ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

Development of drone-borne cal-pulser system

for radio observatories of ultra-high energy air showers

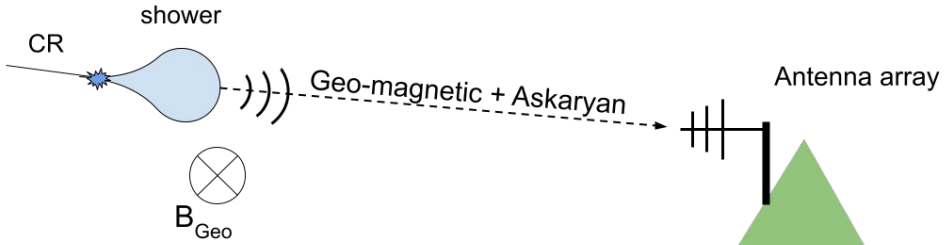
Kuo, Chung-Yun
for the TAROGE collaboration
Department of Physics and Leung Center
for Cosmology and Particle Astrophysics, NTU
2021/07/07

Outline

- Introduction & motivation
- Design and development
  - Pulse transmitter
  - Differential GPS
  - RFI measurement
- Application to TAROGE experiments
- Summary & application

Radio detection of UHE particles

- Radio emission from shower induced by UHE particles
  - Geo-magnetic radiation & Askaryan radiation
  - Coherent radio impulse
- Radio detection
  - Long radio propagation length in air
    ⇒ Large effective area
  - High duty cycle
    ⇒ More exposure
  - Recent RF technology
    ⇒ Cost effective



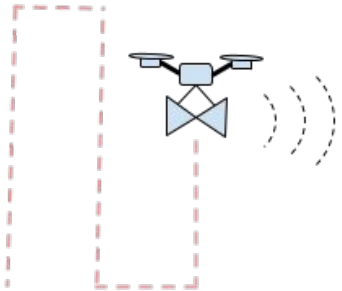
⇒ Radio detection is a promising technique

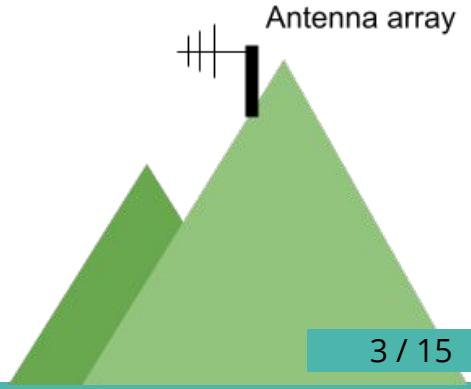
⇒ Like: ANITA, ARA and TAROGE

Motivation

- Cal-pulser is crucial for radio experiment
  - Validation
  - Calibration: Trigger, timing, power (energy)
  - Characterization: RF propagation

- Drone-borne cal-pulser
  - Can cover entire field of view
  - Easy to deploy in the field
  - Programmable flight path

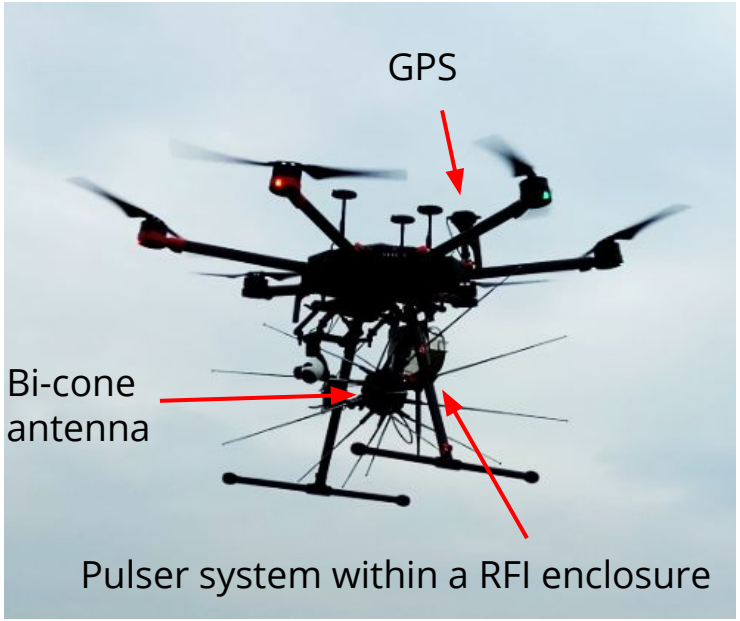




Requirements of the drone-borne cal-pulser

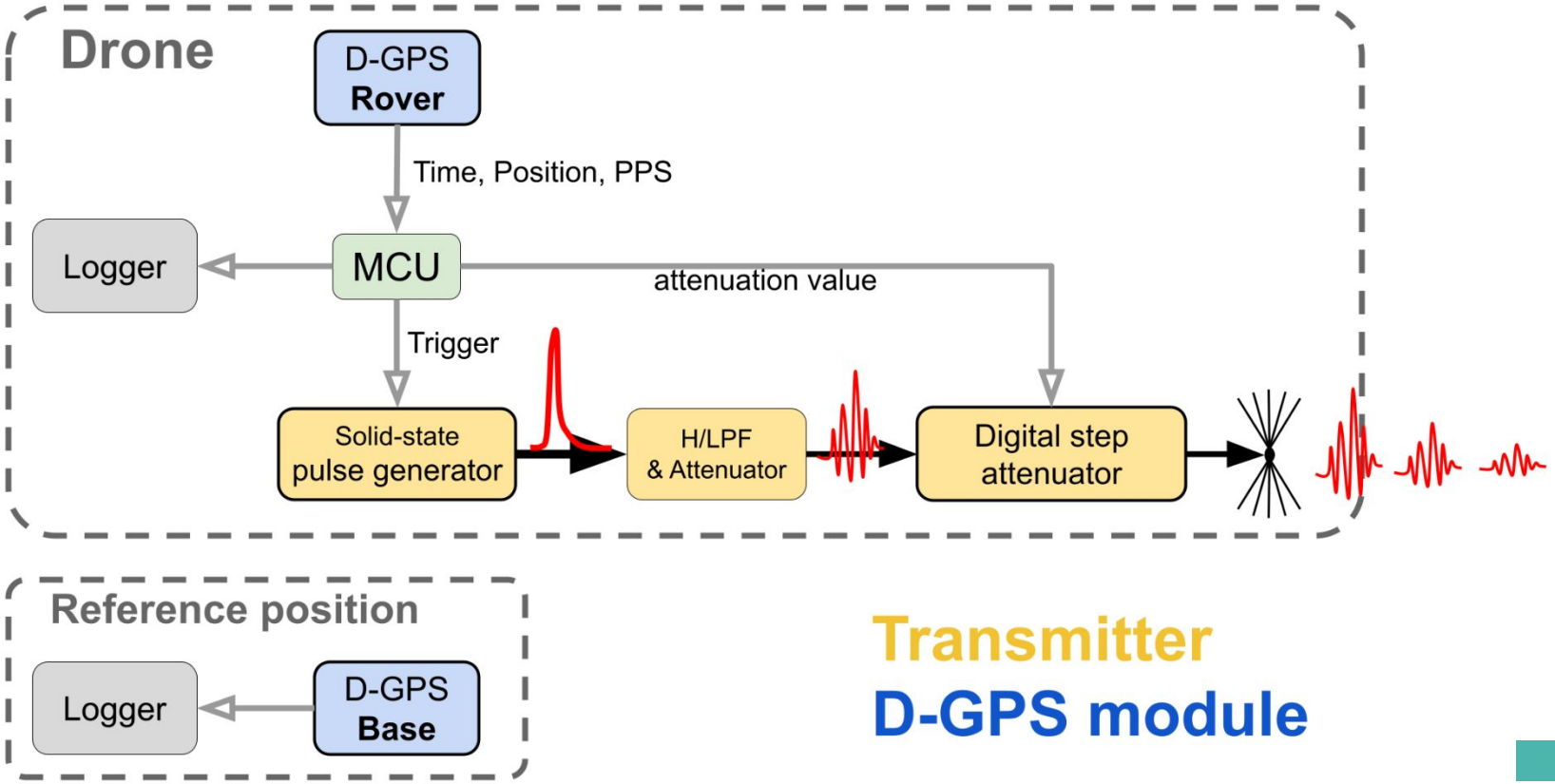
- High power impulse generator for long distance
- Accurate position & time
- Amplitude controller
- Programmable flight path
- Low RFI to ensure clean signal and prevent fake trigger
- Light-weighted and compact to be attached on drone
- Easy to deploy in the field

Design of drone-borne pulser



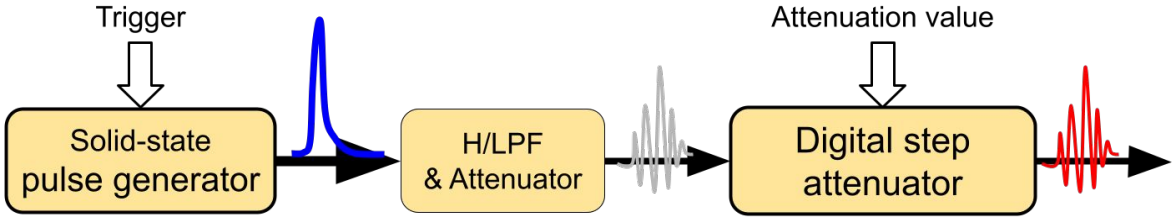
- Solid-state impulse generator
  ⇒ Strong impulse signal
- On-board MCU & digital step attenuator
  ⇒ Amplitude controller
- D-GPS ⇒ Accurate position information (cm)
- RFI enclosure ⇒ Low RFI
- Compact & light-weighted (~1.4kg)
- Longer flight time the better
  ⇒ Typically 30 minutes due to batteries
- Practical flight distance up to 1 km

System diagram



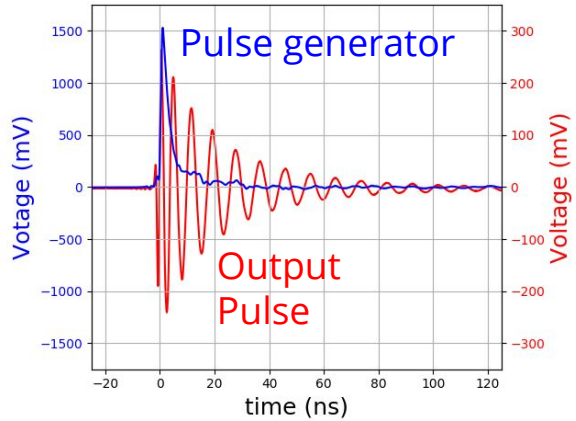
Transmitter:

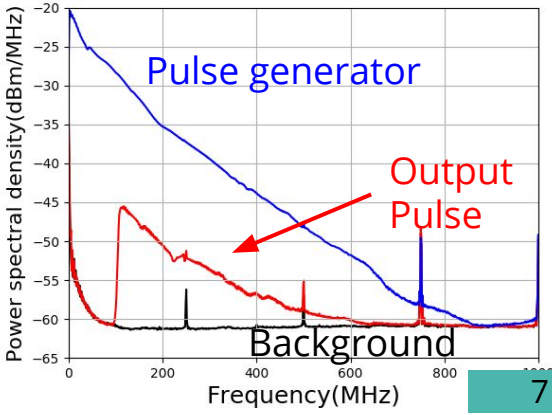
High power impulse generator and amplitude controller



- Solid-state pulse generator
  ⇒ <u>High power</u> and <u>stable</u>:
  Unipolar impulse at 150 ± 3 V
  (Provided by the collaborators in KU.)
- Digital step attenuator (0~-31dB)
  ⇒ Amplitude controller
- H/L pass filter (110MHz~1.2GHz) & -13dB Attenuator
  ⇒ Prevent damage to digital attenuator

⇒ Pulse is powerful enough for long range calibration

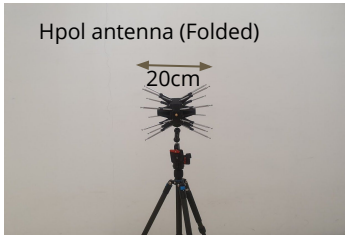


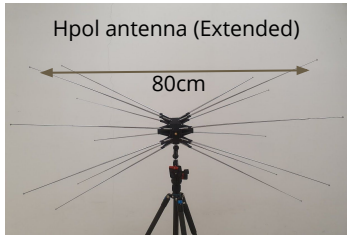


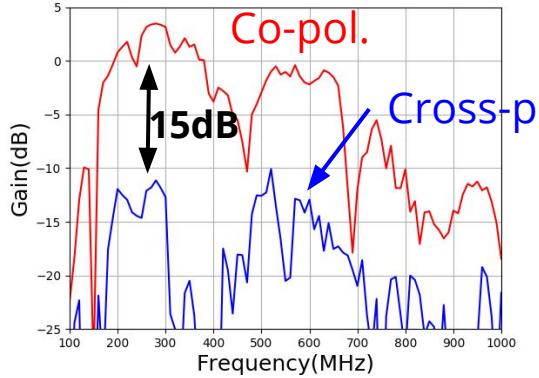
Transmitter:

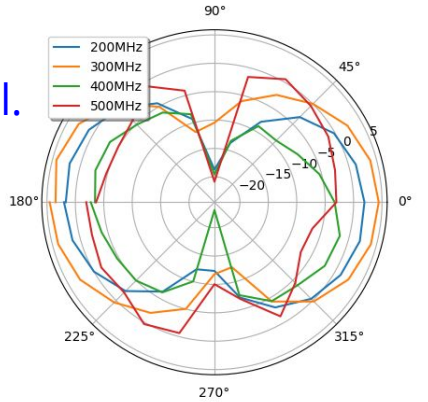
Transmitting antenna

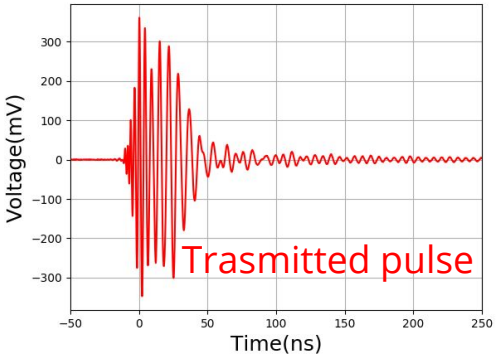
- Broadband bicone
  ⇒ 180~350 MHz
- Well-defined polarization angle
  ⇒ Cross pol. leakage < -15 dB
- Wide beam-pattern
  ⇒ Beamwidth ~ 60°
- Light-weighted & compact size
  ⇒ 600 g
- Wind resistance
- Telescopic bicone antenna
  ⇒ Easy transportation

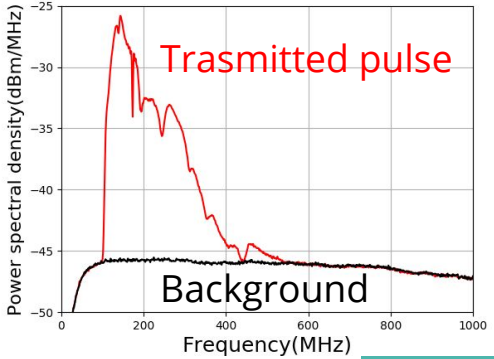








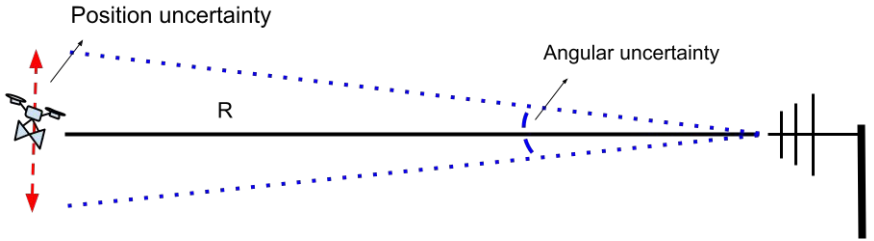


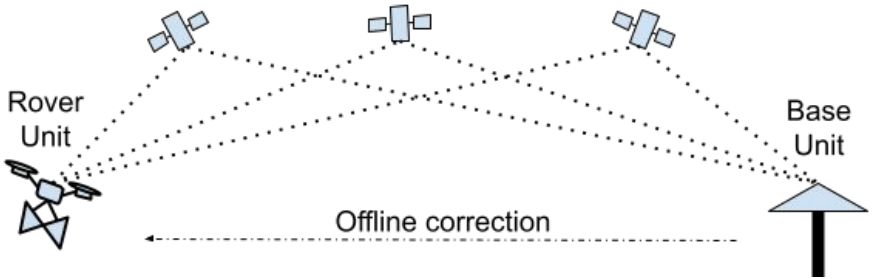


Differential GPS

- GPS:
  ~3 m in x and y, ~10 m in z direction

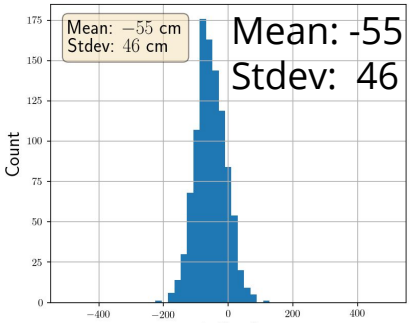
- DGPS:
  2 cm in x,y and z direction
  ⇒ 0.002° at 600m away



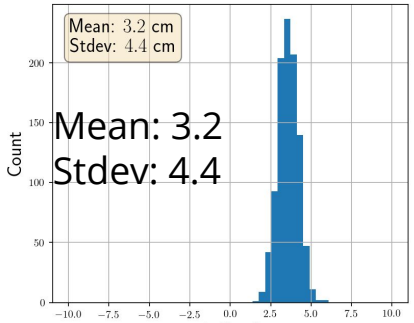


Measurement of distance between two receiver

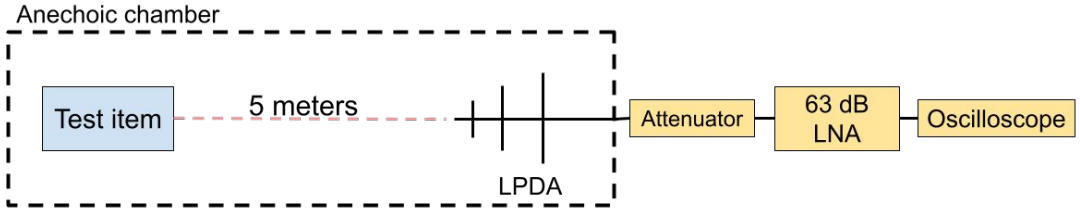
GPS solution



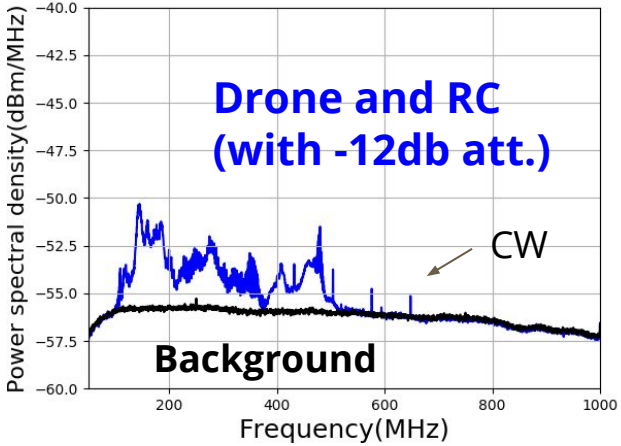
D-GPS solution

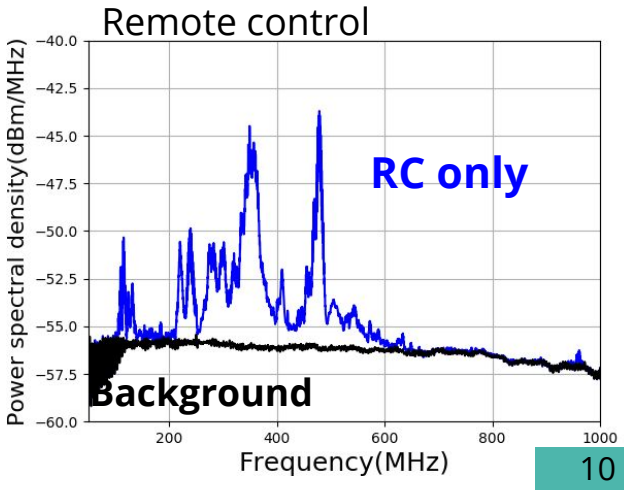


RFI measurement of drone & pulser

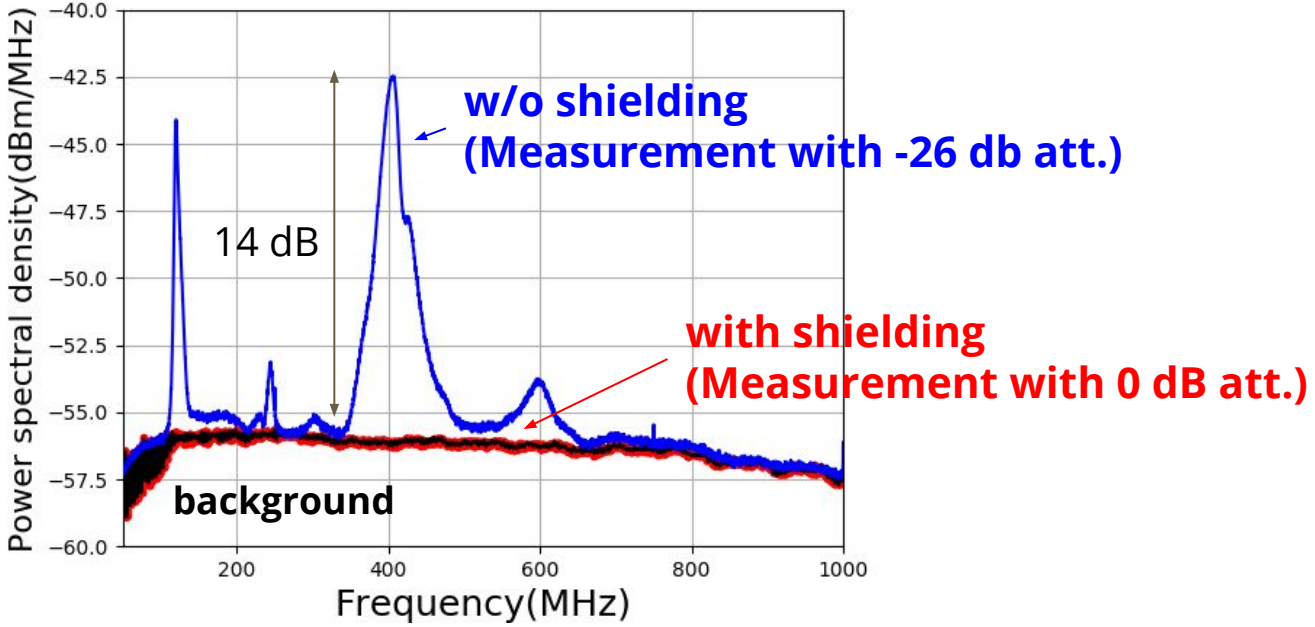


- Drone and remote controller (RC)
  - CW peak and impulsive noise
    ⇒ Neglectable at 150m away
- Remote control
  - Impulsive noise
    ⇒ Neglectable at 50 m away
- Pulser system
  - Strong impulsive noise
    ⇒ Shielding with a RFI enclosure





RF shielding of the pulser board



⇒ Shielding box provide **more than -40 dB attenuation!**

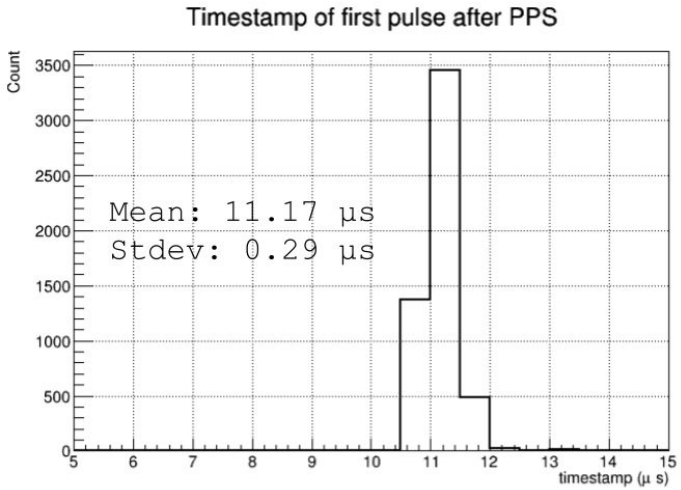
⇒ Light-weighted RF shielding box (**around 300g**)

Application to TAROGE experiment

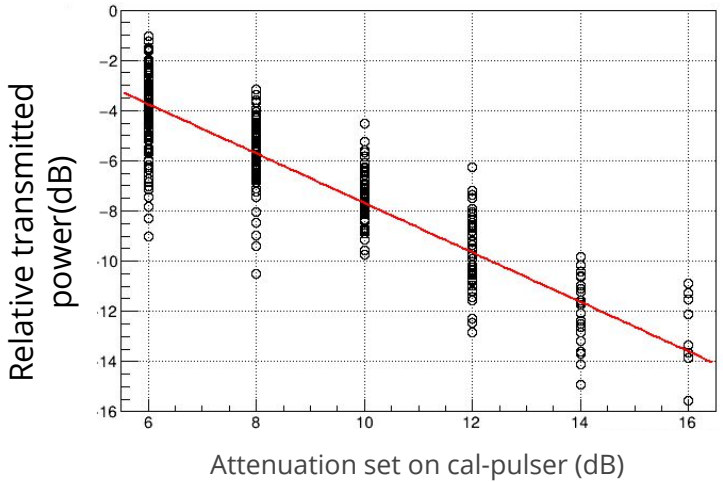
- Successfully applied to the calibration
  - TAROGE-2,3,4 in Taiwan
    - 14 flights for 4 hours
    - Refer to Chen's talk
  - TAROGE-M in Antarctica
    - 2 flights for 30 minutes.
    - Low temp. and high altitude (~2700m)
    - Refer to S.H. Wang's talk

Ref: Y. Chen, PoS(ICRC2021)263
S.H. Wang, PoS(ICRC2021)1173

Pulsing time and amplitude control



Expected attenuation
v.s relative transmitted power



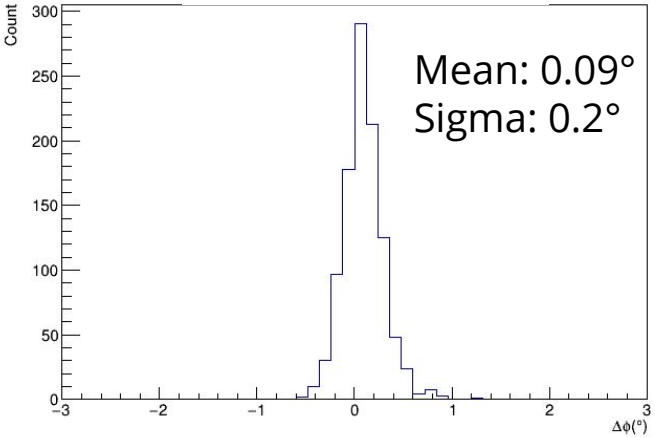
- Precise timing of pulses ⇒ Easier to select pulser events
- Pulse generator and amplitude controller work well

In-air drone position

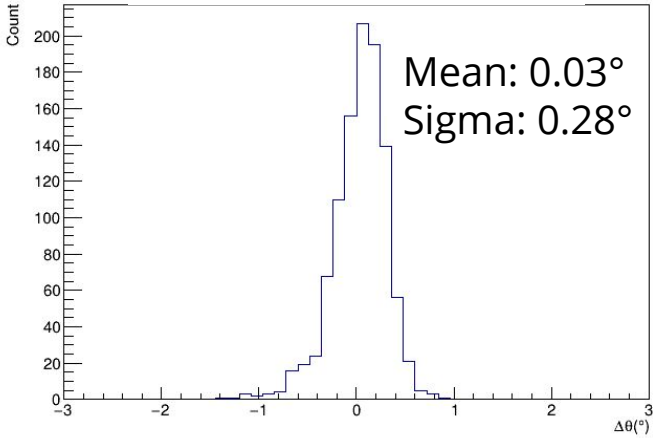
- Comparison between expectation by D-GPS and reconstruction by interferometry
- Select the event with elevation higher than 7° and exclude biased events

Ref: S.H. Wang, PoS(ICRC2021)1173

Δφ distribution



Δθ distribution



⇒ Two results are well-matched up to the resolution limit of interferometry

⇒ Enough for the calibration of antenna array with sub-degree resolution

Summary and application

- New drone-borne radio cal-pulser has been successfully developed
  - Perfect operation in Taiwan and Antarctica
  - Calibration can be done from any direction of interest with drone

- Further application:
  - Modeling the ground interference
    (Detailed information in Y. Chen's talk (**PoS(ICRC2021)263**))