Beam Condition Monitors and a Luminometer Based on Diamond Sensors

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Outline

Introduction

- Beam Condition Monitors, CMS

BCM1F before the current shutdown

- System design, performance, limitations

Upgrade in current shutdown

- Description, design, beam test results

Conclusions

Beam Condition Monitor

Context

- LHC running at unprecedented beam energies and intensities
- Even small beam losses may cause damage to CMS detector components

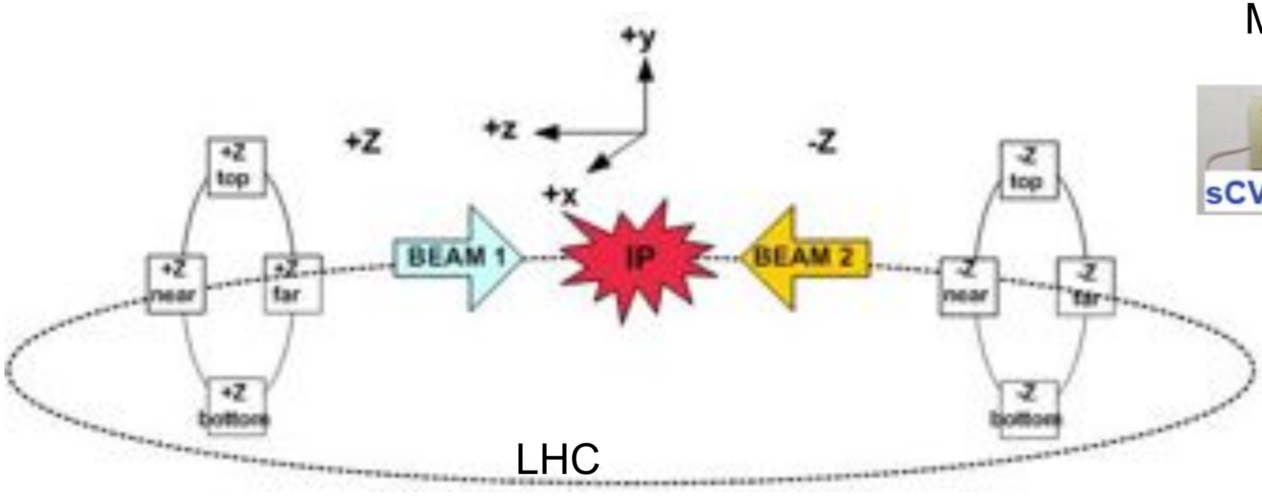
Purpose of Beam Condition Monitors

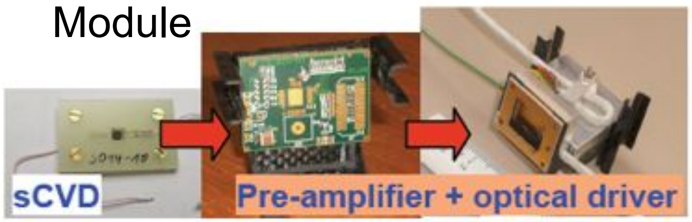
- Monitor particle fluxes near the beam pipe
- Ensure sufficiently low inner detector occupancy for data-taking
- Detect beam loss conditions
- Initiate reactions when necessary (beam abort)

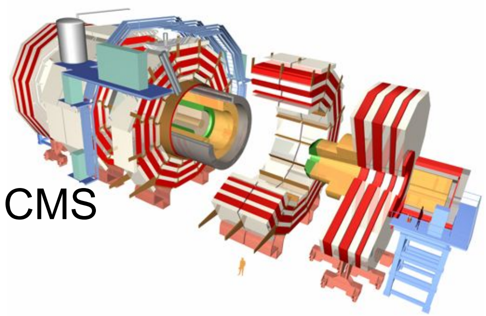
CMS

- Uses different beam condition monitors in its BRM system
- Integrating monitors (signal current) → BCM1L, BCM2
- Bunch by bunch monitors → scintillators and **BCM1F**

Fast Beam Condition Monitor BCM1F (up to 2012)







8 5mm x 5mm single-crystal CVD diamonds (Element 6) positioned around the beam-pipe, radial distance 4.5 cm, 1.8 m from interaction point

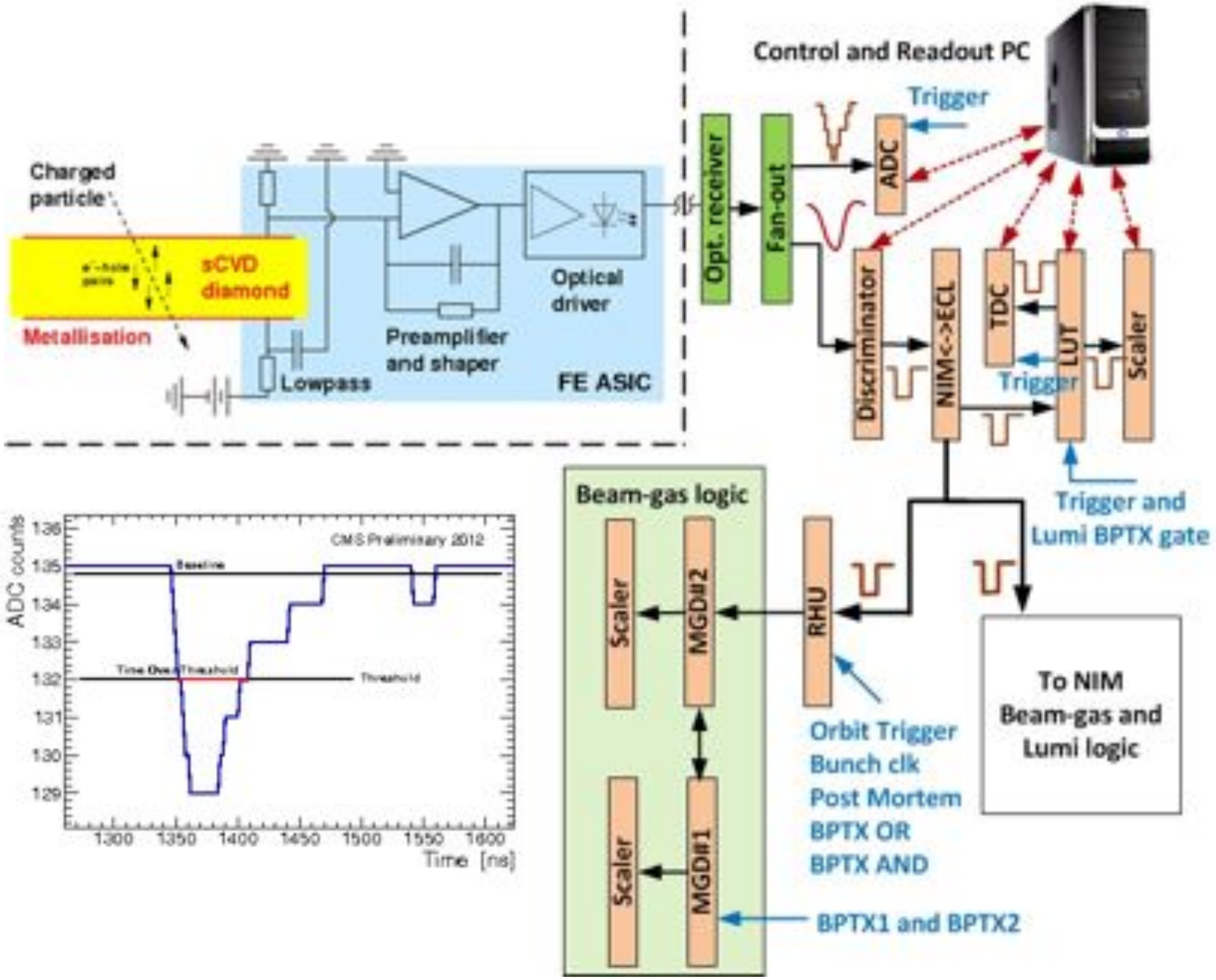
- Diamond → no cooling, robust, radiation-hard
- Sensor module: diamond, radiation-hard preamplifier, optical driver

Bunch-by-bunch information on flux of beam halo and collision products

- Monitor condition of beam: ensure low radiation for silicon tracker
- Calculate luminosity

Readout independent of CMS DAQ

BCM1F Electronics (up to 2012)



Output:

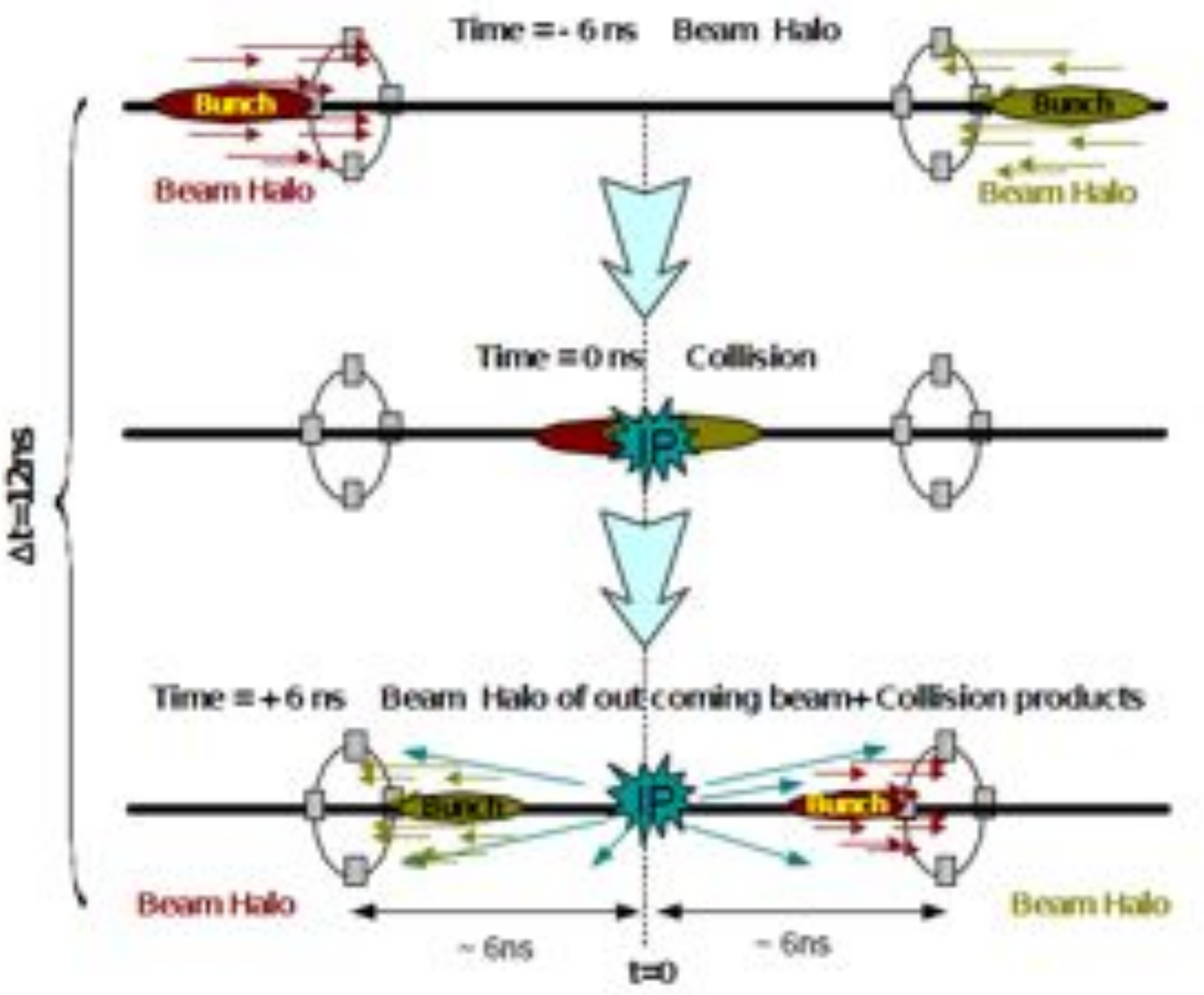
analog spectra
ADC → monitoring

hit rates
Discriminator →

Look-up table
"LUT"

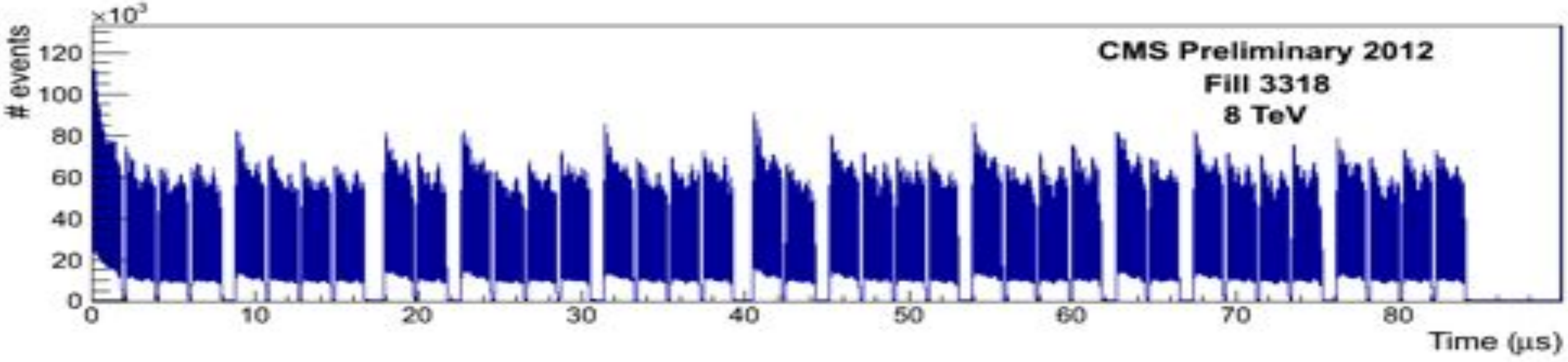
Recording
Histogram
Unit
"RHU"

What can be seen with such a device?



Performance of BCM1F (up to 2012) - 1

- Operated right from the start of LHC → first (splash) beam in LHC already seen
- measures underground rates and time structure of beams
- discovery of “Albedo Effect” (afterglow of slow particles)
- delivers relevant background rates to CMS and to LHC control room
- measures online luminosity



Bunch structure inside LHC, abort gap on the right

Performance of BCM1F (up to 2012) - 2

- Operated right from the start of LHC: first (splash) beam in LHC seen
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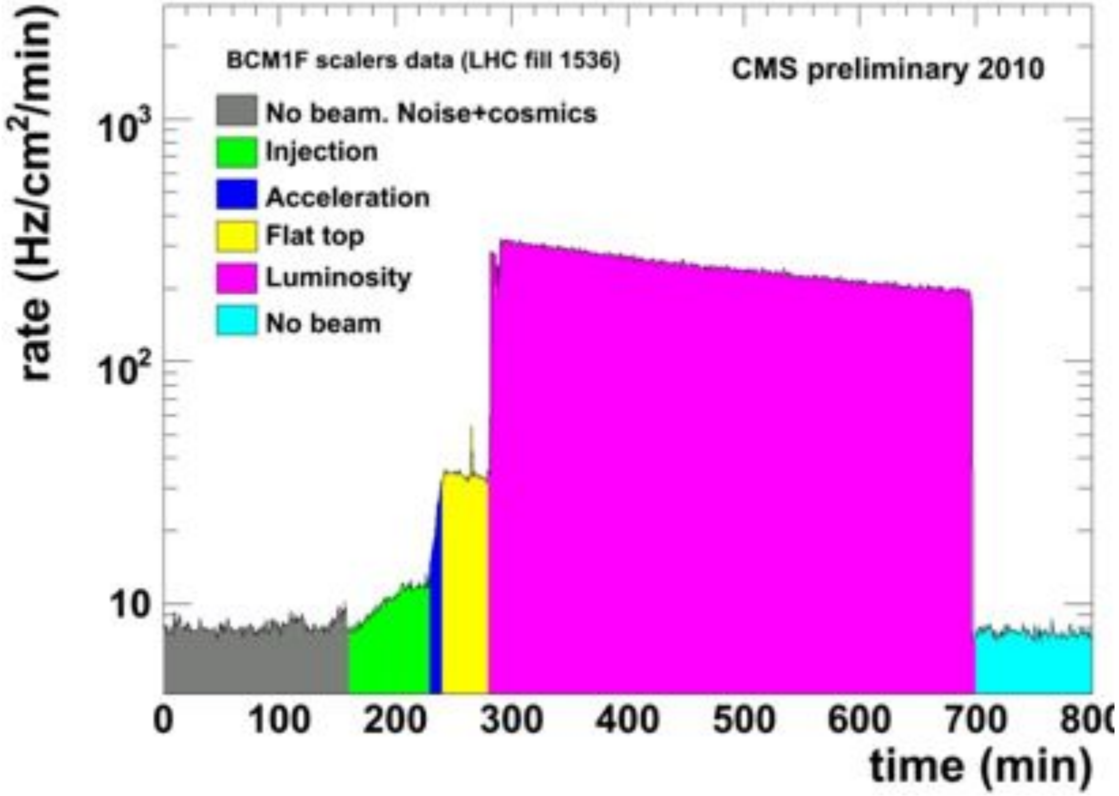

“Life Cycle” of a fill in the LHC

Performance of BCM1F (up to 2012) - 3

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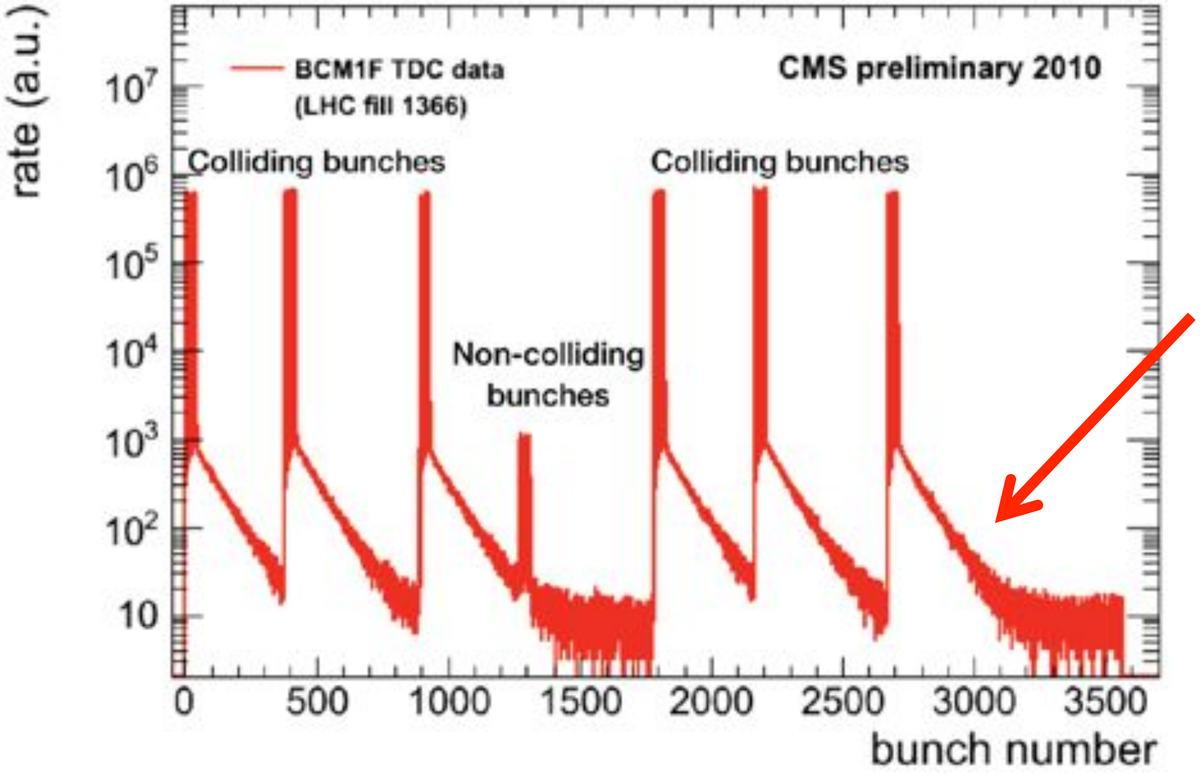

Albedo Effect
after collisions:

- excitation of material
- slow remaining particles
- lifetime ~2 μs

Performance of BCM1F (up to 2012) - 4

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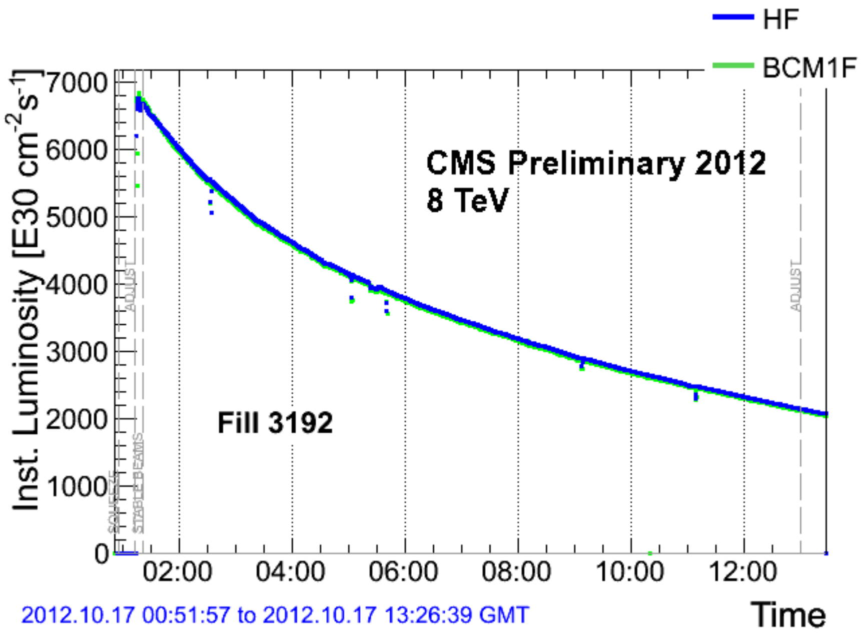

Collision rates (LUT) are used for luminosity measurements:

- Requires calibration
- online luminosity in CMS done by Hadron Forward Calorimeter (HF)

Test of BCM1F as online luminometer:

- good agreement
- validated with calculations of HF, pixels
  → has potential as online luminometer
- advantage: decoupled from CMS DAQ

Limitations of BCM1F (up to 2012)

- preamp has 25 ns shaping time – to slow for 25 ns bunch spacing
- preamp needs a long recovery time from large input signals (overdriven, saturated)
- laser diodes (analog signal transmission) have radiation damage
- diamond sensors show radiation damage → polarization → how to cure?
- only 4 sensors on each side of the interaction point → saturation / pile-up problems

Upgrade Program of BCM1F in the current Shutdown

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Design of a new preamp:
- rise time below 12 ns
- fast recovery from overdrive
- differential outputs

- Moving of laser diodes to a less exposed area
- Adding slow control for current and gain (compensation

- use of components with extended high voltage tolerance

- metallization of sensors split into two pads

- use of 12 sensors with two pads each → 24 channels per side

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Upgrade Program of BCM1F in the current Shutdown

Implications of LHC upgrade for BCM1F

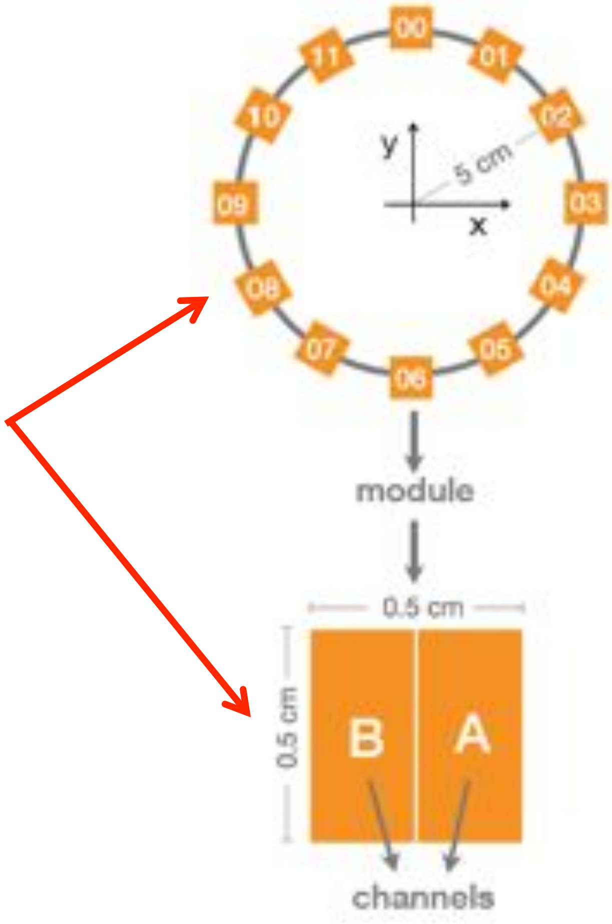
Radiation: Luminosity 10^{34} $cm^{-2}s^{-1}$

→ BCM1F expects charged particle flux ~$3x10^{7}$ $cm^{-2}s^{-1}$

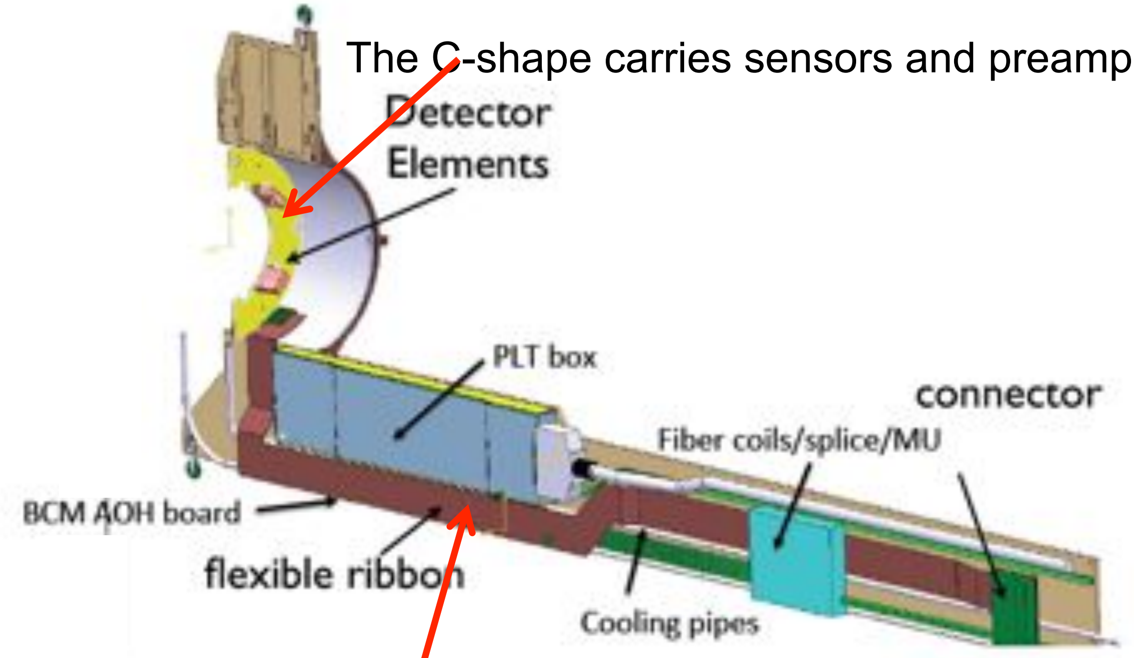
25 ns bunch spacing

High hit rate

- 12 diamonds with 2 pads per diamond, both sides of IP → 48 channels
- Minimize and deal with radiation damage
- Scale up full system from 8 channels
- Faster electronics (preamp)
- Integrate readout with other luminosity subsystems



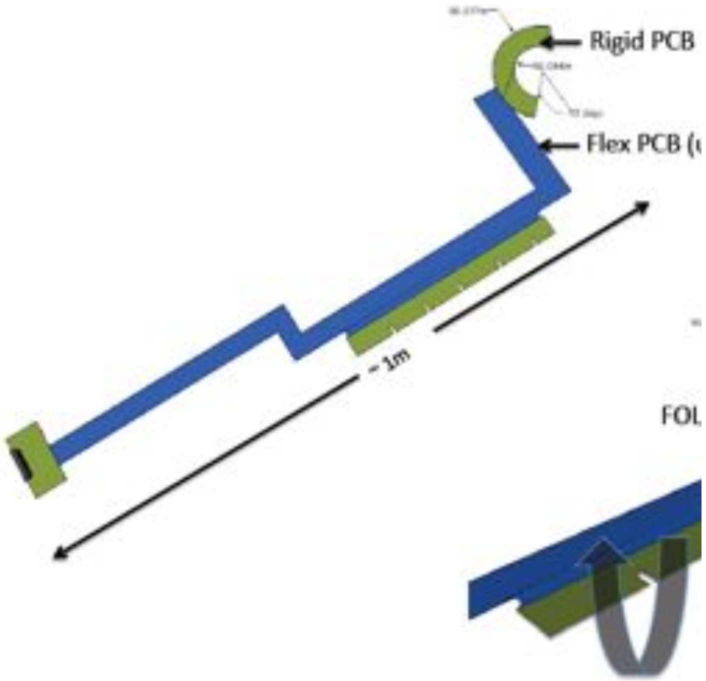
From Plans to Reality: the re-designed carriage



The C-shape carries sensors and preamps.

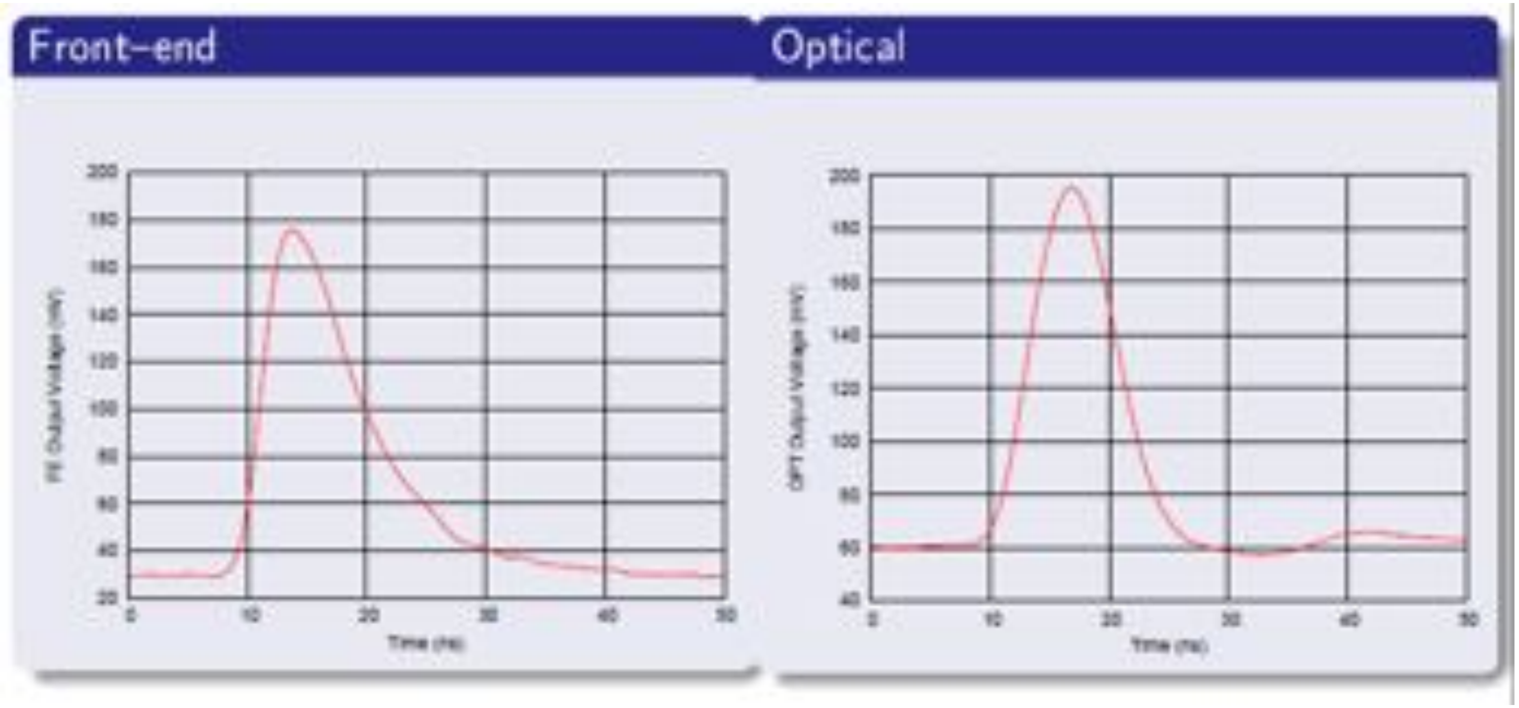
Laser drivers go further away (r, z).

All wiring and support will be located on a ***one-piece-rigid-flexible PCB*** (Printed Circuit Board)



From Plans to Reality: the re-designed frontend chip

- ASIC designed by AGH – Krakow (PL), Designer: Dominik Przyborowski
- IBM CMOS-8RF-130nm technology (radiation hard, submitted via CERN)
- ~50 mV/fC charge gain
- < 1k electrons ENC
- Sophisticated calibration logic
- 4 channels on 1 chip

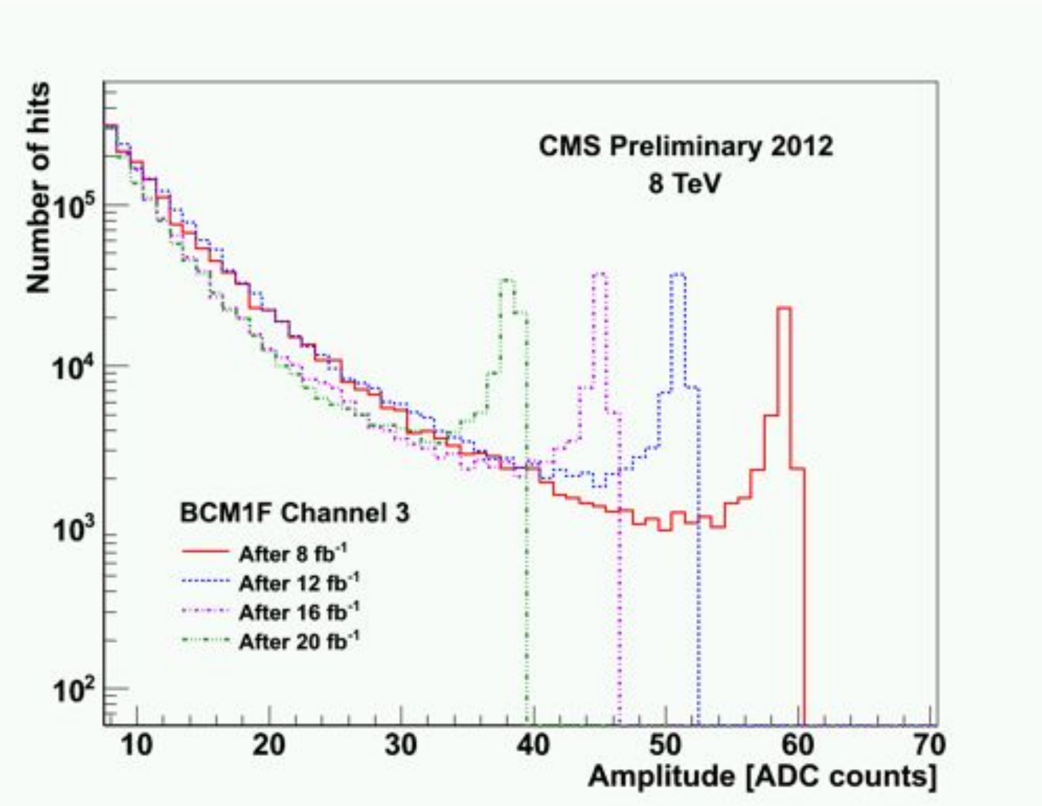


Laboratory measurements of the full readout chain of upgraded BCM1F

From Plans to Reality: improving the optical chain

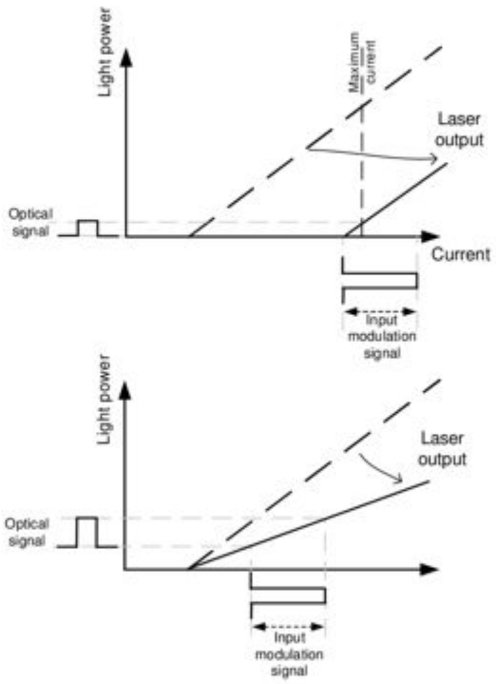
Radiation damage of laser driver visible in decreasing signal amplitude:

- 25% gain lost in BCM1F optical transmission after 30 fb^{-1}

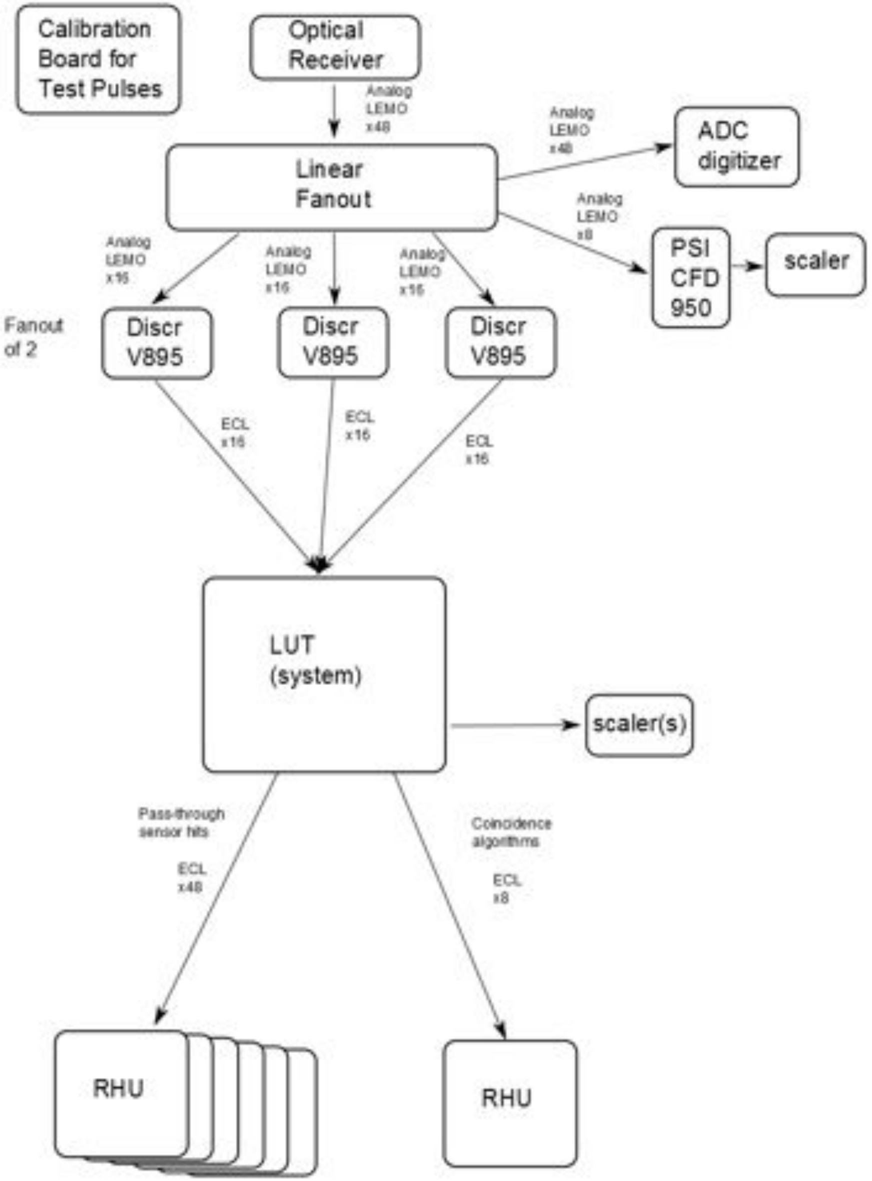


Countermeasures:

- Go away from the “hot” area
- Compensate the loss in gain
- compensate for the shifted laser threshold



Upgrade of Backend Electronics



Use “tried and true” discriminator path for initial running while commissioning digitizer path

→ following slide

LUT: create coincidences between all 48 channels → patterns

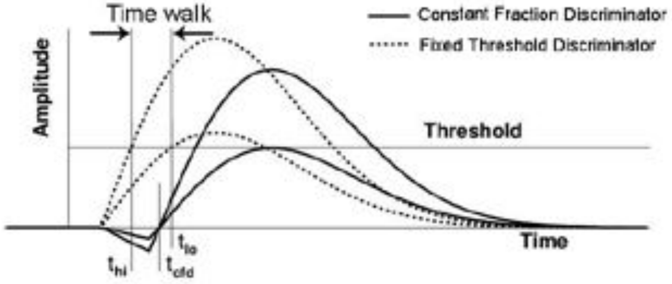
RHU for readout (later slide) → dedicated histograms

Signal Processing

Two parallel tracks to be followed:

<u>Discriminators</u>

Fixed-threshold vs. constant-fraction

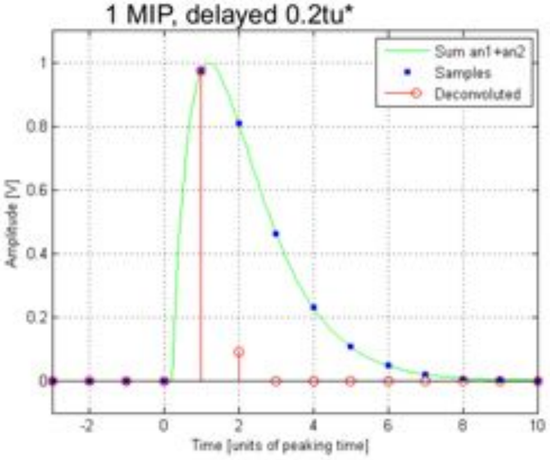


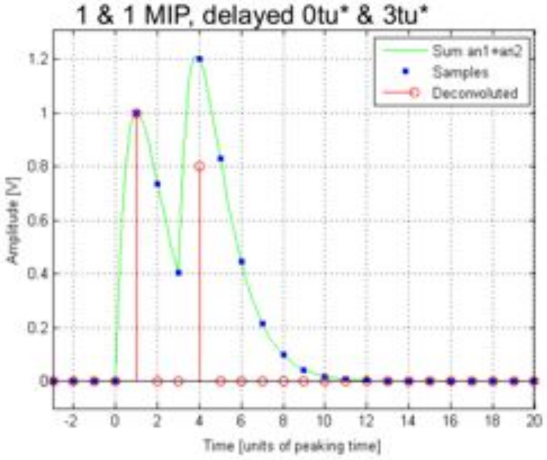
Constant-fraction: better time resolution

Fixed-threshold: lower deadtime

Preliminary conclusion: deadtime outweighs resolution -> use FTD (CAEN V895) for primary path but install CFD to run and test in parallel

<u>Digitizer with fast peak-finding algorithms</u>





*tu – time units

Identify pulse arrival time and peak height, distinguish signals close in time (overlapping) “deconvolution”

Development of algorithms ongoing

Current hardware choice: uTCA ADC FMC mezzanine system. Multiple FMC candidates, to be tested

Recording Histogram Unit (RHU)

RHU: Readout of full-orbit histograms

- No deadtime (buffered readout)
- 8 histogramming input channels
- Bins of 6.25 ns = 4/bunch bucket (14k bins/orbit)
- Bunch clock, orbit clock, beam abort
- Configurable sampling period
- Ethernet readout

- Developed at DESY-Zeuthen
- Prototype installed Sept. 2012,
  validated during 2012-2013 run
- Very flexible unit (FPGA based, own interface and OS)
- Physics friendly data compression for direct access

Conclusions and Outlook

Many improvements in the works to increase effectiveness

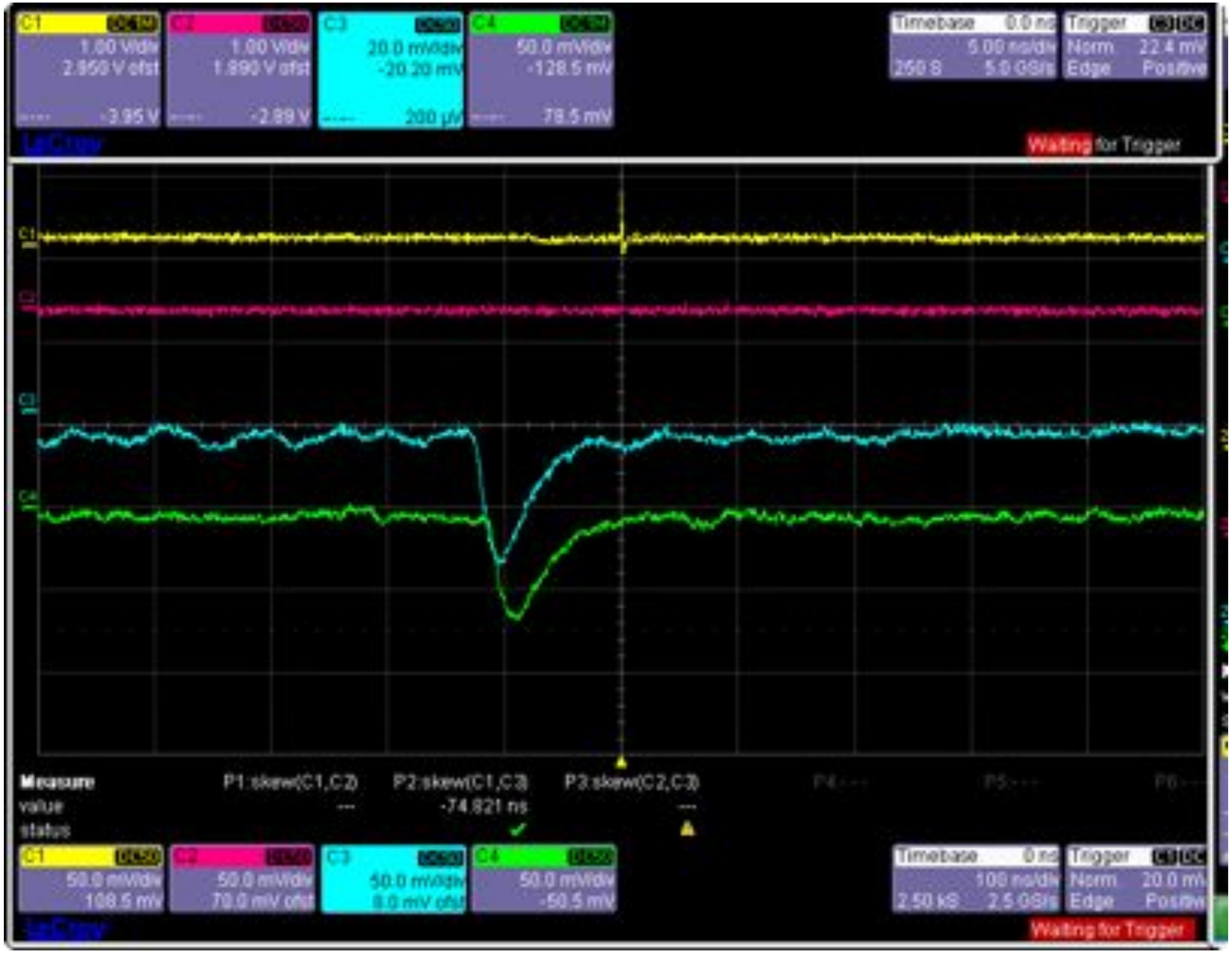
  - ***Carriage***: 48 channels, single PCB
  - ***Diamond sensors***: minimize effects of radiation damage using higher voltage
  - New ***fast front end ASIC*** to reduce inefficiencies
  - ***Optical chain***: lower radiation for laser driver, multi-amplitude test pulses
  - ***Back end***: Discriminator path in parallel with digitizer peak-finding
  - RHU for collection of hit rates
  - Algorithms ***for luminosity measurement***
- Outlook
  - Installation of 4 carriages (full system) planned begin of September
  - Comissioning of all subsystems soon after installation and recovery of the LHC

What should I add?

Thank you for your attention!

Спасибо за вниманию!

Backup Slides (1) - Very first beam in LHC

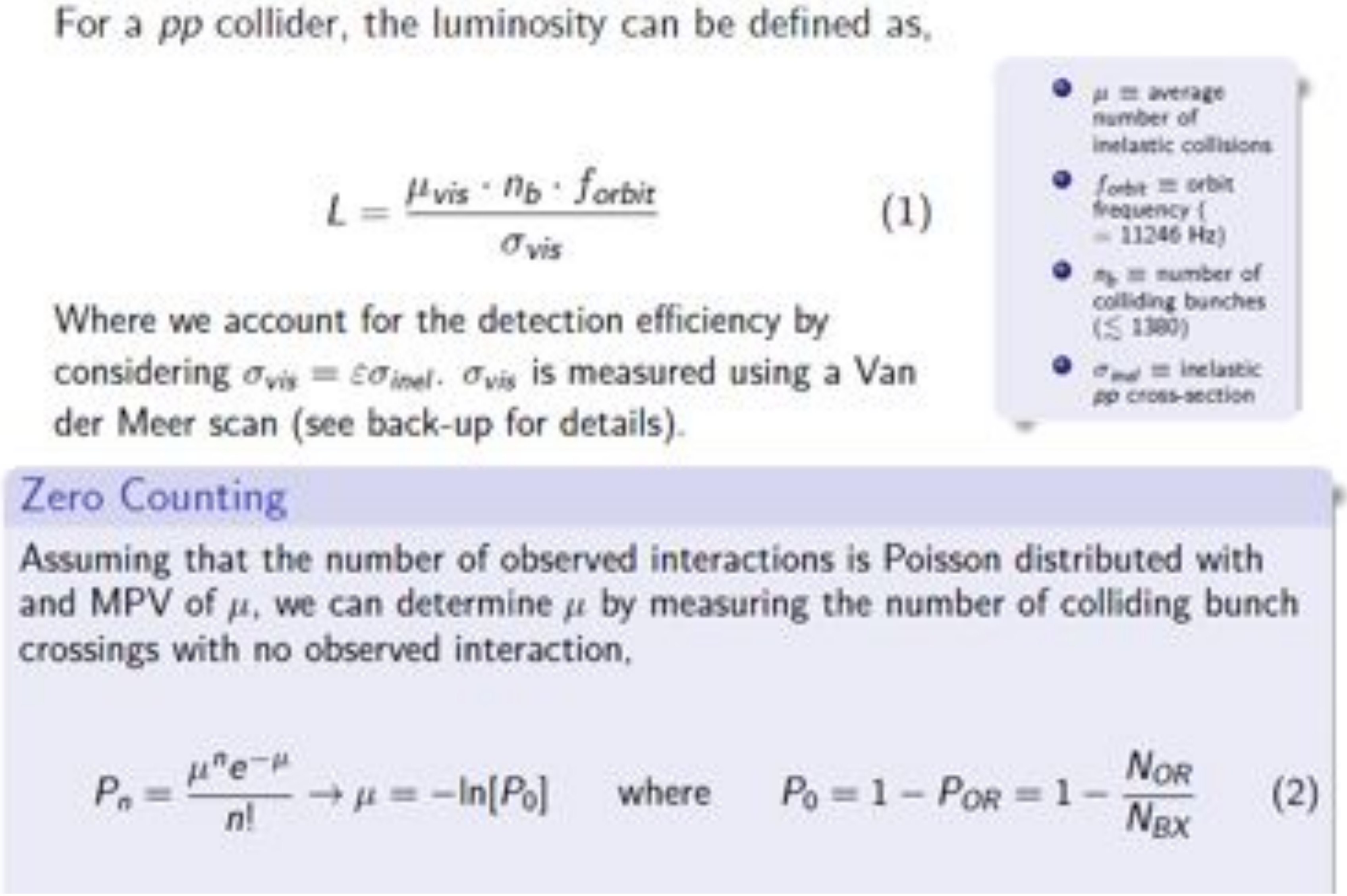


C1 DC1M 1.00 V/div 2.950 V ofst -3.95 V
C2 DC50 1.00 V/div 1.890 V ofst -2.89 V
C3 DC50 20.0 mV/div -20.20 mV 200 µV
C4 DC1M 50.0 mV/div -128.5 mV 78.5 mV
Timebase 0.0 ns 5.00 ns/div 250 S 5.0 GS/s
Trigger C3 DC Norm 22.4 mV Edge Positive

Measure	P1:skew(C1,C2)	P2:skew(C1,C3)	P3:skew(C2,C3)	P4:---	P5:---	P6:---
value	---	-74.821 ns	---			
status		✓	⚠			

C1 DC50 50.0 mV/div 108.5 mV
C2 DC50 50.0 mV/div 70.0 mV ofst
C3 DC50 50.0 mV/div 8.0 mV ofst
C4 DC50 50.0 mV/div -50.5 mV
Timebase 0 ns 100 ns/div 2.50 kS 2.5 GS/s
Trigger C1 DC Norm 20.0 mV Edge Positive

Backup Slides (2) – Luminosity Basics



For a *pp* collider, the luminosity can be defined as,

$$L = \frac{\mu_{vis} \cdot n_b \cdot f_{orbit}}{\sigma_{vis}} \qquad (1)$$

- $\mu \equiv$ average number of inelastic collisions
- $f_{orbit} \equiv$ orbit frequency (≈ 11246 Hz)
- $n_b \equiv$ number of colliding bunches ($\lesssim 1380$)
- $\sigma_{inel} \equiv$ inelastic *pp* cross-section

Where we account for the detection efficiency by considering $\sigma_{vis} = \varepsilon\sigma_{inel}$. σ_{vis} is measured using a Van der Meer scan (see back-up for details).

Zero Counting

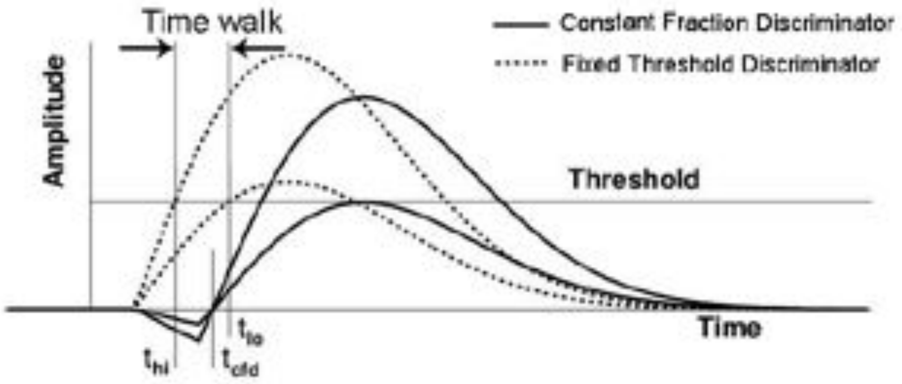
Assuming that the number of observed interactions is Poisson distributed with and MPV of μ, we can determine μ by measuring the number of colliding bunch crossings with no observed interaction,

$$P_n = \frac{\mu^n e^{-\mu}}{n!} \rightarrow \mu = -\ln[P_0] \qquad \text{where} \qquad P_0 = 1 - P_{OR} = 1 - \frac{N_{OR}}{N_{BX}} \qquad (2)$$

Backup Slides (3) – Discriminators

Current discriminator: *CAEN v258B* fixed-threshold discriminator

- Does not discriminate pulses closer than ~12 ns: deadtime causes loss of consecutive signals
- Triggers pulses of different amplitudes at different times: “time walk” ΔT ~12 ns

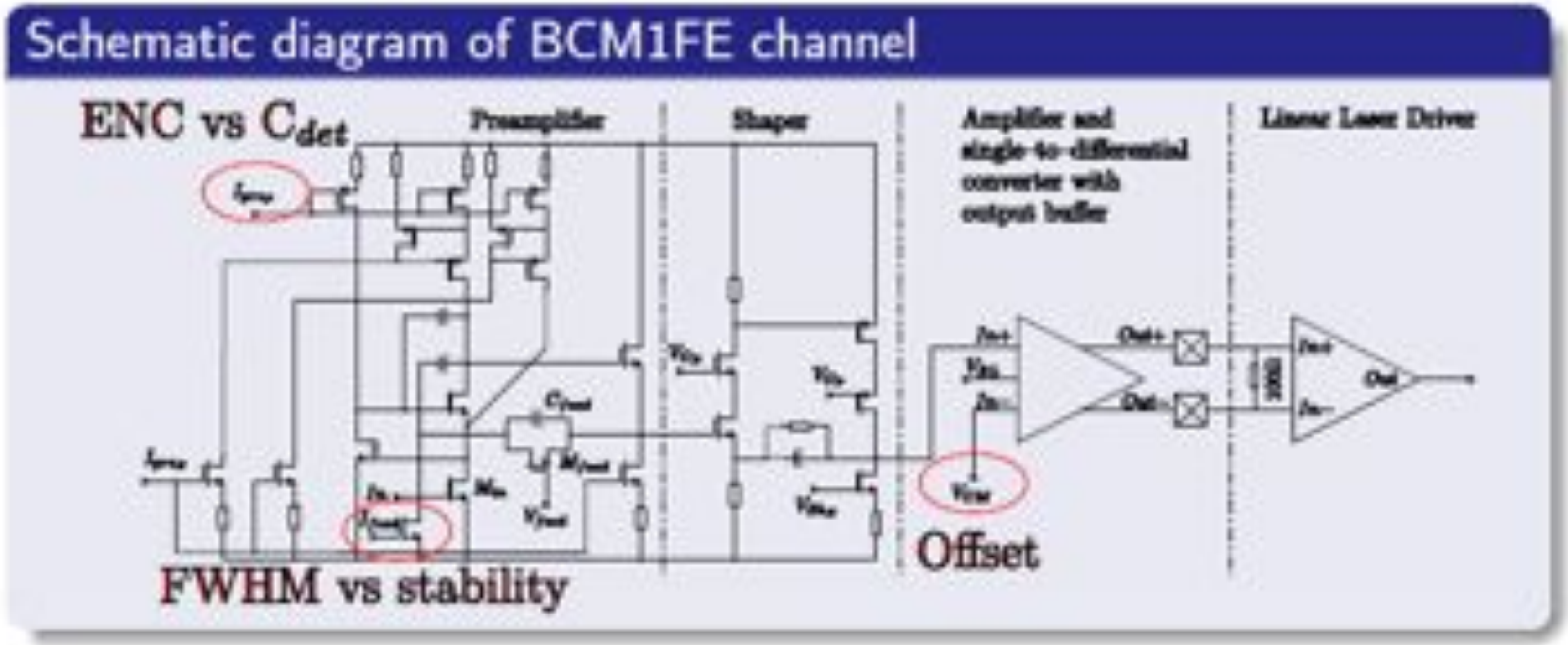


Meanwhile tested: two constant-fraction discriminators: *CAEN V812, PSI CFD950*

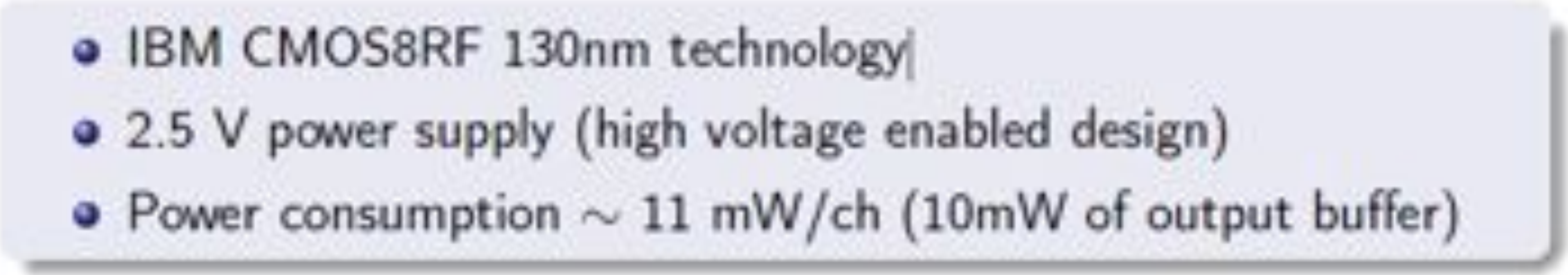
Both CFDs significantly improve on FTD time walk

- V812: better time resolution for trigger of single pulse
- CFD950: better resolution between consecutive pulses

Backup Slides (4) – upgraded frontend ASIC



Schematic diagram of BCM1FE channel



- IBM CMOS8RF 130nm technology
- 2.5 V power supply (high voltage enabled design)
- Power consumption ~ 11 mW/ch (10mW of output buffer)