Absolute calibration of the PBR telescopes

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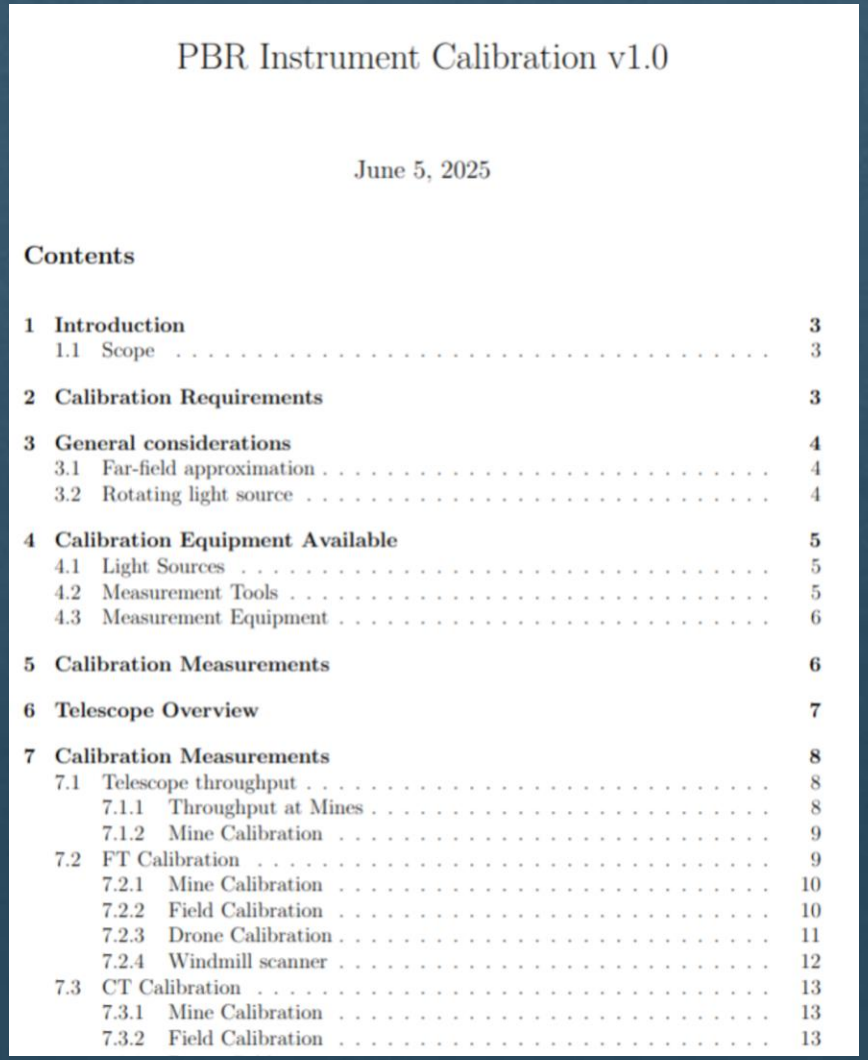
General Idea

- Provide end-to-end calibration for the optical instruments inside of the telescope
  - Telescope characterization
  - FC
  - CC
- Includes:
  - Absolute end-to-end calibration
  - Flat-fielding
- Based on the work Jim Kuznetsov did for EUSO-SPB2

Structural layout

- TBD: Currently all information is here: https://www.overleaf.com/8812244812gqqqnsnbvpdy#2b7ac9
- Will add a wiki page
- Will have a slack channel
- Currently collecting information and ideas to build a calibration plan
- Any thoughts or ideas are welcome!
- Reaching out to George and Giuseppe to more clearly define what is needed



PBR Instrument Calibration v1.0

June 5, 2025

Contents

Requirements

Telescope throughput:

- PSF measurement in different locations
- Throughput measurement at different wavelengths and at different locations

FC Calibration:

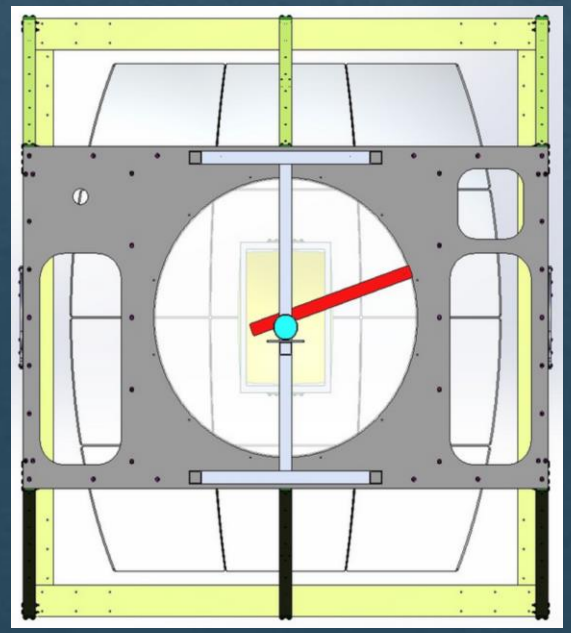
- Response to 30,100,300,1000 photons per pixel per GTU
- Different locations in the camera
- Short pulse measurements to test KI Channel?
- Flat-fielding

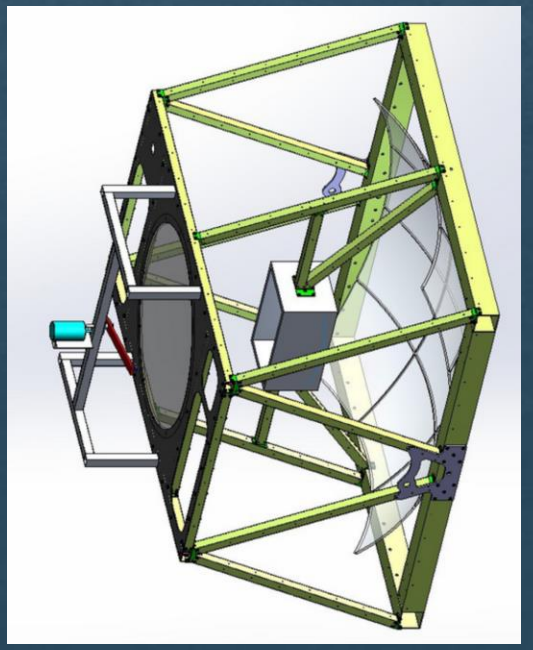
CC Calibration:

- Response to calibrated light pulse that mimics an EAS signal
- Linearity as a function of pulse length
- Linearity as a function of amplitude
- Flat-fielding

Calibration concepts

- **End-to-end calibration:** Shine parallel light of known intensity into the telescope
  - 1m beam (too small but a good starting point)
  - Source far away so that the light is close to parallel
- **Flat fielding:** Flashing at many locations across entrance pupil and averaging the result
  - Method was developed for Auger FT
  - Can be portable to Wanaka



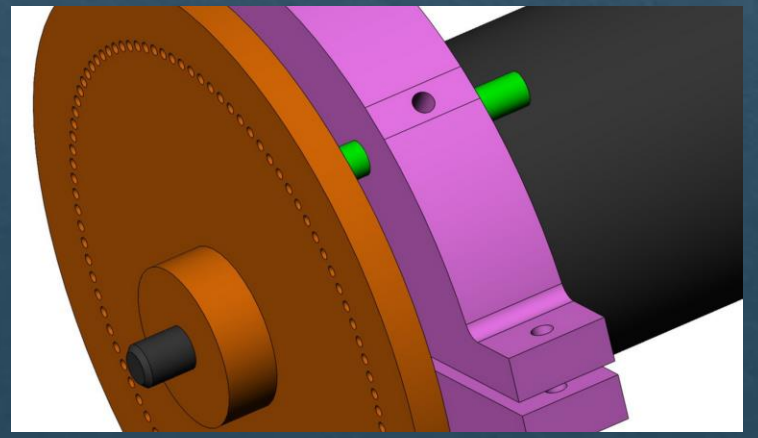


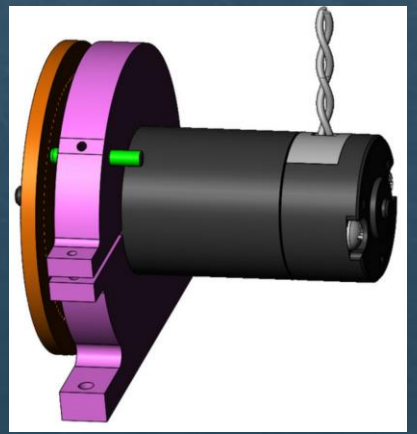
Testing and procurement

- **Absolute Calibration:**
  - Working with Jim Kuznetsov to understand his calibration method
  - In contact with NIST about potential calibration of a light source or LED (may be expensive and too long lead time)
  - Use laser radiometers for far field calibration due to high light levels
  - Reached out to Hallsie Reno and Mike Miller to figure out how it is done for HLED
  - Develop a test setup at Mines to characterize absolute and angular output of light sources
  - Develop test setup to characterize temperature dependence of light sources
- **Procurement:**
  - Want to rebuild setup from Jim Kuznetsov (can start immediately)
  - Develop calibration setup (can start immediately)
  - Working on finalizing design of additional testing equipment
  - Will set up a meeting to discuss details before starting to buy components to make sure the design meets everyone's needs

Other Calibration Ideas

- Using a drone to avoid ground reflections
  - Drone developed by Nathan Woo
  - Can carry a payload up to 1kg for 30min
  - Will be used for mirror alignment
- Mechanical light pulse management
  - Turn on times of ~1ns level are hard to control
  - Mechanically truncating light pulses may be an option
- Adjusting divergence and dimming laser
  - Could be closest we can get to mimicking EAS behavior in CC
  - Easy to control





Main focus
If possible
Low priority

Calibration campaigns

Integration at Mines:

- Uses 1m beam
- Can be performed during integration
- Flat fielding

Measurements:

- Telescope throughput
- Camera calibration (if time allows)

Calibration in Edgar Mine:

- Very dark environment
- Tunnel limited length
- May be dusty

Measurements:

- Telescope throughput
- Camera calibration (if time allows)

Calibration during field tests:

- Flasher calibration similar to EUSO-SPB2
- Calibration from drone to avoid ground reflections
- Calibrations using laser trailer for CC
- Flat fielding

Measurements:

- Telescope throughput
- Camera calibration

Calibration in Wanaka:

- Flasher calibration similar to EUSO-SPB2
- Flat fielding
- Calibration from drone to avoid ground reflections
- Calibrations using laser for CC

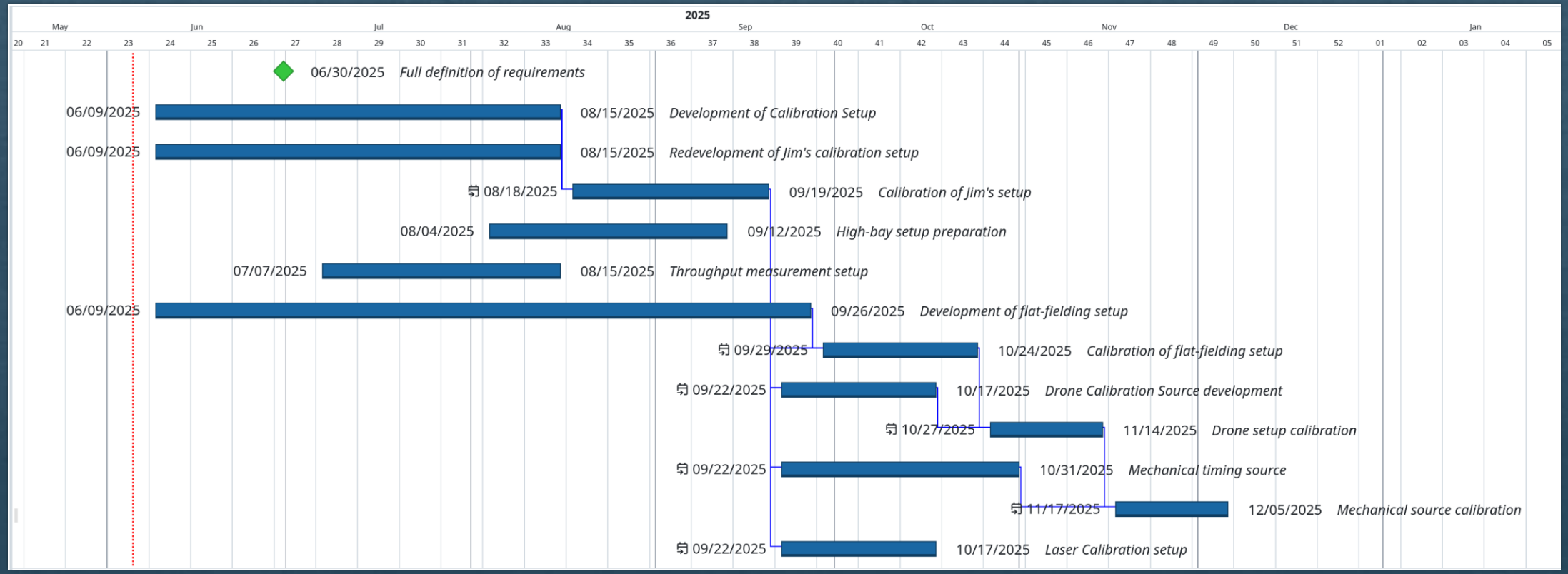
Measurements:

- Telescope throughput
- Camera calibration

System development timeline

Timeline								
Items	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**
Develop calibration setup								
Rebuild Jim’s calibration method								
Develop flat fielding method								
Develop throughput measurements								
Drone calibration								
Mechanical light source								
Laser calibration								

System development timeline



Summary

- Planning for an end-to-end calibration has begun
- Main priority will be reproducing the calibrations provided by Jim Kuznetsov
- Additional calibration measurements and ideas under investigation

- Please let me know if there is anything I am missing!

Telescope throughput Calibration

- Measurement

Table 8: Mines throughput measurement sequence

Meas ID	Task	Duration	Status	Prep	Ref
Mines-TP1	1m beam alignment	3 days	Todo	Todo	9.1.1
Mines-TP2	Find ideal alignment of 1m beam on 1.1 m aperture	3 days	Todo	Todo	-
Mines-TP3	Beam calibration using windmillscanner	1 day	Todo	Todo	9.1.2
Mines-TP4	PSF size scan full spectrum aligned on optical axis	1 hour	Todo	Todo	9.1.3
Mines-TP5	3D throughput scan full spectrum aligned on optical axis	1 night	Todo	Todo	9.1.4, 9.1.2
Mines-TP6	PSF size scan FC spectrum aligned on optical axis	1 hour	Todo	Todo	9.1.3
Mines-TP7	3D throughput scan FC spectrum aligned on optical axis	1 night	Todo	Todo	9.1.4, 9.1.2
Mines-TP8	PSF size scan full spectrum aligned ±5°,10°,15°, left-right, up-down from optical axis	1 hour	Todo	Todo	9.1.3
Mines-TP9	3D throughput scan full spectrum aligned ±5°,10°,15°, left-right, up-down from optical axis	1 night	Todo	Todo	9.1.4, 9.1.2
Mines-TP10	PSF size scan FC spectrum aligned ±5°,10°,15°, left-right, up-down from optical axis	1 hour	Todo	Todo	9.1.3

FC Calibration

Table 10: Mine FC calibration measurement sequence

Meas ID	Task	Duration	Status	Prep	Ref
Mine-FC1	Construct blinds to reduce wall reflections	3 days	Todo	Todo	9.2.1
Mine-FC2	FC calibration measurement 10 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.1
Mine-FC3	FC calibration measurement 10 photons per pixel aligned ±5°,10°, left-right, up-down from optical axis	1 hour	Todo	Todo	8.1
Mine-FC4	FC calibration measurement 30 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.1
Mine-FC5	FC calibration measurement 30 photons per pixel aligned ±5°,10°, left-right, up-down from optical axis	1 hour	Todo	Todo	8.1
Mine-FC6	FC calibration measurement 100 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.1
Mine-FC7	FC calibration measurement 100 photons per pixel aligned ±5°,10°, left-right, up-down from optical axis	1 hour	Todo	Todo	8.1
Mine-FC8	FC calibration measurement 300 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.1
Mine-FC9	FC calibration measurement 300 photons per pixel aligned ±5°,10°, left-right, up-down from optical axis	1 hour	Todo	Todo	8.1

CC Calibration

Table 15: Field CC calibration measurement sequence

Meas ID	Task	Duration	Status	Prep	Ref
Field-CC1	CC calibration measurement 10 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.4
Field-CC2	CC calibration measurement 10 photons per pixel aligned ±5°,10°, left-right, up-down from optical axis	1 hour	Todo	Todo	8.4
Field-CC3	CC calibration measurement 30 photons per pixel aligned on optical axis	1 hour	Todo	Todo	8.4