Progress in Air Shower Universality

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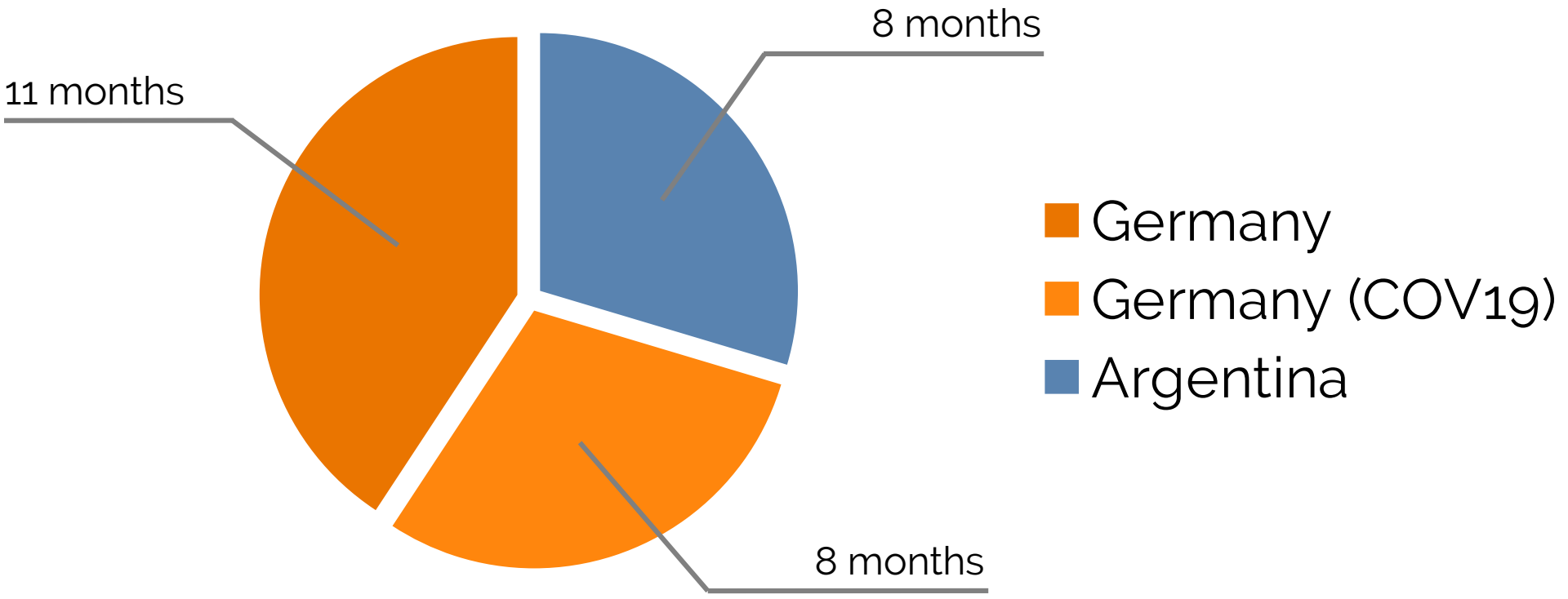
HIRSAP meeting - November 2020

time spent


8 months
11 months
8 months
Germany
Germany (COV19)
Argentina

flashback

→ Nov 18 *Buenos Aires*

very first steps,
work proposal

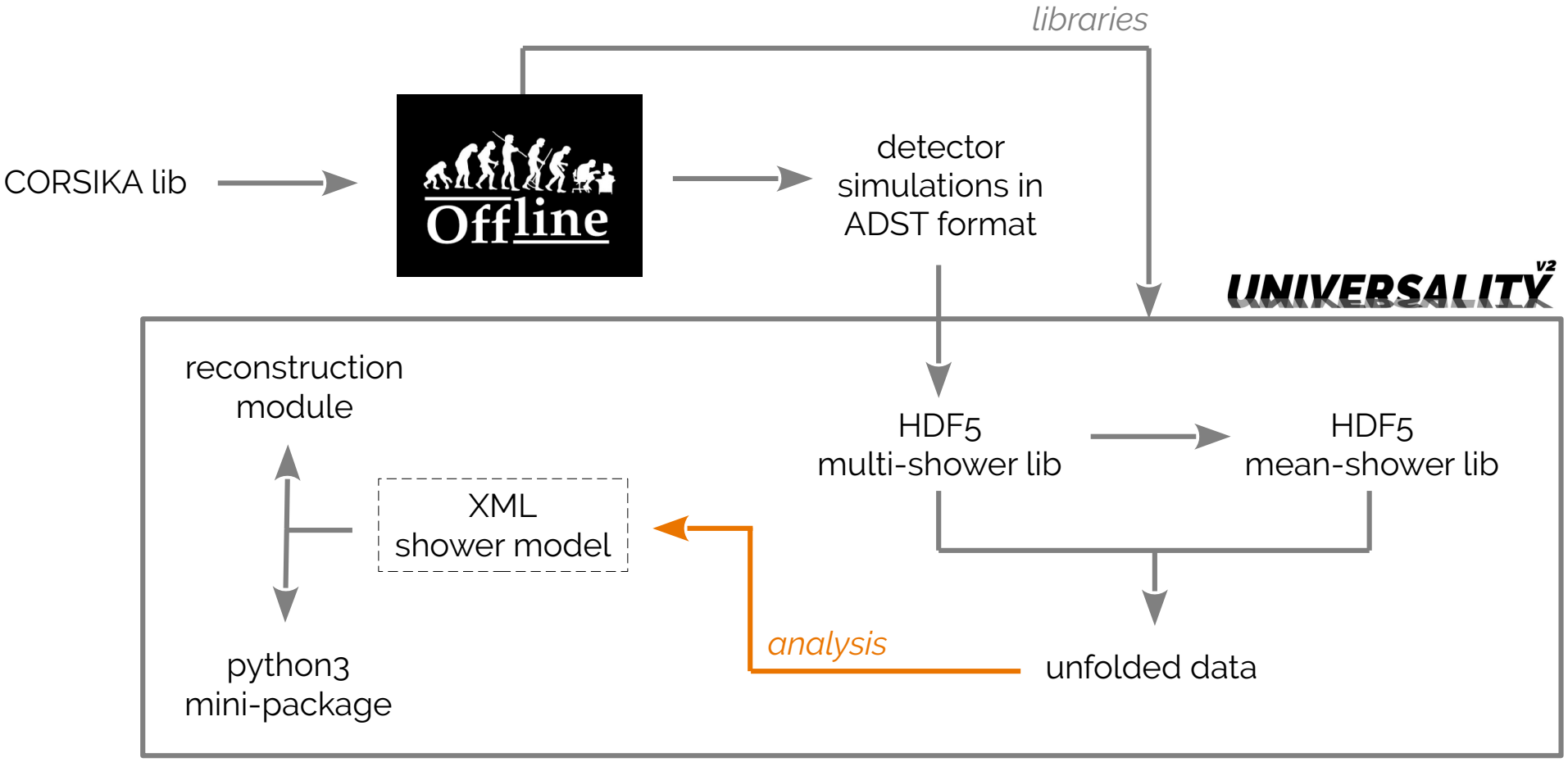
→ Nov 19 *Karlsruhe*

idea of *universality-v2*,
a lot of coding

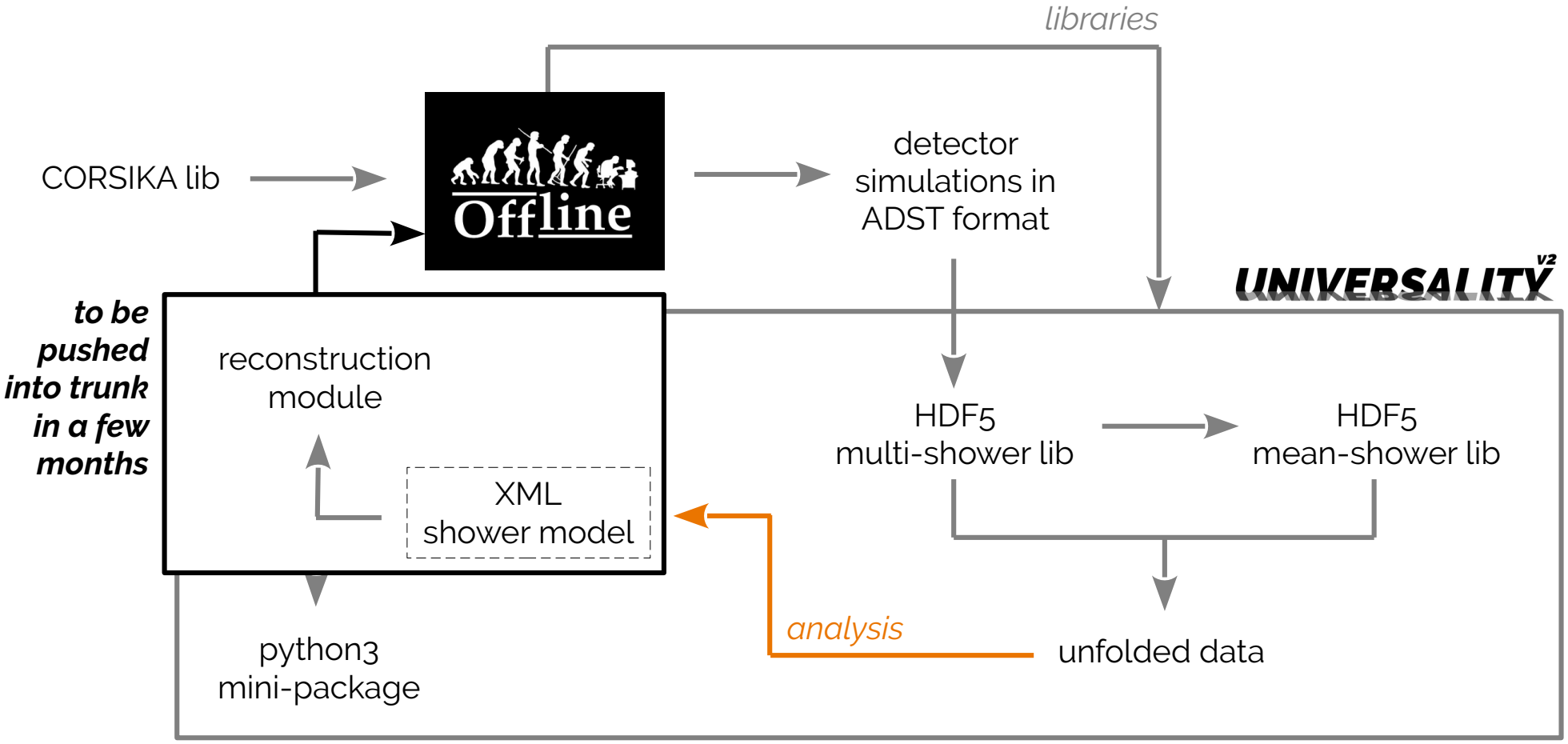
→ Nov 20 *online*

finished model in an
almost finished framework

mechanics of the code



mechanics of the code



the status of universality

signal size model

WCD (& ASCII)	M. Ave
WCD & MD	J. Hulsman

+ **revisited model for WCD & SSD**

signal timing model

start & WCD quantiles	M. Ave
WCD shape	A. Schulz
WCD & MD shape	J. Hulsman

+ **new start time model, new trace shape model for WCD & SSD**

Offline reconstruction

Bariloche	M. Ave
Karlsruhe	A. Bridgeman

+ **new but simple reconstruction using all of the above**

innovations in universality

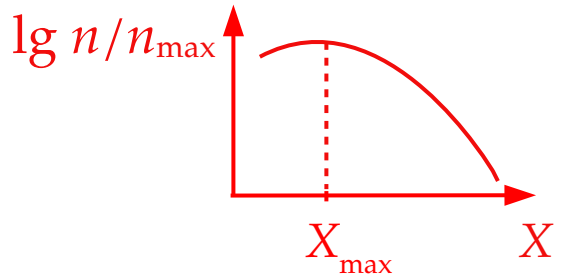
→ code is flexible and is designed to be maintainable

→ *"new"* profile function for lateral distribution of particles
true NKG, takes 1 instead of 4 extra parameters

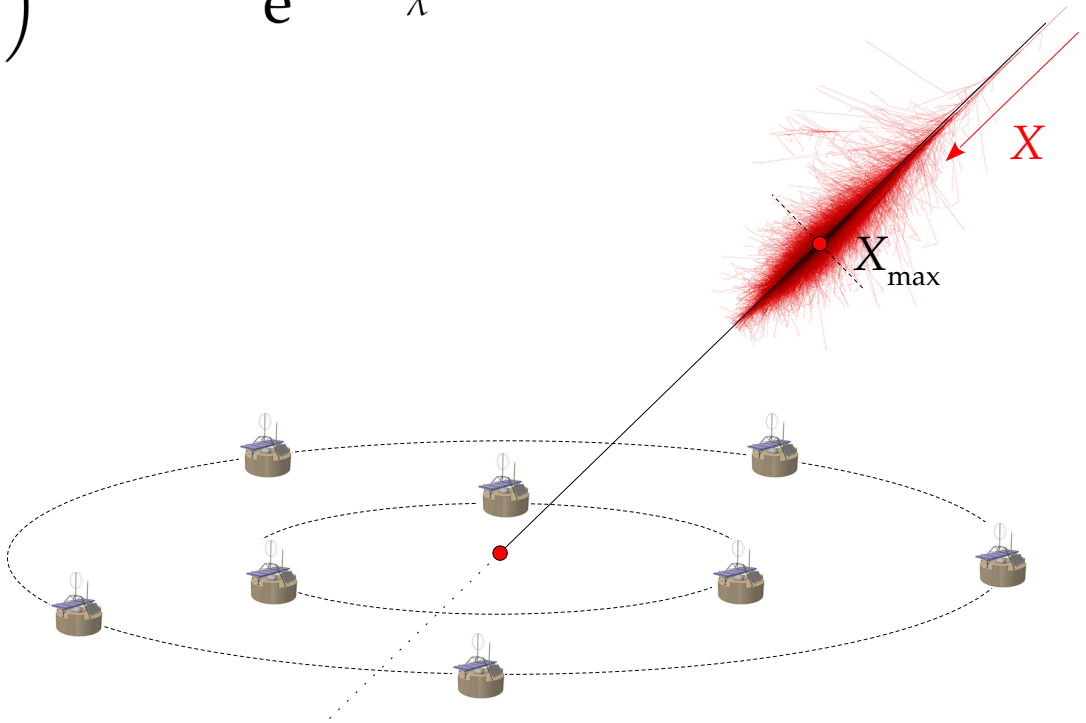
→ analytical expression for projected shower age, DX, using quasi-log-linear atmosphere
very fast, quite accurate

→ completely new formalism for the signal timing model
stay tuned!

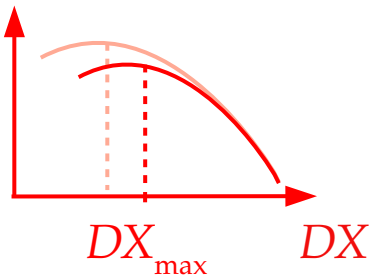
signal size model



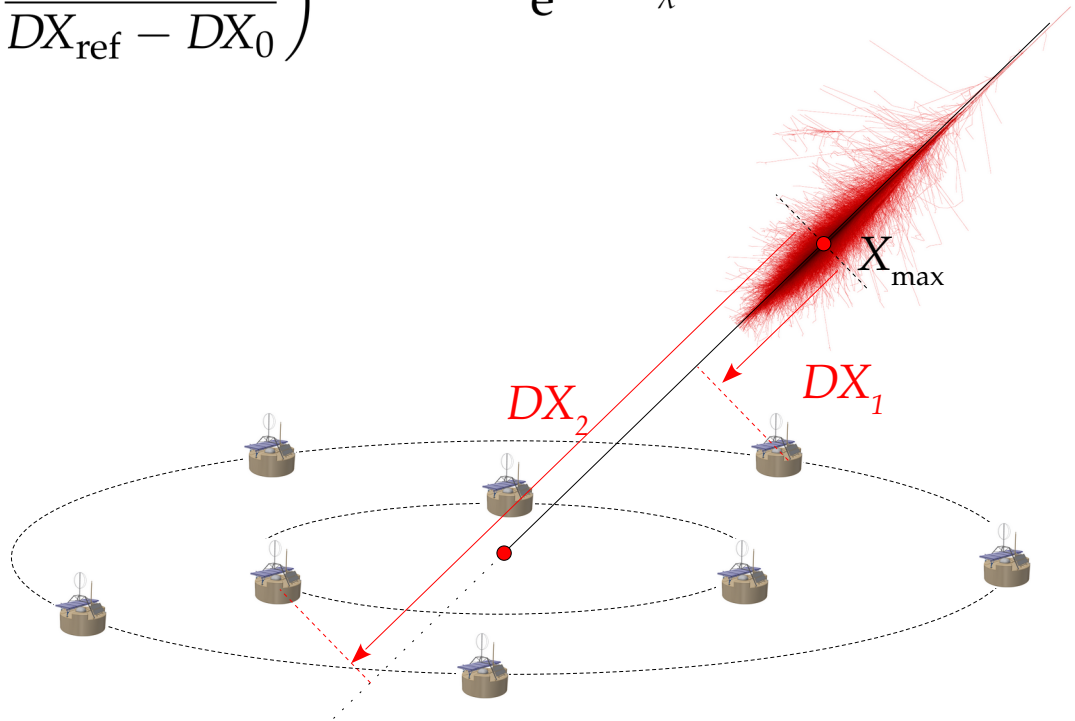
$$\frac{n(X)}{n_{max}} = \left(\frac{X - X_0}{X_{max} - X_0} \right)^{\frac{X_{max} - X_0}{\lambda}} e^{-\frac{X - X_{max}}{\lambda}}$$



signal size model



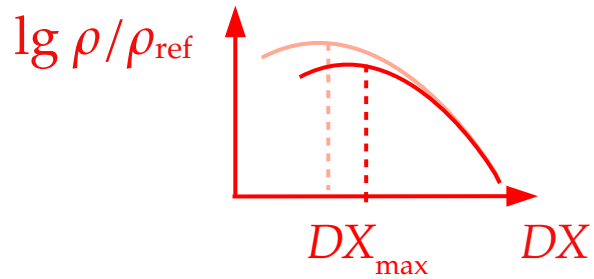
$$\varrho(r, DX) = \varrho_{\mathrm{ref}}(r) \left(\frac{DX - DX_0}{DX_{\mathrm{ref}} - DX_0} \right)^{\frac{DX_{\max} - DX_0}{\lambda}} \mathrm{e}^{-\frac{DX - DX_{\mathrm{ref}}}{\lambda}}$$

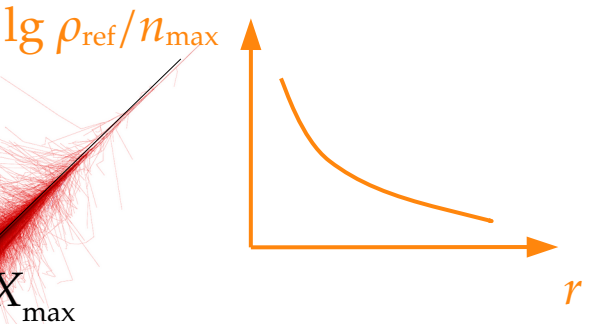


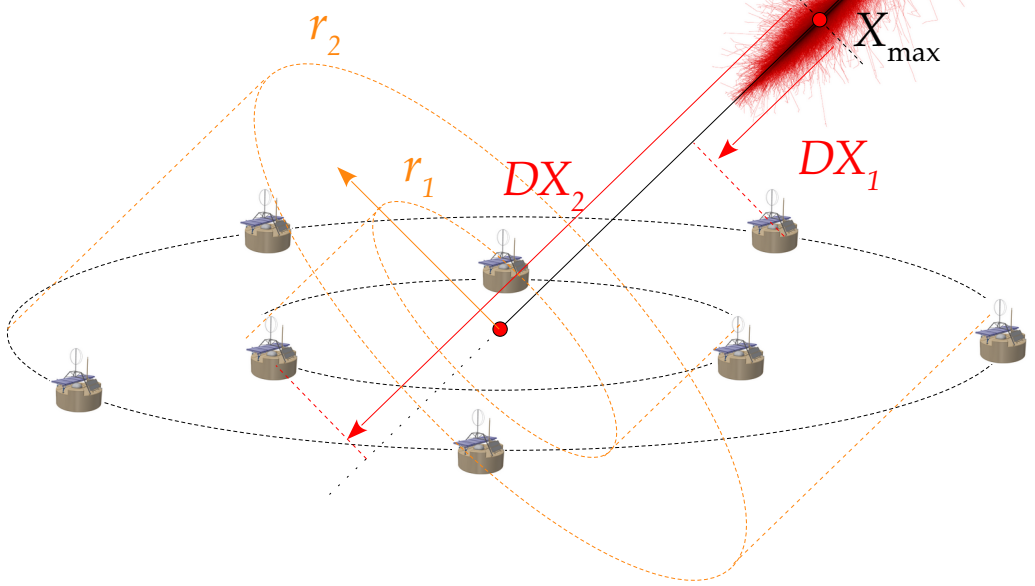
signal size model

$$\varrho(r, DX) = \varrho_{\mathrm{ref}}(r) \left(\frac{DX - DX_0}{DX_{\mathrm{ref}} - DX_0} \right)^{\frac{DX_{\max} - DX_0}{\lambda}} \mathrm{e}^{-\frac{DX - DX_{\mathrm{ref}}}{\lambda}}$$

$$\varrho_{\mathrm{ref}}(r) = \frac{n_{\max}}{2\pi r_{\mathrm{G}}^2} \frac{\Gamma(4.5-s)}{\Gamma(s)\Gamma(4.5-2s)} \left(\frac{r}{r_{\mathrm{G}}} \right)^{s-2} \left(1 + \frac{r}{r_{\mathrm{G}}} \right)^{s-4.5}$$



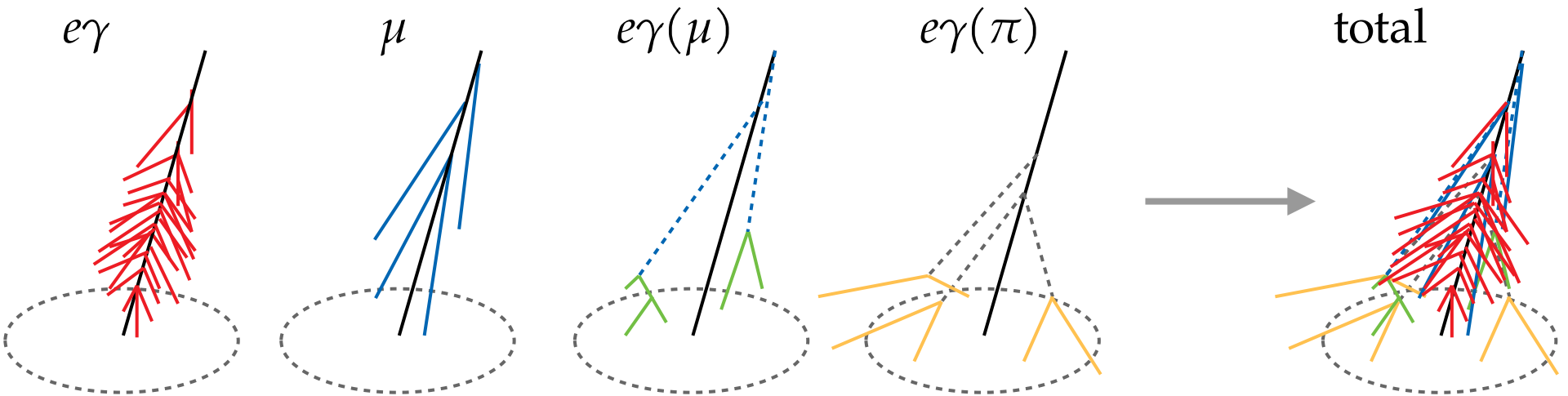




$S \sim \rho$

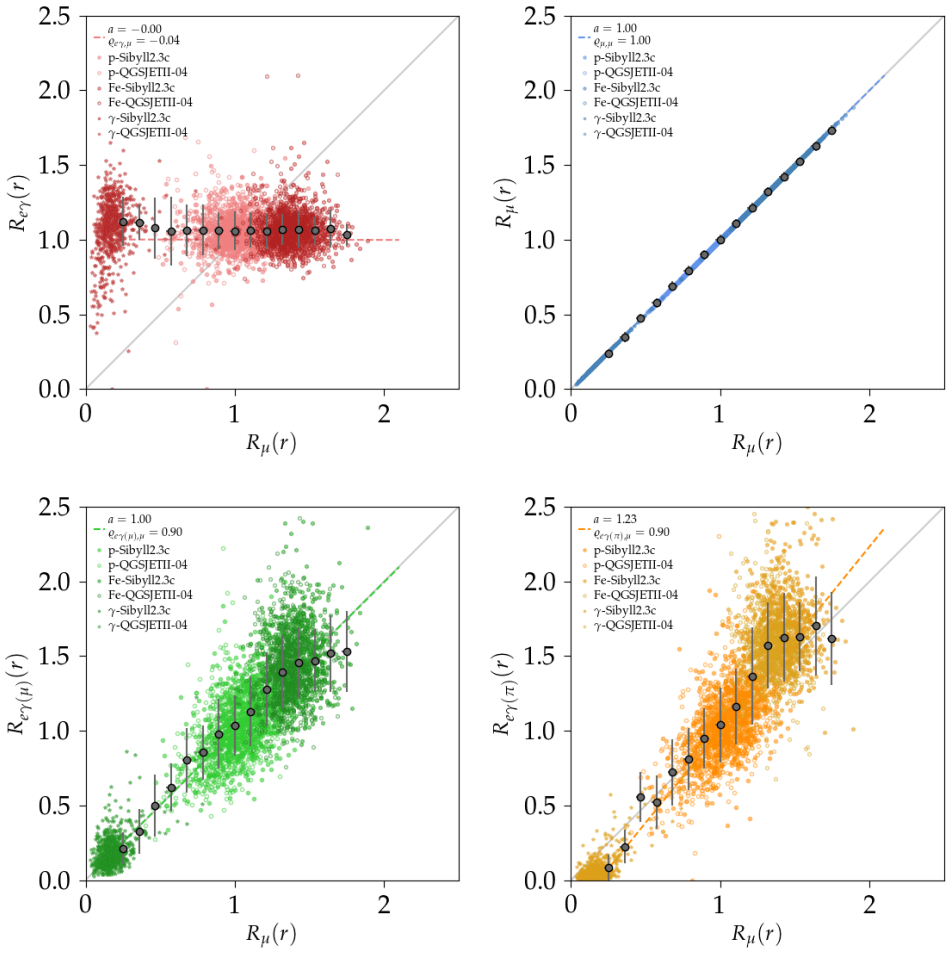
individually,
for each type of detector
and particle component

signal size model



$$S_{e\gamma} + R_{\mu}\left(S_{\mu} + \alpha S_{e\gamma(\mu)} + \beta S_{e\gamma(\pi)}\right) = S_{\text{total}}$$

signal size model

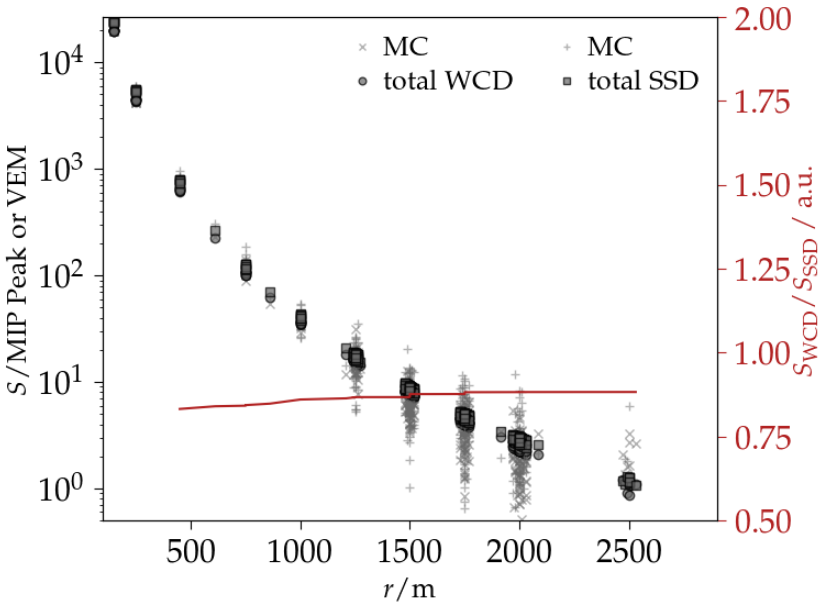


behaviour of signal size with respect to R_μ is independent of hadronic interaction model or primary particle

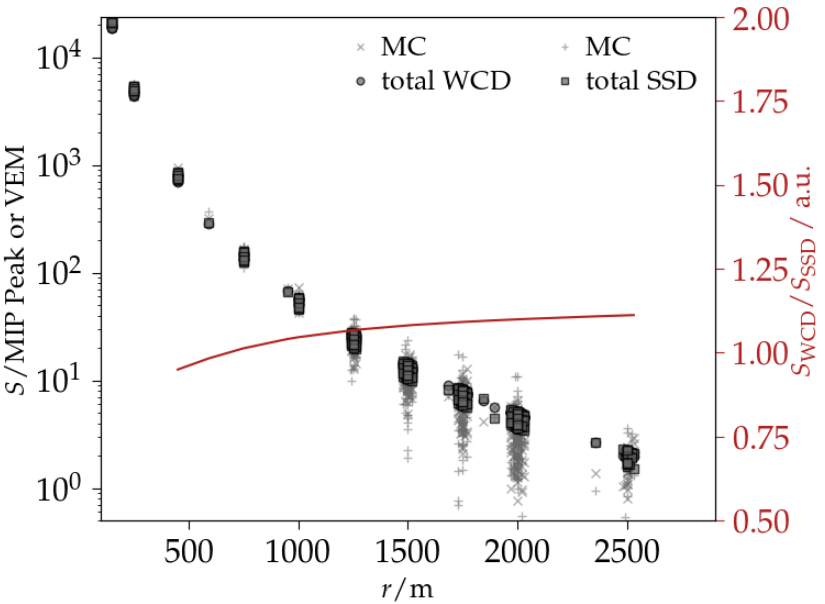
it's universal

signal size model

p Sibyll2.3c

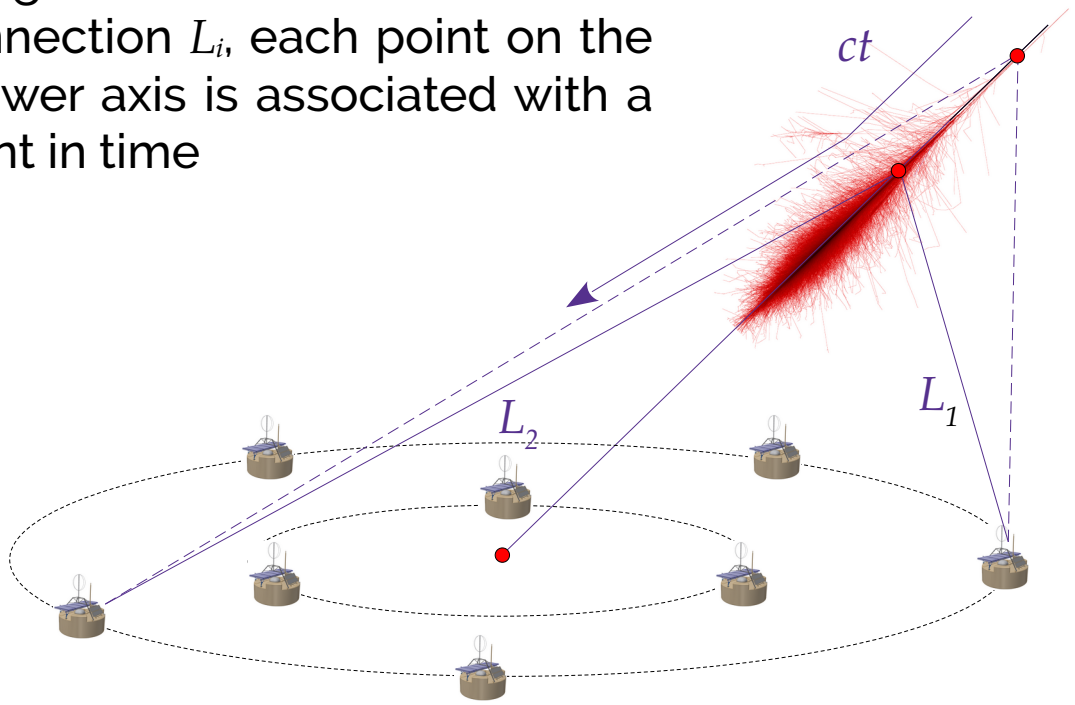


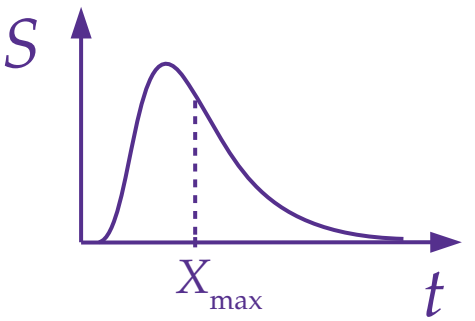
Fe Sibyll2.3c



new time model

using DX and a rectilinear connection L_i, each point on the shower axis is associated with a point in time

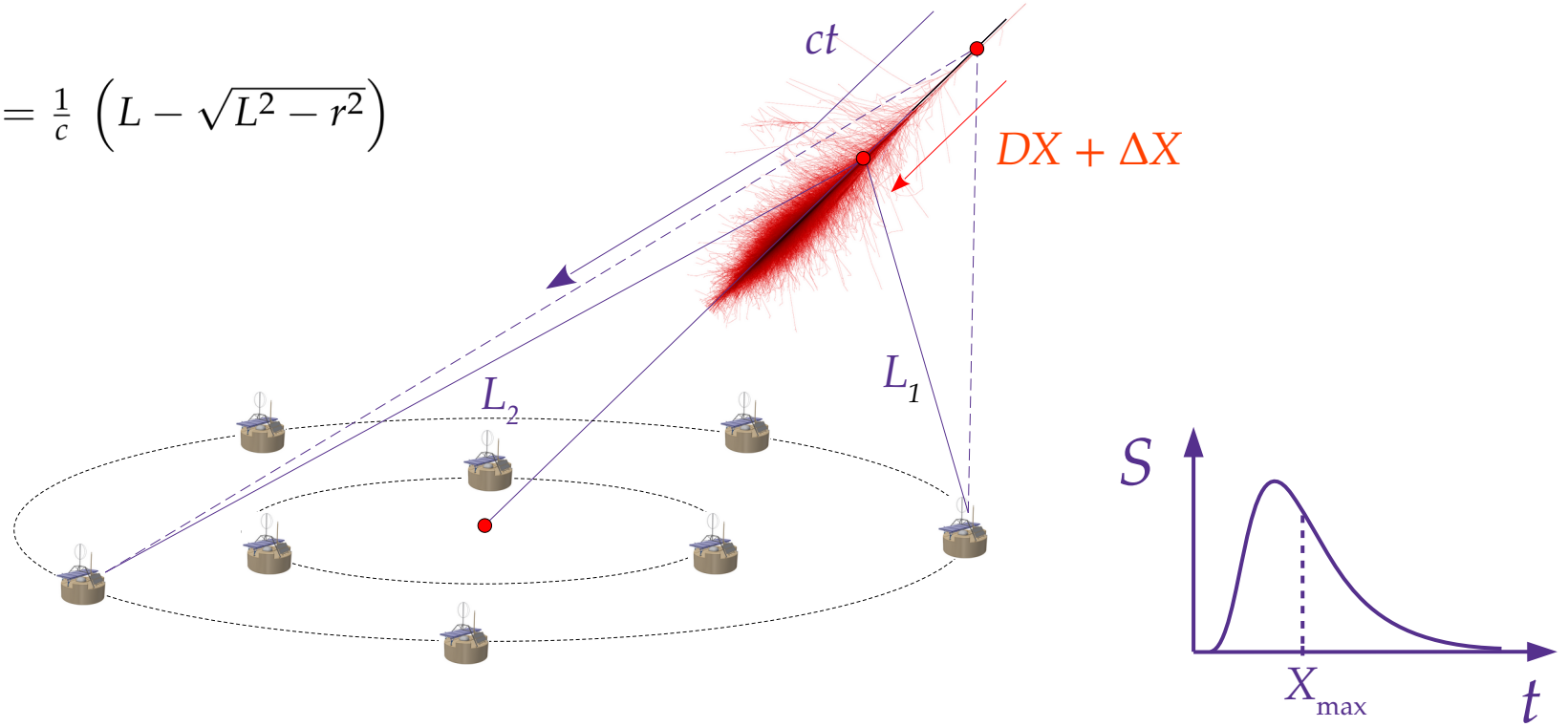




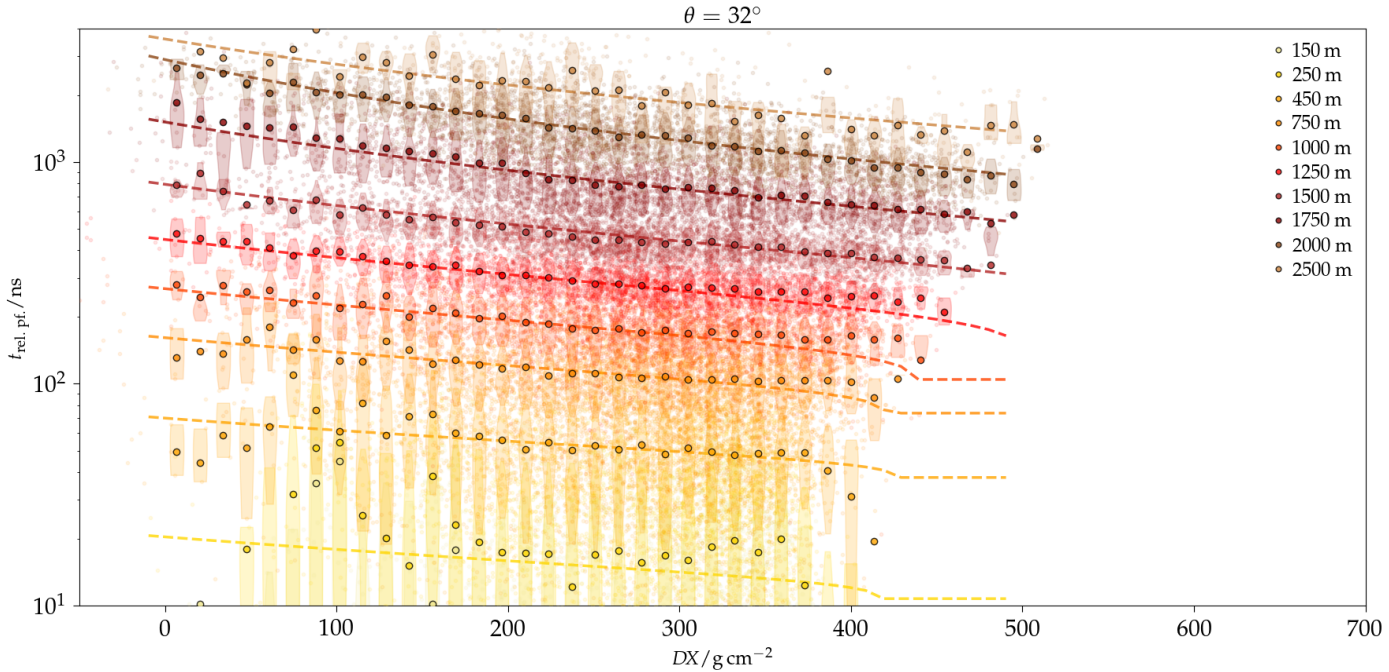
new time model

$$L = \sqrt{\frac{h_s^2}{\cos^2\theta}\,\ln^2\left(\frac{1}{e^{-\frac{r\sin\theta\,\cos\psi}{h_s}} - \frac{(DX+\Delta X)\cos\theta}{X_{vg}}}\right) + r^2\sin^2\psi + \left[r\cos\psi - \tan\theta\, h_s\,\ln\left(\frac{1}{e^{-\frac{r\sin\theta\,\cos\psi}{h_s}} - \frac{(DX+\Delta X)\cos\theta}{X_{vg}}}\right)\right]^2}$$

$$t_{\text{rel. pf.}} = \frac{1}{c}\left(L - \sqrt{L^2 - r^2}\right)$$



new time model



p, Fe using Sibyll2.3c / QGSJETII-04

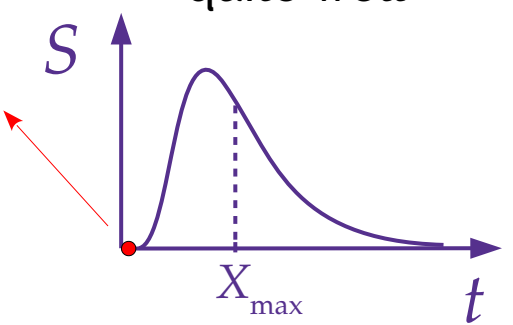
$$\lg(E/\mathrm{eV}) = 19$$

using

$$c \simeq 95\%\, c_0$$

$$\Delta X \simeq 600\,\mathrm{g\,cm^{-2}}$$

plus parabolic shape correction, the prediction of the arrival time describes the simulation data quite well



next step for new time model

→ find absolute time scale with at least one trace quantile

→ fit the trace shape using uncertainty model w.r.t. X_{max}

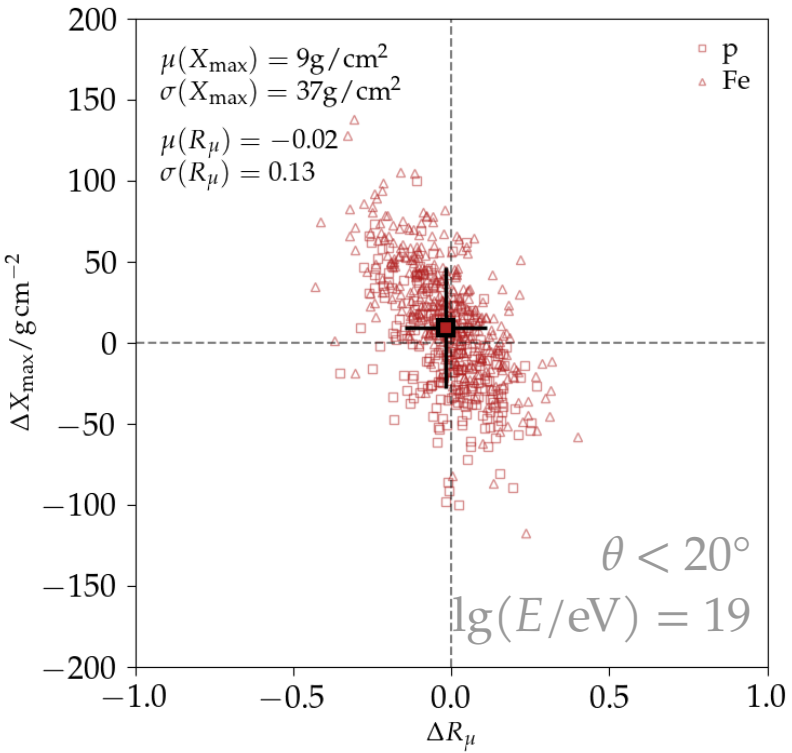
→ use

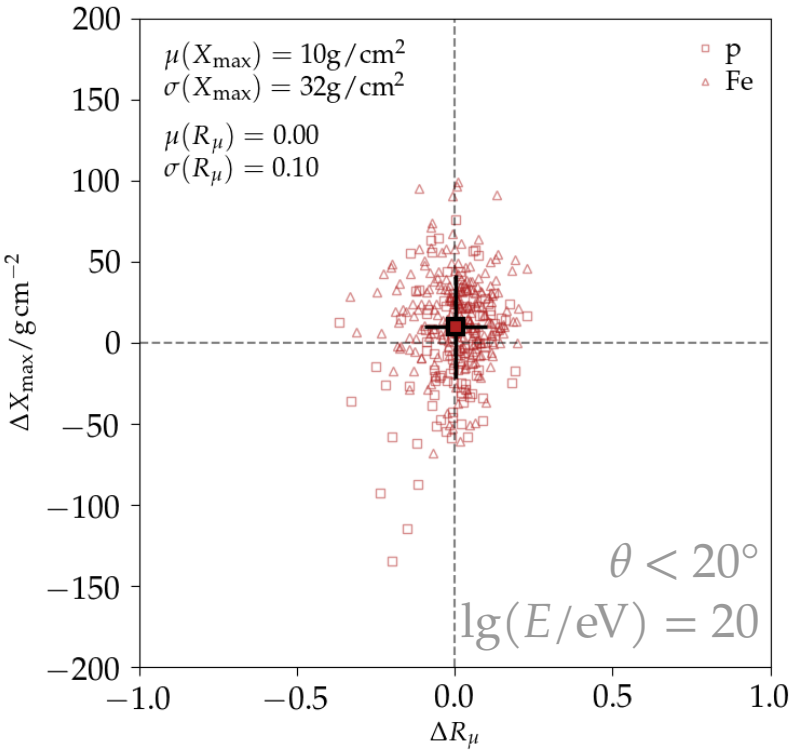
$$q_{X_{\mathrm{max}}} = 1 - \frac{\frac{\lambda}{X_{\mathrm{max}}}\Gamma\left(\frac{X_{\mathrm{max}}+\lambda}{\lambda}, \frac{X_{\mathrm{max}}}{\lambda}\right)}{\Gamma\left(\frac{X_{\mathrm{max}}}{\lambda}, 0\right)} \simeq 0.4$$

instead of q_0

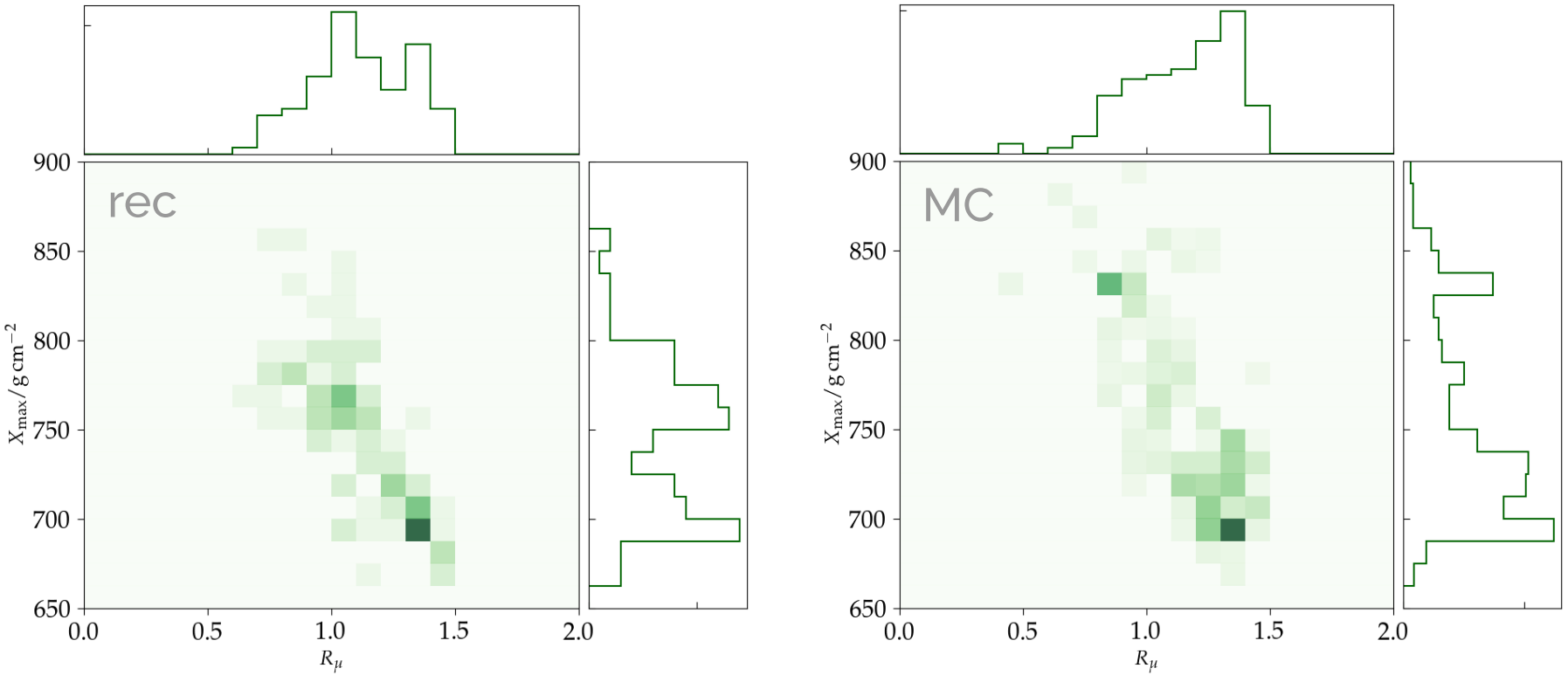
application to simulation data

using only the arrival time and the signal size, R_μ and $X_{\max}$ can already be estimated for very vertical showers



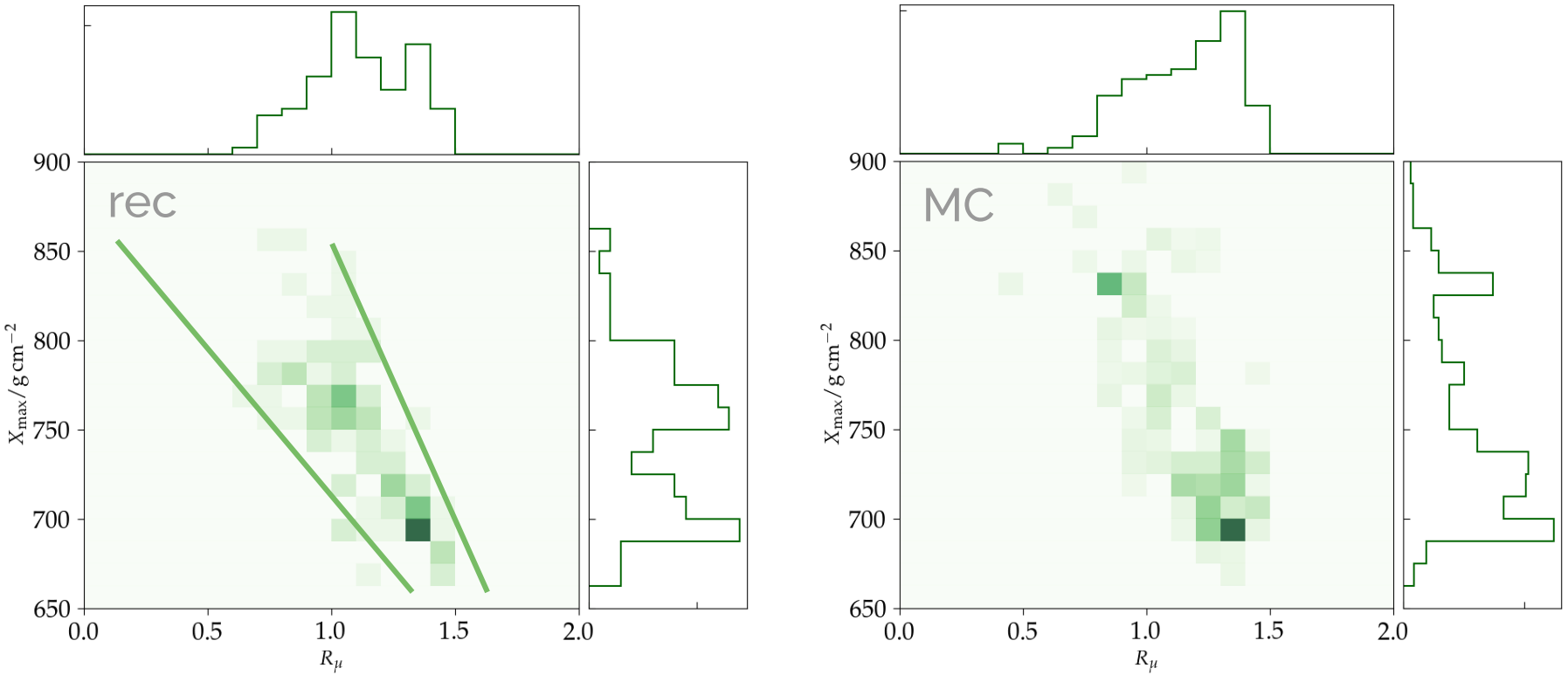


application to simulation data



p Fe mix Sibyll2.3c $\lg(E/\mathrm{eV}) = 19$

application to simulation data



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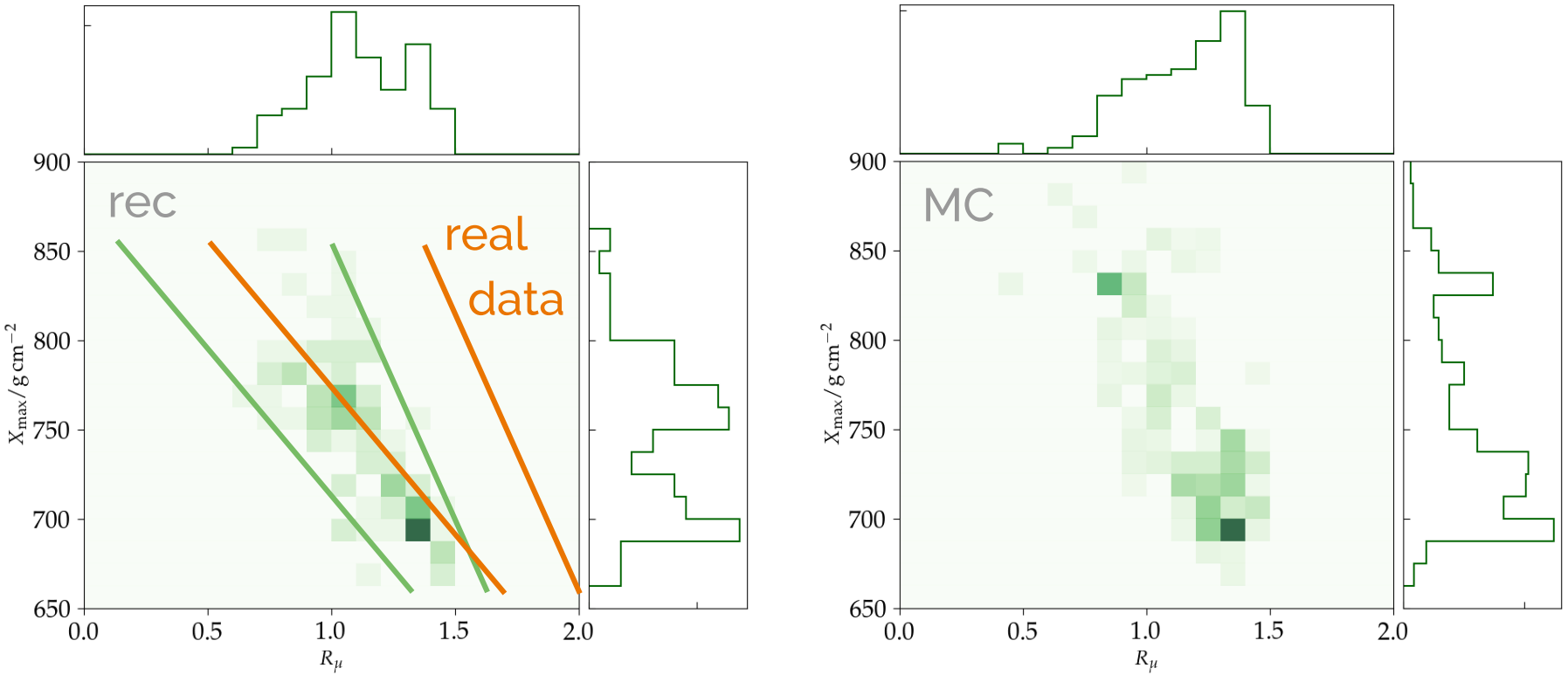
application to simulation data



p Fe mix Sibyll2.3c $\lg(E/\mathrm{eV}) = 19$

summary

→ universality revisited, now more physics driven and consistent than previous work

→ new WCD and SSD signal and time model developed based on dense station information

outlook

→ calibrate reconstruction using X_{max} from Hybrid data

→ reconstruct R_{μ} and X_{max} using combined WCD and SSD data

Thank you for your attention!

backup

using start time formalism to map longitudinal profile to time trace:

$$n(DX) \rightarrow I(DX(t))$$

$$I(t) = \exp\left[-\frac{X_{vg}^2}{2\,X_{max}\,\lambda}\left(1 - e^{\frac{r^2}{2\,h_s\,ct} - \frac{ct}{2\,h_s}}\right)^2\right]$$

post-diction of the trace shape and new trace model, including shape uncertainty