Universality "v2"
the final* chapters

*not really final

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Engel - Sanchez - Roth - Veberic

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METHOD:

→ the air-shower symmetry known as *universality* motivates a model of EAS where the overall development of the particle cascade is a function of X_{max} and R_{μ}

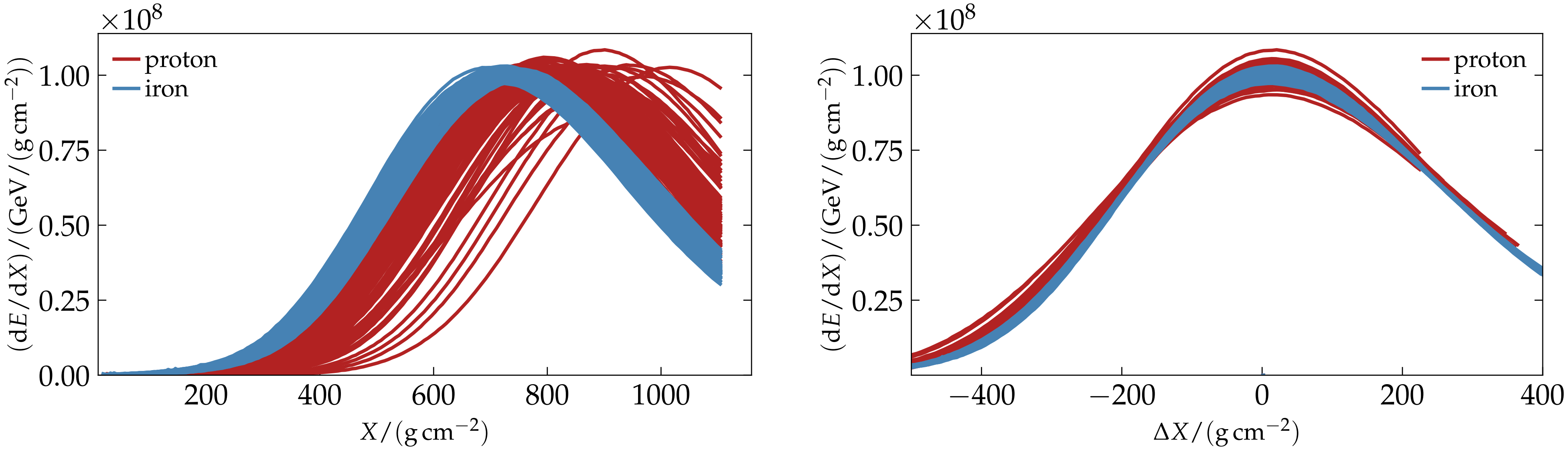
TASK:

→ *(re-)*paremtrize expected WCD & SSD signals
→ develop model for the time-dependent signal and uncertainty
→ calibrate using Golden Hybrid events
→ find a method to directly reconstruct $\ln A$ from X_{max} and R_{μ}
→ see what data tells us

WHY?:

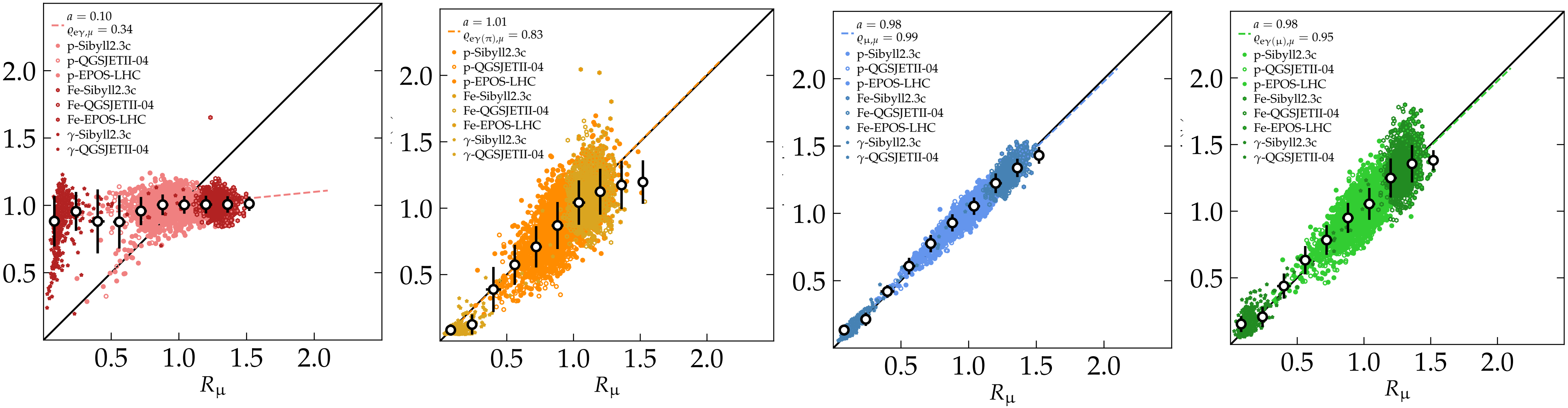
→ this way we can estimate the masses of CRs *event-by-event*

THE SYMMETRY - LONGITUDINAL PROFILE

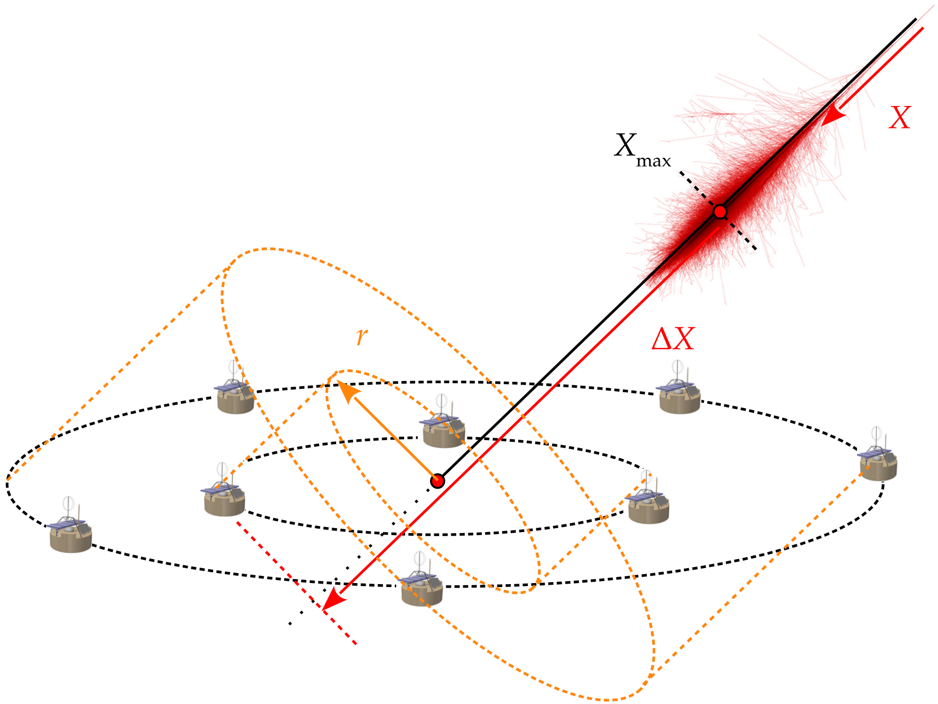


THE SYMMETRY - FOUR COMPONENTS

$$\frac{S_i}{\langle S_i^{\mathrm{p}} \rangle} \qquad i \in \{\mathrm{e}\gamma, \mu, \mathrm{e}\gamma(\pi), \mathrm{e}\gamma(\mu)\}$$

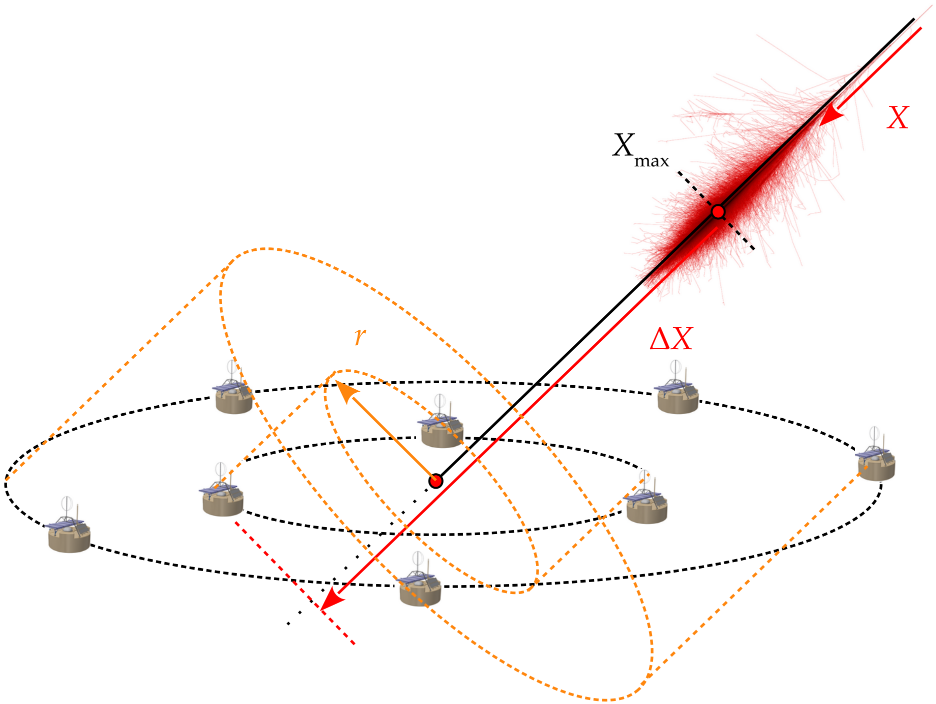


THE MODEL - LONGITUDINAL & LATERAL PROFILE

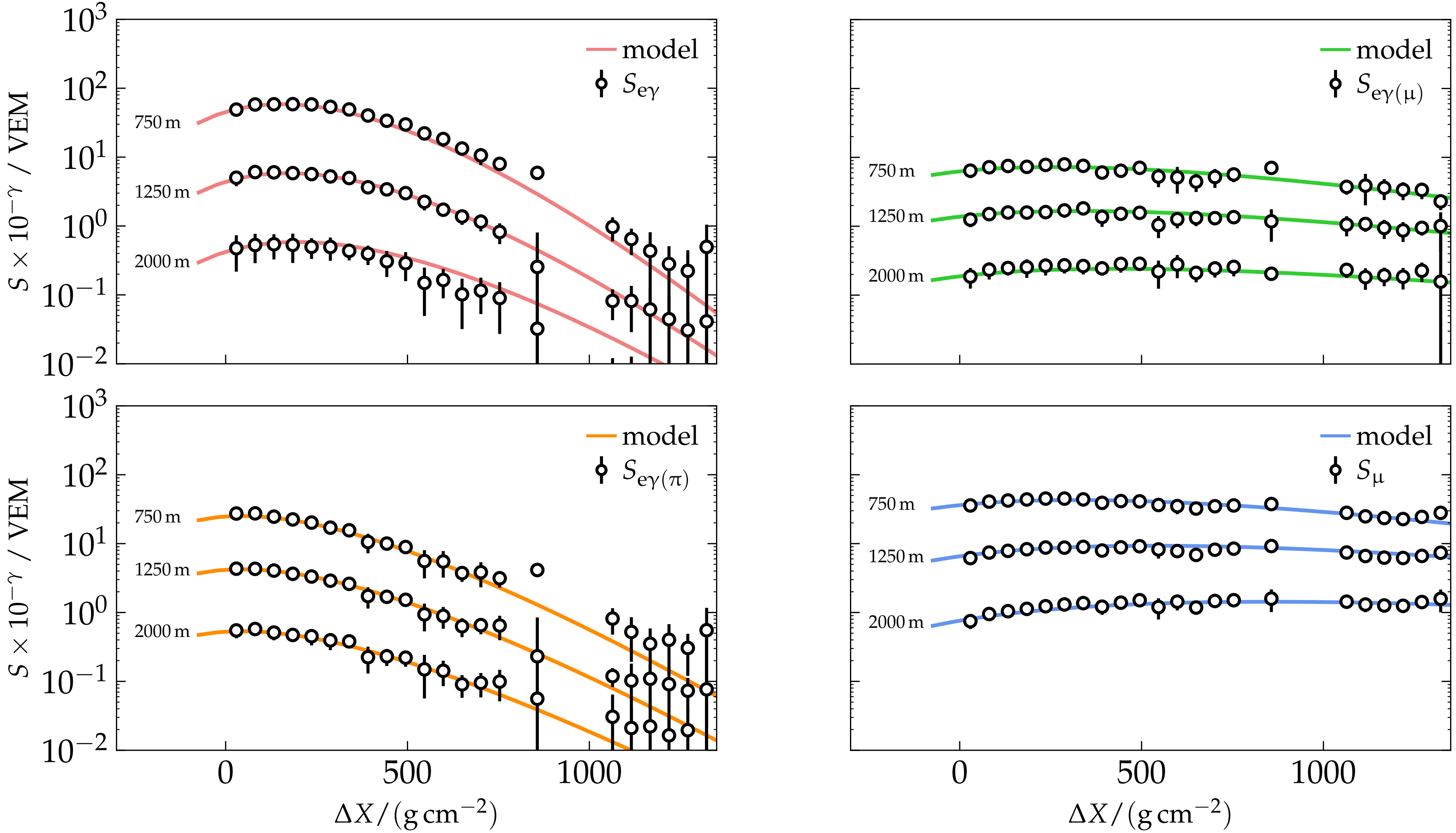


THE MODEL - LONGITUDINAL & LATERAL PROFILE

$$\varrho(E,\Delta X,r) = \left(a\left(R_{\mu}-1\right)+1\right)\left(\frac{E}{10^{19}\,\mathrm{eV}}\right)^{\gamma}\left(\frac{\Delta X-\Delta X_1}{\Delta X_{\mathrm{ref}}-\Delta X_1}\right)^{\frac{\Delta X_{\mathrm{max}}-\Delta X_1}{\lambda}} \mathrm{e}^{-\frac{\Delta X-\Delta X_{\mathrm{ref}}}{\lambda}}\,\frac{N_{\mathrm{ref}}^{19}}{2\pi r_{\mathrm{M}}^2}\,\frac{\Gamma(\frac{9}{2}-s)}{\Gamma(s)\Gamma(\frac{9}{2}-2s)}\left(\frac{r}{r_{\mathrm{M}}}\right)^{s-2}\left(1+\frac{r}{r_{\mathrm{M}}}\right)^{s-\frac{9}{2}}$$

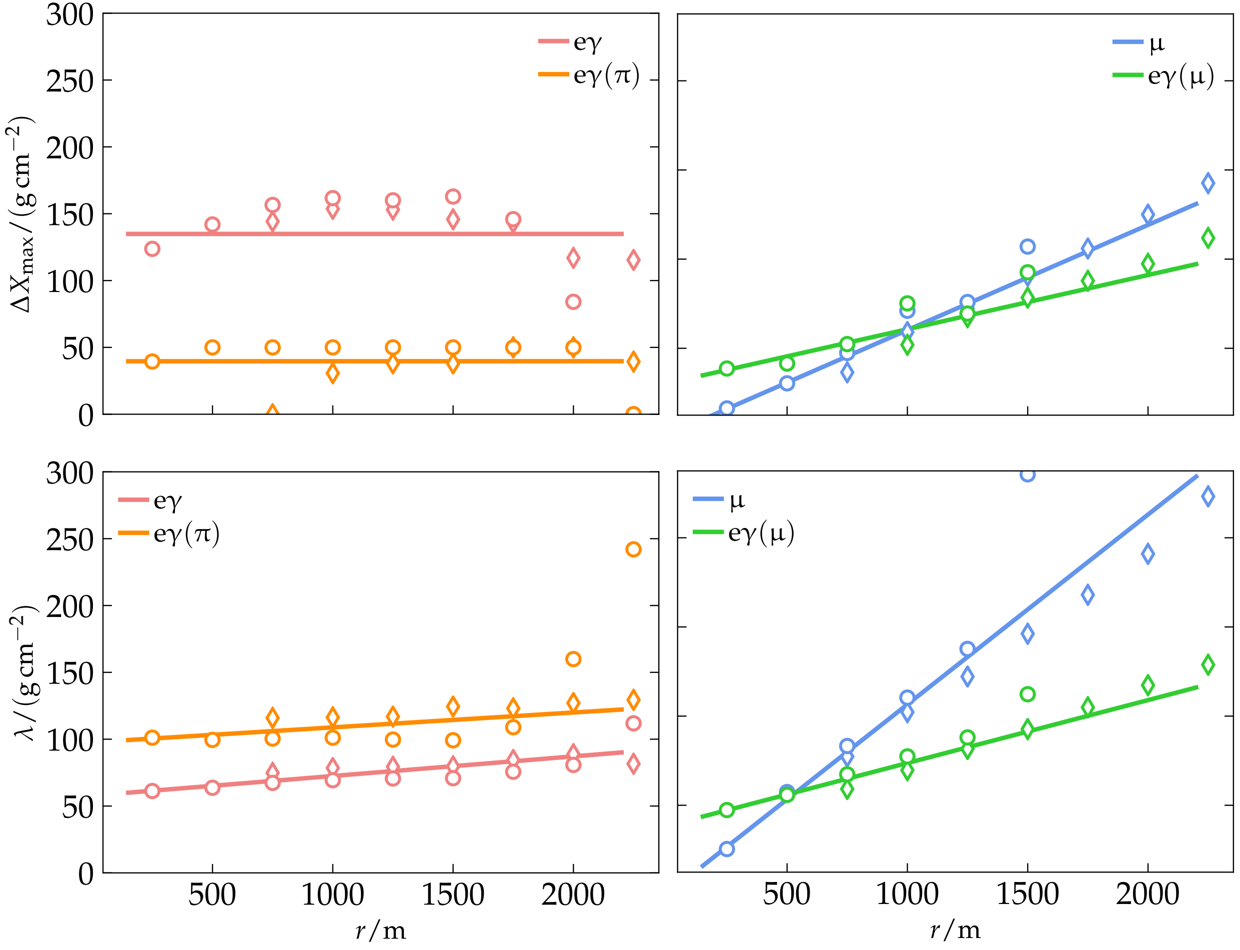


component scaling
energy
longitudinal development
lateral distribution

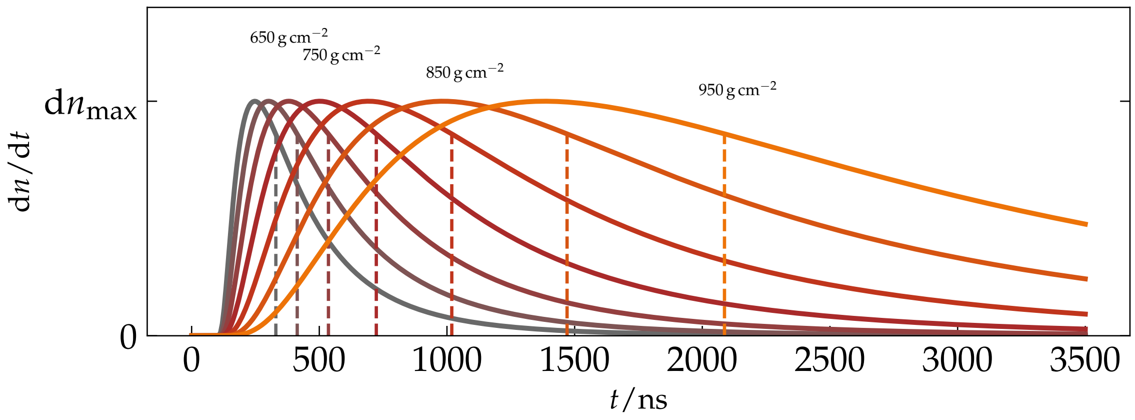

model
$S_{e\gamma}$
model
$S_{e\gamma(\mu)}$
model
$S_{e\gamma(\pi)}$
model
S_{μ}
750 m
1250 m
2000 m
$S \times 10^{-\gamma}$ / VEM
$\Delta X / (\mathrm{g\,cm^{-2}})$
0
500
1000
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

retardation of
the shower maximum

“GH” interaction length,
ca. 3/2 interaction length



THE MODEL - ARRIVAL TIMES / TIME TRACES



$$\frac{dn}{dt} = n_{tot}\,\mathfrak{ln}(t_{40},\sigma) = \frac{n_{tot}}{\sqrt{2\pi}\,\sigma\,(t-t_0)}\,e^{-\frac{1}{2\sigma^2}\left(\ln\left(\frac{t-t_0}{t_{40}-t_0}\right)+\sqrt{2}\sigma\,\mathrm{erf}^{-1}(2\times0.4-1)\right)^2}$$

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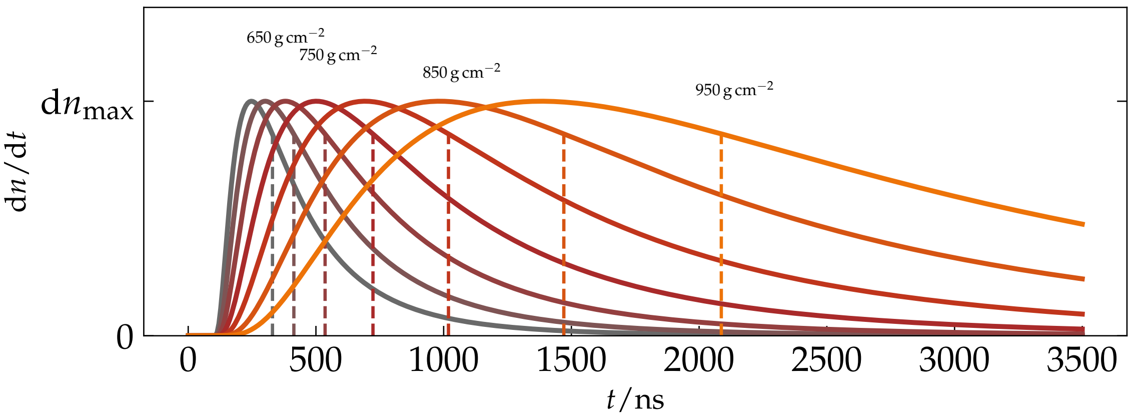
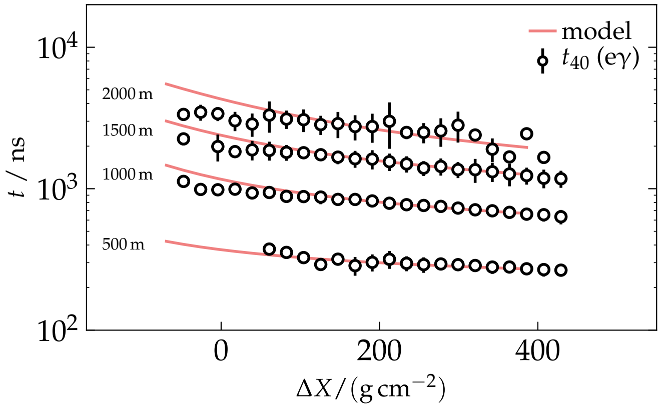
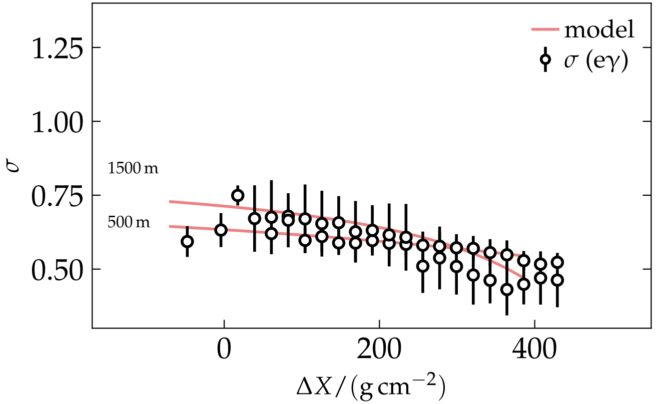


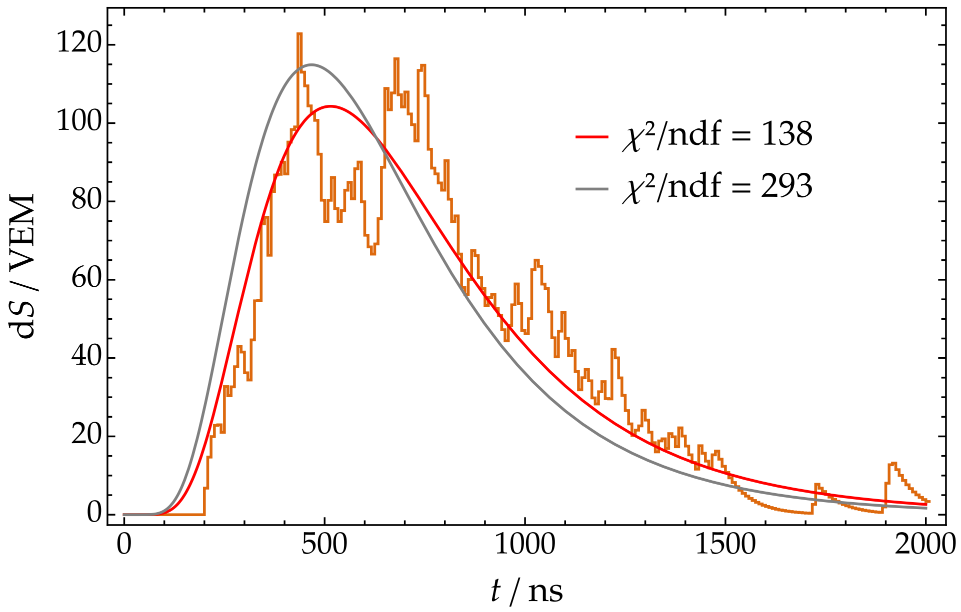




$$\frac{\mathrm{d}n}{\mathrm{d}t} = n_{\mathrm{tot}}\, \ln(t_{40}, \sigma) = \frac{n_{\mathrm{tot}}}{\sqrt{2\pi}\,\sigma\,(t-t_0)}\, \mathrm{e}^{-\frac{1}{2\sigma^2}\left(\ln\left(\frac{t-t_0}{t_{40}-t_0}\right)+\sqrt{2}\sigma\,\mathrm{erf}^{-1}(2\times 0.4-1)\right)^2}$$

THE MODEL - ARRIVAL TIMES / TIME TRACES

model works perfectly for the arrival time of muons, but needs tuning for different particles and realistic detectors



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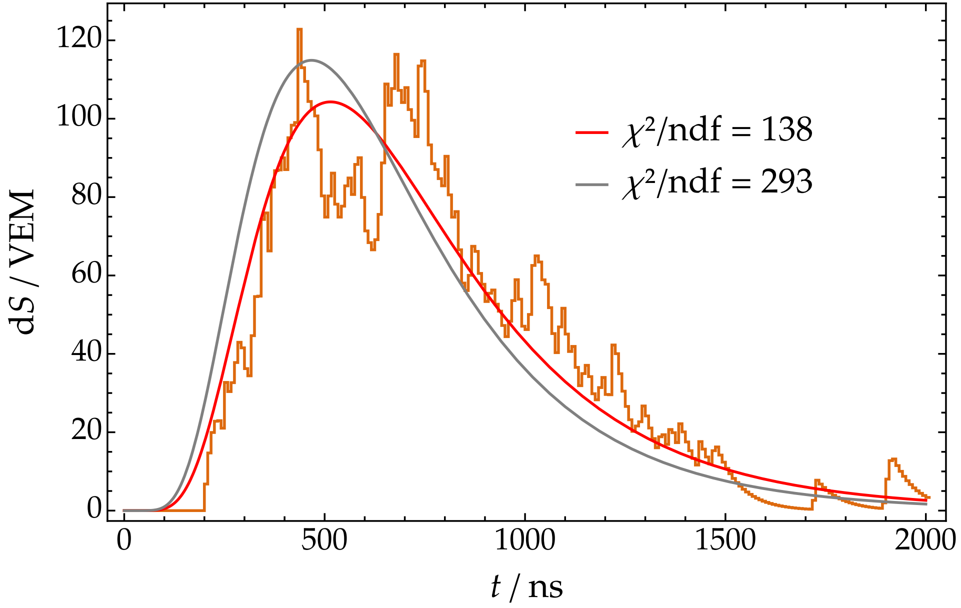
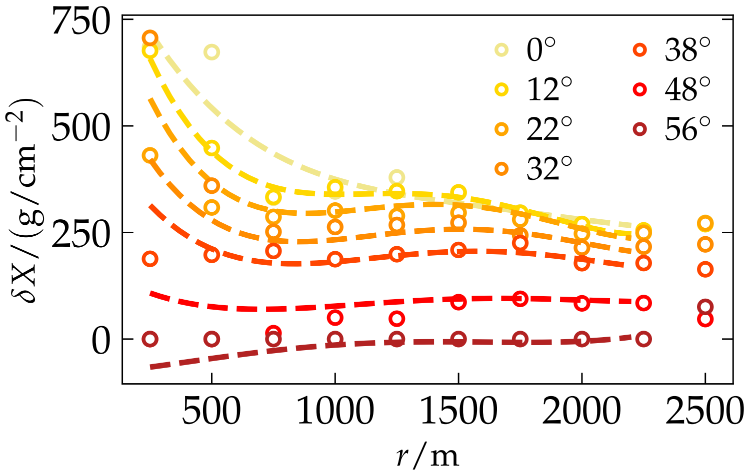
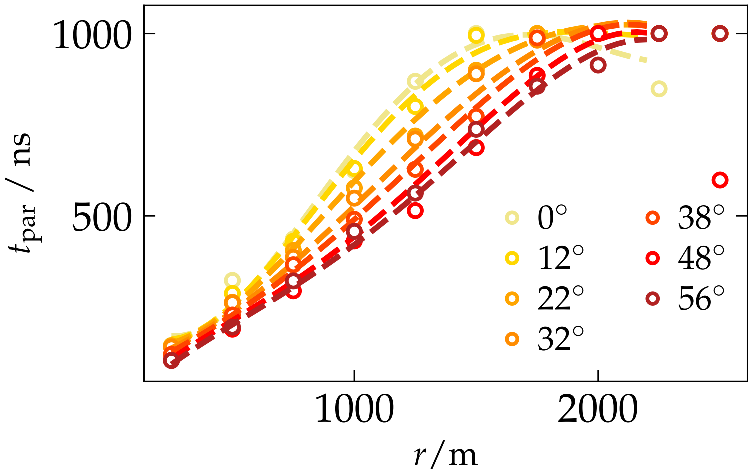
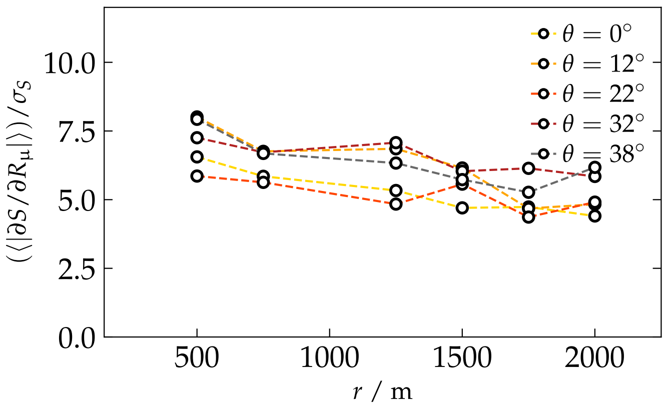


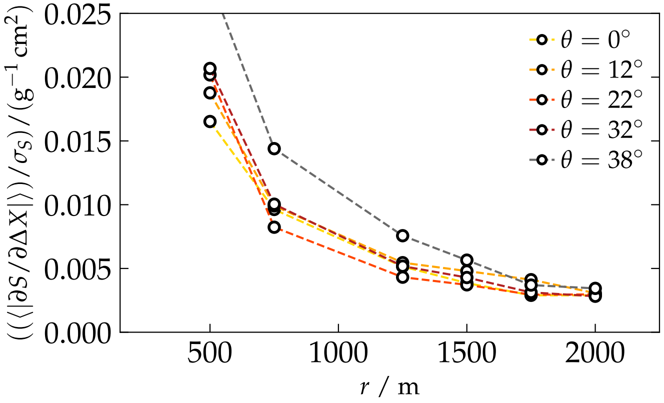


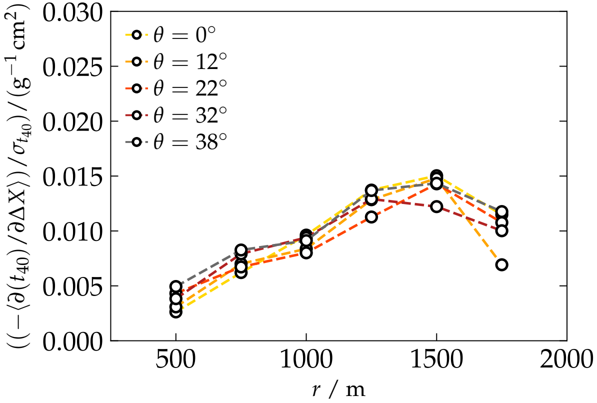


EXPECTED SENSITIVITY

assume **perfectly** reconstructed energy and geometry, how much information does the signal from a single station actually contain?







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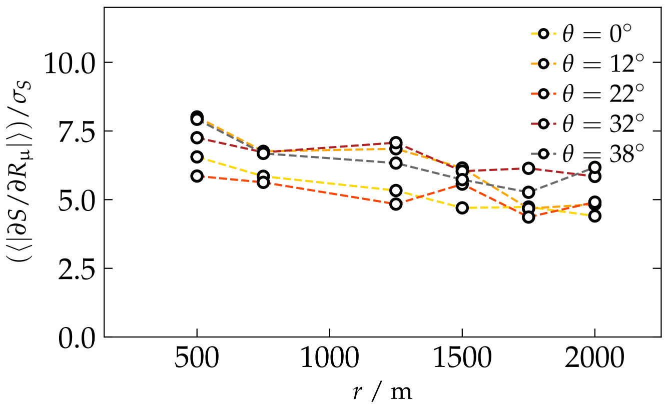
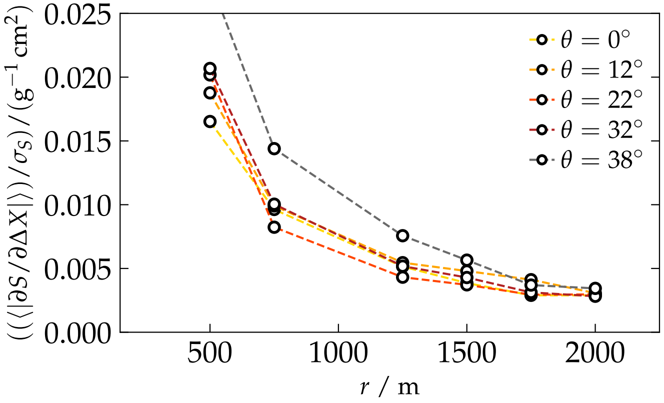
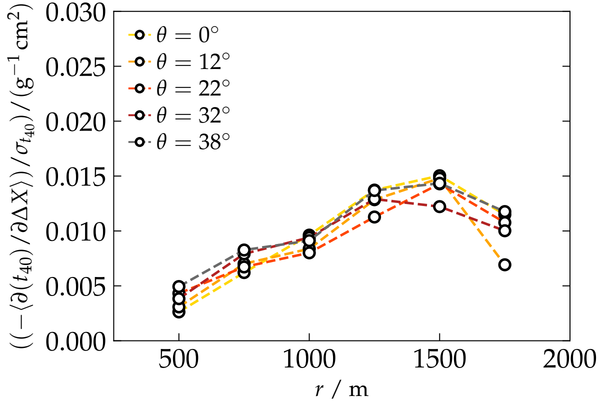


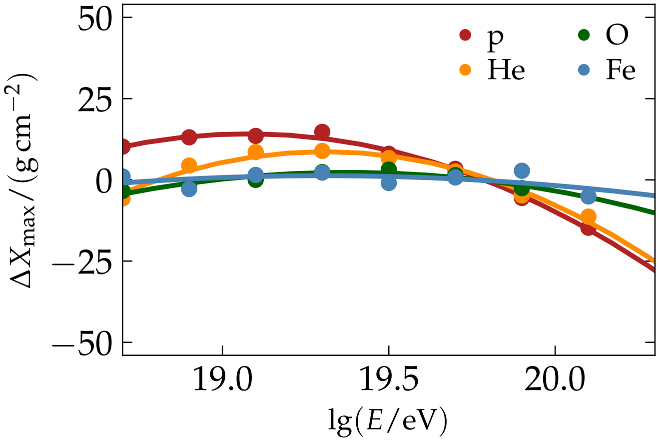


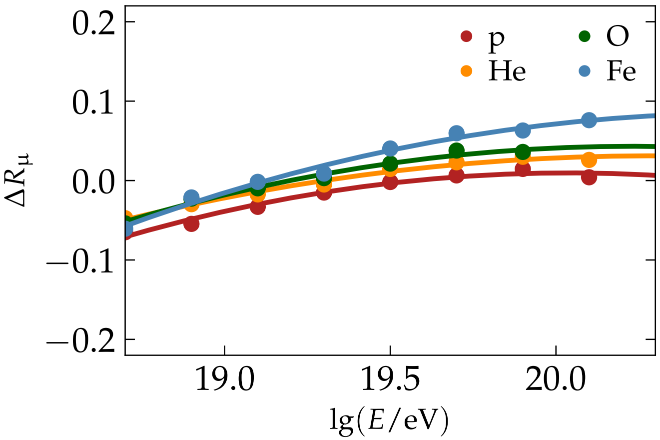


$$\sigma_{R_\mu} \simeq 0.15 \qquad \sigma_{X_{\max}} \simeq 70\,\mathrm{g\,cm^{-2}}$$

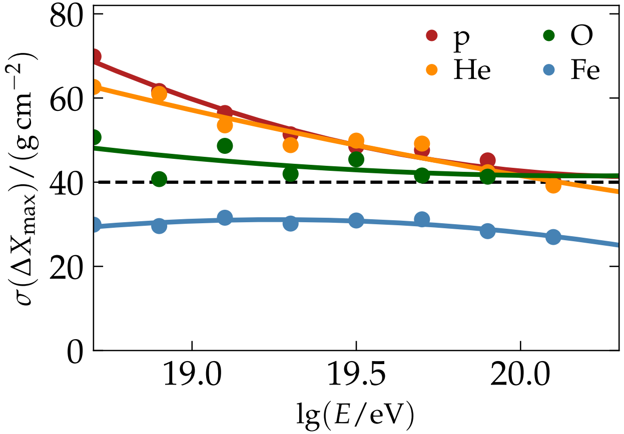
RECONSTRUCTION

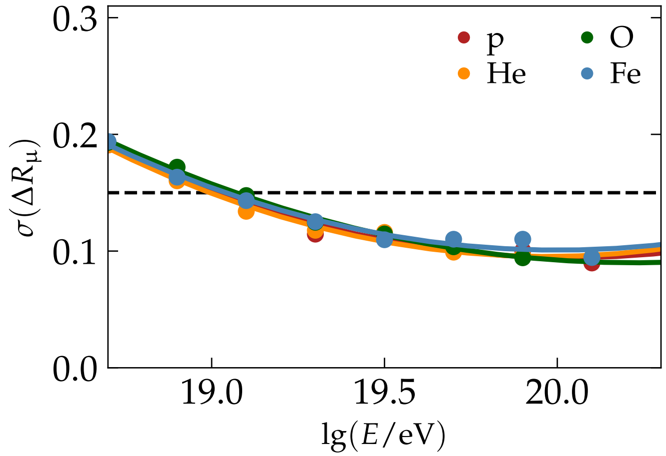
bias



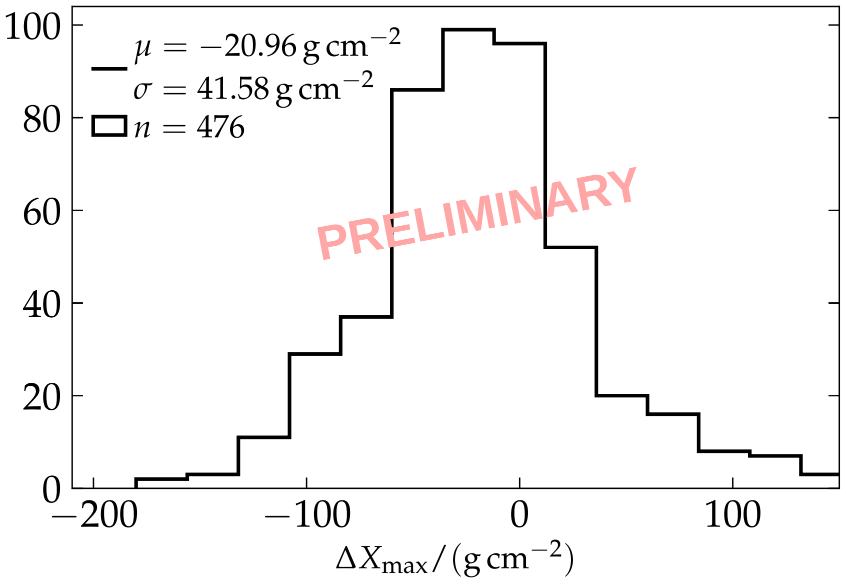


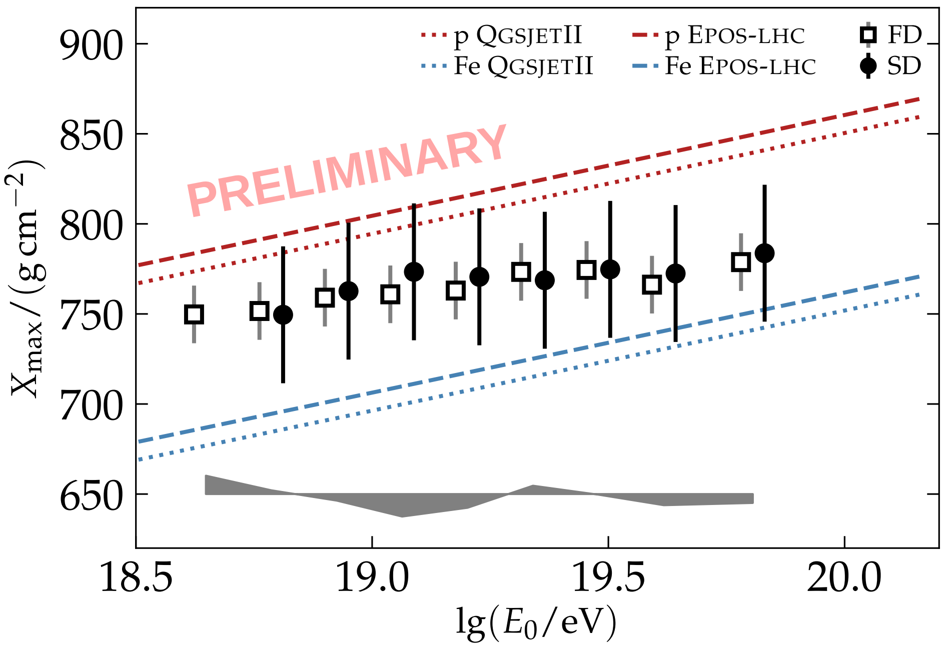
resolution



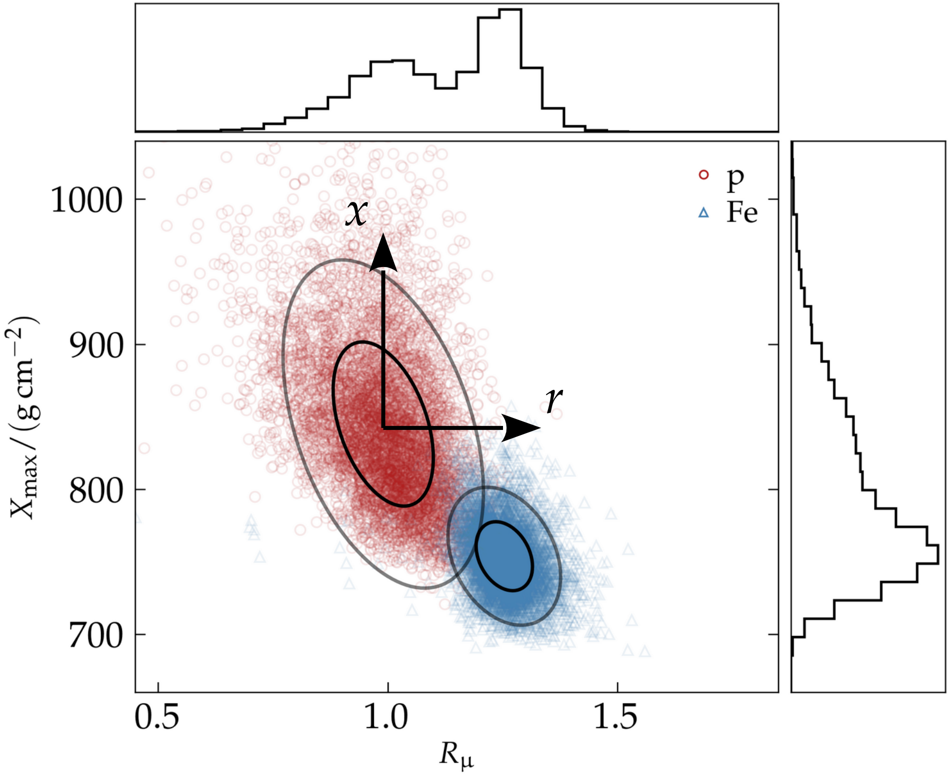


VALIDATION USING FD





BASE TRANSFORMATION METHOD



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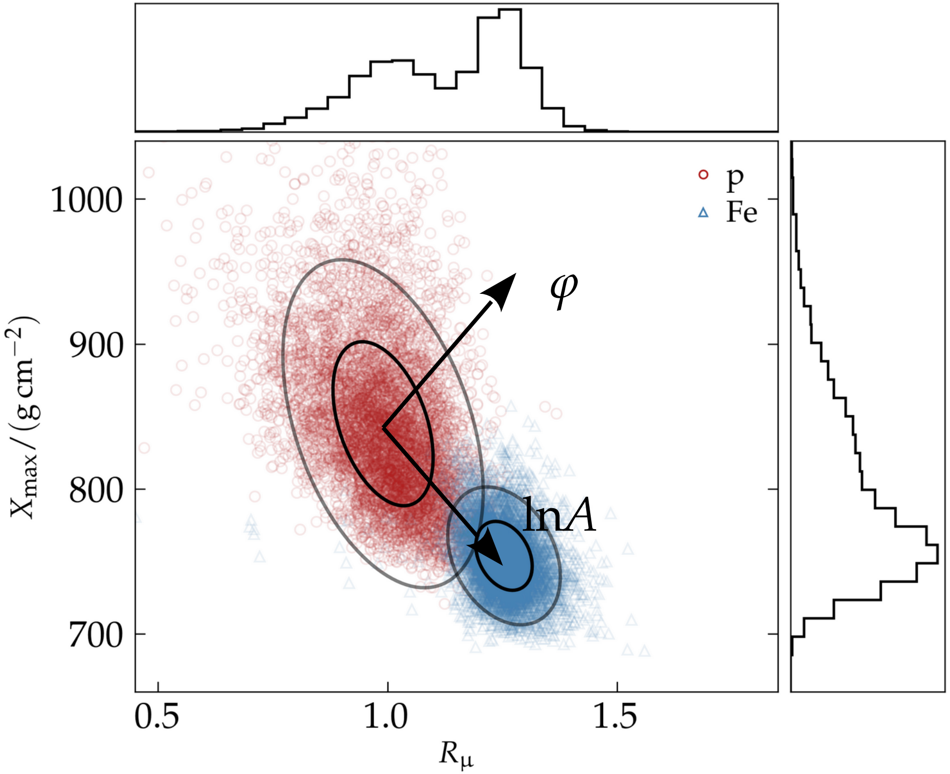

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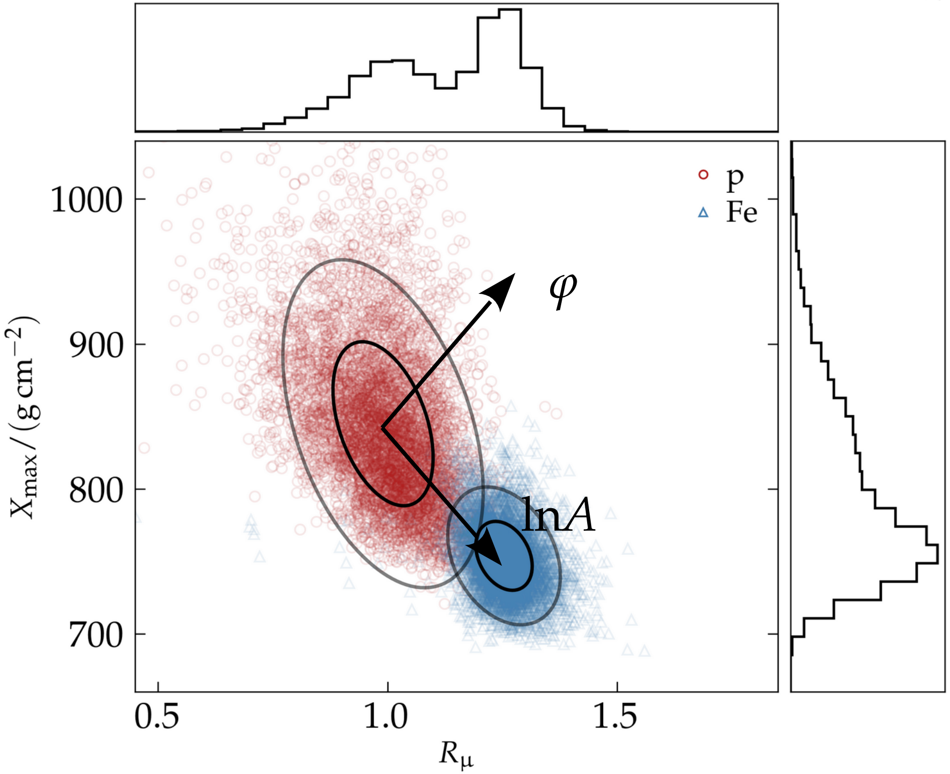


$$\mathfrak{T}\left(\left(\ln R_\mu - \ln R_\mu^{p}\right)\hat{r} + \left(X_{max} - X_{max}^{p}\right)\hat{x}\right) = \ln A\,\hat{e}_{\ln A} + \varphi\,\hat{e}_{\varphi}$$

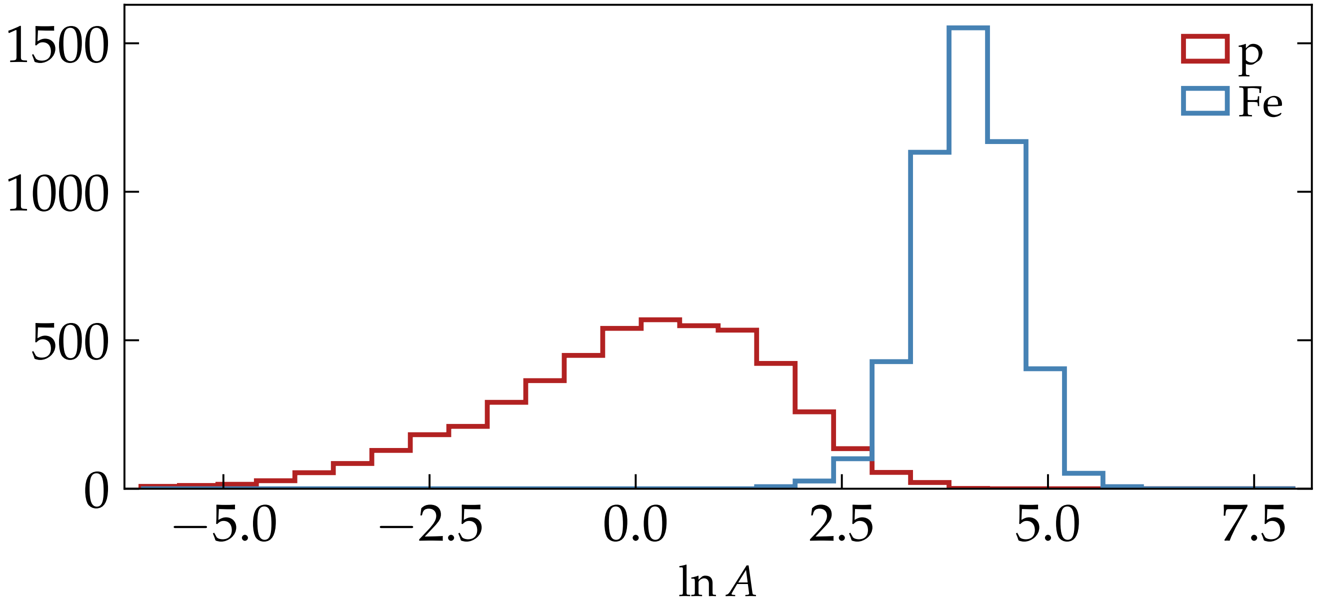
$$\mathfrak{T} = \frac{1}{\beta(\lambda+\varphi_0)}\begin{pmatrix}\varphi_0 & -\beta \\ \lambda & \beta\end{pmatrix}$$

$$\varphi_0 = \frac{\beta^2\,\sigma^2_{X_{max}}}{\lambda\,\sigma^2_{\ln R_\mu}}$$

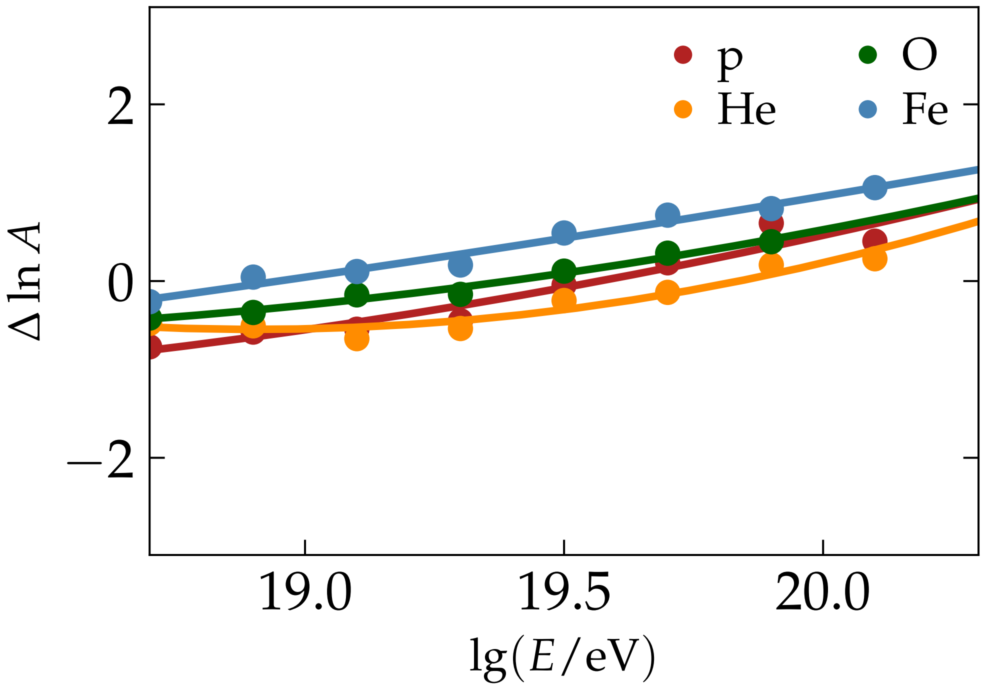
$$\sigma_{\ln A} = \sqrt{\frac{\sigma^2_{\ln R_\mu}\sigma^2_{X_{max}}}{\lambda^2\sigma^2_{\ln R_\mu}+\beta^2\sigma^2_{X_{max}}}}$$

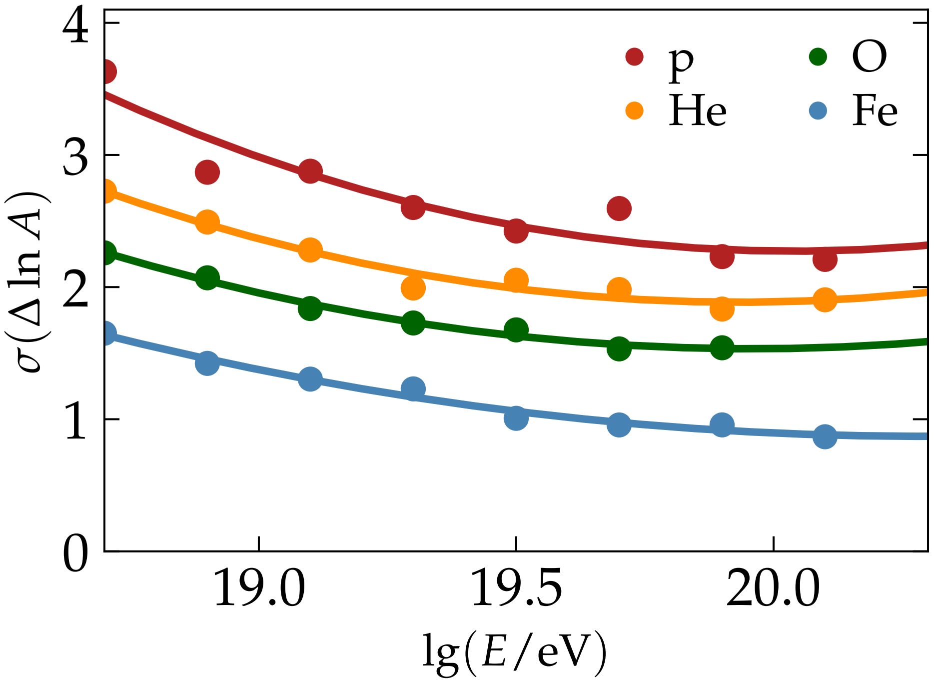
BASE TRANSFORMATION METHOD

benchmark for $\ln A$
yields $\mathrm{foM} = 2.3$
!!! only on MC values !!!

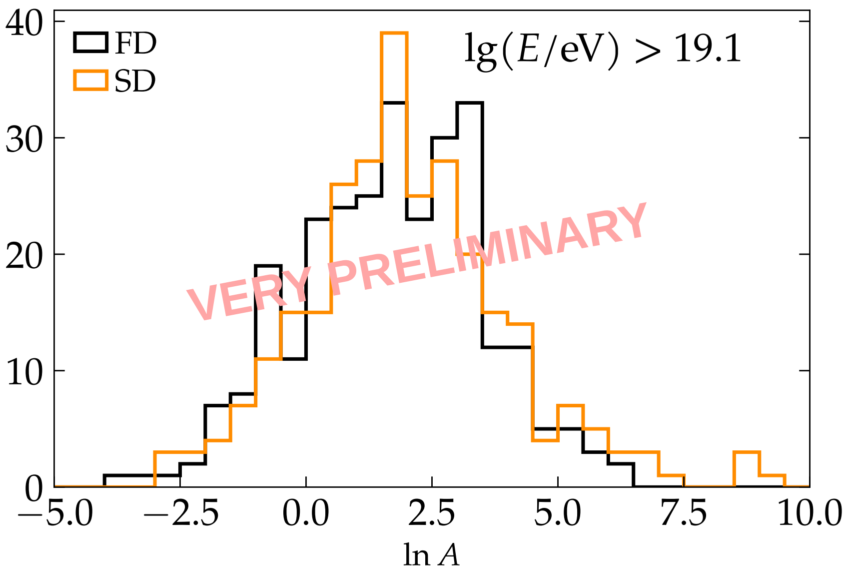


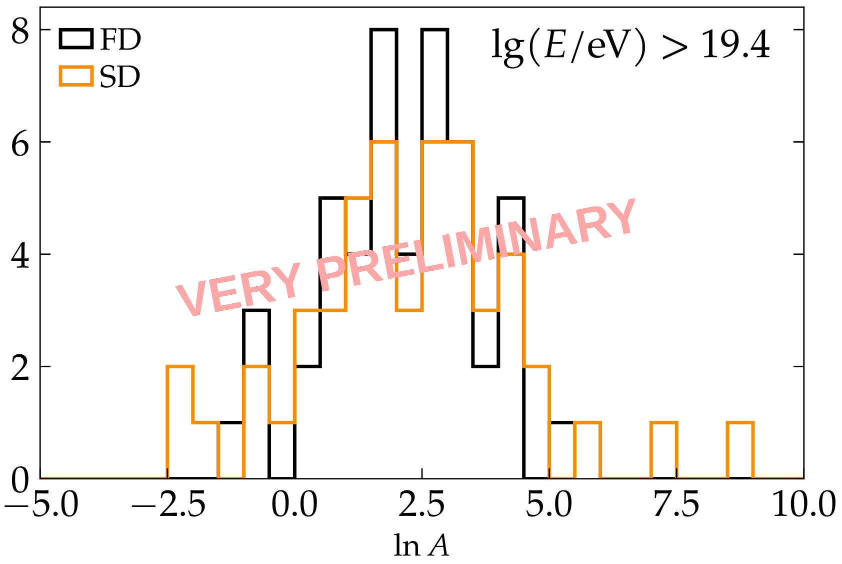
ESTIMATED PRECISION





FINAL DESTINATION: DATA





THANKS FOR LISTENING!

QUESTIONS?