Mapping distributions of production variables of UHECR-air interactions onto the (X_{max}, N_μ) space

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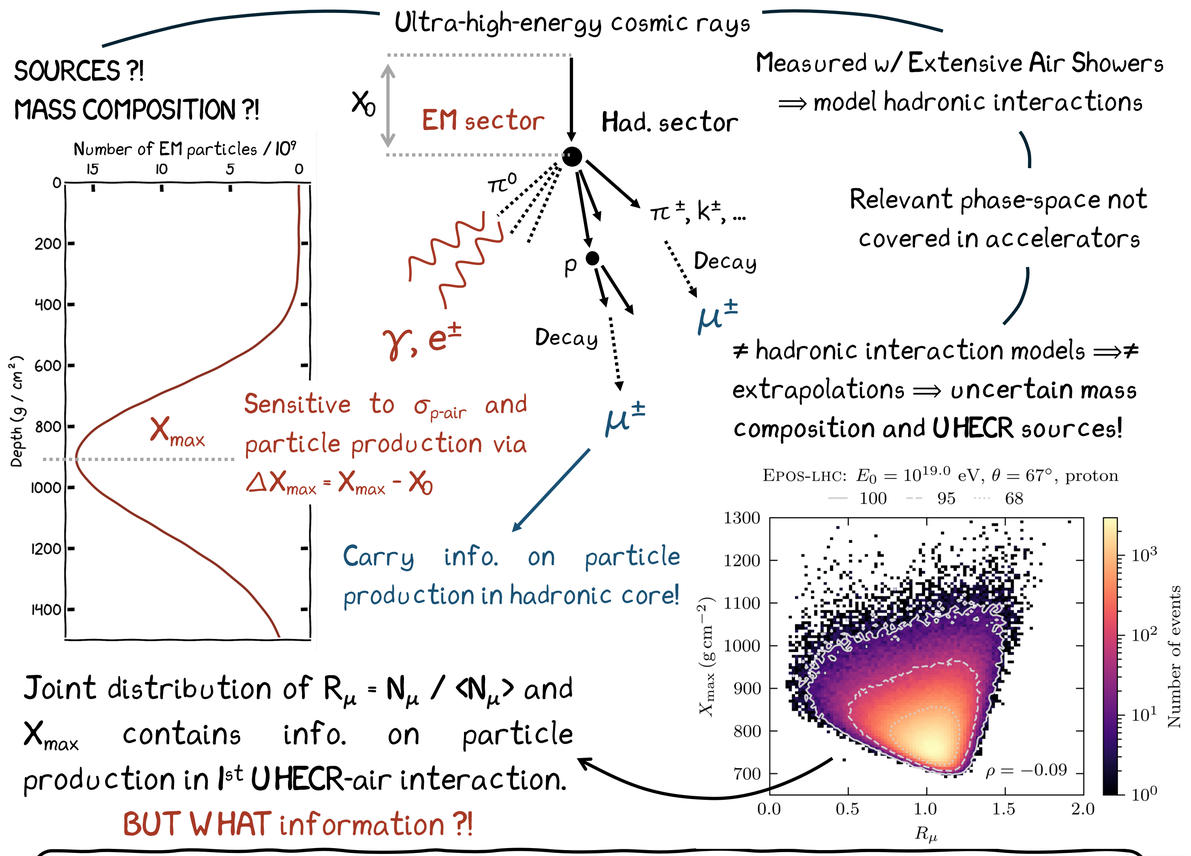
SCAN ME

What you need to know



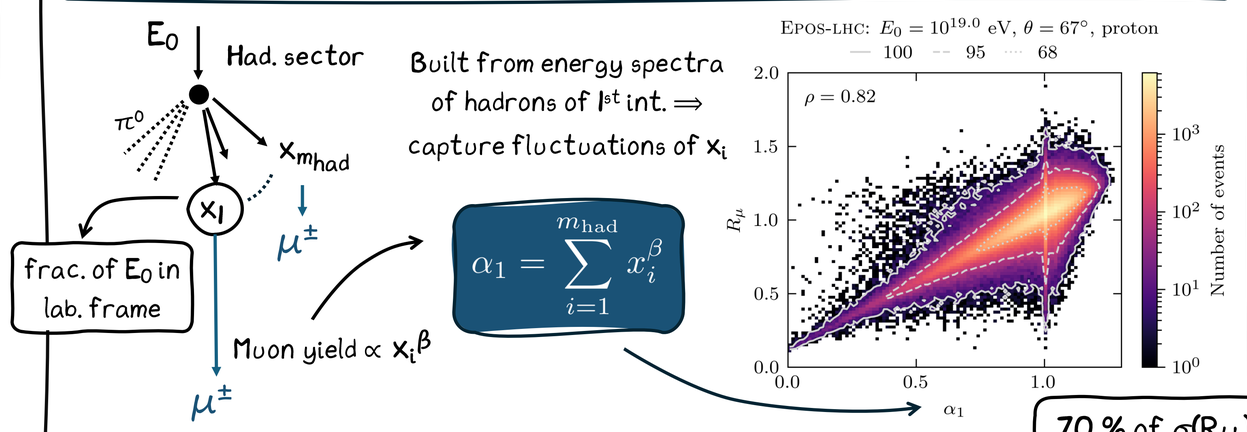
Joint distribution of $R_\mu = N_\mu / \langle N_\mu \rangle$ and X_{max} contains info. on particle production in 1st UHECR-air interaction.

BUT WHAT information ?!

GOALS:

1. Review model for fluctuations of N_μ in terms of 1st int. variables
2. Derive model for fluctuations of X_{max} in terms of 1st int. variables
3. Map new 1st int. variables onto the joint distribution of N_μ and X_{max}

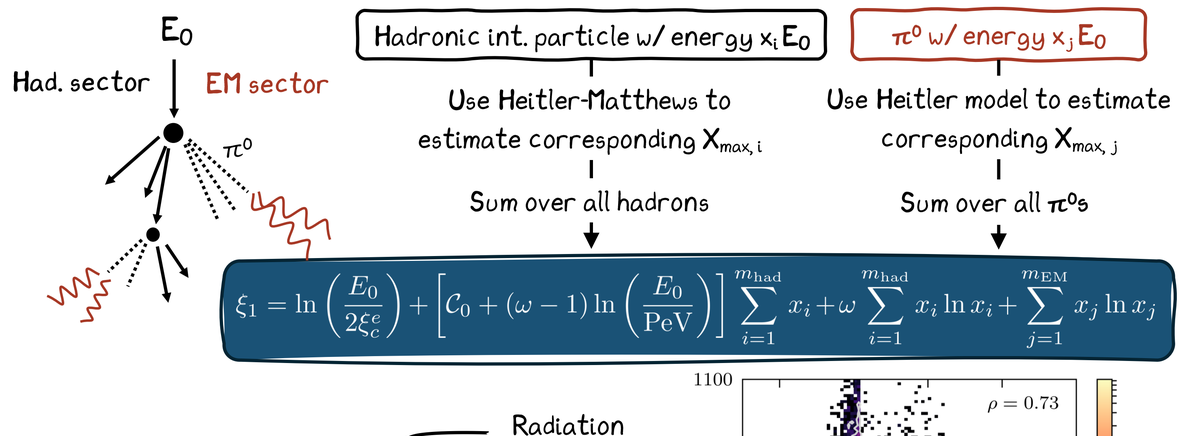
2. Mapping fluctuations in the 1st interaction onto N_μ



CONCLUSION: distribution of N_μ mostly shaped by distribution of α_1

70 % of $\sigma(R_\mu)$ due to $\sigma(\alpha_1)$!

3. Mapping fluctuations in the 1st interaction onto X_{max}



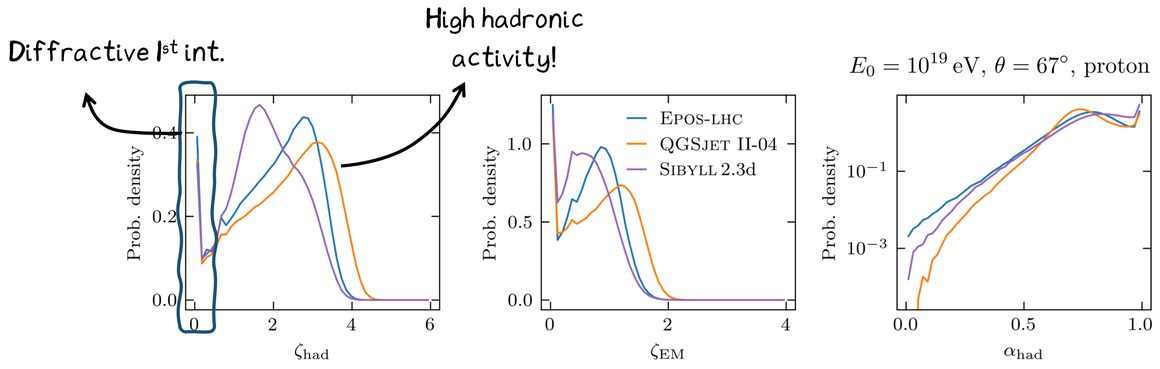
- 50 % of $\sigma(\Delta X_{max})$ due to $\lambda_r \sigma(\xi_1)$
- Shower-by-shower value of ξ_1 predicts ΔX_{max} within 30 gcm^{-2}

CONCLUSION: distribution of ΔX_{max} mostly shaped by distribution of ξ_1

4. New macroscopic variables of 1st interaction

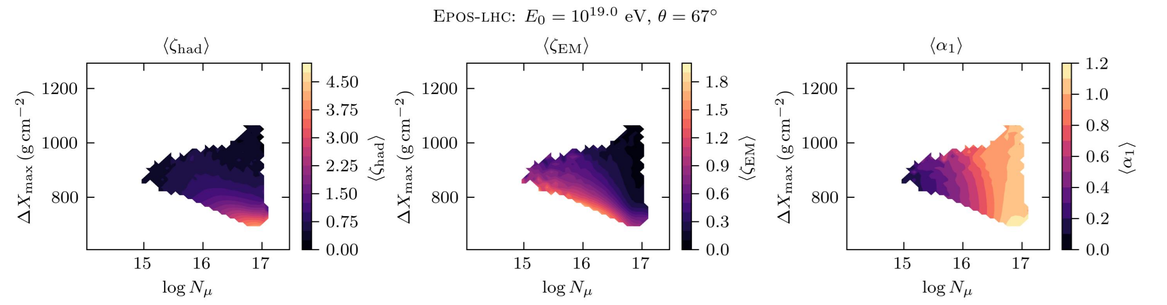
INTERPRETATION:
Sensitive to number of secondaries and how evenly energy is shared among them

$$\zeta_{had} = -\sum_{i=1}^{m_{had}} x_i \ln x_i \qquad \zeta_{EM} = -\sum_{j=1}^{m_{EM}} x_j \ln x_j$$



CONCLUSION: Shapes of distributions of ζ_{had}, ζ_{EM} and α_{had} extremely dependent on hadronic interaction model ⟹ high constraining power!

5. New macroscopic variables of 1st int. in (X_{max}, N_μ) plane



CONCLUSION: Relevant features of (N_μ, ΔX_{max}) joint p.d.f correspond to ≠ values of ζ_{had}, ζ_{EM} and α_1 ⟹ natural description of (N_μ, ΔX_{max}) plane in terms of 1st int.!

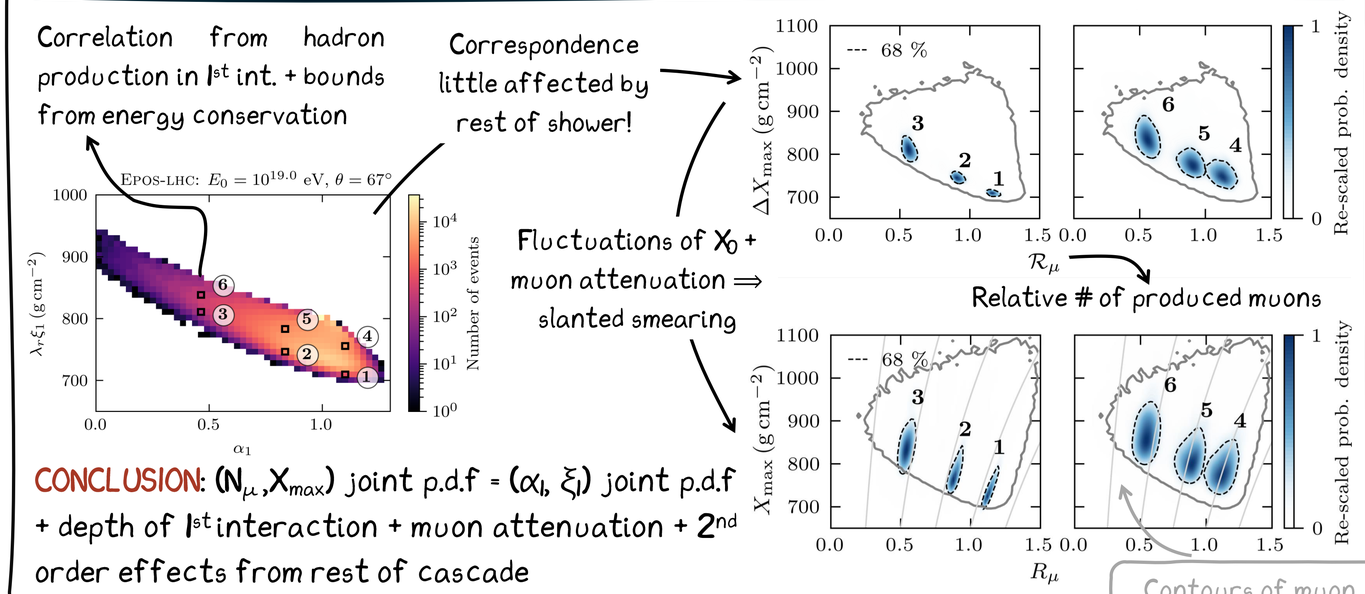
6. Direct map: (α_1,ξ_1) onto (X_{max}, N_μ)

Correlation from hadron production in 1st int. + bounds from energy conservation

Correspondence little affected by rest of shower!

Fluctuations of X_0 + muon attenuation ⟹ slanted smearing

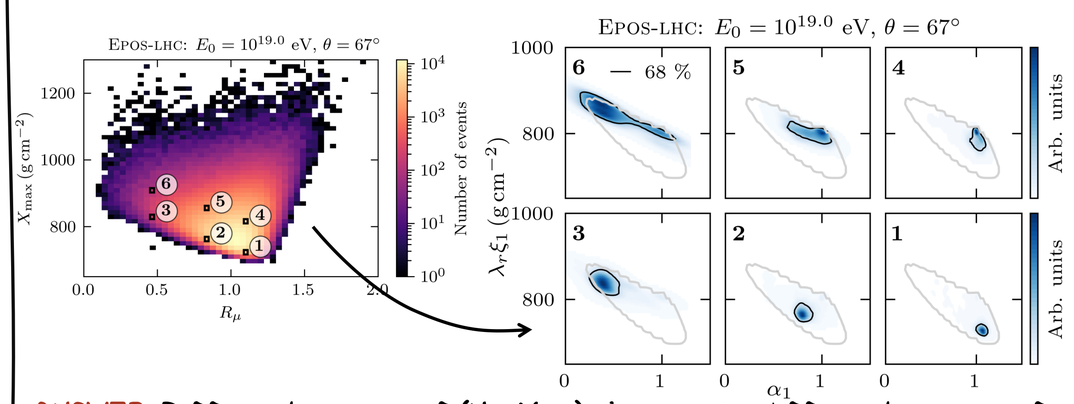
Relative # of produced muons



CONCLUSION: (N_μ,X_{max}) joint p.d.f = (α_1, ξ_1) joint p.d.f + depth of 1st interaction + muon attenuation + 2nd order effects from rest of cascade

7. Inverse map: (X_{max}, N_μ) onto (α_1,ξ_1)

QUESTION: Can we use the joint distribution of N_μ and X_{max} to probe the joint distribution of (α_1, ξ_1) a.k.a. 1st int. properties?!



ANSWER: Different regions of (N_μ, X_{max}) plane probe different regions of (α_{had}, ξ_1) joint distribution ⟹ IT SEEMS WE CAN!

Yeah cool ...TL;DR ?

- Interpretated fluctuations of X_{max} in terms of a single 1st interaction variable ξ_1
- Full description of shape of joint distribution of X_{max} and N_μ in terms of joint distributions of variables of 1st interaction: (α_1, ξ_1)
- Mapping between 1st variables and joint distribution of X_{max} and N_μ can be inverted ⟹ constrain hadronic interactions beyond LHC capabilities using UHECRs!

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