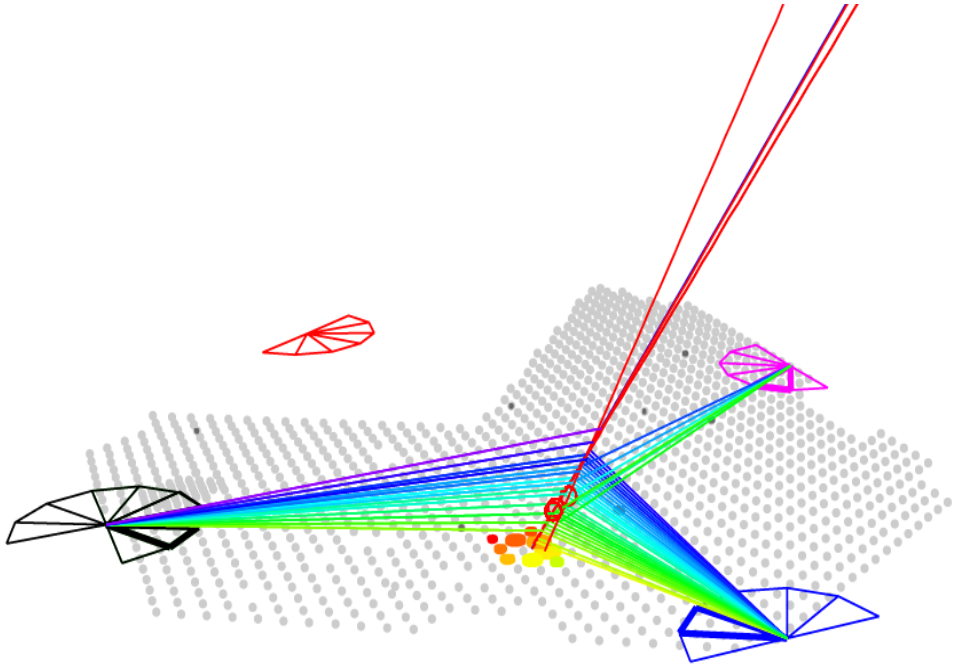
Electromagnetic and muonic cosmic ray shower profiles

Francisco Diogo
on behalf of the Auger Group at LIP

23^{rd} April 2012

Extensive air showers



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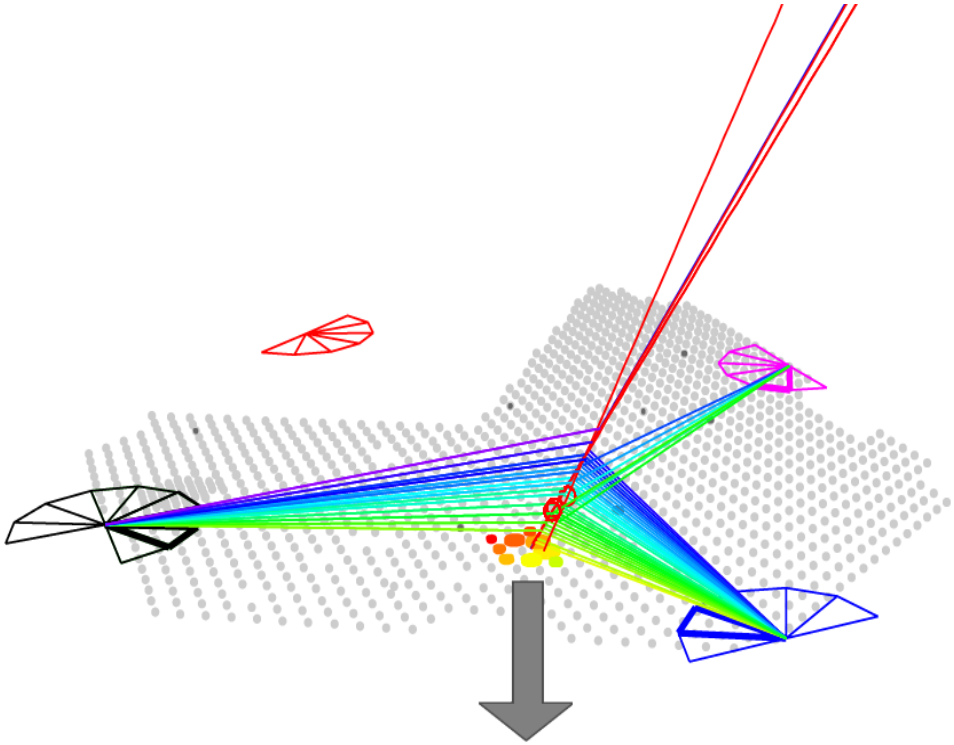

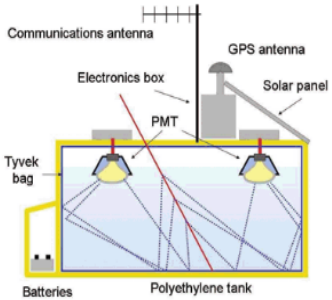

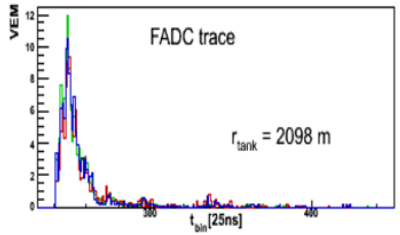

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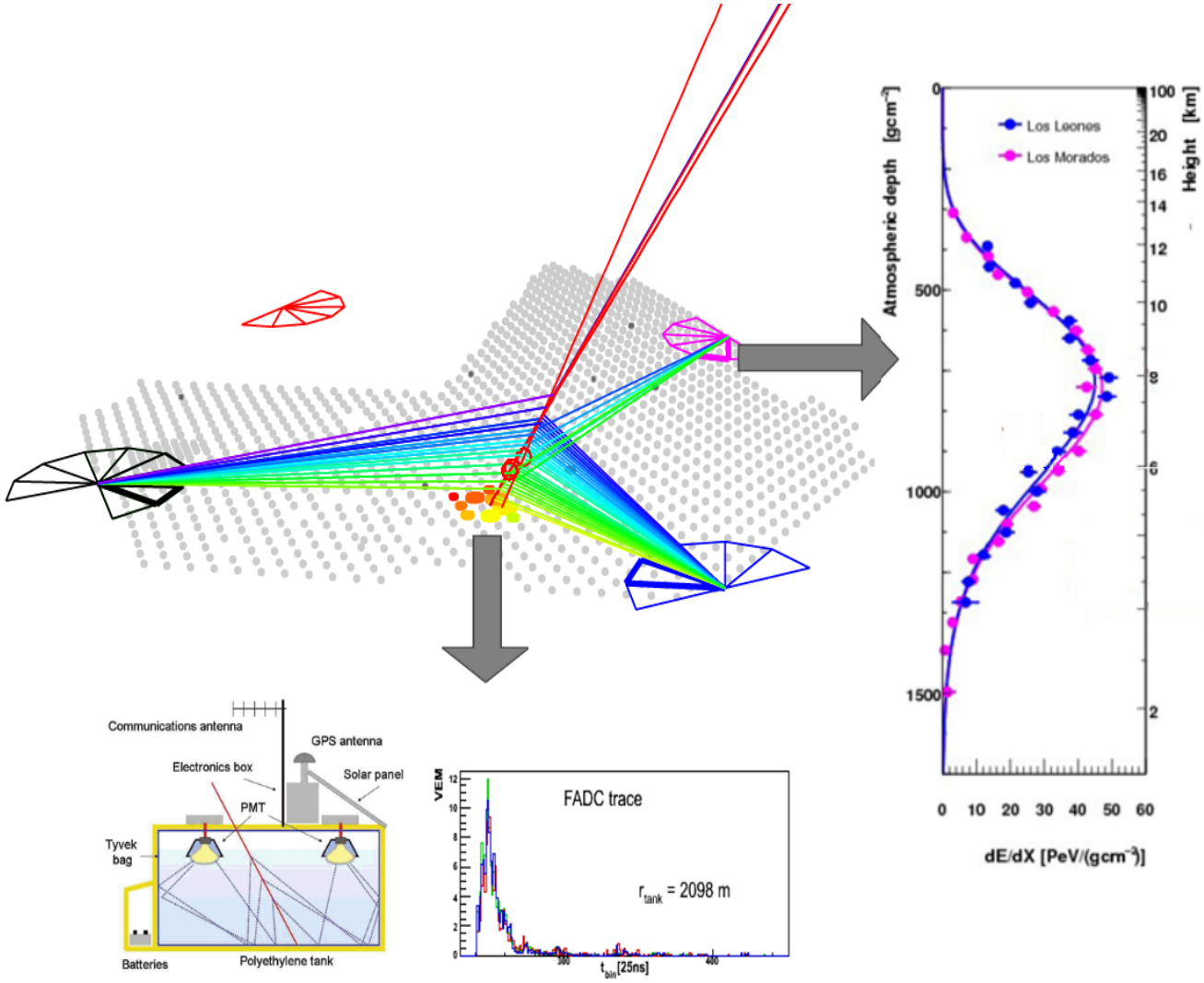

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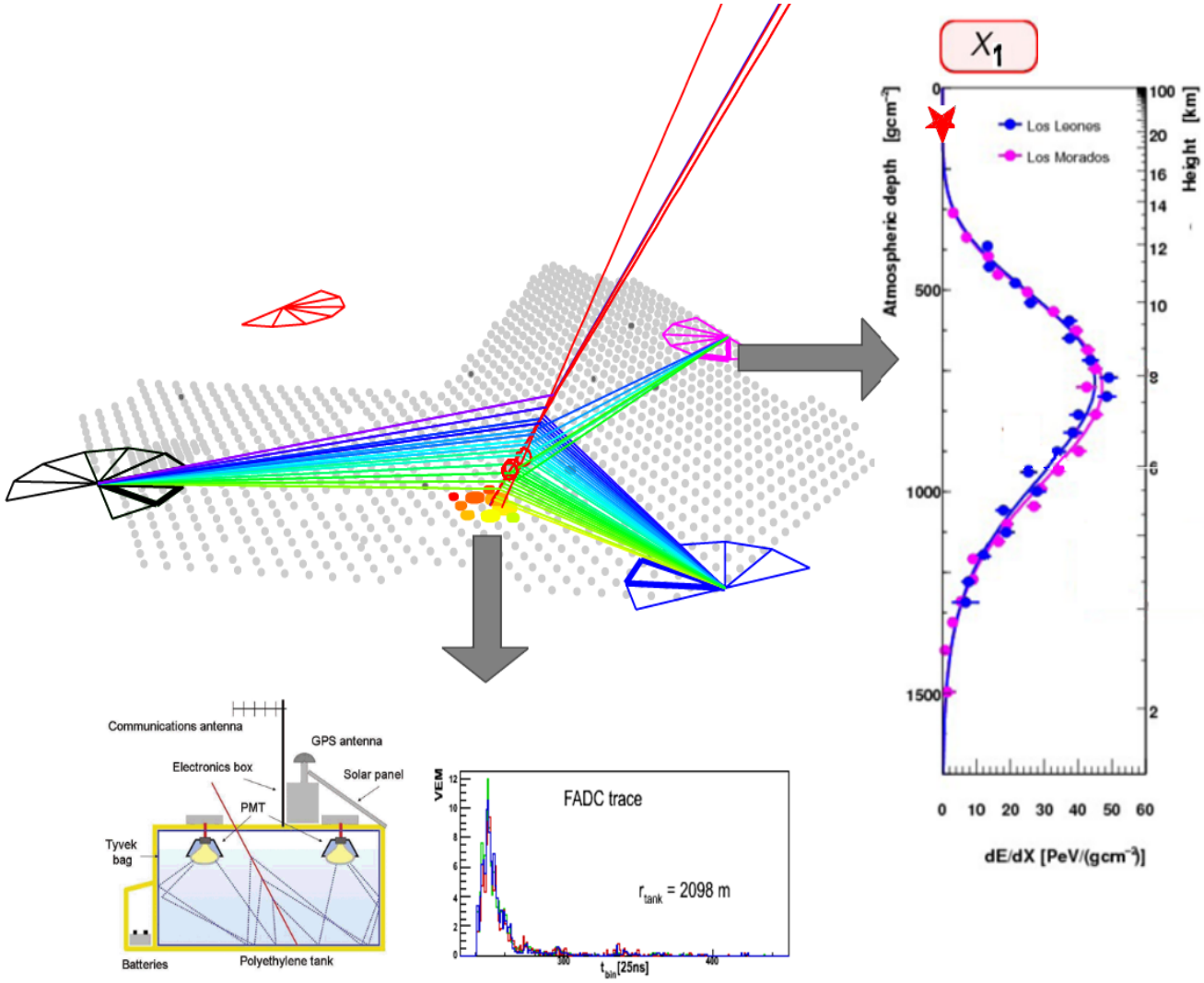

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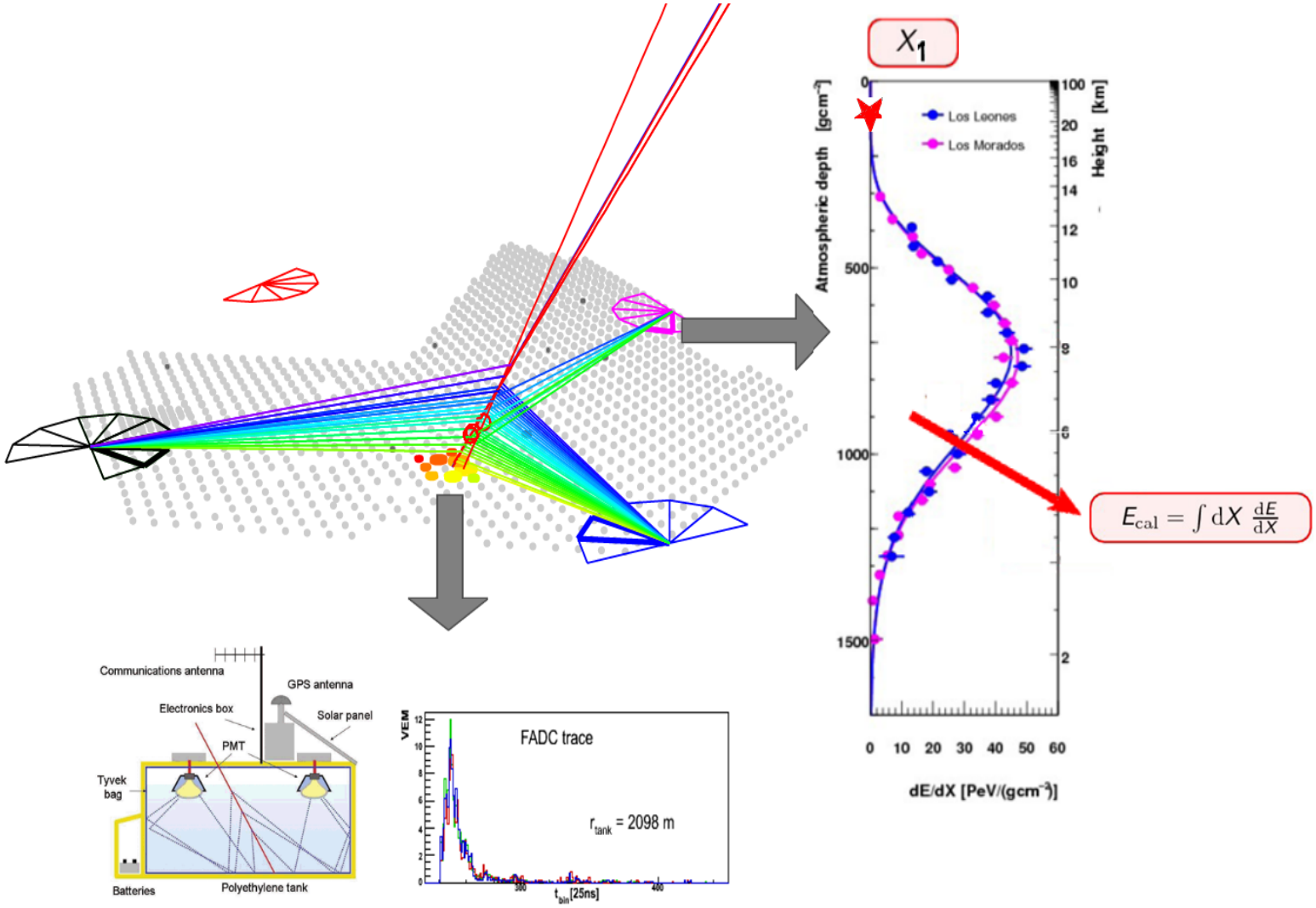

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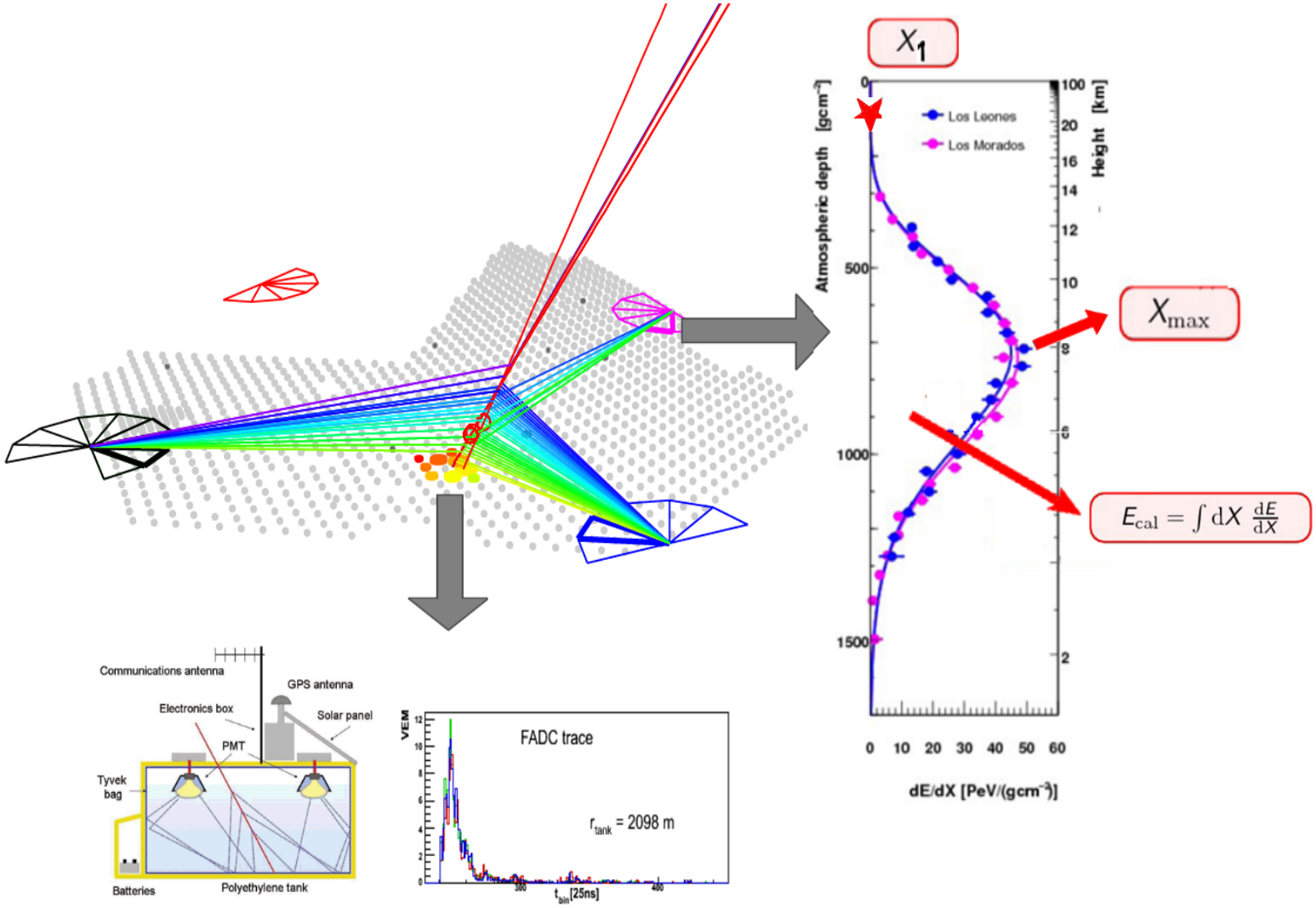
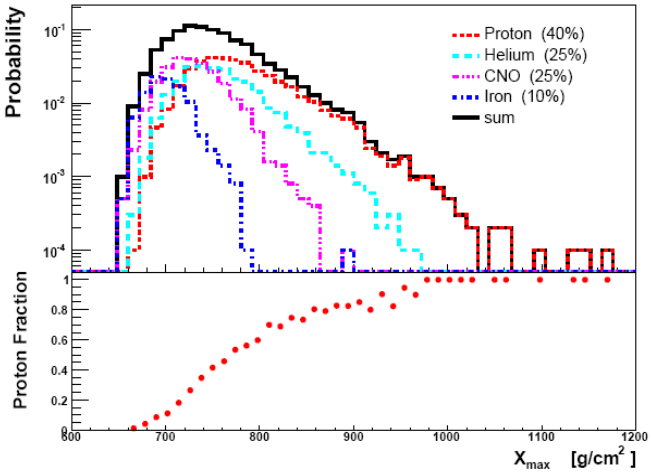


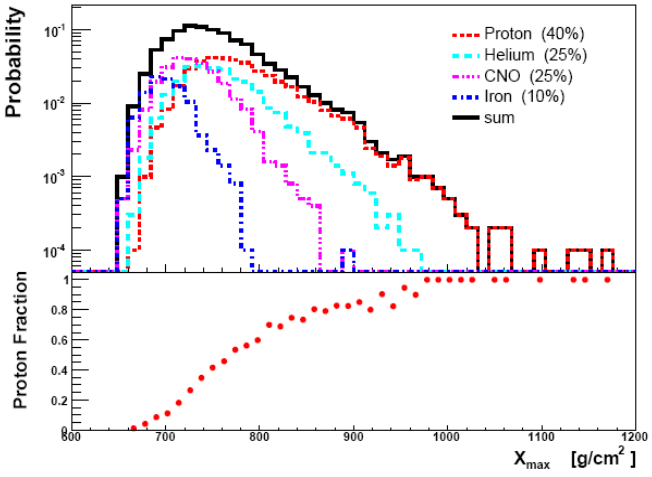
Electromagnetic Longitudinal Profile - X_{max}

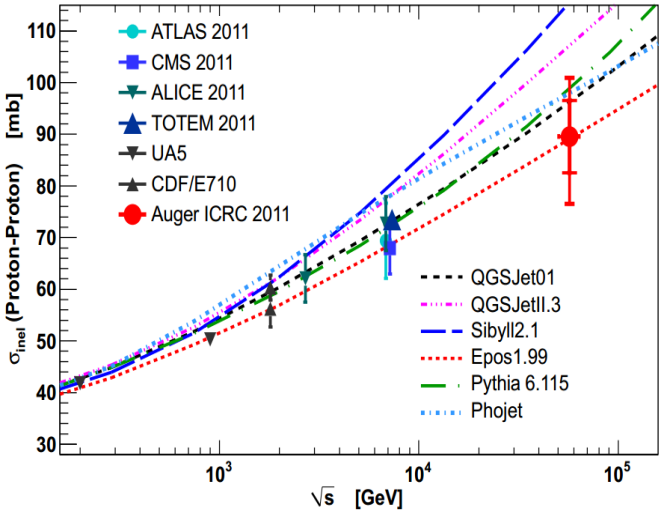


The electromagnetic longitudinal profile is a very powerful analysis tool, and its main variable is X_{max}:

- sensitive to the mass of the primary particle

Electromagnetic Longitudinal Profile - X_{max}

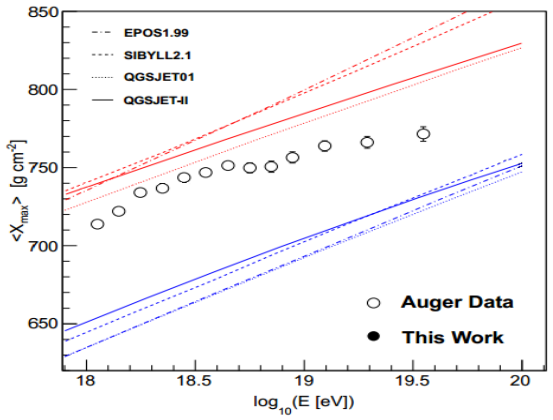


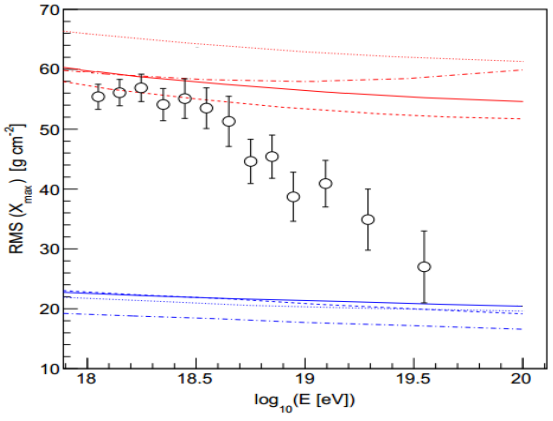


The electromagnetic longitudinal profile is a very powerful analysis tool, and its main variable is X_{max}:

- sensitive to the mass of the primary particle
- the $X_{max} = X_1 + \Delta$ distribution tail is dominated by showers with large X_1 - proton-Air inelastic cross-section measurement
- Particle physics at energies greater than LHC

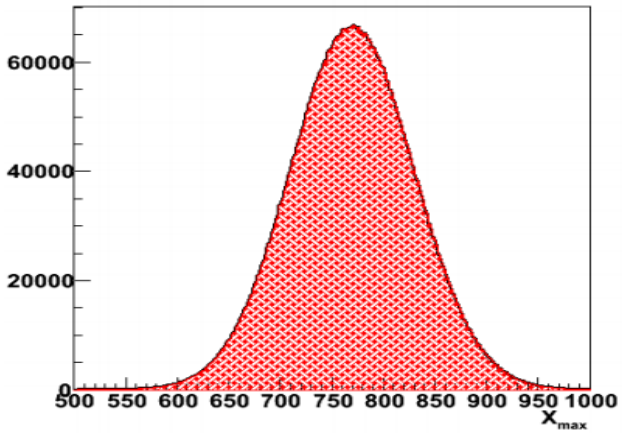
X_{max} and $RMS(X_{max})$ joint interpretation

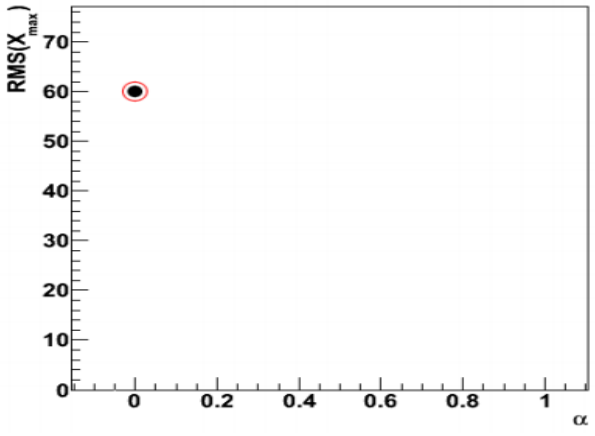




X_{max} and $RMS(X_{max})$ joint interpretation

Transition from proton to iron at highest energies, α=iron percentage





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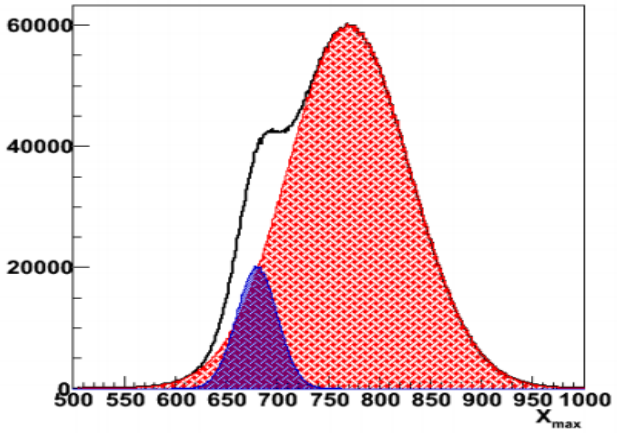

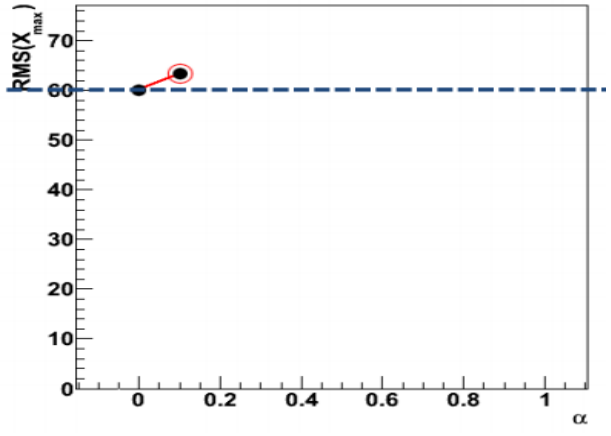

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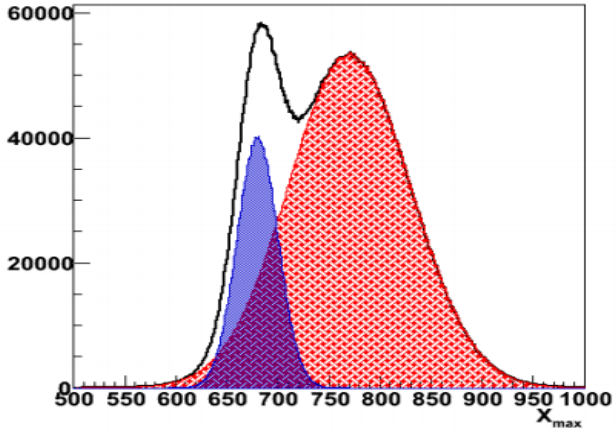

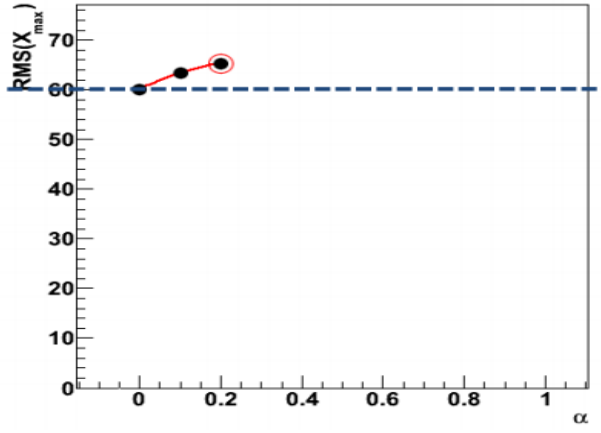

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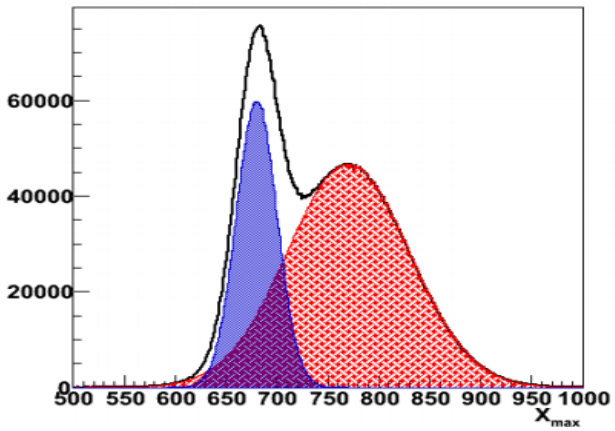

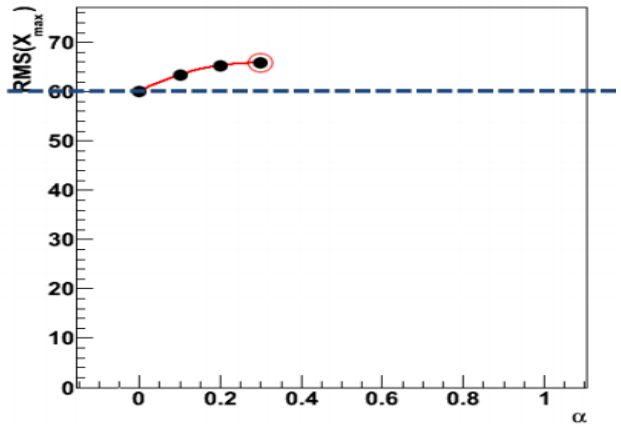

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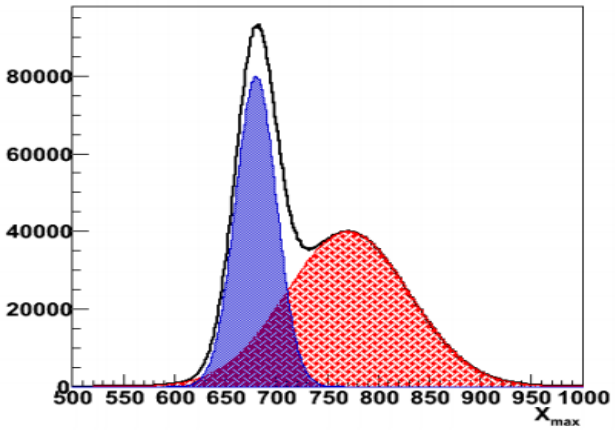

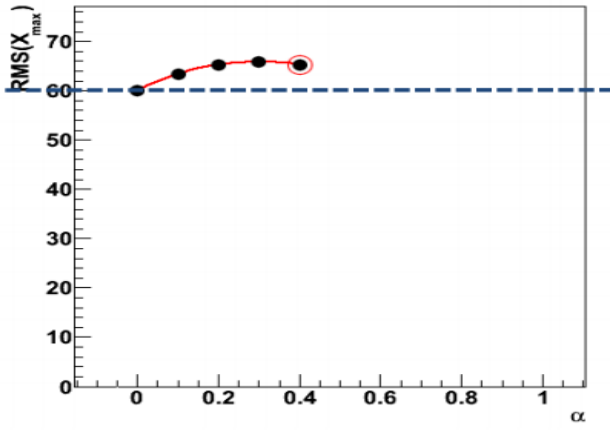

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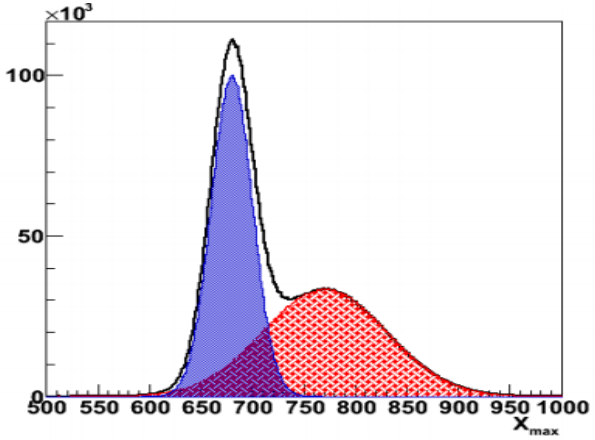

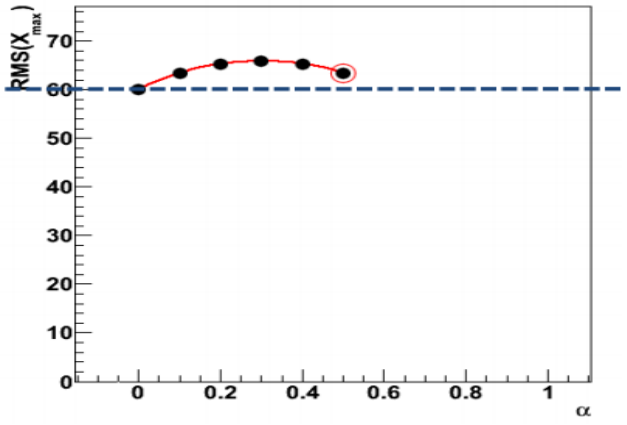

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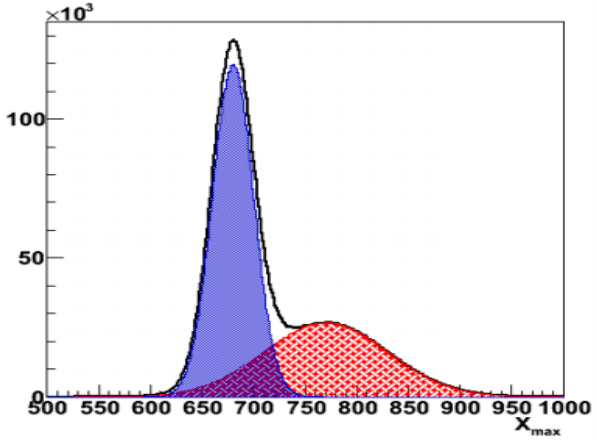

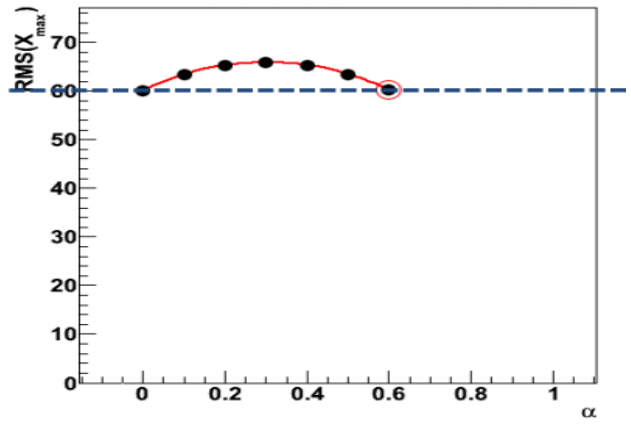

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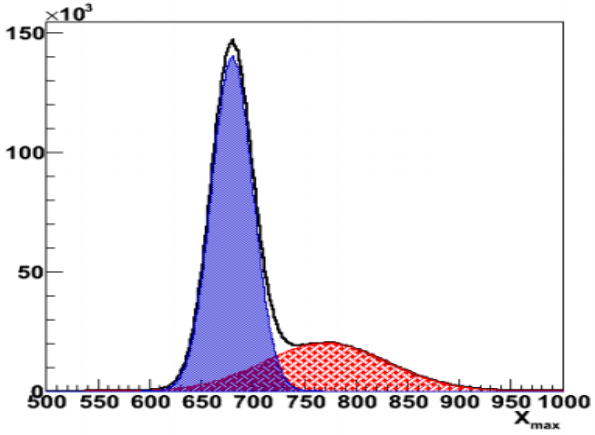

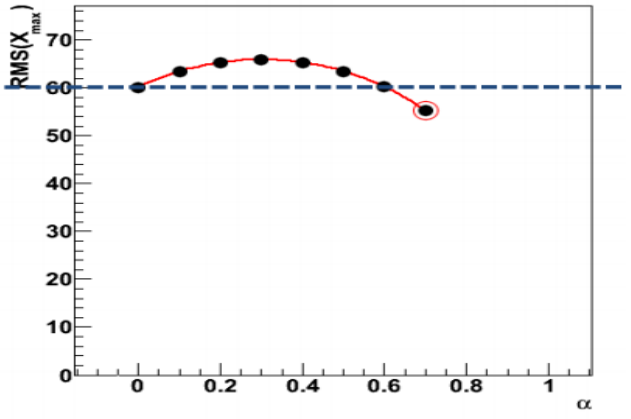

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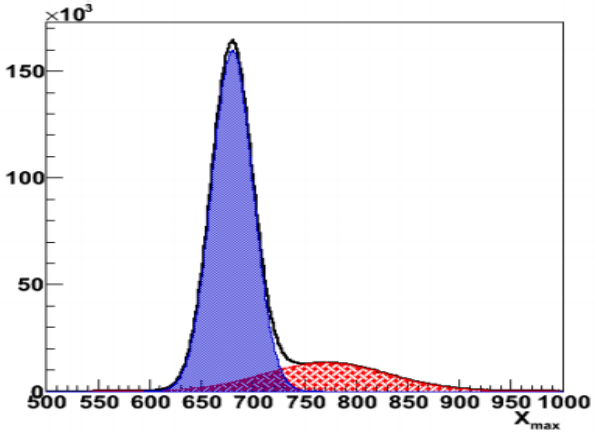

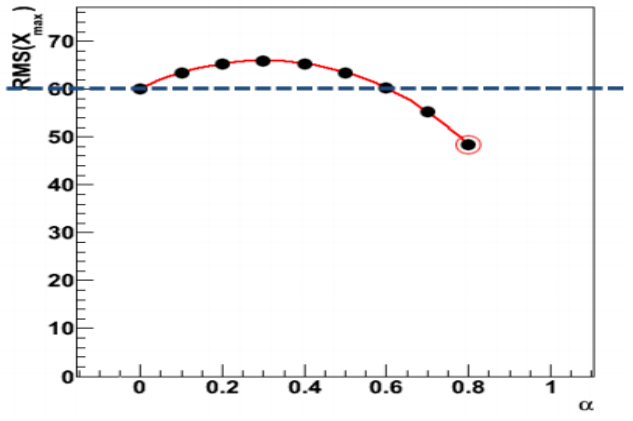

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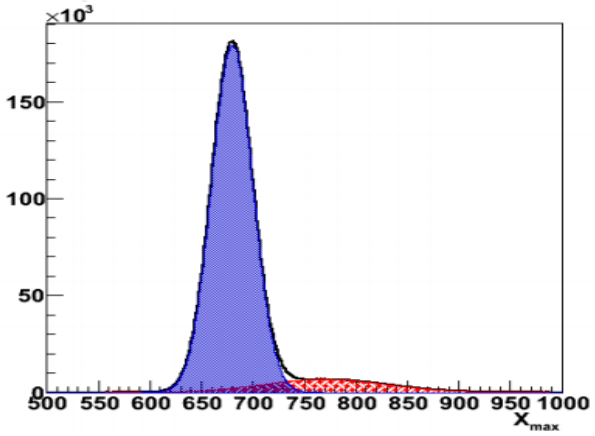

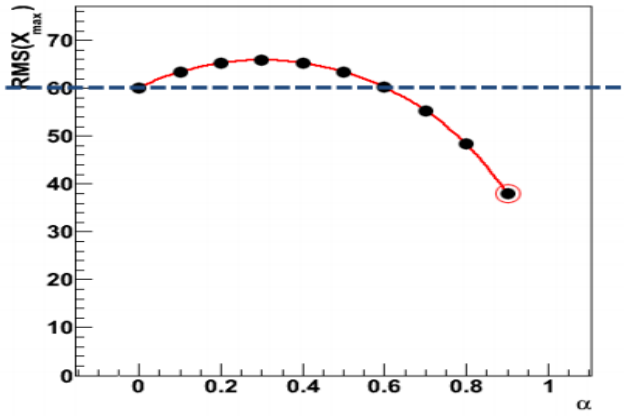

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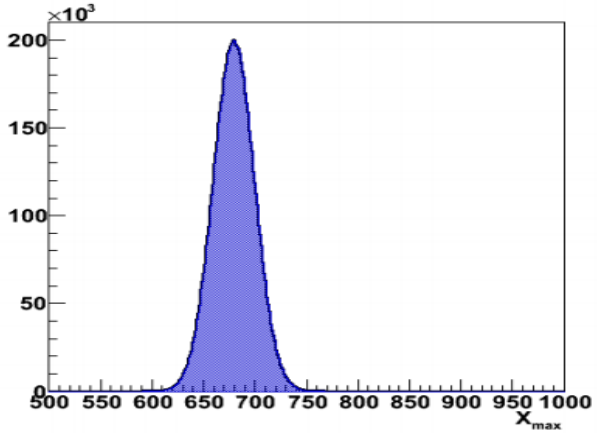

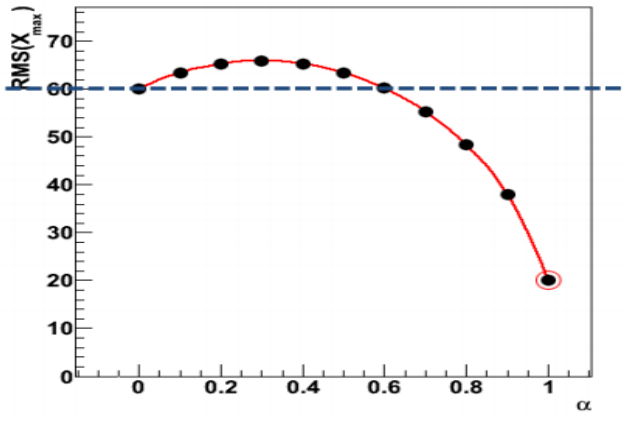

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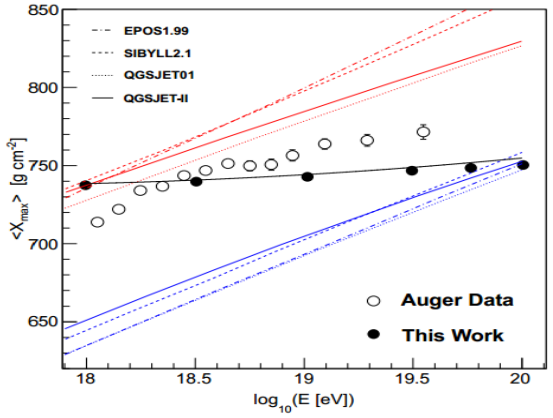

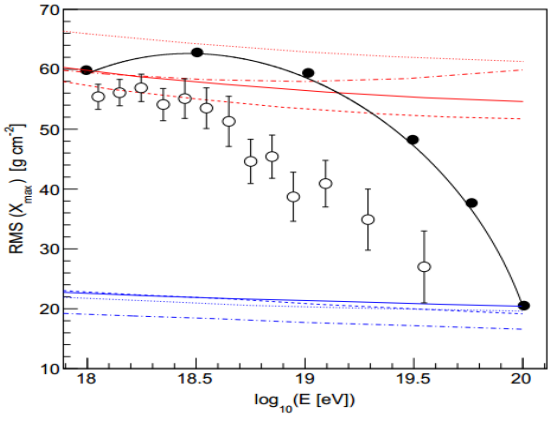

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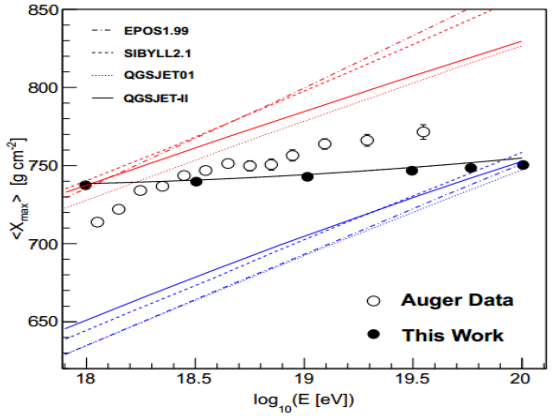
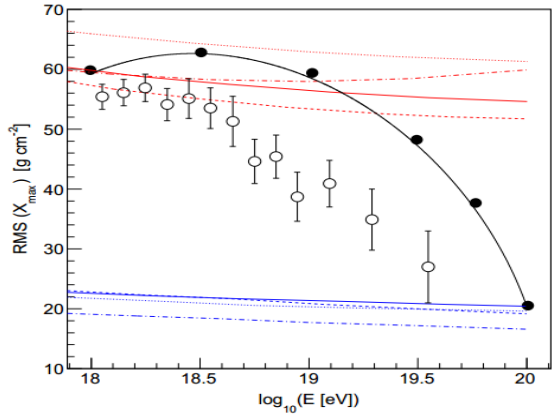
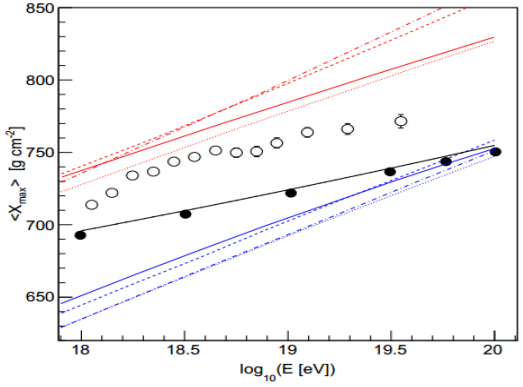
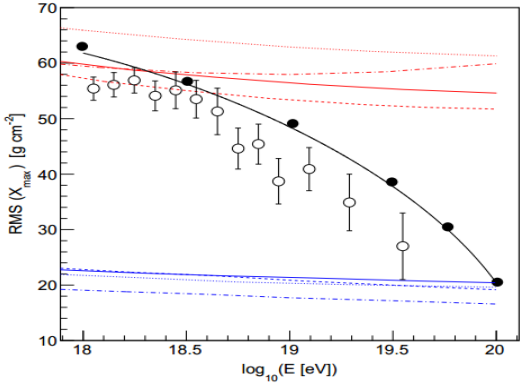




Transition from 50% proton/50% iron





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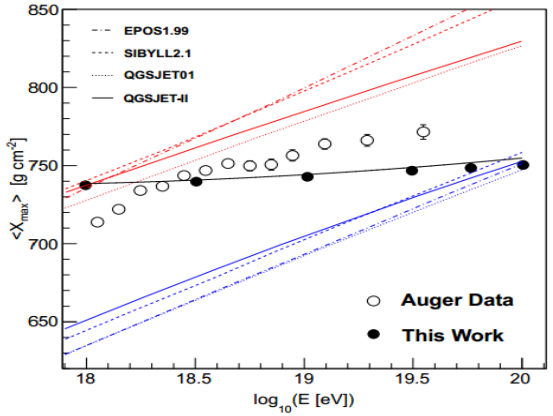

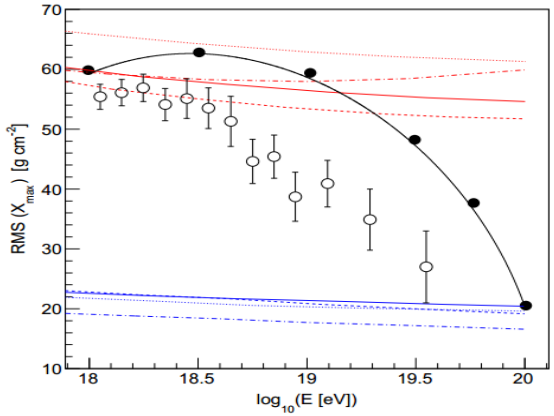

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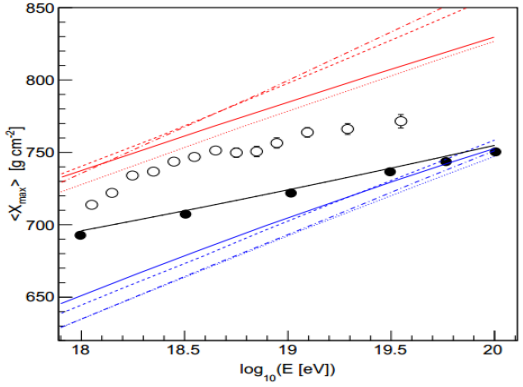
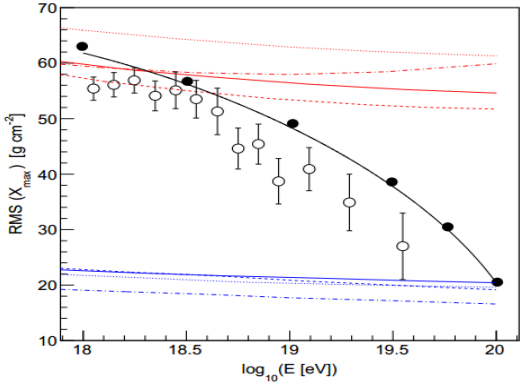
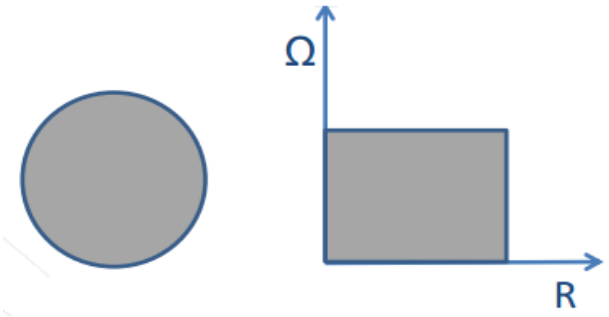


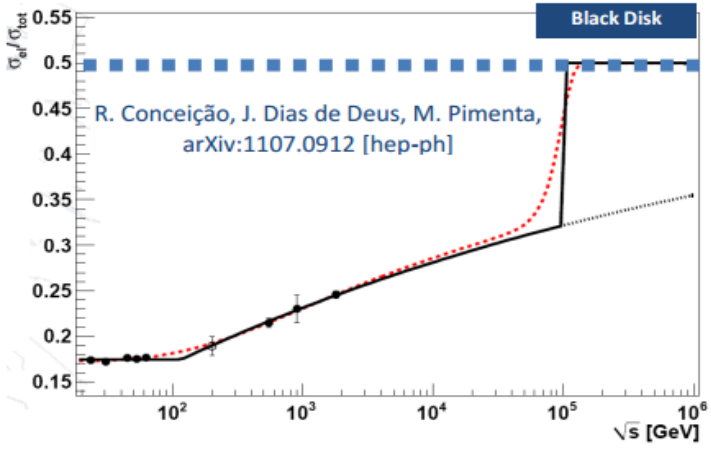


No simple scenario of transition from proton to iron explains data!

Grey Disk Model



$$\frac{\sigma_{el}(s)}{\sigma_{tot}(s)} = \frac{1}{2}\left(1 - e^{-\overline{\Omega}(s)}\right)$$



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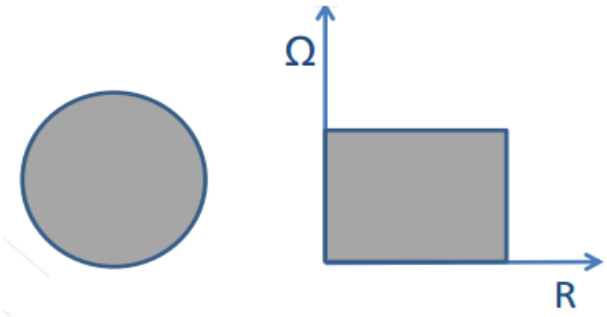

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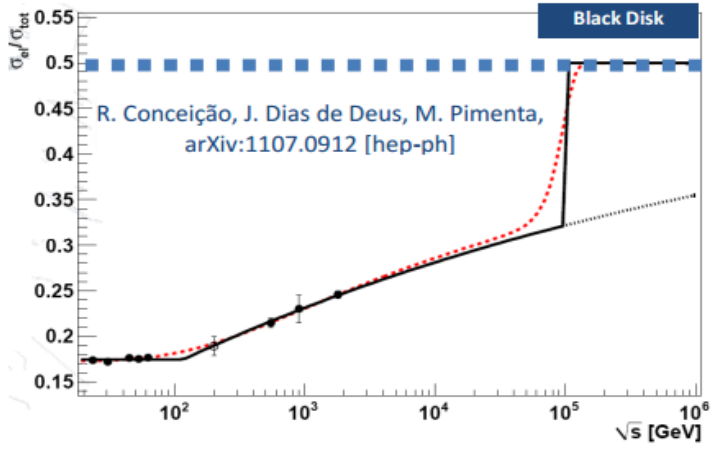
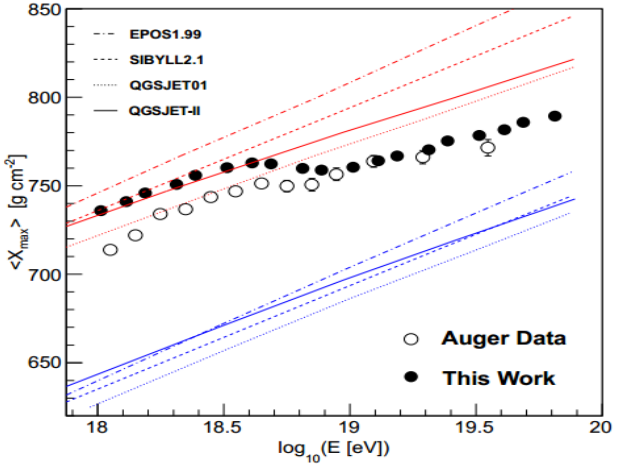
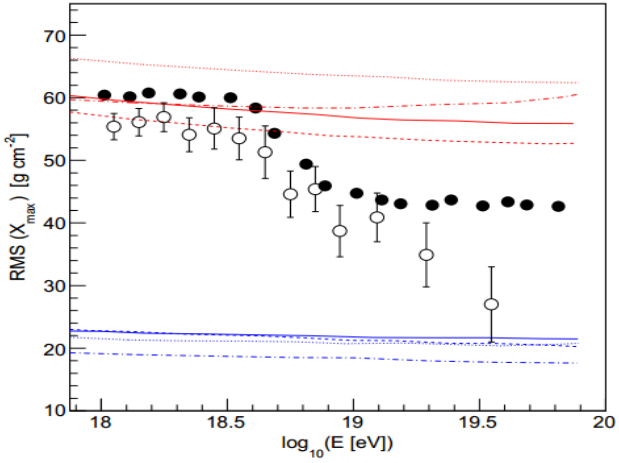


Proton turning into a black disk at 10^{19} eV





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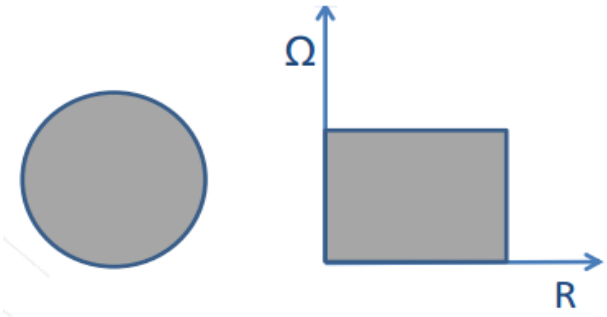

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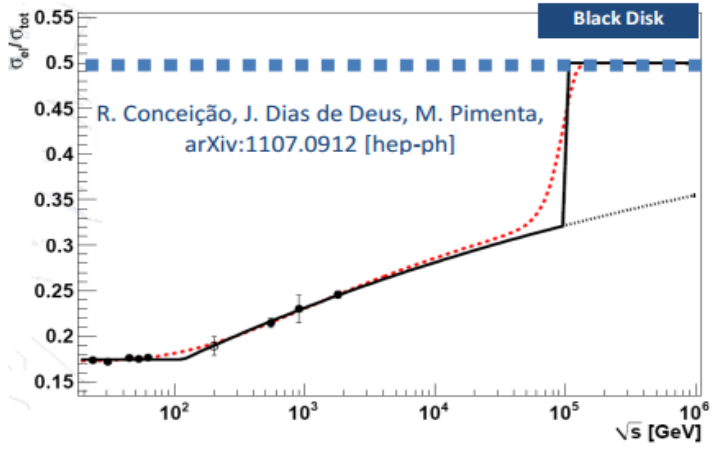

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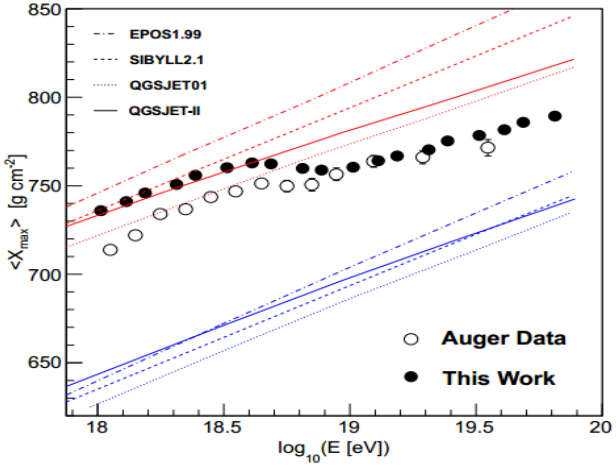
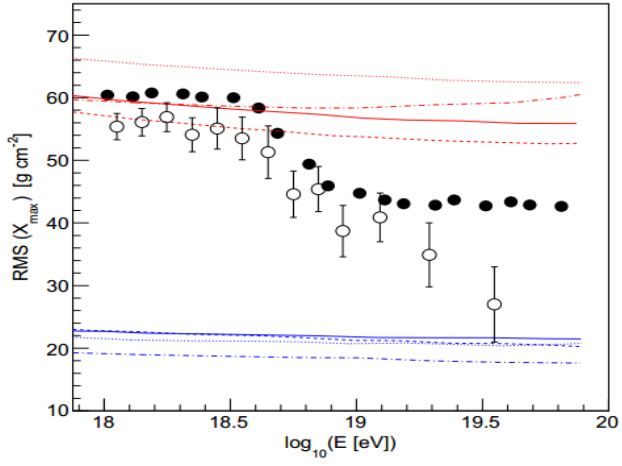
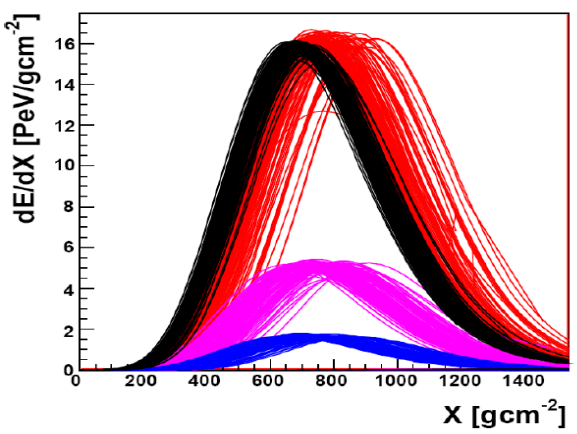
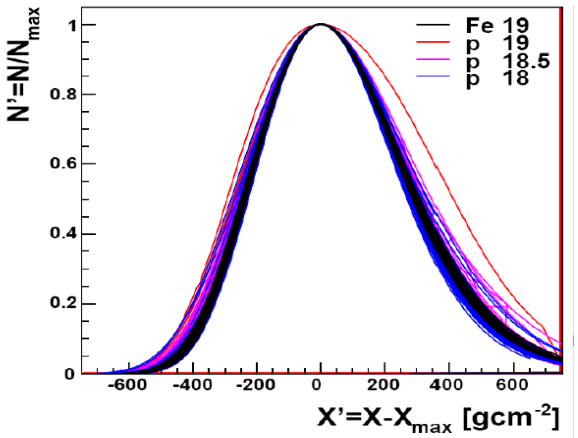




To interpret data we need a better understanding of the first interaction

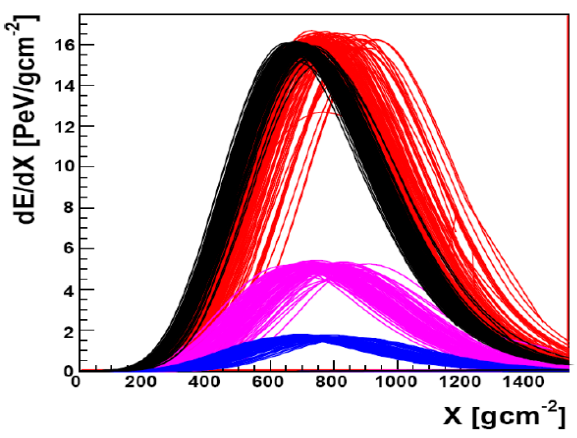
Universal Shower Profile

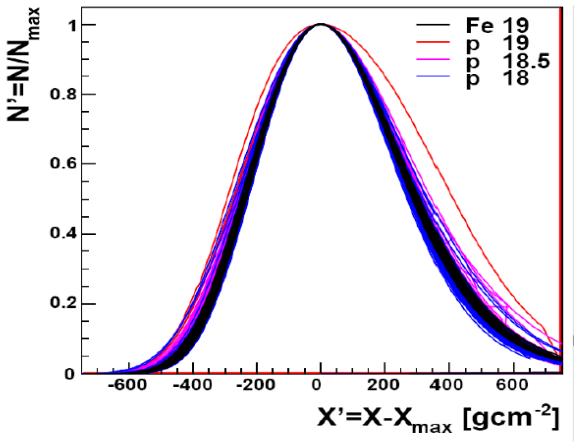




Deconvoluting information from N_{max} and X_{max} the shape of the electromagnetic profile is (almost) universal

Universal Shower Profile

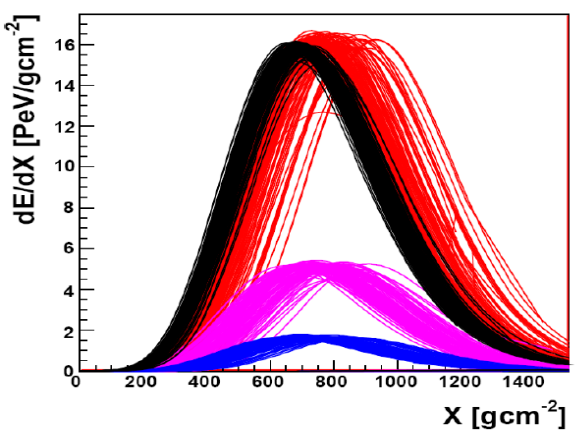


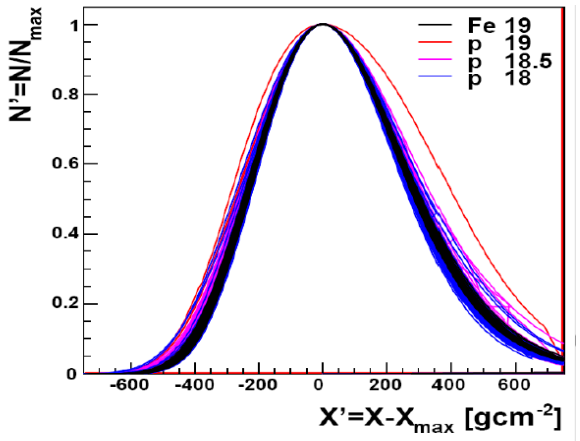


Deconvoluting information from N_{max} and X_{max} the shape of the electromagnetic profile is (almost) universal
In LIP, a new parameterization was introduced, in which the profile assymetry is described by a parameter R'

- is a measure of the shower development speed $\Delta = X_{max} - X_1$
- is independent of X_1
- is sensitive to composition of the primary particle

Universal Shower Profile





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- is a measure of the shower development speed $\Delta = X_{max} - X_1$
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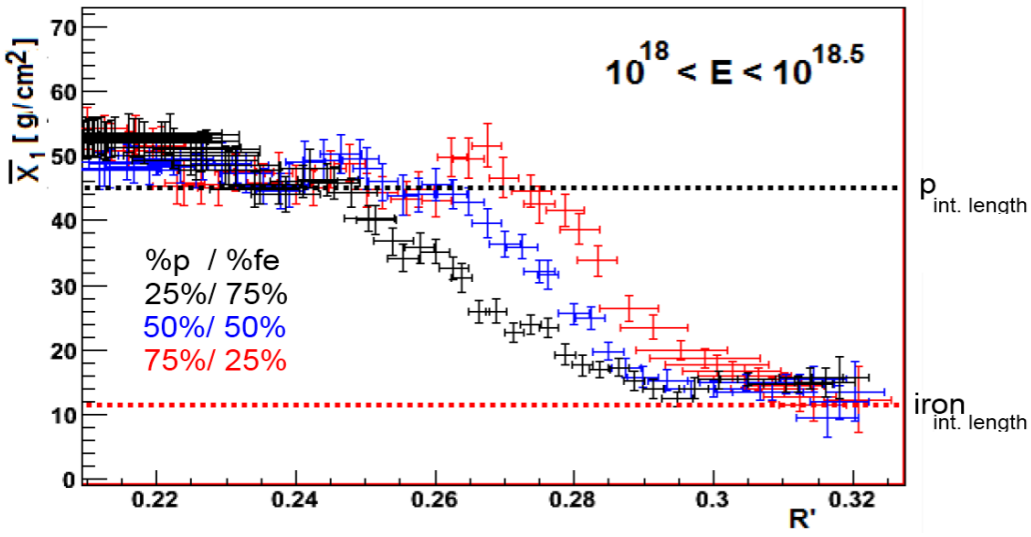
Possible to measure $X_1 = X_{max} - \Delta(R')$

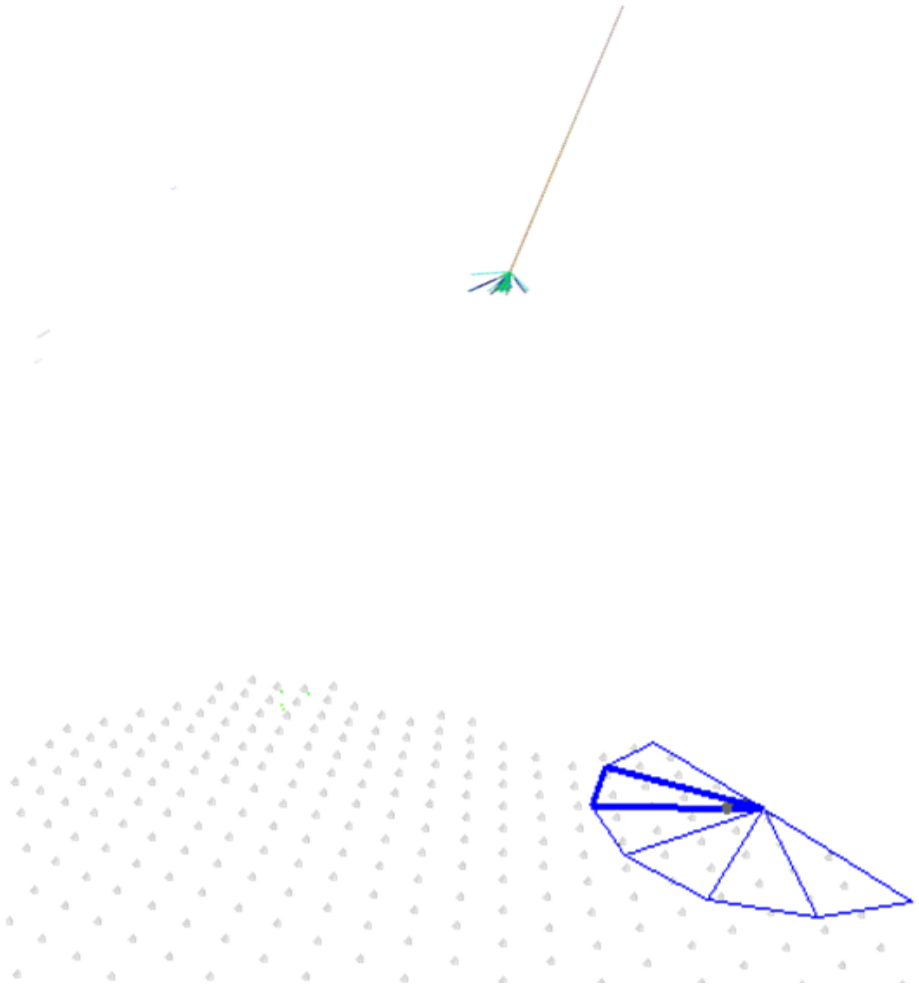
$X_1(R')$



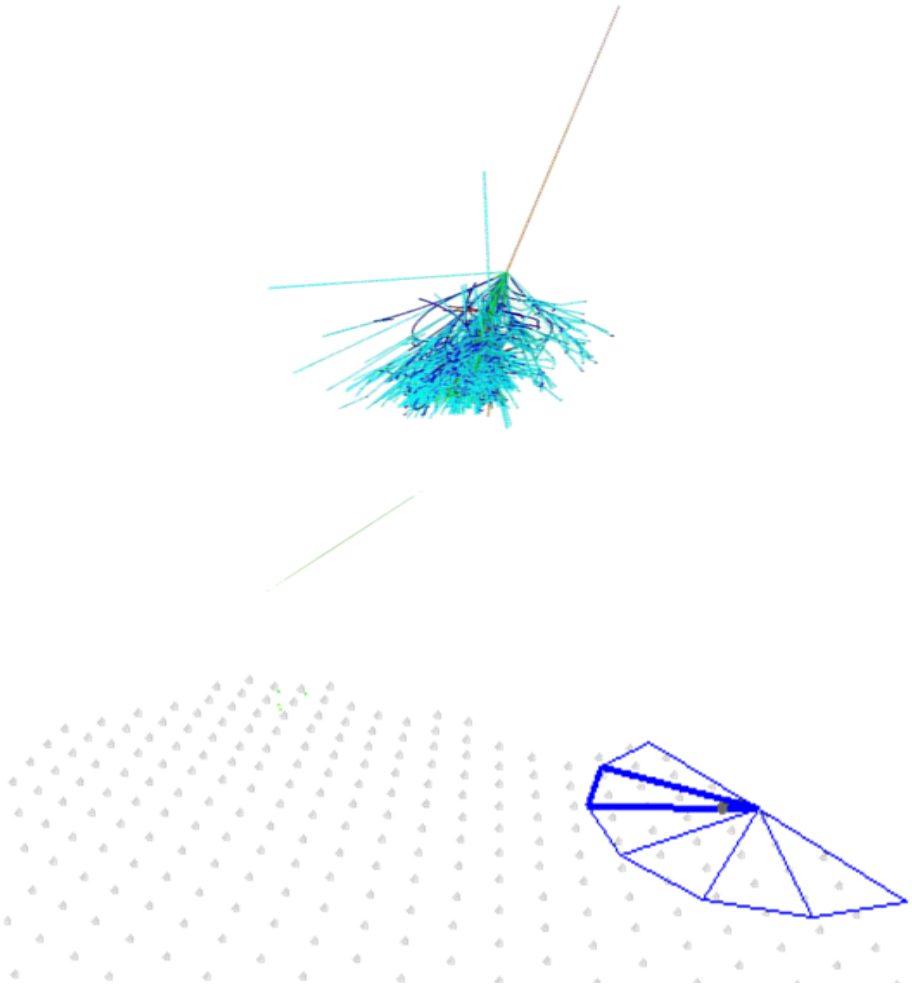
Francisco Diogo
Master Thesis

- $\overline{X_1}$ for mixed iron/proton samples
- Extreme bins in R' allow for a measure of both cross-sections
- Only done in simulations, still need to analyze data

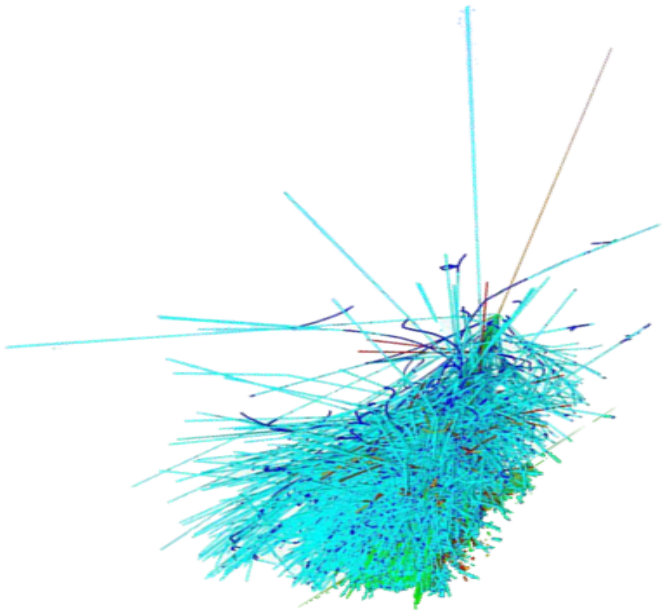
EAS components

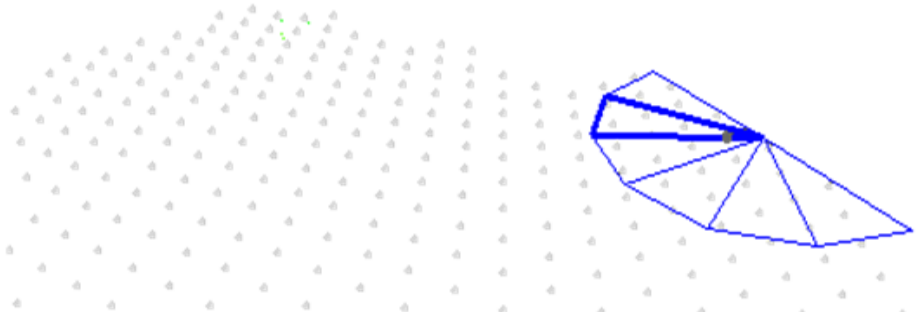


EAS components



EAS components





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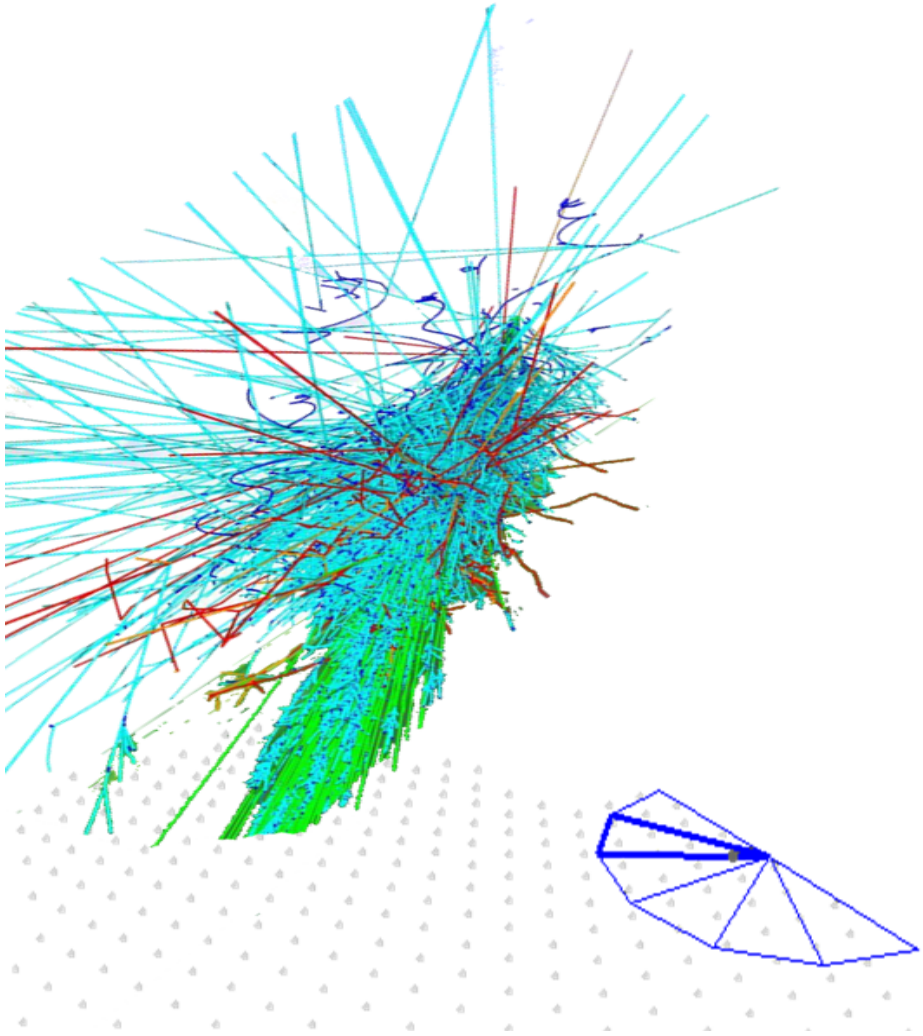

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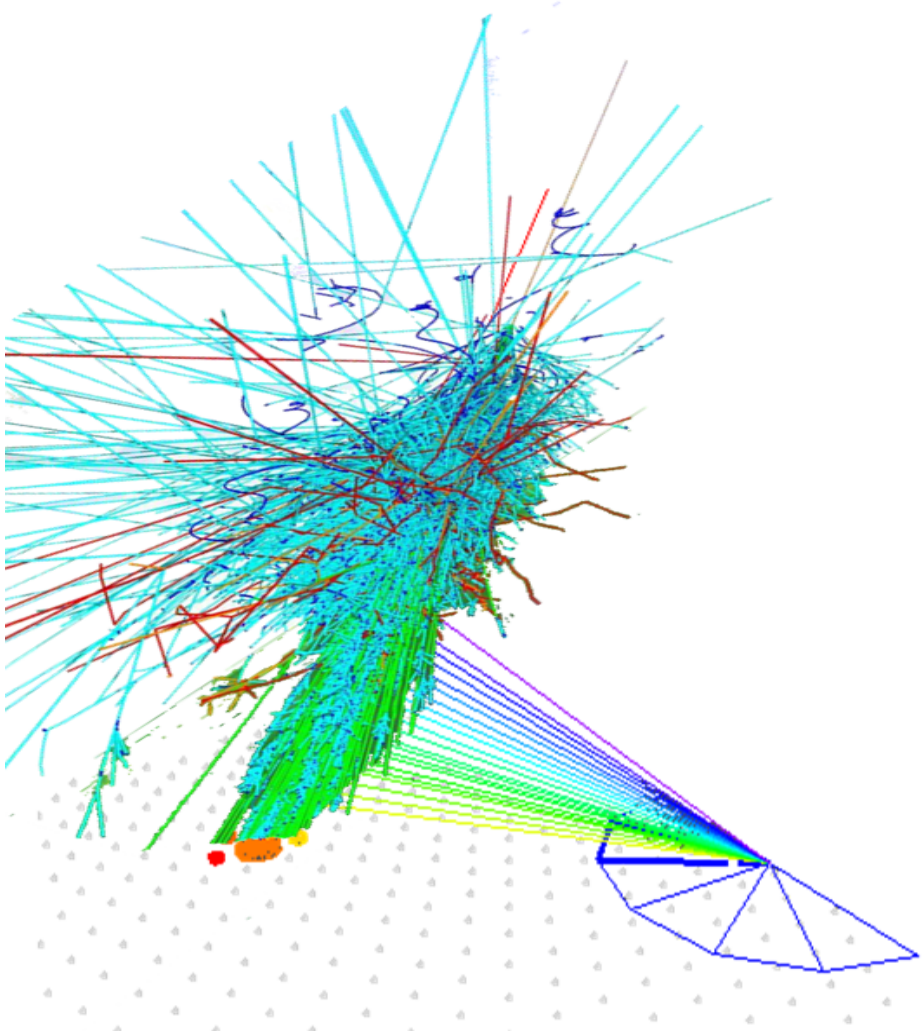
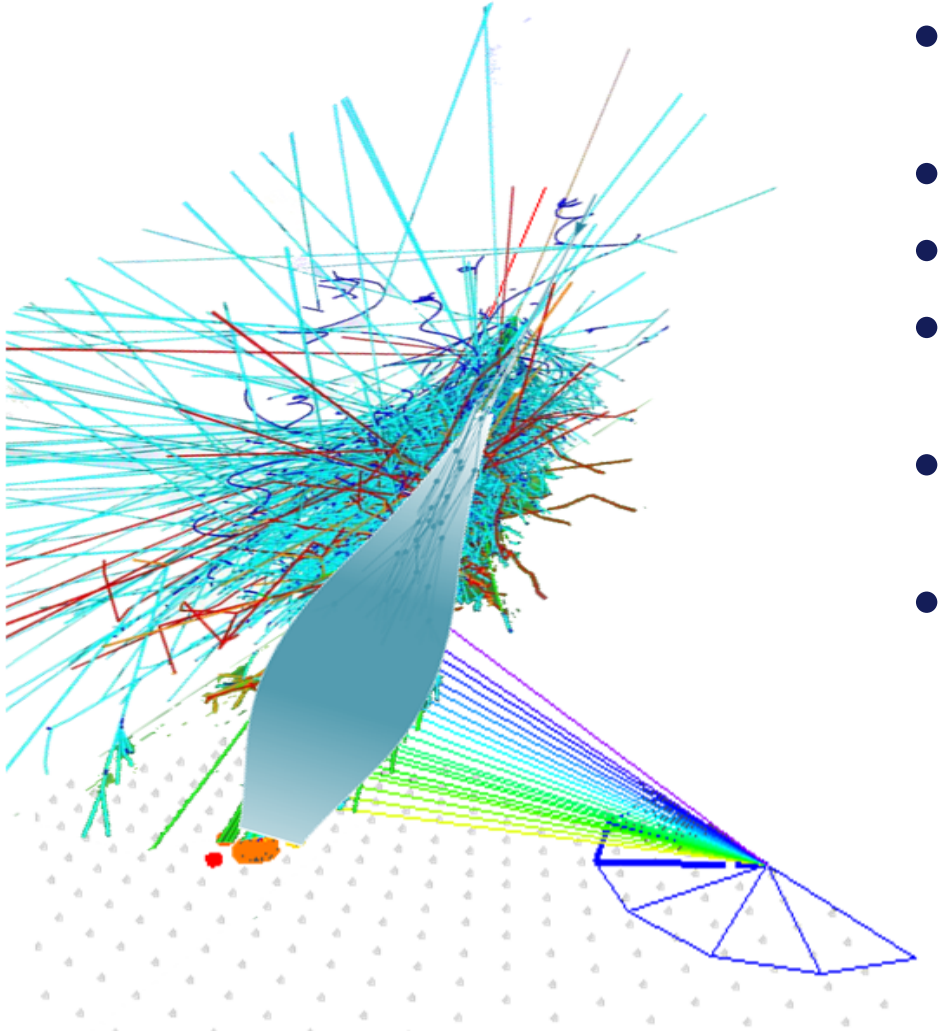


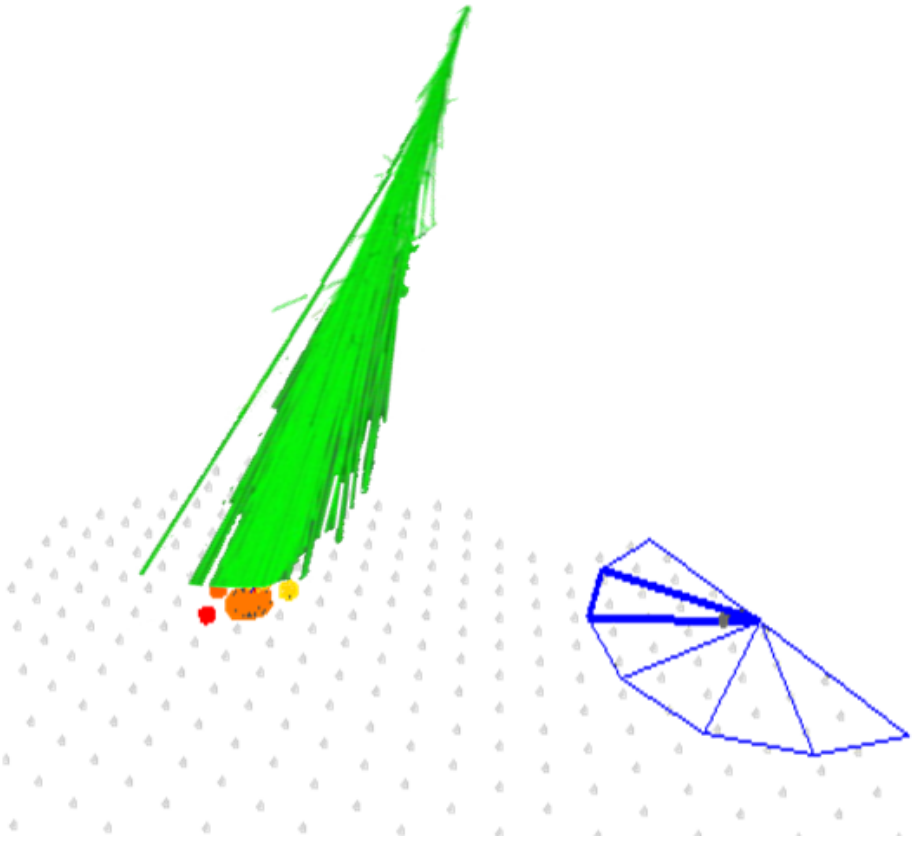
EAS components



Electromagnetic

- carries most energy (90%) of developed showers
- visible in both SD and FD
- easy to measure near maximum
- only visible in dark nights with clear sky
- very difficult to measure near the inital region
- first interaction information is 'dilluted'

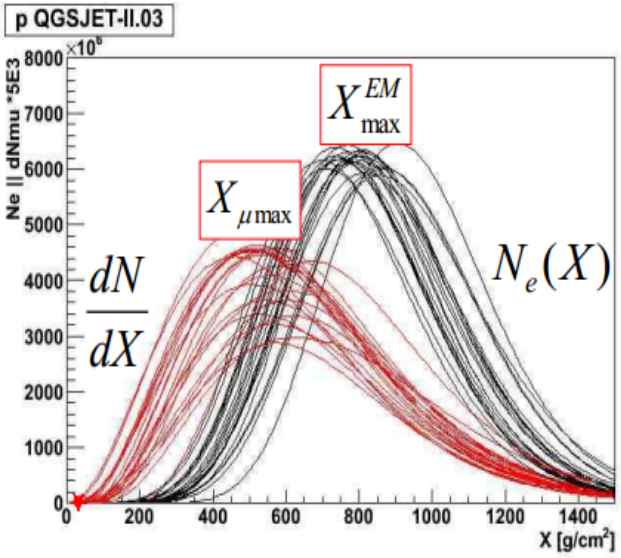
EAS components



Muonic

- hard to measure - no signal in FD, difficult to disentagle from e.m signal in SD
- muons interact scarcely with the atmosphere
- high energy muons preserve information from first interaction

The muonic longitudinal shower profiles at production



The number of muons produced in the shower as a function of depth can be described by the same function as the e.m. profile
The fast rise allows a more direct probing of the initial interactions

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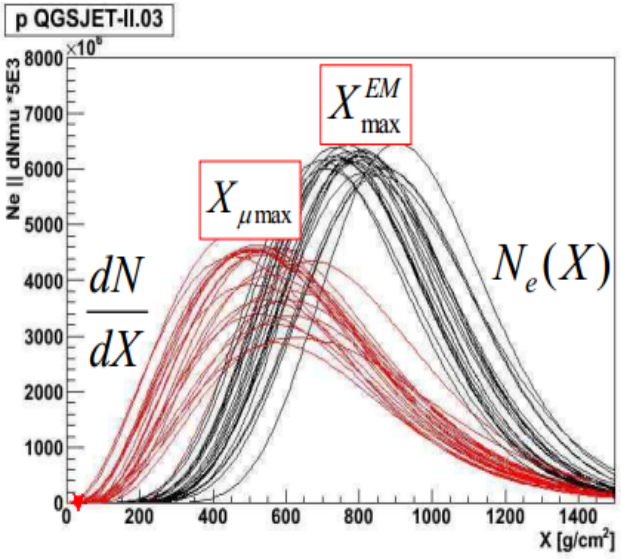
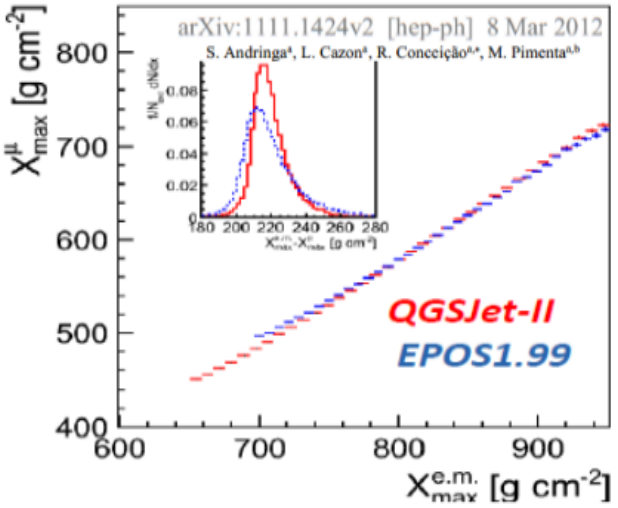
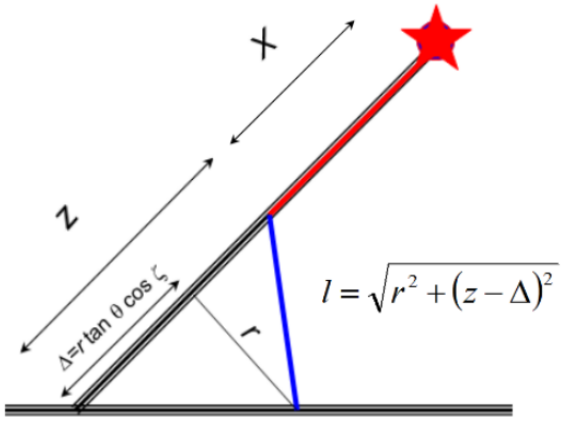




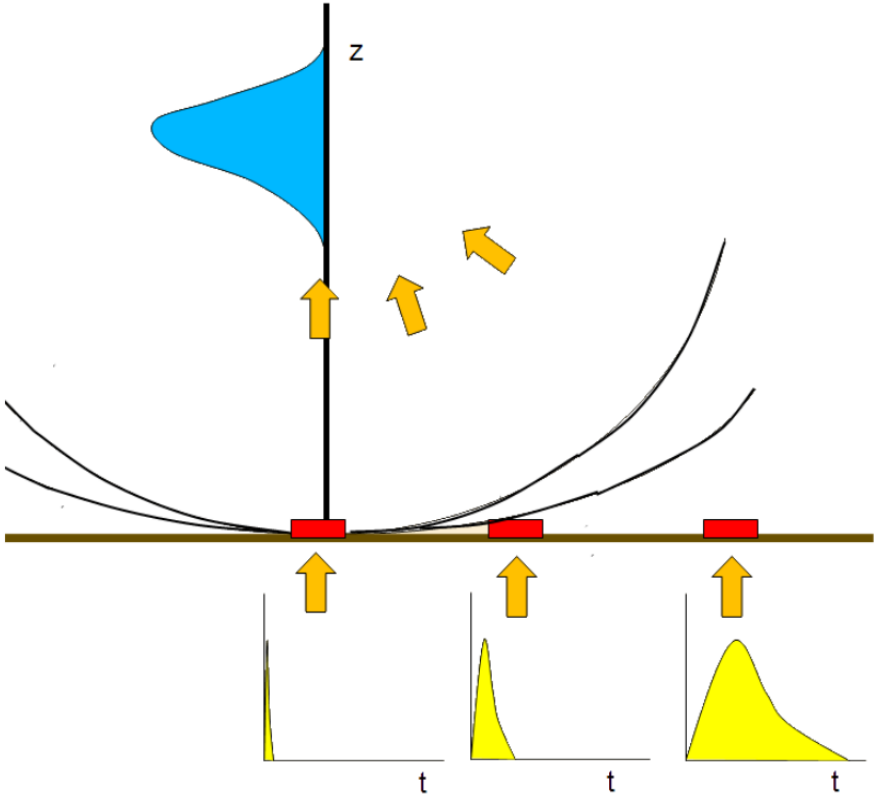
The number of muons produced in the shower as a function of depth can be described by the same function as the e.m. profile
The fast rise allows a more direct probing of the initial interactions
The profiles are heavily correlated: both X_{max} and the shape parameters of one profile can be estimated by knowing the other

- Inconsistencies give important information on hadronic models

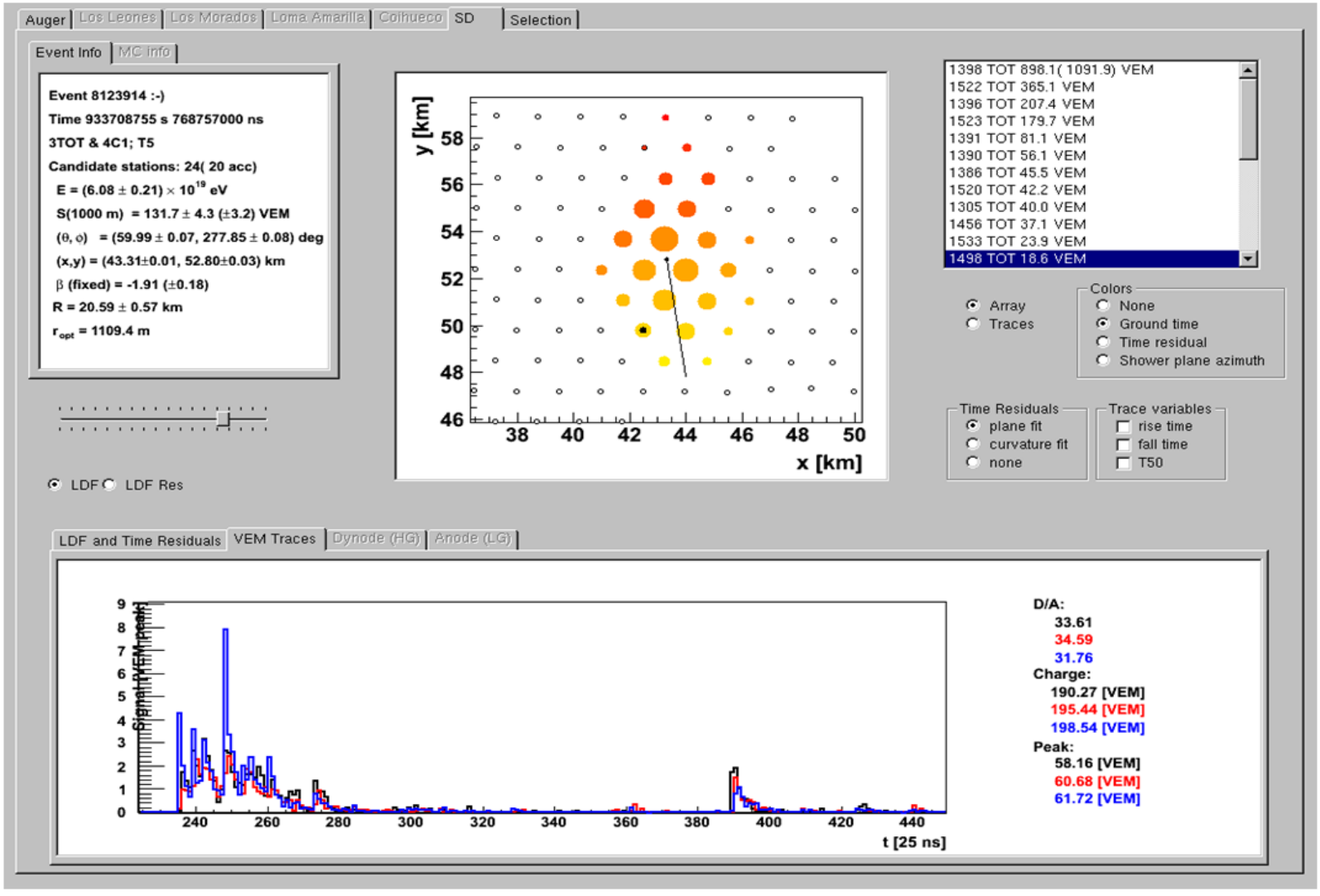
Muon Production Depth (MPD)



Muons travel in straight lines.
Knowing their arrival time,
we can get the depth
of their production, z.



Measuring the muonic profile - Muon Production Depth (MPD) method



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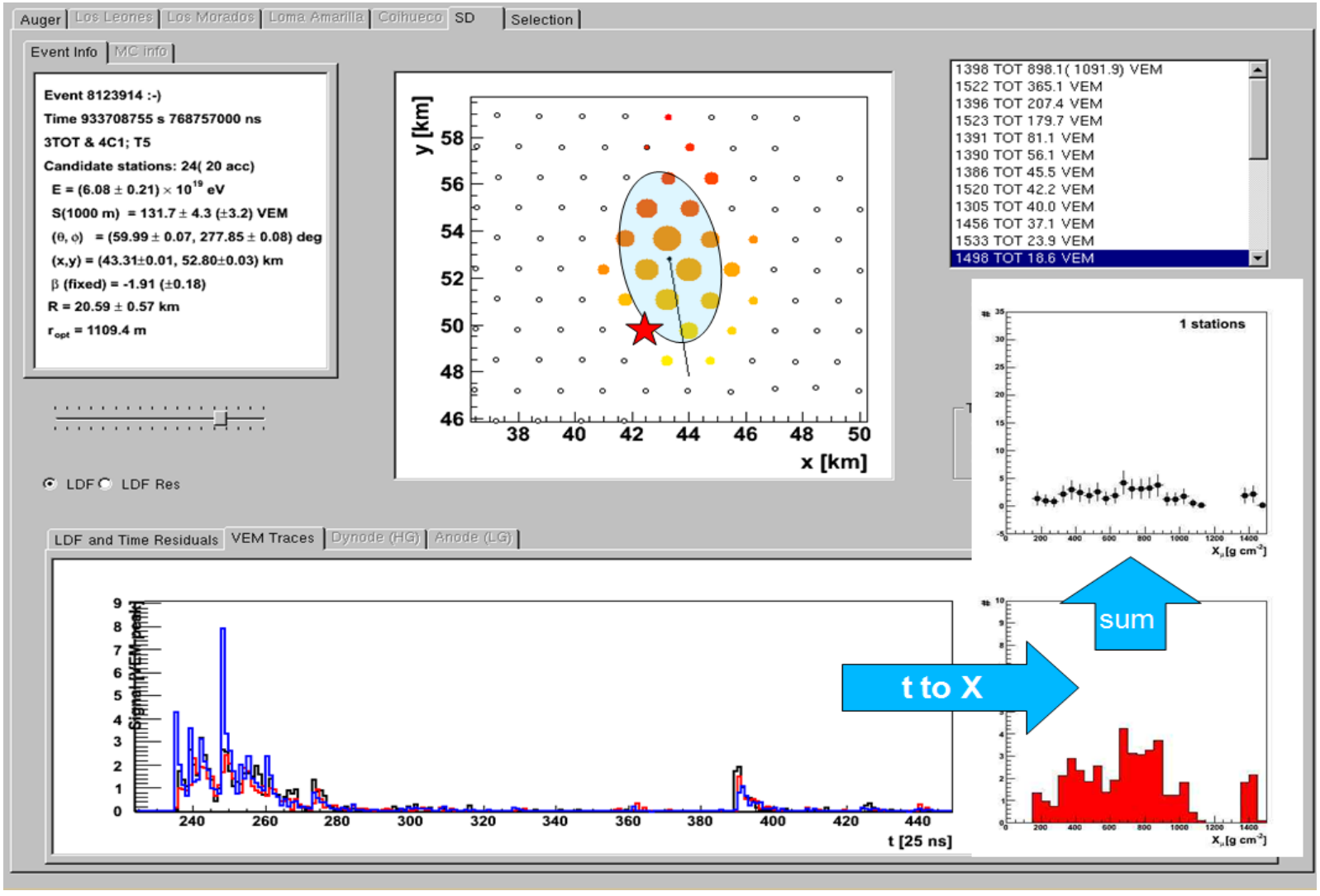

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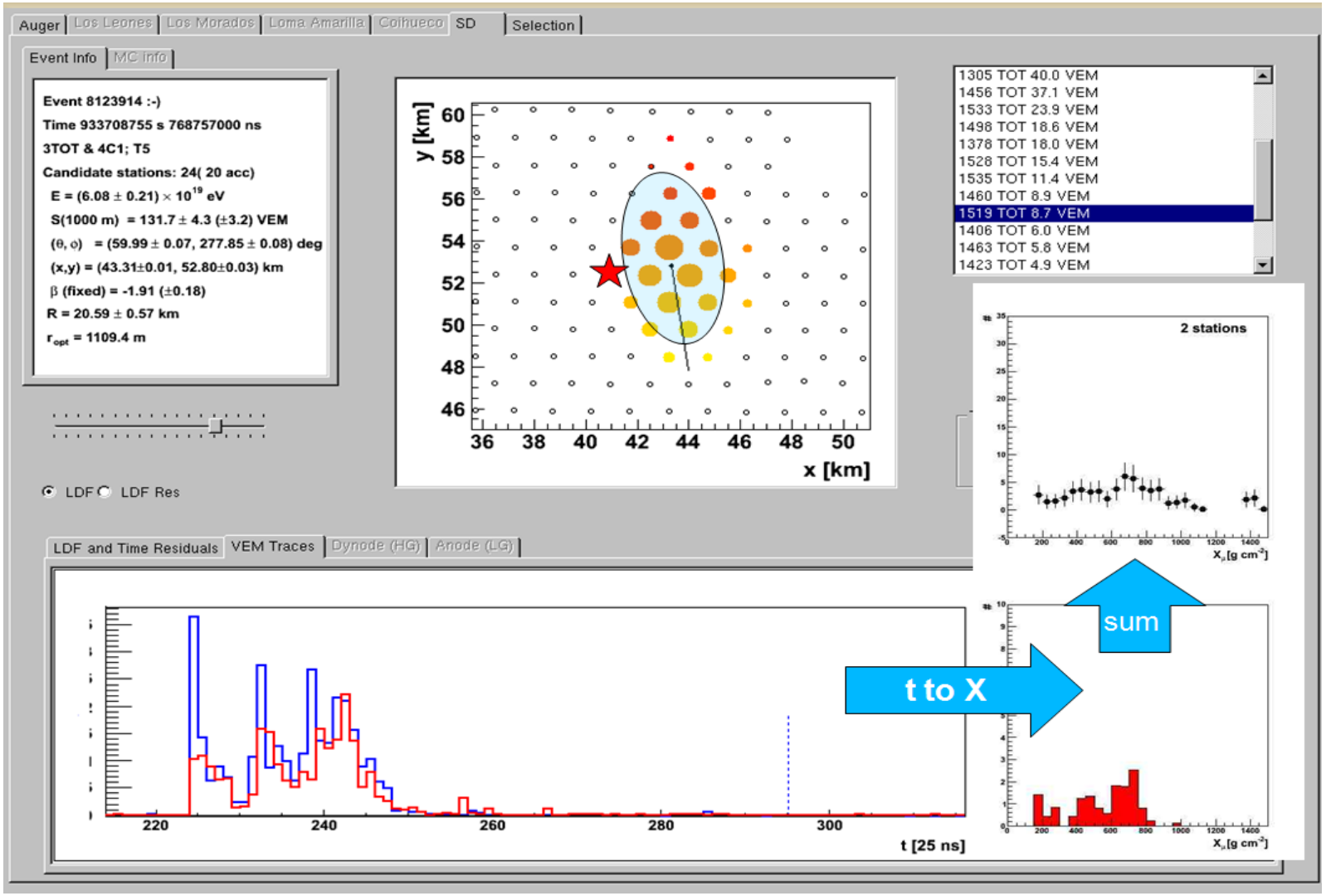

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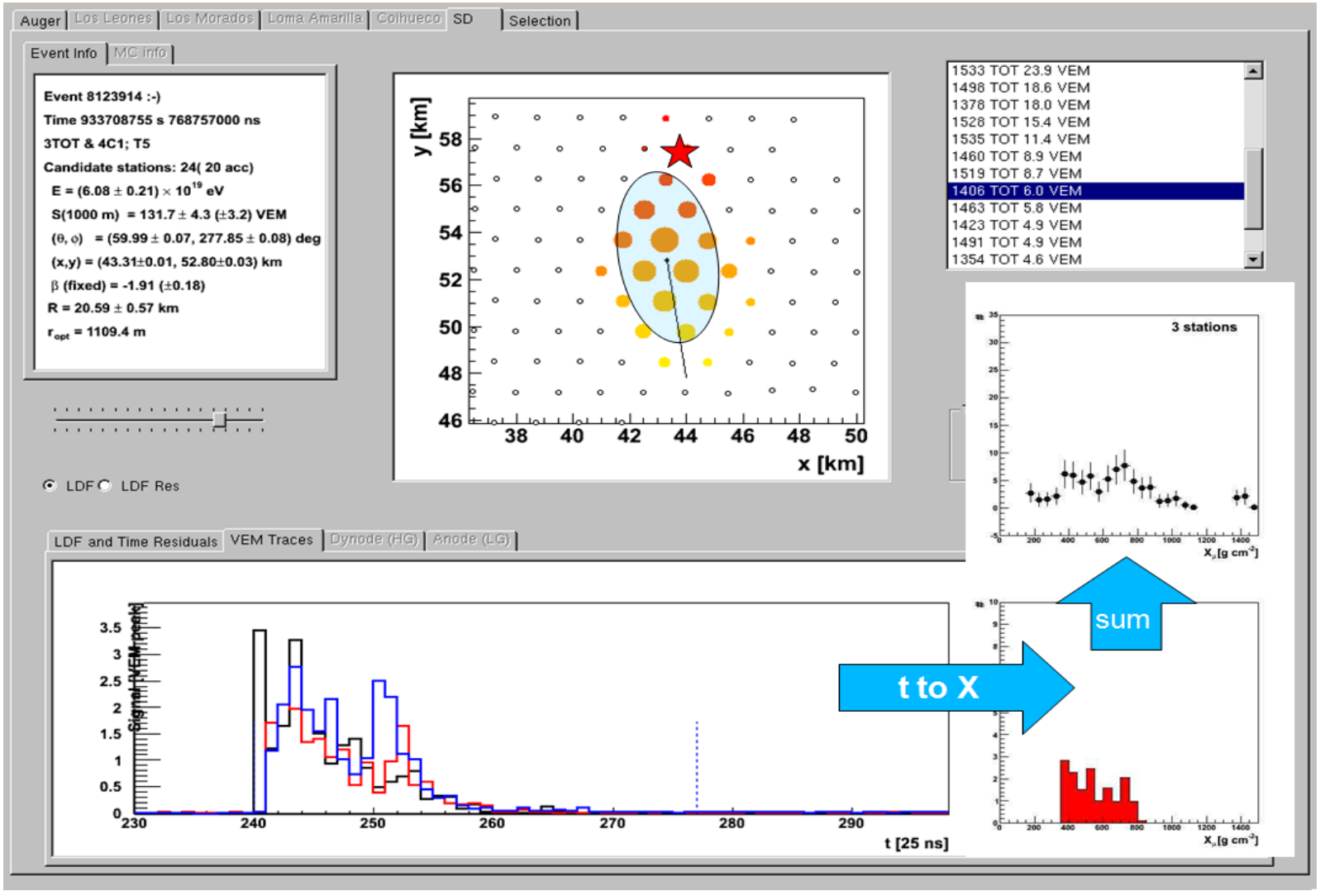

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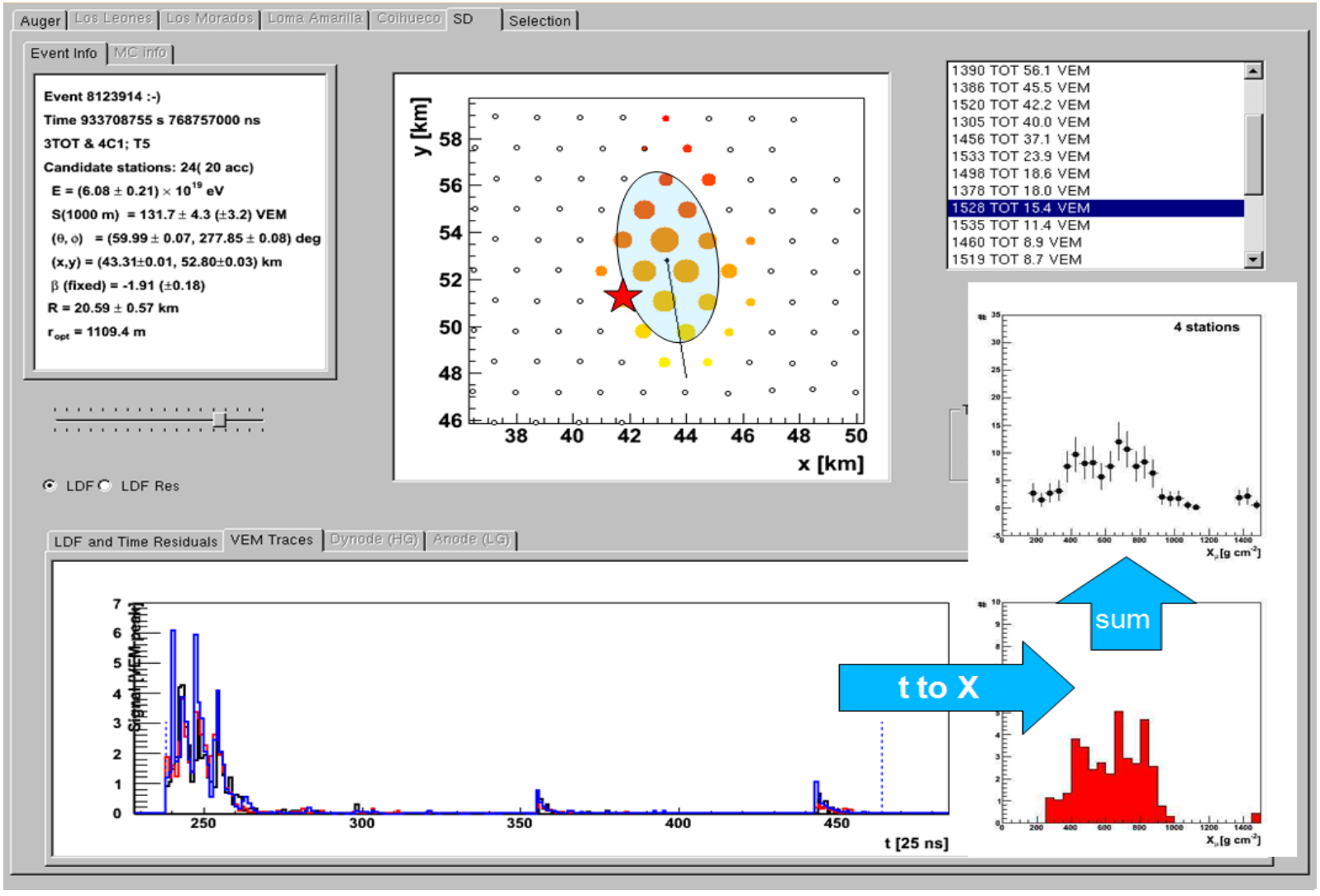

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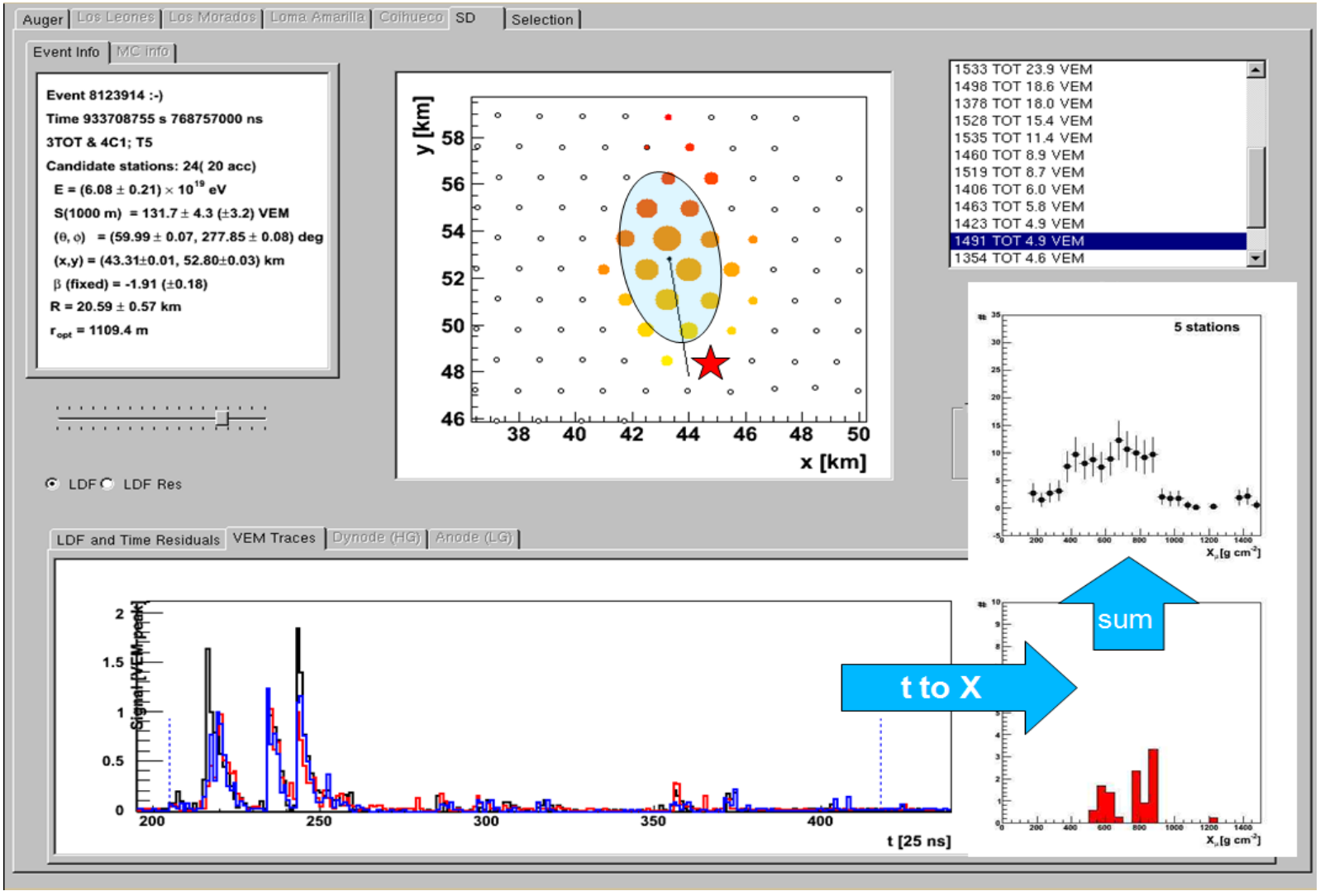

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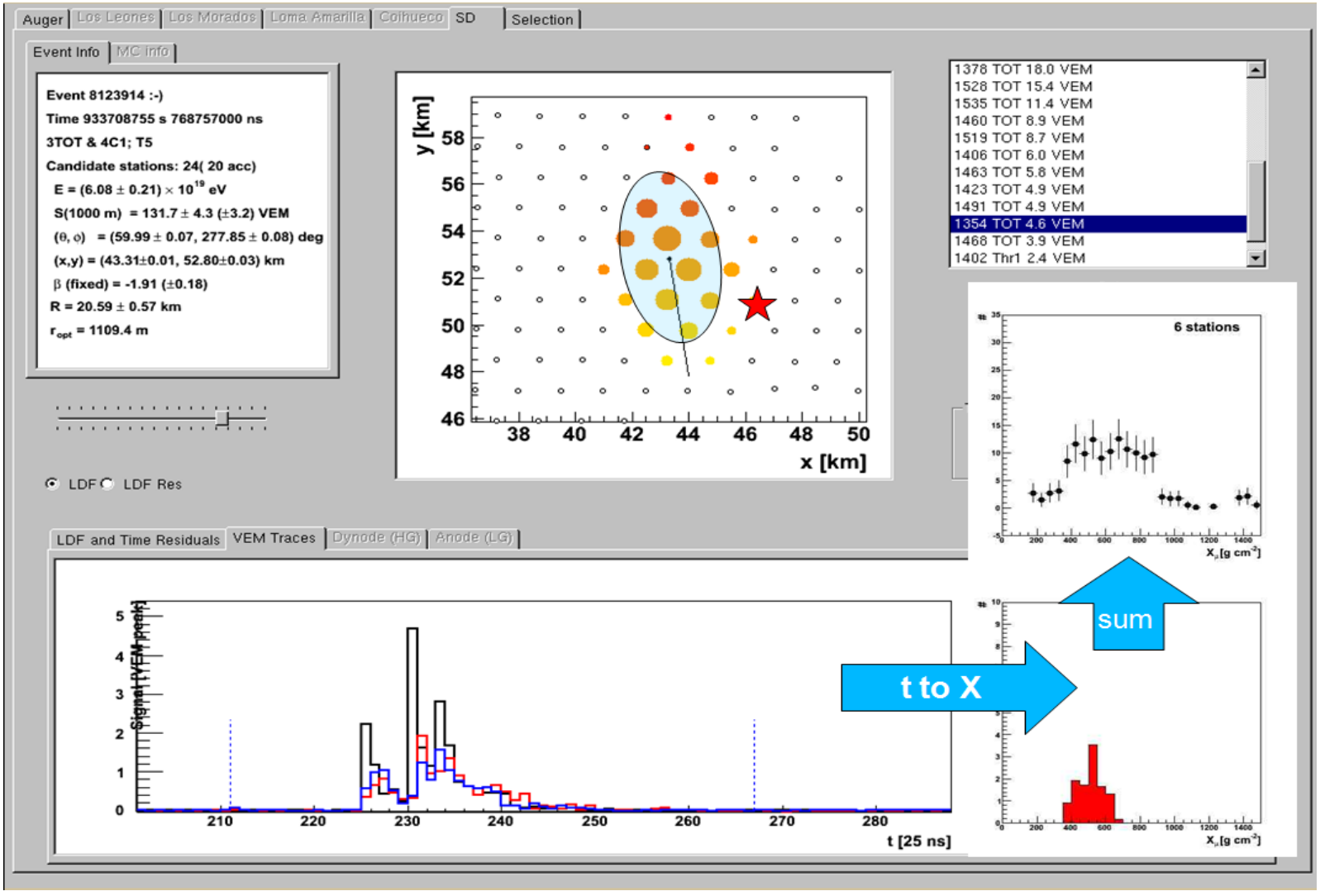

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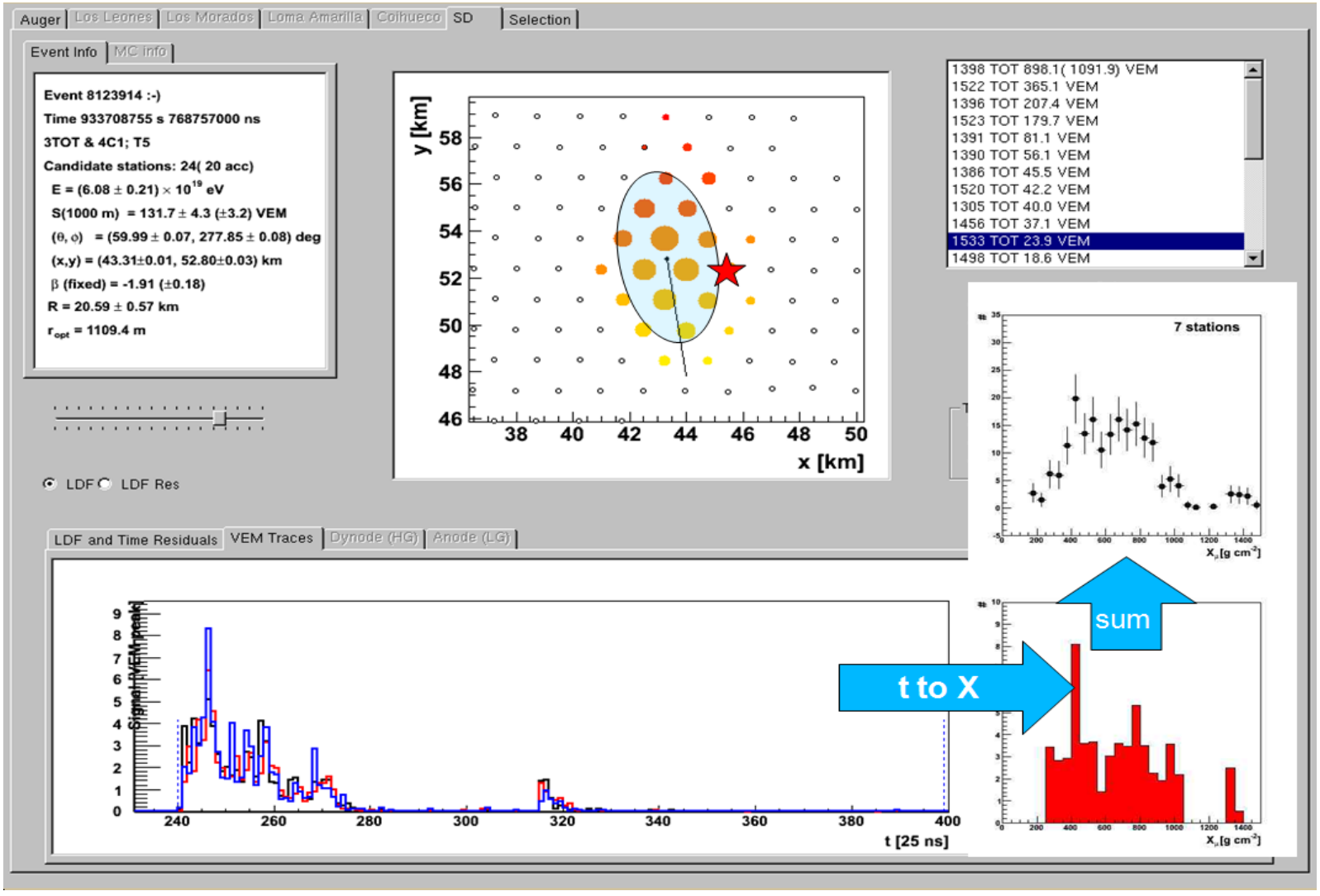

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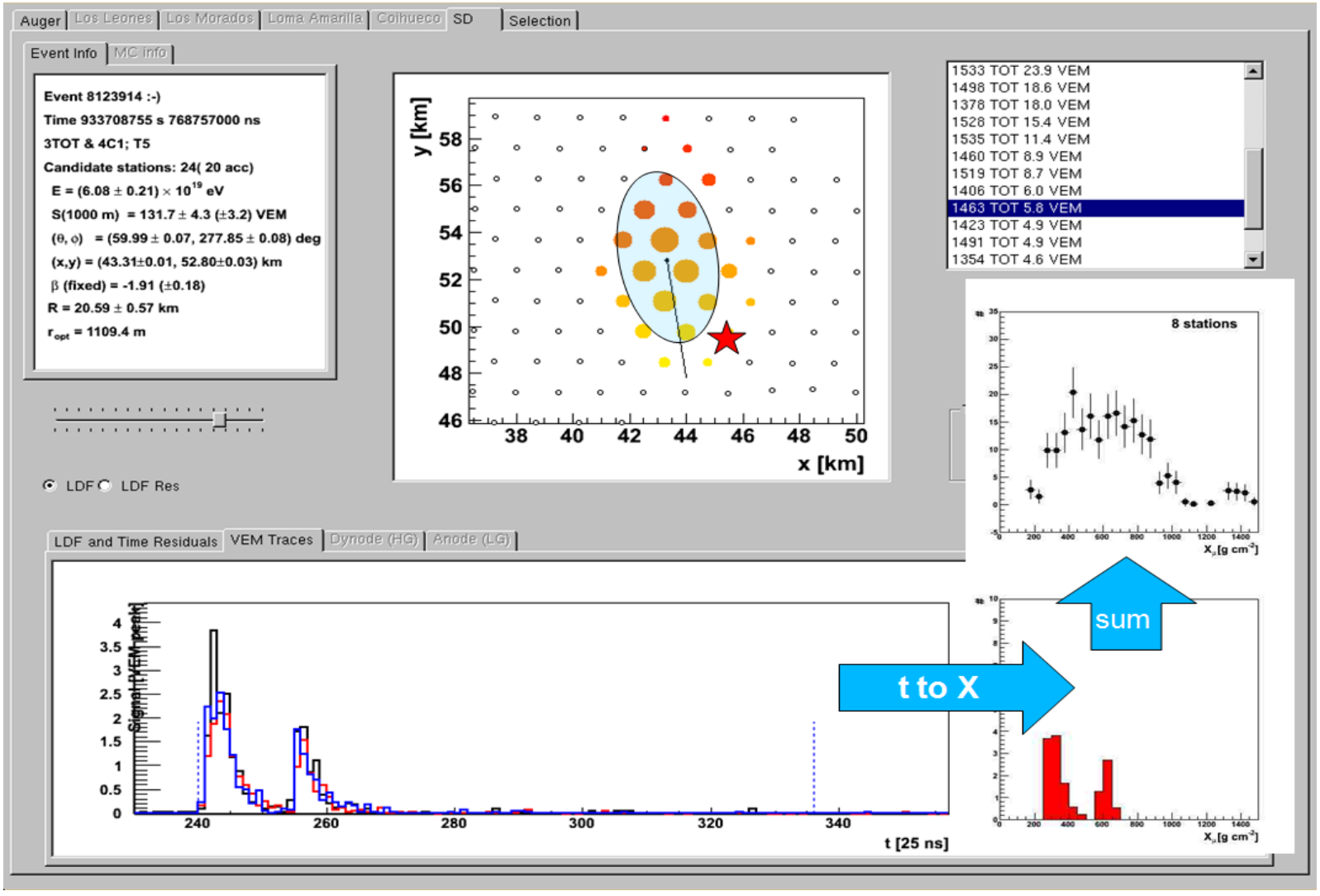

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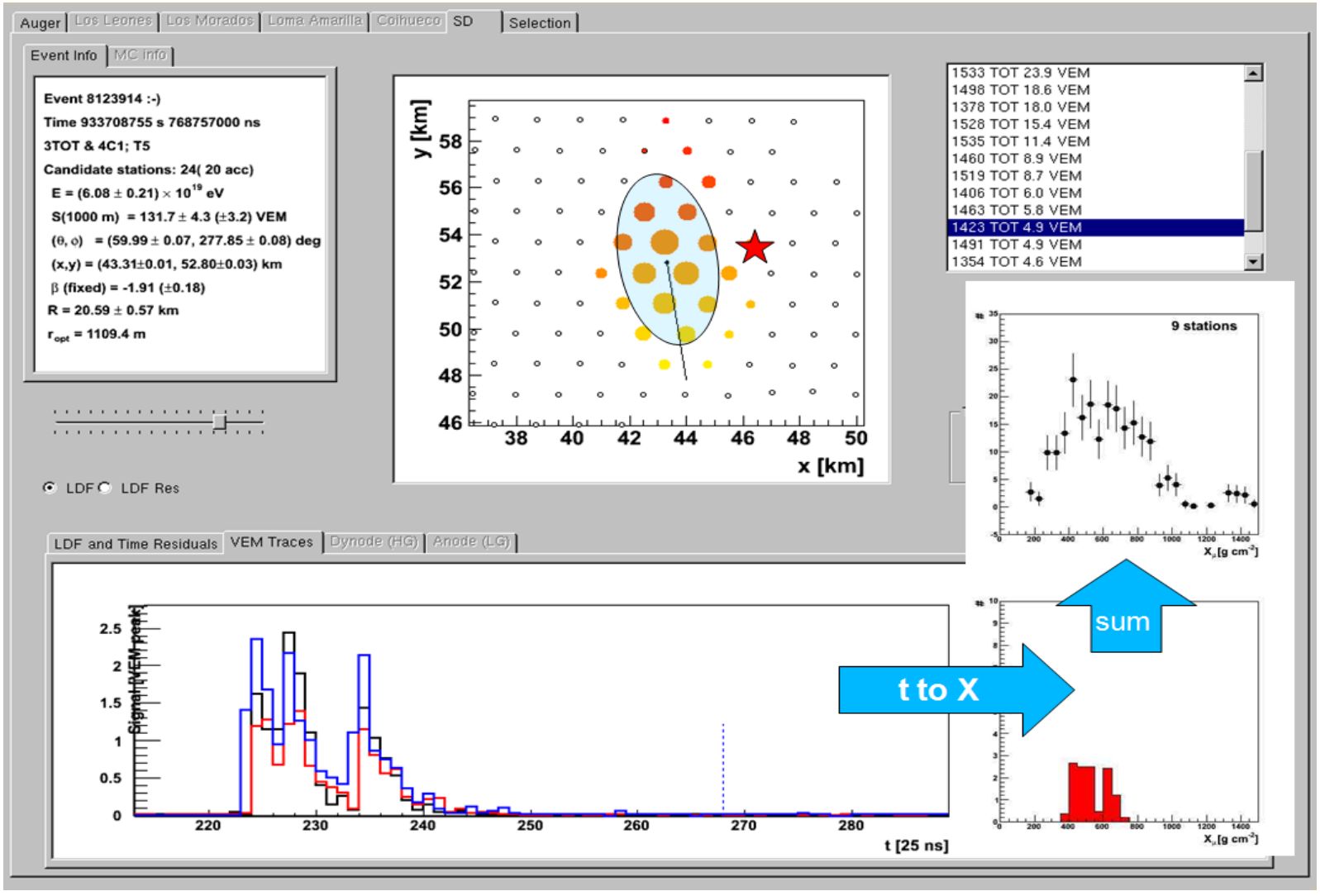

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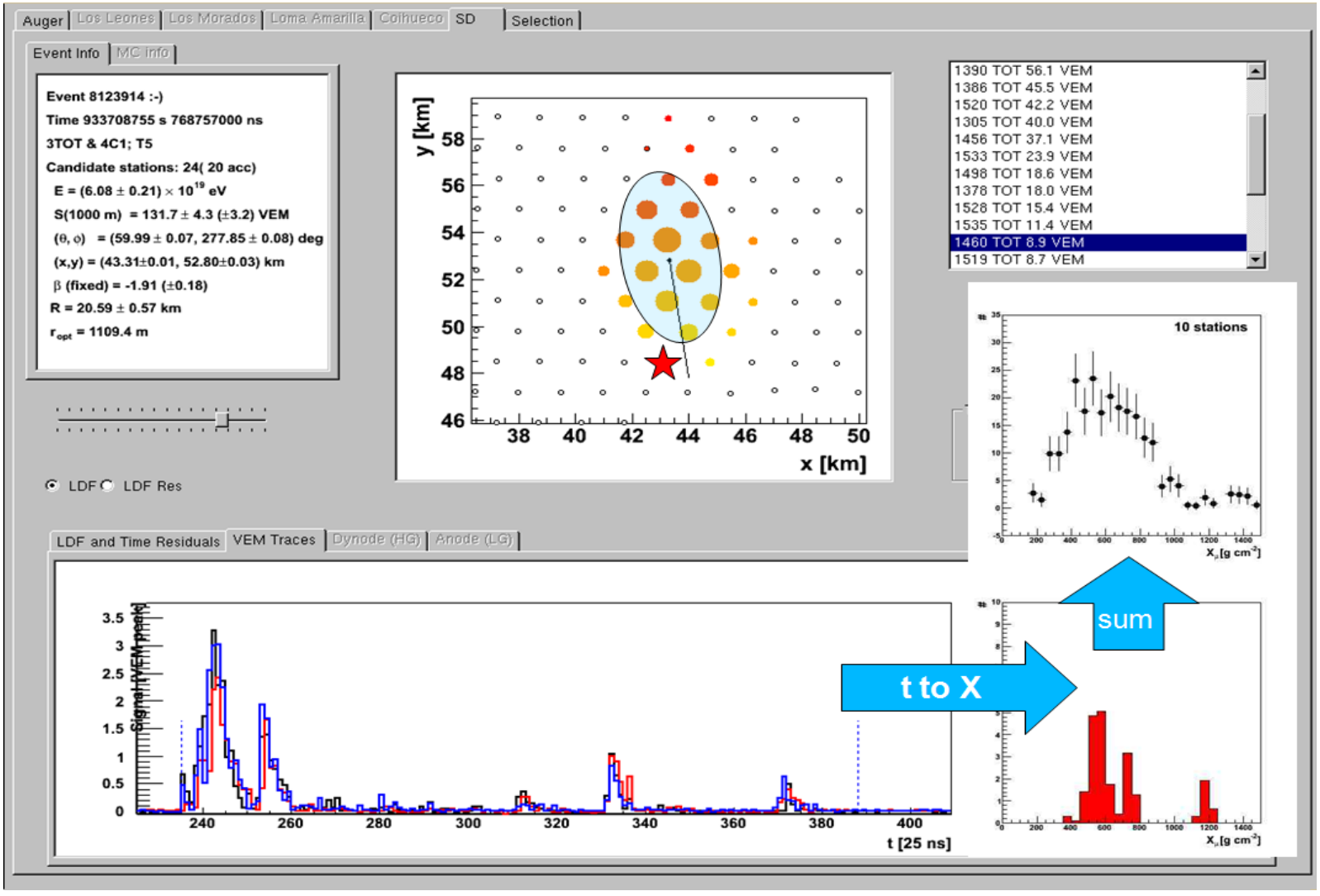

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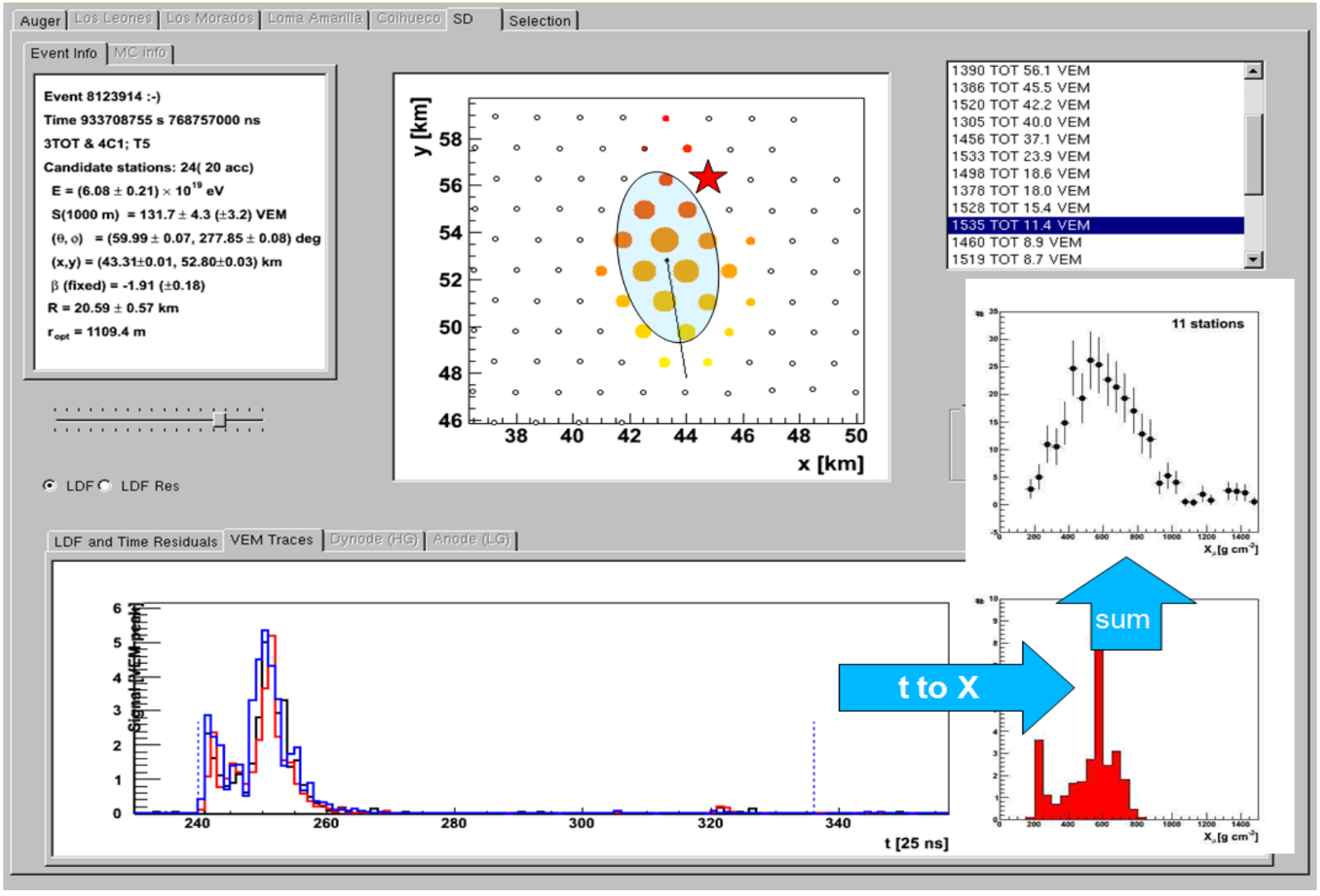

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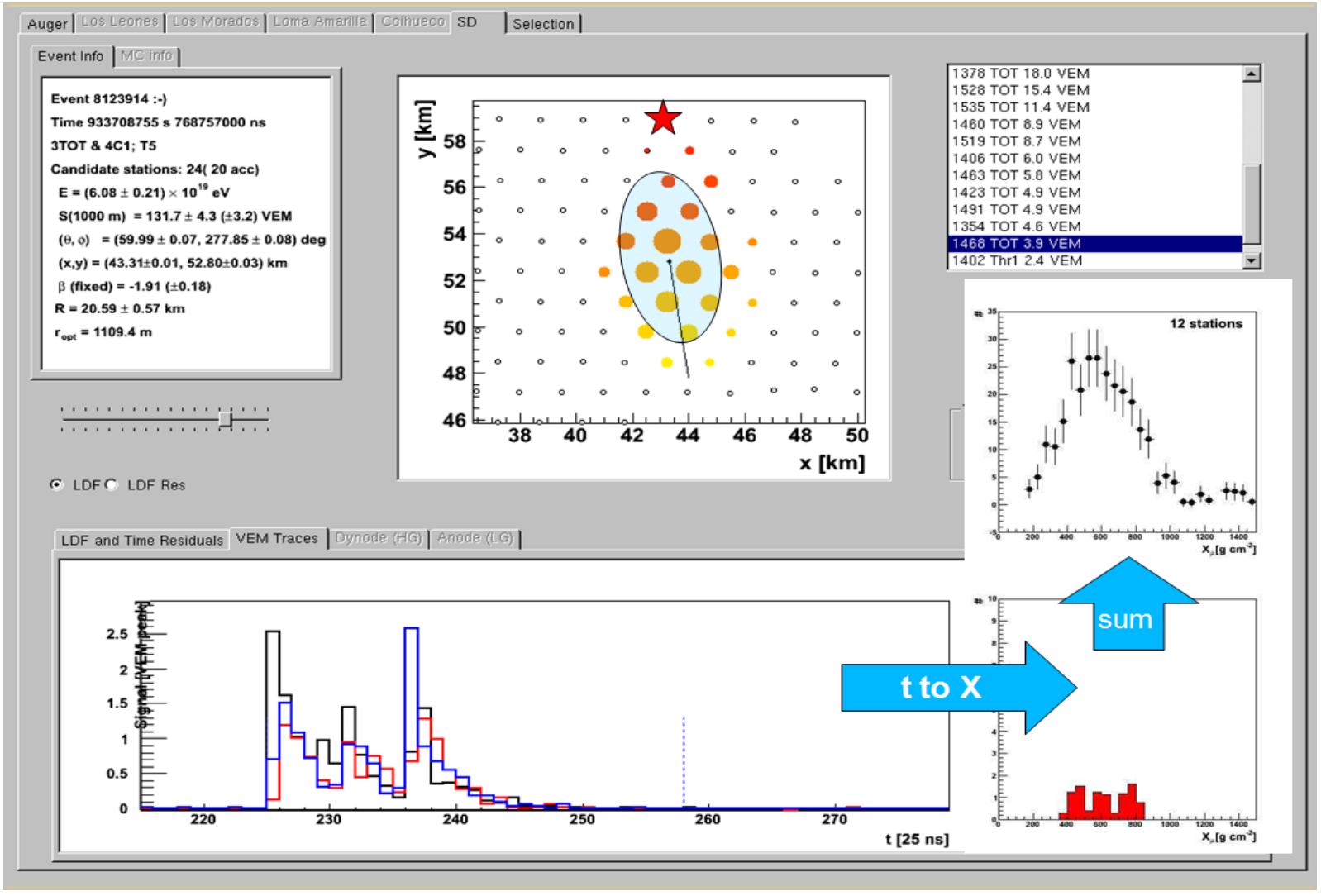

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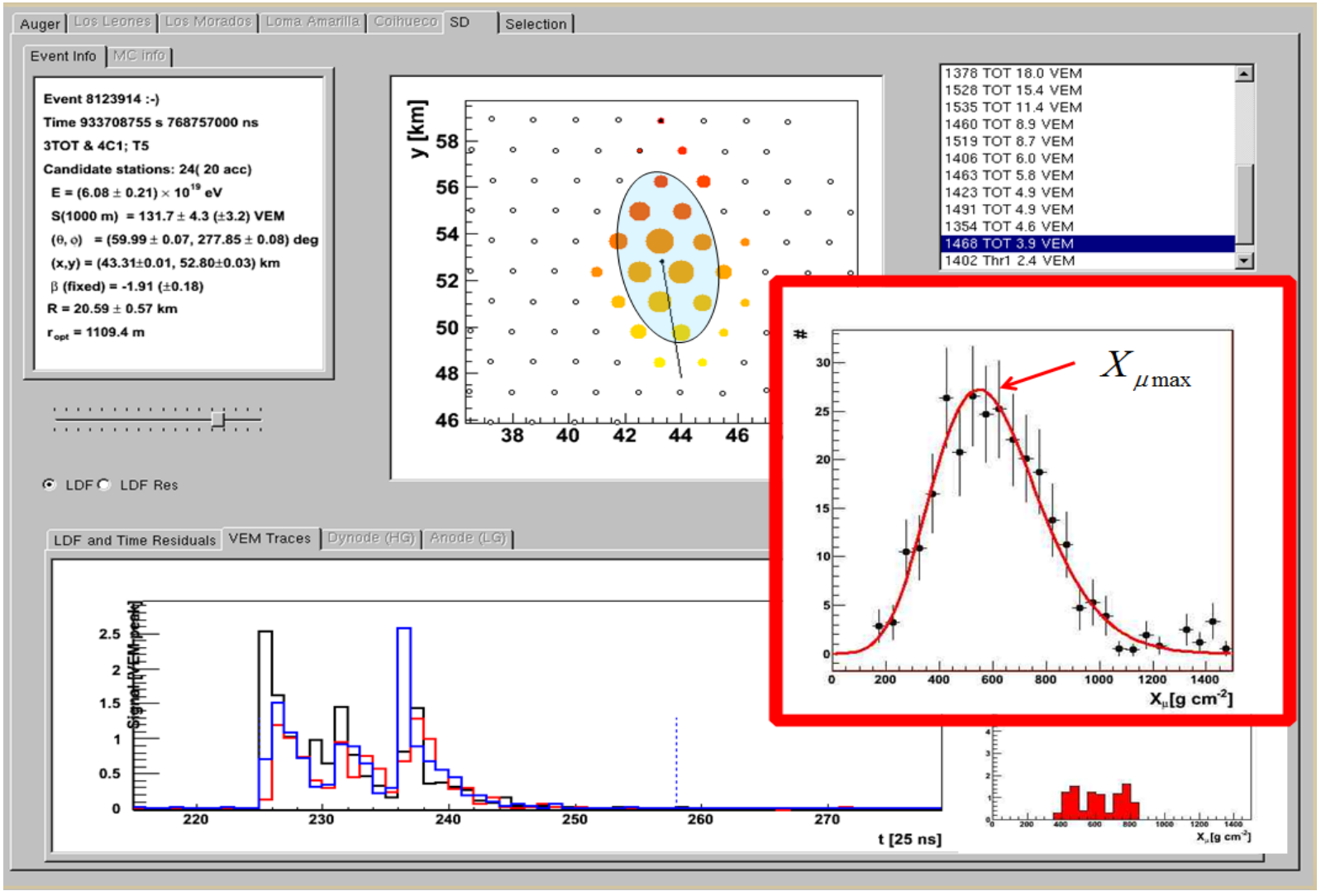
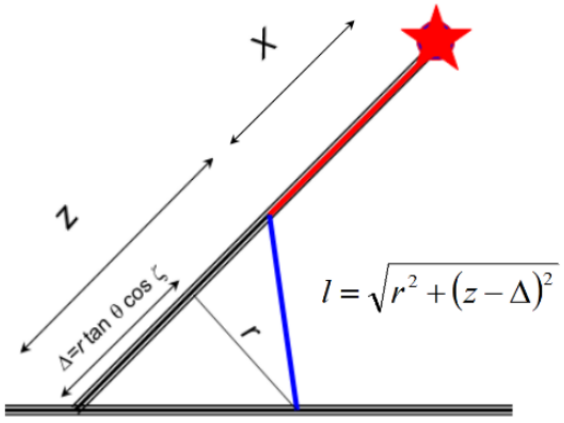
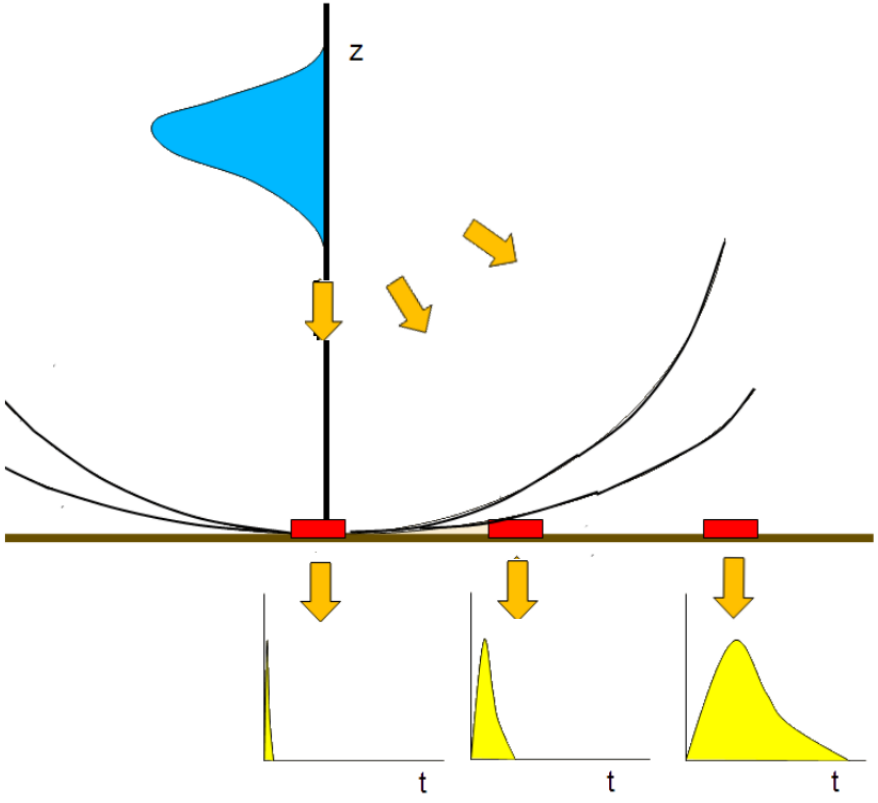


MPD 2

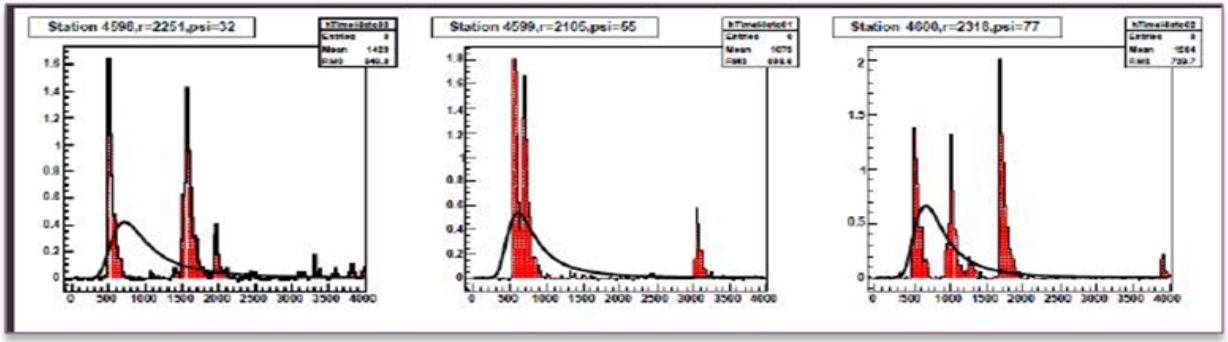


Muons travel in straight lines. Modelling their p_t distribution, and correcting for decays and atmospheric effects we can calculate the likelihood that a muon reaches a tank at time t_i



MPD 2 global fit

- **Fits directly over the stations FADC traces**



Eva dos Santos PhD thesis

$$\log L = \sum\sum \log[(t_i) * pdf(t_i, X^{\mu}_{\max}, L, R)]$$

USP

[Detector ⊗ (Geometry ⊗ Kinematics)] && Muon decay

MPD 2 global fit

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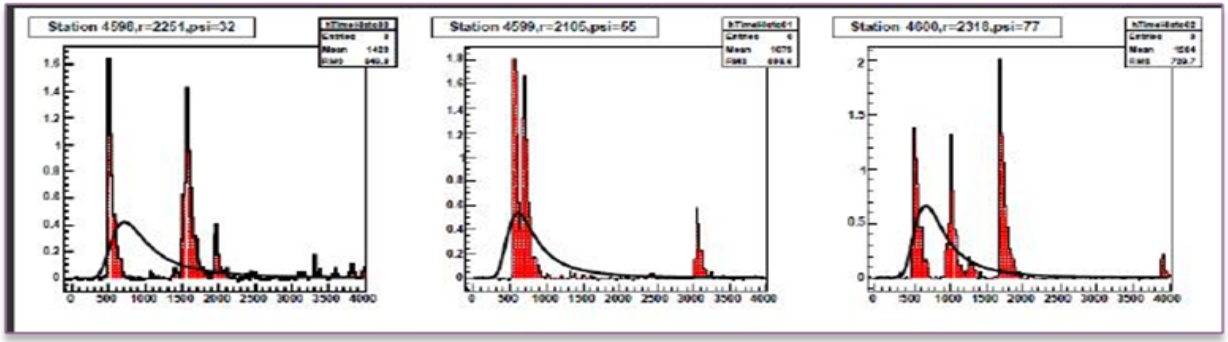

Eva dos Santos
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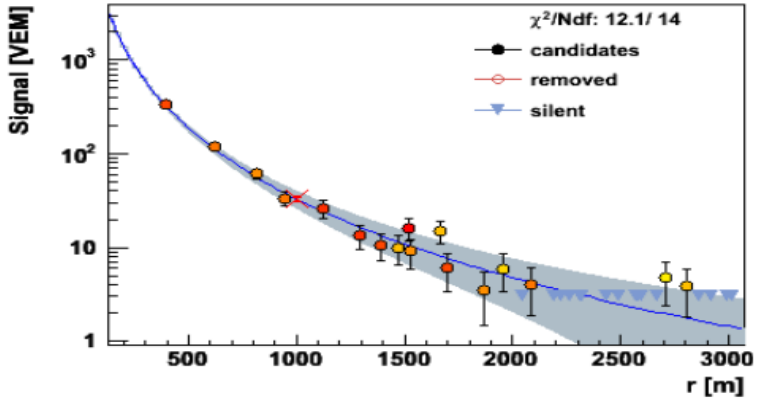
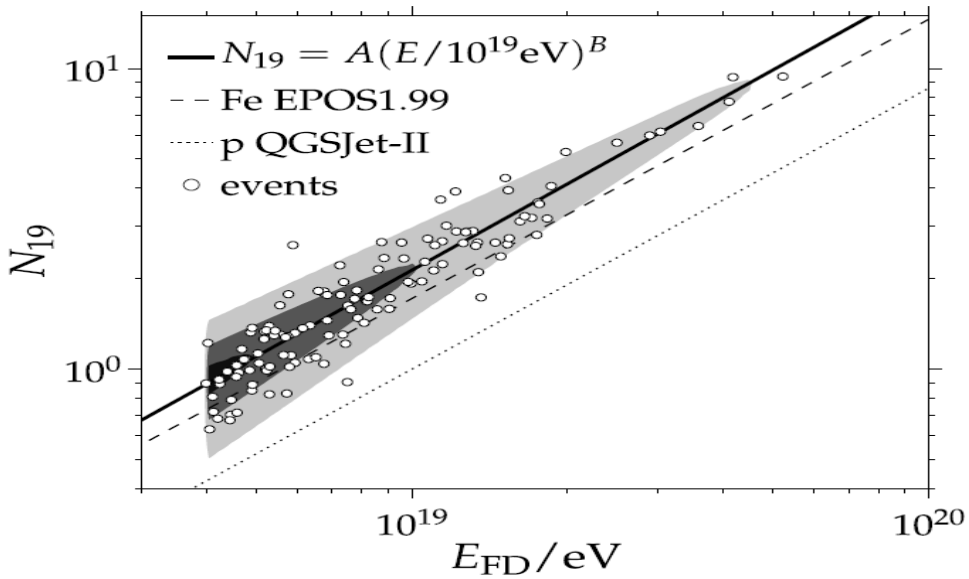


Micael Oliveira
Master Thesis

Muon excess

Understand the 'muon excess' problem at Auger



$$N_\mu = 2.13 \pm 0.04(stat) \pm 0.11(syst)$$

with respect to QGSJET-II protons at $10^{19} eV$

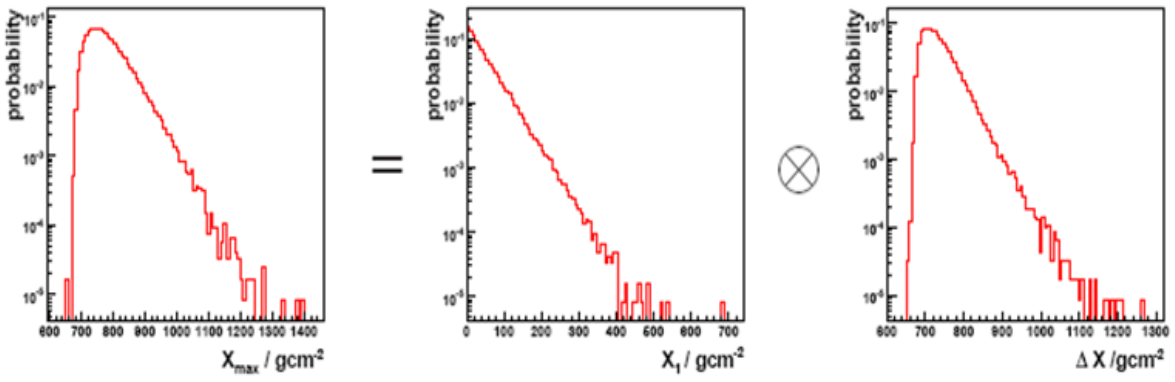
Conclusion

- Auger data presents particle physics puzzles
- the longitudinal profiles of both the electromagnetic and muonic component are the key for building powerful observables
- the LIP Auger team is deeply involved in this task

Backup

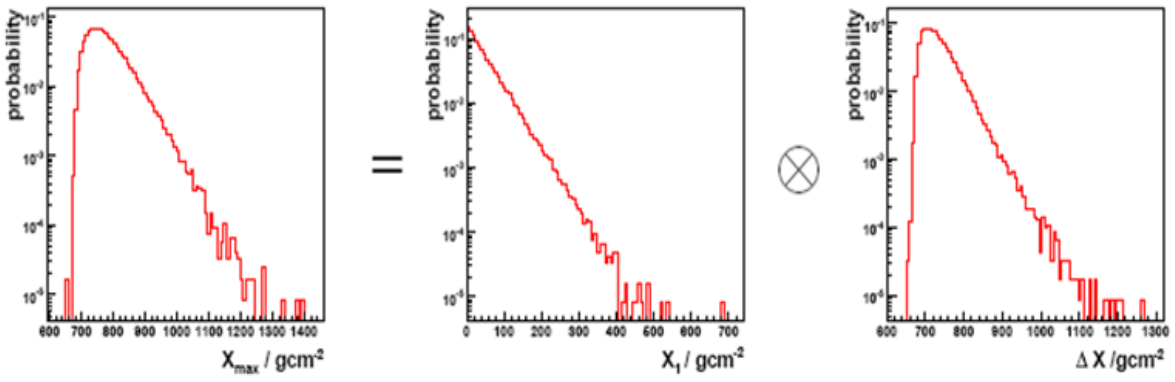
BACKUP
SLIDES

Cross-section measurement



X_1 is an interaction length, and therefore follows an exponential distribution

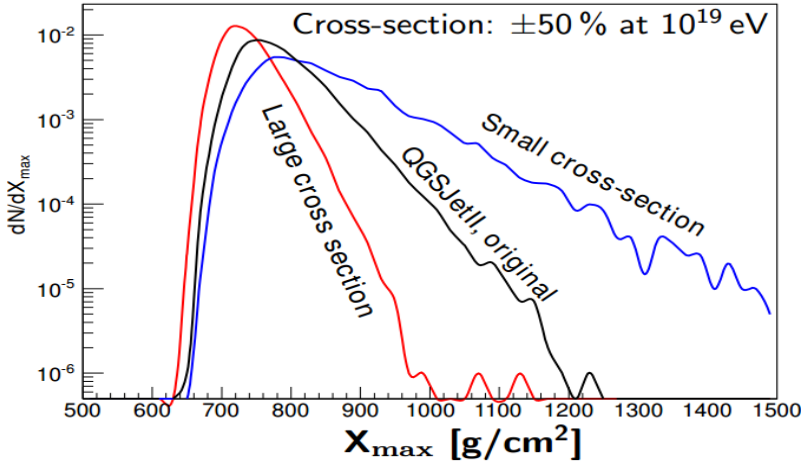
Cross-section measurement



X_1 is an interaction length, and therefore follows an exponential distribution

The end of the X_{max} distribution tail is dominated by this exponential → cross section measurement

$\sigma_{in} = 1/\overline{X_1}$



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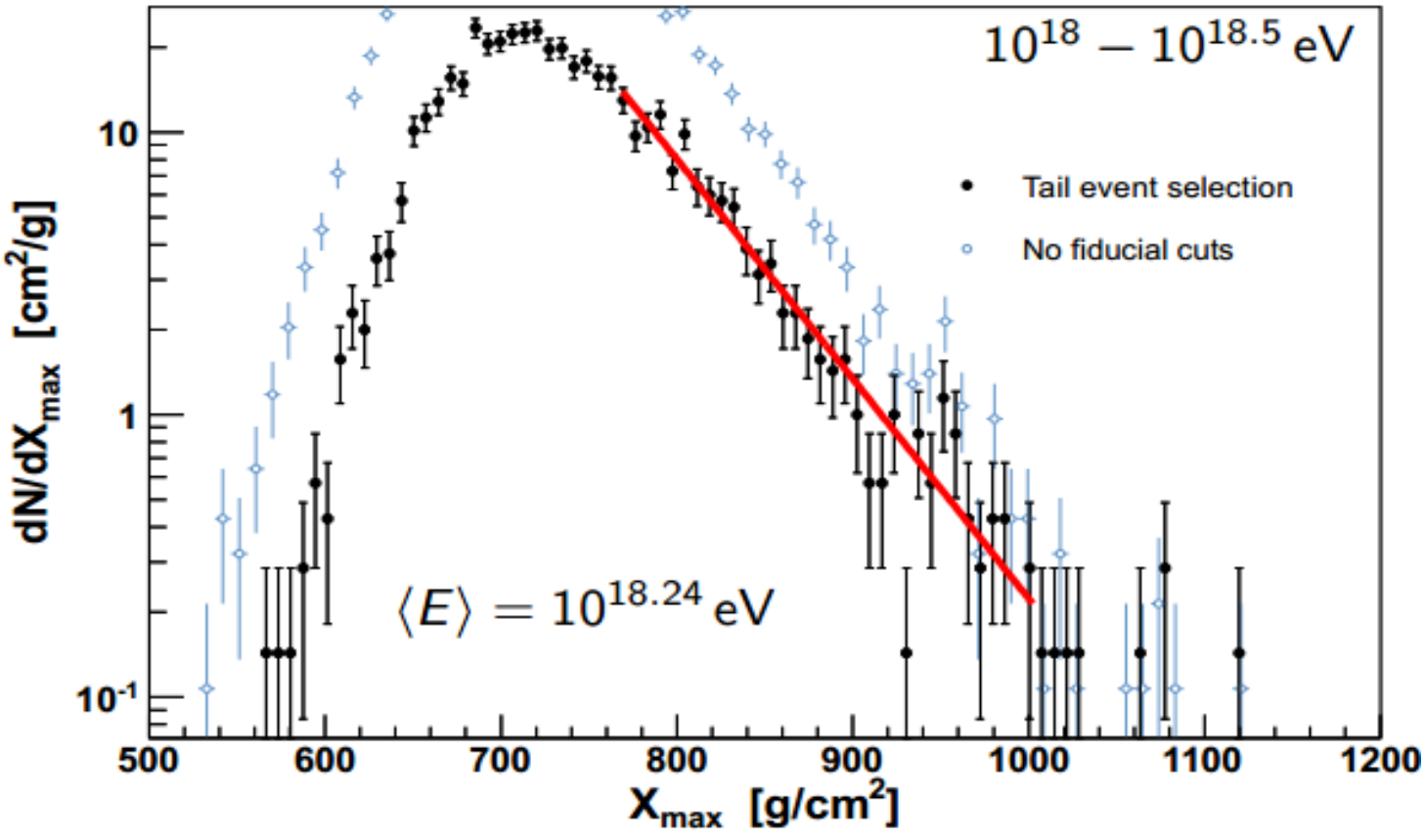
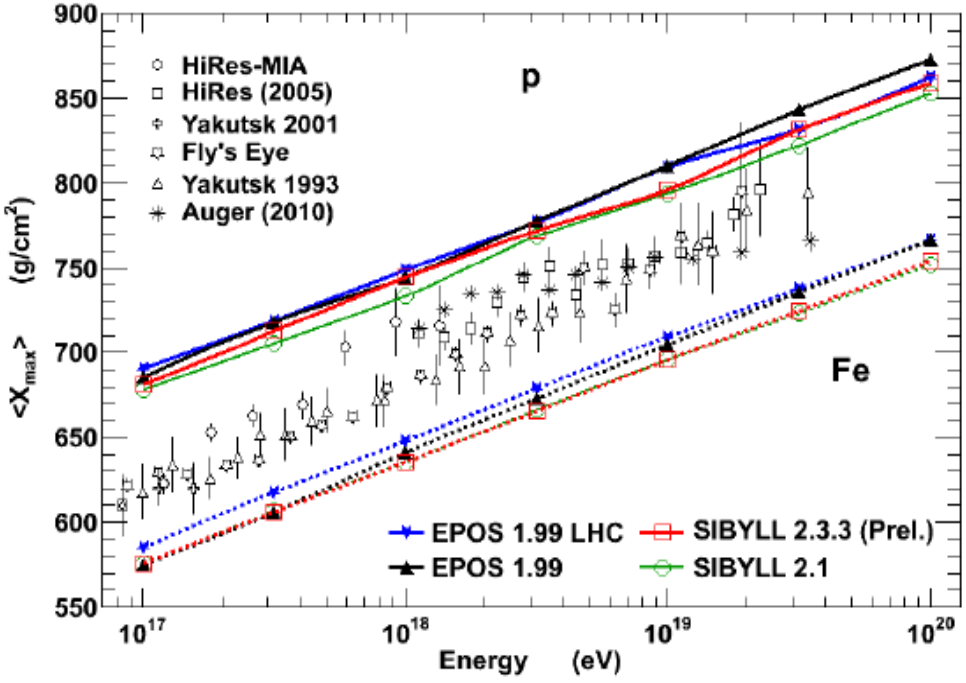
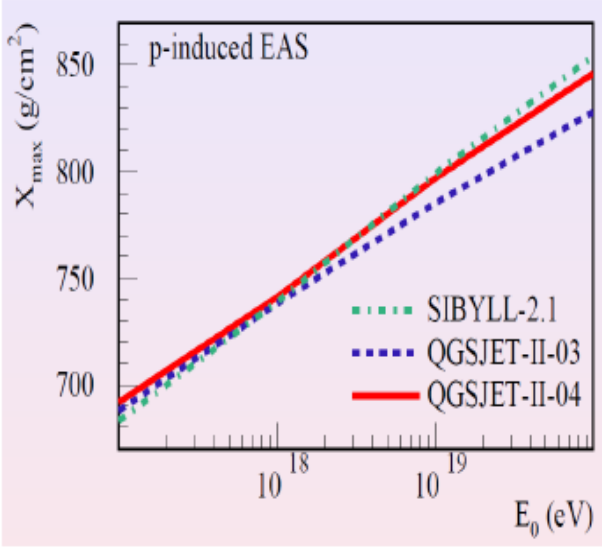


$$\Lambda_\eta = [55.8 \pm 2.3_{\mathrm{stat}} \pm 1.6_{\mathrm{sys}}]\ \mathrm{g/cm^2}$$

Learning from the LHC

- **Cross section and multiplicity fixed at 7 TeV**
  - smaller $\langle X_{max} \rangle$ for EPOS and larger for QGSJETII
  - re-tuned model converge to old Sibyll 2.1 predictions
    - reduced uncertainty from ~50 g/cm^2 to ~20 g/cm^2 (difference proton/iron is about 100 g/cm^2)





from S. Ostapchenko