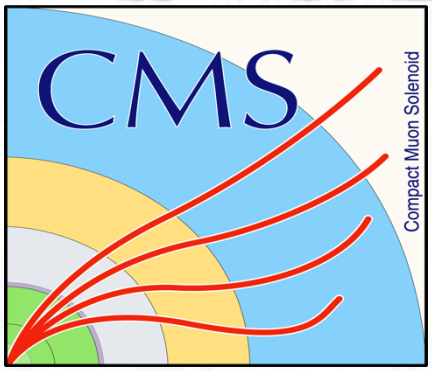
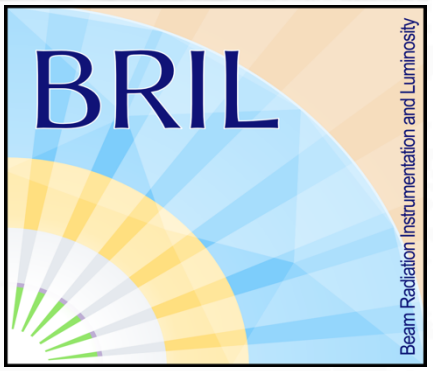




Luminosity measurement at CMS.

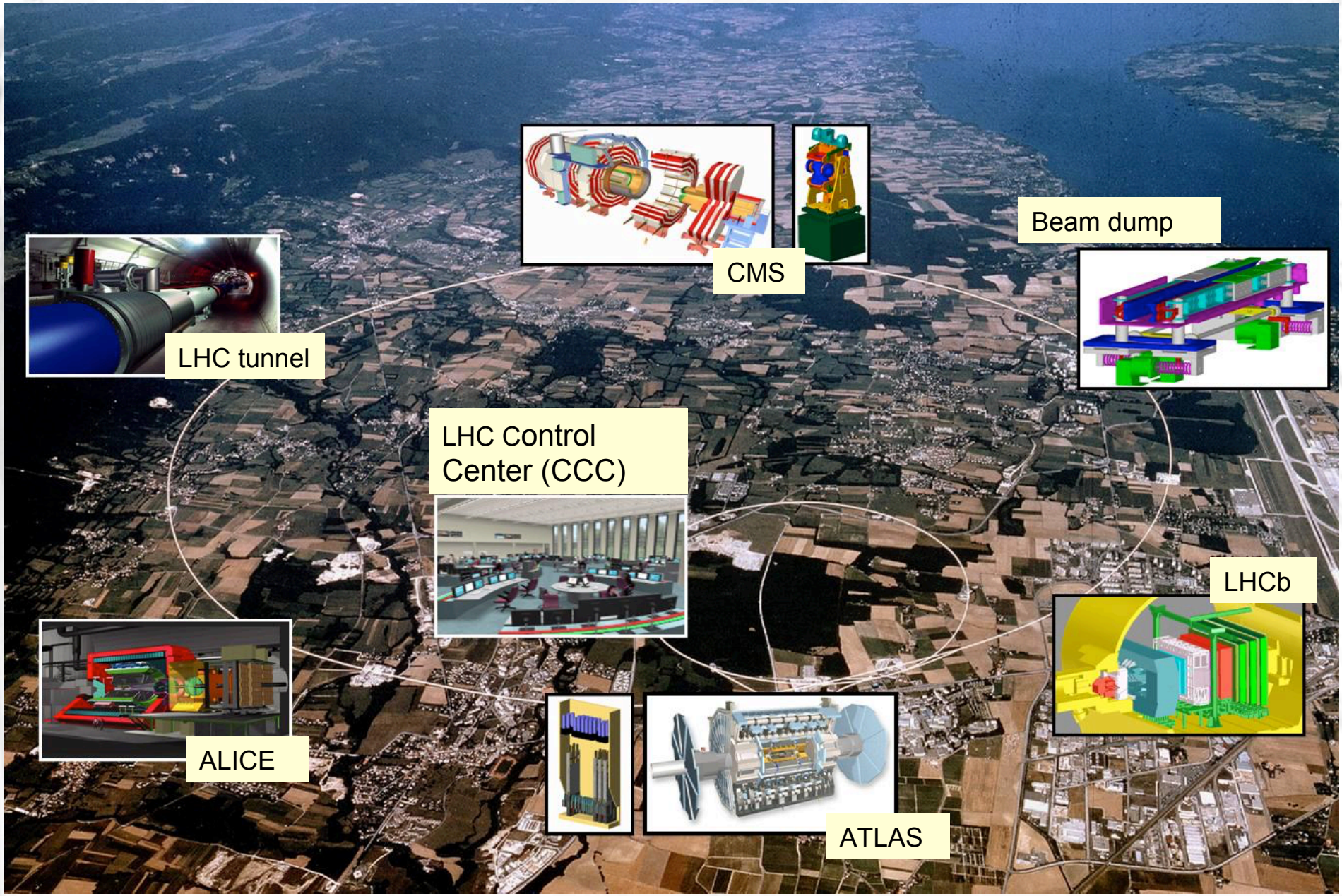
Olena Karacheban on behalf of BRIL

11 April 2019, Geneva, CERN

Outline

- LHC and the CMS experiment.
- BRIL project and online luminosity and background measurements.
- Tests and installation of BCM1F detector and first beam in the LHC Run 2.
- Van der Meer scans programs:
  - Absolute calibration;
  - Corrections;
  - Stability and special emittance scans.

LHC — proton-proton collider, $\sqrt{s}$ = 14 TeV



LHC Run 2, 2015-2018

- Energy per beam:

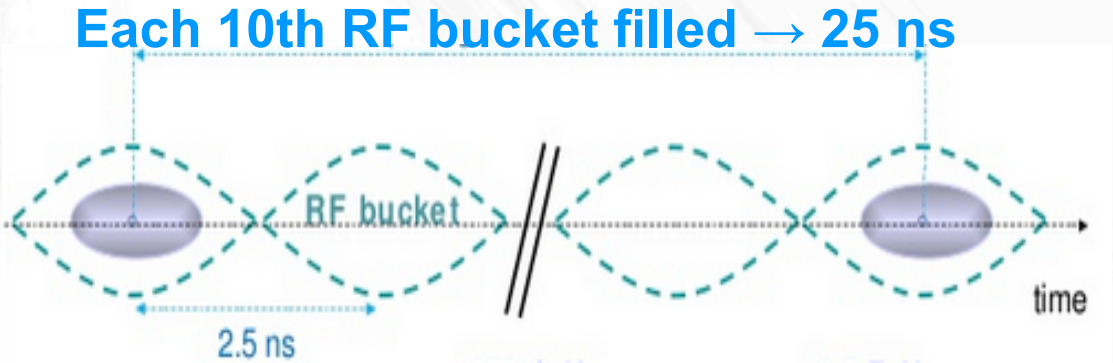
6.5 - 7 TeV

- The beam:

3564 proton bunches

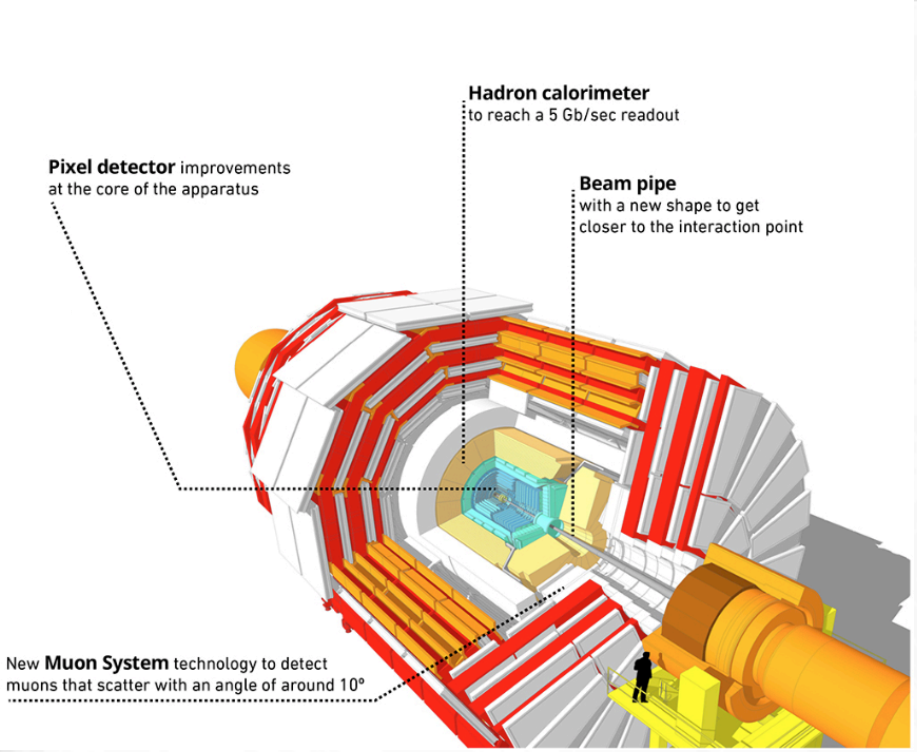
10^{11} protons per bunch

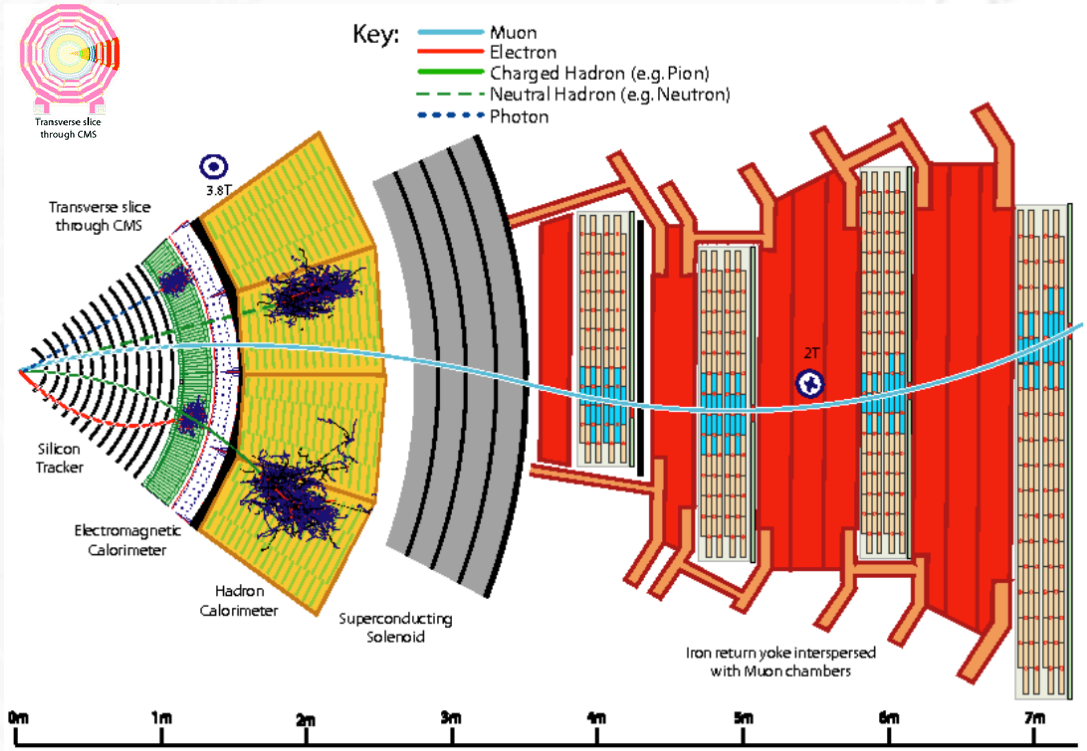
- **Bunch spacing 25/50 ns**
- Beam width: ~20 um

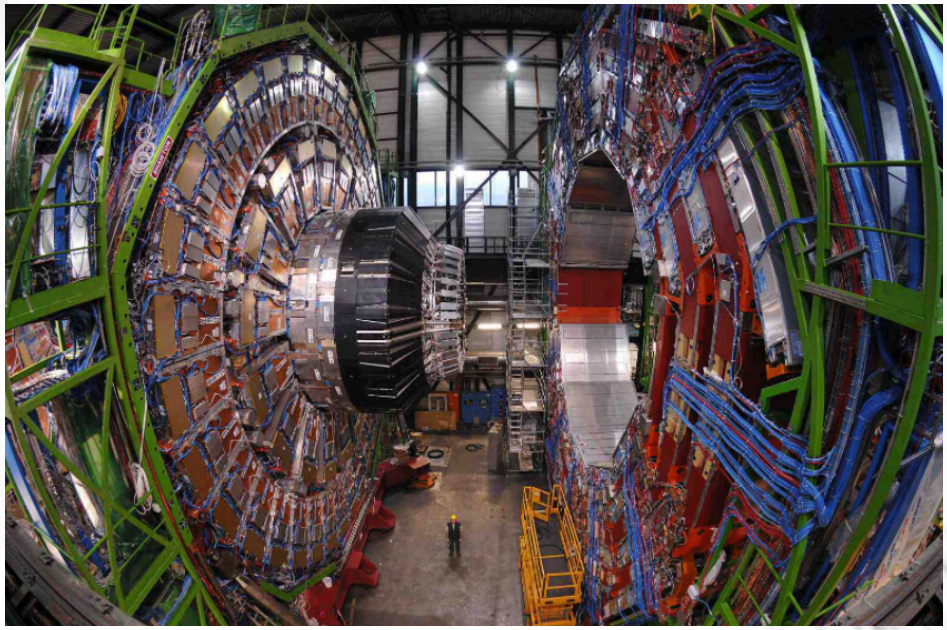


Our goal bunch by bunch Luminosity and background measurements!

CMS detector







Rates → Luminosity

- **Luminosity (*L*)** is a key quantity of any collider, which allows for the determination of the absolute cross section (the cross section,σ) from the observed rate in a detector (the rate,R):

$$R = \sigma L$$

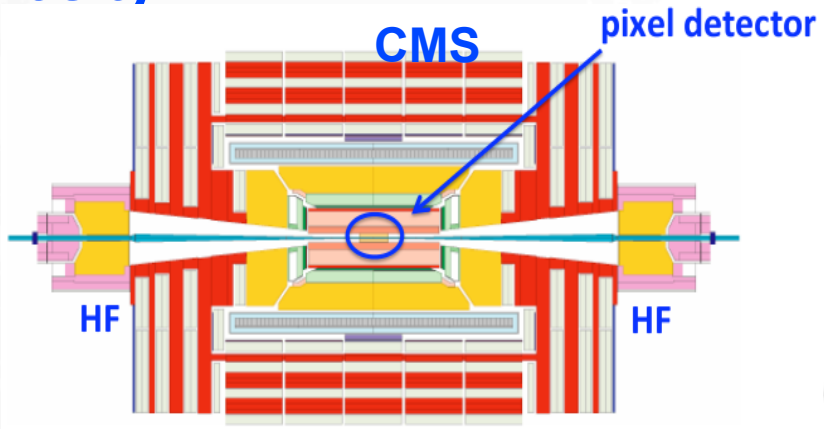
- **Luminosity is needed to monitor the accelerator performance.**
- **The uncertainty of the cross section measurement cannot be better than the uncertainty of the luminosity measurement.**

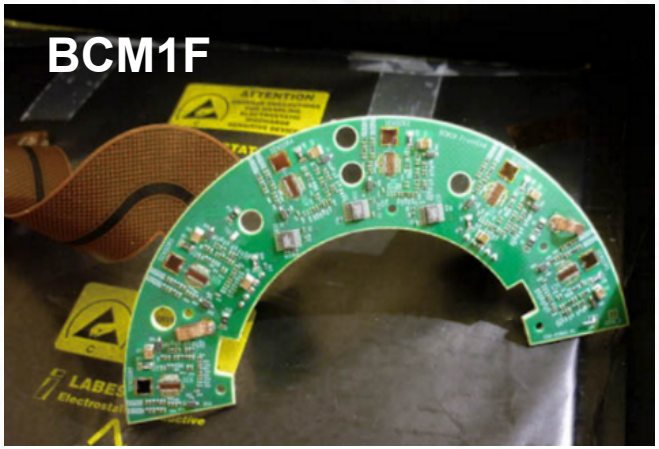
- **Luminosity measurement at the LHC requires collaborative work of all experiments and of the machine!**
- For the information exchange and development of shared methods and tools in the LHC special group is created:

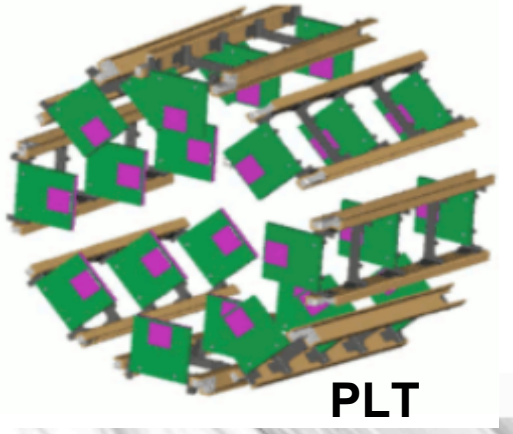
Luminometers of the CMS experiment

- **Any detector, which can provide particles hit rates can be used as a luminometer.**
- **A luminometer with a linear response produces a signal that is proportional to the instantaneous luminosity.**
- In the CMS following Luminometers are used:

  - Pixel Detector
  - Forward calorimeter (HF)
  - Fast Beam Conditions Monitor (BCM1F)
  - Pixel Luminosity Telescope (PLT)

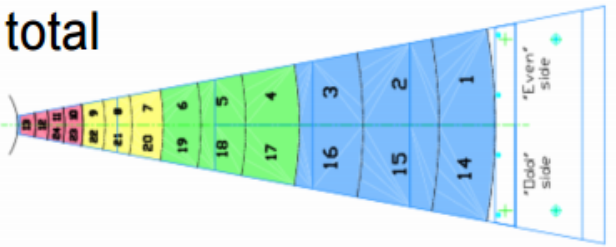






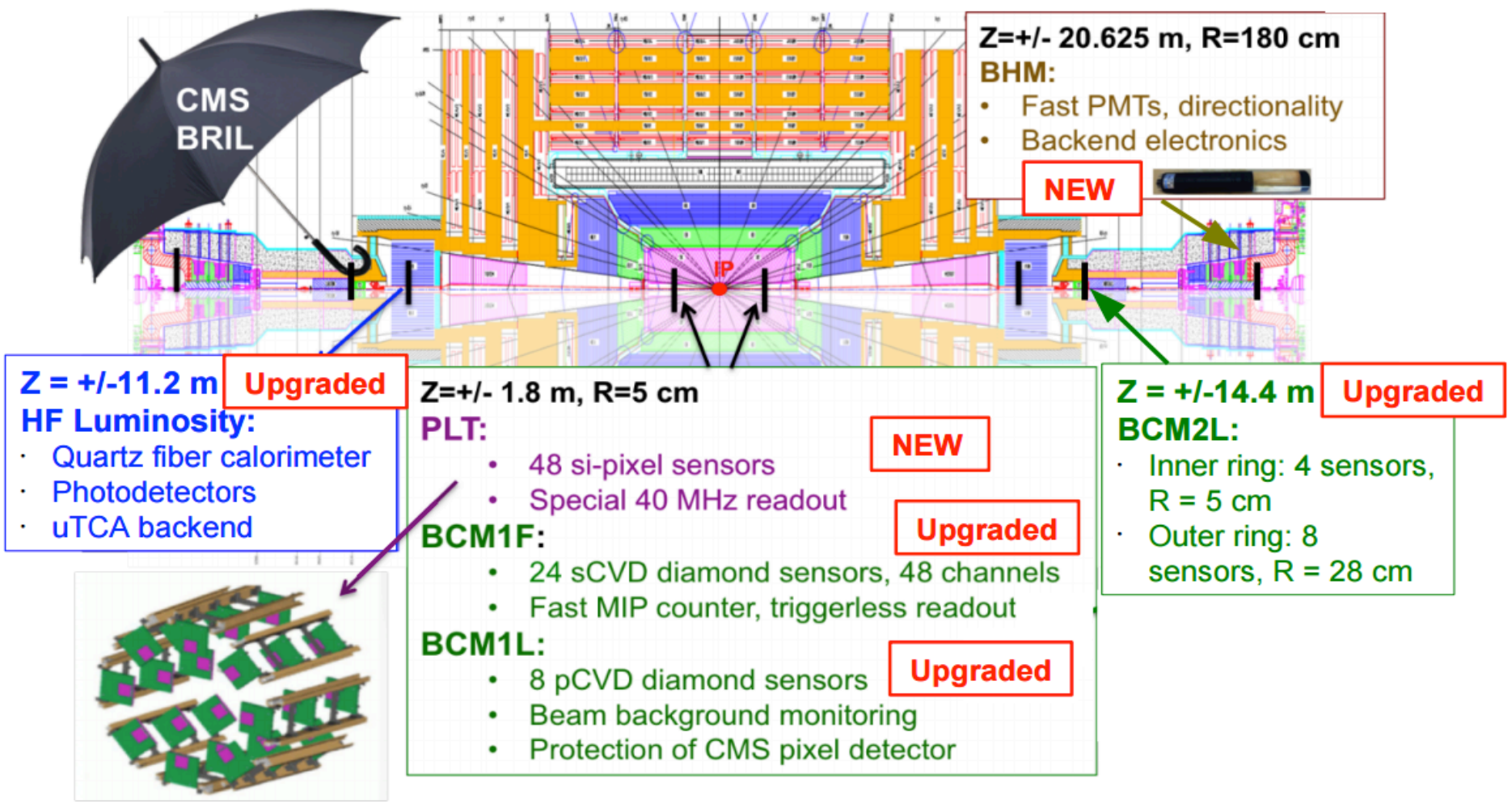
HF wedge

36 wedges in total



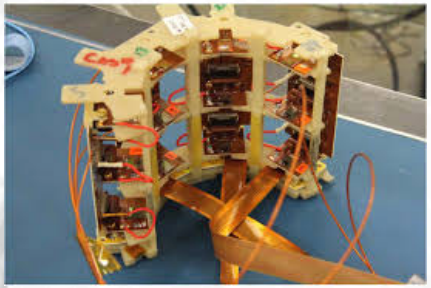
How do they all work together? - In a BRIL group!

Beam Radiation Instrumentation and Luminosity (BRIL)



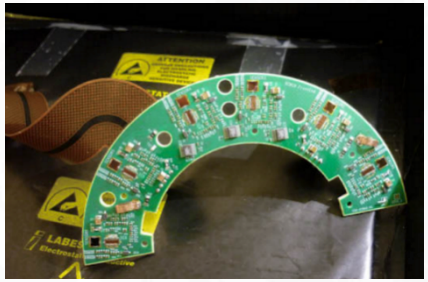
The subsystems of BRIL provide independent online Luminosity and Machine induced background measurements. BCML2 is included in the beam abort system to ensure safe operation of the pixel detector.

Unique inner carriage



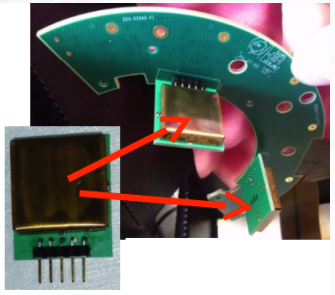
4 PLT telescopes on titanium alloy SLM cassette

+



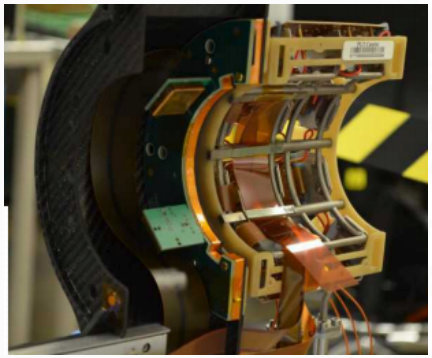
6 BCM1F sensors and dedicated ASICs mounted on PCB

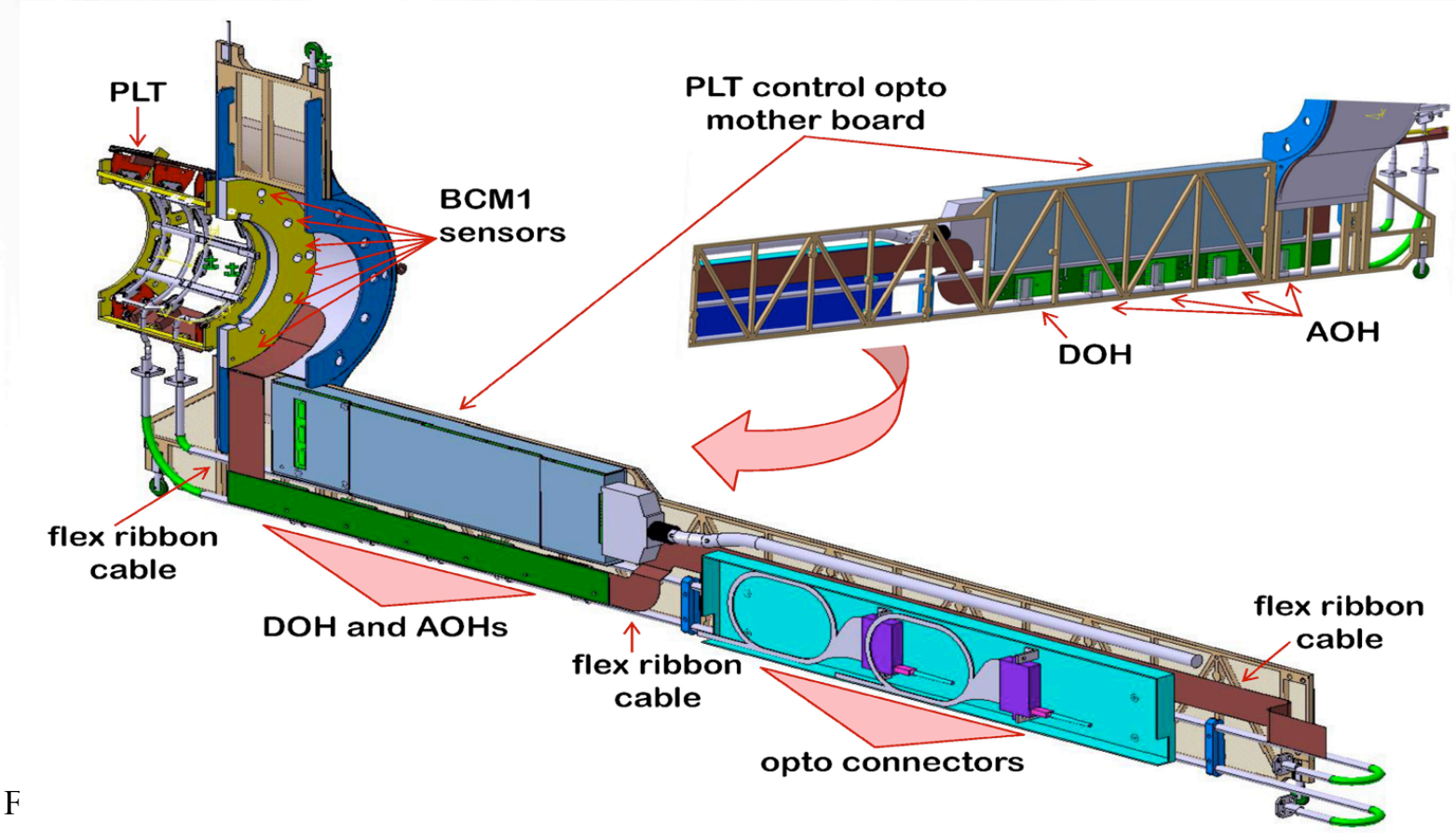
+



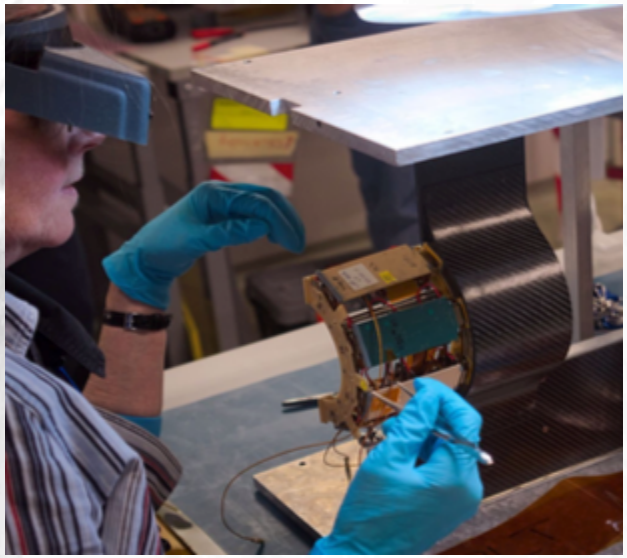
BCM1L traces soldered onto PCB (C-shape)

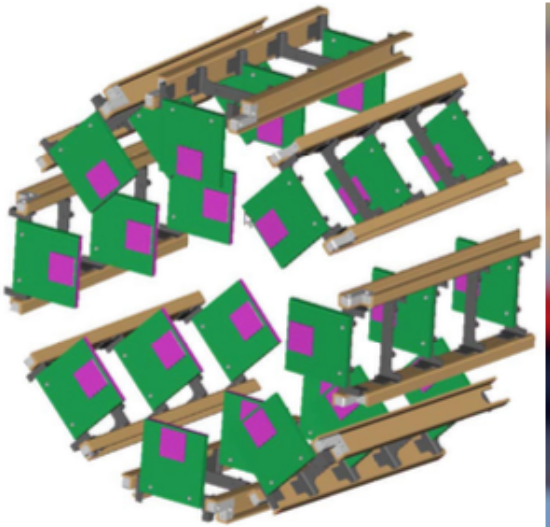
=

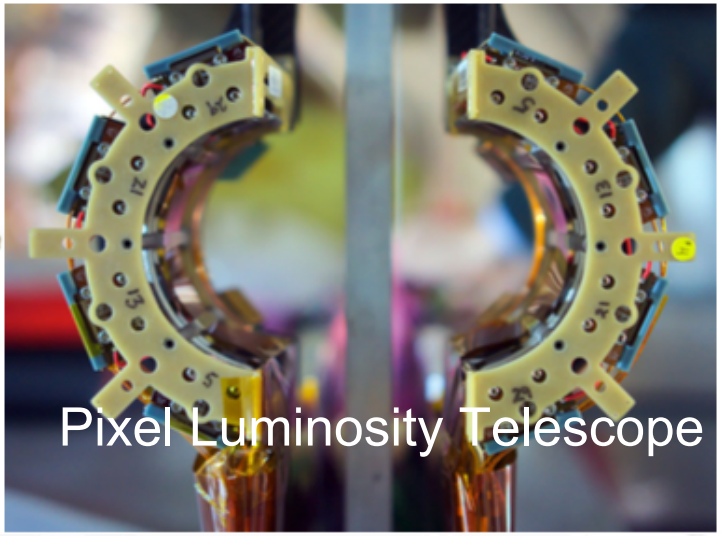


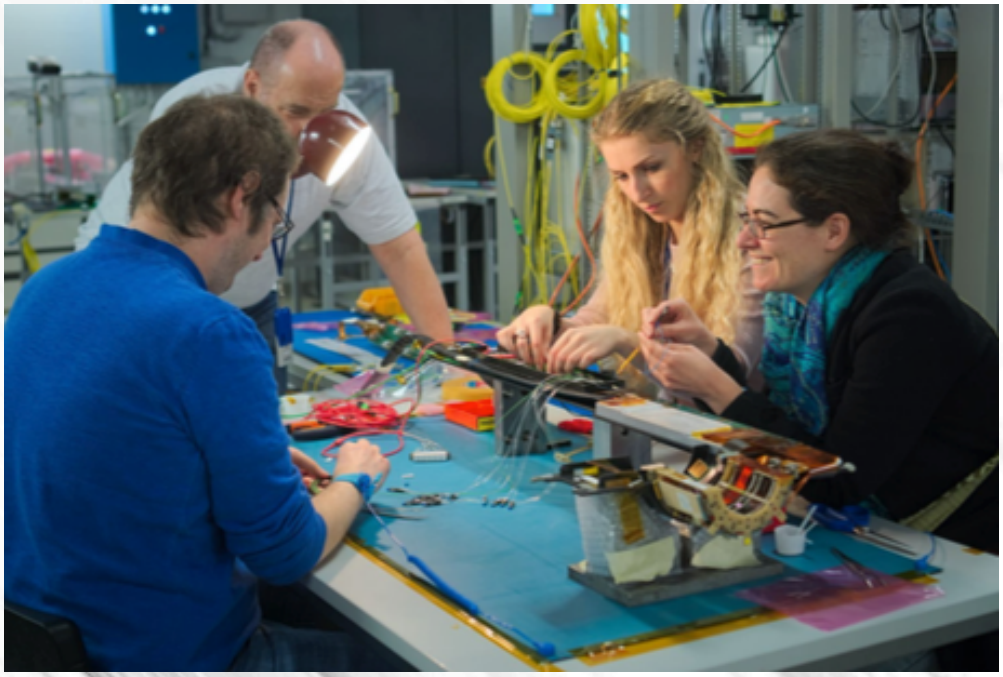


Detector assembly and tests in the laboratory





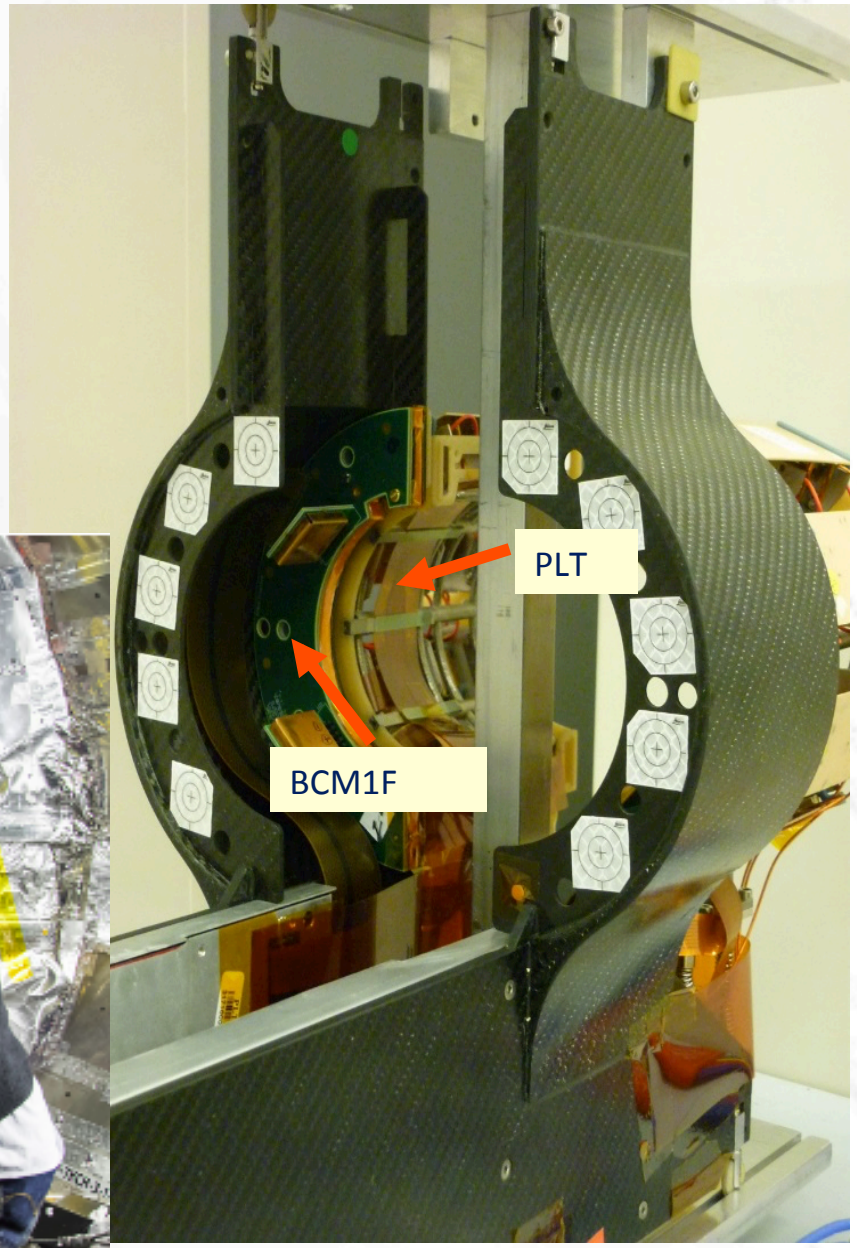




Happy BRIL team before installation 2015

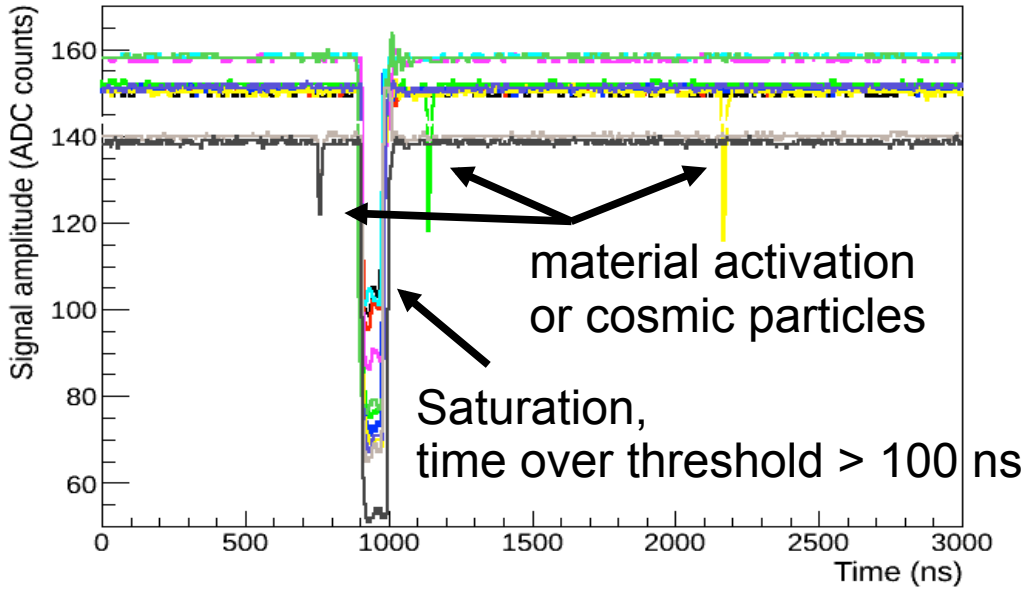
Before installation #2 (2017)

Installation 2015



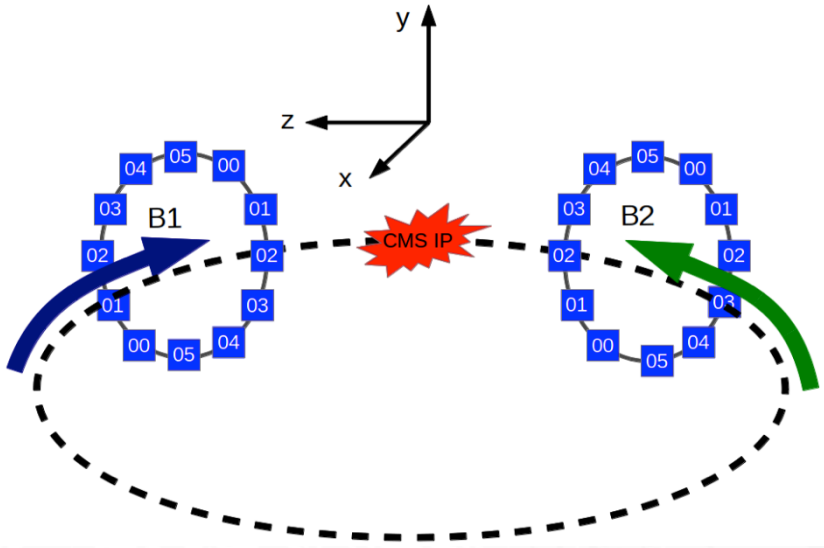
Easter present 2015: beam splashes at LHC!

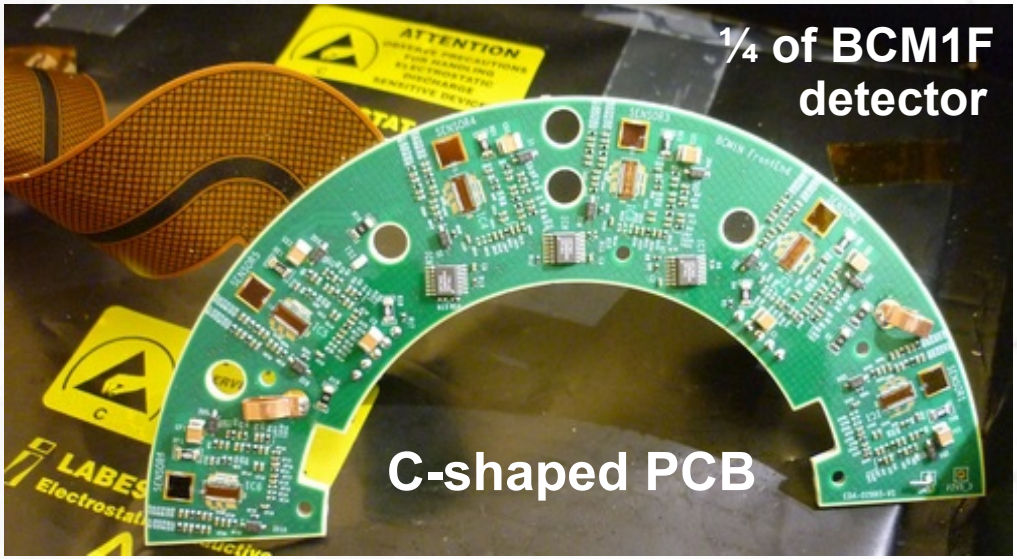
CMS *Preliminary* *Beam Splash 2015, 450 GeV*



- Splash event: a single bunch is dumped in a collimator just upstream of the experiment.
- Since many particles cross the sensor simultaneously the signal amplitude saturates.
- First data recorded by the VME ADCs: the response of diamond sensors in splash events.

Fast Beam Condition Monitor (BCM1F)





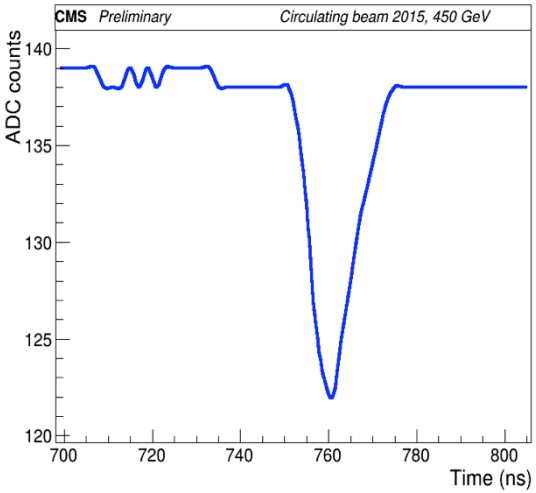
- 2 C-shaped PCB from both ends of CMS, 1.8 m from interaction point;
- 2015:

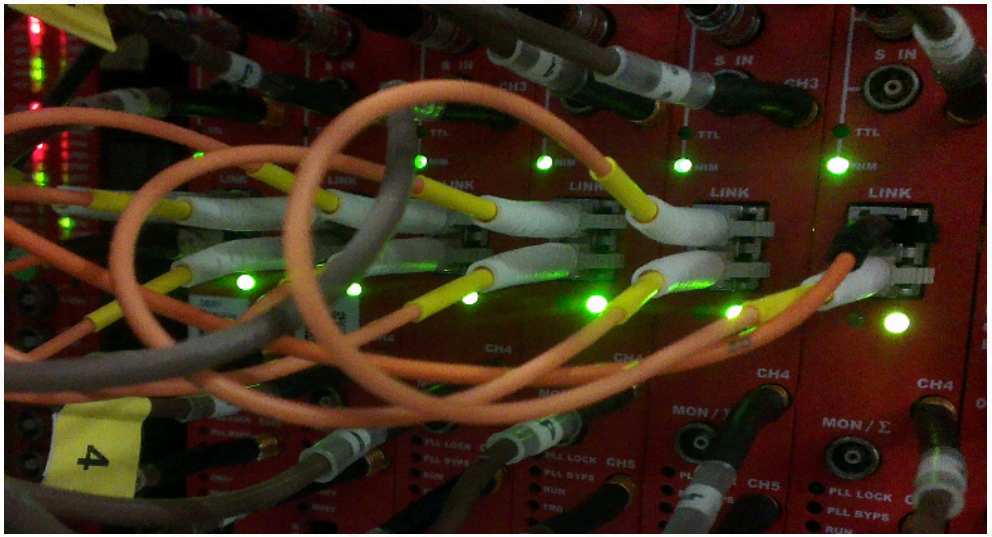
  6 diamond sensors with 2 pad metallization per C-shape — 12 channels per C-shape, 48 total;
- 2017 upgrade:

  1 single crystal diamond, 3 poly-crystal diamonds and 1 silicon sensor per C-shape

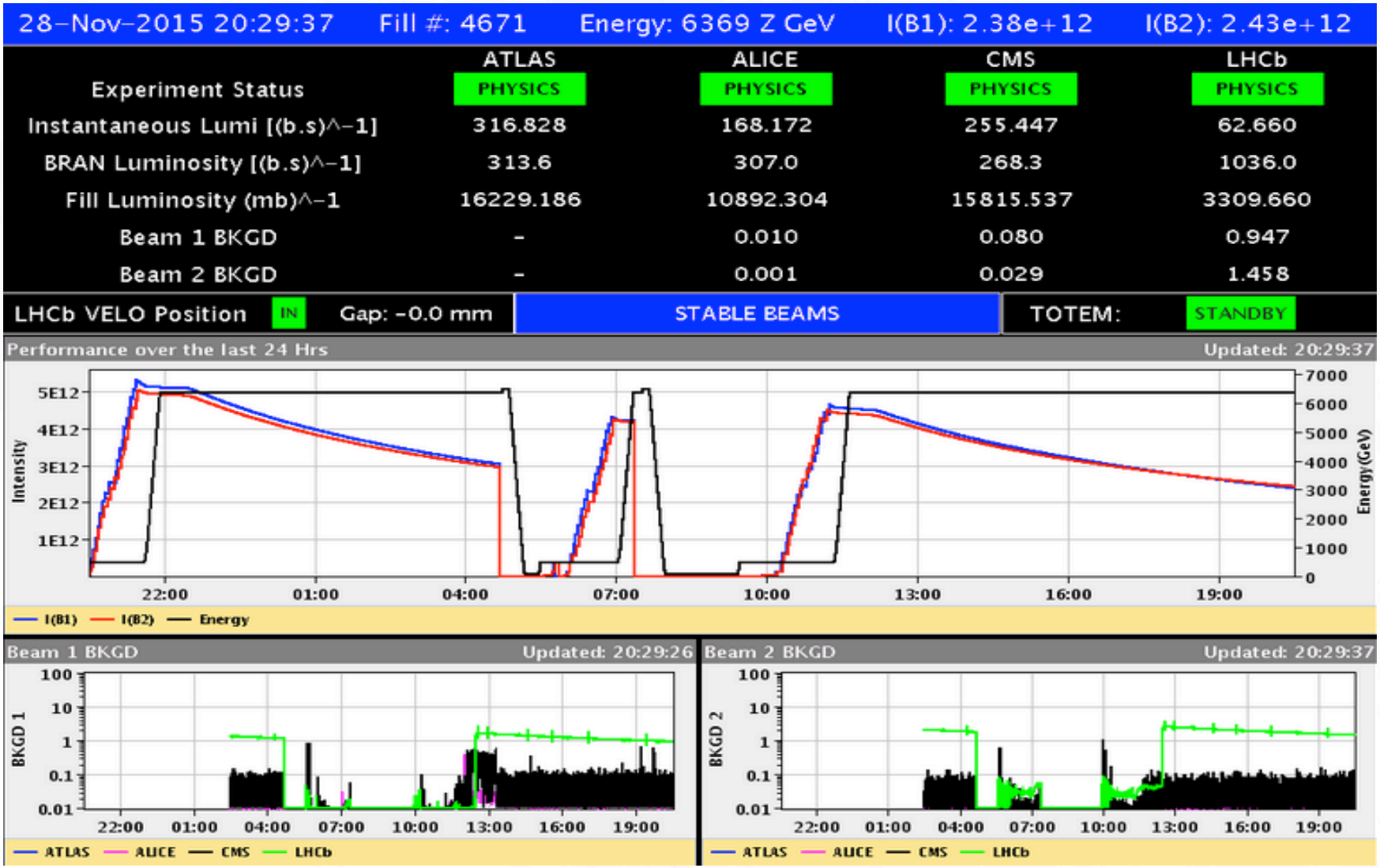
Part of the back-end: VME ADCs

- 48 channels of BCM1F are served by CAEN v1721 ADCs:
  - 8 channels 8 bit 500 MS/s Digitizer (2 ns sampling time);
- 6 ADC boards are daisy chained and read out via optical link with transfer rate up to 80MB/s.
- Whole LHC orbit (89 μs) is buffered for each channel:
  - Clock: internal;
  - Trigger for readout: external - LHC orbit clock.

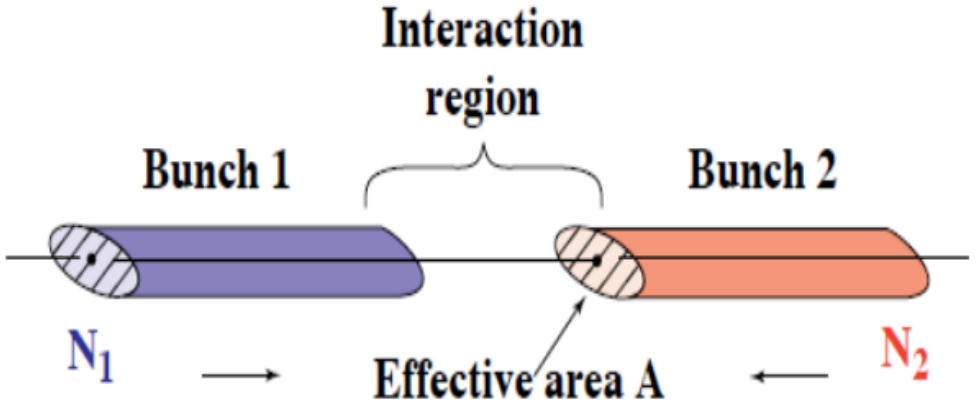


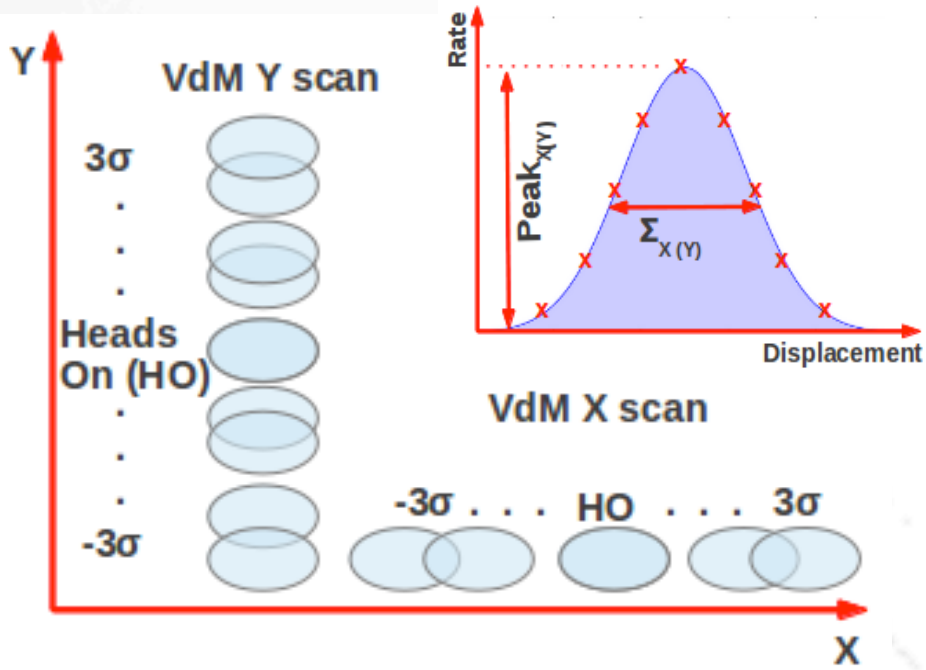


ONLINE Luminosity and Background measurements



Calibration of the luminometers



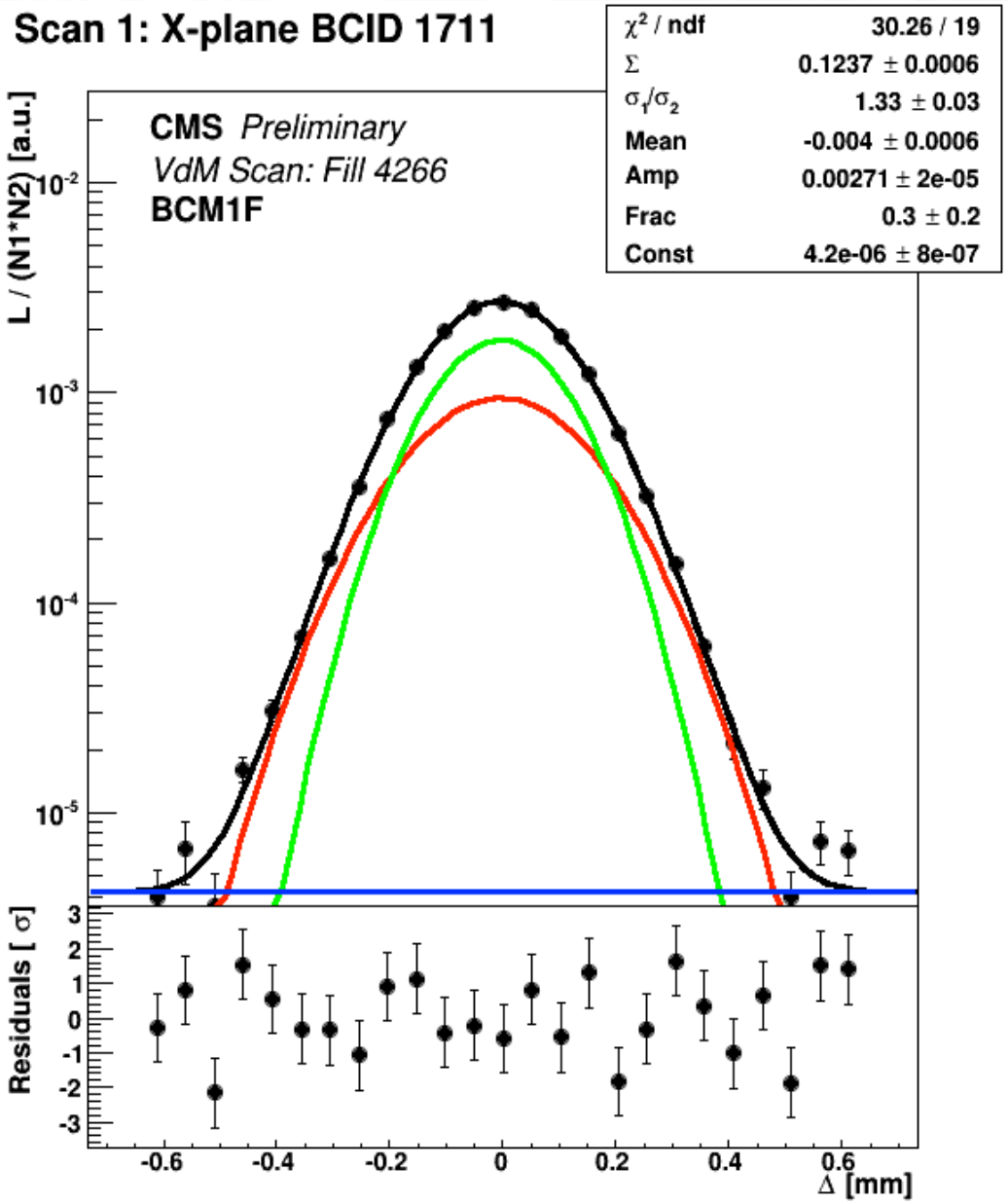


$$L = N_1 N_2 f n_b / A_{eff},$$

where N_1, N_2 - number of protons in beams 1 and 2, f - LHC orbit frequency, n_b - number of colliding bunches, A_{eff} - effective area.

- ***Van der Meer scan method*** proposed by Simon van der Meer: determine A_{eff} by measuring rates as a function of the beams displacement. Scans obtained in X and Y planes separately.

Visible cross section measurement



- Analysis framework is used to fit beam overlap and calculate visible cross section - the effective cross-section seen by the luminometer:

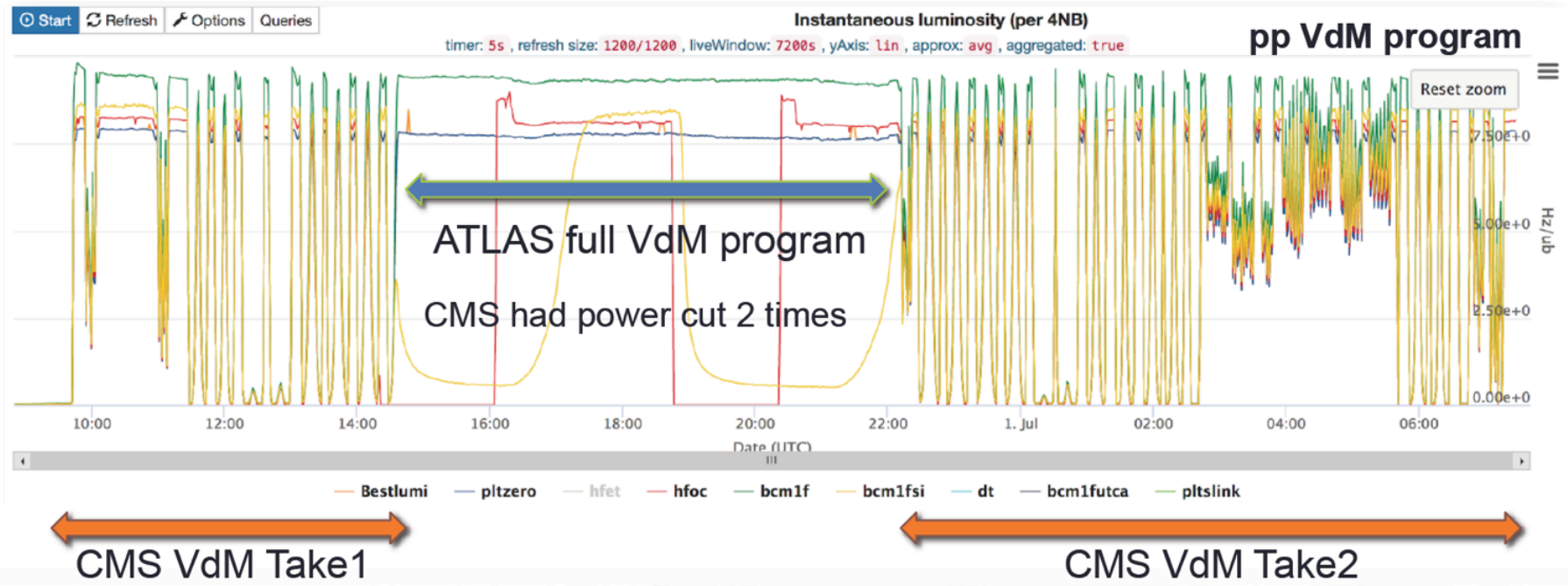
$$A_{eff} = 2\pi \Sigma_1 \Sigma_2,$$

$$\sigma_{vis} = \frac{2\pi \Sigma_X \Sigma_Y}{N_1 N_2 f n_b} \left(\frac{Peak_X + Peak_Y}{2} \right).$$

- The distribution is fitted with a Double Gaussian + Constant fit
- σ_{vis} is the important quantity, since it is used than for the data taking fills as the cross section from which the actual luminosity is measured.

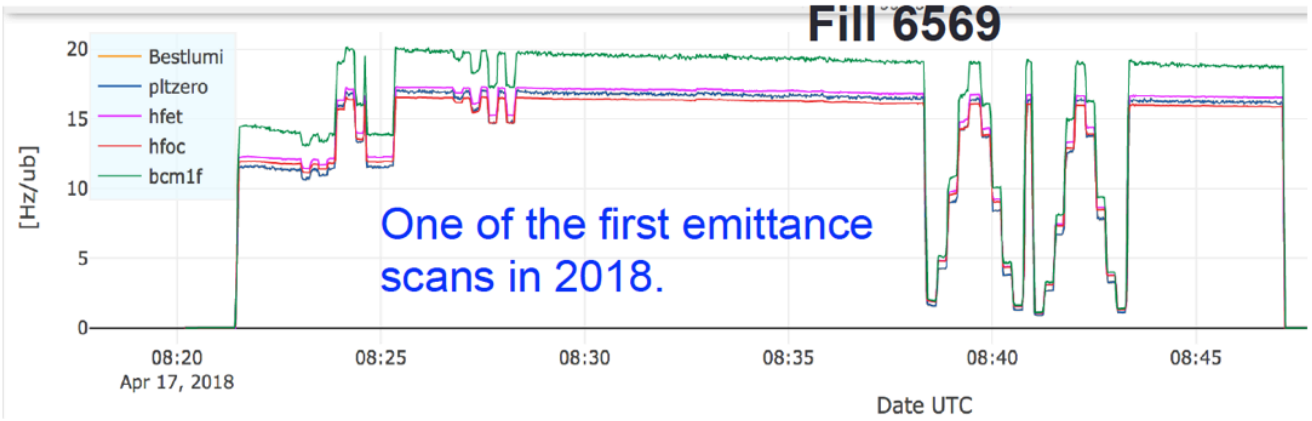
Example of the Van der Meer scans program

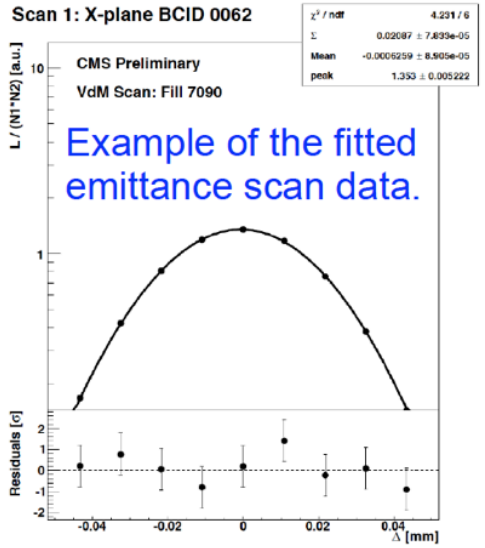
- **Very complete pp VdM program, Fill 6868, July 2018:**
  - 7 pairs of VdM scans (3 pairs are Imaging scans with one beam fixed), 2 offset scans, 5 emittance scans;
  - length scale calibration with fixed and alternating separation;
  - 2 super separation measurements of background.



Special emittance scans for performance monitoring

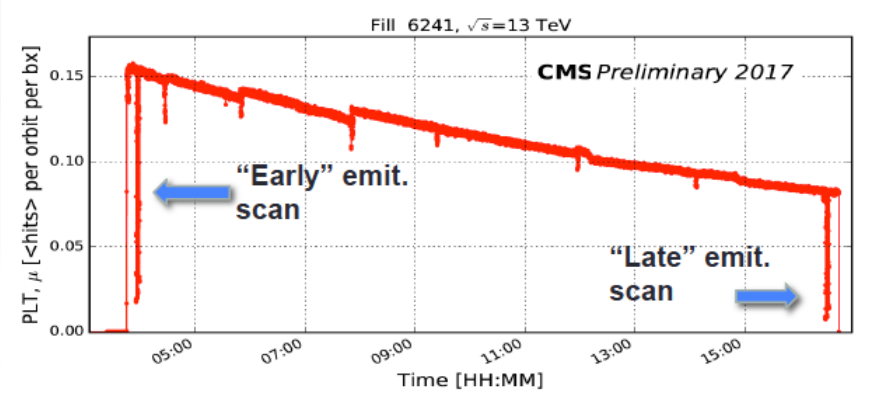
- From 2017 CMS is using emittance scans – mini Van der Meer scans performed in 9 steps of beam separation.
- In 2017 it was demonstrated that emittance scans are powerful tools to monitor the detector performance.
- In 2018 from the first days with beams in the LHC emittance scans were used to cross check performance of the luminometers and correct calibrations for online purposes.
- Excellent online web-monitors allowed to display updating in real time luminosity in control room and accessible remotely.

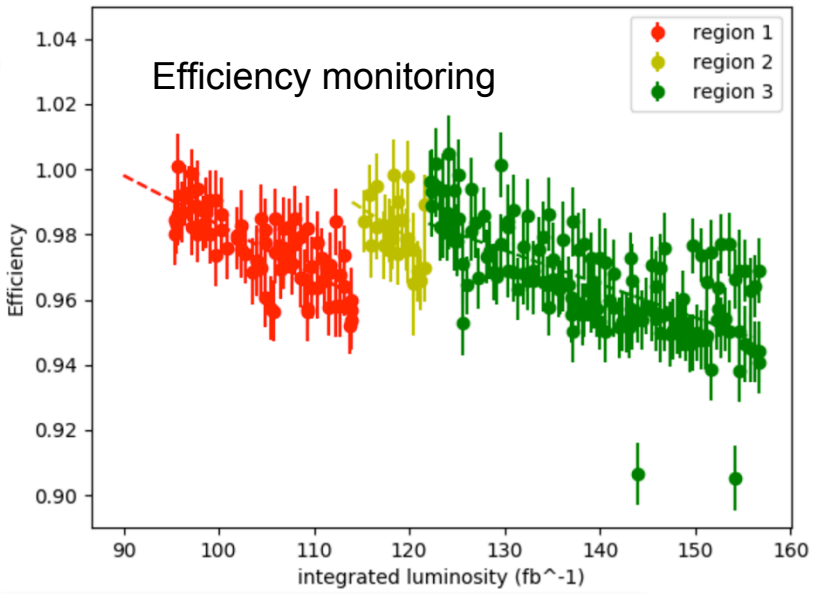


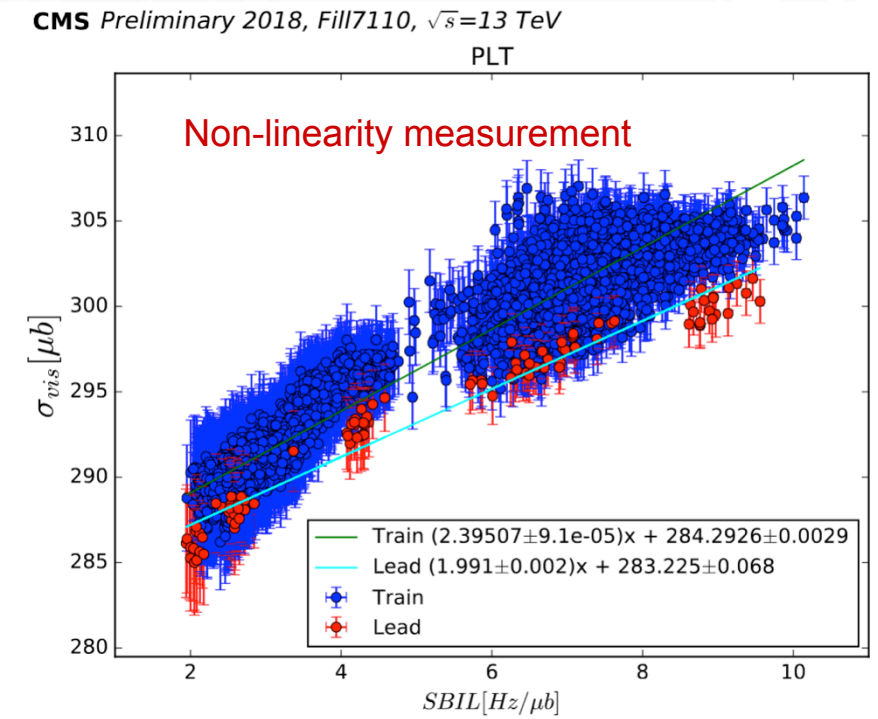


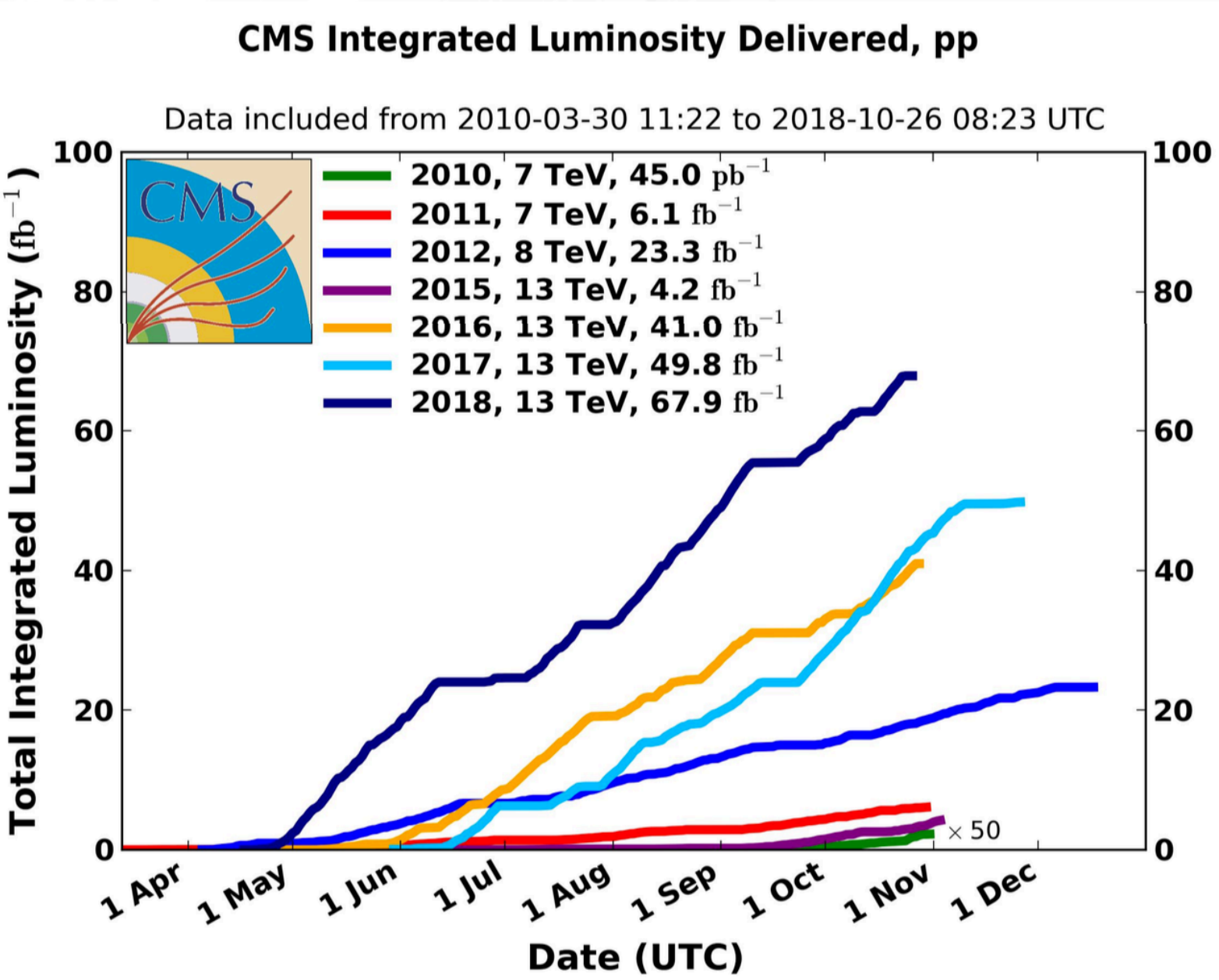
Application of emittance scans

- 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.
- Through the whole year emittance scans are employed to track the performance of the detectors and correct for efficiency drops.





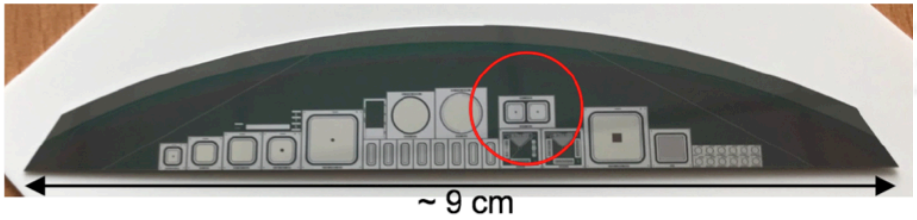



CMS Integrated Luminosity Delivered, pp
Data included from 2010-03-30 11:22 to 2018-10-26 08:23 UTC
CMS
2010, 7 TeV, 45.0 pb^{-1}
2011, 7 TeV, 6.1 fb^{-1}
2012, 8 TeV, 23.3 fb^{-1}
2015, 13 TeV, 4.2 fb^{-1}
2016, 13 TeV, 41.0 fb^{-1}
2017, 13 TeV, 49.8 fb^{-1}
2018, 13 TeV, 67.9 fb^{-1}
× 50
Total Integrated Luminosity (fb^{-1})
0
20
40
60
80
100
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
Date (UTC)

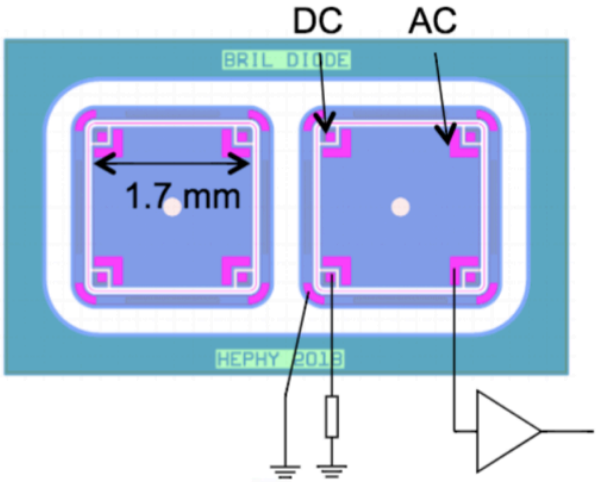
Next generation of the detectors

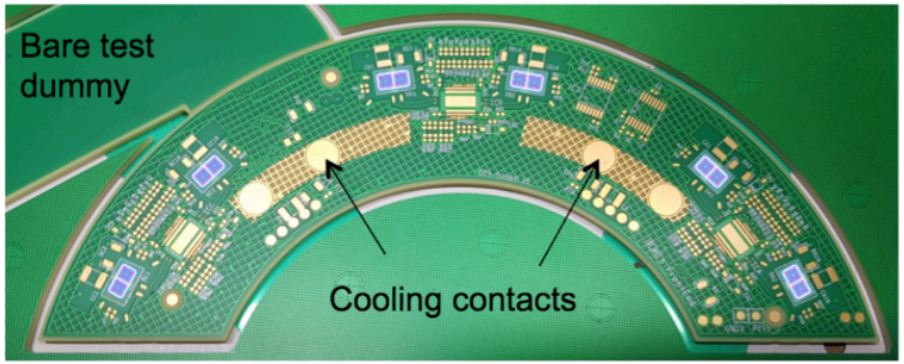
BCM1F for Run3

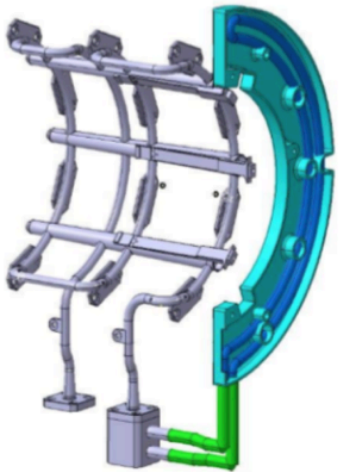
Planning talk



- 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







Cooling diverted from PLT cooling line