



Lightning Location Systems: part I

Lightning Location Systems

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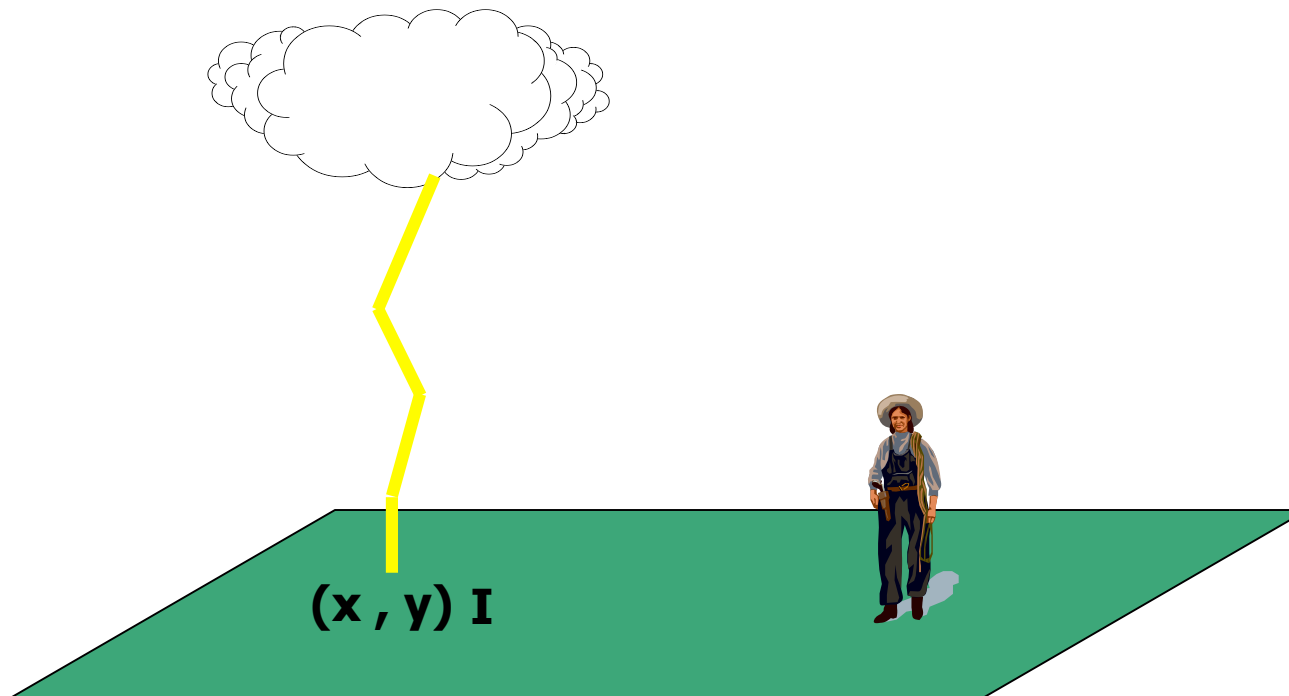


Outline

- The main lightning location techniques
- Performance issues

What is lightning location?

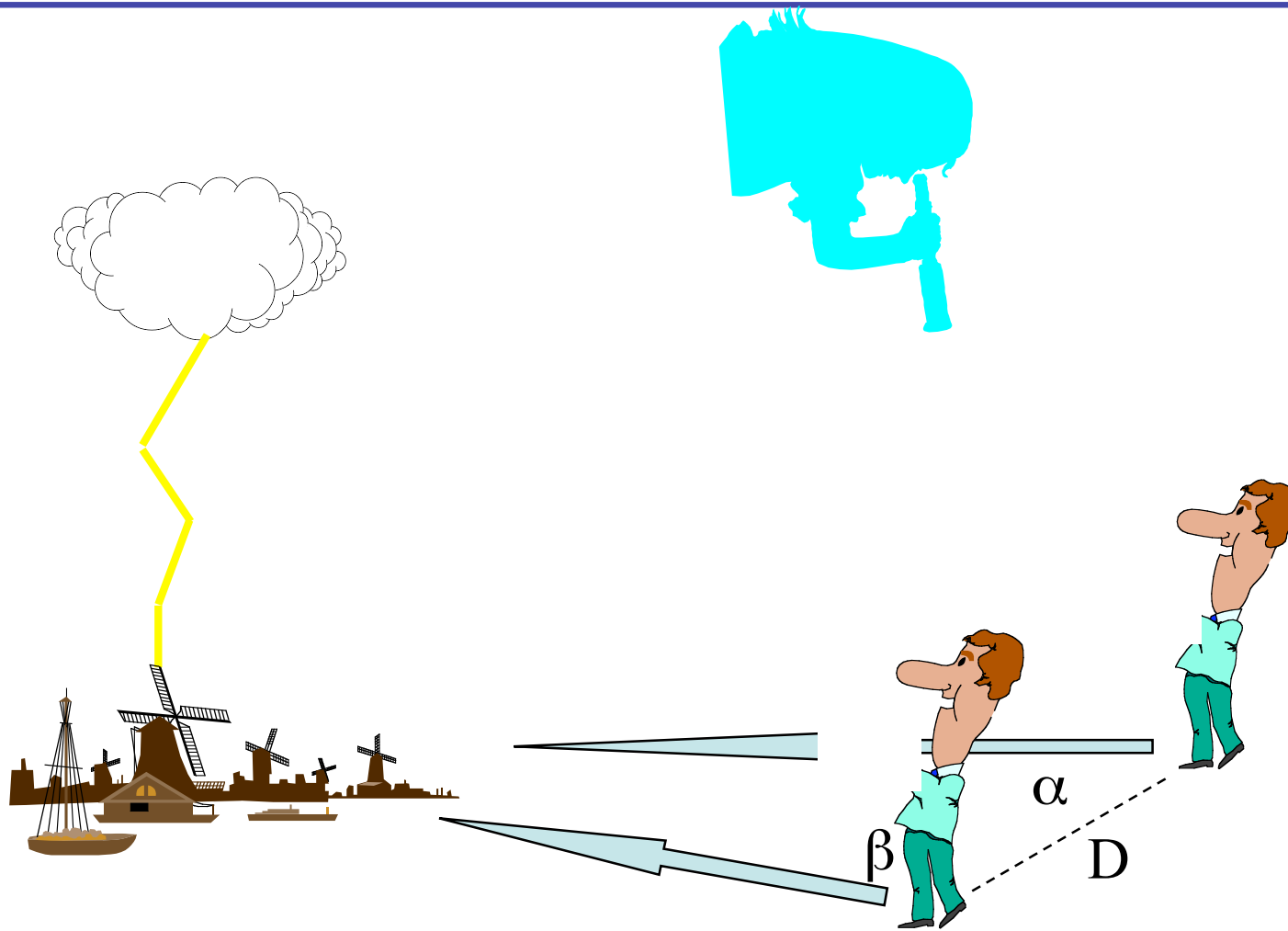
- Locating the strike point of cloud-to-ground lightning



How is lightning located?

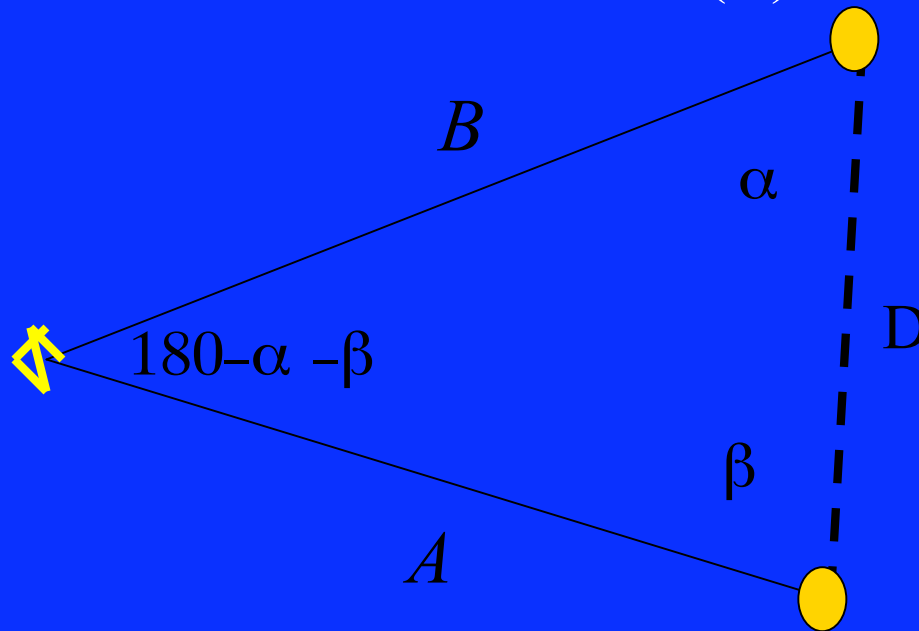
1. Magnetic Direction finding (MDF or DF)
2. Difference in Time of Arrival (TOA or DTOA)
3. Combination TOA/DF
4. Interferometry
5. Field component methods
6. Time to Thunder

1. Magnetic Direction Finding



Sine theorem:

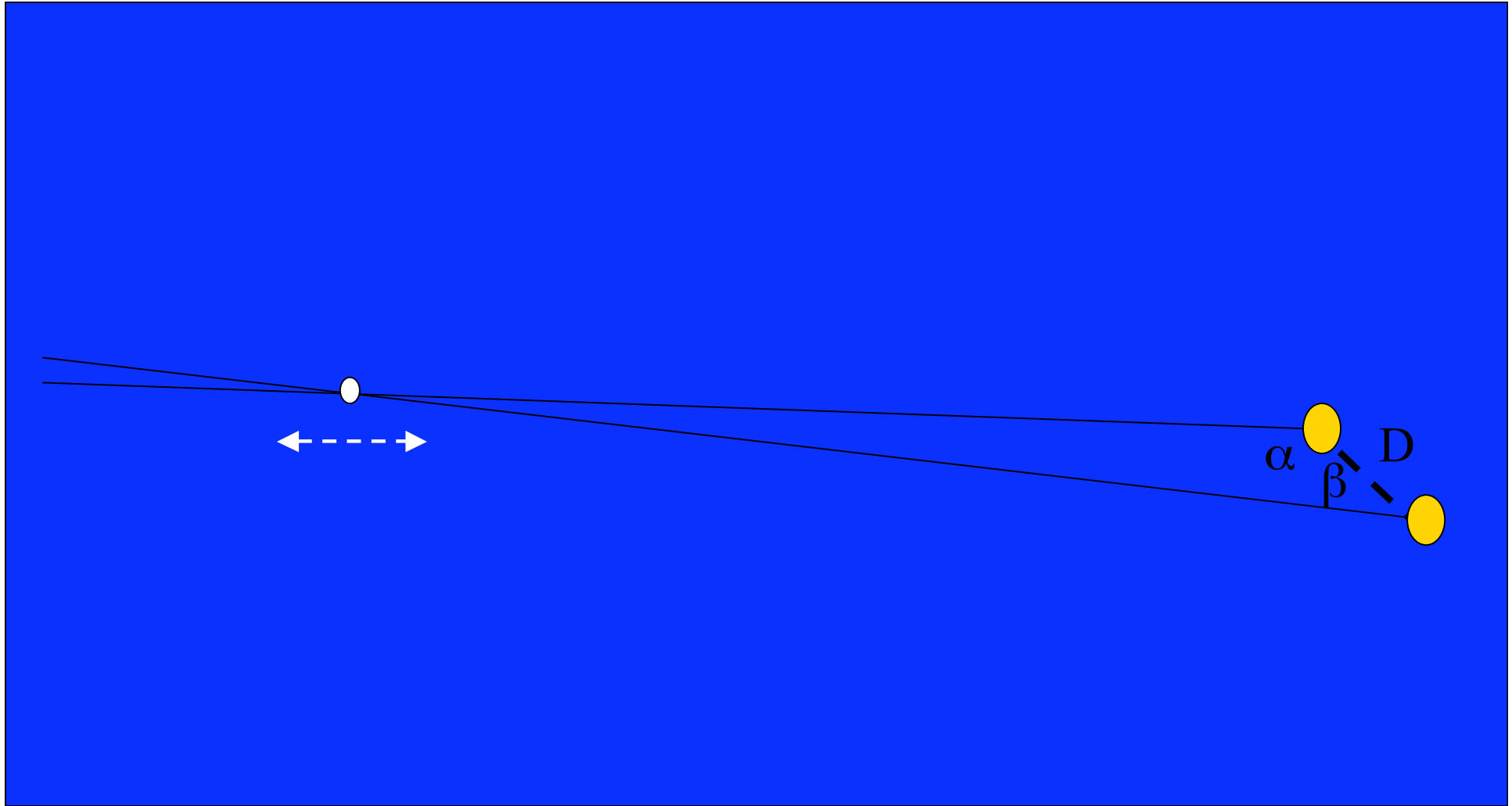
$$\frac{A}{\sin(\alpha)} = \frac{B}{\sin(\beta)} = \frac{D}{\sin(180 - \alpha - \beta)}$$



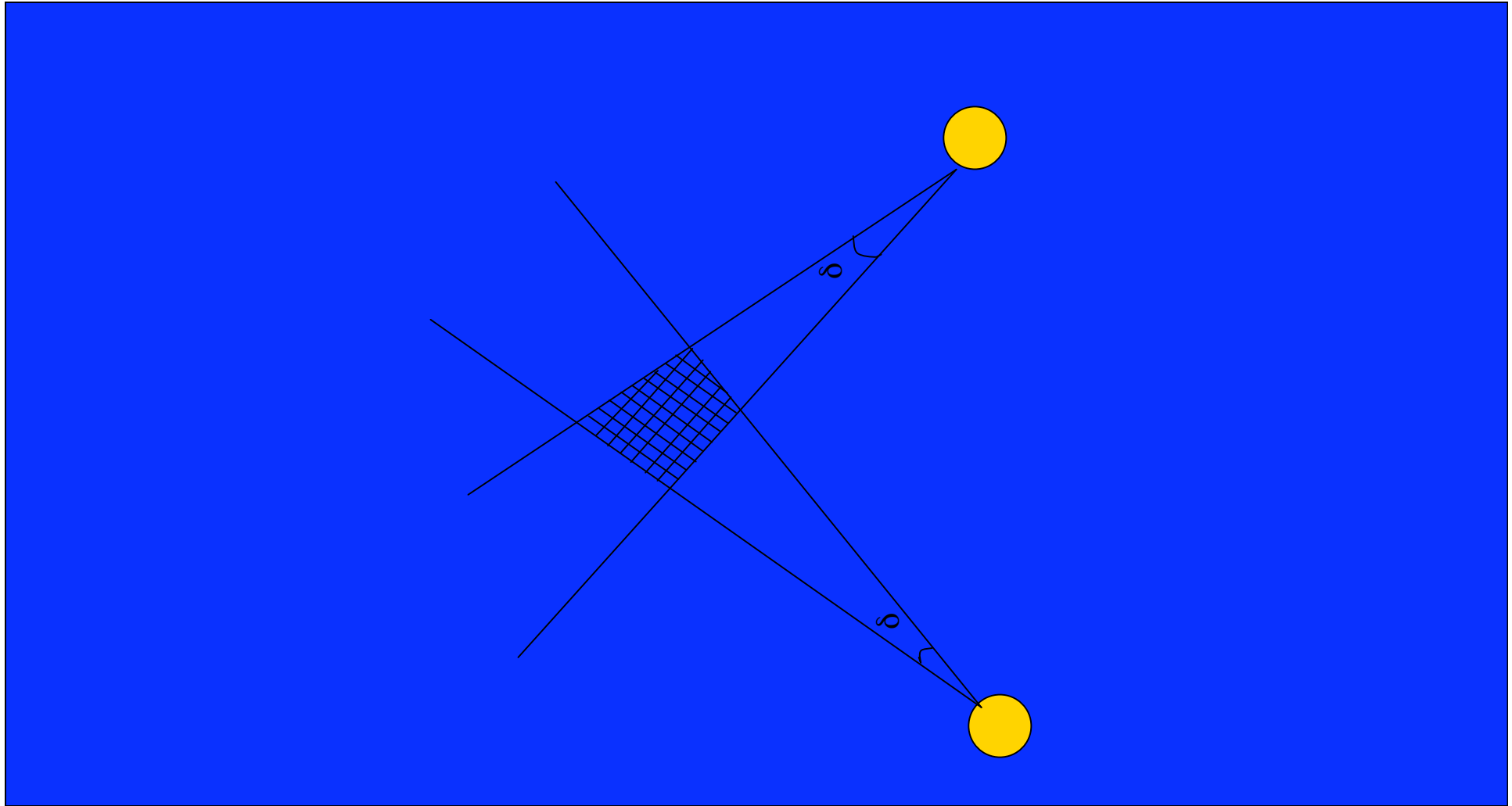
$$A = \frac{D \sin(\alpha)}{\sin(180 - \alpha - \beta)}$$

$$B = \frac{D \sin(\beta)}{\sin(180 - \alpha - \beta)}$$

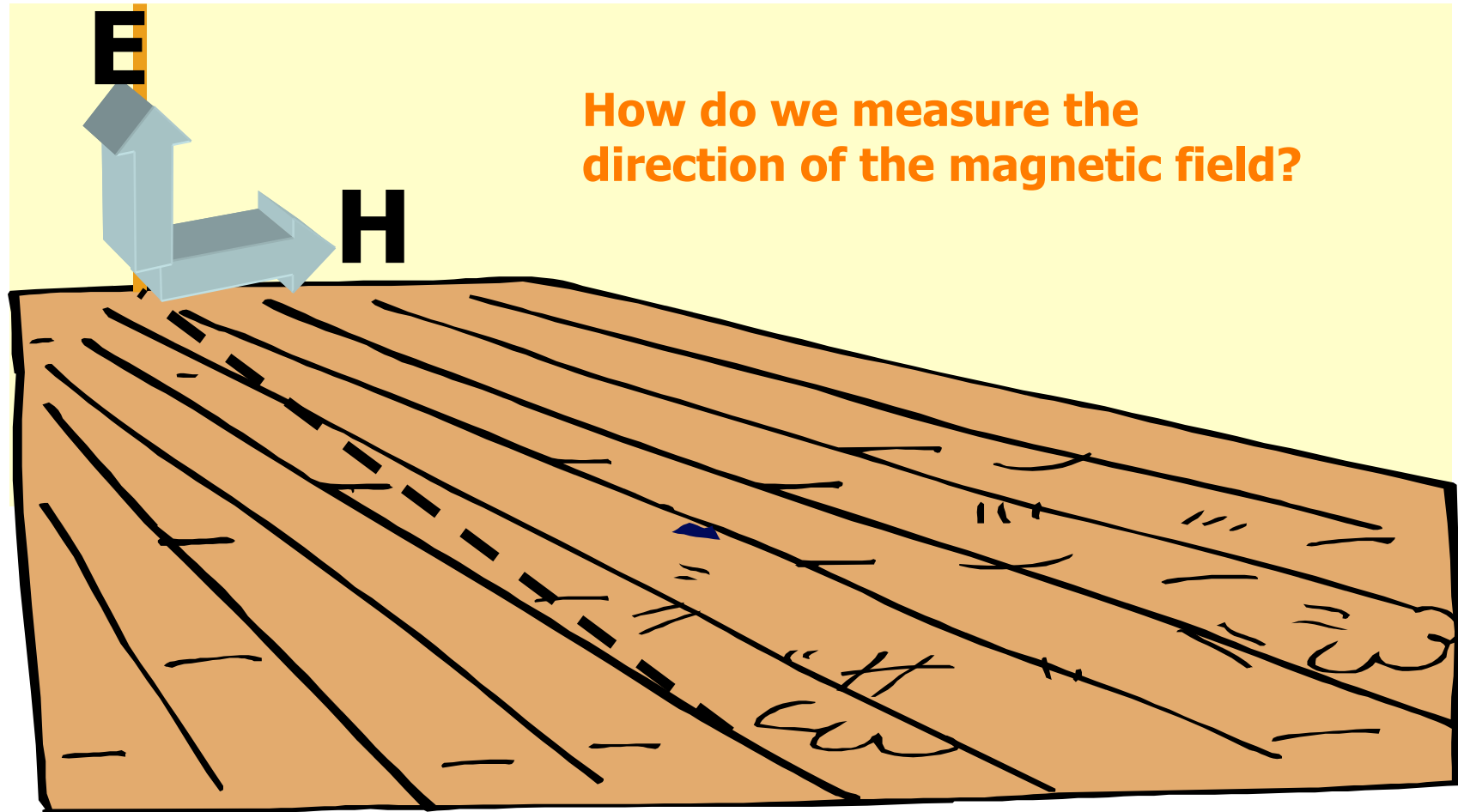
Small errors in the direction can result in big errors in the location



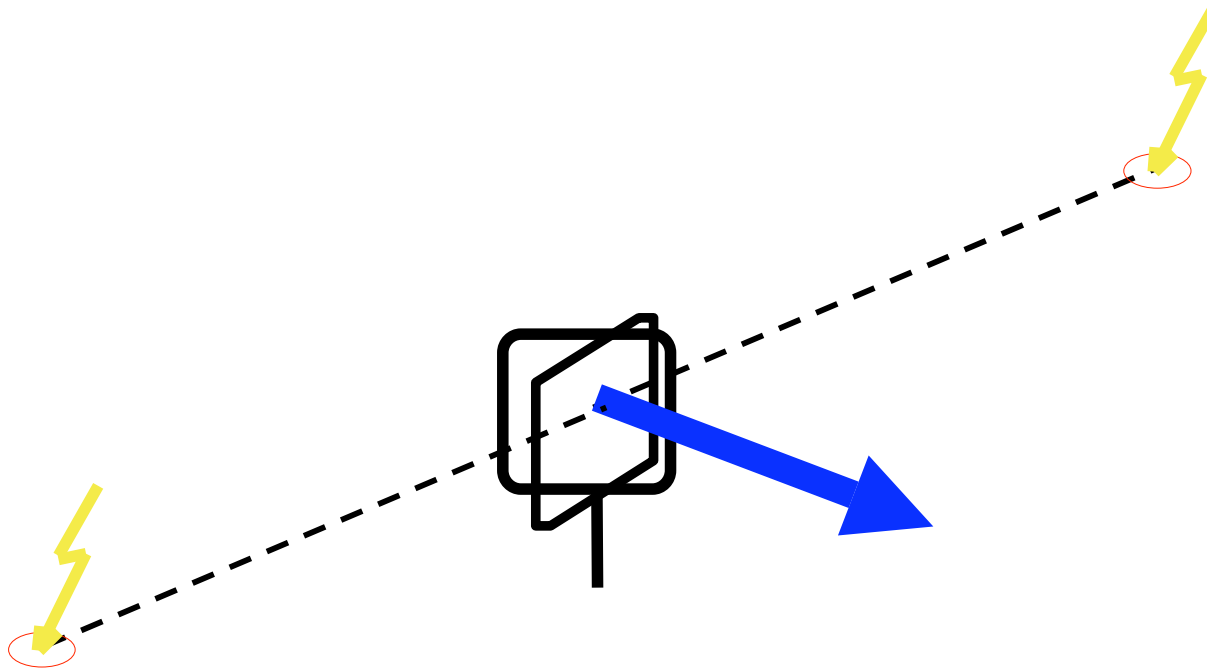
If the azimuth error is bounded, one can give a location surface instead of a location point



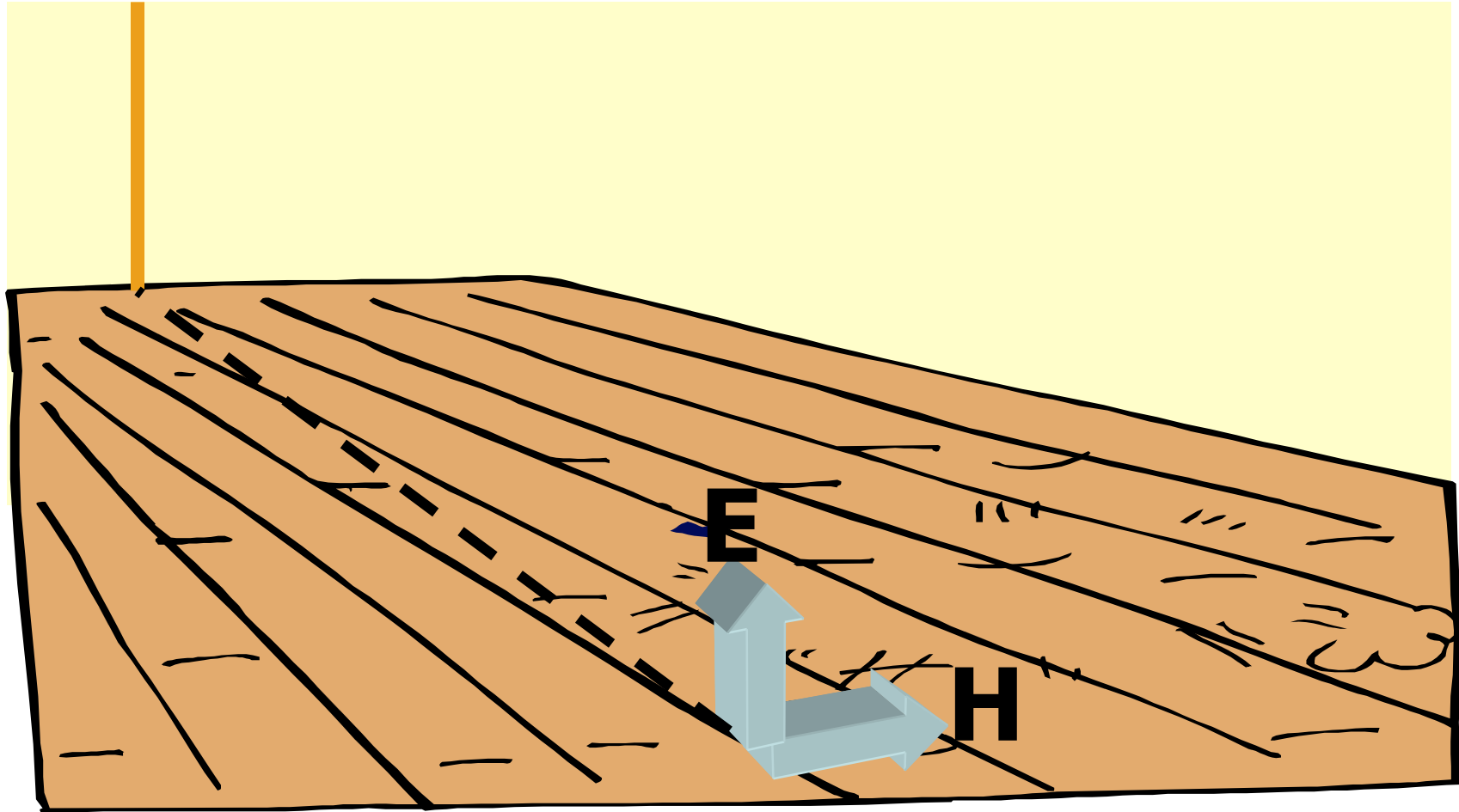
How is the direction actually found?



Measuring two perpendicular components...

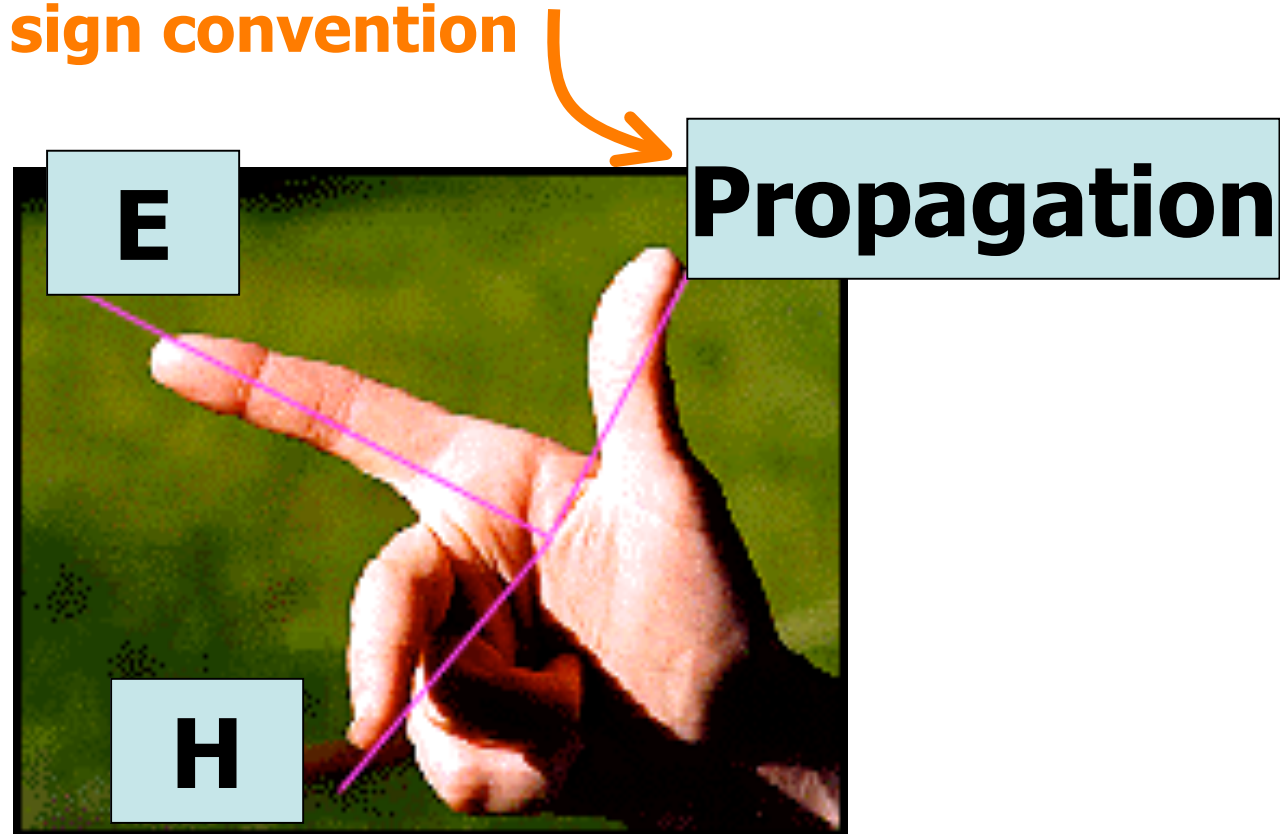


To resolve the ambiguity in single station location, measure the vertical electric field

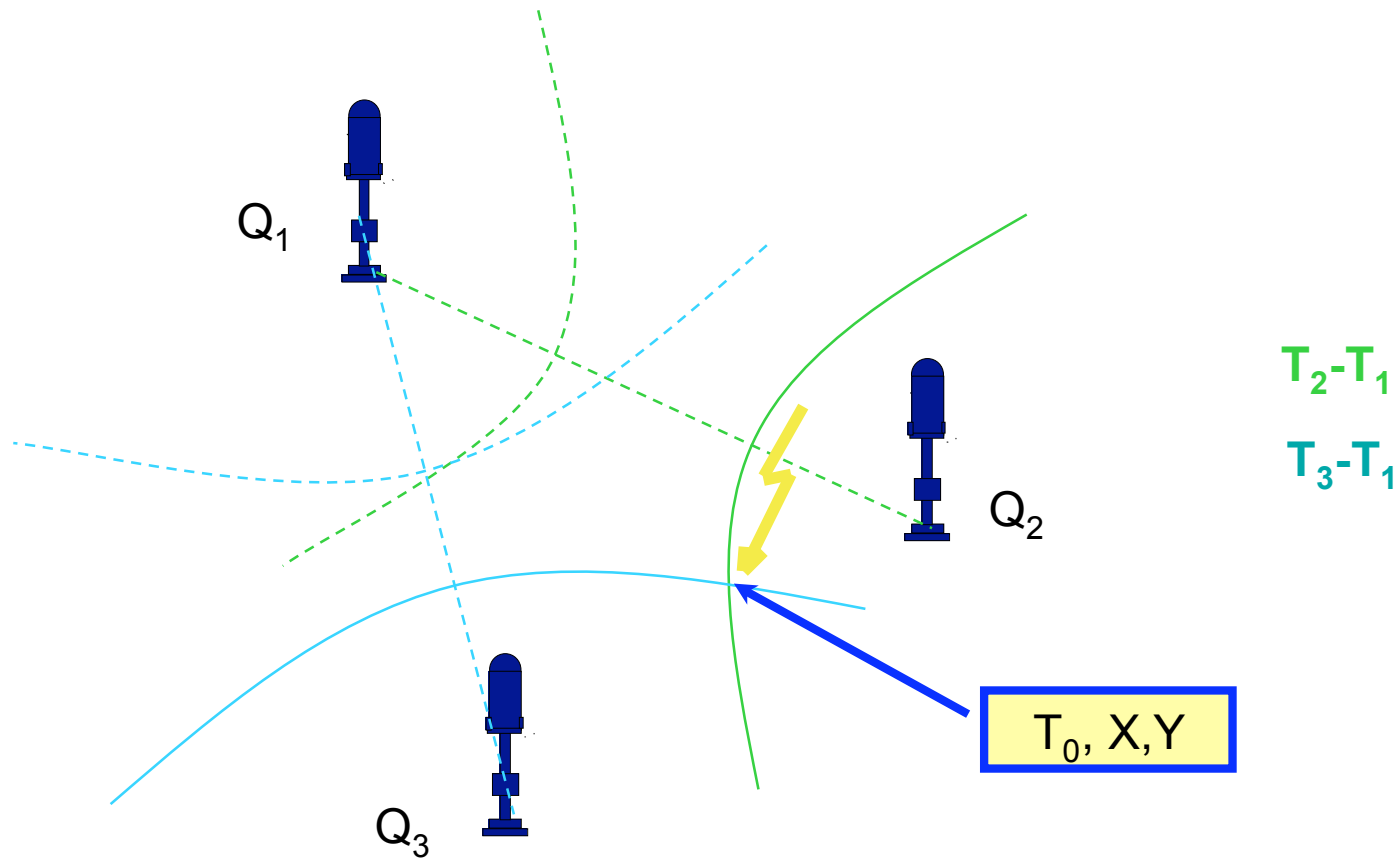


To resolve the ambiguity in single station location, measure the vertical electric field

Opposite of this for atmospheric electricity sign convention



2. Time of Arrival TOA



$$c\Delta t_i = PQ_0 - PQ_i \quad PQ_i = PQ_0 - c\Delta t_i \quad (PQ_i)^2 = (PQ_0 - c\Delta t_i)^2$$

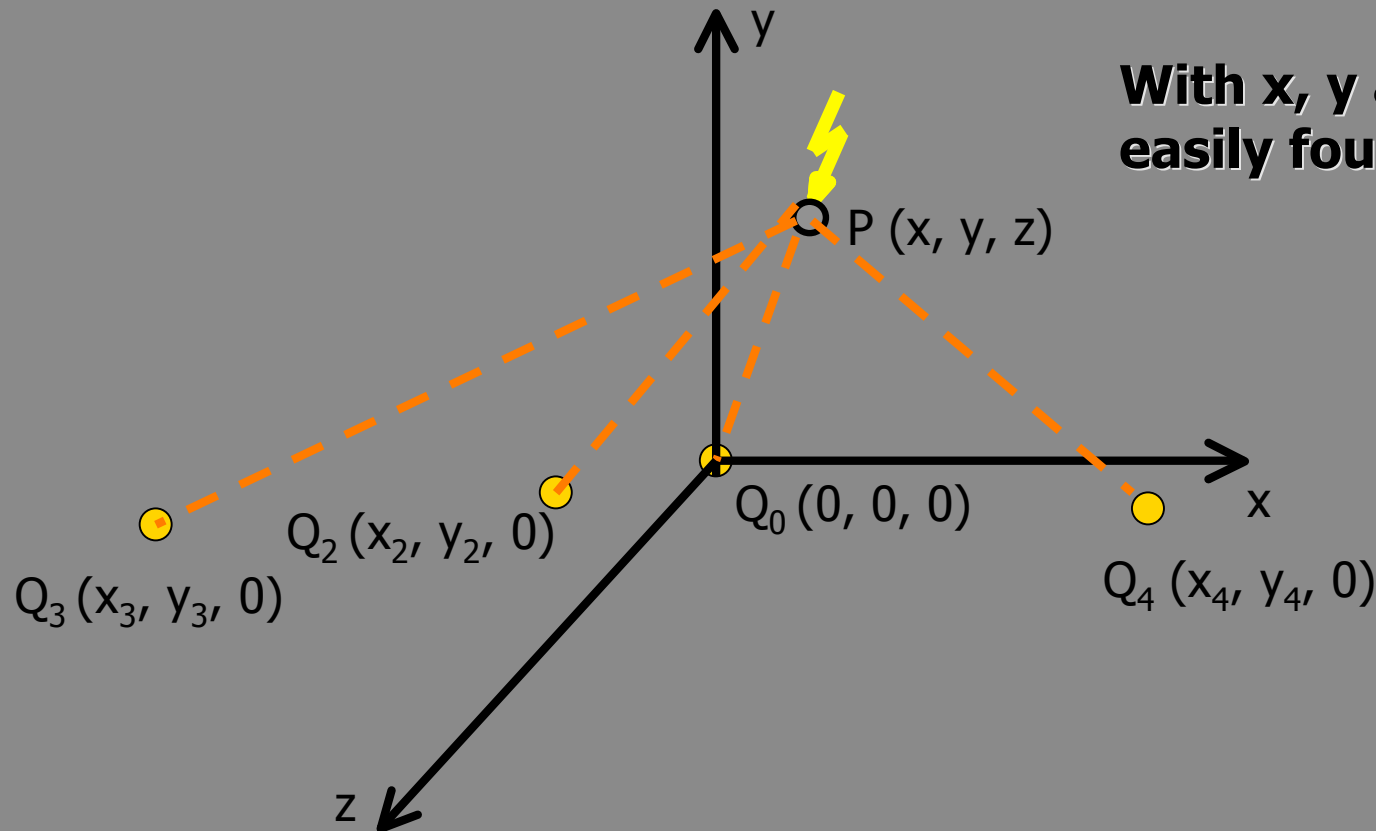
$$PQ_0^2 = PQ_0^2 - 2c\Delta t PQ_0 + c^2\Delta t_i^2 = (x - x_i)^2 + (y - y_i)^2 + z^2$$

$$(x - x_i)^2 + (y - y_i)^2 + z^2 = x^2 + y^2 + z^2 - 2c\Delta t PQ_0 + c^2\Delta t_i^2$$

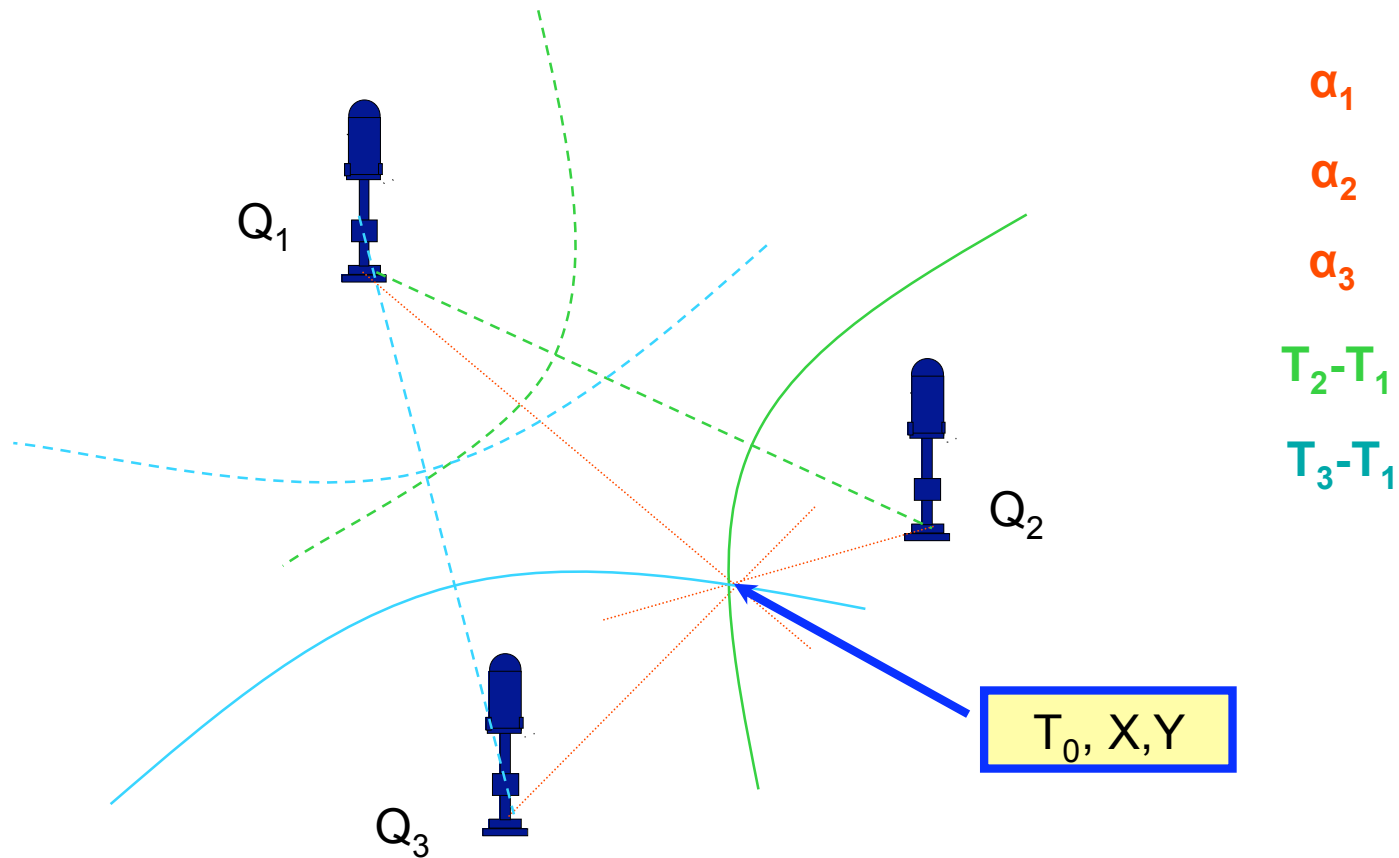
$$x_i^2 - 2x_i x + y_i^2 - 2y_i y = -2c\Delta t PQ_0 + c^2\Delta t_i^2$$

System of 3 linear equations with 3 unknowns

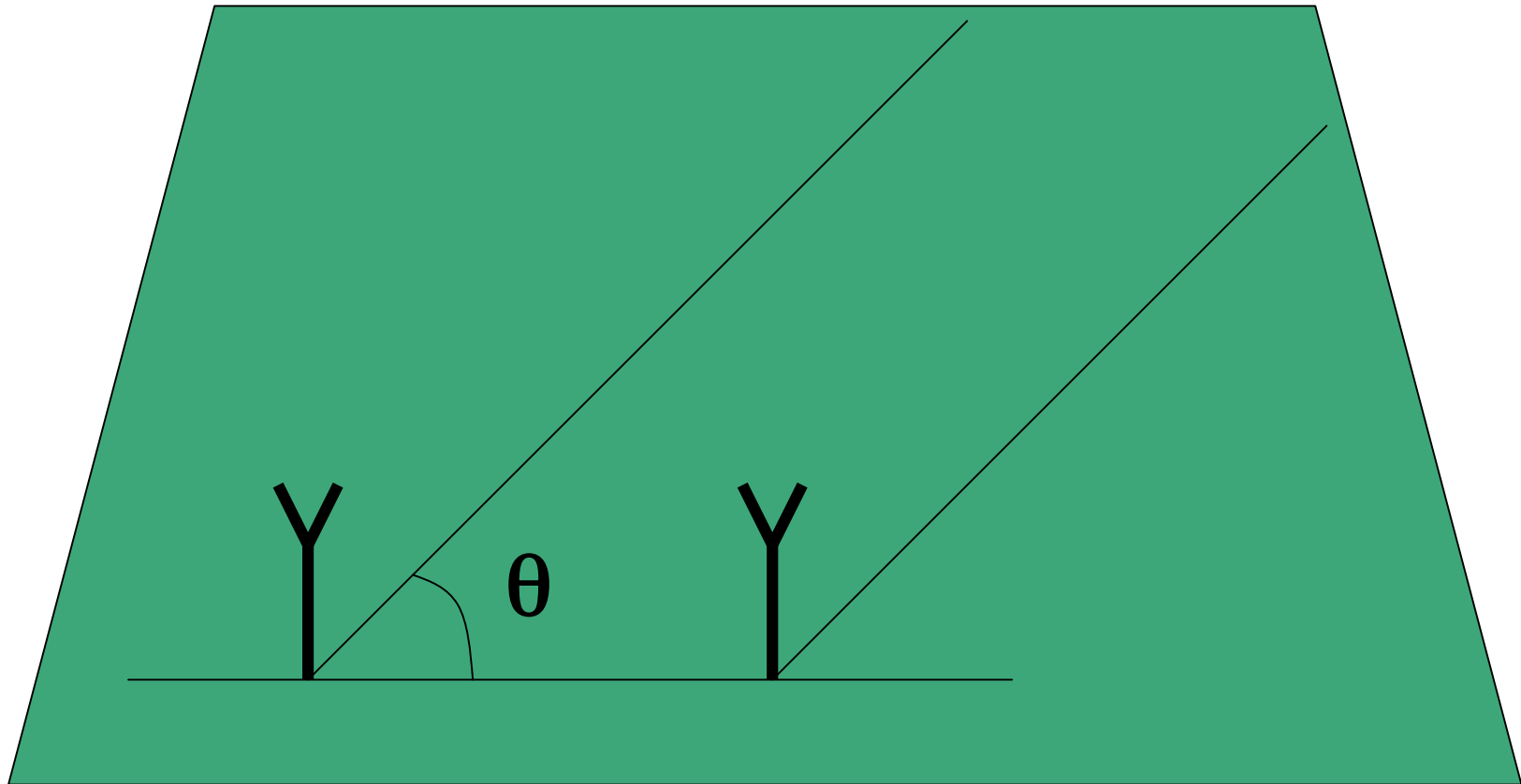
With x , y and PQ_0 , z can be easily found



3. Combination DF/TOA



3. Interferometry



Performance issues

Performance Parameters

1. Location Accuracy
2. Peak Current Amplitude Reports
3. Detection Efficiency
4. Grouping of strokes

1. Location Accuracy

- Known location strike objects (towers, windmills, buildings, etc.)
- Triggered lightning
- Different strokes from the same flash
- Theoretical estimates
- Currently a few hundred meters



2. Peak Current Amplitude Reports

- Model-based
- Empirical formula-based

Model-based Current Estimates

$$i(0, t - r / c) = - \frac{2 \pi \epsilon_0 c^2 r}{v} E_{dist}(r, t)$$

Transmission Line Model
Distant Field - Current Link

Model-based current amplitude report: some important points

1. $I-E$ relations are 'return-stroke model dependent'
2. Influence of return-stroke velocity
3. Influence of propagation over mountainous terrain and resistive soil
4. Influence of the strike object
5. Reports are better for statistical values than for single events

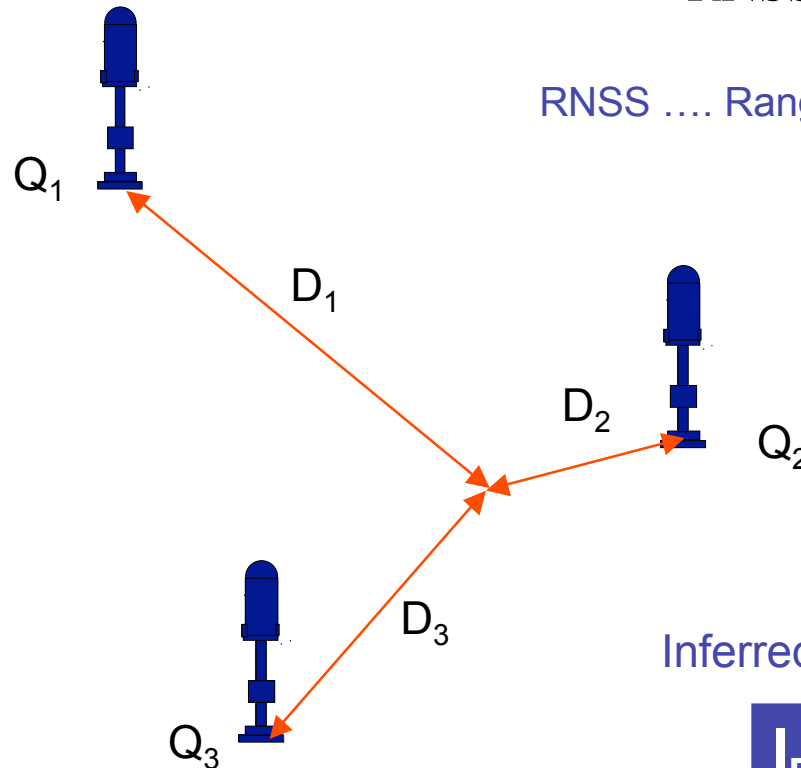
Empirical formulas

- Use triggered lightning to derive empirical relation
- Adapt to already measured statistical distribution from Berger (from the early forties to the early seventies)

Empirical relation-based current estimates

$$\text{RNSS} = \text{SS} * \left(\frac{D}{100} \right)$$

RNSS Range Normalized Signal Strength



Inferred Lightning Peak Current I_p :

$$I_p = 0.185 * \text{RNSS}$$

3. Detection Efficiency

- Stroke Detection Efficiency
- Flash Detection Efficiency
- Storm Detection Efficiency

Stroke Detection Efficiency (SDE)

- It is the percentage of strokes that are detected in a given area

Flash Detection Efficiency (FDE)

- It is percentage of flashes that are detected by the system

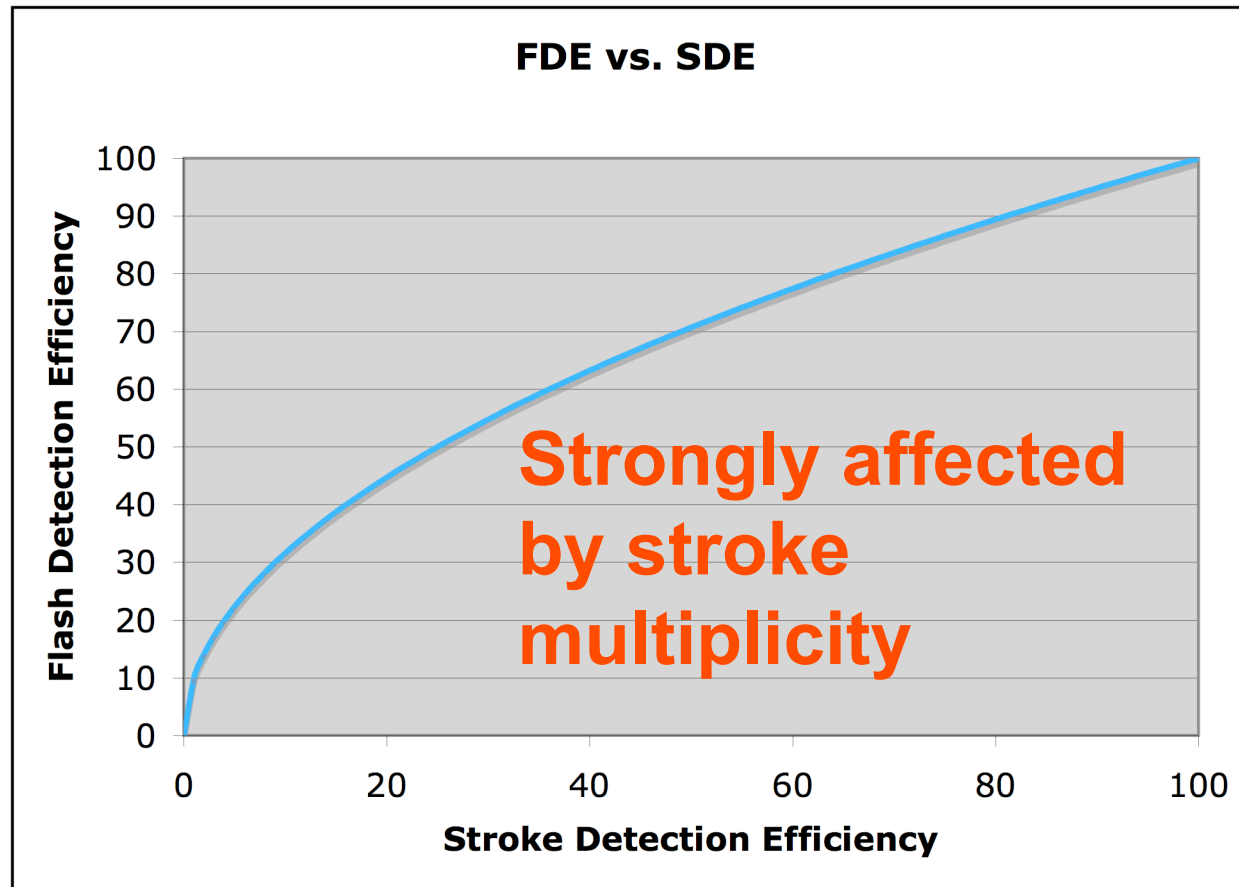
Storm Detection Efficiency (STDE)

- It is the percentage of storms that are detected by the system

What is the relation between the SDE, FDE and STDE?

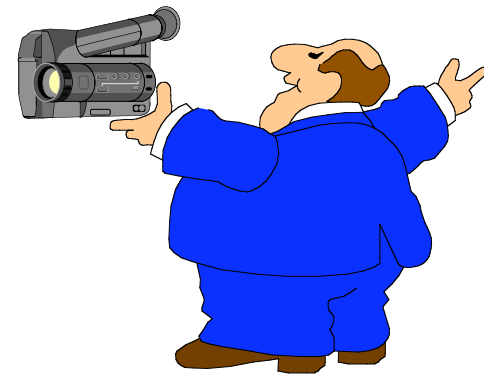
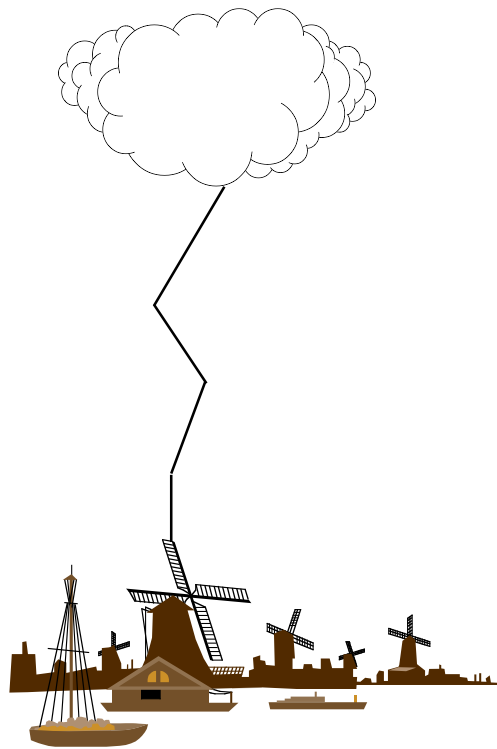
- SDE: The system has one chance to detect and locate each stroke
- FDE: The system has as many chances to catch a flash as the number of strokes in it
- STDE: The system has as many chances to detect a storm as strokes in a storm

Relation between stroke and flash detection efficiency (illustration)

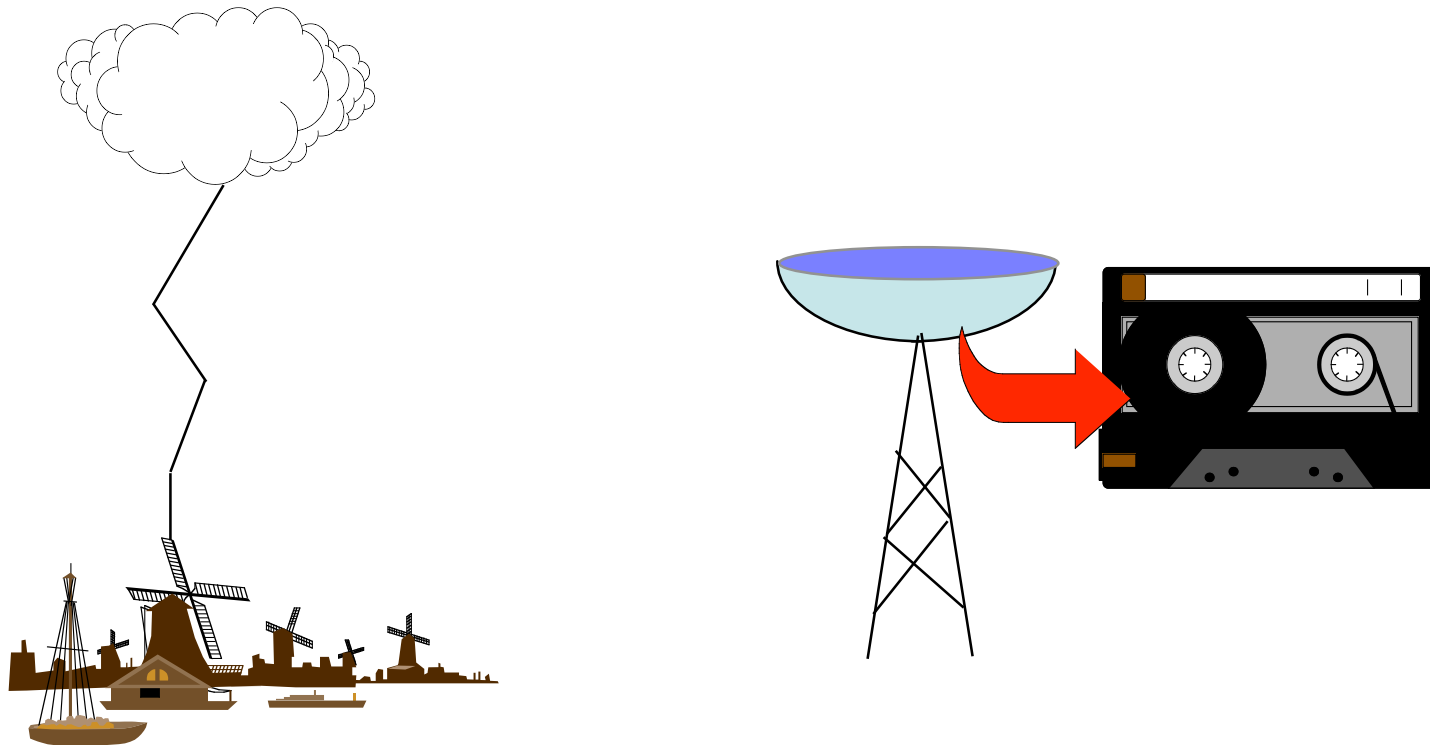


Measuring the detection efficiency (SDE, FDE, STDE)

Using a video camera to Measure the Detection Efficiency



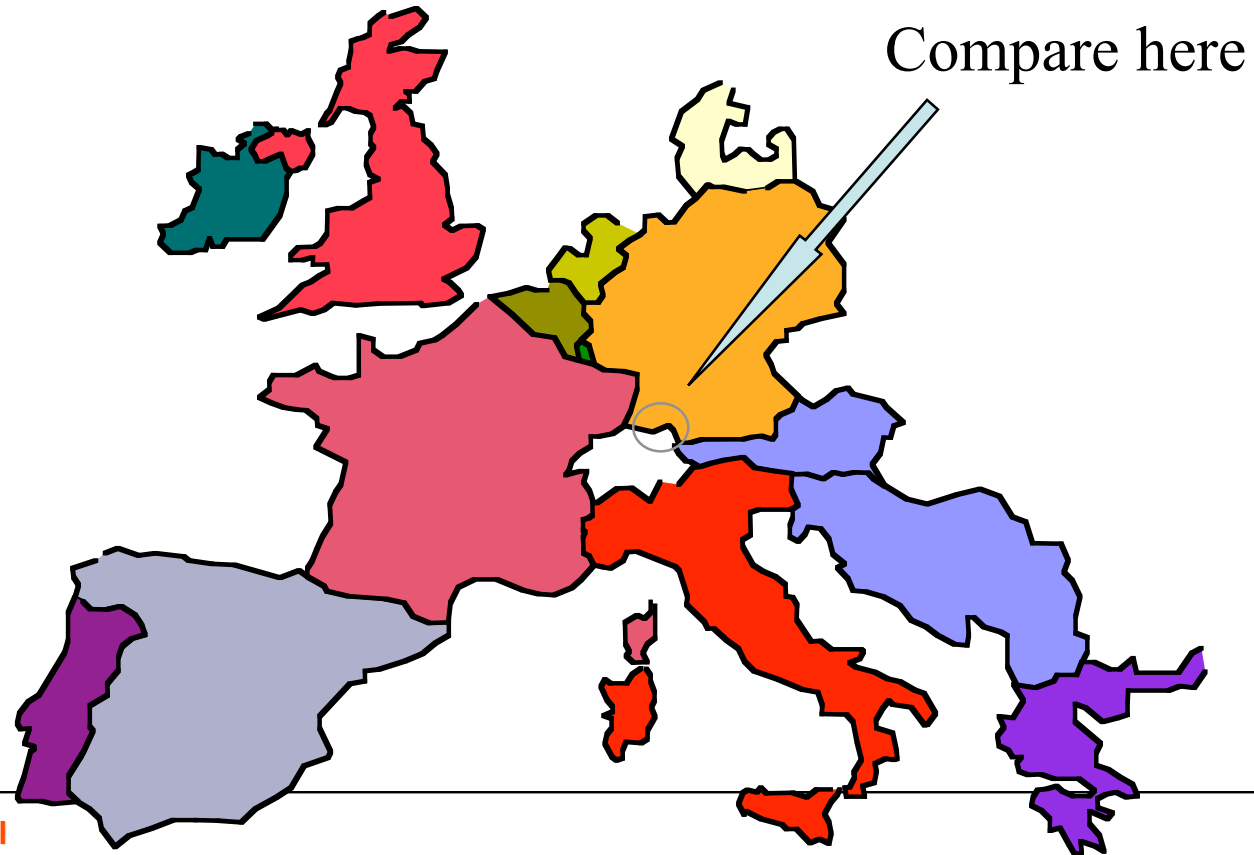
Using continuous field measurements to estimate the Detection Efficiency



Comparing adjacent systems

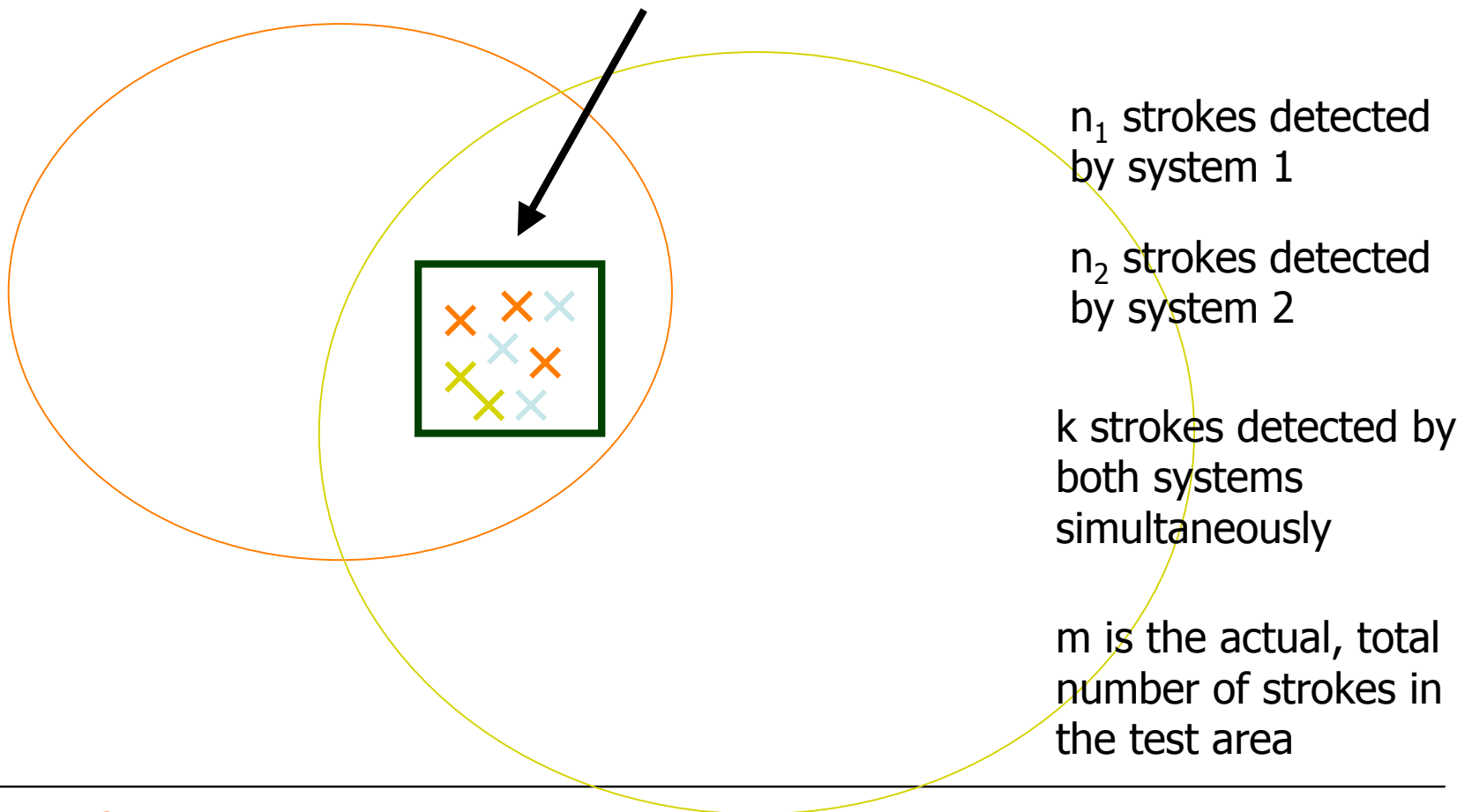
What is the detection efficiency if...

- Both systems detect the same strokes?
- Each system detects a different set of strokes?



Two adjacent systems

Area where SDE will be estimated

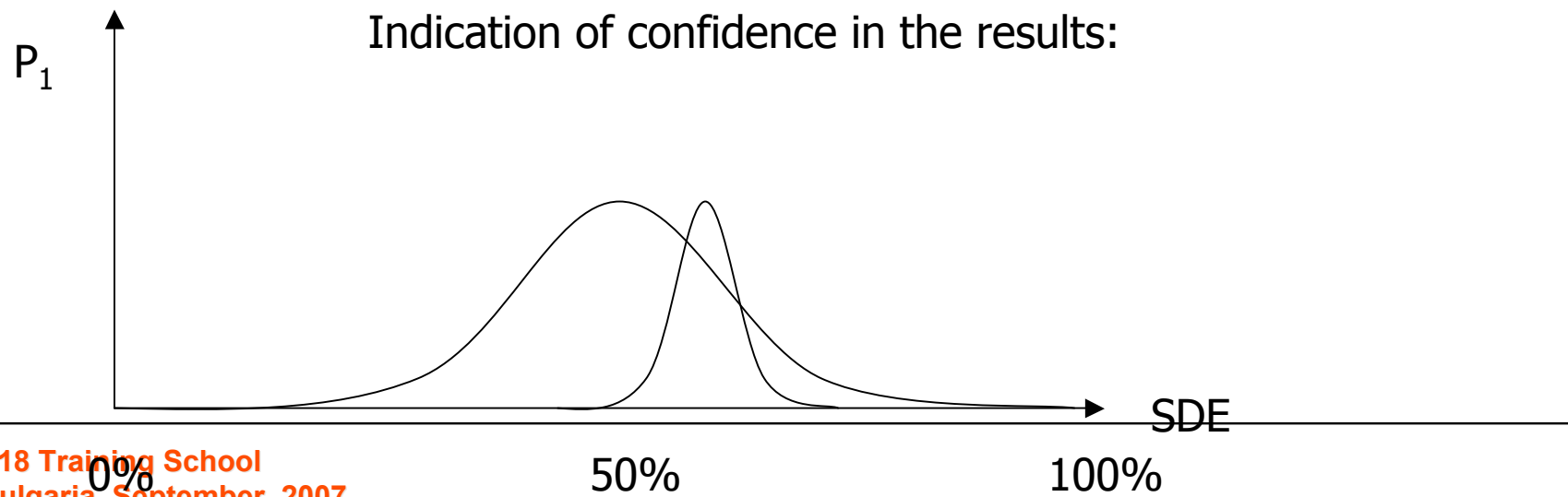


What can be expected intuitively?

- If the detection efficiency of both systems were 100%, what would be the relation between n_1 , n_2 , and k ?
 - $n_1 = n_2 = k$
- If $n_1 = k$ but much smaller than n_2 , is the stroke detection efficiency of system 1 high or low?
 - Low

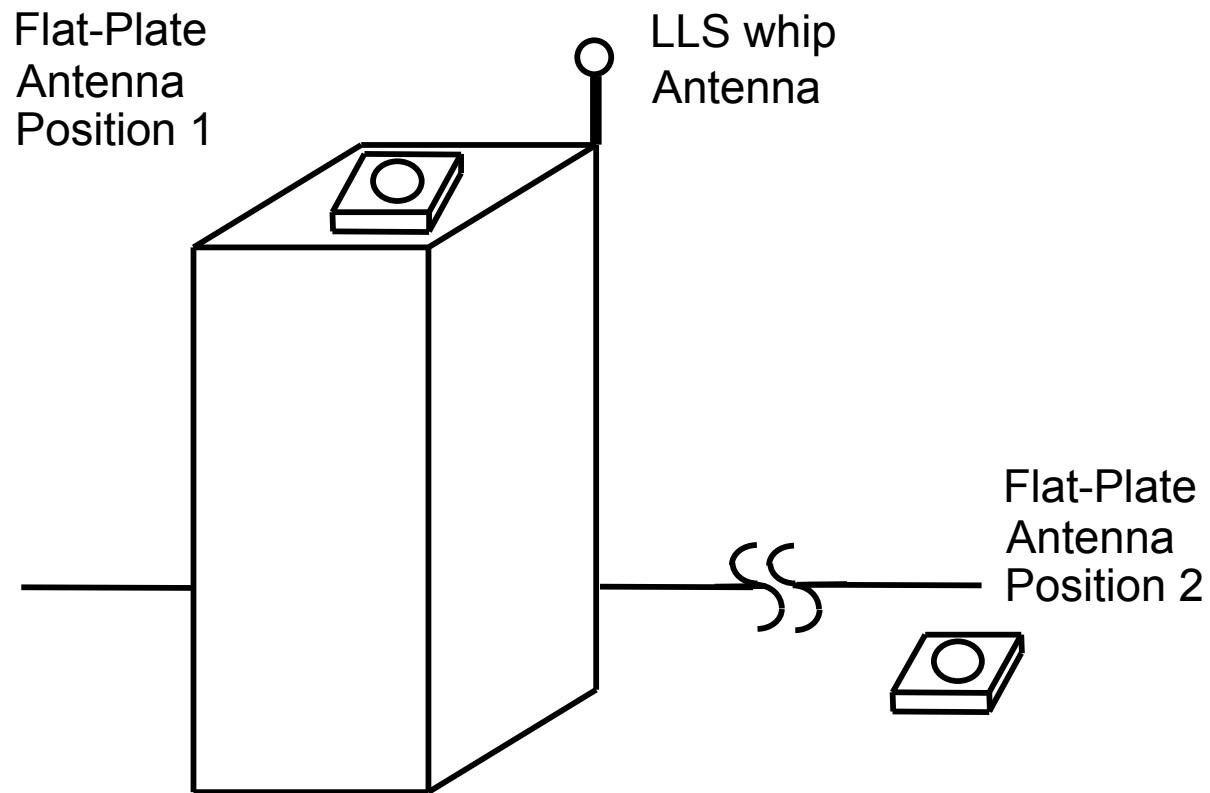
Formulas

Most likely detection efficiencies:



Calibrating for Amplitude

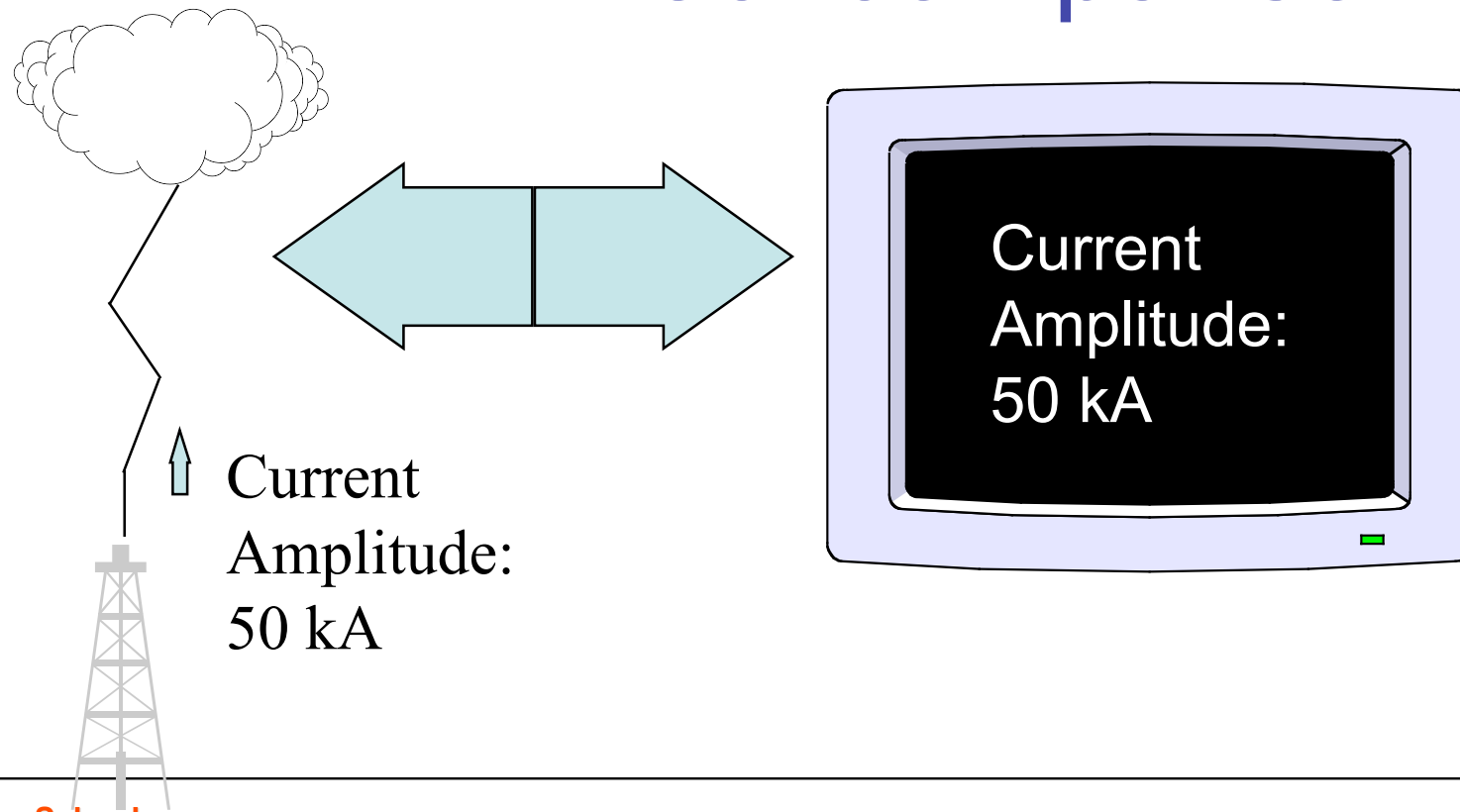
Accuracy of current amplitude report



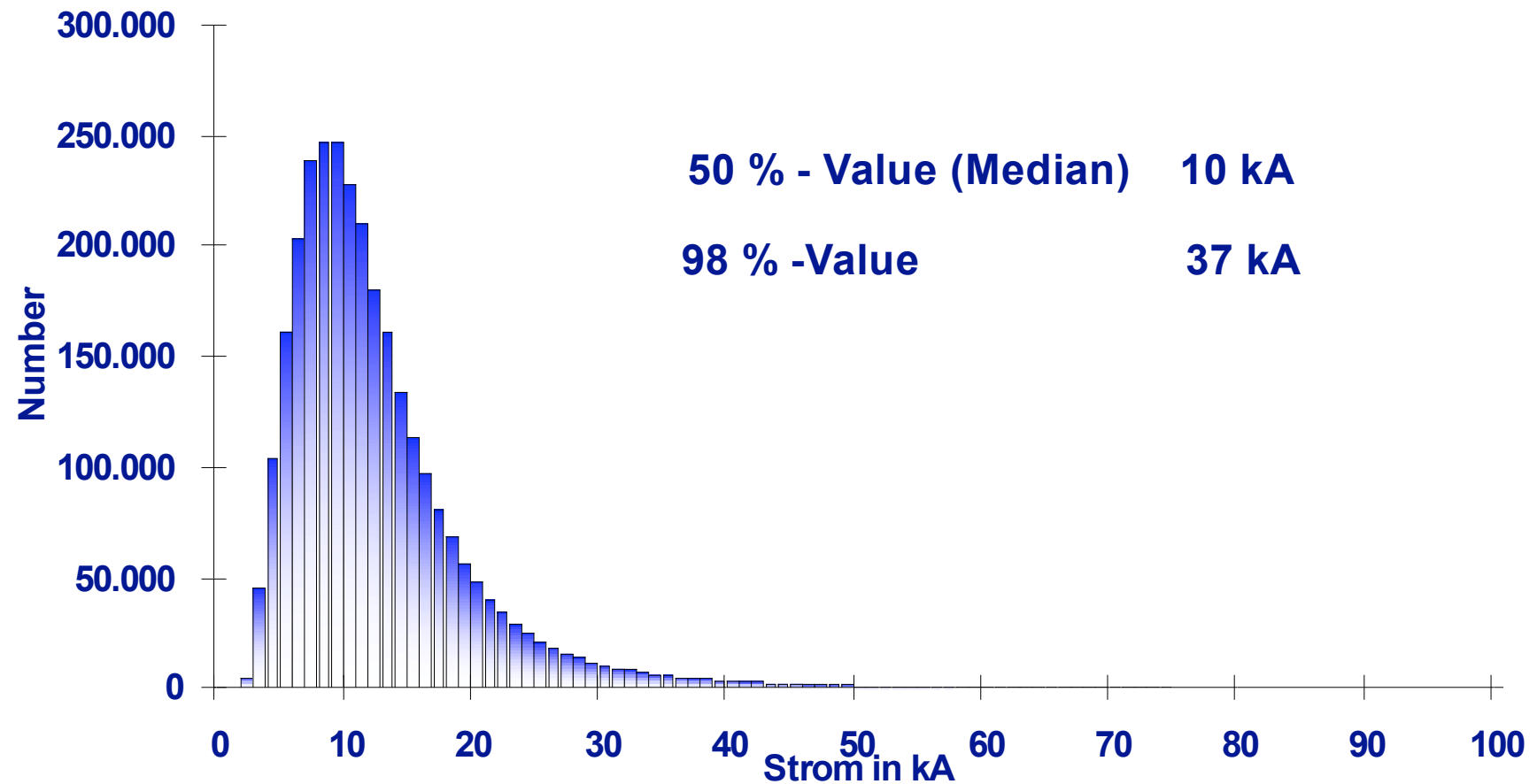
Calibration system for E fields ...

With reliable fields, can use direct measurements or statistical data

Direct comparison



Empirical Amplitude Estimation: Adjust reported to measured distribution



Questions?