CMS LUMINOSITY MEASUREMENT IN 2018

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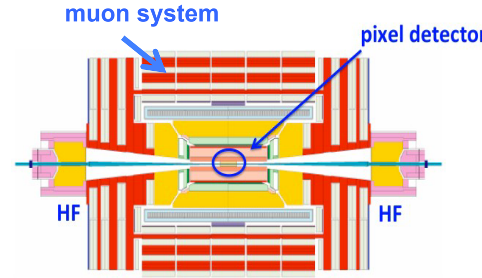
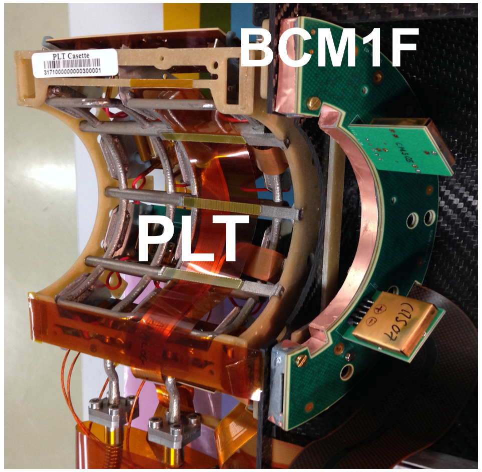
Luminosity measurement

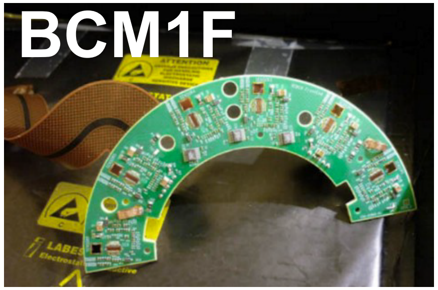
- ***Luminosity*** is obtained from the observed ***rate in a detector (R)*** and calibration constant, called ***visible cross section (σ_{vis})***:

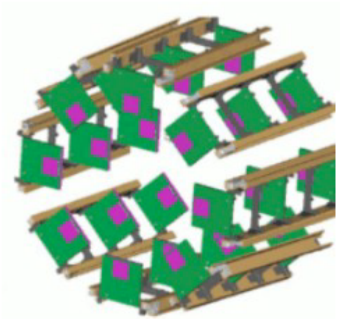
  $$L = R/\sigma_{vis.}$$

- In the CMS following detectors are used for luminosity:
  - *Forward calorimeter (**HFOC and HFET**, online)*
  - *Fast Beam Conditions Monitor (**BCM1F**, online)*
  - *Pixel Luminosity Telescope (**PLT**, online)*
  - *Drift Tubes (**DT**, muon system, online, cross-calibrated)*
  - *Pixel Detector (cluster counting **PCC**, semi-online)*
  - *Vertex counting (offline, used in VdM calibration only)*
  - *Rradiation monitoring devices (**RAMSES**, offline, cross-calibrated)*





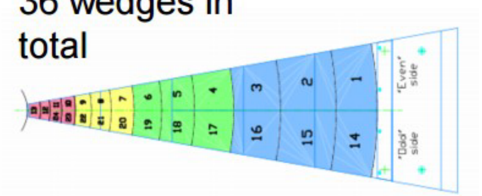




PLT

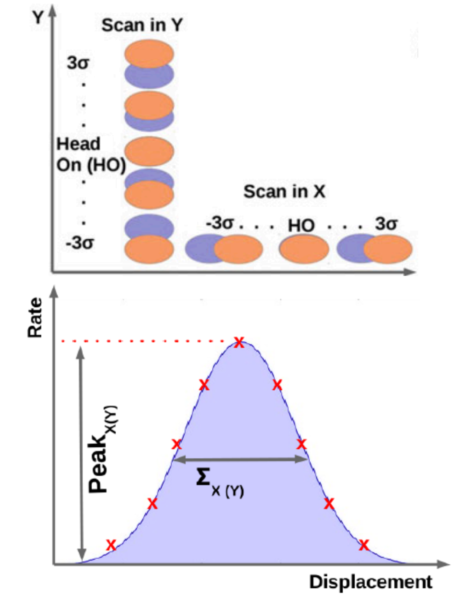
HF wedge

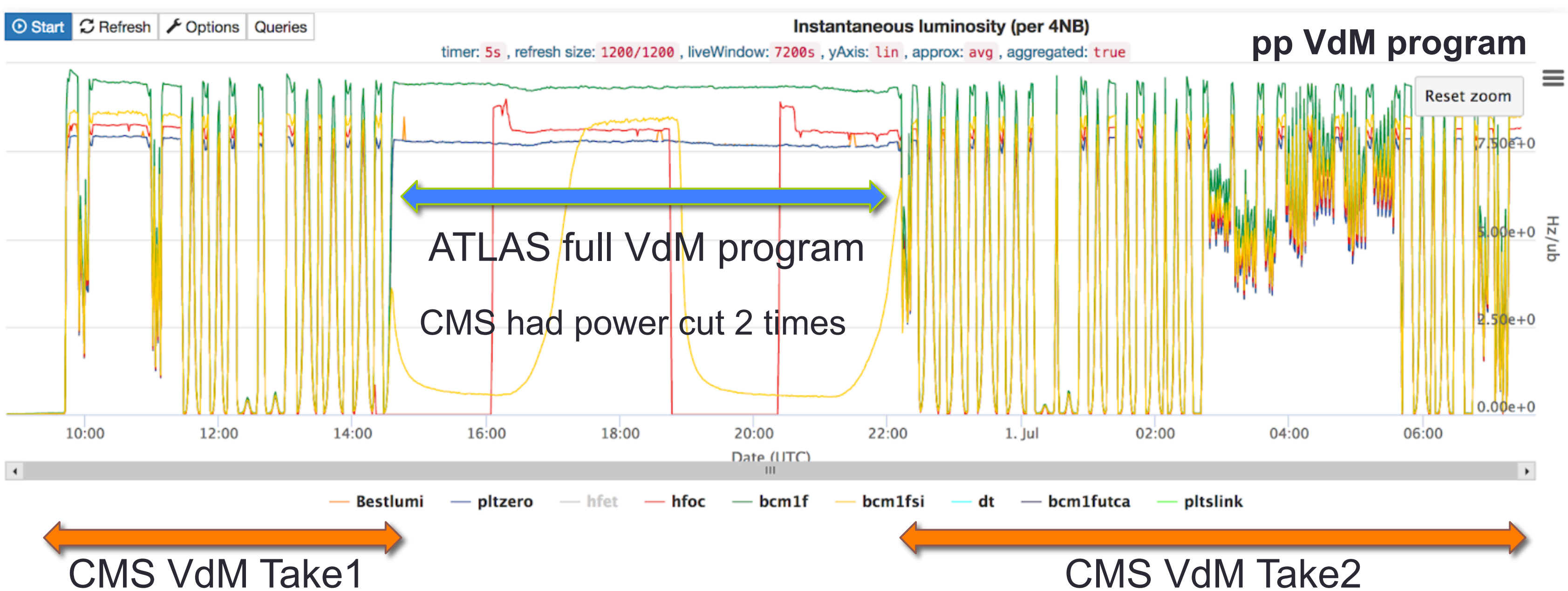
36 wedges in total



Absolute calibration in VDM fill (1)

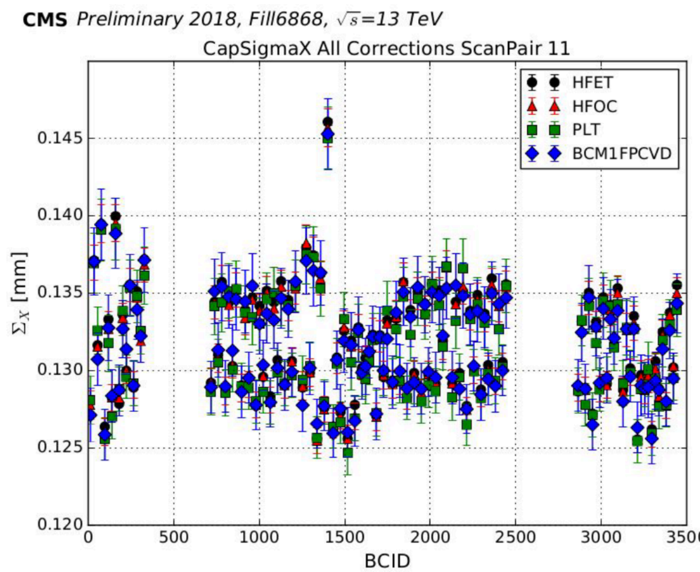
- **Van der Meer scan method is used for LHC luminosity calibration.**
  - The proton beams are scanned against each other to determine the effective overlap of the beams at their point of collision and the visible cross section (σ_{vis}) of the luminometer.
  - Scans are done in 25 separation steps with only solo bunches in the fill
- **Very complete pp VdM program, Fill 6868, July 2018:**
  - 7 pairs of VdM scans (3 pairs are Imaging scans with one beam fixed), 2 offset scans, 5 emittance scans;
  - length scale calibration with fixed and alternating separation;
  - 2 super separation measurements of background.

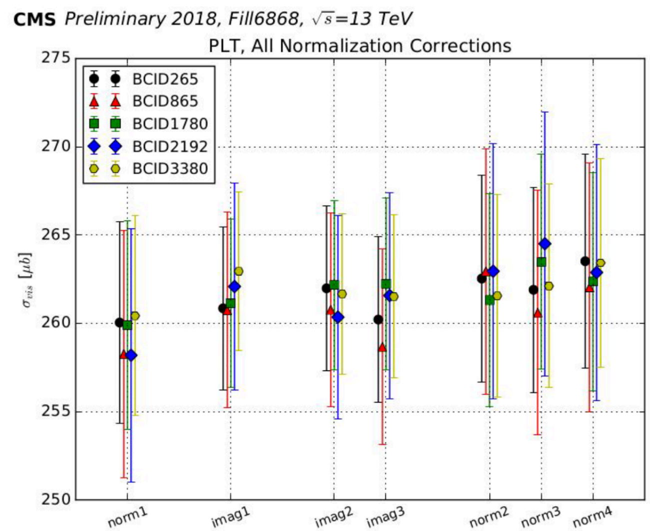


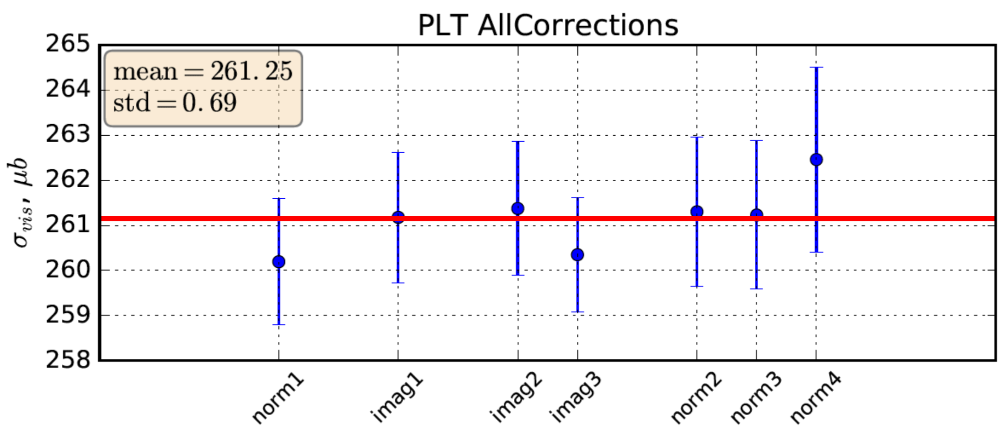


Absolute calibration in VDM fill (2)

- For each colliding bunch crossing (BCID) convoluted beam width and maximum count rate are measured to deliver absolute calibration (σ_{vis}) for each luminometer.
- Convoluted beam width is the beam property. Agreement between different luminometers measurements is better than 1%.
- σ_{vis} is the property of the luminometer and is constant for stable detector configuration.
- Average of all bunch crossings is used to deliver σ_{vis} in each VdM scan.







Corrections and uncertainties

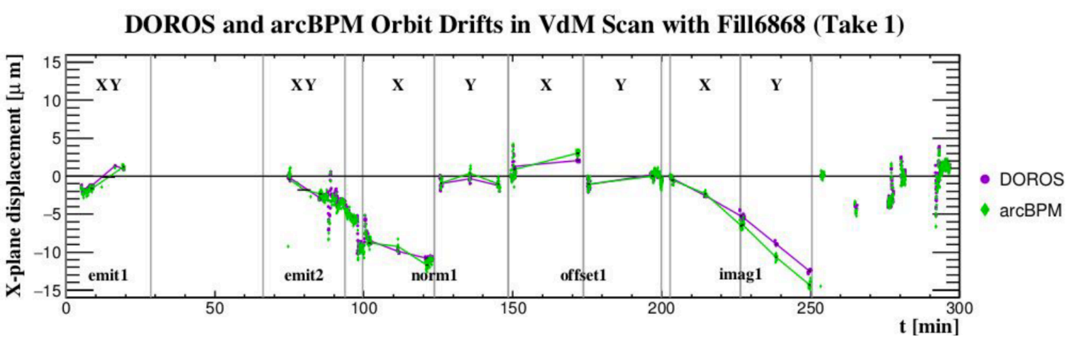
Contributions to the luminosity precision

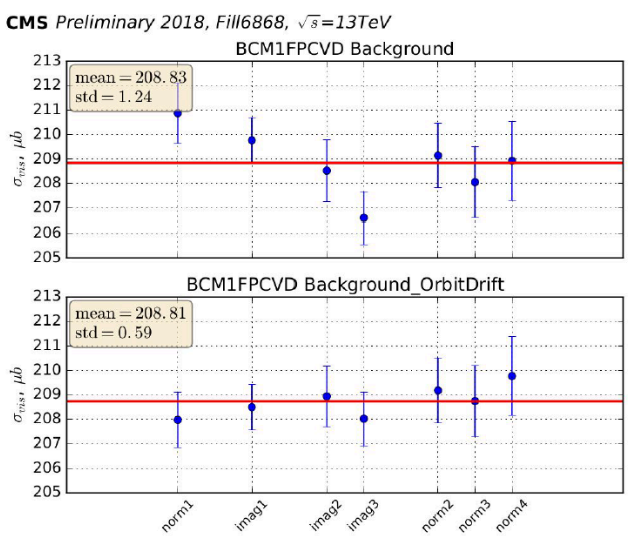
- **Normalization** corrections are common for all luminometers, as they are originated from vdM scan methodology assumptions, beam quality and beam effects.
- **Integration** uncertainty covers the stability and linearity of all luminometers and their compatibility along the whole year.
- Detailed analyses is published in the CMS LUM-18-002 (link).

	Systematic	Correction (%)	Uncertainty (%)
Normalization	Length scale	−0.8	0.2
	Orbit drift	0.2	0.1
	x-y correlations	0.0	2.0
	Beam-beam deflection	1.5	0.2
	Dynamic-β^*	−0.5	
	Beam current calibration	2.3	0.2
	Ghosts and satellites	0.4	0.1
	Scan to scan variation	—	0.3
	Bunch to bunch variation	—	0.1
	Cross-detector consistency	—	0.5
	Background subtraction	0 to 0.8	0.1
Integration	Afterglow (HFOC)	0 to 4	$0.1 \oplus 0.4$
	Cross-detector stability	—	0.5
	Linearity	—	1.1
	CMS deadtime	—	<0.1
	Total		2.5

Normalization uncertainties (1)

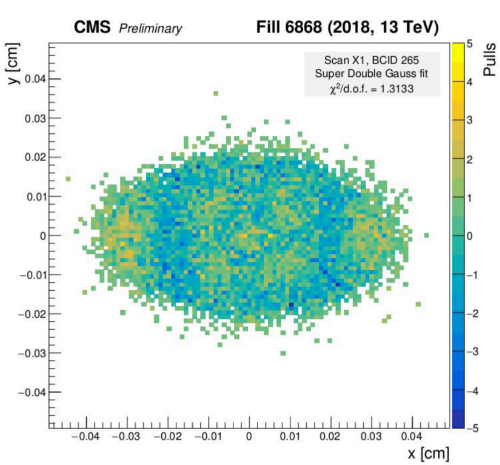
- Length scale calibration and orbit drift are corrections to the nominal beam separation.
  - **Length scale calibration** is needed in the VdM scan as beams are steered in the range wider than magnets are calibrated for normal operation.
    - CMS tracker and reconstructed primary vertices are used for this analyses. The beamspot position is plotted against the nominal beam position to obtain the correction.
  - **Orbit drift correction** is derived using beam position monitors measurements before the scan, in the middle and after each VdM scan.

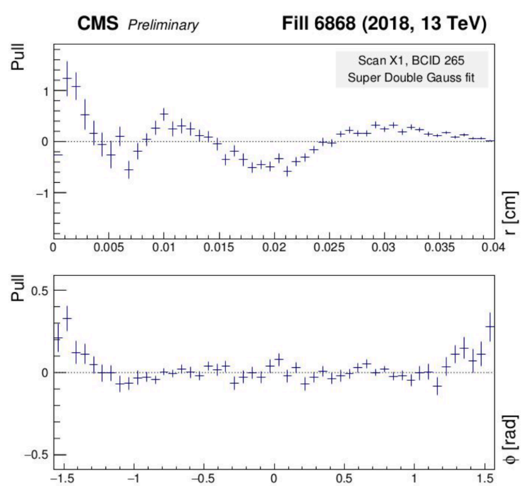


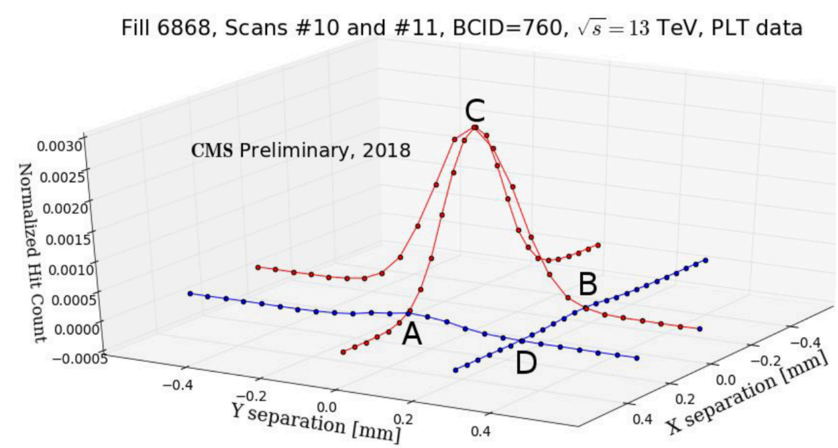


Normalization uncertainties (2)

- VdM method assumes factorization of the proton densities in X and Y plane: ρ(x,y) = ρ(x)ρ(y).
- Presence of non-factorization introduces bias to the VdM calibration.
- To test non-factorization of the beam (***x-y* correlations**) multiple methods are employed by CMS:
  - Beam Imaging analyses, where image of each beam obtained in X and Y from 4 special scans;
  - NEW: Offset scans allowing for better understanding of the “tails” of VdM scans;
  - NEW: Beam spot analyses for study of the evolution of the rotation of the beam duding VdM program.

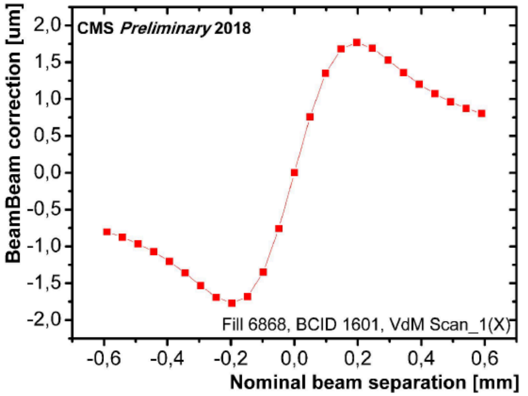


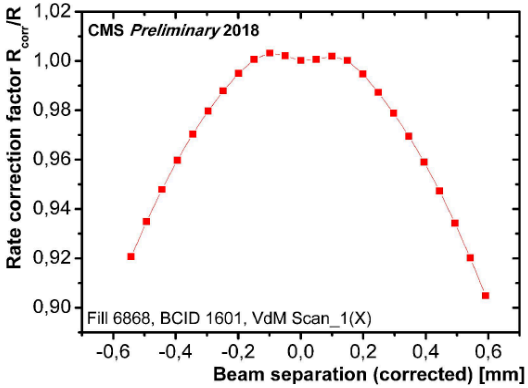




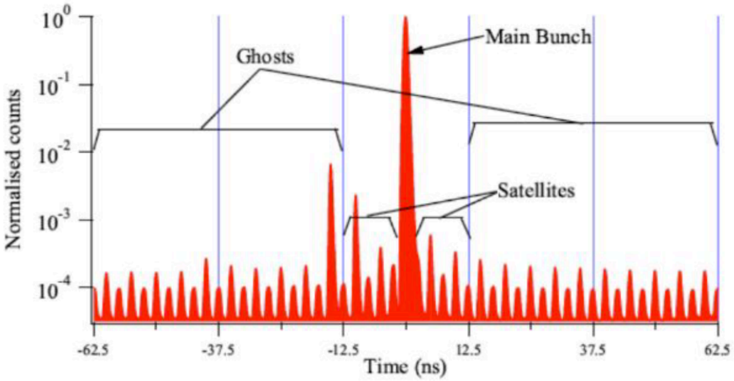
Normalization uncertainties (3)

- The two proton beams influence each other via electromagnetic forces. This is factored into:
    - Collective effect on trajectory (separation) →
      Beam - Beam deflection
    - Change in bunch structure (defocusing) →
      Dynamic β* effect





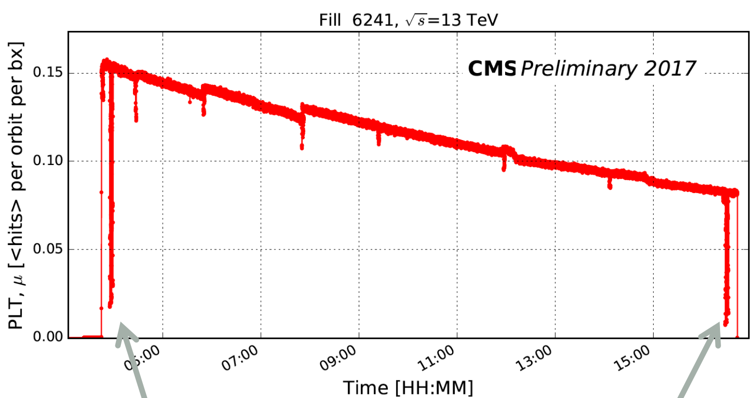
- Bunch current is used for each bunch crossing measured rate normalization. Presence of the charges in the not nominally filled RF buckets should be take into account.
    - **Ghosts and satellites correction**



Integration, linearity and stability

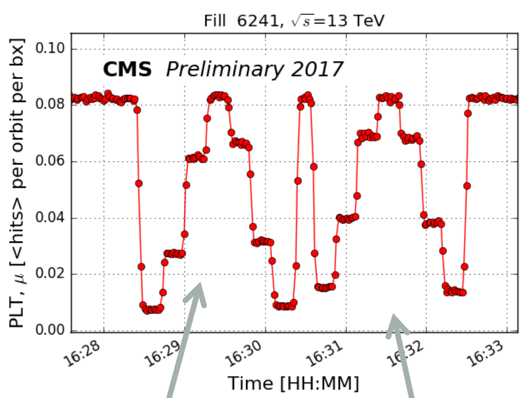
Emittance scan difference from VdM scan

- **VdM scan program is performed only once per year.** An other handle was required to monitor stability and linearity of the detectors.
- **Emittance scans** are employed since 2017: short Van der Meer type scans performed at the beginning and at the end of LHC fills.
  - Beams are scanned in 7-9 displacement steps (19-25 steps in VdM);
  - 10 s per step (30 s per step in VdM);
  - The same beams as in physics data taking (in VdM fill special beam optics is used);
  - Single Gaussian fit is used to fit the emittance scan shape and to extract Peak and beam overlap in X and Y.



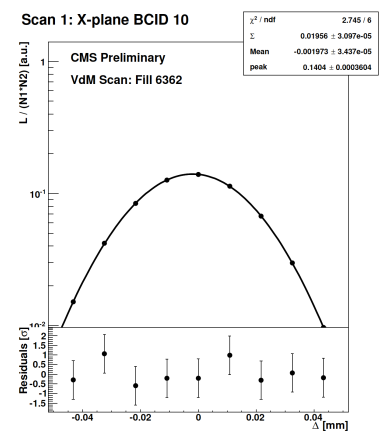
Beginning of fill

End of fill



Scan in X plane

Scan in Y plane



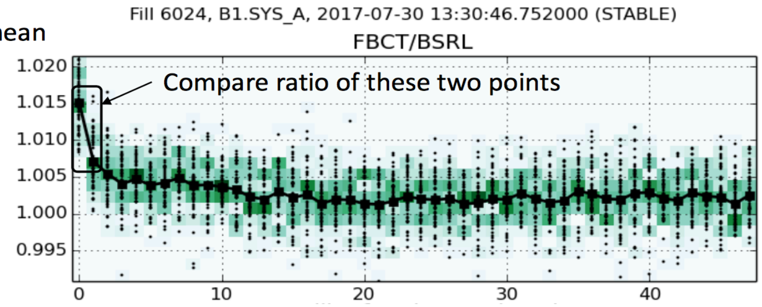
Example of the fit

Corrections to the emittance scans

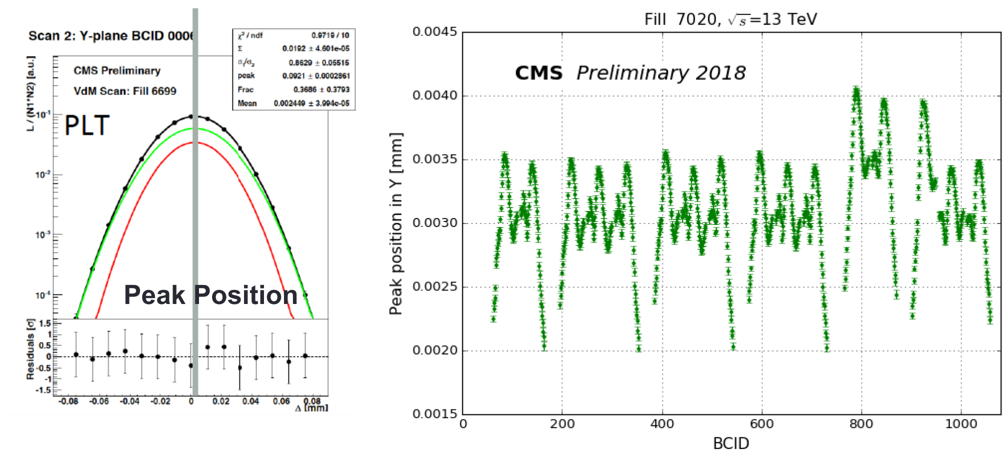
- There are effects which can be only taken into account correctly when per bunch crossing measurements are performed.
- Corrections applied offline to emittance scans before the final data re-processing:
  - 1% correction to current of the fits bunch in the train;
  - Bunch current normalization in every scan to the total beam current;
  - Beam-beam deflection correction varies in the bunch train due to different size of the bunches;
  - Long range interactions result into different displacement of the orbit depending from the position in the bunch in the train. Peak position correction in the bunch train is applied to take shift in the non-scanning plane into account.

FBCT/BSRL ratio along train

- Black line: mean of all trains
- Black dots: individual bunches
- Colormap: distribution

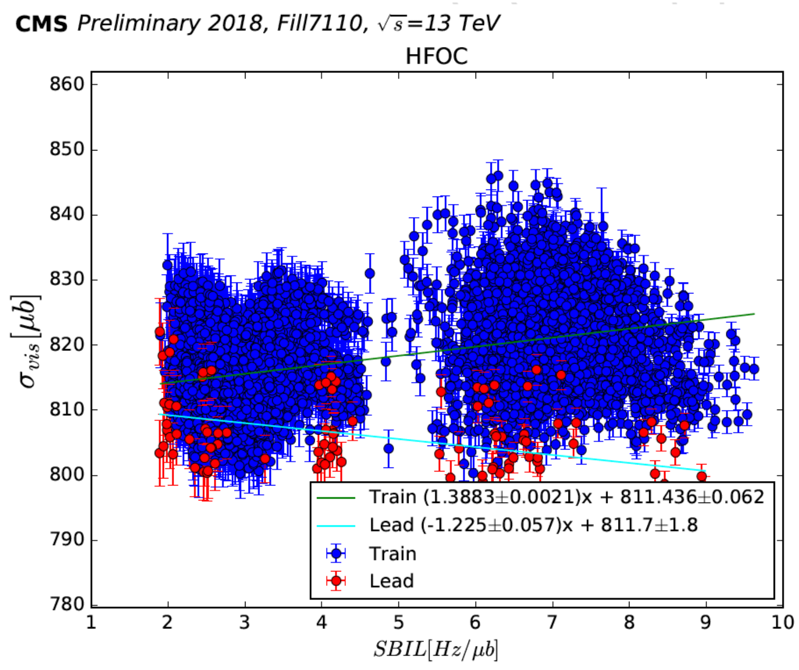


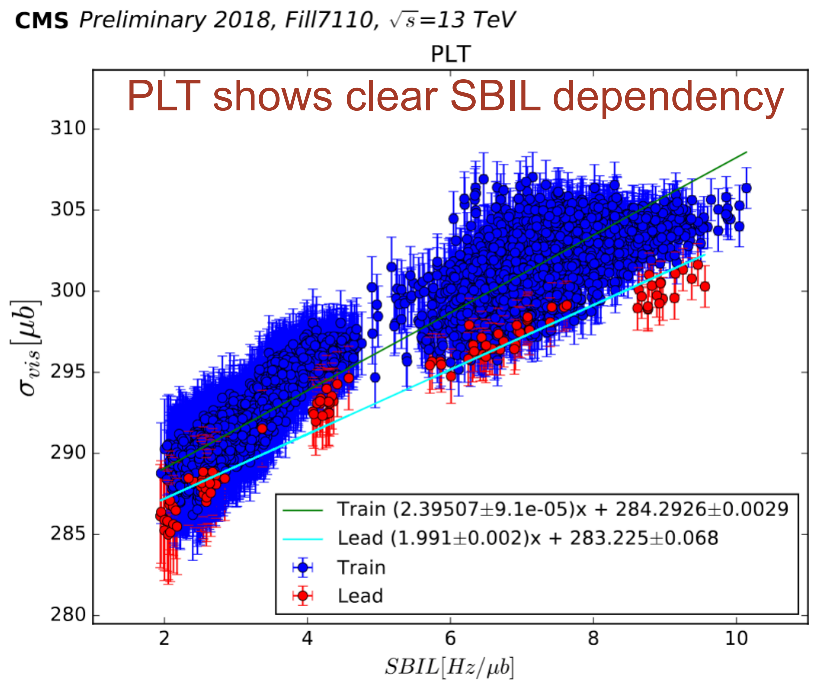
Beam position in the bunch train



Emittance scans for non-linearity measurement

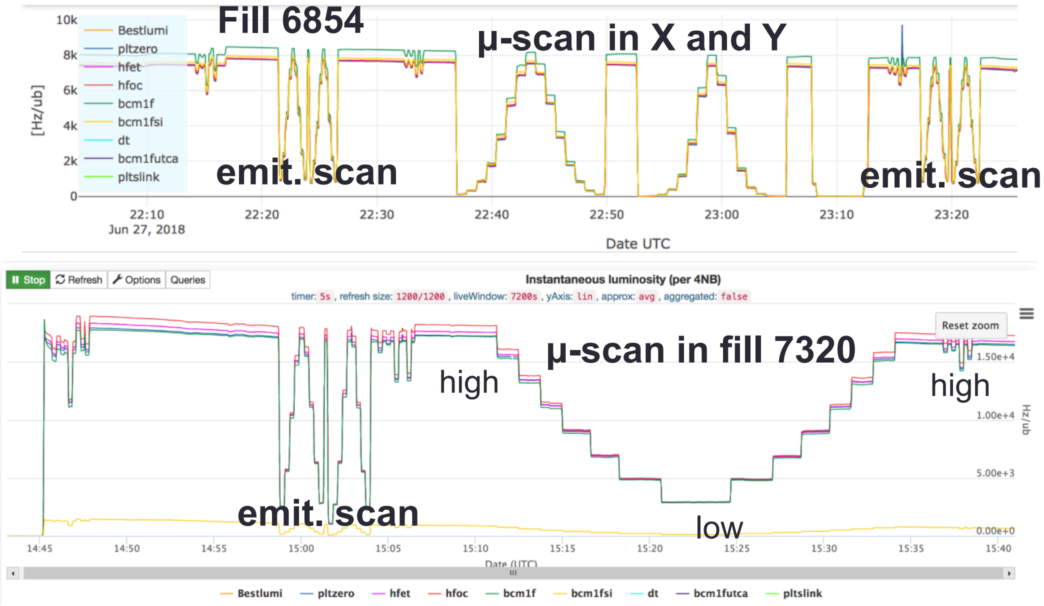
- Wide range of Single Bunch Instantaneous Luminosity (SBIL) is covered in each LHC fill.
- Emittance scans early in the fill and towards the end of the fill allow for non-linearity measurement of online luminometers in each fill.
- Leading and train bunches showed difference in the behavior. Effects are also detector dependent, important to be studied and taken into account in the corrections.

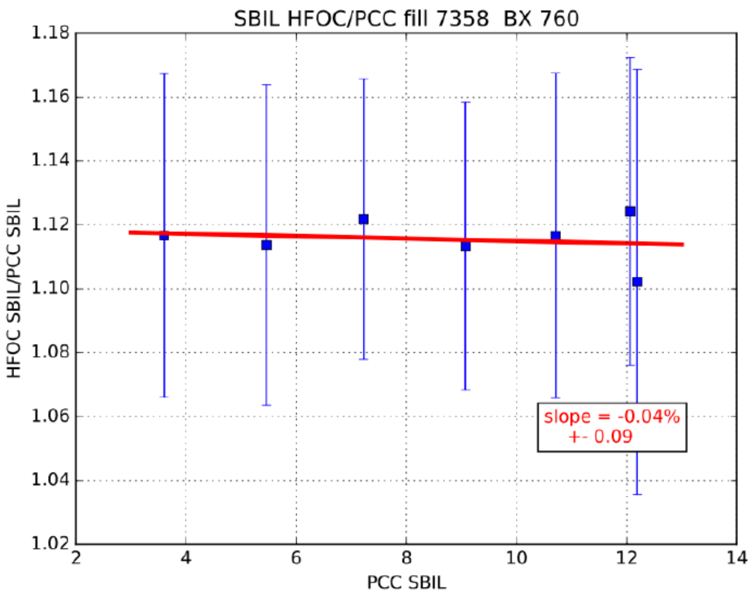




μ-scans for relative non-linearity measurement

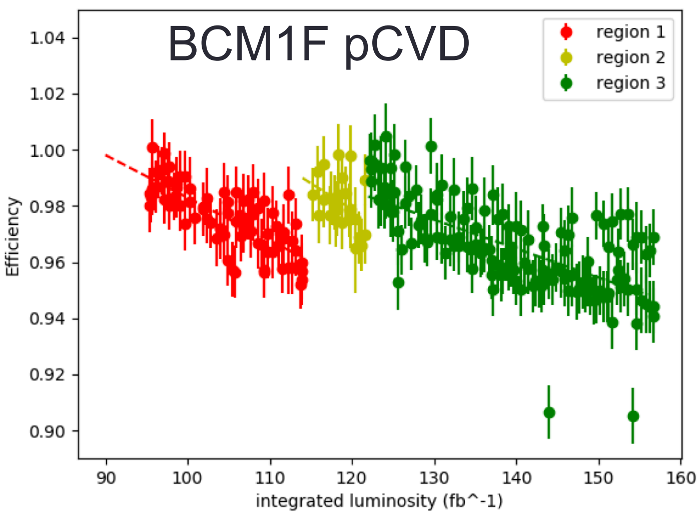
- μ-scans are beam scans in separation steps, similar to emittance scans, however with equal steps in SBIL and longer step duration. One sided (high-> low) and two sided scans can be performed (high->low->high).
- *μ-scans are used for cross-comparison of linearity measurement*. It does not matter what non-linearity is, if it can be measured precisely and be corrected for, only residual non-linearity matters (for current detectors residual non-linearity is typically ~0.1% per SBIL).

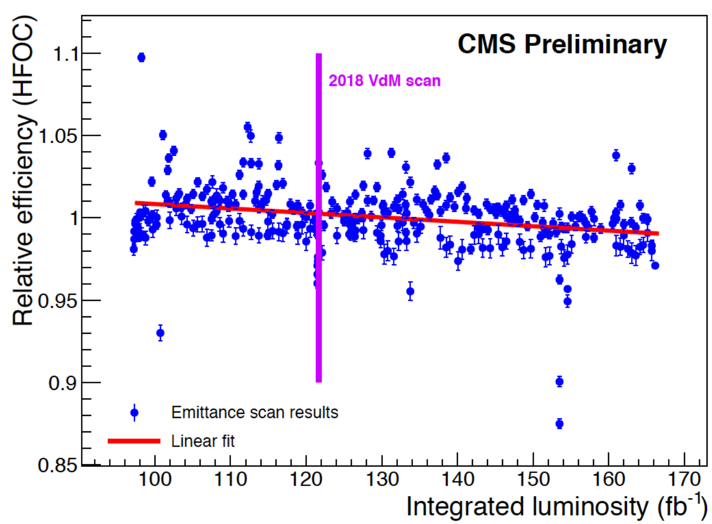




Emittance scans for stability measurement

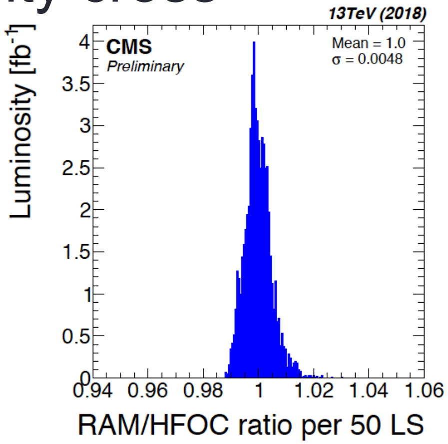
- Due to radiation damage the efficiency of the luminometers decreases along the year.
- To take into account this decrease efficiency correction is applied based on the slopes measured from the whole year emittance scans.
- Different eras can be considered in the efficiency correction. Measured slope changes after technical stops due to recovery of the detectors or due to settings and thresholds changes, etc.

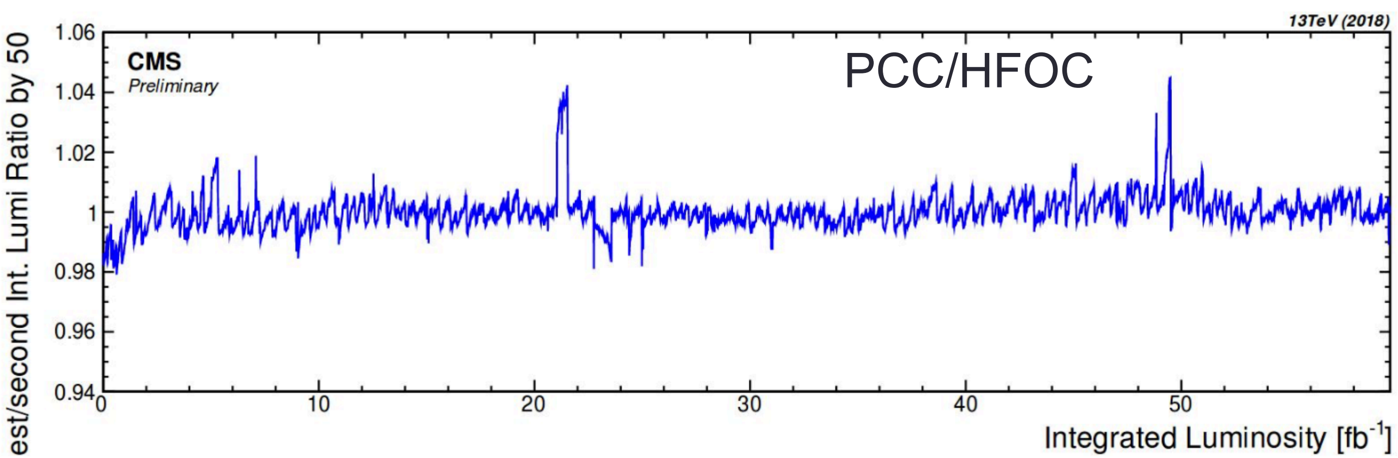


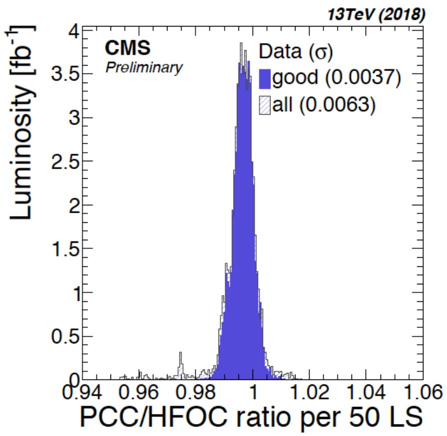


Cross detector stability

- After non-linearity, efficiency corrections and detector specific corrections were applied, ratio of luminosity for each pair of detectors is studied for the whole year.
- RAMSES and DT are two detectors which are not available per bunch crossing, but used for stability and linearity cross check.
- Excellent stability in 2018! Standard deviation of the luminosity weighted ratio for HFOC/PCC is 0.6%. It is taken as stability uncertainty.

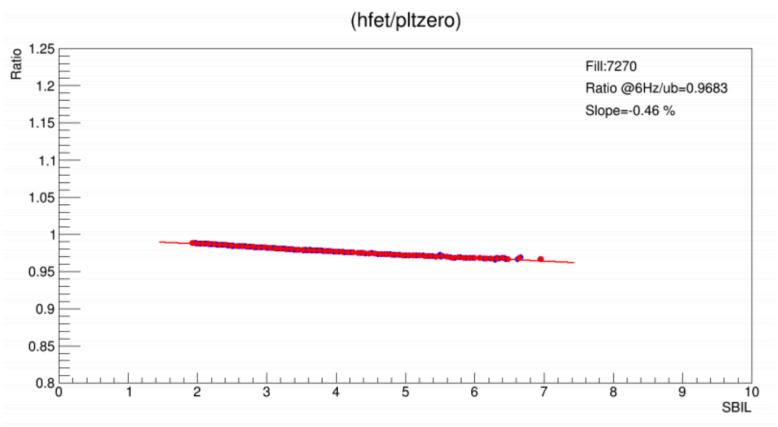


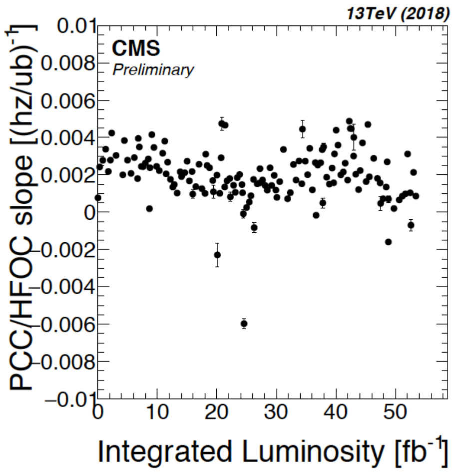


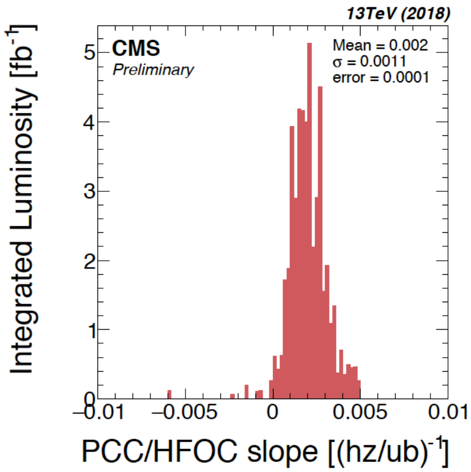


Residual non-linearity

- For each pair of luminometers to measure residual non-linearity ratios of luminosity vs. SBIL in each fill are used.
- Measured slopes are filled in the histogram and standard deviation is taken as an estimate of the luminosity uncertainty due to linearity.
- For HFOC/PCC offset of the mean is taken as residual non-linearity, as standard deviation does not cover the offset of the mean from 0.
- 0.2% residual non-litearity results in 1.1% uncertainty on the whole year luminosity.

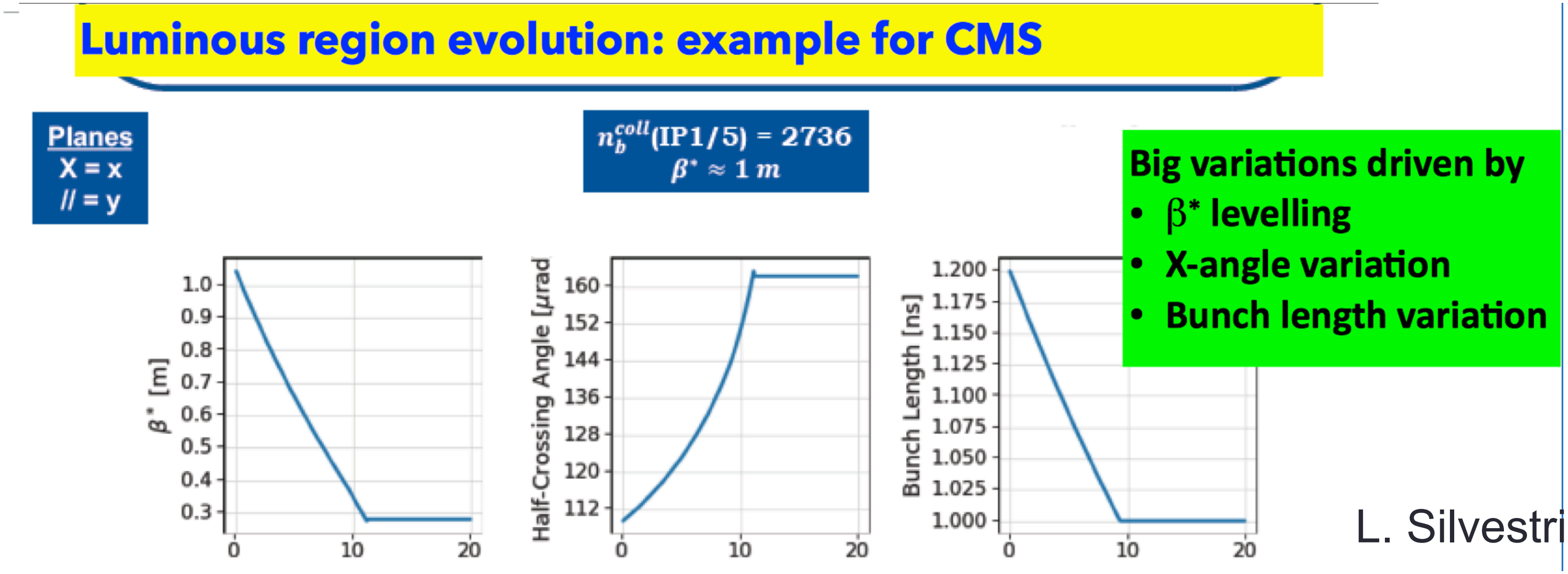






Challenges in Run 3

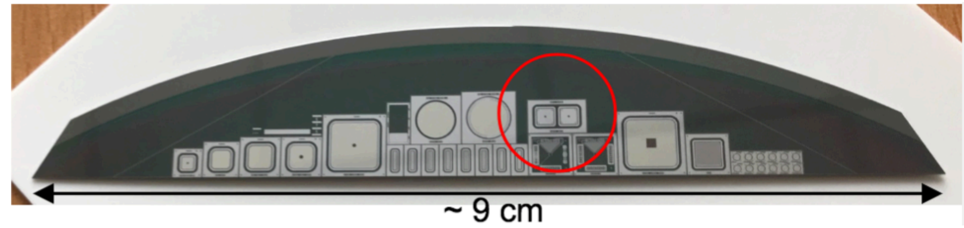
- Run 3 is transition between LHC & HL-LHC. What will change?
  - Beam energy from 6.5 TeV to 7 TeV
  - Bunch charge from 1.1 10^{11} in 2018 up to 1.8 10^{11} in Run 3
  - To keep the PU at the same level that does not affect physics data taking quality operations will be more challenging. Changing beam condition will also challenge emittance scans technique:
    - β* will be changing in wide range (from 1m and wide beams to 30 cm and narrow beams)
    - Half-crossing angle will change from 110 μrad to 160 μrad along the fill



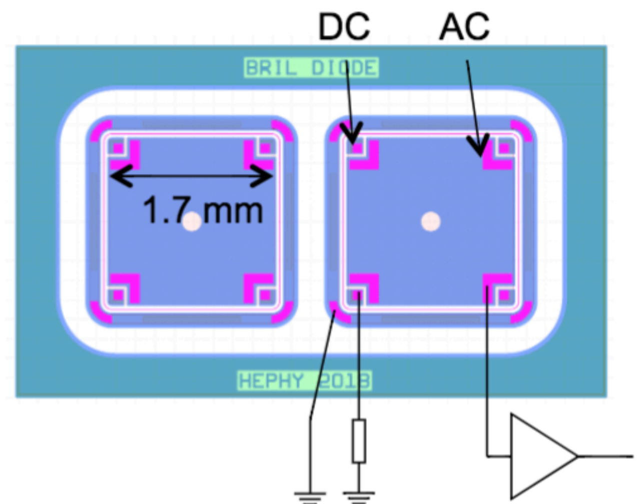
L. Silvestris talk

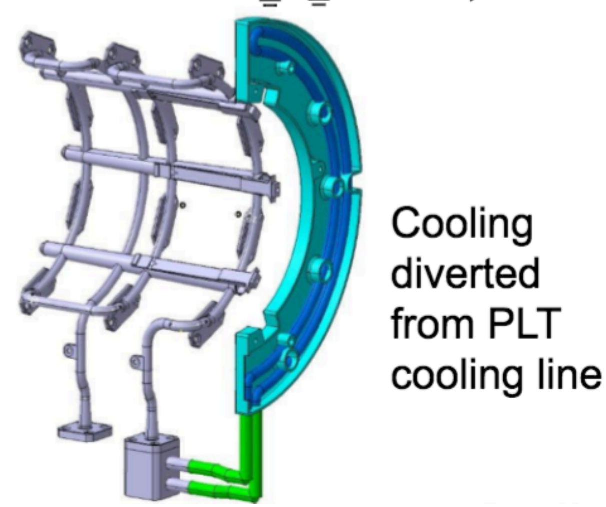
BCM1F for Run3

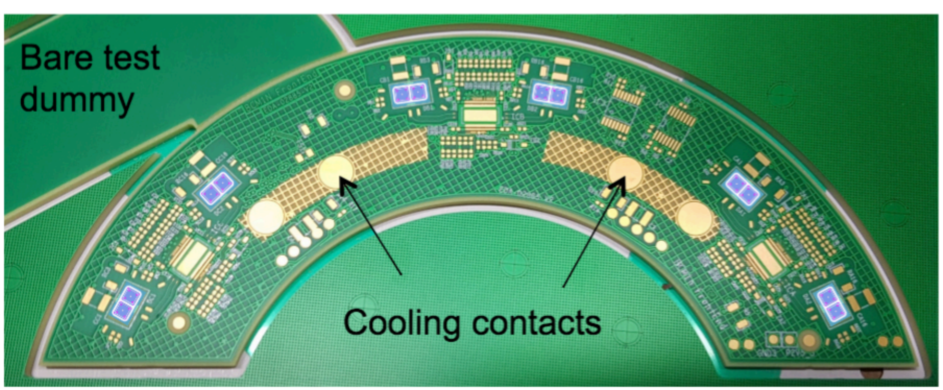
Planning talk by M.Guthoff



- Desired Si sensors, but no leakage current into FE-ASIC
  - AC coupling
- New sensor design: AC coupled double diodes, external bias resistor.
- First batch with recent HGCal sensor production.
- PCB features active cooling and various other improvements







Summary

- Most of the systematic uncertainties have been improved in 2018 in comparison to 2017.
- All BRIL detectors are independently calibrated in VdM scan. Excellent cross detector stability and linearity across the year.
- New techniques are employed to study x-y correlations

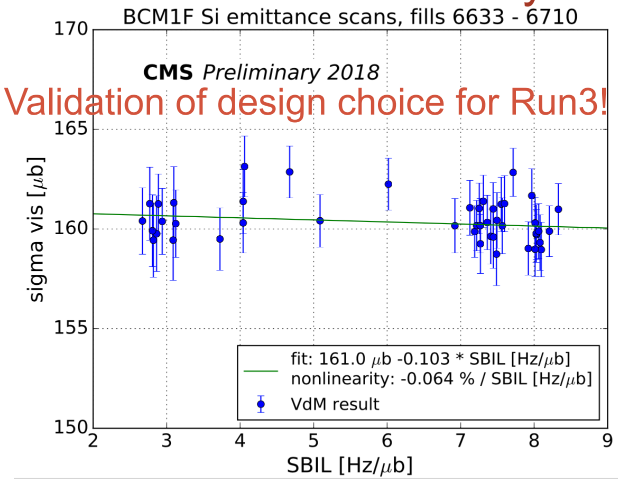
- Improved technic of emittance scans is powerful handle for non-linearity measurement of online luminometers and efficiency monitoring.
- Bunch by bunch measurement allowed to gain understanding of beam evolution and apply corrections accordingly. E.g. beam-beam correction, bunch current normalization, peak position.
- It is planed to extend 2018 analyses technique on the 2017 data and prepare combined precision luminosity measurement by the end of 2019

BCM1F in operations (2018)

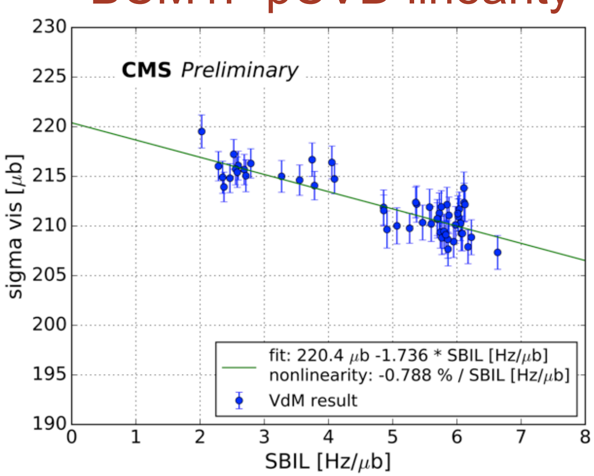
- Highest availability detector in 2018! 99.5% of the time. Robust background measurement!
- pCVD based detector and Si (prototype sensor):
  - pCVD showed much better HV stability as we had for sCVD in 2015-2016.
  - Si was used for Run3 potential performance validation. It showed excellent stability and linearity, but could be only used in the second half of the running period due to absence of direct cooling and high leakage current after significant radiation damage.

BCM1F Si linearity

Validation of design choice for Run3!



BCM1F pCVD linearity



BCM1F pCVD efficiency