11:15 **Long-term monitoring of delivered luminosity & calibration stability in CMS** 25m

- Monitoring & stability, of luminosity and associated calibrations in Run-II
- Introduction to emittance-scans and data analysis

Speaker: Olena Karacheban (CERN)

LONG-TERM MONITORING OF DELIVERED LUMINOSITY & CALIBRATION STABILITY IN CMS

Olena Karacheban on behalf of CMS Collaboration

LHC Lumi Days Workshop 2019,
4-5 June 2019, CERN, Geneva
https://indico.cern.ch/event/813285/timetable/

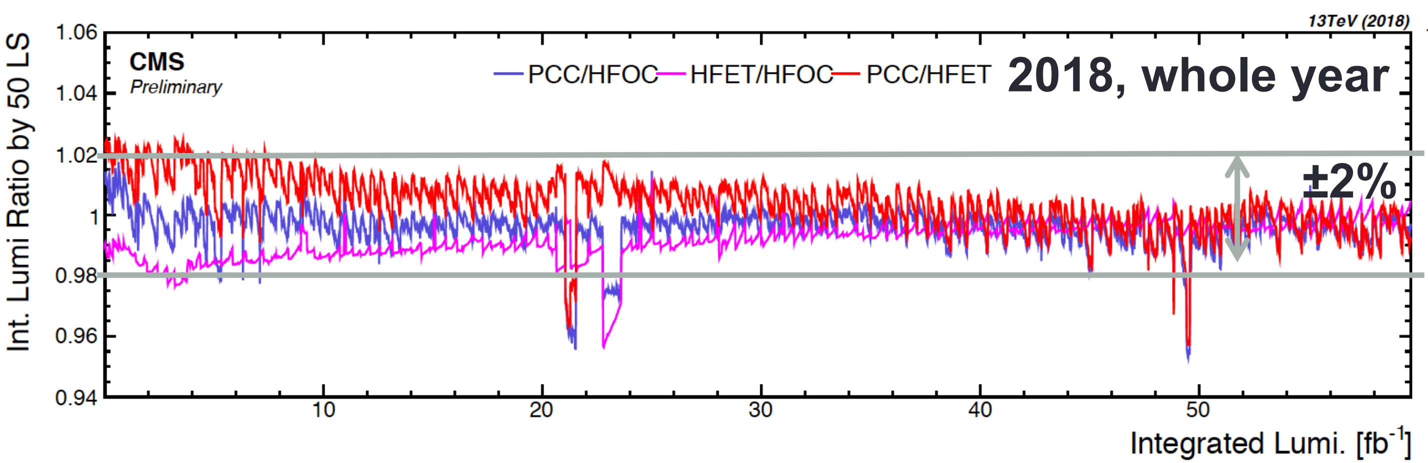
2017-2018 from operations to offline lumi

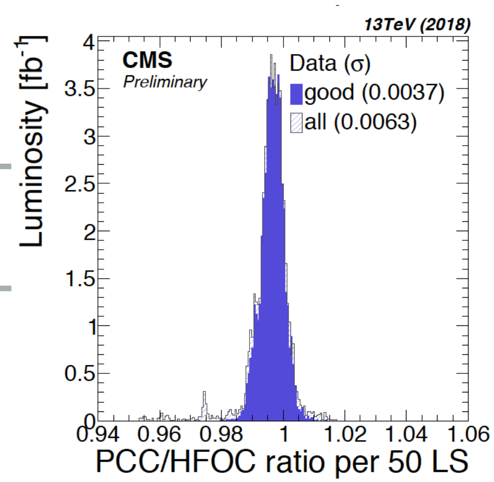
- Multiple operational online luminometers provided uninterrupted luminosity measurement to CMS and LHC.
- CMS detectors used for luminosity measurement:
  - **HFOC, HFET, PLT, BCM1F per bunch crossing** (one is sent online)
  - Offline per bunch: **pixel detector (**cluster counting, **PCC)**
  - Cross-calibrated, used for total luminosity, not per bunch: **drift tubes (DT+RPC), radiation monitoring devices (RAMSES)**
- Periods of instability of particular luminometers are excluded from final luminosity data set.
  - After each fill “offline fill validation” is performed to exclude obvious instability or periods of known detector interventions
  - At the end of the year based on comparison of the detectors (at least 3 detectors) other problematic lumi-sections are identified and fixed or excluded

2017-2018 from operations to offline lumi

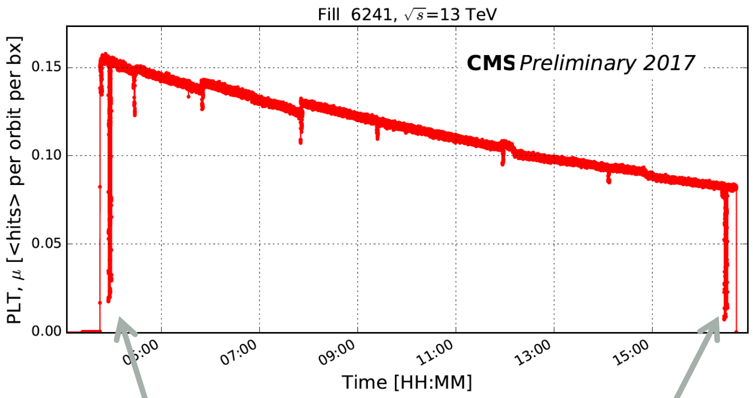
- The whole year data with final linearity and efficiency corrections is used to derive stability and residual non-linearity uncertainty on luminosity measurement.
  - In 2017: uncertainty due to stability 0.5%, due to residual non-linearity 1.5%
  - In 2018: uncertainty due to stability 0.6%, due to residual non-linearity 1.1%

- Emittance scans play a role for both of these measurements!



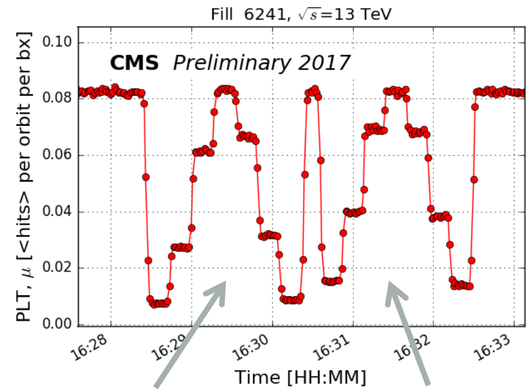


Emittance scan difference from VdM scan

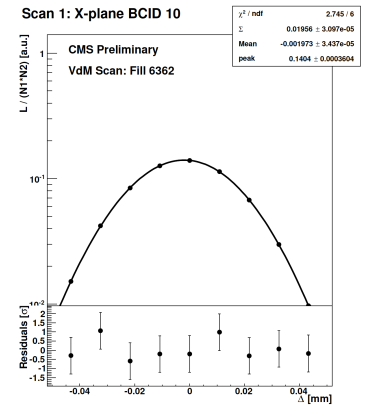


Beginning of fill "early scan",
β*=30cm, α/2=160μrad

End of fill "late scan",
β*=25cm, α/2=130μrad



Scan in X plane **Scan in Y plane**



Example of the fit to measure beam overlap $\Sigma_{X(Y)}$ and peak

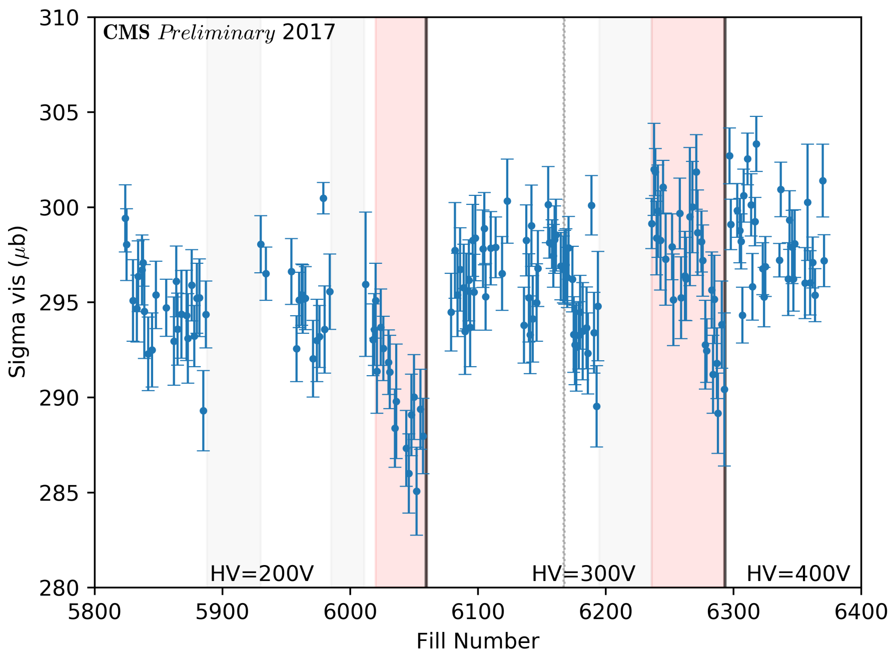
$$\sigma_{vis} = \frac{2\pi\Sigma_x\Sigma_y}{N_1 \cdot N_2 \cdot f} \cdot R_{peak}$$

	VdM scan	Emittance scan
Filling scheme	Only solo bunches (~30-130)	Bunch trains (up to ~2500)
Beam conditions	β*=19 m (~100μm wide beams), no crossing angle α/2=0	Changing β*=25-30cm (~10μm beams), changing α/2=130-160μrad
Scan steps	25 steps 30 sec each	7-9 steps 10 sec each
Scan range	6 beam sigmas	3.5-4 beam sigmas
Peak pileup	~0.5	~60
Utility	Absolute luminosity calibration	Stability/linearity

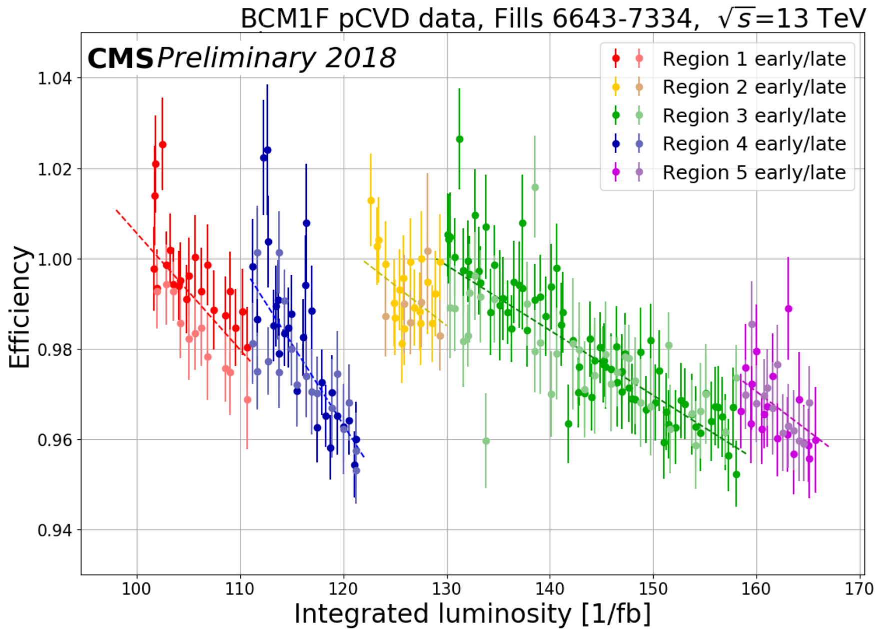
Emittance scans for stability monitoring (1/2)

- Any change in σ_{vis} reflects changes of the detector performance!
- Emittance scans provide the access to relative change of the σ_{vis} with respect to the absolute calibration carried out in VdM program:
  - corrections derived “eras” or “regions” of different efficiency

PLT stability in 2017



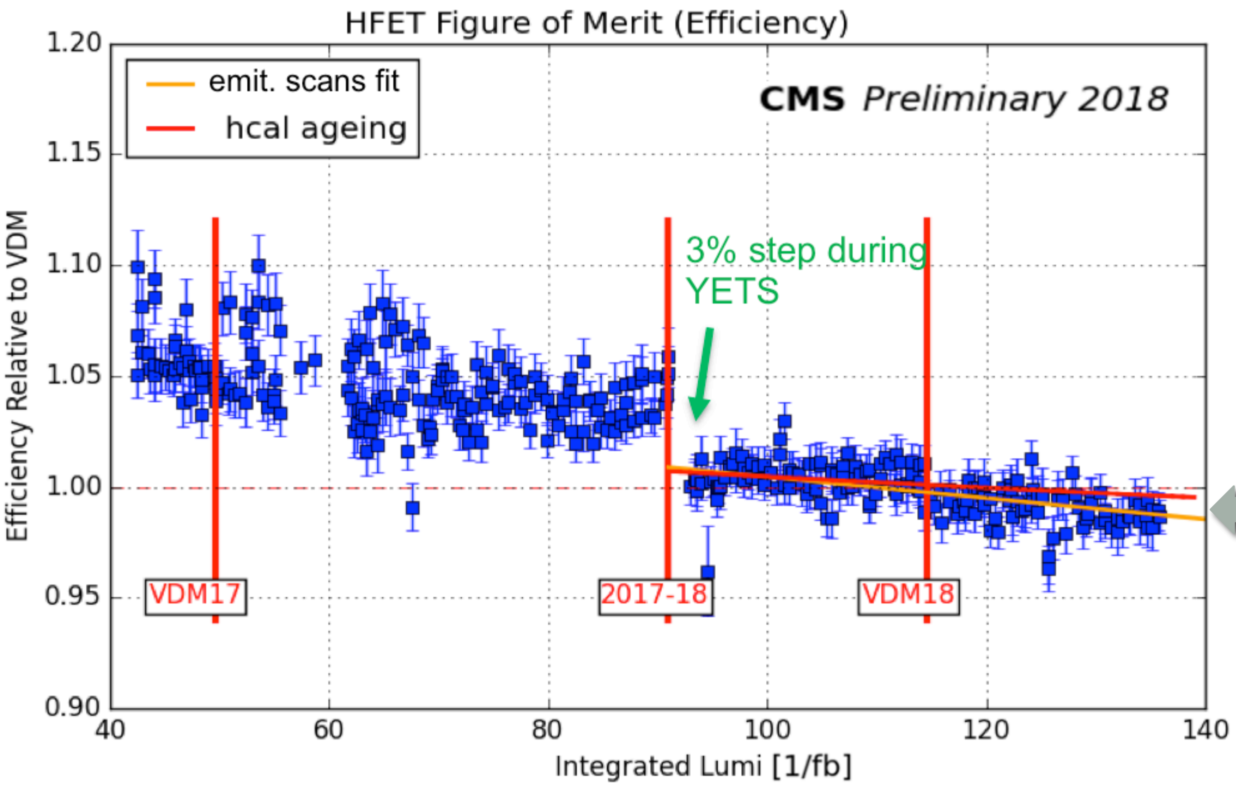
BCM1F pCVD stability in 2018



Emittance scans for stability monitoring (2/2)

- Less scatter in 2018 emittance scans
  - more optimized beam conditions and more consistent filling schemes (in 2017 filling scheme was changed several times).

- Detector performance change was spotted from the first emittance scans in the year in 2018 after YETS HF!

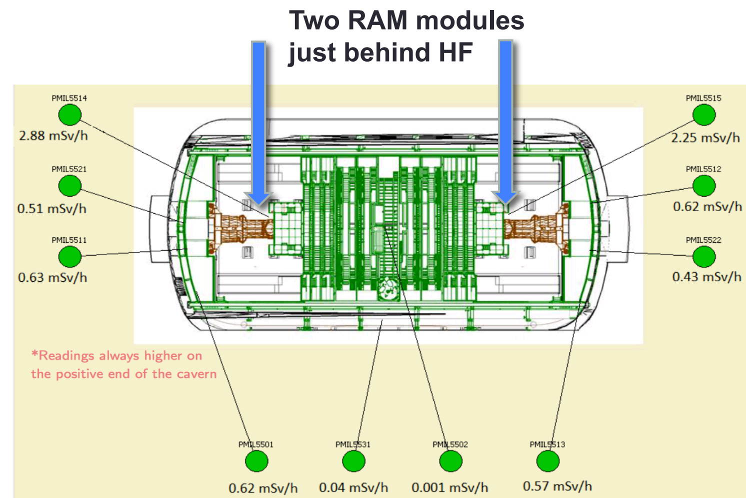


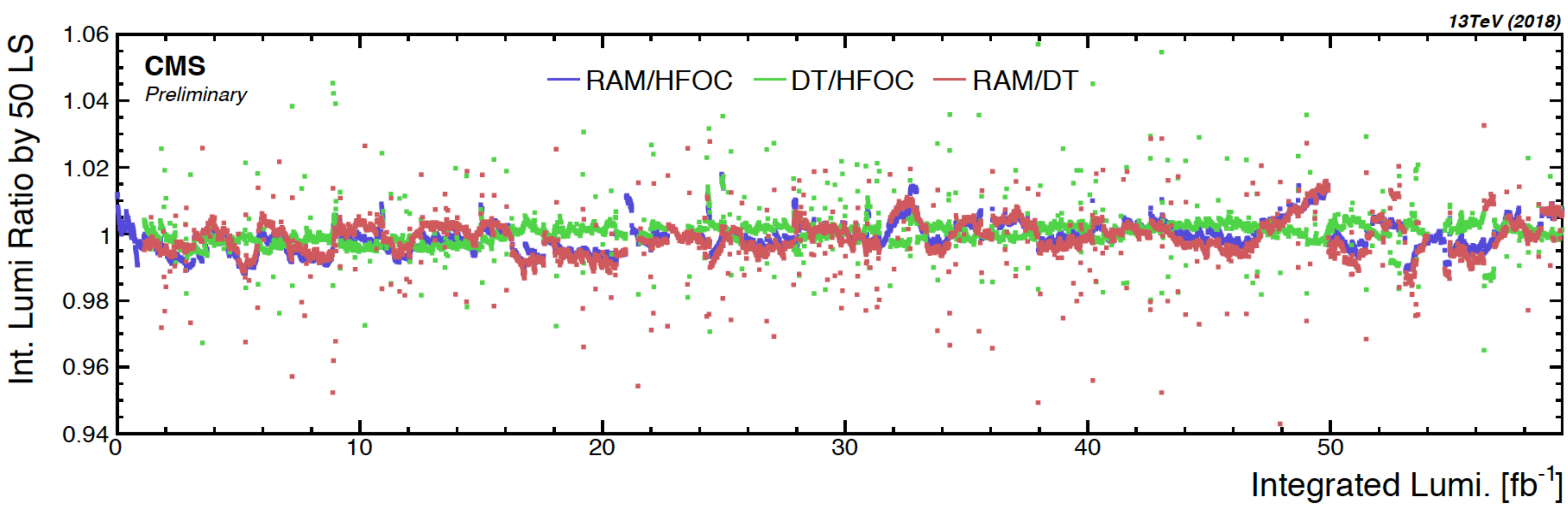
Radiation damage measured from emittance scans is slightly more pronounced than predicted by HCAL ageing model.

RAMSES and DT+RPC for stability

- RAMSES monitors are part of the radiation monitoring system (ionization chambers filled with air at atmospheric pressure).
- DT – drift tubes, CMS muon system.

- RAMSES and DT do not provide per bunch crossing measurement, but they are important complementary measurements for per fill linearity and for stability check over the year.

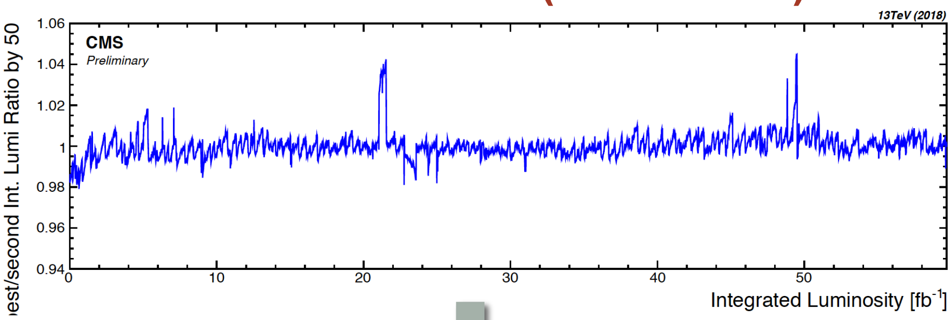


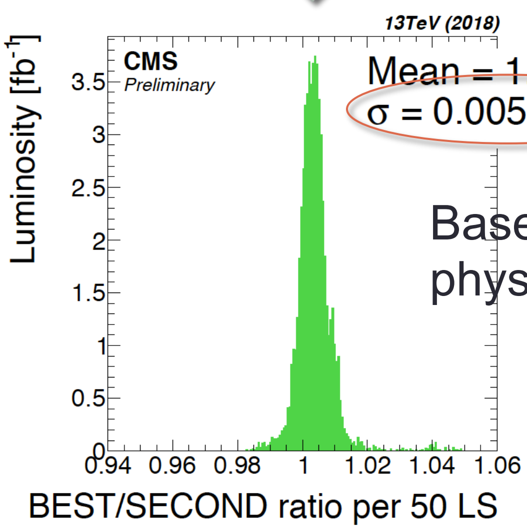


Final luminosity uncertainty due to stability

- The ratio of the best luminometer in the priority list to the second-best luminometer is used to define stability in 2018 (0.6%).
  - after efficiency correction where required!

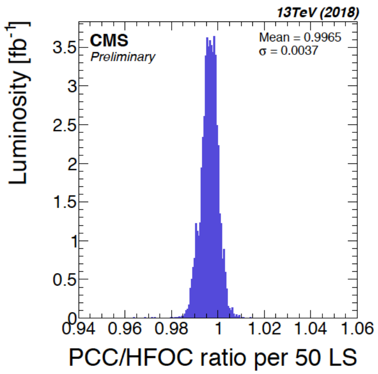
Best / second best (cover 99%)

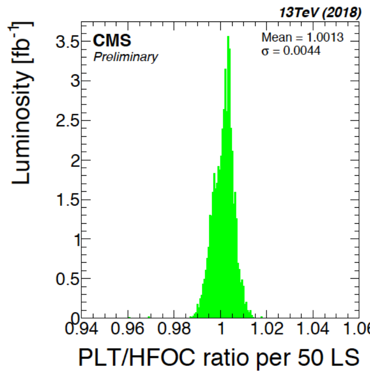


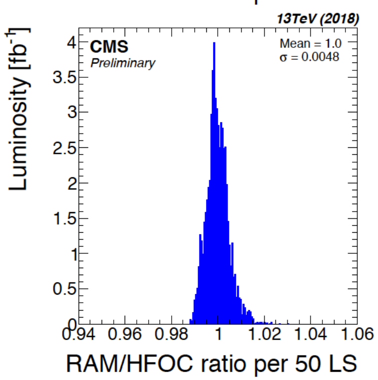


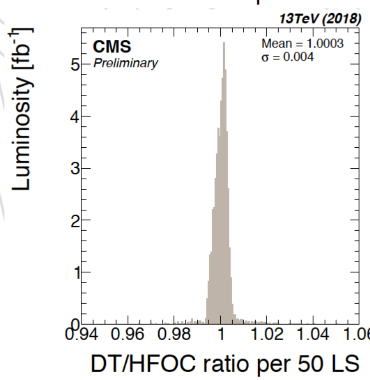
Based on full physics data set.

Similar ratios for all other detector pairs



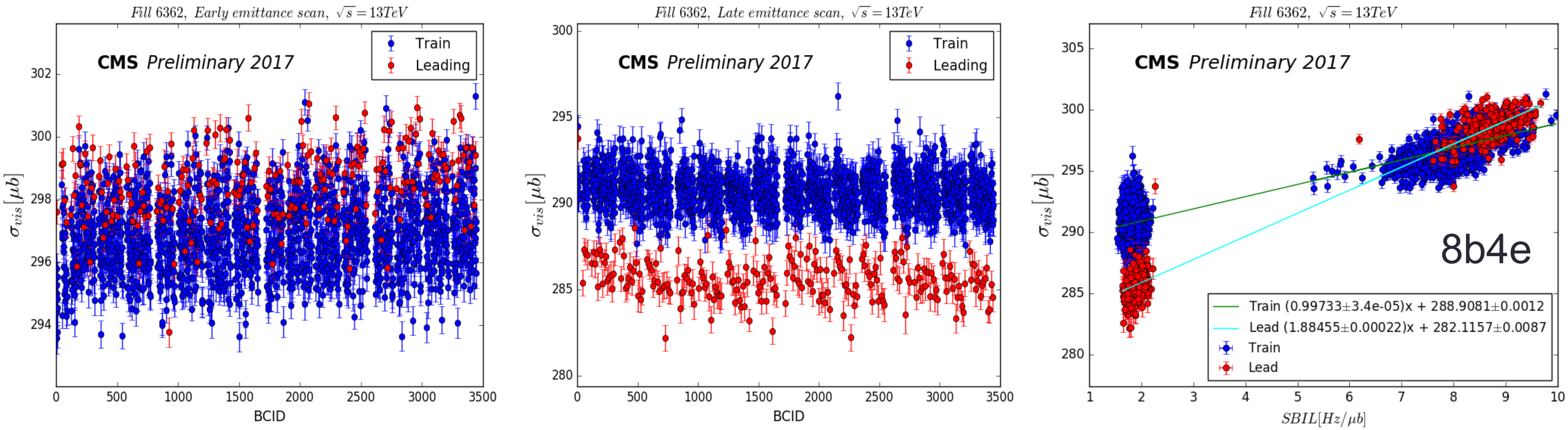






Emittance scans for non-linearity measurement (1/2)

- Wide range of single bunch instantaneous luminosity (SBIL) in physics fills allows for non-linearity measurement.



- Non-linearity correction is extracted:
  - per detector ➔ self-consistent check
  - per fill / per scan ➔ early and late scans can be used separately (next slide)
  - per bunch crossing ➔ leading and train bunches have different evolution of emittance and also show different linearity

Emittance scans for non-linearity measurement (2/2)

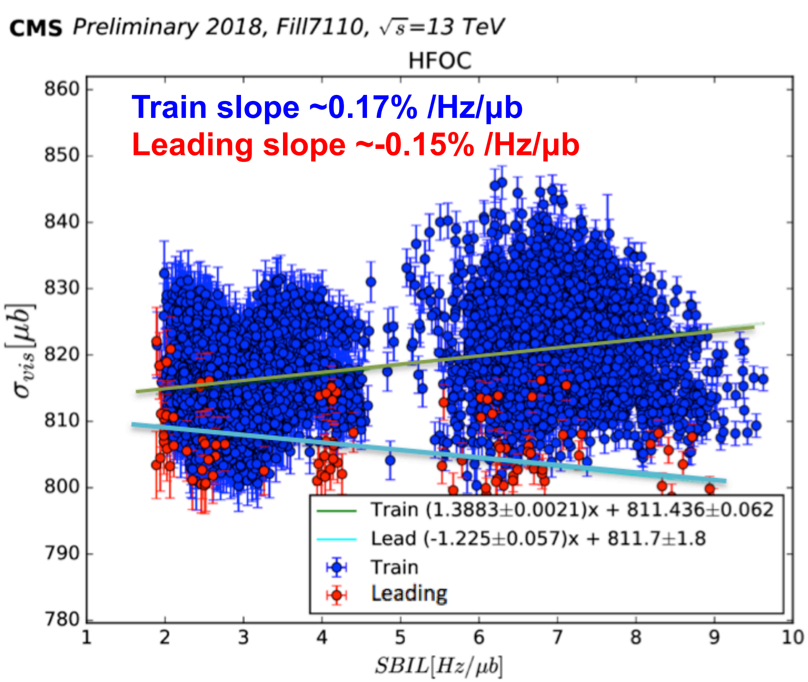
- The linear fit to σ_{vis} vs. SBIL is used for non-linearity correction (quadratic term):

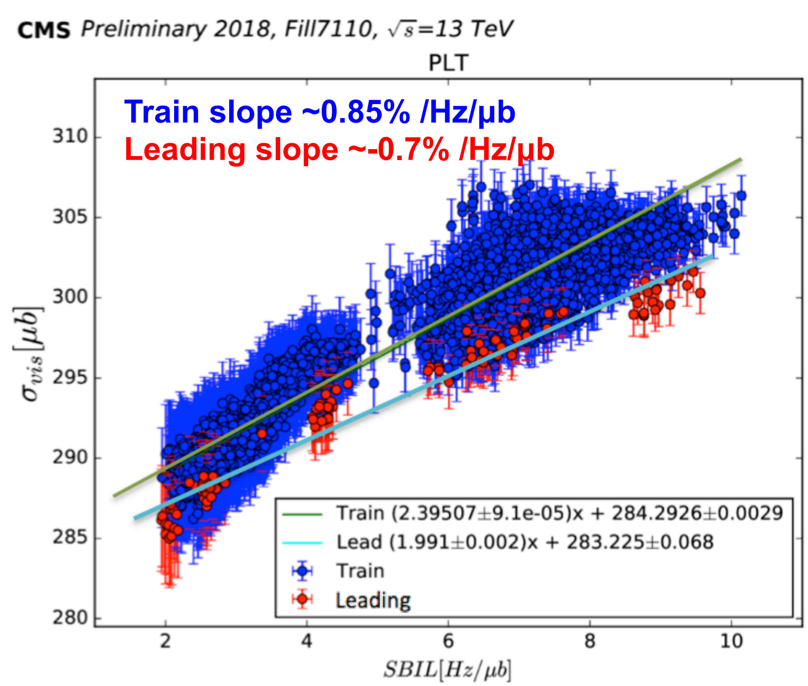
$$L = k\,\mu + s\,k^2\,\mu^2,$$

μ average number of hits per orbit per bunch crossing (equivalent to rate),

k = f_{LHC}/σ_{vis0}, σ_{vis0} – VdM calibration (at SBIL 0), **s** slope per unit of SBIL in $(Hz/\mu m)^{-1}$.

- Dynamic beta correction is not yet applied (effort is ongoing in collaboration with T.Pieloni).

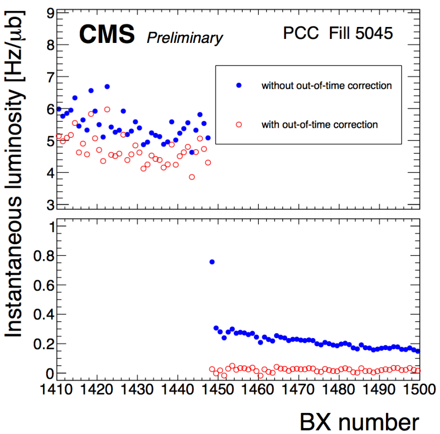




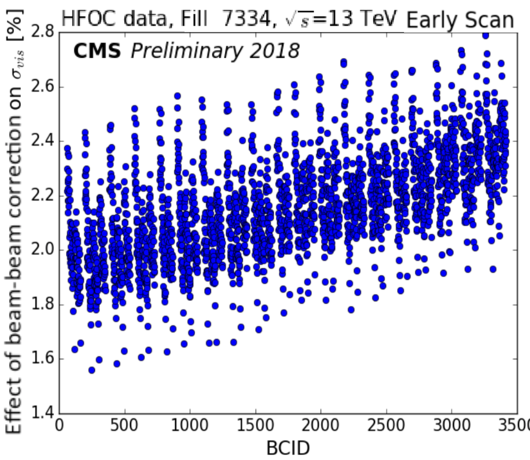
Corrections applied per bunch crossing

- Afterglow correction per bunch crossing:
  - afterglow type1 – fast component and type2 – slow component from material activation.
  - Employed for HF, BCM1F and PCC.
- Single beam-beam deflection correction (function of bunch intensity and bunch width);
- Corrections to bunch current:
  - -1% correction to FBCT current of the fits bunch in the train;
  - FBCT/DCCT normalization in every scan;
- Offset of the in the peak position of bunches in the train due to long range beam-beam interactions ("peak position correction").

Out of time response correction (afterglow)

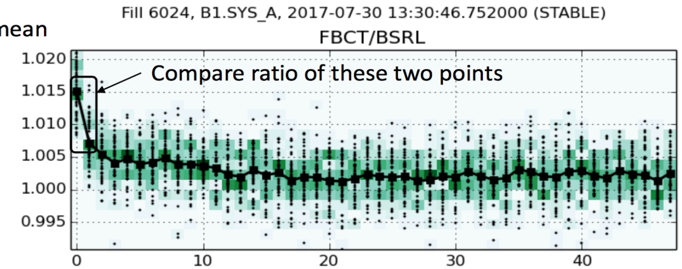


Single beam-beam deflection per BCID



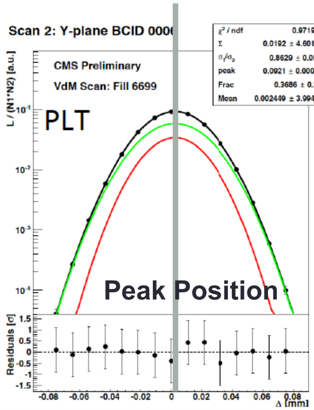
FBCT/BSRL ratio along train (linked talk)

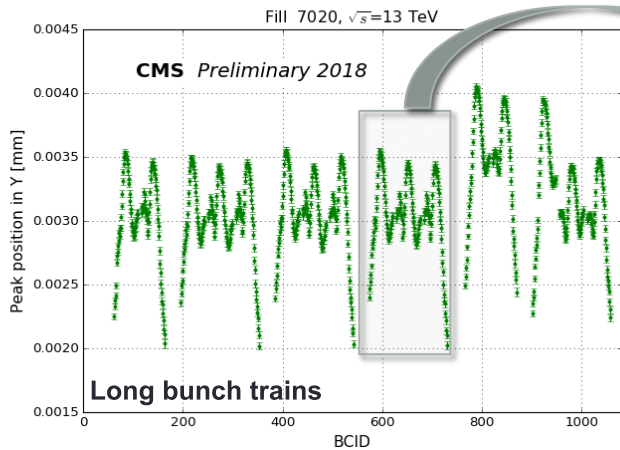
- Black line: mean of all trains
- Black dots: individual bunches
- Colormap: distribution



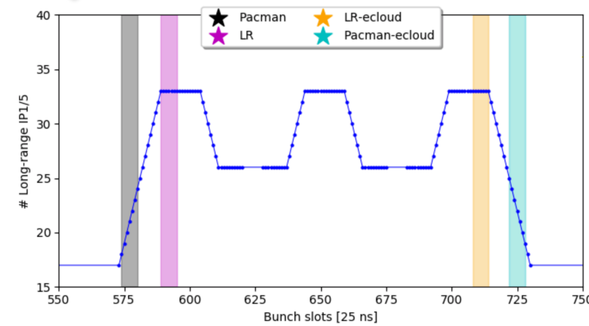
M.Palm (BE-BI-PM)

Correction to the position of the peak

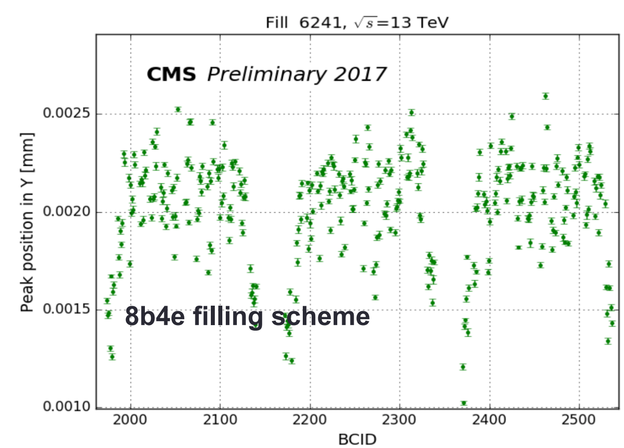




[Bunch classes, Evian2019]



- Offset of the peak varies within the train:
  - Due to crossing angle and long range interactions .
- The correction is derived assuming Gaussian shape of the beam and measured offset of the peak.
  - Limitation: if offset is big and bunches have non-Gaussian shape, estimate of the peak correction is 2-3% wrong.
  - To avoid big offsets before the scan we always need beam optimizations. (Adding it in the automated scan file?)

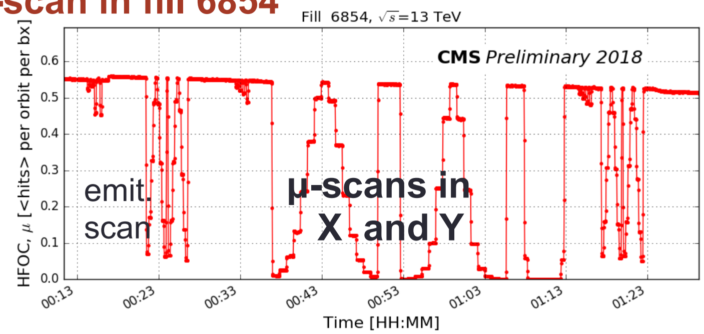


$$Peak_{corrected,X} = Peak_{measured\ at\ 0,X} * (Peak_{centered\ at\ 0,Y} / Peak_{measured,Y})$$

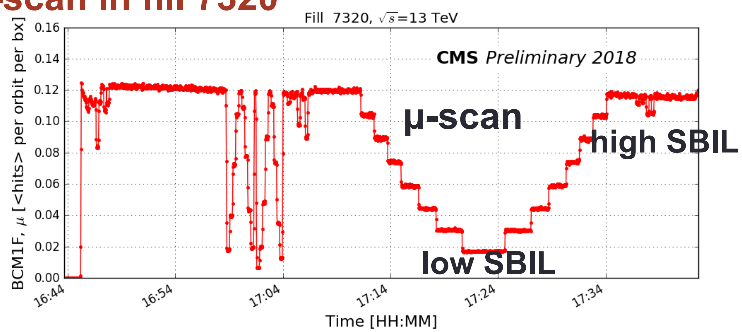
μ-scans for cross-detector linearity comparison

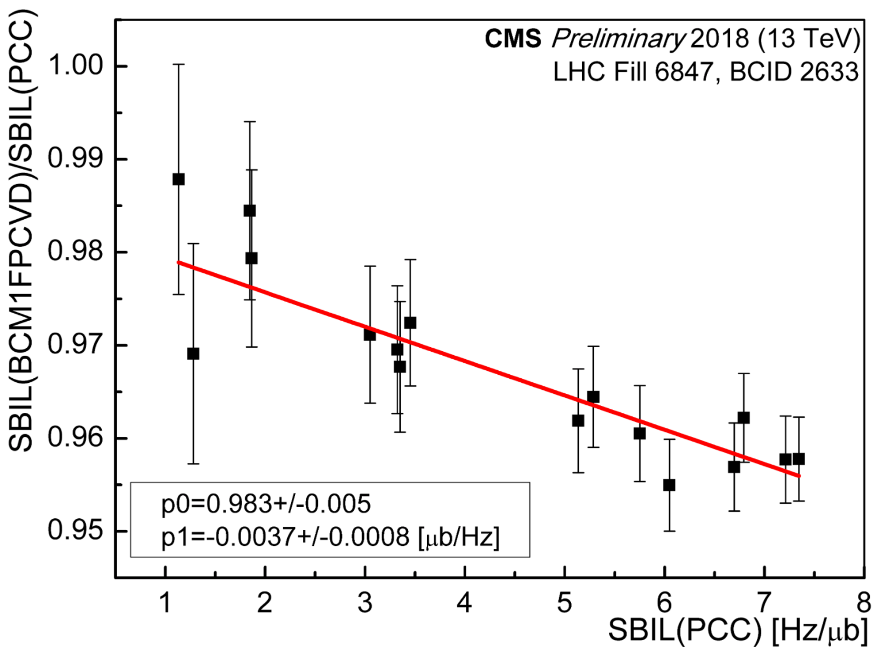
- μ-scans are similar to emittance scans, however with equal steps in SBIL and longer step duration for better statistics.
- Ratio of measured by two independent detectors luminosity (SBIL) in every step of **μ-scan** is the measure of cross-detector linearity. Additional cross check for emittance scans method.

μ-scan in fill 6854



μ-scan in fill 7320





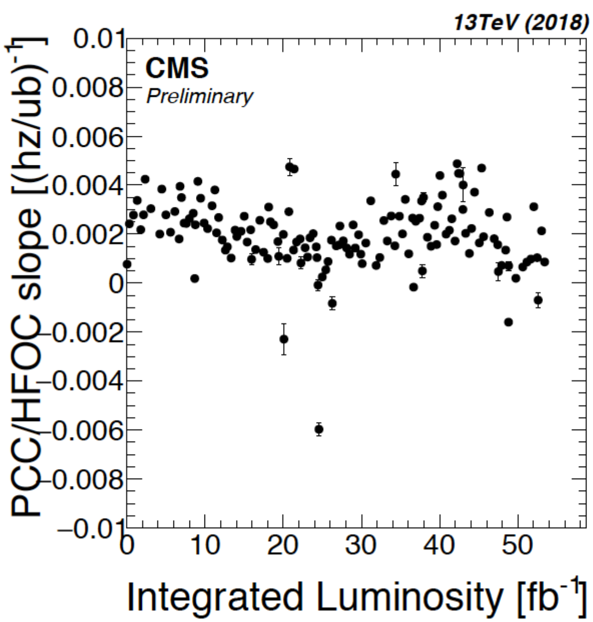
It does not matter what is the size of the non-linearity, if it can be measured precisely and be corrected for!

Final luminosity uncertainty due to non-linearity

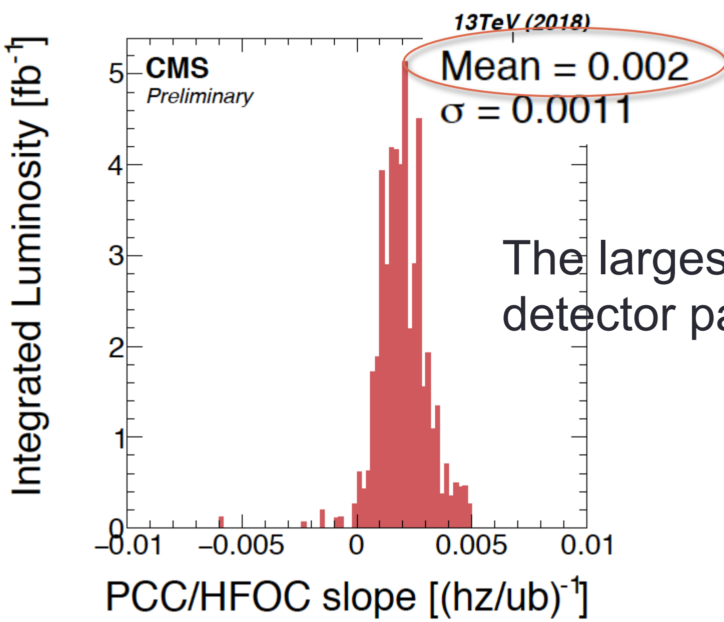
- “End of year comparison” ➔ residual slope per fill:
  - to measure residual non-linearity (after non-linearity correction)
  - the linear fit to the ratio of measured luminosity vs. SBIL (for each detectors pair)

- The largest residual non-linearity among all detector pairs is propagated to the whole year luminosity to estimate effect on the integrated luminosity (e.g. 0.2% $(Hz/\mu m)^{-1}$ slope in the ratio leads to 1% non-linearity uncertainty).

residual slope per fill



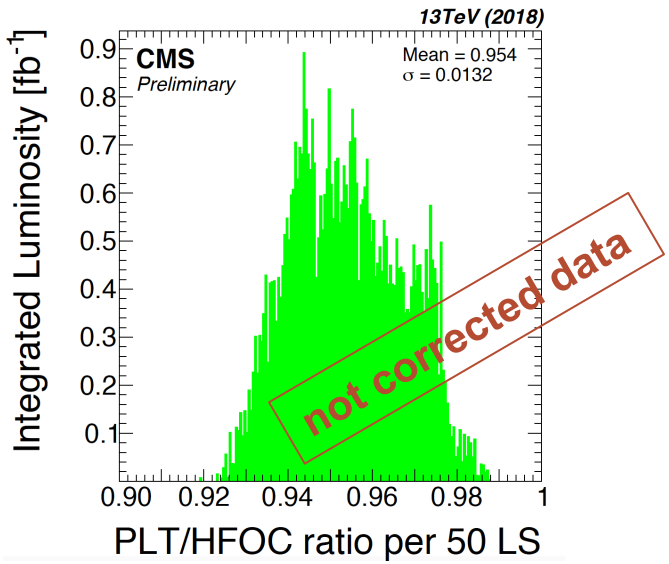
residual slope per fill, weighted with integrated luminosity



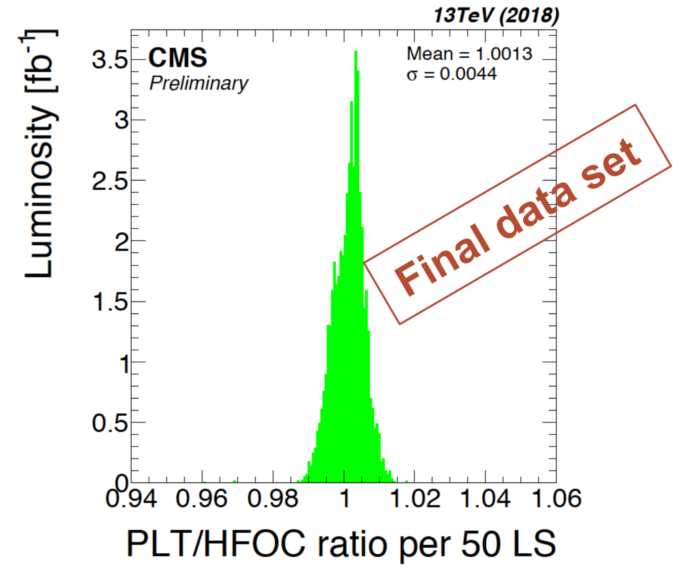
The largest across all detector pairs in 2018.

Conclusions

Starting point



End point



- Poorly behaved channels excluded
- Per-cannel weighted data
- Efficiency correction
- Linearity correction

Current values (based on the CMS PAS LUM-17-004 and LUM-18-002):
2017 uncertainty due to stability 0.5%, due to residual non-linearity 1.5%
2018 uncertainty due to stability 0.6%, due to residual non-linearity 1.1%

Work is ongoing to finalize 2017-2018 measurement using improved in 2018 analyses technique.