

# Strategy for SD/FD Energy Cross Calibration

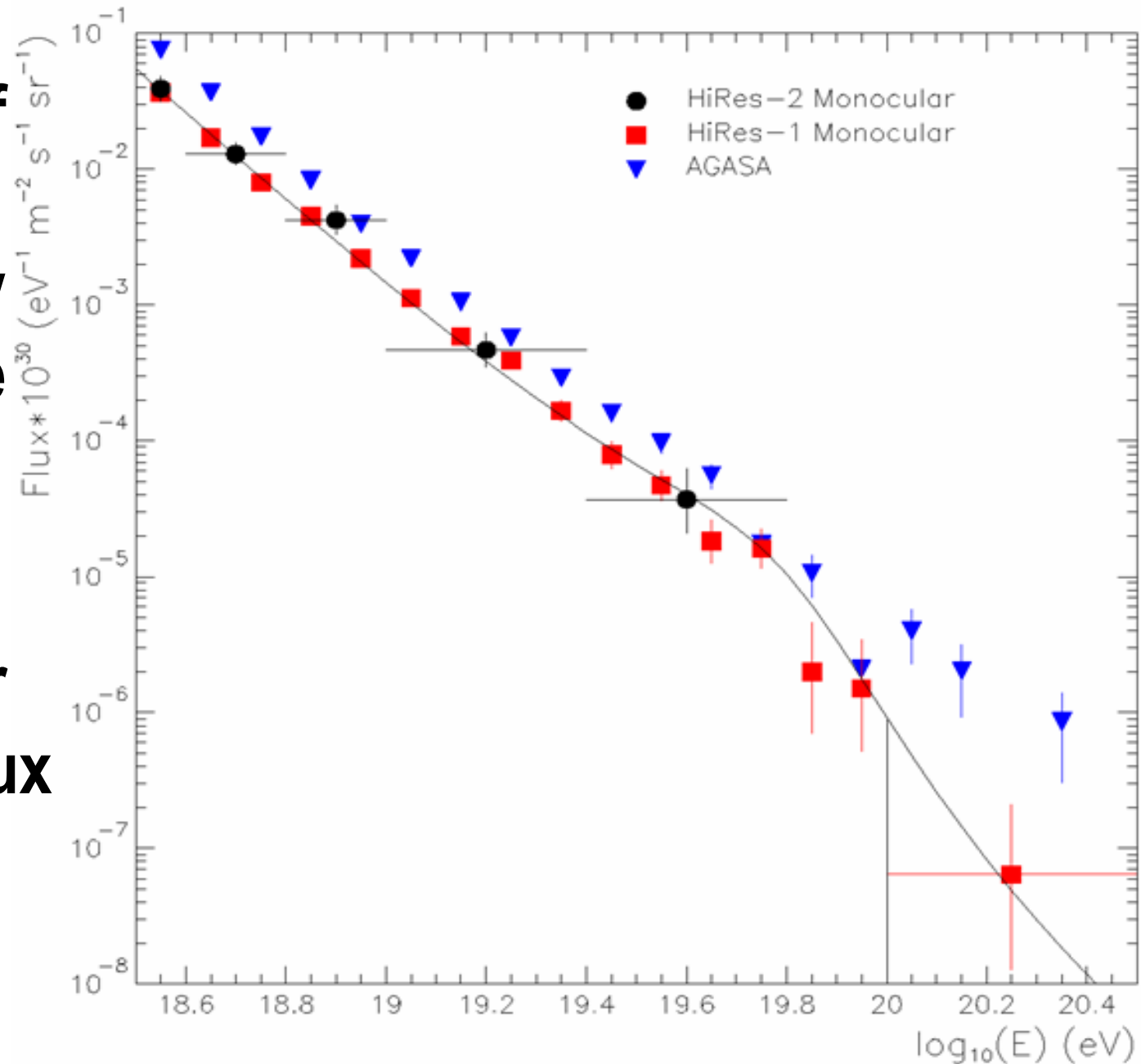
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# HiRes vs. AGASA

- Flux difference of the factor of two can be explain by energy difference of  $\sim 30\%$ .
- Is there any systematics error contributing to flux distortion above GZK cutoff?



# What are we facing?

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➤ Is the Pierre-Auger going to uncover their mistakes and fix them?

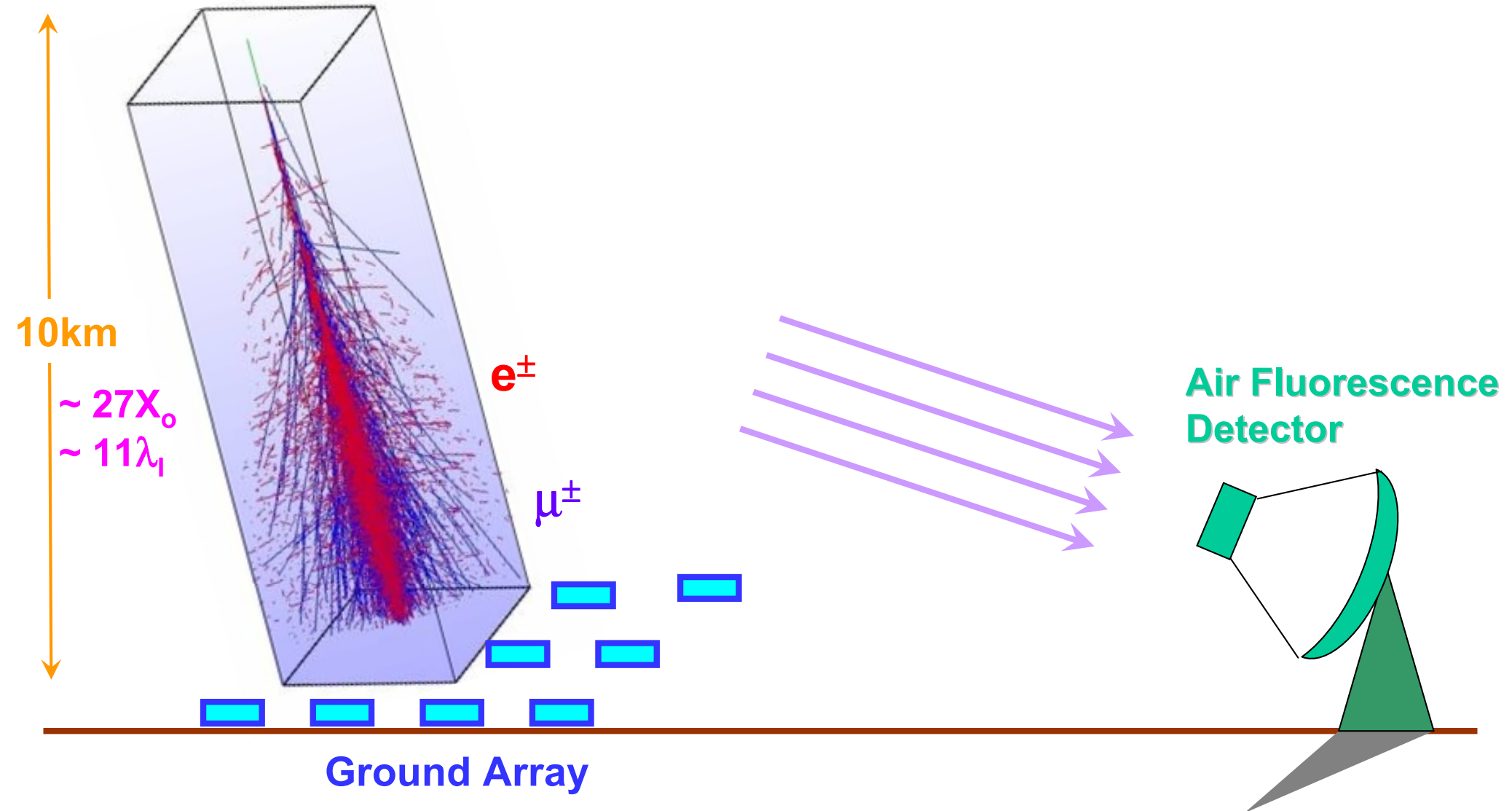
*or*

➤ Are we going to repeat the same mistakes?

➤ That is the question of systematics, not statistics.

# Principle of Hybrid Detection

MC Simulation of  
 $10^{19}$  eV Proton Shower



# Comparison of Systematic Error

	AGASA	HiRes	Auger-SD		Auger-FD	
		Arisaka's Estimate	Current Estimate	Afer Im-provement	Current Estimate	Afer Im-provement
<b>Detector Calibration</b>	9.1%	18.0%	8.7%	5.2%	10.0%	6.0%
<b>SD Energy Estimate</b>	13.2%		11.5%	7.7%		
Lateral Distribution Function	7%		7%	5%		
Simulation Code	5%		5%	3%		
Shower Front Structure	5%		2%	2%		
Delayed Particles	5%		2%	2%		
Height Correction	5%		5%	3%		
S(600/1000) fluctuation	5%		5%	3%		
<b>FD Energy Estimate</b>		26.0%			21.8%	13.7%
Photon Yield		16.6%			16.6%	7.8%
Atmospheric Correction		18.7%			12.2%	8.7%
Cherenkov Contamination		5%			5%	5%
Unobserved Energy		5%			5%	5%
<b>MC Model (both FD/SD)</b>	7.8%	7.1%	11.2%	5.8%	7.1%	7.1%
Interaction Models	6%	5%	5%	5%	5%	5%
Chemical Composition	5%	5%	10%	3%	5%	5%
<b>Total Systematic Error</b>	<b>17.8%</b>	<b>32.4%</b>	<b>18.2%</b>	<b>11.0%</b>	<b>25.0%</b>	<b>16.5%</b>

**Strongly Correlated!**

# Which is better, FD or SD?

- In Auger, currently, the estimated systematic errors in absolute energy are **~17% in SD** and **~25% in FD**.
- Systematics in SD absolute energy scale is expected to be reduced to **~11%** level in the future.
- With proposed end-to-end calibration in FD (using  $^{90}\text{Sr}$  + Lasers), FD error could be reduced to **~17%**.
- The absolute energy scale will be established more reliably by SD than by FD, contrary to the conventional wisdom.

# Systematics vs. Statistics

Statistical event-by-event fluctuation is smaller in FD than in SD. On the other hand, systematic error is smaller in SD, which determine the absolute energy scale.

	AGASA	HiRes	Auger-SD		Auger-FD		Auger-Hybrid
		Arisaka's Estimate	Current Estimate	After Improvement	Current Estimate	After Improvement	
<b>Total Systematic Error</b>	<b>18%</b>	<b>32%</b>	<b>17%</b>	<b>11%</b>	<b>25%</b>	<b>17%</b>	<b>10%</b>
<b>Corellation</b>							
SD Only	9%		9%	7%			
FD Only		17%			17%		
Common to All	7%	7%	7%	6%	7%	6%	5%
<b>Statistical Fluctuation (at <math>10^{20}</math> eV)</b>	<b>21%</b>	<b>10%</b>	<b>21%</b>	<b>21%</b>	<b>8%</b>	<b>8%</b>	<b>6%</b>

# Is FD useful to calibrate SD events?

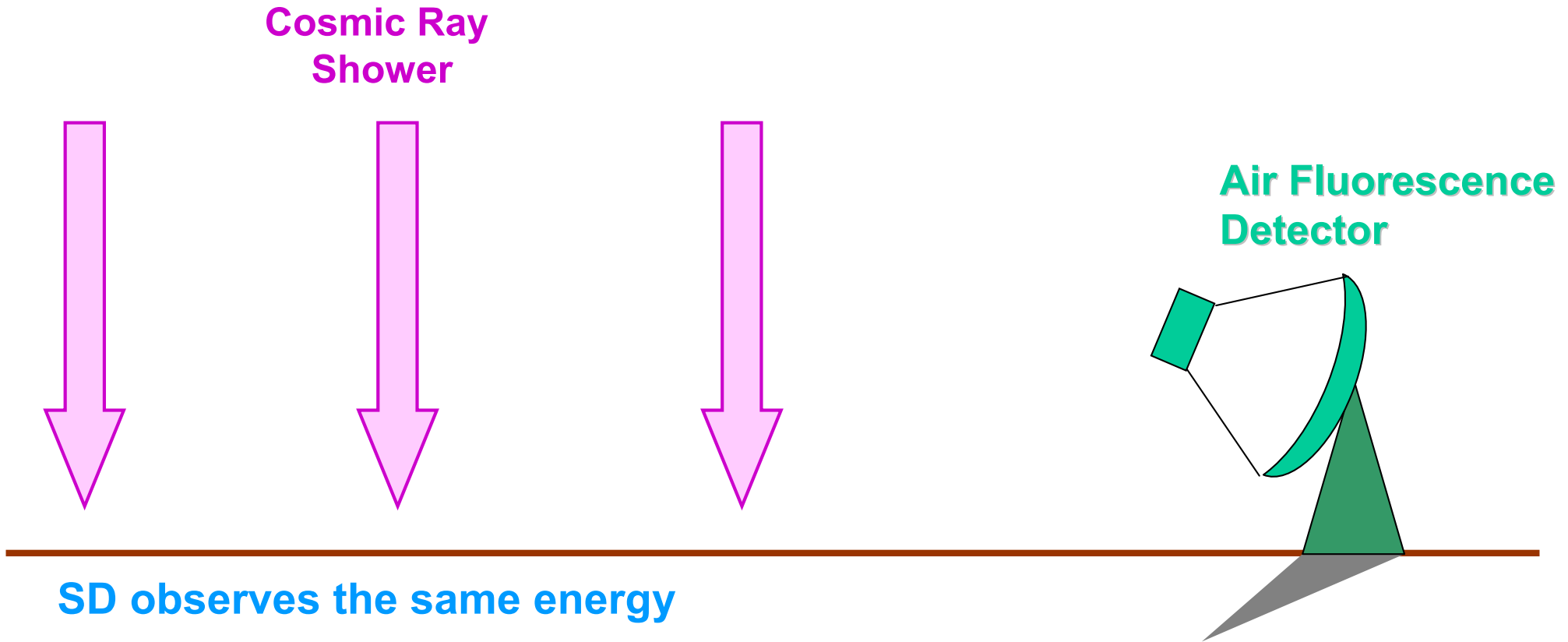
- As the overall energy scale will be established more reliably by SD, **FD is not useful to set the energy scale of “SD only” events.**
- However, once the absolute energy scale is established by SD, FD is useful to minimize even-by-event fluctuation of energy measurement for “Hybrid events”.
- “To be exact, for the Hybrid events,, **the best energy scale can be established by “Hybrid event reconstruction”.**

# How to Perform Cross Energy Calibration

- Don't try to compare SD energy and FD energy prematurely; it will introduce unwanted biased calibration from one side to the other.
- FD calibration can be improved as proposed, which is likely to take more than a year of labor-intensive efforts to complete.
- From geometrical reconstruction of Hybrid events, some of systematics can be reduced.
  - Atmospheric correction
  - Cherenkov contamination
  - Primary composition

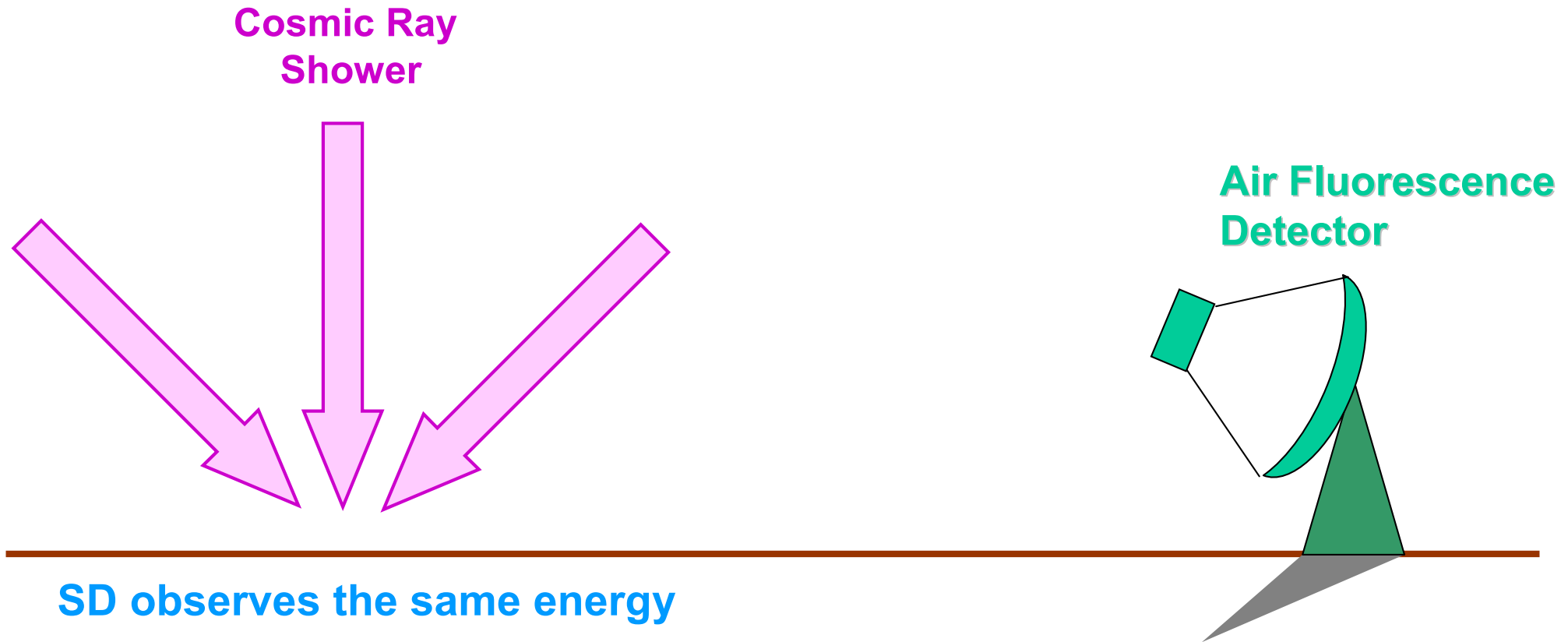
# How to Evaluate Atmospheric Correction

Reconstruct showers at the same energy and direction, but different distance from the Telescope.



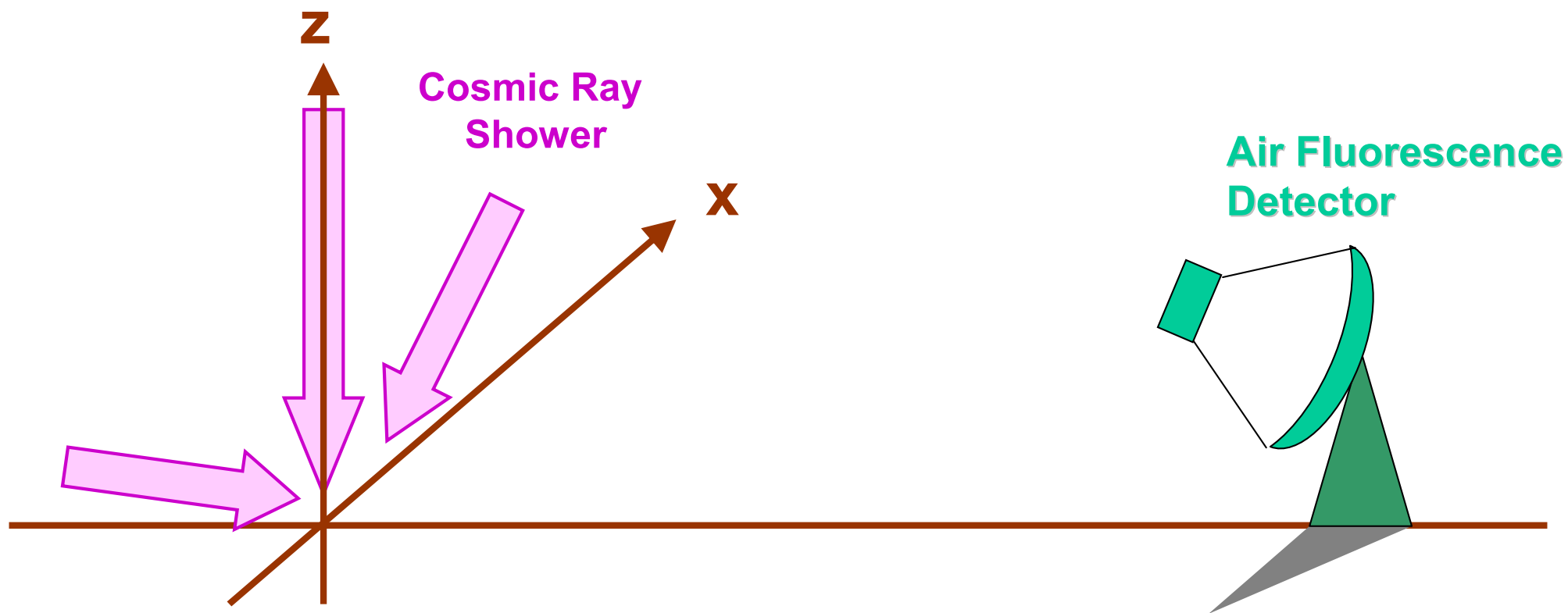
# How to Evaluate Cherenkov Contamination

Reconstruct showers at the same energy and distance, but different angles.



# SD Energy vs. Zenith Angle and Composition Study

Reconstruct showers at the same energy and distance, but different angles (in x-z plane).



FD observes the same energy

# My Proposed Procedure of Hybrid Reconstruction

1. Use Stereo-FD to determine the **direction vector** of the event.
2. Use SD timing to improve the **core location**.
3. Fit a longitudinal shower profile on FD, locate  $X_{\max}$  (and the initial interaction point.)
4. Fit LDF on SD, together with pulse shapes and  $X_{\max}$ , identify **composition**, then estimate  $E_{SD}$ .
5. Determine the absolute normalization of  $E_{FD}$  by  $E_{SD}$  (by averaging over multiple events).
6. Use “normalized  $E_{FD}$ ” as the event **energy** (to minimize even-by-event fluctuation).

# Concluding Remarks

- “**Absolute energy**” calibration of FD is far more complicated than previously thought. There are many non-linear effects as well.
- “**ZGK-cutoff**” observed by HiRes may be due to their energy-dependent systematic error in atmospheric correction. (or else AGASA Log-Amp introduced “over-linearity”.)
- Hires’ **lower energy** (than AGASA) may be due to poor calibration of PMT by Kakimoto in photon yield study.
- To minimize systematic error in FD, truly “**End-to-end**” calibration should be carried out prior to SD/FD cross calibration.
- The absolute energy scale is likely to be determined not by FD but by SD.

# Back to the original question: What are we facing?

- Is the Pierre-Auger going to uncover AGASA and/or HiRes mistakes and fix them? or are we going to repeat the same mistakes?
- That is the question of systematics, not statistics.
- To solve this discrepancy in Auger, we should aim at
  - Auger-SD:  $\leq 10\%$
  - Auger-FD:  $\leq 10\%$

# Conclusion and Proposal

- We are free from non-linear effects in HiRes and/or AGASA.
  - Yes, we can answer the confusing situation of the GZK structure.
- However, our current FD calibration scheme (and SD water tank) is not good enough to address 20-30% energy scale discrepancy in AGASA and HiRes.
- To achieve this goal, systematics must be reduced to 10% each (in FD and SD) by
  - FD – Mobile ACE
  - SD – Infill with muon counter