Update on Luminosity monitoring for HL-LHC

M. Palm (BE-BI-PM)

OUTLINE

- BRAN: Overview & the HL-LHC Prototype
- Degradation
- HL-LHC FLUKA Simulations: BRAN implications
- Feasibility study: Air-based BRAN

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BRAN: Beam RAte of Neutrals

- Machine Luminosity Monitors
- Beam collisions → Neutral forward particles → Shower of charged particles in TAN (Neutral beam absorbers)

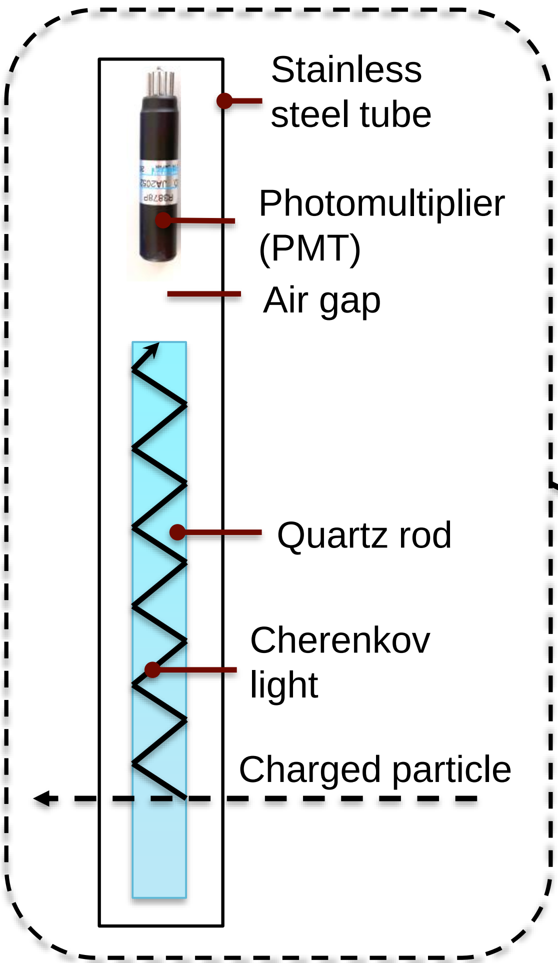
- **Backup** for luminosity measurement from experiments
- **Sanity check** of luminosity measurement from experiments
- **Finding collisions**

<u>Revised requirements (OP)</u>

- ❑ Bunch-by-bunch luminosity not needed
- ❑ Absolute accuracy: not important (proportional measurement + empirical scaling factor sufficient)
- ❑ Precision (short-term): ~2%
- ❑ Precision (fill-to-fill): ±10%

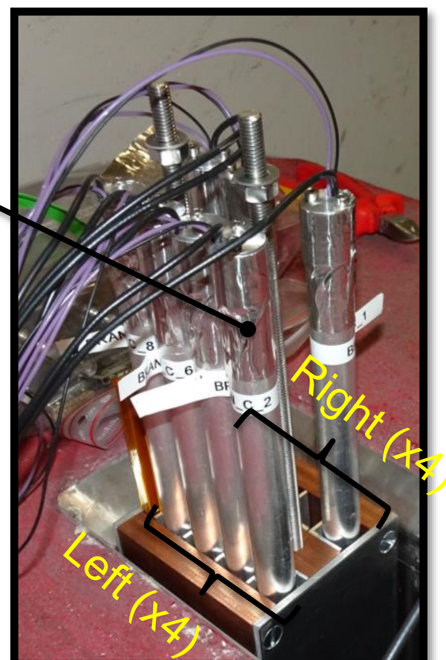
BRAN prototype for HL-LHC

Principle

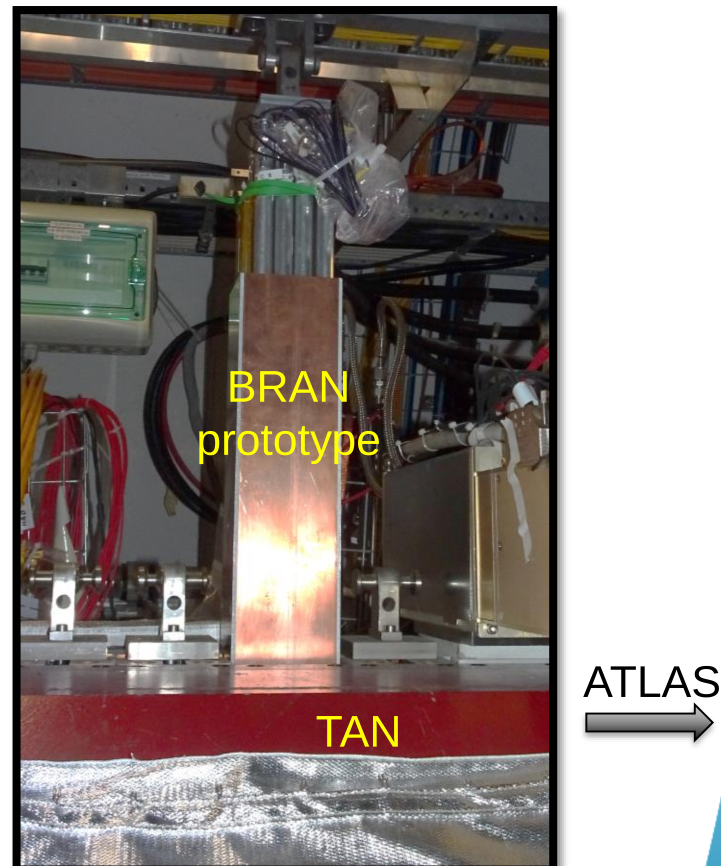


Configuration (2016)

- 6 quartz rods (Spectrosil, Suprasil)
- 1 Empty tube (air) with reflective Al-foil on inside
- 1 Blacked PMT (reference)

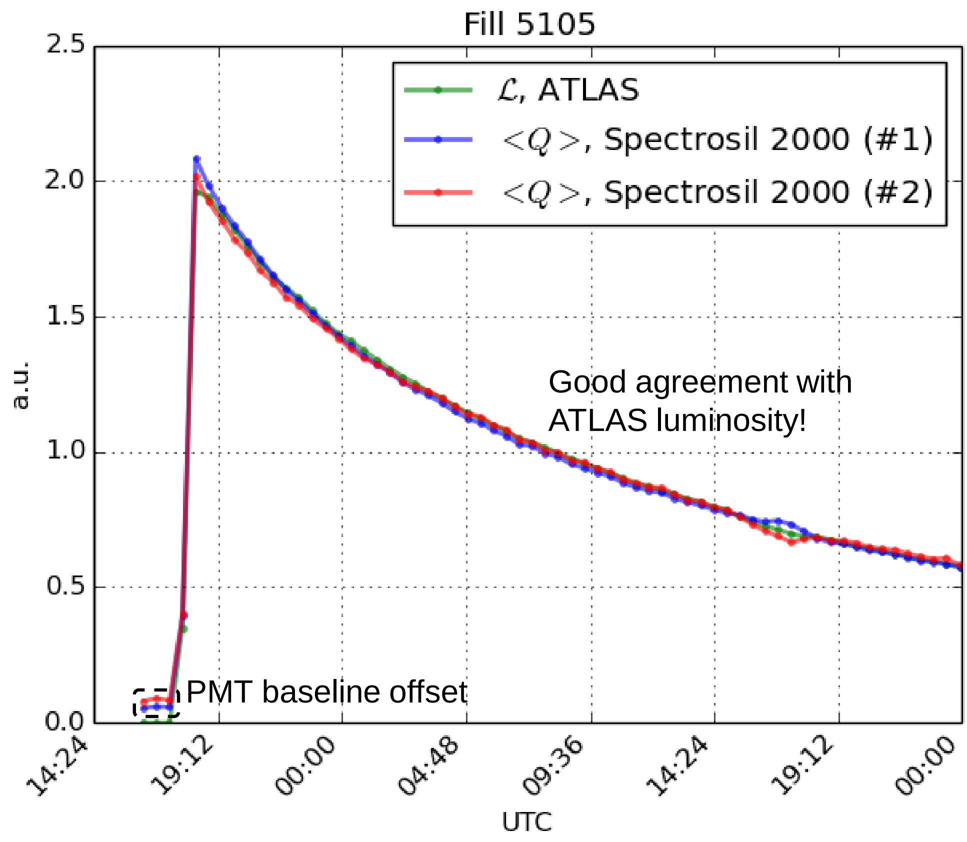


Installation into TAN



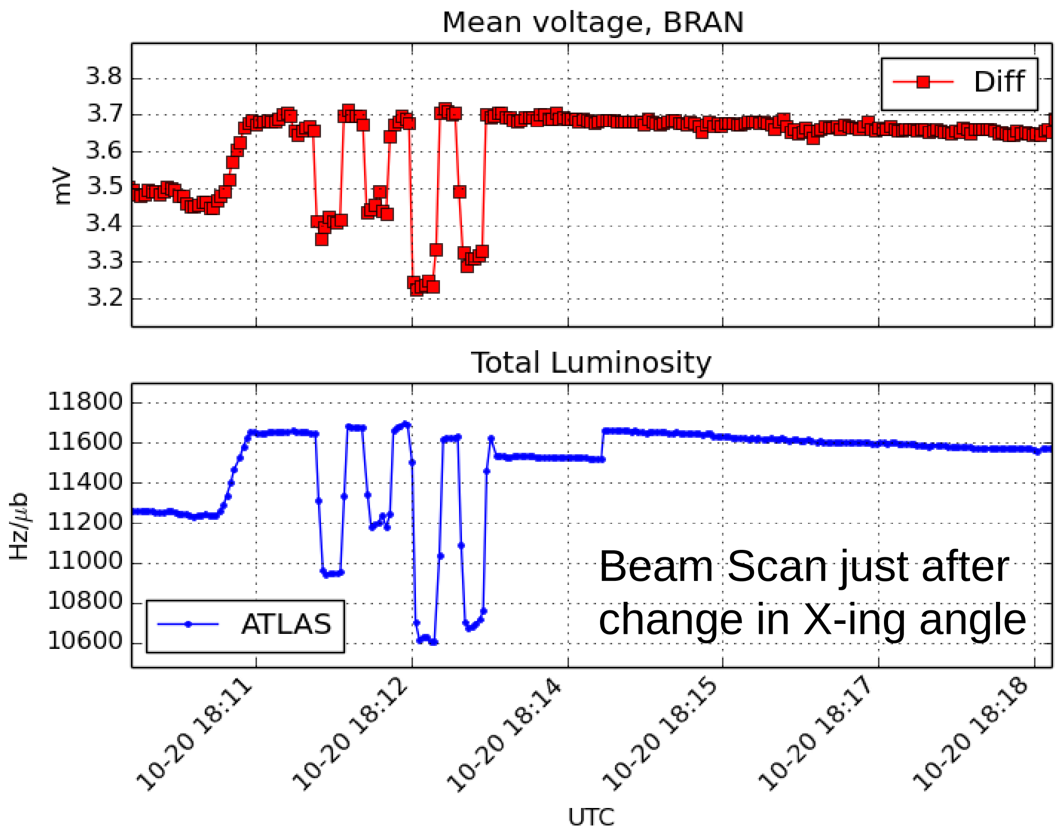
Prototype: data acquisition

- PMT charge integral around single bunch pair (total luminosity not monitored)
- Every 30 minutes, save:
  - Accumulated charge histogram
  - 1 oscilloscope trace
- Analysis: compare to ATLAS luminosity



Luminosity during beam scans

- Here: Acquisition via Picoscope (no dedicated frontend hardware/electronics)
- Good qualitative agreement with ATLAS luminosity data (single rod)



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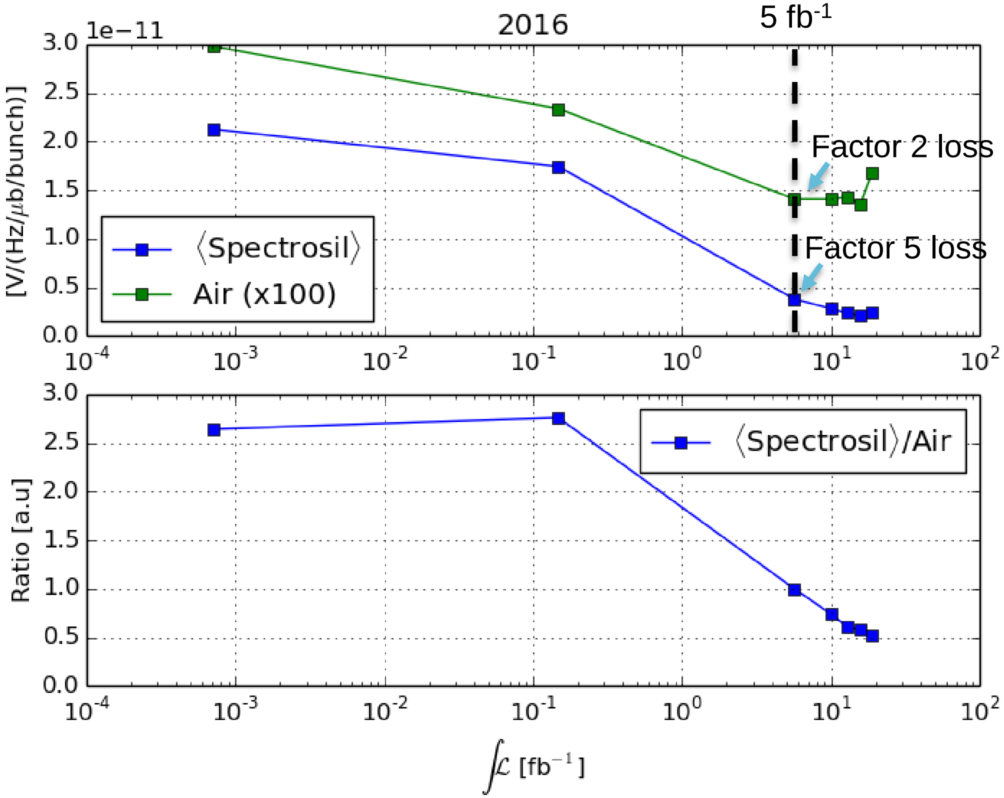
Prototype performance: degradation

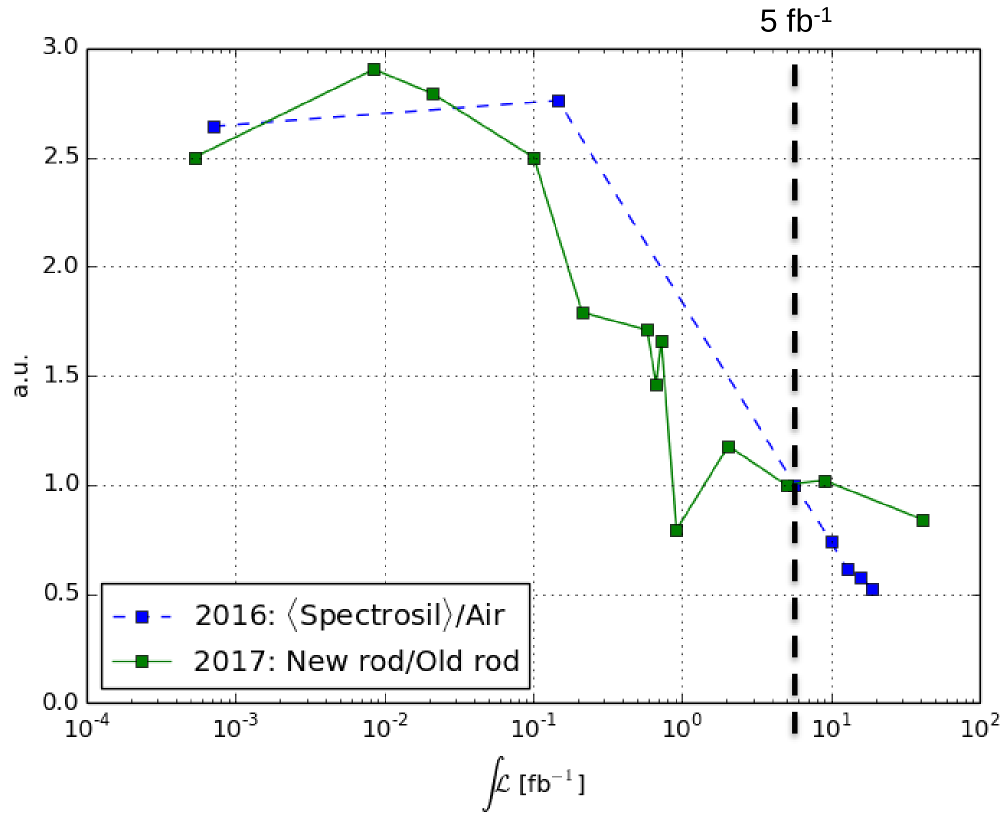
- 2016: Rapid drop in signal yield first few fb^{-1}
- Not only a quartz effect



Comparison: Spectrosil rods and Air-coupled PMT

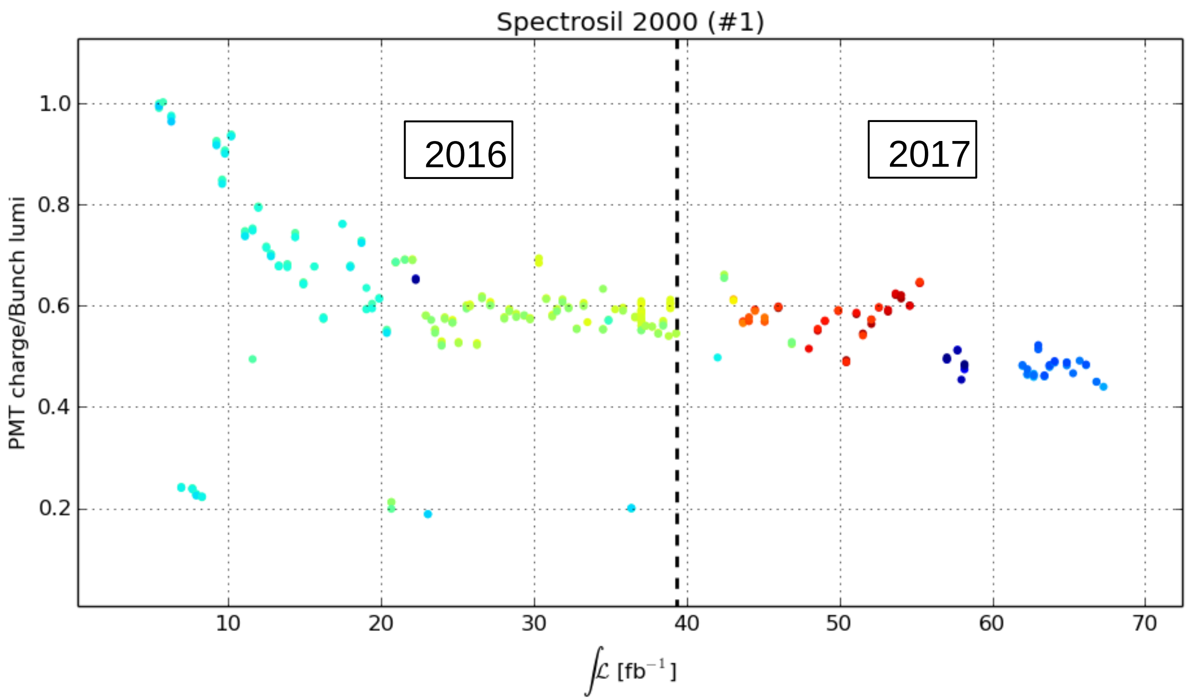
Prototype performance: degradation

- 2017: Installation of new quartz rod to study initial degradation
- 2016 result (~factor 2.5 loss first 5 fb^{-1}) reproduced



Long term

- No significant quartz deterioration observed during 2017 (<15%)



- Filter: >1600 bunches & L_{mean}=3.4-3.6 Hz/μb/bunch
- Color $\propto L_{tot}$

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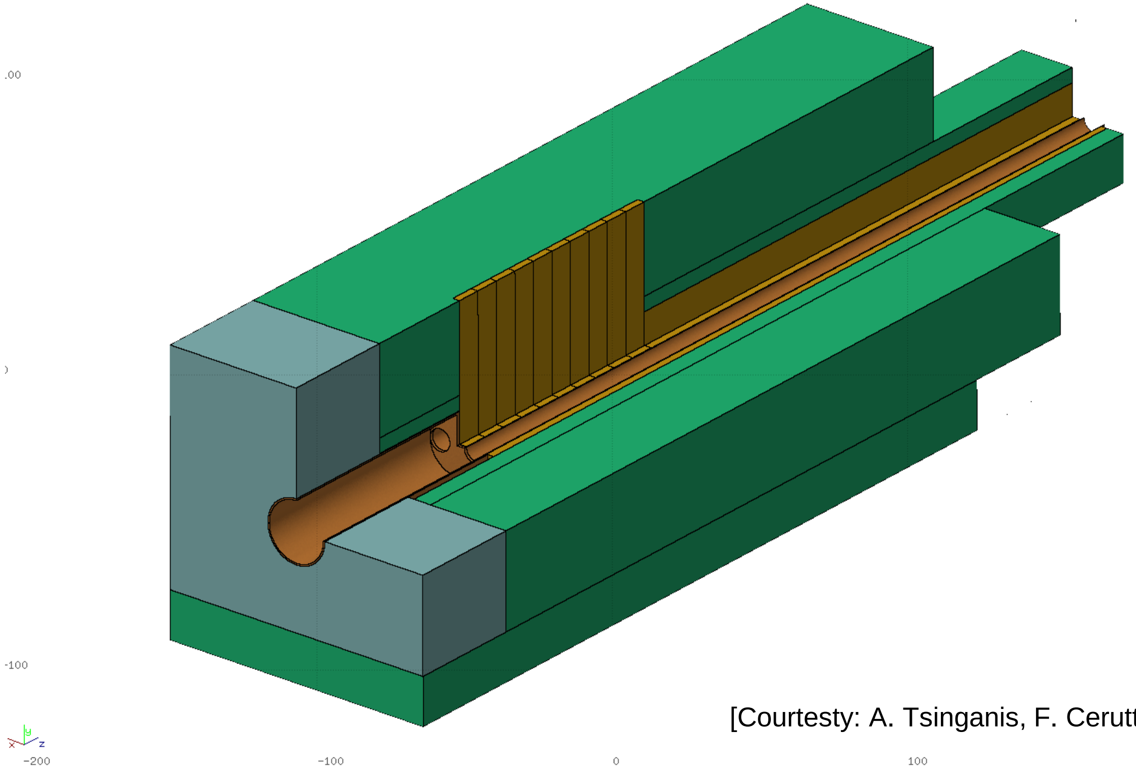
HL-LHC FLUKA simulations

- Energy deposition & particles fluence distribution simulated in new TAN
- Note: TAN slot reduced to 5 cm!

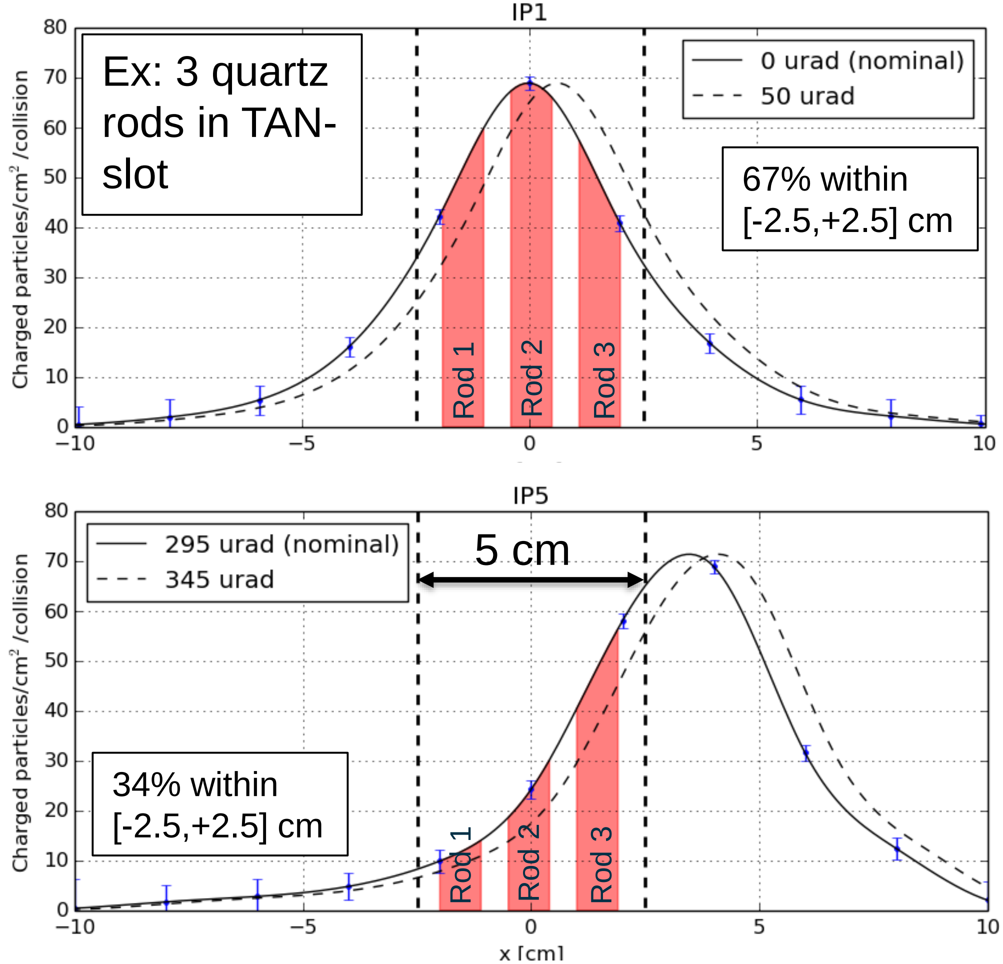


[Courtesty: A. Tsinganis, F. Cerutti]

Geometrical limitations

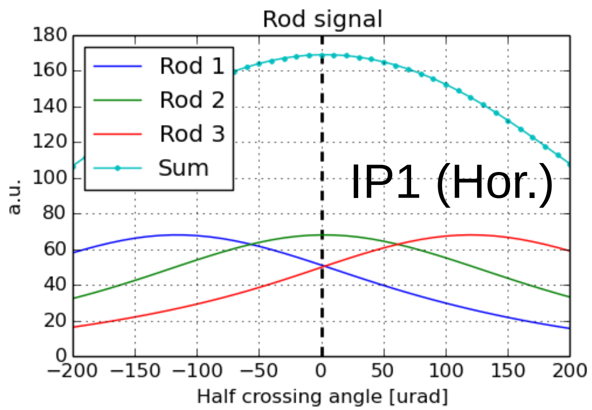
- TAN slot reduced to 5 cm → Not all charged particles can be intercepted
- IP1: Vertical X-ing → Shower horizontally centered in TAN
- IP5: Horizontal X-ing → BRAN will intercept the fluence “tail”

Charged particle fluence distribution at peak



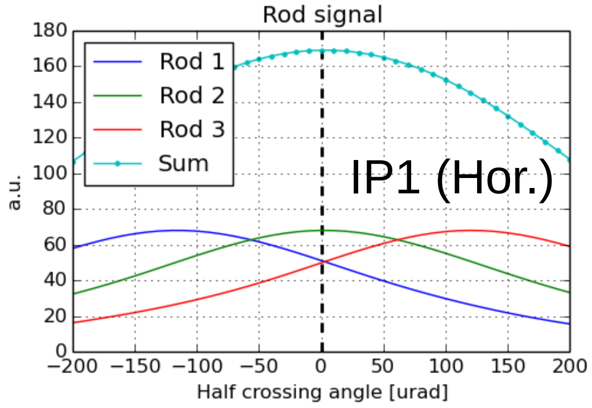
Effect of X-ing angle

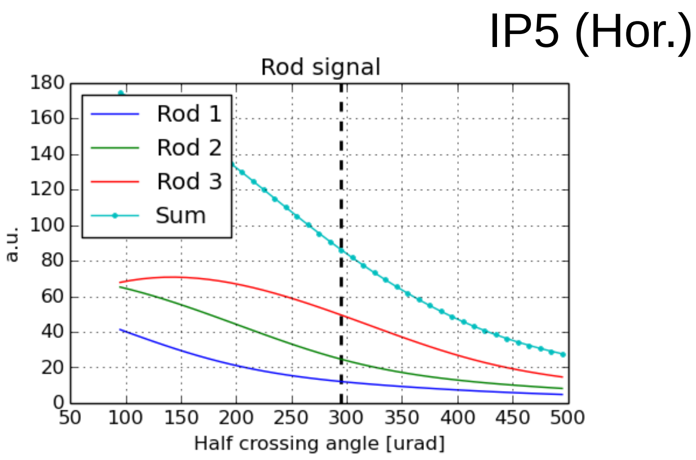
- IP1: Limited impact of change in vertical X-ing angle (different part of quartz hit)



Effect of X-ing angle

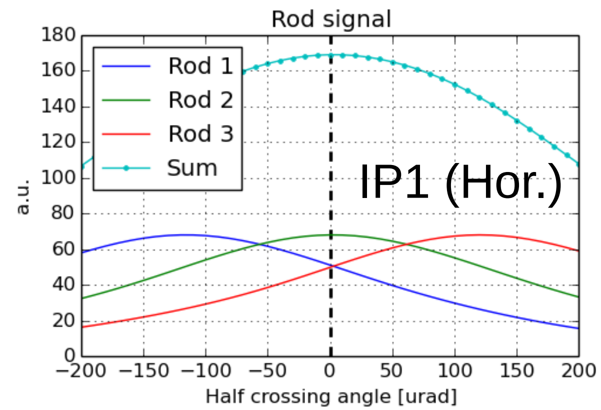
- IP1: Limited impact of change in vertical X-ing angle (different part of quartz hit).
- IP5: Change in X-ing angle will increase/decrease signal on all rods. Similar effect as change in luminosity.
  - Max rod signal not achieved at nominal crossing angle

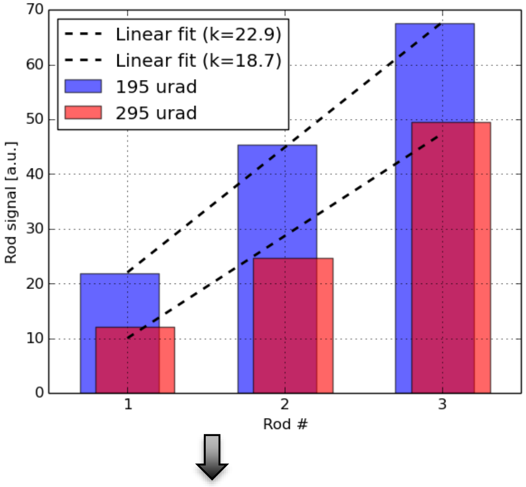




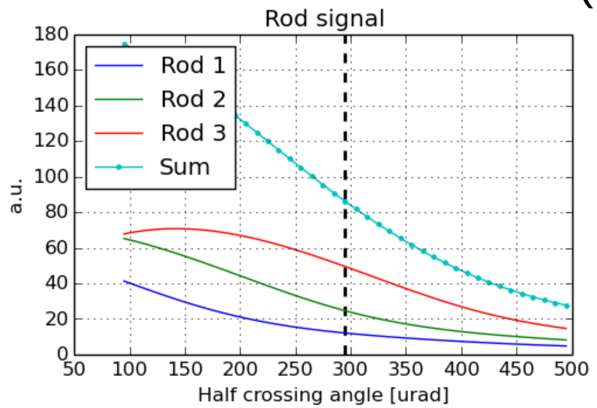
Effect of X-ing angle

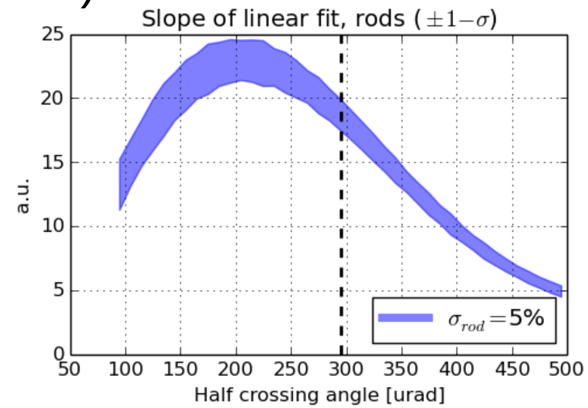
- IP1: Limited impact of change in vertical X-ing angle (different part of quartz hit)
- IP5: Change in X-ing angle will increase/decrease signal on all rods. Similar effect as change in luminosity.
  - Max rod signal not achieved at nominal crossing angle
  - In theory: deduce X-ing angle from rod signals (e.g. slope of linear fit to signal from three rods).
  - In reality: difficult in range 100-300 μrad when taking rod uncertainty into account
  - Not a show stopper (X-ing angle fixed during beam scans), but operators need to be aware of limitations





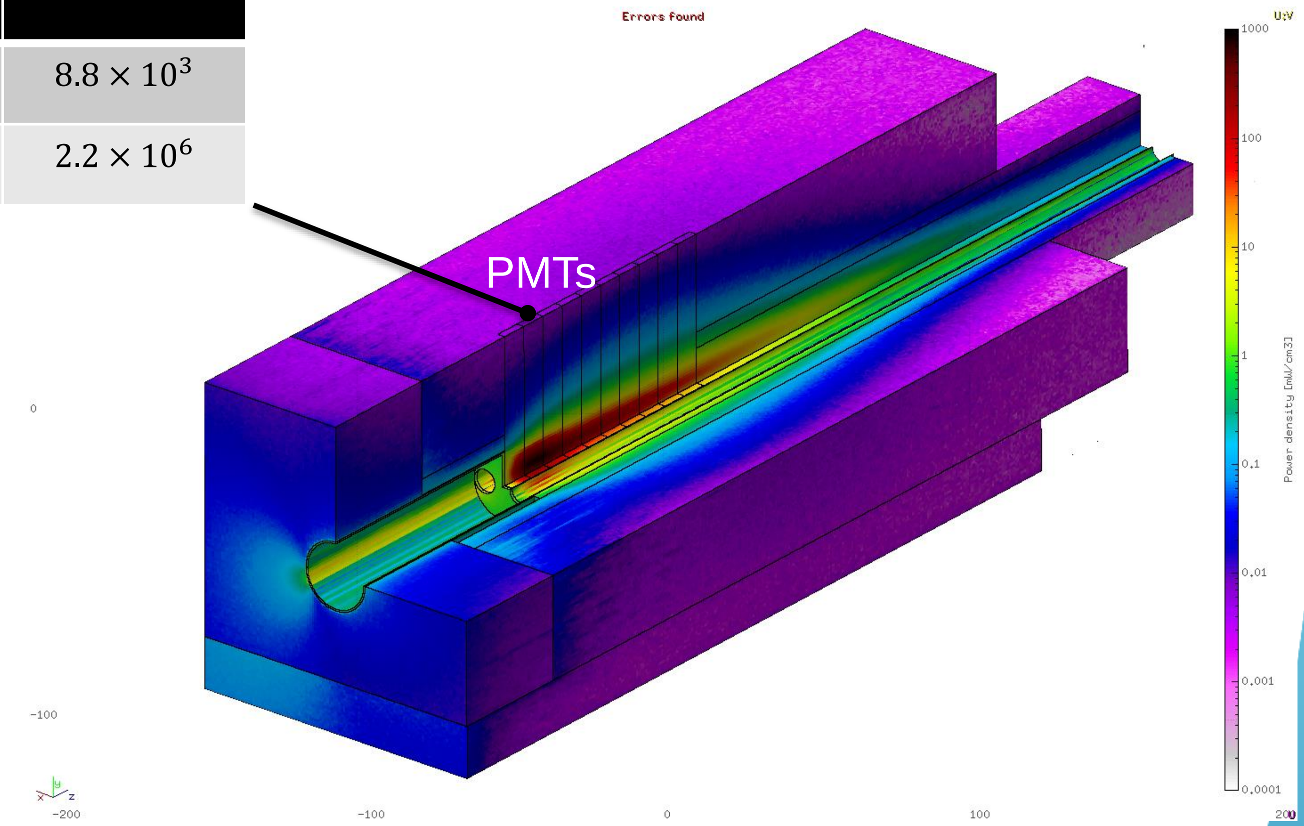
IP5 (Hor.)





PMT radiation damage?

Integrated luminosity	Neutrons [n/cm²]	Dose [Gy]
1 fb^{-1}	1.7×10^{13}	8.8×10^{3}
1 year (250 fb^{-1})	4.3×10^{15}	2.2×10^{6}



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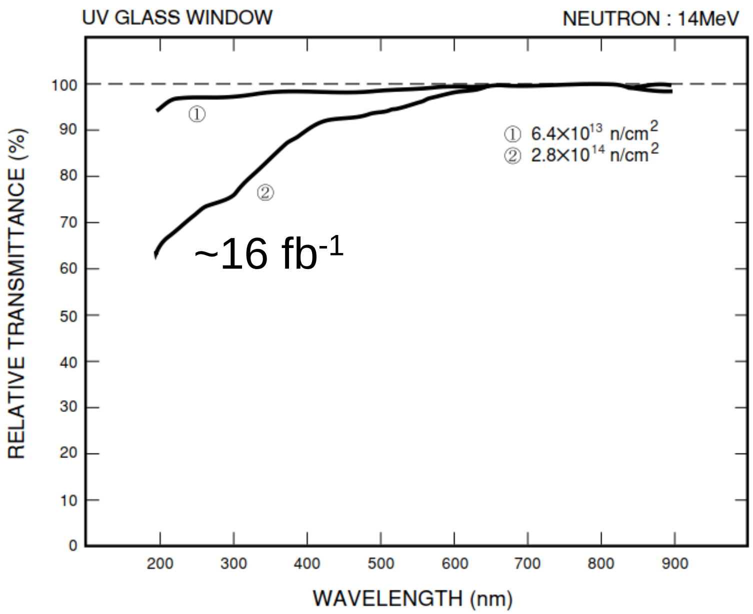

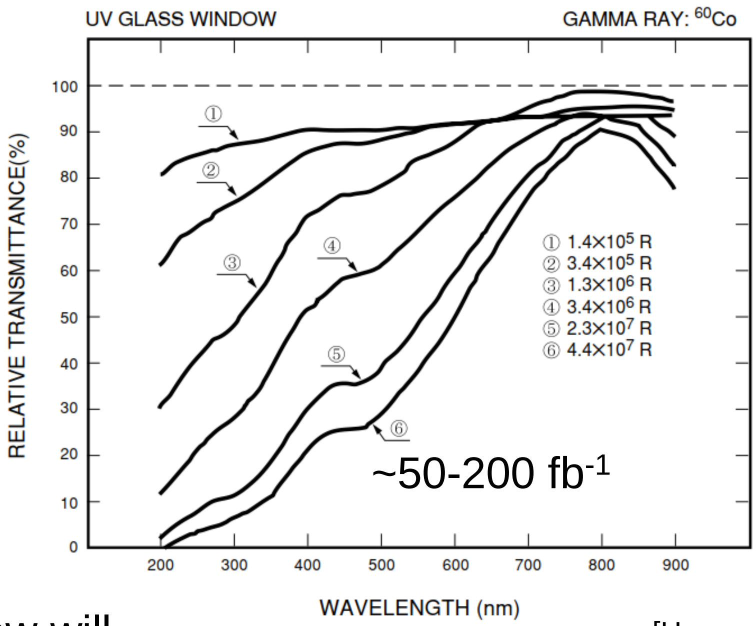

[Hamamatsu]

UV glass window will suffer significant transmission loss in 1 year

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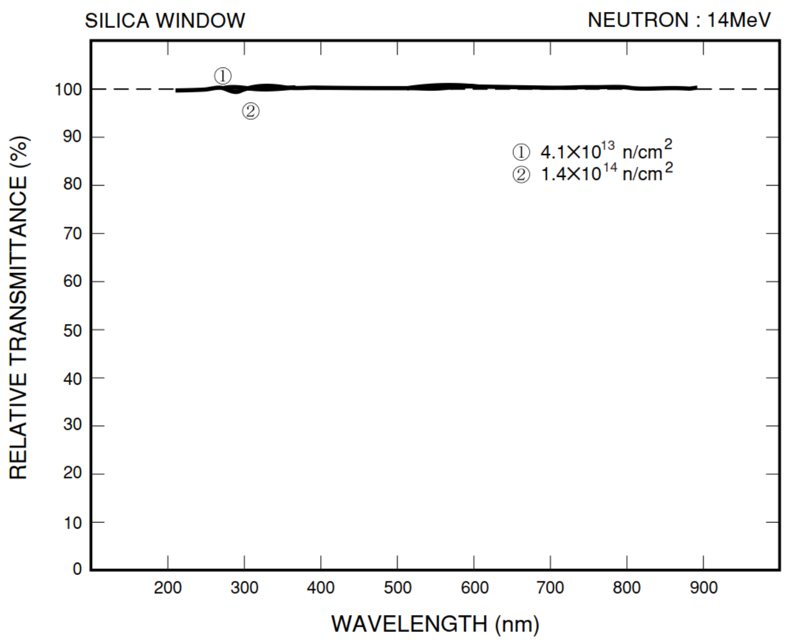

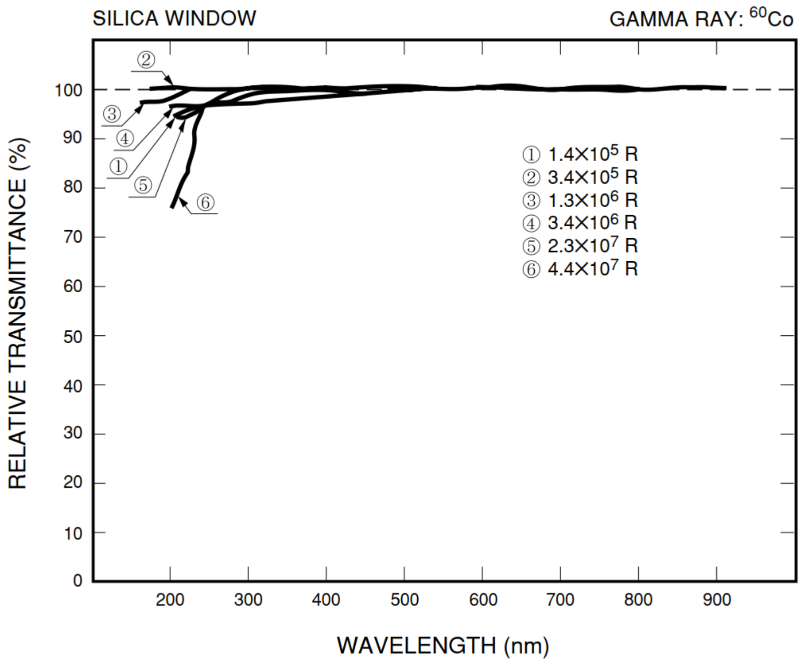

Fused silica window a better option.

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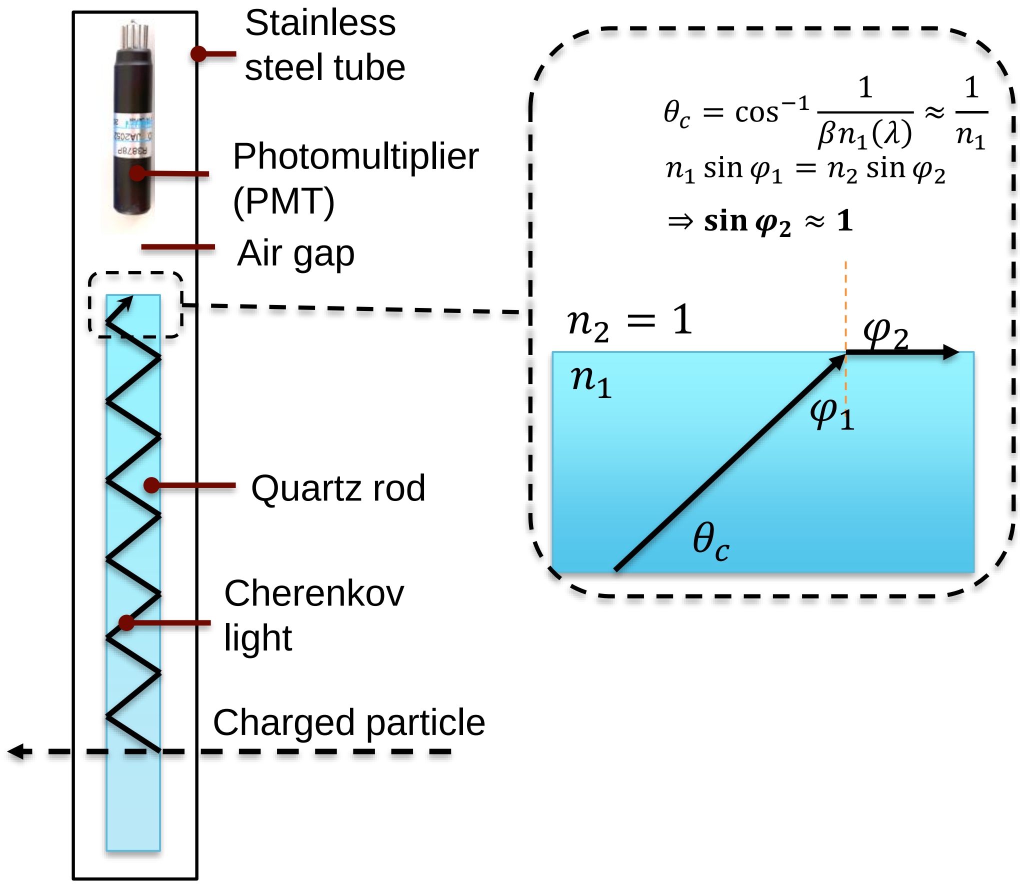
Quartz rod vs. air

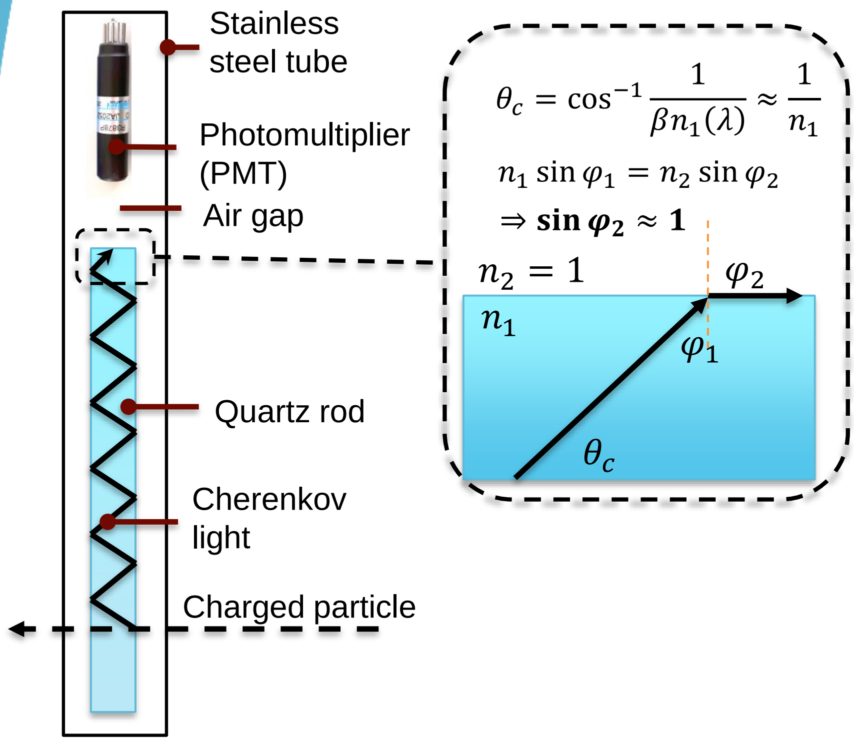


Quartz rod drawbacks

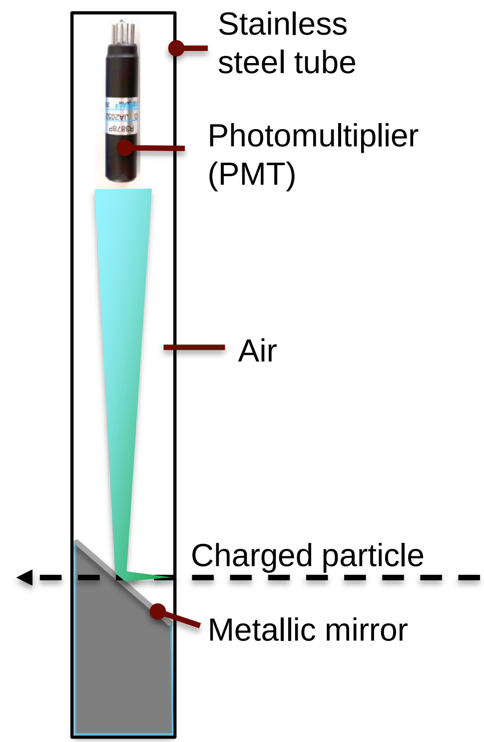
- **Transit time spread** & light loss from large number of internal reflections
- **Degradation**
- Current setup: **Light loss** at top or rod (critical angle) → Only a small fraction of Cherenkov light will reach PMT

Quartz vs. air

Quartz



Air



Cons

- Lower photon yield

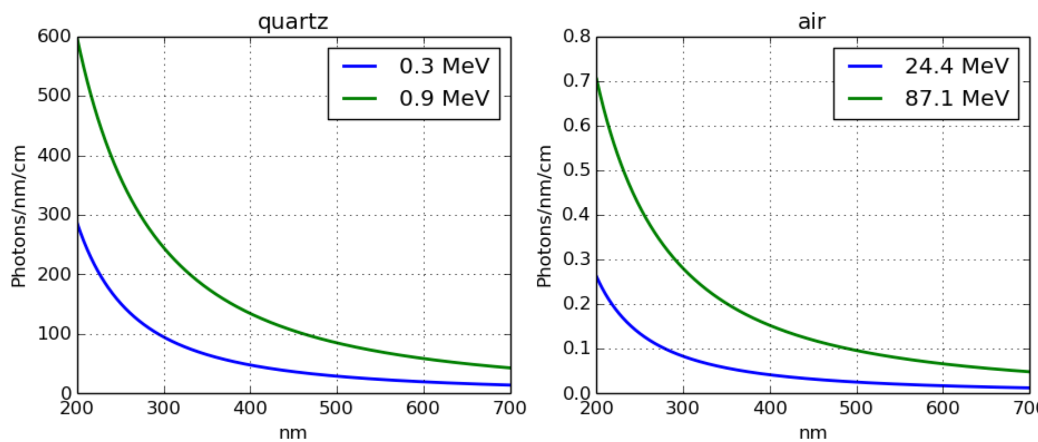
Pros

- No degradation of Cherenkov medium
- Reduced transit time spread
- Cherenkov cone ~1° → More efficient light collection on PMT
- Easy to increase Cherenkov radiation volume

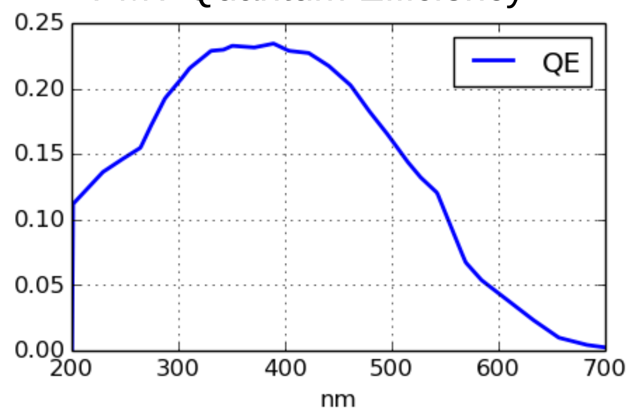
Feasibility: air-based Cherenkov monitor

- Around 3 orders of magnitude less light in air compared to quartz

Cherenkov radiation yield, electrons

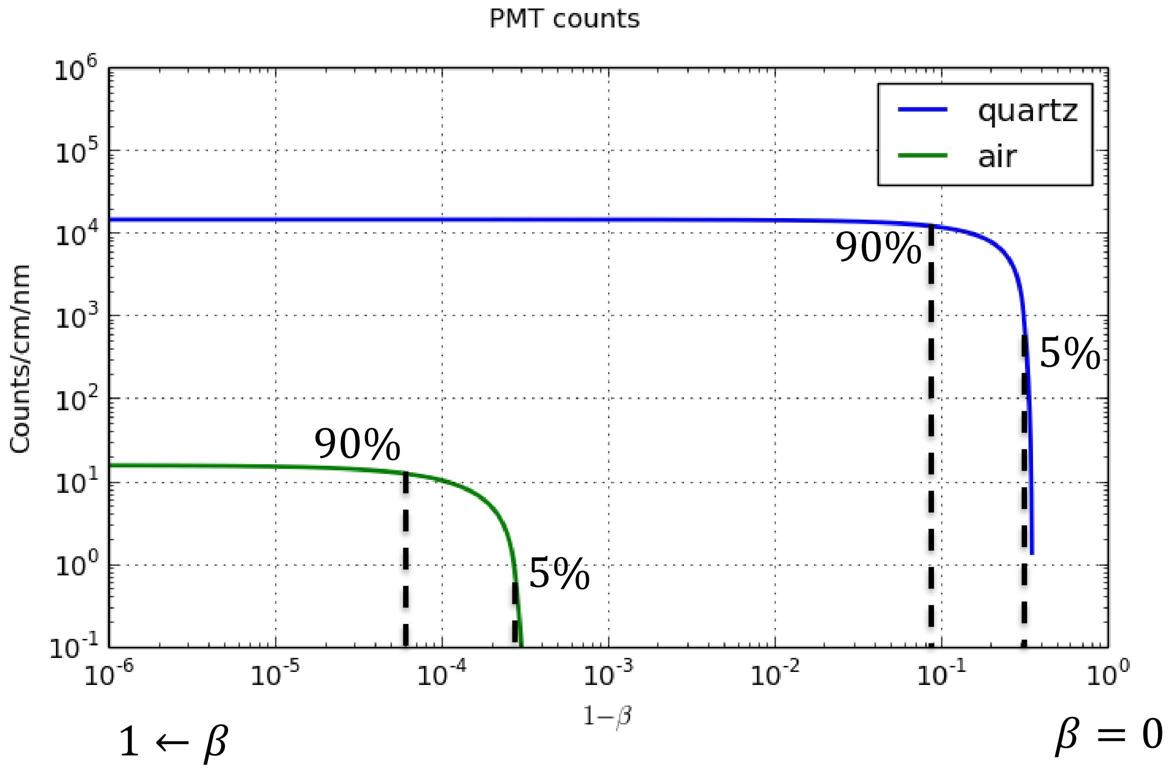


PMT Quantum Efficiency



Signal yield vs. energy

- Plateau reached fairly quickly with increasing energy
- FLUKA: score all charged particles above 5% and 90% β-thresholds to estimate signal yield in TAN volume

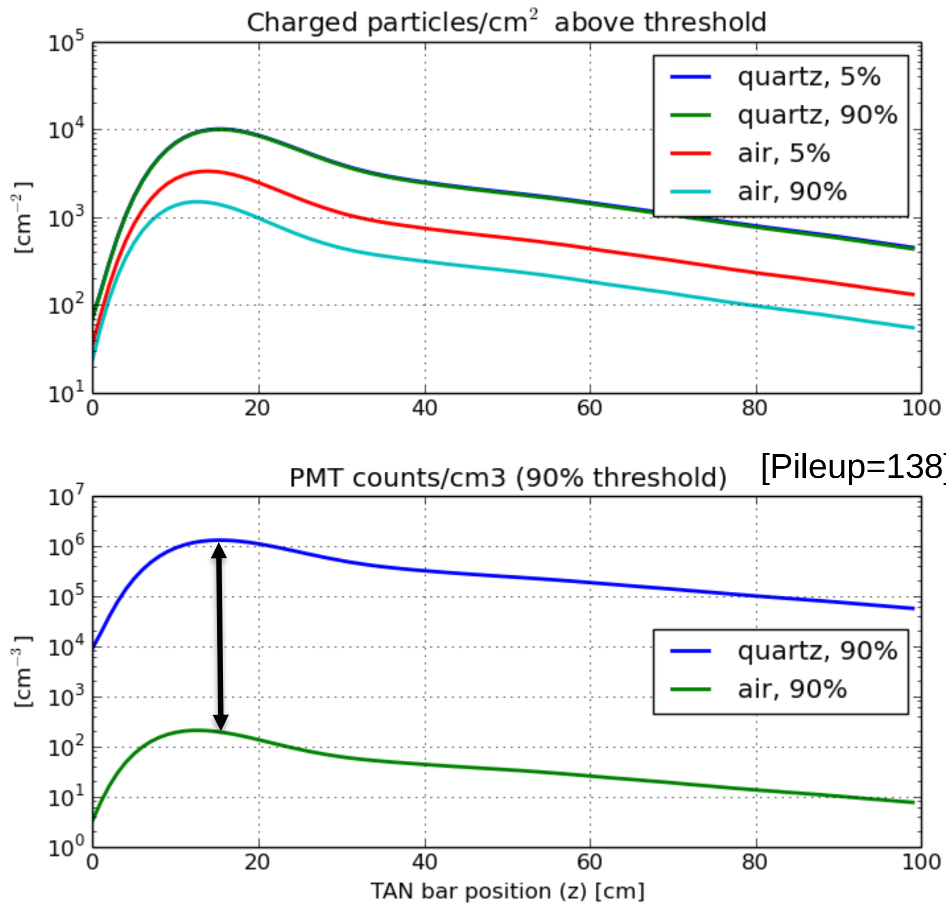


Signal yield vs. energy

- Quartz: almost all particles above 90% β-threshold
- Air: Only 1/3 of charged particles above 90% β-threshold
- Air: ~10^{-4} fewer photoelectrons (p.e) per collision.
- Still: about 200 p.e per nominal bunch (2.2E11) collision per cm^3 detector volume (pessimistic: only particles >90% threshold included)
- Ex: Finding collisions@IP5 (1 bunch pair, 1E11 protons), 25 cm^3 Cherenkov volume, 0.1% of head-on luminosity → 3,800 p.e/s

→ **Rod with mirror will be installed during YETS**

Cherenkov radiation yield along TAN copper bars [IP1]



Summary & Outlook

- BRAN prototype follows luminosity well (~10% fill-to-fill variations)
- Rapid quartz signal loss first 5 fb^{-1}
- After that, slow photoelectron yield loss (~15% during 2017)
- PMT window needs to be replaced for HL-LHC

- [ ] Air-based Cherenkov monitor is feasible → Installation next YETS

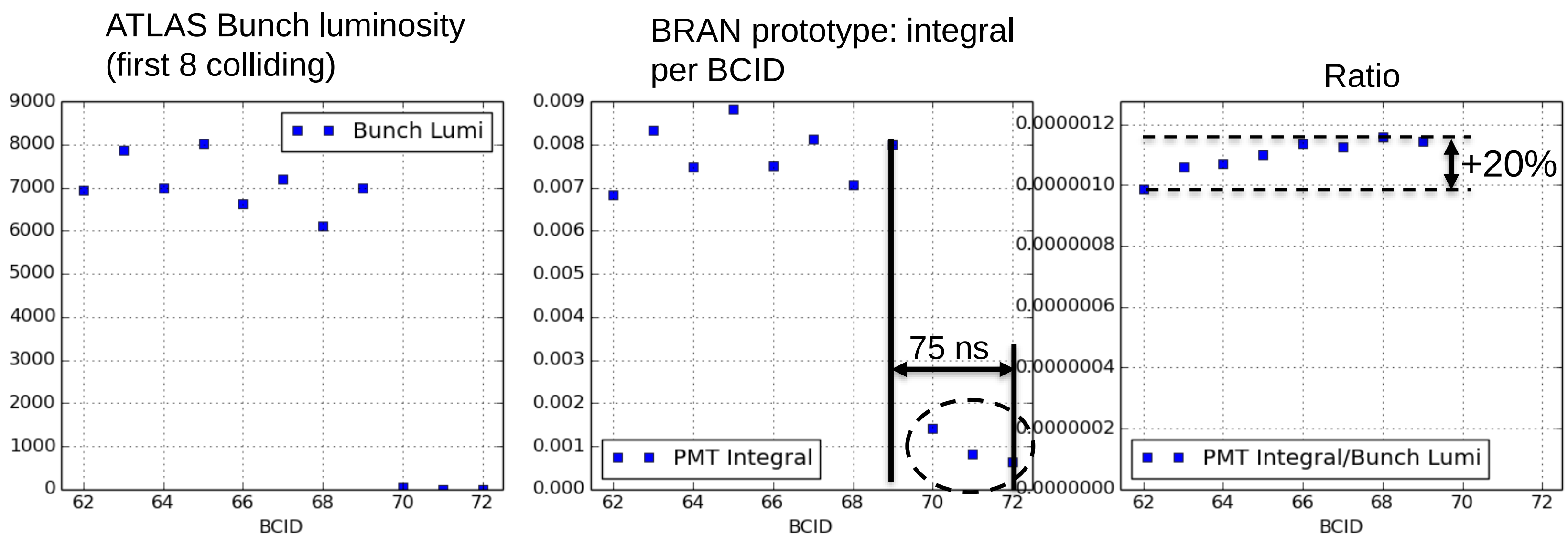
- Thank you for your attention!

- Many thanks to:
  - Sune Jakobsen
  - Enrico Bravin
  - Federico Roncarolo

Backup slides

Bunch-by-bunch luminosity

[Picoscope acquisition: bunch train]

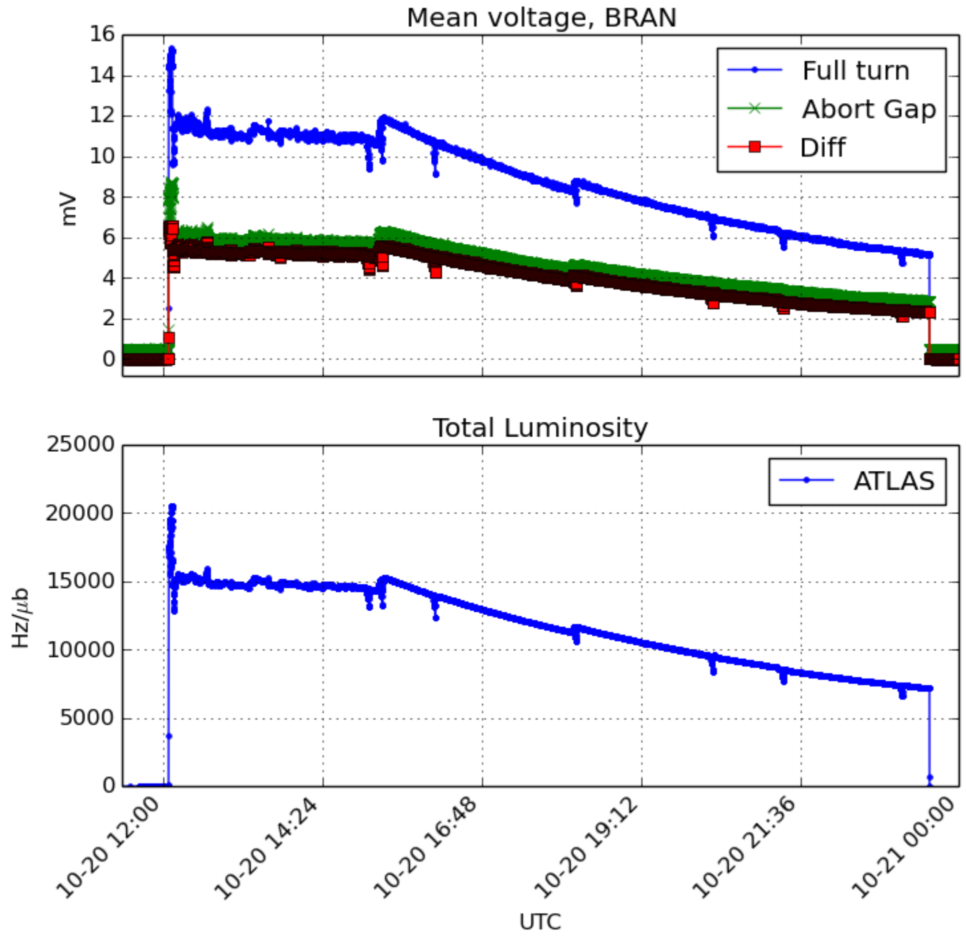


[Fill 6272]

- Signal does not decay within 75 ns
  - Likely causes: Cable impedance, light path spread in quartz
- Bunch-by-bunch measurement would need correction

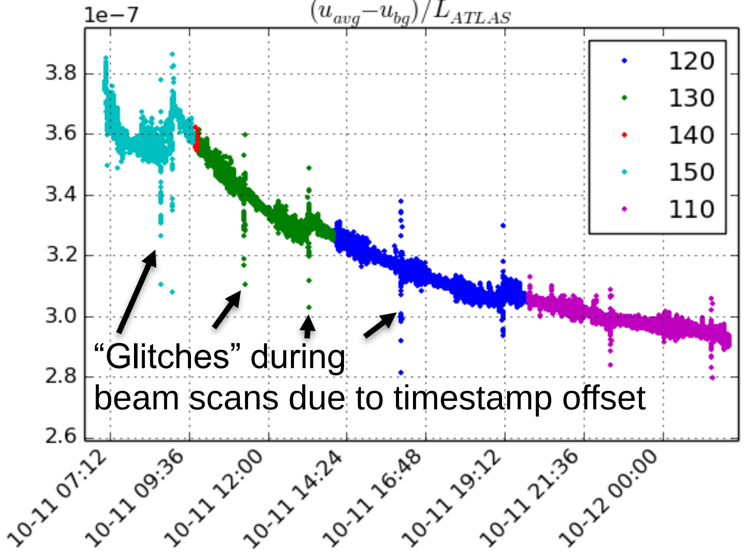
Total luminosity

- Picoscope installed to monitor total luminosity at higher rate (~1 Hz)
- Measure $\langle\int U\rangle_{Full\ turn}$ and $\langle\int U\rangle_{Abort\ gap}$ (for baseline subtraction)
- Signal level in abort gap region also follows total luminosity(!)
  - Very long tails…

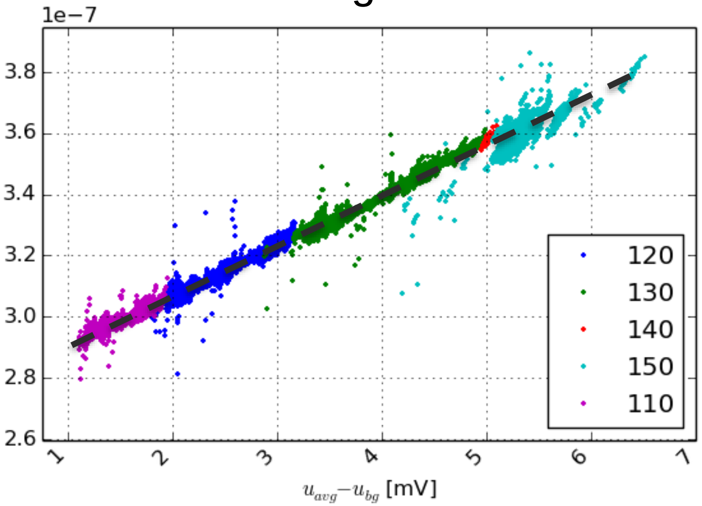


BRAN prototype linearity

BRAN signal/Luminosity
vs. time



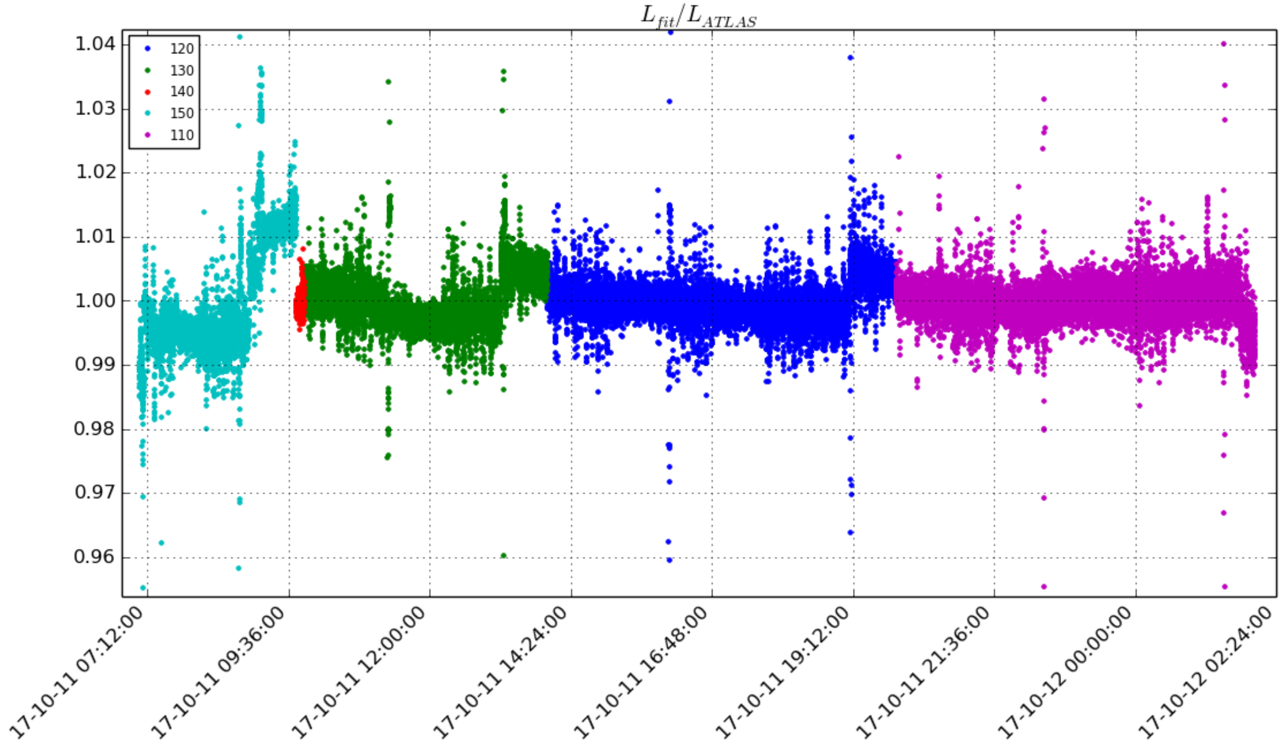
BRAN signal/Luminosity
vs. BRAN signal



- (Vertical) Crossing angle has limited impact
- Appears to have more PMT charge/collision for higher luminosity(!?)
  - →Apply (empirical) linear correction to model luminosity

BRAN prototype linearity

Modeled luminosity from BRAN prototype / ATLAS luminosity



Air-coupled PMT: Al-foil degradation

- Loss trend more pronounced, compared to quartz
- Likely caused by radiation damage in the MgF_2 coating on the Al-film