Update on Luminosity monitoring for HL-LHC

M. Palm (BE-BI-PM)

Outline

- BRAN: HL-LHC luminosity monitor
- Results & observations
  - Fused silica
  - Aluminum mirrors
- Design considerations
- Summary & Outlook

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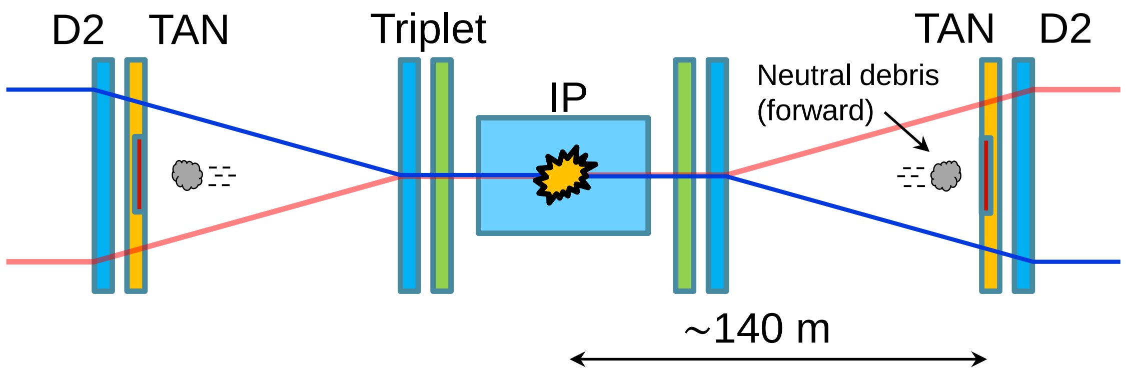
Overview

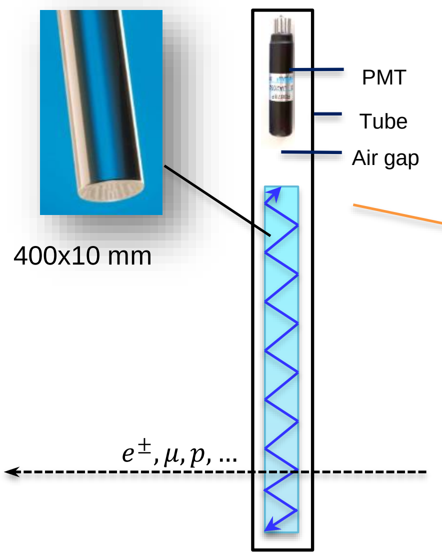


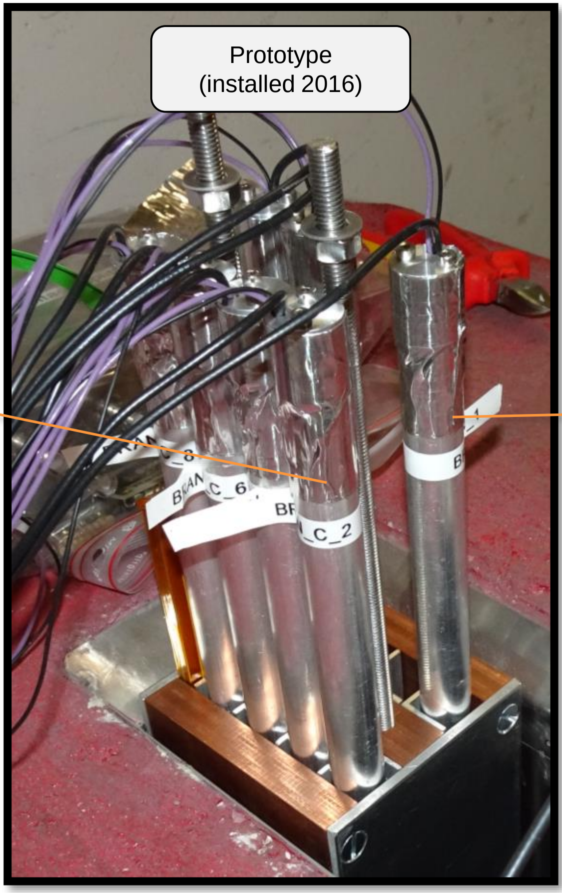
- **BRAN:** Beam RAte of Neutrals
- **What:** Machine luminosity monitors
- **Where**: IP1/5, IP2, IP8
- **Use cases**: Finding collisions, backup instrument for OP (if no data from experiments), cross-check experiments, sanity check, …
- **Precision**: ~1% @ 1 Hz (absolute luminosity not necessary)
- **Challenges**: Large dynamic range, radiation (IP1/5: 180 MGy/year), limited space
- **HL-LHC**: Cherenkov radiation based monitors

BRAN prototype

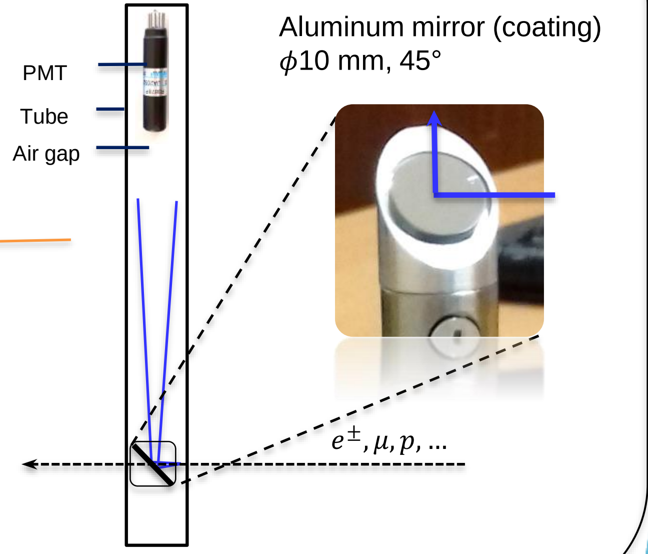
Luminosity monitoring
Forward Neutral debris from IP → Absorption in TAN → Charged secondaries → Cherenkov radiation

Fused silica rods





Air + Mirror



- 2 different Cherenkov media tested in LHC (TAN, Left of IP1)

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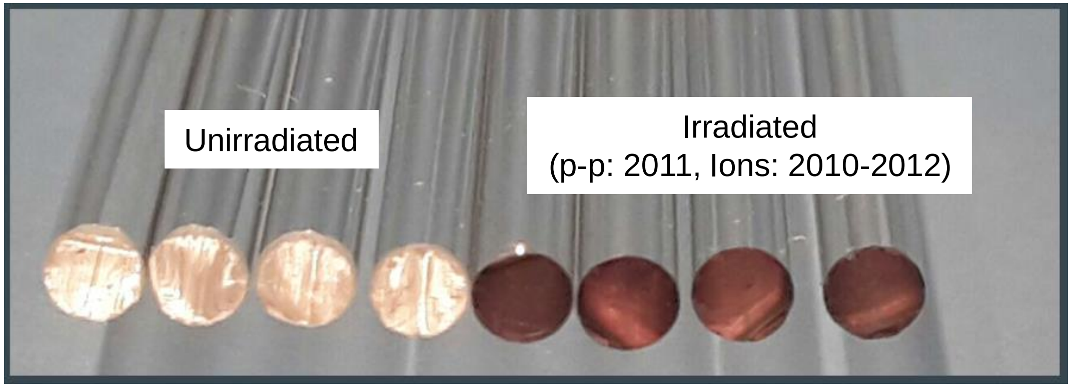
Radiation effects - Transmission

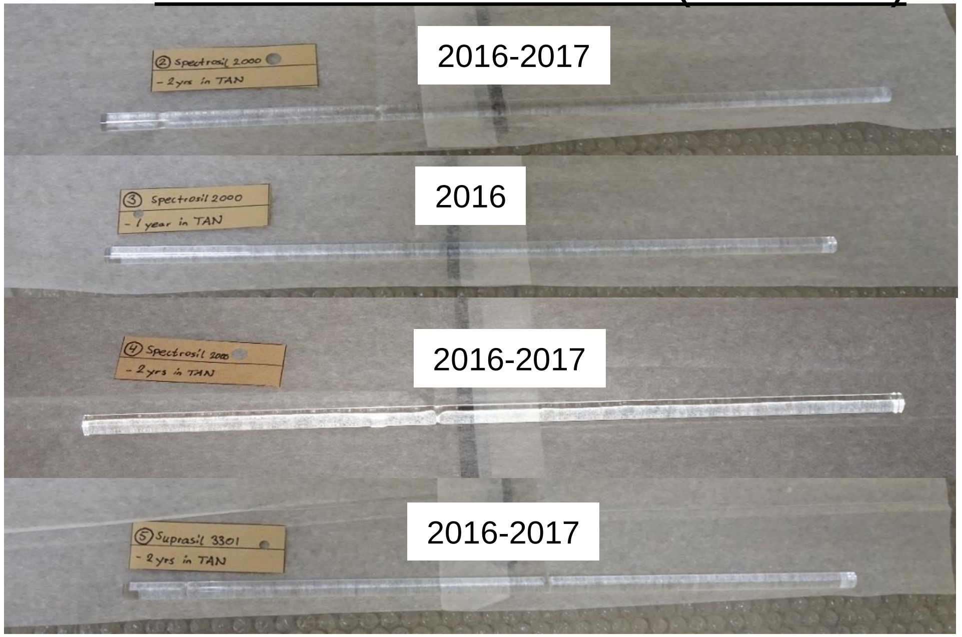
- Main concern: reduced optical transmission
- 4 rods recuperated from TAN after 1-2 years of LHC operation
  - No visible discoloration or opacity (by eye)
- Shipped to ZDC group at University of Illinois for measurements

<u>ZDC Quartz rods</u>



[Courtesy: M. Phipps & G. Avoni]

<u>BRAN Fused silica rods (irradiated)</u>

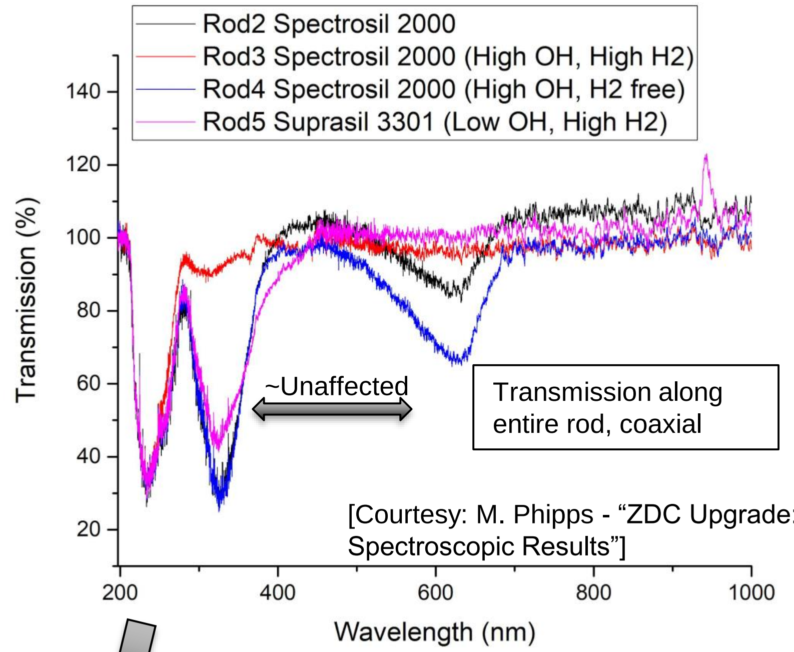


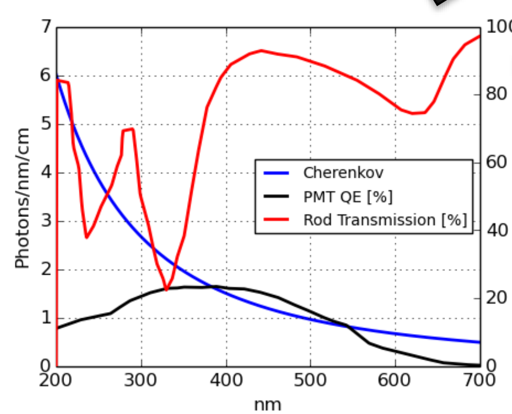
Measured rod transmission

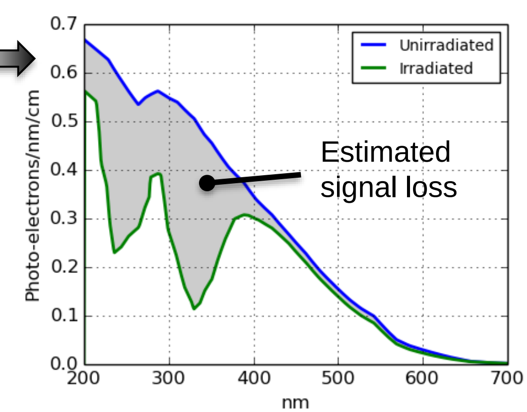
- Sharp absorption centers in UV range (214 nm, 325 nm
  - Most of the Cherenkov light is in this region
- Broad absorption around 630 nm

- Note:
  - Rod #3 (red) only exposed during 2016. 1.5 years of annealing.
  - Other rods: 2016-2017, 0.5 years of annealing

- Conclusion
  - Quartz type matters…
  - Visible range will still provide a signal even if UV transmission should drop to 0. “Signal floor”.

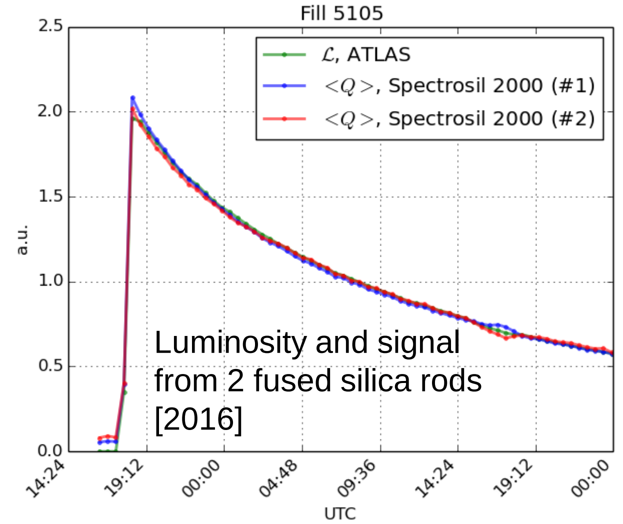






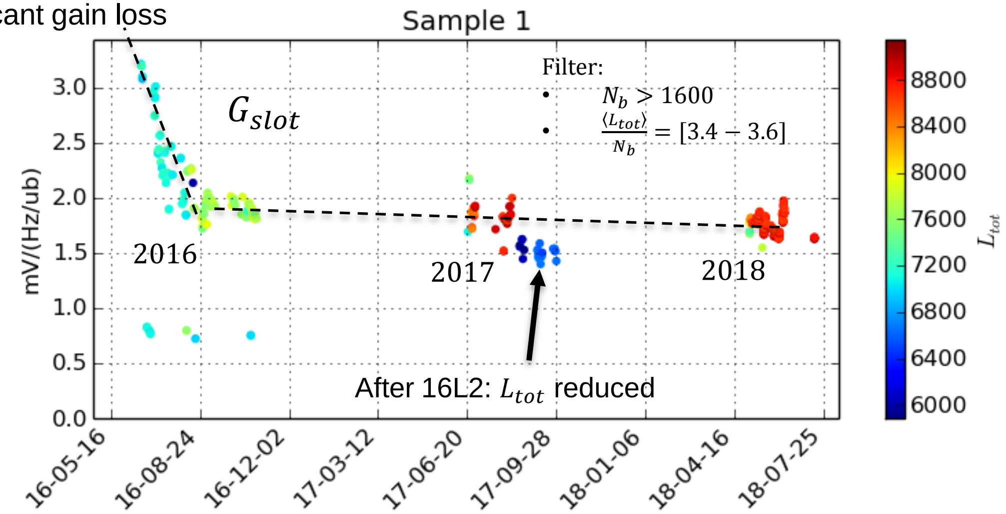
General performance

- Good agreement between prototype signal and ATLAS luminosity



- Signal "gain":
  - $G_{slot} = \frac{\langle U_{slot} \rangle}{L_{tot}/N_b}$
- Fairly stable gain from mid-2016 until today

First few fb[-1]: significant gain loss



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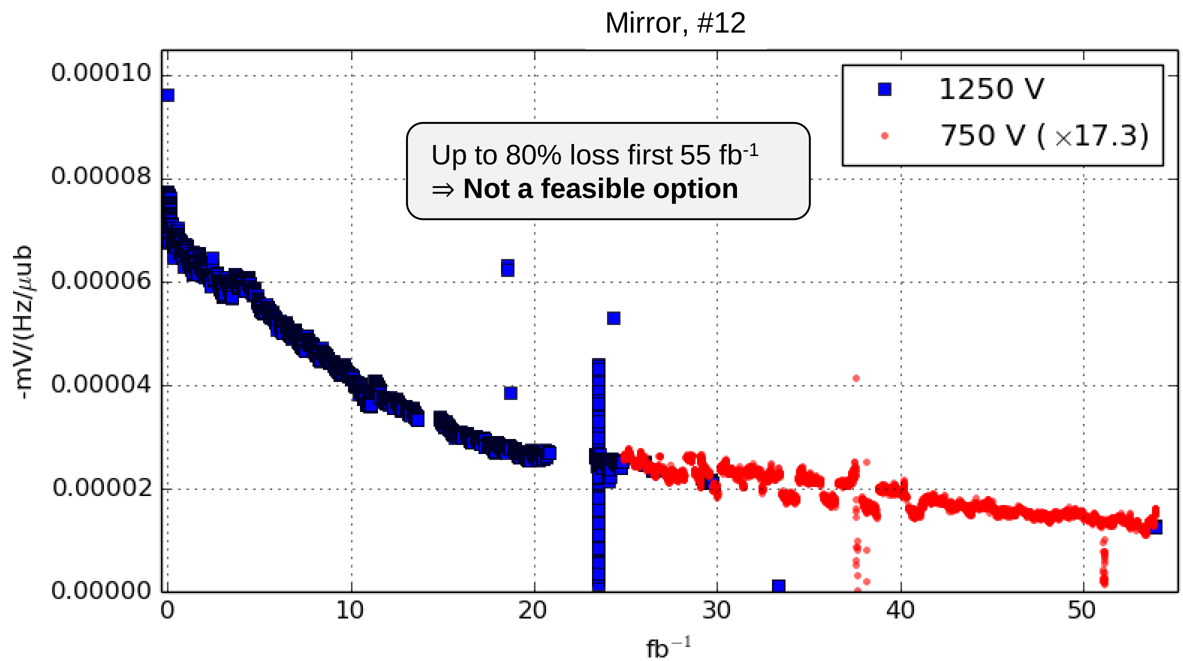
Aluminum mirrors

- 3 mirrors installed
- Different heights



- Mirror with largest signal (#12) has also degraded the most
  - Currently: -20%/10 fb^{-1}
  - No sign of flattening out…
- Reflectivity will be re-measured during LS2 to verify if signal loss is due to mirror degradation.
  - Other possibility: diffuse reflections?
- ⇒ **<u>Fused silica rods seems to be the best option.</u>**

	Mirror #10	Mirror #11	Mirror #12
Initial gain [compared to quartz rod]	0.6%	2.8%	**8.3%**
Gain loss up to 54 fb^{-1}	-32%	-43%	**-83%**

HiLumi HL-LHC PROJECT CERN

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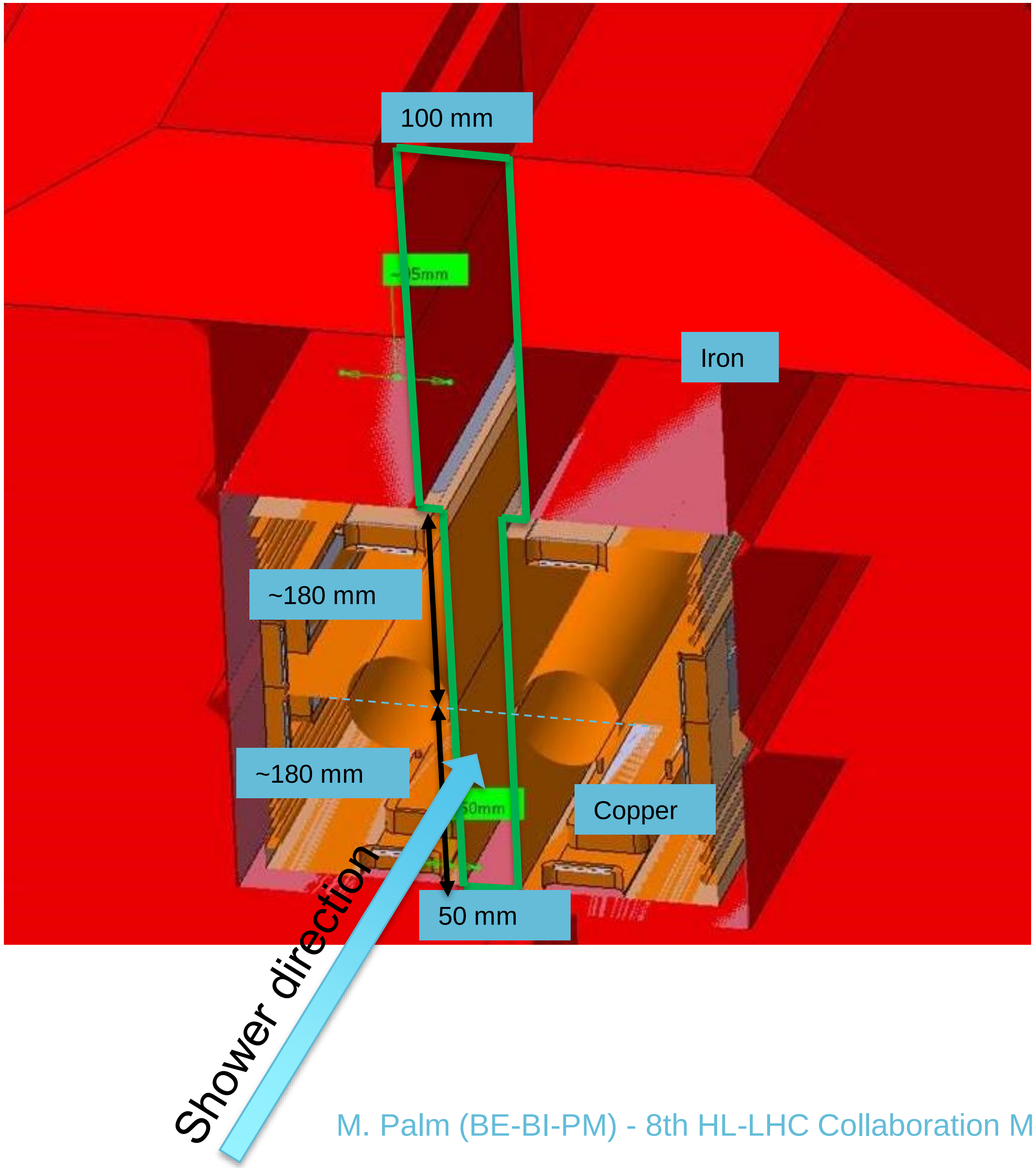
  - Aluminum mirrors
- <u>Design considerations</u>
  - Available space
  - X-ing angle
  - Dynamic range
- Summary & Outlook

Available space

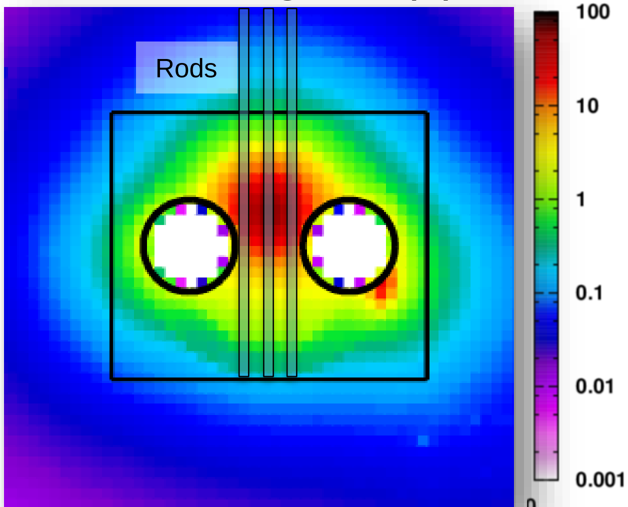
- **50 mm** available between beam pipes
- 100 mm available above copper block

TAXN cross section

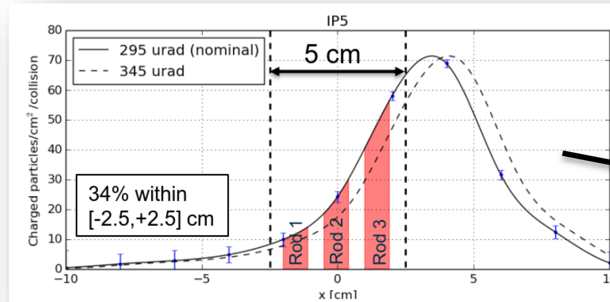


X-ing angle

Vertical X-ing, IP5(?)

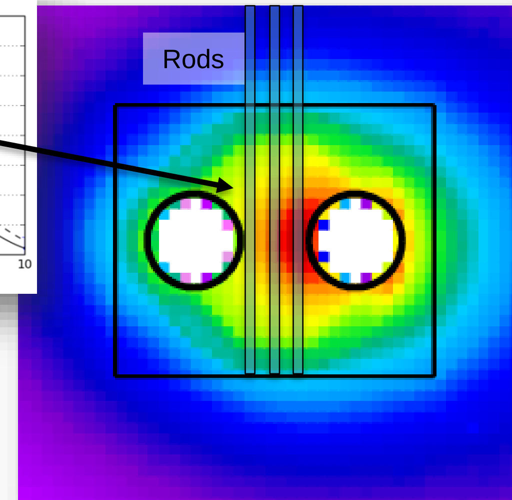


- Shower is centered
- Robust against X-ing angle changes



- Cannot only intercept fraction of shower → X-ing angle dependence
- Luminosity-levelling by X-ing angle
- X-ing angle drift/shift during beam separation scans?
  - HL-LHC: no precise estimate (LHC: <1 μrad [preliminary est.])

Horizontal X-ing, IP1(?)



- Off-centered: BRAN intercepts "tail"
- Fluence gradient: ~0.5%/μrad

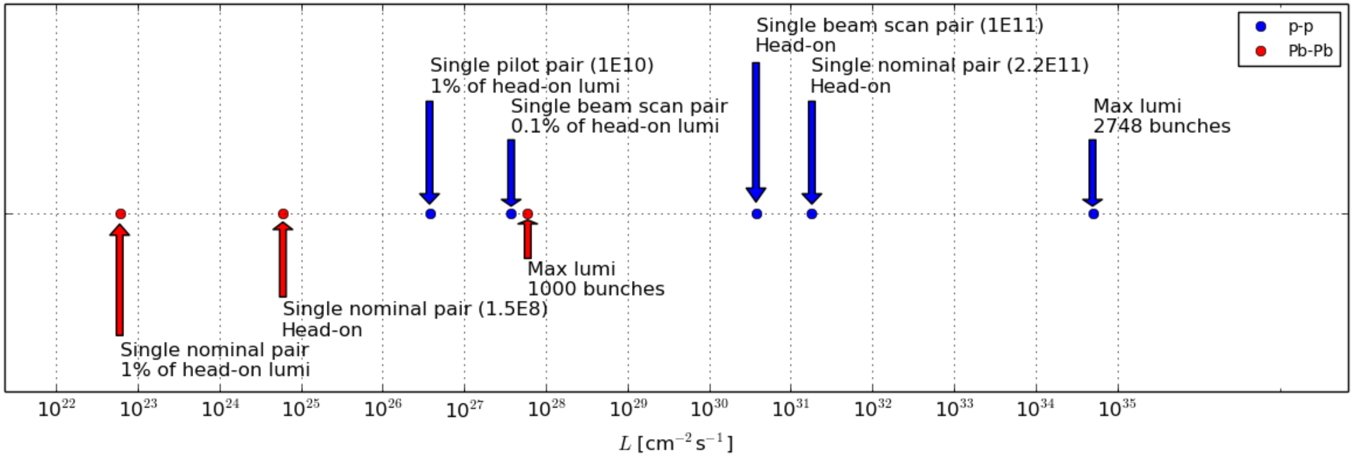
[Simulations: Courtesy A. Tsinganis & F. Cerutti]

- Infer X-ing angle from rods between pipes?
  - Need very precise calibration…
  - Dose rate in left/right rods is different → rod transmissions will change at different rates
- Shorter rods above beam pipes?
  - Wider profile → Less precision
  - Dose rate ~2-3 orders of magnitude lower → Transmission slowly degrading over several years (~1000 fb^{-1})

- **Conclusion: for horizontal X-ing, the measured BRAN luminosity will have a X-ing angle dependence**

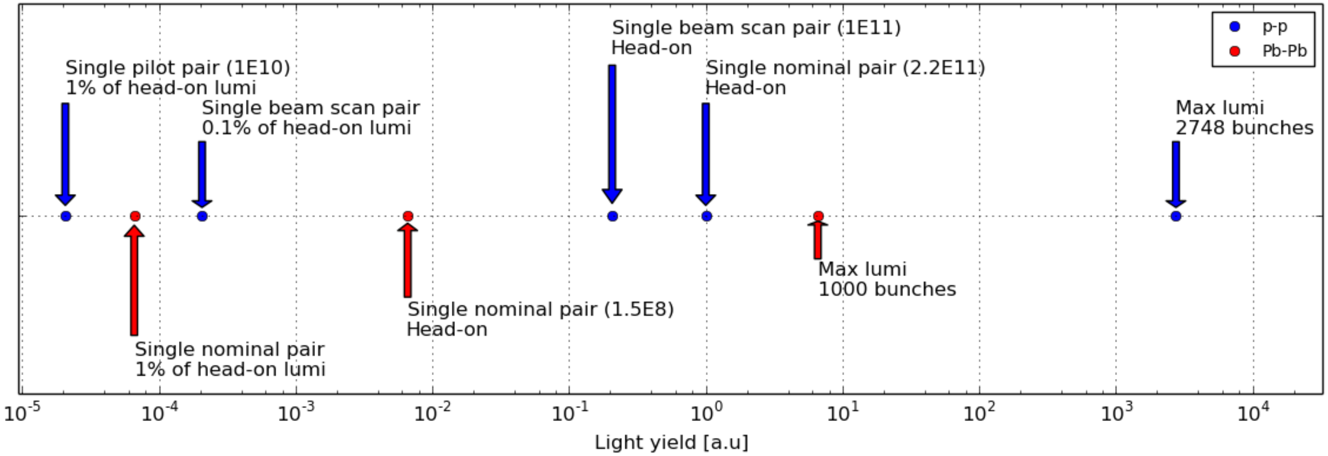
Dynamic range

- Luminosity range (p-p & Pb-Pb)



Total luminosity: 12 orders of magnitude

- Signal range
  - ~20,000 times more signal for Pb-Pb than p-p for a given luminosity
  - Light yield per bunch crossing “only” spans 4-5 orders of magnitude.



Total light yield: 8 orders of magnitude

Light yield per bunch: ~4-5 orders of magnitude

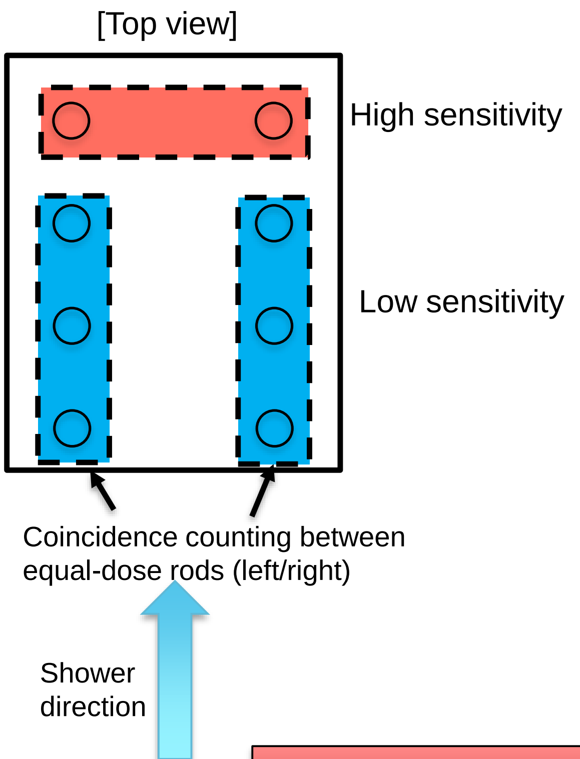
Design considerations: summary

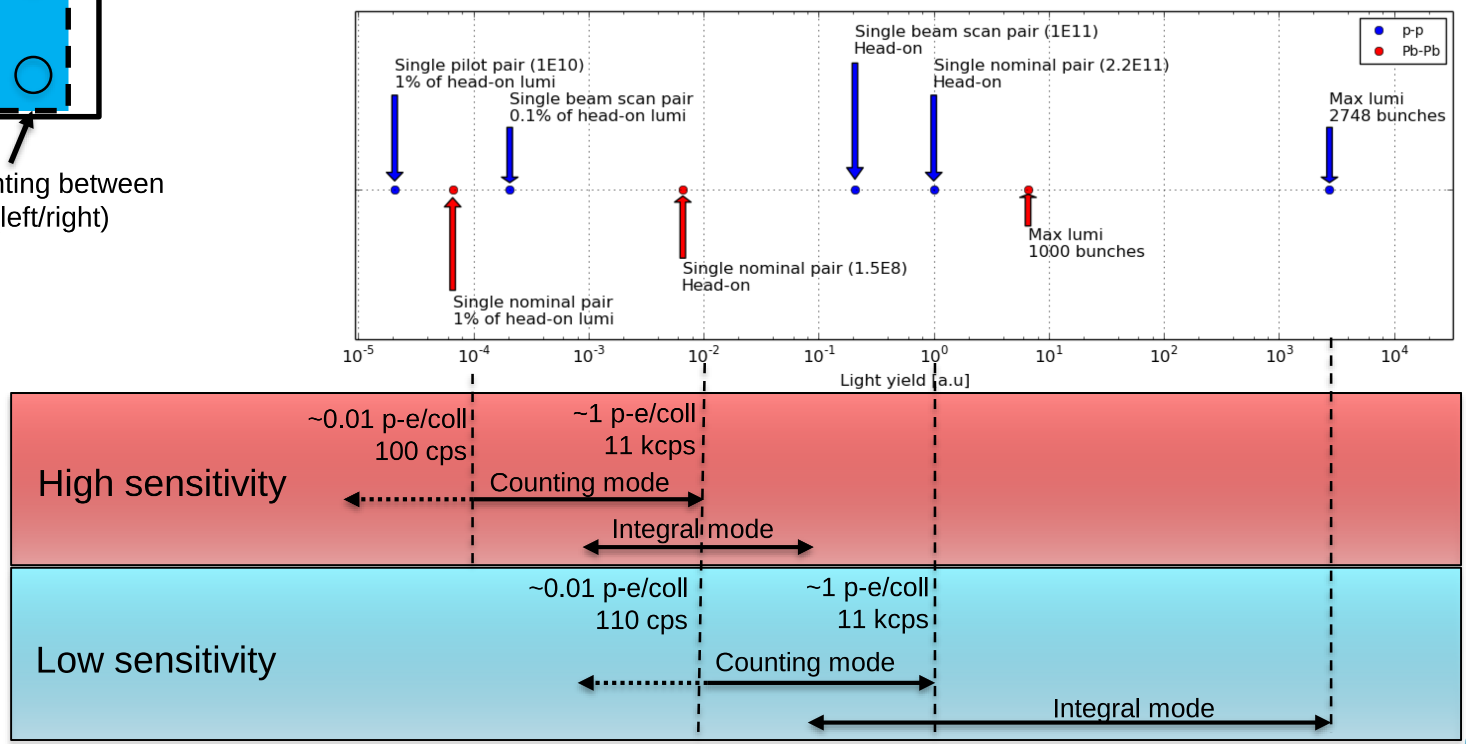
- Fused silica rods/~~Aluminum mirrors?~~
- X-ing angle dependence (horizontal)
  - We have to live with it.
- Physical space constraints
  - Difficult to fit more than two parallel quartz rods + PMT + “cross-talk shielding” in 50 mm
- Dynamic range
  - 4-5 orders of magnitude in terms of photons/collision should be covered
- Available light
  - If we extract a sufficient fraction of light from the fused silica rod to the PMT, we can cover a very large dynamic range
- Transmission loss
  - Almost all observed transmission loss of fused silica occurs within first ~10 fb^{-1}, but then remains stable.
  - Foresee (manual) adjustment of light yield e.g. at first technical stop after installation.
  - Design constraint: this should be quick and simple!

- Also: If we can’t handle X-ing angles very well, then we should at least make sure that the BRAN has an “impressive” dynamic range.

- Warning: the TAN/TAXN is a beast against which many detectors have failed…
  - **“Simple but reliable” better than “Perfect but complex”**

Channel sensitivity range

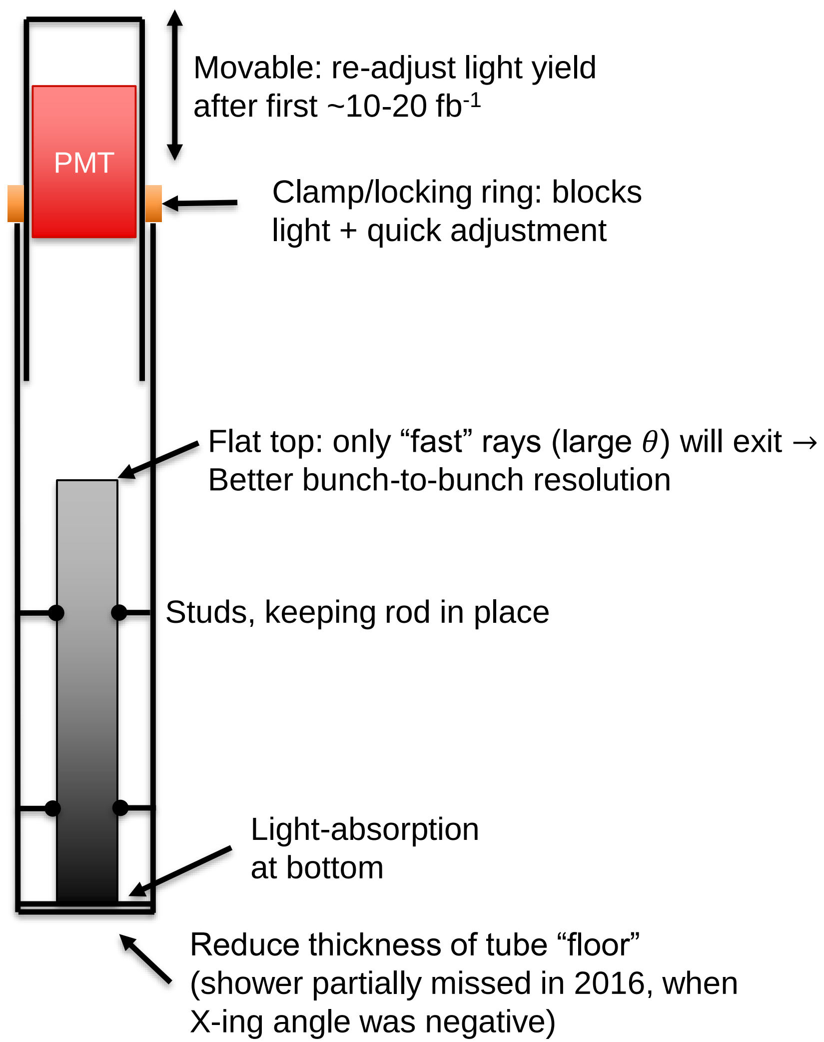




p-e = photoelectron
cps = counts per second

Low sensitivity channel

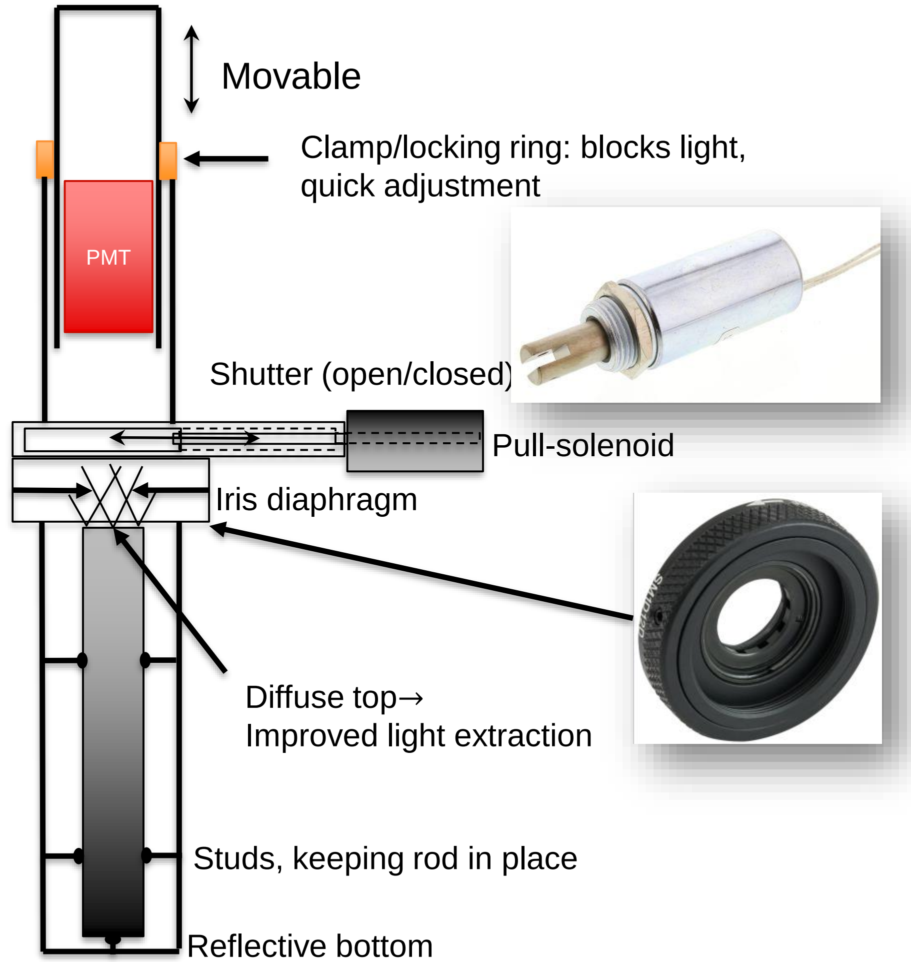
- Current prototype serves as baseline for precise light yield estimates and dimensions



High sensitivity channels

- HV off and cathode shielded at normal operation
  - Add pull-solenoid shutter

- Light yield tuning:
  - PMT-Rod distance
  - Graduated iris diaphragm



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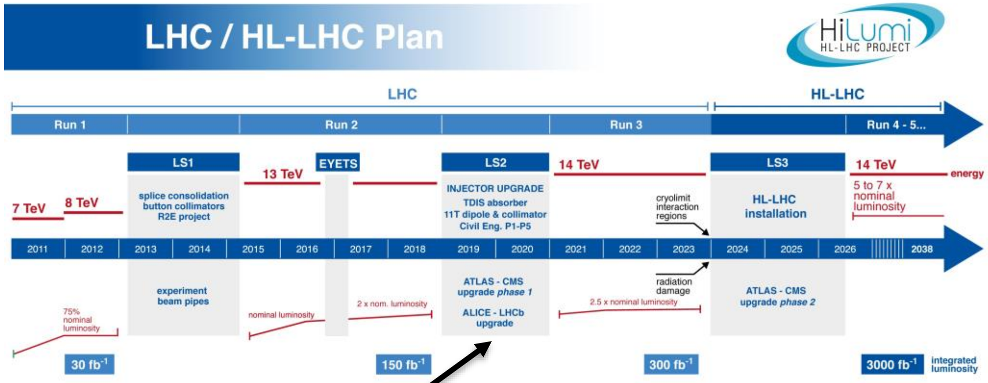
Summary & Outlook

- Fused silica is a feasible Cherenkov medium for the TAXN environment
- Aluminum mirrors still degrading
- Horizontal X-ing angle dependence
- HL-LHC BRAN will measure luminosity over 12 orders of magnitude
- LS2: Replace 2 BRAN-A monitors (ionization chambers) with 2 fused silica BRANs



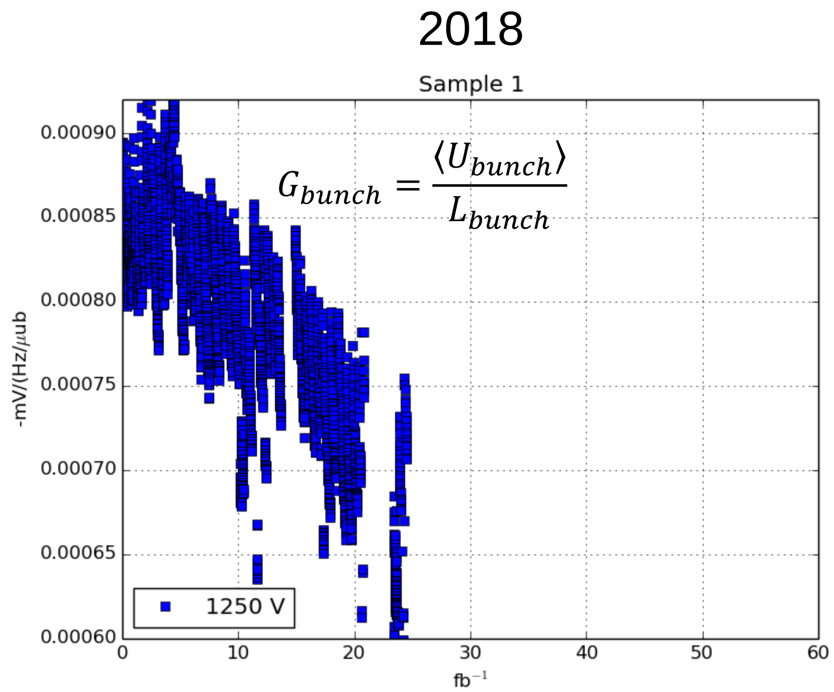
- Thank you for your attention!

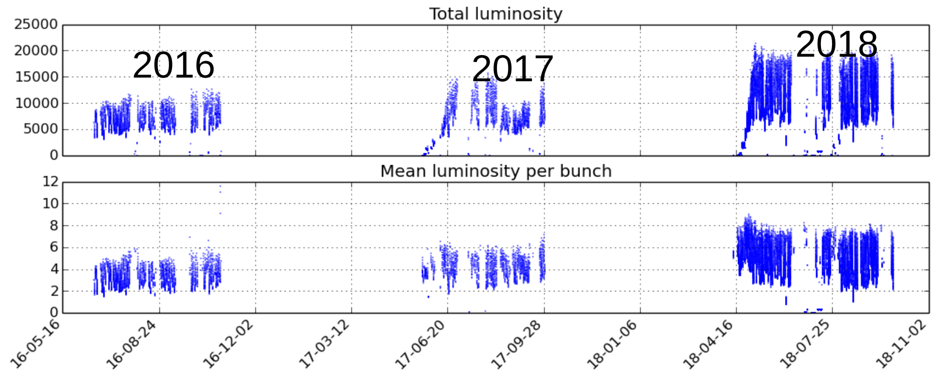
Acknowledgments:
E. Bravin, F. Roncarolo,
T. Schneider (Al-mirrors),
M. Phipps et.al (ZDC)

Backup slides

PMT saturation

- 2018 trend: Gain loss
- Prototype: light yield on PMT cannot be easily tuned → Change voltage instead (1250 V → 750 V)
- PMT recovered!
- Gain returned (slowly) to initial level
- Gain variation during fill stabilized: from ~10% to ~1% variation





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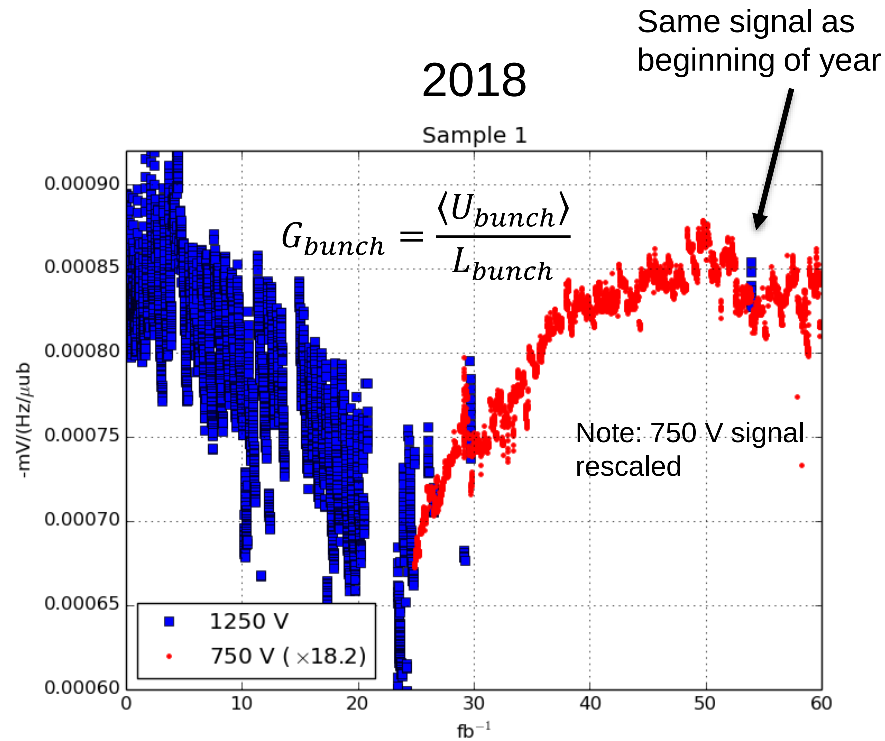
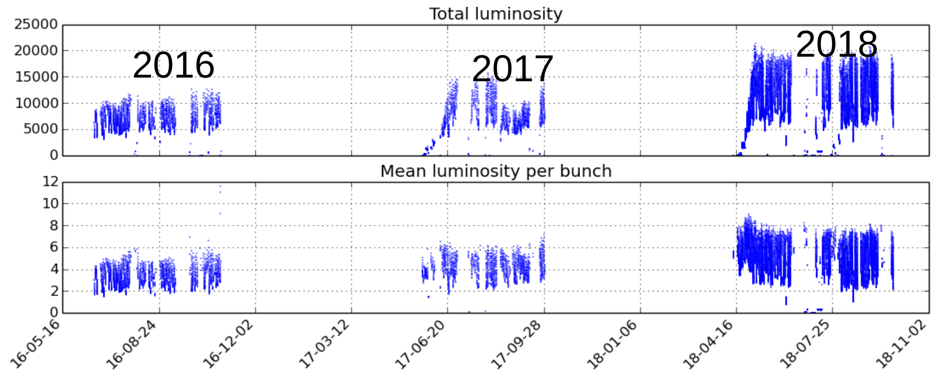
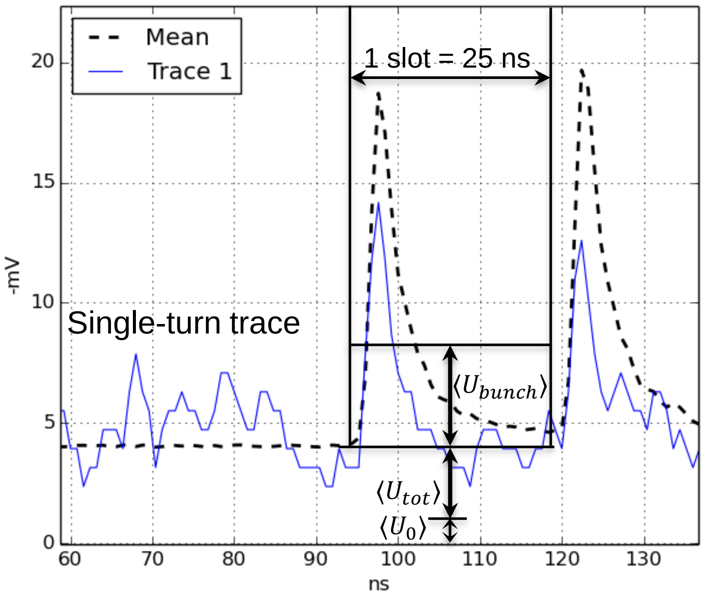


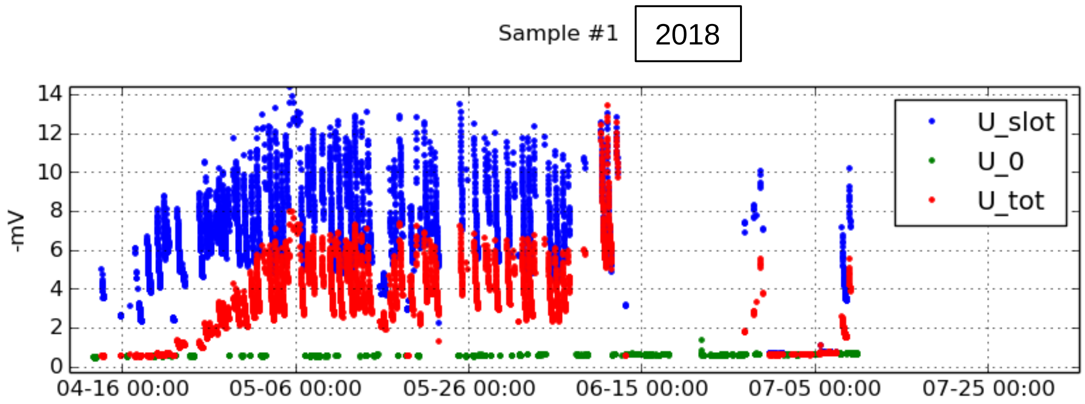


Recap: data acquisition

- Voltage-integral histogram of *single bunch pair* logged
  - 25 ns window (=1 slot)
  - 2016-2017: No baseline correction
- Slot-integral has 3 components
  - $\langle U_0 \rangle$ = Background signal
  - $\langle U_{tot} \rangle$ = Baseline shift during collisions.
  - $\langle U_{bunch} \rangle$ = Mean signal from single bunch pair collision
  - $\langle U_{slot} \rangle = \langle U_0 \rangle + \langle U_{tot} \rangle + \langle U_{bunch} \rangle$



- Significant baseline shift with higher PMT current
  - $\propto I_{mean}$
  - ~Half(!) the voltage integral comes from baseline (red) at high luminosity
  - Not logged 2016-2017
  - 2018: detailed logging
  - →Restrict long-term evaluation to data points with similar luminosity



Terminology

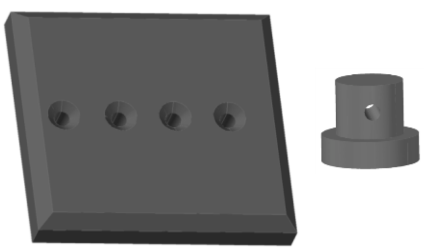
- Quartz
  - Natural or synthetic
  - ***Crystalline*** SiO_2
  - Purity: case-by-case

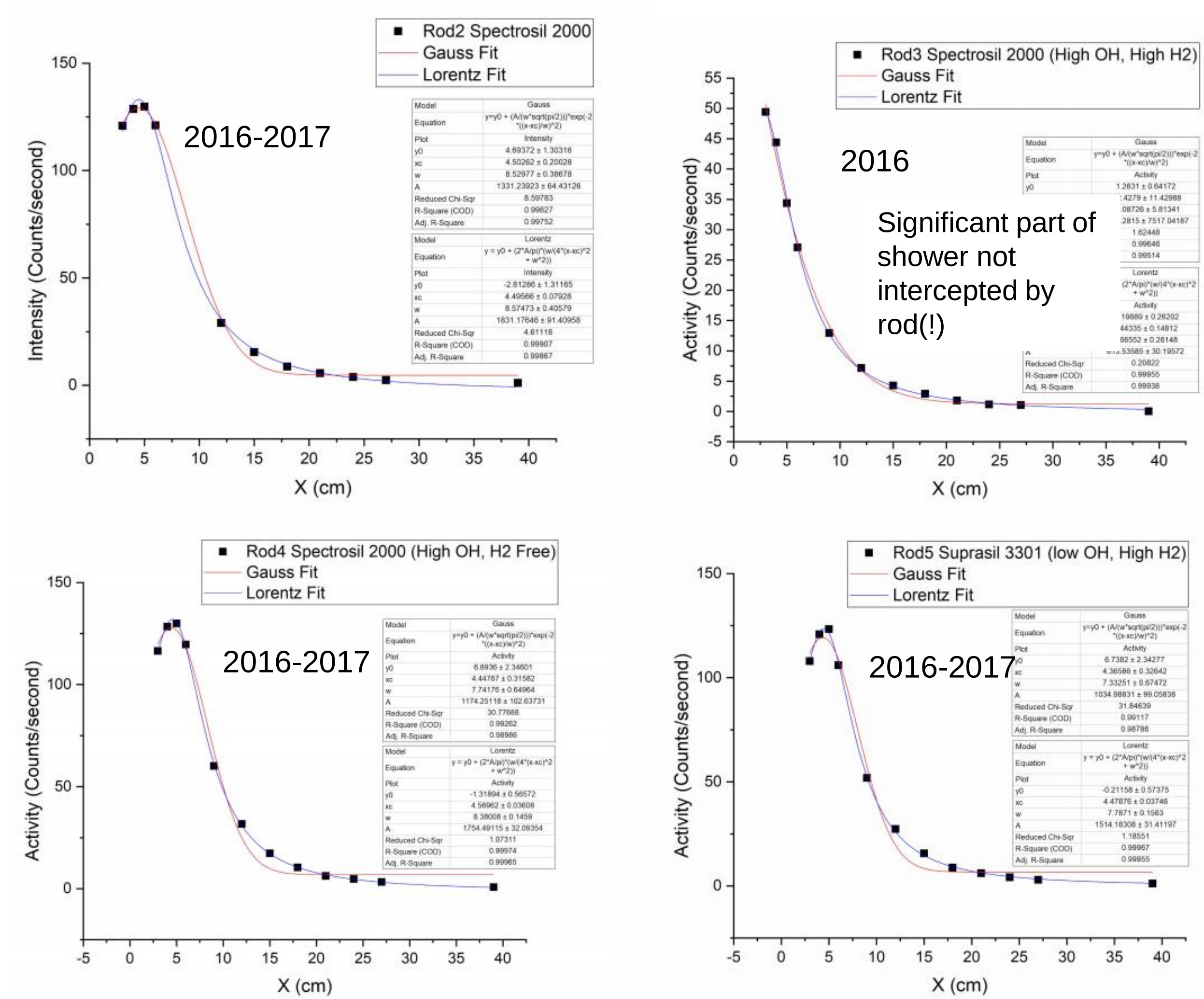
- Fused quartz
  - ***Amorphous*** SiO_2
  - Made from natural crushed quartz
  - Natural impurities may persist into finished product

- Fused silica
  - Synthetic amorphous SiO_2
  - Made from oxidized Si-gas
  - Potentially ultra-pure

Absorbed dose (Gamma spectroscopy)

- 2016: Negative X-ing angle
- 2017: Positive X-ing angle
- Current design: 30 mm gap: TAN-floor to end of quartz rod
- → BRAN "floor" should be made thinner.



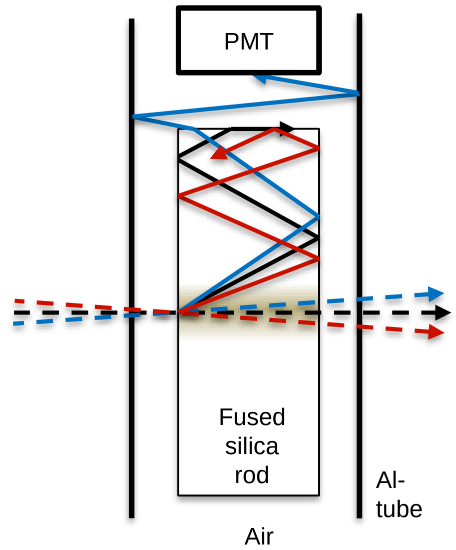


Activity vs. vertical rod coordinate (0 = bottom of rod)

Light yield

- Light from particles going exactly forward won't reach PMT (total internal reflection at top)
  - Light extraction efficiency is pretty low
  - Angular divergence of charged secondaries ≠0
  - Each collision at μ=138 generates light equivalent to 2 million PMT "counts"
- →We can have as much signal as we need
  - Light yield on PMT can be tuned by adjusting Rod-PMT gap

Track length/event (charged particles) @ Dose peak	98 cm/cm^3
Photon yield, quartz	1003 photons/cm^3
Equivalent PMT counts (incl. QE)	145 counts/cm^3
PMT counts/event	**14210**
Nominal pile-up, HL-LHC	138
PMT counts/crossing (1 cm^3 fused silica at dose peak)	=> 2,000,000



Aluminum mirrors

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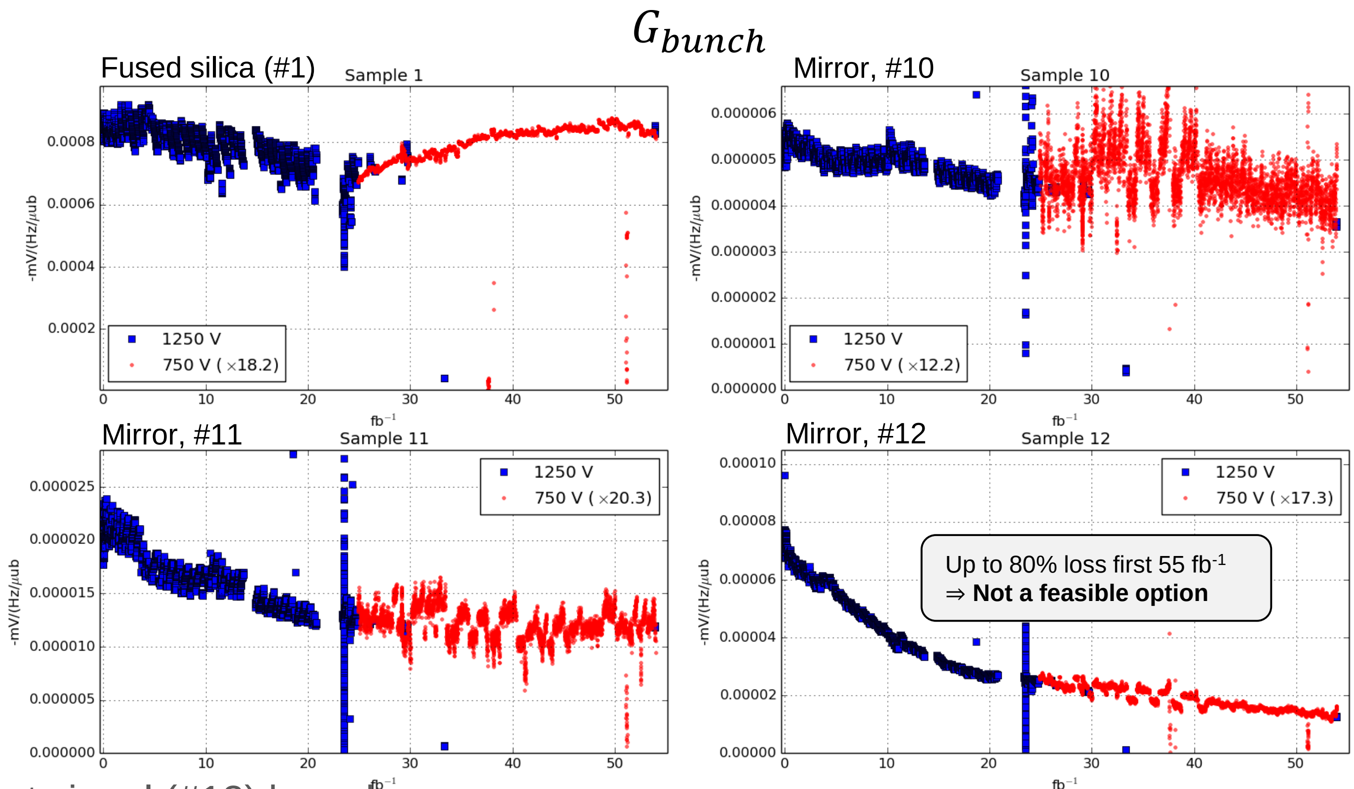

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  - Other possibility: diffuse reflections?
- ⇒ **We will go for fused silica rods.**

	Mirror #10	Mirror #11	Mirror #12
Initial gain [compared to quartz rod]	0.6%	2.8%	**8.3%**
Gain loss up to 54 fb^{-1}	-32%	-43%	**-83%**