Upgrades to the Beam Condition Monitors at CMS

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on behalf of the Beam Radiation Instrumentation and Luminosity project (BRIL) of CMS

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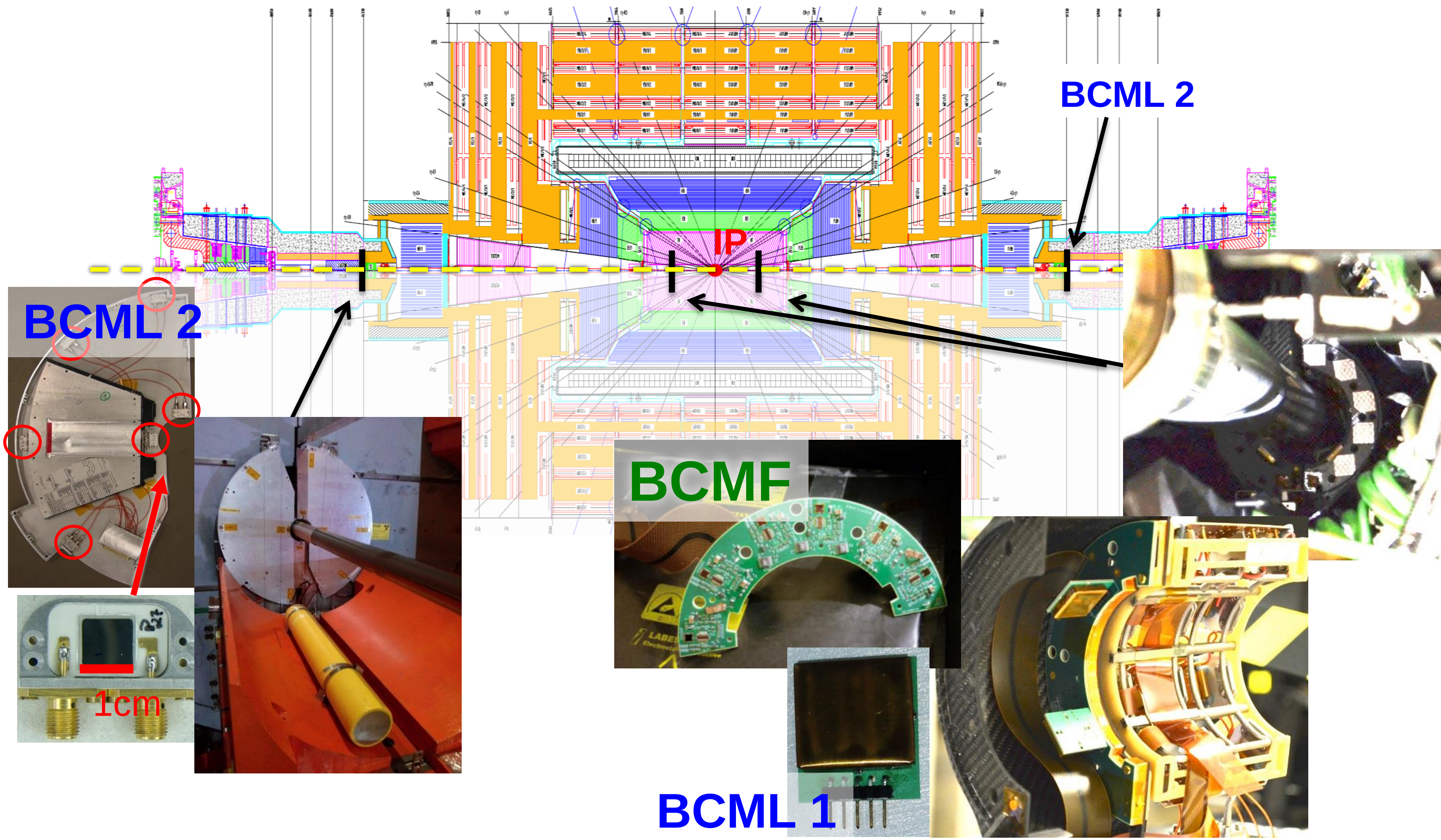
Overview

- **Introduction to currently used diamond based beam monitoring systems.**
  - **System overview of BCMF and BCML**
  - **Problems related to diamond detectors**
- **CMS phase 2 upgrade (HL-LHC)**
  - **Requirements for beam monitoring detector**
  - **Possible detector technologies**
  - **Radiation environment**



BCML 2
IP
BCML 2
1cm
BCMF
BCML 1

Detector system features

BCMF

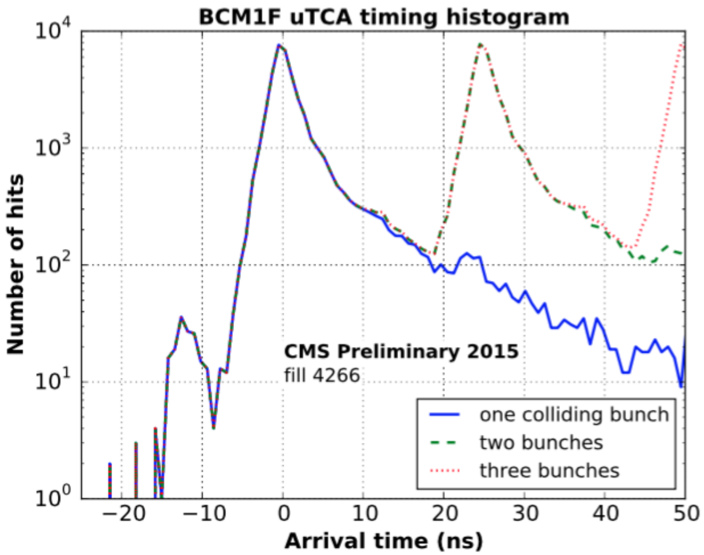
- **Concept:** Fast particle counter
- **Application:**
  - Machine induced background measurement
  - Luminosity measurement
- **Detector:**
  - 5x5mm^2 sCVD
  - Two pad metallization to reduce pile up.
- **Electronics:**
  - Fast preamp
  - Optical transmission
  - Discrimination + time histogramming; ADC; FPGA signal processing.

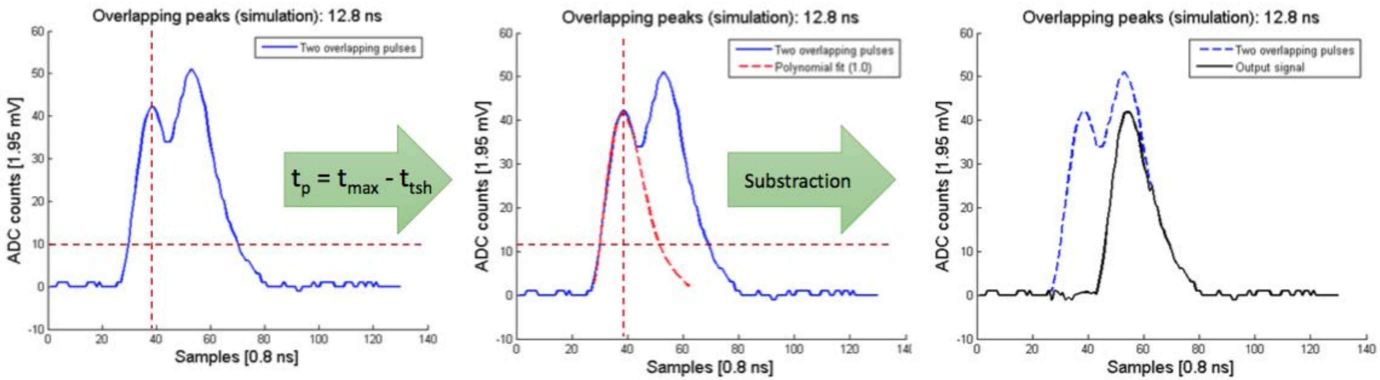
BCML

- **Concept:** Detector current measurement
- **Application:**
  - Beam loss monitoring (fast & intense events)
  - Active protection
- **Detector:**
  - 1x1cm^2 pCVD
  - Replaces LHC BLM ionization chamber
- **Electronics:**
  - LHC BLM readout electronics (40us integration)
  - Will follow changes made by LHC.

BCMF: Backend signal processing

- VME based (used in production):
  - Realtime Histogramming Unit
  - ADC data acquisition
- uTCA based (under development):
  - FMC125 ADC signal processing in FPGA.
    - Amplitude histogram, timing histogram, RAW ADC acquisition
    - In the future signal de-convolution to mitigate pileup

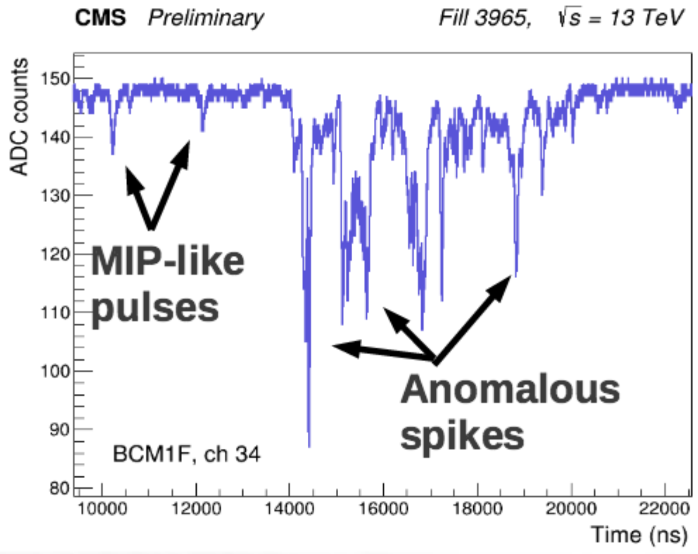




A. Zagozdzinska:
IEEE NSS 2015
Note in preparation

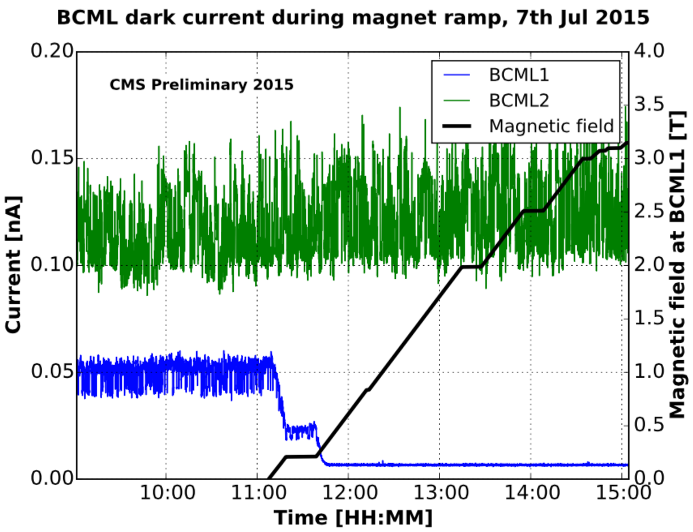
BCMF: features and problems

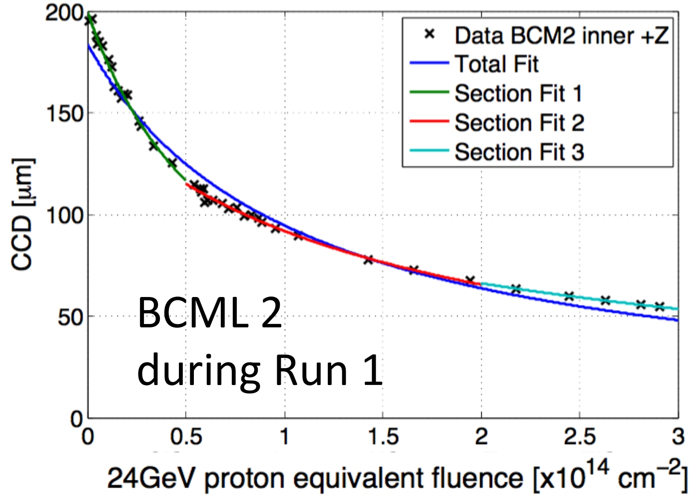
- **Detector & front end system:**
  - **Newly built in 2014, installation in Jan 2015.**
    - **24 sCVD diamonds with 48 channels**
    - **Design specification for HV rating: 1000V**
  - **Problems:**
    - **Noisy channels, HV trips (I > 3uA).**
      - **Expected current per diamond O(100nA))**
    - **Reduction of HV necessary: 50-250V "left"**
    - **Will do test beam with spare detector on hadron beam line to investigate further.**



BCML: features and problems

- **Measurement of detector current**
  - ➢ **Sensitive to erratic current behavior**
  - – **Magnetic field at BCML1 helps, at BCML2 not strong enough.**
- **BCML1 survivability good**
  - – **Has to rely on magnetic field**
  - – **Durability to be studied next year**
  - – **But:**
    - **~100m front end cable: More noise, flattening of fast pulses**
    - **BCMF problems reflect also on BCML 1**
      - – **Only 6 out of 8 channels working**
- **BCML2:**
  - – **Operational HV limited to about 200V with pCVD diamonds.**
    - **Radiation hardness depends on applied HV.**
  - – **Estimations predict failure after 100 fb^{-1}**





CMS phase 2 Upgrade

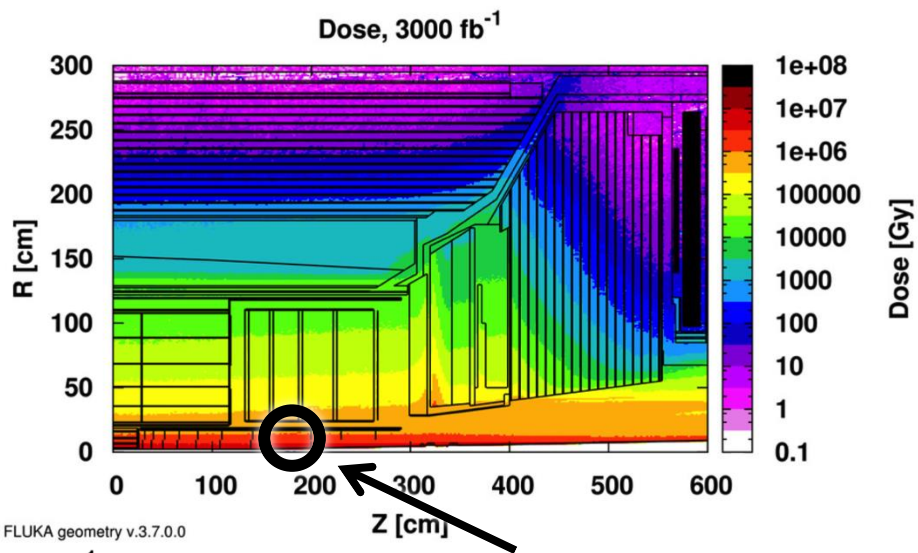
- **Upgrade of the CMS detector in the scope of the HL-LHC project.**
  - **Goal: deliver 3000 fb^{-1} (Run 1: 30 fb^{-1}, LHC lifetime 300 fb^{-1})**
  - **Instantaneous luminosity: 5×10^{34} $cm^{-2}s^{-1}$ -> 4 billion collisions per second (LHC design 1×10^{34} $cm^{-2}s^{-1}$)**
  - **Up to 140 collisions per bunch crossing (at the same time) (currently ~20)**

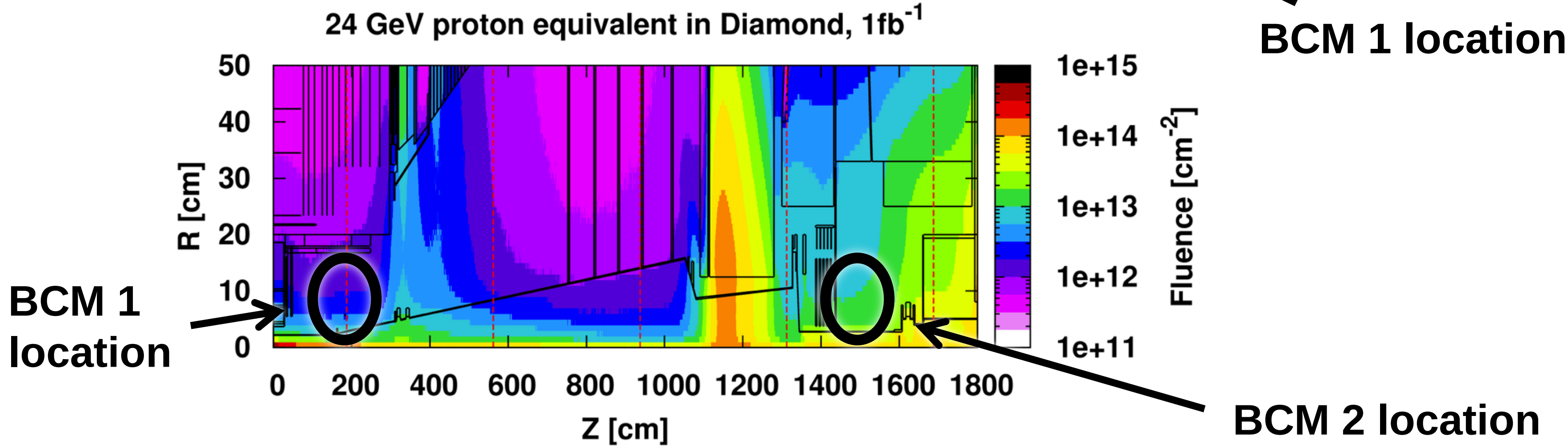
- **Continued need for two beam monitoring systems**
  - **Fast particle counter**
    - **Precision luminosity measurement**
    - **Machine induced background measurement**
  - **Detector current measurement**
    - **Active protection**
    - **Monitoring of fast & intense loss events**

Radiation tolerance needed

Target 3000 fb^{-1}:

- **Dose: O(10 MGy)**
- **24 GeV-p-eq fluence:**
  - **At pixel: ~10^{16} cm^{-2}**
  - **Forward region: ~3×10^{16} cm^{-2}**





BCMF upgrade

- **Expected rates:**
  - Luminosity: 100 - 200 MHz/cm2
  - Machine induced background: ~100 kHz/cm2
- **Detector size:**
  - Low rates require sufficient total detector area
    - Commissioning, Heavy Ion, Van der Meer scans
    - Beam background measurements
  - ➢ At lease same total detector area: Currently ~12cm^2
- **Detector granularity**
  - Minimize pile up at high rates with granularity
  - ➢ Decrease detector size by factor 3 (currently 0.125 cm^2)
- ➢ **Need > 150 channels**
  - ➢ Could use pixelated or strip detector.
- **Sensor technology:**
  - Diamond: no cooling required, R&D necessary
  - Silicon: Cooling available at Central Tracker, unlikely for potential detector at forward location

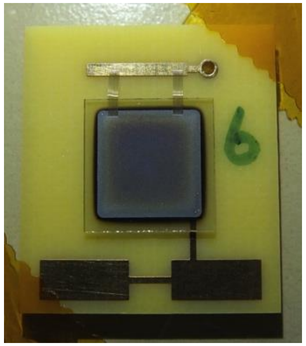
BCML upgrade

- **Detector requirements:**
  - **High dynamic range**
    - **Low dark current while high saturation**
    - **Nominal beam background rates: ~10^5 Hz/cm^2**
    - **Collision products: ~10^8 Hz/cm^2**
    - **Beam abort threshold: ~10^6 Particles per event (~10^{10}Hz/cm^2)**
  - **Size & Material budget**
    - **Has to be optimized for detectors at Pixel location.**
- **Detector location:**
  - **More flexibility since it does not require timing**
  - **Sensitive to beam background**
  - **Accessibility (especially if replacements needed)**
    - **Residual dose environment make access undesirable**

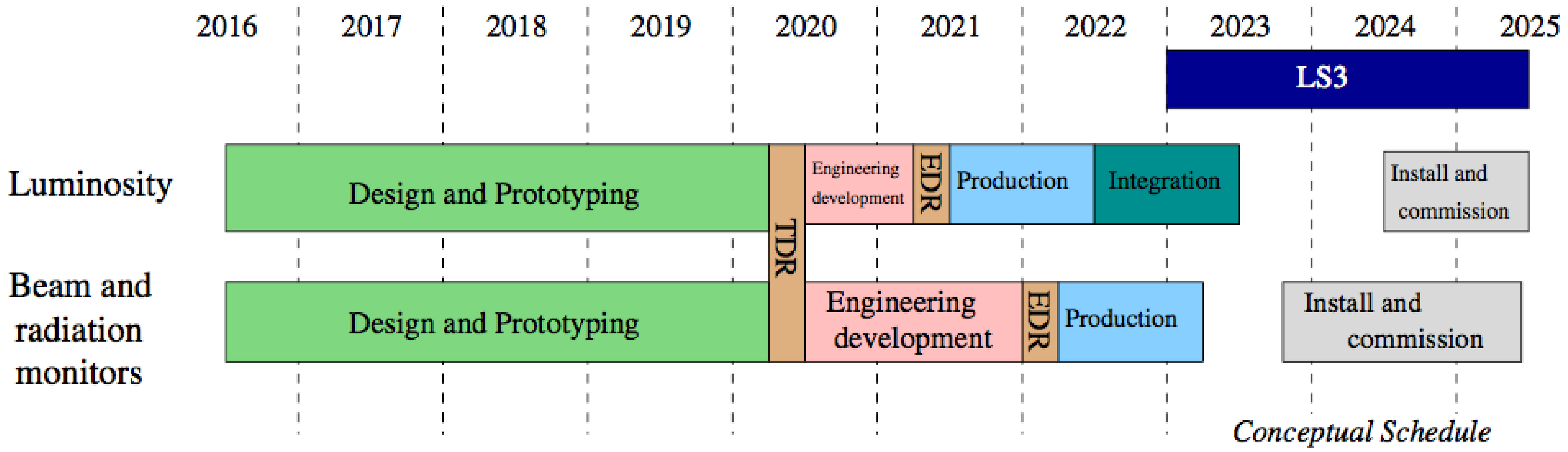
BCML upgrade

Possible detector technologies:

- **Diamond detectors:**
  - Radiation hardness only achievable with sufficient HV
    - Need magnetic field to suppress erratic currents.
- **Sapphire detectors:**
  - Compensate very low signal with increased detector area
  - Prototype campaign ongoing
- **Ionization chambers:**
  - Impossible to place inside CMS
  - Potentially for BCML2 location.



Timeline phase 2 upgrade



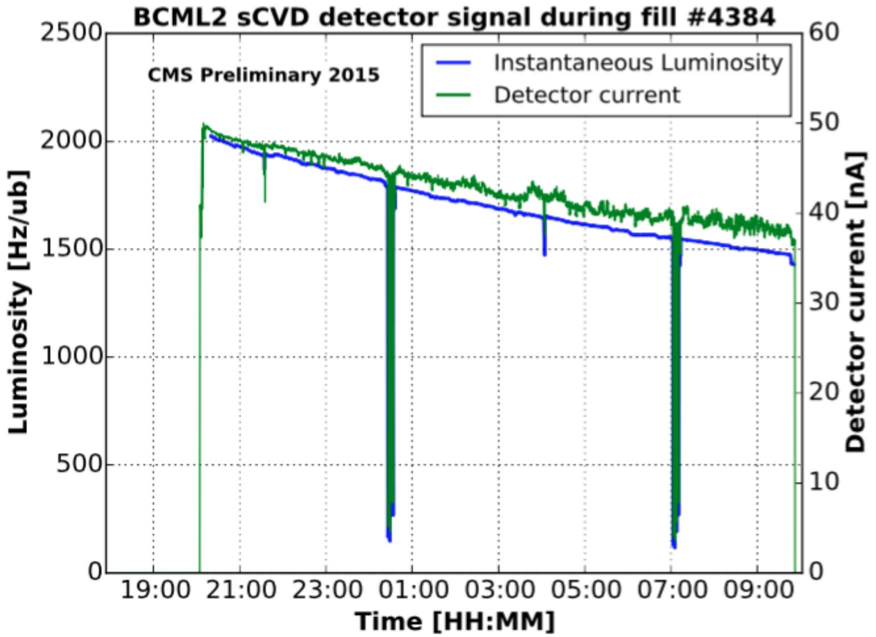
- **Technical design report in 2020**
- **Detector R&D in the next 2-3 years !**

Summary

- Continued needs for beam monitoring and detectors suitable for luminosity measurement.
- Currently installed diamond detector based system with various problems.
  - HV stability / noise. -> No possibility to overcome radiation damage
  - Granularity not suitable for Luminosity upgrade
- Detector R&D ongoing
  - New detector designs necessary to fulfill the requirements in HL-LHC

THANK YOU

BACKUP

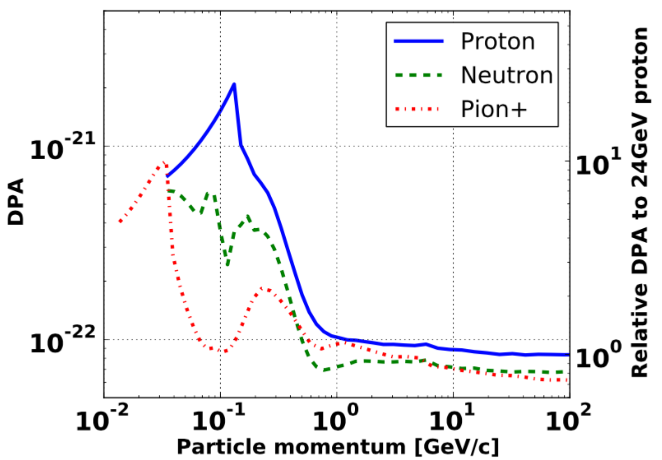


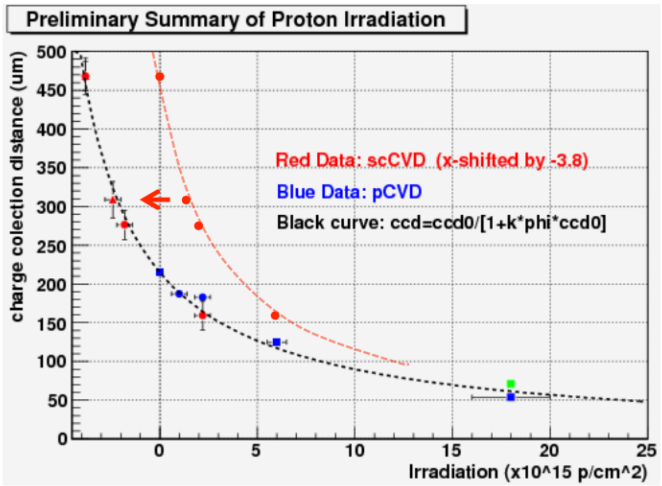
- **sCVD in BCML (500V)**
- **random current bursts occurring at high rates**
- **Similar symptom to pCVD erratic currents but less pronounced**

24 GeV proton equivalent in Diamond

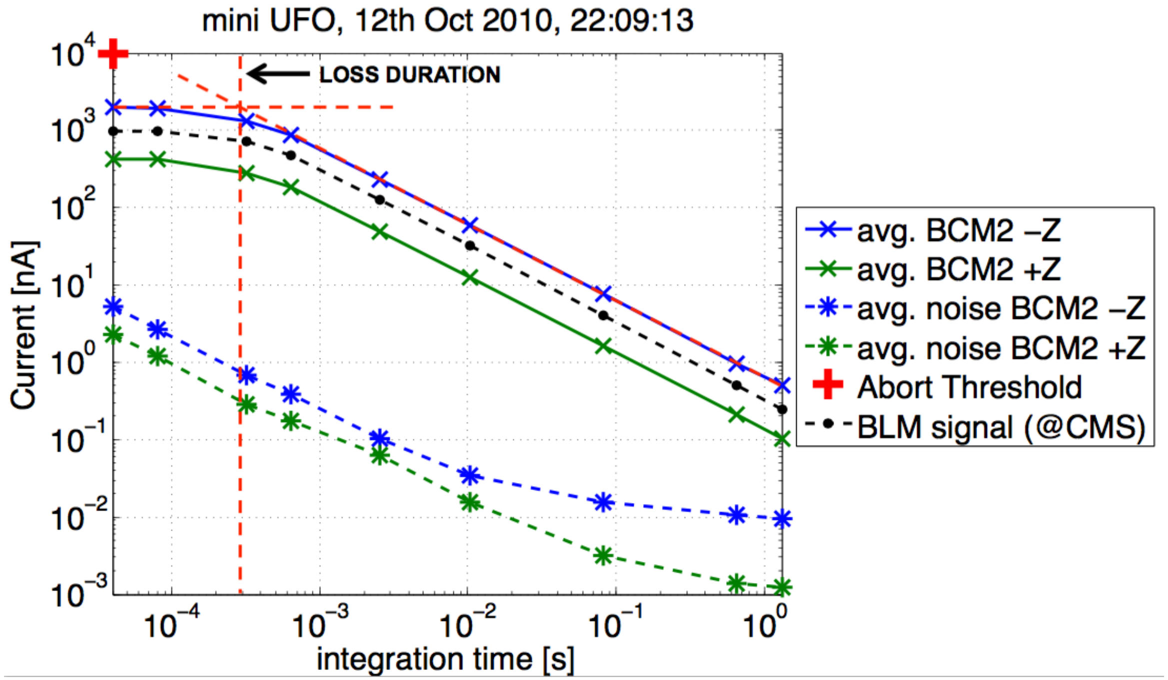
- Similar defined to 1 MeV neutron equivalent in silicon.
- Relative damage potential of each particle is weighted with the damage potential of the reference particle.

$$Flux_{24\,GeV-p-eq}\left[\frac{24\,GeV\ protons}{cm^2 \times s}\right] = \frac{DPA_{simulation}\left[\frac{1}{s}\right]}{DPA_{norm}\left[\frac{cm^2}{24\,GeV\ protons}\right]}.$$





Monitoring with BCML



- **BCML data includes different integration times to allow an analysis of fast beam loss events.**
- **Fast events are not significant in BCMF and**

Electronics

- New front end electronics has to be identified:
  - Fast good timing
  - Trigger less readout
  - Dead time free
  - Digital readout
- Optical path
  - Currently no rad-hard solution for analogue transmission.
  - Digital optical data transmission used by CMS tracker
- Back end electronics:
  - Fast time histogramming
  - Signal amplitude measurement
  - Pileup mitigation.
  - Advanced FPGA based signal processing being developed already for current system.