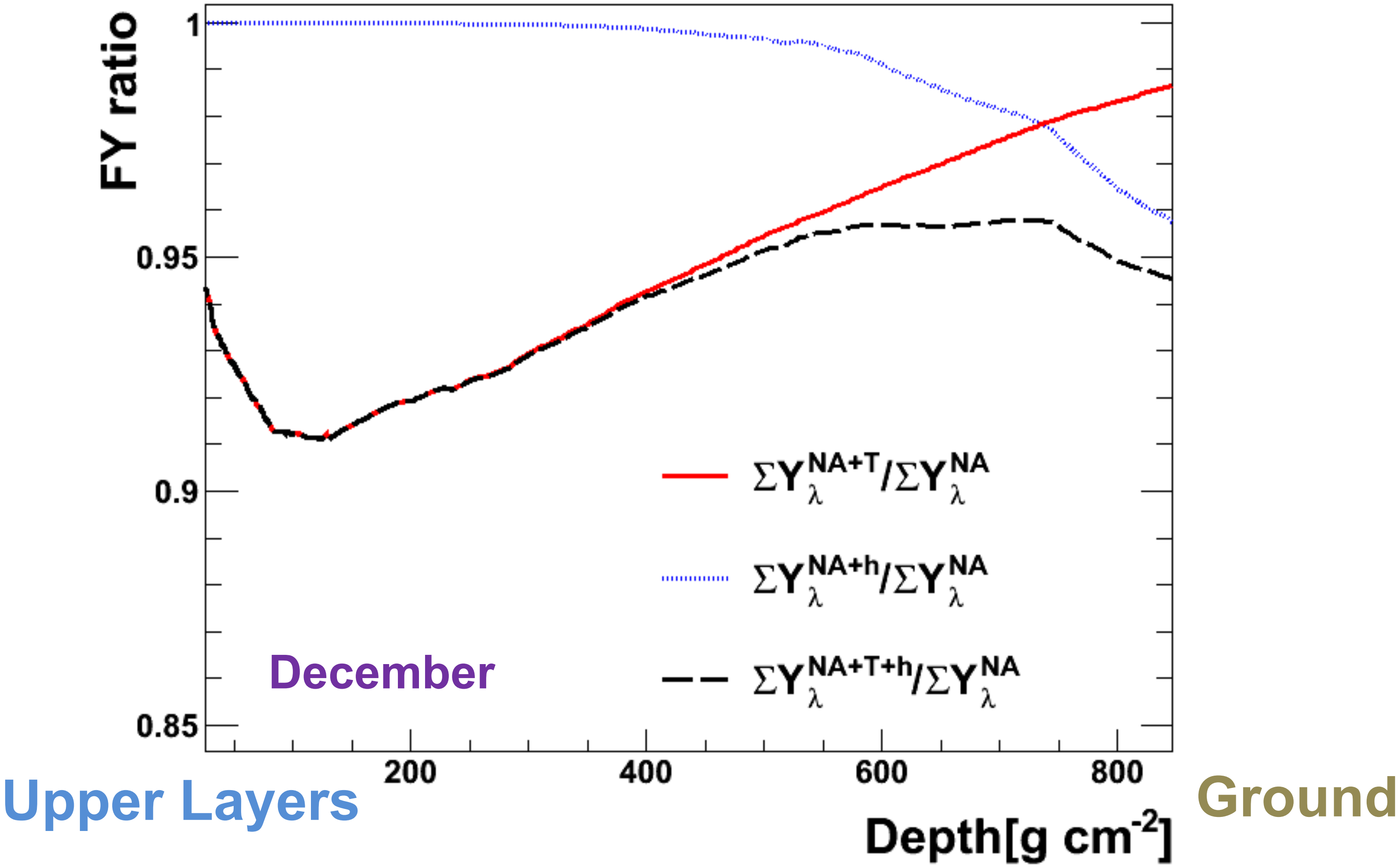
2.- Negligible effect on X_{max}

RESULTS:
T AND H EFFECTS

FY(T,h) vs Depth

Y^{NA} = fluorescence yield from the Nagano-Airfly dataset

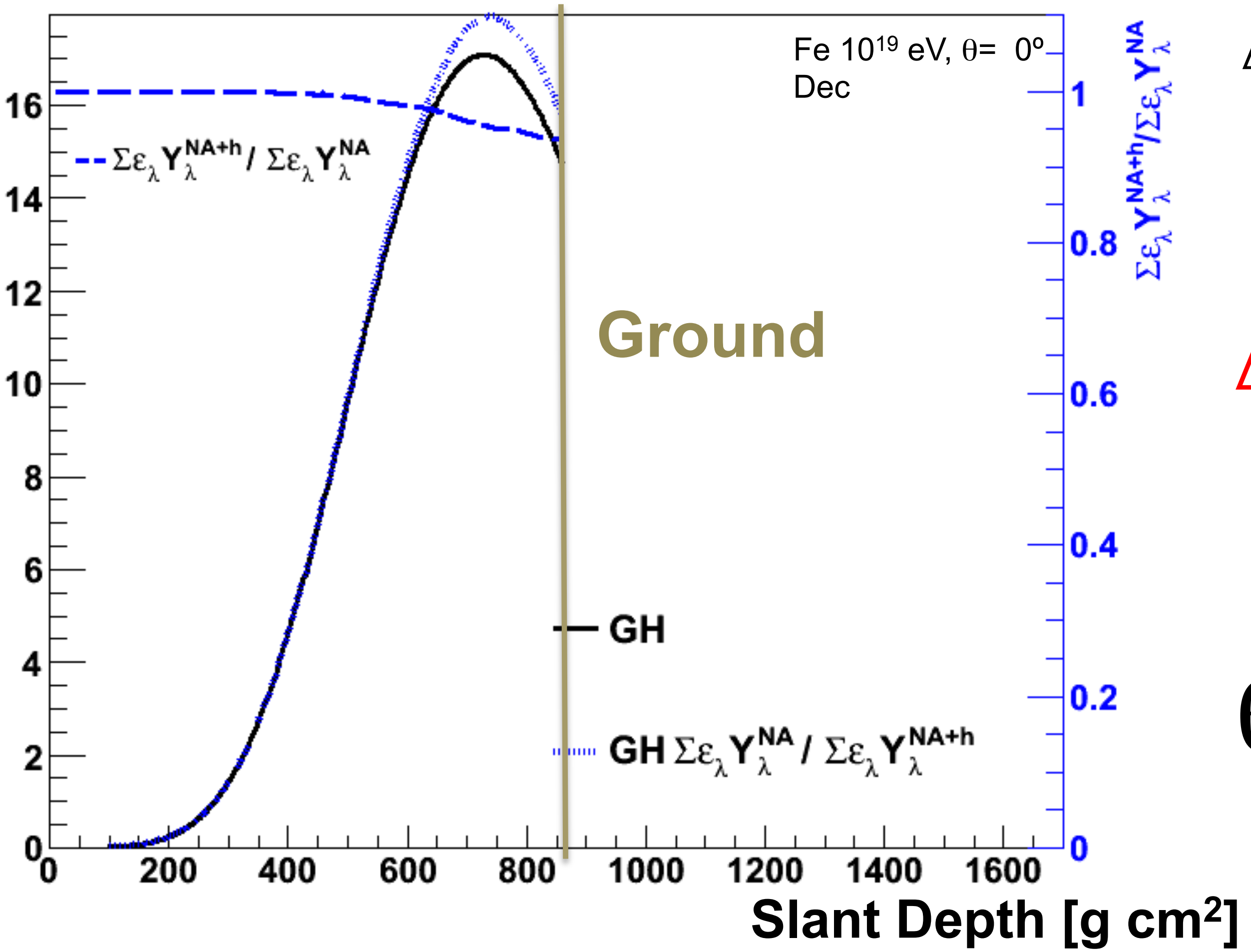
Y^{NA+T+h} = fluorescence yield including T and/or h contributions



Effect of humidity

$\delta E = (E' - E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

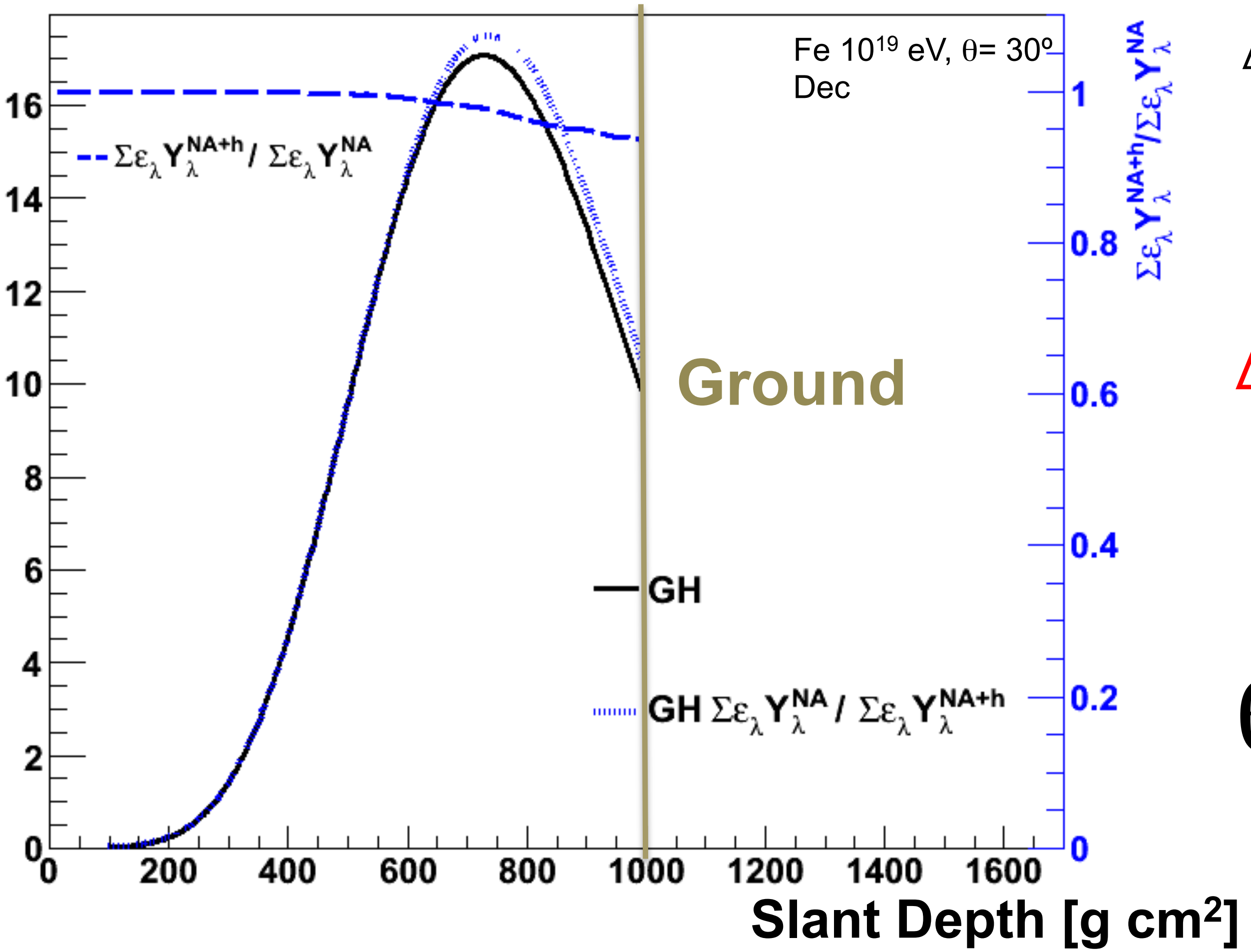


δE = 6.1 %

ΔX_{max} = 10 g·cm^{-2}

$\theta = 0^o$

Effect of humidity



$\delta E = (E'-E)/E$

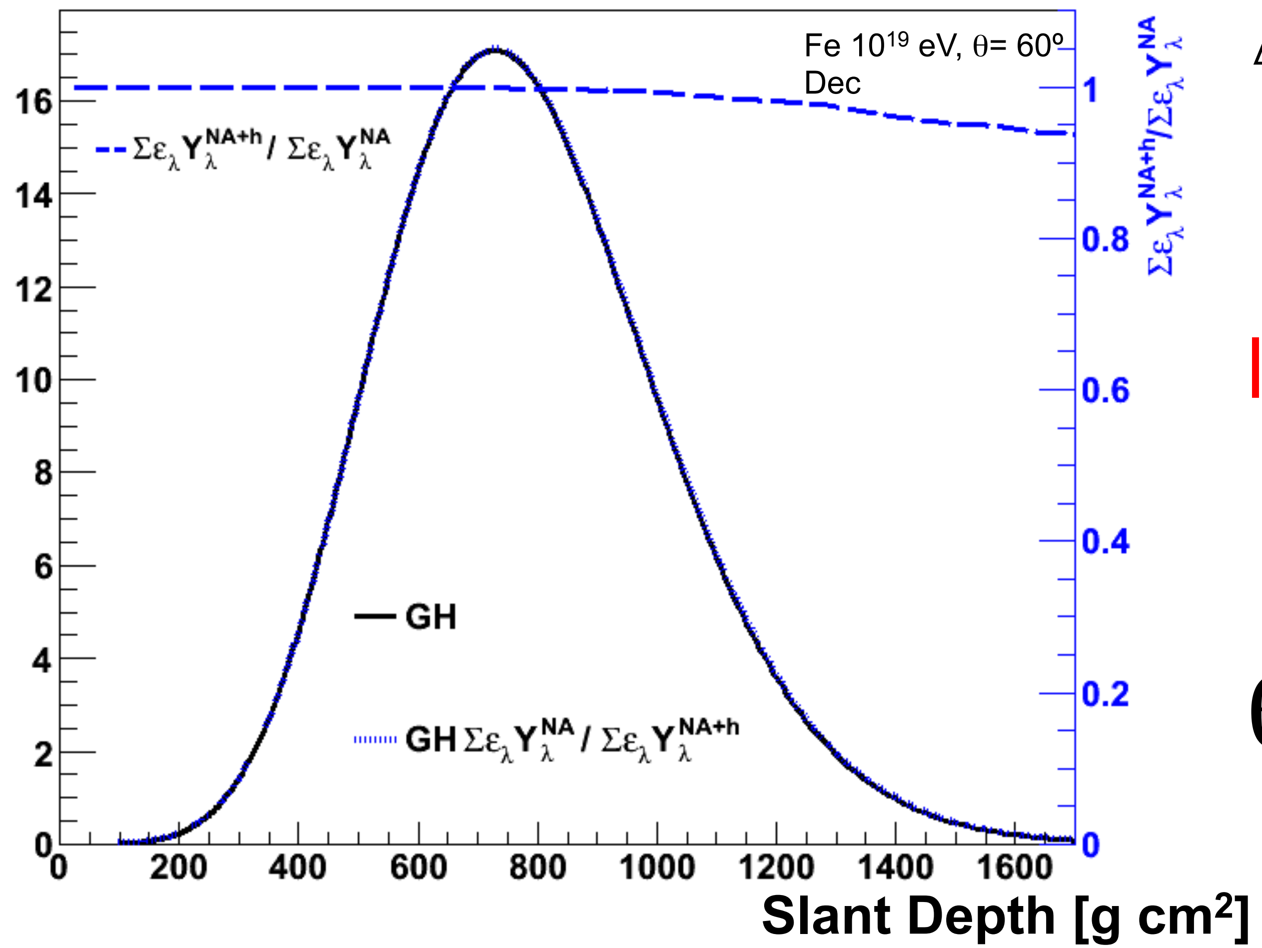
$\Delta X_{max} = X'_{max} - X_{max}$

$\delta E = 4.3\%$

$\Delta X_{max} = 8\ g \cdot cm^{-2}$

$\theta = 30^o$

Effect of humidity



$\delta E = (E' - E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

$\delta E = 0.5\%$

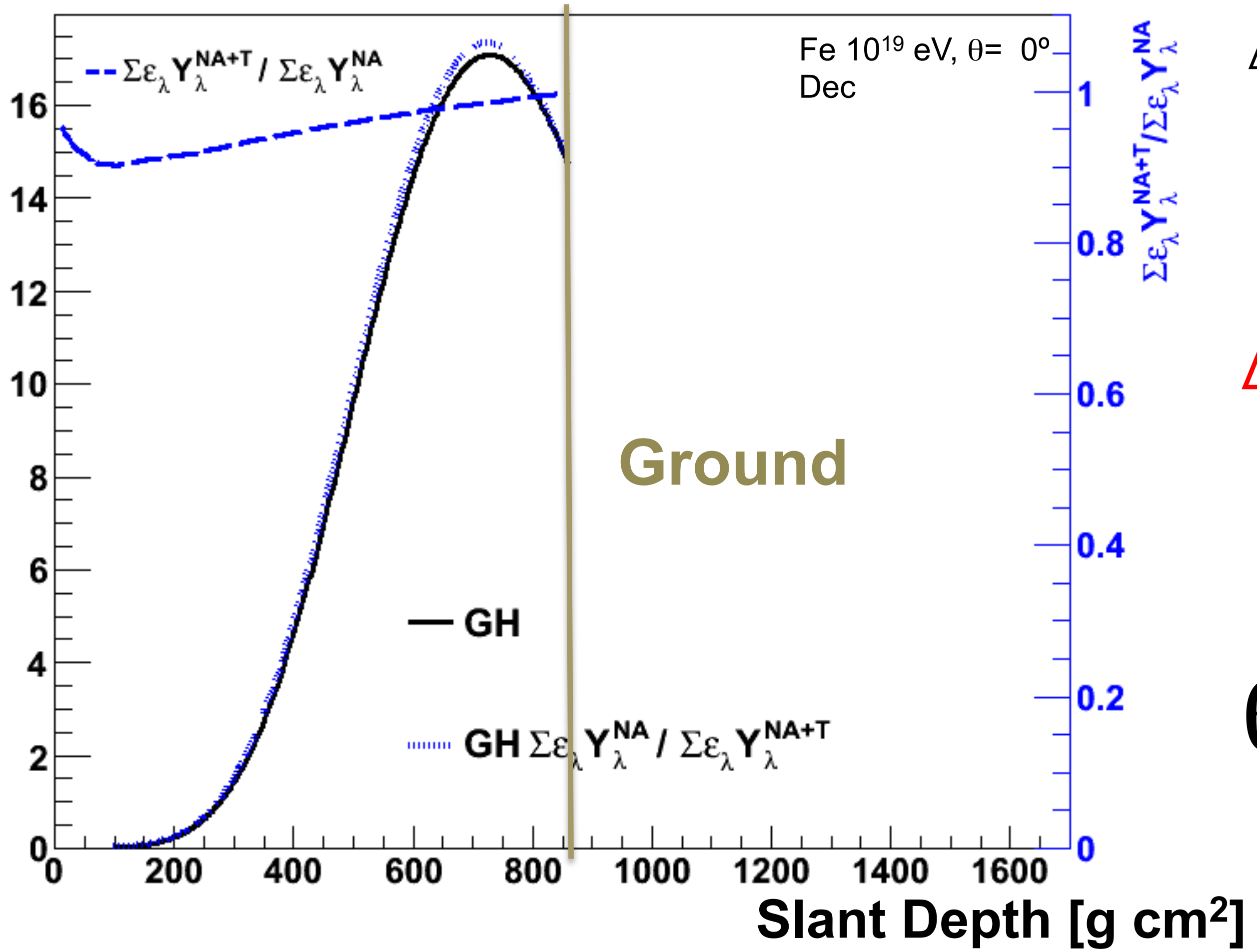
$|\Delta X_{max}| < 1\ g \cdot cm^{-2}$

$\theta = 60^o$

Effect of temperature

$\delta E = (E'-E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

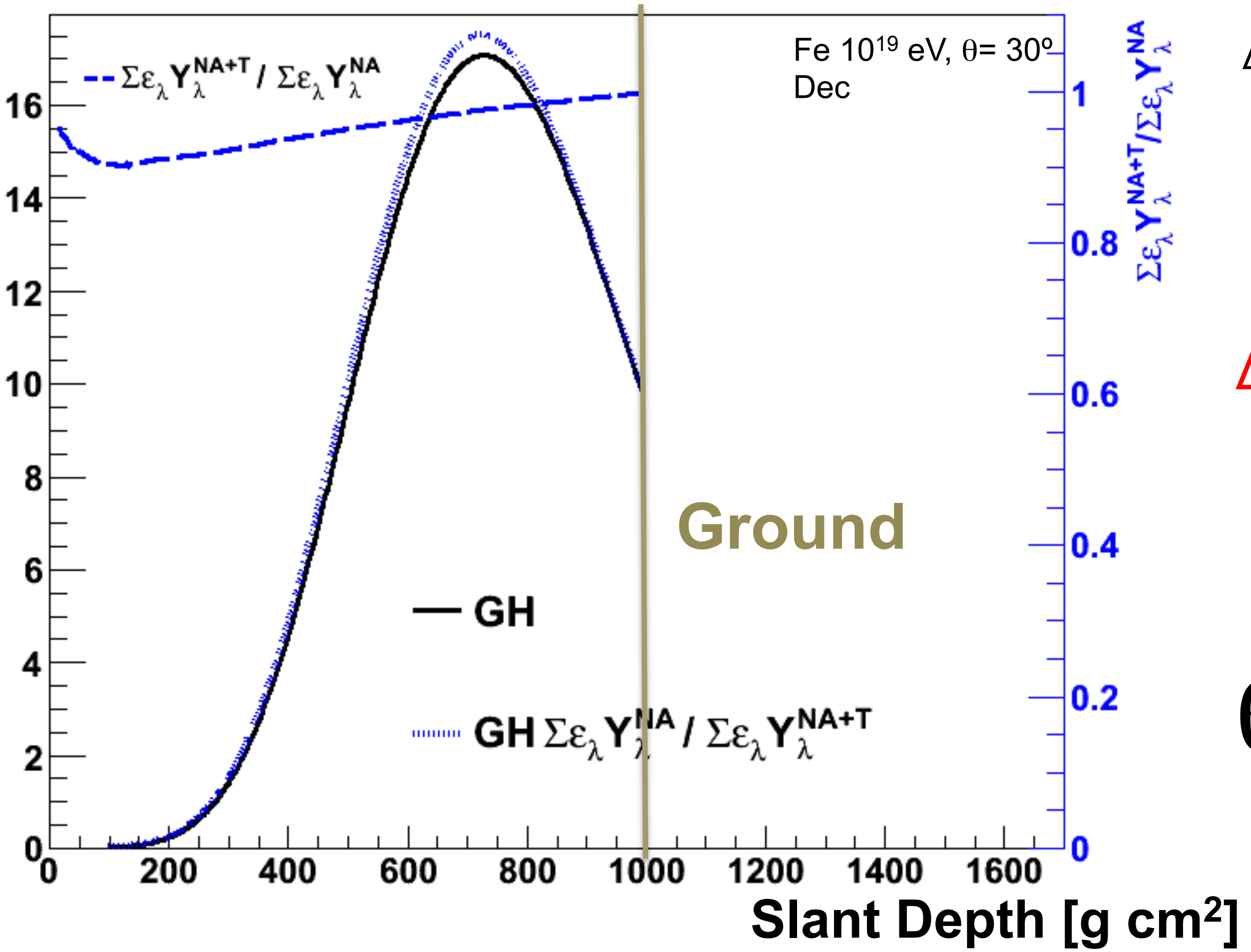


$\delta E = 2.0\%$

$\Delta X_{max} = - 5\ g{\cdot}cm^{-2}$

$\theta = 0^o$

Effect of temperature



$\delta E = (E' - E)/E$

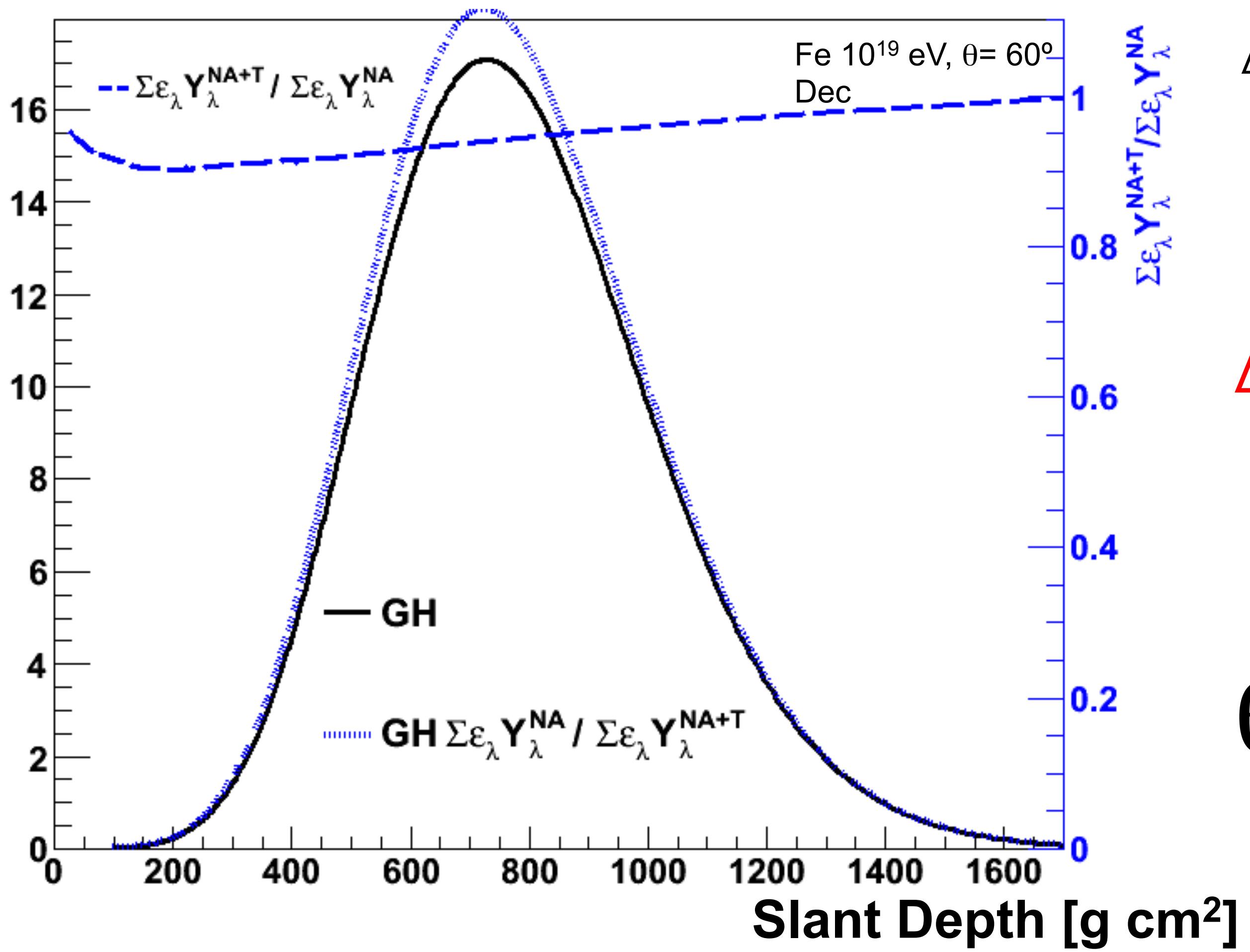
$\Delta X_{max} = X'_{max} - X_{max}$

$\delta E = 2.4\%$

$\Delta X_{max} = -5\ g\cdot cm^{-2}$

$\theta = 30^o$

Effect of temperature



$\delta E = (E' - E)/E$

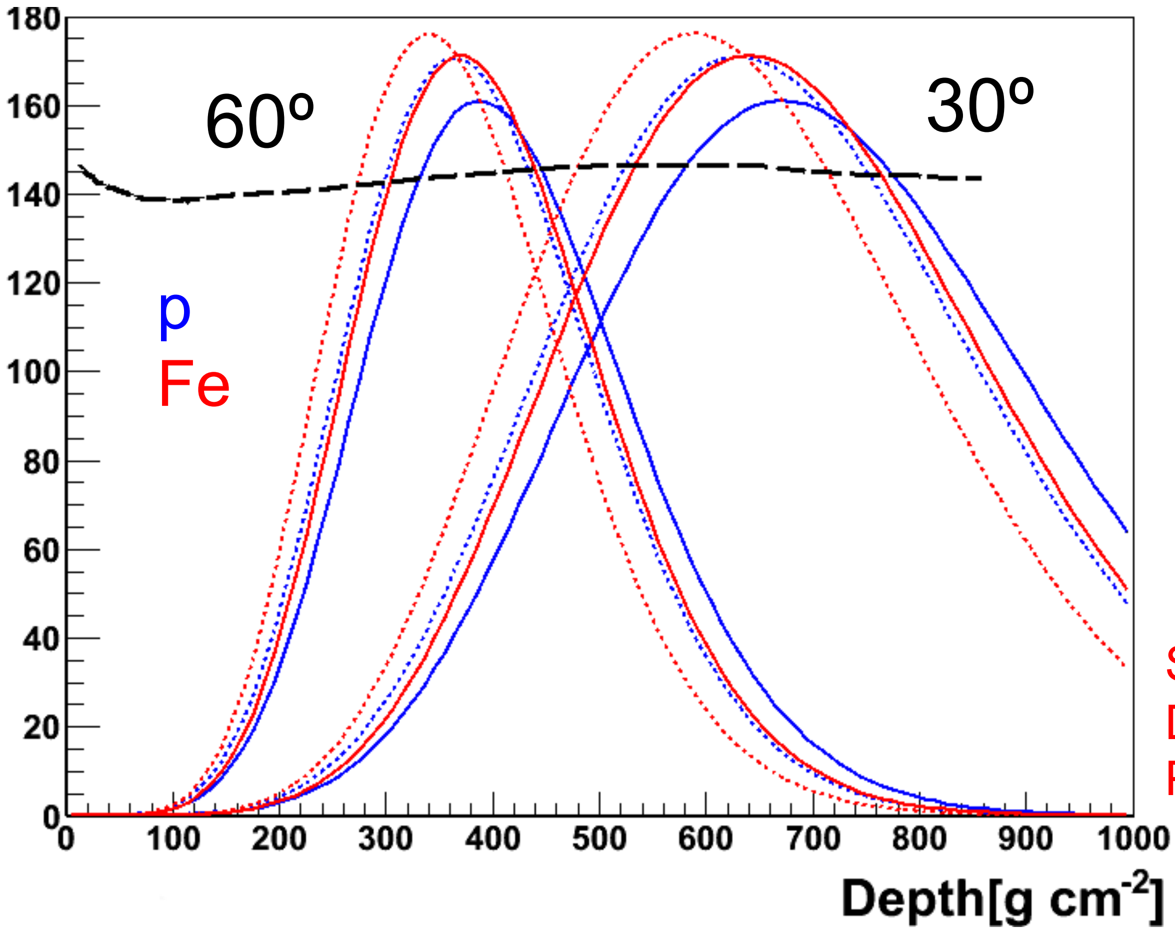
$\Delta X_{max} = X'_{max} - X_{max}$

$\delta E = 6.1\%$

$\Delta X_{max} = -5\ g \cdot cm^{-2}$

$\theta = 60^o$

T+h Combined Effect



- Geometry dependent

- Vertical showers affected by humidity.

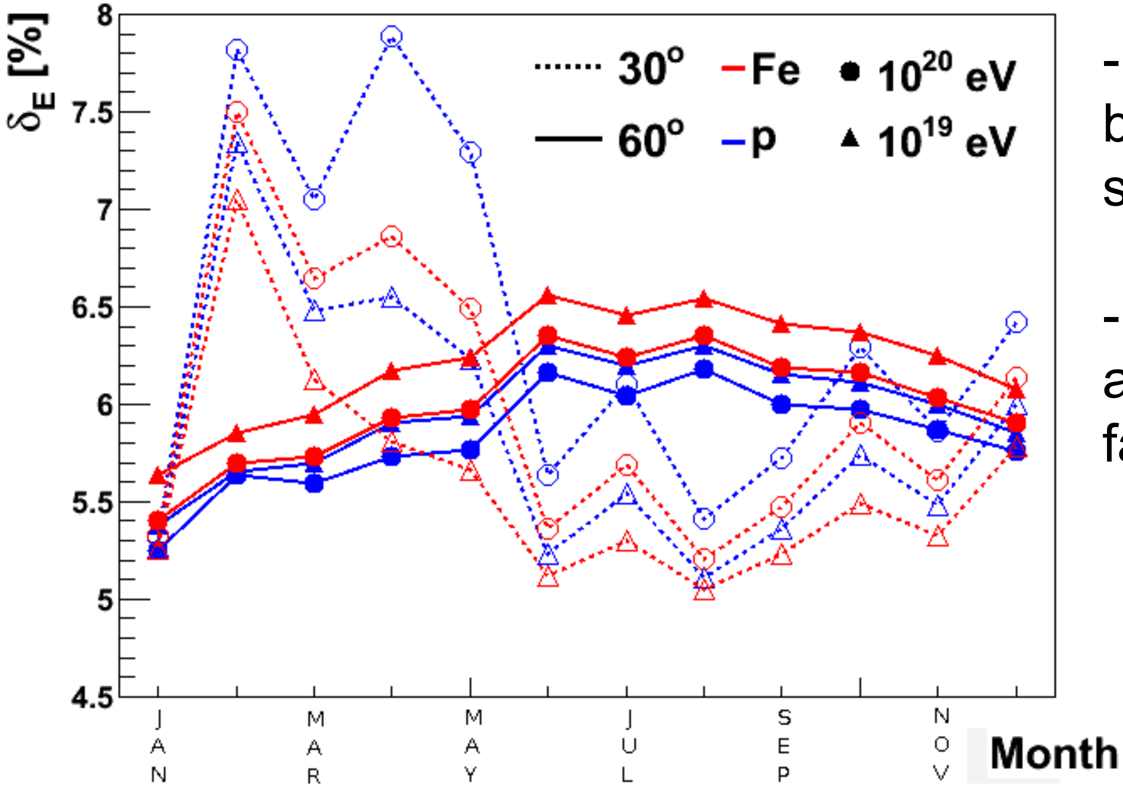
- Inclined showers affected by temperature.

- The slope of the FY ratio will determine ΔX_{max}.

Solid line 10^{20} eV
Dotted line 10^{19} eV
Profiles not scaled

Results on E

Effect of T + h on reconstructed primary energy



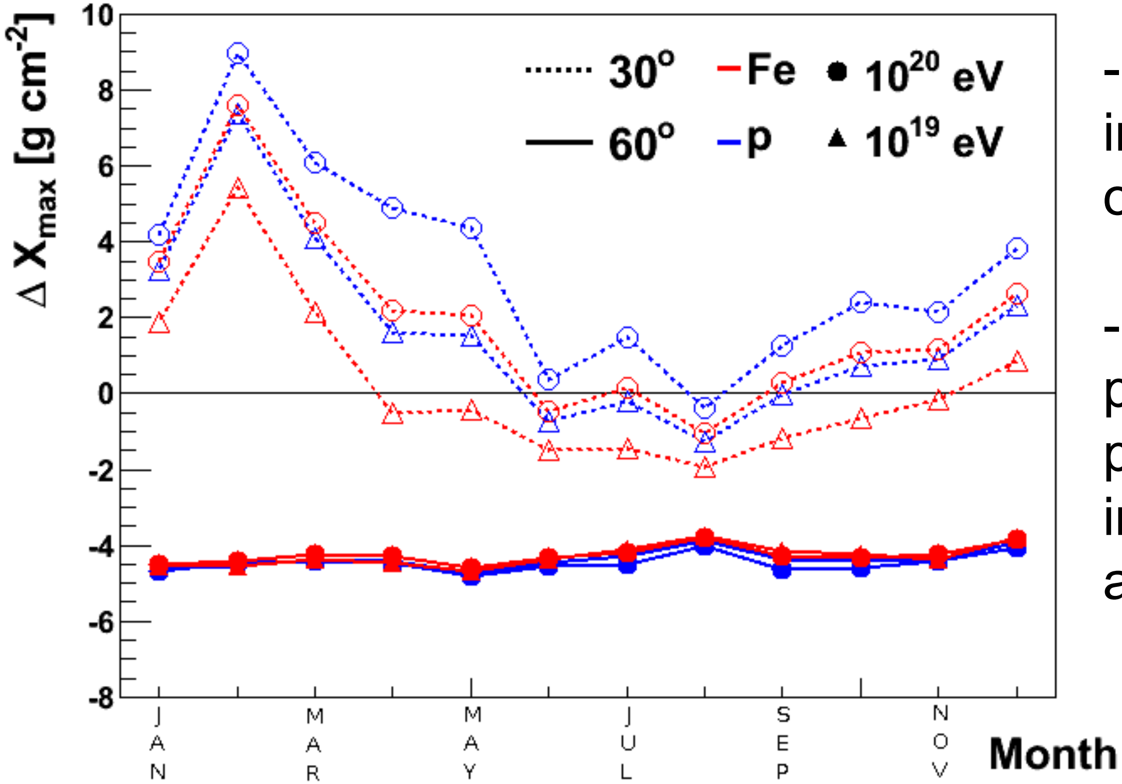
- Vertical showers (affected by humidity) show a strong seasonal dependence.

- Inclined showers (more affected by temperature) are fairly regular.

Invisible energy taken into account:
$E_{inv} \approx 10\% \Rightarrow \delta E_{tot} = \delta E_{cal}/1.1$

Results on X_{max}

Effect of T + h on shower maximum depth



- As vertical showers develop in the transition zone, the effect on X_{max} is highly variable.

- In inclined showers the X_{max} position decreases due to positive slope of the FY ratio in the upper layers of the atmosphere.

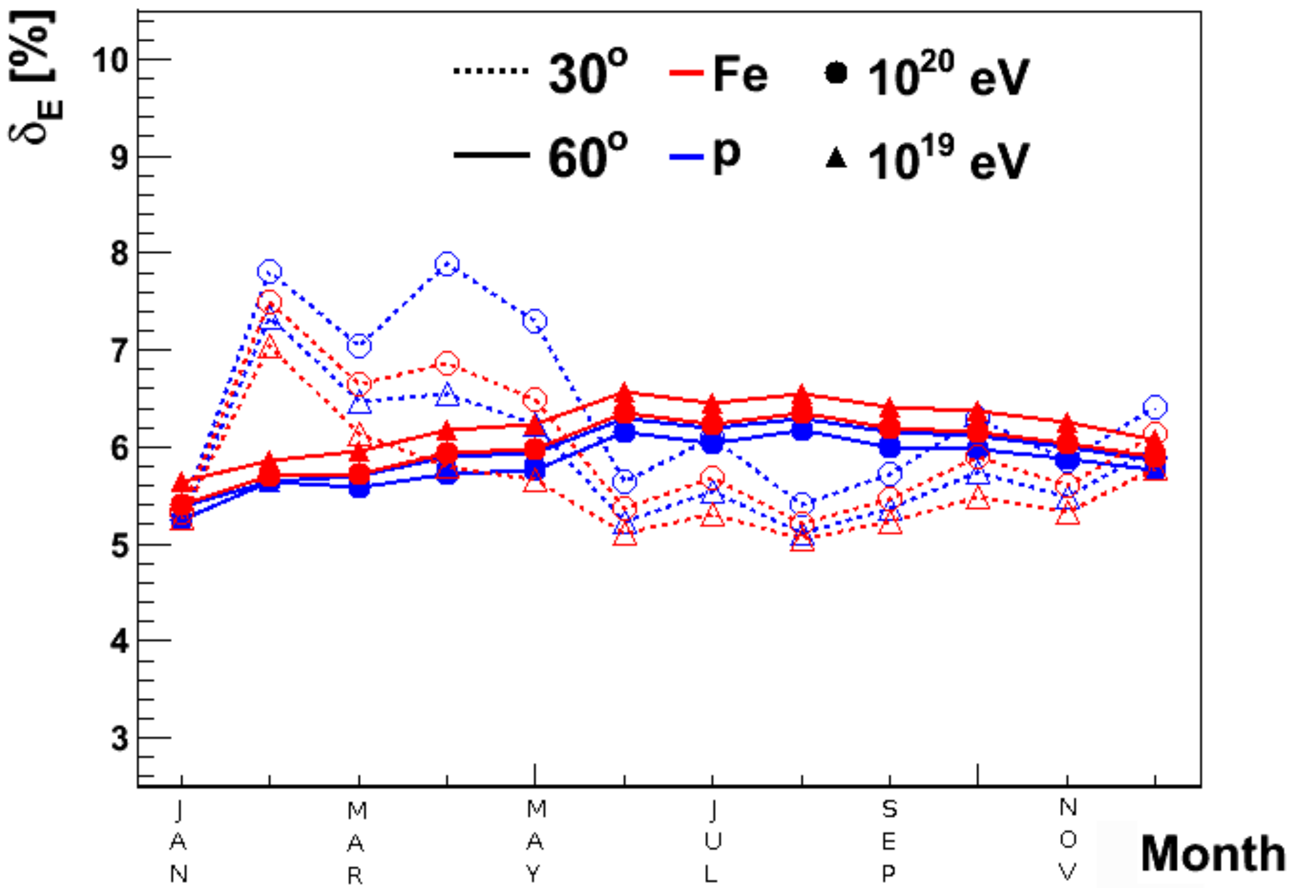
EFFECT OF UNCERTAINTIES

Effect of uncertainties in quenching parameters

- α and P'_w are difficult to measure and its uncertainties are still very large.

- To explore the effect of this uncertainties we have repeated the calculations increasing (decreasing) α values 50% and P'_w values 20%

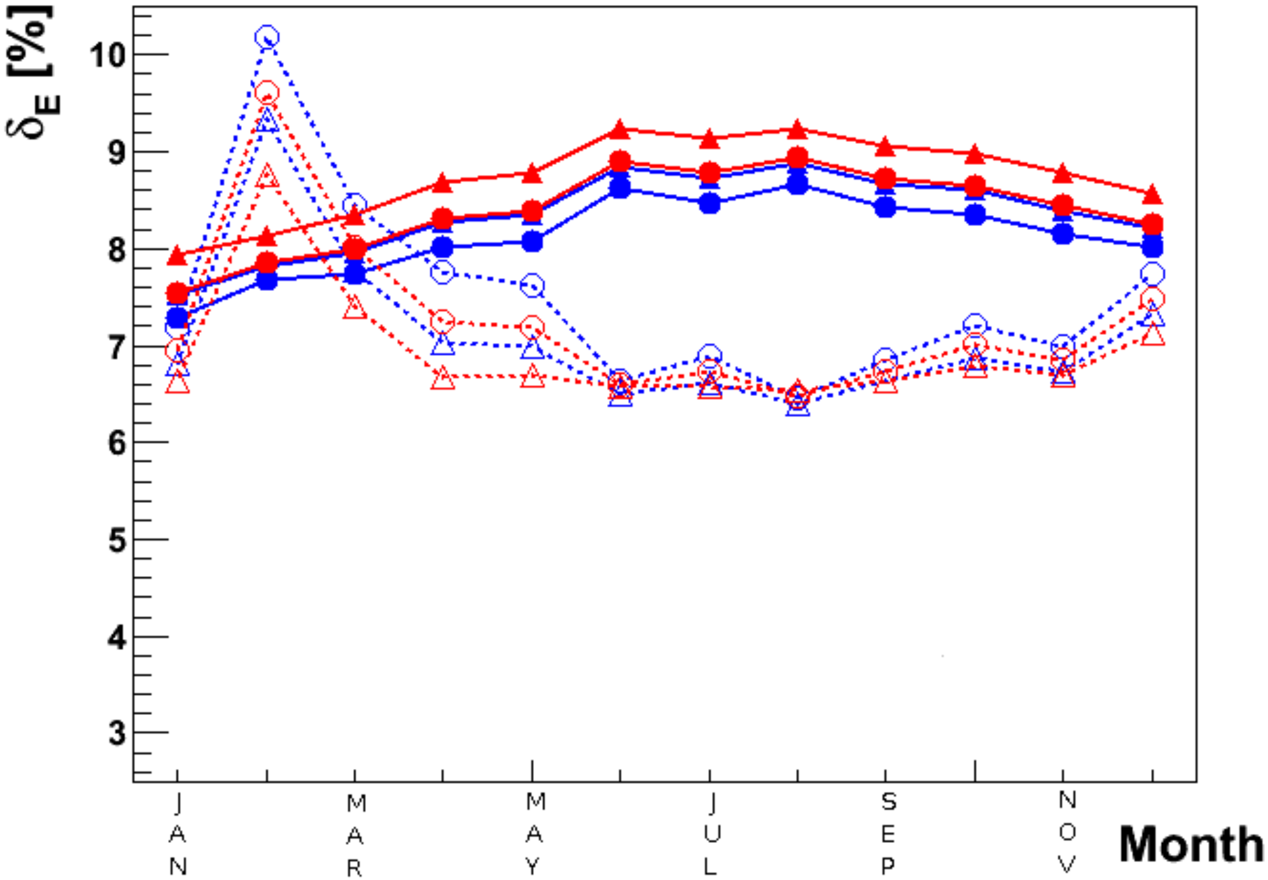
Effect of uncertainties in quenching parameters



α

P'_w

Effect of uncertainties in quenching parameters

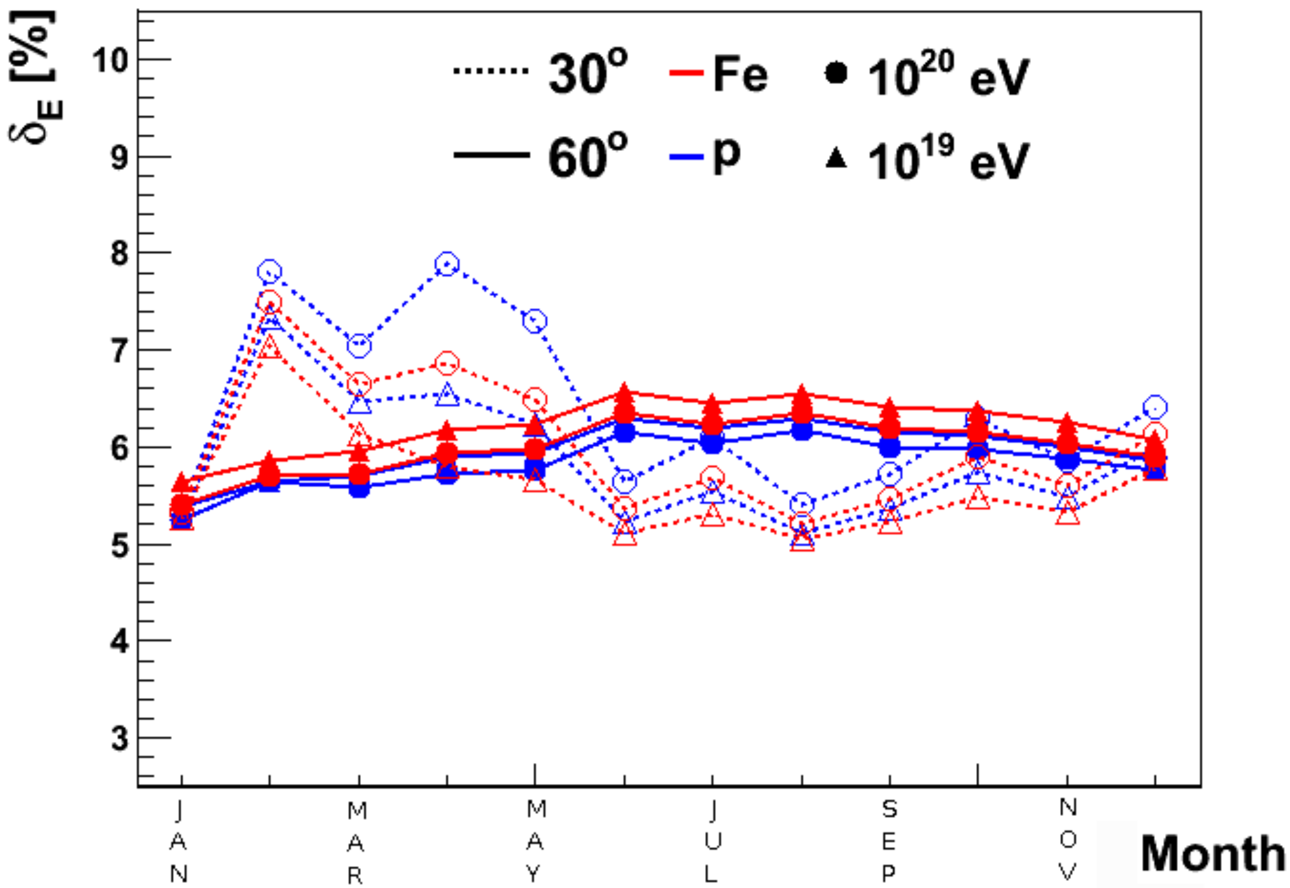


1.5 α

0.8 P'_w

Only 2% increase

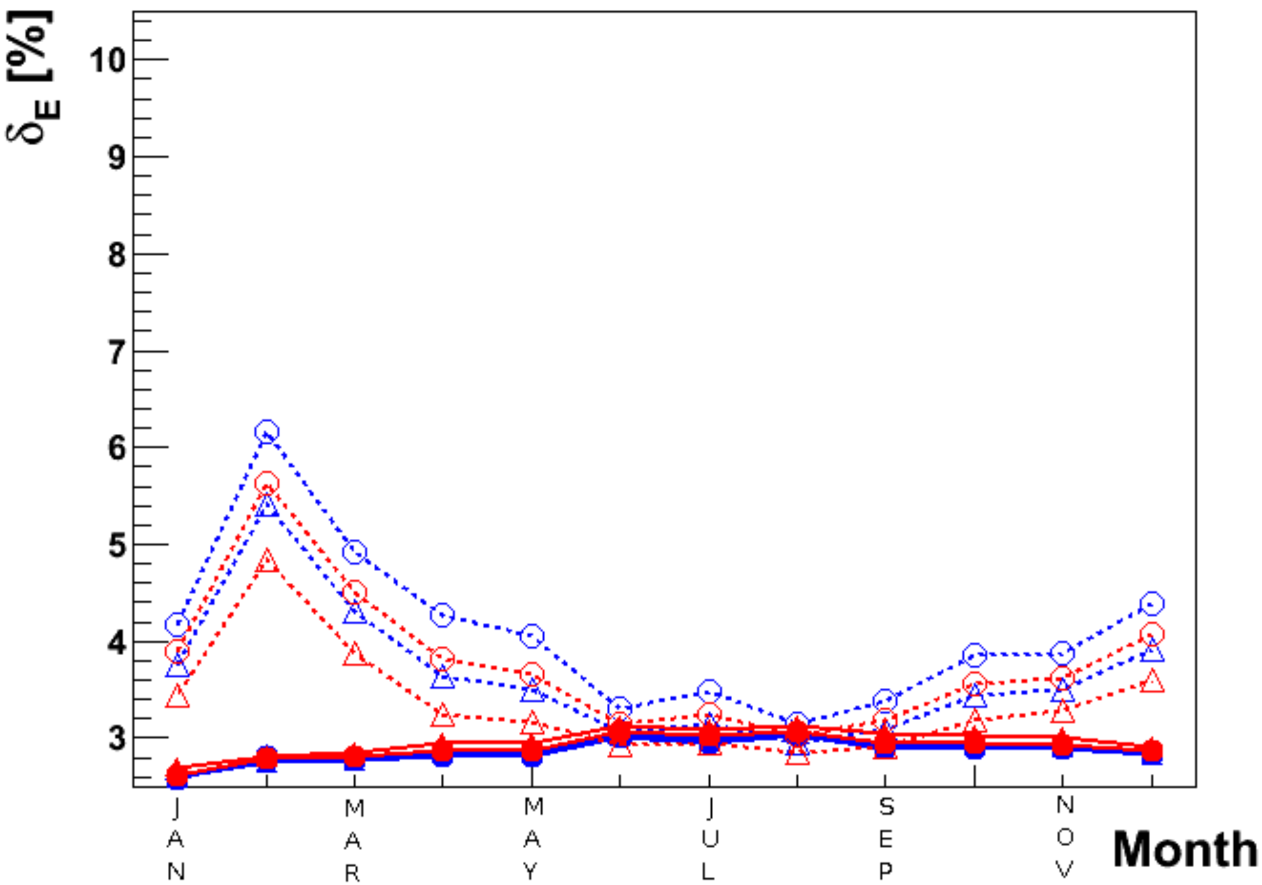
Effect of uncertainties in quenching parameters



α

P'_w

Effect of uncertainties in quenching parameters

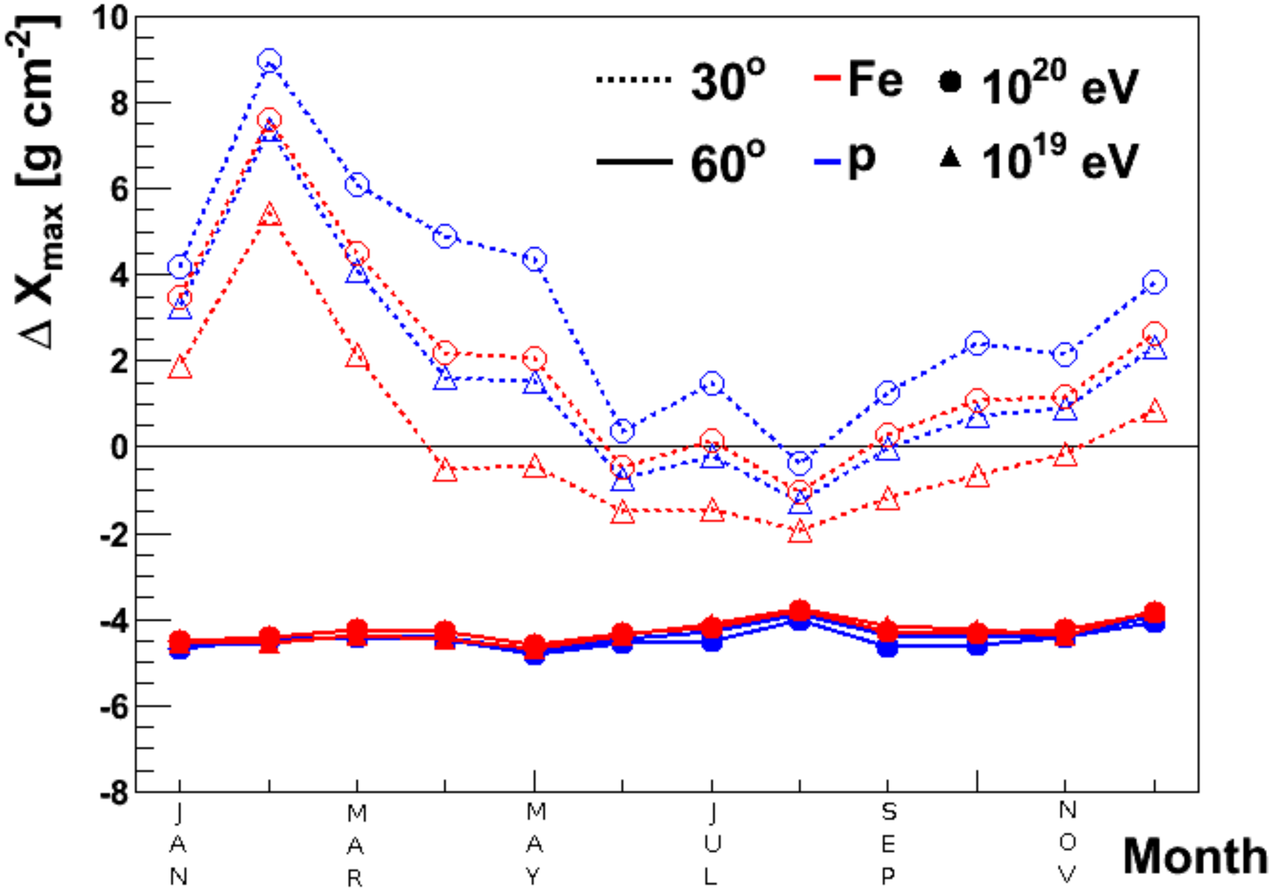


0.5 α

1.2 P'_w

Only 2% decrease

Effect of uncertainties in quenching parameters

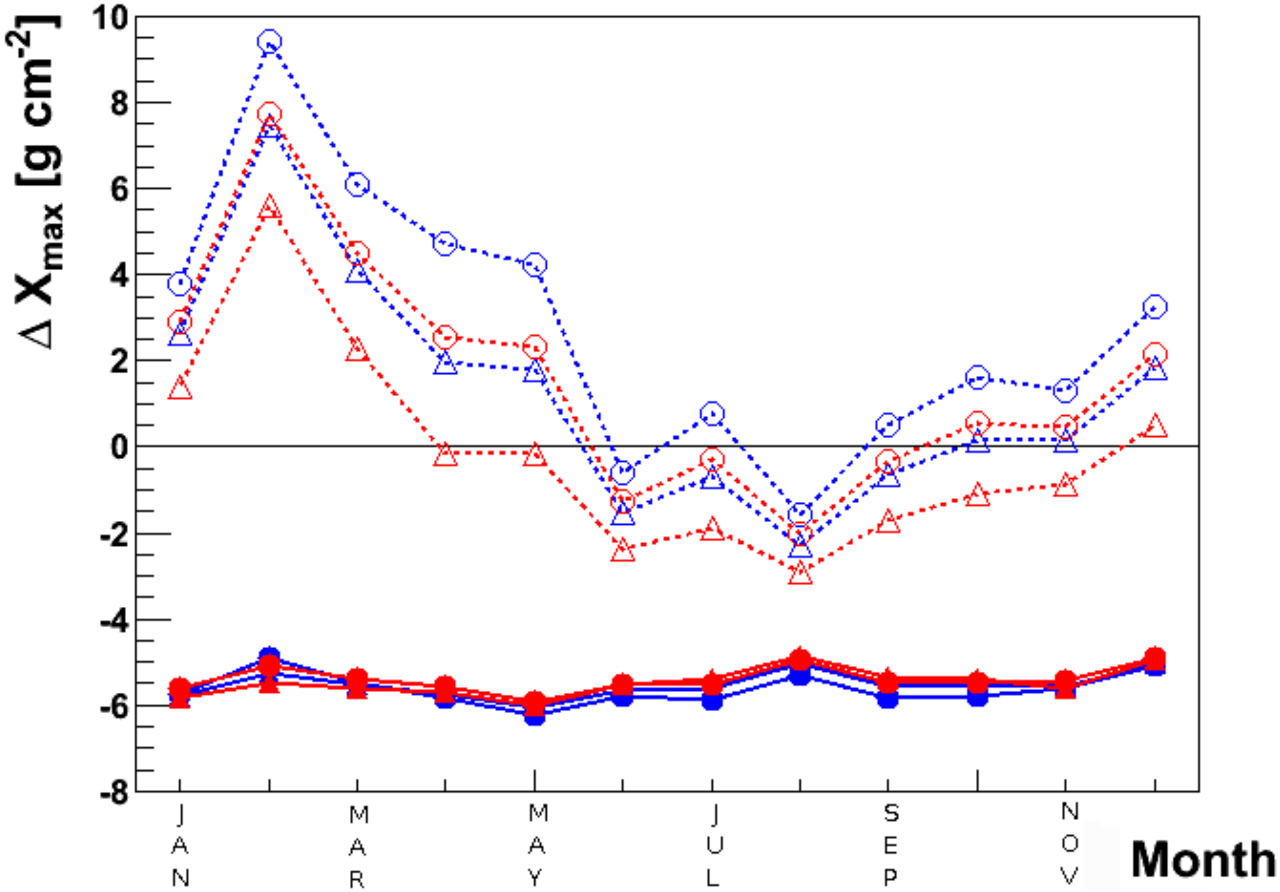


α

P'_w

Same for X_{max}

Effect of uncertainties in quenching parameters

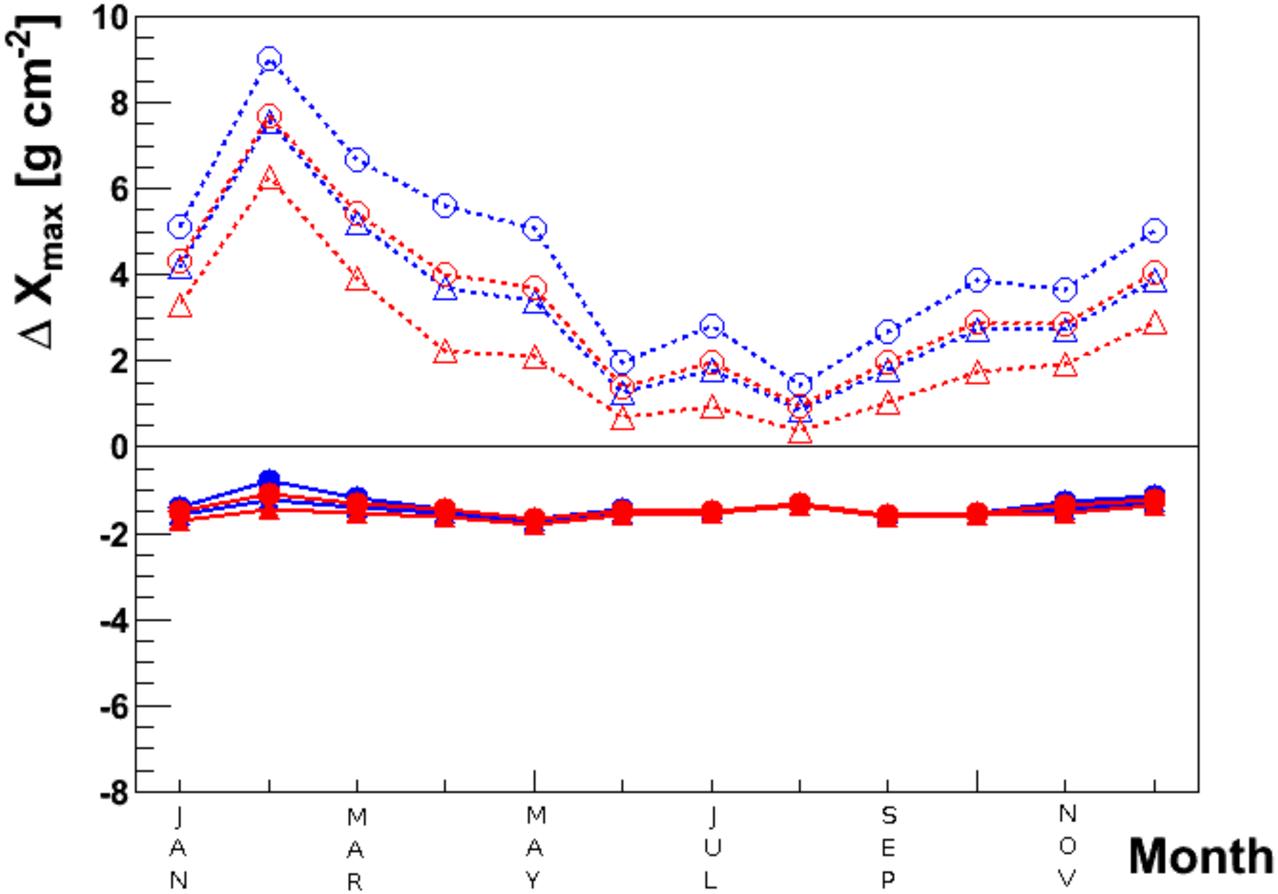


$1.5\ \alpha$

$0.8\ P'_w$

Only up to $2\ g \cdot cm^{-2}$ variation

Effect of uncertainties in quenching parameters



$0.5\ \alpha$

$1.2\ P'_w$

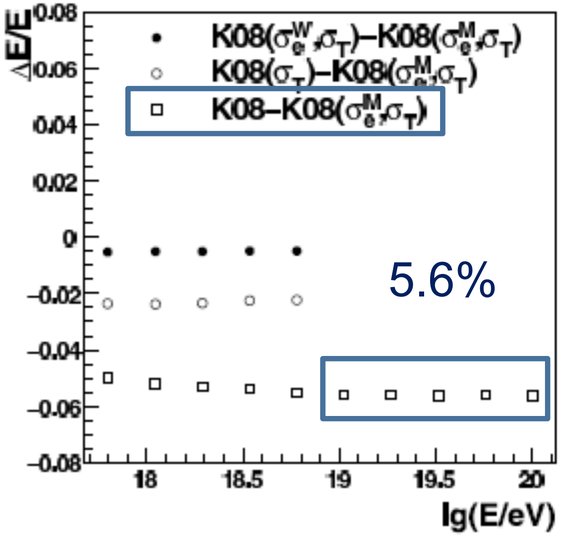
Only up to $2\ g{\cdot}cm^{-2}$ variation

Large uncertainties in α and P'_w do not translate to the reconstructed shower parameters

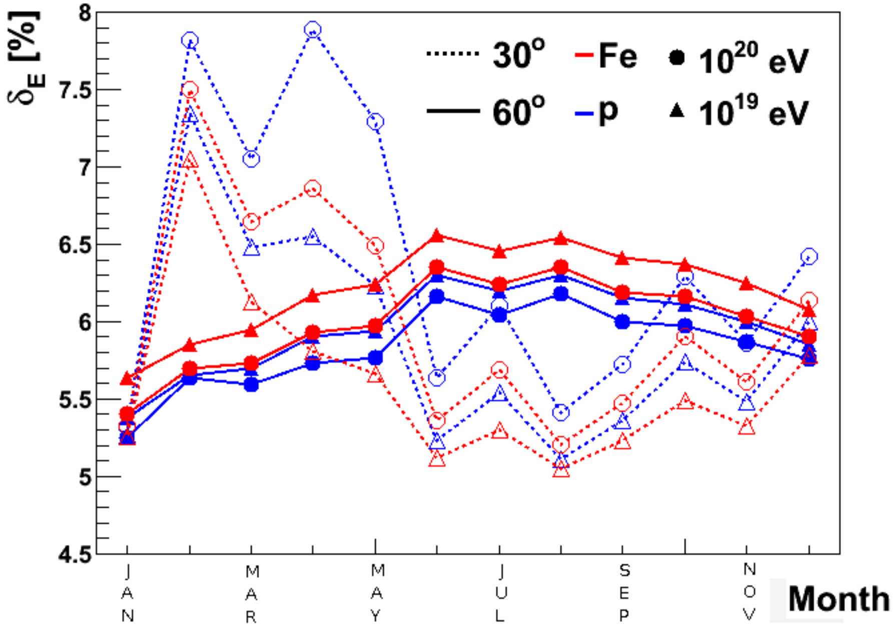
CROSS-CHECKS

Comparison with previous results on δE

B. Keilhauer and M. Unger
31st ICRC



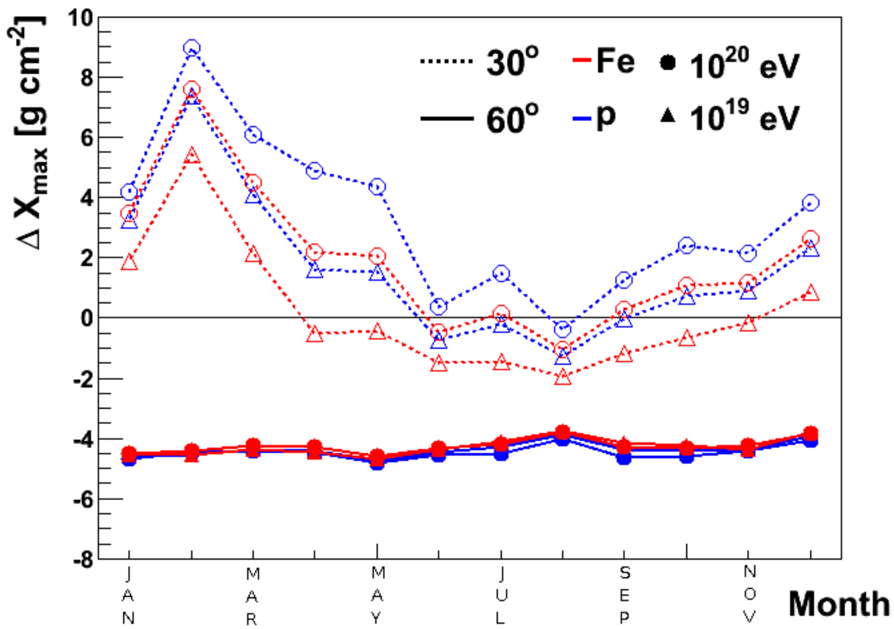
MC Sample

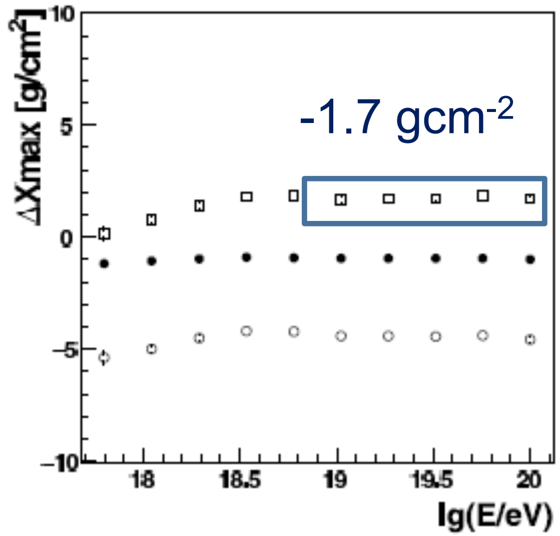


Reasonable agreement with detailed reconstruction

Comparison with previous results on ΔX_{max}

B. Keilhauer and M. Unger
31st ICRC

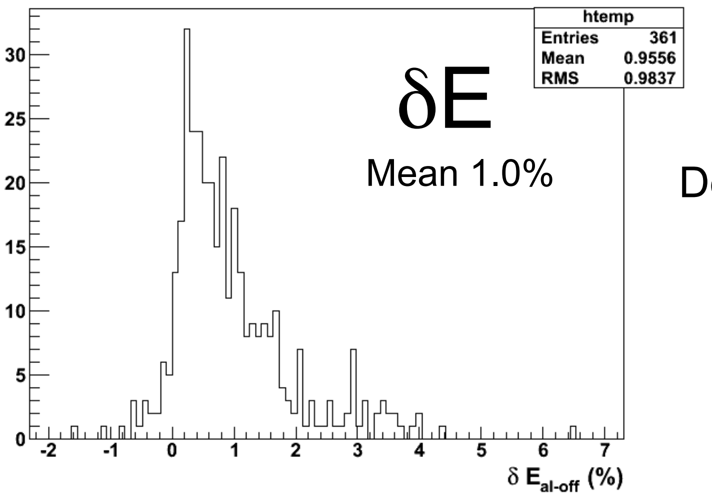


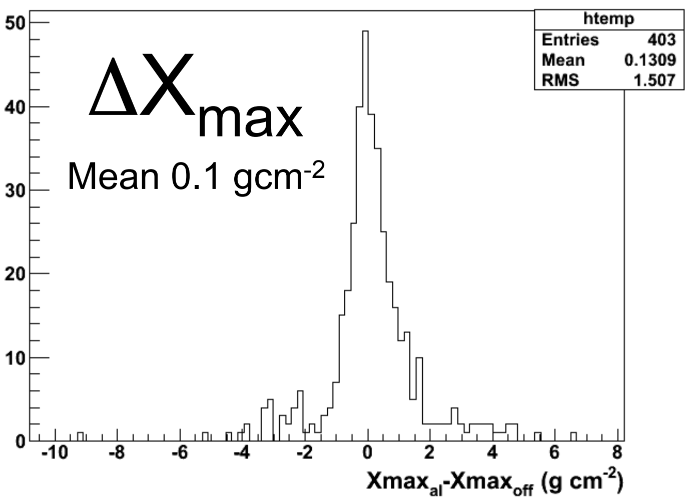


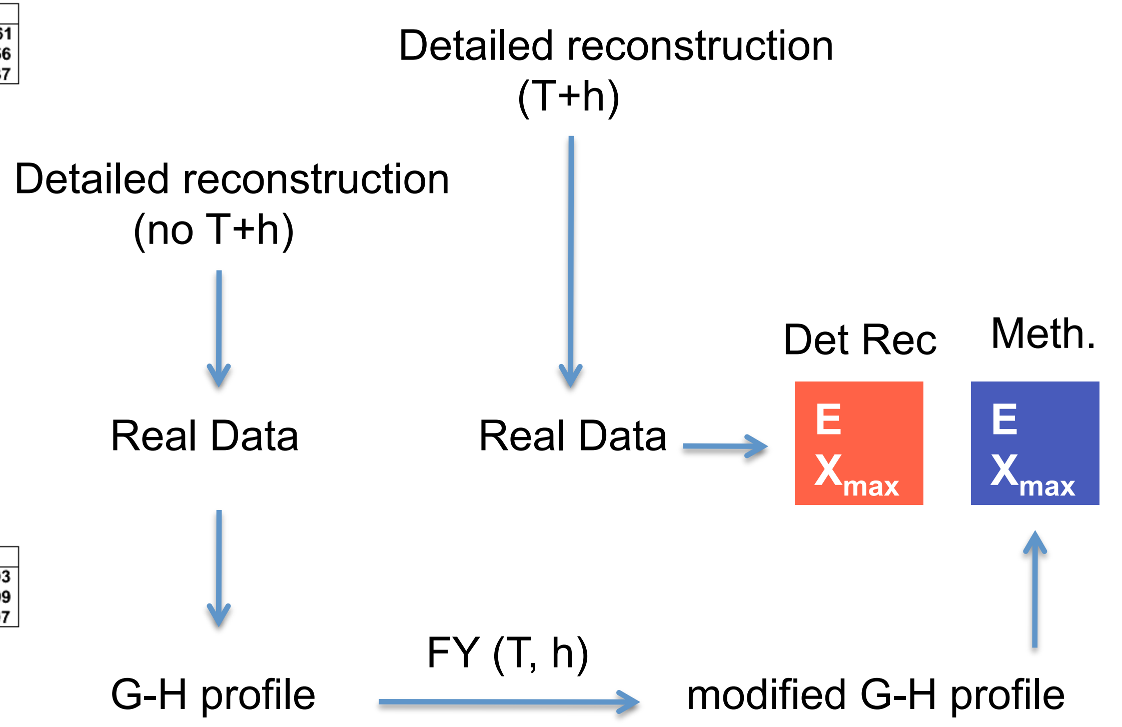
MC Sample

Reasonable agreement with detailed reconstruction

Simple cross-check with real data







Det Rec results in agreement with our simple analythical method (within 1 % percent in E and 0.1 g cm^{-2} in Xmax)

COMMENTS
&
CONCLUSIONS

Some comments on these calculations

- In a real case only a fraction of the longitudinal development is available for the reconstruction. We have recalculated the modified profile using typical intervals $X_1 – X_2$ (field of view of the FD in real showers). No significant effects have been found.

- Cherenkov light information is not taken into account in this simple model. The effect of neglecting this is not yet studied, but could explain this small discrepancies on δE.

Conclusions

- A simple analytical procedure for the evaluation of the effect of changing the FY dataset on the reconstructed energy and X_{max} has been developed
- Effect of dataset choice (K-B, Nagano, N-A) almost negligible
- Effect of neglecting h and T on E and X_{max} reconstruction strongly dependent on shower geometry.
- Large uncertainties in α and P'_w do not translate to the reconstructed shower parameters
- On average, reasonable agreement with detailed reconstruction.

THANKS

Detector efficiency and atmospheric transmission

The number of observed fluorescence photons depends on detector efficiency ε_λ and air transmission T_λ (X,X_0) (including both molecular and aerosol effects).